ATLAS Trigger Performance

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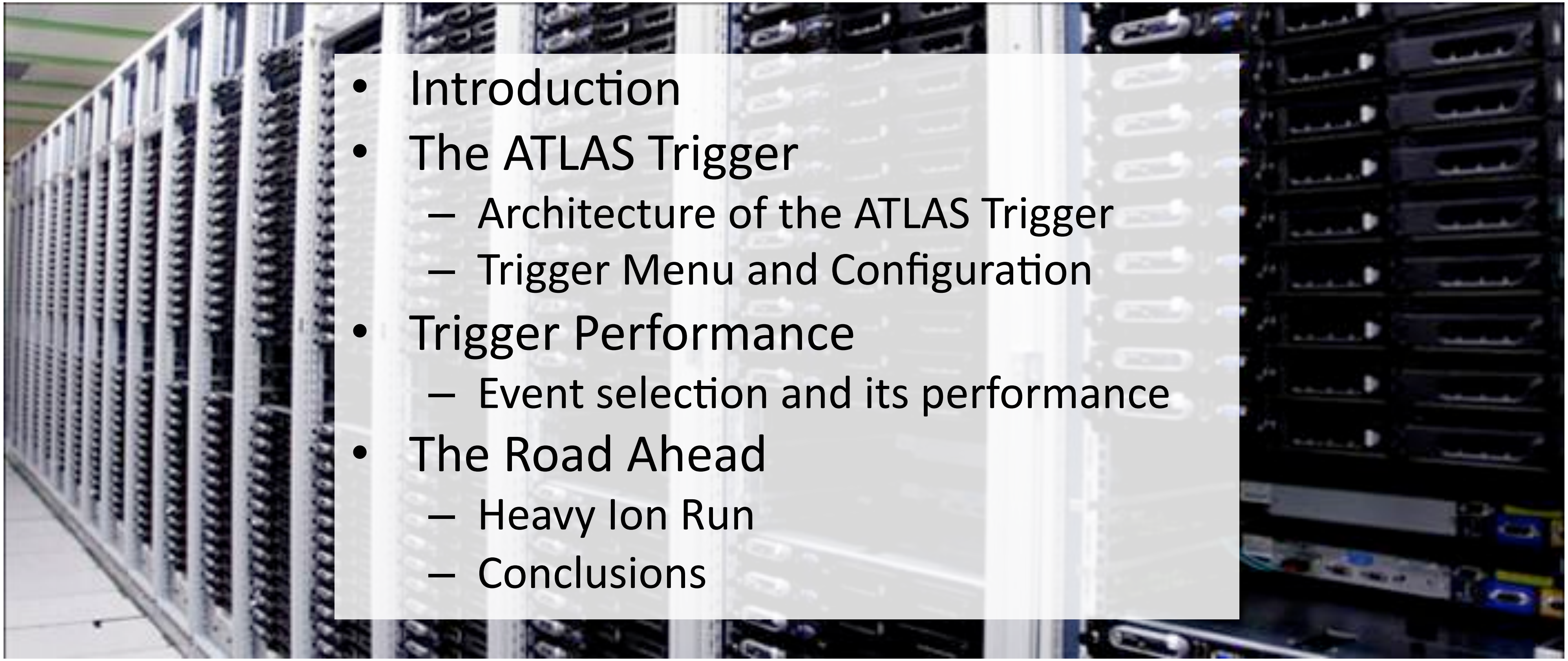
Royal Holloway University of London
On behalf of the ATLAS Collaboration

LHC Days at Split, 4-8 October, 2010

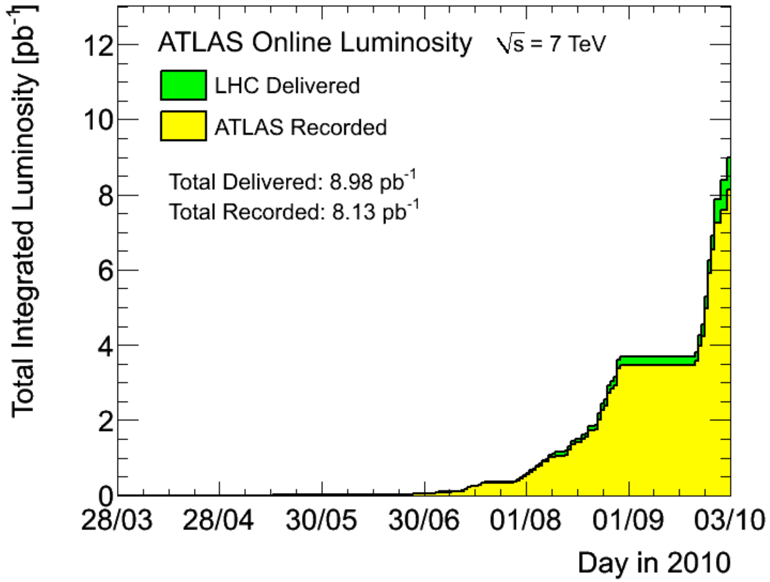
Outline

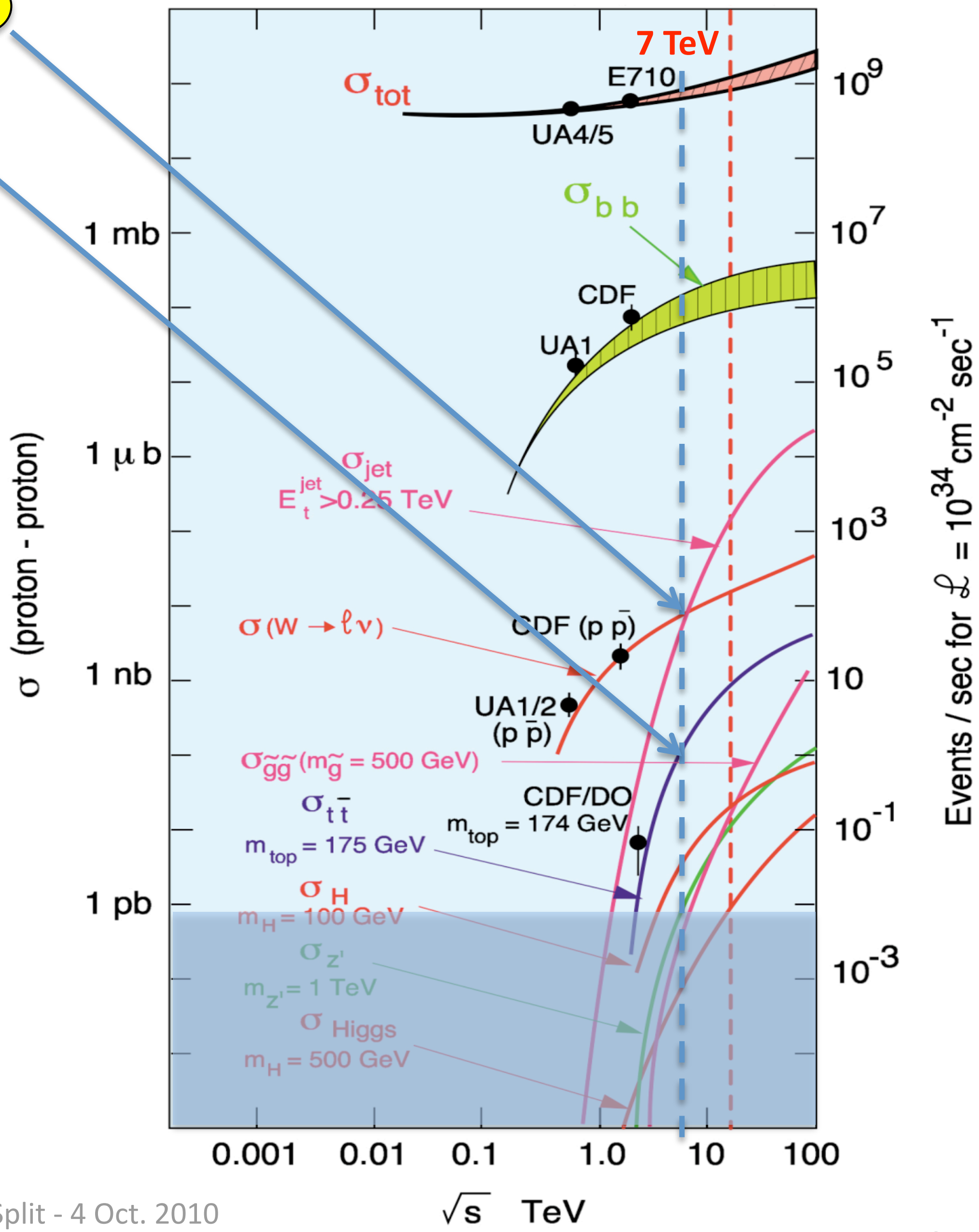


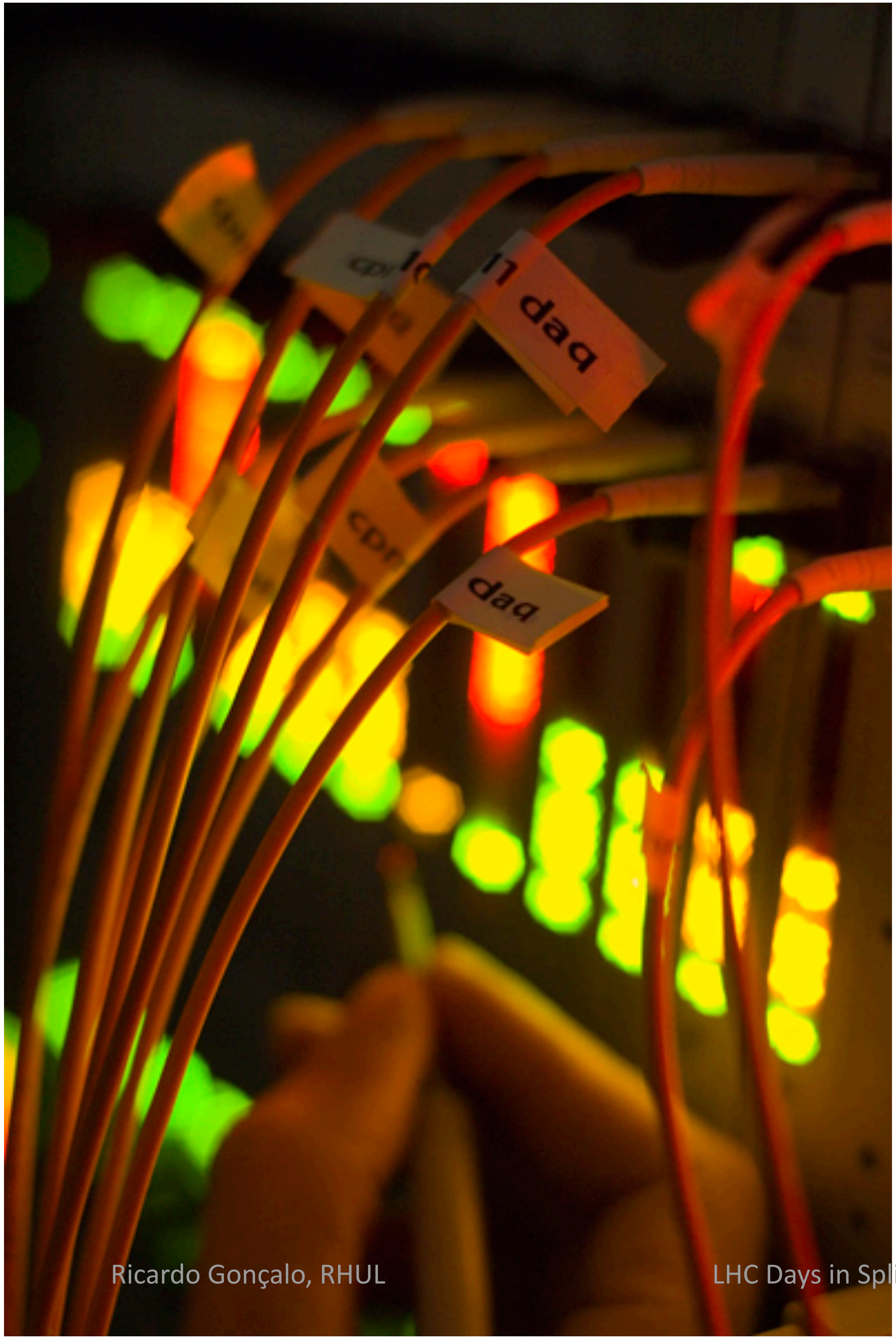
- Introduction
- The ATLAS Trigger
  - Architecture of the ATLAS Trigger
  - Trigger Menu and Configuration
- Trigger Performance
  - Event selection and its performance
- The Road Ahead
  - Heavy Ion Run
  - Conclusions

- ATLAS collected ∫ L dt > 8 pb^{-1} (±11%)
  - At ≈ 94% efficiency and improving
  - First W and Z cross section measurements
  - Handful of top candidates seen
- LHC running smoothly at √s = 7 TeV
  - Started 30 March 2010 with L≈$10^{27}cm^{-2}s^{-1}$
  - Crossed L = $10^{31}cm^{-2}s^{-1}$ milestone in August
  - Aim to achieve L = 10^{32} $cm^{-2}s^{-1}$ in October
  - p-p run until early November, followed by heavy-ion run
  - Plan for √s = 14 TeV in 2013 after shutdown
- Trigger coping with ≈10^5 increase in LHC luminosity over 7 months

