Towards a full Run 2 W mass measurement at LHCb

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European Research Council

Established by the European Commission

Recent evolution of the W mass measurement

The Electroweak theory

Main magnitudes ruling EW interactions
are related to each other:

Abdus Salam, Steven Weinberg and Sheldon Lee Glashow

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

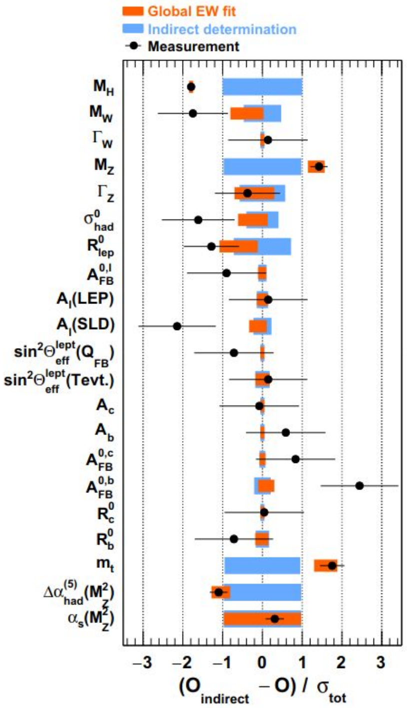
$$\Gamma_W \propto G_F m_W^3$$

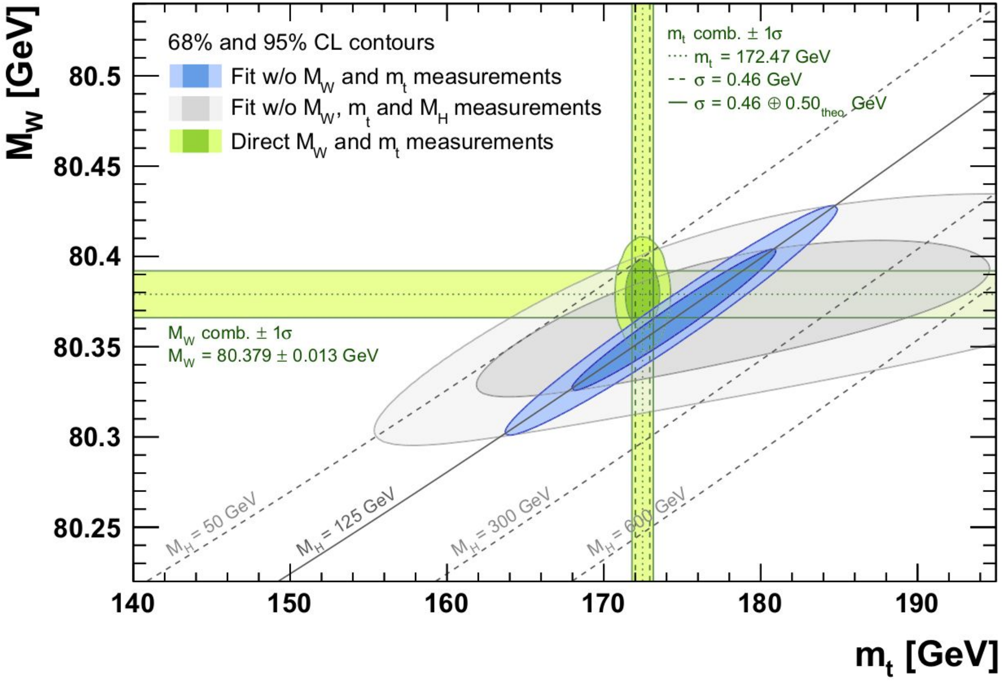
Higher order corrections

$$\sin^2\theta_W = 1 - \frac{m_W^2}{m_Z^2}$$

The global EW fit

Global fits to EW observables allow to test current (and new) theoretical model(s)

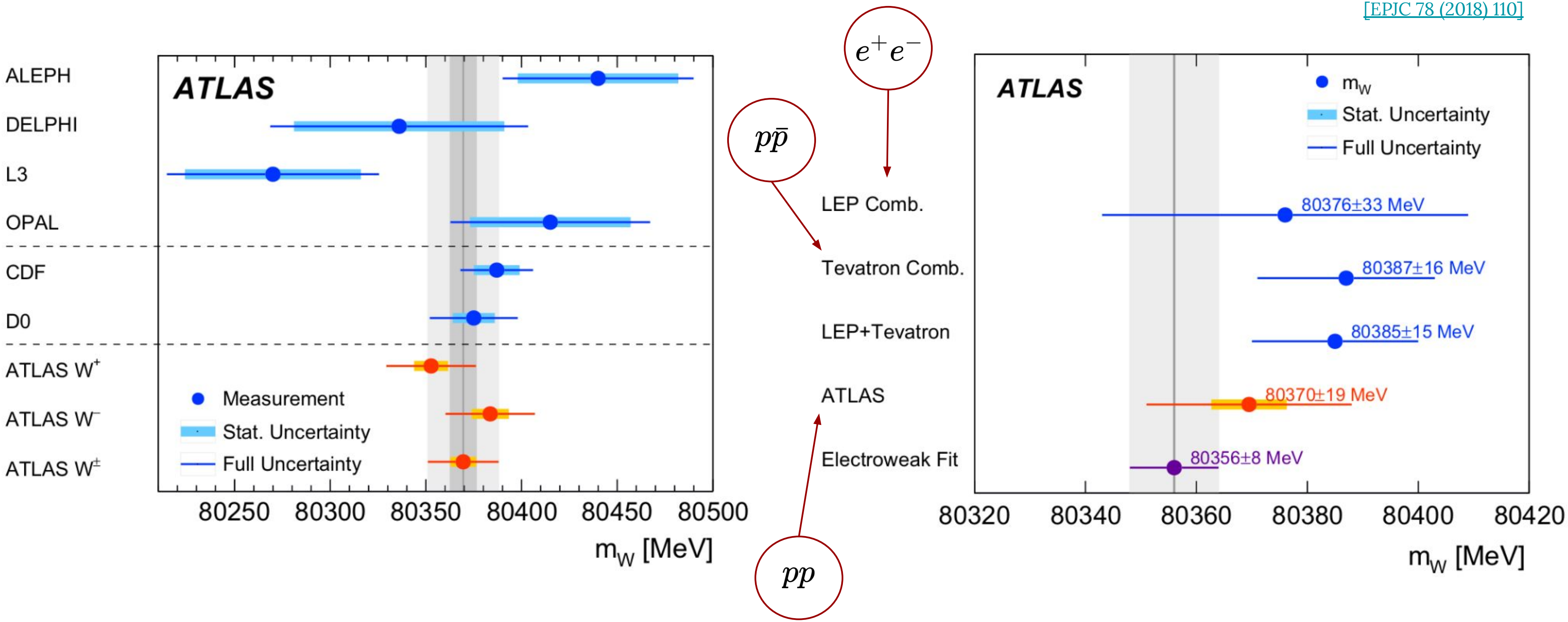




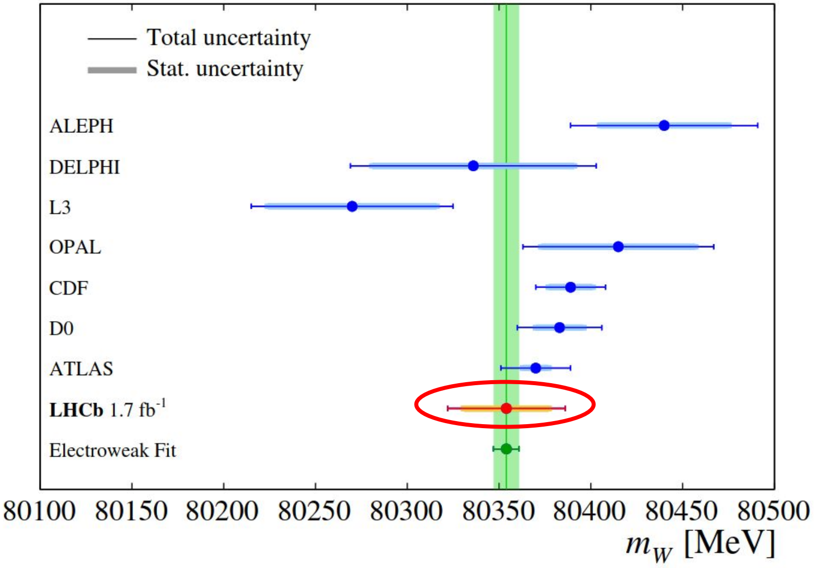
[EPJC 78, 675 (2018)]

