Precision electroweak measurements: LHCb

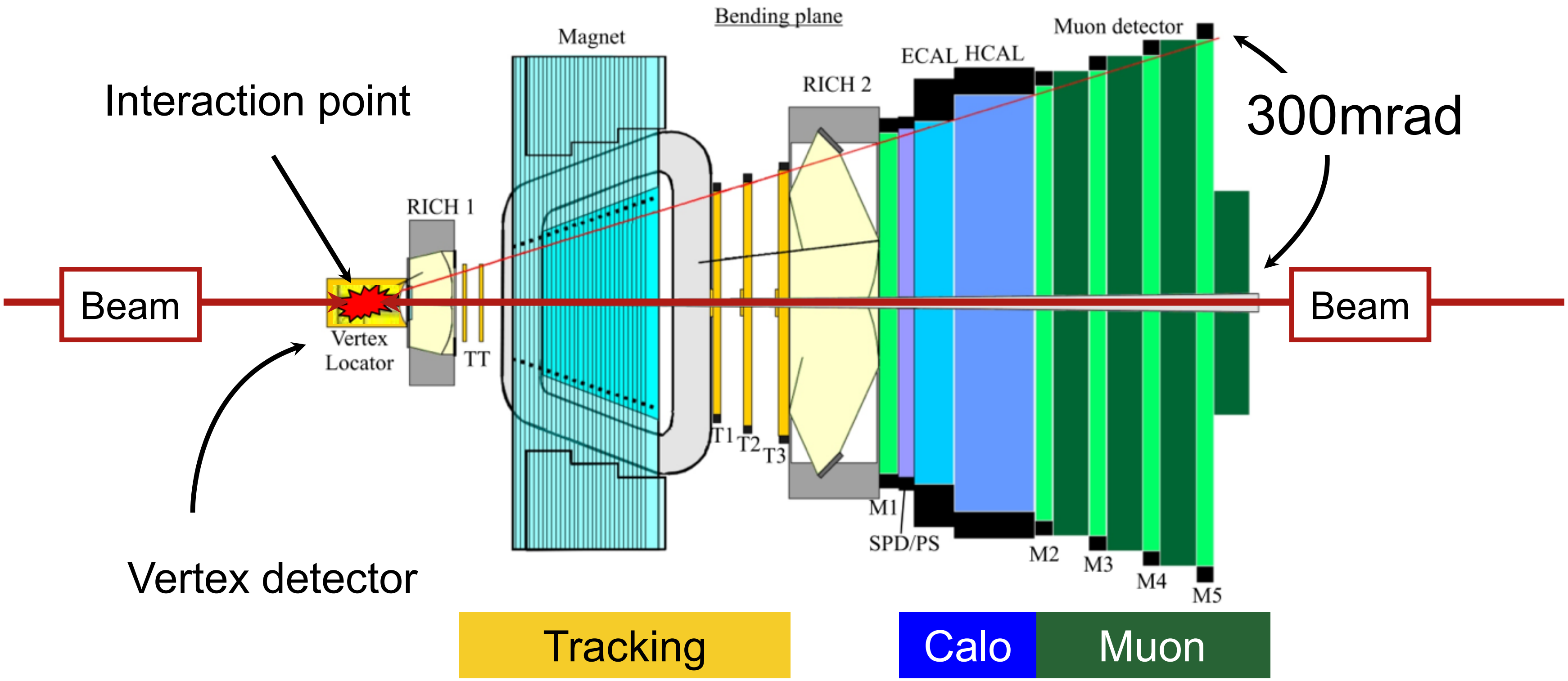
Tara Shears,
On behalf of the LHCb collaboration

Introduction

Cross-sections: Z, W, ratios

Outlook: PDF sensitivity, A_{FB}

Conclusions



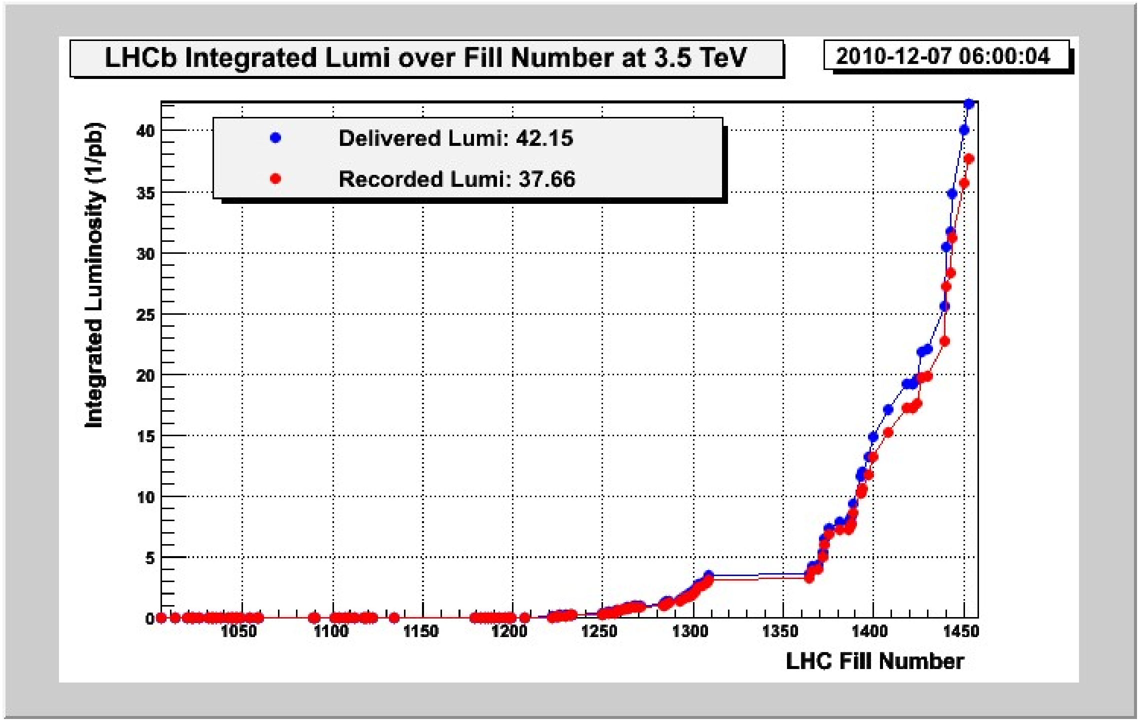
Fully instrumented within $1.9 \leq \eta \leq 4.9$

Trigger: $p_{\mu} > 3$ GeV, $pt_{\mu} > 0.5$ GeV, $m_{\mu\mu} > 2.5$ GeV

2010:

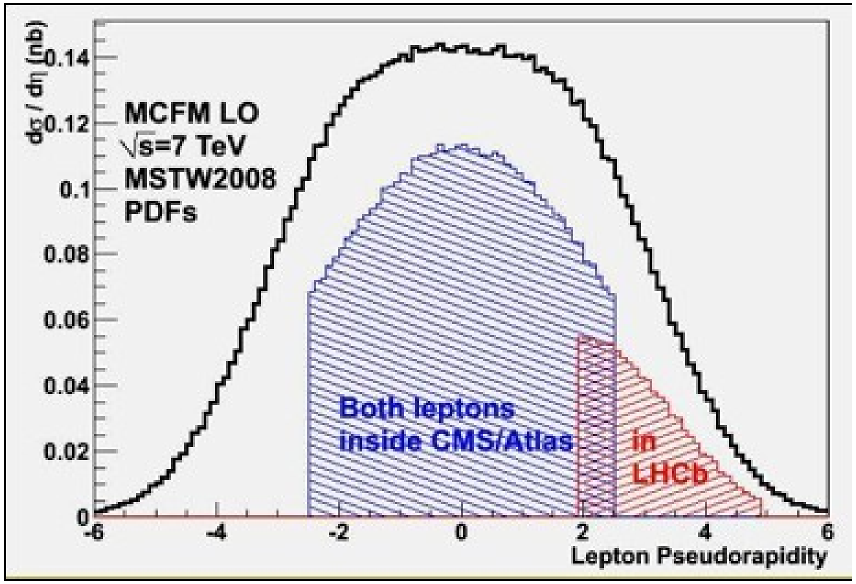
37.7 pb^{-1} data recorded

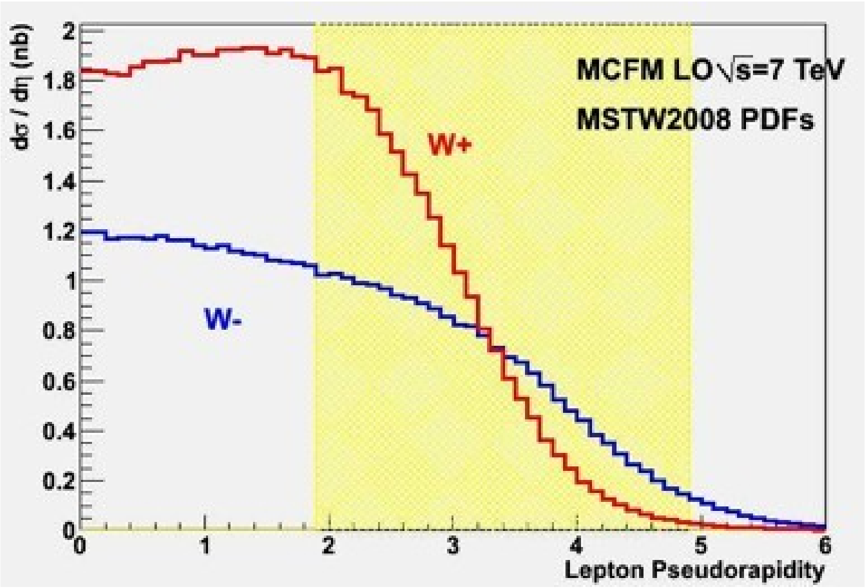
16.5 ± 1.7 pb^{-1} used



2011:

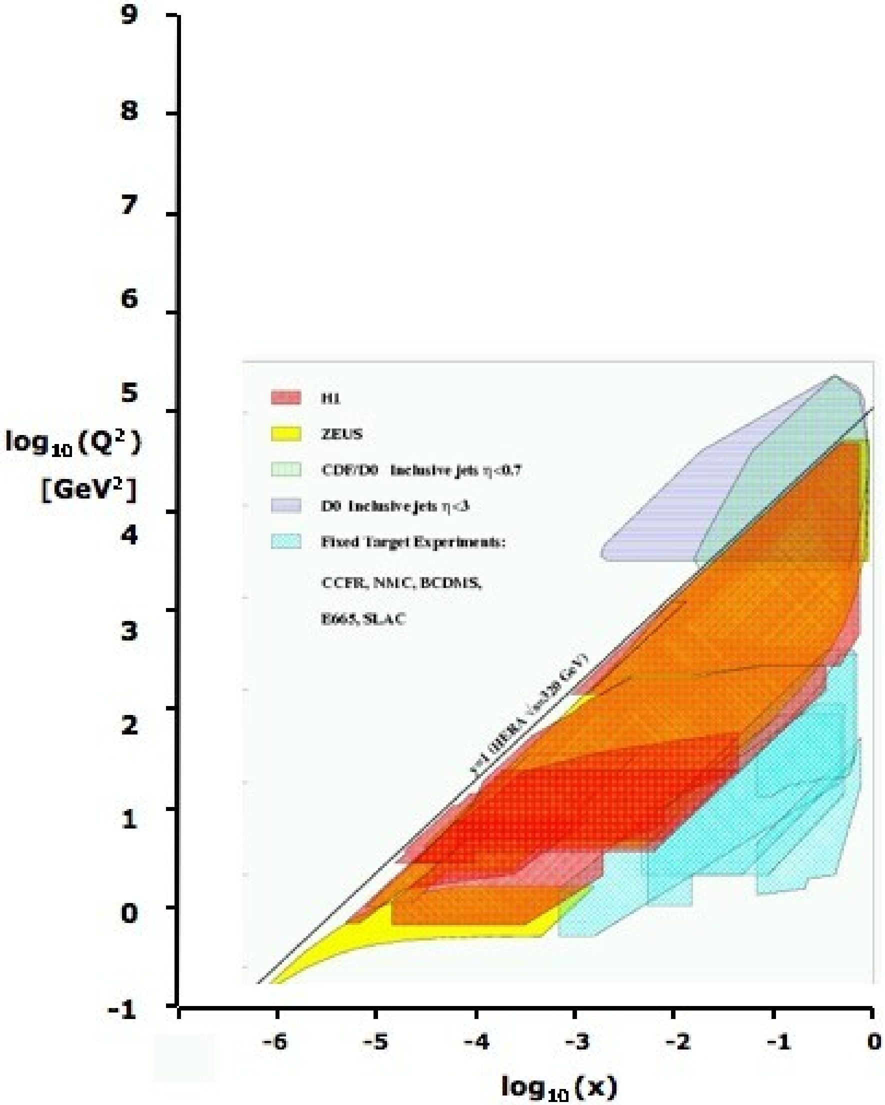
hope for 1-2 fb^{-1} of data



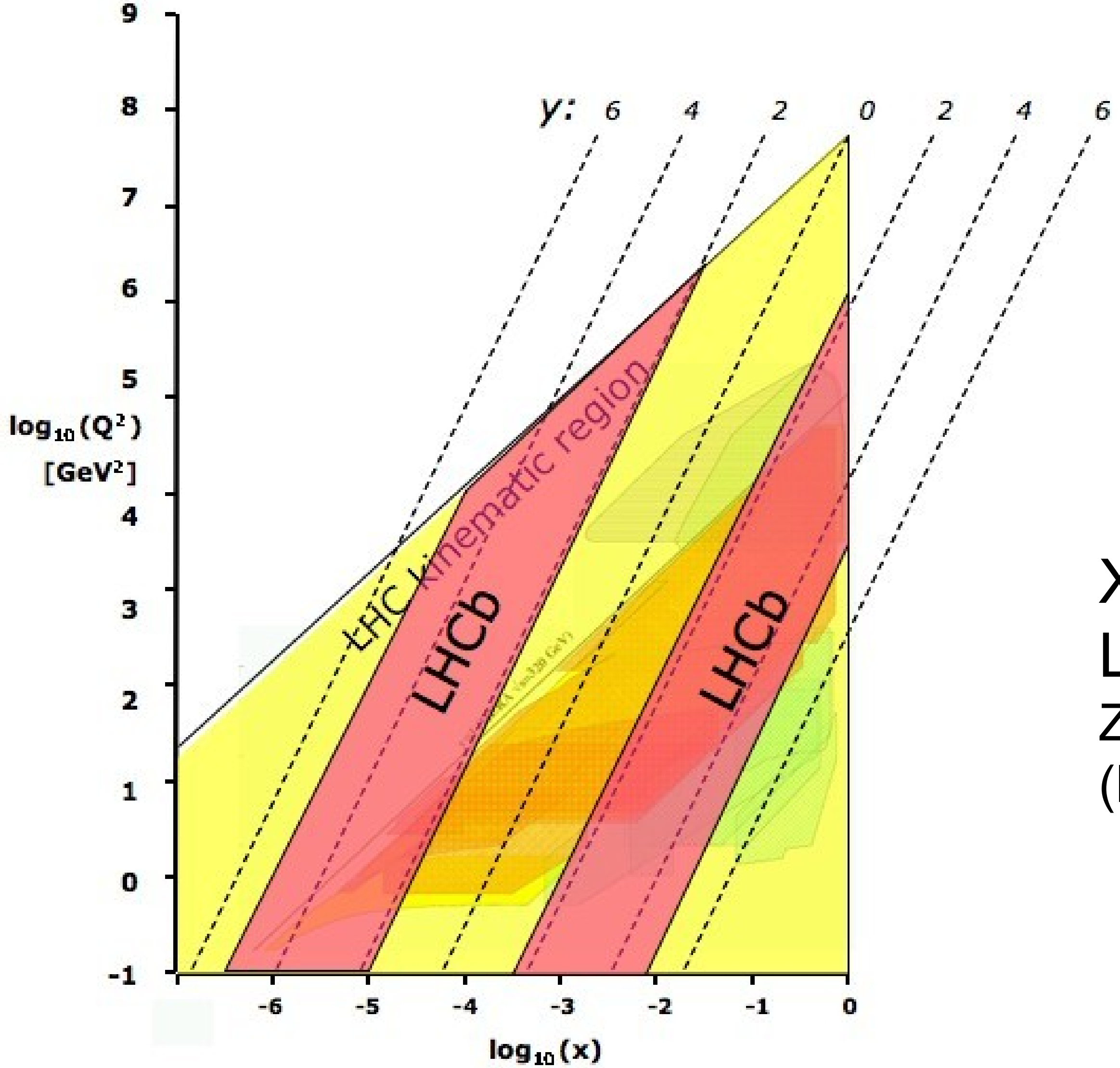


8% of Z within LHCb acceptance

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



X, Q^2 explored by previous experimental data

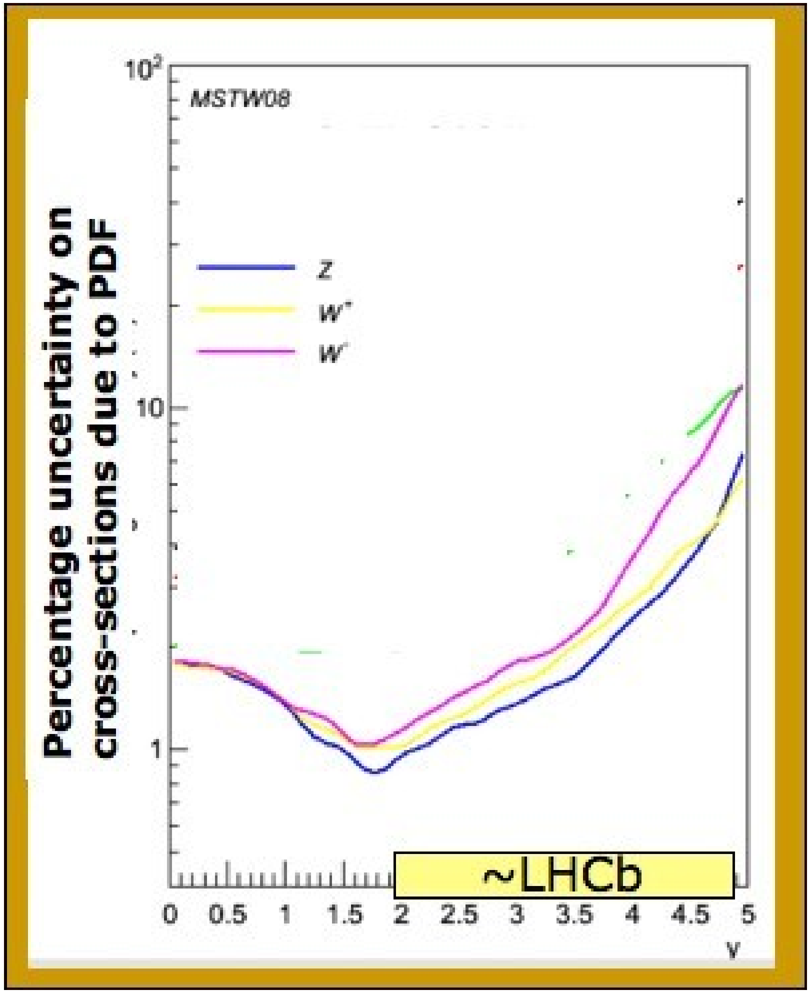


X, Q^2 explored by LHCb.

Z, W: x of 10^{-4}, 10^{-1}

(low mass $\gamma^* \rightarrow 10^{-6}$)

Cross-sections known to NNLO
PDF uncertainty dominates
Known to ~1% at y ~1.5-2, 6-8% at y~5

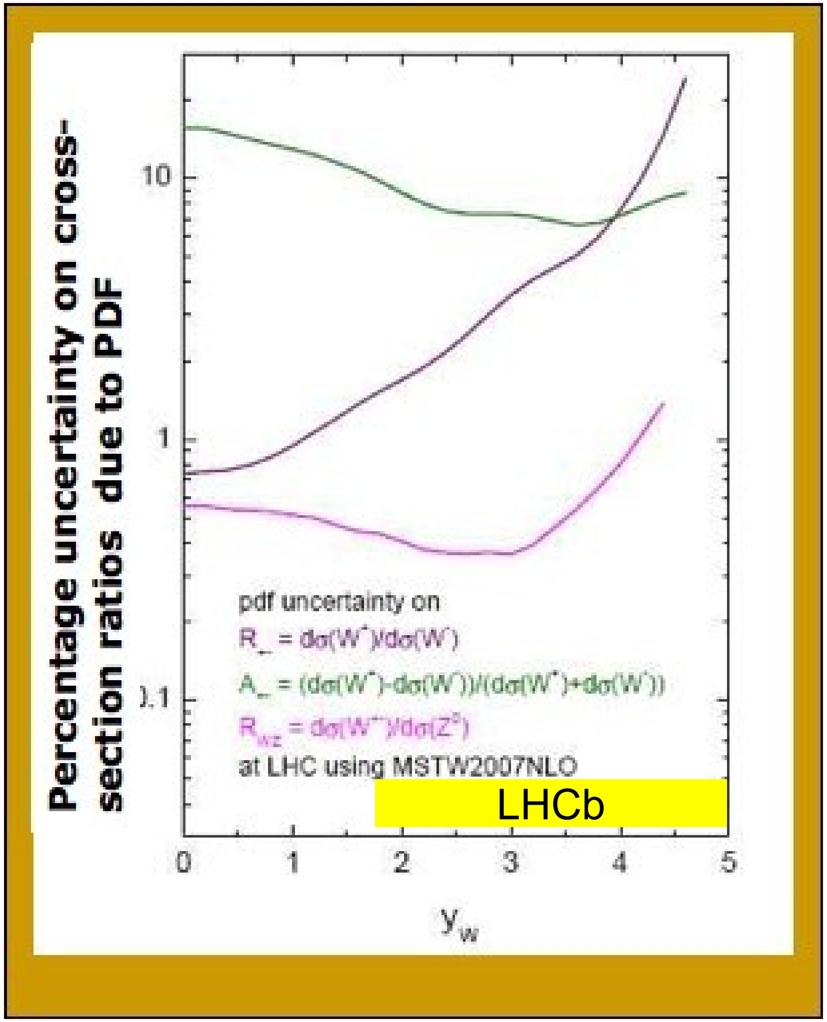


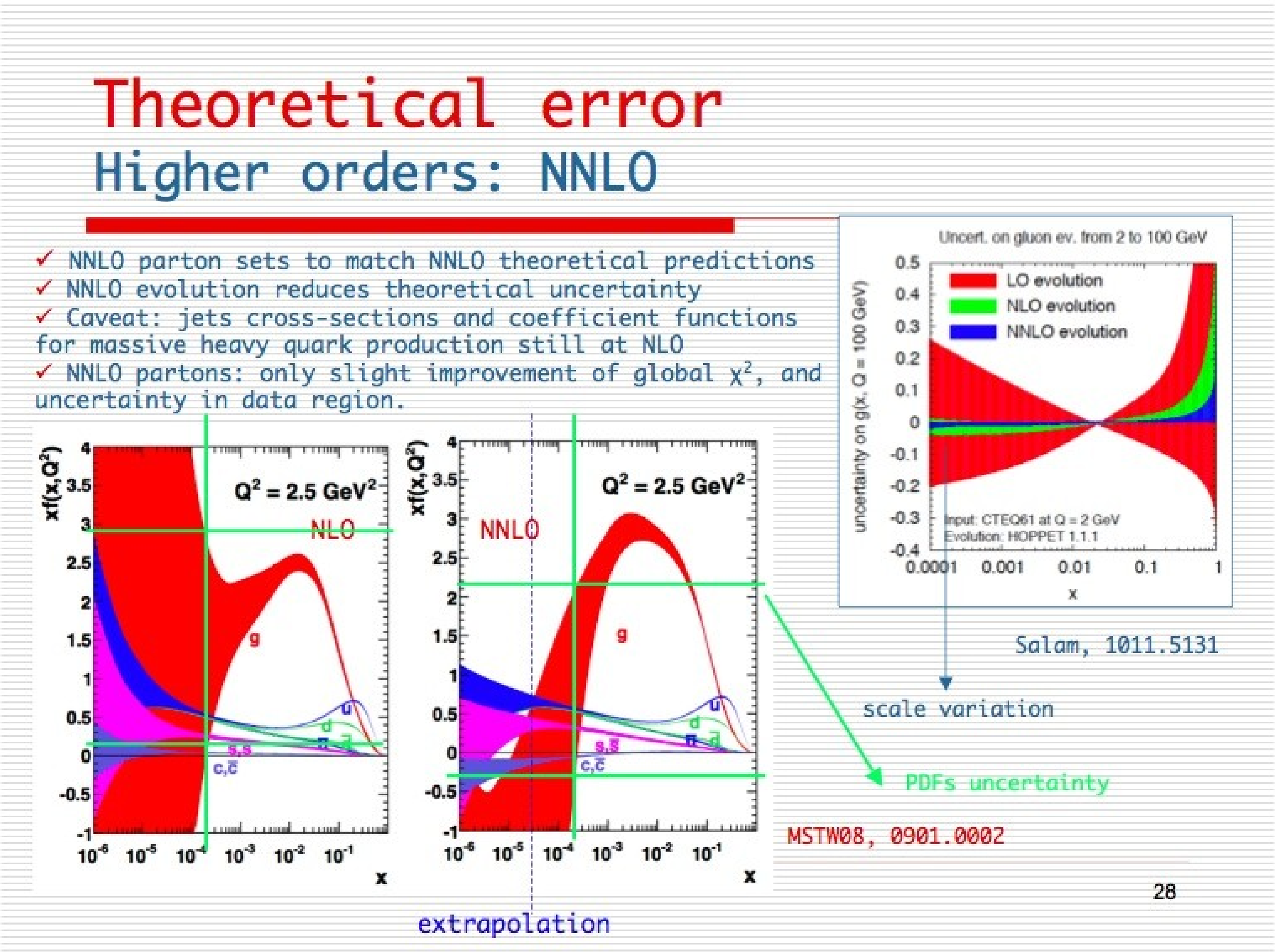
Cancel or highlight PDF uncertainties with ratios

R_+ tests d_V/u_V ratio

A_W tests difference between u_V and d_V

R_{WZ} almost insensitive to PDFs





PDFs have large uncertainty at low x

(Maria, yesterday)

Definition of measured cross-sections:

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

(as function of Z rapidity)

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

(as function of muon pseudorapidity)

$$\sigma_{Z\to\mu\mu}(\Delta y) = \frac{N_{tot}^{Z} - N_{bkg}^{Z}}{\varepsilon_Z L}$$

Z selection

Z background estimation

Trigger:

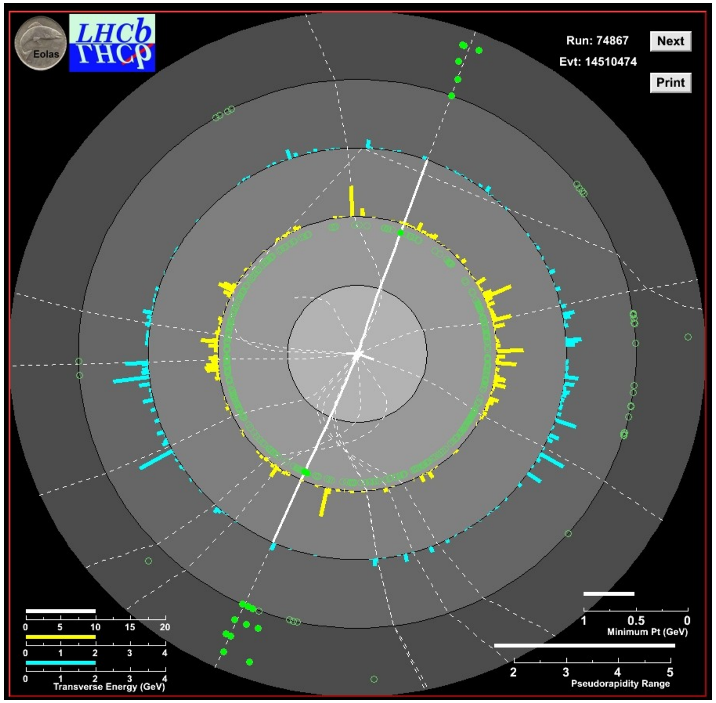
Single μ, $p_T > 10$ GeV

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

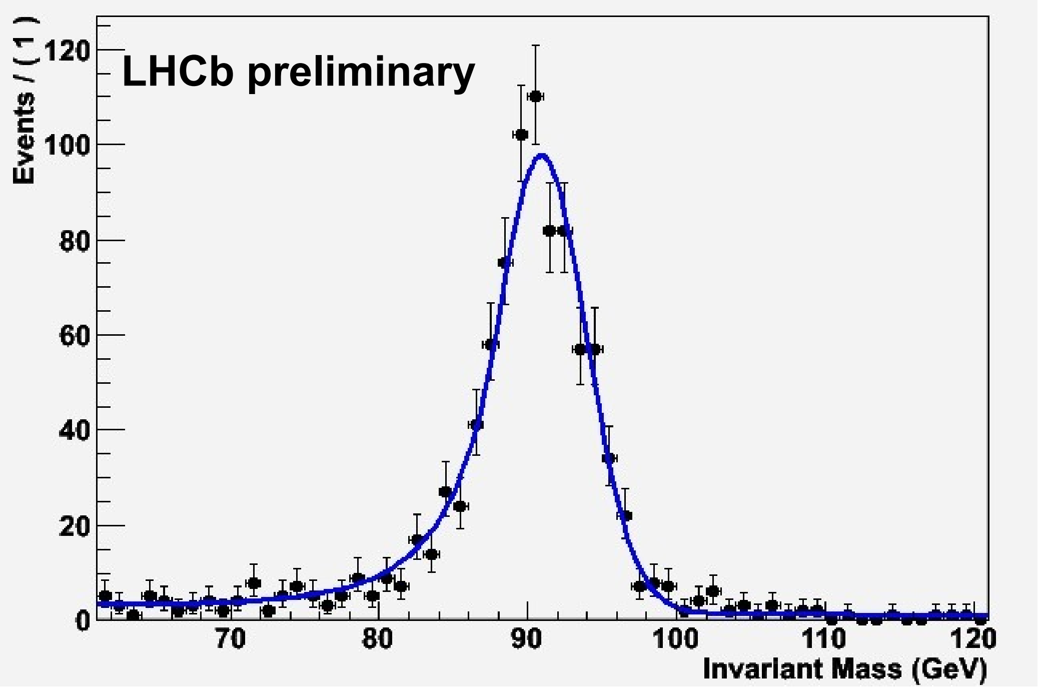


$\varepsilon_Z = 1.00$ (by definition to compare with theory)

