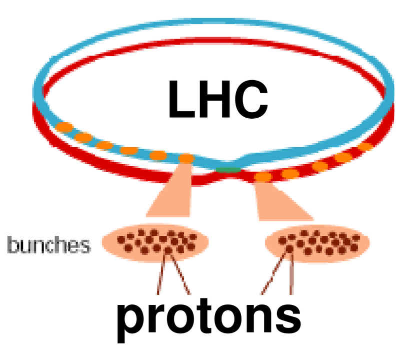
Indirect luminosity at LHCb using $Z \to \mu\mu$, $W \to \mu\nu$ and $pp \to p + \mu^+\mu^- + p$ events

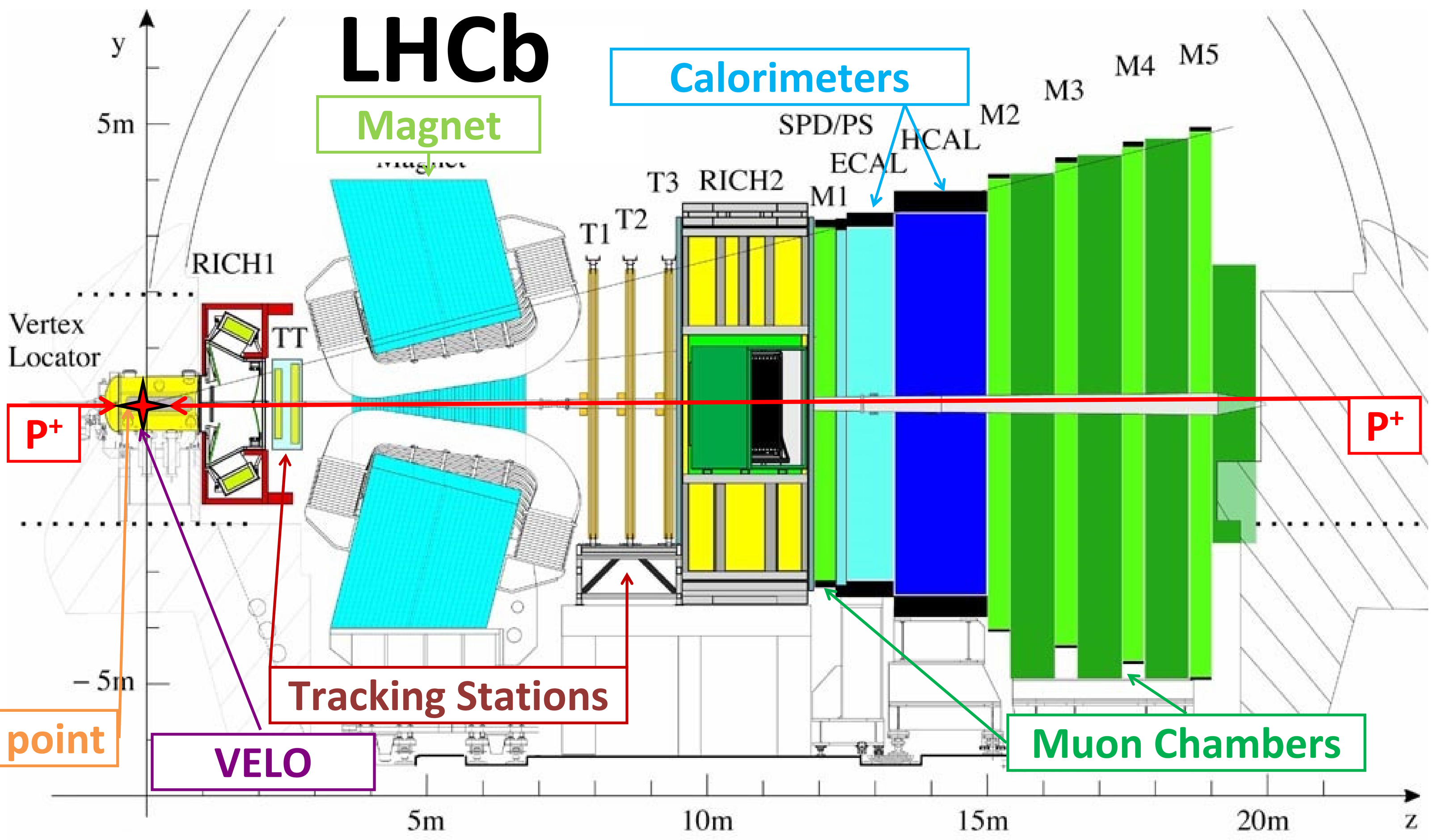
Francesco de Lorenzi, Ronan McNulty, Dermot Moran, UCD Dublin
Tara Shears, University of Liverpool

