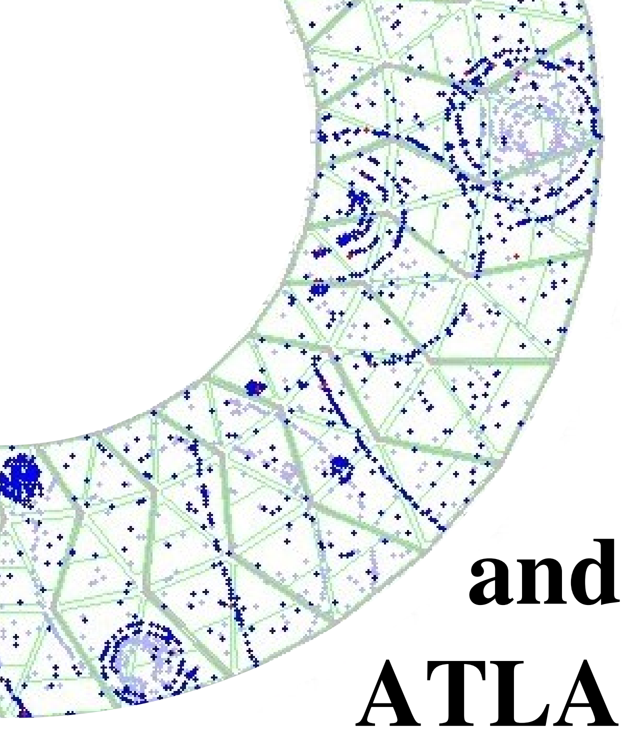
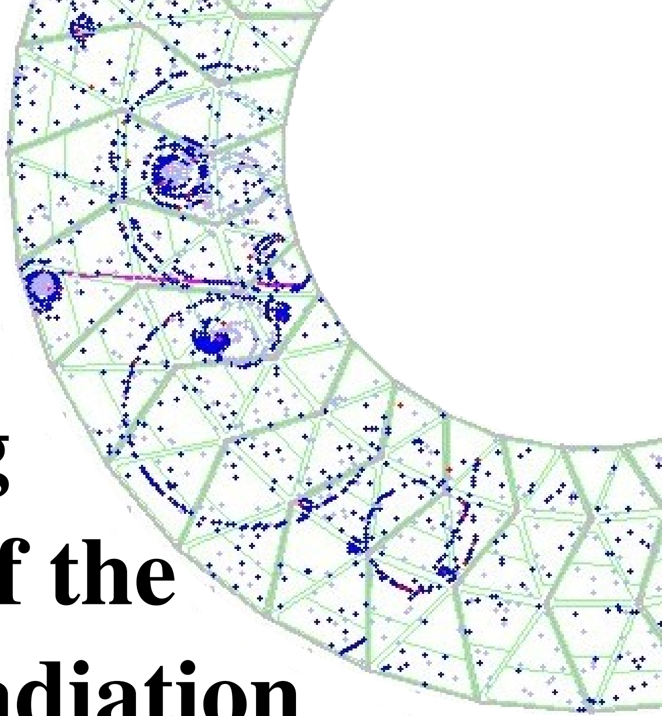




Commissioning and Performance of the ATLAS Transition Radiation Tracker with Cosmic Rays and First High Energy Collisions at the LHC

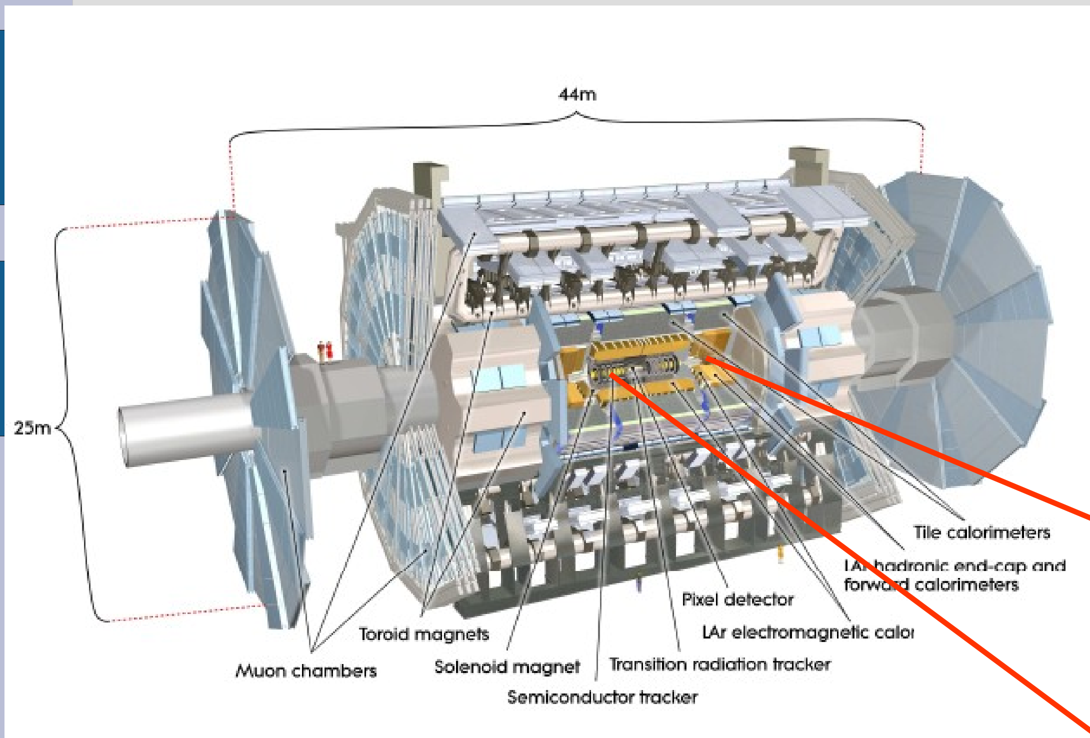
Peter Wagner
University of Pennsylvania

on behalf of the ATLAS Collaboration

Outline

- ATLAS Inner Detector and Transition Radiation Tracker (TRT)
- TRT Design
  - "R-T" Calibration
  - Transition Radiation Calibration
- Electronics
  - Tracking Thresholds
  - Active Readout Fraction
  - TRT Fast-OR Trigger
- Timeline of Commissioning and Milestones
- Readout Timing
- Position Resolution
- Gas & Powering
- Latest Improvements

ATLAS Inner Detector



Design goals:

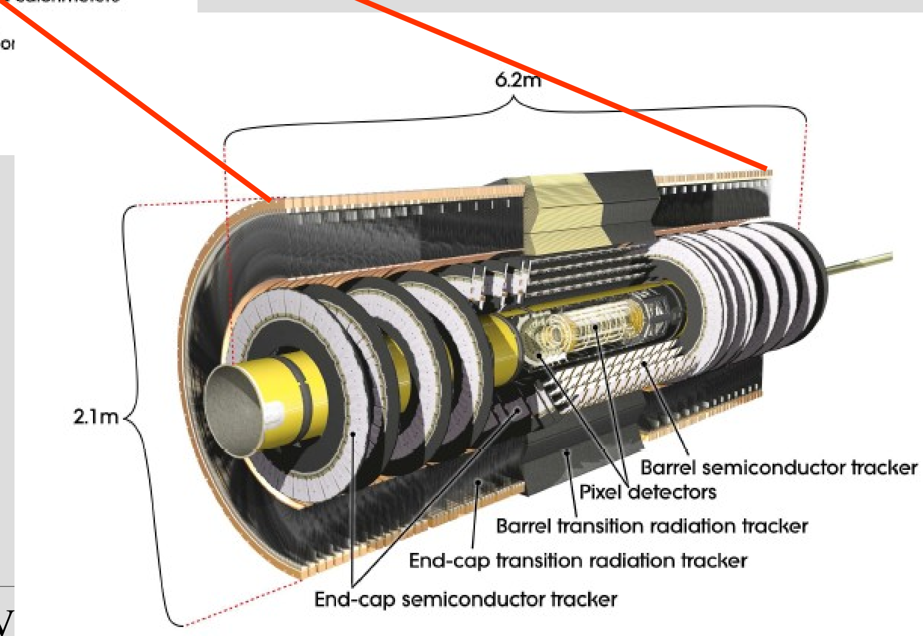
Momentum resolution: $\sigma(p_T)/p_T = 0.05\% p_T \oplus 1\%$

Charged track above 0.5GeV, $|\eta|<2.5$

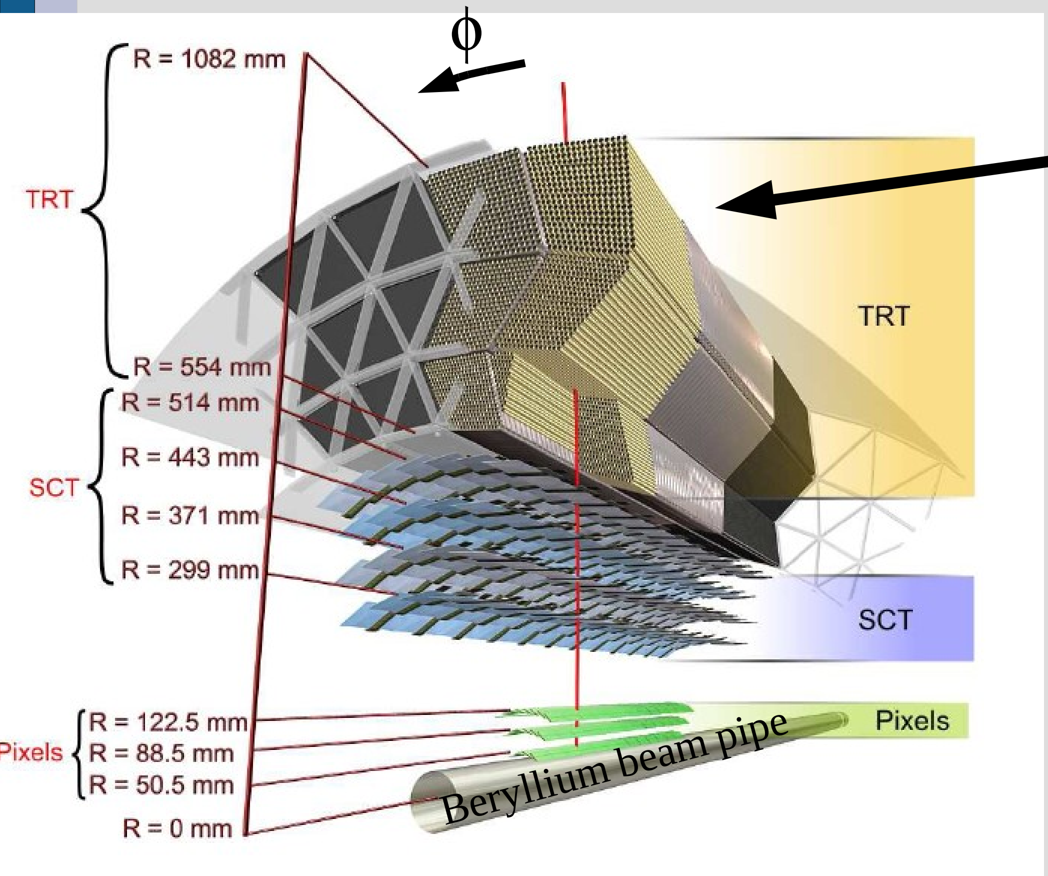
Electron identification :

$|\eta|<2$ & $0.5<p_T<150$ GeV

Immersed in 2T B-field



The ATLAS Transition Radiation Tracker



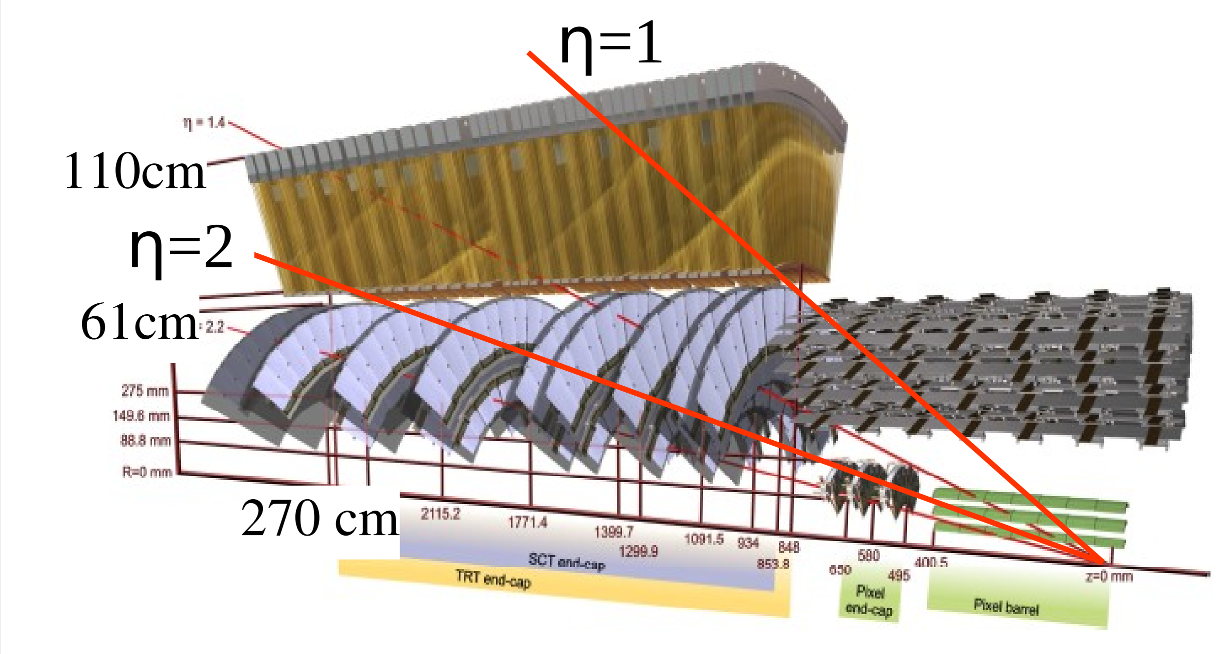
TRT barrel

- 3 * 32 modules
- 1.44 m straws parallel to beam axis
- wires electrically split in the middle to reduce occupancy (~1.5cm dead region)
- each end read out separately
- 105088 readout channels total
- 2 triangular front end electronics boards per module