$N_Z = 833$

Backgrounds:

- $Z \rightarrow \tau\tau$ (~ 0.2)
- Heavy flavour (~ 1)
- K/π (< 0.03)
- $N_{bkg} = 1.2 \pm 1.2$



Data, simulation

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

W selection

W background estimation

Trigger:

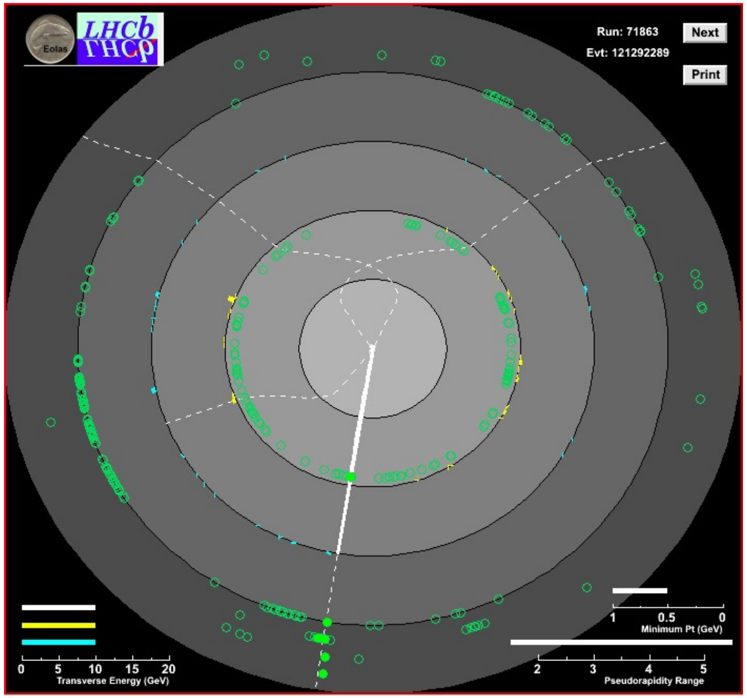
Single μ, $p_T > 10$ GeV

Muon:

Good track quality (σ_p/p, χ^2 probability)
$p_T > 20$ GeV
$2.0 < \eta < 4.5$
Impact parameter significance < 2
Σp_T in $R=\sqrt{(\Delta\eta^2+\Delta\phi^2)}=0.5$ cone around $\mu < 2$ GeV

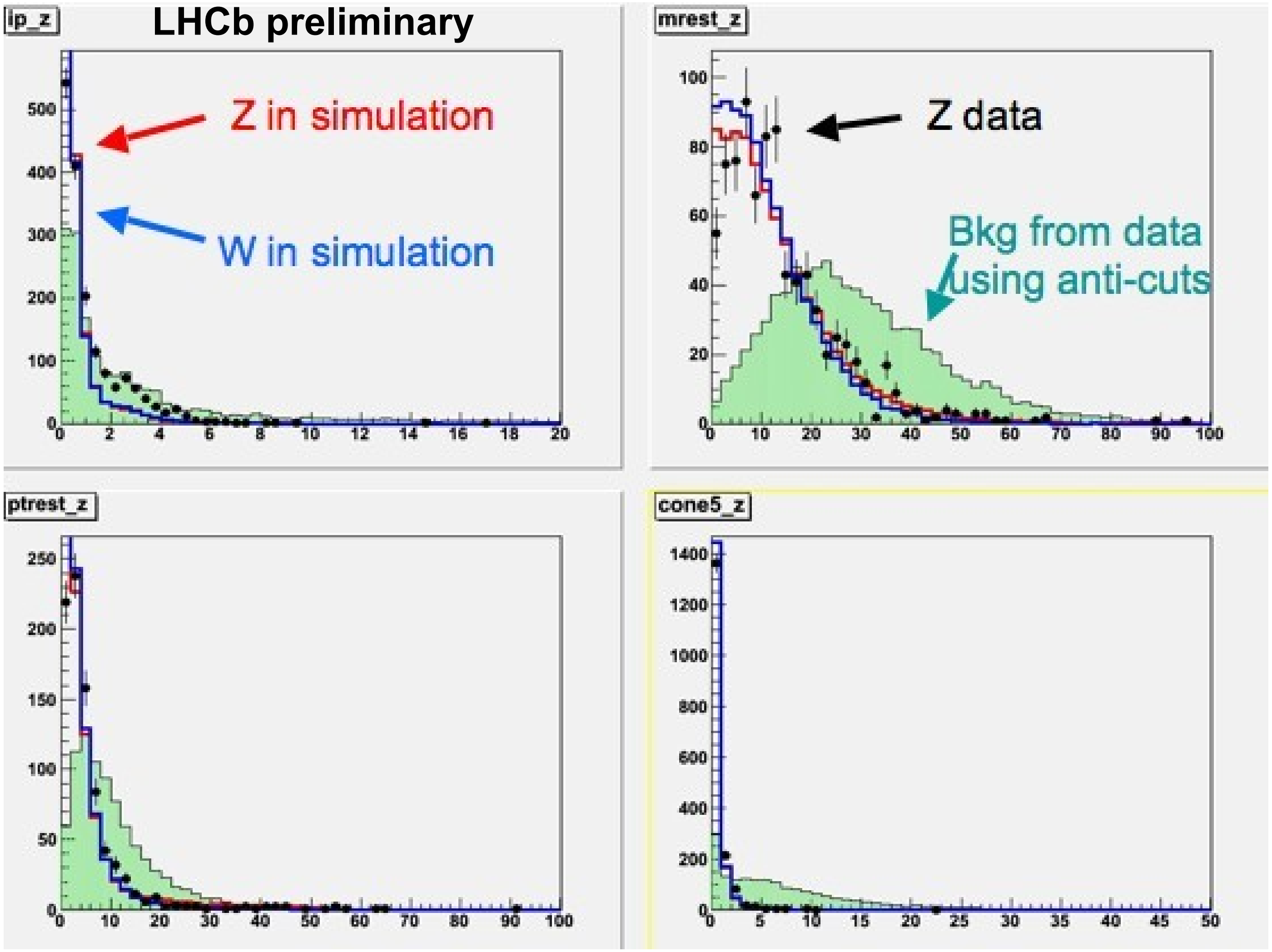
Rest of event:

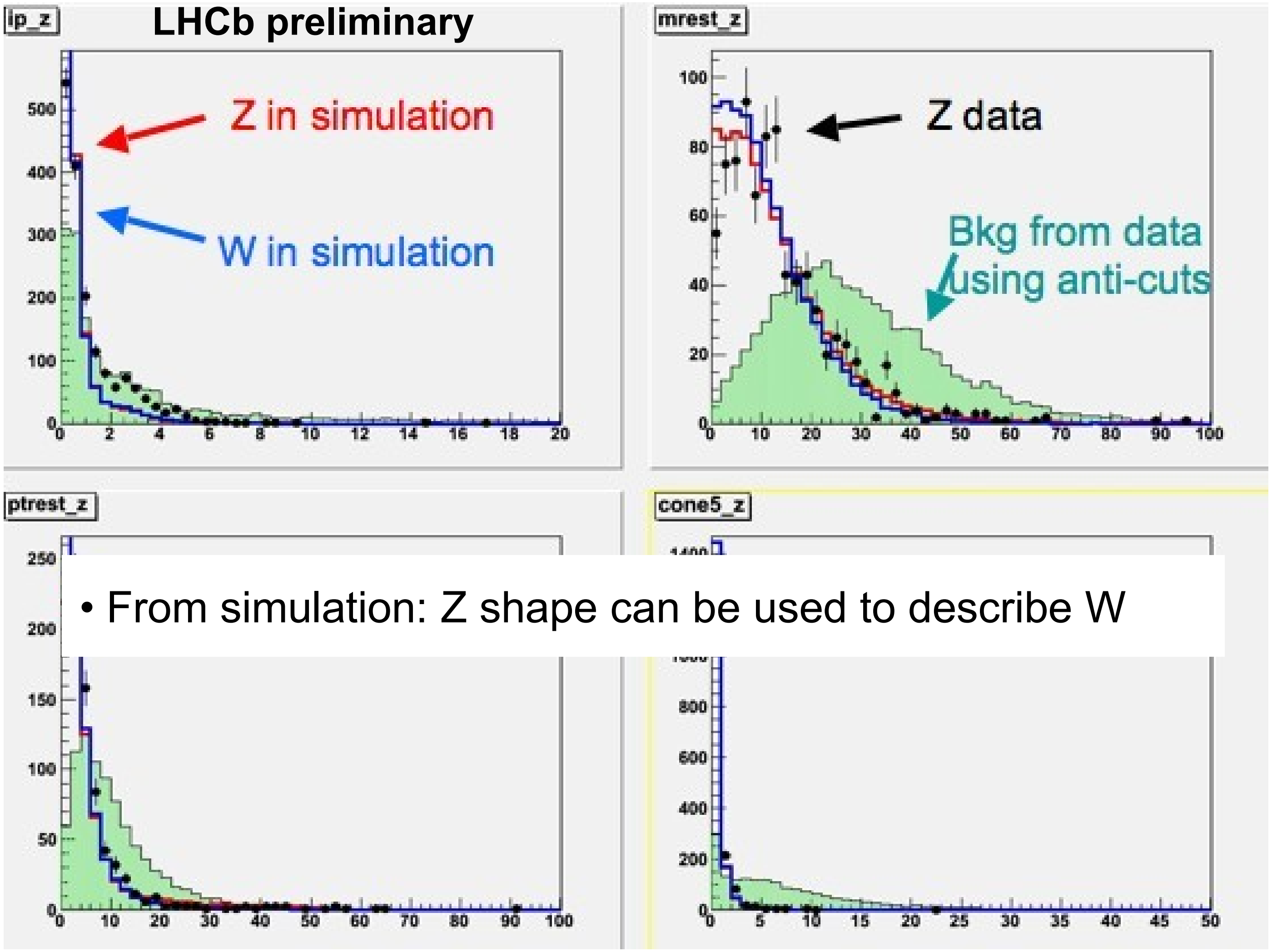
Mass < 20 GeV
$\Sigma p_T < 10$ GeV



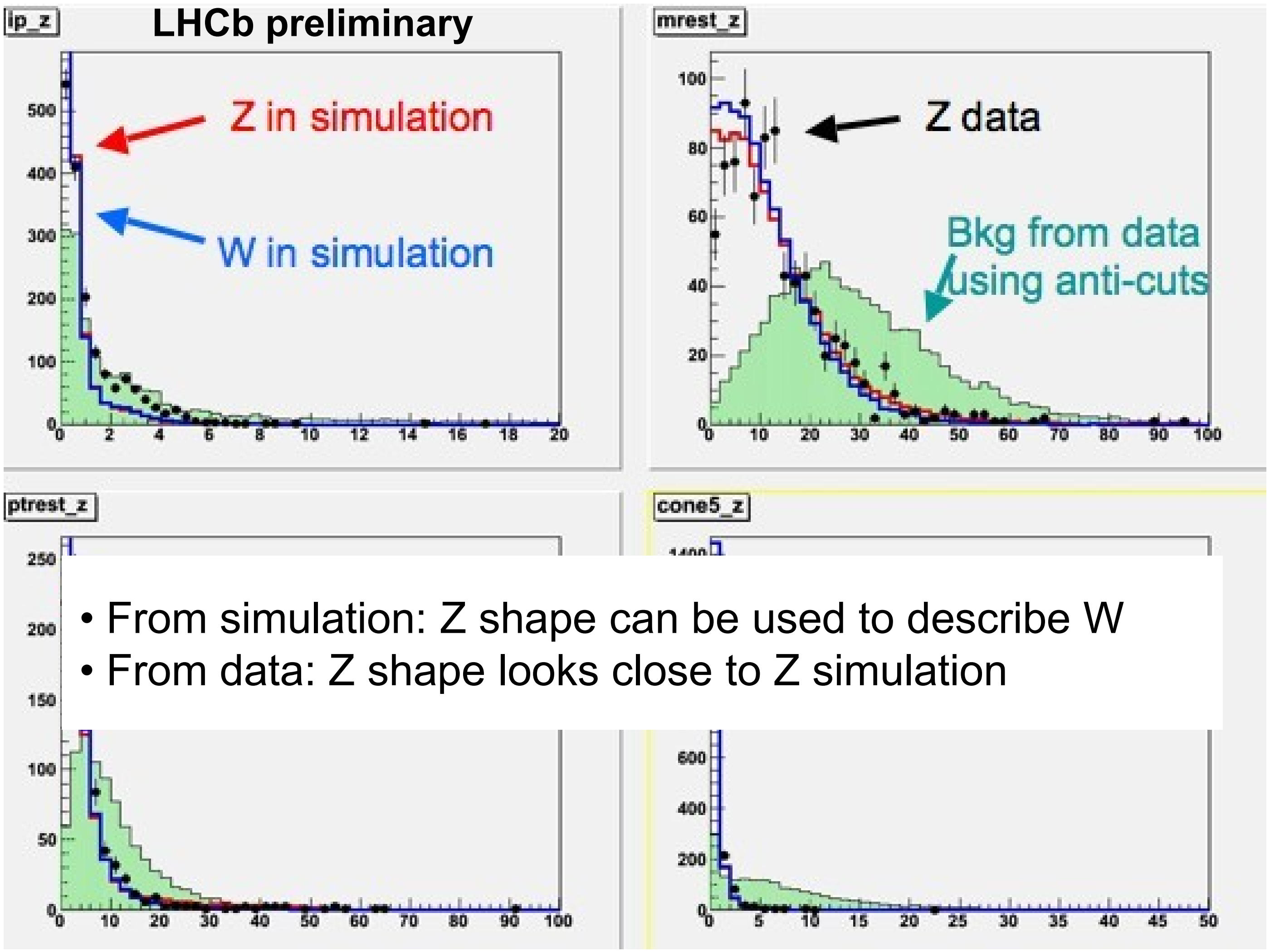
$\varepsilon_W = 55.0 \pm 1.0\%$

(data driven, using Z events)

