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Electroweak Measurements at LHCb and their interplay with proton PDFs

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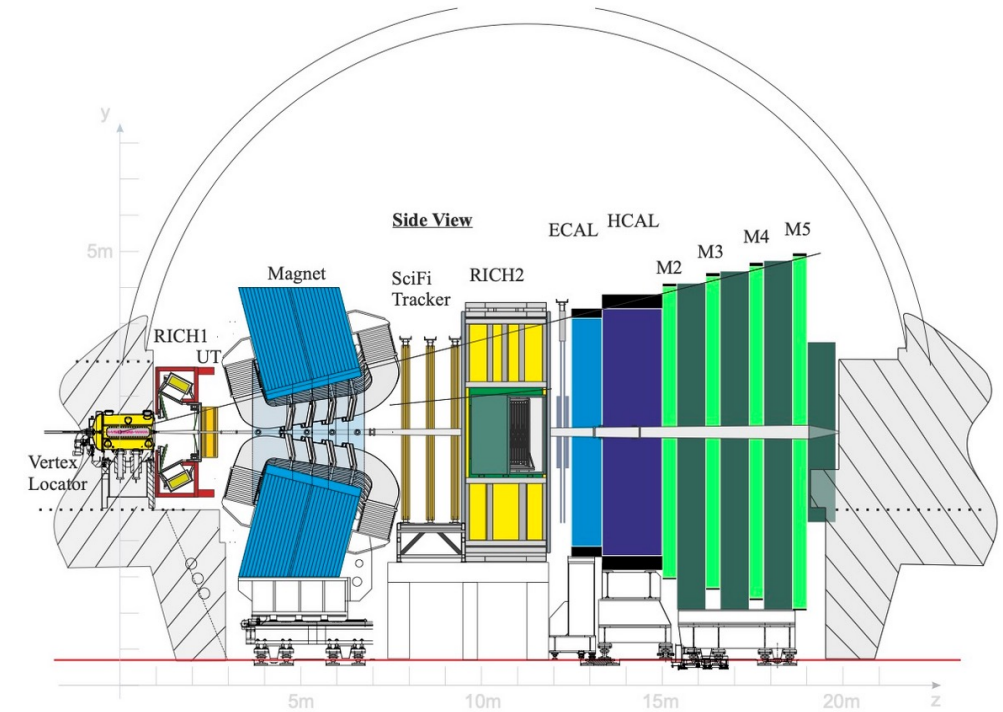
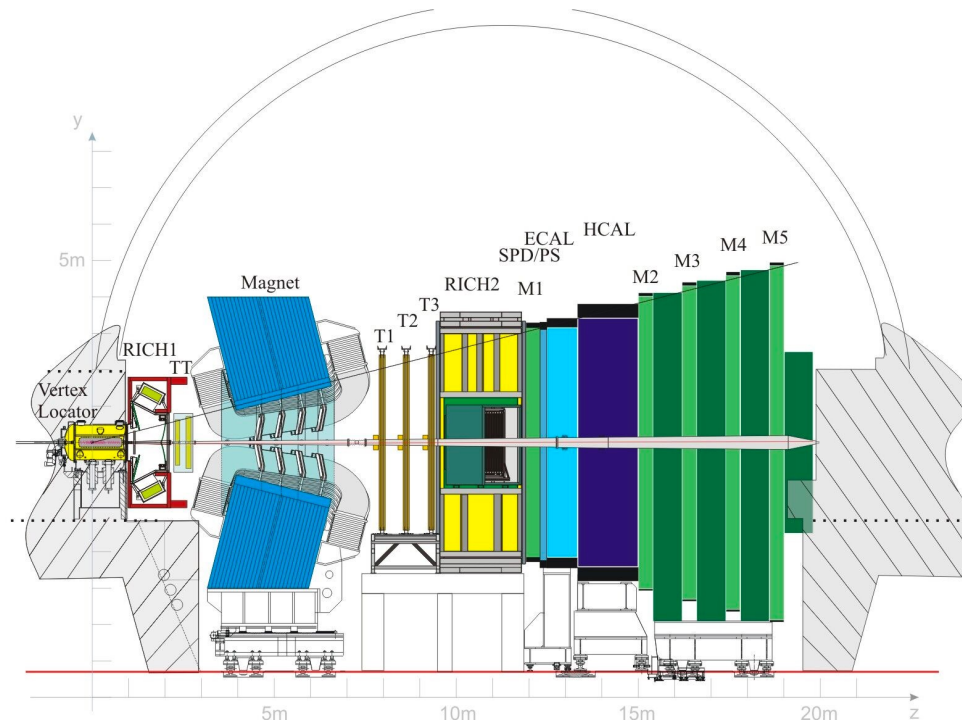
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Introduction

- Will cover two recent analyses from LHCb:
 - W boson production cross-section and charge asymmetry @ 13 TeV [PRL 137 (2026) 111801 and PRD 114 (2026) 052003]
 - W boson helicity @ 13 TeV [arXiv: 2609.22555]
- Will also cover older precision-EW results:
 - Z boson mass using 13 TeV data [PRL 135 (2025) 161802]
 - Weak mixing angle using 13 TeV data [JHEP 12 (2024) 026]
 - W boson mass using 13 TeV data and using 5 TeV data [JHEP 01 (2022) 036 and JHEP 03 (2026) 148]
 - As this is a QCD session, I will attempt to coherently discuss these results and focus on the impact of knowledge of proton PDFs.

