# EWK physics: Measurements and prospects from LHCb

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On behalf of the LHCb Collaboration

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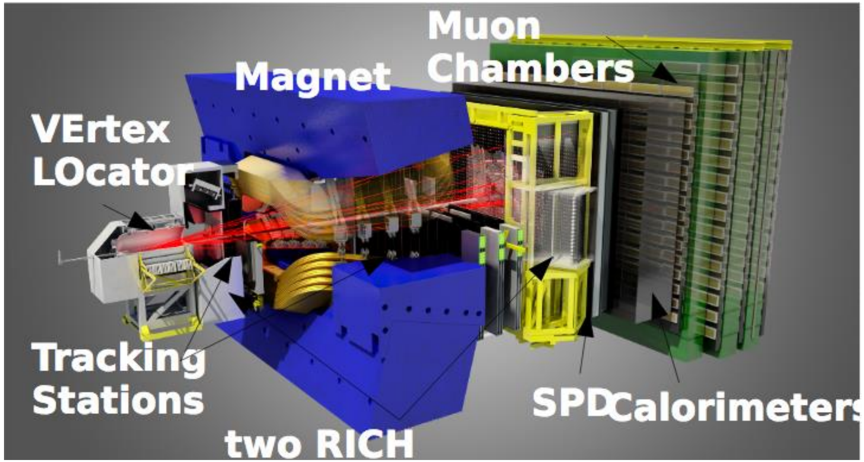
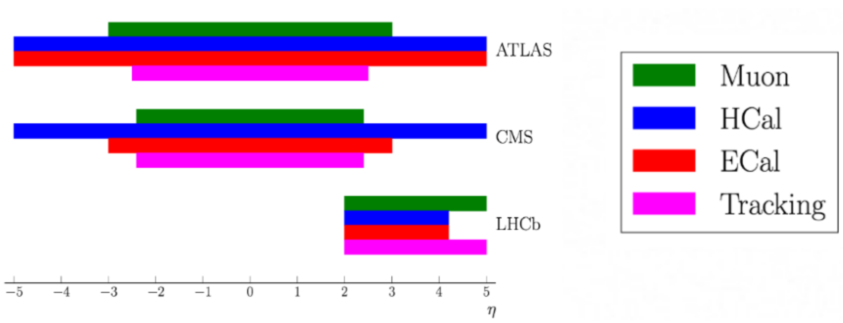
# LHCb detector Int. J. Mod. Phys. A30 (2015) 1530022

- Forward region: unique acceptance within the LHC experiments ($2 < \eta < 5$)
- Momentum resolution: 0.4% at 5GeV, 0.6% at 100 GeV
- Muon ID efficiency: 97% with 1-3% $\mu \rightarrow \pi$ mis-identification
- Electron reconstruction: bremsstrahlung recovery and well-measured direction
- Excellent vertex reconstruction: tagging of b and c jets.

