The ATLAS Detector

Its Commissioning without Beam

Aspen Winter 2009 - Workshop on Physics at the LHC era

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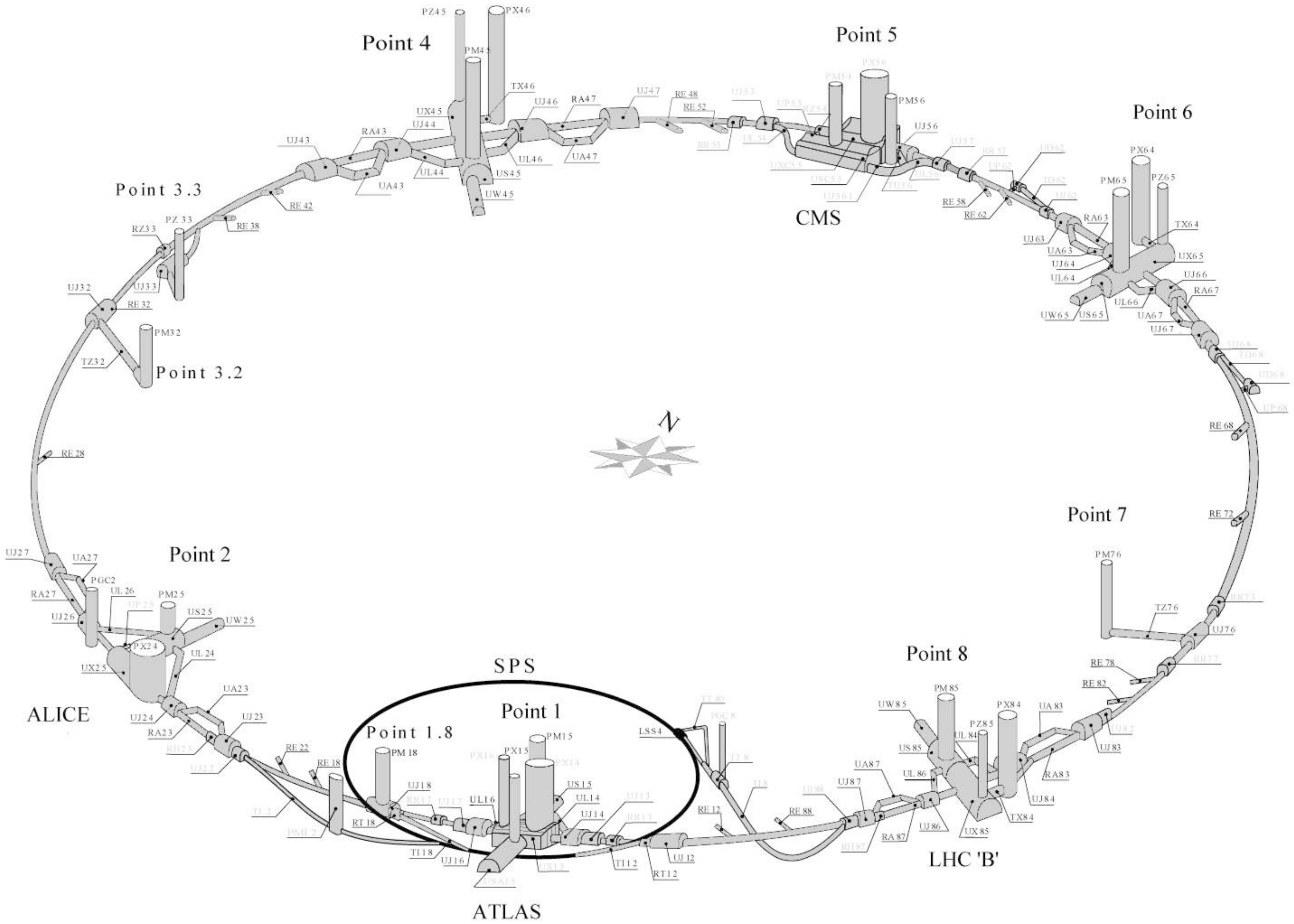
on behalf of the ATLAS Collaboration

Introduction

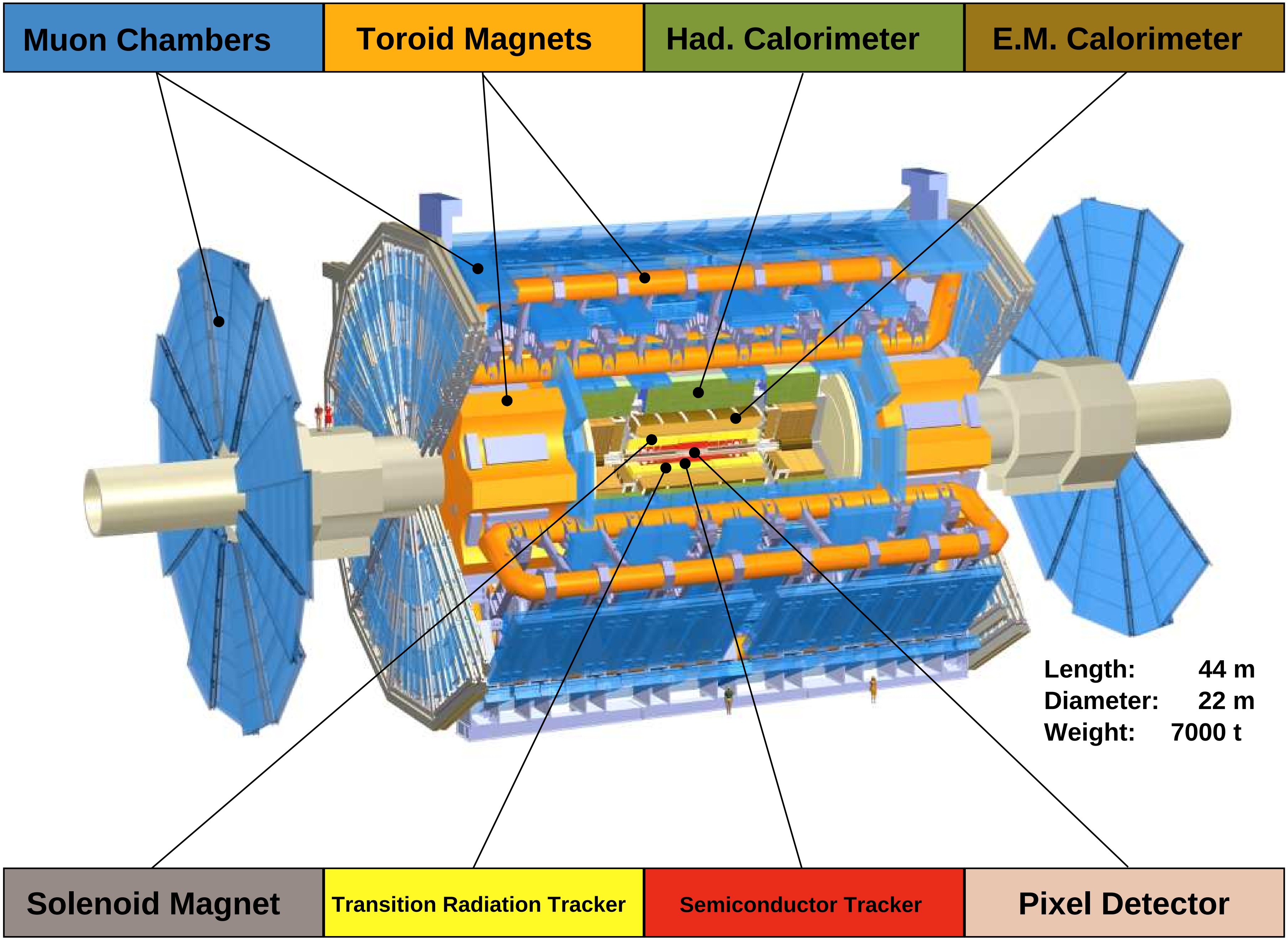
37 Countries — 169 Institutions — 2500 Scientific Authors

LARGE HADRON COLLIDER



- pp collisions at $\sqrt{s}$ = 14 TeV
- Luminosity: 10^{34} cm^{-2} s^{-1}
- 40 MHz bunch crossing frequency
- 27 km circumference
- 4 main experiments:
  ALICE, ATLAS, CMS, LHCb

