Operational Experience and Performance with the ATLAS Pixel detector

THE OHIO STATE UNIVERSITY

Christopher B. Martin

For The ATLAS Collaboration

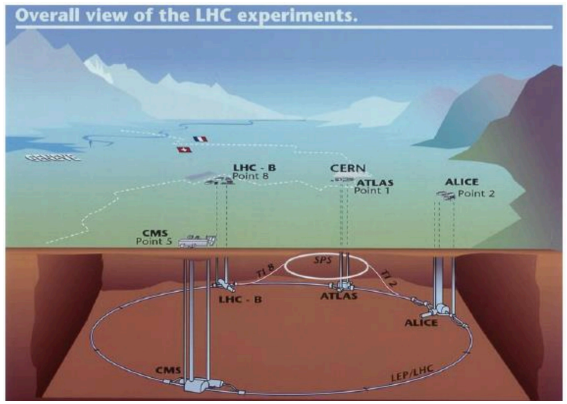
December 12, 2017

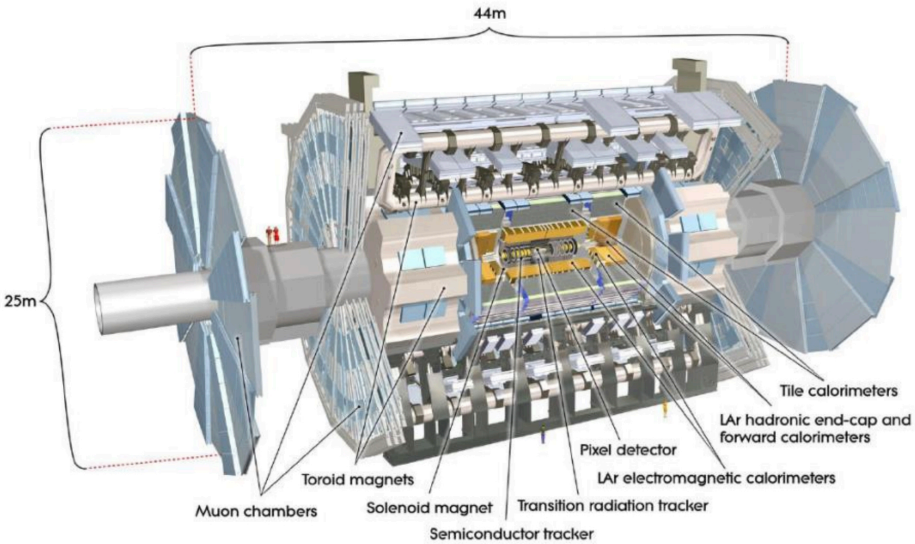
ATLAS & LHC

THE OHIO STATE UNIVERSITY

- LHC - Large Hadron Collider
  - Operating beyond design specifications!
  - Many records in 2017
  - Leveling at request of experiments!

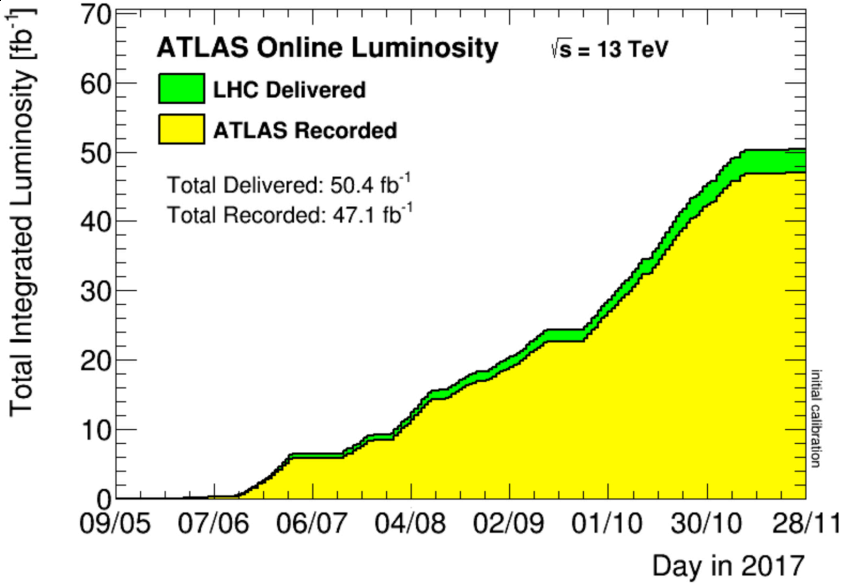
	Design	2017 Records	2017 ATLAS Leveling
Beam Energy [TeV]	7	6.5	6.5
Nominal Luminosity [$cm^{-2}s^{-1}$]	1E+34	2.06E+34	1.53E+34
Bunches per Beam	2808	2544	1866
Max Avg. Events per Bunch Crossing	23	78.6	58

