Operational experience with the ATLAS Pixel detector at the LHC

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On behalf of the ATLAS Collaboration

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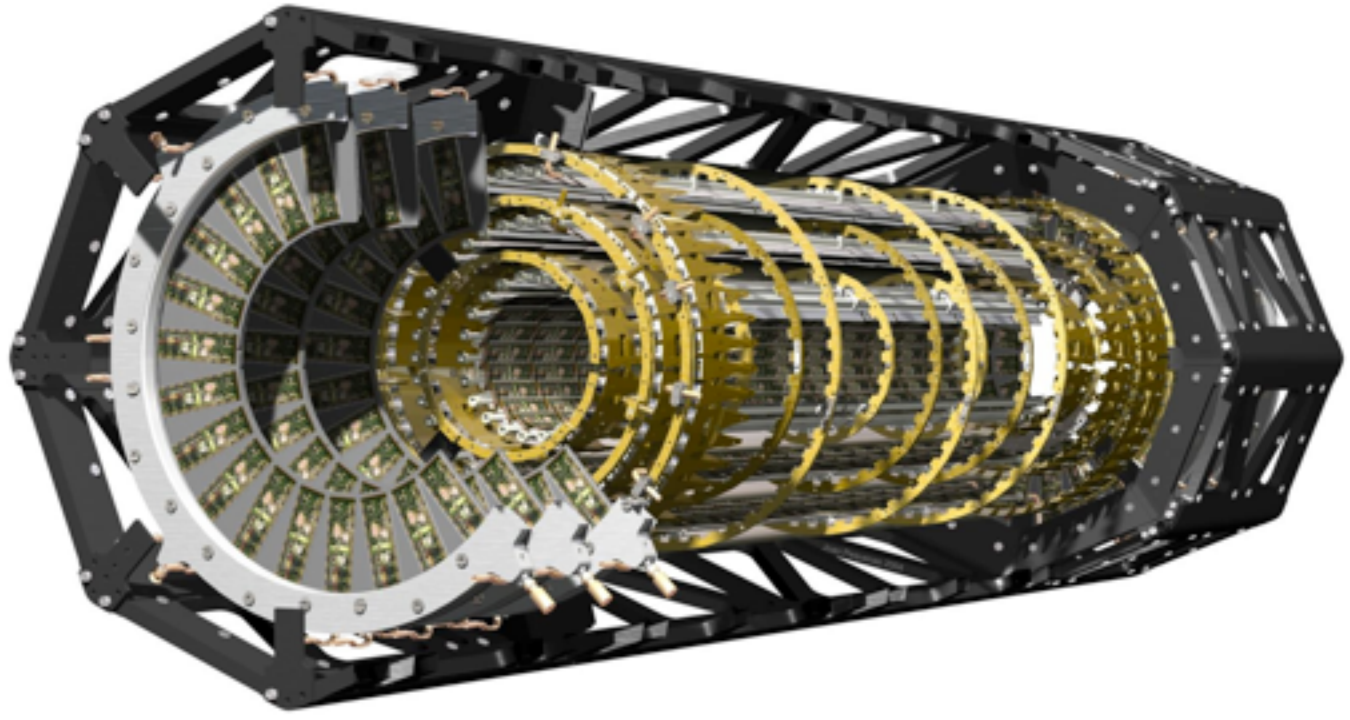
Outline

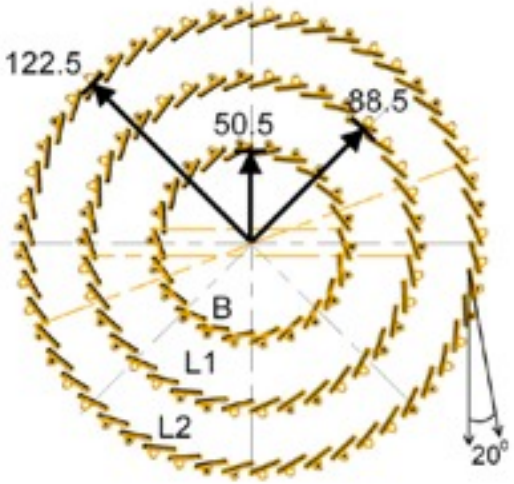
- The ATLAS Pixel detector
- Operational experience: calibration, tuning and performance
  - Threshold and noise
  - Charge measurement and efficiency
  - Timing
  - In-time threshold
- Radiation damage: simulation and monitoring

The ATLAS Pixel detector

- **Requirements**
  - Position resolution in radial and forward directions < 15 µm
  - 3 track points for $|\eta| < 2.5$
  - Time resolution < 25 ns
  - Hit detection efficiency > 97%

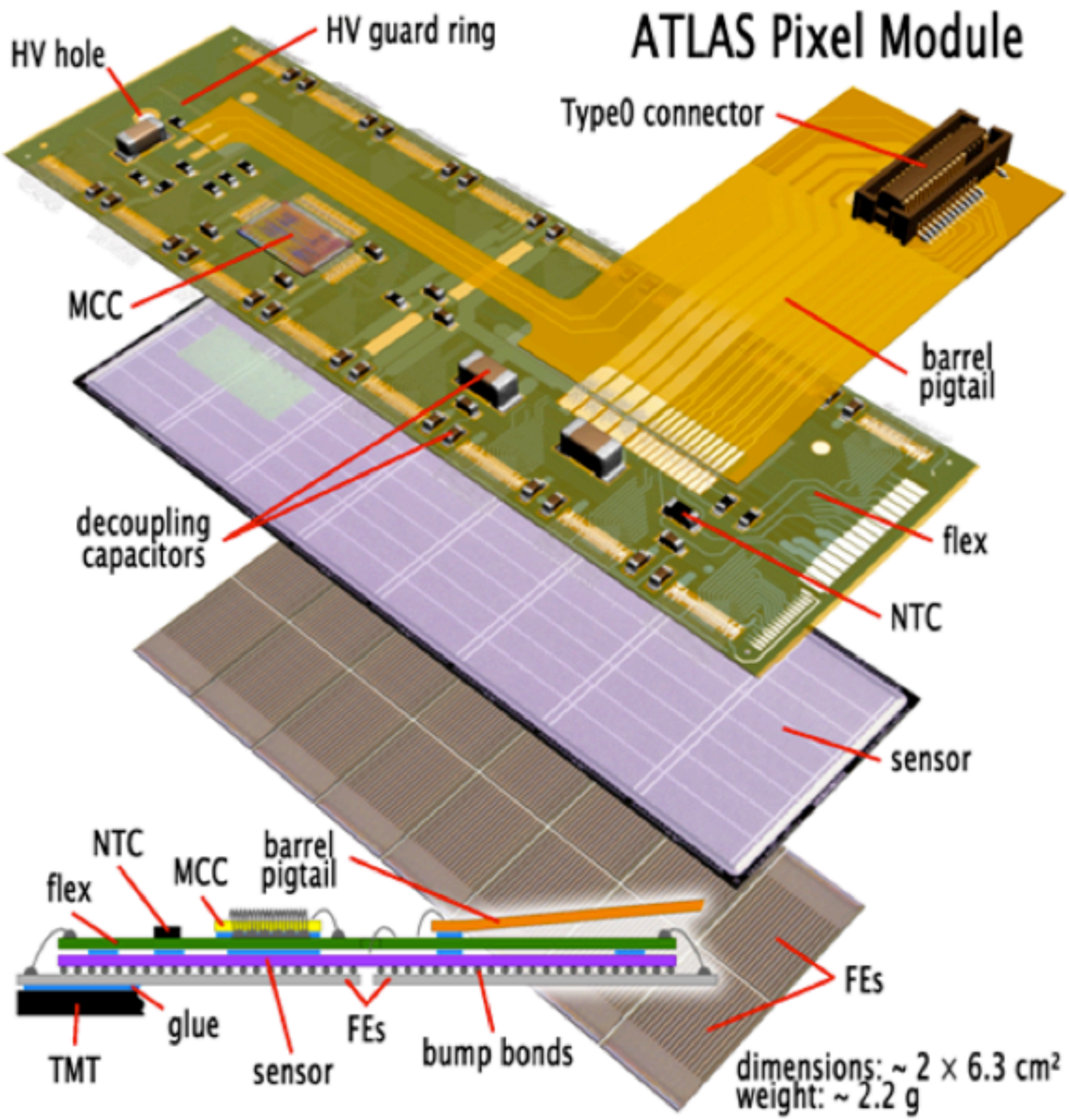


- **Basic properties**
  - 3 barrel layers with 1456 modules
  - 3 disks per endcap with 288 modules
  - 80M of readout channels
  - Innermost layer at 50.5 mm
    - Radiation tolerance 50 MRad/10^{15} 1 MeV neqcm^{-2}
  - Evaporative C3F8 cooling integrated in the local support structures



The ATLAS Pixel module

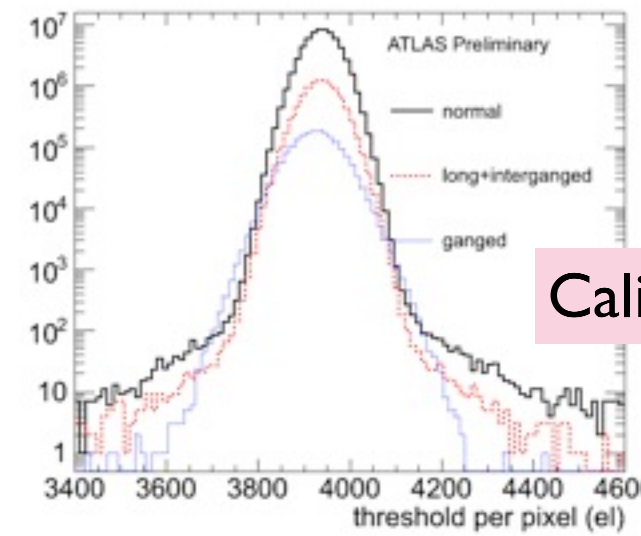
- Sensor
  - 250 µm thick n-in-n Si sensor
  - 47232 (328x144) pixels, 46080 readout channels
  - Typical pixel size of 50x400 µm
  - Bias Voltage 150 - 600 V
- Readout
  - 16 FE chips with 2880 pixels each
  - Pulse height measured with Time-over-Threshold (ToT)
  - Zero suppression in the FE chips, Module Chip Controller (MCC) builds the module event
  - Data transfer speed of 40-160 MHz, depending on the layer



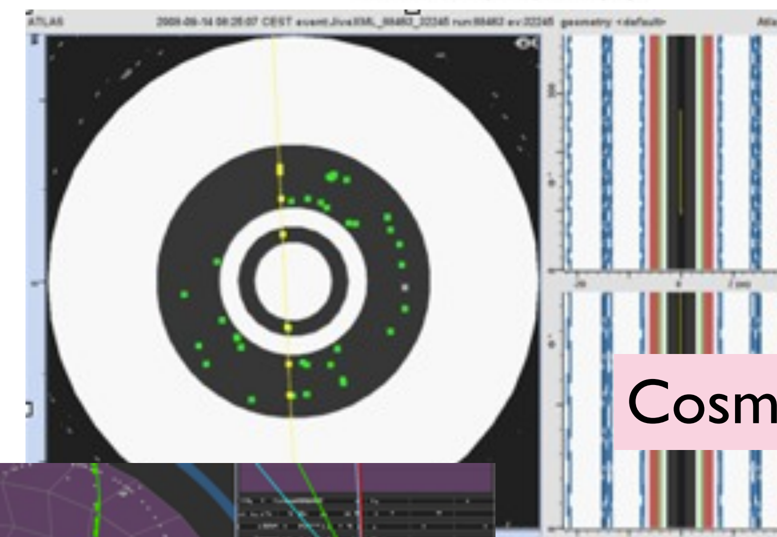
Timeline

- May 2007 – Installation in ATLAS
- Sept 2008 – First cosmic events
- Oct 2008 – LHC incident
- Nov 2009 – First beam 450 GeV
- Dec 2009 – 0.9 TeV and 2.36 TeV collisions
- March 2010 – 7 TeV Collisions
- End 2010 – Heavy Ions: great period!
- May 2011 – Luminosity 10^{33} cm^{-2} s^{-1}