The ATLAS Transition Radiation Tracker

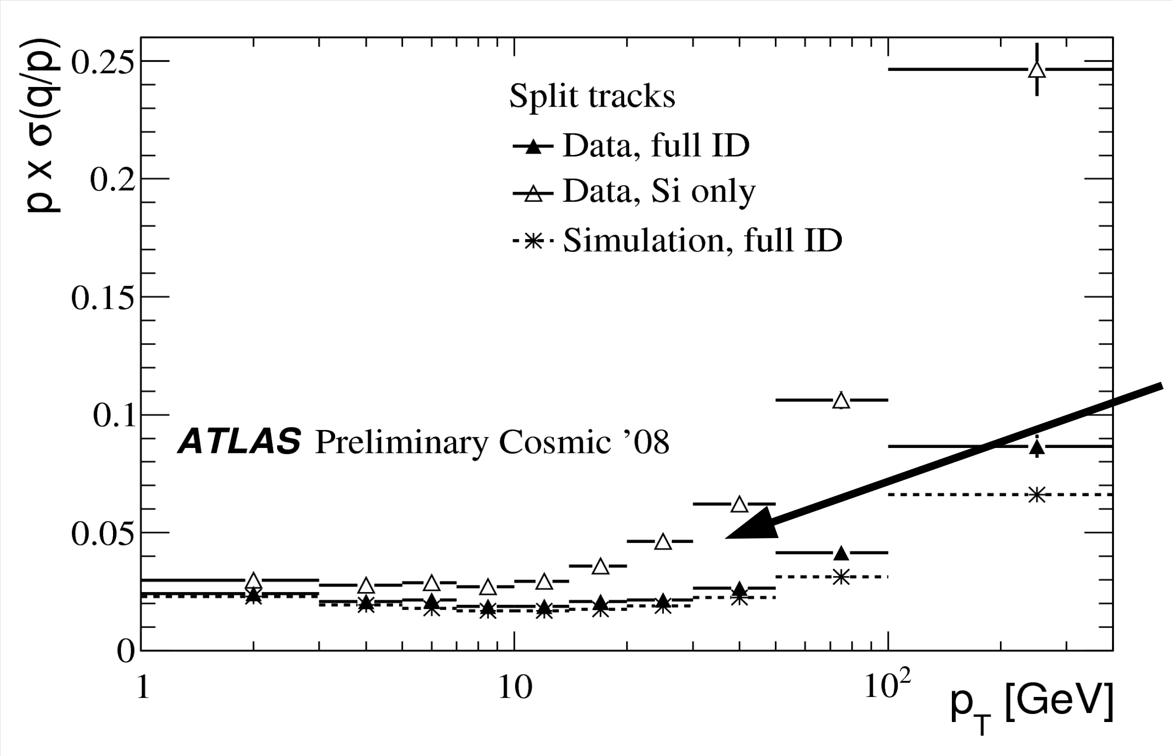
2 TRT end-caps, each with

- 20 “wheels” with 8 layers of straws each
- 39cm long radial straws
- 122880 readout channels



The ATLAS Transition Radiation Tracker

- Crucial role for measuring transverse momenta with high precision in conjunction with the Si tracking detectors

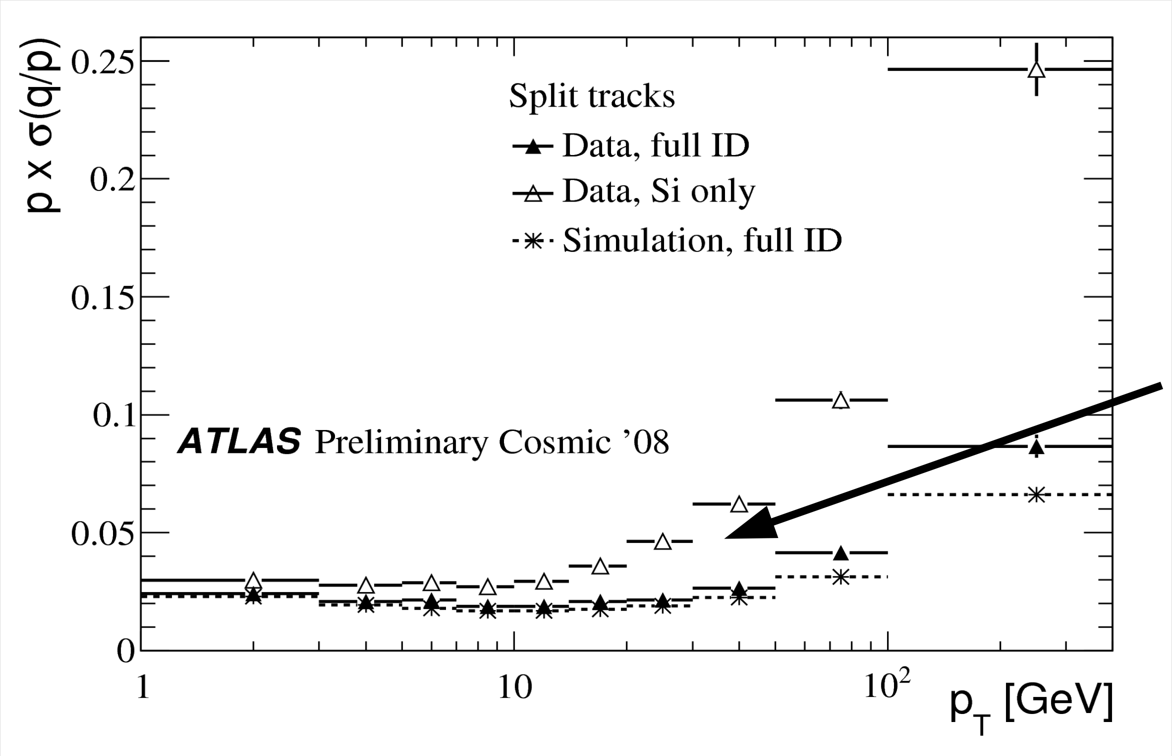


Major contribution to momentum resolution!

- Discrimination between electrons and hadrons via transition radiation detection
  - e.g., pion rejection factor between 20 and 100 (see performance plots later)

The ATLAS Transition Radiation Tracker

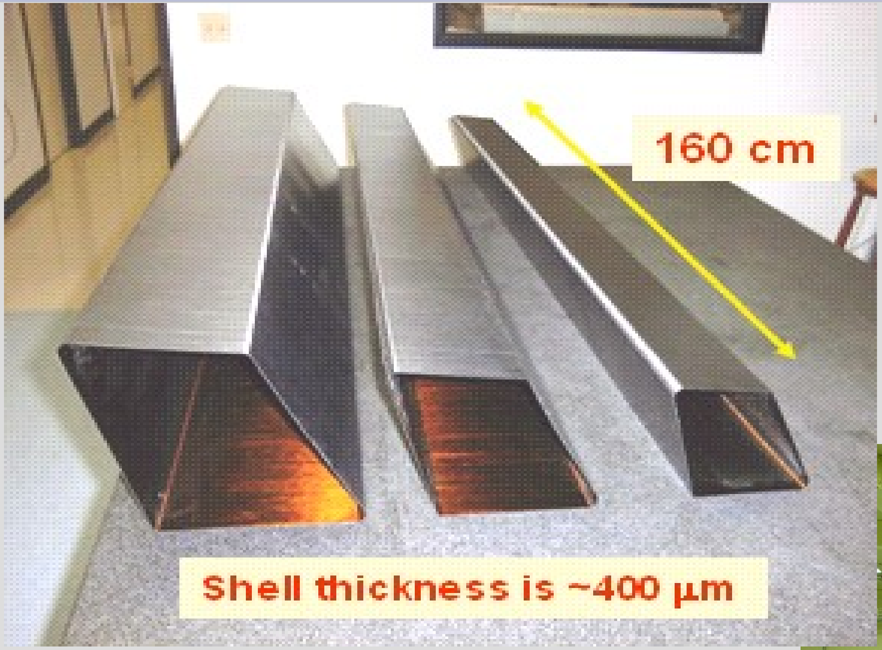
- Crucial role for measuring transverse momenta with high precision in conjunction with the Si tracking detectors



Major contribution to momentum resolution!

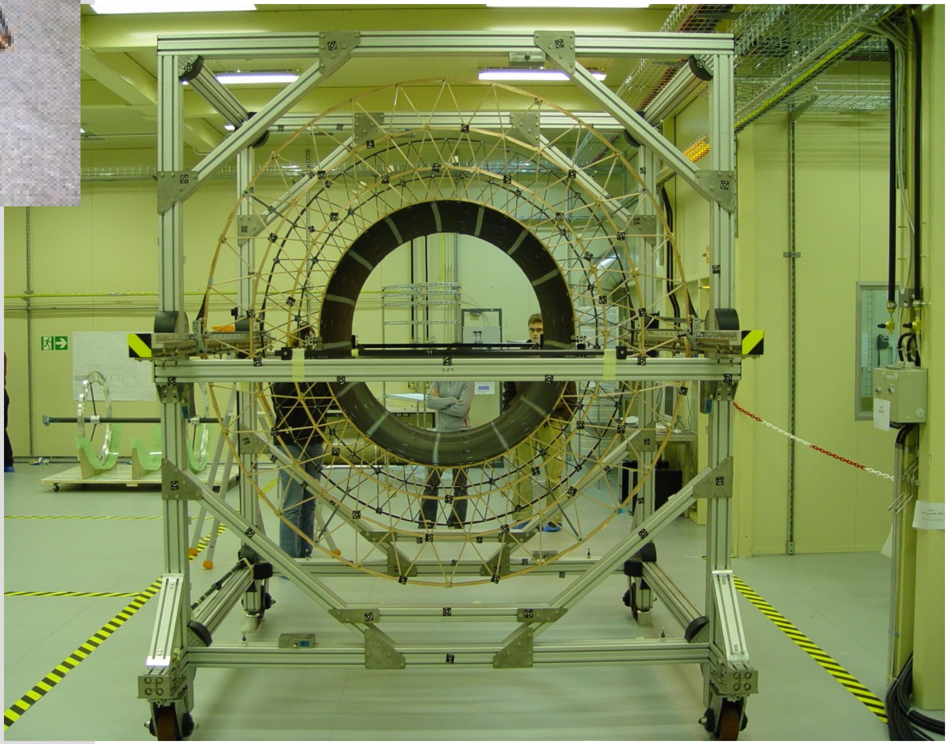
- Discrimination between electrons and hadrons via transition radiation detection
  - e.g., pion rejection factor between 20 and 100 (see performance plots later)
- Developed during commissioning: TRT Fast-OR Trigger important tool in ATLAS commissioning (see later)

The ATLAS Transition Radiation Tracker



General Detector Design

- Used light materials for straw and support structure
    - Barrel module support structure: 400 um thick Carbon fiber laminate
- Tolerances: < 30 um in distortions of support structure



The ATLAS Transition Radiation Tracker

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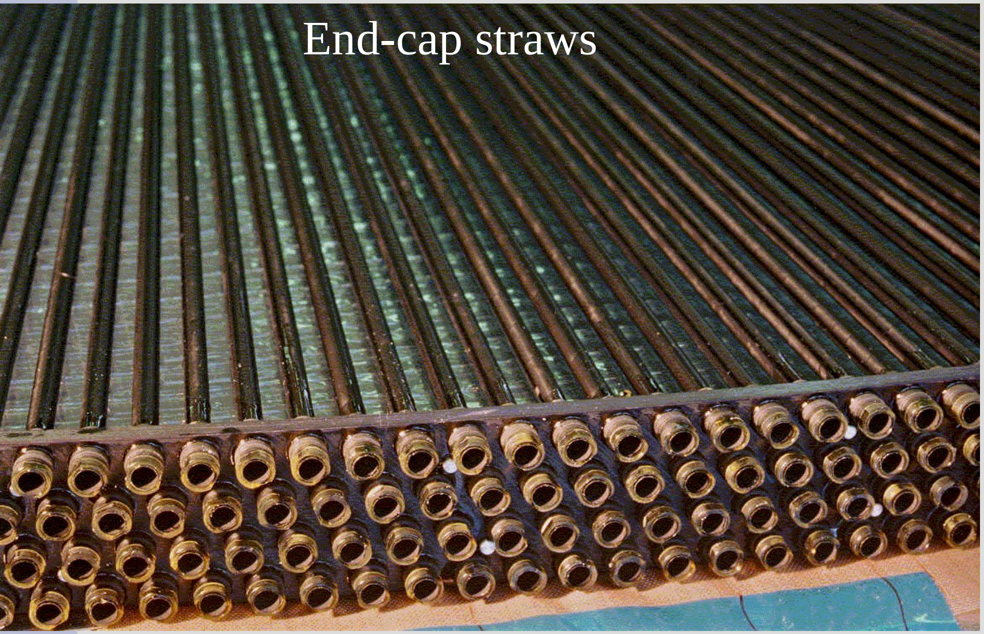
- "Continuous" tracker
  - Large number of hits (~30) per track
  - Hit precision of 130um
- Modular structure (e.g. staggered pattern in barrel) is linked to stability requirements of space frame

