# ATLAS pixel detector

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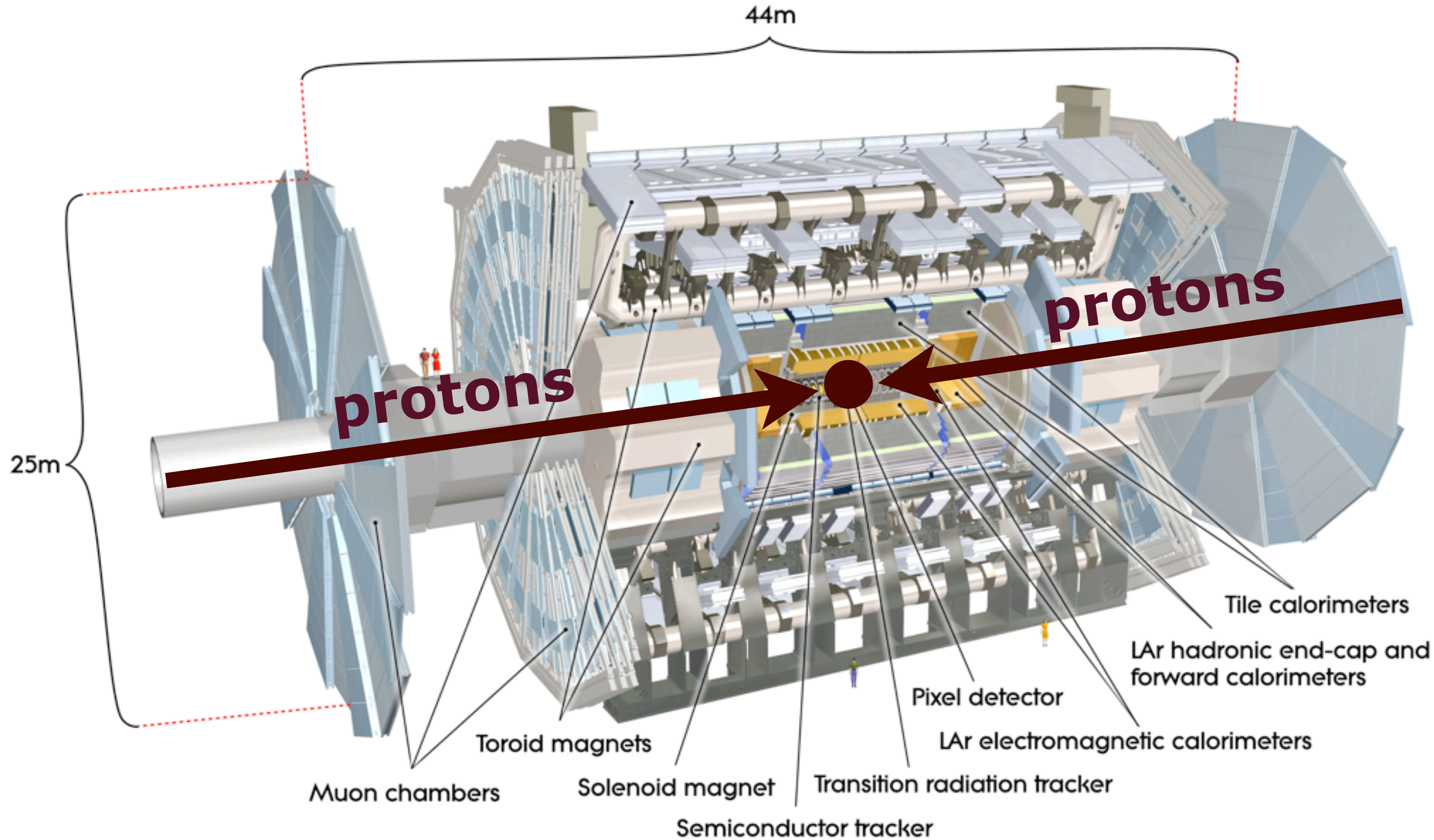
on behalf of the ATLAS Collaboration

Outline:

- Introduction
- Operation
- Calibration
- Performance
- Upgrade
- Summary

# ATLAS experiment




- Primary goals include discovery of the Higgs boson and potential extensions to the SM involving evidence of new physics.
- At design, 14 TeV LHC collisions providing 22 events per 25 ns at luminosity of $10^{34}$ $cm^{-2}s^{-1}$. In 2010, 45 $pb^{-1}$ of data at 7 TeV and peak luminosity of $2x10^{32}$ $cm^{-2}s^{-1}$.

