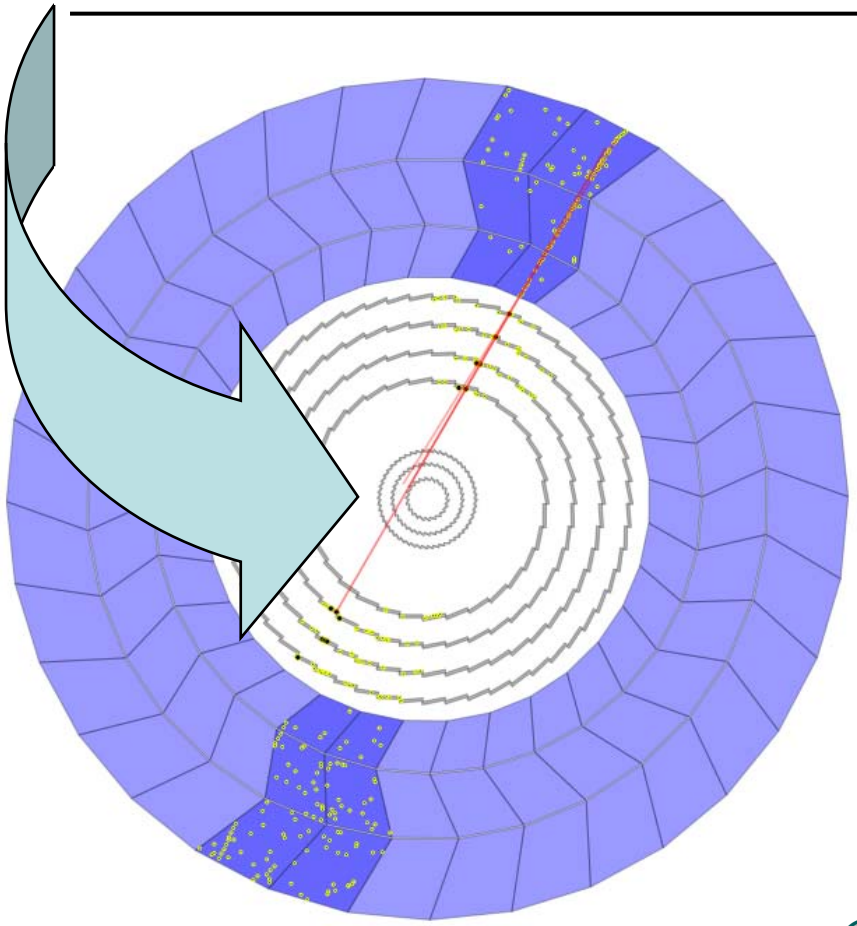
Commissioning of the ATLAS Pixel Detector with Cosmic Data

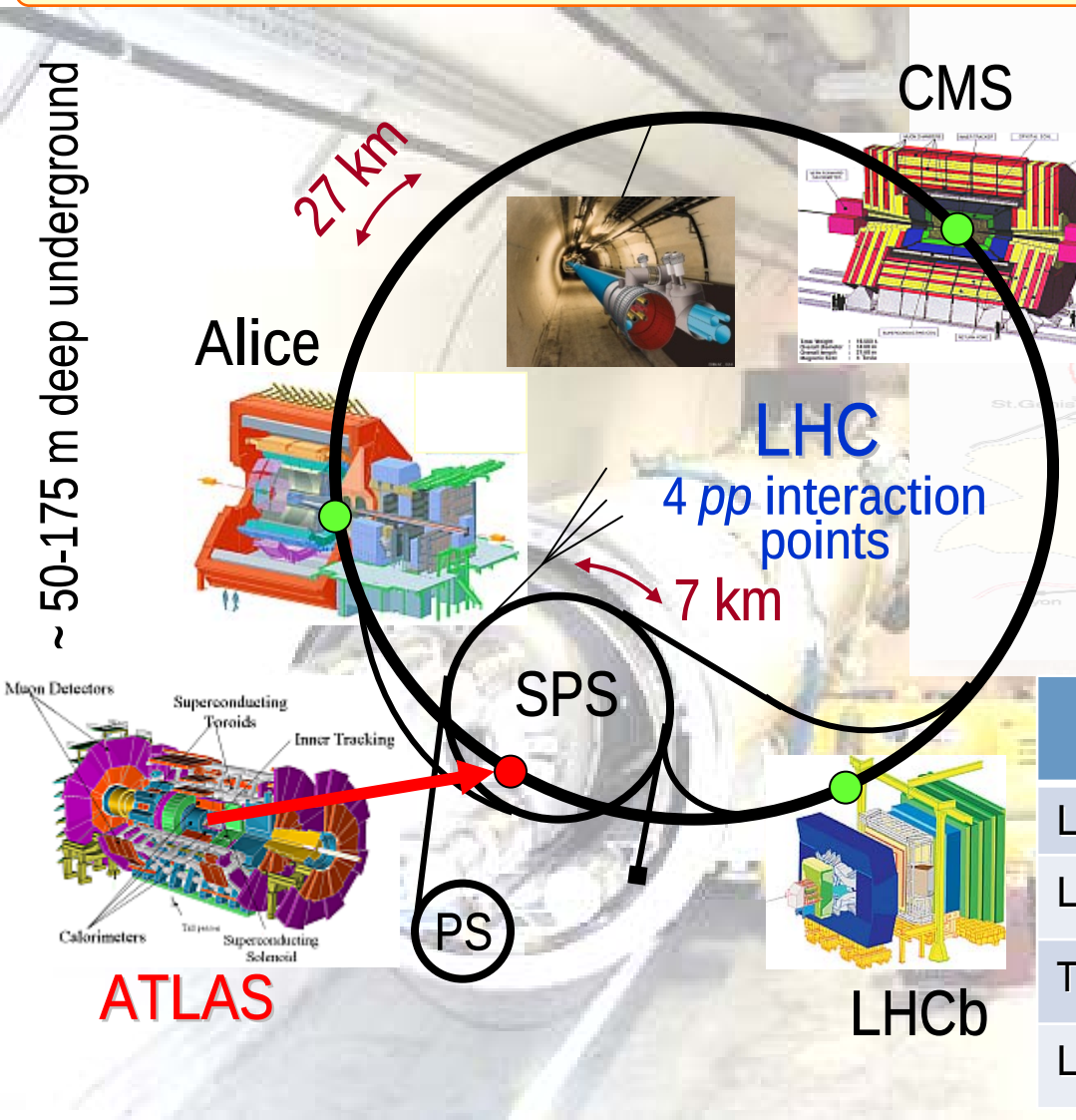


- Overview
  - LHC and ATLAS
  - Pixel Detector
- Commissioning
- Readout
- Calibration
- Cosmic Runs

Evgeny Galyaev
(University of Texas at Dallas)
On behalf of the ATLAS Pixel Collaboration

LHC: Large Hadron Collider

MOTIVATION: To find Higgs Boson and discover New Physics beyond Standard Model

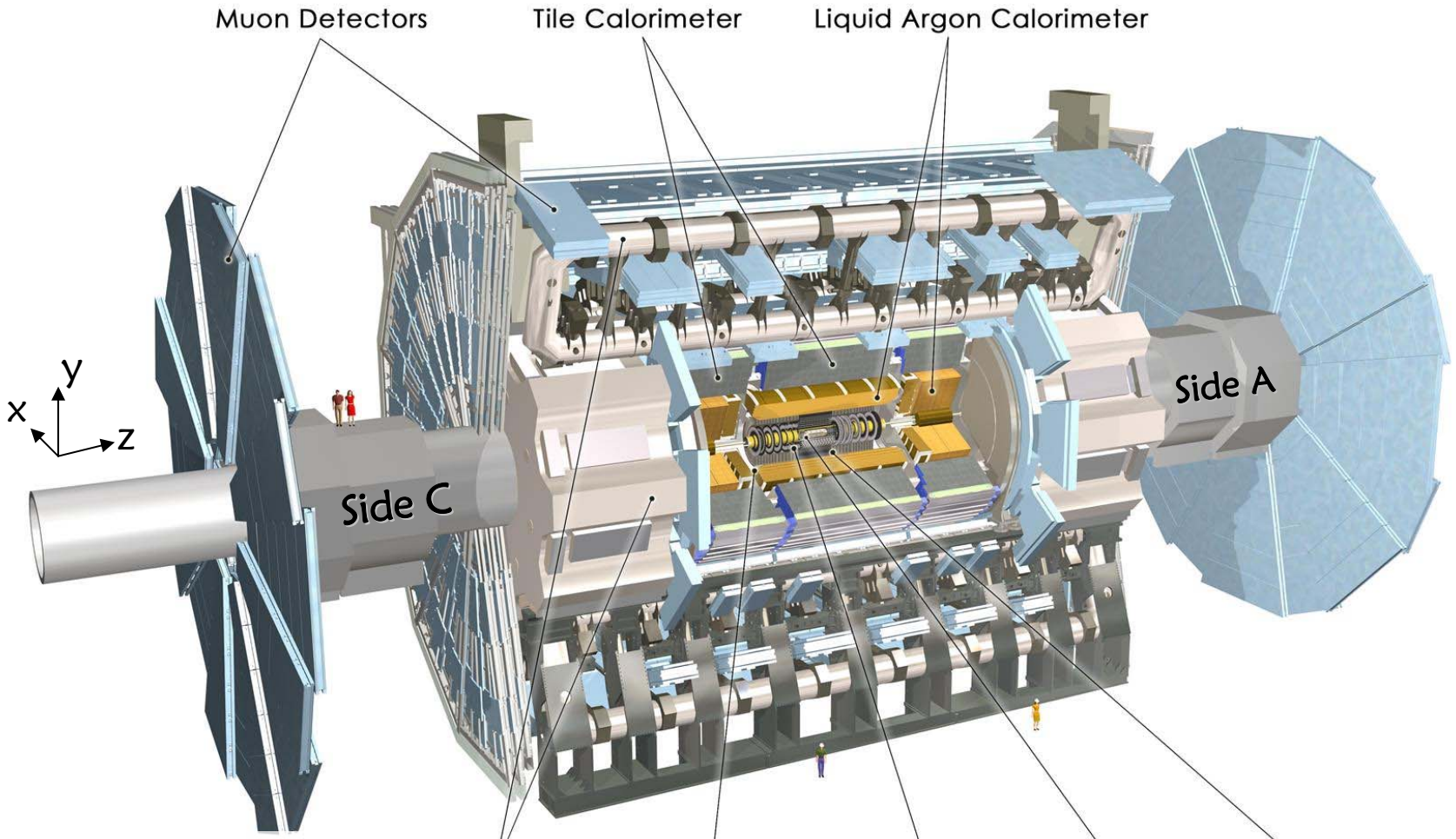


- 1232 dipoles, 858 quadrupoles;
- Dipole field 8.3T at 1.9°K;
- 96 tons of liquid *He*;
- 2808 proton bunches
- 25 ns bunch crossings
- ~1.15 x 10^{11} protons / bunch
- 40M collisions / second!
- 350MJ stored energy / beam

37 kgs worth of cheese fondue!