See also previous talk by Daniel Fournier



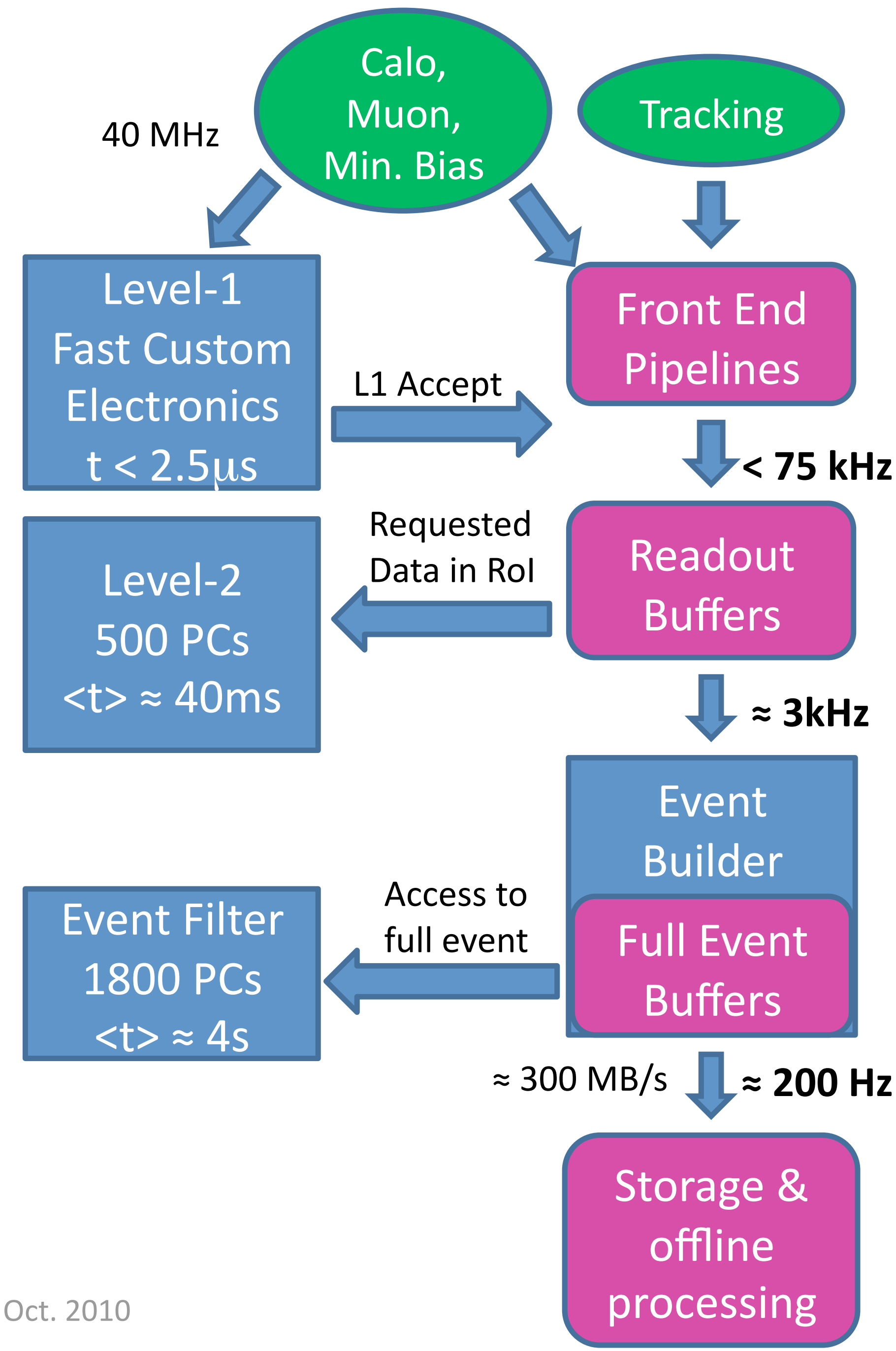


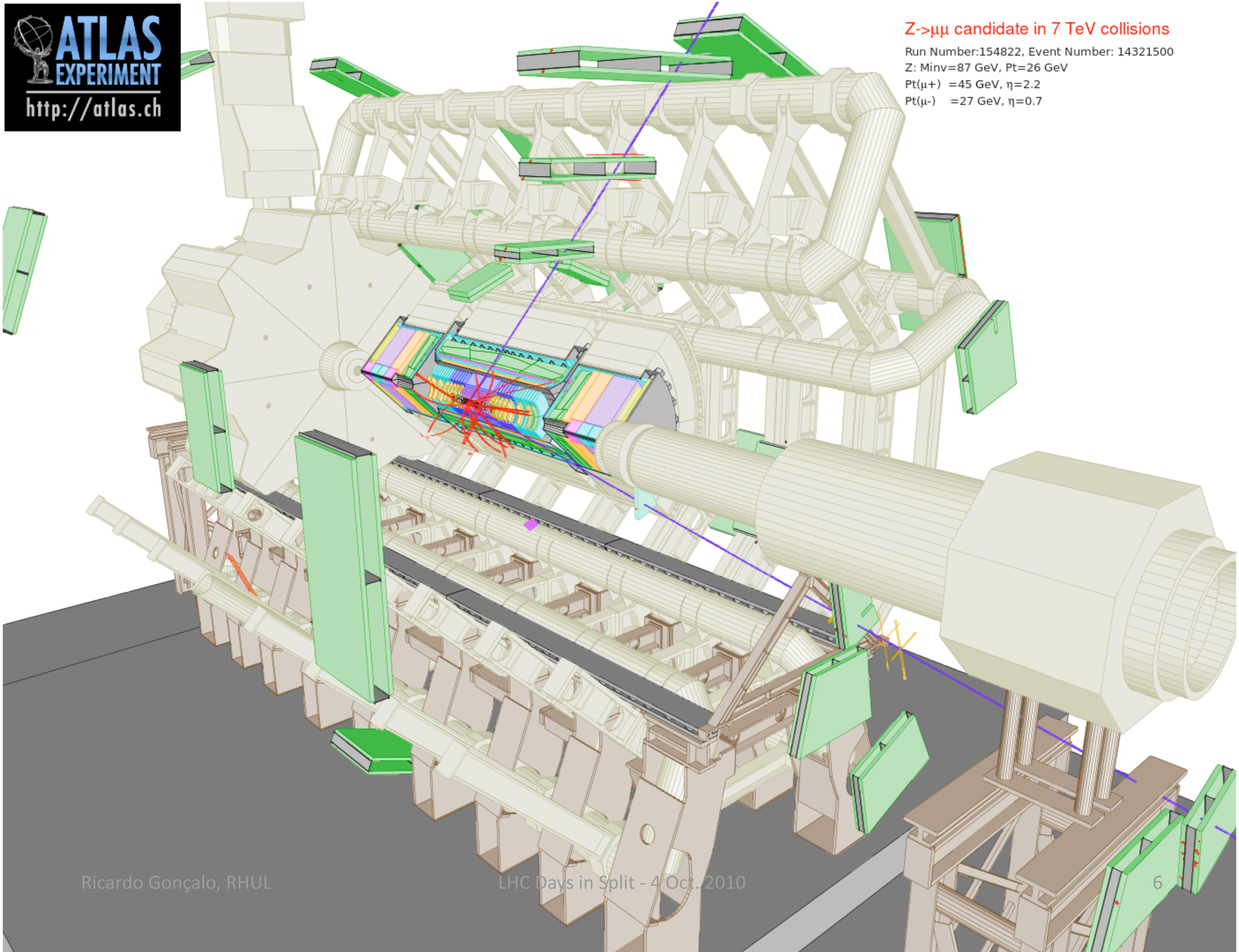


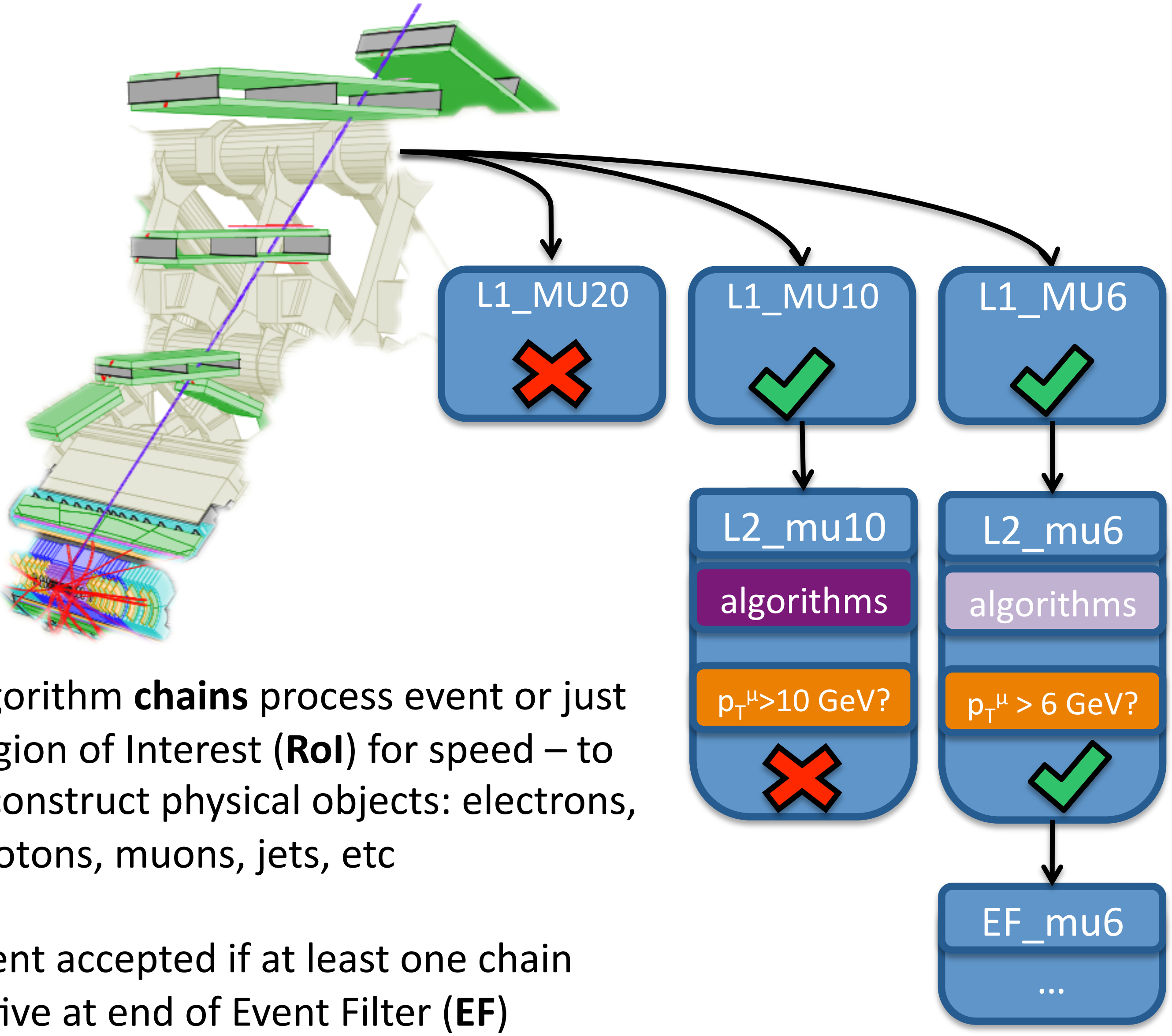
THE ATLAS TRIGGER

Architecture

- Level 1 (L1): < 75 kHz
  - Fast **Custom-built electronics**
  - Input mainly from **Calorimeter** and **Muon** spectrometer
  - Inputs combined in Central Trigger Processor
- High Level Trigger (HLT):
  - Level 2 & Event Filter (third level)
  - **Software based** running on large PC farm
- Level 2 (L2): ≈ 3 kHz
  - **Fast** custom algorithms
  - reconstruction mainly in **Regions of Interest** (RoI) ➔ limited data access
- Event Filter (EF): ≈ 200 Hz
  - Third trigger level
  - **Offline** tools inside custom wrappers,
  - Access to **full event** information




Z->μμ candidate in 7 TeV collisions
Run Number:154822, Event Number: 14321500
Z: Minv=87 GeV, Pt=26 GeV
Pt(μ+) =45 GeV, η=2.2
Pt(μ-) =27 GeV, η=0.7



L1 muon candidate (RoI) fires 2 thresholds

Each seeds one or more L2 algorithm chains

Algorithm result cached: only run heavy algorithms once

If signature not confirmed, de-activate chain

Active chains seed other chains in next level

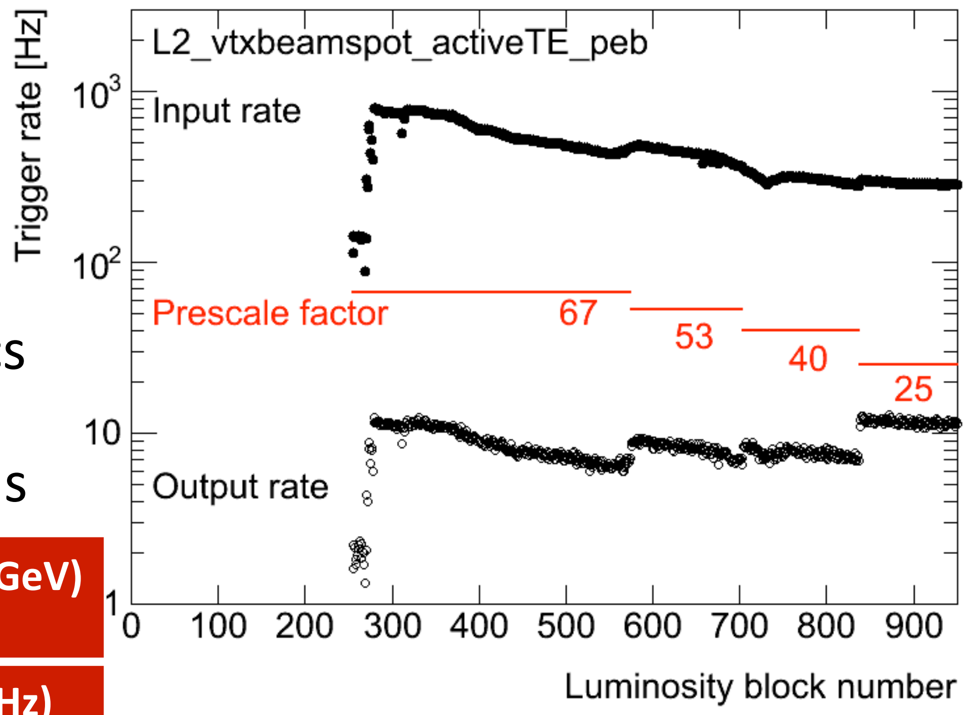
Algorithm **chains** process event or just Region of Interest (**RoI**) for speed – to reconstruct physical objects: electrons, photons, muons, jets, etc

Event accepted if at least one chain active at end of Event Filter (**EF**)

All chains executed – since trigger result used to stream events (inclusive data streams)

Trigger menu:

- Collection of trigger signatures
- ≈200 – 500 algorithm chains in current menus
- Algorithms re-used in many chains
- Selections dictated by ATLAS physics programme
- Also calibration & monitoring chains

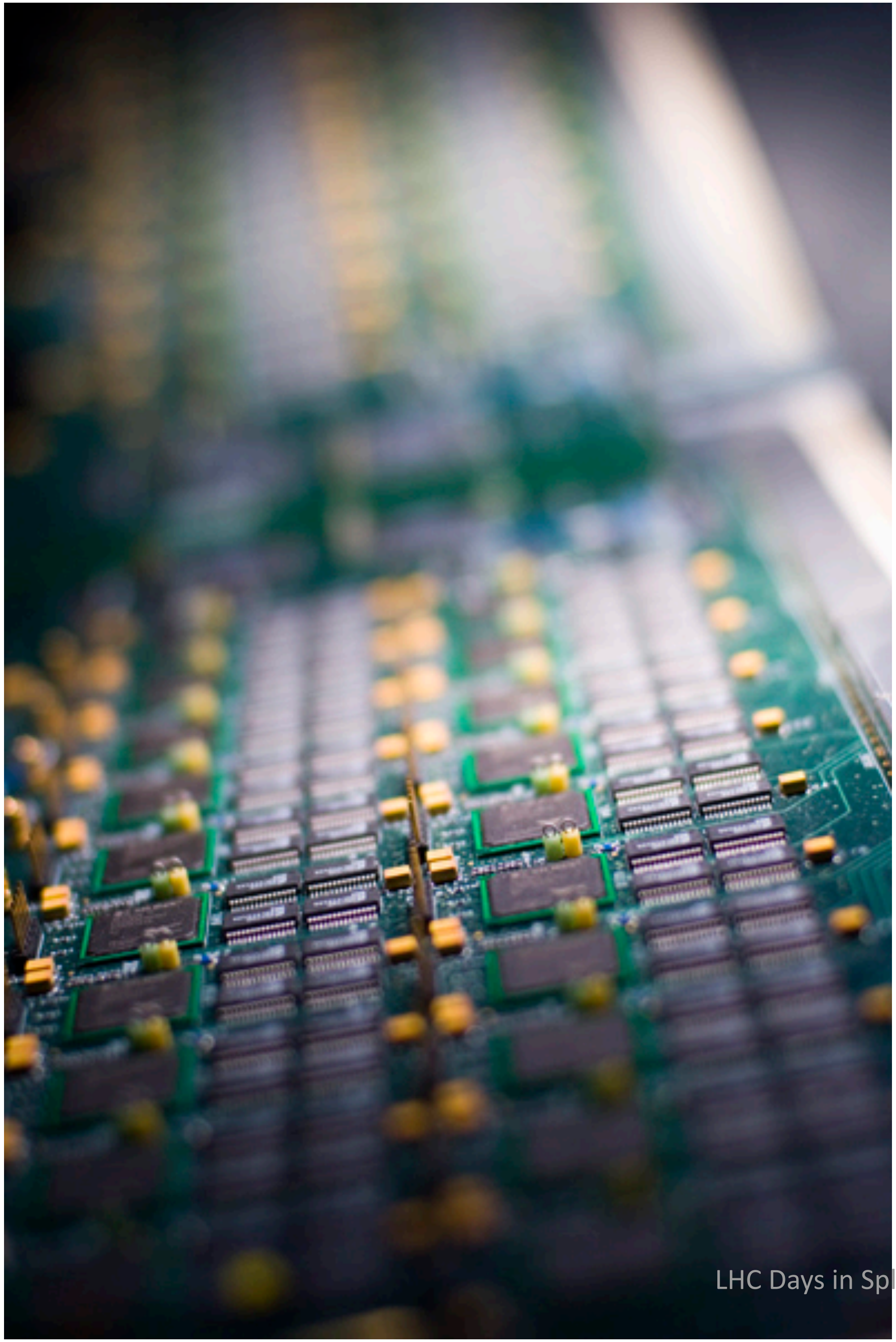


Trigger physics objects	Lowest unprescaled E_T thresholds (GeV) at $L \approx 1x10^{32}$ $cm^{-2}s^{-1}$		
	L1	HLT	Rate (Hz)
Electron	10	15	21
Photon	14	40	7.3
Tau	20	50	3.7
Muon	4	13	18
Missing E_T	20	35	3.2
Jet	75	115	2.0
ΣE_T	200	350	1.6

Also chains for B-tagged jets & B-physics signatures

Configuration infrastructure

- Very flexible!
- Pre-scale factors employed to change menu while running
- Adapt to changing LHC luminosity

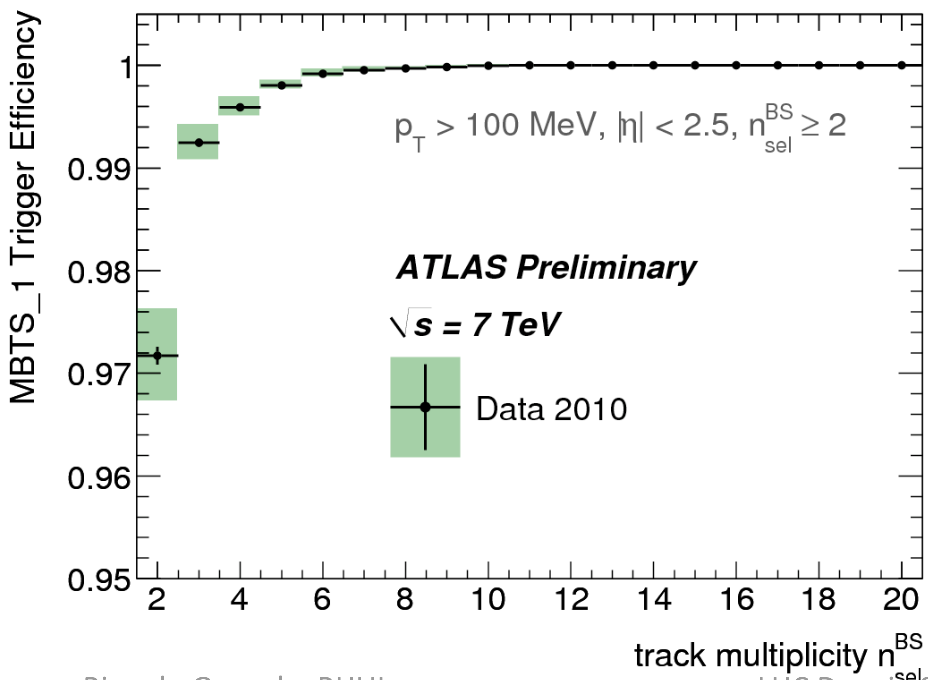


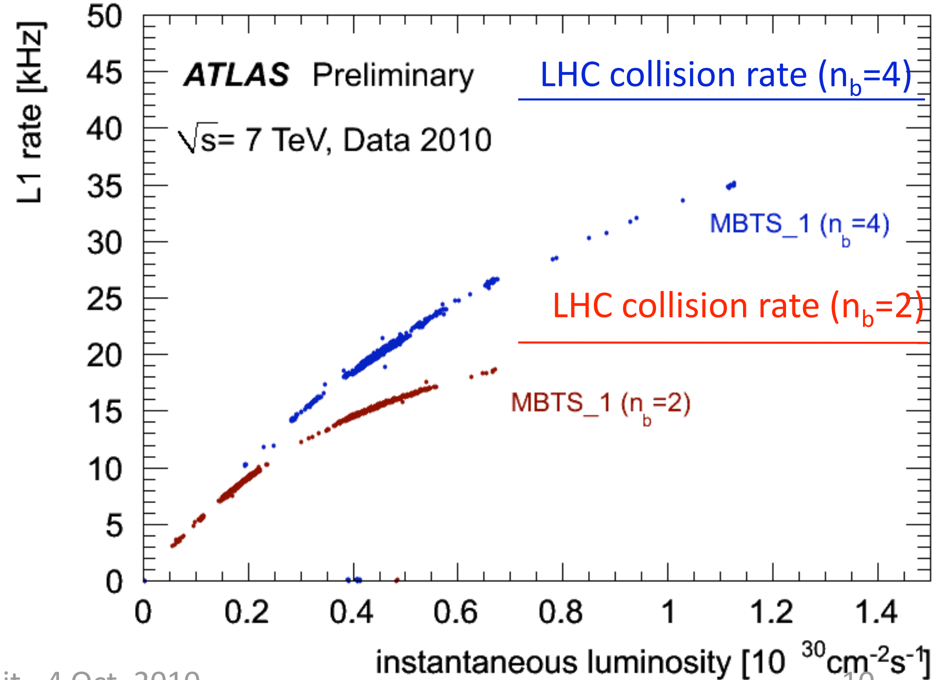
PERFORMANCE

Minimum Bias Trigger

- Soft QCD studies
- Provide control trigger on p-p collisions; discriminate against beam-related backgrounds (using signal time)
- Minimum Bias Scintillators (MBTS) installed in each end-cap;
  - Example: MBTS_1 – at least 1 hit in MBTS
- Also nr. of hits its in Inner Detector

Minbias Trigger Scintillator:
32 sectors on LAr cryostat
Main trigger for initial running
η coverage 2.1 to 3.8





