# ATLAS Pixel Insertable B-Layer

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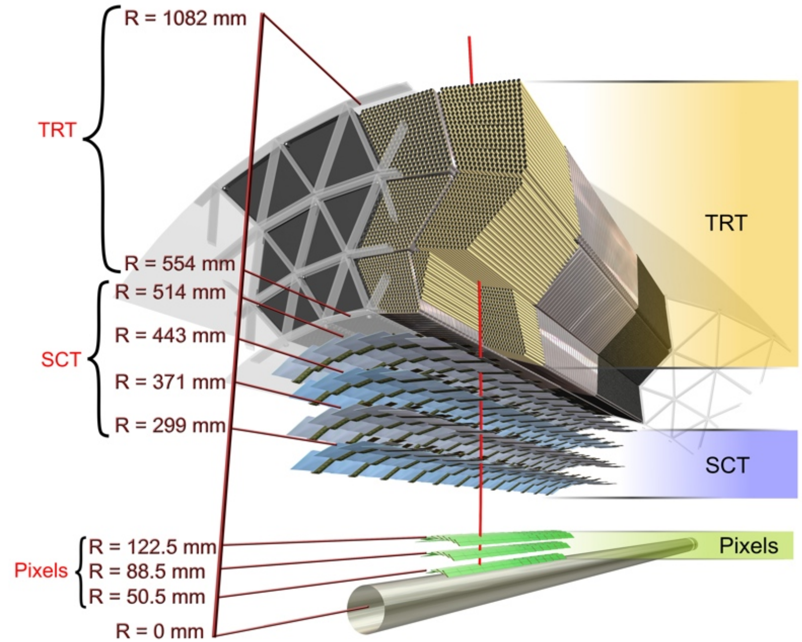
on behalf of the ATLAS collaboration

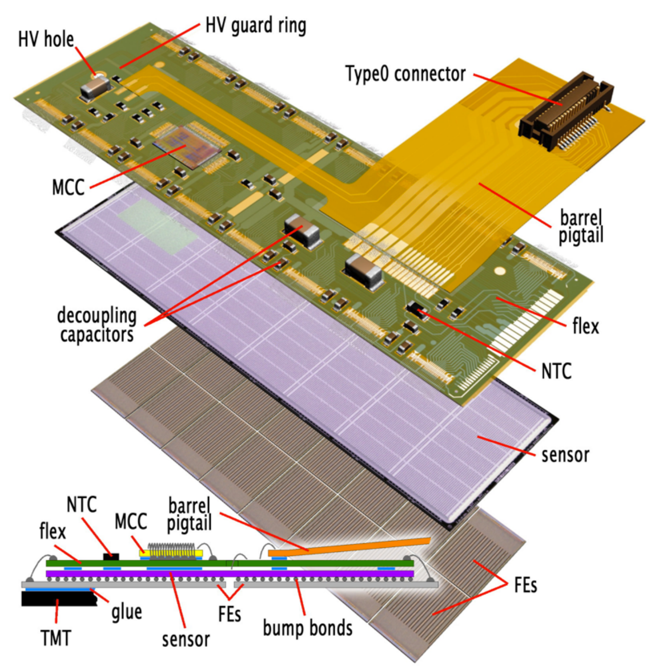
Outline:

- Why upgrade?
- Construction
- Installation
- Commissioning
- Summary

# Run-1 pixel detector

- 80 million channels; analog readout
- 50x400 $\mu m^2$ pixel size
- 10 μm and 110 μm resolution in Rφ and in z
- Radiation hard up to NIEL $10^{15}$ 1 MeV $n_{eq}/cm^2$ and 500 kGy
- Operating temperature of about -13°C
- 250 μm thick n-in-n silicon sensor with an active area of 16.4x60.8 $mm^2$
- 2x80 Mb/s readout in innermost b-layer, 80 Mb/s in layer 1 and disks, and 40 Mb/s in layer 2
- 99.9% data taking efficiency
- 95% of the detector active end of Run-1



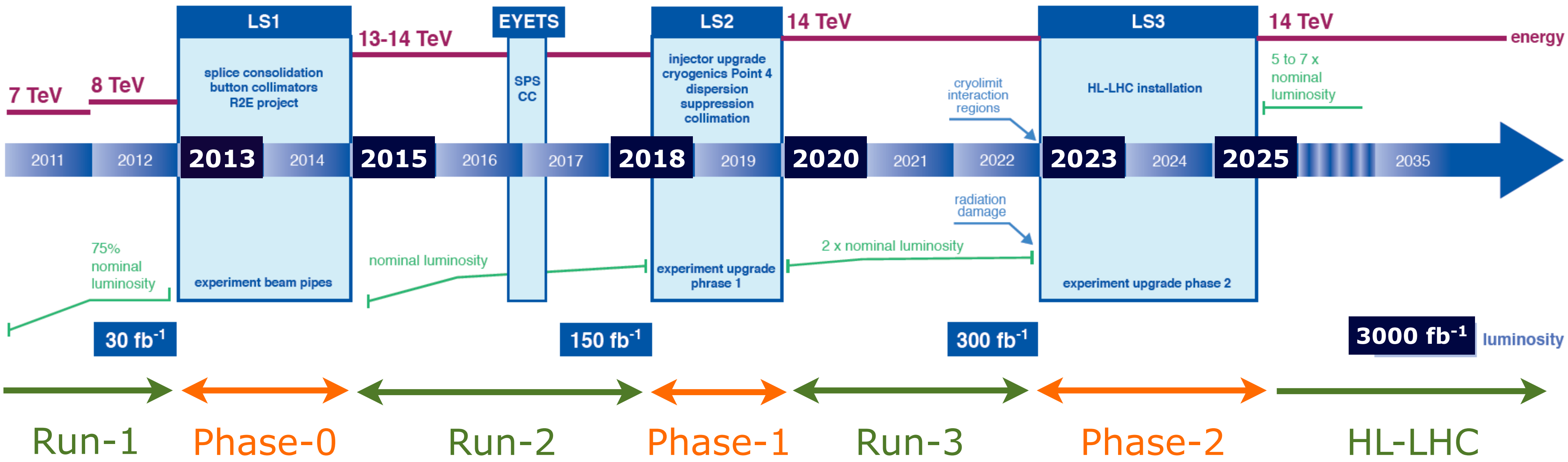
# Why upgrade? (I)