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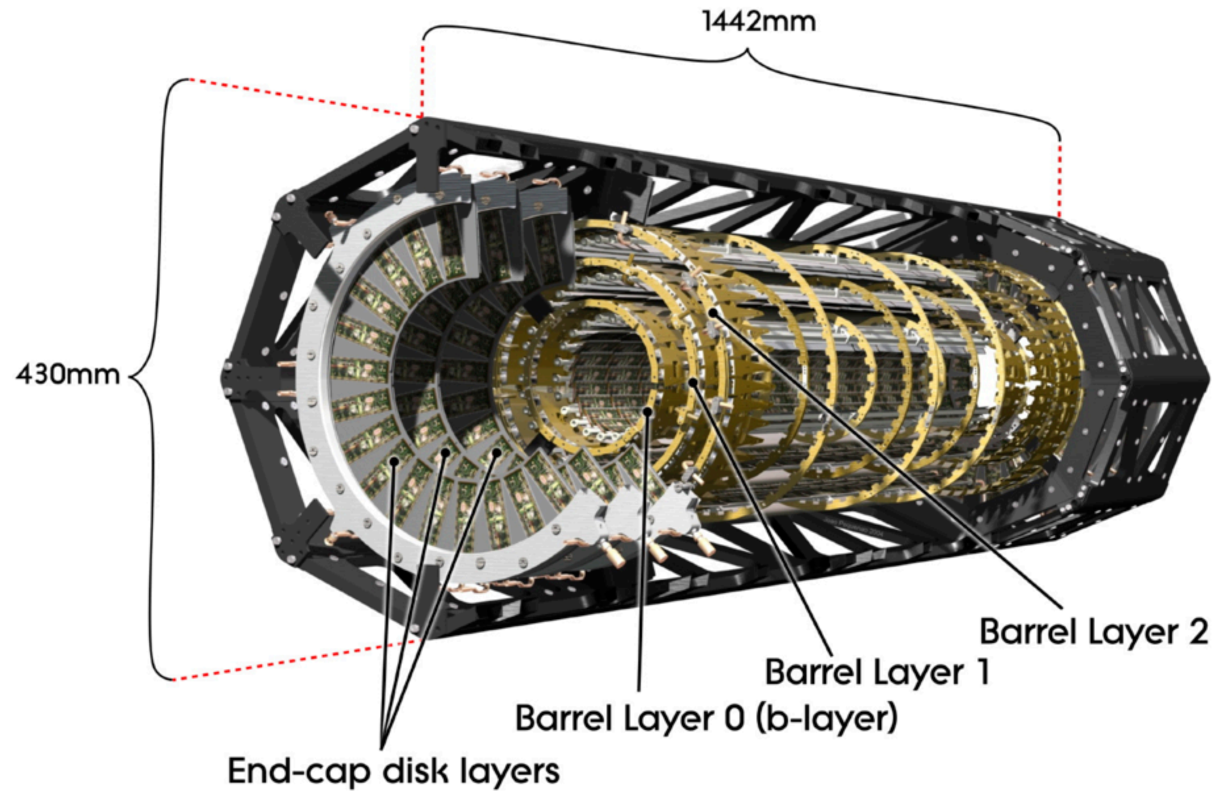
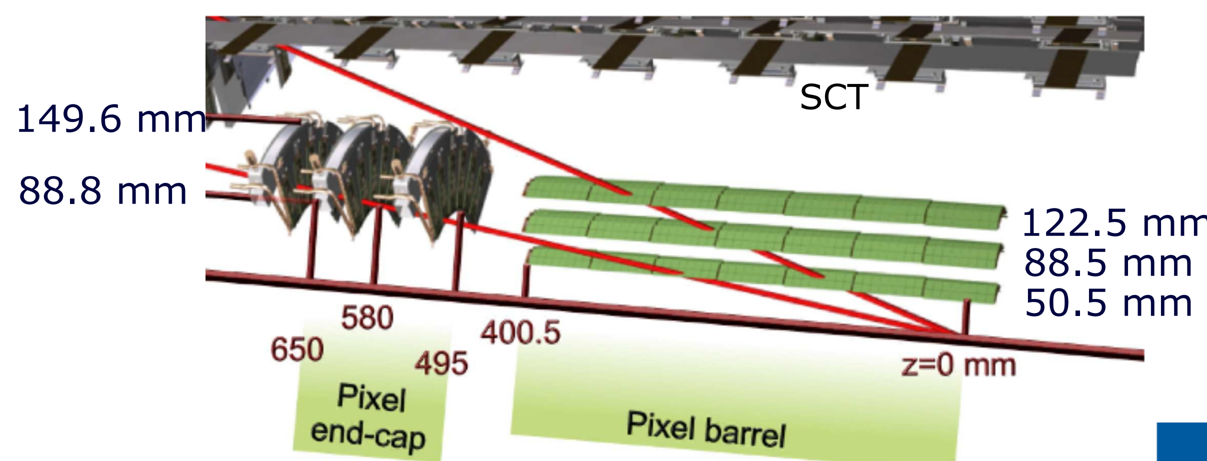
# Pixel detector

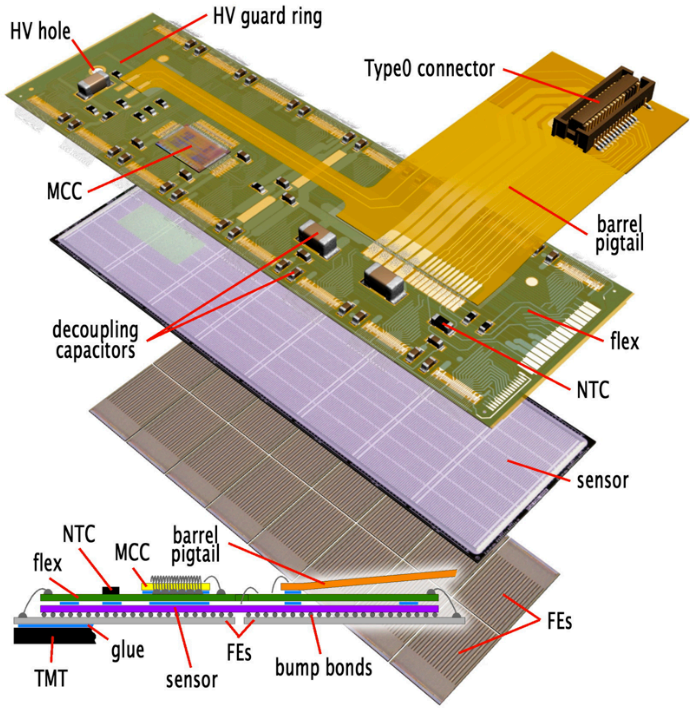
- 2 T magnetic field.
- 1456 modules in three layers of barrel region. 288 modules in three layers of end-cap regions.
- Barrel modules tilted by 20° in Rφ plane against the Lorentz angle to reduce occupancy.
- 80 million channels.
- 10 μm resolution in Rφ and 110 μm in z.
- Modules operating at -15 °C temperature.

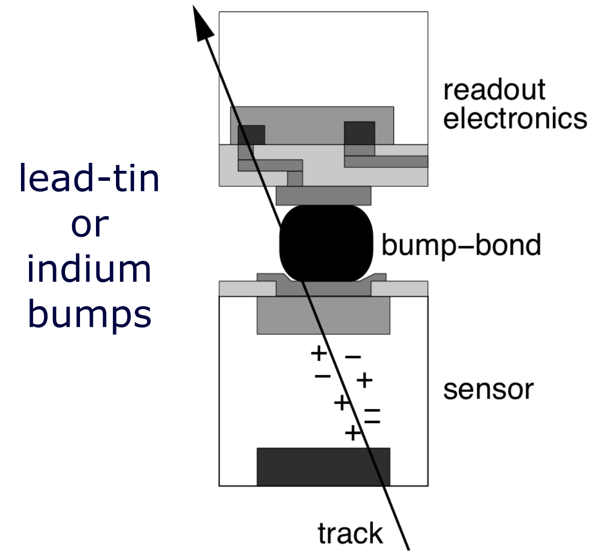


# Pixel module

- 250 µm thick silicon sensor with an active area of 16.4x60.8 $mm^2$.
- 16 front-ends (FEs) per module bump bonded to the sensor.
- Radiation hard up to NIEL $10^{15}$ 1 MeV $n_{eq}/cm^2$ and 30 MRad.
- 47232 pixels per module. Most with size 50x400 $µm^2$. Special pixels (long and ganged) to cover regions between FEs.
- Module controller chip (MCC) to send trigger, commands and configuration data, and to perform event building.
- 2x80 Mbps readout in b-layer (innermost), 80 Mbps in layer 1 and disks, and 40 Mbps in layer 2.



