

First data taking with the ATLAS Detector at the Large Hadron Collider at CERN

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funded by CPAN

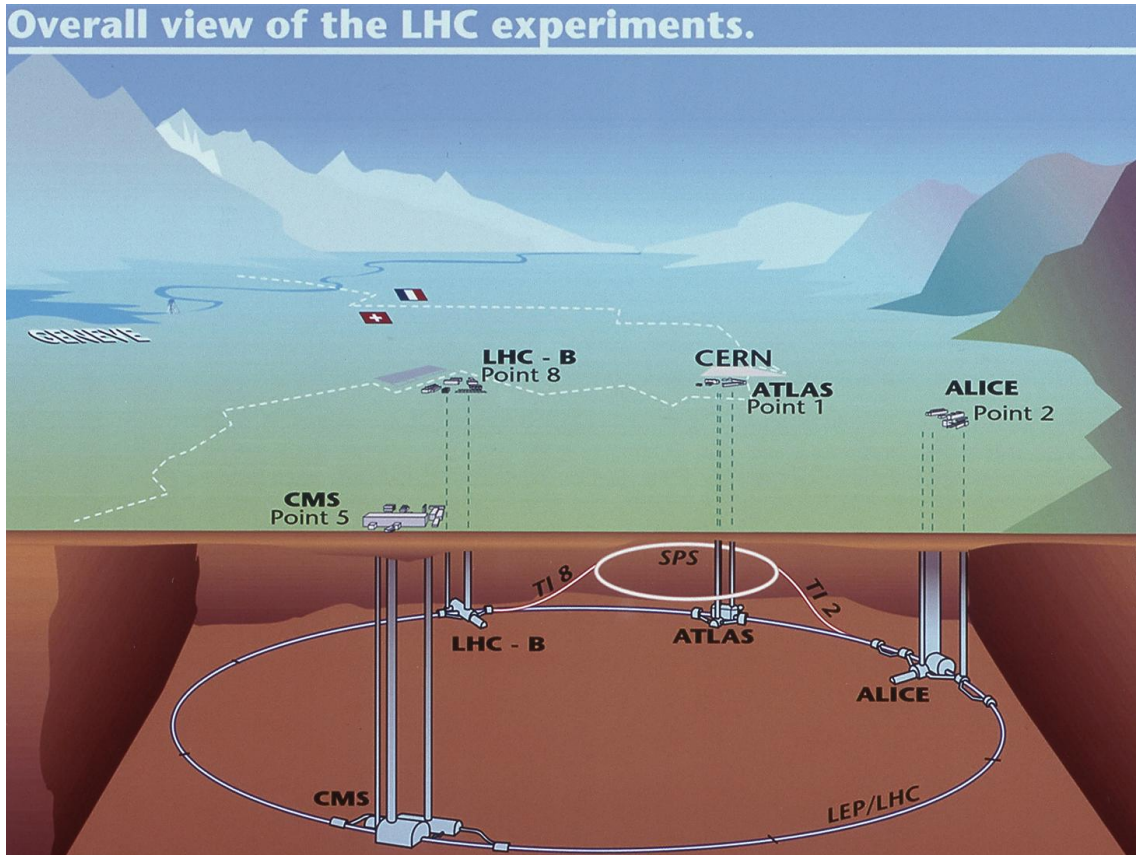
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Outline

- The Large Hadron Collider
- The ATLAS Detector
- Overview of Data Taking in 2009
- Plots, plots, plots …
- Outlook

The Large Hadron Collider

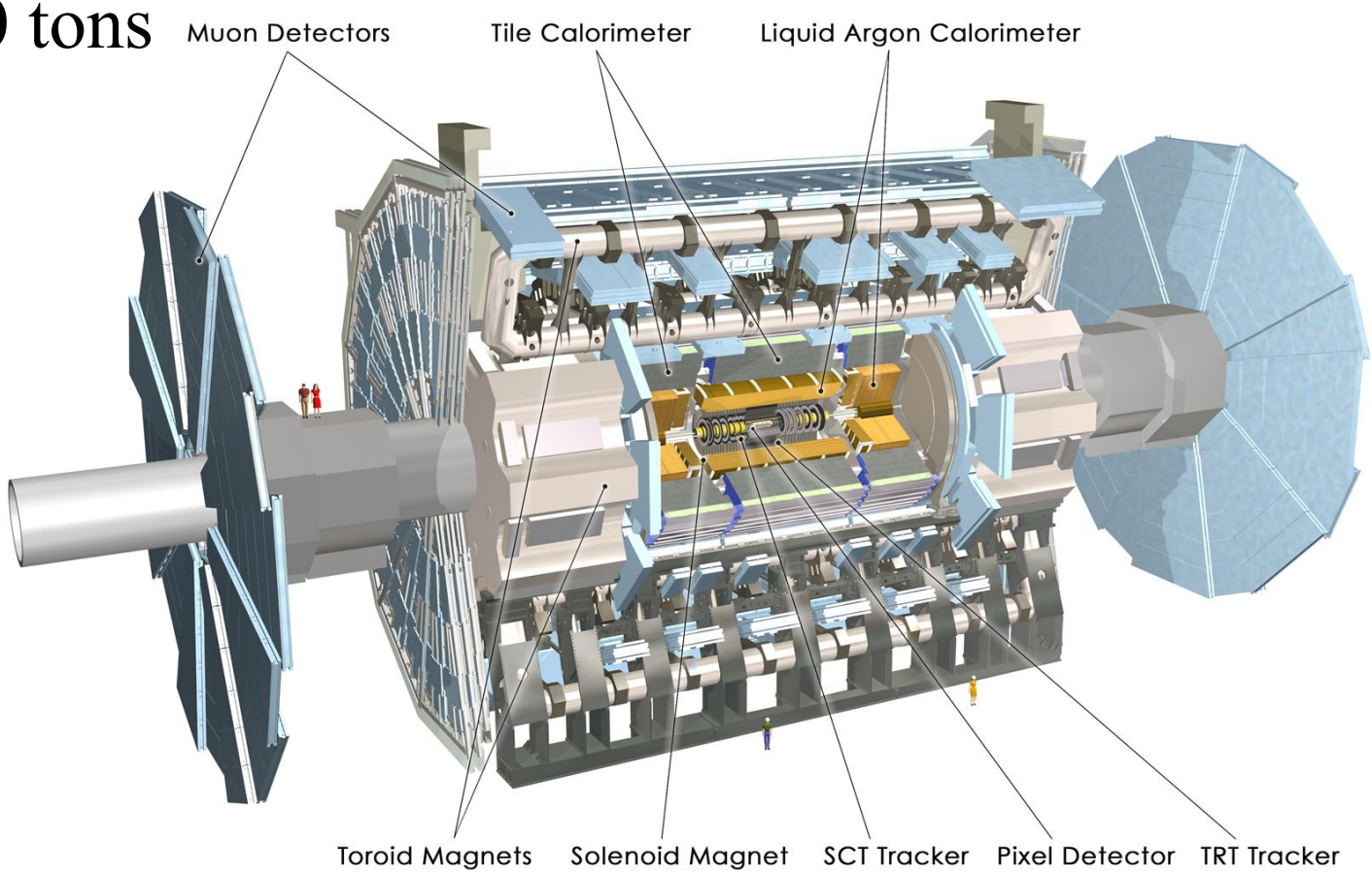
- Proton-proton collider
- 27 km circumference
- Design parameters:
  - E_{cm} = 14 TeV
  - Luminosity ~ 10^{34} $cm^{-2}s^{-1}$
  - p-p bunch crossings every 25ns (40 MHz)
  - ~24 p-p collision per crossing!



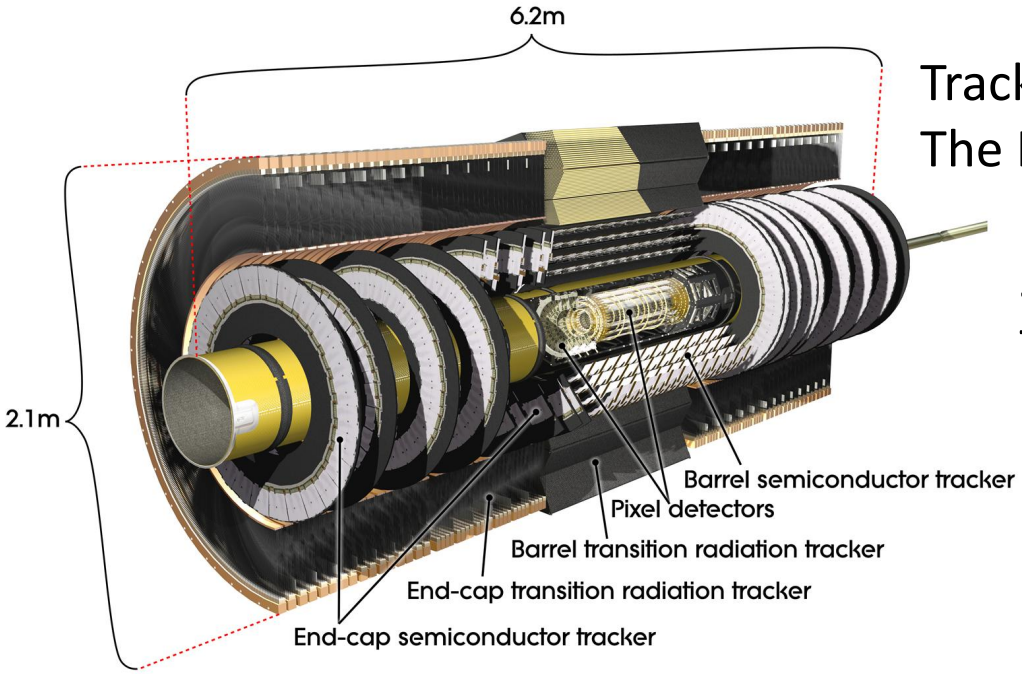
- At 4 interaction points, detectors measure the outcome of the collisions:
  - ATLAS, CMS, Alice, LHCb

The ATLAS Detector

- **A T**oroidal **L**HC **A**pparatur**S**: multi-purpose particle detector to cover large range of physics measurements
- mass ~ 7000 tons
- 25m high
- 45m long
- ~90 million read out channels



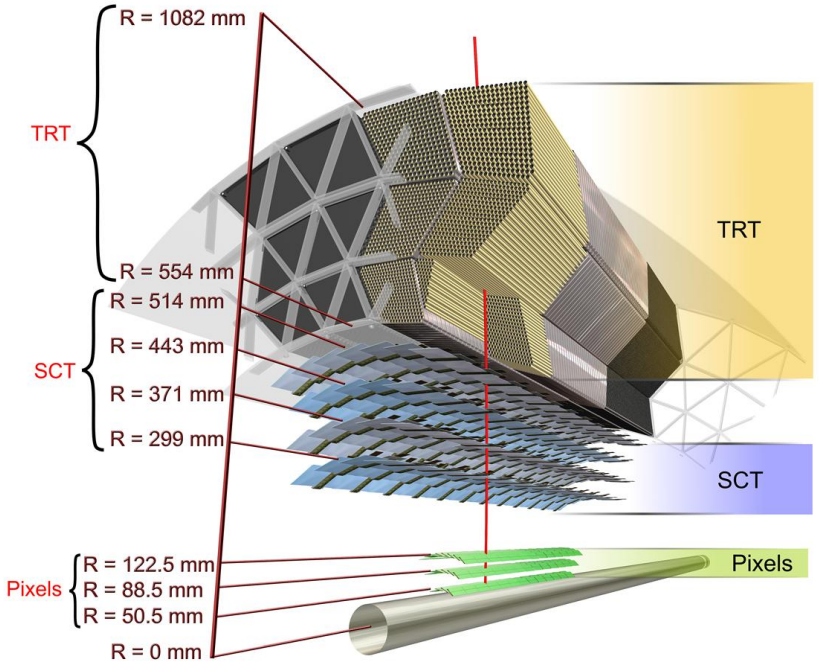
Inner Detector



Tracking detector with 2 Tesla solenoid field

The ID contains 3 sub-detectors: (resolution)

- Pixel detector: 10/115 μm in Rϕ/z
- Silicon strip detector (SCT): 17/580 μm
- Transition radiation tracker (TRT):~ 130μm in Rϕ

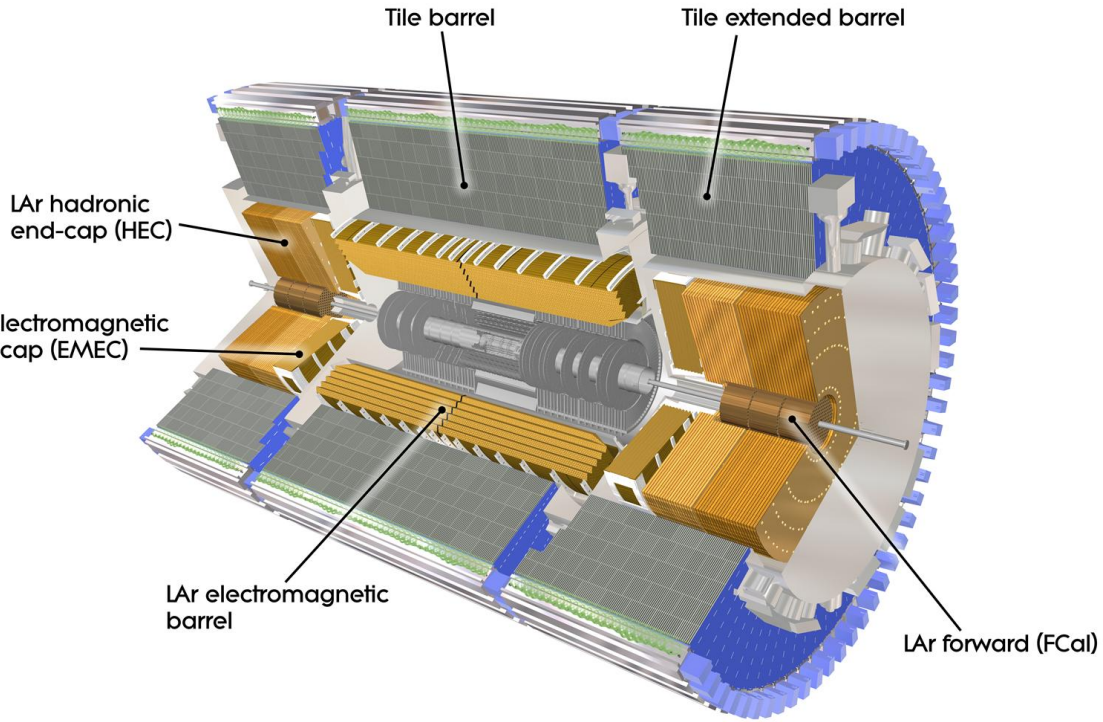


The ID provides on average 3 pixel, 4 SCT and at best 36 high precision measure-ments per charged track. $|\eta| < 2.5$

Allows for accurate track and vertex reconstruction.

