FCC Group – Future Circular Collider

LIP Advisory Board Meeting
27 April 2023

LIP

Ricardo Gonçalo – UC / LIP

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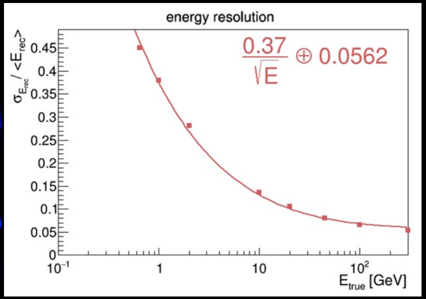
UNIVERSIDADE D COIMBRA

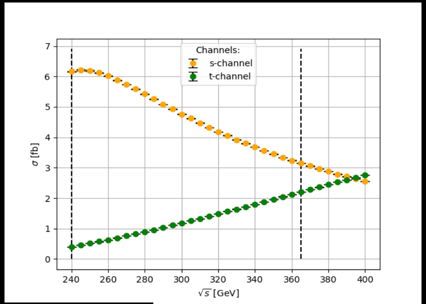
FCC Group

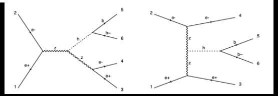
Group dedicated to future collider studies – main focus on FCC-ee
Increasing cross-talk with ECFA Detector R&D roadmap activities – DRD collabs.

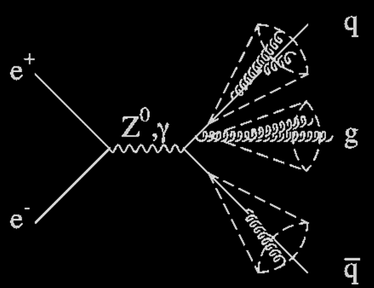
Activity:

- Rad-hard scintillator development
  - PET/PEN samples under testing
- Calorimeter simulation for FCC-ee
  - Joined proposed scintillator+Fe/Pb HCAL option
  - Optimizing geometry, material, granularity, depth, compensation etc, including M.Learning
- Higgs at FCC-ee
  - Pheno. study of Higgs production channels
- 3-jet cross section and event shapes
  - Preparing for ultra-precise measurement of α_s at FCC-ee Z-pole run









Strengths, Weaknesses, Opportunities and Threats

- Strengths:
  - Experienced team from different LIP sites and universities – access to students
- Weaknesses:
  - Little researcher time devoted to FCC – not the main interest of researchers in the group
- Opportunities:
  - Contributing to feasibility study – long-term, unique facility in particle physics
  - Good opportunity for student training
  - Technological studies have wide applicability
- Threats:
  - Shortness of dedicated research time
  - Limited specific funding

Team: Grigorios Chachamis, Guilherme Milhano, Inês Ochoa, João Nuno Pires, Michele Gallinaro, Patricia Conde, Rute Pedro, Beatriz Pinheiro Pereira (PhD), Francisco Casalinho (MSc), Joana Reis (MSc)

Bonus slides

LIP

LET'S INSPIRE PEOPLE

Status of Global FCC Collaboration

FCC-ee:

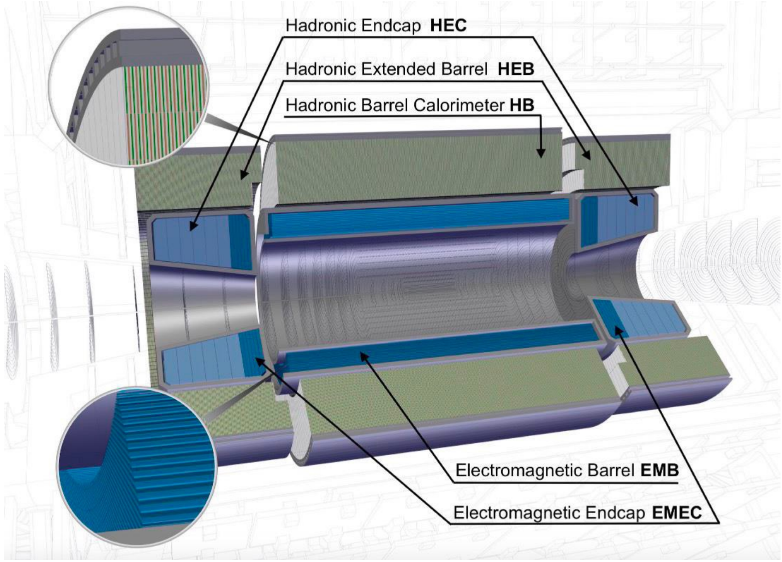
Physics requirements

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_T) \sim 2 \times 10^{-5}$
$H \to \mu^+\mu^-$	$\mathrm{BR}(H \to \mu^+\mu^-)$		$\oplus 1 \times 10^{-3}/(p_T \sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$\mathrm{BR}(H \to b\bar{b},\ c\bar{c},\ gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p \sin^{3/2}\theta)\ \mu\mathrm{m}$
$H \to q\bar{q},\ VV$	$\mathrm{BR}(H \to q\bar{q},\ VV)$	ECAL, HCAL	$\sigma_E^{\mathrm{jet}}/E \sim 3-4\%$
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (GeV)

- Very good momentum resolution.
- Very good vertex resolution.
- Excellent Hadronic calorimetry.
- Good, but not extreme, EM calorimetry
- Good tau identification capabilities and ability for polarisation measurements, very good PID.

Hadronic calorimetry at FCC-hh

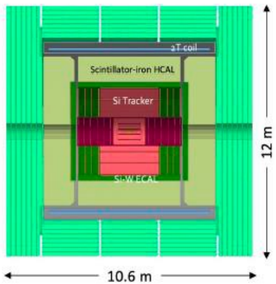
- For FCC-hh a barrel hadron calorimeter Tilecal like in the central region is straight forward
- Better granularity and new photosensors are key to get better performance keeping a low cost
- Radiation hardness of the scintillators and WLS fibers are potential issues, improvement needed tocope with ~10 kGy



Design for FCC-ee central calorimeter system

CDR

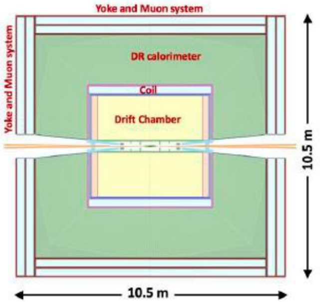
CLD



- Full Silicon vertex detector + tracker;
- Very high granularity, CALICE-like calorimetry;
- Muon system
- Large coil outside calorimeter system;

- Possible optimization for
  - Improved momentum and energy resolutions
  - PID capabilities

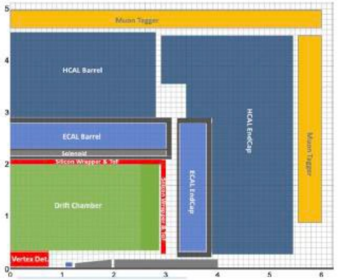
IDEA



- Si vertex detector;
- Ultra light drift chamber w. powerfull PID;
- Monolitic dual readout calorimeter;
- Muon system;
- Compact, light coil inside calorimeter;

- Possibly augmented by crystal ECAL in front of coil;

