PDF uncertainties on m_W

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Work done in collaboration with
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Why measure m_W?

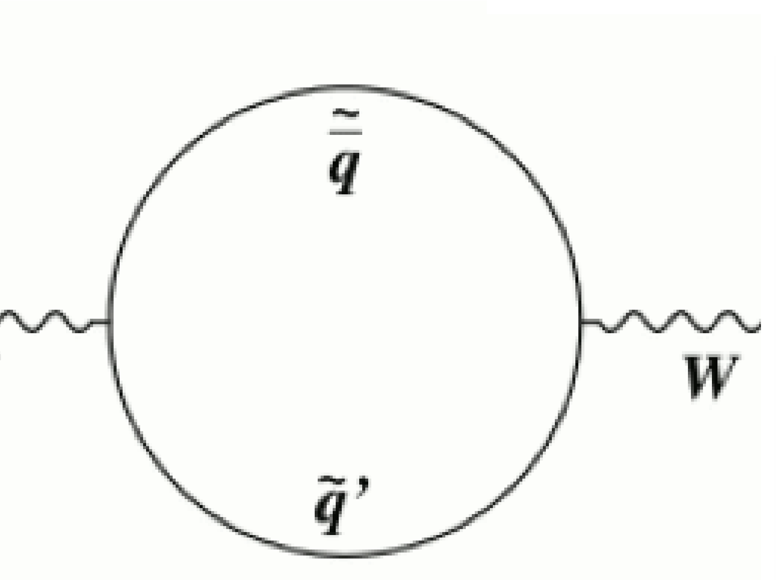
Indirect search for new physics in radiative corrections

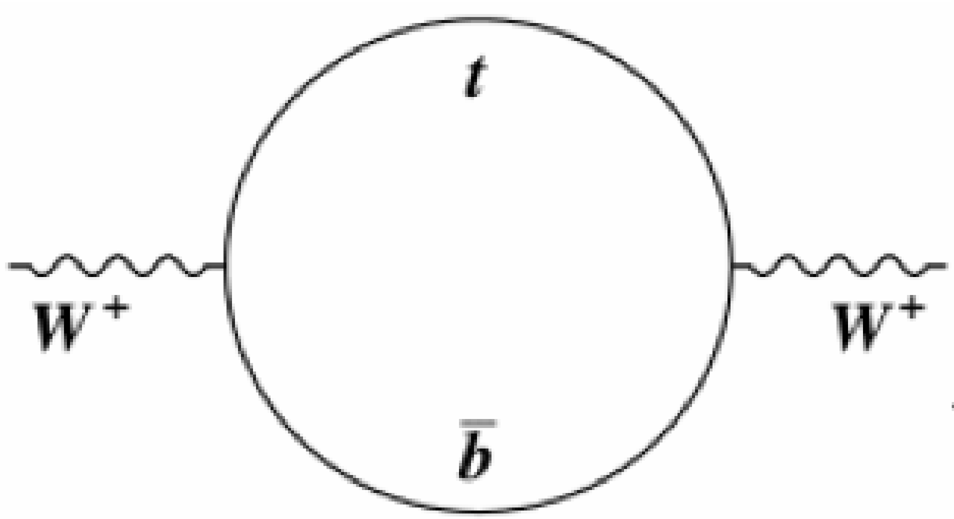
$$M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G_F}}\frac{1}{\sin\theta_W\sqrt{1-\Delta r}}$$

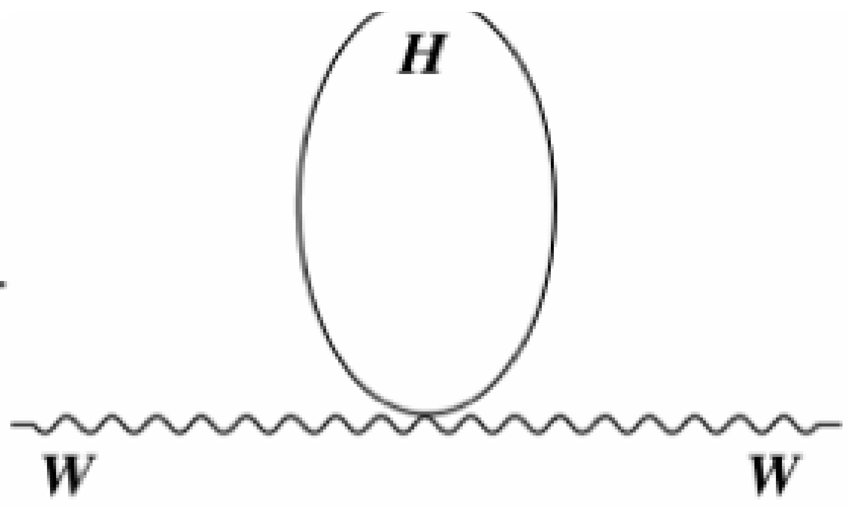
??

