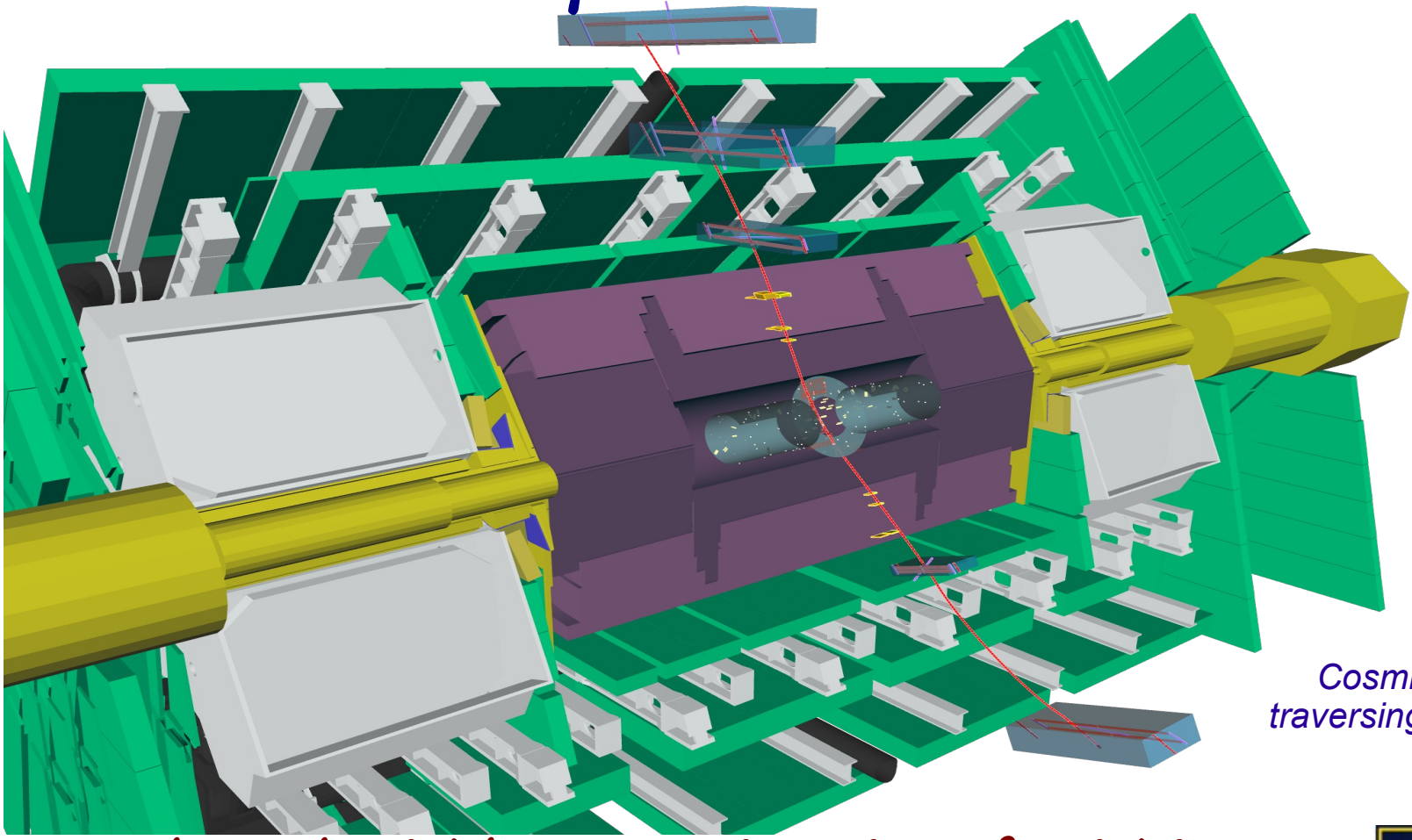
Commissioning of the ATLAS Muon Spectrometer



Cosmic ray traversing ATLAS

Edward Diehl University of Michigan

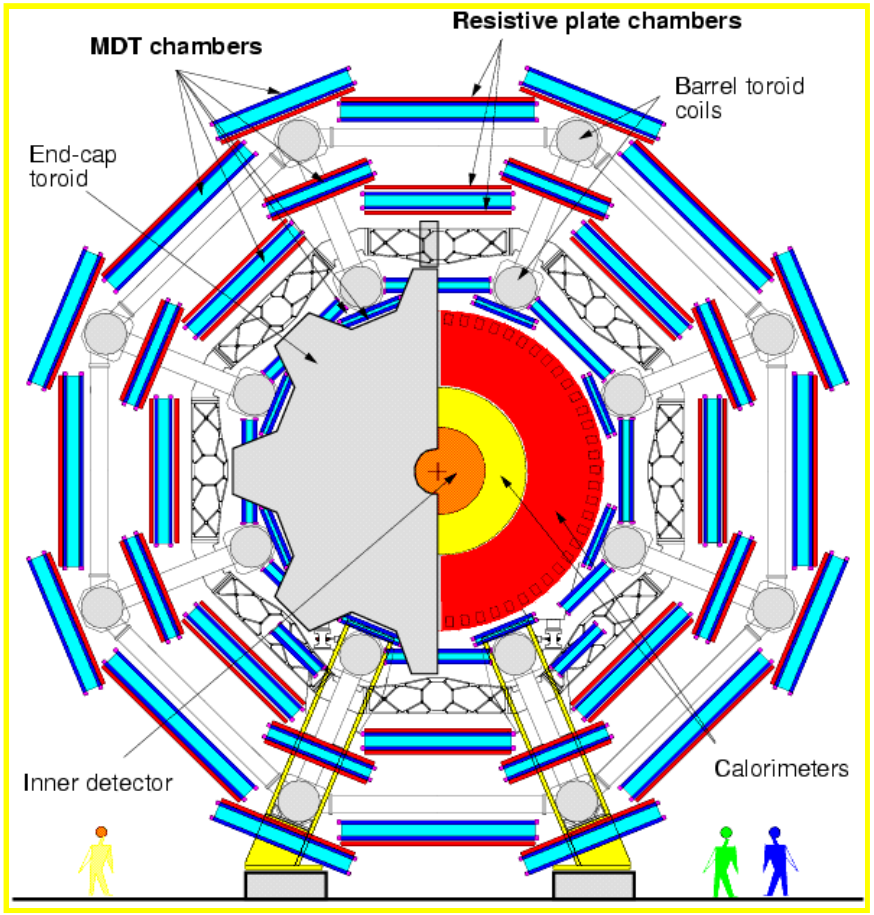
On behalf of the ATLAS Muon collaboration

Spectrometer Overview

- Designed to trigger on and measure muons with Pt ≳ 3 GeV with resolution 3% < 250 GeV to 10% @ 1 TeV.
- Magnetic field from air-core toroids: barrel + 2 endcap
- Trigger detectors (trigger + 2nd coordinate measurement)
  - 0<η<1.0 (Barrel) Resistive Plate Chambers (RPC) 373k chan
  - 1.0<η<2.4 (Endcap) Thin Gap Chambers (TGC) 318k chan
- Precision detectors (Δx≃60-70μm)

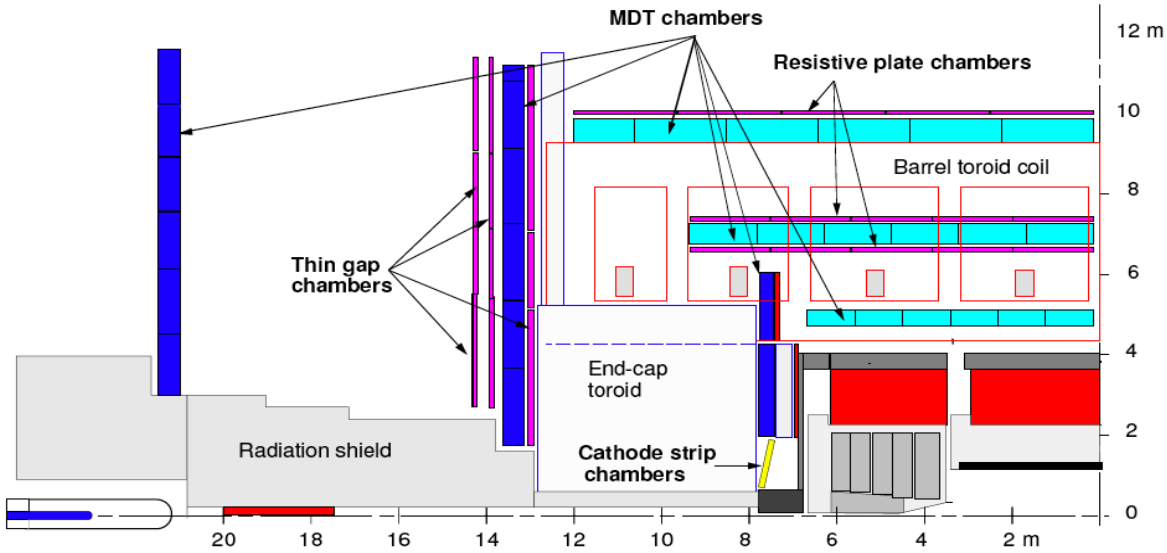
  0<η<2.7 Monitored Drift Chambers (MDT) 354k chan
  - *Monitored* ⇨Positions monitored by an alignment system
  - 2.0<η<2.7 Cathode Strip Chambers (CSC) 30.7k chan
- Alignment system – determine chamber positions to ~50 μm
  - Separate optical alignment systems for barrel & endcap complemented by alignment with tracks.