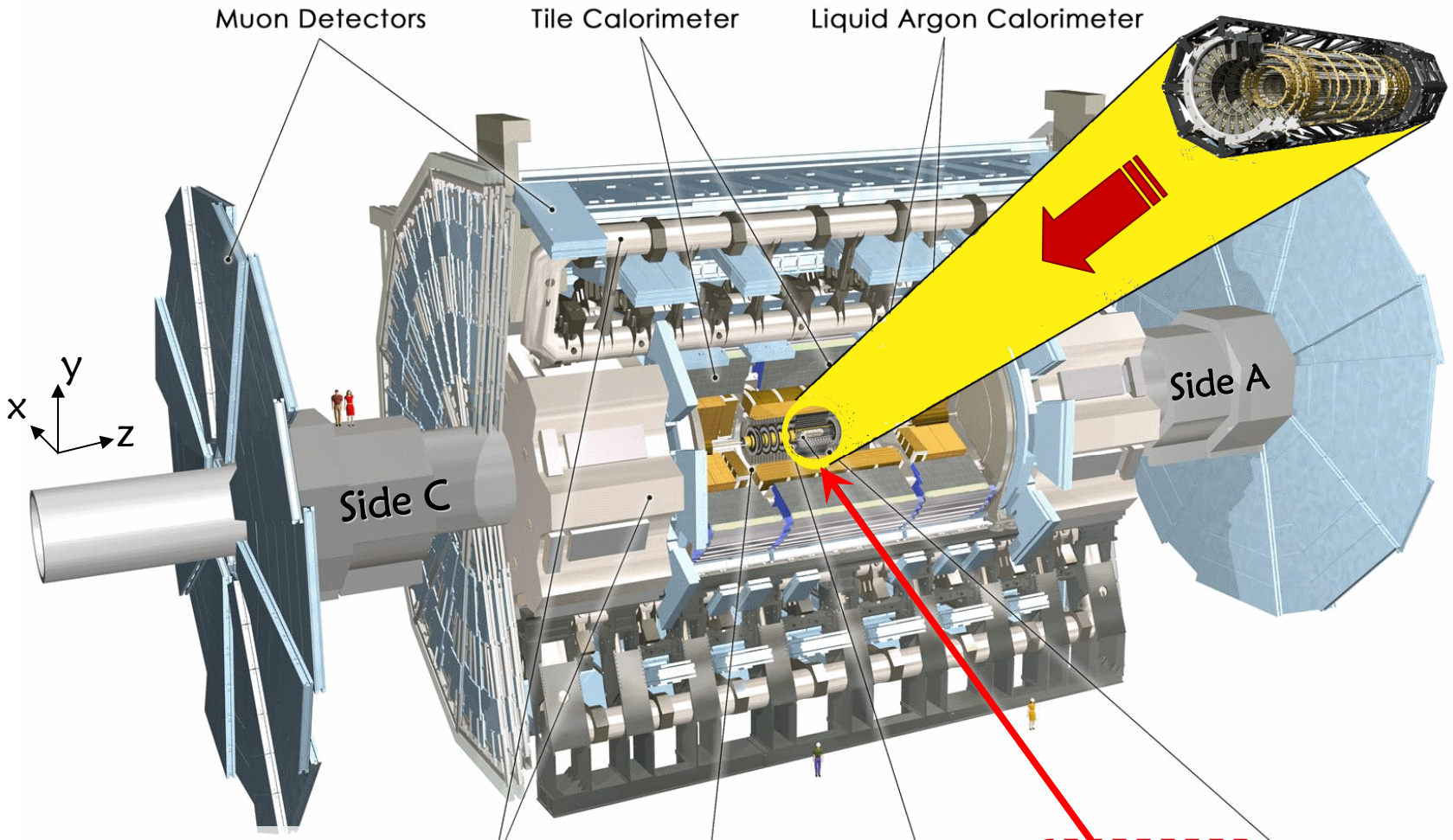
Machine	Beams	Energy	Luminosity
LHC	p p	14 *TeV*	10^{34} $cm^{-2}s^{-1}$
LHC	Pb Pb	5.5 *TeV*	10^{27} $cm^{-2}s^{-1}$
Tevatron	p $\bar{p}$	2.0 *TeV*	10^{32} $cm^{-2}s^{-1}$
LEP	e^+ e^-	200 *GeV*	10^{32} $cm^{-2}s^{-1}$

ATLAS: A Toroidal LHC ApparatuS



- 44m long;
- 22m high;
- 7K tons heavy;

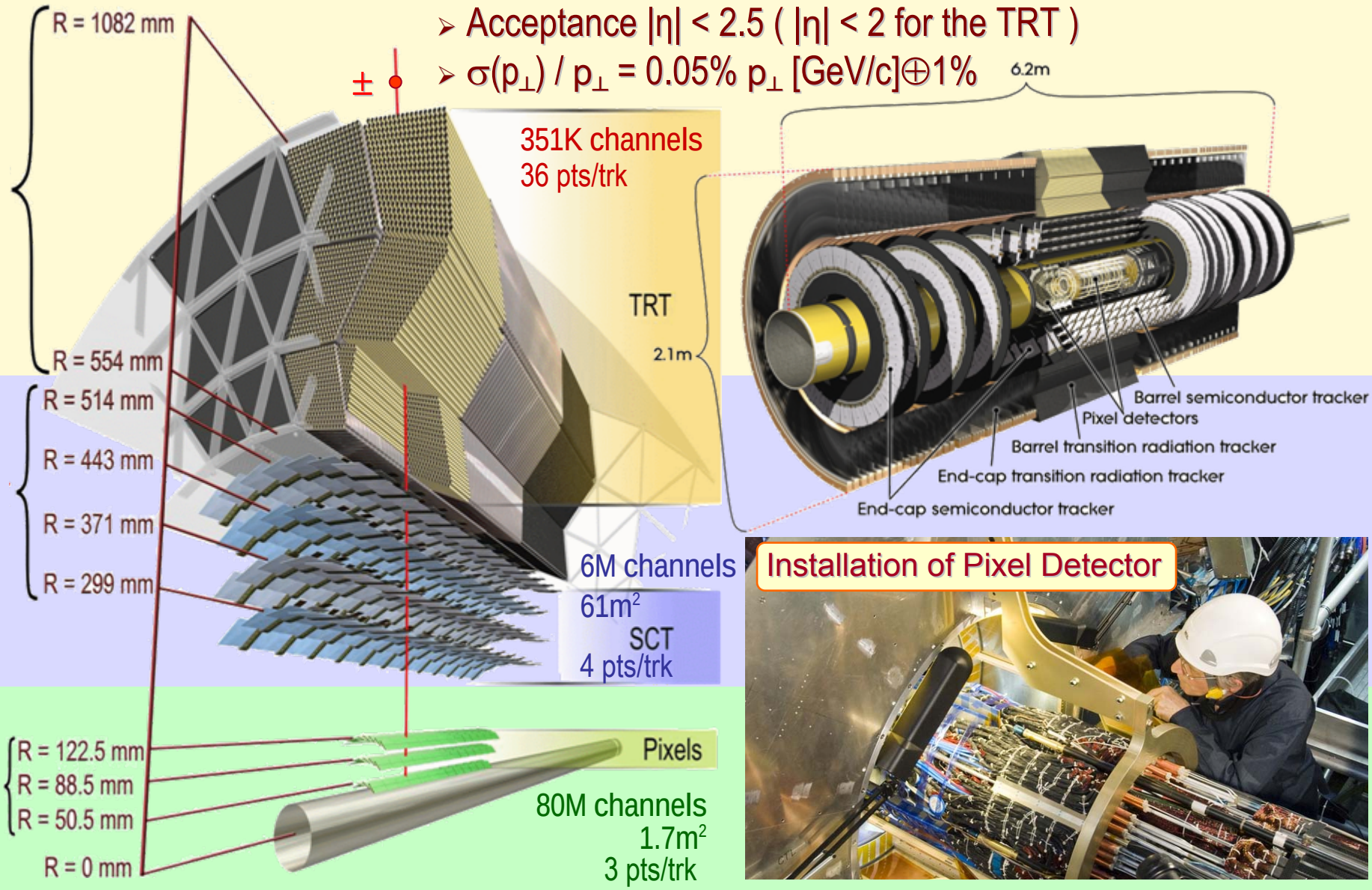
ATLAS: A Toroidal LHC ApparatuS



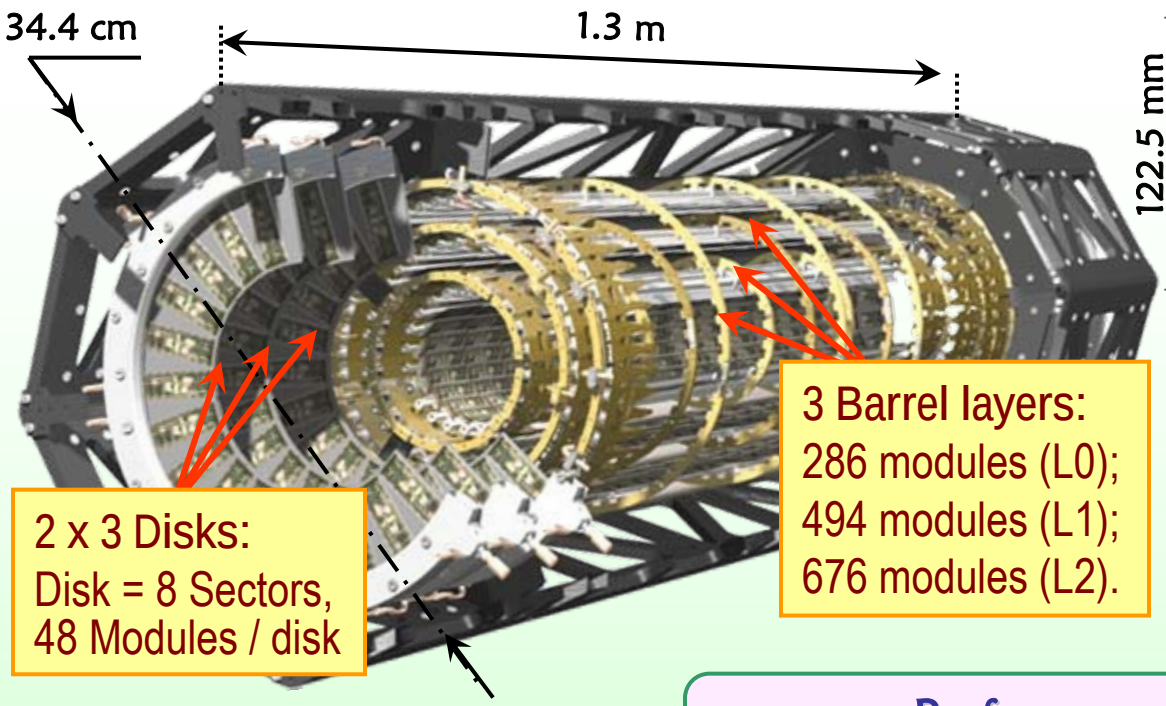
- 44m long;
- 22m high;
- 7K tons heavy;

