Commissioning of the ATLAS detector with cosmic rays and first LHC beams

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On behalf of the ATLAS Collaboration

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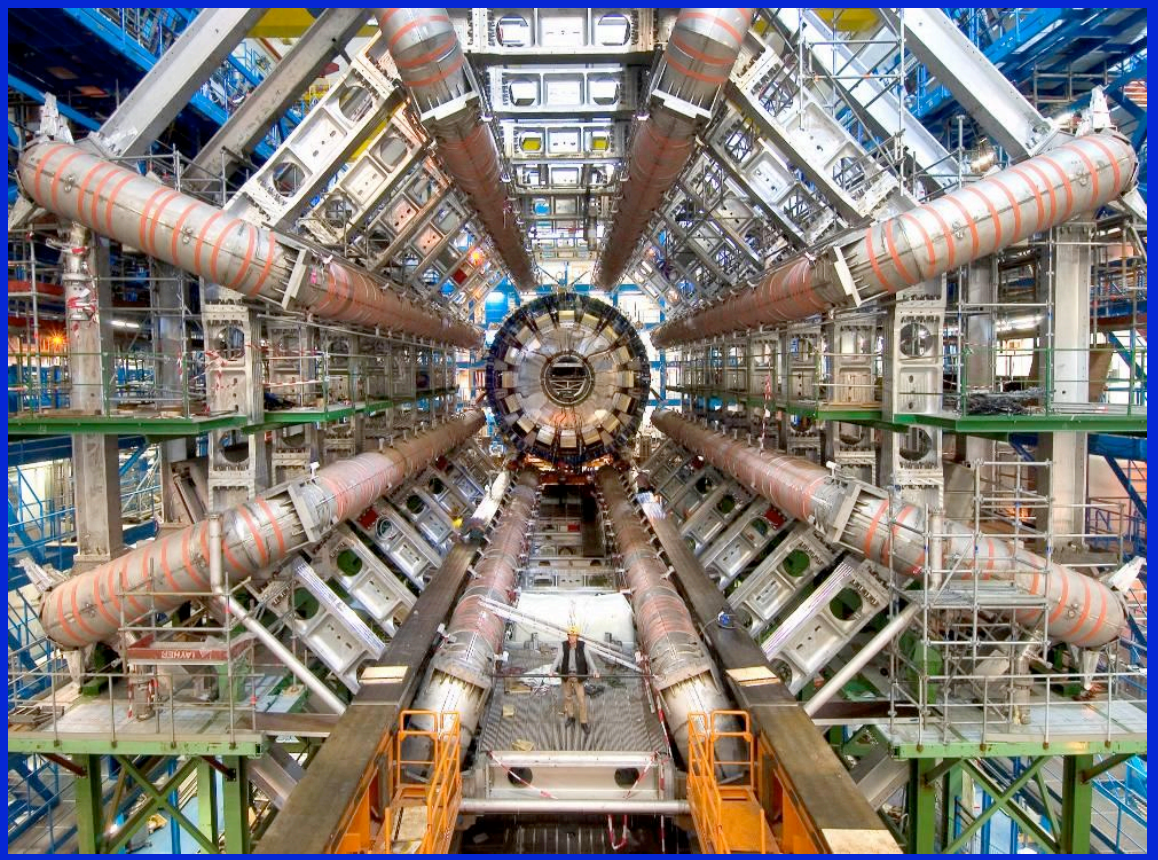
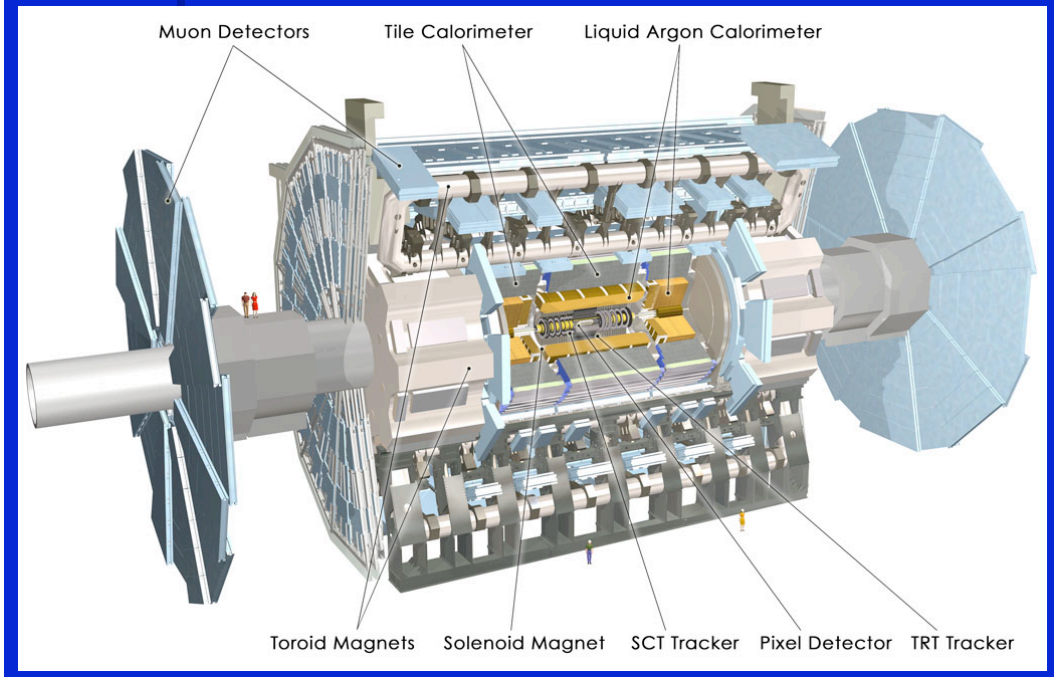


The ATLAS detector and its commissioning



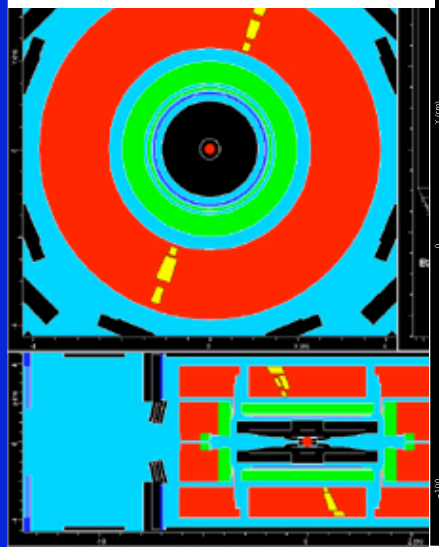
- Commissioning with cosmic rays started > 3 years ago in parallel to detector installation. Main Motivation:
  - Gain experience on the detector operation (from TDAQ up to analysis in the grid Tier2 centers)
  - Understand detector performance towards achieving the physics requirements.
  - Obtain first alignment and calibration constants and list of bad channels.

Inner Detector ($|\eta|<2.5$, B=2T):
- Pixels and micro-strips (SCT)
- Transition radiation Tracker TRT (e/π separation)

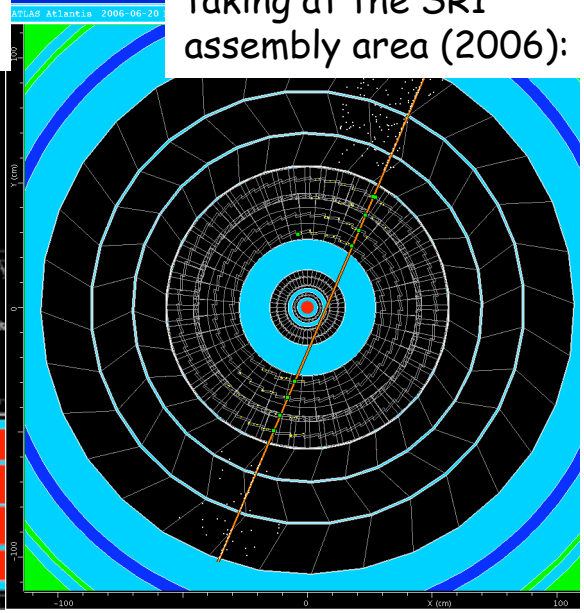
Calorimeters($|\eta|<4.9$):
- EM: Pb-LAr
- HAD: Fe/scintillators (central), Cu/W-LAr (foward)

Muon Spectrometer ($|\eta|<2.7$, B=0.5T):
- aire core toroids and muon chambers (MDT, CSC for high precision tracking and RPC, TGC for triggering)

First tracks collected at the Pit by the HAD Calorimeter (2005):



Inner Detector data taking at the SR1 assembly area (2006):



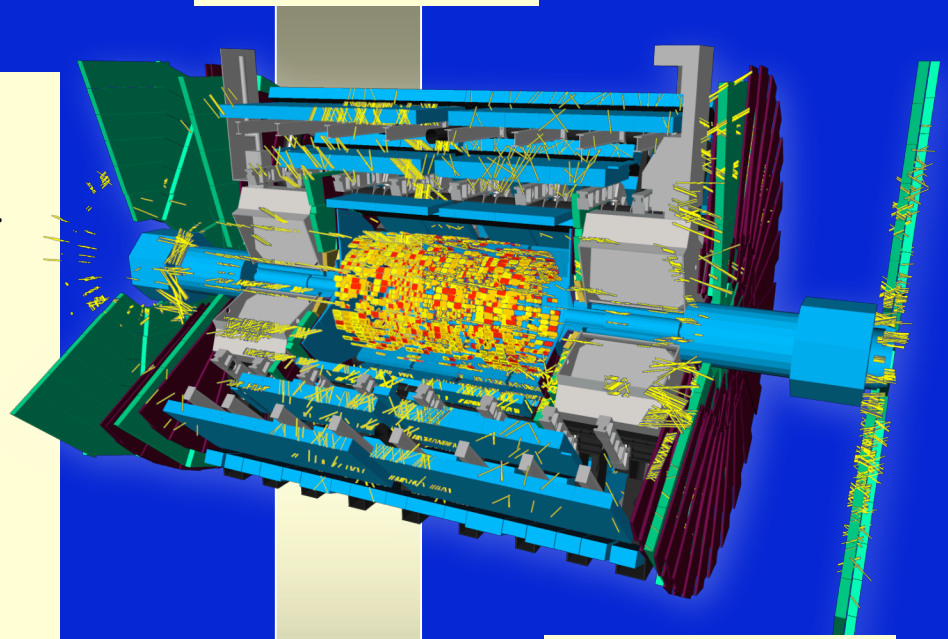
Cosmic rays and single beam data taking

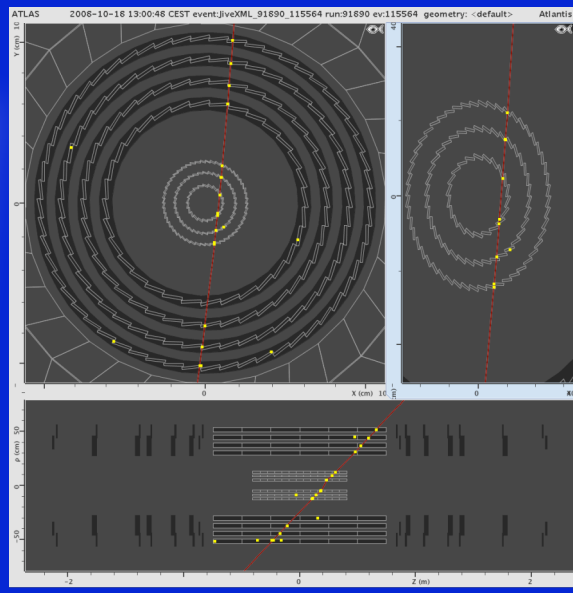
Cosmic rays

LHC
single beam
10-12 Sept

Cosmic rays

- Cosmic rays were taken with different detector and magnet configurations as systems were ready.
- In July ATLAS entered in a semi-continuous operation mode.
- Full cosmic simulation also available.

