From Monte Carlo to Reality - Experiences from ATLAS.

Experiences from 2010 and 2015

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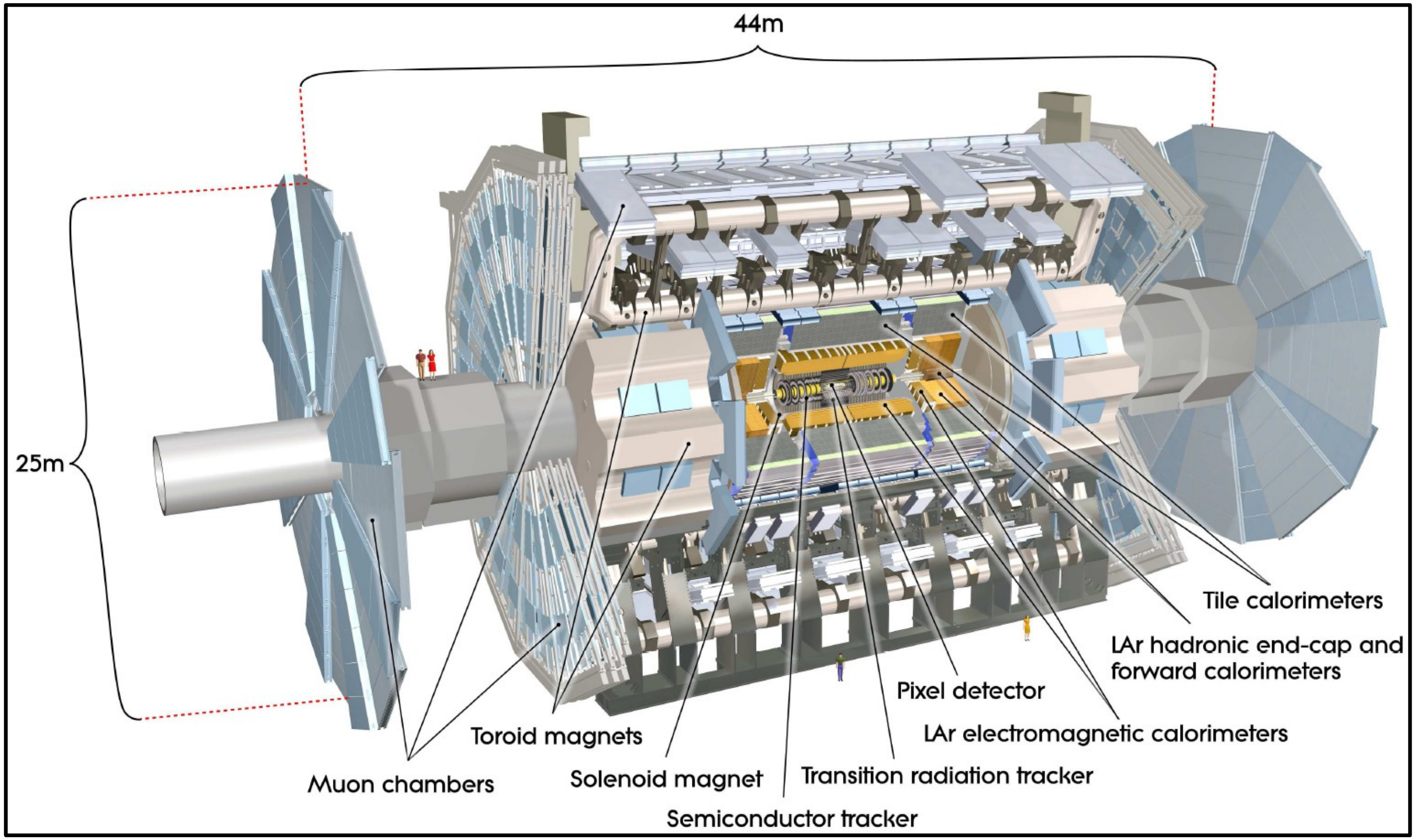
ILD Software and Optimization Workshop
DESY,
25/02/2016

HELMHOLTZ
GEMEINSCHAFT

DESY

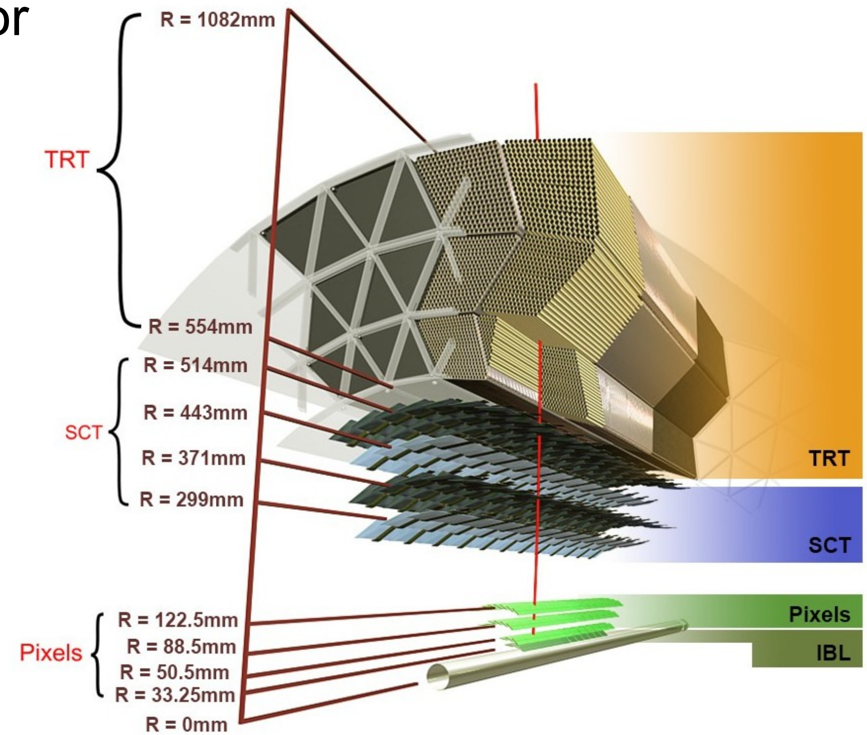
The ATLAS Experiment



- General Purpose Detector at CERN LHC
  - Covers very broad physics program
  - 'Classical' collider experiment layout – forward-backwards symmetric cylindrical detector
  - Separated into barrel & two endcaps

ATLAS Inner Detector

- **>** Innermost component of ATLAS detector
  - Responsible for precision reconstruction of charged particle trajectories
  - Primary/secondary vertexing
  - Electron reconstruction (together with calo)
  - Muon reconstruction (together with MS)
  - B-tagging, Tau identification...
- **>** Comprises 3 different detector technologies
  - High-granularity planar Silicon (Pixels)
  - Silicon Microstrips (SCT)
  - Gaseous Straw Tubes (Transition Radiation Tracker - TRT)



Insertable B-Layer (IBL) added in 2014 – to be discussed later

ATLAS Timeline (up to end of Run 1)