ATLAS Inner Tracking Volume

- Acceptance $|\eta| < 2.5$ ($|\eta| < 2$ for the TRT)
- $\sigma(p_\perp) / p_\perp = 0.05\% \, p_\perp \, [\mathrm{GeV}/c] \oplus 1\%$



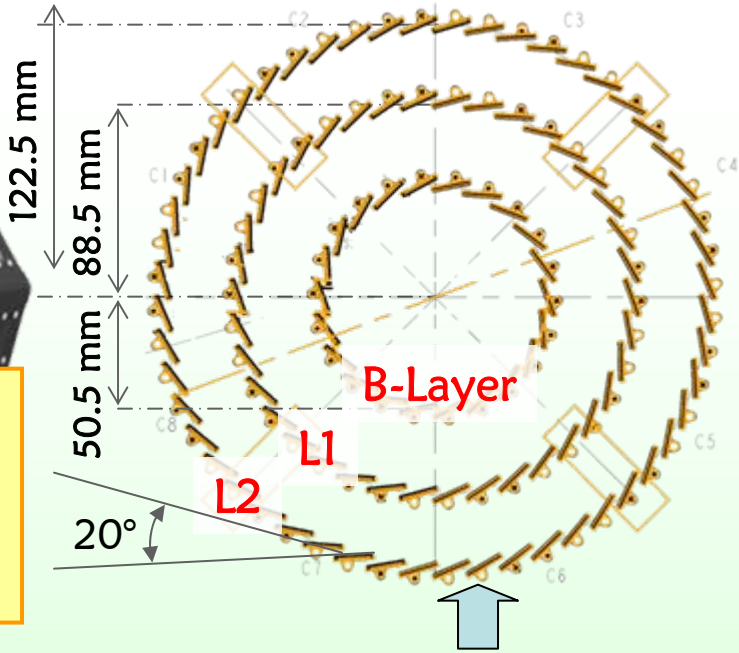
The Pixel Detector Overview



2 x 3 Disks:
Disk = 8 Sectors,
48 Modules / disk

3 Barrel layers:
286 modules (L0);
494 modules (L1);
676 modules (L2).

Barrel Cross Section



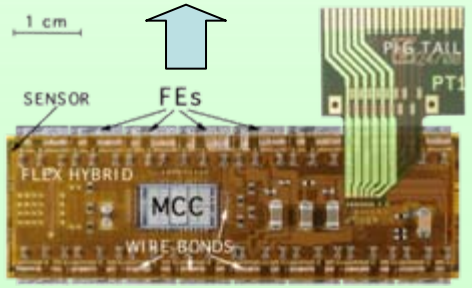
Construction

- Package weight ~ 4.5 kg
- Active sensor area ~ 1.7 m²
- Bi-phase C_3F_8 cooling
- 500 kGy or 10^{15} n_{eq}/cm^2
  ⇒ inner layer: 5 years

Performance

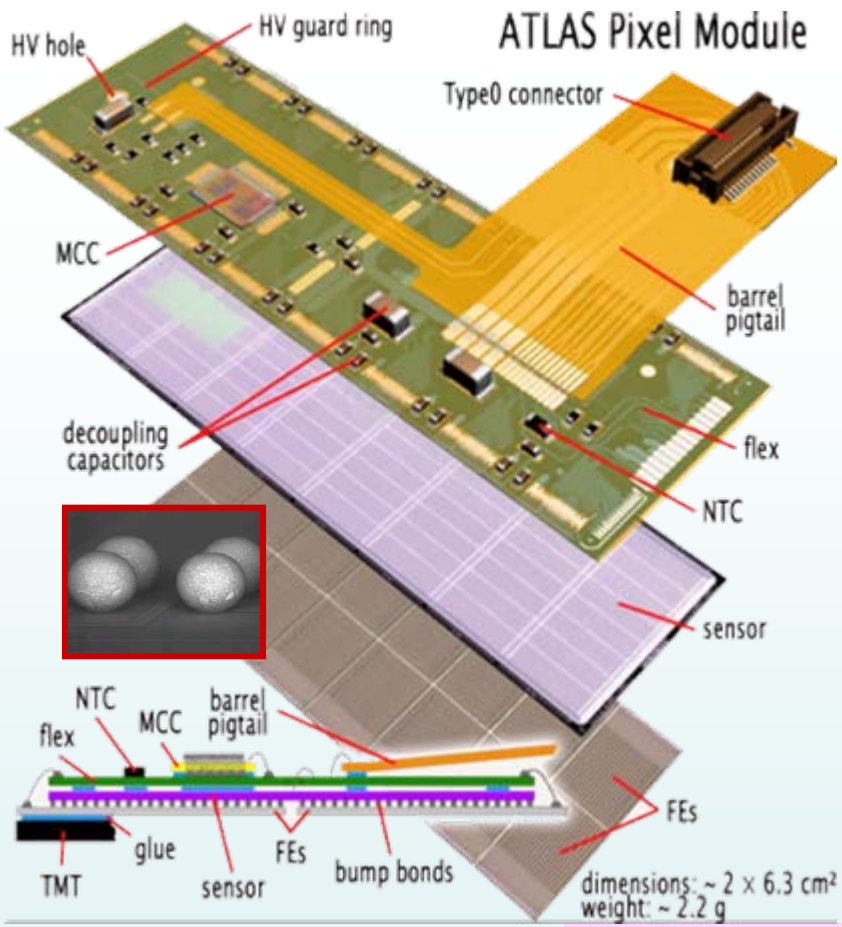
- 1744 pixel modules
- Total of ~ 80M channels
- 3-Hit Tracks
- $|\eta| \leq 2.5$
- Spatial resolution:
  15 μm in R-ϕ, 115 μm in Z

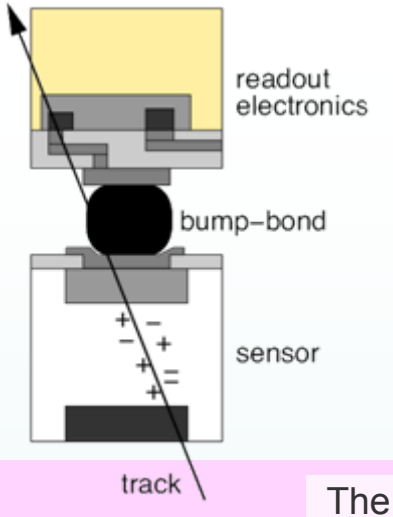
Staves with 13 Modules



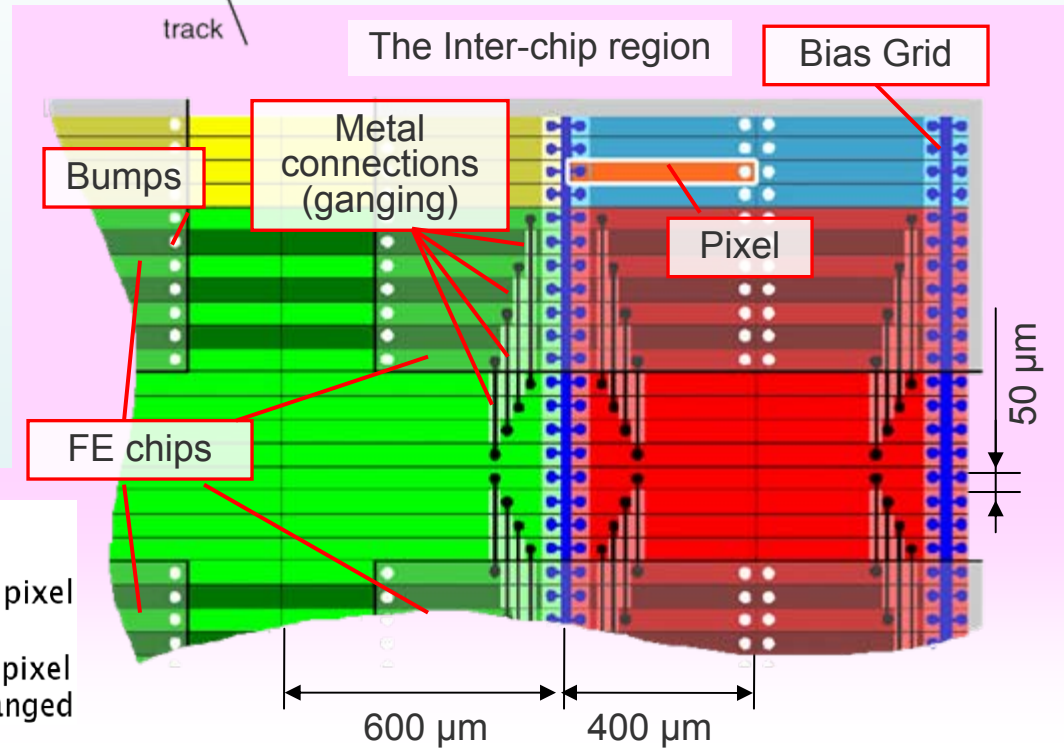
Pixel Module
= 46080 channels

The Pixel Module





- Sensor = 47232 pixels
- n^+-in-n DOFZ
- Bias 150-600 V
- 2 x 8 Front End chips
- 18 x 160 cells each



- Charge-sensitive preamps in cells
- Local threshold generators in cells

pixel
ganged pixel
inter-ganged pixel
long pixel
long+ganged pixel
inter-long+ganged

Pixel Detector: The Timeline

2007

June 22-27 — Insertion into the ATLAS Inner Detector ★

★ Pixel detector is disconnected, with no access to it

2008

February - April — Initial connection, connectivity tests and pixel detector sign-off

May - August — Environmental systems commissioning, Final integration in ATLAS DCS

July — Beampipe bakeout: successful, on-time

Pixels are on the beampipe, cooled!

August — First pass calibration (communication links)

End of August — Detector is cooled, modules are powered

September 14th to November — Combined cosmic data taking: continuous calibration adjustments, modules recovery

September 19th — LHC accident in sectors 3-4

Cosmic running becomes the top priority

Detector Tuning: Communication and Readout

1. Opto-Link Tuning

Goal: Reliable communication between the modules and off-detector Back-Of-Crate readout cards via optical links.

- Find optimal conditions for modules
- There are 6 or 7 modules on each link ⇒ not an easy task!

OFF-DETECTOR READOUT

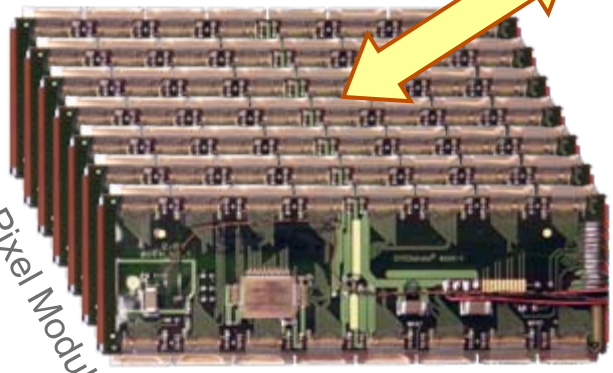
Optical communication links: commercial laser arrays and receiving diodes at both ends

~100m long optical cables

288 boards, 40/80/160 mb/s

Opto-boards

Data readout: Data-push
Receiving: Cell control logic signals: Thresh, ToT, test charge…



Pixel Modules

ON-DETECTOR

2. Module Tuning

Motivation: Initial homogenous detector response; account for degradation due to irradiation in the future.