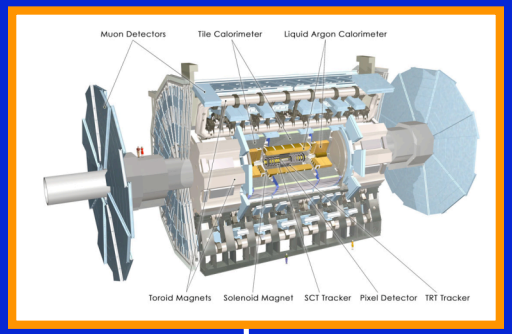




Global
Combined
Cosmic run

July August September October November December

Operation chain overview



Will focus more on the software and analysis aspects

Dedicated streams for calibration and alignment

Trigger

Online Reconstruction & Monitoring

Data Quality Monitoring histograms Event Displays

Tier 0

Data Quality Monitoring histograms

Calibration centers

Reconstruction

Calibration & Alignment

Tier 1

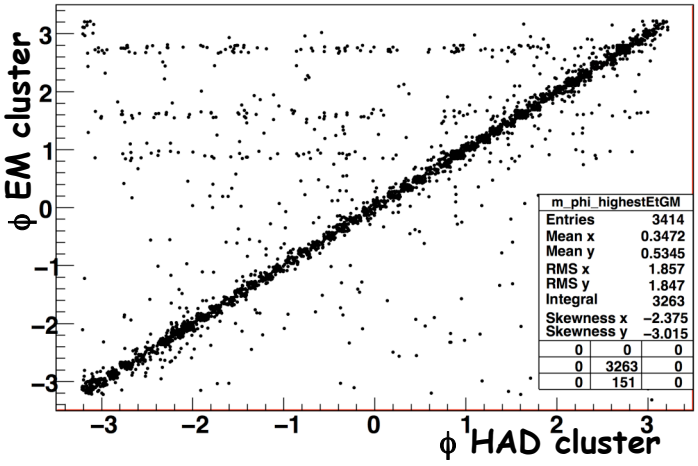
Re-processing

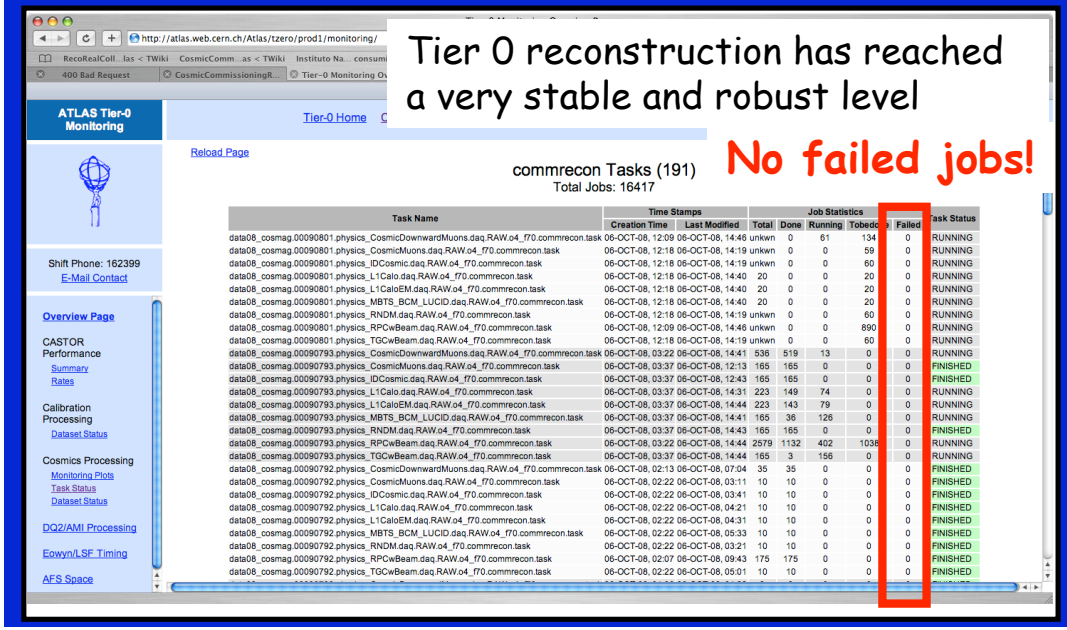
Tier 2

Operation chain overview

- Full chain working for real data but (apart from the obvious differences between these data and collisions):
  - Data quality information stored in the conditions database with some delay.
  - Tier0 processes all data once as soon as it becomes available
  - 24h calibration & alignment loop not yet used
  - Re-processing at Tier1s: tests done and about to start a large scale production of ~300M events.

Monitoring and data quality checks continuously done

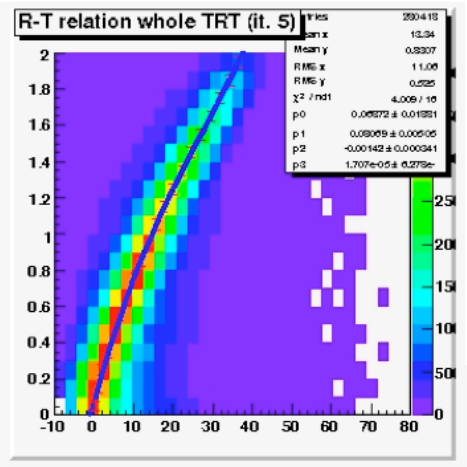


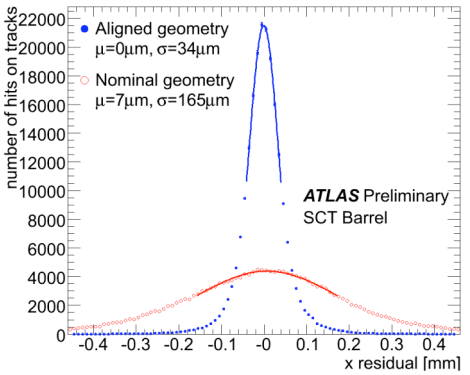


Tier 0 reconstruction has reached a very stable and robust level

No failed jobs!

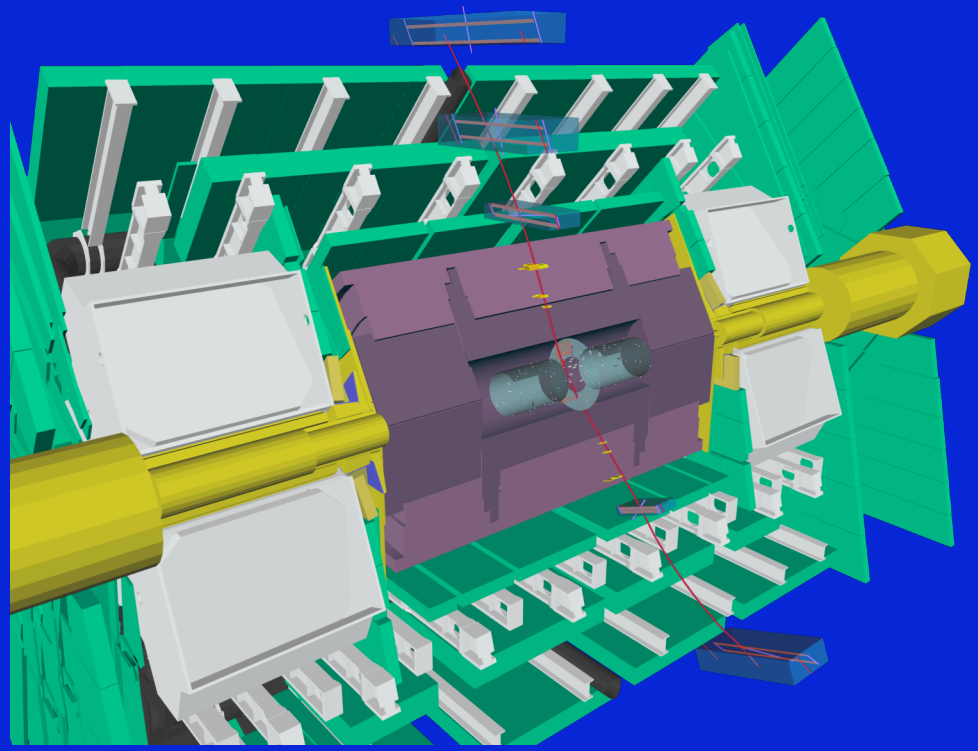
Alignment and calibration processes running at the calibration centers and leading to very significant improvements





Cosmic rays

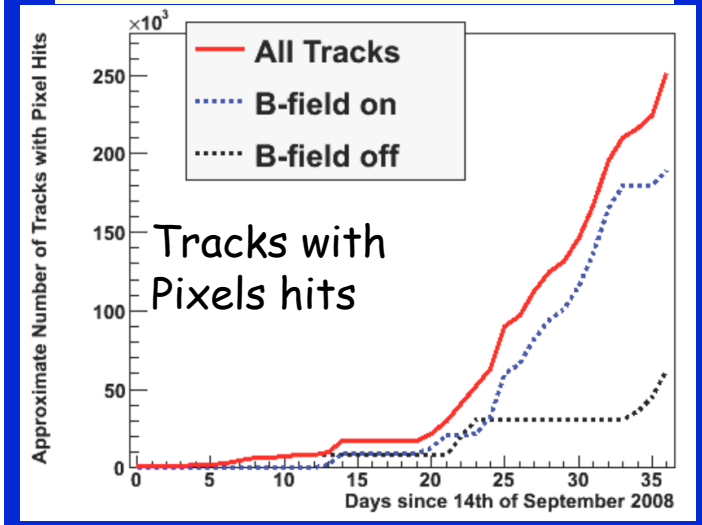
- Data collected
- What have we learnt from it? (some analysis results)