$\mathcal{L}$ = 7x10$^{33}$ cm$^{-2}$ s$^{-1}$
pile-up ~ 25

$\mathcal{L}$ = 1x10$^{34}$ cm$^{-2}$ s$^{-1}$
pile-up ~ 40

$\mathcal{L}$ = 2x10$^{34}$ cm$^{-2}$ s$^{-1}$
pile-up ~ 70

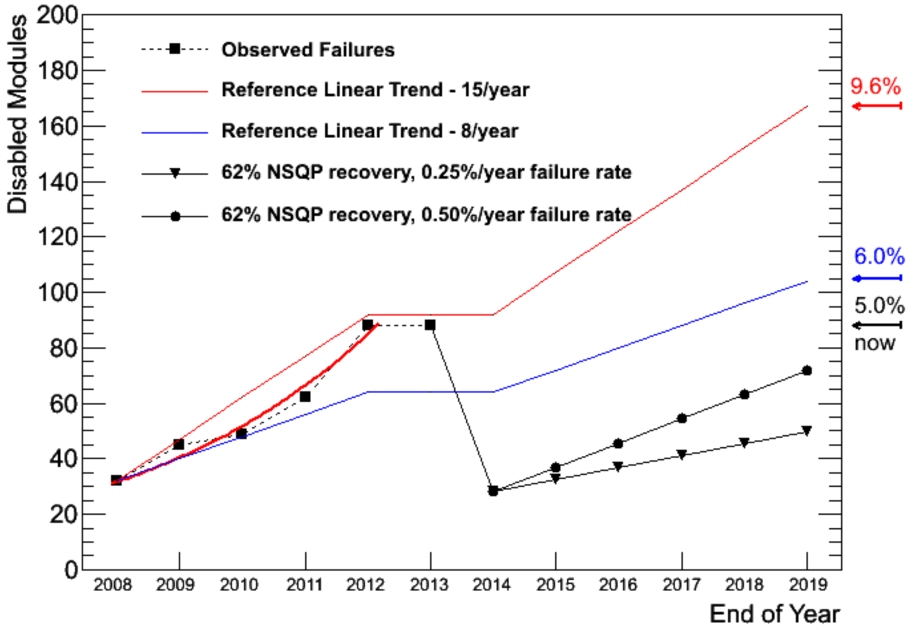
$\mathcal{L}$ = 5x10$^{34}$ cm$^{-2}$ s$^{-1}$
pile-up ~ 140




- LHC designed originally for
  - $\mathcal{L}$ = 1x10$^{34}$ cm$^{-2}$ s$^{-1}$
  - Pile-up ~ 22
- LS1: long shutdown-1
- Pile-up: superposition of interactions from the same or near-by bunch crossings

discovery of rare physics
requires high luminosity
and sufficient collision energies

# Why upgrade? (II)



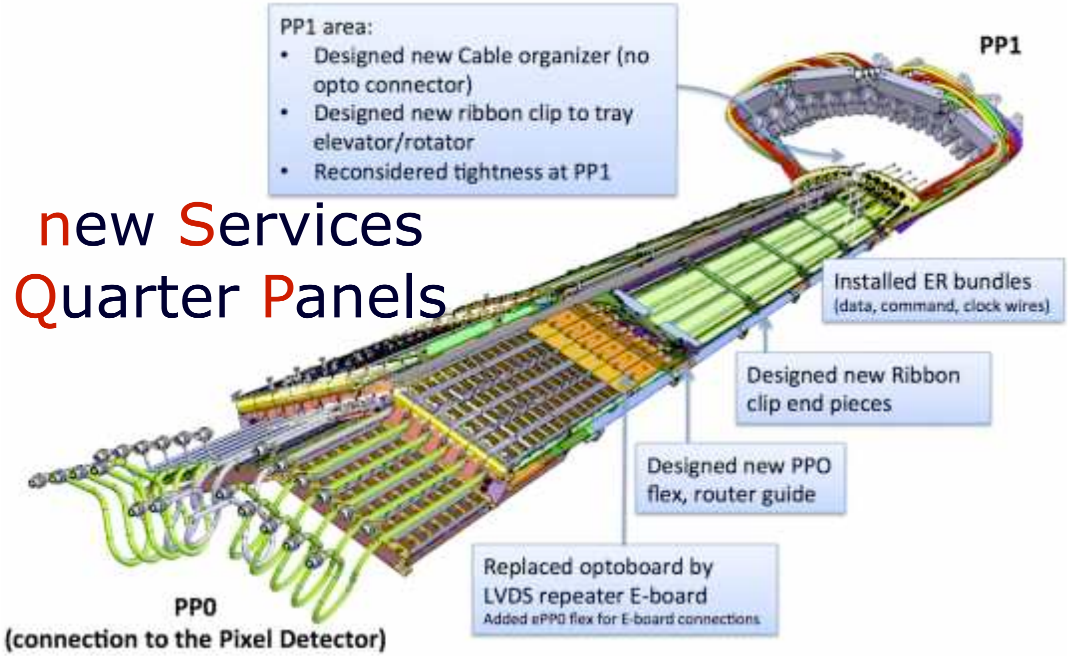

| Link occupancy at 75 kHz L1 Trigger | | | | | |
|---|---|---|---|---|---|
| | μ | B-Layer | Layer 1 | Layer 2 | Disks |
| 50 ns | 37 | 39% | 34% | 52% | 30% |
| 25 ns; 13 TeV | 25 | 35% | 31% | 48% | 27% |
| | 51 | 53% | 59% | 66% | 39% |
| | 76 | 71% | 73% | 111% | 64% |

| Link occupancy at 100 kHz L1 Trigger | | | | | |
|---|---|---|---|---|---|
| | μ | B-Layer | Layer 1 | Layer 2 | Disks |
| 50 ns | 37 | 51% | 45% | 69% | 40% |
| 25 ns; 13 TeV | 25 | 47% | 42% | 65% | 37% |
| | 51 | 71% | 67% | 88% | 52% |
| | 76 | 95% | 97% | 148% | 75% |

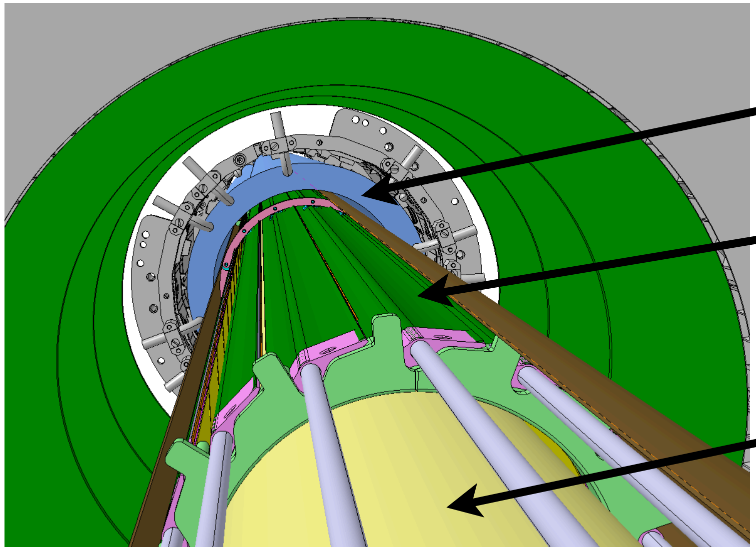
- Readout limitations and module failures would degrade pixel performance before radiation damage does

# Pixel upgrades in the Long-Shutdown-1

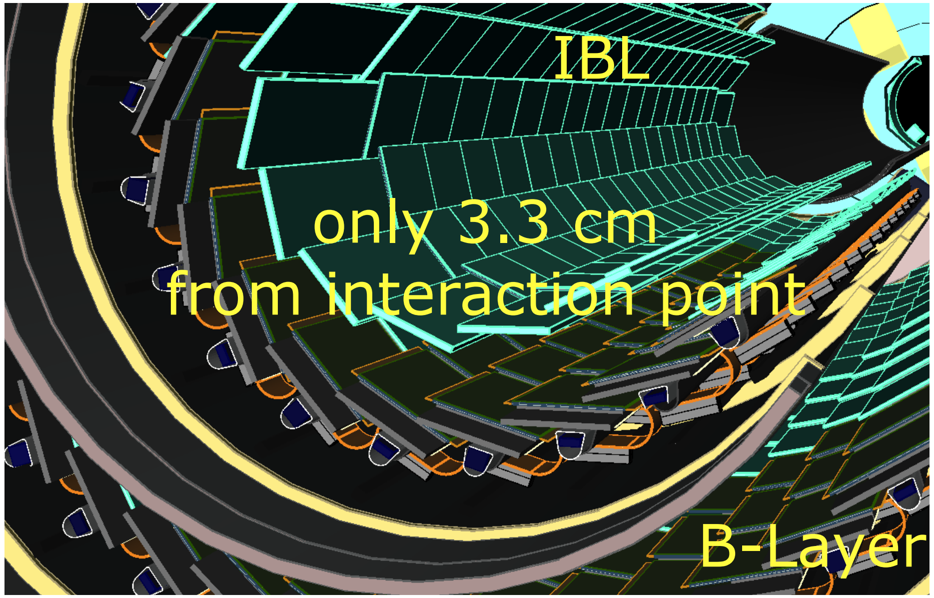
- nSQPs allow for
  - moving the optical components outside the detector volume for easier access to repair failures in future
  - doubling readout speed for layer-1 when needed
  - recovering some of the non-operational modules




