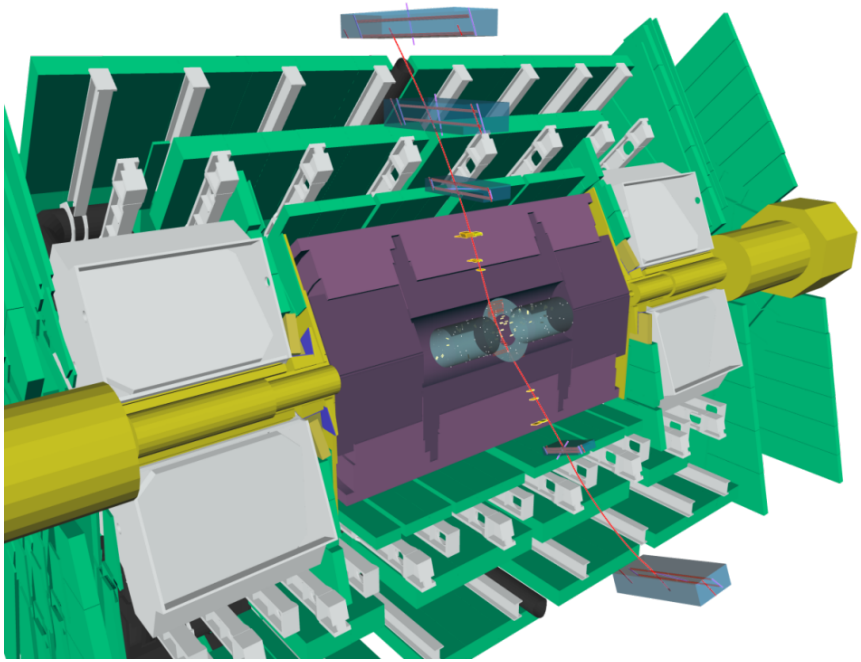
Muon combined reconstruction in the ATLAS detector with first data



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Ciudad Real, September 2009

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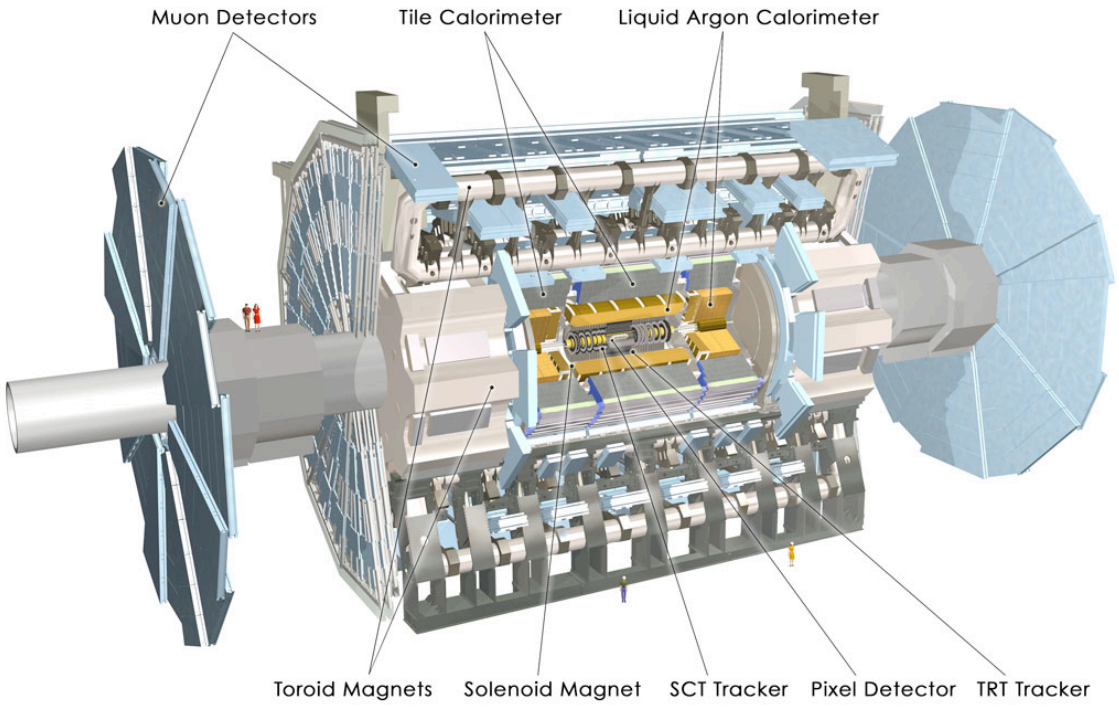
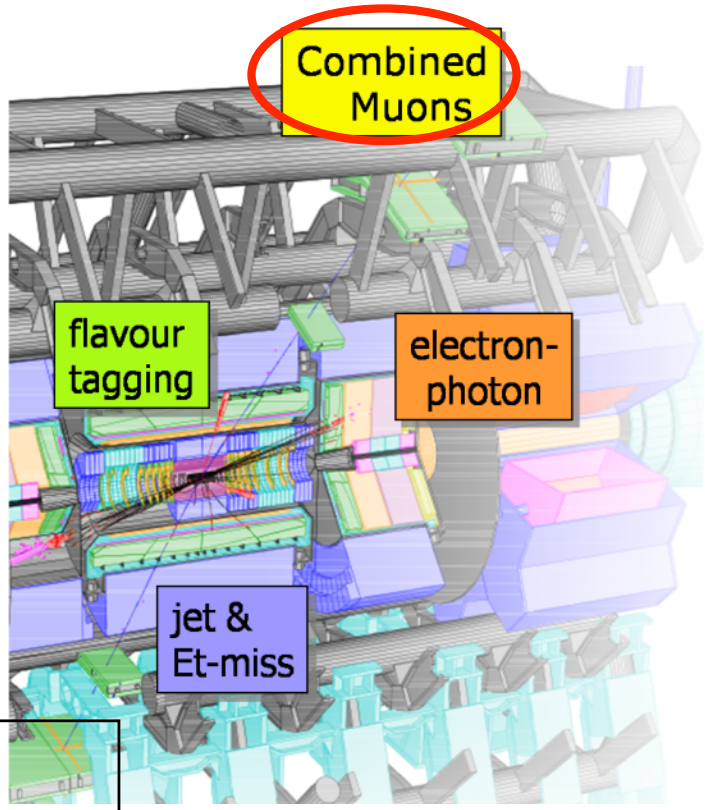
Introduction:
A Toroidal LHC ApparatuS (ATLAS)