Letter of Intent
1992

Technical Proposal
1994

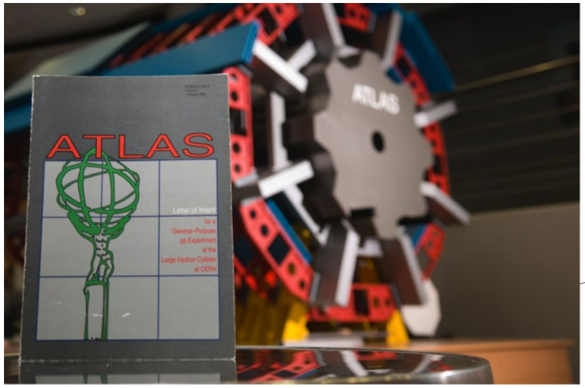
Technical Design Report
1999

Detector Paper
2008

CSC Note
(Expected Performance)
2009

First Physics Paper
2010

Higgs Discovery
2012



Inauguration of Cavern
2003

Switch-on of Toroid
2006

Commissioning with Cosmics
2008/9

First 7 TeV events
2010

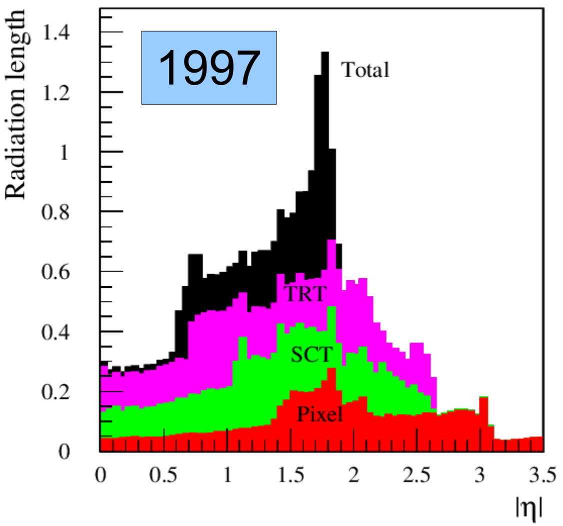
First 8 TeV Events
2012

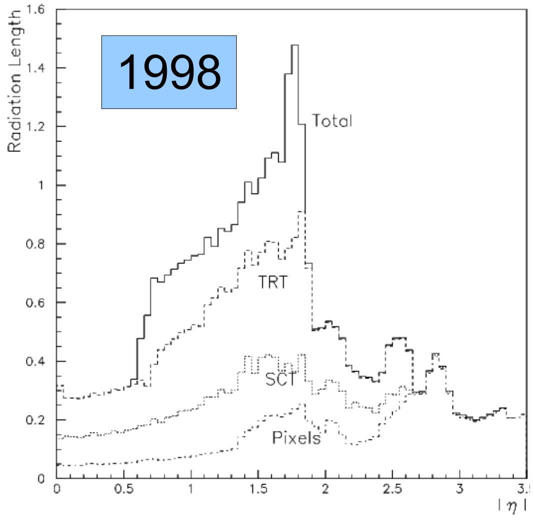
ATLAS EXPERIMENT

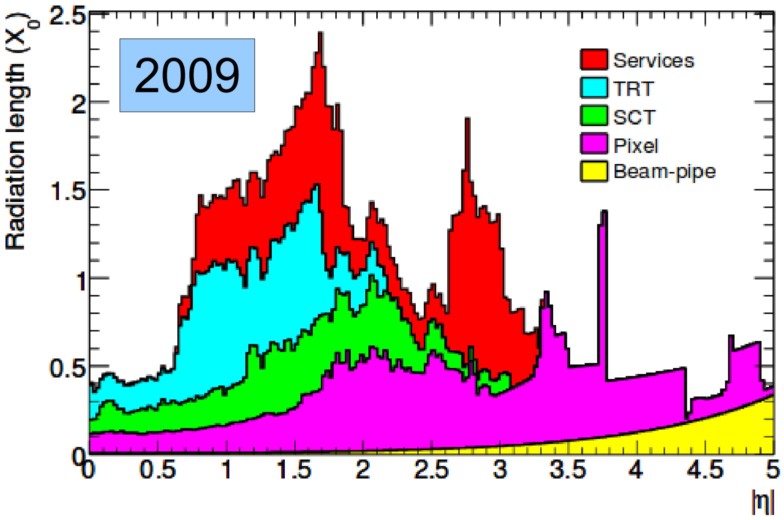
Unexpected changes to schedule...

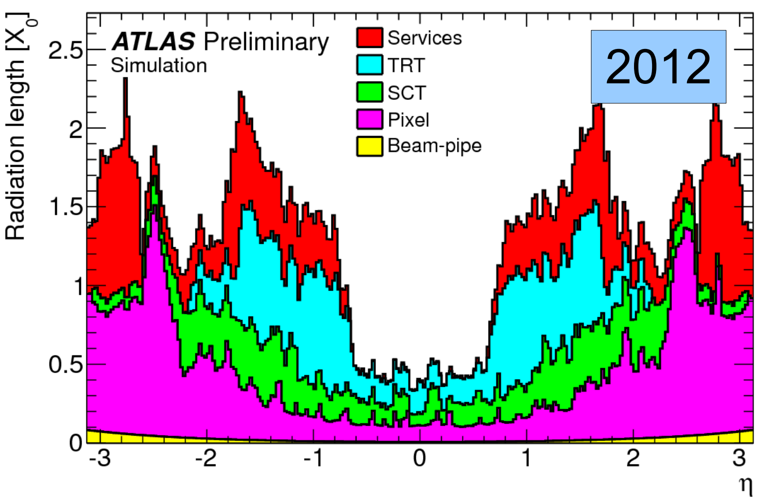
- Delays from LHC Machine schedule allowed extra time to prepare for data
  - Allowed ATLAS to be very well prepared when first collisions arrived!

Development of Detector Material Description









- Amount of material in ID detector description grew significantly since TDR
  - Factor 2 or more increase in some regions!
  - Has significant effect on tracking performance
  - Note differences between shortly-before and after the start of data taking...

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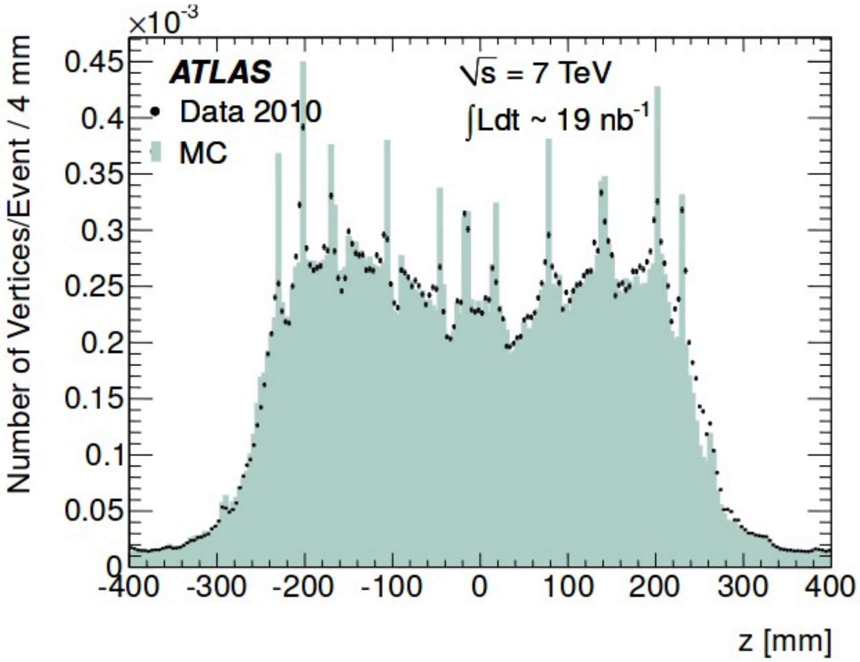
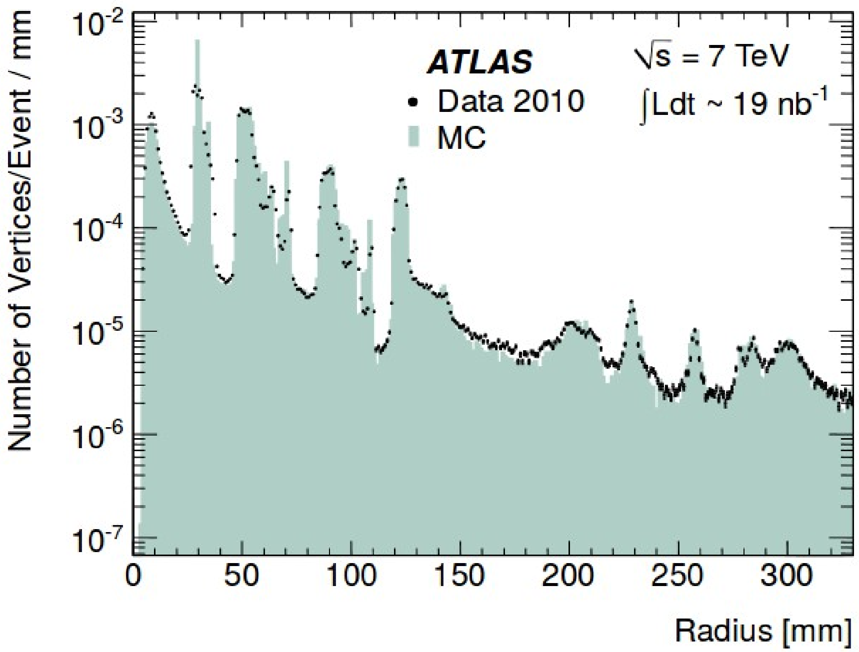
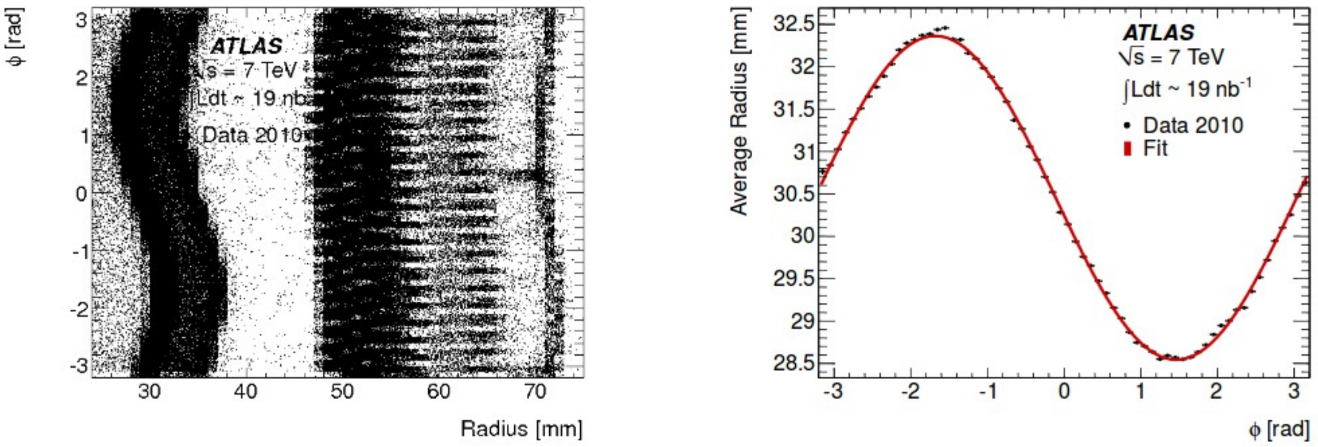
Material Studies in Early Data