Noble Liquid ECAL based



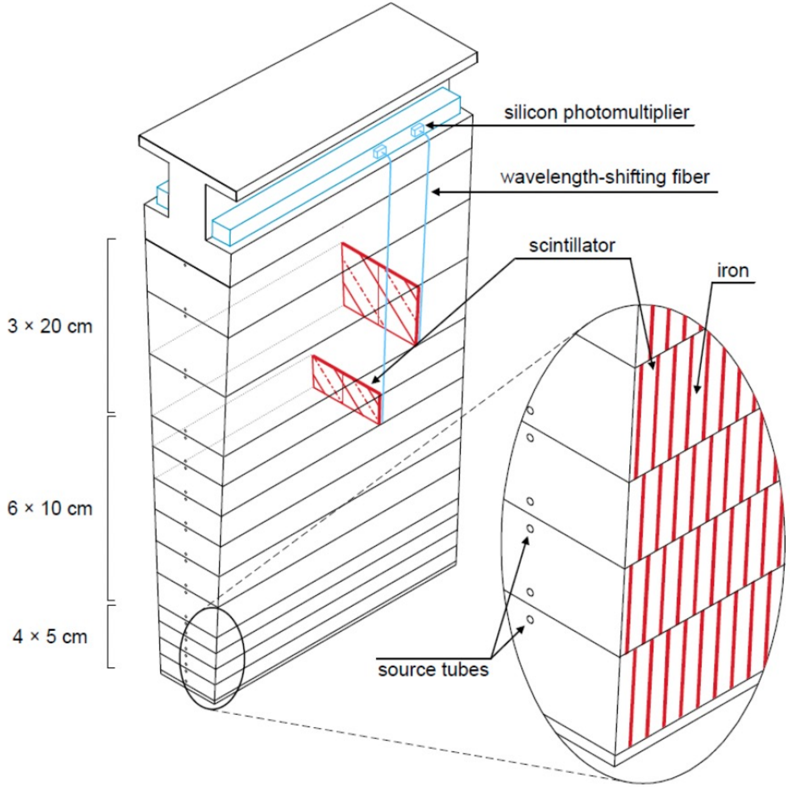
new

- High granularity Noble Liquid ECAL as core;
  - PB+LAr (or denser W+LCr)
- Drift chamber (or Si) tracking;
- CALICE-like HCAL;
- Muon system;
- Coil inside same cryostat as LAr, possibly outside ECAL.

M. Aleksa et. al.

A **new** proposal for a HCAL alternative: scintillating tile barrel calorimeter with Fe/Pb

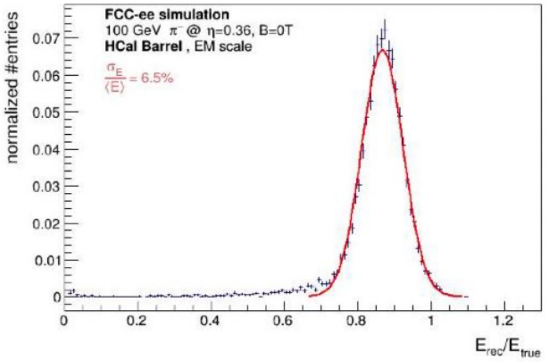
Design for FCC-ee central calorimeter system



Base is the same as FCC-hh design, but

- Removed the Pb plates
- HCAL acts as return yoke for the central solenoid
- 13 layers in depth

Work on optimisation of segmentation and reconstruction starting



Scintillator development - Dlight project

DLight exploratory project, R. Pedro et al

Exploration of alternative scintillators based on PEN and PET

Get radiation hard and relatively cheap injection mould plastic scintillators

Collaboration of LIP and Institute for Polymers and Composites of U. Minho

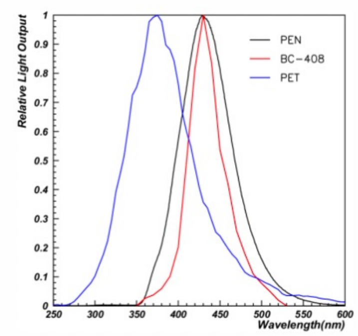
- Characterisation of material.

- Develop PEN/PET granulate process by extrusion/injection moulding.

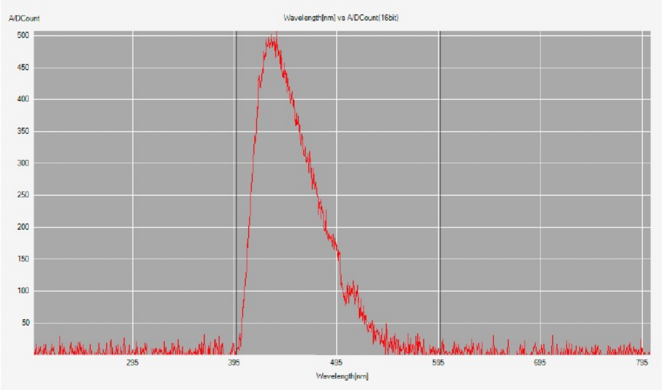
- Setup scalable manufacturing process.