Spectrometer Layout



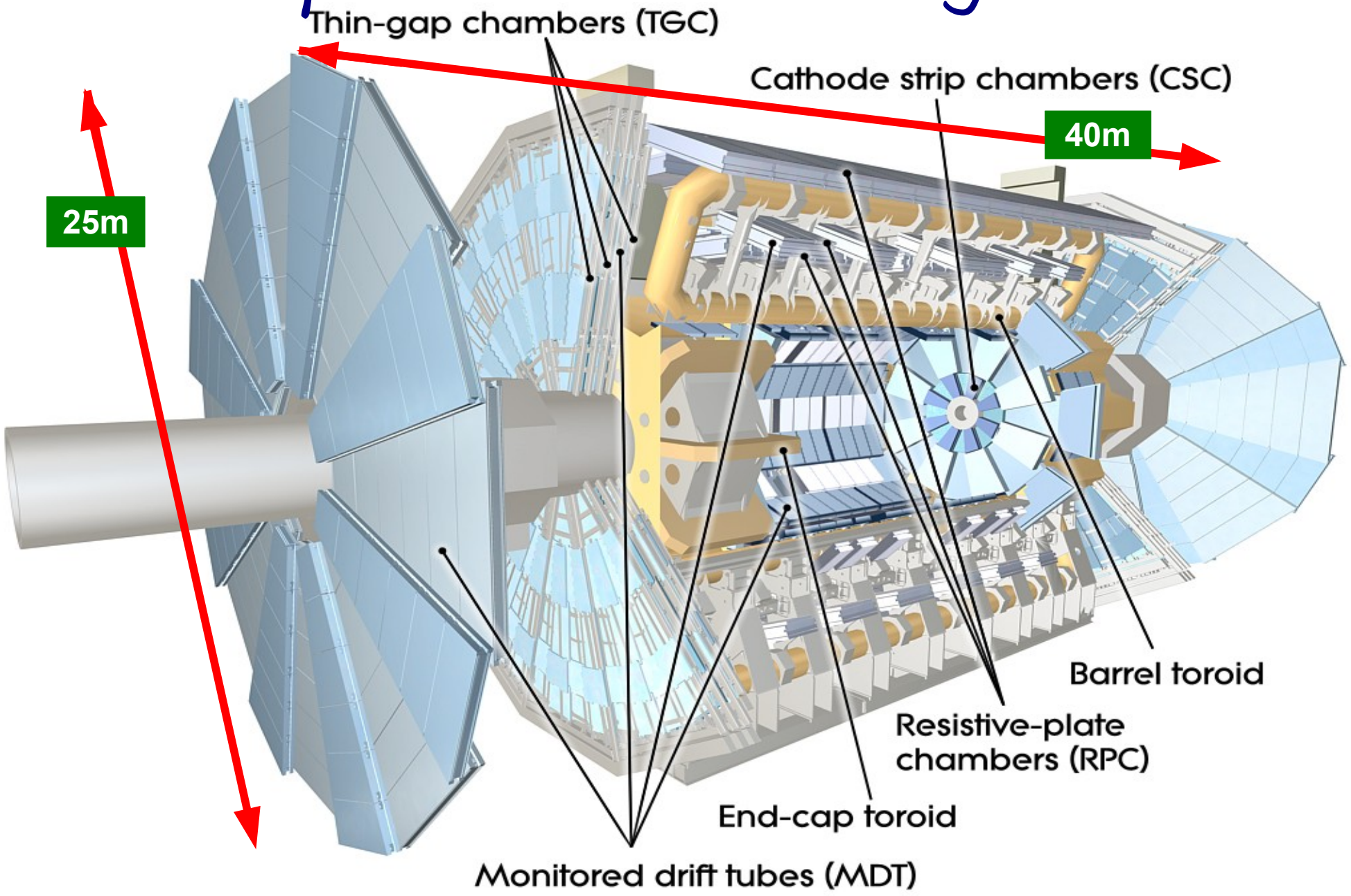
Barrel Cross-section

Endcap cross-section

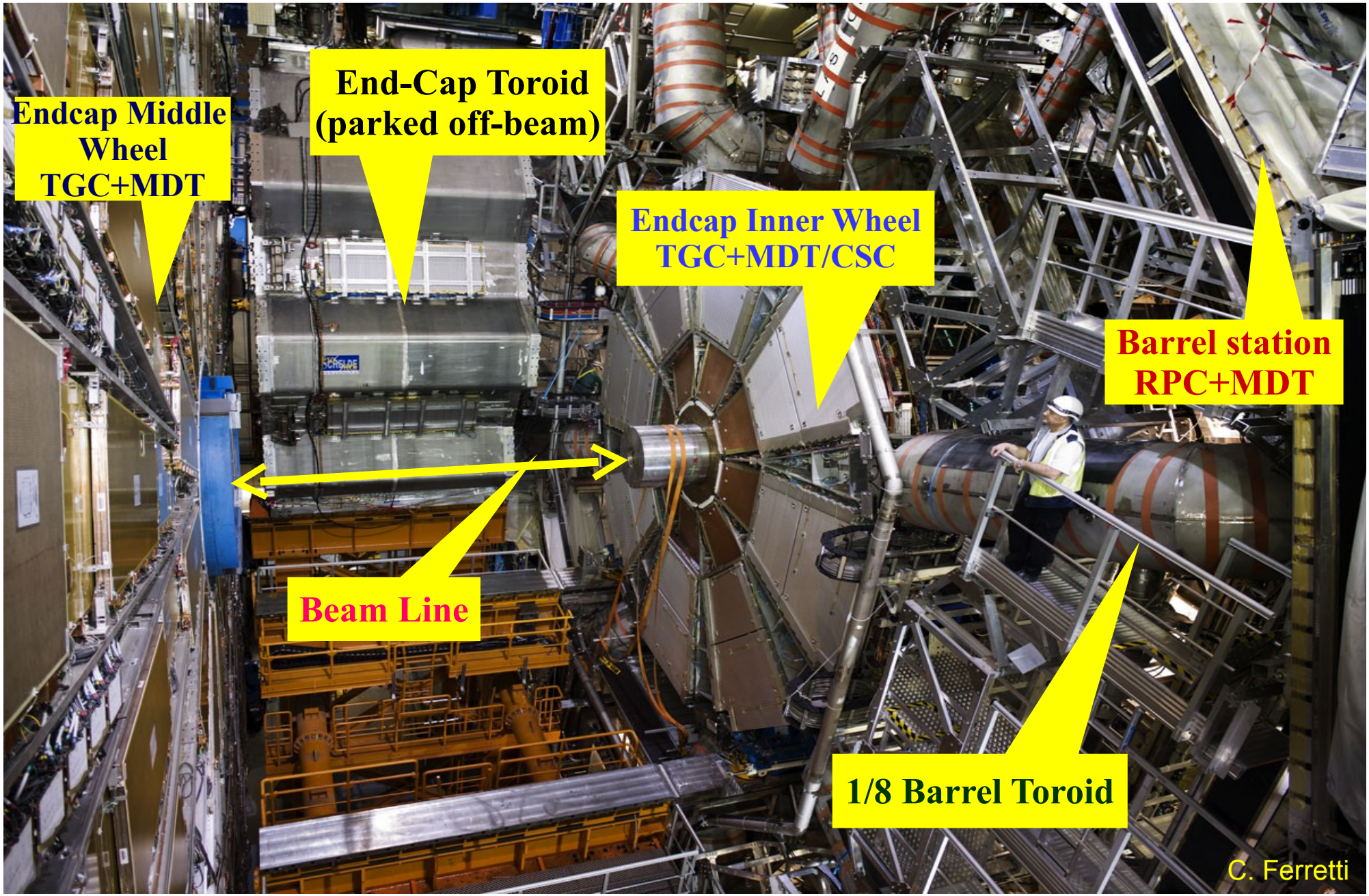


- Muons cross 3 layers of precision chambers for sagitta measurement
- Trigger chambers are placed on both sides of middle precision layer (+ a few elsewhere).