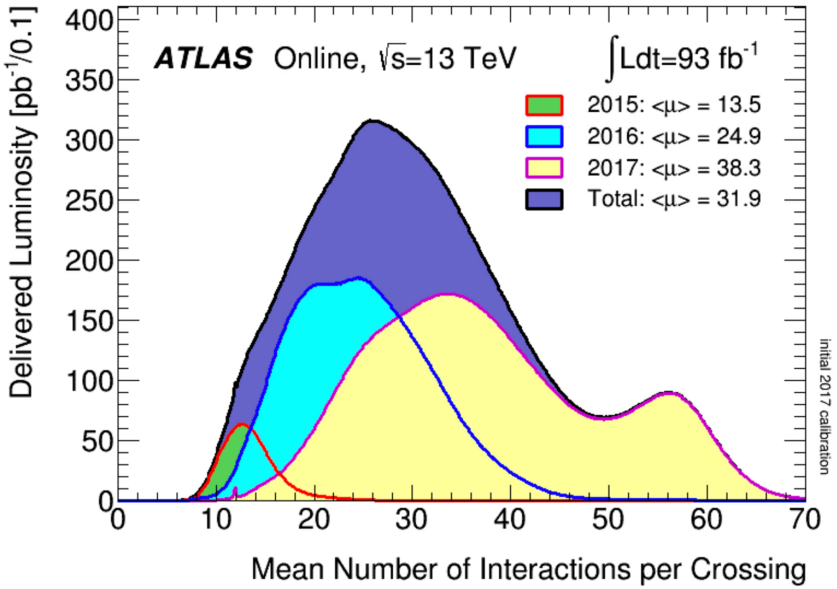


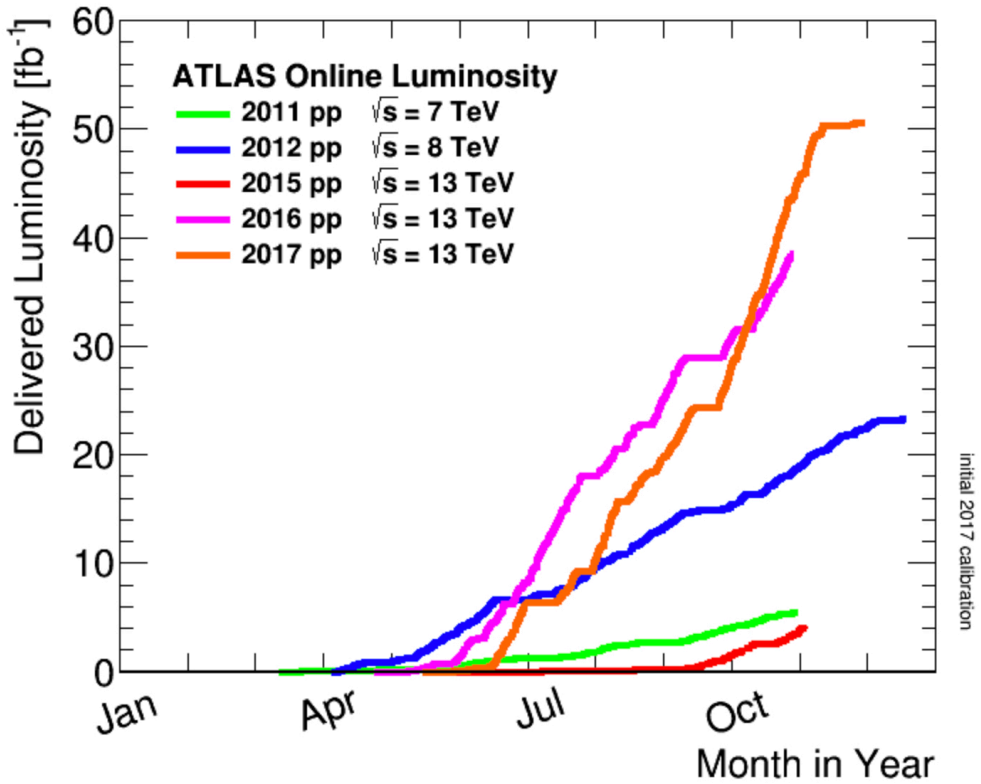


- ATLAS - Multipurpose Detector
  - Investigate fundamental physics at the TeV scale
  - Search for Higgs boson (Check!)
  - Search for beyond standard model particles
  - Make precision standard model measurements

ALTAS & LHC Metrics







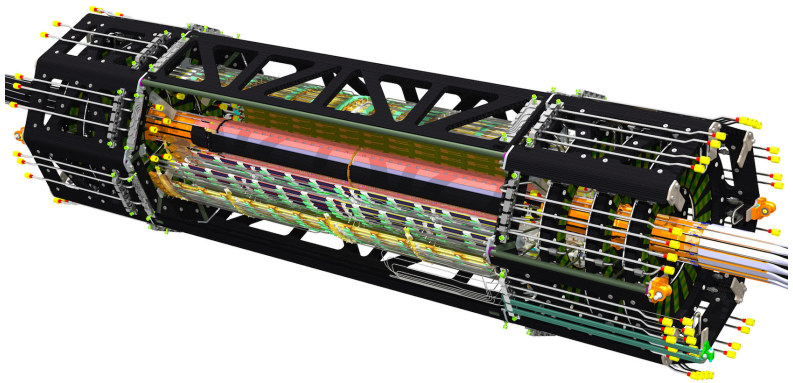
ATLAS pp 25ns run: June 5-October 8 2017

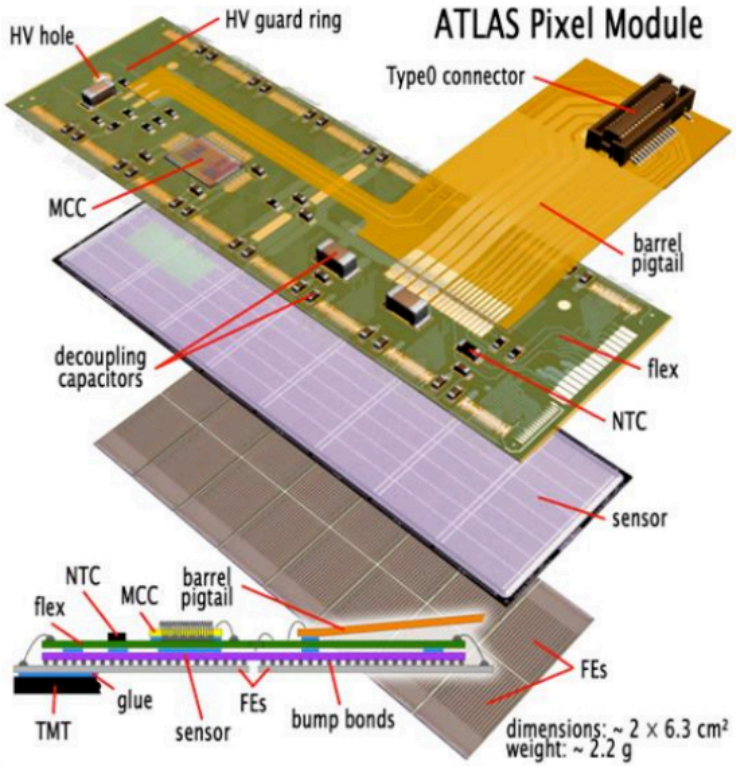
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
100	99.9	99.6	99.2	99.9	99.9	98.0	99.8	100	100	98.7

Good for physics: 94.1% (28.7 fb^{-1})

ATLAS Pixel Detector

- Originally 3 barrel layers and 2 × 3 endcap disks
- 4th barrel layer was added in 2014
- Angular Coverage: $|\eta| < 2.5$
- Barrel Radii:
  - 3.2 (IBL), 5.05 (B-Layer), 8.85, 12.25 cm