Dlight short term plans

- Produce 3mm thick scintillators with larger areas
- Setup UV LEDs to excite PET at lower wavelengths
- Use PET and PEN blends, later add suitable dopants
- Transparency and light yield of the scintillators need improvement



PET, PEN and BC-408 emission spectra

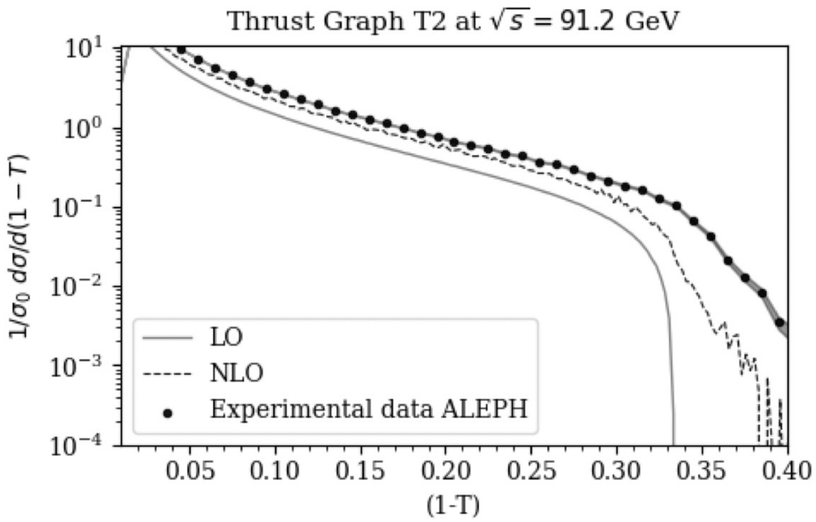


PEN emission spectrum measured at LIP

Thrust distribution of $\gamma \to q\bar{q}g$ using **EErad3**

EErad3 is a Monte Carlo program able to simulate jet showers from 3-jet decay $\gamma, Z \to q\bar{q}g$, using radiative corrections up to NNLO from pQCD. This program provides us event shape distributions such as Thrust (T), normalised heavy jet mass, the wide and total jet broadening, C-parameters, Durham jet algorithm…

We are able to obtain a fit of the value of the running α_s through the perturbative expansion of these event shapes.



In this thesis we use mainly the event shape distribution of the Thrust, defined as,

$$T = \max_{\vec{n}} \left(\frac{\sum_i |\vec{p_i} \cdot \vec{n}|}{\sum_i |\vec{p_i}|} \right)$$

- When $T \to 1$, the maximum value of thrust, we have the limit where there are only two particles in the event (pencil-like configuration).
- When $T \to 2/3$, we reach the minimum value of thrust for a three-particle event (Mercedes-like configuration).

ALEPH Collaboration *et al* , *Studies of QCD at e+e− centre-of-mass energies between 91 and 209 GeV* , Eur. Phys. J. C 35, 457–486 (2004) (DOI 10.1140/epjc/s2004-01891-4)

Future work

To do:

1. Apply similar analysis for the more complex case $\gamma^*, Z \longrightarrow q\bar{q}g$ up to NLO correction for the massless quark limit. (In development)

2. Run EErad3 to obtain the distribution of the event shape Thrust and cross-section of $\gamma^*, Z \longrightarrow q\bar{q}g$ for analysis. (In development)

3. Obtain the renormalized running $\alpha_s(M_Z)$ from 3-jet to 2-jet ratio $\frac{\sigma(e^+e^- \to 3jets)}{\sigma(e^+e^- \to 2jets)}$ (Not done yet)

4. Include the bottom quark mass (around 4 GeV) and follow the same steps above. (In development)

5. Finally, analyse obtained event shapes distributions between the massless and b-quark mass limits.

LO	$\gamma^* \to q\,\bar{q}g$	tree level
NLO	$\gamma^* \to q\,\bar{q}g$	one loop
	$\gamma^* \to q\,\bar{q}\,gg$	tree level
	$\gamma^* \to q\,\bar{q}\,q\bar{q}$	tree level