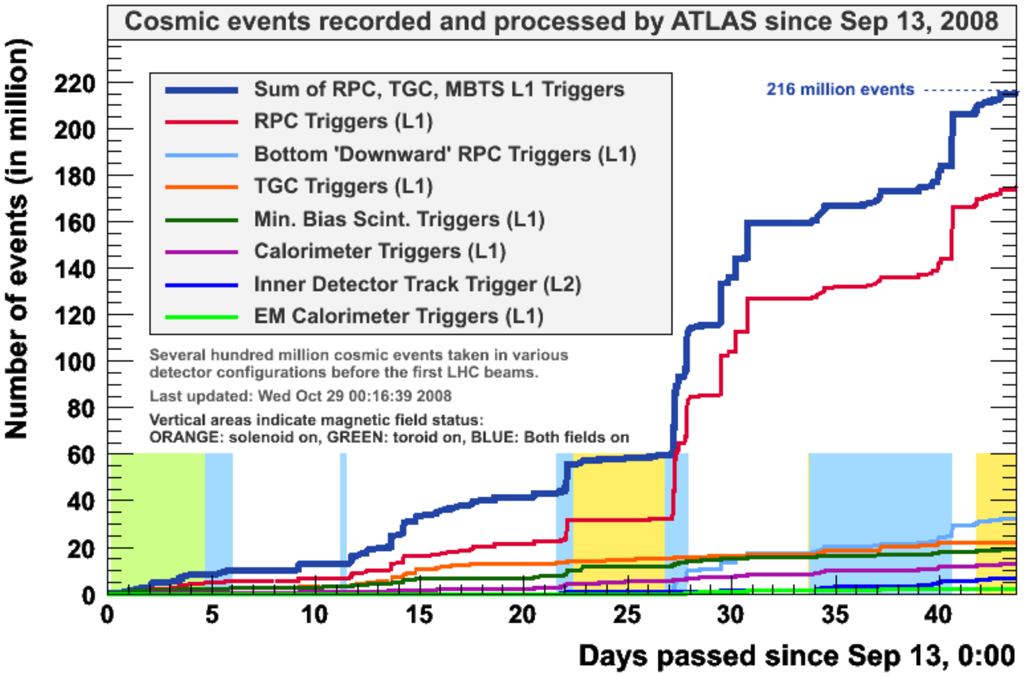
A TOROIDAL LHC APPARATUS



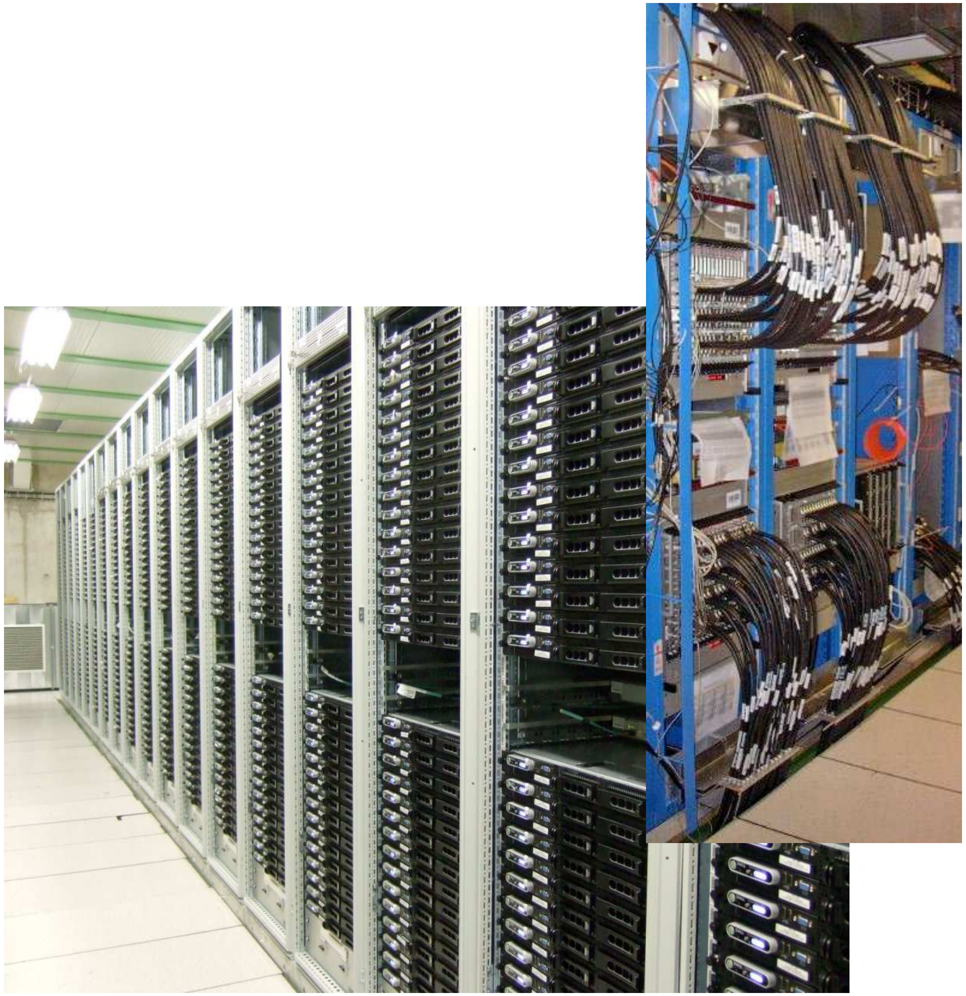
Commissioning started in 2005 in parallel with the detector installation

- Test channel mapping and timing
- Determine dead and noisy channels
- Verify stability of hardware components during operation
- Gain experience in detector operation and control, data acquisition and analysis chain
- Obtain first calibration and alignment constants
- Develop and test monitoring tools
- Understand and improve detector performance

- Most of cosmic data taken in Fall 2008



Trigger and Data Acquisition



Trigger and Data Acquisition — Design

Level 1

- Hardware implementation
  Synchronous at 40 MHz (LHC clock)
- Reduced granularity and detector information
- Selects Regions of Interest (ROI)
- Maximum output rate: 75KHz (upgradable to 100 KHz)
- 2.5 μs latency

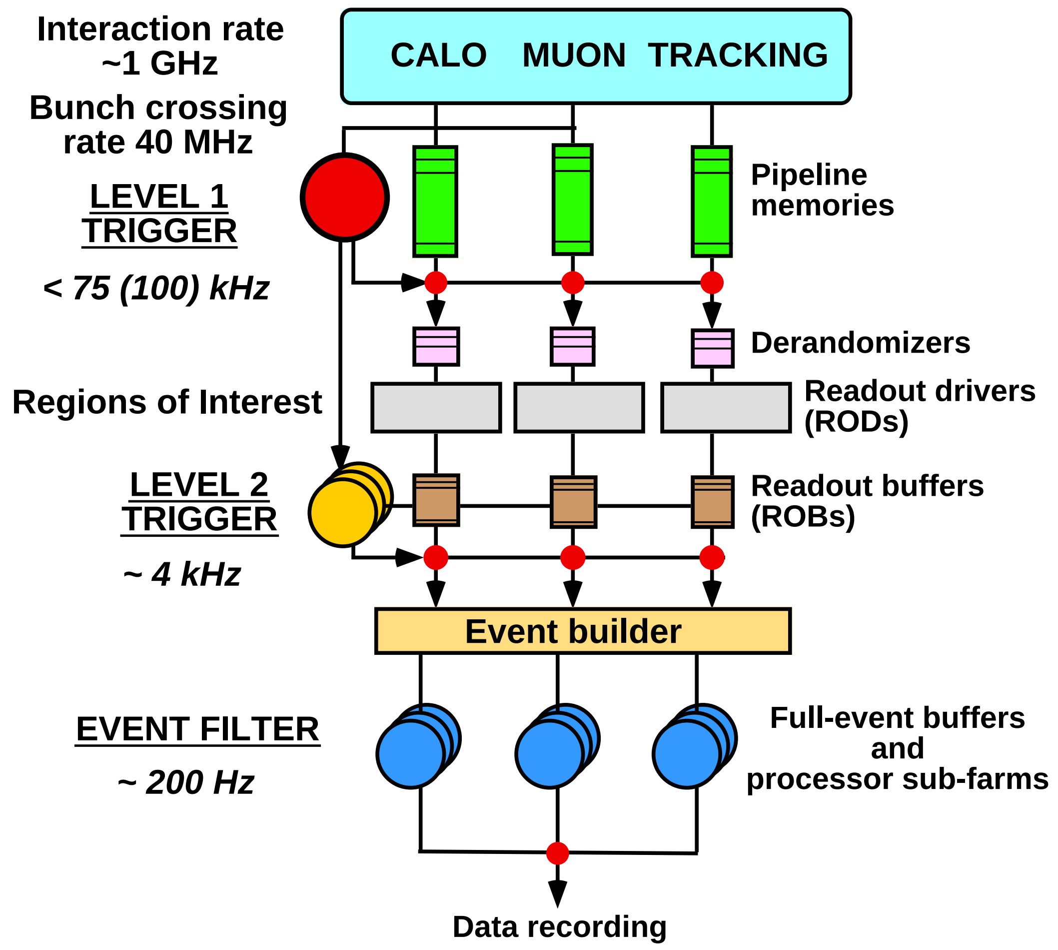
Level 2

- Software implementation
- Full detector information only for ROI
- Source of high statistics calibration streams
- Maximum output rate: $\sim$4 KHz
- 40 ms latency

Event Filter

- Software implementation
- Full detector information
- Maximum output rate: $\sim$200 Hz
- 4 s latency

High level trigger (HLT)



Event size: 1.5–2 MB

Trigger and Data Acquisition — Status

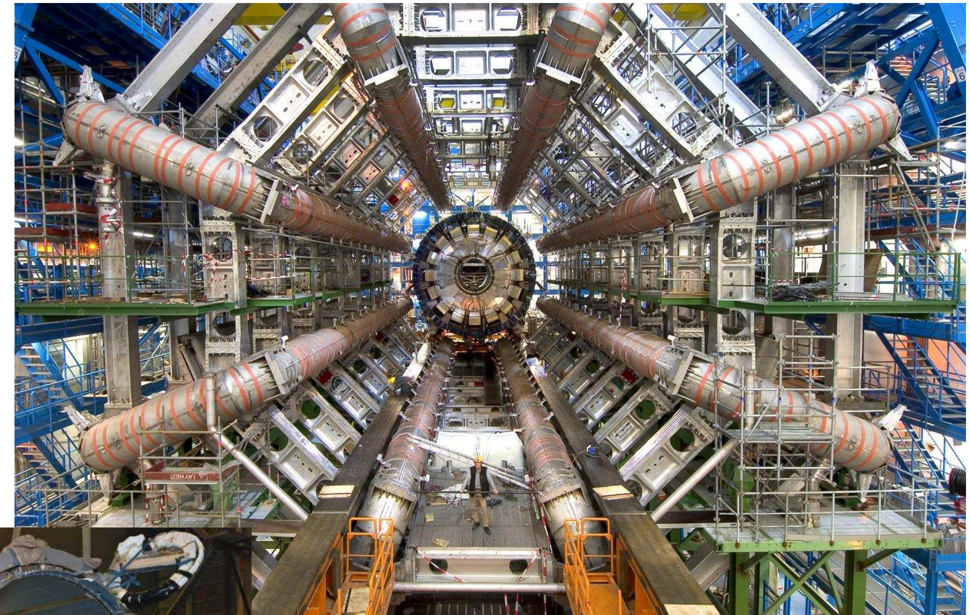
Level 1 Trigger

- System completely installed
- Rate test successful up to 40 KHz (random trigger) to be improved to nominal rate of 75 KHz in 2009
- Timing of all trigger work in progress

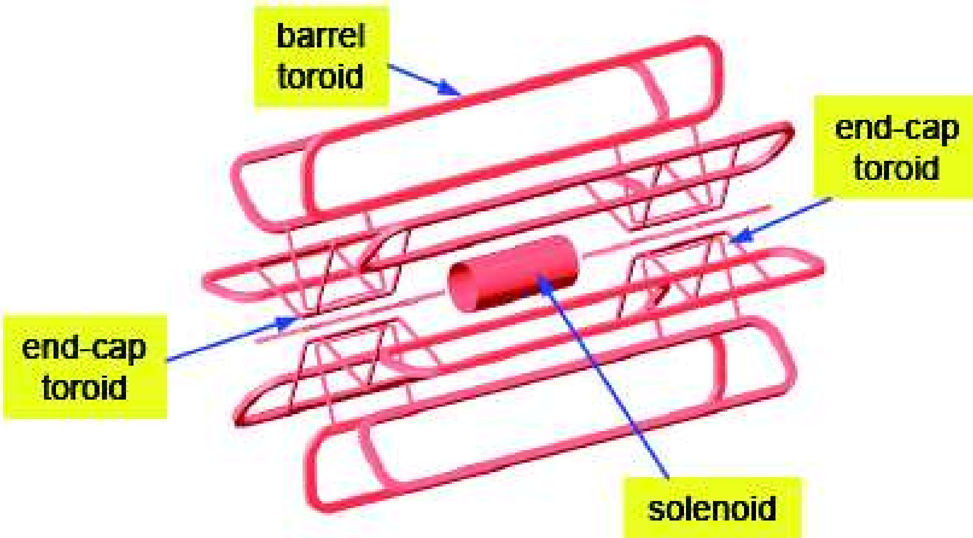
High Level Trigger (Level 2 + Event Filter)

- Current configuration
  - 850 PCs in 27 racks (can either be used by Level 2 or Event Filter)
  - Capable of 60 KHz sustained rate
- Final configuration
  - 500 PCs for LVL2, 1800 PCs for Event Filter (PC: 8 cores, 2.5 GHz with 2 GB / core RAM)
  - 17 Level 2 racks, 62 Event Filter racks (28 racks configurable)
  - Finalization of system will be luminosity driven
- Level 2 muon calibration stream working
  - Single muons
  - Nominal rate: $\sim$1 KHz
- HLT (tracking algorithms) used to enrich cosmic samples for inner detector studies

Magnet System



Magnet System — Design



Barrel Toroid

- Length: 25.3 m
- Outer diameter: 20.1 m
- 8 coils with individual cryostats
- Nominal current: 20.5 kA
- Field strength: 0.2–2.5 T
- Stored energy: 1100 MJ

