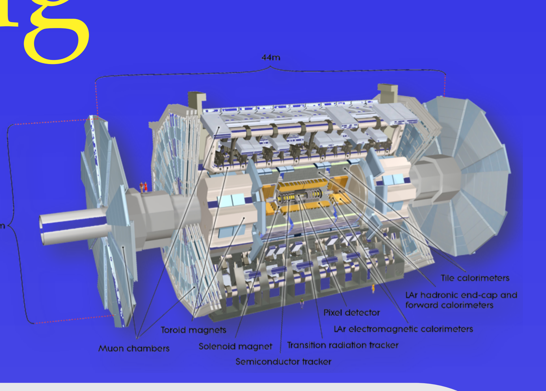
Luminosity and Beam Spot Determination Using the ATLAS Detector

David W. Miller (SLAC), on behalf of the ATLAS Collaboration



Introduction

We present the algorithms and results of the reconstruction of the luminous region (also known as the "beam spot") and measurement of the luminosity in the ATLAS experiment during the first LHC run at center-of-mass energies of $\sqrt{s} = 900$ GeV and $\sqrt{s} = 7$ TeV.

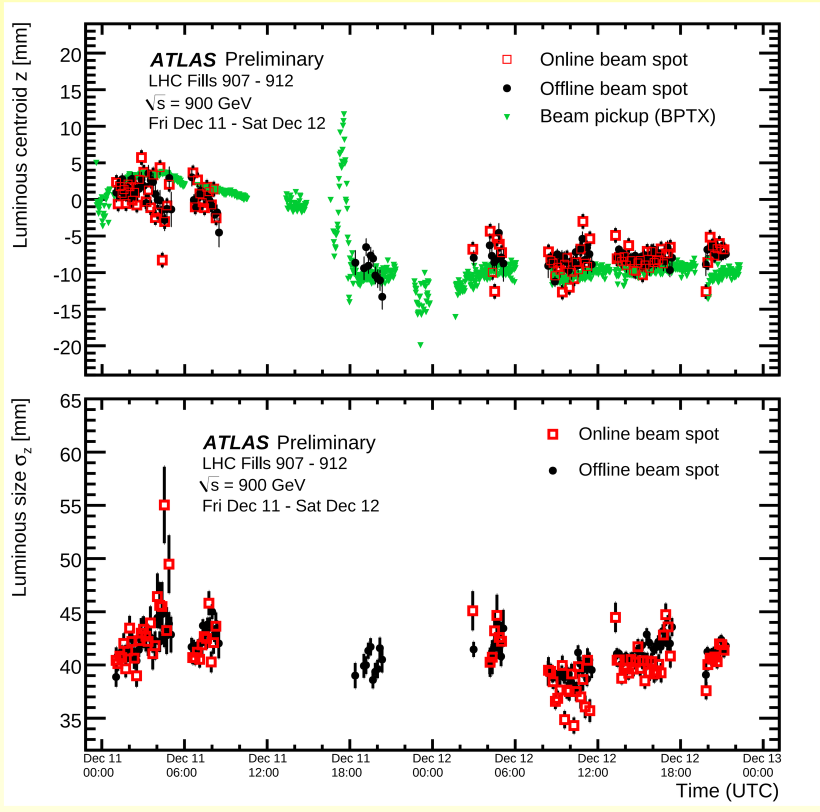
The spatial distribution of pp interactions is reconstructed both online (in the High-Level Trigger system) and offline (utilizing the full detector precision) using Inner Detector tracks for event-by-event primary vertices [1].

The LHC luminosity is determined in real time, approximately once per second, using a number of detectors and algorithms. These results are displayed in the ATLAS control room and archived every two minutes [2].

Van der Meer or "beam separation" scans provide an **absolute** calibration of the luminosity measured by ATLAS, that improves the uncertainty by a factor ×2 over Monte Carlo values.

