Commissioning of the ATLAS Pixel Detector and performance with first data

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on behalf of the ATLAS Collaboration

12th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD10)

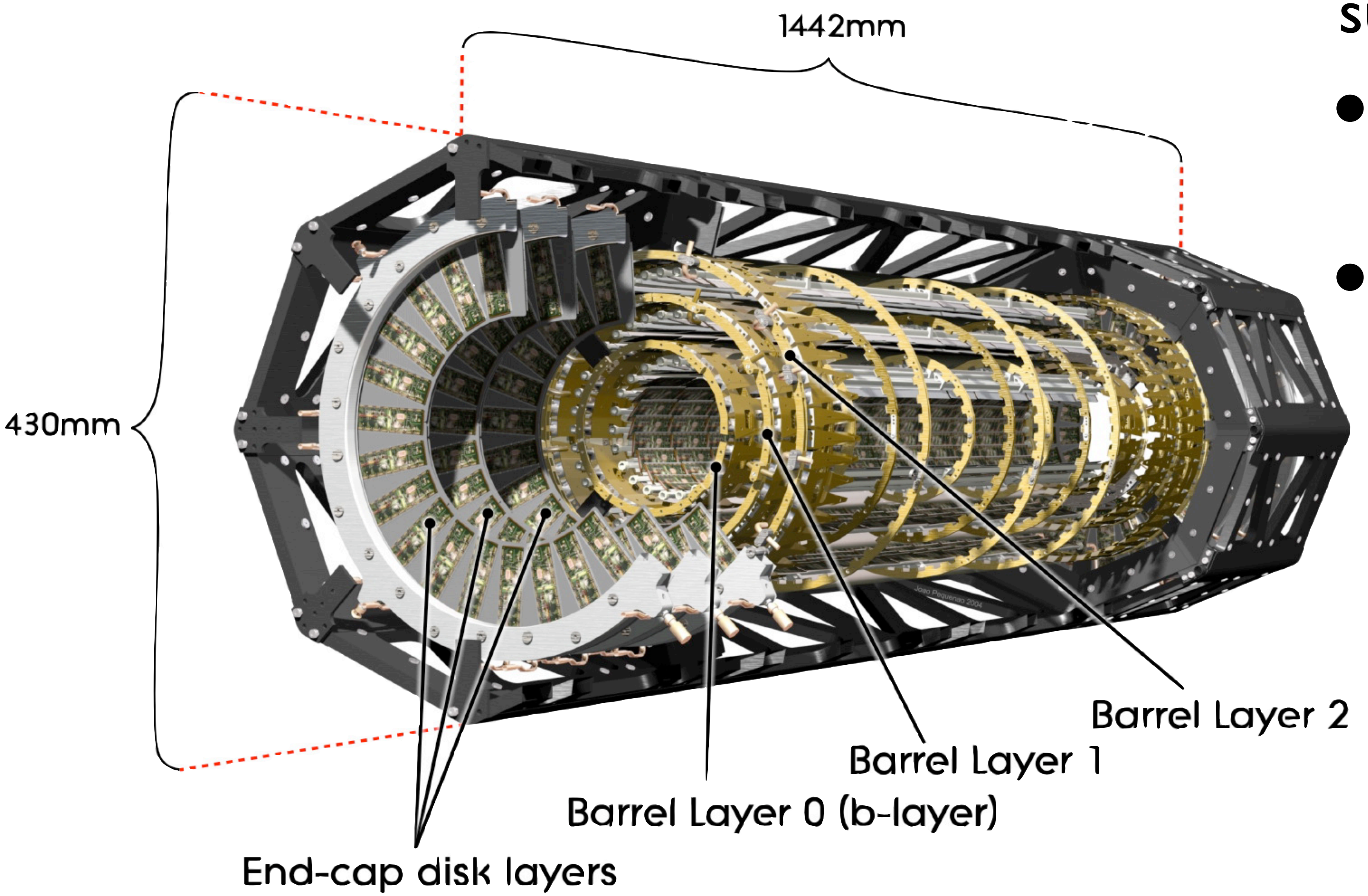
ATLAS EXPERIMENT
http://atlas.ch

Outline

- The Pixel Detector at the ATLAS experiment
- Commissioning & present status
- Read-out optimization
- Clustering studies & resolution optimization
- Experience with first data

The ATLAS Pixel Detector

- Three Barrel Layers:
  - Partially overlapping staves (13 modules)
- 2 End-caps (3 disk layers):
  - disk sectors (6 modules/sector)

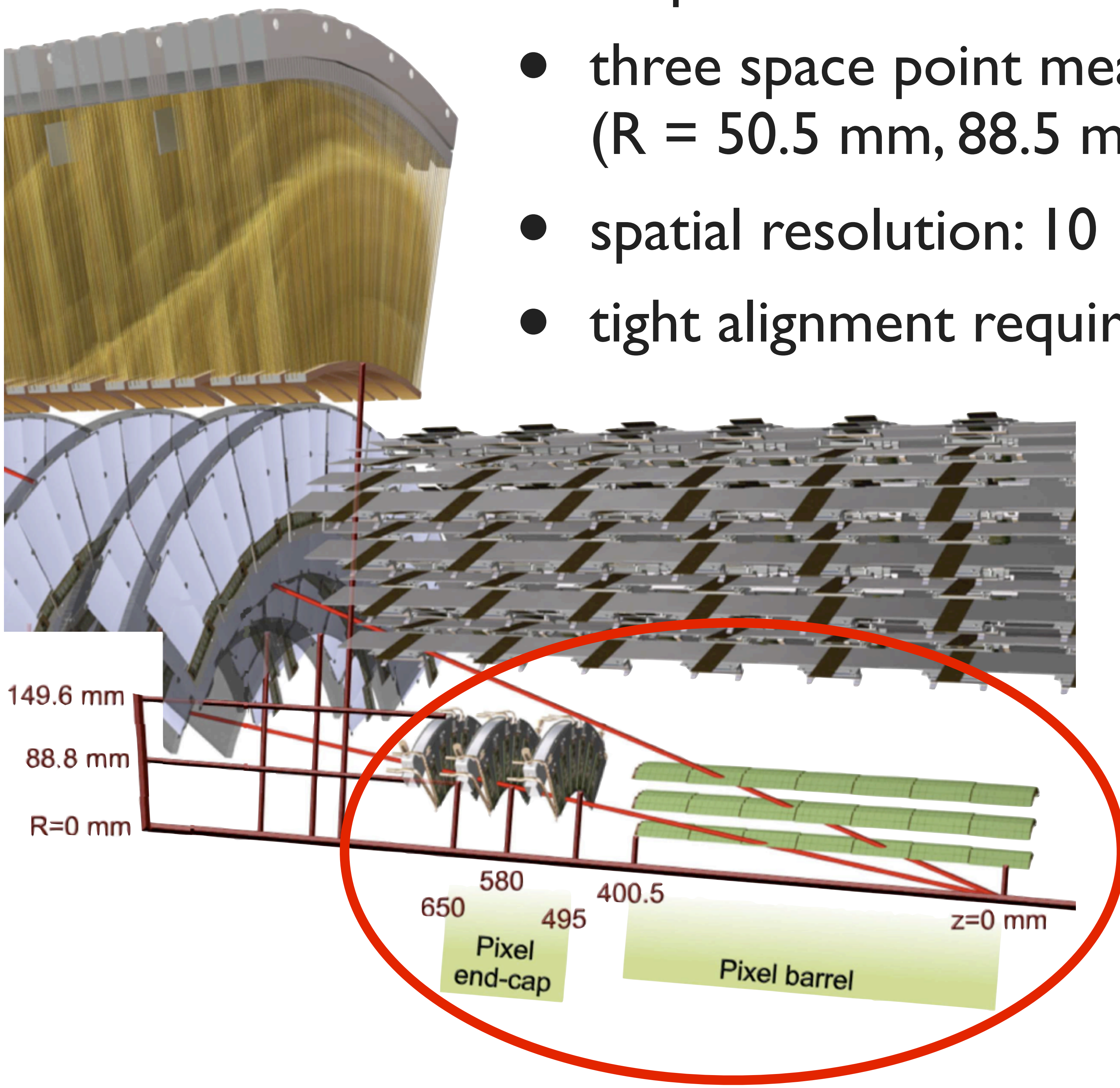


- Low mass carbon-fiber support structure:
  - integrated bi-phase cooling system
  - ~3% of X_0 from each layer structure

80 million pixels
1.7 m^2 surface

The ATLAS Pixel Detector

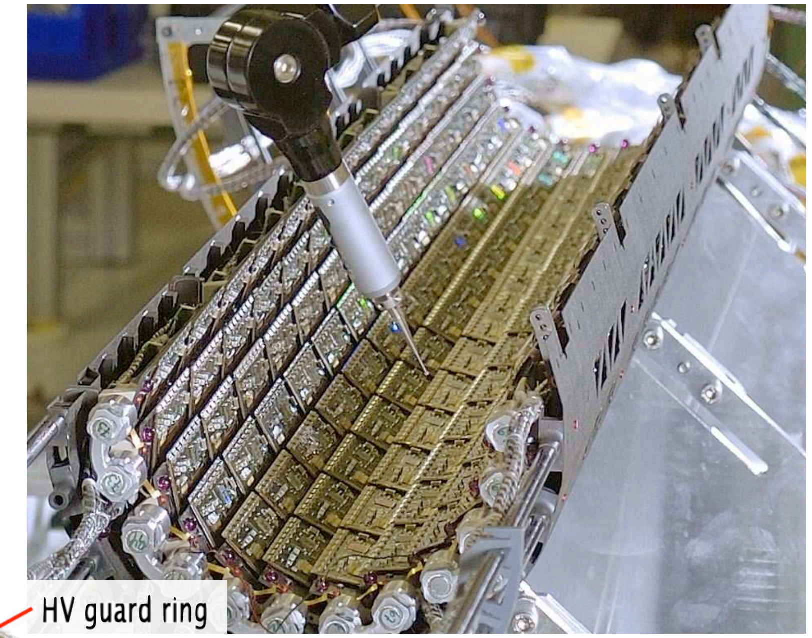
- Inner part of the ATLAS tracking system:
  - three space point measurements per track (R = 50.5 mm, 88.5 mm, 122.5 mm for the barrel)
  - spatial resolution: 10 μm (RΦ), 115 μm (z or R)
  - tight alignment requirements (see next talk!)

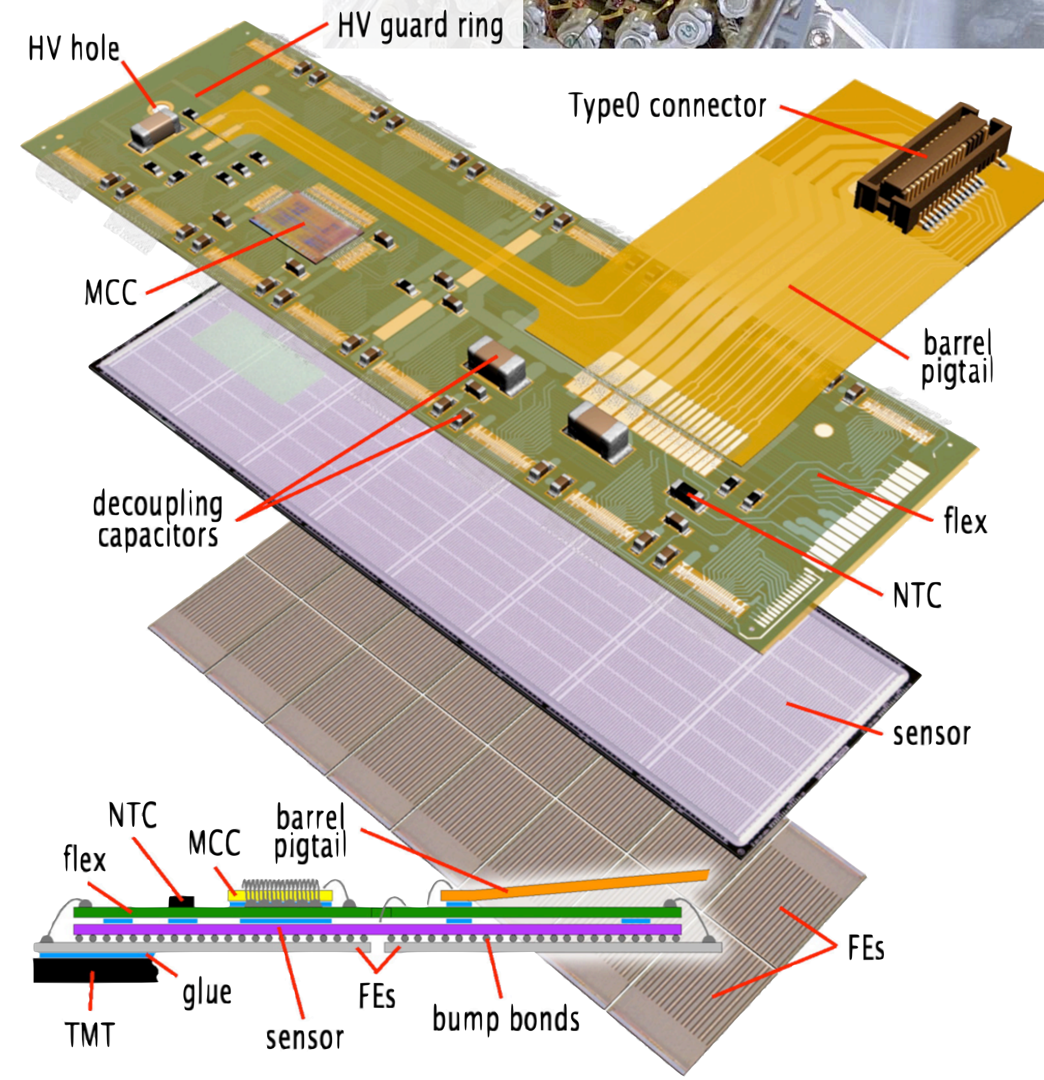


- radiation resistance: 500 Gy dose, 10^{15} n_{eq} cm^{-2} fluence (5 years at 10^{34} $cm^{-2}s^{-1}$ luminosity for b-Layer)
- read-out clock: 25 ns, 0.3 ns adjustment per module

Pixel Detector Module

- Sensor:
  - 47 232 pixels (typically 50 x 400 μm^2) short side in RΦ direction
  - 250 μm thickness, 150 V bias voltage
- 16 readout Front End chips (see in the following)
- Flexible Kapton PCB:
  - Passive components
  - Module Controller Chip
    - FE configuration
    - Trigger Timing & Control
    - Basic event building