The ATLAS Transition Radiation Tracker



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  - Large number of hits (~30) per track
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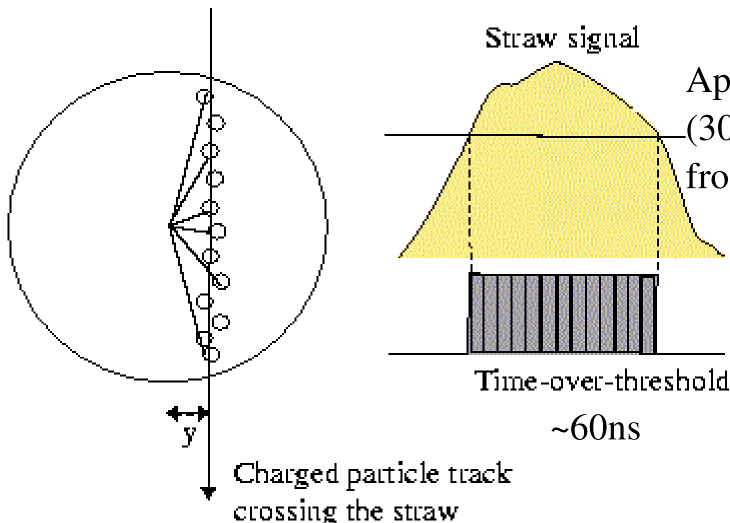
- Modular structure (e.g. staggered pattern in barrel) is linked to stability requirements of space frame
- Wires in individual gas envelopes: "straws"
  - Ø 4mm
  - Limits maximum drift time (50ns) and the occupancy on the wire
  - Prevents broken wire from doing further damage
  - Separation between active gas and transition radiation medium
  - Counting rate per wire: up to 20 MHz at design luminosity
  - High Voltage between wire and straw: 1.5 kV

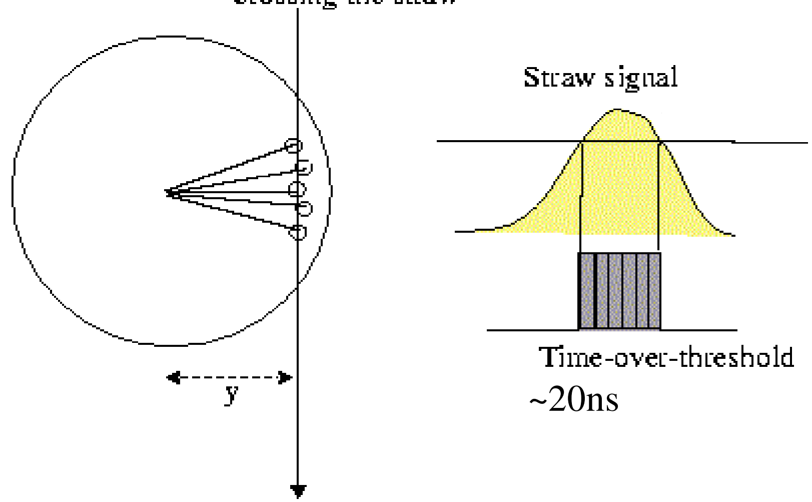
Straw Signal & "R-T Relation"

Duration of straw signal varies with distance of track from wire:

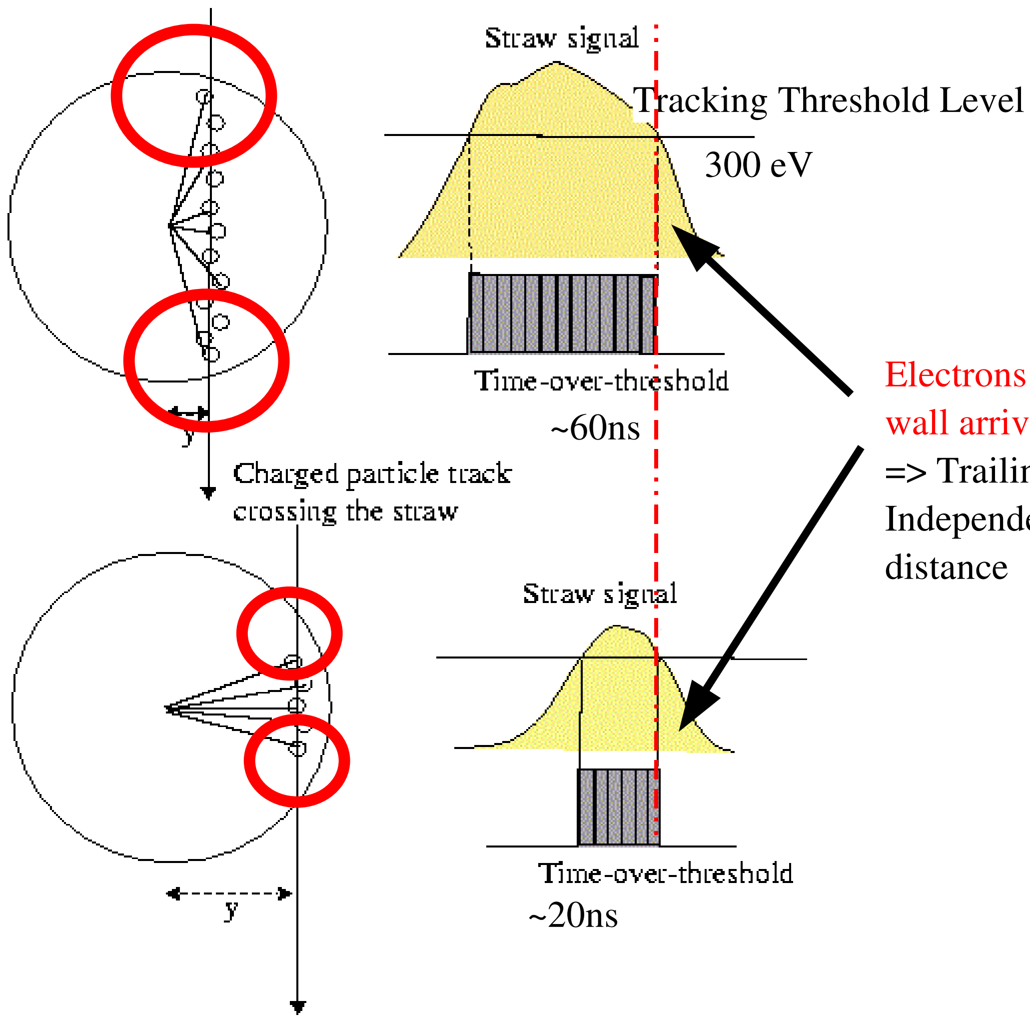


Apply tracking threshold (300 eV) to discriminate from noise

Measurement of straw signal in 8 time bins per 25ns => 130um hit precision achievable



Straw Signal & “R-T Relation”

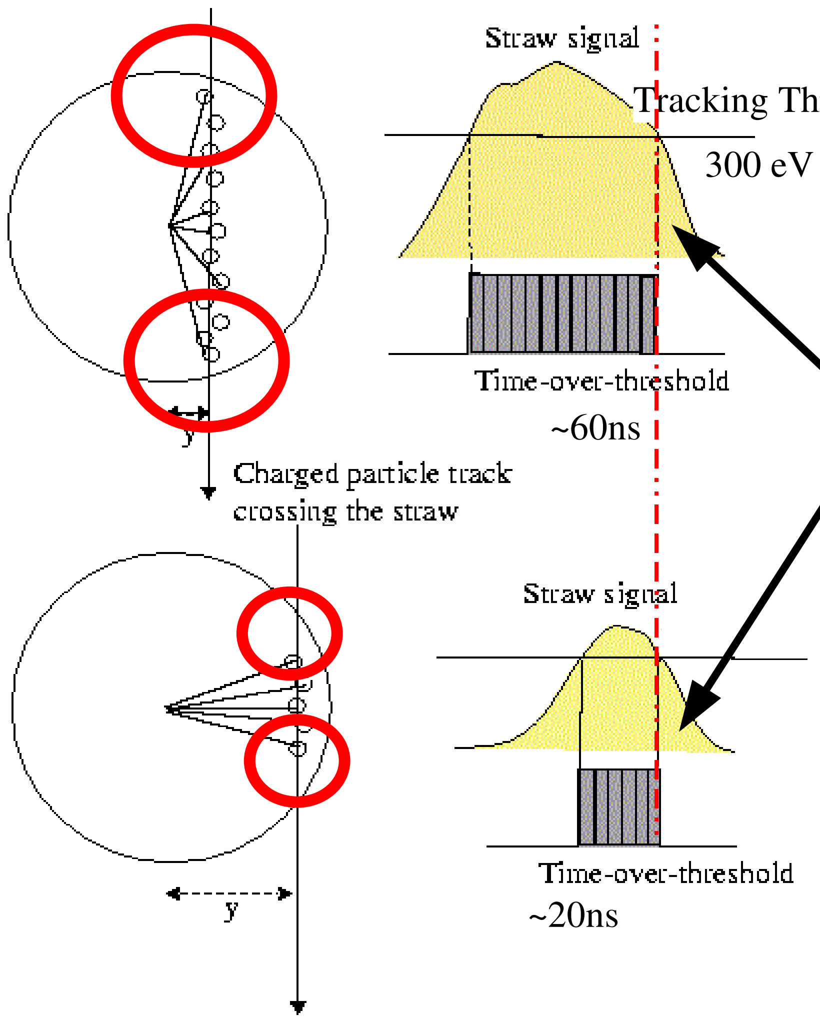


Electrons from close to the straw wall arrive latest

=> Trailing edge:

Independent of the track to wire distance

Straw Signal & "R-T Relation"



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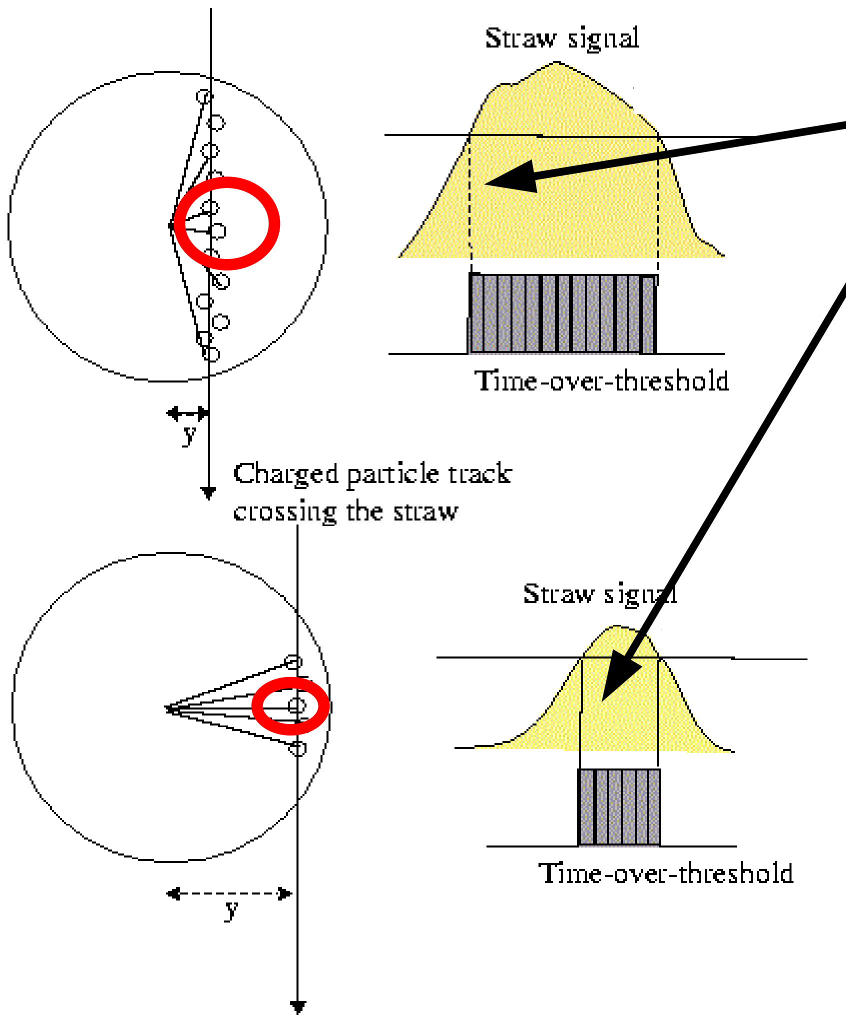
=> Trailing edge:
Independent of the track to wire distance

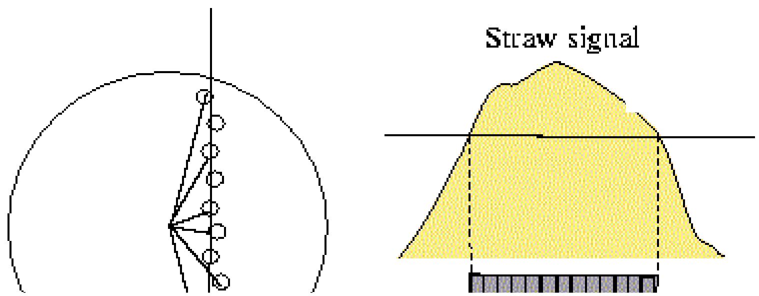
Needs Calibration

Straw Signal & "R-T Relation"