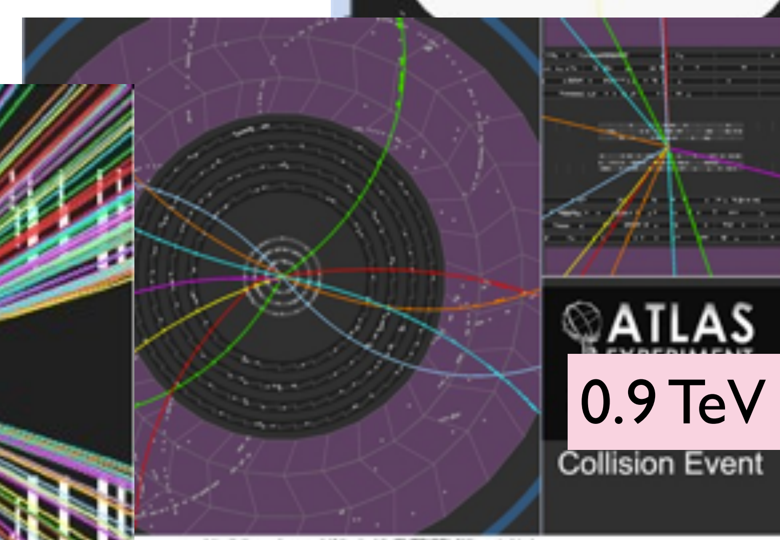
Installation



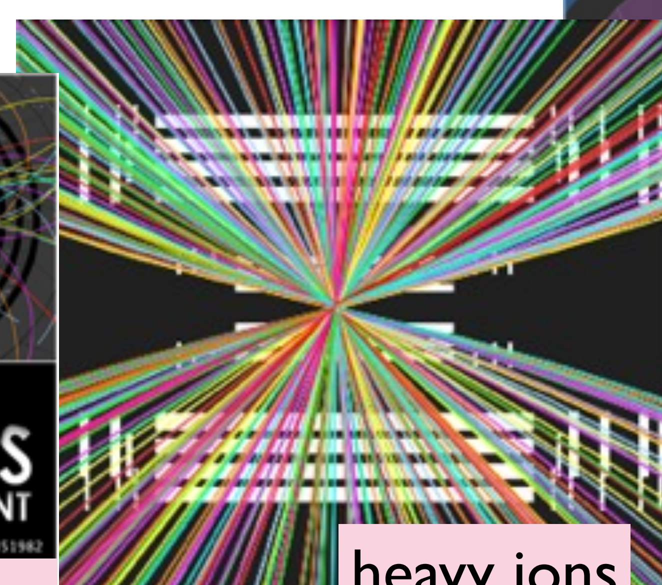
Calibration



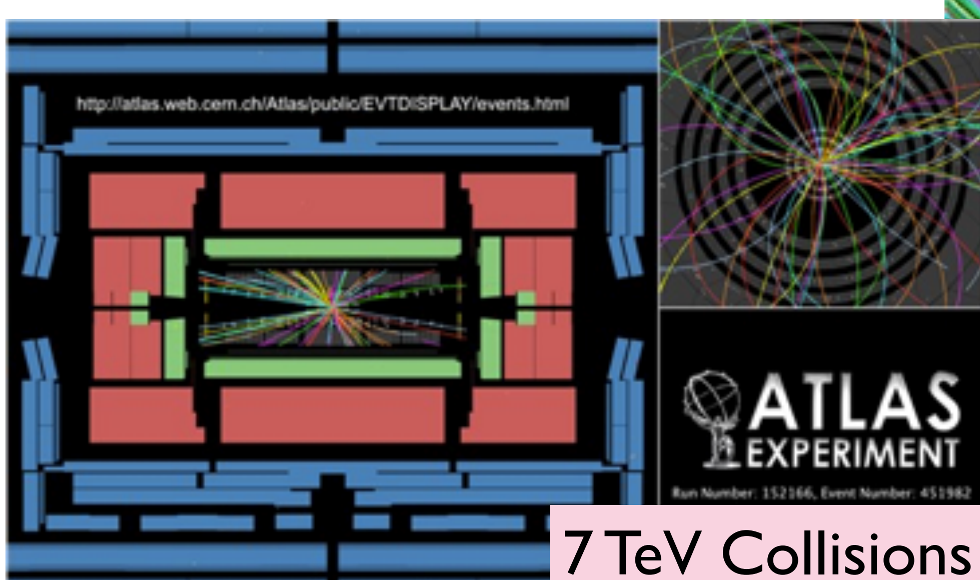
Cosmics



0.9 TeV Collisions



heavy ions

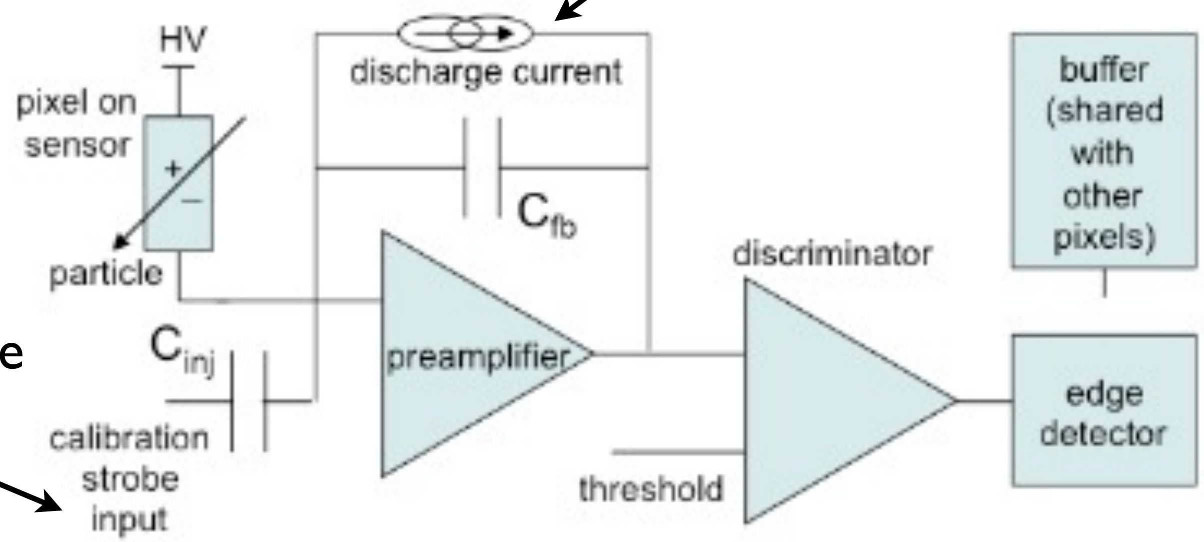


7 TeV Collisions

Pixel Calibration

defines charge measurement
precision and dynamic range

test charge
injection

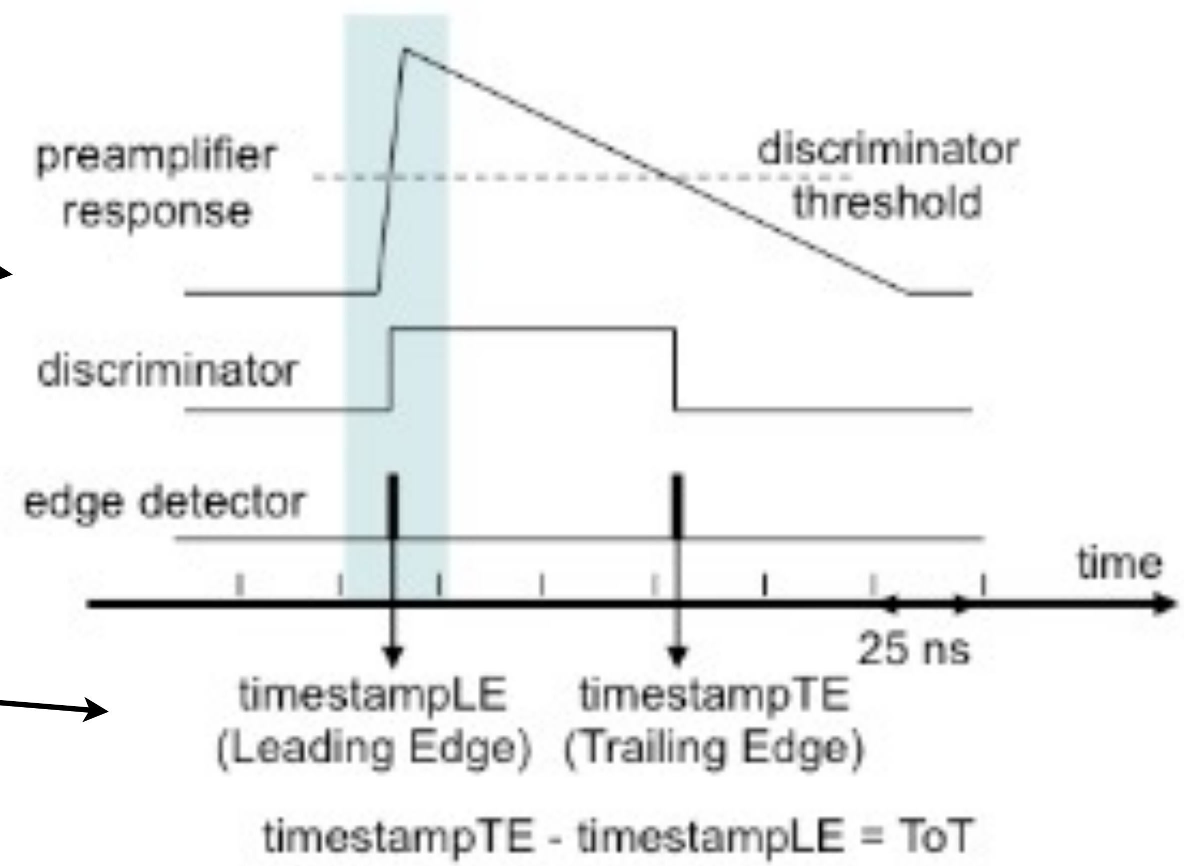


Only data with the correct timestampLE is retrieved by an external trigger to build the event.

Can readout up to 16 consecutive timestamps (corresponding to 16 LHC bunch-crossings)

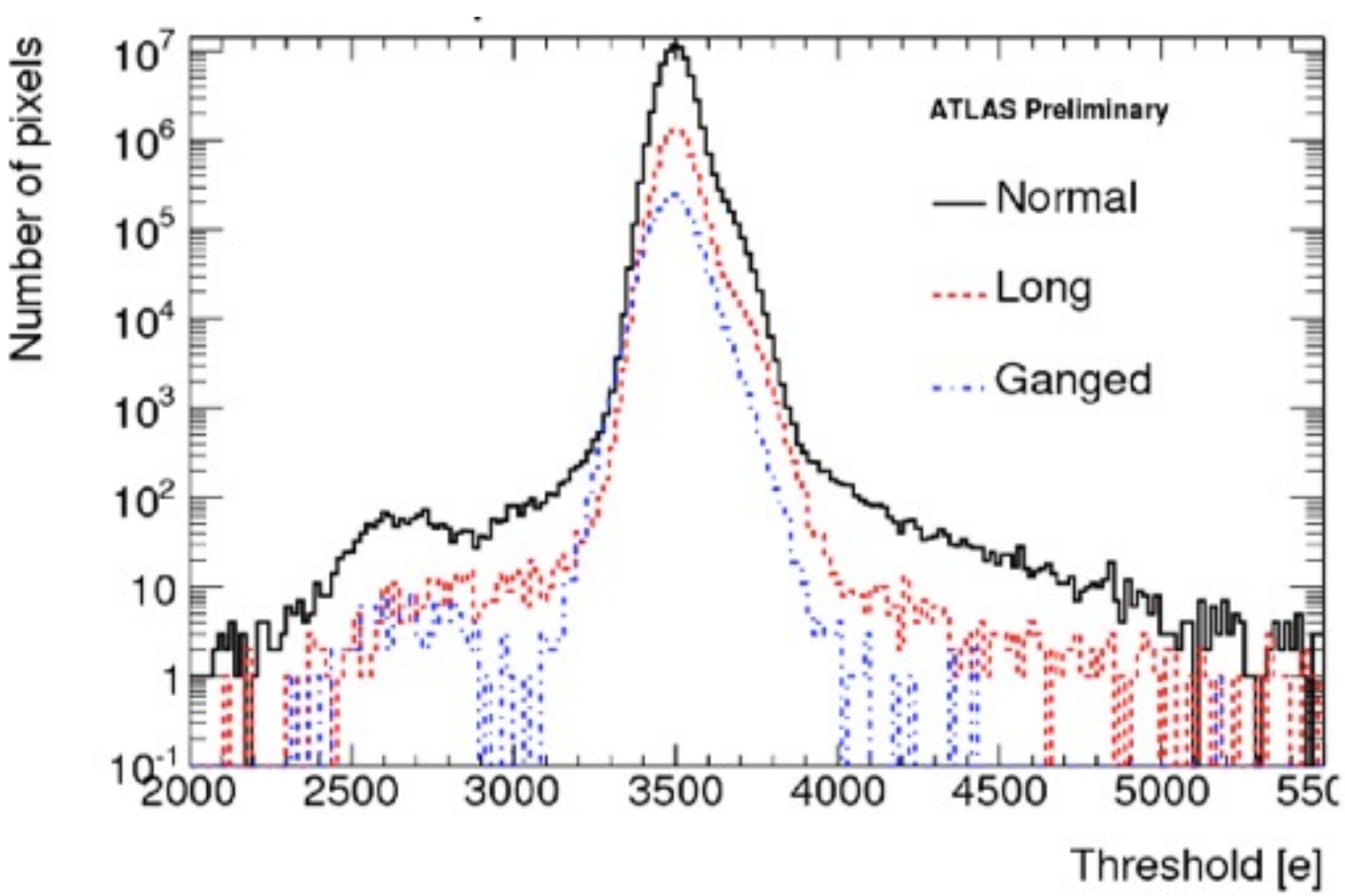
the length of the discriminator pulse (ToT) is proportional to the deposited charge

