Commissioning of the ATLAS Pixel Detector with Cosmic Ray Data

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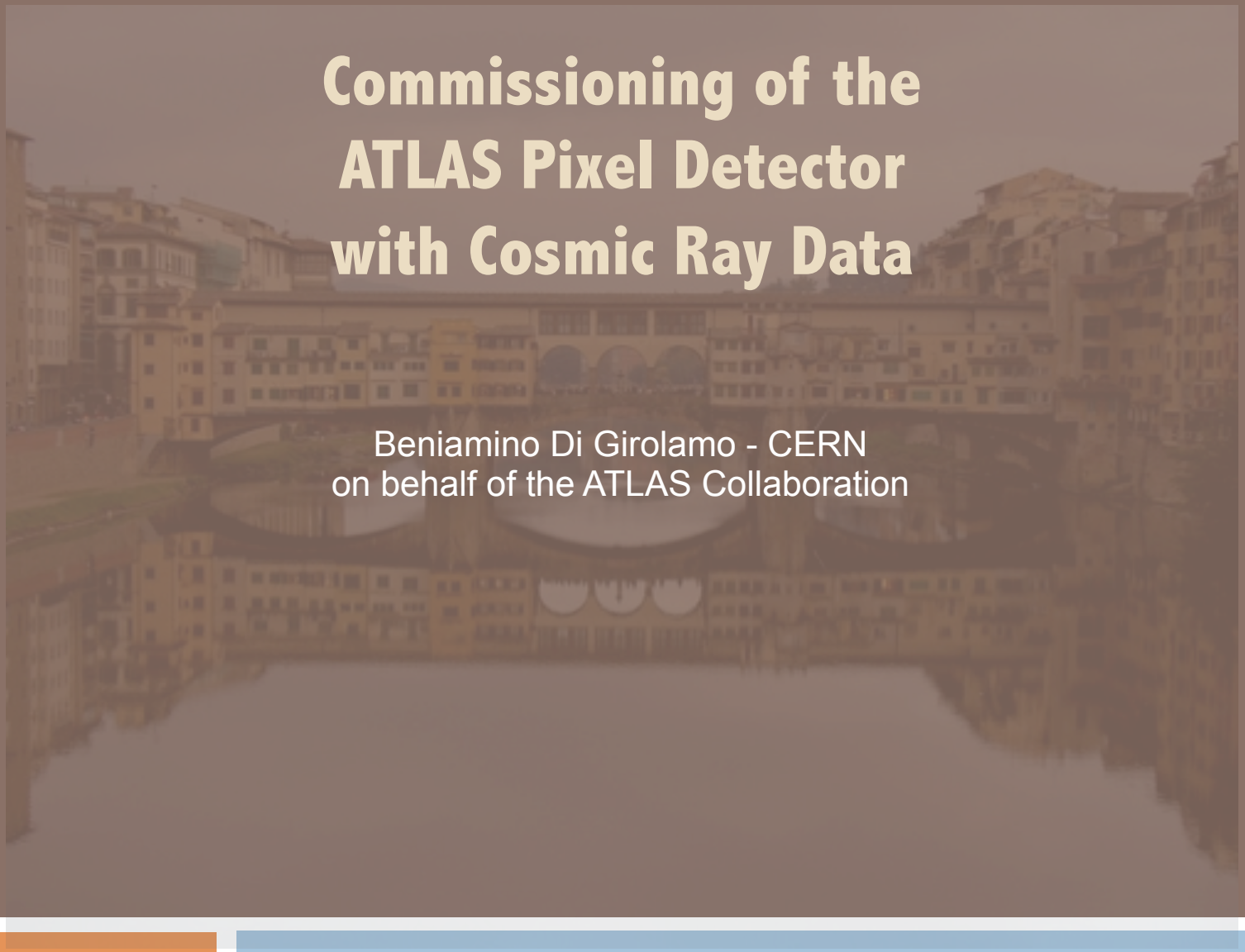
on behalf of the ATLAS Collaboration

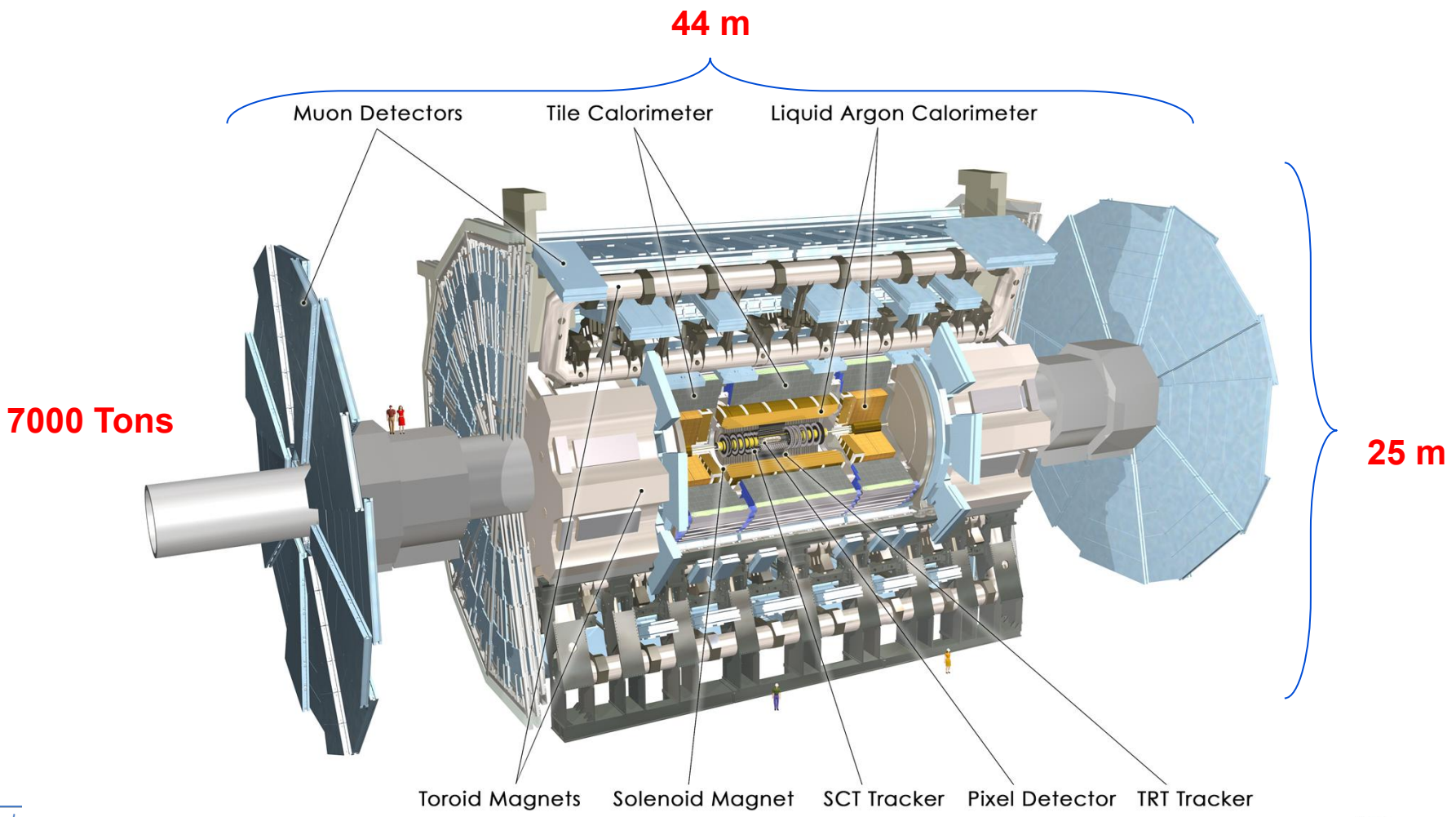


9th International Conference on Large Scale Applications and Radiation Hardness of Semiconductor Detectors
30 September - 2 October 2009, Florence, Italy