Inner Detector (ID), B=2T :
- Silicon pixels and strips (SCT)
- Transition radiation tracker TRT (separates e/π)

Calorimeters:
- EM: Pb-LAr accordion shape
- HAD: Fe/scintillator (central), Cu/W-LAr (forward)

Muon Spectrometer (MS), B=0.5T/air-core :
- 4 technologies: MDTs and CSCs (precision), RPCs and TGCs (trigger)
- air-core toroid system

Length ~ 46 m
Diameter ~ 25 m
Weight ~ 7000 tons

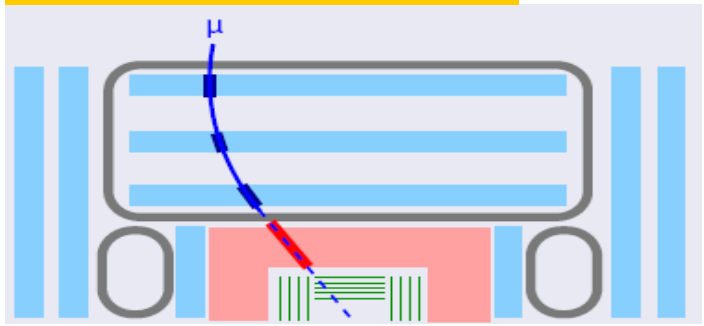
Muon reconstruction in ATLAS

LHC physics requires an excellent identification and measurement of muons in a large energy range:

~GeV (B physics) and ~TeV (new physics)

→It is essential to combine information of the sub-detectors in ATLAS

Standalone tracking

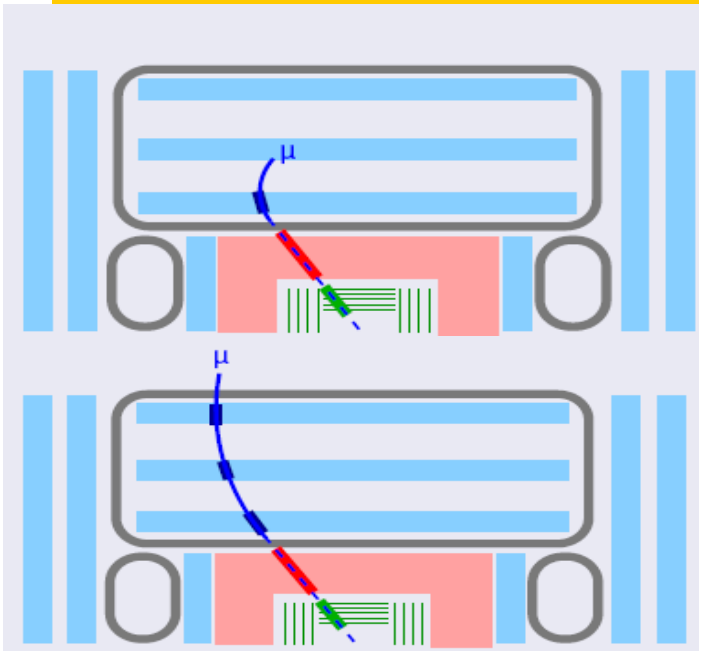


Muon spectrometer

Calorimeters

Inner detector

Combined tracking: ID+MS



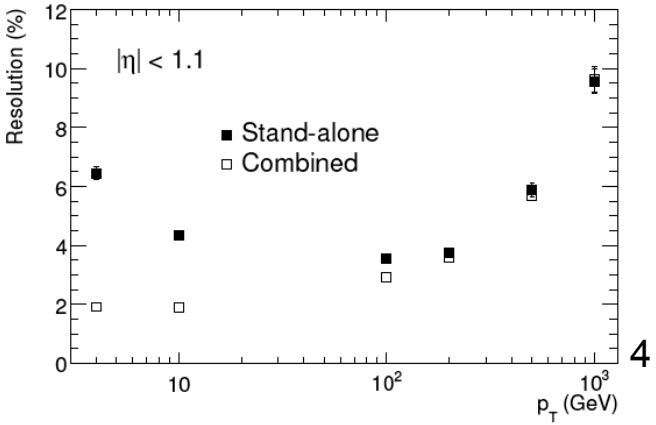
Not enough:

- There are dead regions

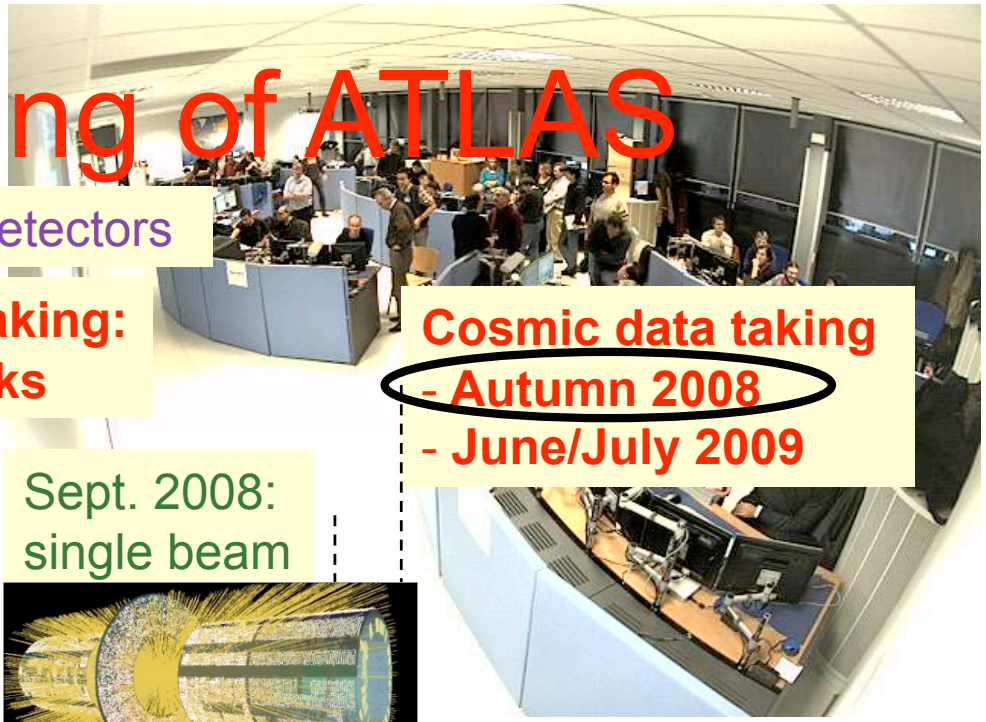
→ ID and calorimeters info needed

- low p_t muons:
  - signal only in first chambers
  - worst p_t resolution

→ combined (MS+ID) reconstruction needed

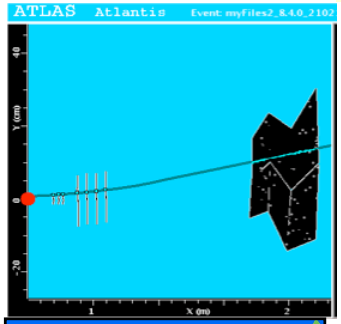


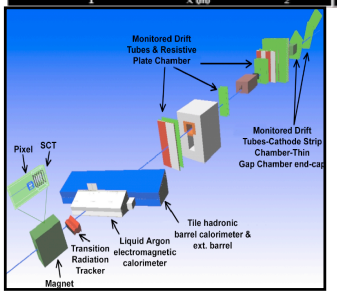
Commissioning of ATLAS



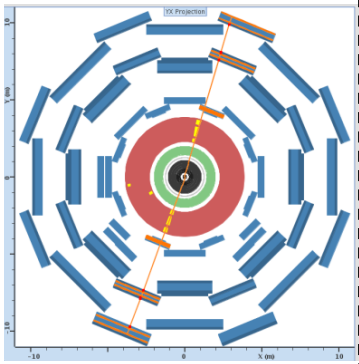
Test beams

Instalation of the sub-detectors





Cosmic data taking: Milestone weeks



Sept. 2008: single beam

Cosmic data taking
- Autumn 2008
- June/July 2009

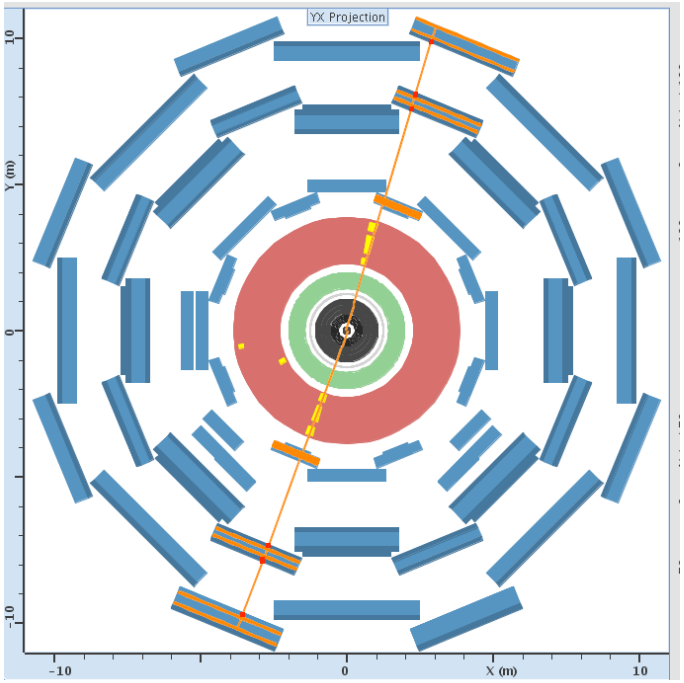
Fall 2009: Single beam

2010: Proton collisions

2005 2006 2007 2008 2009

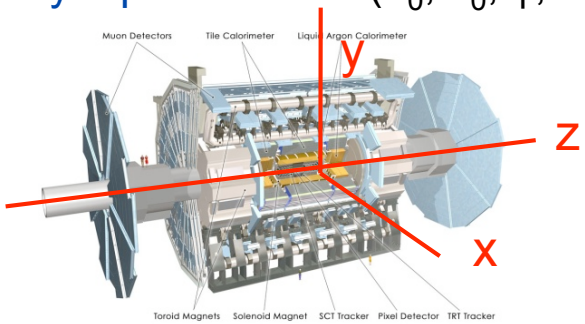
In autumn 2008, several weeks of combined cosmic ray data taking involving the whole ATLAS detector took place. Several million tracks with and without B field were reconstructed.
This work will study the performance of the Global χ^2 combined (ID +MS) tracking with cosmic data.

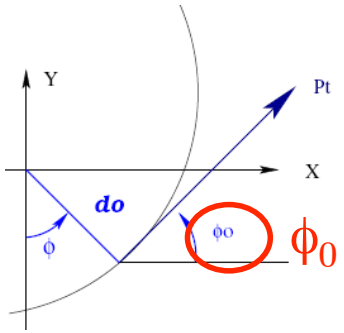
Correlations between Inner Detector & Muon Spectrometer tracks

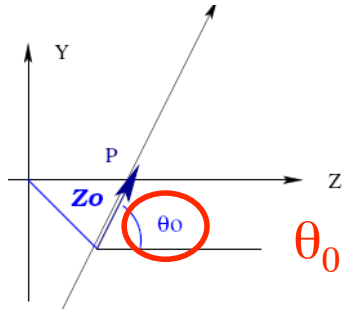


Correlation ID and MS tracks

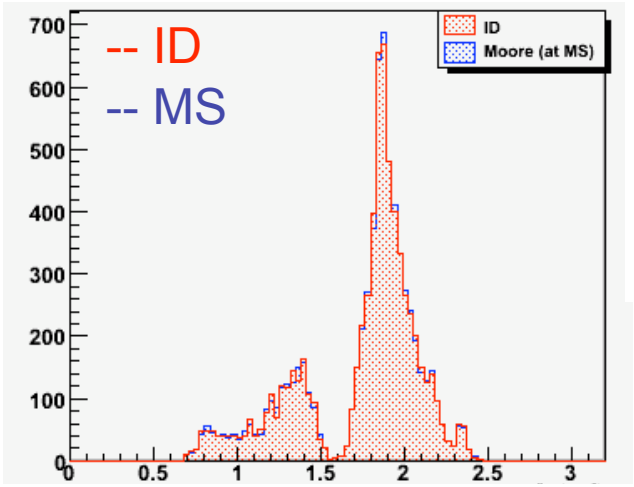
Tracks are characterized
by 5 parameters: (d_0, z_0, ϕ, θ, q/p)