LHCb Detector

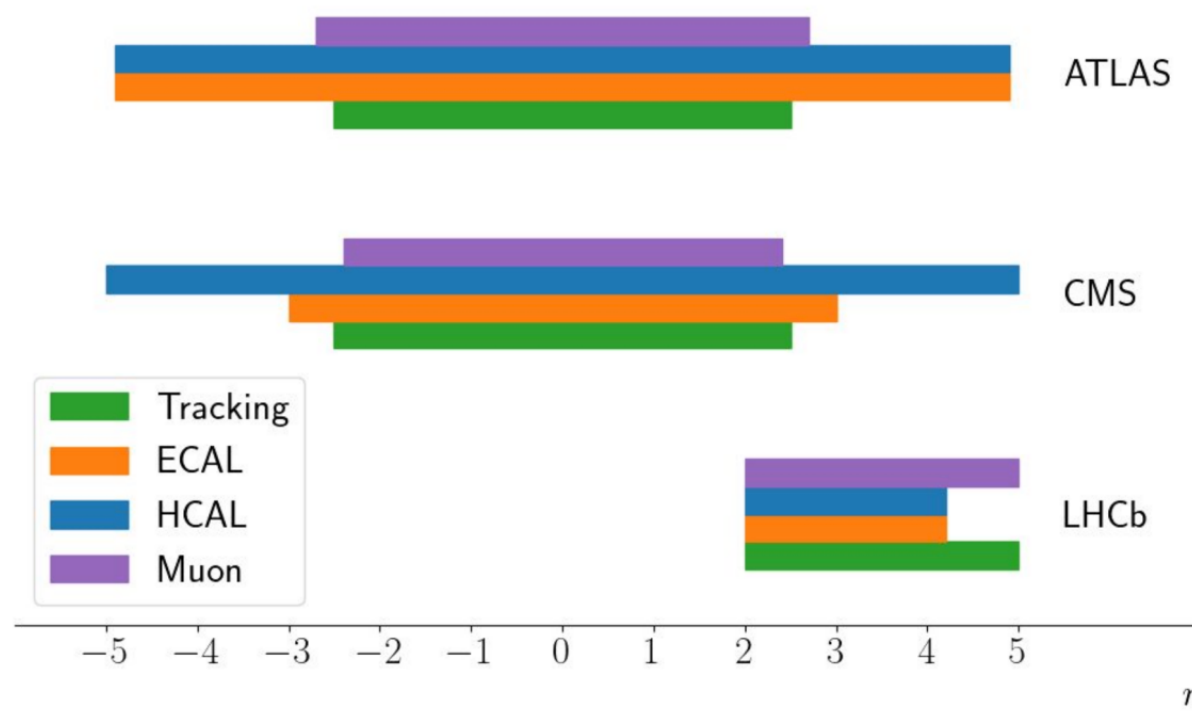
- Single arm spectrometer, fully instrumented in the forward region.