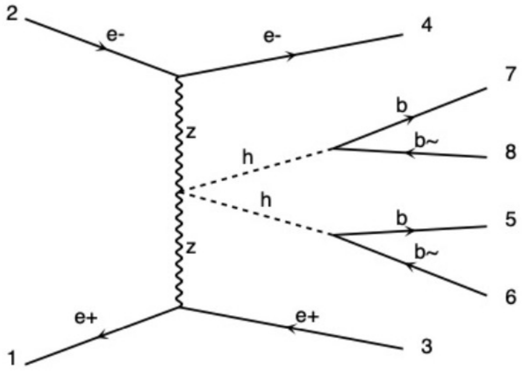


diagram 1 QCD=0, QED=6

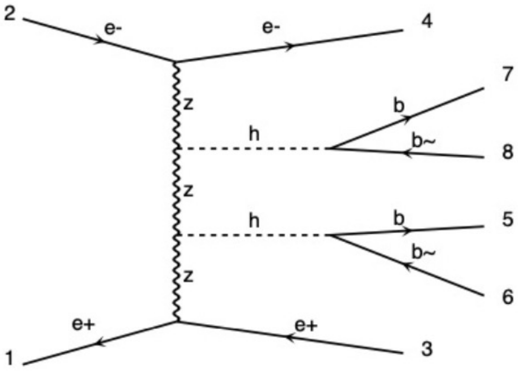


diagram 2 QCD=0, QED=6

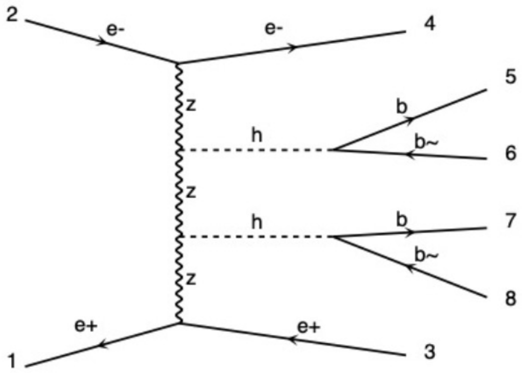


diagram 3 QCD=0, QED=6

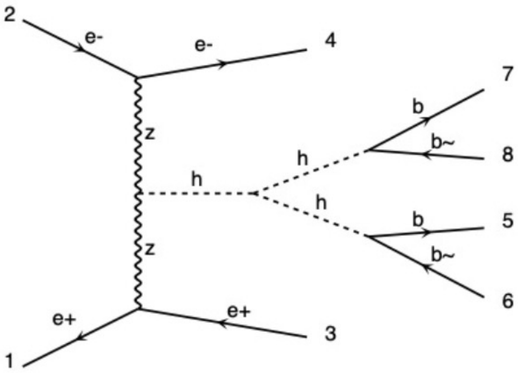
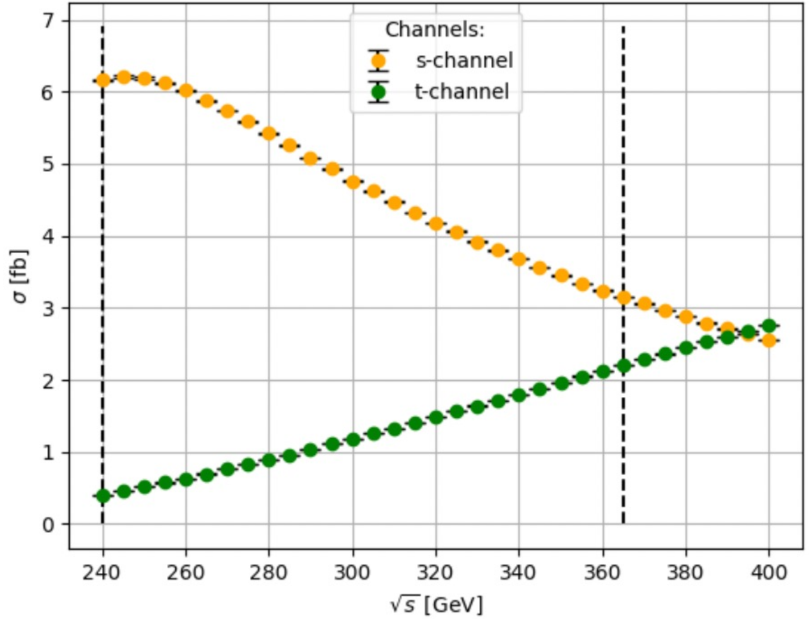
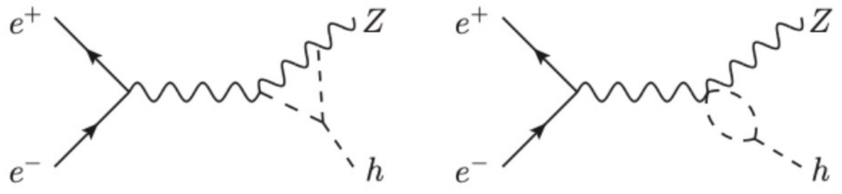


