IBL a Phase 0 detector
A quick overview

ACES 2016, Mach 7th – 10th at CERN

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on behalf of the ATLAS collaboration

IBL – Introduction

Pixel detector originally designed to replace innermost Pixel layer called B-Layer

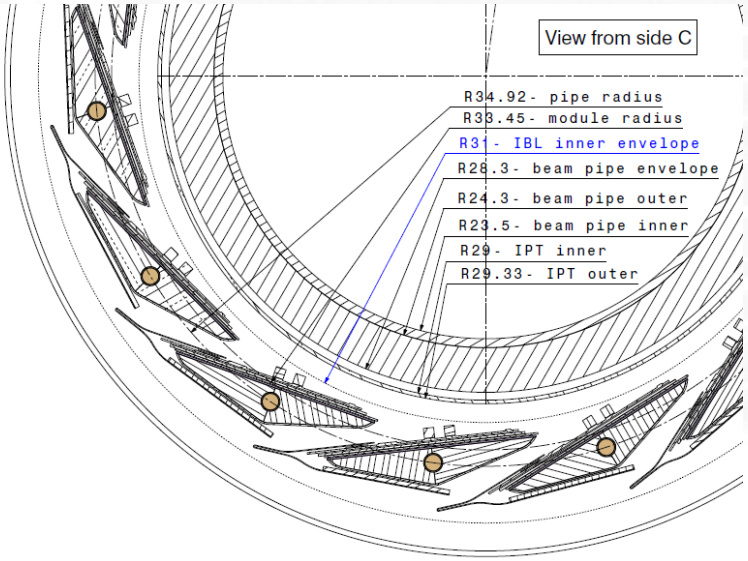
Reduced LHC beam pipe radius (OR of 24.3 mm) **offers a new option → IBL**

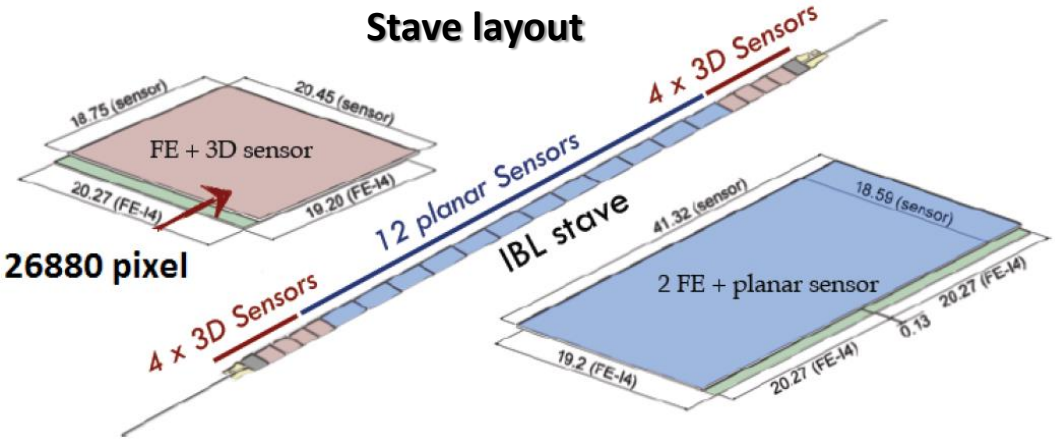
- Improved tracking performance and robustness
- Improvements to sensors, front-ends, back-ends, module design, cooling

IBL description:

- **14 staves overlapping in phi**, surrounding beam pipe at ~3.3 cm from the beam axis
- **0.13 m^2** of silicon surface and **12M** of readout channels
- I**nstrumented stave** (32 FE chips) consists of **12 planar** and **8 3D** sensor modules **along 664mm**
- **IBL package** of 7 m long and **inside only an envelope of 10 mm in radius** (clearance < 1mm)

IBL cross section view





Main IBL Features

Sensor

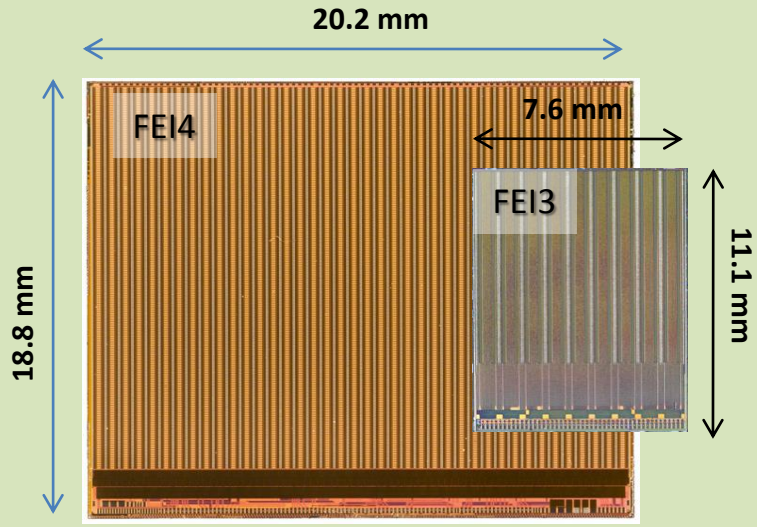
3D and planar technology are used in combination on the same stave

Features	Planar	3D
Thickness (nominal) [μm]	200	230
Depletion voltage [V]	~50	10 - 25
Working voltage after LHC fluence ($5x10^{15}$ 1MeV n_{eq}/cm^2) [V]	~1000	~160
Pixel [FE x Row x Column]	2x336x80	1x336x80
Active size WxL [mm^2]	16.8 x 40.9	16.8 x 20.0
Inactive edge along beam axis [μm]	200	200

FE readout

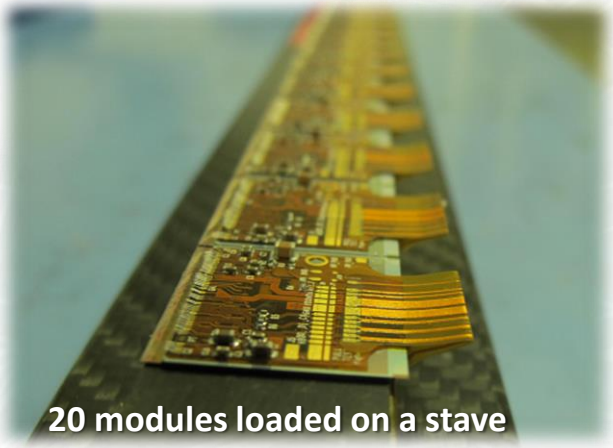
FEI4 main features:

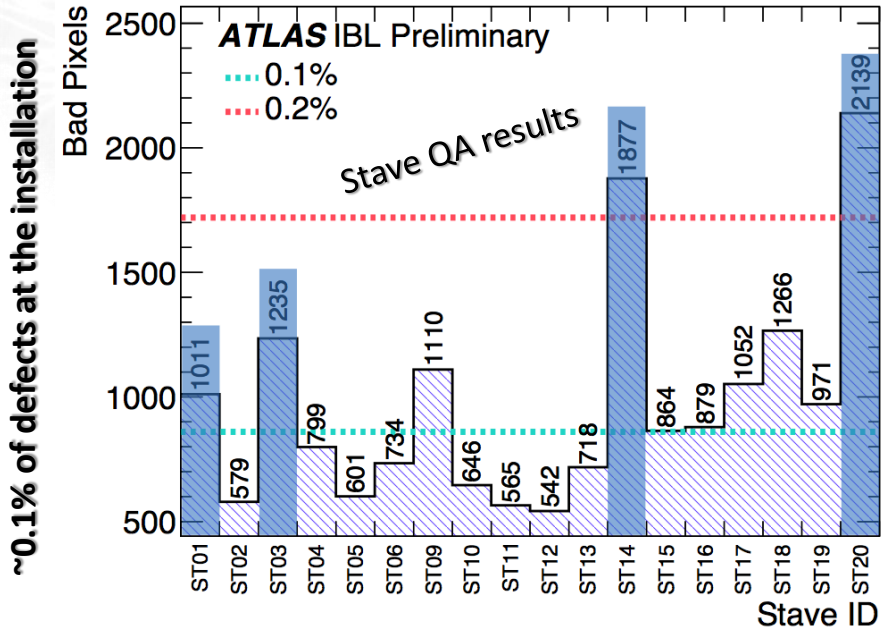
- IBM (130 nm)
- 70 Million transistors
- 26880 pixels (50 x 250 μm^2)
- Lower noise than FEI3 (~150e- with sensor)
- Lower threshold operation
- Higher rate capability
- Radiation hard to >250Mrad
- In use for pixel R&D and towards Upgrade phase2

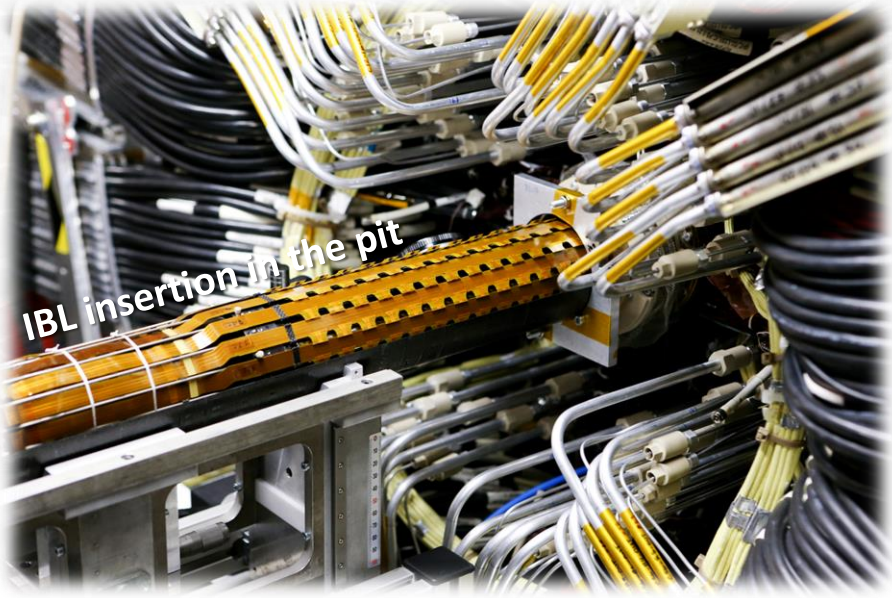


IBL Project on Very Fast Track

R&D and prototyping: ~3 years
Production, integration, and installation: ~2 years



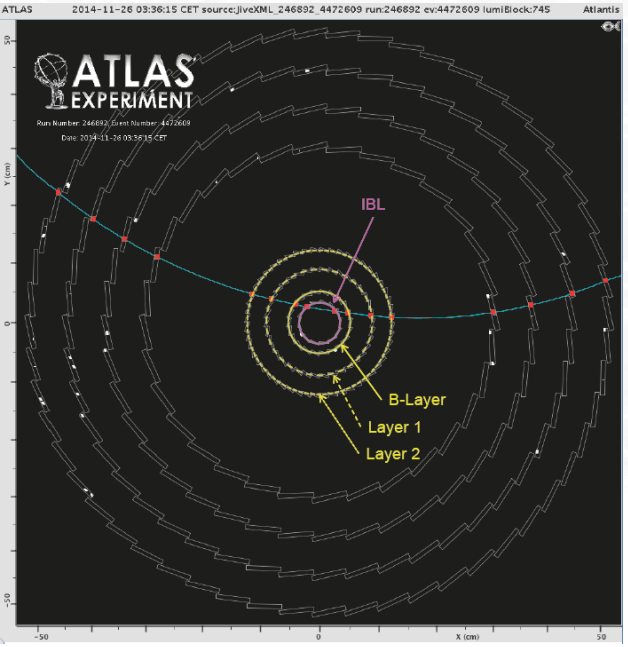




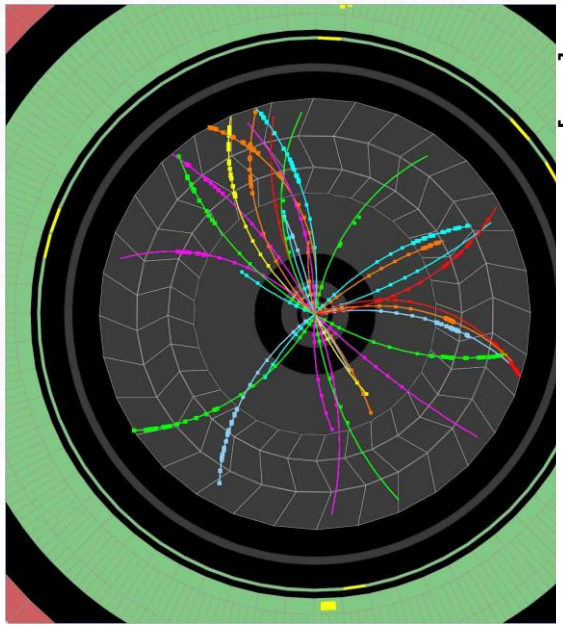
IBL Commissioning in ATLAS

- Aug 2014 – March 2015: Integration into ATLAS DAQ, Cosmic data taking with 2T B- field
- October 2014: LHC beam pipe bake-out @ 230 °C & IBL < 0°C, stable CO_2 cooling
- May 2015: First low luminosity, "Quiet Beam" collisions to commission experiment