# Pixel operation

- 97.3% of pixel detector operational. 47/1744 (2.7%) modules and 44/27904 (0.16%) FEs are disabled.
- For pixel safety, high voltage (HV) is not turned on until LHC declares STABLE BEAMS.
- Preamplifiers are also off before switching on HV to avoid excessive noise which can block data acquisition (DAQ).
- Once stable beams declared, apply WARM START procedure which includes checking background rates in beam conditions monitor (BCM) and collimator positions, ramping up the HV and switching on preamplifiers.
- Pixel data taking efficiency is 99%. Loss dominated by warm start procedure.

| Inner Tracking Detectors | | | Calorimeters | | | | Muon Detectors | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Pixel | SCT | TRT | LAr EM | LAr HAD | LAr FWD | Tile | MDT | RPC | CSC | TGC |
| 99.0 | 99.9 | 100 | 90.5 | 96.6 | 97.8 | 94.3 | 99.9 | 99.8 | 96.2 | 99.8 |

Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams in pp collisions at $\sqrt{s}$=7 TeV between March 30th and October 31st (in %). The inefficiencies in the calorimeters will largely be recovered in a future data reprocessing.

- Automatic disable of modules blocking DAQ.

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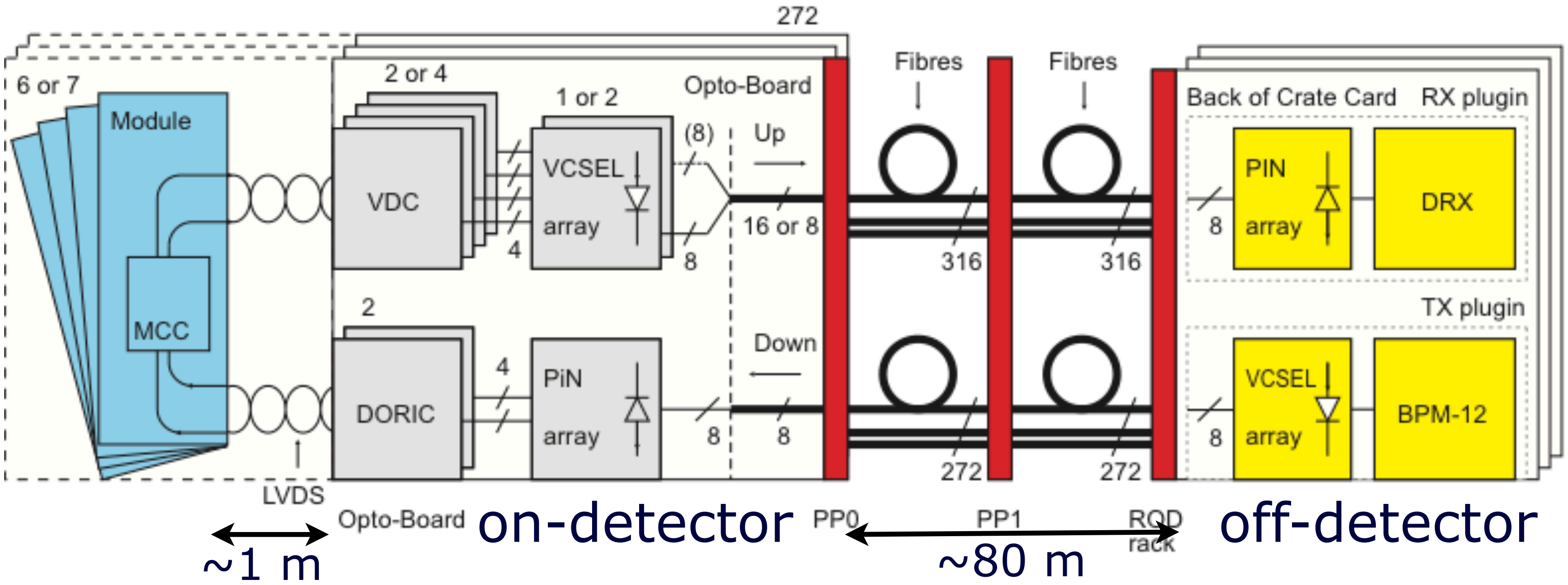
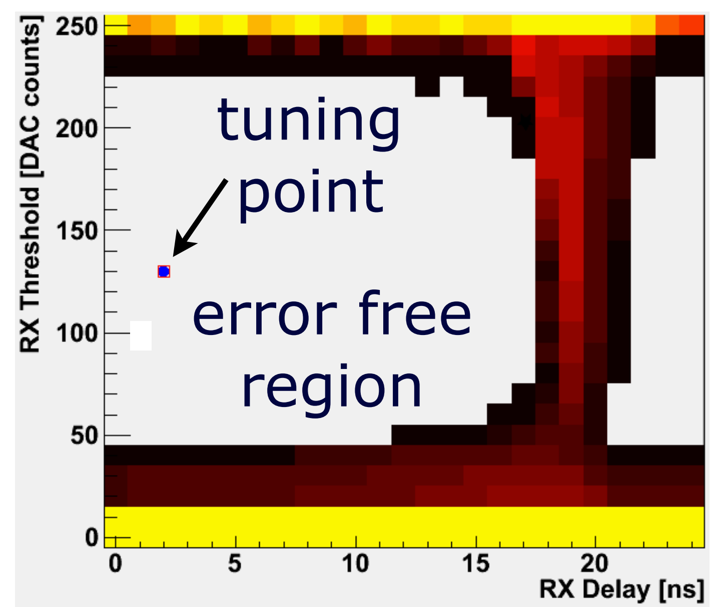
# Optolink calibration




- On-detector laser power, and off-detector sampling threshold and phase are tuned to settings that avoid data readout errors.
- Boundaries between error-free regions (EFR) and error regions are not equally stable, so optimal operating point not in the centre of EFR.