History of Pixel Detector

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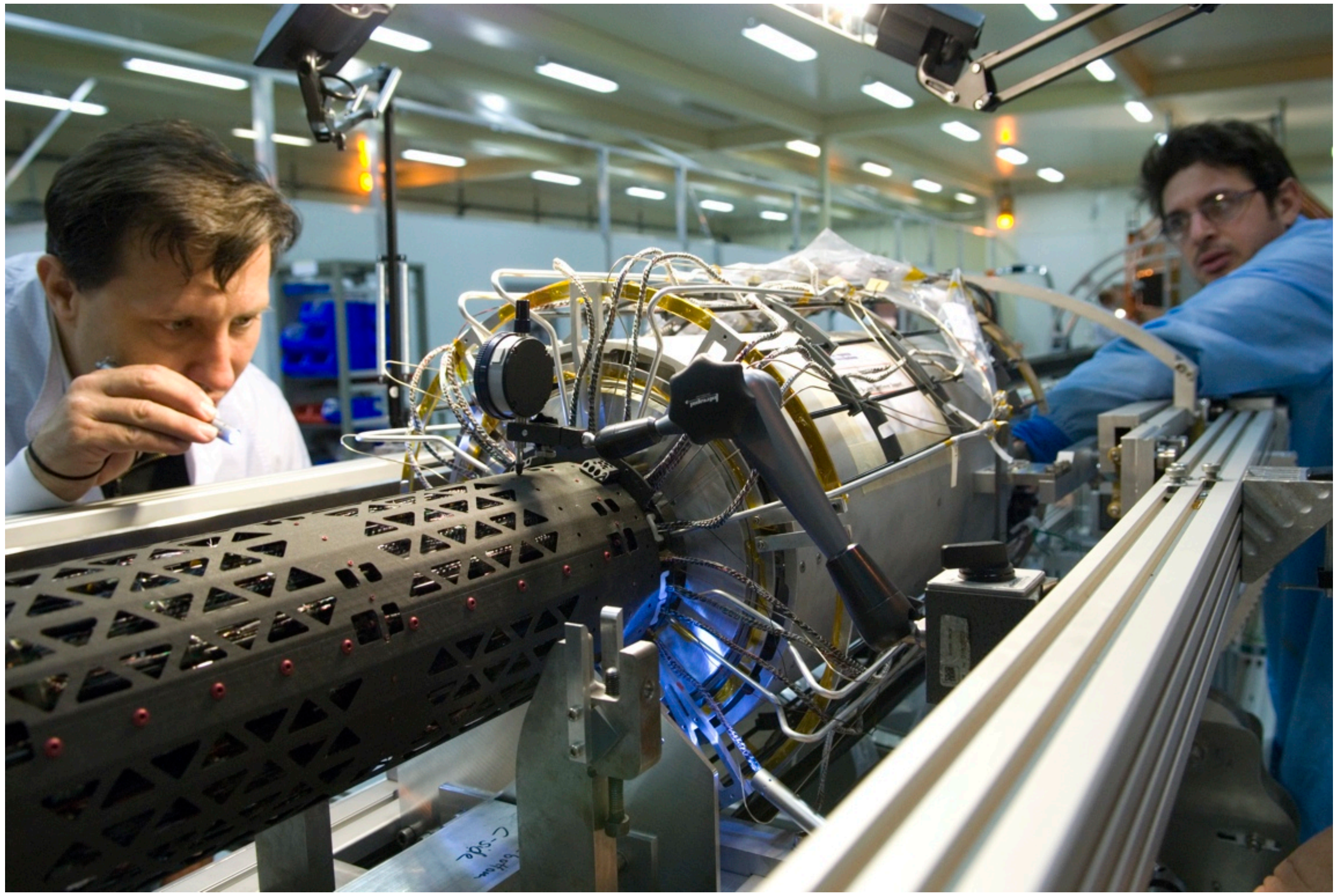
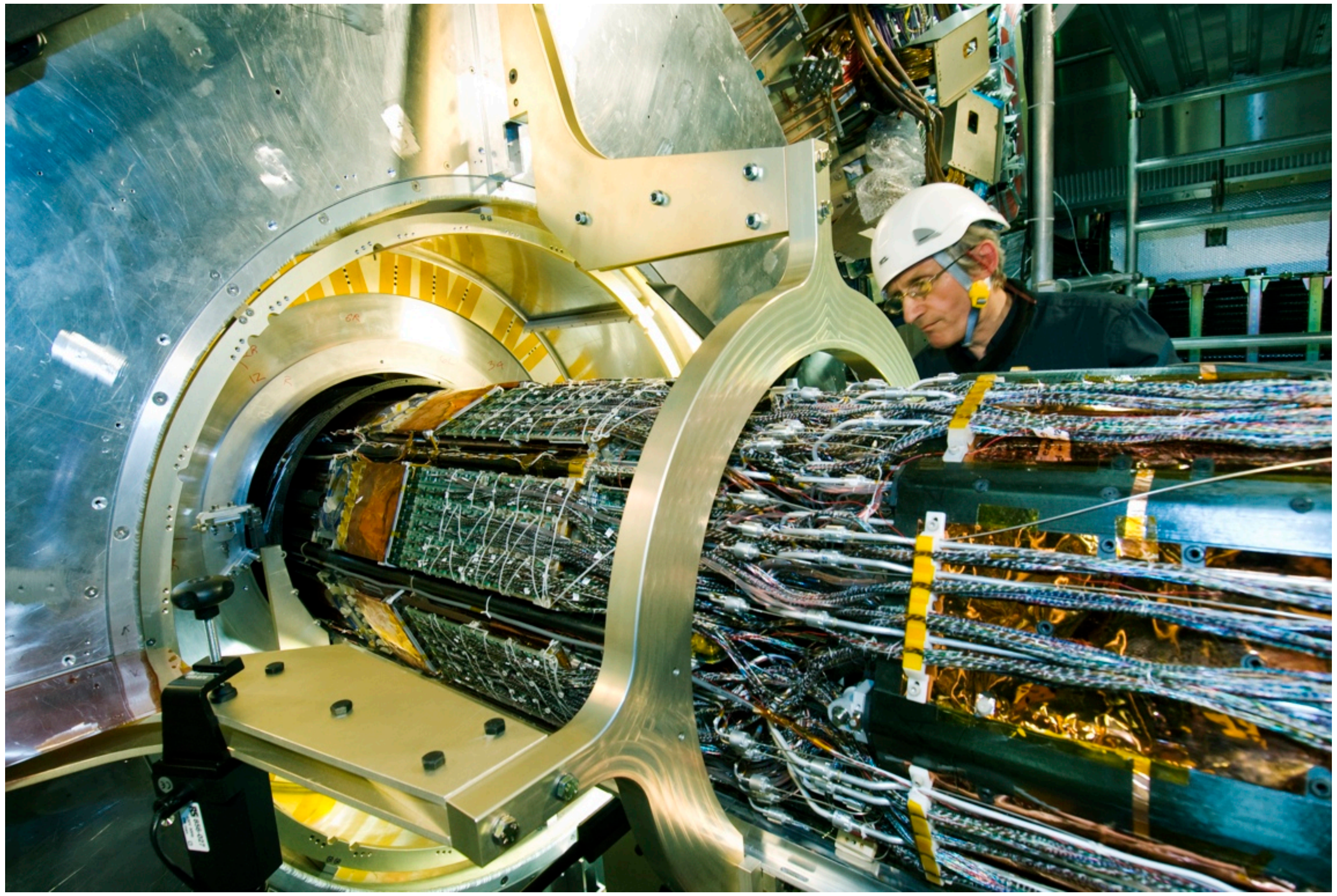
- Assembly
  - Started in 2006



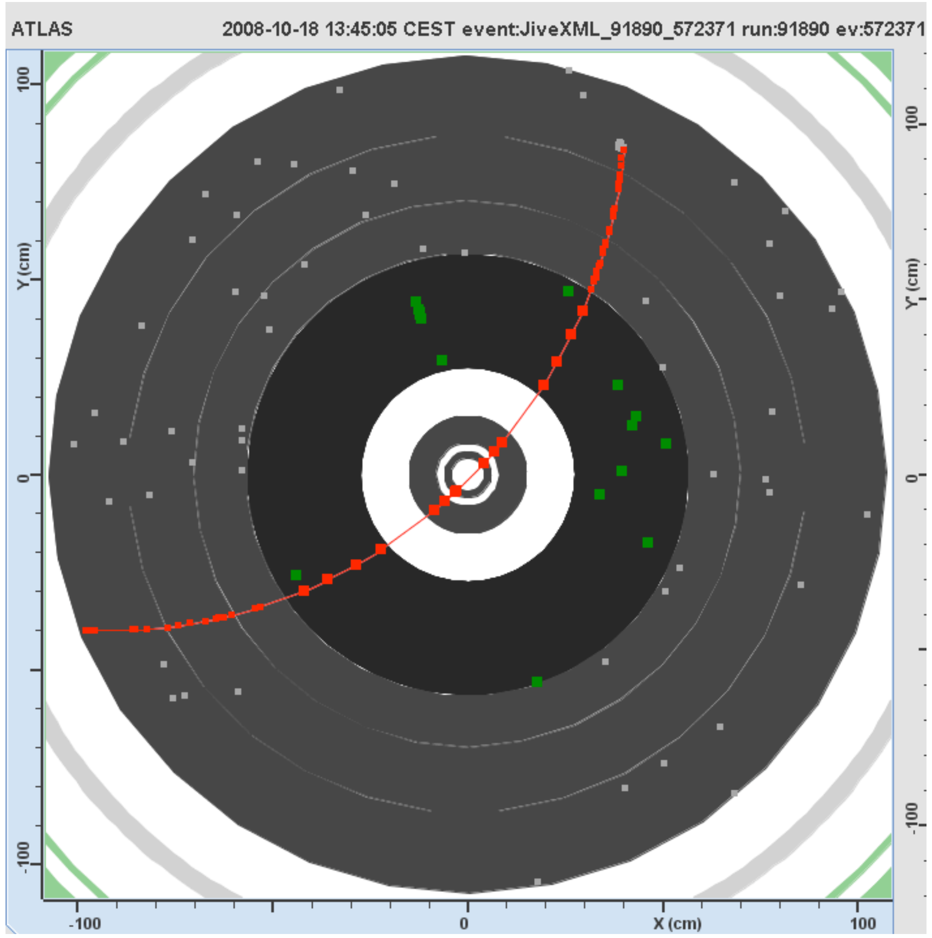
History of Pixel Detector

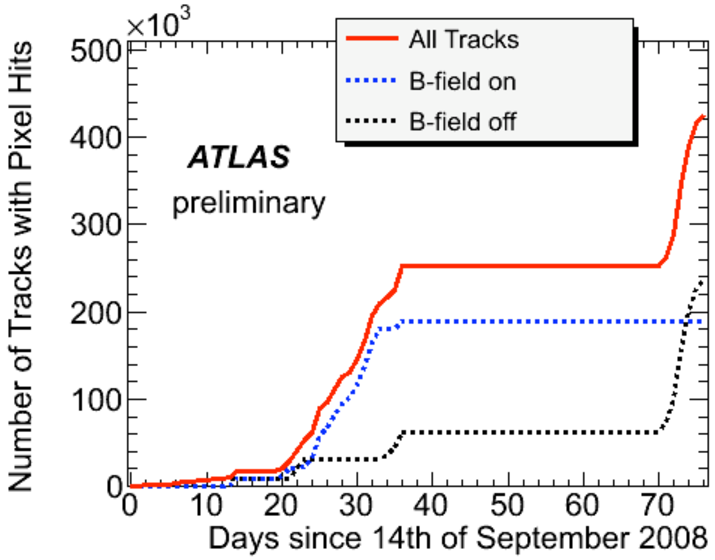
- Assembly
  - Started in 2006
- Installation
  - June 2007

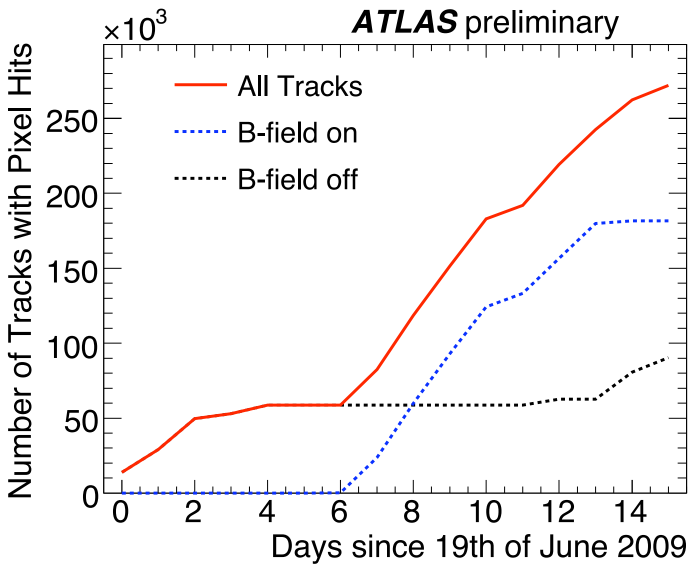


History of Pixel Detector

- Assembly
  - Started in 2006
- Installation
  - June 2007
- Cosmic ray data taking
  - 2008 -- 2009