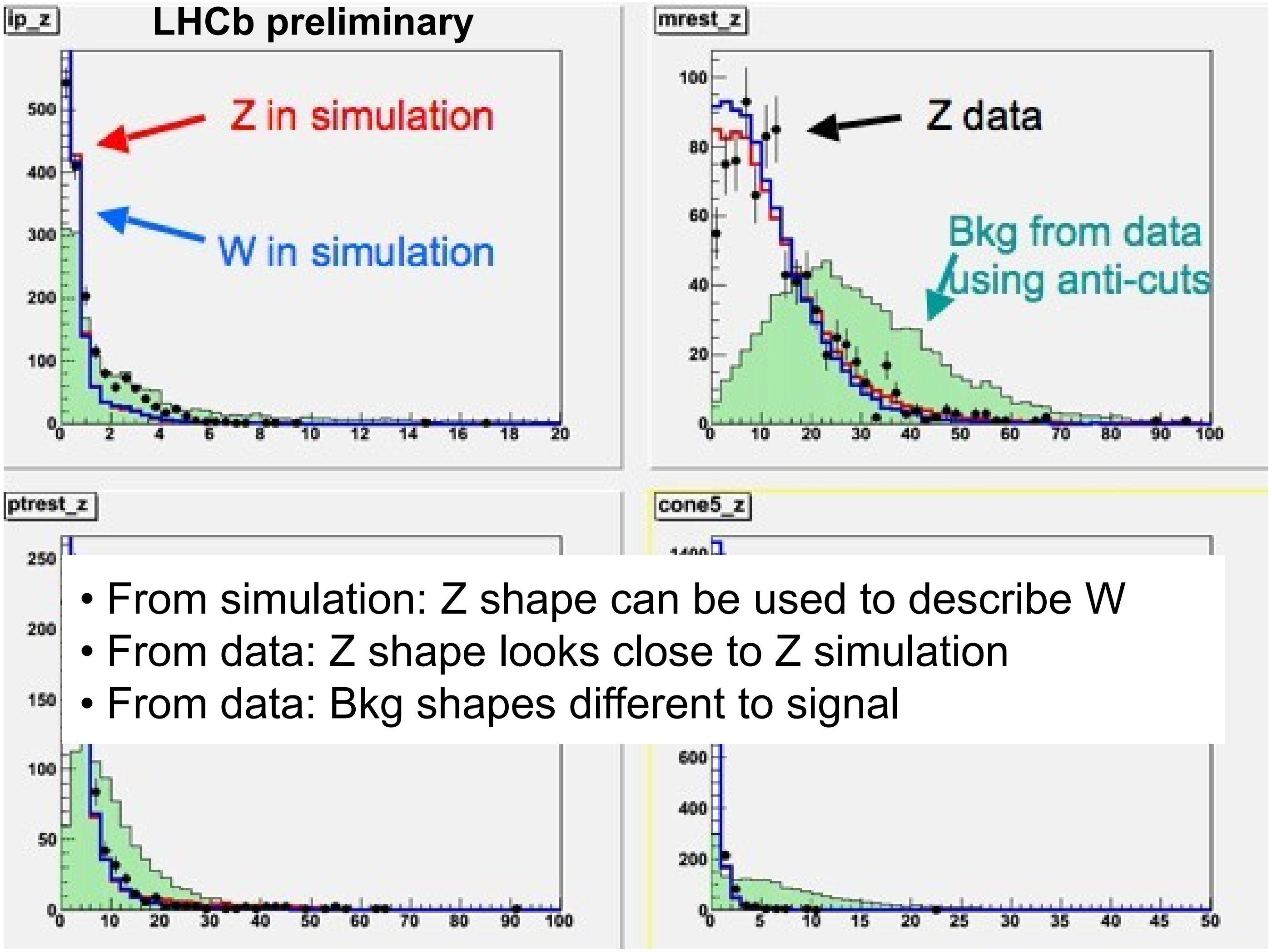

ip_z
LHCb preliminary
Z in simulation
W in simulation
mrest_z
Z data
Bkg from data
using anti-cuts
ptrest_z
cone5_z



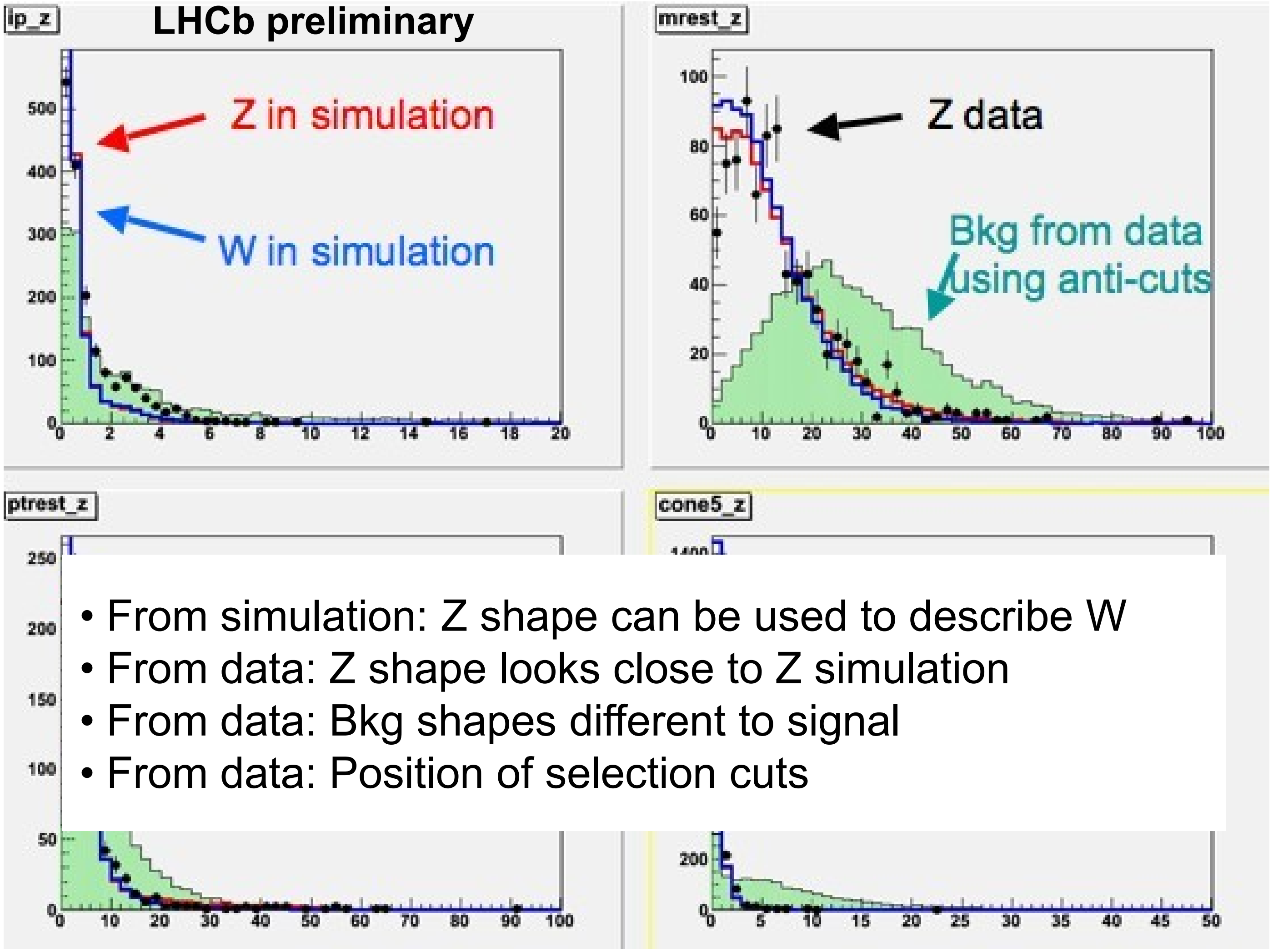
• From simulation: Z shape can be used to describe W



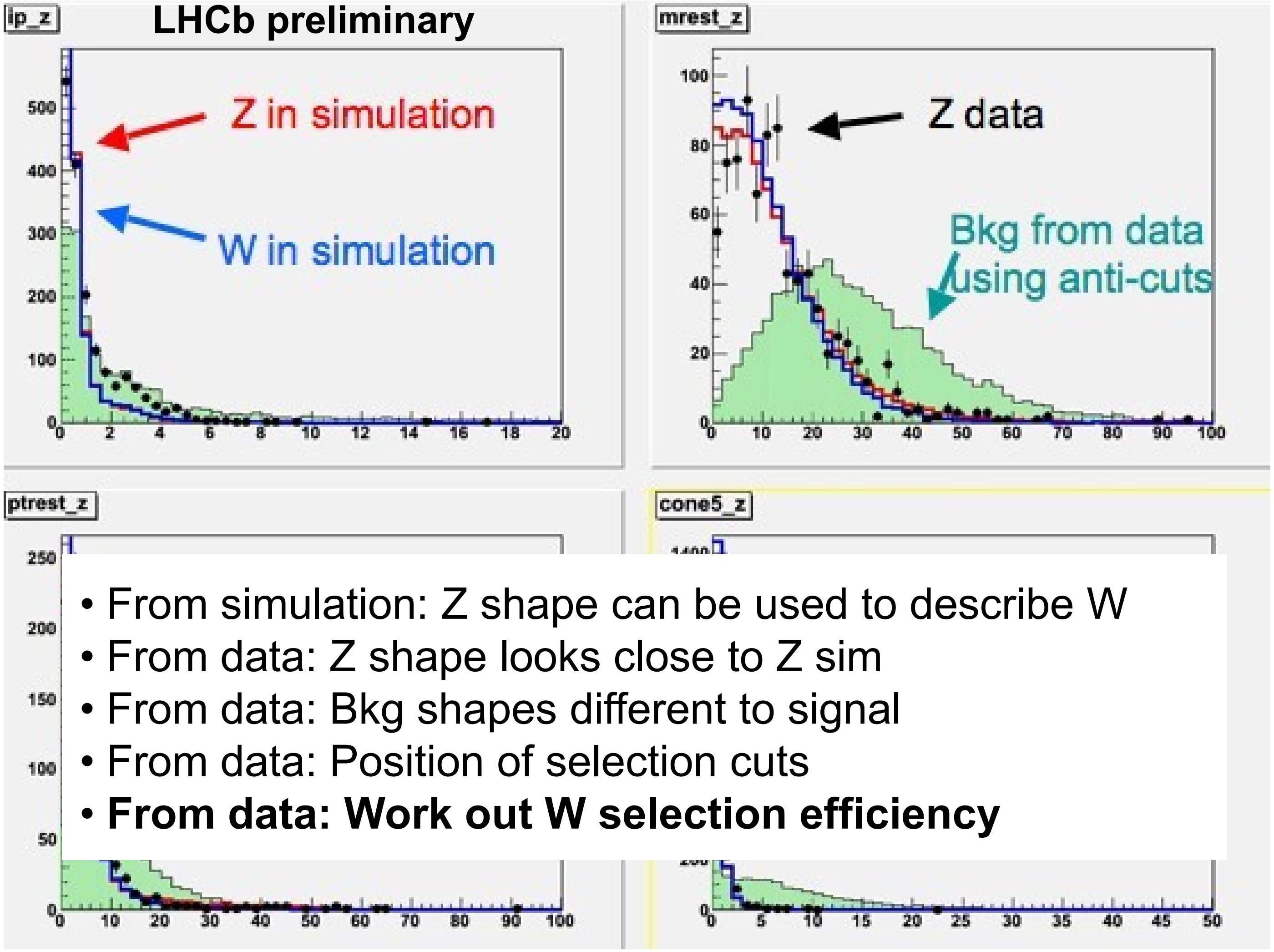
- From simulation: Z shape can be used to describe W
- From data: Z shape looks close to Z simulation



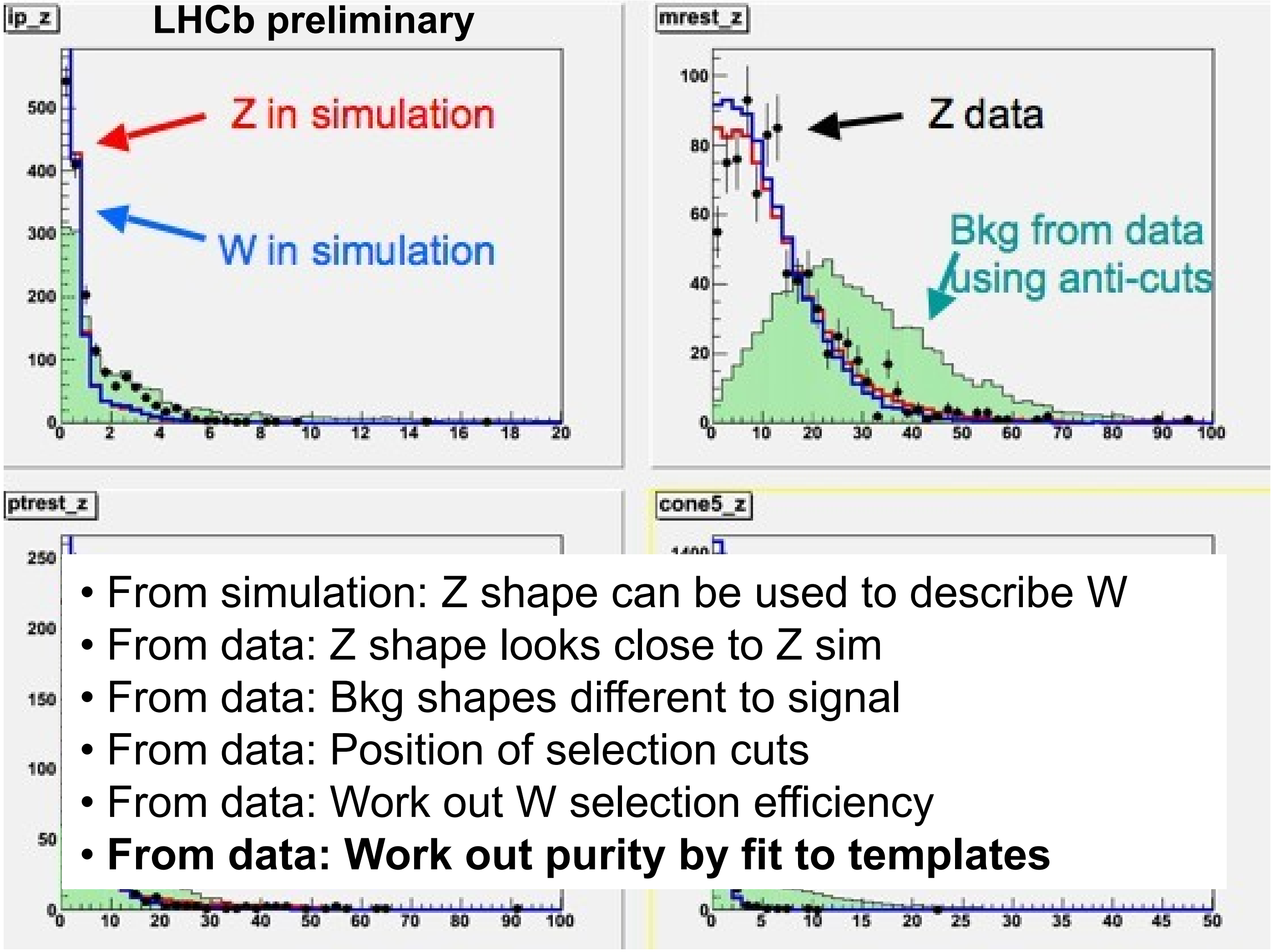
- From simulation: Z shape can be used to describe W
- From data: Z shape looks close to Z simulation
- From data: Bkg shapes different to signal