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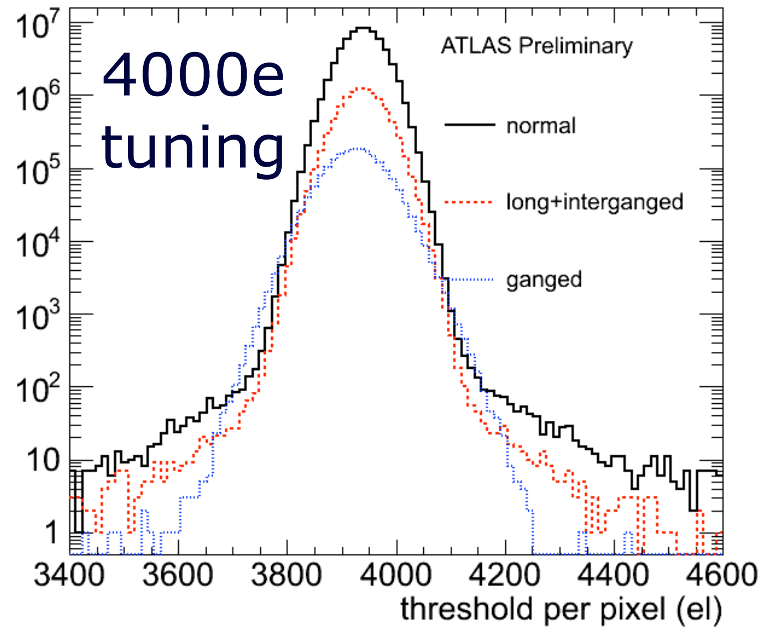
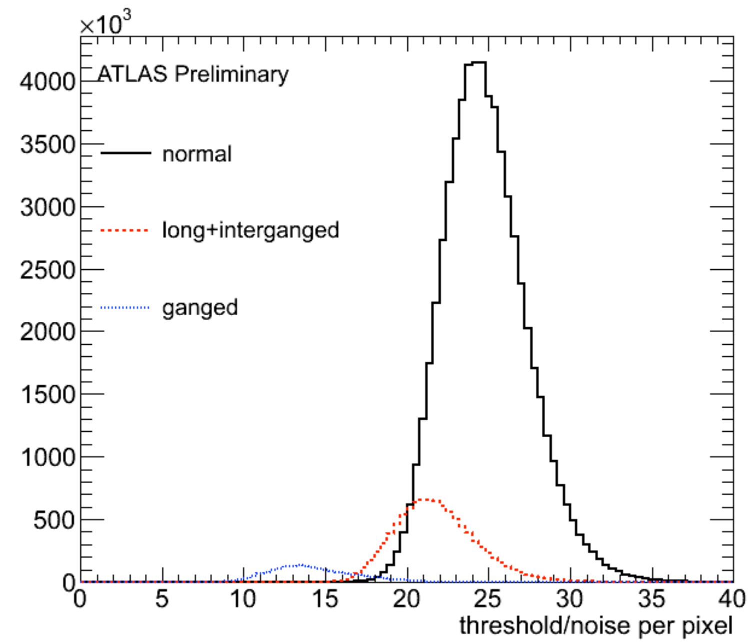
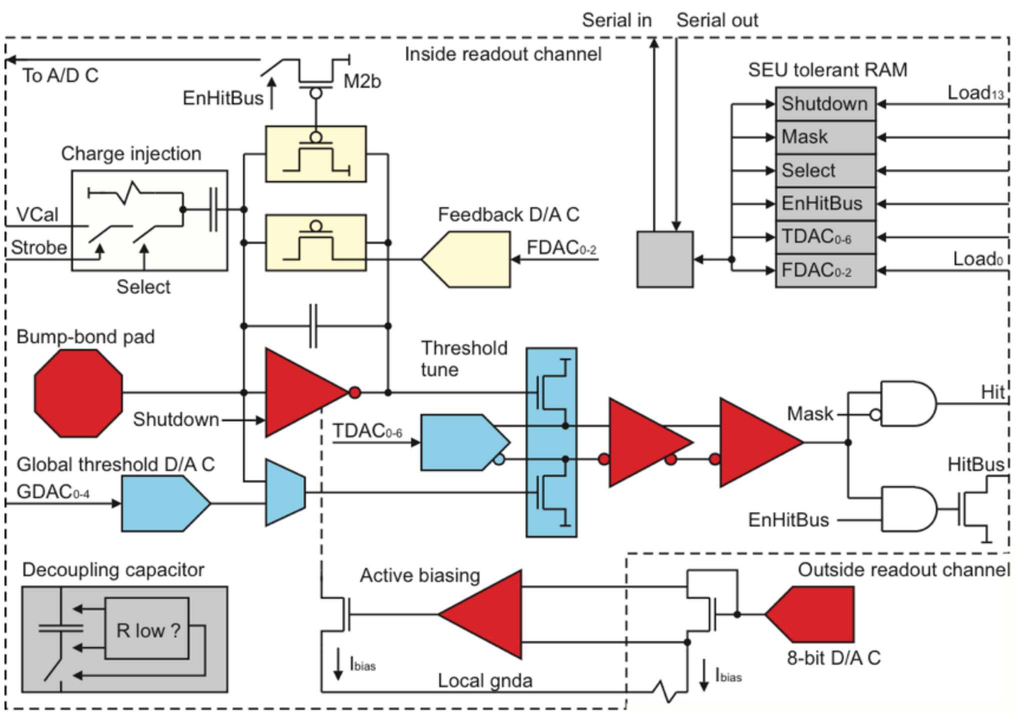
# Threshold calibration

- Inject # of test charges at target threshold, vary 7-bit DAC per pixel and count generated hits. Optimal value is at 50% efficiency.
- For 2010 collisions, threshold tuned to 3500e. Dispersion is about 40e.
- 0.1% of noisy pixels are masked.