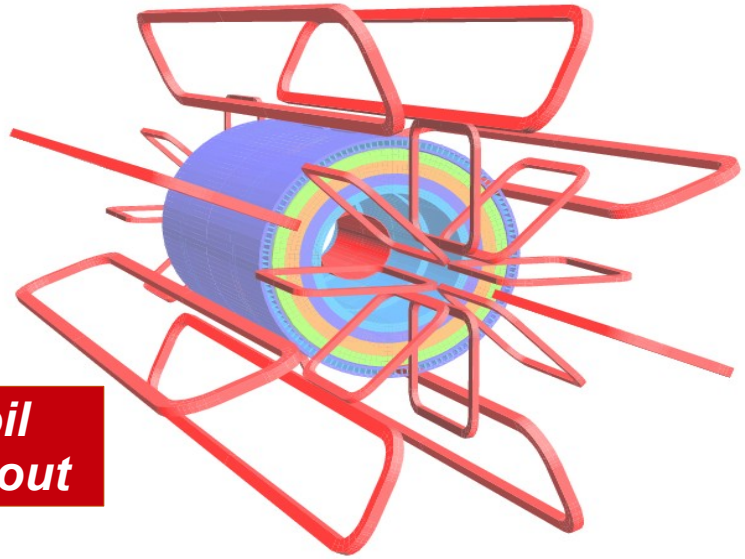
Spectrometer Layout



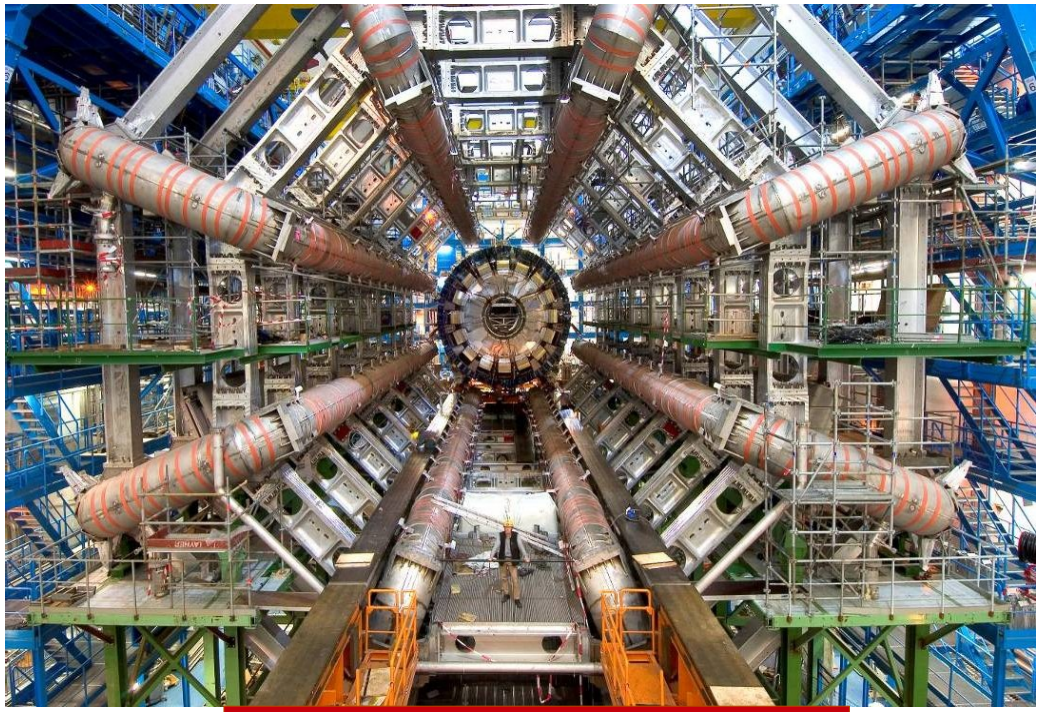
ATLAS Cavern



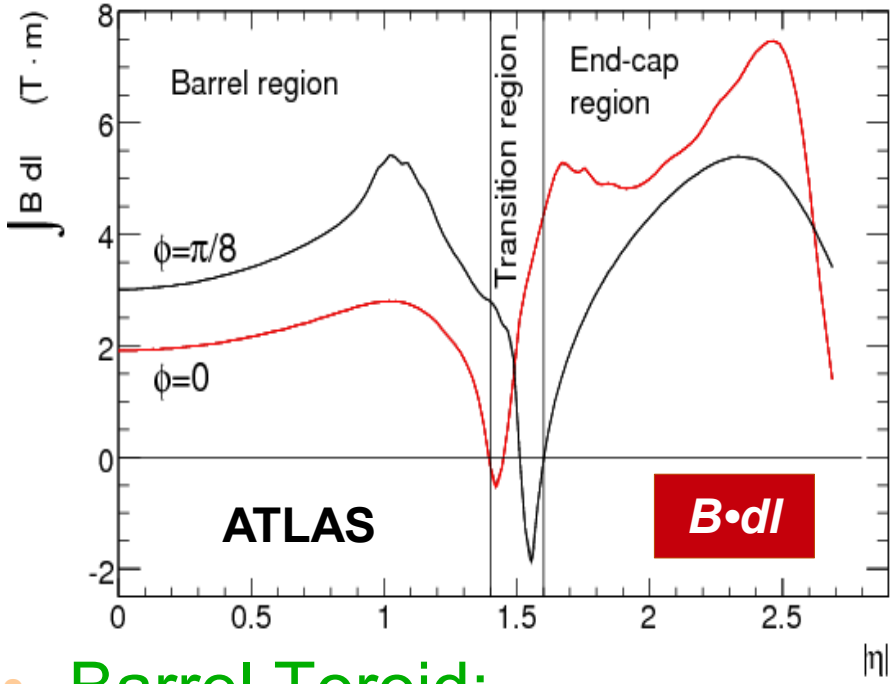
Magnet System



Coil Layout



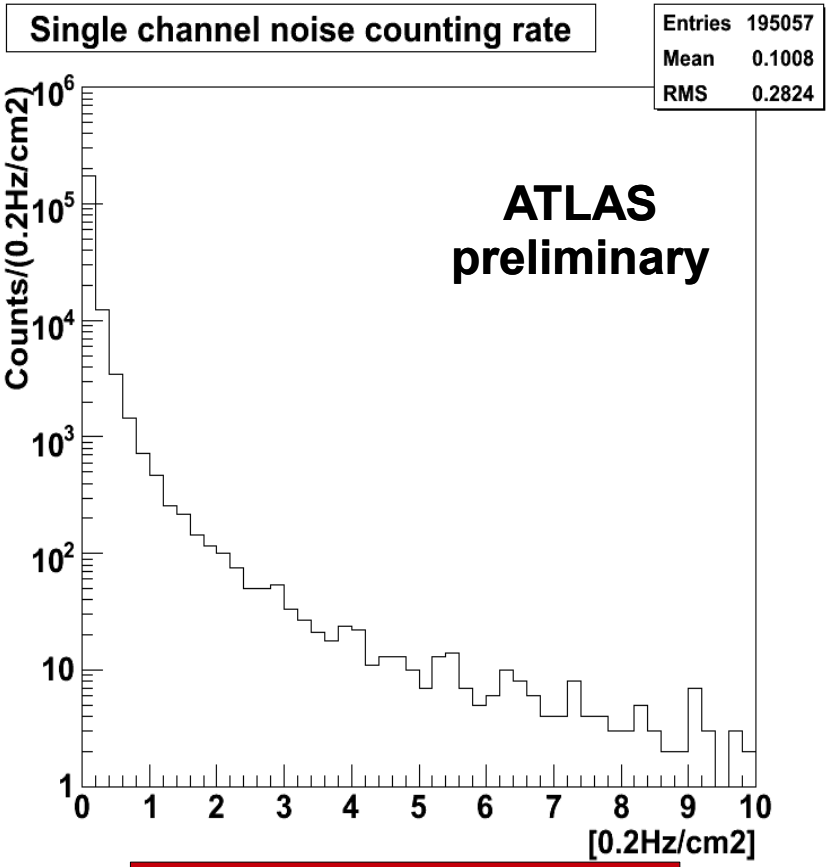
Barrel Toroid End View



- Barrel Toroid:
  - 8 coils 25m X 7m, ~0.5T
- Endcap Toroids (2)
  - 8 coils 9m X 4m, ~1.0T
- Non-uniform field – parameterized by detailed modeling + 1850 Hall sensors