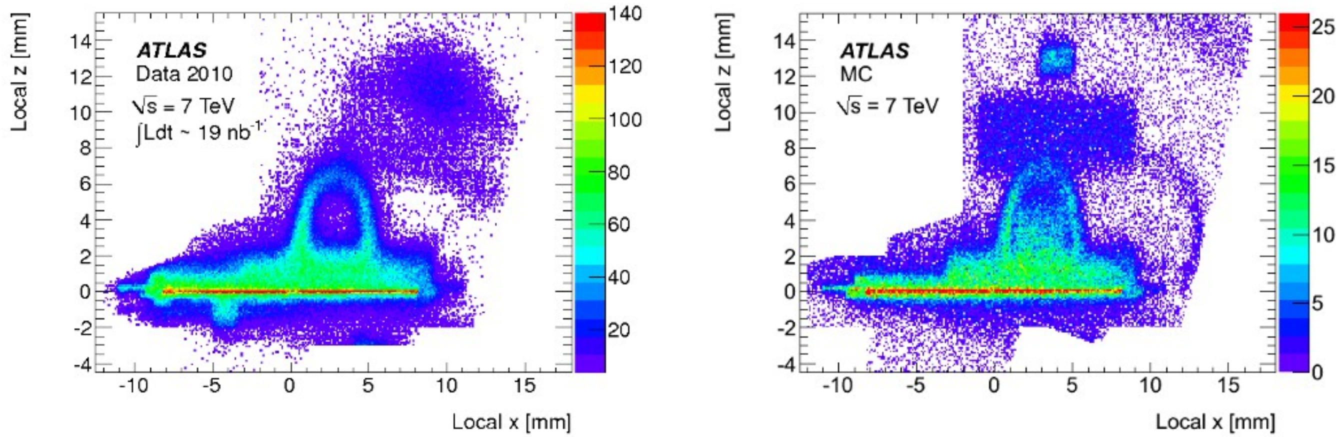
- Inner Detector material probed through hadronic interactions
  - Reconstruct secondary vertices
  - Number and location of secondary decay vertices maps distribution of ID material
  - Makes detailed, precise, comparisons of simulated detector to real detector possible
- Similar studies also performed using photon conversions

Differences between simulation and reality



(a) ϕ vs. R (b) ϕ profile at beam pipe

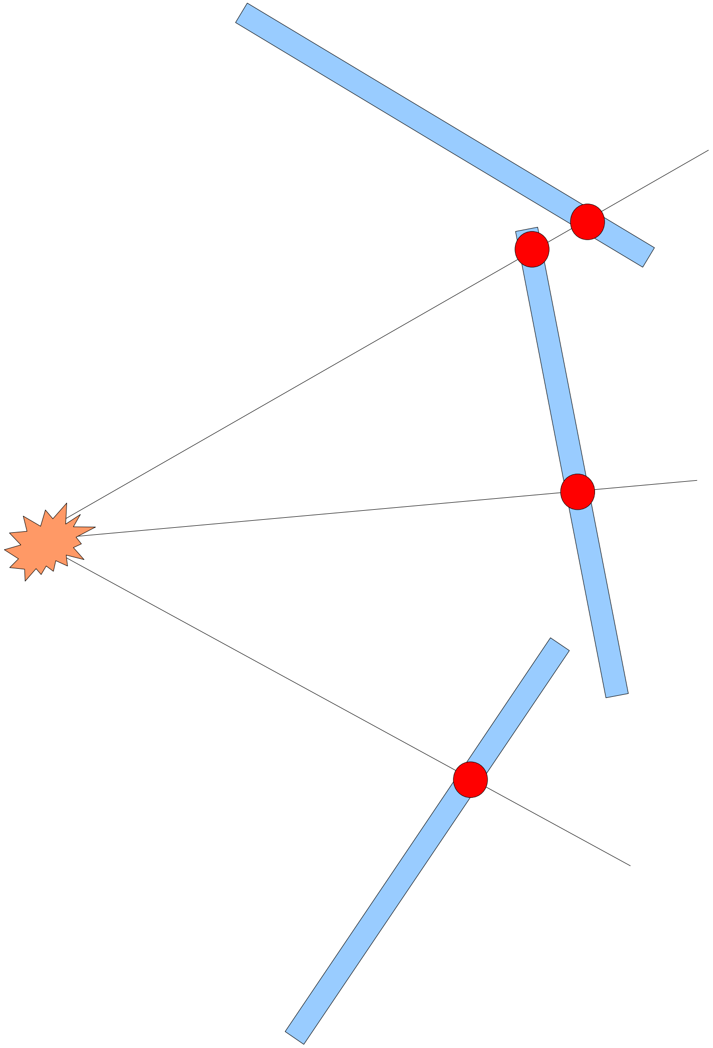
- Beam pipe not located at nominal centre of detector



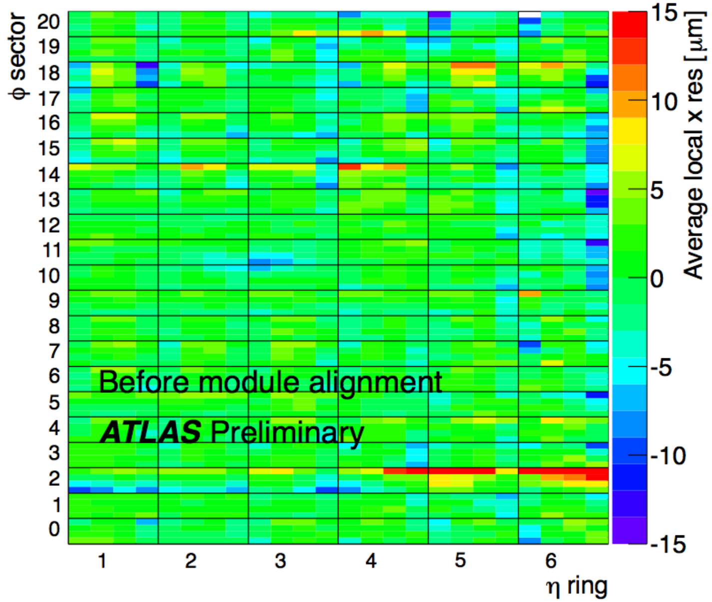
- Phase discrepancies in pixel module coolant cause density differences