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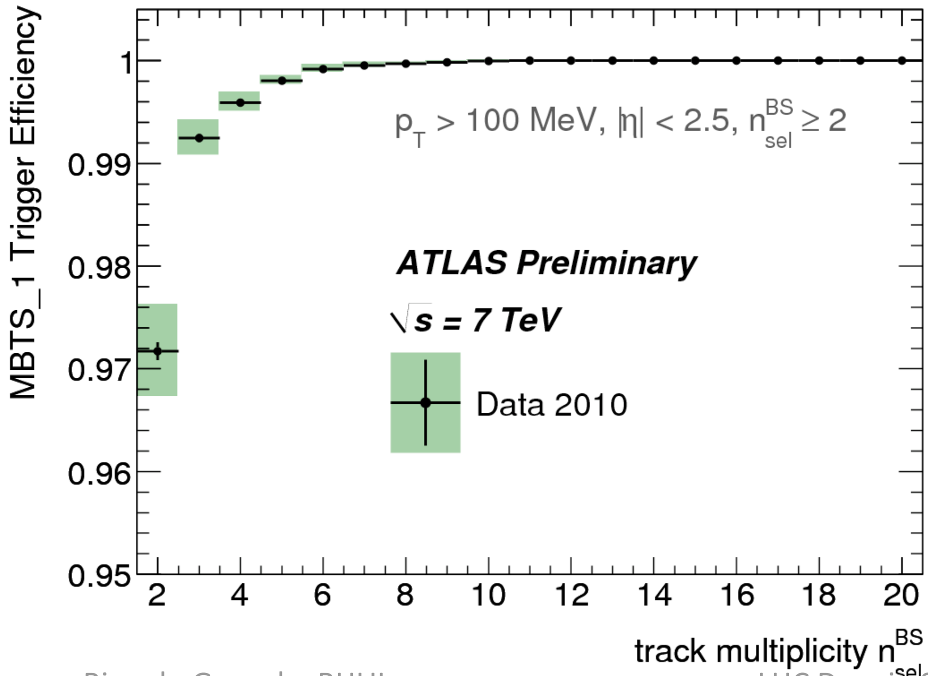
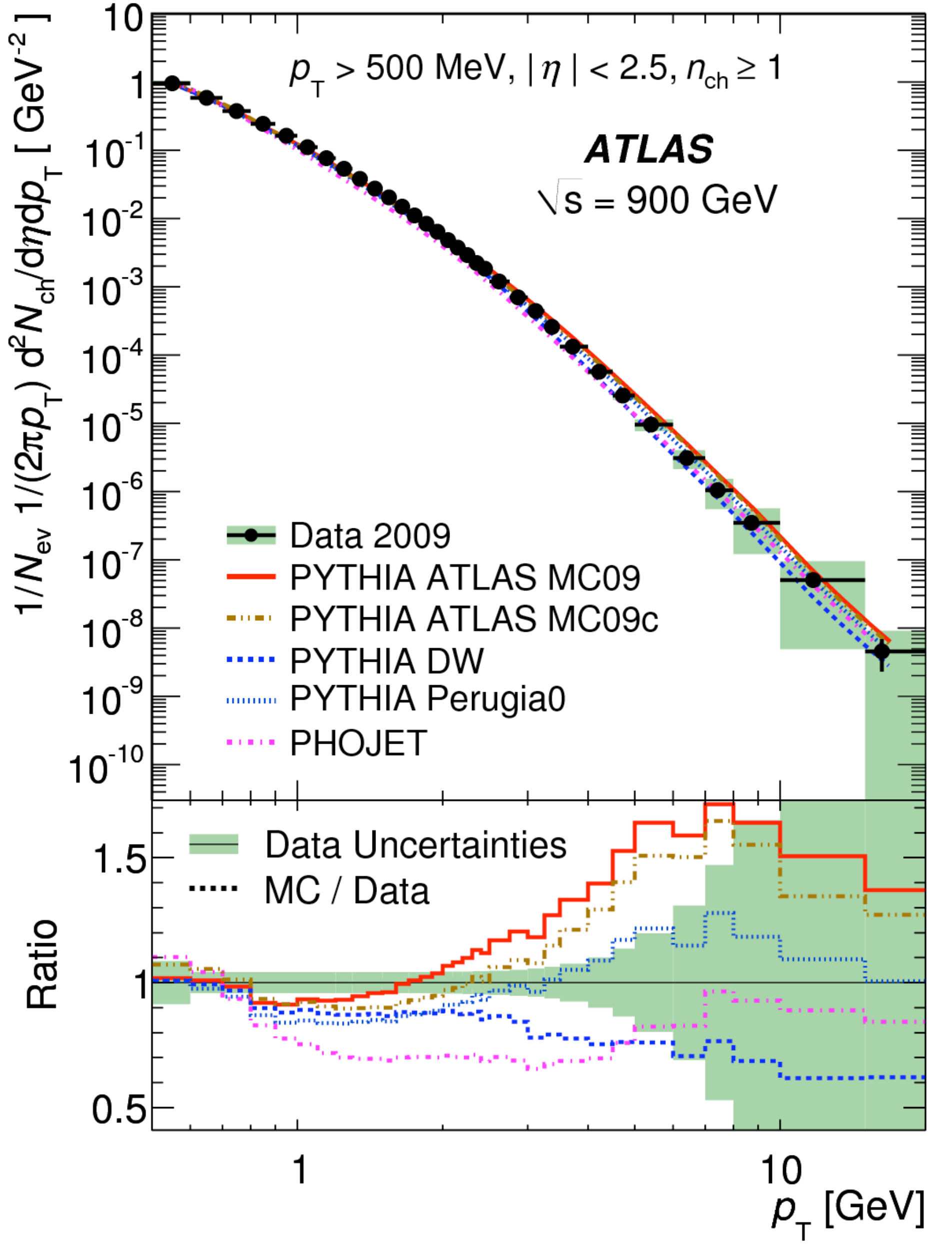




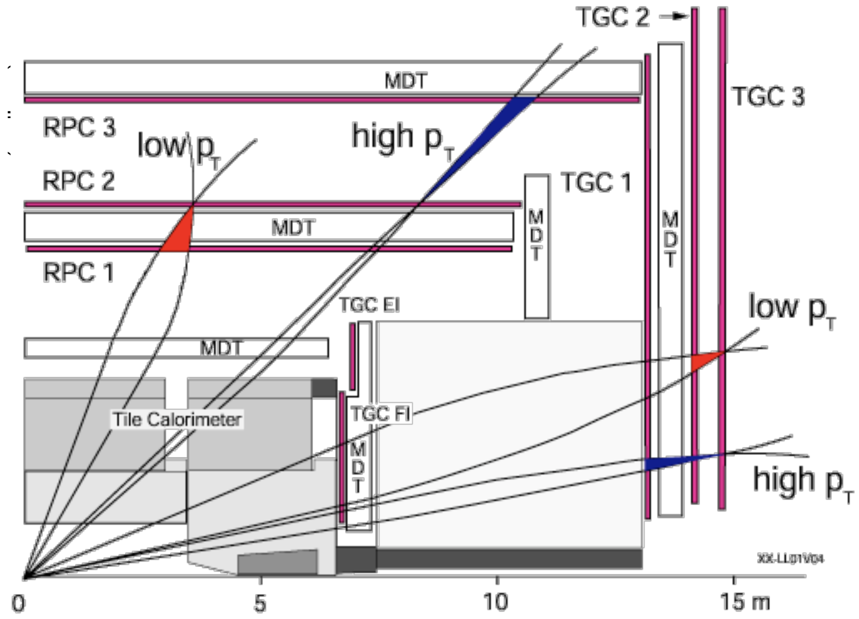
Muon Trigger

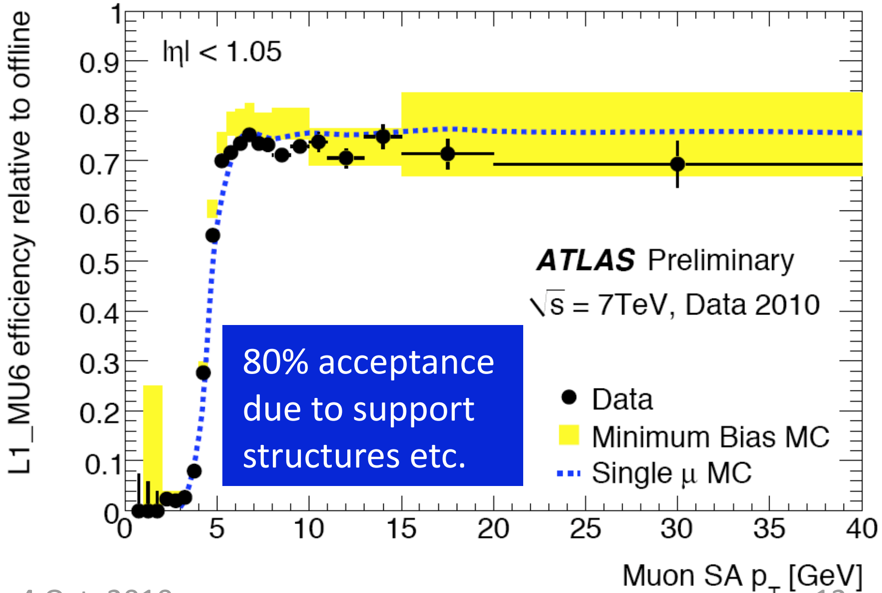
- Low P_T: J/Ψ, Υ and B-physics
- High P_T: H/Z/W/τ→μ, SUSY, exotics

- Level 1: look for coincidence hits in muon trigger chambers
  - **R**esistive **P**late **C**hambers (barrel) and **T**hin **G**ap **C**hambers (endcap)
  - **p_T** resolved from coincidence hits in **look-up table**

- Level 2: refine Level 1 candidate with precision hits from Muon Drift Tubes (MDT) and combine with inner detector track

- Event Filter: use offline algorithms and precision; complementary algorithm does inside-out tracking and muon reconstruction





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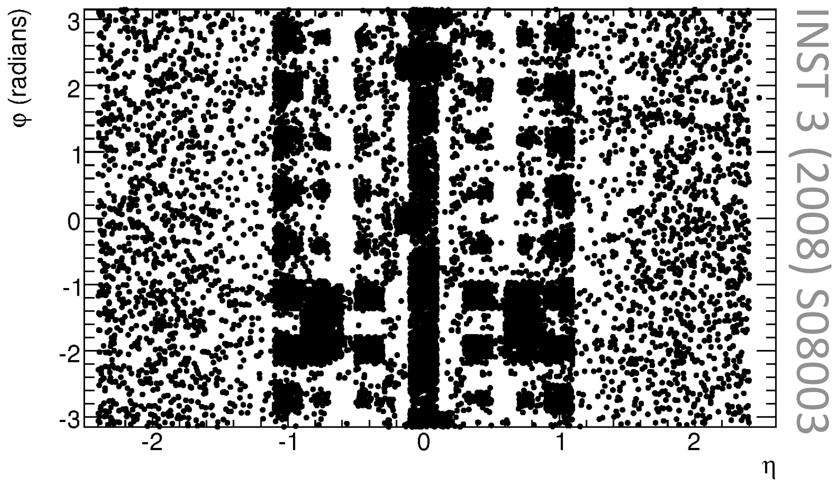

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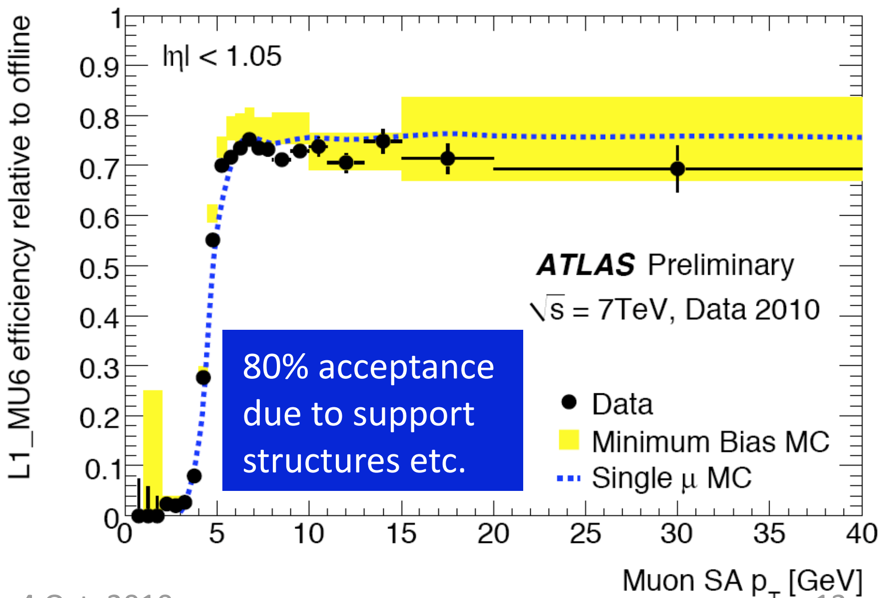
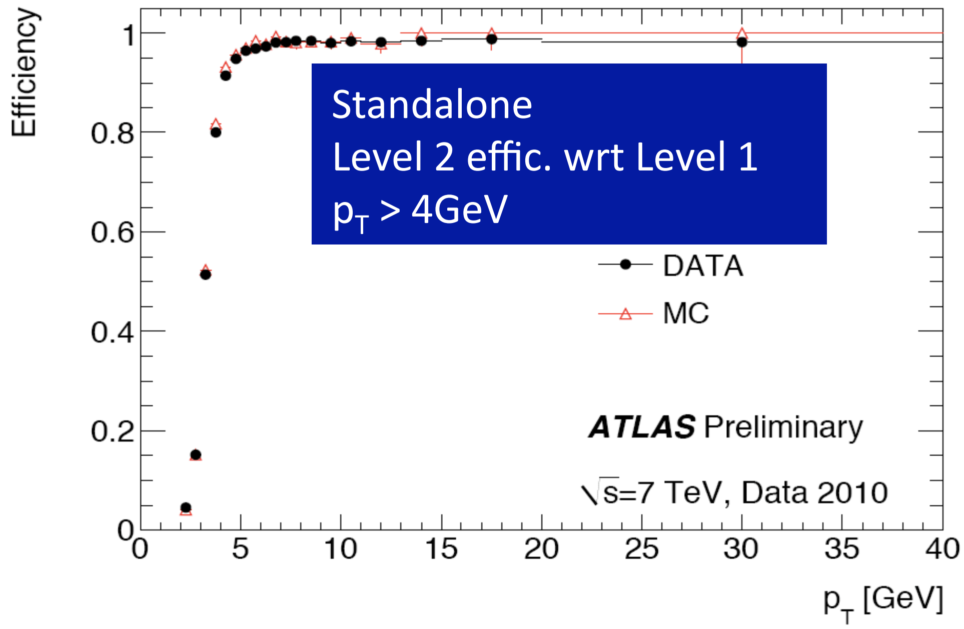
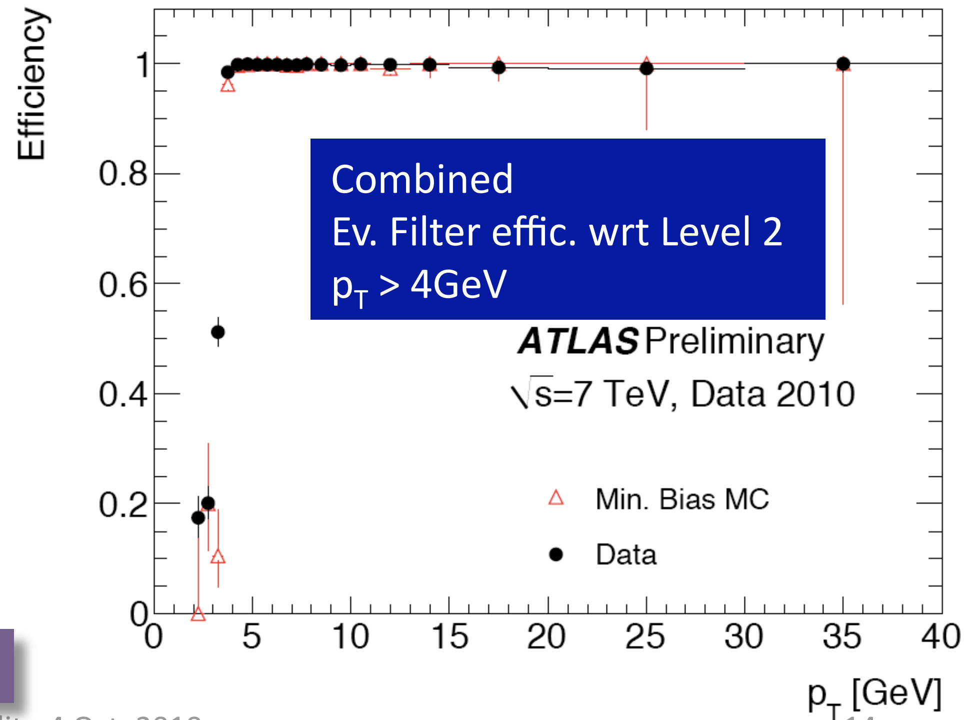


- Stand-alone: muons reconstructed from Muon Spectrometer information only
  - L2 efficiency > 98% w.r.t. L1 for muons with p_T > 4 GeV
  - Good agreement with simulation
- Combined: muons reconstructed from Muon Spectrometer segment combined with Inner Detector track
  - Sharp turn-on and high efficiency
  - Good agreement with simulation
- Alternative inside-out algorithm also used in Event Filter

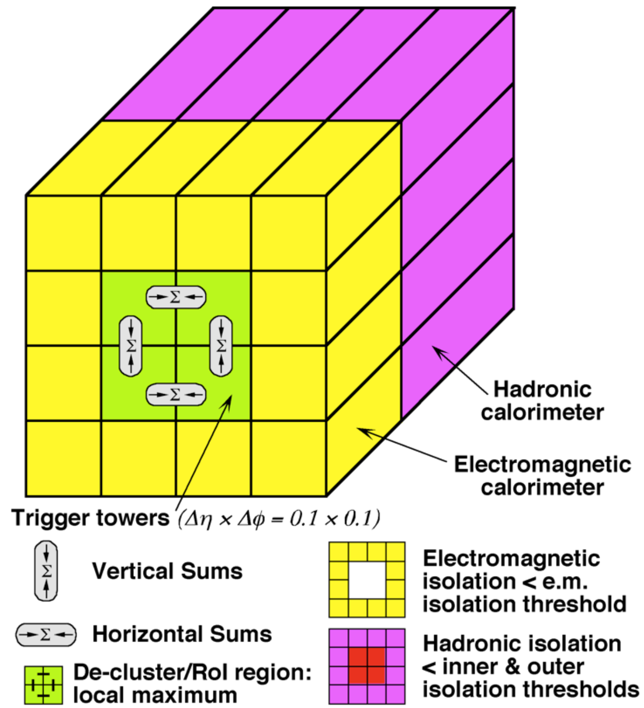


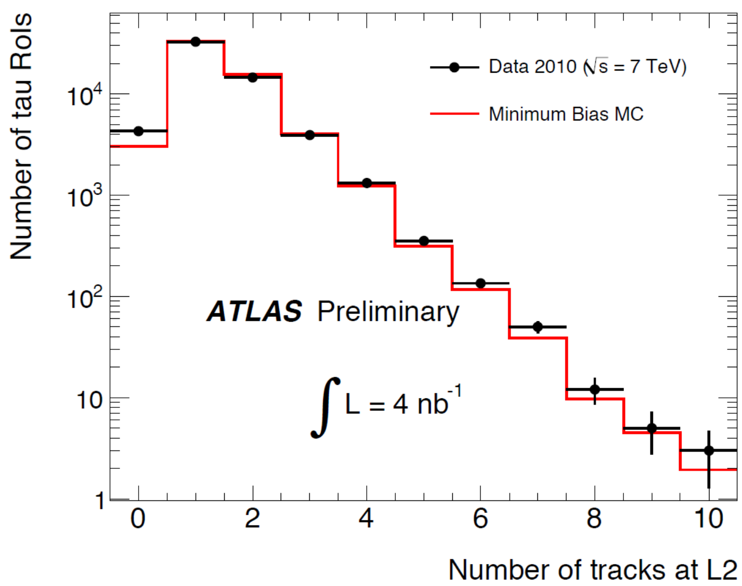


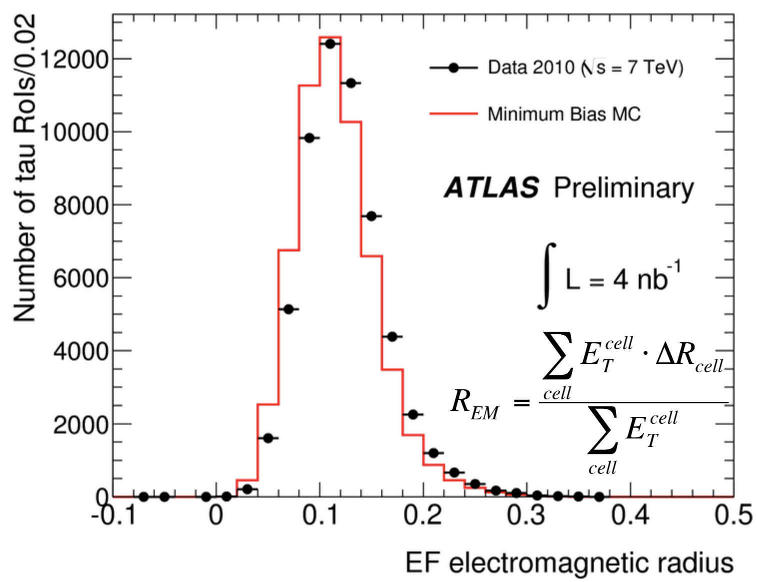
More details in talk by Alexander Oh this afternoon