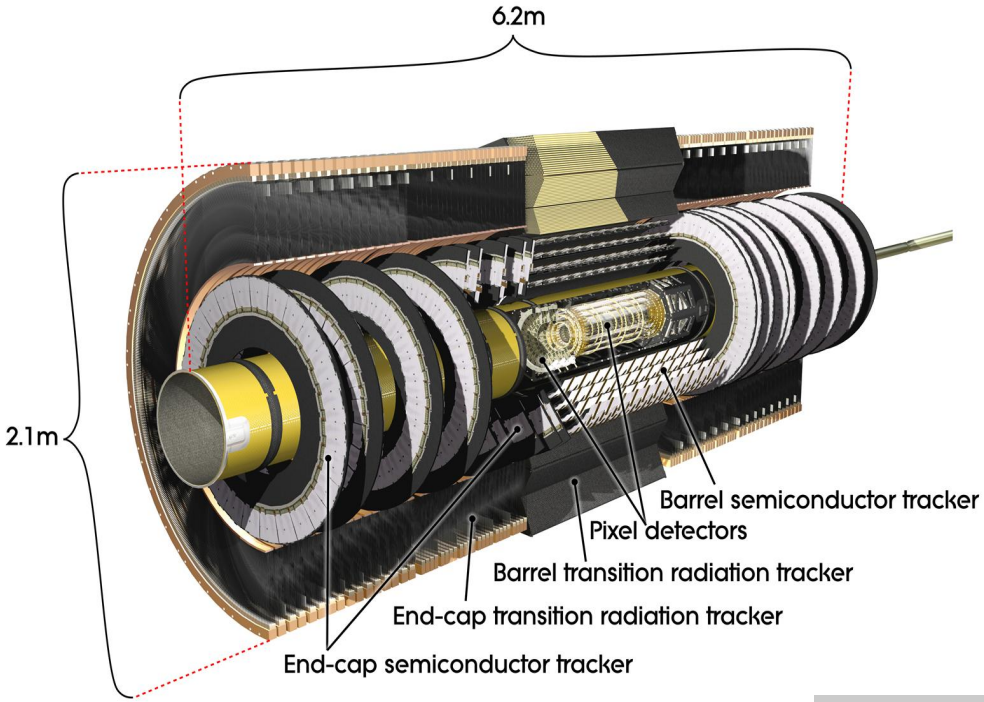
Outline

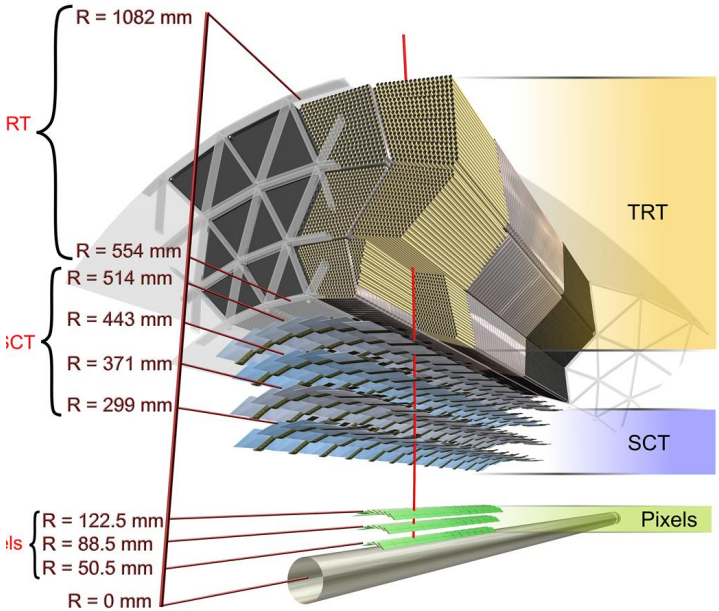
- ATLAS and its Inner Detector
- The ATLAS Pixel Detector and its commissioning
  - Calibration and Cosmic ray data taking
    - Threshold, noise and masked pixels
    - Time-over-Threshold and timing
    - Resolution, efficiency and noise occupancy
    - Lorentz angle
- Status and expectations
  - Readiness for collisions and long term operations

The ATLAS Detector



The ATLAS Inner Detector



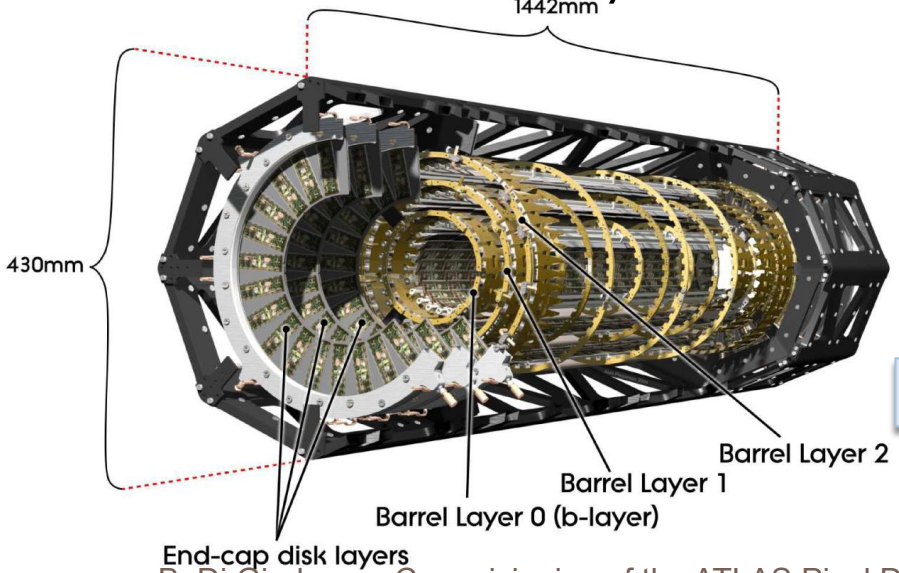


- 2 T solenoidal magnetic field
- Acceptance $|\eta|<2.5$
  (transition radiation tracker $|\eta|<2$)

- Momentum resolution
  $\sigma(p_T)/p_T = 0.05\%\ p_T\ [\text{GeV/c}] \oplus 1\%$
- Impact parameter resolution $(0.25<|\eta|<0.5)$
  $\sigma(d_0) = 10\ \mu\text{m} \oplus 140\ \mu\text{m} / p_T\ [\text{GeV/c}]$

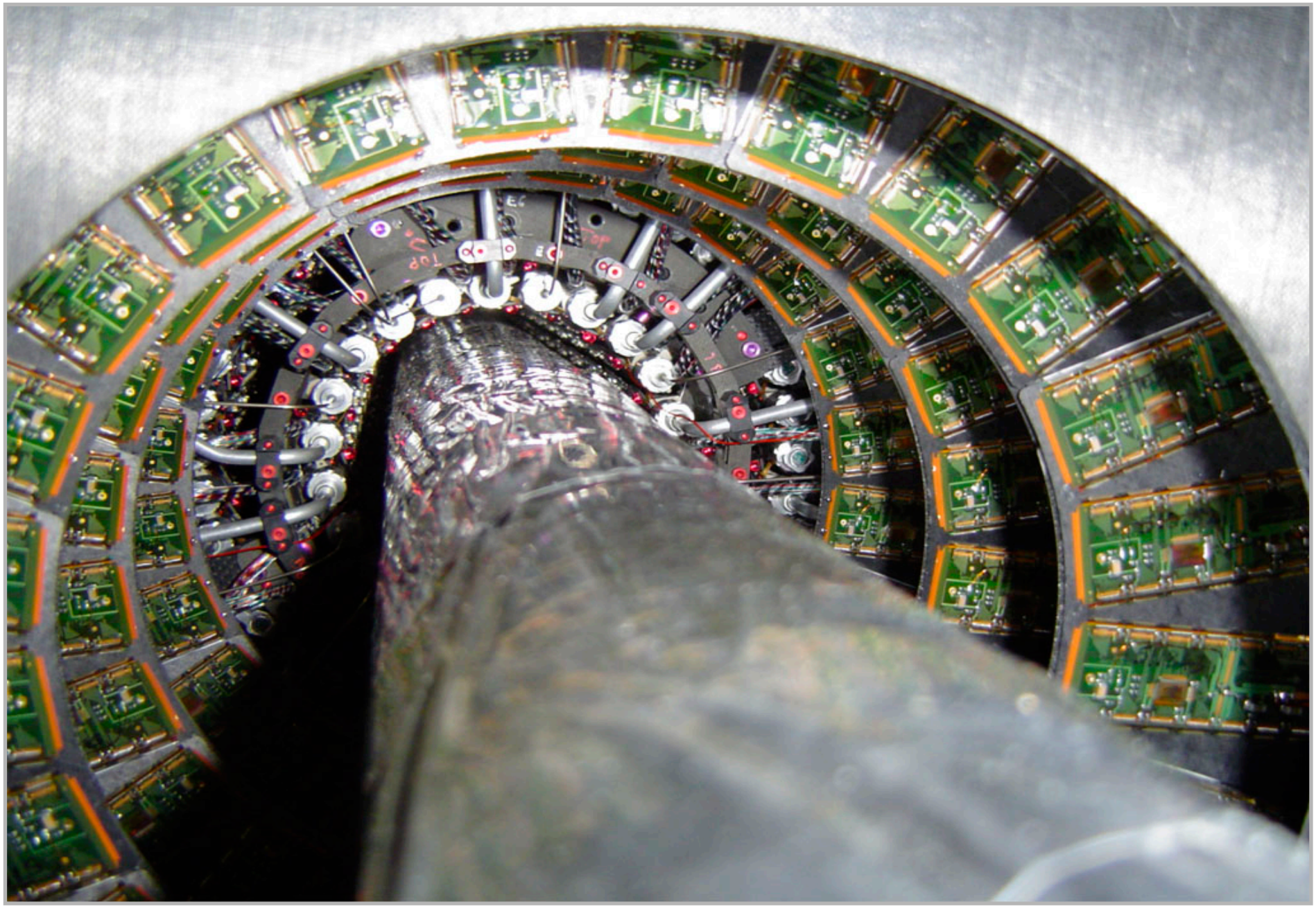
The ATLAS Pixel Detector

- Requirements:
  - Position resolution in rϕ-direction < 15 μm
  - 3 track points for $|\eta| < 2.5$
  - Time resolution < 25 ns
  - Hit detection efficiency > 97%