- IBL: additional pixel layer with advanced technology to maintain and improve the pixel detector performance
- Layer-2 DAQ hardware upgrade to double readout speed

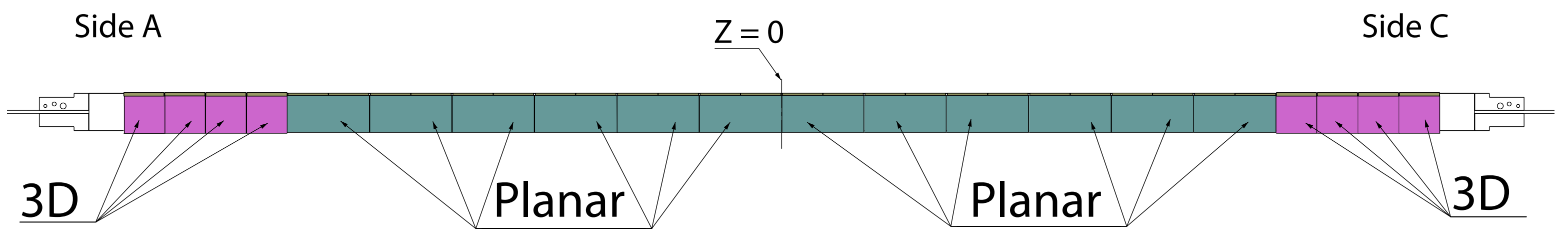


# Insertable B-Layer

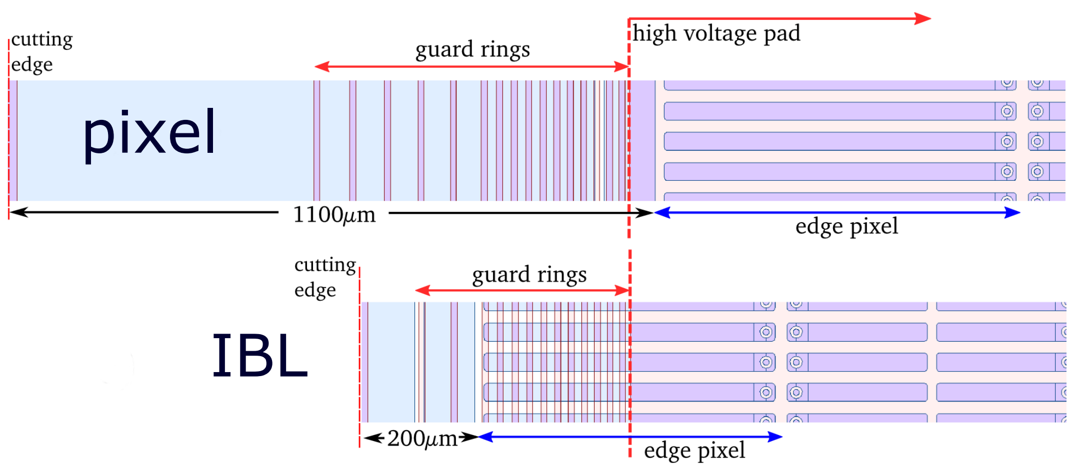



- The major ATLAS phase-0 upgrade
- Improves tracking, vertexing and b-hadron identification
- 12 million channels
- 50x250 $\mu m^2$ pixel size; finer granularity than b-layer
- 14 staves, each with 32 FE-I4 readout chips, mounted on the new smaller radius beam pipe
- 200 µm thick planar n-in-n and 230 µm 3D n-in-p sensors; thinner than b-layer
- Radiation hard up to NIEL $5 \times 10^{15}$ 1 MeV $n_{eq}/cm^2$ and 2500 kGy; 5x more radiation tolerant than b-layer
- $CO_2$ cooling at -40°C coolant temperature

