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preparing for the future in cosmic ray shower detectors

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LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

LIP NEWS
edição n.15 Dezembro 2018

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EDITORIAL

Neste número do Boletim, a palavra de ordem é preparar o futuro. Em MARTA, na pampa Argentina, abrem-se novos caminhos no desenvolvimento de detectores de chuveiros atmosféricos mais poderosos, que nos permitirão saber mais sobre as partículas cósmicas que estão na sua origem (p. 4-7). É uma das tarefas importantes no momento em que a astronomia multi-mensageiros assume papel de grande relevo, depois de dois anos de grandes sucessos, que aqui são passados em revista, em que prometem continuar (p. 8-9). O ano termina com o fim do segundo período de tomada de dados do LHC. O desempenho do acelerador superou todas as expectativas, mas esta paragem é sobretudo o início da preparação para o futuro (p. 10-11). E não são só o acelerador e as experiências que preparam o futuro, mas toda a comunidade de física de partículas, teórica e experimental. Por isso, e embora haja ainda muitos dados para analisar, passamos em revista o estado da arte tal como foi apresentado nas conferências de verão — o estado do modelo padrão e a incessante procura de desvios em relação às suas previsões (p. 12-14). E a palestra convidada fala-nos dos desafios que os teóricos enfrentam para fazer cálculos e previsões à altura das cada vez mais precisas medidas experimentais que aí vêm (p.15-17). Voltamos um pouco à nossa realidade mais concreta, com as habituais breves do LIP e do mundo das partículas (p. 18-21), e passando em revista conferências, momentos de partilha com a comunidade (p. 22-23). Mas o mote continua a ser o futuro, e fala-se por isso dos mais jovens, daqueles que serão os investigadores do futuro. O Boletim apresenta o livro de resumos do Programa de Estágios de Verão do LIP 2018 (p. 24-28), em que mais de seis dezenas de estudantes, em Lisboa, Coimbra e Braga, se juntaram a nós nesta aventura. Ainda no

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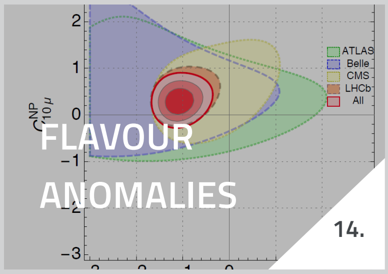

capítulo da formação avançada, surgem os shifts de CMS na sala de controlo LIP@IST, assegurados pelos estudantes de doutoramento, e da presença em Lisboa da rede internacional de doutoramento MVA4NewPhysics (p. 29). A todos desejamos um grande futuro, e, para começar, um excelente 2019!

MARTA: preparing for the future in cosmic ray shower detectors

P. Assis, M. Ferreira, R. Conceição for the LIP MARTA Team

MARTA is an R&D project that aims to provide the tools for high-precision and direct cosmic muon measurements, paving the way for next generation experiments. The construction and installation of a MARTA engineering array at the Pierre Auger Observatory site in the Argentinian pampa is a partnership between Portugal and Brazil. The project is well under way and data taking will start in 2019.

Muons in the highest-energy cosmic showers

Ultra high-energy cosmic rays (UHECR) are the most energetic known particles. Despite having been discovered nearly a century ago, their origin and nature remains a mystery. The scarce flux of these particles makes their detection possible only through the analysis of the giant particle showers (extensive air showers, EAS) generated by the interaction of UHECR with the atmosphere: above 10^{19} eV, about 1 particle/ (km^2 century) arrives at the Earth.

The Pierre Auger Observatory is the largest experiment in the world dedicated to the study of UHECR. It is a hybrid detector consisting of a giant surface detector array (SD) sampling the shower at ground and a set of fluorescence detectors (FD) detecting the light produced by the shower in the atmosphere above the array. Over the years its data have helped to considerably improve our knowledge about these particles:

- they are accelerated in astrophysical sources, as we don't see photons or neutrinos hinting the decay of supermassive relic particles;
- they display a dipole in the sky, which suggests that they are not accelerated in our galaxy;
- At the highest energies the energy spectrum of UHECR has a cutoff.

To understand the origin of the cutoff it is necessary to know the mass composition of primary UHECR, and there have been several developments along this line. In particular, Auger has been using EAS observables that are sensitive to the primary mass composition. The data seem to have a light mass composition, mostly protons, around 10^{18} eV and to evolve gradually to intermediate mass states, such as helium and nitrogen, with nearly no iron. This is an unexpected astrophysics scenario, as intermediate mass states should be destroyed due to the cosmic microwave background. Furthermore, it is known that the description of EAS has problems.

Measurements of the muon content in EAS are an important primary composition probe. Muons arise from the decay of charged mesons and can reach ground. This means that these particles provide a link to the high-energy hadronic interactions that rule the shower development. Auger has not only demonstrated that state-of-the-art simulations, tuned with the latest accelerator data, show a deficit in the number of muons at ground, but also that they fail to provide a consistent solution in terms of primary mass composition for both surface detector related observables and fluorescence detector ones.

This can be seen in figure 1 where the muon content in the shower (Rμ, measured by the SD) is shown against the atmospheric depth at which the shower reaches its maximum (X_{max}, an FD observable). It is worth stressing that Rμ is connected to the muonic (hadronic) sector of the shower while X_{max} is measuring the electromagnetic activity in the shower.

The accurate measurement of the EAS muon distributions is therefore crucial to further understand the shower development mechanisms and constrain hadronic interaction models in energies and kinematic regions that are currently unreachable by human-made accelerators. At present, muon measurement capabilities in Auger are indirect and limited. The R&D carried out in MARTA will considerably enhance muon measurement capabilities in UHECR detectors.

Beyond UHECR, the R&D carried out in MARTA will be important in the development of future cosmic and gamma ray experiments. In particular, it opens new possibilities for detailed, precise and redundant shower measurements, through very good time and space resolution, improved geometrical reconstruction and intercalibration of different sub-detectors. An example of such future experiments in the LATTES project for a ground-based gamma-ray observatory to be built in South America, in which LIP is deeply involved.

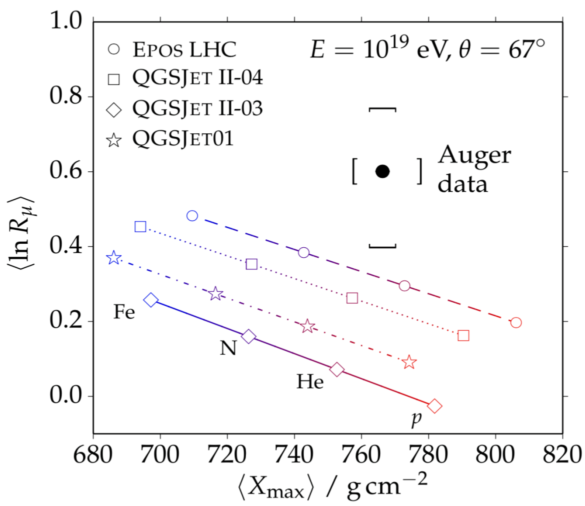

Figure 1: Average EAS muon content (Rμ) as a function of the average shower maximum depth (X_{max}) at 10^{19} eV. There is a clear discrepancy between models and the Auger measurement. The lines display different primary mass composition scenarios for each hadronic interaction model.

// DESTAQUE

The MARTA engineering array (EA) at the Pierre Auger Observatory

The surface detector of the Pierre Auger Observatory is an array of Water Cherenkov Detectors. These detectors are instrumented water tanks (cylinders of 10 m^2 by 1.2 m height) where the light generated by relativistic charged particles is collected. The amount of Cherenkov light allows to estimate the number of particles and, to some extent, to extract information about the muonic component: light particles are abundant but travel short distances in the water producing a blunt dim light; muons, however scarce, will trespass the whole tank producing light in its path that accumulates in a peak. Nevertheless, disentangling peaks from the underlying electromagnetic component is a complex procedure, and muon identification capabilities are limited.

The MARTA detector unit is a hybrid system composed of two sub-detectors: a water Cherenkov detector (WCD) sitting on top of resistive plate chambers (RPC). The WCD detects the shower particles (both the electromagnetic and the muonic component) and acts as shielding for the electromagnetic part, allowing for the RPC to detect only muons. Moreover, the signals in the two subdetectors can be combined to extract further information from the shower and reduce the systematic uncertainties through intercalibrations.

While WCD are the standard detector stations in Auger, adding RPC can considerably improve the measurement of showers performed by the Observatory. RPC are well-established and widely used gaseous detectors for charged particles. They are low-cost and robust detectors characterized by their high efficiencies and good spatial and time resolutions. The sensitive gaseous volume is enclosed withing glass resistive plates defining gas gaps. A uniform electric field is created in the gas gaps by applying a high voltage to the outer glasses, where a resistive layer is deposited. Whenever a charged particle crosses the detector it ionizes the gas, initiating an avalanche process that will induce a signal on the pick up electrodes. The glass structure is sealed in a plastic box on top of which is placed the readout plane with pickup electrodes. The avalanche induces a fast signal on the electrodes, which is then collected by the front-end electronics.

The LIP-Coimbra team holds world-leading expertise in RPC. For several years, the team pursued an R&D line on RPC for cosmic ray detection, able to operate outdoors under harsh conditions, with little maintenance. The RPC used in MARTA were designed to assure the correct operation at the Auger altitude, providing a good efficiency while operating with a low gas flow and low maintenance.

The engineering array of MARTA will consist of a hexagonal unitary cell of 7 Auger stations that will be transformed into MARTA stations. Each of these tanks will be emptied and lifted for the installation of a support structure that will hold the RPC detectors. This design and procedure were already tested using prototypes in the field. The structures have been produced locally and are going to be installed during this Austral summer.

Only a very small part of the Auger SD will be converted into MARTA stations. It was thus necessary to find the best place to install the detectors. Bearing in mind that higher statistics and correlation with other detectors is an advantage, the choice fell on the so-called Infill region: an area with a denser grid of detectors and thus a lower energy threshold. In the Infill region event rates are higher, and several complementary Auger detectors are installed. Such is the case of the AMIGA detector, a buried scintillator to detect muons. Unlike MARTA, AMIGA will have a different energy threshold with respect to the WCDs.

The installation close to AMIGA is important for both logistics and science reasons. Concerning logistics, AMIGA will provide power, communications and also synchronization with the full array. As for the science, this creates an opportunity to integrate the data, perform cross-calibrations and study the muon component just under the tank and about 3 m underground.

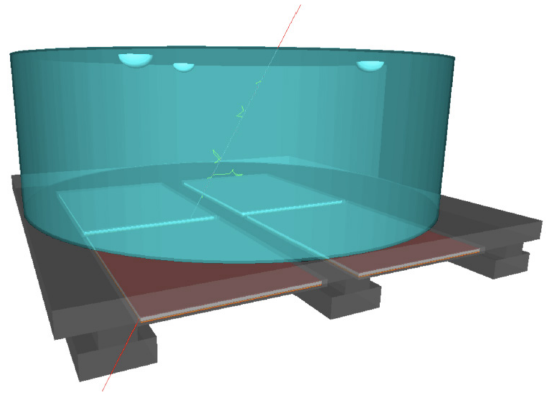

Figure 2: Representation of a MARTA unit with the RPC (in brown) under the water Cherenkov tank.

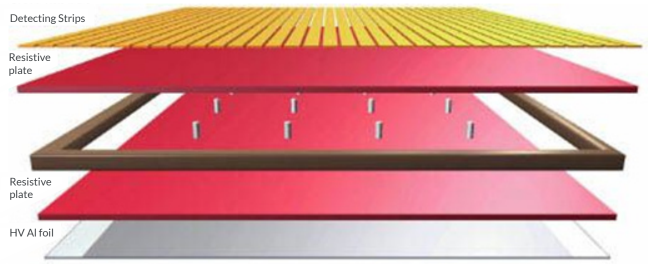

Figure 3: Structure of an RPC

Given the size of the EA and the cosmic ray flux, most of the recorded showers will have energies around 10^{17} eV. The equivalent center-of-mass energy for protons of this energy is roughly the energy achieved at the LHC (about 13 TeV). This means that the showers recorded with MARTA can be used to perform very strong tests to hadronic interaction models, in particular, to their ability to describe showers and consequently to be used to infer the UHECR mass composition.

Building MARTA

The MARTA EA is a Portuguese-Brazilian partnership, jointly funded by the science funding agencies in Portugal (FCT) and in the state of São Paulo, Brazil (FAPESP).

The gaseous volumes, the active part of the RPC detectors, are built at LIP-Coimbra. They then travel to São Carlos, in the state of São Paulo, Brazil, where the pickup modules and the enclosure boxes, which protect the system from the weather and from electronic noise, are built. The electronics developed at LIP, in Lisbon and in Coimbra, will then join in, to make a fully functional RPC detector.

The next journey takes the detectors to Malargüe, the home of the Pierre Auger Observatory. Upon arrival, some tests and verification are performed, to make sure everything is in perfect conditions. They will then be installed in the support structures and start detecting signals.

The MARTA EA project is well underway. In the next months we foresee the deployment of the support structures. All gaseous volumes have been produced. The first 20 detectors were concluded in Brazil and will be shipped to Argentina in early 2019. We foresee to install them and start taking data in the second quarter of 2019.

LIP's Electronics for Cosmic Ray Experiments Laboratory (e-CRLab) has recently completed the production of important elements of the MARTA EA data acquisition system (DAQ). The board Marta DAQ V consists of a MAROC3 ASIC with 64 analog entries controlled by an FPGA, which processes and transmits the data to a PC via USB or via two fast links. All the system had to be optimized for very low power consumption and high reliability, as it will be installed outdoor and have very little maintenance.

The main requirements of the MARTA front-end were:

- To be able to count particles for both the high and low particle density regions of the shower, using charge measurement when necessary;
- Fast signal digitization, to deal with the fast RPC pulses;
- Low power consumption (a few watts per64-channel RPC);
- Stable and reliable, for low maintenance operation;
- Compact design, due to space limitations inside the aluminum case;
- Trigger inputs and outputs for synchronization with the other detectors in the system;
- Fast lines for communication and data transfer;
- Power fail safe and watchdog mechanism to prevent any damage to the system.

The low power and compact design requirements made a system based on an ASIC much more appealing than one based on discrete electronics. The MAROC3 ASIC developed by the company OMEGA fills the criteria stated above with a power consumption per channel of 3 to 5 mW and a total area of 16 mm^2. It has 64 input channels, 64 discriminated outputs and is able to perform charge measurements.

The boards have been designed, optimized and produced at LIP. 55 DAQs have already been assembled at Systion, a Portuguese company. An intelligent error management system (watchdog) was also developed, allowing the MARTA DAQ to automatically recover from any error situation. Power supplies powering all the systems of the detectors with an efficiency of 97% have also been developed, and 40 of them are already produced. The gas system monitoring and the high-voltage power supplies have been fully developed at LIP-Coimbra.

In order to monitor the atmospheric conditions when the system is installed in the field, sensors for temperature measurements have been included. The sensors can be accessed using I2C by the FPGA or by an external device through a dedicated connector.

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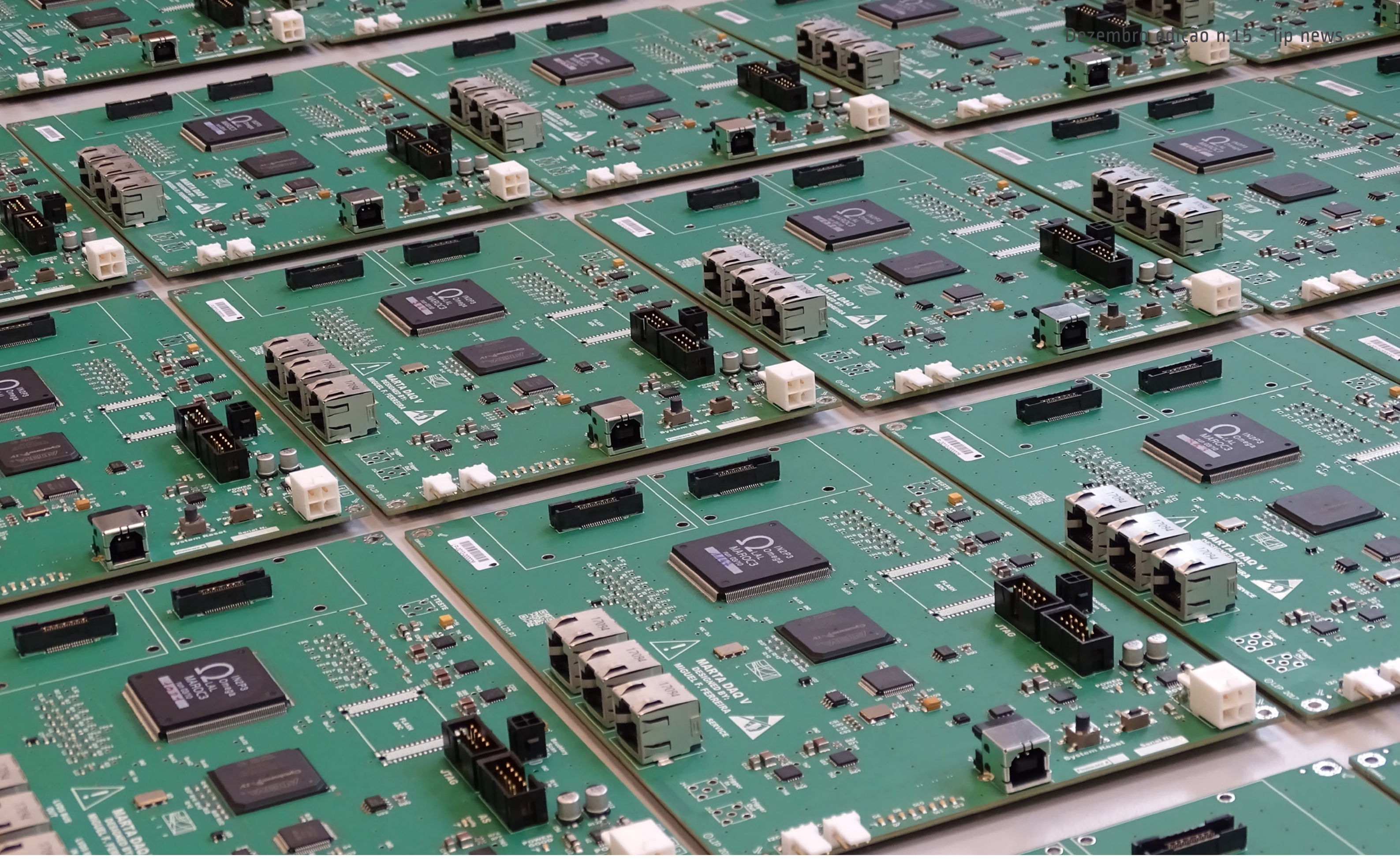


The MARTA DAQ in full detail

The signal is input into the pre-amplifiers, where a variable gain up to 4 is applied. It then goes on to three different branches: fast shaper branch, slow shaper branch and sum branch. The fast shaper branch is responsible for particle counting. The signal follows to one of the variable fast shapers and then to a discriminator, where a threshold is applied. The charge measurement is performed by the slow shaper branch. A variable RC circuit followed by an also variable slow shaper are applied to the amplified signal. The signal is then held by two sample-and-hold circuits and input into a Wilkinson ADC to be converted to digital. Finally, the sum branch outputs eight sums of the pre-amplified signals. A test input, Ctest, is available in an SMA connector and can simulate an input charge through a 1 pF capacitor. The 800+ configurable parameters of the ASIC determine, among others, which components are to be used (e.g. the fast shapers), what configuration is applied to this components (variable pre-amplifier, slow and fast shaper), the threshold ADC value and which channels use the Ctest as input. Crosstalk between channels in the MAROC is less that 1%.

