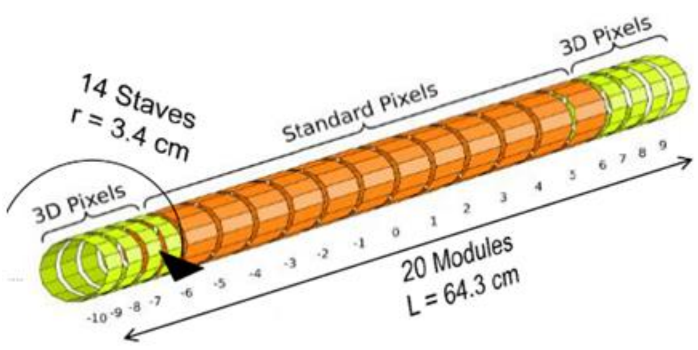
New Technique for Luminosity Measurement Using 3D Pixel Modules in the ATLAS IBL Detector

Peilian Liu[1] on behalf of the ATLAS Collaboration

[1]Lawrence Berkeley National Laboratory

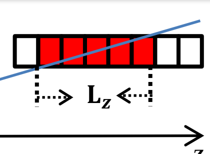


IBL

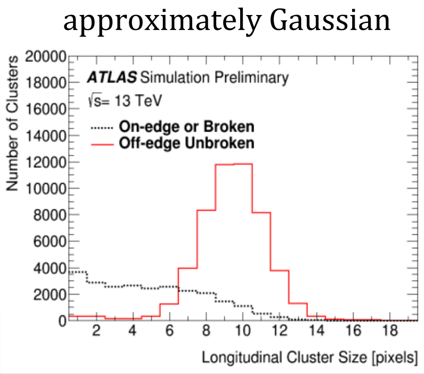
The Insertable B Layer (IBL) is a cylindrical silicon pixel detector that consists of 14 staves placed around the beam pipe. Each stave consists of 12 planar modules and 8 3D modules.

3D modules - FE-I4B chip is bump bonded to 3D sensor
- 80×336 pixels
- pixel size: 250×50 μm^2

✦ $L_z = \frac{\text{sensor thickness}}{\text{pixel pitch}} \cdot \frac{z_{IP} - z_{3D}}{r_{IBL}}$



z_{IP} distribution is expected to be approximately Gaussian



Broken and **on-edge** clusters are **removed** from analysis to preserve a Gaussian shape of the signal

Broken: one pixel gap along z

Luminosity-determination methodology

✦ The bunch luminosity produced by a pair of colliding bunches is given by $\mathcal{L}_b = \frac{\mu \cdot f_r}{\sigma_{inel}}$

✦ ATLAS monitors $\mathcal{L}_b$ by measuring μ_{vis}

$$\mathcal{L}_b = \frac{\mu_{vis} \cdot f_r}{\sigma_{vis}}$$

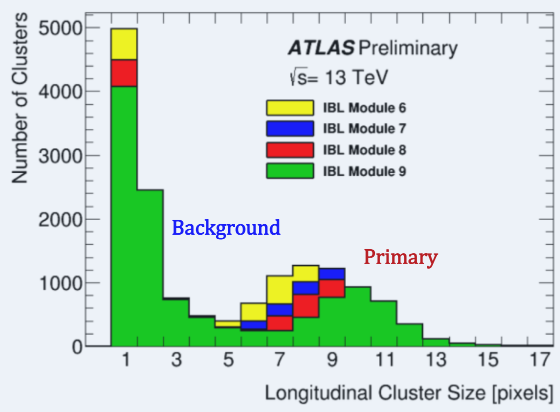
✦ μ_{vis} is calibrated with σ_{vis} by the "van der Meer scan" method[1]

- ✓ μ : number of inelastic interactions per bunch crossing
- ✓ f_r : bunch revolution frequency (11245.5Hz at LHC)
- ✓ $\sigma_{inel} = pp$ inelastic cross section
- ✓ ϵ: efficiency of the detector and algorithm
- ❖ $\mu_{vis} = \epsilon \cdot \mu$
- ❖ $\sigma_{vis} = \epsilon \cdot \sigma_{inel}$

Pixel Cluster Counting (PCC) Algorithm

The principle of the PCC-based luminosity measurement: the number of primary clusters is assumed to be proportional to the luminosity, and the absolute PCC luminosity scale is fixed by cross-calibrating it to LUCID in a reference run.