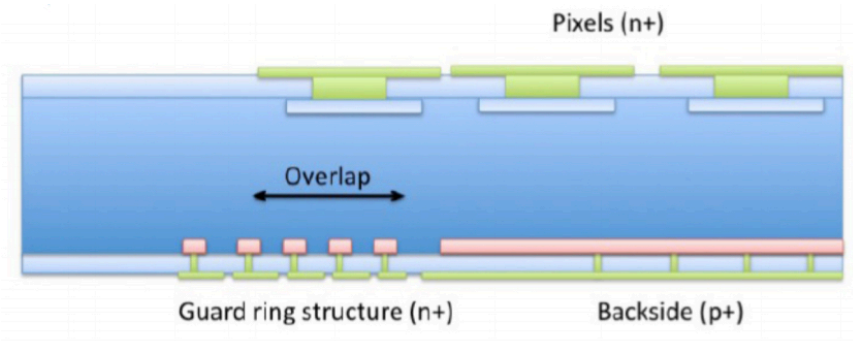


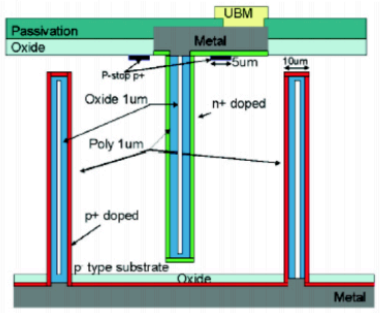


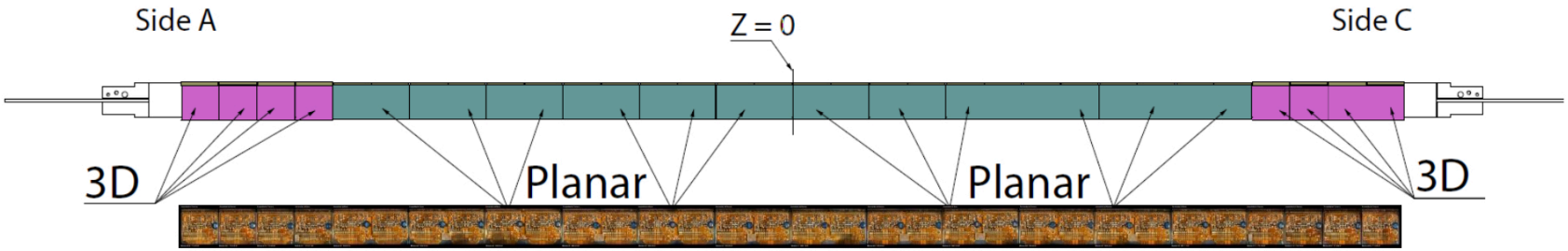
- Each module is made from:
  - A planar n-on-n sensor 60.8 mm × 16.4 mm active area, 250 µm thick.
  - 16 FEi3 frontend chips plus a controller (0.25 µm CMOS)
  - Frontends are bump-bonded to the sensor.
  - A flex for electrical connections
- 46080 pixels, size 50 × 400 µm
- The data rate per module is 40/80/160 Mbps

Insertable B-Layer (IBL)

- Added in 2013-2014 LHC Shutdown
- Innermost Layer of ATLAS Pixel Detector
- Each module is made from:
  - Two sensor technologies:
    - Planar slim edge n-on-n, 200 µm
    - 3D, two electrodes per pixel, 230 µm
    - Planar sensors in the central region, 3D outside
  - Sensors bump bonded to 2×1.8 cm FEi4 Frontend chips (130 nm CMOS)
- 26880 pixels per frontend: 50 × 250 µm
- 160 Mbps data rate per frontend



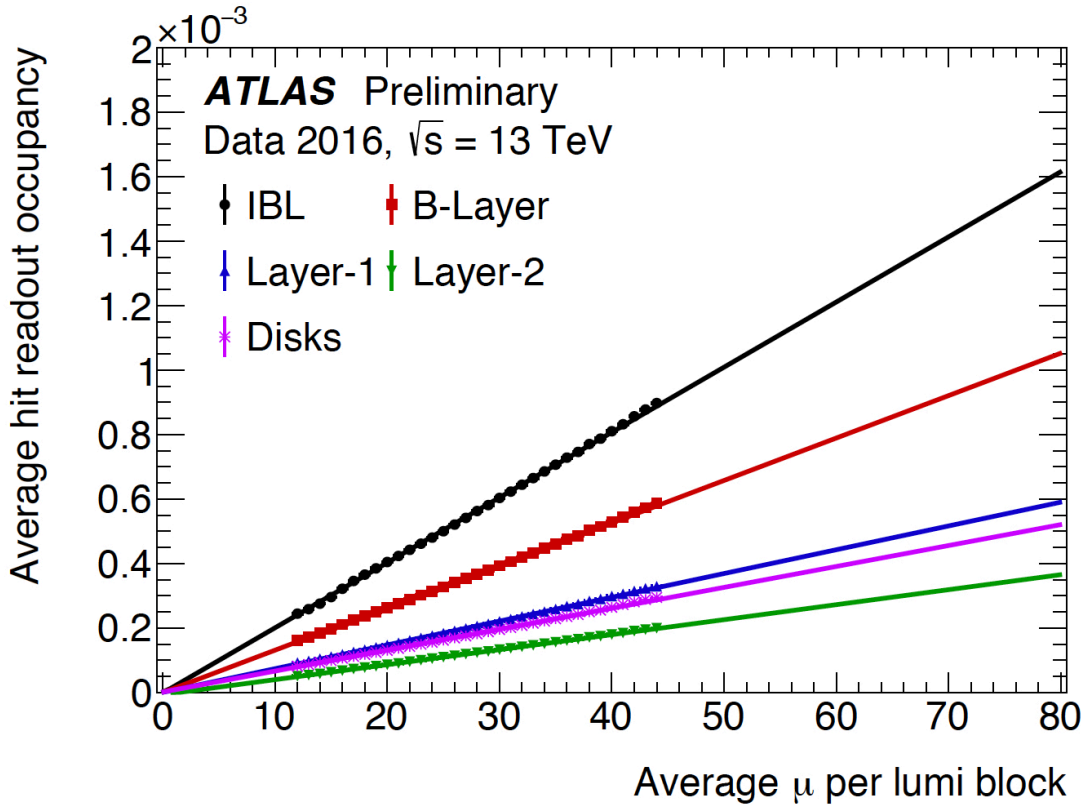




Designed with ITk in mind! (3D sensors, CO_2 Cooling, etc...)

Projections

- Large effort on ATLAS to project how the detector will behave in future conditions
- Determine actions to maintain pace with LHC performance
  - Backend Readout Upgrade
  - Threshold changes



Module Occupancies

Module Link Occupancy at 100kHz L1					
	μ	B-Layer 160Mbps	Layer-1 160Mbps	Layer-2 80Mbps	Disks 80Mbps
25ns 13 TeV (Estimation based on Run2)	30	50%	33%	49%	62%
	50	71%	92%* → 46%	139%* → 69%	86%
	80	101%	125%* → 63%	188%* → 94%	115%