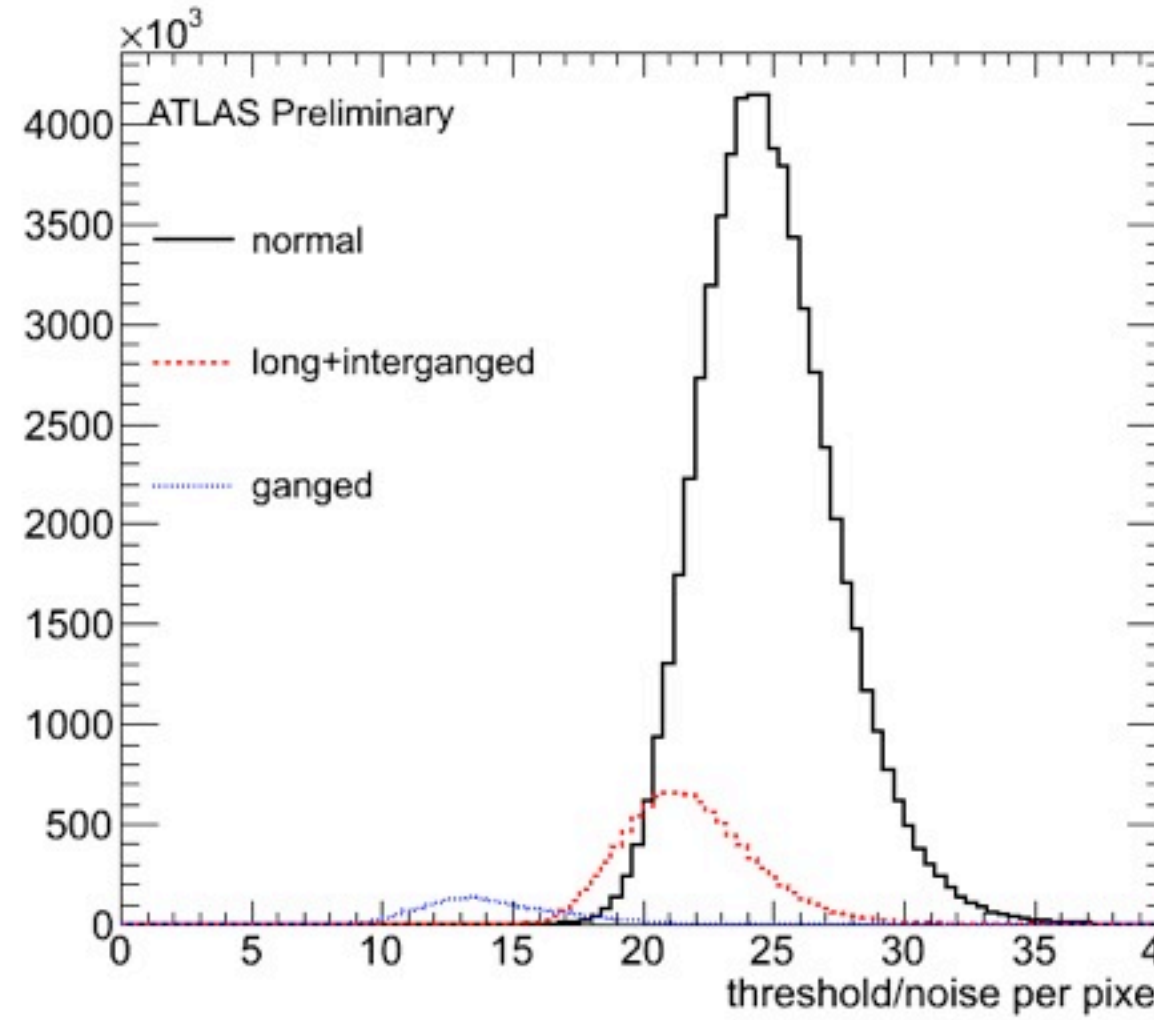
ToT, timestampLE (leading edge of the pulse sourced by the module clock) and hit position are stored in the buffer for every hit



Operation parameters

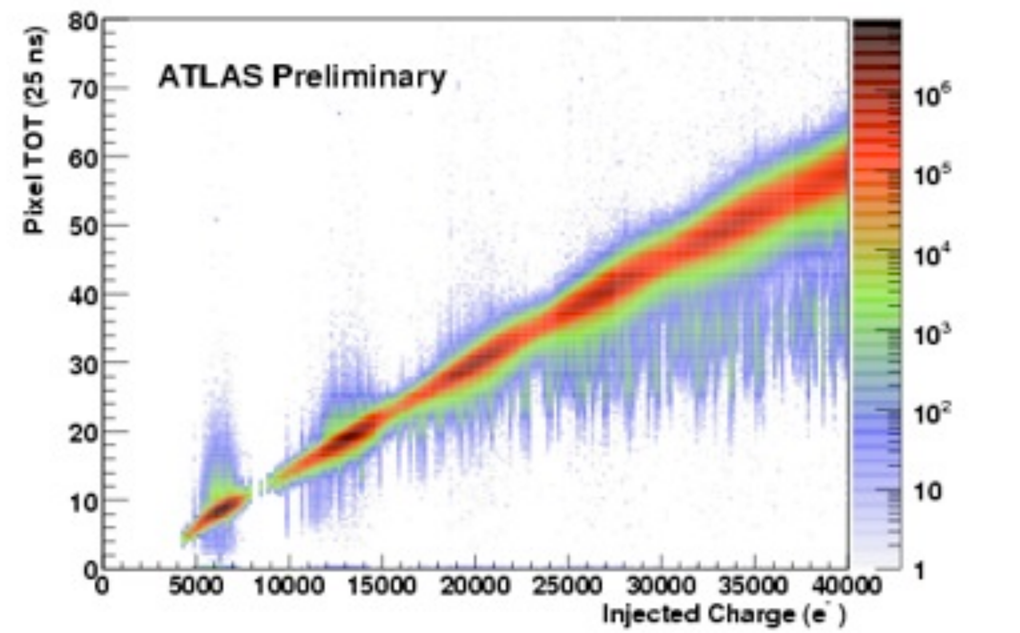
- Threshold is set to 3500e, with a typical dispersion of ~40e after tuning
  - Noise for normal pixels is ~170e (~300e for ganged -higher capacitance- pixels)
  - Threshold / noise ~ 25 (~12) for normal (ganged) pixels

