The ATLAS Detector at LHC
Part 2: How well does it work ?

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on behalf of the ATLAS collaboration

The Actual Problems of Microworld Physics - GOMEL09

July 17, 2009

Outline

Expected performance

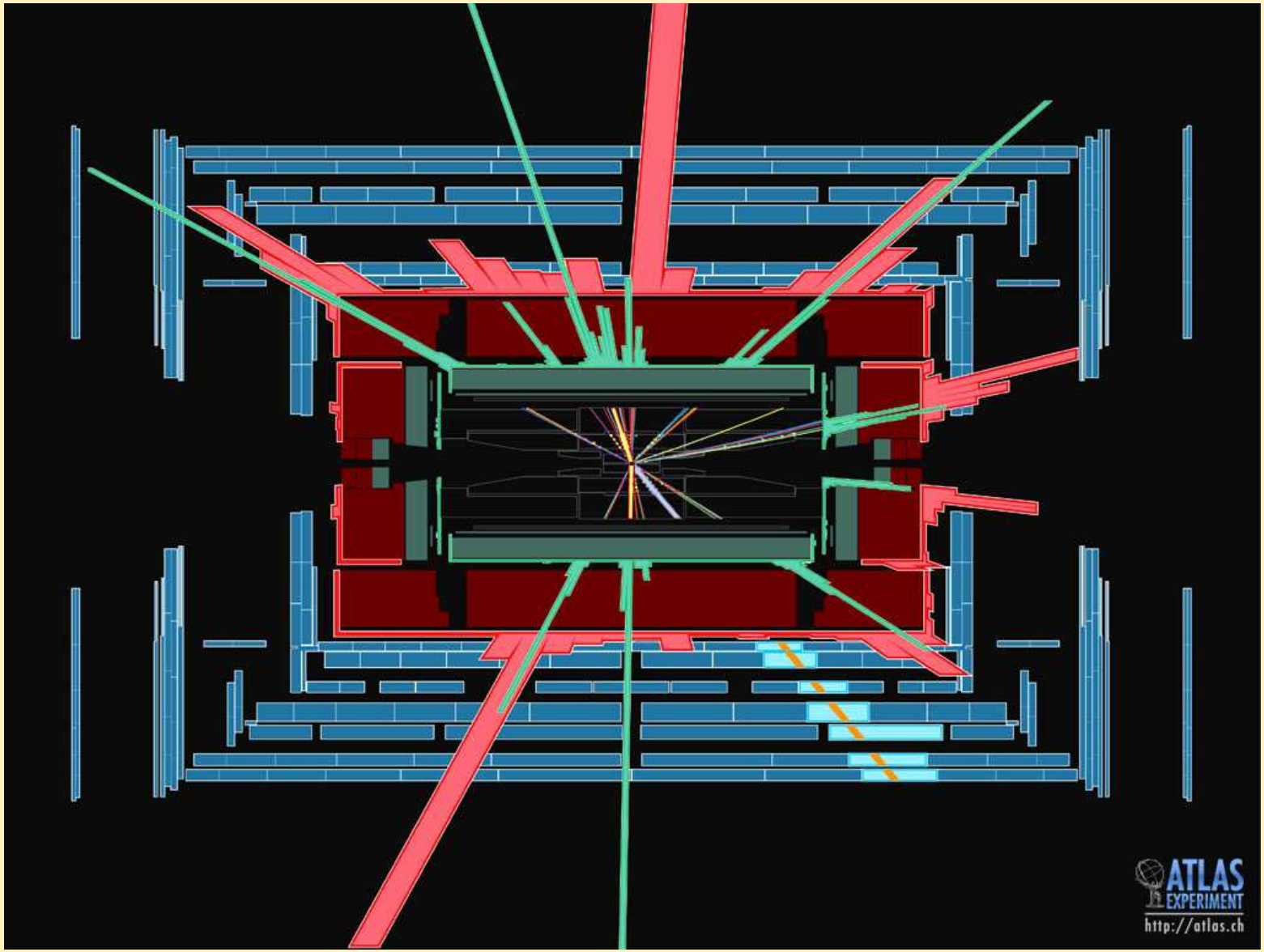
Cosmic rays in 2008

Single beam events

Summary

Expected performance

An ATLAS event



The Challenge

Two aspects of commissioning detectors and their performance

- Hardware commissioning: how well are the detector active elements working with respect to their specifications/requirements?
- Physics commissioning: how well are the physics objects we are interested in reconstructed and identified and can they be used to see new (and "old") physics?

Understanding the detector(s)

In order to evalute how well ATLAS is going to work when having real LHC collisions, we can use different tools:

- Simulation of LHC data (Monte Carlo) with different realistic scenarios:
  - Nominal luminosity and energy
  - Low luminosity samples (start-up strategies)
  - Low energy (revised LHC start-up plans)
  - With/without pile-up
  - With misalignment
- Using cosmic rays
- Added Bonus: Using single beam data from September 2008

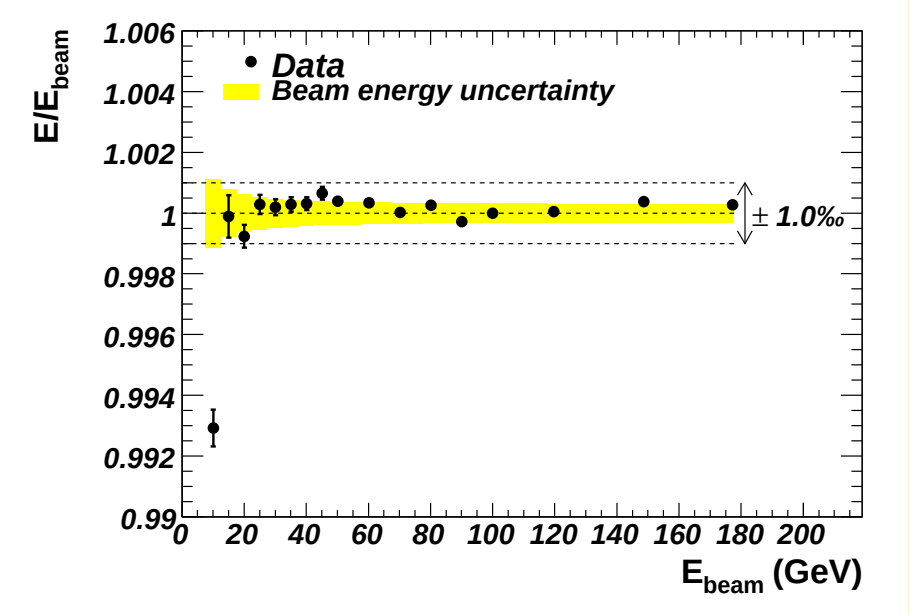
Inner detector accuracies

Subdetector	R-ϕ	z (R)
Pixel	10 μm	115 μm
SCT	17 μm	580 μm
TRT	130 μm	

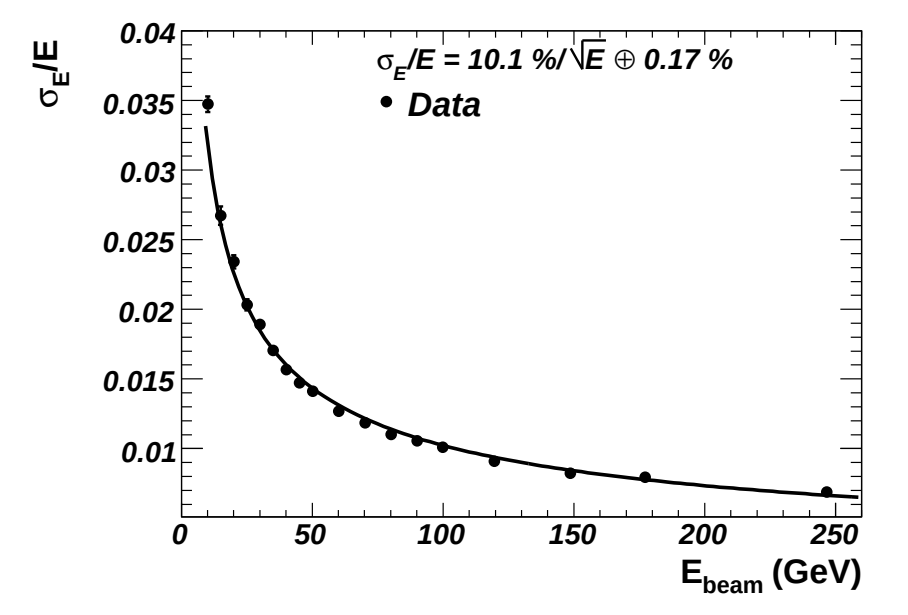
- Pixel single-module accuracy
- SCT effective single-module accuracy
- TRT drift time accuracy of a single straw

LAr Calorimeter resolution & linearity

$$\frac{\sigma(E)}{E} = \frac{(10.1 \pm 0.4)\%}{\sqrt{(E)(GeV)}} \oplus (0.2 \pm 0.1)\%$$



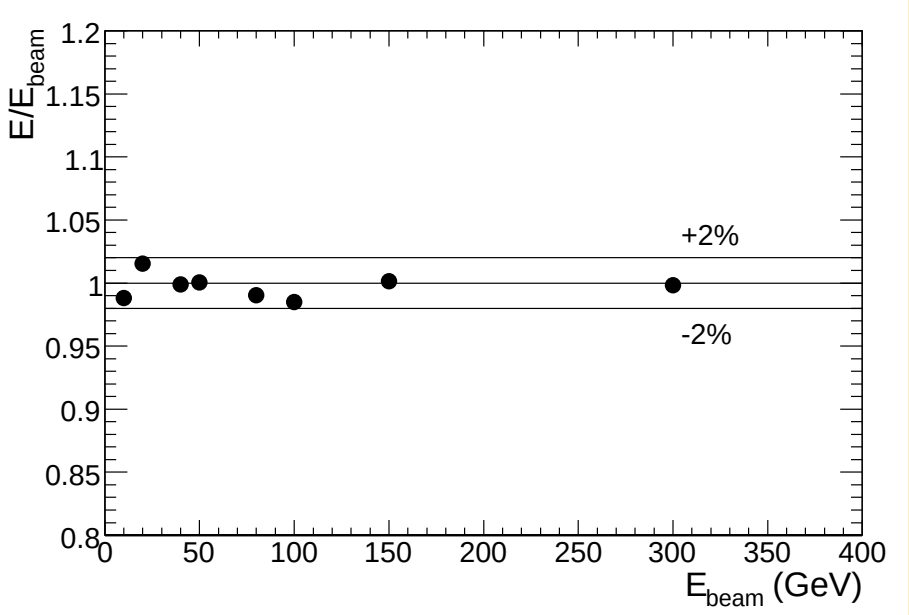
Linearity at $|\eta|$=0.687



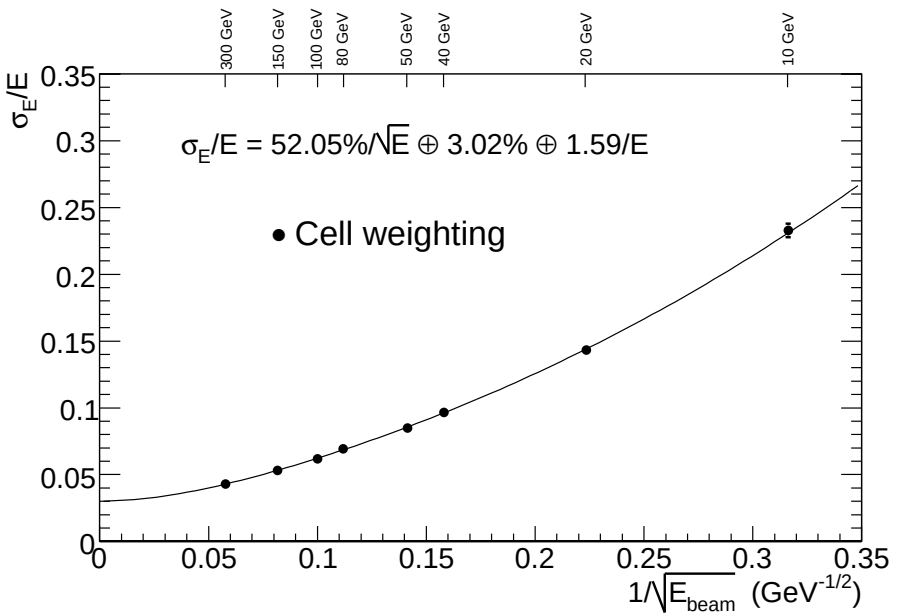
Fit for resolution at $|\eta|$=0.687

Tile Calorimeter resolution & linearity

$$\frac{\sigma(E)}{E} = \frac{(56.4 \pm 0.4)\%}{\sqrt(E)(GeV)} \oplus (5.5 \pm 0.1)\%$$



Linearity for combined LAr and Tile at $|\eta|$=0.25



Fit for resolution for combined LAr and Tile at $|\eta|$=0.25

Muon chambers

Subdetector	z (R)	ϕ	time
MDT	35 μm	—	—
CSC	40 μm	5 mm	7 ns
RPC	10 mm	10 mm	1.5 ns
TGC	2-6 mm	3-7 mm	4 ns

Fast trigger decision requires good time resolution, but not so good space resolution

Reconstruction of Physics objects

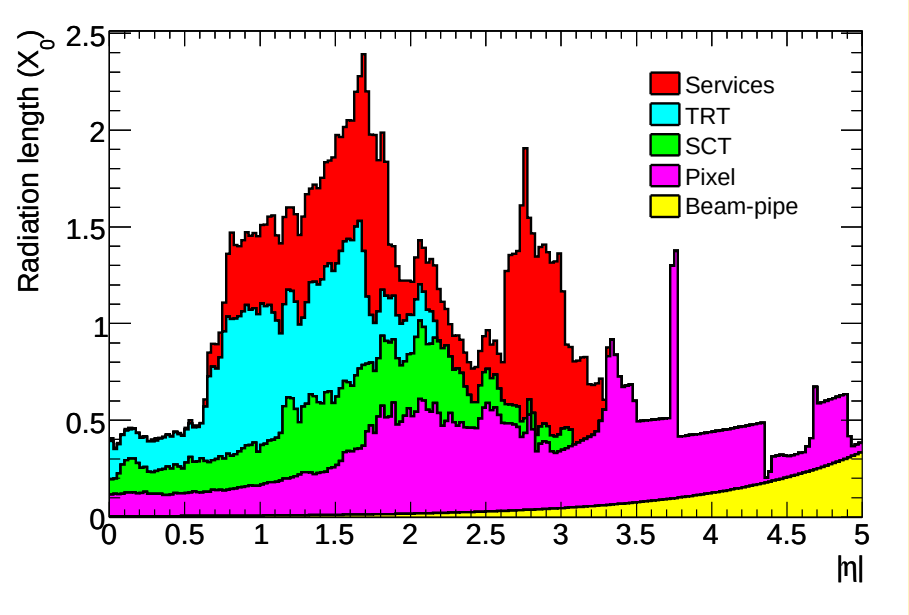
How do we find physics object candidates in the ATLAS detector?

