ATLAS IBL operational experience

September 26th, 2016

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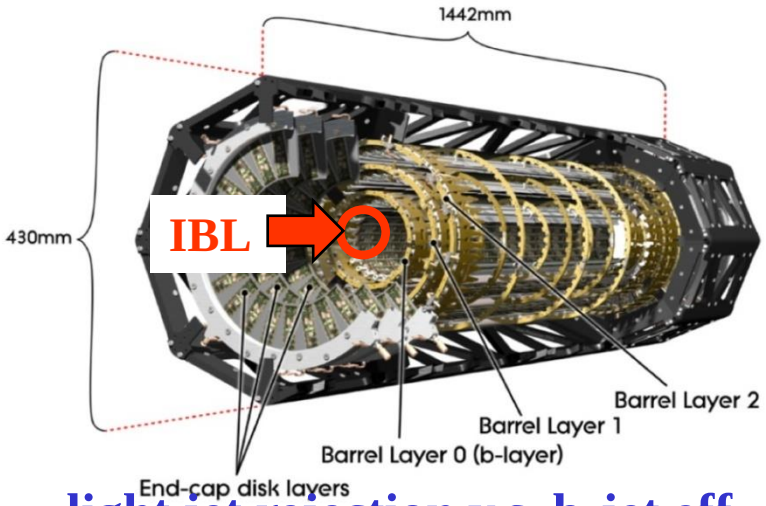
On behalf of the ATLAS Collaboration

VERTEX2016, Isola d'Elba, Italy

Insertable B-Layer (IBL)

What is IBL?

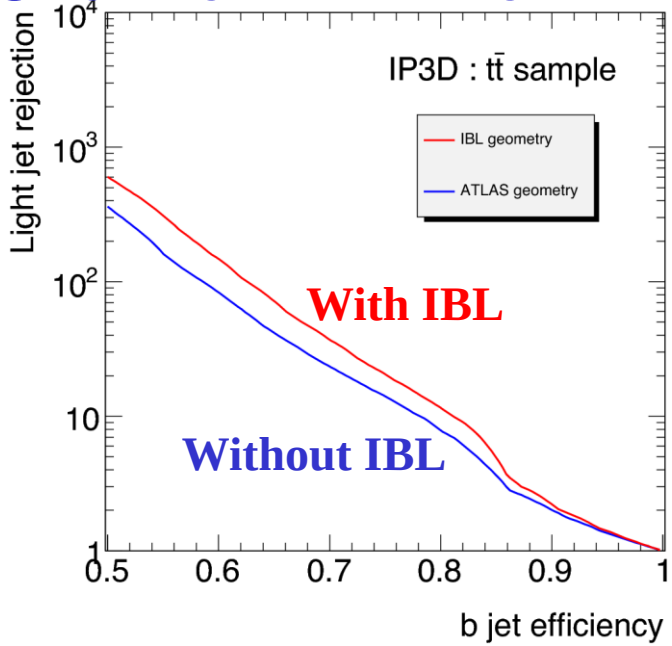
- The new innermost pixel layer installed in 2014 (r=33mm).
- The original pixel layers are called as "Pixel" to distinguish from IBL.



Motivation

- Original motivation: B-Layer replacement
  → New innermost layer
- Tracking and physics performance improvements mainly for b-tagging.
- Operational until ATLAS Run-3 with peak luminosity of $2 \times 10^{34}\,cm^{-2}s^{-1}$ or more.

light jet rejection v.s. b-jet eff.



ATLAS physics results in ICHEP2016

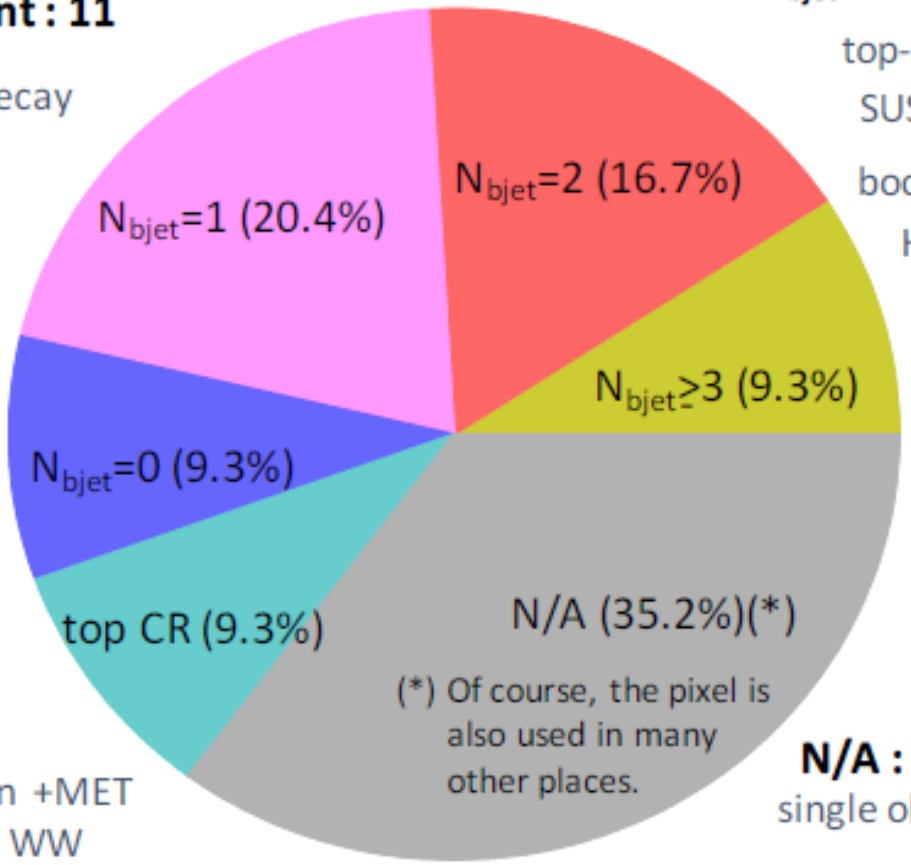
65% of the analyses use b-jets!

N_{bjet} =1 requirement : 11

SUSY: stop->exotic decay
single top,
MSSM Higgs, H+
ttH->multi-lepton
new bb-resonance

N_{bjet} =2 requirement : 9

top-pair : 5
SUSY: stop->dilepton
boosted / H topology: 4
H->bb, dark matter



N_{bjet} =0 (b-veto) : 5

SUSY: multi-jet
di-boson high mass
H->WW/ZZ

$N_{bjet} \geq$ 3 requirement : 5

multi-top topology: 5
SUSY: stop/sbottom searches,
Higgs: ttH, HH, tH+

TopCR : 5

SUSY: photon +MET
H->γγ , WBS WW
+ several

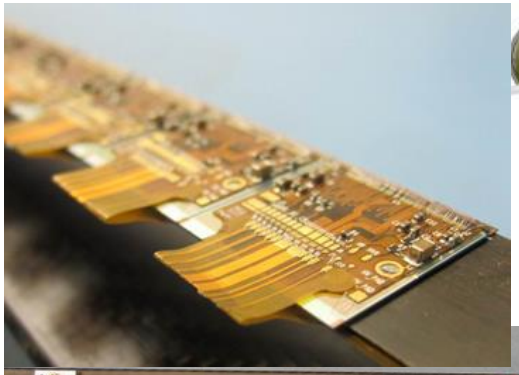
N/A : 19

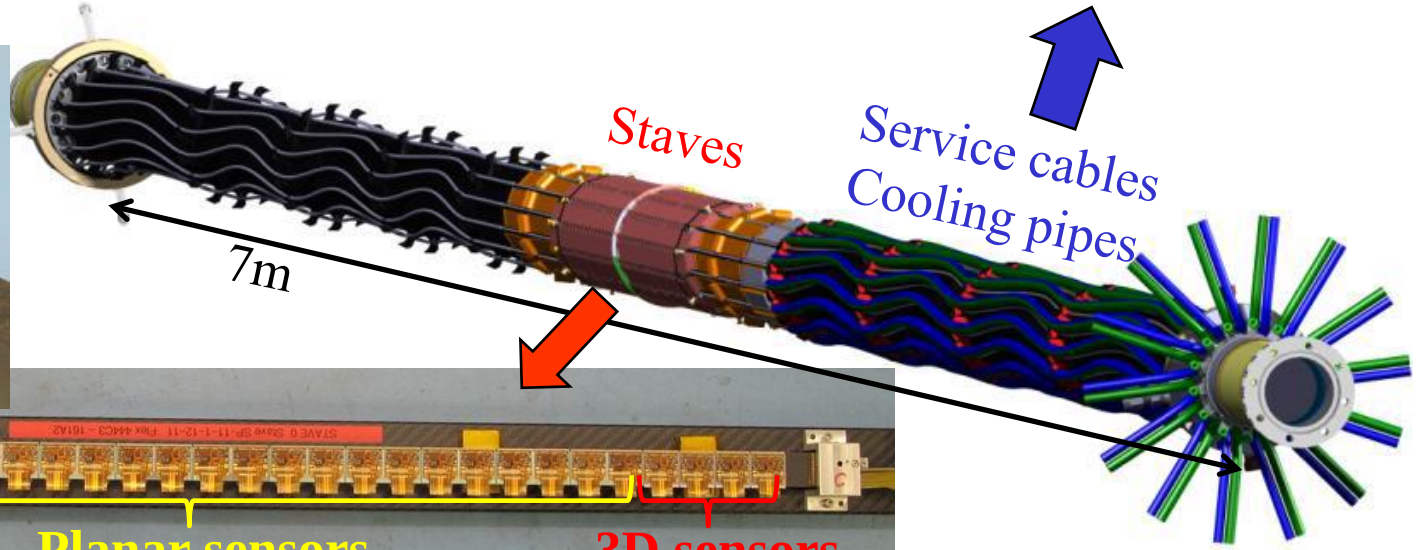
single object : di-jet, di-lepton,
γγ resonance,
multi-lepton

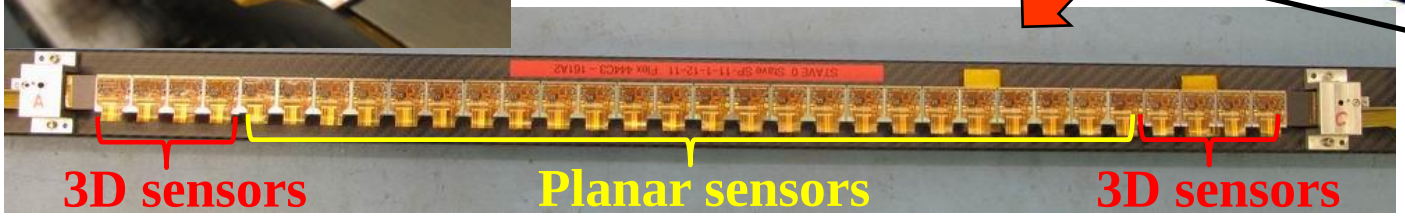
Presented by S. Tsuno at Pixel 2016

IBL on-detector components

- Sensor modules:
  - Planar sensor (75%), 3D sensor (25%)
  - The planar slim-edge of 200 um is adopted.
  - 3D sensor technology: The first time used in HEP experiment
- 14 staves (12 planar and 8 3D modules per stave)
- Service cables: installed with the detector
- Ti pipe with 1.5 mm diameter for CO_2 cooling



