



# EW/QCD/Top Physics at LHCb

尹航

华中师范大学

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第6届LHCb前沿物理研讨会

# Outlines

- **Physics topics (focus on the LHCb-China contributions):**
  - Electroweak physics: precision W/Z mass
  - QCD physics: W boson cross-section, double parton scattering (DPS)
  - Top physics: cross section, charge asymmetry
- **Prospects**
- **Summary**

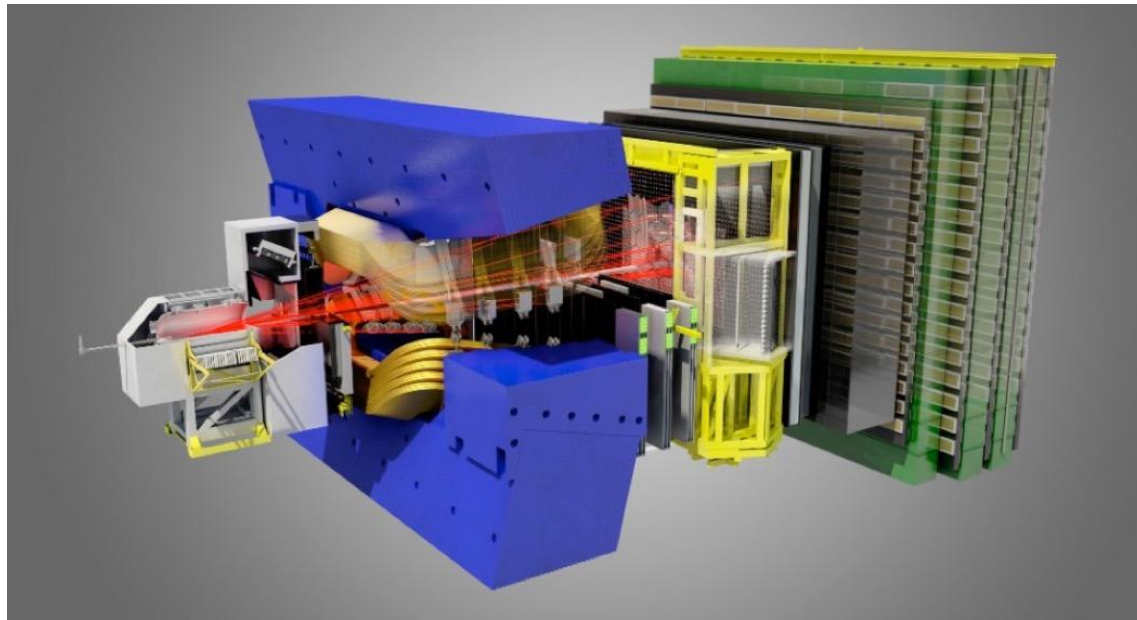
# Unique acceptance of LHCb

The  $x$  value of interacting partons is correlated with the boson rapidity

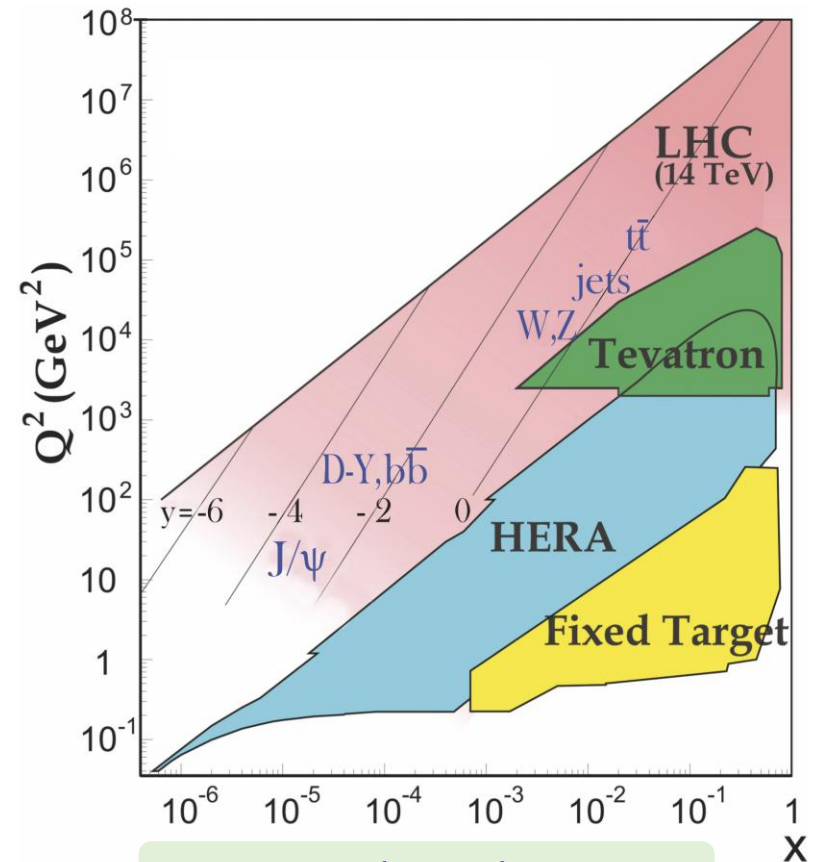
● Rapidity ( $y$ ):  $y = \frac{1}{2} \ln \frac{x_1}{x_2}$

Track momentum resolution: 0.5% at low momentum, 1% at 200 GeV

- Large rapidity: either very large  $x$  (up to 0.8) or very small  $x$  ( $5 \times 10^{-5}$ )



JINST 3 (2008) S08005



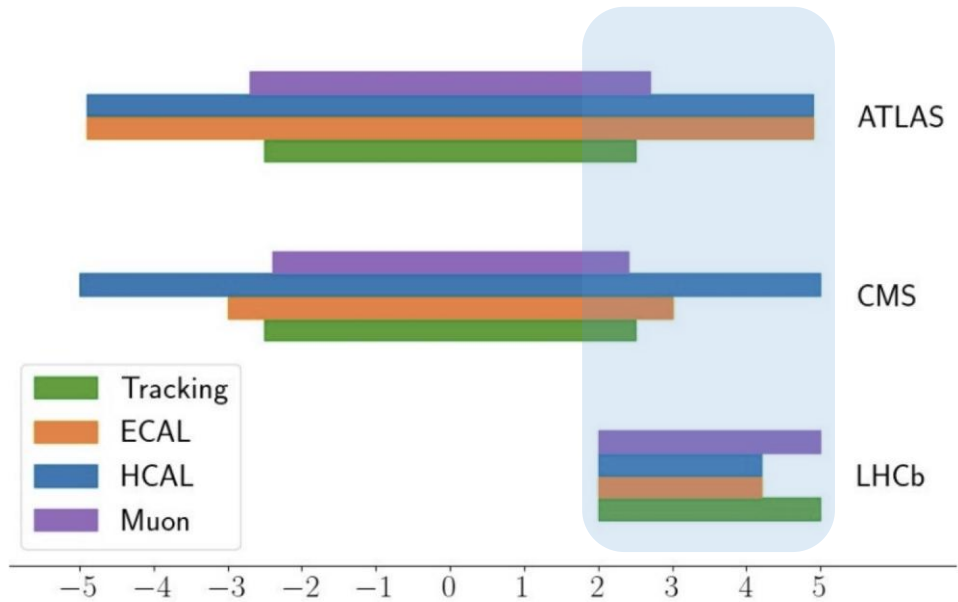
PRD 110, (2024) 030001

# Unique acceptance of LHCb

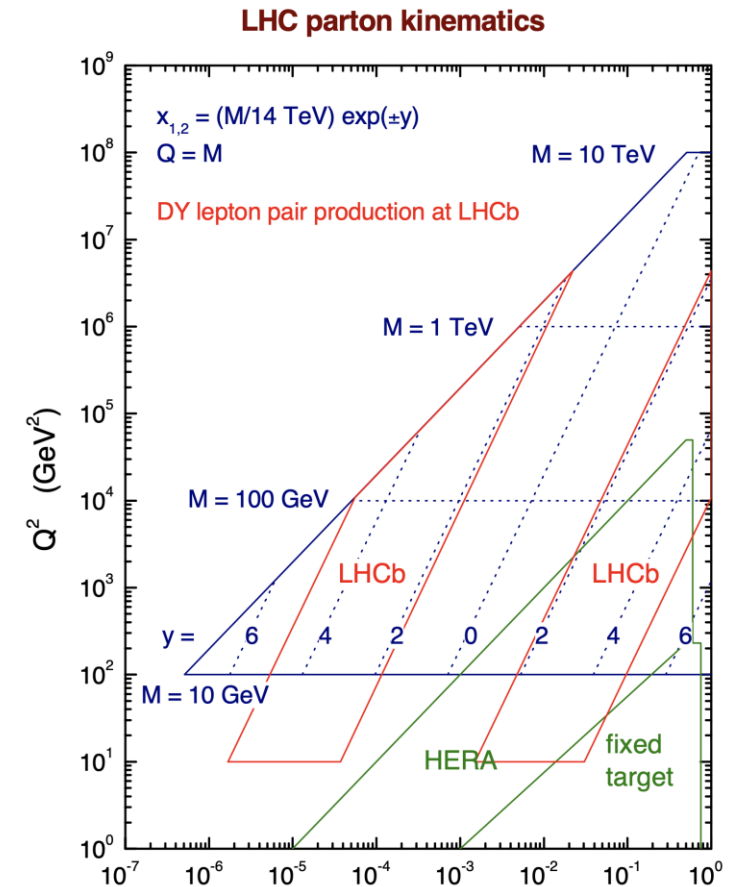
Forward acceptance!