Beam spot evolution with time

Real-time measurements from the trigger and high-precision offline measurements track the LHC beams over time (every ≈ 2 min):



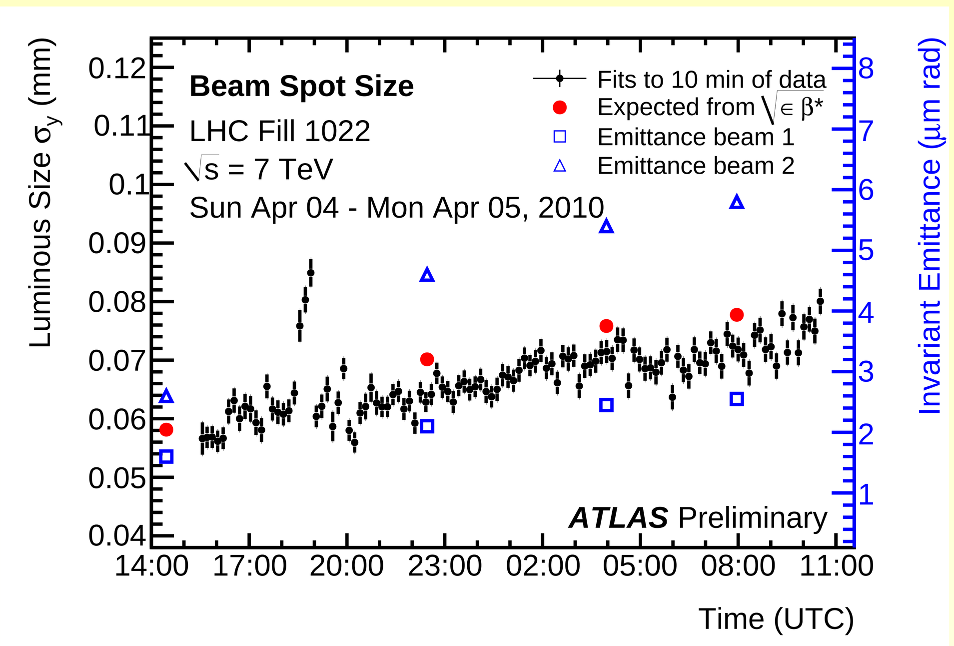
Z position (top) and length (bottom) at $\sqrt{s} = 900$ GeV measured online (red squares), offline (black circles), and using the LHC beam sensors (BPTX, green triangles, top)

Beam size measurements

The offline maximum-likelihood fit extracts vertex-resolution corrected luminous sizes ($\sigma_{x\mathcal{L}}, \sigma_{y\mathcal{L}}$), related to the individual beam sizes as:

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

and compare to the expected sizes from β^* and beam emmitance measurements from LHC.



Black: resolution corrected beam spot size. Red: predicted size from emittances, and IP β-functions measured by accelerator techniques at $\sqrt{s} = 7$ TeV data.