- From simulation: Z shape can be used to describe W
- From data: Z shape looks close to Z simulation
- From data: Bkg shapes different to signal
- From data: Position of selection cuts



- From simulation: Z shape can be used to describe W
- From data: Z shape looks close to Z sim
- From data: Bkg shapes different to signal
- From data: Position of selection cuts
- **From data: Work out W selection efficiency**



- From simulation: Z shape can be used to describe W
- From data: Z shape looks close to Z sim
- From data: Bkg shapes different to signal
- From data: Position of selection cuts
- From data: Work out W selection efficiency
- **From data: Work out purity by fit to templates**

$N_{W+} = 7624$
$N_{W-} = 5732$

Background sources:

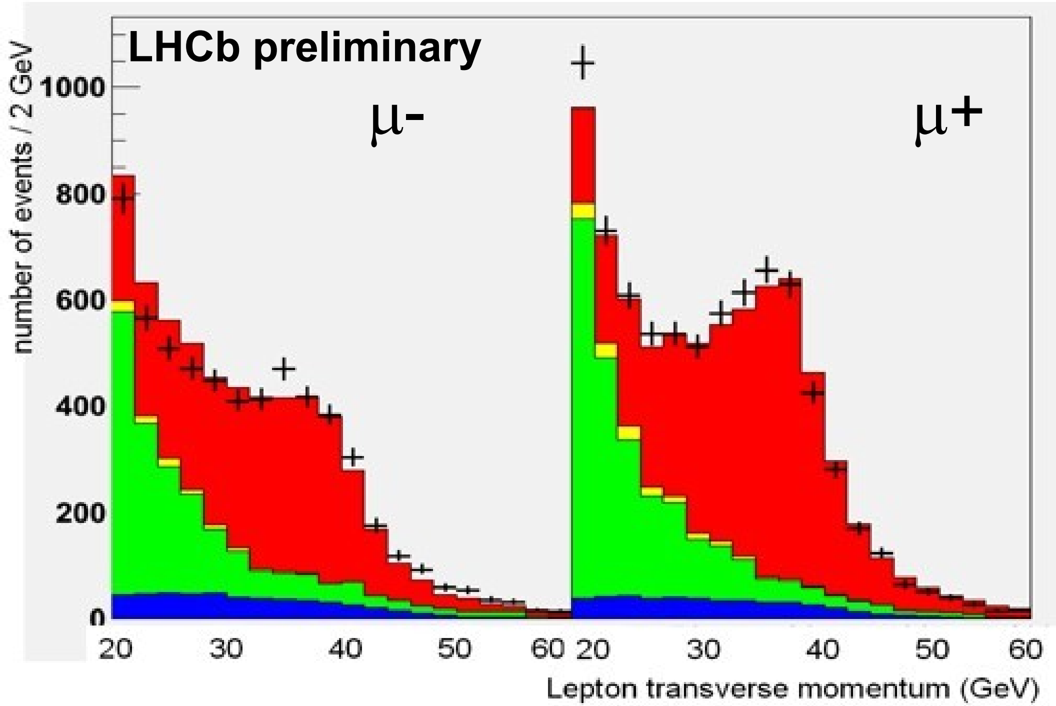
- $Z \rightarrow \mu\mu$ (1 μ in acceptance)
- $Z \rightarrow \tau\tau$
- $W \rightarrow \tau\nu$
- Hadronic events

Data
Simulation
Data + simulation

Fit muon p_T spectrum in data to expected shapes for signal and background, extract N_{bkg+}, N_{bkg-}

N_{bkg+} = 2194 ± 150

N_{bkg-} = 1654 ± 150



Perform fit in η bins
for differential results

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

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

$$\varepsilon_W = A_W \varepsilon_W^{trig} \varepsilon_W^{track} \varepsilon_W^{muon} \varepsilon_W^{selection}$$

↑

Measurements made in kinematic acceptance

A_Z, A_W = 1

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

$$\varepsilon_W = A_W \varepsilon_W^{trig} \varepsilon_W^{track} \varepsilon_W^{muon} \varepsilon_W^{selection}$$

↑

Determine from data (Z sample)

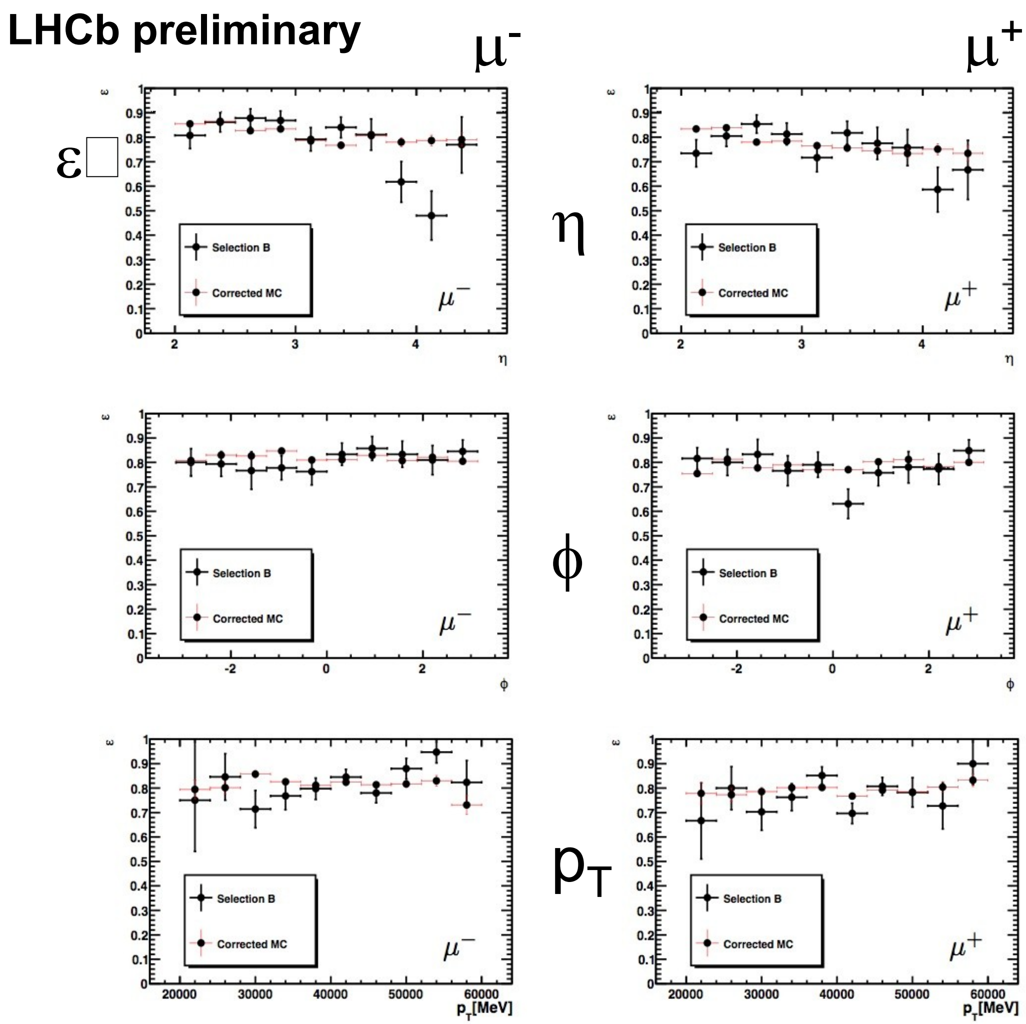
Tag: 1 identified muon having fired single muon trigger

Probe: 1 identified muon

Efficiency is **flat** in η, ϕ, p_T.

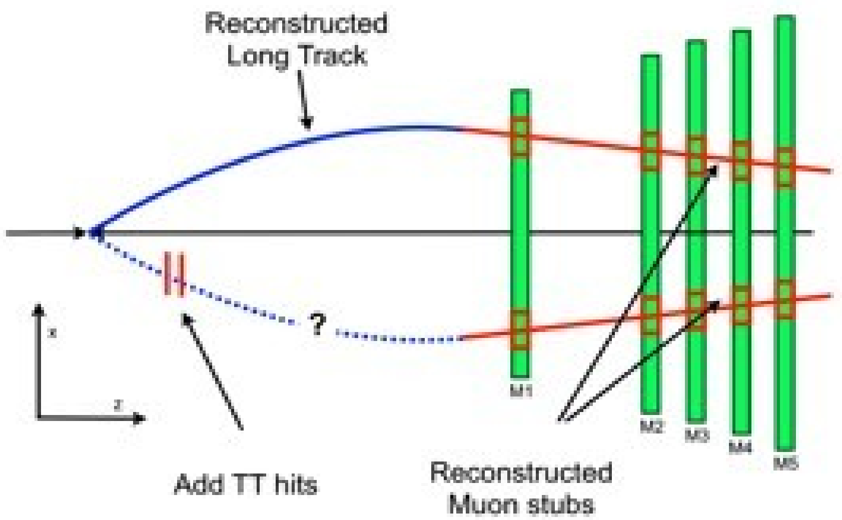
No evidence for charge bias

$\varepsilon_W = 72 \pm 1\%$
$\varepsilon_Z = 86 \pm 1\%$



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

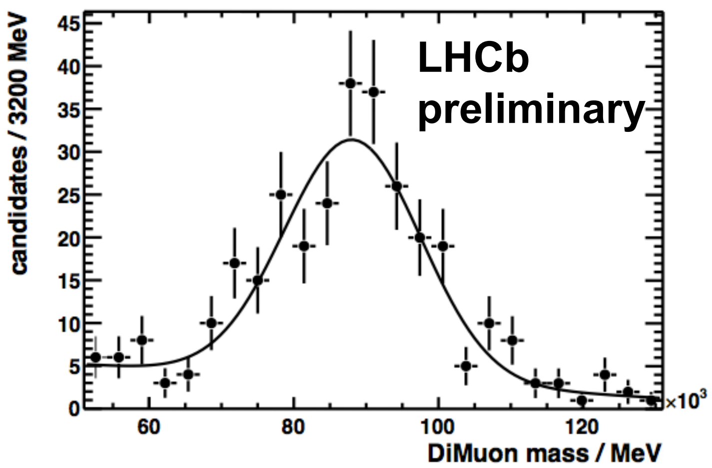
$$\varepsilon_W = A_W \varepsilon_W^{trig} \varepsilon_W^{track} \varepsilon_W^{muon} \varepsilon_W^{selection}$$



Determine from data (Z sample)

Tag: 1 identified muon

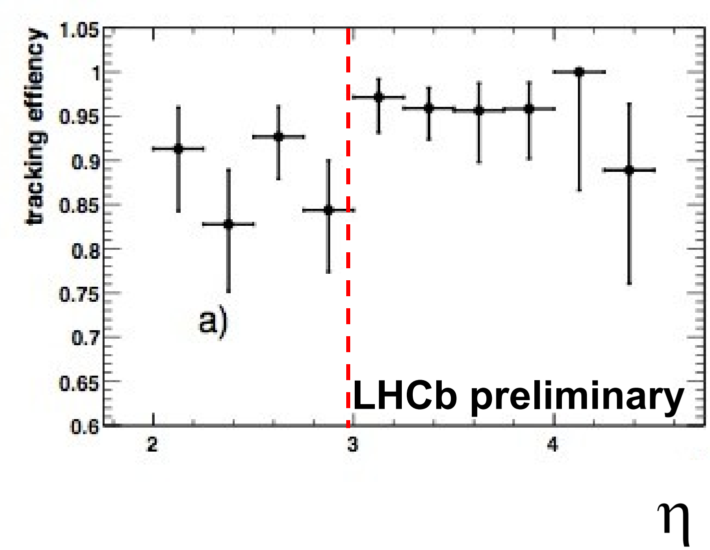
Probe: 1 muon stub + TT hit
(TT not used in tracking)



Efficiency **flat** in ϕ, p_T

Two regions considered in η

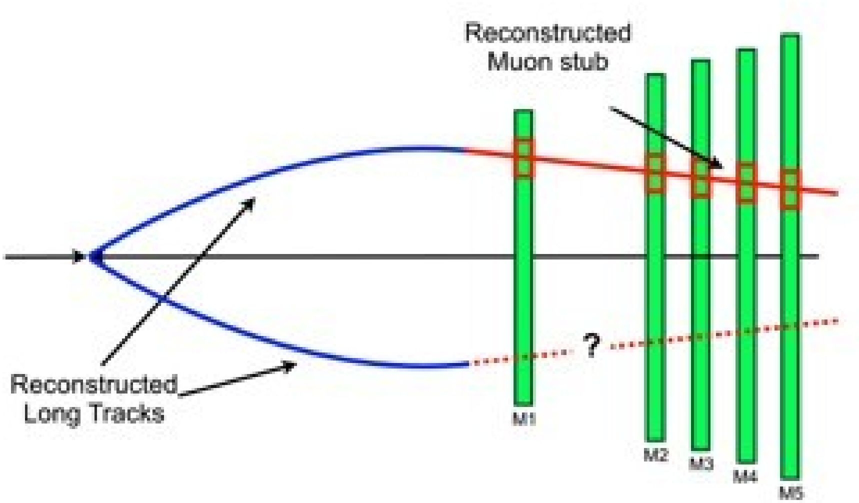
$\varepsilon_{W+}= 73 \pm 3\%$
$\varepsilon_{W-}= 78 \pm 3\%$
$\varepsilon_Z = 83 \pm 3\%$



(+, - different average efficiency due to different η distribution)

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

$$\varepsilon_W = A_W \varepsilon_W^{trig} \varepsilon_W^{track} \varepsilon_W^{muon} \varepsilon_W^{selection}$$



Determine from data (Z sample)