Recent past of the W mass measurement (2018)

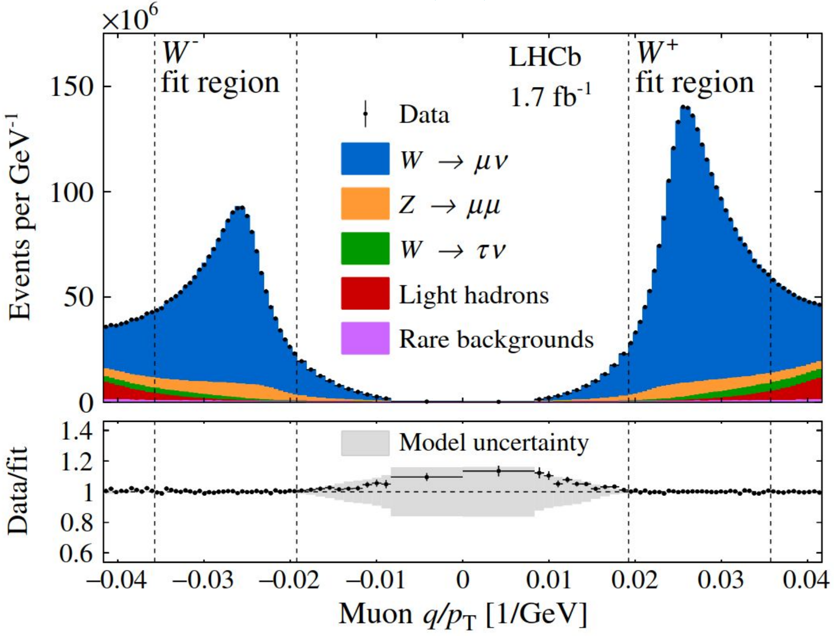
[EPJC 78 (2018) 110]



LHCb measures the W mass! (2022)



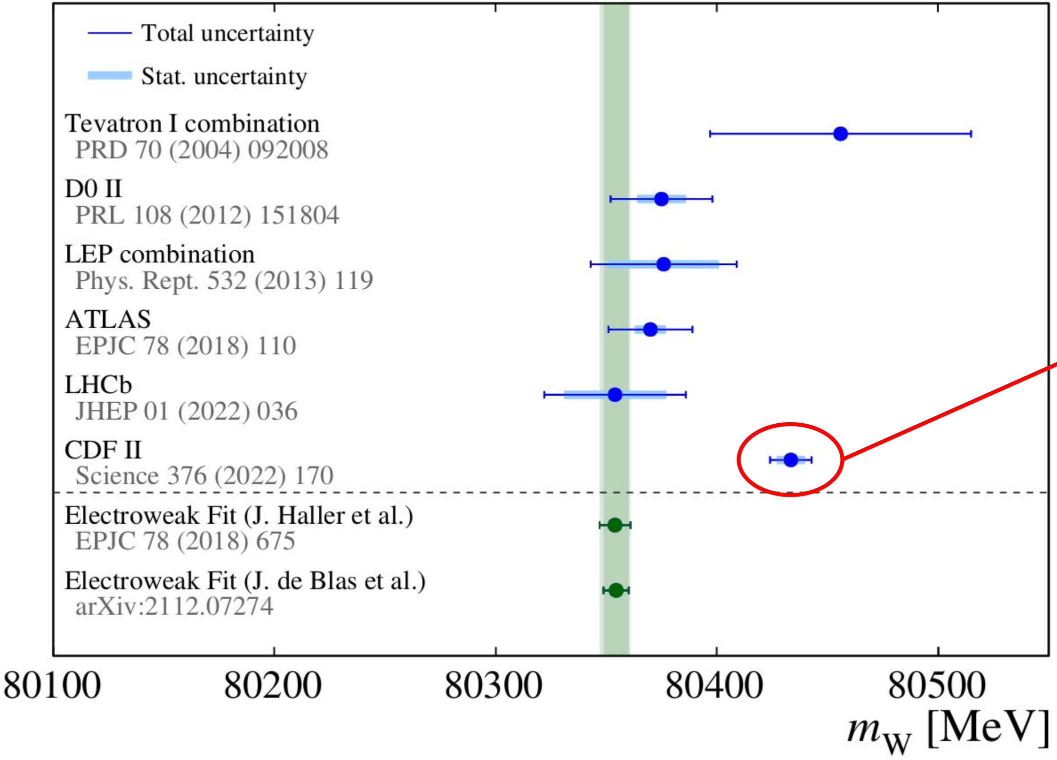
[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024]



$$\boxed{m_W = 80354 \pm 23_{\text{stat}} \pm 10_{\text{exp}} \pm 17_{\text{theory}} \pm 9_{\text{PDF}}\ \text{MeV}}$$

… and an elephant appeared in the room

[LHCB-FIGURE-2022-003]



7.2σ w.r.t SM

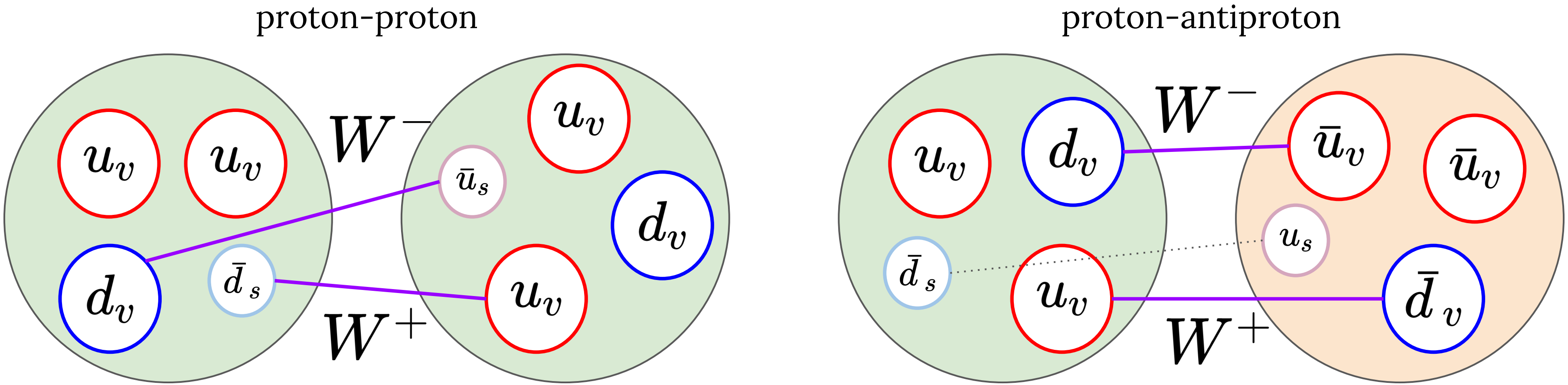
4σ w.r.t LHC + D0 II

3.5σ w.r.t LHC

Complete disagreement with the SM prediction and in tension with the other experiments