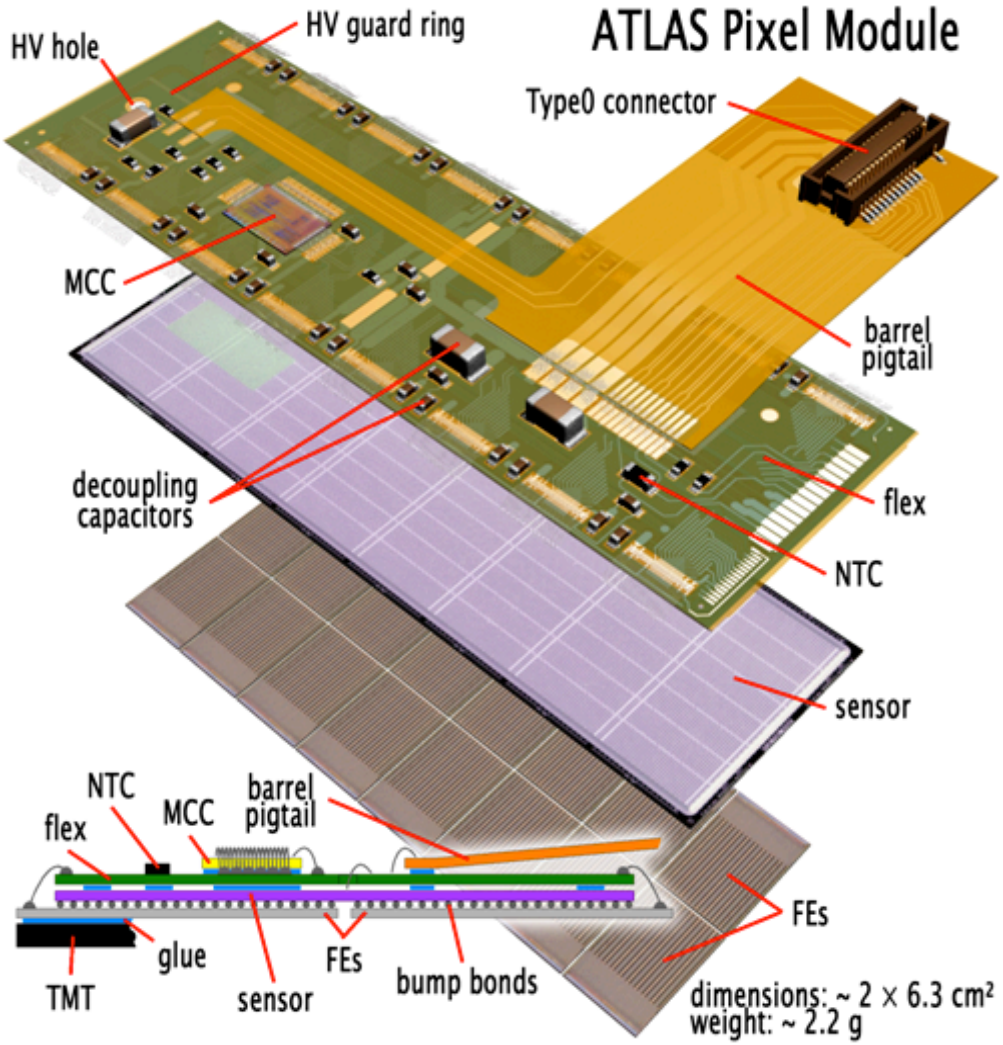
- Basic Properties:
  - 1744 Pixel Modules on three barrel layers and 2 x 3 disks
  - 80M readout channels
  - Innermost layer at 5 cm
    - Radiation tolerance 500 kGy / 10^{15} 1 MeV $n_{eq}cm^{-2}$
  - Evaporative C_3F_8 cooling integrated in local support structure → Module temperature below 0 °C

How close to the beam pipe? See next slide

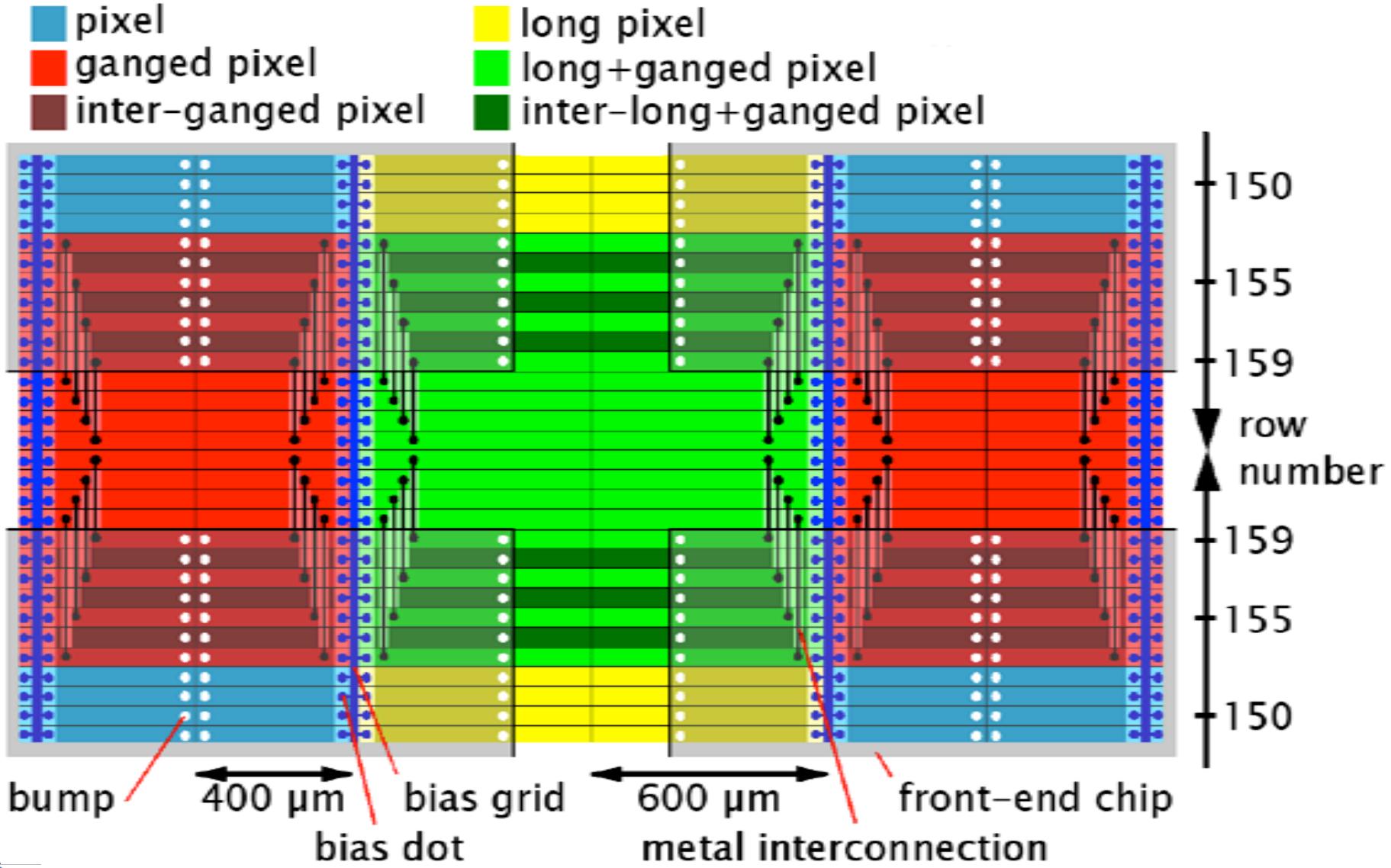


The ATLAS Pixel Module

- Sensor
  - 250 µm thick n-on-n Si sensor
  - 47232 (328 x 144) Pixels (46080 read channels)
  - Typical pixel size 50 x 400 µm (50 x 600 µm pixels in gaps between FE chips)
  - Bias voltage 150 – 600 V
- Readout
  - 16 FE Chips with 2880 pixels each
  - Pulse height measured by means of Time over Threshold
  - Zero suppression in the FE chips, MCC chip builds module event
  - Data transfer 40 to 160 MHz depending on layer (occupancy)



