Luminosity: experimental prospects and challenges, LHCb

LHC Lumi Days 2012, CERN

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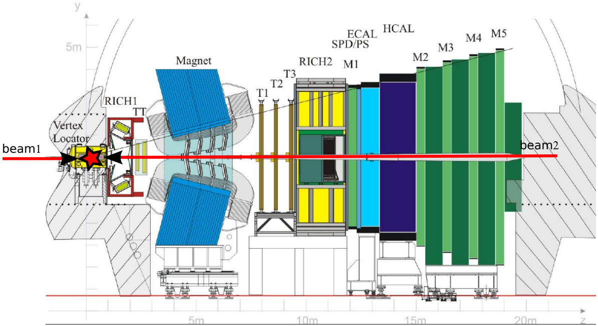
On behalf of the LHCb collaboration

Outline

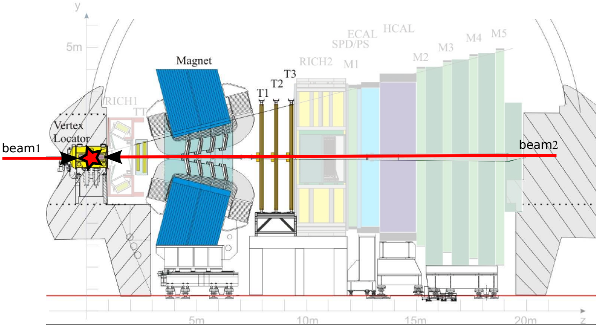
- Overview of the LHCb detector.
- Luminosity measurements @ LHCb.
- W,Z production measurements, luminosity and PDF uncertainties.
- Potential for luminosity measurement with W,Z and exclusive di-μ from photon fusion.
- Impact of luminosity measurements on hadron cross section measurements.

2008 JINST 3 S08005



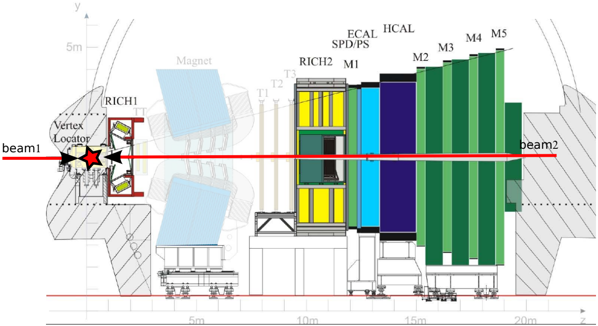
- Designed for CP violation studies in B decay and rare decays.
- Single arm spectrometer, $\sim$ 30% of $b\bar{b}$ pairs produced in the acceptance.
- So far $\sim 0.3nb^{-1}$ recorded at $\sqrt{s} = 900GeV$ and $\sim 1.1fb^{-1}$ at $\sqrt{s} = 7TeV$.
- For muons $2 < \eta < 2.5$ overlap with Atlas/CMS, $2.5 < \eta < 5$ unique to LHCb.

2008 JINST 3 S08005



- Tracking efficiency $\sim 95\%$
- $\delta p/p \sim 0.5\%$
- partial backward coverage in the VELO $-4. < \eta < -1.5$

2008 JINST 3 S08005



- Muon ID for μ from W $> 98\%$.

Muon trigger for EW measurements:

- Di-muon trigger $m_{\mu\mu} > 2.7\ GeV/c^2$ or $m_{\mu\mu} > 1.\ GeV/c^2$ and $p_{T\ \mu\mu} < 900\ MeV/c$.
- single high p_T muon trigger: $p_{T\ \mu} > 10\ GeV/c$.

Direct measurements J. Instrum. 7 (2012) P01010

- Two methods are used to measure the parameters of the beams

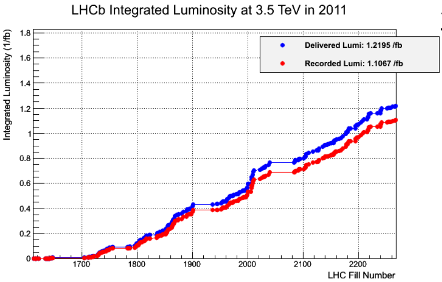
see Massi and Vladislav talk.

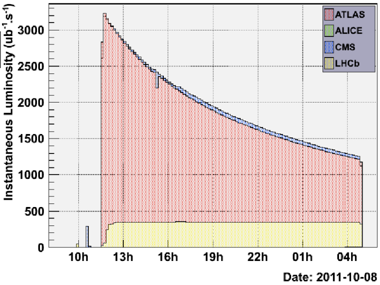
- Van der Meer scan method.
- Beam gas imaging method.
- Average on large datasets: 3.5 % uncertainty on the luminosity measurement.
- Both methods are limited by the bunch current knowledge.

Indirect measurements

- Measure the rate of a **theoretically well known process**, with **small experimental uncertainties**
- At LHCb the two candidates are:
    - W and Z production
    - Exclusive di-μ produced by photon fusion.

Luminosity @ LHCb





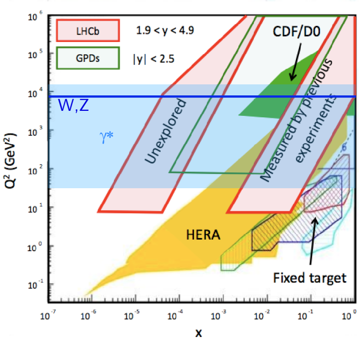
- Low average number of visible interaction per bunch crossing: $<\mu>= 1.4$ most of the year.
- During 2011 data taking, luminosity leveling was used

$\rightarrow$ Constant instantaneous luminosity.

$$\sigma_{pp\to Z} = \int dx_a dx_b f_{a/p_1}(x_a, Q^2) f_{b/p_2}(x_b, Q^2) \hat{\sigma}_{ab\to Z}$$

- Partonic cross-section: Accuracy of ~ 1 % for W and Z @ NNLO.
- PDF: parametrized using data from previous experiments.

- Small x from one proton, large x from the other.
- Drell-Yan production probe x as low as 10^{-5} (soon)



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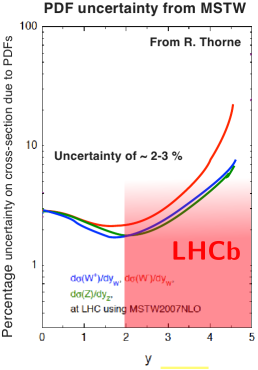
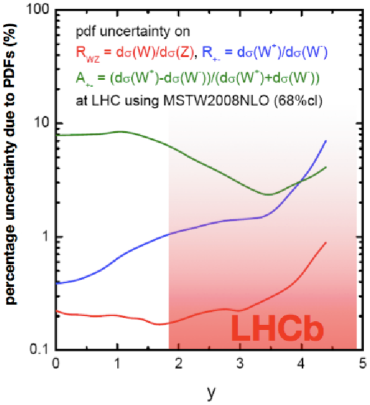
- Partonic cross-section: Accuracy of ~ 1 % for W and Z @ NNLO.
- PDF: parametrized using data from previous experiments.

- Good knowledge of the luminosity
  → better constraint of the PDFs.
- Good knowledge of the PDFs
  → indirect measurement of the luminosity



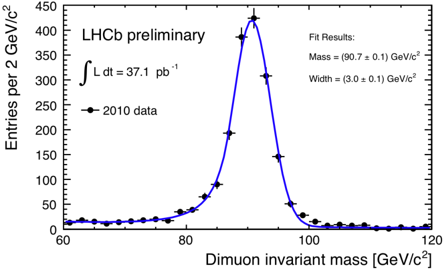
- Luminosity uncertainties cancel through ratios:
  - $R_{WZ} = \frac{d\sigma(W)}{d\sigma(Z)}$
  - $R_{+-} = \frac{d\sigma(W^+)}{d\sigma(W^-)}$
  - $A_{+-} = \frac{d\sigma(W^+)-d\sigma(W^-)}{d\sigma(W^+)+d\sigma(W^-)}$
- Production ratios R_{+-} and A_{+-} are strong handle to constrain PDFs.



2010 Dataset: 37.1 pb^{-1}

- TRIGGER: Single muon with $p_T > 10\ GeV/c$.
- RECONSTRUCTION: Two muons with $p_T > 20\ GeV/c$, $2. < \eta_\mu < 4.5$ and $60\ GeV/c^2 < m_{\mu\mu} < 120\ GeV/c^2$
- BACKGROUNDS: $Z \to \tau\tau$ (from MC), heavy flavour (from data).

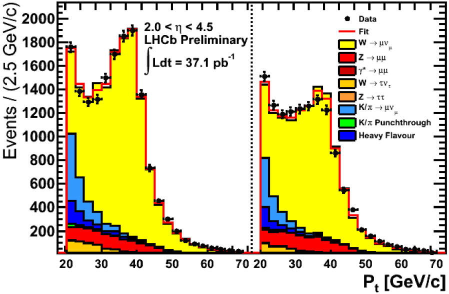
- Signal candidate: 1966 ± 44
- Background : 4.9 ± 2.0



$W \to \mu\nu$ selection

2010 Dataset: 37.1 pb^{-1}

- TRIGGER: Single muon with $p_T > 10\ GeV/c$.
- RECONSTRUCTION: One muons with $p_T > 20\ GeV/c$, $2. < \eta_\mu < 4.5$ and isolation criteria ($P_{T\ (ch.+neut.)\ in\ cone\ of\ R=0.5\ around\ \mu} < 2\ GeV/c$, with $R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$)
  No extra muon with $p_{T\ \mu} > 5\ GeV/c$, $IP_\mu < 40\mu m$, $E/p < 4\%$.
- BACKGROUNDS:
  - $Z \to \mu\mu, Z \to \tau\tau, W \to \tau\nu$ (from MC).
  - K/π punch-trough and decay in flight (from data).
  - Heavy flavour (from data).

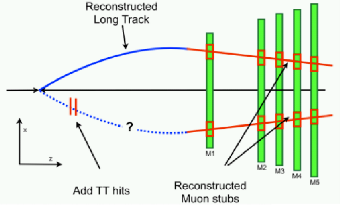


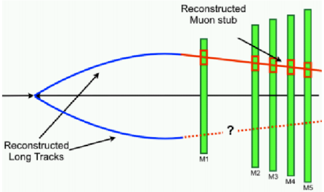
- Signal candidate:
  W^+ 15608 ± 125, W^- 12301 ± 111
- Purity : $W^+ \sim 80\ \%$, $W^- \sim 78\ \%$

$$\sigma = \frac{N_{candidates} - N_{background}}{A \times \epsilon_{Trigger} \times \epsilon_{Tracking} \times \epsilon_{ID} \times \epsilon_{Selection} \times \int L}$$

From $Z \to \mu\mu$ data with tag and probe method:

- A: 1. by definition of the kinematic range.
- $\epsilon_{Trigger}$:
  - Tag: triggered muon
  - Probe: offline reconstructed muon.
- $\epsilon_{Tracking}$
  - Tag: identified muon.
  - Probe: muon stubs.
- ϵ_{ID}
  - Tag: identified muon.
  - Probe: long track.
- $\epsilon_{Selection}$
  - For $W \to \mu\nu$:Use $Z \to \mu\mu$ with one muon removed to simulate a ν.
  - For $Z \to \mu\mu$: 1. by definition



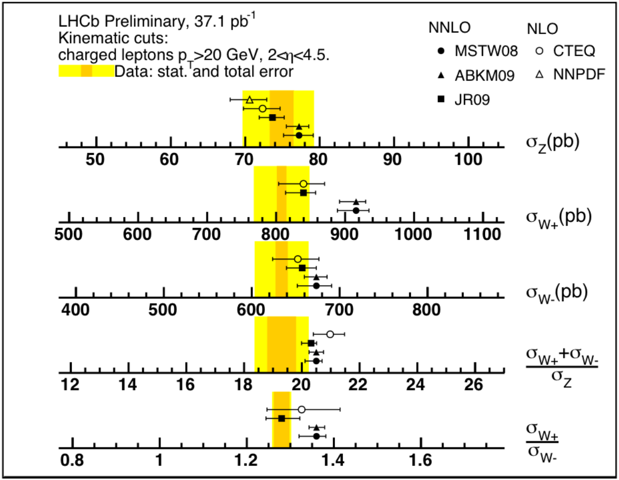


The systematics associated to these efficiencies are statistical in nature.

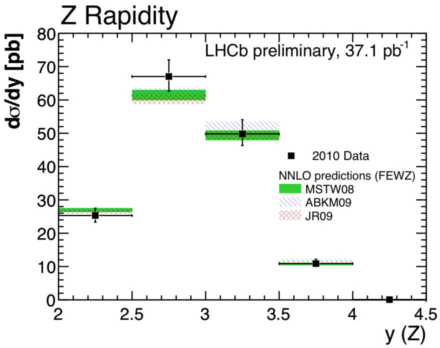
	$Z \to \mu\mu$	$W^+ \to \mu^+\nu$	$W^- \to \mu^-\nu$
Statistical	2.1	0.9	1.1
Shape	n.a.	1.9	1.7
Background contamination	0.4	1.6	1.6
Efficiencies	5.1	2.5	2.3
FSR	0.3	0.2	0.2
Luminosity	3.5	3.5	3.5

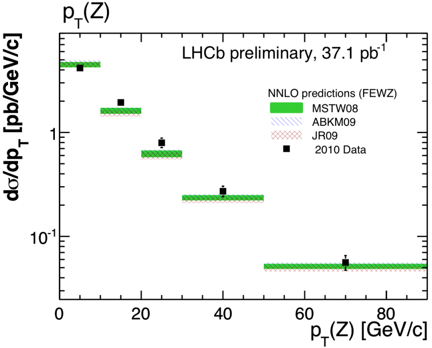
Efficiencies uncertainty are already at the level of the luminosity uncertainty with 2010 data sample.

LHCb-CONF-2011-012/LHCb-CONF-2011-039

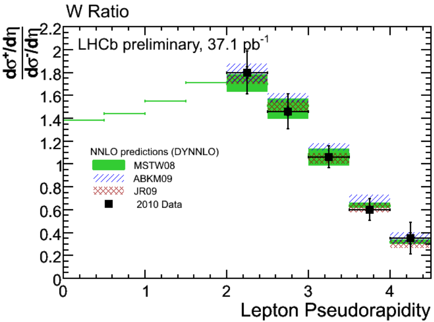


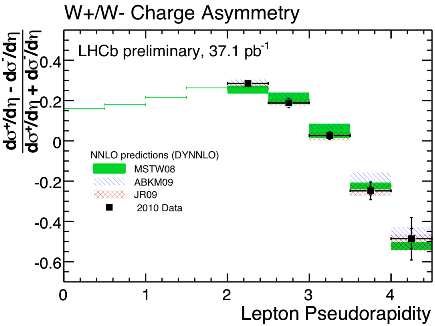
LHCb-CONF-2011-012/LHCb-CONF-2011-039





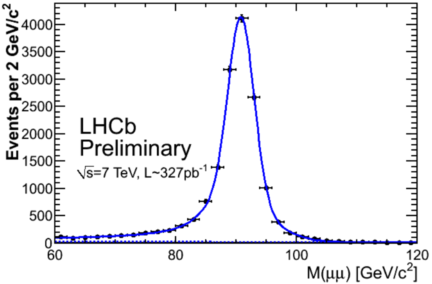
LHCb-CONF-2011-012/LHCb-CONF-2011-039





- Luminosity uncertainties cancel through the ratio.
- Most sensitive measurements.

- Luminosity levelling gives stable running condition.
- **Trigger thresholds are unchanged** with respect to the 2010 dataset.
- **Analysis is stable**.
- 30$\times$ **more candidates**
  $\rightarrow$ naive expectation: uncertainties related to statistics reduced by $\sim$ 80%.

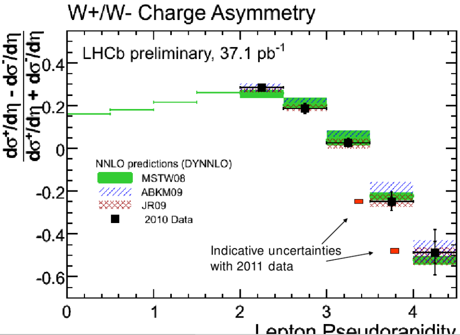


See Ronan Mcnulty talk @ EW precision measurements at the LHC WG, Nov 2011.

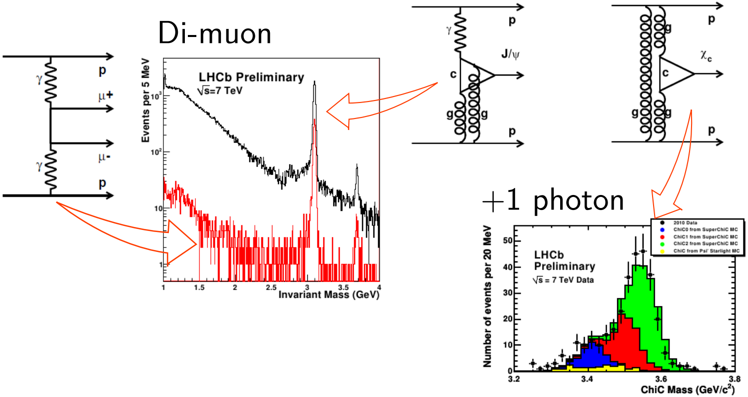
Caveat: this is assuming the systematics scales with the statistics.
But they might reach some non statistical limits.

Uncertainty	$Z \to \mu\mu$ 2010	$Z \to \mu\mu$ 2011	$W \to \mu\nu$ 2010	$W \to \mu\nu$ 2011
Statistical	2.2% (2k Z)	0.4% (60k Z)	0.7% (20k W)	0.1% (600k W)
Purity	0.1%	0.0%	3.1%	1.% (?)
Efficiencies	4.0%	0.7%	2.8%	0.5%
Luminosity	3.5%	3.5 %?	3.5%	3.5 %?

- For R_{+-}:
  in 2010: 1.5 % stat. 0.2 % syst.
  in 2011 0.3 % stat. 0.2 % syst.
- For A_{+-}, depending on η_μ:
  in 2010: from 1.4 % to 5.8 %
  in 2011 from 0.3 % to 1.0 %



Select event with exactly two muons forward and no backward tracks.

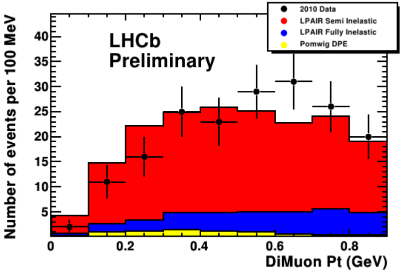


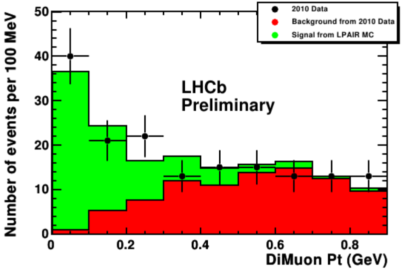
- Large theoretical uncertainty on resonant exclusive di-μ ($O(15\ \%)$)
- For $\gamma\gamma \rightarrow \mu\mu$, QED process uncertainty $< 1\ \%$.

Non-resonant exclusive Dimuons

Signal selection

- $\gamma\gamma \rightarrow \mu\mu$ is candidate for indirect measurement of the luminosity.
- Purity of the signal is the main issue.
- Background:
  - Di-μ from double pomeron exchange.
  - Di-μ from inelastic di-photon fusion
  - MisID (found to be negligible)
- Background shape is taken from inelastic events.
- Purity extracted by template fit (signal shape from MC)





LPAIR: J. Vermaseren, Nucl. Phys. B229, 347 (1983), Pomwig: B. E. Cox, J. R. Forshaw, Phys. Comm. 144:104-110, 2002, arXiv:hep-ph/0010303v3

Preliminary result, LHCb-CONF-2011-022:

$$\sigma_{pp \to p\mu^+\mu^- p}(2 < \eta_{\mu+}, \eta_{\mu-}, m_{\mu\mu} > 2.5\ GeV/c^2) = 67 \pm 10(stat) \pm 7(sys) \pm 15(lumi)pb$$

- Naive extrapolation for 2011:

Uncertainty	2010	2011
Statistical	16%	2.3%
Efficiencies	9%	1%
Purity	2%	0.3%

- 2010: most efficiencies taken from MC, 2011: most taken from data.
- Should give an improved luminosity uncertainty

$\rightarrow$ better constraint from W and Z production cross-section measurements.

Impact of luminosity on cross section measurements in 2010/2011

- Eur. Phys. J. C 71 (2011) 1645: J/ψ production cross section measurements @ $\sqrt{s} = 7\ TeV$.
  Unknown J/ψ polarisation at the level of the luminosity uncertainty $O(10\ \%)$.

  $\rightarrow$ Plan to measure J/ψ polarisation
  Luminosity uncertainty will become the largest systematic.
- LHCb-CONF-2011-016 and LHCb-CONF-2011-026 : $\Upsilon(1S)$ and $\psi(2S)$ production cross section measurements @ $\sqrt{s} = 7\ TeV$.
  Polarisation uncertainty dominates but the luminosity uncertainty is amongst the highest contribution.
- Those measurements are planned to be repeated at $\sqrt{s} = 8\ TeV$.

- LHCb-CONF-2011-009 Double J/ψ production @ $\sqrt{s} = 7\ TeV$.
  On the whole 2011 data statistics, the 3.5 % luminosity uncertainty would be dominant.
  No plan though to redo the cross section measurement.

- Phys. Lett. B 694 (2010) 209-216 $pp \rightarrow \bar{b}b + X$ cross section @ $\sqrt{s} = 7\ TeV$
  Tracking efficiency and luminosity are both $O(10\ \%)$ (early 2010).
  17.3 % systematic uncertainty, without luminosity 14. %
- LHCb-PAPER-2011-043 $B^{\pm}$ production cross section @ $\sqrt{s} = 7\ TeV$
  7.5 % systematic uncertainty, without luminosity 6.6 %
- Will be performed @ $\sqrt{s} = 8\ TeV$

- LHC seminar 07.02.12 Double Charm and $J/\psi +$ Charm
  24 modes. Dominant systematic is due to uncertainties for hadron interactions in detectors and charm branching ratio, $J/\psi + D_0$ might benefit from improved luminosity.

Outlook

- W and Z production measurements already put constraints on PDFs with 2010 dataset.
- 2011 measurement will be dominated by luminosity uncertainty.
- $pp \rightarrow p\mu\mu p$ should be able to provide an indirect measurement of the luminosity.
- W and Z production can also provide an indirect measurement of the luminosity.
- Other production cross section measurements at LHCb would benefit from reduced luminosity uncertainties.