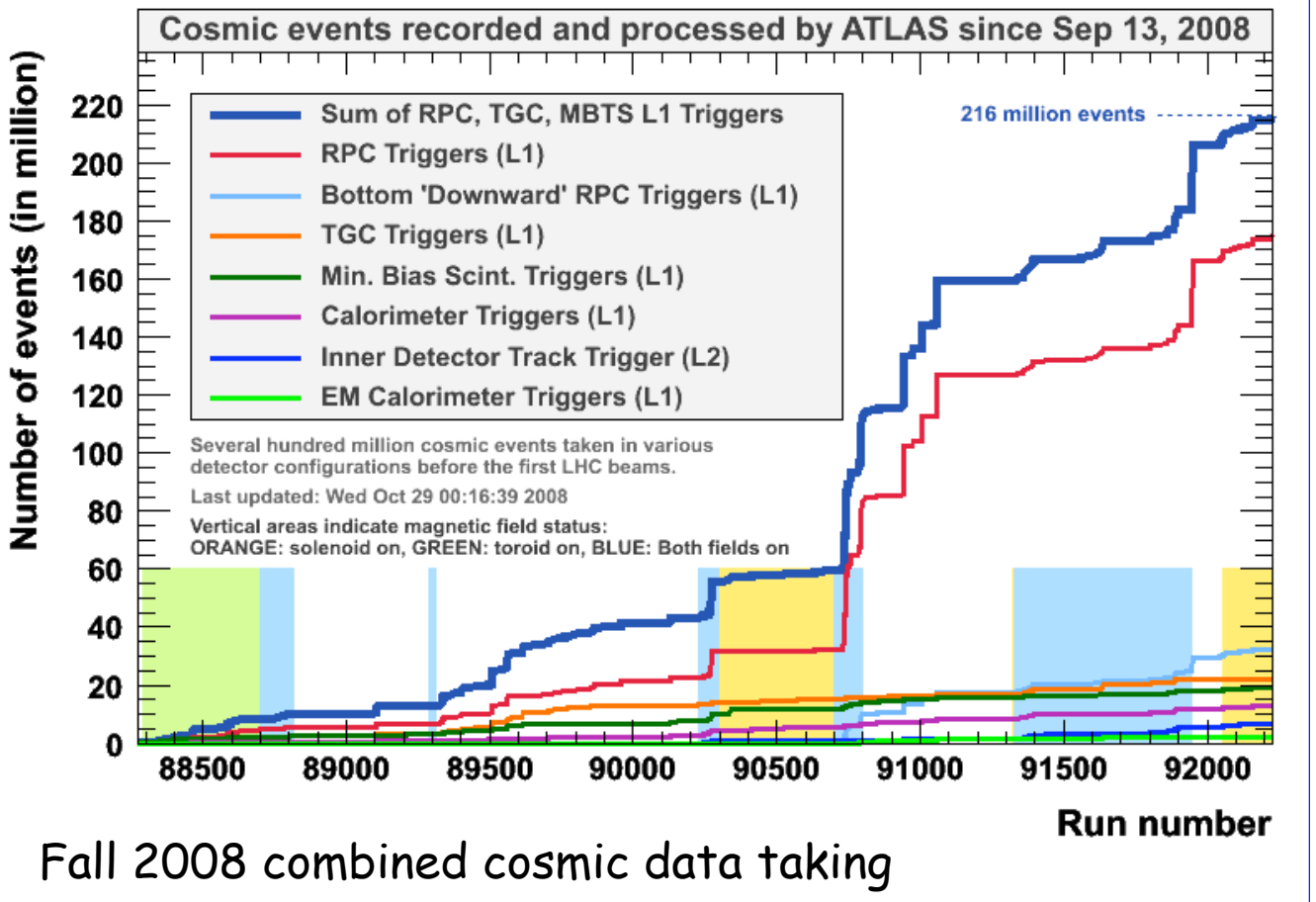


Data accumulated

- A large amount of cosmic rays have been collected by ATLAS with different detector and magnet configurations.

Total data volumes 2008:
#events: > 500M
Raw data: >1.2 PB
Derived data: ~ 700 TB



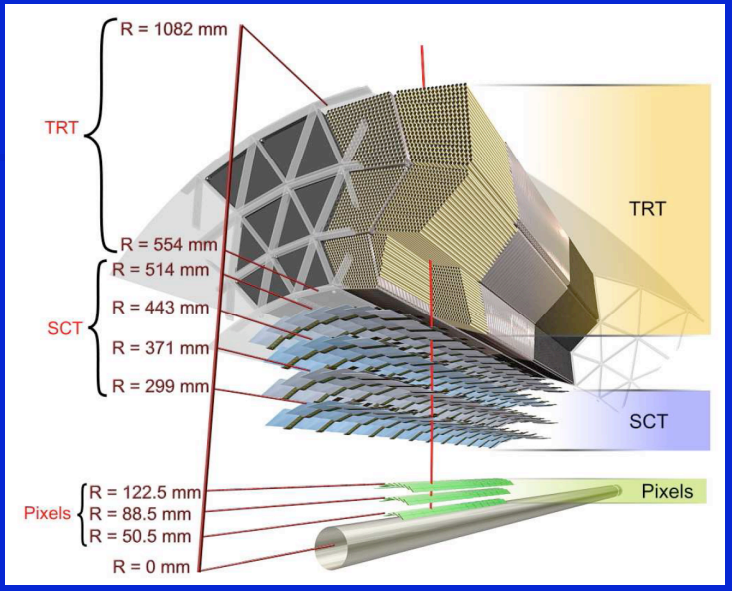


Fall 2008 combined cosmic data taking

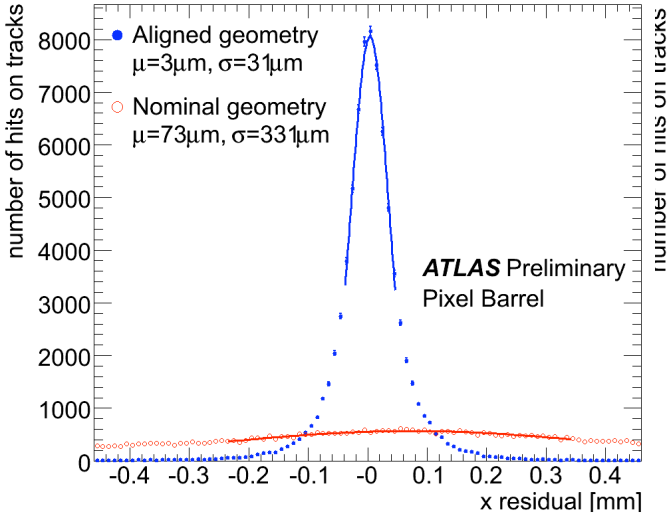
Nice statistics to perform many detector studies but not enough for others (e.g. Muon alignment ~ 36M tracks , ID alignment requires O(1M) Tracks) → ATLAS continues recording cosmic rays!!!

Inner Detector studies

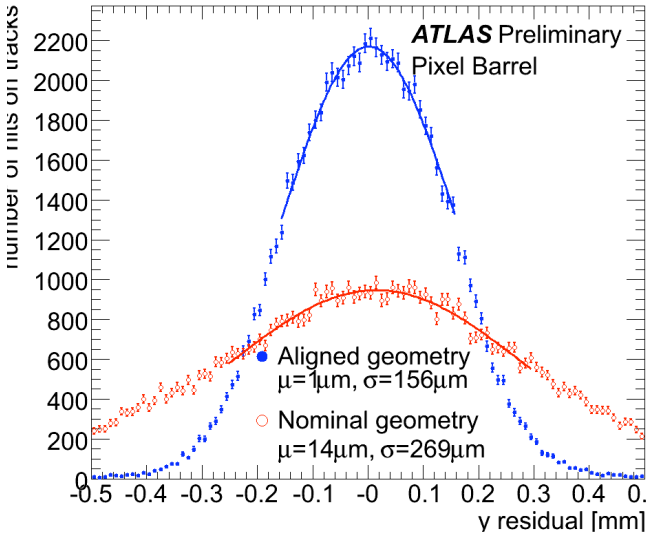
- Alignment performed in increasing levels of granularity as more data comes in (more statistics needed specially for endcaps)
- TRT R(t) relations and Pixel calibrations provided.
- Dead and noisy channels available.
- Tracking and detector performance studies being done.



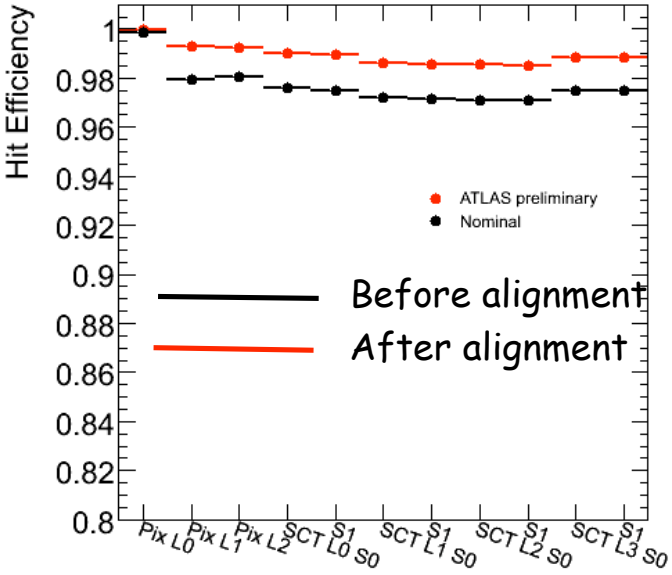
Ex: Alignment of the Pixels and SCT detectors → Great improvement in residuals and efficiencies



x residual [mm]

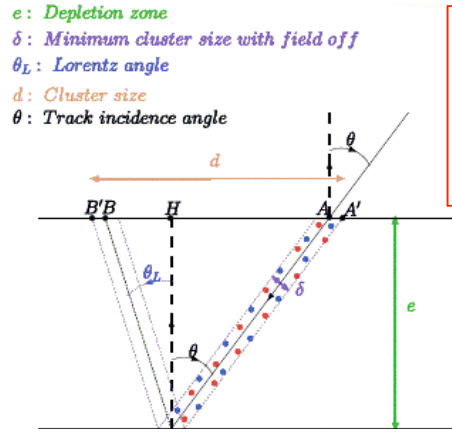


y residual [mm]