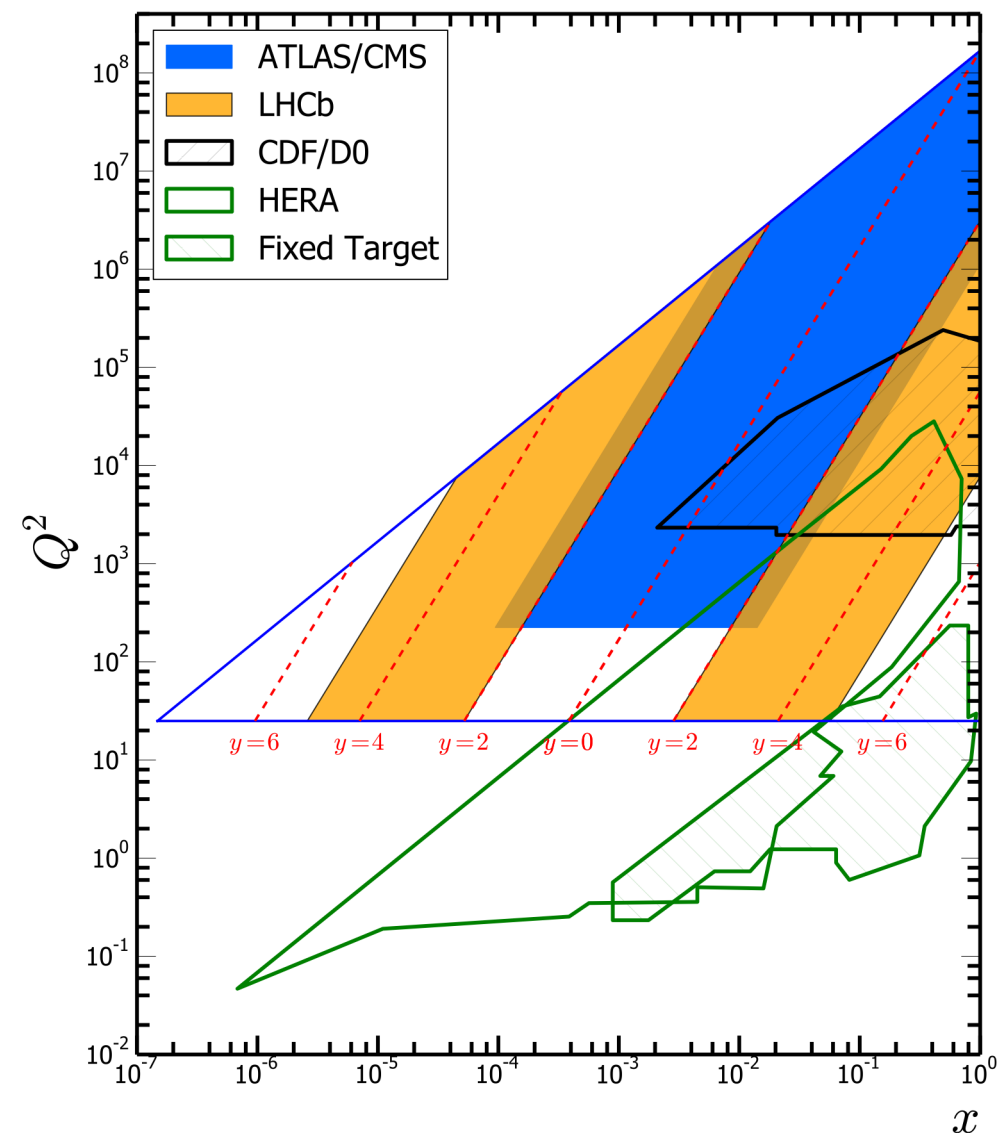
- Designed for flavour physics – but also able to act as general purpose forward detector.
- Probes the forward region at the LHC (roughly $2 < \eta < 5$).

LHCb Coverage

(very rough guide!)

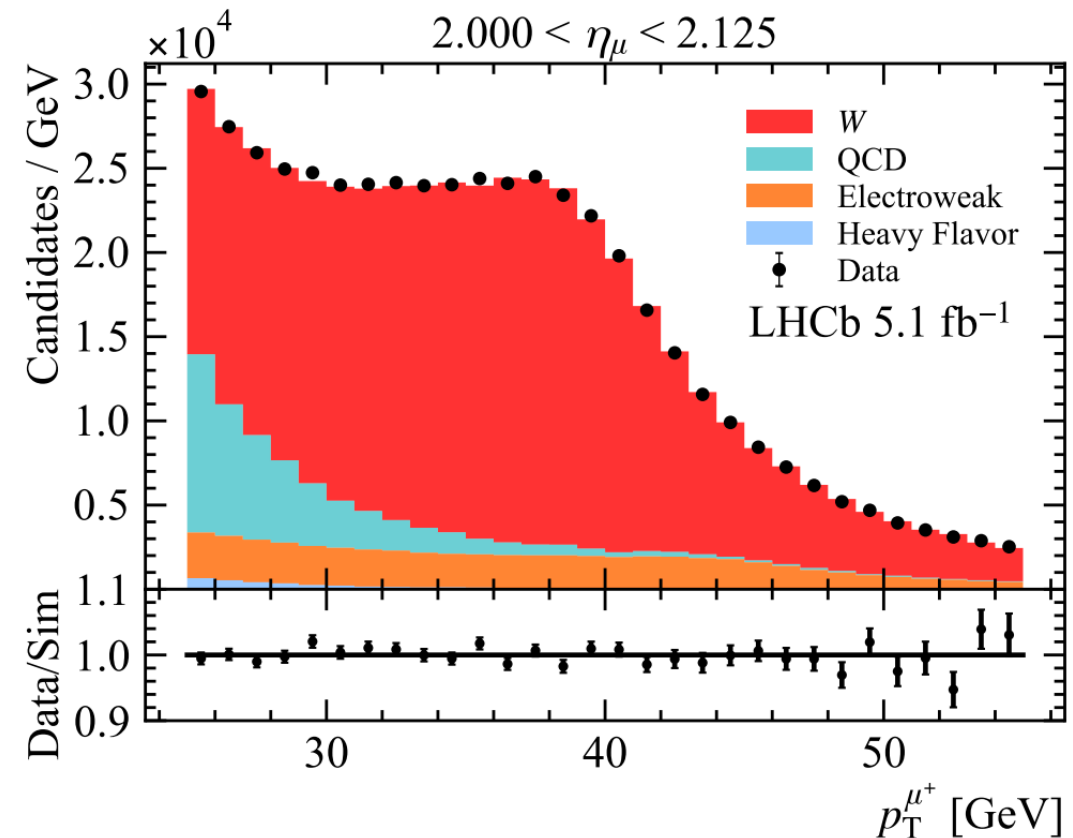


LHC 13 TeV Kinematics



W boson cross-section and charge asymmetry

- Study LHCb Run 2 (13 TeV) data.
- Select isolated muons within the detector – roughly 11M events considered with purity > 80%.
- Template fit to muon p_T to extract signal yields in fiducial region ($2 < \eta < 4.5$).
- Efficiencies are determined from simulation, weighted to match data.