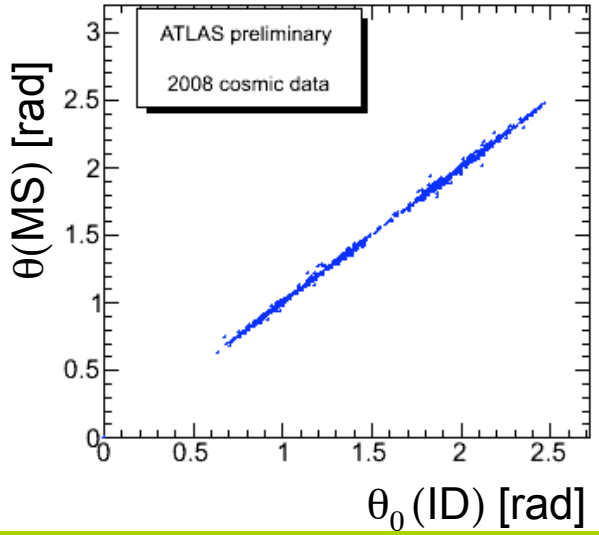


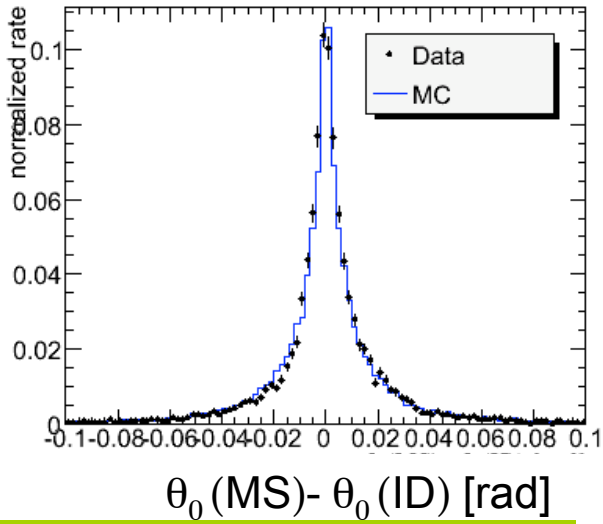




θ_0





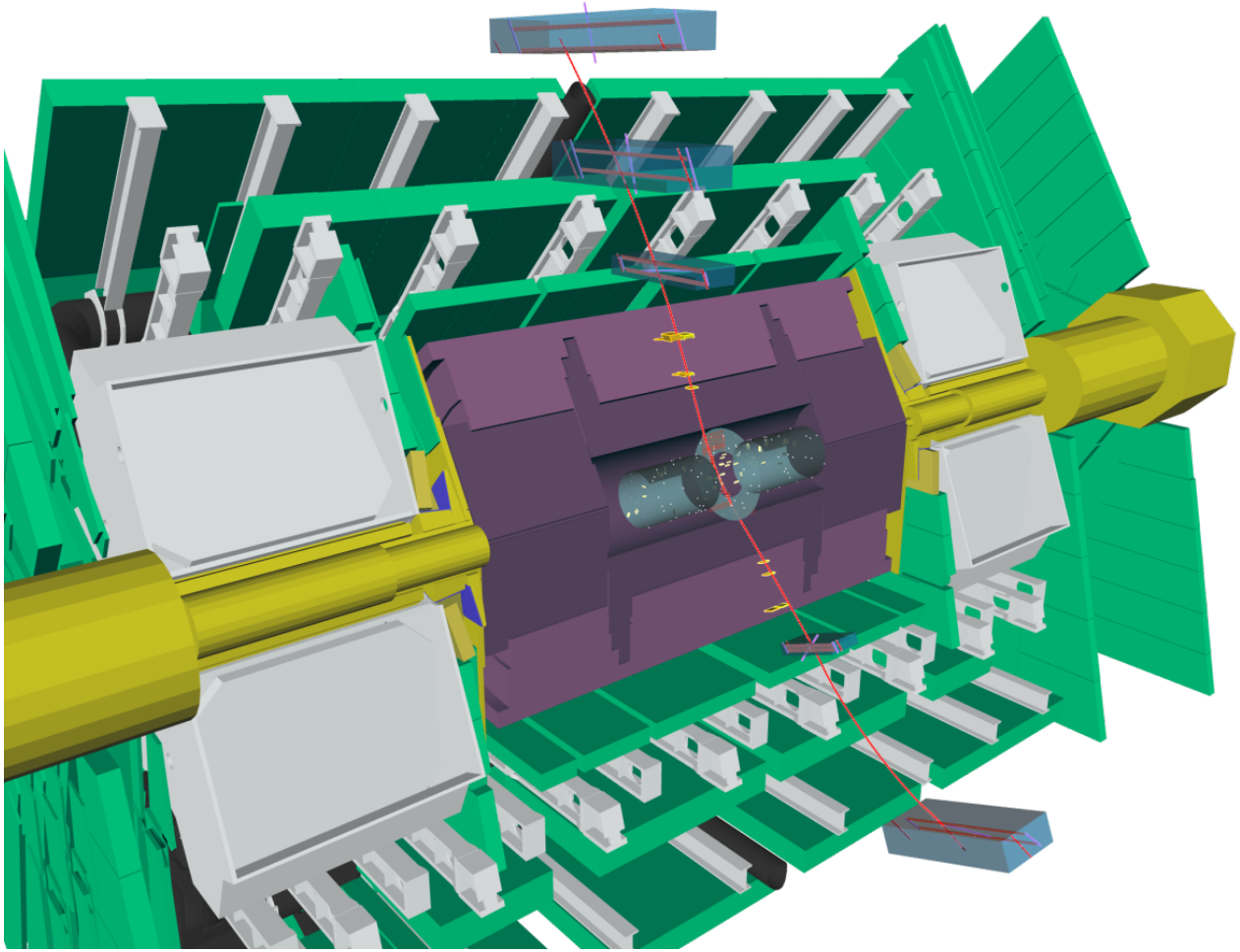


- ID and Muon tracks show the same acceptance since events with ID tracks are selected.
- Good correlation between the parameters measured in both sub-detectors

ID and MS are synchronized and aligned → combined tracking can be attempted.