$\Delta r_t \propto M_t^2$

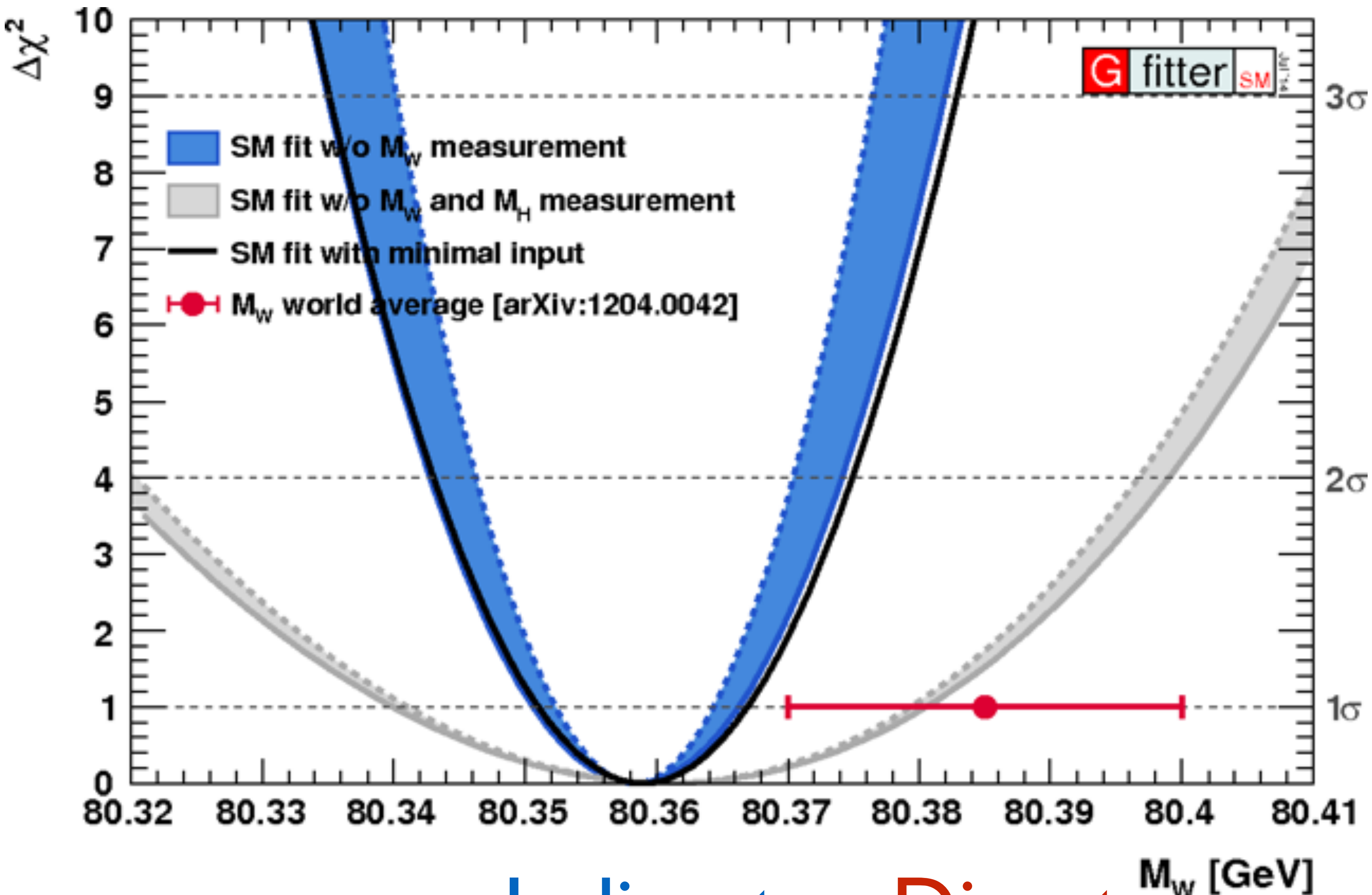
$\Delta r_H \propto \log M_H$







Global EW fit and m_W

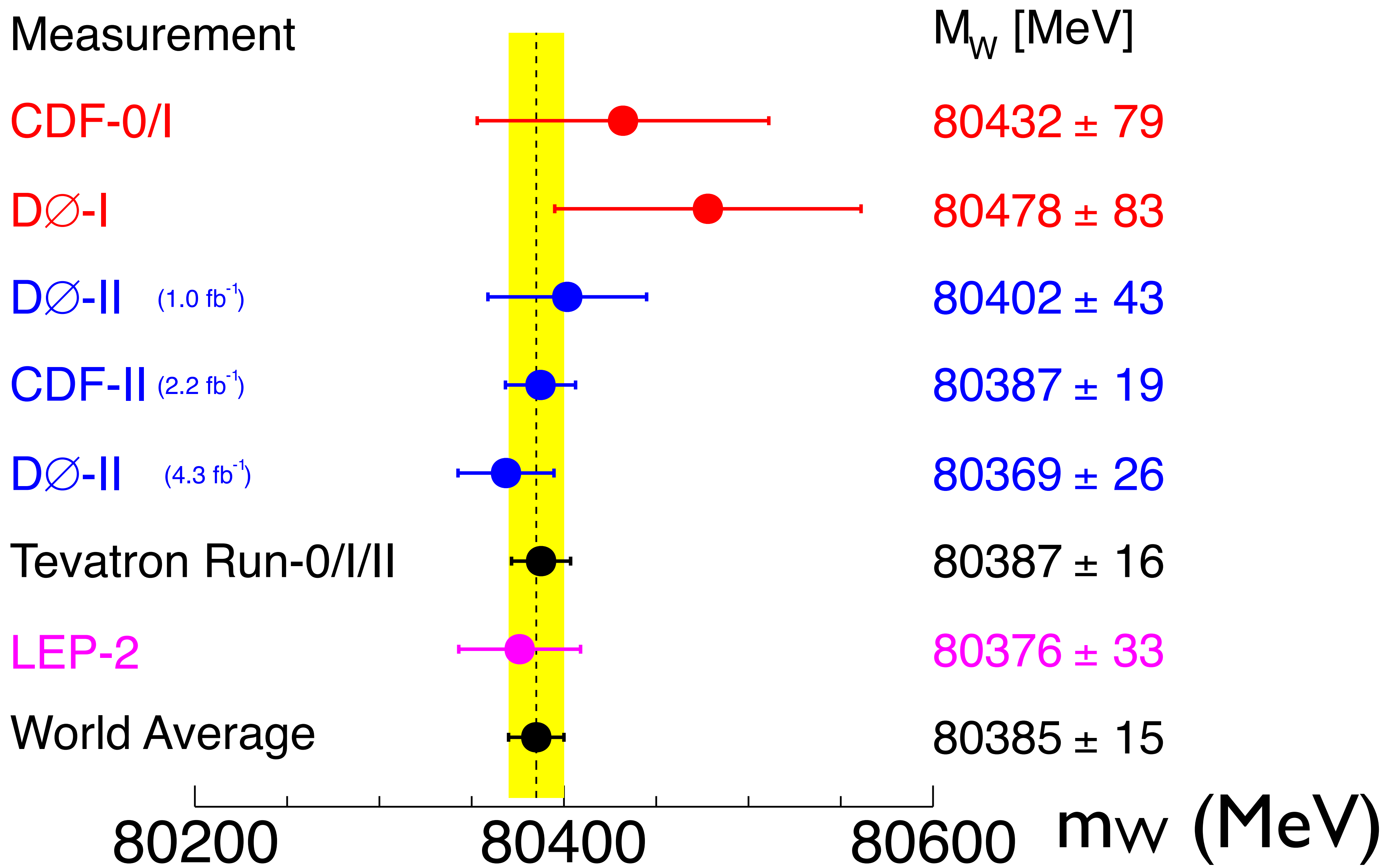


Indirect ± 8 MeV

Direct ± 15 MeV

Thus, room for new physics

State of the art, direct

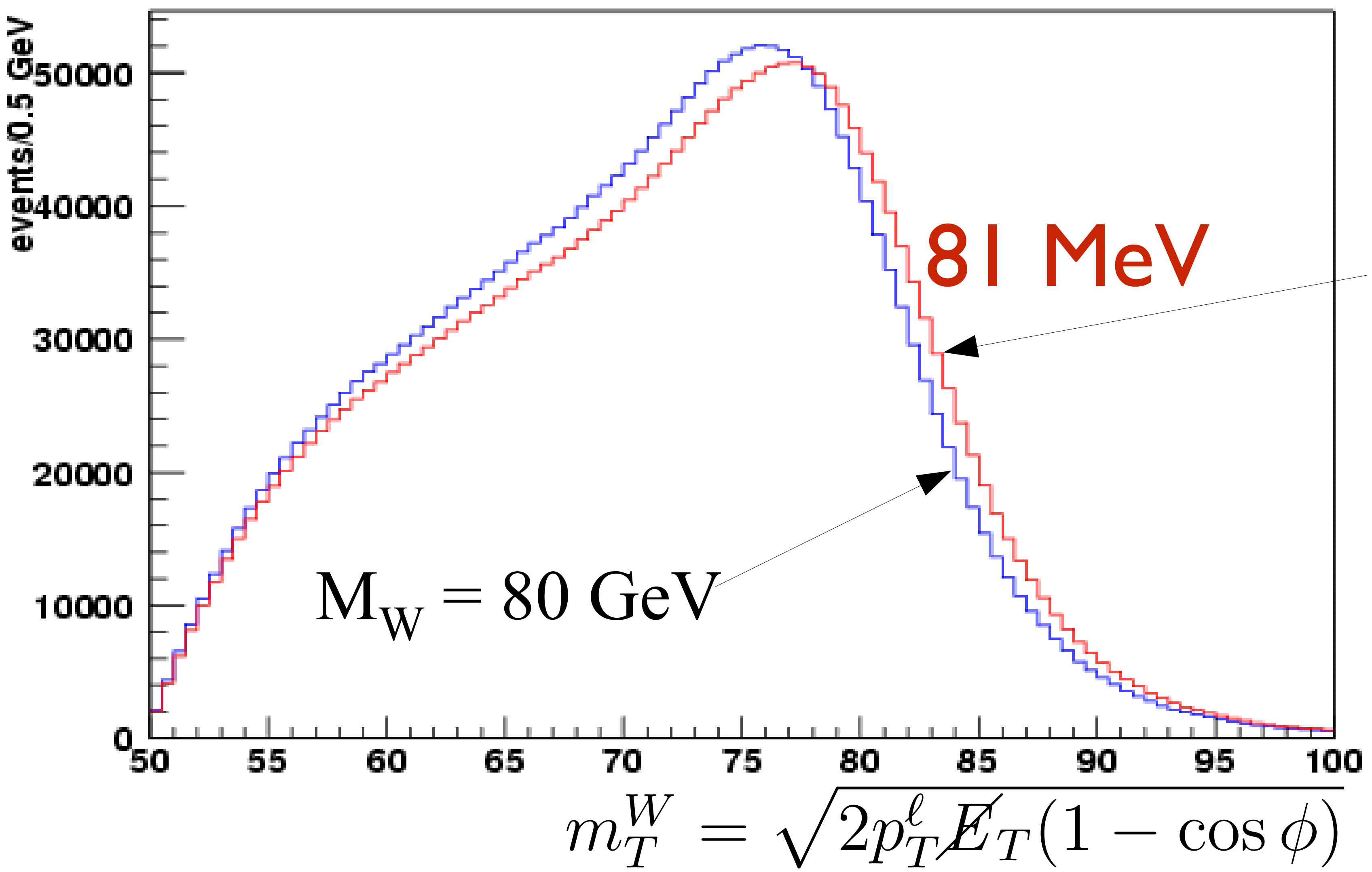


Still to come: full Tevatron Run-II dataset and LHC!

Natural target: the indirect constraint (< 10 MeV)

Hadron collider method

Compare distributions of the charged lepton p_T, missing E_T, and transverse mass to QCD templates



It is likely that the LHC experiments will focus on the charged lepton p_T which is less affected by pileup.

Uncertainties, Tevatron

With ~¼ of the CDF dataset:

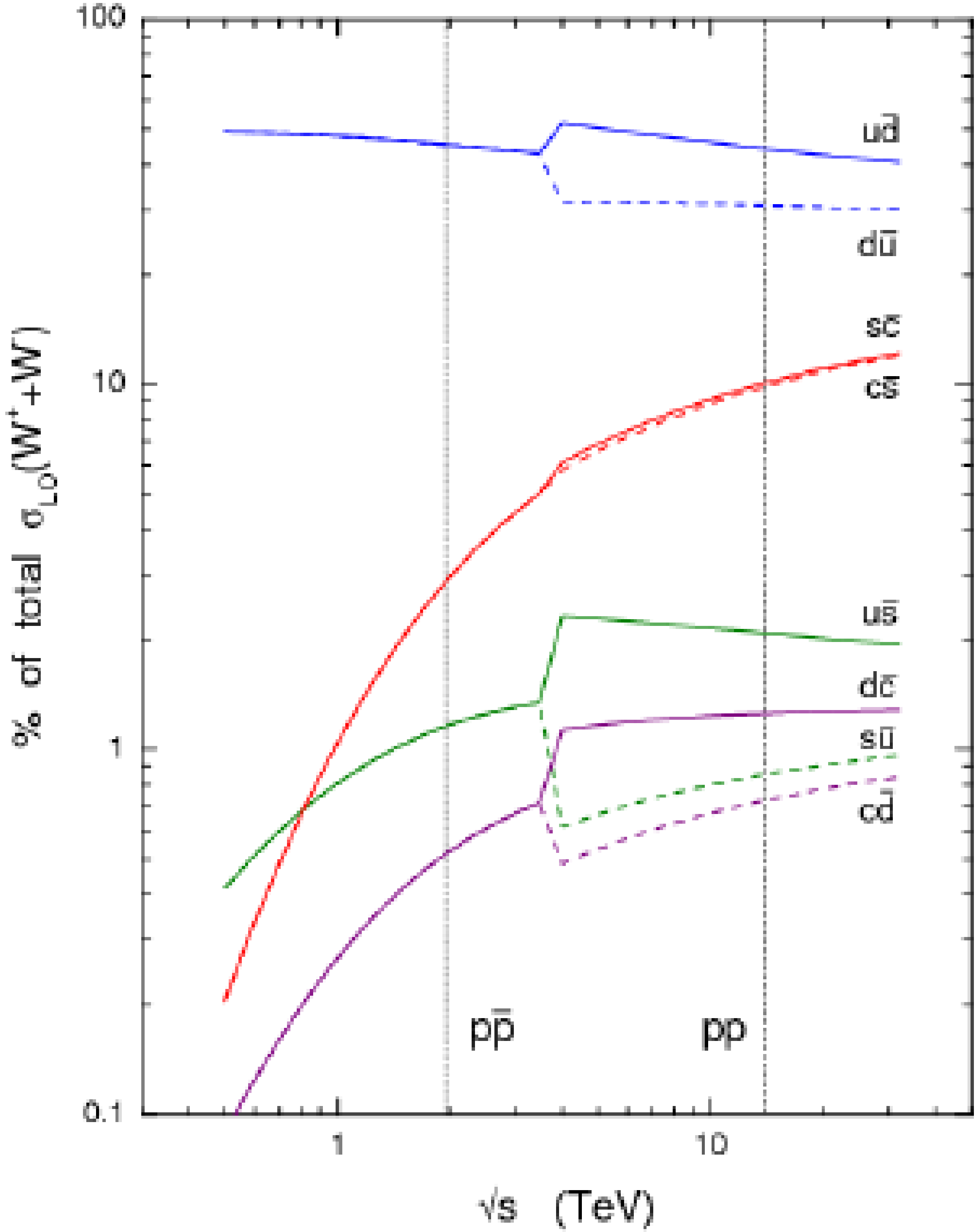
Phys. Rev. Lett. **108**, 151803

TABLE II. Uncertainties for the final combined result on M_W.

Source	Uncertainty (MeV)
Lepton energy scale and resolution	7
Recoil energy scale and resolution	6
Lepton removal	2
Backgrounds	3
$p_T(W)$ model	5
Parton distributions	10
QED radiation	4
W-boson statistics	12
Total	19

Are PDFs going to be the limiting uncertainty?
Especially at the LHC…

Flavour composition

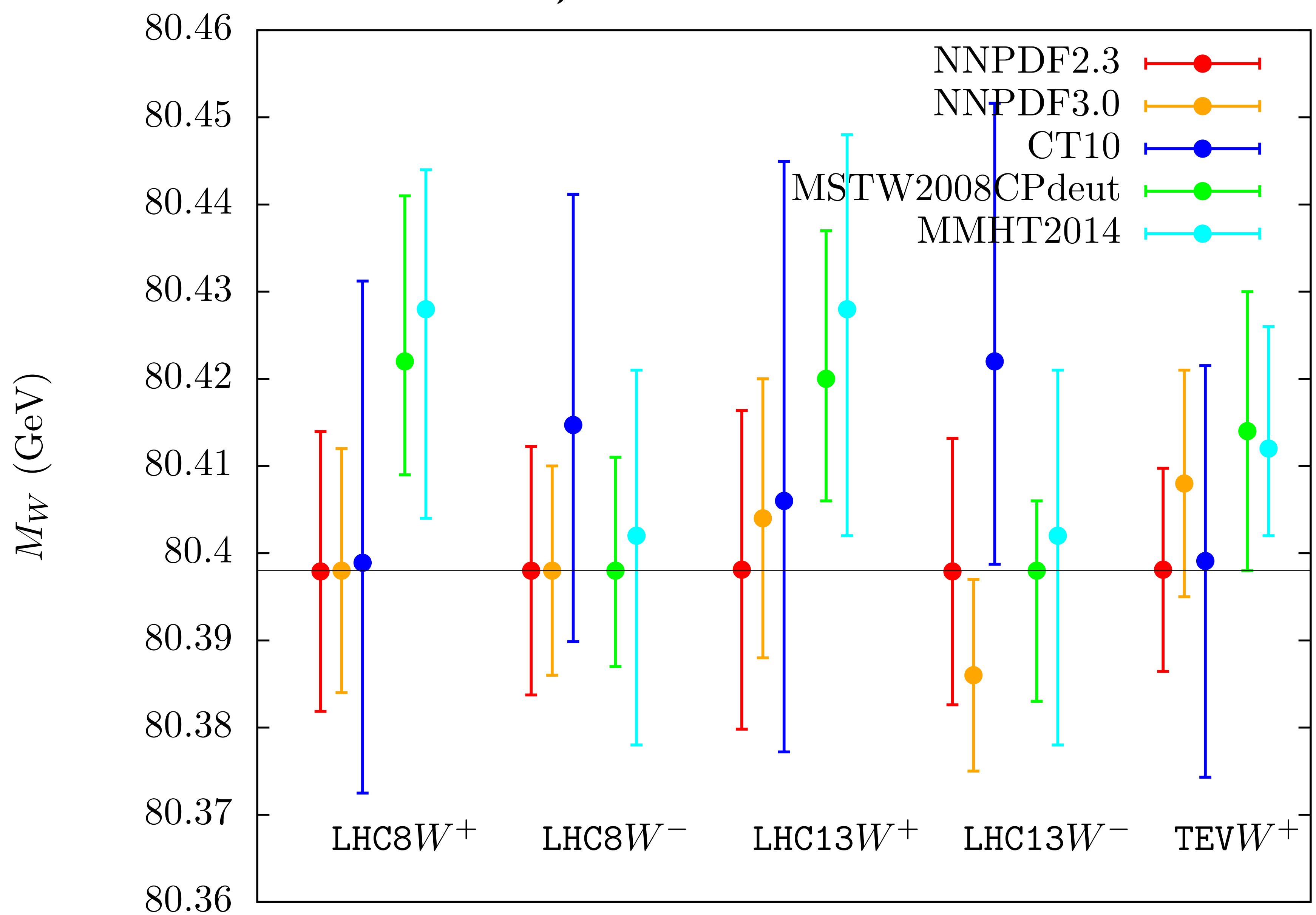


A much discussed problem

- …
- Krasny *et al.*, **EPJC 69 379-397** (2010)
- Bozzi *et al.*, **PRD 83:113008** (2011)
- Rojo *et al.*, **1309.1311** (2013)
- ATL-PHYS-PUB-2014-015
- Bozzi *et al.*, **1501.05587** (2015)
- Quackenbush *et al.*, **PRD 92, 033008** (2015)
- …

Example of charged lepton p_T fit

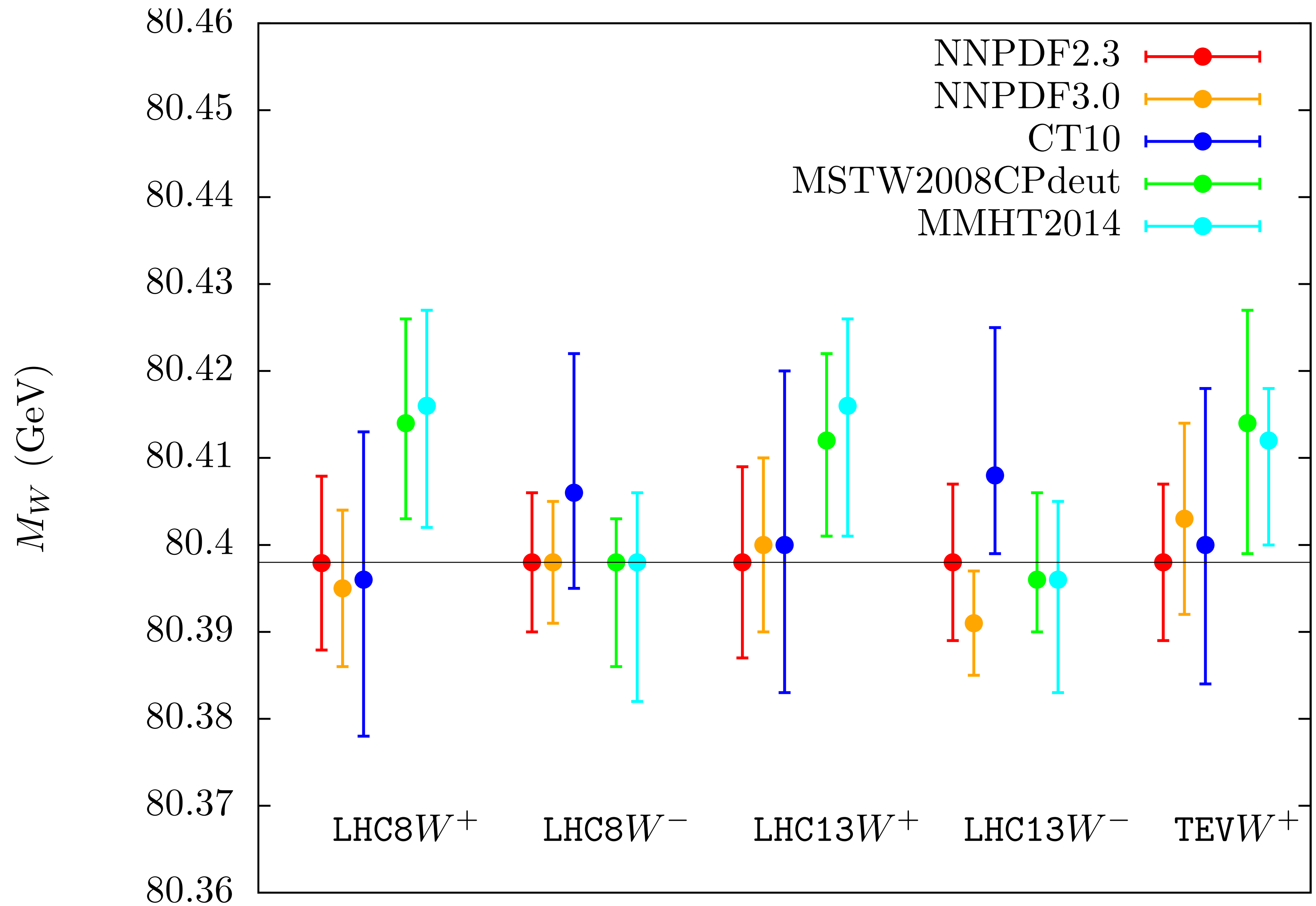
Bozzi *et al*, **1501.05587**



With the previous PDF4LHC recommendations (**1101.0538**), they estimate a 20-30 MeV uncertainty for the LHC measurements