Leading edge from electrons closest to wire
=> Correlated to distance of track to wire

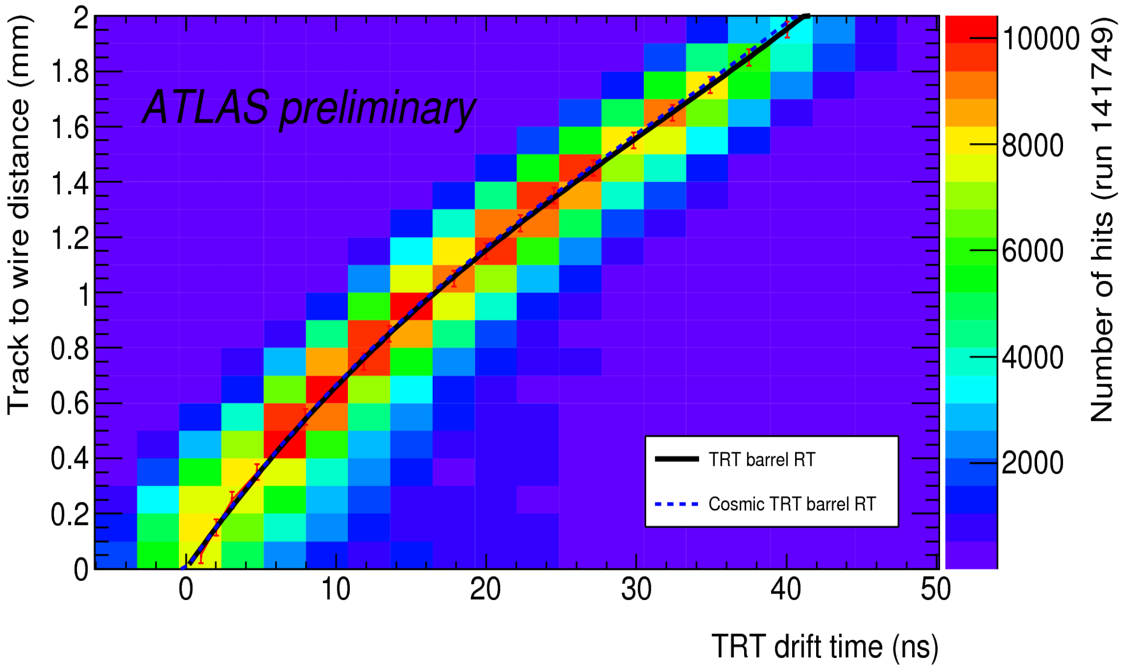
Straw Signal & “R-T Relation”



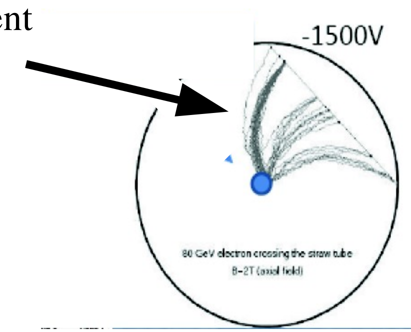
Leading edge from electrons closest to wire
=> Correlated to distance of track to wire

Needs Calibration

=> Driftdistance-Drifttime (“R-T”) relation:

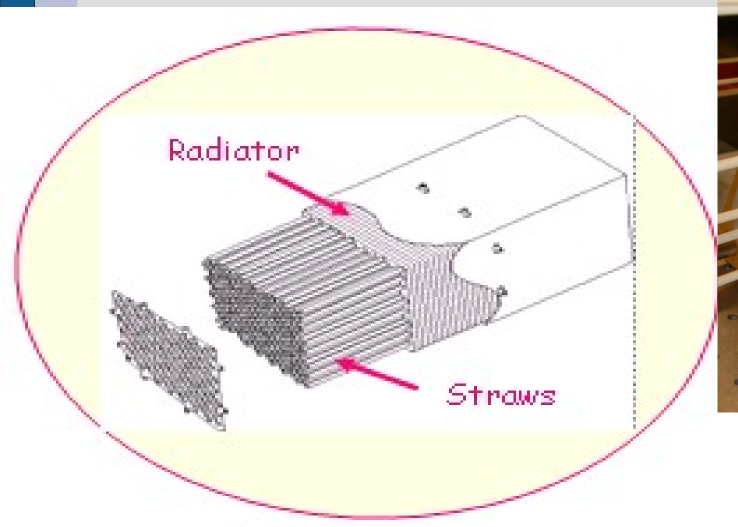


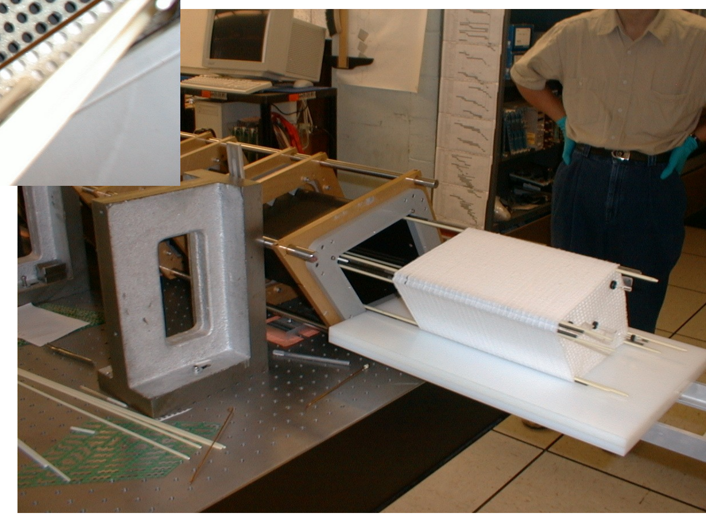
B-field dependent

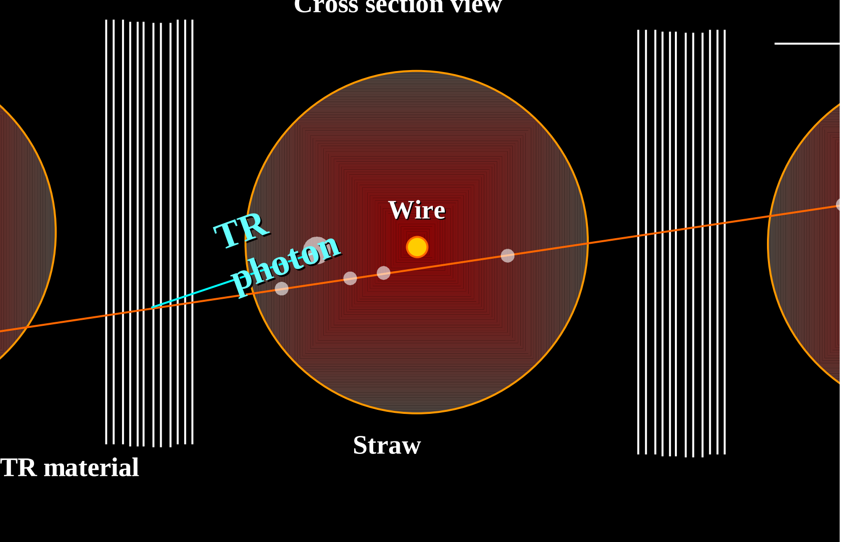


The ATLAS Transition Radiation Tracker

General Detector Design





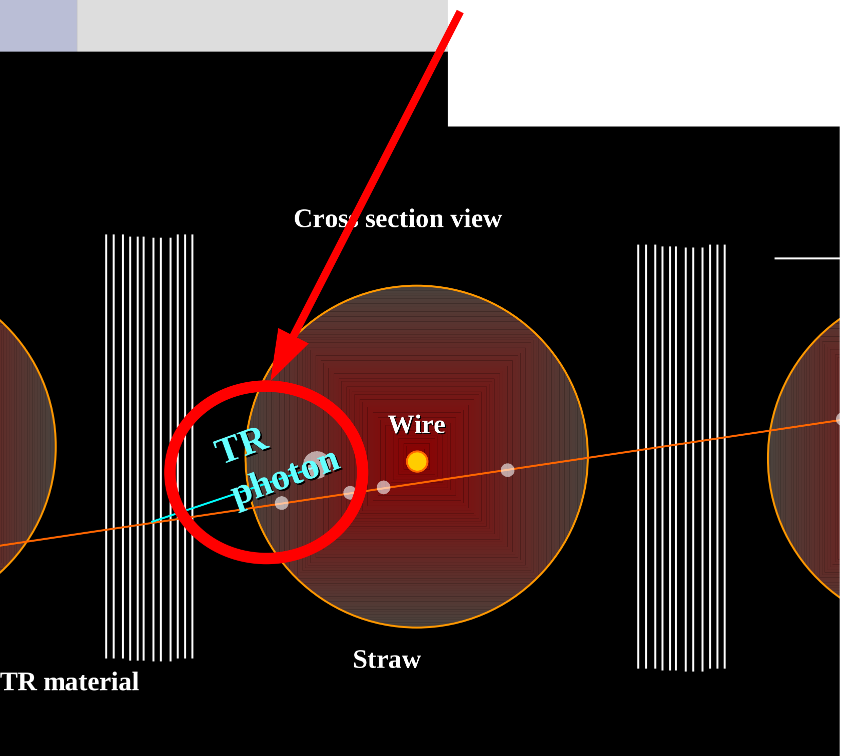


- Active gas: Xe(70%)-CO_2(27%)-O_2(3%)
  - Good transition radiation (TR) absorption
  - Less expensive Ar(70%)-CO_2(30%) for most of commissioning but no TR capabilities
- Straws embedded in radiator medium (for barrel)
  - Maximizes probability to absorb TR photon

The ATLAS Transition Radiation Tracker

General Detector Design

- Causes high energy deposits in straw (~6 keV)
- TRT electronics can discriminate these from regular tracking hits using "high threshold"



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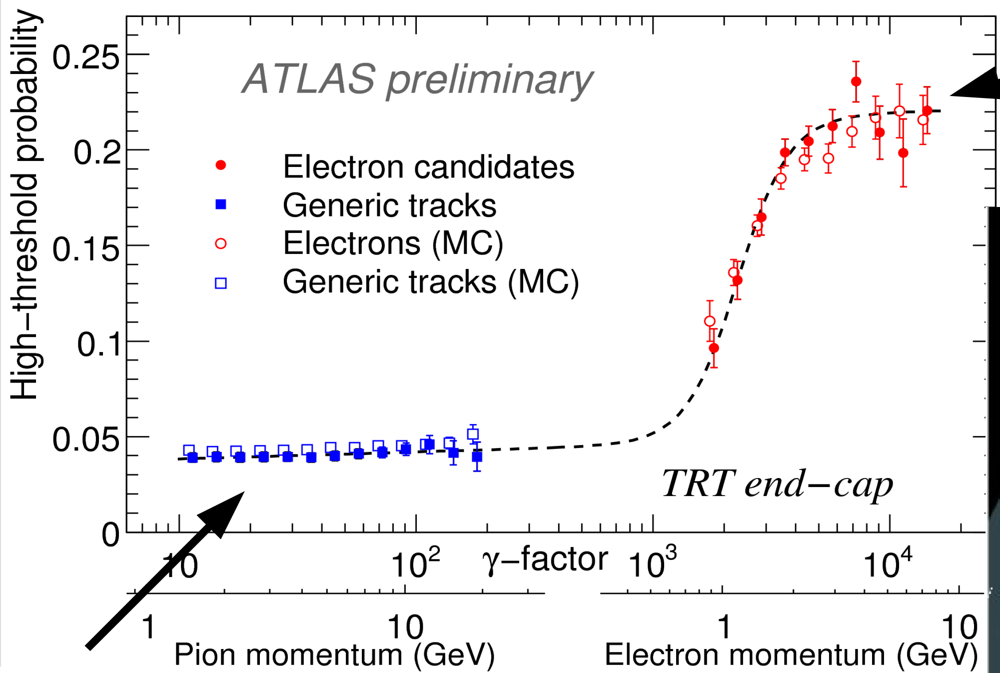
  - Good transition radiation (TR) absorption
  - Less expensive Ar(70%)-CO_2(30%) for most of commissioning but no TR capabilities
- Straws embedded in radiator medium (for barrel)
  - Maximizes probability to absorb TR photon

TR Threshold Equalization

- Threshold needs to be accurate to 1.2% for optimal pion-electron separation
- Current precision is close to this value, improvements ongoing

Collision data Dec 2009:

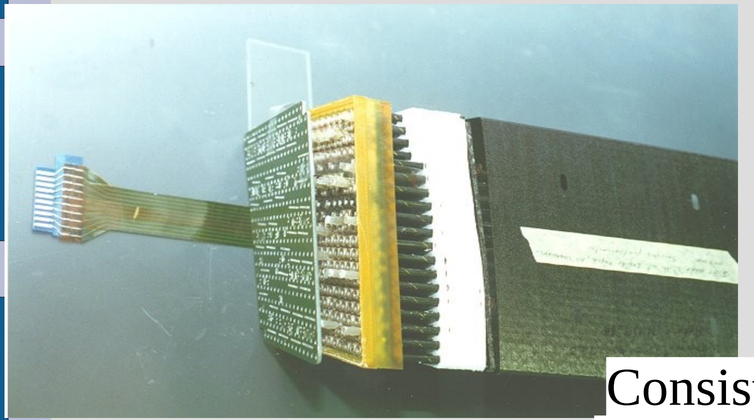


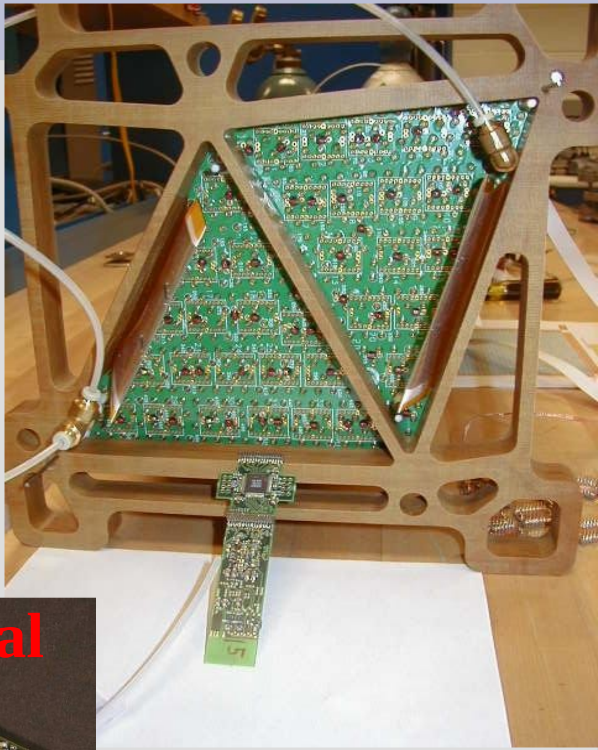
Electrons from photon conversions:

Probability for any track to have dE/dx above TR threshold

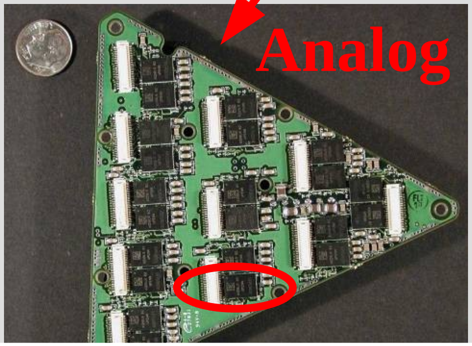
TRT Electronics

TRT Electronics





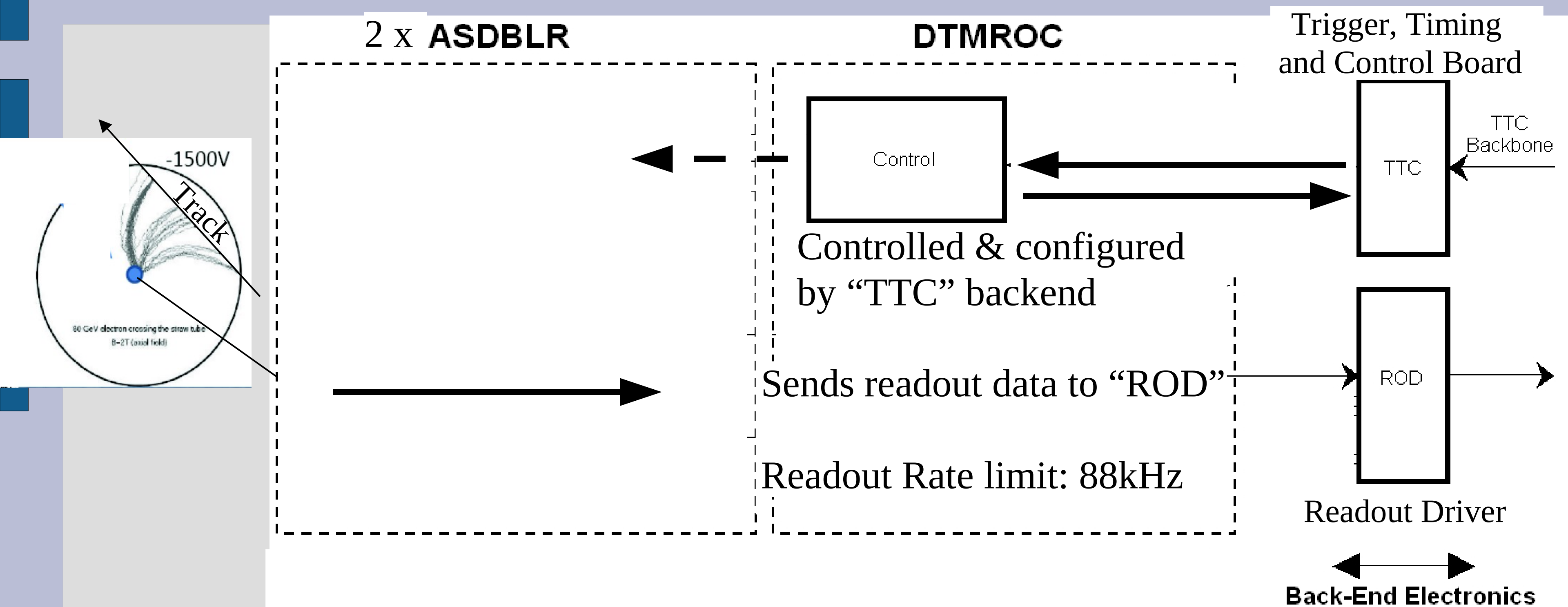
Consists of two parts mounted back to back:



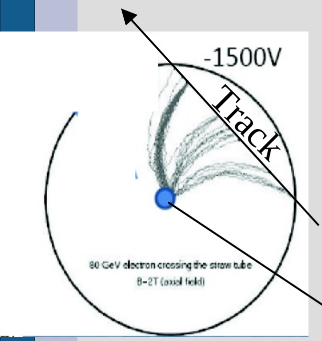
"ASDBLR":
"Amplifier Shaper Discriminator Baseline Restorer"

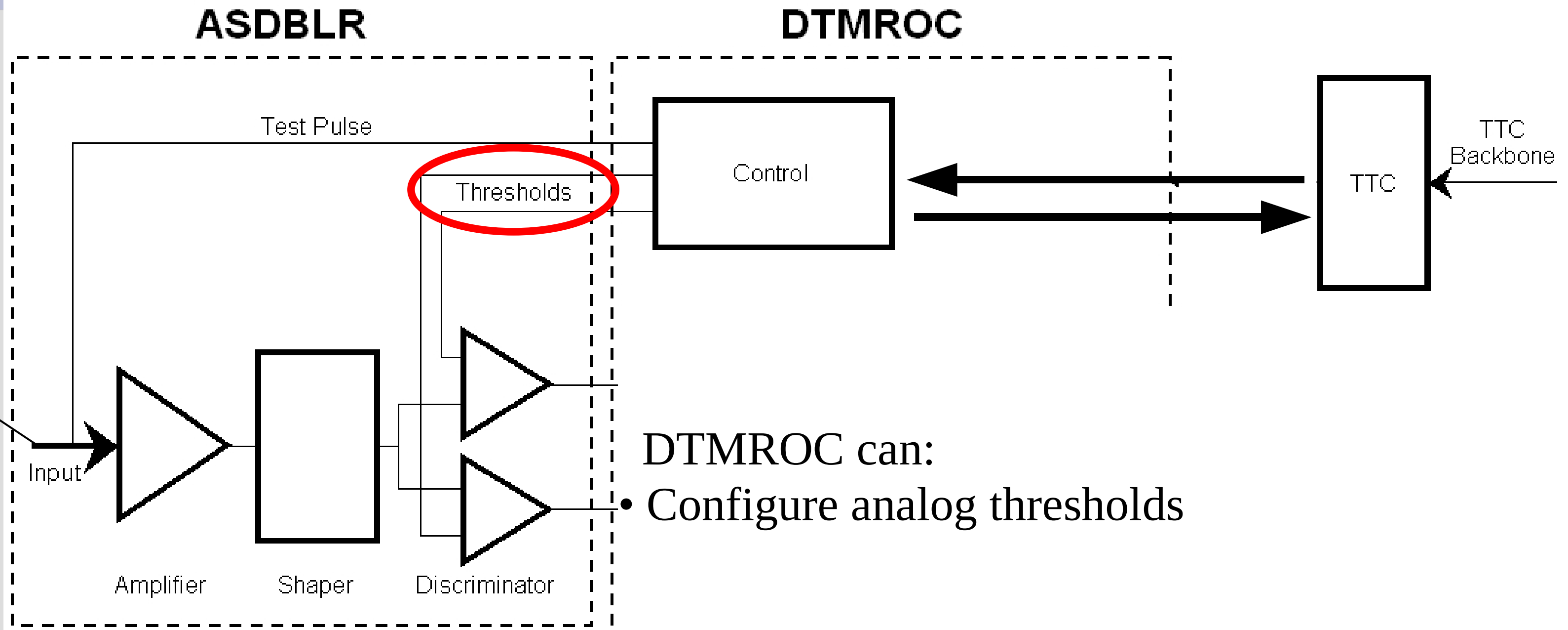
"DTMROC": "Digital Time Measurement Readout Chip"

TRT Electronics - Basics



TRT Electronics - Configuration





DTMROC can:
- Configure analog thresholds

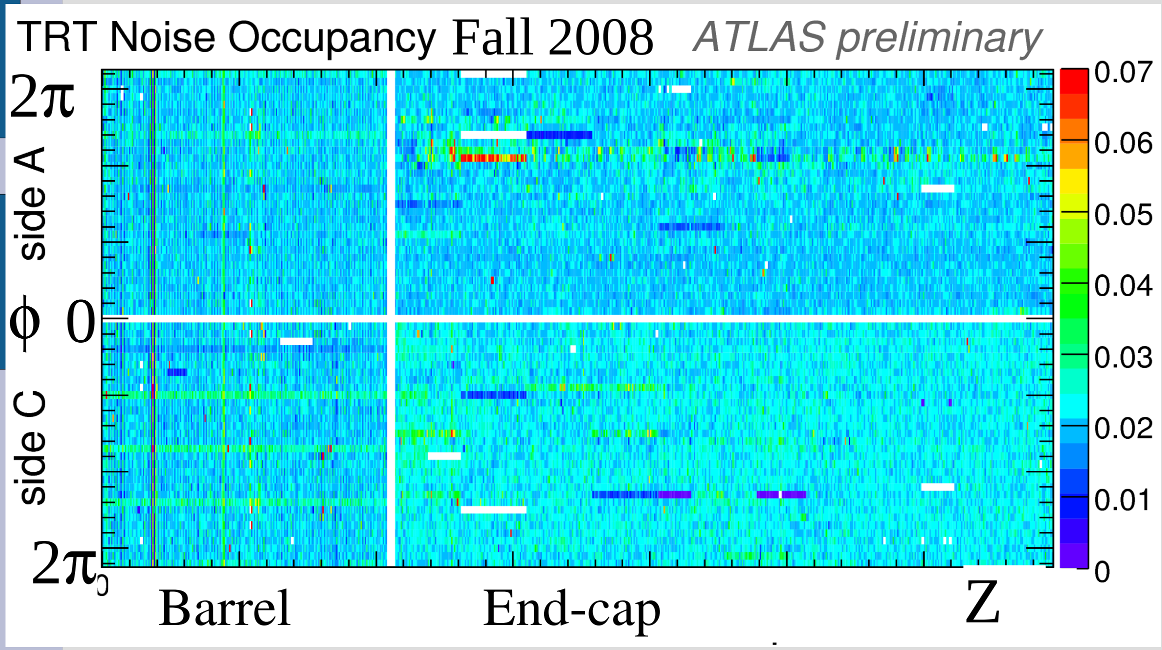
- Analog and digital boards powered separately (in barrel: grounds separated by impedance)
- Inaccurate board powering (low voltage) can have an effect on thresholds

Tracking Thresholds

- Need to equalize tracking thresholds to ensure homogeneous detector response
- Tuned using noise data
  - Easy to do! Recorded “standalone” using a simple fixed frequency trigger
  - 2% straw noise occupancy (equivalent to 250 eV straw threshold)
- Further fine tuning on the way to optimize tracking efficiency

=> Straw noise map: next slide!

