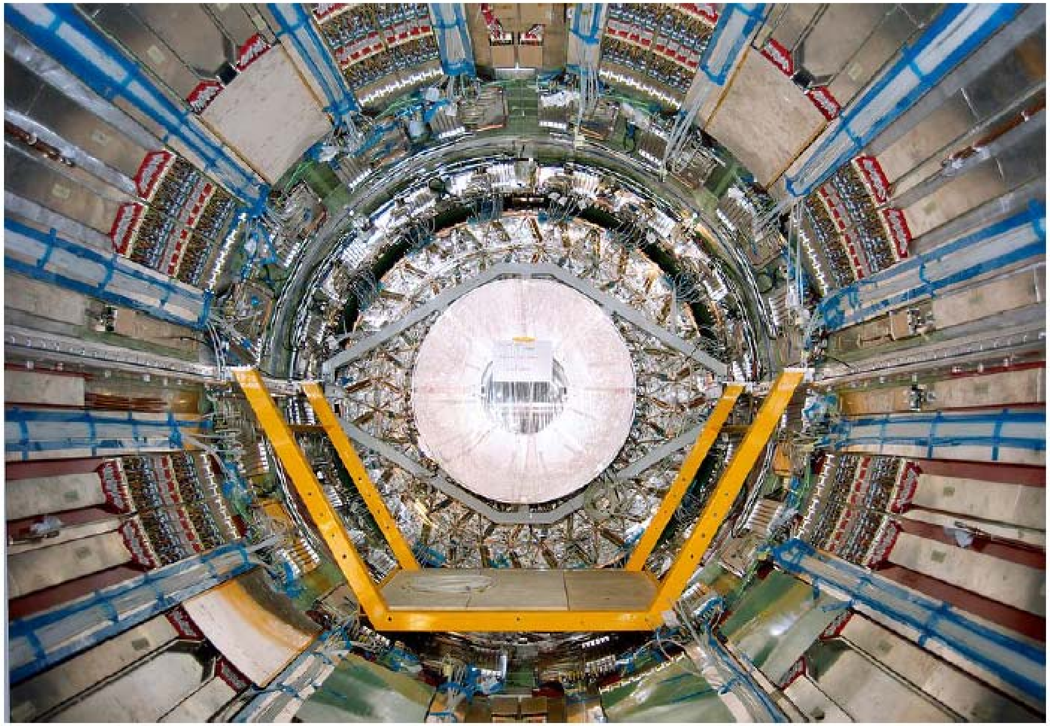
The ATLAS Transition Radiation Tracker



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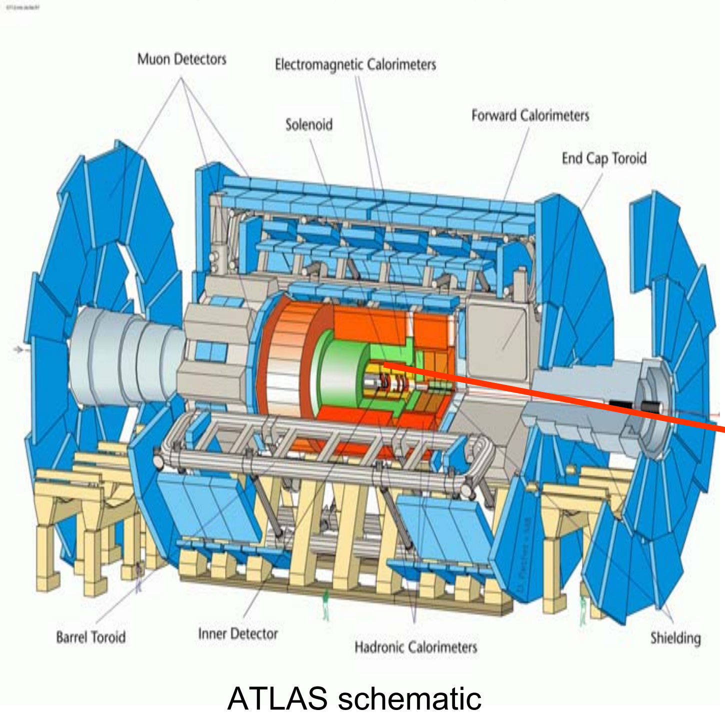
NEPPSR 2007

Outline

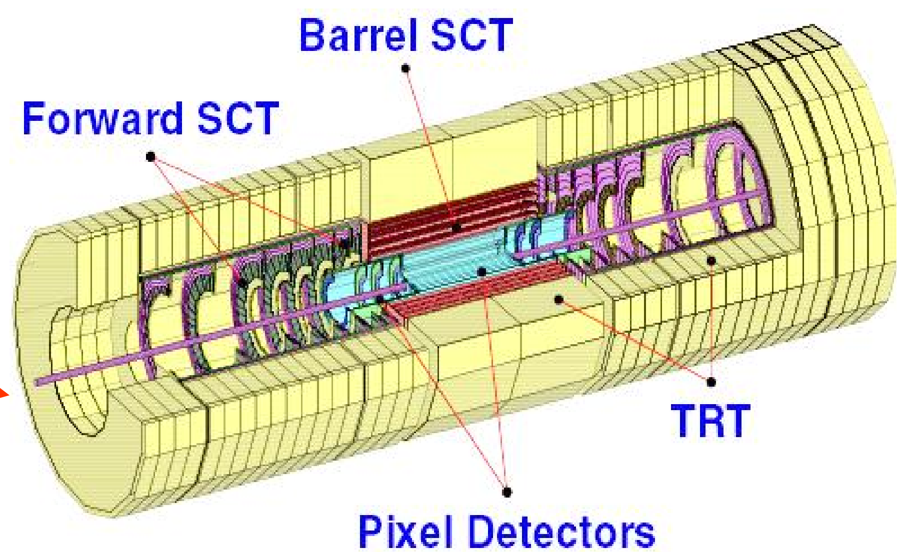
- ATLAS Inner Detector Overview
- TRT Detector
- Electronics
- Performance
- Obstacles along the way
- Current status