References

[1] ATLAS, ATLAS-CONF-2010-027

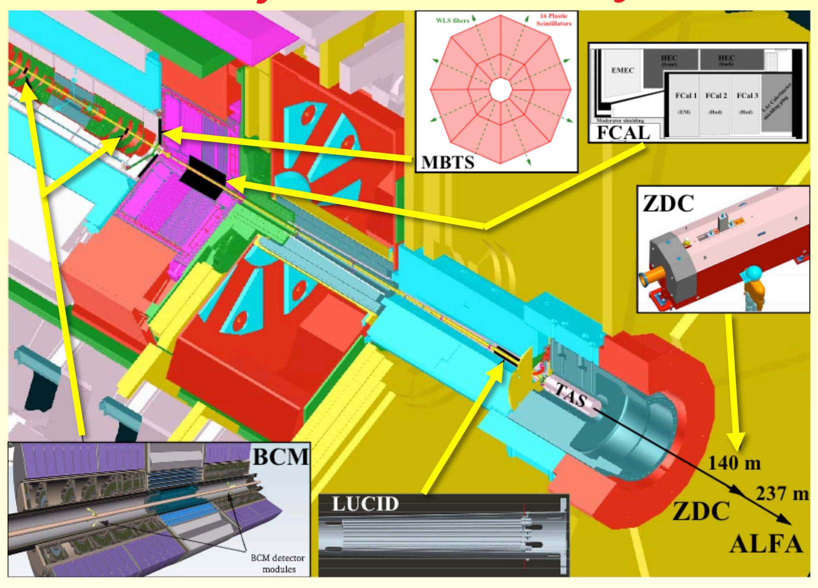
[2] ATLAS, ATLAS-CONF-2010-061

The ATLAS Detector and the LHC

The **large dynamic range** in luminosity ($10^{26} - 10^{32}$cm^{-2}s^{-1}) and beam conditions expected by the end of 2011 requires a **diverse, robust approach** to monitoring the collision point and measuring the luminosity **for the very first LHC data**.

Luminosity: ATLAS uses **multiple detectors**, with different acceptances, systematics and sensitivity to background

- **Tracker:** tracks & vertices, $|\eta| < 2.5$
- **MBTS:** scintillators, $2.09 < |\eta| < 3.84$
- **LAr:** liquid-Ar calo., $2.5 < |\eta| < 4.5$
- **LUCID:** Cerenkov+PMT, $|\eta| \approx 5.8$
- **ZDC:** W, steel+quartz+PMT, $|\eta| > 8.3$



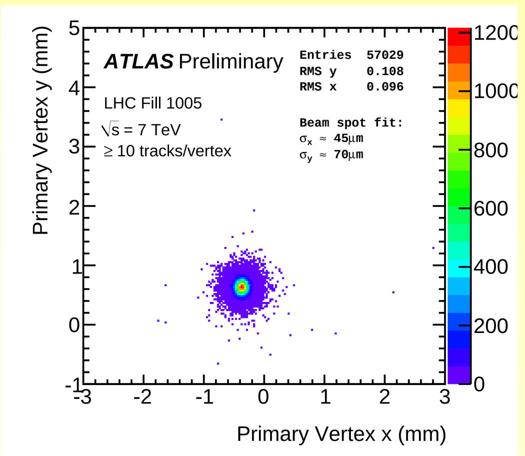
Luminous Region: Use **online** and **offline** methods.

- **L2 Trigger:** fast, limited by trigger bandwidth.
- **Offline:** precise, uses only logged events.

Interaction region characterization: measuring the "beam spot"

Methodology: event-by-event vertex finding

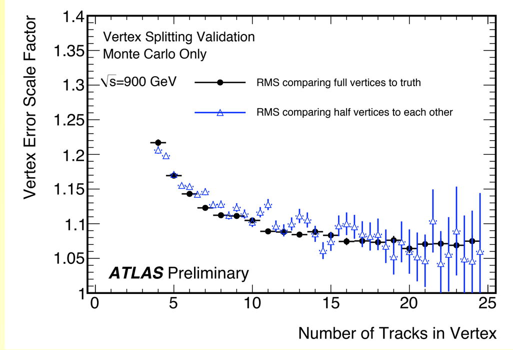
- Vertices with at least 4 tracks ($p_T^{\text{track}} > 150$ MeV) are used in an unbinned maximum likelihood fit of luminous region.
- Position, size and tilt of luminous region extracted

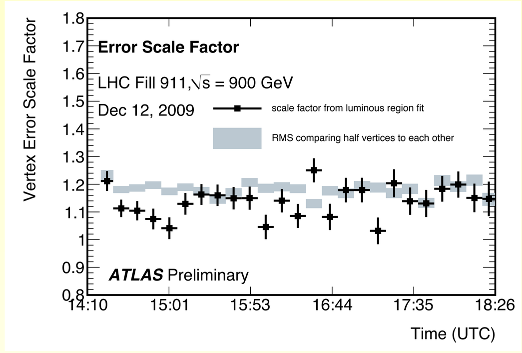


Offline primary-vertex distributions in the x-y plane, uncorrected for resolution, at $\sqrt{s} = 7$ TeV

Intrinsic resolution subtraction: vertex splitting

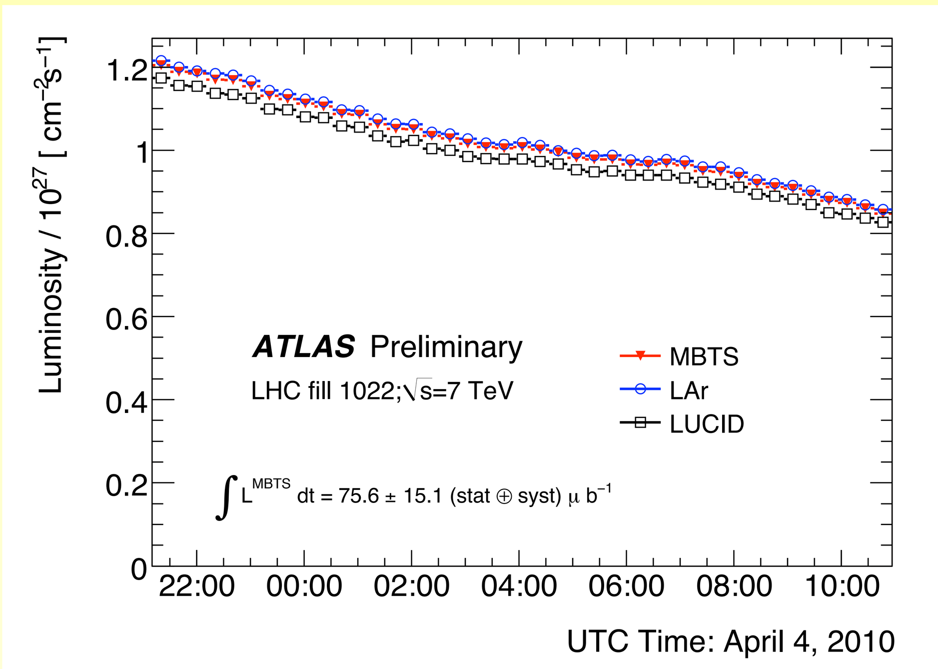
- **Data-driven** resolution determination.
- Split tracks into groups, fit each.
- Compare to truth resolution (in MC).
- Good agreement and stable with time in data.





Luminosity determination at $\sqrt{s} = 900$ GeV and $\sqrt{s} = 7$ TeV

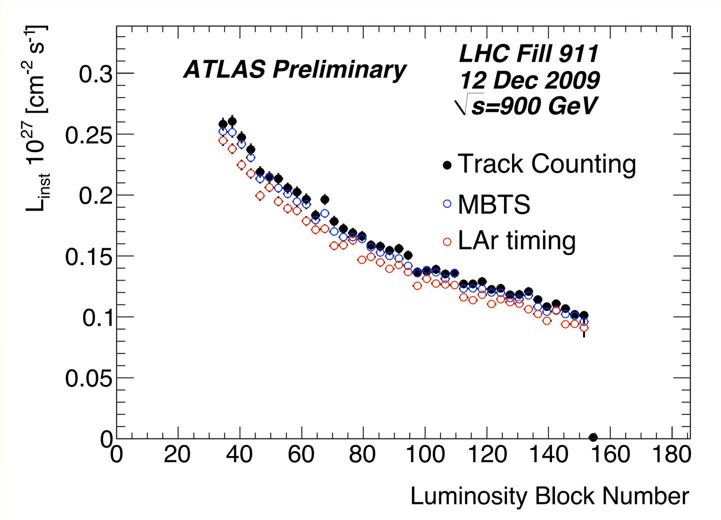
Monte Carlo-based luminosity calibration



Comparison of absolute luminosity from different detectors based on Monte Carlo calibrations. **±20% overall scale uncertainty**, yet excellent relative agreement at both $\sqrt{s} = 900$ GeV (right) and $\sqrt{s} = 7$ TeV (above).

$$\mathcal{L} = \frac{\mu n_b f_r}{\sigma_{inel}} = \frac{\mu^{meas} n_b f_r}{\varepsilon \sigma_{inel}} = \frac{\mu^{meas} n_b f_r}{\sigma_{vis}}$$

μ is the # of pp collisions per bunch crossing, n_b the # of colliding bunch pairs, f_r the LHC revolution freq., σ_{inel} the inelastic pp cross section, ε the detector eff., $\mu^{meas} = \varepsilon\mu$ the # of events. The "visible" cross section σ_{vis} is the luminosity calibration constant, measured via van der Meer scans.



Van der Meer (beam-separation) Scans: Absolute $\mathcal{L}$ calibration

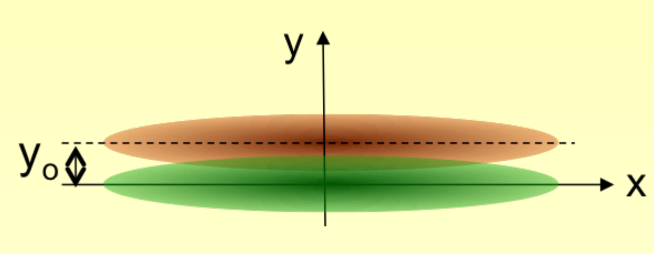
The **ultimate luminosity calibration** is obtained by moving one beam across the other and using **machine parameters only** to measure the luminosity ($\mathcal{L}$) via the **bunch currents** (I_1, I_2) the **overlap integral**, and the **counting rate at the peak from any of the luminosity detectors**.

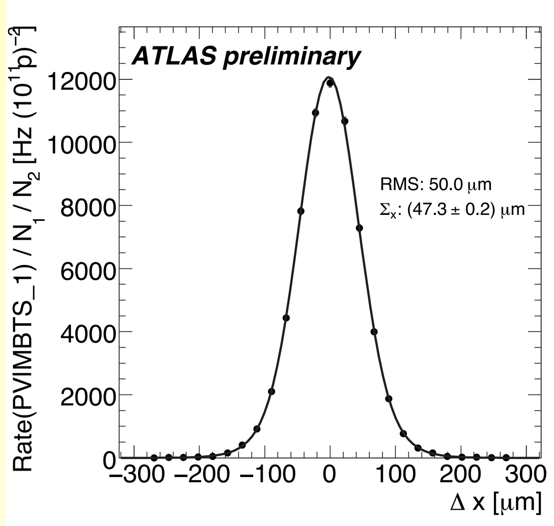
Luminosity via machine parameters:

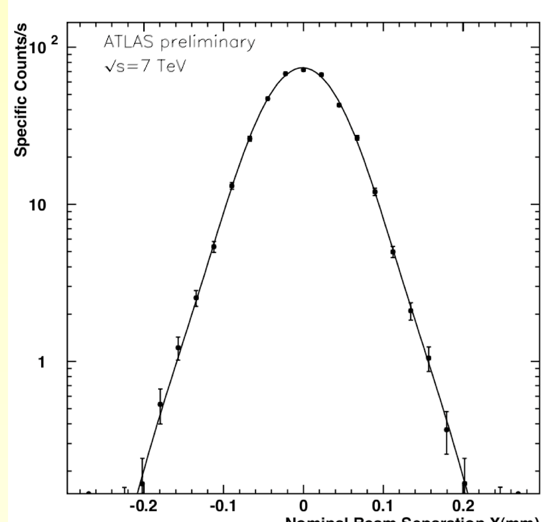
$$\begin{aligned}\mathcal{L} &= n_b f_r I_1 I_2 \int \rho_1(x,y)\rho_2(x,y)dxdy \\ &= \frac{n_b f_r I_1 I_2}{2\pi\Sigma_x\Sigma_y} \left(\text{with } \Sigma_j^2 = \sigma_{j1}^2 + \sigma_{j2}^2\right)\end{aligned}$$

Procedure:

- Center the beams at the IP
- Move one beam by $\pm 6\sigma_{ib}$ in 27 steps in X
- Repeat the procedure in Y







Source	Unc. on $\mathcal{L}$ (%)
Beam Intensities	10
Length Scale Calibration	2
Imperfect Beam Centering	2
Non-Reproducibility	3
μ Dependence	2
Total	11

The scans (measured via primary vertex counting (left) and LUCID (right)) provide a direct measure of the absolute luminosity of the LHC, and a factor ×2 precision over Monte Carlo calibrations.