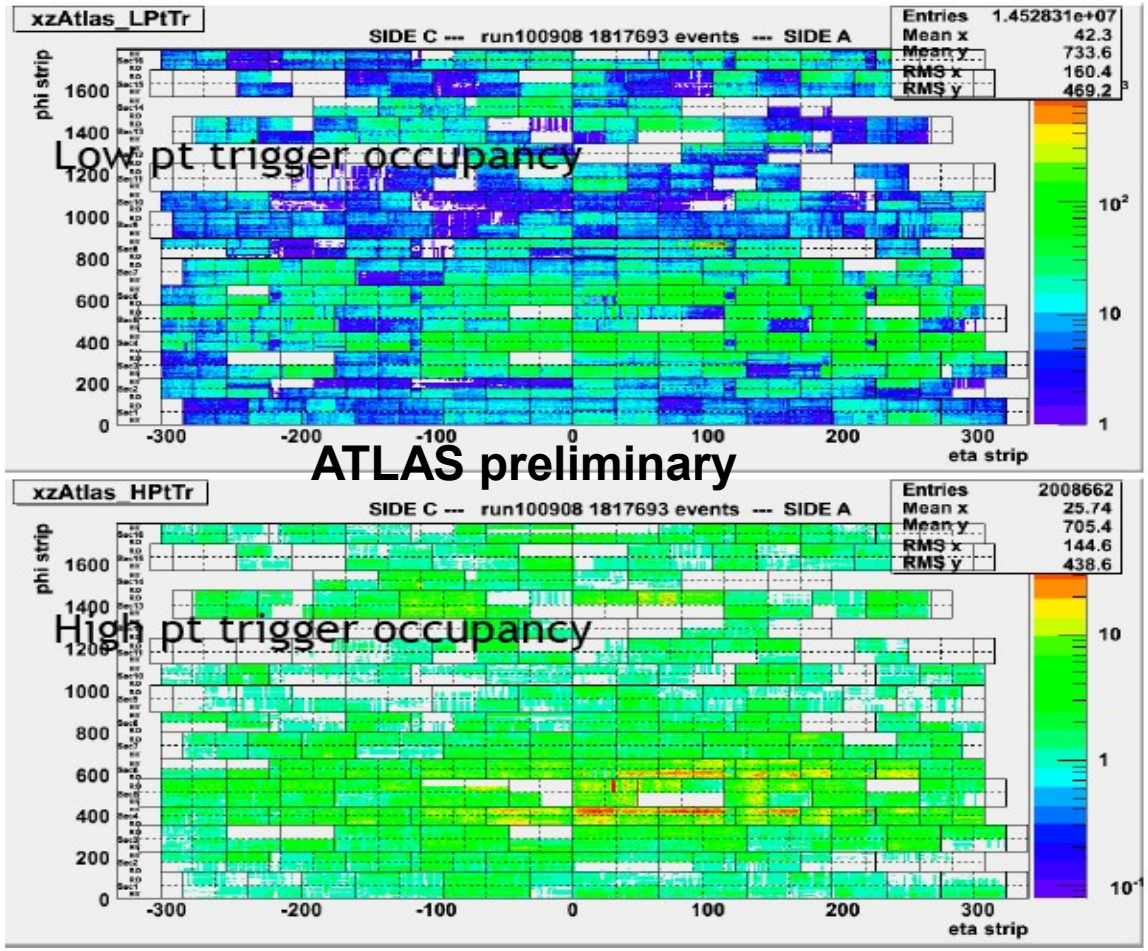
Resistive Plate Chambers

- 606/606 chambers installed – Working - 95.5% coverage



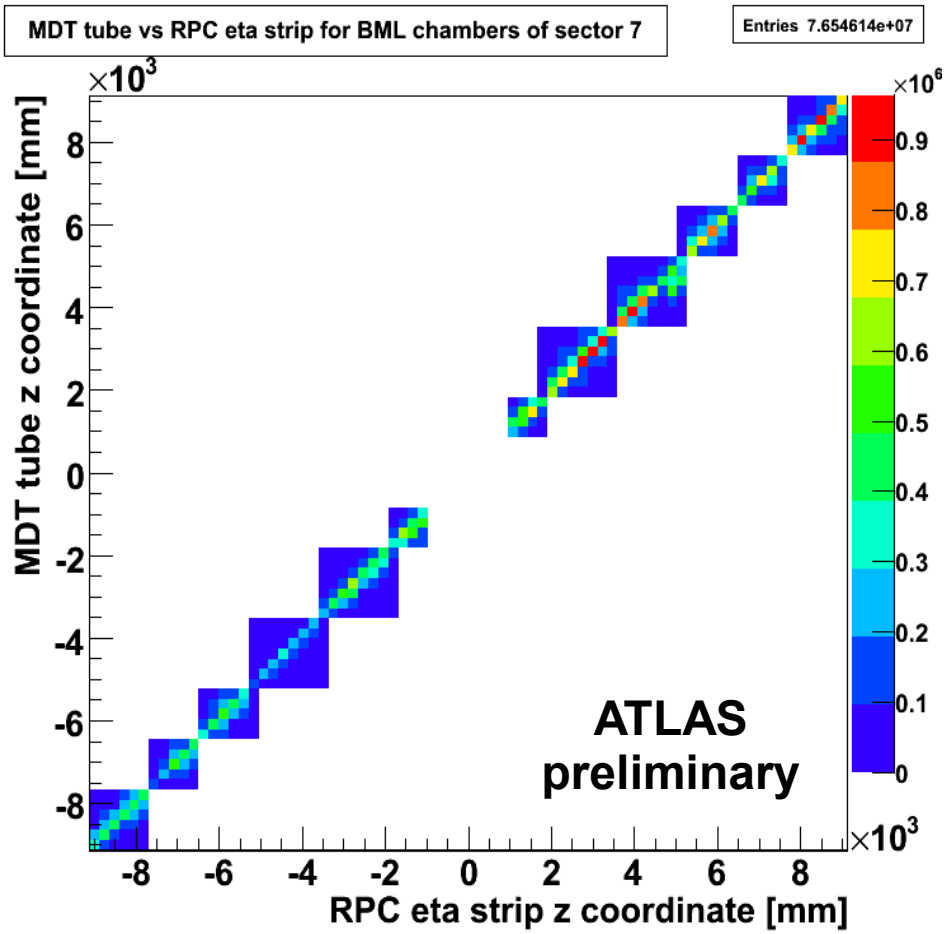
RPC Noise Rates
0.1 Hz/cm² average

RPC Hit Occupancy Φ strip vs η strip



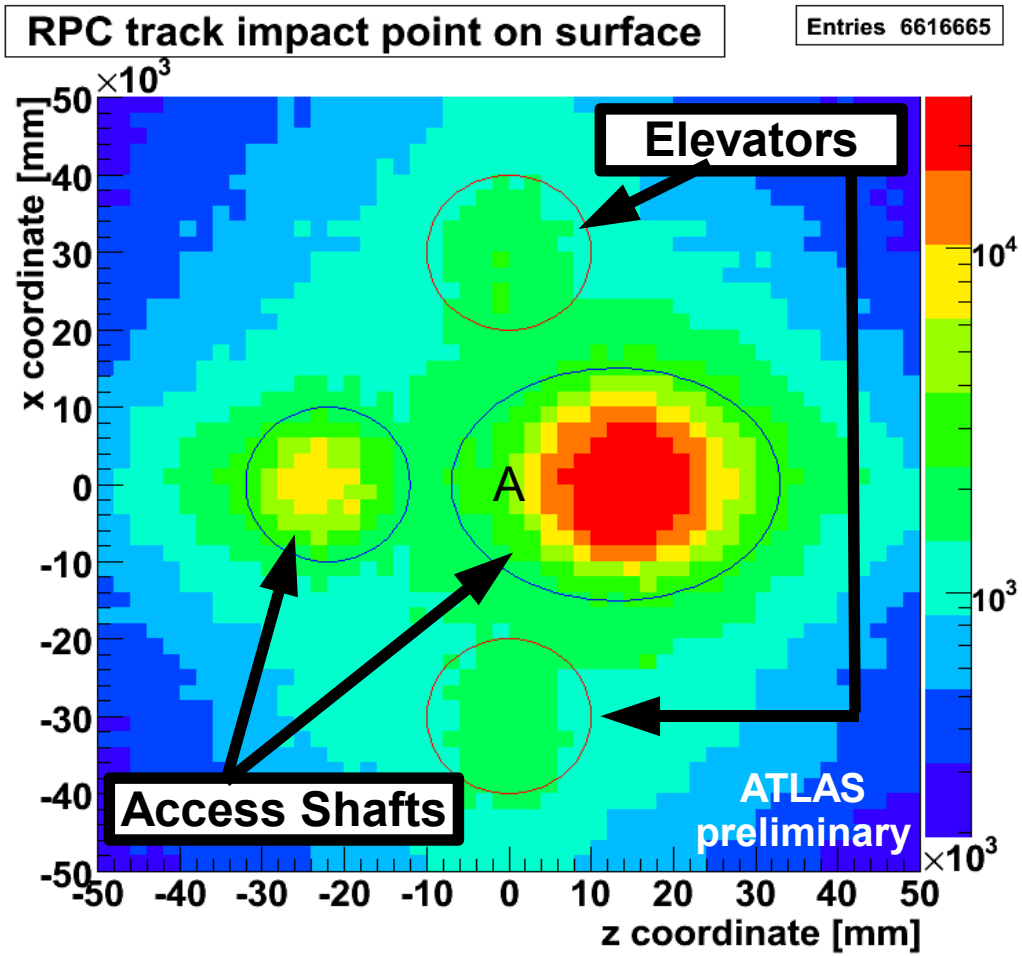
Data: Cosmic Rays

Resistive Plate Chambers



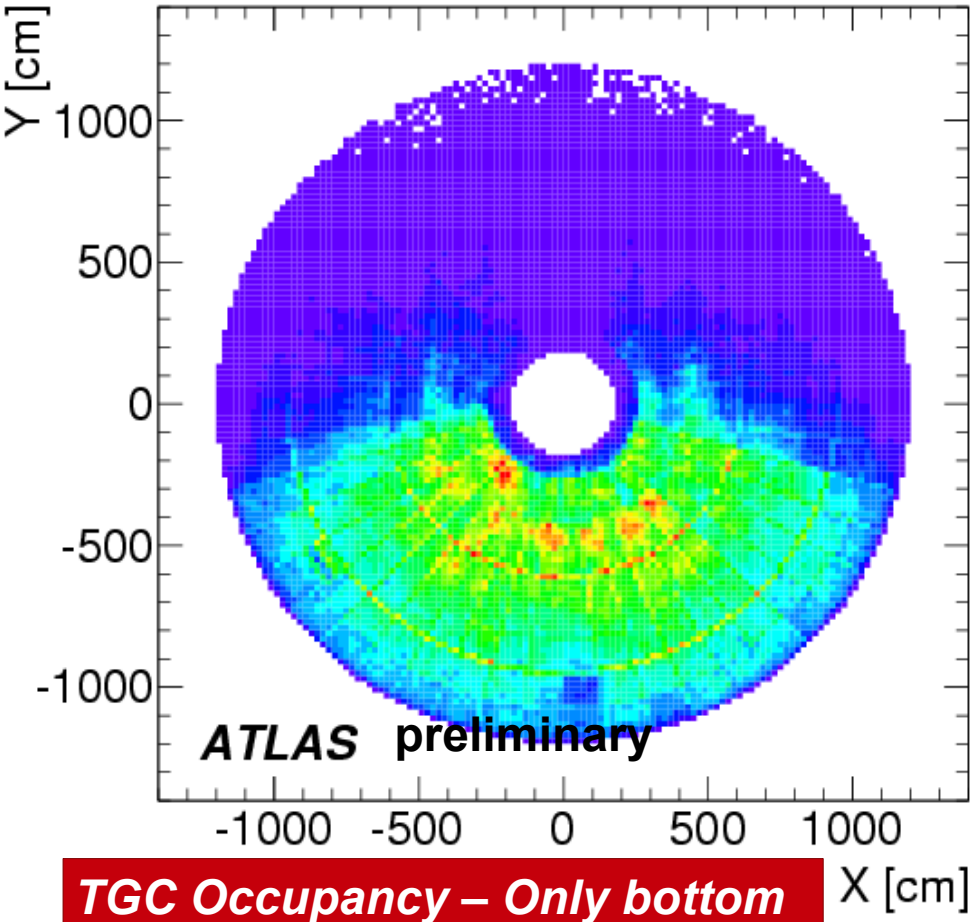
MDT vs RPC correlation

Cavern Tomography with RPC tracks

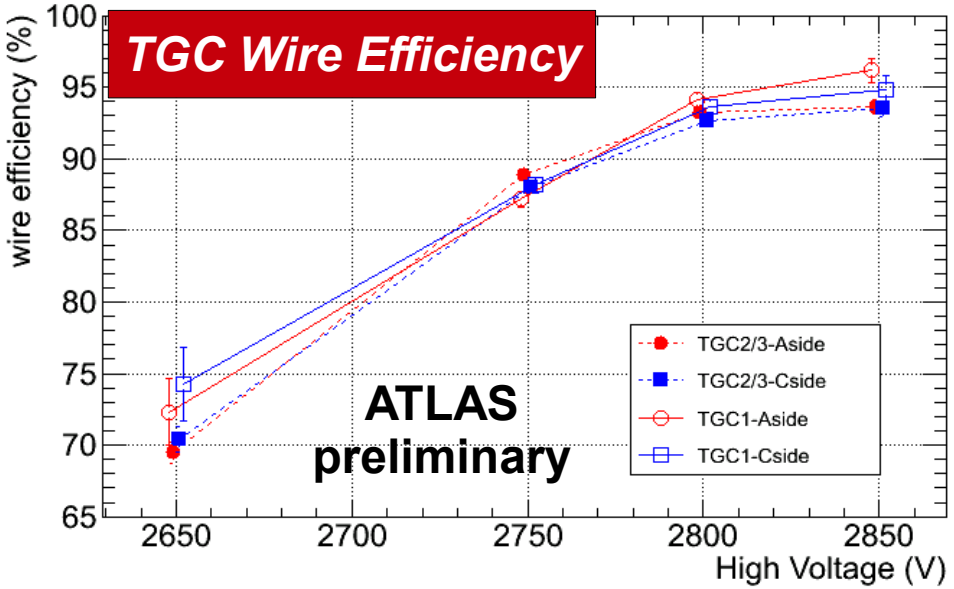


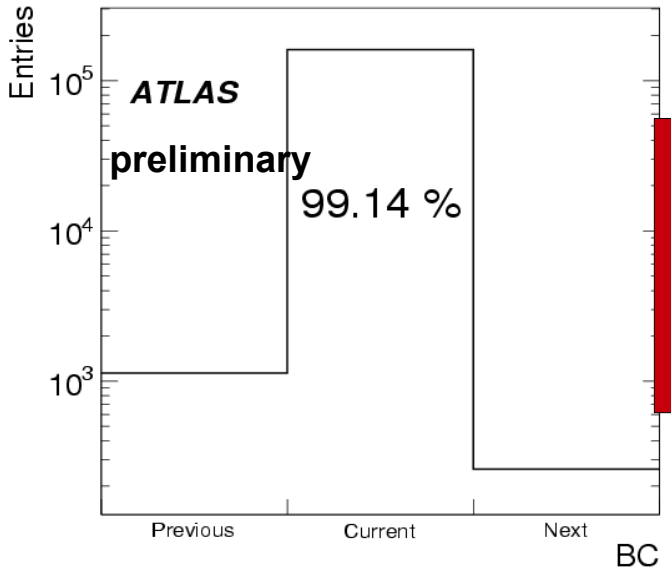
Thin Gap Chambers

- 3588 TGC chambers installed – 99.9% coverage



TGC Occupancy – Only bottom of wheel triggering to select cosmic muons pointing to IP