Hadronic Tau Trigger

- W/Z → τ, SM &MSSM Higgs, SUSY, Exotics
- Level 1: start from hadronic cluster – local maximum in ΔηxΔφ = 0.2x0.2 – possible to apply isolation
- Level 2: track and calorimeter information are combined – narrow cluster with few matching tracks
- Event Filter: 3D cluster reconstruction suppresses noise; offline ID algorithms and calibration are used







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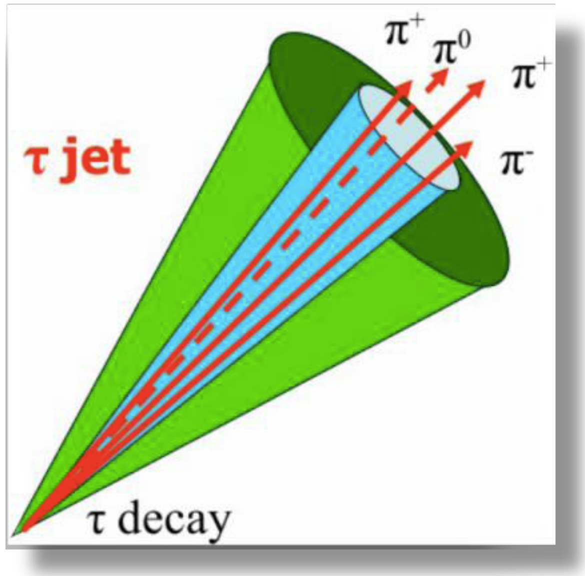
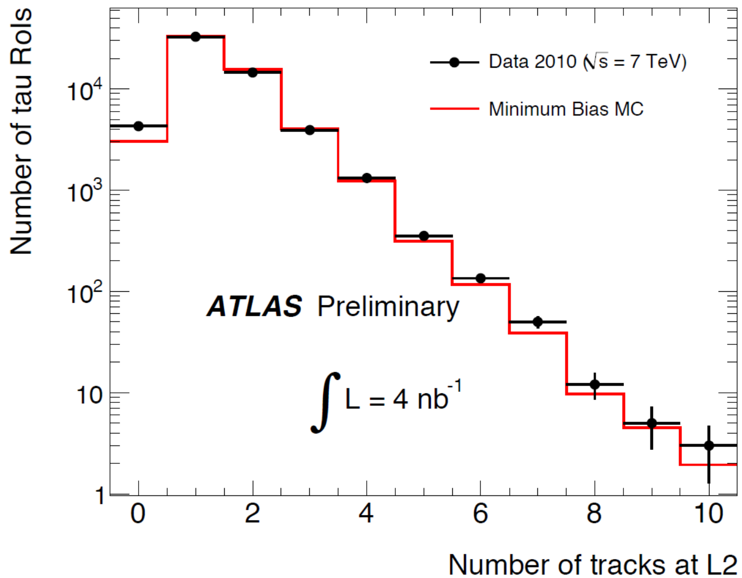
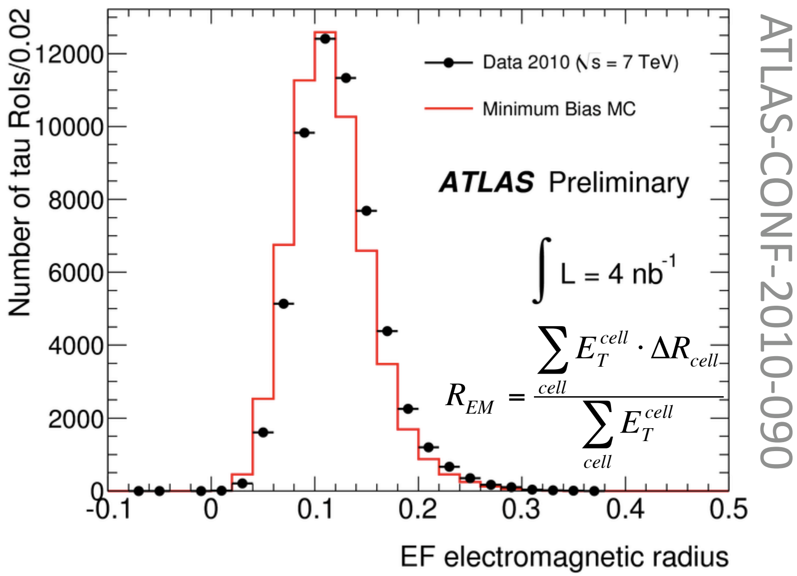
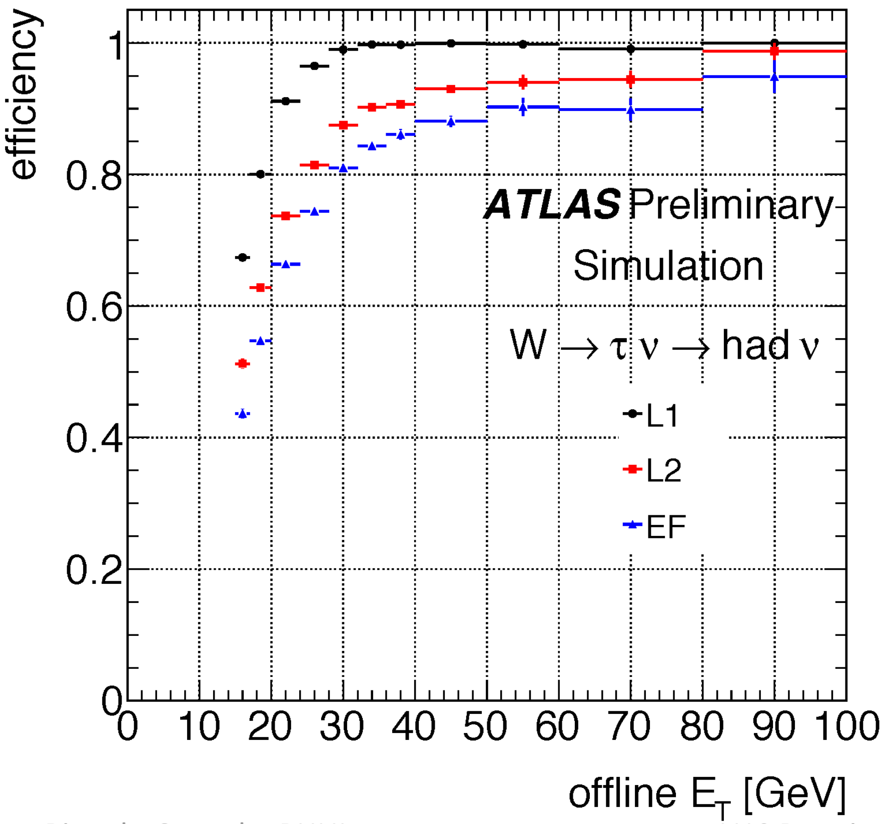


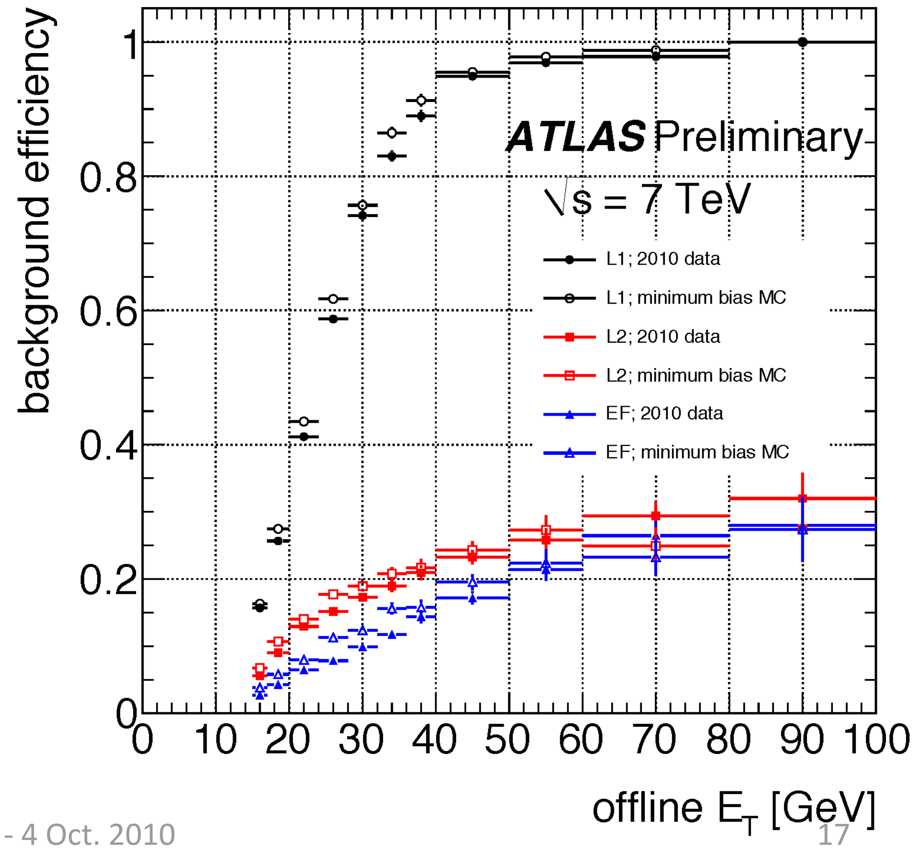




- Typical background rejection factor of ≈5-10 from Level 2+Event Filter
  - Right: fake rate for loose tau trigger with p_T > 12 GeV – aka tau12_loose
  - MC is Pythia with no LHC-specific tuning
    - Better agreement is expected after underlying-event tuning

- Left: EF efficiency ≈80% above threshold for true taus (simulation_
  - Obtained for true taus, with respect to taus from offline reconstruction
  - Thresholds (tau12_loose): 5GeV (Level 1), 7GeV (Level 2), 12GeV (Ev. Filter)

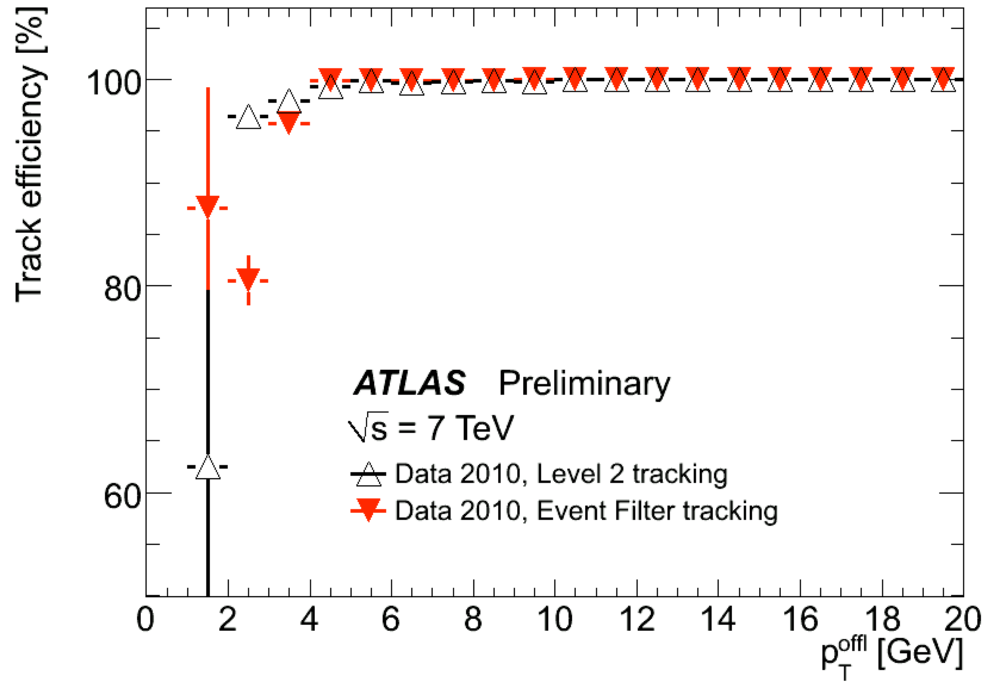


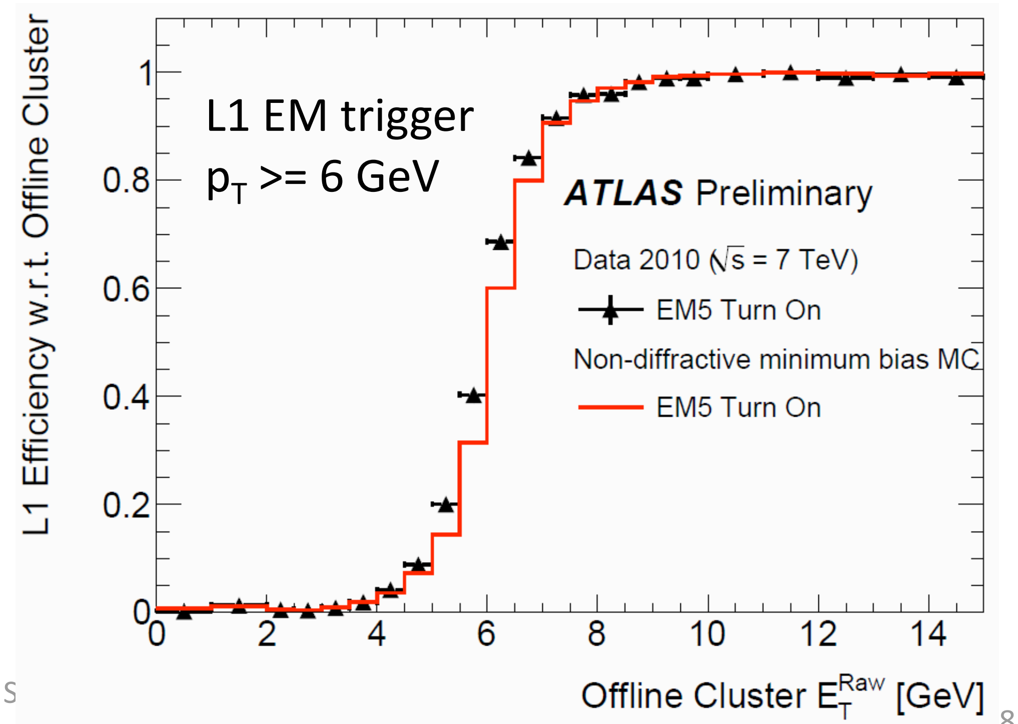


e/γ Trigger

- p_T≈3-20 GeV: b/c/tau decays, SUSY
- p_T≈20-100 GeV: W/Z/top/Higgs
- p_T>100 GeV: exotics

- Level 1: local E_T maximum in ΔηxΔϕ = 0.2x0.2 with possible isolation cut
- Level 2: fast tracking and calorimeter clustering – use shower shape variables plus track-cluster matching
- Event Filter: high precision offline algorithms wrapped for online running





e/γ Trigger

- $p_T \approx 3$-20 GeV: b/c/tau decays, SUSY
- $p_T \approx 20$-100 GeV: W/Z/top/Higgs
- $p_T > 100$ GeV: exotics

