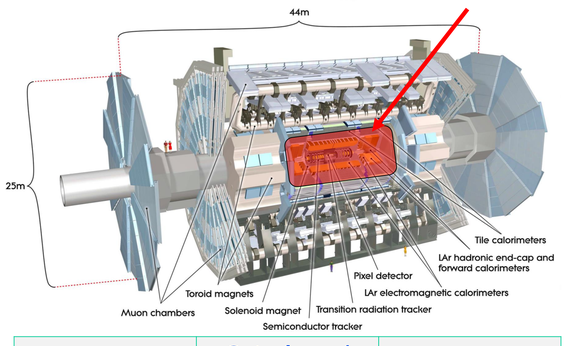
Operational Experience and Performance with the ATLAS Pixel detector at the Large Hadron Collider

G. Balbi on behalf of the ATLAS Pixel Collaboration
INFN Bologna
gabriele.balbi@bo.infn.it

THE ATLAS DETECTOR AT LHC

PIXEL DETECTOR



	Outer layers/ disks (B-Layer/L1/L2)	Inner Layer (IBL)
Sensor Technology	n-in-n only planar	n-in-n / n-in-p (planar/3D)
Sensor Thickness	250 um	200/230 um
Front end Technology	FE-I3 250 nm CMOS	FE-I4 130 nm CMOS
Pixel Size (typical)	50 x 400 um^2	50 x 250 um^2
Radiation Hardness	50 Mrad 1 x 10^{15} (1 MeV) n_{eq} cm^{-2}	250 Mrad 5 x 10^{15} (1 MeV) n_{eq} cm^{-2}
Chip size	7.6 x 10.8 mm^2	20.2 x 19.0 mm^2
Radius	50.5/88.5/122.5 mm	33 mm

ATLAS is a general-purpose particle physics experiment at the Large Hadron Collider (LHC), built to investigate the Standard Model (SM) and beyond at TeV scale. One of the main parts of the ATLAS detector is the Inner Tracker constituted by the Pixel detector, the Silicon Strip detector (SCT) and the Transition Radiation Tracker (TRT). The Pixel detector is the innermost of them and it can be depicted as a 4-Layer (**Insertable B-Layer**, **B-Layer or L0**, **Layer1** and **Layer2**) tracking detector in the barrel region with **3 disks on each endcap side**. The Pixel detector was built with different technologies.

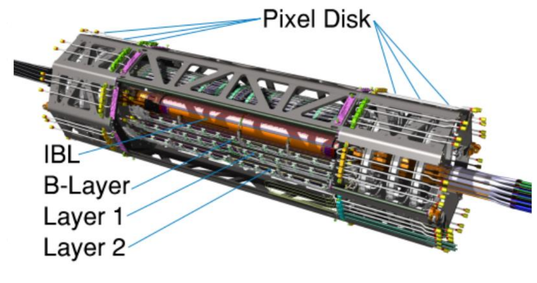
The **outer layers L0, L1 and L2** installed in 2007 are built with hybrid pixel modules. Each module is composed by:

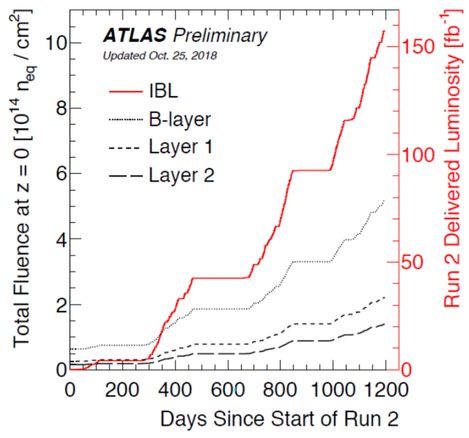
- **16 front-end chips FEI3** (250 nm CMOS technology)
- **a planar n-in-n sensor**

The most recent layer **Insertable B-Layer (IBL)**, added during the LS1 in 2014, is built by modules made up of:

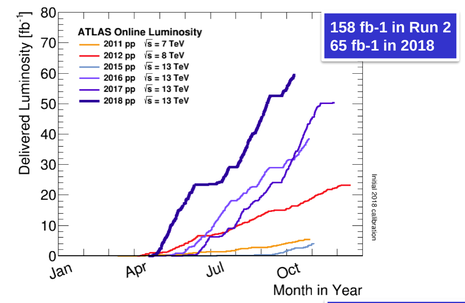
- **a front-end chip FEI4** (130 nm CMOS technology)
- **a planar n-in-n (or 3D n-in-p) sensor**

The detector covers the range of **|η| < 2.5** with a resolution of **10 × 115 μm² / 8 × 40 μm²** per layer (PIX/IBL). The radiation level is very challenging. The accumulated fluence at the end of Run 2, depending on the layer, ranges from **4.5 to 9 × 10¹⁴ [n_{eq} /cm²]** corresponding to 40-50 % of the total fluence that can nominally be tolerated by the modules.