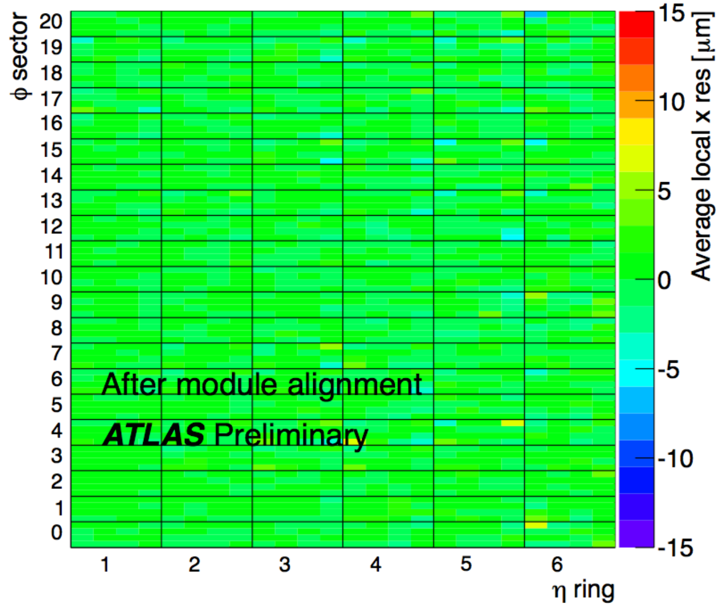
Detector Alignment

- Detector aligned at 3 levels
  - Level 1: Largest structures – barrels, endcaps
  - Level 2: Layers, disks, TRT modules & Wheels
  - Level 3: Individual modules, TRT wires
- Track-based alignment technique
  - Assume track model – minimize hit-to-track residuals
  - Use both “global” and “local” (i.e. with respect to neighbours) X^2 minimization
- Additional constraints
  - Module overlaps offer additional constraints
  - Constraint also from beam spot
  - Especially important for class of distortions under which X^2 is invariant – aka “weak modes”...

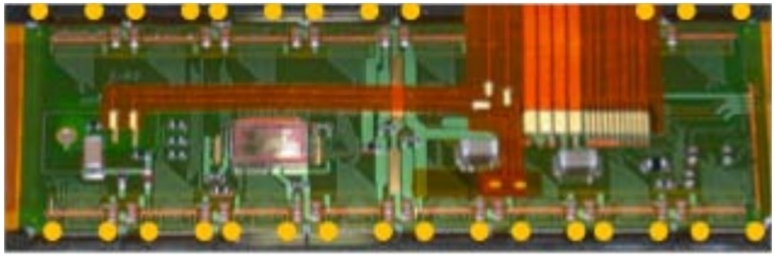


Local Alignments and Pixel Module Distortions

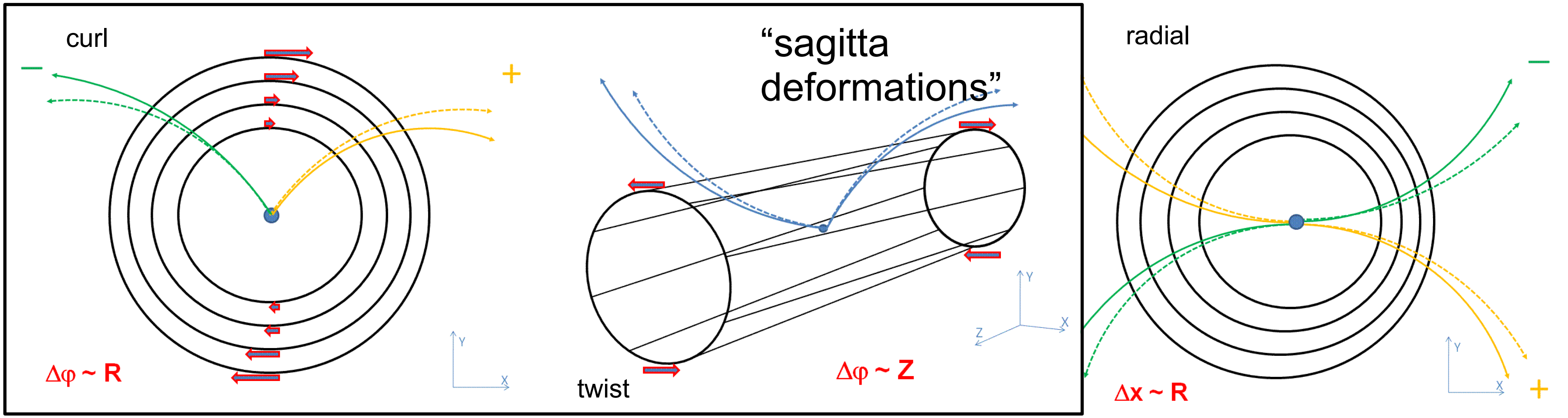




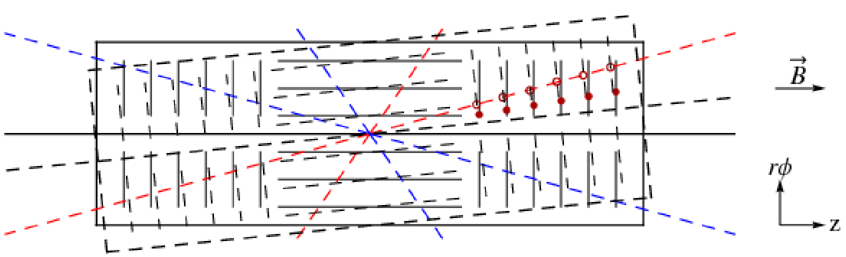
- Pixel modules not flat...
  - Seen from surveys – probably mechanical stress from mounting
  - 'bowing' of modules also correct in alignment
  - Local X^2, only using overlapping modules
  - Minimal SCT bowing

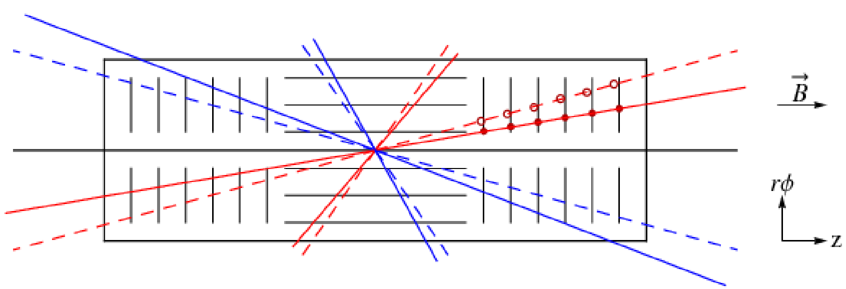


Alignment Weak Modes



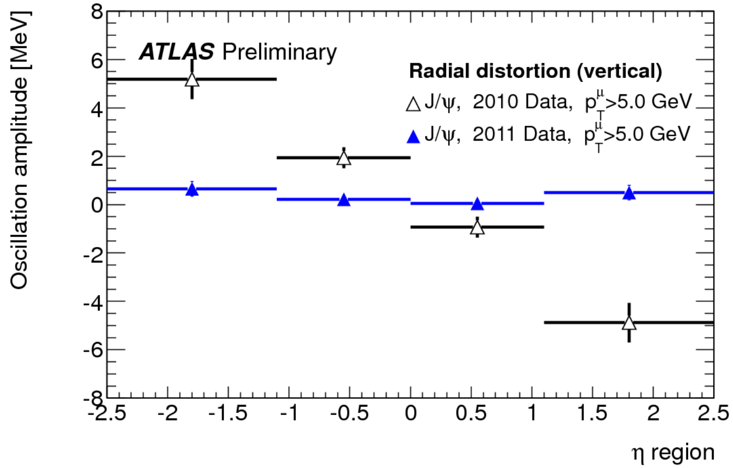
- Both Charge-symmetric and Charge-asymmetric (“sagitta”) deformations possible
  - Affect mainly momentum measurements - B-field misalignments also affect transverse impact parameter d_0