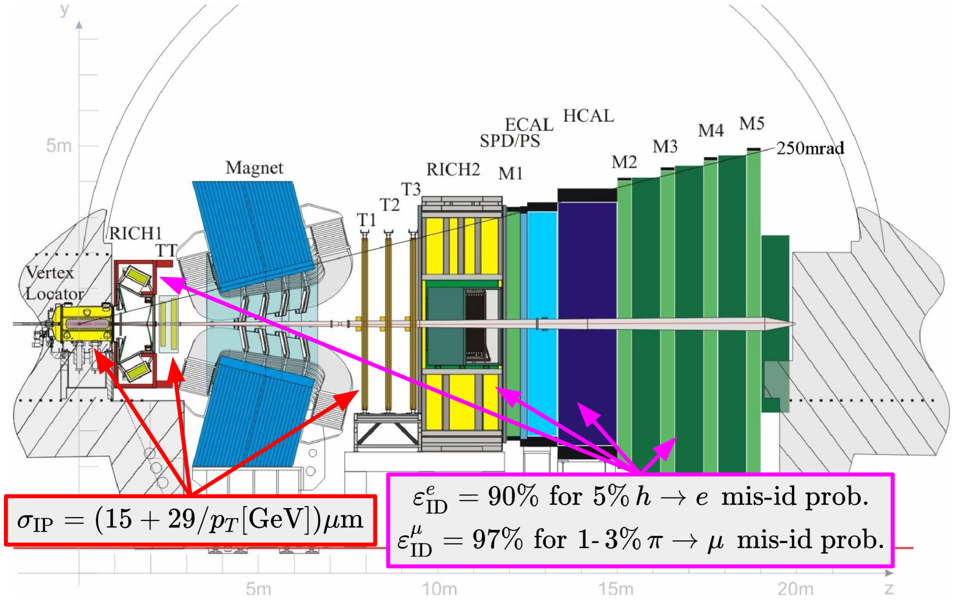
The W mass measurement at LHCb

Production mechanism



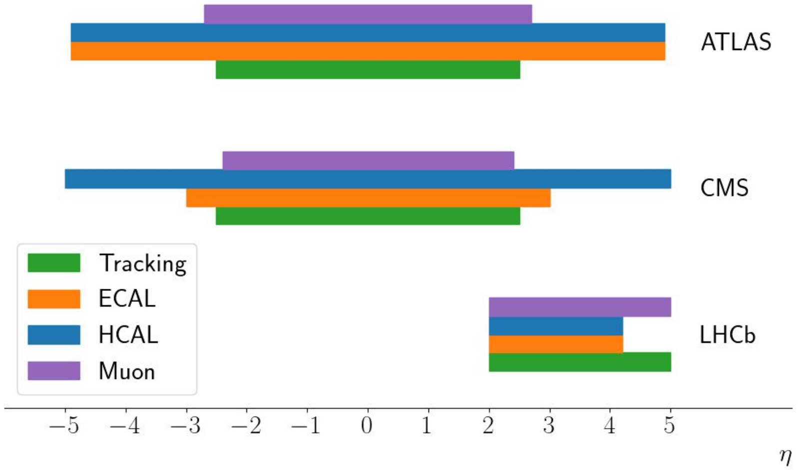
- A proton-proton collider is a challenging environment to measure the W mass:
  - W bosons are produced in a mixture of positive and negative helicity states
  - Must accurately describe the angular cross-section (larger uncertainties)
  - More backgrounds through heavy-flavour processes
- Profit from a higher total production cross-section and larger calibration samples

Related detector features



$\sigma_{\text{IP}} = (15 + 29/p_T[\text{GeV}])\mu\text{m}$

$\varepsilon^{e}_{\text{ID}} = 90\%$ for 5% $h \to e$ mis-id prob.
$\varepsilon^{\mu}_{\text{ID}} = 97\%$ for 1-3% $\pi \to \mu$ mis-id prob.

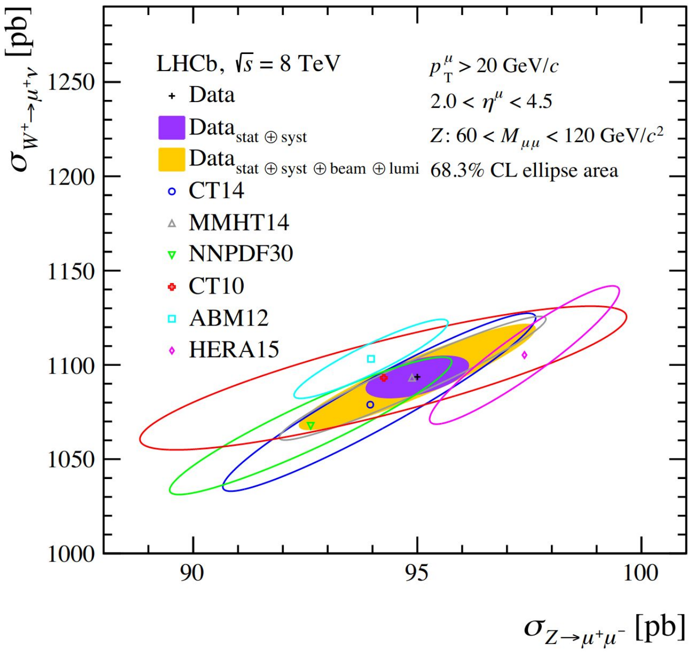


- Detector in the forward region with excellent momentum and vertex resolutions
- Coverage is complementary to ATLAS and CMS (with some overlapping at low pseudorapidity)

W and Z production at LHCb

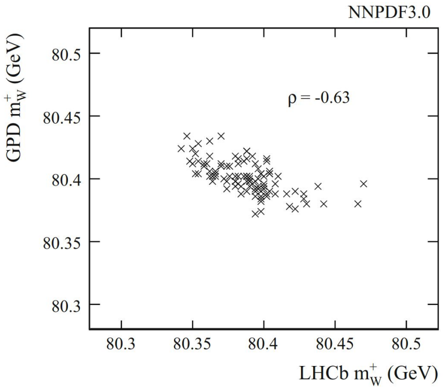
- Z decays constitute the most natural way of controlling muons from W decays and the production cross-section
    - Most of the W mass analyses rely on extrapolating the knowledge from the Z to the W
- Interesting anti-correlation of the PDF uncertainties at the LHC

[JHEP01(2016)155]



Up to a factor of 2 of reduced systematic uncertainty from PDFs

Eur. Phys. J. C 75, 601 (2015)