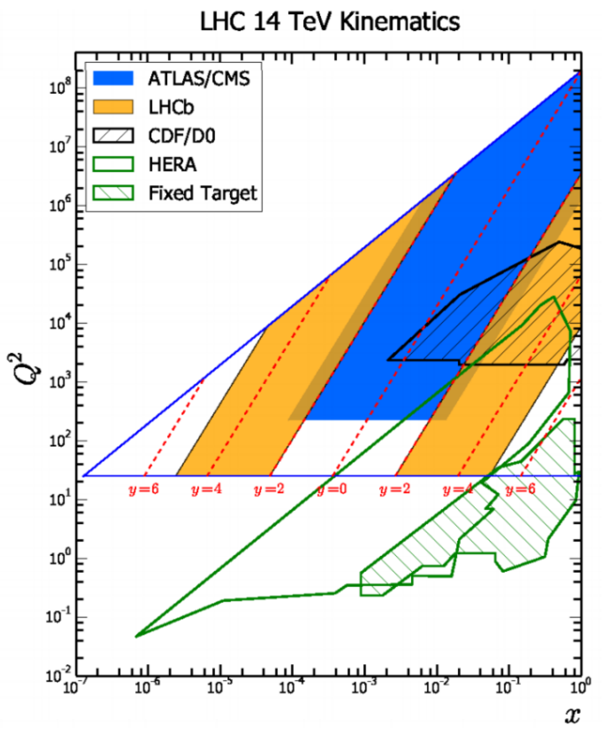



LHCb demonstrated its capability in EW and jet physics

# LHCb sensitivity to parton density function

- **LHCb:**
  - Unique **forward region** coverage, access new kinematic regions
  - Offers a complementary phase space region with respect to ATLAS/CMS for electroweak measurements
  - Provide access to PDF in two different regions:
    - ✓ At high x values;
    - ✓ At low x values, unexplored by other experiments.

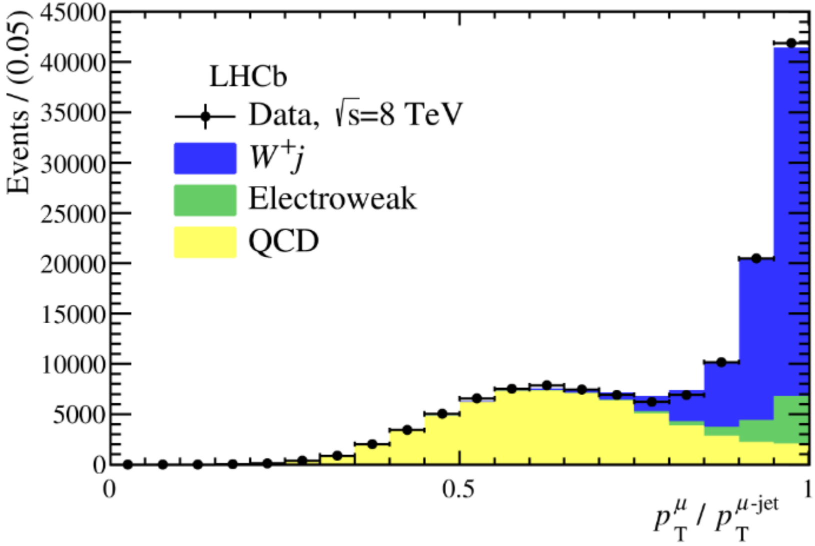


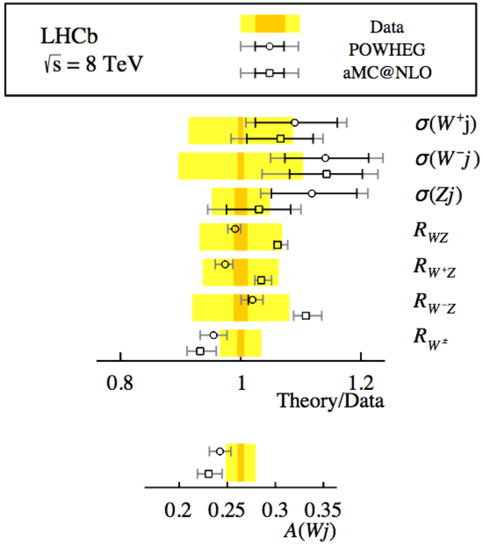
# $W/Z+$jet production at 8TeV JHEP 05 (2016) 1-23

- $W \to \mu\nu$ and Z $\to \mu\mu$ decay channels
- Fiducial region:

$$p_T(\mu) > 20\text{GeV}, 2.0 < \eta(\mu) < 4.5, p_T(\text{jet}) > 20\text{GeV}, 2.2 < \eta(\text{jet}) < 4.2, \Delta R(\text{jet}, \mu) > 0.5$$

- Fit to the muon isolation to extract the $W+$jet yield
- W/Z ratios and $W^+/W^-$ asymmetry are also determined
- Measurements are in good agreement with theory predictions