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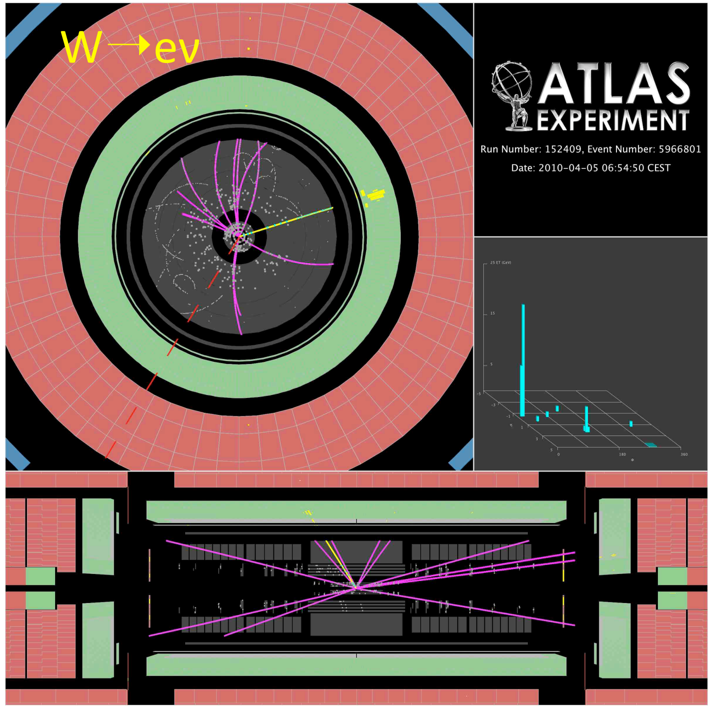
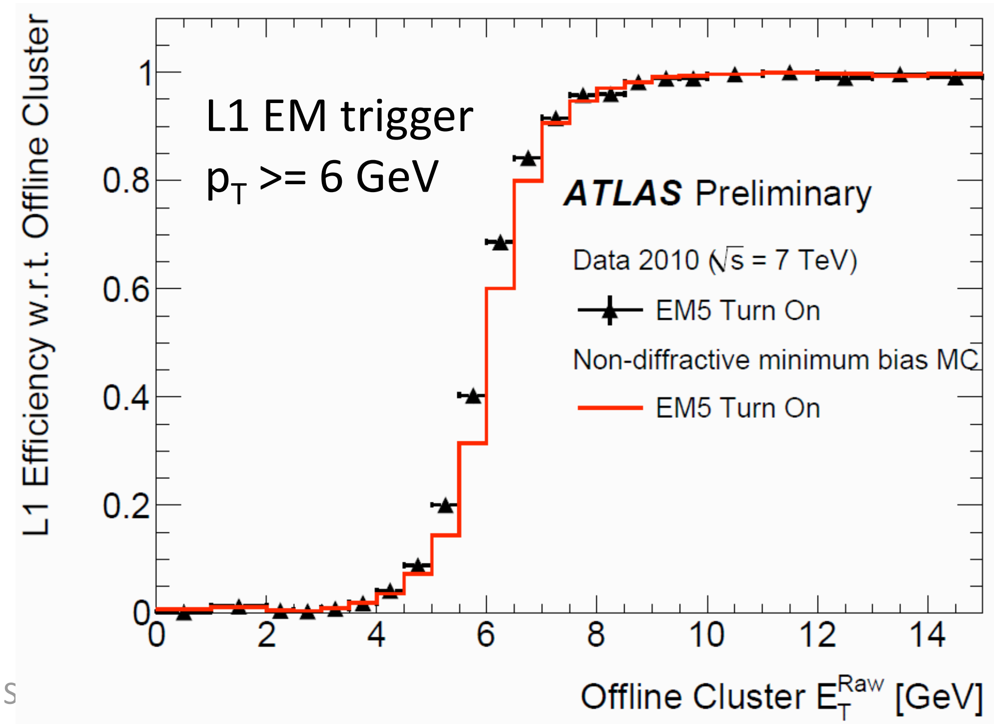
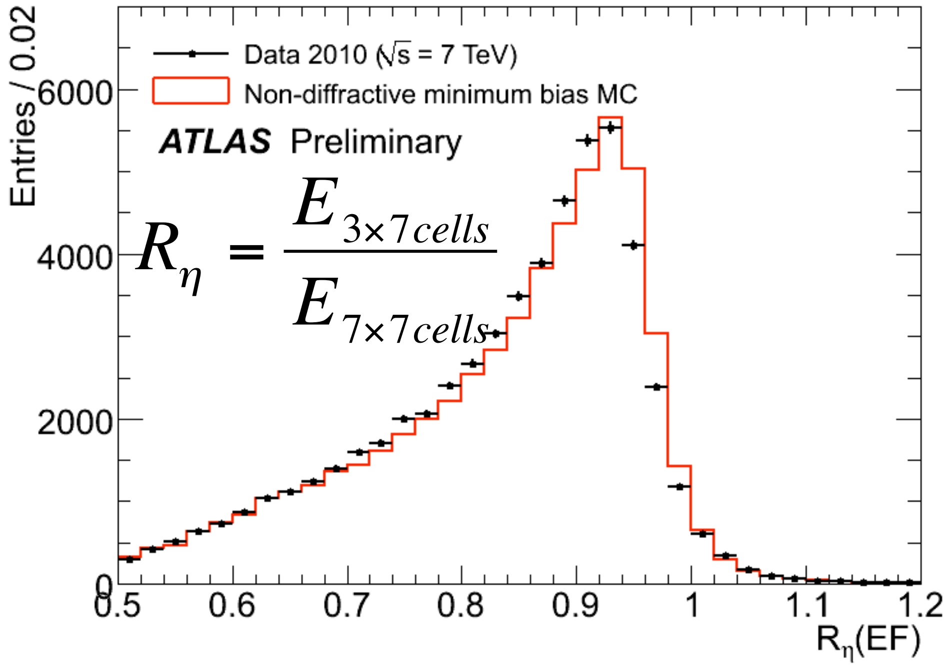
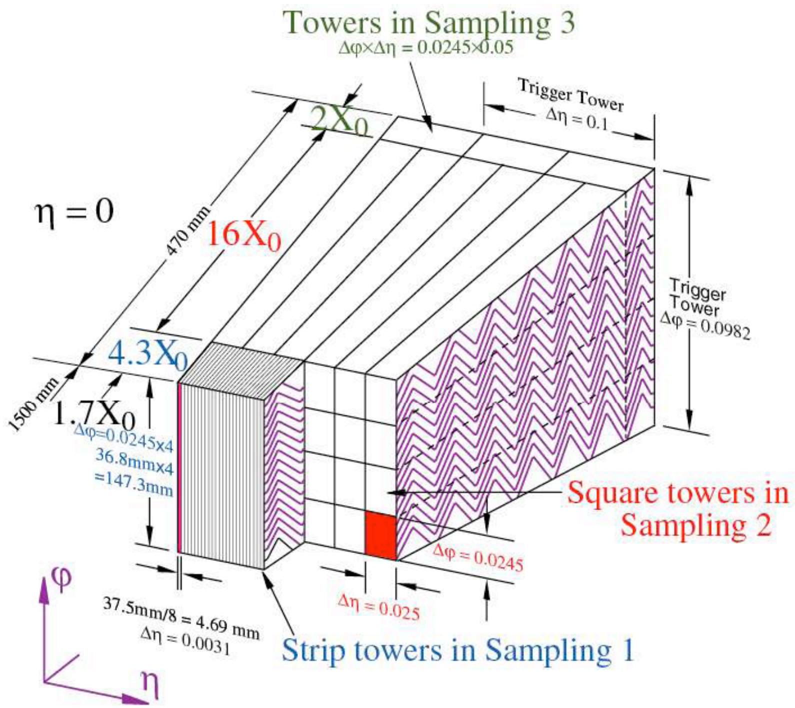
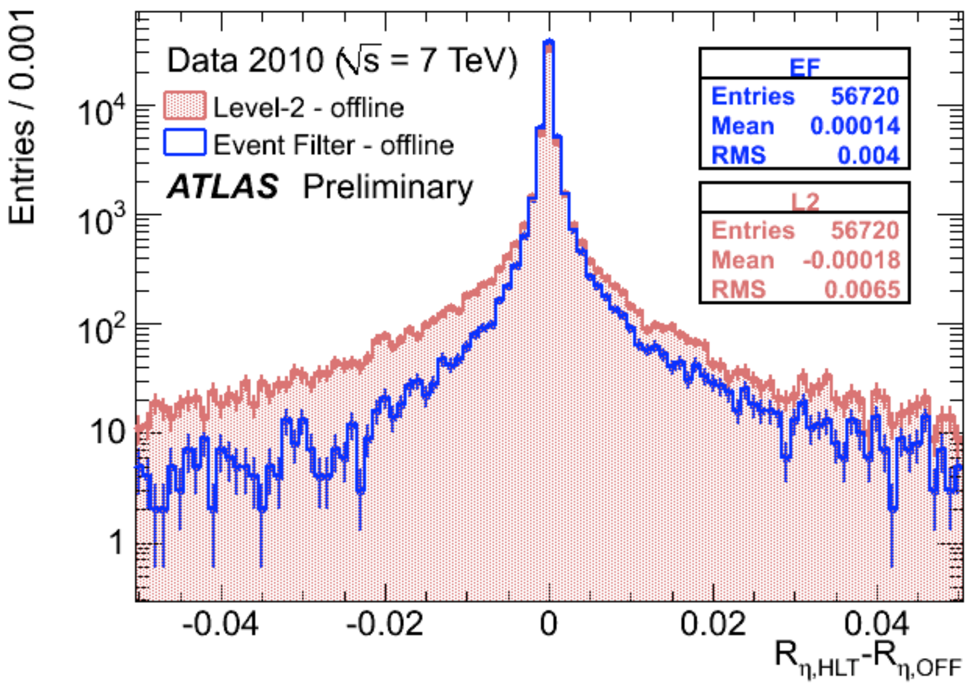




- Discriminate against hadronic showers based on shower shape variables
- Use fine granularity of LAr calorimeter
- Remaining differences between real data and simulation consistent with expected precision of the simulation
- Resolution improves in Event Filter with respect to Level 2

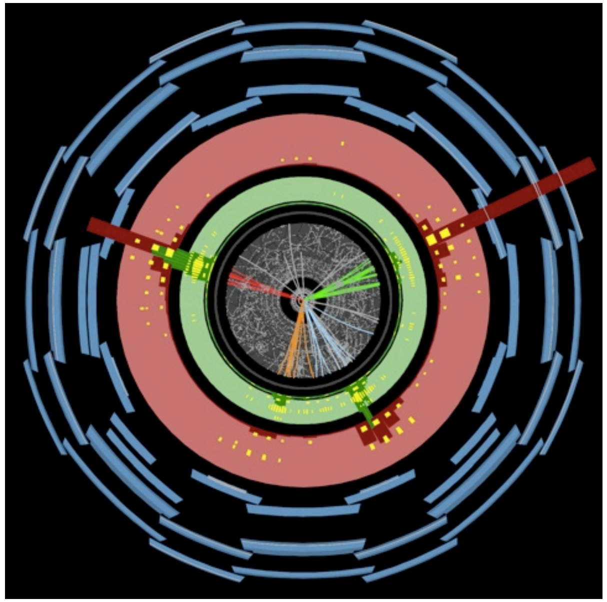






Jet Trigger

- QCD multijet production, top, SUSY, generic BSM searches
- Level 1: look for local maximum in E_T in calorimeter towers of $\Delta\eta x \Delta\phi$ = 0.4x0.4 to 0.8x0.8
- Level 2: simplified cone clustering algorithm (3 iterations max) on calorimeter cells
- Event Filter: anti-k_T algorithm on calorimeter cells; currently running in transparent mode (no rejection)
- High Level Trigger running at EM scale plus jet energy scale corrections at the moment



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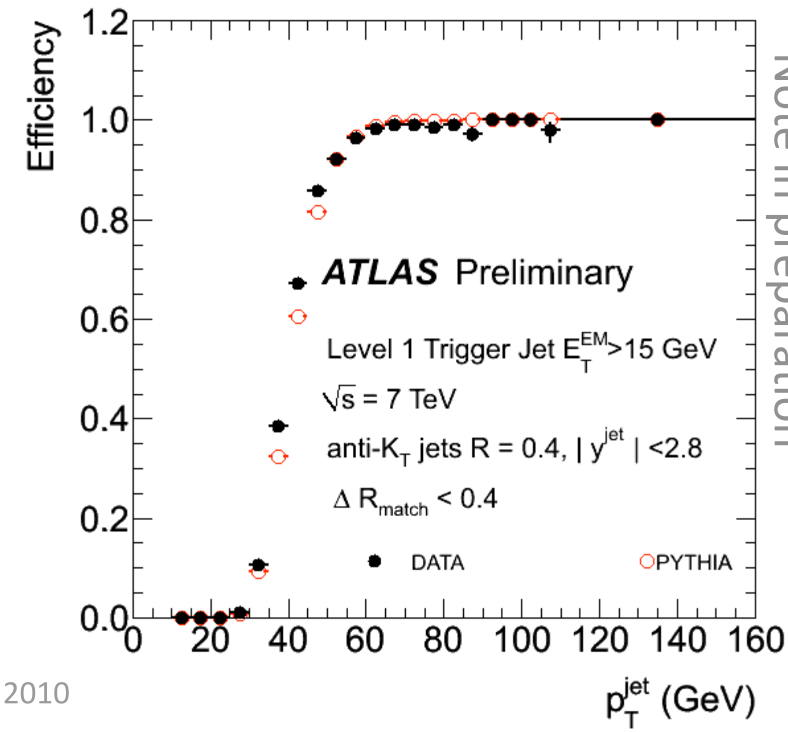

Note in preparation

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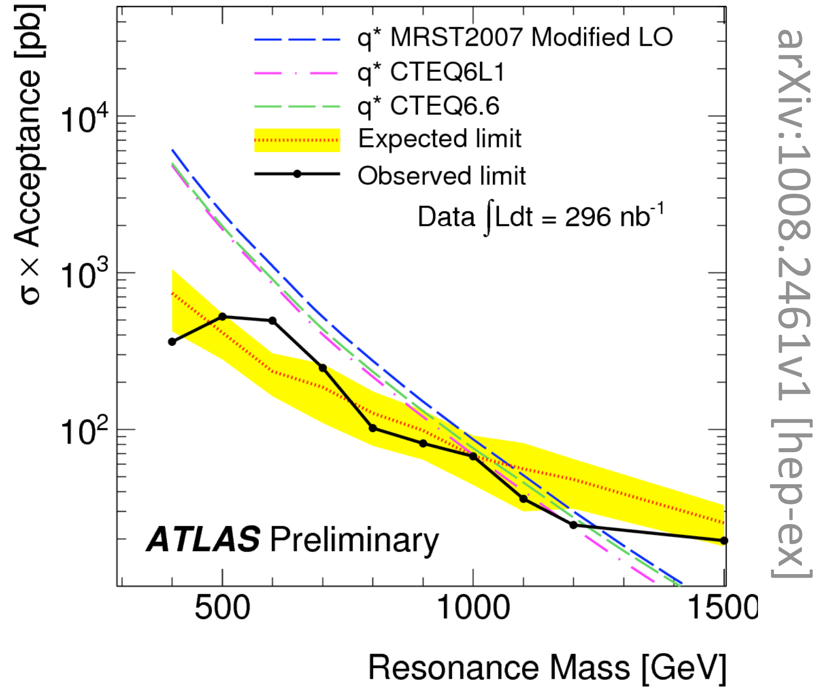
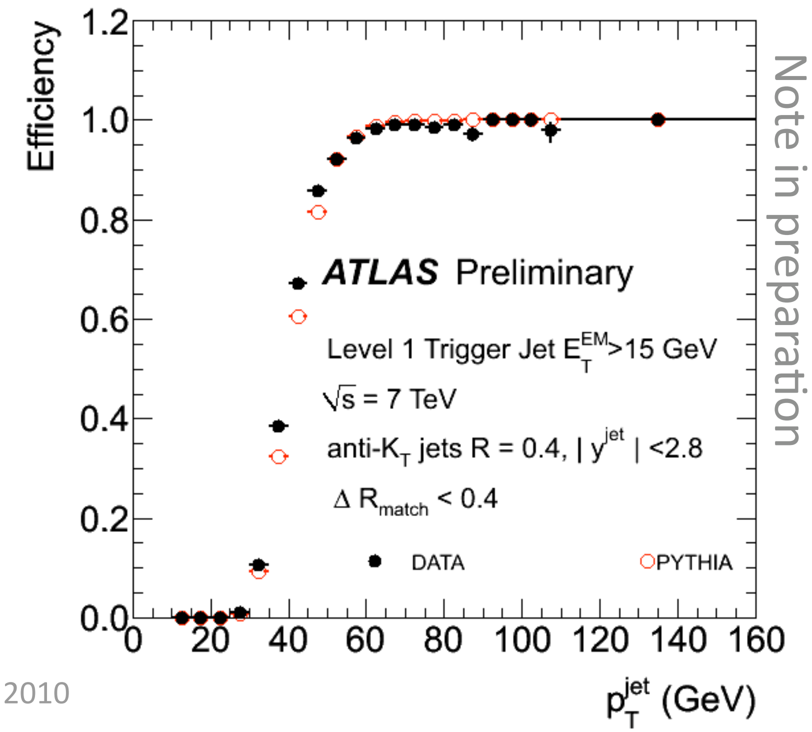
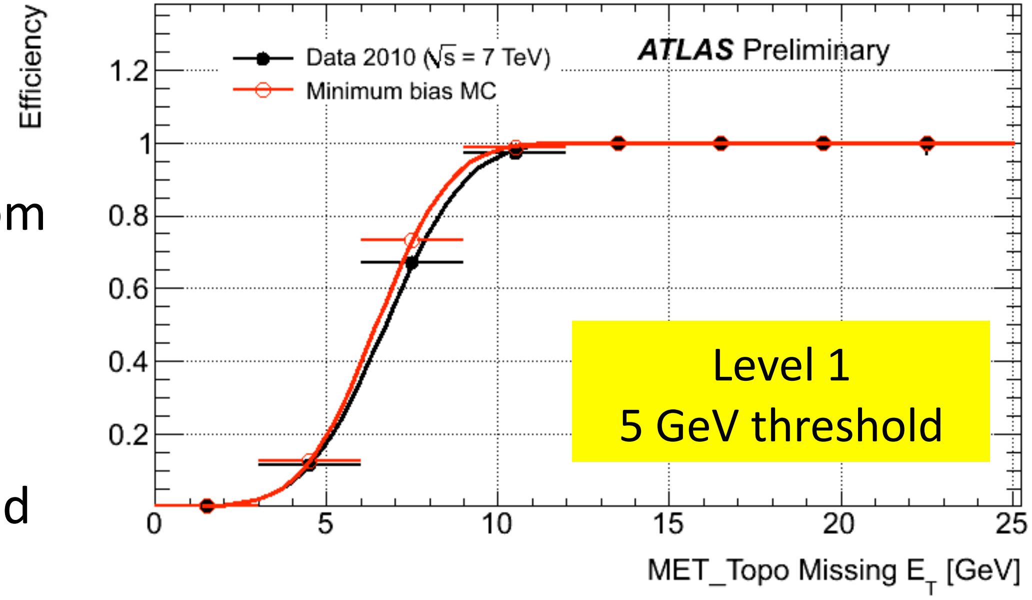
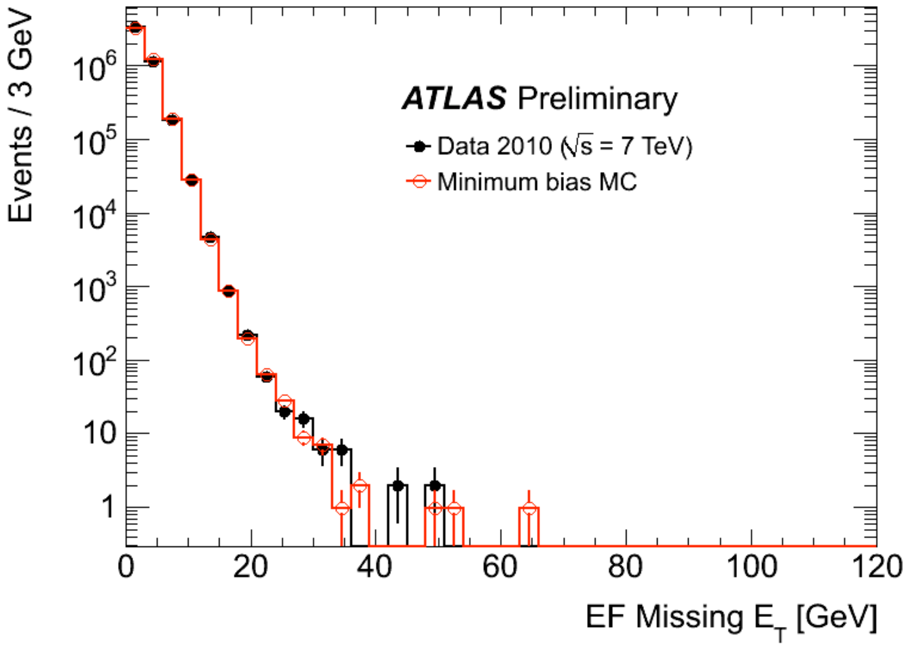


