Characterization of Interaction-Point Beam Parameters Using the *pp* Event-Vertex Distribution Reconstructed in the ATLAS Detector at the LHC

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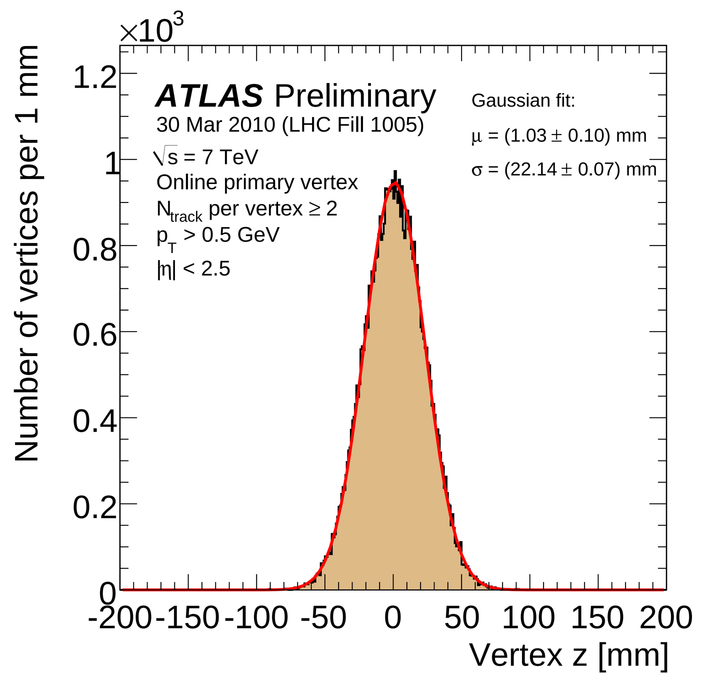
(1) Abstract

We present results from the measurement of the 3-D luminosity distribution with the ATLAS Detector during early running. The spatial distribution of *pp* interactions is reconstructed by a dedicated algorithm in the High-Level Trigger that fits tracks and primary event vertices in real time, and by an offline algorithm that takes full advantage of the high tracking efficiency and resolution of the Inner Detector through an unbinned maximum-likelihood fit. The number of vertices provides online monitoring of the instantaneous luminosity, while luminous-centroid motion mirrors IP-orbit and RF-phase drifts. Similarly, the x, y and z luminous widths reflect the evolution of the transverse and longitudinal emittances. The length scales of the IP orbit bumps, which directly impact the accuracy of the transverse convolved beam sizes measured during beam-beam scans, are calibrated offline against the measured displacement of the luminous centroid; this significantly improves the absolute accuracy of the luminosity calibration by the van der Meer method. The simultaneous determination, during such scans, of the transverse convolved beam sizes (from the luminosity variation) and of the corresponding luminous sizes can be used to disentangle the IP sizes of the two beams.

(2) Event Vertex Distributions

Online Selection High Rate, Live Feedback

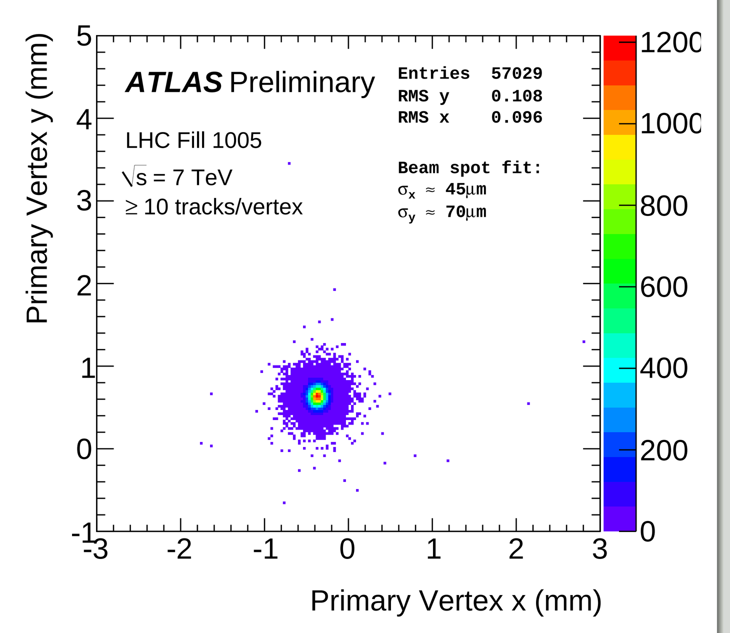
- The Level 2 Trigger measurements are initiated by signals from Level 1 minimum-bias trigger scintillators.
- Pattern recognition and track fitting on Data from the entire Inner Detector must be done within only a few tens of milliseconds.
- A fast vertex fitter reconstructs primary vertices with ≥ 2 tracks of $p_T > 1$ GeV and $|\eta| < 2.5$.