The processing of digital signals is performed by a low power Intel Cyclone IV FPGA (EP4CE30F23C8L). This has a good balance of PLLs and I/Os, enough true LVDS pins and a good speed grade for this application. It is responsible for data management, data storage and the interface with the other components of the front-end. Firmware programming can be done using a USB blaster through active serial connected to an EPROM or using JTAG. While the EPROM saves the firmware and programs it to the FPGA each time the system is started, the JTAG allows for firmware debugging.

Trigger interface and communications between the FPGA and a concentrator central unit are implemented through high speed and low noise LVDS (Low Voltage Differential Signal) lines using RJ45 connectors. For versatility and debug, alternatives to this LVDS lines are available like a USB port using an FT2232HL chip for direct USB communication with a computer and SMA connectors routed directly to the FPGA. Additional features were added to the front-end to increase its flexibility and to assess the system performance. These include an analogue acquisition of the RPC signal, environmental and power monitoring and general purpose I/O ports. The analogue acquisition of the RPC is based on the digitization of the MAROC sum output by a flash ADC (up to 250 MHz) in a mezzanine board. In this way the sum of up to 64 signals can be acquired for the estimation of the total charge deposited or for calibration purposes. Such an ADC consumes a high amount of power when compared with the power available for this application. For that reason a switch connected to the FPGA is available that can disable it when this measurement is not necessary. There are also 8 single ended lines connected to 8 LEDs that can be routed to internal firmware flags, like for example if the ASIC is configured or not.

The DAQ PCB has 8 layers, where the top and bottom layer are ground planes to shield the analog signals. In order to avoid ground loops the PCB was stitched with ground vias. The power supply voltage used is 5 V, which is then regulated to 5 different voltages to be used by the components: 3,3 V for logic, 1 V for the FPGA core, 2,5 V for LVDS lines,1,5 V and 3,5 V for the ASIC. In the case of the ASIC bias, these are also filtered to guarantee a clean and stable supply. The RPC coaxial cables are soldered to a mezzanine board, which is connected to the front-end using MICTOR connectors to match the cable impedance. Transmission lines with 50 ohm impedance are then used to connect the front-end to the ASIC input to avoid reflections. In this way an equilibrated line is obtained from the pad to the MAROC.

The board is equipped with a system reset and a power boot switch to reset and reboot the front-end manually. A watchdog system was included as a power fail safe mechanism. In this way, whenever the power supply goes below or above a threshold voltage the system is turned off making sure that none of the components are affected. Boundary scan was also include for production quality control purposes, making it possible to test the connectivity between devices (FPGA, ASIC and external ADC).

The current version was produced in medium scale and all tests show performances as expected. The production yield is quite high (>90%) with minor problems. The next version is currently being designed to prepare for new versions of the ASIC.

A astrofísica multi-mensageiros

Alessandro De Angelis

Em 1610, Galileu publica o tratado astronómico “Sidereus Nuncius”, o primeiro trabalho científico baseado em observações feitas com o telescópio. No livro, Galileu comenta e interpreta a observação das montanhas da Lua, de centenas de estrelas nunca antes vistas, e dos satélites de Júpiter. Todas essas observações foram possíveis graça à luz emanada dos corpos celestes: segundo Galileu, a luz é o nuncius (mensageiro) das estrelas. A história dos mensageiros cósmico começa, portanto, com os fotões, as partículas de luz que representam os quanta do campo eletromagnético, e até hoje o fotão é o mensageiro supremo. Sendo neutros, os fotões não são desviados pelos campos magnéticos do Universo e da Via Láctea, e por isso é possível localizar as suas fontes.

Os humanos só conseguem ver uma parte muito pequena (por isso chamada “visível”) das ondas eletromagnéticas que formam os fotões. São visíveis ondas com um comprimento da ordem de algumas décimas de micrómetro, isto é, com energias da ordem de um eletrão volt (eV), cerca de 10^{-19} joule. São as energias que os electrões atómicos libertam quando transitam para um nível de energia mais baixo. E nosso cérebro interpreta as diferenças de energia e comprimento dessas ondas como cores. O azul do oceano tem uma energia 10% maior que o verde das florestas.

A partir da década de 1930, o espectro de ondas que conseguimos observar no cosmos tem-se expandido continuamente. Graças a novos instrumentos científicos começámos a ver novas “cores” invisíveis ao olho humano: as primeiras ondas rádio produzidas pelas estrelas, milhares de milhões ou milhões de vezes menos energéticas do que a luz visível; depois, as microondas e, finalmente, os raios X e raios gama, milhões e milhares de milhões de vezes mais energéticos do que a luz visível, directamente originados no coração dos geradores de energia dos corpos celestes. A história da astronomia entre 1930 e 2015 foi uma viagem à descoberta das “cores” do universo invisíveis a olho nu, e graças à comparação entre os sinais em vários comprimentos de onda aprendemos muito sobre a origem e a evolução do Universo.

Muitas das descobertas dos últimos anos foram devidas à detecção de fotões gama de alta energia. Em particular, demostrou-se que restos de supernova na Via Láctea aceleram raios cósmicos até alguns milhares de TeV, e que há grandes aceleradores que são sistemas binários dos quais um é um objecto compacto (um buraco negro ou uma estrela de neutrões). Observaram-se os mecanismos de acreção e radiação de buracos negros supermassivos noutras galáxias. Vimos lentes gravitacionais causadas por buracos negros com milhares de milhões de massas solares, que originam também o sinal gama detectado ainda ao fim de alguns dias. Tudo isso foi possível graças à novas tecnologias de detecção, geralmente provenientes da física de partículas. Mas os novos conhecimentos trouxeram novas perguntas. O que aconteceu nos primeiros momentos da vida do Universo? O que é a matéria escura que parece dominar a matéria no Universo? Como nascem e evoluem os buracos negros?

A ciência evoluiu de repente e, em parte, inesperadamente, nos últimos anos. Em Fevereiro de 2016, foi anunciada a primeira detecção de uma onda gravitacional. As ondas gravitacionais são produzidas na aceleração de massas com assimetria esférica. Elas deformam o espaço-tempo e aumentam e diminuem, com uma cadência constante, as distâncias no espaço em duas direções a 90 graus uma das outra, perpendiculares à direção do movimento da onda. O efeito é muito pequeno: para uma energia libertada correspondente a cerca de 3 massas solares, como no primeiro evento detectado pelo instrumento LIGO em 2015, o efeito relativo na Terra é de cerca de 10^{-22} — é como se a distância entre a Terra e o Sol variasse de um átomo. Einstein era da opinião de que a radiação gravitacional era pequena demais para ser detectada. Ainda assim conseguimos, graças à interferometria laser. Os dois detectores LIGO, separados por 3000 quilómetros, que à velocidade da luz implicam uma diferença de tempo de cerca de 10 milissegundos, são interferómetros de Michelson. Cada braço do interferómetro é composto por dois grandes espelhos separados por 4 quilómetros, suspensos numa plataforma de controle activa que realiza o isolamento sísmico.

Dois buracos negros orbitam um em torno outro e depois fundem-se enquanto emitem radiação gravitacional; o colapso dura alguns segundos na sua fase final. As ondas gravitacionais prometem uma revolução na astrofísica, abrindo uma maneira completamente nova de observar os eventos mais violentos do Universo: elas viajam desimpedidas à velocidade da luz e fornecem informações exclusivas sobre os primeiros momentos de colisões cataclísmicas. Pela descoberta das ondas gravitacionais, o Prémio Nobel da Física de 2017 foi atribuído a Barish, Thorne e Weiss.

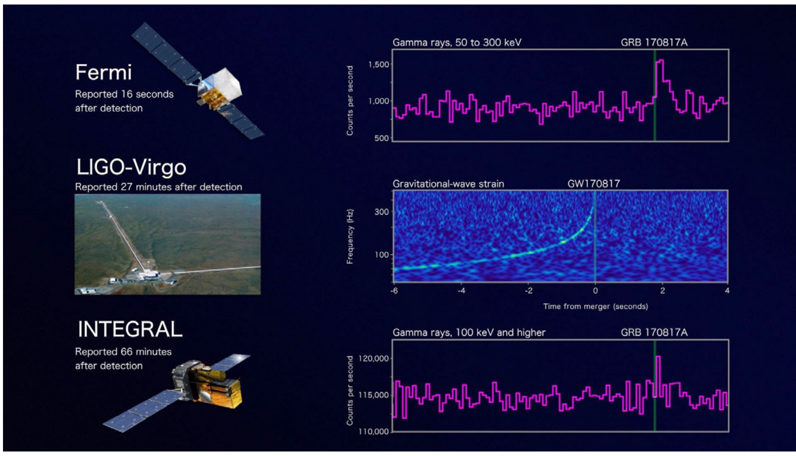


Figura 1 - Observação da onda gravitacional denominada GW170817 e, alguns segundos depois, do flash de raios gama GRB 1709817A. Fonte: ESA.

Em Outubro de 2017, outro anúncio revolucionário: pela primeira vez, ondas gravitacionais foram detectadas em conjunto com raios gama, no processo de fusão de duas estrelas de neutrões. Duas estrelas de neutrões em órbita uma em torno da outra perdem energia emitindo ondas gravitacionais e, ao longo do tempo, essa perda de energia aproxima-as cada vez mais, até que se fundem. Alguns cientistas sugeriram que a fusão de estrelas de neutrões poderia produzir a maioria dos elementos mais pesados que o ferro na tabela periódica, sendo, pois, fundamental para o desenvolvimento da vida como a conhecemos — é pelo menos claro que esses elementos têm de ser formados num ambiente rico em neutrões. Suspeitava-se de que o sinal de tal evento cobrisse rapidamente o espectro eletromagnético, dos raios gama aos raios X, luz visível e infravermelho. Alguns pensaram que uma das consequências poderia ser a formação de um flash de raios gama muito enérgicos. Por fim, todas as peças do quebra-cabeça se encaixaram com a observação de uma onda gravitacional feita pela colaboração LIGO/Virgo e, quase simultaneamente, de observações de flashes de fotões ao longo de todo o espectro eletromagnético realizadas por astrónomos e astrofísicos em todo o mundo (figura 1). Por um lado, isto confirma a hipótese de que a fusão de estrelas de neutrões produz flashes curtos de raios gama; por outro lado, estabelece as bases para os modelos de fusão nuclear suportados pela física teórica e por observações do mundo real. É um acontecimento raro ver algo novo, e ainda mais raro que isso confirme antigas teorias.

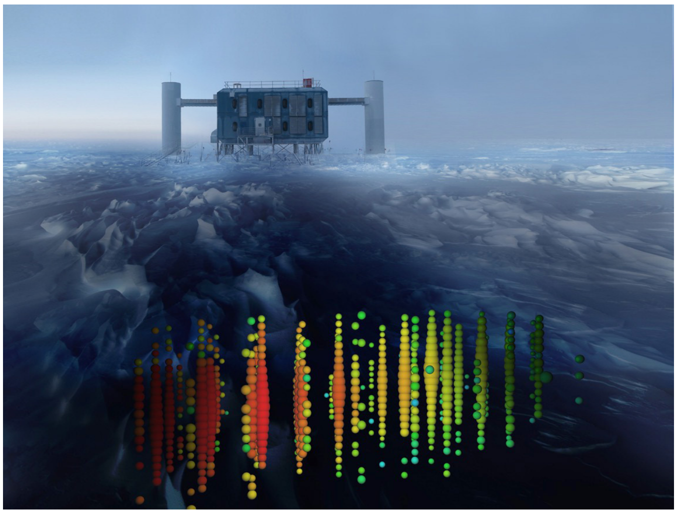


Figura 2 – Edifício do observatório IceCube no Pólo Sul e traço de um muão proveniente do neutrino de 300 TeV gerado pelo blazar TXS 0506 +056. Fonte: NSF.

Finalmente, em Julho de 2018, outro "big bang" na ciência. As colaborações IceCube, Fermi e MAGIC anunciaram a detecção simultânea de um sinal de raios gama e de um neutrino (figura 2) do blazar TXS 0506 +056, um buraco negro supermassivo (de milhares de milhões de massas solares) no centro de uma galáxia, que "engorda" rapidamente à custa da massa circundante, com jactos de energia que apontam para a Terra. Mais uma vez, conseguiu-se resolver um mistério: a comparação das energias de neutrinos e raios gama revelou que na vizinhança do blazar a matéria (núcleos de hidrogénio) é acelerada até energias dezenas de milhares de vezes mais altas que as do LHC, e revelou o mecanismo de produção de raios gama e neutrinos — colisões subnucleares entre protões e um "mar" de fotões de baixa energia.

As ondas gravitacionais e os neutrinos, tal como os fotões, "apontam" directamente para a sua fonte de produção: a observação simultânea de dois ou mais desses mensageiros abriu o campo da astrofísica multi-mensageiro, interligando ainda mais a física de partículas e a astrofísica. Hoje, podemos começar a responder a algumas das questões fundamentais que pareciam estar para além da fronteira do cognoscível. Depois de construir instrumentos capazes de observar novas cores, estamos a desenvolver novos "sentidos". Como o tacto, o olfato, a audição e o paladar nos dão informações sobre a realidade que nos rodeia, completando o que nos aparece pela visão, estamos agora a começar a colectar e a analisar novas informações de regiões remotas do Universo transmitidas por mensageiros diferentes da luz: raios cósmicos, ondas gravitacionais, neutrinos.

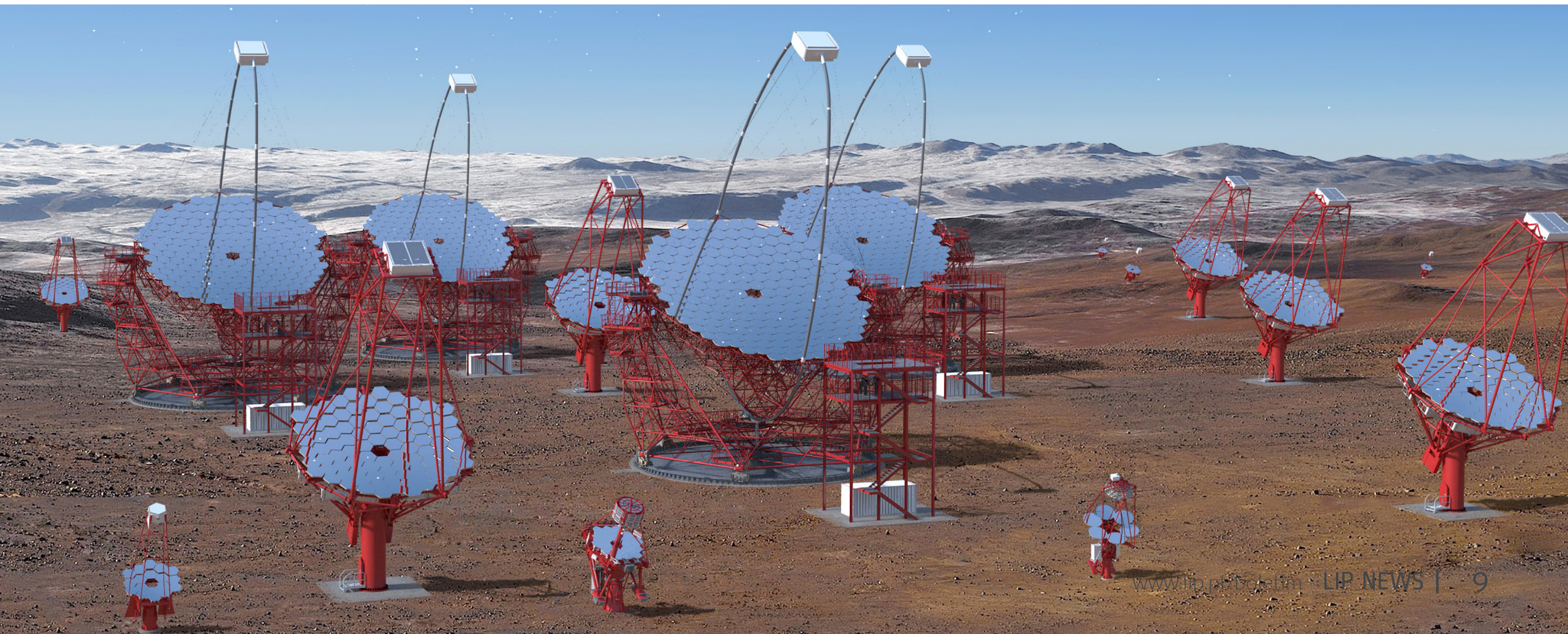
O que aprendemos nos primeiros três anos desta nova astronomia? Explicámos o mecanismo que gera a explosão de raios gama curta (coalescência de estrelas de neutrões) e longa (colapso de supernovas de grande massa), até há alguns anos um quebra-cabeça astrofísico. Revelámos uma galáxia que emite simultaneamente neutrinos e raios gama, descobrindo no seu centro um acelerador de dezenas de milhões de GeV. Vimos como os átomos mais pesados que o ferro são criados, e isso é importante para compreender a vida. Descobrimos que o Universo é surpreendentemente cheio de "pequenos" buracos negros de massas de algumas dezenas de massas solares.