* Assuming bandwidths before the upgrade

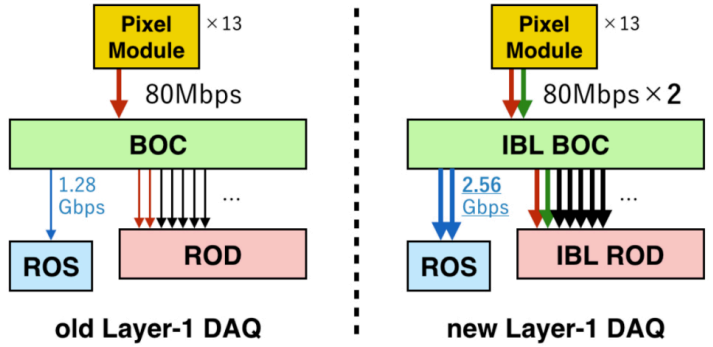
Bandwidth Limitations

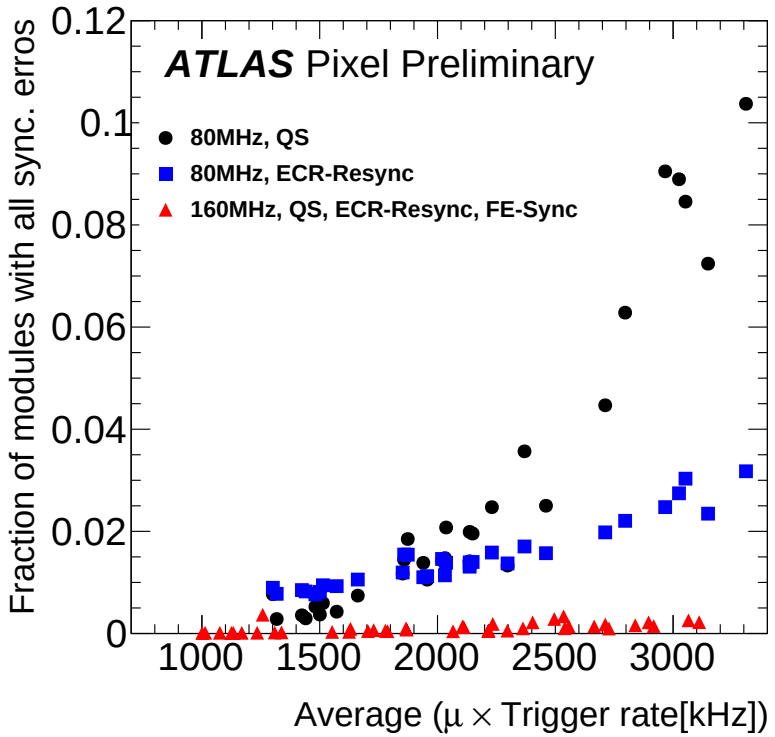
IBL not considered bandwidth limited

Backend Readout Upgrade

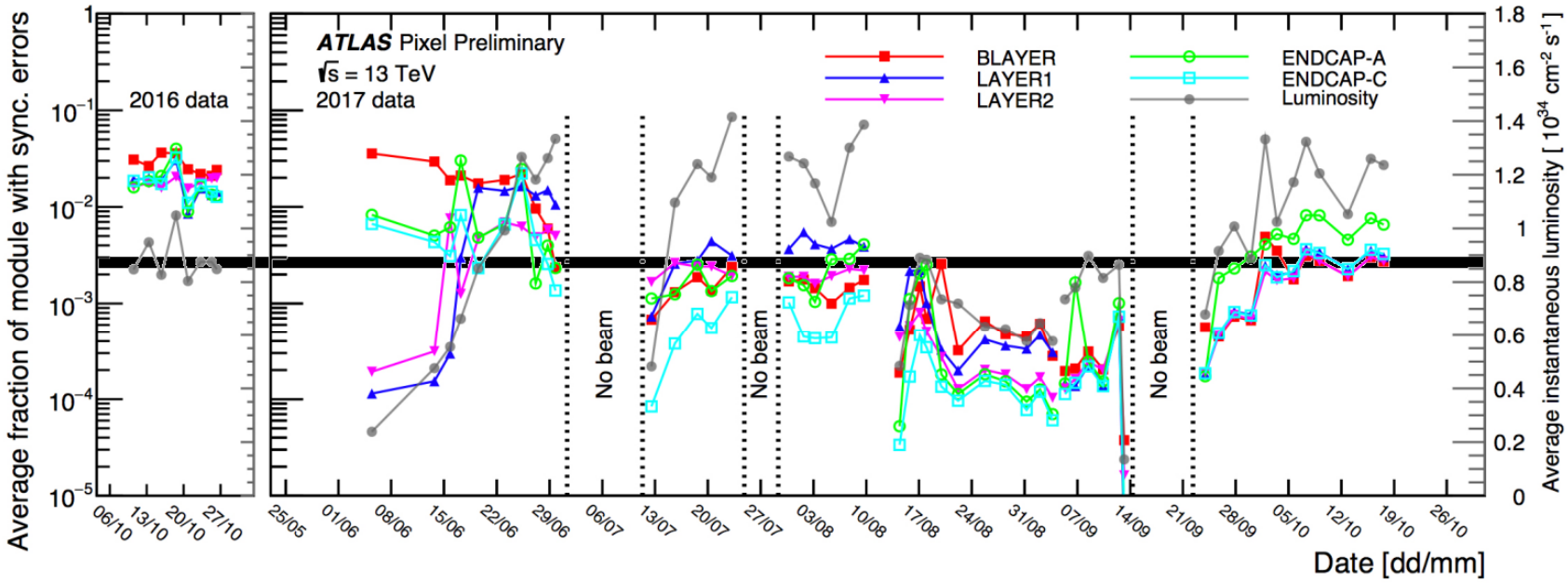
THE OHIO STATE UNIVERSITY

- Outer layers would have already surpassed readout bandwidth limit!
  - Layer 2 was upgraded in Dec. 2015
  - Layer 1 was upgraded in Dec. 2016
  - This doubled the Readout Bandwidth
- Consolidation of remaining layer & endcaps in winter 2017
  - No bandwidth upgrade possible
- Greatly improves event synchronization!
  - Ability for ALTAS match data to an event
  - Periodic flushing of Backend FIFO's
  - Periodic resetting of frontend counters
  - Software automated reconfiguration and disable



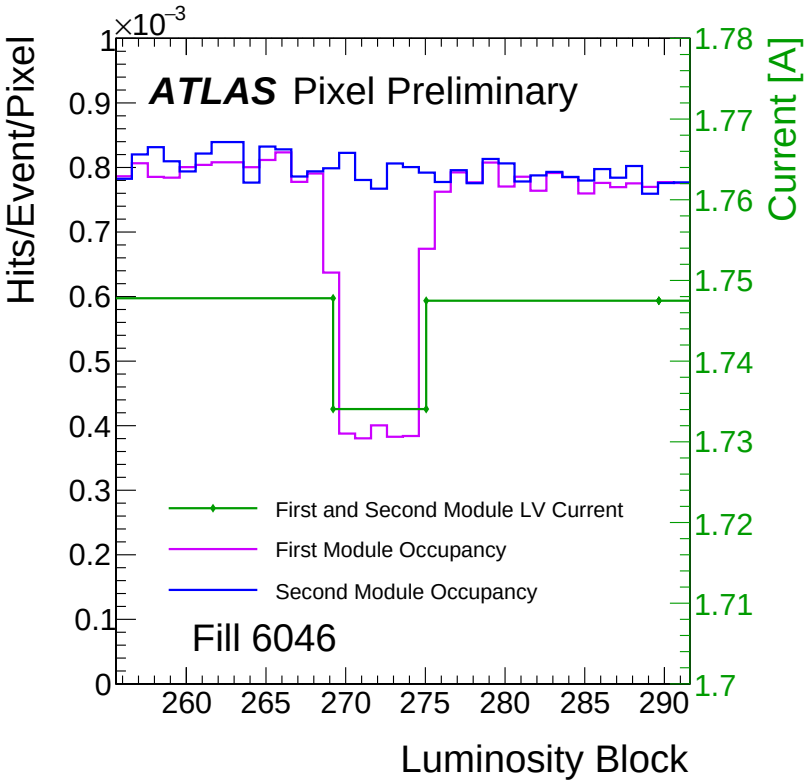


New Features



- These new features were also deployed for the other layers during the year!
- Rate of Desynchronization significantly reduced in 2017
- Even with the intense conditions, increased data quality!
- Most features take advantage of a central ATLAS Event Counter Reset Signal (ECR) and the 2ms window with no triggers around it