Abstract: We report on studies of indirect luminosity measurements, using events containing muon final states, in LHCb. The first method exploits elastic two photon dimuon production in LHCb. The process has a theoretical uncertainty of less than 1%, making it an ideal choice for use in performing an indirect luminosity measurement in hadron colliders. Strategies for triggering, selection and background rejection are discussed. Our studies indicate that a measurement precision of 1% can be obtained with 1 fb^{-1} of data. The second method uses the muon decays of the electroweak bosons where a similar precision can be obtained. Together, it should be possible to measure the luminosity to better than 1% precision.

Luminosity measurement

Knowledge of the luminosity is essential in order to make any absolute cross-section measurements and to accurately predict backgrounds to new physics, since the number of events, N, seen for a particular process is related to the cross-section, σ, and the beam luminosity L by : **N = L / σ**



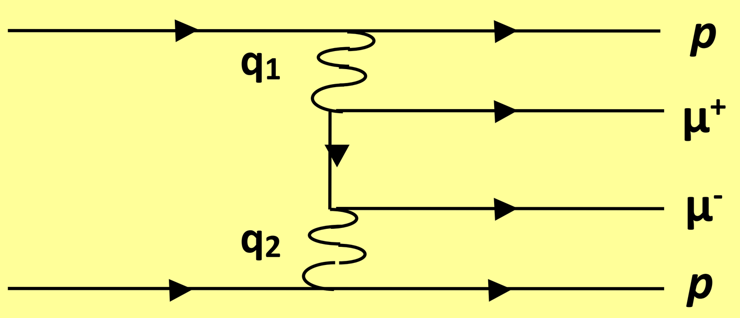


Direct and Indirect measurements

Traditional luminosity measurements involve the direct measurement of the beam current and shape. However this technique has associated uncertainties of ~ 10%. Indirect measurements of the luminosity can be obtained from **L = N / σ** if one can find a process which is both theoretically well known and produces a sufficient number of events that can be detected with a well-determined efficiency and purity.

Exclusive production of dimuons

The QED process p+p -> p+μ+μ+p is theoretically known to better than 1%, and has an effective cross-section of ~ 70pb inside LHCb.



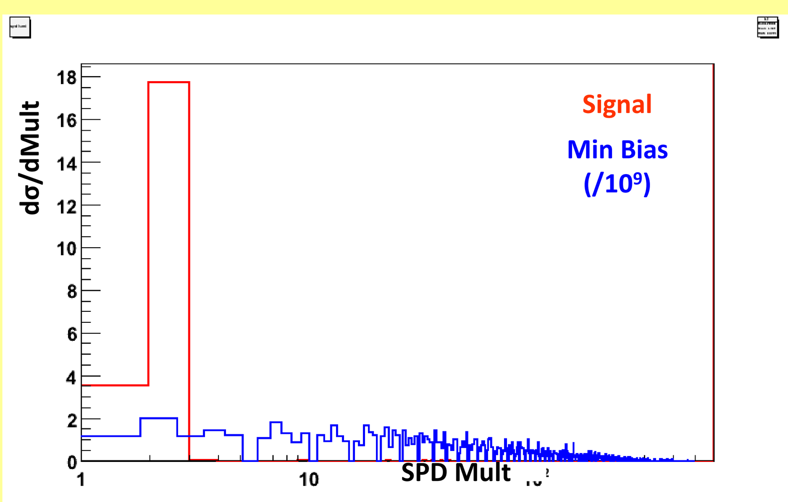
Characteristic experimental signature:
2 back-to-back muons + nothing else