Solenoid

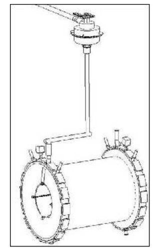
- Length: 5.3 m
- Outer diameter: 2.63 m
- 1 coil
- Nominal current: 7.73 kA
- Field strength: 2 T
- Stored energy: 39 MJ
- Thickness: 0.66 X_0

Two Endcap Toroids

- Length: 5 m
- Outer diameter: 10.7 m
- 2 $\times$ 8 coils with common cryostats
- Nominal current: 20.5 kA
- Field strength: 0.2–3.5 T
- Stored energy: 2 $\times$ 250 MJ

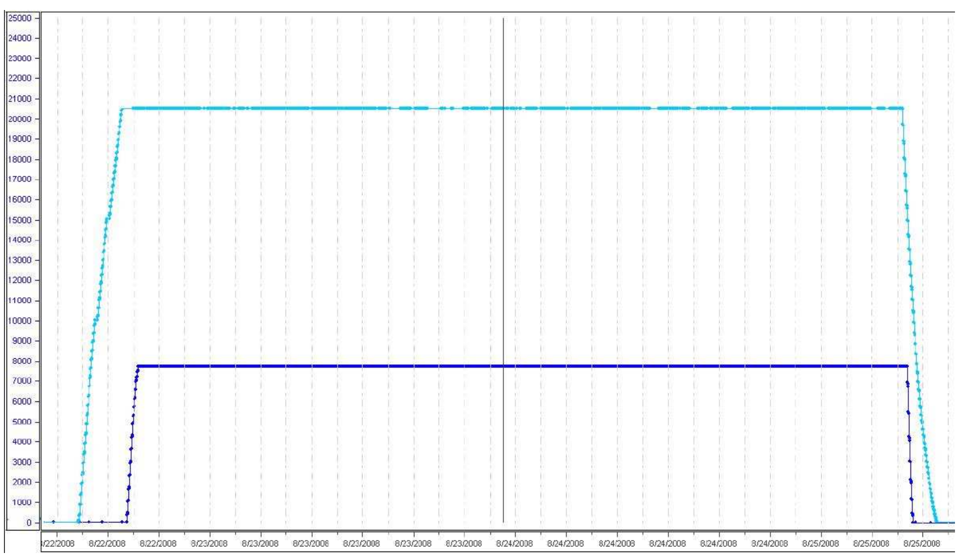
Stable continuous operation at nominal field

- Endcap toroid A required some training
  Nominal toroid current now at 20400 A
- Central solenoid works together with barrel toroid
  - Bus bars and instrumentation cables traverse toroid field

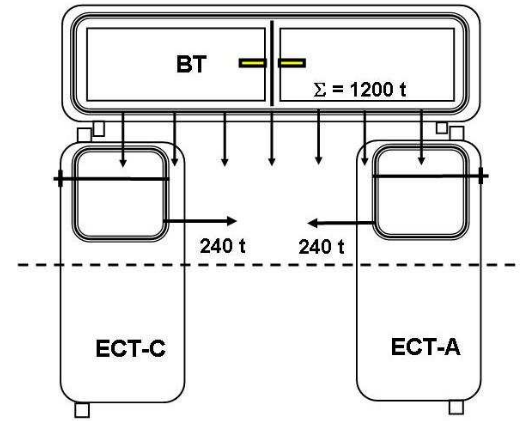


- Stress and heat distributions during fast quench (in case of loss of superconductivity) are safe
- Recovery of cryogenics after fast quench: 4 days

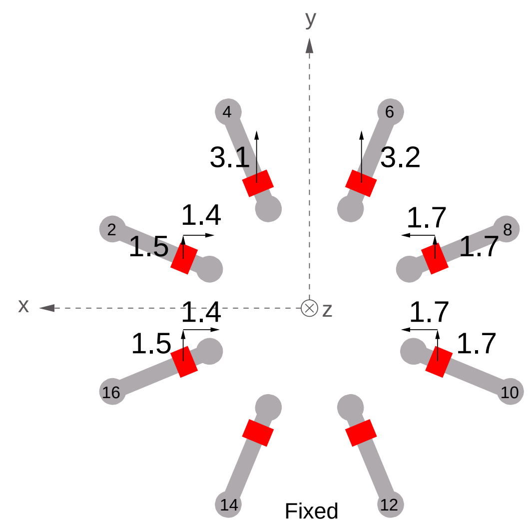
First test of complete magnet system in Aug. 2008



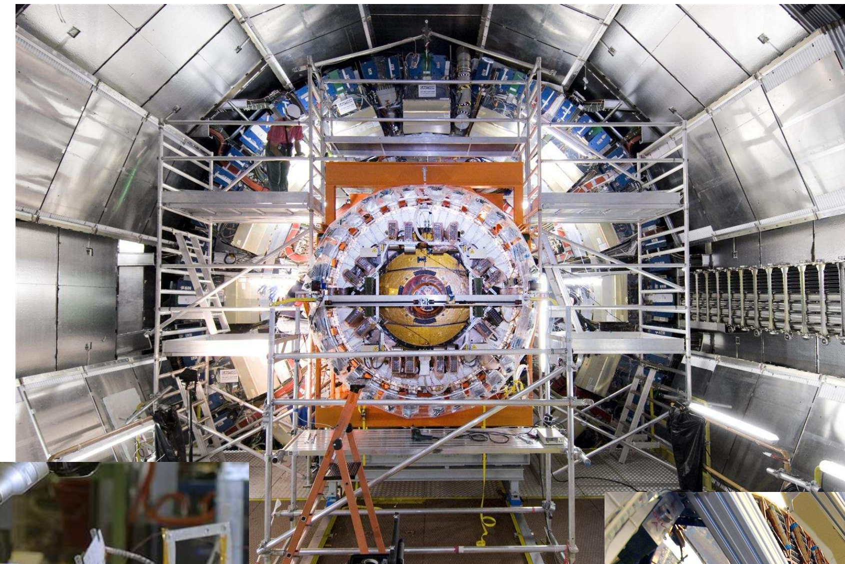
- Load transfer endcap - barrel toroids OK

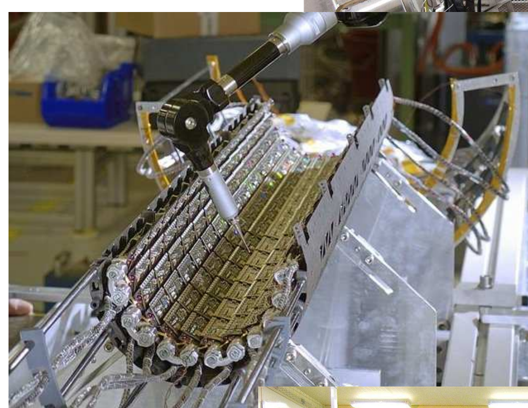


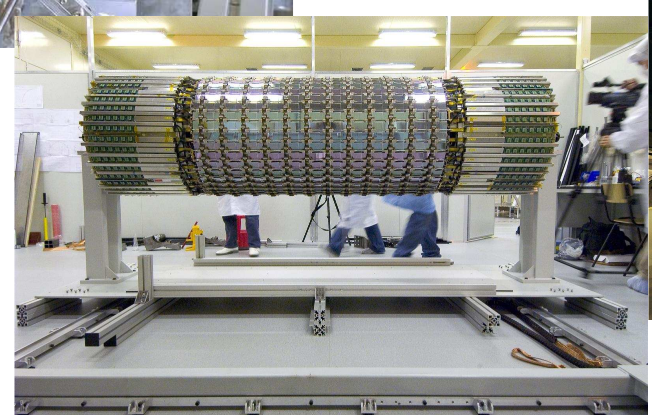
- Geometrical distortion of barrel toroid with field on as expected (light support structure)

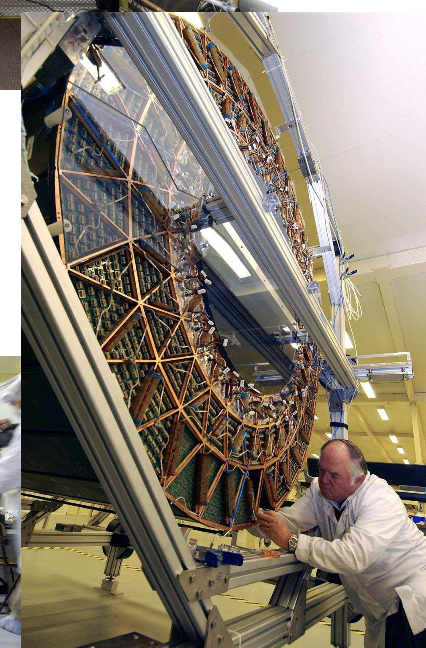


Inner Detector



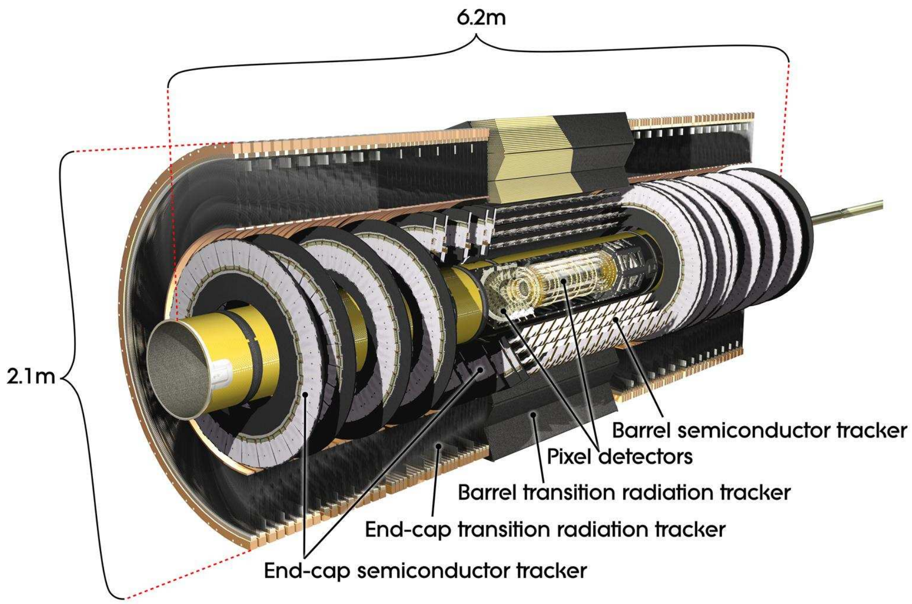






Operated inside 2 Tesla solenoidal field, coverage $\eta < 2.5$ (Transition Radiation Tracker $\eta < 2.0$)

$\sigma/p_T = 0.05\%\ p_T \oplus 1\%$



Semiconductor Tracker (SCT)

- 4 cylindrical double layers with radius 30, 37, 44, 51 cm in barrel region
- 2×9 disks in forward regions
- 4088 modules with 80 μm strips
- 6 M channel
- Resolution: 17 μm $\times$ 580 μm

Transition Radiation Tracker (TRT)

- Polypropylen-polyethylene fibers (barrel) polypropylene foils (endcap) as radiator
- 4 mm diameter straw tubes with 35 μm anode wires
- 73 layers in barrel region with axial straws
- 2×160 (20 disks each) with radial straws in forward region
- 351 K channel
- e-π identification: 0.5 GeV $<$ E $<$ 150 GeV