The  $x$  value of interacting partons is correlated with the boson rapidity

- Rapidity ( $y$ ):  $y = \frac{1}{2} \ln \frac{x_1}{x_2}$
- Large rapidity: either very large  $x$  (up to 0.8) or very small  $x$  ( $5 \times 10^{-5}$ )
- ATLAS/CMS and LHCb: complementary to each other



EW Physics at LHCb



arXiv:0808.1847

# Z mass measurement

○ Fundamental parameters of SM electroweak sector

○ Couplings between **fermions** and **Z** boson: ( $V - A$ )

● Vector couplings:  $V = I_3 - 2Q \sin^2 \theta_W$

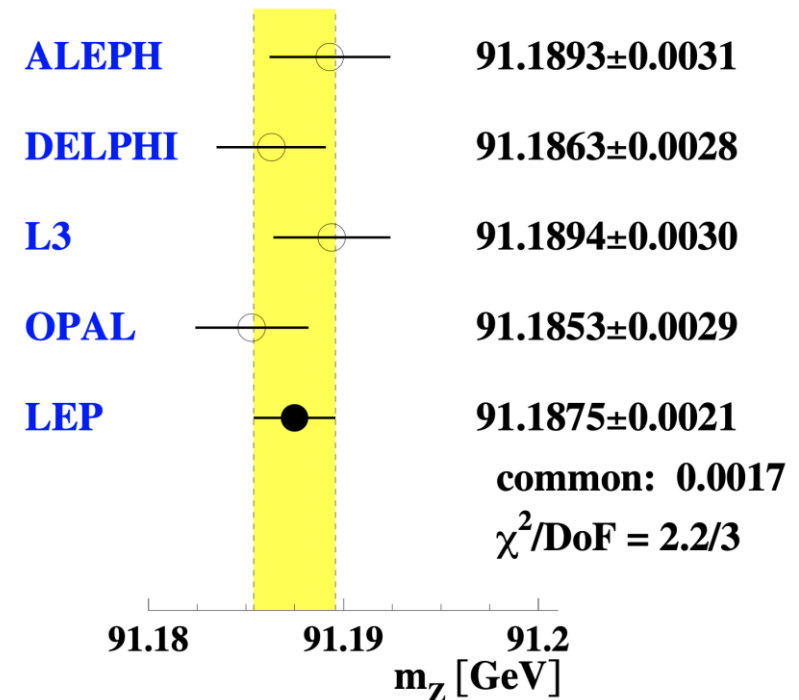
● Axial-vector coupling:  $A = I_3$

○ In the tree level,  $\sin^2 \theta_W = \left( 1 - \frac{m_W^2}{m_Z^2} \right)$

●  $\cos \theta_W = \frac{m_W}{m_Z}$

● How about a  $m_Z$  measurement at LHCb?

→ The measurements of  $m_W$  and  $\sin^2 \theta_W$  are published



Legacy measurement from LEP:  
Phys. Rept. 427 (2006) 257-454

# Z Mass: Results

PRL 135 (2025) 161802

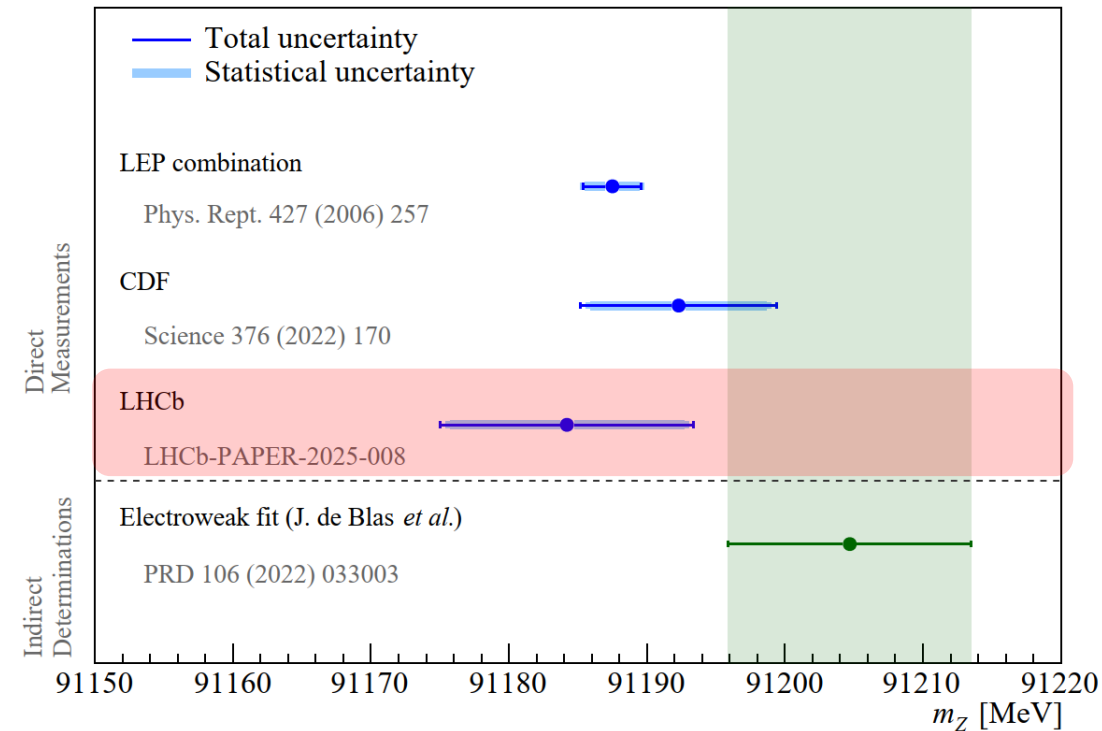
Source	Uncertainty [MeV]
Momentum calibration	4.1
Signal QED corrections	0.8
Parton distribution functions	0.7
Detection efficiency	0.1
Total systematic uncertainty	4.3

- First dedicated measurement of  $m_Z$  @LHC
- Reached the **EW fit precision!**

$$m_Z = 91184.2 \pm 8.5 \pm 4.3 \text{ MeV}$$

2025/07/18

EW Physics at LHCb



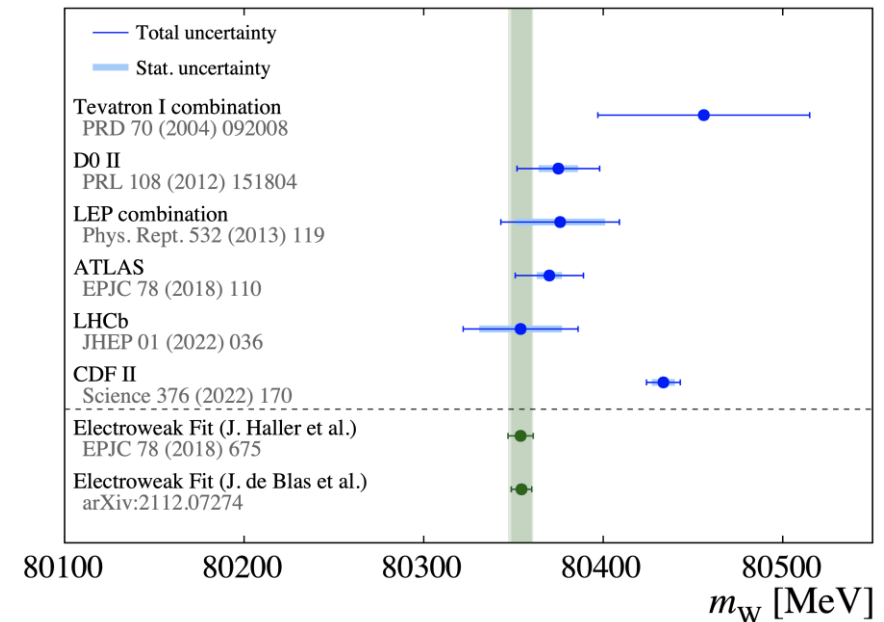
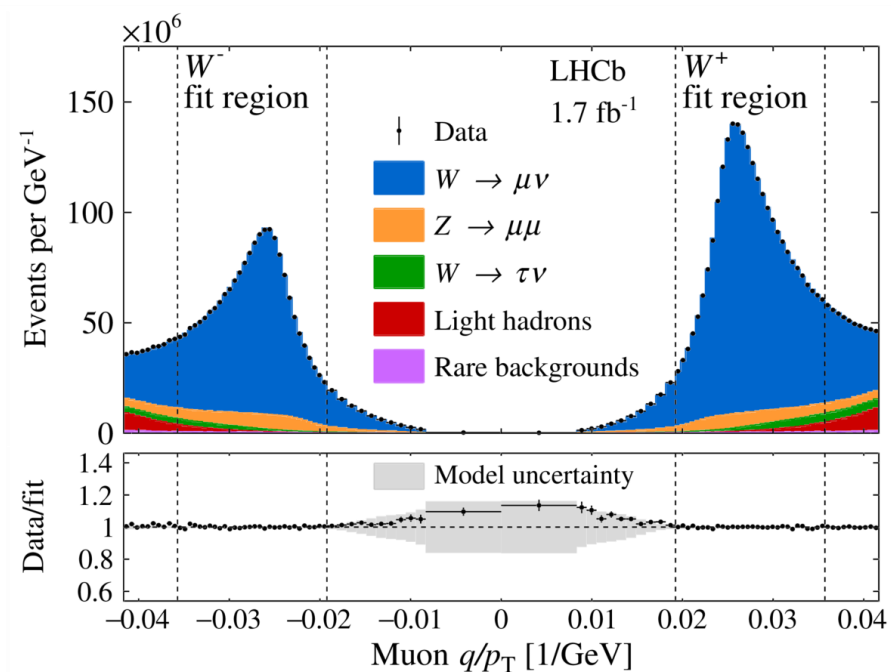
# W mass: LHCb