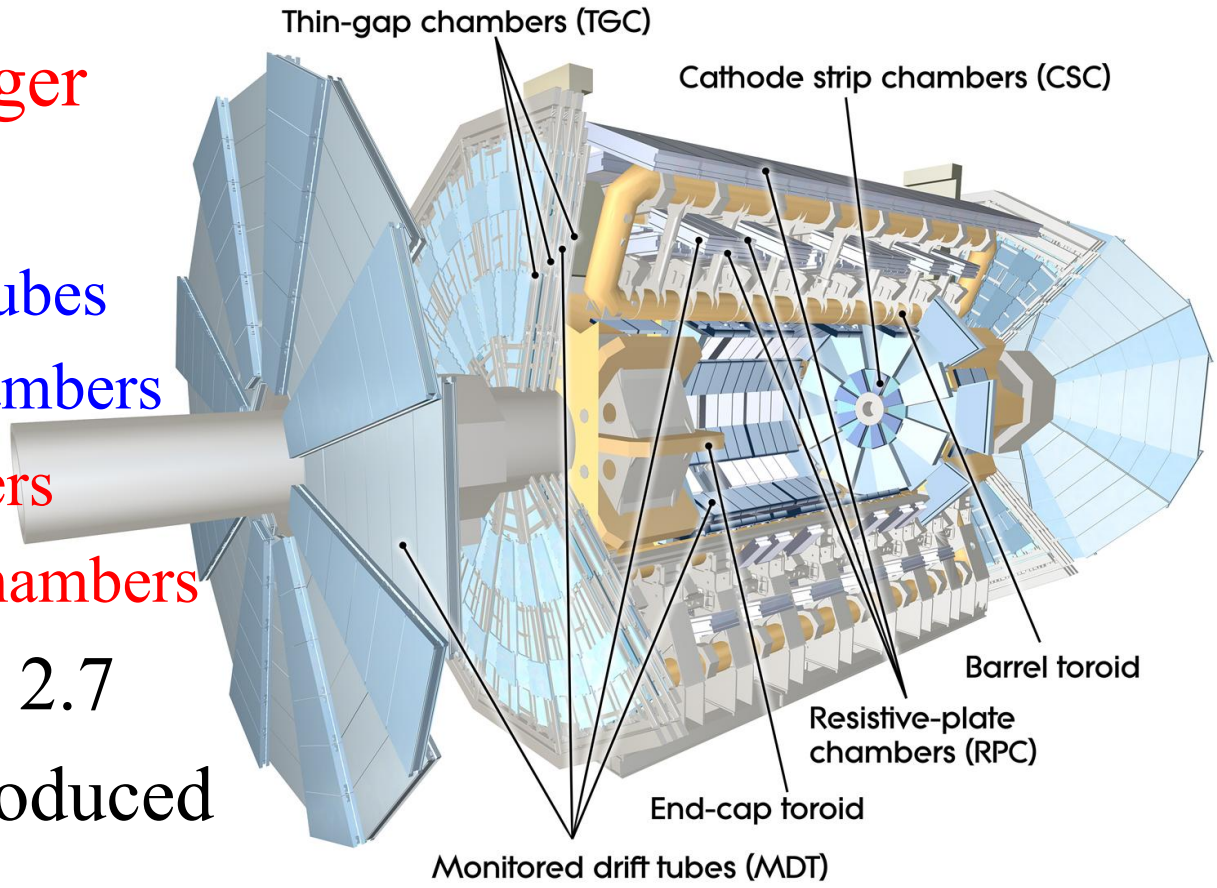
Calorimeters

- Measures energy deposit
- Electromagnetic (LAr):
  - Precision measurements of photons and electrons
  - $|\eta|$ coverage up to 4.9
- Hadronic (Tile):
  - Measure energy deposit of hadrons
  - $|\eta|$ coverage up to 1.7



Muon Spectrometer

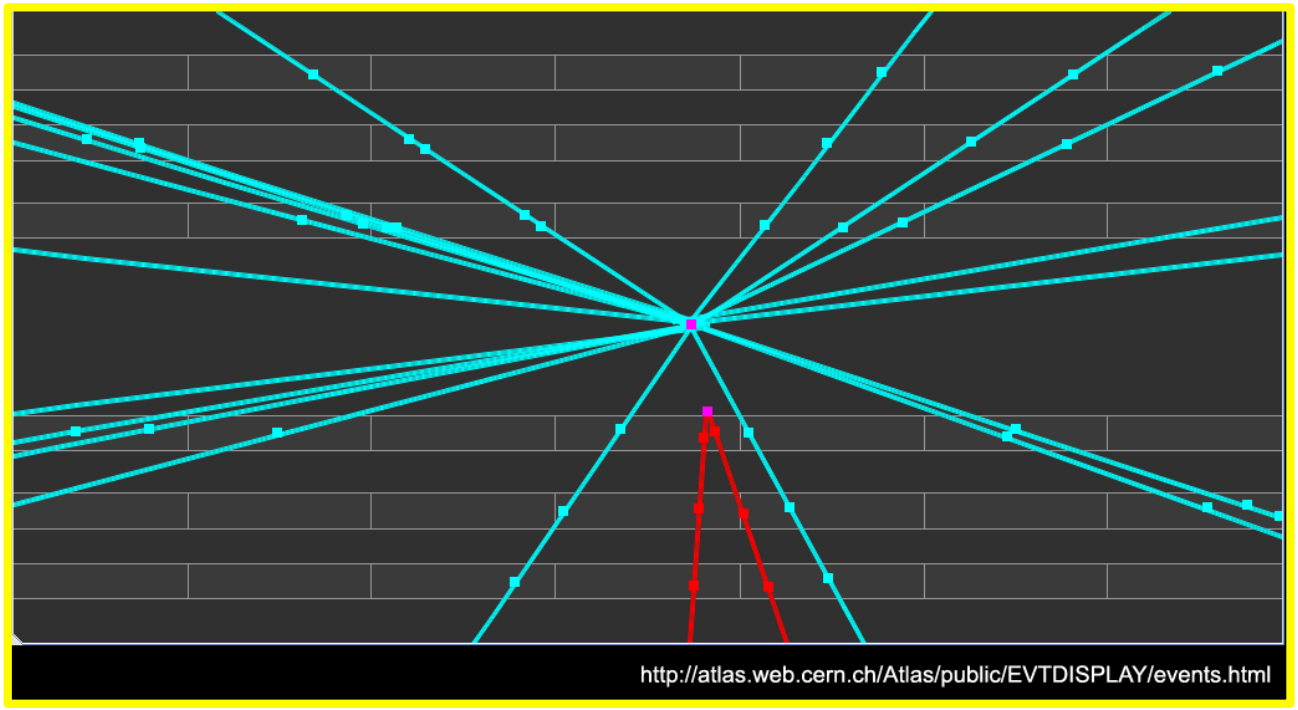
- Tracking and trigger
- 4 detector types:
  - Monitored drift tubes
  - Cathode drift chambers
  - Thin-gap chambers
  - Resistive plate chambers
- |η| coverage up to 2.7
- Magnetic field produced by 3x8 large coils
- O.5 – 1 T magnetic field



Data Taking in 2009

Very First Data

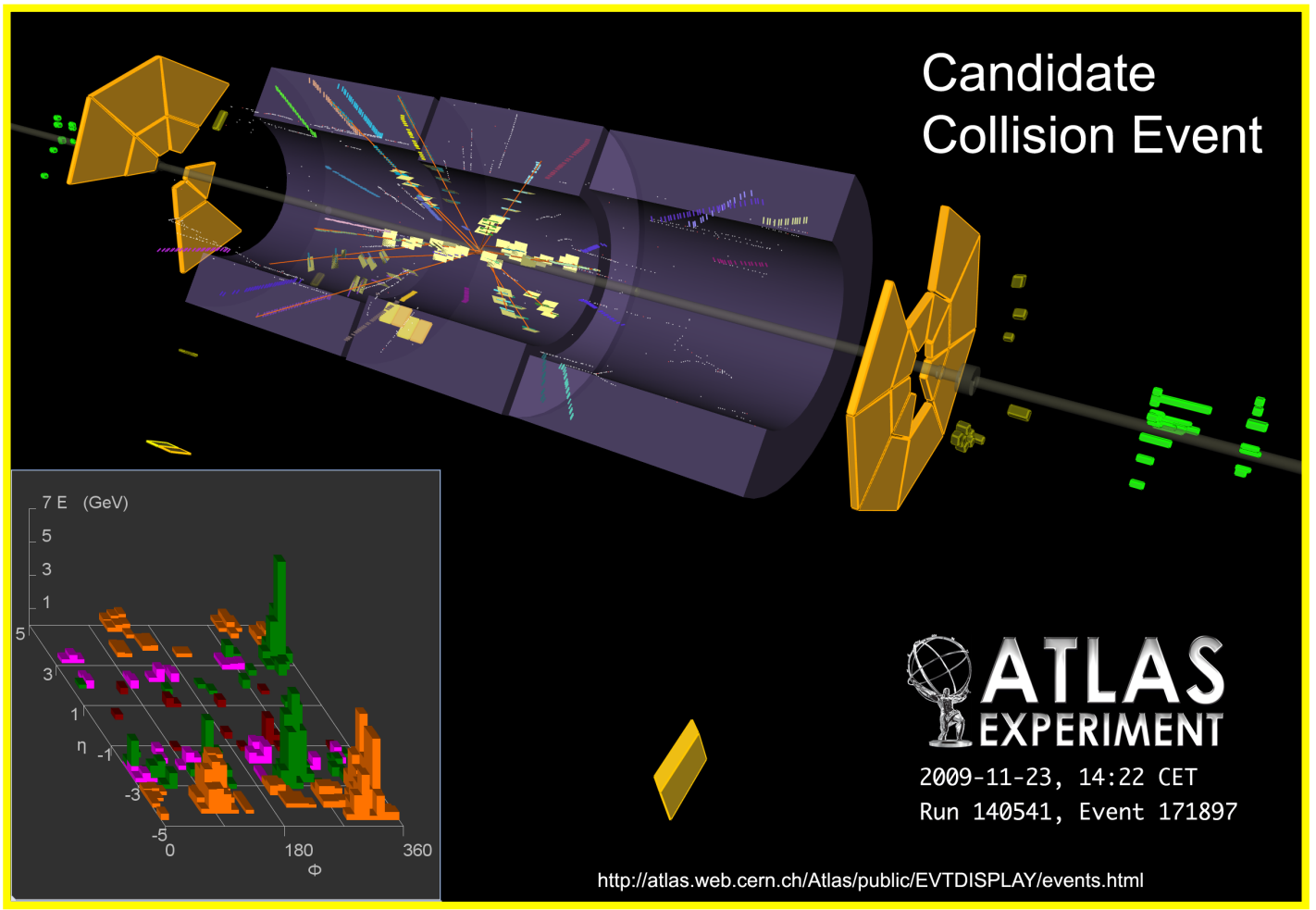
900 GeV



2.36 TeV

First Data Taking

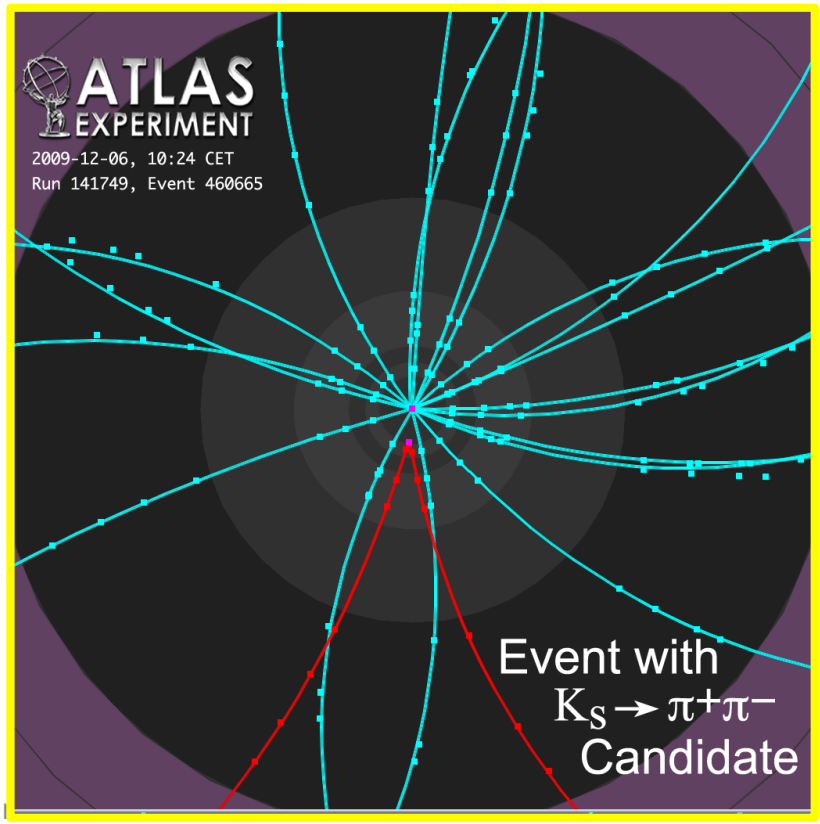
- The very first p-p collision in the ATLAS experiment was recorded on 23 November 2009 at 14:22!