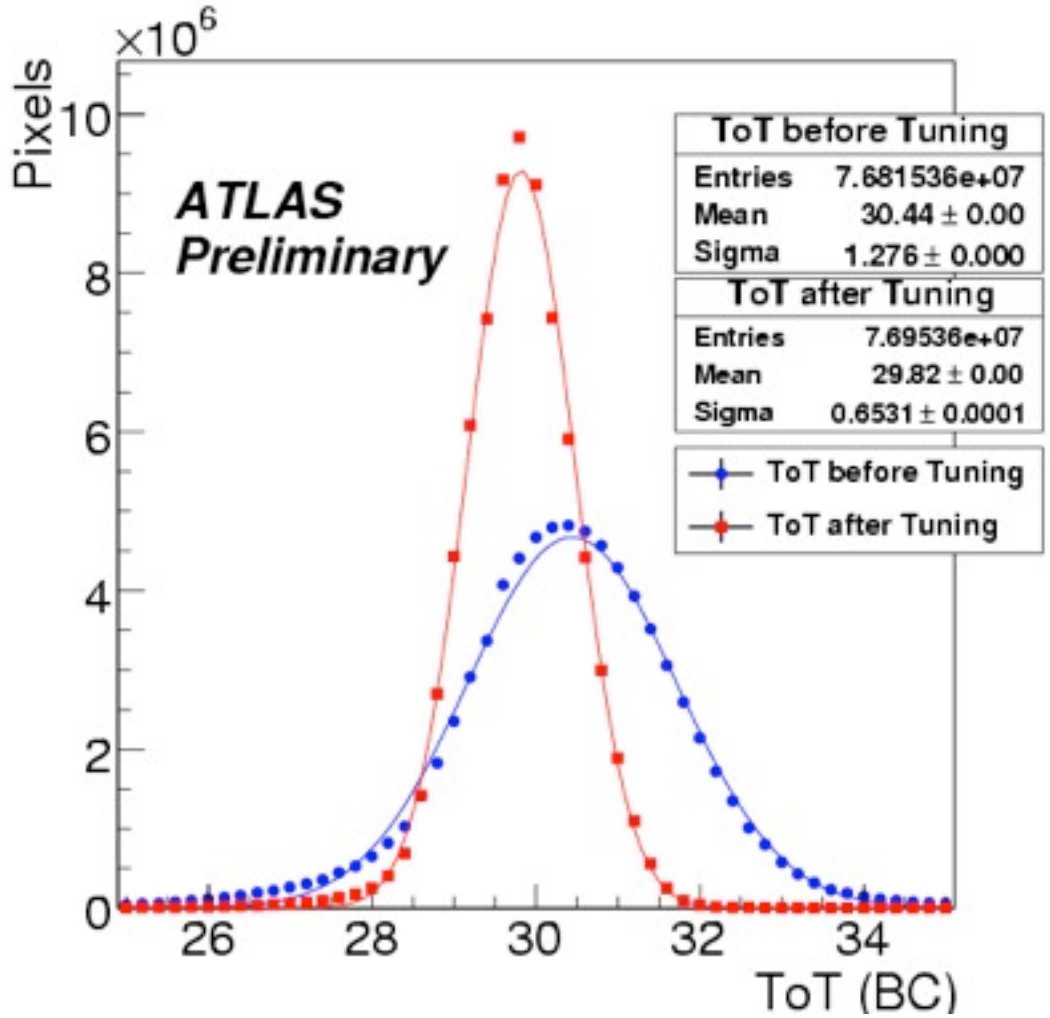


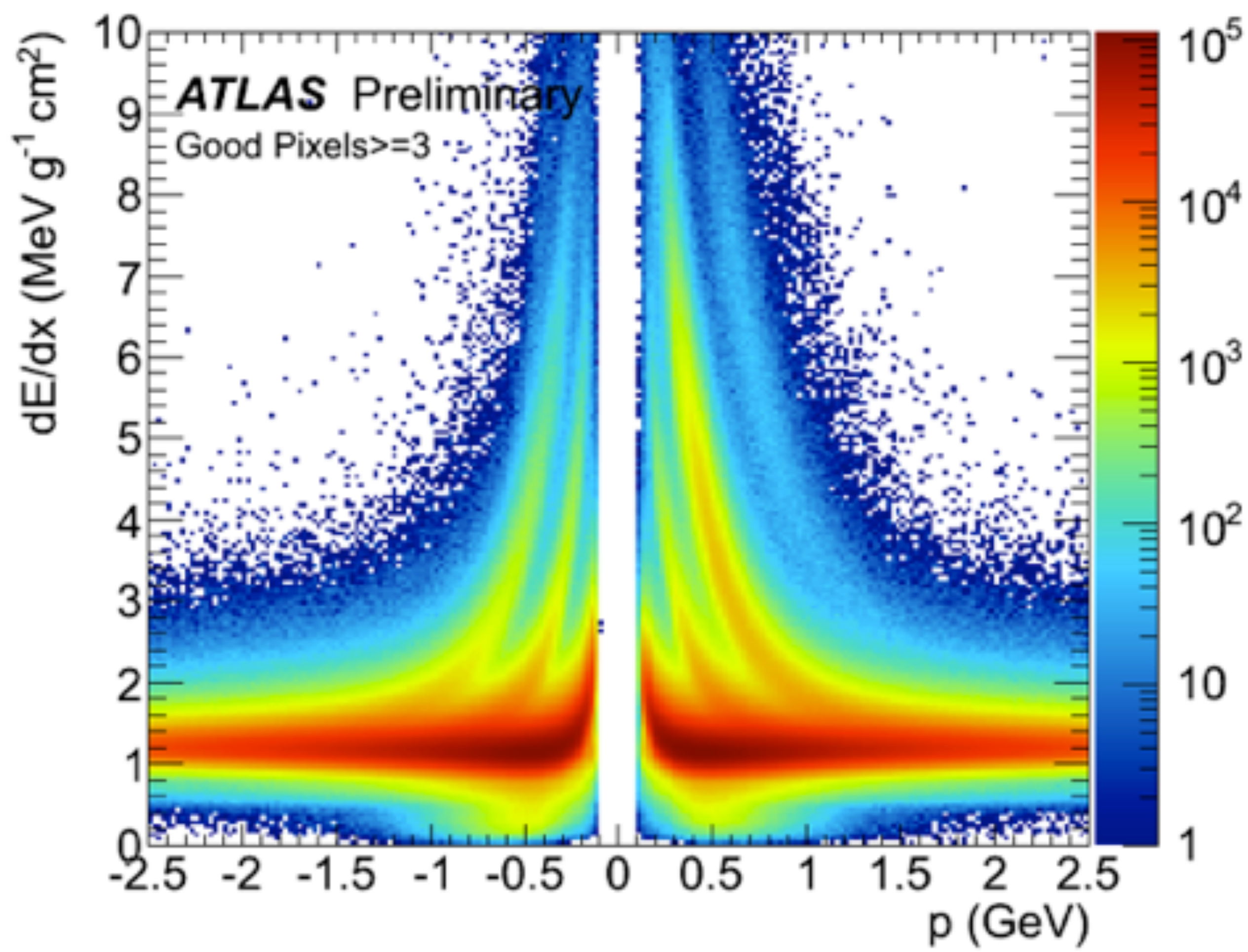


ToT tuning and calibration

- ToT is tuned pixel by pixel to 30 BC at 20Ke
- The ToT calibration is done with charge injections and reconstructing the measured charge offline
- Track dE/dx is measured from the pixel ToT - bands for pions, kaons and (anti)protons clearly visible!

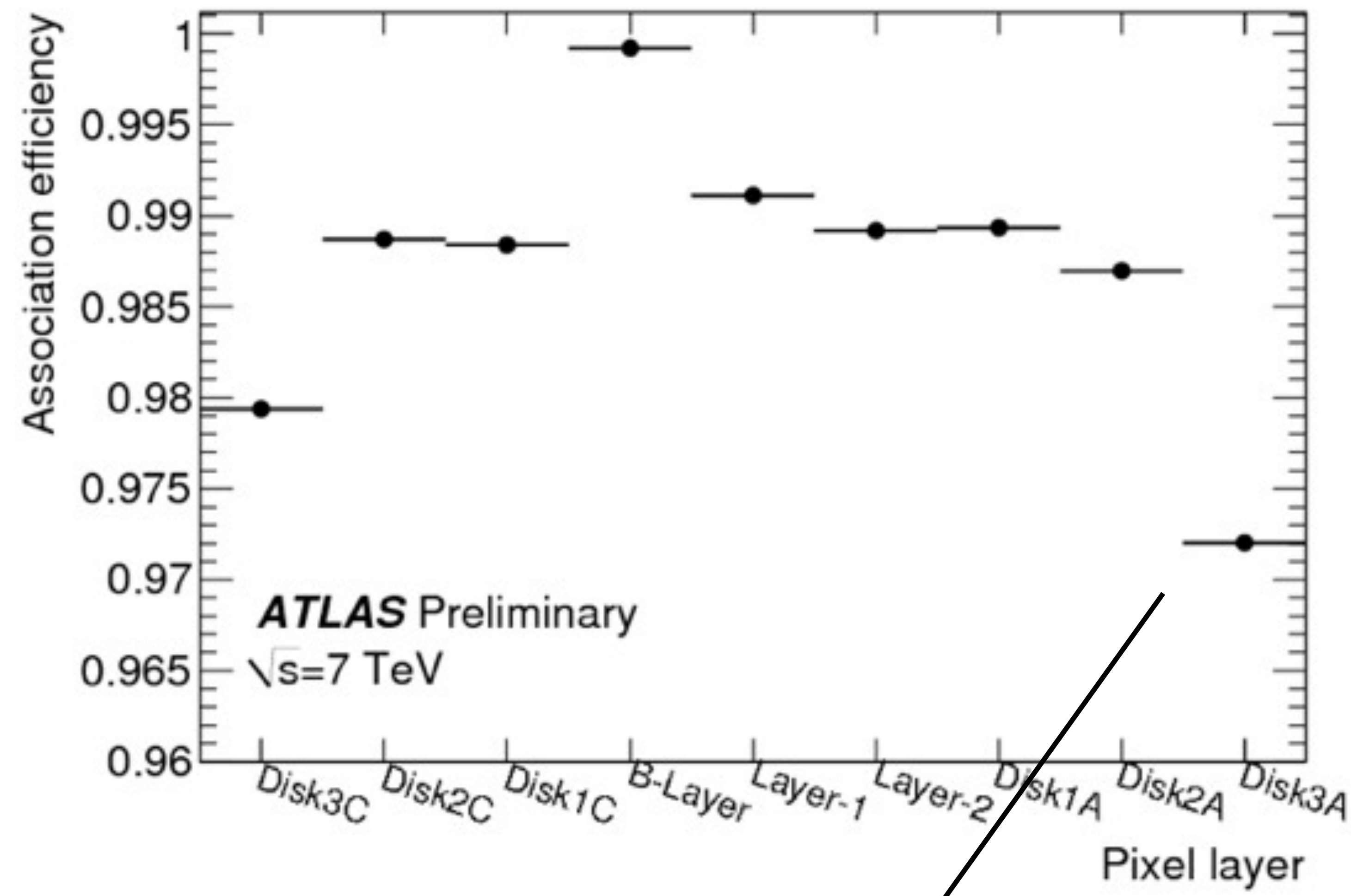


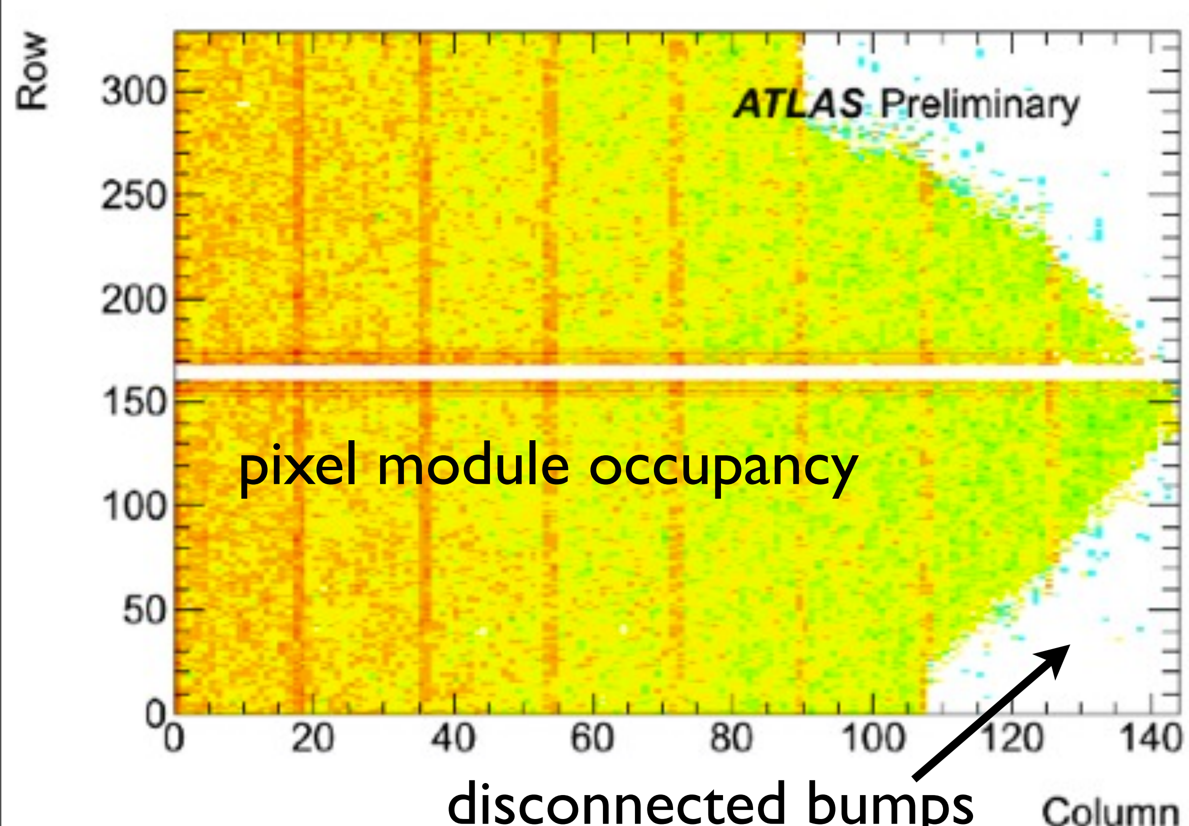


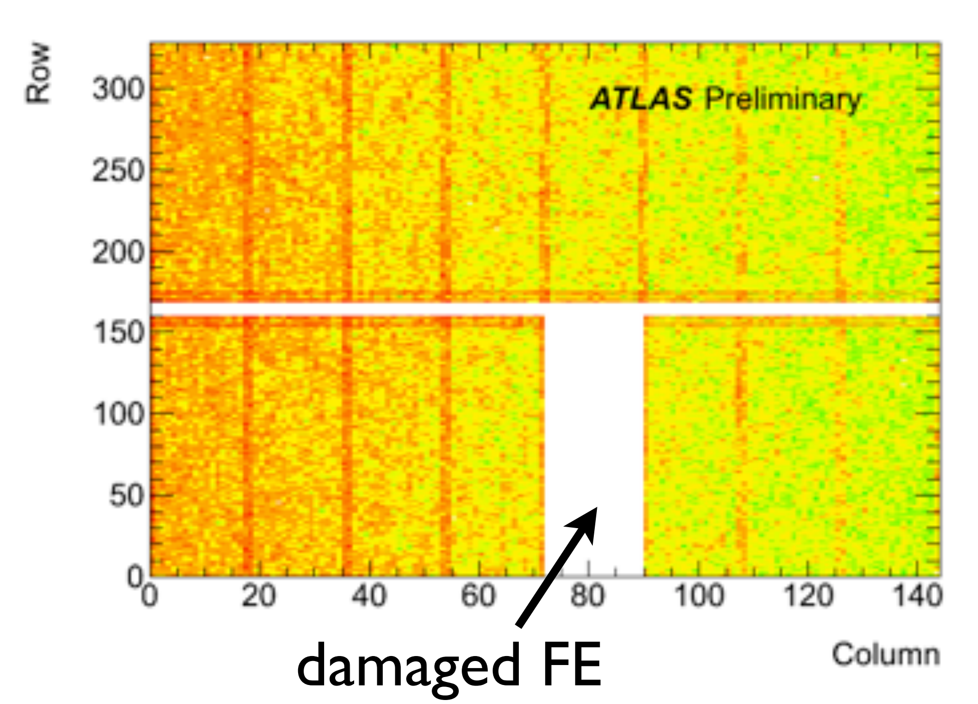


Hit-to-track association efficiency

- The hit-to-track association efficiency is near 99% for all of the detector parts
  - 100% for b-layer by construction due to track reconstruction algorithm
  - Disabled modules are excluded, but not dead regions