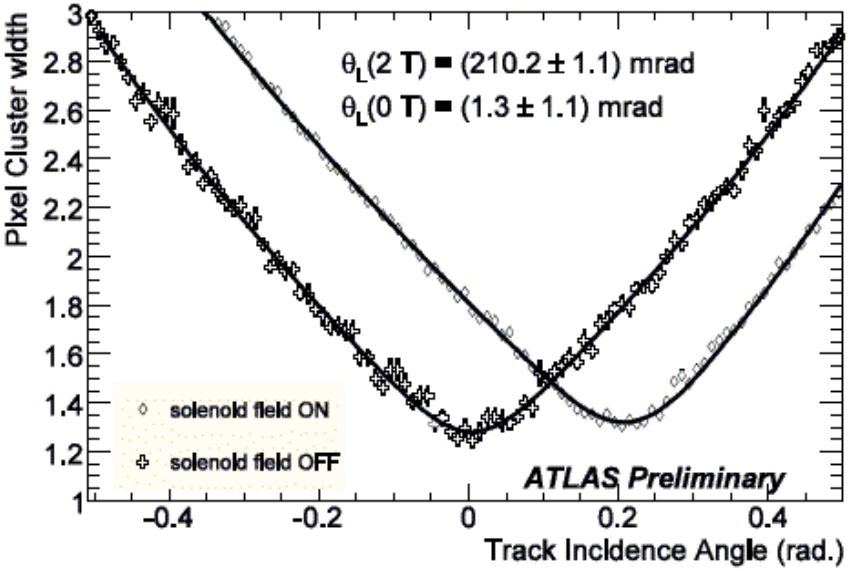


Inner Detector studies

Ex: Measurement of the Lorentz angle in Pixels

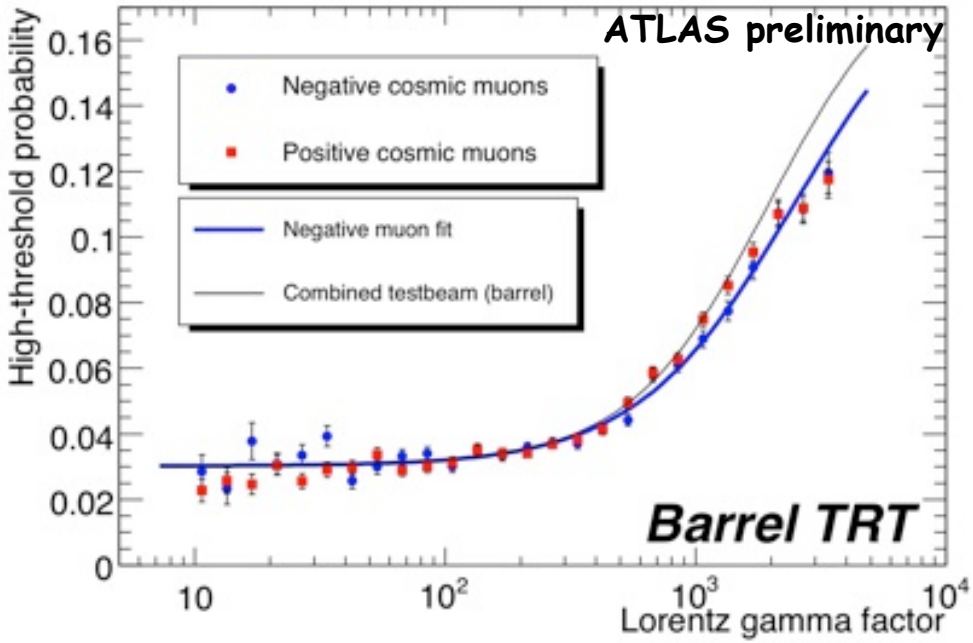


Essential measurement to get the expected precision in the silicon detectors



θ_L(2T,expected)= = 224 mrad (150V, -4°C)
No systematic uncertainties taken into account yet

Ex: Transition radiation performance in the TRT

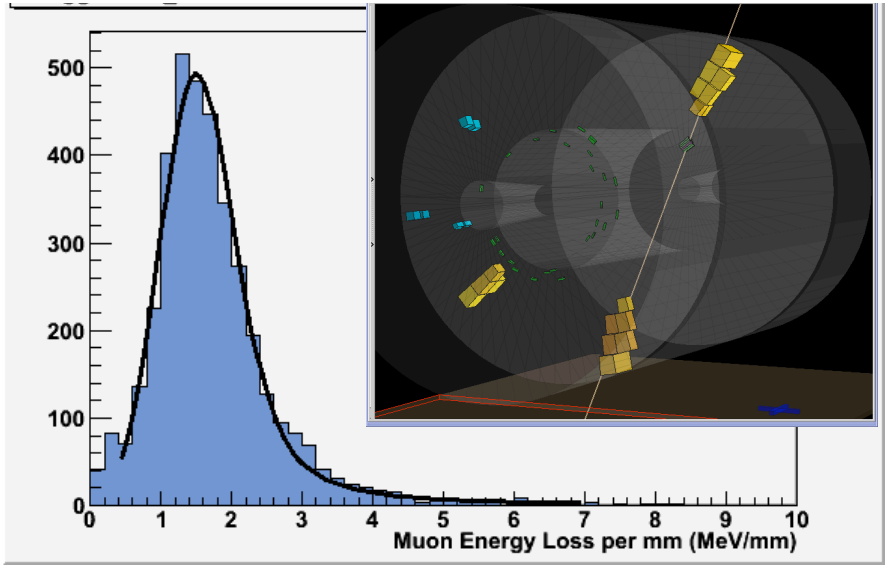


Probability of transition radiation in the TRT for cosmic rays (muons) is in good agreement with the test beam results.

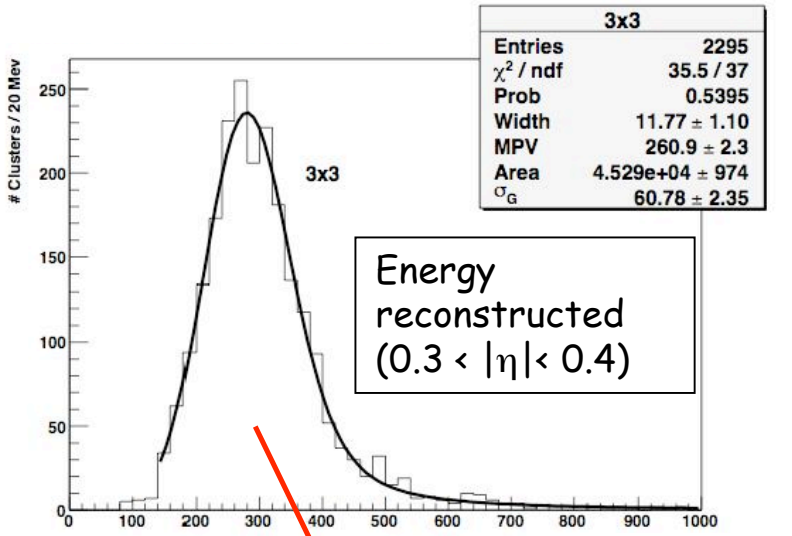
Calorimeters studies

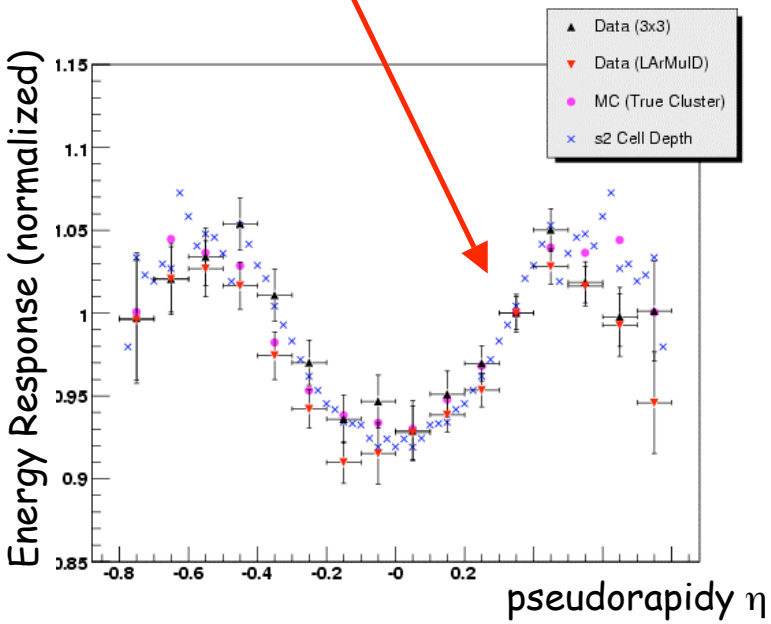
- Detailed studies in the calorimeters have allowed to verify:
  - The timing and energy calibrations
  - The uniformity of the energy response
  - The performance of the clustering algorithms
- Alignment with respect to the inner detector is also being done.

Ex: Validation of the energy calibration in the HAD Calorimeter



Ex: EM Calorimeter uniformity study

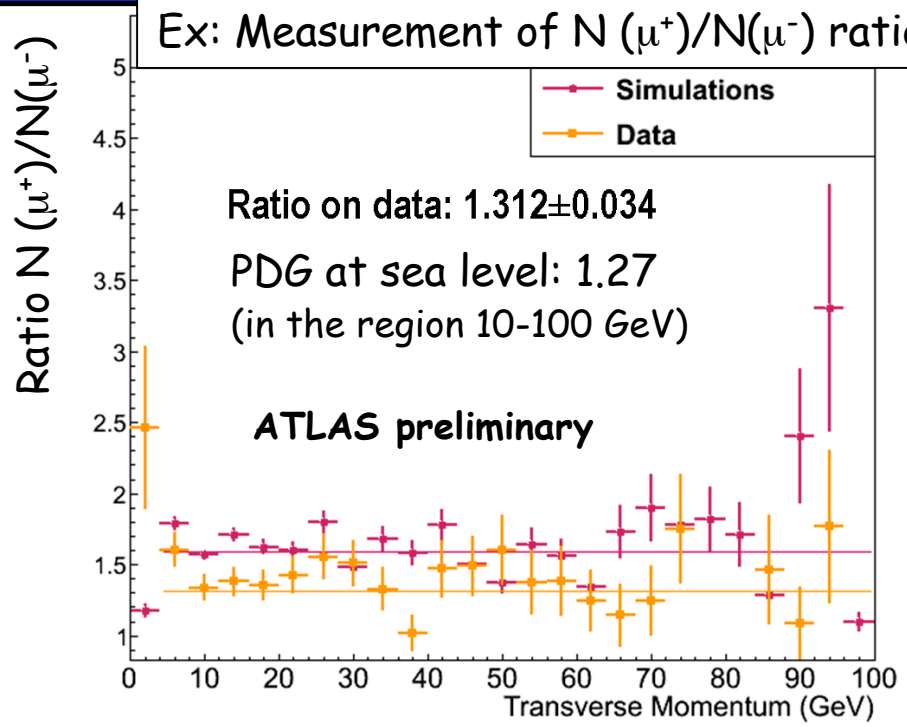




Muon spectrometer studies

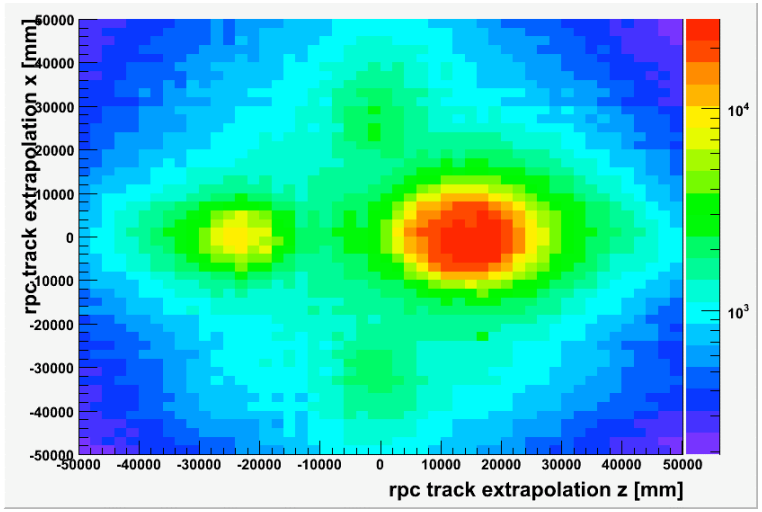
- Alignment, calibrations and list of bad channels are being provided.
- Detector properties, trigger and tracking performance studies have been done.
- First attempt to measure the ratio N (μ^+)/N(μ^-)