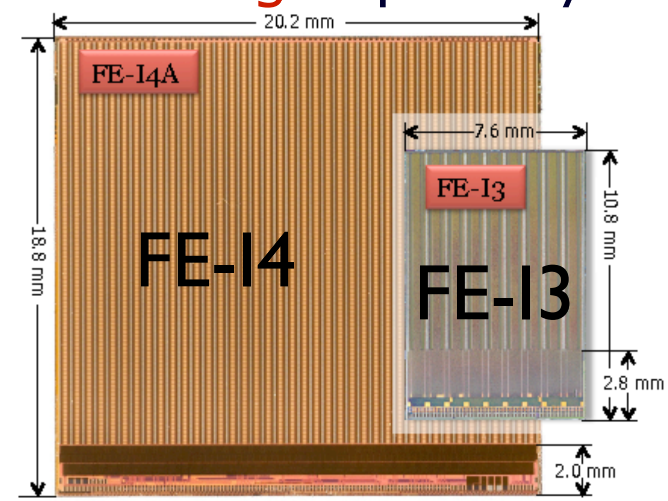
# Module technologies



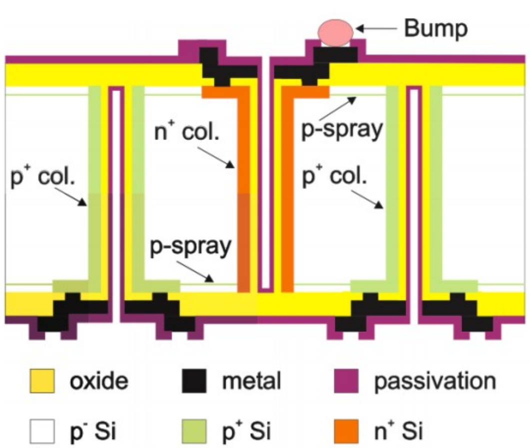

much smaller inactive planar edge

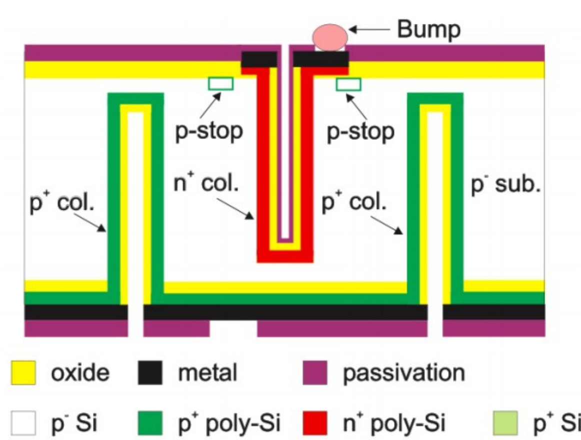



6x more hit buffering capability

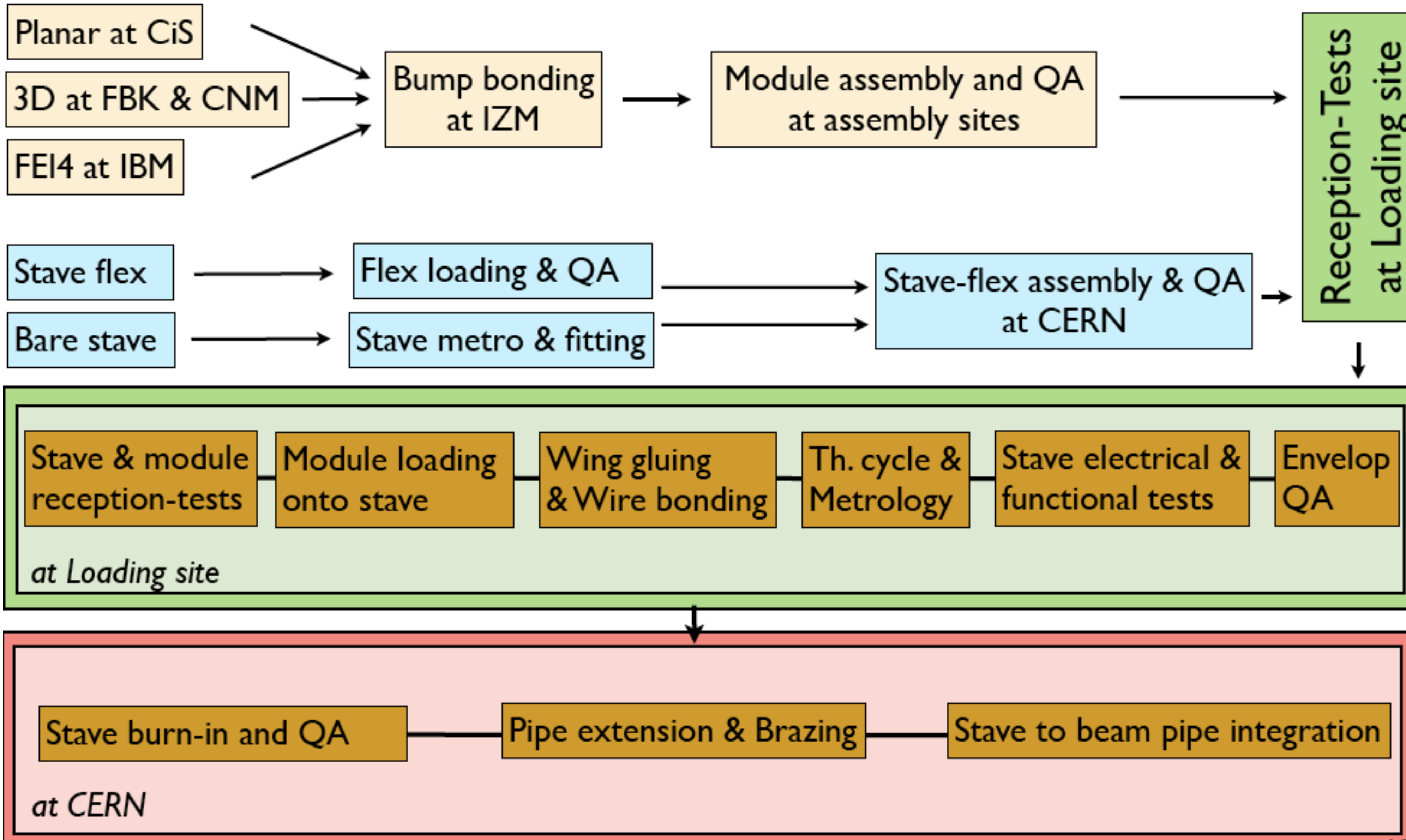



shorter distance to the electrodes in 3D design, resulting in need of much smaller bias voltage