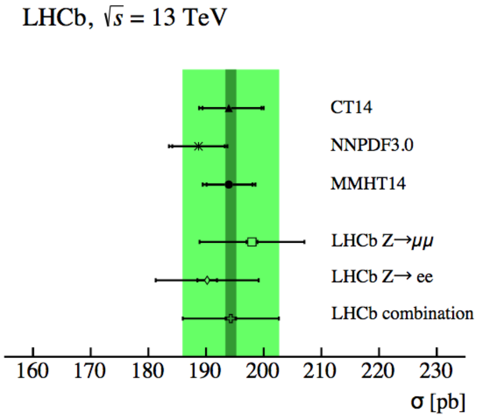


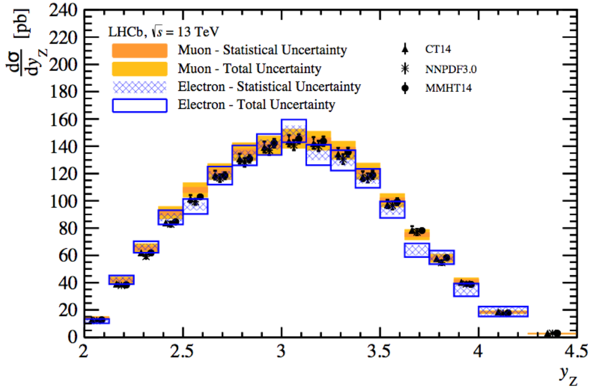



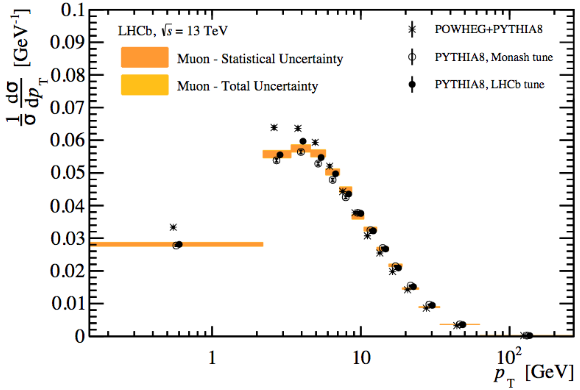
# Z production at $\sqrt{s} = 13\text{TeV}$ JHEP 09 (2016) 136

- Lepton final states $Z \to \mu\mu$ and $Z \to ee$, $294\text{pb}^{-1}$
- Fiducial region:

  $2.0 < \eta(\mu/e) < 4.5, p_T(\mu/e) > 20\text{GeV}, 60 < \text{M}(\mu\mu/ee) < 120\text{GeV}$
- High purity samples: 99.2% for $Z \to \mu\mu$ and 92.2% for $Z \to ee$
- $Z \to \mu\mu$ and $Z \to ee$ measured cross-section are compatible within the uncertainties
  - $\sigma_Z^{\mu\mu} = 198.0 \pm 0.9(\text{stat}) \pm 4.7(\text{sys}) \pm 7.7(\text{lumi})$ pb
  - $\sigma_Z^{ee} = 190.2 \pm 1.7(\text{stat}) \pm 4.7(\text{sys}) \pm 7.4(\text{lumi})$ pb
  - $\sigma_Z^{ll} = 194.3 \pm 0.9(\text{stat}) \pm 3.3(\text{sys}) \pm 7.6(\text{lumi})$ pb