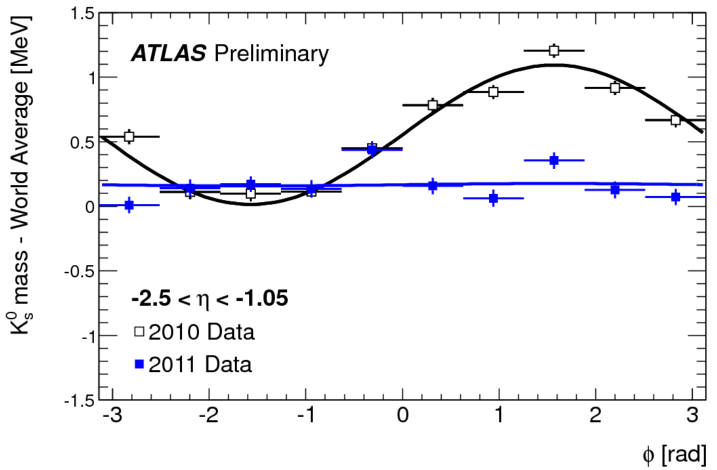




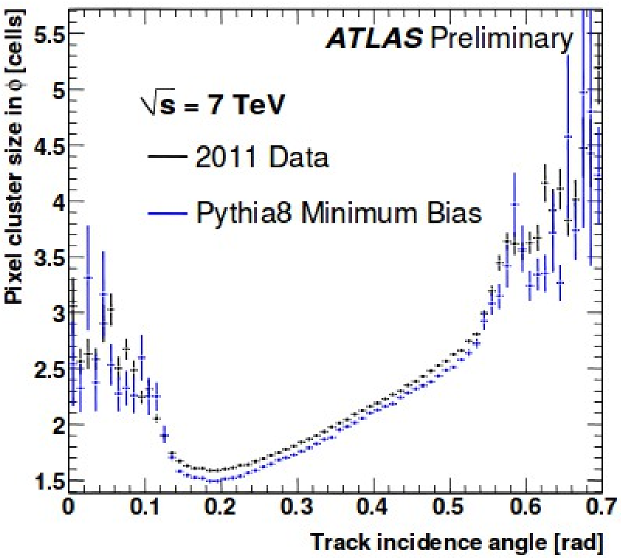
Constraining Weak Modes

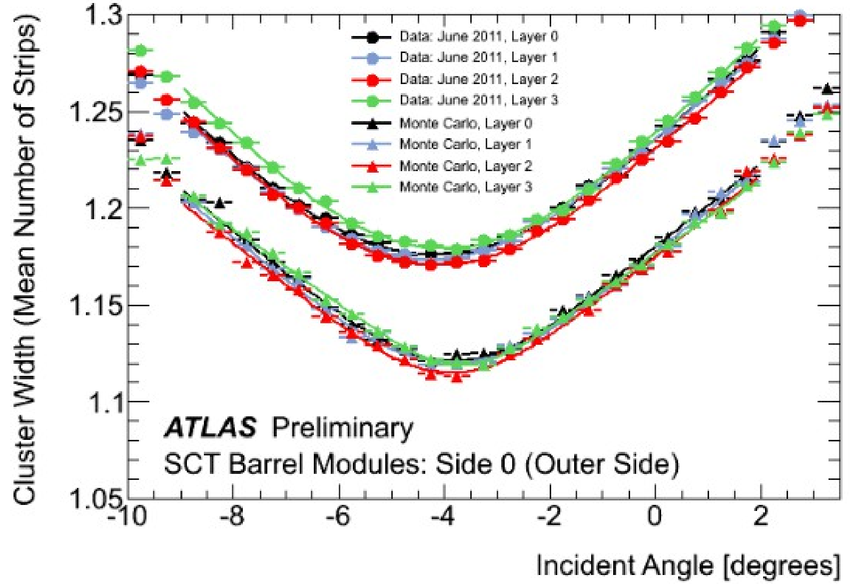
- Reconstructed values of physics parameters allow weak modes to be constrained
  - J/Ψ, Z, K_s^0 mass
  - Ratio of calorimeter Energy to ID momentum
- Used very successfully
  - Revealed B-field tilt wrt Z axis
  - Evidence of twist-like deformation in one endcap
  - No curl-like deformations observed
- 'Iterative' procedure also applied
  - Allows local deformations to be identified with high granularity





Cluster sizes

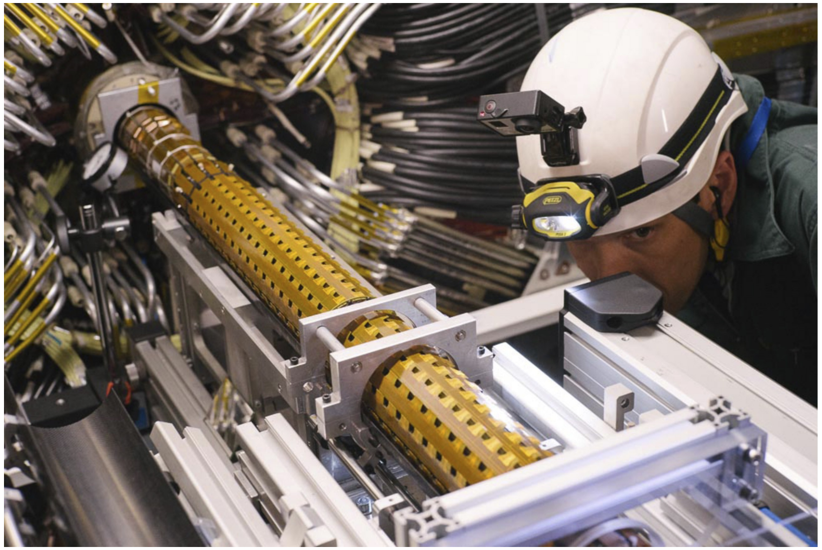


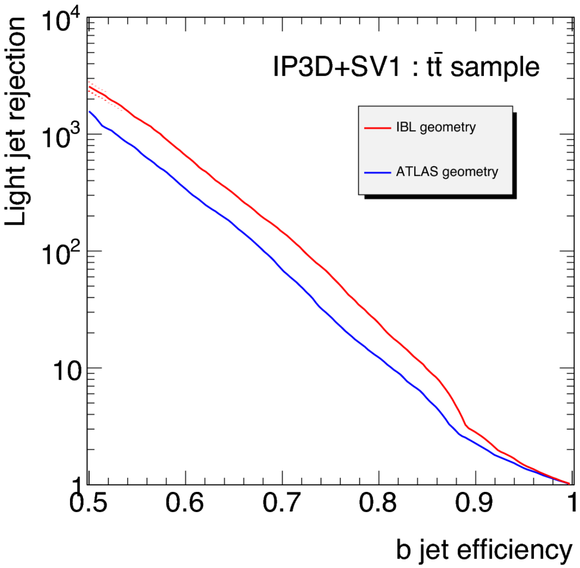


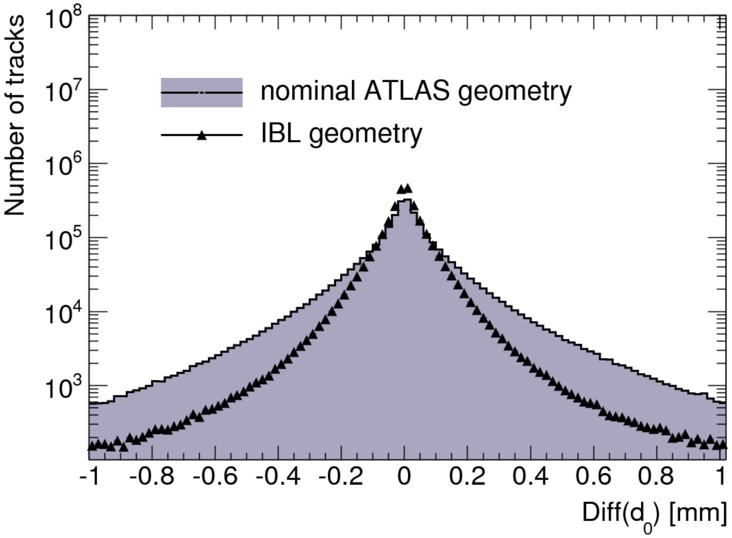
- In both Pixel and SCT discrepancies in sizes of clusters between Monte Carlo and data
- For pixel, Neural Network-based approach applied to clusters to identify deposits from multiple particles
  - Especially useful in high-p_T jet cores