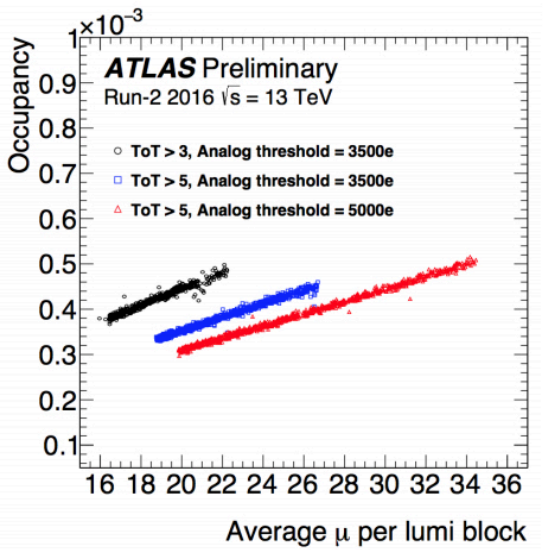
IBL Single Event Upsets

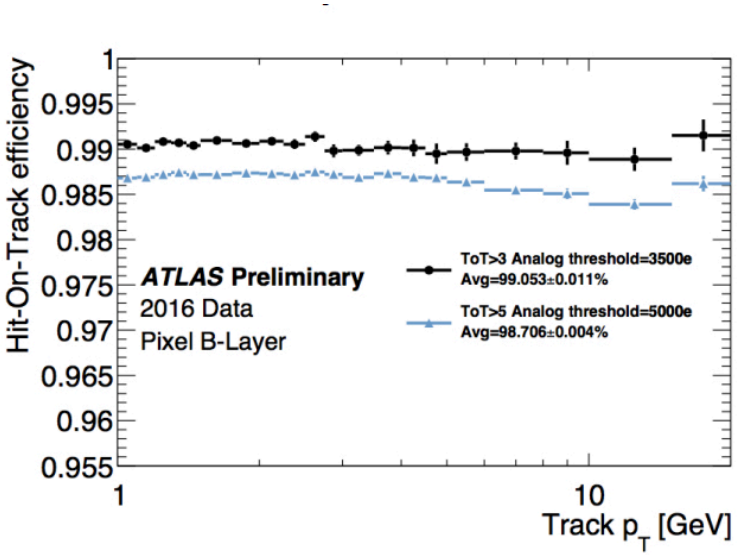


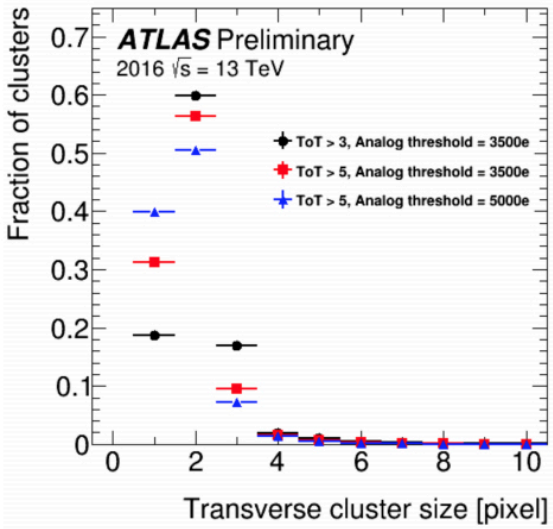
- IBL faces many Single Event Upsets (SEU) flipping bits in the module configuration
- Loss of occupancy &/or change in current consumption
- New Feature to periodically reconfigure the global registers
  - coarse threshold, calibration mode, ...
- Reconfiguration normally much faster than a bin here.

Threshold Adjustments

- Where bandwidth has not been increased, data volume reduced by increasing Threshold
  - Decreases number of hits
  - B-Layer: time-over-threshold cut from 3 to 5 bunch crossings
  - Threshold: B-Layer up to 5000e (2016) and Disk up to 4500e (2017) from 3500e
- Tracking efficiency impacted at sub-percent level
- Cluster shapes are affected
- Examples from B-Layer