ATLAS Inner Detector: Overview

- For all tracks with transverse momentum Pt > .5 GeV, Inner Detector geometry optimized to provide:
  - 3 high resolution 3D space point measurements in the Pixel Detector
  - 4 3D space points with good resolution in bending plane in semiconductor tracker (SCT)
  - On the order of 36 measurements in the transition radiation tracker (TRT)
- Physics-wise, requirements of the Inner Detector:
  - good vertex resolution – correctly tag jets originating from particles with relatively long life times, such as b-quarks and taos
  - Good Pt resolution for all particles
  - High tracking efficiency (reconstruct 95% of particles with Pt>2.5 GeV)

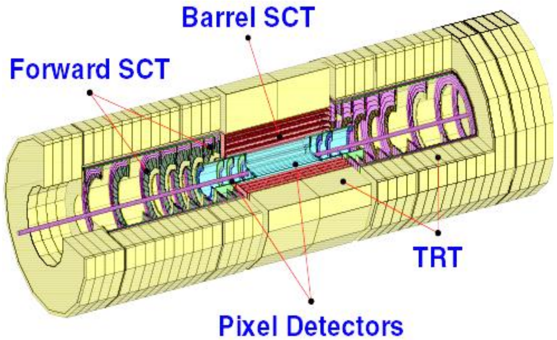


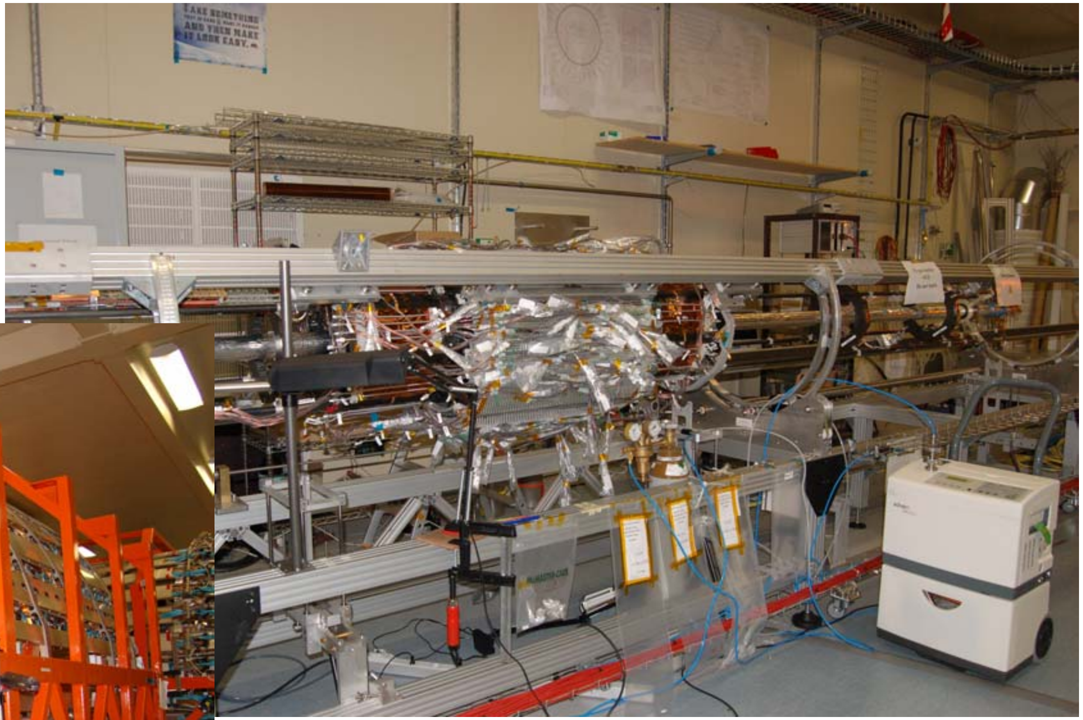
ATLAS schematic



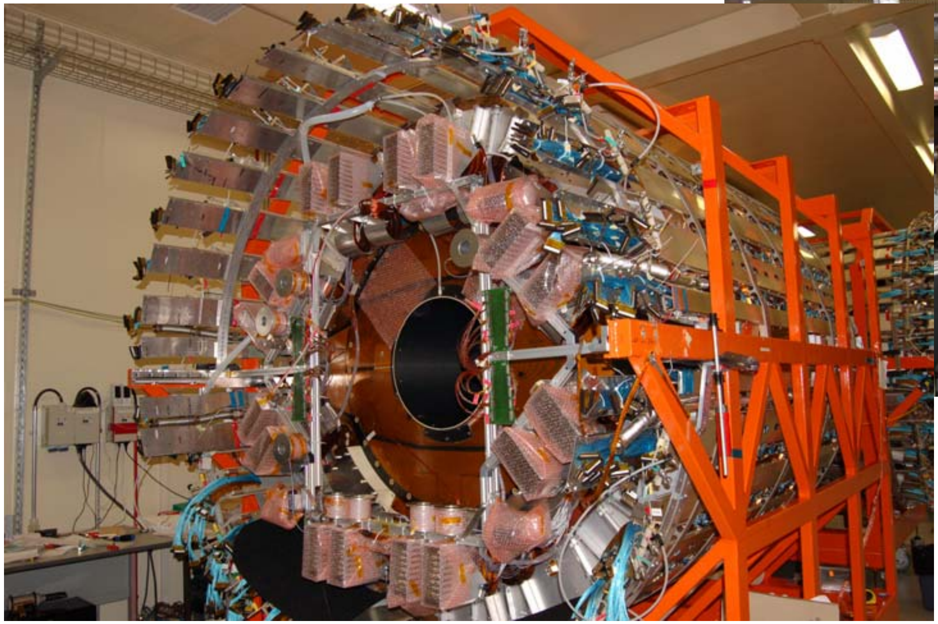
Inner Detector schematic

ATLAS Inner Detector: photos





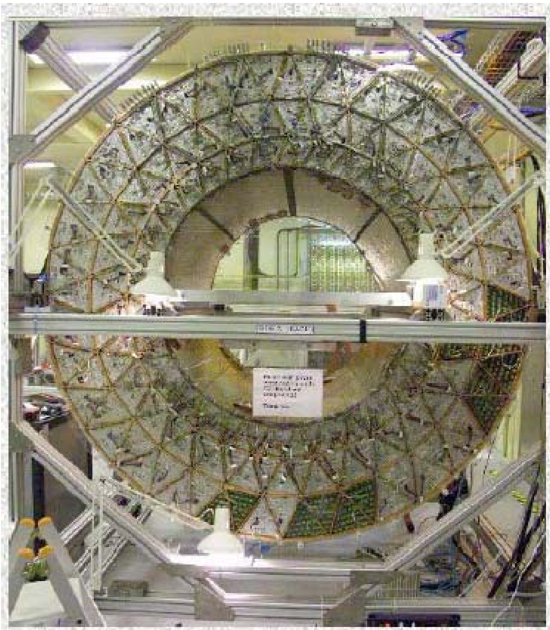
Pixels and beam pipe in SR1



TRT and SCT endcap in SR1

TRT overview and requirements

- Outermost layer of inner detector
- Design goals:
  - Provide continuous tracking at larger radius and enhance momentum resolution
  - Particle identification capabilities (transition radiation)
  - Fast level-2 trigger information
- Requirements for the detector:
  - Radiation hardness