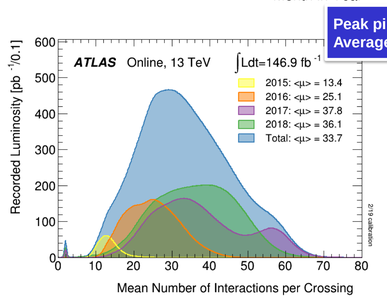




LHC CONDITION

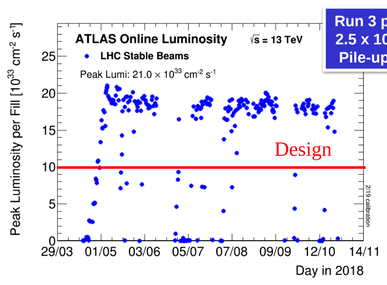


- The design conditions for the ATLAS Pixel Detector were overtaken during the Run 2
- Instantaneous peak luminosity **L ≈ 2x10³⁴ cm^{-2} s^{-1}** and peak pile-up **μ ≈ 60** are abundantly above the nominal values (L_{nom} = 1x10³⁴ cm^{-2} s^{-1} and μ_{nom} ~ 20)



✓ Pixel data taking over LHC Run 2 has been particularly challenging due to radiation level and number of tracks

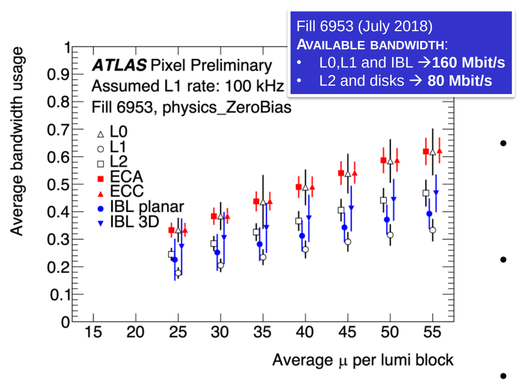
✓ Big stress for hardware (Single Event Effects, damages in the FE chips and in the sensor bulk)



More than 11 years after its first installation in ATLAS and at twice the LHC design luminosity, the Pixel Detector is performing well.

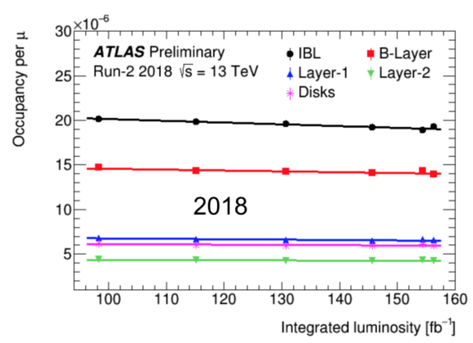
By the end of Run 3, the expected delivered luminosity will reach ~ 400 fb^{-1} , a very impressive and challenging scenario for Pixel detector

DETECTOR OPERATION

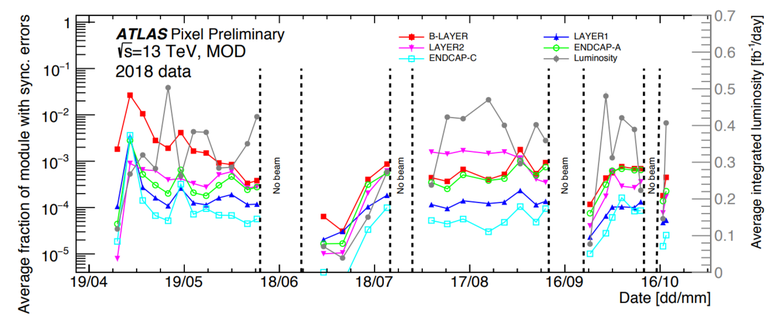


GREAT STABILITY OF THE DAQ OF PIXEL DETECTOR

- **Bandwidth usage rises** with rising pile-up μ
  → Crucial attention to bandwidth saturation, buffer overflow
- **Pixel hit occupancy** (number of hits per pixel per event) per unit of μ decreases due to radiation damage
  → Thresholds were decreased for the first time in 2018
- **Dead time and desynchronization issues reduced** drastically since the begin of Run 2
  → Pixel dead time below 0.2% by the end of 2018. Continuous improvements along the years of Read Out Driver (ROD) Fw and Sw