Trigger: LHCb has a fast hardware trigger (L0) with an output rate of 1MHz and a software trigger (HLT), running on a computing cluster, with an output rate of 2kHz. To select our signal, the trigger must record two types of event:

1) Single events: contains a single collision of type $pp \to p + \mu^+\mu^- + p$
2) Pileup events: >1 collision. One $pp \to p + \mu^+\mu^- + p$ and the other of any type

L0: The trigger requires at least one muon with transverse momenta>1GeV, in coincidence with a low number of hits (multiplicity) in the SPD (Silicon Pad Detector).

HLT: Starting from L0 muon and dimuon triggered events, the invariant mass of dimuon candidates is required to be greater than 1 GeV.

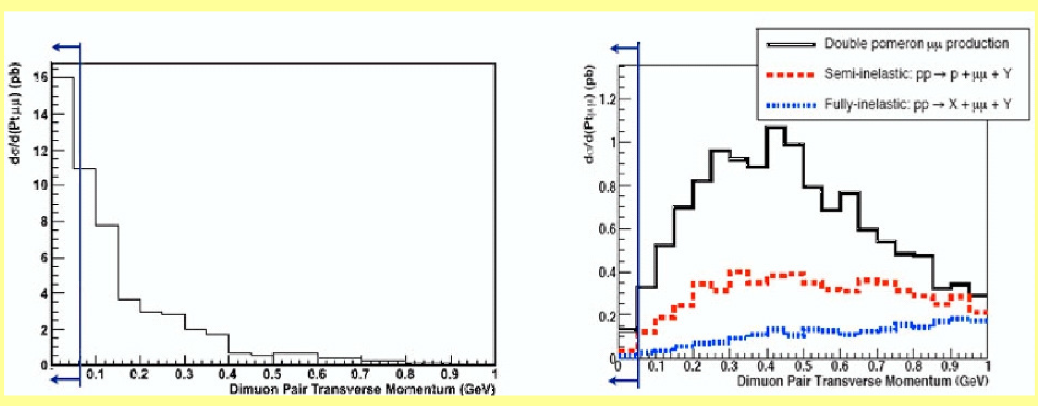


SPD multiplicity for signal and minimum bias events.

Trigger Level	Single efficiency	Pileup efficiency	MB* efficiency
L0	0.85	0.73	0.056
HLT	0.9	0.88	0.001
Total	0.77	0.64	0.000056

*minimum bias

Offline Selection: The dominant background comes from double pomeron exchange. After cutting at 50 MeV on the dimuon transverse momentum, 17% of signal events remain with a purity of 96%.