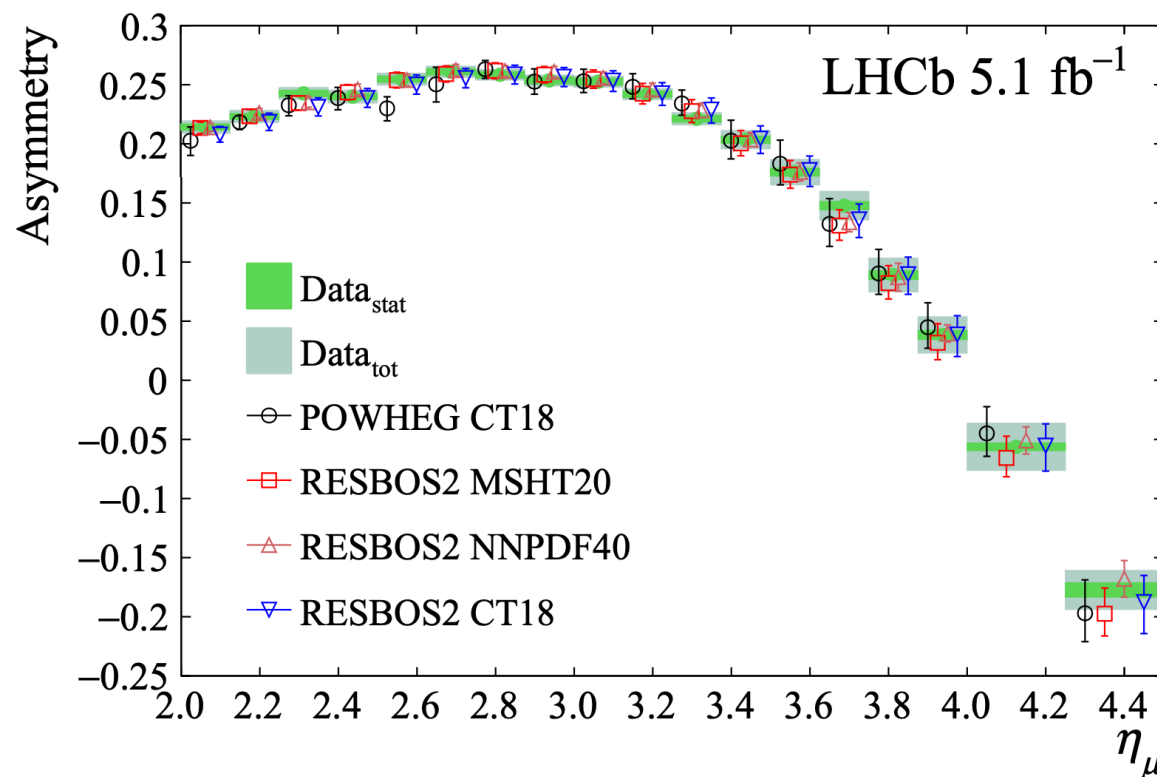


W boson cross-section and charge asymmetry

- Charge asymmetry defined as:

$$\mathcal{A}(\eta_\mu) \equiv \frac{d\sigma_{W^+ \rightarrow \mu^+ \nu} / d\eta_{\mu^+} - d\sigma_{W^- \rightarrow \mu^- \bar{\nu}} / d\eta_{\mu^-}}{d\sigma_{W^+ \rightarrow \mu^+ \nu} / d\eta_{\mu^+} + d\sigma_{W^- \rightarrow \mu^- \bar{\nu}} / d\eta_{\mu^-}}$$

- To first order probes ratio of up and down quarks in proton.
- Dominant uncertainty from modelling of signal shape.
- Broad agreement seen with ‘modern’ PDFs.
- Cross-section measurement also available.