Online primary-vertex distributions along the beam axis at $\sqrt{s} = 7$ TeV

Offline Selection High Tracking Efficiency, High Precision

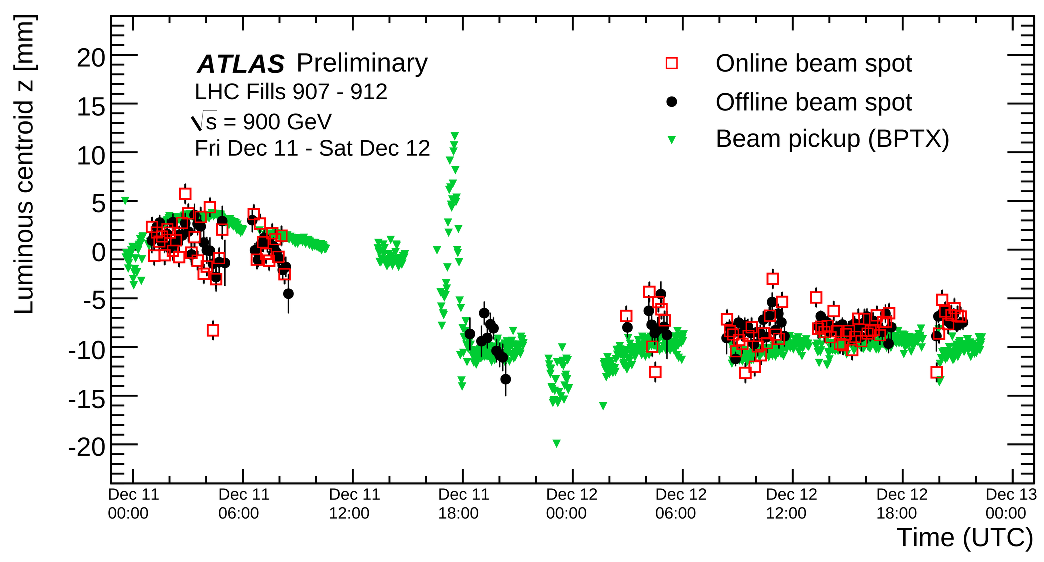
- Several tracking algorithms build tracks from Inner Detector raw hits.
- Tracks are refit and assigned a score which favors hits in the more precise detectors – only tracks with a high score are kept.
- A final inside-out tracking pass resolves tracks down to a p_T of 150 MeV.
- Vertices with ≥ 4 tracks are used in the unbinned maximum-likelihood fit of the luminous region.



Offline primary-vertex distributions in the x-y plane, uncorrected for resolution, at $\sqrt{s} = 7$ TeV

(3) Luminous Centroid Position

The distribution of event vertices can be characterized very precisely due to the high rate of usable events. The time-evolution of the position is recorded in approximately 2-minute intervals.