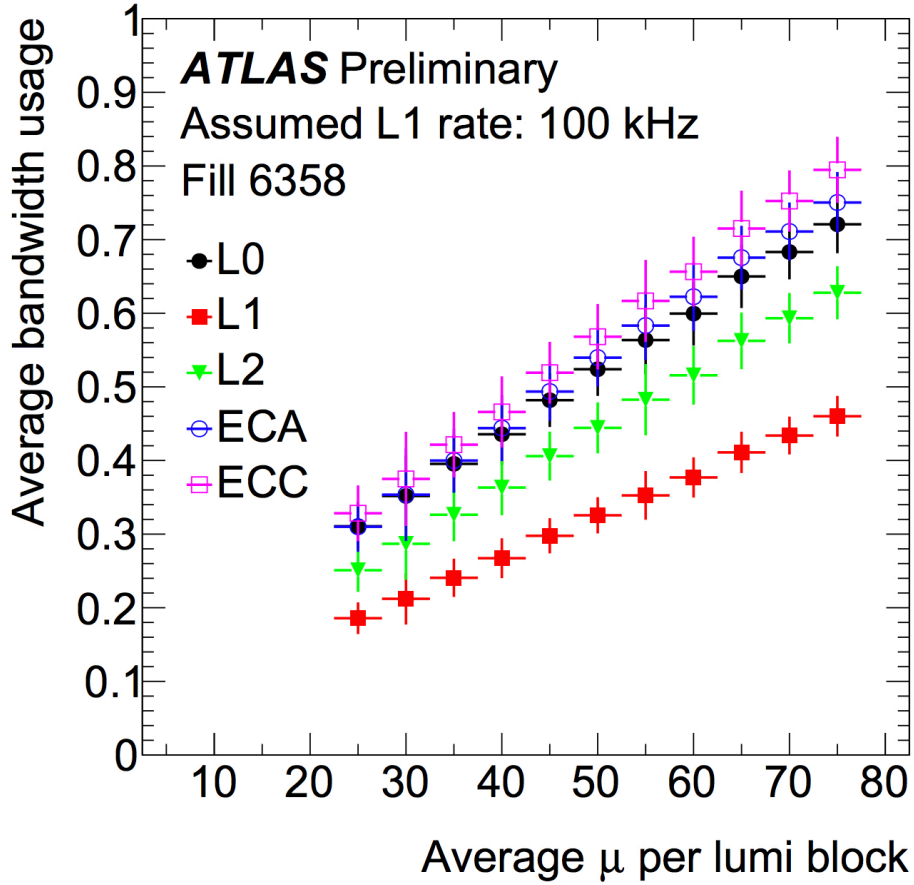




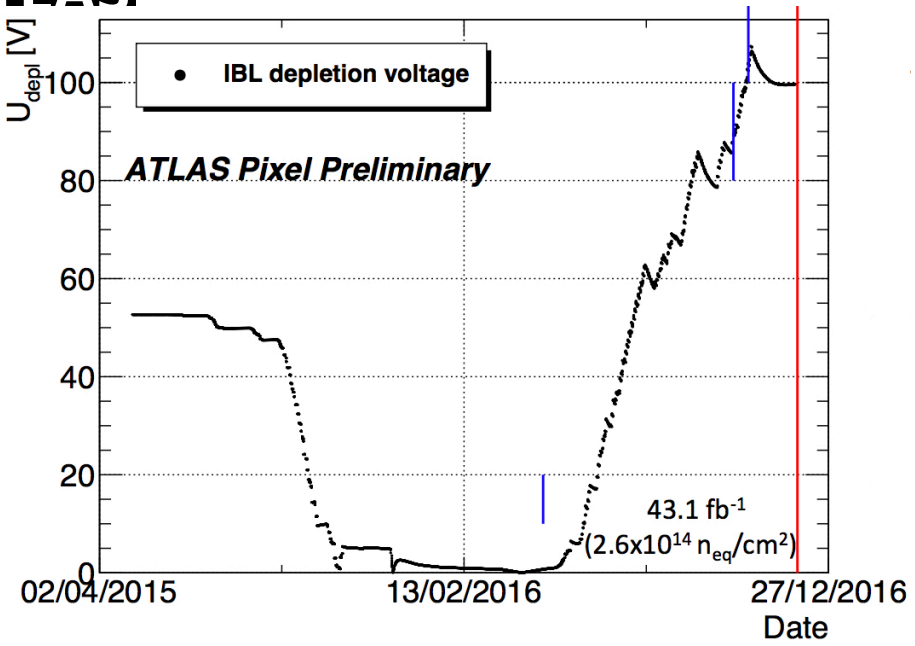
Bandwidth Limitations

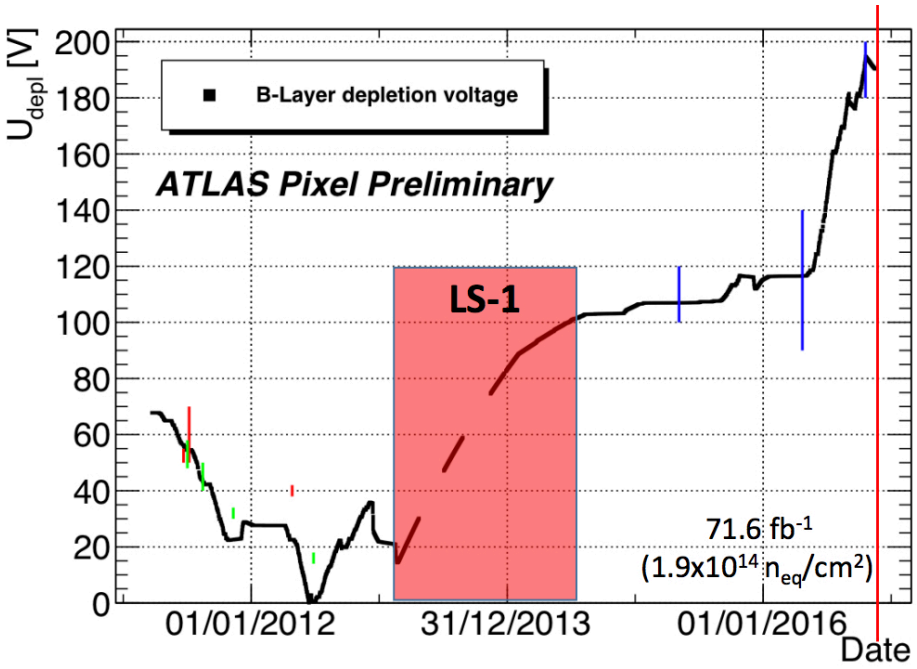
- All of these features combined significantly reduced the bandwidth usage!
- Operational limit of 80% bandwidth usage
- Large pileup is now under control!

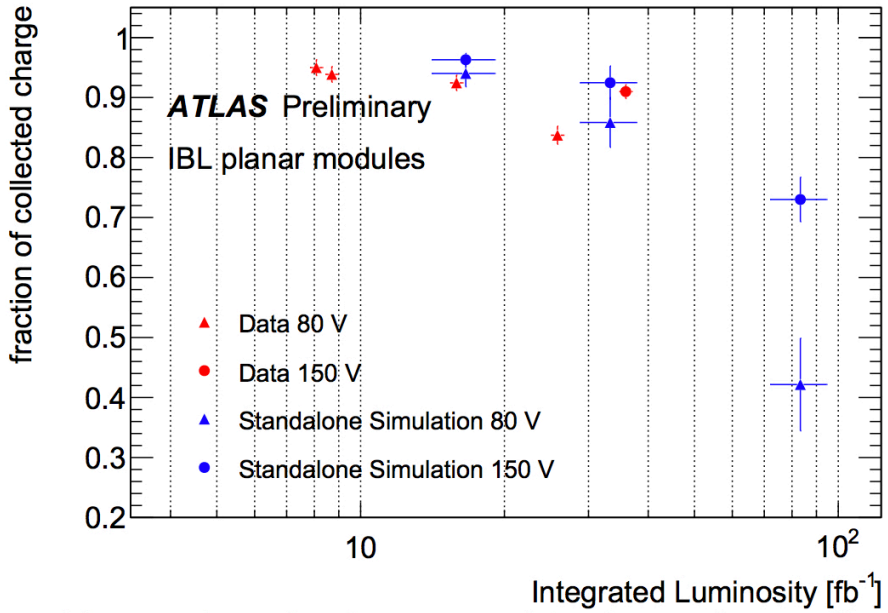
Avg. μ	L0	L1	L2	ECA	ECC
25	31.1 ± 3.4	18.6 ± 2.2	25.1 ± 3.0	31.0 ± 3.5	32.8 ± 3.8
30	35.2 ± 5.5	21.2 ± 3.5	28.7 ± 4.9	35.4 ± 6.3	37.5 ± 6.4
35	39.5 ± 4.0	24.1 ± 2.6	32.6 ± 3.7	40.0 ± 4.4	42.1 ± 4.5
40	43.6 ± 4.2	26.7 ± 2.8	36.3 ± 3.8	44.4 ± 4.5	46.6 ± 4.9
45	48.2 ± 3.7	29.8 ± 2.4	40.6 ± 3.4	49.4 ± 4.0	51.9 ± 4.2
50	52.4 ± 3.7	32.6 ± 2.5	44.4 ± 3.5	54.0 ± 4.0	56.8 ± 4.5
55	56.4 ± 4.7	35.3 ± 3.4	48.3 ± 4.9	58.3 ± 4.7	61.7 ± 5.6
60	60.0 ± 4.4	37.7 ± 2.8	51.6 ± 4.0	62.2 ± 4.7	65.6 ± 4.8
65	65.0 ± 4.3	41.1 ± 2.9	56.2 ± 3.9	67.6 ± 4.4	71.5 ± 5.2
70	68.3 ± 3.8	43.4 ± 2.6	59.3 ± 3.5	71.1 ± 4.0	75.2 ± 4.2
75	72.1 ± 4.0	46.0 ± 2.8	62.8 ± 3.7	75.0 ± 4.2	79.5 ± 4.5