  - Relatively low cost (silicon too expensive at volume and date of design)
- Combines traditional charged-particle track reconstruction with transition radiation information



TRT Barrel

TRT Endcaps

Detector: straw tubes

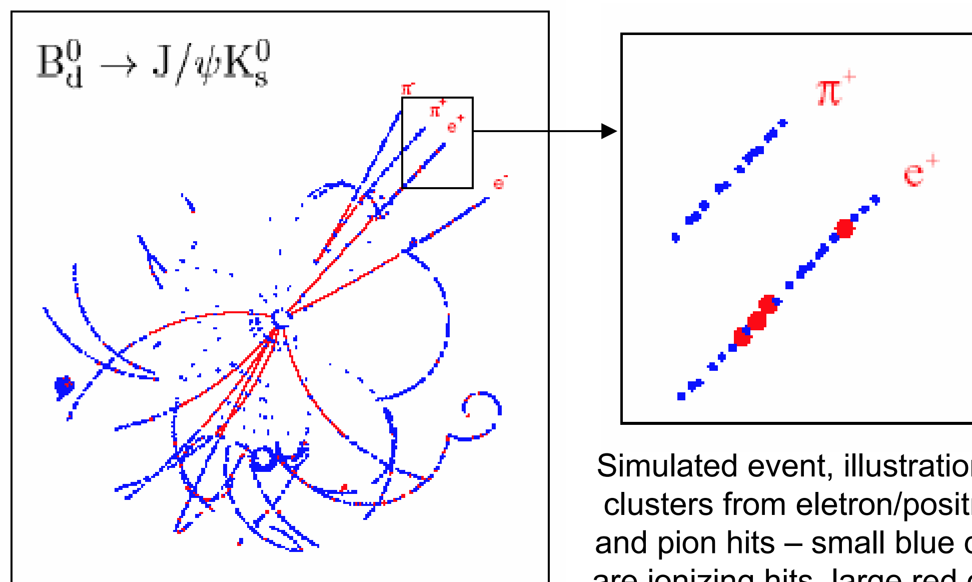
- Straw design:
  - 4 mm diameter (compromise between speed of response, number of ionization clusters, and mechanical stability)
  - 60 μm thick multi-layer film of carbon-polyimide-aluminum-Kapton-polyurethane tube functions as cathode
  - 30 μ m gold-plated tungsten wire serves as anode
  - Anode kept at ground and negative high voltage applied to tube
  - Gas mixture of 70 % Xenon, 27% CO_2, 3% O (quick response, good X-ray absorption, gas stability and safety)

Endcap straws and straw in detail

Detector: transition radiation

- Transition radiation: radiation produced by highly relativistic charged particles when they cross the boundary between two mediums of different dielectric constants ($C0_2$ and polypropylene foil/fibers in TRT)
- Total energy loss of particle depends on Lorentz factor – for two particles of a given energy, lighter particles have a higher γ and therefore radiate more than heavier particles
  - Provides stand-alone discrimination between pions (139 MeV^2/C^2) and electrons (.5 MeV^2/C^2)