Longitudinal position at $\sqrt{s} = 900$ GeV measured online (red squares), offline (black circles), and using the electrostatic beam pickups (BPTX, green triangles)

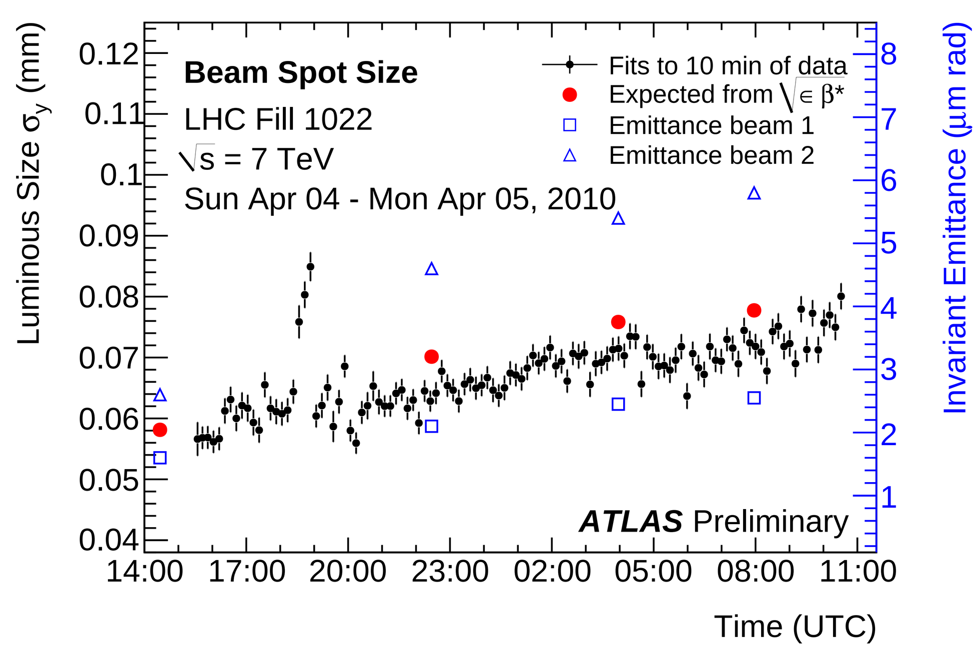
(4) Transverse Luminous Widths

The offline vertices are reconstructed by a fit which extracts vertex-resolution corrected luminous sizes ($\sigma_{x\mathcal{L}}$, $\sigma_{y\mathcal{L}}$) which is related to the sizes of the two beams:

$$\sigma_{y\mathcal{L}} = \left(\frac{1}{\sigma_{y1}^2} + \frac{1}{\sigma_{y2}^2}\right)^{-1/2}.$$

These measurements are compared to the expected sizes from:

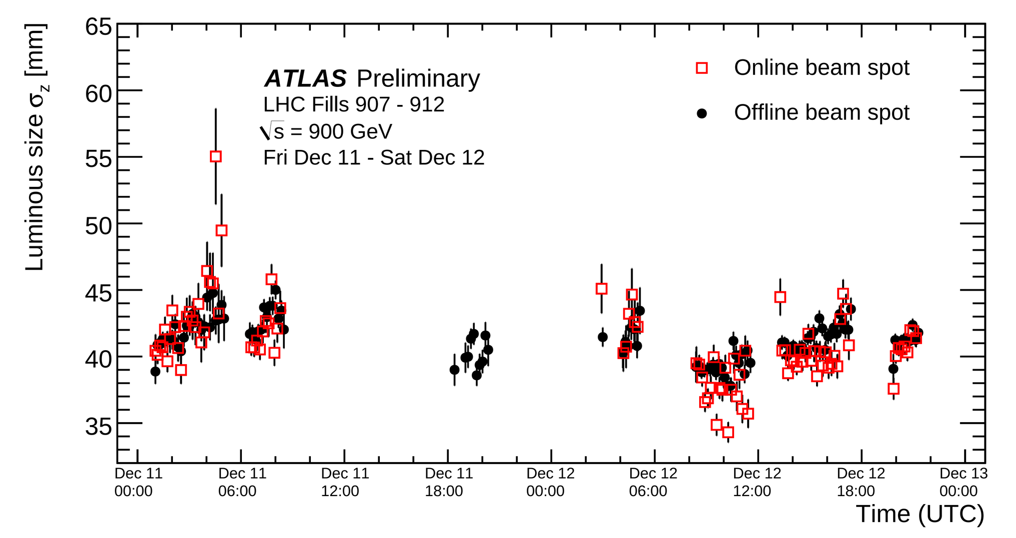
- the β^* measured by the phase-advance technique ($\pm 10\%$?).
- the horizontal and vertical emittances of each beam from wire-scanner measurements.