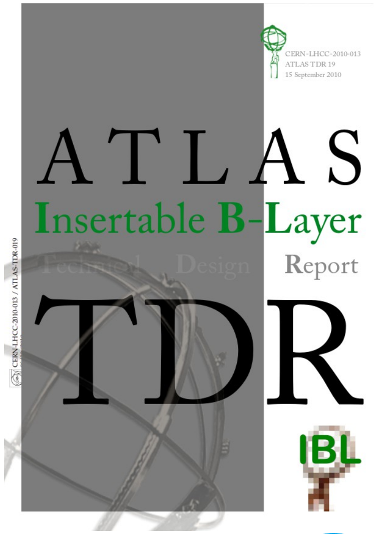
Improving the detector for Run 2

- New innermost pixel layer, 'Insertable B-Layer' (IBL)
  - TDR in September 2010, Inserted May 2014
  - Now inserted into ATLAS pixel detector for Run 2
  - Replaced "Service Quarter Panels" - recovered lost optical links
  - Relocated Optoboards for "intervention without extraction" in future



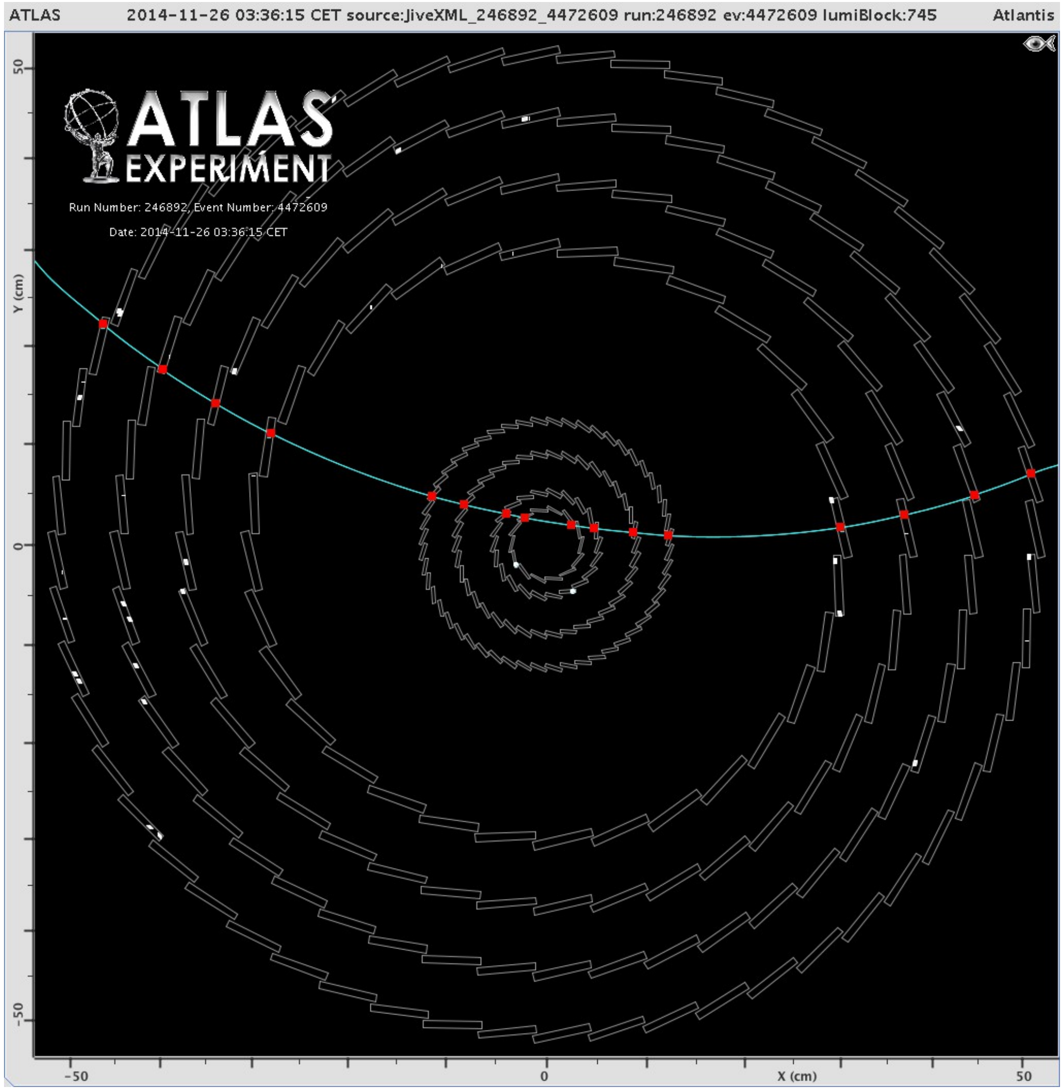




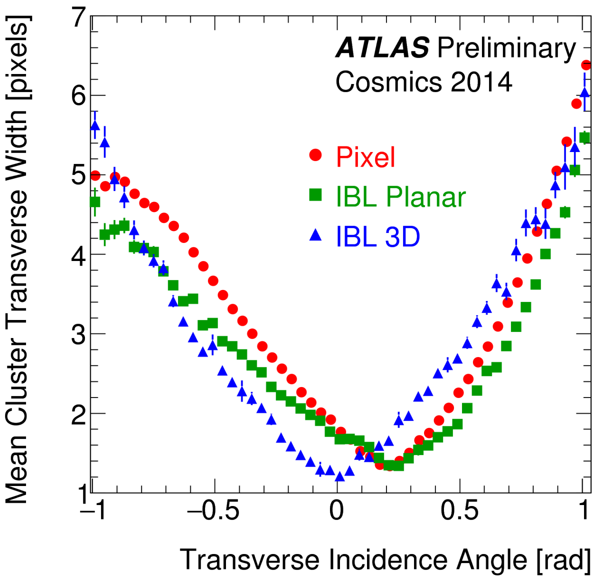


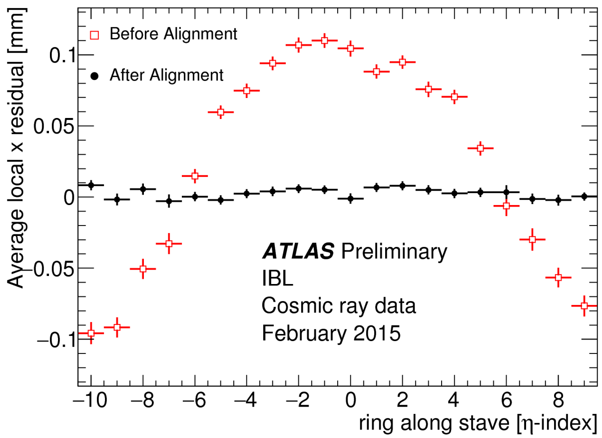
Cosmic Data Taking in 2014

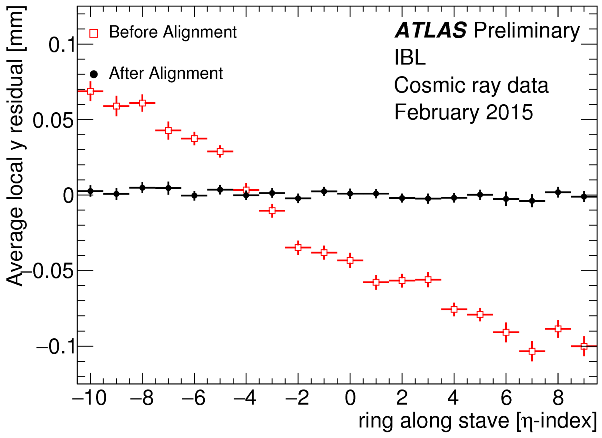
- After extensive program of detector and reconstruction software upgrades...
  - ...big relief to see cosmic tracks with hits in the IBL
  - Physics coordinator commented *“OMG that is so beautiful!”*