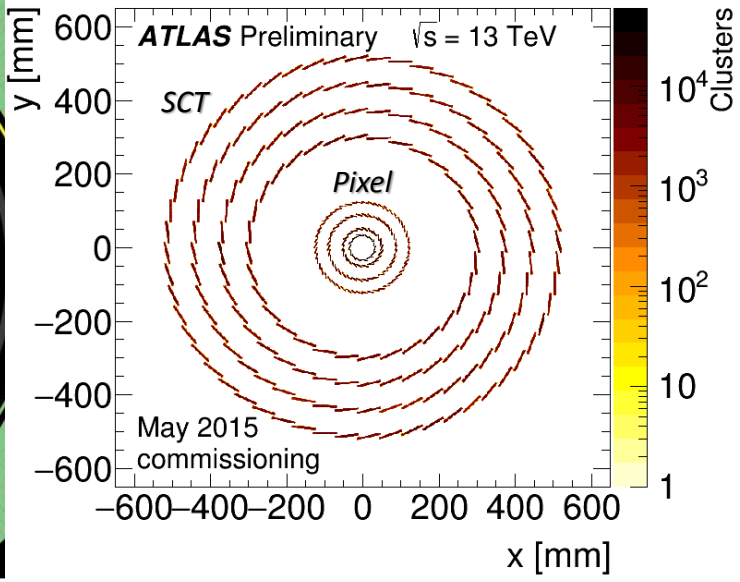
Cosmic track reconstructed in 4 pixel layers



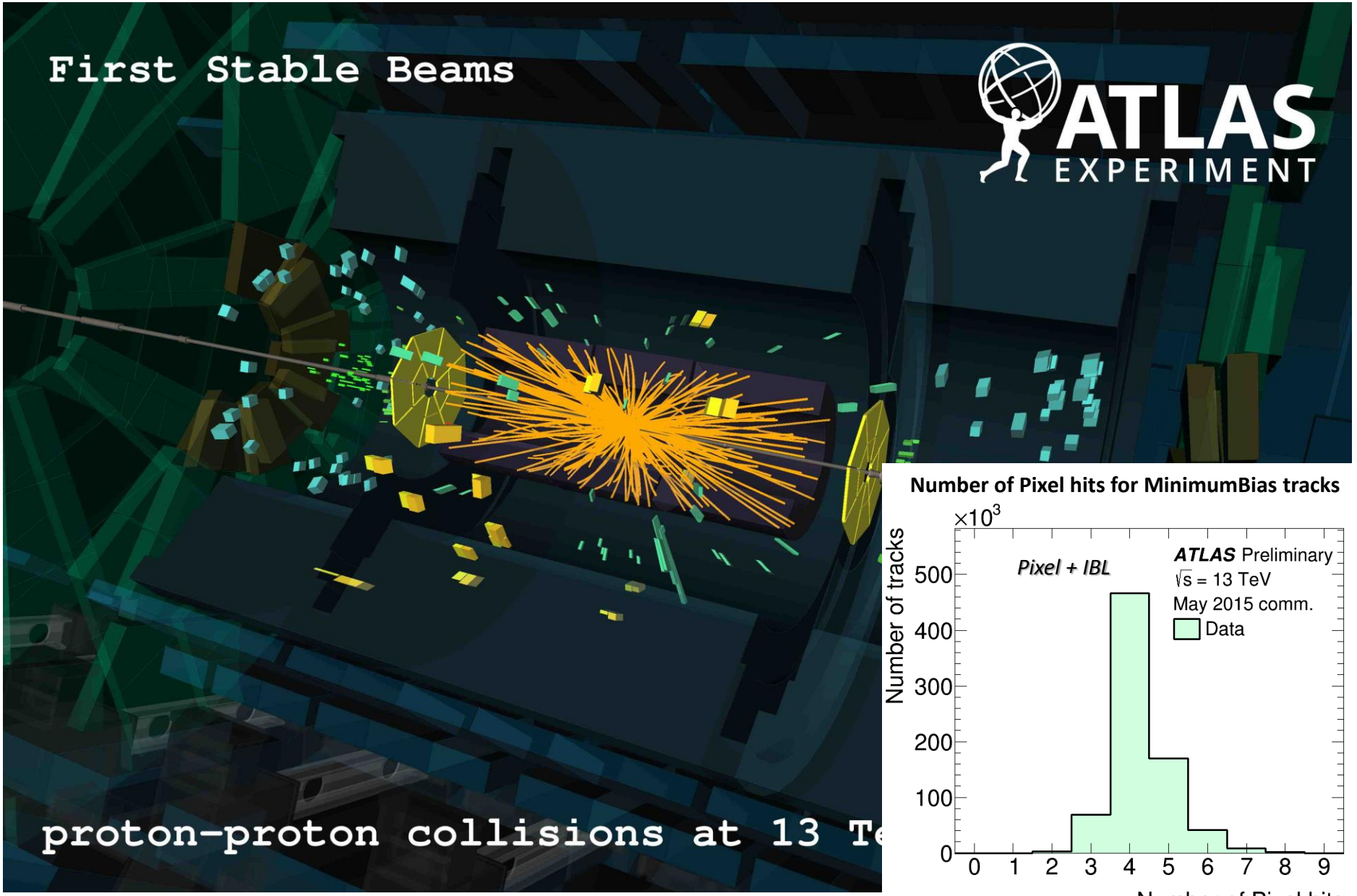
900 GeV pp collisions during beam commissioning in May 2015