Pixel Detector

- 3 cylindrical layers with 5, 9, 12 cm radius in barrel region
- 2×3 disks in forward regions
- 1744 modules, each with 46860 pixel of 50 μm $\times$ 400 μm
- 80 M channel
- Resolution: 10 μm $\times$ 110 μm

Inner Detector — Status

Evaporative Cooling System

- Cooling system to operate silicon detectors at -7 ^{o}C
- Compressor damage with partial pollution delayed commissioning of Pixel and SCT (May – July 2008)
- Cracks at piping of compressors under repair

Pixel Detector

- $>$ 95% of modules operational
- Noise occupancy: $5 \cdot 10^{-9}$
- Hit efficiency: $>$ 98%
- 3 leaking cooling loops in endcaps (affect 3 of 24 modules) under investigation
- Problem with dying off-detector optical links (to be replaced)

SCT

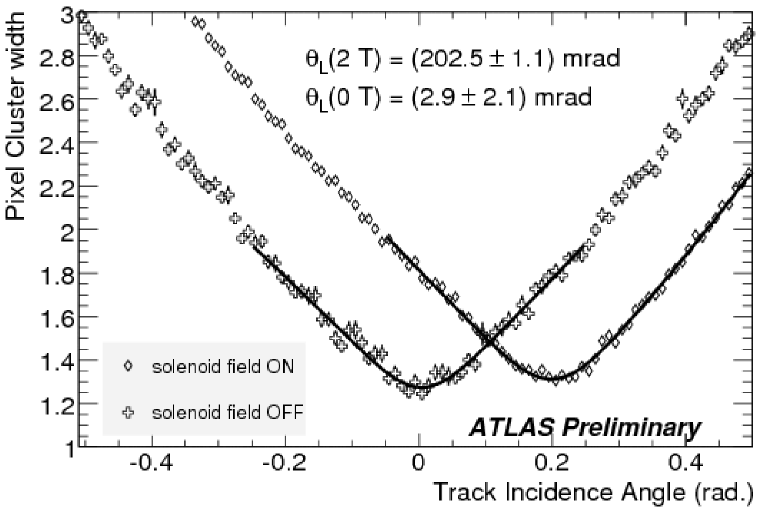
- $>$ 99% of barrel and $>$ 97% of endcap modules operational
- Noise occupancy: $4.4 \cdot 10^{-5}$ (barrel), $5 \cdot 10^{-5}$ (endcap)
- Hit efficiency: $>$ 99%
- 2 cooling loops in endcaps not operated (to be repaired in shutdown)
- Problem with dying off-detector optical links (to be replaced)

TRT

- 98% of channel operational (2% dead from assembly and installation)

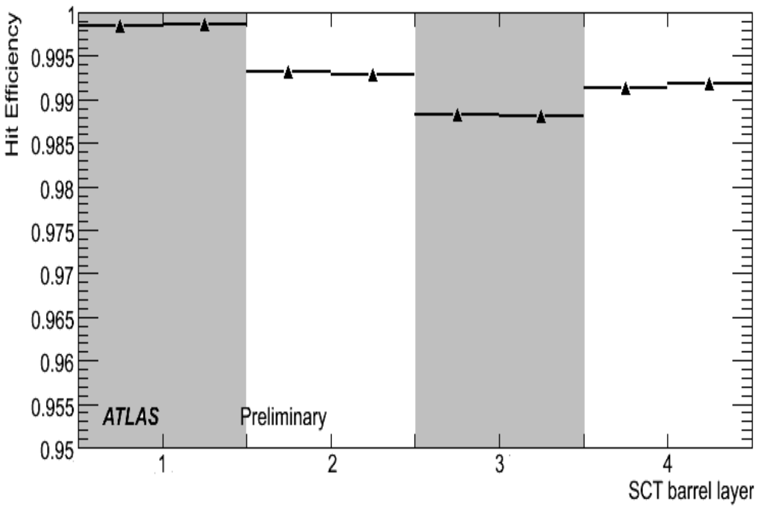
Measurement of cluster width in pixels

Determination of Lorentz angle, essential to reach final spatial precision (MC prediction: 224 mrad)



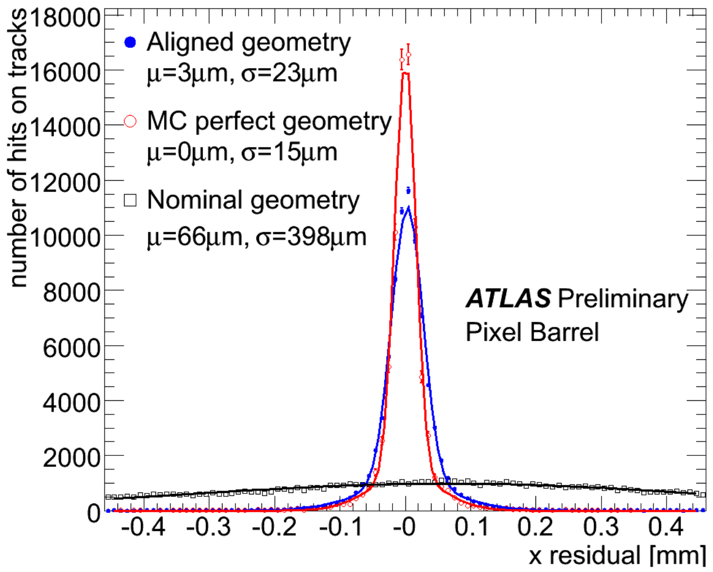
Measurement of barrel SCT efficiencies

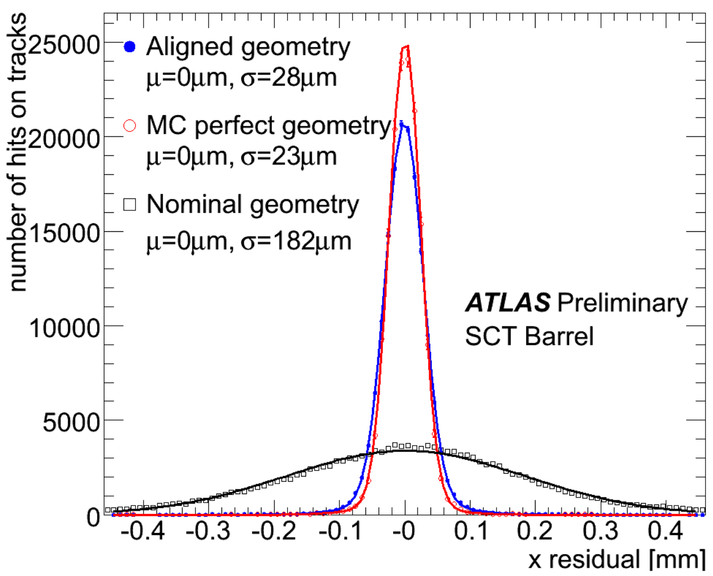
Systematic differences between layers due to preliminary alignment

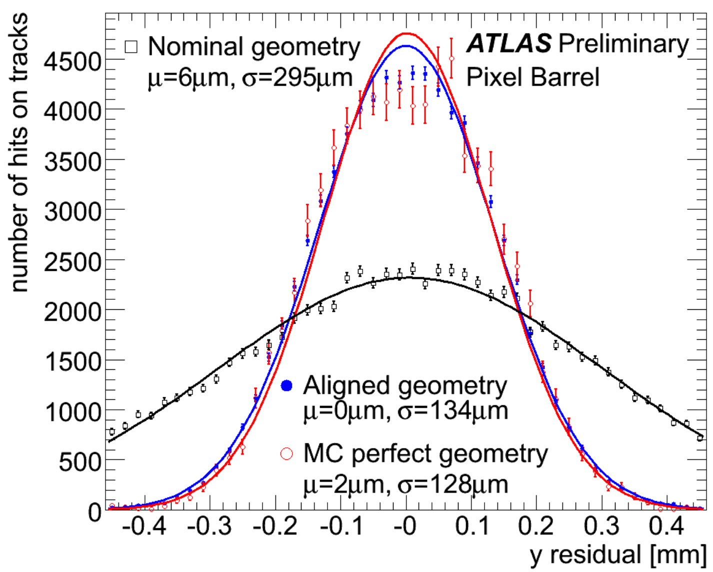


Alignment with tracks

- Alignment performed in steps of increasing number of DoF
  - O(1M) tracks needed for full alignment
- Track residuals close to perfect geometry for barrel region
- Limited statistics for endcaps

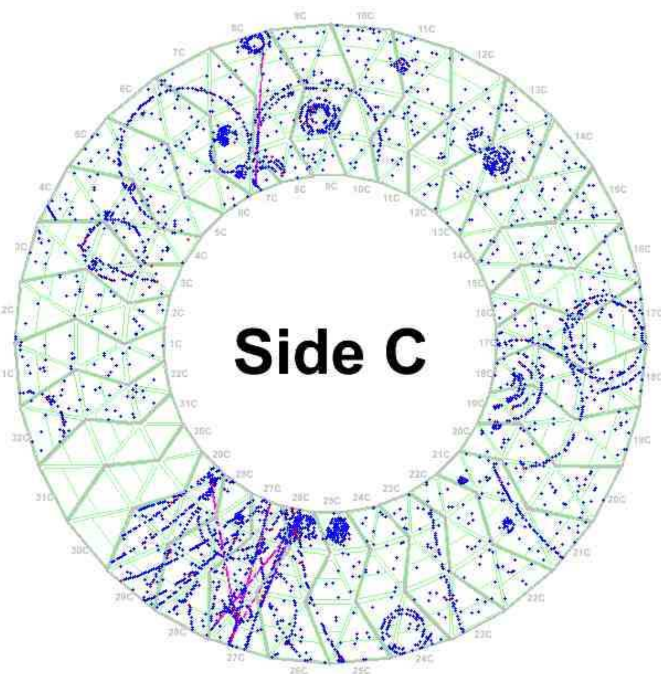






Transition Radiation Tracker

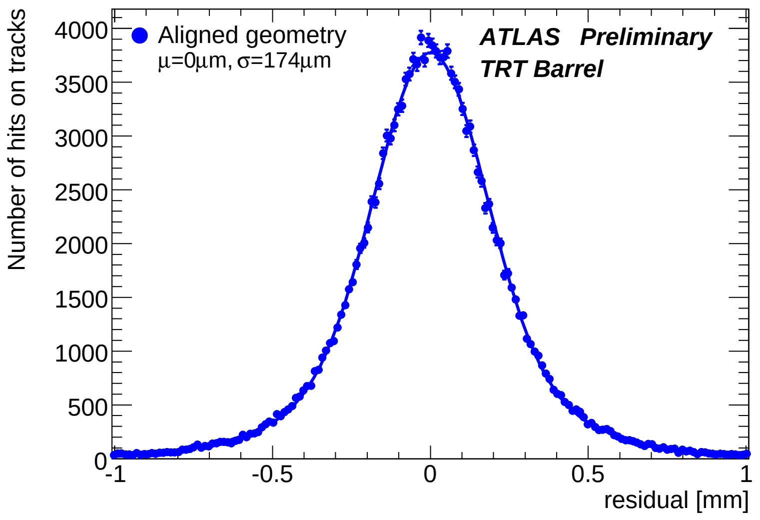
Bubble Chamber like events displays



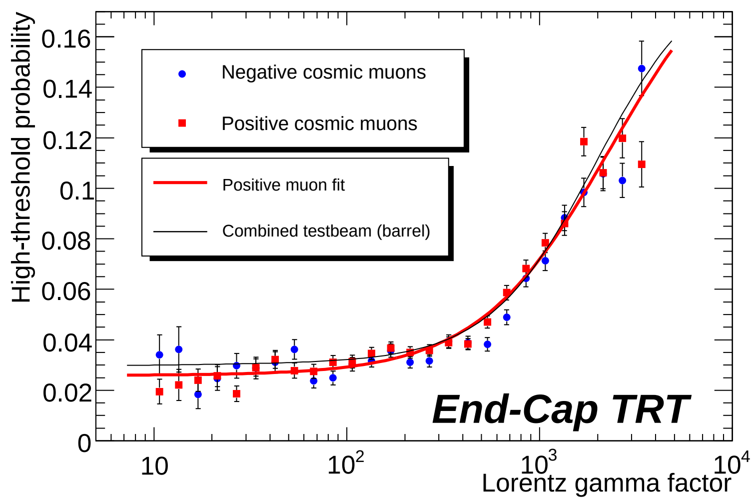
Right: Measurement of the probability of transition radiation