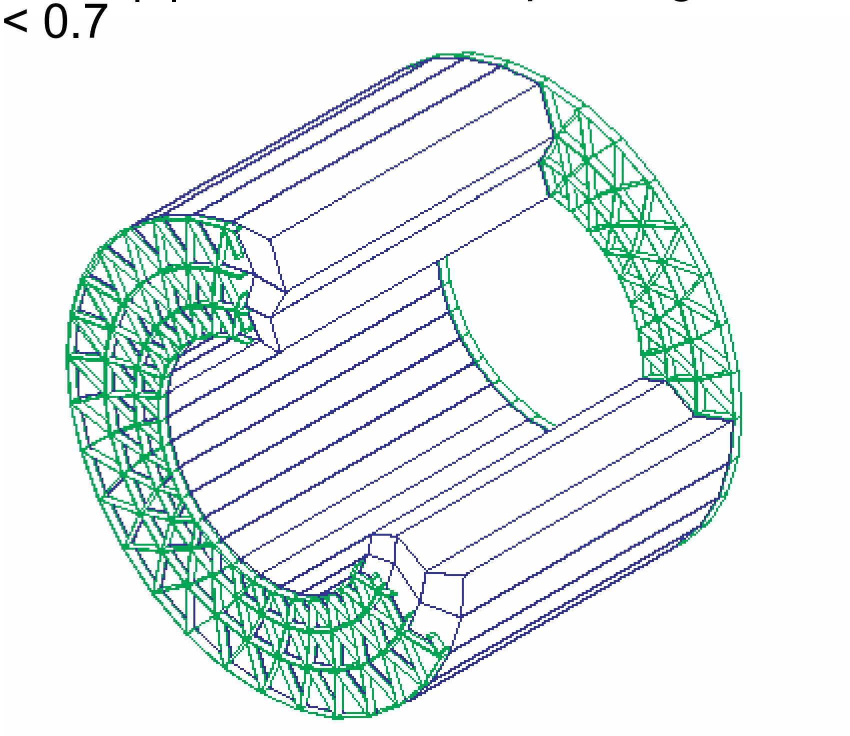
- Photon emission spectrum peaks between 10-30 keV, X-ray range
- Energy deposited in TRT, average event:
  - Sum of ionization losses of charged particles: ~2.5 keV
  - Deposition due to transition radiation photon absorption: >5 keV



Simulated event, illustration of clusters from eletron/positron and pion hits – small blue dots are ionizing hits, large red dots are TR hits

Detector: geometry

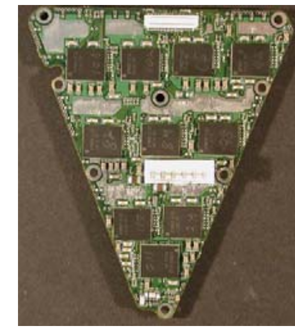
- TRT: 6.8 m in length and (.75 -) 2.2 m in diameter; 1500 kg
- Barrel:
  - 52,444 straws in barrel each straw 150 cm long; (split in two electrically)
  - region between 56 < r < 107 cm and |z| < 72 cm, corresponding to a pseudorapidity coverage of $|\eta| < 0.7$
- Endcap:
  - 159,744 straws per end-cap, split into 18 separate “wheels”
  - region between 63 < r < 103 cm and 83 < |z| < 340 cm, corresponding to a pseudorapidity coverage of $0.7 < |\eta| < 2.5$



Schematic of TRT barrel modules

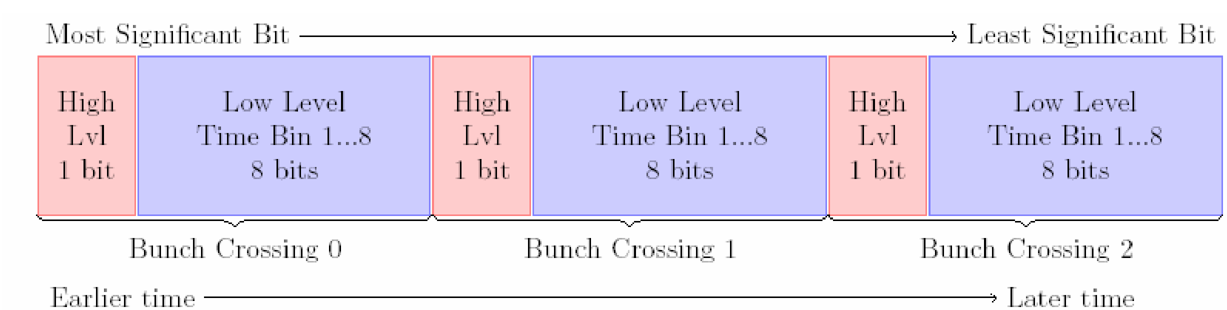
Electronics: front-end

- Front-end electronics contain analog and digital elements
  - ASIC does amplification, shaping, discrimination, and base-line restoration (ASDBLR)
    - Two thresholds:
      - tracking threshold from minimally ionizing particles around 200 eV
      - Transition radiation threshold around 6-7 keV
    - Ternary output
      - 0 if no threshold
      - 1 if either low or high threshold crossed
      - 2 if both low and high threshold crossed
    - Each ASDBLR monitors 8 straws and passes data to DTM ROC
  - Drift-Time Measuring Read Out Chip (DTM ROC): analog to digital conversion
    - Every 25 ns, DTMROC samples output of ASDBLR 8 times per straw
    - Each time bin, one bit tells whether straw was over low level threshold – one additional bit tells if high threshold reached anytime during 25 ns
    - When trigger received, DTM ROC packages three bins worth of data for each straw and sends data to ROD (via patch panel)