- The data/MC agreement is fairly good.

Performance of the COMBINED TRACKING (Inner Detector + Muon Spectrometer)



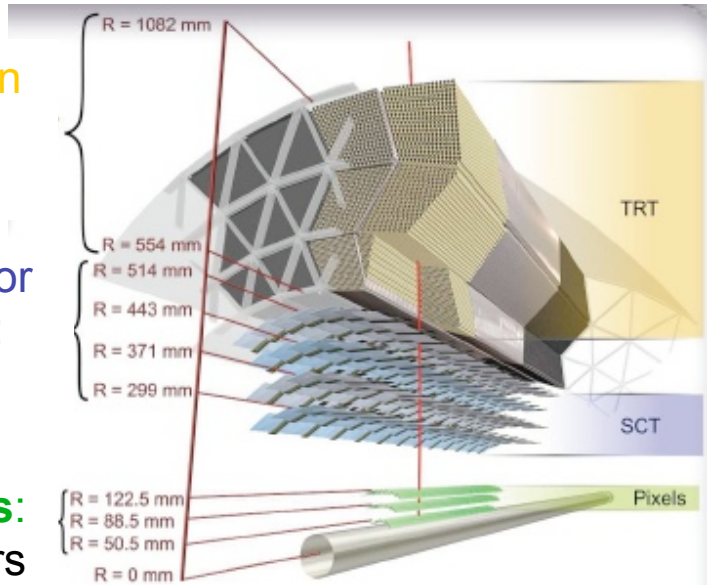
Performance of the combined tracking

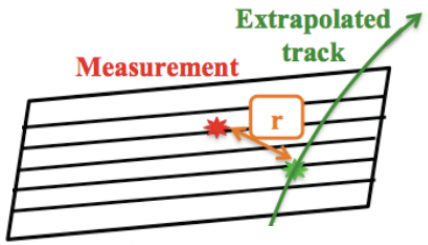
Most of the tracks come through the **barrel** and **cross the whole detector**.
In each half (top or bottom) there are:

Transition Radiation Tracker (**TRT**):
36 straw layers

Semi-Conductor Tracker (**SCT**):
4 barrel layers

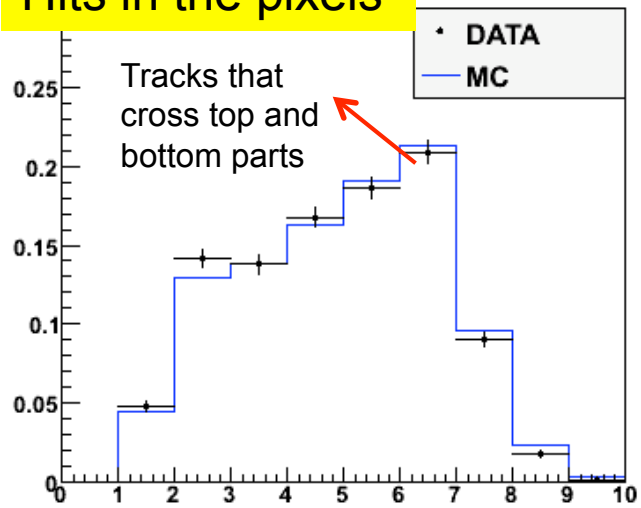
Silicon **pixels**:
3 barrel layers





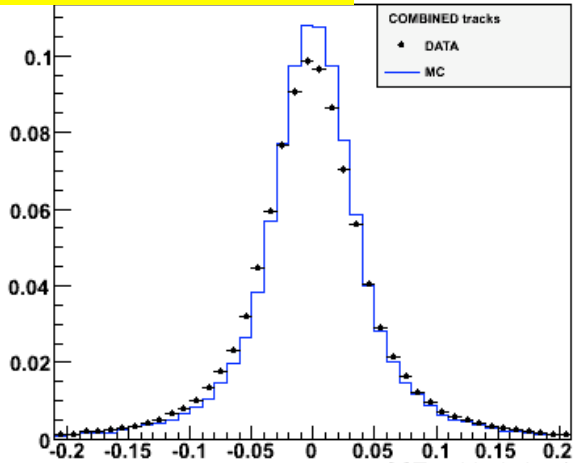
$$\sigma_{\text{residuals}} = \sqrt{\sigma^2_{\text{detector}} + \sigma^2_{\text{track}} + \sigma^2_{\text{alignment/calibration}}}$$

Hits in the pixels



Pixel hits

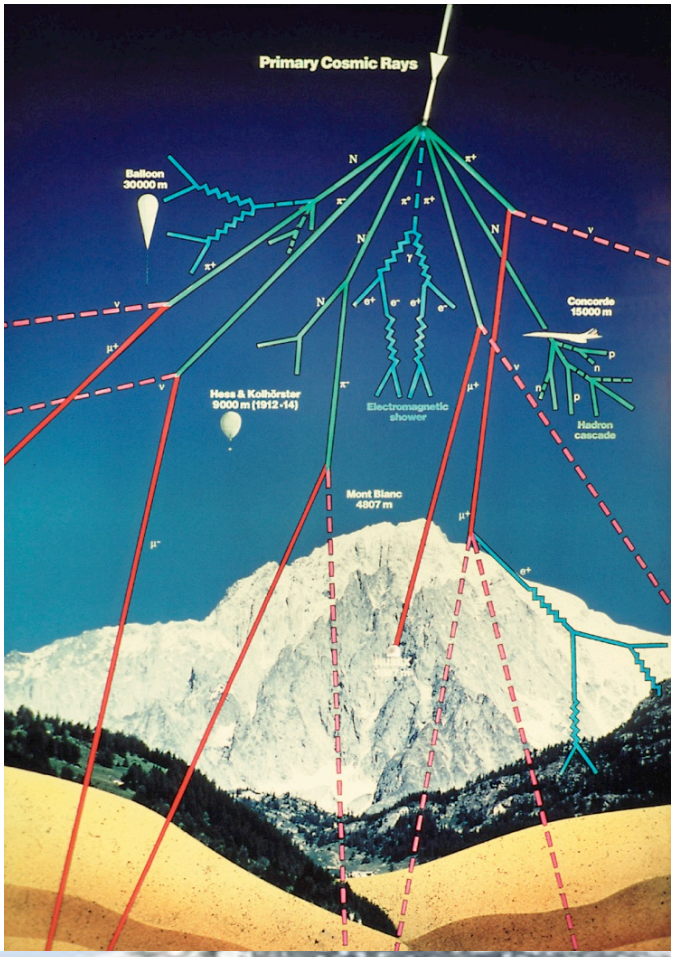
SCT residuals



SCT residuals [mm]