○ CDF (2022):  $m_W = 80433 \pm 9 \text{ MeV}$

○ LHCb (2022):

●  $m_W = 80354 \pm 23(\text{stat.}) \pm 10(\text{exp.}) \pm 17(\text{theory}) \pm 9(\text{PDF})$

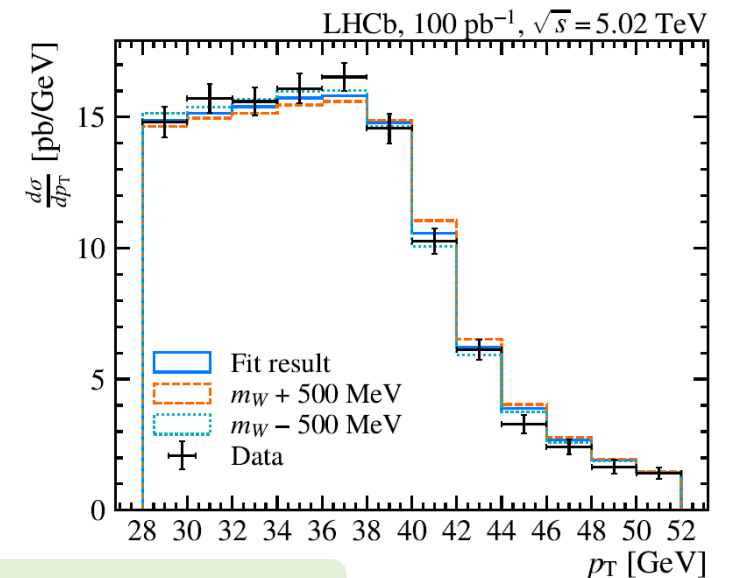
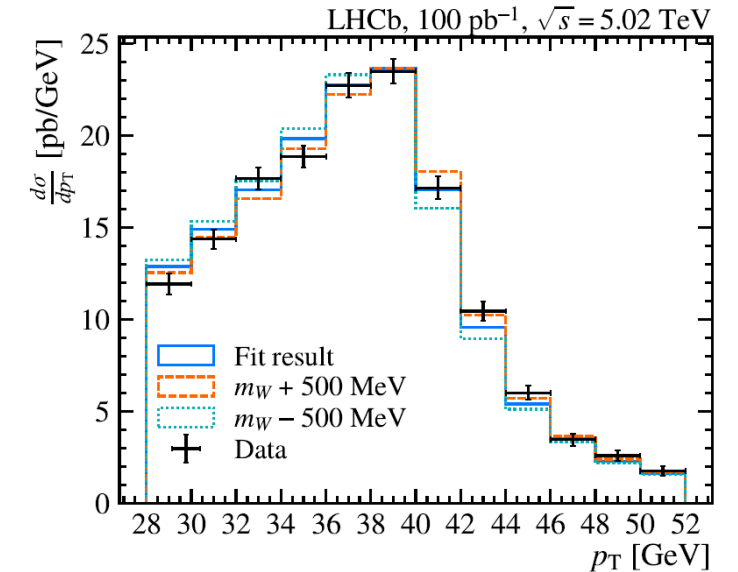
Science 376 (2022) no.6589, 170-176



JHEP 01 (2022) 036

# W mass: new strategy

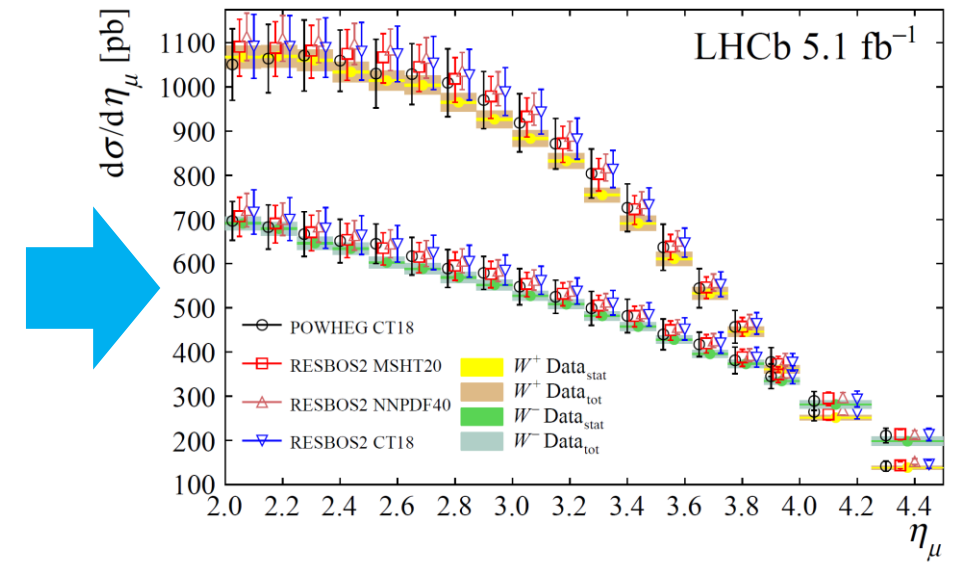
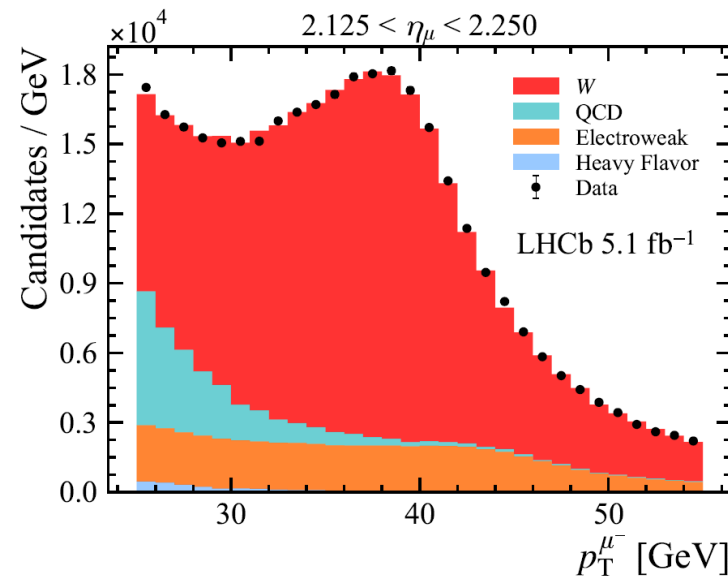
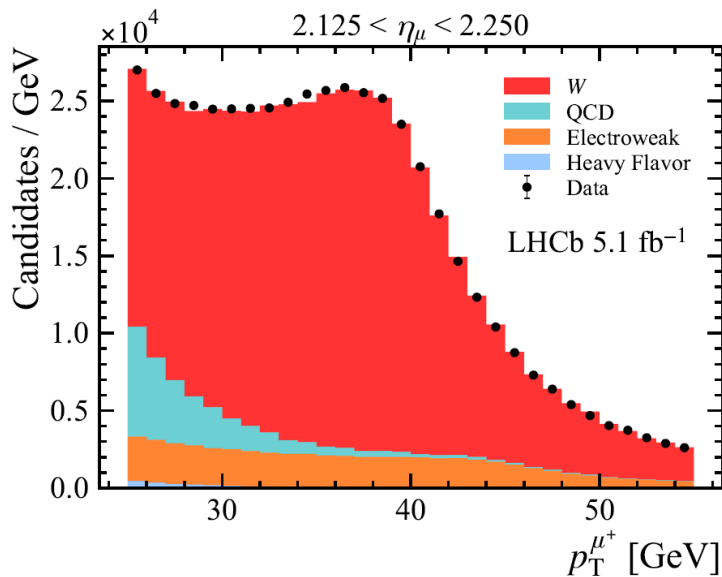
- Different generators were used in experiments
  - Including ResBos, DYTurbo, Powheg ...
- New approach:
  - Differential cross section: removal of detector effects
  - Perform  $m_W$  fit with any of generators
- Proof of principle: 5 TeV  $pp$  dataset ( $100 \text{ pb}^{-1}$ )
  - $m_W = 80369 \pm 130 \pm 33 \text{ MeV}$
- Full Run-2 analysis underway: within 2 years