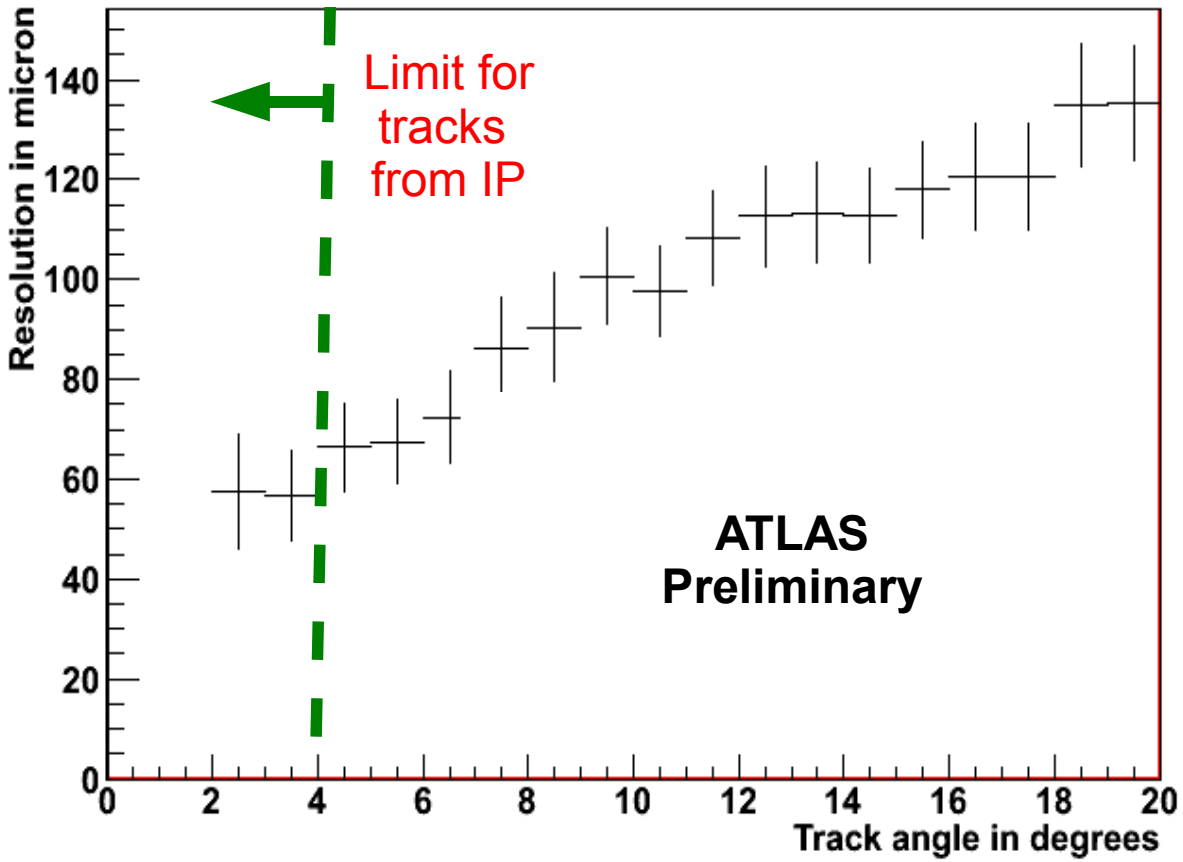


TGC Bunch Timing Adjustment

Cathode Strip Chambers

- 32/32 chambers installed; 98.5% layers working.
- Readout firmware being re-written; test-stand results are encouraging; anticipate no problems when beam arrives.

CSC Resolution vs Track incident angle

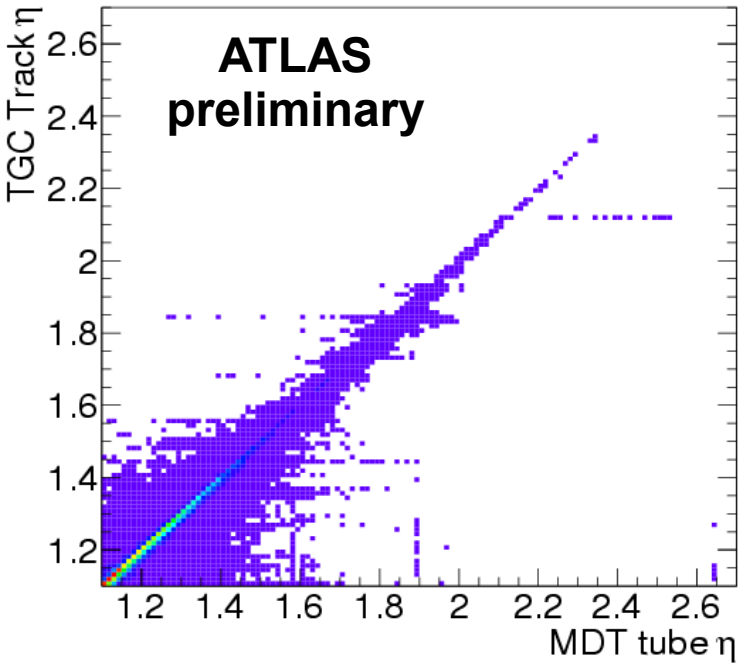


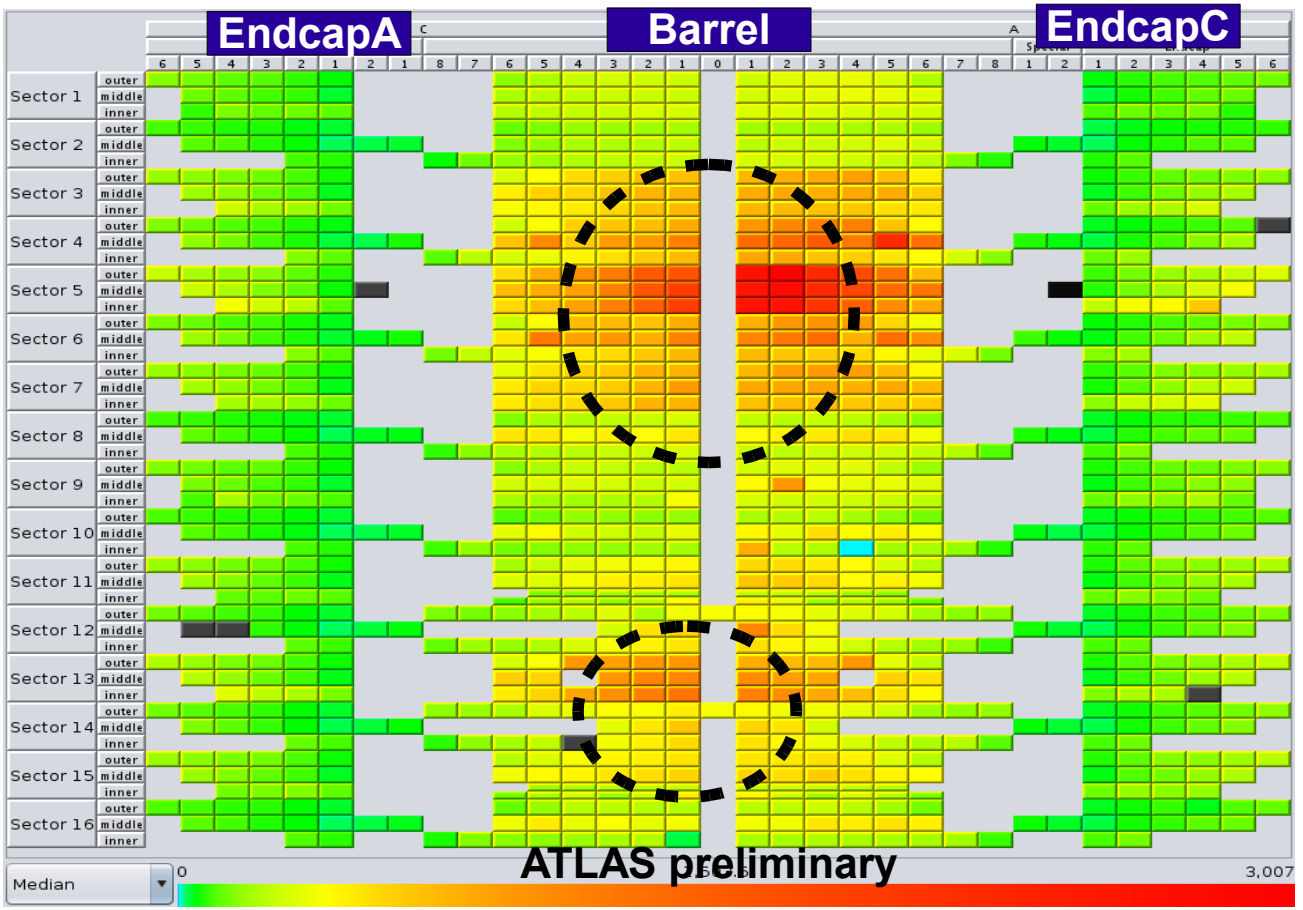
- Resolution plot (left) from cosmics data.
- Cosmics commissioning data is not very useful:
  - Acceptance/statistics poor due to vertical incidence of cosmic rays
  - Resolution poor since CSC resolution degrades as $\tan\theta_{incident}$