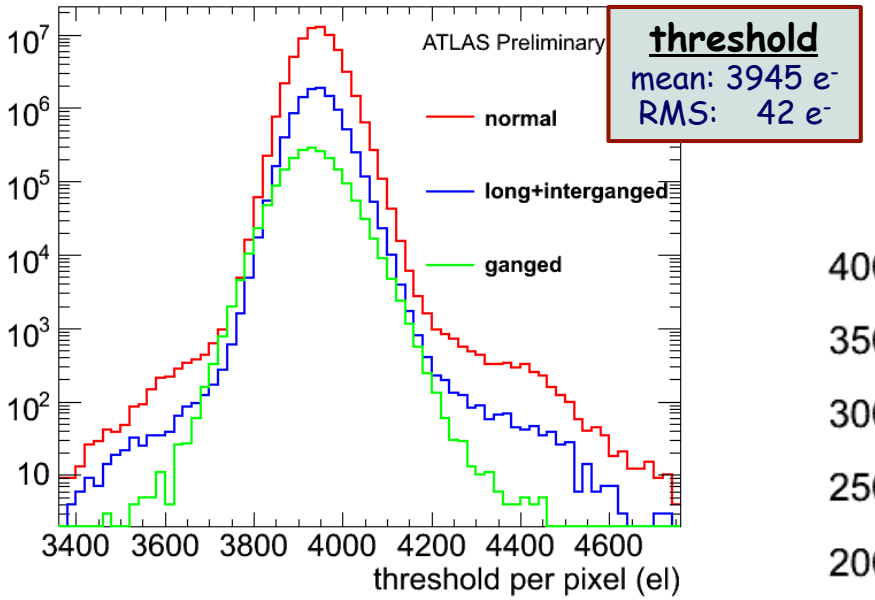
Inter-chip Region



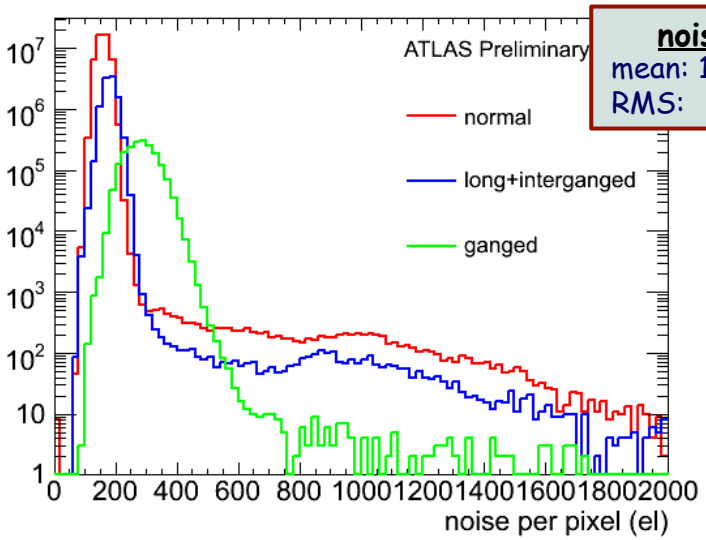
The Pixel Detector commissioning

- August-December 2008
  - Functionality checks, calibrations and cosmic ray data
  - 240 k tracks with field off, 190 k tracks with field on
- May-July 2009
  - Short calibration period and cosmic ray data
  - 90 k tracks with field off, 180 k tracks with field on
- Restarted mid-August 2009
  - 5 weeks for calibration and very soon in continuous cosmic ray data taking until beam comes

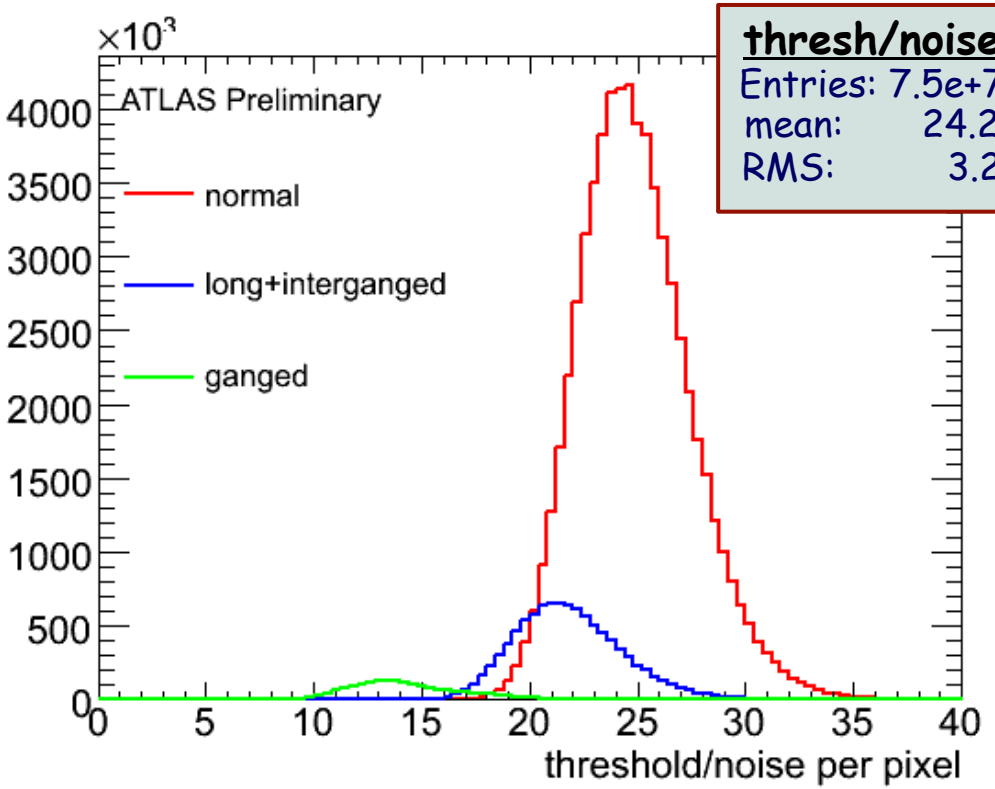
Threshold and Noise



threshold
mean: 3945 e⁻
RMS: 42 e⁻



noise
mean: 166 e⁻
RMS: 29 e⁻

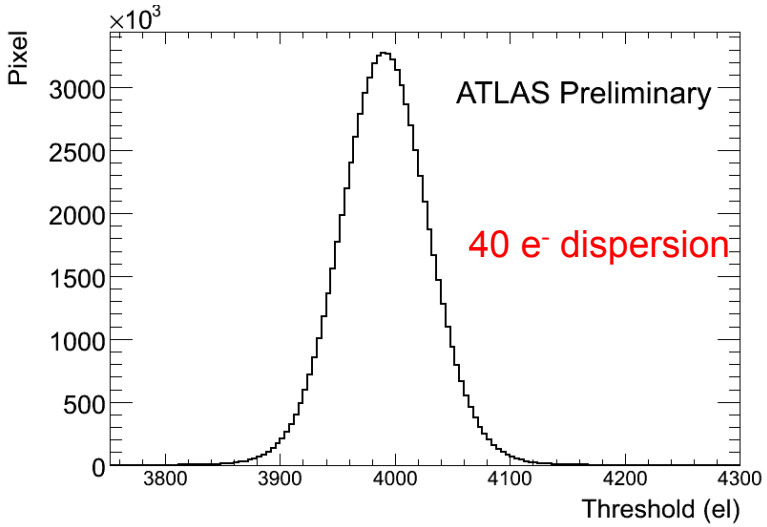


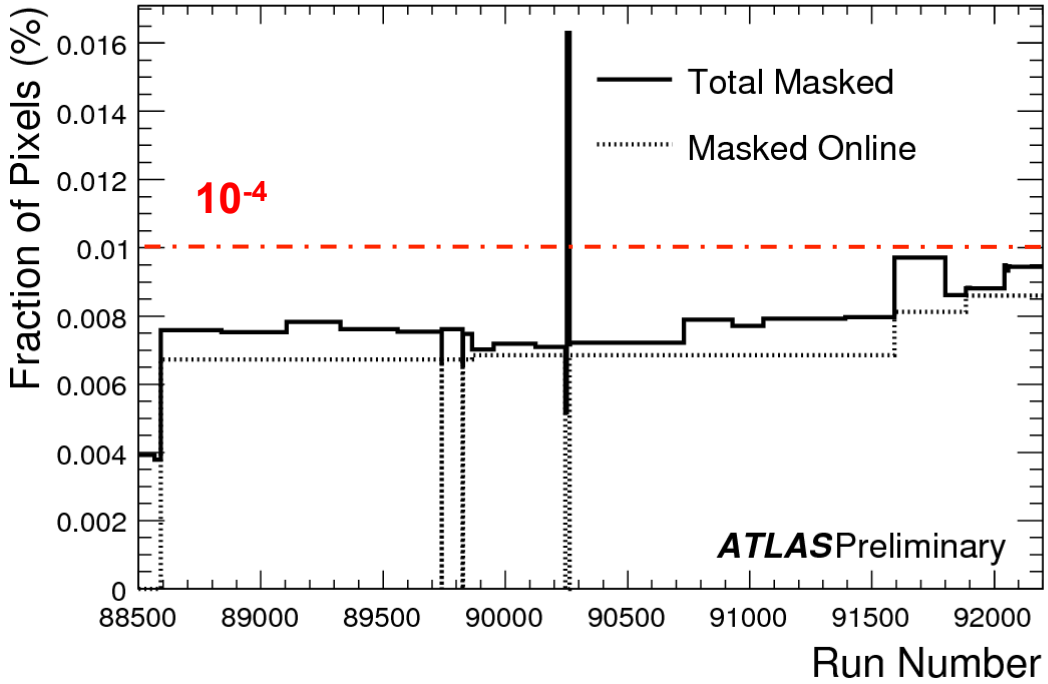
thresh/noise
Entries: 7.5e+7
mean: 24.2
RMS: 3.2

75M pixels in the plots!
Noise approx. 200 e⁻ for most pixels,
slightly higher for special pixels
Threshold/Noise approx. 25 for normal pixels

