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

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Luminosity-determination methodology

- The bunch luminosity produced by a pair of colliding bunches is given by $L_B = \frac{n_{\text{inel}}}{\sigma_{\text{inel}}}$
- ATLAS monitors $L_B$ by measuring $n_{\text{inel}}$ and $\sigma_{\text{inel}}$
- $n_{\text{inel}}$ is calibrated with $\sigma_{\text{inel}}$ by the "van der Meer scan" method.[1]
- $\mu$: number of inelastic interactions per bunch crossing
- $f_r$: bunch revolution frequency (11245.5Hz at LHC)
- $\sigma_{\text{inel}}$: pp inelastic cross section
- $\epsilon$: efficiency of the detector and algorithm

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 $|y|$, 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

The 14 modules in the same ring have the same acceptance

Number of clusters vs ID$_B$

$A \cdot \cos \left( \frac{2\pi}{14}(\text{ID}_B-B) \right) + C$

The interaction point (IP) is not always centered in x-y plane.
More clusters in module closer to IP. (ID$_B$: S nave 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 used as proxy to estimate the luminosity

Correction for the $z_{IP}$ Dependence

- $n = n_0 (1 + p_2 (z_{IP} - z_0))^2$ clusters produced by one interaction happening at the IBL center $z_0$
- $N = \int n_0 < \mu > [1 + p_2 (z_{IP} - z_0)^2] \text{Gauss}(z_{IP}, \mu_0, \sigma_0) dz_{IP}$

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

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 $L_{\text{PCC}}$ (as measured by the number of clusters) to $L_{\text{LUCID}}$ 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 $\sim 40$ to $\sim 16$.