Radiation Effects

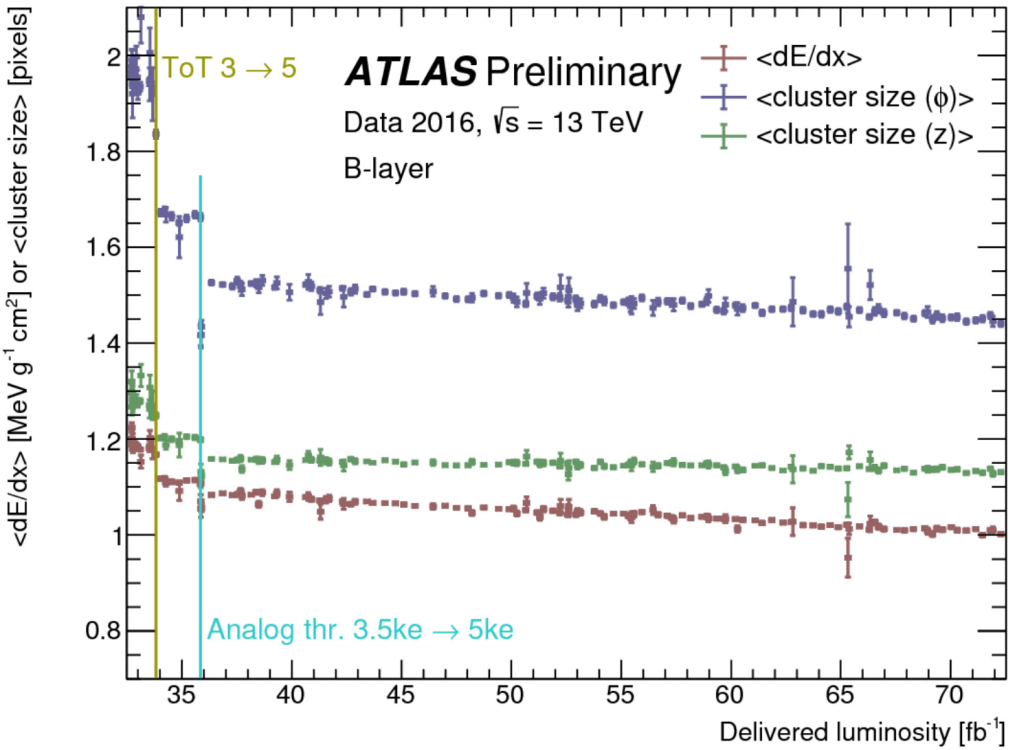




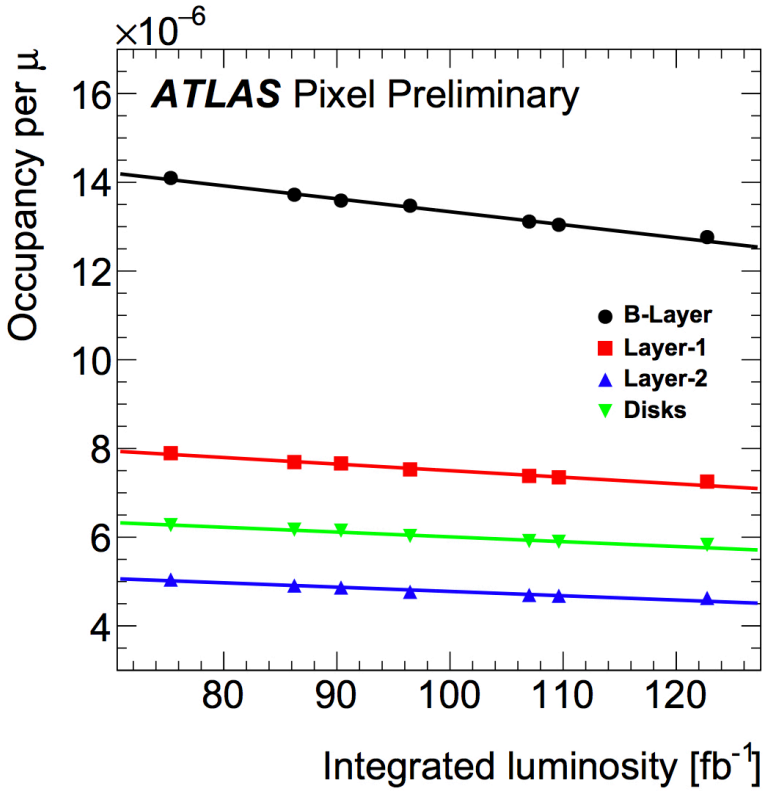


- Huge effort now to model and measure the Radiation impact in the detector
- Large Radiation starting to show!
- See Poster by G. Giugliarelli