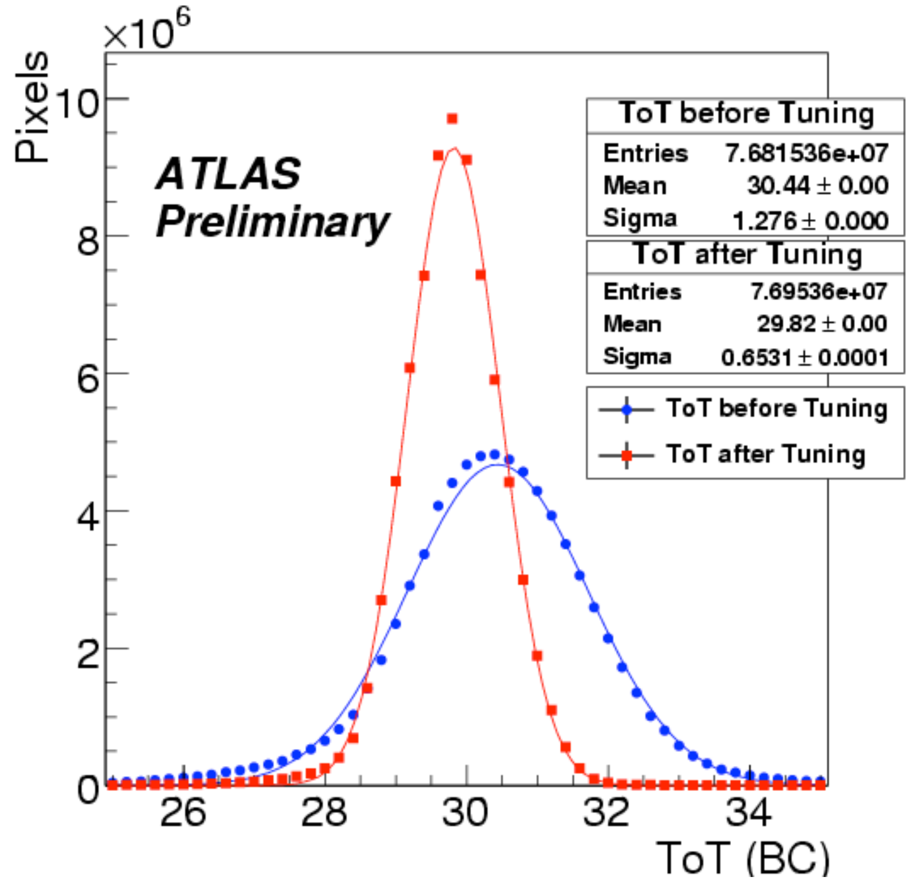


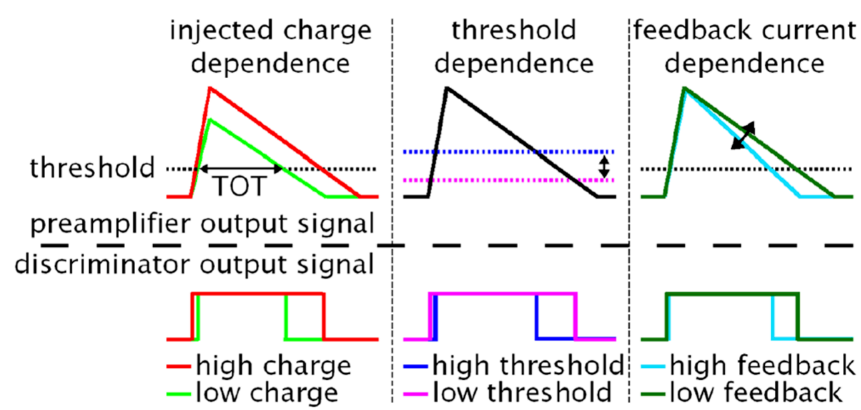



# ToT calibration

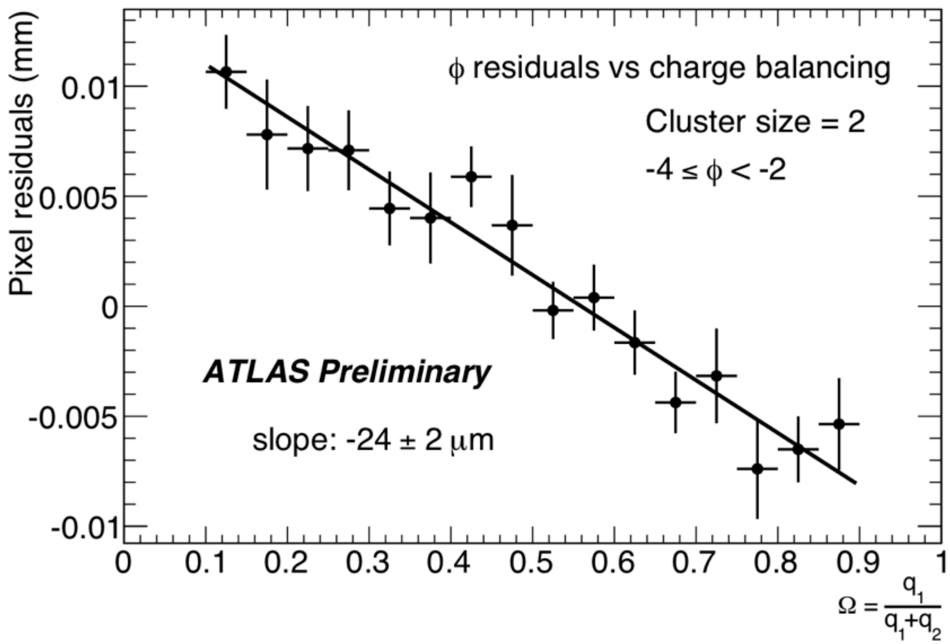
- Time over threshold (ToT) is the time in which signal is above threshold. In units of bunch crossings (BCs), i.e. 25 ns. ToT = $p_0(p_1+Q)/(p_2+Q)$.
- Tuning target is 30 BCs for a charge of 20ke (most probable for m.i.p.). Resolution ~1 BC.
- Inject # of test charges at 20ke, vary 3-bit DAC per pixel to find optimal point resulting closest to target ToT.
- Low charge hits may end-up in the next BC due to slow rise above threshold. Compensated by copying to previous BC.