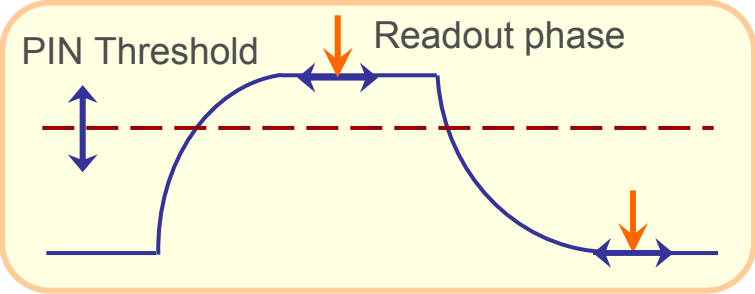
Threshold – level to tell signal from noise

Time-Over-Threshold – ToT, indirect measurement of the deposited charge from the above-threshold signal amplitude

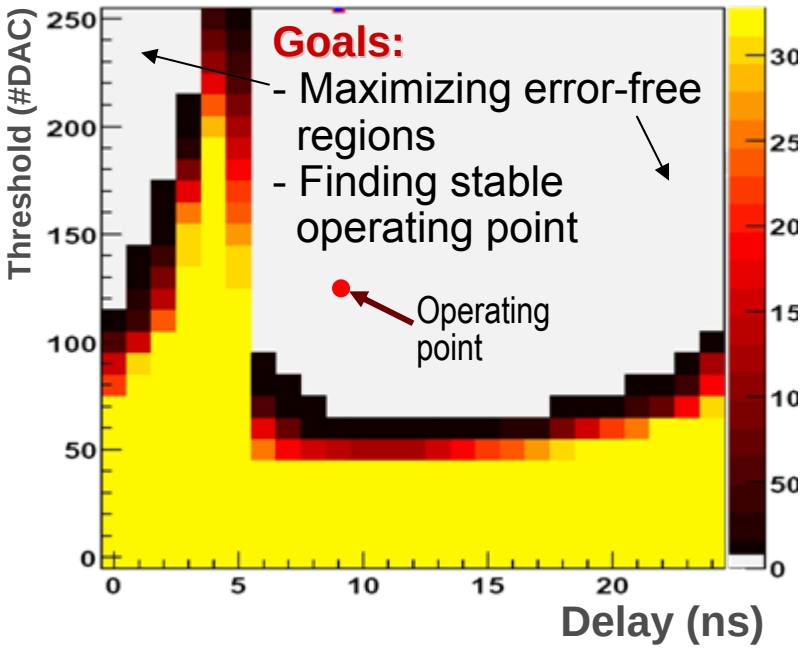
For every pixel cell

Optical Link Tuning

- The optical communication uplink is tuned by adjusting
  - The power of the on-detector lasers
    - Power of VCSEL lasers is temperature-dependent
    - One laser power setting per opto-board (6/7 channels)
  - The delay of the off-detector sampling clock
  - The PiN current threshold of the off-detector receiver diode

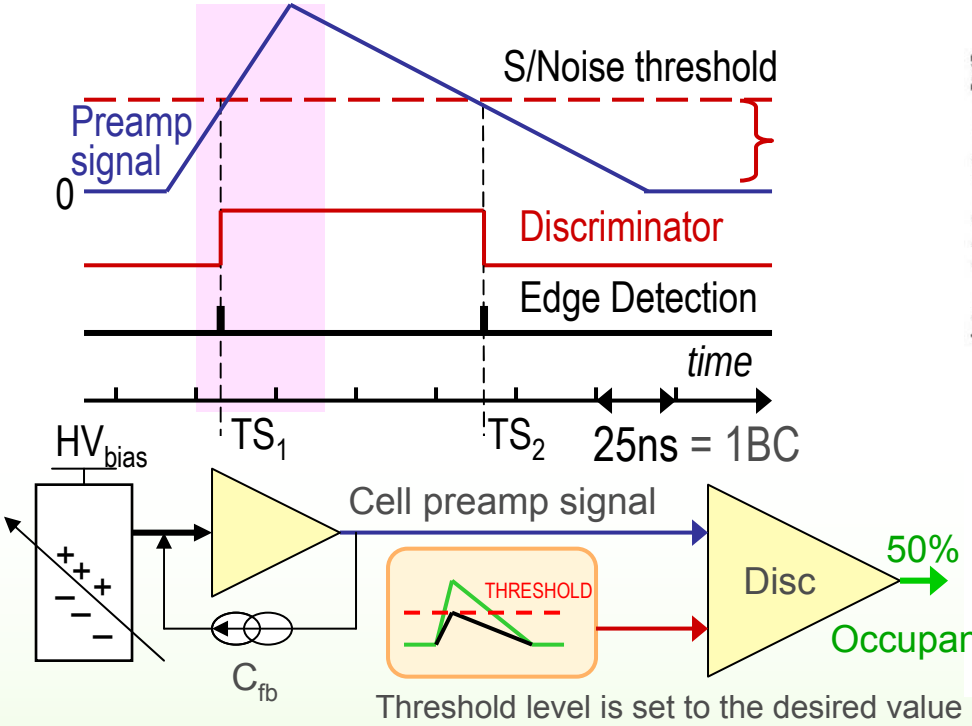


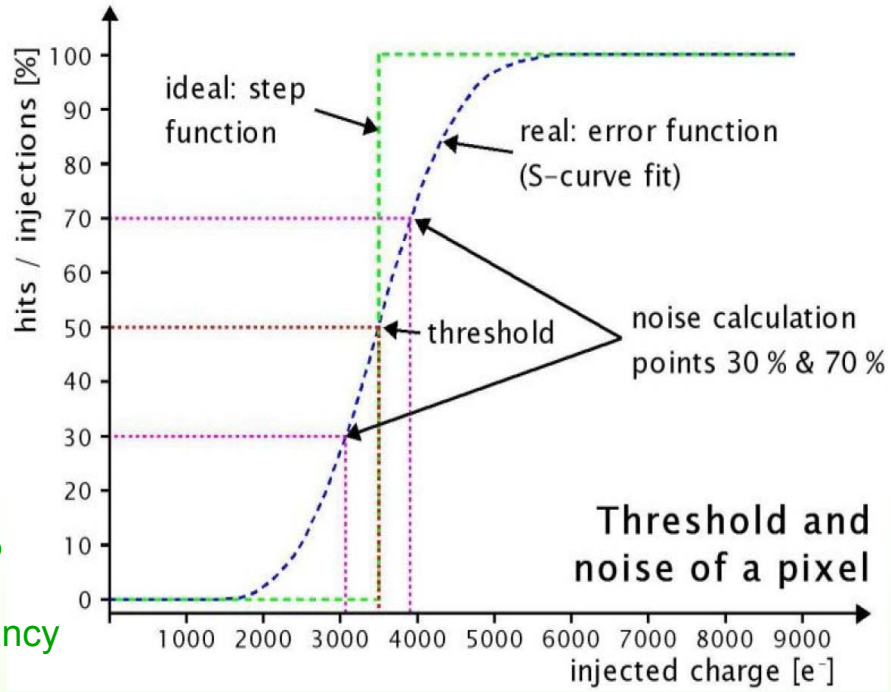
- Modules cannot be operated without good optical tuning
- Scanning 2-D parameter space
- Common stable operating point for 6/7 links has to be found
- Tuning takes ~15 min (all links)



Error rate when sending a 20 MHz clock 0-1-0-1 pattern

Threshold Tuning

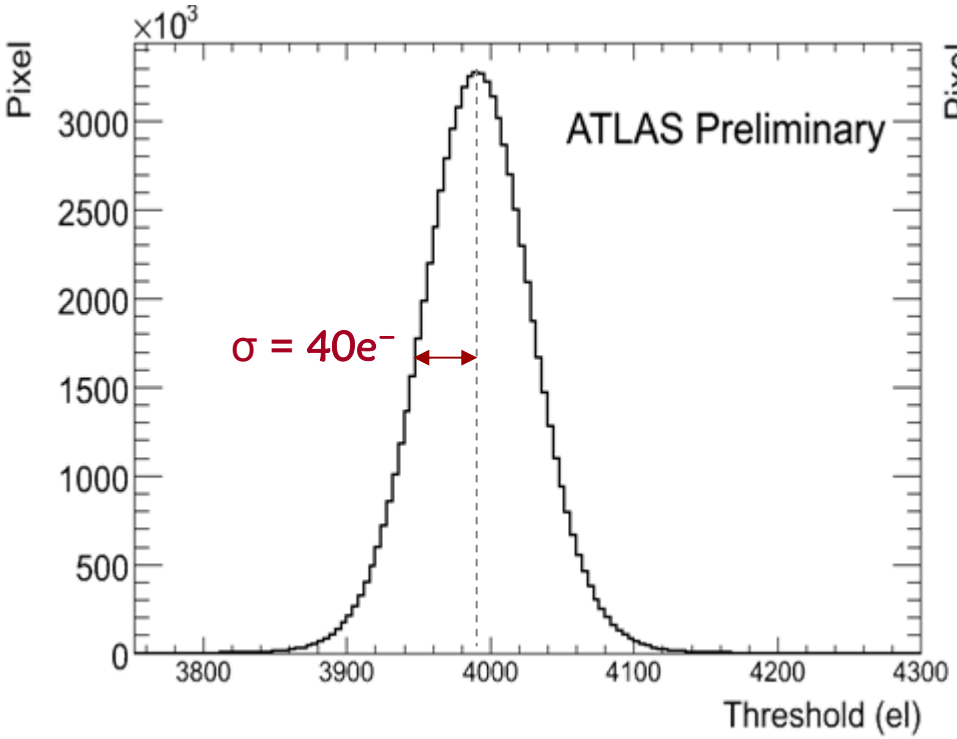


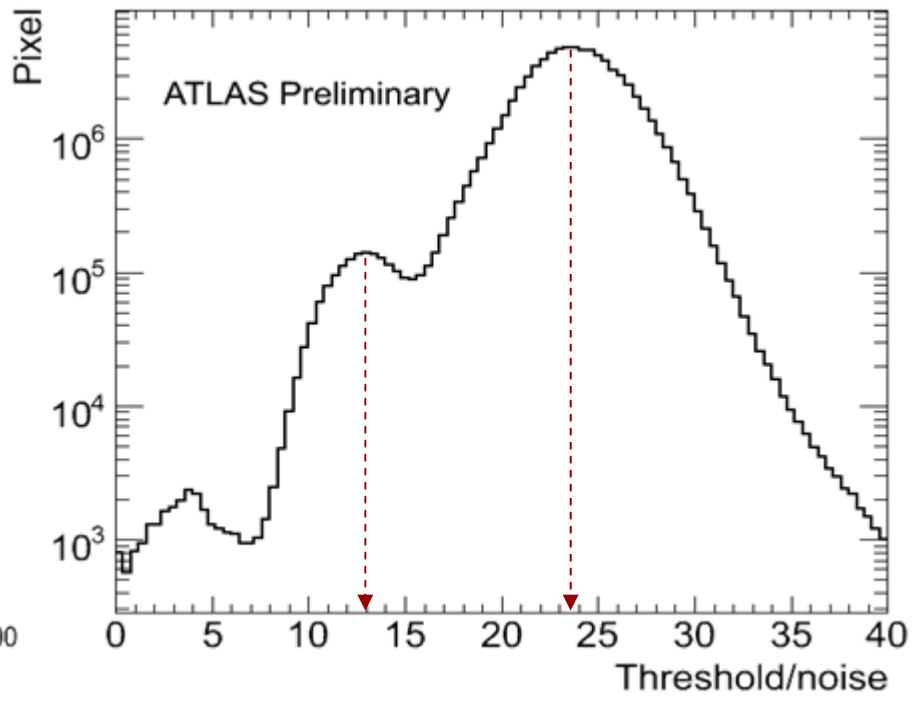


- Threshold is adjusted on pixel cell level
  - Varying charge injections in the preamp of each pixel cell via integrated in-cell calibration circuitry;
  - Fit error function to number of events vs. charge;
  - 1.5 hrs to tune the entire detector.
- September cosmic runs ⇒ production tuning
- November runs ⇒ fully tuned configuration