O que planeamos fazer e aprender nos próximos dez anos? Novos satélites sensíveis a fotões na região de energia entre o MeV e o GeV e novos instrumentos na Terra sensíveis a fotões de centenas de GeV (como o telescópio CTA, figura 3) e mais além abrirão o caminho para a compreensão dos mecanismos de produção das energias mais elevadas do Universo e, provavelmente, a descoberta de novos fenómenos físicos, em particular em sinergia com detectores de neutrinos e de ondas gravitacionais. As cores dos fotões serão enriquecidas com novos sabores no contexto multi-mensageiro.

Esta década será lembrada na história da ciência pelo nascimento da astronomia multi-mensageiro, e telescópios inovadores prometem agora descobertas revolucionarias. Estamos a construir instrumentos científicos cada vez maiores e tecnologicamente mais avançados. IceCube, que revelou o primeiro sinal de neutrino, é um instrumento com um quilómetro cúbico situado no gelo da Antártida — vamos ter que aumentá-lo para 10 quilómetros cúbicos. O Cherenkov Telescope Array (CTA) cobrirá superfícies centenas de vezes maiores que os telescópios de raios gama actuais. Novos satélites exigirão novas tecnologias no campo de detectores de silício e detectores de luz sensíveis a um só fotão.

Para saber mais: A. De Angelis and M. Pimenta, "Introduction to particle and astroparticle physics: multimessenger astronomy and its particle physics foundations", 2nd edition, Springer-Nature 2018.

Figura 3 - Rendering do sistema multi-telescópico CTA, em construção. Fonte: CTA.



LHC em paragem para preparar o futuro

Que balanço e que desafios?

No dia 3 de Dezembro de 2018, de manhã cedo, na sala de controlo do CERN, os operadores desligaram o Large Hadron Collider (LHC), dando por concluído o muito bem sucedido segundo período de funcionamento (run 2) do mais poderoso acelerador de partículas do mundo, iniciado na primavera de 2015. O complexo de aceleradores do CERN estará parado durante cerca de dois anos para profundos trabalhos de melhoramento e renovação. Os protões voltam na primavera de 2021, para colisões a 14 TeV e em maior quantidade.

O Boletim perguntou aos responsáveis dos grupos portugueses em CMS e ATLAS que balanço fazem do run 2 e quais as expectativas para o futuro.

João Varela, CMS

1. Este run 2 do LHC durou cerca de 3 anos e meio. Que balanço fazes?

Tanto da parte do acelerador como da experiência o balanço é notável. Durante o Run 2, o LHC forneceu colisões de protões (pp) à energia recorde de 13 TeV. Trata-se de um aumento considerável relativamente ao período de tomada de dados anterior (7 e 8 TeV no Run 1) e o maior previsto para o LHC. CMS acumulou neste período uma luminosidade de mais de 150 fb^{-1}, uma quantidade de dados mais de 5 vezes superior à do Run 1. Estes dois elementos por si só significam um aumento considerável da sensibilidade das buscas de fenómenos novos e raros e da precisão das medições. Entre os variadíssimos resultados já alcançados destaca-se no sector de Higgs a detecção dos acoplamentos Yukawa aos fermiões da 3ª família. Também no caso das colisões de iões pesados, a energia por nucleão quase duplicou e a luminosidade acumulada aumentou de um factor de cerca de 10. Tal permitiu, por exemplo, que mesões B tivessem sido reconstruídos pela primeira vez em iões pesados (PbPb) e a que o quark top tivesse também ele sido detectado em colisões protão-chumbo (pPb) – fornecendo assim novas sondas para o estudo do QGP.

2. Evidentemente que ainda há muita análise de dados em curso, mas que resultados destacarias como fruto do trabalho do grupo do LIP?

Efectivamente, embora este período de tomada de dados tenha terminado, tal não quer dizer que a totalidade dos dados tenha sido explorada. Antes pelo contrário — por exemplo, os dados acumulados durante 2018 (cerca de 40% do Run 2) deverão ser ainda processados, com as calibrações detalhadas do detector. Enquanto que a tomada de dados de iões pesados essa acaba apenas de terminar. Há portanto muito trabalho e oportunidades de análise e potencial de descoberta com base na elevada quantidade de dados acumulados durante o Run 2.

O grupo do LIP tem explorado o novo limiar de energia em colisões pp alcançado pelo LHC no Run 2 para realizar medidas de base, nomeadamente de produção dos quarks top e b (medidas de secção eficaz, fragmentação, polarização). Realizou buscas directas de novas partículas, tais como do parceiro supersimétrico do quark top, e buscas indirectas através do estudo de decaimentos raros de mesões B. O envolvimento do grupo no sector do Higgs tem também várias frentes — produção de pares de Higgs, decaimento para um par de leptões τ, e decaimentos raros para quarkonia e fotão — todos eles sensíveis a potenciais efeitos de nova física. O grupo do LIP liderou o desenvolvimento do novo espectrómetro de protões (CTPPS), e com os dados acumulados com este detector em 2016-17 produziu a medição da produção exclusiva de pares de leptões. No que respeita a iões pesados, temos estado envolvidos primariamente no estudo de mesões B como novas sondas do plasma de quarks e gluões.

3. É o fim do run 2 mas ainda há muito LHC pela frente. No imediato, quais são os maiores desafios?

Os principais desafios — ou melhor, oportunidades! — para os próximos dois anos, em que o LHC estará parado para melhoramentos, envolvem a análise de física dos dados já acumulados e o desenvolvimento do detector para a fase de alta luminosidade do LHC (HL-LHC). Com efeito, e em paralelo com o desenvolvimento de análises com os dados do Run 2, o grupo realizou estudos da sensibilidade (nomeadamente de $B\rightarrow\mu\mu$ e $HH\rightarrow\tau\tau bb$) que poderá ser alcançada nos runs futuros, decorrentes da elevada quantidade de dados (300 fb^{-1} no Run 3 até 2023, e 3000 fb^{-1} até 2037) e dos melhoramentos planeados para o detector CMS. O grupo está activamente envolvido nestes melhoramentos, nomeadamente dos calorímetros electromagnético e hadrónico, e principalmente no futuro novo detetor temporal, BTL, no qual o LIP tem uma posição de liderança no desenho e construção do sistema de leitura de dados.

Patricia Conde Muiño, ATLAS

1. Este run 2 do LHC durou cerca de 3 anos e meio. Que balanço fazes?

Acho que o balanço é, definitivamente, muito positivo. O LHC conseguiu atingir os objectivos pretendidos em termos de luminosidade total integrada, 150 fb^{-1} de colisões protão-protão, para as duas grandes experiências, ATLAS e CMS, e também de colisões de iões pesados Pb-Pb (aprox. 1.2 nb^{-1}), protão-Pb, e ainda Xe-Xe. E as experiências conseguiram registar e processar esses dados. Do ponto de vista de ATLAS, é de destacar a alta eficiência de aquisição de dados, 94%, assim como a alta fracção de dados com boa qualidade para as análises de física (também 94% dos dados adquiridos). Este êxito foi possível graças ao esforço da colaboração durante os últimos quatro anos, para pôr a funcionar e operar um detector com importantes melhorias em relação ao Run 1, assim como para monitorizar a qualidade dos dados e resolver possíveis problemas prontamente. O grupo português de ATLAS contribuiu para este esforço com entusiasmo e dedicação nos sistemas de controlo do calorímetro hadrónico TileCal e dos detectores *forward* (ALFA, AFP), trigger de jactos, identificação de jactos b em colisões de iões pesados, operação do sistema de computação distribuída, calibrações, etc. Os dados que adquirimos foram utilizados já para inúmeros estudos de física, muitos dos quais ainda estão em andamento, por forma a tirar o melhor proveito da luminosidade total integrada e dos melhores métodos de calibração (ainda em desenvolvimento ou afinação).

2. Evidentemente que ainda há muita análise de dados em curso, mas que resultados destacarias como fruto do trabalho do grupo do LIP?

O grupo do LIP teve um papel de relevância/liderança em muitas análises. Por um lado estão as medições de processos previstos pelo Modelo Padrão, em que se destacam dois resultados que confirmaram de forma directa a interação do bosão de Higgs com os quarks da segunda família: a primeira observação do Higgs a decair em pares de quarks b e observação da produção associada do Higgs com pares de quarks top. Ambos os canais são afectados por fundos muitos grandes, sendo o sinal do Higgs muito difícil de observar, daí ter-se demorado tanto tempo a chegar a uma significância suficientemente grande. O nosso grupo está envolvido nestes estudos há muito tempo, tendo contribuído para melhorar as análises a diversos níveis: calibrações, métodos multivariáveis, combinação estatística. Os resultados observados são compatíveis com as expectativas do Modelo Padrão, que descreve a interação do Higgs com os quarks através de um acoplamento de Yukawa, mas serão precisos muitos mais dados para poder medir com precisão ambos os acoplamentos.

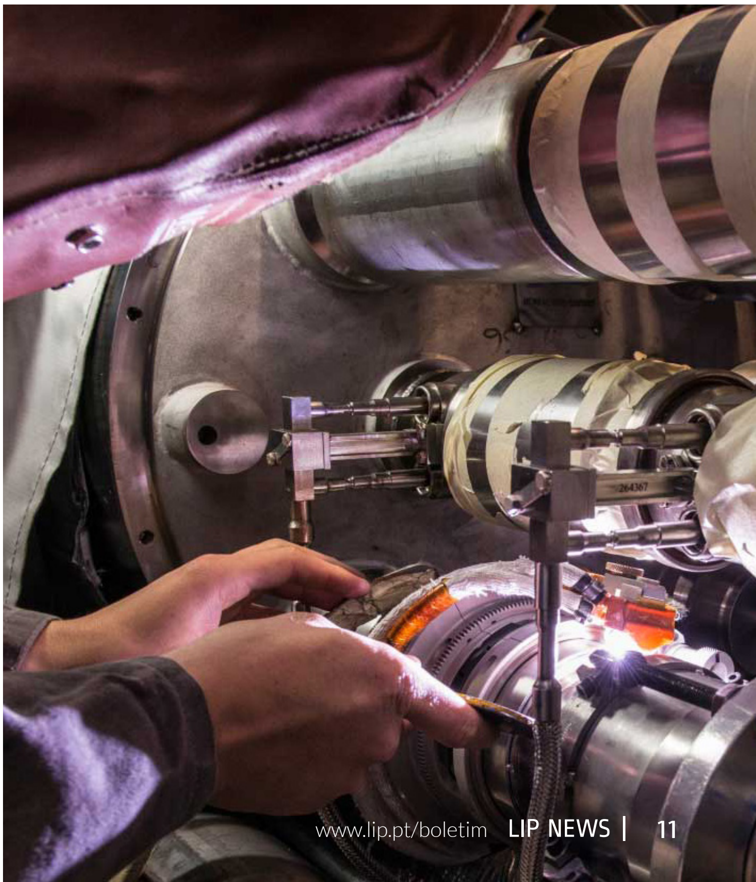
Por outro lado, temos avançado também muito nas pesquisas de nova física. O nosso grupo contribuiu directamente para dois resultados de grande relevância: as pesquisas de correntes neutras com mudança de sabor (FCNC na sua sigla em inglês) e as pesquisas de quarks vectoriais. Se o Run 1 do LHC trouxe medidas de precisão das propriedades do quark top, no Run 2 o top apresentou-se como uma das ferramentas fundamentais para pesquisas de nova física. As FCNC nos decaimentos do top no Modelo Padrão são altamente suprimidas, enquanto modelos de nova física permitem valores suficientemente altos para serem observados no LHC. O nosso grupo lidera duas das análises que procuram FCNC, uma delas na produção e outra no decaimento do quark top. Nenhum sinal foi observado, pelo que limites na fracções de decaimentos para $t \rightarrow uZ$ e $t \rightarrow cZ$ foram obtidos com a combinação das diversas análises, e estendidos até valores de 0.017% e 0.023%, respectivamente. Estes resultados constituiram os limites mais fortes a nível mundial na altura da sua publicação. No Modelo Padrão a massa tão pequena do bosão de Higgs é difícil de explicar, porque precisa de correcções muito grandes que se cancelam "miraculosamente". Muitas das teorias de nova física que tentam explicar a massa do bosão de Higgs contêm quarks vectoriais, quer dizer, um novo tipo de quarks com propriedades específicas de transformação do grupo de simetrias do Modelo Padrão (as suas componentes direitas e esquerdas transformam-se da mesma forma). O nosso grupo lidera uma das análises, no canal Zt/b+X, e contribui ainda para a combinação de todas as análises. Os últimos resultados foram publicados recentemente e destacados numa das "Physics Briefings" da colaboração ATLAS.

Com respeito às colisões de iões pesados, os dados acabam de ser tomados, e as análises estão em curso. Tendo contribuído no Run 1 para a observação e medições posteriores da assimetria de produção de jactos, uma das assinaturas mais claras do plasma de quarks e gluões (QGP), o próximo passo é estudar como se comporta esta assimetria para quarks pesados, ou seja, os quarks b. Este estudo é fundamental para perceber melhor a natureza da perda de energia dos quarks à medida que atravessam o QGP, e em particular ajudará a elucidar se esta é por radiação ou por colisões. Foi preciso desenvolver e optimizar algorítmos de identificação de jactos b em ambientes extremadamente densos, como são as colisões de iões de chumbo, um esforço que o nosso grupo também lidera. As análises estão em andamento e esperamos ter resultados num futuro próximo.

3. É o fim do run 2 mas ainda há muito LHC pela frente. No imediato, quais são os maiores desafios?

O maior desafio neste momento está na diversidade de actividades que estão em andamento: por um lado, a construção e preparação do Run 3, que requer intervenções para melhorar os nossos detectores, enquanto terminamos, em paralelo, as análises do Run 2, com a melhor precisão possível. O nosso grupo é responsável pela preparação e controlo de qualidade das fibras WLS (deslocamento de comprimento de onda) que leem os cintiladores instalados na região de separação entre calorímetros. Nessa região, o nível de radiação é muito grande, que exige mudar tanto os cintiladores como as fibras. As actividades de preparação das fibras estão em desenvolvimento no laboratório LOMaC neste momento.

Além deste esforço, estamos também a preparar a Fase II dos Upgrades, que acontecerão em 2024-25 (durante a paragem técnica que se seguirá ao Run 3). Mesmo faltando ainda muito tempo para isso, a Fase II implica uma mudança muito grande nos detectores, que terão de ser capazes de operar com luminosidades instantâneas entre 5 e 7 vezes maiores que aquelas para as quais o detector ATLAS foi desenhado. O nosso grupo é o responsável pela produção do novo sistema de distribuição de alta tensão do TileCal, e pela produção das placas de comunicação do sistema de trigger de traços (HTT = Hardware Track Trigger), assim como pelo desenvolvimento de algorítmos de trigger que utilizem placas gráficas ou outro tipo de aceleradores de hardware. Os protótipos estão a ser produzidos agora, incluindo um demonstrador que será instalado no detector ATLAS durante a paragem técnica, e o trabalho tem também de ser desenvolvido em paralelo.



HEP circa 2018

Current (selected) highlights in high energy physics

Nuno Leonardo

On occasion of its 50th anniversary, the standard theory of particle physics (SM) appears alive and well. A wealth of experimental data renders it, until further notice, as an admirable and unexpectedly robust effective theory up to the TeV scale. Some conspicuous, tantalising departures from its expectation emerge nonetheless from the data. The journey towards establishing new physics (NP) is actively pursued in different and complementary ways. The end of LHC Run 2 offers a timely occasion to take stock.

Higgs

Six years after the discovery of the 125 GeV scalar, the direct observation of all its main production and decay modes has been achieved. The recent observations by ATLAS and CMS of the H decay to τ-lepton pairs, of its decay to b-quark pairs, and of ttH, amount to the direct detection of the couplings to the third generation fermions — and of a new kind of interaction, i.e. Yukawa's. Access to the lighter generations is however considerably more challenging, as the involved processes are either rare or drowned in the sea of QCD background. While the sensitivity to the H decay to a muon pair is well within the Run 2+3 reach, the limits to charm lie currently two orders of magnitude above SM expectation. As for the self-coupling, accessible via HH production, the reached sensitivity is about 13xSM. A precision on the mass measurement at permill level (0.2%) and on the cross section within 10% of the SM has been reached. Remarkably, the scalar we call Higgs has now joined the flavour and gauge sectors in the era of the differential measurements. And while all seems to align well with the SM expectation, the name of the game is to detect potential deviations in precision measurements of its properties hinting towards NP effects.

Electroweak

A large suite of processes, many accessed for the first time or probed with increasingly high precision, involving in particular the vector bosons, the b and top quarks, in addition to H, results in an impressive agreement with the SM expectations — confirming its robustness as an effective theory up to the energies probed so far. Some tensions ($<2\sigma$) are nonetheless detected between direct measurements and global SM fits, e.g. in the CKM gamma angle or the H mass constrained from those of W and top. The large top-quark data set that has been accumulated at the LHC is used for searching for rare and NP sensitive decays. Previously detected deviations in top spin correlations in Run 1 data have reached the 3σ mark with 2016 data; these seem not to be confirmed however with additional data and improved calculations (NNLO). This well demonstrates the need for improved simulation tools, to match the unprecedented level of precision that is being attained in the data. Associated production of single top and Z (tZq) is an example of a recent observation, obtained with only part (half) of the Run 2 data. This illustrates the potential for exploring even rarer and FCNC NP-sensitive processes.