Monitored Drift Tube Chambers

- 1090/1150 Chambers installed – 99.6% operational

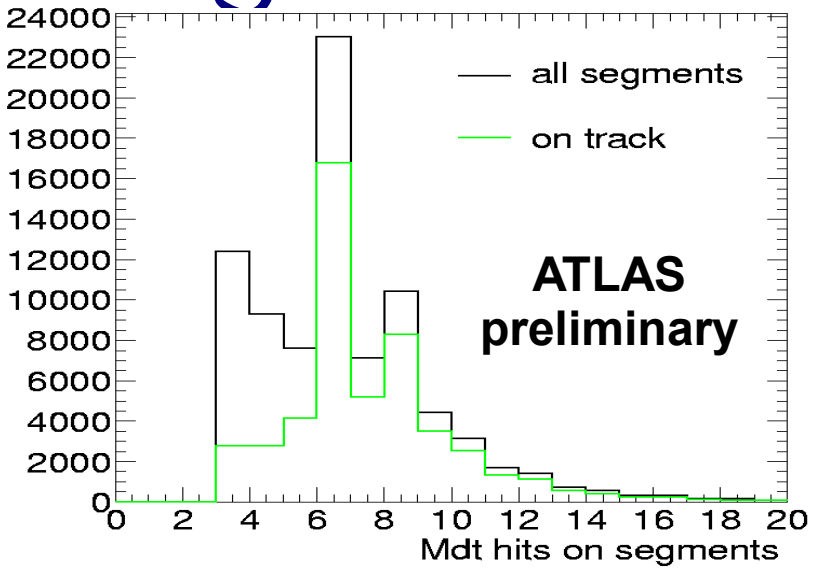
TGC vs MDT correlation
Lines ↔ noisy channels





MDT Occupancy – chamber Φ vs η
Circles = hot spots due to access shafts

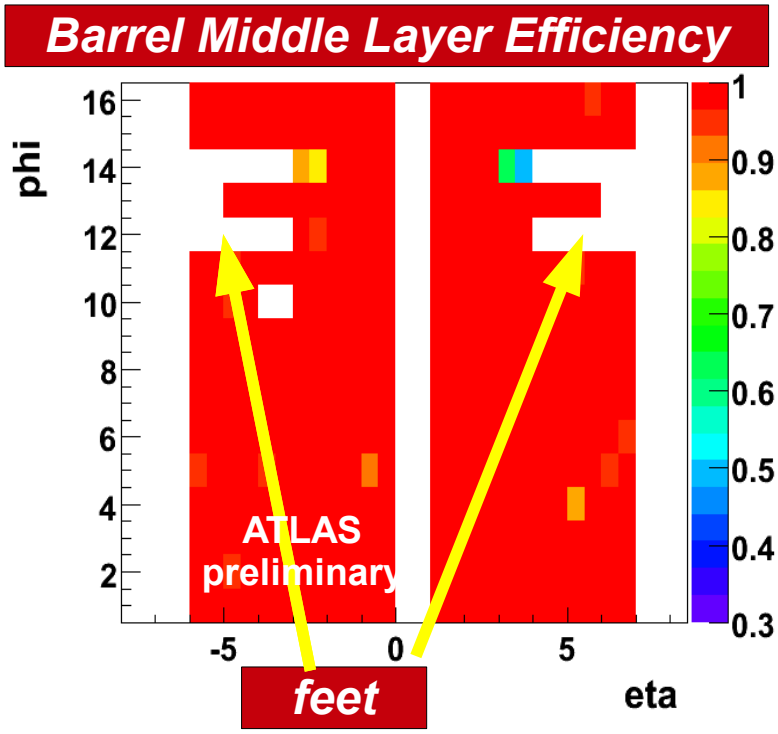
Segment/Track Reconstruction



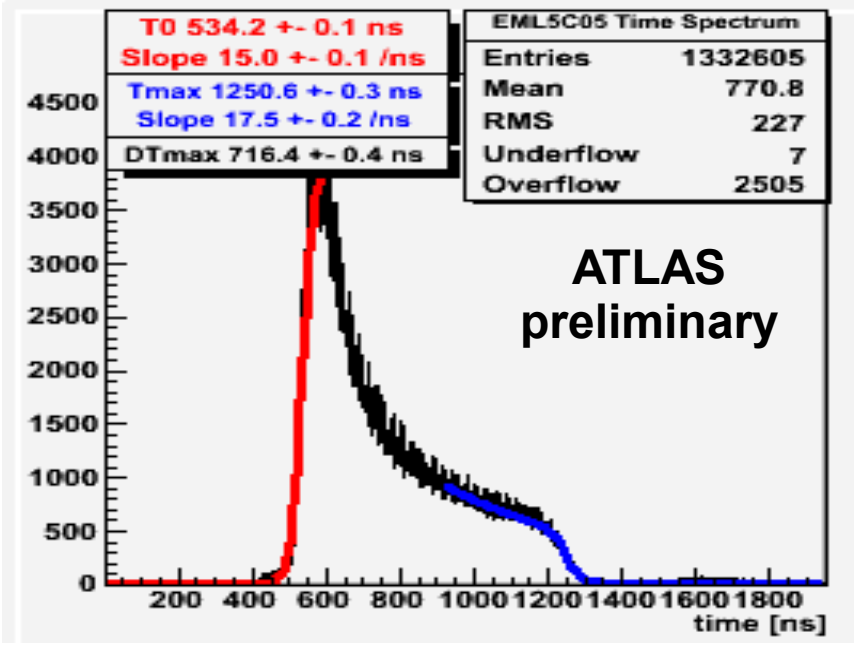
- Segment ⇒ track segment within a single MDT chamber
- Track ⇒ combine segments
- Peaks at 6 & 8 tubes reflect number of layers in MDT chambers

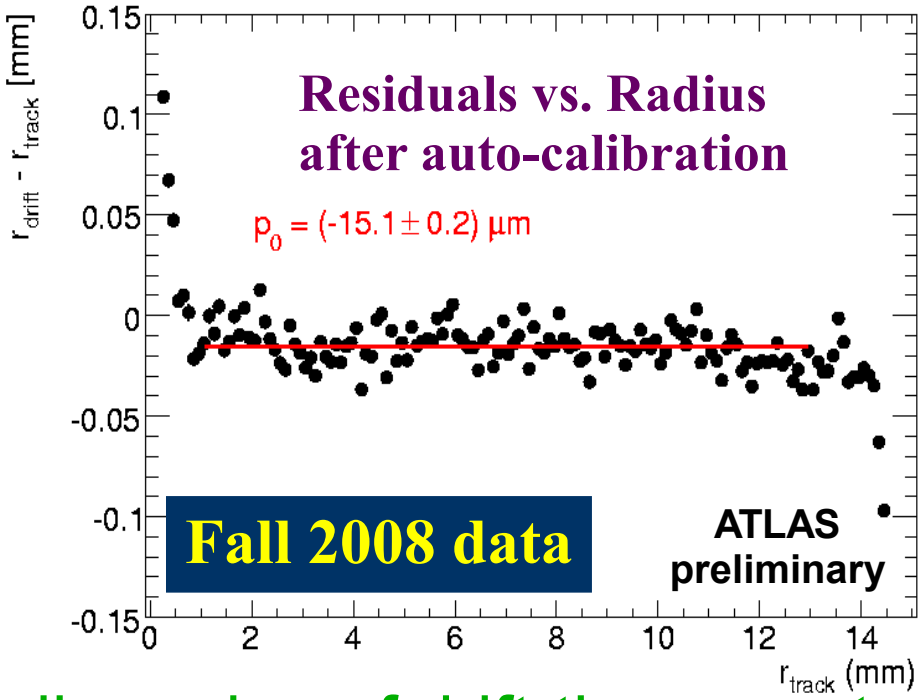
- Segment Efficiency from clean sample:
  - No showers (#segments<20)
  - Tracks with 2+ segments: extrapolate to 3rd chamber
- Cosmics: enlarged single-hit error and matching angle

$$Efficiency = \frac{\#Segments(found)}{\#Segments(expected)} > 98\%$$



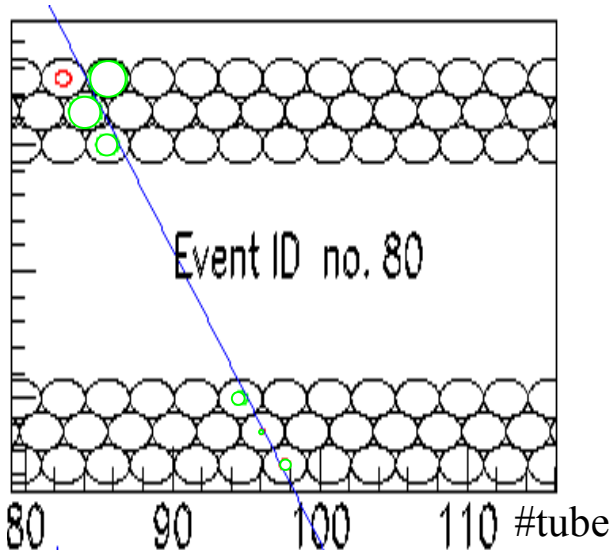
MDT Calibrations





- Timing offset (T_o) – from fit to leading edge of drift-time spectrum. Cosmics are non-synchronous with beam clock; cosmics jitter recovered with T_o tuning algorithm.
- Time-to-space function (RT function) – non-linear (Ar-CO_2 97:3), from autocalibration or from dedicated gas monitor chamber
- Calibrations from special high-statistics datastream sent to 3 calib centers and completed within 36 hours (See S. McKee talk)

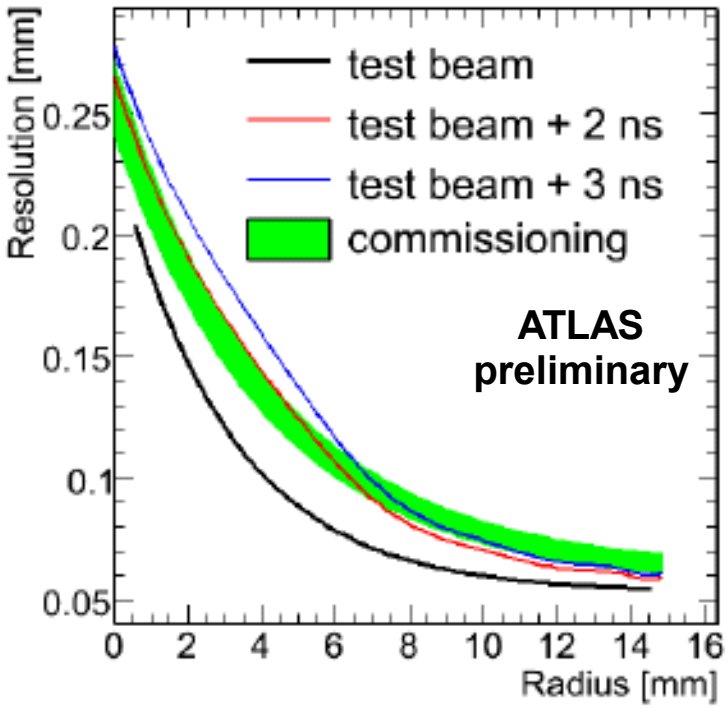
Single MDT Tube Resolution



- Resolution determined by fitting track segment with one tube removed.
- Resolution is residuals of refits with tracking error removed