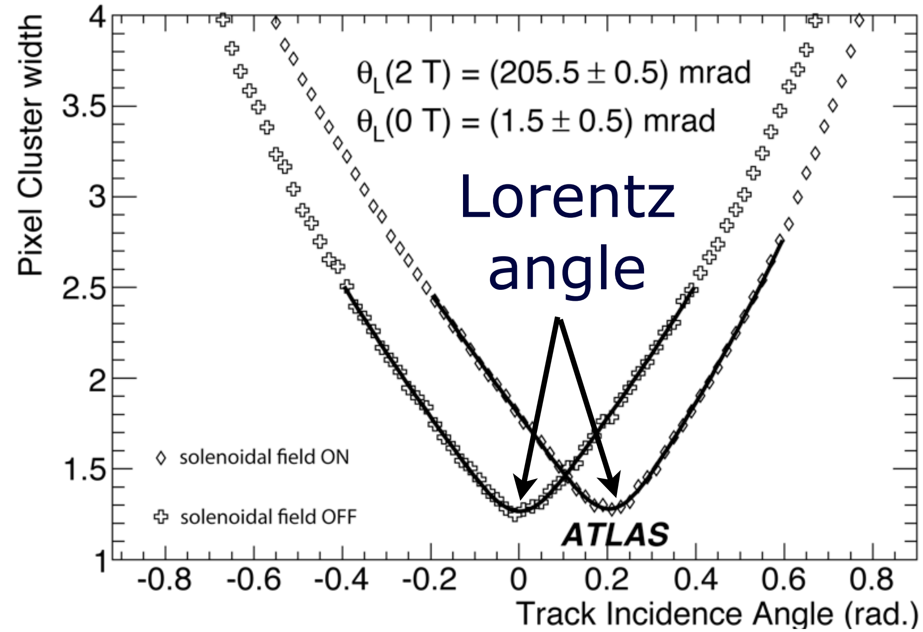


# Charge sharing and Lorentz angle

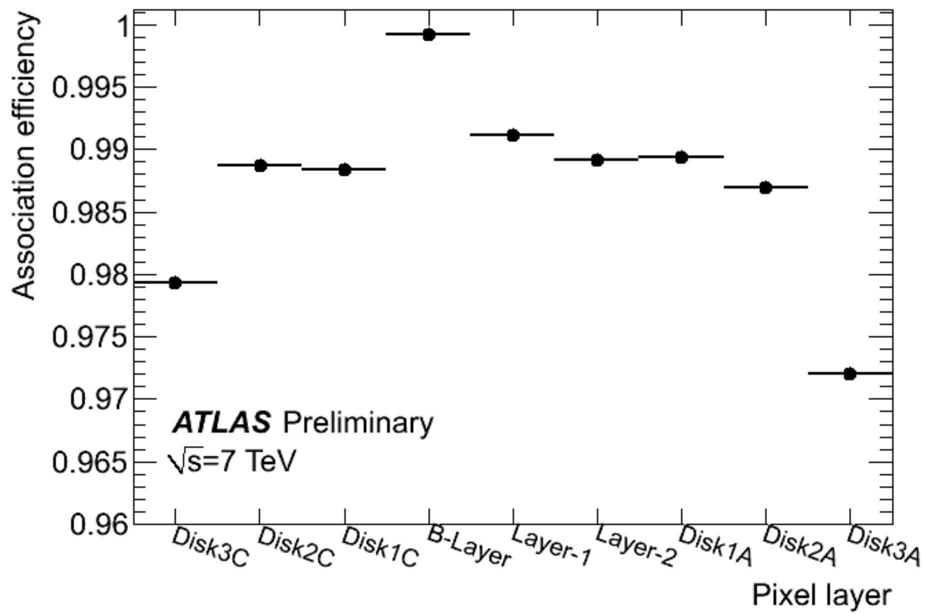
- Position residuals of pixels in a cluster depend on relative charge sharing between the pixels.
- Cluster position is calculated using charge weighted position of contributing pixels.
- Lorentz angle corresponds to track incident angle resulting in min cluster size. 12.11±0.09° for collisions.
- In a magnetic field, charge carriers drift at an angle w.r.t the normal of electrode surface. Displacement is about 30 µm.