Example of charged lepton p_T fit

Bozzi *et al*, **1501.05587**



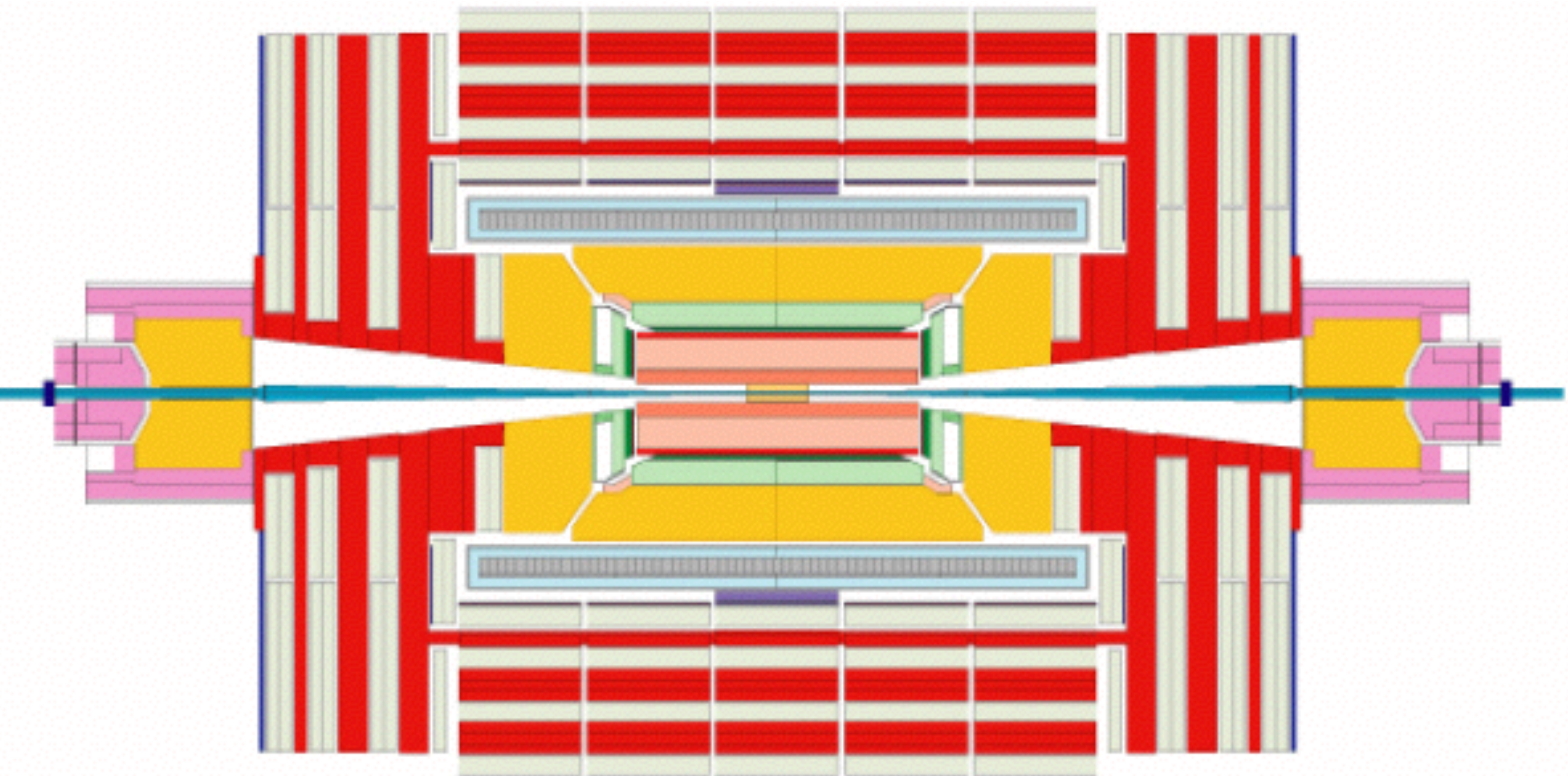
Factor of ~2 smaller with $p_T(W) < 15$ GeV,
but still preventing our < 10 MeV goal.

Cause of PDF uncertainty

- Polarisation
  - Valence quark PDFs polarise the Ws, which affects the final state particle distributions that we fit for m_W.
- Acceptance
  - Due to the limited angular acceptance of the detectors, a change in the rapidity distribution will sculpt the p_T and m_T distributions.