Threshold and Noise: Masked Pixels

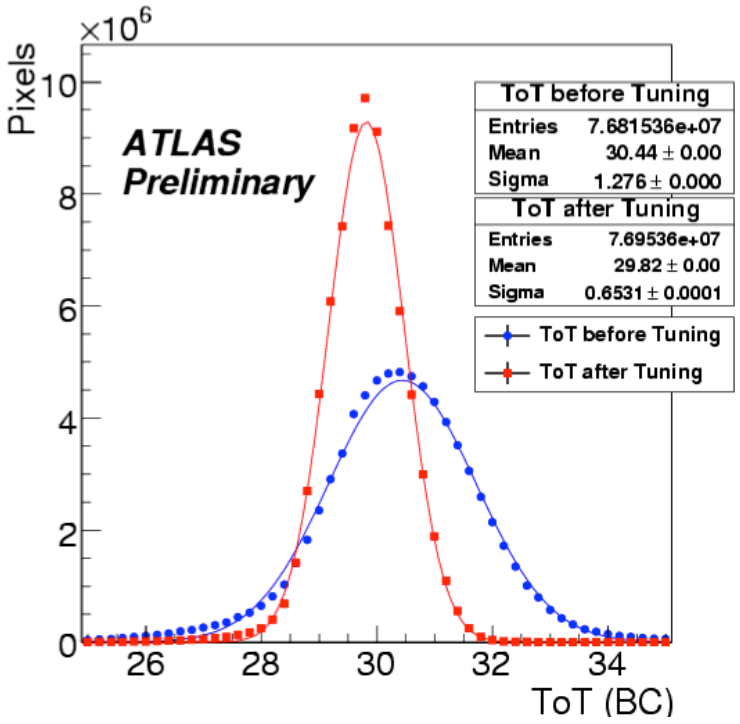
- Threshold setting: 4000 e^-
- Threshold tuned pixel by pixel, threshold dispersion ~ 40 e^-
- Fraction of masked pixel ~ 0.01%

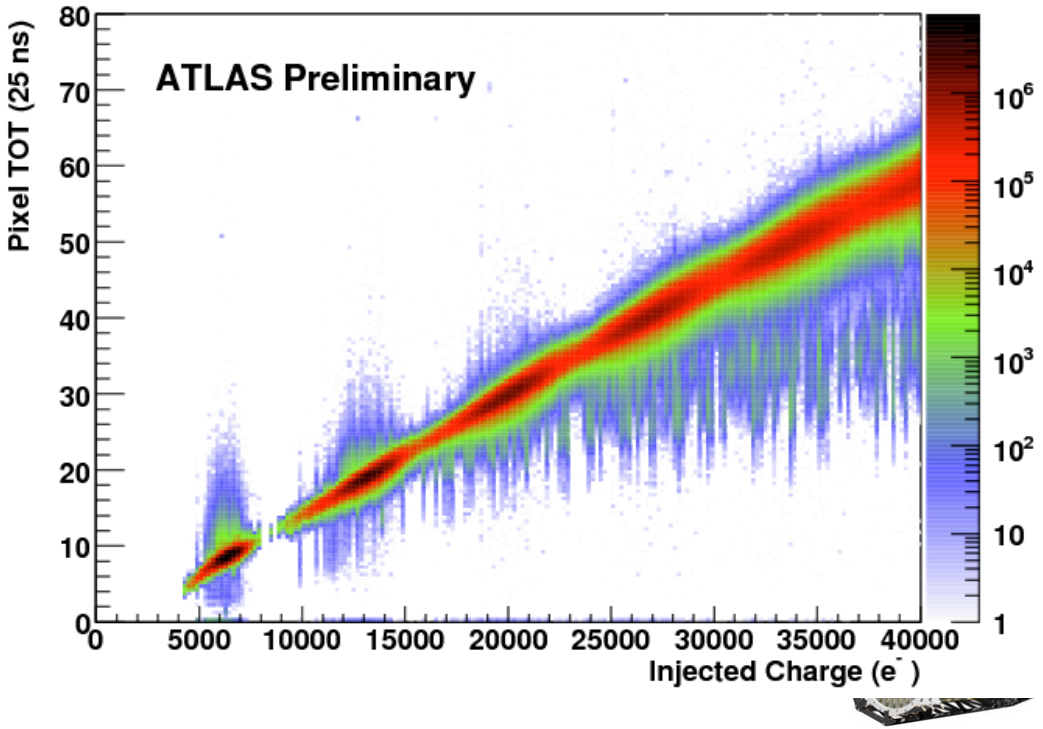




Time over Threshold

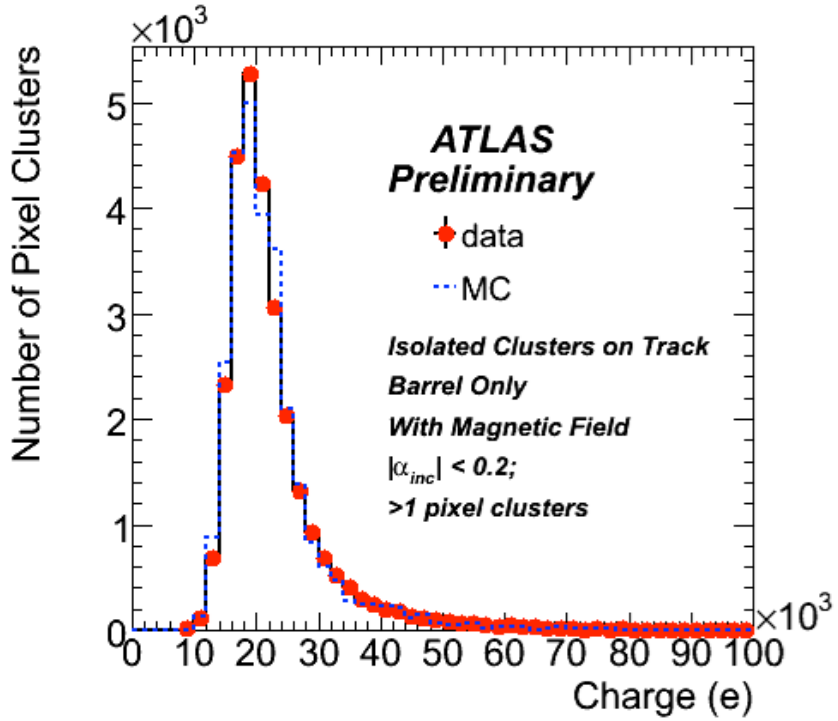
- FE chips provide Time over Threshold information for each hit
  - Nearly linear dependence on deposited charge
- Pixel-by-pixel tuning; chosen tuning: 30 BC for 20 ke$^-$
- Calibration by means of test charge injection