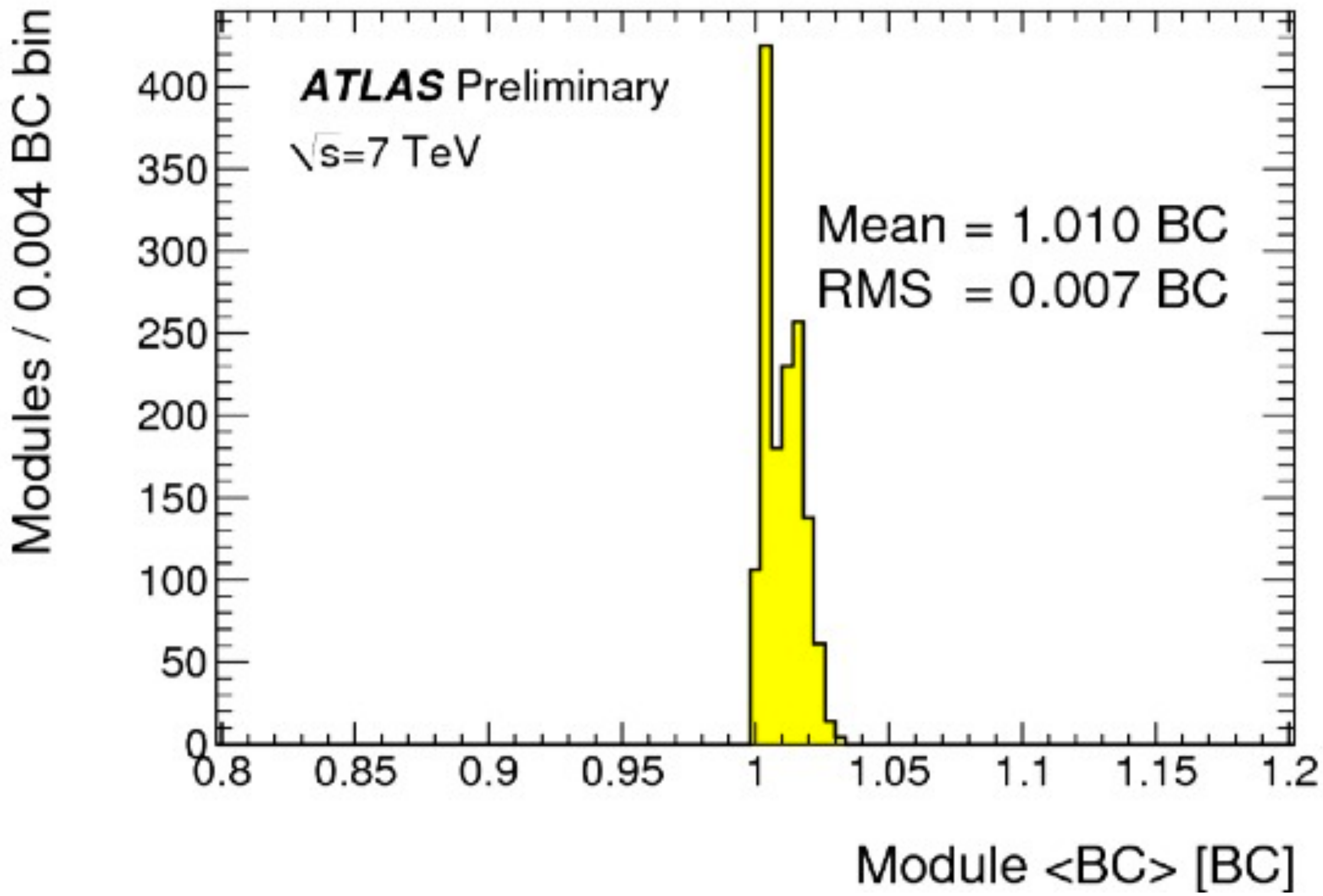




- Efficiency slightly lower in the outer disks due to individual modules

Timing: Homogeneity and stability

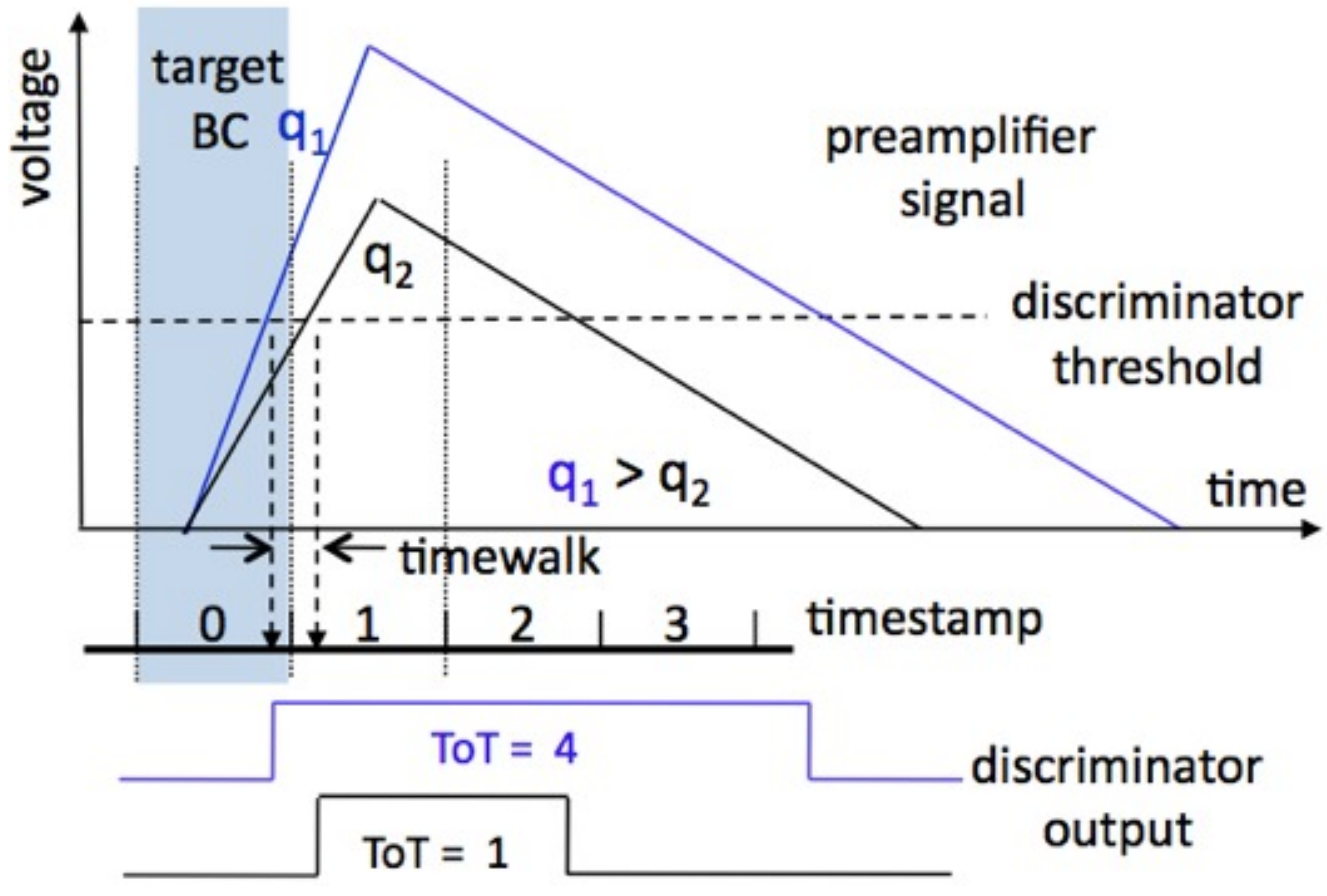
- Several steps for adjusting timing:
  - Trigger delays: from cosmic ray data
  - Cable lengths: measured during installation
  - Final adjustment: timing scans with collisions

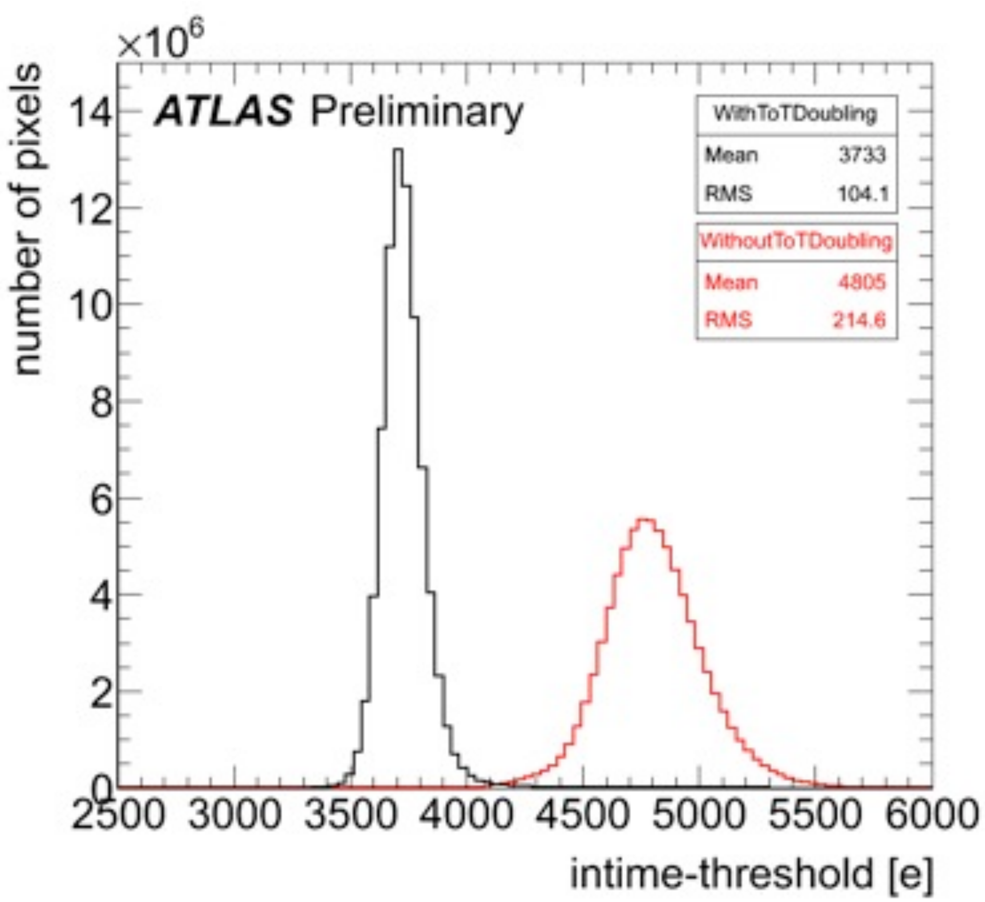


- After all adjustments: very small module-to-module dispersion (of 0.007BC corresponding to ~0.17 ns)

Time-walk and in-time threshold

- Signals with lower amplitude pass the threshold later
  - They are assigned to the next timestamp, and might be lost for reconstruction
- This leads to an "in-time" threshold higher than the discriminator threshold for a hit detection "in time"