Start of Data Taking

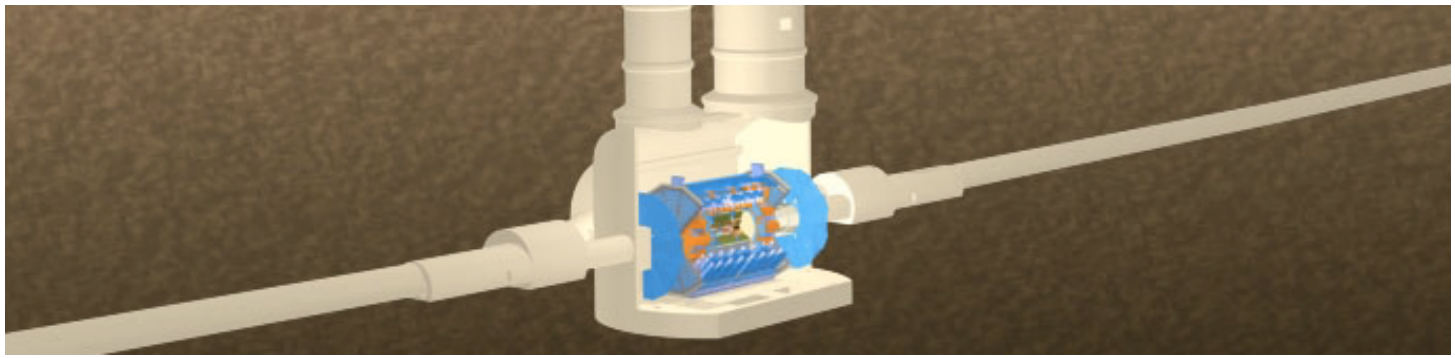
- Sunday 6th December 2009, early morning:
  - LHC declares stable colliding beams at 900 GeV!
  - "Unfortunately" we were sent home at 4:30 a.m. with the message "no stable beam before Sunday evening"
  - with stable beams the ATLAS detector has been fully turned on for the first time since the LHC started!

Data Taking has started!

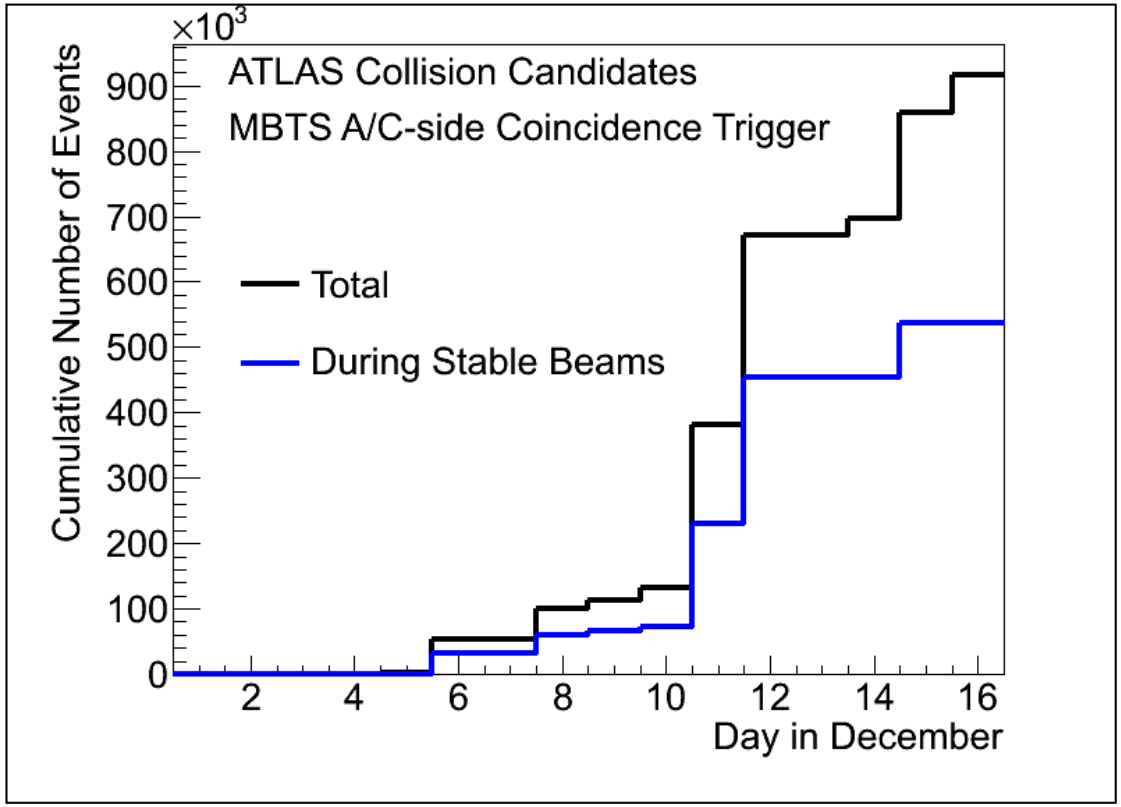


Data Taking in 2009

- Data taking lasted for about 2 weeks (6.-16.12.)
- The baseline energy for collisions was 900 GeV
- For a few days the energy was raised to a world record of 2.36 TeV!
- The ATLAS detector was (mostly) fully operational and the full data taking chain from online to offline was performing very satisfactory!



Data Taking

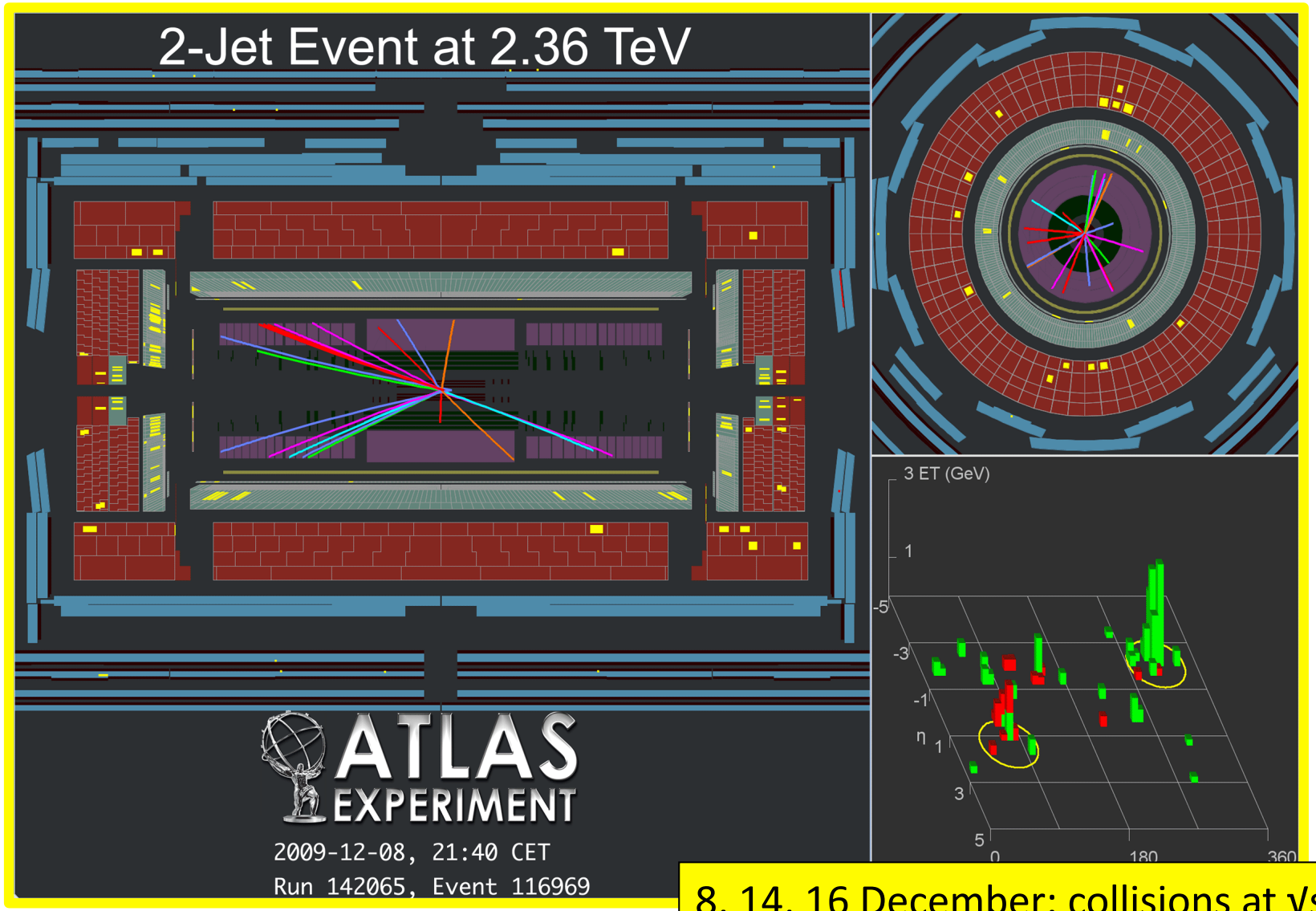


Max peak luminosity seen by ATLAS :
~ 7 x 10^{26} cm^{-2} s^{-1}

LHC design luminosity:
~ 10^{34} cm^{-2} s^{-1}

Recorded data samples	Number of events
Total	~ 920.000
900 GeV with Full Detector On (LHC stable beams)	~ 540.000
2.36 TeV (world record), Pixel and SCT off	~ 34.000

Collisions at 2.36 TeV!

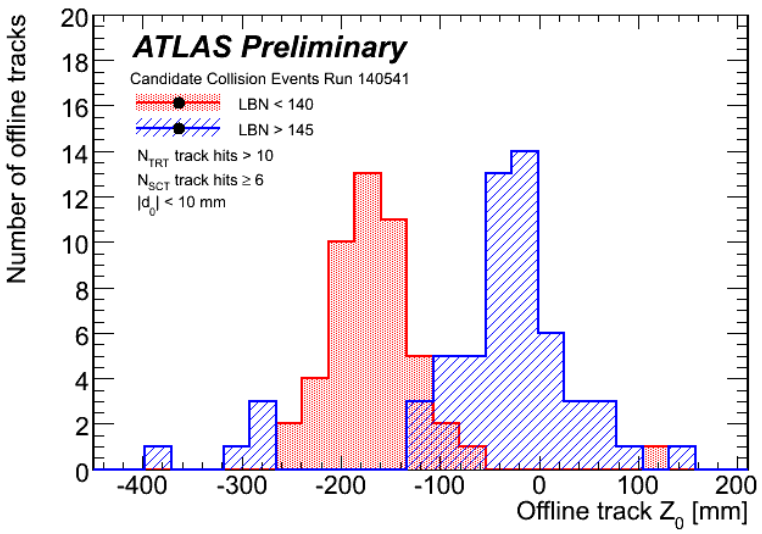


8, 14, 16 December: collisions at √s = 2.36 TeV
→ATLAS records ~ 34000 events

First data – what now?

- With real data the real work (and fun) starts!
- Finally we can start to (try to) …
  - "understand the detector" – it's a large apparatus!
  - Calibrate the detector
  - Align the detector
  - Understand performance using known physics
  - "Confirm" already published results
  - debug the software, improve things, and and and …
- Start of data taking is just the tip of the iceberg!
- But the 900 GeV data is very important to be ready for the higher energy collisions up to come in 2010!

Very First Data (23.11.09)

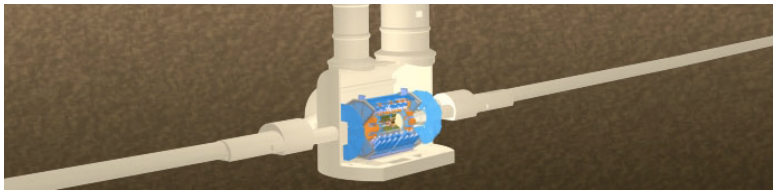


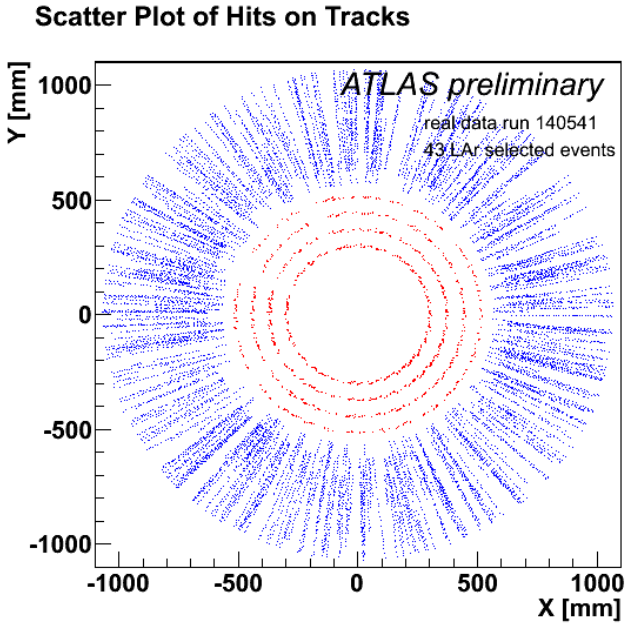
Track z position in the very first collision data:

- offset in track z was observed (red line)!
- offset is confirmed by beam pickup system
- ID tracking experts are happy!