13 TeV pp collisions during beam commissioning in May 2015

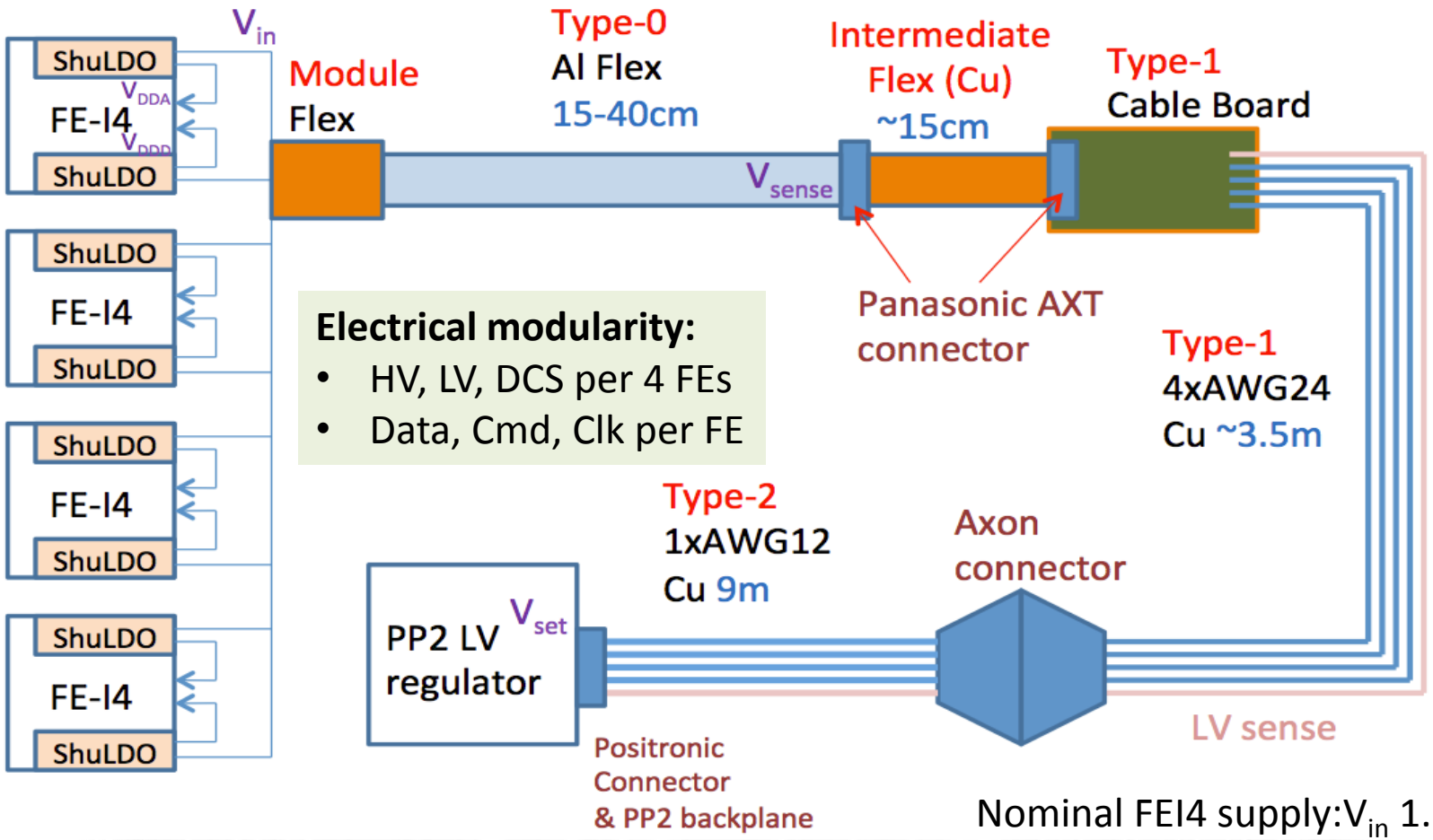


pp collisions at 13 TeV in 2015



Now time for some details and challenges met…

IBL service distribution



LV service type	Resistance [mΩ]
Type-0 Al-flex	150-230 depend of the LV group
Type-1	139
Type-2	97

Nominal FEI4 supply:V_{in} 1.8V
→Must not exceed 2.5V

WARNING: Transient overvoltage

FE-I4 partial shunt guarantees minimum current of 260mA while nominal consumption 400 to 800???

IBL Challenges

IBL is a new detector built relatively quickly and with a short R&D time
An excellent test bed for next generation silicon tracker for HL-LHC

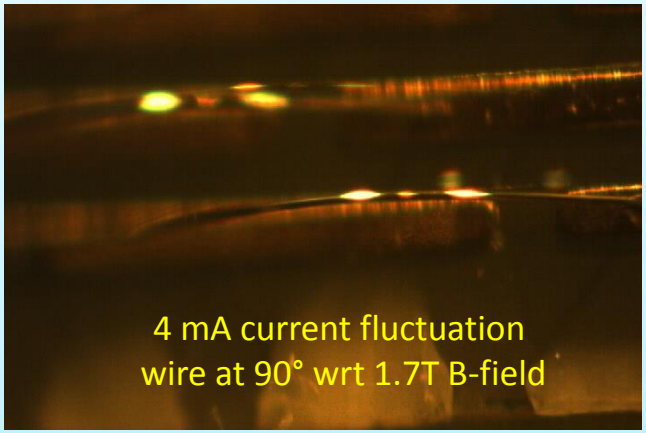
Challenges met during production, integration, commissioning and operation:

- **Bump bonding issue:** intolerable amount of open and short pixels discovered at an early stage of the production
  - consequences: delay and cost
- **Wire bond corrosion:** Met in the middle of the stave loading production
  - consequences: delay and extra work load
- **Type 1 service** Cu-clad Al wire crimping issue → led to use Cu-wire
  - Consequence: More material in the forward region
- **Wire bond oscillation** → led to implement protection mechanism into the readout chain
  - Consequence: dead time when machine is not fully filled leading to possible trigger limitation
- **IBL distortion:** discovered during cosmic run commissioning period
  - Consequence: tracking is affected →Mitigated by alignment correction
- **FE LV current drift:** Discovered in September 2015 during data taking
  - Consequences: Module trip (or disabled) and rather "chaotic" temperature increase → distortion

Wire Bond Oscillation

- **IBL wire bonds susceptible** to some resonance frequencies during data taking
- **Protection Scheme** implemented into the readout chain firmware

Lab measurements

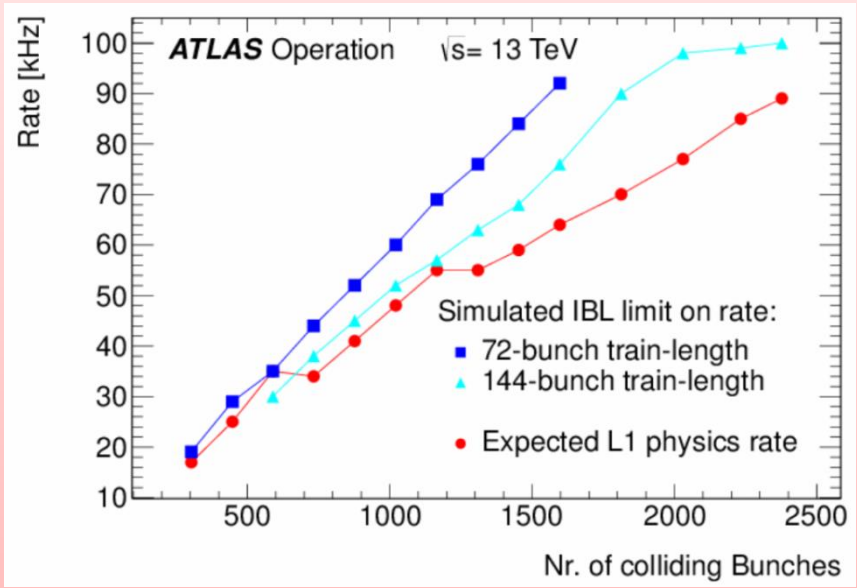


Lab measurements could show that even with IBL orientation wires could break when at the resonance frequency or in one of the harmonic or sub-harmonic modes.