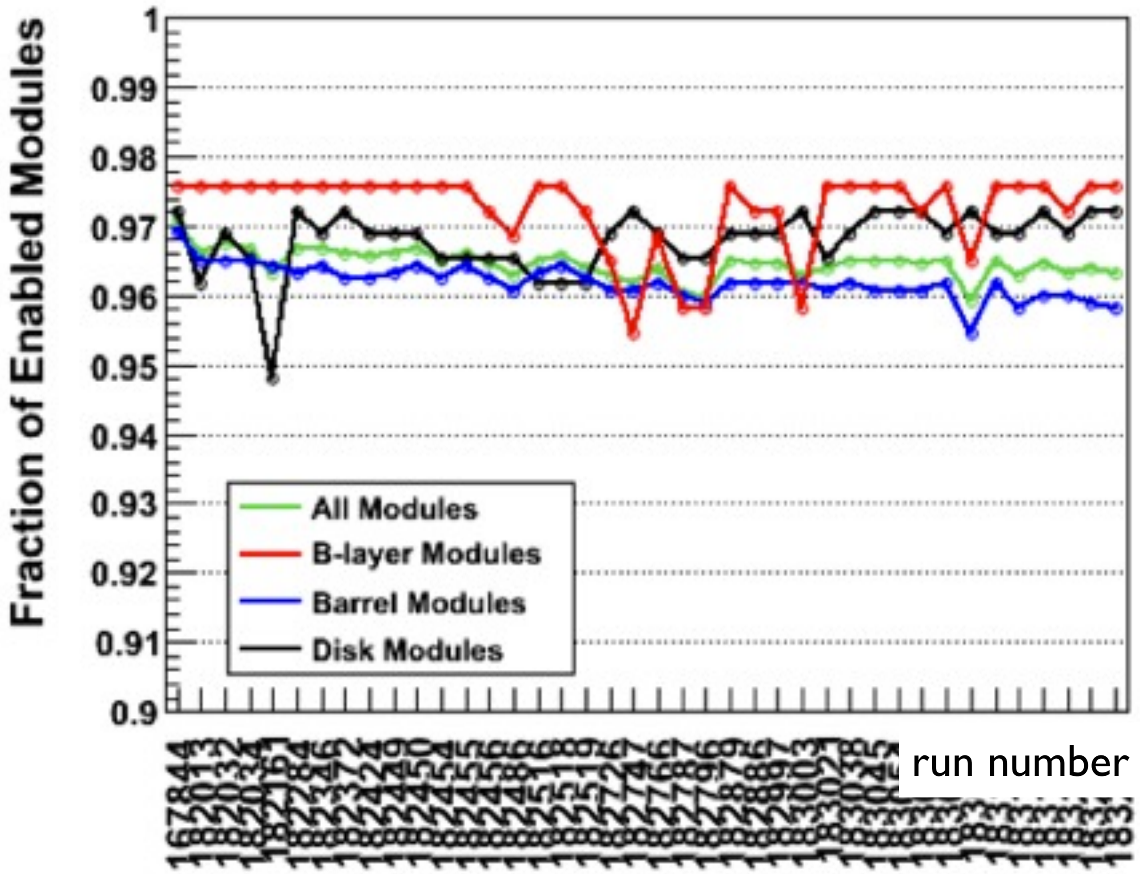




- At 3500e threshold, the in-time threshold is of 4800e for normal pixels
- Time-walk can be compensated by on-chip hit doubling using ToT information
  - Using this method the in-time threshold for normal pixels is reduced to 3700e, with an overdrive of only 200e

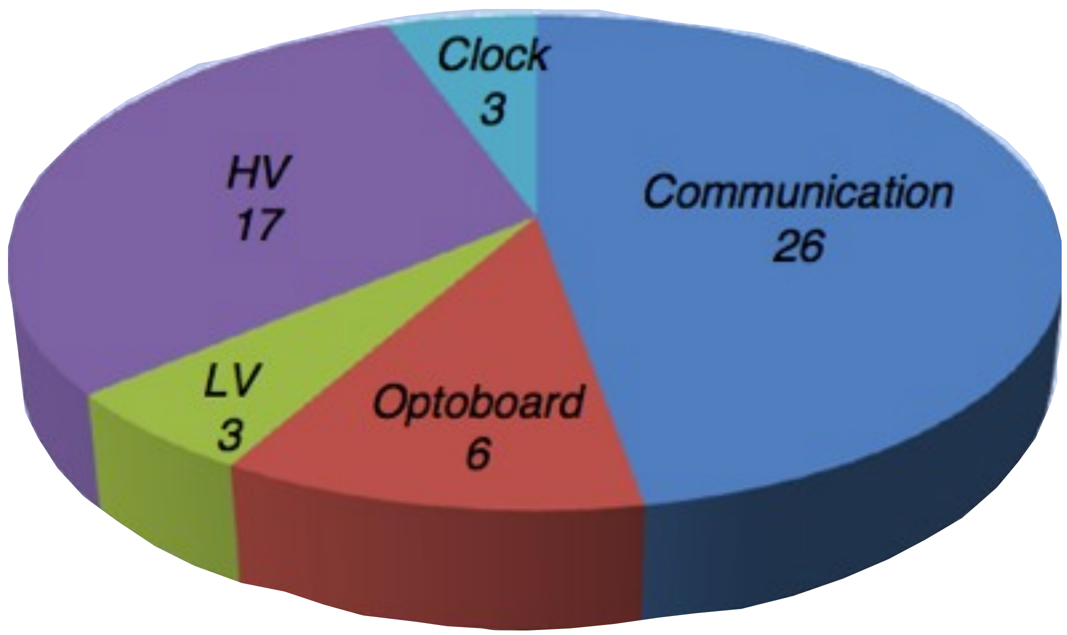
Status of the Pixel detector

- 96.8% of the modules are active in data-taking
  - 55 modules disabled (6 of them due to a single optoboard failure)
  - 47 FE chips disabled (0.17%)
- Failures are generally linked to thermal cycles
  - If possible, keep always the cooling ON
  - If the cooling goes OFF use a two-step temperature adjustment to cool down the modules

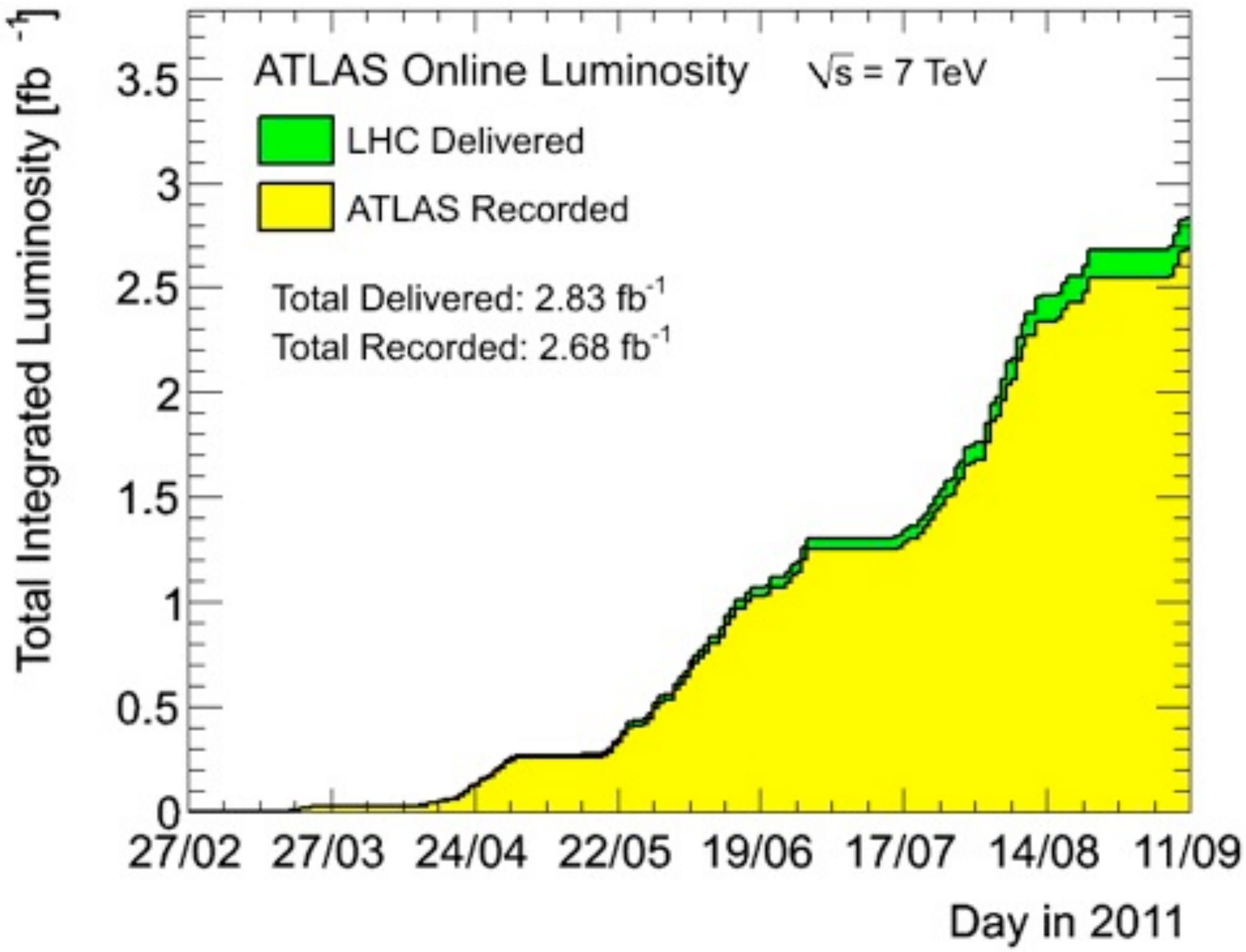


Inactive fraction per layer	
b-layer	3.1%
L1	1.4%
L2	4.6%
Endcap A	2.8%
Endcap C	2.8%

disabled modules by failure type



Data-taking efficiency



The LHC is doing great, more than 2.5 fb^{-1} have been delivered already!

Small difference between delivered and recorded luminosity: ATLAS is doing great too!

Pixel data-taking efficiency 99.9%
Mainly dominated by switch-on time, now being reduced

Inner Tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.9	100	90.0	91.3	94.8	98.2	99.5	99.7	99.9	99.6	99.6	99.4

Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at √s=7 TeV between March 13th and August 13th (in %). The inefficiencies in the LAr calorimeter will largely be recovered in the future.