Flavour physics

A wealth of flavour enriched data sets is allowing to reach unprecedented levels of precision and to explore new observables and rare processes — that are highly sensitive to NP. Tests of the CKM paradigm and charge-parity violation (CPV) have benefitted from large precision improvements from both theory and experiment. The least well measured angle (γ) of the unitary triangle has now reached a 5° precision. SuperKEKB, the first new collider since the LHC, has delivered first collisions this year. Belle II is having a successful commissioning run and with the targeted 50 ab^{-1} (by 2025) significant levels of precision are projected. In the strangeness sector, new results from NA62 (charged kaon) and KOTO (neutral kaon) are approaching SM expectations. On the charm front, LHCb observed the rarest (D meson) decay yet, and various new decay processes have been observed and corresponding absolute branching fractions measured with BESIII operating at threshold. On the beauty realm, following the flagship Run 1 observation of $B_s \to \mu\mu$, further precision and additional, mixing-related observables are pursued in the B_s system, along with the search for the rarer B^0 channel, by the LHC experiments. Searches for (charged) lepton flavour violation are pursued, through transitions of muon to electron with various efforts being prepared (MEGII, COMET, Mu2e, Mu3e), and tau to muon (LHC, Belle II, SHiP). As for the long-standing tension of the anomalous magnetic moment of the muon, at the level of about 4σ, significant advancements are being achieved, in lattice calculations and form-factor determination from electron-positron data, and especially with first results from the muon g-2 experiment at FNAL expected next year. A more recent set of anomalies in the flavour sector is highlighted separately (see page 12).

Direct searches (for new heavy particles)

Direct searches for NP particles are conducted across the energy spectrum, from sub-GeV to multi-TeV scales. At the LHC, this being a paramount goal, an increasing multitude of final states, involving a variety of combinations of physics objects (H included), is pursued. Missing momentum signatures have been explored thoroughly since the turn-on of the LHC. Very massive states result in highly boosted topologies, for which dedicated reconstruction techniques have been more recently developed and deployed. Additional, less standard signatures are increasingly explored, with the goal of leaving no stone unturned. A compelling class of the exotic flavour consists of long-lived scenarios, which could leave striking signals in the detectors. Current exclusion limits depend on benchmark models adopted and range from ~ 0.1 to 10 TeV in the mass dimension. Other dimensions (e.g. couplings, lifetime) are further probed. The so-called flavour anomalies detected at lower energies are motivating a renewed and dedicated look into high mass spectra, and their tails. Searches for new gauge bosons (Z') and especially leptoquarks (LQs) are as a result particularly trendy right now.

Quantum Chromo Dynamics

Studies of QCD are important for improving our understanding of the underlying theory, the structure and formation of hadrons, the behaviour of hadronic matter at high temperatures/densities, as well as means for searching for new phenomena. Some of the puzzles being pursued with different machines and energies (from few GeV to TeV) relate to hadron spin, hadron production, and hot medium properties. In the spectroscopy realm, some new hadrons have been reported, both expected (conventional) and unexpected (exotic), some with independent confirmation and others still lacking it (e.g. Bc(2S), X(5568)). While by now more than 30 exotic hadron (XYZP) states have been detected, no model interpretation seem to offer a whole picture. In the heavy ion front, large advancements continue to be achieved using different collision types, systems, energies, probes. A variety of hadron states, some of which reconstructed for first time in ion collisions, provide a rich set of information on sequential melting, energy loss mechanisms and collective behaviour. QGP-like effects are detected also in smaller systems (pp, pPb), implying a rupture with the traditional paradigm: small systems are more than just a baseline. In the theory front, lattice QCD entered a precision era for simple systems (flavor, g_μ-2, pdf) and begins reliable calculations for larger systems (namely nuclei, needed also for neutrino and dark matter studies).

Neutrinos

20 years after the observation of neutrino oscillations, there are good prospects for studying CPV in the leptonic sector. T2K data already gives first CPV hint, with null $\sin(\delta_{CP})$ excluded at 2σ level. NOvA provides evidence (at 4σ level) of electron anti-neutrino appearance. The normal hierarchy seems favoured by data (three experiments T2K, NOvA, SK at 1-2σ each), with the inverted hierarchy being disfavoured at the 3σ level. MiniBooNE, with doubled dataset, reinforces the LSND signal (yielding a combined significance of 6σ); while this anomaly favors the sterile neutrino hypothesis, models for the latter fail nonetheless to account for all available data. With double beta decay observed for 12 nuclei, neutrino-less double beta decay searches start pressing, reaching the 100 meV mark, with improved sensitivities reachable in medium and long term projects that are taking shape. Ongoing but also upcoming endeavours, both reactor— (e.g. JUNO) and accelerator—based (e.g. DUNE), will allow a comprehensive program of neutrino oscillation studies, leading to precision measurements of the PMNS matrix elements, and the paramount determination of CPV in the lepton sector as needed insight into the origin of the matter-antimatter asymmetry.

Dark sector

Searches for dark photons (that couple/mix with the SM counterpart) are pursued at different colliders (including B factories and LHC), probing mass ranges from 0.01 to 100 MeV. Dark matter (DM) is searched for at colliders through initial-state radiation or associated production, leading to mono-object plus missing-mass signatures, among others; limits are reported for mass ranges from sub-GeV to TeV scales. Direct DM searches are pursued by a multitude of experiments, ongoing and planned. Amongst the diverse paths probed, WIMPS and axions are emphasised. Limits on WIMPS continue to be pushed at both high and low masses (approaching the 'neutrino floor'). The most recent bound reported is by XENON1T. The DAMA/LIBRA signal (at 13σ significance) remains unresolved, lacking independent confirmation, which is being pursued. Axions, offering to address two problems at once (strong CP and DM), are actively searched for in a variety of ways, with a fair number of projects also planned.

Cosmic front

New results arrive from space-borne experiments, exploring cosmic rays with energies up to TeV. The rise with energy of the positron to electron flux reported by AMS, inline with earlier Pamela findings, may not be describable by propagation models or astrophysical sources, and remain thus as hint of primary origin, namely TeV dark matter. Improved sensitivity is expected through the ISS lifetime ca. 2024. Rigidity (p/Z) spectra are found similar for p, p^-, e^+, and differ from e^-; differ also between primary (p,He,C,O) and secondary (Li,Be,B) cosmic rays, with N flux (primary+secondary components) sitting in between. New results reported on secondary/primary (e.g. B/C) ratios. Several unexpected results, with improved theory predictions badly needed. Following the 2017 gravitational wave event detected by LIGO/Virgo and associated gamma rays subsequently detected by several detectors; the detection of the September 2017 IceCube 290 TeV neutrino event then followed by associated photon observations in ground and space; are certainly important coordinated milestones, identifying and revealing complementary information about the sources of the detected astrophysical objects. More on the newborn paradigm of multi-messenger astronomy in the article by A. De Angelis (page 8).

Wrap-up

A wealth of experimental data along with advancements in theoretical computations are facilitating unprecedented reach and precision. The large suite of precise measurements matching the expectation from the standard theory, the observation of its scalar, followed more recently by that of the Yukawa interaction, and the absence of unambiguous direct signals beyond it, leave the SM reinforced as an effective theory up to the electroweak symmetry breaking scale and arguably beyond into the TeV scale. That NP has not been unequivocally and prominently revealed by the data so far may be due to it featuring relevant signatures beyond those so-far probed, it coupling very weakly to the SM sector, or its scale lying above that directly accessible at present colliders. All these possibilities are complementarily targeted by the energy, intensity, and cosmic HEP frontiers. Various anomalous signals have however been hinted already in the data. The majority of the anomalies tend to come and go, with additional data and independent inspections (recall e.g. the 750 GeV $\gamma\gamma$ excess from three years ago). Some anomalies however remained or got reinforced. This gives tantalising evidence that NP is within reach, and that it may soon be established, with data already collected or soon to be gathered. The path towards establishing NP may well be through extended correlated analyses of ensembles of sensitive observables across the board — in a multi-messenger fashion. Data is bound to tell — and plenty of it is already or will be there for us to exploit and learn from.

Disclaimer: This overview of current highlights in HEP is, of necessity, not comprehensive — it reflects a personal selection of topics. It stems from preparing the summary talk at BEACH 2018 and participation in ICHEP'2018 and other HEP gatherings over the last months.

Poster of ICHEP 2020, to be held in Prague. A diagram imprinted on the wall illustrates one of the main processes and observables through which the so-called “flavour anomalies” are detected. This illustrates the relevance of such anomalies, and the excitement by the community at large, towards the goal of establishing signs of phenomena beyond the standard model of particle physics.

Flavour Anomalies

First hints of New Physics at the LHC?

Nuno Leonardo

Over the last few years, a persistent set of deviations from the Standard Model (SM) predictions has emerged from the data. These have been detected in decays of b-quark hadrons. While the deviations are not sufficiently significant if considered individually, when taken together they are. These so-called "flavour anomalies" stand currently as a most exciting indication of New Physics (NP) and a hottest topic in the field of HEP at the moment.

New phenomena beyond the standard theory of particle physics are pursued in a multitude of paths. At the LHC, a main path, which explores the energy frontier, aims at directly detecting new heavy particles, beyond those of the SM. These NP particles may be produced in the collisions, and their presence detected through the products of their decay. Another path, which explores the luminosity frontier, aims at detecting the presence of NP indirectly, through precision measurements. Here, NP particles may virtually contribute to the amplitude of SM-allowed processes, and be revealed through measured deviations relative to the SM expectation, in observable particle properties. The two approaches are complementary and each is actively pursued by exploring a large variety of processes.

Hints of the presence of NP may accordingly be revealed through excesses in distributions (e.g. a bump in the mass spectrum) or measured deviations (e.g. on a particle's decay rate). And as it happens, several such hints, of both kinds, have turned up in the LHC data. However, so far, none of sufficiently high statistical significance, so as to unequivocally exclude possible background fluctuations as their source. Nonetheless, in the case of certain b-hadron decays, several such deviations from theory expectation seem to conspire together — while each individual deviation is still not significant *per se*, the coherent pattern displayed by their ensemble is.

Each deviations is associated to one of two underlying b-quark transitions: (i) $b \to sll$, i.e. bottom to strange quark plus pair of opposite-charge leptons, and (ii) $b \to cl\nu$, i.e. bottom to charm quark plus charged lepton and neutrino. The former can occur only at loop level in the SM (flavor changing neutral current, that is forbidden in SM, at tree level), with high sensitivity to NP (where NP particles can run in the loops). The latter (charged current) occurs at tree level.

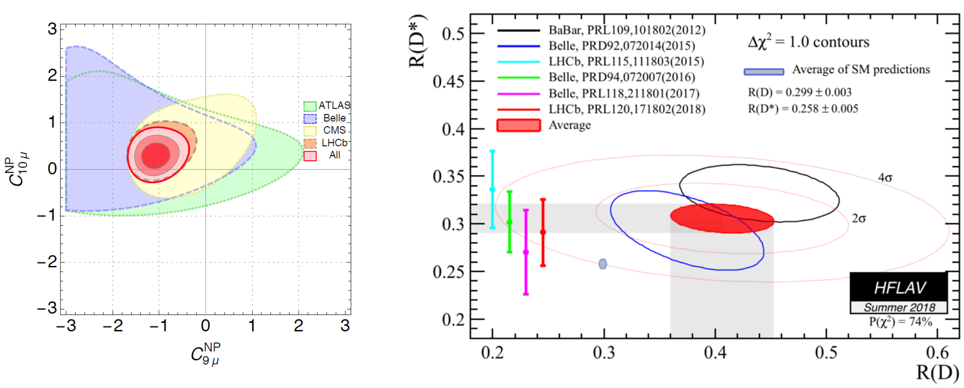
The neutral-current transitions, $b \to sll$, are realised in various rare B decays, both leptonic, e.g. $B_s \to \mu^+\mu^-$, and semileptonic, e.g. $B \to S\mu^+\mu^-$, where S stands for a strange-quark hadron (e.g. K, K*, Φ, Λ). In addition to decay rates, the latter class offers many NP-sensitive observables associated to the angular distributions of the decay products. Deviations are detected with varying degree in many of these. The departure from theory was initially detected by LHCb in one such angular observable, denoted P'_5, in the decay $B^0 \to K^{*0}\mu^+\mu^-$. It should be remarked here that for this decay a challenge arises in calculating the theory predictions — specifically, going from the underlying quark-level transition $b \to sll$ to the experimentally observed B-meson decay, there are QCD contributions involved whose estimation is non-trivial. And while the P'_5 observable is constructed in such a way as to be more robust in terms of such QCD ($B \to S$) form-factor determinations, some debate persists on the theory front.

There is another major chapter in the saga of flavor anomalies. And this time perhaps even more dramatic: it involves violation of lepton flavor universality (LFU). Apart from the differences in their masses, the SM interactions do not distinguish between the different leptons. This means, for example, that the rates of the decays $B^0 \to K^{*0}\mu{+}\mu{-}$ and $B^0 \to K^{*0}e^+e^-$ involving muons and electrons should be comparable.The LHCb data has however revealed that their ratio, R_{K^*}, seems to display a noticeable departure from unit. Important to remark here is that the above-mentioned form-factor uncertainties cancel in the ratios, rendering these observables rather robust theoretically. Indications of LFU violation had actually been also detected earlier at the B factories (BaBar and Belle experiments), between taus and muons, in the decays $B \to D^{(*)}\tau\nu$ and $B \to D^{(*)}\mu\nu$, where the corresponding ratios, R_D and R_{D^*}, exhibit departures from their SM expectations (see figure). These were quite unexpected, with the underlying transitions $b \to cl\nu$ occurring at tree level.

Naturally, the anomalies have raised a large excitement amongst both experimentalists and theorists. After all, the ensemble of anomalies when interpreted collectively appear to indicate a departure from the SM, with a significance above the 5σ mark (see figure). Theorists have been actively putting forward classes of models that attempt to explain the anomalies, along with other tensions in the flavor sector, e.g. $(g\text{-}2)_\mu$, while simultaneously accommodating other experimental constraints, e.g. from B_s mixing and dilepton mass spectra. Among these, models with extra gauge bosons (Z') or leptoquarks (LQ) appear to be favoured.

From the experimental side, a clarification will be sought by thoroughly exploiting the LHC Run 2 data. Not only will the LHCb measurements be repeated to reach increased precision, contributions from ATLAS and CMS will offer independent input with orthogonal systematics. For example, during 2018 a large, dedicated dataset has been collected by CMS specifically for this purpose. Belle2 is coming online, and within a few years its data will provide decisive input. Dedicated searches for scenarios addressing the anomalies, including Z' and LQ, will be pursued at the LHC.

Whether the source of the anomalies turns out to be more mundane statistical fluctuations, underestimations in theory calculations, or genuine NP, it is exciting that a clarification is within reach over the next few years. A confirmation of these flavour anomalies would point to new particles or interactions and have profound implications for our understanding of particle physics.



Current status of the flavor anomalies. Left: Global fit to $b \to sll$ observables, with results projected on the plane of two EFT coefficients. Right: Fit to $b \to cl\nu$ observables. The red elipses represent the regions favoured by the data. The SM lies at the origin (0,0) of the left plot and on the small region at about (0.3,0.25) on the right plot. The tension between data and SM is clearly visible.

// INVITED TALK

Towards a high-precision description of multi-particle final-states at the LHC

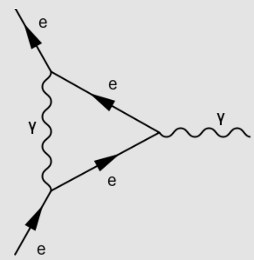
João Pires (CFTP)

The past four years of data taking at the LHC have been amazingly successful. As we approach the end of Run 2 both ATLAS and CMS have collected a record wealth of data, achieving L=150 fb^{-1} of proton-proton collisions at a center-of-mass energy of 13 TeV, with an unprecedented level of precision. As a consequence, a theoretical description of hadronic collisions that is similarly precise is fundamental to probe the validity of the Standard Model at the TeV energy scale and to look for new physics.

Setting the framework

The three Standard Model interactions are expressed mathematically in the form of quantum eld theories of the electromagnetic (QED), weak (EW) and strong interaction (QCD). While with present-day techniques it is not possible to evaluate observables in an exact form, predictions can be made using the framework of perturbation theory. In this approach, every observable is expanded as a power series in the coupling constant of the theory, with the coefficients of the series being consistently and systematically calculable from first principles. In this way, the Lagrangian of the theory dictates all the interactions that are allowed between the particles of the Standard Model, through the Feynman rules, from which the predictions of the theory follow from the evaluation of all the diagrams contributing to the observable. Higher-order corrections may therefore allow to obtain ever more precise results and shrink theory uncertainties. However, the complexity of the calculation increases with each further order.

The first textbook example of this approach is the prediction of the electron anomalous magnetic moment whose deviation from the result obtained by applying the Dirac equation is calculable in QED. The one--loop (or next-to-leading order NLO prediction) pioneering calculation of Schwinger and Feynman from the 1950's is obtained by calculating the vertex function as shown in the diagram.



The result, expressed as function of the fine structure constant is $\alpha_e^{th,nlo} = \alpha/2\pi = 0.0011614$. The most up-to-date prediction from Kinoshita et. al. including contributions up to 5- loops, $\alpha_e^{th,n5lo}$=0.001159652181643(25)(23)(16)(763) agrees with the experimentally measured value to more than 10 significant figures, α_e^{exp}= 0.00115965218073(28), making the magnetic moment of the electron the most accurately verified prediction in the history of physics.

Going precise with QCD at the LHC

In the LHC environment the goal is to probe the Standard Model at the highest possible energy scales. When protons collide at 13 TeV we are looking for the production of high-mass states of the electro-weak sector, namely Z ,W vector boson production, Higgs production as well as jet and top quark production, from the scattering of the strongly interacting quark/gluon initial state. The larger value of the strong coupling constant makes QCD effects predominantly present in the final states produced at the LHC, making perturbative QCD the theoretical tool to study LHC physics.

In a nutshell, QCD is present at the LHC in:

a) the parton-distribution functions, needed to describe the internal structure of the colliding protons in terms of quark and gluon distributions;

b) the description of the hard scattering process including loop corrections;

c) the parton shower needed to simulate final-state QCD radiation;

d) the hadronization phase needed to describe the transition to the hadronic final states reconstructed and observed by the experiments.

Ideally we would like to know all the components with high-precision. Focusing on exclusive observables (e.g., differential cross sections), the present level of automation in the description of the hard scattering process is next-to-leading order (NLO) precision. For several phenomenological analyses this level of precision is insufficient as theory uncertainties exceed the experimental erros. For this reason, significant work from the theoretical community is to develop modern tools to perform high-precision calculations and make them accessible to the experimentalists as NNLO Monte-Carlo generators. As an example, we show in figure 1, the anatomy of a next-to-next-to-leading order (NNLO) calculation for vector-boson pair production at the LHC.