Barrel front-end board

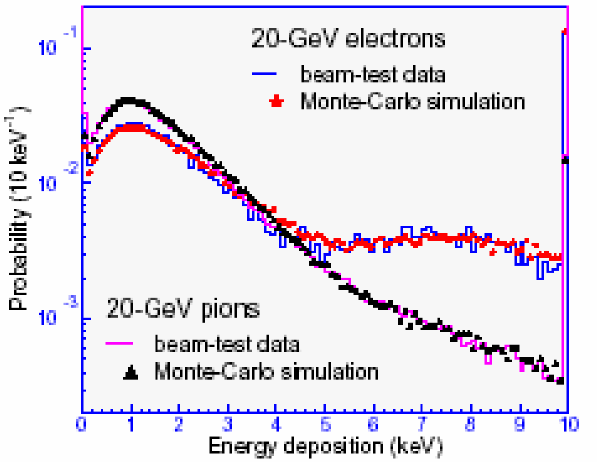
Single DTM ROC data format – 27 bits



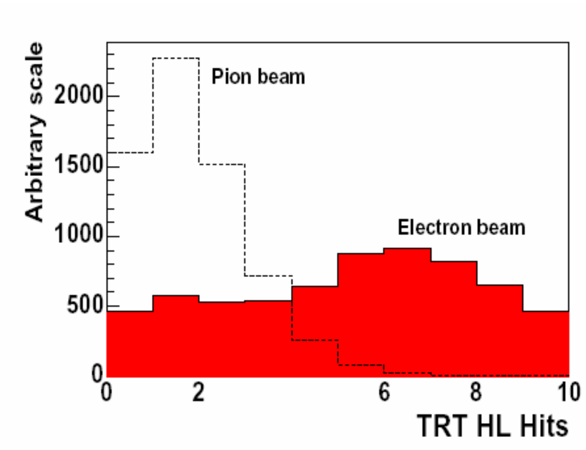
Performance: some numbers

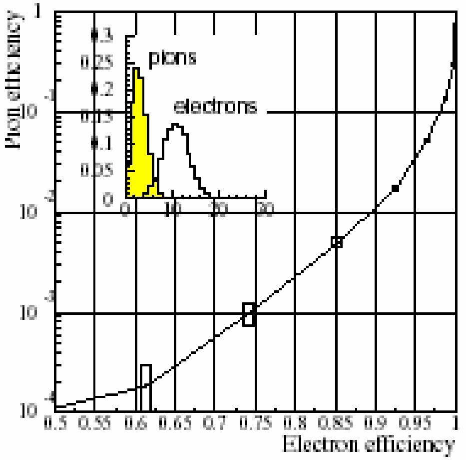
- Maximum drift time ~ 40 ns, varies by straw
- Time-over-threshold (roughly charge deposition) up to 25-30 ns
- Straw noise occupancy: 2-5%
- From test beams
  - low counting rates, position accuracy of 132 μm
  - Drift-time measurement efficiency 87%
  - Overall hit registration efficiency close to 96%
  - Pt resolution .8%-2.4% for 20-100 GeV pions (~2 Telsa magnetic field)
- Particles traverse ~ 36 straws through TRT

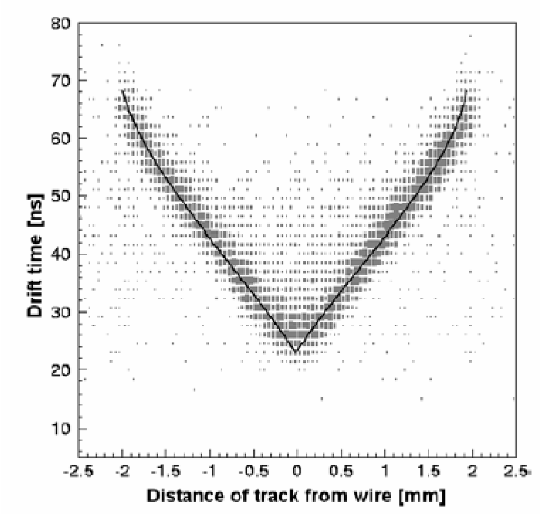
Performance: some plots (from test beam)



Differential energy spectra from data and simulation for a single straw with radiator