- Low-p_T charged particle: any track in the ID which doesn't have a calorimeter cluster associated to it
- Electron: an ID track matching a EM calorimeter cluster in η and ϕ.
- Photon: An EM calorimeter cluster without an ID track match
- Jet: A hadronic calorimeter cluster
- Muon: A track in the muon spectrometer matching an ID track

More criteria are applied to each of them to determine the quality of the candidate

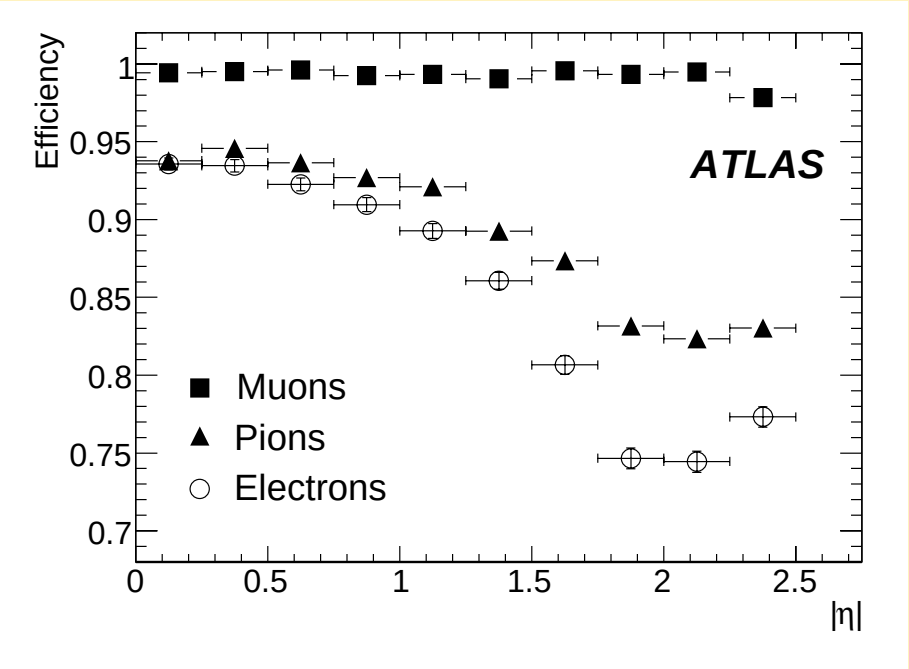
Material Budget in the Inner Detector

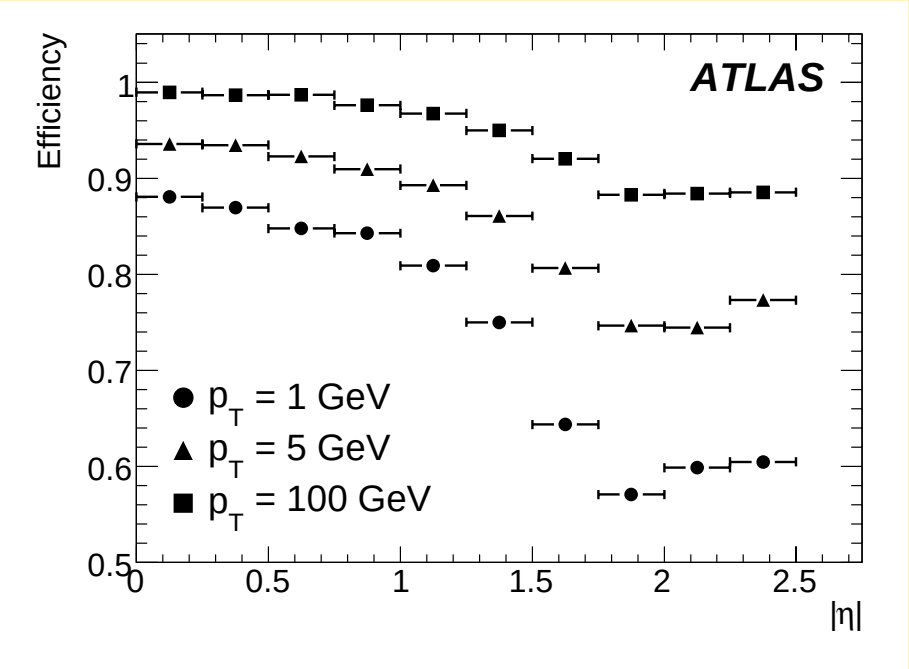
When building a tracking detector, should always aim for as low a material budget as possible



- Services almost doubles the material in front of the calorimeter
- Consequences are:
  - More bremsstrahlung
  - More Electron/photon conversions
  - Energy loss before particles reach the calorimeter

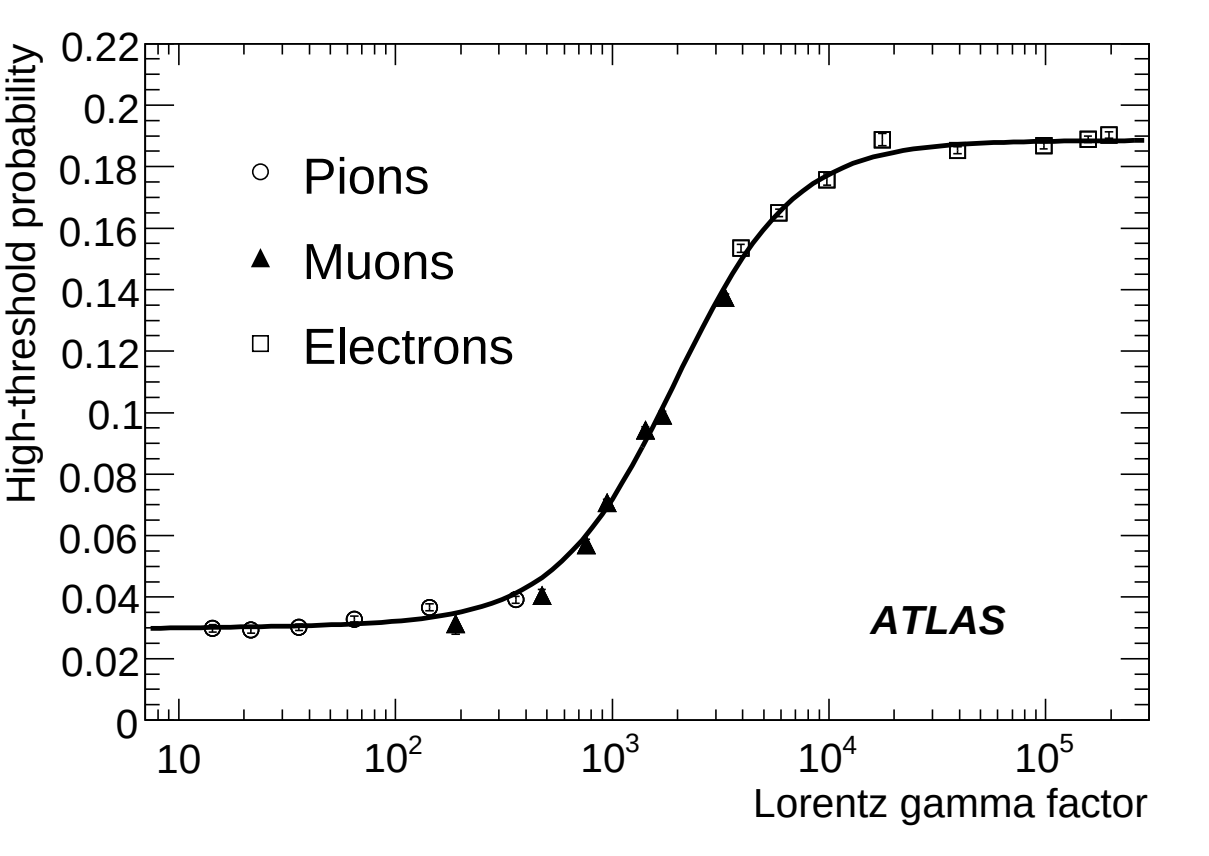
Tracking efficiency





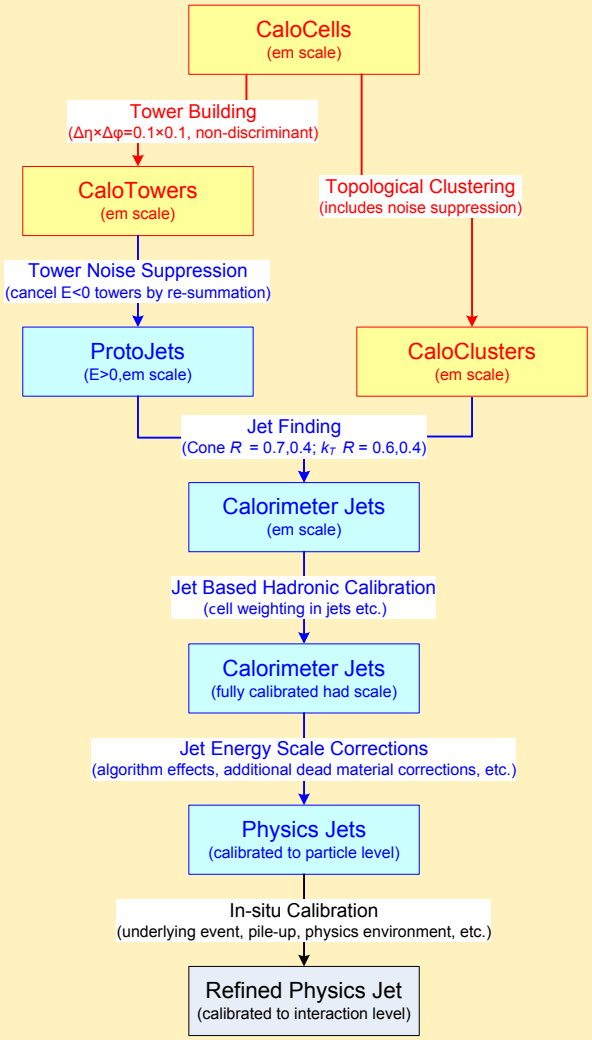
- Left: comparison between muons, pions and electrons tracking efficiency in the Inner detector.
- Right: efficiency for electrons of different p_T
- Muons don't suffer from material effects
- Low energy electrons interact more with material

Electron/pion separation with the TRT



- Using Combined Test Beam data (2004)
- In the energy range 2 to 350 GeV
- Showing good separation between different particles

Jet reconstruction



- ATLAS initially was using the Cone algorithm (R=0.4) and the k_T algorithm
- Tower clustering: Sum of cells on a $\Delta\eta$ x $\Delta\phi = 0.1$ x 0.1 grid
- Topological clustering: Build 3D cluster from a seed and add neighbouring cells above noise
- Starting in Spring 2009, ATLAS will concentrate jet calibration efforts on the anti-k_t algorithm

Jet algorithms overview

Cone

- Seed objects found in the calorimeter above a p_T threshold, fixed-size cone around it to form a jet
- Iterative process to optimize the direction using four-momenta of objects inside the cone
- Split and merge jets using shared p_T fraction to deal with jet overlaps