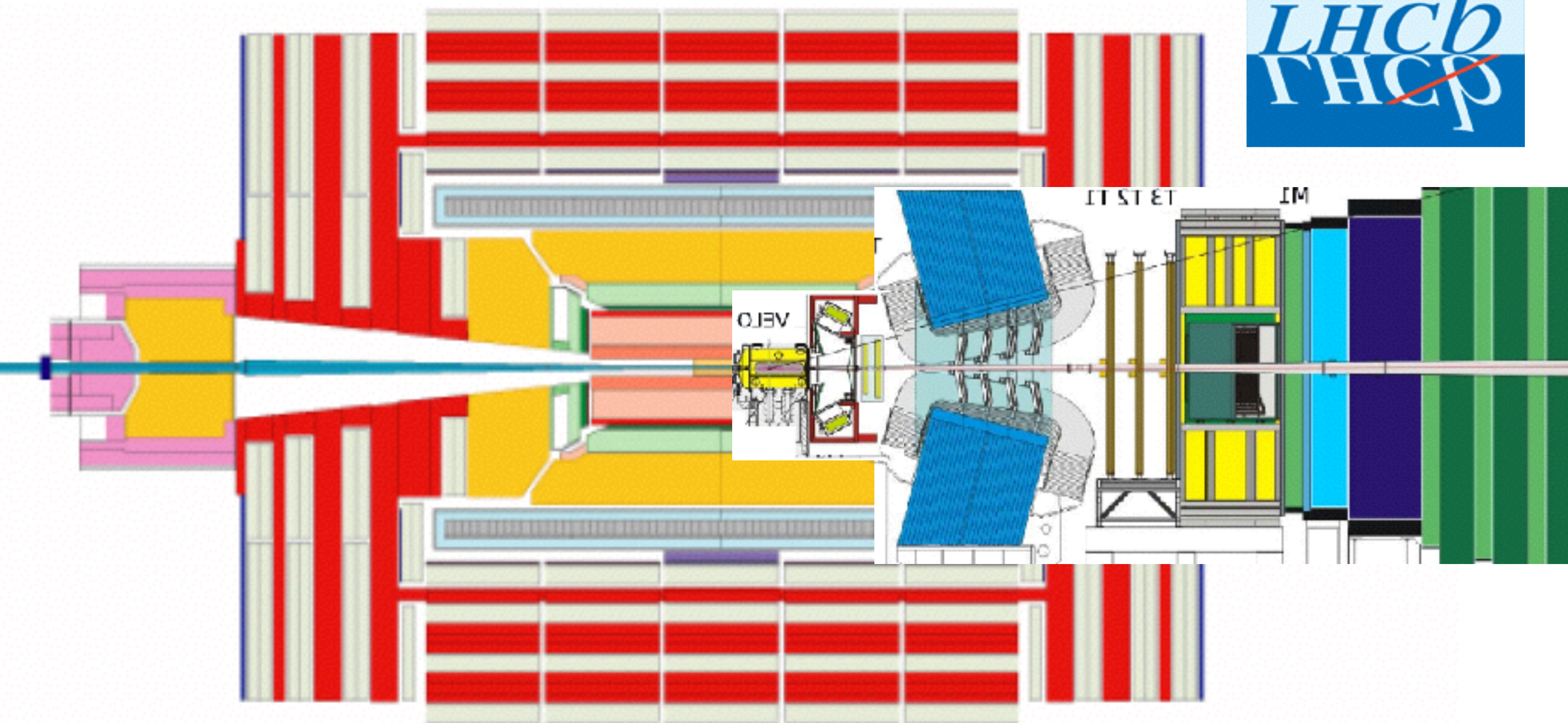
Acceptance

$|\eta_{lept}| < 2.5$

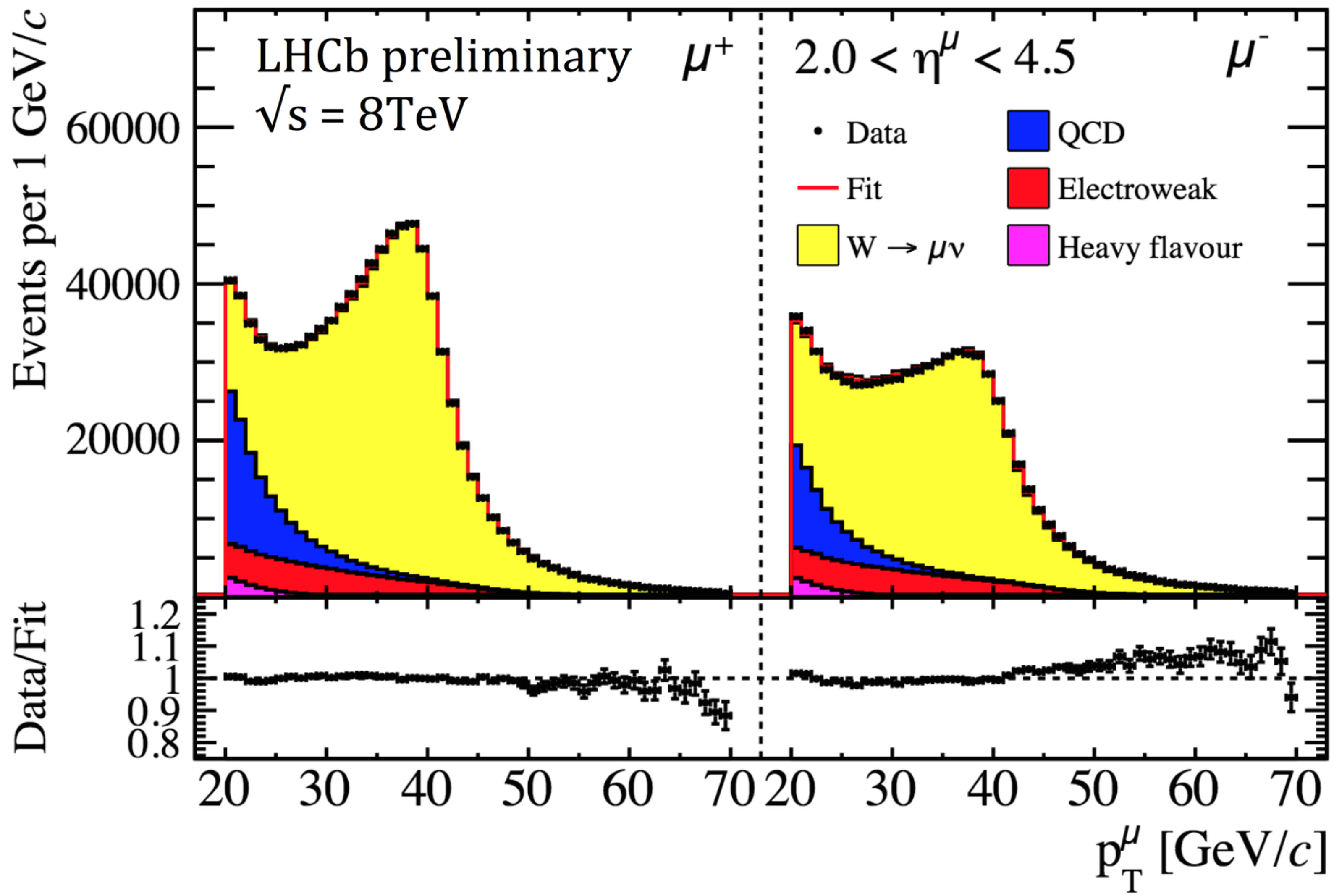


Acceptance

$|\eta_{lept}| < 2.5 \quad + \; 2 < \eta_{lept} < 5$



W →μν @ LHCb



See Will Barter's CERN **seminar** today

Latest LHCb measurements of Electroweak Boson Production in Run-1

We present the latest LHCb measurements of forward Electroweak Boson Production using proton-proton collisions recorded in LHC Run-1. The seminar shall discuss measurements of the 8 TeV W & Z boson production cross-sections. These results make use of LHCb's excellent integrated luminosity determination to provide constraints on the parton distribution functions which describe the inner structure of the proton. These LHCb measurements probe a region of phase space at low Bjorken-x where the other LHC experiments have limited sensitivity. We also present measurements of cross-section ratios, and ratios of results in 7 TeV and 8 TeV proton-proton collisions. These results provide precision tests of the Standard Model.

The seminar shall also present a measurement of the forward-backward asymmetry (A_FB) in Z boson decays to two muons. This result allows for precision tests of the coupling of the Z boson to left and right handed particles, providing sensitivity to the effective weak mixing angle (sin^2(theta_W^eff)). The A_FB distribution visible in the LHCb acceptance is particularly sensitive to sin^2(theta_W^eff), as the forward phase-space means that the initial state quark direction is better known than in the central region. This reduces theoretical uncertainties in extracting sin^2(theta_W^eff) from A_FB, and allows LHCb to make the currently most precise determination of sin^2(theta_W^eff) at the LHC.

Extending…

Bozzi *et al.*, 1508.06954 (2015)

- ..the (Bozzi *et al*, 1501.05587) study to include LHCb
- It only considers the charged lepton p_T, which is anyway the only observable that is available to LHCb.

Define:

"GPD"	**Charged lepton:** $p_T > 25$ GeV, $\lvert\eta\rvert < 2.5$ **Neutrino:** $p_T > 25$ GeV **p_T(W)** < 15 GeV
LHCb	**Charged lepton:** $p_T > 20$ GeV, $2 < \lvert\eta\rvert < 4.5$

Technicalities

Bozzi *et al.*, 1508.06954 (2015)

- Simulate pp → W → lν @ 13 TeV using POWHEG +PYTHIA and [NNPDF3.0, MMHT2014, CT10]
- Produce a lepton p_T template with a given PDF set and m_W and call this the "pseudo-data".
- Compare it to templates with different m_W values and find the best fit.
- Repeat with different PDF sets for the pseudo-data.

PDF uncertainties

Bozzi *et al.*, 1508.06954 (2015)

Using the prev. PDF4LHC prescription (1101.0538):

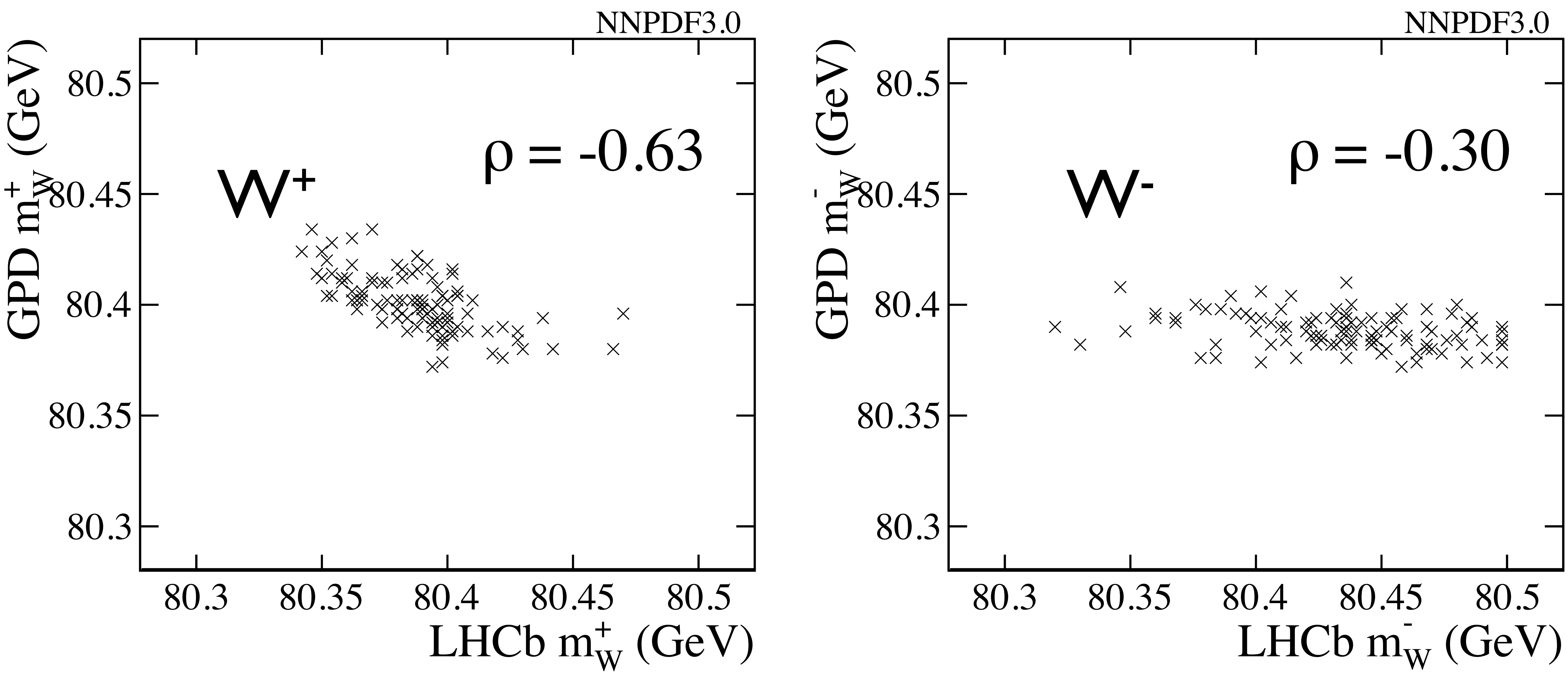
	GPD W^+	GPD W^-	LHCb W^+	LHCb W^-
m_W envelope (MeV) [*NNPDF3.0, MMHT2015, CT10*]	30 MeV	24 MeV	35 MeV	84 MeV
m_W envelope (MeV) [*NNPDF3.0, MMHT2015*]	25 MeV	13 MeV	27 MeV	50 MeV

LHCb has larger uncertainties due to poorer known densities at low/high-x, and the inability to cut on the recoil p_T.