→ *Also confirmed with ANSYS FEA*

Digital supply line is susceptible to current fluctuation when receiving triggers

Trigger rate for physics and IBL limitation

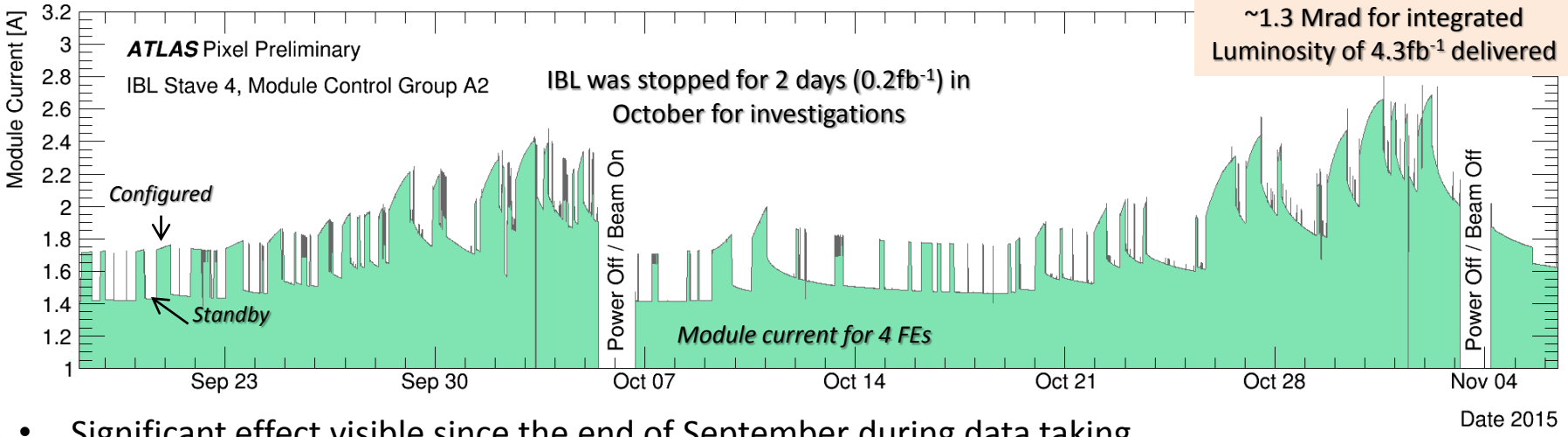


- **IBL protected** against wire bond oscillations by limiting the number of triggers in resonance region.
- Protection is called **FFTV** (Fixed Frequency Trigger Veto).

Level of protection was:

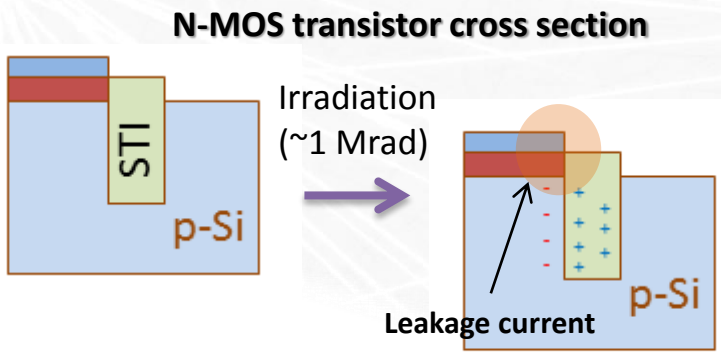
- Dependent of the LHC filling scheme and bunch pattern
- **Essential** during some trigger mishandling
- **Never a limitation** for data taking (even if close)

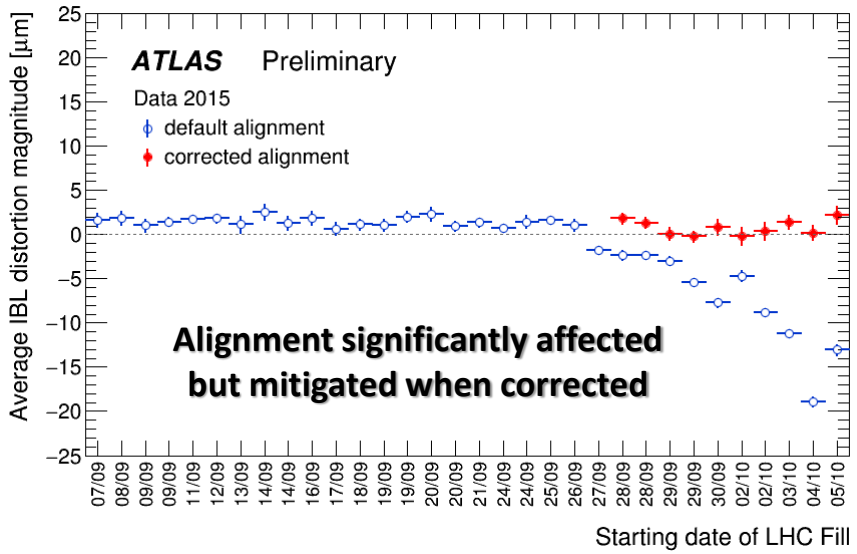
IBL - LV FE Current Drift



- Significant effect visible since the end of September during data taking
- Understood to be a FE N-MOS transistors leakage due to charged defects built-up at the Silicon Oxide interface and cumulated by ionizing dose → *Known features but not tagged during construction*
- It is an effect that is related to dose rate (traps built-up at the STI) and temperature (annealing)
- Lab investigations are ongoing → operational recommendations are expected

See overview from Federico on Monday





IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 52, NO. 6, DECEMBER 2005

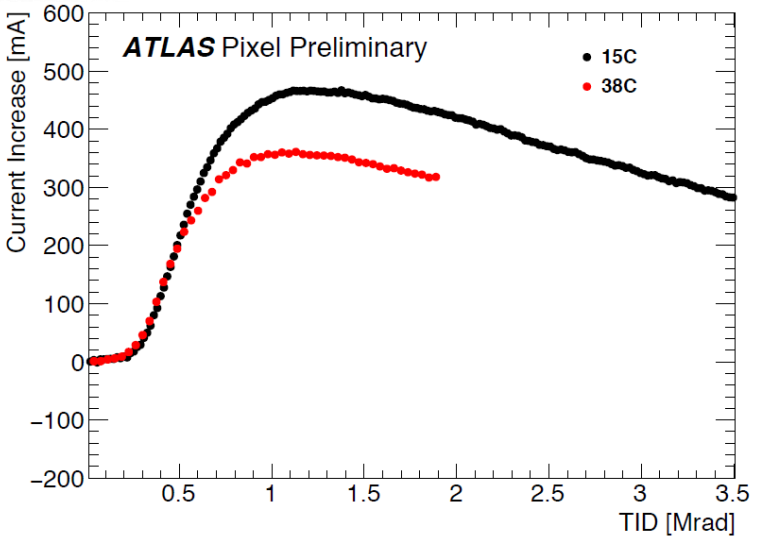
IBL- Front-end LV current drift

Effects in the FE-I4 readout chip related Total Ionization Dose (TID)