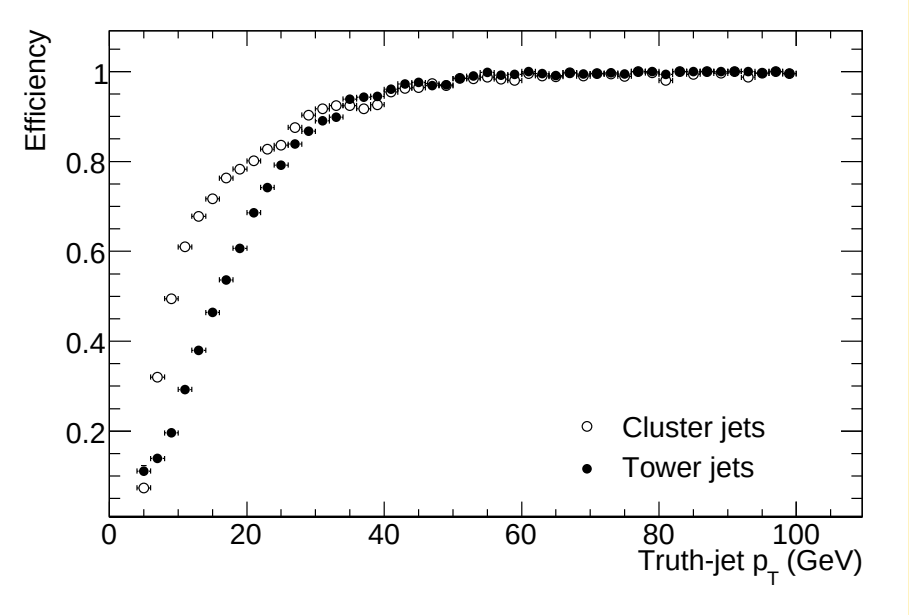
k_T

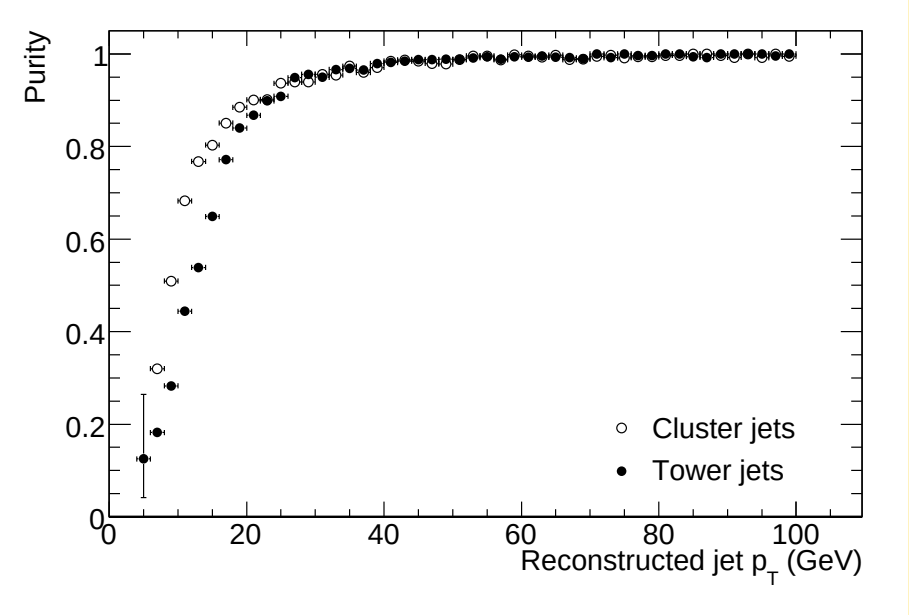
- Sequential recombination algorithm using distance measures, adding objects to the jets until all inputs are used.
- Minimum of relative squared p_T and single object squared p_T is calculated. If single object, a jet is formed. If relative, two objects are combined and a new object added to the original list of inputs.

Anti-k_t

- Generalisation of k_T, using the power of the momentum in the distance measure as parameter
- Jet shape less influenced by soft particles, showing advantages from Cone and k_T

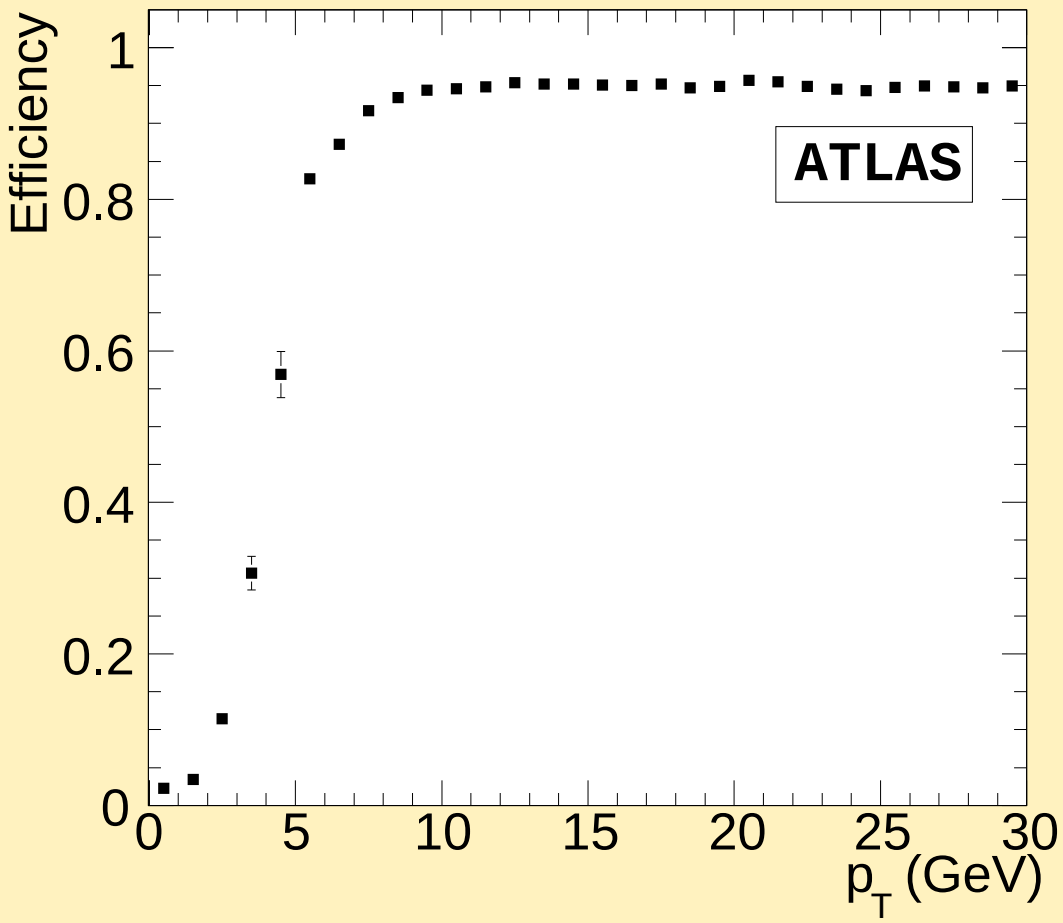
Jet reconstruction efficiency





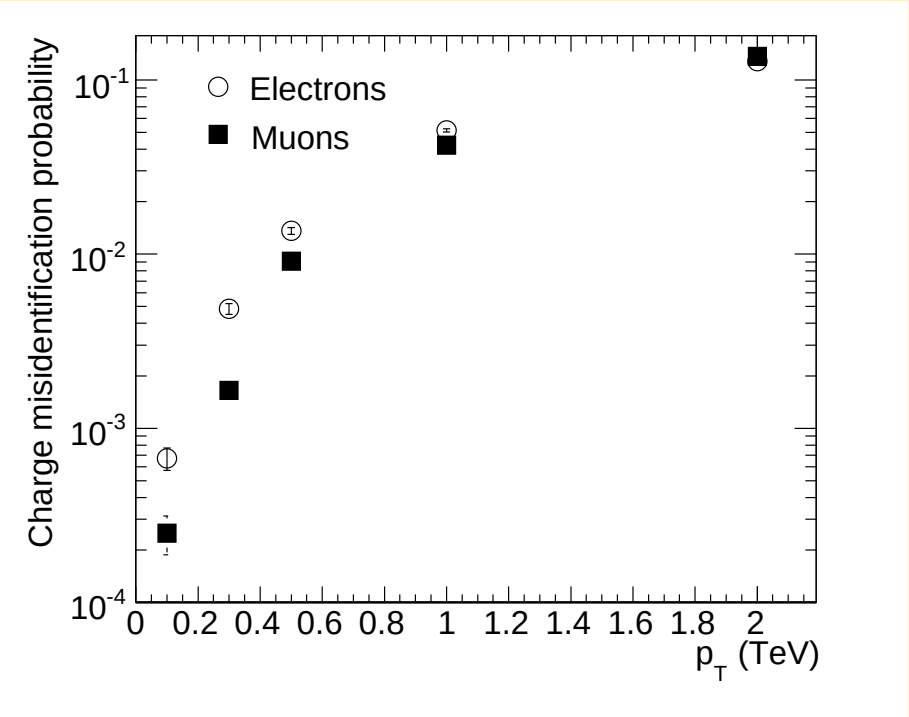
- Jets from Vector Boson Fusion (VBF) Higgs decay.
- Cone size for tower and cluster reconstruction: $\Delta R = 0.7$
- Topo Clusters doing a better job at low energy

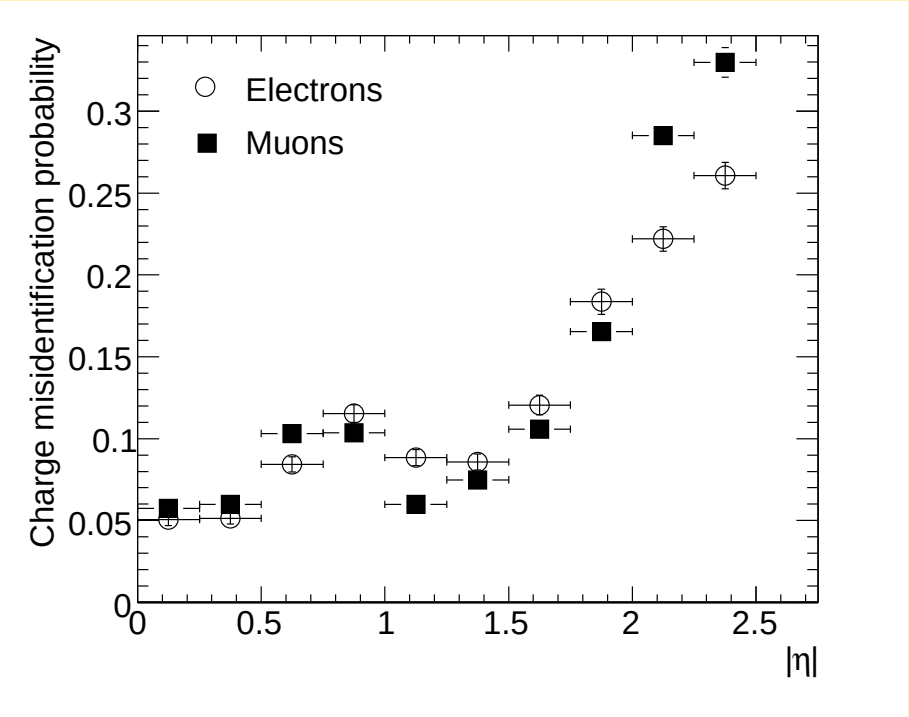
Muon reconstruction efficiency



- Good reconstruction efficiency for $p_T > 5$ GeV
- Integrated over $|\eta| < 2.7$ and ϕ