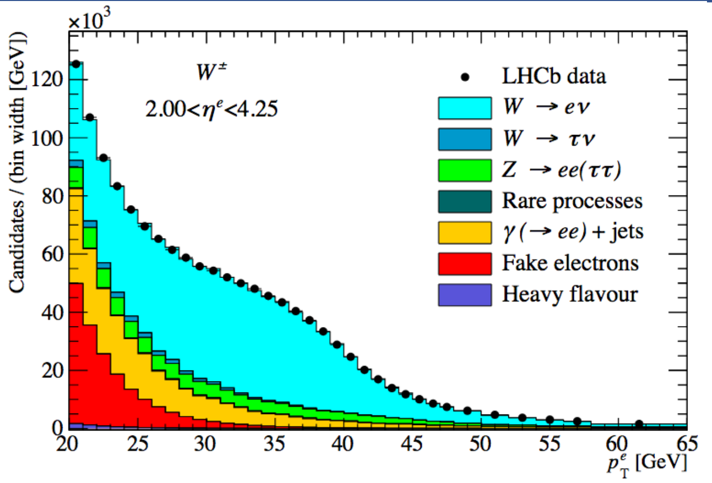


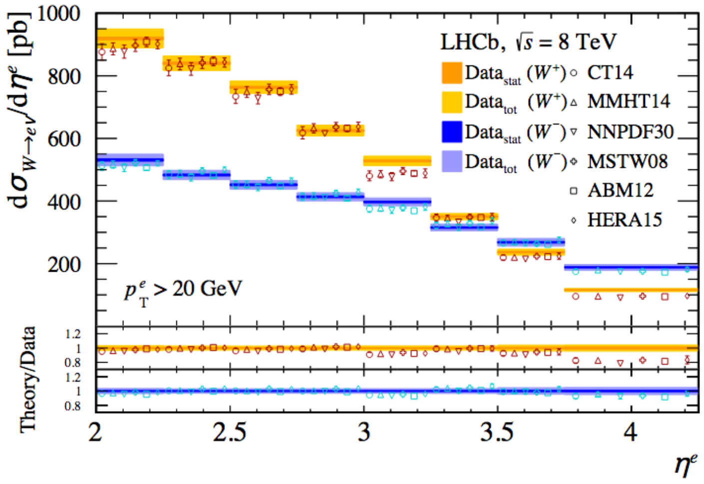



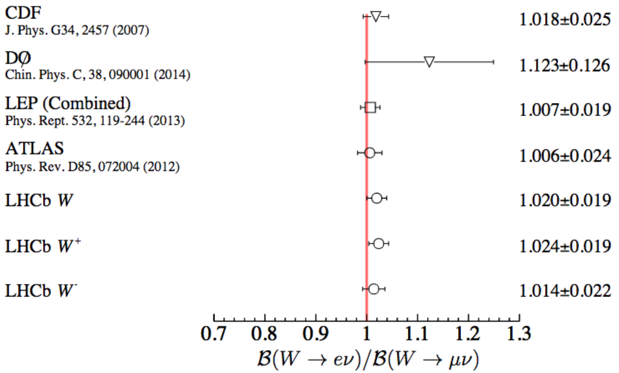



# $W \to e\nu$ production at 8TeV JHEP 10 (2016) 030

- Important measurement to validate the high $p_T$ $e$ reconstruction and identification at LHCb
- Fiducial region: $p_T(e) > 20\text{GeV}, 2.0 < \eta < 4.25$
- Fit to the electron $p_T$ distribution to extract the W yield
- Differential cross section as a function of the electron $\eta$ is compatible with the prediction