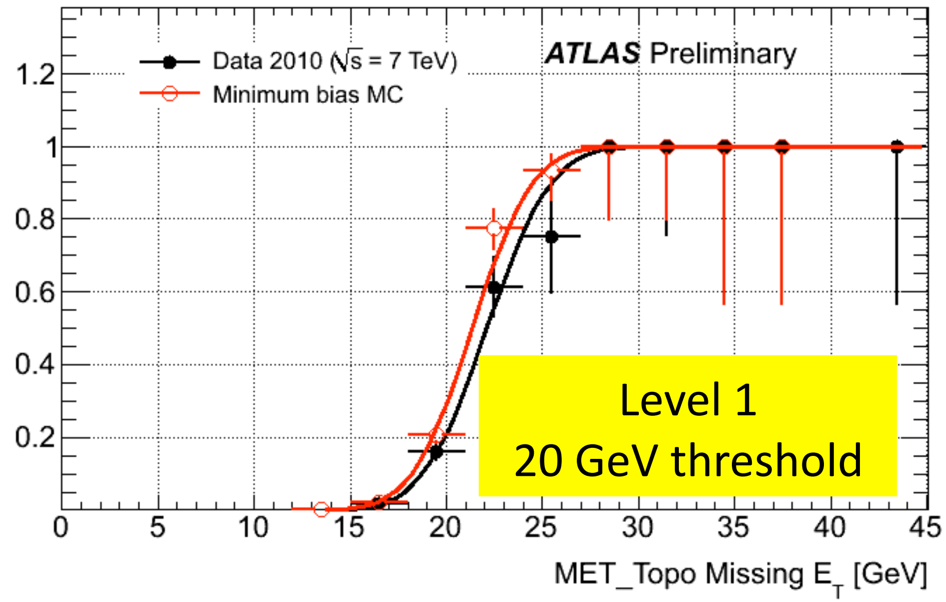


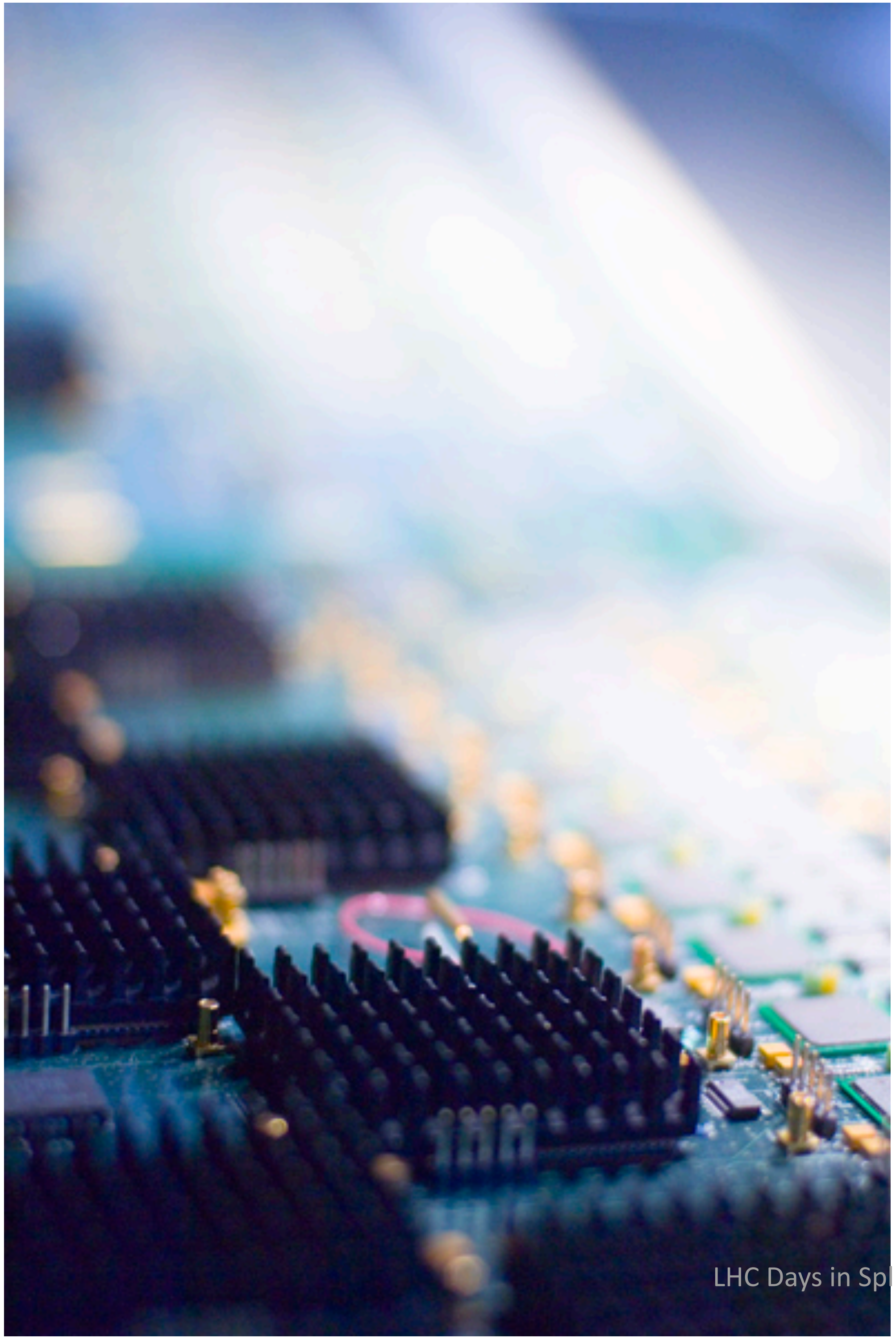
Missing E_T Trigger

- SUSY, Higgs
- Level 1: E_T^{miss} and E_T calculated from all calorimeter towers
- Level 2: only muon corrections possible
- Event Filter: re-calculate from calorimeter cells and reconstructed muons









The Road Ahead

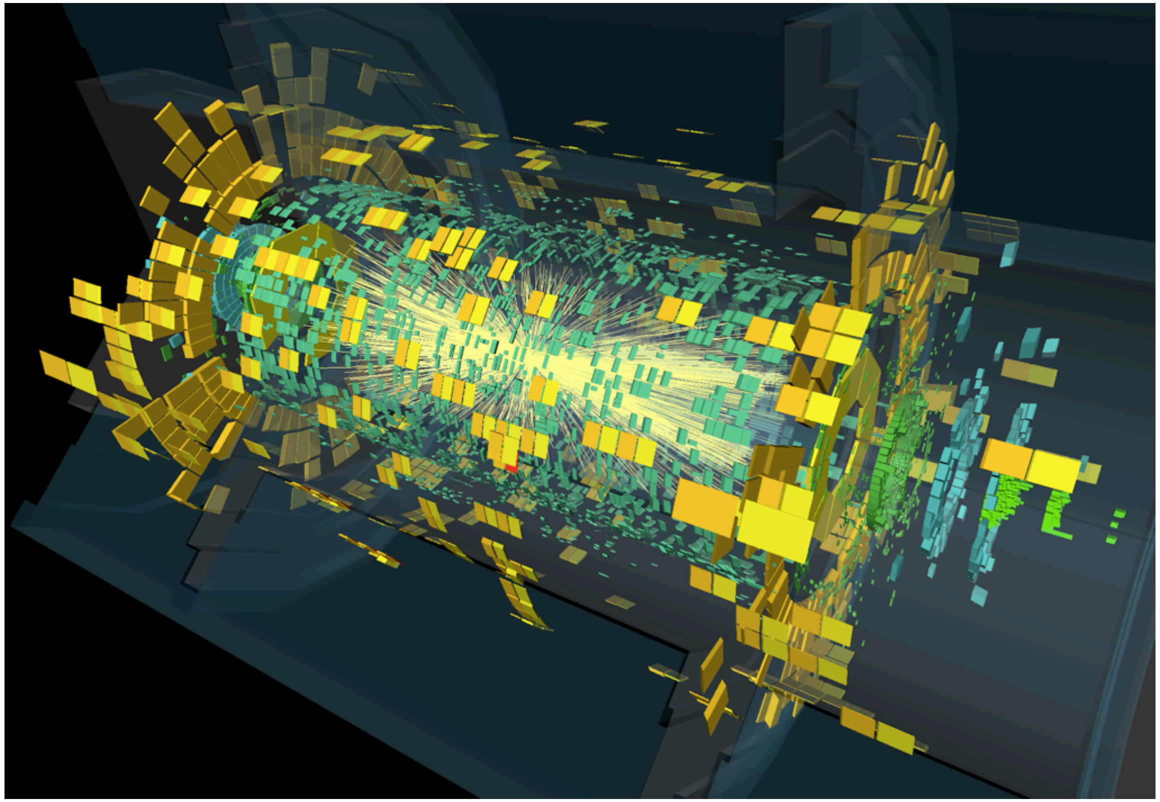
Plans for Heavy Ion Run

- Collect ≈3μb^{-1} of Pb-Pb collisions at 2.76 TeV/nucleon during 4 weeks in November

- Take advantage of ATLAS capabilities
  - Good angular coverage
  - Good particle ID
  - Forward scintillators and Zero Degree Calorimeters

- Trigger rate ≈ 140 Hz
  - σ_{Pb+Pb}≈ 7.6 barn
  - L ≈ 1x10^{25}cm^{-2}s^{-1} (1% of design)
  - I.e. around 100Hz of collisions

- Use modified L1 menu only
  - Use as little High Level Trigger as possible
  - Avoid tracking if possible (1000s of tracks for central collisions)



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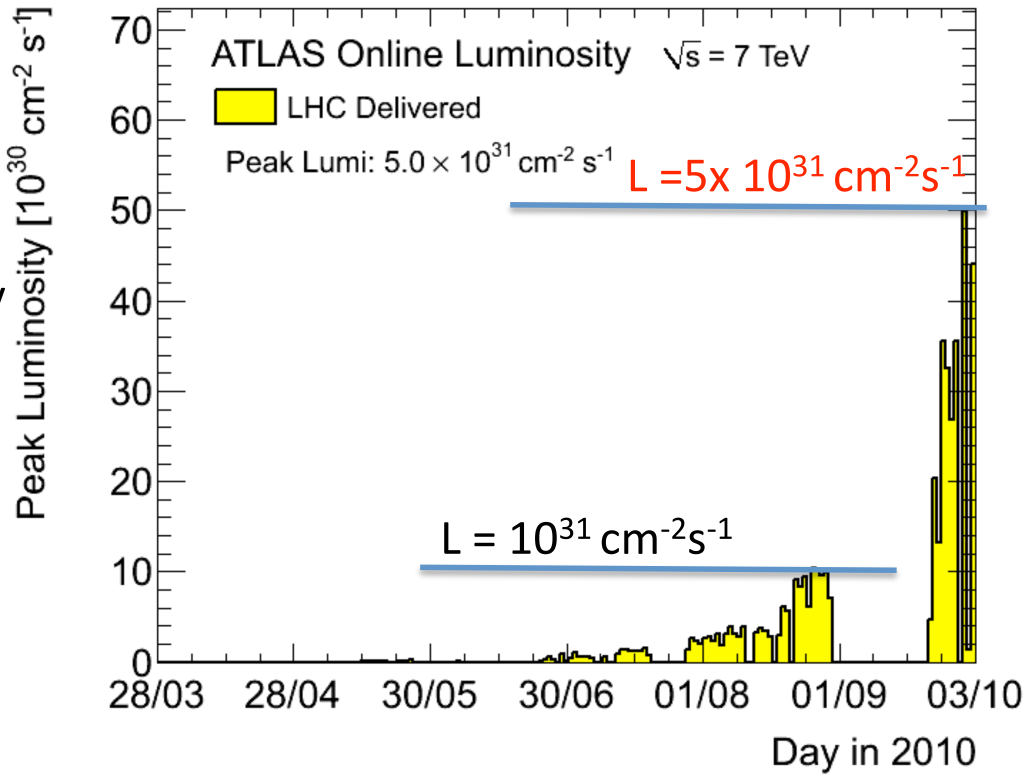
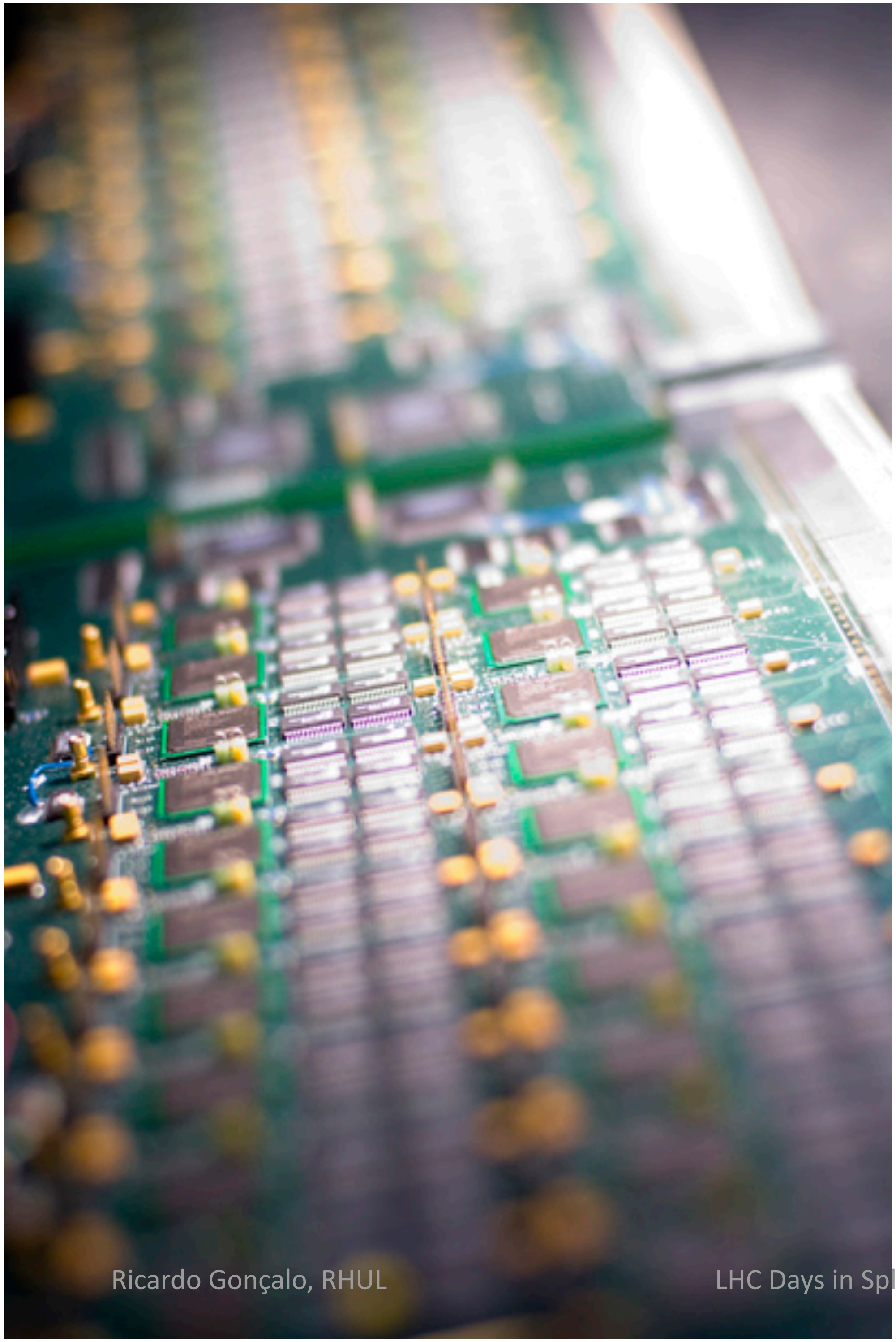
Trigger	Triggers, thresholds, etc
Minimum bias	Hits in forward scintillators, zero-degree calorimeter, luminosity detectors etc for wide eta coverage Primary triggers for heavy ion run
ΣE_T	50, 500, 1000, 2000 GeV Centrality trigger and centrality veto to enhance peripheral collisions
Jets	Single and di-jet triggers, scalar sum of jet energy for centrality veto
EM	Single photon and electron triggers
Muons	Single muon and di-muon triggers
Tau	Single tau and di-tau triggers

Conclusions

- The ATLAS Trigger has successfully coped with a LHC luminosity spanning almost 5 orders of magnitude
- It is a flexible and robust system thanks to years of planning, prototyping, commissioning and lots of dedicated work by many people
- More sophisticated triggers will be actively used as needed: jets with b-tagging, B physics, jet algorithms at the Event Filter, use of isolation requirements, etc
- There is space to evolve! The current selections will continue to be optimized to cope with even higher luminosities
- The heavy-ion run will test the ATLAS trigger in a new environment
- The ATLAS trigger was instrumental in delivering data for first ATLAS physics measurements and will continue to do so!