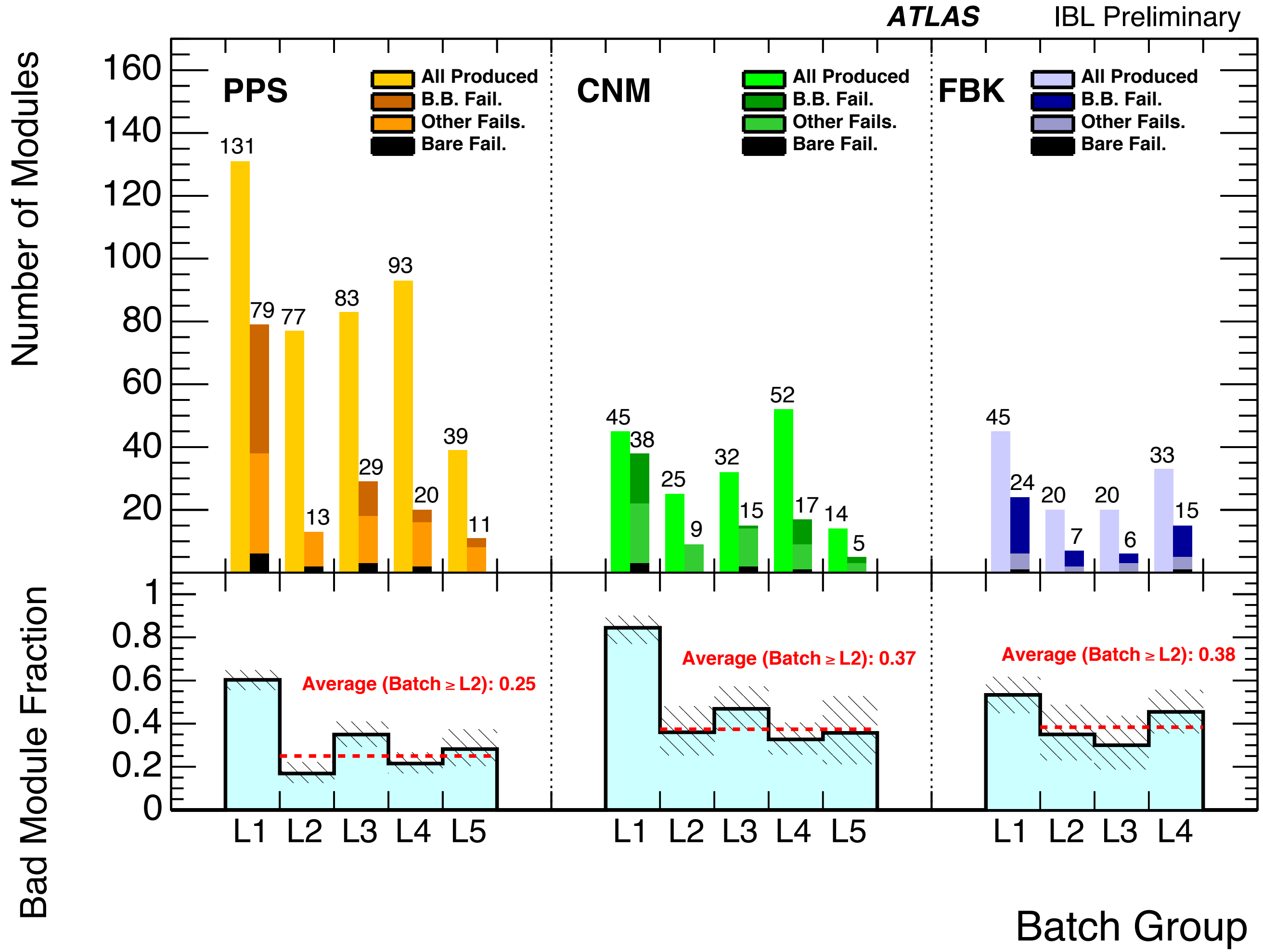


# Production chain

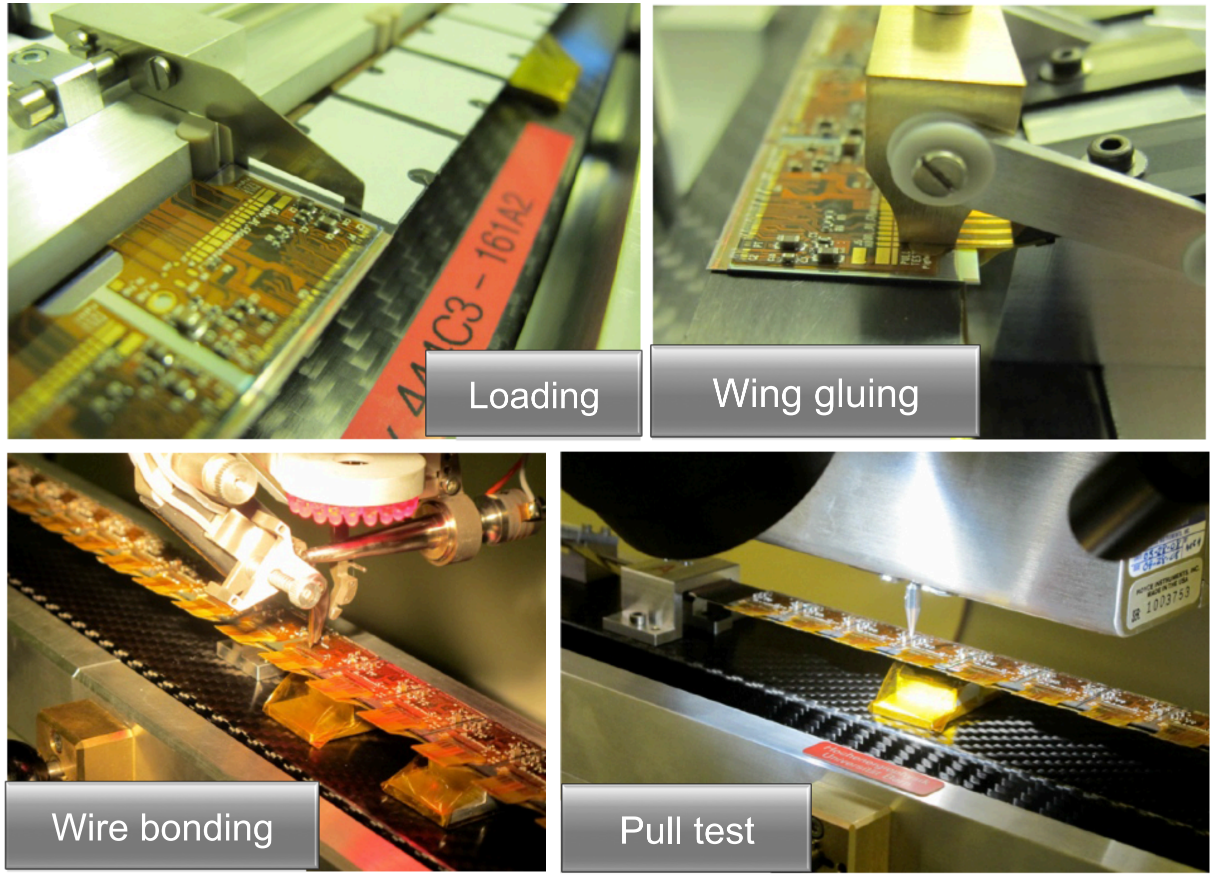


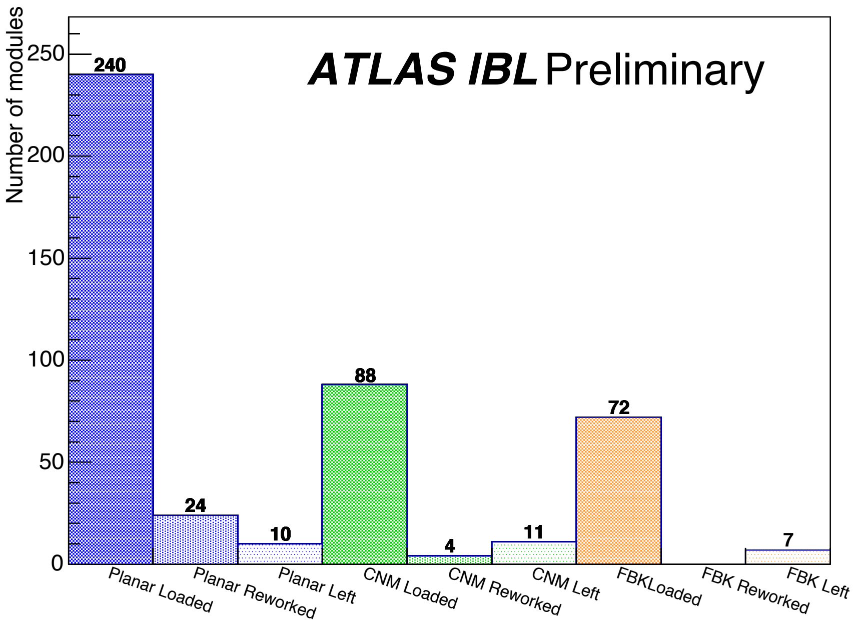
# Module production



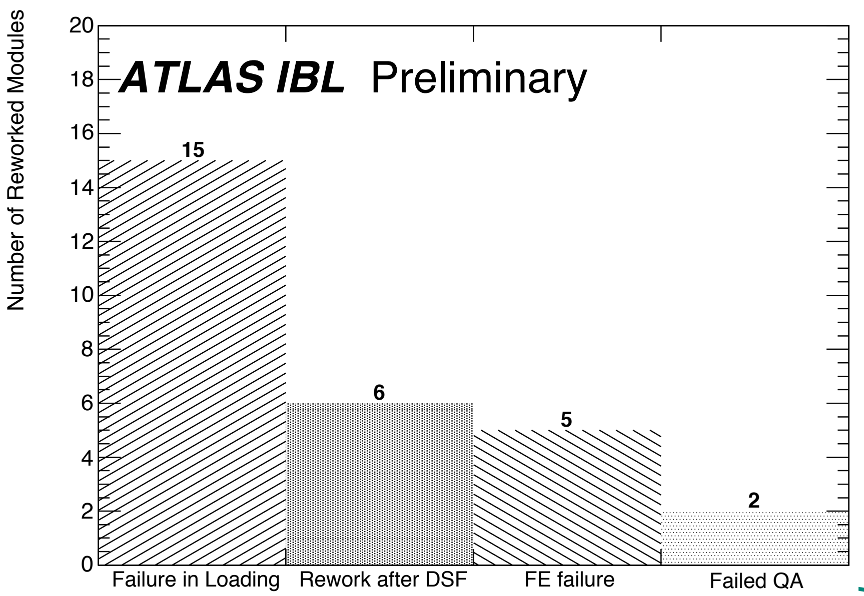

- Completed in September 2013
- 75% yield for planar and 62% yield for 3D after the initial bumpy start