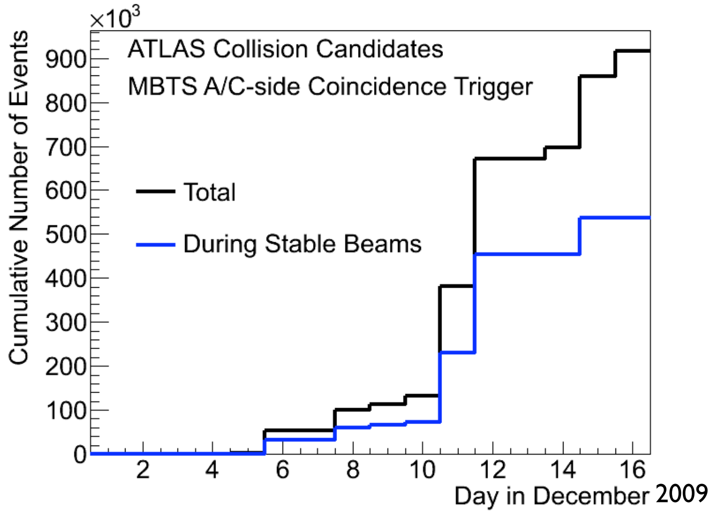


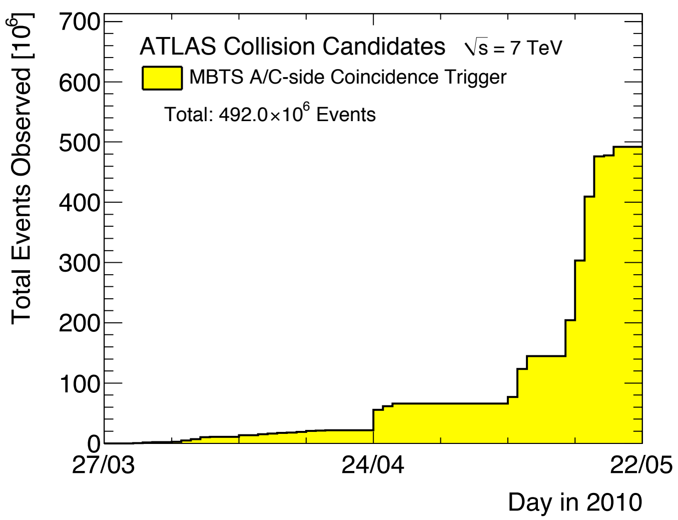


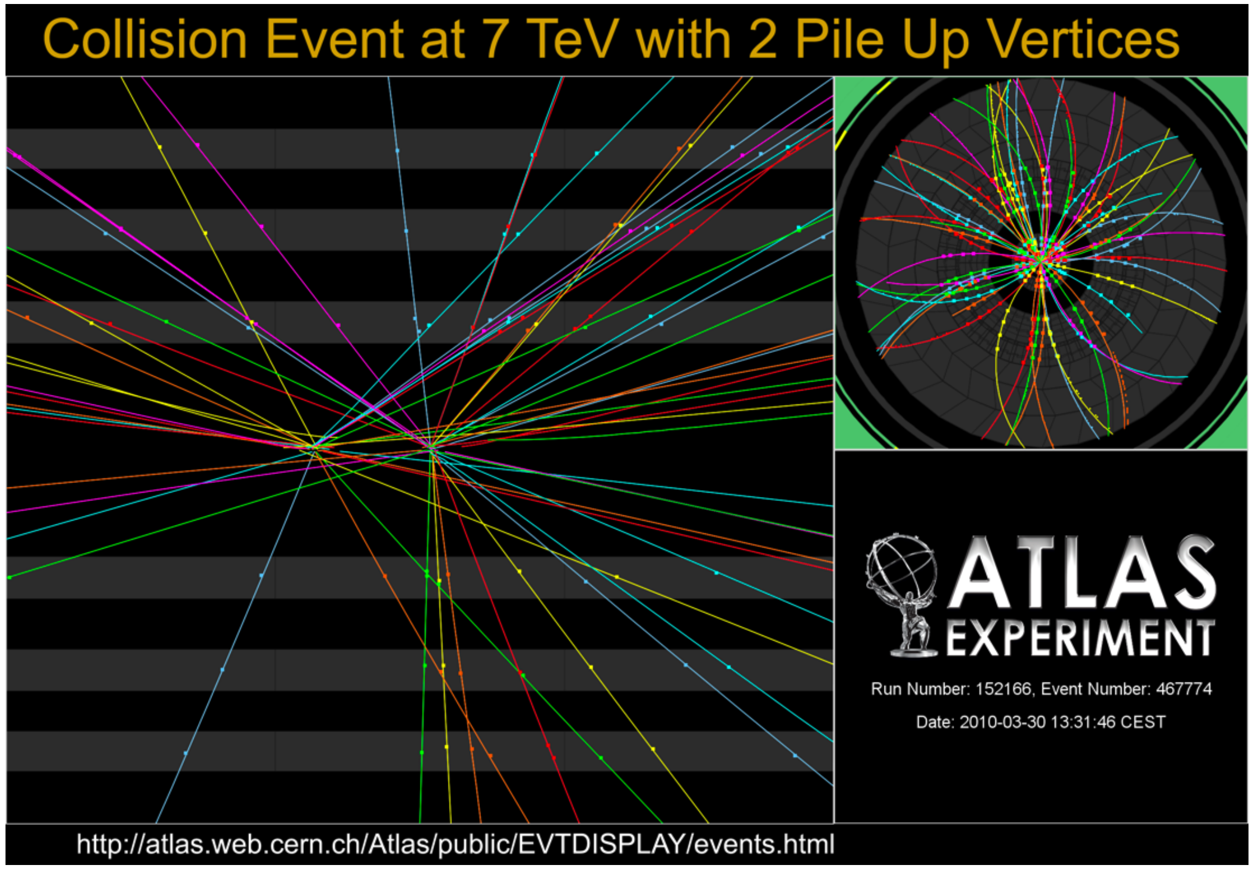


History of Pixel Detector

- Assembly
  - Started in 2006
- Installation
  - June 2007
- Cosmic ray data taking
  - 2008 -- 2009
- Collisions
  - since Nov. 2009







Present situation

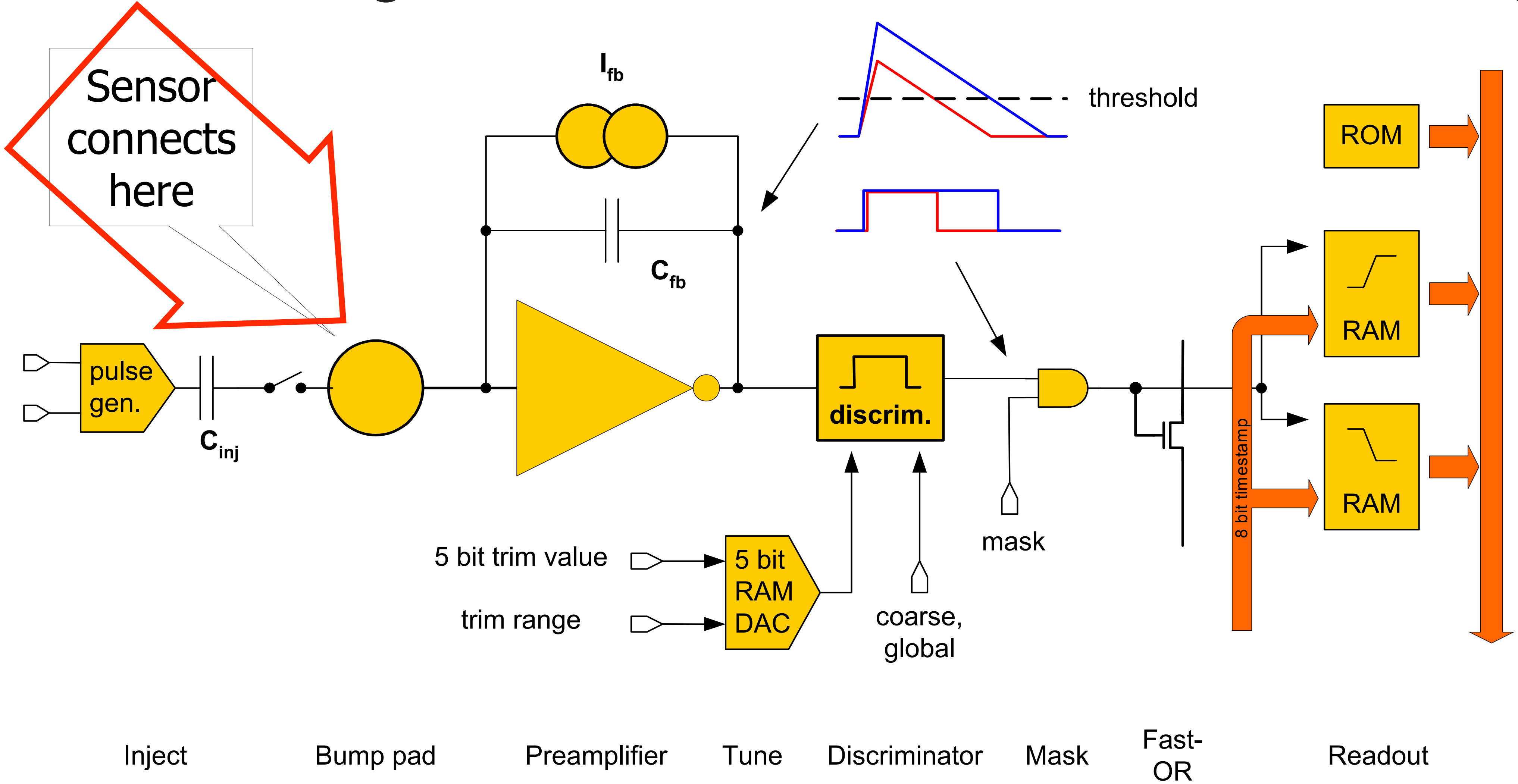
- Pixel Detector integrated in ATLAS data taking
  - special procedures to turn detector ON/OFF
  - Operational: 92.5% of the "stable beam" period
- Intrinsic efficiency: 99.974%
  - measured with cosmic ray data
  - inefficiency mainly due to defective channels known since construction
- Few operational failures

Affected system	Type	Total	Failures	%
Type-0 cables	High Voltage	1744	16	0.92%
	Low voltage		2	0.11%
	Clock		2	0.11%
Opto-boards	Dead board	272	1	0.37%
Modules (optical transmission?)	No data	1744	10	0.57%
	No clock		7	0.40%
	Scan fail		2	0.11%
	No configuration		1	0.06%
TOTAL	**Modules**	**1744**	**46**	**2.64%**

Only 6 in b-Layer

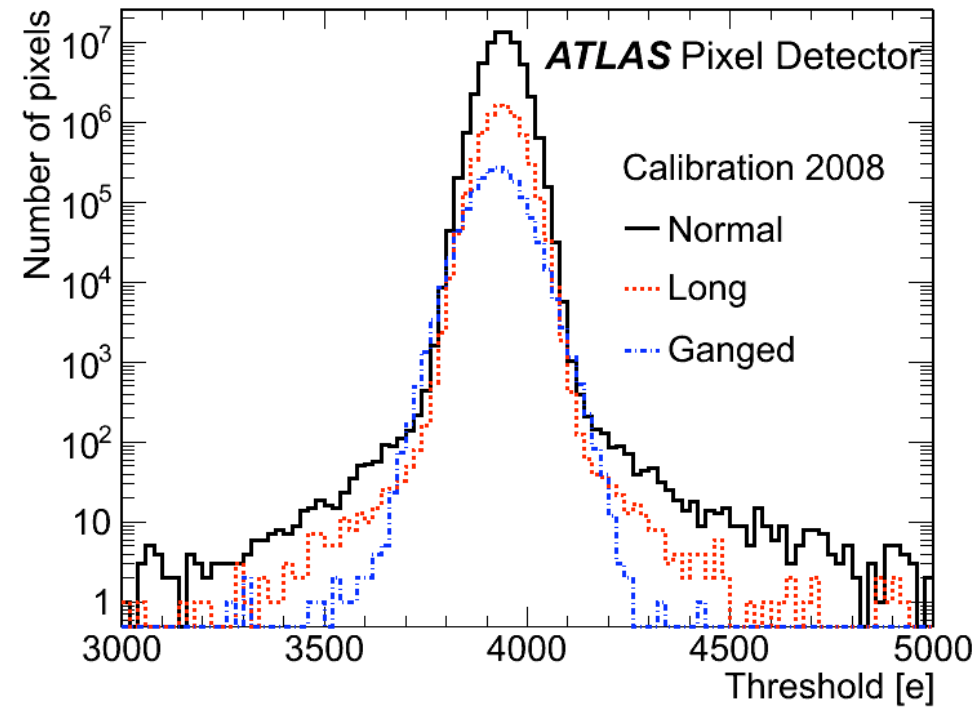
Front End chip

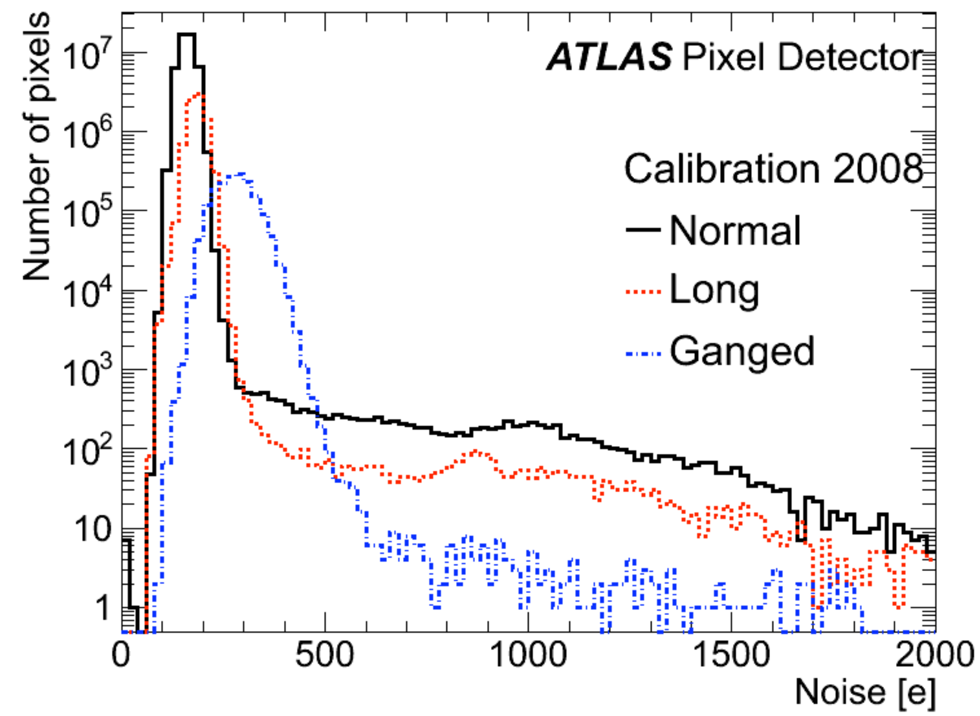
- Constant current feedback:
  - high stability, fast shaping
  - linear decay
  - 100 nA leakage tolerance
- Individual configuration of:
  - Threshold (7-bit DAC)
  - Feedback current (3-bit DAC)
  - Readout or masking