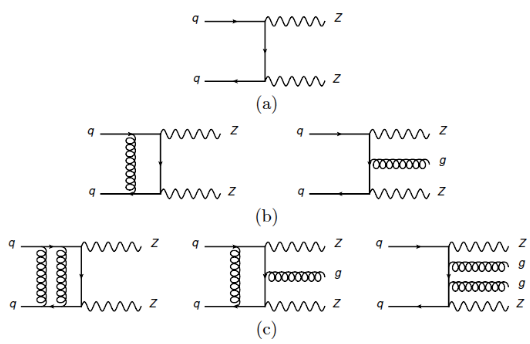


Figure 1: Sample diagrams at LO (a), NLO (b) and NNLO (c) for the calculation of inclusive ZZ production at the LHC. The total number of diagrams contributing at each order is 2 (a), 26 (b), 638 (c).

Despite not having reached yet a stage where one could have a tool that performs these computations automatically, there has been enormous progress on the theory side in delivering several NNLO calculations for processes of interest at the LHC. In figure 2, is summarized the state-of-the art of NNLO calculations available for the LHC as a function of time.

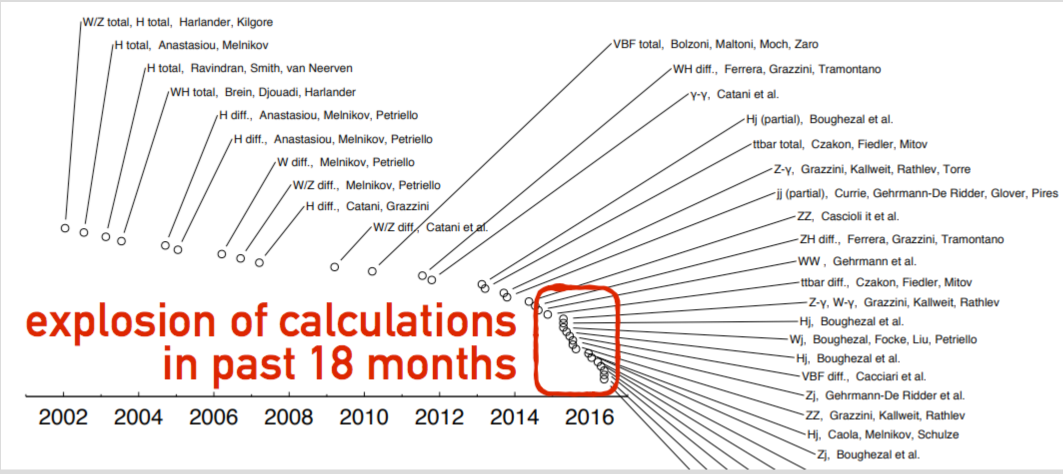


Figure 2: Very recent developments in the field of NNLO calculations allowed substancial progress in delivering results for on-going phenomenological studies of LHC data with NNLO generators for the final-states shown.

As an example of the importance of having these results, we show in figure 3 the predictions in perturbative QCD for the Higgs boson production cross section at the LHC. For the dominant Higgs boson production modes the perturbative accuracy of the calculations is NNLO(QCD)+NLO(EW) with the gluon-fusion process known presently at three-loops N3LO(QCD)+NLO(EW). When comparing these predictions with a partial Run 2 dataset from ATLAS, we observe an excellent agreement with the data for the different Higgs boson production mechanisms with the experimental statistical uncertainty being the dominant error in the extraction of the signal strengths. On the other hand, we observe a good control on the theoretical uncertainties in this analysis with the inclusion of NNLO diagrams in the calculations.

By applying suitable cuts, one can study more exclusive observables such as the transverse momentum distributions or the rapidity distributions of the final-state. As an example, CMS has recently released a measurement of the W-boson transverse-momentum distribution shown in figure 4. We observe percent-level experimental precision in this measurement. The data is compared with predictions at NLO and NNLO. The effects of including higher-order corrections are significant. The discrepancies in the description of the distribution at NLO are resolved by the NNLO prediction, as the shape of the data closely follows the NNLO predictions with greatly reduced theoretical uncertainties, as shown by the size of the bands in the ratio plot in the lower panel.

Process	σ [pb] $\sqrt{s}$ = 13 TeV	Order of calculation of σ
ggH	48.52	N^{3}LO(QCD)+NLO(EW)
VBF	3.78	NNLO(QCD)+NLO(EW)
WH	1.37	NNLO(QCD)+NLO(EW)
$q\bar{q}' \to ZH$	0.76	NNLO(QCD)+NLO(EW)
$gg \to ZH$	0.12	NLO+NLL(QCD)
$t\bar{t}H$	0.51	NLO(QCD)+NLO(EW)

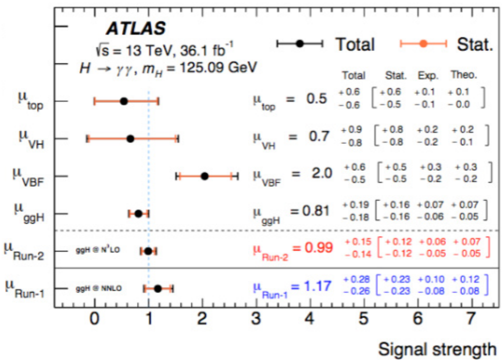


Figure 3: Perturbative QCD predictions (and accuracy of the prediction) for the dominant Higgs boson production processes (gluon fusion, vector-boson fusion, associated VH production and ttH) at the LHC at 13 TeV, and summary of the latest signal strengths measured by ATLAS for the different production processes (ggH, VBF, VH, ttH and globally) with breakdown of theoretical and experimental uncertainties.

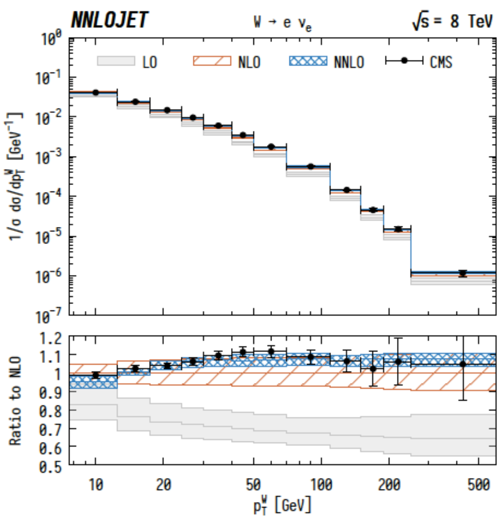


Figure 4: W-boson transverse momentum distribution measurement by CMS at 8 TeV together with NLO and NNLO predictions computed with the Monte-Carlo NNLOJET. The shaded bands assess the theoretical uncertainty of the calculation.

// INVITED TALK

Probing the Standard Model with vector-boson pair production

As demonstrated in the previous examples, the use of Monte Carlo generators with high precision to analyse LHC data has an impact in maximising our chances of identifying new physics effects beyond the Standard Model (BSM). To this end, it is useful to study in detail processes sensitive to new physics effects. As an example, vector-boson pair production ($pp \to VV$) is a process that can be used to look for anomalous vector boson gauge couplings in the EW sector of the Standard Model. Such anomalous triple gauge couplings (aTGCs) are forbidden in the Standard Model but can arise in BSM extensions at higher energies. Both ATLAS and CMS have made a measurement of the Z-boson pair production at the LHC at 13 TeV with a partial Run 2 dataset. The experimental signature of this process is the fully leptonic decay ($Z \to ll$) to electron/muon final states of the produced Z bosons. The four-lepton final state is fully reconstructed in the detector, allowing a measurement of the ZZ inclusive cross section with an experimental uncertainty below 6%.

Theorists have also been interested in studying in this process from first principles. Formally a pure electro-weak process, the pair production of vector bosons at the LHC receives very large QCD corrections from additional strong interaction vertices appearing at higher-orders (as shown in the diagrams in figure 1). As a result, new partonic initial state channels, quark-gluon and gluon-gluon, contribute to the cross section for the first time at NLO and NNLO respectively. The full ZZ inclusive cross section is know up to NNLO in QCD and predictions for the LHC at a center-of-mass energy of 13 TeV are shown in figure 5.

Looking at the results we observe very large (43%) NLO QCD corrections and large (18%) NNLO QCD corrections to the ZZ production cross section. For this reason, the agreement with the very precise measurements from ATLAS and CMS is significantly improved when the data is compared with the NNLO prediction. In particular, by performing the comparison with NLO theory, one would find a 3 sigma discrepancy between the theory and the data and wrongly observe an evidence of a new physics signal. The possibility of observing anomalous triple gauge couplings (aTGCs) at the LHC as deviations from the NNLO vector-boson pair production cross section remains open as the full Run 2 dataset is currently being analysed.

Extrapolating the above phenomenological analyses to the upcoming Run 3 and to the future High-Luminosity LHC stage, it is clear that the need for precision on the theory side will increase further in order to face the challenge of ever more accurate data. The use of the latest developments in NNLO calculations by the experiments is still somewhat in its infancy but we have already observed a remarkable improvement in the description of LHC data in a variety of processes and a significant reduction of the theoretical uncertainties. Going forward, a strong interaction between theorists and experimentalists to discuss the phenomenology, observational results and new theoretical tools is the key for maximising the success of the LHC physics program.

$pp \to ZZ$	σ [pb]
LO	$9.85^{+5.2\%}_{-6.2\%}$
NLO	$14.10^{+2.9\%}_{-2.4\%}$
NNLO	$16.69^{+3.1\%}_{-2.8\%}$
ATLAS	17.3 ± 1.0
CMS	17.2 ± 1.0

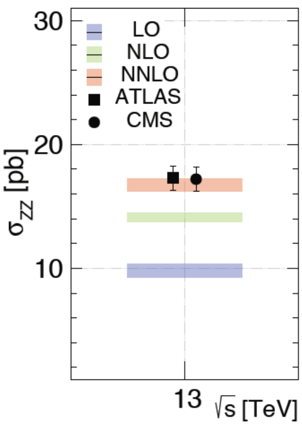


Figure 5: Inclusive cross section predictions for ZZ production at the LHC a center-of-mass energy of 13 TeV at LO, NLO and NNLO, together with the measurements from ATLAS and CMS.

João Pires graduated from the Faculty of Sciences of the University of Lisbon, and got his PhD in the Institute for Particle Physics Phenomenology (IPPP) at Durham University in 2010. At present, he is a postdoctoral researcher at the CFTP, working in higher order NNLO calculations for precision tests of the Standard Model at the LHC and in the development of the parton level event generator NNLOJET currently used by ATLAS and CMS.

BREVES

do LIP e do mundo das partículas

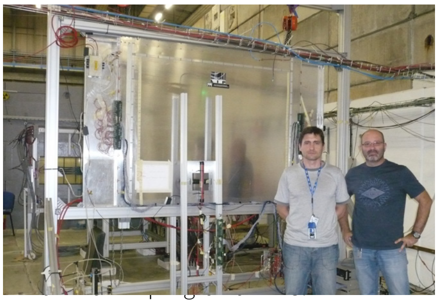
As notícias desta secção foram elaboradas a partir de conteúdos preparados para a página web e o facebook do LIP pelos vários grupos do LIP; ou a partir de notas de imprensa das instituições envolvidas. Contribuições: A. Blanco, A. Nunes, C. Abreu, C. Manuel, C. E. Santo, D. Galaviz, H. Gomes, J. Pina, L. Coimbra, L. Apolinário, N. Antunes, N. Castro, N. Leonardo, P. Abreu, R. Gonçalo, T. Vale

Estratégia Europeia para a Física de Partículas 2020

Está em curso o processo de revisão da Estratégia Europeia de Física de Partículas. O processo envolverá toda a comunidade no desenvolvimento de uma visão comum para o futuro da física de partículas na Europa.

A comunidade de físicos de partículas nas universidades e laboratórios de investigação em todos os países foi já convidada a enviar contribuições escritas (até 18 de Dezembro 2018). Seguir-se-ão uma reunião aberta (Granda, Espanha, 13-16 Maio 2019) em que será debatida a orientação futura da física de partículas na Europa, e uma sessão de escrita de uma versão preliminar do documento (Bad Honnef, Alemanha, 20-24 Janeiro 2020). Espera-se que a estratégia revista seja aprovada pelo Conselho do CERN em Maio de 2020.

O planeamento estratégico para a física de partículas na Europa é um processo aberto e inclusivo, iniciado em 2005, que se baseia nos resultados científicos nesta área e tem em conta o panorama mundial da física de partículas e os desenvolvimentos em áreas relacionadas. Nas palavras da presidente do Conselho do CERN, Sijbrand de Jong, "o processo de definição da estratégia Europeia é essencial para que a Europa mantenha a sua posição de líder mundial dos avanços em física de partículas ao longo do século".



(investigação & desenvolvimento) para a futura experiência SHiP, membros do LIP testaram, na linha T9 do acelerador PS no CERN, um novo conceito de RPC para a medida do tempo de voo de partículas.

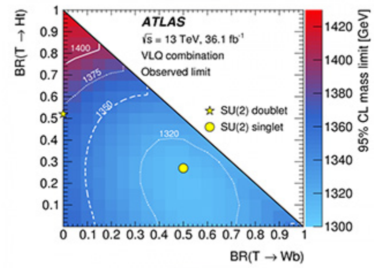
Inicialmente desenvolvido pelo grupo do LIP para o Observatório Pierre Auger, este novo conceito de RPC é agora aplicado na medida de tempo de voo. Com resoluções temporais claramente abaixo de 100 ps em grandes área (da ordem de 2 m²), e a baixo custo, o novo conceito permitirá cobrir áreas extensas em futuras experiências de altas energias.

As RPC (resistive plate chambers) são detectores gasosos robustos, adaptáveis a uma grande diversidade de aplicações, e que permitem obter uma excelente medida do tempo de chegada das partículas. O grupo de RPCs do LIP-Coimbra é líder mundial nesta área.

SHiP é uma nova experiência que será instalada no SPS com um diversidade de objectivos, da procura de partículas escondidas previstas numa série de modelos recentes (Hidden Sector) às oscilações de neutrinos e à origem da assimetria bariónica no Universo.

XXVIII ENAA

O XXVIII Encontro Nacional de Astronomia e Astrofísica, decorreu a 10 e 11 Setembro 2018, em Coimbra, Portugal no Observatório Geofísico e Astronómico da Universidade de Coimbra, em parceria com o LIP e a Sociedade Portuguesa de Astronomia. Contou com cerca de 3 dezenas de participantes que apresentaram trabalhos repartidos por diversas sessões temáticas, e o LIP esteve muito bem representado em várias delas.



Procura de quarks exóticos em destaque na PRL

O artigo da colaboração ATLAS sobre a procura de quarks exóticos a 13 TeV no LHC, com o título "Combination of the searches for pair-produced vectorlike partners of the third-generation quarks at sqrt(s) = 13 TeV with the ATLAS detector", publicado na revista Physical Review Letters, foi destacado como Sugestão do Editor.

A equipa de ATLAS do LIP contribuiu significativamente para este resultado, liderando uma das análises que integram a combinação e tendo um papel fundamental na própria combinação.

Os quarks exóticos surgem em diversos modelos que procuram ir para além do Modelo Padrão da Física de Partículas e resolver algumas das suas limitações. São uma das muitas assinaturas de nova física procuradas no LHC, beneficiando a elevada energia no centro de massa.

Rede IDPASC tem novos membros

Na sua mais recente reunião de coordenação, em Oviedo, Espanha, a rede de doutoramento IDPASC deu as boas vindas a três novos membros: a Universidade de Rijeka (Croácia), o Instituto de Física da Academia Checa de Ciências, e o Instituto de Ciência do Gran Sasso (Itália). A IDPASC, International Doctorate in Particles, Astrophysics and Cosmology, é uma rede interdisciplinar que tem o objectivo de formar uma nova geração de investigadores com uma formação profunda e alargada nas áreas PASC — partículas, astrofísica e cosmologia. A rede é coordenada pelo LIP.

O LIP na Hard Probes 2018

A edição de 2018 da International Conference on Hard & Electromagnetic Probes of High-Energy Nuclear Collisions realizou-se este ano em Aix-le-Bains, França, de 30 de Setembro a 5 de Outubro e contou com mais de 250 participantes. Este ano, a conferência esteve centrada na descrição da sub-estrutura de jactos (aglomerados de partículas hadrónicas de altas energias) como uma das possíveis sondas mais precisas para extrair informação do plasma de quarks e gluões, a matéria densa que é criada em colisões de iões pesados de altas energias e que terá existido nos primeiros instantes de existência o Universo. Os dois grandes colisionadores de iões pesados a altas energias (RHIC nos EUA e o LHC na Europa) apresentaram os novos resultados, e realizou-se uma sessão dedicada às novas propostas de futuros aceleradores de iões pesados que fazem parte da estratégia europeia para a física de altas energias.

O grupo de fenomenologia do LIP esteve mais uma vez muito bem representado: Liliana Apolinário apresentou uma revisão plenária sobre os modelos de Monte Carlo dedicados à descrição de jactos em colisões de iões pesados, João Barata apresentou os resultados do grupo na identificação da modificação de jactos iniciados por quarks e gluões que atravessam o meio criado neste tipo de colisões, e Korinna Zapp fez a revisão plenária dos resultados teóricos de jactos apresentados ao longo da conferência. Trabalho com participação do grupo de Fenomenologia do LIP foi apresentado noutras cinco apresentações paralelas. A próxima edição será em, Austin, Texas.

DI4R em Lisboa

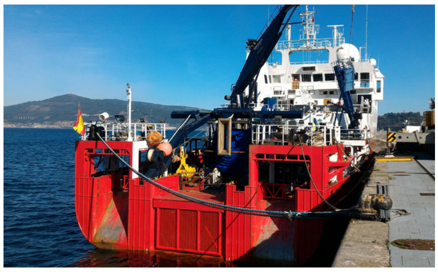
A 3ª edição da conferência internacional Digital Infrastructures for Research (DI4R) decorreu em Lisboa no ISCTE, de 9 a 11 de Outubro de 2018. Teve cerca de 400 participantes, juntou investigadores e infraestruturas digitais para a ciência. Alguns dos temas em destaque nesta edição estão relaccionados com as políticas de acesso a dados e serviços disponibilizados para a investigação, tendo sempre como pano de fundo o objectivo do avanço científico através do paradigma da ciência aberta. A DI4R2018 é organizada pelo EOSC-hub, GÉANT, OpenAIRE e PRACE. Este ano a organização local esteve a cargo do LIP, em colaboração com o INCD e a IBERGRID.