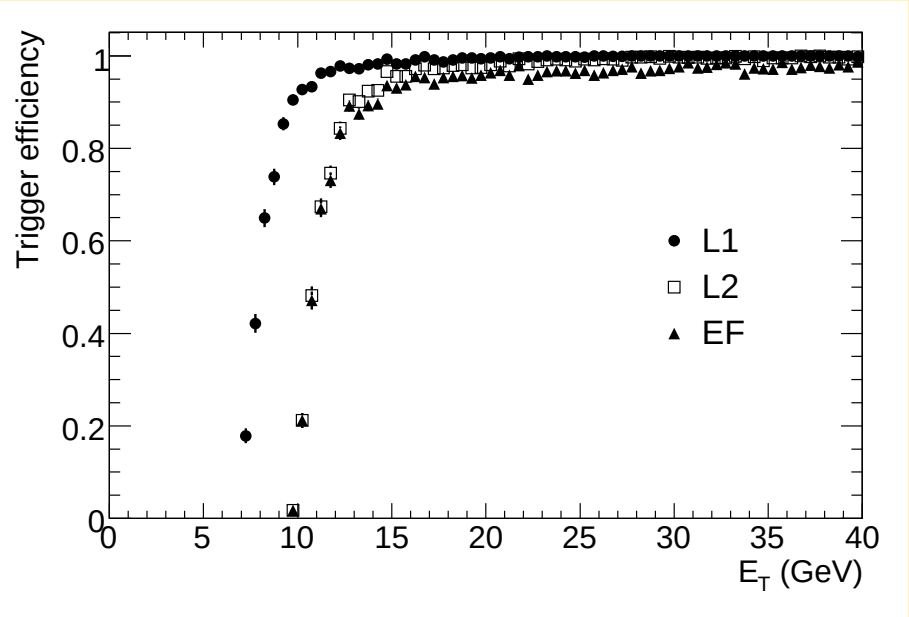
Charge misidentification



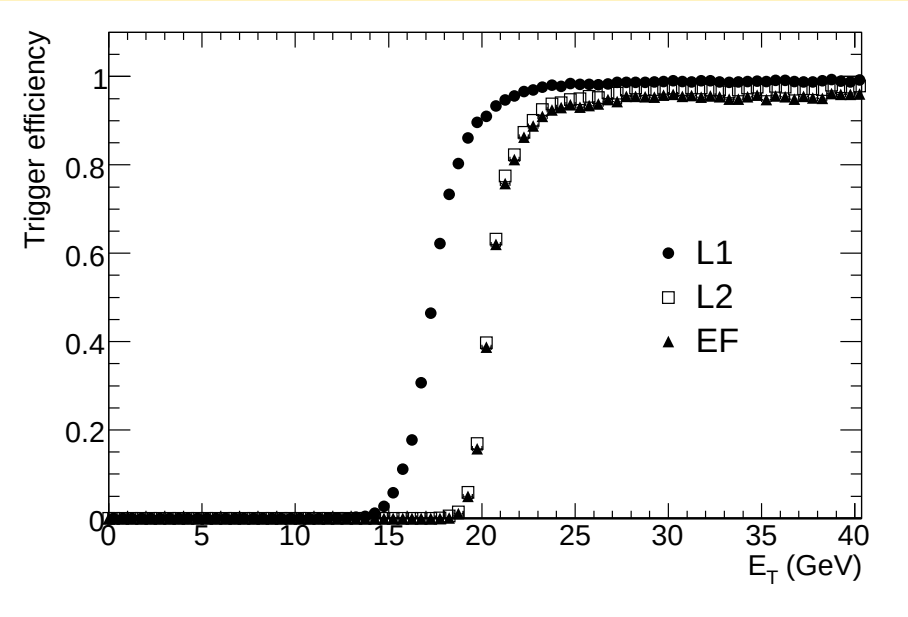


- Tracks bend more at low energy → easier charge identification
- Higher p_T tracks ($p_T > 1$ TeV) almost straight
- Right plot: $p_T = 2$ TeV

Electron/Photon trigger efficiency



Electron trigger efficiency for e10 chain (10 GeV electron with 7 GeV EM cluster at L1)

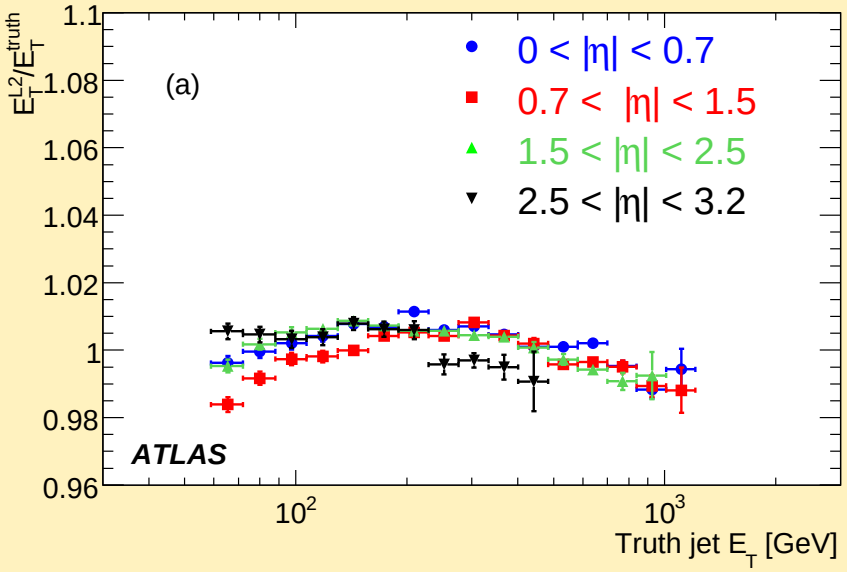


Photon trigger efficiency for g20i chain (20 GeV isolated photon with 18 GeV isolated EM cluster at L1)

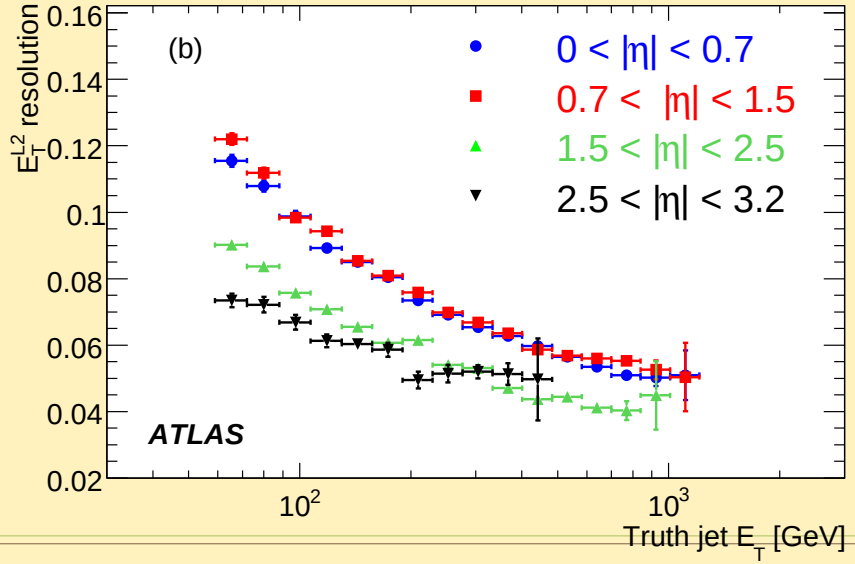
L1 trigger selects more fakes, HLT has more information to make a better selection

Jets in trigger

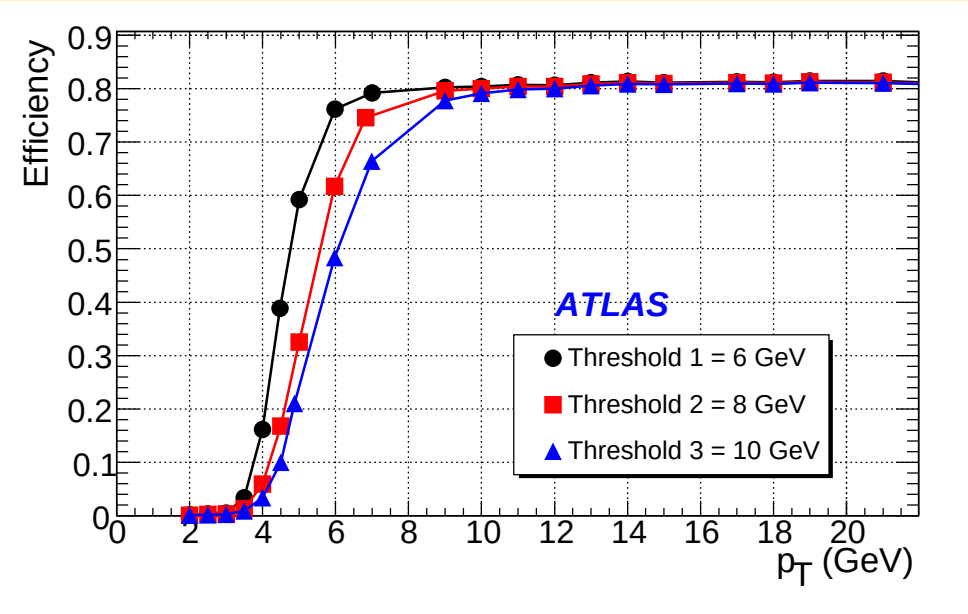
- Jet Energy Scale at L2 trigger

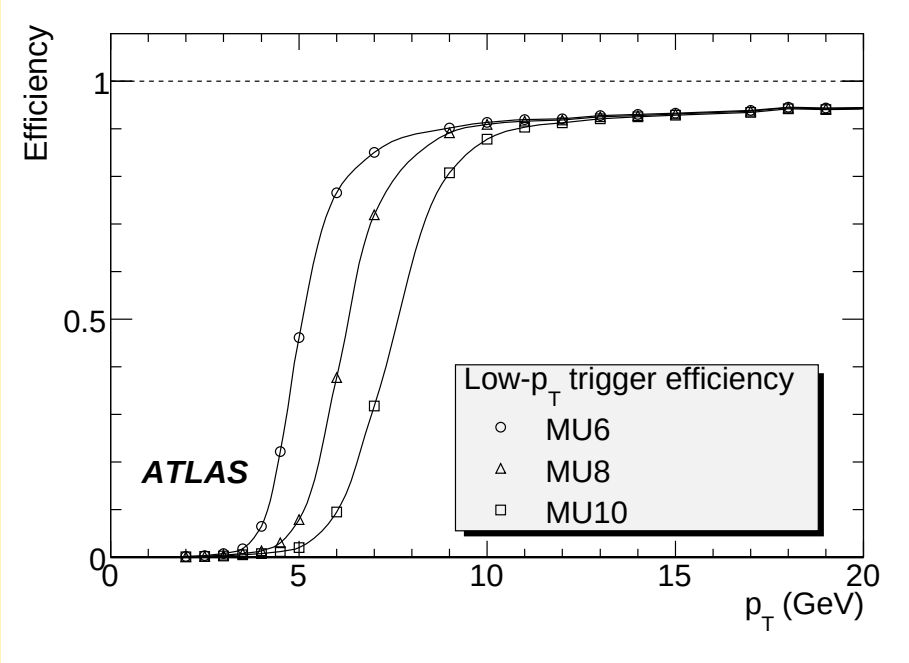


- Jet Resolution at L2 trigger



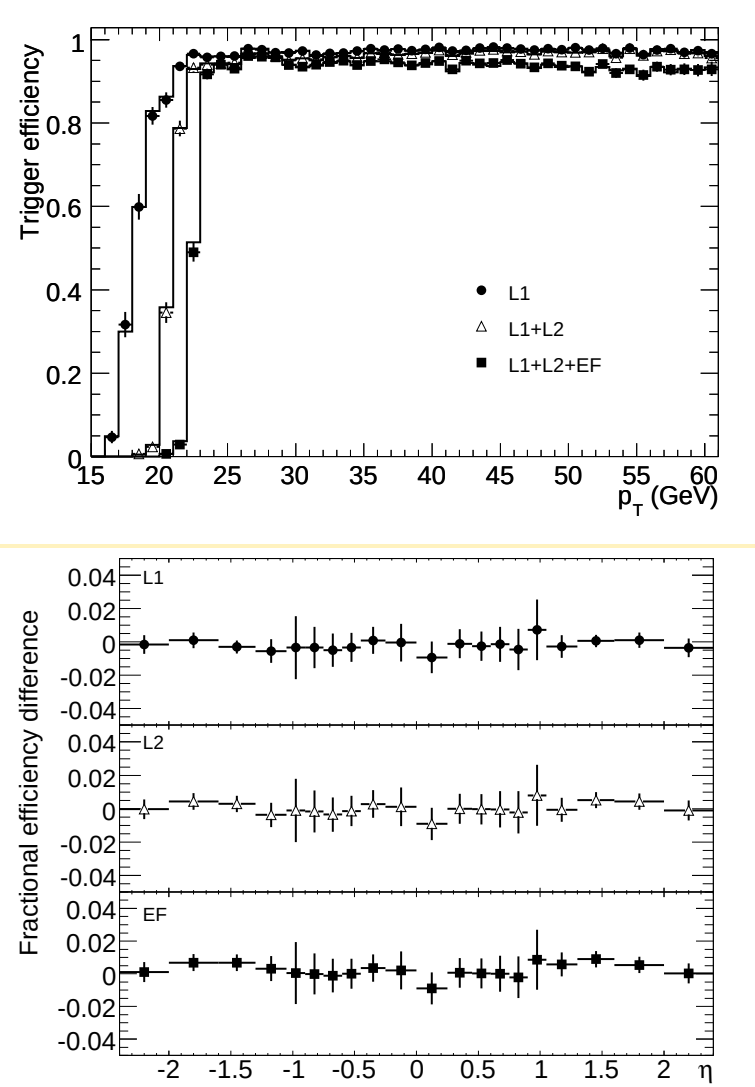
Muon trigger efficiency





- Left: Barrel, Right: End-Cap
- For low p_T muons
- Geometrical regions in Barrel not covered by RPC chambers → lower efficiency

Trigger efficiency from "data"



- Electron trigger efficiency for Z→ee events measured with in-situ methods, i.e. as if we had data.
- Trigger chain e22i was used (22 GeV isolated electron)
- Efficiency measured wrt offline selection
- Sample equivalent to 100 pb^{-1}
- Good agreement between MC and In-situ measurements (difference shown in bottom plot)