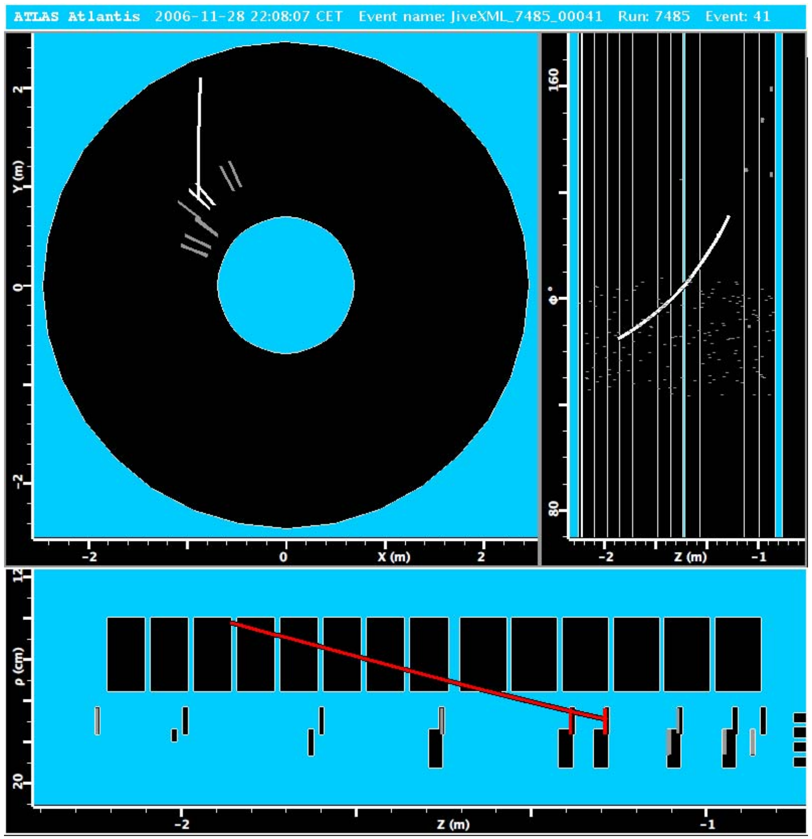
For a single straw, radius v. time measurements

Top: Test beam, 50 GeV pion and electron beam, number of High Threshold hits

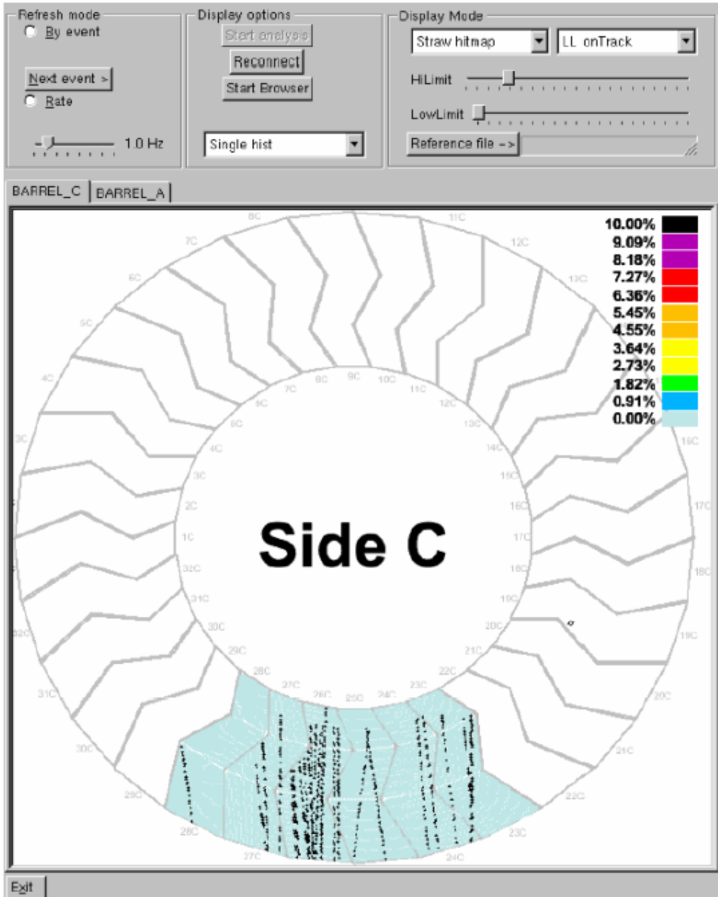
Bottom: Pion efficiency versus electron efficiency at 20 GeV (small plot is number of high threshold hits)

for electron efficiency of 90%, pion efficiency is 1.2% (20 GeV)

Performance: some tracks



SCT/TRT endcap cosmics in fall 2006 – first combined tracks – seen in ATLAS Atlantis



Integrated cosmics in pit during M3 run in spring 2007 - seen with TRT Viewer

Problems along the way

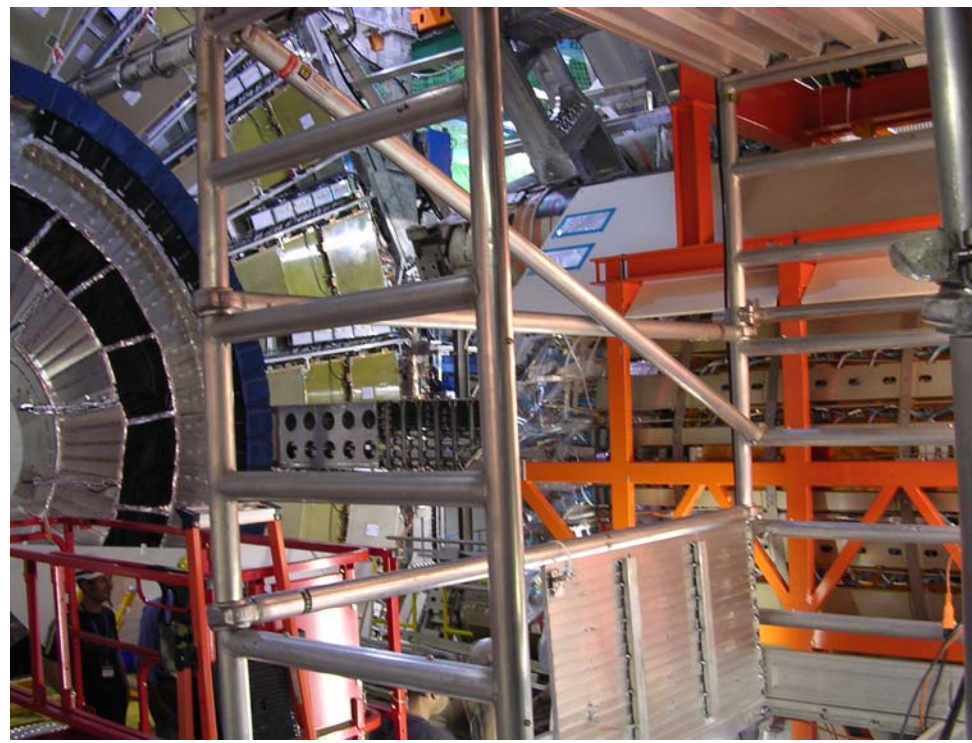
- C wheels – eventually dropped because of cost
- Gas mixture – originally was Xenon 70%, CF_4 20%, CO_2 10% - found that CF_4 decayed to fluoro-based active species tat degraded glass bead; additionally, hydrofluoric acid produced when water is present, which damaged gold plated wire
- RODs – problems with production in Israel (plus delays)