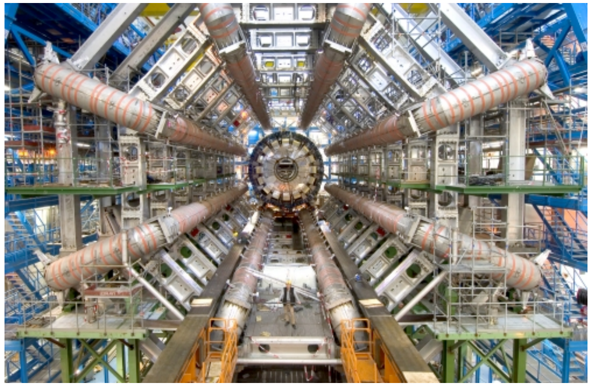


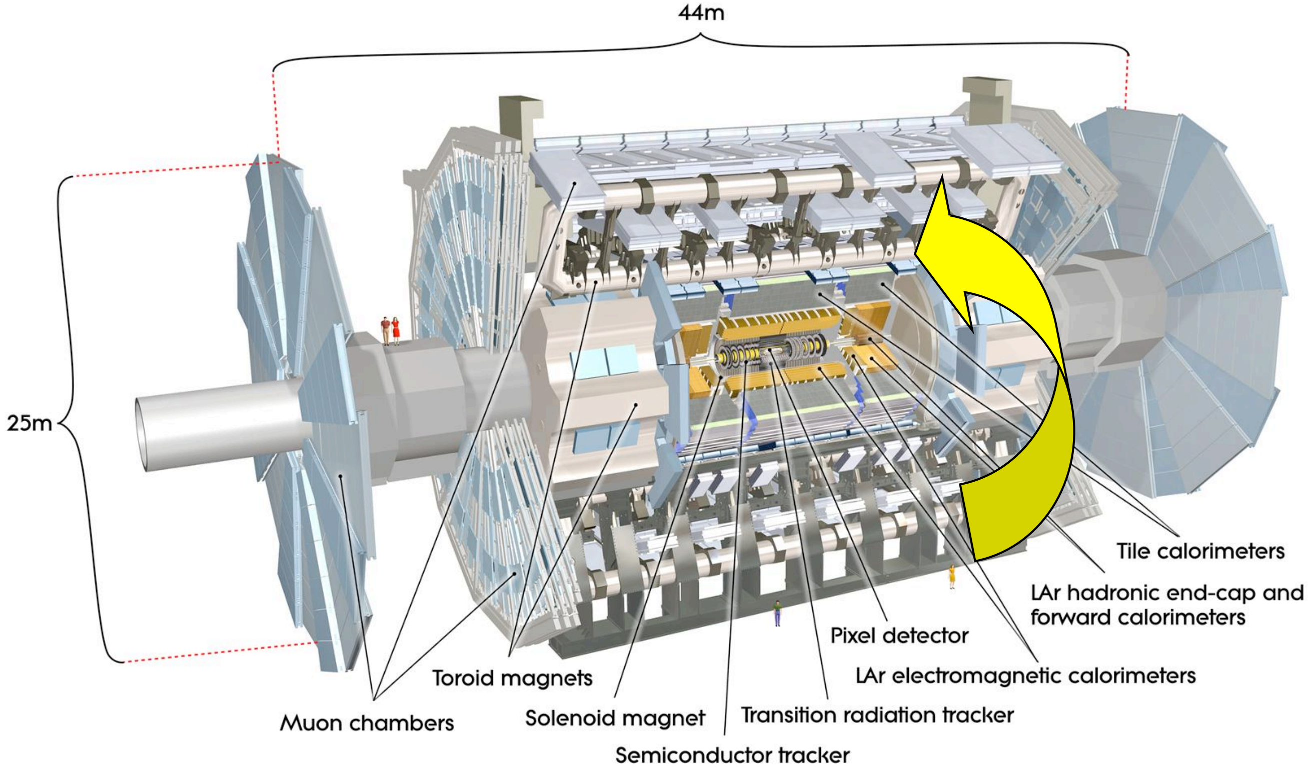


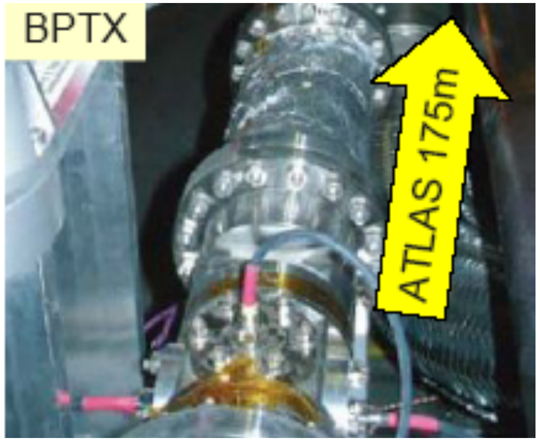
BACKUP SLIDES

The ATLAS Detector

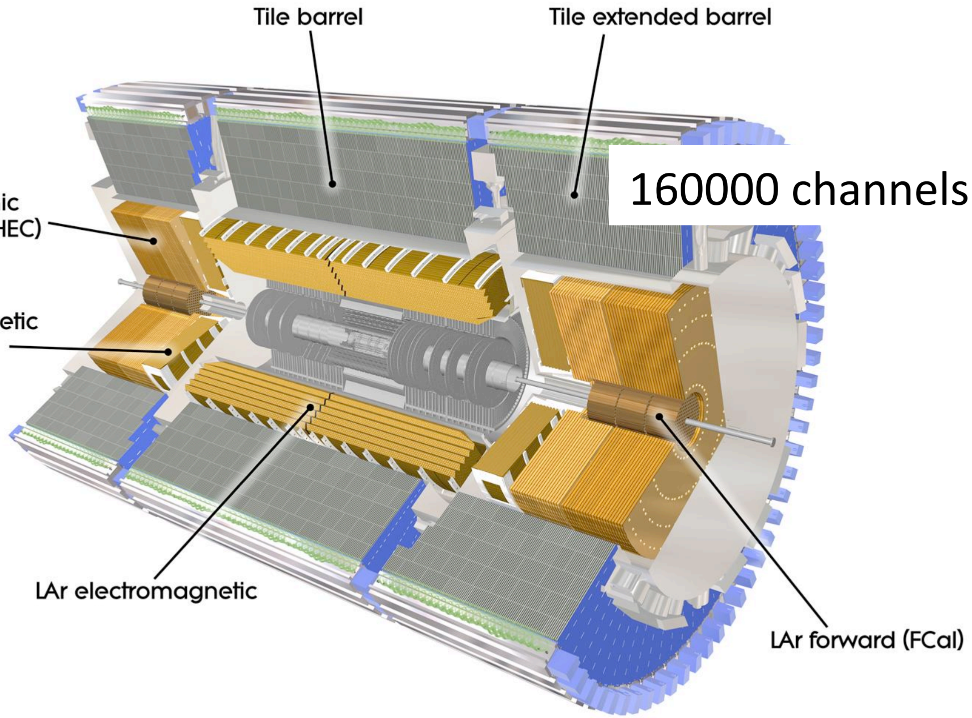
- Large angular coverage: $|\eta|<4.9$; tracking in $|\eta|<2.5$
- Inner detector: pixels, Si-strips and transition Radiation Tracker in for particle identification
- Liquid Argon electromagnetic calorimeter with accordion geometry
- Iron-scintillating tile hadronic calorimeter; tiles placed radially and staggered in depth
- Toroidal magnetic field (peak 4T) in air-core toroids; 2T in solenoid around Inner Detector



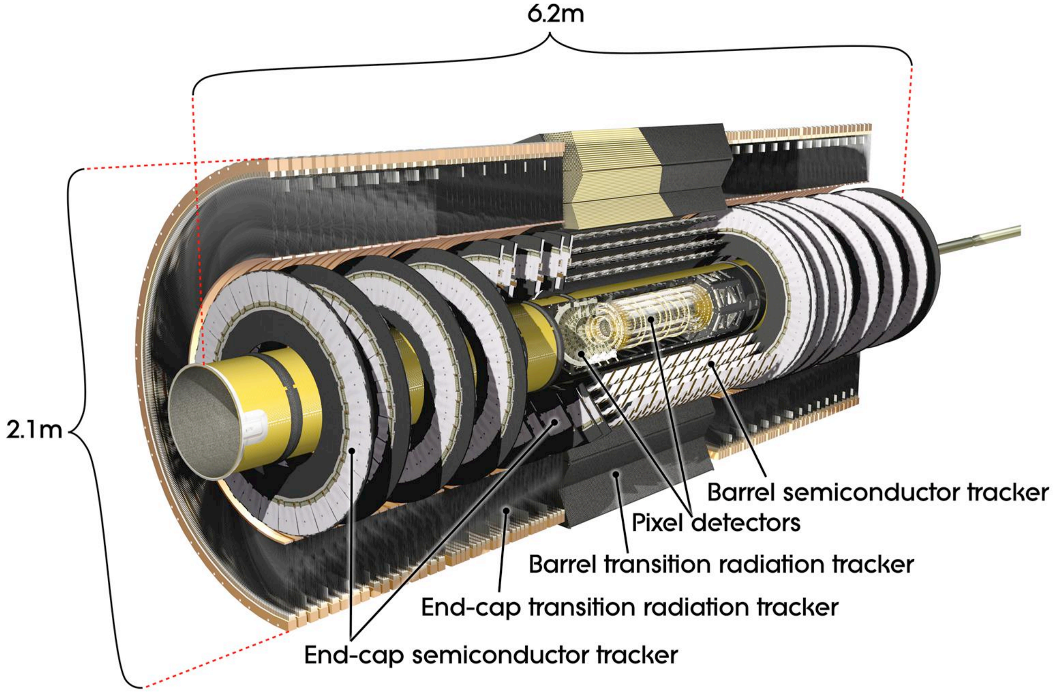




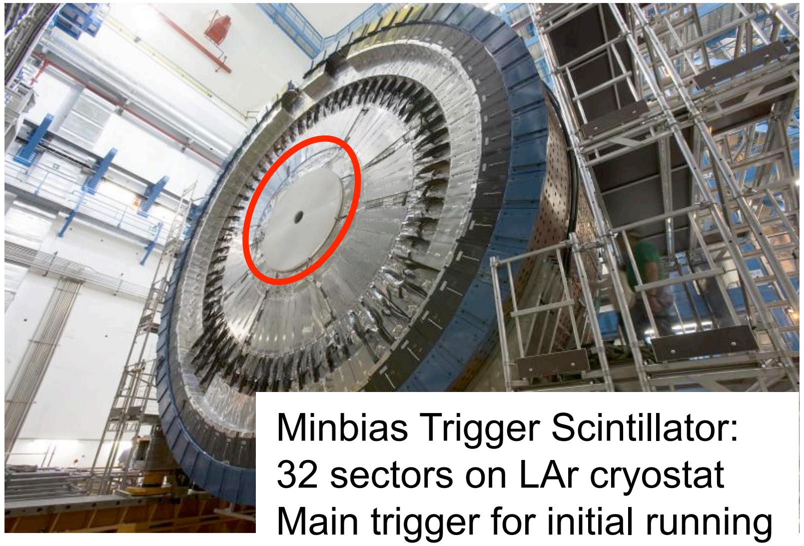
Beam Pickup: at ± 175m from ATLAS
Trigger on filled bunch
Provide the reference timing



160000 channels

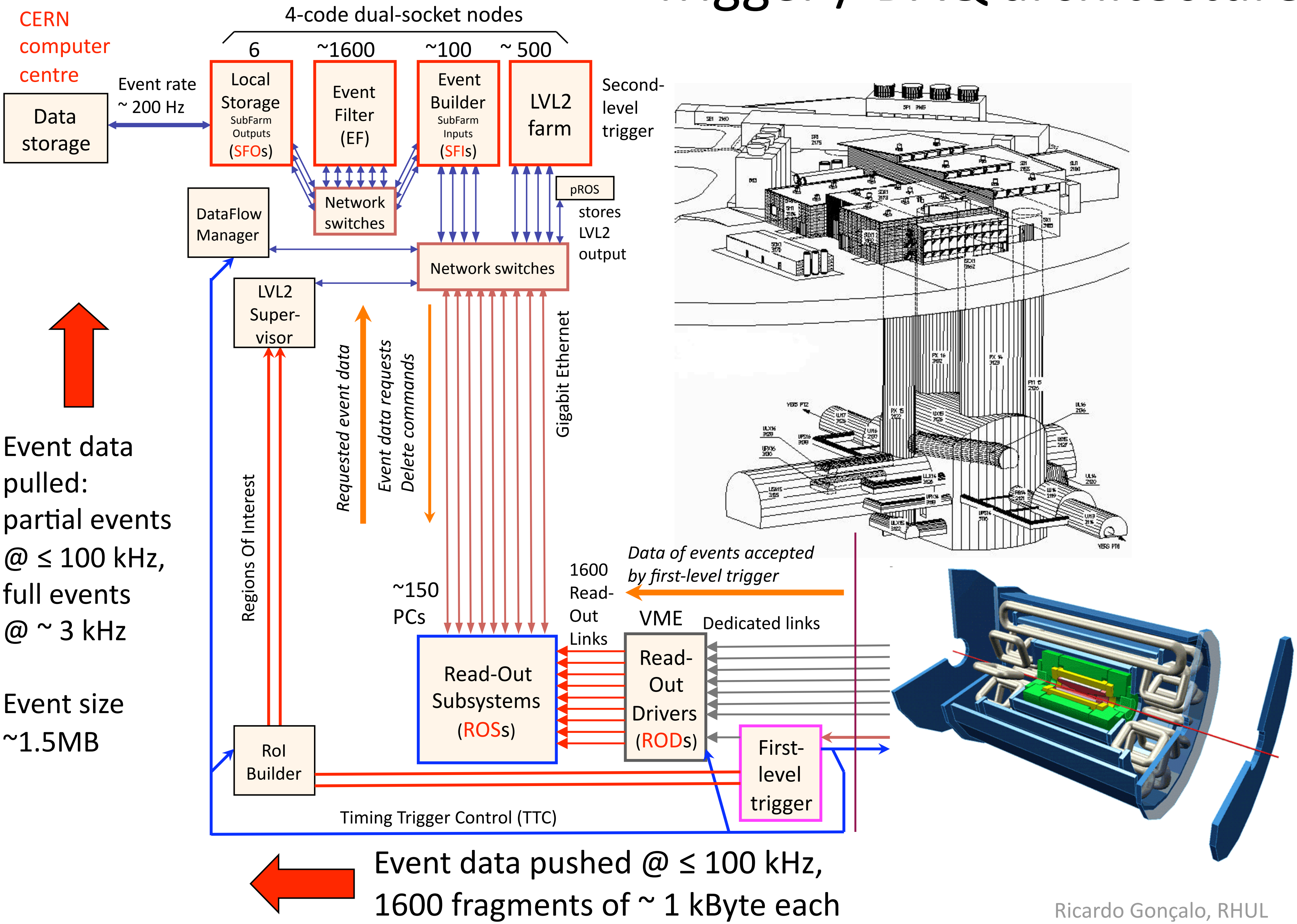


Pixel: 10x100µm; 80 M channels
Strips: 80µm; 6 M channels



Minbias Trigger Scintillator:
32 sectors on LAr cryostat
Main trigger for initial running
η coverage 2.1 to 3.8

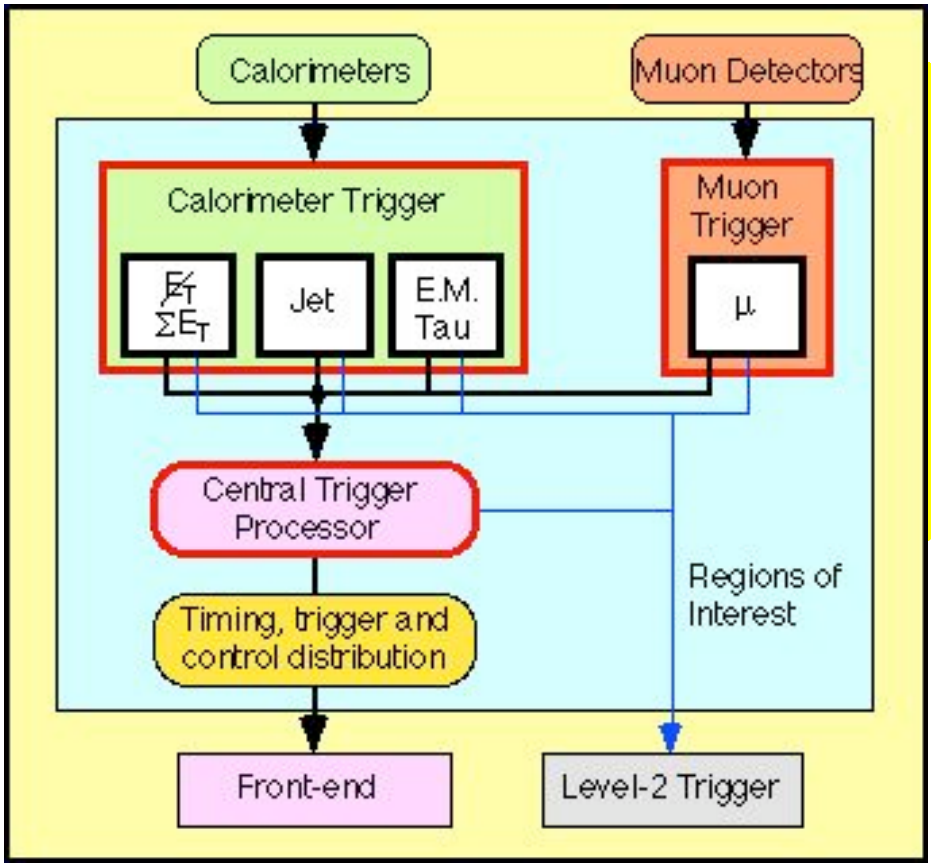
Trigger / DAQ architecture



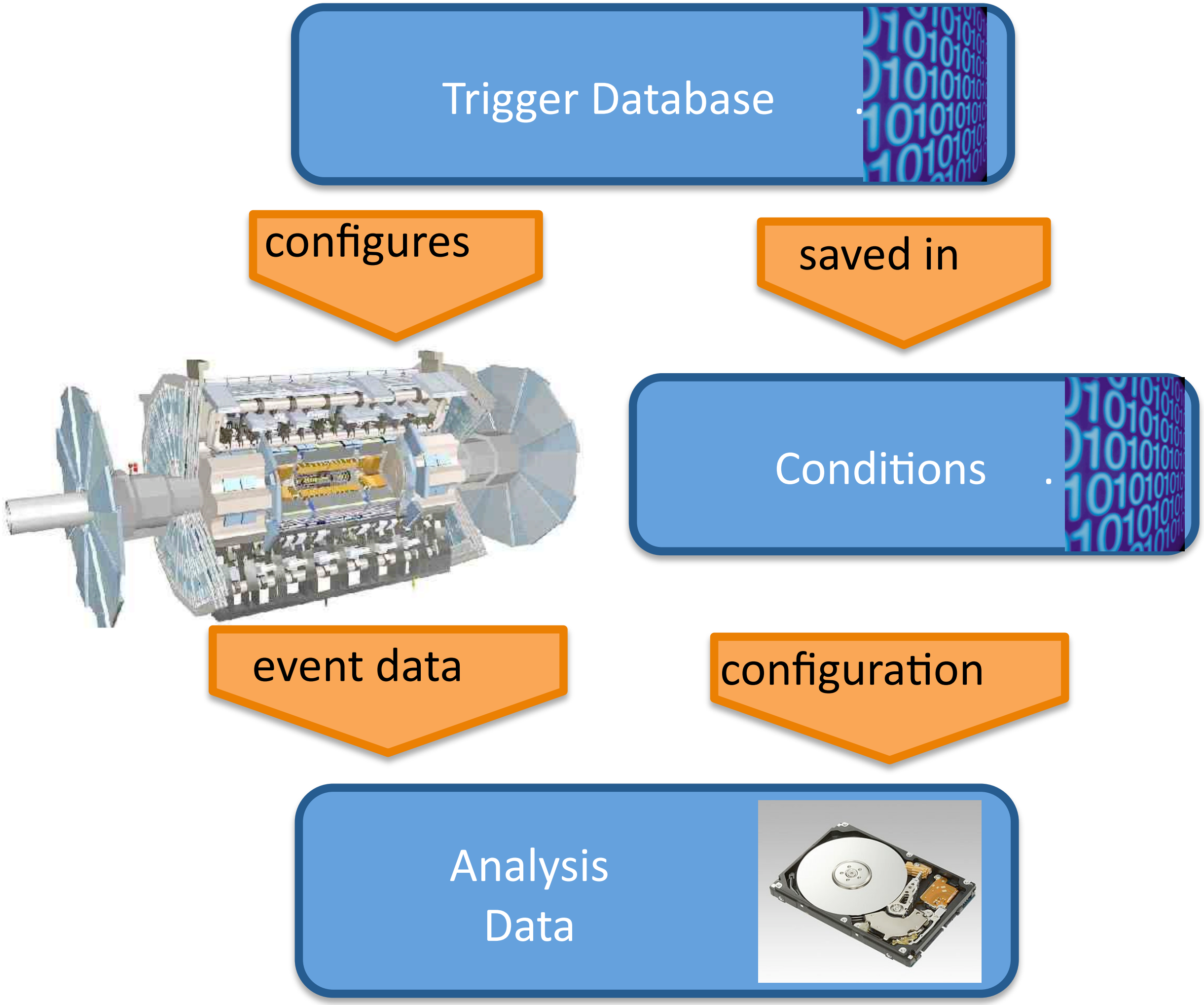
Ricardo Gonçalo, RHUL

Level 1 architecture

- Level 1 uses calorimeter and muon systems only
- Muon spectrometer:
  - Dedicated trigger chambers
    - Thin Gap Chambers – TGC
    - Cathode Strip Chambers – CSC
- Calorimeter:
  - Trigger towers group calorimeter cells in coarse granularity: $\Delta\eta\times\Delta\varphi = 0.1\times0.1$ (EM/Tau); $\Delta\eta\times\Delta\varphi = 0.2\times0.2$ (Jets)
- Identify regions of interest (RoI) and classify them as MU, EM/Tau, Jet
- Information passed to level 2:
  - RoI type
  - E_T threshold passed
  - Multiplicity
  - Location