Consequences for operation:

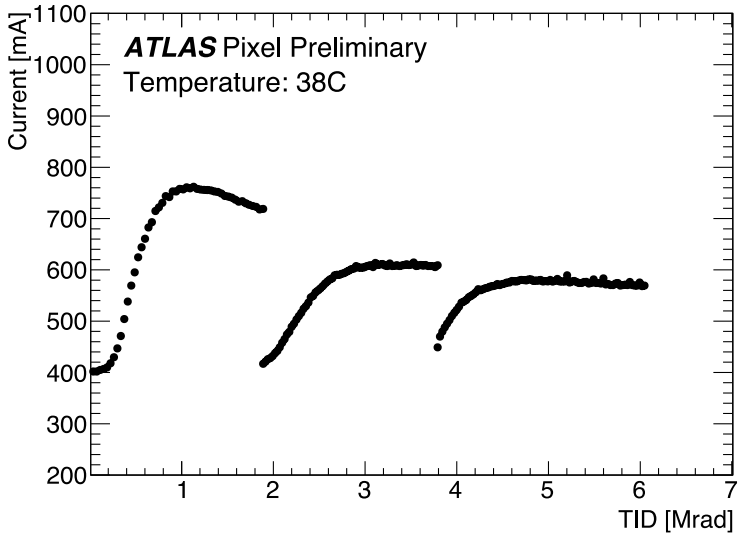
- **Current increase** reaching safety limits. When the limit is reached, 2 cases:
  - Change FE state: Ready → Stdby
  - Power down this module group
- **Drift of the FEI4 tuning** (Threshold, TOT). Need to regularly check tuning in between fills and readjust if necessary

Task Force was set-up and is proactive for the understanding → **Good progress** achieved so far

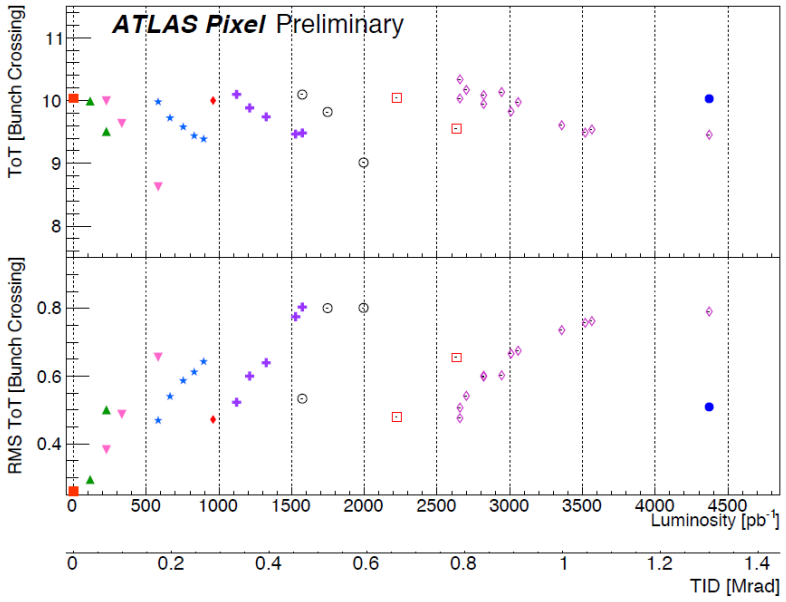


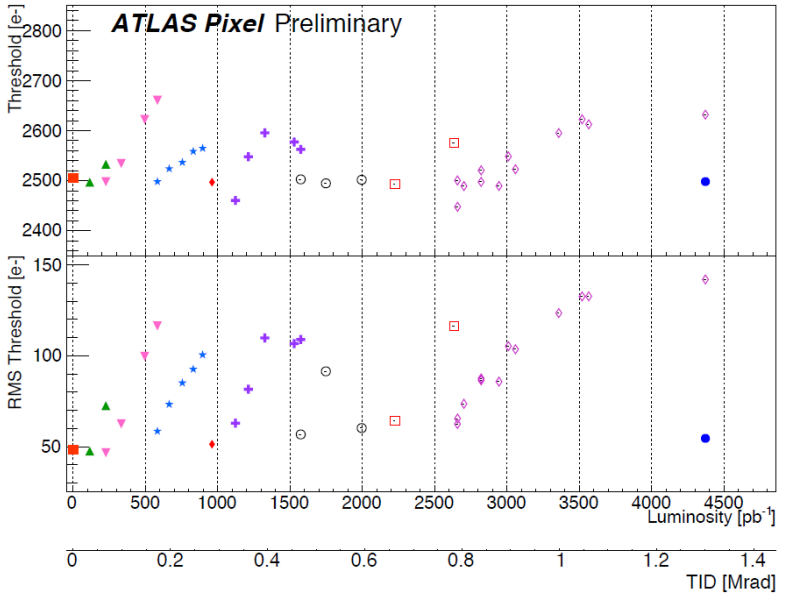
Status quo:

- ❑ **Origin of LV current increase** → source: NMOS transistor trap defects that are built-up at the Si-SiO_2 interface which is inducing leakage current
- ❑ **Temperature dependency** confirmed by several tests.
- ❑ **Successive irradiation and annealing** is measured in lab and is expected to reduce the amplitude of the next peak
- ❑ **Model is under parametrization** to be able anticipate future behavior
- ❑ Irradiator was purchased for dedicated FEI4 lab measurements with realistic operational conditions