Performance After the Threshold Tuning

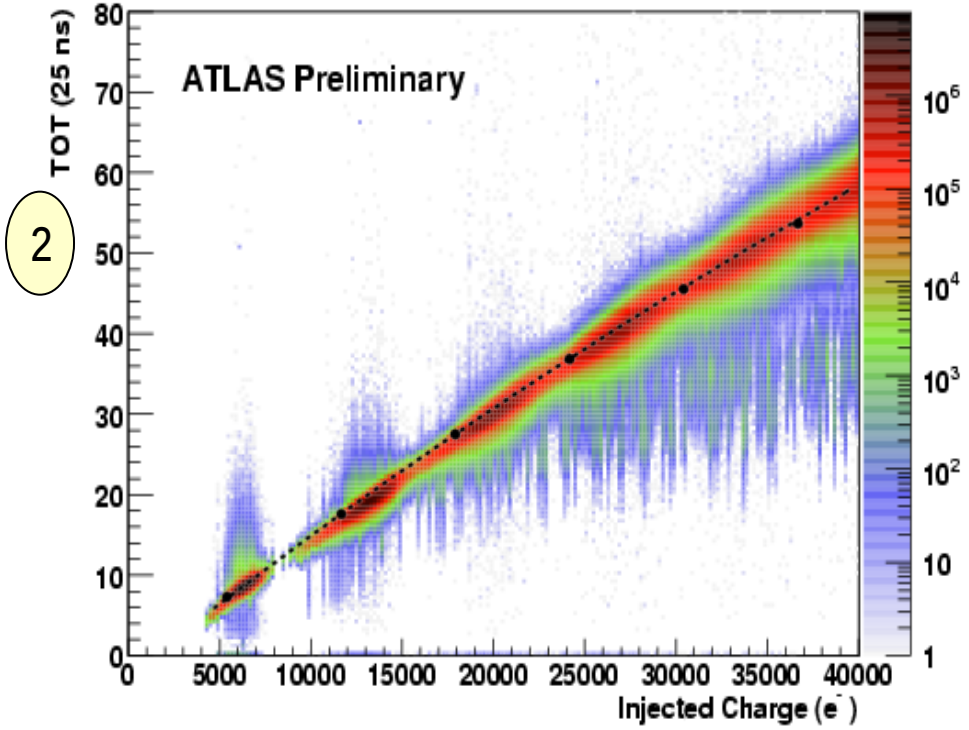
- Thresholds are tuned to 4000 e^- in November
- Dispersion is only ~ 40 e^-
  - Threshold over noise is ~ 24 for most pixels
  - Threshold over noise is ~ 13 for few special inter-chip pixels

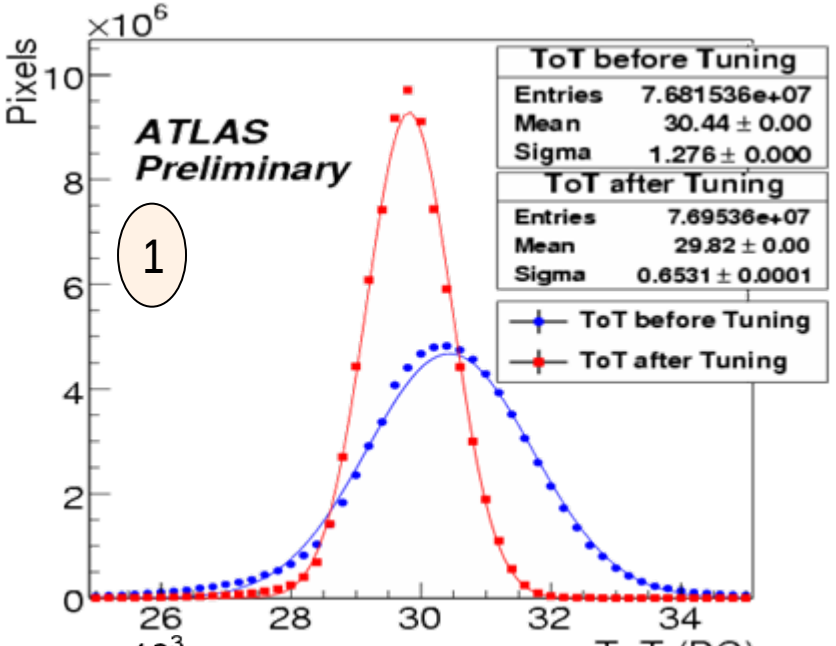


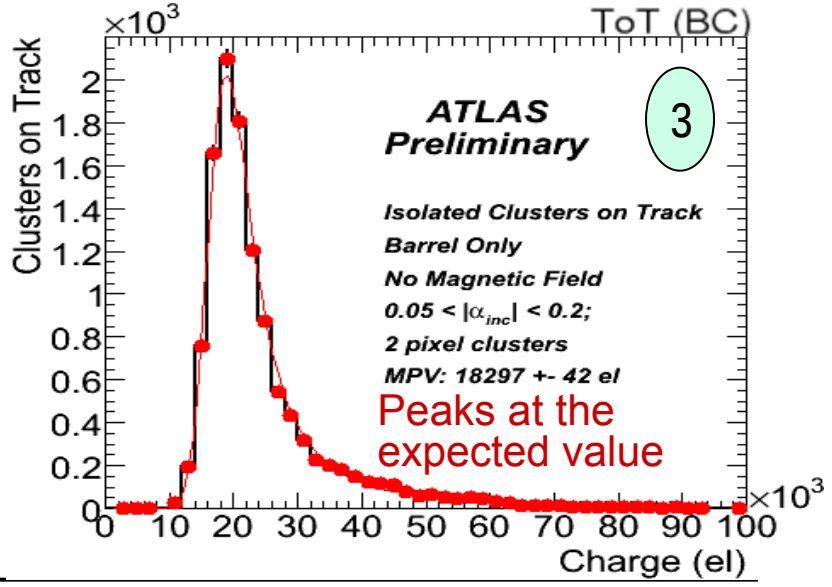


ToT (Time-over-Threshold) Tuning

- Adjust the preamplifier feedback current on FE's until a M.I.P. (20ke$^-$) corresponds to a Time-over-Threshold value of 30
- Uniform response improves accuracy for the cluster position determination
- Extract full ToT vs. charge calibration curve for each FE to use off-line