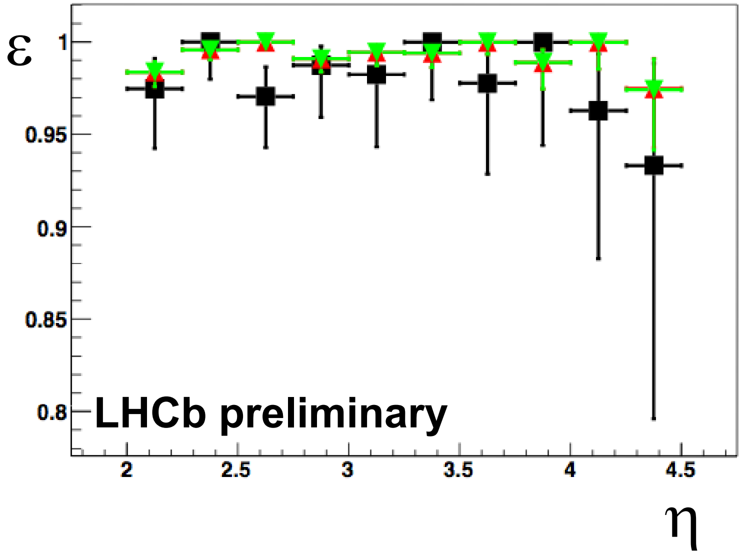
Tag: 1 identified muon

Probe:1 identified track

Efficiency **flat** in η, ϕ, p_T

No evidence of charge bias

$\varepsilon_W = 98.2 \pm 0.5\%$
$\varepsilon_Z = 96.5 \pm 0.7\%$



data
simulation
truth level

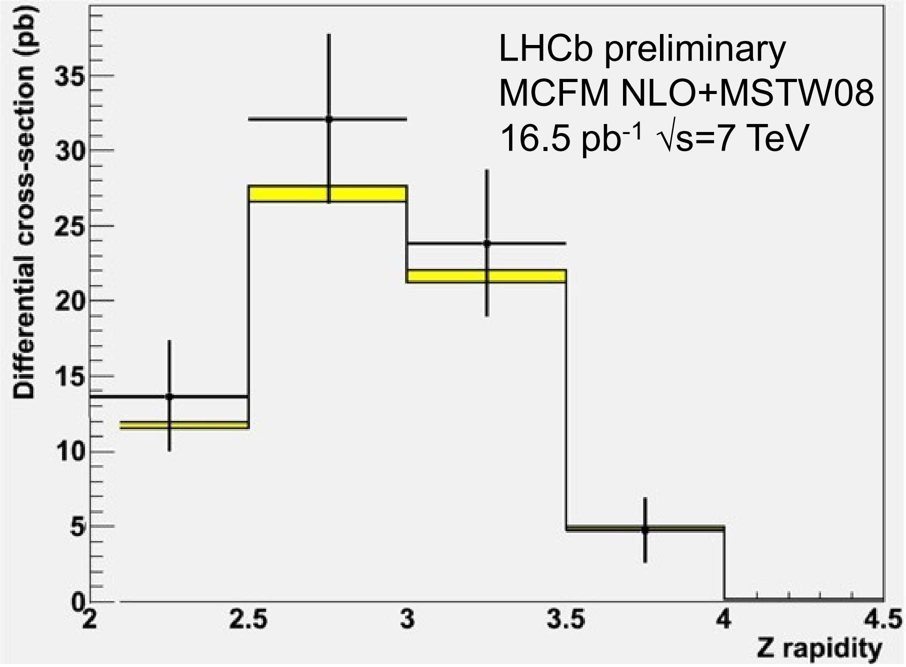
$$\varepsilon_Z = A_Z \varepsilon_Z^{trig} \varepsilon_Z^{track} \varepsilon_Z^{muon} \varepsilon_Z^{selection}$$

$$\varepsilon_W = A_W \varepsilon_W^{trig} \varepsilon_W^{track} \varepsilon_W^{muon} \varepsilon_W^{selection}$$

Found before:
Z: (simulation) 1.00
W: (data driven, using Z events) □55.0 ± 1.0%

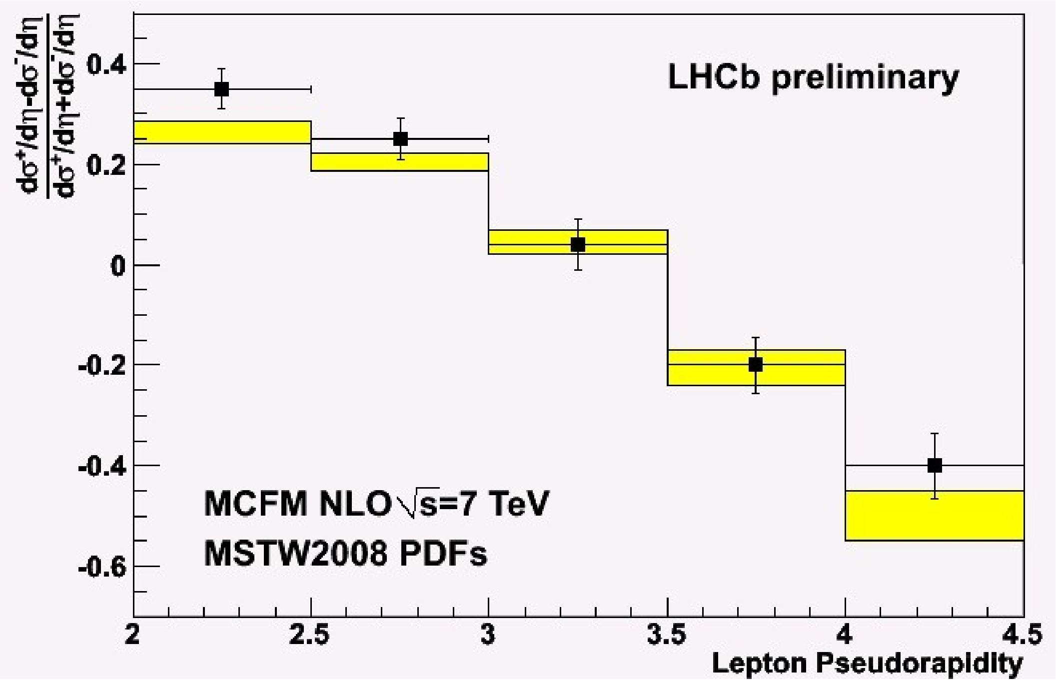
Z cross-section

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.



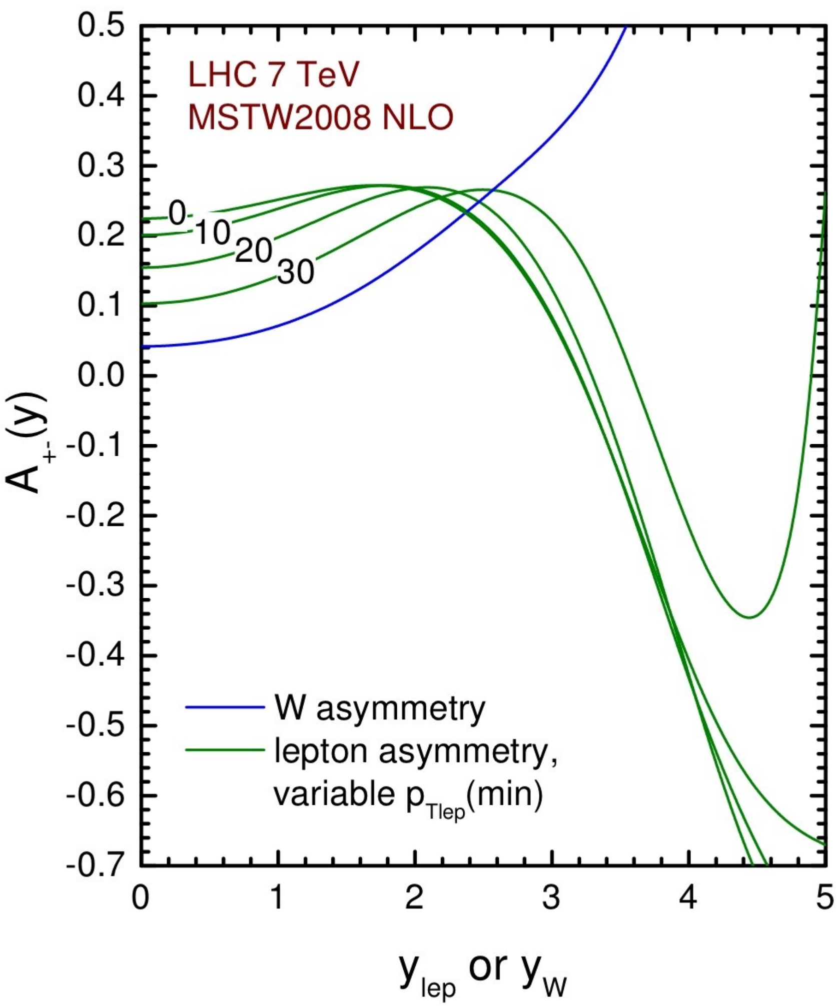
W cross-section, asymmetry

	$W+$	$W-$
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	$16.5 \pm 1.7\ pb^{-1}$	$16.5 \pm 1.7 pb^{-1}$
$\sigma_W(2.0 < y < 4.5)$	$1007 \pm 48 \pm 100$ pb	$682 \pm 40 \pm 68$ pb

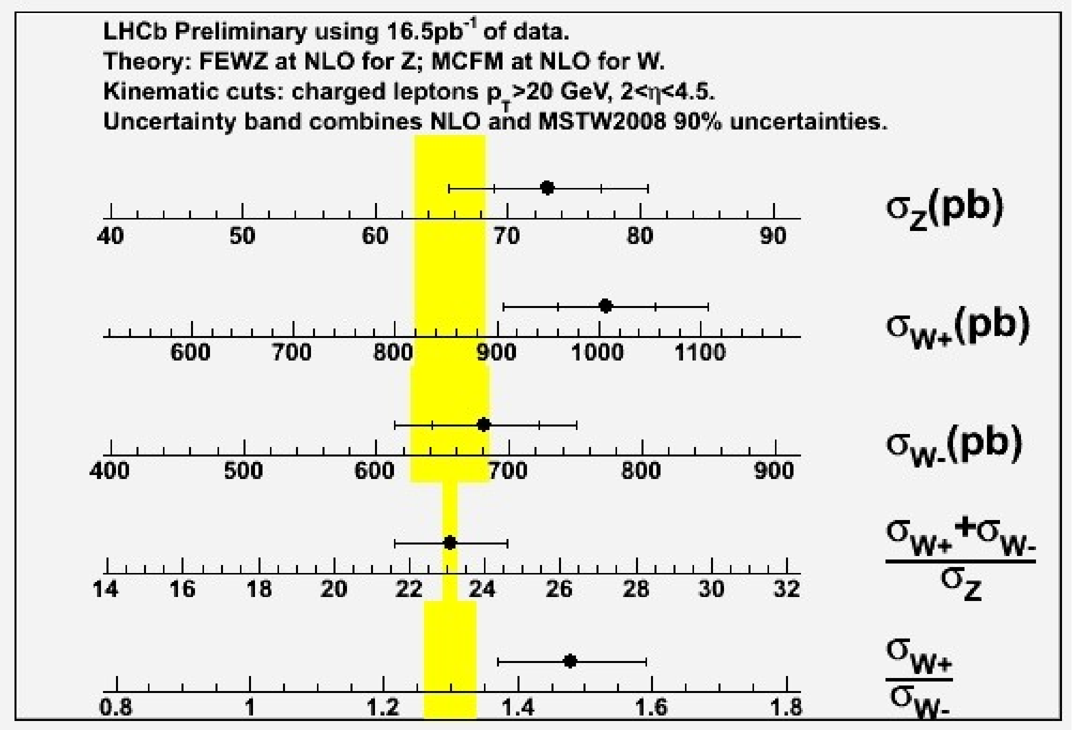


Predicted W asymmetry vs. W and lepton rapidity

(courtesy J. Stirling)



LHCb preliminary



Outlook:

PDF sensitivity studies

A_{FB}

PDF sensitivity studies

A_{FB}

From global fits, PDFs described by a set of orthogonal eigenvectors, which have a ‘central’ value e_0, and ‘uncertainties’ e_i.

$$\frac{d\sigma}{dy}(\delta_1, \delta_2 \ldots \delta_N) = \frac{d\sigma}{dy}(\vec{e_0}) + \sum_i^N \delta_i \left(\frac{d\sigma}{dy}(\vec{e_i}) - \frac{d\sigma}{dy}(\vec{e_0}) \right)$$

(where δ_i is #sigmas along e_i)

Prediction using central value

Deviations from central value according to eigenvector uncertainty

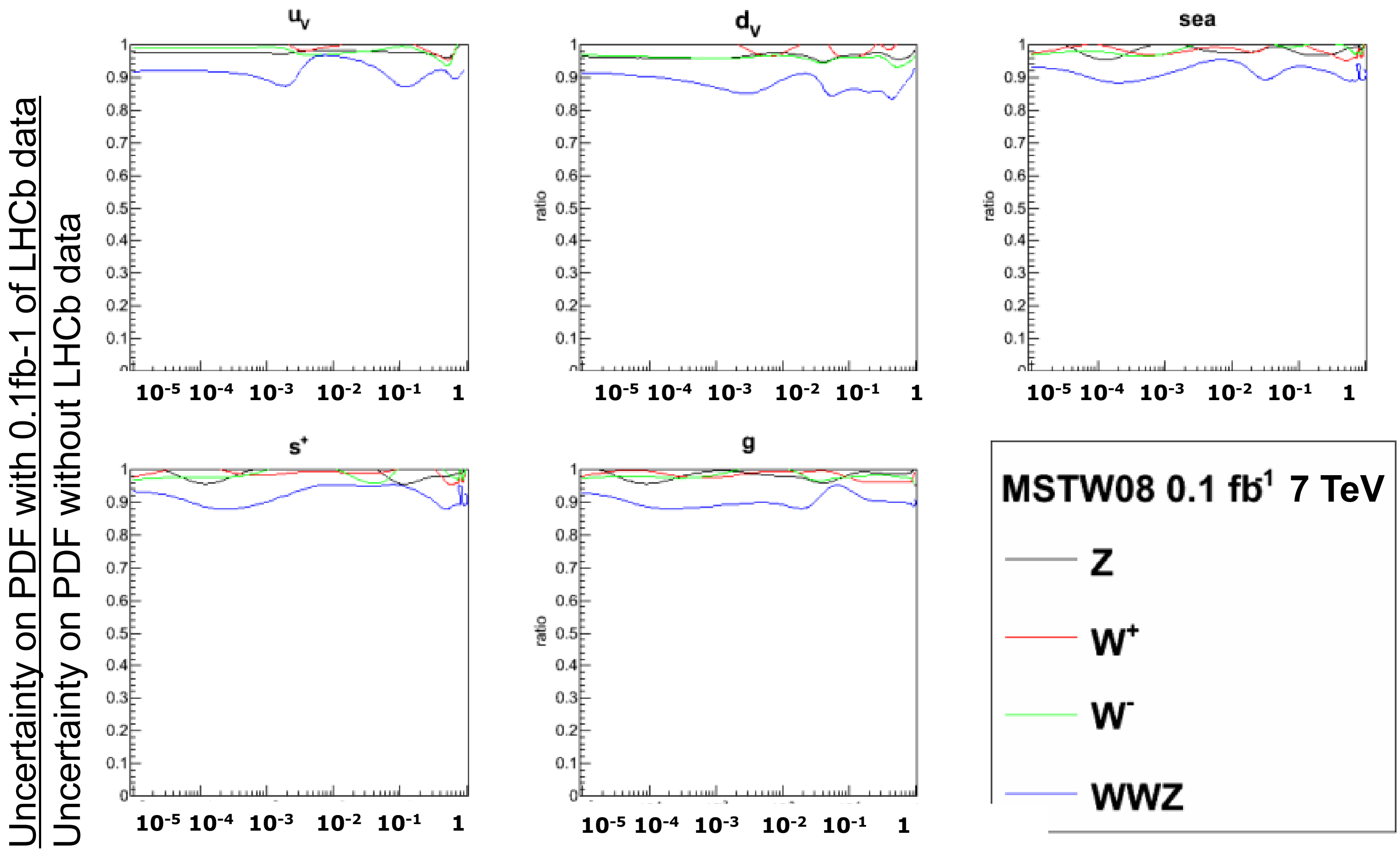
Current knowledge of PDFs mapped out by sampling δ_i from unit multinomial distribution.

Perform pseudo-experiments, generating LHC data and **fitting for δ_i**, to see how eigenvector knowledge improves.

See: F. De Lorenzi, DIS2010; R. McNulty, ICHEP2010.