LHC performs "RF adjustment" to correct z shift:

- offset in track z should vanish and …
- … yes it did (blue line)!
- ID tracking experts are in heaven!





Scatter plot of hits on tracks in first collision events.
TRT hits are shown in blue, and SCT hits in red.
Pixel detector was off, SCT was at reduced voltage.
The solenoid magnetic field was zero,
tracks are straight.

Selection of plots from Sub-Detectors

Alignment

Calibration

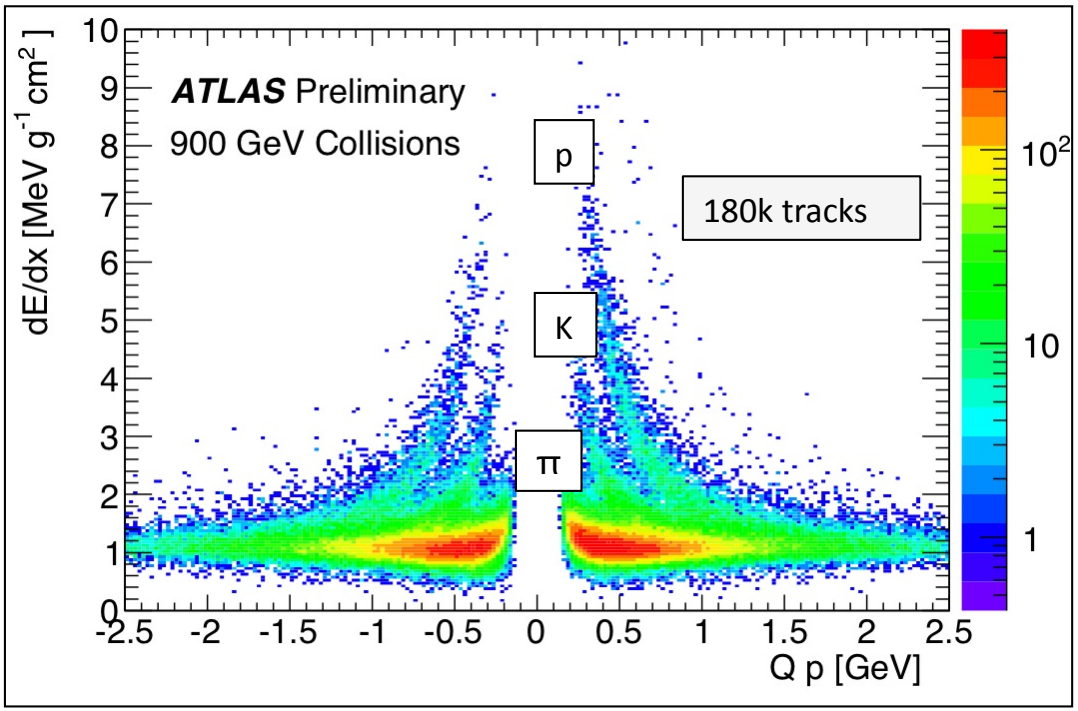
Performance

Pixel Detector

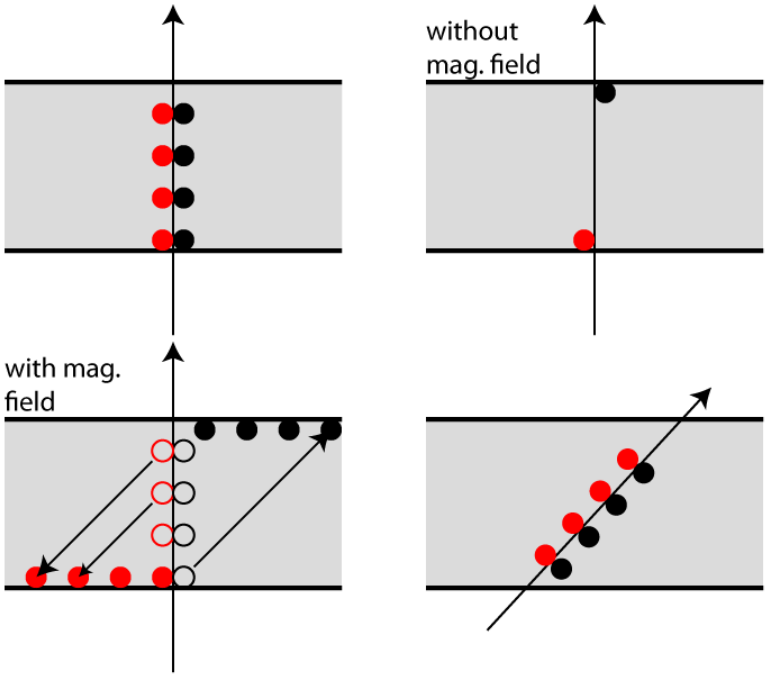
Energy deposit in the pixels:

Due to the analog read out of the pixel system one can measure the energy loss of traversing particles. Protons and kaons are easily identifiable.

For positive charge one can imagine to see deuterons!



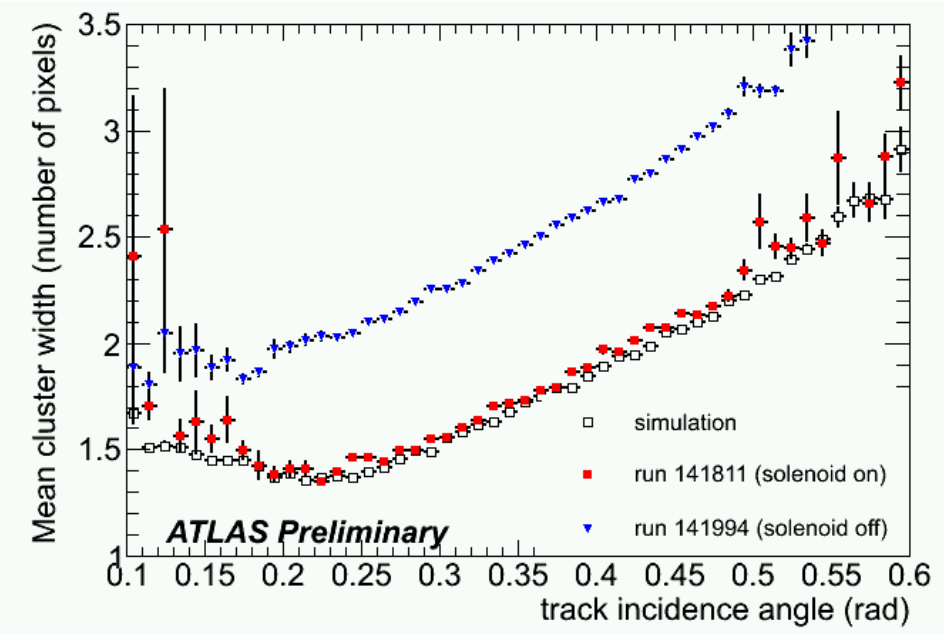
Pixel Detector



Without B field on:
The minimal cluster width is at
0 incident angle

With B field on:
The minimal cluster width is at
the so called lorentz angle

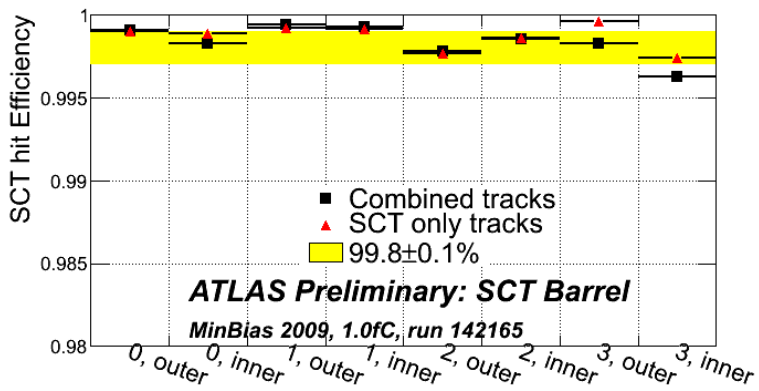
<u>Pixel cluster width and Lorentz angle:</u>
The cluster width depends
on the incident angle of the track.
The magnetic field in the Inner
Detector causes the charge to drift
a bit before it is collected.

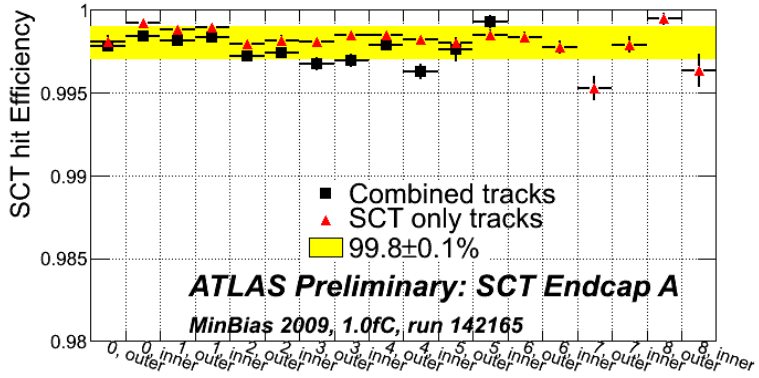


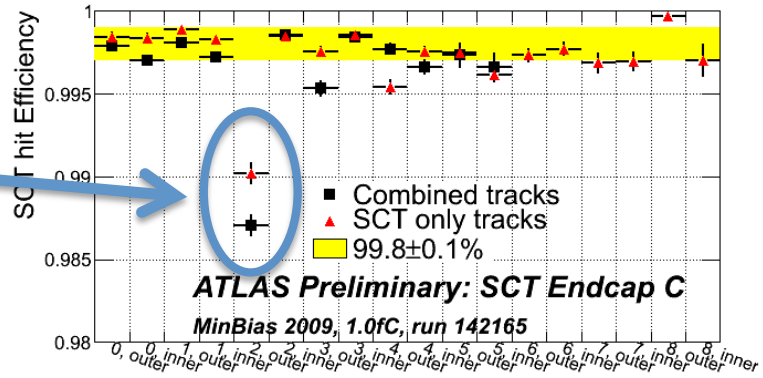
6° → 34°

SCT Detector

- Hit Efficiency:
  - If a charged particle traverses an SCT module, how likely will this be measured?
- This can be computed by looking at well reconstructed tracks and how often they miss hits which should have been recorded!
- The SCT hit efficiency has been measured to be >99.7 %.
- Inefficiencies give hints to possible problems in the hardware or software!

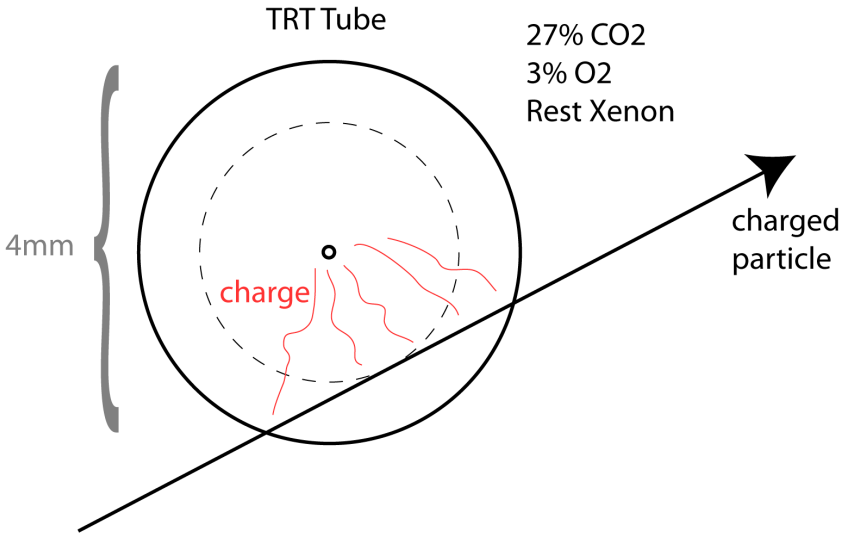


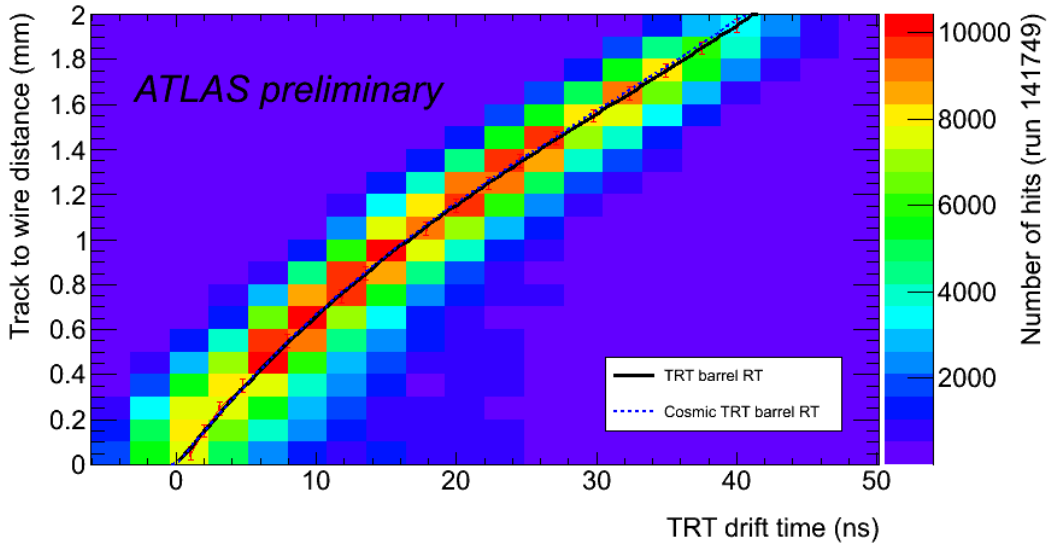




TRT: Calibration

TRT straws are filled with a Xenon gas mixture.
A charged particle ionizes the gas in the TRT.
The free charge drifts to a wire in the the center of the straw and causes an electric signal.
With a tube radius of 2 mm the measurement error is large! (4mm/sqrt(12))