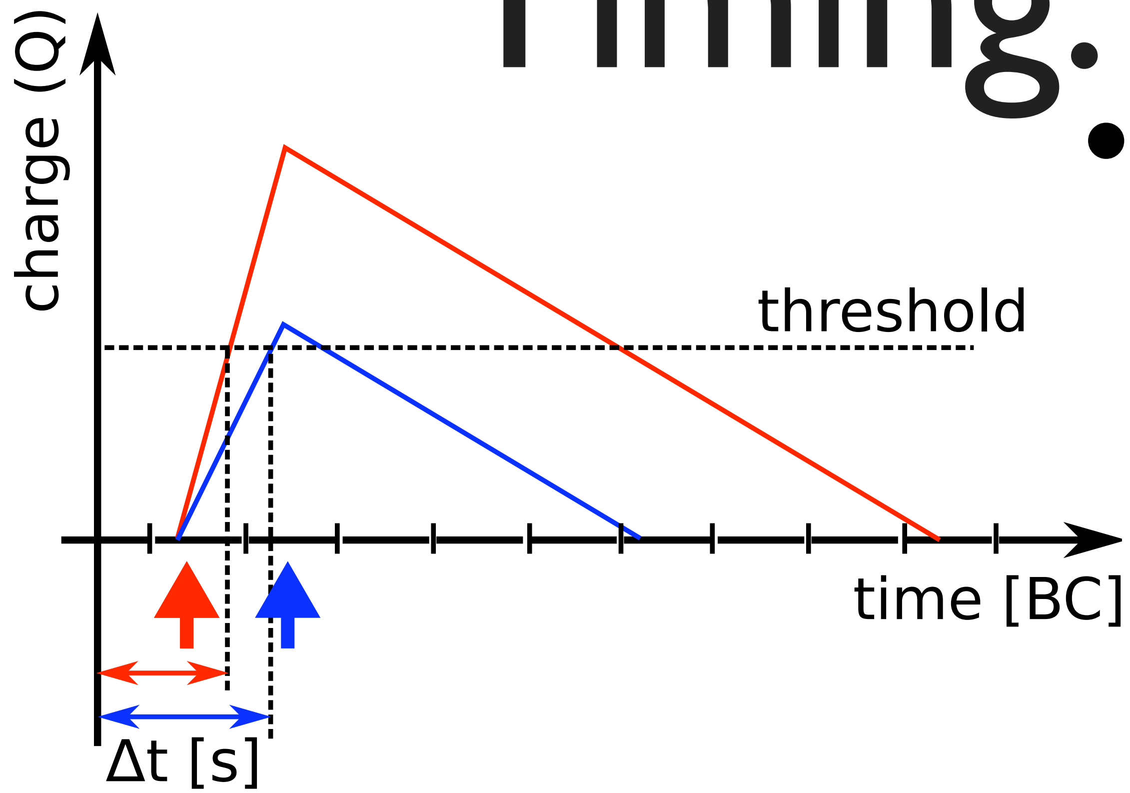
Threshold calibration

- Threshold is optimized for each FE and trimmed for each pixel:
  - 4000 e (used until 2009)
  - 3500 e (tested in 2009, used in 2010 data taking)
  - uniformity: 40 e (RMS) 4×10^{-5} of pixels in the tails (6σ)
- Noise is typically 200 e (1.3×10^{-4} of pixels with > 600 e)
- Threshold / noise for 4000 e threshold:
  - ~ 25 for normal pixels.
  - ~ 10 for ganged pixels

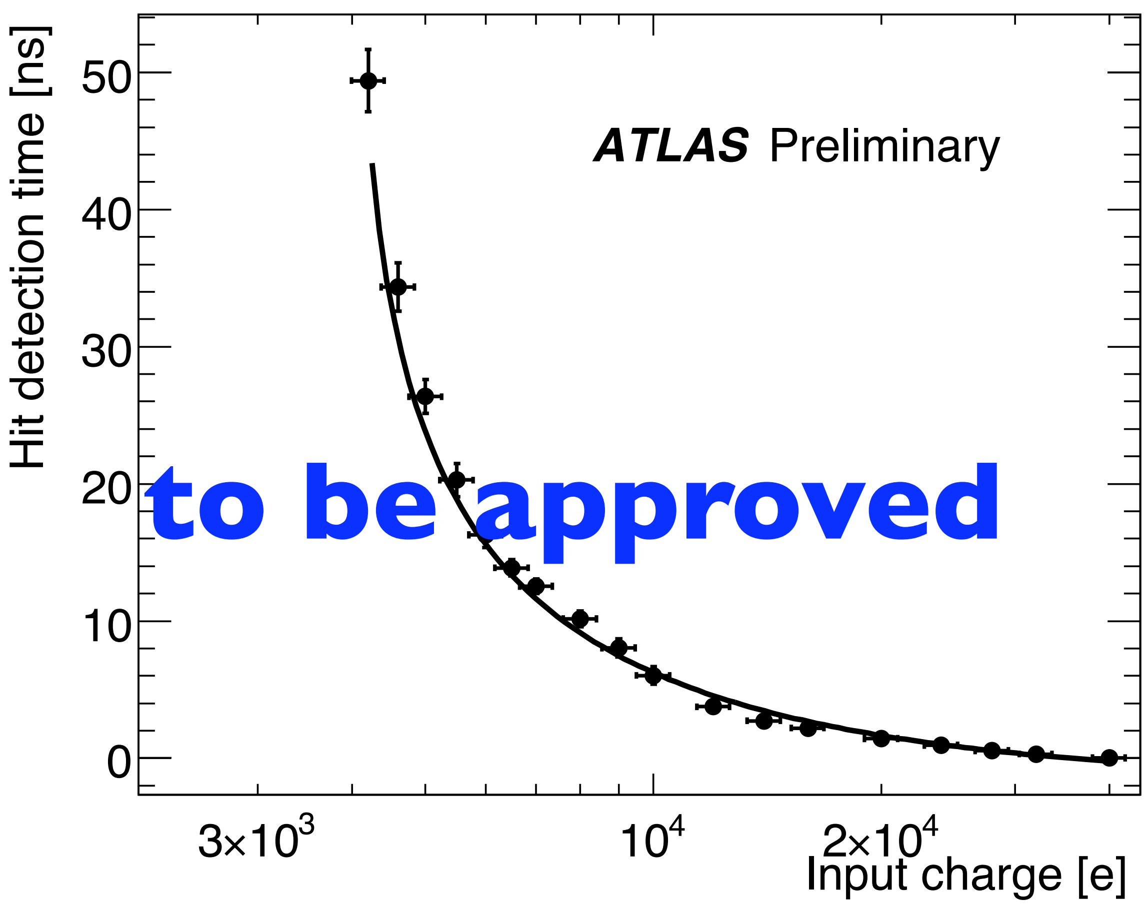




Timing: time-walk

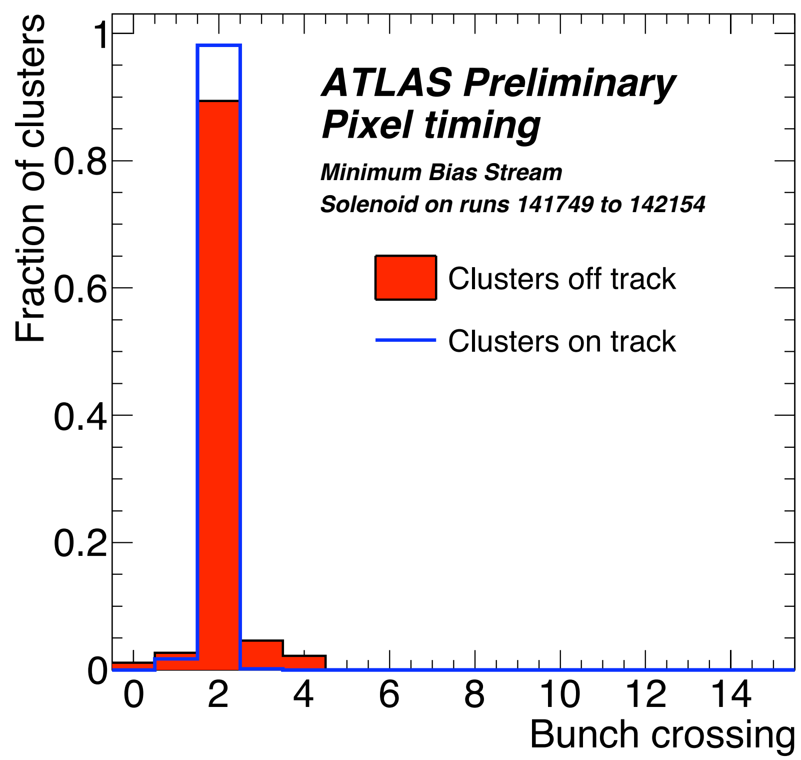


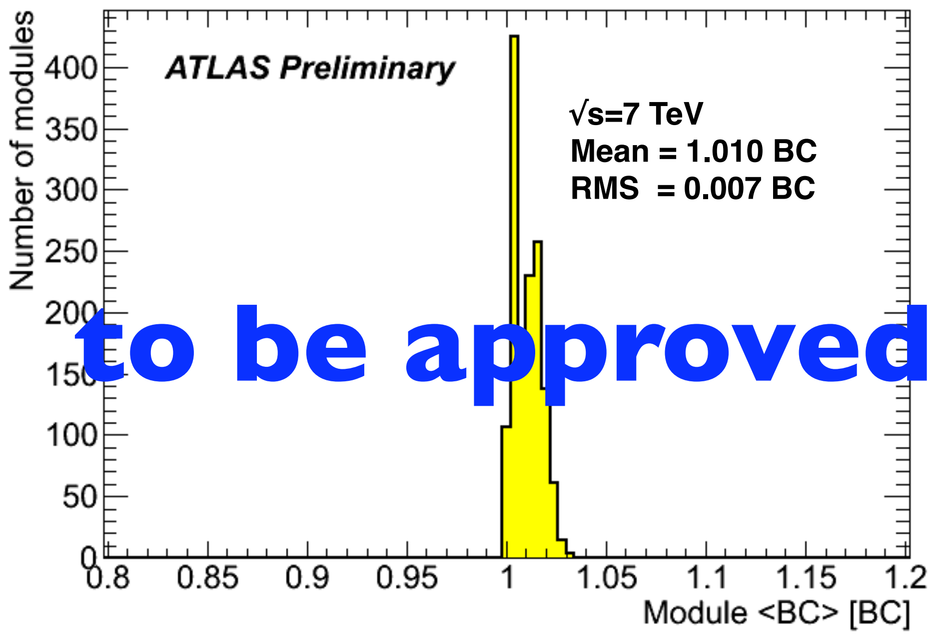
- Due to the delay with which it exceeds the threshold, a hit can be associate to the correct BC or to the following one (time-walk):
  - time-walk depends on hit charge
  - measured with charge injection: $\Delta t = p_0 - p_1 \ln(1 - \text{Threshold} / Q)$



- The minimal signal needed to have correct hit-BC assignment is the in-time threshold
  - 4870 e for 3500 e threshold, independent on pixel type
  - dispersion comparable with the electronic noise (158 e)

Timing: read-out window

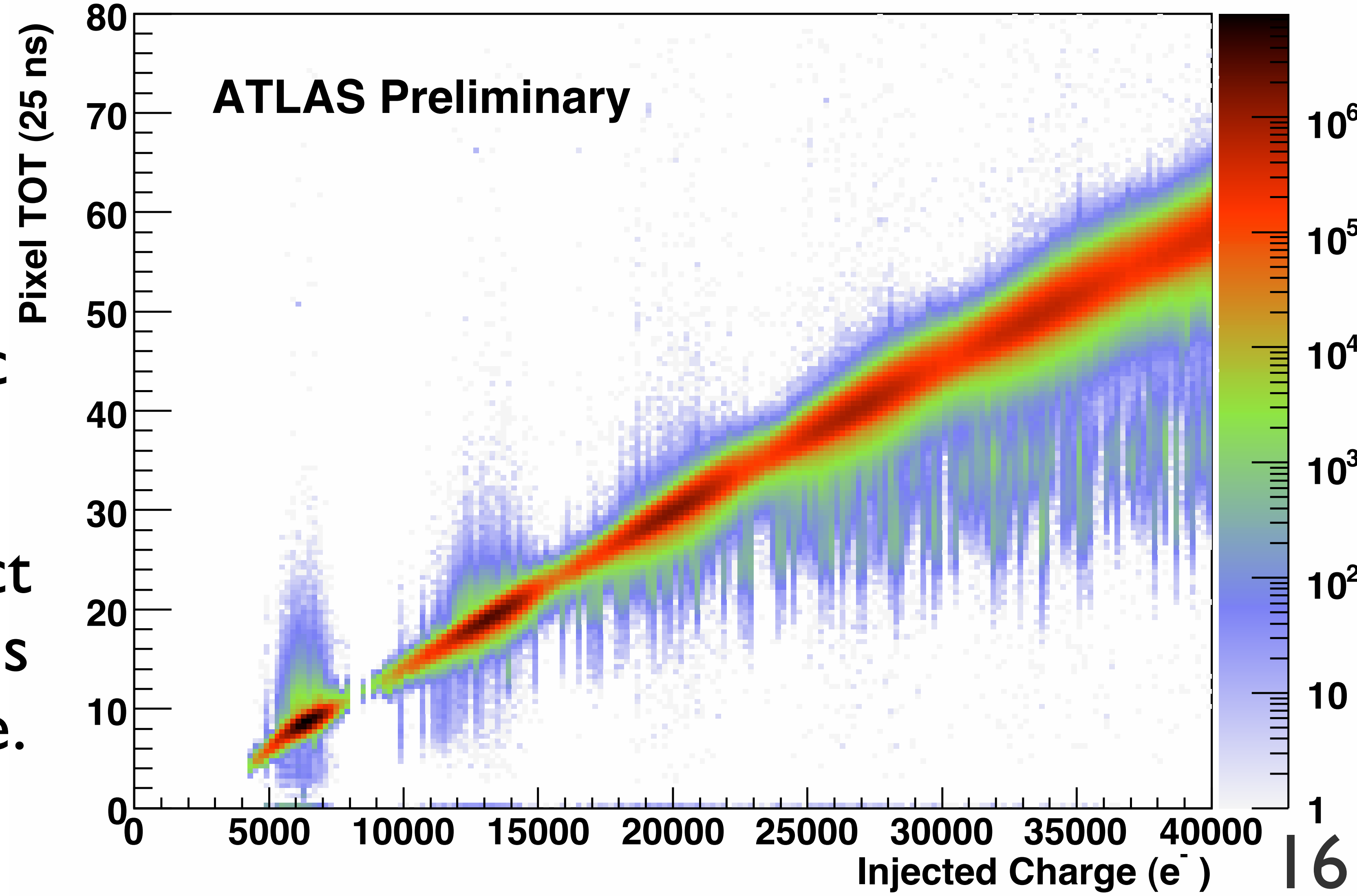




- Optimization of readout window:
  - 5 bunch crossings for low luminosity
  - 3 bunch crossings in 2010 (99.95% efficient for hits on track):
- Clusters out of main BC due to low charge deposit near the edge of the active region or to fakes in the region between two front-end chips (ganged pixels).
- Most of non-associated clusters due to low momentum particles not reconstructed.
- Module synchronization assessed by measuring the average bunch crossing <BC> for high charge single-pixel clusters.