Good agreement with test beam data

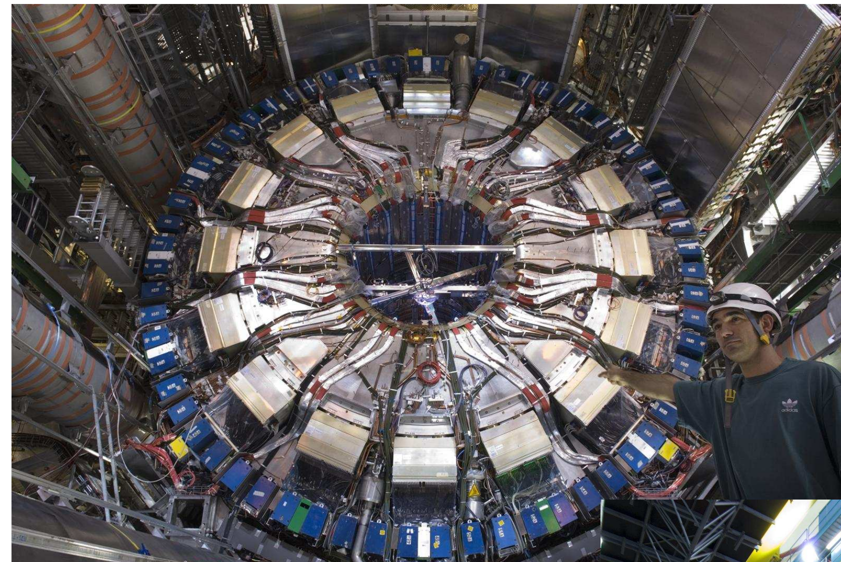
Track residuals

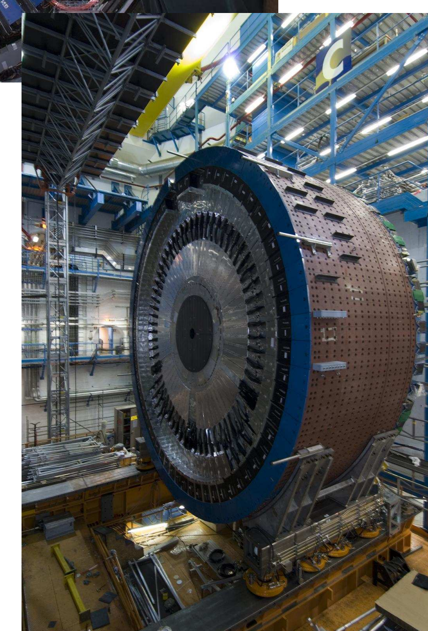


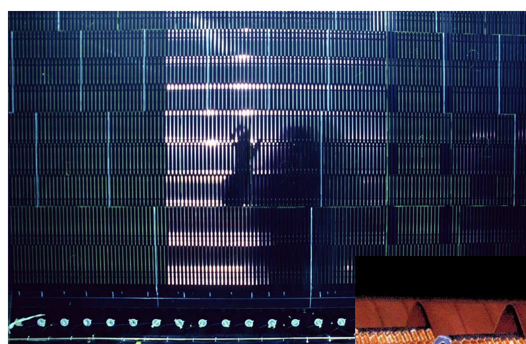
TRT design straw resolution: 130 μm

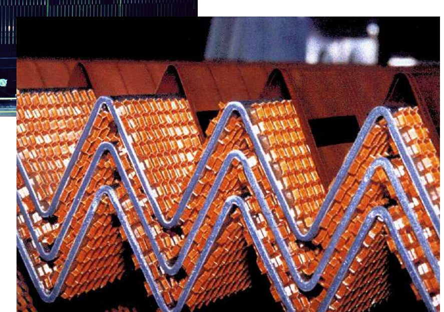


Calorimeters



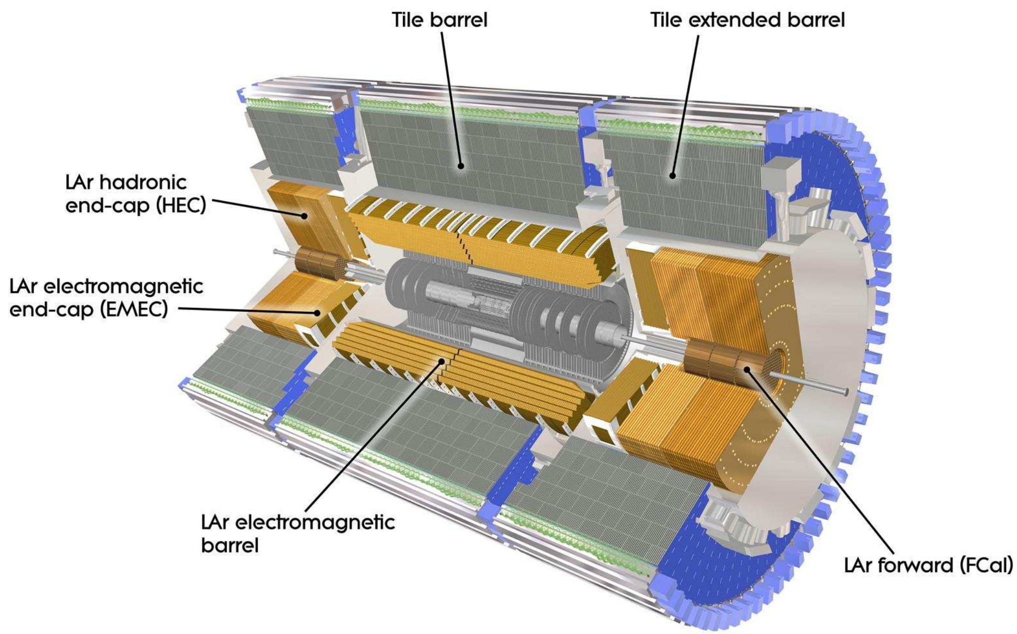






Calorimeters — Design

Complete azimuthal symmetry, coverage $\eta < 4.9$



Electromagnetic Calorimeter

- Pb-LAr accordion geometry
- 3 longitudinal samples $\eta < 2.5$
- Preshower detector $\eta < 1.8$
- 173 K channel
- σ(E)/E = 10%/$\sqrt{E}$ $\oplus$ 0.7%

Hadron Calorimeter

- Barrel: iron-scintillator tiles
  (3 longitudinal samples)
  Endcap/forward: Cu/W-LAr
  (4/3 longitudinal samples)
- 20 K channel
- σ(E)/E = 50%/$\sqrt{E}$ $\oplus$ 3% ($\eta < 3.2$)
  σ(E)/E = 100%/$\sqrt{E}$ $\oplus$ 10% ($\eta > 3.1$)

Calorimeters — Status

Liquid argon calorimeter (electromagnetic, hadron endcap, forward)

- Dead channel: 0.02% (+ 0.9% recoverable in shutdown)
- Noisy channel: 0.1% ($>$ 5 sigma of ϕ-average), bad or no calibration: 0.45%
- Full detector operational with HV
- Electronic calibration procedure operational
  - Calibration constants used online
- Refurbishment of all LV power supplies (arching and problematic capacitors)

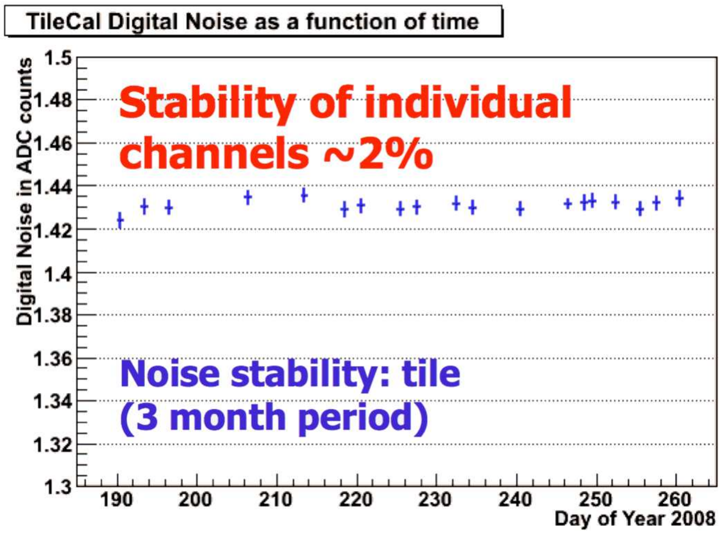
Tile calorimeter

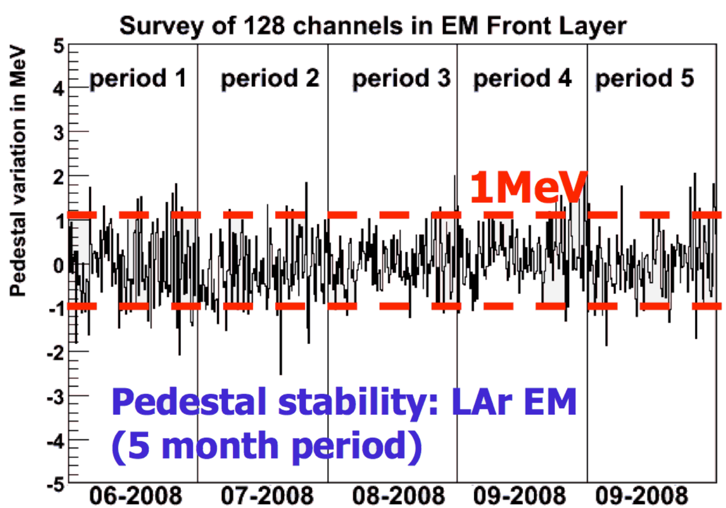
- Dead channel: $<$ 1.4% to be repaired during shutdown
  - LV power supplies and front end electronics
- Calibration system operational
  - Cs source (PMT gain and fiber attenuation)
  - Laser (PMT response and timing)
  - Charge injection (ADC-to-pC with 0.7% precision)

Level 1 Calorimeter Trigger (e/γ, jets, missing E_T...)