Noise occupancy & Active Readout Fraction

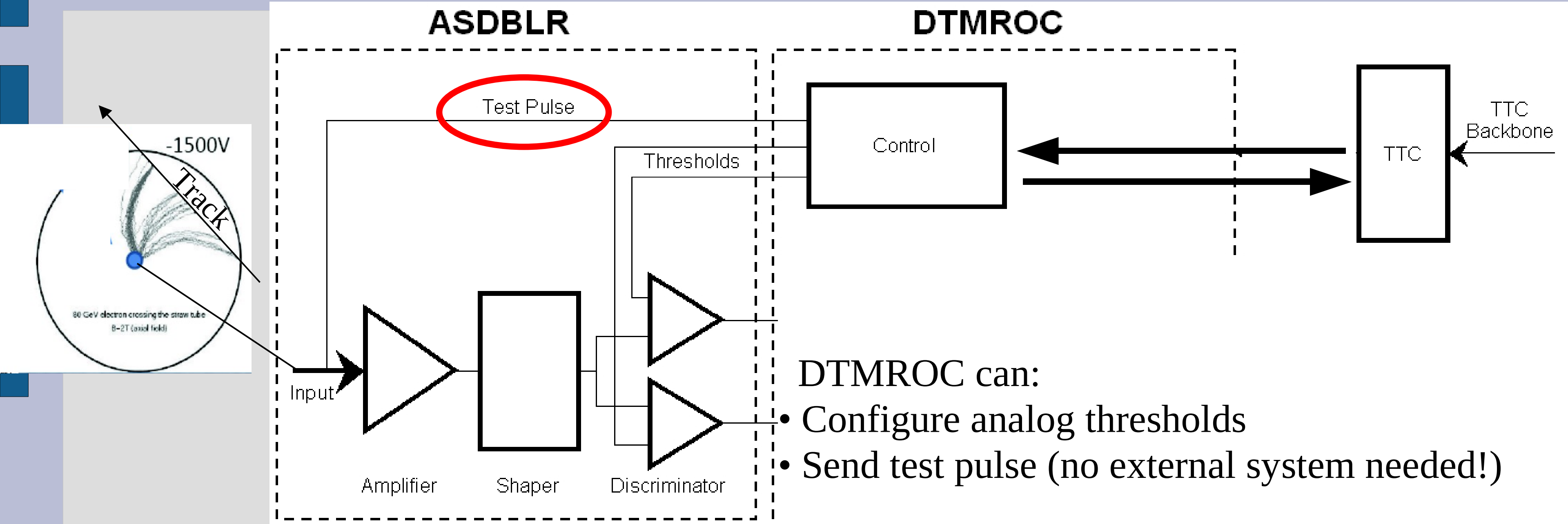


- Uniform noise response
- Shows dead and noisy readout channels: ~2.0%

Most barrel channels (~85%) already found before installation at ATLAS

	Barrel	End-cap
Dead mechan.	2027	1435
Dead electr.	391	3065
Total	**2418 (2.3%)**	**4500 (1.8%)**

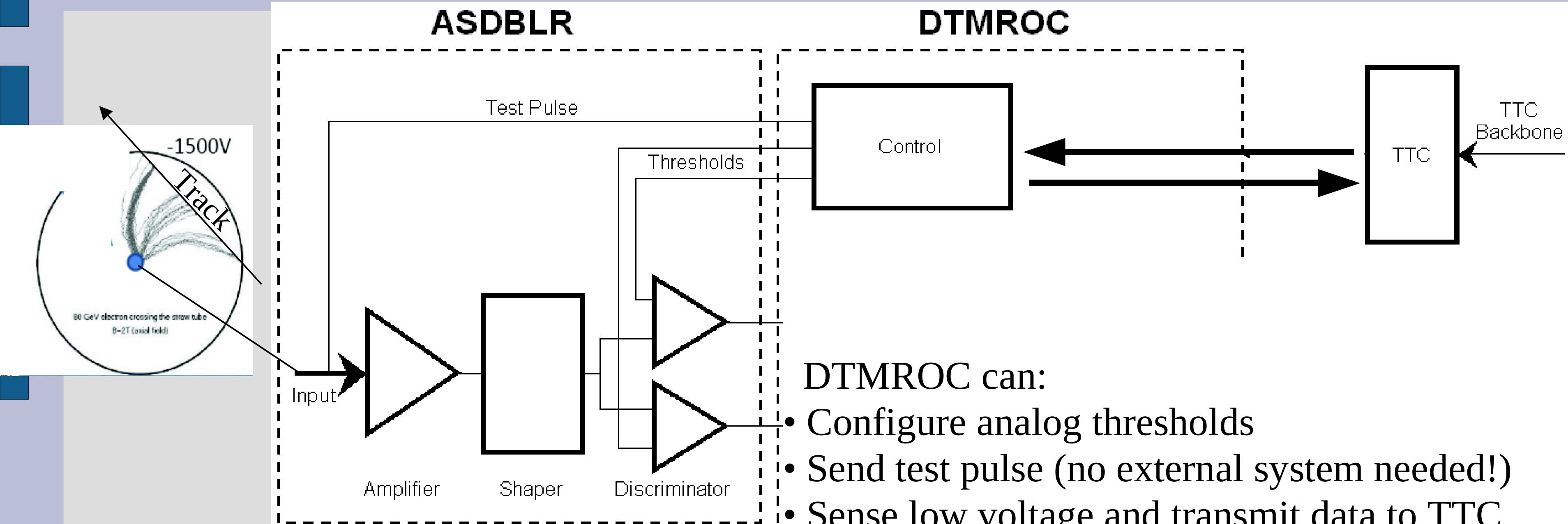
TRT Electronics - Configuration



DTMROC can:

- Configure analog thresholds
- Send test pulse (no external system needed!)

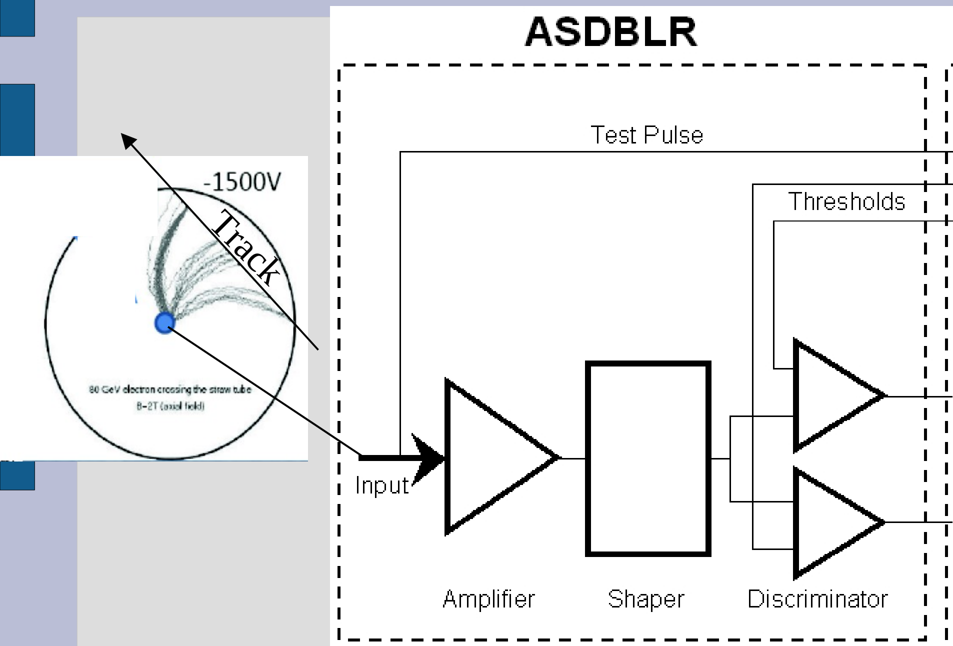
TRT Electronics - Configuration

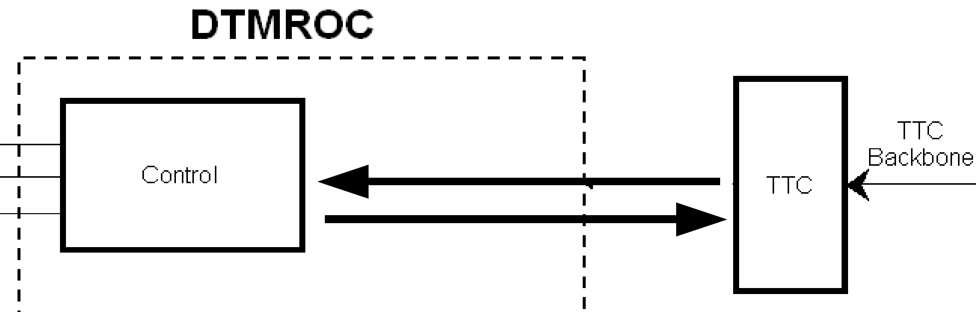


DTMROC can:

- Configure analog thresholds
- Send test pulse (no external system needed!)
- Sense low voltage and transmit data to TTC during data taking

TRT Electronics - Configuration

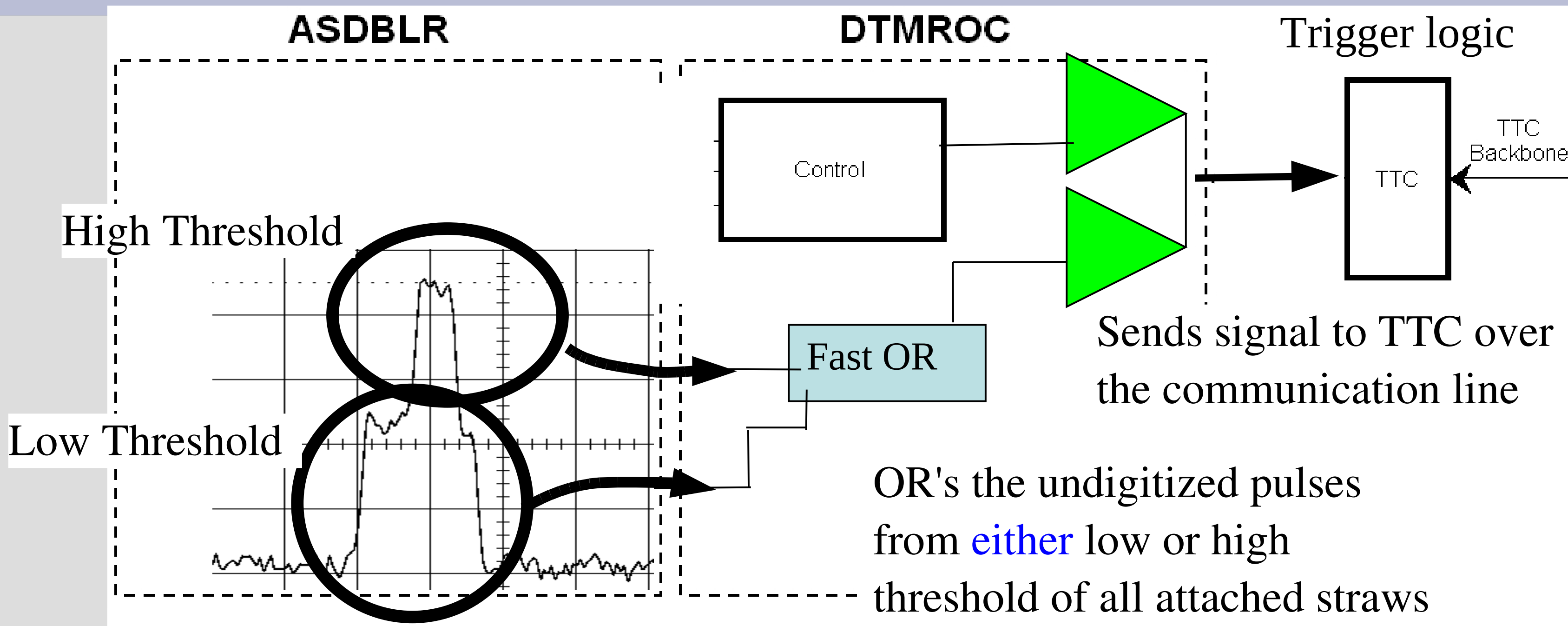




DTMROC can:

- Configure analog thresholds
- Send test pulse (no external system needed!)
- Sense low voltage and transmit data to TTC during data taking
- Send trigger signal ("Fast-OR") to TTC
  -> next slide!