PDF sensitivity studies

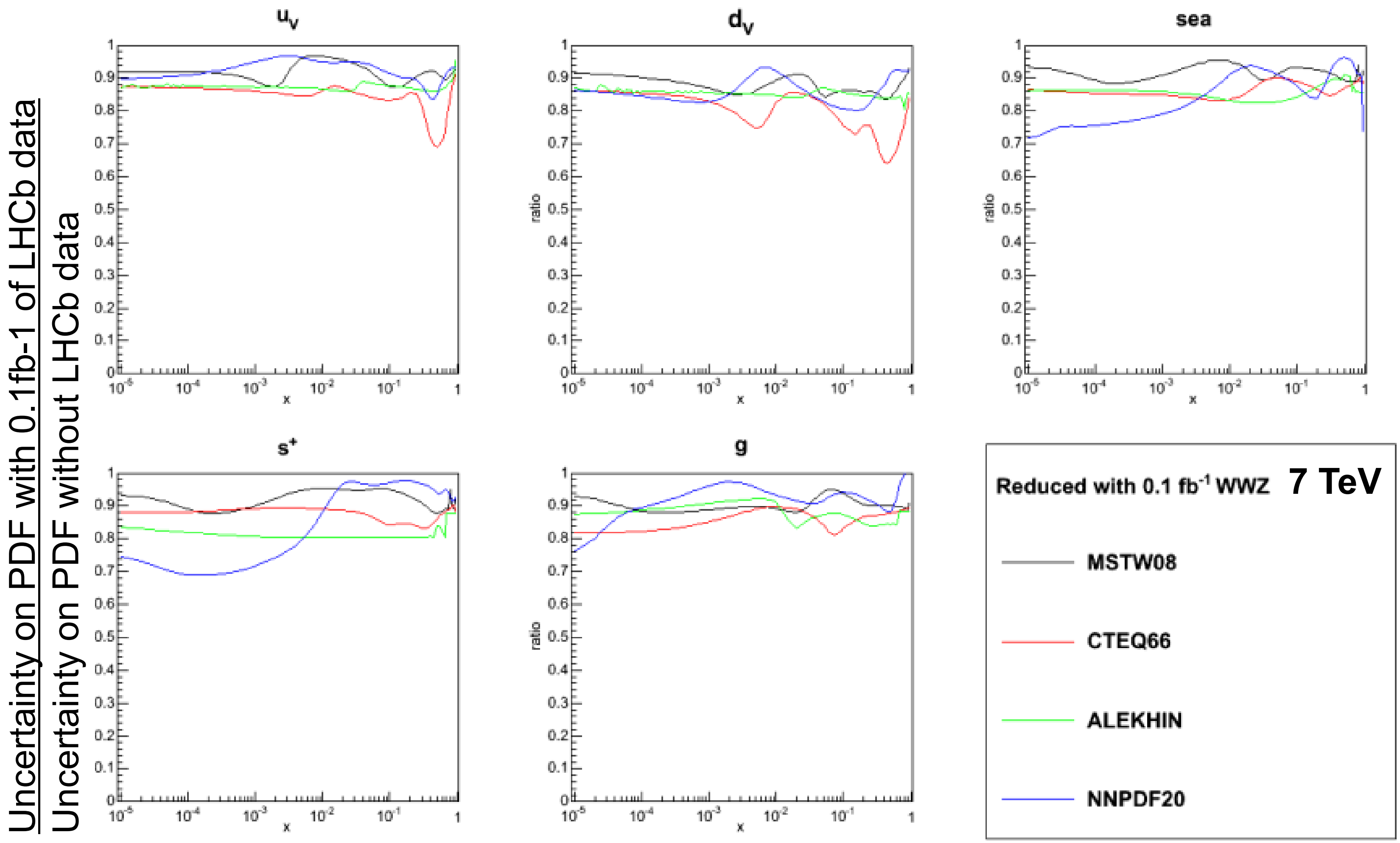
A_{FB}



Modest improvement with small amount of data

PDF sensitivity studies

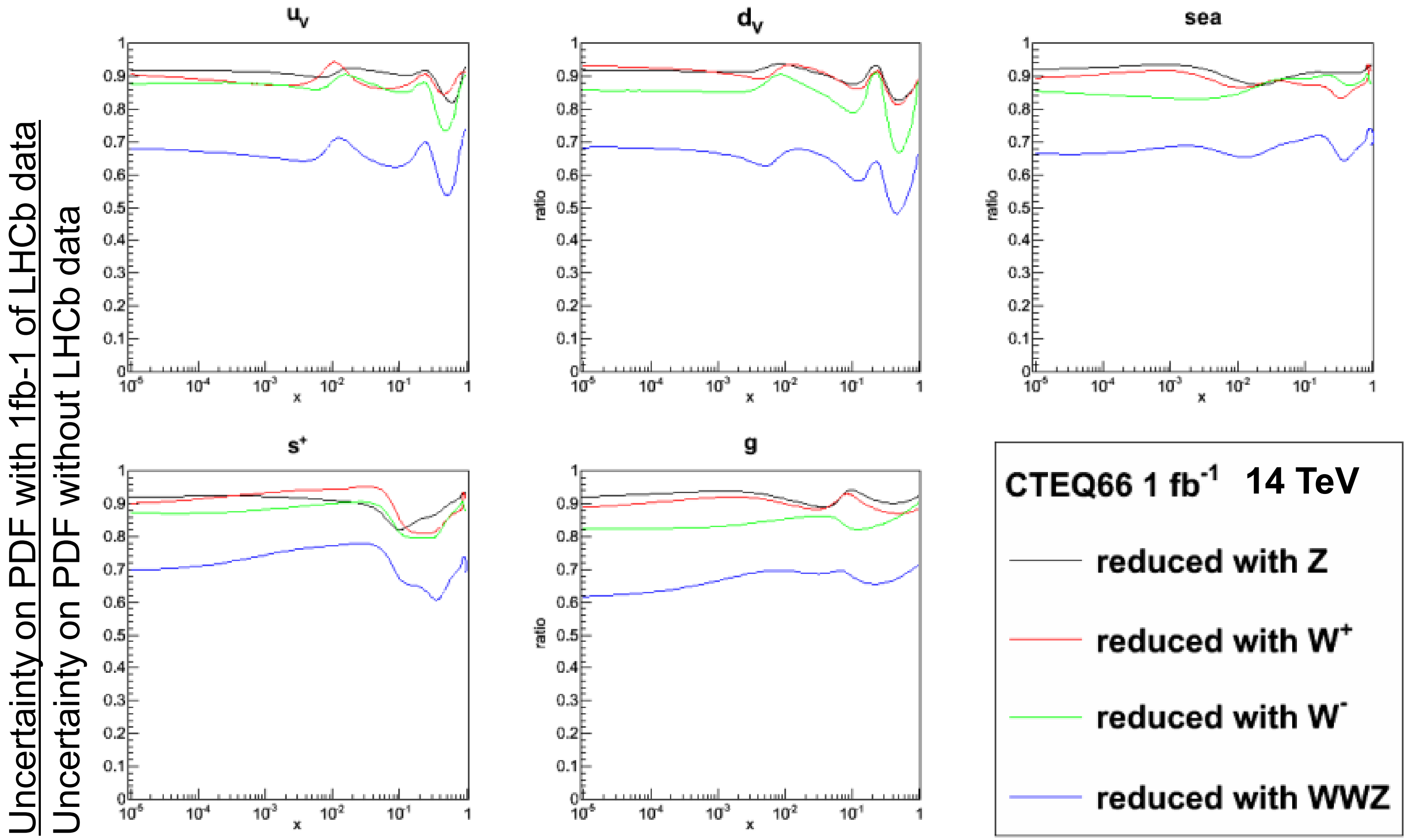
A_{FB}



Similar sensitivity. Ability to distinguish models

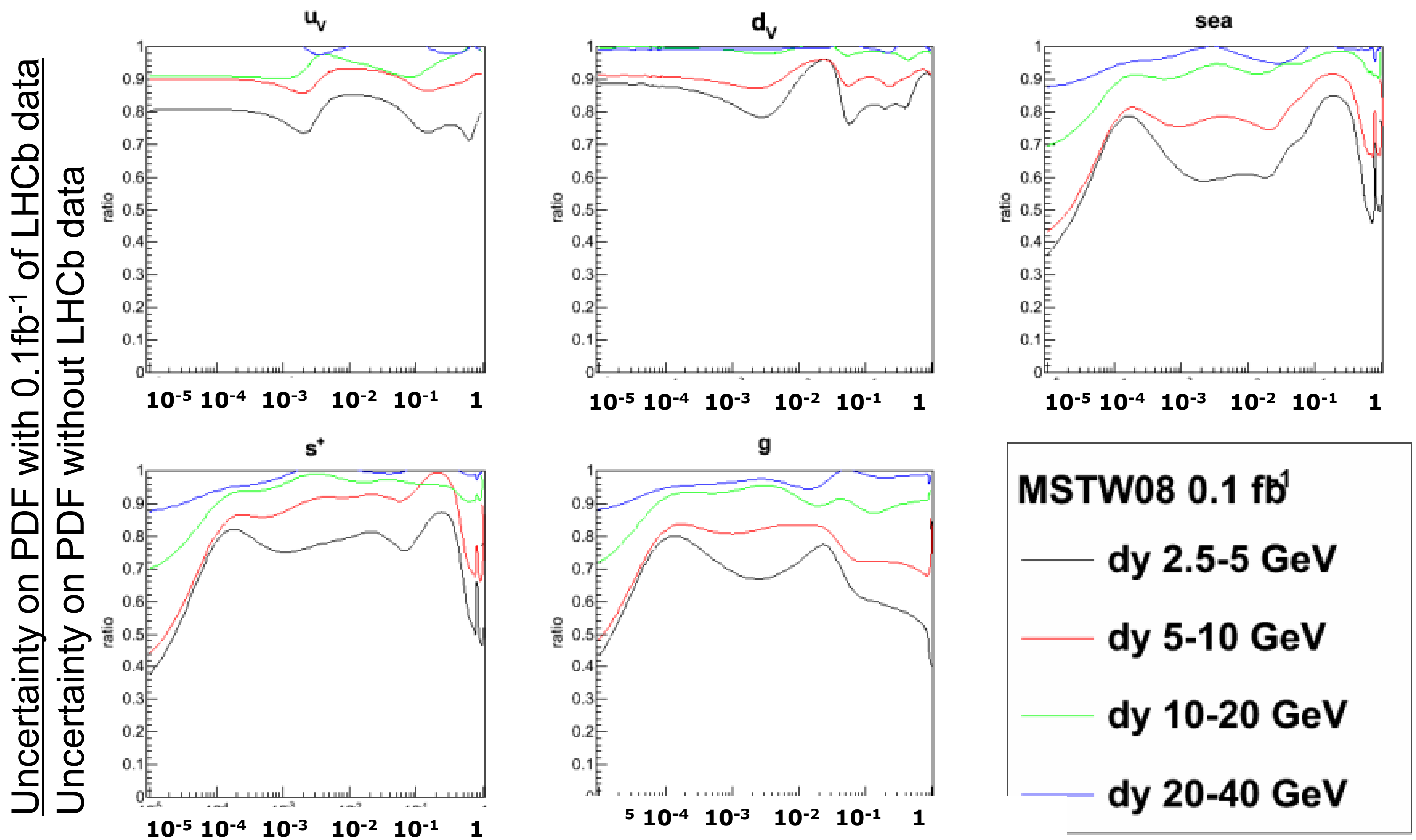
PDF sensitivity studies

A_{FB}

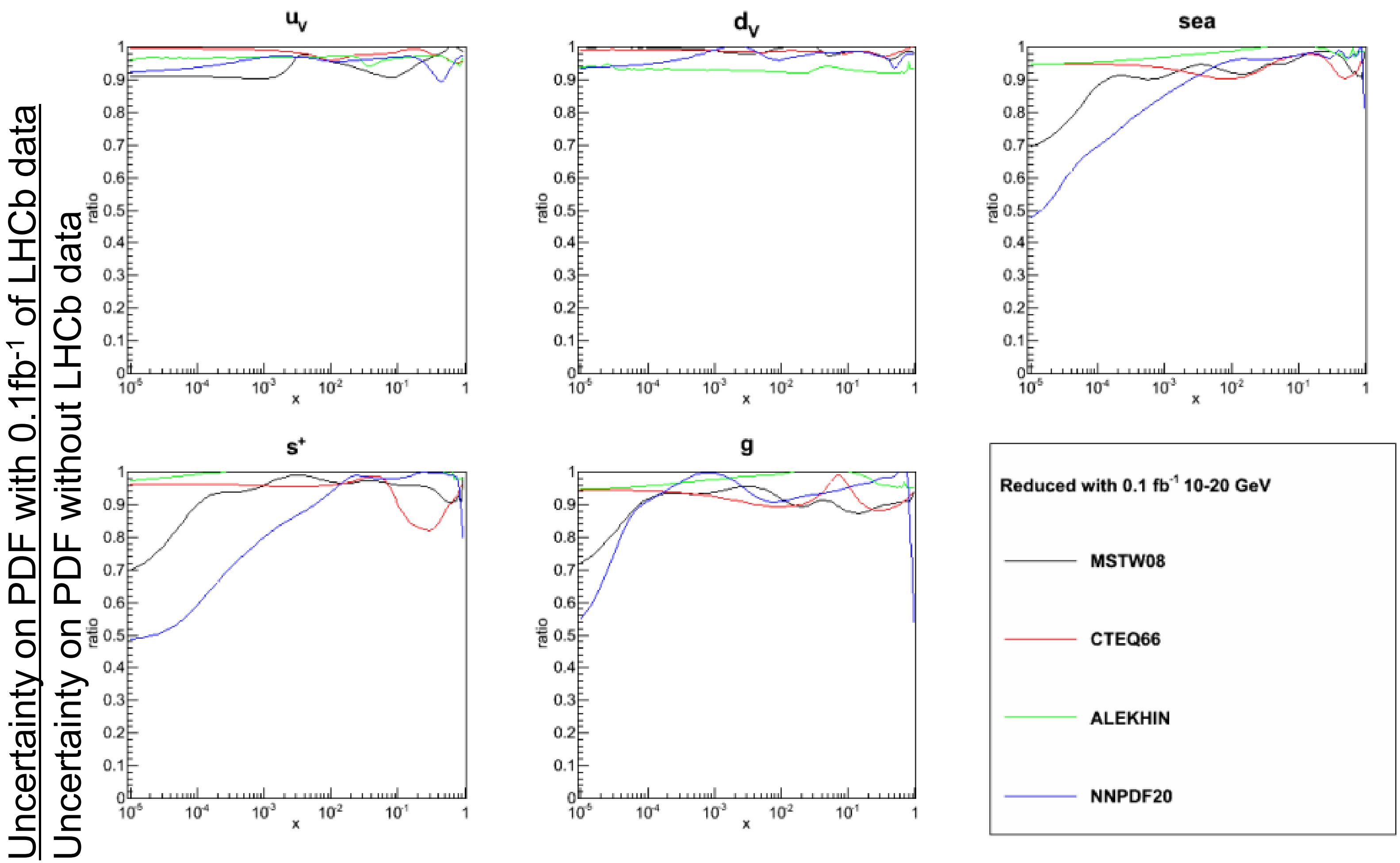


More data and higher energy lead to larger improvements (~30%).