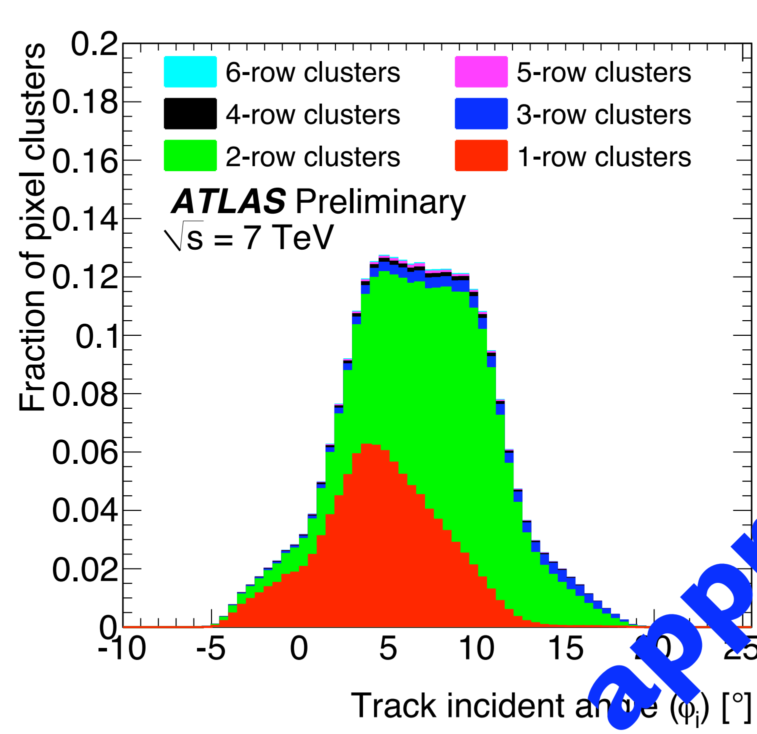
Time-over- Threshold

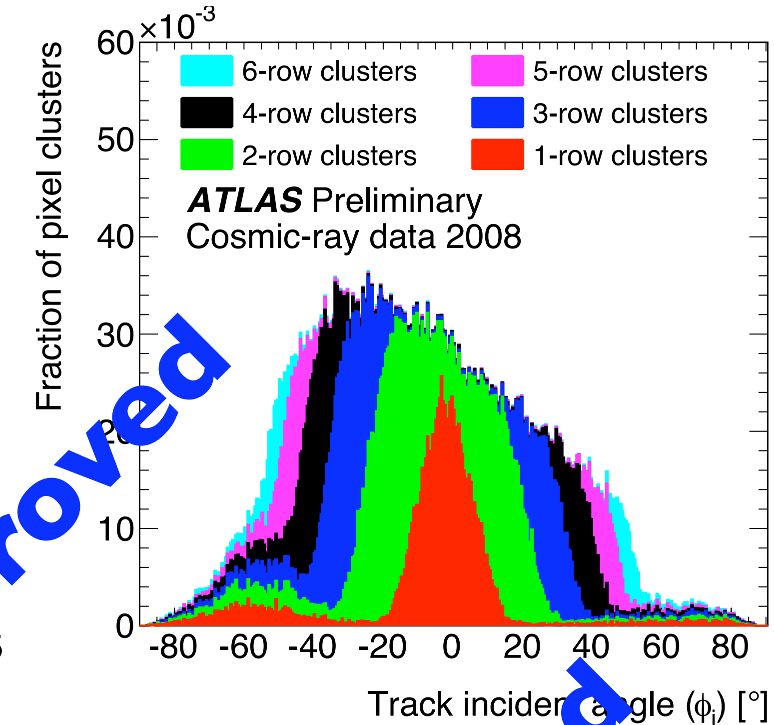
- Charge released in each pixel is measured by ToT, in BC units:
  - Minimum Ionizing Particle signal: 20 ke
  - Feedback current tuning: ToT_{MIP} = 30 BC
- ToT resolution measured for each FE:
  - $\sigma_{ToT} = p_1 + p_2 \times ToT$ typically ~ 1 BC (660 e) for M.I.Ps
  - larger than electronic noise
  - negligible with respect to Landau fluctuations on the charge release.

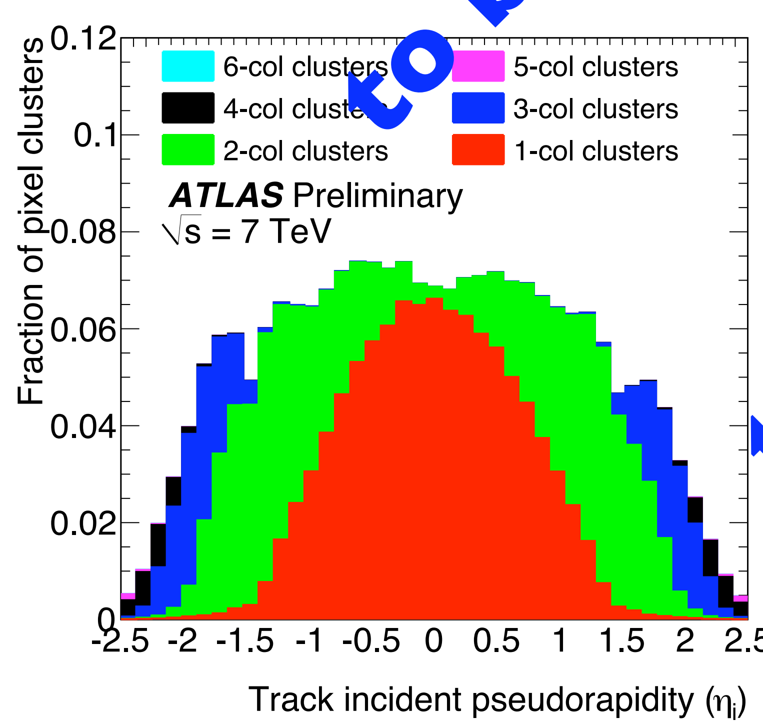


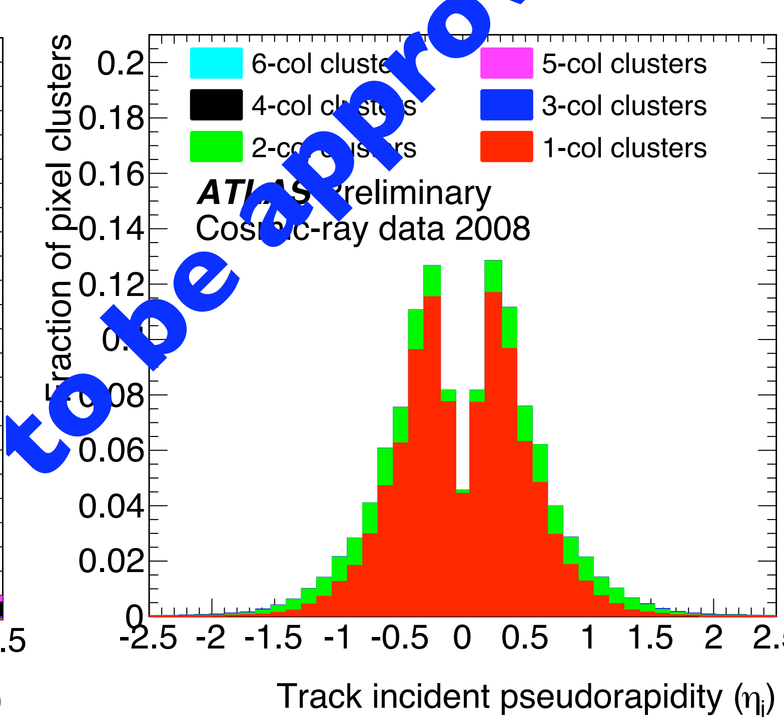
Hit cluster studies

- Cluster properties (size) depends on:
  - particle incident angle w.r.t. module surface.
  - readout threshold
- Different features visible in cosmic ray and collision data:
  - Lorentz angle
  - Noise suppression
  - Position resolution