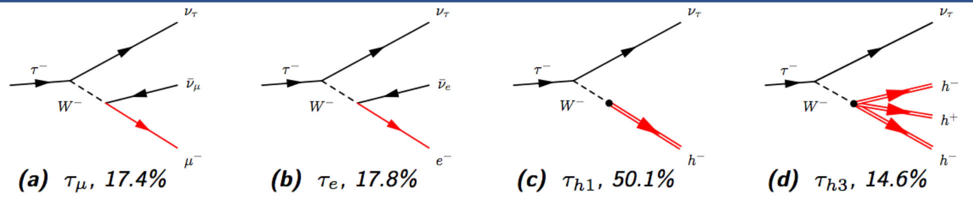



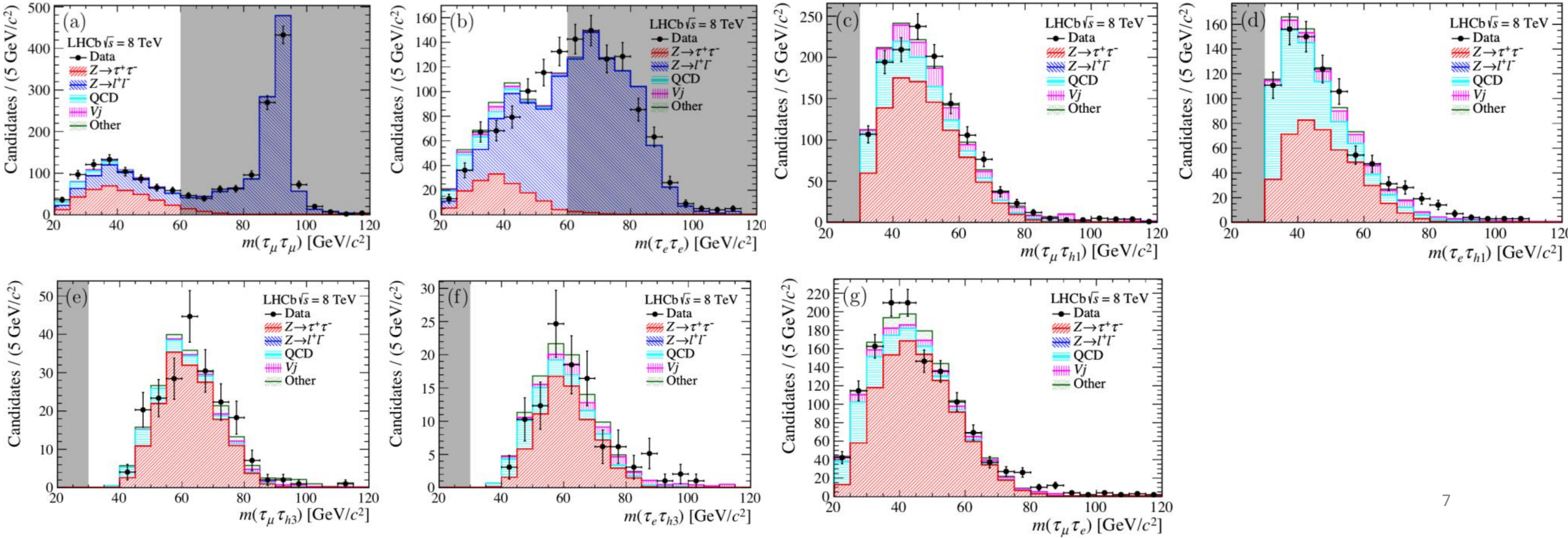



# Forward $Z \to \tau^-\tau^+$ production at $\sqrt{s} = 8$TeV JHEP 09 (2018) 159

- Tau lepton is reconstructed in 4 final states
- Analysis with 8TeV data, ~$2fb^{-1}$
- Fiducial region:

  $2.0 < \eta < 4.5, p_T > 20\text{GeV}, 60 < \text{M}(\tau\tau) < 120\text{GeV}$

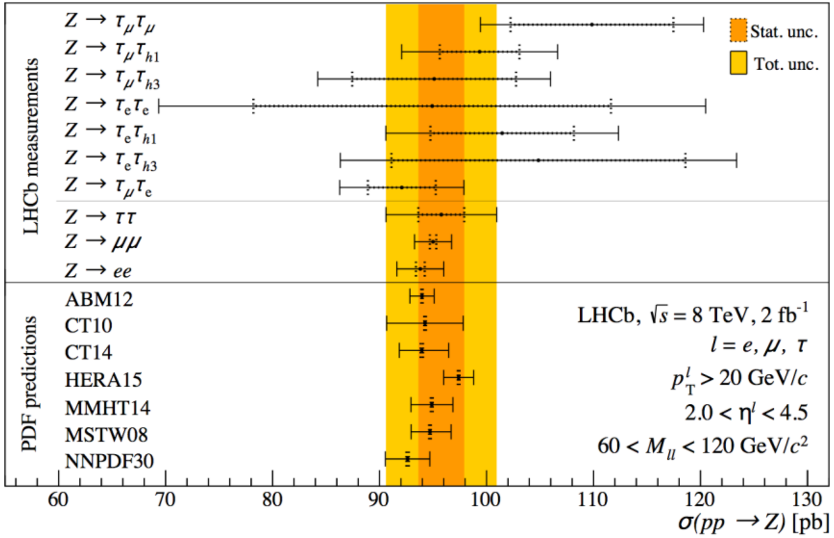


# Forward $Z \to \tau^-\tau^+$ production at $\sqrt{s} = 8\text{TeV}$ JHEP 09 (2018) 159

- Combined cross sections from all channel via BLUE(best linear unbiased estimator), taken in to account uncertainties correlation:

$$\sigma_{pp\to Z\to\tau^+\tau^-} = 95.8 \pm 2.1 \pm 4.6 \pm 0.2 \pm 1.1\text{pb}$$
$$(2.0 < \eta < 4.5, p_T > 20\text{GeV})$$



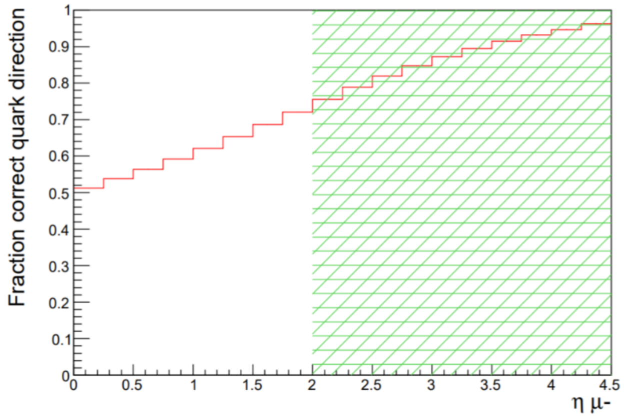

- Lepton universality:

  - $$\frac{\sigma^{8\text{TeV}}_{pp\to Z\to\tau^+\tau^-}}{\sigma^{8\text{TeV}}_{pp\to Z\to\mu^+\mu^-}} = 1.01 \pm 0.05$$

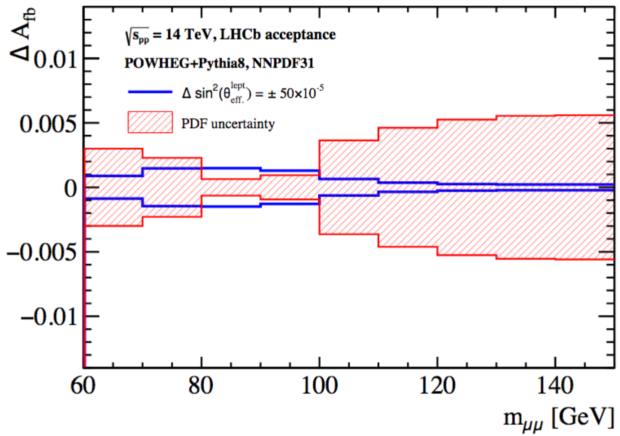
  - $$\frac{\sigma^{8\text{TeV}}_{pp\to Z\to\tau^+\tau^-}}{\sigma^{8\text{TeV}}_{pp\to Z\to e^+e^-}} = 1.02 \pm 0.06$$

