Prospects for indirect luminosity measurements at LHCb

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For the LHCb collaboration

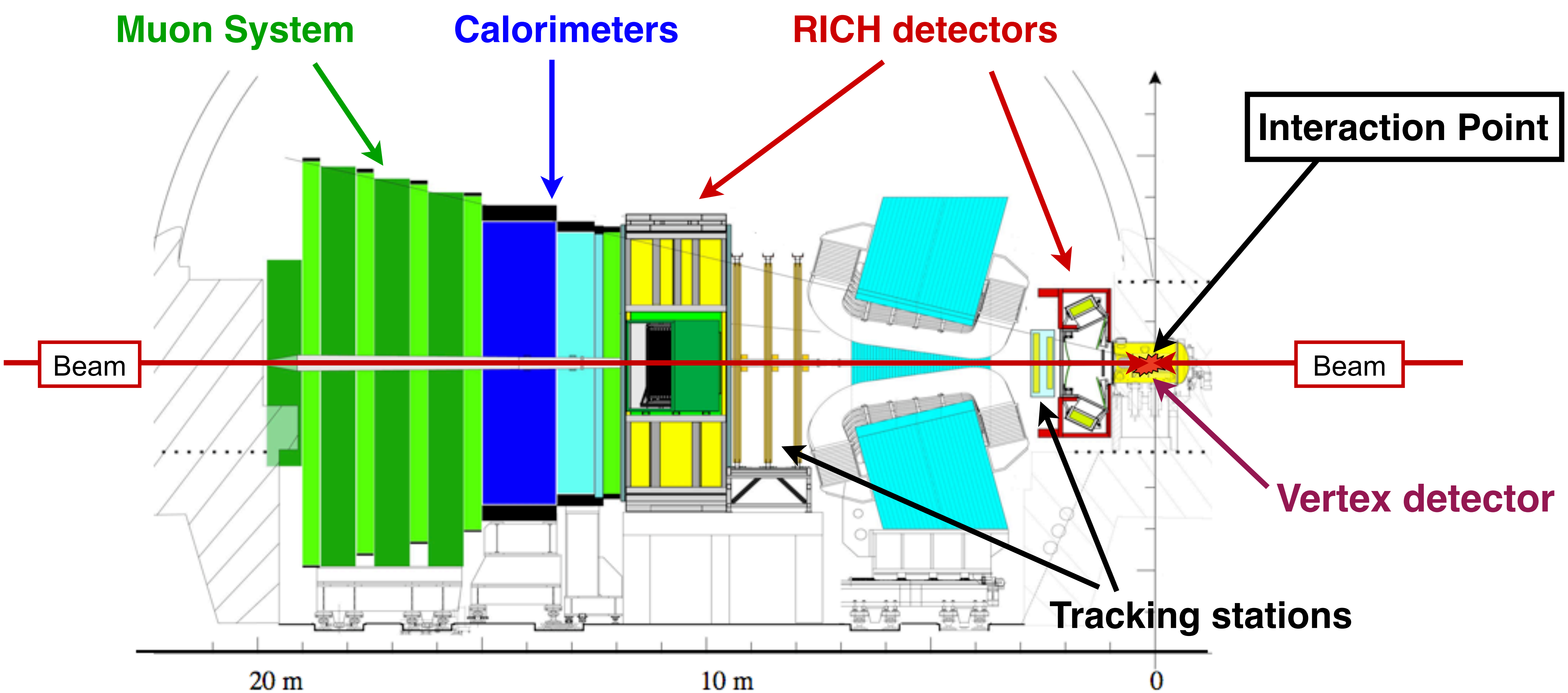
LHCb: A forward spectrometer

Fully instrumented at high rapidities

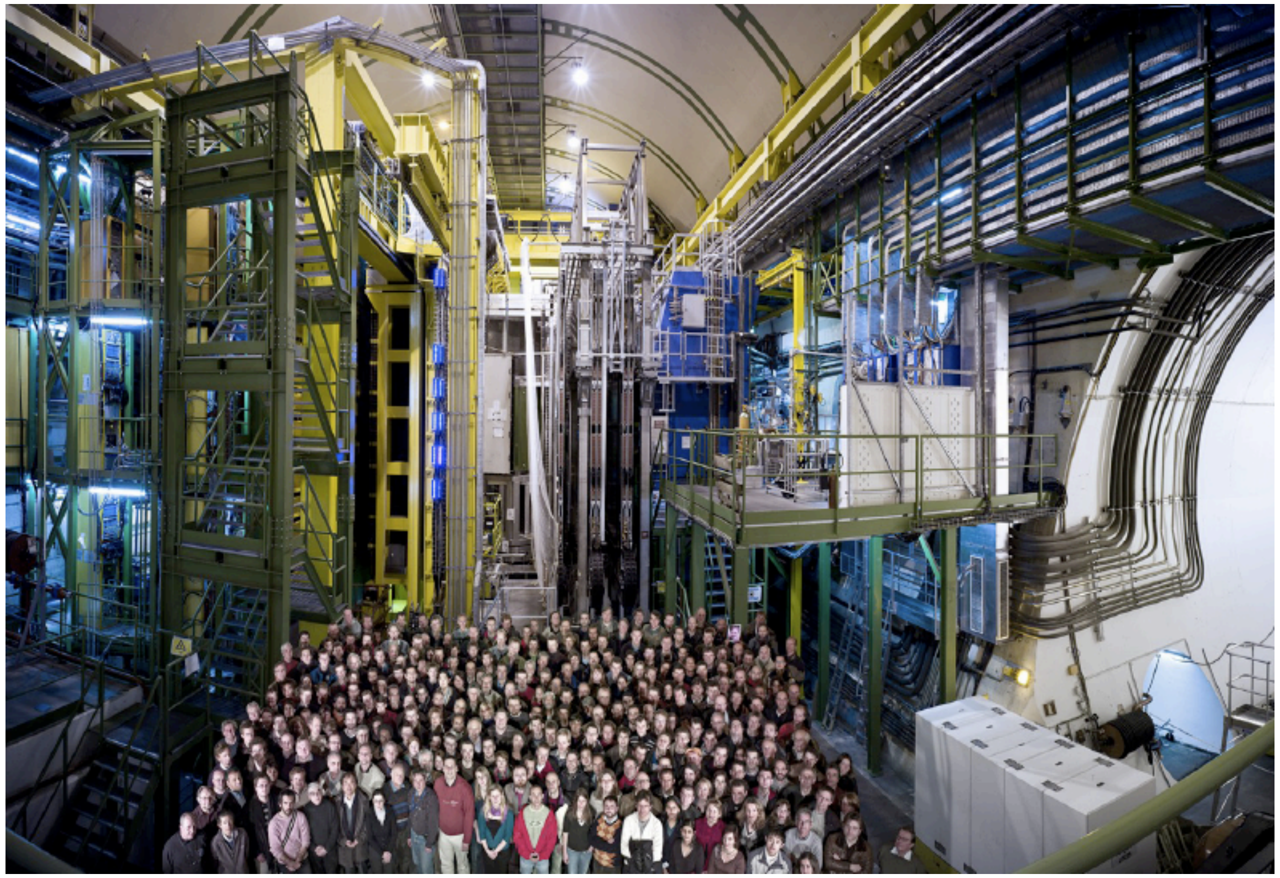
- Overlap region with Atlas/CMS ($1.9 < \eta < 2.5$)
- High rapidities unique to LHCb ($2.5 < \eta < 4.9$)

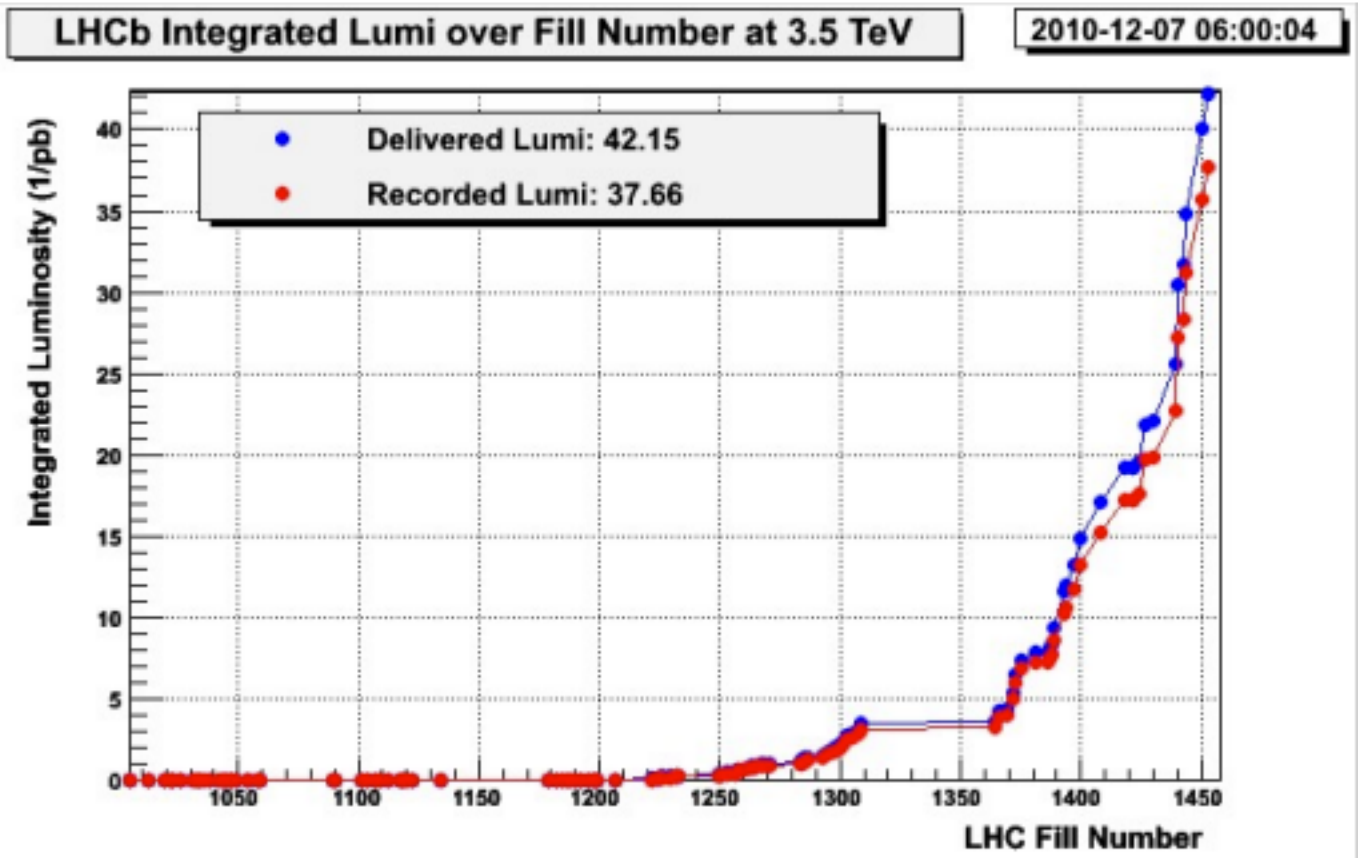
Can record low momentum muons

- Reco: $P > 3$GeV & $P_T > 0.5$GeV
- Trigger: $M_{\mu\mu} > 2.5$GeV & $\Sigma P_T > 1.5$GeV
- Exclusive trigger stream: $M_{\mu\mu} > 1$GeV



LHCb: A forward spectrometer





2010: 37.7 pb^{-1} of data on tape,
16.5 pb^{-1} used thus far for electroweak measurements
2011: Hope for 1-2 fb^{-1} of data

Luminosity measurements at LHCb

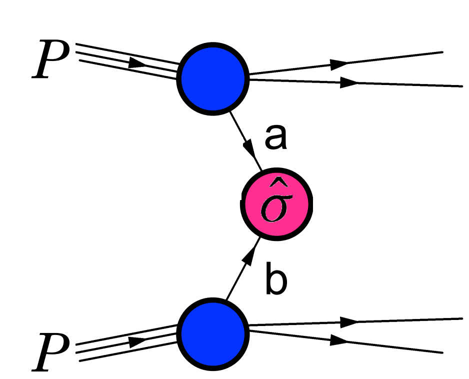
Direct Measurements

- Direct measurement of beam parameters - shape, current etc.
- Two methods employed
  - Van der Meer scan
  - Beam profiling via beam gas interactions
- See talk of Vladislav Balagura in this afternoons session for details

Indirect Measurements

- Measure the event rate of some theoretically well known process
- Precision determined by:
  - The uncertainty on the cross-section prediction
  - Experimental uncertainties (efficiencies etc.)
- Two processes identified at LHCb for this purpose
  - W & Z production
  - Dimuon production via two photon fusion

W & Z production at LHCb

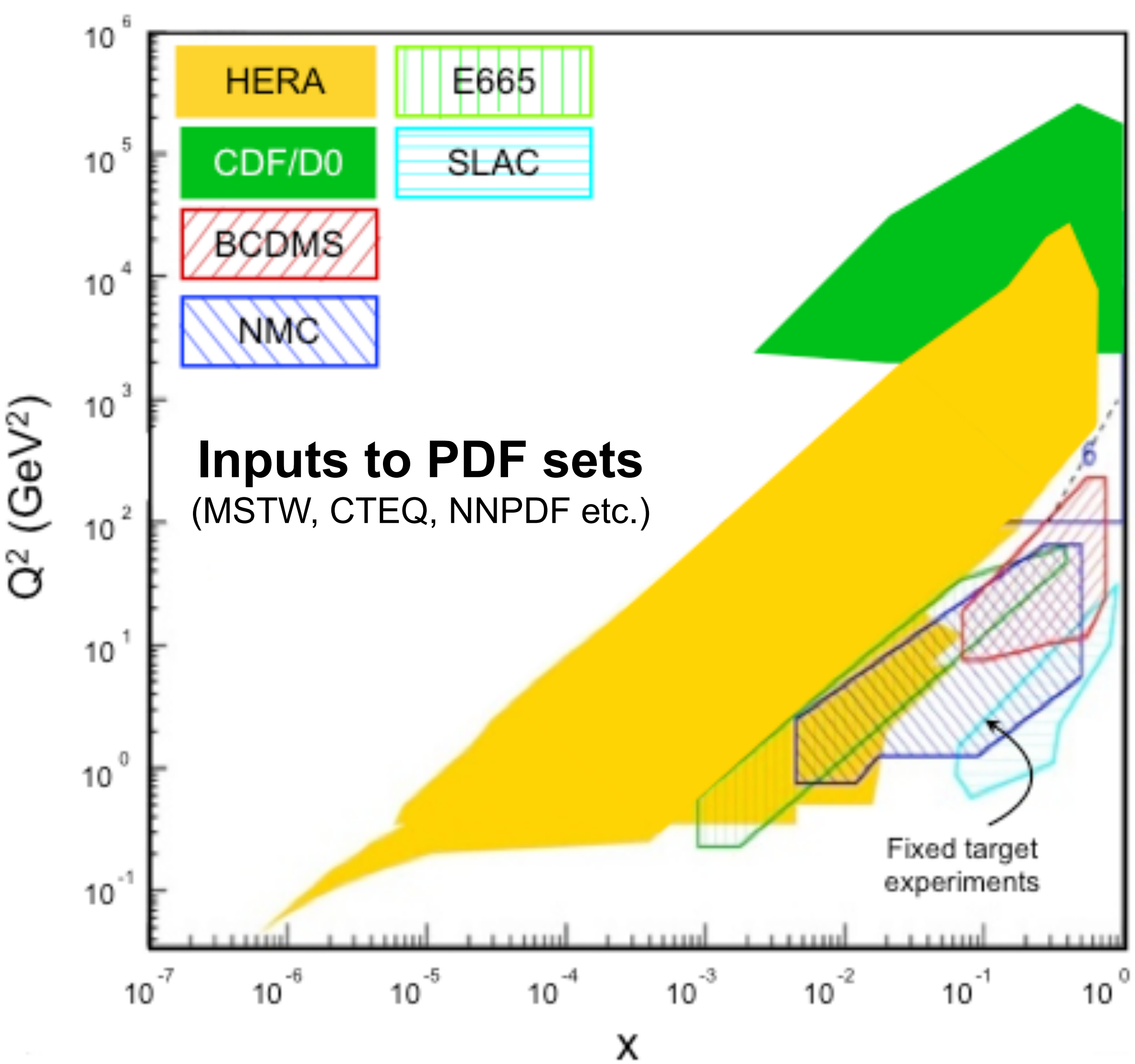


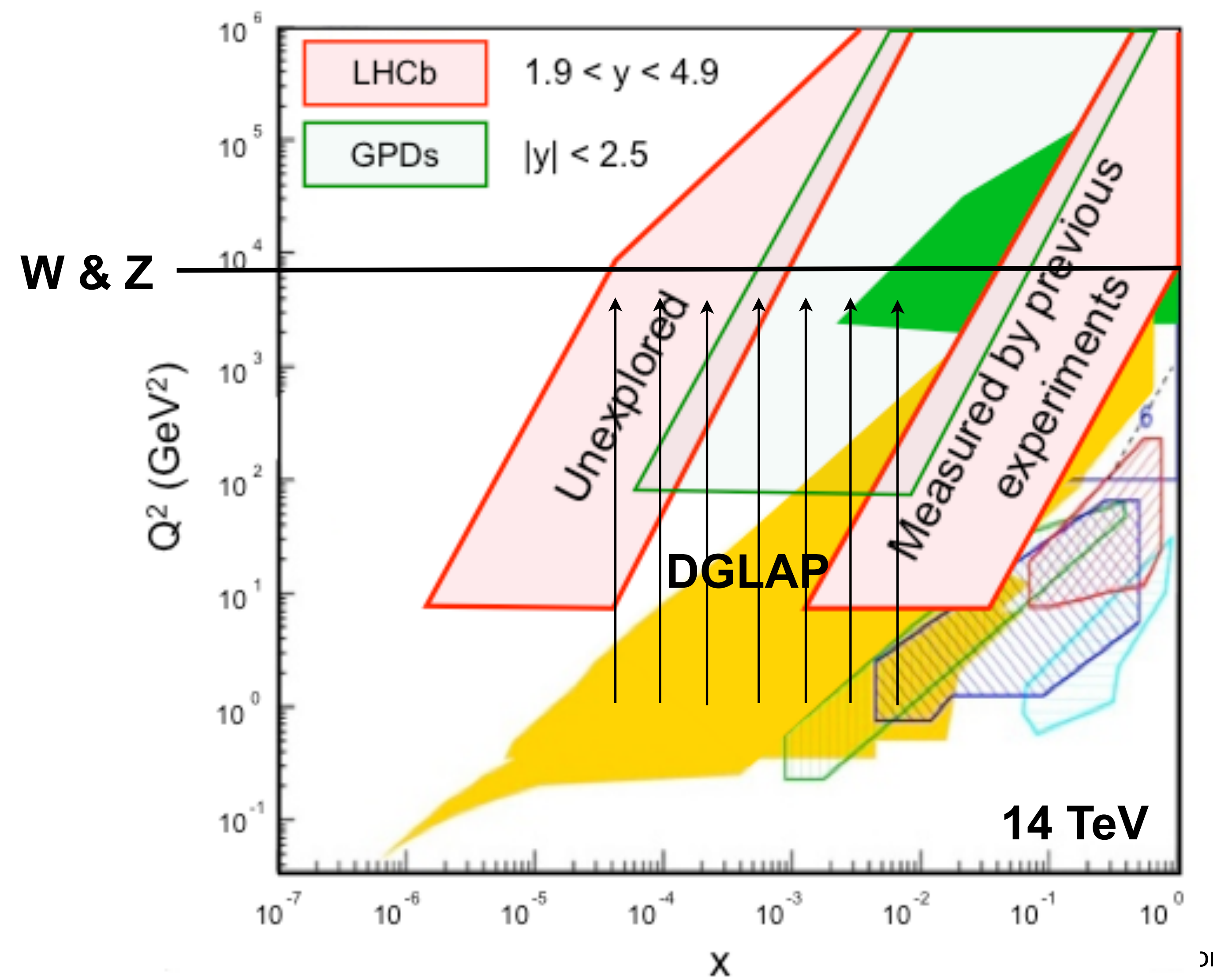
Cross-section calculation must be factorised:

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

PDFs: parameterised using data from previous experiments (HERA, Tevatron, fixed target)

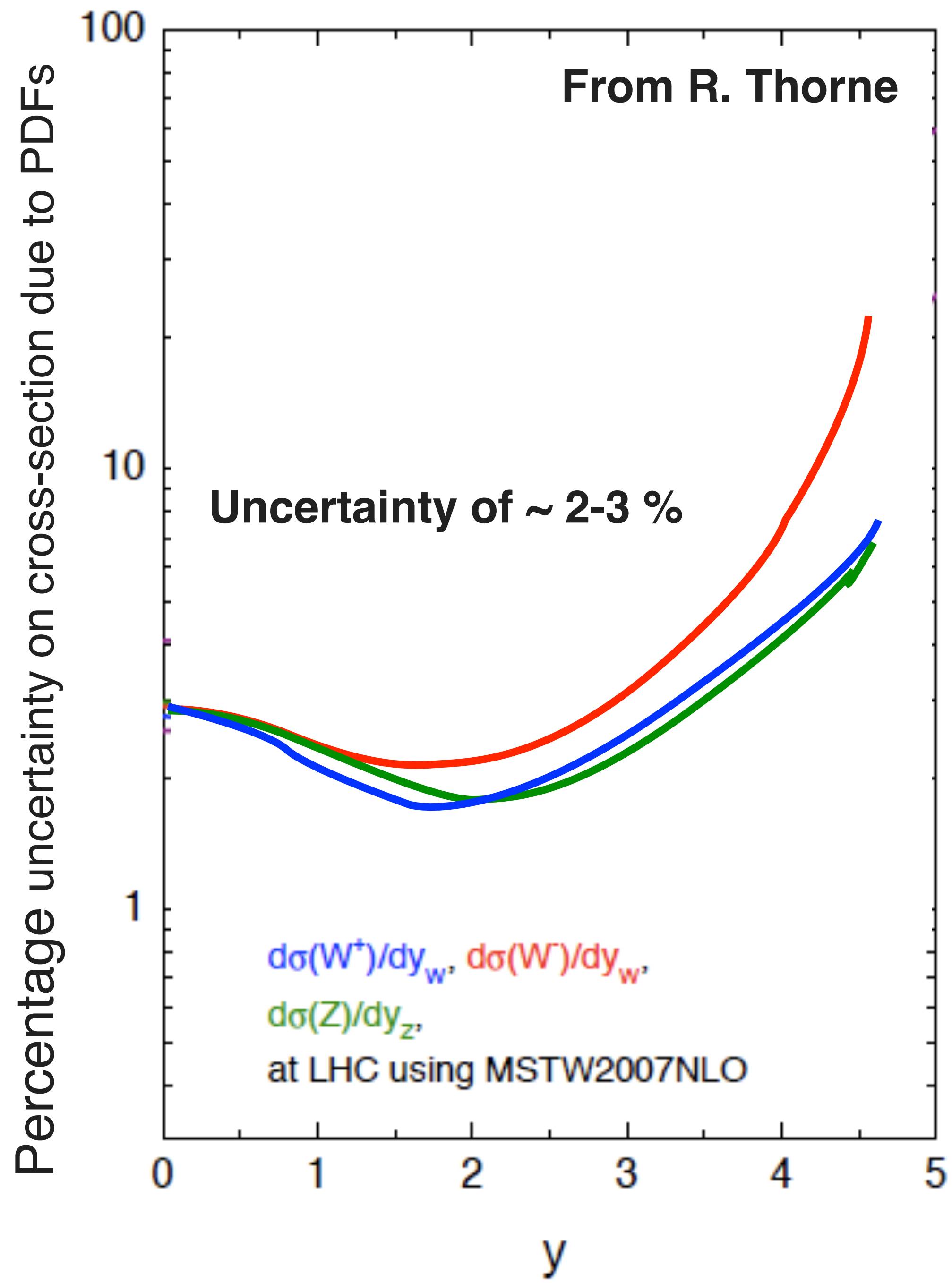
NNLO: accurate to ~1% for W & Z





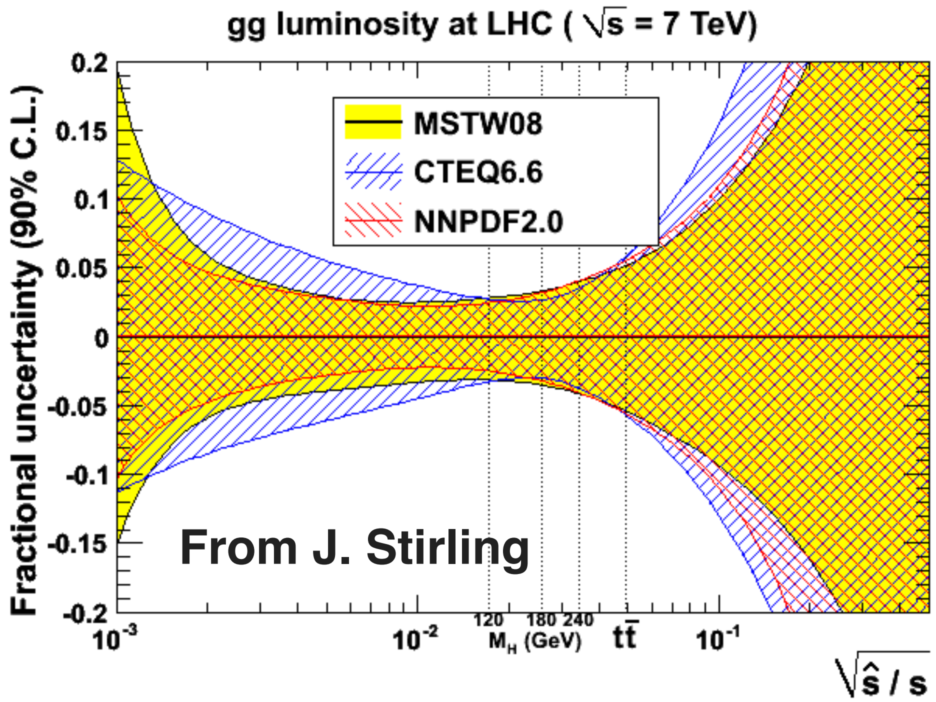
PDF uncertainties at $Q^2 \sim M_Z^2$ at the LHC

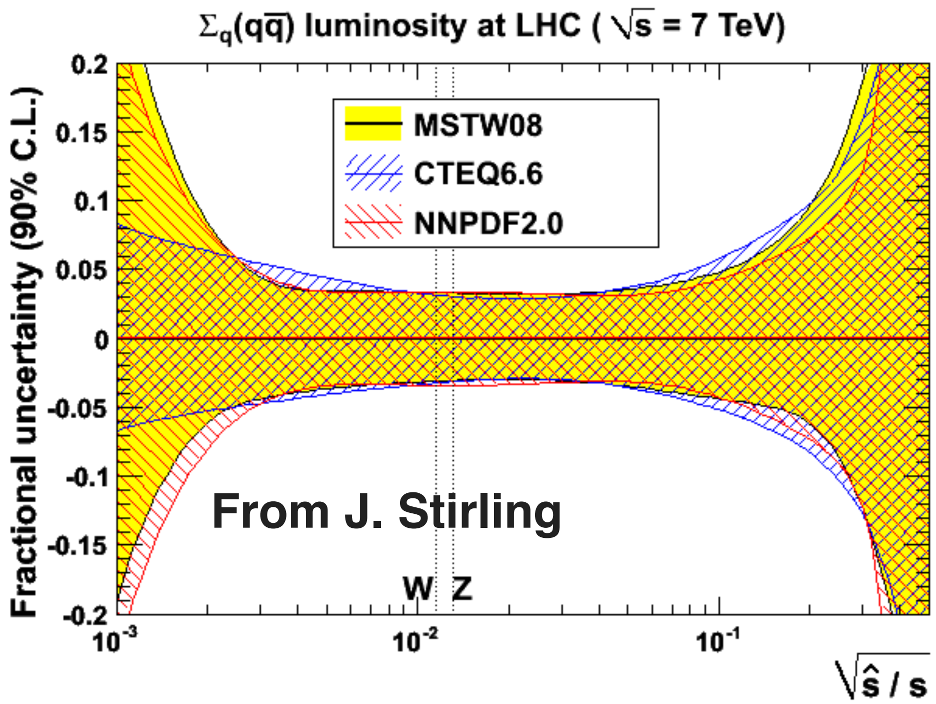
PDF uncertainty from MSTW



LHCb

Comparison with other PDF sets





Overall uncertainty ~ 4-5 %

Z cross-section measurement at LHCb

Trigger:

Single μ, $p_T > 10$ GeV

Muon:

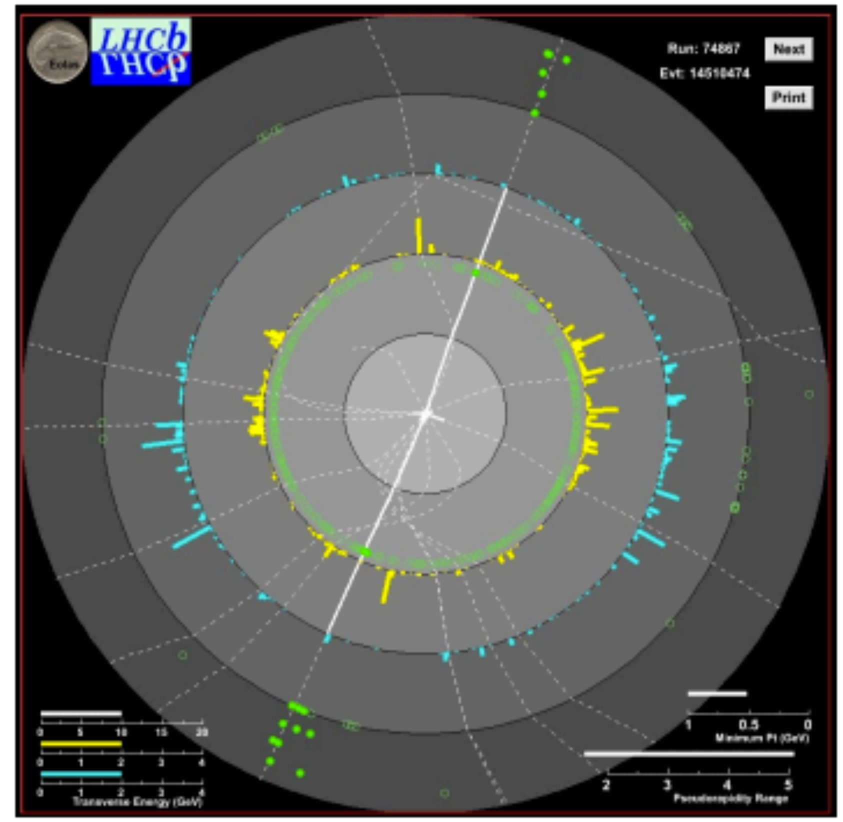
Good track quality (σ_p/p, χ^2 probability)

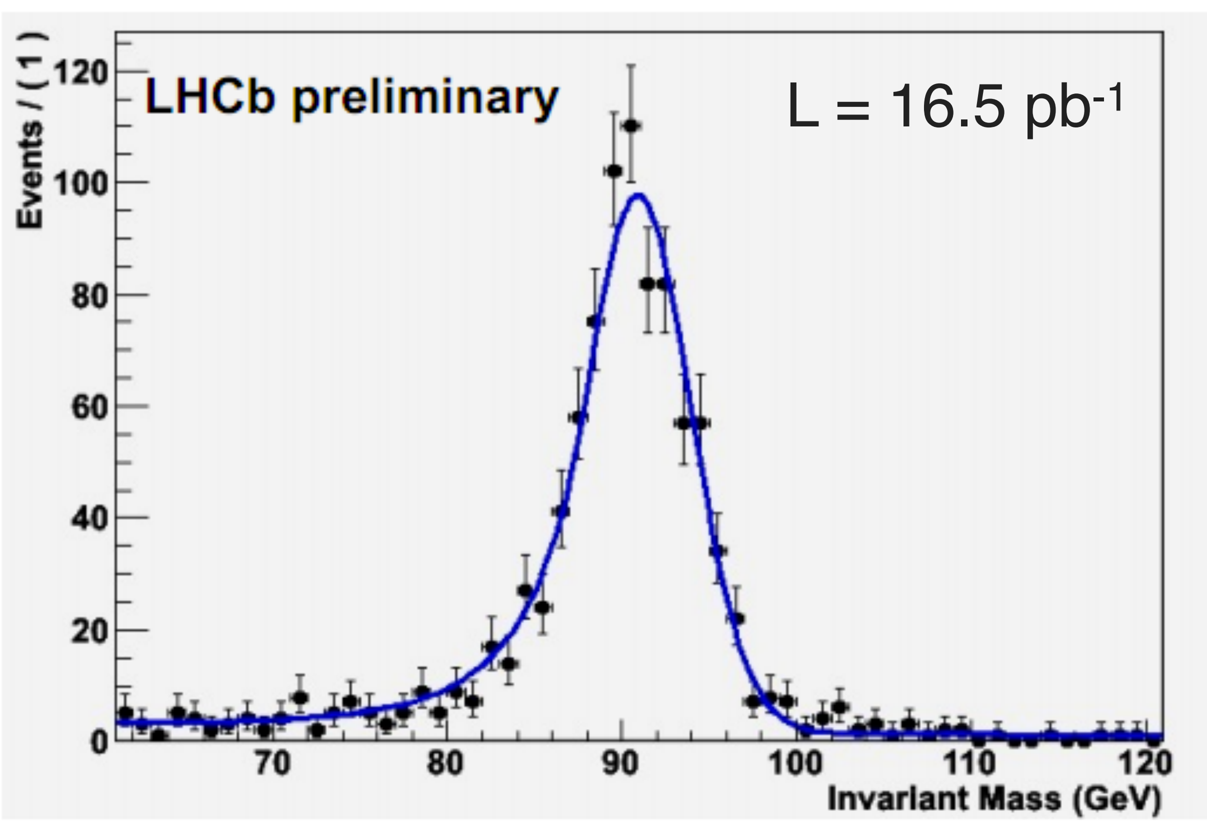
$p_T > 20$ GeV

$2.0 < \eta < 4.5$

Z:

$81 < m(\mu\mu) < 101$ GeV





$N_Z = 833$ (16.5 pb^{-1})

Backgrounds:

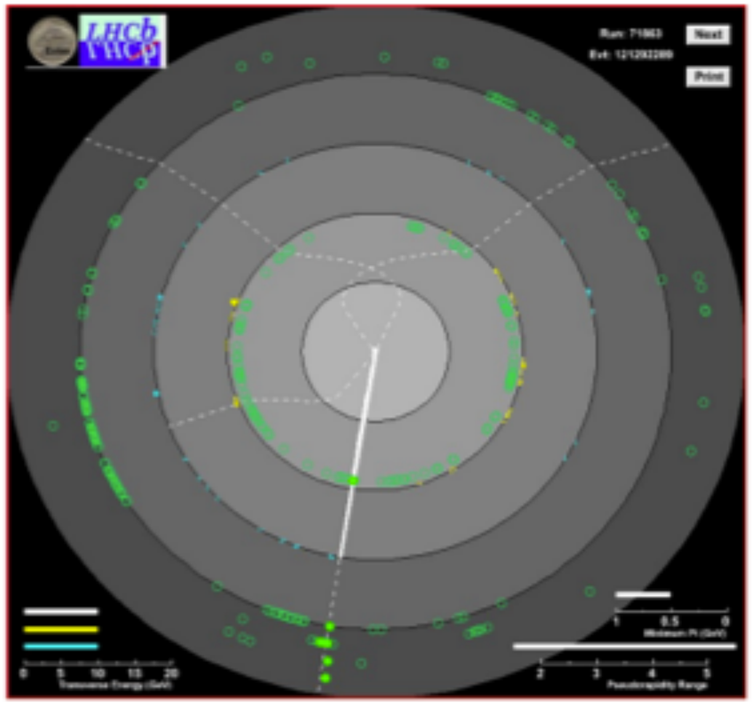
Z -> tautau (~0.2)

Heavy flavour (~1)

Hadron mis-id (< 0.03)

$N_{bkg} = 1.2 \pm 1.2$

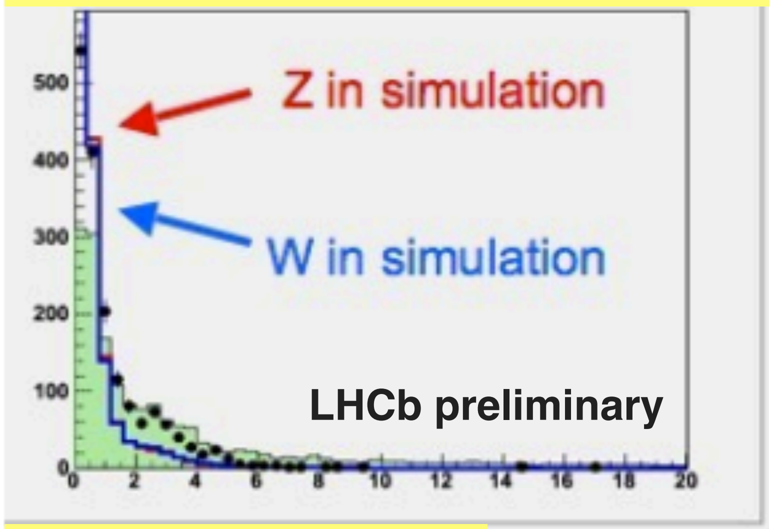
W cross-section measurement at LHCb



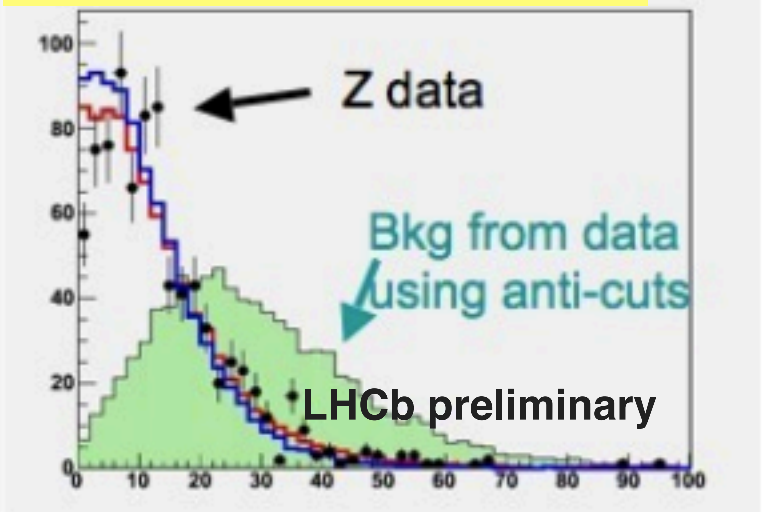
Data driven efficiency and purity determination

W(sim) = Z(sim)
Z(sim) ~ Z(data)
Background(data) != Z(data)

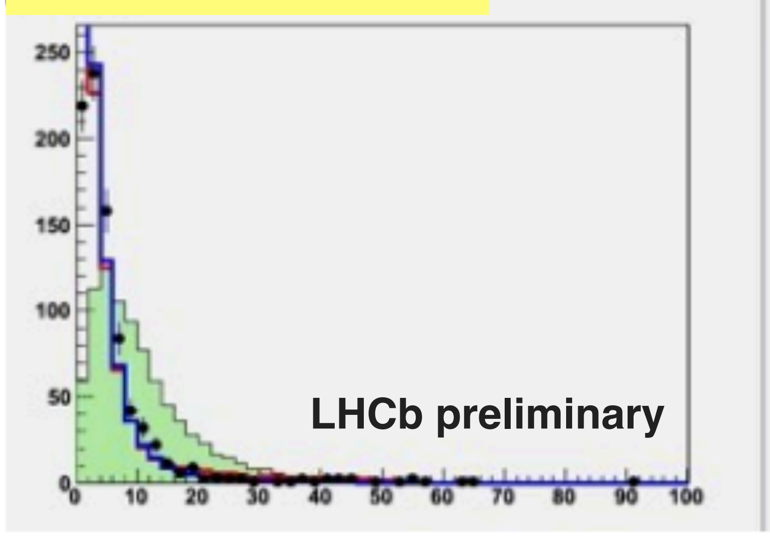
Muon impact parameter significance



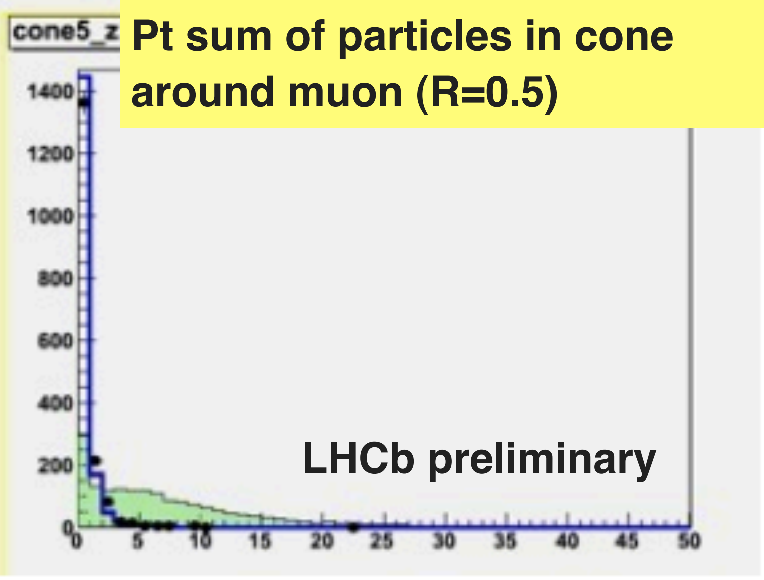
Invariant mass of rest of event



Pt sum of rest of event



Pt sum of particles in cone around muon (R=0.5)



Data derived:

- cuts
- efficiency (sel eff = 55 ± 1 %)
- purity

Cuts applied:

- Muon IPS < 2
- Event mass < 20 GeV
- Event $\sum$Pt < 10 GeV
- Cone $\sum$Pt < 2 GeV

Determination of efficiencies: trigger

$$\varepsilon_Z = A_Z \varepsilon_Z^{trig} \varepsilon_Z^{track} \varepsilon_Z^{muon} \varepsilon_Z^{selection}$$

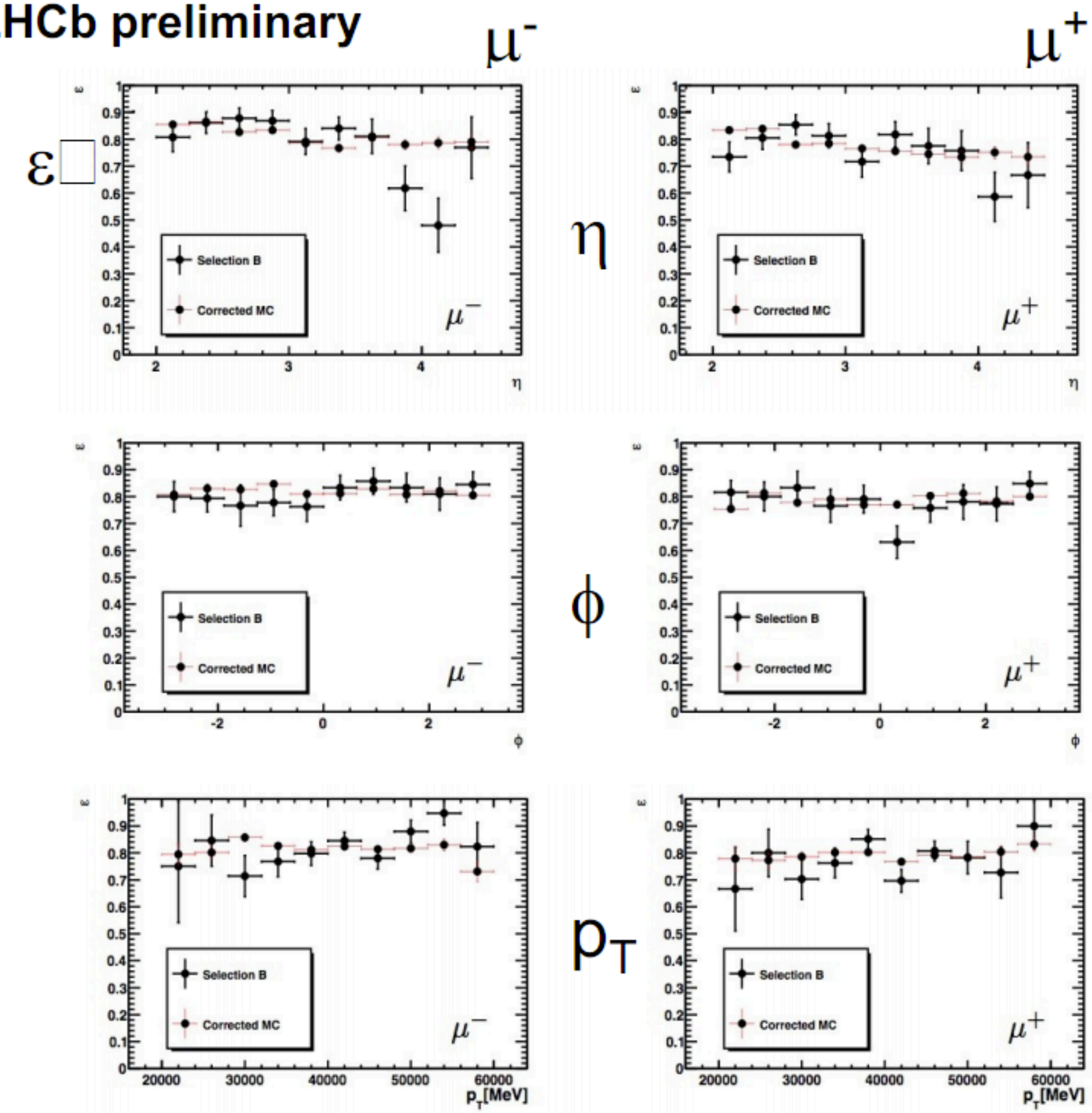
Single muon trigger efficiency

- Determine from data using an offline selected Z sample and tag and probe method
  Tag: muon passing single muon line
  Probe: Offline identified muon
- Efficiency given by how often the probe muon passes the single muon line

Efficiency is flat in eta, phi and Pt
No evidence of charge bias

eff = 86 ± 1 %

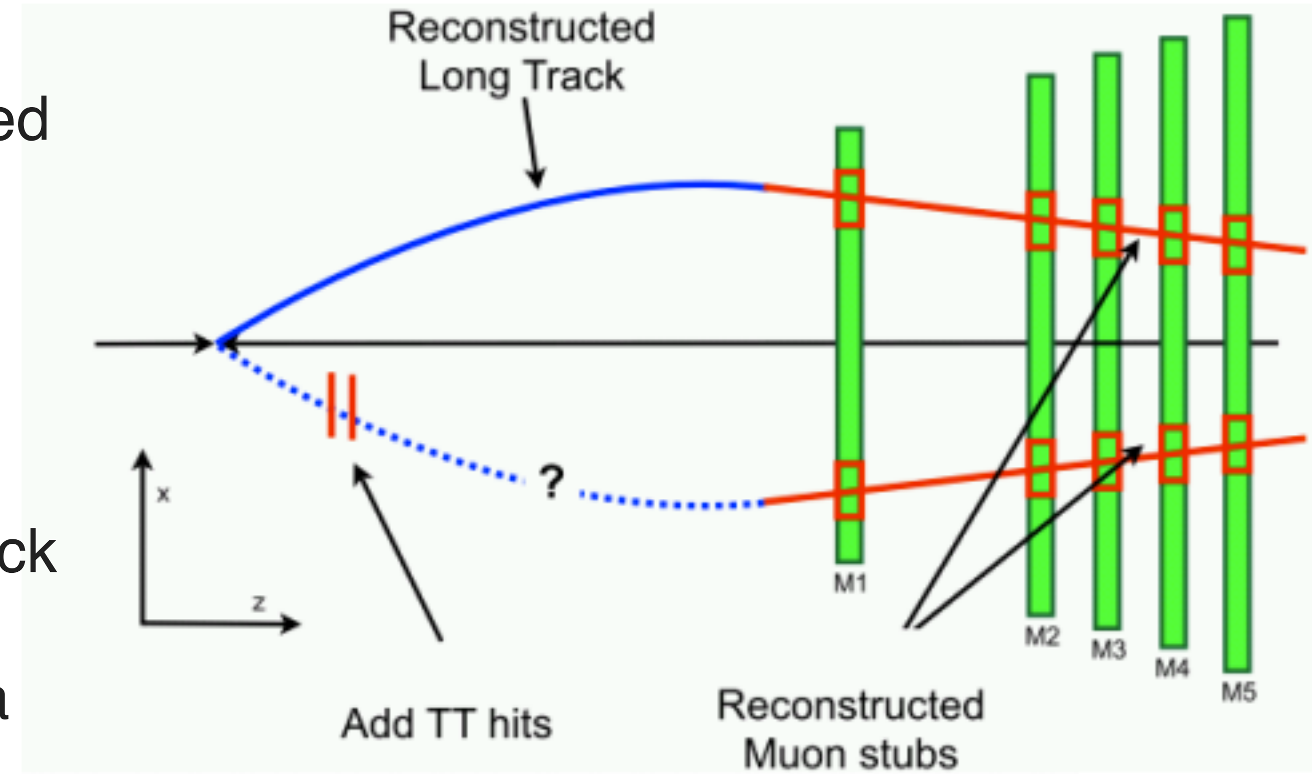
LHCb preliminary



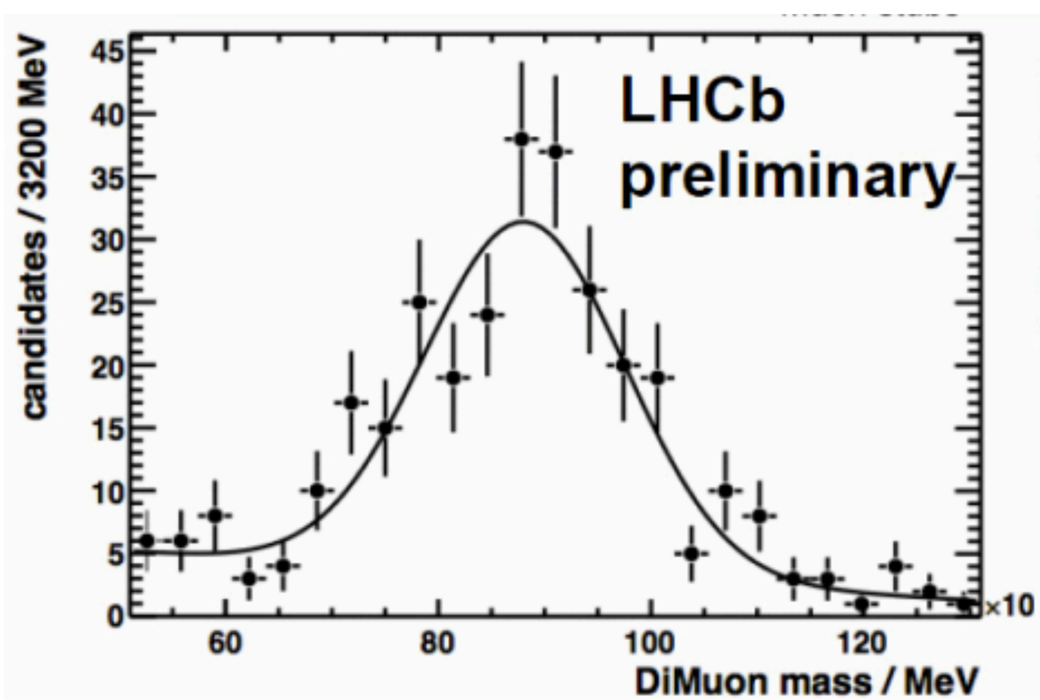
Determination of efficiencies: tracking

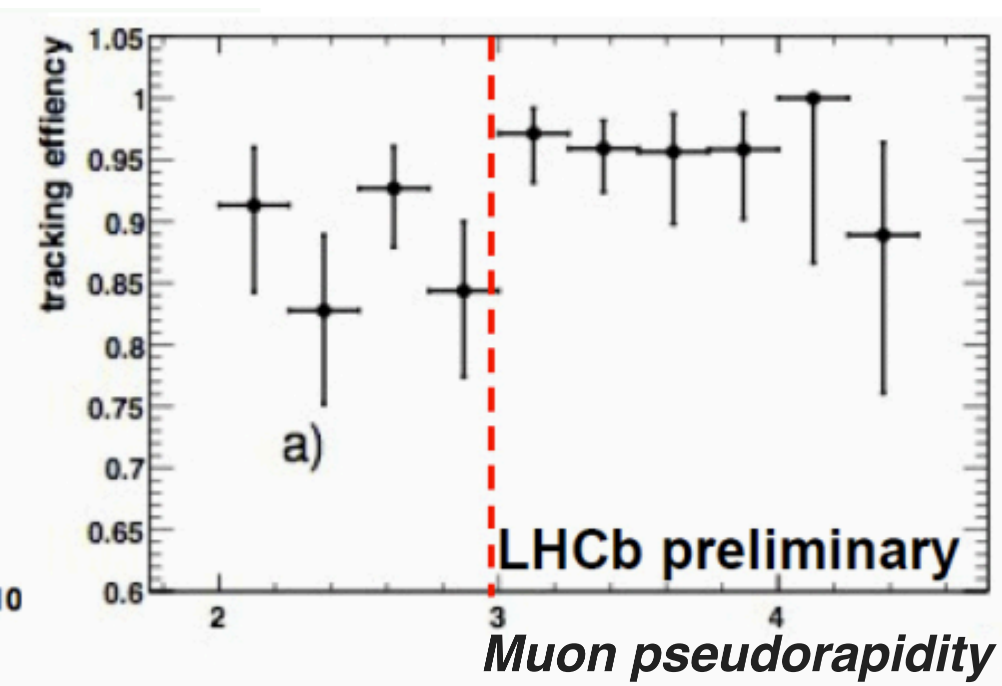
Single muon tracking efficiency

- Determine from data using an offline selected Z sample and tag and probe method
  Tag: long track muon passing trigger
  Probe: Muon stub with TT hits added
- Efficiency given by how often the probe can be matched to a reconstructed long track



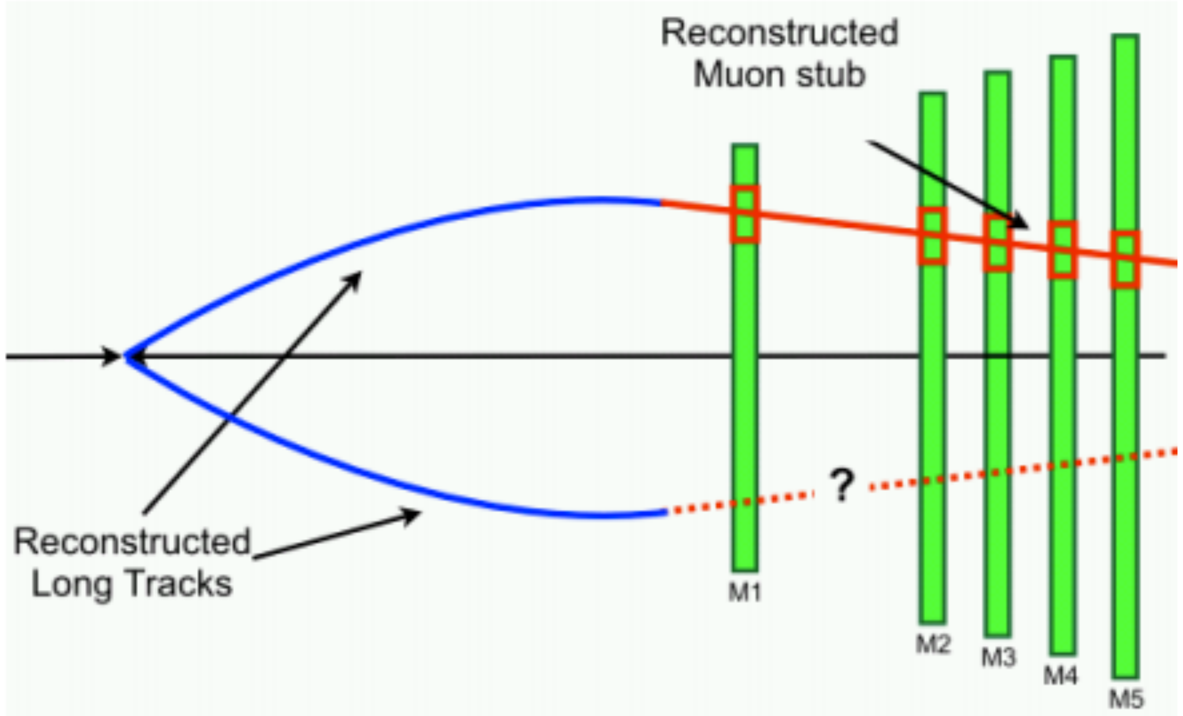
Flat in Pt and phi, 2 regions considered in eta
No evidence of charge bias
eff = 93 ± 1 %





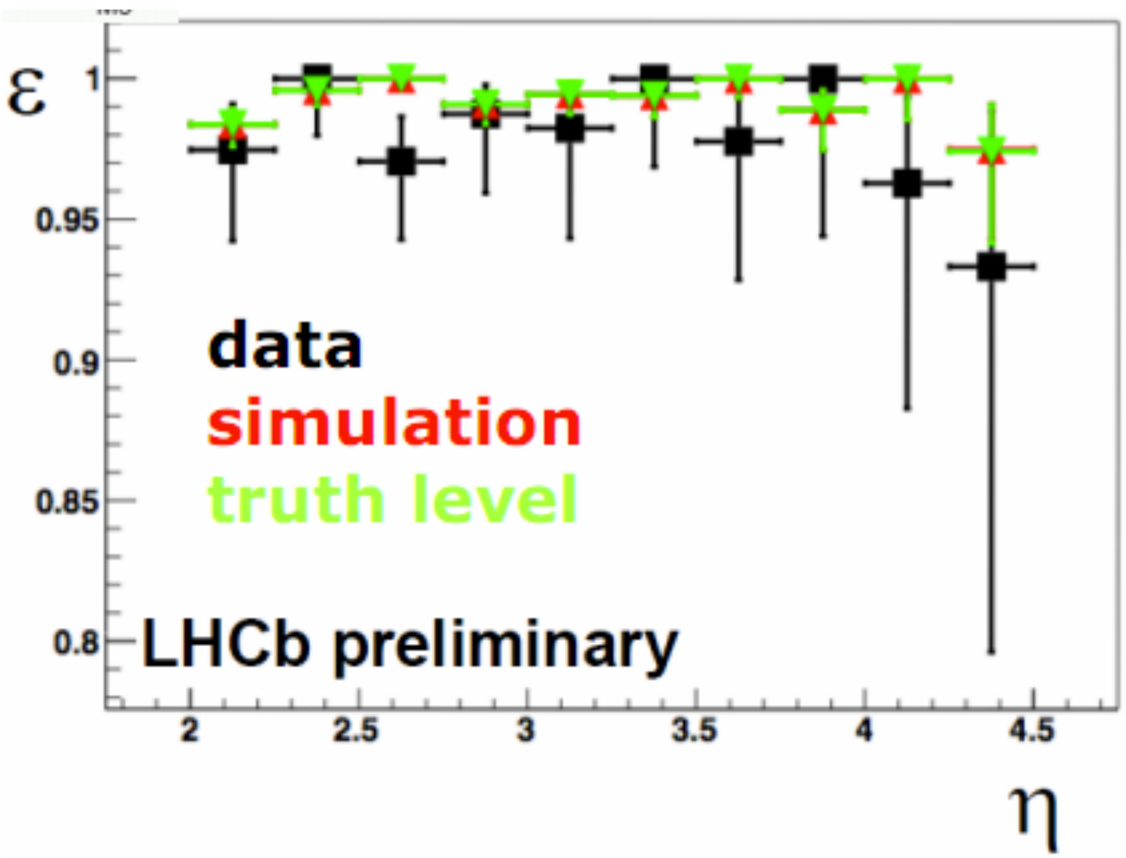
Determination of efficiencies: muon id

$$\varepsilon_Z = A_Z \varepsilon_Z^{trig} \varepsilon_Z^{track} \varepsilon_Z^{muon} \varepsilon_Z^{selection}$$



Single muon identification efficiency

- Determine from data using an offline selected Z sample and tag and probe method
  - **Tag:** long track muon passing trigger
  - **Probe:** Long track
- Efficiency given by how often the probe is identified as a muon



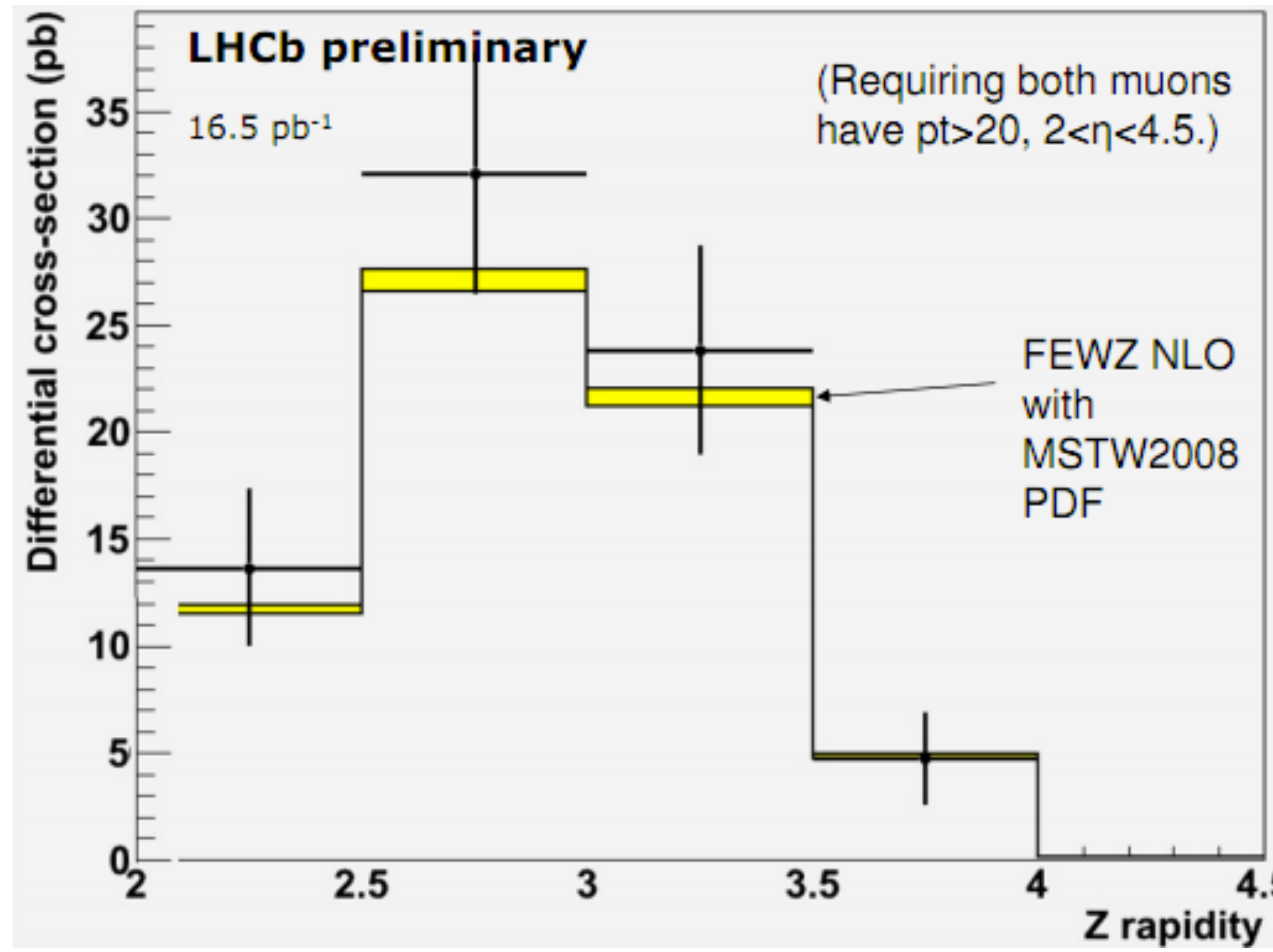
Flat in Pt, phi and eta

No evidence of charge bias

eff = 98.2 ± 0.5 %

Z cross-section measurement at LHCb

N_Z^{tot}	833
$Z \to \tau\tau$	0.2 ± 0.2
Heavy flavours	1 ± 1
Misidentified π/K	$<< 1$
N_Z^{bkg}	1.2 ± 1.2
ϵ_{trig}^Z	0.86 ± 0.01
ϵ_{track}^Z	0.83 ± 0.03
ϵ_{muon}^Z	0.97 ± 0.01
ϵ_{sel}^Z	1.
A^Z	1.
ϵ_Z	0.69 ± 0.03
L	$16.5 \pm 1.7 pb^{-1}$
$\sigma_Z(2. < \eta_1, \eta 2 < 4.5, 81 < m_Z < 101)$	$73 \pm 4 \pm 7$ pb.



W cross-section measurement at LHCb

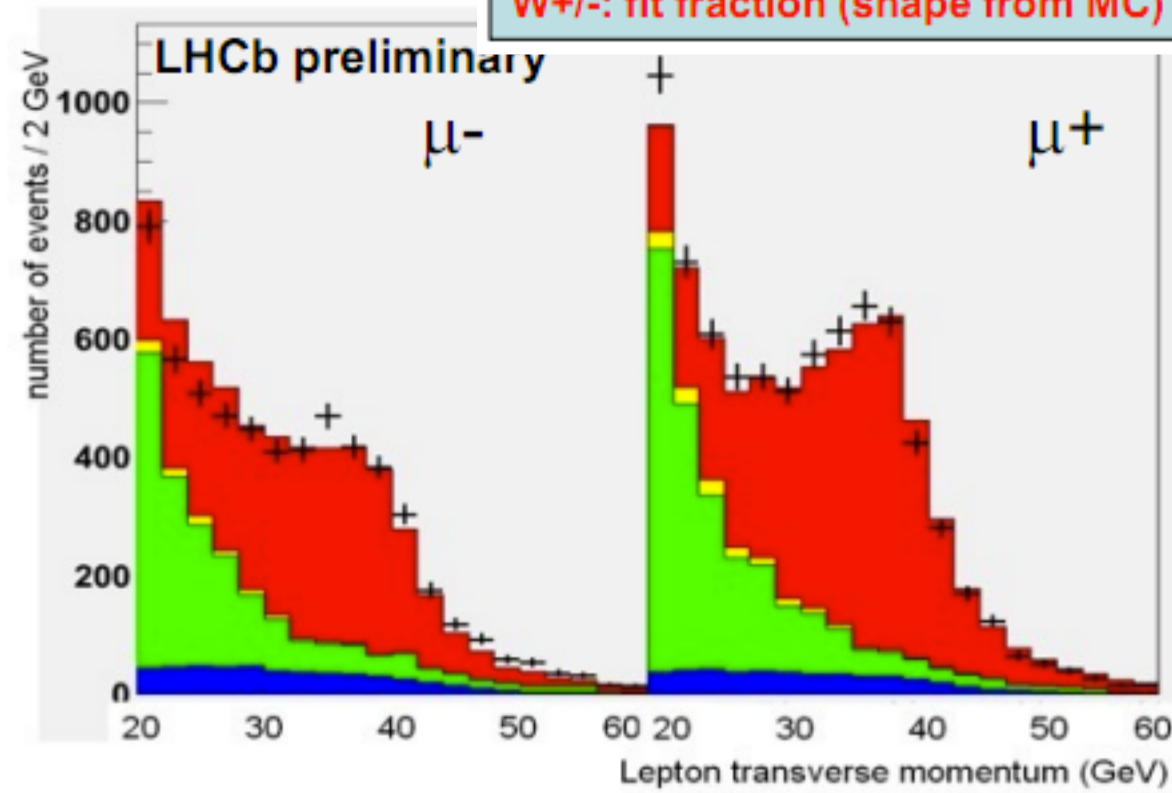
Fit muon Pt spectrum in data to expected shapes for signal and background and extract number of background events

$N_{bkg+} = 2194 \pm 150$

$N_{bkg-} = 1654 \pm 150$

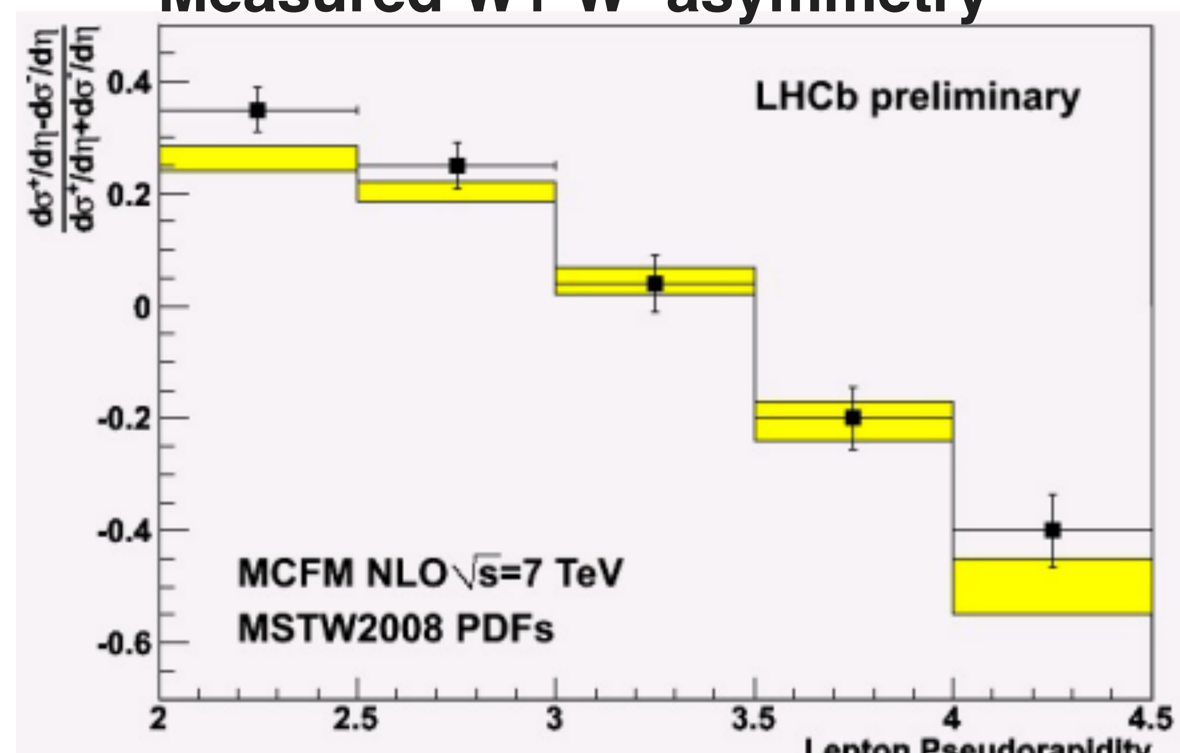
Trigger, tracking and muon-id efficiencies from Z sample and tag and probe

Z (fixed with sim)
τ (fixed and scaled to W)
QCD: fit fraction. (shape from data)
W+/-: fit fraction (shape from MC)



	$W+$	$W-$
N_W^{tot}	7624	5732
$W \to \tau\nu$	151	90
$Z \to \tau\tau$	2	2
$Z \to \mu\mu$	460	506
QCD	2194 ± 150	1654 ± 150
N_W	4817 ± 165	3480 ± 161
ϵ_{trig}^W	0.725 ± 0.03	
ϵ_{track}^W	0.73 ± 0.03	0.78 ± 0.03
ϵ_{muon}^W	0.982 ± 0.005	
ϵ_{sel}^W	0.55 ± 0.01	
A^W	1	1
ϵ_W	0.29 ± 0.01	0.31 ± 0.01
N_W^{tot}	16610 ± 800	11226 ± 650
L	$16.5 \pm 1.7\ pb^{-1}$	$16.5 \pm 1.7pb^{-1}$
$\sigma_W(2.0 < y < 4.5)$	$1007 \pm 48 \pm 100$ pb	$682 \pm 40 \pm 68$ pb

Measured W+ W- asymmetry



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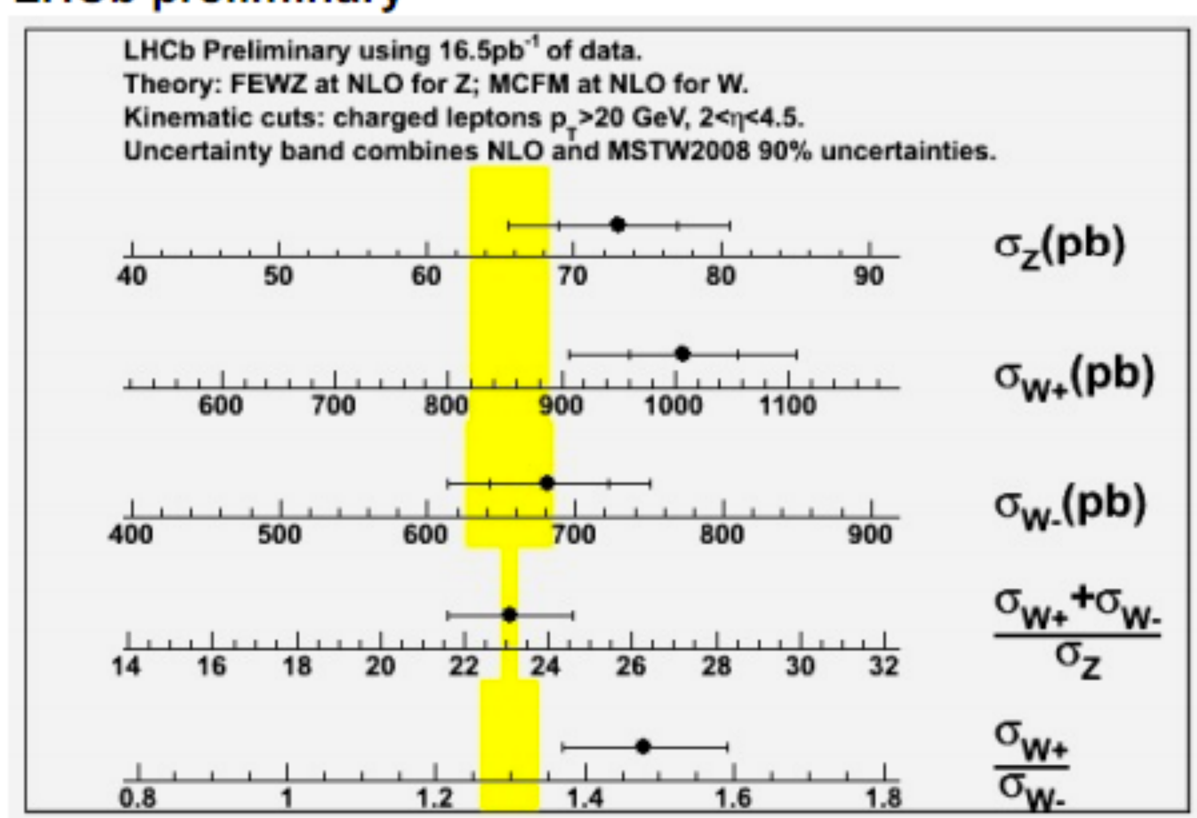
Summary of W & Z measurements

With 16.5 pb-1 we see

- 9500 W's and 833 Z's
- Cross-sections and ratios have been measured and compared to NLO predictions
- This corresponds to ~ half of the 2010 data set.
- Using the Z's alone, a luminosity measurement with an uncertainty of ~ 5 % is possible

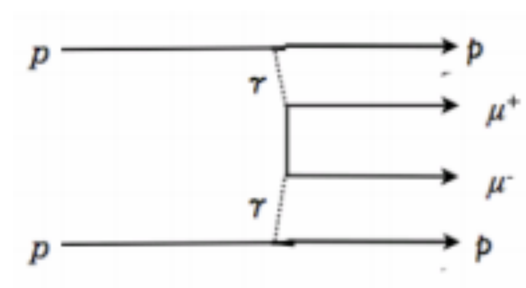
LHCb preliminary



Exclusive particle production at LHCb

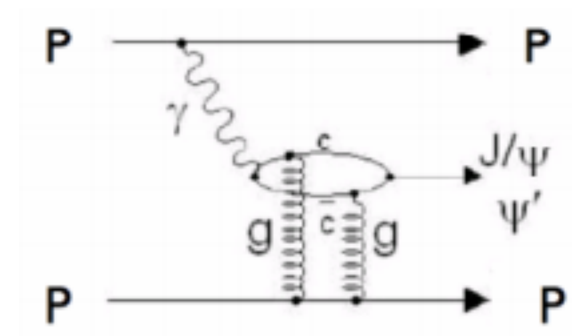
1. Dimuons from photon fusion

- Produced via diphoton fusion
- EM process: uncertainty on CS prediction < 1%
  - Ideal for measuring luminosity
- Modeled by the LPAIR generator
  (A.G. Shamov and V.I. Telnov NIM A 494 (2002) 51)



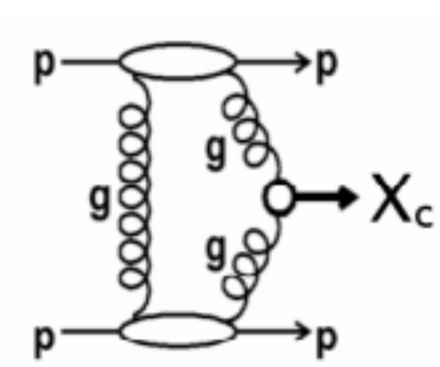
2. Exclusive JPsi, Psi’ (-> mu mu)

- Produced by photon pomeron fusion
- Modeled by the Starlight generator
  (S.R. Klein and J. Nystrand, Phys. Rev. Lett. 92 (2004) 14003)

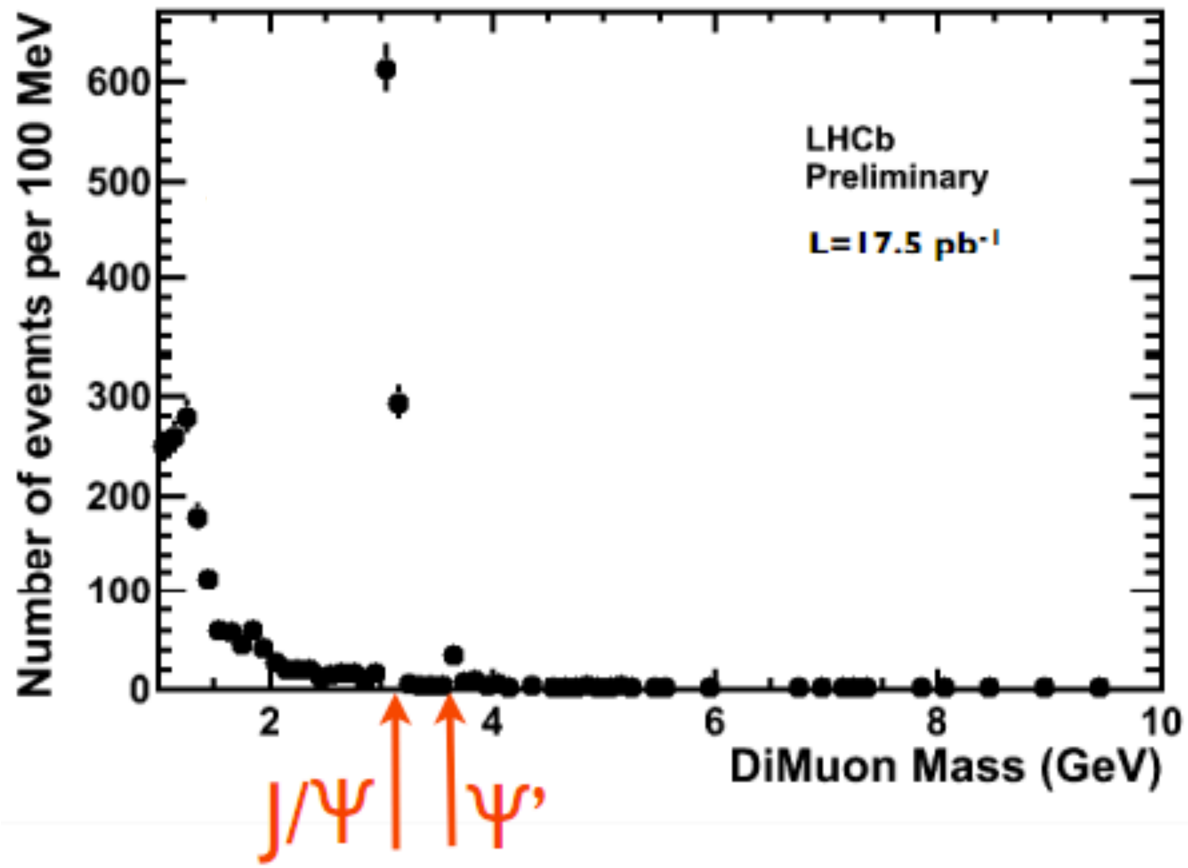


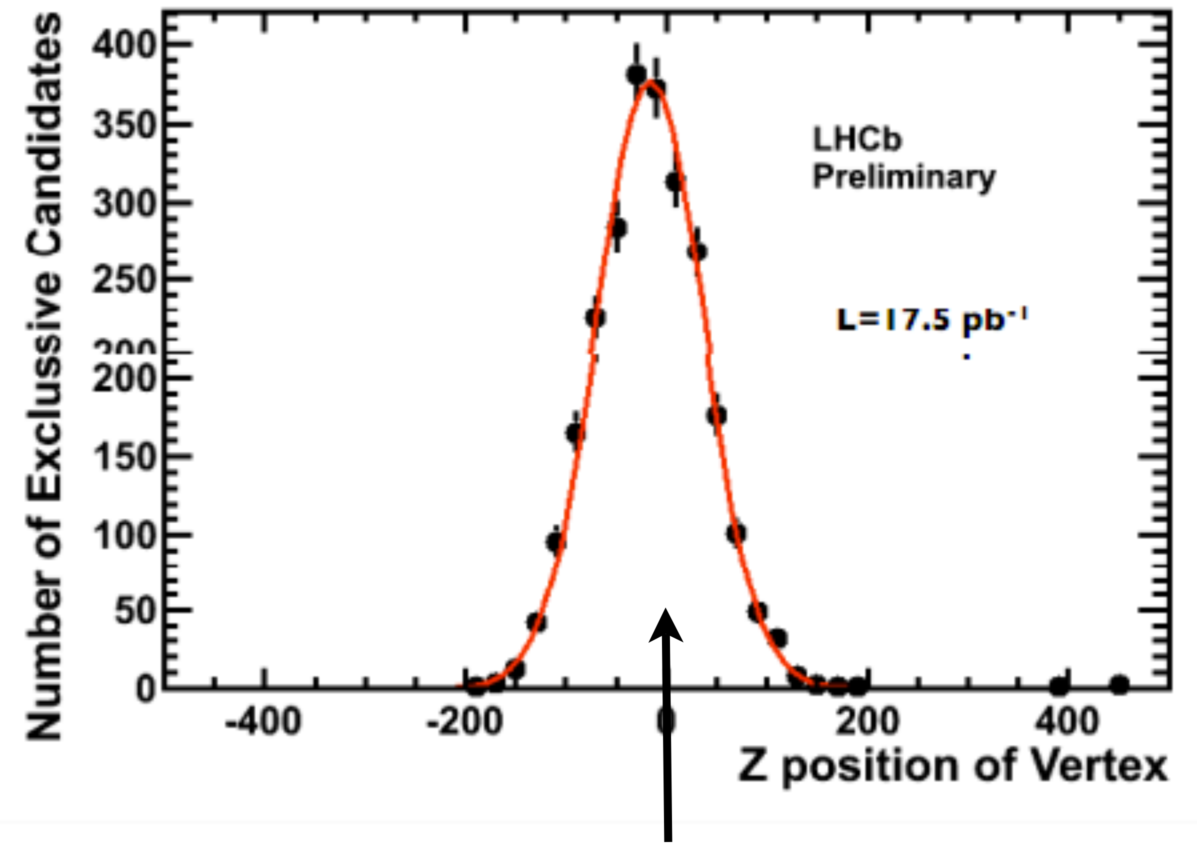
3. Exclusive ChiC (-> mu mu + gamma)

- Produced by double pomeron exchange
- Modeled by the SuperChiC generator
  (L.A. Harland-Lang, V.A. Khoze, M.G. Ryskin, W.J. Stirling
  arXiv:0909.4748 [hep-ph])



Full exclusive dimuon spectrum (17.5 pb^{-1})





Candidates compatible with beam-beam interactions

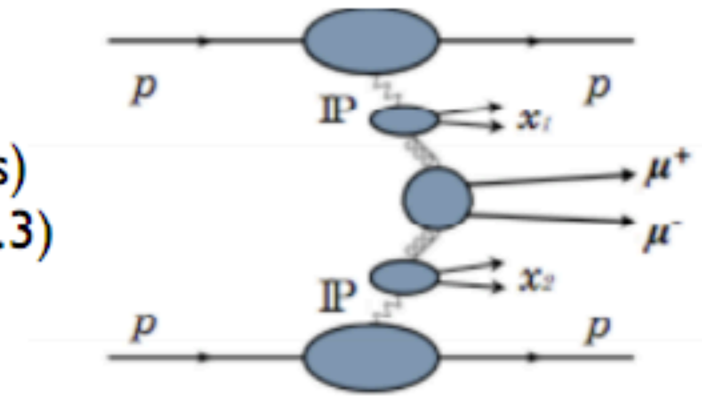
Trigger requirements:

- Just two muons
- Distance of closest approach < 0.15 mm
- Dimuon Mass > 1 GeV
- Dimuon Pt < 0.9 GeV
- SPD multiplicity < 20

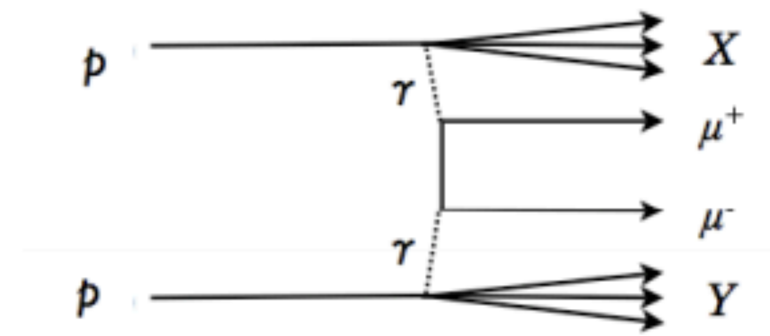
Additional offline requirements:

- No additional tracks in the vertex detector
- SPD multiplicity < 5 offline

Backgrounds for exclusive dimuons from photon fusion



<u>Dimuons from Double Pomeron Exchange (DPE)</u>
Generated with Pomwig (Does not contain Multi Parton Interactions)
Pythia used to estimate effect of MPI (Pomwig predictions scaled by 0.3)
H1 pomeron PDFs (06 and 97 NLO) used



<u>Dimuons from Inelastic diphoton fusion</u>
One or both protons dissociate during interaction
Generated with LPAIR
A.Suri and D.R.Yennie Proton PDFs used

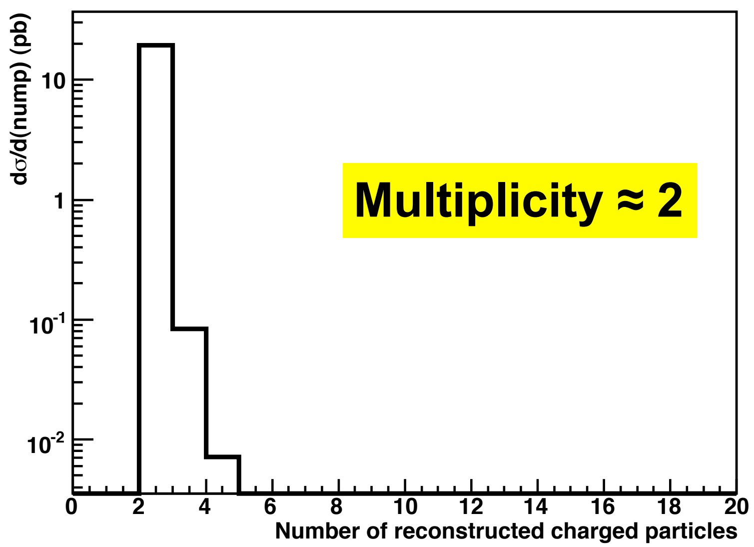
<u>Mis-Id from Min Bias Data</u>
Min Bias events dominated by pions and kaons
Apply all cuts except requiring that the track is a muon
Scale distribution by probability for pions/kaons to be identified as muons
(Mis-Id Probability as a function of Particle P determined in separate study)

← **Negligible contribution**

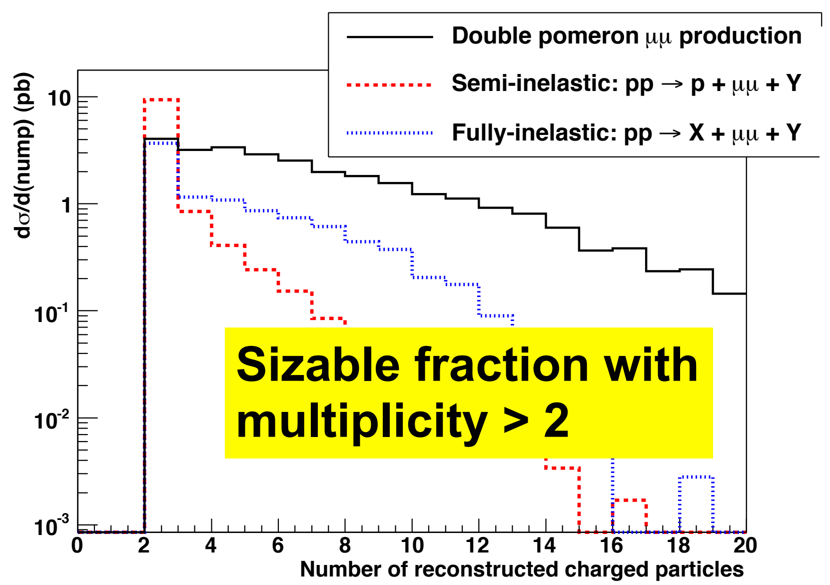
Discriminating variables for background suppression (MC)

Number of tracks

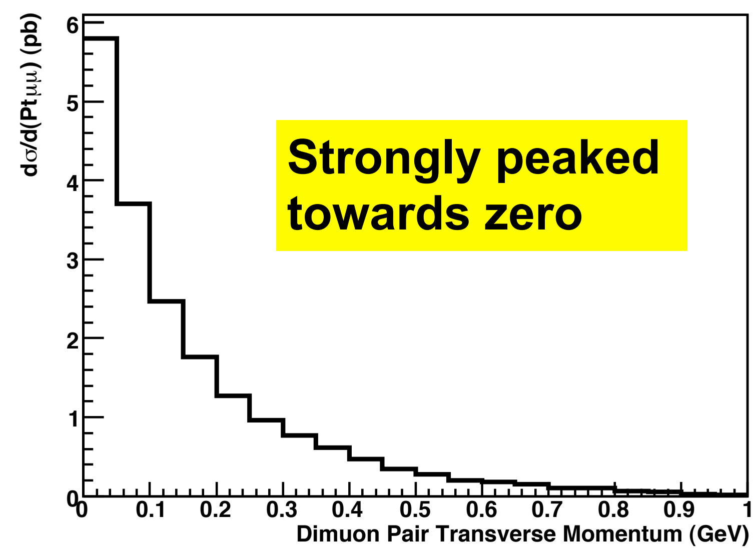
Signal

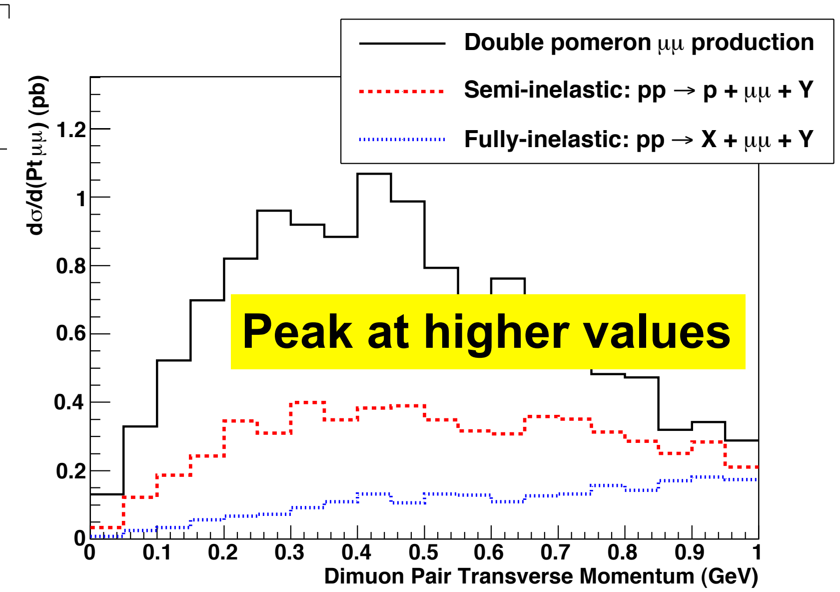


Inelastic & DPE

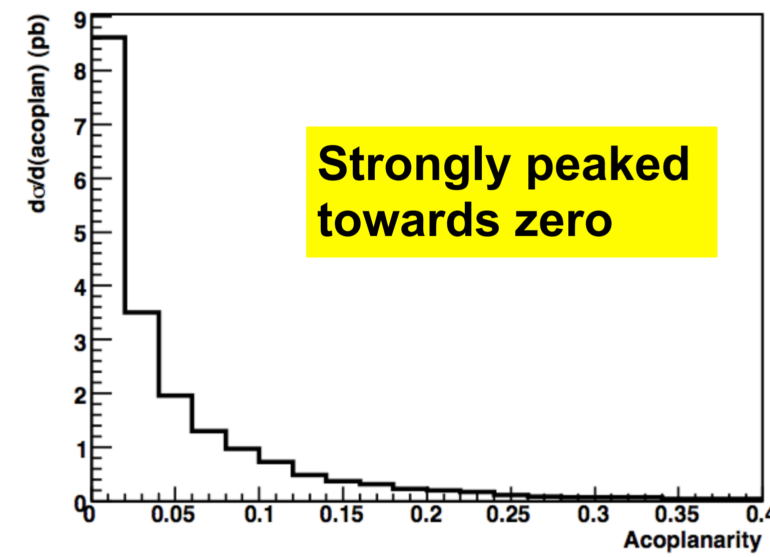


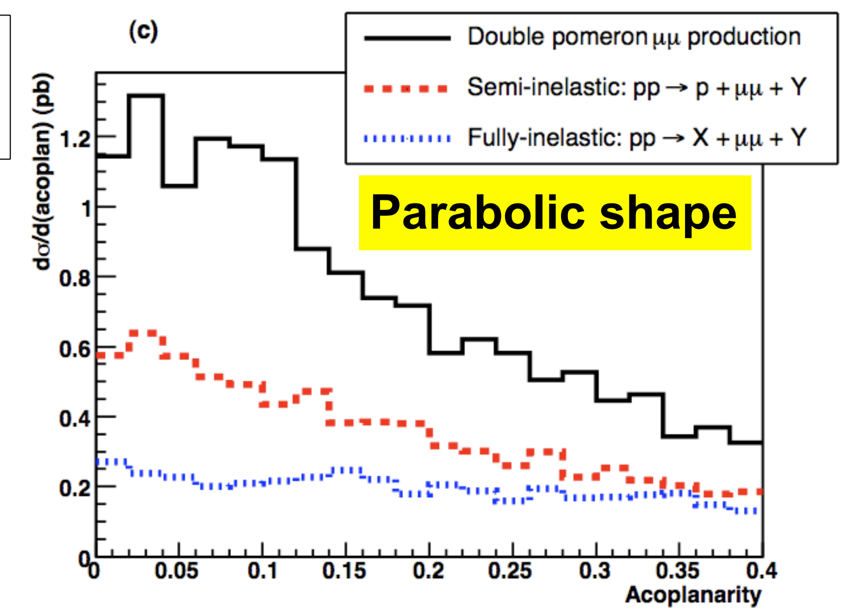
Dimuon Pt



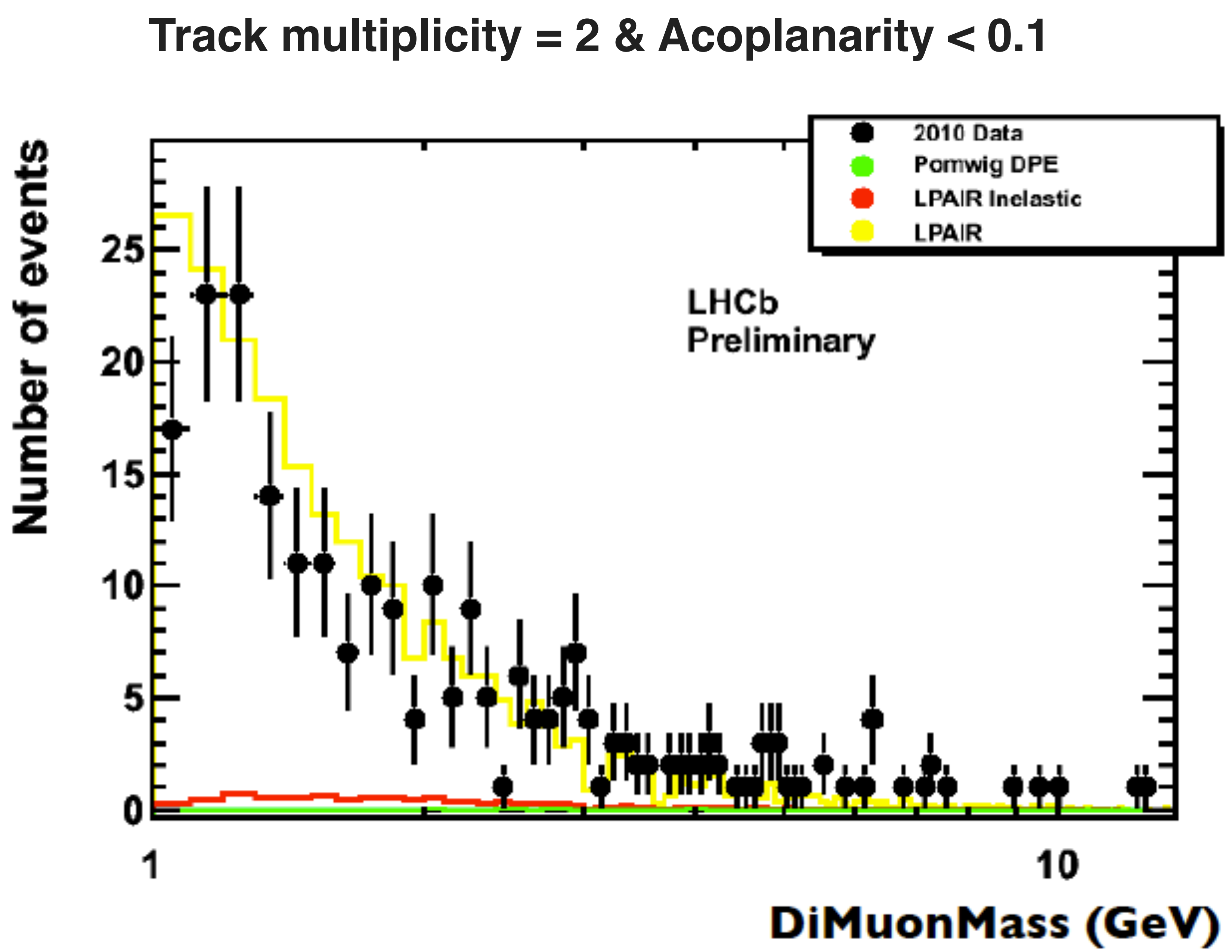


Dimuon acoplanarity





Comparison with Monte-Carlo



Conclusions

Luminosity measurements with W & Z events

- W & Z cross-sections predicted with ~ 4% uncertainty
- Very clean Z sample available with reasonable statistics (833 events in 16.5 pb-1)
- Efficiencies well understood from data
- Full 2010 data-set will enable a luminosity measurement with ~ 5% uncertainty
- W events could also be used. 10 times more stats but lower purity

Luminosity measurements with exclusive dimuons from photon fusion

- Cross-sections predicted with < 1% uncertainty
- 250 candidate events selected in 17.5 pb^{-1}
- Purities seem high (more work needed)
- Work on understanding efficiencies has only just begun
- Exclusive JPsi, Psi' and ChiC events have also been isolated and compared to MC