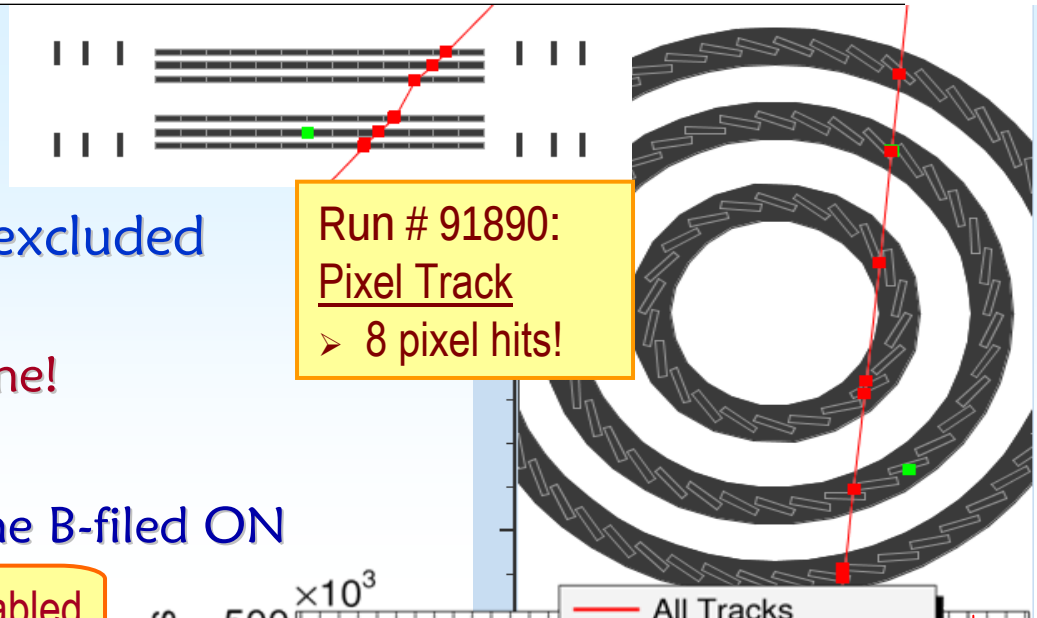


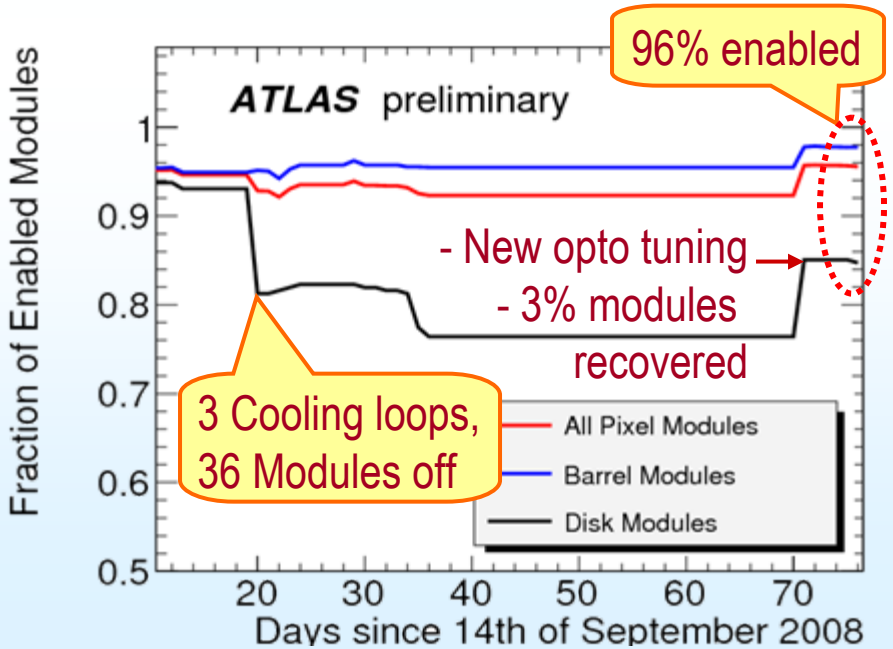


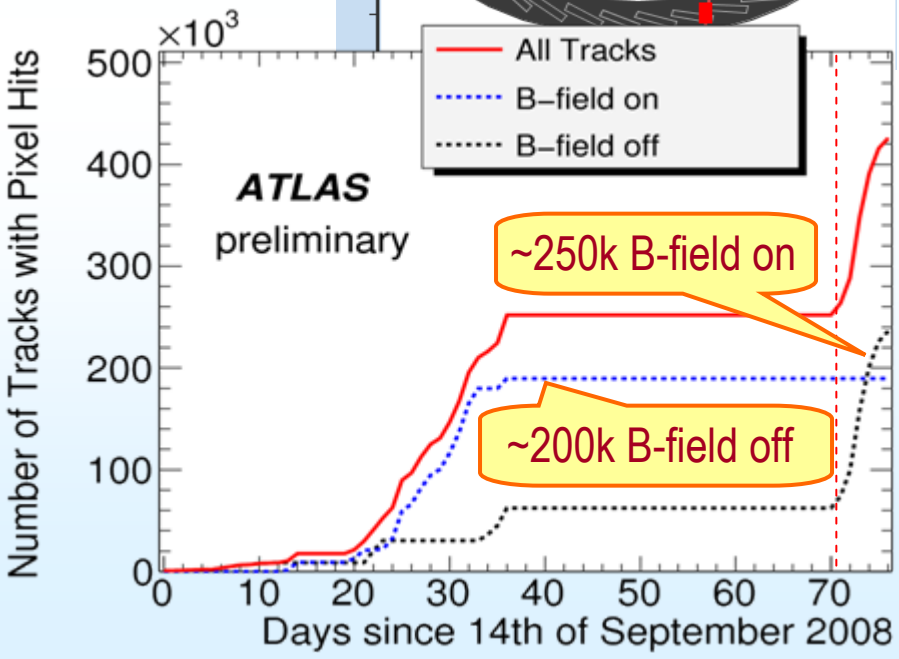


Cosmic Data Taking

- Sept 14th : First tracks!
  - Trigger used: muon triggers
- Some modules were initially excluded
  - Improved optical tuning ⇒ most modules now are on-line!
- During cosmic data taking:
  - 2/3 time B-field OFF, 1/3 time B-filed ON



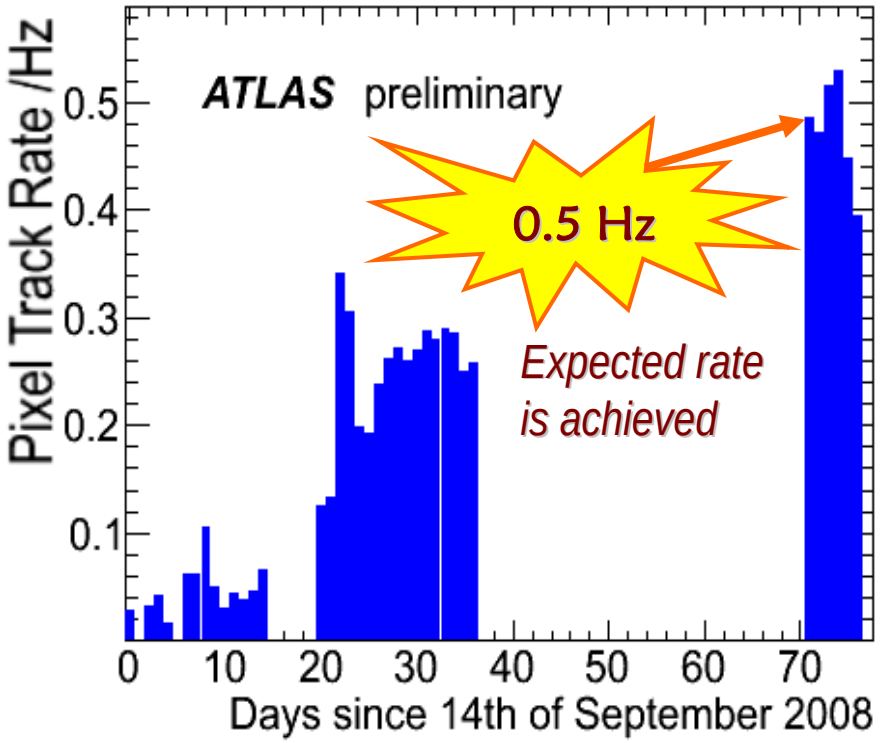


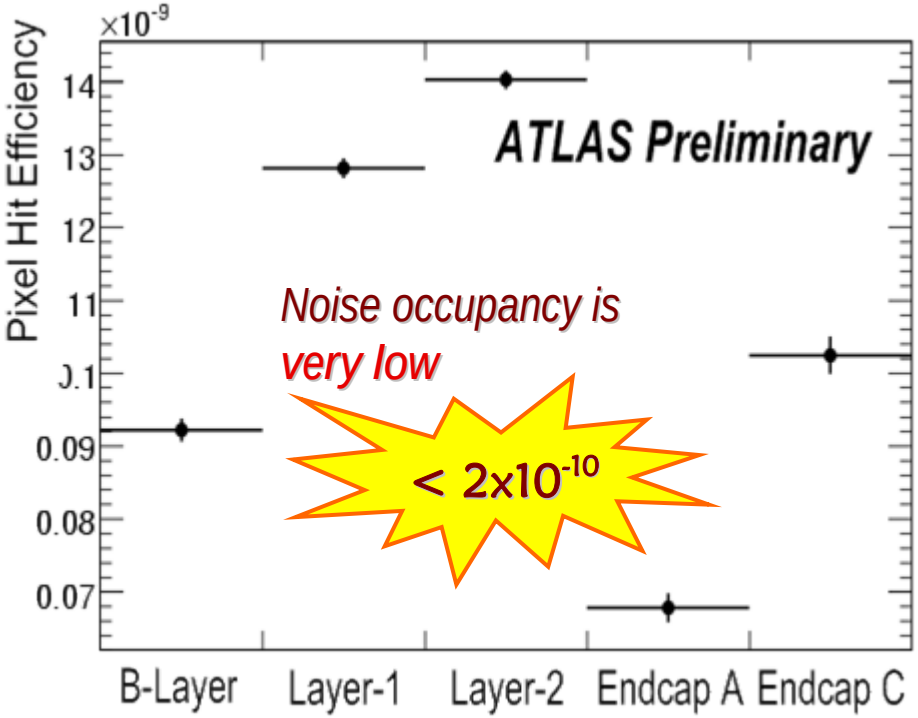


Running With the Cosmic Data

- improvements to muon trigger timing
- commissioning of HLT & TRT L1 triggers

➔ increased pixel track rate to ~0.5Hz (expected from sim.)



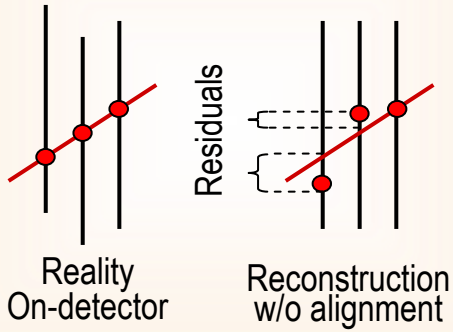


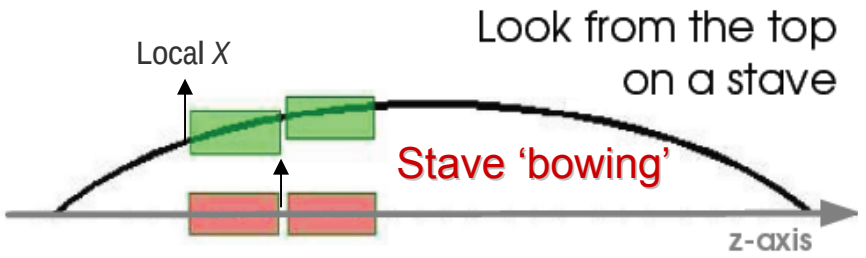
Noise: < 2×10^{-10} pixel / crossing

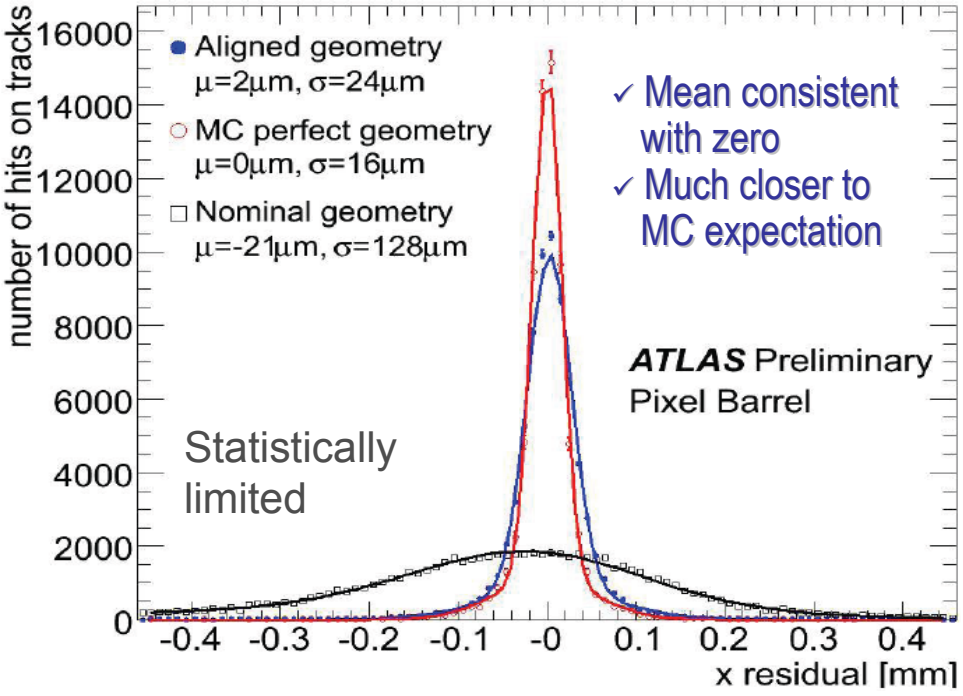
0.3-0.7 noise hits in full detector per crossing!