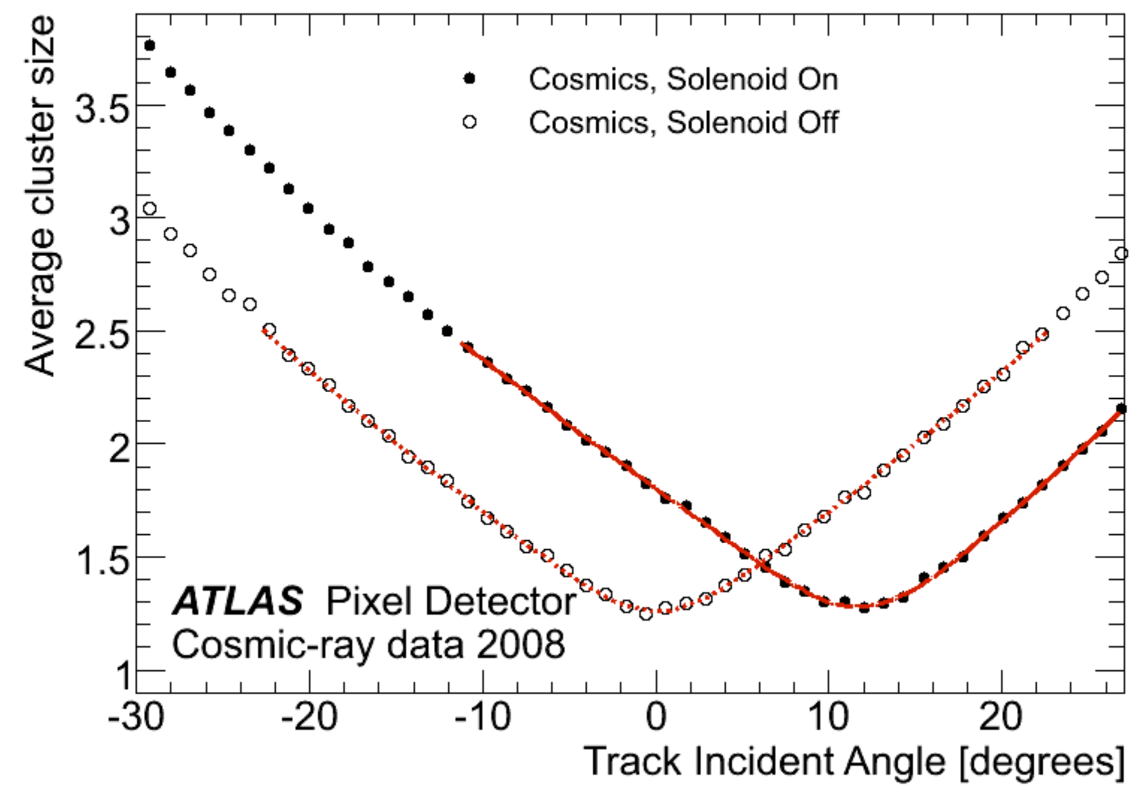


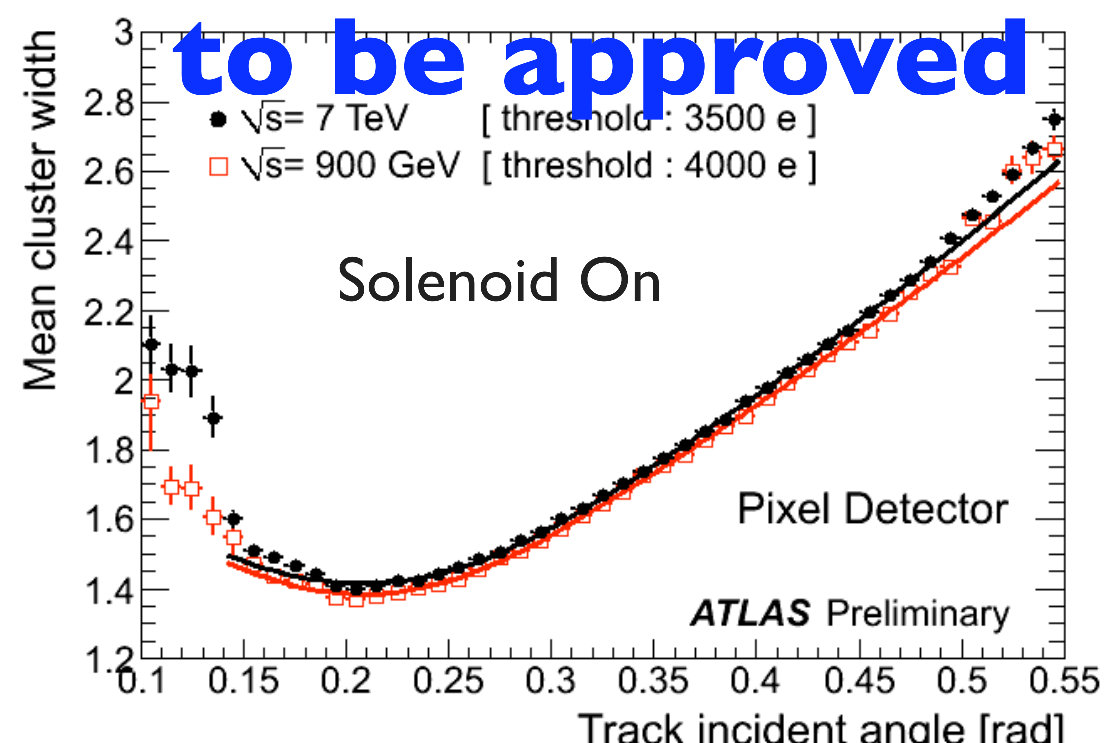




Lorentz angle

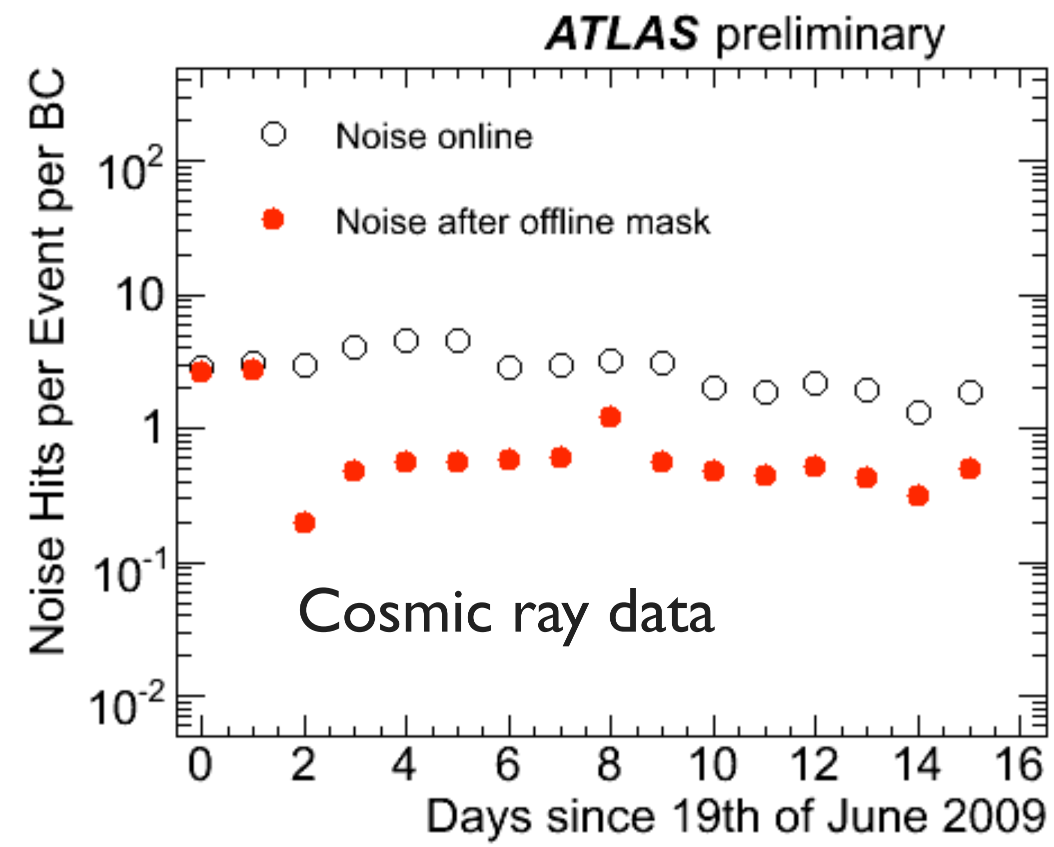
- Charge carriers drift with an angle with respect to the normal to the sensor surface (2 T solenoidal magnetic field in ATLAS tracker)
  - used for particle crossing point estimation (~30 µm correction)
  - measured as the particle incident angle at which cluster size is minimum
- Lorentz angle was measured in each phase of commissioning:
  - cosmic ray data: 11.77° ± 0.03° full study of systematics
  - collision data (3500 e): 12.1° ± 0.09°

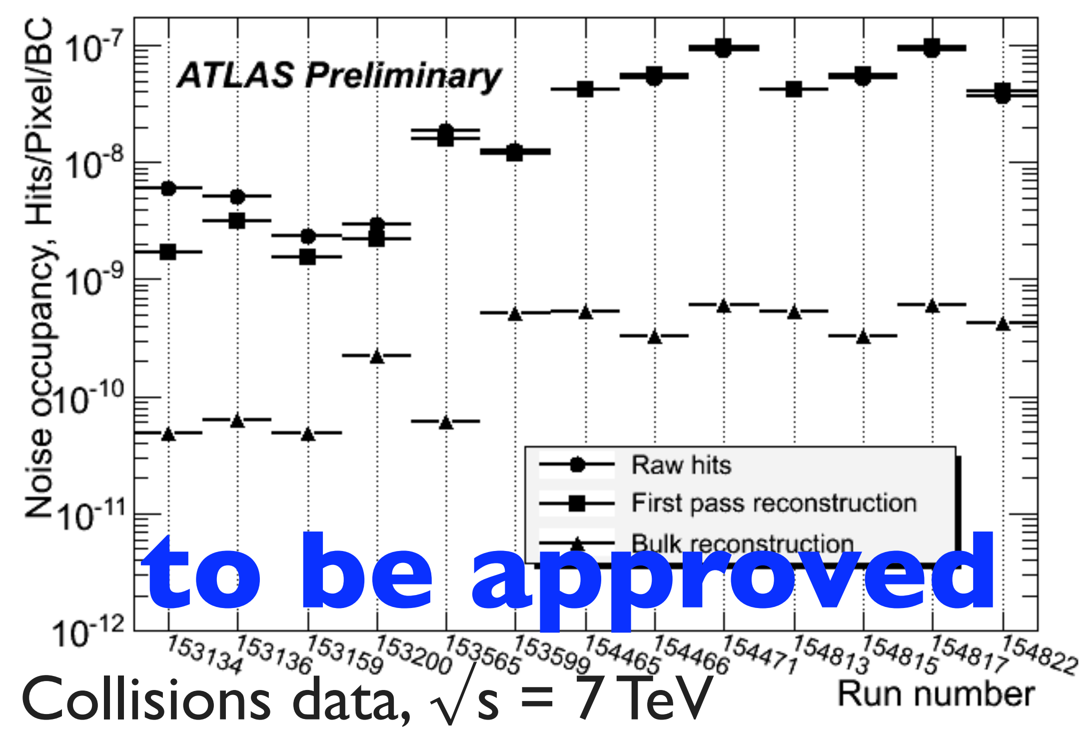




Noise suppression

- Noise rate dominated by few pixels (300-1500 out of 80M):
    - Online masking: pixels not read out
    - Offline masking: pixels excluded from reconstruction
- Noisy pixels detected run-by-run:
    - Calibration stream: randomly triggered events with empty bunches
    - Noise mask computed using a “prompt calibration loop” (36 h)
    - In the bulk processing, noise occupancy is $<10^{-9}$ hit / pixel / BC.





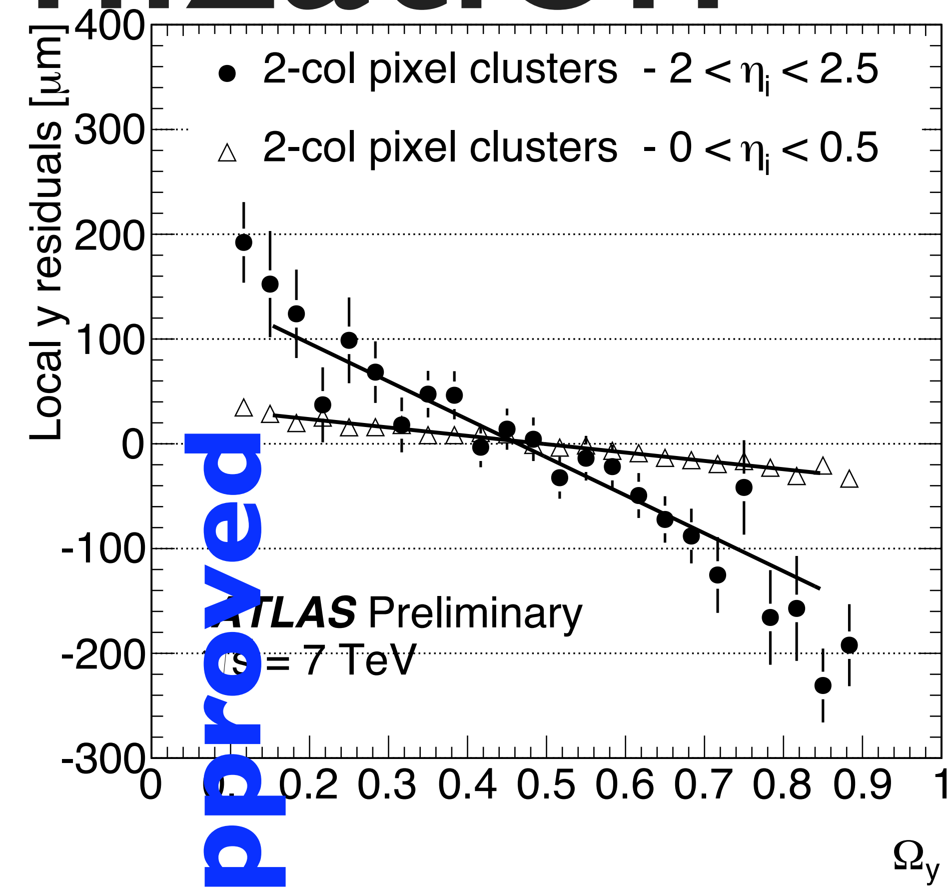
Resolution optimization

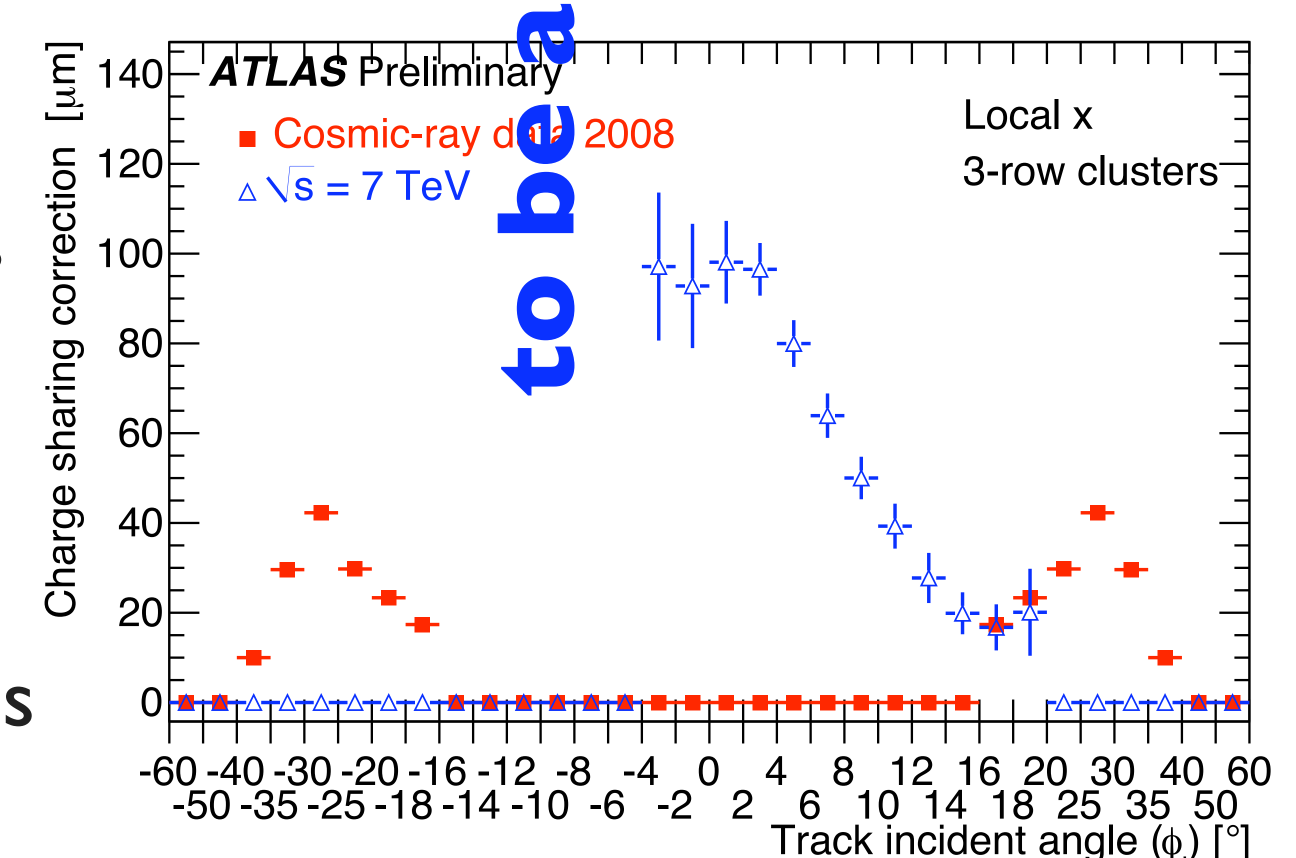
- Pixel cluster position:
    - use the centre of the cluster
    - use analog information (charge sharing):

$$\Omega_x = \frac{Q_{last\ row}}{Q_{last\ row} + Q_{first\ row}} \qquad x = x_{centre} + \Delta\left(\Omega_x - \frac{1}{2}\right)$$

$$\Omega_y = \frac{Q_{last\ column}}{Q_{last\ column} + Q_{first\ column}} \qquad y = y_{centre} + \Delta\left(\Omega_y - \frac{1}{2}\right)$$

