Prospects for measuring the W boson mass with LHCb

Martina Pili, on behalf of the LHCb Collaboration
University of Oxford

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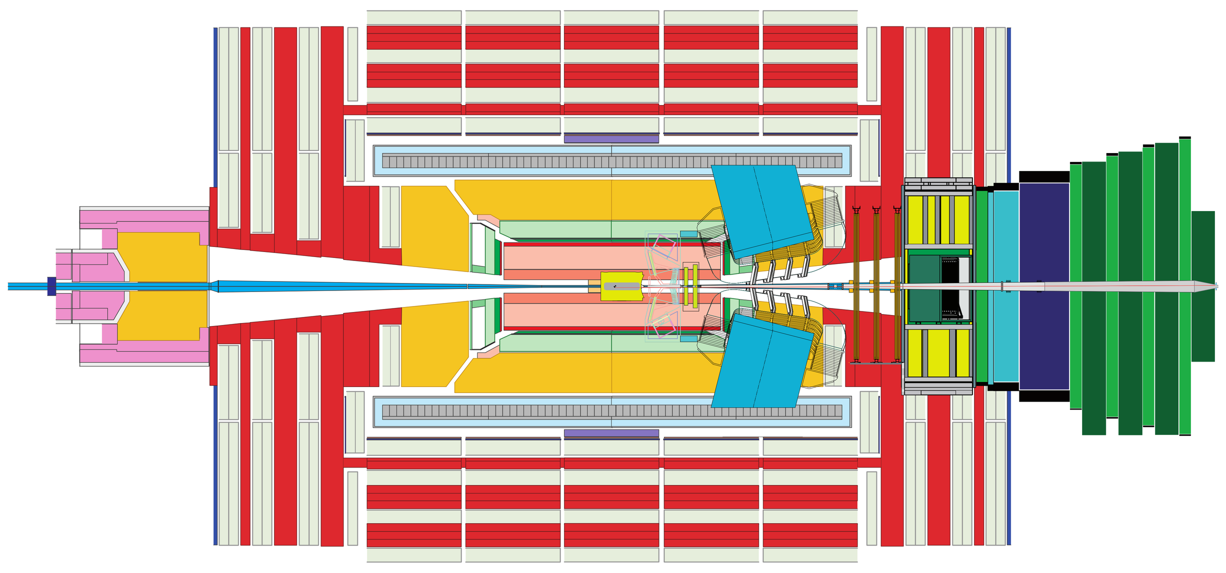
1 - Motivation

Precision electroweak tests are a powerful probe of physics beyond the Standard Model

Global Electroweak Fit 2018 [1]	Direct Measurement (PDG) [2]
$M_W = 80354 \pm 7\,\mathrm{MeV/c^2}$	$M_W = 80379 \pm 12\,\mathrm{MeV/c^2}$

- M_W measurements at the LHC are largely affected by PDF uncertainties
- An analysis with Run 1 and Run 2 data could yield a M_W measurement with a statistical uncertainty of roughly 10 MeV/c^2
- PDF uncertainties would be anti-correlated with those of ATLAS and CMS [3], increasing the precision of a combined measurement

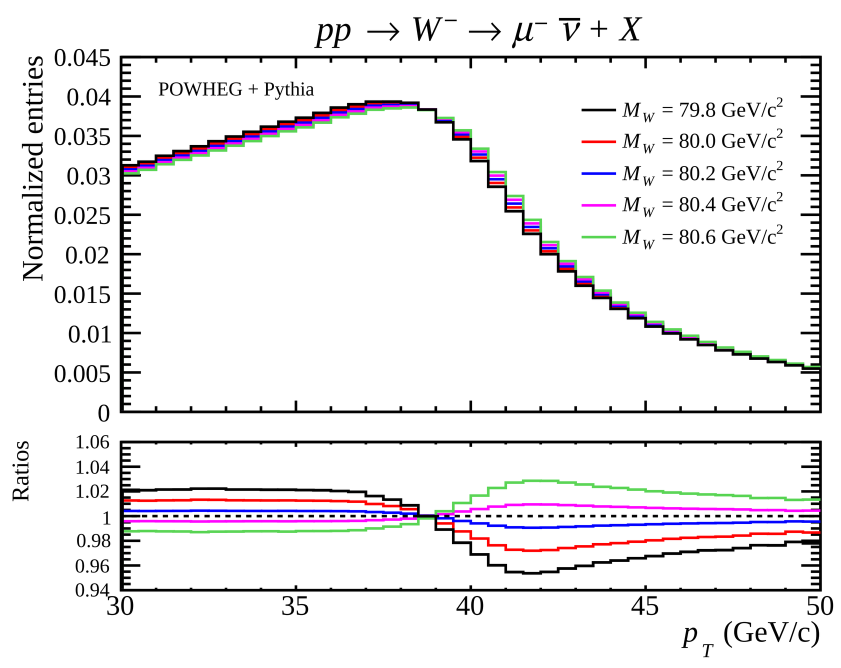


Complementary acceptance regions:

LHCb: $2 < \eta^{\ell} < 5$ ATLAS, CMS: $|\eta^{\ell}| < 2.5$

2 - Measuring M_W

The extraction of M_W relies on a template fit of transverse momentum (p_T) distribution of the muon from $W \to \mu\nu$ decays

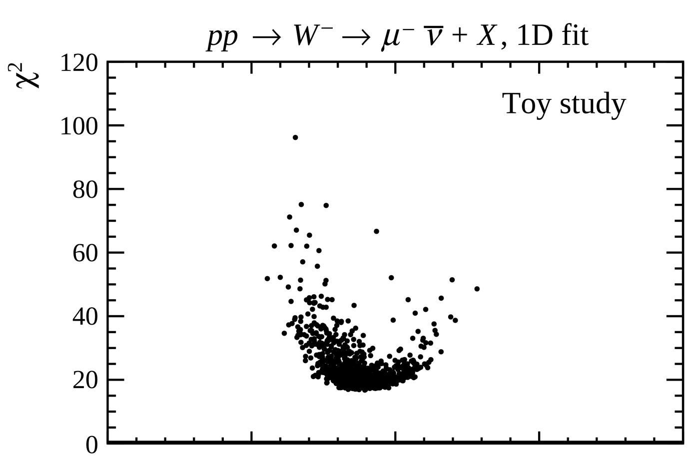


The simulated muon p_T distributions in $W \to \mu\nu$ decays with five different M_W hypotheses and ratio with respect to the predictions with $M_W = 80.3\,\mathrm{GeV/c^2}$

- Jacobian Peak at $M_W/2$
- Need good modelling of the muon p_T spectrum

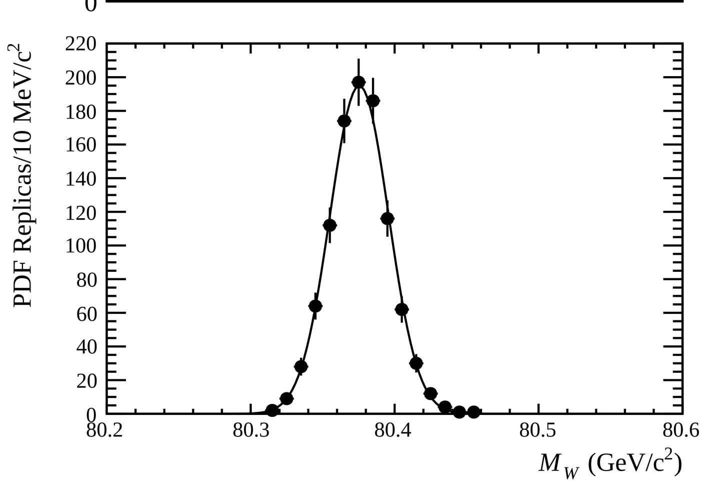
3 - Analysis Strategy [4]

- Monte Carlo sample of $W \to \mu\nu$ decays (Powheg + Pythia)
  - Selected $\mathcal{O}(10^7)$ events in $30 < p_T < 50\,\mathrm{GeV/c}$ and $2 < \eta < 4.5$
- Toy dataset: scaled to LHCb collected luminosity during Run 2 (6 fb^{-1})
- Templates: $M_W\times$ PDF hypothesis weights (using NNPDF3.1, 1000 *replicas*)



Template fit to a single toy dataset: for each PDF replica scan over all the M_W hypotheses