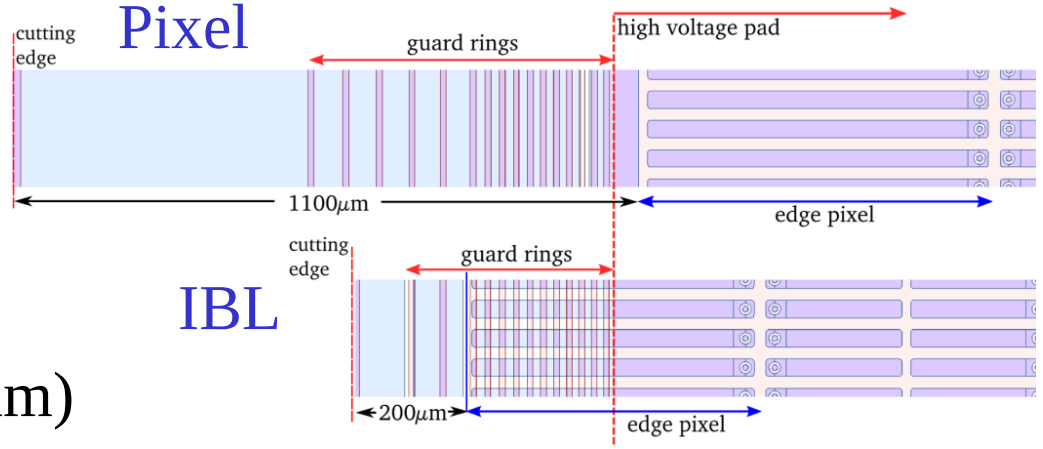




IBL sensor technology

- Planar and 3D sensors are used for IBL.
- Pixel size: 50 x 250 um^2

  (Pixel detector : 50 x 400 um^2)

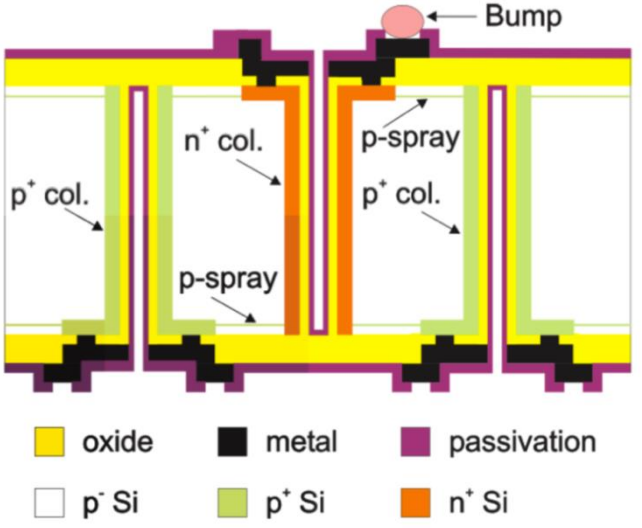


Planar sensor

- n^+-in-n technology
- Thickness: 200 um (Pixel: 250um)
- Small inactive edge region of 200 um with long pixels under the guard-ring.

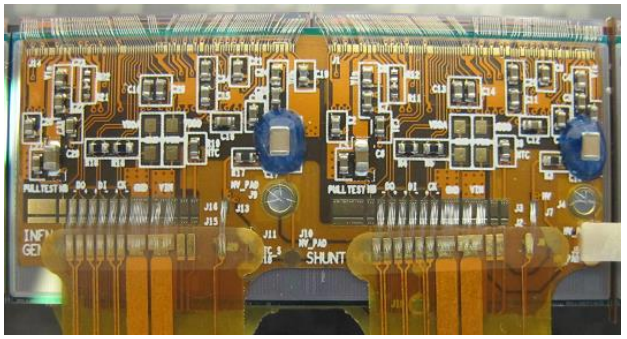
3D sensor

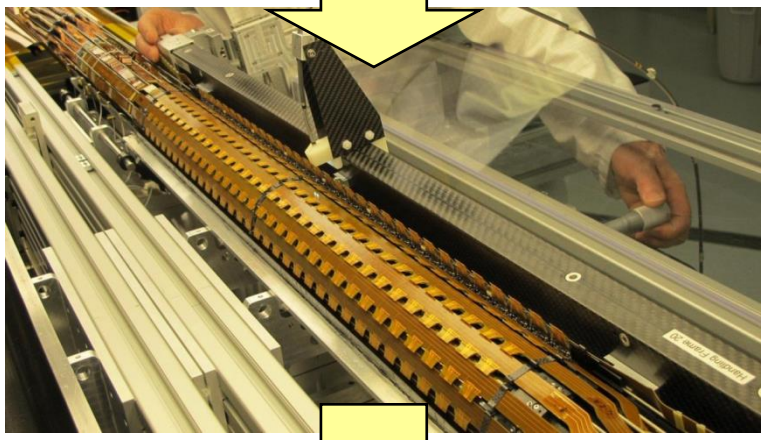
- Double-side double type columns process
- n^+ and p^+ implant for HV and GND
- Thickness: 230 um
- Guard ring fence: 200 um inactive area

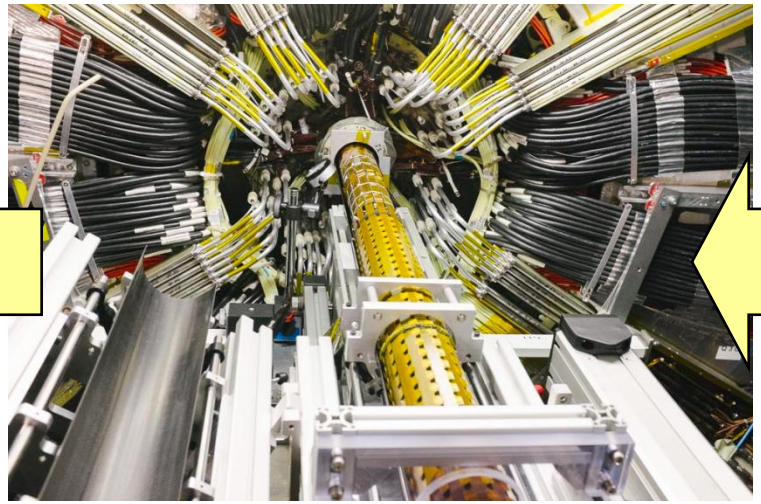


IBL installation

- The modules are mounted on the staves.
- The 14 staves were integrated on a support tube on surface.
- 7 m long of IBL package within the limited radial envelop space (10 mm).
- IBL was moved to ATLAS experimental hall at 90 m underground and installed into the ATLAS on May, 2014.
  - The insertion clearance less than 0.1 mm



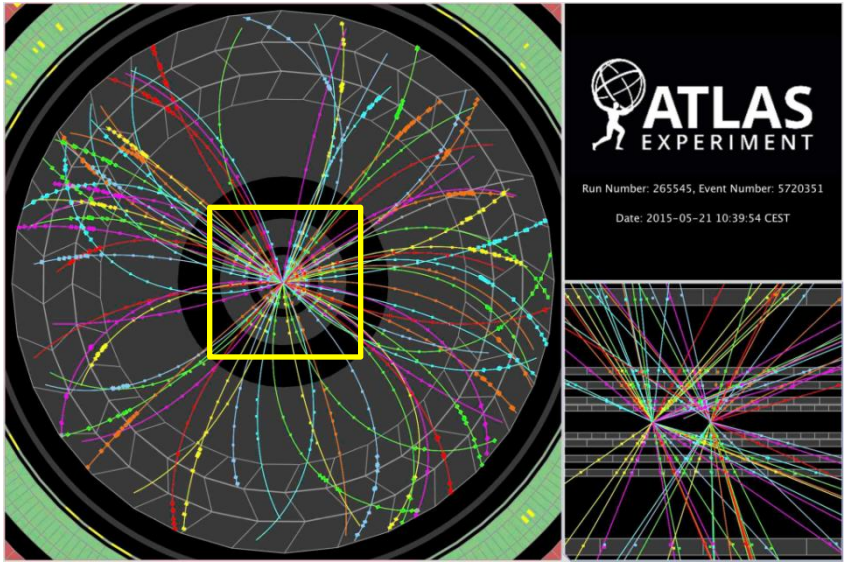




Data-taking at ATLAS Run-2

- ATLAS started to take data at 13 TeV colliding energy in 2015 (Run-2).
- IBL is operational within $|\eta|=3$ (ID tracking: $|\eta|<2.5$).
- The first tracks with IBL in the beam collision was obtained on May, 2015.
- IBL shows excellent performance and has been operated in stable condition, facing challenges in the operation.

Performance and challenges in the operation will be presented.