It gets interesting when we consider correlations…

Correlations

Bozzi *et al.*, 1508.06954 (2015)



As expected, we see a large anti-correlation between the GPD and LHCb uncertainties.*

Q: What happens to the LHC average?

*Above plots are only NNPDF3.0, but we see very similar correlations with the other two sets that we considered.

Bozzi *et al.*, 1508.06954 (2015)

LHC average?

Four measurements*

G=GPD, L=LHCb

$$\delta_{\text{PDF}} = \begin{pmatrix} \mathbf{G}^+ & 24.8 \\ \mathbf{G}^- & 13.2 \\ \mathbf{L}^+ & 27.0 \\ \mathbf{L}^- & 49.3 \end{pmatrix} \qquad \rho = \begin{pmatrix} & \mathbf{G}^+ & \mathbf{G}^- & \mathbf{L}^+ & \mathbf{L}^- \\ \mathbf{G}^+ & 1 & & & \\ \mathbf{G}^- & -0.22 & 1 & & \\ \mathbf{L}^+ & -0.63 & 0.11 & 1 & \\ \mathbf{L}^- & -0.02 & -0.30 & 0.21 & 1 \end{pmatrix}$$

(MeV)

Average

Scenario	δm_W PDF envelope of NNPDF3.0, MMHT14	Weight in average			
		G^+	G^-	L^+	L^-
GPD only	**10.5 MeV**	26%	74%	—	—
GPD + LHCb	**7.7 MeV**	30%	45%	21%	4%

*This considers the example of the envelope to the two most recent sets in our study

LHC average?

Bozzi *et al.*, 1508.06954 (2015)

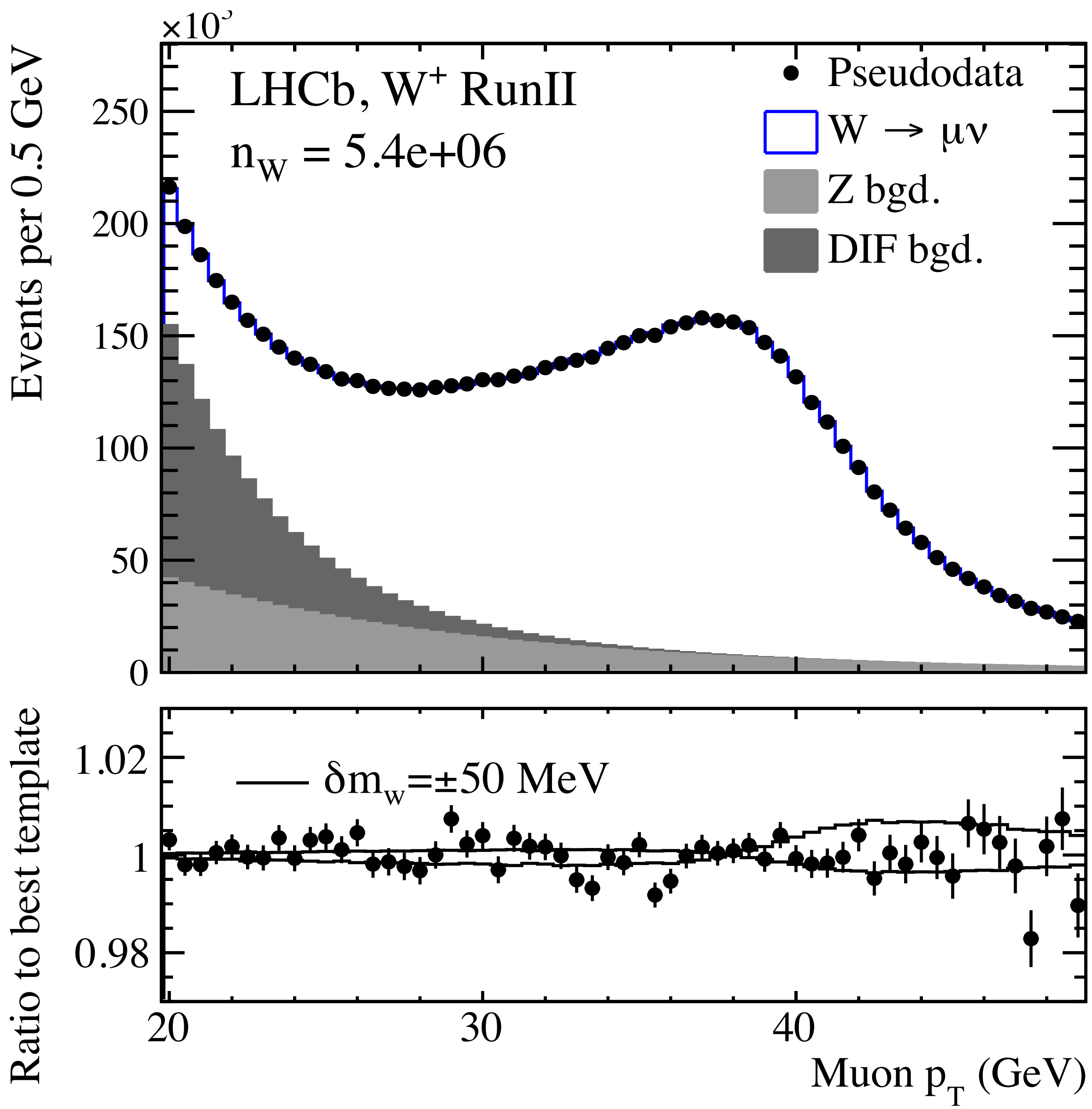
PDFs	Experiments	δ_{PDF} (MeV)	α
PDF4LHC(2-sets)	2×GPD	10.5	$(0.26, 0.74, 0, 0)$
PDF4LHC(2-sets)	2×GPD + LHCb	7.7	$(0.30, 0.45, 0.21, 0.04)$
PDF4LHC(3-sets)	2×GPD	16.9	$(0.50, 0.50, 0, 0)$
PDF4LHC(3-sets)	2×GPD + LHCb	12.7	$(0.43, 0.41, 0.11, 0.04)$
NNPDF30	2×GPD	5.2	$(0.50, 0.50, 0, 0)$
NNPDF30	2×GPD + LHCb	3.6	$(0.35, 0.47, 0.16, 0.02)$
MMHT2014	2×GPD	9.2	$(0.45, 0.55, 0, 0)$
MMHT2014	2×GPD + LHCb	4.6	$(0.39, 0.14, 0.46, 0)$
CT10	2×GPD	11.6	$(0.33, 0.67, 0, 0)$
CT10	2×GPD + LHCb	6.3	$(0.38, 0.20, 0.40, 0.03)$

Whichever set or sets of PDFs are considered, LHCb has a > 30% impact on the PDF uncertainty

LHCb sensitivity

Bozzi *et al.*, 1508.06954 (2015)

Scale the same templates to the expected yields in the full Run-II dataset (take lower end of 7-10 fb^{-1} projection)



Statistical precision:
W^+: 9 MeV
W^-: 12 MeV

Sufficient Z and ϒ samples to control momentum scale uncertainty to around 4 MeV

Bozzi *et al.*, 1508.06954 (2015)

LHC average

Assumption: ATLAS and CMS each measure m_W with 7 MeV precision for each charge, with 50% +ve correlation between charges. (CMS-NOTE-2006-061, EPJ C57:6270651 (2008))

Total* uncertainty on LHC average

Scenario	δm_W (MeV) PDF envelope of NNPDF3.0, MMHT14	Weight in average			
		G^+	G^-	L^+	L^-
2 x GPD	**13.1** (6.0_{exp}, 11.6_{PDF})	22%	78%	—	—
1 x GPD + LHCb	**10.9** (6.6_{exp}, 8.7_{PDF})	26%	44%	25%	5%
2 x GPD + LHCb	**9.8** (4.7_{exp}, 8.6_{PDF})	25%	48%	22%	4%

- ***Caveat:** don't yet address an important source of uncertainty in the W p_T model (±5 MeV for CDF/D0).
- Nevertheless, it seems clear that LHCb should make a direct measurement of m_W.

A big table with many different choices of PDFs, and assumptions on the uncertainties

Summary/outlook

- PDFs may be the key challenge in improving our direct constraint on m_W.
- LHCb can help by making a direct m_W measurement (**1508.06954**).