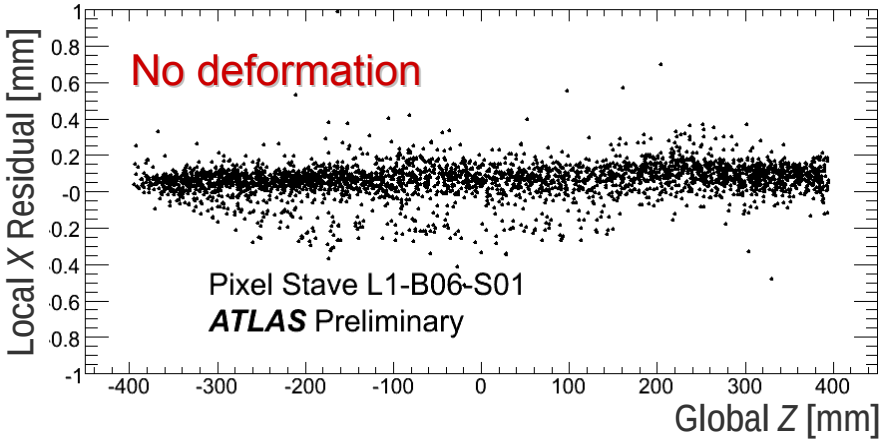
Detector Alignment with Cosmic Data

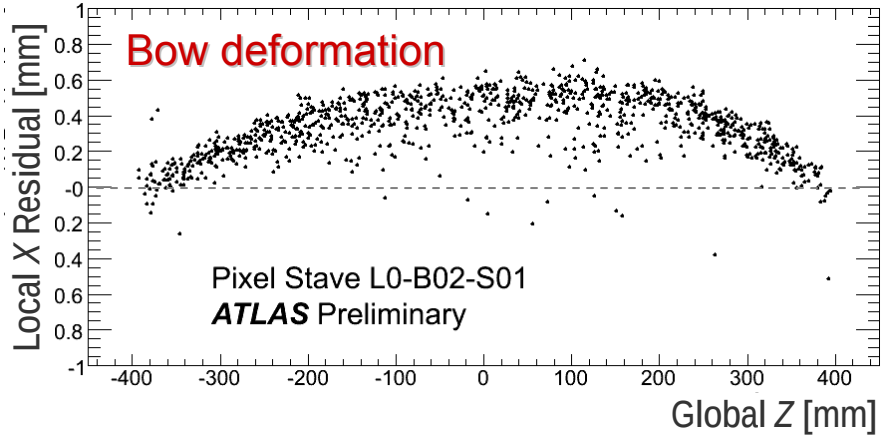
Alignment task:
Minimization of the Residuals





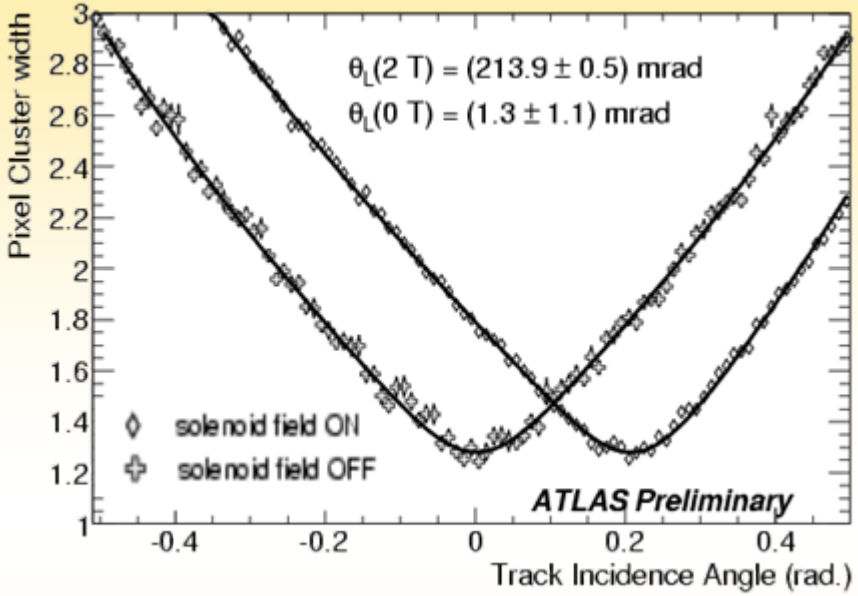






Results from Cosmic Runs: Some of the Studies

Lorentz angle: 214 ± 0.5 mrad (expect ~224 mrad)

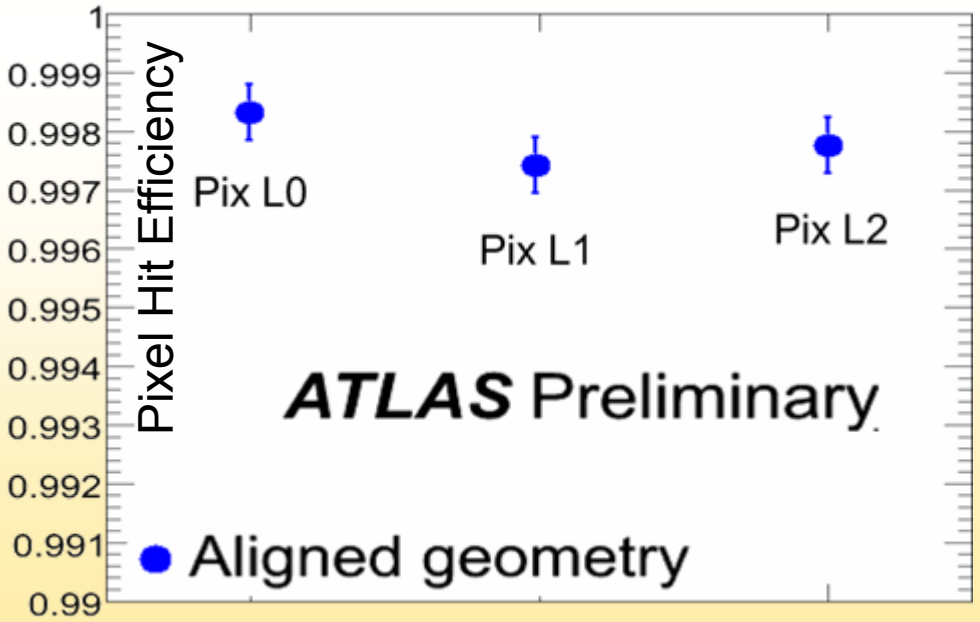


- Quantifies the electron drift in the sensor due to the B-field.
- Measured by fitting the cluster size vs. the incidence angle.
- Data measurement agrees with the expectation to within 5%.
- Angle with the B-field OFF is consistent with zero.

- Improvements with alignment
- Hit efficiency in barrel layers

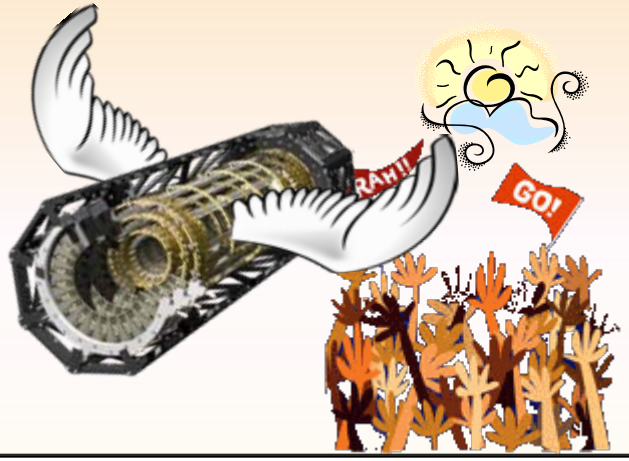
> 99.7%

Alignment: Hit Efficiency (Barrel Layers)



Summary

- Extremely tight commissioning schedule was successfully met.
- 96% of all modules are included in data taking.
- 2% were disabled due to problematic cooling loops (all in the disks):
  - ⇒ Year 2009: all cooling loops are operating;
  - ⇒ June 2009: Modules on these loops are qualified, tuned, and operate!
- Hit efficiency in the enabled modules (barrel layers) is above 99.7%.
- Noise occupancy is $< 10^{-10}$ ⇒ Well below one noise hit per event.
- Resolution after recent alignment with available cosmics ~24 μm.
- Pixel detector is performing very well.



We are ready to take data in 2009!

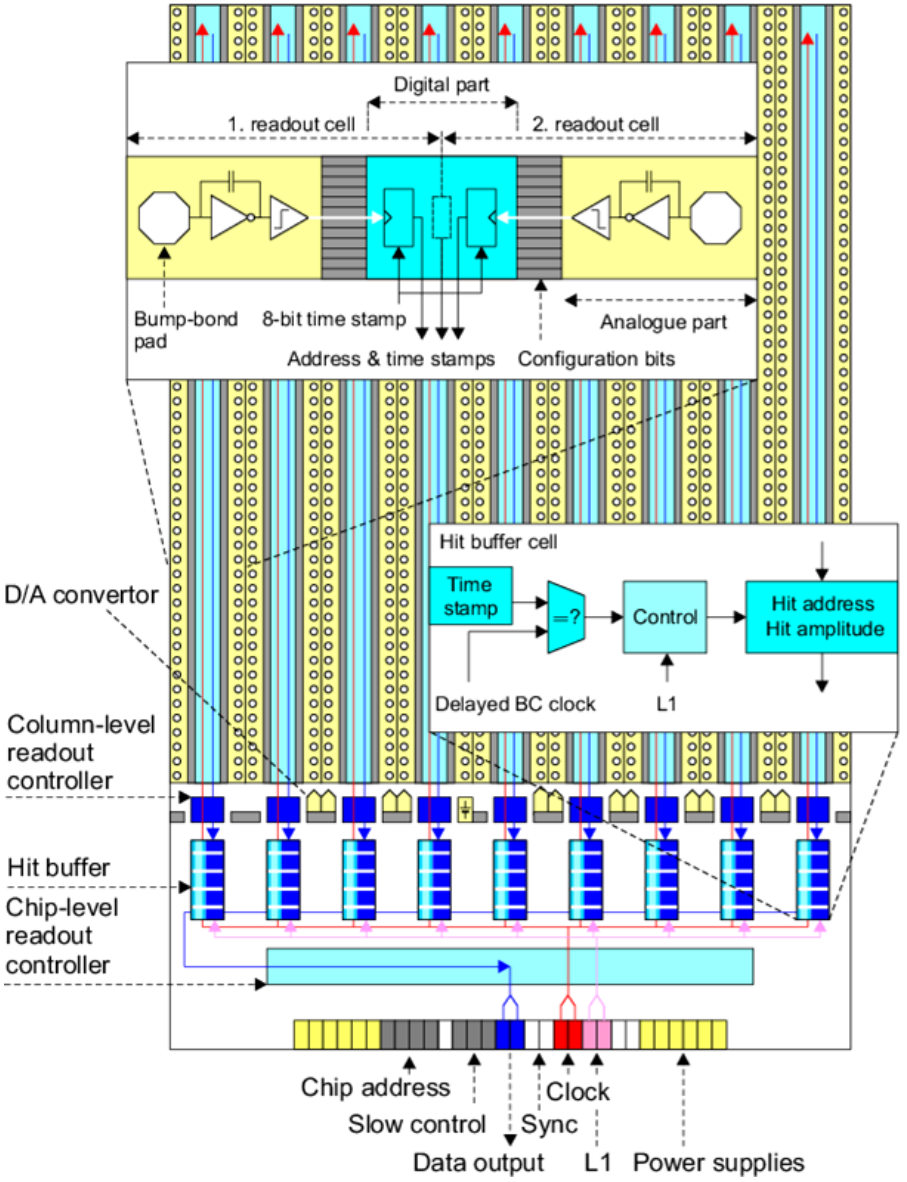
Thank you for your attention!