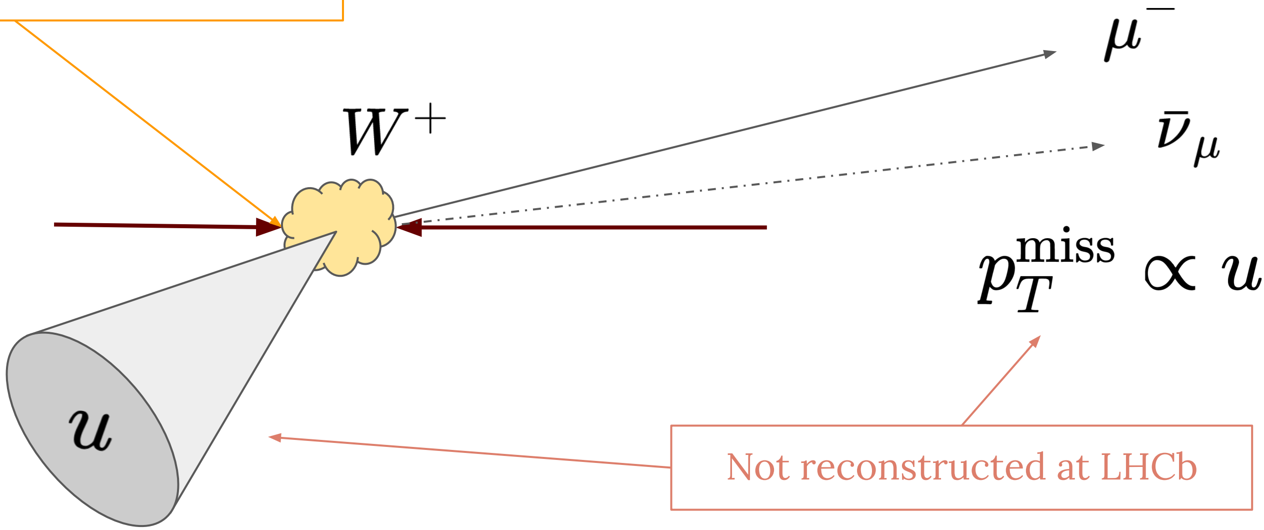
CMS & ATLAS

Single event signature

Precise modelling of the production of W bosons and backgrounds

Must carefully determine the momentum of the outgoing muon

$$p_T^{\mu} \sim \, m_W \times f(\theta, \phi) + p_T^{W} \times g(\theta, \phi)$$



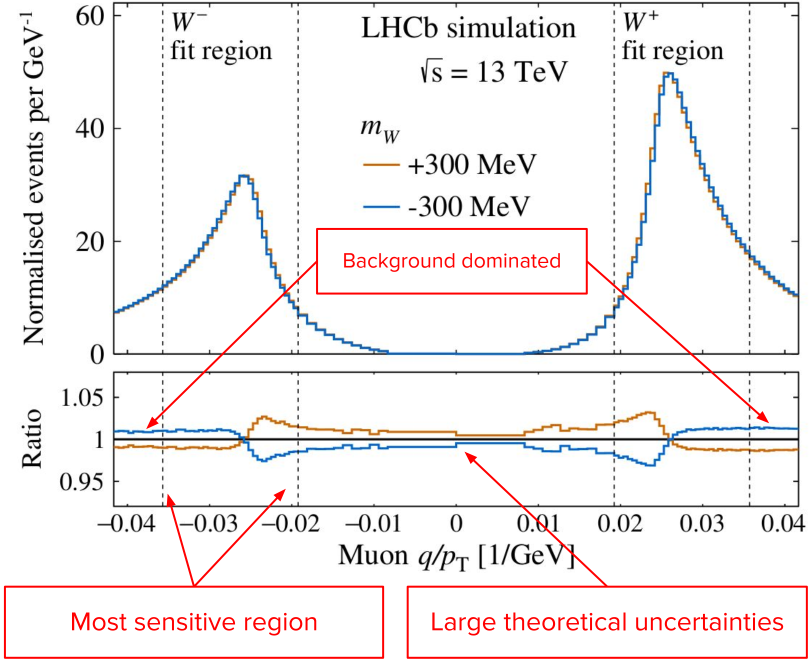
$$p_T^{\text{miss}} \propto u_T$$

Not reconstructed at LHCb

Analysis strategy

- Carefully measure the muon transverse momentum
- Use plain LHCb Pythia8 simulation and reweight using samples with generator-level information from different models
- Corrections due to the efficiencies of the different selection steps (reconstruction, trigger, topological, offline selection)
- Study and determine background from simulation (except for the contribution from hadrons originating decays-in-flight)
- To obtain the W mass we fit dynamically reweighted simulation histograms to the data with several floating nuisance parameters and the W mass

[JHEP 01 (2022) 036]



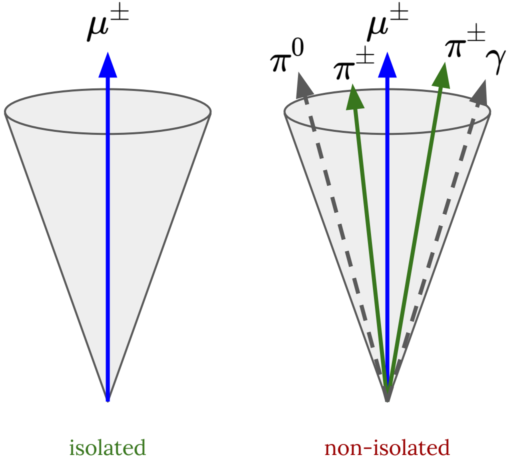
Background dominated

Most sensitive region

Large theoretical uncertainties

Selections

- EW physics with leptons in the final state can be studied at LHCb with simple selections based on the transverse momentum, impact parameter, isolation and particle identification
- Selection biases studied in data and simulation for Z and Υ(1S) decays (isolation biases only studied in the former)
  - Associated systematic uncertainties determined by varying the binning scheme, parametrizations and selections

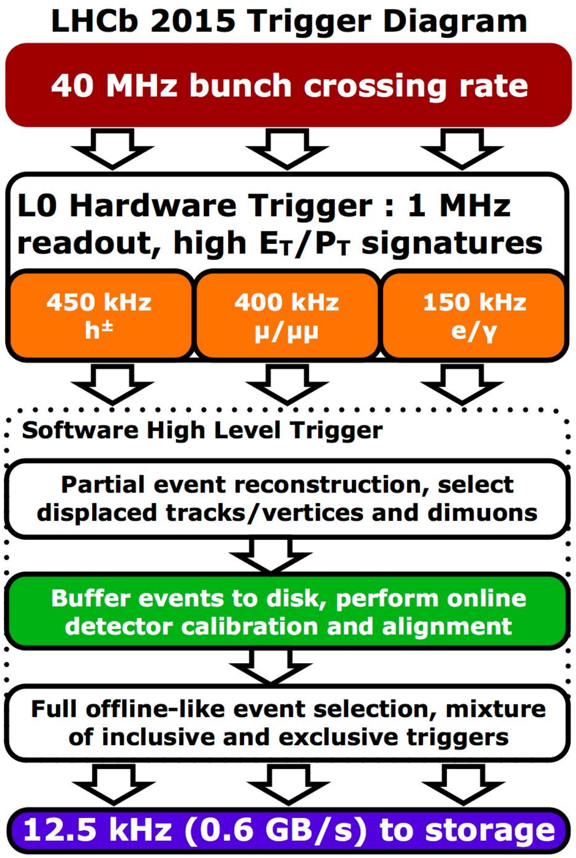


$$I = \sum_i^n p_T^i \in \mathrm{cone}$$

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2\left(\mathrm{rad}^{-2}\right)}$$

Detector alignment and calibration

- The LHCb trigger changed significantly for Run 2
- Real-time alignment and calibration can be optimized offline for EW studies
- Need to re-process the data using dedicated tools
- Apply corrections and smearing to simulation to account for subtle effects that significantly affect the momenta distributions