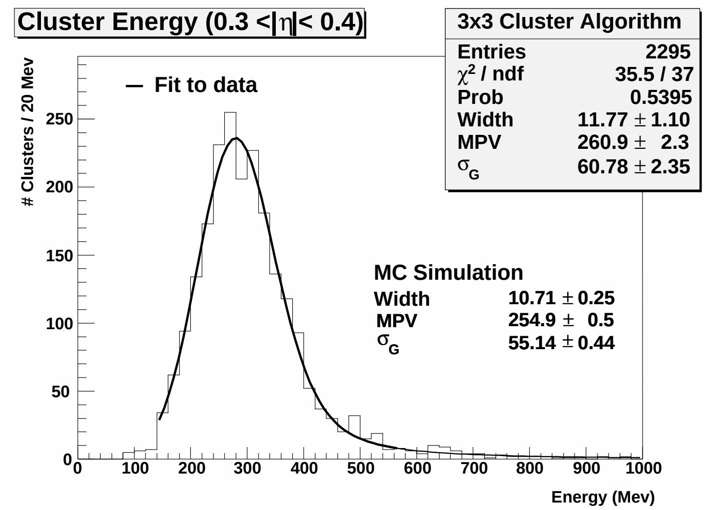
- Dead channel: $<$ 0.4% (+ 0.3% recoverable in shutdown) of 7200 analog channel
- Channel-to-channel noise suppression allows E_T = 1 GeV cut (aim: 0.5 GeV)

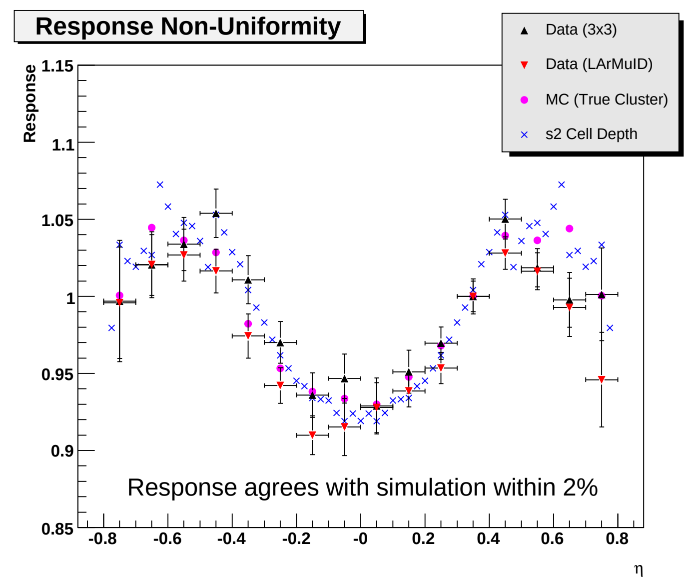
Stability of Tile and LAr calorimeters





Uniformity of LAr calorimeter

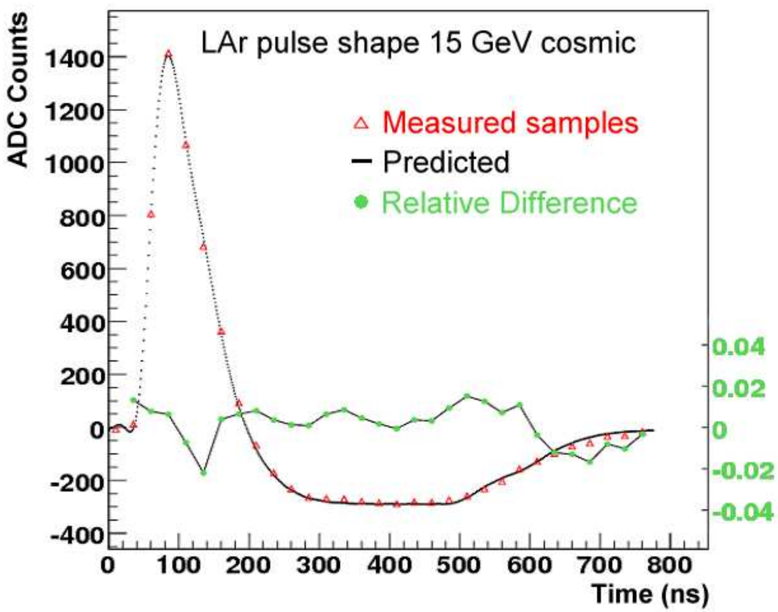


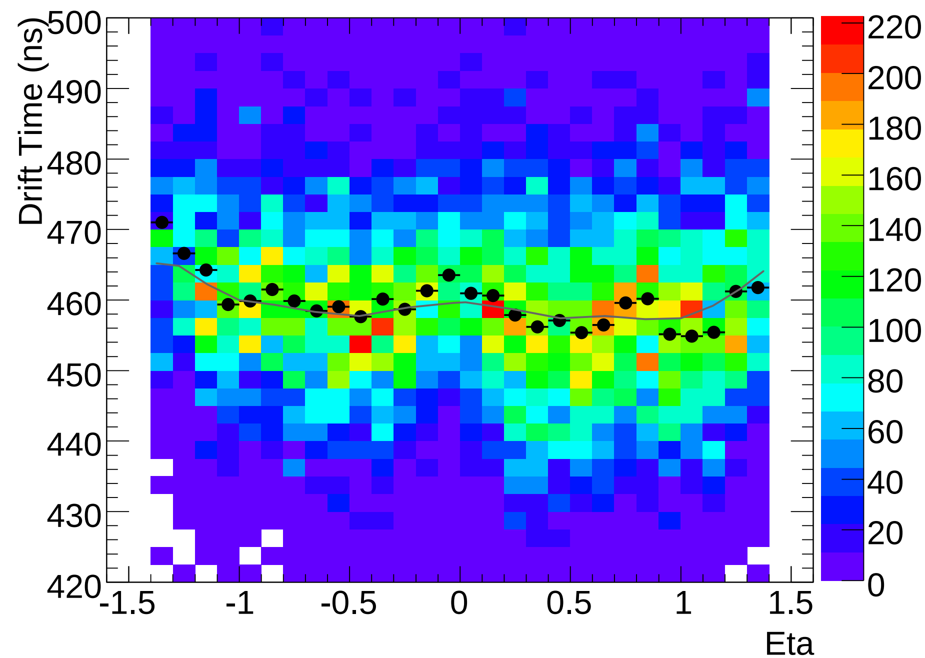


LAr calorimeter: pulse shape studies

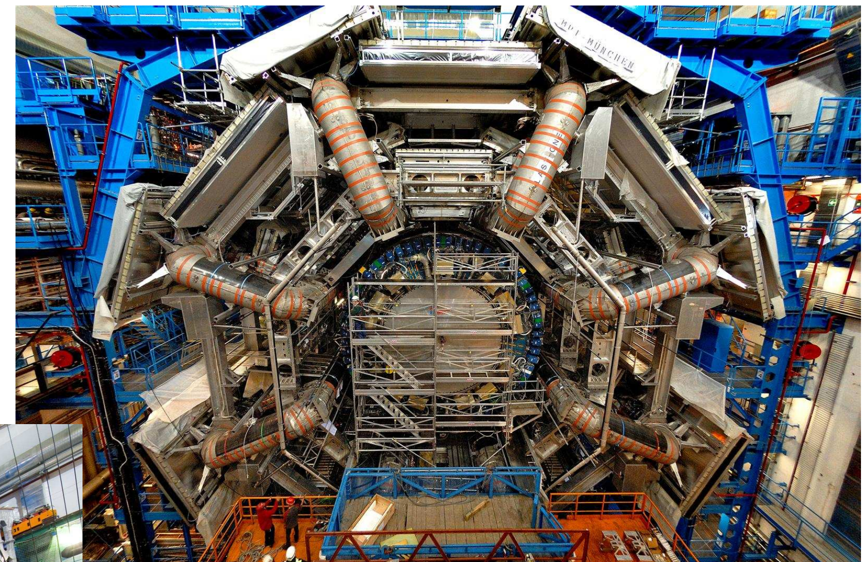
Detailed studies of pulse shape (32 samples instead of 5 sample during physics) allow very good understanding of electronic chain, drift properties and cell geometry

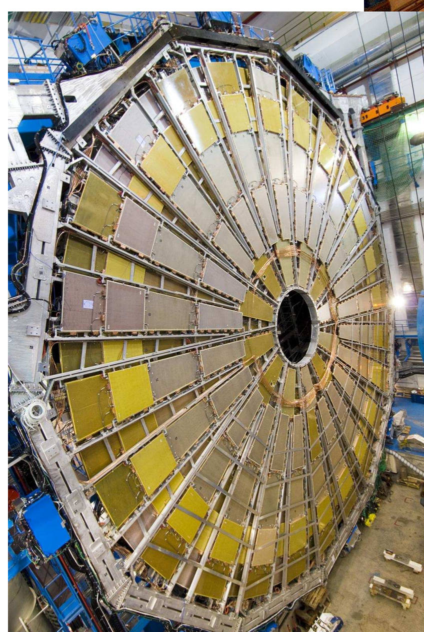
Example: Distribution of drift time derived from undershoot of pulse shape. Comparison with prediction from measurement of gap thickness during production