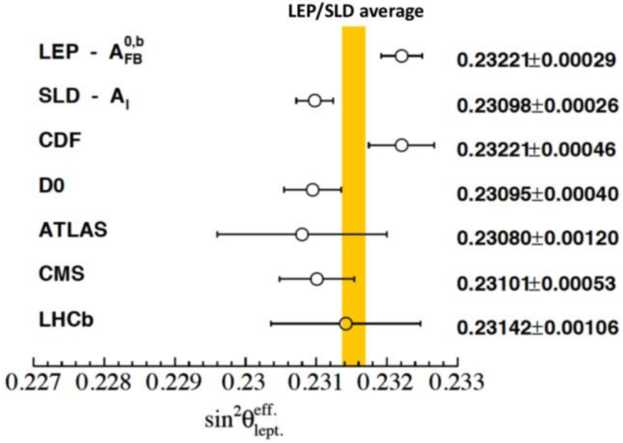
# Weak mixing angular measurement – why LHCb

- Key parameter in Electroweak sector of the Standard Model
- LHCb has the potential to make the most sensitive measurement of the weak mixing angle at the LHC
  - Forward-backward asymmetry increases (and sensitivity to Weinberg angle increases) as rapidity of Z boson increases
  - The dilution effect (the possibility of wrong direction determination) decreases in **high *y***



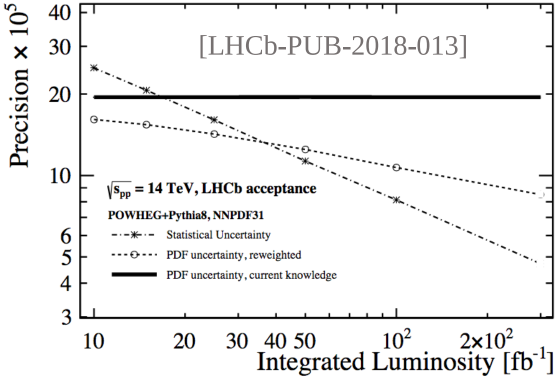

[LHCb-PUB-2018-013]



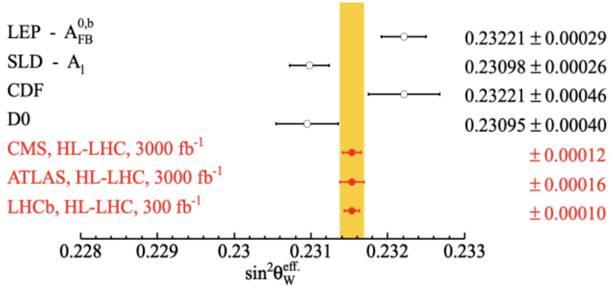



# Weak mixing angular measurement – LHCb future

- With sufficient control of other sources of uncertainty, a measurement at LHCb using the full dataset (300 $\mathrm{fb}^{-1}$), can be significantly more precise that the combination of measurements at LEP and SLD ($5 \times 10^{-6}$)
  - Statistics uncertainty: is expected to be roughly $\mathbf{5 \times 10^{-5}}$
  - Systematic uncertainty: all of them are statistic limited in Run-I result, with the increase the statistics, it is expected to be decreased
  - PDF uncertainty: can be reduced to below $\mathbf{10 \times 10^{-5}}$ using the reweighting technique