Cosmic Data Studies



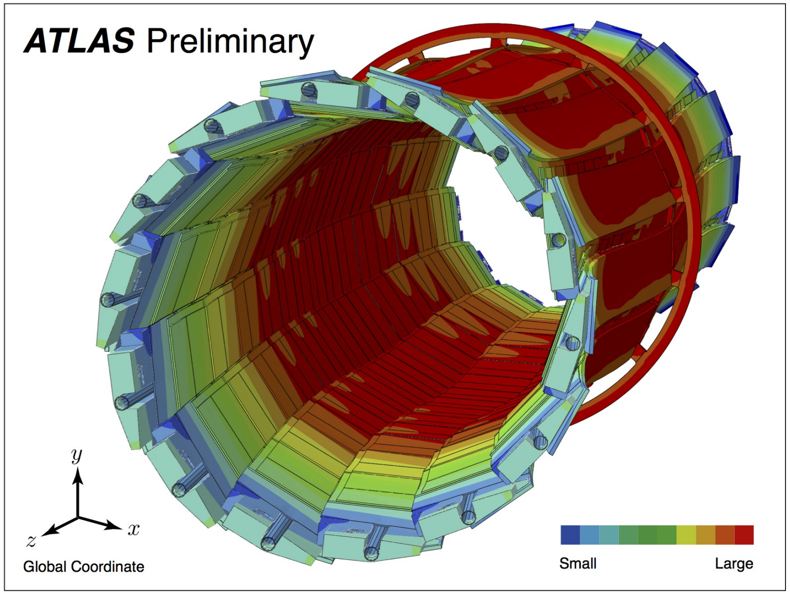


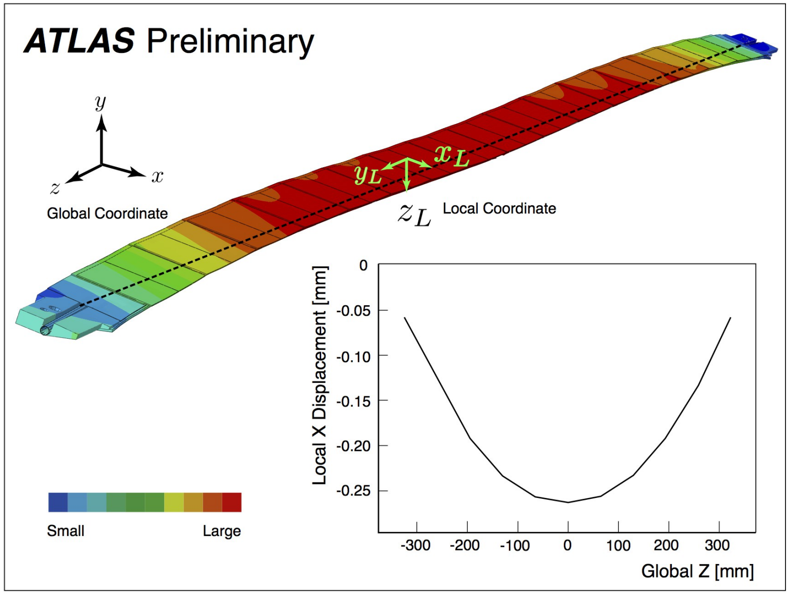


- Cosmic data used for a number of studies
  - Measurement of cluster properties (including Lorentz angle) in pixel sensors (IBL contains both Planar and 3D silicon sensors)
  - Alignment of IBL (obviously..)
  - Also revealed an issue which was somewhat unexpected...

IBL Bowing Issue

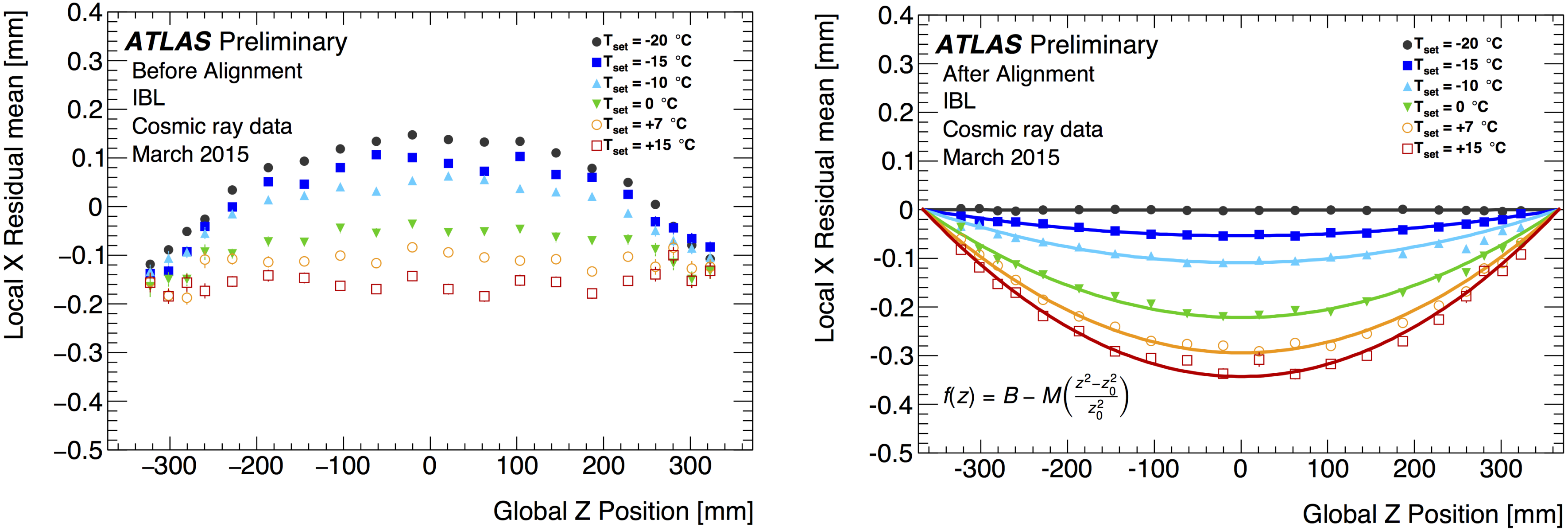
- Large differences in tracking properties between cosmics runs observed
  - Cause not immediately obvious initially...
- Due to Coefficient of Thermal Expansion (CTE) mismatch in stave components
  - Investigated with Finite Element Analysis





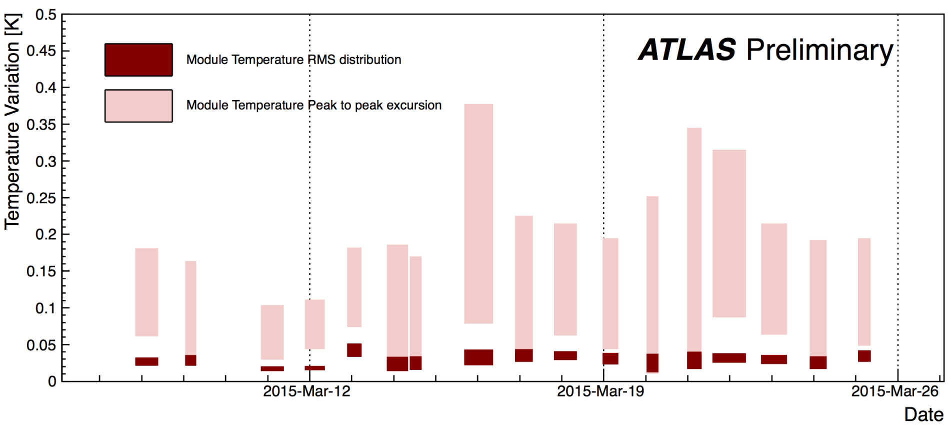
Distortion magnified 20x to aid visualization

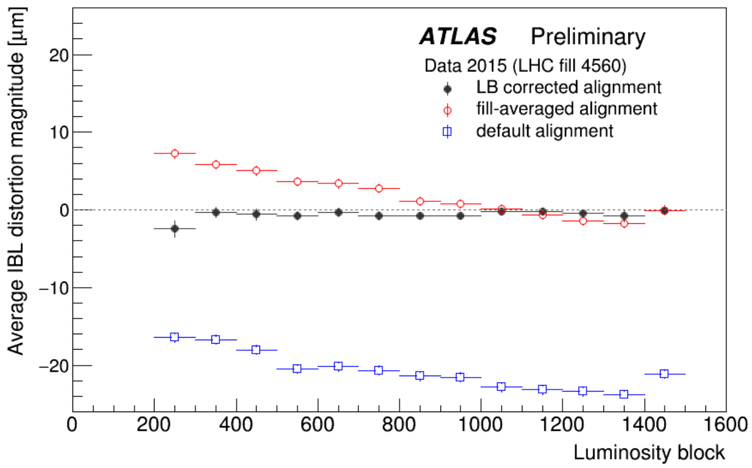
Bowing Corrections



- Effect obvious when data viewed in temperature slices
  - Minimal bowing at ~room temperature
  - Maximally ~100µm at planned operating temperature of -20°C
- Temperature-dependent corrections allow effect to be compensated for