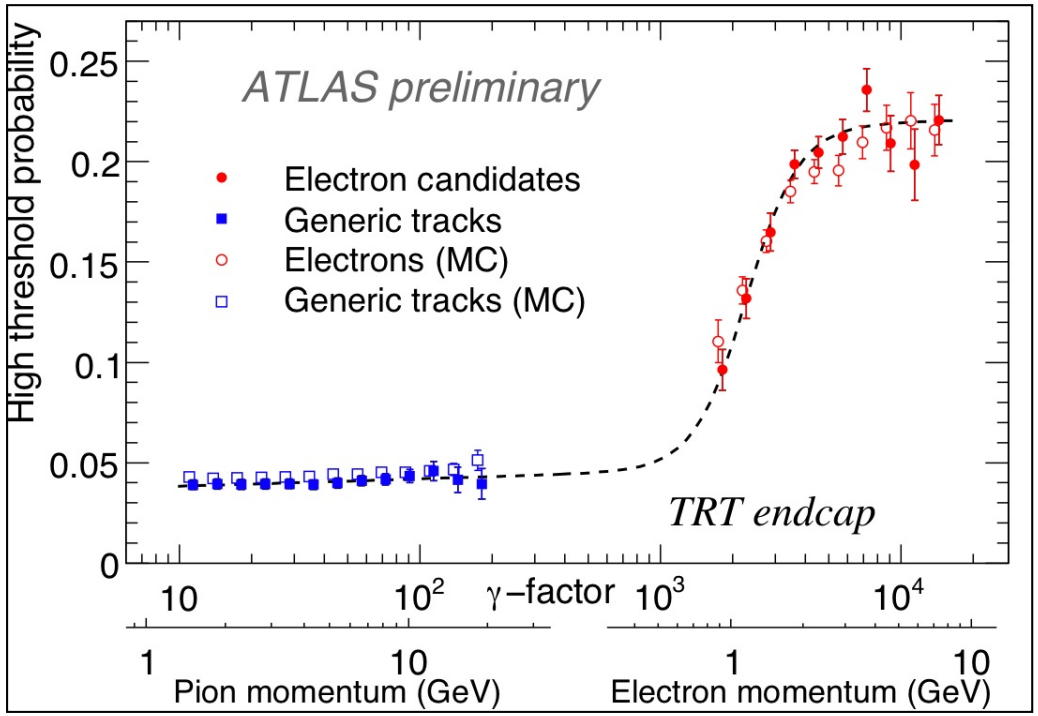
Radius-Time relation:
Knowing the dependence of the track to wire distance on the charge drift time improves the measurement (to ~150 um).

Particle Identification in the TRT

A charged particle traversing the TRT emits photons (== transition radiation)
The intensity of this radiation is proportional to the Lorentz (gamma) factor $\gamma = E/m_0c^2$ of the traversing particle.

This can be used separate particles:

Pions are heavier (m~500 MeV), than electrons (m~0.5 MeV). Therefore pions with the same momenta as electrons have a much smaller Lorentz factor!

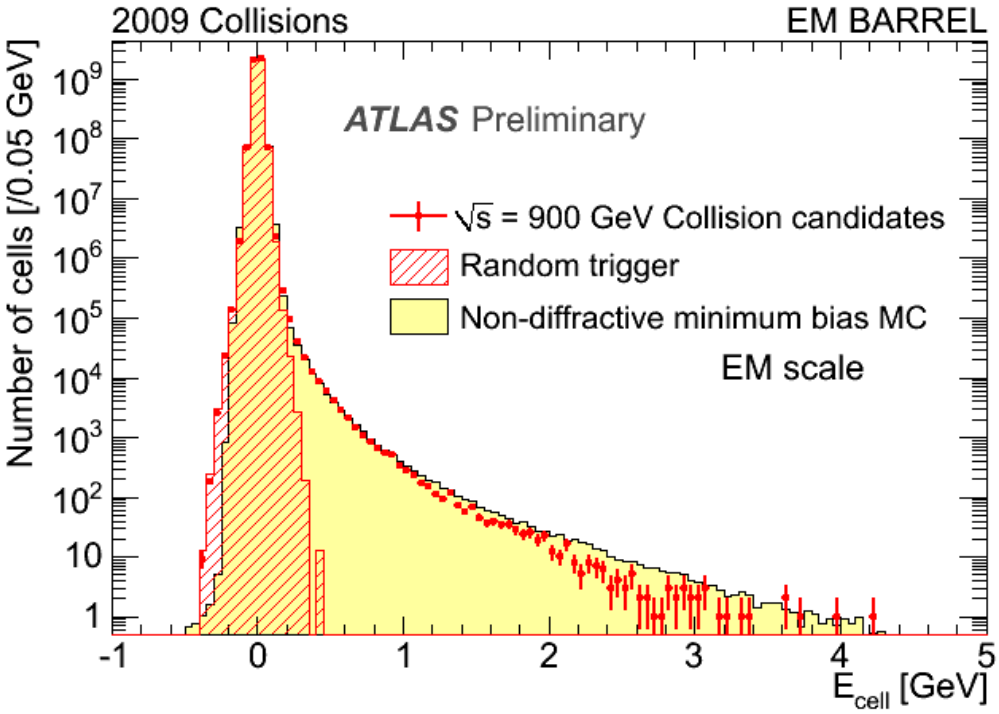


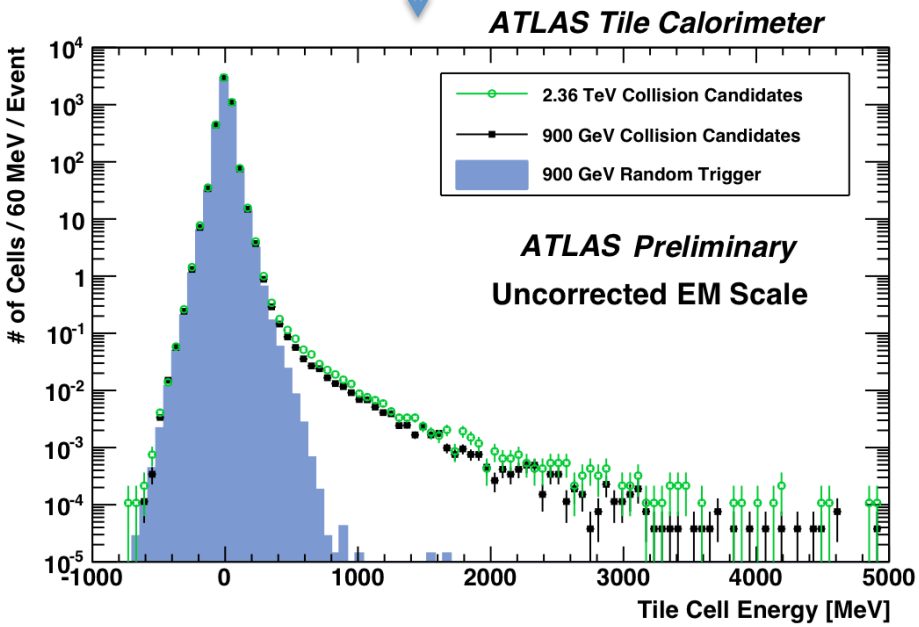
By requiring a certain amount of high threshold hits on a track in the TRT one can separate pions from electrons!

Cell Energies in the Calorimeters

Distribution of cell energies in the barrel of the electromagnetic liquid argon calorimeter

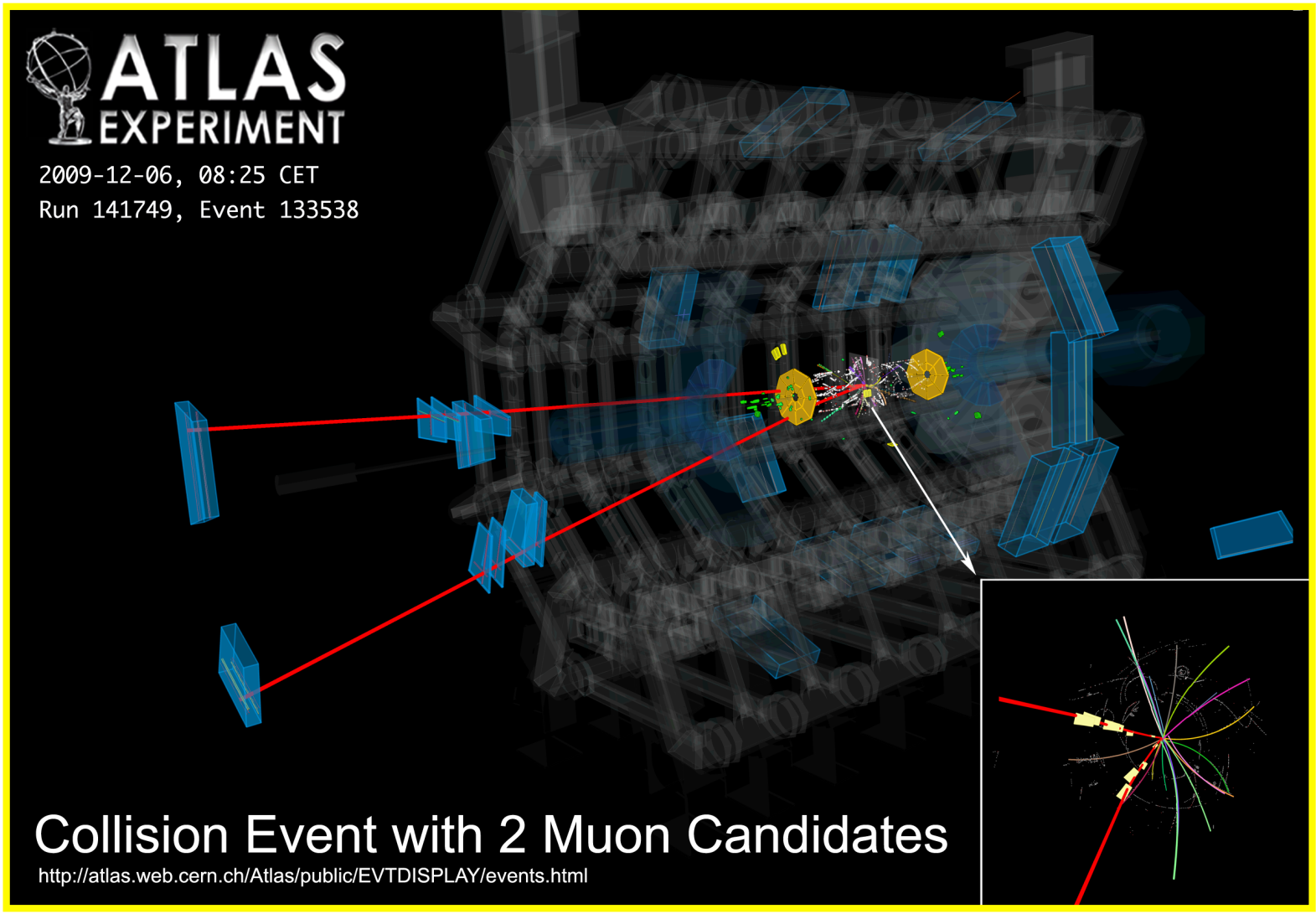
and in the hadronic tile calorimeter





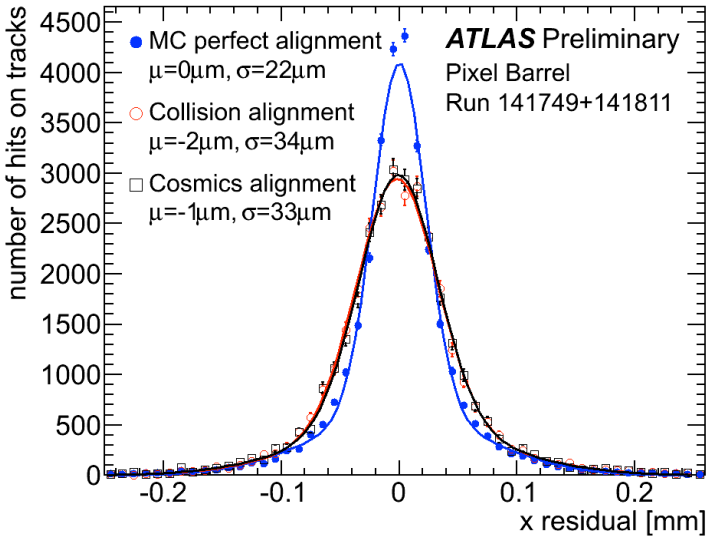
Most cells have no energy deposit
("min bias" events are not very busy …)