Cosmic rays in 2008

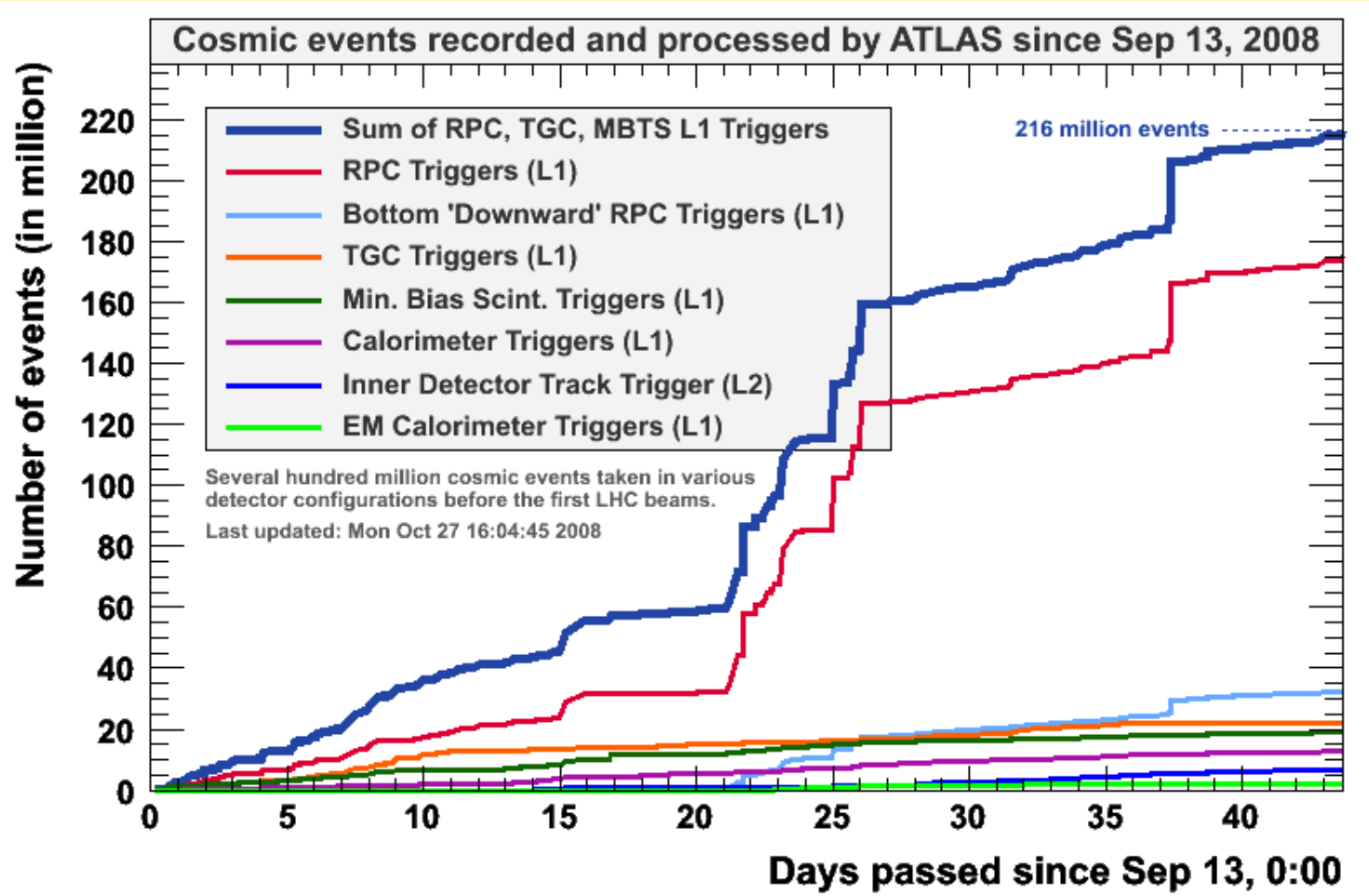
Commissioning activities

Cosmic rays are used since 2005 to perform all sorts of commissioning:

- Combined testing on surface of SCT+TRT, Barrel and End-Cap
- Pixel End-Cap surface tests.
- LAr tests underground
- Muon detectors tests underground
- Alignment and detector commissioning for the Inner Detector underground
- Main goals: detector alignment and calibration, dead and noisy channel determination, timing

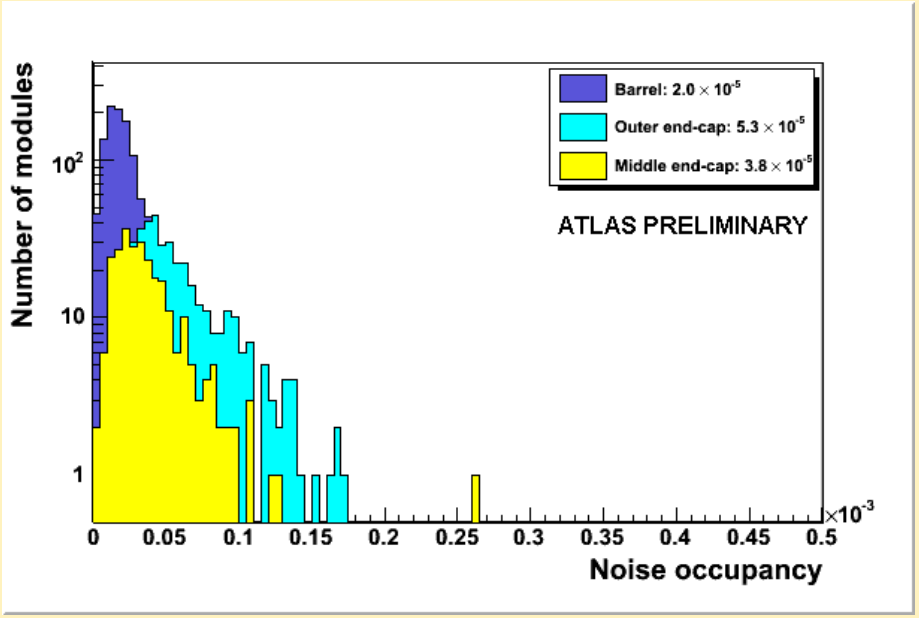
By collecting cosmic rays, we are gaining significant experience in using this complex machinery!

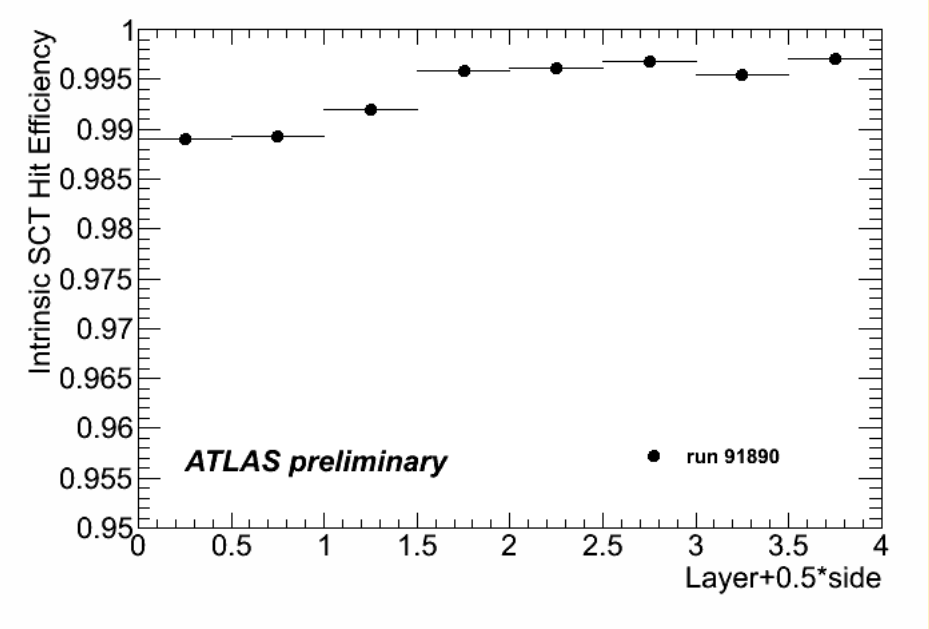
Combined Cosmic runs - fall 2008



- Over 200 million events collected with full detector running
- ∼7 million events recorded by the L2 ID track trigger

SCT efficiency & noise

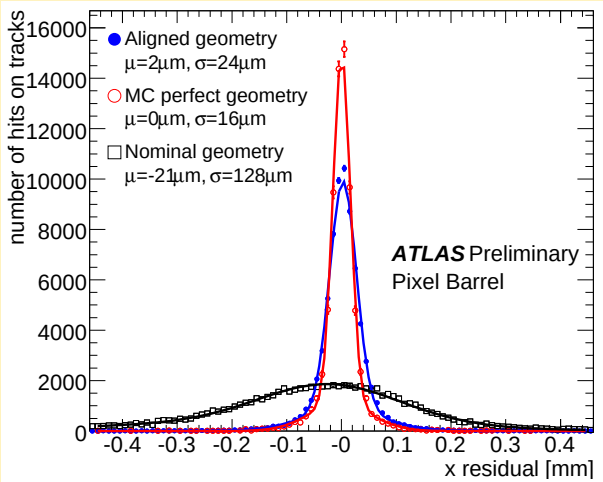


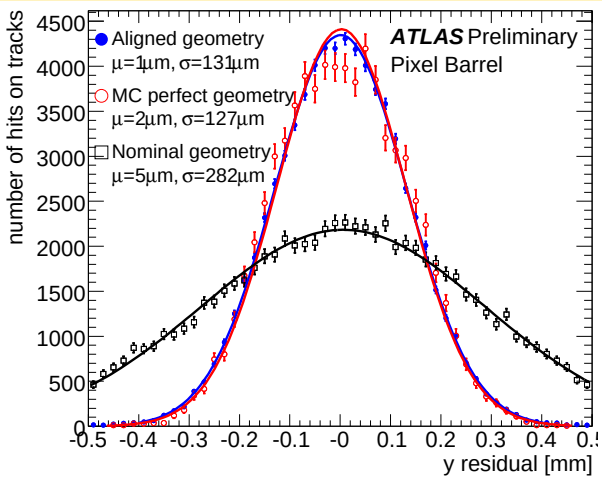


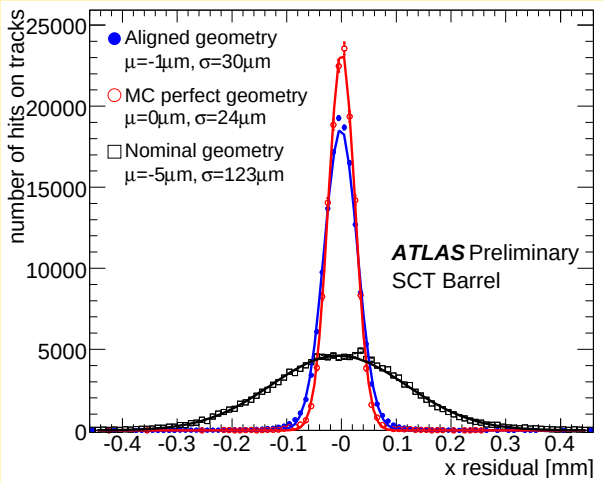
- Noise occupancy = fraction of the time spent in a module collecting noise
- Measured in December 2008, after the full comics sample was collected with 150 V bias voltage
- Well below specifications (5×10^{-4}).

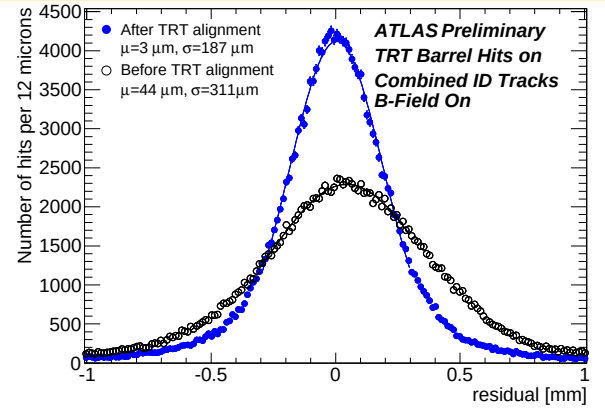
- SCT Hit efficency > 99%
- Hit: A cluster with a least one strip on each side of the module
- Small number of inactive SCT module taken out of the plot