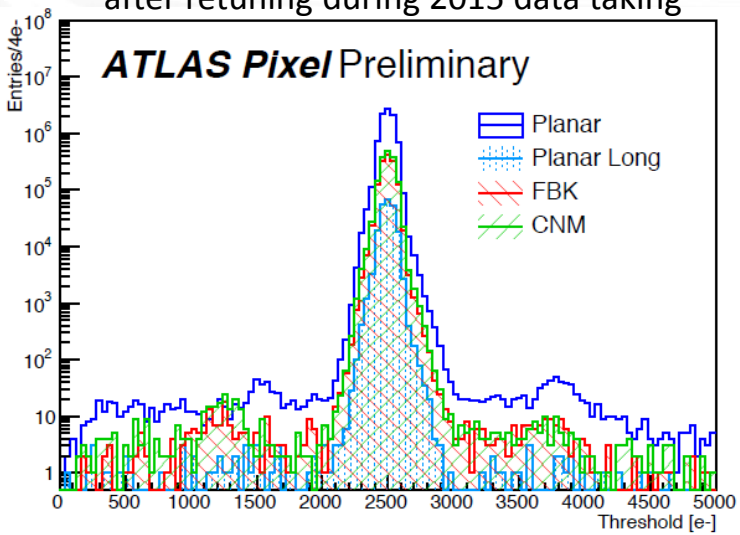


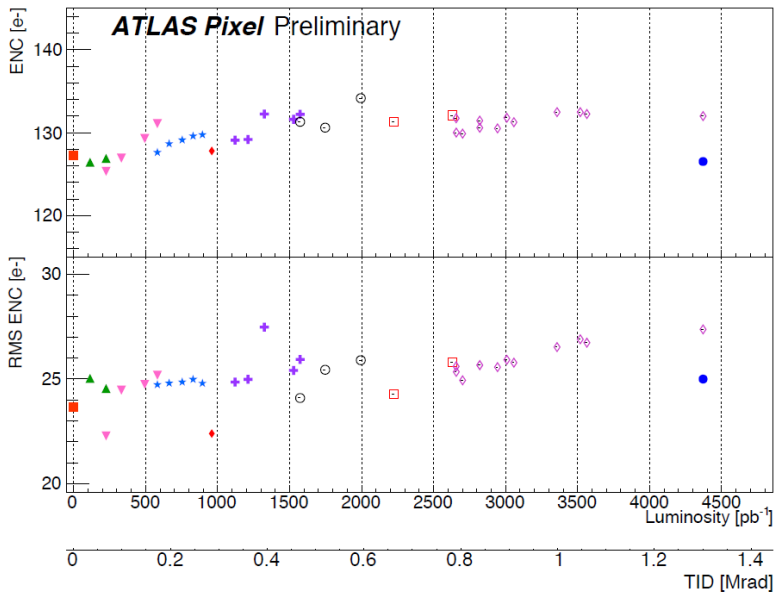
TID effects on FEI4 calibration parameters





Average threshold distribution of IBL after retuning during 2015 data taking





Conclusions

- Significant **Pixel upgrades** took place during **LHC 1st long shutdown**:
  - **Pixel nSQP**: led to improve a number of defective modules
  - **IBL**: new innermost layer as close as 3.3 cm from the IP

- Pixel was re-installed in the pit end of 2013 while IBL installation took place in May 2014

- **IBL is a nice jewel for ATLAS** and towards ITK for HL-LHC leading to **improved tracking performances.**

- **LHC Run 2 with 13 TeV pp collisions started at the beginning of June 2015** with **successful** data taking for ATLAS Pixel and IBL → also opening a new era for physics searches

- IBL met various issues affecting the operation and alignment but there was always a solution to mitigate the effect thanks to a lot of dedication inside our community

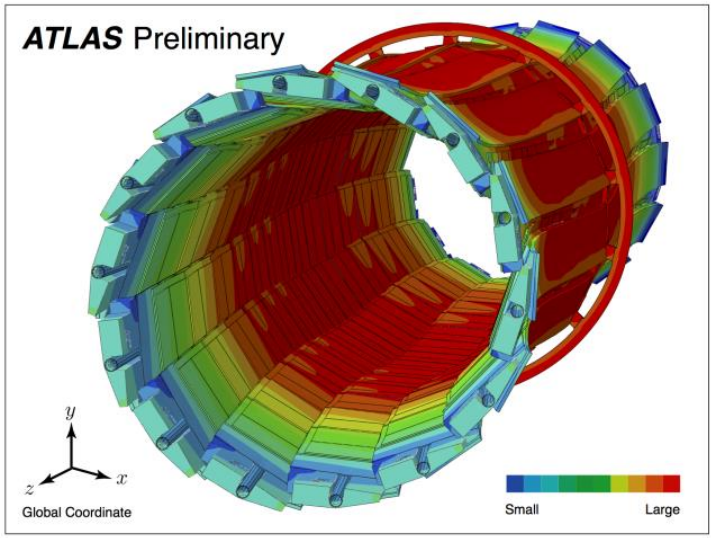
- ATLAS and Pixel is now getting prepared and upgraded during this Winter Shutdown to take data in **2016 with significantly more integrated and instantaneous luminosity** than last year

Many thanks for your attention

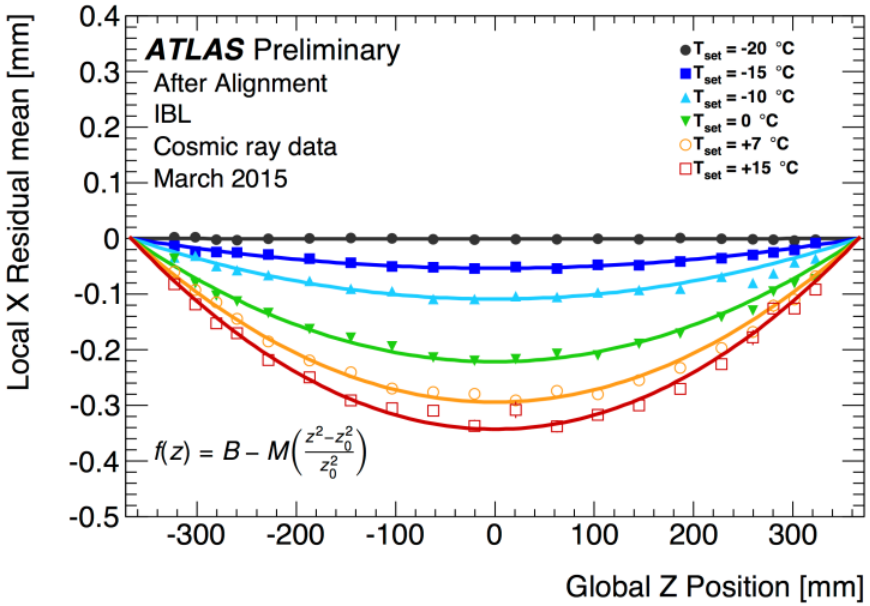
IBL Mechanical Distortion

IBL distortion summary:

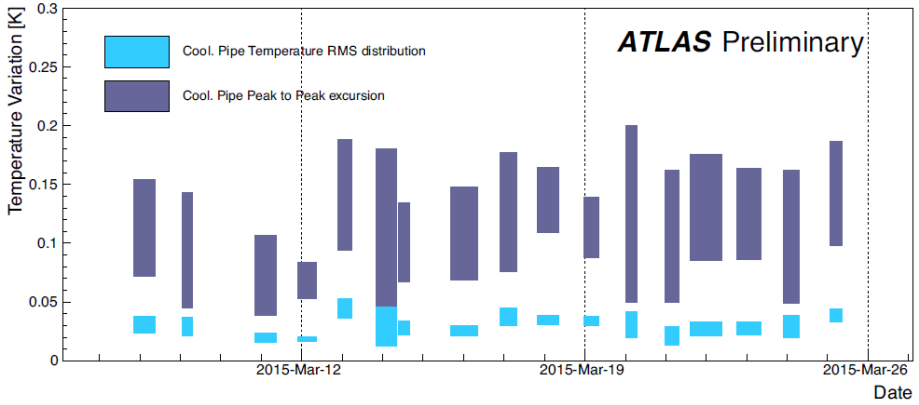
- Issue discovered early in 2015 during cosmic runs
- **Temperature dependency** exhibited - O(10 µm/K)
- Origin: **CTE mismatch** between the service bus and stave that twists the stave and a rotation free central ring
- Confirmed by the mechanical engineers with 3D simulations and lab measurements
- Direct **impact on the tracking** performance
- **Alignment correction was sufficient to mitigate** the effects
- Temperature and cooling stability ok until September



Distortion versus cooling temperature



Early studies of the IBL cooling and stave stability was satisfactory and rms not exceeding 0.2K which is also compliant for the required alignment stability



IBL Corrosion

Discovery:

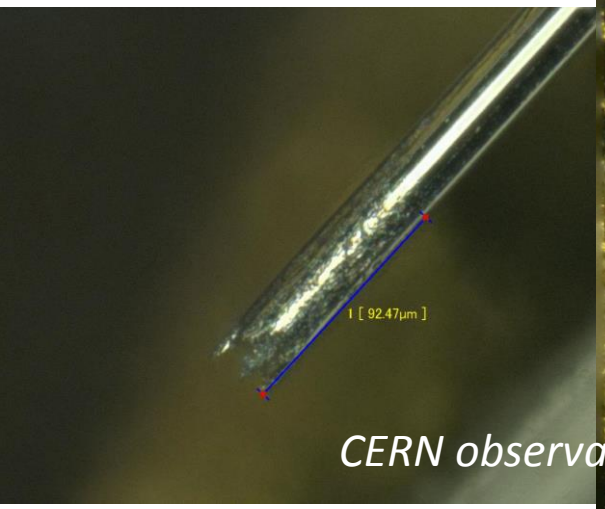
September 2013**: Corrosion issue** found accidentally after 2 staves got frozen and identified that the half of the already produced staves were affected.

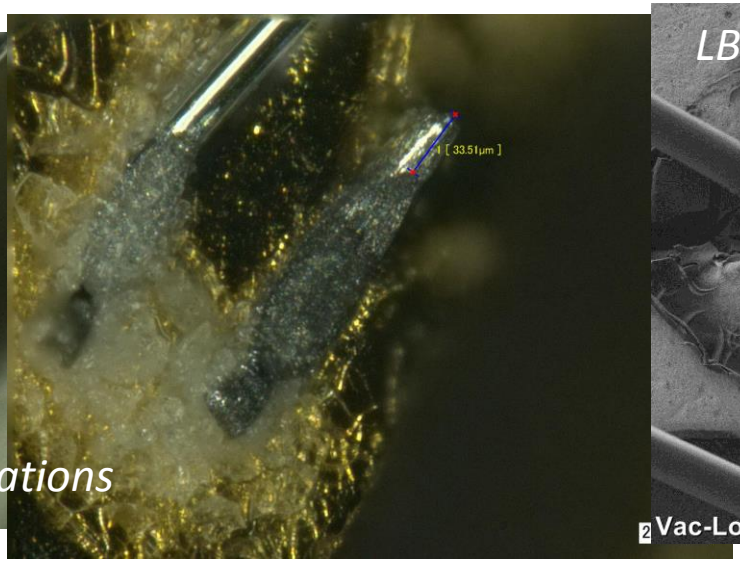
→ A complete rework of the staves took place and with an impact on the schedule

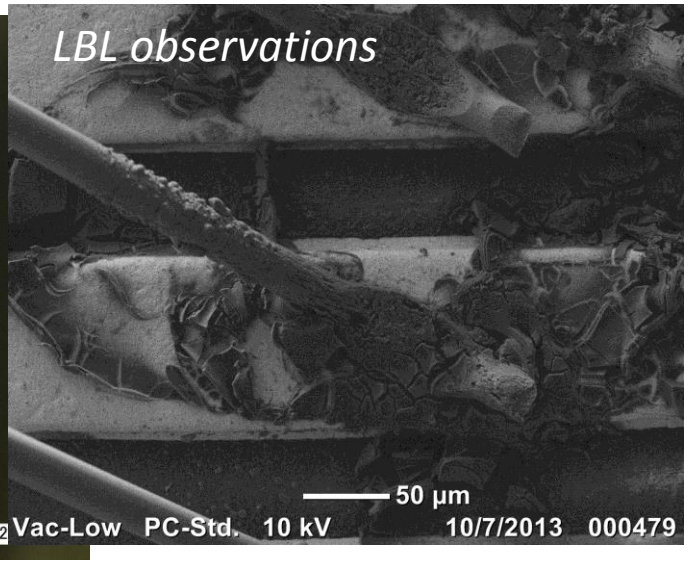
- **Origin:** DI water tests allowed to observe an extreme sensitivity of wet flex surface which with the galvanic coupling and the presence halogen explained the chemical attack of the Al-wire.
  - White persistent residue Al(OH)3
  - Detected halogen in samples taken from production staves after corrosion spotted
- **Further investigations:** Intense cleaning of bare flex, alternative metallization (ENIG, Galvanic) was always showing susceptibility to the chemical attack

Conclusions & recommendations for future project:

Protection of the wire bond feet is the solution to guarantee against surface water contamination







Lessons for Future

IBL is a new detector built relatively quickly and with a short R&D time
An excellent test bed for next generation silicon tracker for HL-LHC

- **Major issues discovered late** in the production, during commissioning, and during data taking but **no show stoppers**
- **Successfully IBL running during 2015 – A big plus for tracking performance.**

Very shortly the lessons learned:

- A new detector even if built by experienced people needs time for R&D, reviews with senior experts, extensive qualifications in all domains
- Wire bond oscillation: potting, thick wires, no wire (TSV + laser bond)
- Mechanical distortion: Stiff structure, low susceptibly to temperature (low CTE)
- FE NMOS transistor leakage current:
  - Qualification to radiation should not be done only for intermediate to high doses but also low dose and for realistic dose rates
  - Enclosed transistors significantly reduces the effect

"Those who cannot remember the past are condemned to repeat it." – George Santayana