# W boson cross section

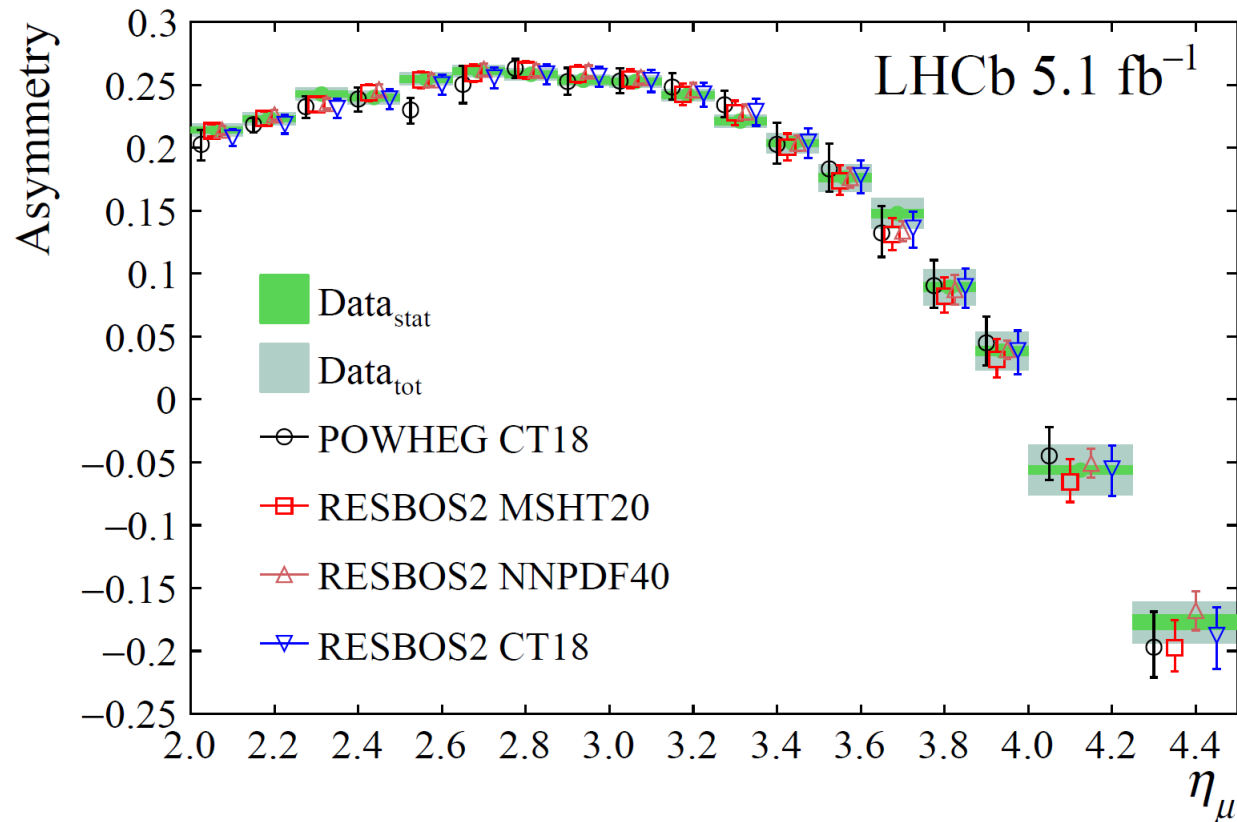
- Full Run-2 analysis: a very challenging measurement
- Unique acceptance range: the very forward region
  - Wide Bjorken- $x$  range:  $10^{-4} - 10^{-1}$
  - Small- $x$  and large- $x$

arXiv:2604.12706  
Submitted to PRD



# W boson charge asymmetry

- Most precise determination of W boson charge asymmetry in the forward region



arXiv:2604.12593  
Submitted to PRL

# Z + J/ψ: DPS measurement

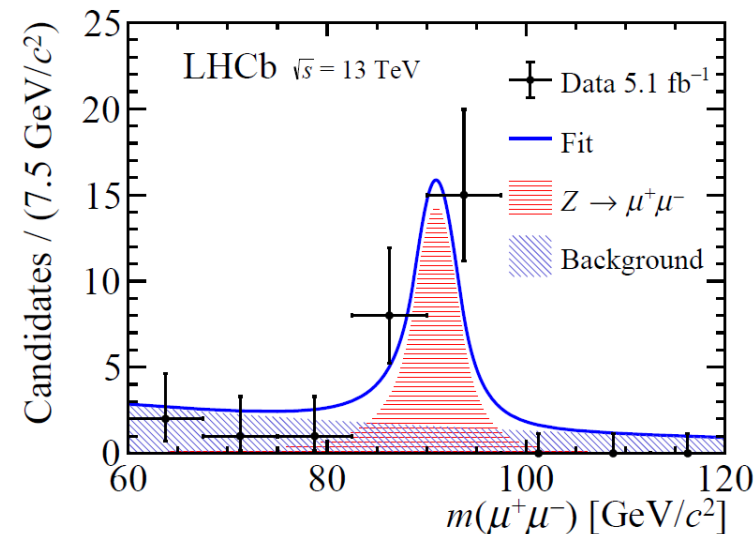
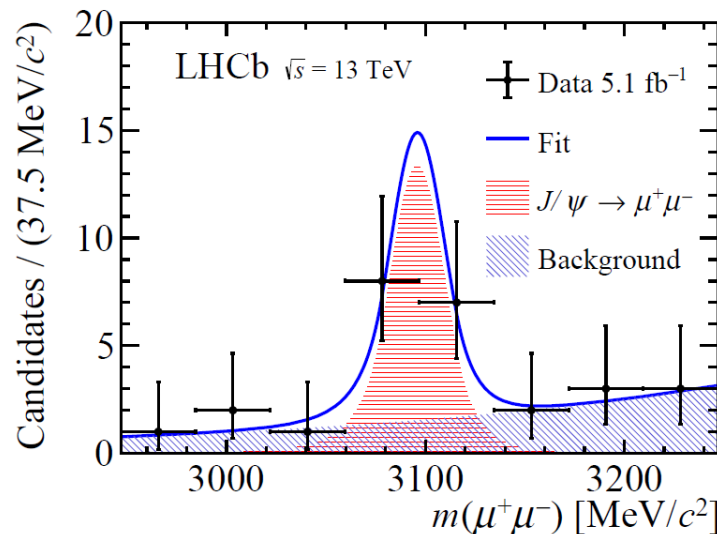
LHCb-Paper-2025-054  
To be Submitted to PRL

## ○ DPS (double parton scattering):

- Two independent hard partonic interaction in a single pp collision
- Transverse structure of the proton

## ○ Effective cross-section:

- $\sigma_{eff} = 16.55 \pm 4.4 \pm 1.52 \text{ mb}$



# Top physics

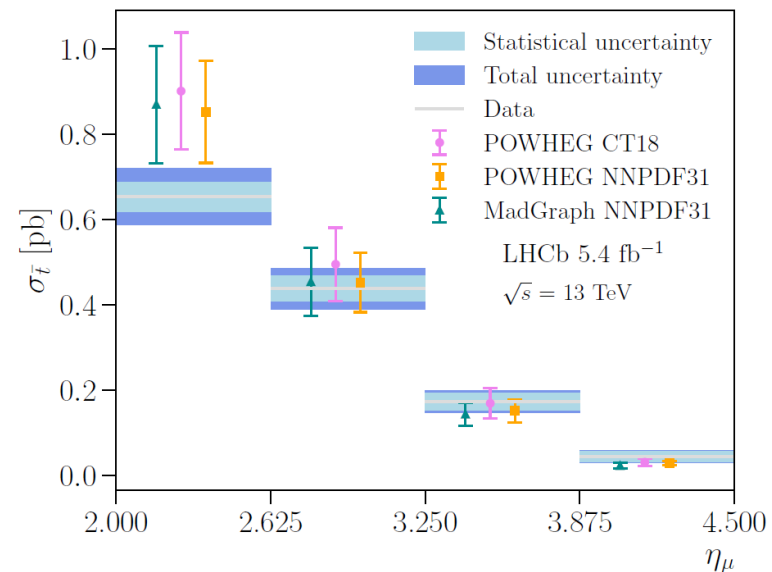
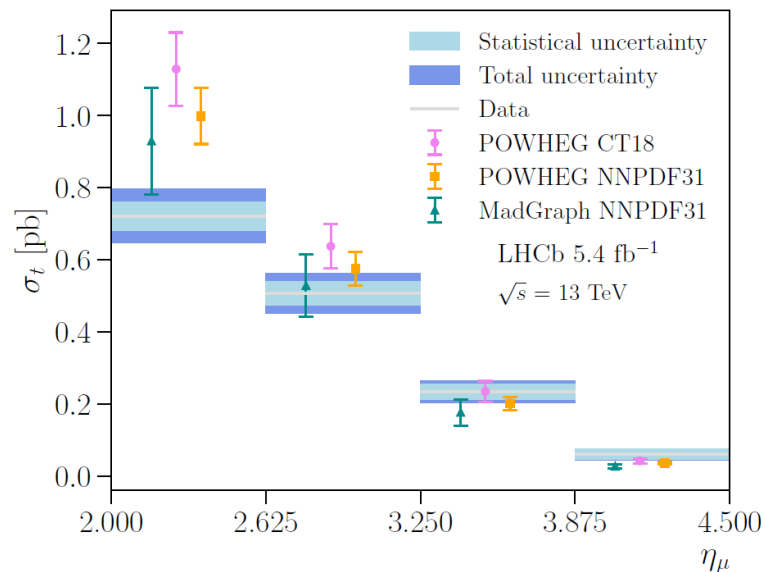
arXiv:2512.11324  
Accepted by PRL