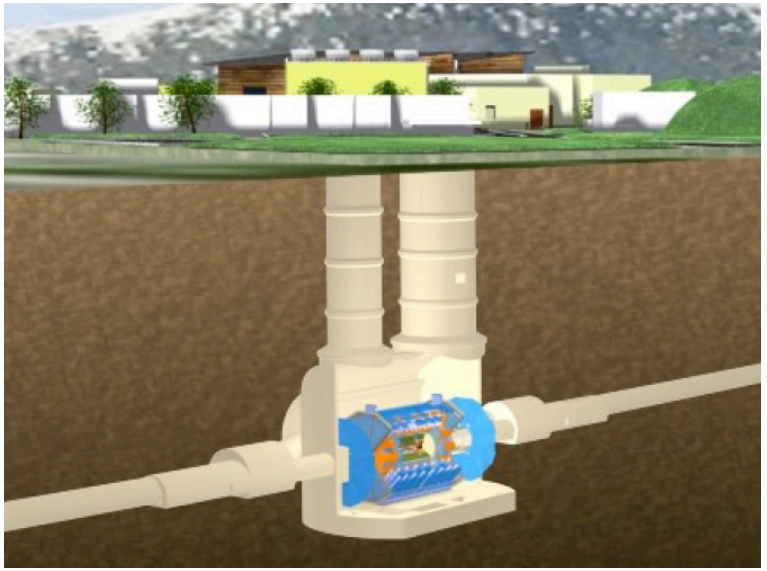
Ex: Measurement of N (μ^+)/N(μ^-) ratio



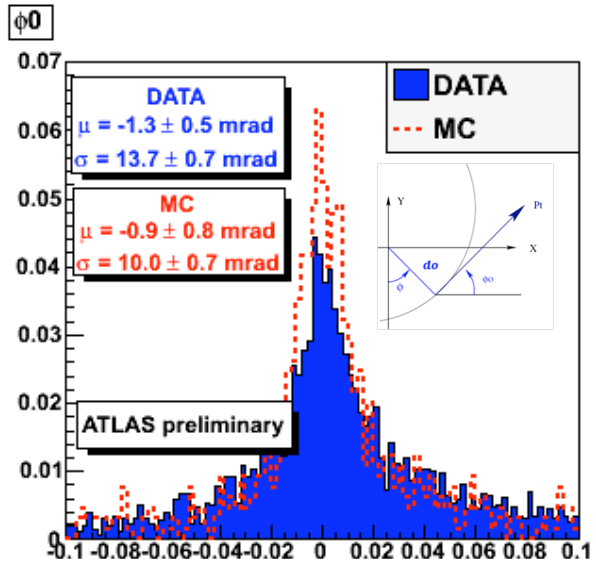
- Only statistical uncertainty considered
- No correction applied due to the trigger setup.

Track parameters x-z extrapolated to the surface: more tracks coming from the shafts and elevators holes as expected

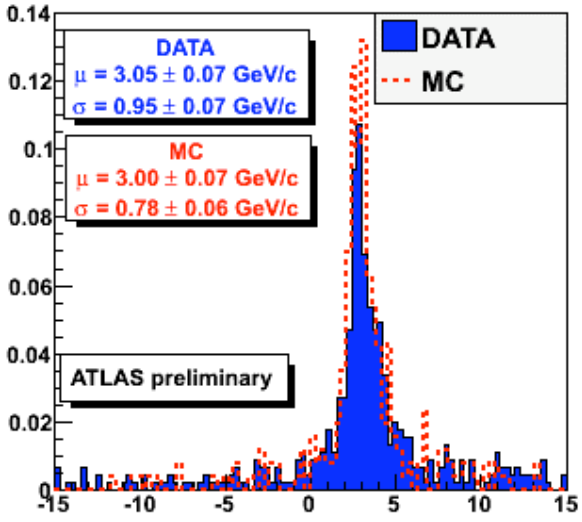




Combined studies



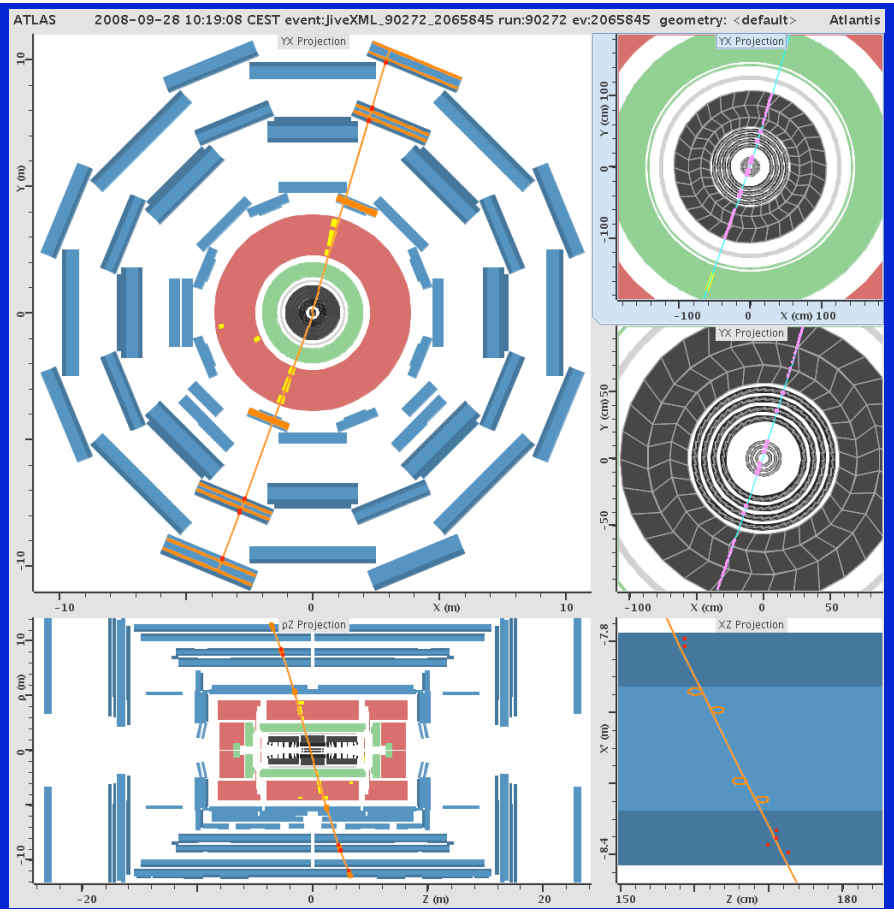
ϕ_0 (inner detector) - ϕ_0 (Muon system) (rad)



p (inner detector) - p (Muon system bottom) (GeV)

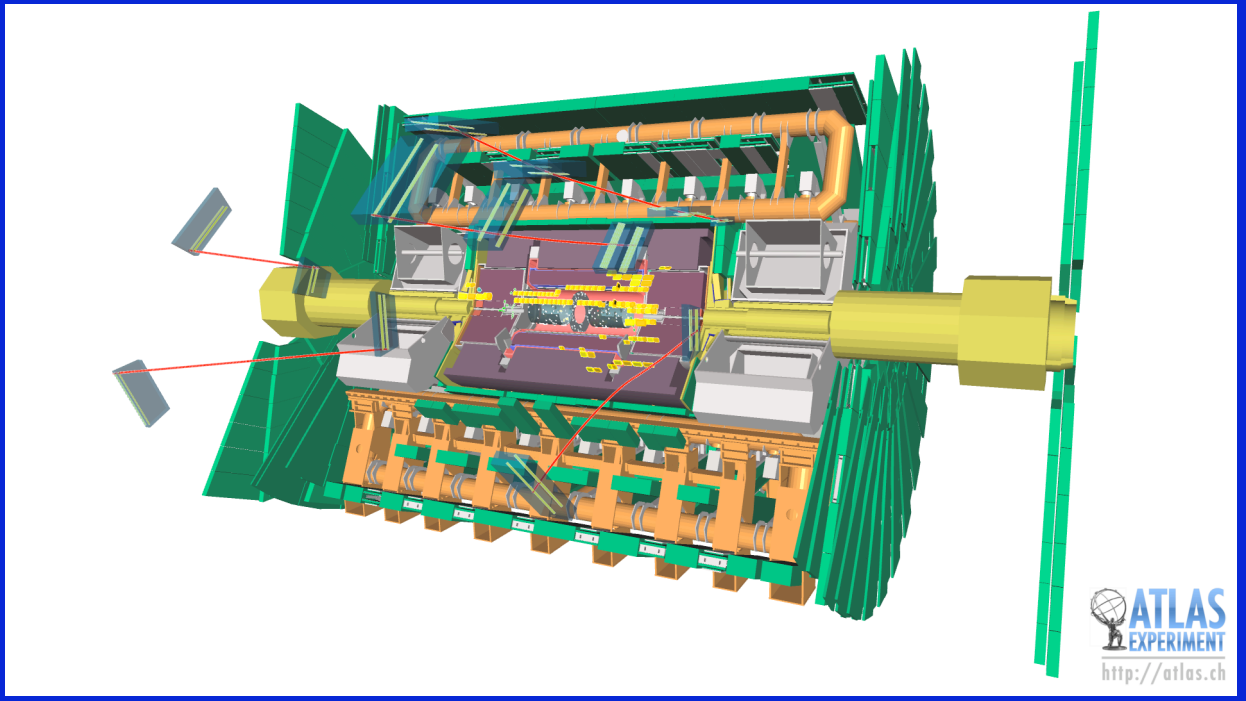
Ex: Combined tracking studies with the inner detector and muon systems:

- Comparison of tracks reconstructed in each system (sensitive to alignment, material effects, track resolutions) have been done and compared with MC
- Combined tracks are being reconstructed.