ID alignment



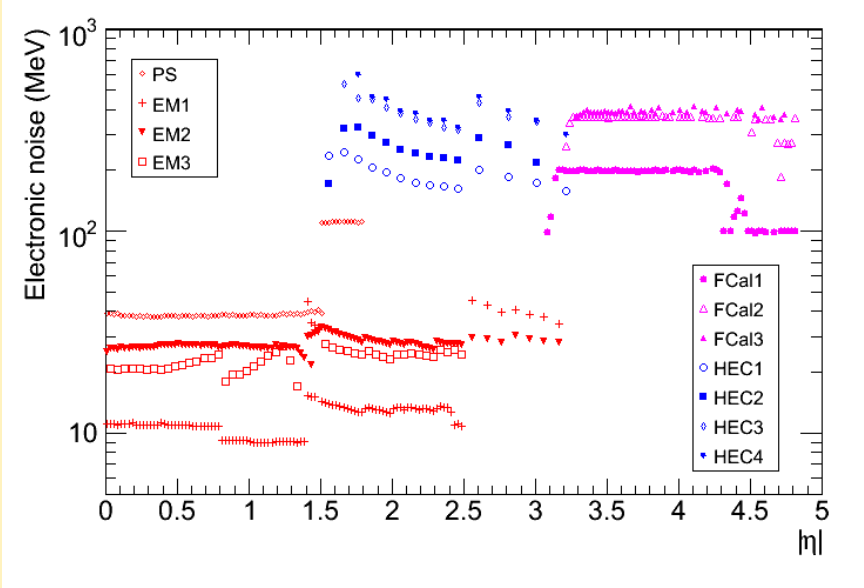


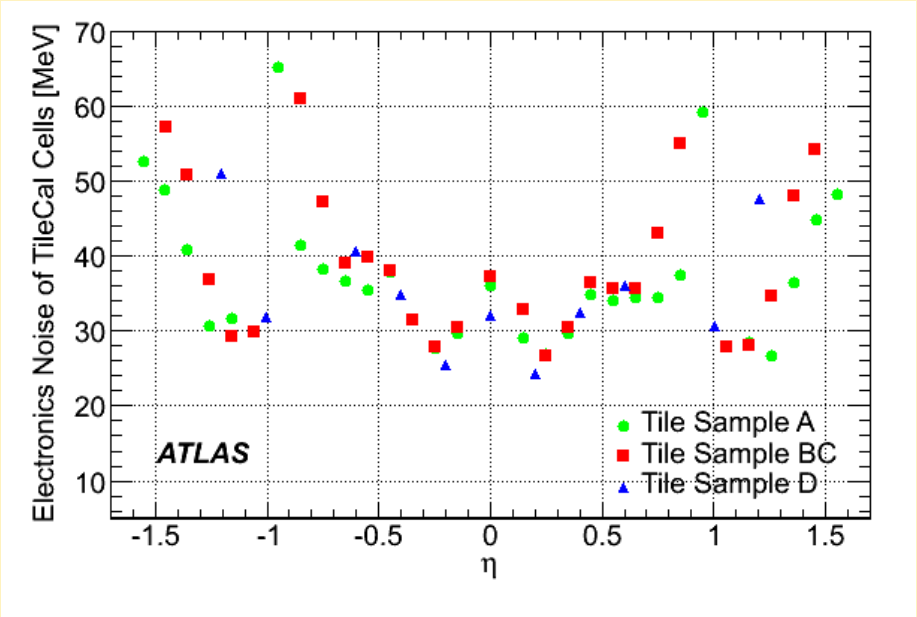




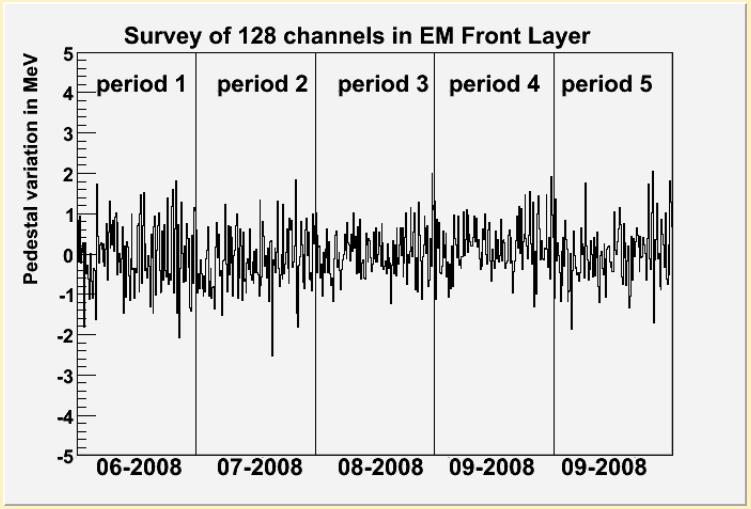
- ID tracks collected with Solenoid ON
- Tracks residuals close to perfect MC geometry
- Need more statistics in the End-Cap

Noise measurement in Calorimeters

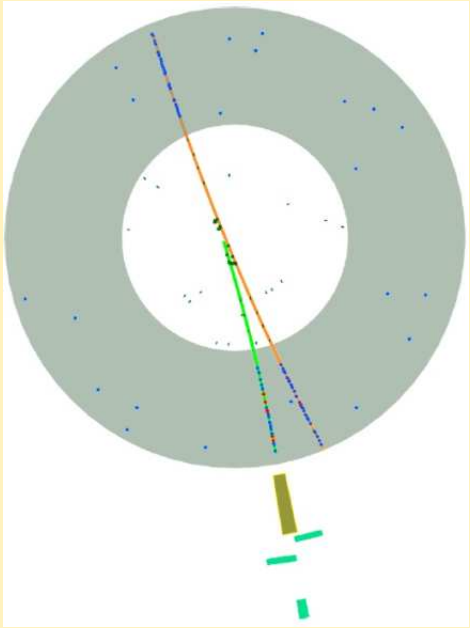




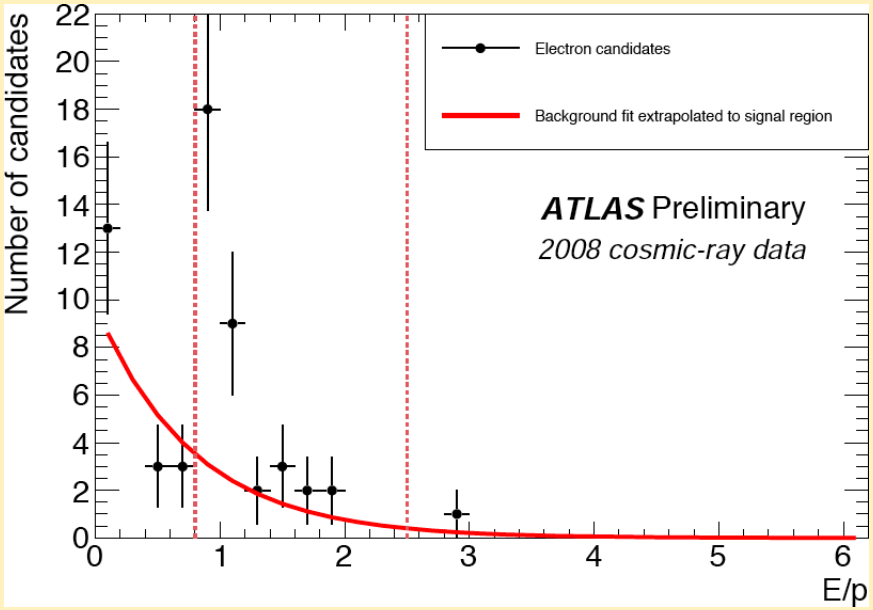
- Use random triggers to measure noise
- Good uniformity over months



Electrons in Cosmics

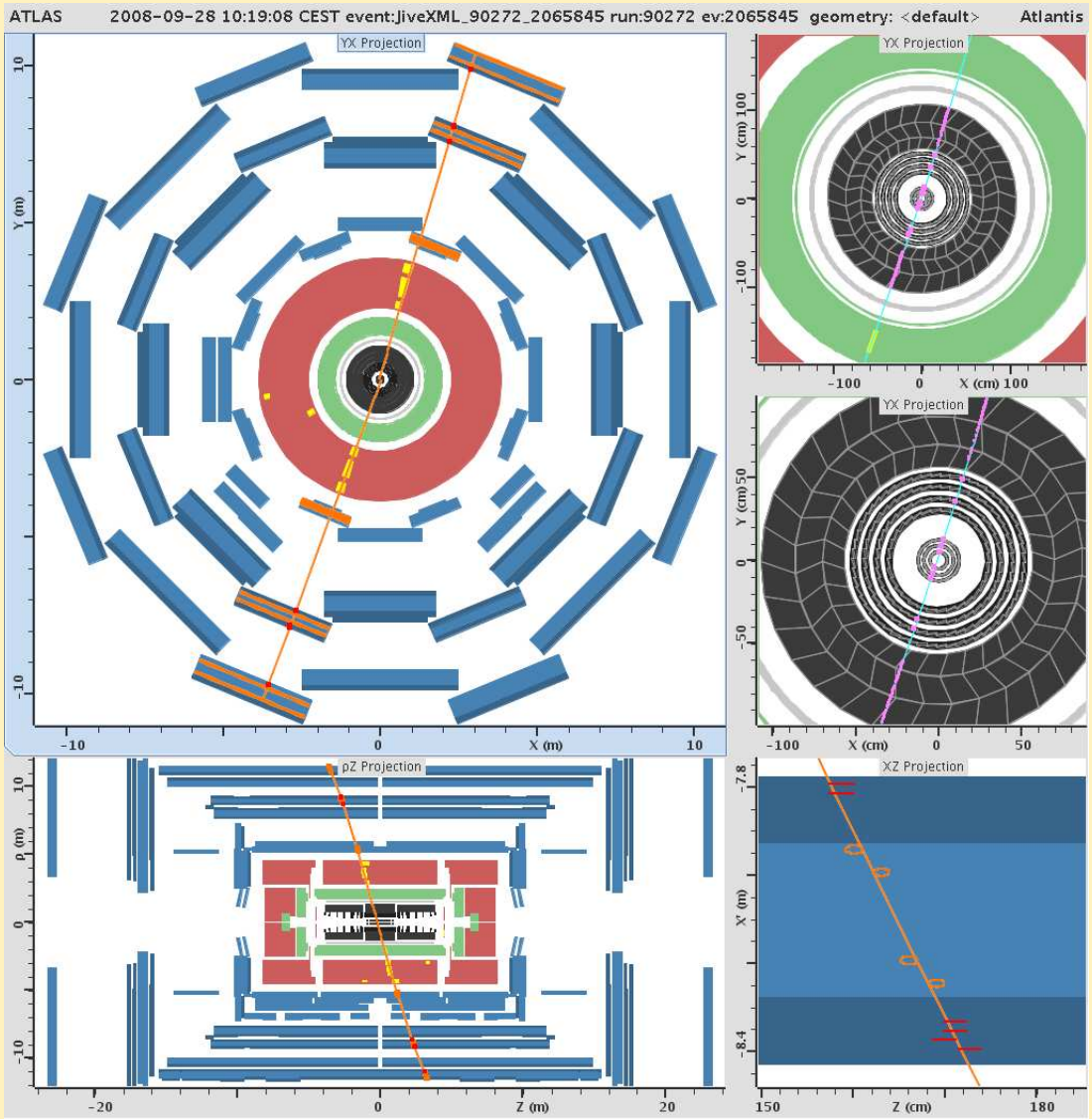


Electron ionisation candidate event display.



E/p for ionisation candidates ($\geq$2 ID tracks). Cut on high- to low-threshold TRT hits. 36 events in signal region.

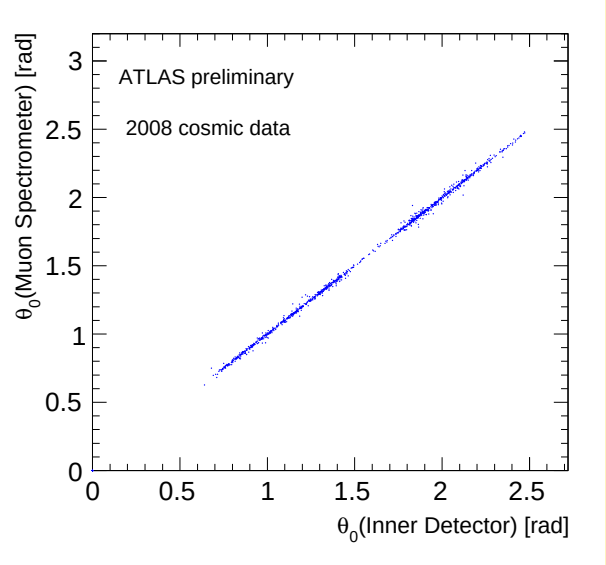
Muon-ID combined cosmic track

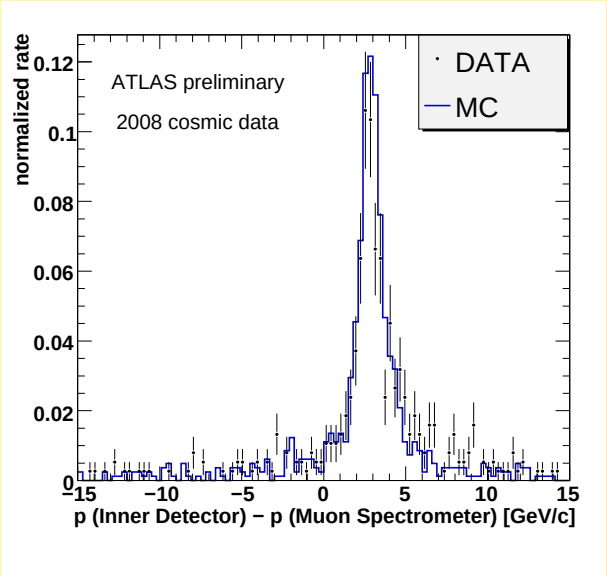


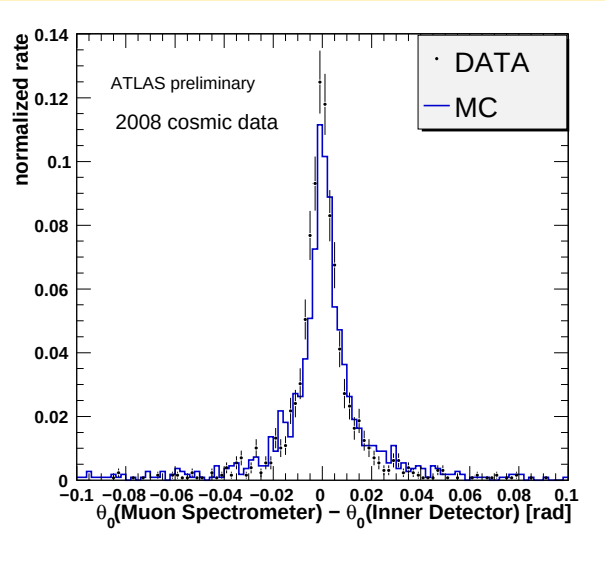
Cosmic ray track recorded in the Muon Spectrometer and the ID with magnetic field on.
Quite an achievement!