$\sigma_{y\mathcal{L}}$ (resolution corrected), values predicted using emittances, and IP β-functions measured by accelerator techniques for $\sqrt{s} = 7$ TeV data.

(5) Longitudinal Luminous Size

Because the resolution is negligible compared to $\sigma_{z\mathcal{L}}$, the long. distribution is a perfect Gaussian.

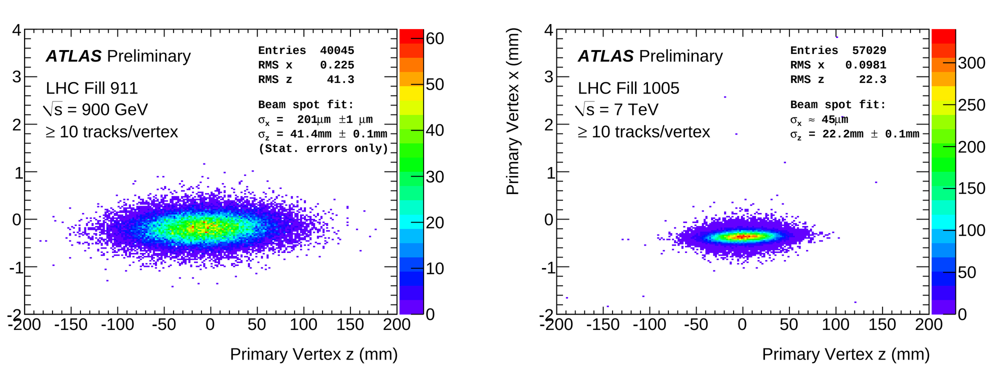


Time history of the luminous length in Dec. 2009 ($\sqrt{s} = 900$ GeV).

An increase of $\sim$2.5% over 3.5 hours indicates an emittance growth in the LHC, which is reproducible from fill to fill.

The smaller length in 2010 Data is attributed to:

- the smaller injected longitudinal emittance
- different RF voltages

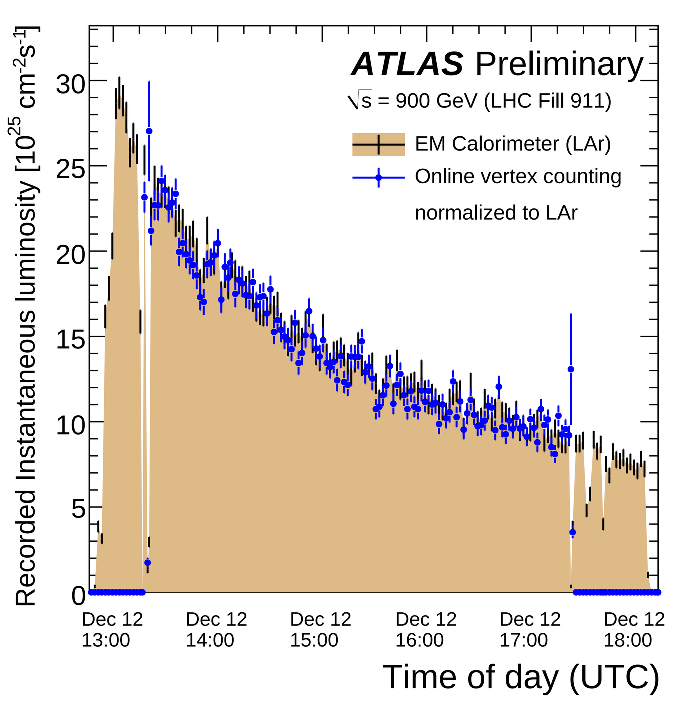


Primary vertices in the x-z plane at $\sqrt{s} = 900$ GeV (left) and $\sqrt{s} = 7$ TeV (right).