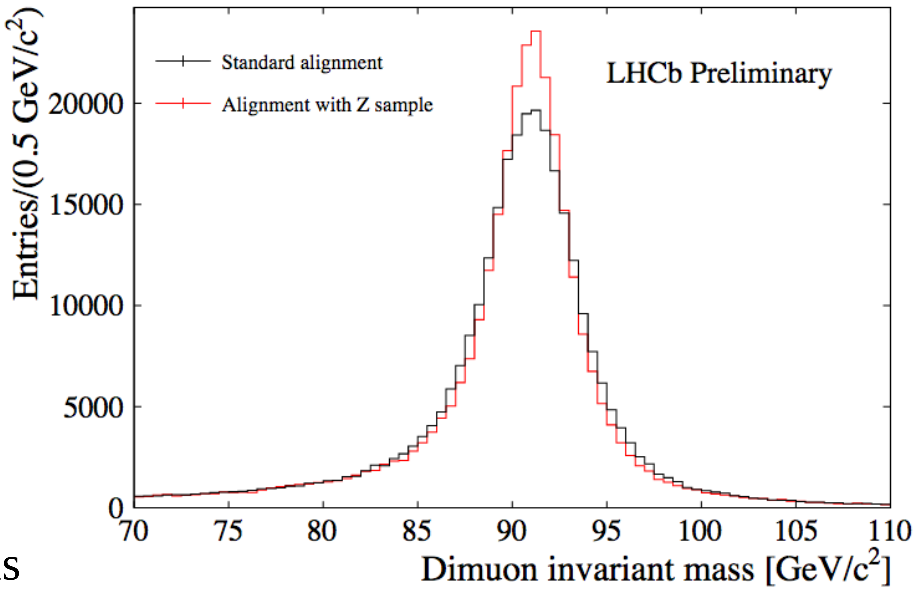

LHC Yellow Report [CERN-LPCC-2018-03]



# Weak mixing angular measurement – LHCb ongoing work

- Run-II analysis is in process
  - Weak mixing angle measurement
    - Full angular distribution of Z boson decays contains more information than forward-backward asymmetry
  - Z angular coefficient measurement($A_i$)

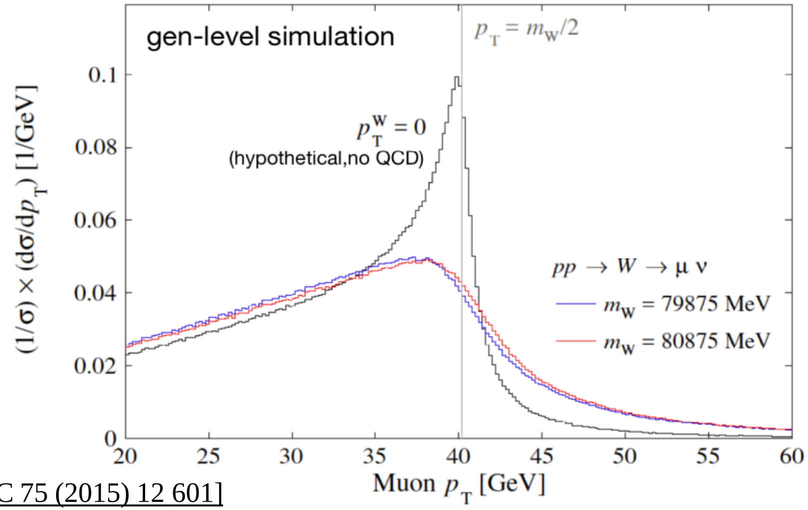
[LHCb-FIGURE-2020-009]




- An additional alignment performed offline
  - A **35%** improvement in the mass resolution is observed
  - Have a better understanding of the detector

# W mass measurement

- Motivation:
  - Electroweak fit predicts $m(W)$ with 7 MeV uncertainty, the best experiment uncertainties ~20MeV
  - The $p_T(\mu)$ distribution is strongly influenced by QCD, the details of which have long been considered a source of irreducible uncertainties in measurements by ATLAS and CMS alone
- Why LHCb?
  - LHCb Run-II data permit ~**10 MeV statistical precision**
  - Parton distribution function uncertainty would partially cancel in an average of LHCb with ATLAS+CMS
  - PDF uncertainties can be tightly constrained with a fit to the double differential distribution in $p_T$ and $\eta$
  - Possible to simultaneously constrain the W $p_T$ shape and fit the W mass, to mitigate the QCD uncertainties




[EPJC 75 (2015) 12 601]
[EPJC 79 (2019) 497]
[1907.09958 (2019)]

# Conclusion

- LHCb performed measurements of EW in the forward region of pp collisions, unexplored by other experiments
- Provide unique tests of the Standard Model and constraints to the PDFs
- A lot of works are in progress for new exciting measurements!