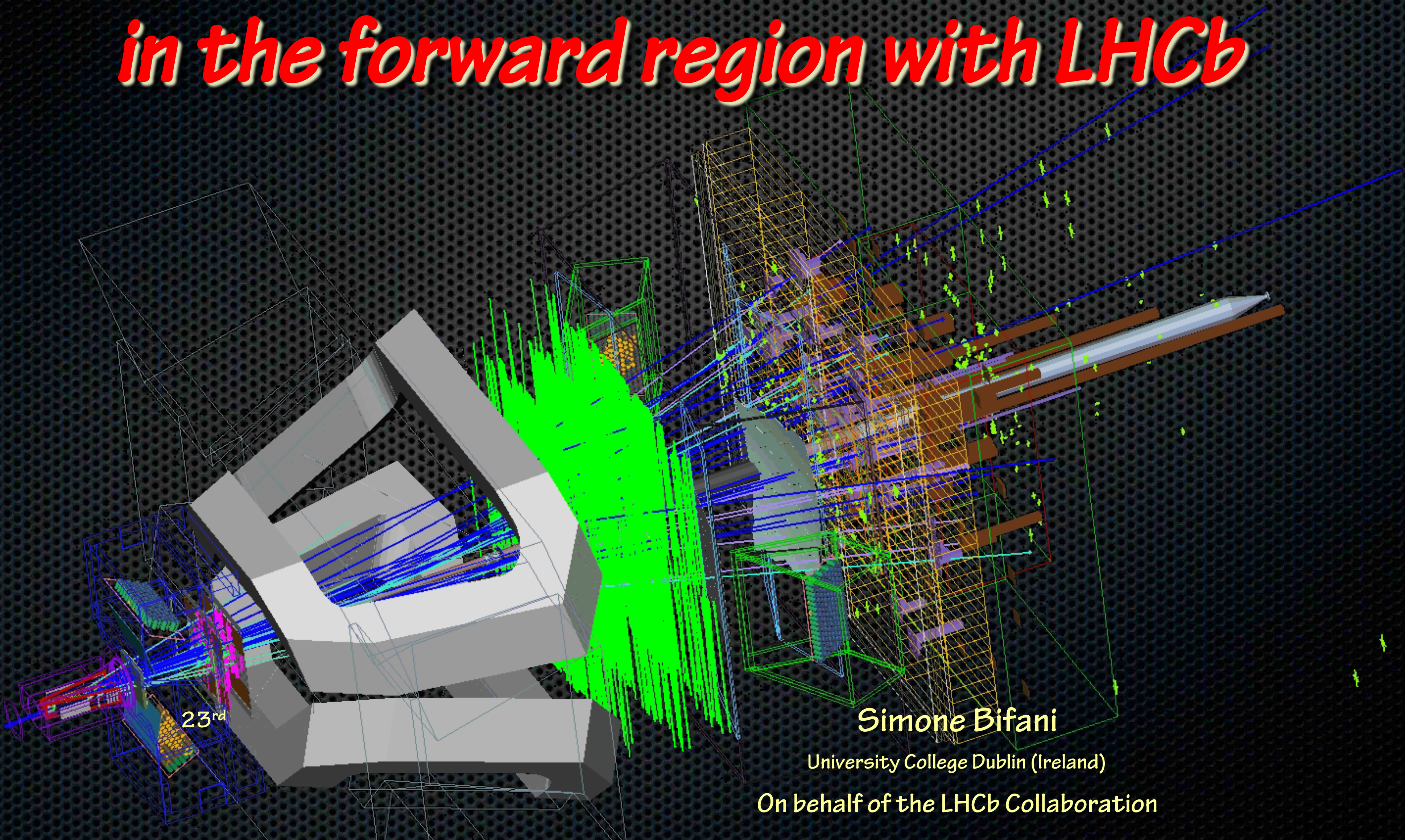
Electroweak and QCD studies in the forward region with LHCb



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On behalf of the LHCb Collaboration

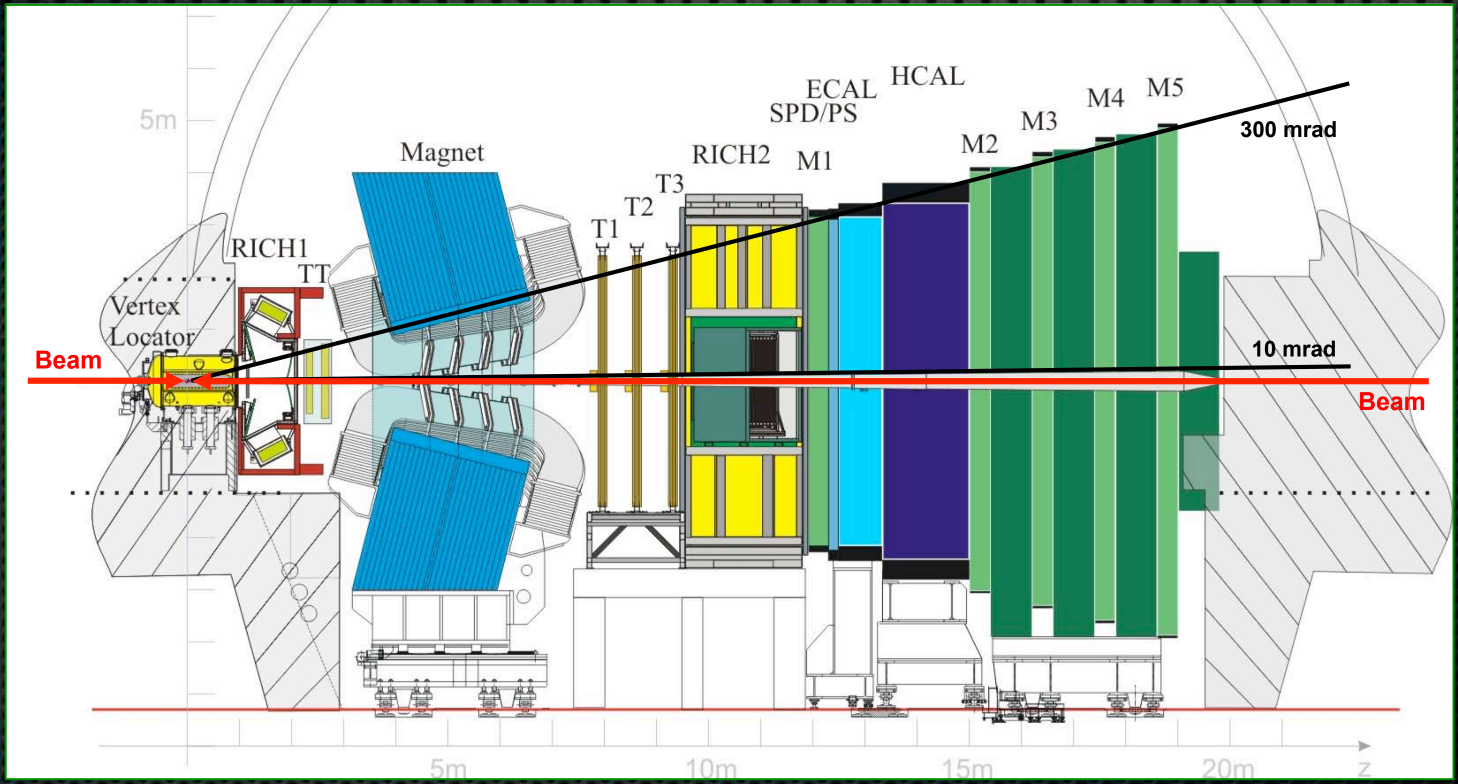
23rd Rencontres de Blois – Château Royal de Blois (France), 29th May – 3rd June 2011

Outline

- >LHCb Overview
- >W&Z Production and PDF Sensitivity
- >Preliminary Results
- >Other Studies
- >Summary and Outlook

LHCb – A Forward Spectrometer

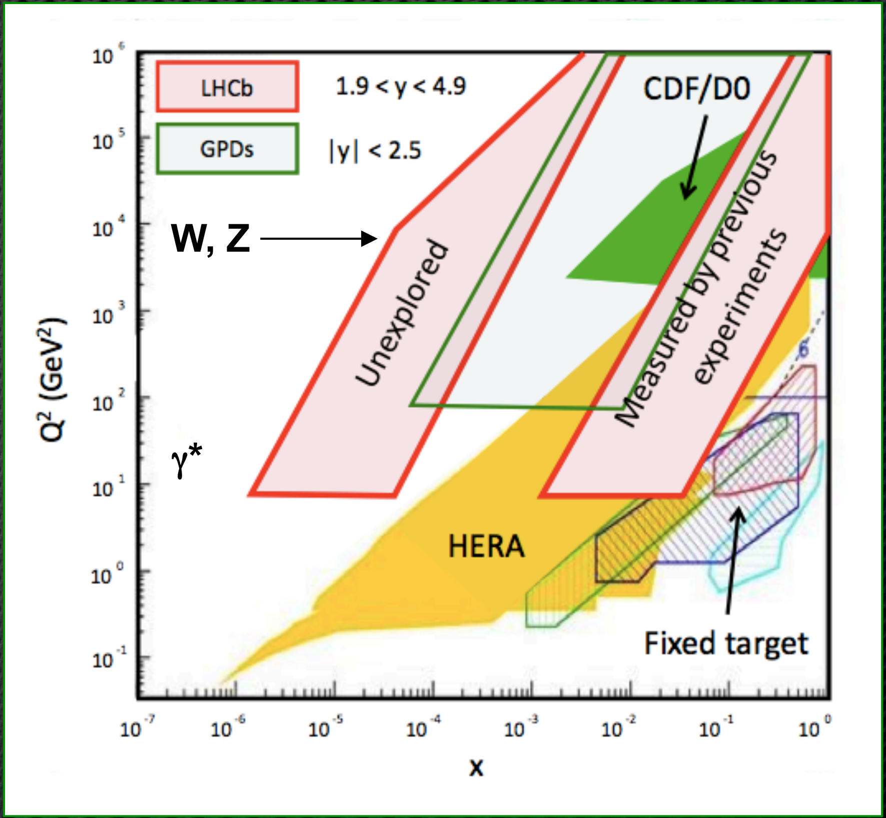
- Designed to look at CP violation in B decays @ LHC
- Fully instrumented within $1.9 \leq \eta \leq 4.9$
- Muon reconstruction capabilities: $P > 3 GeV/c$, $P_t > 1 GeV/c$, $m_{\mu\mu} > 2.5 GeV/c^2$



- $\int L_{2010} \sim 38\ pb^{-1}$ on tape, $\int L = (16.5 \pm 1.7)\ pb^{-1}$ these analyses

W&Z Production and PDFs

- LHCb's forward acceptance provides very interesting possibilities for PDF studies
- Take large-x from one proton and a small-x from the other
  -> probe two distinct regions in (x, Q^2) space
- Can probe the low-x, high-Q^2 region inaccessible to other experiments (PDF predictions for this region are more sensitive to model changes than in central acceptance)
- Explore with W, Z (x of 10^{-4}, 10^{-1}) and low-mass Drell-Yan (x -> 10^{-6})

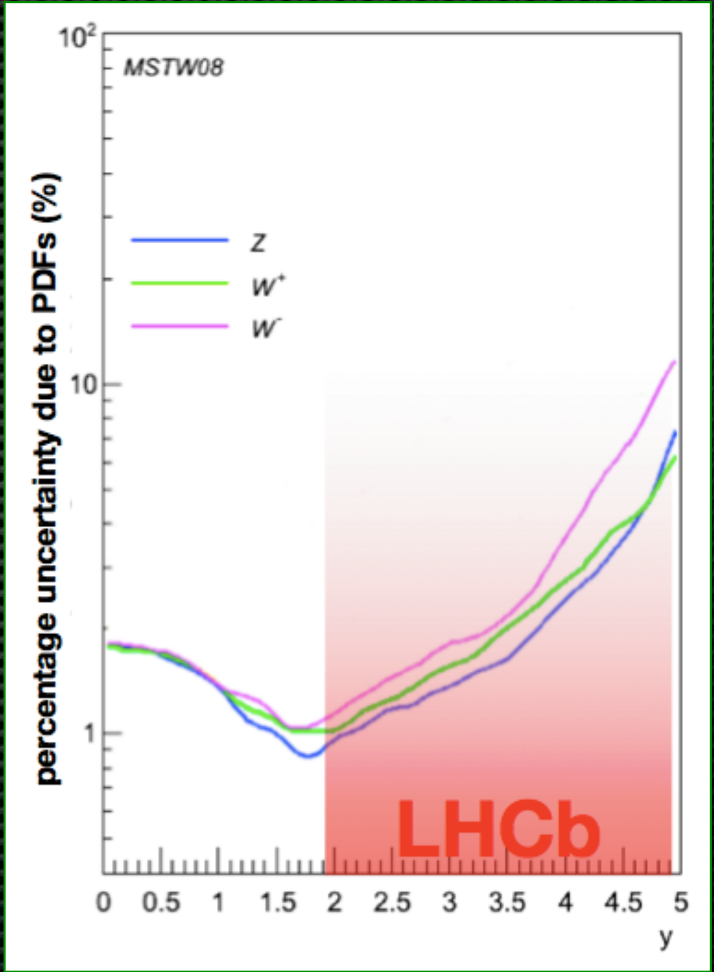


$$Q^2 = M^2 \ , \ x = \frac{M}{\sqrt{s}} \cdot e^{\pm y}$$

W&Z Production and PDFs

- **Theoretical predictions**
  - Cross-sections known @ NNLO to 1%
  - PDF uncertainty dominates @ large rapidities (1% @ y<2, 6-8% @ y~5)

$$\underbrace{\sigma(x,Q^2)}_{\text{hadronic } x-\text{sec.}} = \sum_{a,b} \int_0^1 dx_1\, dx_2 \underbrace{f_a(x_1 Q^2) f_b(x_2 Q^2)}_{\text{PDFs } 2-8\%} \quad \underbrace{\hat{\sigma}(x_1, x_2, Q^2)}_{\text{partonic } x-\text{sec.}: \text{NNLO } 1\%}$$



- **Experimental measurements**
  - Clean signature
  - Easily reconstructible final state
  - Low statistical and systematic errors

Cross-section measurements @ LHCb can constrain PDFs

W&Z Production and PDFs

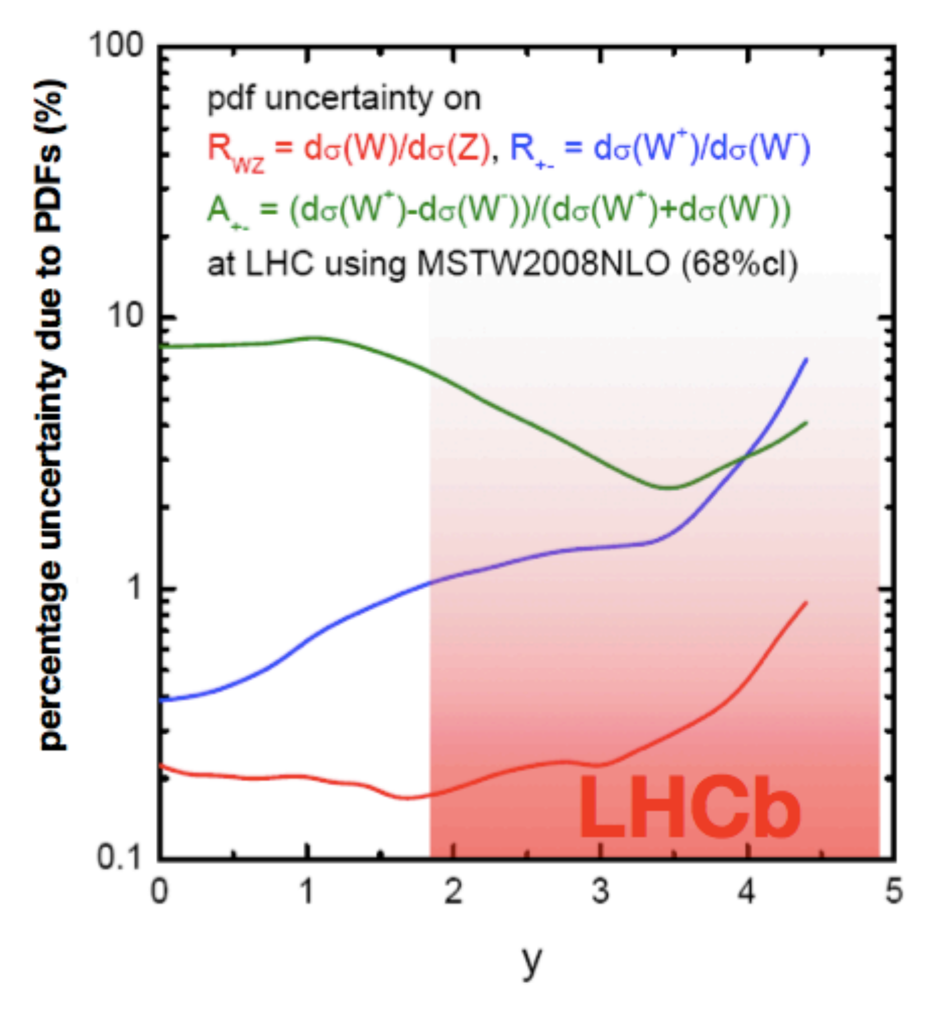
› Cancel or highlight PDF uncertainties with ratios

» $A_{+-} = (d\sigma_{W+} - d\sigma_{W-}) / (d\sigma_{W+} + d\sigma_{W-})$
tests u_V and d_V difference

» $R_{+-} = d\sigma_{W+} / d\sigma_{W-}$
tests d_V/u_V ratio

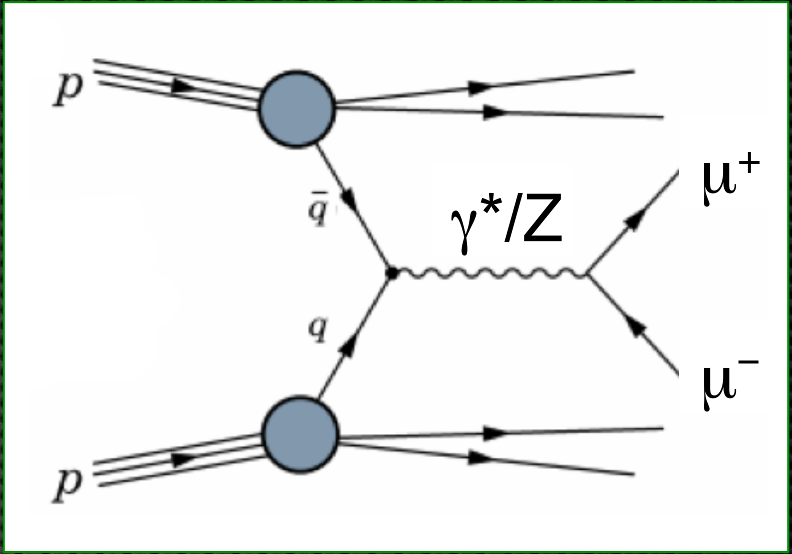
» $R_{WZ} = d\sigma_{W+-} / d\sigma_Z$
almost insensitive to PDFs
precise test of SM

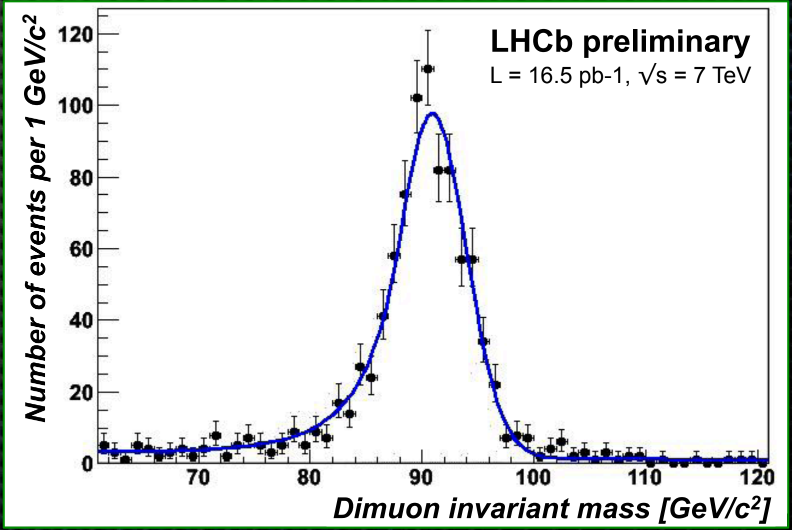
Many systematic errors cancel



$Z \to \mu\mu$

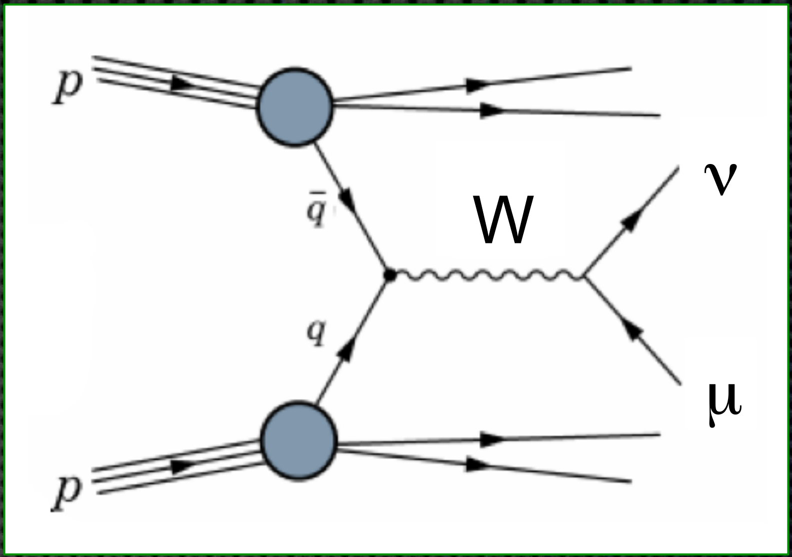
- Single muon trigger: $P_t > 10$ GeV/c
- 2 reconstructed muons
  - » $P_t > 20$ GeV/c
  - » $2.0 < \eta < 4.5$
  - » $81\ GeV/c^2 < m_{\mu\mu} < 101\ GeV/c^2$
- Backgrounds
  - » $Z \to \tau\tau \sim 0.2$ (MC)
  - » Heavy flavour ~ 1 (Data)
  - » π/K mis-ID < 0.03 (Data)
- $N^{Z}_{candidates} = 833$
- $N^{bg} = 1.2 \pm 1.2$



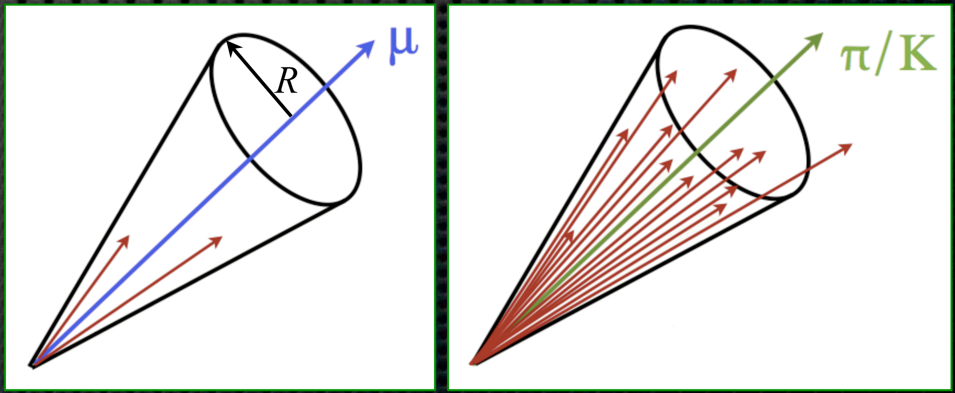


$W \to \mu\nu_\mu$

- **Single muon trigger:** $P_t > 10$ GeV/c
- **1 reconstructed & isolated muon**
  - » $P_t > 20$ GeV/c
  - » $2.0 < \eta < 4.5$
  - » Impact parameter significance < 2
  - » ΣP_t in cone around muon < 2 GeV/c (R=0.5)



- **Rest of the event**
  - » $M < 20$ GeV/c^2
  - » $\Sigma P_t < 10$ GeV/c

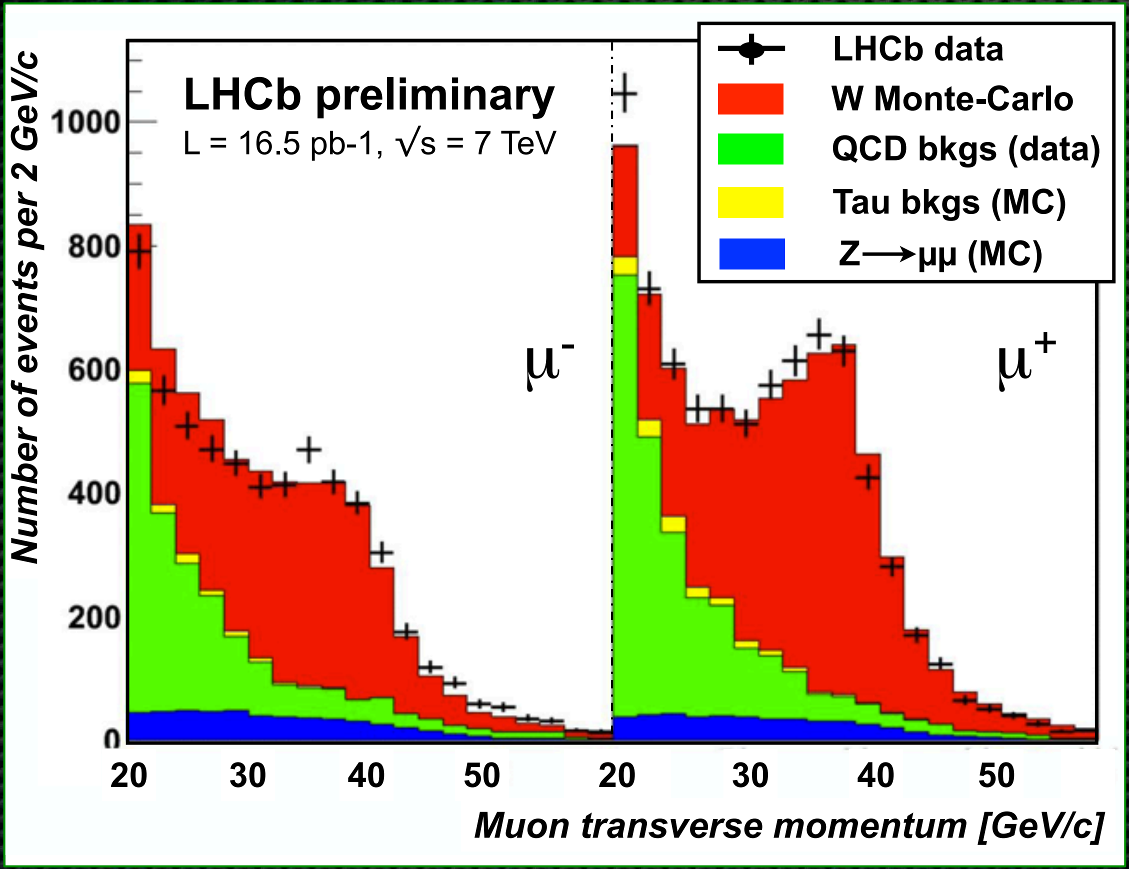


$$R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

- **Backgrounds**
  - » Z->μμ (1 muon in acceptance)
  - » Z->ττ (data+simulation)
  - » W->τν (simulation)
  - » QCD background (data+simulation)

$W \to \mu\nu_\mu$

- Fit muon P_t spectrum in data to expected shapes for signal and backgrounds (perform fit in η bins for differential results)



$N^{W+}_{candidates} = 7624$

$N^{W-}_{candidates} = 5732$

$N^{bg+} = 2194 \pm 150$

$N^{bg-} = 1654 \pm 150$

- QCD background is large and charge asymmetric

Efficiencies

- The cross-section for boson production can be expressed as

$$\sigma = \frac{N_{candidates} - N_{bg}}{\varepsilon \cdot \int L}$$

- The overall efficiency for selecting signal candidates can be factorized as

$$\varepsilon = A \cdot \varepsilon_{trigger} \cdot \varepsilon_{tracking} \cdot \varepsilon_{\mu-ID} \cdot \varepsilon_{selection}$$

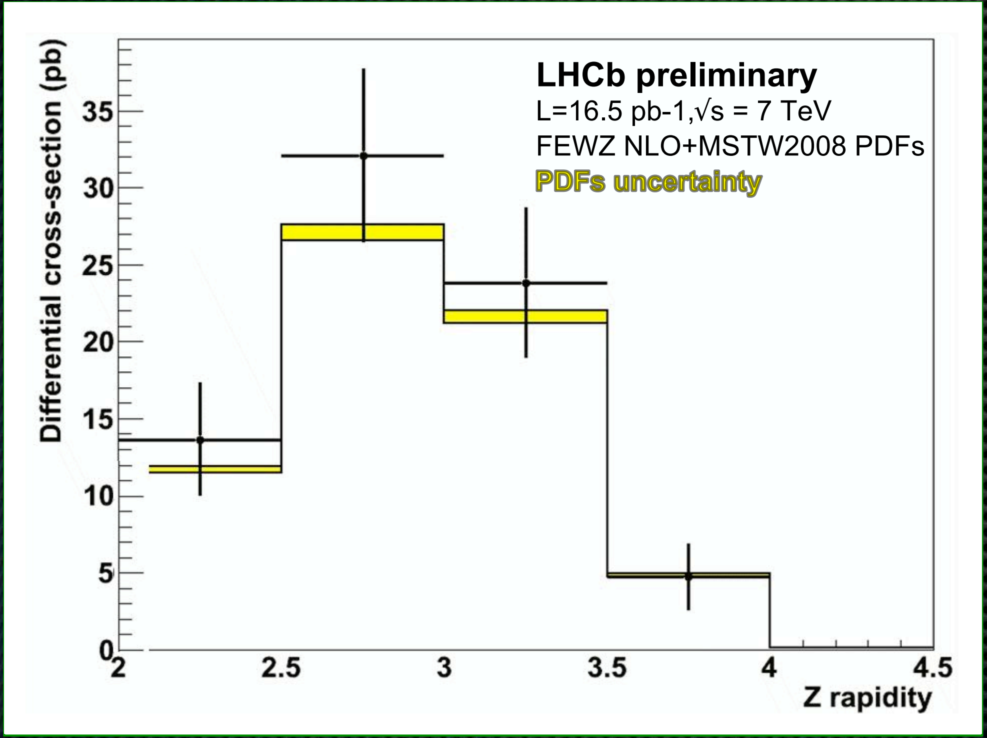
- Measurements will be performed in the forward region ($2.0<\eta<4.5$) for muons with $P_t > 20$ GeV/c (no 4π extrapolation) -> A = 1 by definition
- All efficiencies determined from data and cross checked with simulation

- Selection efficiency
  - Z selection criteria define the measurement kinematic region -> $\varepsilon^Z = 1$
  - W: determined from Z data with 1 muon masked -> $\varepsilon^W = (55 \pm 1)$ %

Z Cross-Section

LHCb-CONF-2011-012
LHCb Preliminary

$$\sigma_{Z\to\mu^+\mu^-} = \frac{N^Z_{candidates} - N_{bg}}{\varepsilon^Z \cdot \int L}$$



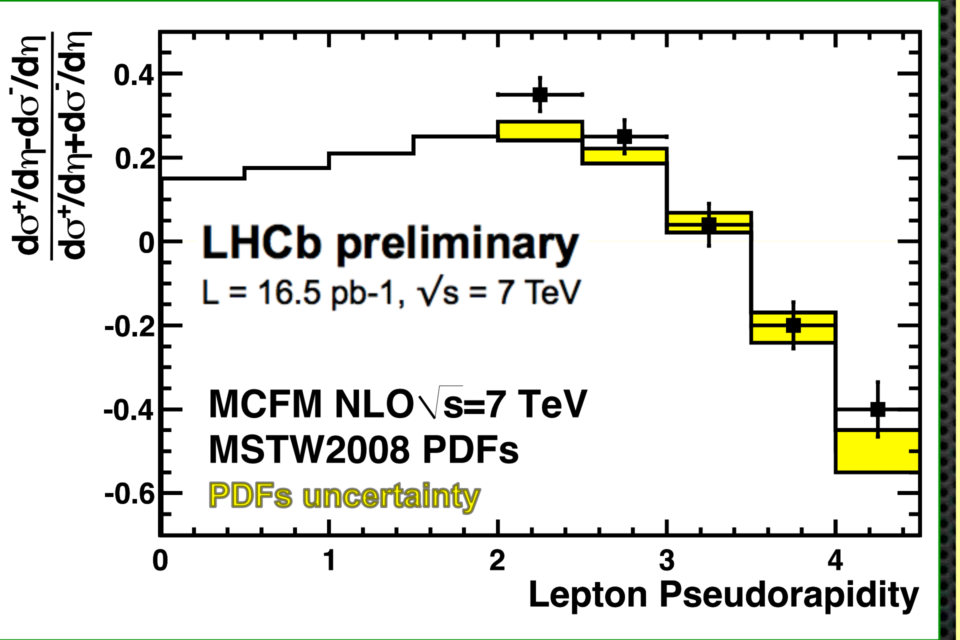
Result not corrected for FSR

$2<\eta<4.5$, $81 GeV/c^2 < m_{\mu\mu} < 101 GeV/c^2$	
$N^Z_{candidates}$	833
N_{bg}	1.2 ± 1.2
$\varepsilon_{tracking}$ [%]	83 ± 3
$\varepsilon_{\mu\text{-}ID}$ [%]	97 ± 1
$\varepsilon_{trigger}$ [%]	86 ± 1
$\varepsilon_{selection}$	1
A	1
ε^Z [%]	69 ± 3
$\int L$ [pb^{-1}]	16.5 ± 1.7
σ_Z [pb]	$73 \pm 4_{stat\&syst} \pm 7_{lumi}$

W Charge Asymmetry

LHCb-CONF-2011-012
LHCb Preliminary

$$A_{+-} = \frac{\sigma\left(W^+ \to \mu^+ \overline{\nu}_\mu\right) - \sigma\left(W^- \to \mu^- \nu_\mu\right)}{\sigma\left(W^+ \to \mu^+ \overline{\nu}_\mu\right) + \sigma\left(W^- \to \mu^- \nu_\mu\right)}$$



Result not corrected for FSR

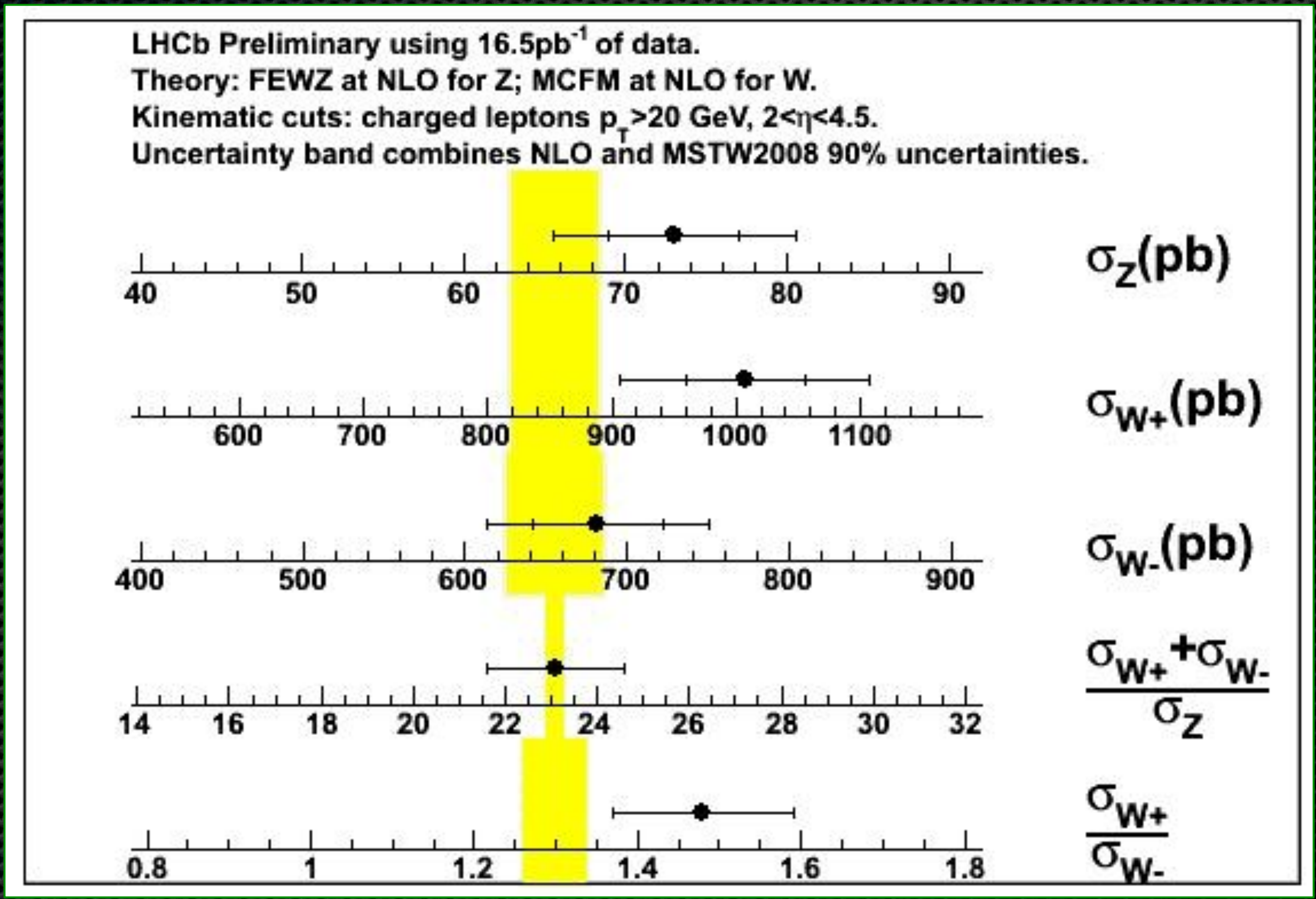
$2<\eta<4.5$	+	-
$N^W_{candidates}$	7624	5723
$Z\to\mu\mu$	460	506
$W\to\tau\nu$	151	90
$Z\to\tau\tau$	2	2
QCD	2194 ± 150	1654 ± 150
N^W	4817 ± 165	3480 ± 161
$\varepsilon_{tracking}$ [%]	73 ± 3	78 ± 3
$\varepsilon_{\mu\text{-ID}}$ [%]	98.2 ± 0.5	
$\varepsilon_{trigger}$ [%]	73 ± 1	
$\varepsilon_{selection}$ [%]	55 ± 1	
A	1	
ε^W [%]	29 ± 1	31 ± 1
$\int L$ [pb^{-1}]	16.5 ± 1.7	
σ_W [pb]	1007±48±101	680±40±68

± stat&syst ± lumi

Comparisons

LHCb-CONF-2011-012
LHCb Preliminary

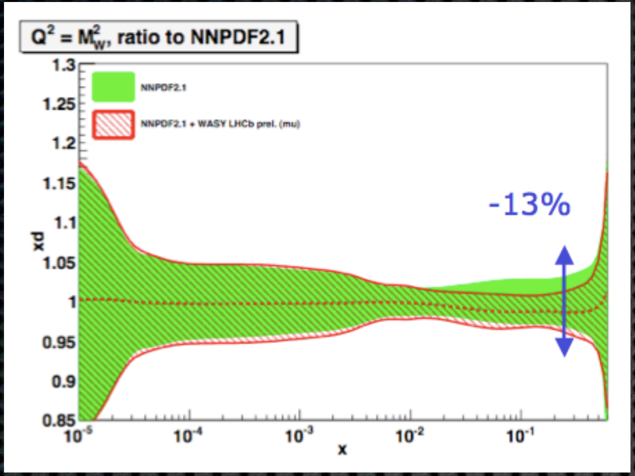
- All W and Z observations are consistent with NLO predictions (MSTW08)

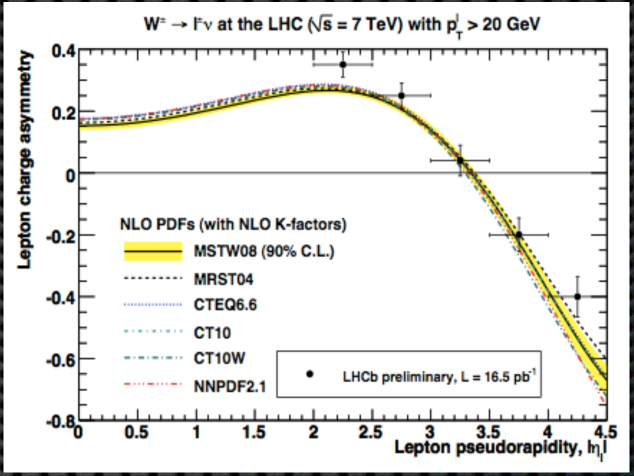


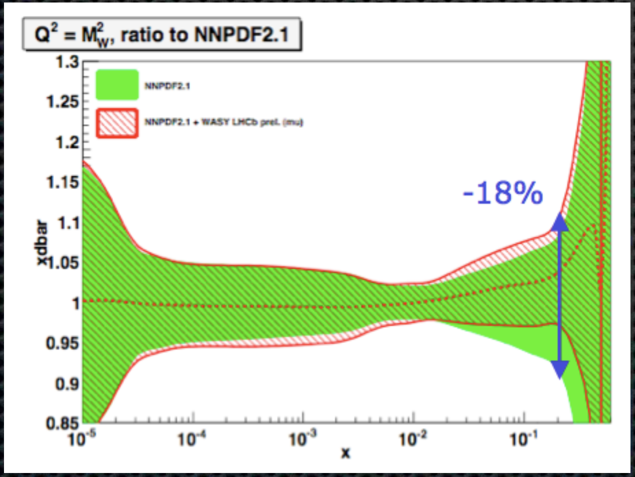
Results not corrected for final state radiation

Improvements on PDFs

- LHCb measurement of the W charge asymmetry slightly reduce the uncertainty in the large-x region while small-x is unchanged (EW@LHC)







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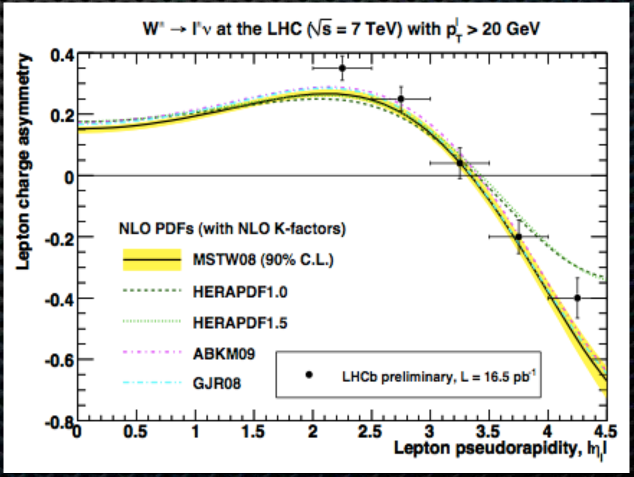
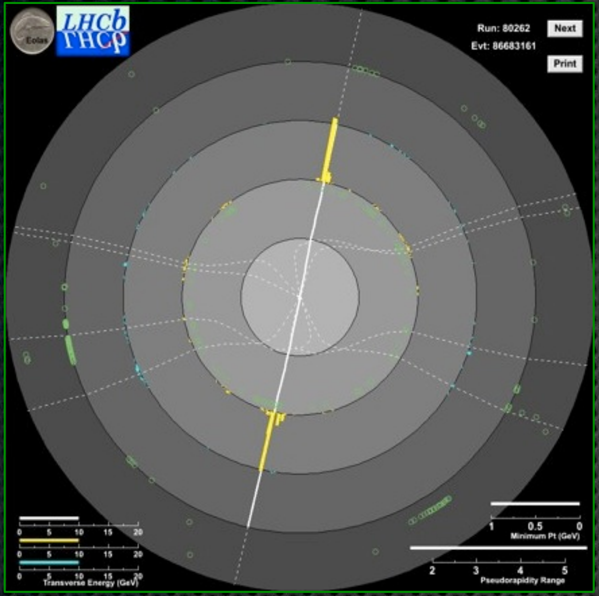


G.Watt

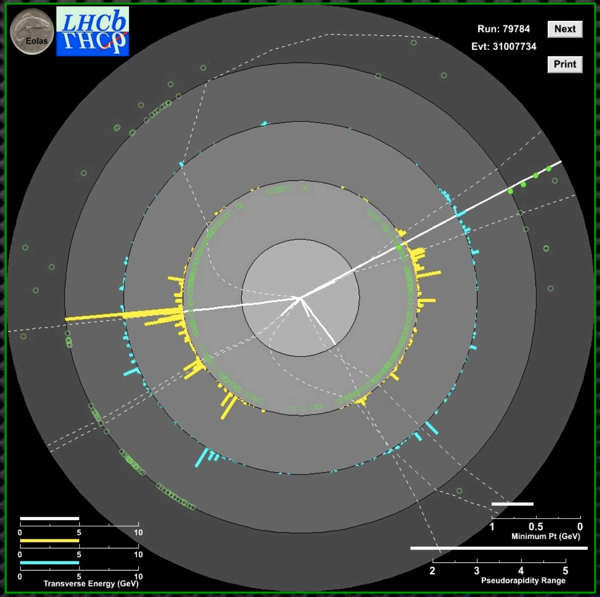
Other Studies

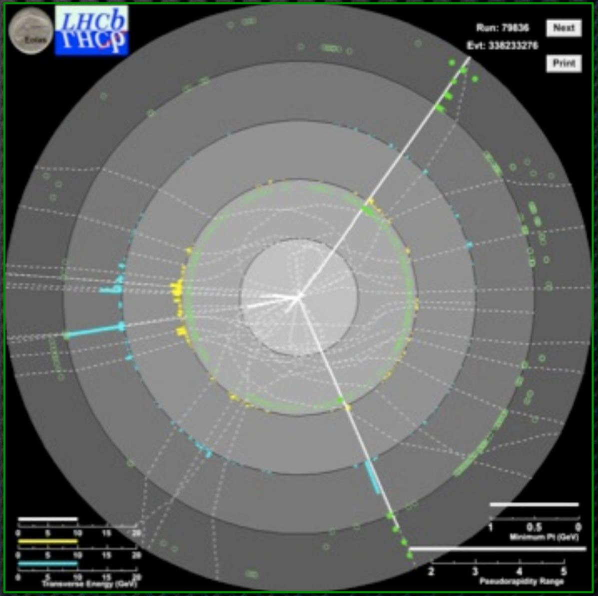
- Work ongoing on other channels: W->eν, Z->ee and Z->ττ
- W&Z+jets: test pQCD, sensitivity to gluon PDF and background for many searches



Z->ee

Z->ττ->μeνννν

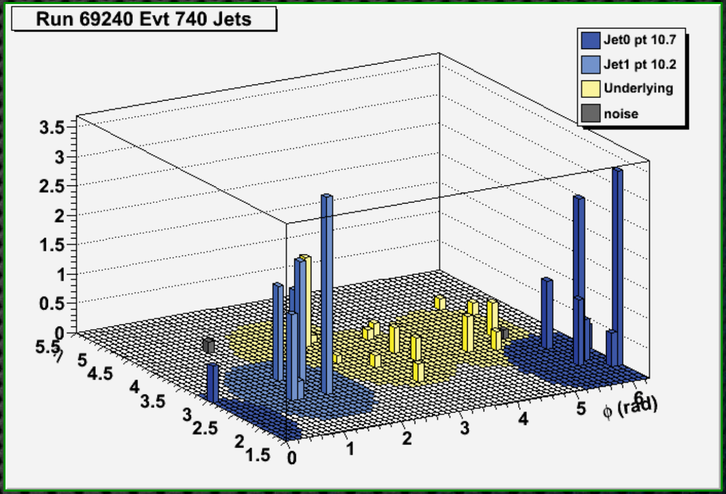


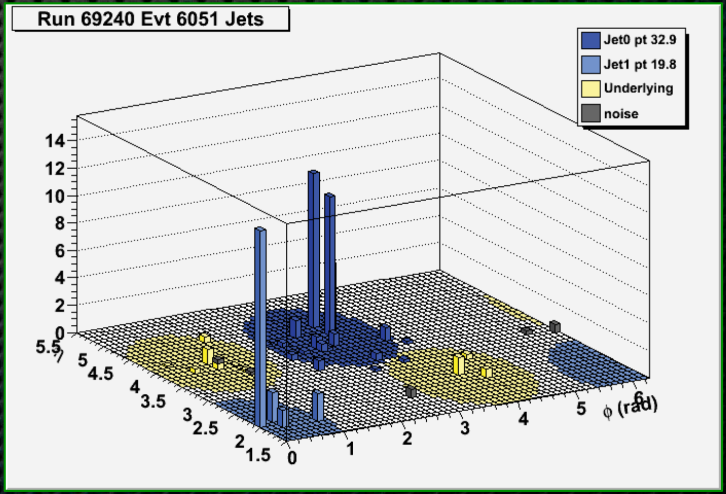


Z->μμ+jet

Jet Studies

- Inclusive jet and dijet events in the forward region can provide valuable information on PDFs ($x < 10^{-3}$)
  - » Clustering with K_T algorithm
  - » Track + unassociated π^0
  - » Energy correction ongoing

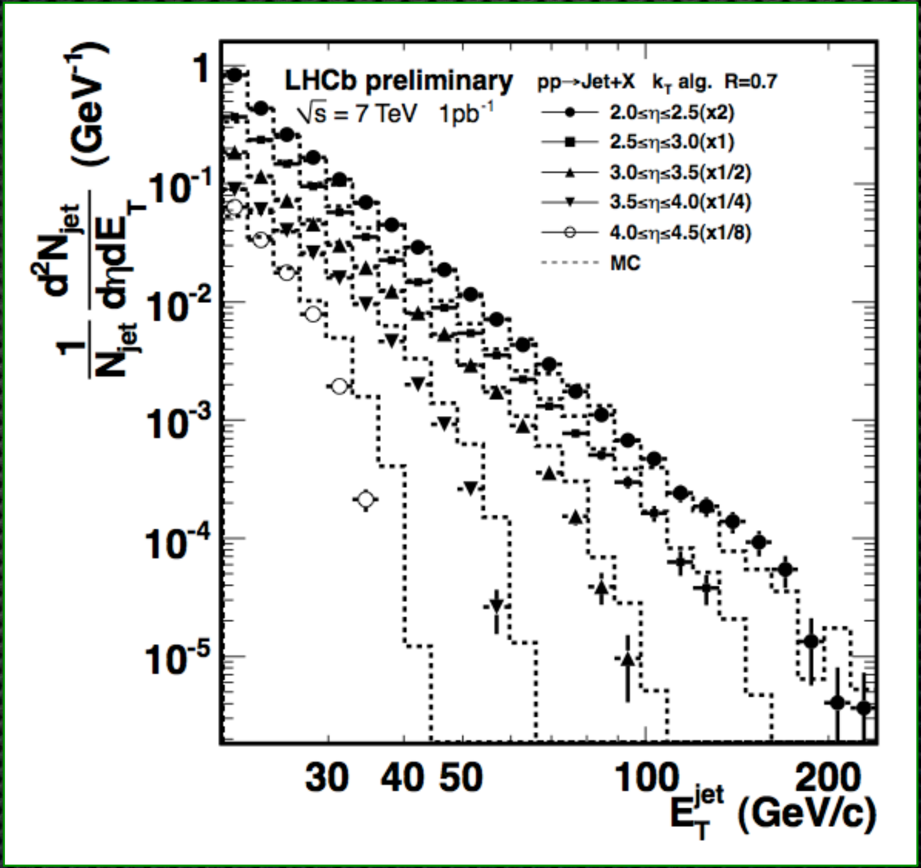




- To do
  - » Calibrate E_T on data
  - » Efficiencies
  - » Compare to NLO simulation

Jet Studies

- Inclusive jet E_T spectrum
  - Uncorrected for acceptance, jet energy scale and resolution
  - MC: Pythia 6.4 + PDF CTEQ6 LO and detector response simulation

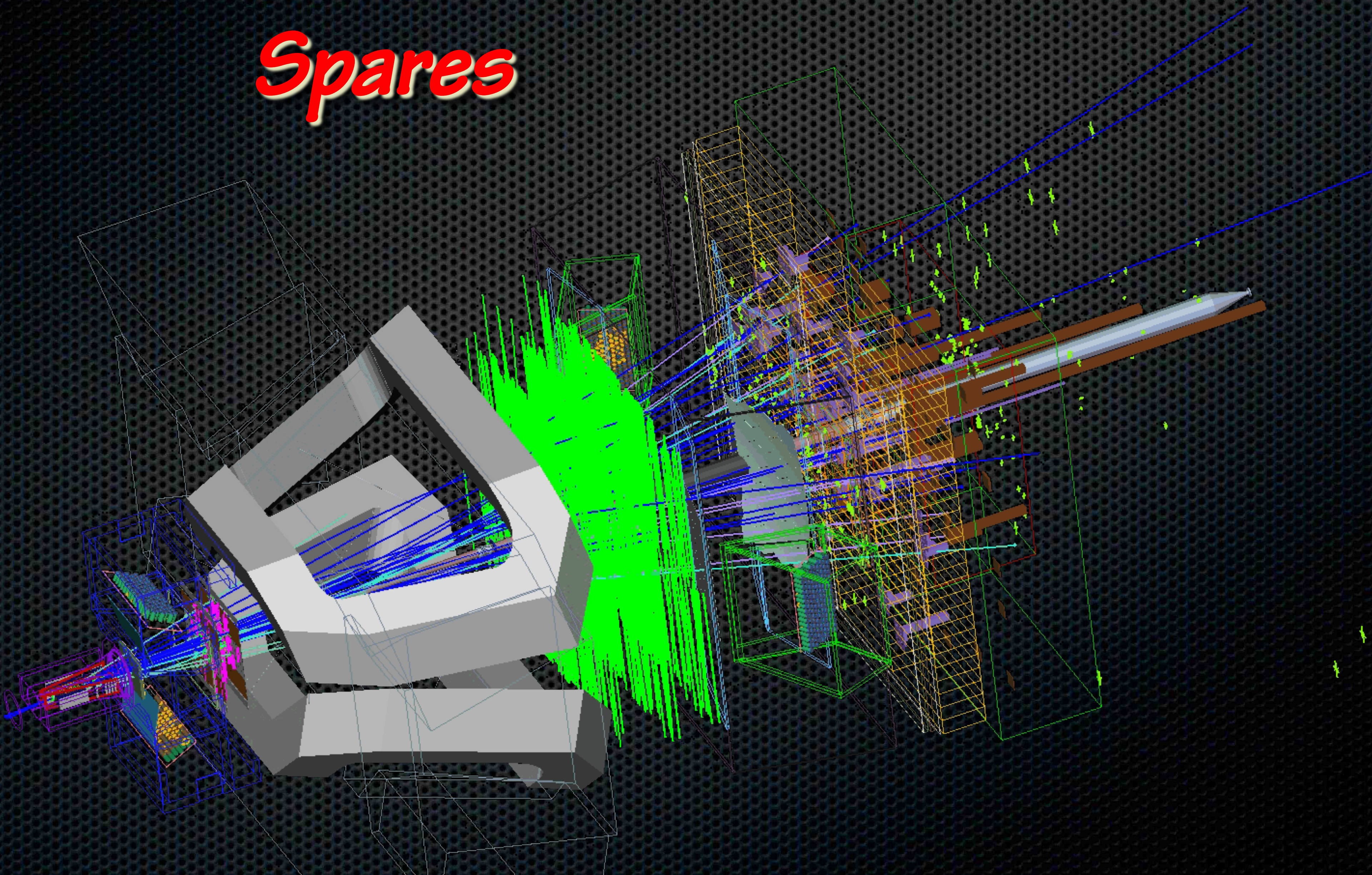


Summary and Outlook

- Cross-sections for W and Z @ 7TeV (P_t>20 GeV/c, 2<η<4.5)
- All observations consistent with current NLO predictions
- Luminosity uncertainty dominates cross-section results
- Inclusive jets characteristics can be measured @ LHCb

- Expect to collect ~1 fb^{-1} in 2011
  -> analyses limited by systematics
- Probe PDFs in previously unexplored region
- Distinguish different PDF models

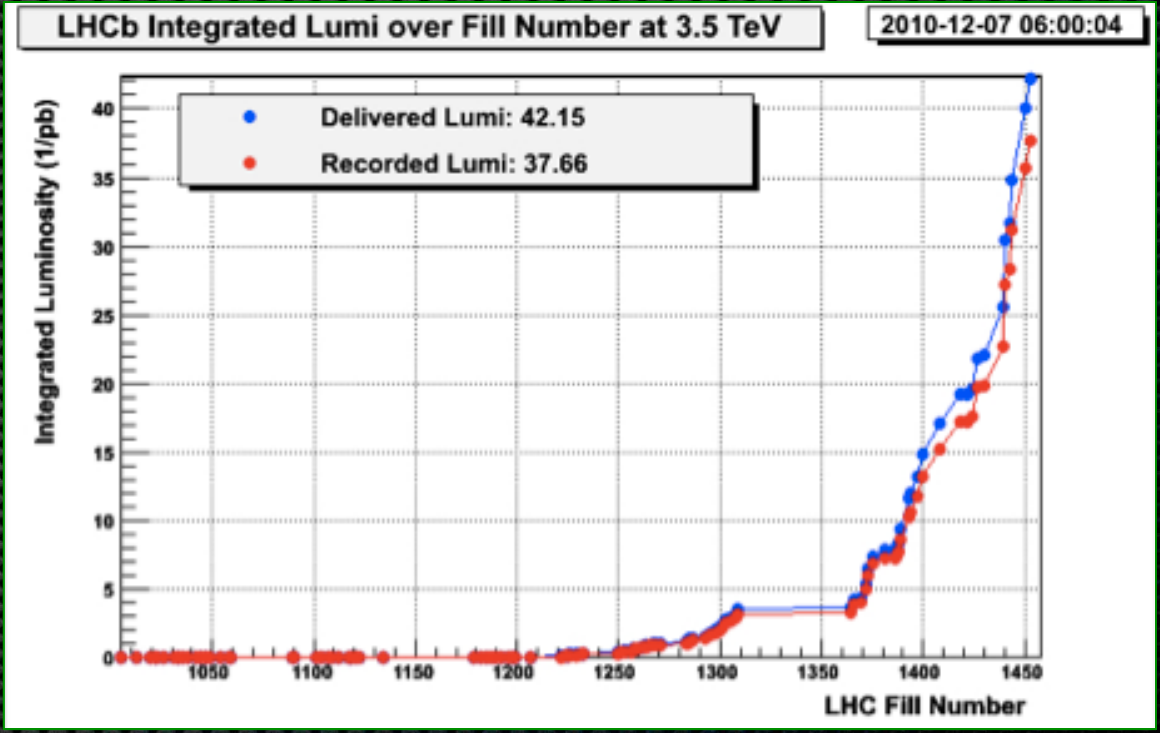
Spares



2010 Data Taking

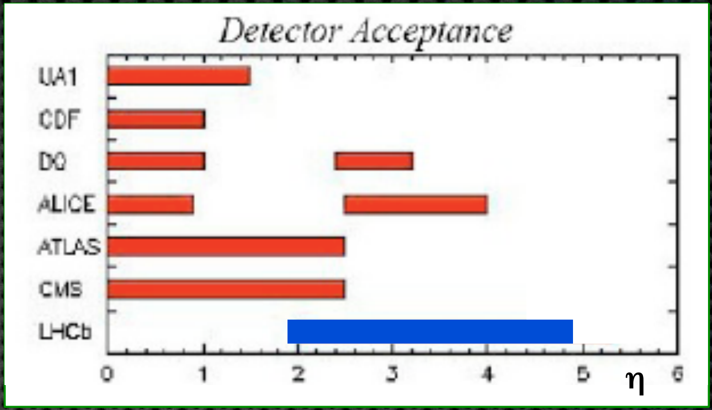
- $\int L_{2010} \sim 38\ pb^{-1}$ on tape
- $\int L = (16.5 \pm 1.7)\ pb^{-1}$ this analyses
- $\int L_{2011} \sim 1\ fb^{-1}$

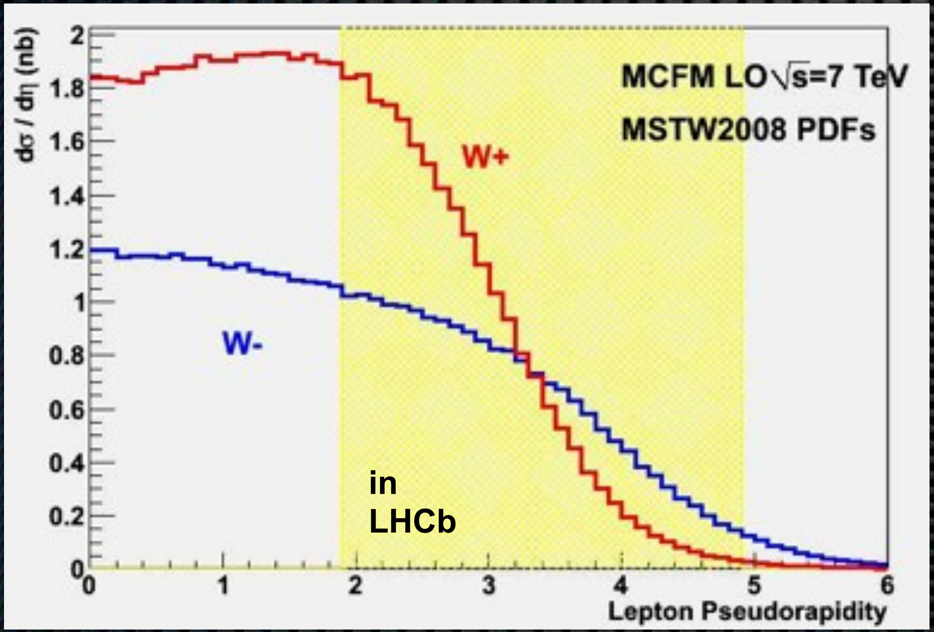
- Initial design: 1 single proton collision in each event
- Last fills: over 2 on average
- Triggers evolved through the year



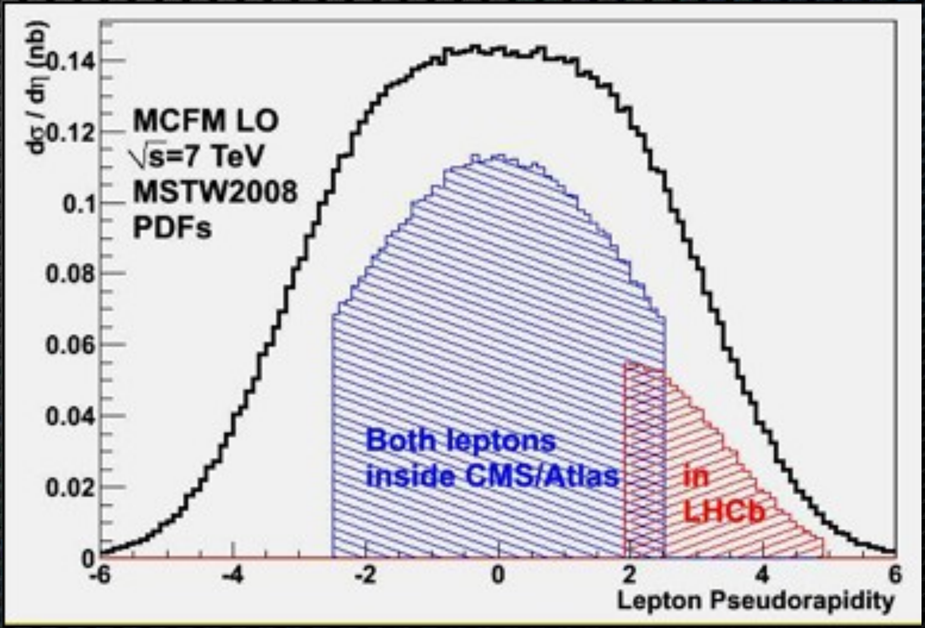
W&Z Production and PDFs

- Complementary η range to Atlas/CMS
  - » Overlap for cross check
    $1.9 \le \eta \le 2.5$
  - » Unique to LHCb
    $2.5 \le \eta \le 4.9$





17%(16%) of W^+(W^-) within LHCb

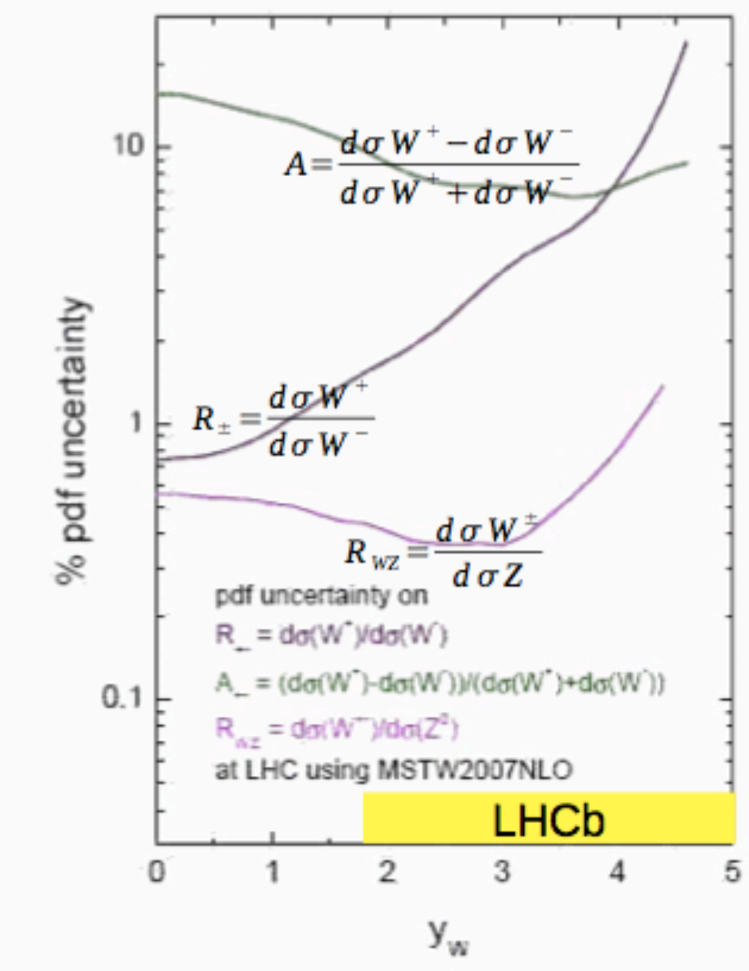


8% of Z within LHCb

W&Z Production and PDFs

- R_{+-}=dσ(W^+)/dσ(W^-)
  tests valence quarks: d_V/u_V ratio

$$R(y)=\frac{d\sigma/dy(W^-)}{d\sigma/dy(W^+)}\approx\frac{d(x_1)\bar{u}(x_2)}{u(x_1)\bar{d}(x_2)}\approx\frac{d(x_1)}{u(x_1)}$$

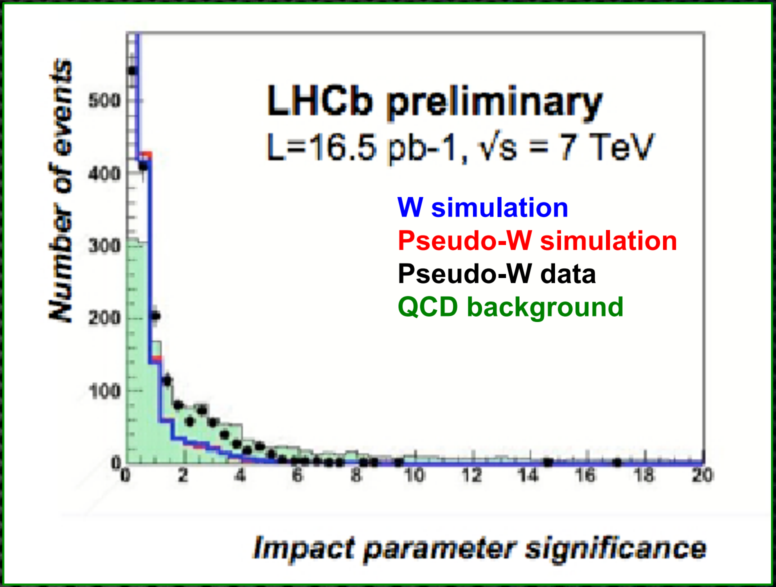


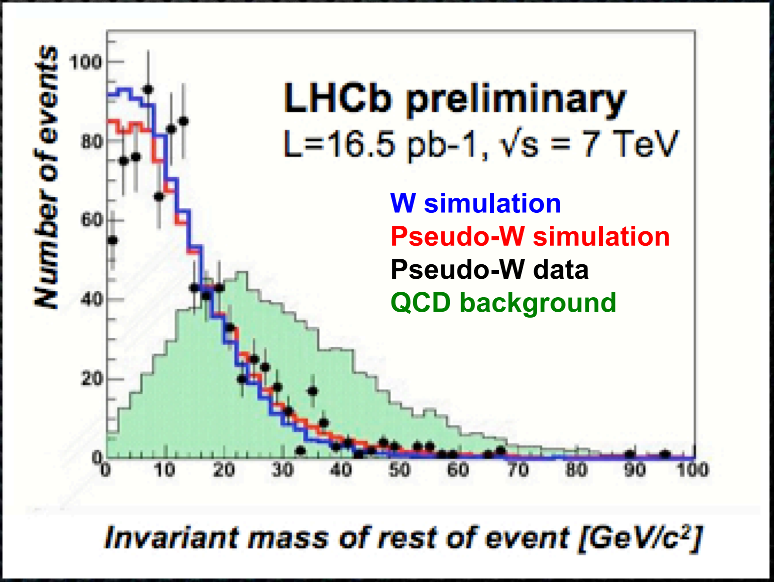
- A_W =(dσ(W^+)–dσ(W^-))/(dσ(W)+dσ(W^-))
  tests valence quarks: difference btw. u_V and d_V

$$A(y)=\frac{d\sigma/dy(W^+)-d\sigma/dy(W^-)}{d\sigma/dy(W^+)+d\sigma/dy(W^-)}\approx\frac{u(x_1)\bar{d}(x_2)-d(x_1)\bar{u}(x_2)}{u(x_1)\bar{d}(x_2)+d(x_1)\bar{u}(x_2)}\approx\frac{u(x_1)-d(x_1)}{u(x_1)+d(x_1)}$$

$W \to \mu\nu_\mu$

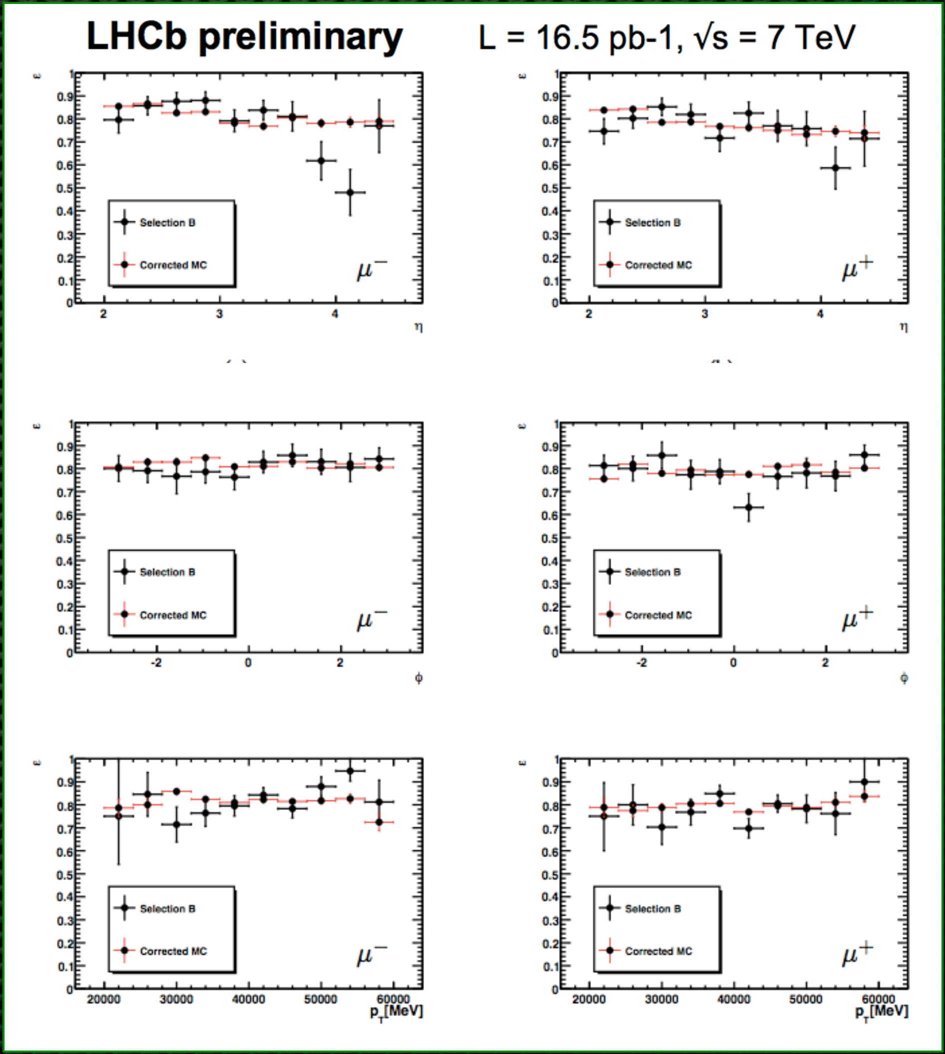
- QCD background defined by anti cuts
  - Impact parameter significance > 4
  - ΣP_t in cone around muon > 5 GeV/c (R=0.5)
  - M rest of event > 40 GeV/c^2
  - ΣP_t rest of the event > 15 GeV /c
- Pseudo-W (Z events with 1 muon masked)
  - Pseudo-W and W simulated distributions look similar
  - Pseudo-W data described by simulation
  - Signal can be modeled with Pseudo-W data
- Efficiency from data (Pseudo-W)
- Purity by fit to templates





Efficiencies – Trigger

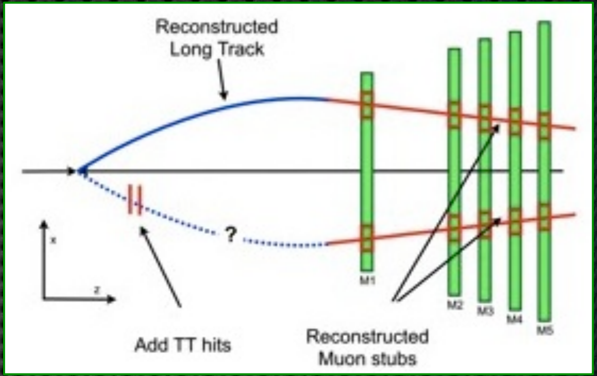
- Single muon trigger
  - » P_t > 10 GeV/c
- **Efficiency flat in ϕ, P_t, and η**
  - » No evidence for charge bias
  - » $\varepsilon^W = (73 \pm 1)\ \%$
  - » $\varepsilon^Z = (86 \pm 1)\ \%$



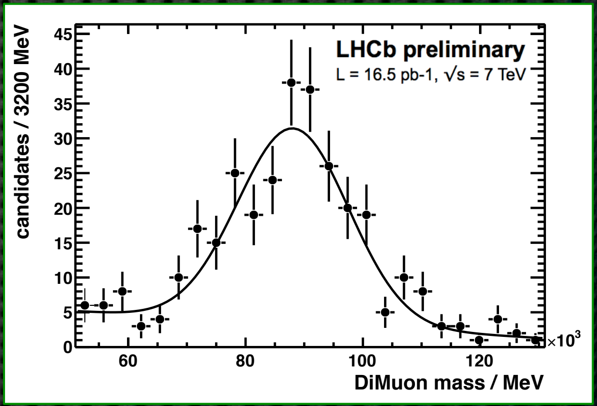
- Results include global trigger cuts on maximum event multiplicity

Efficiencies – Tracking

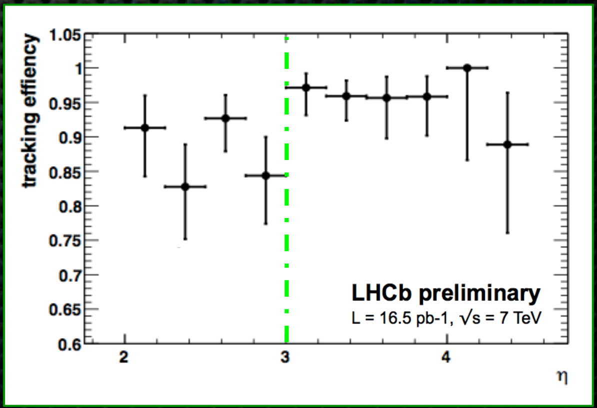
- Tag&Probe method in Z sample
  - Tag: identified muon track
  - Probe: rough trajectory from muon stub and minimal tracking information (TT)



- Efficiency flat in ϕ and P_t, two regions in η
  - $\varepsilon^{W+} = (73 \pm 3)\,\%$
  - $\varepsilon^{W-} = (78 \pm 3)\,\%$
  - $\varepsilon^{Z} = (83 \pm 3)\,\%$

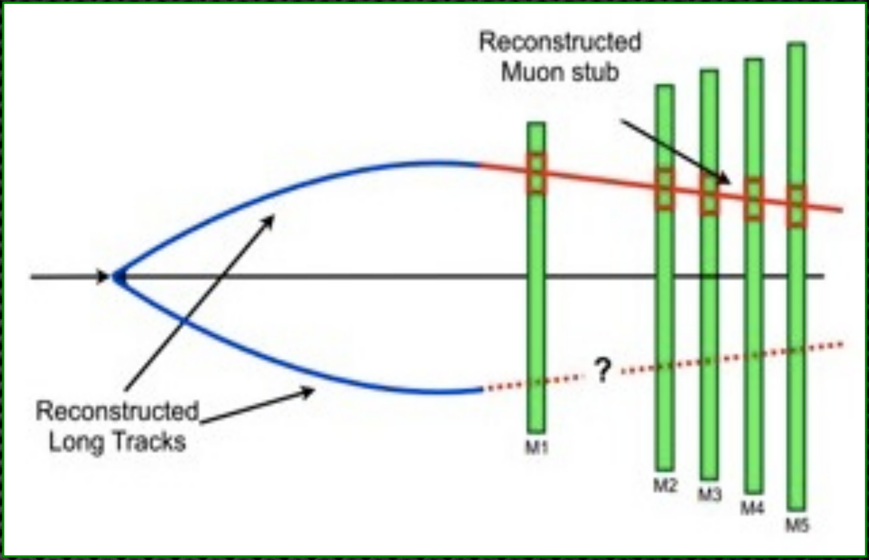


- Different W^+/W^- average efficiency due to different η distribution
- Harsher tracking cuts in W analysis lead to a lower efficiency wrt Z

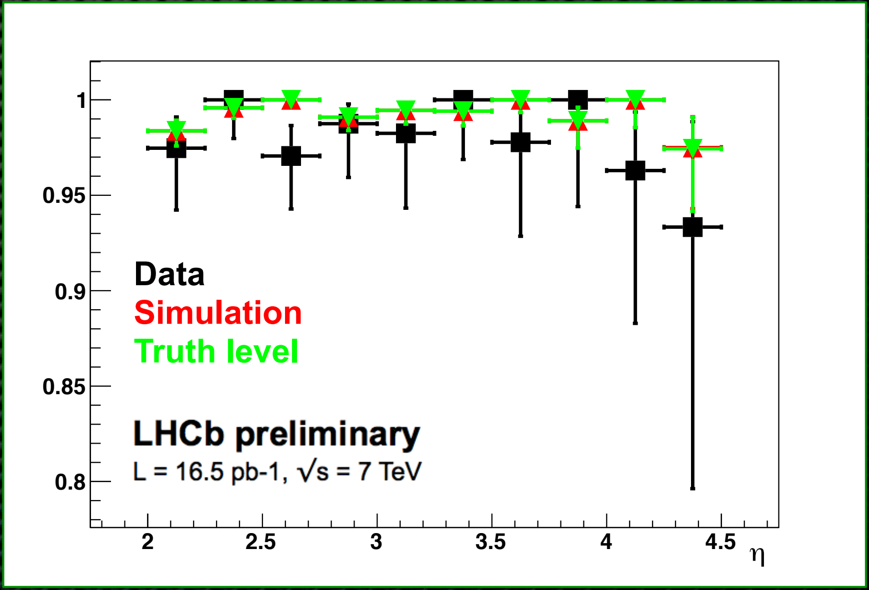


Efficiencies – μ-ID

- **Tag&Probe method in Z sample**
  - »Tag: identified muon
  - »Probe: identified track



- **Efficiency flat in ϕ, P_t, and η**
  - »No evidence of charge bias
  - »$\varepsilon^W = (98.2 \pm 0.5)\ \%$
  - »$\varepsilon^Z = (96.5 \pm 0.7)\ \%$



Systematics

- Efficiency uncertainties dominated by limited statistics
- Luminosity error dominant
- Background error large for W because of uncertainty on shapes

Source	Z	W^+	W^-
Background	0.1	3	5
$\varepsilon_{tracking}$	1	1	1
$\varepsilon_{\mu\text{-}ID}$	0.7	0.5	0.5
$\varepsilon_{trigger}$	4	4	4
$\varepsilon_{selection}$	-	2	2
$\int L$	10		
$\sigma_{systematic}$	11	11	12
$\sigma_{statistical}$	4	1	1

relative error

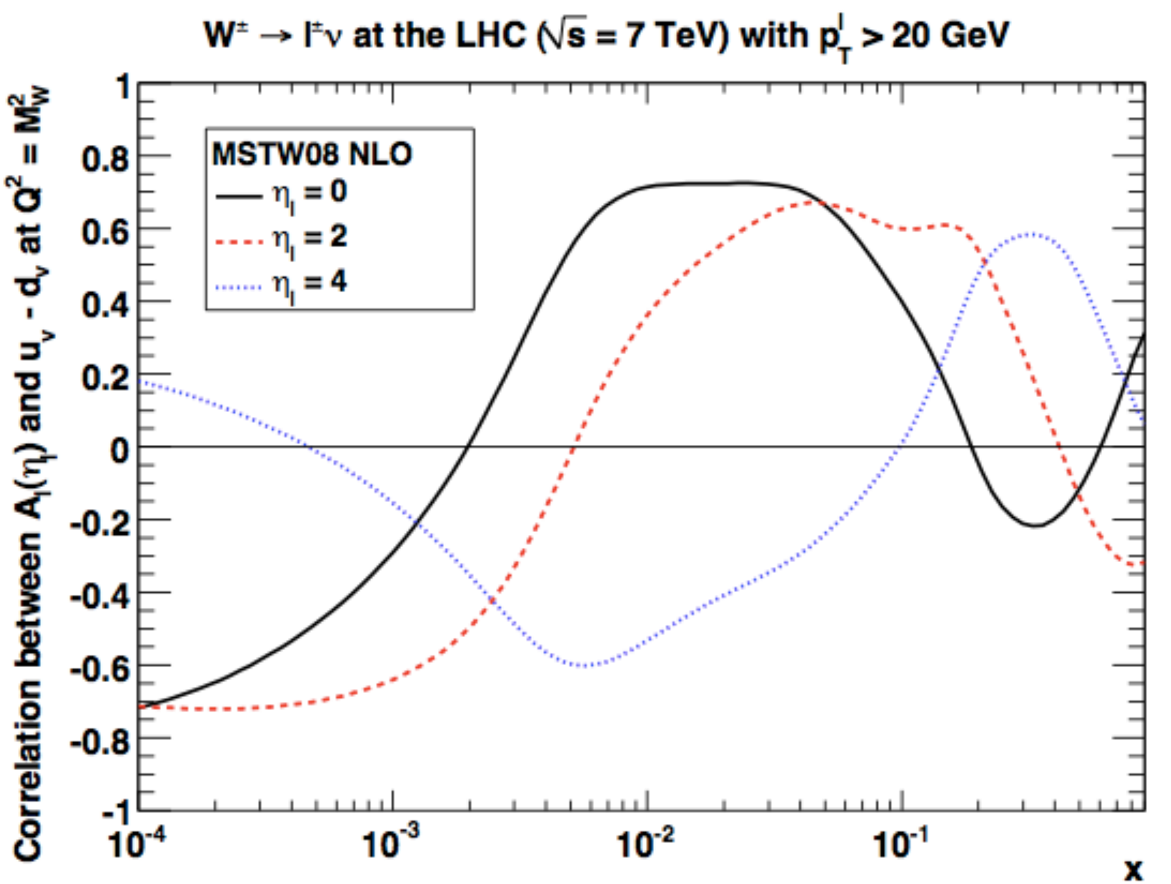
Comparisons

- All W and Z observations are consistent with NLO predictions (MSTW08)

Generator	PDF Set	$\sigma(Z)$	$\sigma(W+)$	$\sigma(W-)$	$\sigma(W)/\sigma(Z)$	$\sigma(W+)/\sigma(W-)$
FEWZ	MSTW08NLO	$65.7^{+2.9}_{-2.5}$				
	CTEQ66NLO	$66.6^{+2.6}_{-2.4}$				
	NNPDF2.0	65.0 ± 2.4				
MCFM	MSTW08NLO	$65.5^{+2.8}_{-2.5}$	851 ± 35	656 ± 30	23.1 ± 0.2	1.30 ± 0.04
Data		$73 \pm 4 \pm 7.5$	$1007 \pm 48 \pm 101$	$682 \pm 40 \pm 68$	23.1 ± 1.5	1.48 ± 0.11

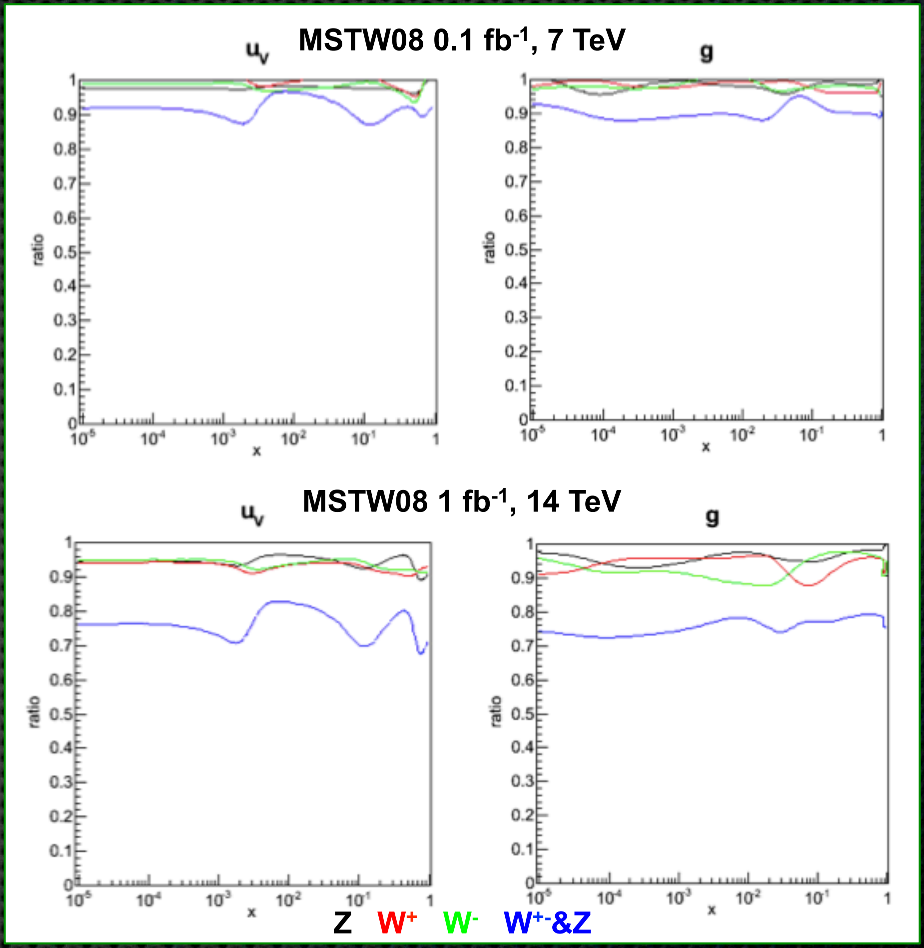
Improvements on PDFs

PDF correlation between asymmetry and u_v-d_v versus x



Improvements on PDFs

$$ratio = \frac{\sigma_{PDF}\ \text{with LHCb data}}{\sigma_{PDF}\ \text{without LHCb data}}$$

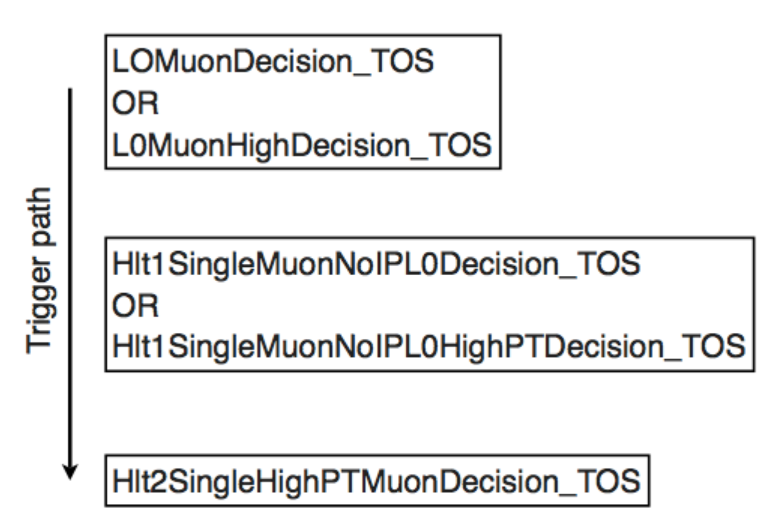


- **MSTW08 0.1 fb^{-1}, 7 TeV**
  small improvement with small amount of data

- **MSTW08 1 fb^{-1}, 14 TeV**
  higher energy, more data
  -> improvement up to 30%

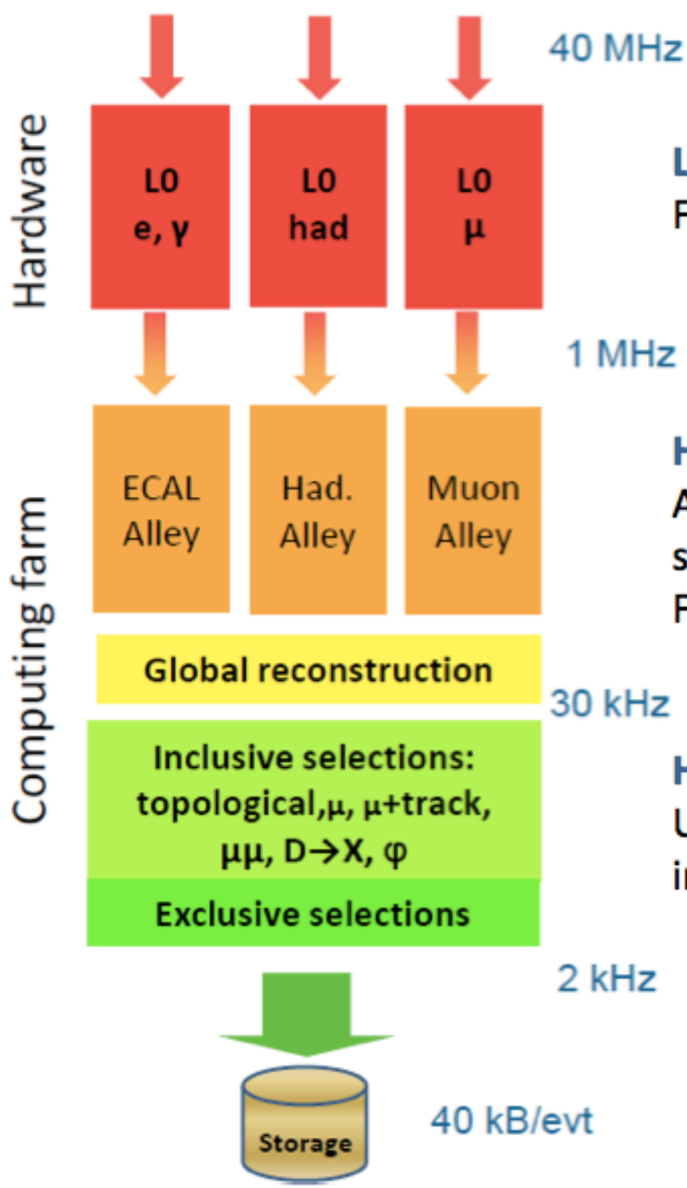
- Differences between PDF sets larger than uncertainties
  -> W, Z measurements will allow to distinguish between different PDF models

Efficiencies – Trigger



L0	
L0Muon	Pt > 1.75 GeV (35 counts) & SPD mult < 900
L0MuonHigh	Pt > 3.0 GeV (60 counts) & SPD mult < 900
HLT1	
Global cuts	Present
Muon quality cuts	FitMuChi2 < 16 & FitChi2/Ndf < 10
LowPTNoIP	Pt > 1.8 GeV 20% of sample has prescale (x0.2)
HighPTNoIP	Pt > 5.0 GeV
HLT2	
HighPTNoIP	Pt > 10 GeV

Efficiencies – Trigger



Level 0 : Hardware triggers
From Muon system & calorimeters

HLT1 : Software triggers
Add information from VELO and tracking stations to Level 0 information
Find proton-proton vertices etc.

HLT2 : Software triggers
Use all of the detector information to make inclusive and exclusive selections

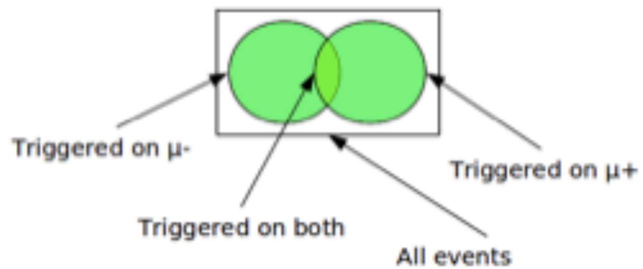
Efficiencies – Trigger

University of Zurich[UZH]

Physics Institute

Albert Burshe

Method



$$\begin{aligned}
\varepsilon^{+} &= n_{+\wedge-}/n_{-} && (1)\\
\varepsilon^{-} &= n_{+\wedge-}/n_{+} && (2)\\
\varepsilon^{-\vee+} &= \varepsilon^{+}+\varepsilon^{-}-\varepsilon^{+}\varepsilon^{-} && (3)\\
\varepsilon^{\text{at least one muon TOS}} &= \varepsilon+\varepsilon-\varepsilon\varepsilon = 2\varepsilon+\varepsilon^{2} && (4)\\
\varepsilon^{\text{both muons TOS}} &= \varepsilon^{2} && (5)\\
\frac{n_{\text{both muons TOS}}}{n_{\text{at least one muon TOS}}} &= \frac{\varepsilon^{2}}{2\varepsilon+\varepsilon^{2}} =: \gamma && (6)\\
\varepsilon &= \frac{2\gamma}{\gamma+1} && (7)
\end{aligned}$$

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Efficiencies – Tracking

Michel De Cian

LHCb-INT-2010-058

2.1 General Procedure

In the following the procedure to measure the tracking efficiency is described:

- Reconstruct a long track with $p_T > 20$ GeV, require that is has been positively identified by the muon system, and that it has triggered the event (i.e. the track is TOS[2]).
- Run a pattern recognition which reconstructs a standalone track in the muon system. Calculate the momentum of this standalone track by requiring it to have come from the primary vertex. Extrapolate the track through the TT detector and add hits which lie in a certain window around the track (at least 2 hits in the TT need to be found). Add these hits to the track and refit it. This track is subsequently called muonTT track.
- Require the muonTT track to have $p_T > 5$ GeV.
- Perform a vertex fit of the long track and the muonTT track.
- This can be done twice, as once the positively charged muon can be taken as "tag", once the negatively charged.
- Compare the LHCbIDs of the muonTT track with the ones of all the long tracks in the event with the same charge as the muonTT track. Apply a criterium for the number of LHCbIDs which have to match to call the track associated.

Efficiencies – μ-ID

Introduction

Tag + Probe

James Keaveney

- μ ID efficiency is defined as the fraction of real muons which are reconstructed as long tracks that are subsequently matched to muon tracks and pass 'isMuon'

$$\epsilon_{\mu} = \frac{\text{true muon long tracks w/ isMuon==1}}{\text{true muon long tracks}} \quad (1)$$

- μ ID efficiency at the Z peak must be well understood as we proceed towards a $\sigma \cdot \mathrm{Br}(Z -> \mu\mu)$ measurement.
- The classic "Tag Probe method" is a suitable data-driven method to measure this efficiency.
- With ≈ 83 $Z -> \mu\mu$ events in $1\mathrm{Pb}^{-1}$ we are still statistically limited but enough Zs to test and tune the method.

Efficiencies – μ-ID

Method

Tag+Probe methodology

- Tag -
  - Take all candidates from the stripping line Z02MuMuNoPIDs in $\approx 1Pb^{-1}$
  - Apply track pre-selections (P(χ^2), σP/P)
  - Apply tight μ ID to one of the muons, (isMuon==1, PIDmu> -3)
  - require surviving candidates to have $75GeV < M_{\mu\mu} < 107GeV$. (Close to Z peak)
- Probe -
  - The fraction of these candidates in which the unbiased muon passes isMuon==1 estimates the single muon efficiency.
  - From this we deduce the dimuon ID efficiency $\epsilon_{\mu\mu} = (\epsilon_\mu)^2$