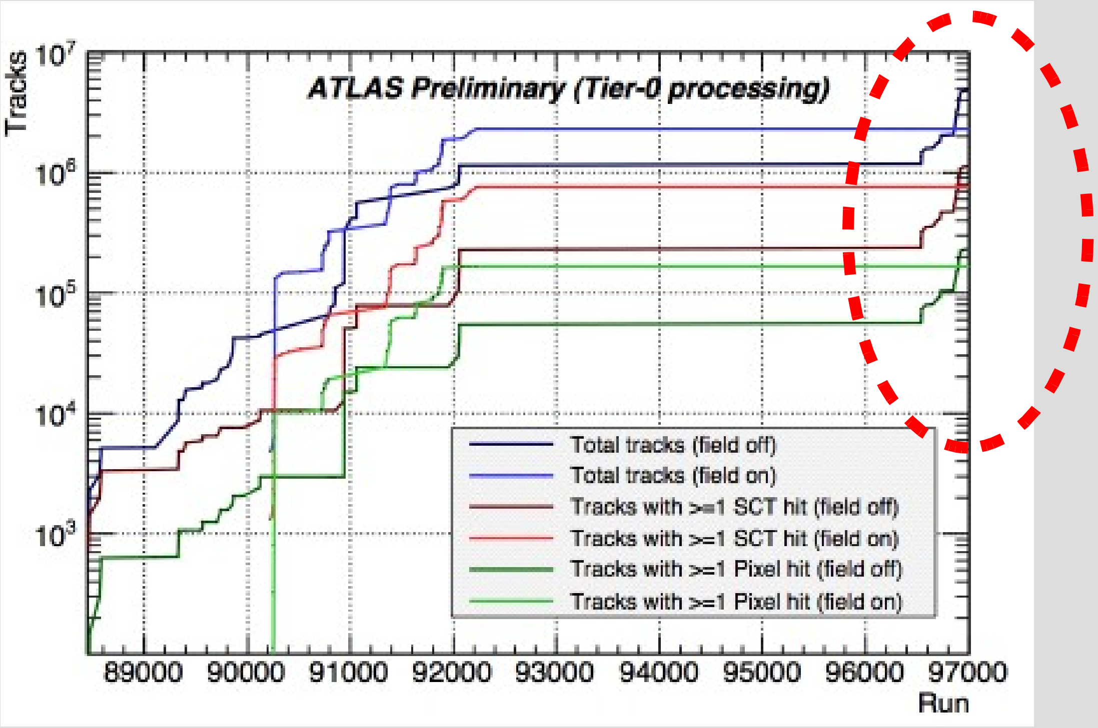
TRT Electronics – Fast-OR Trigger



Resulting pulse at the TTC board:
“OR” of ~15 attached DTMROCs

The TRT Fast-OR Cosmics Trigger

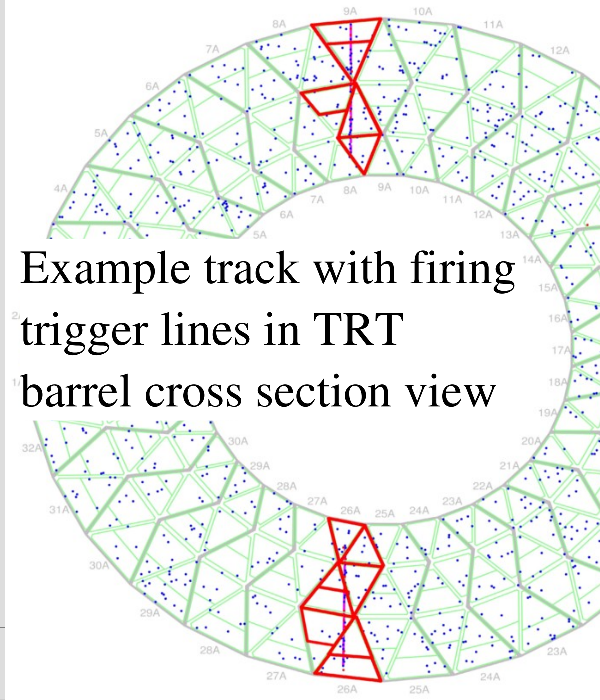
- Motivation:
  - High good-track rate in standalone and combined running
  - High track rate in the end-cap region
  - Independence from other subsystems



Statistics doubled within a week!

The TRT Fast-OR Cosmics Trigger

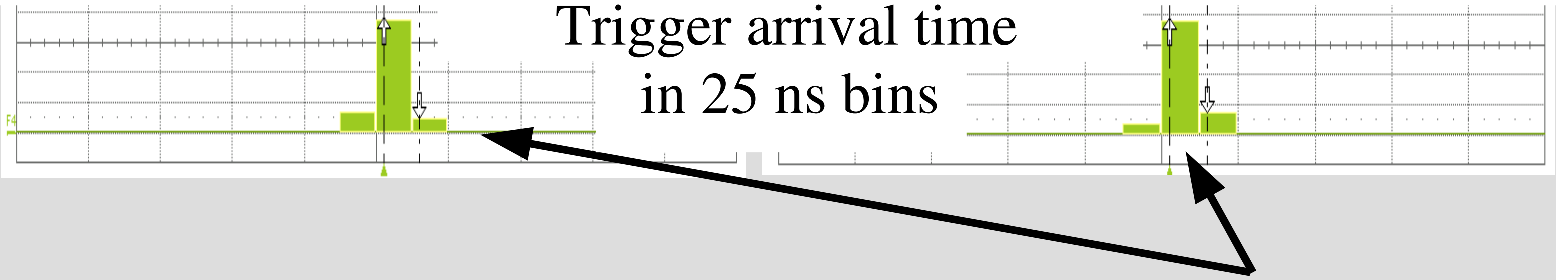
- Motivation:
  - High good-track rate in standalone and combined running
  - High track rate in the end-cap region
  - Independence from other subsystems
- After Sept. 2008 LHC incident -> decision to finalize the trigger
- Configuration: Use DTMROC high threshold signals lowered to MIP levels
  - ~a third of all straws that the track crosses have hits
  - Advantage: very low noise
  - Minor disadvantages: makes TR-threshold calibration difficult (see later), no configuration data transmission from front end possible
- Implementation was quick: First tracks Oct 29th 2008, timing-in completed May 2009



Example track with firing trigger lines in TRT barrel cross section view

The TRT Fast-OR Trigger - Barrel

A side C side

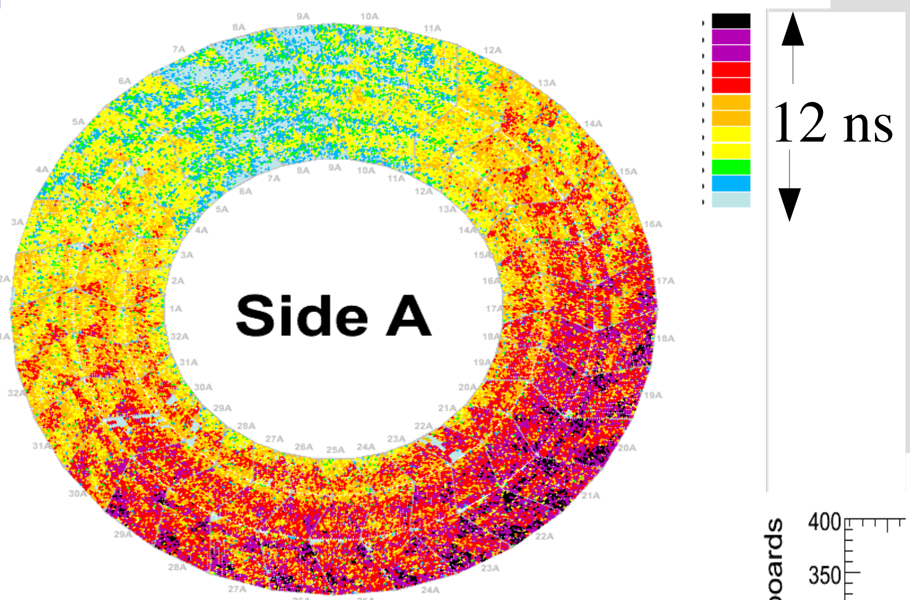


- Very good trigger timing jitter of 9ns: (>90% of triggers within 1 clock)
- Trigger rate ~10Hz with a high purity of >90% events with tracks
- Overall very successful! A major player in ATLAS commissioning:
  - Reference trigger for timing-in of other ATLAS triggers
  - Helped improve muon system trigger (RPC) timing jitter of initially several clock cycles (designed to be accurate to 1 clock)
  - Helped SCT and Pixel readout timing
- Public note already available: ATL-INDET-PUB-2009-002

Beam splashes: Readout Timing

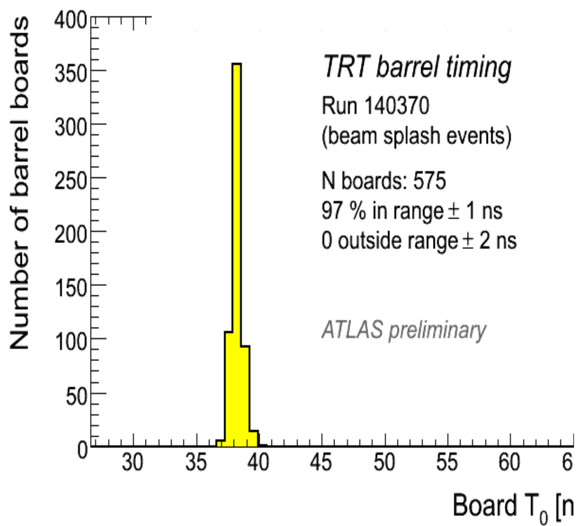
- Need to ensure that full straw signal is contained in 3*25ns readout window
- Before beam splashes most of barrel already timed in with cosmics to a few ns

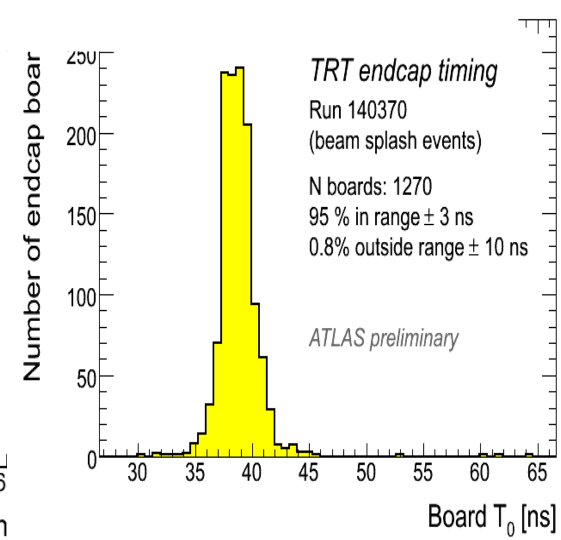
Arrival time of straw signals



- First beam splashes Sept. 10th 2008
- ~100 particles per straw => Enough to time in the detector at one event!
- We know: all particles arrived at the same time => can use this plot to convert from cosmics timing to collision timing!

Status Fall 2009:



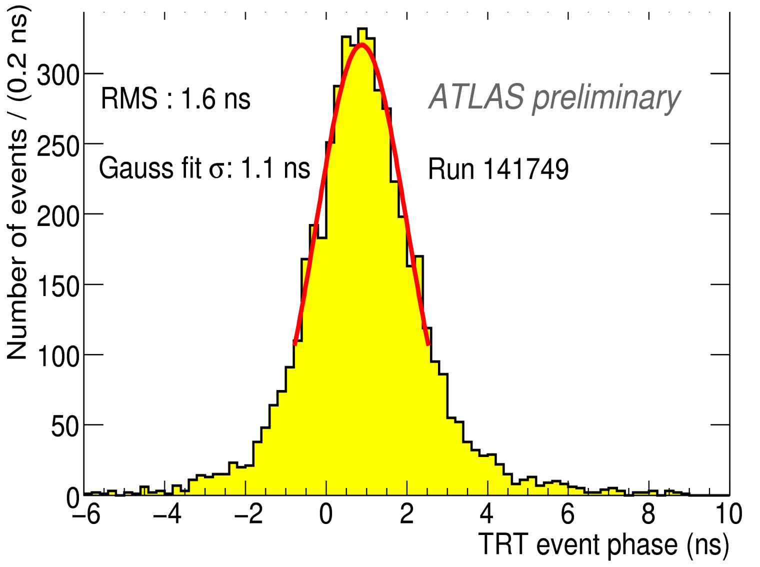


Current hardware timing good to ~ns

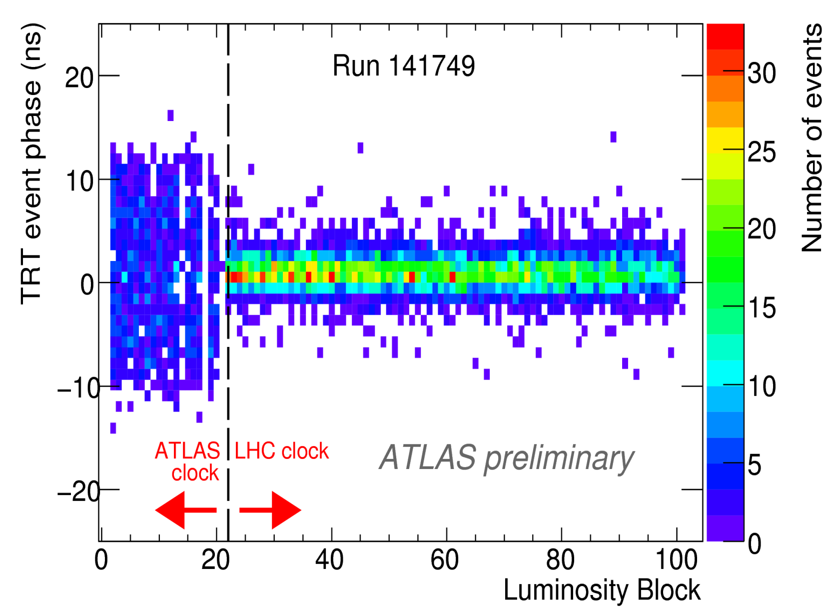
TRT Event T0

- Can do lots of fun things with a well timed in detector!
- Event T_0 is a measure of the time of the interaction determined from time measurements of all hits on track in an event

Accuracy of T_0 measured using collisions tracks: 1ns



Can see the switch from the ATLAS to the LHC clock!