# Stave production (I)



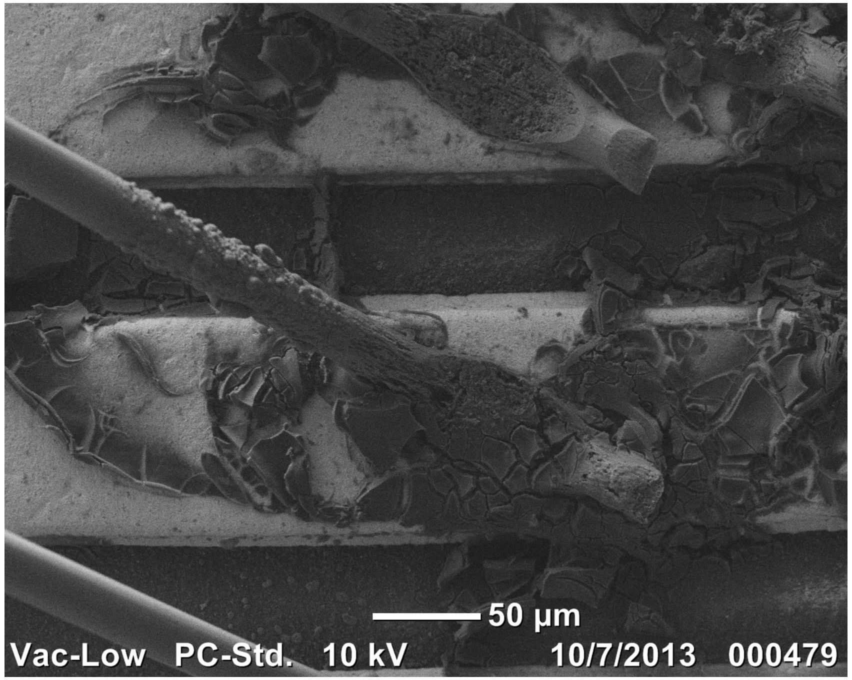



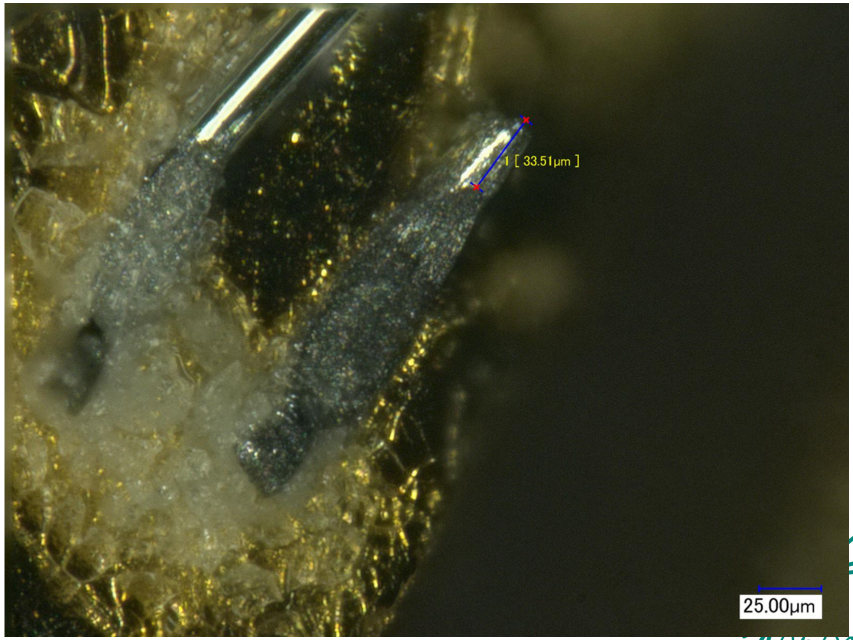

- Completed in February 2014
- 400 modules loaded on 20 staves
- 28 reworks on stave due to various failures



# Stave production (II)

- Two staves were exposed to severe condensation due to an accident during testing midway through production
- Further inspection revealed corrosion on most staves produced thus far
- Chemistry lesson of a near disaster scenario: never bring Al, Halogen (Cl, F) and $H_2O$ together at once
- Corrosion could be reproduced even on well cleaned bare flex with drop of DI water
- Intensive rework program to carefully clean corrosion residue and replace wirebonds

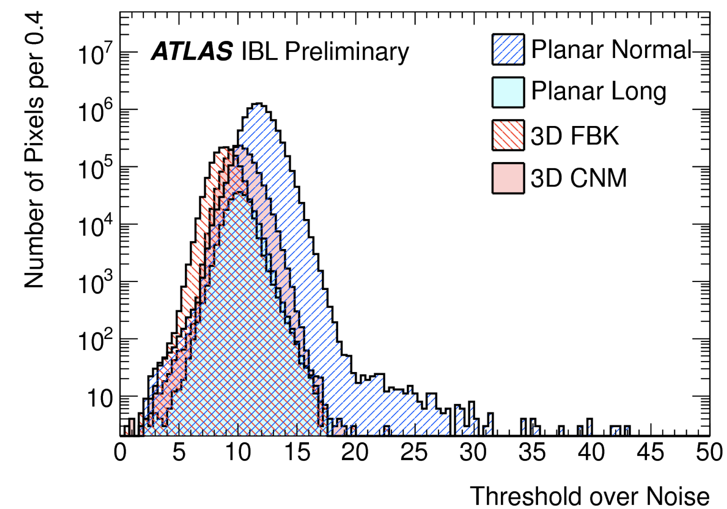


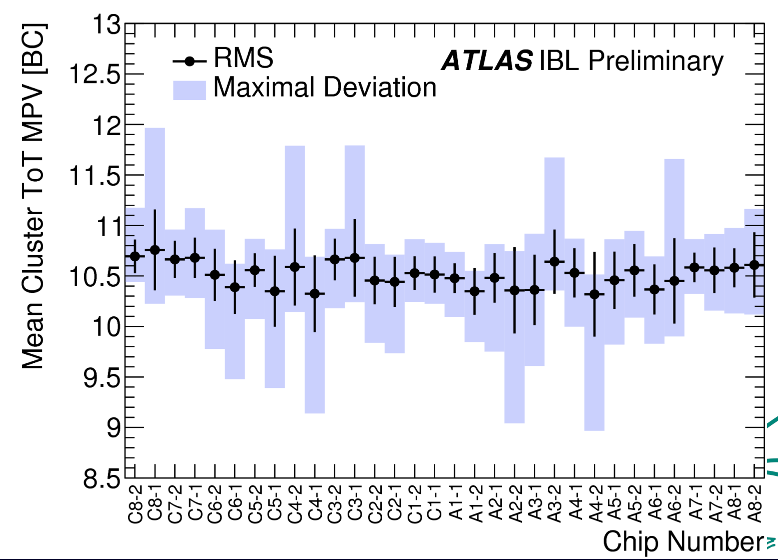



# Quality assurance (I)

| Day 1 | | Day 2 | | Day 3 | Day 4 | |
|---|---|---|---|---|---|---|
| Optical inspection | Installation | Power up & Reception test | Warm tuning & source scan | Cold tuning & thermal cycles | Removal | Optical inspection |