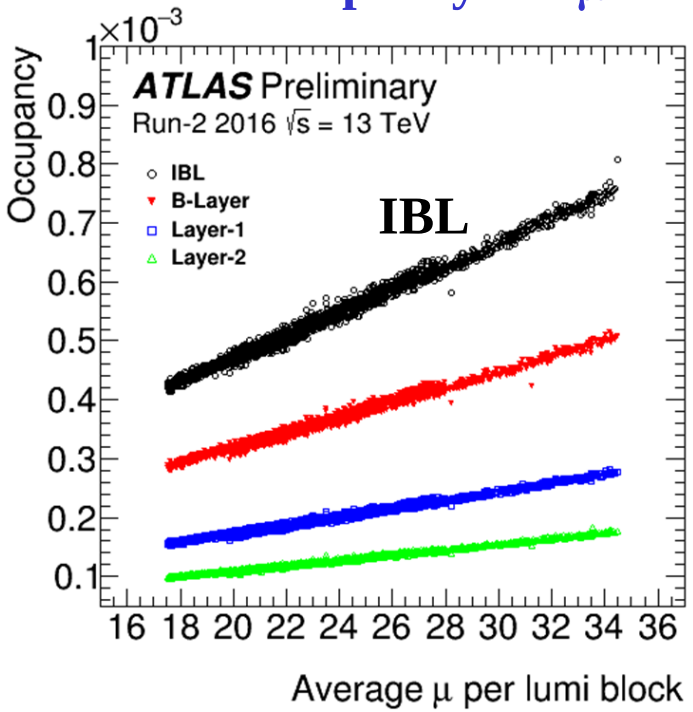


IBL performance

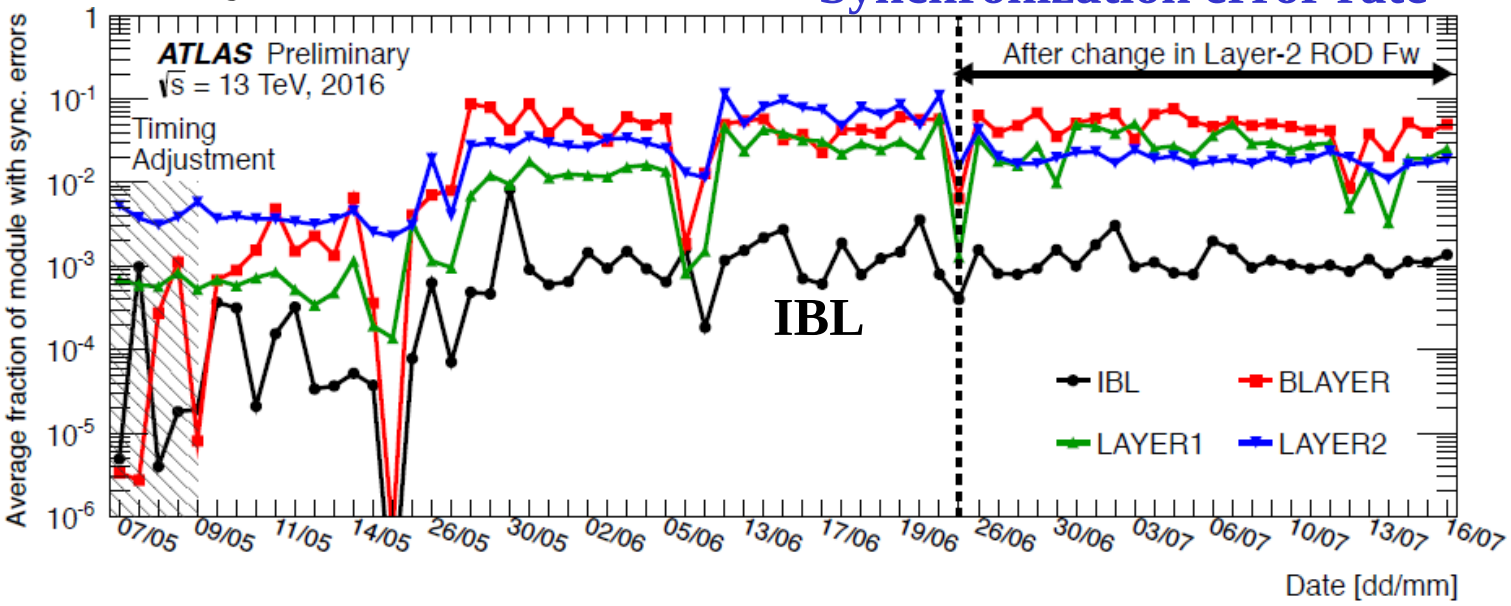
Operation stability

- Hit occupancy of IBL reaches 0.8x10^{-3} at the number of pile-up (μ) of 35 in 2016.
  - Peak luminosity ~ 1.2x10^{34}.
- The synchronization error rate is of the order of 0.1%.
- The backend readout system was replace for Layer-2 by the same system as IBL in 2016.

Hit occupancy v.s. μ



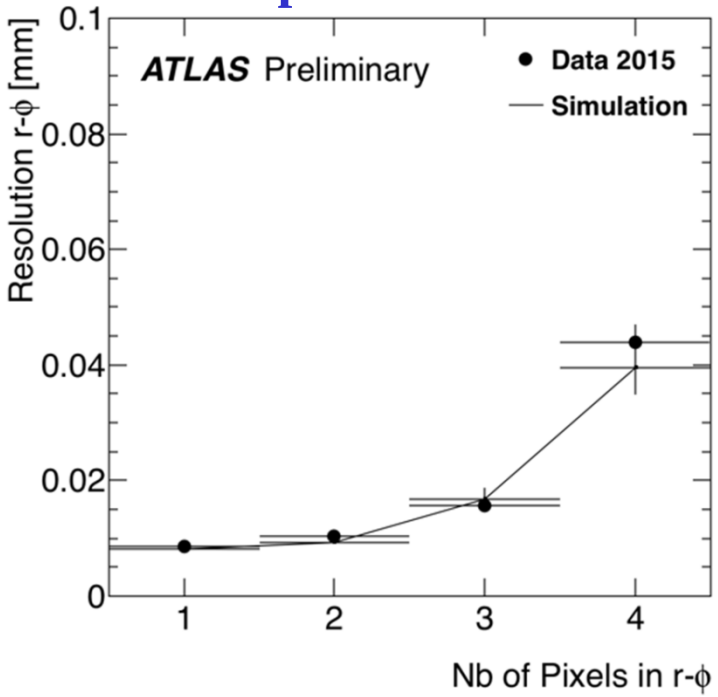
Synchronization error rate



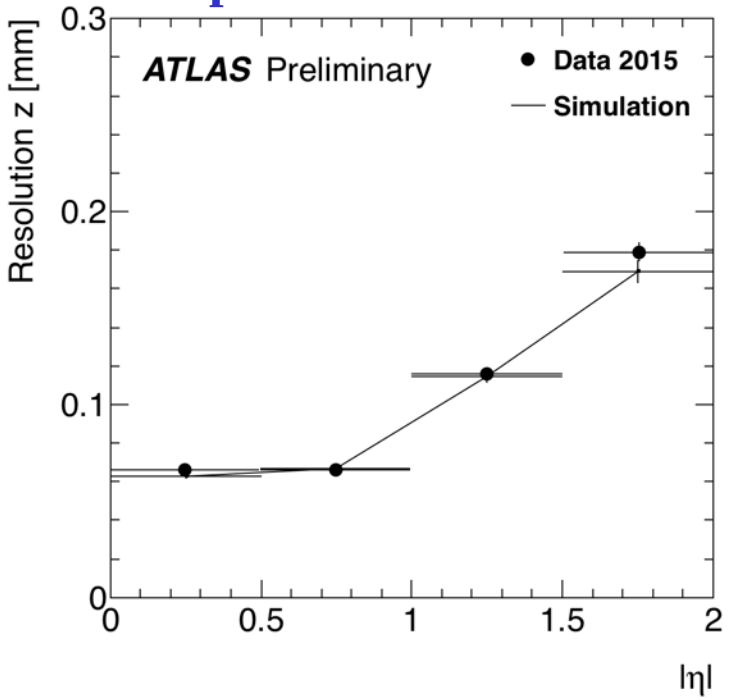
Position resolution

- The position resolution of IBL is 10.0 um (r-ϕ) and 66.5 um (z).
  - Z→μμ, |η|<2 for r-phi, |η|<1 for z
  - The resolution is consistent with MC prediction
- The clusters with more than 2 pixel hits in r-ϕ direction typically include δ-ray, and it degrades the special resolution.

Radial position resolution

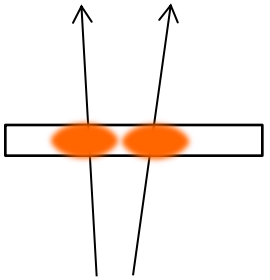


Z-position resolution

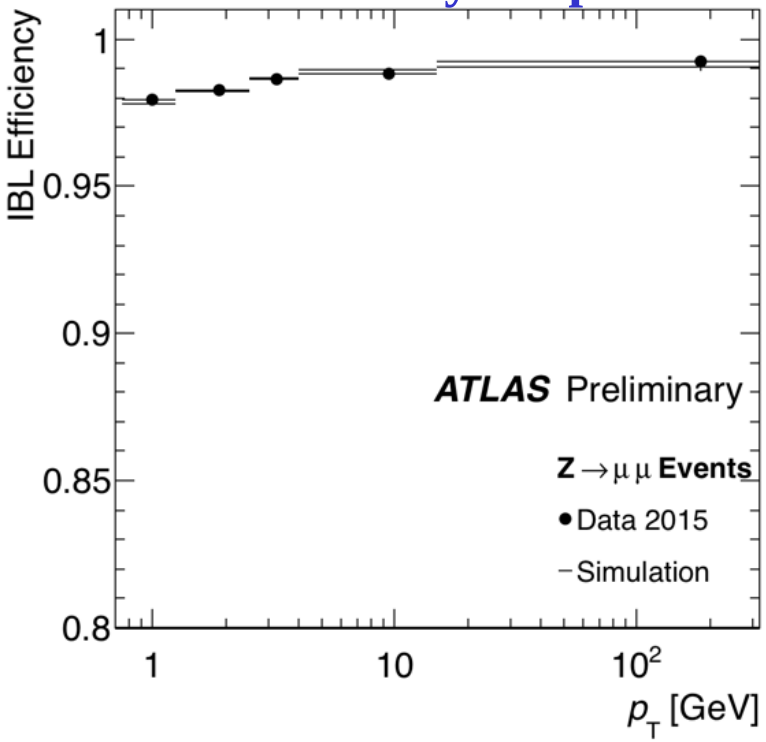


IBL efficiency

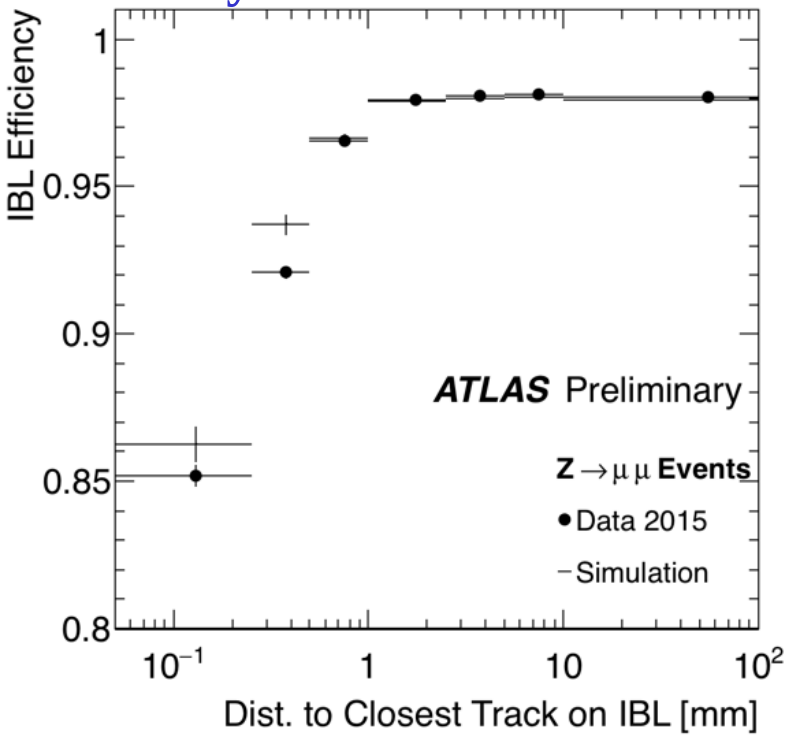
- IBL shows good efficiency above ~98% for pT > 0.7 GeV.
  - Z→μμ, distance to the closest track on IBL > 2.5mm
- Small pixel size of IBL provides the separation capability of the merged cluster of ~0.75 mm.