W boson helicity fractions

- Neglecting the muon mass, we can write at leading order

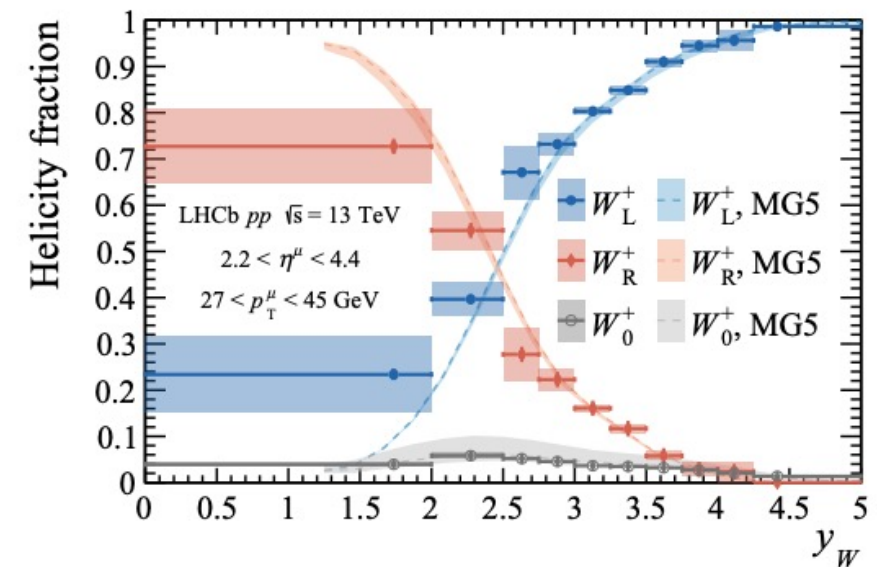
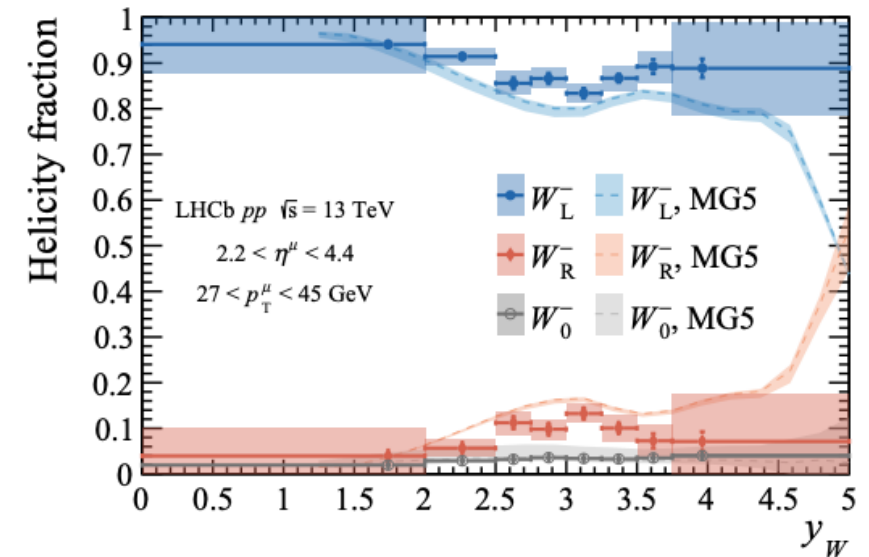
$$\frac{1}{\sigma} \frac{d\sigma^+}{d\cos(\theta)} = \frac{3}{8} [(1 \mp \cos(\theta))^2 f_L^\pm + (1 \pm \cos(\theta))^2 f_R^\pm + 2(1 - \cos^2(\theta)) f_0^\pm]$$

where $\cos(\theta)$ is the angle of the muon in the Collins-Soper frame.

- Cannot reconstruct CS-frame for W given missing energy of neutrino, so instead rely on a fit to the distribution in $p_T - \eta$ space.
- Measurement performed as a function of W rapidity.
- All this increases impact of modelling of signal distributions - nominal distribution uses aMC@NLO, with POWHEG considered as a variation.

W boson helicity fractions

- Uncertainties naturally smallest in regions LHCb probes most ‘easily’; signal modelling dominates at low rapidity, with PDF uncertainties dominating at higher rapidity.
- Measurement tests chiral nature of charged and shows good agreement with the SM expectation.

