Luminosity Measurements at LHCb for Run II

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Abstract

A precise measurement of the luminosity is a necessary component of many physics analyses, especially cross-section measurements. At LHCb two different direct measurement methods are used to determine the luminosity: the "van der Meer scan" (VDM) and the "Beam Gas Imaging" (BGI) methods. A combined result from these two methods gave a precision of less than 2% for Run I and efforts are ongoing to provide a similar result for Run II. Fixed target luminosity is determined with an indirect method based on the single electron scattering cross-section.

Luminosity

The observed rate of a physical process at a collider can be written as the product of the **luminosity** of the collider and the **cross-section** of the process:

$$R = \mathcal{L}\sigma$$

Thus, for a process with a precisely known cross-section, the luminosity can be measured **indirectly** by counting the number of observed events.

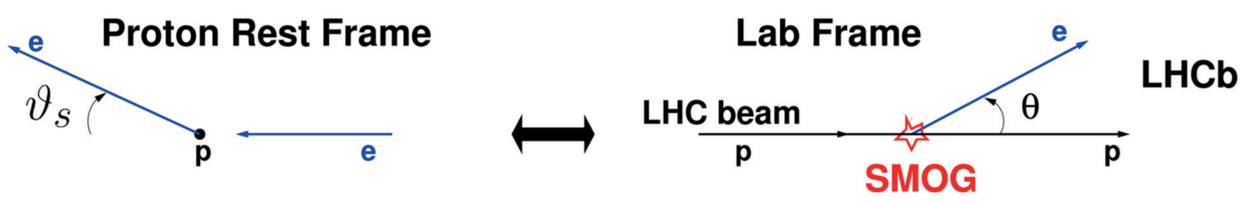
Alternatively, the luminosity can be measured **directly** from the machine parameters. The luminosity in a single bunch crossing is proportional to the **intensities** ($N_{1,2}$) of the two colliding bunches and their geometrical **overlap** (O):

$$\mathcal{L} = k\frac{N_1 N_2}{\mathcal{O}}$$

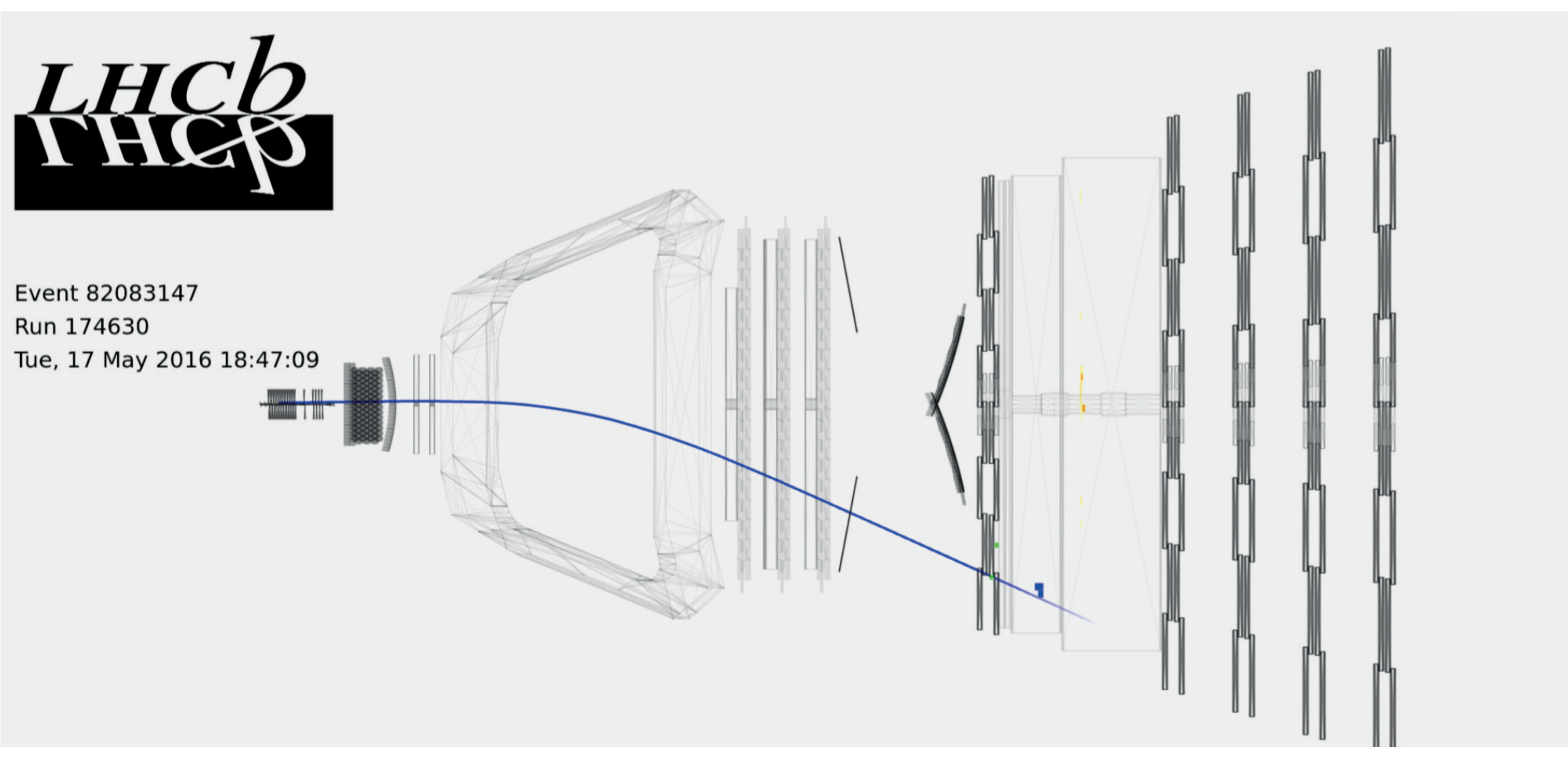
Fixed Target Luminosity

During Run II LHCb has developed a rich programme of fixed target physics, looking at collisions between the LHC beam and a variety of noble gases. This gas target is injected by the **S**ystem for **M**easuring the **O**verlap with **G**as (**SMOG**), which links a high pressure gas volume to the LHCb vacuum.

The luminosity of these datasets cannot be determined directly as it is not possible to make a precise measurement of the pressure of the gas target.



Instead an indirect measurement is made by precisely measuring a process with a well known cross-section. **Single electron scattering** is a process with a clean signature in the detector and its cross-section can be calculated from first principles to within an uncertainty of 1%. A candidate event is shown below:



These events are identified by a single low momentum and low p_T electron track, with no other activity in the detector. A **large background** comes from soft inelastic nuclear interactions. These can be subtracted due to their **charge symmetry** by reconstructing **both single electron and single positron** events and taking the difference in the e^- and e^+ yields as the signal yield.

The reconstruction **efficiency** for these events is strongly affected by both bremstrssrahlung losses and material interactions and is determined from simulation. Other relevant corrections, due to **pile-up** and the beam's interactions with residual gas, are determined from data.

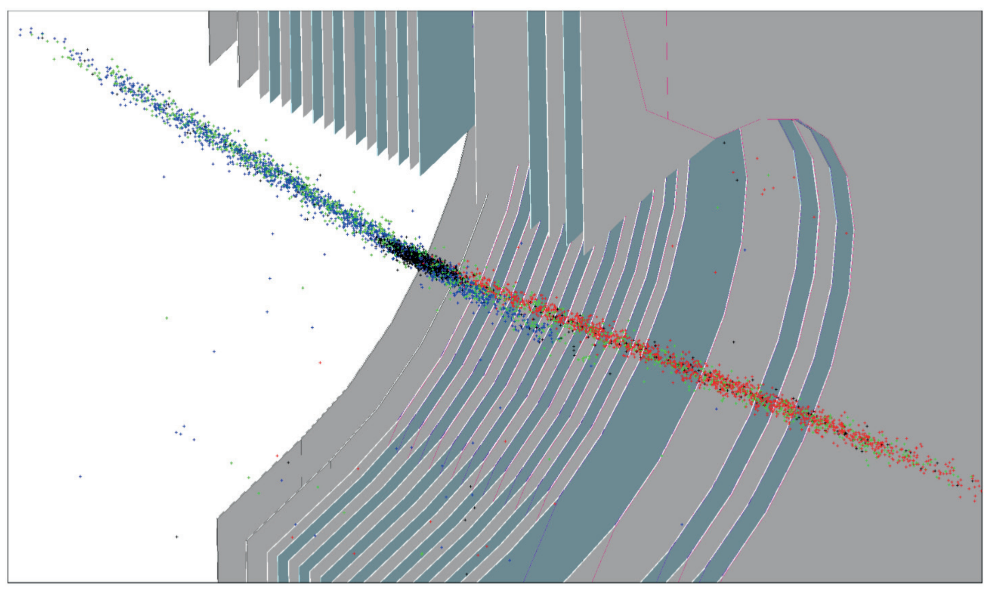
This technique was used for the first time during Run II to determine the luminosity of a **pHe** sample at an energy of $\sqrt{s}$ = 110 GeV and with a luminosity of:

L = 0.433 $\pm$ 0.011 (stat) $\pm$ 0.027 (syst) nb^{-1}

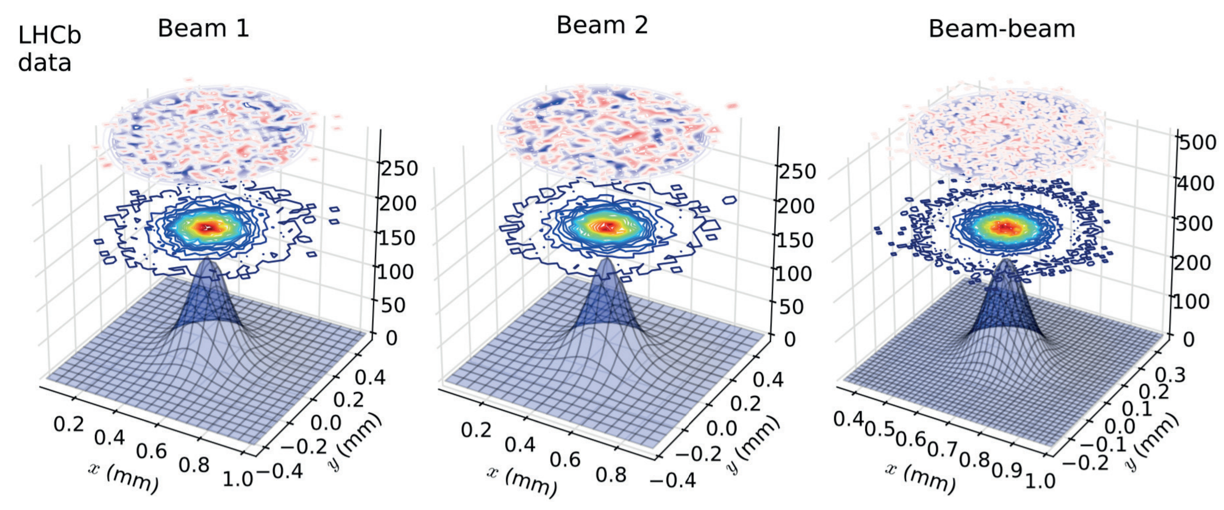
This luminosity was used for the first direct measurement of antimatter production in pHe collisions, putting new constraints on the physics of **cosmic rays**.

Beam Gas Imaging

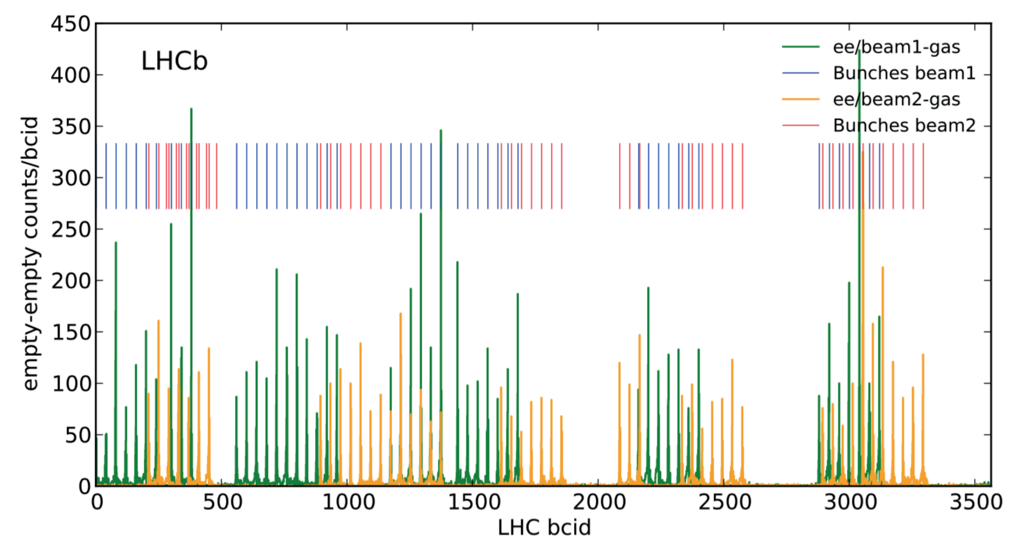
The BGI method takes advantage of the excellent resolution of LHCb's **VELO** subdetector to reconstruct **beam-gas** interactions and thus measure the **beam sizes** and **distributions** independently for each beam. These beam parameters can then be used in a global fit to calculate the **overlap** between the two beams.



Beam-gas vertices are selected based on their longitudinal and transverse **position**, their **multiplicity** and according to the forwardness of their tracks, with vertices containing only **forward tracks** assigned to beam 1 and those with only **backward tracks** to beam 2. The vertex distributions are then unfolded with the VELO **resolution function**: a function of both the multiplicity and the longitudinal position. These unfolded distributions are then fitted with a 2D double-Gaussian fit model:



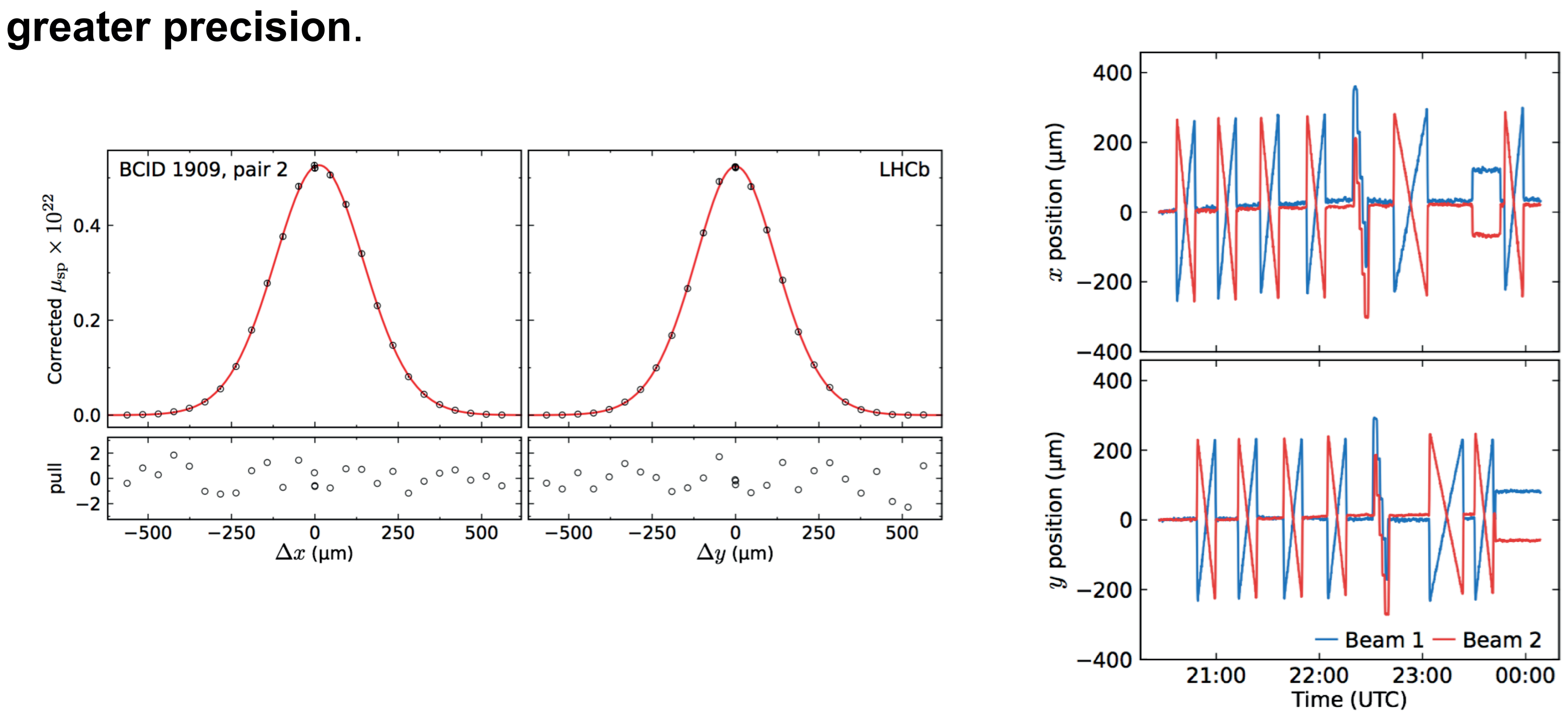
The other ingredient necessary for a luminosity measurement is the **intensity**. The total beam intensity and the bunch charges are provided by LHC instrumentation. It is then necessary to correct for the **Ghost Charge**, that is the charge in unfilled bunch slots. This can be achieved using the BGI method by comparing the beam-gas rates in beam-empty and empty-empty crossings.



A first BGI result for Run II p-p data at $\sqrt{s}$ = 13 TeV based on data taken in early 2015 gives an uncertainty of 3.9%.

Van der Meer Scans

Van der Meer scans determine the beam overlap by measuring the change in interaction rate as the two beams are swept across each other. This method is used across **all LHC experiments**. It is complementary to the BGI method as the two measurements are largely **independent** and thus can be **combined** to achieve **greater precision**.



References

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