Efficiency v.s. pT



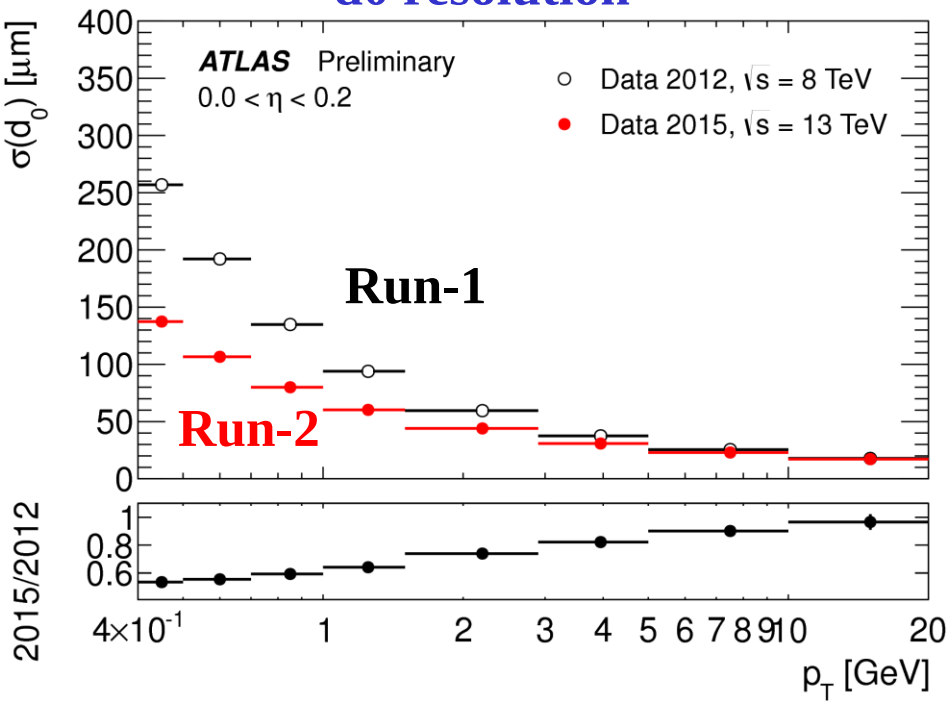
Efficiency v.s. dist. to the closest track



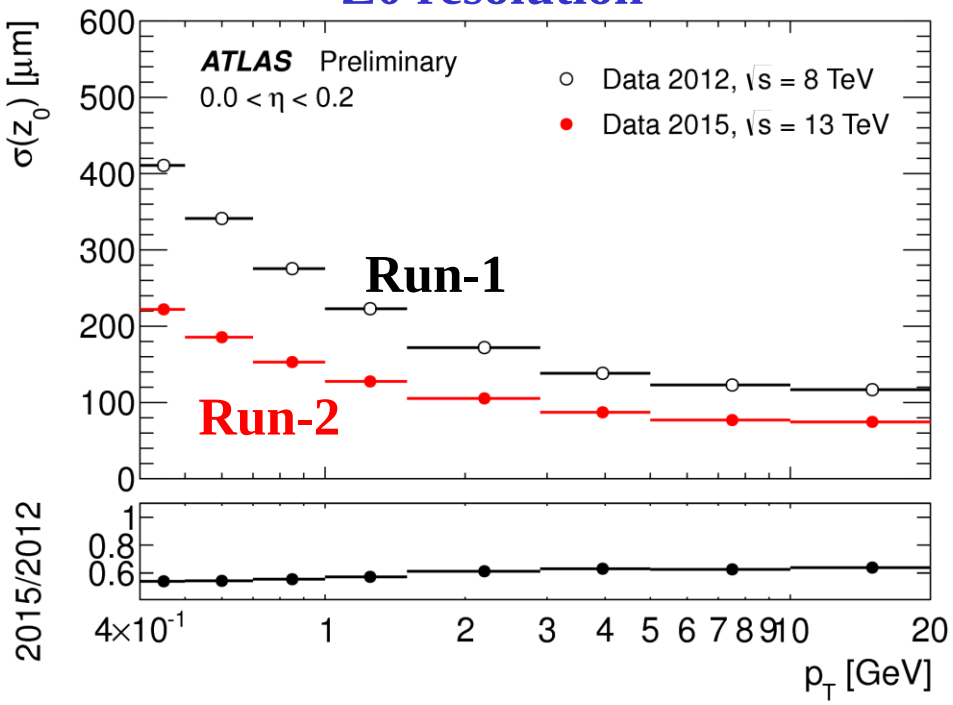
Impact parameter resolution

- The good impact parameter resolution is important for b-jet tagging, pile-up suppression and object identification.
- The impact parameter resolution is significantly improved with IBL especially at low-pT.
  - reduced by ~40% for d0 and Z0 at the maximum

d0 resolution

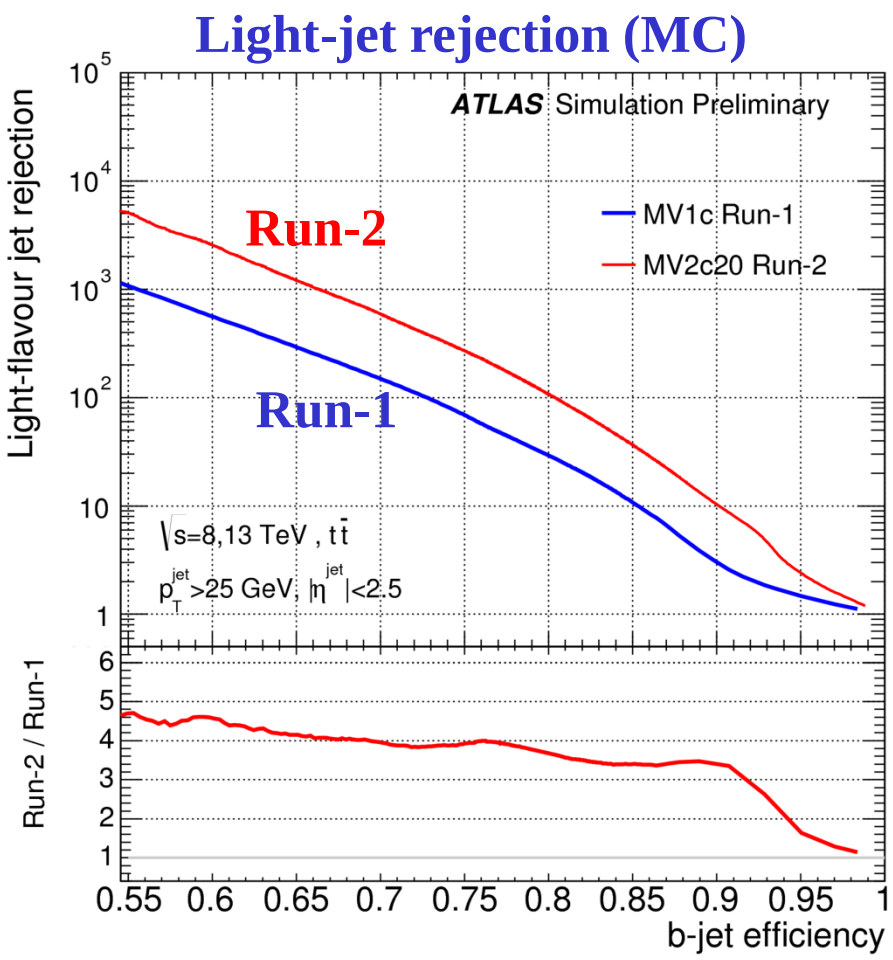


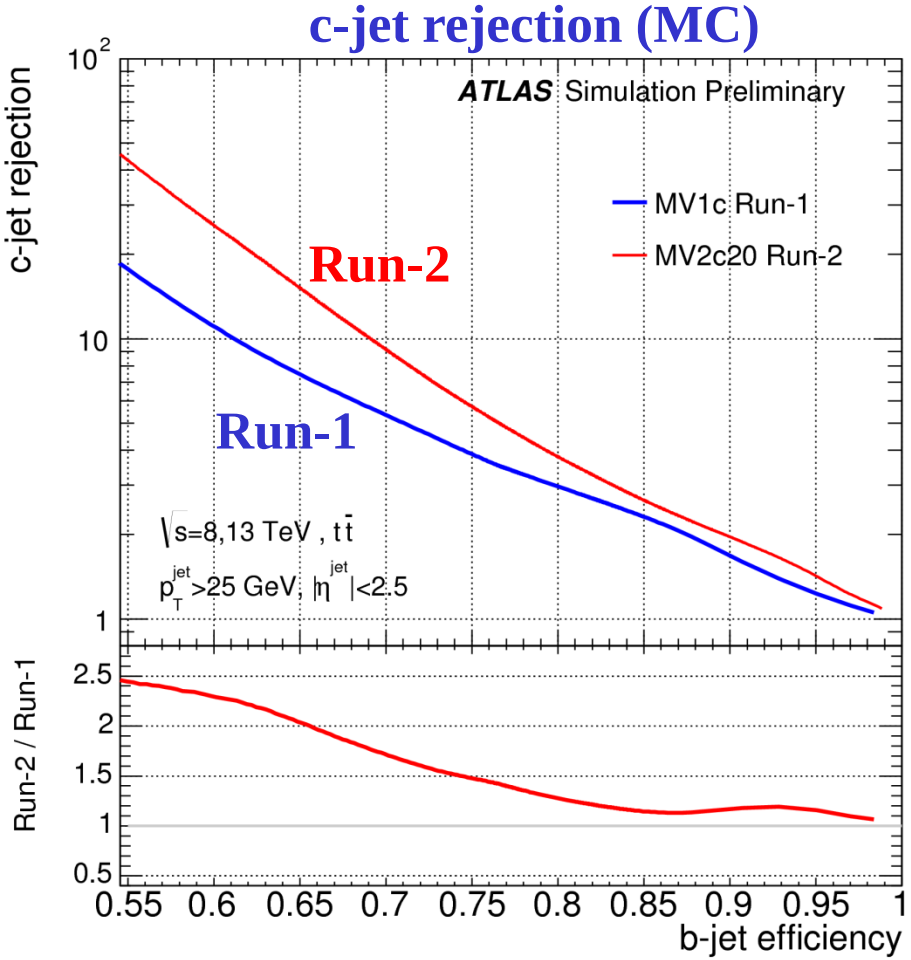
Z0 resolution



Improvement in flavor tagging

- The better track extrapolation resolution improves b-tag performance.
- The light jet rejection is increased by ~4 times for ε_b=70%.

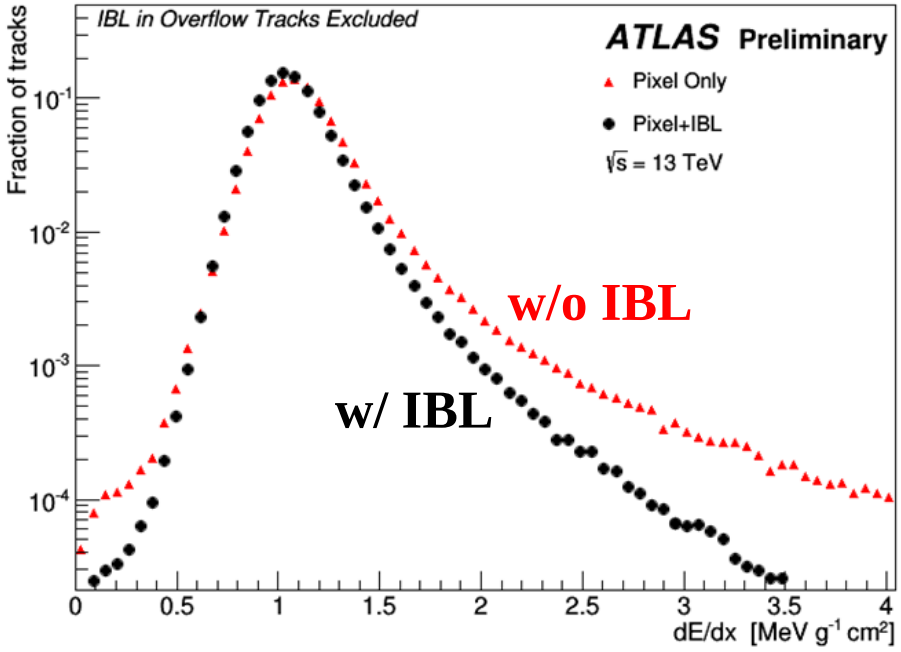




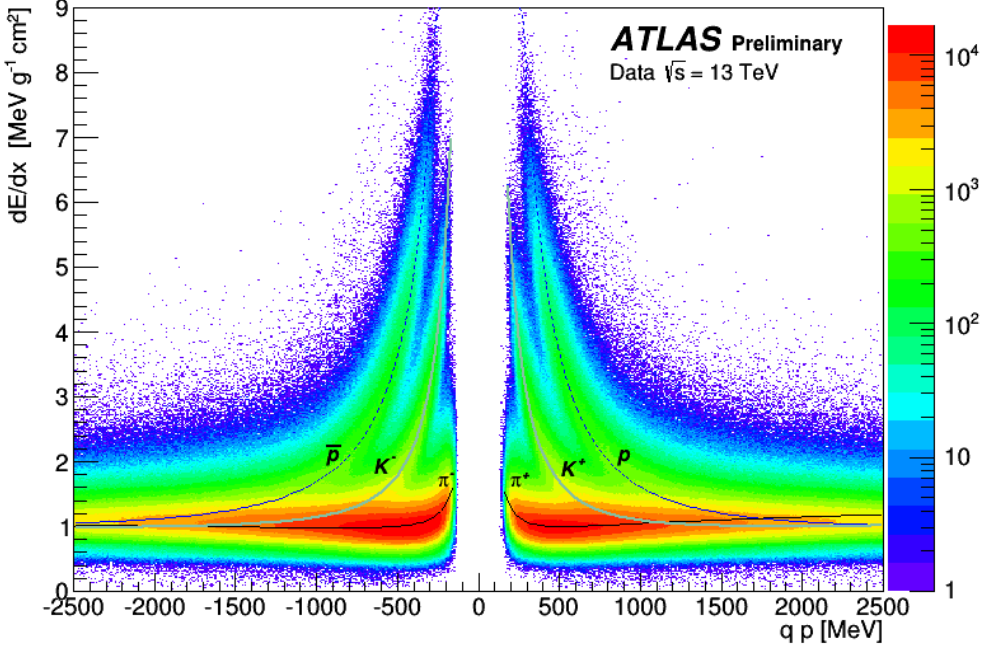
dE/dx performance

- dE/dx information is important for physics analysis to find a new heavy particles predicted in physics beyond the standard model.
- dE/dx distribution becomes narrower with more hit points on IBL.
- The difference of dE/dx for each particle type can be clearly seen.

dE/dx distribution



dE/dx v.s. qp

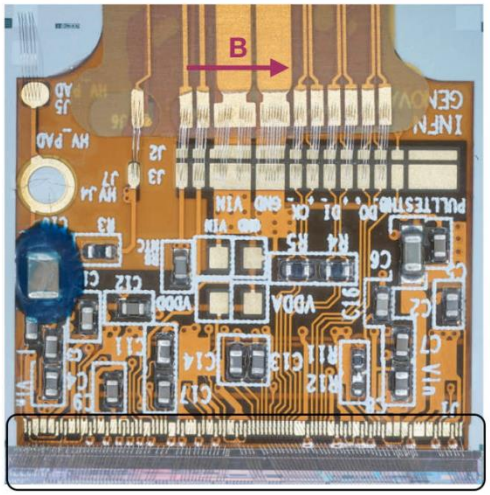


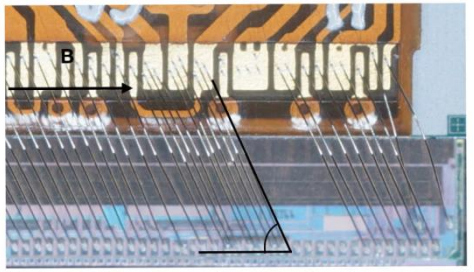
Challenges in IBL operation

Wire-bond oscillation

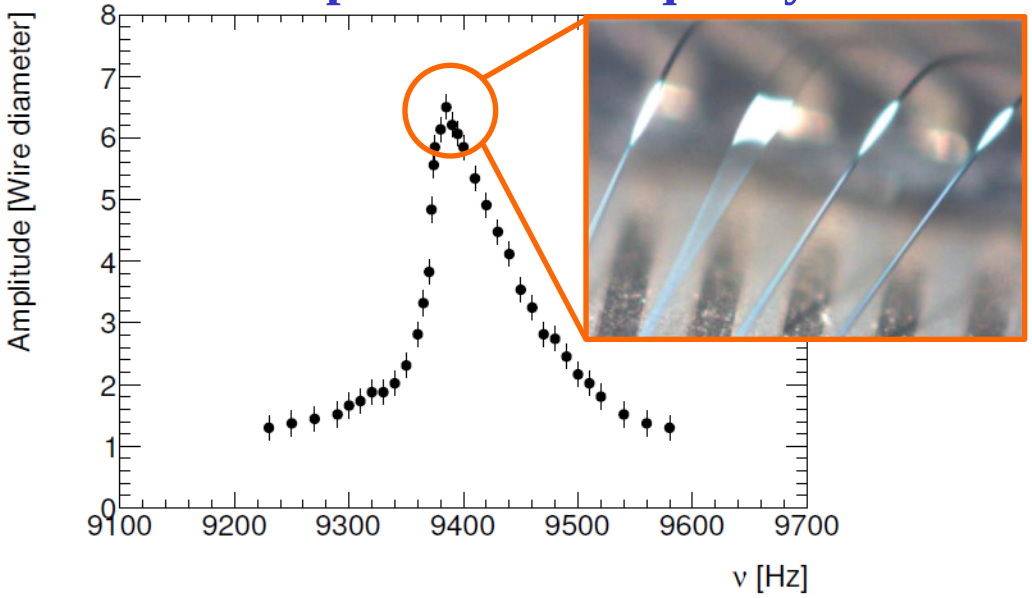
- FE chips (FE-I4B) consumes high AC current by consecutive triggers or calibration scan.
- The wire bonds oscillate in 2T magnetic field and can break at the resonance frequency.

→ FFTV (Fixed Frequency Trigger Veto) was implemented to limit the number of triggers in resonance region.

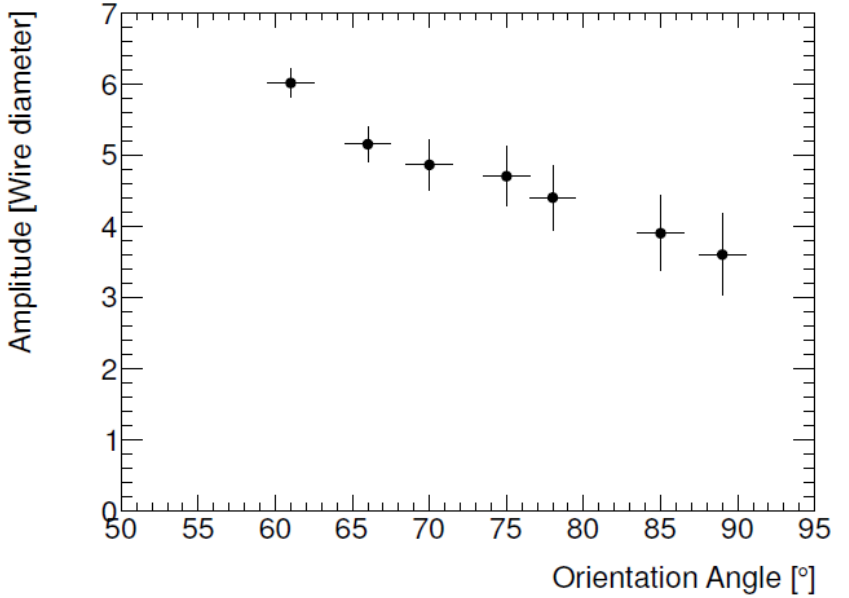




Oscill. amplitude v.s. frequency

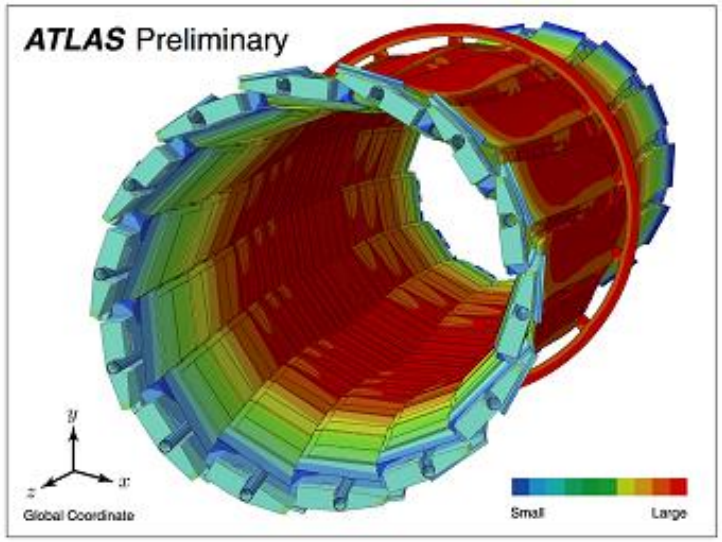


Oscill. amplitude v.s. orientation angle

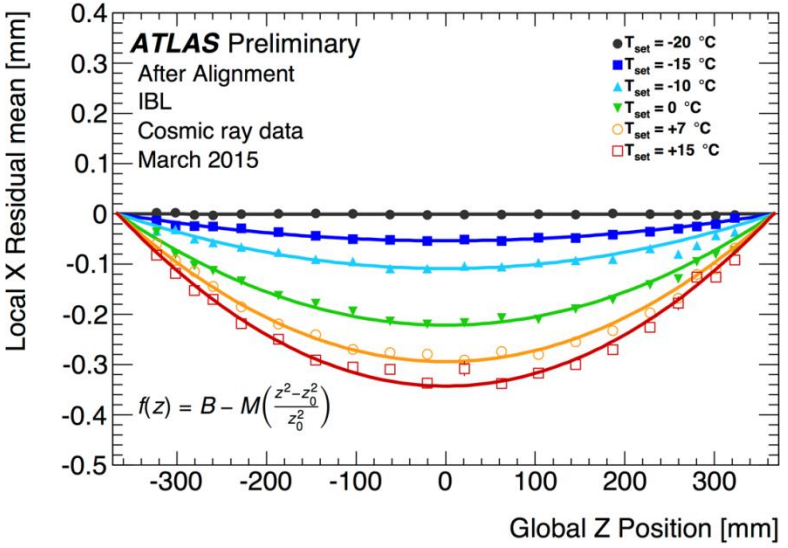


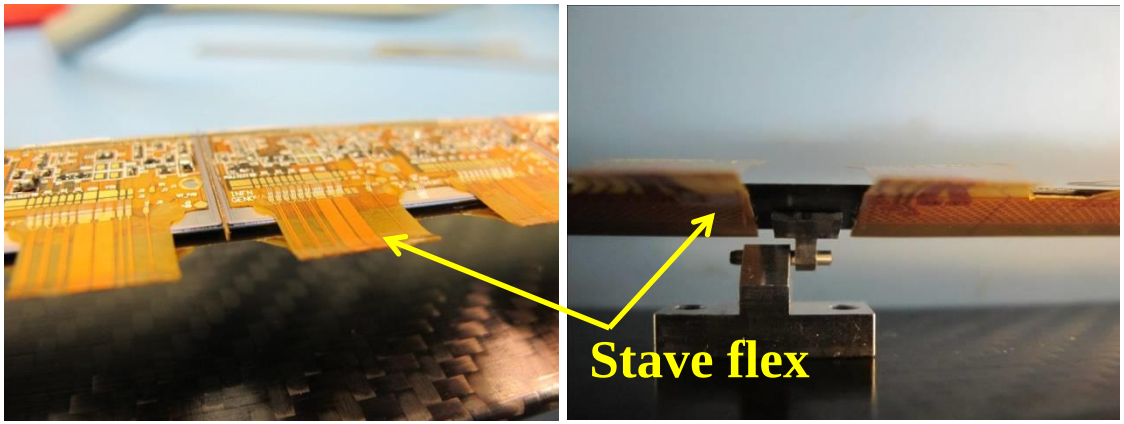
Mechanical distortion of IBL stave

- The bowing of the staves was observed during the commissioning period in 2015.
  - Due to CTE mismatch between service buses and staves.
- Order of 10 um/K twisting of the stave in r-phi direction.
- The impact of this effect is **mitigated by temperature control** at the level of 0.2 K and **alignment correction in offline**.



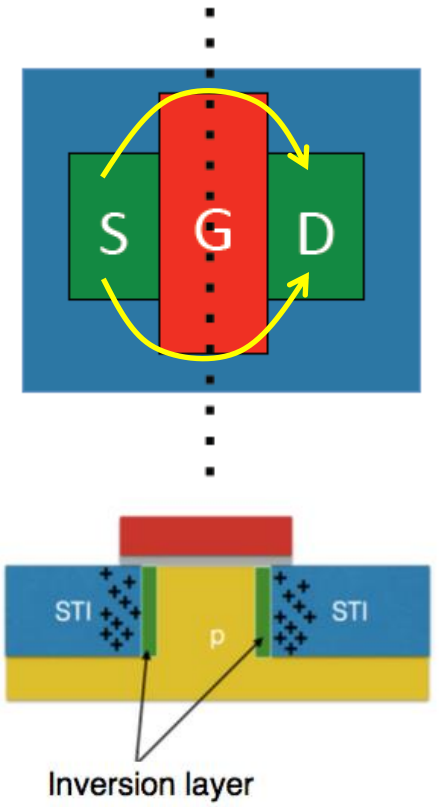
Local x-residual v.s. z-position





TID effect on FE chips (1)

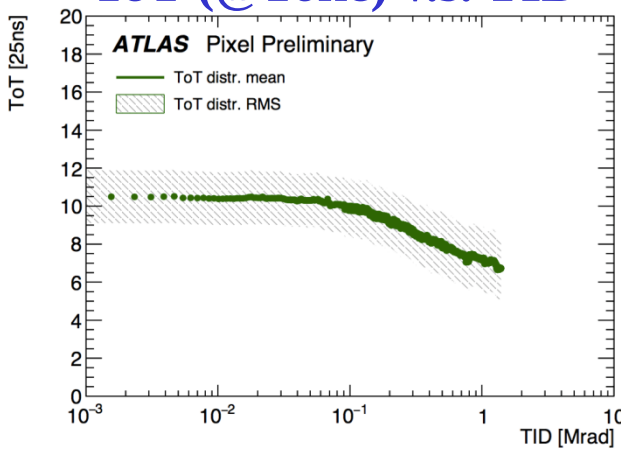
- LV current in FE chips (FE-I4B) increased due to the effect of total ionization dose (TID) in 2015.
- Leakage current was induced by positive charge trapped in STI (Shallow Trench Isolation).



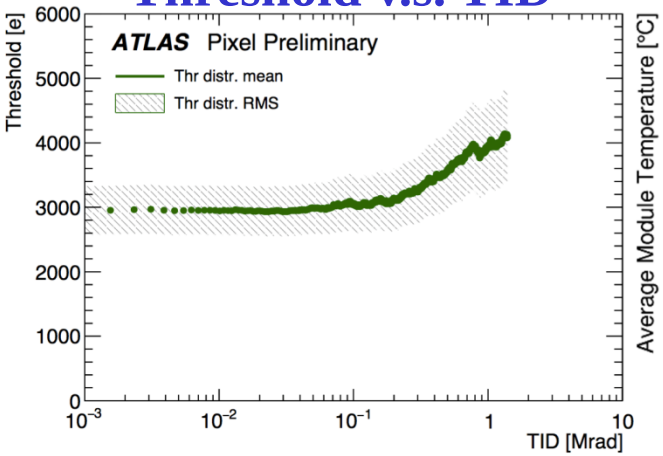
Impact on operation by LV current increase

- Integrity of the detector in terms of current limitation
- Detuning of ToT (Time Over Threshold) and threshold
- Distortion of the stave due to temperature change

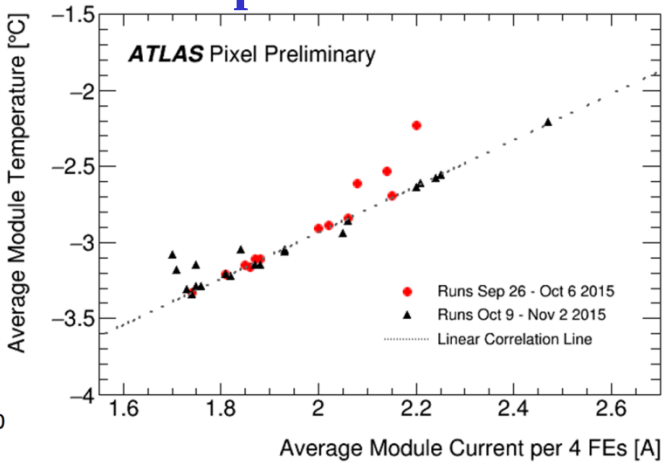
ToT (@16ke) v.s. TID



Threshold v.s. TID

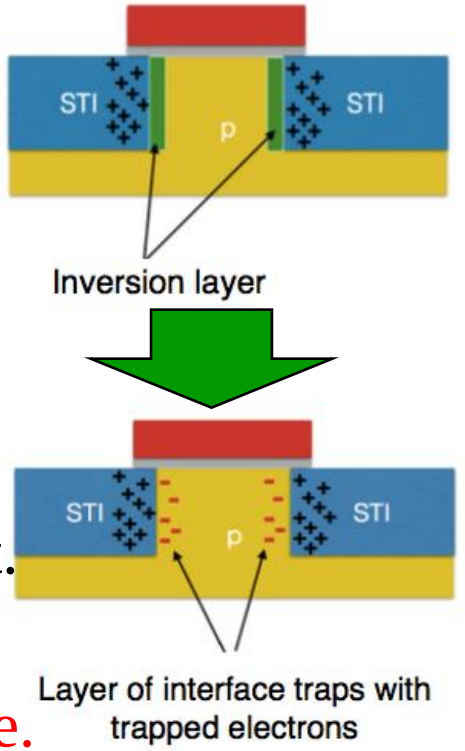


Temp. v.s. LV current



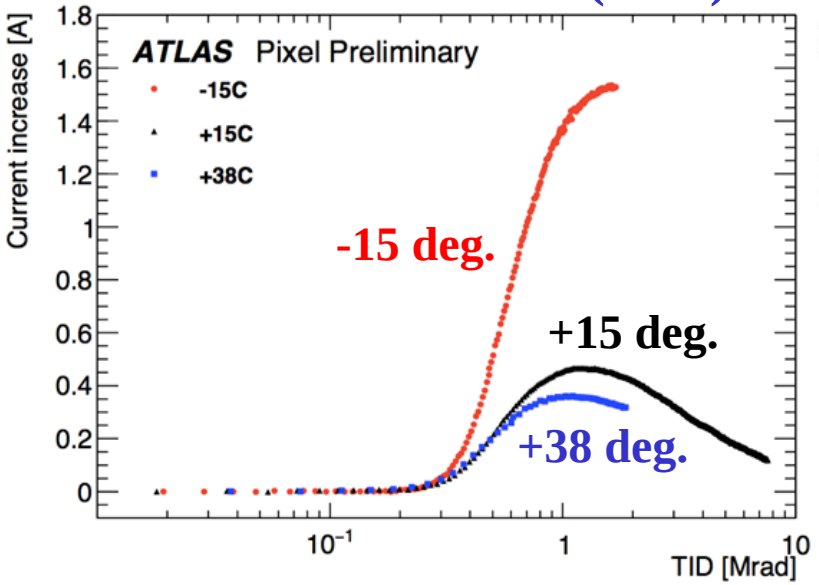
TID effect on FE chips (2)

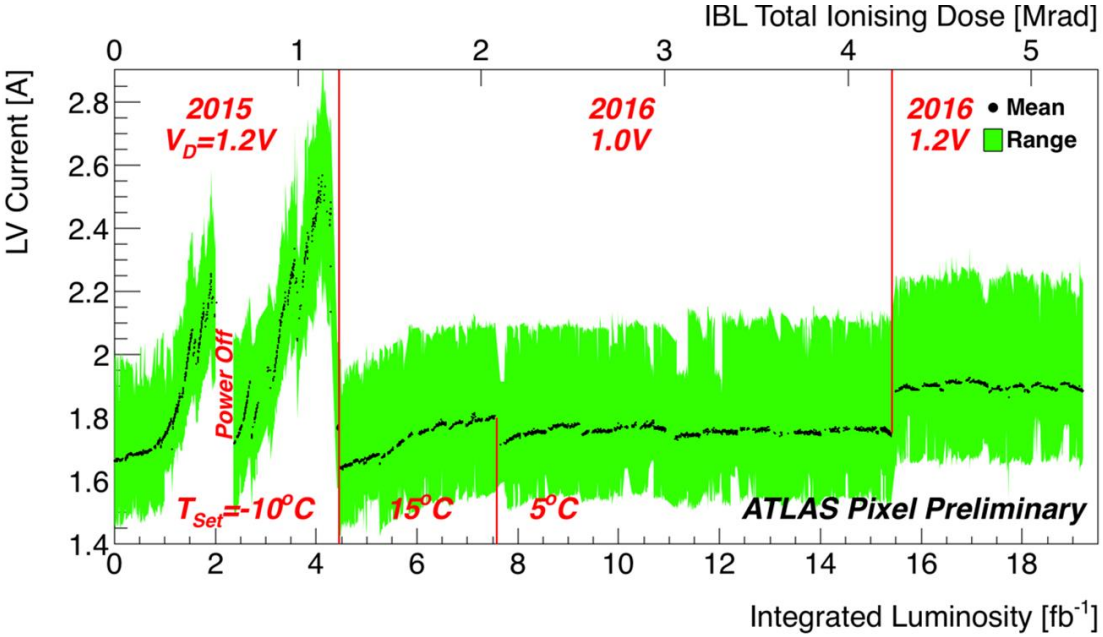
- The effect of TID was studied in lab-measurement.
- LV current decreases after irradiation of ~1 Mrad.
  - 1.3 Mrad at the end of 2015 operation.
- Higher temp. mitigates LV current by annealing effect.



LV current was contained thanks to higher operational temp. and lower digital supply voltage.

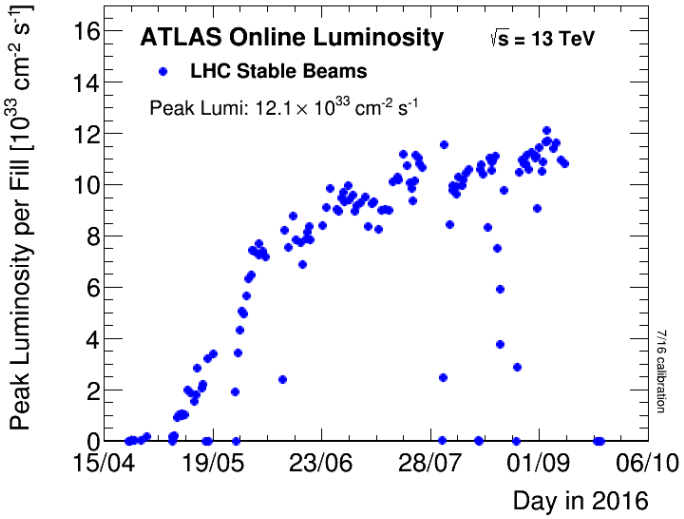
LV current v.s. TID (Lab.)





Data-taking overview

IBL/Pixel work with good data-taking eff. at higher peak luminosity.

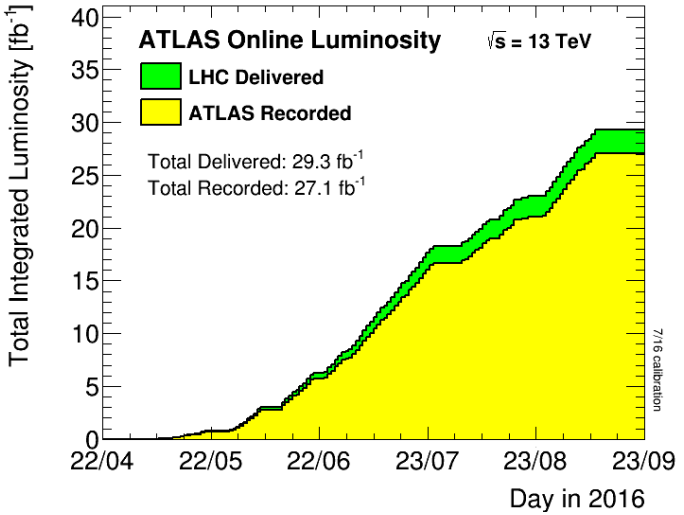


ATLAS pp 25ns run: August-November 2015

Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
93.5	99.4	98.3	99.4	100	100	100	100	100	100	97.8

98% without two runs of IBL-off (0.2fb^{-1})

Luminosity weighted relative detector uptime and good data quality (DQ) efficiencies (in %) during stable beam in pp collisions with 25ns bunch spacing at √s=13 TeV between August-November 2015, corresponding to an integrated luminosity of 3.7 fb^{-1}. The lower DQ efficiency in the Pixel detector is due to the IBL being turned off for two runs, corresponding to 0.2 fb^{-1}. Analyses that don't rely on the IBL can use those runs and thus use 3.4 fb^{-1} with a corresponding DQ efficiency of 93.1%.



ATLAS pp 25ns run: April-July 2016

Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
98.9	99.9	100	99.8	100	99.6	99.8	99.8	99.8	99.7	93.5

Good for physics: 91-98% (10.1-10.7 fb^{-1})

Luminosity weighted relative detector uptime and good data quality efficiencies (in %) during stable beam in pp collisions with 25ns bunch spacing at √s=13 TeV between 28th April and 10th July 2016, corresponding to an integrated luminosity of 11.0 fb^{-1}. The toroid magnet was off for some runs, leading to a loss of 0.7 fb^{-1}. Analyses that don't require the toroid magnet can use that data.

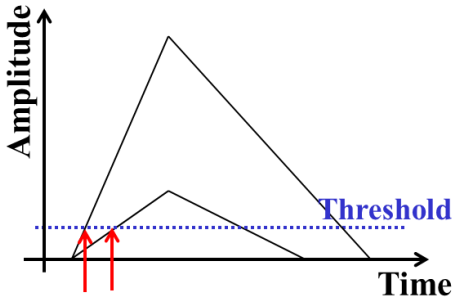
Summary & Conclusions

- IBL is a new innermost ATLAS-Pixel layer installed in 2014.
- IBL shows excellent performance and has been operated in stable condition, facing several challenges.
- Tracking performance is significantly improved with more hit points on IBL.
- The efficiency above ~98% and the separation power of the merged cluster of ~0.75mm were obtained.
- The impact parameter resolution is improved by ~40% at the maximum.
- The light jet rejection is increased by ~4 times for ε_b=70%.

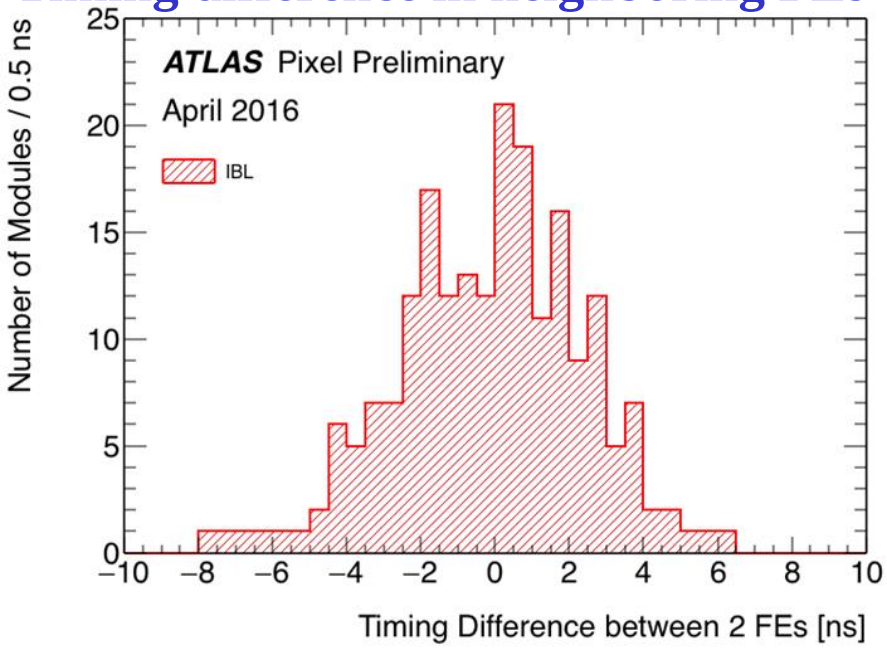
Backup

Performance of timing adjustment

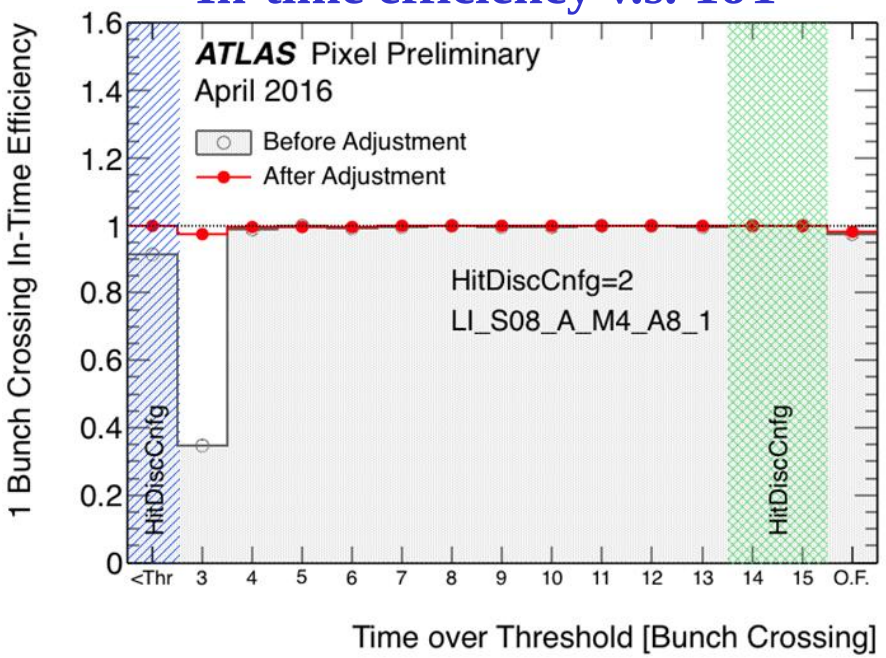
- One bunch-crossing (BC) readout window is used in IBL.
- The readout timing must be adjusted to store physics hits in one BC window (25 ns).
  - Minimize time-walk effect at low ToT is important.
- Good in-time efficiency is obtained for all ToT region.