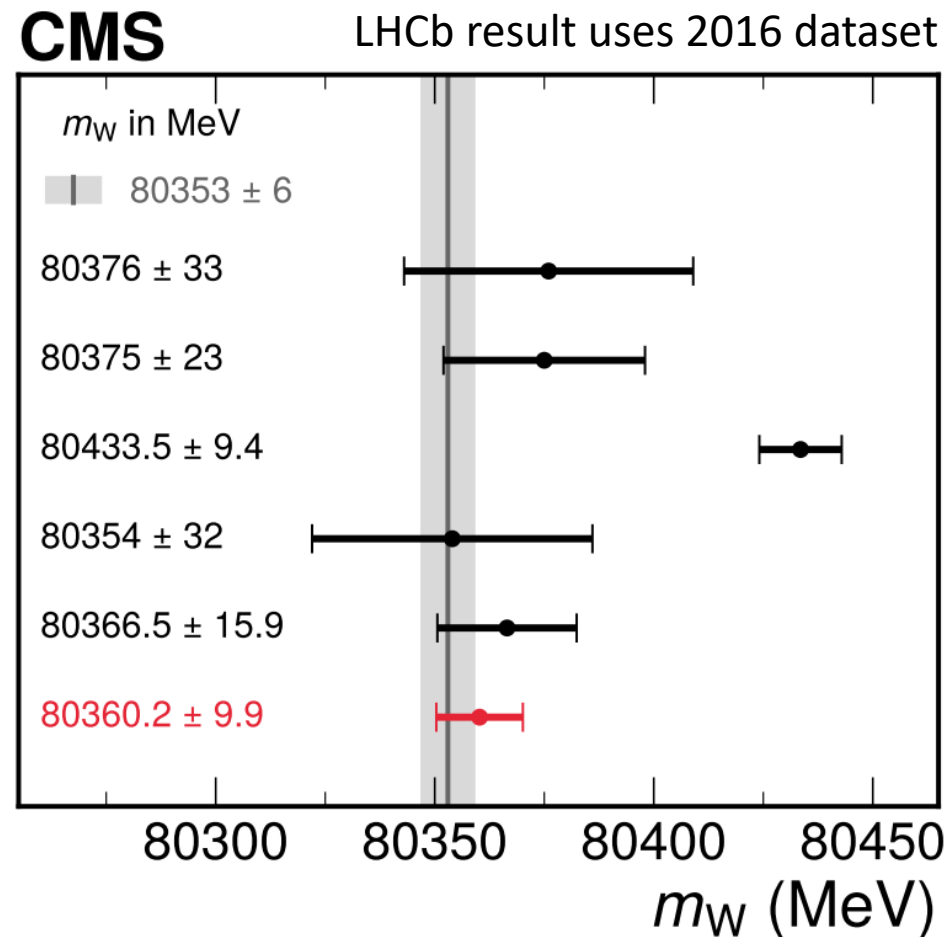


Precision Studies of Electroweak Physics

- Three fundamental parameters of EW physics can be measured at hadron colliders:
 - W boson mass
 - Z boson mass
 - Weak mixing angle – responsible for the interactions of Z bosons.
- In the SM, all three are directly related:
 - at leading order $\sin^2 \theta_W = 1 - m_W^2 / m_Z^2$
- LHCb has measured all three parameters.

Precision Studies of Electroweak Physics

Electroweak fit
PRD 110 (2024) 030001
LEP combination
Phys. Rep. 532 (2013) 119
D0
PRL 108 (2012) 151804
CDF
Science 376 (2022) 6589
LHCb
JHEP 01 (2022) 036
ATLAS
EPJC 84 (2024) 1309
CMS
This work



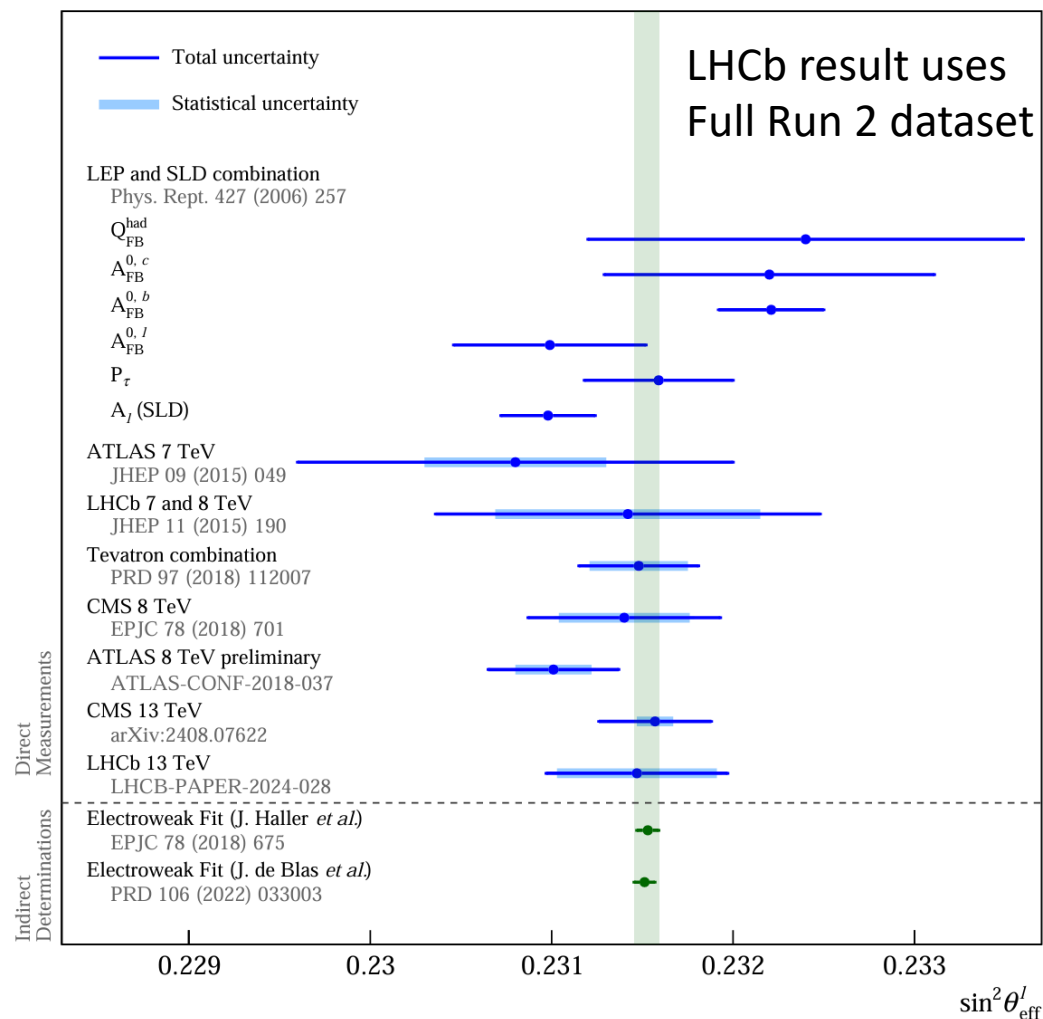
LHCb total unc: 32 MeV

LHCb stat unc: 23 MeV

LHCb PDF unc: 9 MeV

We have also published a pathfinder result using 5 TeV data using new method to extract muon p_T distribution – allows easier post-measurement interpretation