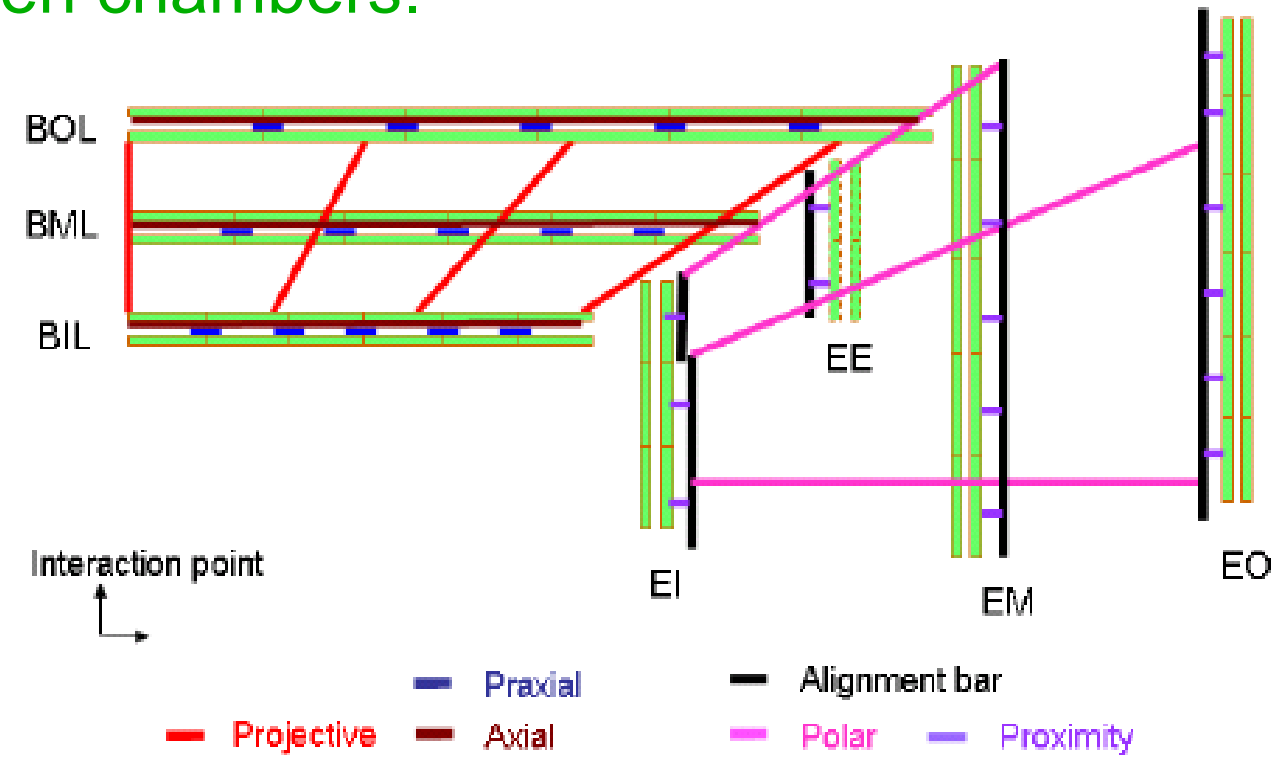
$$\sigma_{resol}(r) = \sqrt{\sigma^2_{resid}(r) - \sigma^2_{SLfit}(r)}$$

- Resolution with cosmic rays (i.e. current data) is consistent with resolution from test beam + 2ns jitter.
- 2 ns jitter is consistent with error from time correction from RPCs (to correct non-synchronous arrival of cosmic-rays with respect to beam clock.

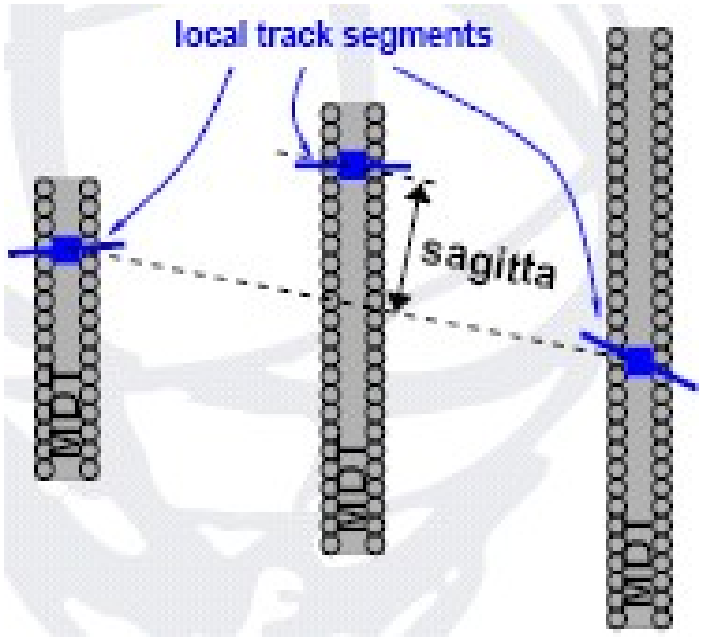


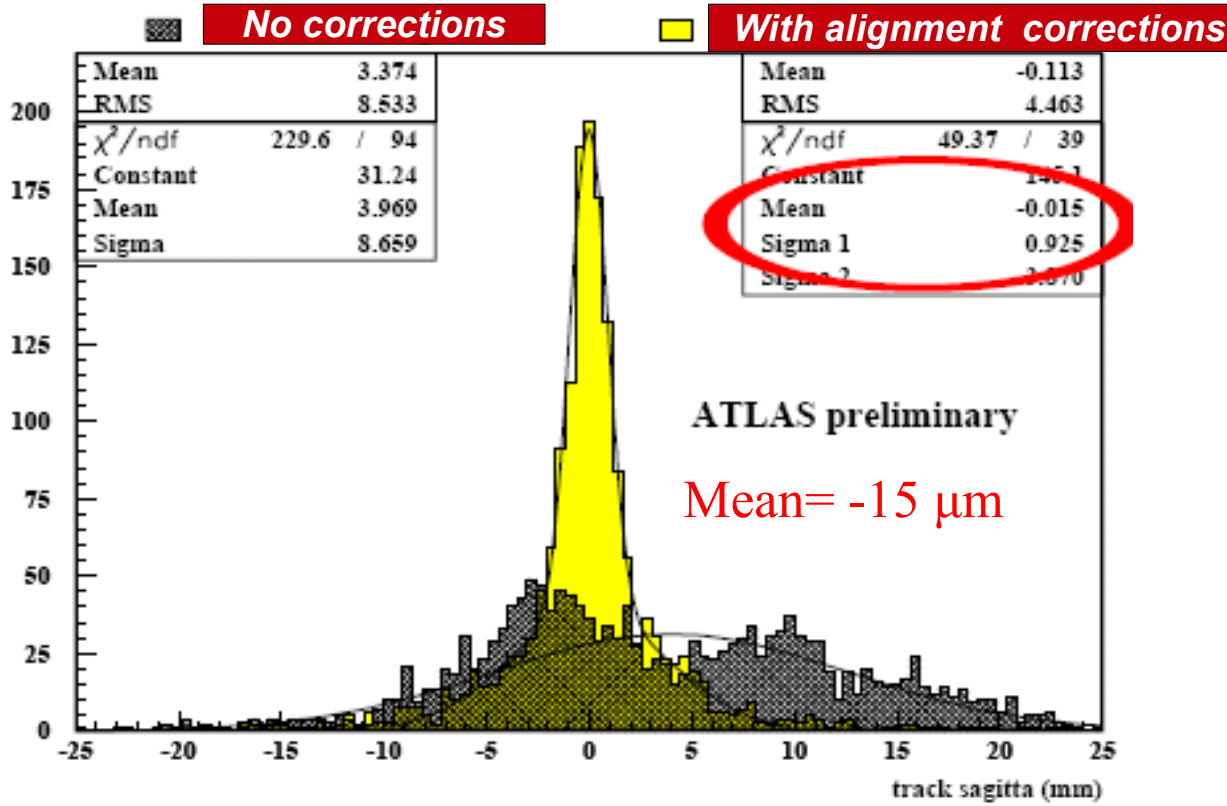
Alignment System

- Grid of 12k optical sensors measure chamber relative positions, rotations, & deformations
- Endcap: polar lines between wheels, radial alignment bars, chamber-to-bar proximity sensors.
- Barrel: Project lines between layers, proximity (praxial+axial) between chambers.
- Track-based alignment between barrel large & small chambers, as well as inner detector-muon spectrometer