Pixel Radiation Impact



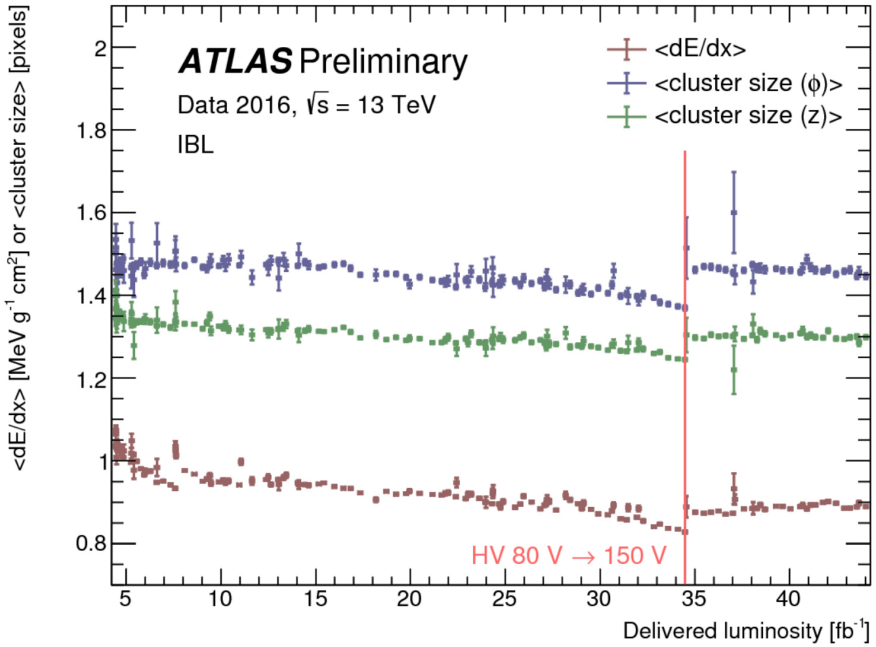
dE/dx and cluster size for B-Layer



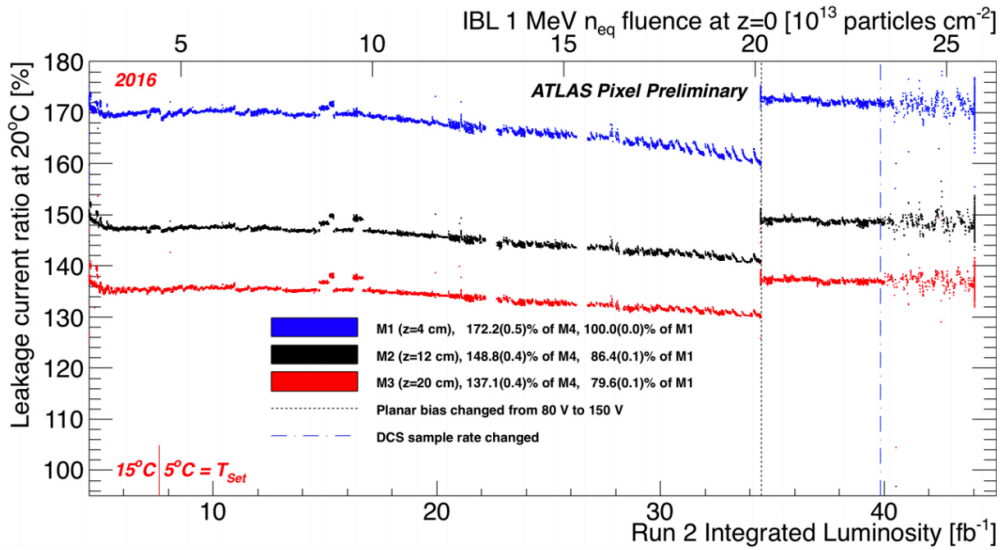
Occupancy trend in 2017

- Starting to see impact of NIEL on original pixel layers
- Transitioning now to phase where we make changes to maintain performance

IBL Sensor Depletion



dE/dx and cluster size for IBL

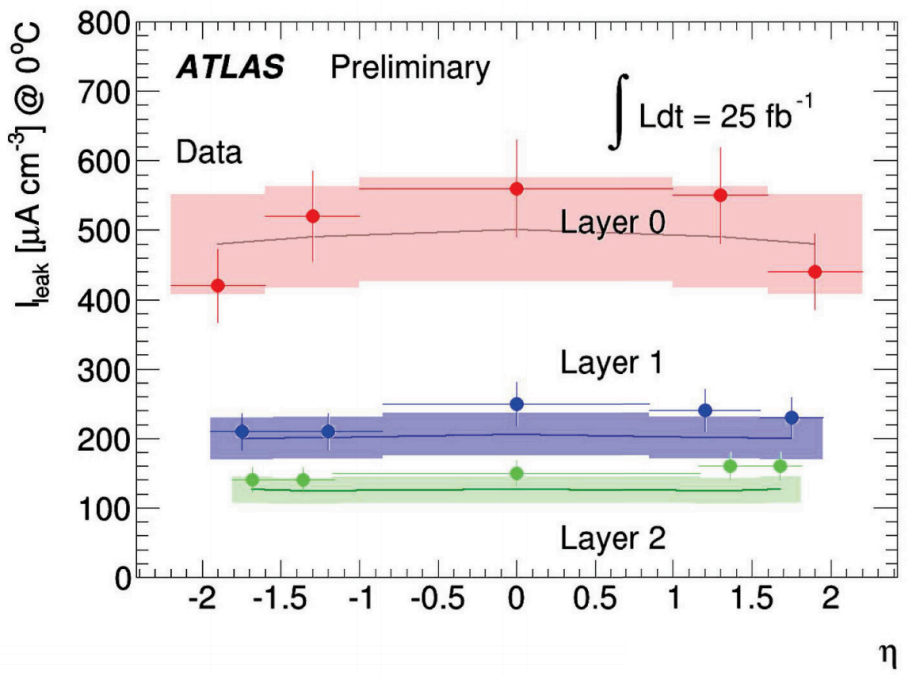


Ratio between planar and 3D IBL modules

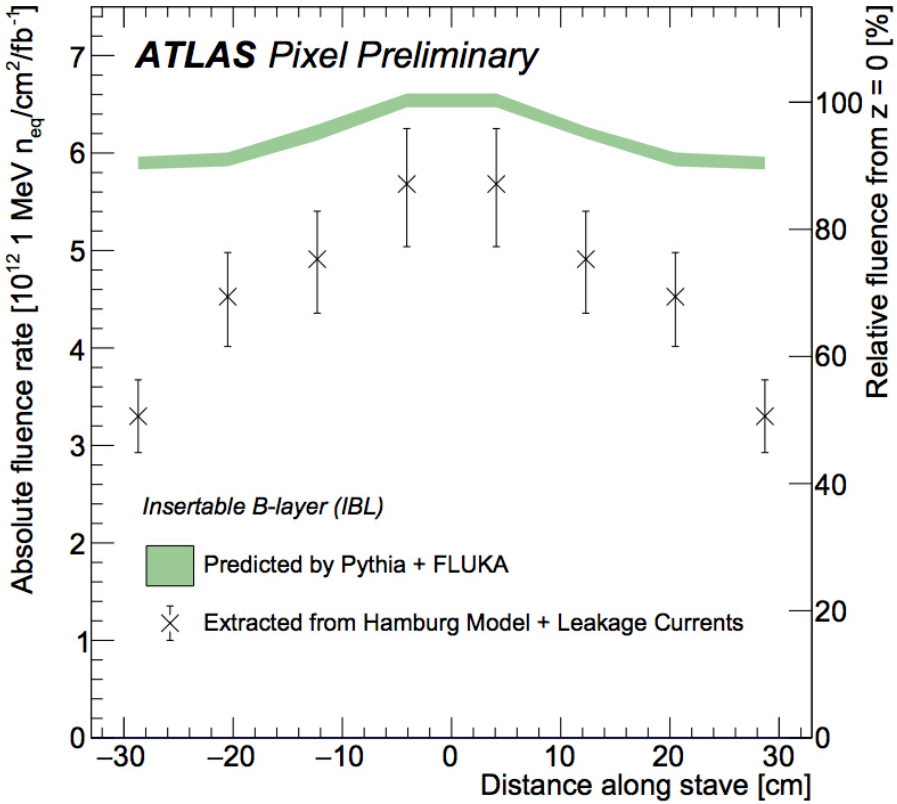
- In IBL we have a new and unique way to observe if our detector is fully depleted
  - Ratio of Leakage current between planar and 3D modules
- IBL not yet facing steady degradation that B-Layer does

Radiation Modeling

- ATLAS is working hard to put these Radiation effects into our standard simulation
- Great effort to create a good model for each layer



Data & Simulation of 3-layer Pixel Radiation effects



Data & Simulation for IBL Radiation effects

Conclusions

- 2017 was a very challenging year for ATLAS Pixels
  - Competing performance with machine and radiation impacts
- Overall, best performance of any year in Run 2!
- Now able to cope with machine conditions
  - Readout Upgrade
  - New Features
- Challenge now is to deal with Radiation
  - Complex models
  - New Simulations & Measurements
  - Effects should now be compensated by threshold reduction
- ATLAS Pixel is well poised for continued successful operation
- Excellent lessons and observations can be useful for future detectors!
  - Corrective actions
  - Radiation effects
  - Radiation modeling

Backup

LHC Metrics cont'd