Precision Studies of Electroweak Physics

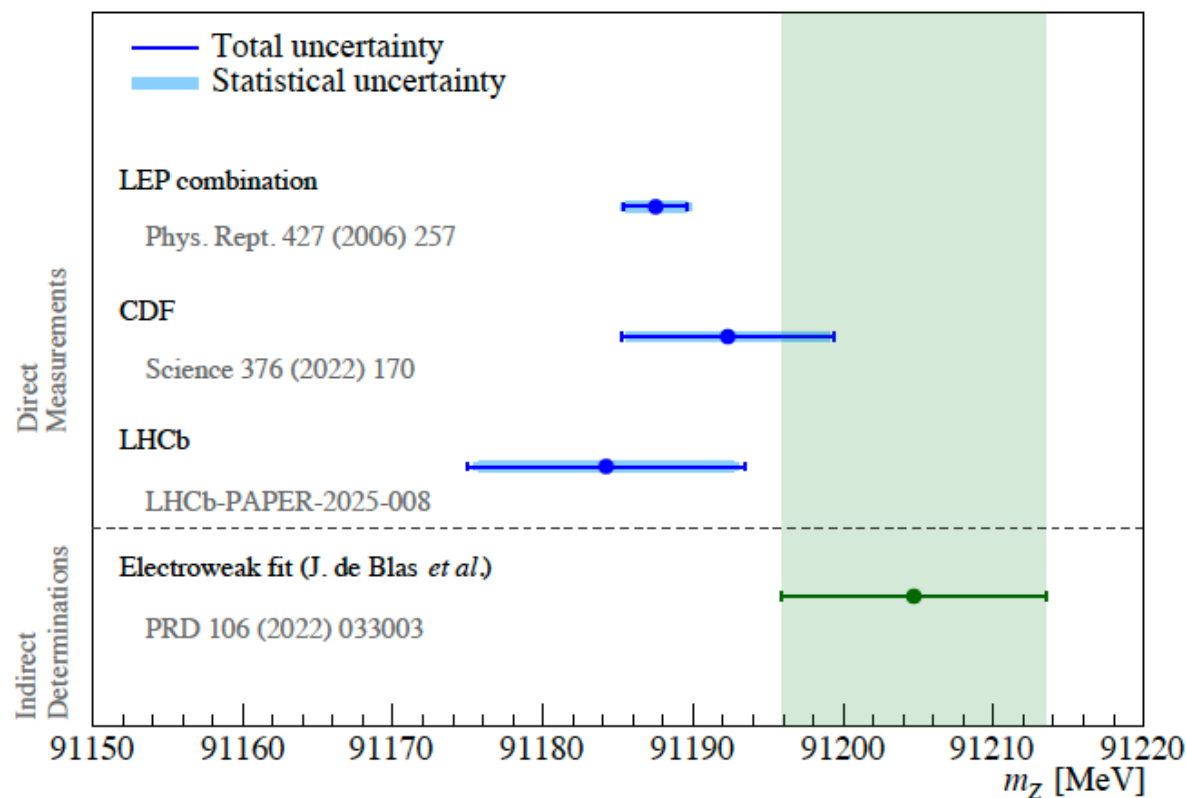


LHCb total unc: 50×10^{-5}
LHCb stat unc: 44×10^{-5}
LHCb PDF unc: 23×10^{-5}

PDF uncertainties in forward-backward asymmetry measurement are intrinsically small in forward region.

Precision Studies of Electroweak Physics

LHCb result uses 2016 dataset



LHCb total unc: 9 MeV

LHCb stat unc: 8 MeV

LHCb PDF unc: < 1 MeV

Z boson mass measurement is less dependent on PDFs - as $m_{\ell\ell}$ is a Lorentz-invariant quantity.