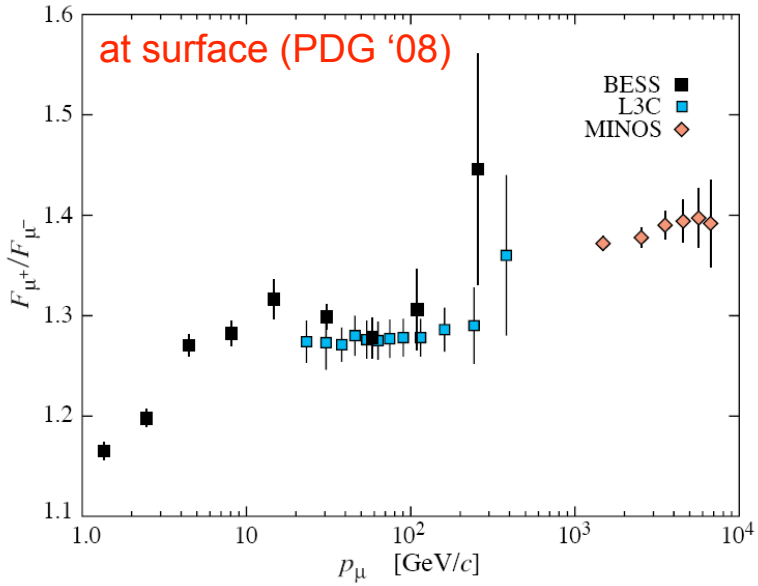
- The data/MC agreement is fairly good for all sub-detectors with the current alignment constants.
- Slightly more associated hits in simulation than in data.

Charge muon ratio measurement



Charge muon ratio measurement

- Cosmic rays are mostly protons
  - Excess of π^+ / K^+ over π^- K^- in shower development
- Expect to see some excess of positive muons.
- Useful and fun exercise.



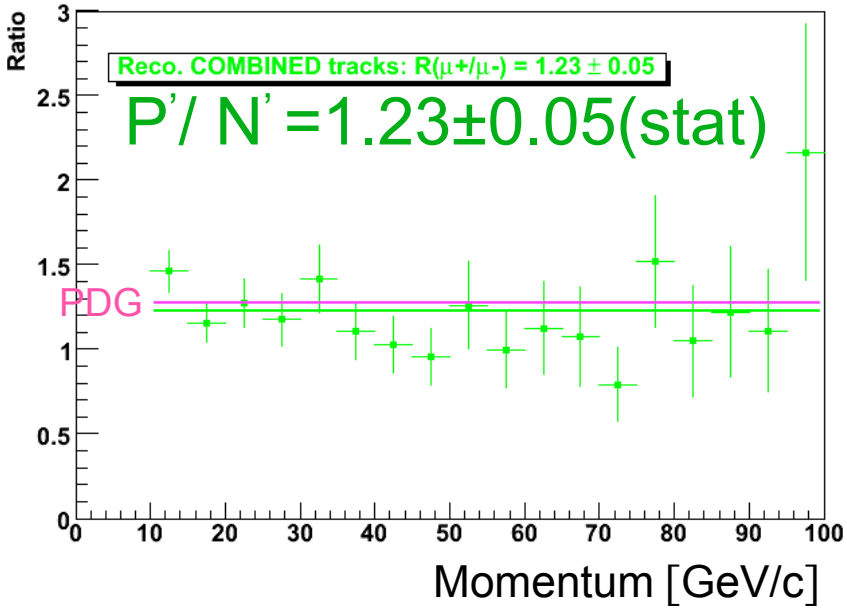
Measurement strategy:

tracks *measured* as positive

 # tracks measured as negative

- Raw Ratio, Center of ATLAS
  - P'/N' (versus p')
- Corrected Ratio, Center of Detector
  - P/N (versus p') = $\varepsilon^-/\varepsilon^+ \cdot f(P', N', c)$
- "Unsmeared" Ratio, Center of Detector
  - p' → p
- Ratio at sea level

wrong charge probability



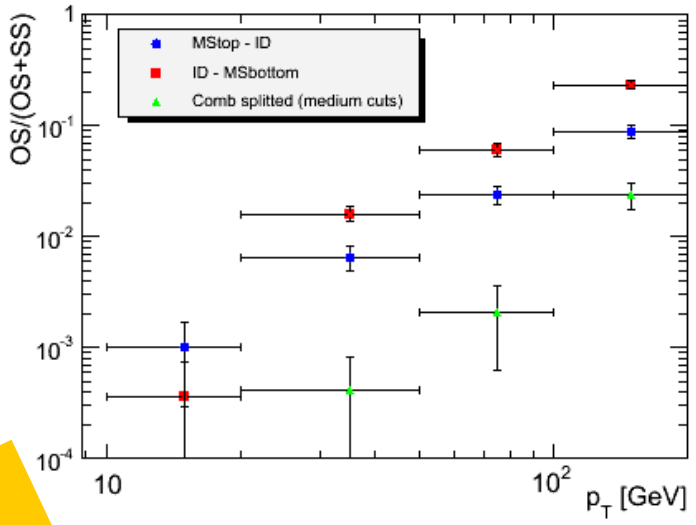
Understanding the systematics

- A physics quality measurement of the charge muon ratio requires to understand:

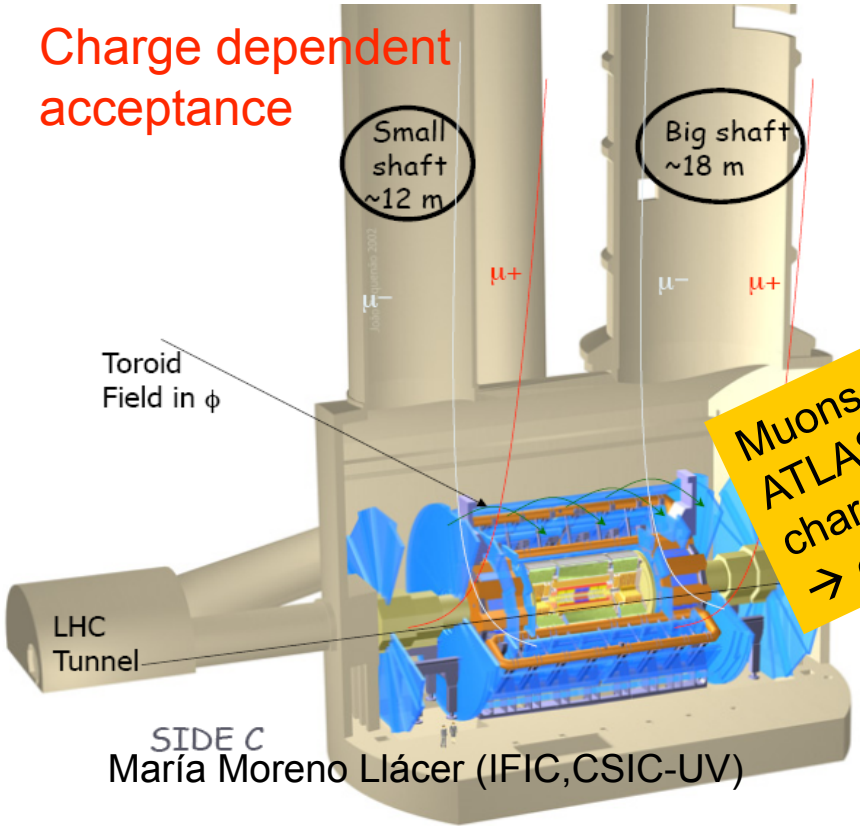
  - trigger acceptance, efficiency & timing
  - ID & MS tracking efficiency
  - charge confusion
  - track parameters resolution
  - extrapolate to surface (to compare with PDG)

Charge confusion

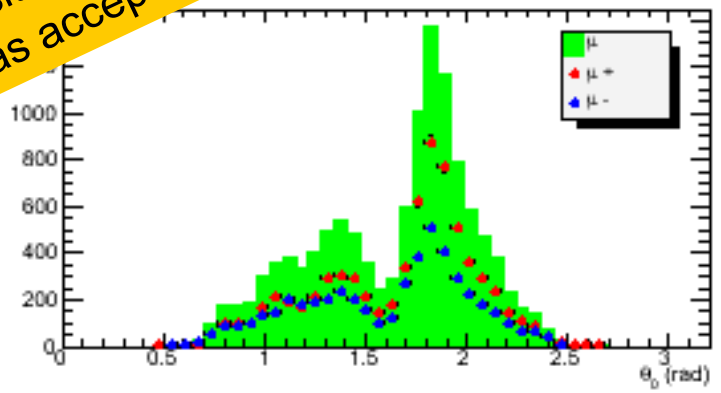
OS: opposite sign
SS: same sign



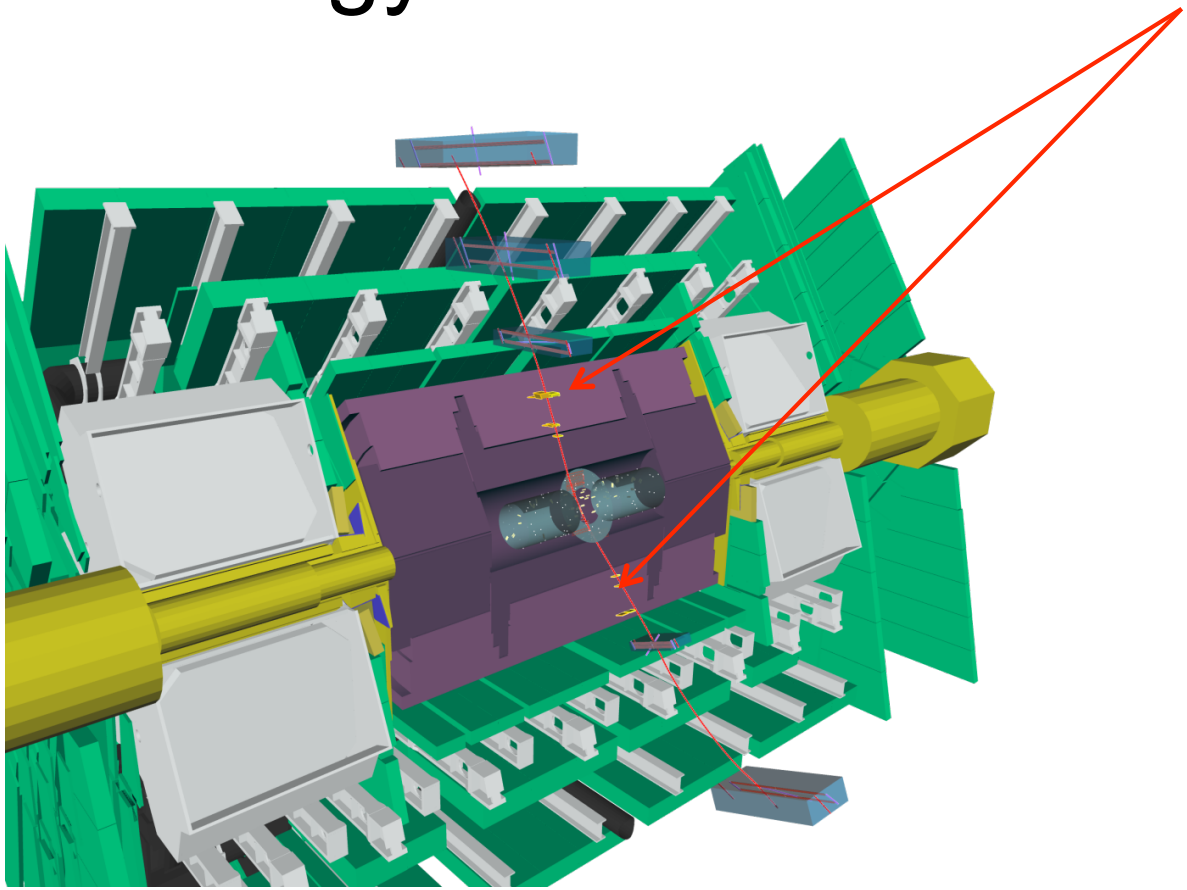
Charge dependent acceptance



Muons are bend out of ATLAS depending on its charge and position → charged bias acceptance.