Alignment Results – Endcap

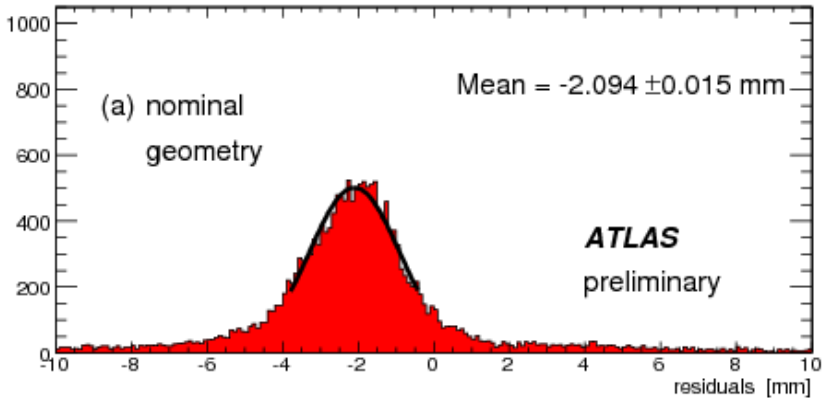


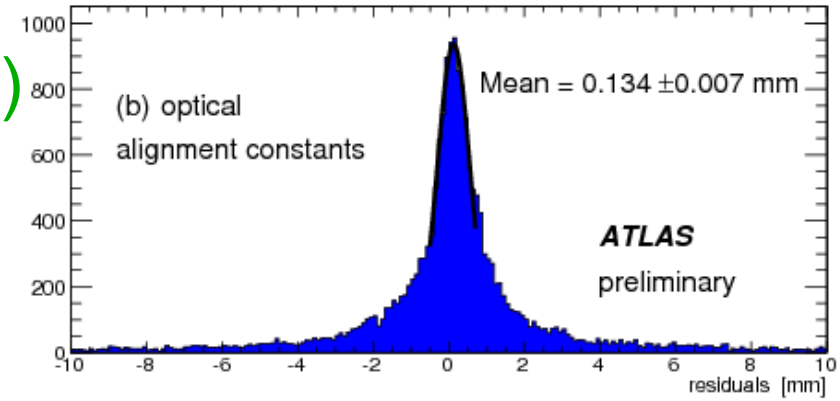


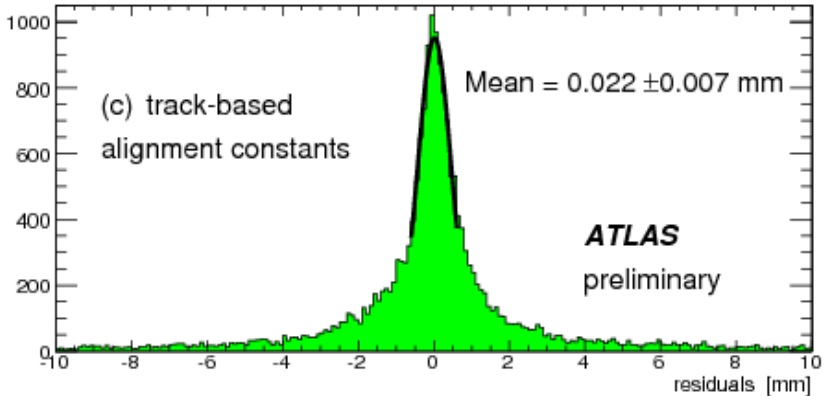
- 500 μm sagitta for 1 TeV muon; ∴ 10% ΔPt ⇨ Δsagitta≃50μm
- With B=0 define sagitta as deviation of track segment in middle MDT layer from a track fit to segments from inner+outer layer.
- Perfect alignment with B=0 expect mean sagitta of 0; measure 15 ± 42 μm after alignment corrections are applied.

Alignment Results – Barrel

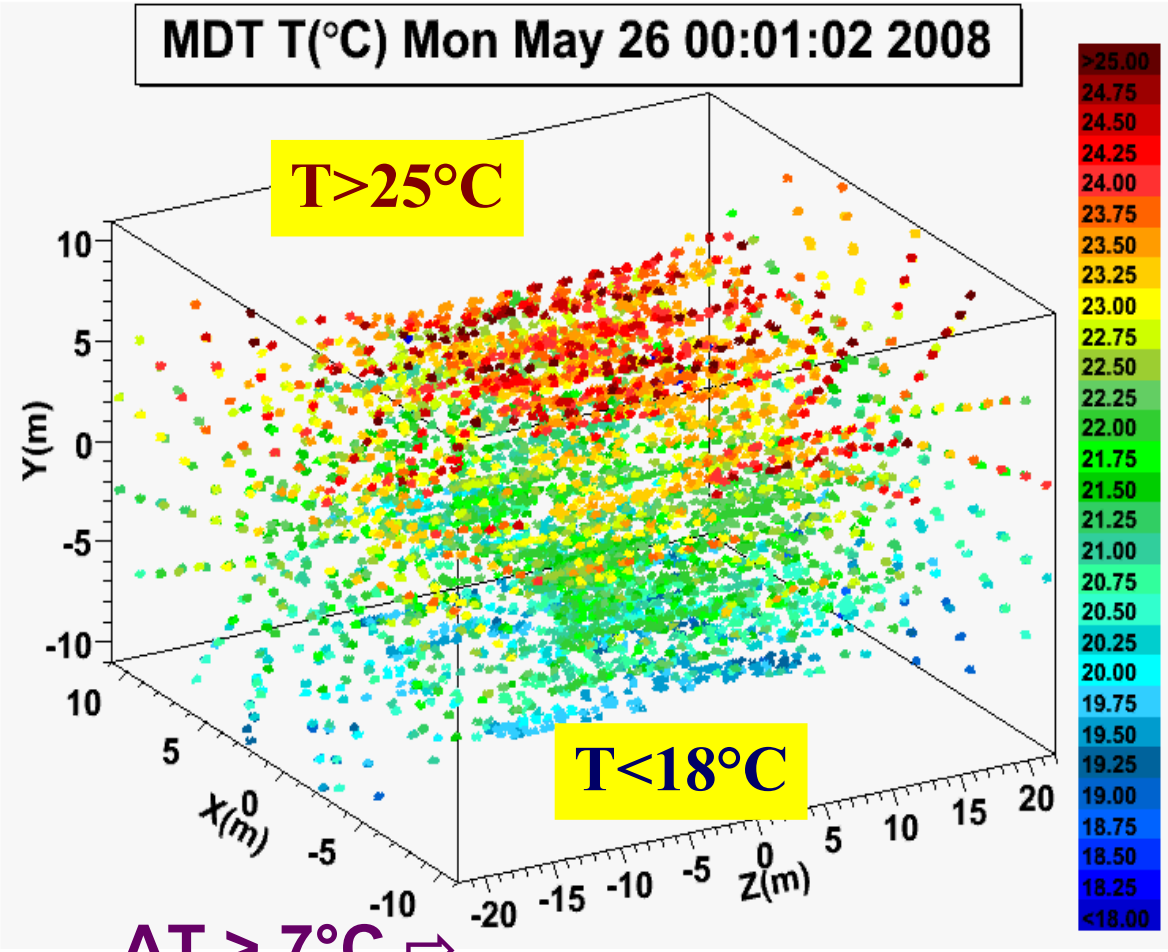
- Optical alignment system only on ½ barrel chambers ("large" chambers), "small" chambers aligned with tracks.
- Need 10^5 tracks (20 GeV) to align large chambers to 30 μm in relative mode. 5X stats needed for small chambers (few hours @ 10^{31} $s^{-1}cm^{-2}$)
- Data selection (cosmic rays):
  - Magnet off
  - Tracks near IP, crossing 3 chambers
  - Sagitta from middle chamber relative to line between inner & outer chambers.
  - Measure sagitta = 22±7 μm
  - Current normal resolution = 50/200 μm (large/small chambers)







Detector Control System (DCS)

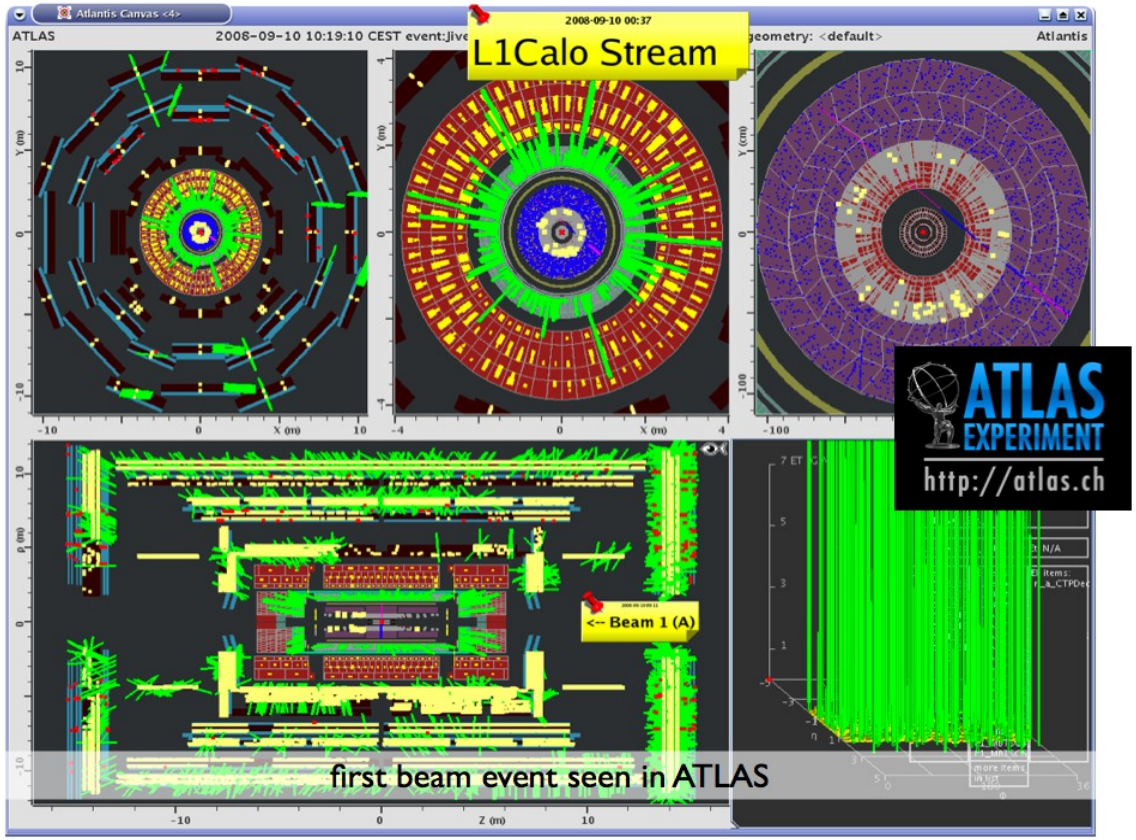


ΔT > 7°C ⇨
drifter≃17ns
ΔR_{drift}≃340 μm
>4 times tube resolution.

- System used for chamber initialization, control and sensor read-out.
- MDT sensors:
  - 18.8 k chan of electronics voltages/temps
  - 2k Hall probes
  - Alignment system
- MDT temperature and magnetic sensors readings used to correct drift time.

Conclusions

- ATLAS Muon spectrometer is installed and operational.
- Detectors and alignment system are performing at design specs with a few exceptions.
- Bring on the beam!



Beam splash event
Fall 2008