## Recent resumption of top quark measurements at LHCb

- Unique acceptance region: enhanced  $q\bar{q}$  contribution relative to ATLAS/CMS
- High sensitivity to gluon PDFs in the high Bjorken- $x$  region

## Inclusive analysis strategy:

- $\mu + b$  channel using the full Run-2 analysis



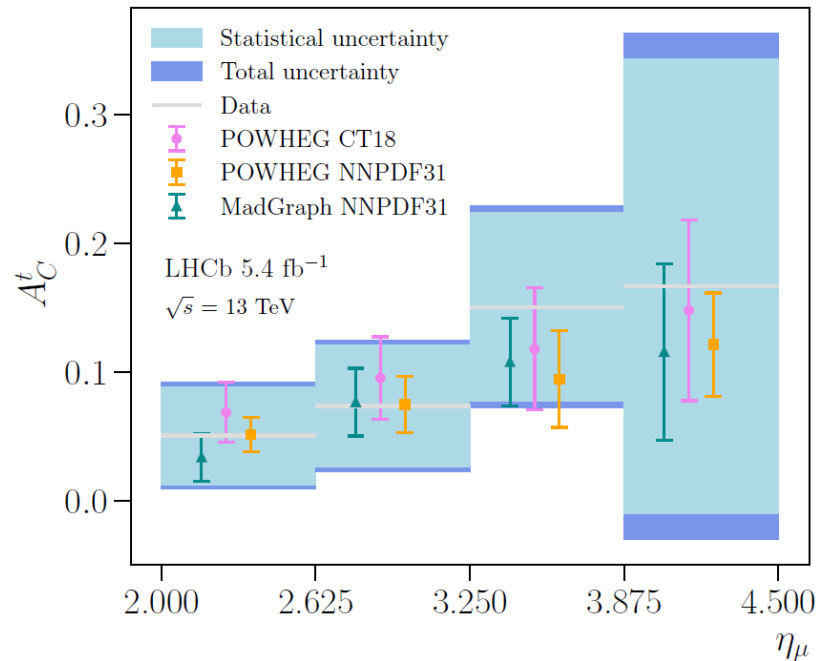
# Top charge asymmetry

arXiv:2512.11324  
Accepted by PRL

## ○ Top charge asymmetry:

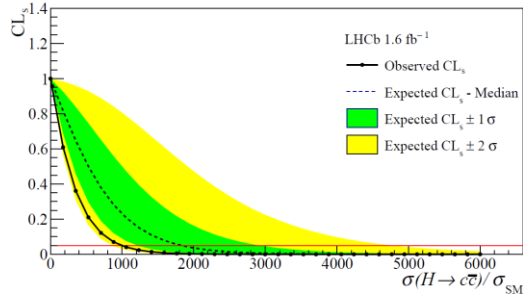
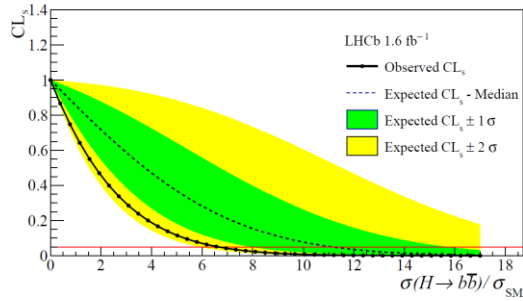
- NLO QCD effects: interference between initial- and final- state radiation, Born and box diagrams

## ○ Enhanced sensitivity in the forward region



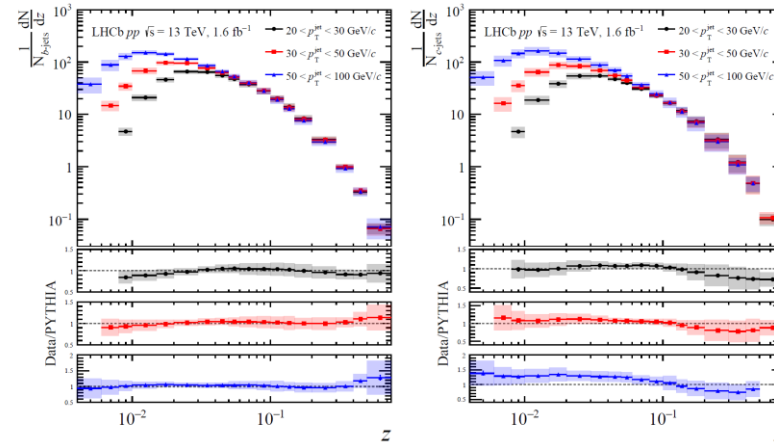
$\eta_\mu$ range	$A_C^t$	significance
2.000–2.625	$0.05 \pm 0.04 \pm 0.02$	1.22
2.625–3.250	$0.07 \pm 0.05 \pm 0.02$	1.44
3.250–3.875	$0.15 \pm 0.07 \pm 0.03$	1.91
3.875–4.500	$0.17 \pm 0.18 \pm 0.09$	0.85
2.0–4.5 (combined)	$0.08 \pm 0.03 \pm 0.01$	2.64

# Other jet related measurements



$H \rightarrow b\bar{b}, c\bar{c}$

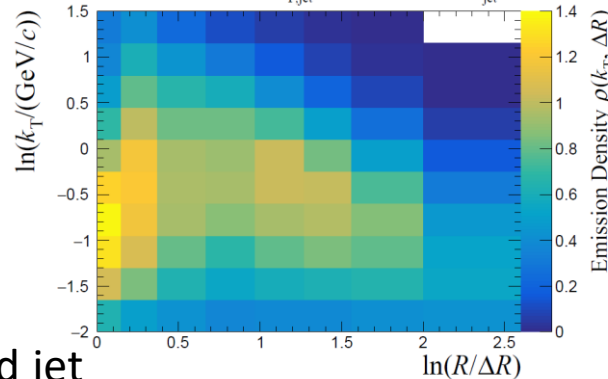
Submitted to JHEP  
arXiv:2601.16802



Charged hadrons in HF jet  
JHEP 04 (2026) 029

LHCb,  $pp \sqrt{s} = 13 \text{ TeV}$   
Z+jets

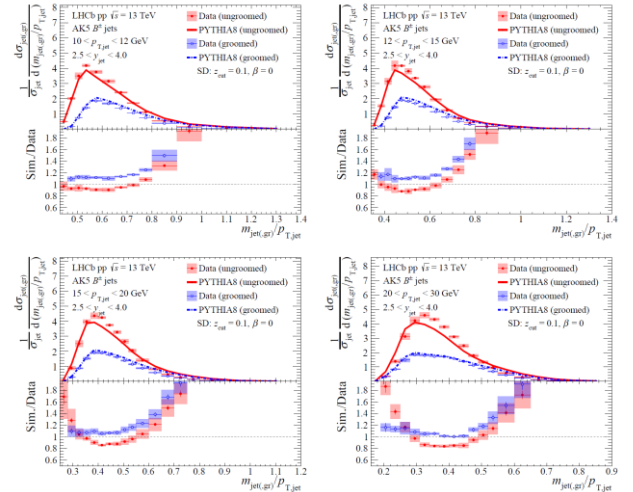
Anti- $k_T$  jets,  $R = 0.5, p_{T,jet} > 20 \text{ GeV}/c, 2.5 < y_{jet} < 4.0$