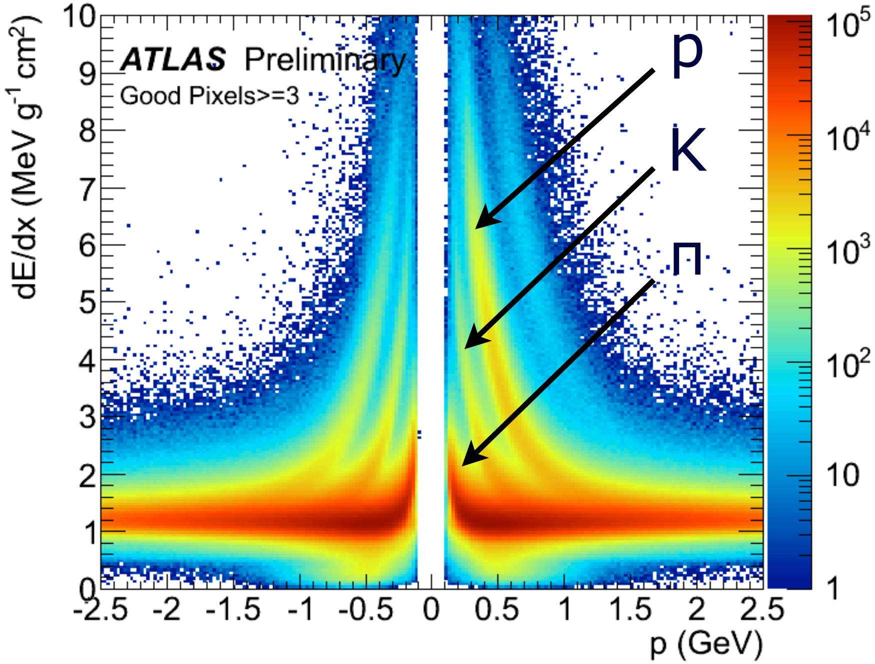


# Hit to track association and particle-id

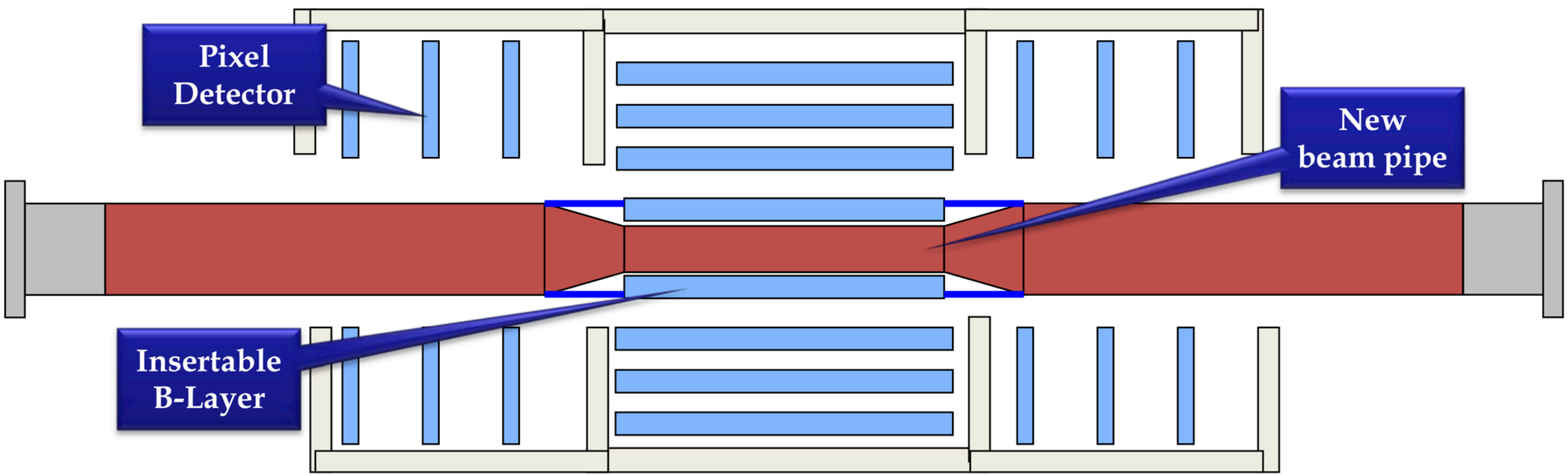
- Efficiency of a track having hits for pixel detector layers crossed is about 99%. Dead modules excluded.
- Full efficiency in b-layer due to track selection.
- Association inefficiency mostly due to known dead regions (pixels and or FEs) in modules.
- Charged particles with $m >> m_e$ traversing material loses energy mostly via ionization and excitation, described by Bethe-Bloch formula.
- Energy loss proportional to collected charge.



# Pixel upgrade (I)

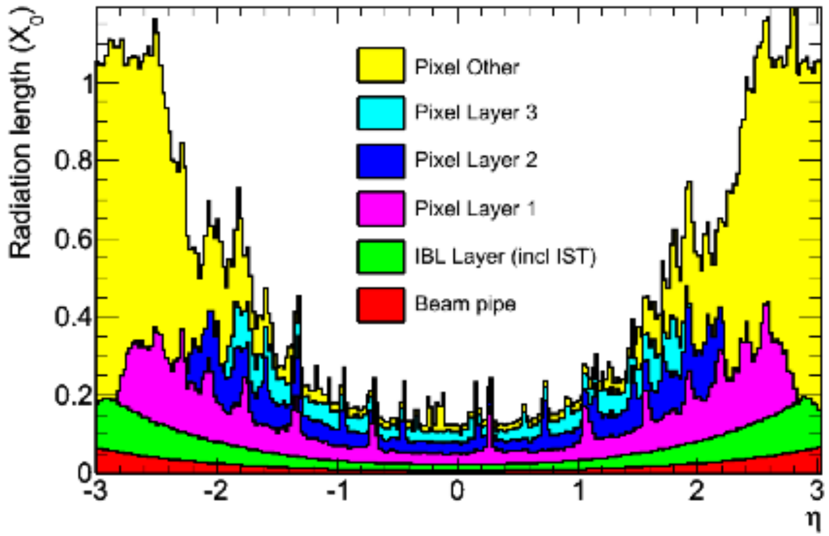
- LHC plans to reach peak luminosity of $2x10^{34}$ $cm^{-2}s^{-1}$ by 2016. Expected NIEL $3x10^{15}$ 1 MeV $n_{eq}/cm^2$.
- Additional insertable b-layer (IBL) to be placed at radius 3.2 cm inside the current b-layer. Requires new narrower beam pipe.
- New technologies including FE-I4 (larger chip, smaller pixel size, storage of hits until trigger arrives and lower power), 3D silicon or CVD diamond sensors and $CO_2$ cooling. Radiation hard up to NIEL $5x10^{15}$ 1 MeV $n_{eq}/cm^2$ and 250 MRad.