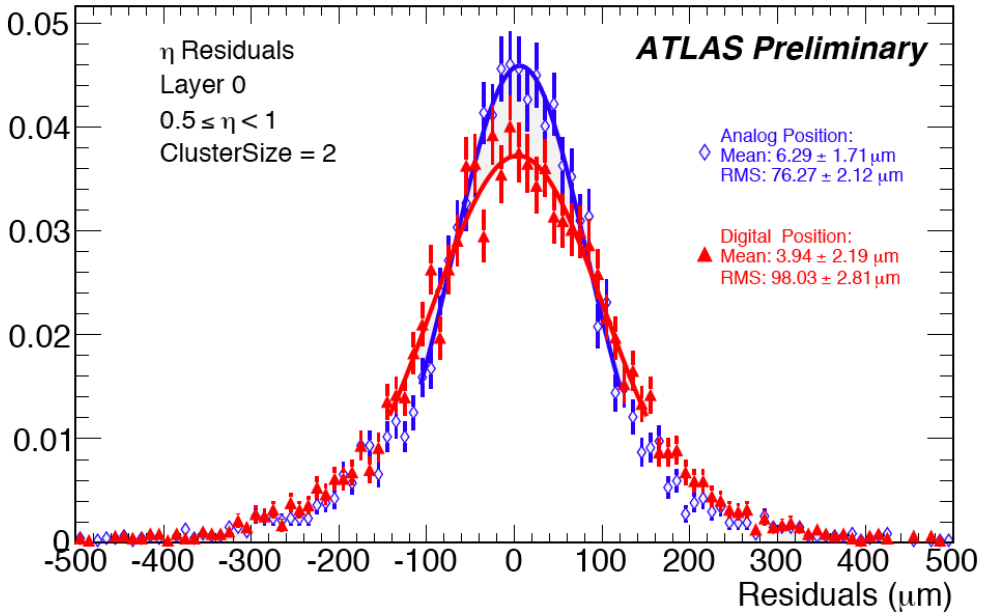




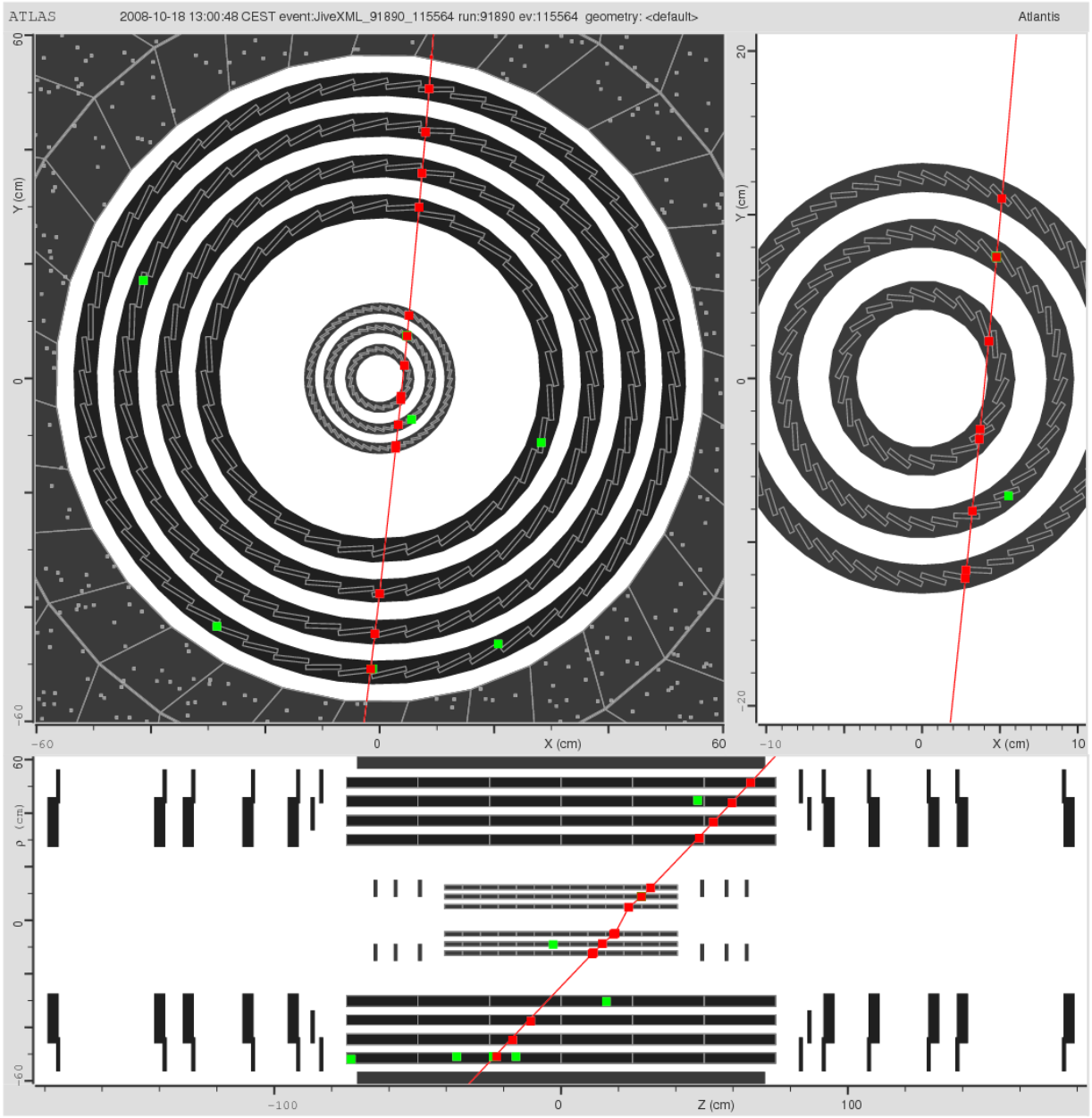
Time over Threshold and Resolution

- Charge measurement with ToT in cosmic ray data taking
  - "Landau" peak at 18300 e^- (Simulation 19000 e^-): Confirms ToT Calibration
- Impact on resolution: still limited by statistics, but noticeable





σ : 98 μm → 76 μm

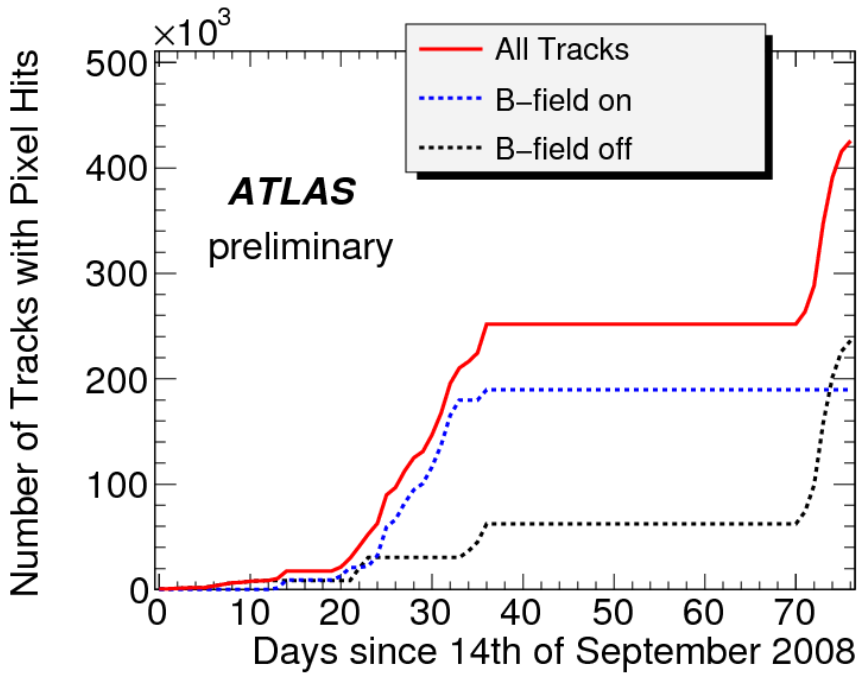


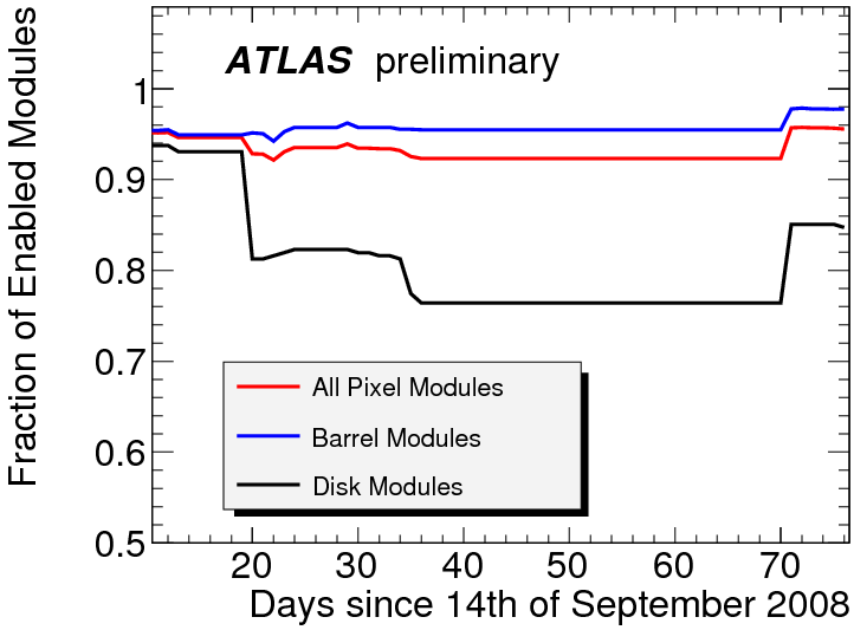
Tracks

- Track with 8 pixel hits on track (2 x 2hits in module overlap regions)
- Red: hits on track
- Green: isolated hits (noise)
- Noise occupancy:

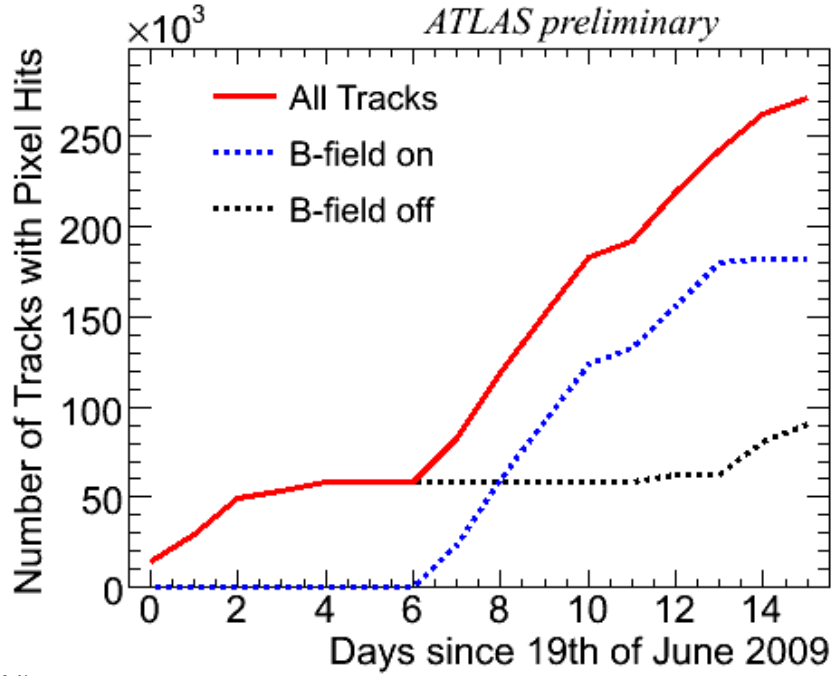
~ 10^{-10} hits/pixel/BC

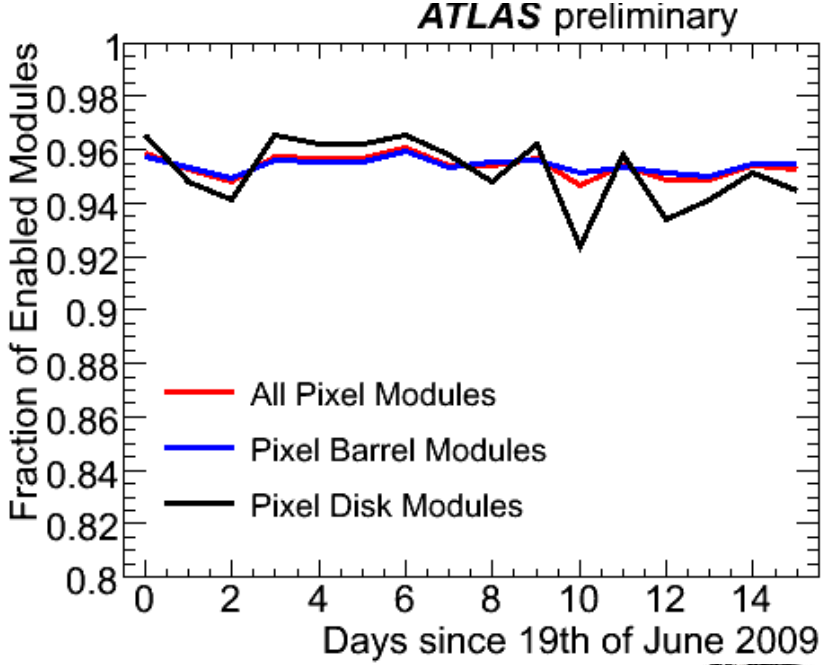
2008


×10^3
All Tracks
B–field on
B–field off
ATLAS
preliminary
Number of Tracks with Pixel Hits
Days since 14th of September 2008


ATLAS preliminary
All Pixel Modules
Barrel Modules
Disk Modules
Fraction of Enabled Modules
Days since 14th of September 2008

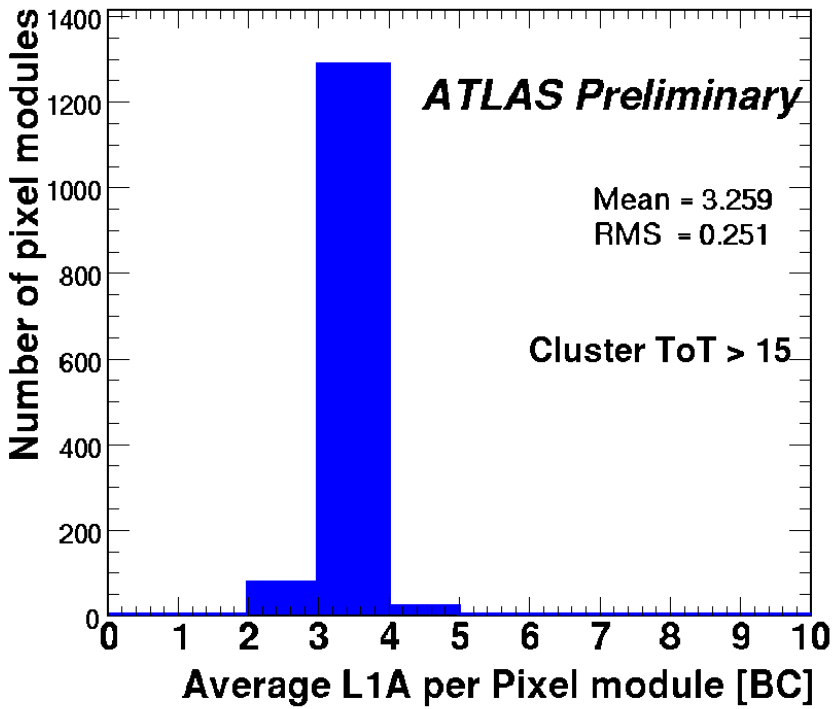
2009


ATLAS preliminary
×10^3
All Tracks
B-field on
B-field off
Number of Tracks with Pixel Hits
Days since 19th of June 2009


ATLAS preliminary
All Pixel Modules
Pixel Barrel Modules
Pixel Disk Modules
Fraction of Enabled Modules
Days since 19th of June 2009

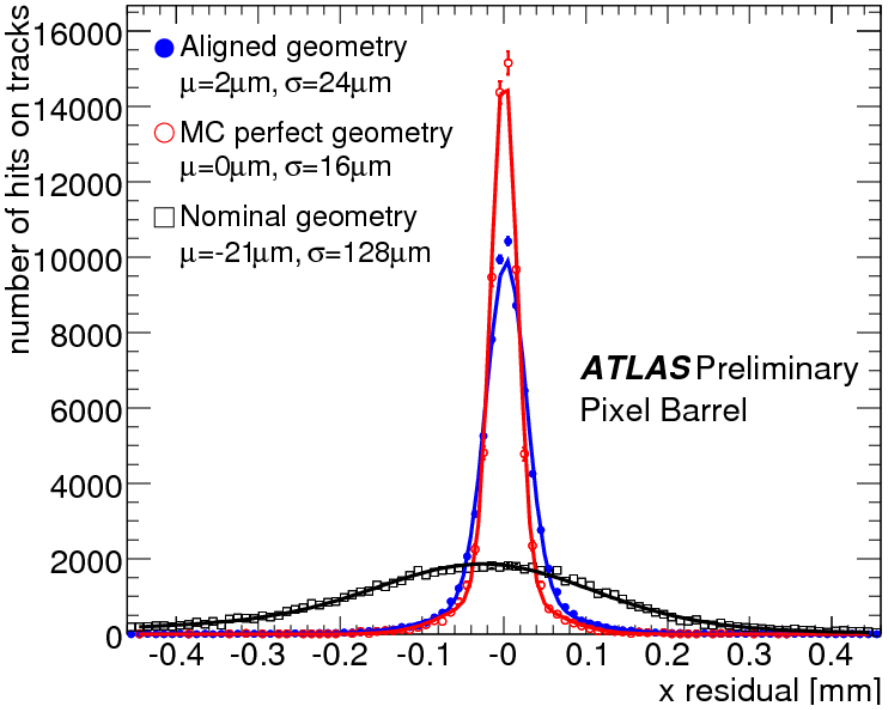
Timing

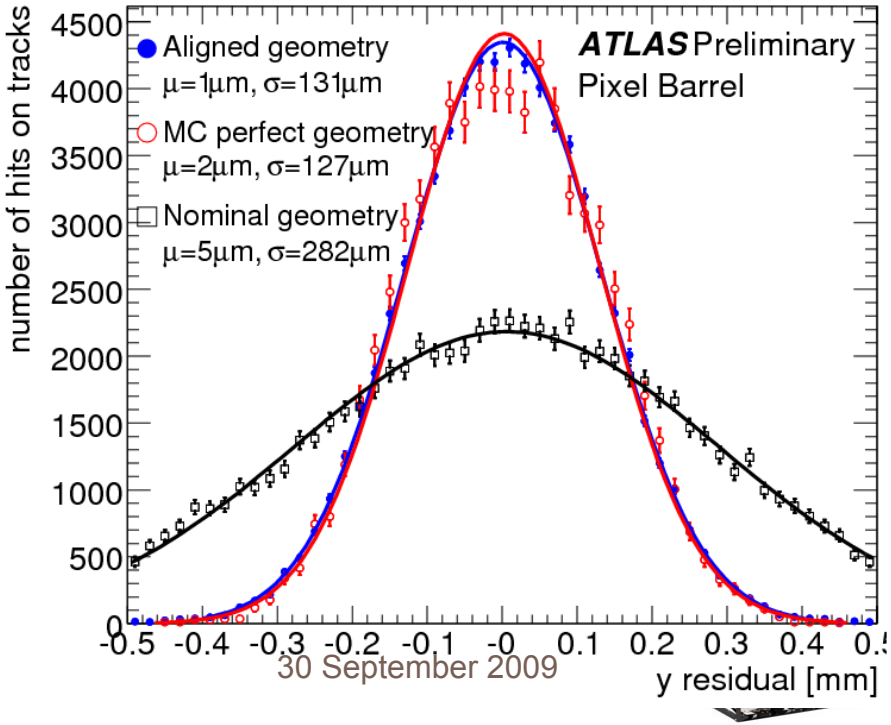
- Each hit has to be assigned to the correct bunch crossing (25 ns)
- Module clocks have to be precisely aligned with the bunch crossing clock
- In cosmic ray data taking: readout of 8 consecutive BCs (plot shows hit time w.r.t. beginning of readout window)
- Correction of propagation delays:
  - First step: time alignment of readout crates (oscilloscope measurements)
  - Second step: time alignment of modules (using cable length data)
- Remaining effects:
  - Trigger jitter
  - Random phase of cosmics
  - Timewalk; "in-time" for less than ~5000 e^-
- Plan to start data taking with 5 BC, later reduce readout window to 3 BC and 1 BC