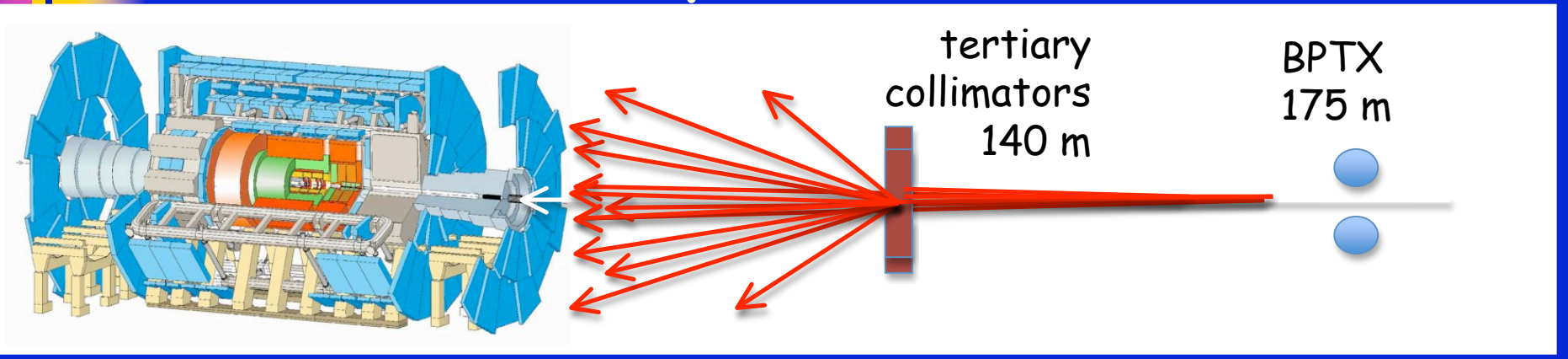


LHC single beam

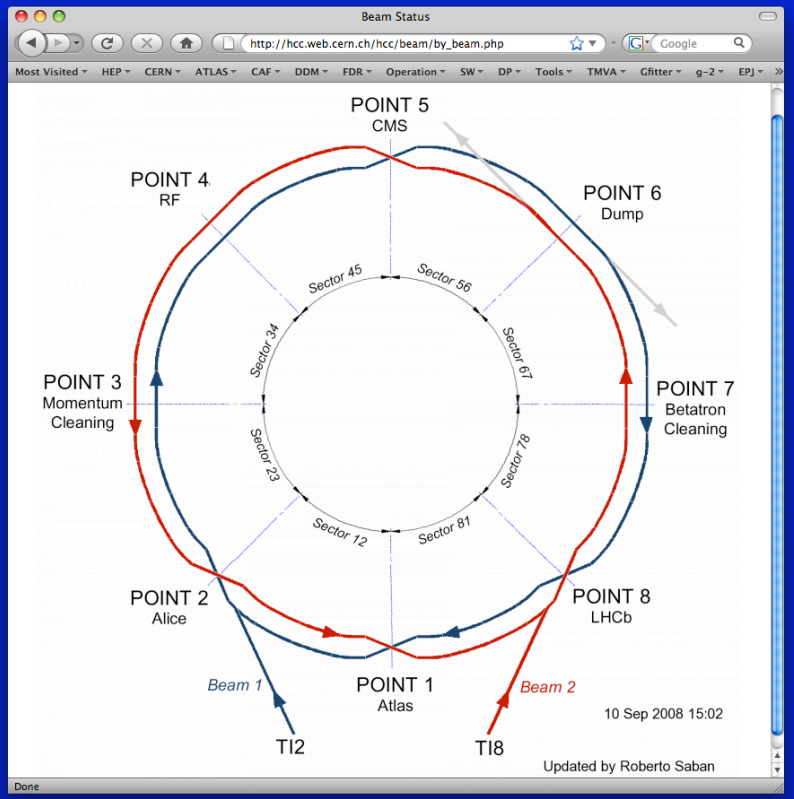
- Data collected
- What have we learnt from it? (some analysis results)



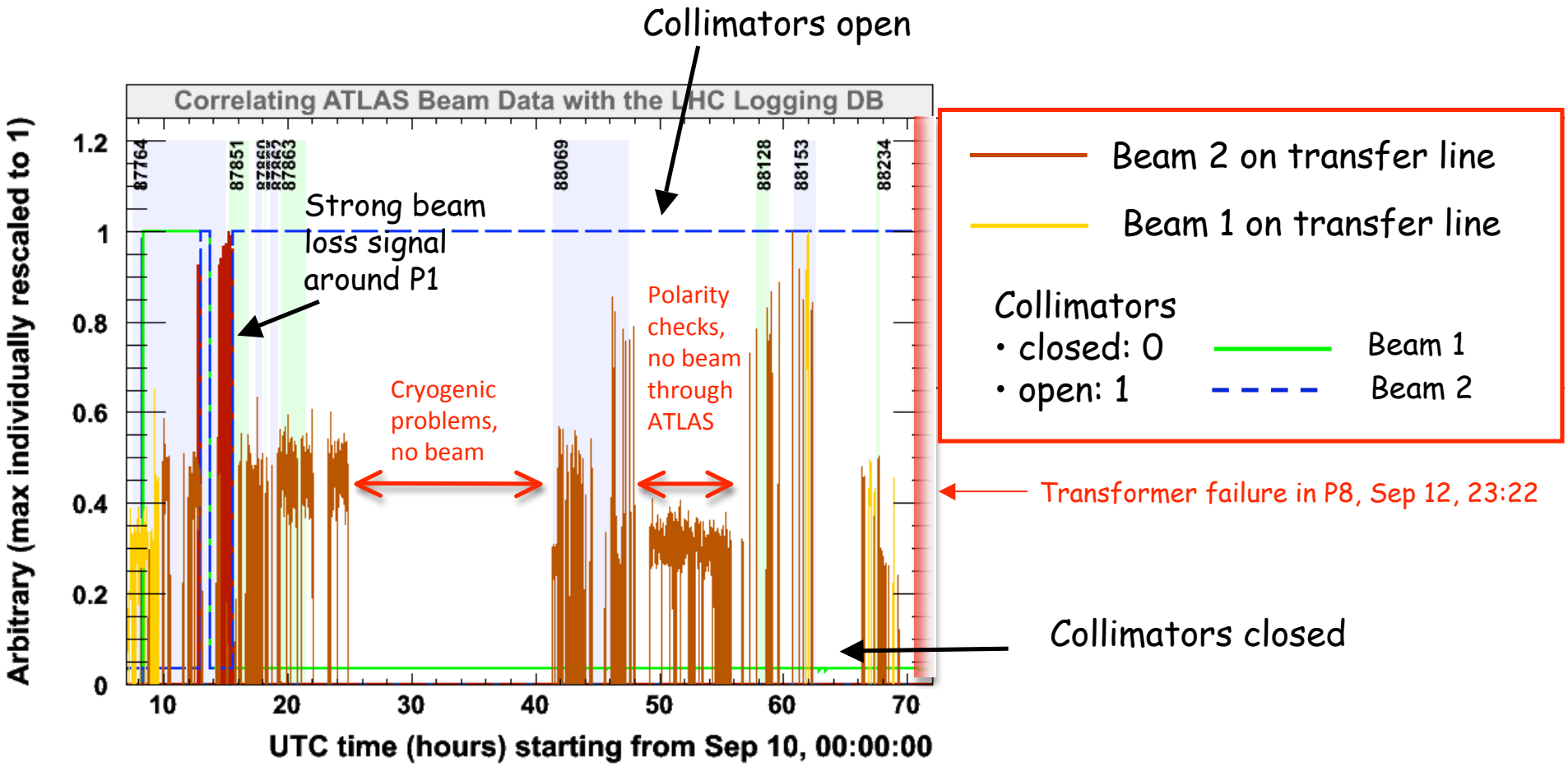
LHC start-up conditions



- LHC data in ATLAS (Sep 10th-12th):
  - 1 bunch of $2 \cdot 10^9$ p at 450 GeV
  - Start stopping beam on collimators, re-align with center, open collimators, keep going → expected:
    - Splash events when collimators closed
    - Beam halo and beam-gas events
  - RF capture beam from day 2.
- ATLAS was ready for first beam:
  - SCT, muon chambers and forward calorimeter at reduced HV and Pixels OFF for safety reasons.
  - LVL1 processor and DAQ up and running, HLT available (but only used for streaming)



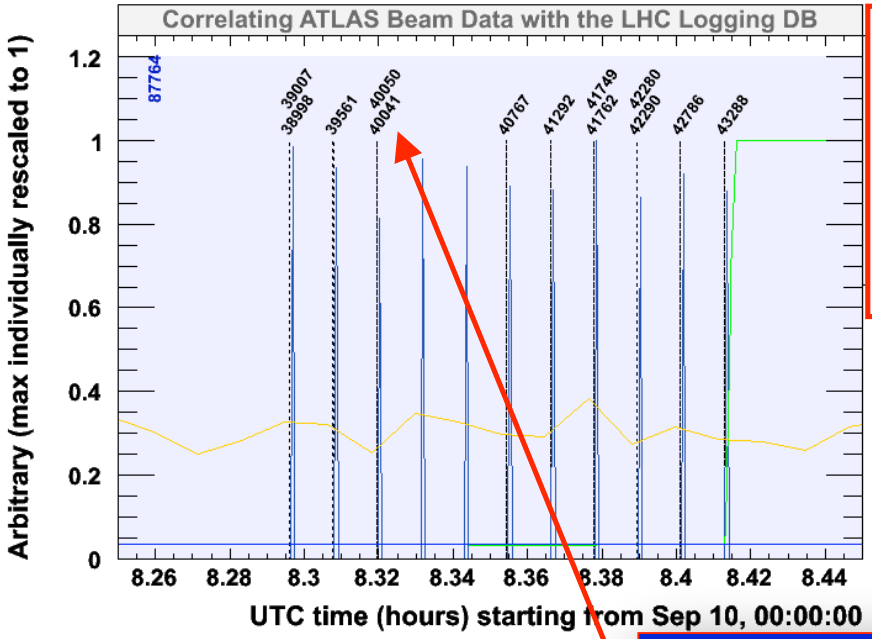
Overview of beam injections and ATLAS runs



- ATLAS saw the LHC beam during 3 days.
- Both beams went through ATLAS but mostly beam 2

Collimator splash events

Zoom into first period of beam splashed activity

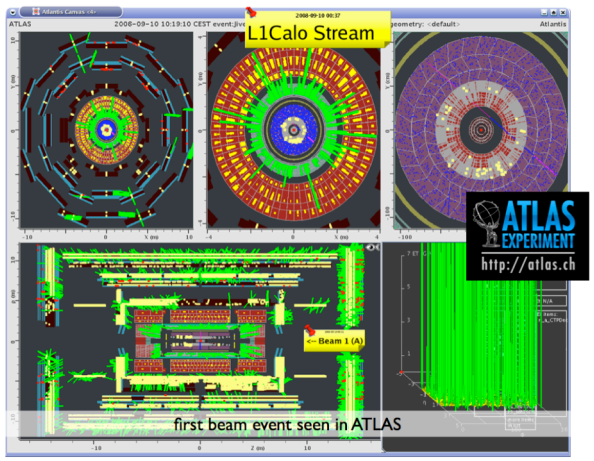


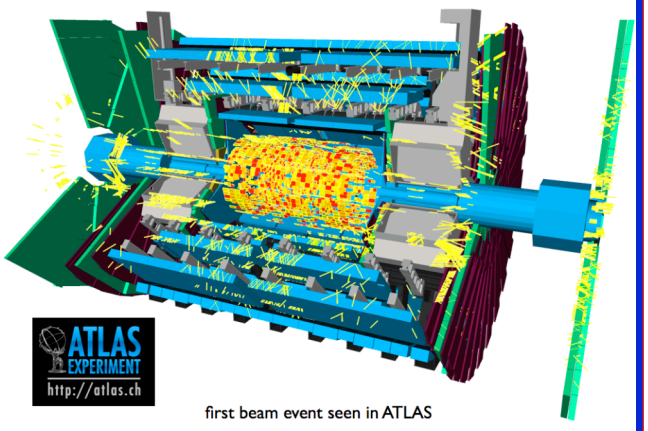
ATLAS observed splash event (#hits MDT>100K)

Beam 1 injections

First event seen in ATLAS!!