LHCb 2015 Trigger Diagram

40 MHz bunch crossing rate

L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures

450 kHz $h^{\pm}$

400 kHz $\mu/\mu\mu$

150 kHz e/γ

Software High Level Trigger

Partial event reconstruction, select displaced tracks/vertices and dimuons

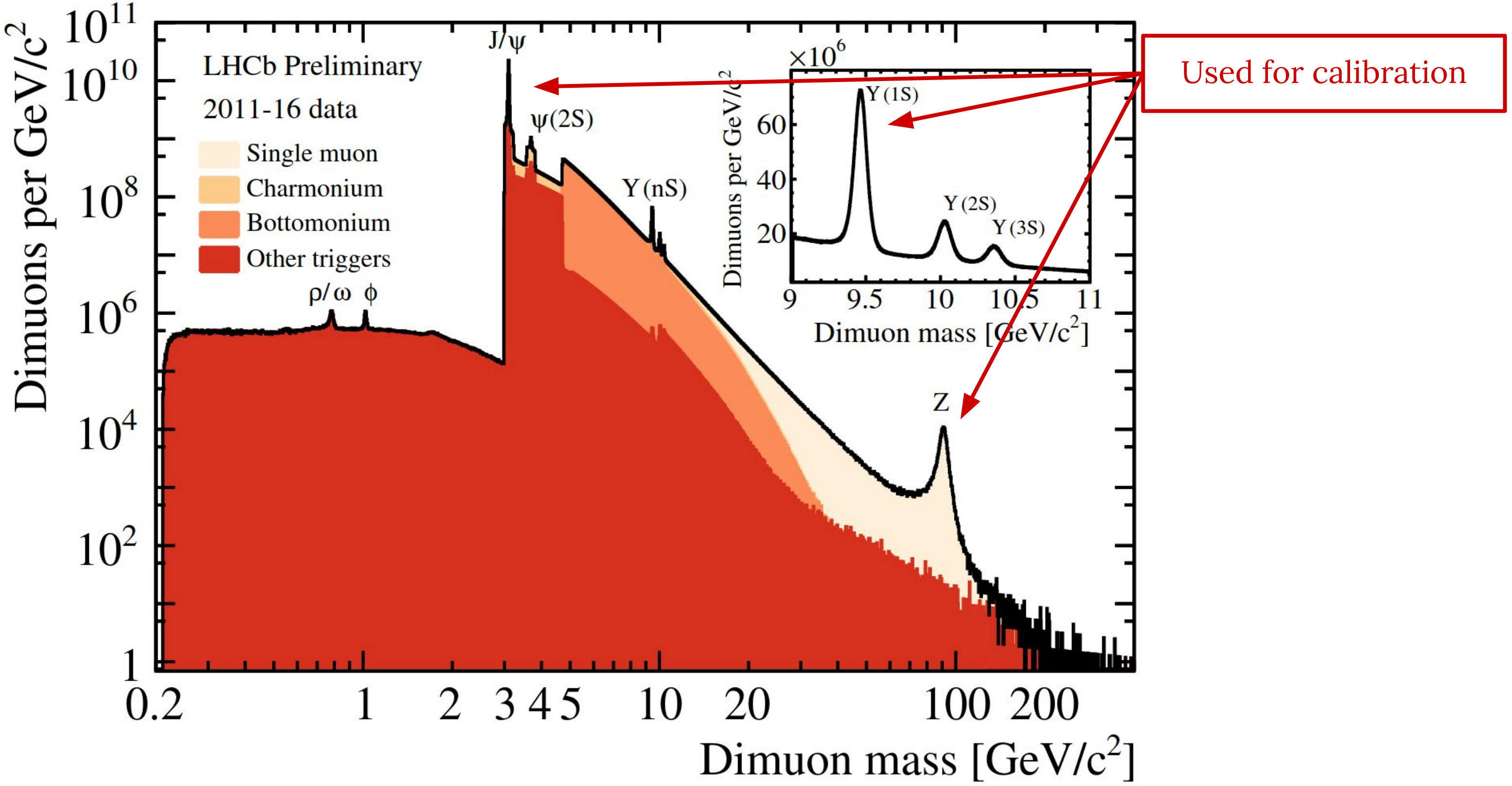
Buffer events to disk, perform online detector calibration and alignment

Full offline-like event selection, mixture of inclusive and exclusive triggers

12.5 kHz (0.6 GB/s) to storage

Calibration using muons

[LHCb-CONF-2016-005]



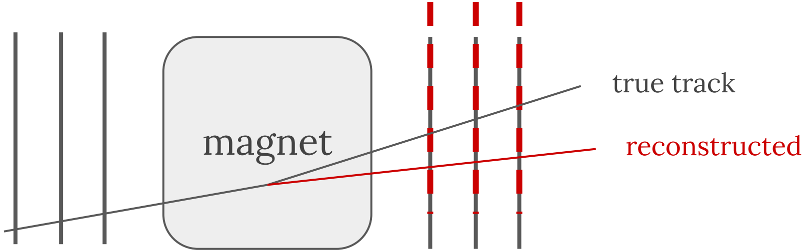
Used for calibration

Charge-dependent curvature biases

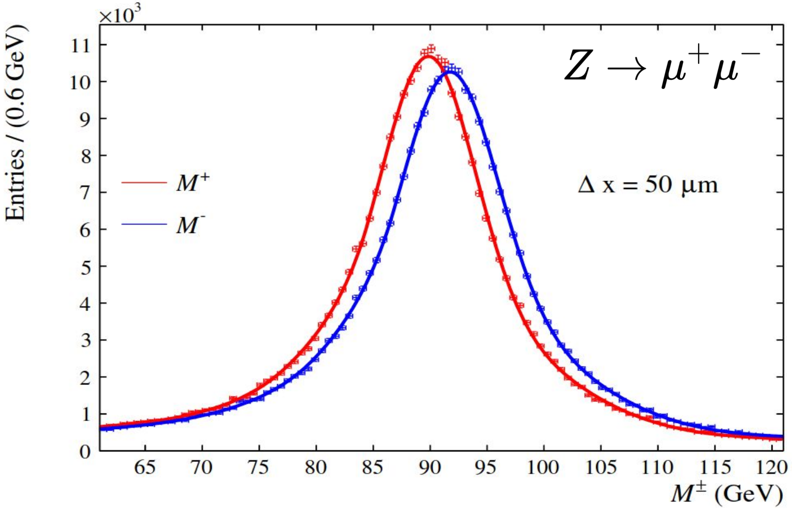
- The analysis depends highly on the detector alignment
  - A misalignment of 10µm translates into a O(50MeV) shift
- Default LHCb alignment and calibration not suitable to study candidates with high transverse momentum
- For 2016 we re-run the alignment and calibration offline using Z decays
- Avoid double bias from the momentum resolution using the pseudo-mass method:

$$M^{\pm} = \sqrt{2p^{\pm}p_T^{\pm}\frac{p^{\mp}}{p_T^{\mp}}(1-\cos\theta)}$$

Inspired by Phys. Rev. D 91, 072002



EPJ-C 81 (2021) 3, 251

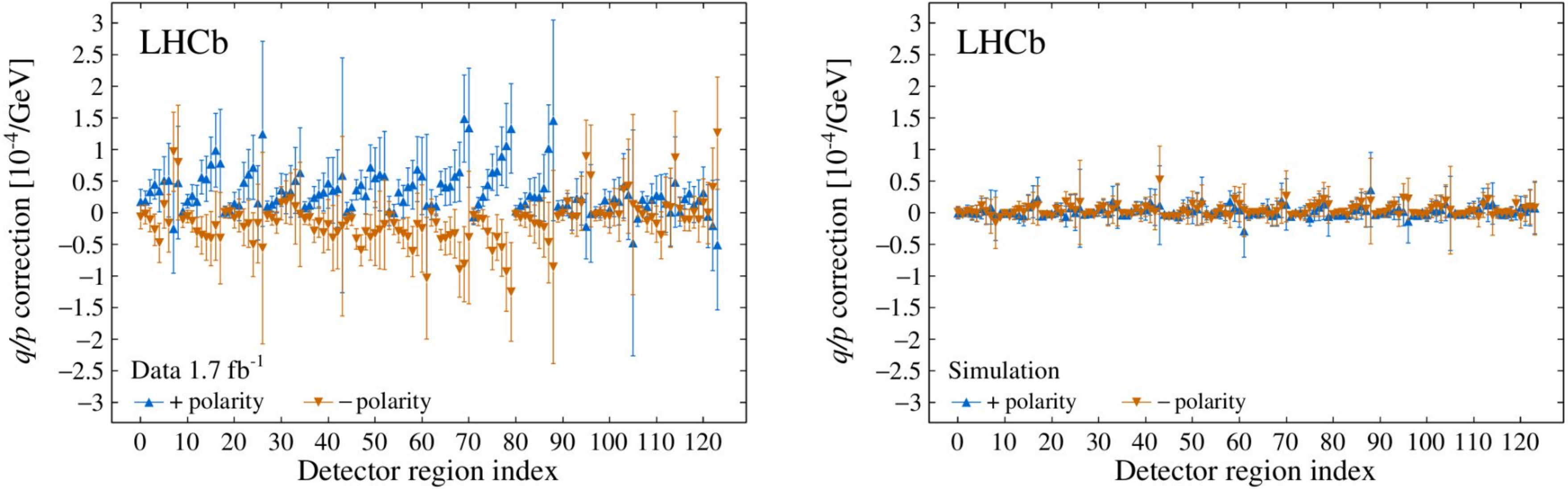


Corrections with the pseudomass method

Fit the asymmetries to the pseudomass and translate this into shifts in q/p

$$\frac{q}{p} \to \frac{q}{p} + \delta(\eta,\phi) \text{ where } \delta(\eta,\phi) \sim 10^{-4}$$

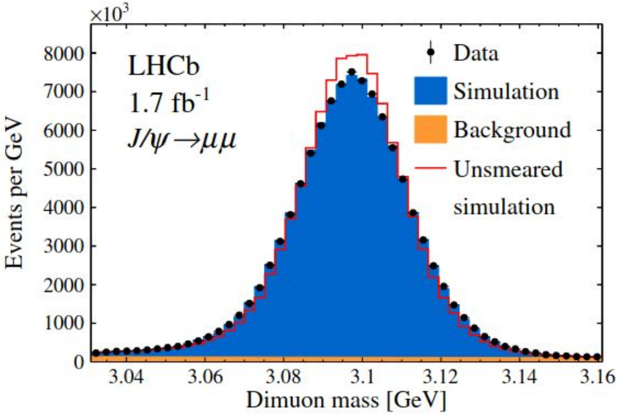
[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024]

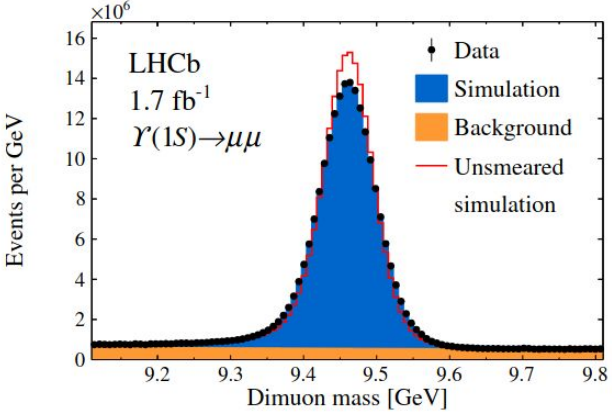


This will be the only curvature-bias correction for the full Run 2 analysis

Smearing the simulation

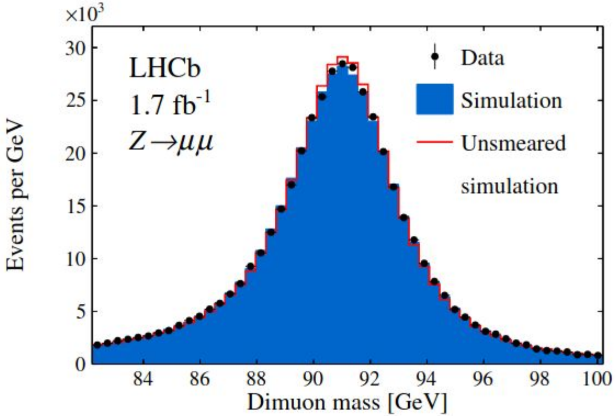
[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024]





Need to smear the momentum to account for:

- momentum scale
- multiple scattering



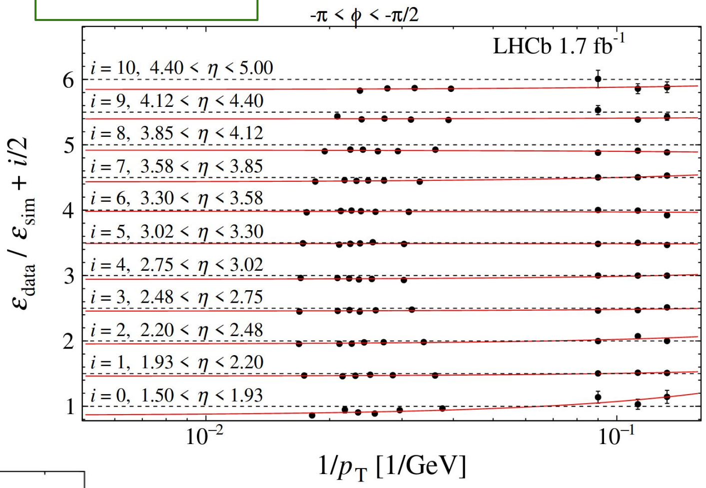
For the 2016 analysis there was an additional factor accounting for residual curvature biases, now excluded

Determining the efficiencies

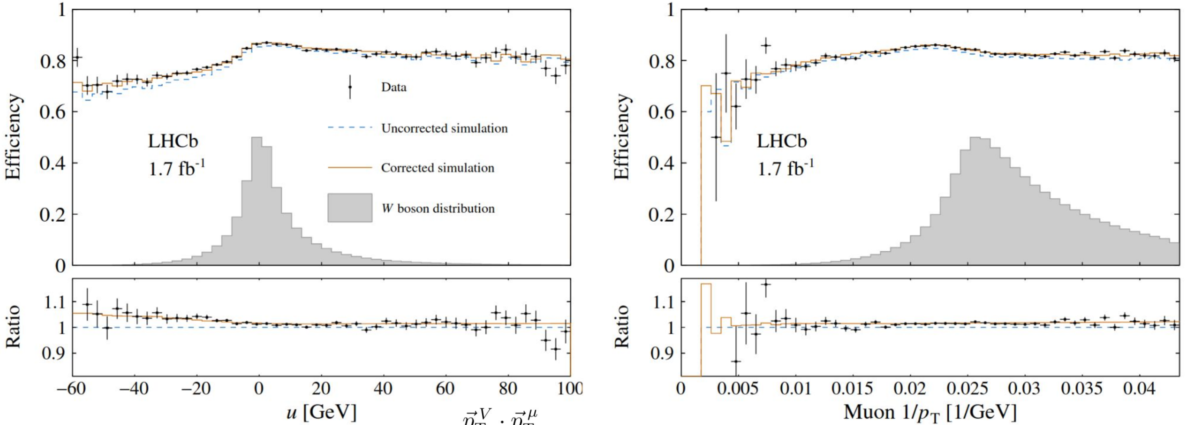
Three main sources of acceptance biases:

- Trigger efficiencies
- Muon-identification efficiencies
- Isolation requirements