Muon-ID alignment

- Good correlation between ID and Muons
- ∼3 GeV difference: expected energy loss in calorimeters
- Good agreement with MC







Single beam events

What happened last September?

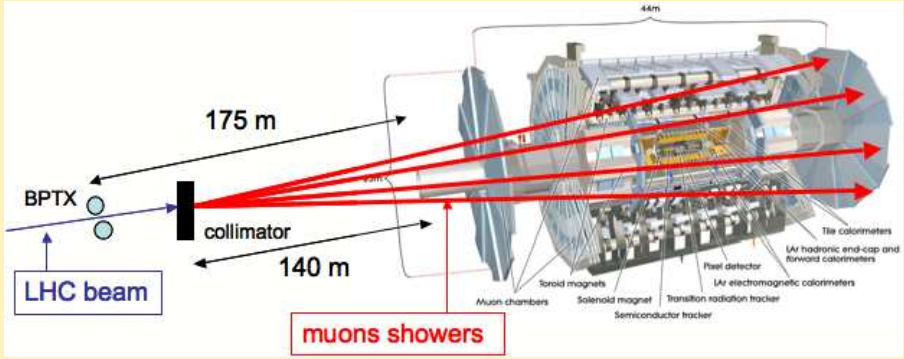
September 10th, 2008: Big day for LHC and LHC experiments people. A lot of journalistic excitement and a huge success: circulating beams in both directions.

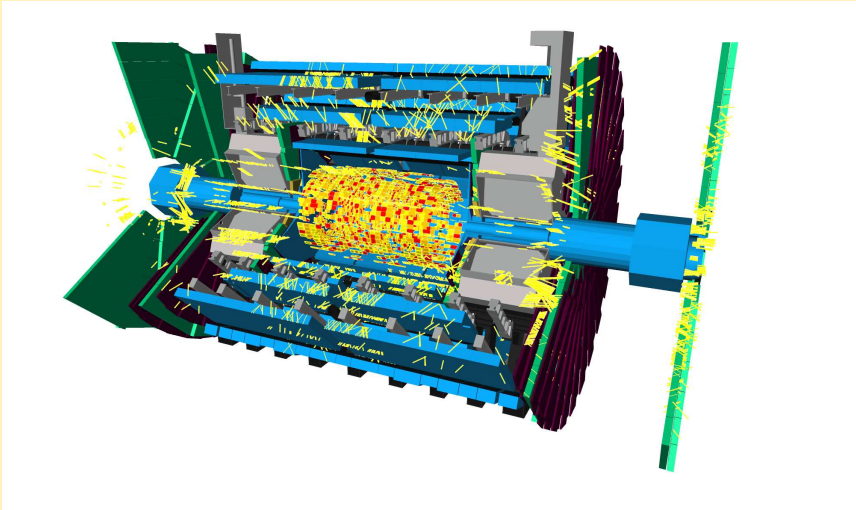
On the same day, *special* events were recorded by ATLAS called beam splash events. To produce them, a collimator was moved in the beam line in front of ATLAS and the beam was sent straight on it. The result: a large amount of muons crossing ATLAS at the same time.

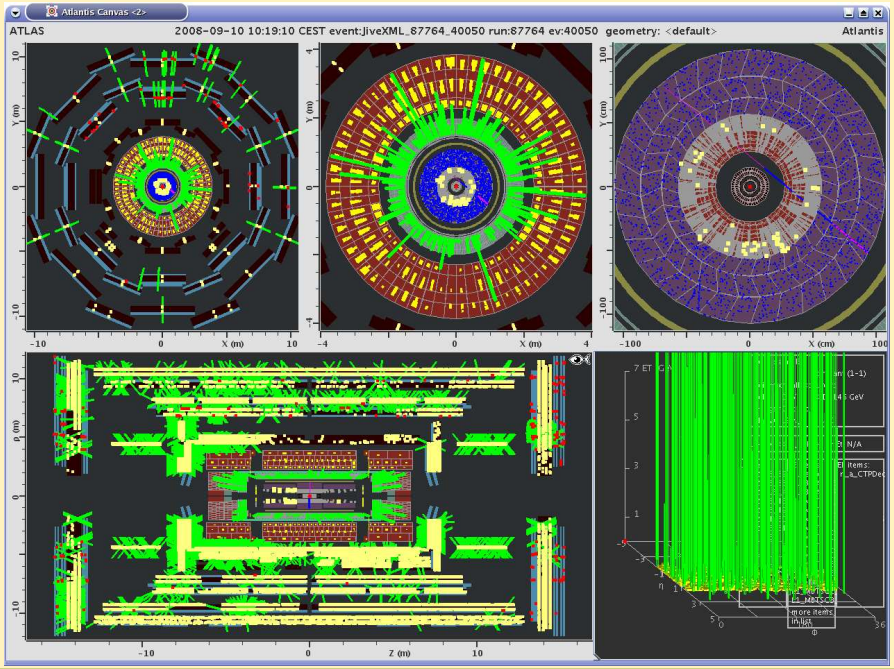
A few days later, a transformator malfunction forced LHC operators to try training the magnets to 5 TeV.

The rest is history: September 19th, an accident stopped us from collecting any more beam events...

ATLAS beam splash events







Top: Collimator setup and beam splash on ATLAS. Right: First beam event recorded in ATLAS, at the bottom with the Atlantis Event Display (courtesy of http://atlas.ch)

Single beam events

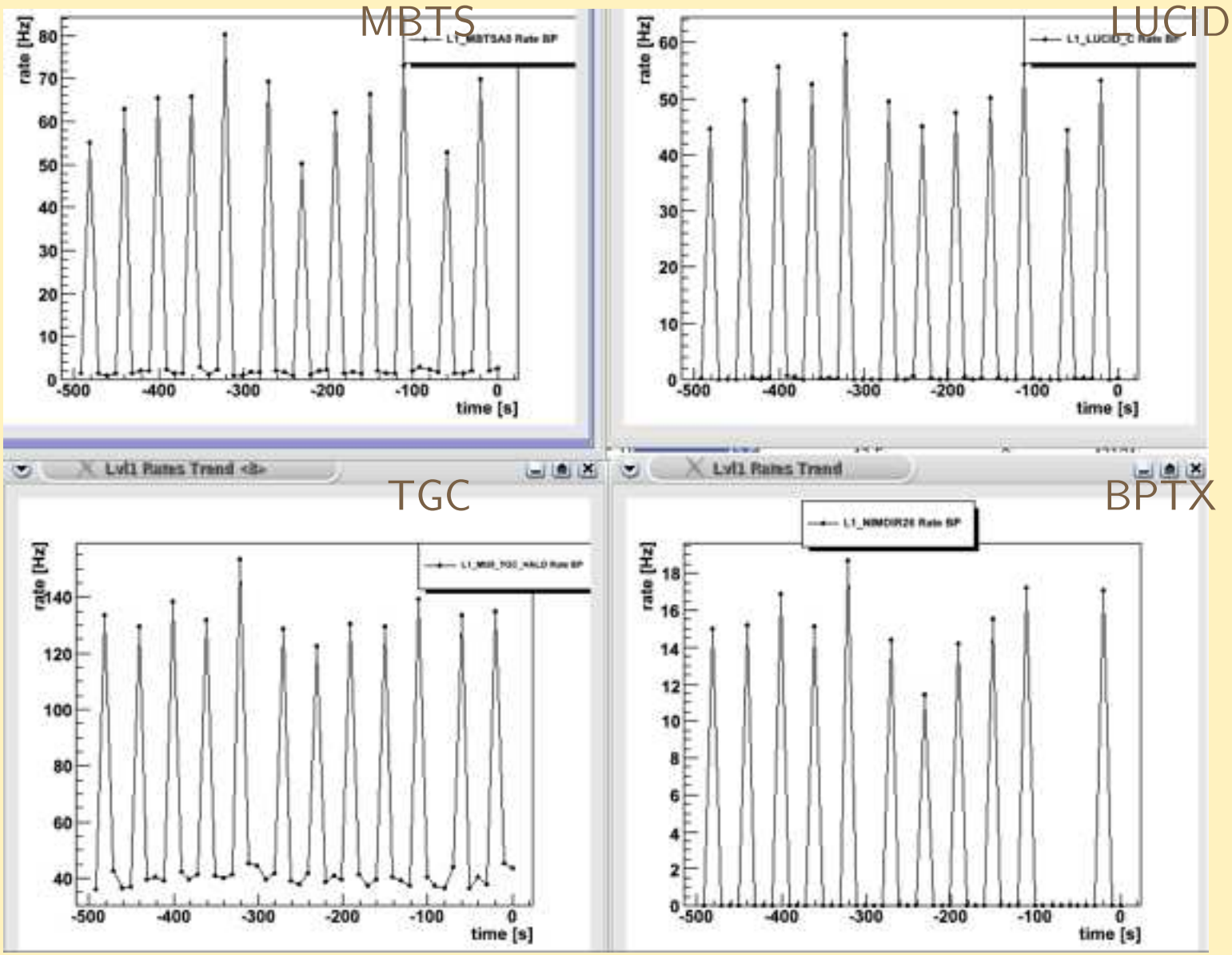
- Beam splashes obtained with both beams (i.e. in both directions)
- High energy deposits in the calorimeter (up to ∼1000 TeV).
- Later on, beams were circulating for ∼100 turns and events were collected too (less deposited energy).
- Collimator "shots" every 42 s
- About 2x10^9 protons/bunch
- Loads of muons (actually, millions) thrown at ATLAS to light up the detectors!

Detector readiness on D Day

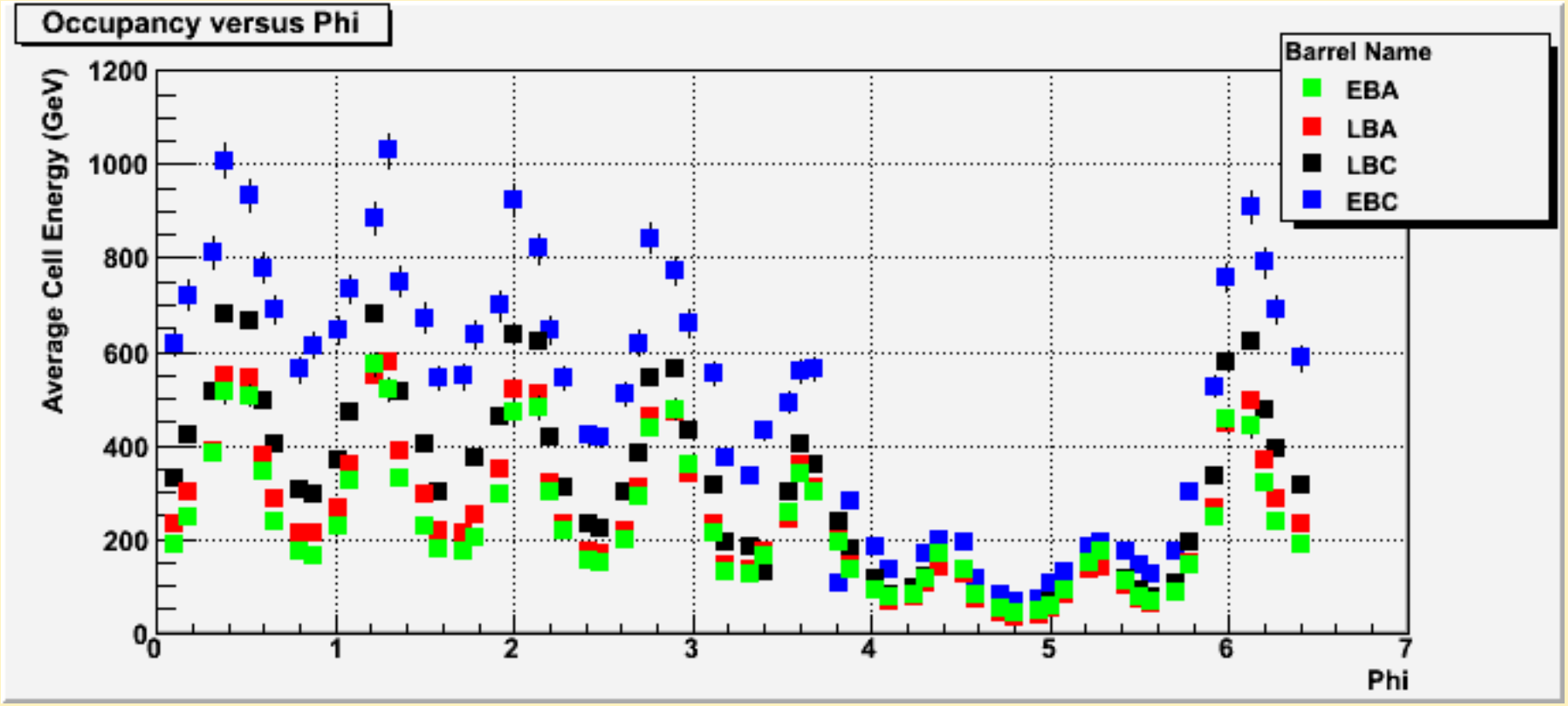
ATLAS was ready to receive beam on September 10th