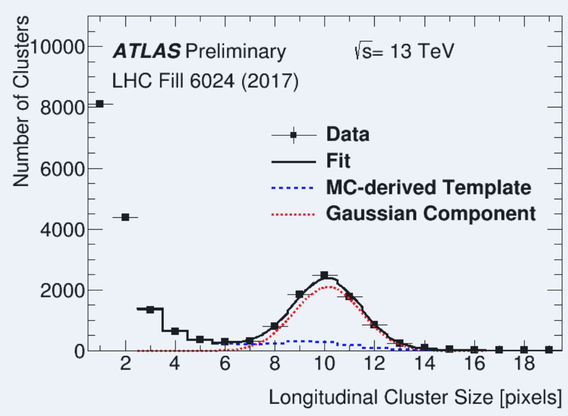
Counting primary clusters in 3D modules produced by primary particles from pp collisions



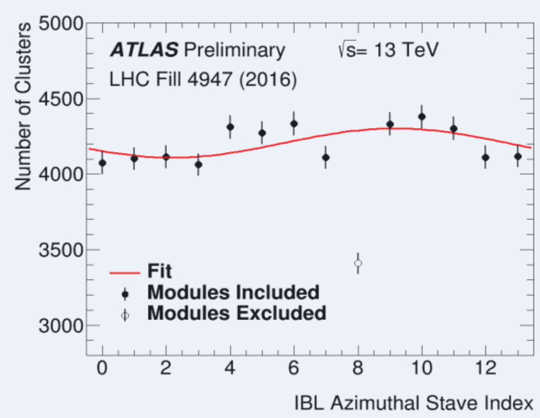
Because **3D modules** are located at high $|\eta|$, particles from the interaction point traverse them at grazing incidence, producing longer primary clusters and thereby improving the signal-background separation.

Background clusters tend to be shorter and arise from:

- Secondary clusters — by secondary particles from the interaction of primary particles with material
- Afterglow — delayed hits from radioactive decay or material activated by previous collisions
- Beam backgrounds and noise



Gaussian distribution of primary clusters
MC-derived template of secondary clusters (other background clusters are mainly shorter than 2 [pixels])



The 14 modules in the same ring have the same acceptance

Number of clusters vs ID_ϕ

$$A \cdot \cos\left(\frac{2\pi}{14} \cdot (ID_\phi - B)\right) + C$$

The interaction point (IP) is not always centered in x-y plane. More clusters in module closer to IP.

(ID_ϕ: Stave index)

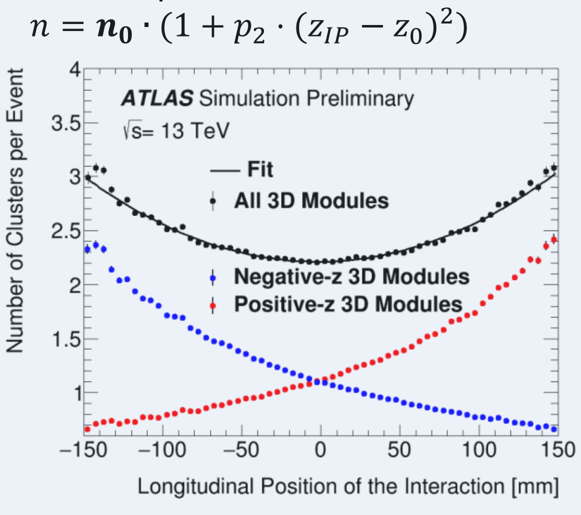
✦ Fit gives correct cluster count even when modules with a transient problem are excluded (as shown)

✦ The parameter C is the average number of clusters per module in the ring and is what is used as proxy to estimate the luminosity

Correction for the z_{IP} Dependence

Clusters produced in all 3D modules by the interaction happening at z_{IP}:

$$n = n_0 \cdot (1 + p_2 \cdot (z_{IP} - z_0)^2)$$



n_0: clusters produced by one interaction happening at the IBL center z_0

Well constrained x_{IP} and y_{IP} because of the small (~10μm) transverse beam size

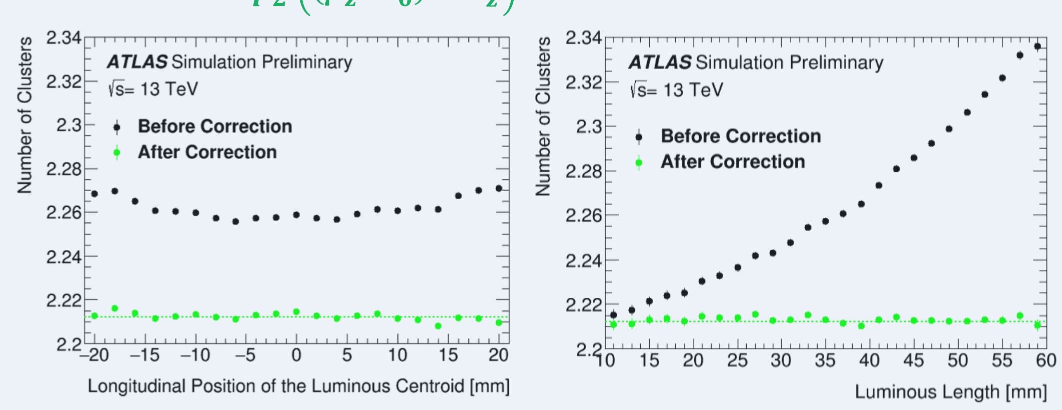
Clusters produced by all interactions ($< \mu >$) in the luminous region ~ Gauss(μ_z, σ_z)

$$N = \int n_0 \cdot <\mu> \cdot (1 + p_2 \cdot (z_{IP} - z_0)^2) \cdot \text{Gauss}(z_{IP}; \mu_z, \sigma_z) dz_{IP}$$

$$= n_0 \cdot <\mu> \cdot \left[1 + p_2 \cdot \left((\mu_z - z_0)^2 + \sigma_z^2\right)\right]$$

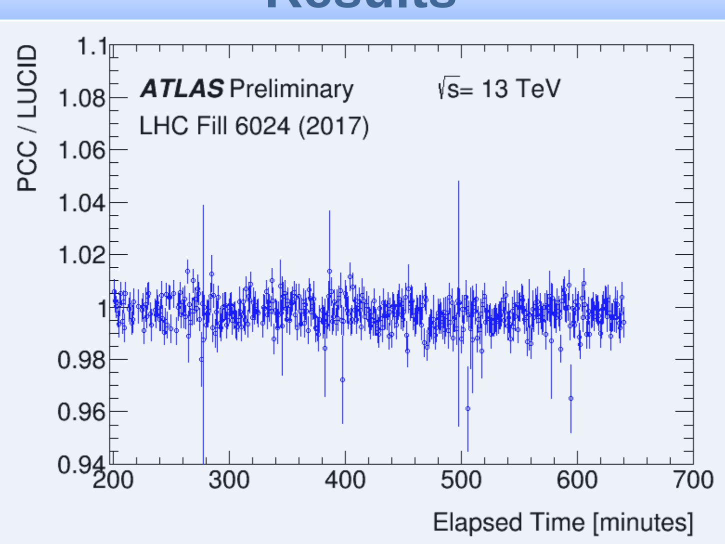
- ○ A longer luminous region produces more clusters
- ○ A luminous region longitudinally off-center in the IBL produces more clusters

Correction: $\frac{N}{1 + p_2 \cdot \left((\mu_z - z_0)^2 + \sigma_z^2\right)}$



The correction is designed to return the ideal number of clusters that would have been observed if all interactions happened at the IBL center ($\mu_z = \sigma_z = 0$) and therefore the corrected number of clusters is expected to not depend on μ_z nor σ_z anymore.

Results



An accurate measurement of the delivered luminosity

- ✦ Vital to cross-section measurements
- ✦ Important in the search of new physical phenomena

The PCC algorithm will contribute to understand and reduce systematic uncertainties, in particular from

- – The long-term stability and consistency of other luminometers
- – The transfer of the van der Meer calibration to the high-luminosity physics regime

✦ LUCID: ATLAS-preferred luminometer for run2 data

✦ The ratio of $\mathcal{L}_{PCC}$ (as measured by the number of clusters) to $\mathcal{L}_{LUCID}$ is constant over LHC fill 6024, and therefore independent of the bunch-average pile-up parameter $< \mu >$. Studies of more fills are on-going.

✦ In this fill, the average number of interactions per bunch crossings ranges from ~40 to ~16.

[1] ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s}$ = 8TeV using the ATLAS detector at the LHC, Eur. Phys. J. C 76, 653 (2016).

ATLAS EXPERIMENT