Lund jet

PRD 112 (2025) 072015

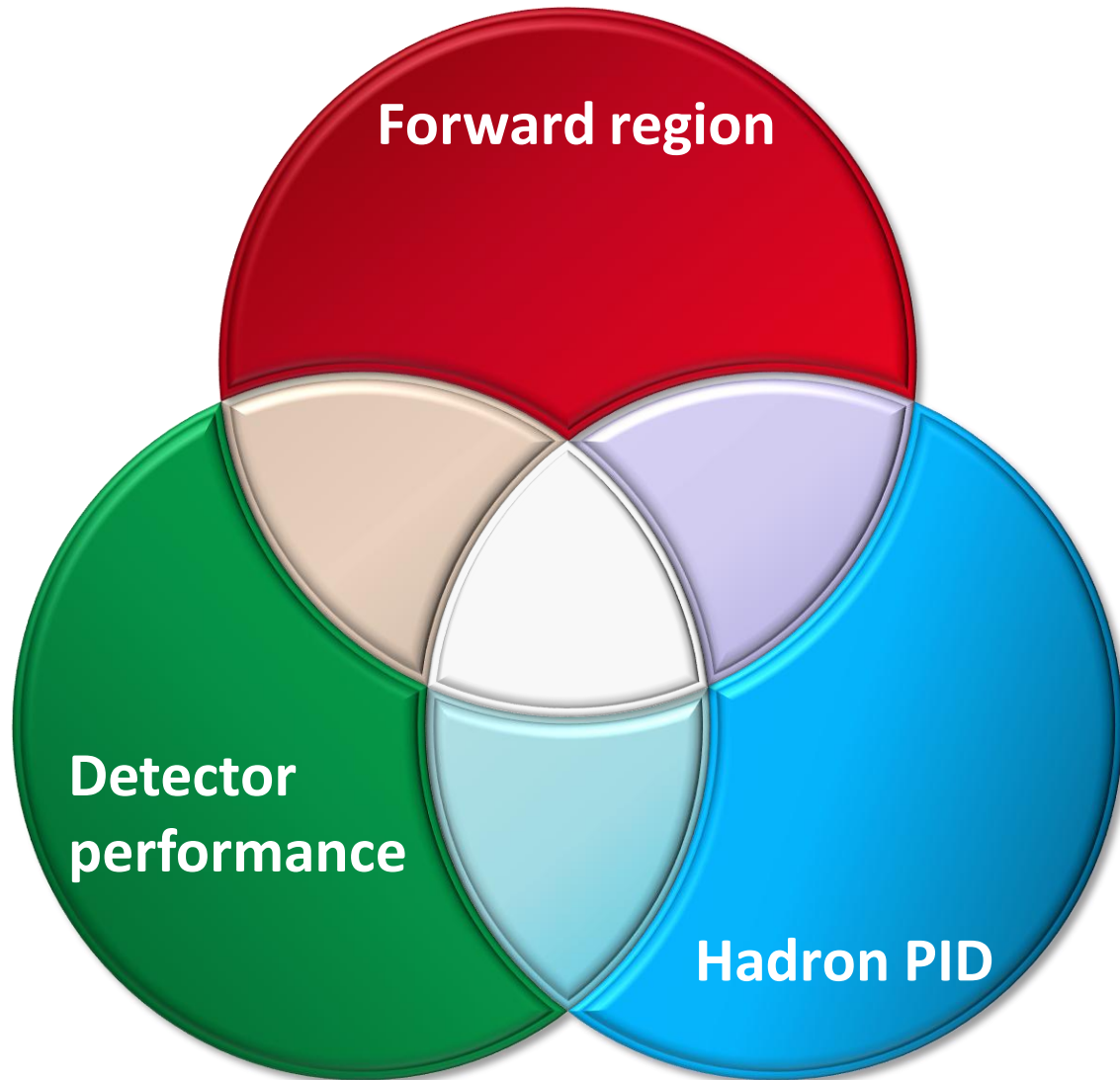
EW Physics at LHCb



B-jet mass

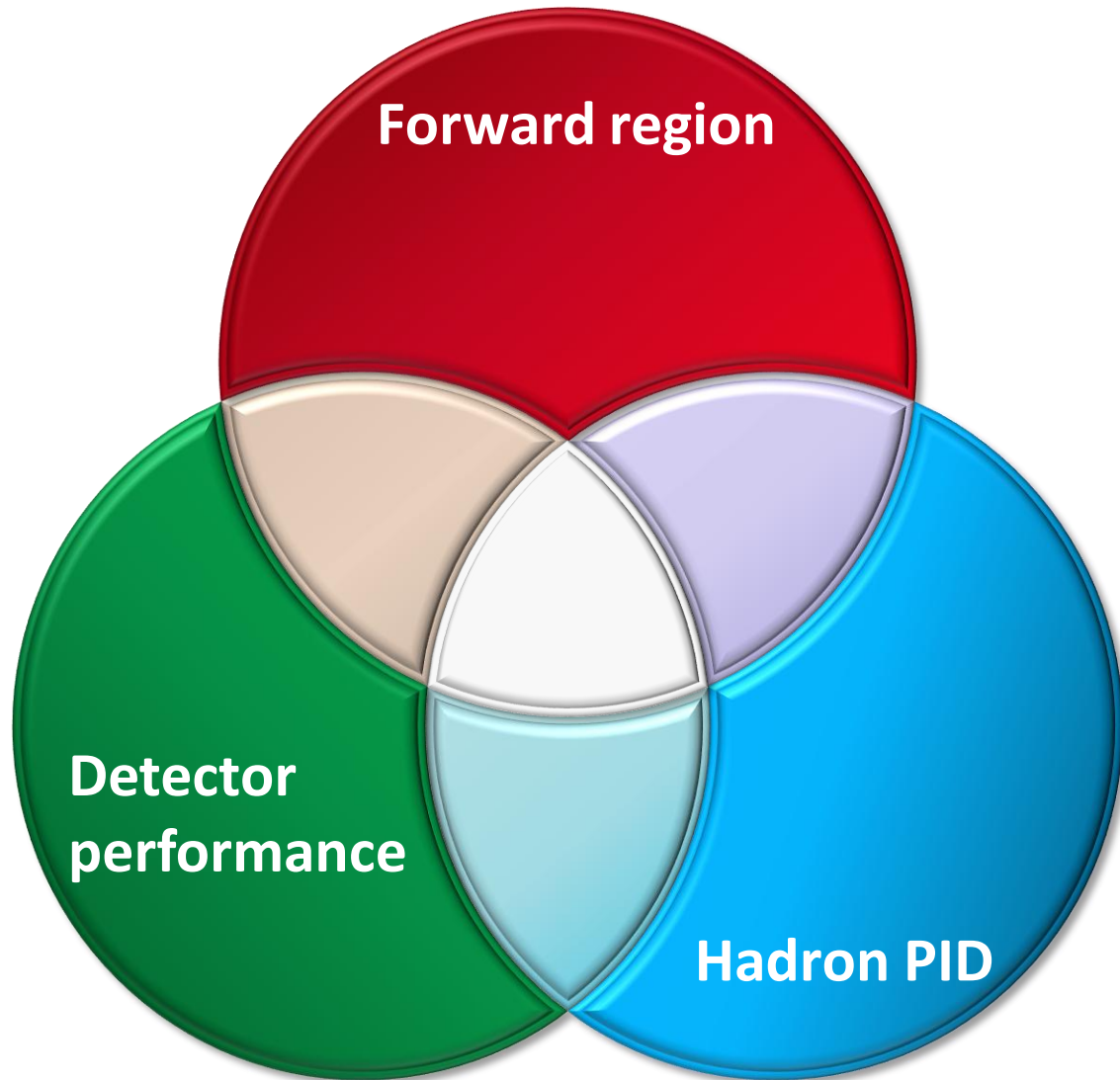
PLB 869 (2025) 139854

# Prospects: LHCb-China group



- **EW precision measurements:**
  - $W$  Xsec (5.02 TeV, 13 TeV, 13.6 TeV), leptonic  $WW, ZZ$  Xsec
  - Mass of  $W/Z$  boson,  $W$  helicity,  $Z$  angular coefficient (Run-1/Run-3)
- **$V$ +Jet measurements:**
  - $W/Z$ +Jet,  $W/Z + c$ ,  $W/Z + b$
  - Hadron in jets ( $\Lambda, K_S^0$  etc.)
- **Top physics :**
  - $e + \mu + b, \mu + b + jets$
  - Charge asymmetry, mass

# Prospects: LHCb-China group + theorists



- Higher order predictions
- Global fits of PDFs
- Implementation of LHCb results
- Brilliant ideas on novel observables

# Summary

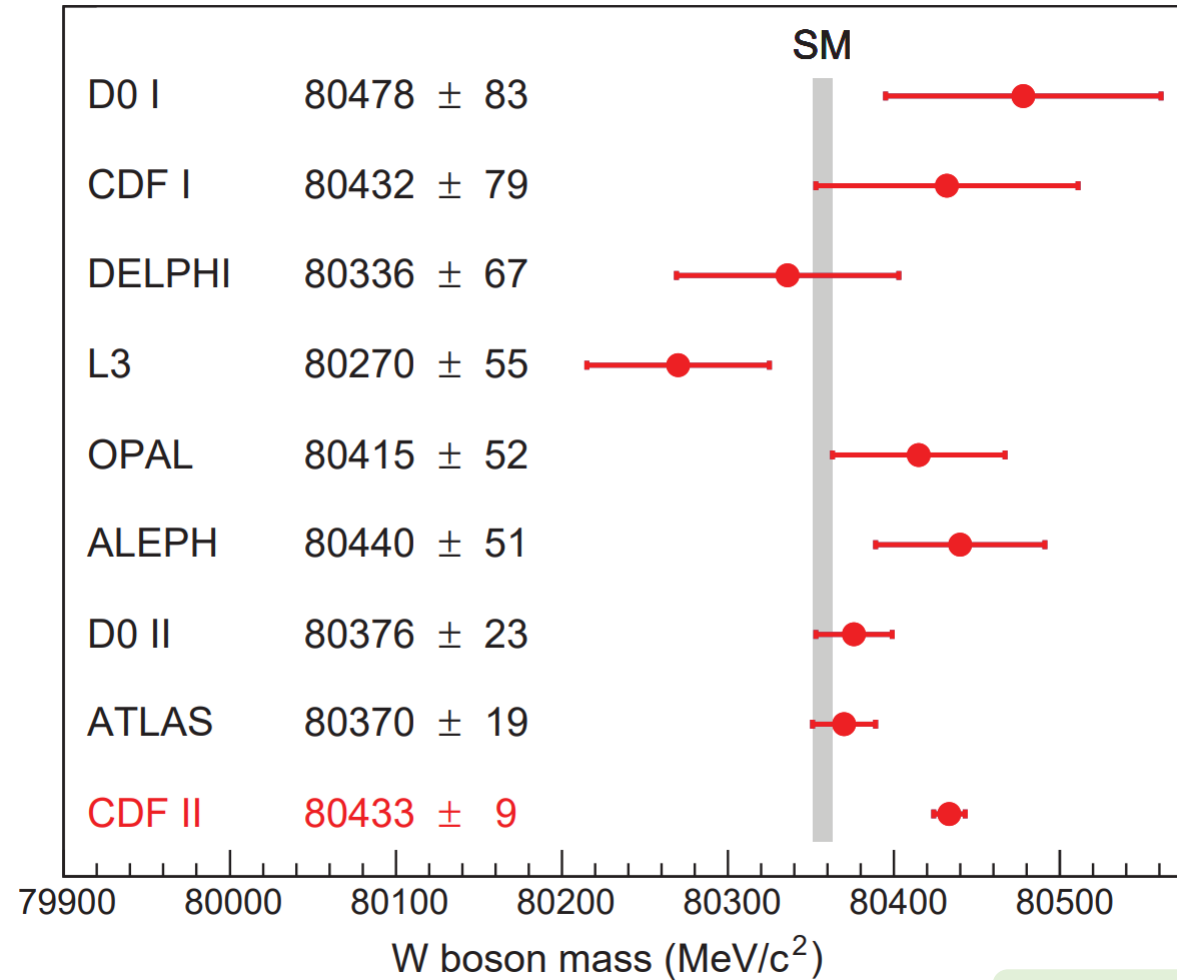
- **LHCb has an extensive program on EW/QCD/Top measurements**
  - Provide essential inputs for PDFs global fitting: **unique acceptance**
  - Precision measurements: **weak mixing angle,  $m_Z$ ,  $m_W$  ...**
- **At LHCb, EW-scale analyses activity is a **small group** with a **huge phase space** to cover**
  - Collaboration with theorists to make more impacts measurement with limited manpower
- **Run-3 data pp taking is done**
  - Much larger data-set, compared to Run-2

# Backup

# Prospects: $m_W$ measurement

- Including 2017+2018 data
  - Cross-check between years, polarities ...
- Goal: 20 MeV
  - Predicted statistical precision of 14 MeV
- Improvements on theoretical predictions
  - From POWHEG -> DYTurbo
  - New PDF sets
- Calibrations, momentu scale and efficiencies optimised
  - Pseudo mass method to curvature bias correction

# W mass measurement: CDF

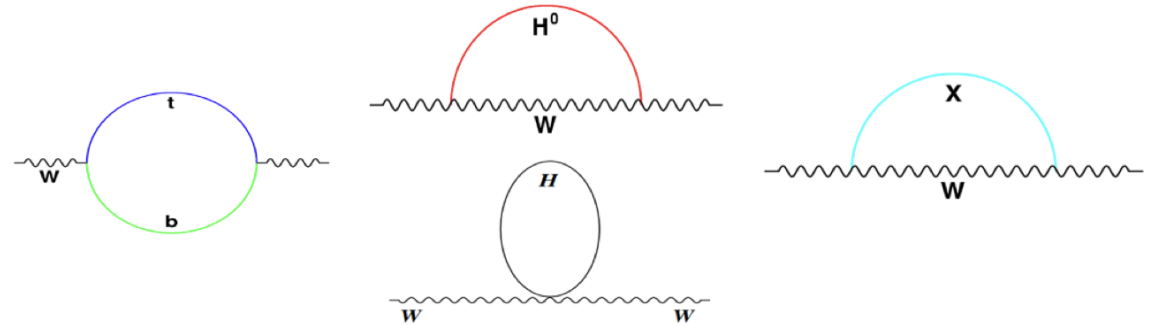


Science 376 (2022) no.6589, 170-176

# W mass measurement

- $m_W$  is related to other fundamental parameters in SM EW sector

$$m_W^2 \left( 1 - \frac{m_W^2}{m_Z^2} \right) = \frac{\pi\alpha}{\sqrt{2}G_F} (1 + \Delta)$$



- Radiative corrections dominated by top quark and Higgs loop, also can be affected by **new physics contributions**
- The LHCb measurement is complementary to the ATLAS and CMS results
  - PDFs uncertainty could partially cancel in the combination of LHC measurements

EPJC 75 (2015) 601

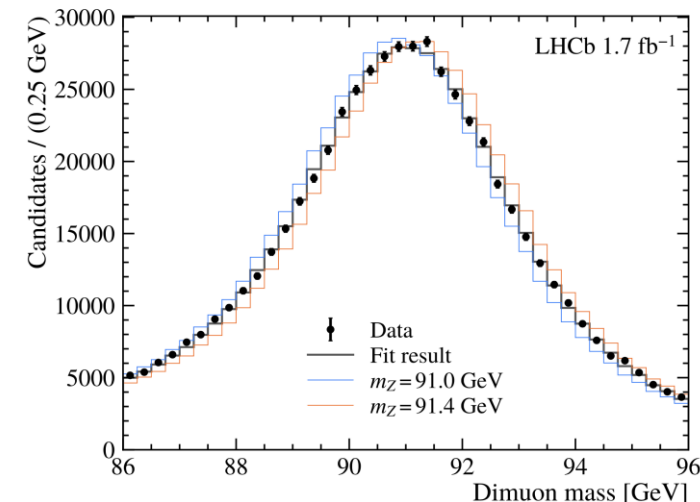
# The $m_Z$ measurement at LHCb

- Only using part of Run-2 dataset (2016)
  - Feasibility study
  - Same dataset used for  $m_W$  measurement
- Using  $Z \rightarrow \mu^+ \mu^-$  events
  - Narrow cut on  $\eta_\mu$ : 2.2 – 4.4
  - Selection cuts: similar cuts to weak mixing angle
  - 173k selected data
- Same analysis framework as  $m_W$ ,  $\sin^2 \theta_W^\ell$

# A challenging measurement at hadron collider

arXiv:2505.15582

- Pseudomass method to correct charge-dependent **curvature biases** in the data
  - Improves the  $Z$  mass resolution by  $\mathcal{O}(20\%)$
- **Time varying momentum** scale applied to data
  - Use  $\Upsilon(1S)$  to calibrate the momentum scale drift of  $\mathcal{O}(10^{-4})$
- **Direction dependent** momentum scale applied to MC
  - Use  $\Upsilon(1S)$  data and MC
- Momentum **smearing** to MC



# Generator used in $m_Z$ measurement

## ○ POWHEG-EWNLO

Eur. Phys. J. C 73 (2013) 6

- Includes QED predictions at NLO
- EW theory inputs scheme:  $(G_F, m_W, m_Z)$
- Samples generated with varying  $m_Z$

## ○ FSR:

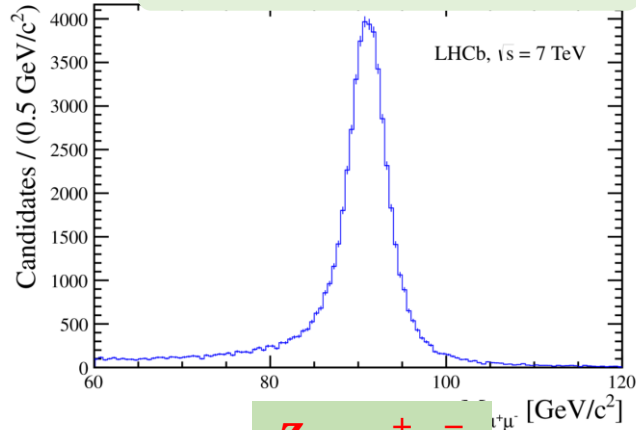
- The first photon emission is computed by POWHEG: ISR, FSR and their interference
- Additional FSR emission handled by PHOTOS: resummation of log-enhanced terms
- Uncertainty on  $m_Z$  **0.8 MeV**: alternative prescription with PYTHIA