Trigger Configuration



Trigger Commissioning

Commissioning with cosmics, single-beam 2008 & 2009:

- Initial timing in of Level-1 signals, ready for first collisions

First Collisions : Dec 2009 : 900 GeV; Mar 2010 : 2.36 TeV; 30 March 2010 : 7 TeV

- Level-1 active
- HLT running online in monitoring mode - no HLT rejection*:

Luminosity $cm^{-2}s^{-1}$

10^{27} $2x10^{27}$ $5x10^{27}$ 10^{28} $2x10^{28}$ $5x10^{28}$ 10^{29} $2x10^{29}$ $5x10^{29}$ 10^{30} $2x10^{30}$ $5x10^{30}$ 10^{31} …10^{32}

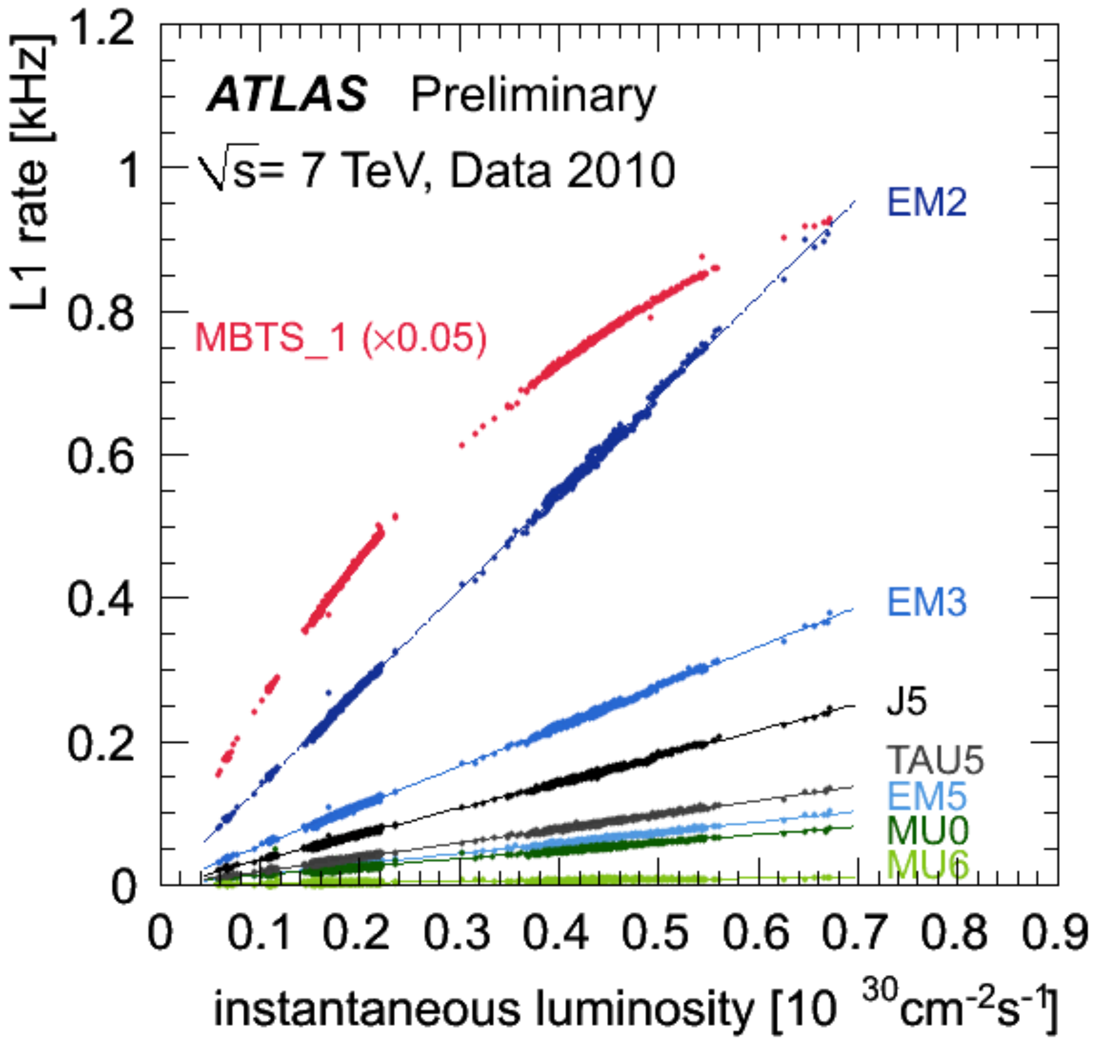
2010	April	May	June	July	August onwards
	Level-1 Active HLT Monitoring Mode		**Progressively activate HLT**		**HLT active**
	Min. Bias trigger records all collisions	Min. Bias pre-scaled e, γ, Jet, τ, μ and MET not pre-scaled	1.5×10^{29} : e & γ $4x10^{29}$: τ $6x10^{29}$: forward μ $1x10^{30}$: MET		**Physics menu deployed:** Shift focus from commissioning to physics

Progressive activation of HLT :

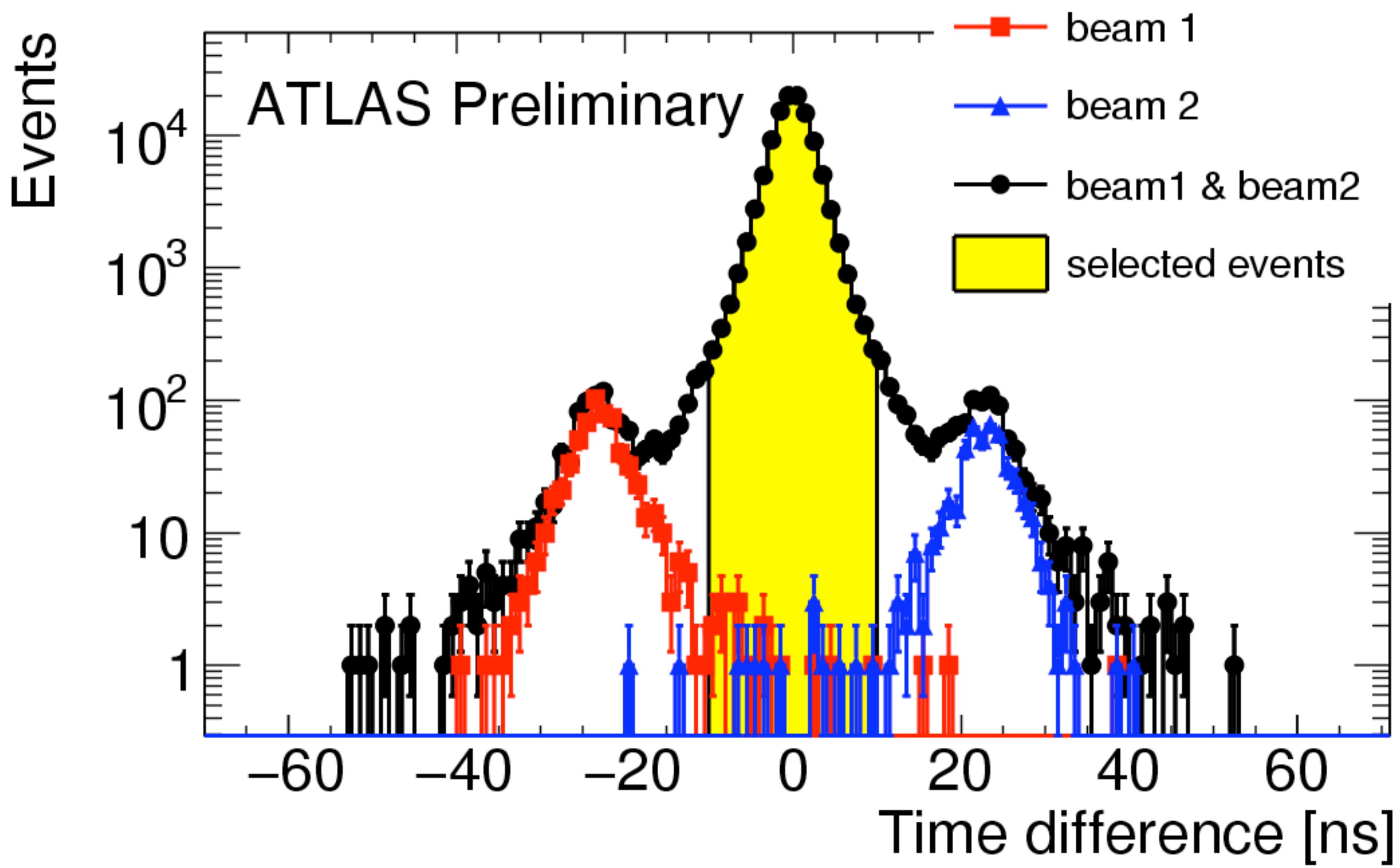
- Prescale sets pre-generated covering fixed luminosity ranges:
  - ➢ Can be updated before or during the run to match machine conditions.

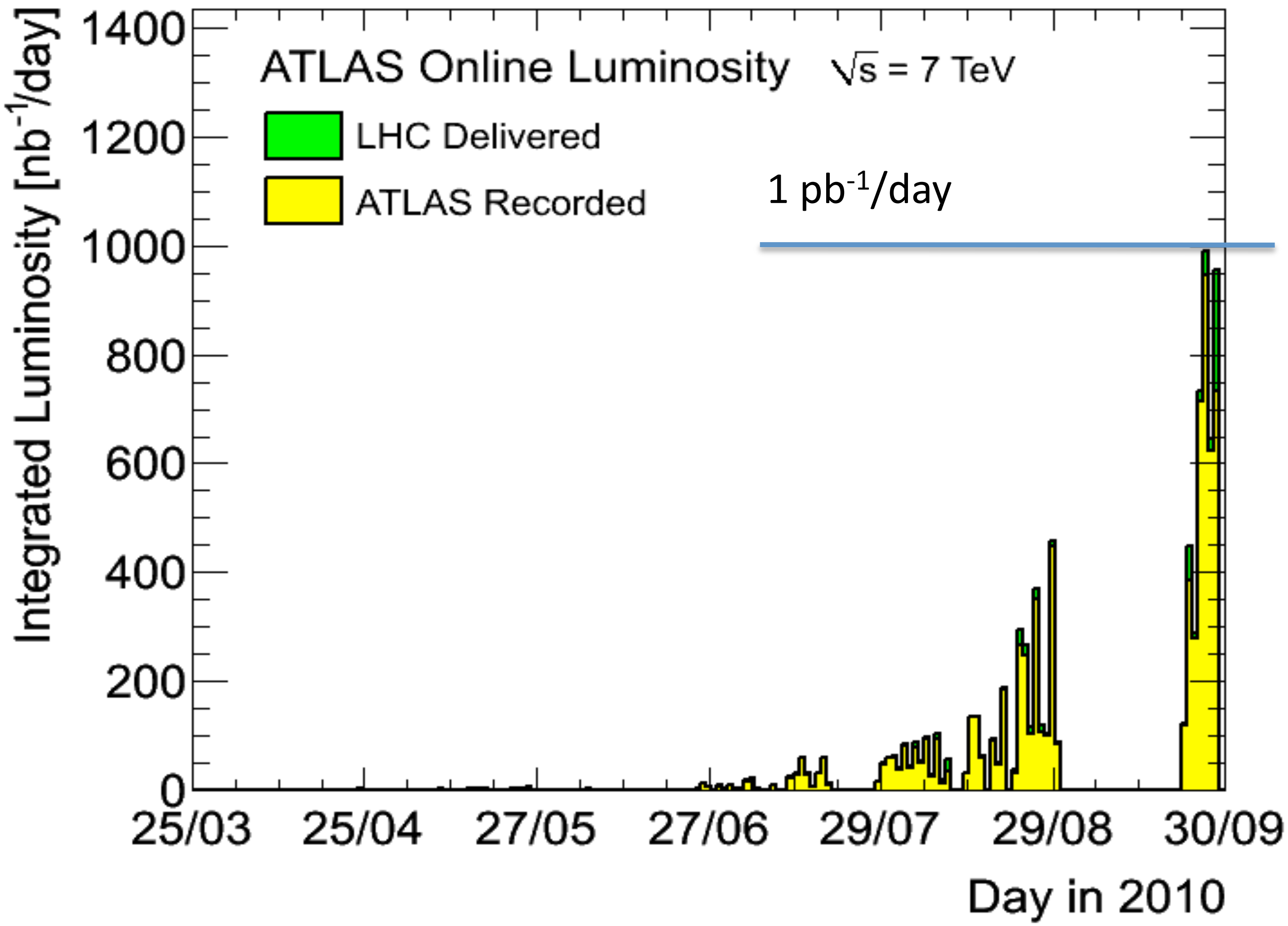
* Control Trigger: Random Bunch crossing + Inner Detector Hits at HLT – 1st trigger actively rejecting - already in 2009.

Level 1 trigger rate for various trigger selections up to L = $7 \times 10^{29} cm^{-2}s^{-1}$



• Time Difference between forward and backward counters signal collisions events:



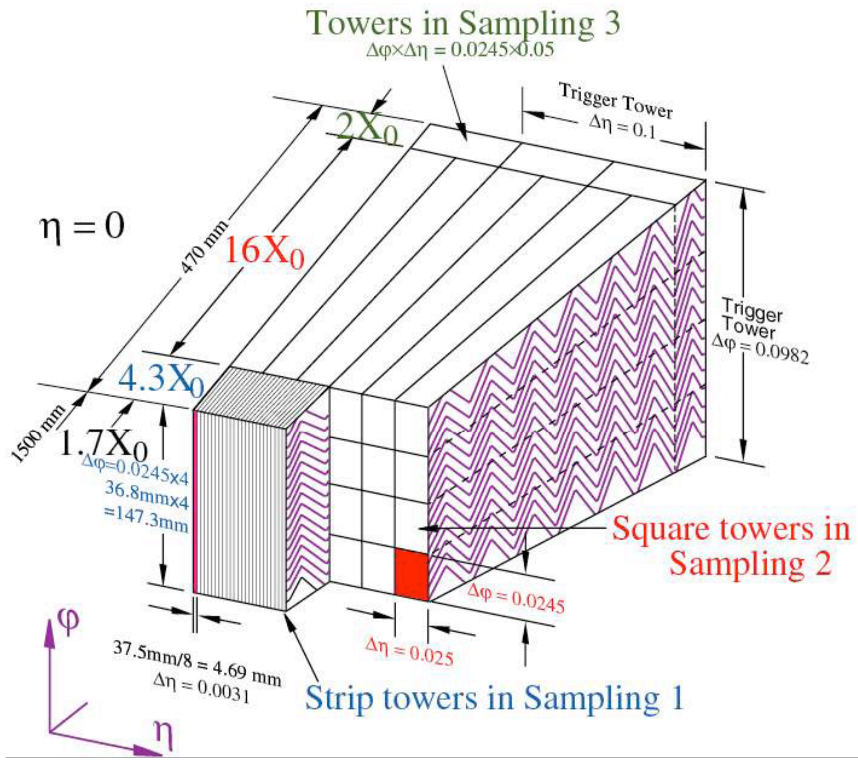

ATLAS Online Luminosity √s = 7 TeV
LHC Delivered
ATLAS Recorded
1 pb-1/day
Integrated Luminosity [nb-1/day]
1400
1200
1000
800
600
400
200
0
25/03
25/04
27/05
27/06
29/07
29/08
30/09
Day in 2010

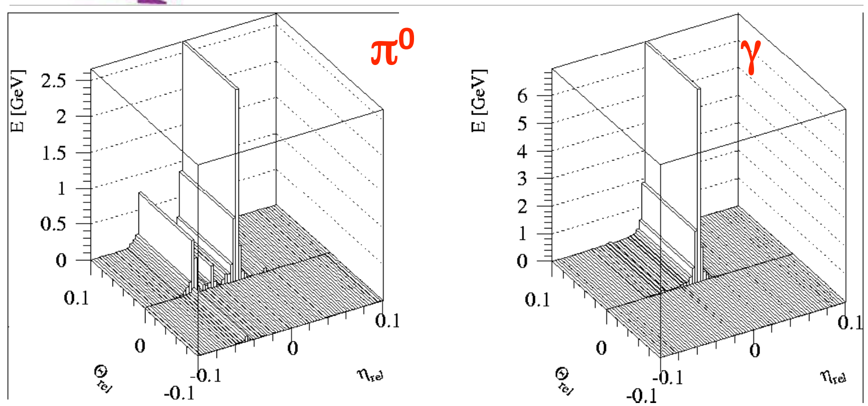
Example: level 2 e/γ calorimeter reconstruction

- Full granularity but short time and only rough calibration

- Reconstruction steps:
  1. LAr sample 2; cluster position and size (E in 3x3 cells/E in 7x7 cells)
  2. LAr sample 1; look for second maxima in strip couples (most likely from $\pi^0 \rightarrow \gamma\gamma$, etc)
  3. Total cluster energy measured in all samplings; include calibration
  4. Longitudinal isolation (leakage into hadronic calorimeter)

- Produce a level 2 EM cluster object





Example: level 2 tracking algorithm

1. Form pairs of hits in Pixel and SCT in thin ϕ slices;
   - extrapolate inwards to find Z_{vtx} from a 1D histogram
2. Using Z_{vtx}, make 2D histogram of hits in η-ϕ plane;
   - remove bins with hits in too few layers
3. Do 2D histogram using space point triplets in $1/p_T$-ϕ plane;
   - Form tracks from bins with hits in >4 layers
4. Use Kalman technique on the space points obtained in previous steps
   - Start from already estimated parameters: Z_{vtx}, $1/p_T$, η, ϕ

- Full granularity but short time
- Algorithms optimised for execution speed, including data access time
- Produce level 2 tracks