Alignment

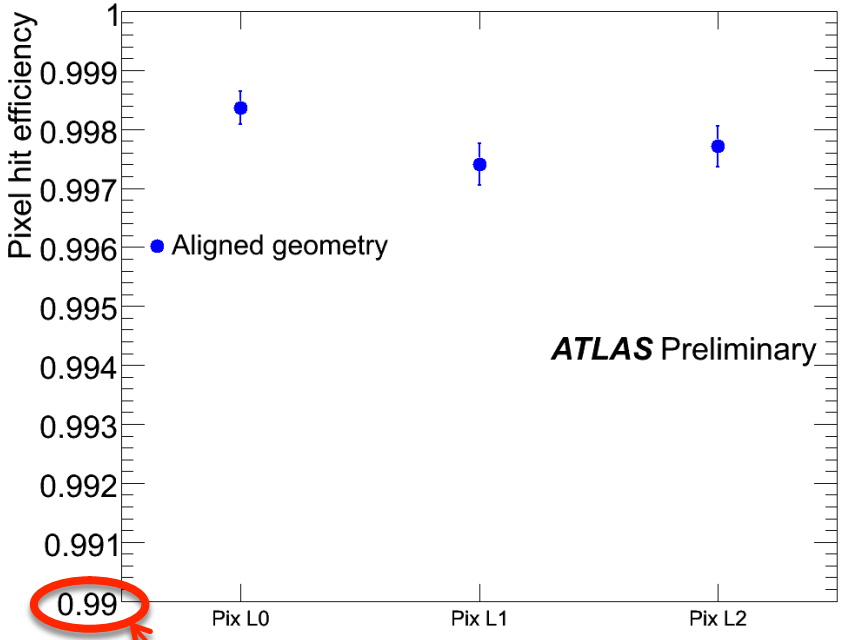
- Alignment of pixel barrel modules from cosmic data
  - Beam data needed for end-cap alignment
- Alignment not yet perfect due to limited statistics, but large improvement w.r.t. nominal geometry and good starting point for alignment with beam:
  - Precision direction: 128 µm → 24 µm
  - beam direction: 282 µm → 131 µm



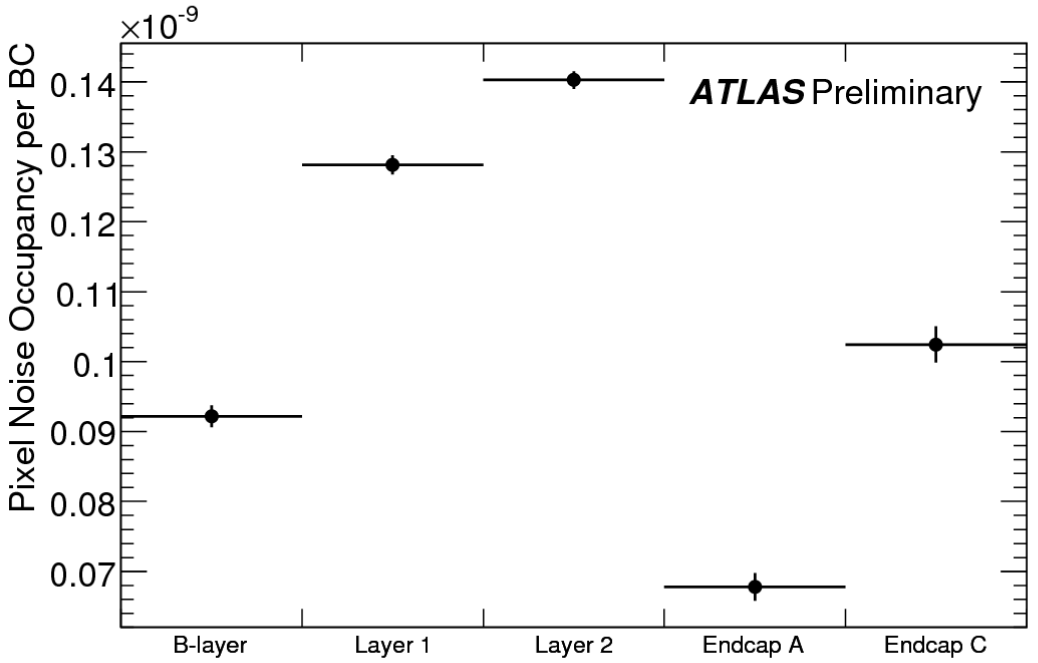


Efficiency and Noise Occupancy

- After alignment measured efficiency is > 99.7% for active modules
- Noise occupancy after masking of noisy pixels: ~ 10^{-10}
  - Fraction of masked pixels: 10^{-4}

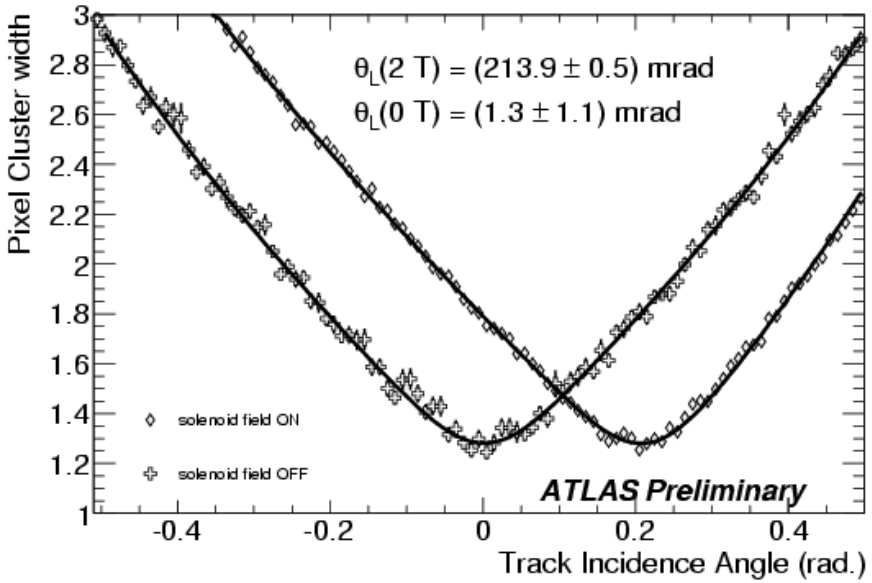


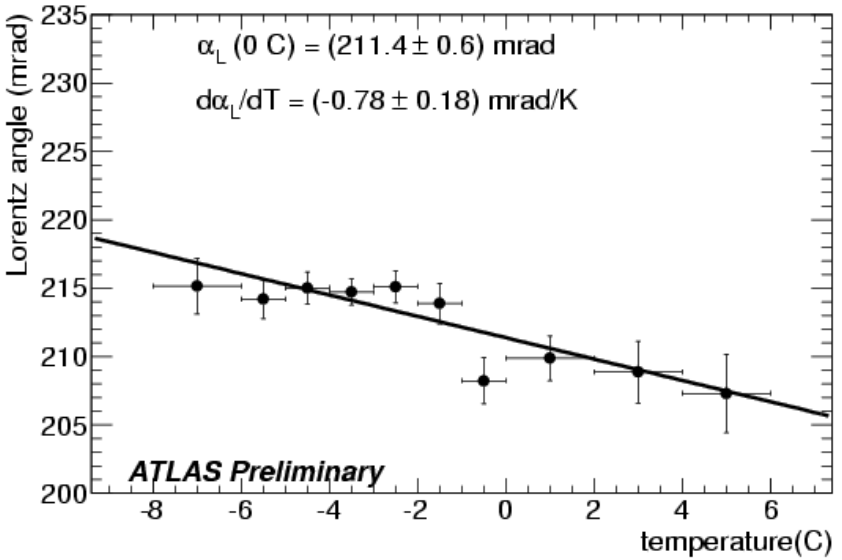
Zoom!



Lorentz Angle Measurement

- Cluster size vs. track angle with and without magnetic field → Measurement of the Lorentz angle
- Measured value close to expected value (225 mrad)
- Theoretically expected dependence on mobility can be nicely seen when including modules of different temperature
  - Measured: (-0.78 ± 0.18) mrad/K, expected: -0.74 mrad/K





Status and expectations

- The ATLAS Pixel Detector has been commissioned in a relatively short time
- Noise ~ 200 e^-, threshold tuned at 4000 e^- with a dispersion ~ 40 e^-, m.i.p. signal at ~19000 e^-
- The cosmic data taking has been extremely useful
  - Timing already in good shape: plan to reduce the readout window rapidly
  - Resolution ~ 24 μm in the precision direction, efficiency > 99.7 %
  - Noise occupancy ~ 10^{-10}, 10^{-4} fraction of masked pixels
- Many Pixel notes and a summary article in preparation
- Starting from this year all cooling loops are operated
  - Modest amount of coolant leak: studying the effects under irradiation
- 1.6 % of the detector is not functional due to on-detector failures
- Tuning at lower thresholds for beam related studies

The Pixel Detector with ≥ 98% working modules is ready for LHC