Components at PCB Technologies in Israel – all CERN components jumbled and many missing

Current status

- Barrel and Endcaps installed
- Barrel connections complete and fully tested
- Endcap A fully connected and tested
- Work on Endcap C connections and testing continues

- DAQ integrated with ATLAS DAQ (for M3)
- Reading out 6/32nd of barrel (for M3)
- Hoping to read out 16/32nd of barrel for M4 – depends on ROD availability!



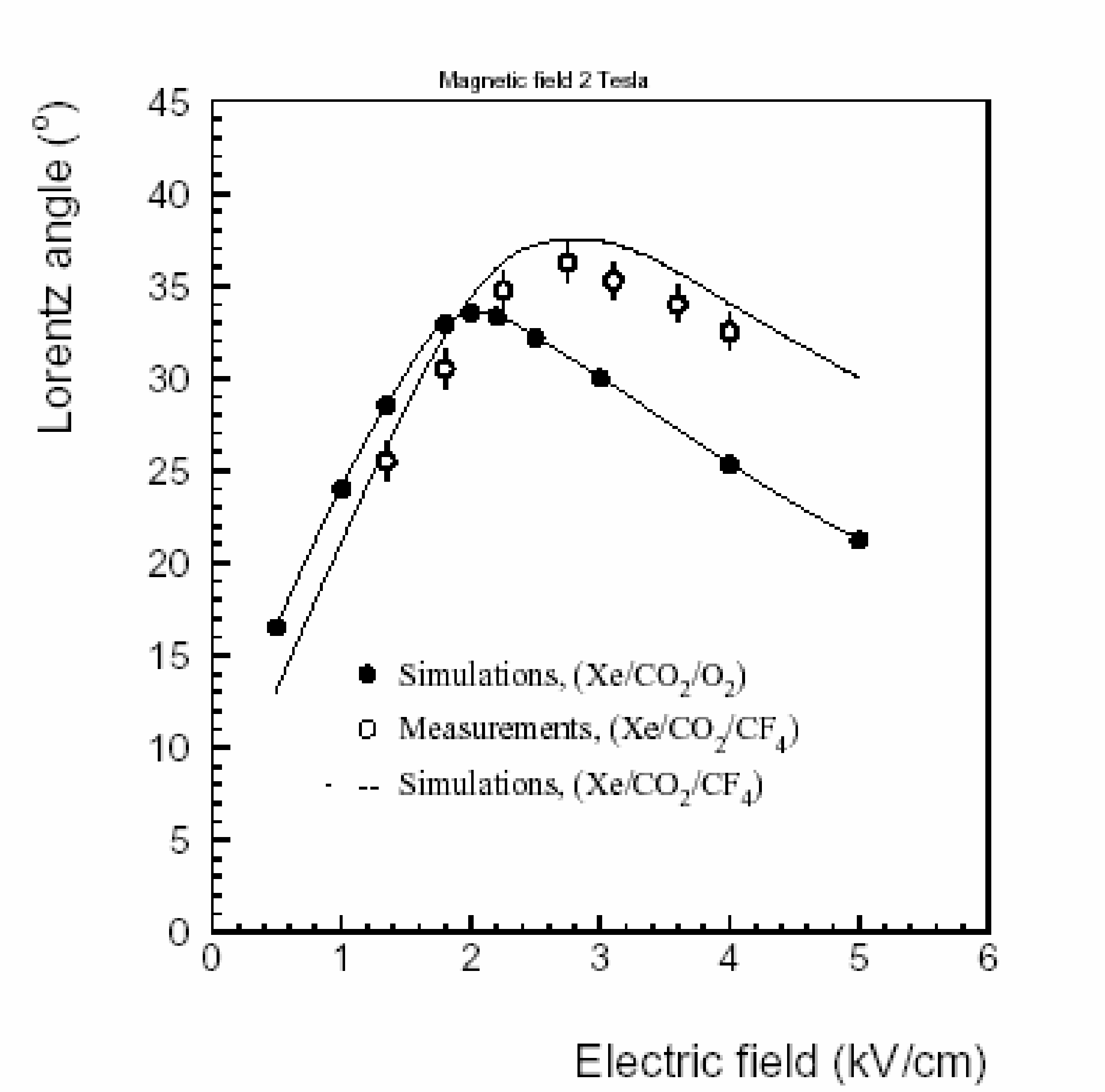
TRT endcap A (right) before insertion

Sources

Plots, schematics, figures, photos taken from:

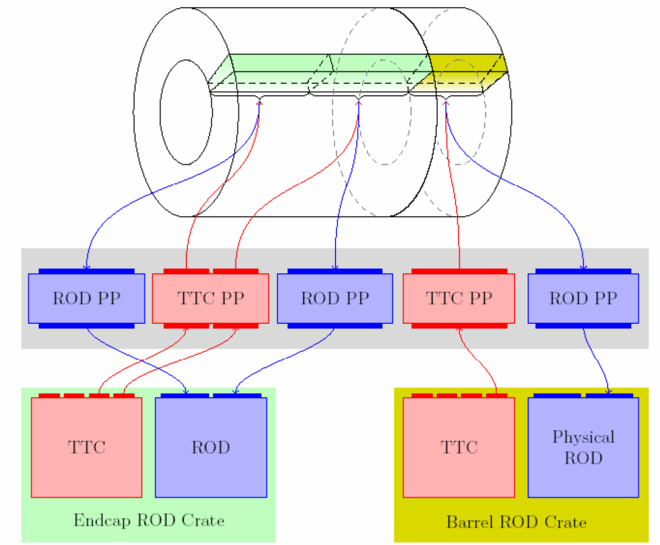
- Peter Cwetanski's thesis, *Straw performance studies and quality assurance for the ATLAS transition radiation tracker*
- Valeria Perez Reale's thesis, *Electron/Photon Identification and Standard Model Higgs Process Studies at the High Level Trigger for the ATLAS experiment*
- Mar Capeans's talk: ATLAS Transition Radiation Tracker, 2002 in Siena
- Brig William's PENN DOE Review, 2007
- Mike Hance's documentation, *Readout of the ATLAS Transition Radiation Detector,* 2006
- ATLAS Collaboration's ATLAS Note: *ATLAS TRT straw chamber design and performance,* 2007
- V. A. Mitsou's paper, *The ATLAS Transition Radiation Tracker*, 2003
- The pit

Backups



Magnetic field 2 Tesla
Lorentz angle (°)
45
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
Simulations, ($Xe/CO_2/O_2$)
Measurements, ($Xe/CO_2/CF_4$)
-- Simulations, ($Xe/CO_2/CF_4$)
Electric field (kV/cm)

Electronics: patch panels



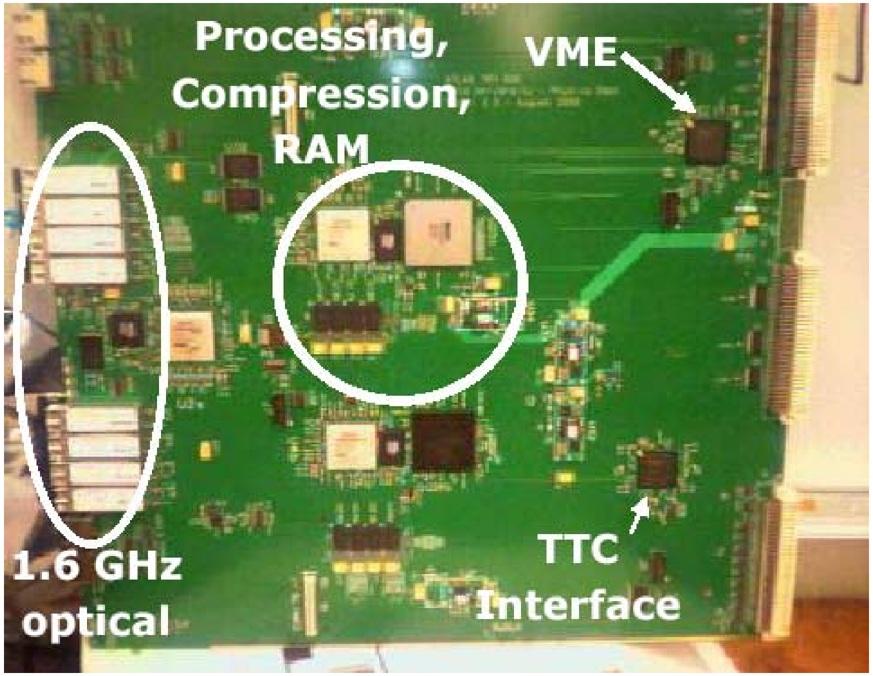
Schematic, patch panel distribution

- 10 patch panel locations (outside of cryostat, awkwardly placed among muon chambers) provide control and data halfway station
- Connectors also for high voltage and detector interlock system
- Issue of delays: lots of time spent calibrating delays between clock and data to achieve maximum data readout and to have stable readout – a big part of configuring the detector is getting these delays right

- Three types of boards: low-voltage, TTC, and data
  - –Low voltage: distribution of low-voltage supplies for front-end boards
  - –TTC: distribution of timing and trigger information for front-end boards
  - –Data: converts signals on parallel copper wires to serial optical transmission

Electronics: back-end

- TTC: Timing, Trigger and Control
  - 48 cover full detector
- ROD: Read-Out Driver
  - 96 boards cover full detector
  - 1920 32-bit straw words per event (16 straws per DTM ROC, 120 DTM ROCs per patch panel) plus event header, footer



TRT ROD