Good correlation between the LHC beam injections and the splash events recorded by ATLAS





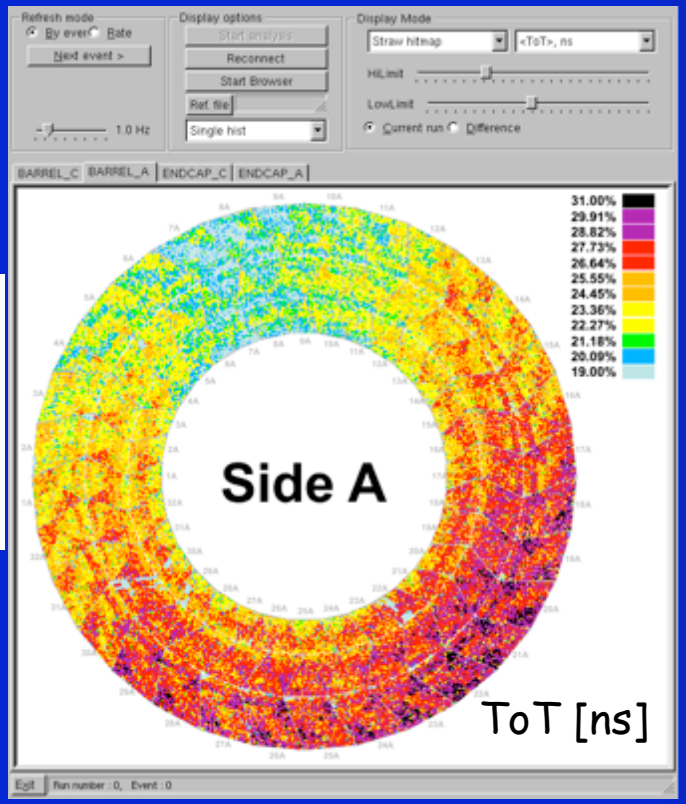
first beam event seen in ATLAS

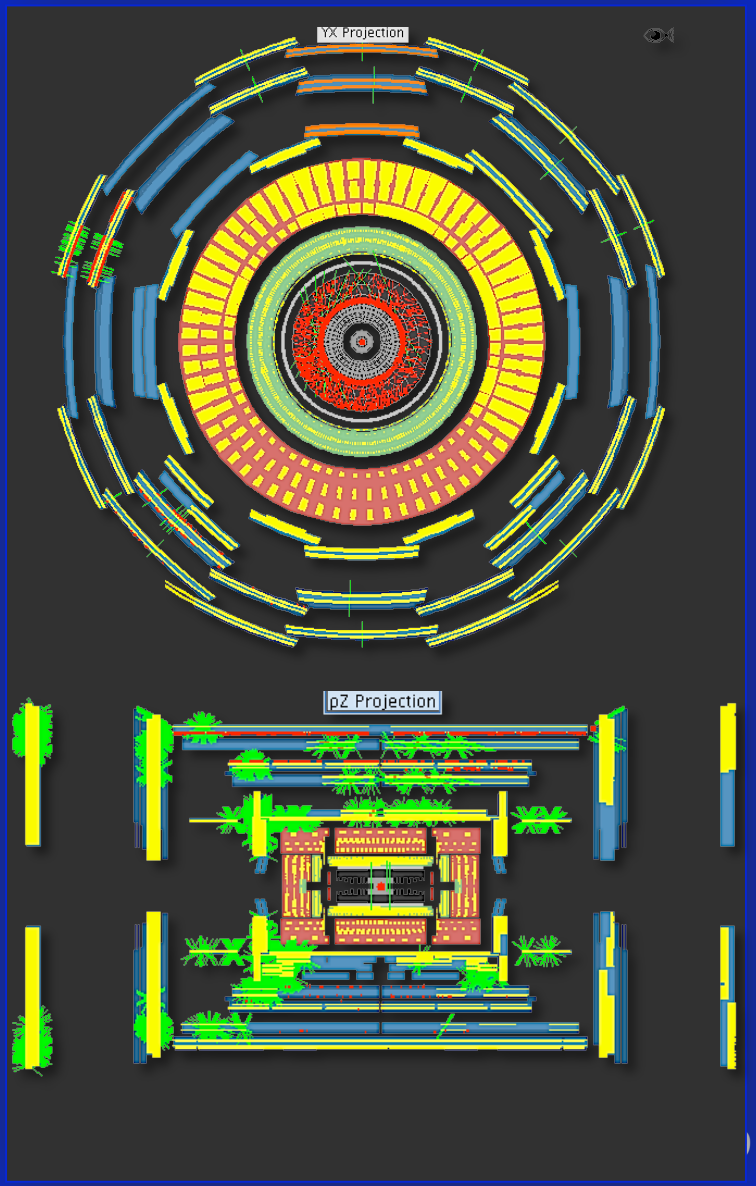
Celebrated in the ATLAS control room

Splash events

- Events characterized by:
  - Huge number of signals in the detector
  - Huge energy deposited (HAD cal > 1000 TeV, EM Cal ~ several TeV)
- Excellent for timing studies and to find dead channels.

Beam splashed event in the TRT: These events were used to time in the detector at the ~ 1ns level.

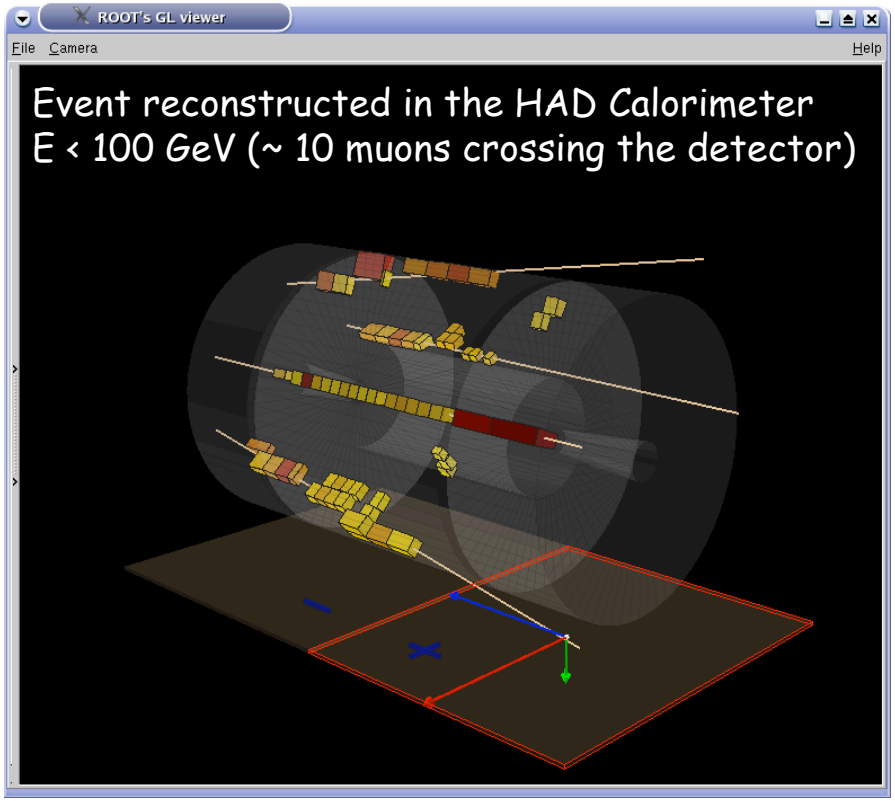


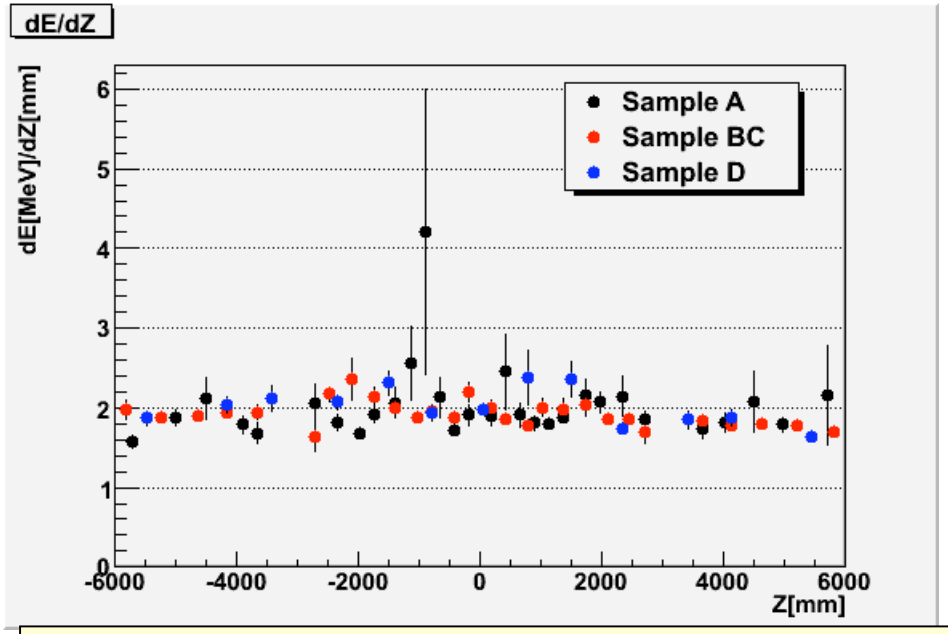


Beam halo events

- Single LHC proton beam circulating.
- Without RF capture, the beam was not well focused → quite a few particles (muons) crossing horizontally the detector.

Ex: Validation of the energy calibration in the HAD calorimeter





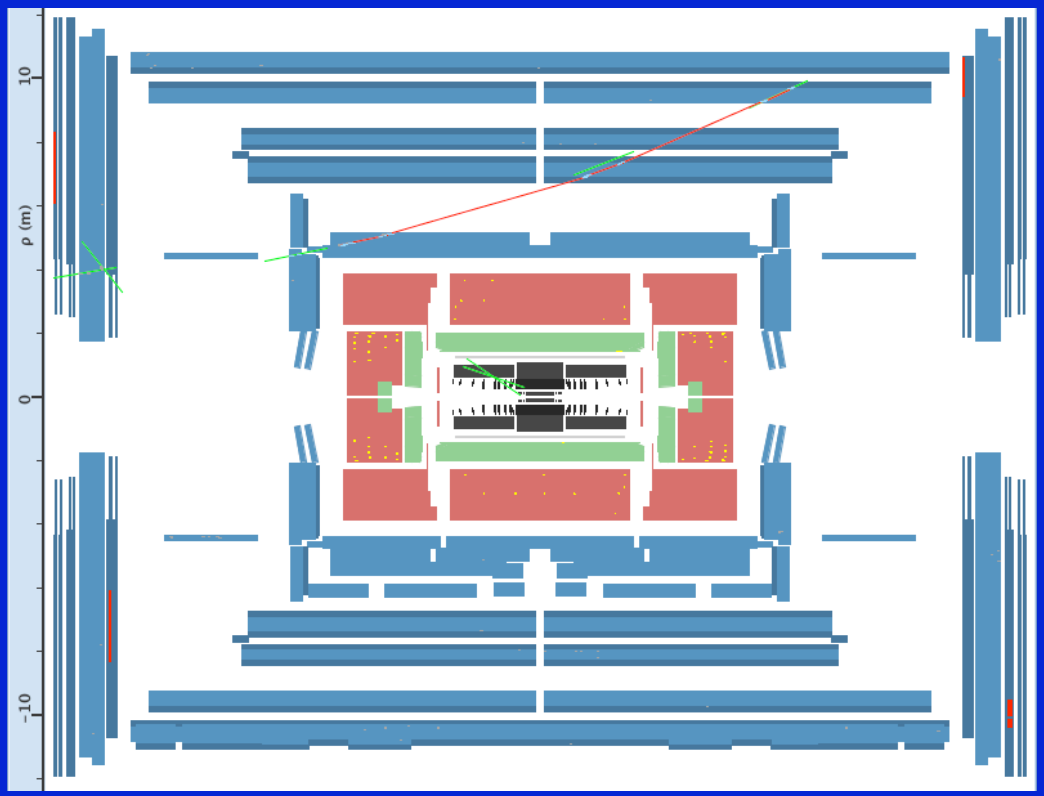
- Beam data: dE/dz = 1.9±0.2 MeV/mm
- Cosmic data: dE/dz = 1.7±0.3 MeV/mm

⇒ Good agreement of the detector response between cosmic and beam data.

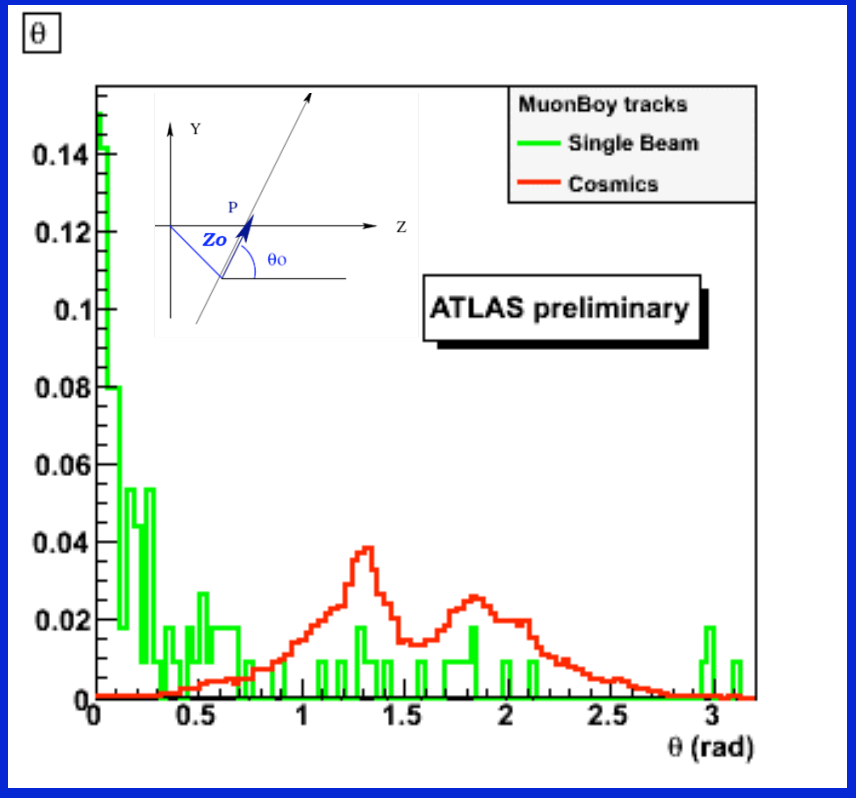
⇒ Uniform response (within 6%)

Beam halo events

- After RF capture achieved, the beam was very clean (good for physics, harder to time in the detector).



LHC single beam data event display

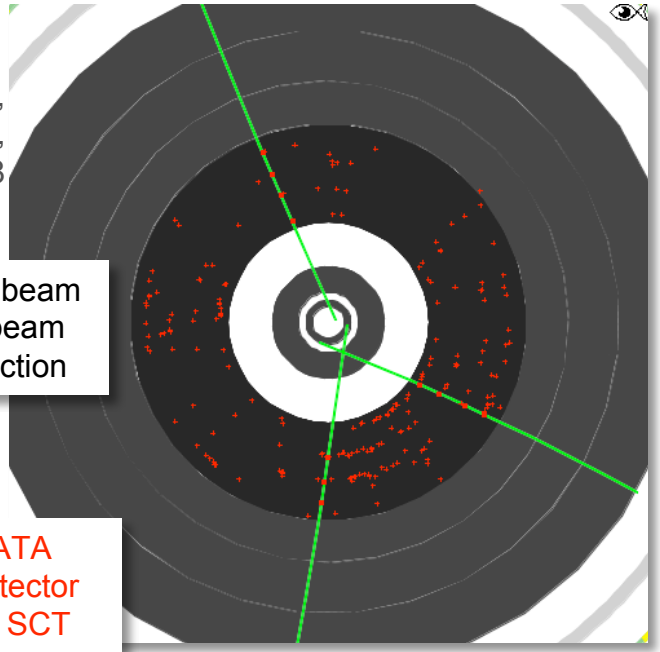


Distribution of the muon spectrometer θ track parameters for single beam and cosmic data.

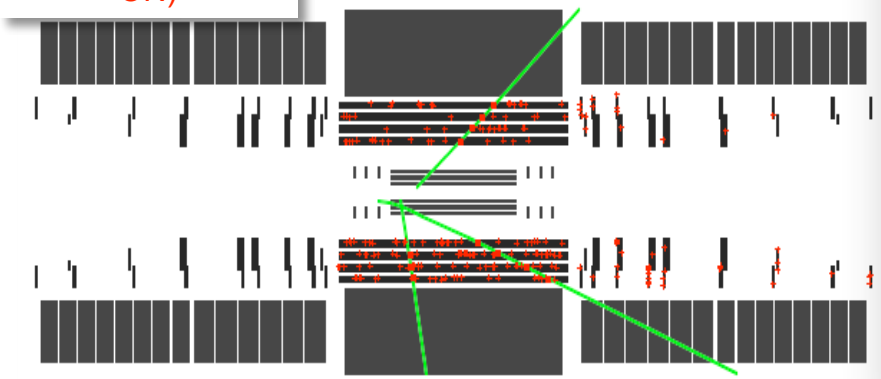
Beam-gas events?

Runs 88153,
Event 12060,
Sep 12, 2008

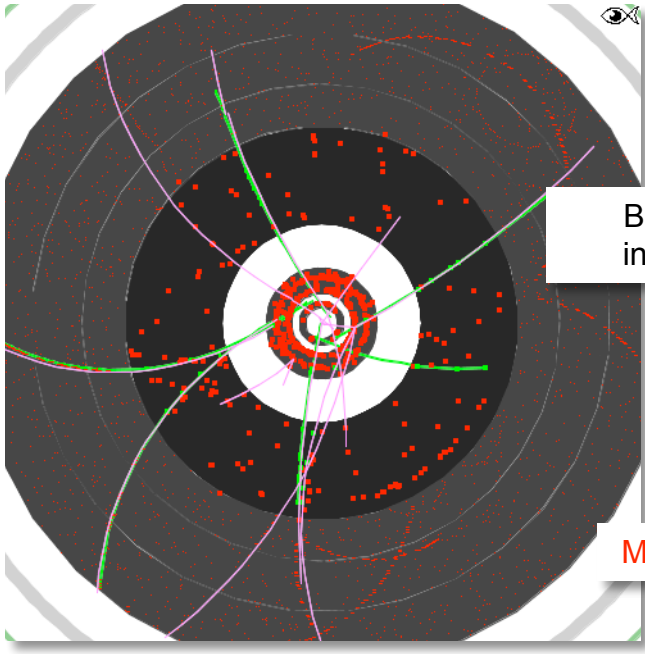
Looks as a beam particle - beam pipe interaction



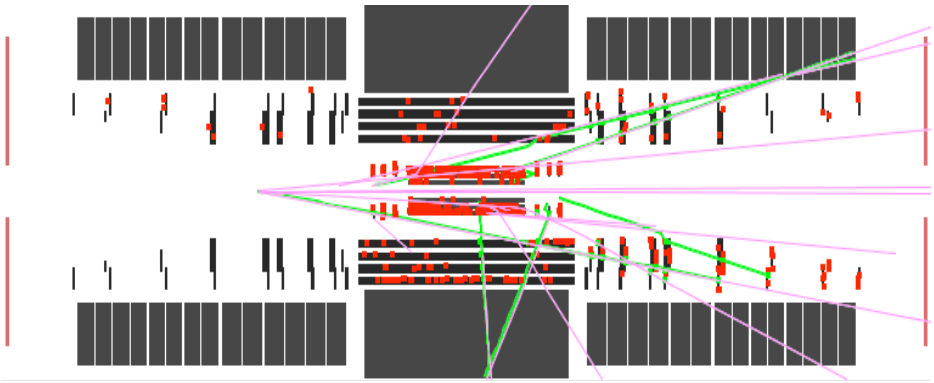
Real DATA (Inner Detector with only SCT ON)



Beam-gas interaction



Monte Carlo



Some candidates for beam hitting the beam pipe found. Beam-gas interactions not observed, probably because of the excellent vacuum in beam pipe but also the Inner detector was not fully ON during this period.

Conclusions

- The commissioning of the ATLAS detector with physics data started more than 3 years ago with cosmic rays.
- This has allowed to put in place the full operation chain (from TDAQ up to analysis all over the world).
- ATLAS was then ready to collect LHC beam data the 10th of September

- The analysis of both cosmic rays and single beam data has allowed to understand and improve the detector, reconstruction, monitoring and simulation software and to get the first calibration and alignment corrections.
- Looking forward now for collisions data but keep exploiting the data we have so far to make sure we are ready for that as well.

Delivered!