IBERGRID 2018

De 11 a 12 de Outubro decorreu o encontro anual da IBERGRID, a infraestrutura GRID da região Ibérica. Este encontro, contou com mais de 40 participantes, dando um novo impulso à infraestrutura, com o tema da participação Ibérica no European Open Science Cloud (EOSC), e os desafios e oportunidades para a região Ibérica. Nesta edição foram homenageados Gaspar Barreira (LIP) e Javier Tobio (CESGA) pelo seu importantíssimo papel no nascimento e afirmação da IBERGRID. A infraestrutura IBERGRID, criada em 2006 engloba actualmente 12 centros de computação e dados em Espanha e Portugal, federando infraestruturas de computação grid e cloud de instituições académicas e de investigação. Tem como coordenadores Isabel Campos (IFCA, Espanha) e Jorge Gomes (LIP, Portugal).

Bandeiras dos 22 Estados Membros voltam à entrada do CERN

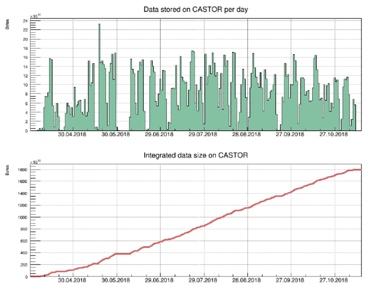
Depois de um longo período de obras, foi hoje inaugurada a Esplanade des Particules, em frente do sítio de Meyrin do CERN, e hasteadas as bandeiras dos Estados Membros, entre eles Portugal. Nas fotos, vemos Gaspar Barreira, Delegado de Portugal ao Conselho do CERN, Paulo Gomes, Liaison do CERN para Portugal. O CERN, que celebrou seis décadas de existência sob o lema 60 anos de Ciência para a Paz, continua a ser um símbolo de união e de colaboração entre os povos em prol da ciência e do bem comum.



RPCs na Antártida

Após a recente instalação do detector TRISTAN no Sarmiento de Gamboa, o navio científico espanhol zarpou a caminho da Antártida". TRISTAN, um telescópio de raios cósmicos baseado na tecnologia RPC, inteiramente desenhado e construido no LIP, foi instalado a bordo do navio científico Sarmiento de Gamboa, com a missão de medir o fluxo de raios cósmicos ao longo de um meridiano, e de forma permanente na Base Espanhola Juan Carlos I. A missão será continuamente monitorizada a partir de Coimbra, e dados relevantes serão mostrados on-line no átrio do departamento de Física.

// BREVES

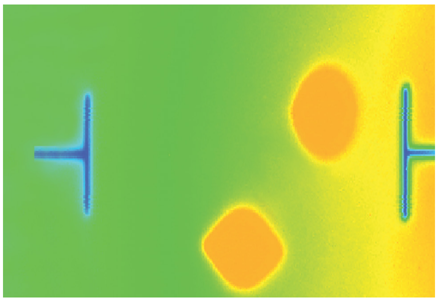


Tomada de dados 2018 em COMPASS

A campanha de tomada de dados de COMPASS de 2018 terminou dia 12 de Novembro, às 8:00. Foi o segundo e último ano de tomada de dados do programa de Drell-Yan, em que o grupo do LIP está fortemente envolvido. Foram usados um alvo de amónia polarizado transversalmente e um feixe de piões de 190 GeV de elevada intensidade.

No processo de Drell-Yan, um quark de um hadrão aniquila-se com um antiquark de outro hadrão, dando origem a um fotão virtual que por sua vez dá origem a um par leptão-antileptão; em COMPASS, um quark de um protão do alvo aniquila-se com um antiquark de um pião do feixe, e são detetados pares muão-antimuão. Este processo é muito raro, o que torna as medições particularmente desafiantes. Pretende-se com estes dados estudar a validade dos modelos do protão que usam TMD PDFs (funções de distribuição partónicas dependentes do momento transverso). Nos gráficos mostra-se o volume de dados coletados em função do tempo, por dia e acumulado.

O Sistema de Controlo de Detetores, da responsabilidade do grupo do LIP, acompanhou a tomada de dados de forma estável, tendo sido feita a integração da monitorização e controlo de novos equipamentos, desde fontes de baixas tensões, a sensores de radiação e a parâmetros do alvo polarizado.

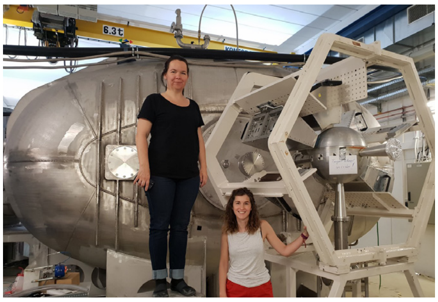


Uma década de protões no LHC

Passaram 10 anos desde que os primeiros protões circularam no LHC, a 10 de Setembro de 2008. Na imagem, que correu mundo, as duas manchas alaranjadas mostram a circulação, com sucesso, de dois feixes no acelerador. Foi nesse momento deixada para trás a longa fase de planeamento e construção, avançando-se, finalmente, em direcção aos dados! O acontecimento teve uma cobertura mediática impressionante, e pôs o CERN e a física de partículas nas bocas do mundo — até a página do Google se transformou num cartoon do acelerador. O LIP participa nas experiências ATLAS e CMS desde o princípio — ou seja, há 25 anos. Os dois grupos viveram com grande emoção esse dia, em que vários dos seus membros estiveram nas salas de controlo das experiências. Nove dias depois do arranque, um acidente causado por um defeito na soldadura entre dois ímans supercondutores (entre os milhares que existem no LHC) forçou a paragem do acelerador para reparações bastante demoradas. Os protões voltaram um pouco mais de um ano depois, tendo as primeiras colisões entre os dois feixes acontecido a 20 de Novembro de 2009.

Coimbra Space Summer School

A Coimbra Space Summer School (CSSS) decorreu entre 12 e 14 de Setembro de 2018. É uma escola dedicada a cativar estudantes para explorar a economia do espaço coordenada pelo ESA Business Incubation Centre em parceria com o LIP e o Observatório Geofísico e Astronómico da Universidade de Coimbra. A quarta edição contou com a participação de cerca de 3 dezenas de estudantes e ainda do ministro Manuel Heitor e do astronauta análogo João Lousada na sessão encerramento.



Preparação da Fase-0 de FAIR

No verão de 2018, vários membros do grupo NUC-RIA do LIP estiveram no GSI, em Darmstadt, Alemanha, a trabalhar na preparação das experiências da Fase-0 de FAIR. Na foto, vemos Pamela Teubig e Elisabet Galiana, do grupo do LIP. A contribuição do grupo centrou-se na verificação do sistema de monitorização online (desenvolvido pelo grupo do LIP em colaboração com colegas do IGFAE na USC, Espanha) do detetor CALIFA , assim como no teste de procedimentos de calibração automáticos do detetor.

FAIR (Facility for Antiproton and Ion Research) é a nova infraestrutura do laboratório GSI, e vai explorar a fronteira entre a física nuclear e a física de partículas. O LIP é membro de dois dos quatro pilares de FAIR: NUSTAR, presente na linha de feixes radioativos relativistas R3B, experiência cuja preparação agora decorreu, e HADES. Em ambas as experiências, tem responsabilidades no desenvolvimento, construção e operação dos detectores, bem como na análise de dados. A Fase-0 de FAIR terá início em breve.

Experiência de Polarimetria em Balão da NASA

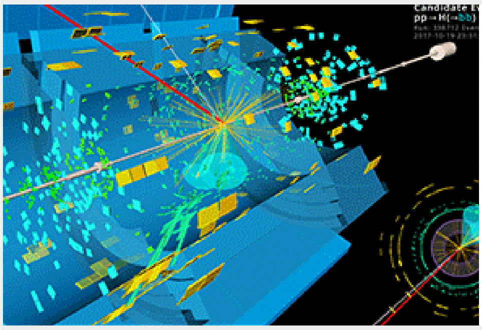
O grupo i-Astro do LIP, em colaboração com o American River College e o INAF-IASF de Bolonha realizou uma experiência de polarimetria para astrofísica de altas energias a bordo de um balão da NASA no âmbito do programa High Altitude Sudent Platform, destinado a estudantes do ensino superior. O lançamento ocorreu no dia 4 de setembro, em Fort Sumner no Novo México, transportando 13 experiências, entre as quais a experiência do LIP. O objectivo foi medir a radiação de fundo a alta altitude que poderá afetar a capacidade de medir a polarização dos futuros telescópios espaciais para astrofísica de altas energias.

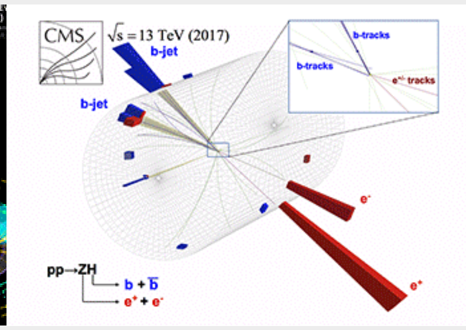
Ciência 2018

No encontro nacional de ciência Ciência 2018, que decorreu de 2 a 4 de Julho, o antigo director geral do CERN Rolf-Dieter Heuer foi distinguido com a medalha de mérito, entregue pelo ministro da ciência, tecnologia e ensino superior Manuel Heitor, pelo contributo e dedicação à ciência. O LIP esteve presente no Ciência 2018 com sete comunicações, distribuídas por várias sessões — dedicadas a computação, infraestruturas científicas e saúde — e a moderação de duas sessões.

Olimpíadas Internacionais da Física 2018 em Portugal

Em 2018, as Olimpíadas Internacionais da Física realizaram-se em Lisboa, de 21 a 29 de Julho. Foram organizadas pela Sociedade Portuguesa de Física e contaram com cerca de 400 estudantes de 87 países. Muitos membros do LIP participaram e puderem testemunhar o ambiente de grande entusiasmo (e trabalho intenso) que se viveu. As IPhO são uma competição anual para estudantes do ensino secundário que tem o objectivo de promover a física e o desenvolvimento de contactos internacionais na educação em física. A competição inclui provas experimentais e provas teóricas individuais. As IPhO realizaram-se pela primeira vez em 1967, na Polónia, com a participação de 15 estudantes de 5 países. Como se vê, cresceram muito desde então!





Observado decaimento do bosão de Higgs em quarks b

Seis anos depois da descoberta do bosão de Higgs, observou-se finalmente o seu decaimento para quarks b, o segundo mais pesado do seis quarks. A descoberta foi apresentada pelas colaborações ATLAS e CMS do acelerador LHC do CERN. O Modelo Padrão prevê que o bosão de Higgs decaia para quarks b em cerca de 60% dos casos. Verificar esta previsão é importante para confirmar o modelo — e a ideia fundamental de que é o campo de Higgs que dá massa a todas as partículas elementares — ou, pelo contrário, minar as suas fundações e procurar indícios de nova física.

Espera-se que este decaimento do Higgs seja o mais frequente de todos. No entanto, detectá-lo é tudo menos fácil, e demorou seis anos. Isto porque, quando fazemos colidir dois protões, há muitas outras formas de produzir quarks b — e é muito difícil distinguir, no meio de tanto “ruído”, os quarks b que têm origem no decaimento do bosão de Higgs dos outros. Pelo contrário, o raríssimo decaimento do bosão de Higgs num par de fotões foi observado logo na altura da descoberta. Isto porque é muito mais fácil de distinguir de outros processos (a que chamamos o “fundo”).

Portugal é membro das experiências ATLAS e CMS desde o início, e os grupos do LIP estiveram profundamente implicados na descoberta do bosão de Higgs. O grupo ATLAS-LIP está directamente envolvido na análise do decaimento do Higgs em quarks b há quase uma década. É, pois, uma longo caminho, que teve agora sucesso, mas que não chegou ao fim. Esta observação abre o caminho para estudar com maior precisão as interacções do bosão de Higgs com os quarks top e b, e assim testar as propriedades desta partícula única.

Para isolar o sinal, as colaborações ATLAS e CMS combinaram dados de vários períodos de funcionamento do LHC, com colisões a 7, 8 e 13 TeV, e empregaram métodos de análise de dados muito complexos. O resultado foi uma observação estatisticamente significativa (mais de 5 sigma) do decaimento do Higgs num par de quarks b. A taxa de decaimento é compatível com a previsão do Modelo Padrão, dentro da precisão conseguida até ao momento.

Com mais dados, as duas colaborações poderão melhorar a precisão desta e de outras medidas, e procurar o decaimento do bosão de Higgs num par de muões (semelhantes aos electrões mas mais pesados; ainda assim de muito menor massa que os quarks b), sempre atentos a possíveis sinais de física para lá do Modelo Padrão. Estes estudos podem vir a responder a alguns dos mais profundos mistérios da física de partículas.

// EVENTOS

BEACH 2018 in Peniche – Sun, Sea and Particle Physics

R. Gonçalo, P. Bordalo, S. Ramos

Last summer, between 17 and 23 June, the 13th International Conference on Beauty, Charm and Hyperon Hadrons (BEACH) conference came to Portugal. With Paula Bordalo as the Chairperson of the organising committee, the conference was organised by LIP in Peniche, a mere few hundred meters from the Atlantic and, of course, from several beautiful white sand beaches.

The biennial BEACH series of conferences started in Strasbourg in 1995. This edition brought to Peniche more than 90 participants from 21 different countries, representing more than 30 experimental collaborations and many theory groups. The high quality of the contributions made this a very interesting meeting, showcasing a broad range of subjects at the forefront of our field. Centre stage was given to the anomalies seen in flavour physics (see page 14), which are at the heart of the traditional programme of this conference. But many other issues were well represented: from neutrinos, to Higgs and electroweak measurements, to beyond the Standard Model searches, as well as new projects and facilities.

The programme combined theory and experimental communications, by a good balance of younger researchers and well-established scientists, in a conference with only plenary sessions. Together with many opportunities for in-depth discussions, which were often triggered by the veteran Stan Brodsky and the physicist Jolanta Brodzicka, this created the right environment for exchanging experience and ideas in a very vibrant meeting. Such opportunities were provided not only by the scientific sessions, but also by a very complete social programme, including, every evening, visits to beautiful places in the region, of great natural or historical interest. Returning from an afternoon-long visit to Berlenga island we even had the company of a family of dolphins!

In addition to Paula Bordalo, this conference involved many of our colleagues at LIP, who made contributions to the programme: Eliza Melo, Helena Santos, Michele Gallinaro, Paulo Brás, Sofia Andringa with Ricardo Gonçalo and Nuno Leonardo giving very nice and excellent review talks. Also, Sérgio Ramos, João Seixas, Fernando Barão, Celso Franco and Pedro Bicudo from IST were members of the Local Organising Committee. Secretariat, media and technical support were in the capable hands of Natália Antunes, João Pedro Santos, José Carlos Nogueira and Carlos Manuel, all highly praised by our visitors but, of course, many others from LIP-Lisbon staff have also contributed with their work to the good achievement of the conference. Besides LIP, the conference had the generous support of Câmara de Peniche, as well as of AFIF and the Institut Français, to whom we extend our thanks.







// OUTREACH

NOITE EUROPEIA DOS INVESTIGADORES ciência na cidade

O LIP na NEI 2018

O LIP esteve na Noite Europeia dos Investigadores em Braga, Coimbra e Lisboa. No Forum Braga, construíram-se detectores de partículas e procuraram-se partículas na cidade. No Museu da Ciência da Universidade de Coimbra, houve tempo para ver os raios cósmicos e para compreender como funciona a tomografia por emissão de positrões. No Planetário Calouste Gulbenkian, em Lisboa, viajámos até ao CERN com uma visita virtual à experiência CMS a e exibição do filme “Particle Fever”. Em todos os casos, o público não faltou e os investigadores estiveram disponíveis para respoder a todas as perguntas. Lá estaremos de novo em 2019!

CIÊNCIA VIVA NO LABORATÓRIO
OCUPAÇÃO CIENTÍFICA DE JOVENS NAS FÉRIAS

Como todos os anos, o LIP fez parte do programa Ciência Viva no Laboratório - Ocupação Científica de Jovens em Férias 2018, da Agência Ciência Viva, recebendo em 3 estágios em Lisboa e em Coimbra cerca duas dezenas de estudantes do ensino secundário, que vieram descobrir a física de partículas e as suas ferramentas. Agradecemos a todos os participantes pelo seu empenho!

Professores de física no CERN, em português

Em Setembro de 2018, realizou-se a 12ª edição da escola para professores de física em língua portuguesa no CERN. Este ano, o programa contou com a participação de 20 professores do Brasil e 20 de Portugal. A Escola é organizada pelo LIP e pelo CERN, com o apoio da Agência Ciência Viva. Obrigada a todos, participantes, palestrantes e organizadores, que contribuíram para tornar esta edição mais um sucesso!

CIENTIFICAMENTE PROVÁVEL

O LIP é parceiro de várias escolas neste programa da Rede de Bibliotecas Escolares. Propõe-se uma viagem ao mundo da física de partículas em que se exploram as suas actividades, ferramentas e processos — um misto de seminários, pesquisa bibliográfica e trabalho no laboratório:

- Palestras sobre física de partículas, a suas ferramentas e processos
- Da notícia de ciência à descoberta científica: um percurso sobre comunicação e cultura científica
- Hands-on no LIP-EduLab: as ferramentas da física de partículas

Neste momento, participam no projectos a Escola Secundária D. Filipa de Lencastre e a Escola Secundária do Restelo, ambas em Lisboa, e a Escola Secundária Padre Benjamim Salgado, em Joane.