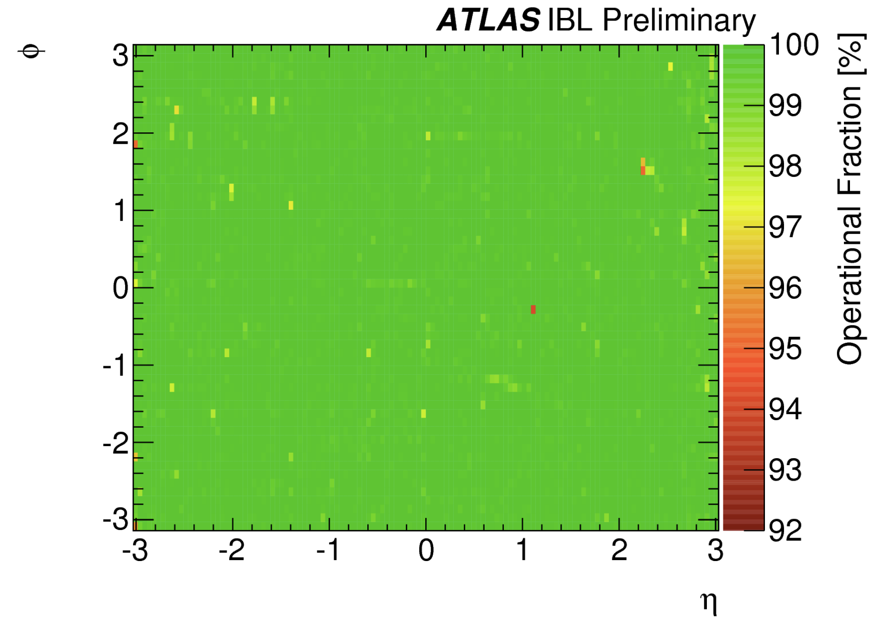
- Compressed four day program after the condensation incident
- Still putting staves through rigorous testing
- Excellent tuning performance down to 1500e target operational discriminator threshold; important after radiation damage
- Uniform response over all staves
- 18 of 20 staves passed QA; 2 failing that saw severe condensation and used as rework practice

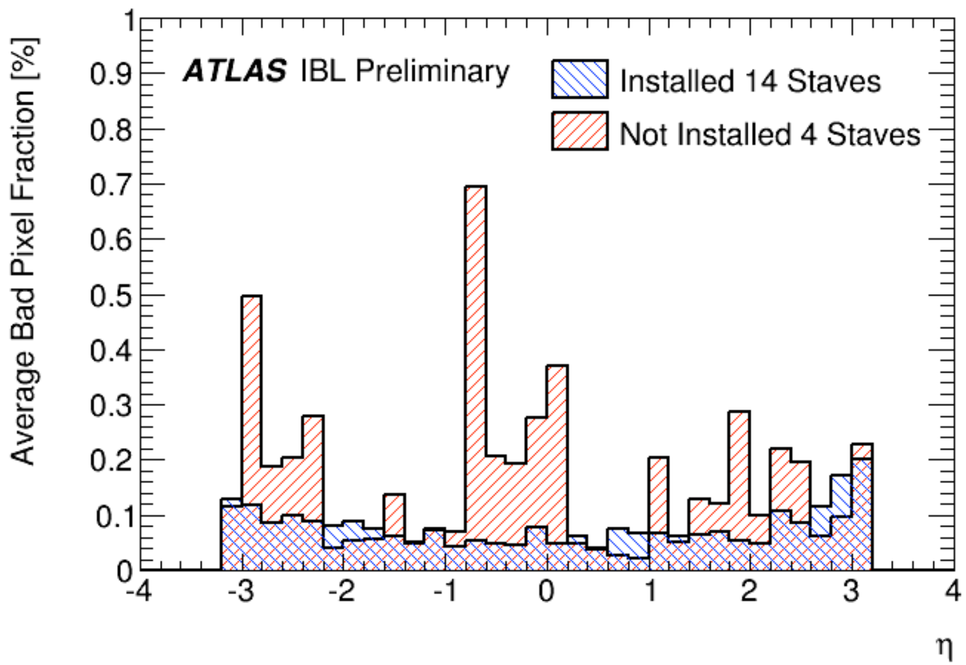


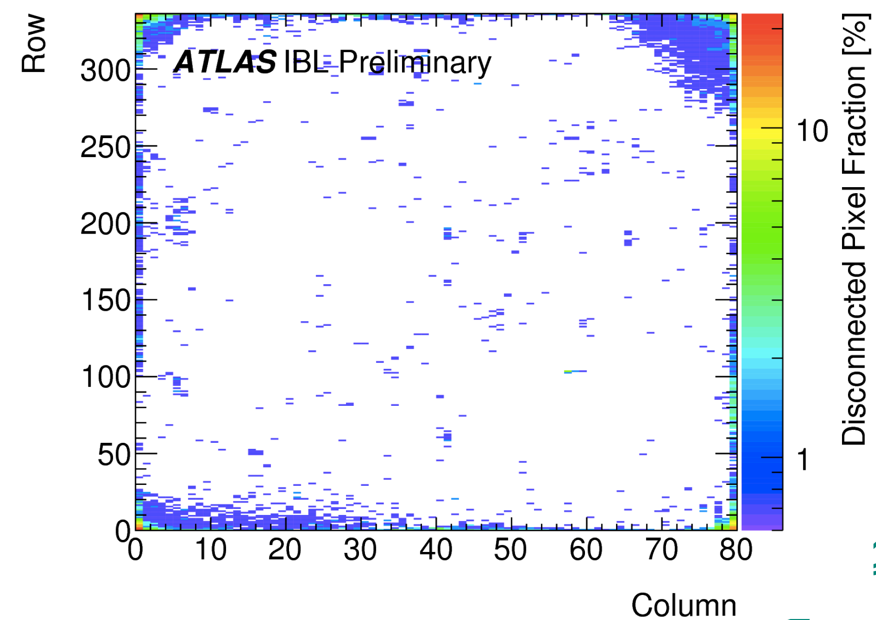



# Quality assurance (II)

- 14 of the 18 qualified staves used for IBL
- 99.9% of pixels operational; impressive given the target of better than 99%
- 0.1% dead pixels cluster on the edges of the chip as is the case for the 3-layer pixel detector