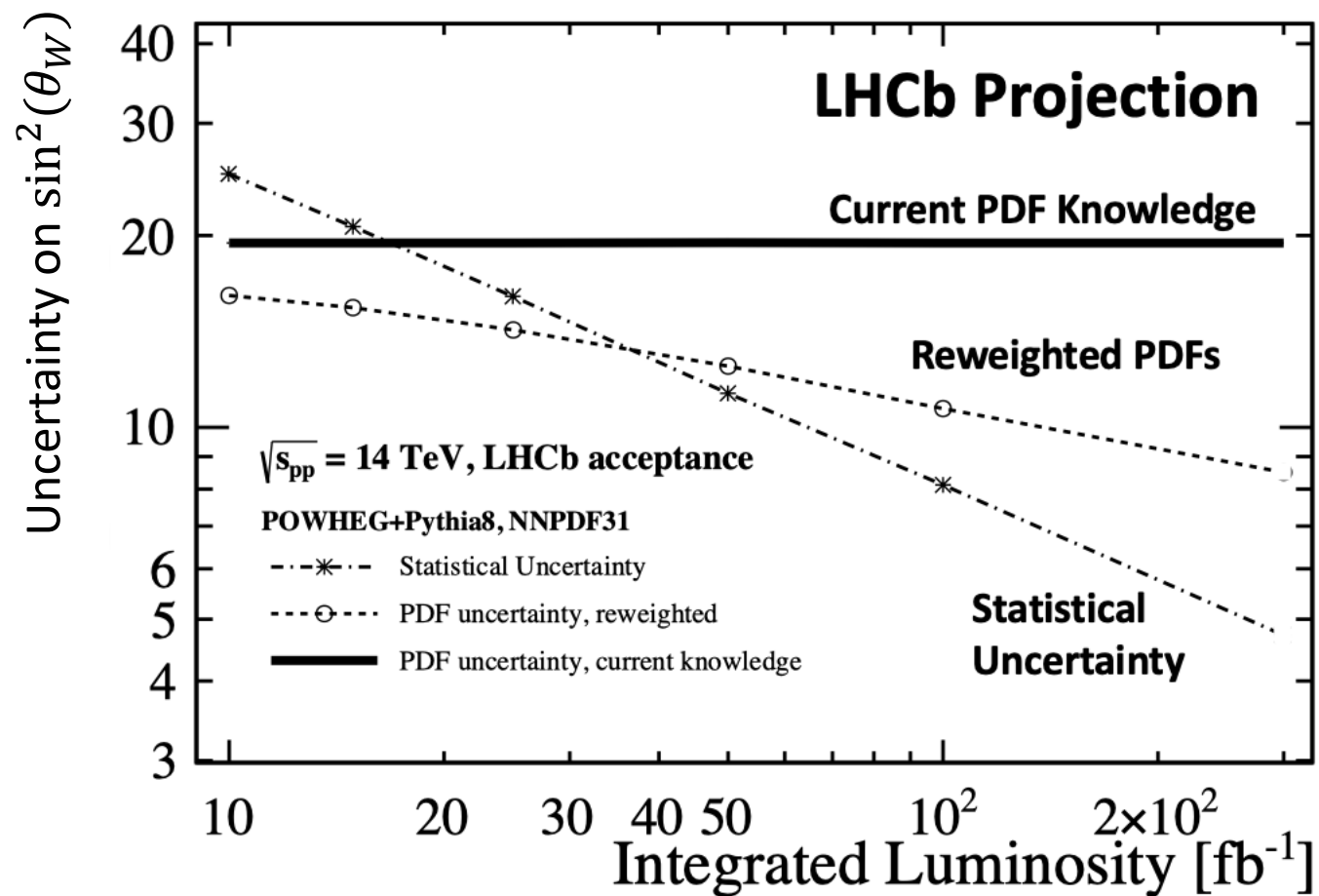
PDF treatment in Precision EW measurements

- For W mass and weak mixing angle we do not have a 'favoured PDF'.
- We use 'same generation' PDFs produced in global PDF fits (i.e. NNPDF31, MSHT20, CT18) that consider 'similar' input datasets.
 - These PDFs also don't fit cross-section results from the same data used in the LHCb precision analyses – no concerns about using/fitting the same data twice.
 - Treat PDFs as fully correlated given this overlap of input data, so central value of quoted result is arithmetic average of different PDFs, and the PDF uncertainty is the arithmetic average of individual PDF uncertainties.
 - We do not inflate uncertainty to cover spread of different PDFs.

PDF treatment in Precision EW measurements

- We do not (yet) profile our results to reduce the PDF uncertainties.
- This is because neither measurement is yet limited by these uncertainties – W boson mass measurement is limited by the sample size and by the generator model; weak mixing angle is statistically limited.
- With Run 3 data, the weak mixing angle measurement is expected to have statistical and PDF uncertainties similar size – so profiling becomes relevant.
 - We will participate in discussions on role of ‘tolerance’ factors in PDFs and impact on profiling with interest.

What if we do profile / reweight PDFs?



Uncertainties on weak mixing angle arising from PDF knowledge:

LHCb (300 fb^{-1}): 9×10^{-5}

(cf 20×10^{-5} without reweighting)

Conclusions

- Measurements of electroweak bosons at LHCb are sensitive to QCD.
 - Allow us to constrain PDFs.
 - Are impacted by our knowledge of PDFs.
- I have discussed recent LHCb measurements that probe PDFs, and the impact of PDFs on the LHCb 'precision measurement' programme.

References – PDFs

CTEQ6	JHEP 07 (2002) 012
CTEQ6.6	PRD 78 (2008) 013004
CT10	PRD 82 (2010) 074024
CT14	PRD 93 (2016) 033006
CT18	PRD 103 (2021) 014013
ABMP16	PRD 96 (2017) 014011
MMHT2014	EPJC 75 (1015) 204
MSHT20	EPJC 81 (2021) 341
NNPDF31	EPJC 77 (2017) 663
NNPDF40	EPJC 82 (2022) 428