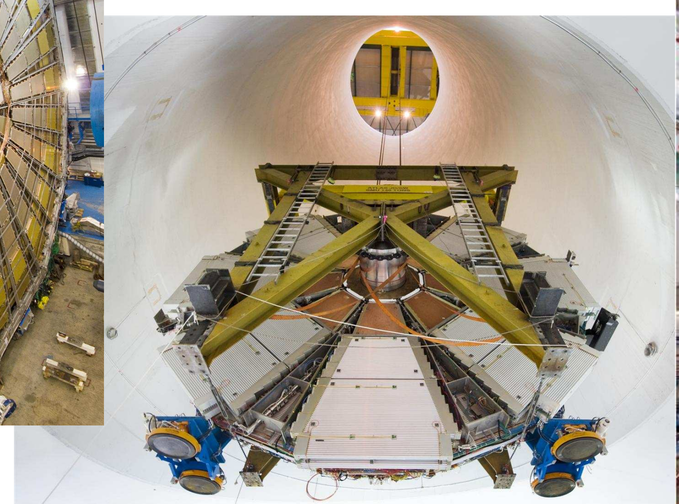


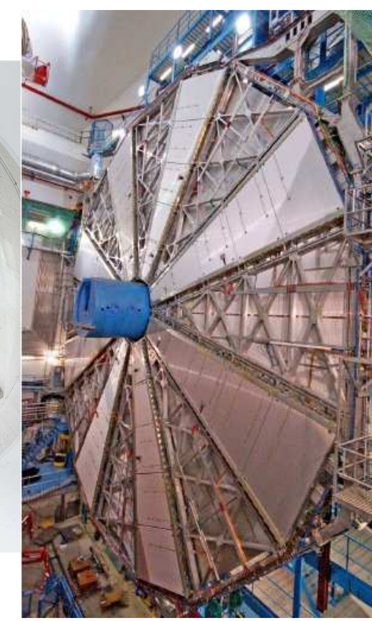


Muon Spectrometer

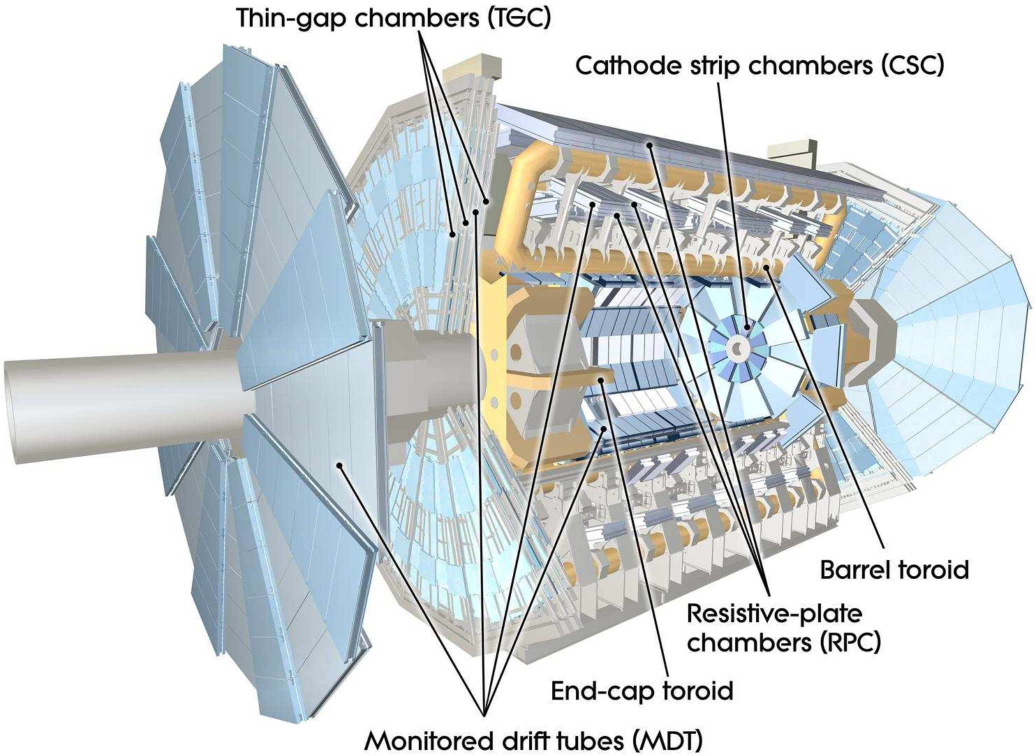








Stand-alone momentum resolution: $\Delta p_T / p_T < 10\%$ up to 1 TeV (independent of η)



Dedicated fast trigger chambers

- RPC: 544 chambers with 359 K ch.
- TGC: 3588 chambers with 318 K ch.
- 2-dimensional readout
- Time resolution < 10 ns
- Spatial resolution 5–10 mm

High precision tracking chambers

- MDT: 1088 chambers with 339 K ch.
- CSC: 32 chambers with 31 K ch.
- Spatial resolution 35–40 μm
- Second coordinate meas. in forward chambers

Optical alignment system, 12232 sensors

Coverage: $\eta < 2.7$ (trigger $\eta < 2.4$)

Air-core toroid magnet system: 1.5–5.5 Tm ($\eta < 1.4$), 1–7.5 Tm ($1.6 < \eta < 2.7$)

Muon Spectrometer — Status

General worries of all systems: power system (improving) and rack turbines (refurbishment planned)

RPC

- 95.5% of chambers operational
- Dead strips: $<$ 2%
- Hot strips/spots: $<$ 1%
- Recirculating gas system working
- Commissioning on-going
- High-p_T trigger lost for one half of 2 projective towers (of 384) and 20 gas gaps disconnected (1 plane of doublet, no loss of coverage) due to gas leaks
- Cooling of upper sectors to be improved

TGC

- 99.8% of chambers operational
- Dead channel: $<$ 0.01%
- Noisy channel: $<$ 0.02% with $>$ 5% occupancy
- 2 chambers lost in overpressure accident (used for 2nd coordinate measurement and background rejection), 1 to be replaced in shutdown
- Full trigger coverage (4 chambers with HV problems, but 3/4 majority logic)

Muon Spectrometer — Status

MDT

- 99.8% of chambers operational
- Dead channel: 0.1% (+ 1% recoverable)
- Noisy channel: $< 0.2\%$ with $> 5\%$ occupancy
- Auto-calibration of space-drifttime-relation working
  - Single muon calibration stream from LVL2 trigger
  - Calibration constants and space-drift time relations regularly provided
- Unexpected number of new gas leaks, reason understood, repair on-going

CSC

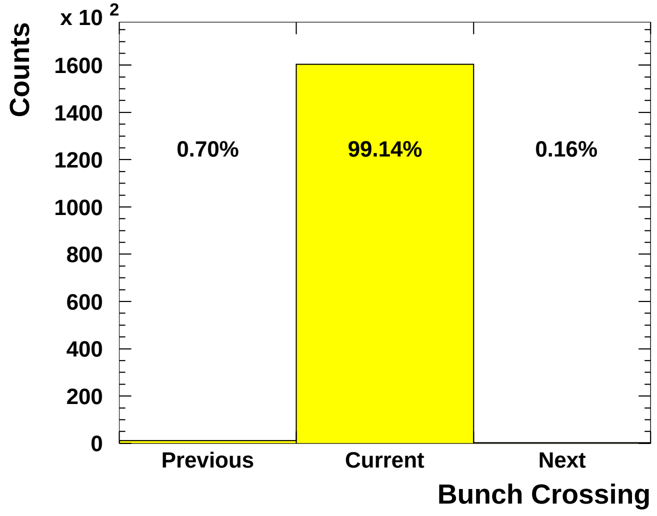
- 100% of chambers operational
- Dead channel $< 0.1\%$
- Two chambers with 1 dead plane (of 4)
- Calibration data collected
- Firmware problem limits stability and maximum read-out rate to O(1 KHz).
  New version expected end of April

Optical alignment

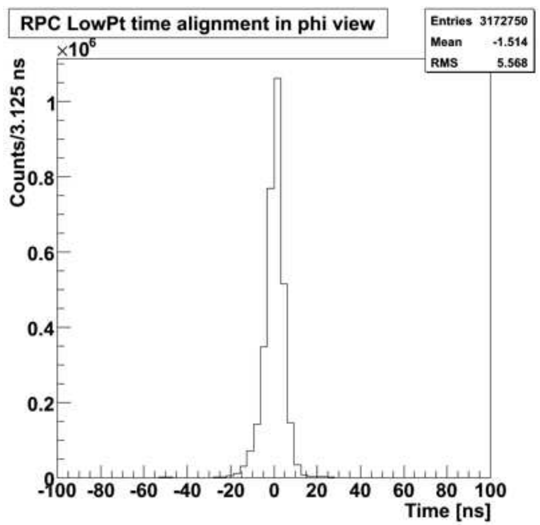
- 99.7% (barrel), 99% (endcap) operational

- Excellent TGC trigger timing (within 1 BC)
- Local RPC trigger timing approaching intrinsic resolution
- Global RPC trigger timing progressing well, but still to be improved

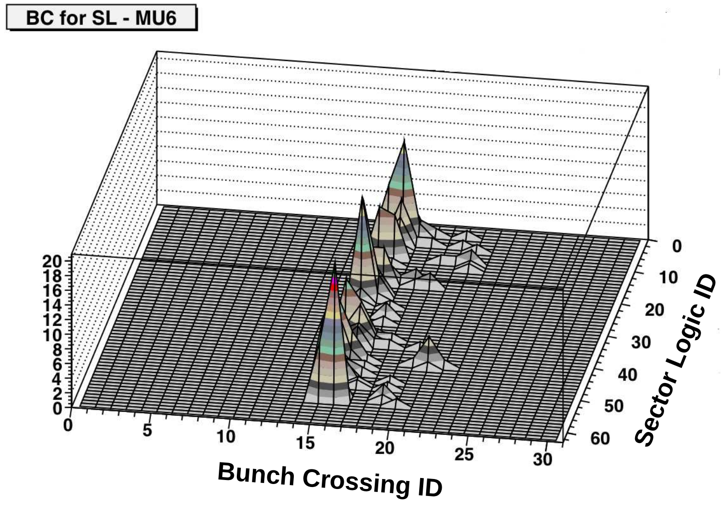
Timing of TGC



Time alignment of RPC low-p_T trigger



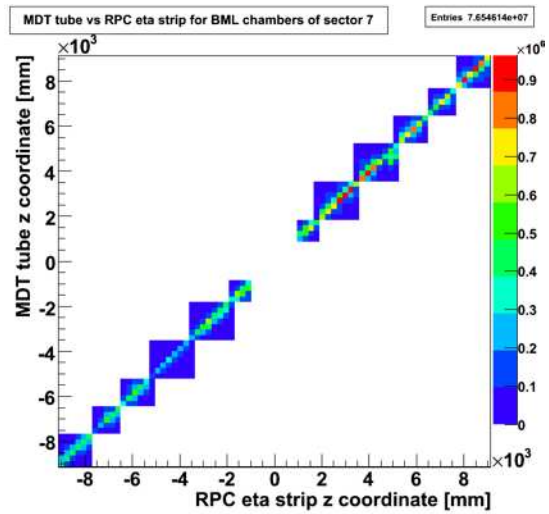
Time alignment of RPC sector logics



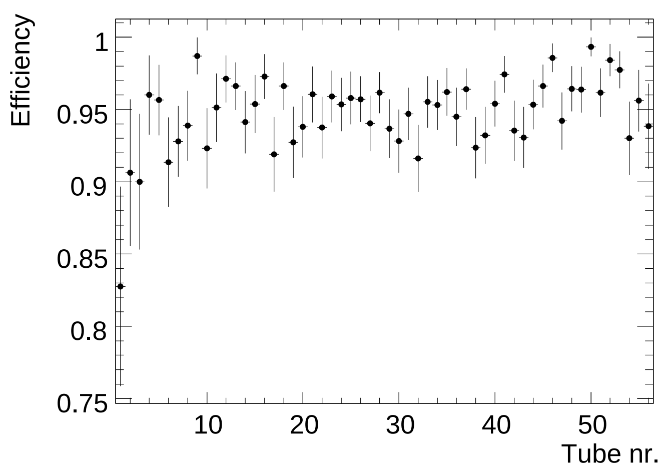
Muon Spectrometer — Results

- Very good correlation between hits in trigger and precision chambers
- Drift tube efficiency as expected (loss of efficiency caused by δ-electrons)
- Drift tube resolution approaching test beam measurements (deviation caused by trigger timing, data being reprocessed)