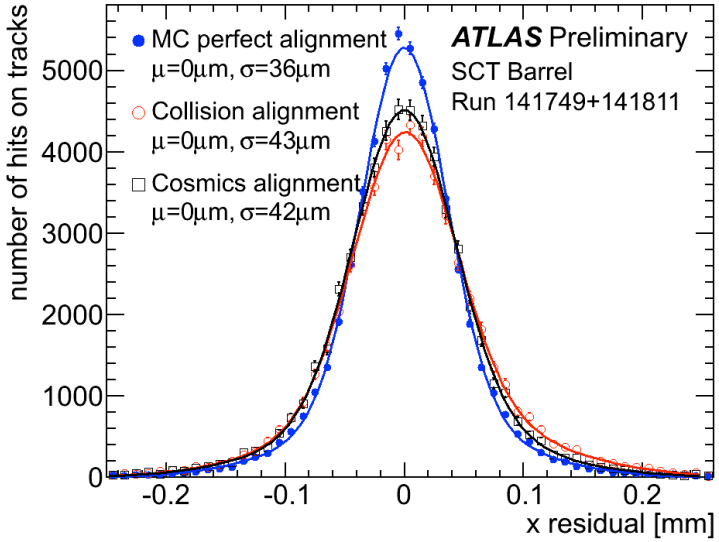
Muon Spectrometer



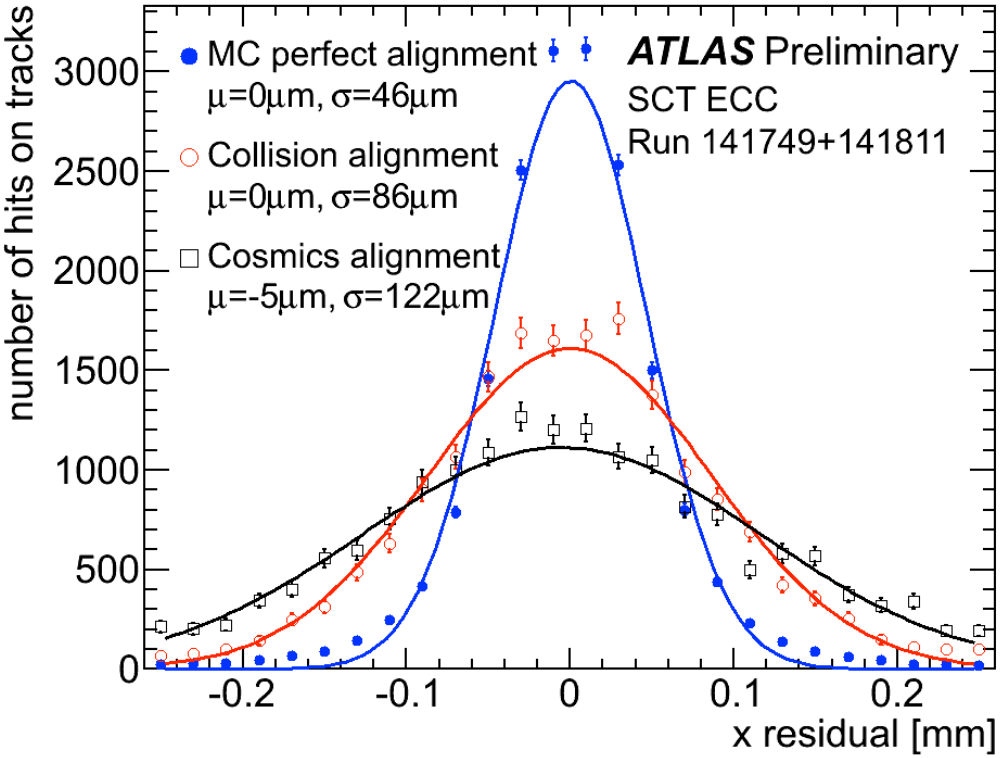
"Alignment" of the Inner Detector

- It actually means to find out where all the detector modules really are – in contrary to where we think they are!
- Data from 2008/2009 cosmic ray data was used for a first alignment of the detector for first data
  - Excellent job done by the Valencia group!
- New alignment with collision data improves residuals further (especially in the endcaps where tracks from cosmic ray data are not very helpful).





Alignment

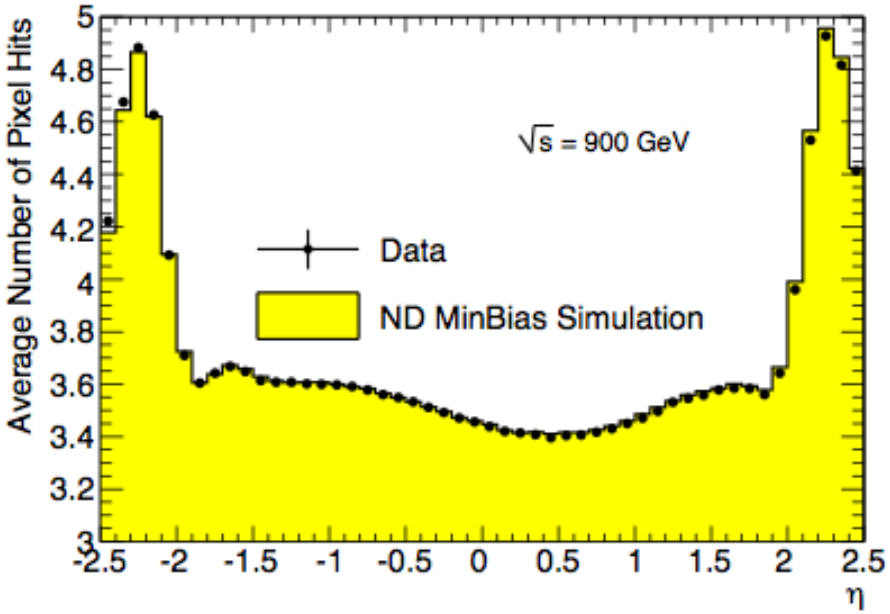


Alignment in endcap C was improved a lot with data from first collisions.
The troubles in the hit efficiencies in endcap C disappeared (second source was a hardware trouble with the cabling).
Unfortunately the new SCT hit efficiency plot proving this has not yet been approved …

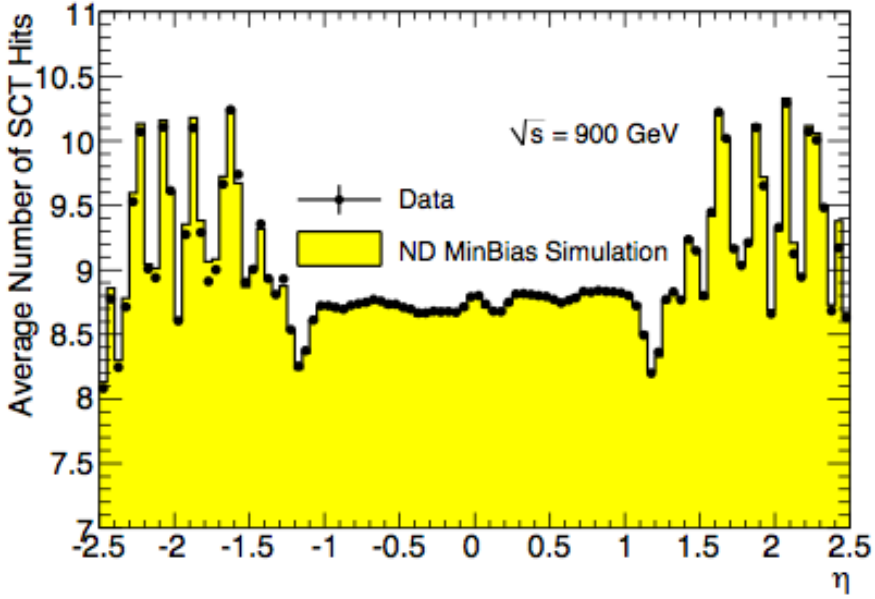
$\langle N_{hits} \rangle$ in Pixel/SCT

- But I can show the latest approved plots showing a MC comparison of average number of hits on track in pixel and SCT barrels (work for min bias paper)
- The agreement is excellent!

Pixel Barrel



SCT Barrel



“Combined” Performance Plots

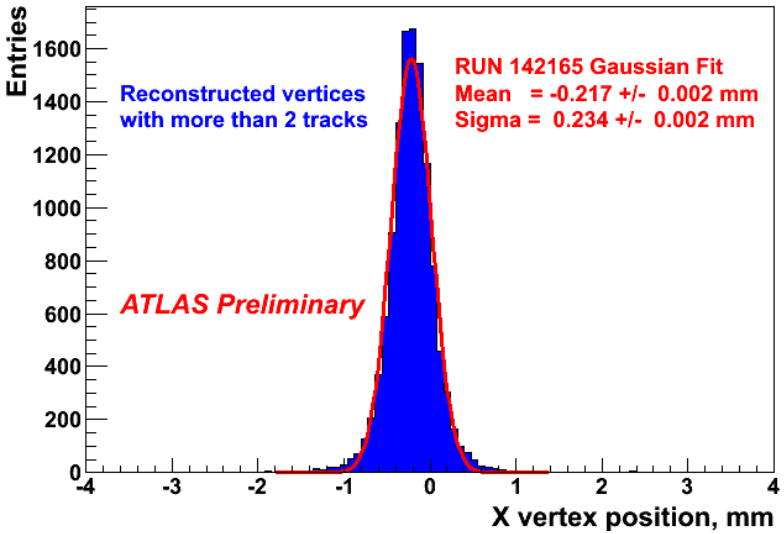
Primary Vertex

Conversions

K_s, Λ, π_0, …

Primary Vertex

- The primary vertex is the point where the two protons collide
- The PV is very important for many physics analyses:
  - First data: the minimum bias analysis of charged track distributions uses it to improve selection of primary tracks



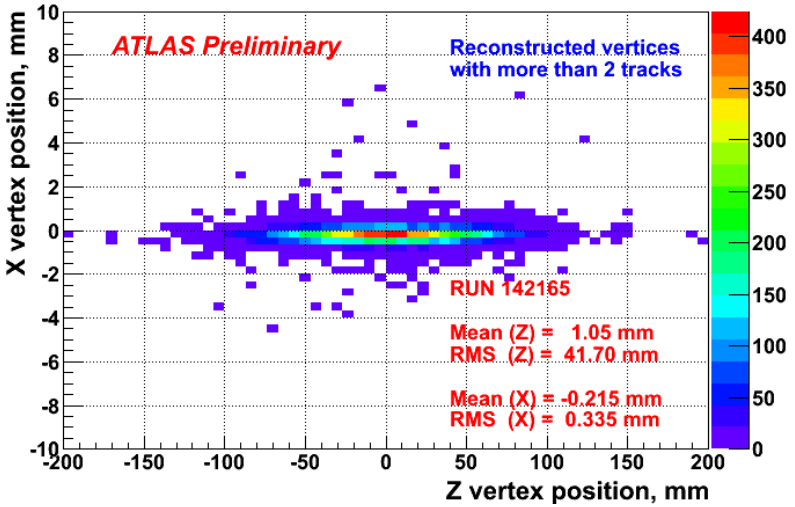
Reconstructed position of PV in x:

The spread is in agreement with what is expected from the LHC!