LIP Summer Students Programme 2018

Book of abstracts

Entre Julho e Setembro de 2018, decorreu a 2ª edição do Programa de Estudantes de Verão do LIP, dirigidos a estudantes universitários de Física, mas também de áreas relacionadas, como a Engenharia. Mais de meia centena de estudantes de licenciatura e mestrado participaram activamente em mais de 30 projetos de investigação, integrados em vários grupos de investigação nos três polos do LIP — Lisboa, Coimbra e Minho. O programa iniciou-se com uma semana de tutoriais e terminou com um workshop em que os estudantes apresentaram o seu trabalho. Nesta secção do Boletim, os participantes apresentam um breve resumo do projecto de investigação que desenvolveram.

LATTES: Looking for astrophysical gammas with a next generation detector

Students: André Torcato, Melissa Serra, José Cordeiro, Sara Marques, José Jesus
Supervisors: Ruben Conceição, Bernardo Tomé, Mário Pimenta

LATTES is a project that aims to build a gamma-ray ground-based experiment to survey the Southern sky. This wide field-of-view experiment is based on a hybrid detector concept (water Cherenkov detectors + resistive plate chambers) to effectively access with a good sensitivity an energy region that is not currently covered by any experiment of this type. While the proof-of-concept is done, this new experiment offers a new set of possibilities to observe the sky that are far from fully explored. This summer we explored some of this opportunities: investigate and optimize the shower core reconstruction of highly energetic events; build an artificial neural network to enhance the gamma (signal) / hadron (background) discrimination; assess the LATTES shower geometry reconstruction for different RPC time resolutions and array configurations. In all these tasks, possible improvement to the current LATTES reconstruction were found which might contribute to enhance its performance in the future.

Development of a framework for multi-messenger observations

Students: Bernardo Dias and Nelson Eiró
Supervisors: Sofia Andringa and Lorenzo Cazon

Cosmic rays, neutrinos, photons and gravitational waves have been observed independently over the last years by different observatories around Earth. However, in the multi-messenger era, one event can be observed simultaneously in all these different channels. Identification of such multi-wavelength emitters is allowing to understand the physics mechanisms involved in the most violent places of the Universe (like the recent observed gravitational wave event GW170817 and the Blazar TXS 0506+056). The objectives of the internship were the development of display tools of the instantaneous sky coverage of the Auger experiment (that can be consulted at http://www.lip.pt/~ev18117/galatica.html) and the identification of relevant source candidates. Calculations of time of flight delay and deflection angles from different relevant sources were also achieved. The work culminated in a poster presented at ENAA — Encontro Nacional de Astronomia e Astrofísica.

Hadron production at the highest energies: on the origin of the α-distribution

Student: Miguel Martins
Supervisors: Lorenzo Cazon, Ruben Conceição, Felix Riehn

Ultra High Energy Cosmic Rays (UHECR) are particles with energies greater than 10^{18} eV which interact with nuclei in the Earth atmosphere producing Extensive Air Showers (EAS). Despite being indirectly detected, UHECR offer an opportunity to study interactions at center-of-mass energies 10 times greater than those of the LHC. It has been recently demonstrated that fluctuations in the muon content of EAS are sensitive to properties of the very first interaction, namely the fraction of energy carried by the hadronic component of the first interaction of the cascade, α. The internship focused on finding the physical causes of the tail structure of the α-distribution given by two hadronic models: EPOS-LHC and QGSjetII-04. We first found that only high multiplicity events contributed to the tail structure, and that its shape does not depend on the nature of the initial particle. Using a Monte Carlo toy model, we were able to reproduce the shape of the tail. Varying the pion spectrum given by EPOS-LHC and QGSjetII-04 we demonstrated that the tail structure is only sensitive to changes in the high-energy (forward) region of the energy spectra, E > 107 GeV.

Cobalt 57 calibration source for the SNO+ experiment

Student: Eduardo Castanho
Supervisor: Valentina Lozza

SNO+ is a neutrino experiment deep underground in Sudbury (Canada). SNO+ in currently in the so-called water phase, i.e., taking data with the detector filled with water. In SNO+, Co-57 could be used to measure the energy scale and check the trigger efficiency as function of the position. Together with other calibration sources it will provide information about the detector response. The goal of this internship was to study the current status of the SNO+ simulation tools for reconstructing the value of energy from the number of hits, and its dependence with the position.

Coincidence signals in the SNO+ water phase

Student: Jéssica Gonçalves
Supervisors: Valentina Lozza and Sofia Andringa

The aim of this project was to search the data for coincident events that were caused by alpha decays, followed by a neutron capture, which is the same coincidence signature as for anti-neutrinos. Different simulations of the process were compared. The behavior of variables such as the number of hits was studied and understood. Several kinematic and topological variables were studied and their relation to the angles between the direction of the two particles in coincidence and to the direction of the produced Cherenkov cones was better understood. The efficiencies of the detector as a function of variables such as the position in z were also studied and interpreted taking into account the energy of the particles.

Assemble and instrument an RPC gaseous detector

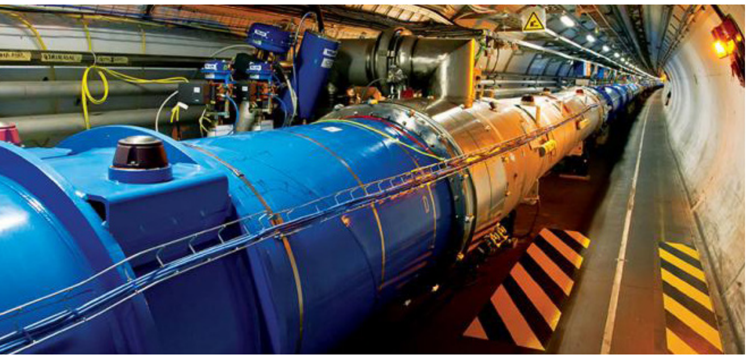
Student: Rodolfo Matias
Supervisors: Pedro Assis and Bernardo Tomé

My internship had as objective to assemble and instrument an RPC (about 40 cm x 40 cm), a prototype of a larger one, to be used for muon tomography demonstration in at the Lousal mine, in Alentejo. The system can also be used as a hodoscope for the Pierre Auger Observatory. RPCs are gaseous detectors consisting of two glass plates painted with a resistive paint, with a gas between them. When a charged particle goes through the detector it ionizes the gas. The electrons are accelerated by means of an intense electric field between the plates leading to an avalanche of electrons. The moving electrons induce a signal in a pad panel above the upper plate that is collected and sent to the data acquisition system. The RPC core (gaseous volume) was built in LIP Coimbra. At LIP-Lisboa, I designed, built and assembled an aluminum case to protect it and provide electromagnetic shielding, and assembled the high voltage system and the gas system. The data acquisition system was not yet ready, but it was possible to see signals directly with an oscilloscope.

Building a muon detector

Students: João Silva, Manuel Silva, Maria Ana Pereira
Supervisor: Francisco Neves

During our summer internship at LIP-Coimbra we built three muon detectors based on a project from MIT, called Cosmic Watch. Our objectives were to study both the muon angular flux and energy spectrum. For that we developed a software-based coincidence unit out of one of the detectors, by modifying the Arduino code provided. The results obtained were then compared with a coincidence system based on standard NIM modules already present at LIP-Coimbra. To finalise our internship, we used the reprogrammed detector as a coincidence unit and two detectors to study the angular flux of muons.



Quasi Online Drell-Yan data analysis

Students: Lara Neves, Nuno Teixeira
Supervisors: Catarina Quintans, Ana Sofia Nunes

The objective of this summer internship was to analyse the COMPASS experiment data from the 2018 Drell-Yan data taking, controlling basic physics quantities to guarantee the good quality of the data measured: we extracted detector efficiencies, monitored detector timings and hit patterns. We further analysed a specific subset of data which had anomalous measurements of momentum, above 250 GeV/c, to determine which detectors, if any, were responsible for these incorrect measurements. We also compared the 2018 data to the 2015 in order to detect whether or not this is a persistent problem which has occurred in both data taking years.

Understanding the quark-gluon plasma in heavy-ion collisions-ΔS_{12}

Student: João Mesquita Lopes
Supervisor: Liliana Apolinário

The quark-gluon plasma (QGP), a result of heavy ion collisions at ultra-relativistic energies, was studied in this internship. Due to its short lifetime, it is not possible to the assess the QGP properties directly. Among the indirect observables, jets, collection of high momentum particles produced from an energetic (hard) scattering, are a valuable probe of this medium. Nonetheless, the particles from the underlying event, unrelated to the hard scattering, are an obstacle to the precision of experimental results. Recently, a new observable, ΔS_{12}, was introduced as a possible tool for accurate studies in heavy-ion collisions. The goal of this internship was to assess the potential of the ΔS_{12} observable. That was achieved by using a proton-proton (pp) Monte Carlo event generator where we applied two different methods to understand the sensitivity of the proposed observable to a high multiplicity background: (i) effective transverse momentum smearing of the sub-jets used in the definition of this observable, (ii) embedding of pp event into a thermal underlying event, followed by the corresponding background estimation and subtraction with a grid-based method. The obtained results indicate that ΔS_{12} is experimentally robust to be applied in a real heavy-ion collision.

Probing QGP with b-Jets

Students: João Bravo, Francisco Lelewell
Supervisors: Helena Santos, Rui Pereira

Due to the high energy density involved in heavy ion collisions at the LHC, there is formation of a quark-gluon plasma (QGP), the state of matter of the Universe up to few milliseconds after the Big Bang. A great probe for studying QGP are the jets originating from bottom quark fragmentation (b-jets). It is therefore imperative to create tools to identify these jets. Our internship consisted, firstly, in developing and optimizing a machine learning algorithm, a Boosted Decision Tree, for identifying b-jets produced in simulated heavy ion (Pb+Pb) collisions embedded on real reconstructed minimum bias data from the ATLAS experiment. And secondly, in analysing those jets, namely their kinematic distributions and their dependence on the collision centrality, in order to improve our method. We ended up with a consistently better performing algorithm than all the methods we used as input, proving machine learning techniques bring strong benefits to this subfield of Physics.

Bottomonium suppression in PbPb collisions at LHC

Student: João Lourenço
Supervisor: Nuno Leonardo

By colliding heavy-nuclei at the LHC we produce droplets of the primordial matter that filled the Universe in its early instants: the quark-gluon plasma (QGP). A flagship signature of the QGP is the melting of heavy quarkonia (bound states of a heavy quark and its antiquark). These states can be used to probe the QGP and infer its temperature. In this internship we measured the suppression of the Υ family of states in PbPb collisions at 5 TeV, analyzing CMS data collected during LHC Run 2. The Upsilon (b-anti-b) states are the heaviest mesons, detected via their decays to a muon pair. The detector resolution allows to clearly separate the 3 states, denoted Υ(nS), with n=1,2,3. By fitting the Υ(nS) peaks in pp datasets taken at different collision energies, an apparent (fake) suppression was obtained: a mimicking kinematic effect! The results obtained using the PbPb data and reference pp data, taken at the same collision energy of 5 TeV, are shown. Systematic uncertainties were evaluated. The sequential suppression phenomena is clearly observed, and results are in agreement with the CMS Run 1 original observation of the phenomenon at lower energy.

Rare decays of the Higgs and Z bosons

Student: Miguel Afonso
Supervisors: Eliza Melo, Nuno Leonardo

We explored the very rare decays of Higgs and Z bosons into a quarkonium state (Q=Υ,J/ψ) and a photon (γ): $H\to Q\gamma$ and $Z\to Q\gamma$. These offer unique sensitivity to both magnitude and sign of the Yukawa couplings of the Higgs boson to quarks. The Z decay serves also as benchmark for the Higgs search. We studied the kinematic characteristics of the final state particles using simulation for signal and background processes. An extended 2D unbinned maximum likelihood fit, to the dimuon and dimuon plus photon masses, was used. From our work, the current amount of LHC data is not yet sufficient to detect SM signals. However physics beyond the SM could cause a measurable enhancement. This is a sensitive analysis to be further carried out during the high-luminosity phase of the LHC (HL-LHC).

Rare beauty decays

Student: Maria Carolina Faria
Supervisors: Ozlem Ozcelik, Nuno Leonardo

The rare meson decays $B \to \mu\mu$ are amongst the most sensitive probes for physics beyond the standard model at the LHC. Following the Run1 flagship observation by CMS and LHCb of $B_s^0 \to \mu+\mu-$, the accumulation of data will allow detailed measurements of the B^0_s channel along with improved searches for the rarer $B^0 \to \mu+\mu-$. In this project, we estimate the sensitivity that will be attainable with the upgraded CMS detector during the high-luminosity LHC (HL-LHC). Using detailed simulations of signal and background processes, we determined expected improvements in mass resolution relative to the current detector. These were then used to generate pseudo-experiments simulating the involved processes. With the sample of $3ab^{-1}$ at 14 TeV that we expect to collect during HL-LHC, major improvements in the measurements will be enabled. In addition to allowing precise measurements of the B_s^0 channel, including of its effective lifetime, a first observation of the B^0 channel will be in reach, with a statistical significance in excess of 6σ.

Measurement of H → 2 tau with multivariate analysis tools

Students: Luís Sintra, Ricardo Cipriano, Tomás Alvim
Supervisor: Pedrame Bargassa

One of the main goals of the CMS collaboration is the precise measurement of the properties of the Higgs boson. The couplings of Higgs to different Standard Model (SM) particles can give a precious hint to whether it belongs to the SM framework, or is otherwise a gateway to physics beyond our present knowledge. The goal of the internship was to improve on the analysis results of $H\to2\tau$ performed with a multi-class neural network (NN) instead of the original cut-and-count approach used for the Higgs boson discovery. Our NN categorizes events in SM processes by exploiting the separation between those processes in the multi-dimensional space of the chosen variables (e.g. missing transverse momentum). The strength of the Higgs signal is extracted from this categorization, and has a higher precision if the latter is more accurate. Focusing on event selection, we explored two ways of improving the categorization accuracy: by diminishing ttbar background with a filter based on the number of b jets; by overall diminishing SM backgrounds (except for the challenging $Z\to2\tau$) with a filter based on the output of a NN trained for the purpose. Our best result hints at an improvement of 11.1% of previous results.

Di-Higgs searches with machine learning

Students: Miguel Bengala, Rodrigo Santo
Supervisors: Giles Strong, Michele Gallinaro

With the proposed upgrades for the CMS detector in the High Luminosity LHC, it is wise to study what kind of results we are expecting to obtain and explore new paths for future analyses. In our project, we took data produced via a Monte Carlo generator and used it to predict the expected discovery significance of non-resonant di-Higgs (HH) production for the upgraded detector. The methods and results were discussed in an analysis note to be included in the Yellow Report. In the project, we explored the potential of advanced machine learning methods to distinguish signal events (HH non-resonant) from several backgrounds. Running the same architecture of deep neural networks (DNN), we implemented several state-of-the-art techniques: finding the optimal learning rate, experimenting with learning rate schedules and data augmentation. These were mostly developed for image recognition, but, adapting them to a high energy physics problem, we managed to incrementally optimise the significance of di-Higgs production.

Search for exclusive top quark pair production

Student: Beatriz Lopes
Supervisors: Pedro Silva, Michele Gallinaro, Jonathan Hollar

The project started with a two-week stay at CERN and then continued at LIP for two more weeks. Its main objective was to outline the start of a hunt for exclusive ttbar production, using data collected in 2017 by CMS. By analyzing dilepton events, and using data from both the CMS central system and the PPS detector, selection categories for both signal and control regions were defined. I could also establish a method to estimate the background and use an algorithm to reconstruct the kinematics of the system from the information given by PPS. Finally, we performed a statistical analysis and were able to estimate an upper limit for the cross-section of this process. An analysis note is being written to document this search.

Higgs boson couplings to heavy quarks

Students: Vânia Nunes, Alexandre Santos, Filipe Barroso
Supervisor: Rute Pedro

The study of the Higgs couplings to different particles is fundamental to test the Standard Model and on the pursuit for new physics. The direct observation of the Higgs decay into a b-jet pair was announce in August, but the story in just beginning. Several projects were developed along these lines, all using Multivariate Analysis techniques (MVA) based on Boosted Decision Tress (BDT).

Vânia Nunes focused on the optimization of the Higgs selection at high pT in ATLAS. To separate signal from background, a set of cuts was applied requiring a $Z \to ll$ selection and $p_T(Z) > 250$ GeV, both to simulated samples and 2017 data. We computed the significance $S/\sqrt{(S+B)}$ for two cut-based methods and trained two BDTs. The significance obtained with both BDTs was more than twice the value achieved with the cut-based analyses, proving the superior performance of MVA.

Alexandre Santos focused on the $H \to b\,\bar{b}\,\gamma$ channel in ATLAS, in view of possible anomalous couplings. An MVA was used to optimize the signal/background separation previously obtained from traditional event selections. We identified the variables with the highest potential in separating signal from background and tested different BDT configurations. A significance value of 0.645 for a luminosity of 300 fb^{-1} was achieved, an increase of 40 % compared to the previous method.

Filipe Barroso focused on optimizing the analysis of double Higgs production with decay to a b-pair at the proposed Future Circular Collider. A BDT was used to isolate signal from background. An increase of nearly a factor of two in significance was observed with respect to traditional selection cut analyses . Three different kinematic and topological regions were identified in the signal. A pre-selection was used to isolate the different regions and the BDT optimized in each of them.

Accelerating the ATLAS trigger algorithms with GPUs

Student: Eduardo Ferreira
Supervisor: Patricia Conde

General Purpose Processing Units (GPU) have been used successfully as hardware accelerators for trigger selection algorithms in many experiments. In ATLAS a GPU demonstrator prototype has been implemented to evaluate the use of GPUs for the trigger upgrades. This prototype uses a client-server architecture, that allows the trigger software to outsource specific code to the GPU. In this project the performance of the GPU calorimeter cluster reconstruction algorithms was evaluated in standalone mode, i.e, a testing client was reading events from file and sending them to the GPU. Racing problems were identified in a part of the algorithm and solved by requiring synchronisation of the GPU cores. The execution time was measured afterwards for different versions of the algorithm.

Exploring the ATLAS open data

Supervisors: Tiago Vale, Nuno Castro, Emanuel Gouveia, Ana Peixoto

At LIP Minho, ATLAS internships were based on the ATLAS open data set and has the duration of a couple of weeks. The students worked on different analyses and develops ways to explore this rich dataset, which has in particular a large potential for educational purposed.