Further progress are foreseen in terms of data recovery/quality with the deployment of a ROD PowerPC (PPC) equipped with a custom Linux version in Run 3



Average fraction of Pixel modules with any synchronization errors at the module level per event in 2018 runs

EFFECTS OF RADIATION

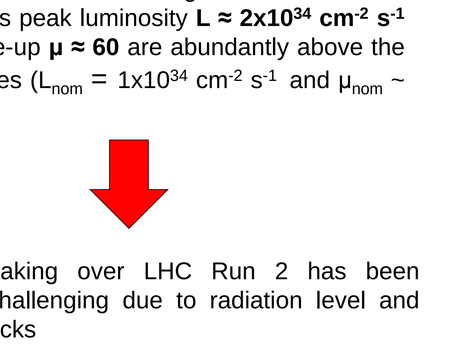
- **Radiation damage changes the charge collection.** This effect is stronger closer to beam pipe, so it is stronger for IBL
- **Adjustment of thresholds, HV and temperature** allows these effects to be contrasted

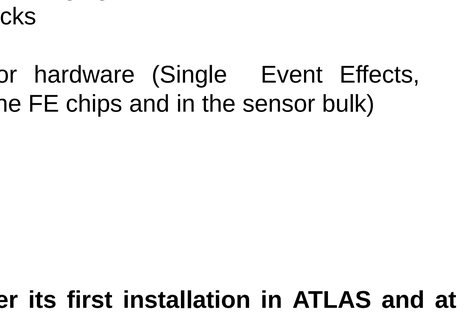
- The ATLAS measured **leakage current grows linearly with delivered luminosity** and it can be described quite well by the Hamburg Model, but scaling factor is however required
- The **ratio of the leakage currents between layers remains quite constant**

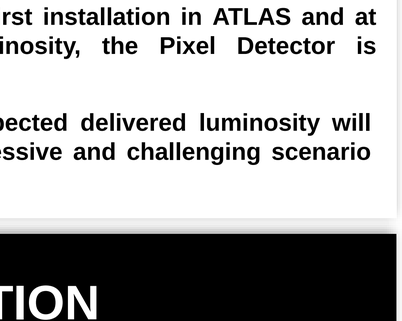
- **Frontend chips** of the ATLAS innermost pixel layer (IBL) **experienced single event upsets** (SEU) in **local** or **global** configuration **registers**.

EFFECTS ON FEI4 GLOBAL REGISTER
- Step on LV current consumption of the FEI4 chip
- Drop of the module occupancy
- **Lowering of the data taking efficiency due the timeout**

EFFECTS ON FEI4 SINGLE PIXEL REGISTER
- Increase noisy pixels
- Increase broken clusters and quiet pixels
- **No major impact on tracking performaces**





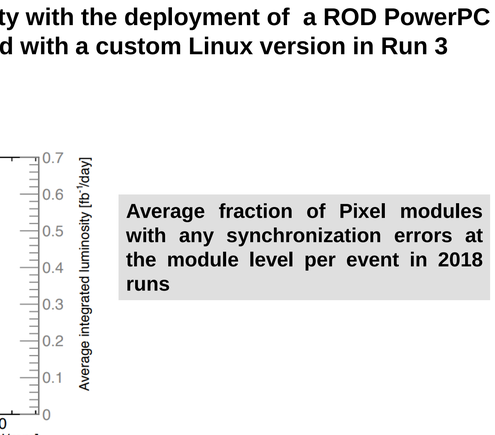


DETECTOR PERFORMANCE

- **Due to the decreasing charge collection efficiency** the observed dE/dx decreases

- **Spatial resolution stable despite increasing radiation damage** → New radiation damage model presented (***JINST 14 (2019) P06012 DOI: 10.1088/1748-0221/14/06/P06012***)

- B Layer **Hit-on-track efficiency** above 98%



Run 2 is over. Despite the large amount of radiation, the ATLAS Pixel detector has provided excellent performance. Radiation damage is becoming perceptible. The operational parameters have to be retuned to guarantee optimal data quality and efficiency.