- For safety reasons, some detectors (more prone to radiation damage) were turned OFF, or used with reduced voltage on that day:
  - ID: Pixel OFF, SCT Barrel OFF, SCT End-Caps at reduced HV, TRT running without Xe
  - LAr calorimeter: Reduced HV in FCal
  - Tile Calorimeter: All ON
  - Muons: Some regions at reduced HV, at high η
- High Level Trigger (HLT) was not run in real time, but L1 was used for streaming data

Beam pick-up: LUCID

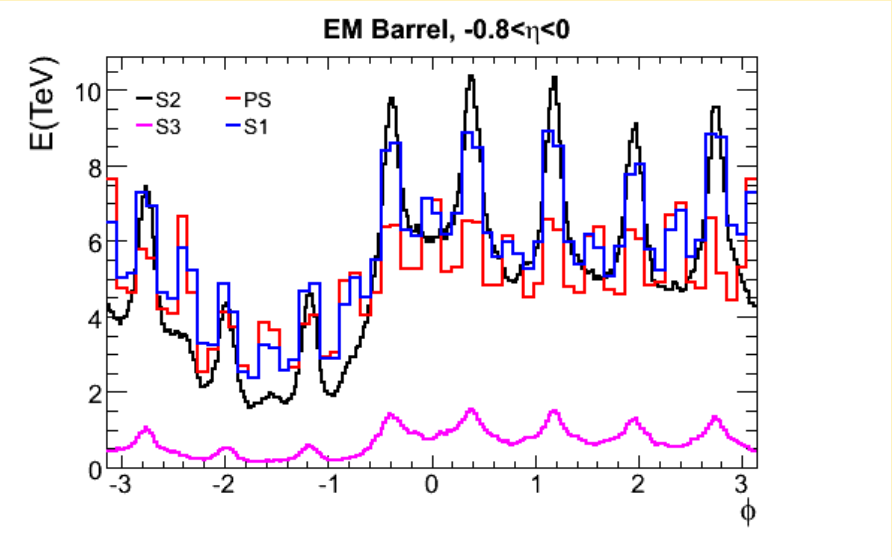


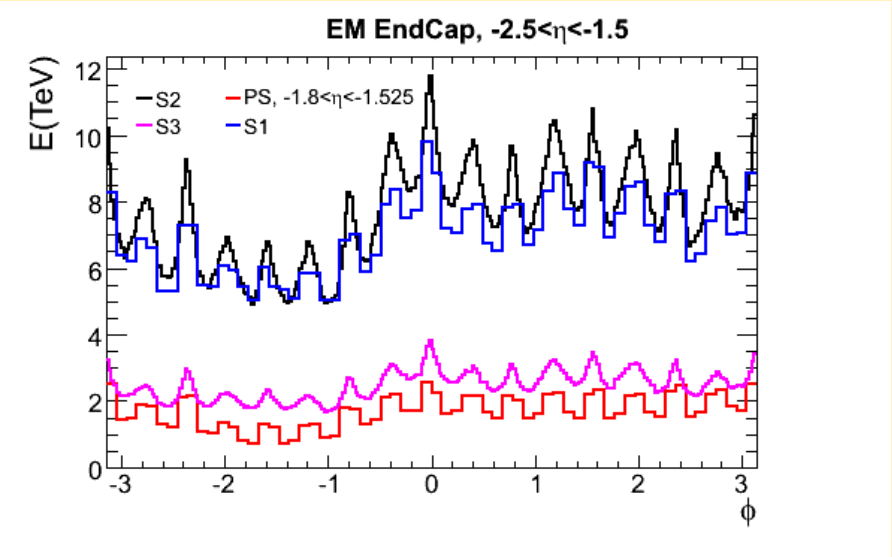
Energy Deposit in Tile Calorimeter



- Eight-fold structure of the End-Cap Toroid clearly visible on the plot
- Dip indicates the bottom of the detector (support pilars of ATLAS)
- Muons reflect the material distribution in the detector

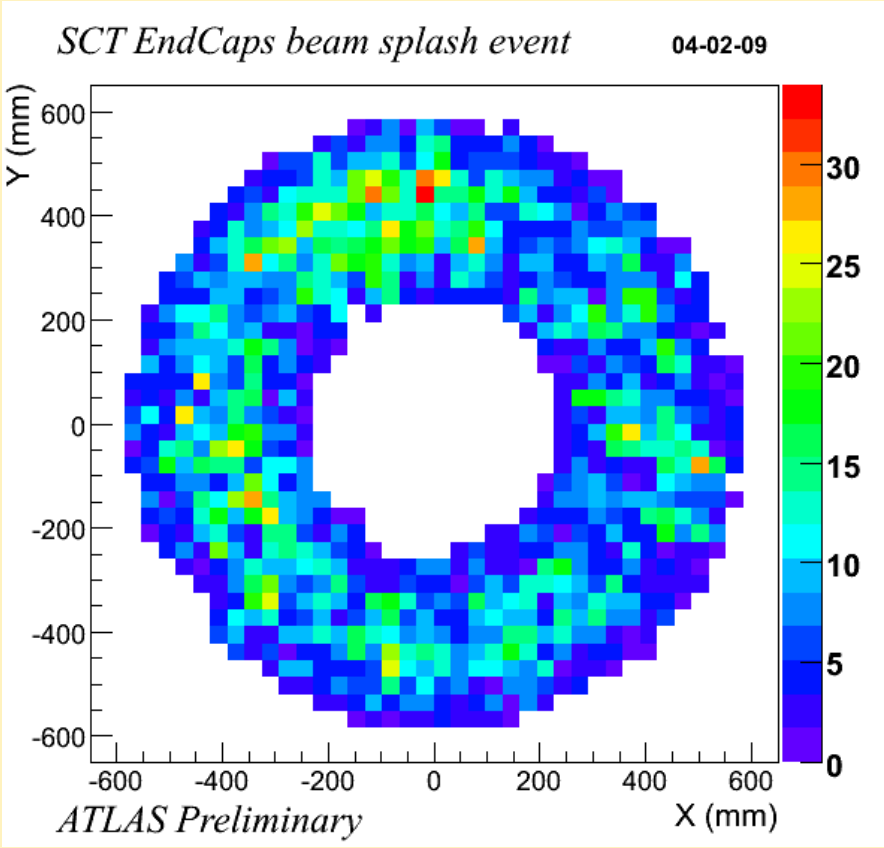
Energy Deposit in LAr Calorimeter



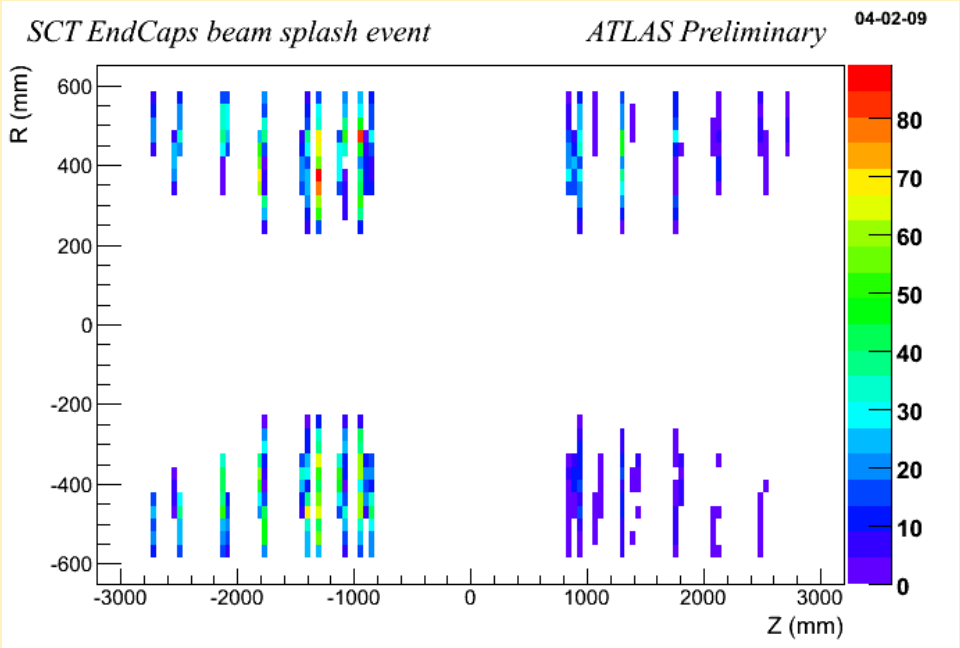


- Same structure as for Tile Calorimeter observed (only different phi scale offset)
- 16-fold structure in End-Cap distribution due to extra material at higher η (mainly shielding components)

Module occupancy in the SCT

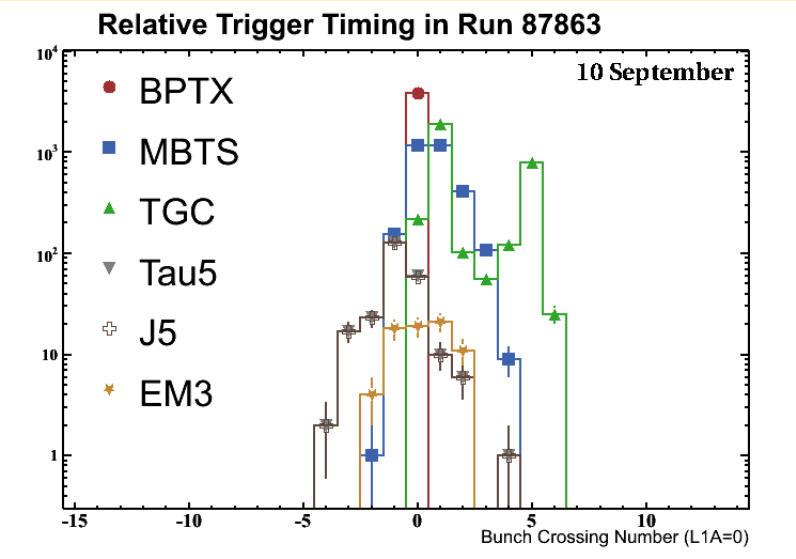


All 18 disks projected in X-Y view. The color scale shows the occupancy of the modules. Average noise has been subtracted.



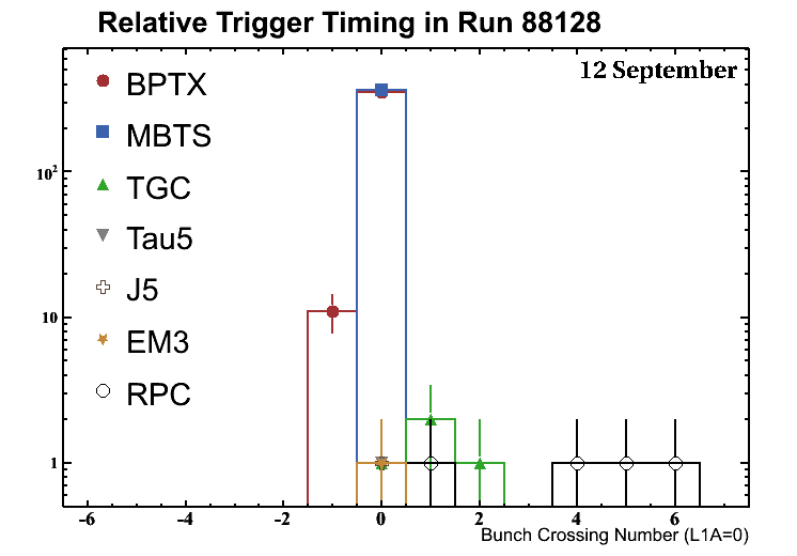
The same event on R-Z view. Each disk is clearly seen and the individual modules are staggered. In this event, the beam was coming from the negative Z direction.

Trigger Timing using Single Beams



- MBTS fired first, was timed in wrt to BPTX (good overlap shown here)
- With collimators in the beamline, but with relatively good beam quality. Less additional triggers can be seen here. (RPC was not completely timed in before this run)

- BPTX trigger used as stable time reference
- Collimators were open, but due to bad beam quality, triggers coming from muon and calorimeter



Concluding and looking ahead

- A giant multi-purpose particle detector, ATLAS, was built underground Geneva over the last 10 years
- Tremendous effort for all the men and women of all work speciality to achieve this

- During this time, physicists were crunching numbers from simulation to determine how well we expected ATLAS to work (with respect to its specifications)
- A lot of improvements put in place during and following September 2008
- The expectations were confirmed quite well by the "real data" periods so far: cosmics and single beams from September 2008
- ATLAS is now ready to receive more beam data

Looking forward for LHC data in 2009-2010!!