Trigger efficiency



Isolation efficiency



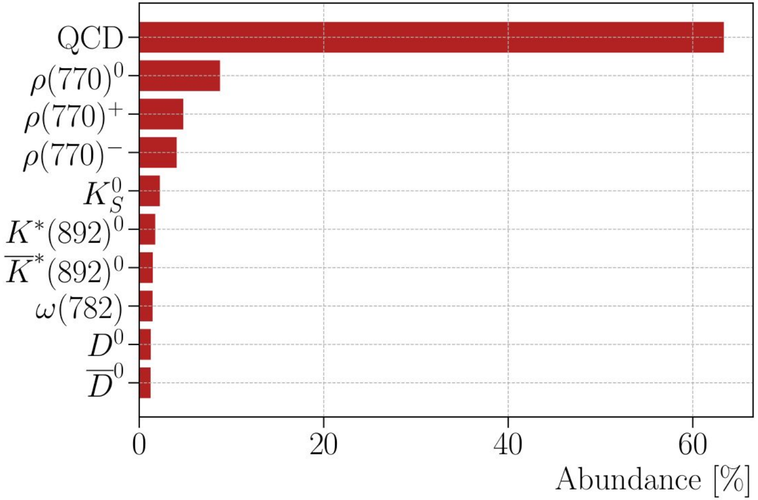
$$u = \frac{\vec{p}_{\text{T}}^{V} \cdot \vec{p}_{\text{T}}^{\mu}}{p_{\text{T}}^{\mu}}$$

Corrections predominantly at the percent level

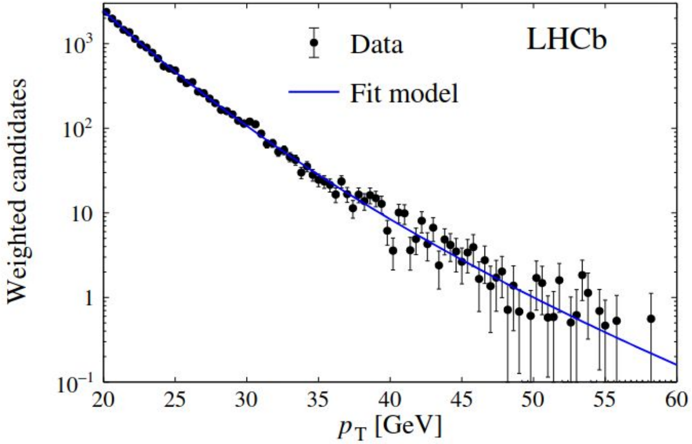
[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024]

Backgrounds

- Most of them modelled from dedicated simulated samples
    - Single-top, quark/anti-quark (t, b, c), Z/W decays, Drell-Yan
    - Cross-sections normalized to W and Z yields
- Description of the QCD background (decays-in-flight) obtained from data
    - Sample with inverted muon-identification requirements
    - Weight and parametrize the data using a Hagedorn distribution
- Accurately describes the Jacobian peak (region with highest sensitivity to m_W)

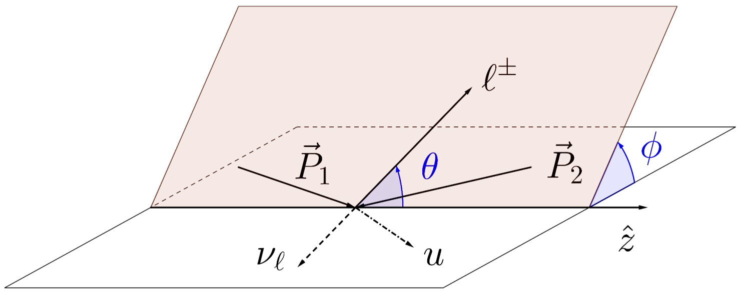


[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024]



The W cross-section

Collins-Soper frame



$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_{\mathrm{T}}^{W}\,\mathrm{d}y\,\mathrm{d}M\,\mathrm{d}\cos\vartheta\,\mathrm{d}\varphi} = \overbrace{\boxed{\frac{3}{16\pi}\frac{\mathrm{d}\sigma^{\mathrm{unpol.}}}{\mathrm{d}p_{\mathrm{T}}^{W}\,\mathrm{d}y\,\mathrm{d}M}}}^{\text{Unpolarized part}}$$

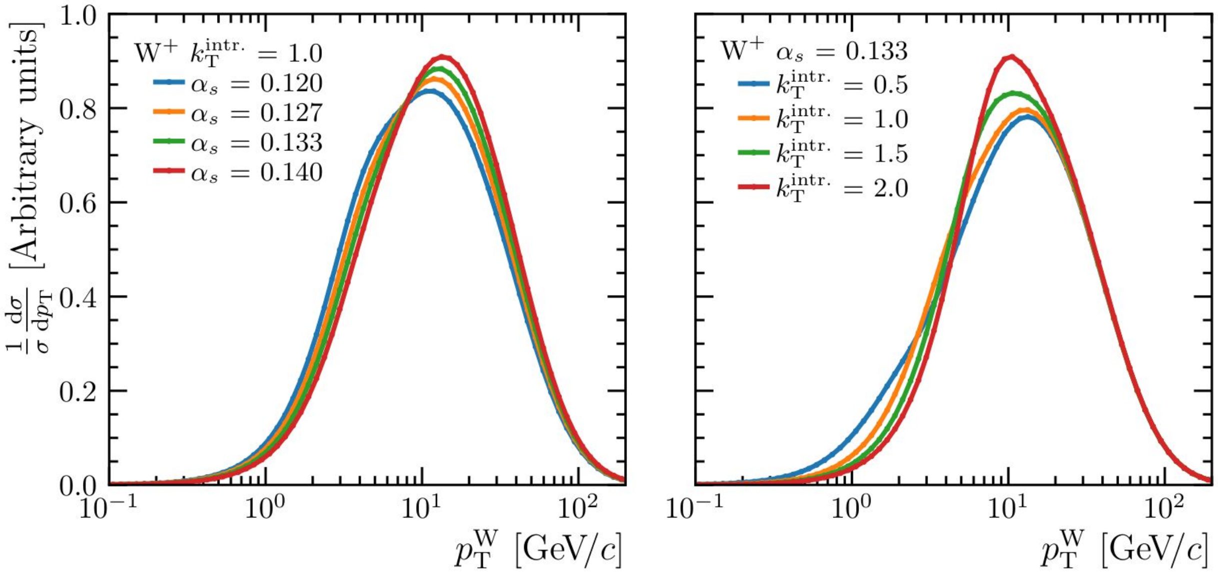
(At order α_s^2)

$$\underbrace{\boxed{\begin{aligned}&\{(1+\cos^2\vartheta) + A_0\frac{1}{2}(1-3\cos^2\vartheta) + A_1\sin 2\vartheta\cos\varphi\\ &+ A_2\frac{1}{2}\sin^2\vartheta\cos 2\varphi + A_3\sin\vartheta\cos\varphi + A_4\cos\vartheta\\ &+ A_5\sin^2\vartheta\sin 2\varphi + A_6\sin 2\vartheta\sin\varphi + A_7\sin\vartheta\sin\varphi\}\end{aligned}}}_{\text{Angular part}}$$

Small dependency on the angular coefficients for the W mass measurement at LHCb except for A_3

Modelling the W boson transverse momentum

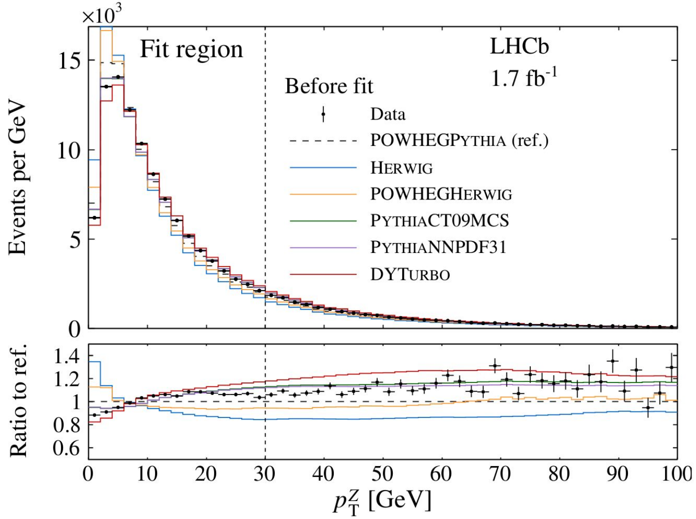
The limited knowledge on the transverse momentum of the W bosons can be compensated by floating QCD parameters [arXiv:1907.09958]