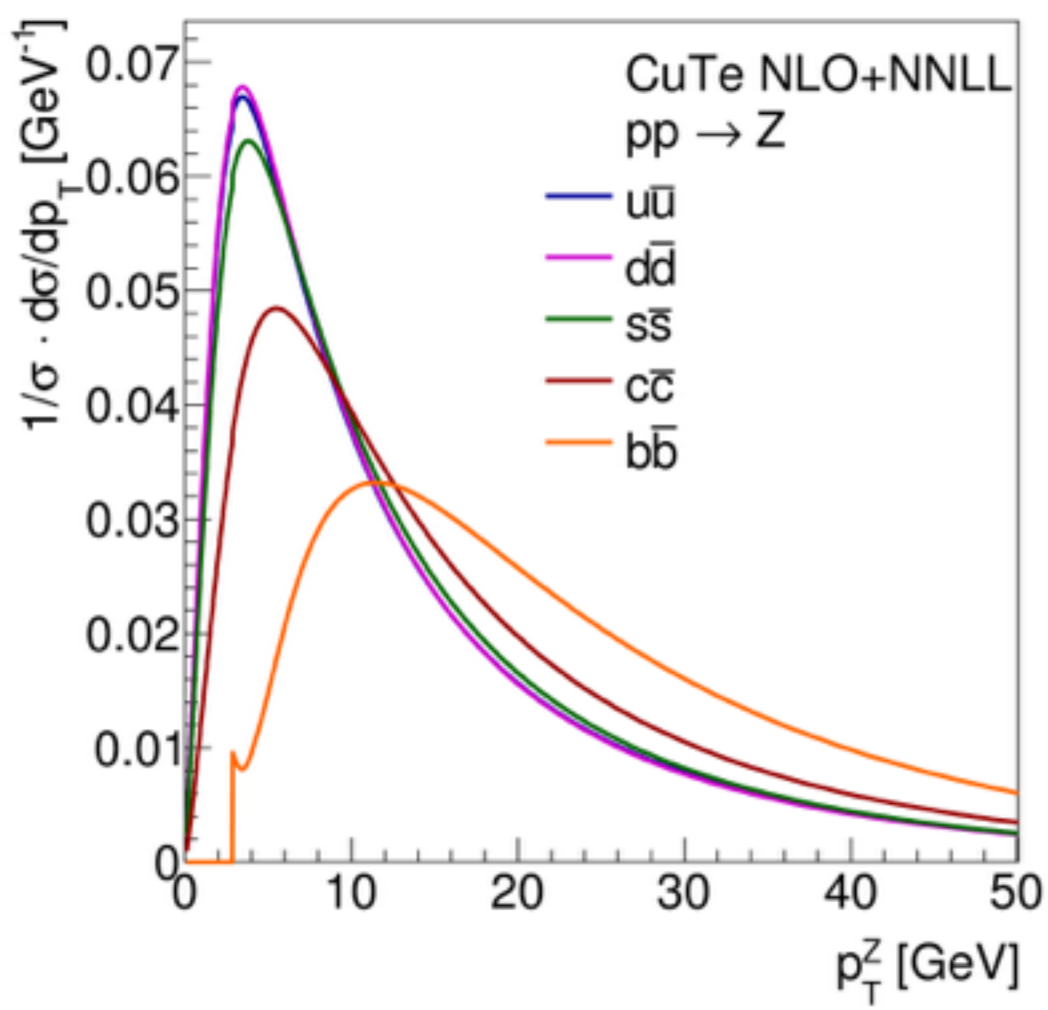
Backup slides

Many other scenarios

Scenario	Experiments	δm_W (MeV) Tot	Exp	PDF	α
Default	2×GPD + LHCb	9.0	4.7	7.7	$(0.30, 0.44, 0.22, 0.04)$
Default	1×GPD + LHCb	10.1	6.5	7.7	$(0.31, 0.40, 0.25, 0.04)$
Default	2×GPD	12.0	5.8	10.5	$(0.28, 0.72, 0, 0)$
PDF4LHC(3-sets)	2×GPD + LHCb	13.6	4.8	12.7	$(0.43, 0.41, 0.12, 0.04)$
PDF4LHC(3-sets)	1×GPD + LHCb	14.6	7.3	12.7	$(0.43, 0.40, 0.12, 0.04)$
PDF4LHC(3-sets)	2×GPD	17.7	5.5	16.9	$(0.50, 0.50, 0, 0)$
$\delta_{\text{exp}}^{\text{LHCb}} = 0$	2×GPD + LHCb	8.7	4.0	7.7	$(0.31, 0.41, 0.24, 0.04)$
$\delta_{\text{exp}}^{\text{LHCb}} = 0$	1×GPD + LHCb	9.8	5.9	7.9	$(0.31, 0.37, 0.28, 0.04)$
$\delta_{\text{exp}}^{\text{LHCb}} = 0$	2×GPD	12.0	5.8	10.5	$(0.28, 0.72, 0, 0)$
$\delta_{\text{exp}}^{\text{GPD}} = 0$	2×GPD + LHCb	7.9	1.9	7.7	$(0.29, 0.48, 0.19, 0.04)$
$\delta_{\text{exp}}^{\text{GPD}} = 0$	1×GPD + LHCb	7.9	1.9	7.7	$(0.29, 0.48, 0.19, 0.04)$
$\delta_{\text{exp}}^{\text{GPD}} = 0$	2×GPD	10.5	0.1	10.5	$(0.26, 0.74, 0, 0)$
$\delta_{\text{PDF}} = 0$	2×GPD + LHCb	4.6	4.6	0.0	$(0.34, 0.34, 0.22, 0.10)$
$\delta_{\text{PDF}} = 0$	1×GPD + LHCb	5.8	5.8	0.0	$(0.23, 0.23, 0.37, 0.17)$
$\delta_{\text{PDF}} = 0$	2×GPD	5.5	5.5	0.0	$(0.50, 0.50, 0, 0)$
$\delta_{\text{exp}}^{\text{LHCb}} \times 2$	2×GPD + LHCb	9.6	5.6	7.7	$(0.29, 0.50, 0.17, 0.04)$
$\delta_{\text{exp}}^{\text{LHCb}} \times 2$	1×GPD + LHCb	10.8	7.6	7.7	$(0.30, 0.46, 0.20, 0.05)$
$\delta_{\text{exp}}^{\text{LHCb}} \times 2$	2×GPD	12.0	5.8	10.5	$(0.28, 0.72, 0, 0)$
$\delta_{\text{exp}}^{\text{GPD}} \times 2$	2×GPD + LHCb	11.2	7.9	8.0	$(0.32, 0.35, 0.29, 0.04)$
$\delta_{\text{exp}}^{\text{GPD}} \times 2$	1×GPD + LHCb	13.9	10.5	9.0	$(0.31, 0.26, 0.37, 0.05)$
$\delta_{\text{exp}}^{\text{GPD}} \times 2$	2×GPD	15.6	11.5	10.6	$(0.32, 0.68, 0, 0)$
$\delta_{\text{PDF}} \times 2$	2×GPD + LHCb	16.0	4.7	15.3	$(0.30, 0.45, 0.21, 0.04)$
$\delta_{\text{PDF}} \times 2$	1×GPD + LHCb	16.7	6.7	15.3	$(0.30, 0.44, 0.22, 0.04)$
$\delta_{\text{PDF}} \times 2$	2×GPD	21.7	5.9	20.9	$(0.27, 0.73, 0, 0)$

W p_T model

- At the Tevatron, we tuned the W p_T model on Z data, giving a 5 MeV uncertainty on the lepton p_T fit.
- Does this really cover all the full PQCD uncertainty? At the LHC, this is complicated by the flavour composition and interplay with PDFs.