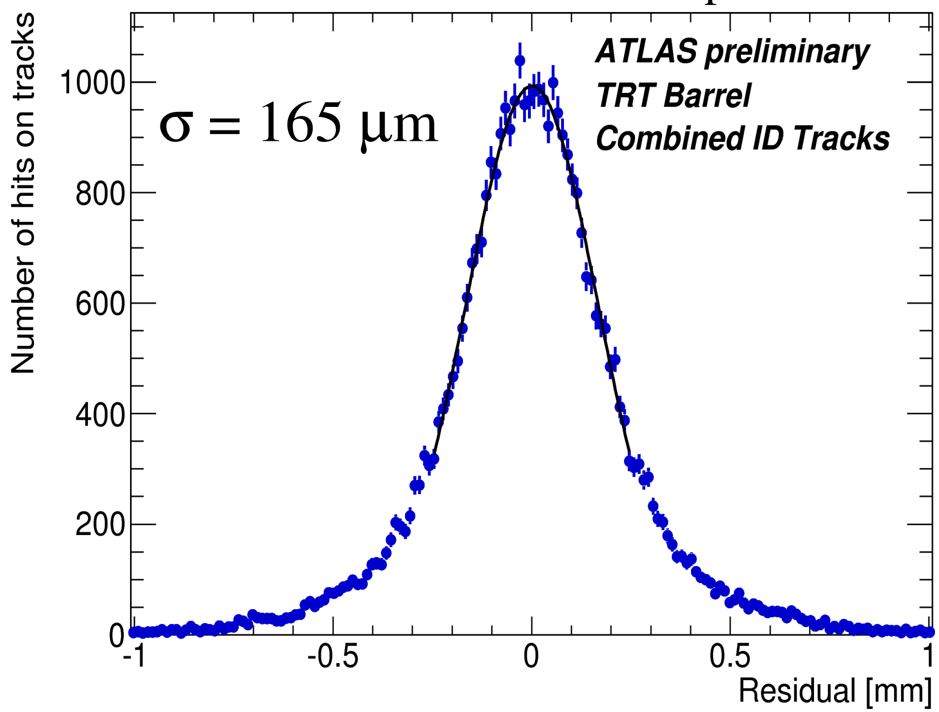
- Also used Event T_0 for cosmic track reconstruction and Fast-OR trigger timing-in 2008/2009

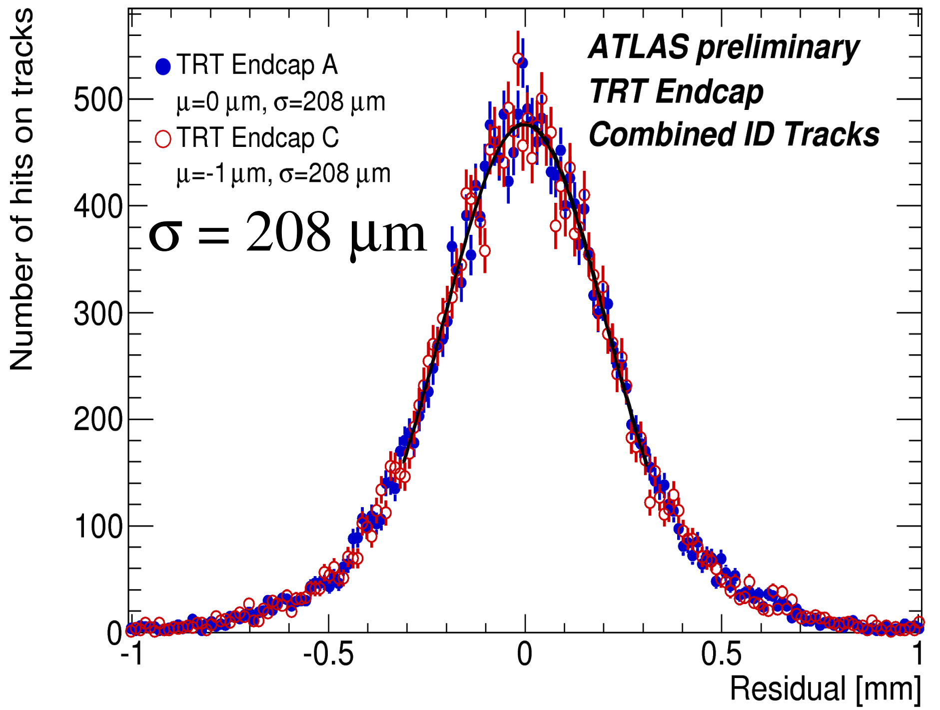
Track position resolution

- Summarizes our efforts: Good readout timing and calibrations very important!
  - Alignment, T_0, R-T constants produced after each data taking run
- Using collision tracks with p_T>1 GeV with >1 hit in SCT/Pixel and >1 hit in the TRT as of Dec. 2009:

Barrel resolution from cosmics data in 2008 already in agreement with design report! Collision data Dec. 2009 matches expectations:

End-caps a bit worse – less studied; also, less data from cosmics for geometric reasons; needs more investigation





Gas & Powering

- Active gas system
  - Continues to have the smallest leak rate of a large volume detector ($2.5m^3$) on the LHC: ~0.41 l/h

- Control and monitoring system ("DCS") of front end powering, high voltage and gas operating smoothly; regularly used as test bed for new ATLAS DCS software

- Straw end-cap cooling & barrel ventilation gas
  - used dry air in the first phase before leak studies between SCT and TRT enclosures have been done
  - commissioned and started to use CO_2 cooling in Sept. 2009 (flow: ~$3m^3$/h in barrel, ~300 m^3/h in end-cap)

“Advanced Features” - 2009/2010

Spent much of the last months on...

- Stopless recovery: Automatically re-configures problematic parts of the detector readout without stopping the run -> maximizes data taking efficiency!
- Resynchronization: TRT system affected by some LHC clock frequency and phase changes:
  - No loss of clock for the proton injection ramping
  - Loss of lock likely for: Frequency ramp up from ion injection energy, Phase changes of > 5ns, interruption of clock
  - => designed a procedure (duration 5-10 sec) to recover the TRT in that case
- Spy readout for “Mini Event Builder”: used for low-rate event sampling directly from the RODs over VME, to have monitoring before high level trigger algorithms

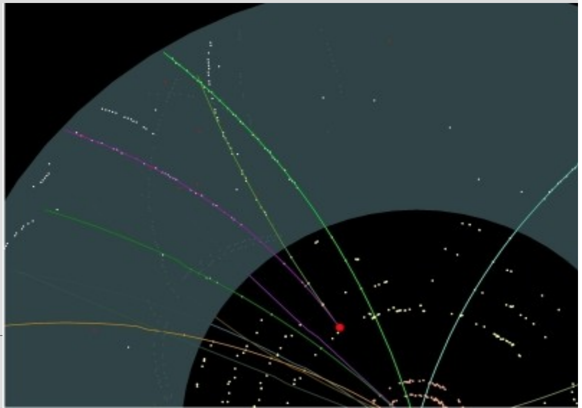
“Advanced Features” - 2009/2010

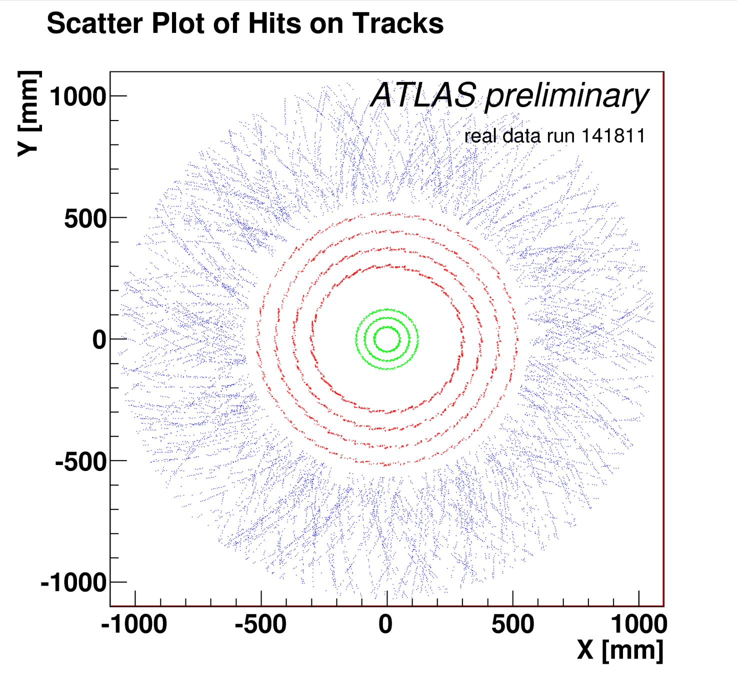
Spent much of the last months on...

- Gas Gain Stabilization System: compensates gas gain variations due to temperature, pressure etc. changes with high voltage adjustments
- Improvement of control room shifter data acquisition and debugging tools (move from expert to shifter handling)

Summary and Outlook

- Very successful commissioning process, TRT continues to operate smoothly
- Continue working on high threshold equalization and end-cap calibrations
- Many analyses of the first collision data already make use of the excellent TRT performance
- TRT is ready to produce more good first analysis data later this year!





Thanks go to...

- All of the TRT community
- Special thanks go to R. Van Berg, M. Hance, D. Olivito, H. H. Williams, J. Alison, A. Bocci, A. Muir, M. Donega, S. Fratina, C. Rembser, F. Dittus, P. Lichard, A. Romaniouk, F. Luehring, P. Cwetanski

Backup

Timeline: 2007/2008

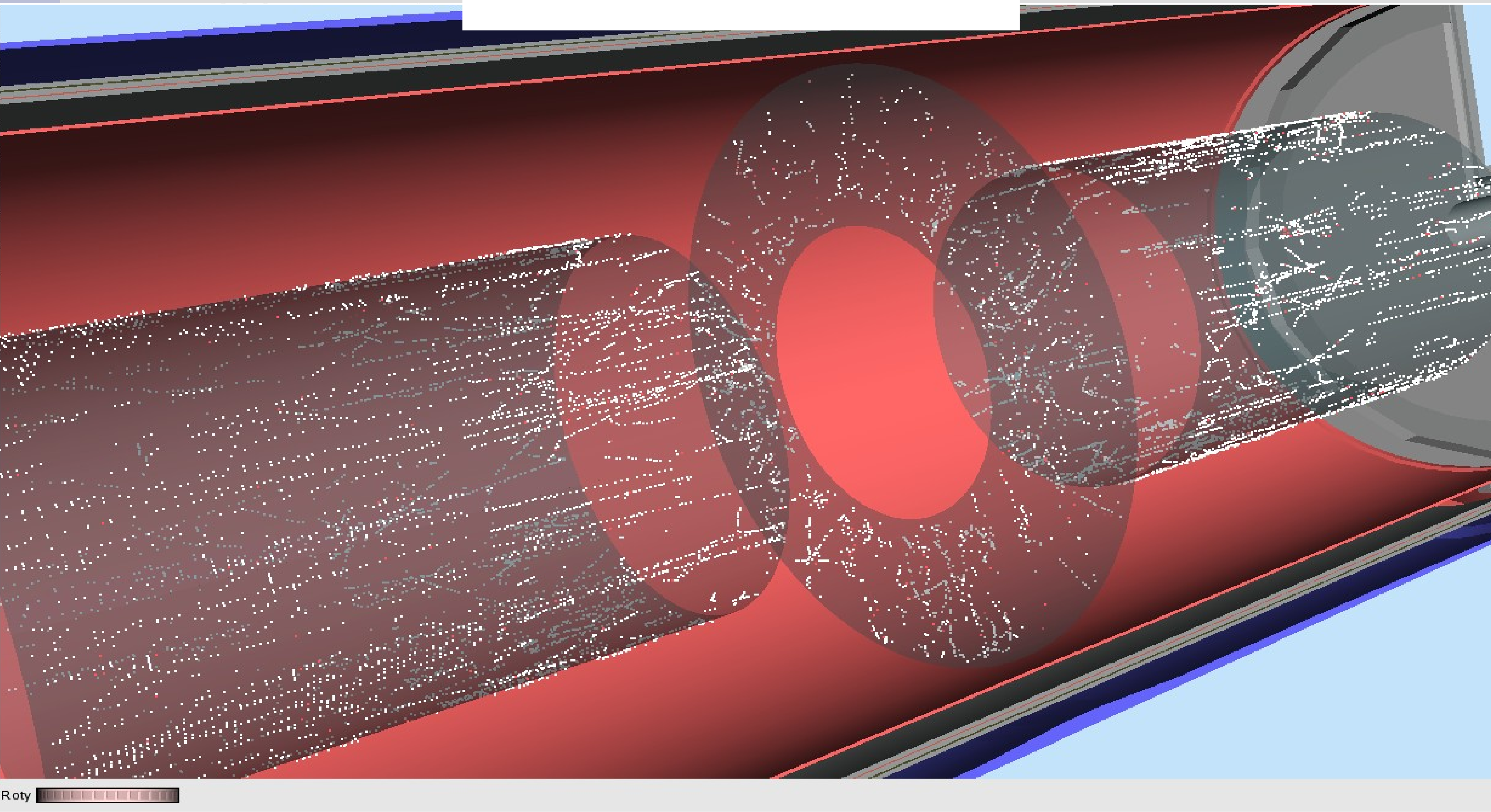
- May 2007: Insertion of last end-cap

- Status Summer 2008:
  - Partially equipped. Reason: RODs and low voltage power supplies not all delivered yet
  - Zero suppression implemented on RODs; with this we could achieve 88kHz readout rate (front end chip limit)
  - Gas: operating with Ar mixture
  - Used TileCal trigger and scintillating plates on top of ATLAS detector (~1Hz, 5% efficiency in the TRT) to record cosmics

- Status Fall 2008:
  - System fully equipped
  - Switched from Ar/CO_2 active gas to $Xe/CO_2/O_2$ to prepare for beam

Timeline: 2007/2008

Beam Halo Event



- **Sept. 10th 2008: First Beam!**

Timeline: 2009

- Implementation of TRT Fast-OR Trigger
- Switched back to Ar gas mixture
- Entire TRT running smoothly
- Improving performance and functionality
  - e.g. shifter-friendly tools for first beam
- Had regular Milestone Runs over the past months:
  - March 12th, March 26th, April 2nd
    - Main objectives RPC timing, Readout tuning, Improvement of monitoring
  - TRT slice week + HLT week: April 27th – May 11th
  - TRT High rate and Clock tests (see next slides): May 27-28
  - ATLAS combined run: June 19th – July 6th
  - Run with RPC detector trigger Aug 18th – 21st