Search for a new Z' boson in top/anti-top events

Students: Pedro Daniel Silva Chaves, José Neto, Sara Salgado

In this project we investigated the existence of a particle called Z' that is not in the Standard Model of Particle Physics. In order to do that, we searched for one of the decays of this particle (into a top-quark pair). No signal was found, and we were able to put limits on the mass of this possible new particles predicted in several extensions of the Standard Model.

ttbar cross section measurement

Students: Maria do Céu Neiva, Francisco Fernandes

The top quark is by far the heaviest of all quarks, and an excellent probe to test the Standard Model and search for hints on new physics. In this project, our goal was to study the production of top quarks pairs in the LHC. ATLAS data from the ATLAS open data set were used. We developed dedicated analyses for the main decay channel and were able to obtained a measurement of the top - anti-top production cross-section.

High-precision timing detectors for HL-LHC

Student: Nelson Rebelo
Supervisor: Tahereh Niknejad

At the High Luminosity LHC an average of 140–200 piled-up events will occur. This can degrade reconstruction, and dedicated detectors for precise timing of particles are need. The Barrel Timing Layer (BTL) is a new timing detector in CMS. It is composed of LYSO scintillator crystals where light is generate, a SiPM to detect this light and a readout ASIC to gather data. With very fast electronics, time accuracy depends on the SiPM. In this internship the main goal was to characterize different SiPM. The Single Photon Time Resolution (SPTR, the worst case scenario time resolution) was measured by exciting the SiPM with a pulsed laser with attenuators such that the SiPM is hit, with higher probability, by only 1 photon. The laser pulse was triggered by the FPGA at a set rate. The time over threshold (ToT) distribution of events within ±1 ns of the expected laser pulse time shows the 1-photon and 2-photon peaks. The rms of the time distribution of events with ToT corresponding to 1 photon provides a measurement of SPTR. With this analysis we were able to characterize the SiPM and better understand their capabilities and applications.

Characterisation of optical materials for the upgrade of the TileCal hadron calorimeter

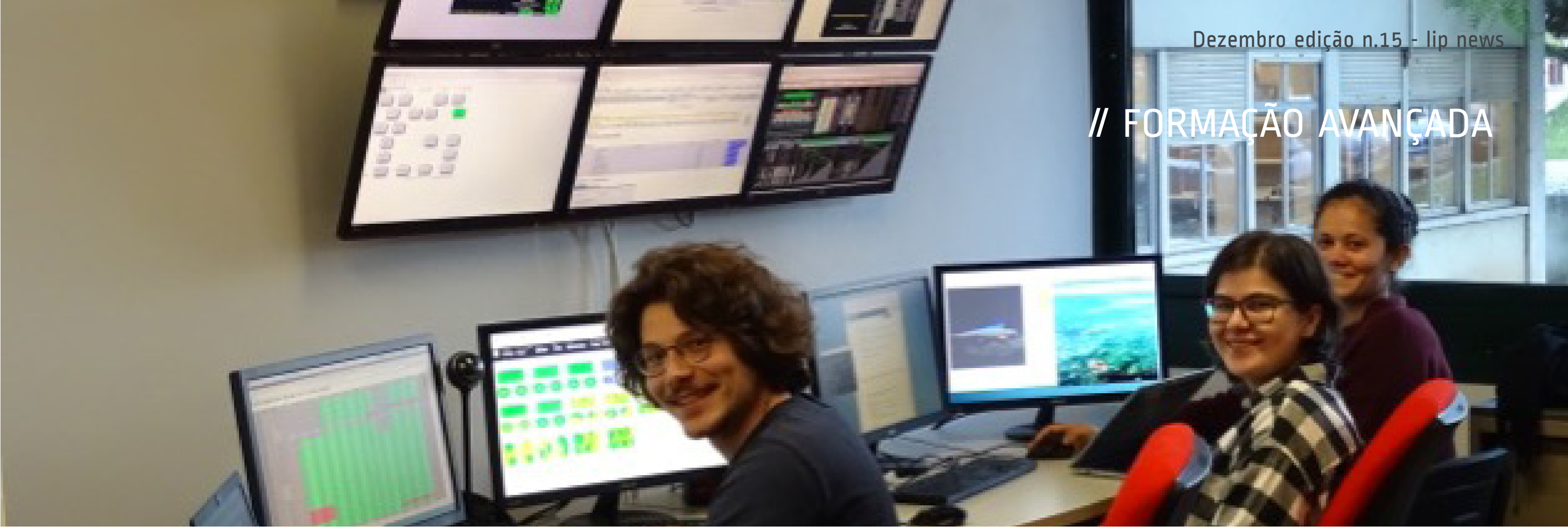
Student: Carlos Vítor
Supervisors: Agostinho Gomes, João Gentil

During this internship, several properties of wavelength shifting fibres and scintillating tiles similar to those of the ATLAS barrel hadron calorimeter TileCal were measured using different experimental apparatuses. Also, some fibres were prepared for further analysis by aluminizing one of the edges with a method based on the magnetron sputtering technique for deposition of thin films. The modification of the fibre emission spectral peaks were analysed. Measurements of the same set of fibres placed separated by various distances were done showing that for the standard operation conditions crosstalk is negligible (<0.1%). The linearity of the PMT was confirmed using different light input intensities. The uniformity of the output signal from a scintillating tile read-out by a fibre in a source position scan was measured.

Production and characterization of thin films

Student: Andriy Myakush
Supervisors: Daniel Galaviz Redondo, Pamela Teubig

Thin films are necessary in nuclear physics experiments, where they are used as sources, beam targets, as well as backings for other materials. The internship involved the production of silver films, and the measurement of their thickness with an alpha source. The production technique used was thermal evaporation in high vacuum: the silver is heated, until it evaporates onto appropriately treated glass substrates. The evaporation itself was done inside a sealed chamber, with pressures of 10^{-7} mbar inside. Once the evaporation was finished, the films were recovered, and their thickness was measured with a U-232 alpha source. The thickness was calculated by dividing the energy loss of the particle while passing through the film (measured with a silicon detector), by the stopping power of the incident particle, calculated with the Bethe-Bloch equation. During the internship, three evaporations were realized, each with a different mass of silver evaporated: 290.4 mg, 189.3 mg, and 100.1 mg. The films produced had the thickness of the order of micrometer, ranging from 1.05 µm to 0.32 µm. The silver films like the ones produced are to be used as backings for targets in future experiments by the LIP NUC-RIA group.



Shifts de CMS em Lisboa, na sala LIP@IST

Diogo de Bastos e Mariana Araújo

Novembro de 2018 marcou o fim do run 2 do LHC, com um mês de tomada de dados de colisões de iões pesados antes da paragem que irá durar até 2021. Foi nesta altura memorável que vários membros da experiência CMS estiveram na sala de controlo LIP@IST a realizar shifts-turnos de monitorização de um subsistema do detector CMS, de modo a garantir a qualidade dos dados tomados.

Estes tiveram lugar nas semanas de 5-11 e 19-25 de Novembro. Os alunos de doutoramento Diogo Bastos e Mariana Araújo realizaram turnos dedicados à monitorização do ECAL (Electromagnetic CALorimeter), que detecta electrões e fotões. Nestes turnos, foi necessário acompanhar em tempo real o sistema de aquisição de dados do ECAL, de modo a avaliar o estado dos diferentes componentes do detector e do sistema de calibração associado. Qualquer problema encontrado deveria ser comunicado imediatamente aos especialistas no local.

Foi ainda tarefa dos alunos certificar a qualidade dos dados recolhidos, com base em informação detalhada do estado e desempenho do ECAL. Os dados que passam esta validação tornam-se disponíveis para serem utilizados em análises de física realizadas pela colaboração CMS, após processamento. É por isso essencial garantir que não houve qualquer problema com o detector que possa comprometer a sua qualidade.

A ajudar a Mariana e o Diogo estiveram os alunos Beatriz Ribeiro Lopes, Beatriz Pereira Lopes, Luís Sintra e Júlia Silva que durante o verão estagiaram no LIP. Quando surgiu a ideia de dinamizar os turnos estes demonstraram logo interesse em colaborar e em aprender mais sobre detectores de física a altas energias.

Deixando aqui um pequeno testemunho sobre a sua experiência: *"Num ambiente descontraído, tivemos o nosso primeiro contacto com um shift de CMS. Certificámos múltiplos runs e identificando vários problemas ocorridos. Agradecimentos ao Diogo e à Mariana por nos orientarem nesta tarefa."* Júlia e Luís

"Ajudar a Mariana e o Diogo nos shifts do ECAL foi uma experiência diferente e enriquecedora. O bom ambiente da sala de controlo permitiu-nos aprender muito sobre o ECAL e sobre as tarefas de um shifter." Beatriz e Beatriz

Artificial Intelligence and Particle Physics

Michele Gallinaro

A stimulating mixture of two difficult topics, starting from the past and extending into the future, by addressing some of the current challenges that science and technology are presently facing.

A well-attended public event took place at the National Library on October 30, 2018. More than 300 people registered for the event. Students, teachers, and curious individuals from many different parts of the society showed up with keen interest, and filled the auditorium to its capacity.

Two lectures on artificial intelligence and particle physics kicked off the discussion that followed. Basic principles and applications both to society and in basic science were addressed. The audience, populated by many young students, stimulated the lively discussion that followed by touching different topics, ranging from clarification of basic principles and deeper scientific understanding to much wider philosophical questions.

The public discussion continued until 8 pm, when the lights were dimmed and the audience started leaving. Some still remained in the hall asking questions to the speakers, some left asking questions to themselves. One day, maybe, we will be able to answer some of these questions. Hopefully, some of the people in the audience will help in this challenging task.

NOVOS MEMBROS DO LIP

Giovanni La Mura

I got my Master and PhD degrees in Astronomy in Padua (Italy), where I worked for some years at the University, as a researcher and assistant lecturer in Astrophysics.
I developed an experience as telescope operator and I joined the Fermi Large Area Telescope Collaboration for the investigation of astrophysical gamma-ray sources. My main research interests are focused in the investigation of Active Galactic Nuclei, the brightest non-transient objects known in the Universe, and in their role in the emission of very-high-energy gamma-rays and in the acceleration of ultra-relativistic particles.

I joined LIP in August 2018, working on the LATTES project for a detector concept that will survey the very high energy gamma ray sky, complementing the scientific objectives of large international facilities like the Cherenkov Telescope Array (CTA).

Ofélia Janeiro

Sou uma alentejana em Lisboa, há quase tantos anos quantos me conheço. Licenciei-me em Relações Internacionais e fiz uma pós-graduação em Direito do Consumo, área na qual trabalhei nos últimos anos. Tenho várias atividades paralelas ao trabalho, e as minhas grandes paixões são os direitos humanos, o conhecimento e o bem público. Foi também por isso que abracei este desafio de vir para o Secretariado do LIP, mudando as agulhas de uma vida profissional centrada no consumo privado e na lógica de mercado, para uma área do conhecimento e do progresso científico, de cariz publico e universal. Espero corresponder da melhor maneira.

Samuel Bernardo

Nasci nas Caldas da Rainha e estou a terminar a dissertação do Mestrado em Engenharia Informática e de Computadores no IST, Universidade de Lisboa. Comecei a minha carreira na área de informática no Departamento de Engenharia Informática (RNL) do IST onde iniciei o trabalho de investigação de sistemas de computação distribuída há 6 anos. Durante esse período tive a oportunidade de interagir com utilizadores de diversas áreas de investigação em projectos de computação nas especialidades de Informática e Matemática.

Dado o meu interesse por HTC e HPC, e no contexto do projecto de utilização dos ciclos mortos de computação de postos de trabalho, organizei uma visita de estudo à sala GRID do LNEC com os colegas da RNL, altura em que tive o primeiro contacto com a equipa do LIP. Passados todos estes anos, o ingresso no LIP foi uma alegria pessoal pela oportunidade de poder desenvolver o meu trabalho na área de investigação pela qual tenho o maior interesse.

O LIP NAS REDES SOCIAIS

TOP POSTS on LIP FACEBOOK

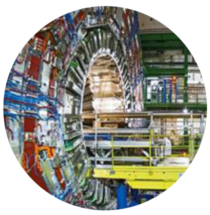
O Quilograma morreu, viva o Quilograma!

798 engagements

Estágio no CERN para Professores de Escolas Portuguesas

668 engagements

O LIP no Público: Bosão de Higgs visto (finalmente) a desintegrar-se em quarks bottom



378 engagements

Programa de estágios de verão do LIP

309 engagements

Shifts de CMS na Sala LIP@IST

267 engagements

O LIP no DN: Astronomia multi-mensageiros

264 engagements

TESES

PhD

Demonstração de um dispositivo de imagiologia por raios ortogonais para apoio à radioterapia externa de fotões

Hugo Simões (UC, Jul 2018)

Novel Techniques for High Pressure Noble Gas Radiation Detectors

André Cortez (UC, Nov 2018)

MESTRADO

Prospective studies of highly boosted Higgs pairs decaying to four b quarks

Ana Luísa Carvalho (IST, Nov 2018)

Study of ttH production with H->bb in ATLAS at the HL-LHC

António Costa (IST, Nov 2018)

agenda

Lisbon Mini-school on Particle & Astroparticle Physics

11 a 13 Fevereiro 2019, Costa da Caparica, Portugal

Encontro Nacional de Estudantes de Física ENEF'19

28 Fevereiro a 03 Março, IST, Lisboa, Portugal

Masterclasses Internacionais de Física de Partículas

08 Março a 06 Abril 2019, Portugal

Workshop and School on Data Science

25 a 29 Março 2019, Braga, Portugal

Aniversário do LIP, Sessão Pública

09 Maio 2019, LIP-Lisboa, Portugal

IDPASC and LIP Student Workshop

01 a 03 Julho 2019

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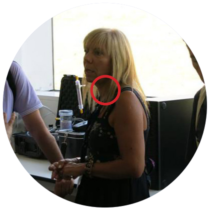
Nobel da Física 2018

250 engagements

Física 2018: Visita ao LabExpoRad gerido pelo LIP na UBI



244 engagements

Olimpíadas Internacionais da Física (IPhO2018)

223 engagements

Ricardo Gonçalo na ES António Damásio na Semana do Espaço 2018

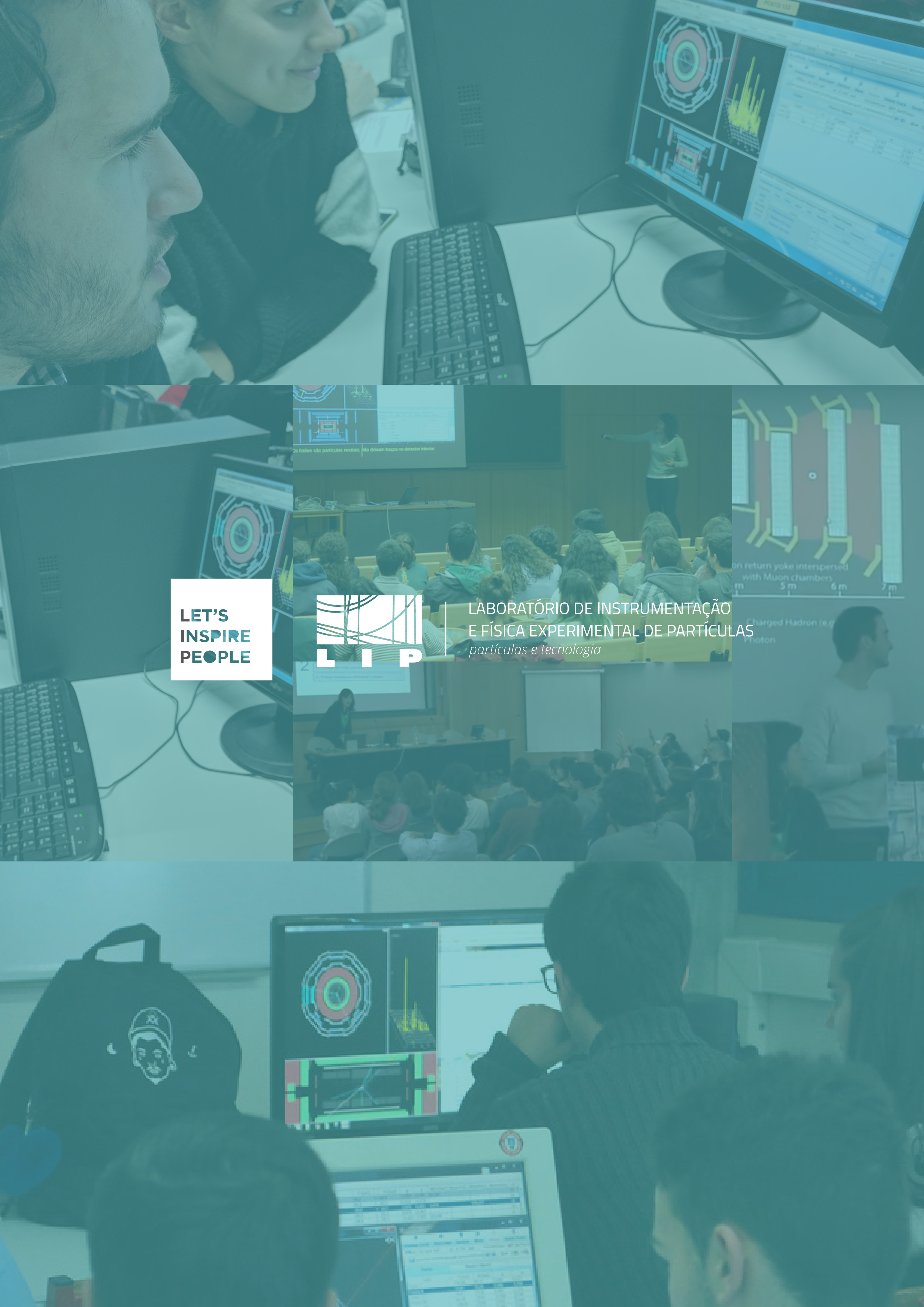
219 engagements

Como observar o maior eclipse da Lua sem cair no "erro romântico" de Galileu

218 engagements

Jornadas do LIP 2018

217 engagements



LET'S INSPIRE PEOPLE

LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia