W, Z cross-sections and A_{FB} at LHCb

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PDF4LHC
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Outline

- Introduction
- Preliminary results on W,Z cross-sections and ratios.
- Potential to measure A_{FB} and requirements from PDFs.

EW physics motivation

$$\sigma_X(Q^2) = \sum_{a,b} \int_0^1 dx_1 dx_2 f_a(x_1, Q^2) f_2(x_2, Q^2) \hat{\sigma}_{ab\to X}(x_1, x_2, Q^2)$$

Hadronic Cross-section

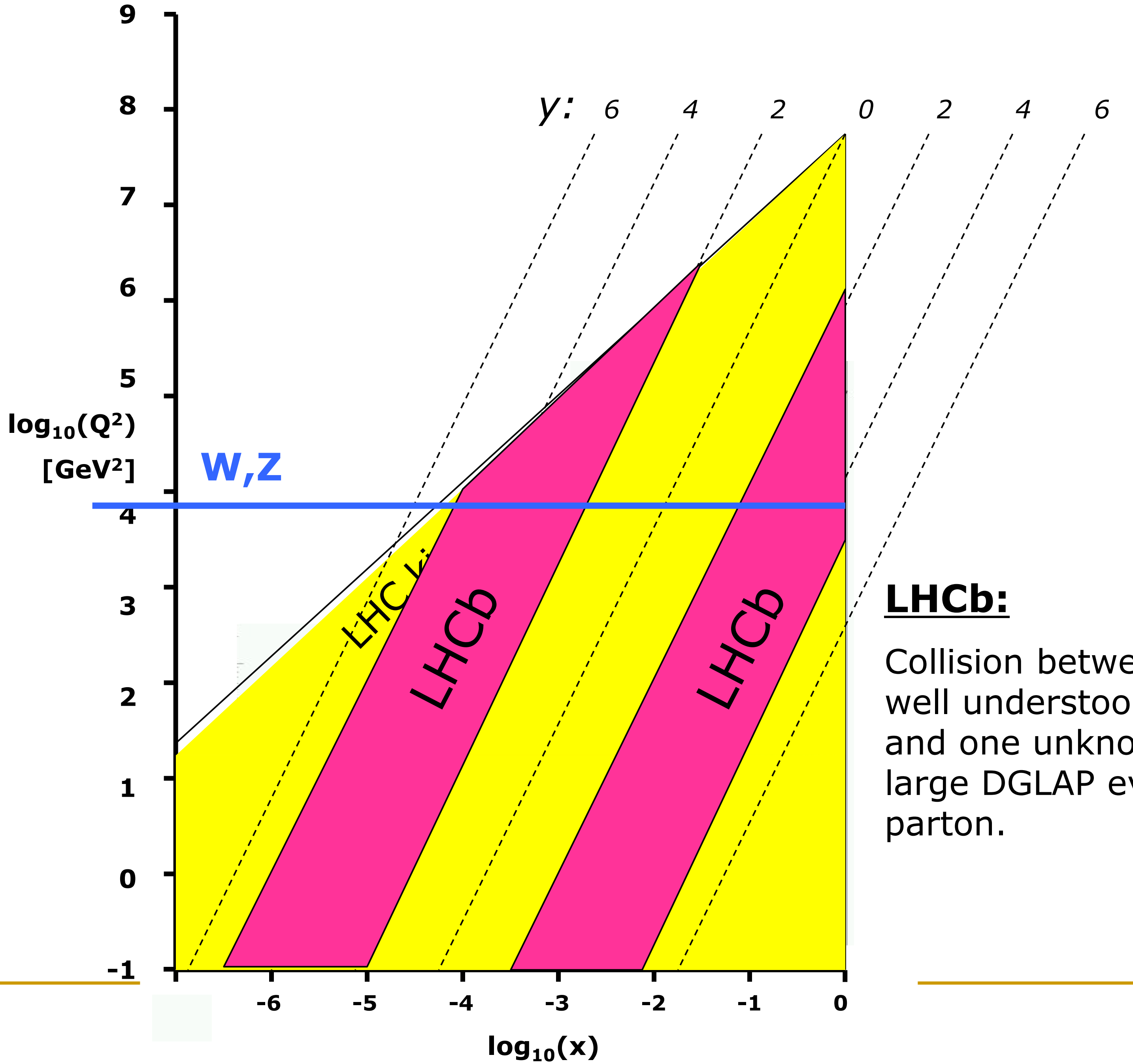
PDFs (3-5%)

Partonic Cross-section FEWZ NNLO(1%)

Test the SM at highest energies

Check out that DGLAP evolution works (test QCD)

Push theory into interesting regions with very soft gluons



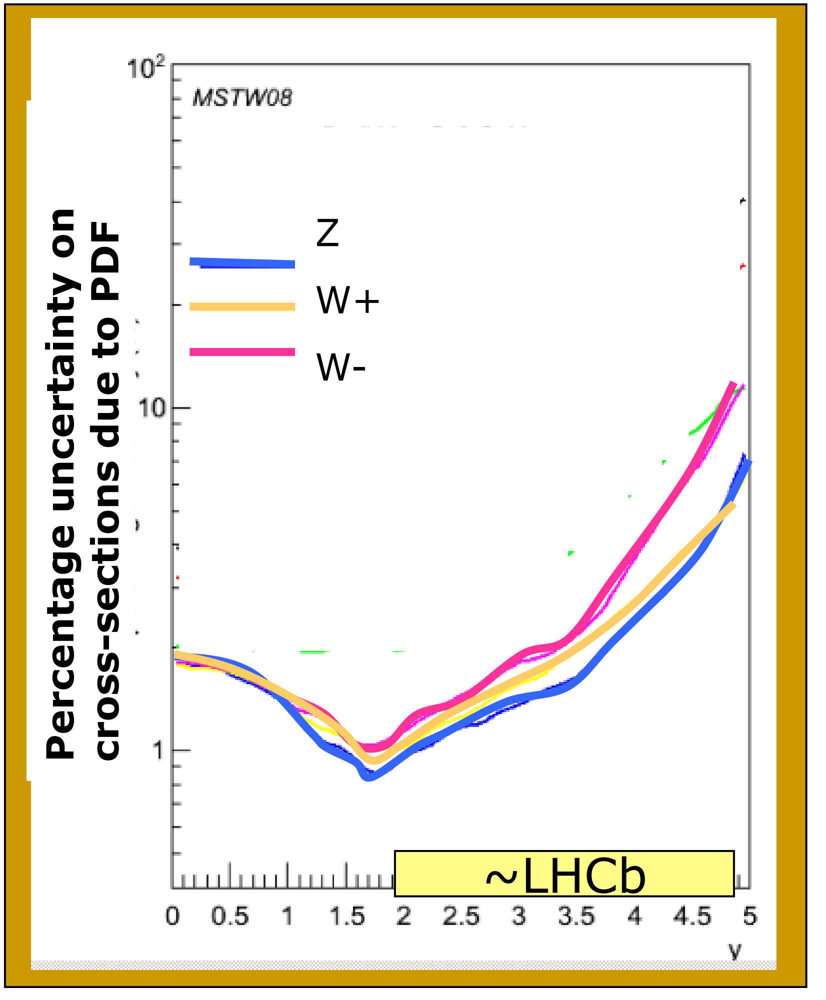
LHCb:

Collision between one well understood parton and one unknown or large DGLAP evolved parton.

Effect of PDF uncertainties on cross-sections

- Region where the most precise EW tests can be made.
- At highest rapidities, PDFs can be constrained.

- Experimental statistical error <<1%.
- Systematic error likely to be ~1%



But you can do better !

$$R_{\mp}(y_W) \equiv \frac{d\sigma/dy_W(W^-)}{d\sigma/dy_W(W^+)} \approx \frac{d(x_1)\bar{u}(x_2)}{u(x_1)\bar{d}(x_2)} = \frac{d(x_1)}{u(x_1)} \cdot \frac{\bar{u}(x_2)}{\bar{d}(x_2)} \approx \frac{d(x_1)}{u(x_1)}$$

So ratio of Ws is sensitive to d to u ratio. (For LHCb d_v/u_v)

$$A_{\pm}(y_W) = \frac{d\sigma/dy_W(W^+) - d\sigma/dy_W(W^-)}{d\sigma/dy_W(W^+) + d\sigma/dy_W(W^-)} \approx \frac{u(x_1)\bar{d}(x_2) - d(x_1)\bar{u}(x_2)}{u(x_1)\bar{d}(x_2) + d(x_1)\bar{u}(x_2)} \approx \frac{u(x_1) - d(x_1)}{u(x_1) + d(x_1)}$$

W asymmetry is sensitive to difference in u and d. (For LHCb u_v-d_v)

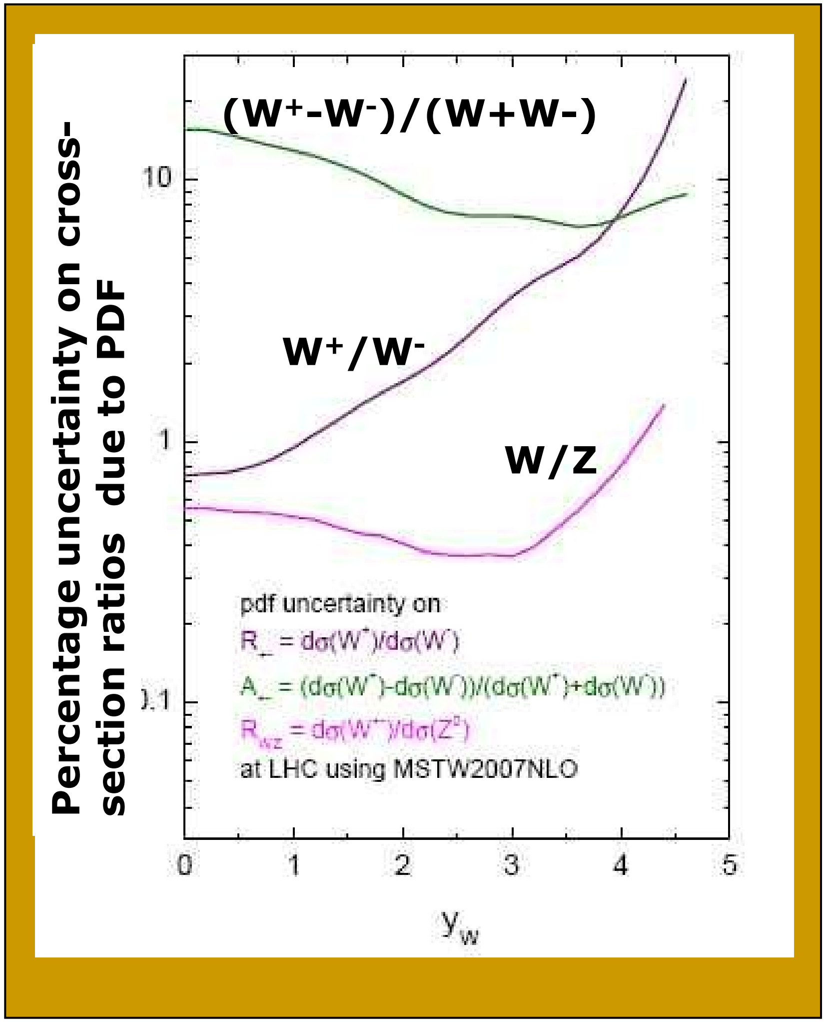
$$R_{Z/W}(y) \equiv \frac{d\sigma/dy(Z^0)}{d\sigma/dy(W^+) + d\sigma/dy(W^-)} \approx \frac{\kappa_u\, u(x'_1)\bar{u}(x'_2) + \kappa_d\, d(x'_1)\bar{d}(x'_2)}{|V_{ud}|^2 \left\{u(x_1)\bar{d}(x_2) + d(x_1)\bar{u}(x_2)\right\}}$$

Ratio of Z to W is almost insensitive to PDFs!

Gold plated test of SM at the highest energies

Effect of PDF uncertainties on cross-sections

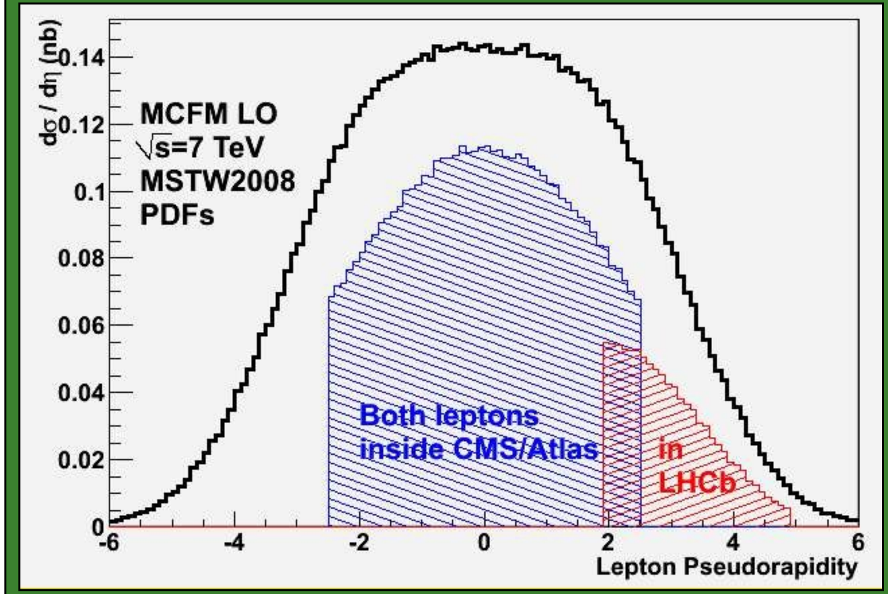
- R_{wz} precise test of SM everywhere.
- Difference in u and d quarks can be significantly improved by all experiments at the LHC.
- Going forward, you increasingly constrain the u-valence to d-valence ratio.

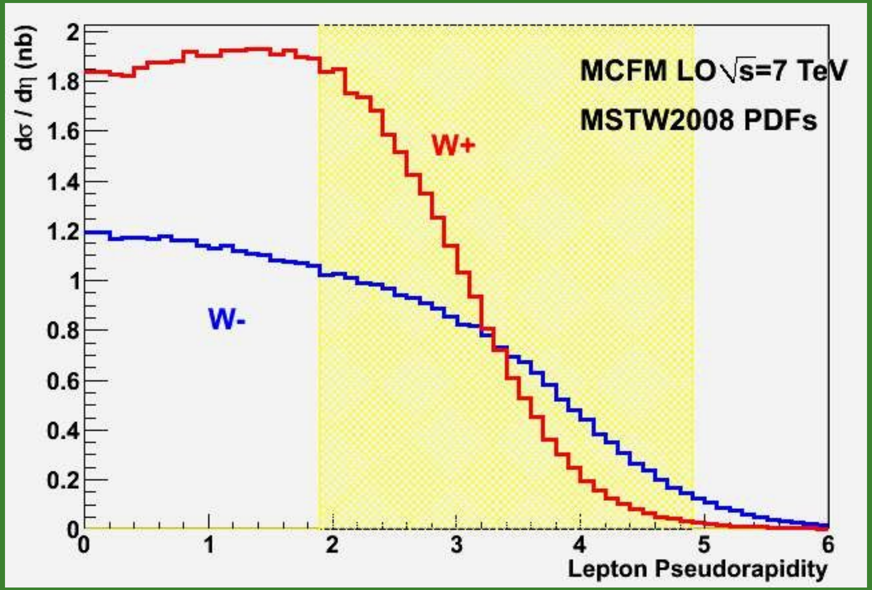


- Even nicer, most experimental systematics (especially luminosity) cancel in the ratio.

Z Cross-section Measurement at LHCb

$$\sigma(Z \rightarrow \mu\mu : 2 < \eta_{\mu} < 4.5, P_{T\mu} > 20\,GeV\;, 81 < M_{\mu\mu} < 101\,GeV\;)$$

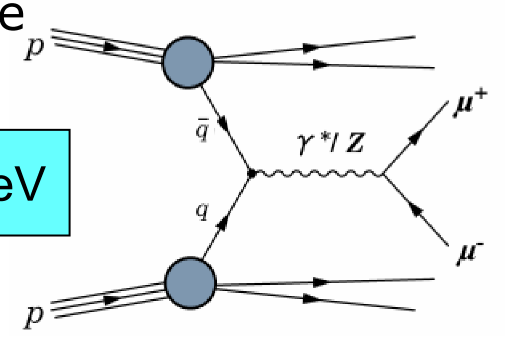




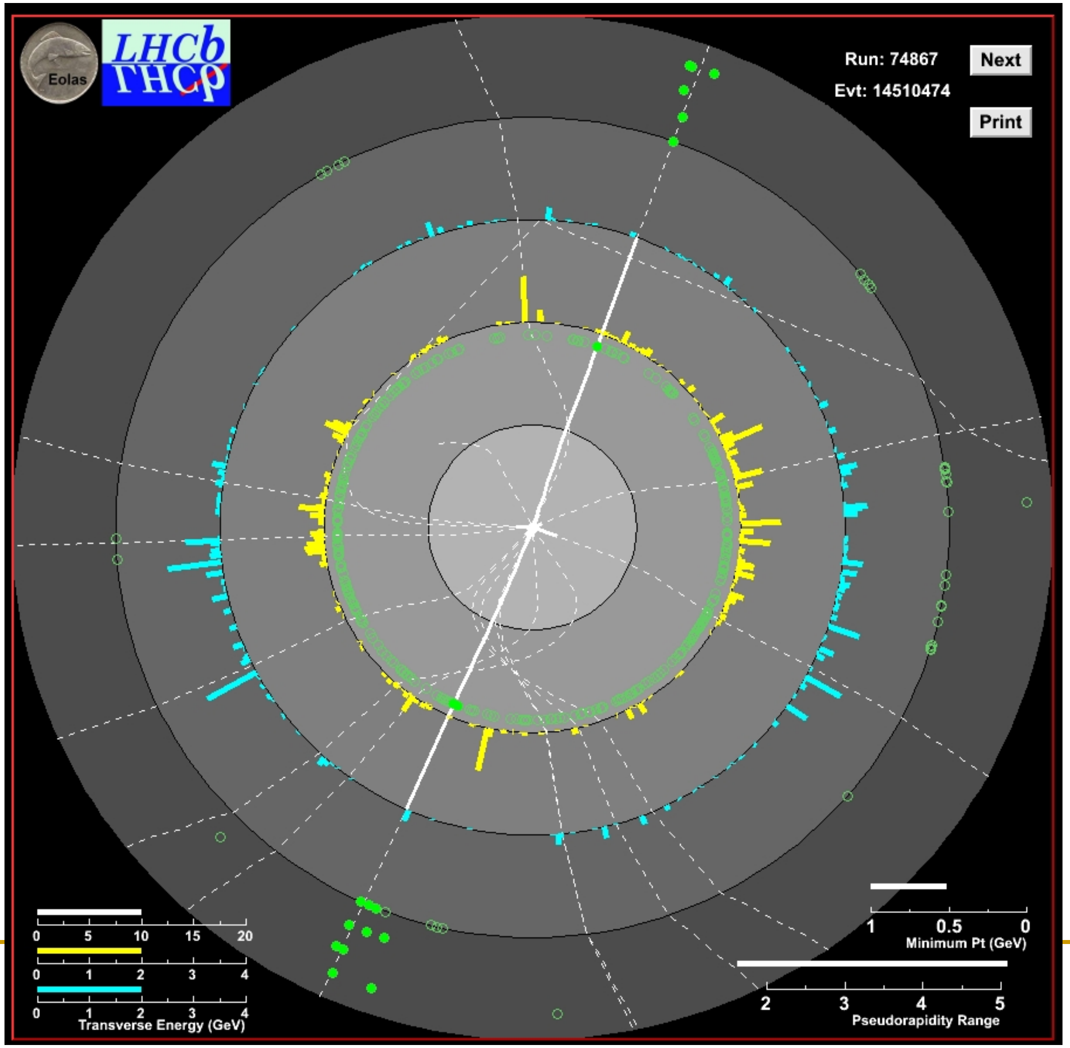
8% of Z within LHCb acceptance

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

Z: Characteristic signature of two high transverse momentum muons with invariant mass m_Z



Require two muons: p_t>20GeV, 2<η<4.5. 81<$M_{\mu\mu}$<101 GeV



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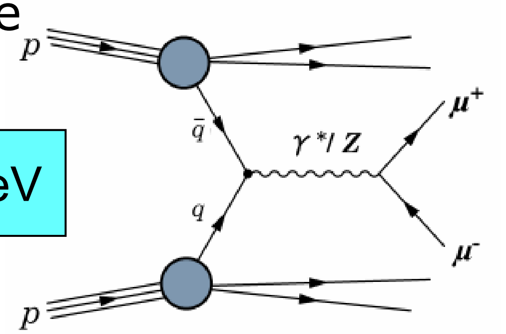

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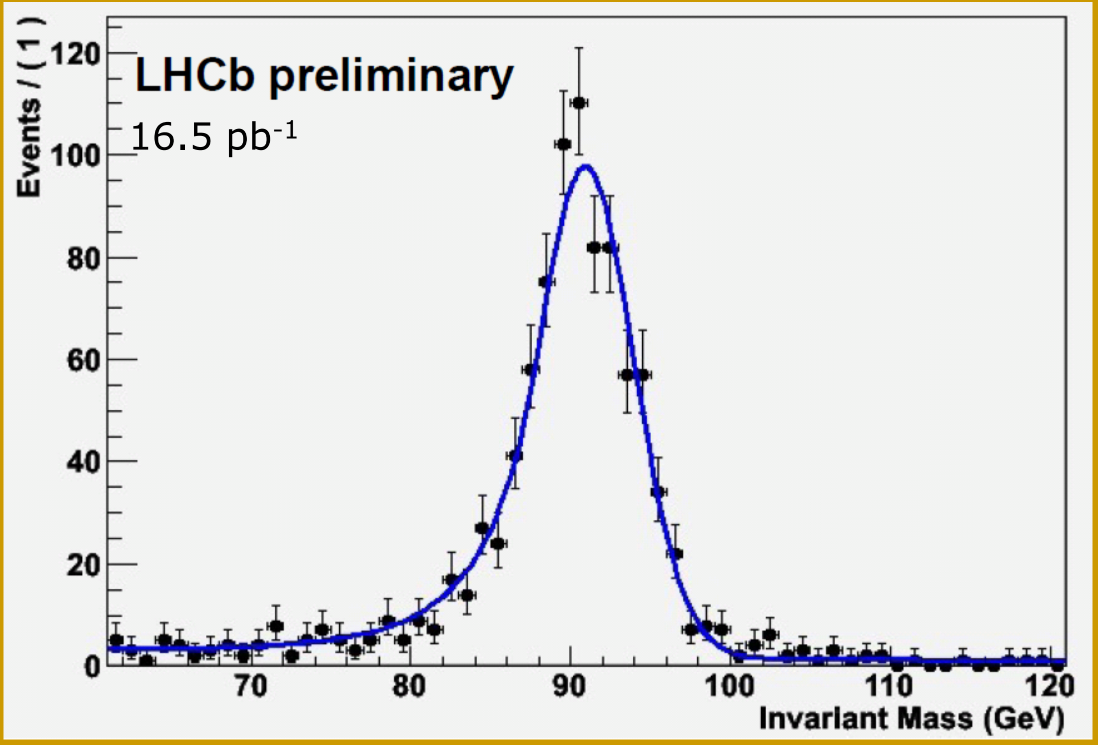


To turn into cross-section:

$$\sigma_{Z\to\mu\mu}(\Delta y) = \frac{N^Z_{tot} - N^Z_{bkg}}{\epsilon_Z L}$$

$$\epsilon_Z = A_z \epsilon_Z^{trig} \epsilon_Z^{track} \epsilon_Z^{muon} \epsilon_Z^{selection}$$

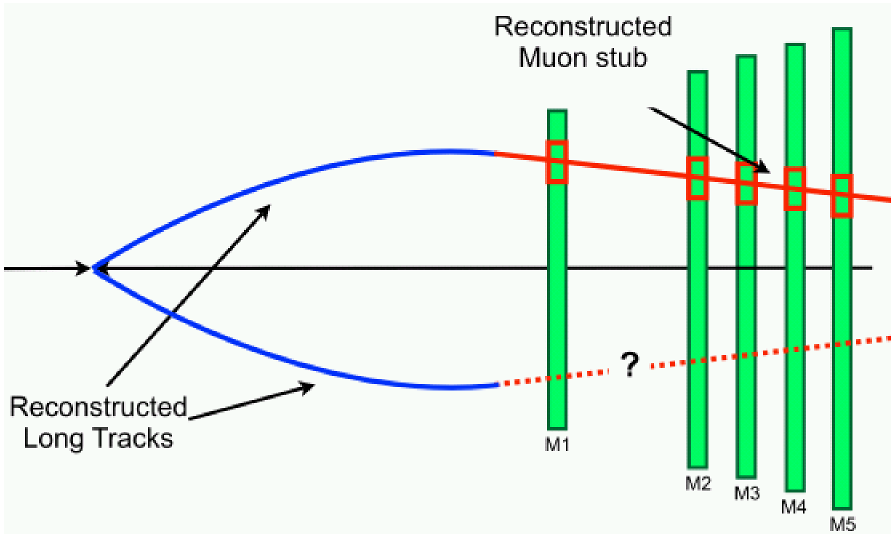
=1 =1

Insomuch as possible, take everything from data.

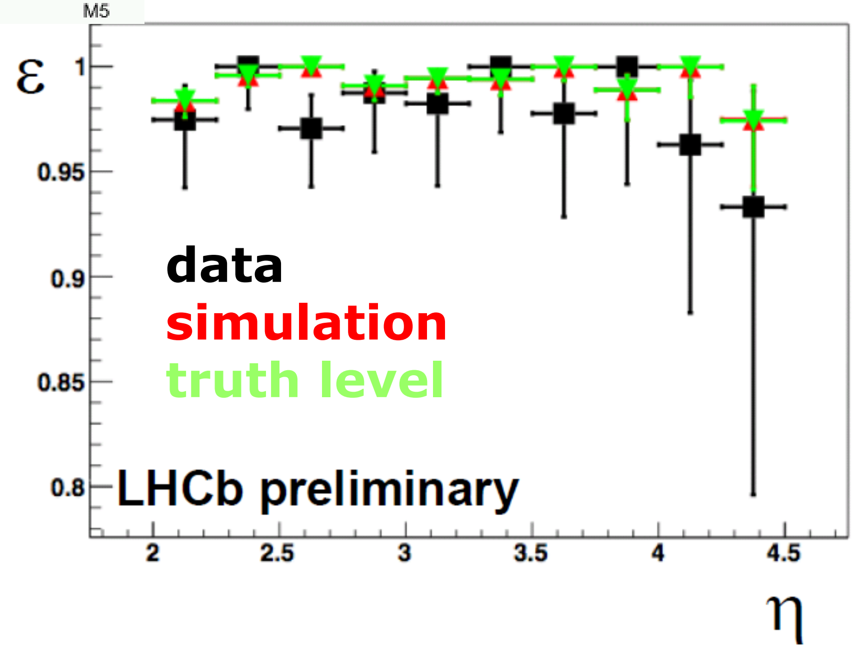
Muon identification efficiency

$$\epsilon_Z = A_z \epsilon_Z^{trig} \epsilon_Z^{track} \epsilon_Z^{muon} \epsilon_Z^{selection}$$

ε_W=98.2 ± 0.5%
ε_Z=96.5± 0.7%



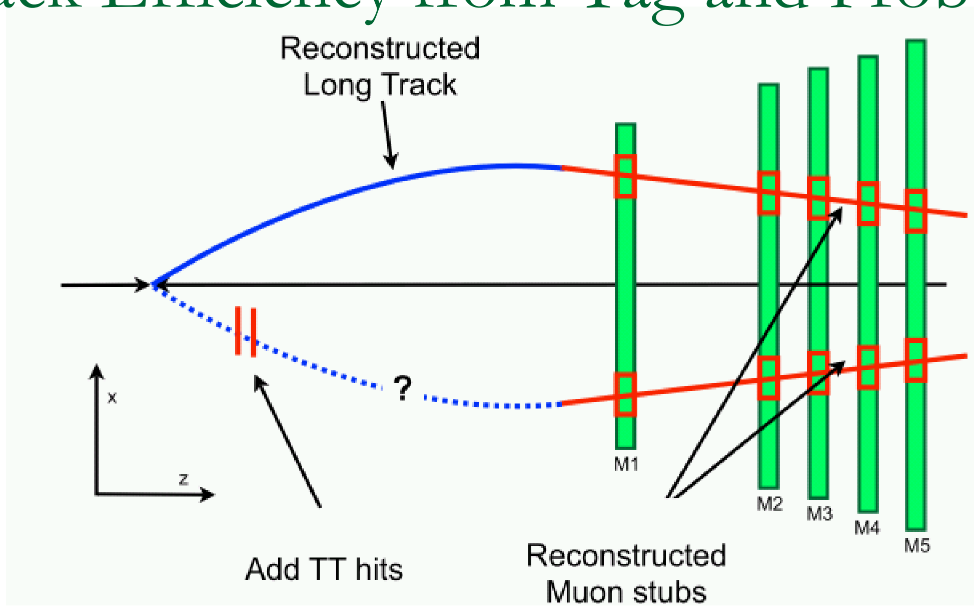
Efficiency flat in p_T,η,ϕ
No evidence for charge bias



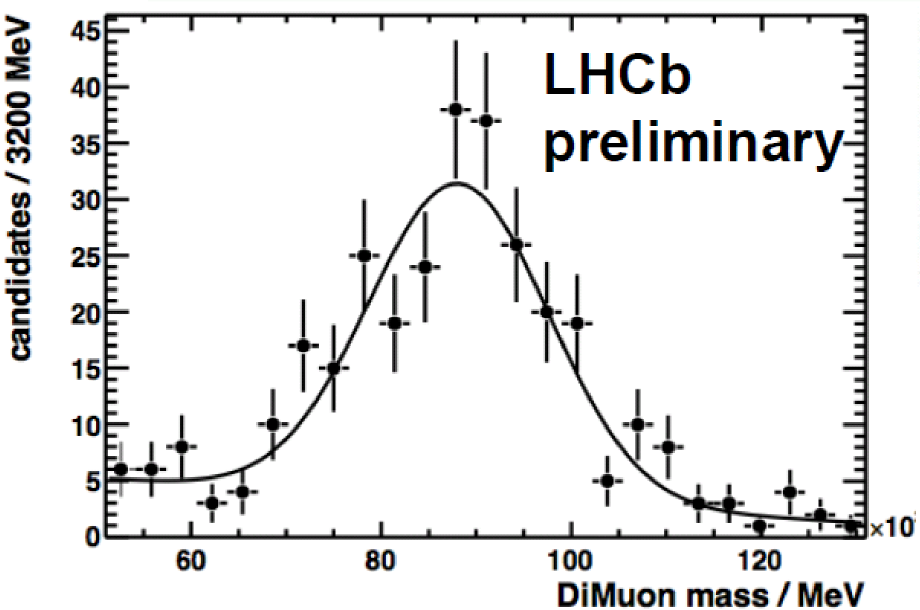
Track Efficiency from Tag and Probe

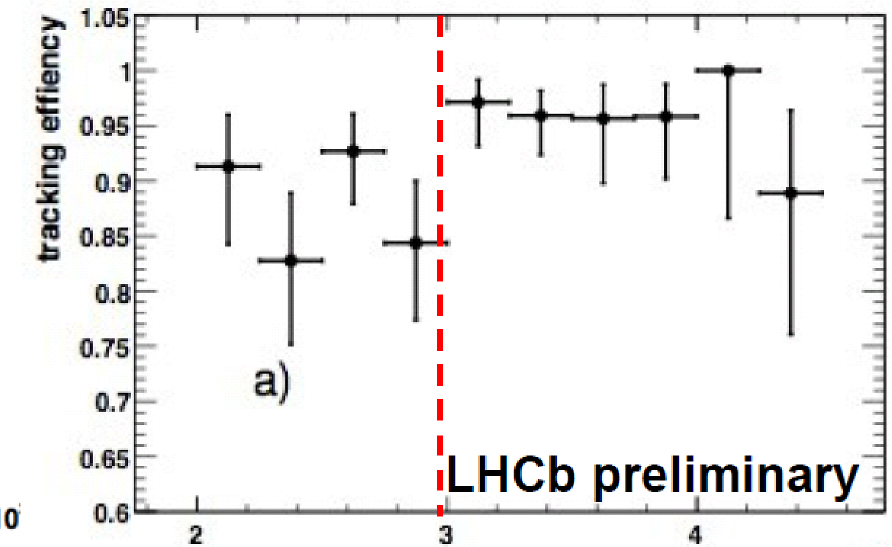
$$\epsilon_Z = A_z \epsilon_Z^{trig} \epsilon_Z^{track} \epsilon_Z^{muon} \epsilon_Z^{selection}$$

ε_{W+}=73 ± 3%
ε_{W-}= 78 ± 3%
ε_Z = 83 ± 3%



(W+/W- differ due to lepton η distribution)



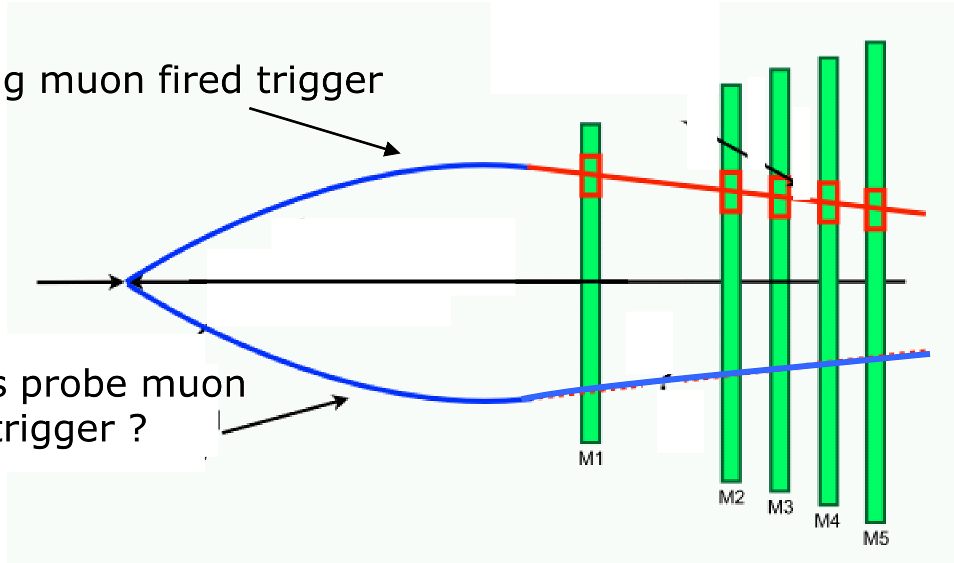


(flat in p_T and ϕ)

η

Trigger Efficiency from Tag and Probe

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



ε_W =0.9*(80.5 ± 1.4)%
ε_Z =0.9*(95.7 ± 0.5)%

(Globel cuts:
Very large events
rejected by trigger)

Trigger path:

LOMuonDecision_TOS — (Muon stub with PT > 1.5 GeV/c)

Hlt1SingleMuonNoIPLOHighPTDecision_TOS — (Long track Muon with PT > 10 GeV/c and no IP requirement)

Hlt2SingleHighPTMuonDecision_TOS

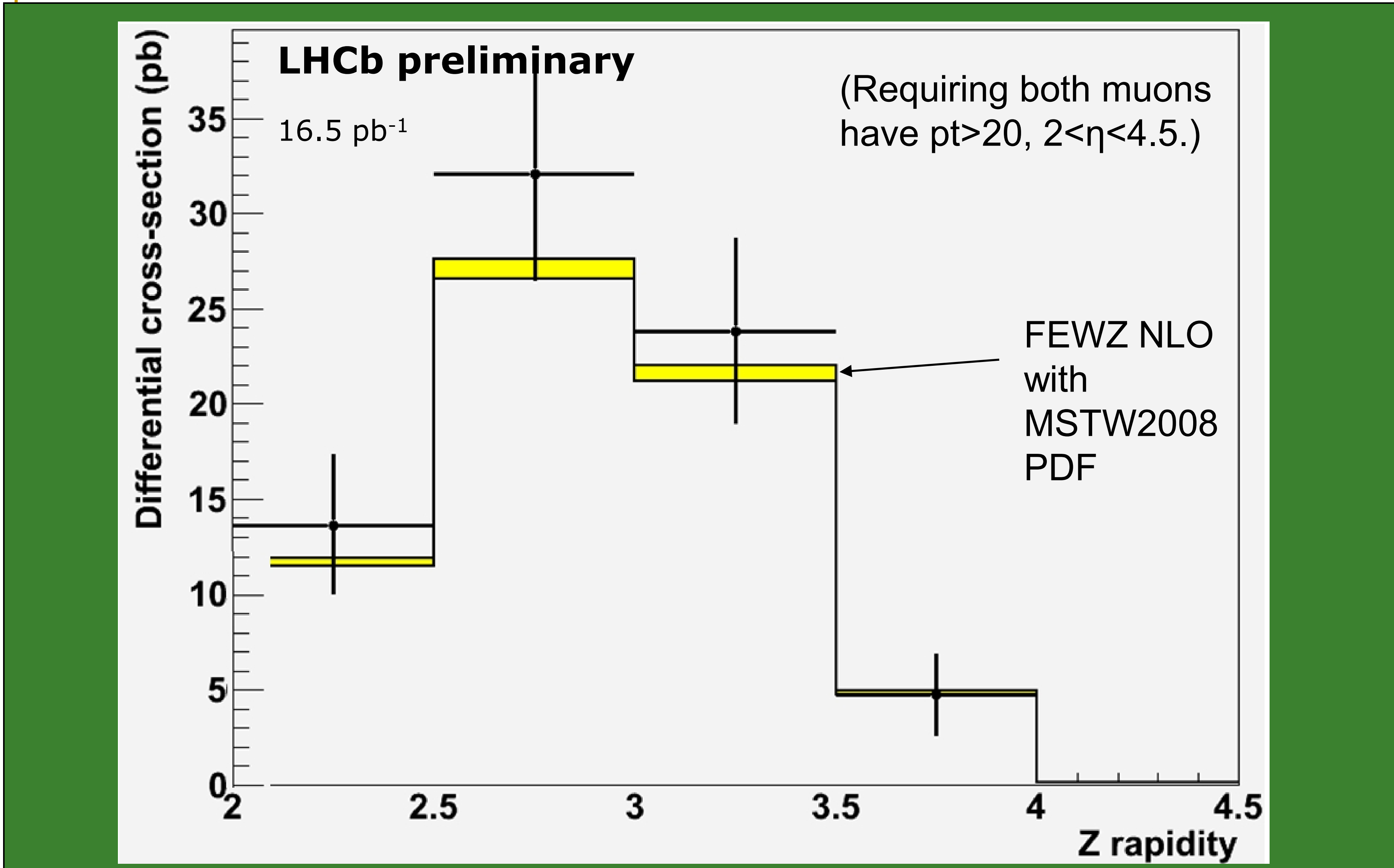
Z analysis

$$\sigma_{Z\to\mu\mu}(\Delta y) = \frac{N^Z_{tot} - N^Z_{bkg}}{\epsilon_Z L}$$

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^Z_{trig}	0.86 ± 0.01
ϵ^Z_{track}	0.83 ± 0.03
ϵ^Z_{muon}	0.97 ± 0.01
ϵ^Z_{sel}	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.

Phase space for measurement

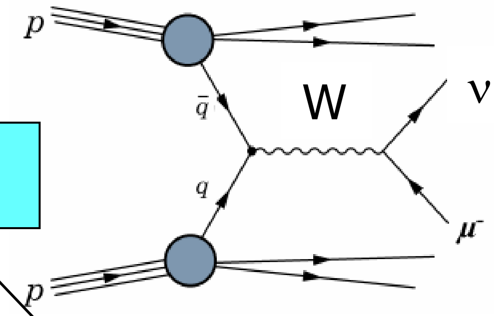
Differential distribution (Z)



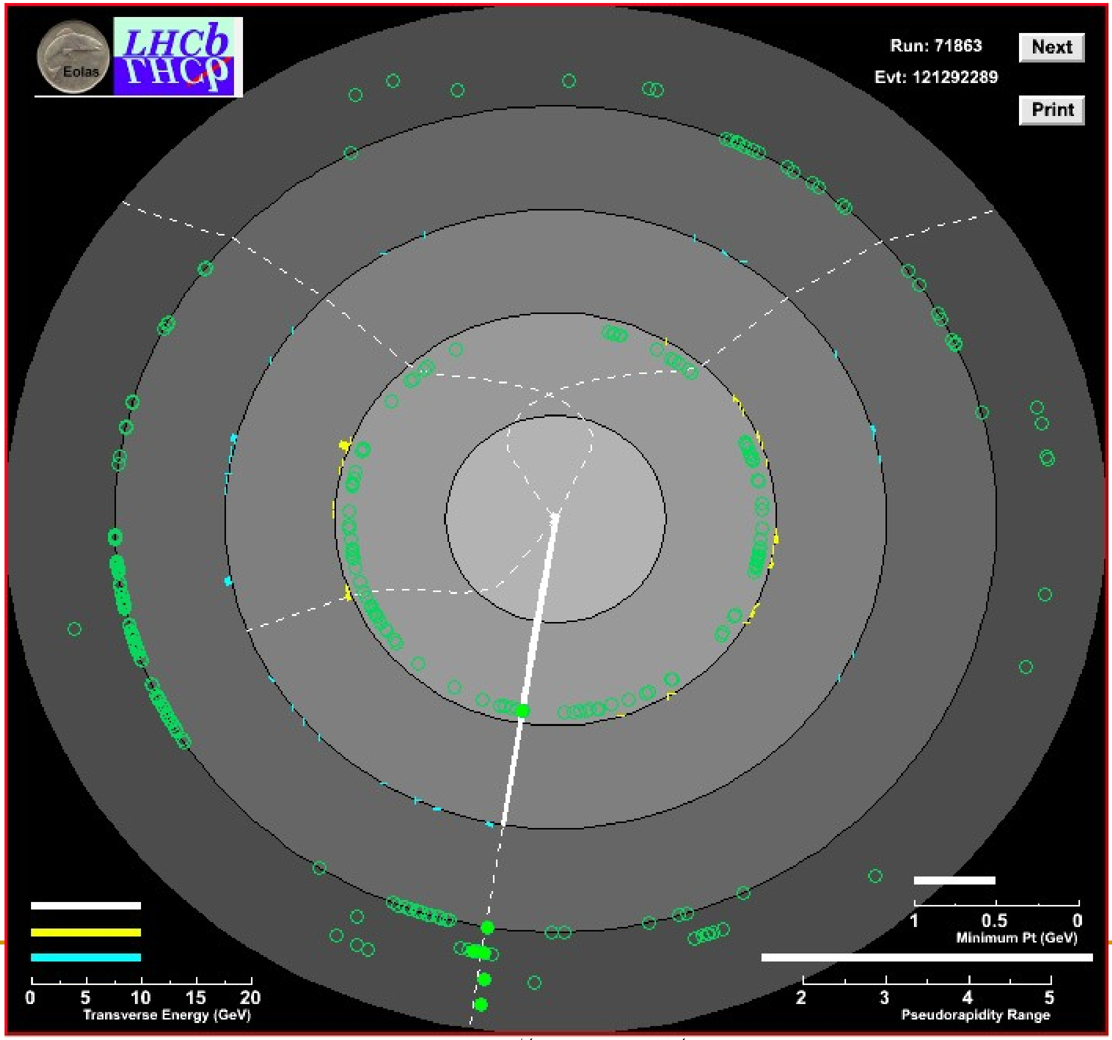
W Cross-section Measurement at LHCb

$$\sigma(W \rightarrow \mu\nu : 2 < \eta_{\mu} < 4.5, P_{T\mu} > 20\, GeV)$$

W: One high transverse momentum muon with little else. Background much larger than for Z



Require muon p_t>20GeV + little activity in 'rest of event'



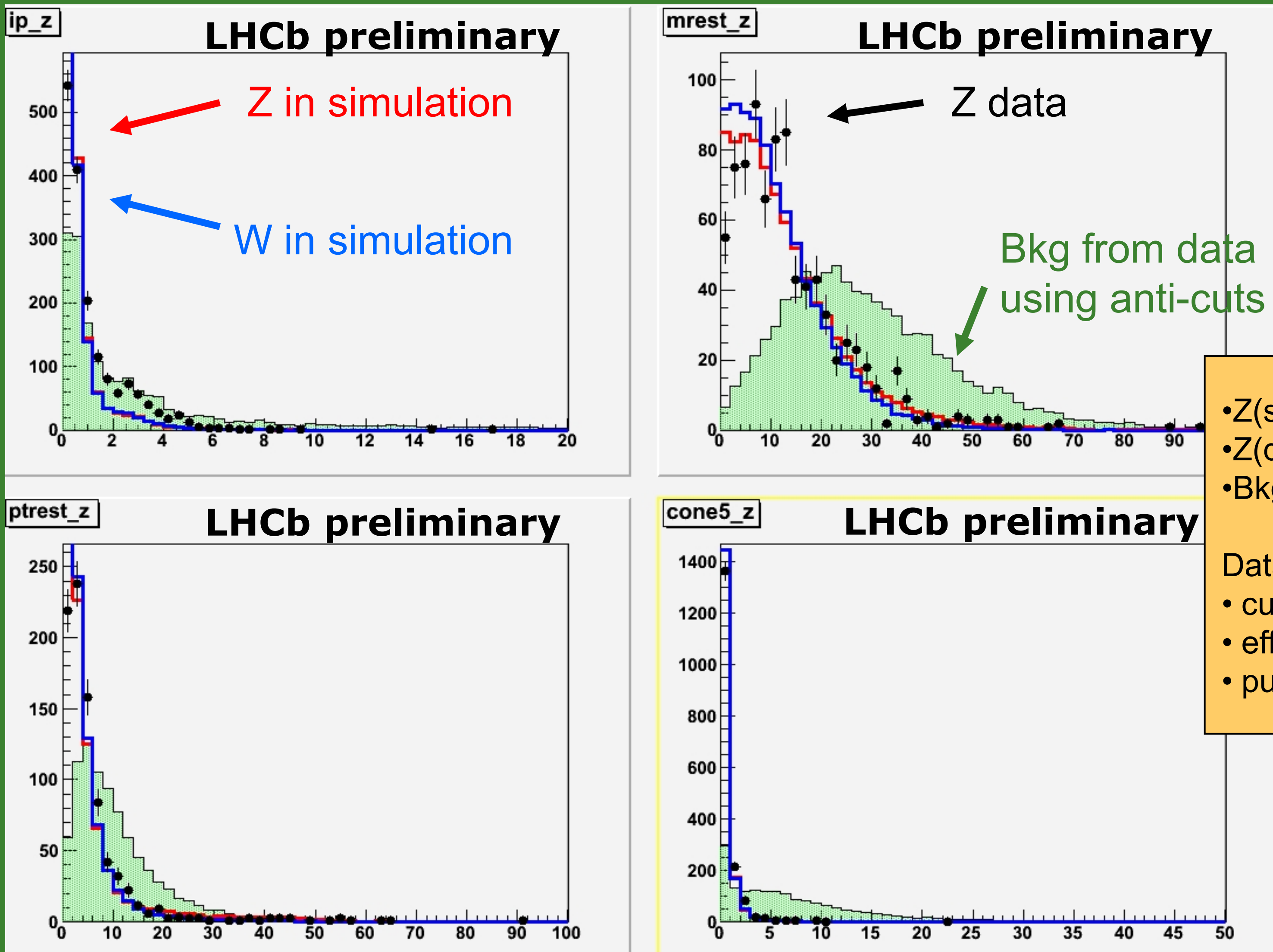
Can be found using Z events **in data**

Selecting W events

- pt of muon (>20GeV)

- ip significance of muon (<2)
- Mass of *rest of event* (<20 GeV)
- Pt of *rest of event* (<10 GeV)
- Charged transverse momentum in cone of 0.5 units of $\sqrt{(\Delta\eta)^2+(\Delta\Phi)^2}$ around muon. (<2 GeV)

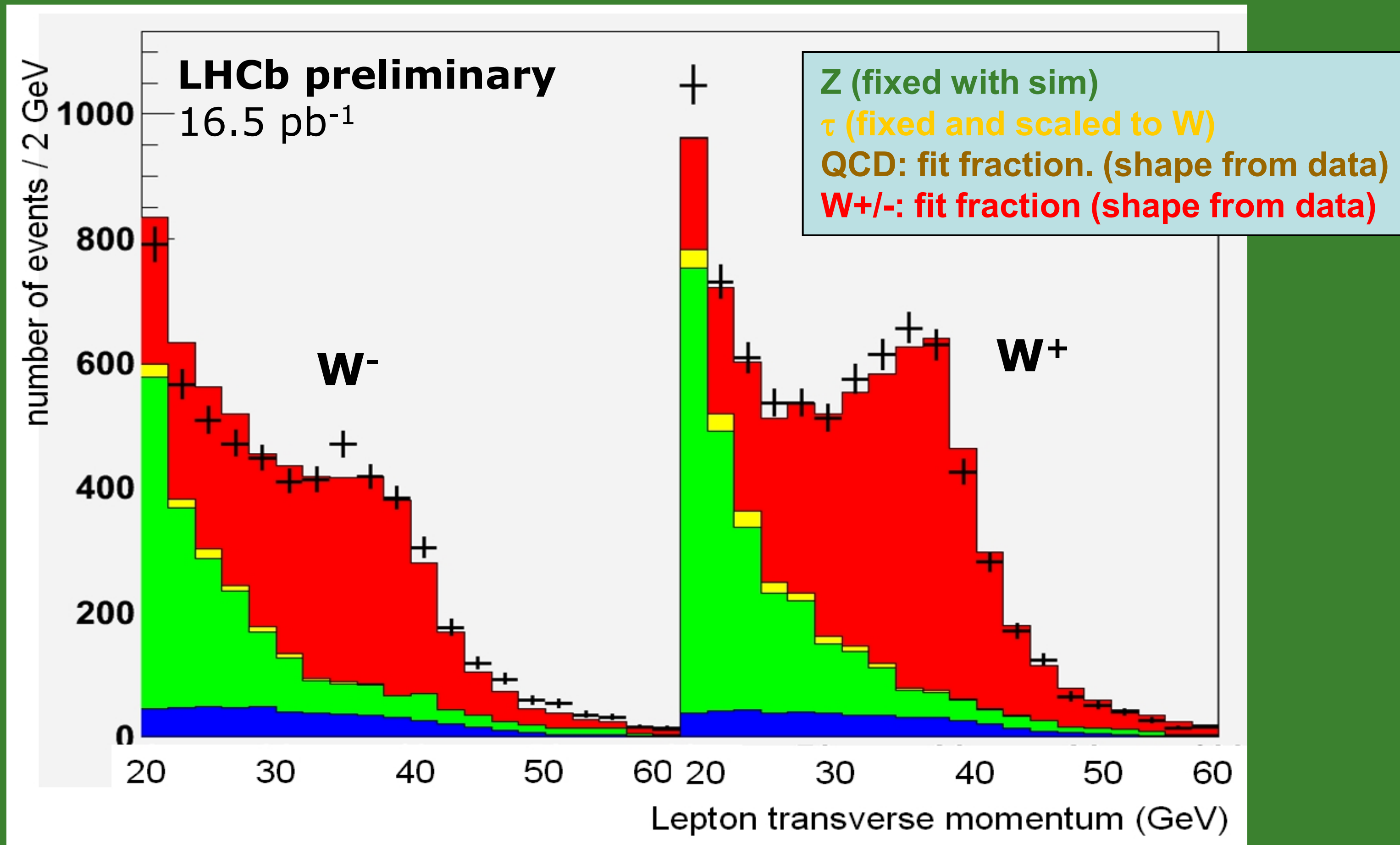
W analysis



- Z(sim) = W(sim)
- Z(data) ~ Z(sim)
- Bkg(data) != Z(data)

Data derived:
- cuts;
- efficiency;
- purity.

W analysis



$$\sigma_{W\to\mu\nu}(\Delta\eta) = \frac{N^W_{tot} - N^W_{bkg}}{\epsilon_W L} \rightarrow \frac{N^W_{tot}}{L}\left(\frac{p_W}{\epsilon_W}\right)$$

and all found from data.

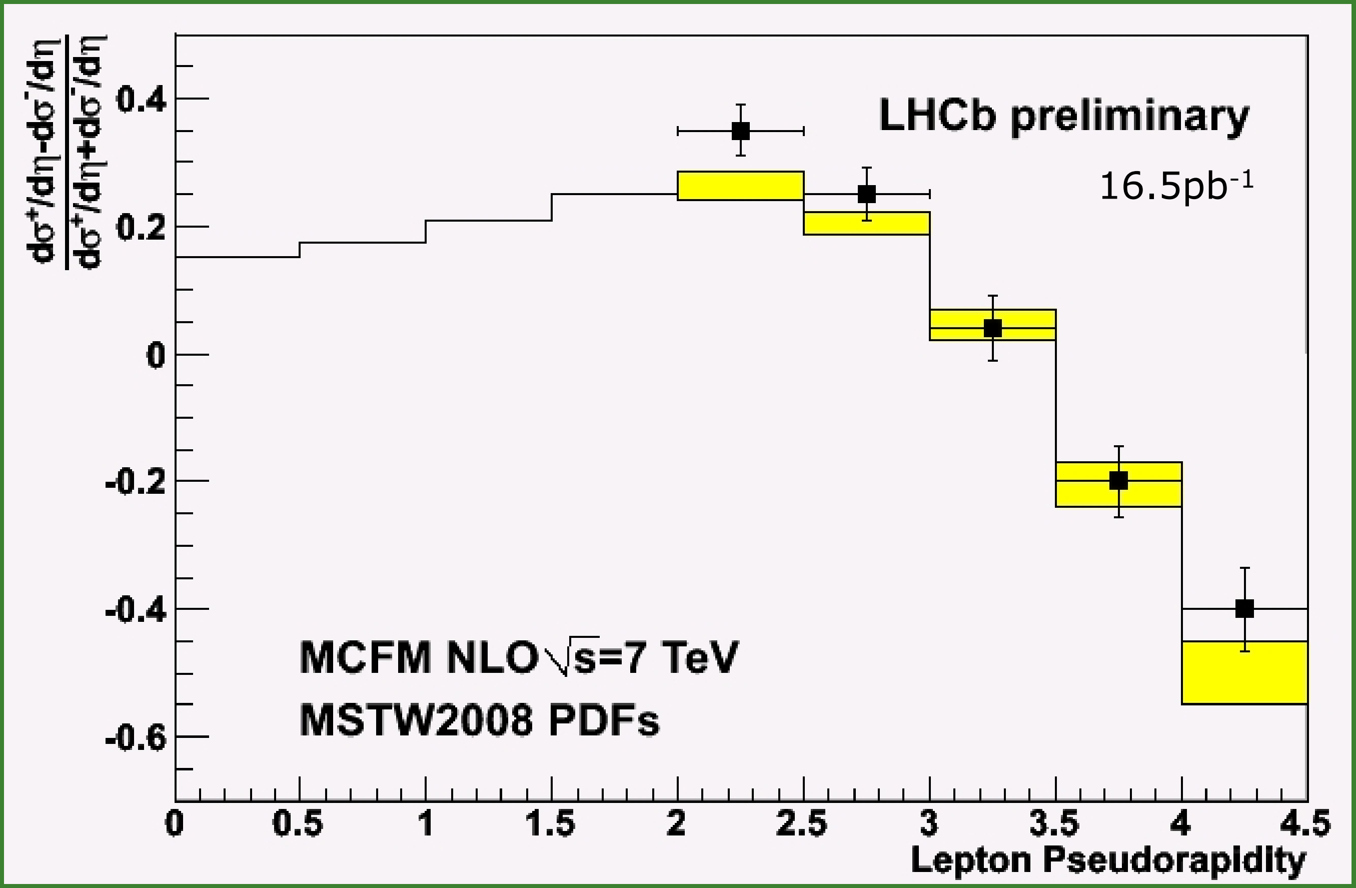
W analysis

$$\sigma_{W\to\mu\nu}(\Delta\eta) = \frac{N^W_{tot} - N^W_{bkg}}{\epsilon_W L}$$

	$W+$	$W-$
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^W_{trig}	0.725 ± 0.03	
ϵ^W_{track}	0.73 ± 0.03	0.78 ± 0.03
ϵ^W_{muon}	0.982 ± 0.005	
ϵ^W_{sel}	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 ± 1.7 pb^{-1}	16.5 ± 1.7pb^{-1}
$\sigma_W(2.0 < y < 4.5)$	$1007 \pm 48 \pm 100$ pb	$682 \pm 40 \pm 68$ pb

(Measurement as function of lepton rapidity)

W asymmetry



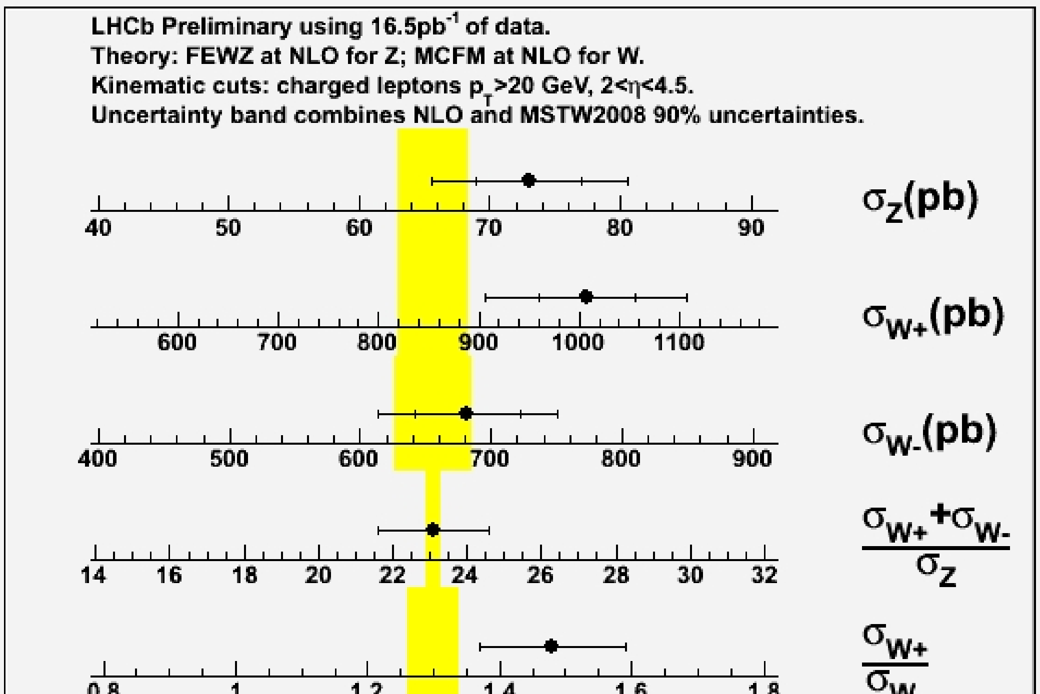
$\frac{d\sigma^+/d\eta - d\sigma^-/d\eta}{d\sigma^+/d\eta + d\sigma^-/d\eta}$
0.4
0.2
0
-0.2
-0.4
-0.6
LHCb preliminary
16.5pb-1
MCFM NLO √s=7 TeV
MSTW2008 PDFs
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Lepton Pseudorapidity

W,Z Summary

$$\frac{\sigma_{W+}(2.0<\eta_\mu<4.5)+\sigma_{W-}(2.0<\eta_\mu<4.5)}{\sigma_Z(2.0<y<4.5)}$$

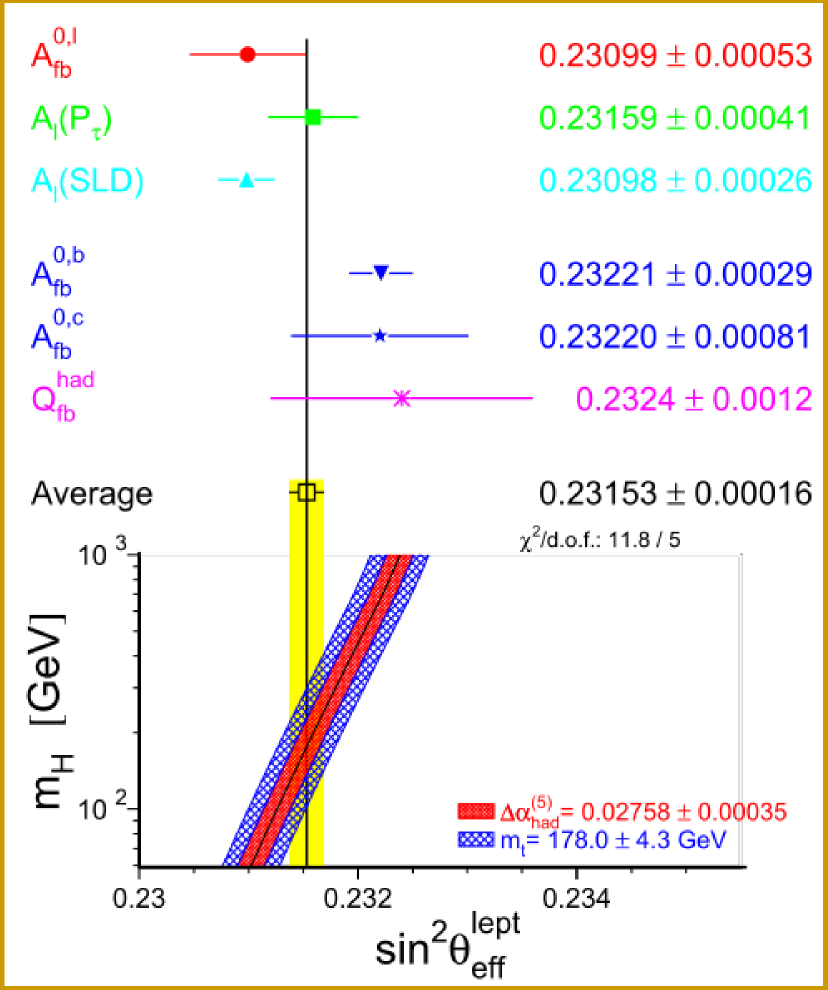
Generator	Order	PDF Set	Z	$W+$	$W-$	$(W^+ + W^-)/Z$	W^+/W^-
FEWZ	NLO	MSTW08NLO	$65.7^{+2.9}_{2.5}$				
		CTEQ66NLO					
		NNPDF2.0					
MCFM		MSTW08NLO	$65.5^{+2.8}_{-2.5}$	855 ± 43	656 ± 39	23.1 ± 0.1	1.30 ± 0.05
		CTEQ66NLO					
		NNPDF2.0					
FEWZ	NNLO	MSTW08NNLO					
Data			$73 \pm 4 \pm 7.5$	$1007 \pm 48 \pm 101$	$682 \pm 40 \pm 68$	23.1 ± 1.5	1.48 ± 0.11

LHCb preliminary



For the future:
Intriguing possibility of a precise measurement of A_{FB}

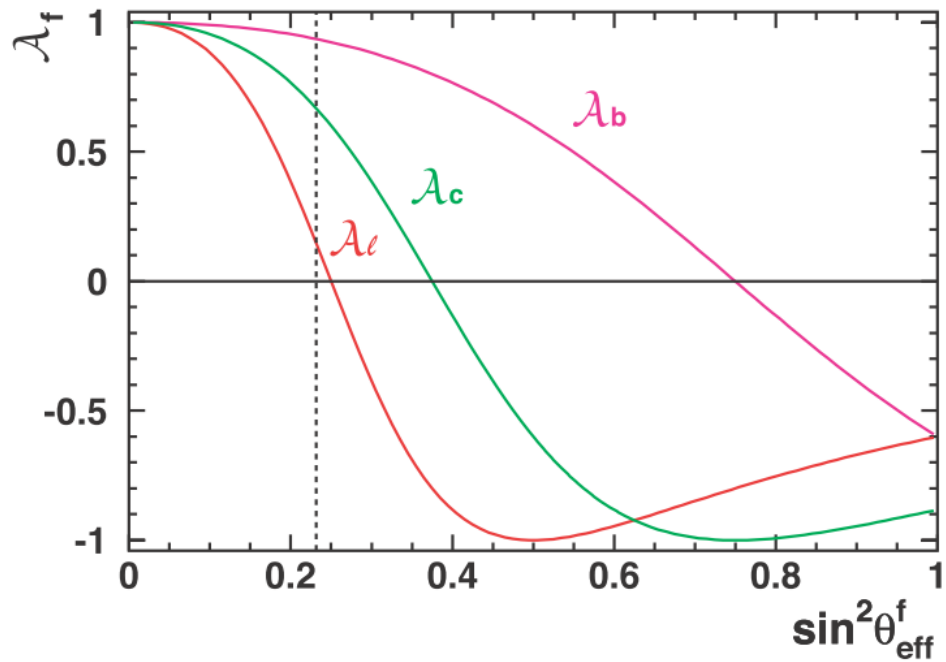
Current precision on $\sin^2\theta_W$



Unsatisfactory that two most precise measurements are >3σ apart, and that W.A. is marginally consistent with either.

$$A_{FB}^{0,f} = \frac{3}{4} A_f (uA_u + dA_d + sA_s) \qquad A_f = \frac{2 g_{Vf} g_{Af}}{g_{Vf}^2 + g_{Af}^2}$$

A_{FB} sensitive to $\sin^2\theta_W$



A_{FB} in muon channel at LHC is about 5 times larger than at LEP.

But sensitivity coming more from A_l rather than A_u or A_d

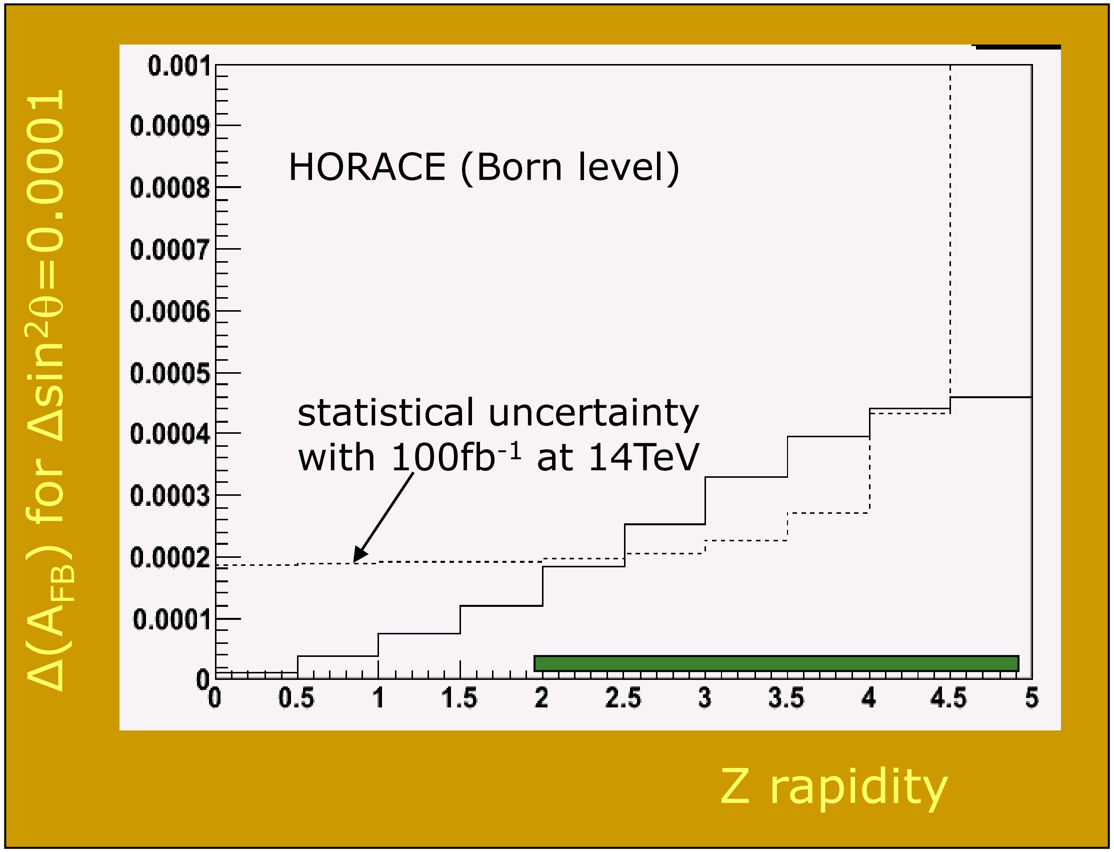
Measuring A_{FB} in pp->Z->μμ ?

$A^0_{FB} = 3/4\, A_\mu (u A_u + d A_d + s A_s)$

LHC Problems:
1. PDF uncertainties
2. Which is quark direction?

Going forward helps….

How confident are we:
- of theory?
- of PDF uncertainties?
- of detector systematics?

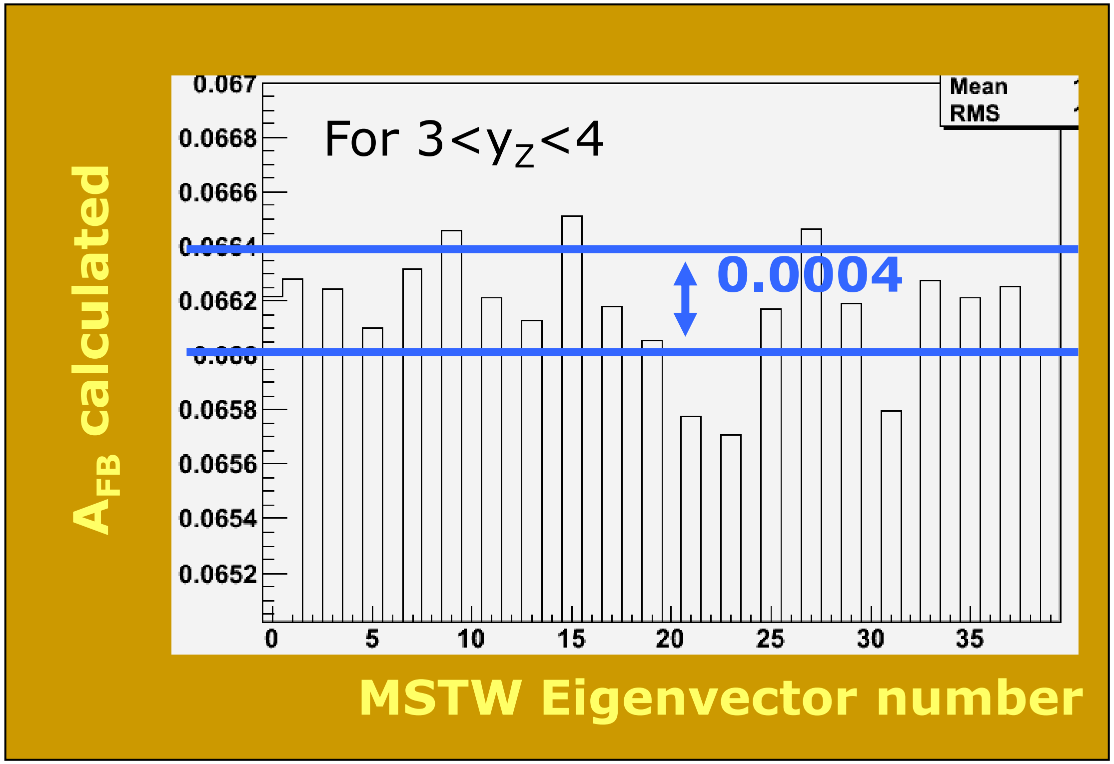


Statistically, a forward detector at high luminosity could measure A_{FB} with better precision than current WA (0.00016).
With 50fb-1, A_{FB} measured to 0.0004, $\sin^2\theta_W$ measured to 0.0001

Uncertainty due to PDF

Uncertainty from PDF (from one PDF set) about the same as statistical uncertainty.

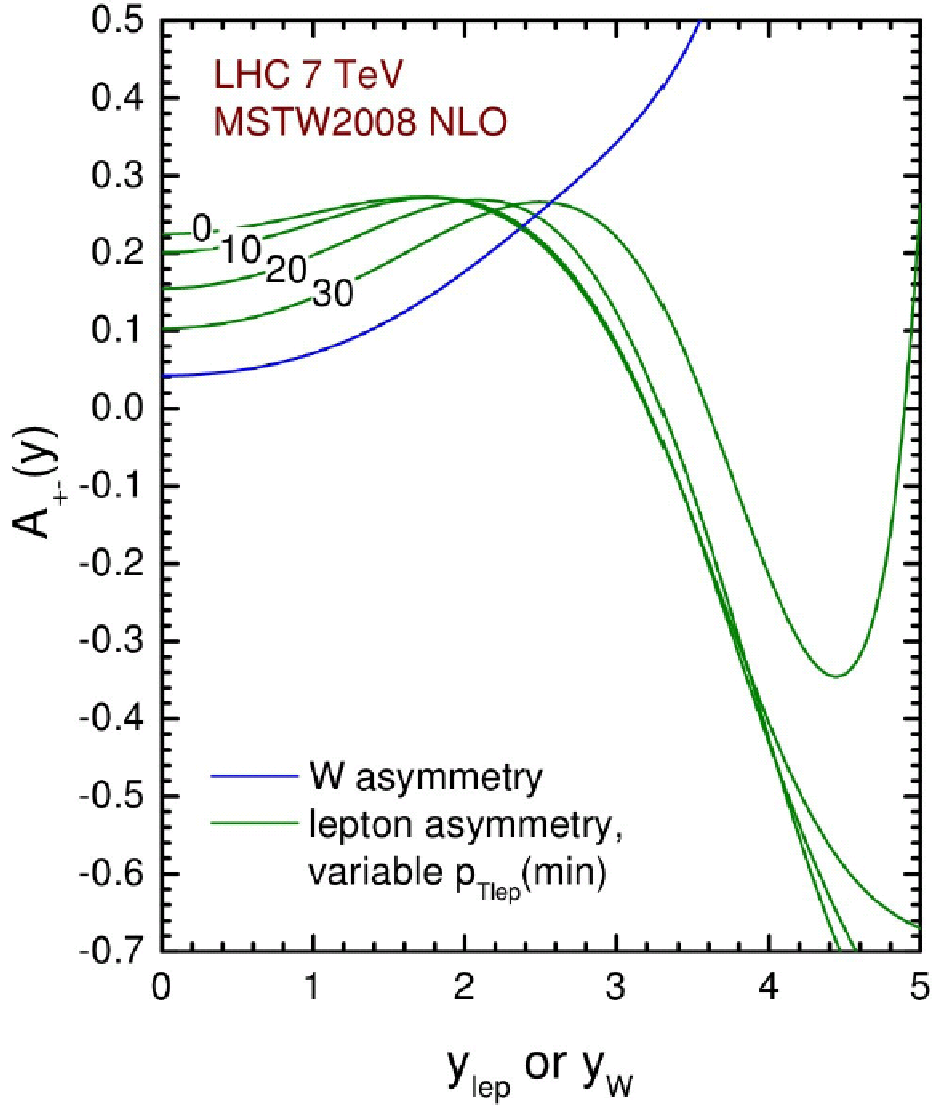
With time, this should improve (~ 50%?)



Summary

- W and Z cross-sections limited by luminosity uncertainty.
- Ratios limited by knowledge of background in W sample

- For the future: PDFs have an impact on theoretical prediction for A_{FB}



from J.Stirling

$$A_{FB}^{0,f} = \frac{3}{4} A_f (uA_u + dA_d + sA_s) \qquad A_f = \frac{2 g_{Vf} g_{Af}}{g_{Vf}^2 + g_{Af}^2}$$

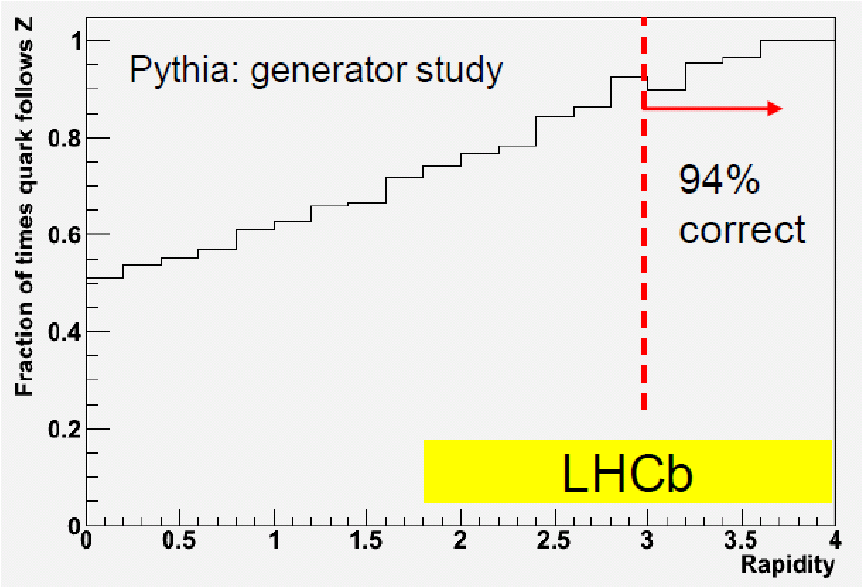
A_{FB} sensitive to $\sin^2\theta_W$

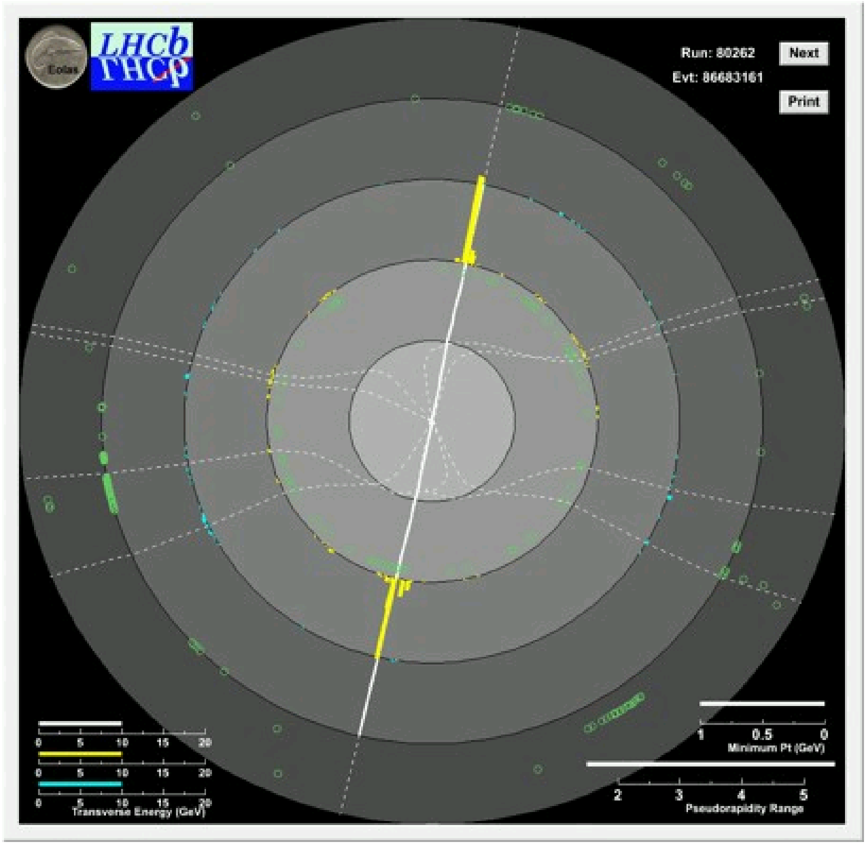
Uncertainties from :

- Forward (quark) direction
- PDF knowledge of sea

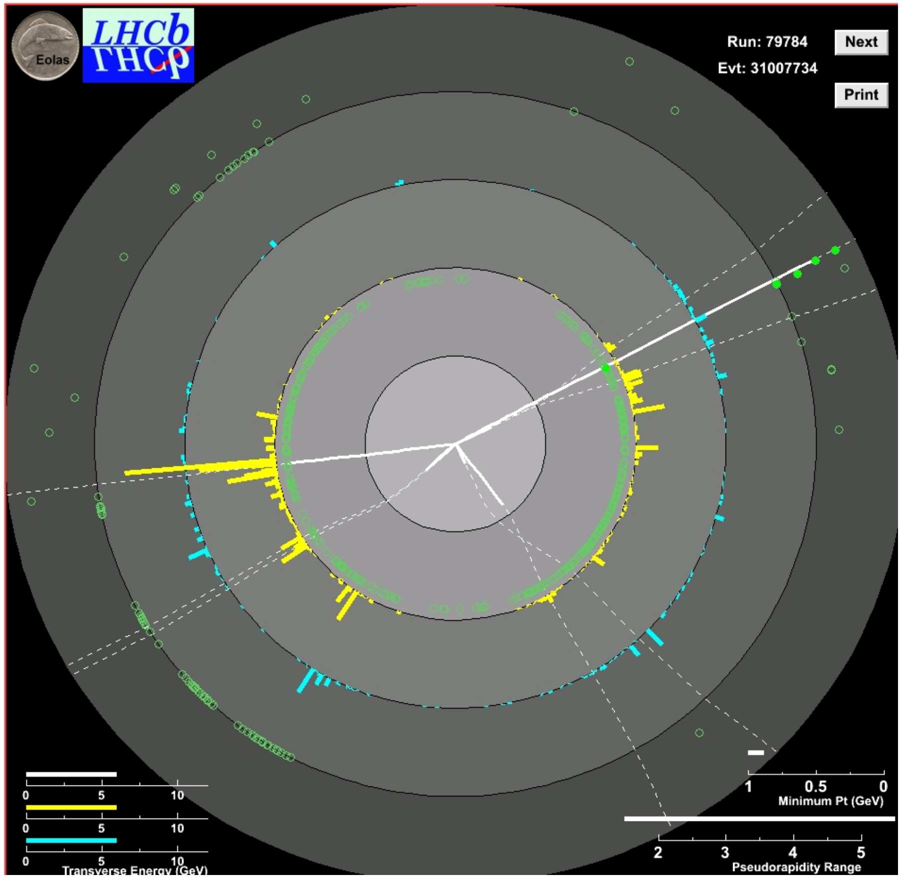
LHCb:

- predominately valence - sea collisions
- ss contribution reduced




LHCb
Eolas
Run: 80262
Evt: 86683161
Next
Print
Minimum Pt (GeV)
Pseudorapidity Range
Transverse Energy (GeV)

Z->ee


LHCb
Eolas
Run: 79784
Evt: 31007734
Next
Print
Minimum Pt (GeV)
Pseudorapidity Range
Transverse Energy (GeV)

Z->tautau