diagram 4 QCD=0, QED=6

Higgsstrahlung





Contributions of NLO to the ZH cross-section: [1]
- ≈2% at 240 GeV
- ≈0.5% at 365 GeV

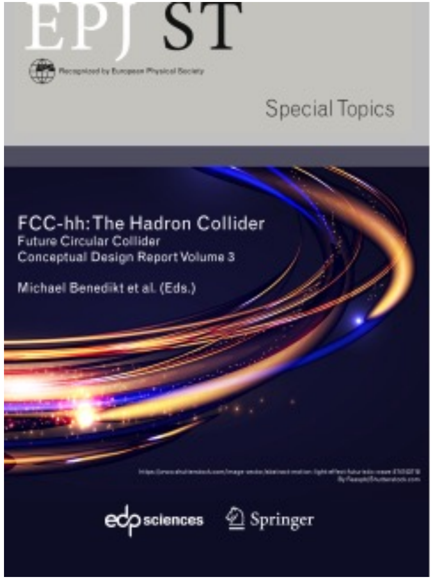
Channel	Order	σ [fb]	√s [GeV]	$\mathcal{L}$ [ab^-1]	Nº of events
s-channel	LO	6,16	240	5	30800
	NLO	0,1232			616
	LO	3,15	365	1,5	4717,5
	NLO	0,001573			2,36

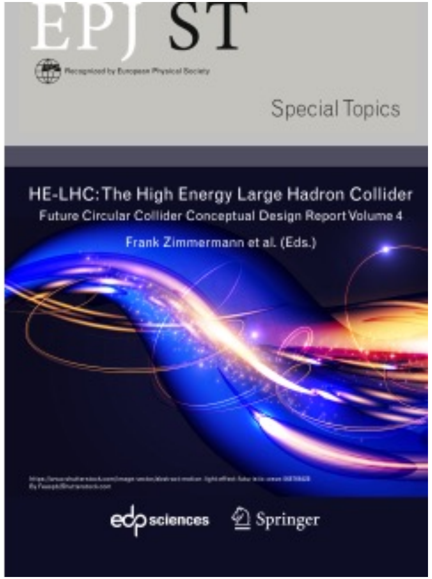
[1] Azzurri, Paolo, et al. "A special Higgs challenge: measuring the mass and production cross section with ultimate precision at FCC-ee." *The European Physical Journal Plus* 137.1 (2021): 23.

Portugal and the FCC

- Several contributions to the FCC Conceptual Design Report
  - Physics: Top, Higgs, Heavy Ion, etc – both theoretical explorations and feasibility studies
  - Detector design and studies

- Most contributors from
  - LHC experimental groups
  - LHC-related theory interests
  - These are the core of people here today





Portugal and the European Strategy for Particle Physics

- Contributed to the 2020 ESPP with local consultation
  - View that next major collider should be based at CERN

- Aligned with priorities set out by ESPP:
  1. Full physics exploitation of the LHC and HL-LHC
  2. Next priority is a **e^+e^- "Higgs factory"**
  3. Increased R&D on enabling accelerator technologies:
  4. Support neutrino projects in US and Japan
  5. Support high-impact scientific diversity programme complementary to high-energy colliders

- First strategy document approved at a special Restricted Session of CERN Council in **Lisbon, 14 July 2006**