- Charge sharing correction (Δ):
    - From centre-of-cluster residuals as a function of the charge sharing (Ω)
    - Correction determined for several track incident angle intervals and for different cluster classes





to be approved

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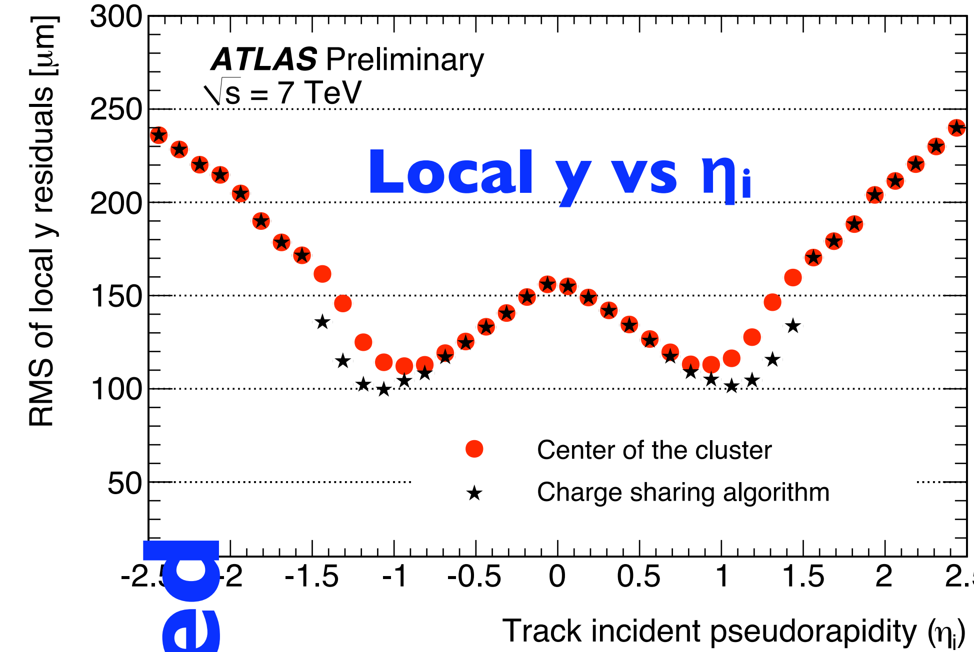
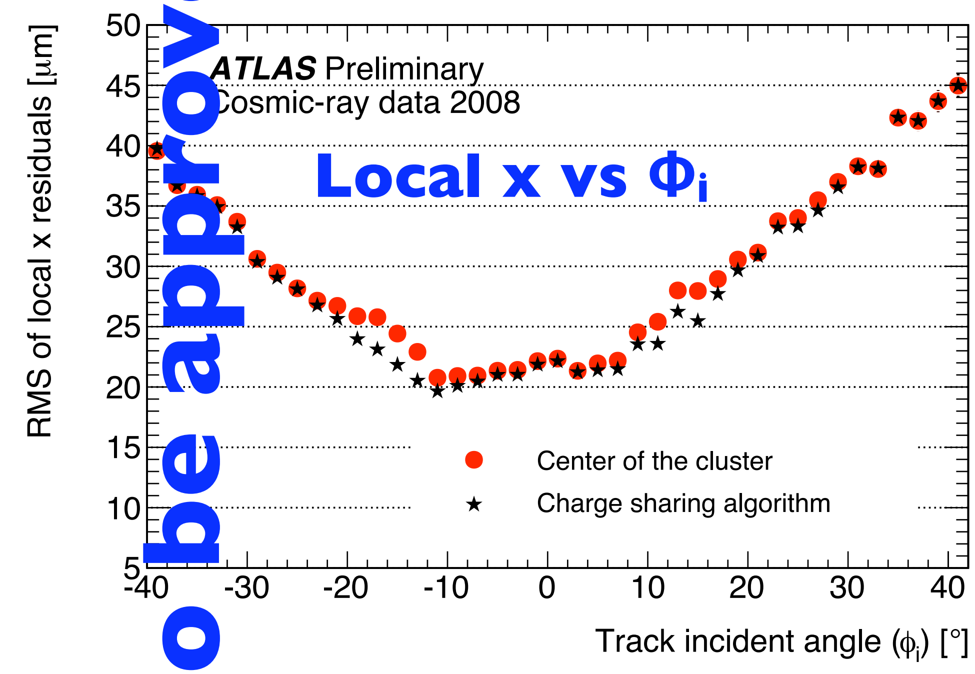
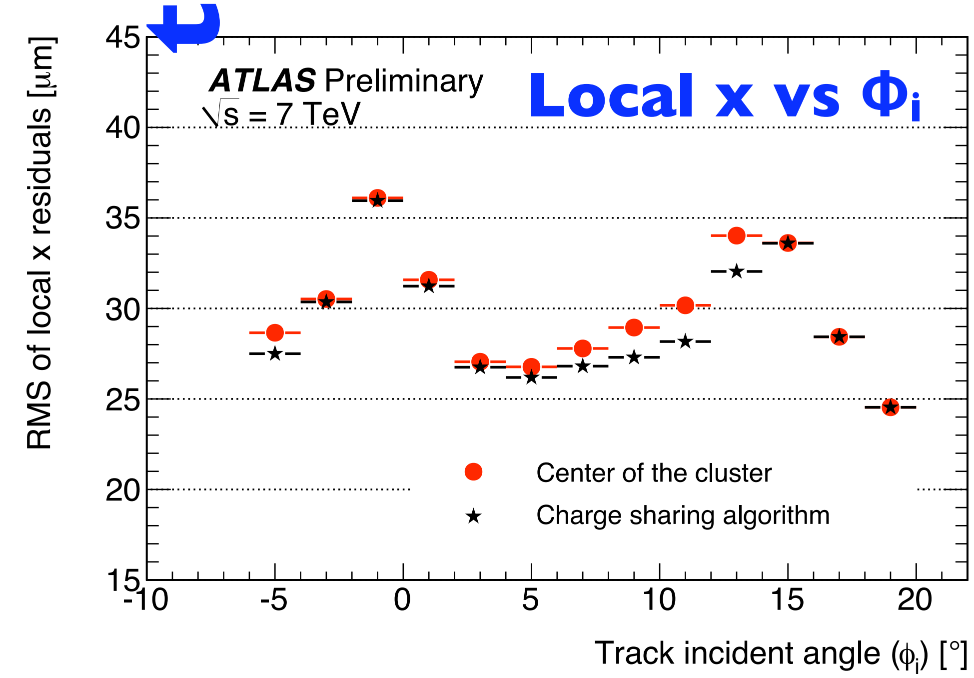
Resolution

- Spatial resolution for the single cluster depends on:
    - clusters properties (size, read-out conditions, ...)
    - particle incident angle
- Use residuals between cluster position and track extrapolation to estimate resolution:
    - include track extrapolation uncertainty (track momentum, detector alignment)
- Charge sharing correction improvement clearly visible for angular range where two-pixel clusters are dominant and correction computation is reliable

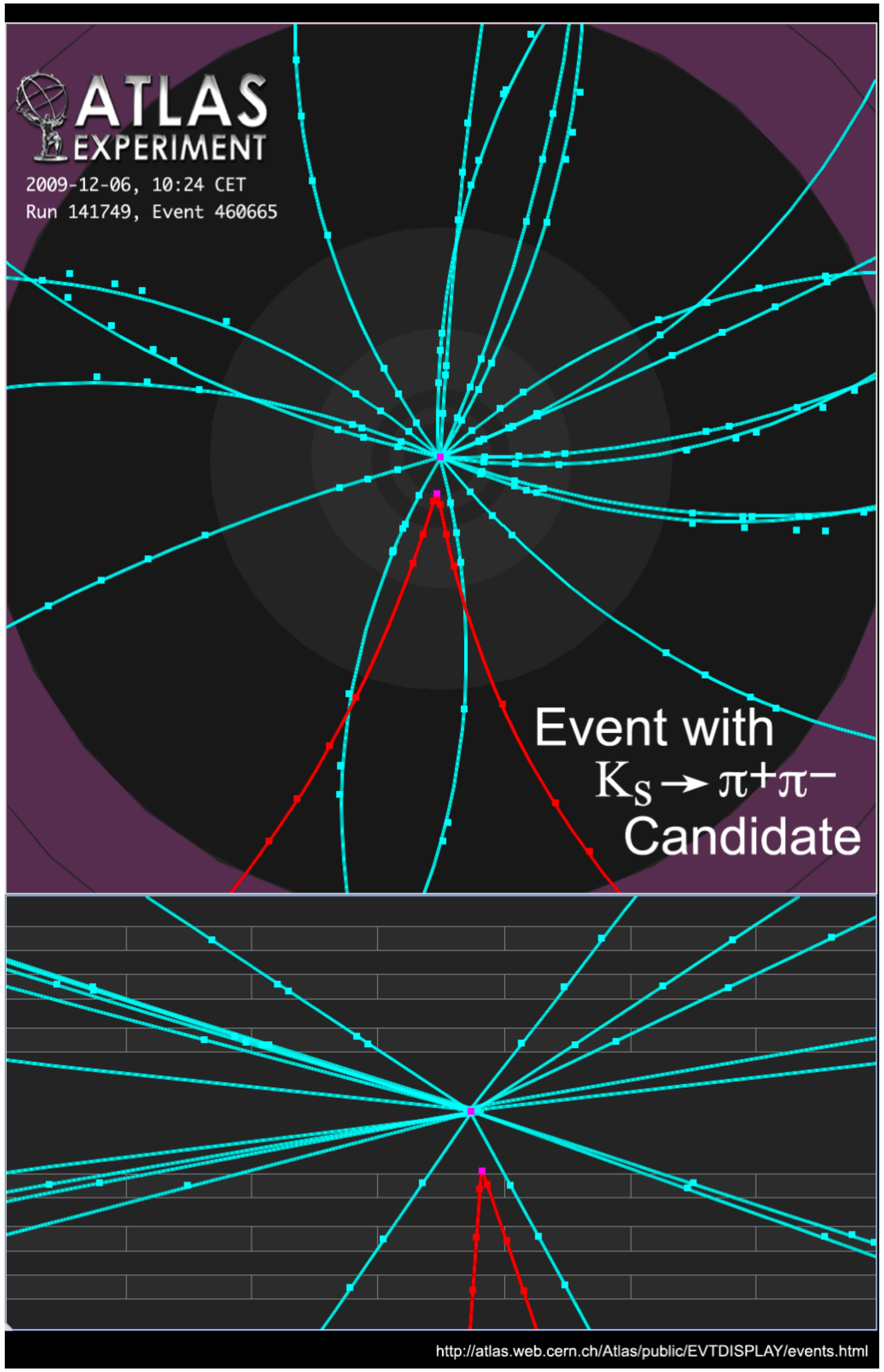






Physics analysis

- Pixel Detector contribution essential for collision data analysis:
    - Vertex determination



Physics analysis

- Pixel Detector contribution essential for collision data analysis:
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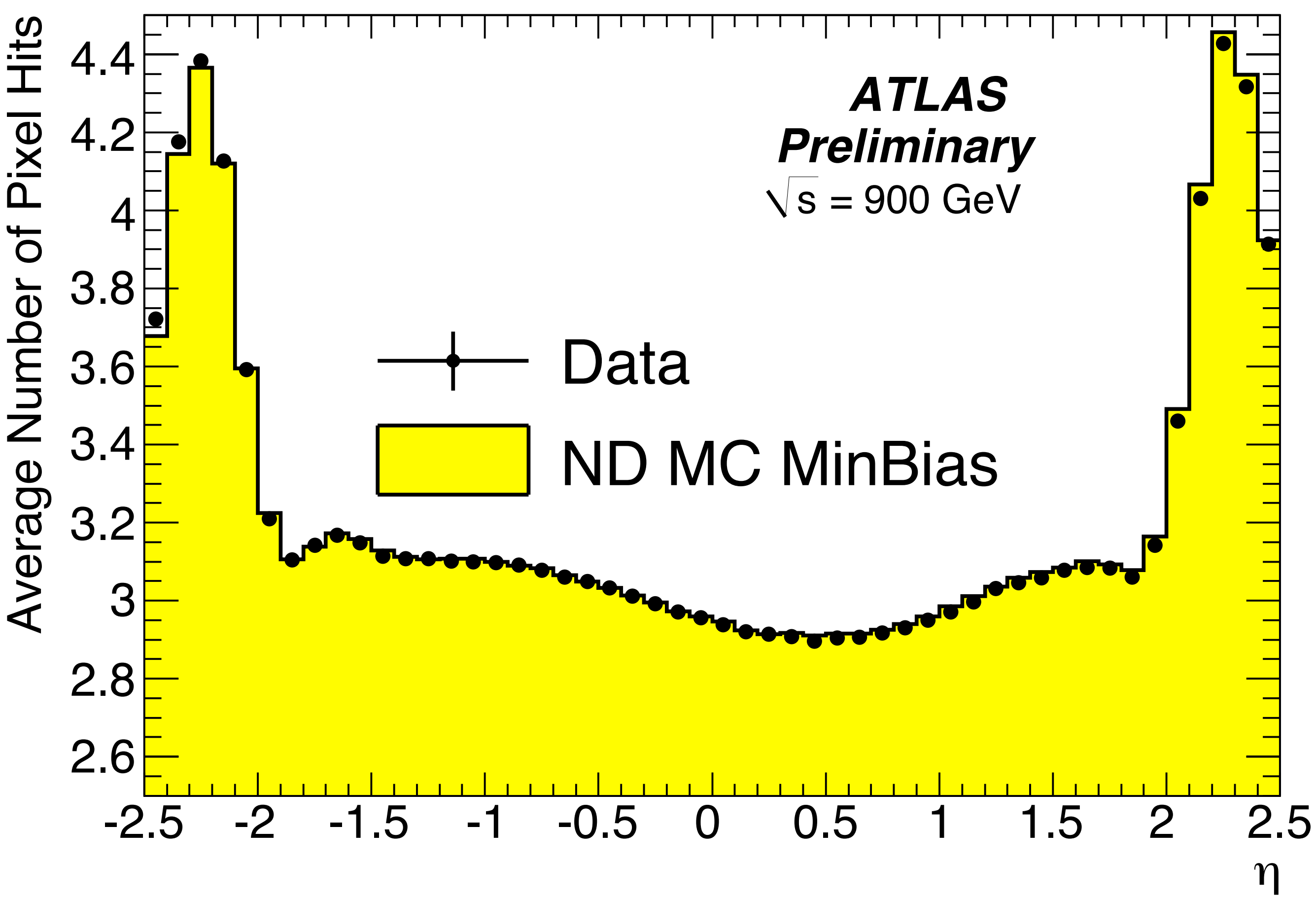
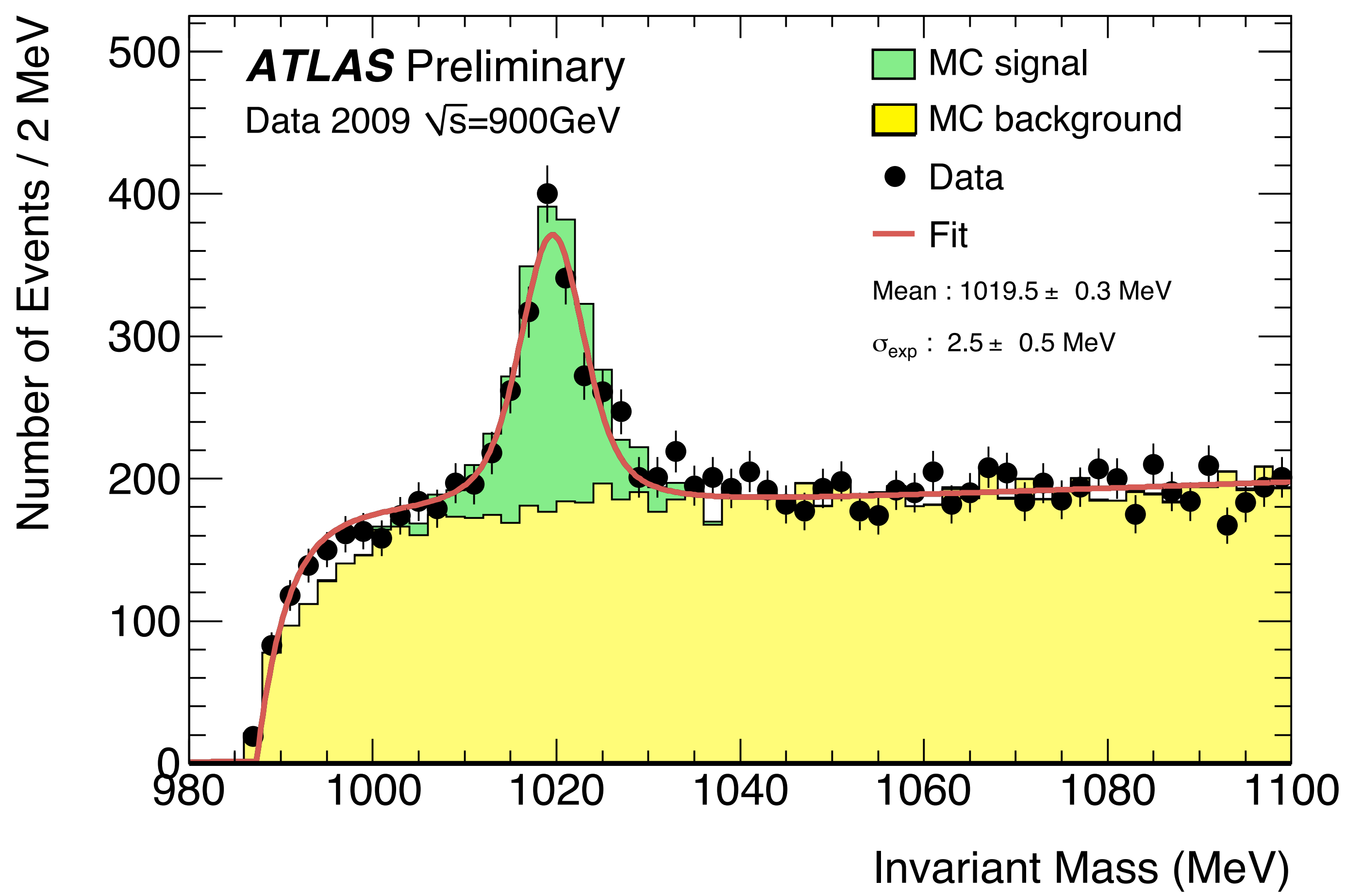
  - Minimum bias studies