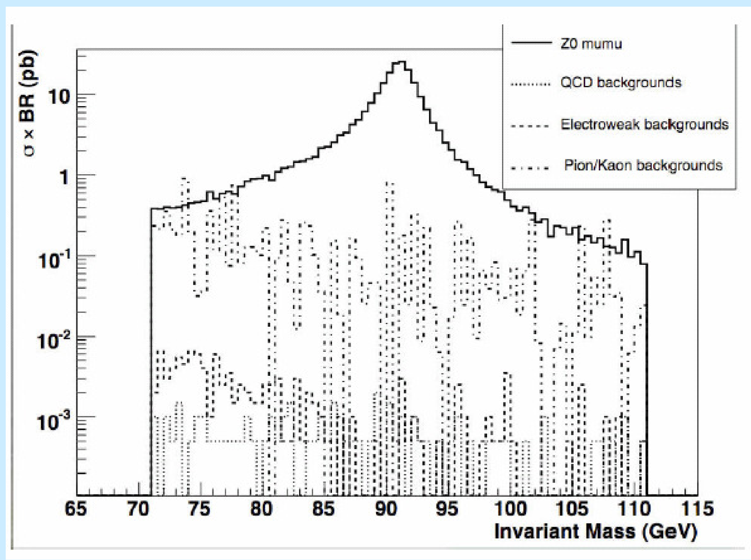


3% precision after 0.1fb^{-1}; 1% after 1fb^{-1} of data

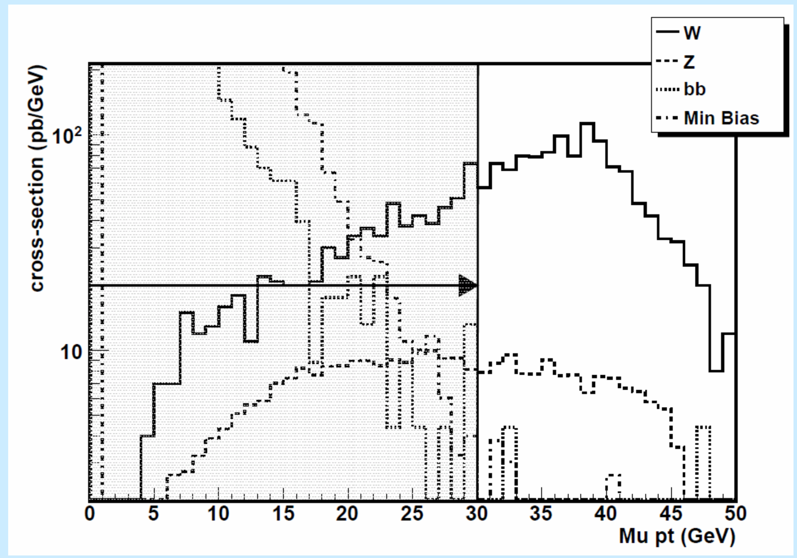
Vector boson production of muons

Electroweak boson production is theoretically known to 2-3%, with most of the uncertainty due to knowledge of the parton distribution functions (PDFs), which have been calculated by several groups using global fits to experimental data.

Experimentally: LHCb has a high efficiency (>90%) for triggering on and reconstructing muons coming from W and Z bosons.
Z bosons can be selected with purities >99% by asking the dimuon invariant mass agrees with the Z mass, and both muons are consistent with the primary vertex.
W bosons can be selected with purities >90% by asking for a single high transverse momentum muon and transverse momentum imbalance in the event.



Invariant mass of the dimuons in Z candidate events



Muon transverse momentum after a cut requiring transverse momentum imbalance.

In 100pb-1 of data, about 20,000 Z, 40,000 W- and 75000 W+ will be selected.

Improving the luminosity estimate

Counting the number of W and Z would determine the luminosity to 2-3%, limited by the PDF uncertainties. These PDFs are quoted either in terms of orthonormal eigenvectors with eigenvalues λ_i^0 and uncertainties δ_i (MSTW, CTEQ, Alekhin) or by multiple equally likely replicas that essentially map out the probability space (NNPDF). However, by fitting the differential cross-section while constraining the PDFs to lie within current bounds, we can obtain a better luminosity estimate.

For MSTW, CTEQ, Alekhin we minimise the quantity:

$$\chi^2(L,\lambda_i) = \sum_{j=1}^{N_{bins}} \frac{(N_j - L\frac{\Delta\sigma}{\Delta y_j})^2}{L\frac{\Delta\sigma}{\Delta y_j}} + \sum_{j=1}^{N_\lambda} \left(\frac{\lambda_j - \lambda_j^0}{\delta_j}\right)^2$$

while for NNPDF we only consider those replicas with a chi-squared probability >1% for the quantity:

$$\chi^2(L) = \sum_{j=1}^{N_{bins}} \frac{(N_j - L\frac{\Delta\sigma}{\Delta y_j})^2}{L\frac{\Delta\sigma}{\Delta y_j}}$$

	MSTW08	CTEQ66	Alekhin02	NNPDF1.0
W+	1.3	2.0	1.5	2.1
W-	1.2	1.9	1.6	2.1
Z	1.4	1.9	1.9	1.8
W+W-Z	0.8	1.7	1.0	1.3

Expected precision on the luminosity with 10fb^{-1} of data

1.7% precision after 0.1fb^{-1}; 1.3% after 1fb^{-1} of data