PIXEL DETECTOR

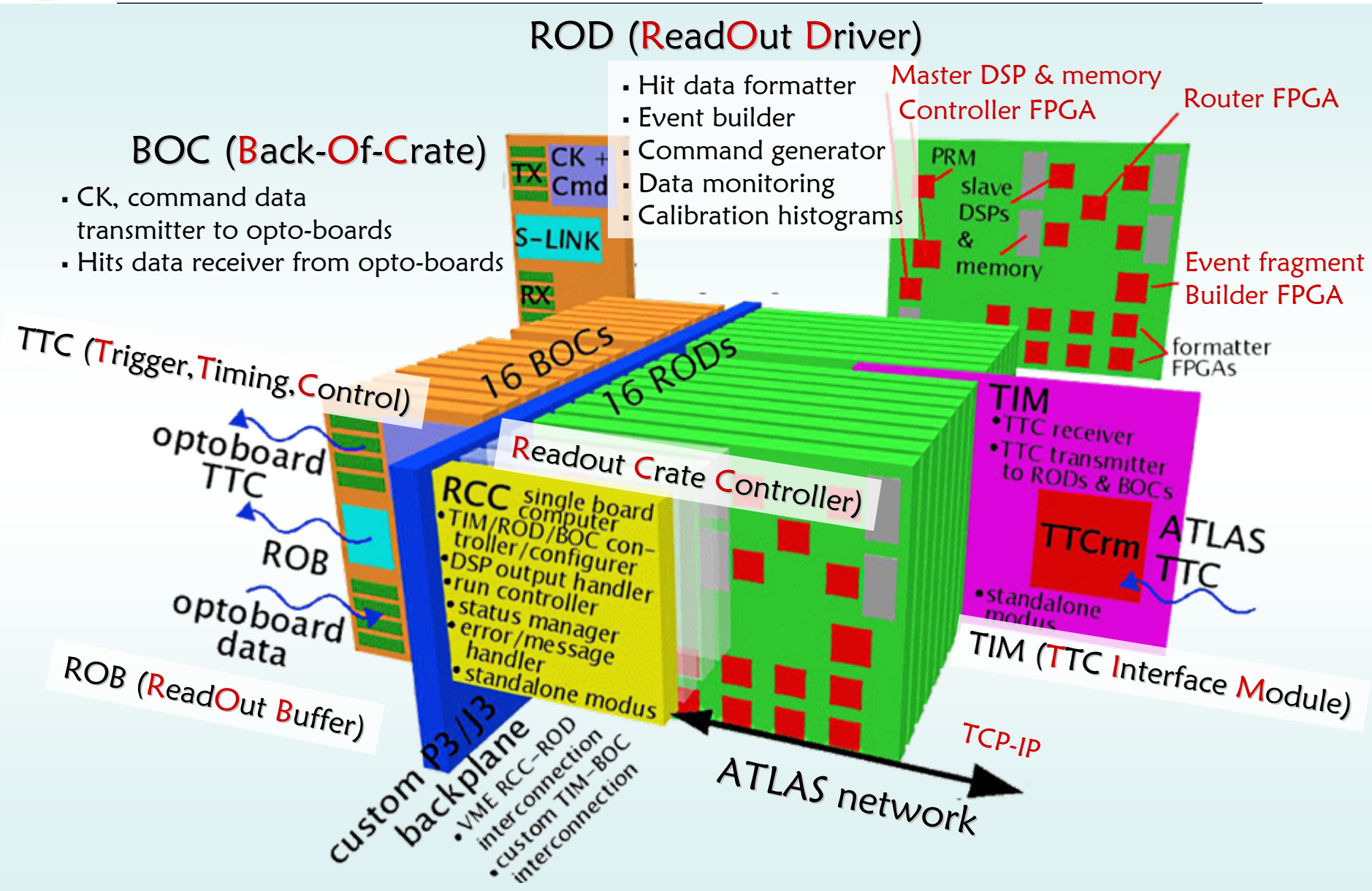
Back-up Slides Follow

The Front End Chip

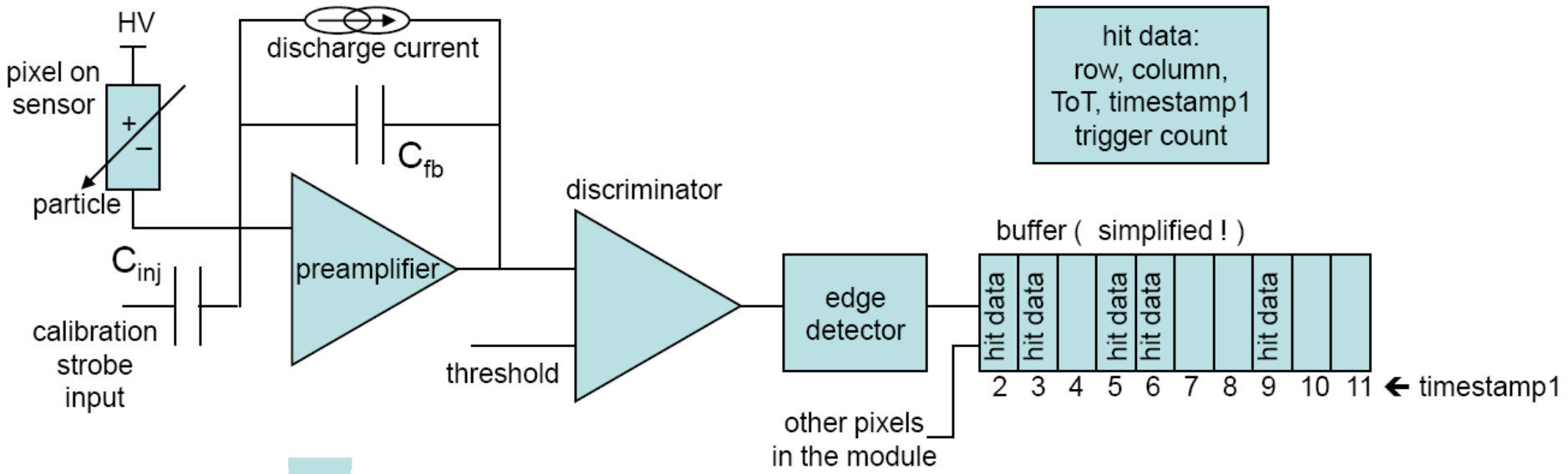
- One front end chip contains 2880 pixel cells organised in 18 columns with 160 rows
- Each pixel cell in the matrix contains preamplifier, discriminator and readout logic, which transfers hits to buffers at the bottom of the chip
- Peripheral region contains 64 hit buffers per double-column, logic for trigger coincidence and data serialisation
- Data is sent to the MCC, which builds the full event and sends it out

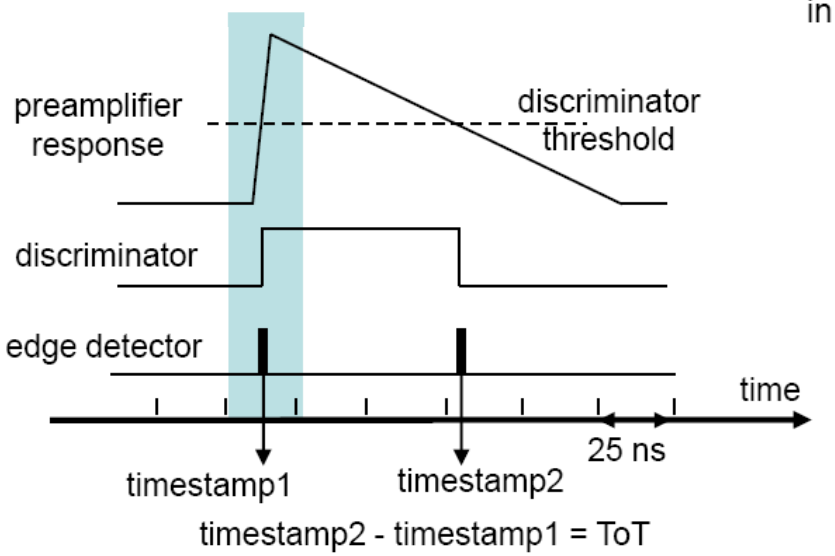


Off-Detector Readout Electronics



Data Sampling in the Pixel Detector



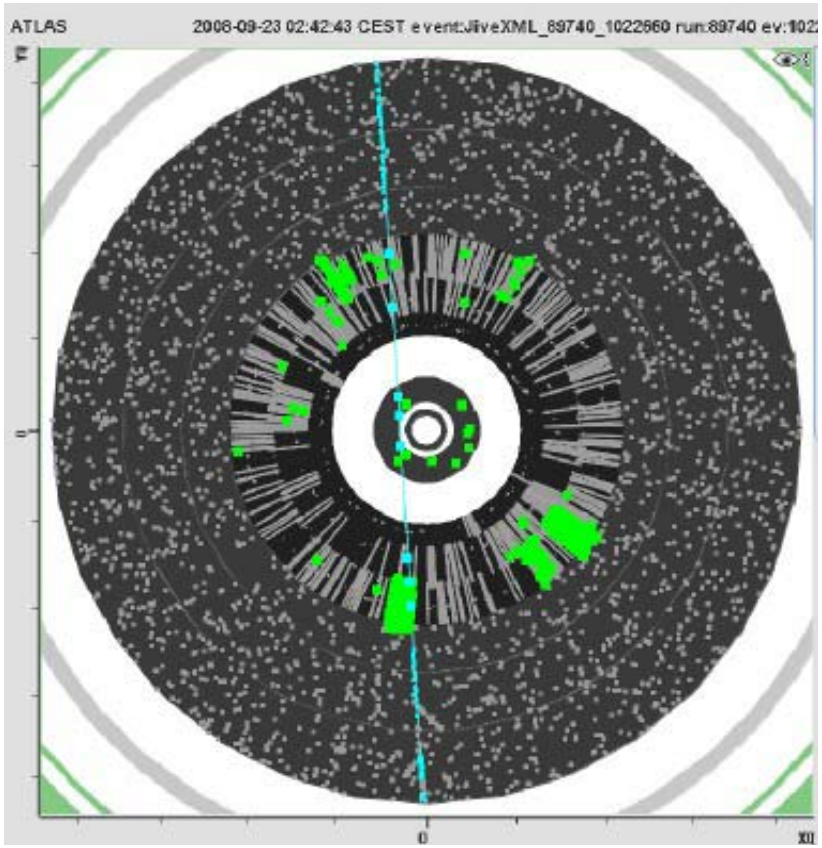


- Timestamps are generated by 40 MHz module clock ⇐ LHC clock
- Length of pulse on discriminator output ⇒ Time-over-Theshold (ToT)
- The only timing information in data is the timestamp of the leading edge

Noise Masking

- Noise mask is created off-line and applied on-line
- Noisy pixels are defined having $\geq 10^{-5}$ hits / event
- ~ 5K pixels are masked $\Rightarrow$ only 0.006% of all pixels

w/o the noise mask



with the noise mask