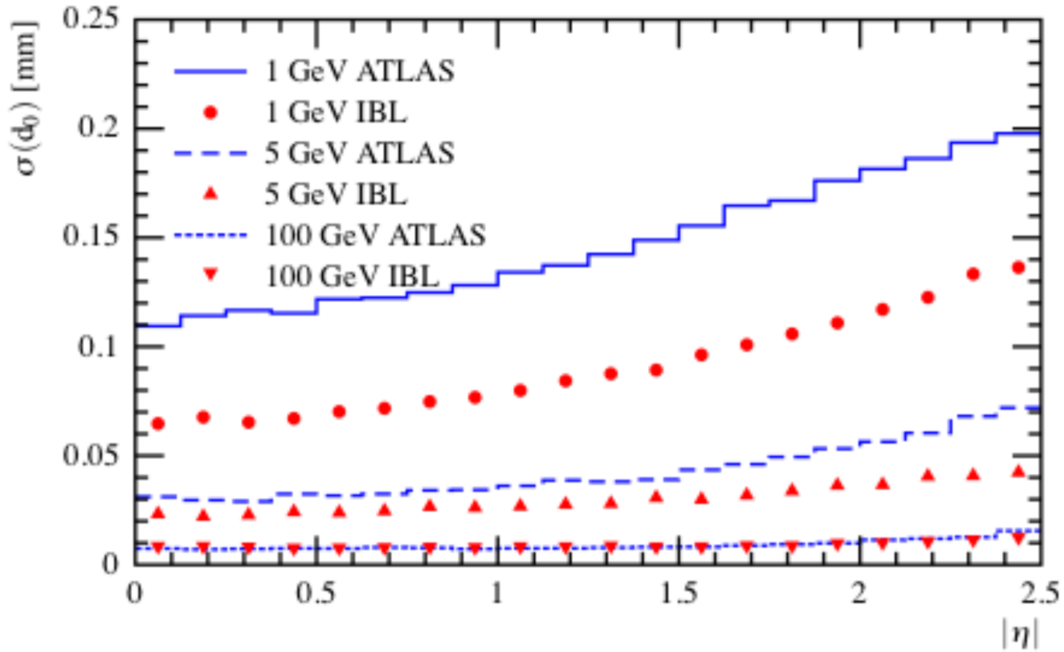


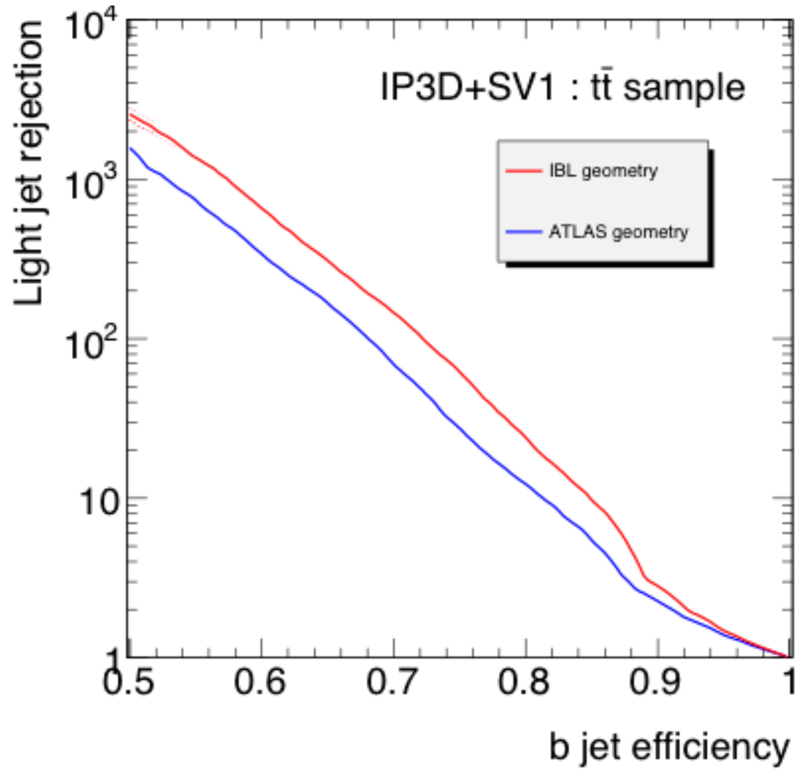

Fabian Huegging (ATL-UPGRADE-SLIDE-2010-260)

# Pixel upgrade (II)

- Placement of IBL at smaller radius combined with low density of material results in improved impact parameter resolution and vertex reconstruction.
- Higher track reconstruction efficiency.
- Increased b-tagging efficiency.

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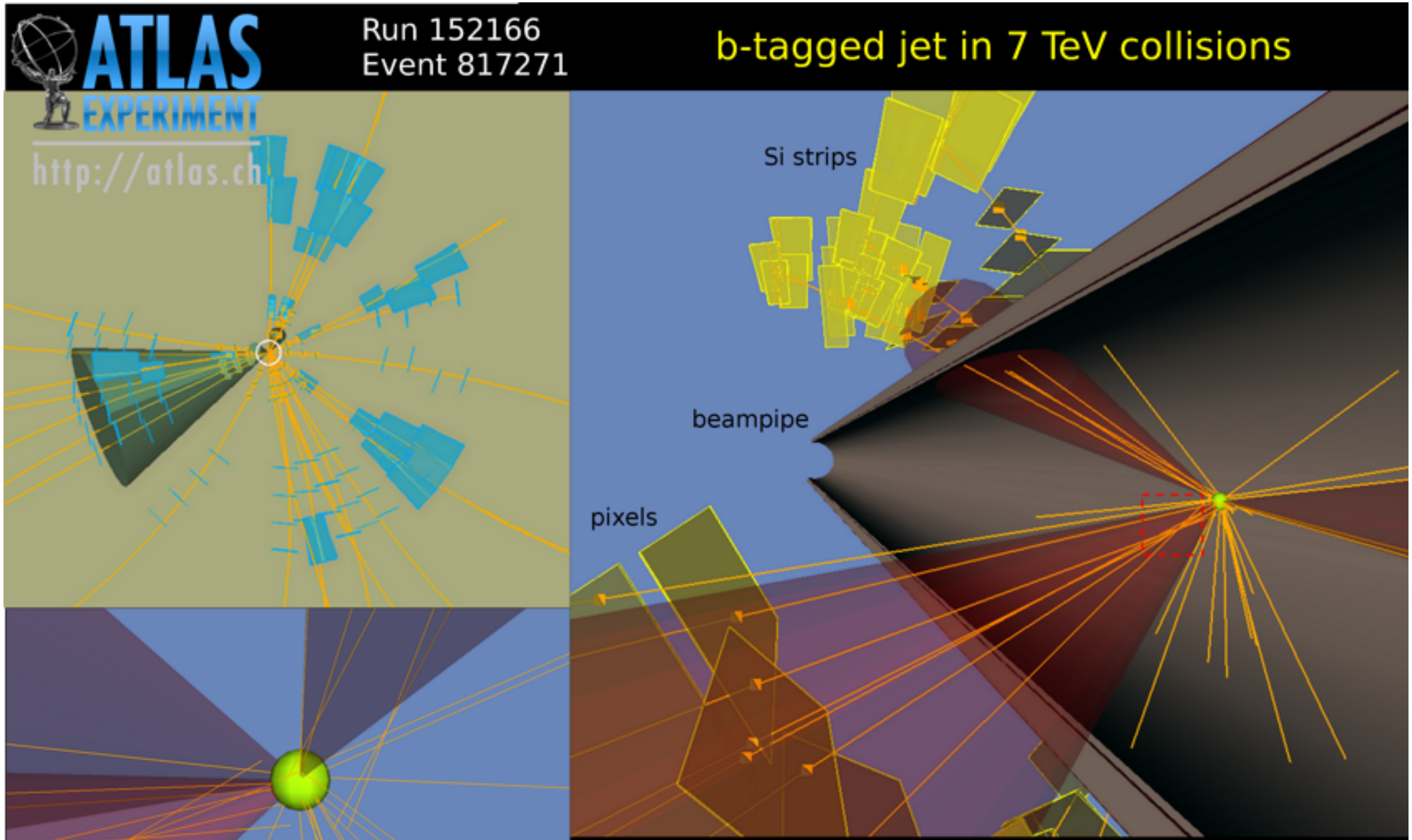
# Summary

- The ATLAS pixel detector is calibrated and performing well. Regular checks of performance and re-tuning when necessary.
- 97.3% of the pixel detector is operational.
- Position resolution 10 μm in Rφ and 110 μm in z.
- Pixel data taking efficiency is 99%.
- Pixel hit to track association efficiency is 99%.
- Upgrade with additional b-layer to be placed at radius 3.2 cm to improve performance and maintain performance of the pixel detector when existing b-layer degrades.

# Questions

# b-tagged jet




$p_T^{jet}$=19 GeV (measured at electromagnetic scale)

4 b-tagging quality tracks in the jet

# Pileup event with four vertices