PV position in X-Z:

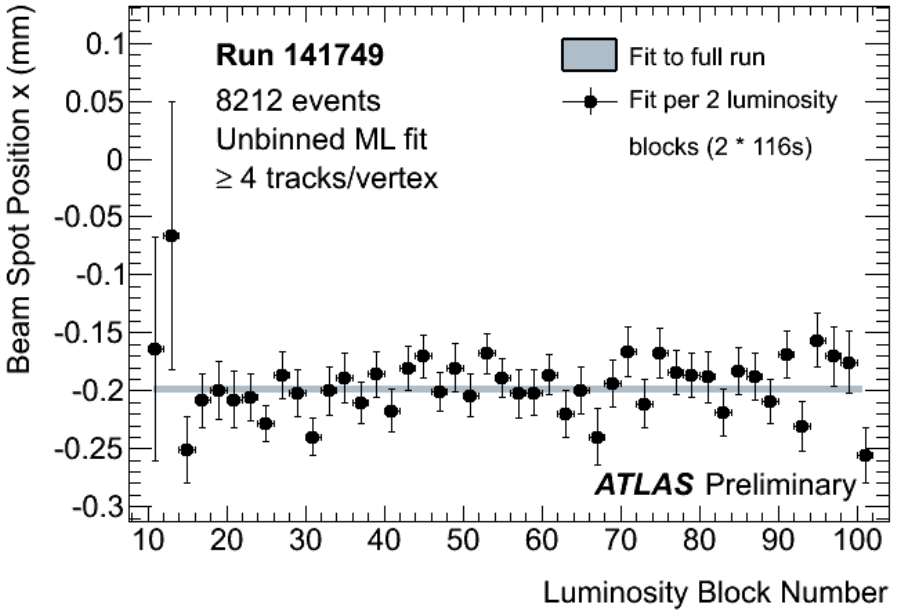
Spread in Z seems to be half the size of What LHC people tell us it should be:

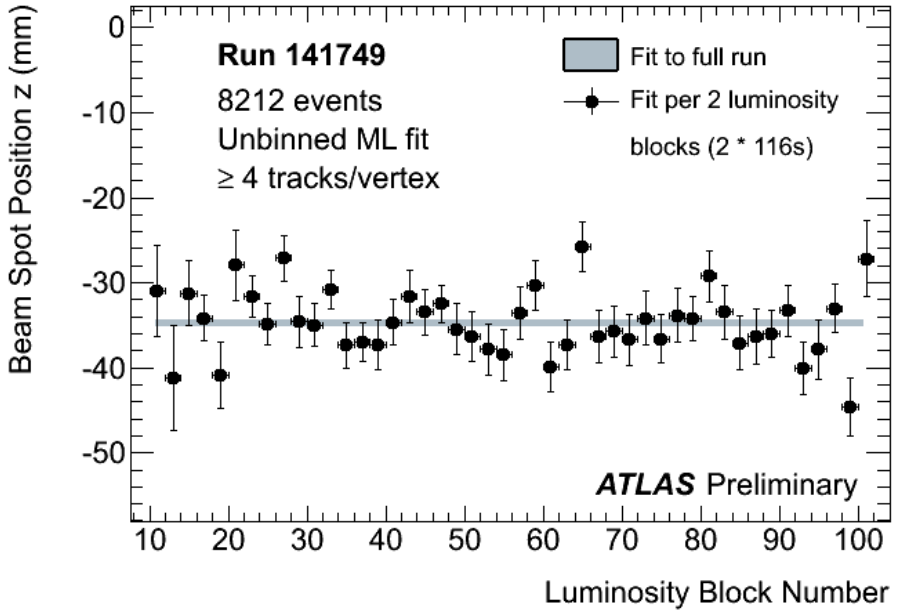
Well … they were wrong! ;-)



Beamspot

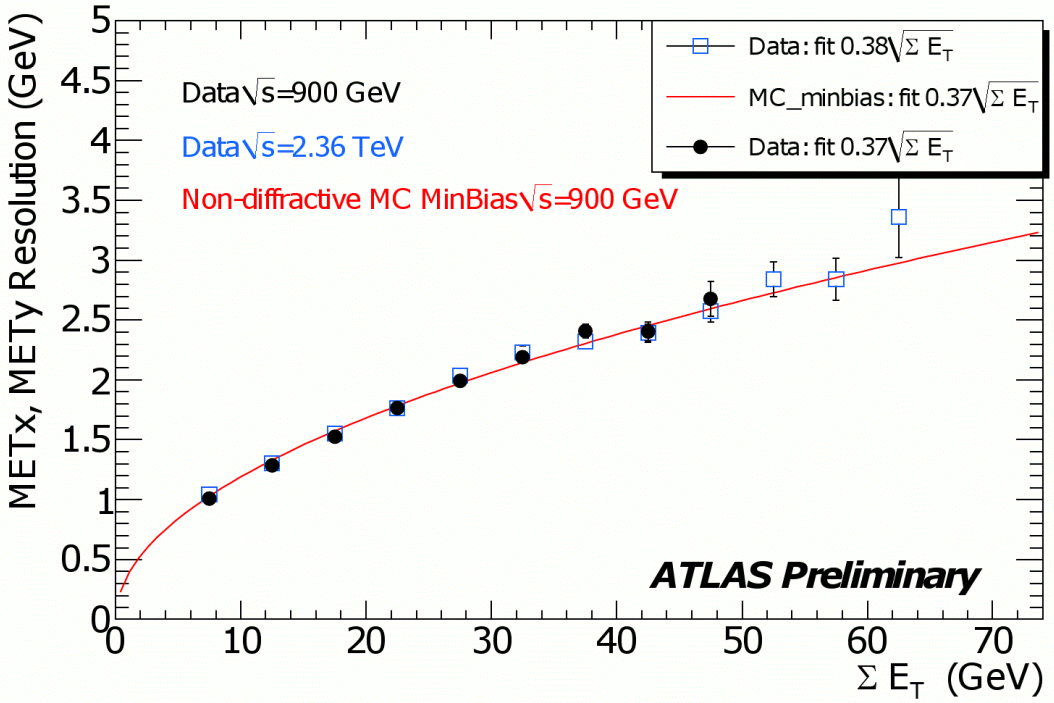
- Beam spot: where on average do the protons collide?
- The position of the beam spot is determined from PV
- In a reprocessing of the data it is used to improve the position of the PV (beam constraint, track selection)





Missing Energy

- Neutrinos "carry away" energy ➔ missing in the detector
- Measurement of missing energy is important especially for SuSY
- Resolution of the x and y components of the missing transverse energy as a function of the total sum of the transverse energy:
- Measured at centre-of-mass energies of
  - 900 GeV
  - 2.36 TeV
  - and a fit to the Monte Carlo simulation

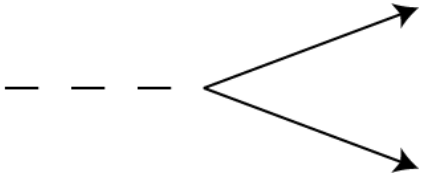


Reconstruction of "Resonances"

- Decays of well known particles are used to test our detector and reconstruction software
- At E_{cm} = 900 GeV these decays are looked at

$$K_s^0 \rightarrow \pi^+\pi^- \qquad \pi^0 \rightarrow \gamma\gamma$$

$$\Lambda \rightarrow p\pi^-,\ \overline{\Lambda} \rightarrow \bar{p}\pi^+$$

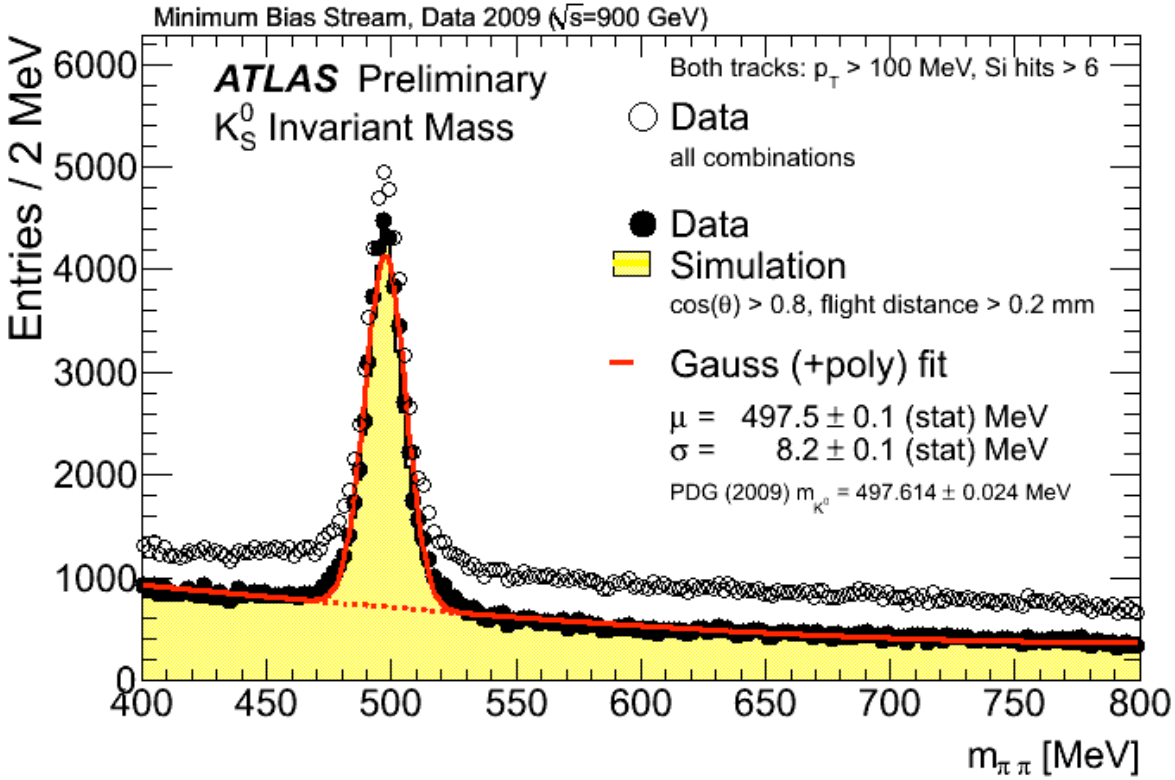


- At higher energies more particle decays can be looked at and used to measure e.g. the tracking efficiency of the Inner Detector, for example:

$$J/\Psi \rightarrow e^+e^-,\ J/\Psi \rightarrow \mu^+\mu^-$$

$K^0_s \rightarrow \pi^+\pi^-$ (BR ~70%)

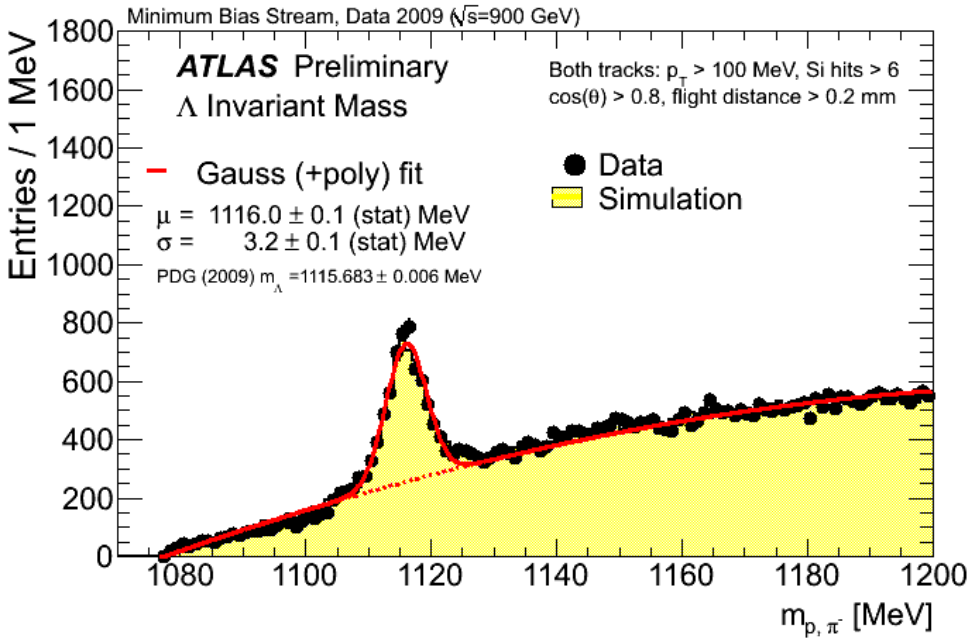
- Invariant mass distribution of two track vertices from 400 to 800 MeV.
- Reconstruction and cuts:
  - No mass constraint during the vertex fit
  - Tracks have opposite charge
  - Distance of reconstructed secondary to primary vertex > 0.2 mm in transverse plane
  - Flight path of the vertex candidate points back to primary vertex
  - Invariant mass is calculated assuming that both tracks are pions

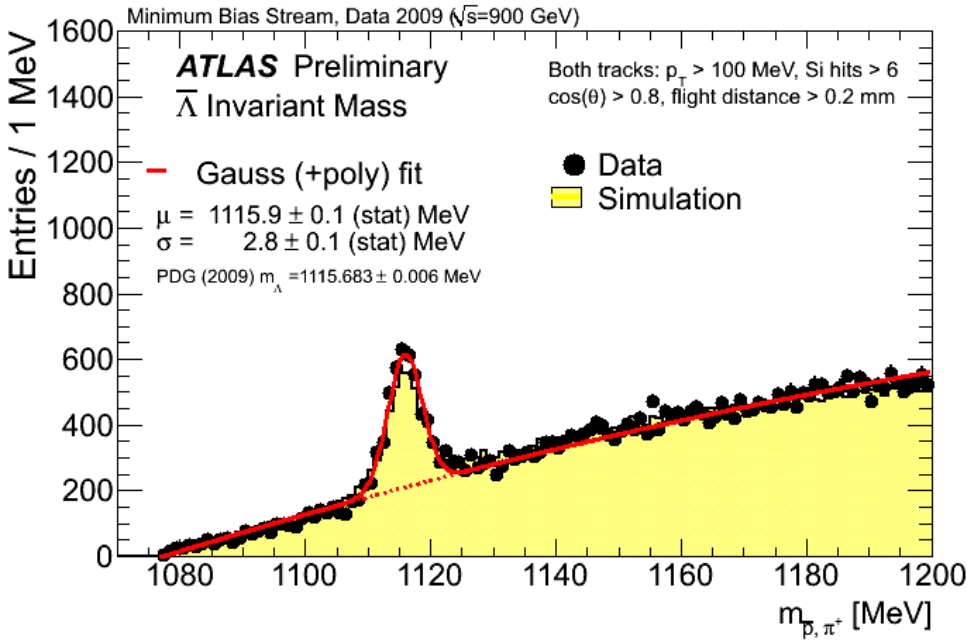


- A peak around 500 MeV is clearly visible.
- (Reminder: we are not trying to measure any K_s cross section here!)