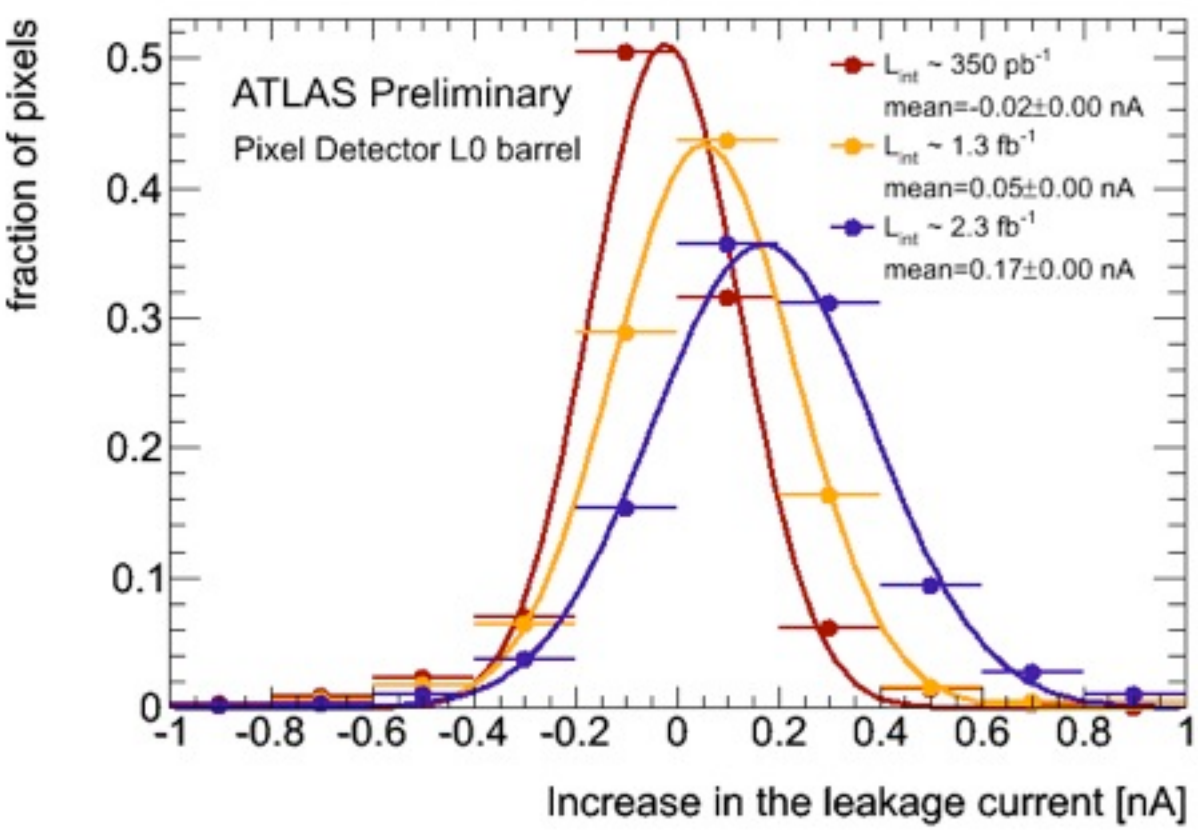
Radiation damage effects

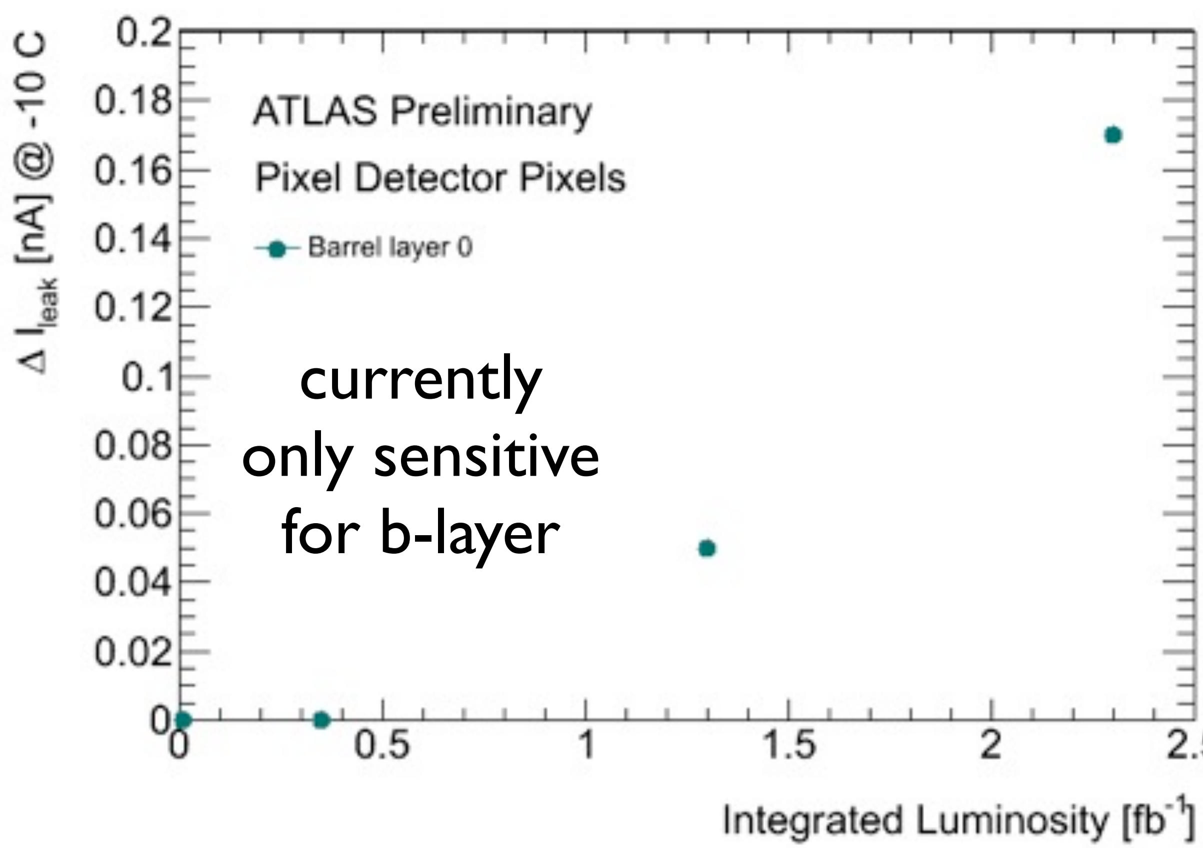
- As the delivered LHC luminosity increases, the pixel detector will receive doses of up to 50 MRad and a fluence of ~10^{15} neq cm^{-2} during the operational lifetime.
  - The innermost layer is expected to undergo type-inversion after 10 fb^{-1} integrated luminosity (with optimal annealing).
- Bulk damage resulting in crystal defects will alter the physical properties of the sensor and change the operating conditions: depletion voltage, increase of the leakage current, reduction of the charge collection efficiency.
- ATLAS has a careful program in order to simulate and monitor the radiation damage effects in the Pixel detector
  - Simulation of the radiation damage effects including charge trapping and a realistic treatment of the signal induction in the pixel electrodes.
  - Monitoring of the leakage current
  - Depletion voltage measurements
  - Regular measurements of the depletion depth using particle tracks (depletion depth has still the nominal value of 250 µm).

Leakage current measurements

- Single pixel leakage current measurements have become sensitive for integrated luminosities of above 1 fb^{-1}
- Measurements of the increase of the leakage current at the module level
  - Dedicated pixel-by-pixel scans
  - HV power supply sensitivity: 80 nA (6 or 7 modules per HV channel)
  - Specialized current monitoring boards with sensitivity of 10 nA