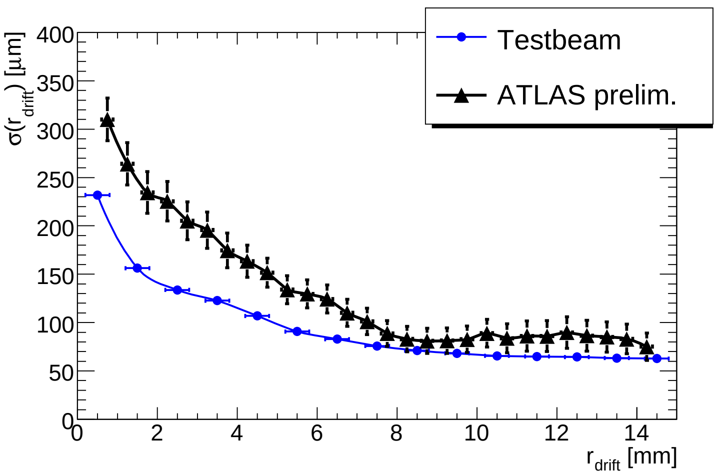
Correlation between RPC and MDT hit



Efficiency of drift tubes



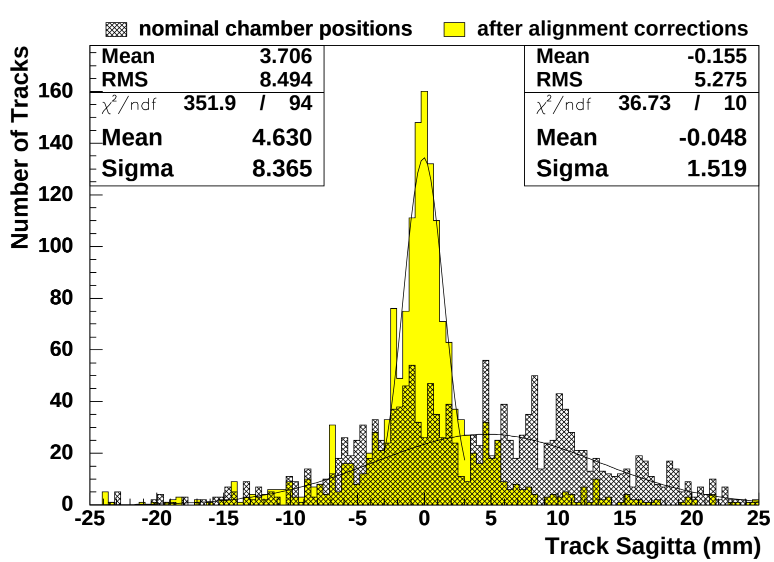
Drift tube resolution from auto-calibration



Optical alignment

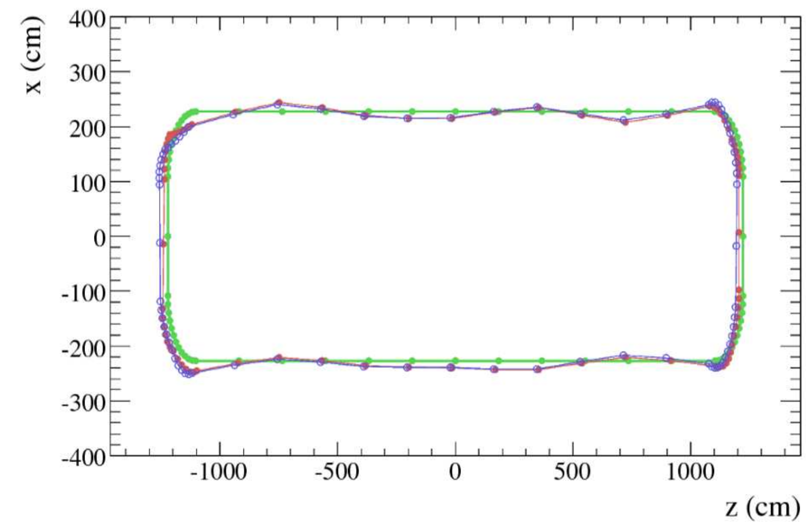
- Goal: precision of 30 μm
- Current precision
  - Endcap: 50–100 μm (absolute meas.)
  - Barrel: 100–200 μm
    up to 1000 μm in sectors with
    no projective alignment sensors
- Absolute barrel alignment with tracks

Track sagitta distribution without and with MDT chamber alignment (Endcaps)



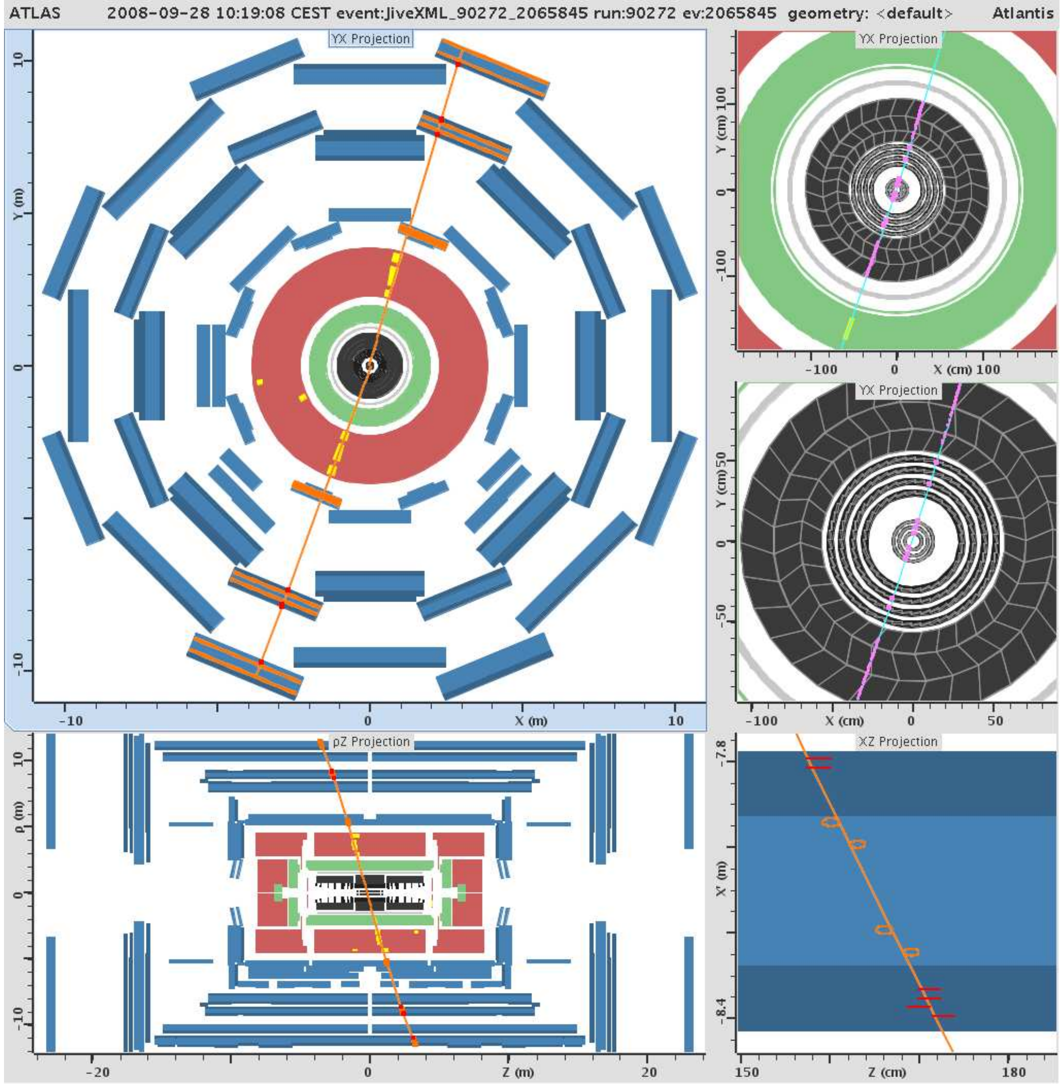
Magnetic field reconstruction

- Goal: 1–2 mT
- 99% of 1834 3d hall probes working
- Reconstruction of coil positions and deformation at the mm level
- Modeling of perturbations (TileCal, feet, access structure, shielding) progressing well
- Est. precision at 1st collisions: 2–10 mT



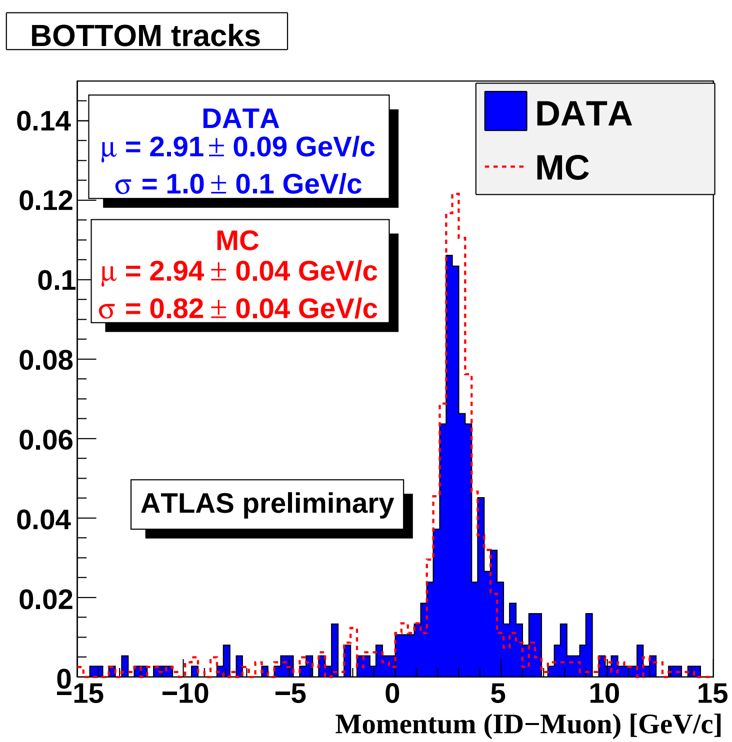
Nominal coil position
Simulated coil position, deviation $\times$ 20
Fitted coil position, deviation $\times$ 20

Combined Studies



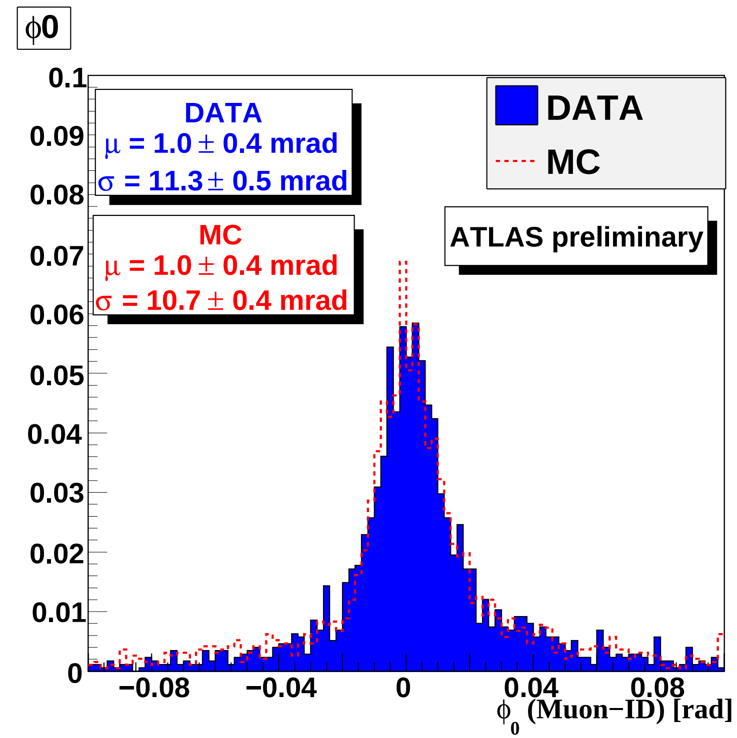
Tracking studies inner detector and muon spectrometer

Muon momentum



Expected shift of 3 GeV from energy loss in calorimeter

Track angle



Good agreement with Monte Carlo studies — but more work needed

Conclusions

Conclusions

- Commissioning of the ATLAS detector started more than 3 years ago
- Understanding of the detector and its infrastructure is still improving steadily
- Large amount of cosmic data with all subsystems included taken in 2008
- ATLAS was ready for 1st beam on Sep. 10th
- During shutdown consolidation of the good detector status will allow us to arrive ready for physics with a better detector at LHC re-start

ATLAS is looking forward to 1st collisions in 2009