Physics analysis

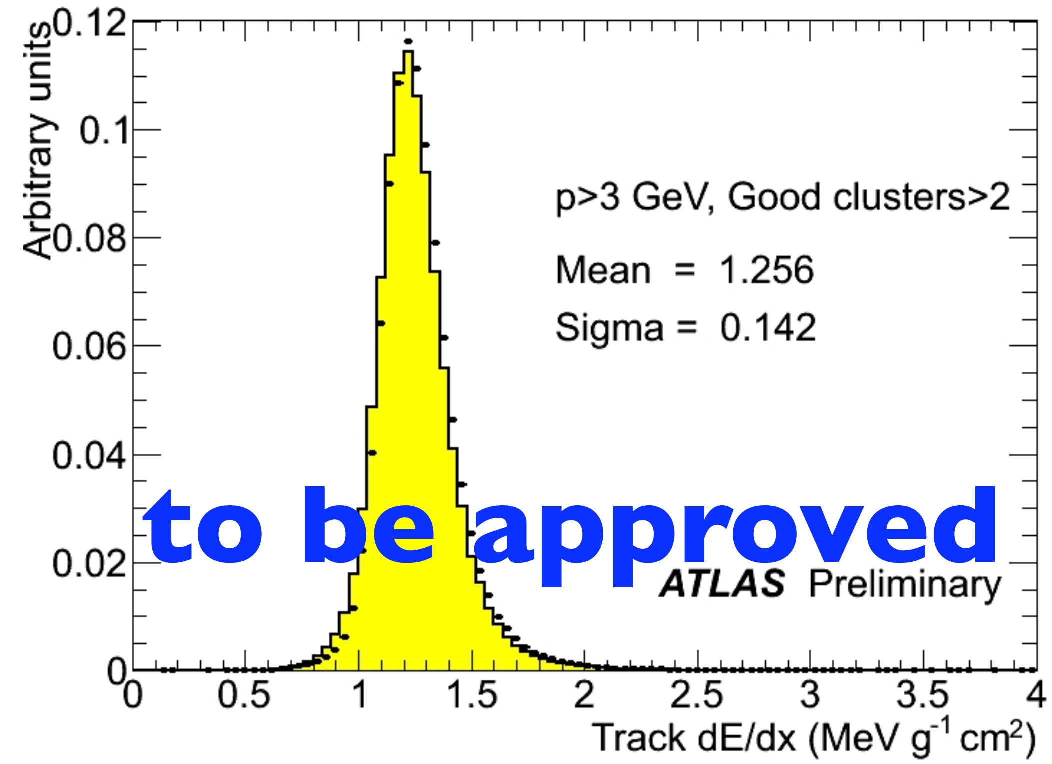
- Pixel Detector contribution essential for collision data analysis:
  - Vertex determination
  - Minimum bias studies
  - Resonance identification…

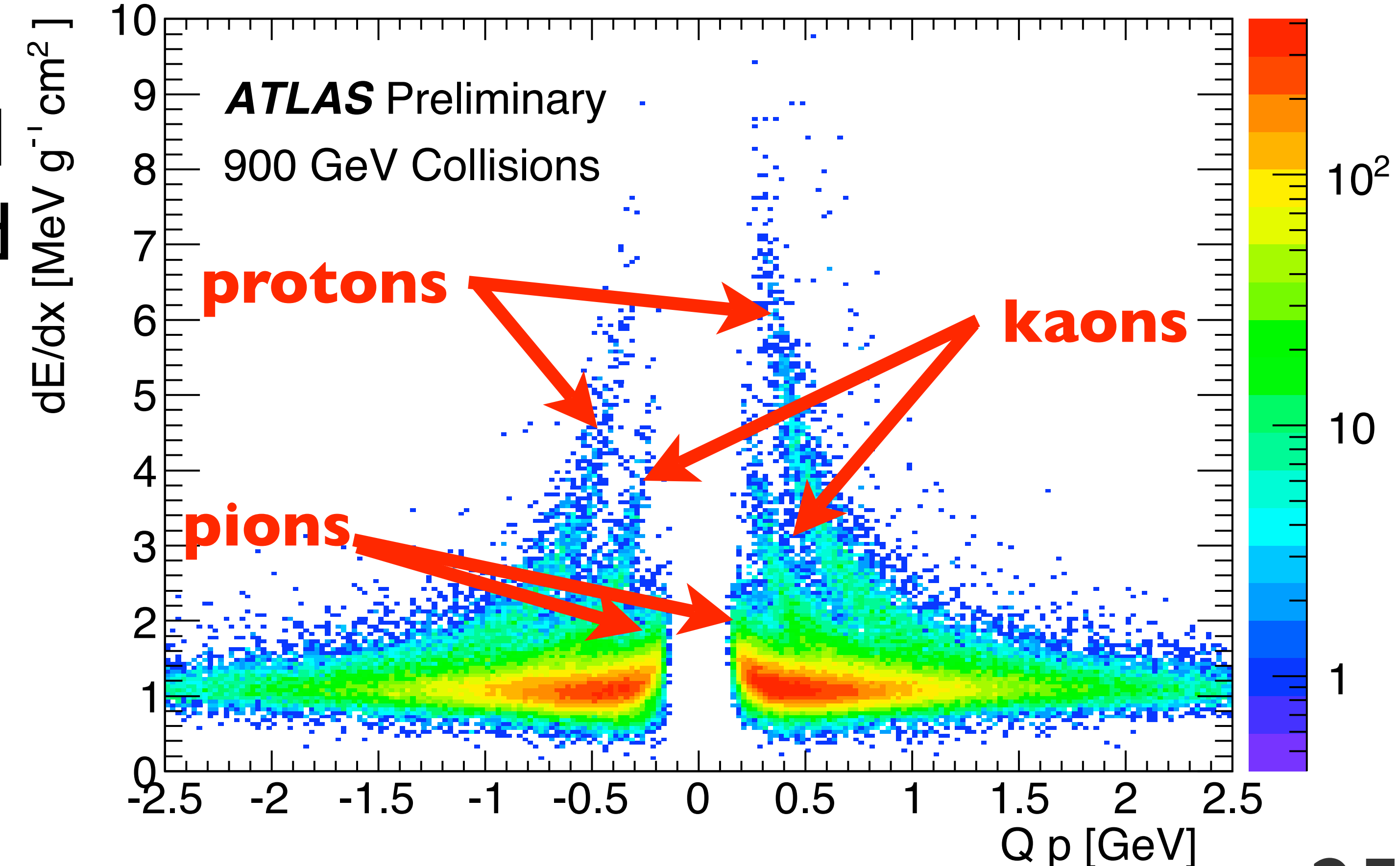
Φ(1020)-meson production: invariant mass distribution of the K^+K^- pairs for |eta| < 2.5.



dE/dx

- Specific energy loss in silicon (dE / dx) described by Bethe-Bloch function
- Energy proportional to charge collected:
    - "track" dE / dx is the truncated mean of cluster energies (but the highest) corrected for path-length (11% resolution)
    - clusters selected to avoid module edges and ganged pixels (91% of clusters, 97% of tracks)
    - selection on number of hits on tracks
- Basic particle identification



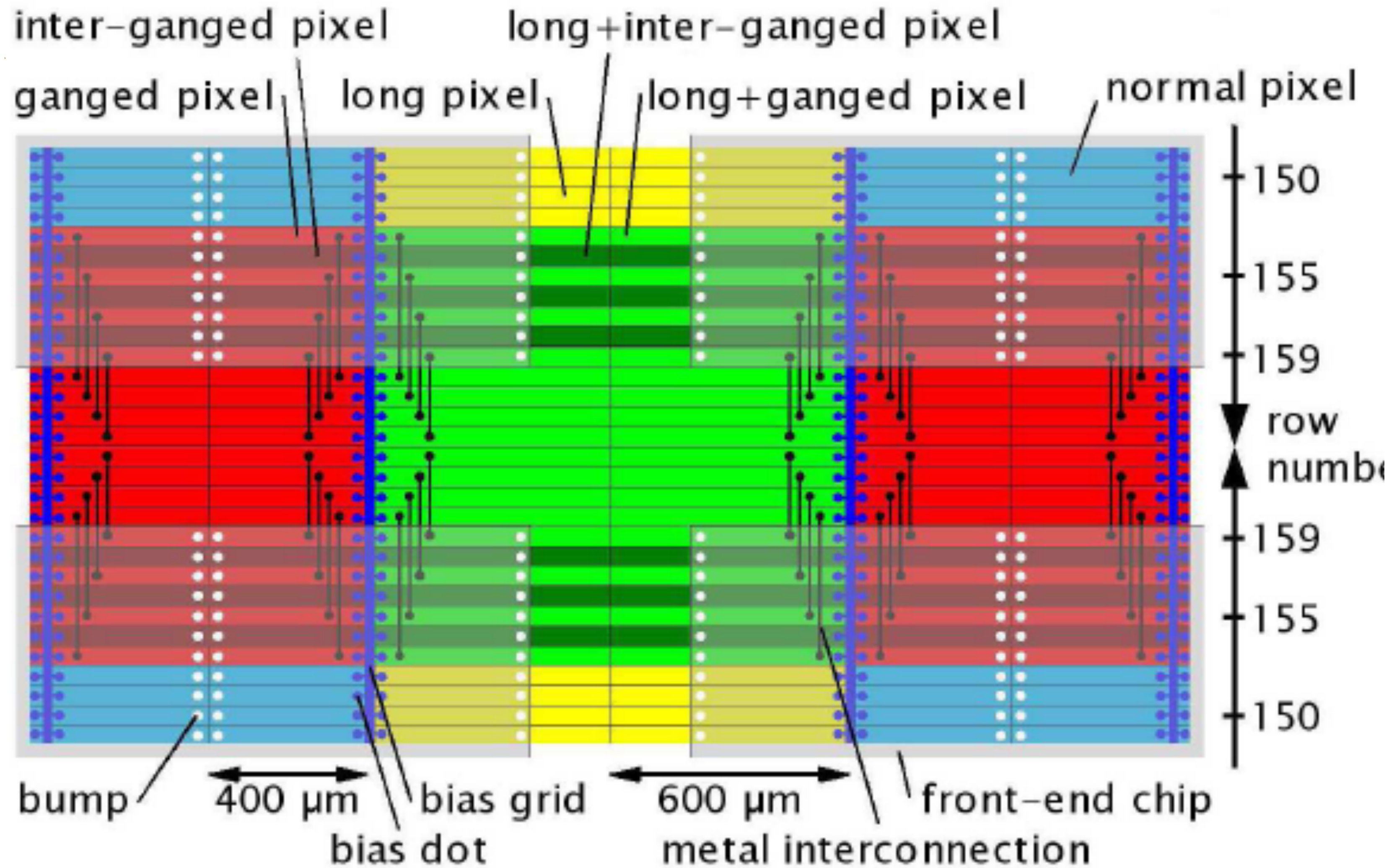


Conclusion

- Pixel Detector commissioned with cosmic ray data taking in 2008:
  - intrinsic efficiency: 99.974%
  - readout thresholds: 4000 e or 3500 e dispersion: 40 e
  - Noise rate $< 10^{-9}$ hit / pixel/BC
  - Charge resolution: 660 e for 20 ke M.I.P.
- Collisions in 2009 and 2010 allowed to finalize performance studies:
  - Lorentz angle measurement
  - Noise suppression optimized using calibration loop
  - Resolution optimization with charge sharing
- Pixel Detector contribution is essential for collision data analysis

Backup

Ganged and Long Pixels



- Ganged pixels are a connection of two pixels to a single readout channel resulting in about twice the noise of a single "normal" pixel.