Improvement to **MSTW08 PDFs** with 0.1fb-1 of low mass vector bosons at 7TeV



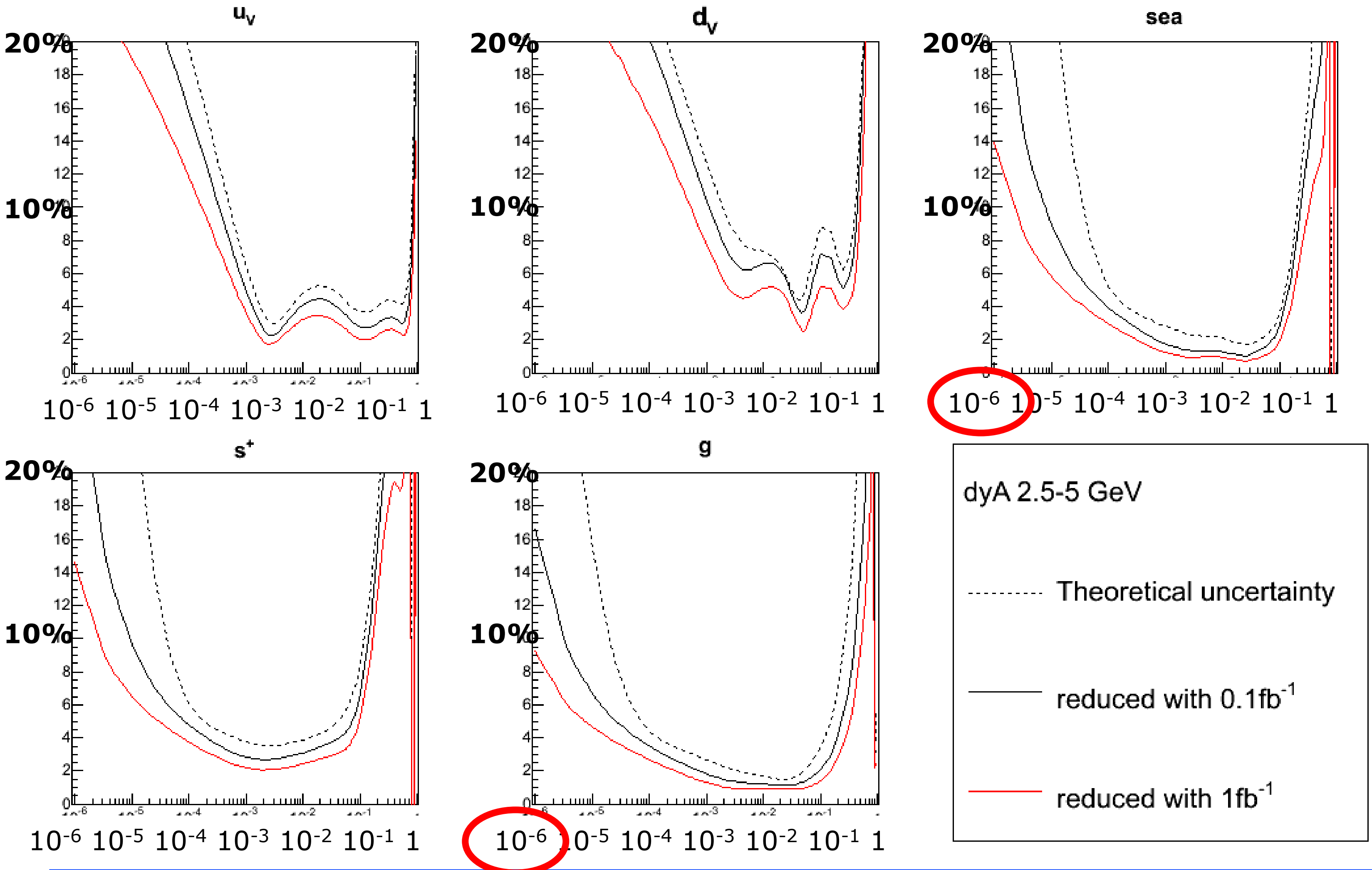
Improvement to different **PDF** sets with $0.1fb^{-1}$ of low invariant mass muons (10-20GeV) at 7TeV



Similar improvements to MSTW, CTEQ and Alekhin PDFs.

Sensitivity exists to distinguish between models.

Current uncertainty on **MSTW08 PDFs** and projections with $0.1 fb^{-1}$, $1 fb^{-1}$ of very low invariant mass muons at 7TeV



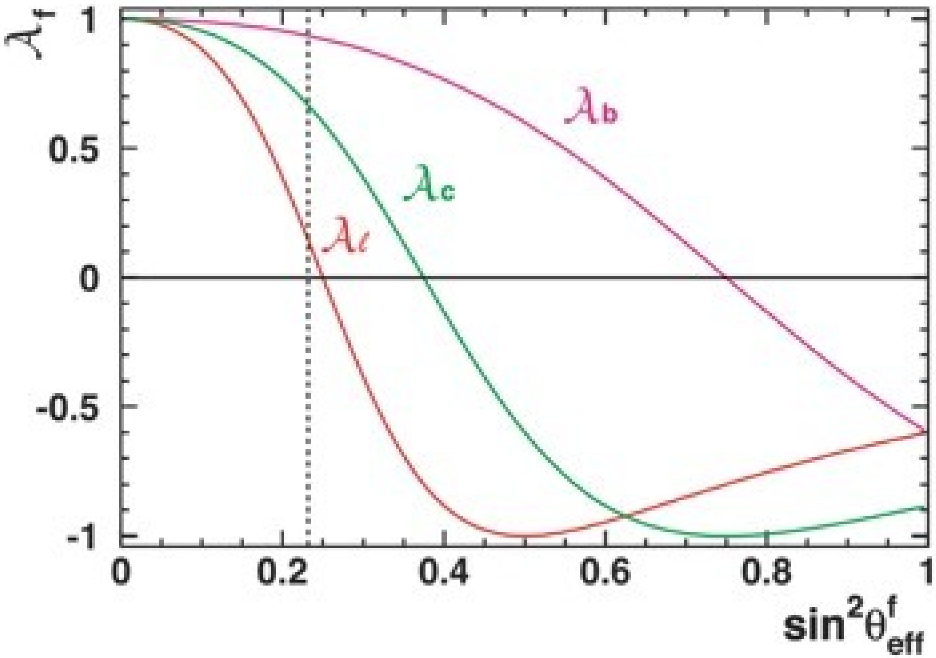
Significant improvements possible with modest amount of data

A_{FB}

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

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

Asymmetry at LHC larger than at LEP (leptonic)



A_{FB}

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

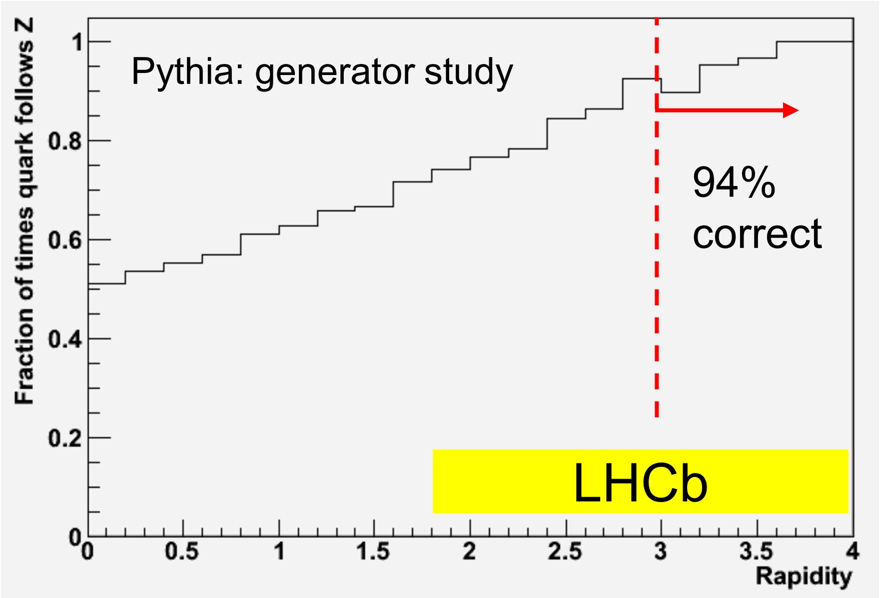
A_{FB} sensitive to $\sin^2\theta_W$

Uncertainties from :

- Forward (quark) direction
- PDF knowledge of sea

LHCb:

- predominately valence - sea collisions
- ss contribution reduced



A_{FB}

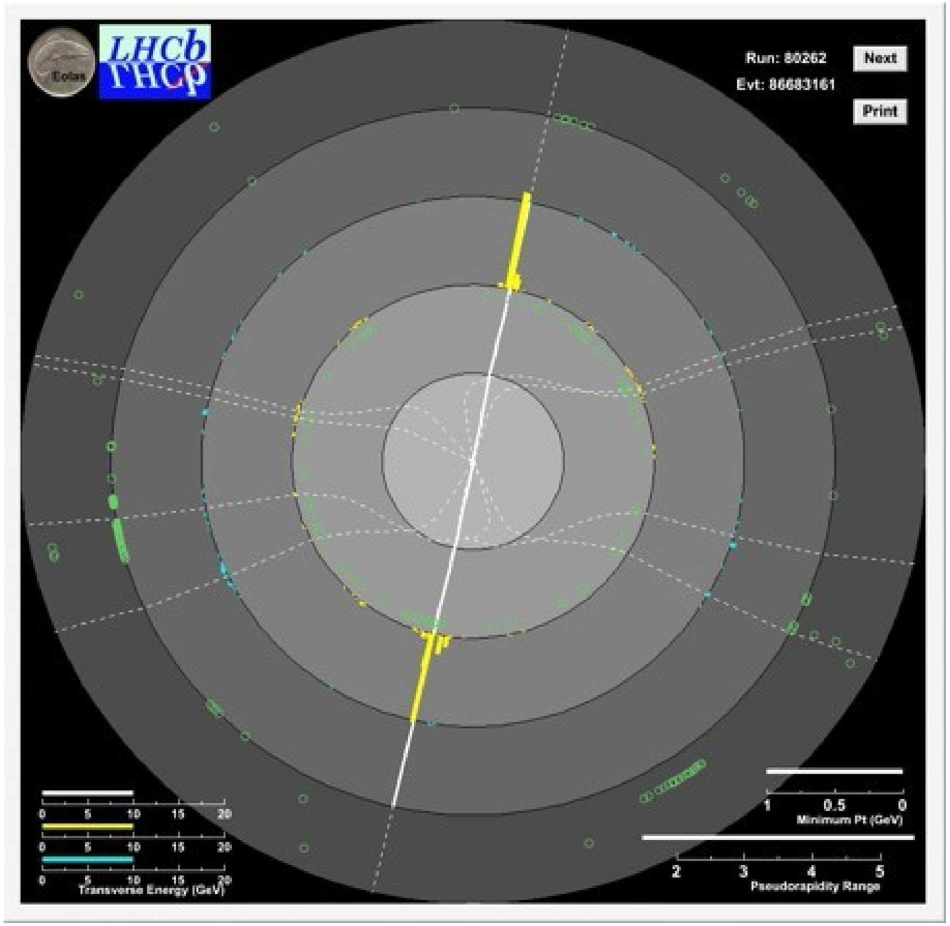
Statistical errors only:
Note: Very preliminary study:

1 fb^{-1} implies 4% statistical precision on A_{FB}
implies 0.15% statistical precision on $\sin^2\theta_W$ (cf. 0.07% world average)

Studies ongoing:
PDF uncertainties (estimated at 0.04%)
Needs theoretical prediction of comparable precision

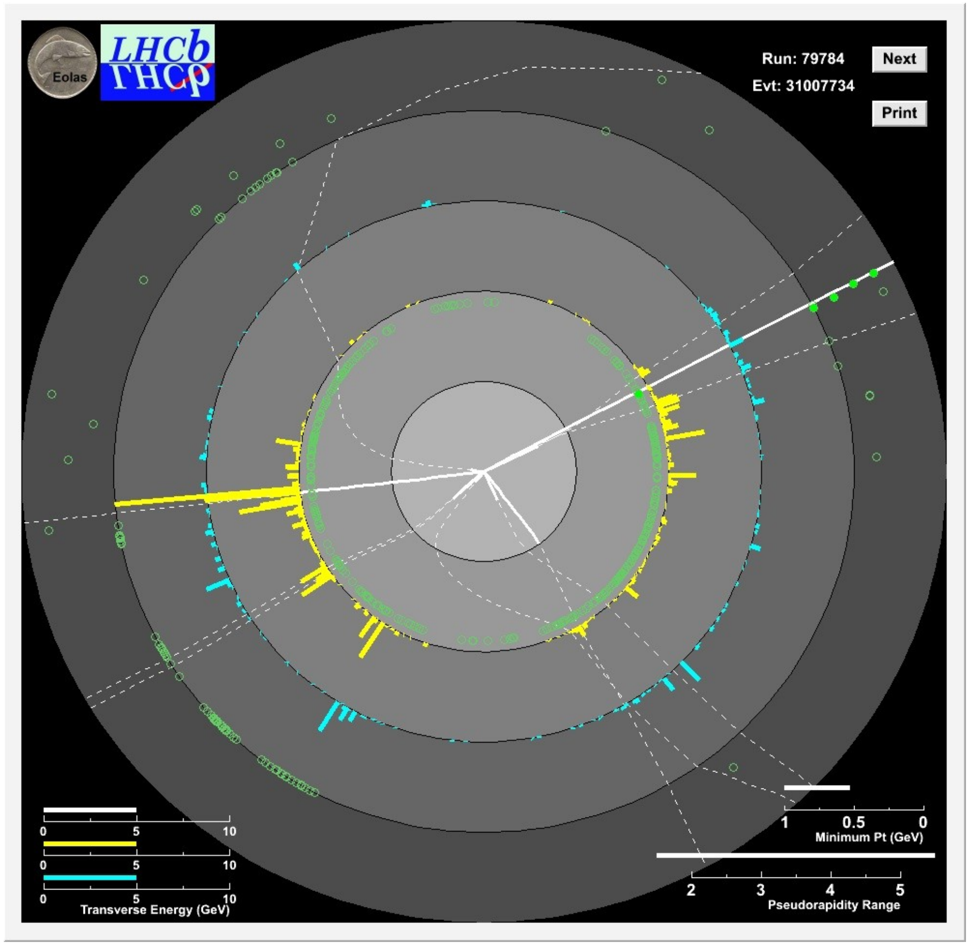
A_{FB}

… and other channels
e.g. $Z \rightarrow ee$



A_{FB}

… and other channels
e.g. $Z \to \tau\tau$



All W,Z observations consistent with NLO theory

Luminosity uncertainty dominates for cross-sections

W/Z ratio tests SM to 6%

Outlook:

- 1 fb^{-1} can improve PDF uncertainty by 30%
- 1 fb^{-1} could allow $\sin^2\theta_W$ measurement to 0.15%