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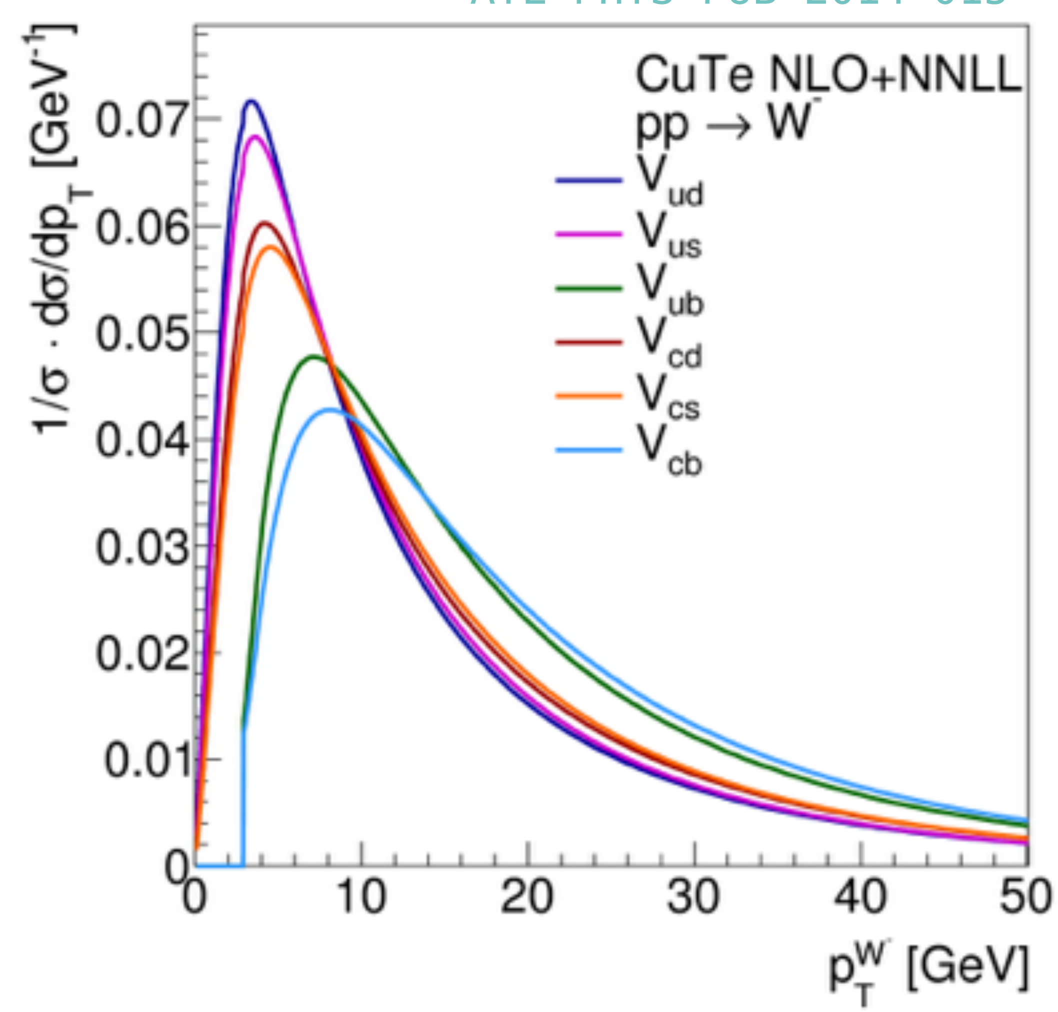
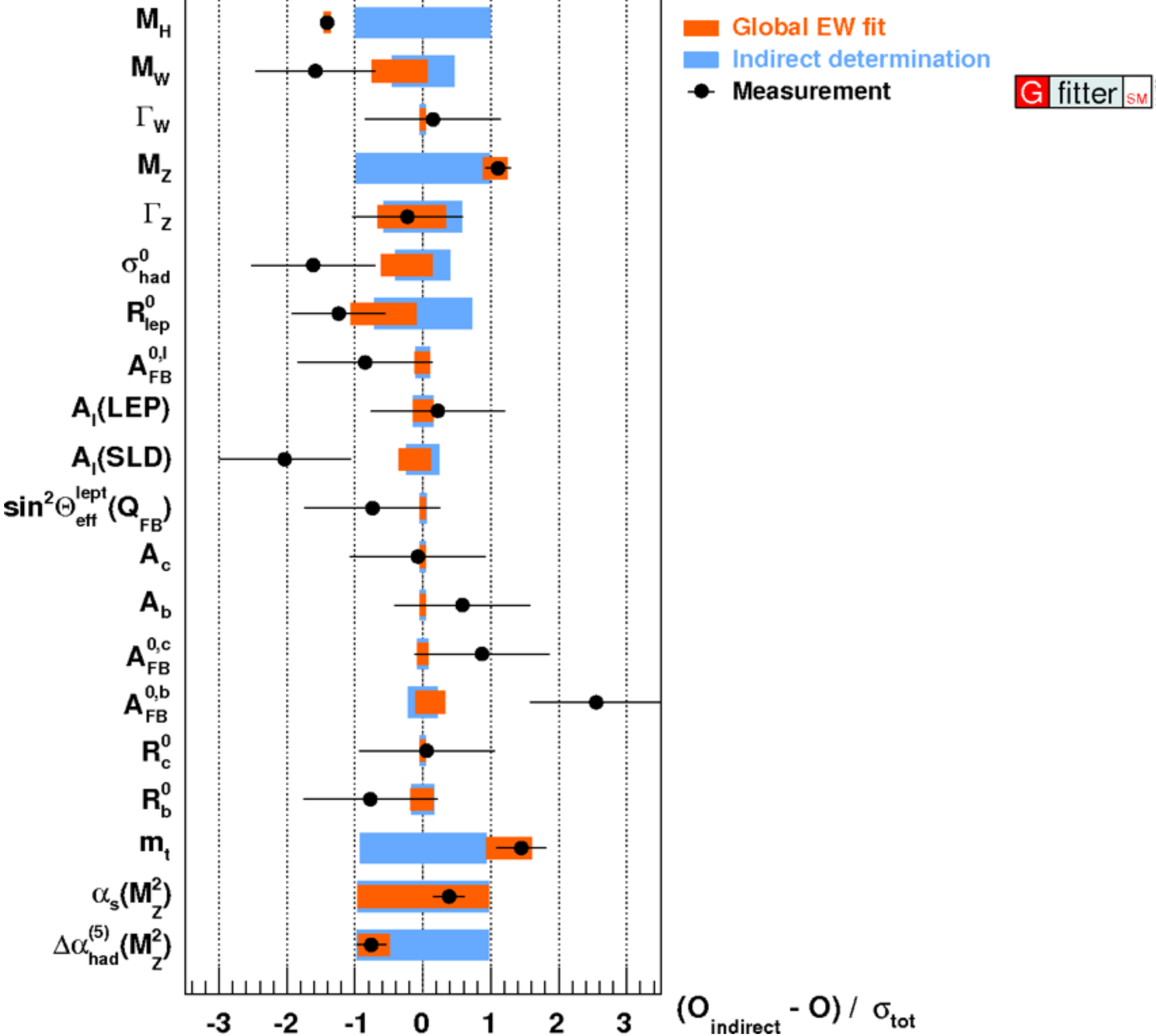
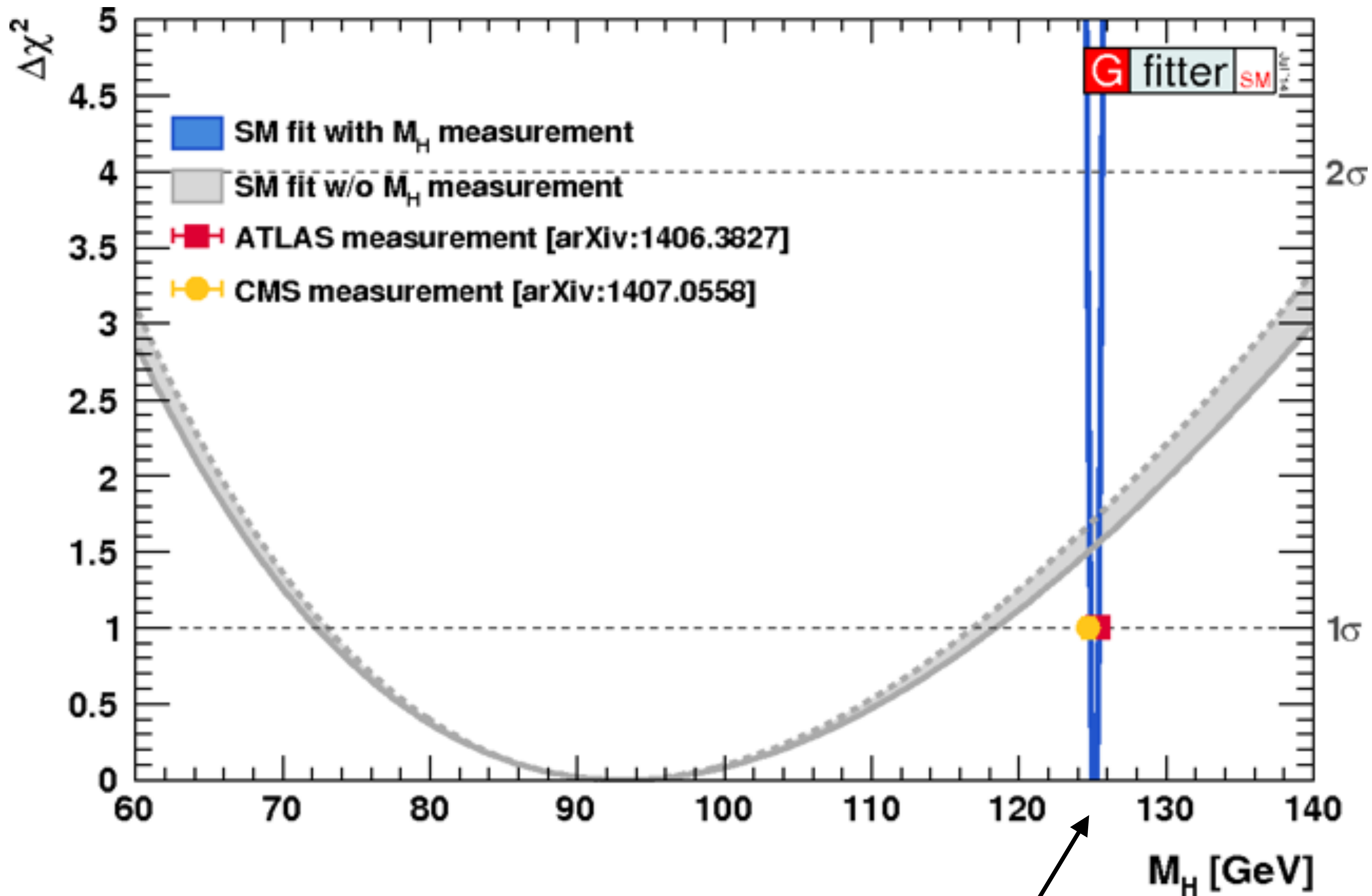




Global EW fit
Indirect determination
Measurement
G fitter SM
Jul '14
M_H
M_W
Γ_W
M_Z
Γ_Z
σ^0_{had}
R^0_{lep}
$A^{0,l}_{FB}$
A_l(LEP)
A_l(SLD)
$\sin^2\Theta^{lept}_{eff}(Q_{FB})$
A_c
A_b
$A^{0,c}_{FB}$
$A^{0,b}_{FB}$
R^0_c
R^0_b
m_t
$\alpha_s(M_Z^2)$
$\Delta\alpha^{(5)}_{had}(M_Z^2)$
-3
-2
-1
0
1
2
3
$(O_{indirect} - O) / \sigma_{tot}$

Indirect Higgs mass constraint



Direct measurement!

m_t and m_W constrain the Higgs mass, but for equal contribution to uncertainty, need $\Delta m_W = 0.006\Delta m_t$!