(6) Luminosity Monitoring and Calibration

Can go beyond measuring just the IP orbits and luminous sizes!

The online vertex count is also a measure of the luminosity – compared here to event counting performed with the Liquid-Argon calorimeter.



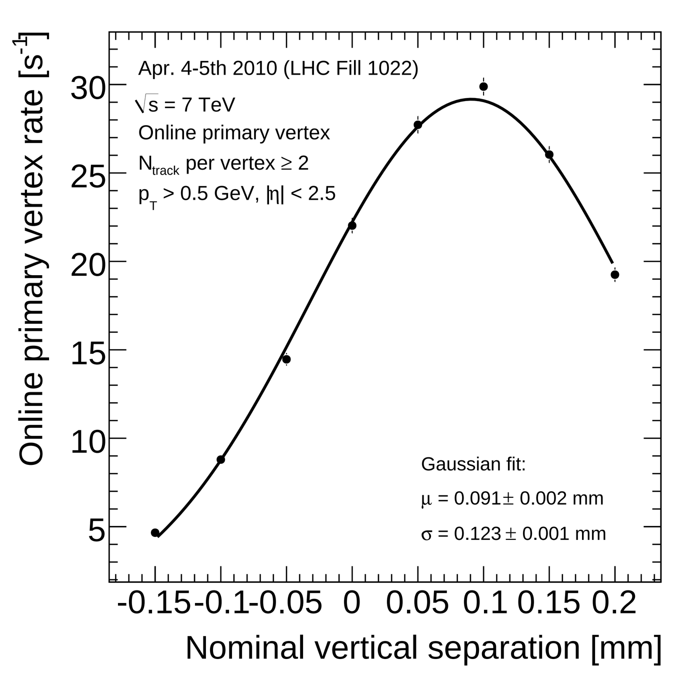
Calorimeter measurement with the vertex-counting rate normalized to the LAr.

Beam-separation scans are used to calibrate the absolute luminosity at zero beam separation.

The transverse convolved beam sizes Σ_x, Σ_y are given by:

$$\Sigma_i = \sqrt{\sigma_{i1}^2 + \sigma_{i2}^2},$$

and can be determined by scanning one beam across the other, first horizontally and then vertically, and recording the relative collision rate as a function of the two-beam separation.



Vertical luminosity scans.

(7) Disentangling of Individual Transverse Beam Sizes

The transverse convolved beam sizes (Σ_x, Σ_y) and the luminous widths depend differently on the single-beam sizes σ_{ib} ($i = x, y;\ b = 1, 2$).

A simultaneous measurement of Σ_x, Σ_y and of $\sigma_{x\mathcal{L}}$, $\sigma_{y\mathcal{L}}$ at zero beam separation yields a direct determination of the individual transverse sizes of beams 1 and 2,

$$\sigma_{1,2}{}^2 = \Sigma^2/2 \pm \sqrt{\Sigma^4/4 - \Sigma^2\,\sigma_{\mathcal{L}}{}^2}\,.$$

Beam (i b)	$\bar{\epsilon}_{ib}$ (μm rad)	$\sigma_{i\mathcal{L}}$ (μm) (exp)	$\sigma_{i\mathcal{L}}$ (μm) (meas)	Σ_i (μm) (meas)	σ_{ib} (μm) (exp)	σ_{ib} (μm) (meas)
x 1	1.71	53.0	46 ± 2	94 ± 1	71.0	59^{+7}_{-6}
x 2	2.15				79.6	73^{+4}_{-7}
y 1	1.85	60.0	60 ± 2	123 ± 1	73.9	77^{+10}_{-6}
y 2	3.60				103.0	96^{+4}_{-9}

The predicted sizes use the emittances measured with wire-scanners

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