## ○ PDFs:

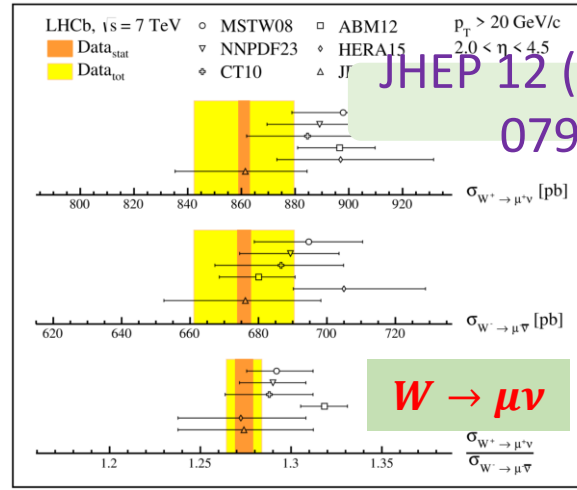
- Central fit from NNPDF3.1 NLO
- Choice of MSHT20NLO and CT19NLO: **0.7 MeV** uncertainty is assigned

# LHCb EW Highlights

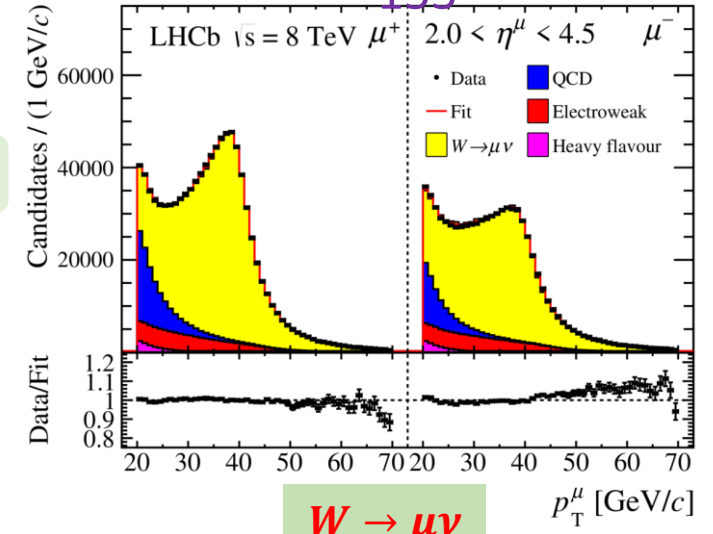
JHEP 08 (2015) 039



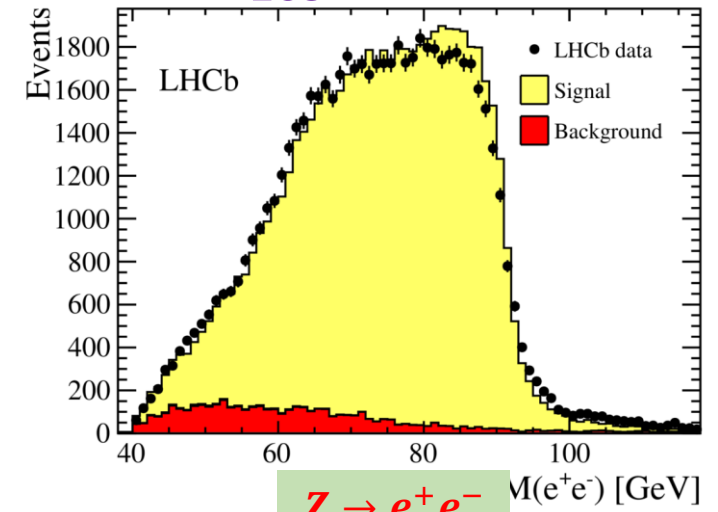
$Z \rightarrow \mu^+ \mu^-$



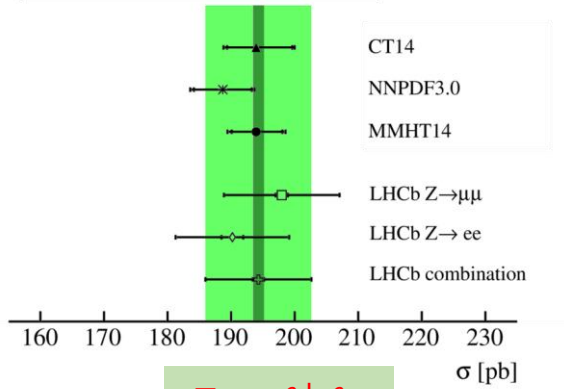
JHEP 01 (2016) 155



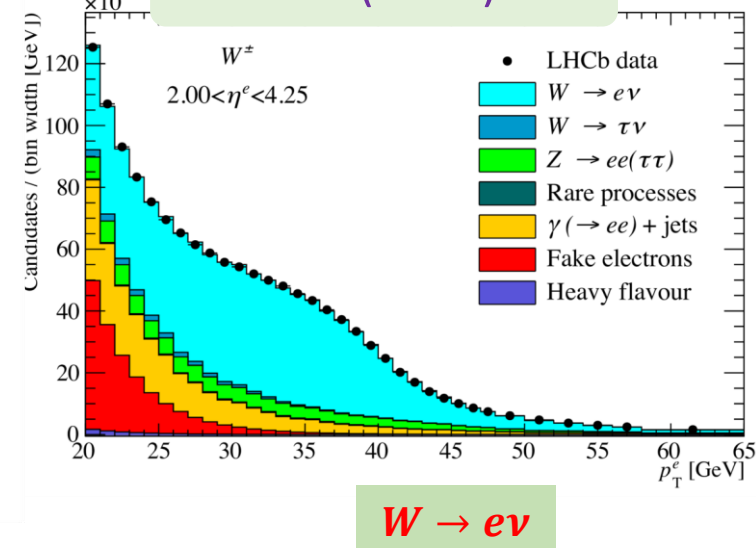
JHEP 05 (2015) 109



JHEP 09 (2016) 136

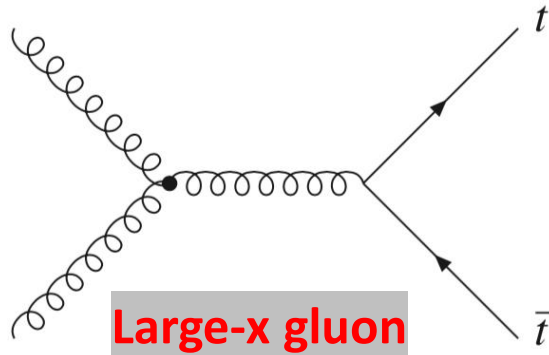


JHEP 10 (2016) 030

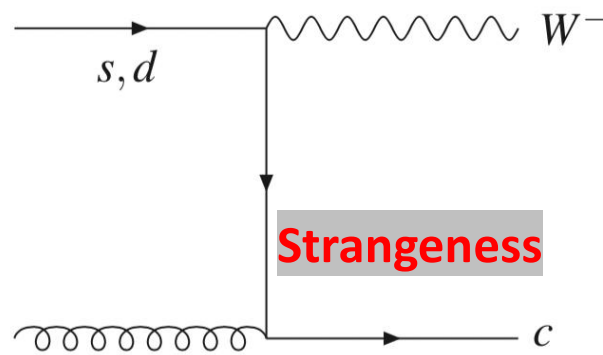


# LHC measurements

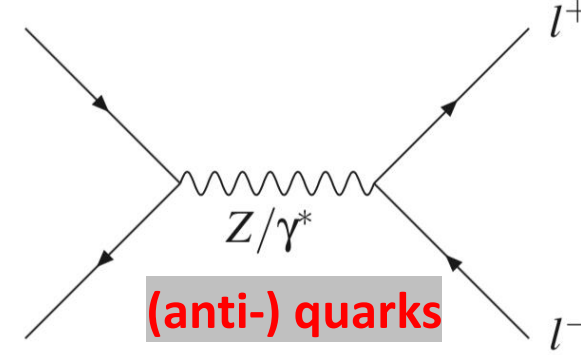
Top quark pair production



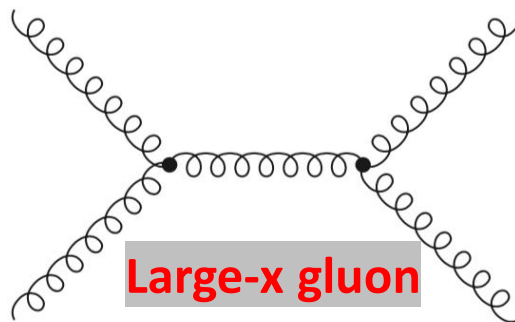
$W + c$  production



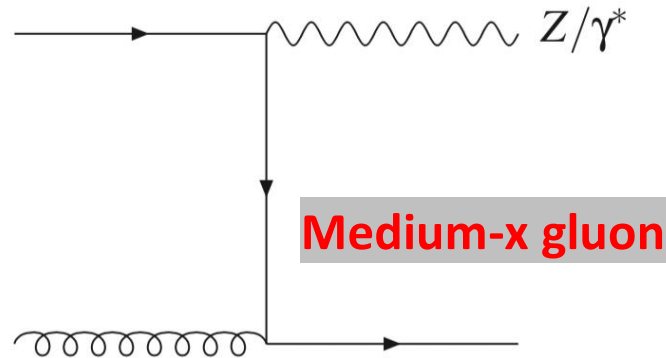
Drell–Yan production



Jet production



$Z p_T$



Direct photon production