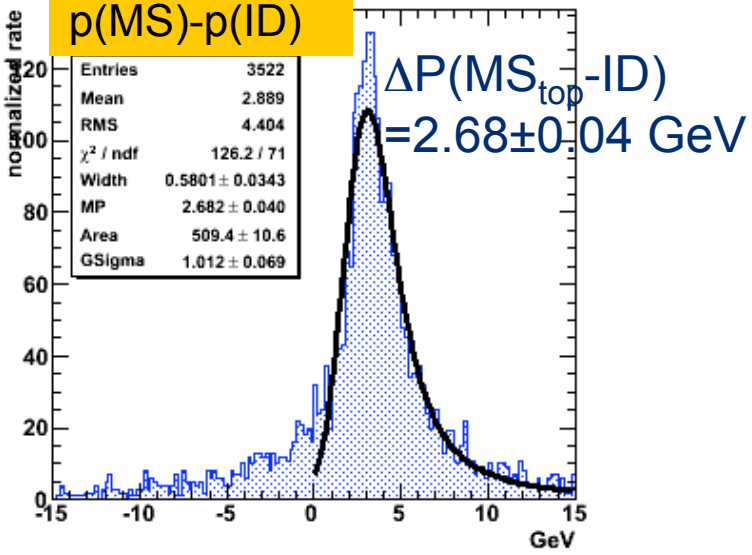
Energy lost in the calorimeters



Momentum difference ID-MS & energy loss

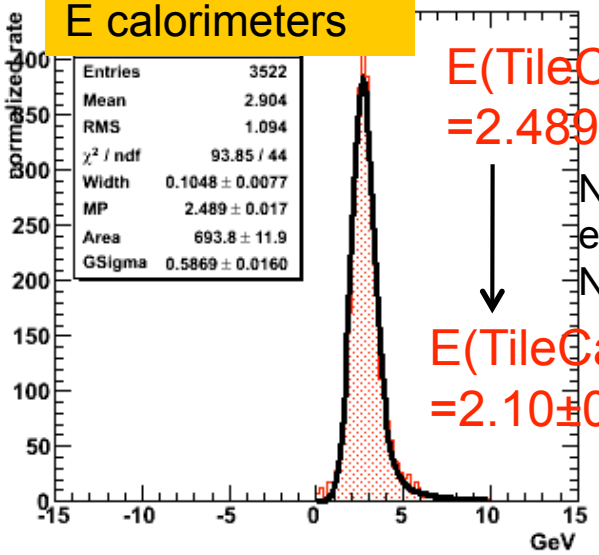
- When a muon traverses the detector material, it undergoes successive deflections and a loss of energy.
- Cosmic muons lose energy in the calorimeters primarly through ionization.
- This energy deposited in the calorimeters is the difference in the cosmic muon momentum before (at the end of the muon system) and after (at the entrance of the inner detector) crossing them.

p(MS)-p(ID)



$\Delta P(MS_{top}\text{-ID})$ =2.68±0.04 GeV

E calorimeters



E(TileCal) + E(LAr) =2.489±0.017 GeV

New calibration: ↓18%
e/μ ratio: 0.9
New reco algorithms: ↑ 11%

E(TileCal) + E(LAr) =2.10±0.02 GeV

- The energy deposited in the calorimeters is smaller than the ID-MS momentum difference.
- Expected difference due to dead material: ~20%
- Present measured discrepancy: ~200 MeV (~7%)
- Next data-reprocessing: expect a discrepancy of ~21%

Conclusions

- The identification and measurement of muons is fundamental for the physics studies in ATLAS.

- The muon reconstruction algorithms have been verified for cosmic rays data using information of all ATLAS sub-detectors (ID, calorimeters and MS) and the performance of the combined tracking has been studied.
The reconstruction has been done using the GRID facilities.

- Muon energy loss studies and a measurement of the μ^+/μ^- assymetry are in progress.

- Data/MC comparisons have been performed and show relatively good agreement with the current alignment and calibration constants.

Thank you very much! ☺

BACK-UP

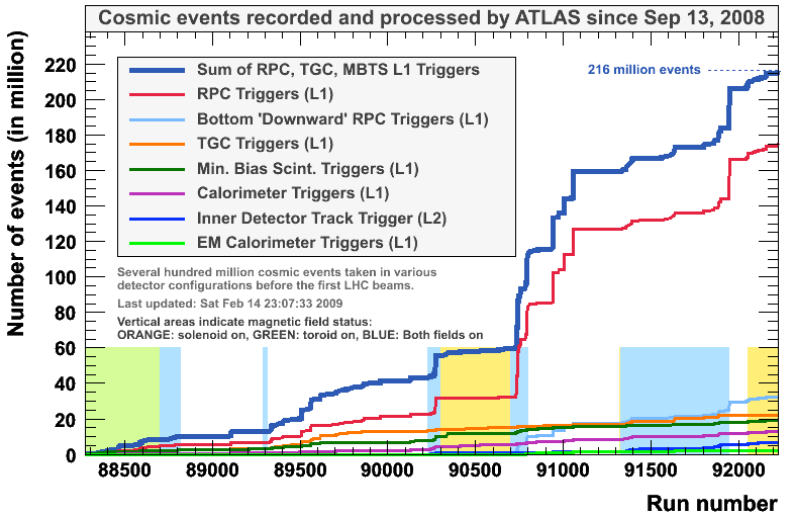
Samples of cosmic data analyzed and event selection

Four "golden" runs with similar detector and readout conditions from late October 2008 have been used in the analysis. Most of the sub-detectors were operated at full coverage and the magnetic field was on.

This work will focus on the performance of the combined tracking:

- Track reconstruction in the ID
- Track reconstruction in the MS

→ **Global χ^2 combined tracking**



→ **Event selection & track quality cuts:**

Select events with:

- 1 track in the ID, >= 1 in the MS & and 1 combined
- Triggered by the muon system
- Select projective muons (impact parameters <30cm)
- Track quality cuts (#hits) applied