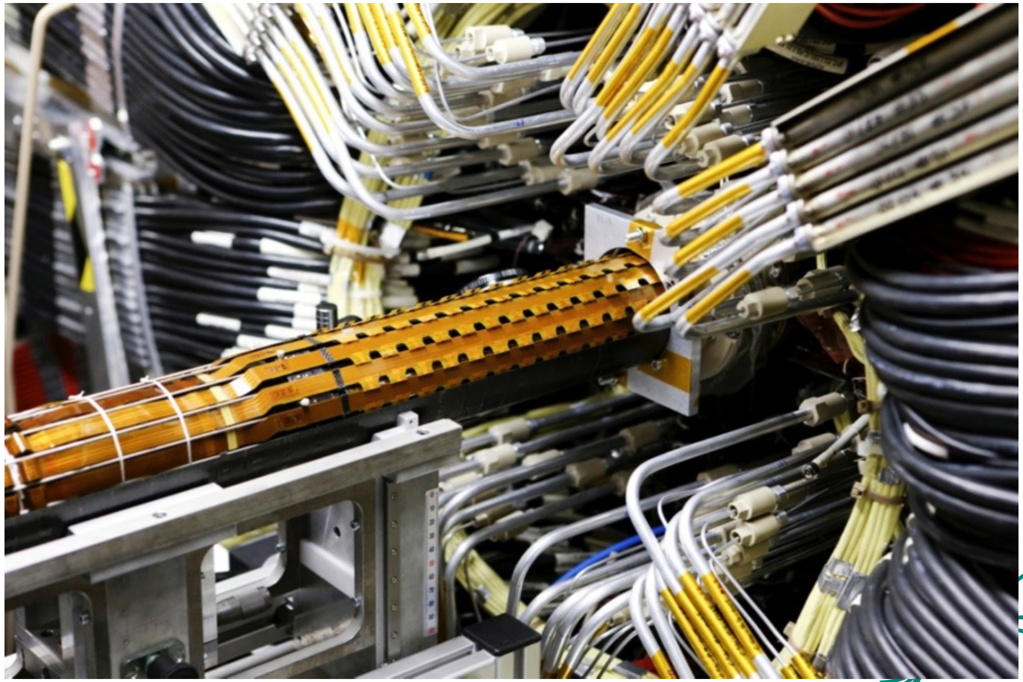



# Integration and installation (I)

last stave integrated around the new beam pipe end of March 2014

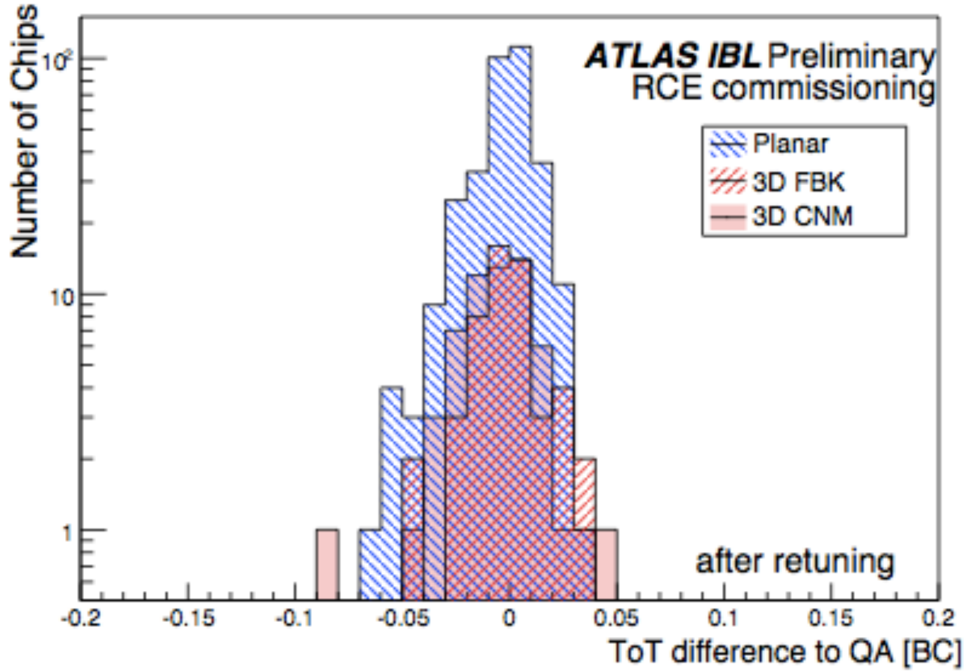
transported to the cavern in May 2014

installation completed end of June 2014



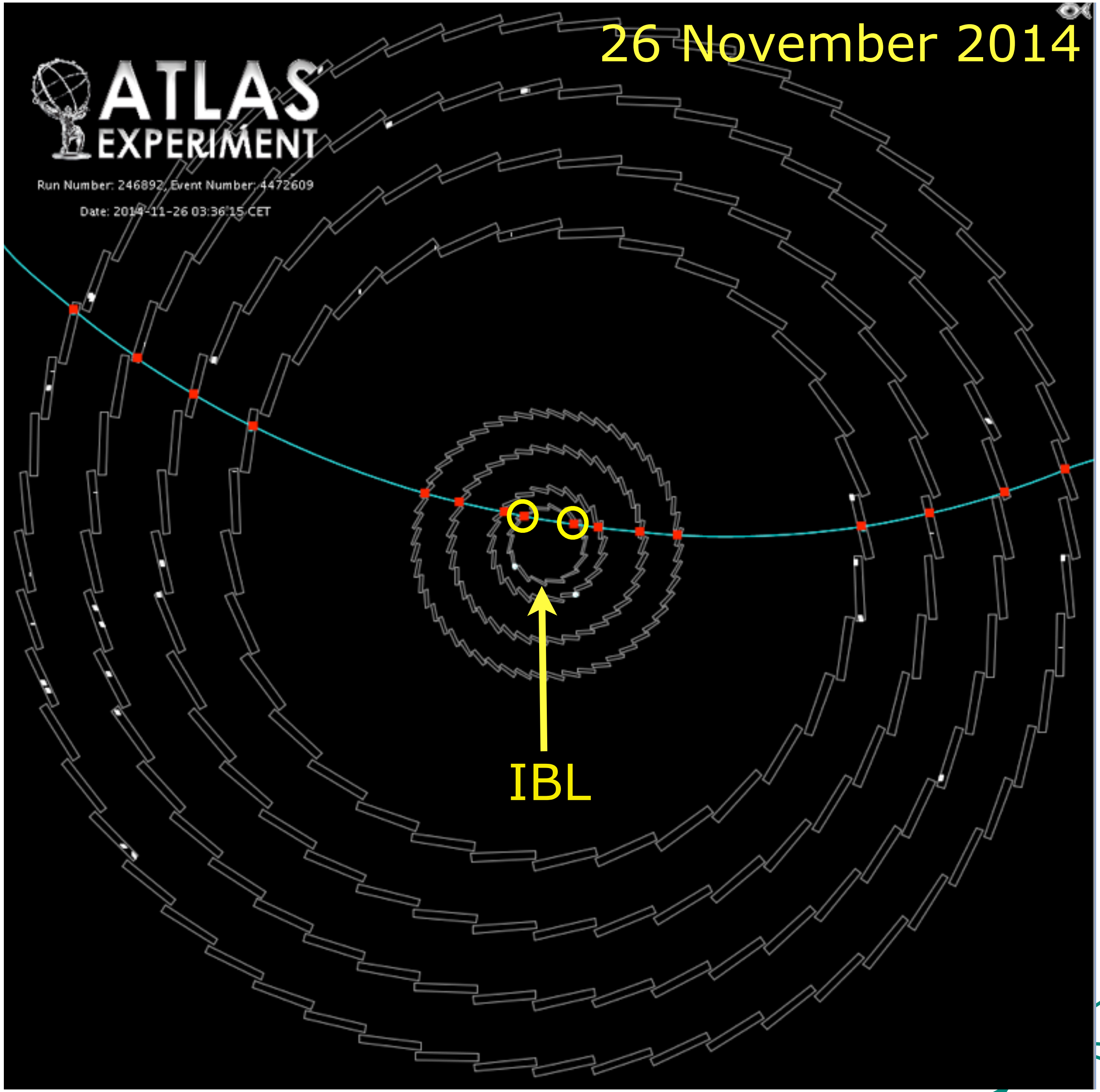
# Integration and installation (II)

- Each stave went through short series of functionality test before and after integration around the beam pipe
- The detector went through QA standard tests right after installation in the cavern using the same RCE readout system from the QA before switching over to the final DAQ system to be used for data taking
- Results confirmed, 100% functional damage free integration, transport and installation of the detector



# Commissioning milestones

- First IBL stave joined ATLAS cosmic runs in September 2014
- $CO_2$ cooling system assured safety of IBL during the bakeout of the new beam pipe at 230$^o$C in October
- 9/14 staves joined ATLAS runs in October 2014
- Full IBL joined ATLAS runs in November 2014 in the presence of a solenoidal magnetic field



# Summary

- The ATLAS detector is now just 3.3 cm away from the LHC collisions and ready for the LHC Run-2 conditions thanks to the new innermost pixel layer: IBL
- Construction and installation completed two years ahead of its original schedule
- Initial commissioning done and already providing space points on charge particle tracks
- On going effort is focusing on the implementations of automatic recovery mechanisms of readout components in the event that they become non-responsive to maximise data taking efficiency, and protections for operational safety of the modules in the presence of magnetic field and beam

Questions?

# First IBL stave in an ATLAS run