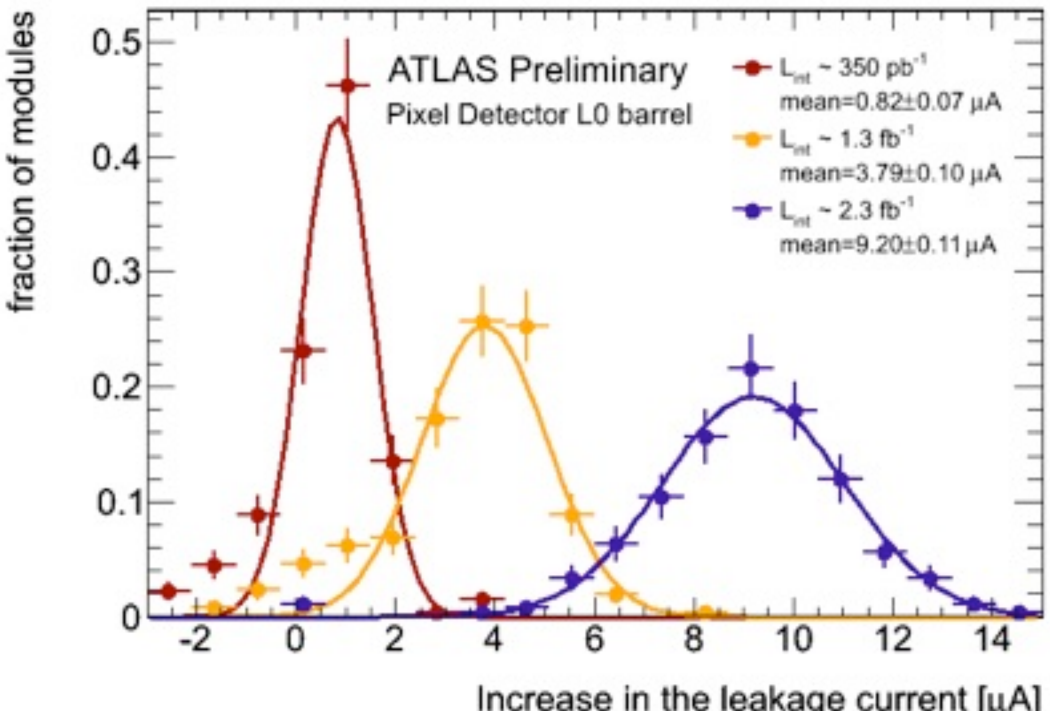
Pixel leakage current measurements

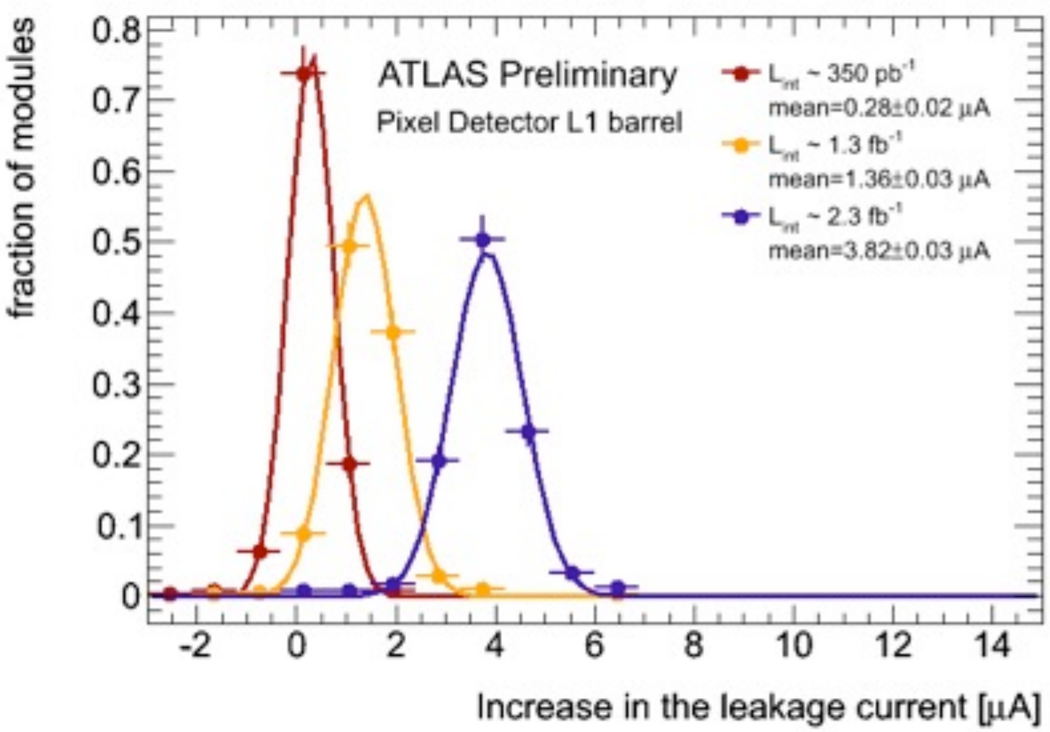


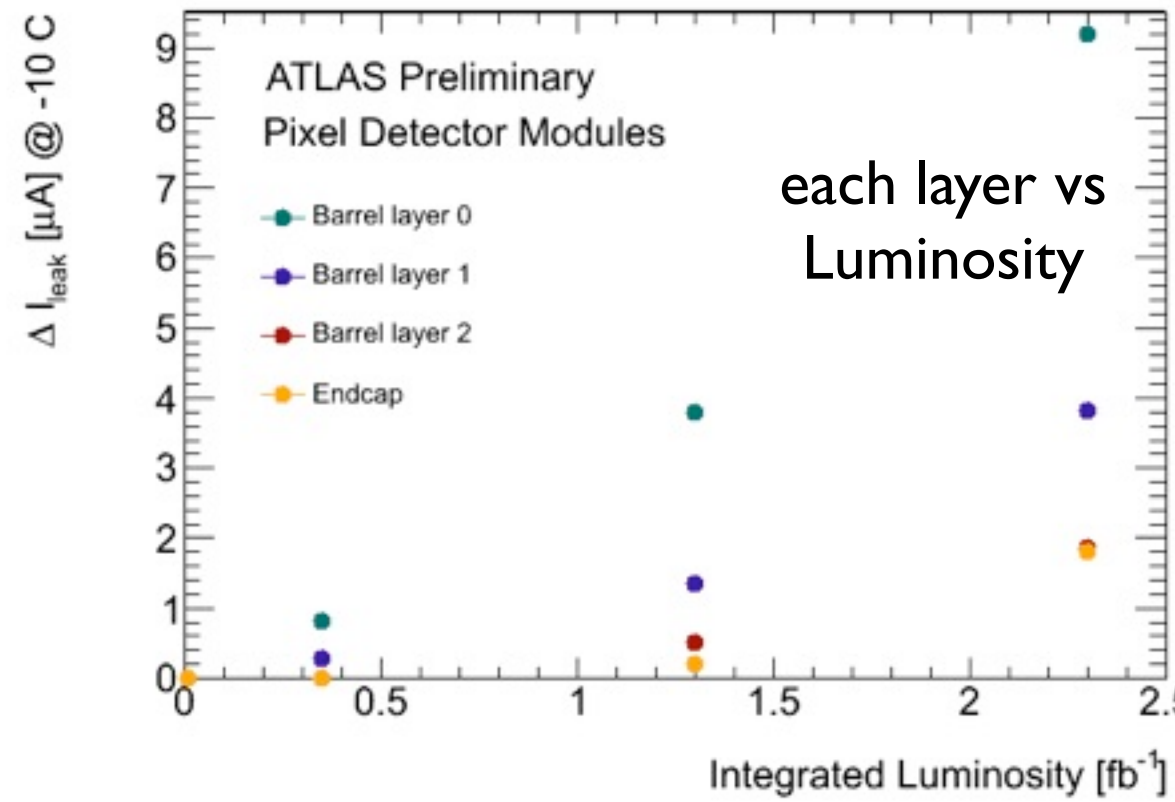


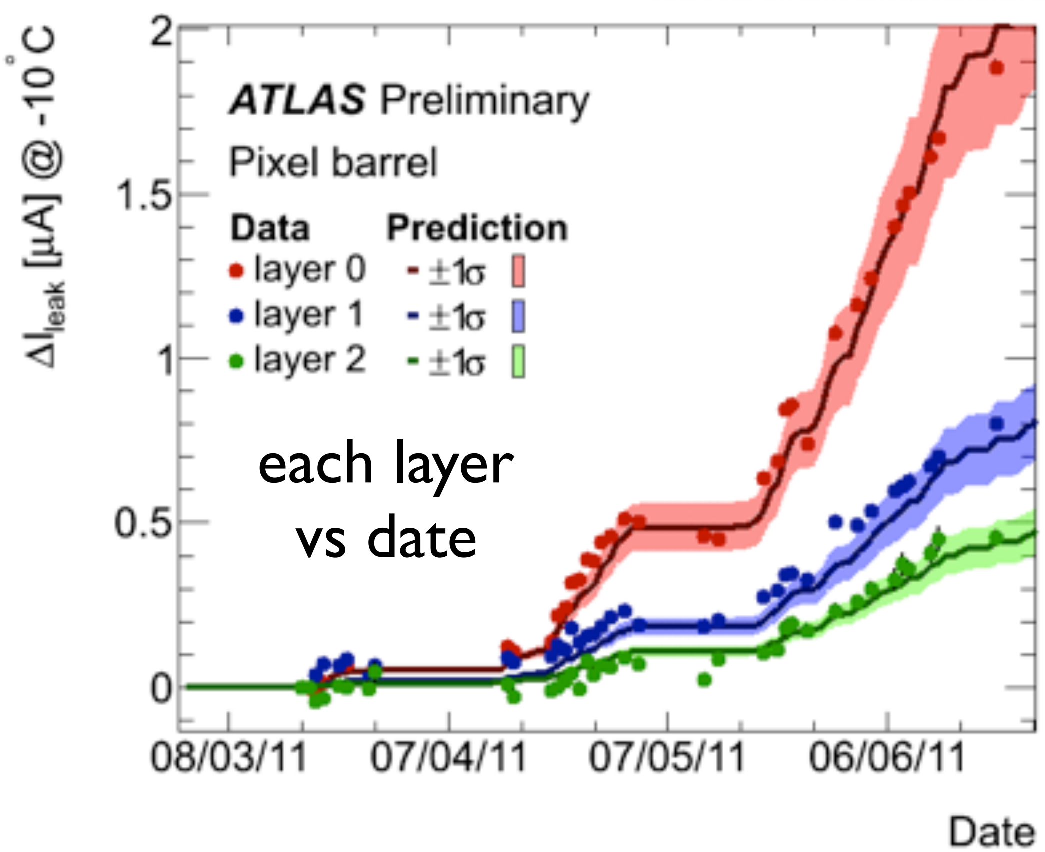
Module leakage current measurements

Leakage current module-by-module increase for different luminosities (inner barrel layers)





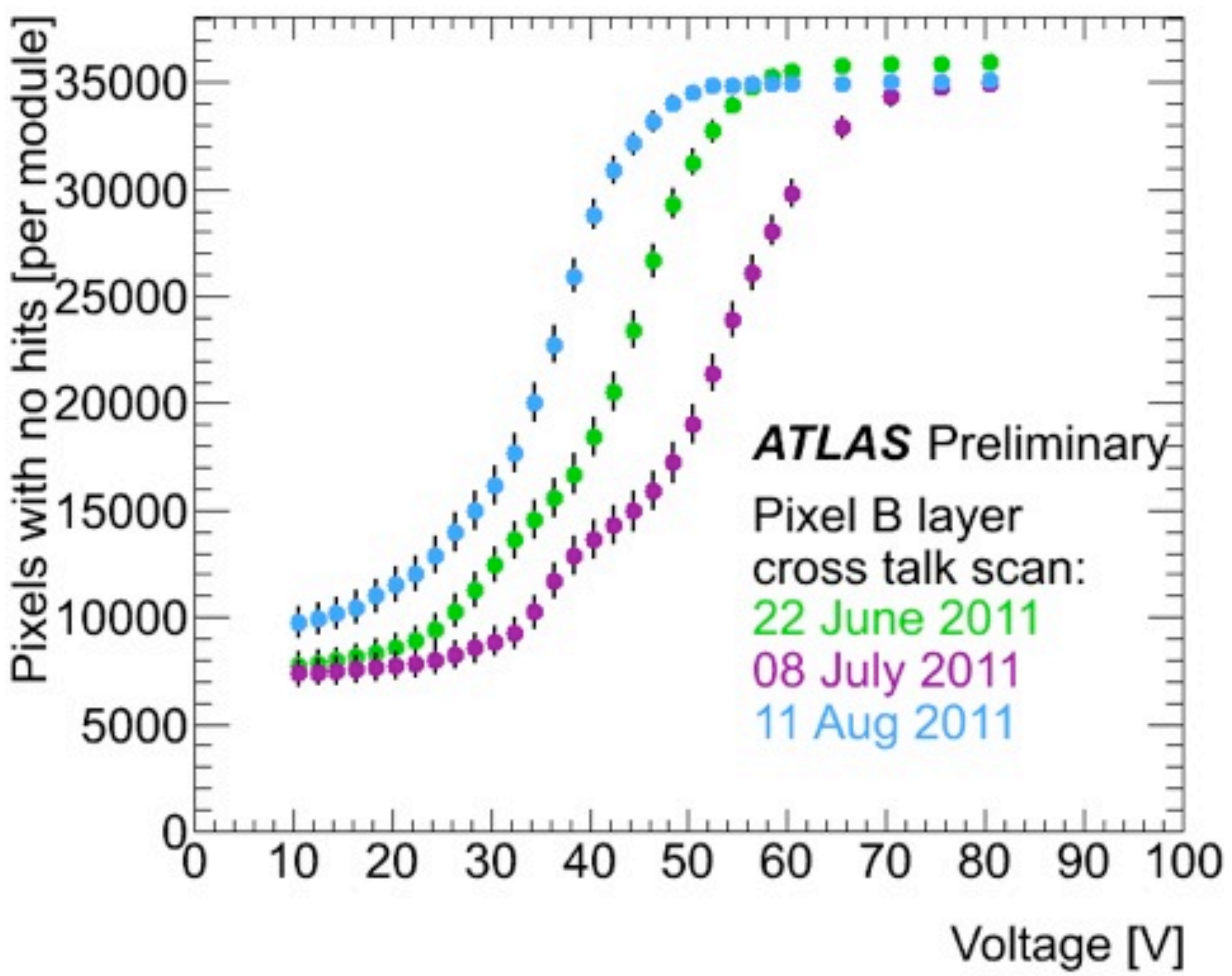




Depletion voltage measurements

- Use cross-talk measurements (before type-inversion):
  - Inject charge into one pixel, read out neighbor.
  - When not fully depleted, high-ohmic short between pixels. When fully depleted, pixels are isolated from each other.
  - Choose injected charge such that cross-talk hits are seen only for Vbias < Vdep

- Observe decrease in average depletion voltage from June to August.
- Annealing effects induced an increase of the Vdep from June to July

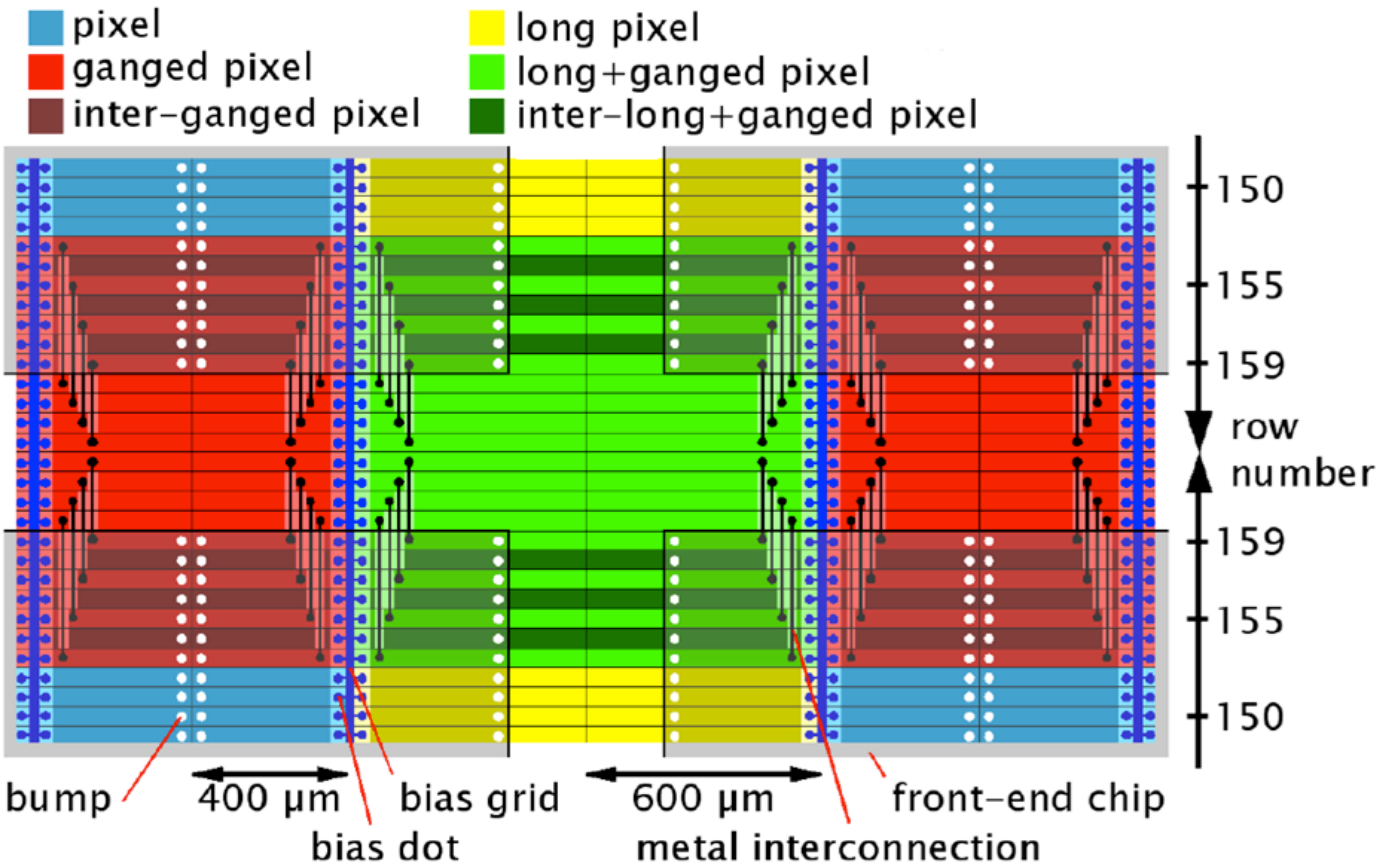


Conclusions

- The ATLAS Pixel detector has been calibrated and tuned to a stable working point
- Good performance
  - Threshold dispersion ~40e, average noise ~170e
  - Data-taking efficiency > 98%
- Very stable detector operations
- Ready for the future: radiation damage effects
  - A first simulation of the radiation damage effects in the pixel detector including charge trapping and a realistic simulation of the signal induction process in the electrodes is available
  - A carefully designed monitoring program is being developed to control the radiation damage effects in the detector
- Very exciting times to come!

Back up slides

The inter-chip region



Spatial resolution

- For details on alignment, see Jochen Schieck's talk.
- The residuals distributions after alignment show a width close to MC for a perfectly aligned detector
- The resolution on the beam direction coordinate is of 115 mm