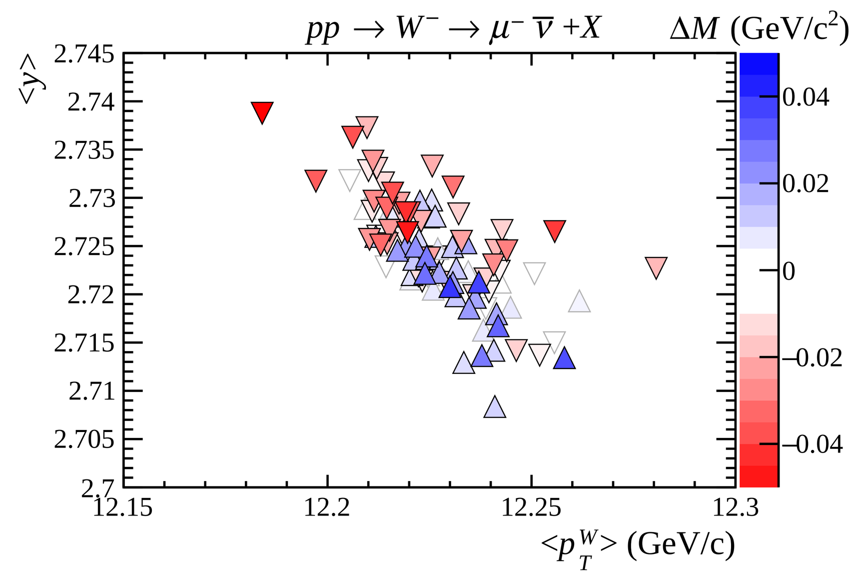
- The extracted M_W value for a certain PDF replica is the mass hypothesis that minimises the χ^2 from the fit



δ_{PDF} is the width of the PDF spread in the M_W values extracted with each replica

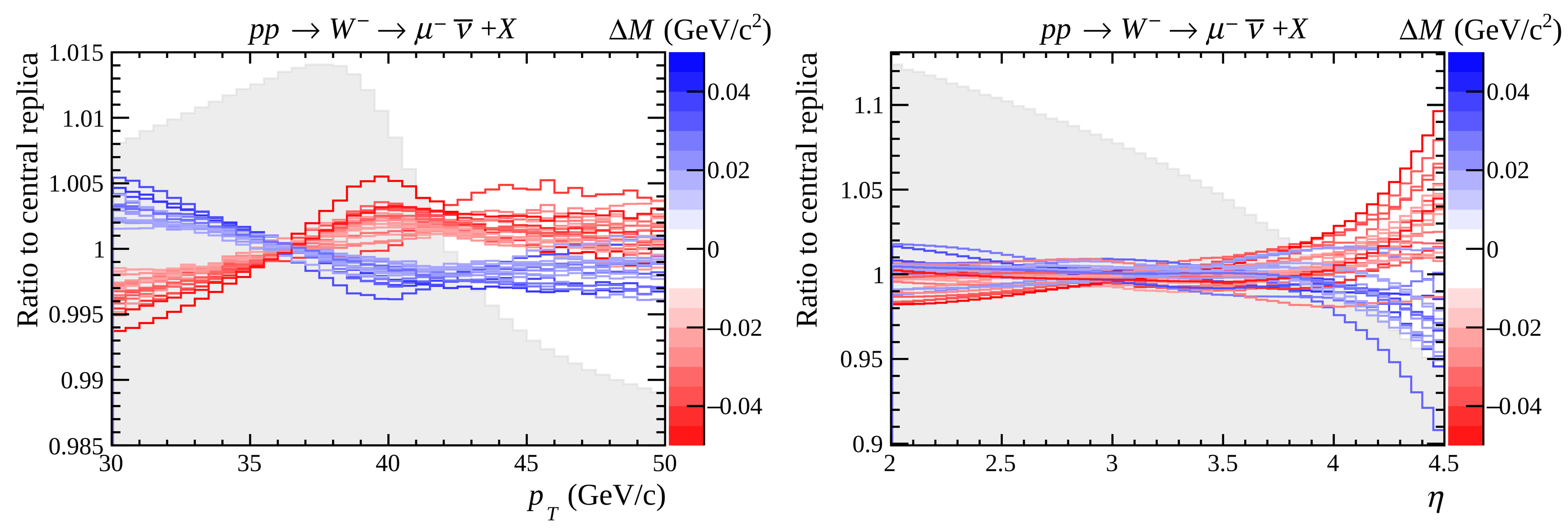
4 - W kinematics

Biases in the determination of M_W are strongly correlated with a mismodelling of the W production kinematics. These kinematics are characterised by the W transverse momentum (p_T^W), rapidity (y) and polarisation distributions



The mean of the y distribution versus the mean of the p_T^W distribution for different PDF replicas

Changes in the extracted M_W values for different PDFs are manifest as changes in muon **measurable** quantities distributions:



The replicas that lead to the largest variations in M_W lead to variation of several percent in the η distribution:

- Exploit the sensitivity of M_W to $\boldsymbol{p_T}$ **and** $\boldsymbol{\eta}$ to reduce the PDF uncertainty

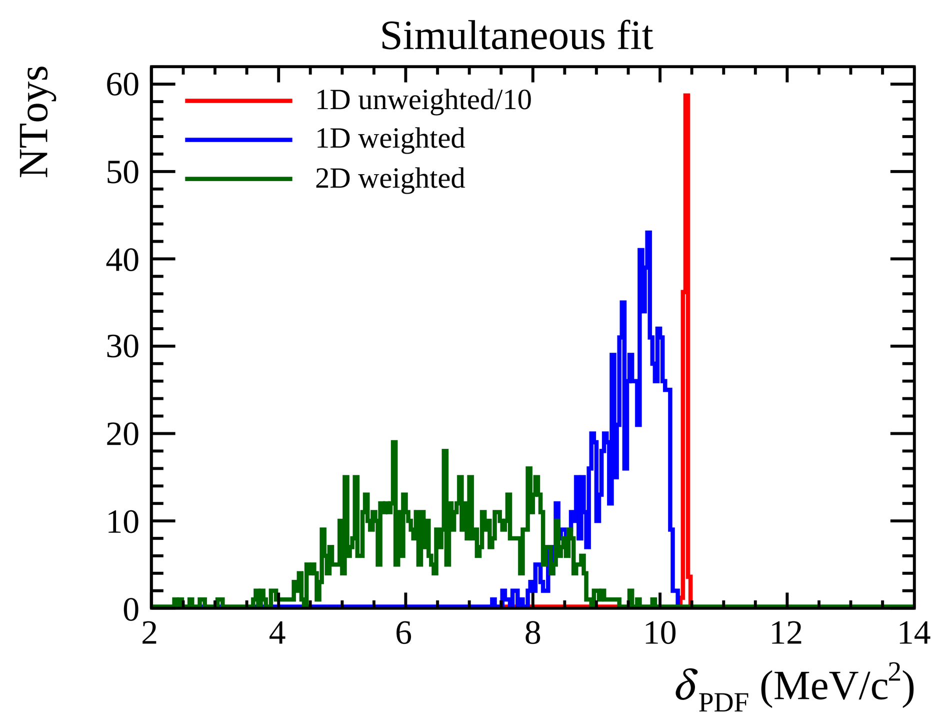
5 - The proposed method

One dimensional fit to muon p_T $\to$ **Two dimensional fit to muon (p_T, η)**

+

PDF weighting [5] each PDF replica is assigned a weight $P(\chi^2) \propto \chi^{n-1} e^{-\chi^2/2}$

- The weighting disgregards PDF replicas incompatible with the data
- Using a simultaneous $W^{\pm}$ fit with W^+ and W^- templates sharing the same normalisation to include the additional constraint of the charge asymmetry
- The PDF uncertainties extracted for multiple toy datasets:



The (p_T, η) fit with weighting reduces δ_{PDF} on average by roughly a factor of 2, assuming the LHCb Run 2 statistics

6 - Next Steps

1. Accurate model of the p_T^W spectrum
2. Muon momentum scale
   - Correct for misalignment effects using $Z \to \mu^+\mu^-$ events
3. Muon efficiencies
4. Control of the backgrounds

References

[1] J. Haller, A. Hoecker, R. Kogler, K. Mönig, T. Peiffer, and J. Stelzer. Update of the global electroweak fit and constraints on two-Higgs-doublet models. *Eur. Phys. J.*, C78(8):675, 2018.
[2] C. Patrignani et al. Review of Particle Physics. *Chin. Phys.*, C40(10):100001, 2016.
[3] G. Bozzi, L. Citelli, M. Vesterinen, and A. Vicini. Prospects for improving the LHC W boson mass measurement with forward muons. *Eur. Phys. J.*, C75(12):601, 2015.
[4] **S. Farry, O. Lupton, M. Pili, M. Vesterinen. Understanding and constraining the PDF uncertainties in a W boson mass measurement with LHCb.** arXiv:1902.04323, 2019.
[5] Richard D. Ball, Valerio Bertone, Francesco Cerutti, Luigi Del Debbio, Stefano Forte, Alberto Guffanti, Nathan P. Hartland, Jose I. Latorre, Juan Rojo, and Maria Ubiali. Reweighting and Unweighting of Parton Distributions and the LHC W lepton asymmetry data. *Nucl. Phys.*, B855:608–638, 2012.

martina.pili@physics.ox.ac.uk