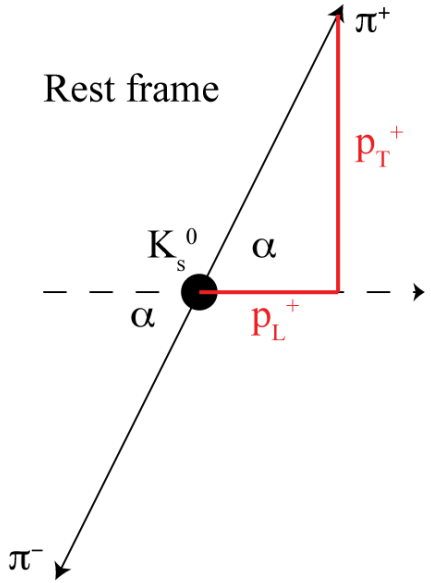
$\Lambda \rightarrow p\pi^-$, $\overline{\Lambda} \rightarrow \bar{p}\pi^+$ (BR ~64%)

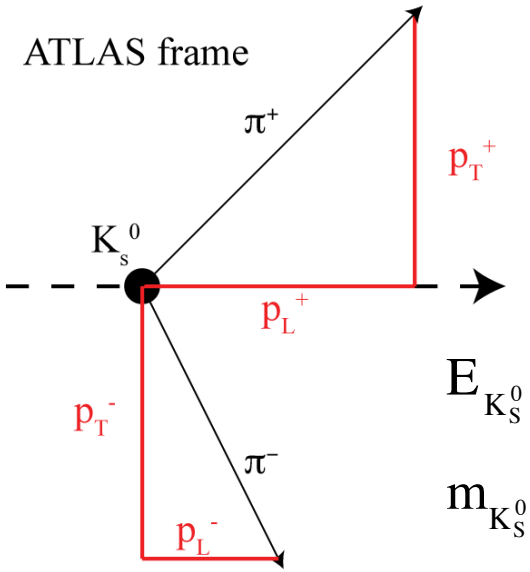
- The reco procedure and cuts are the same as for K_s
- The invariant mass is calculated assuming that the positively charged track is a proton and the negatively charged track is a pion.

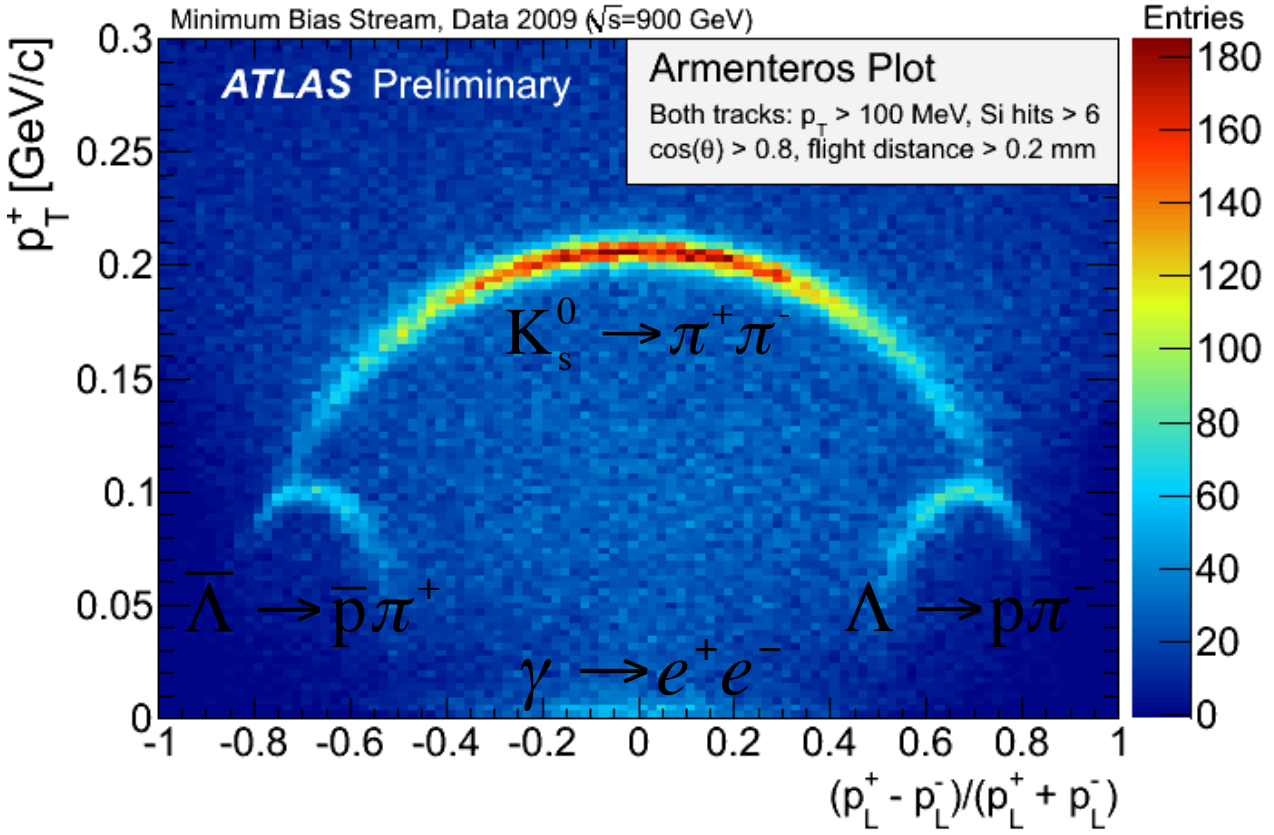




Armenteros Plot







Maximum p_T^+ is when decay is normal to flight axis, e.g. K decay:

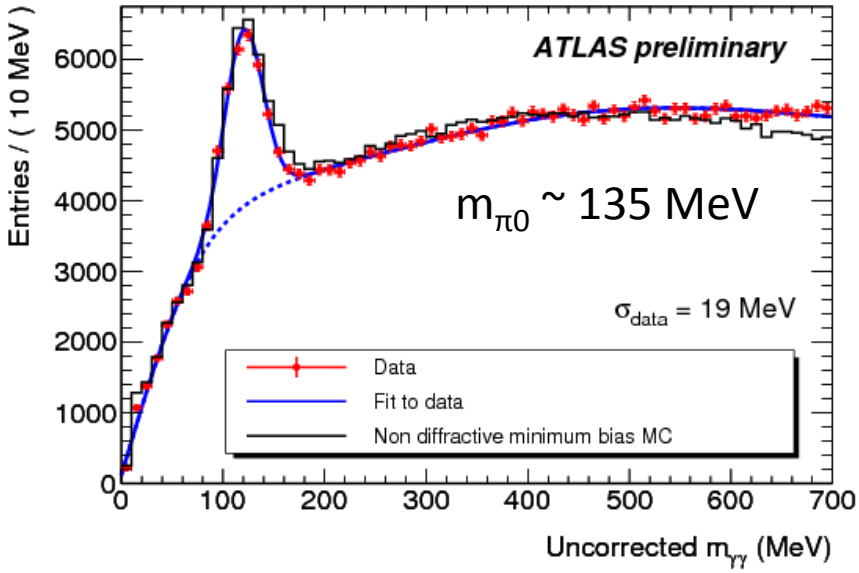
$$E_{K_S^0} = E_{\pi^+} + E_{\pi^-}$$

$$m_{K_S^0} = \sqrt{m_{\pi^+}^2 + p_{\pi^+}^2} + \sqrt{m_{\pi^-}^2 + p_{\pi^-}^2}$$

$$p_{\pi^+} = \sqrt{\left(m_{K_S^0}/2\right)^2 + m_{\pi^+}^2} = 0.206\,MeV$$

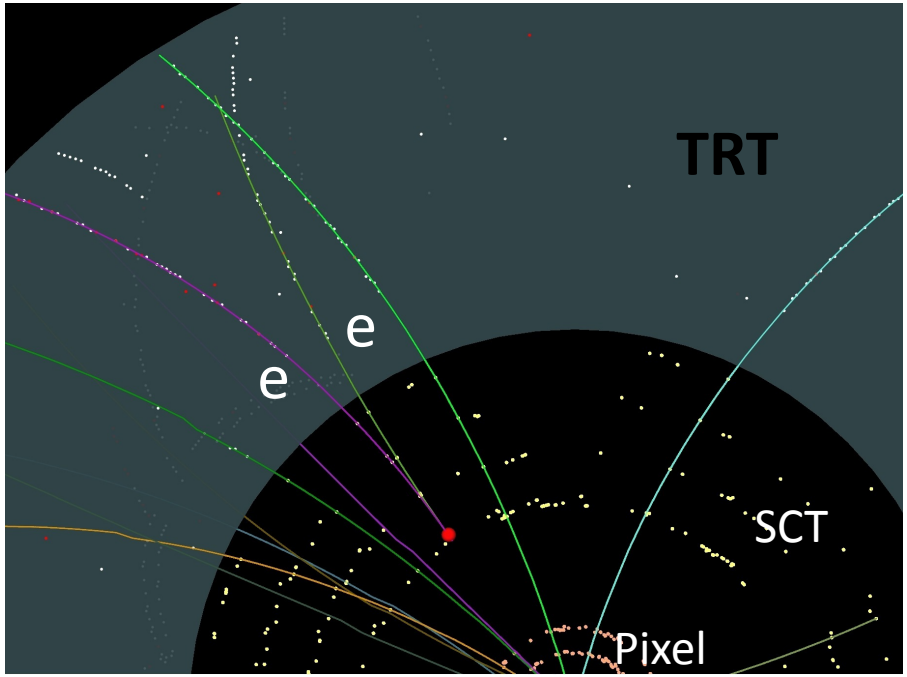
$\pi^0 \rightarrow \gamma\gamma$ BR ~ 98.8%

- Invariant mass distribution of two photon candidates
  - E_t(photon) > 300 MeV
  - E_t(2 photons) > 900 MeV
  - Shower shape compatible with photon
  - No material correction (ID!)
- Peak position difference between data and MC is about 1.5 MeV (1%)
  - which is well within the expected un-certainty known test-beam



- The mass resolution is 19 MeV, it agrees between data and MC
- Other decay of π^0 (Dalitz decay) is possible background to conversions (see next slide): $\pi^0 \rightarrow e^+e^-\gamma$ with BR ~1.2%

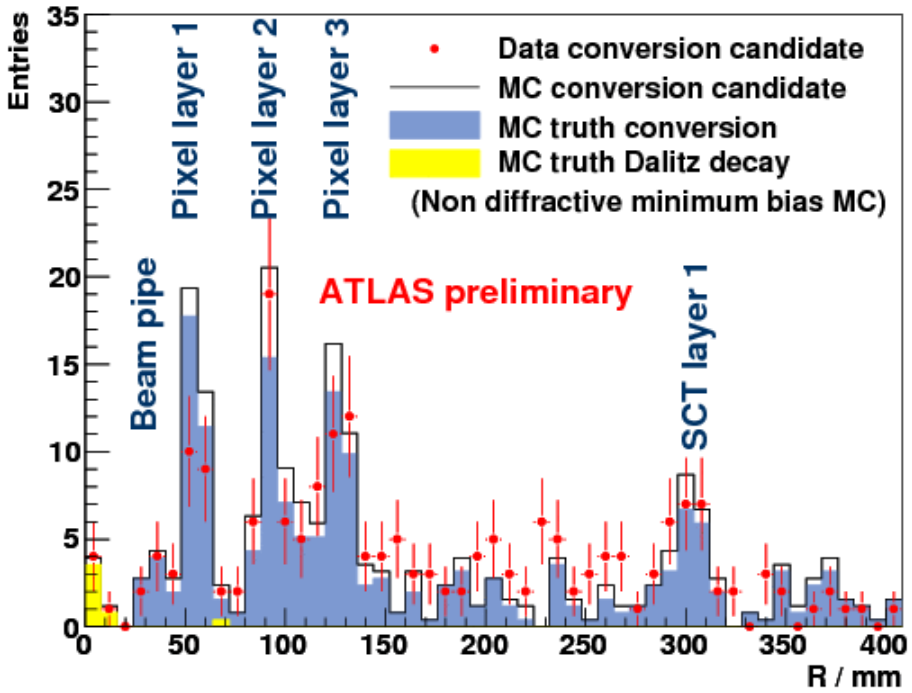
Conversions $\gamma \rightarrow e^+e^-$



Event display of a conversion candidate. The conversion happens in the first layer of the SCT detector.

Conversions are important to map the material in the detector!

Radial distribution of conversion candidates. MC truth conversions are shown in blue and the total conversion candidates in simulation in black. B layer, 1st and 2nd layers of pixel are observed in data in agreement with truth conversion from simulation.



First Physics Paper

The first ATLAS physics paper is about to come! These distributions will be presented:



Draft version 0.2

ATLAS NOTE

February 1, 2010



Charged particle multiplicities from p-p interactions at $\sqrt{s} = 900$ GeV measured at the LHC with the ATLAS detector:

$$1/N_{ev} \cdot \frac{\Delta N_{ch}}{\Delta \eta},$$

$$1/N_{ev} \cdot \frac{\Delta N_{ch}}{\Delta p_T^2},$$

$$1/N_{ev} \cdot \frac{\Delta N_{ev}}{\Delta N_{ch}},$$

$$\langle p_T \rangle \text{ vs. } N_{ch},$$

In support of this paper, 11 internal notes have been written to cover all aspects of the analysis: trigger, tracking, vertexing, corrections, secondaries, …

By the time of this talk the results have not been approved and hence I cannot show anything … sorry!

Outlook and Summary

- Data taking in 2009 was very successful!
- The detector and its performance are much better than we could have imagined at this early stage!
- Several 100 thousand events are currently analyzed to calibrate, align and understand the detector!
- The first ATLAS physics paper
  - Charged Particle Distributions in Min Bias events

  will be published soon!
- ATLAS is ready and looking forward to the 7 TeV data taking in 2010! Stay tuned!

Hector Berlioz, “Les Troyens”, opera in five acts
Valencia, Palau de les Arts Reina Sofia, 31 October -12 November 2009