Timing difference in neighboring FEs

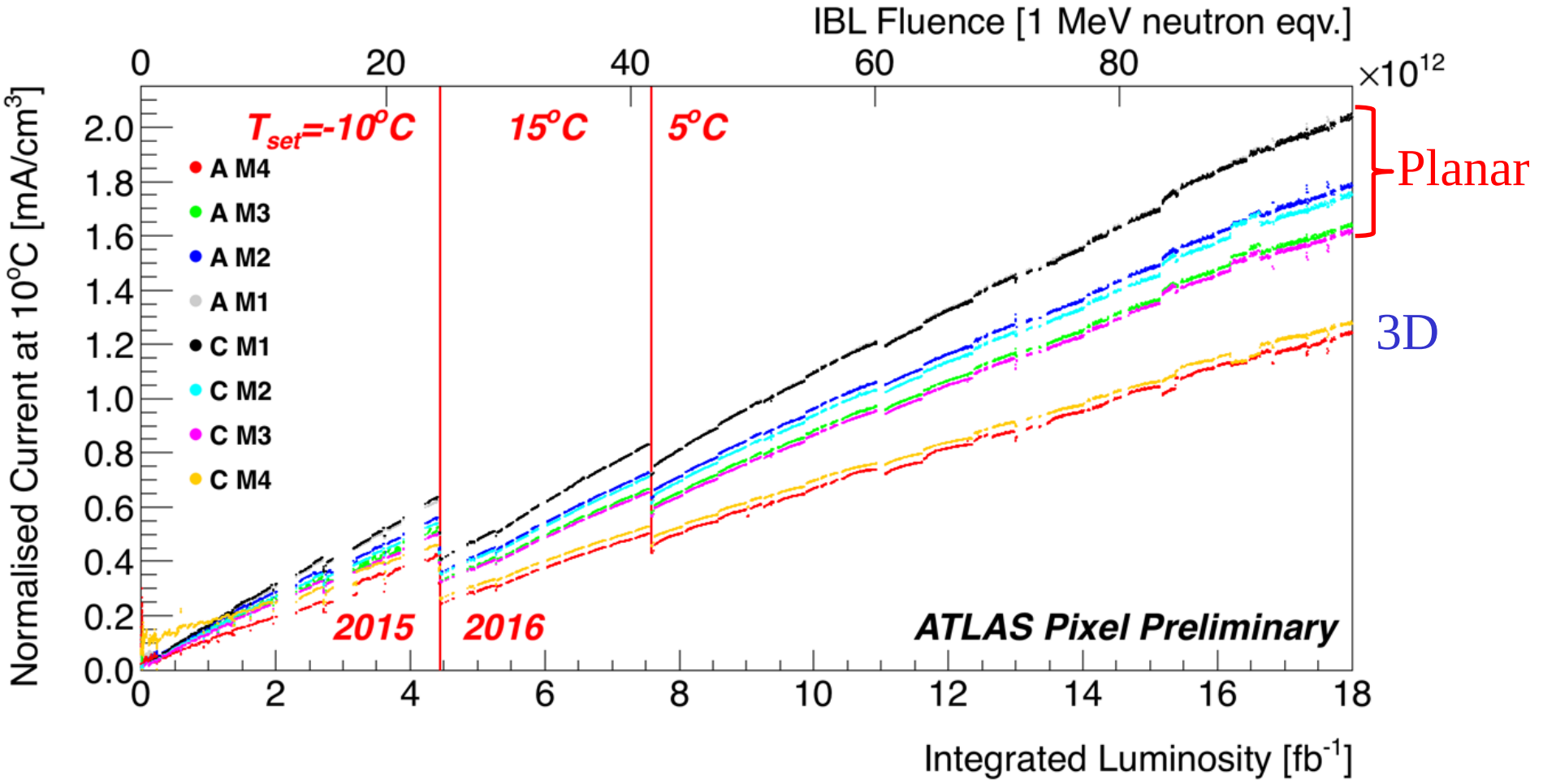


In-time efficiency v.s. ToT

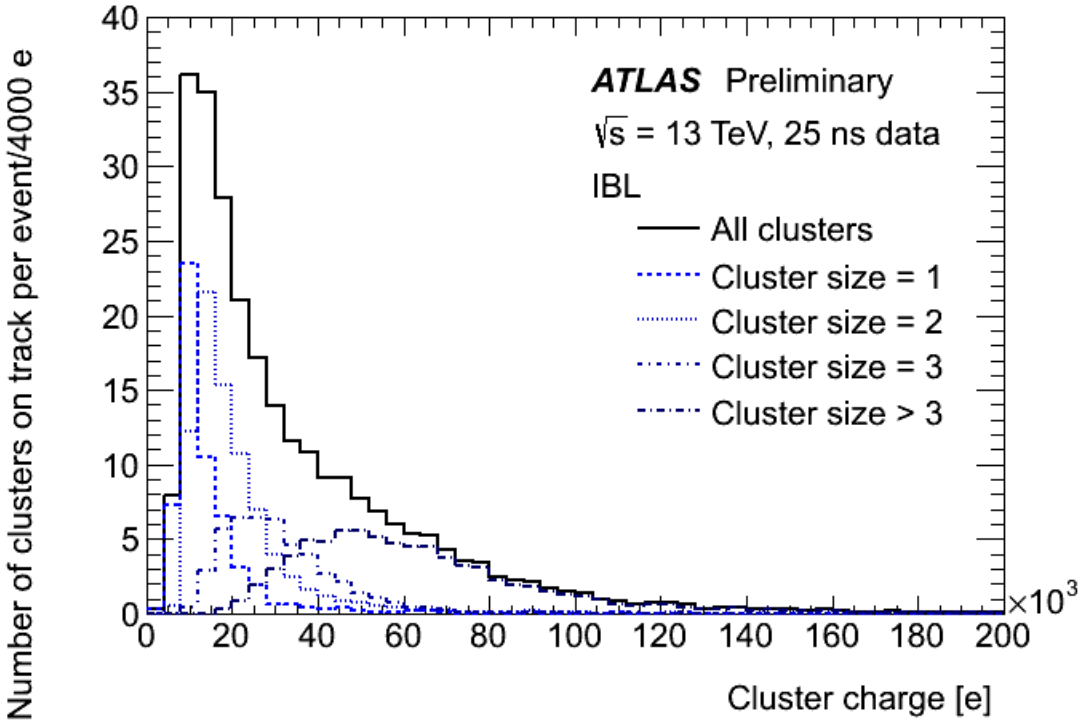


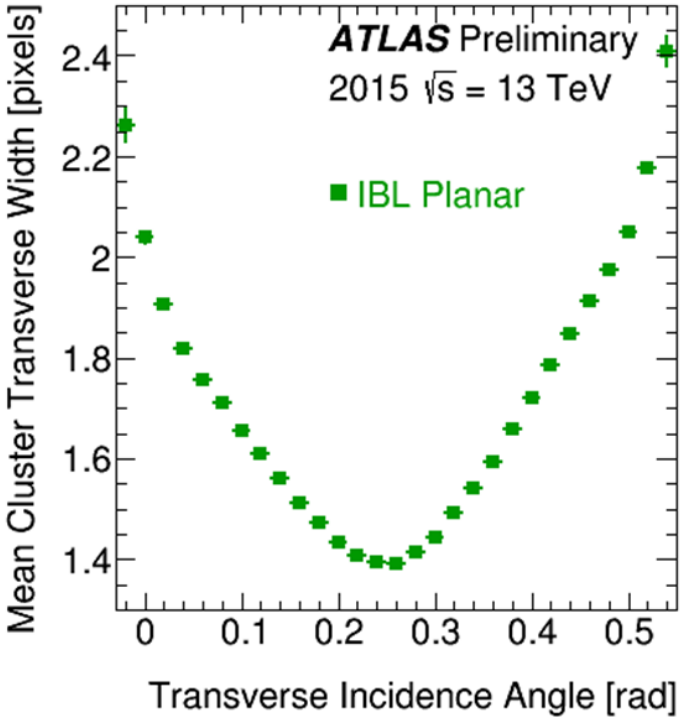
Radiation effect on sensors

- The leakage current is increasing both in planar and 3D sensors as a function of the integrated luminosity.



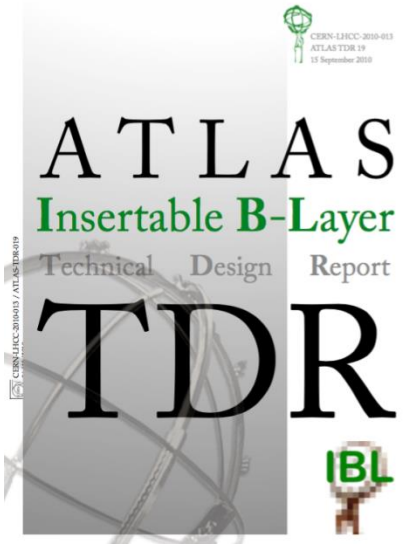
Cluster charge and Lorentz angle

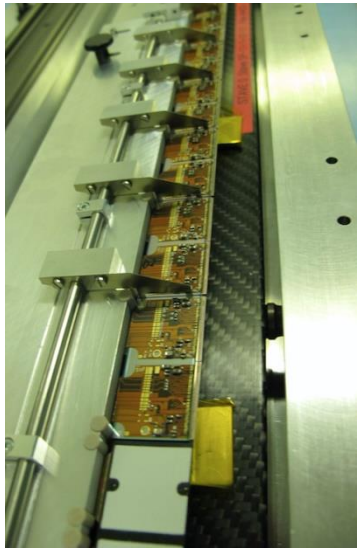


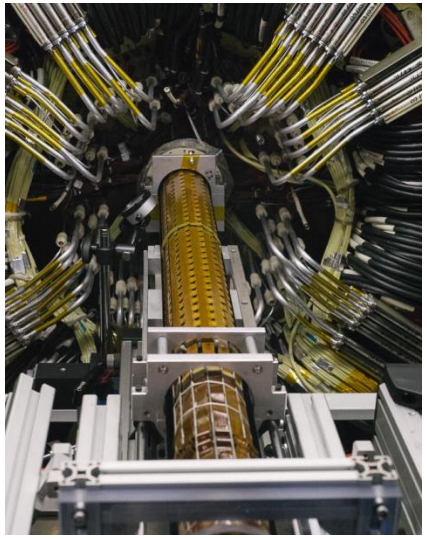


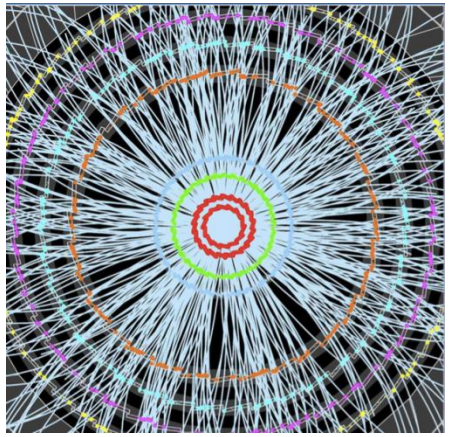
History of construction and operation

September 2010 | Mid 2012 | May 2014 | May~ 2015









Preparation: ~2years | Construction: ~2years | Commissioning: ~1years

- IBL was proposed as the first detector upgrade activity in ATLAS experiment and was installed only in 4 years after TDR!
- Each part of the groups collaborates efficiently to finalize the construction in the limited time of 2 years.