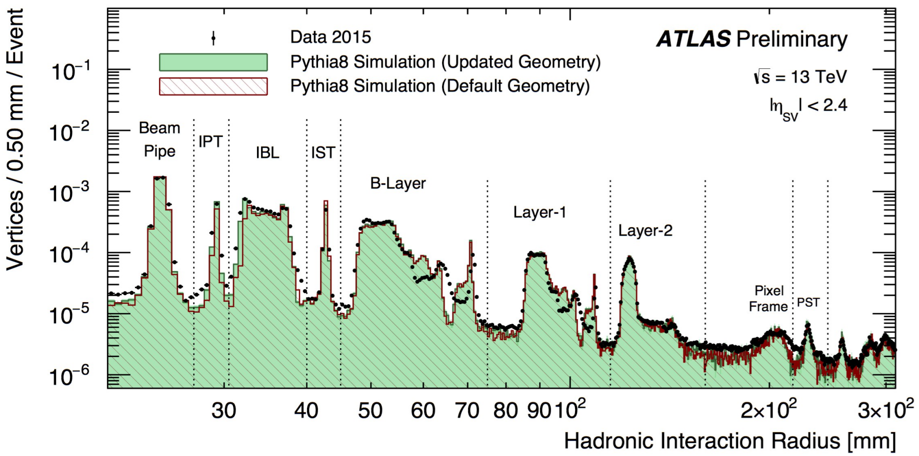
IBL Bowing Stability

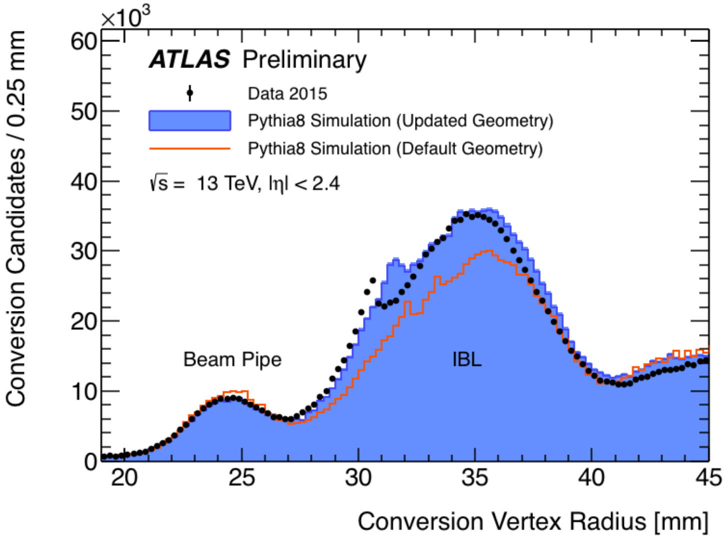




- IBL temperature must be carefully monitored
- Distortion initially thought to be 'stable'
  - Increasing module power consumption means that is not longer true
  - Effect related to total ionizing dose received
- Dynamic alignment correction required
  - Per stave, and per 100 luminosity blocks (period of data taking over which conditions ~constant, approx 1 minute)
- Long-term stability to be carefully investigated

IBL Material Studies

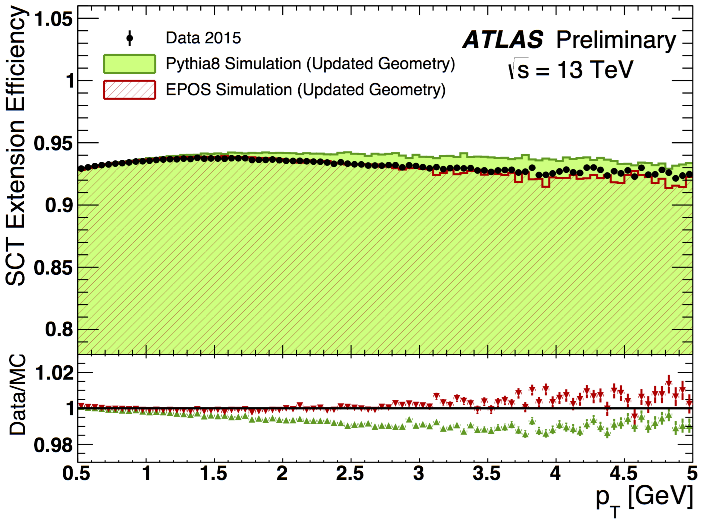


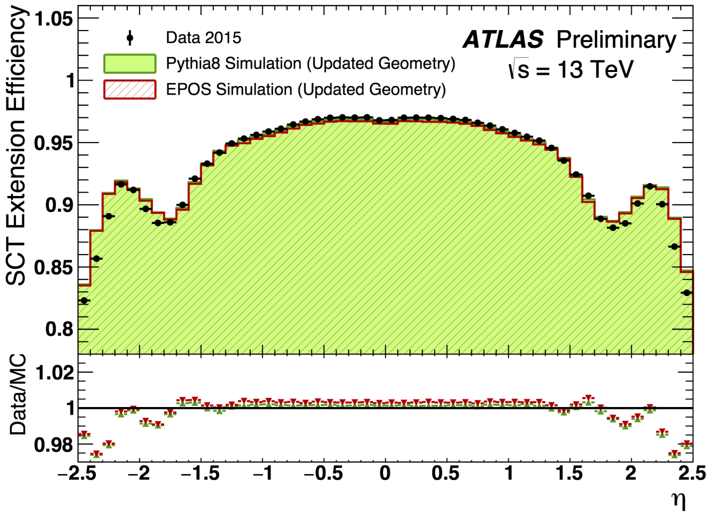


- Initial Run 2 simulation geometry found to have deficiencies
  - Some components (e.g. capacitors, other surface mounted devices) were left out of simulation of IBL
- Updated geometry produced to correct this
  - Improved data/MC agreement observed

SCT Extension Efficiency

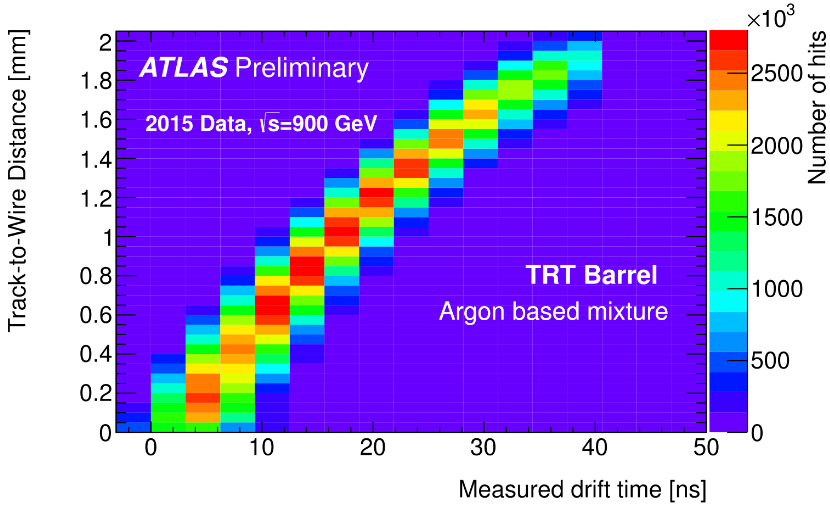
- Complementary method to conversions/hadronic interactions
  - Look at ratio of tracks in pixel to 'full' silicon tracks
- Probes material between pixel and SCT
  - In particular at higher |η| where other methods can't access
  - Location of new Service Quarter Panels for Run 2
- Results suggest some deficiencies remain in geometry description at high |η|
  - Region with much inactive material and complex structures





TRT Gas Mixture

- Leaks developed in TRT Gas system during Run 1
  - Ozone formation caused localized corrosion
- During Run 1, Xenon-based active gas was used
  - This is expensive; ~16 CHF per litre
  - In most affected areas leak >10 litres per hour
- For Run 2 investigate use of different gases
  - Argon and Krypton-based mixes
- Needs to be accounted for in reconstruction
  - Also in Simulation samples



Summary

- Number of unexpected issues arose during ATLAS Inner Detector commissioning/running
  - Both for Run 1 and Run 2
- All of these issues were dealt with, and wide-ranging physics program was (and continues to be) extremely successfully carried out
- Nevertheless, would have been better to include such features in simulation/reconstruction etc from earlier stage
  - Or avoid altogether if possible
- These experiences are now feeding into the design process of the “ITK” tracker for the Phase 2 ATLAS Upgrade
- Hopefully these can also be useful observations for the design process of ILD!