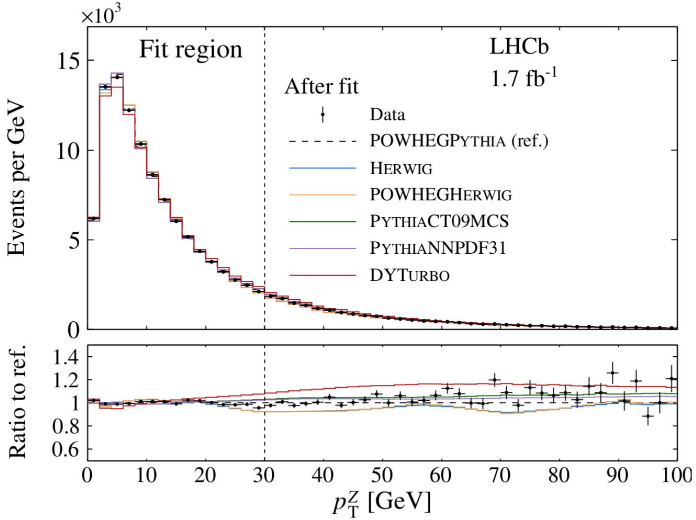
Float $m_W, \alpha_s, \hat{k}_T$ in the fit

Simulating signal decays

[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024]



Tuning of α_s and intrinsic k_T



- POWHEG + Pythia gave the best description of the unpolarized cross-section and was chosen as the baseline generator for the 2016 analysis
  - Varied success with other generators, used to determine systematic uncertainties
- DYTurbo performs well at reproducing the angular cross-section

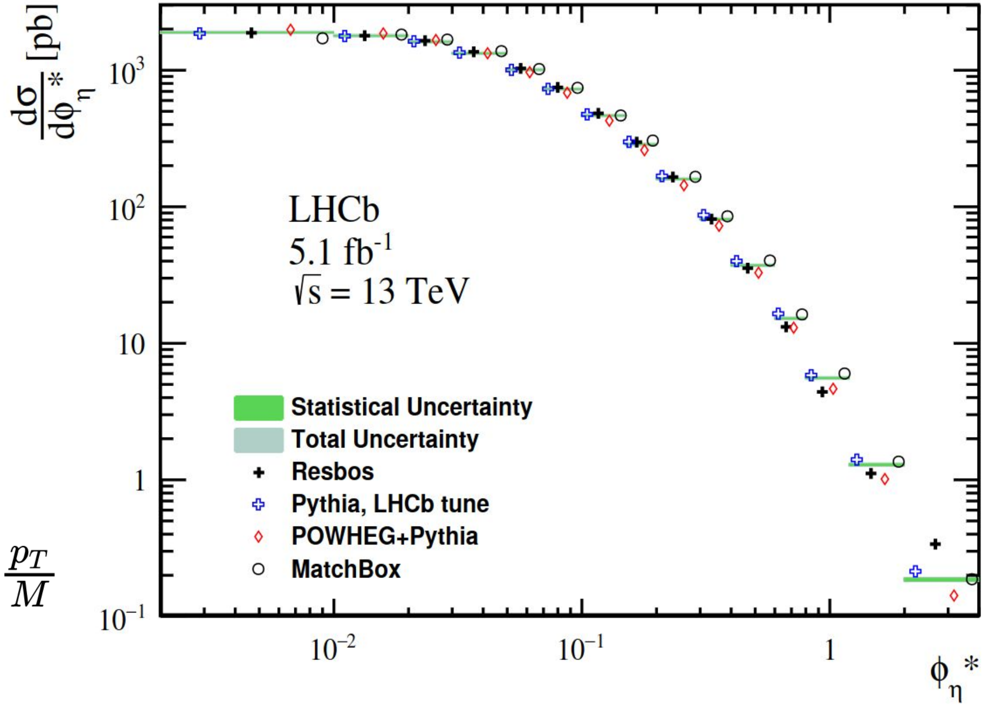
Modelling the boson transverse momentum

- The momentum of the outgoing muon is strictly related to that of the boson
- Must ensure the correlation is maintained after the fit
    - Fit Z variables simultaneously to the W mass fit

$$\phi^* \equiv \arctan\left(\frac{\pi - \Delta\phi}{2}\right) / \cosh\left(\frac{\Delta\eta}{2}\right) \sim \frac{p_T}{M}$$

[EPJC 71, 1600 (2011)]

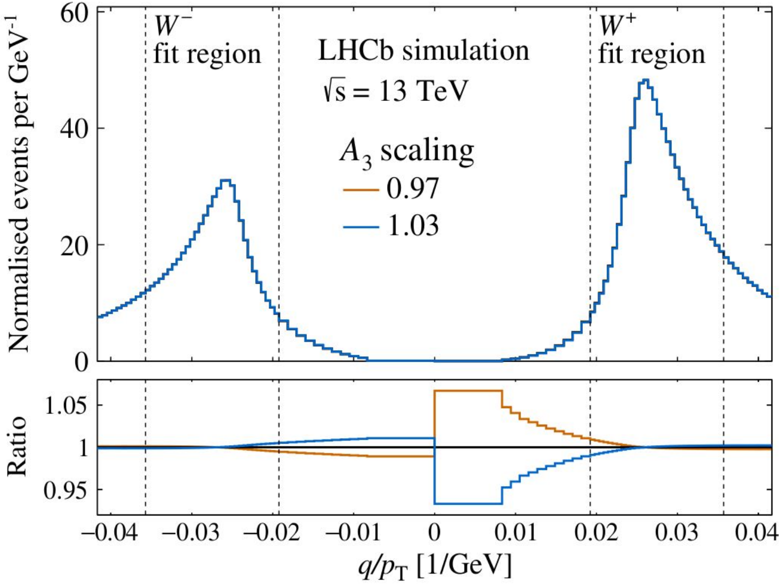
[JHEP 07 (2022) 026]



Polarized cross-section

- The angular part of the cross-section is better described with DYTurbo
- However, the angular coefficients suffer low accuracy at low transverse momentum values [JHEP 11 (2017) 003]
- Uncertainties from DYTurbo mitigated by floating A_3
  - Otherwise the uncertainty would be O(30 MeV)
  - The preferred value in the fit is however consistent with DYTurbo predictions

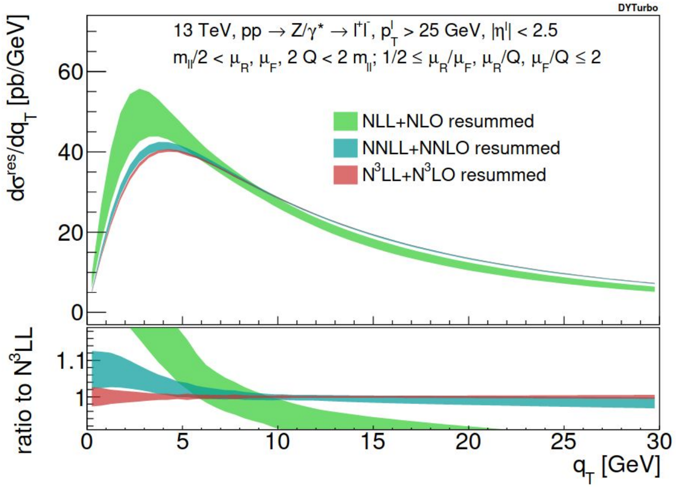
[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024]

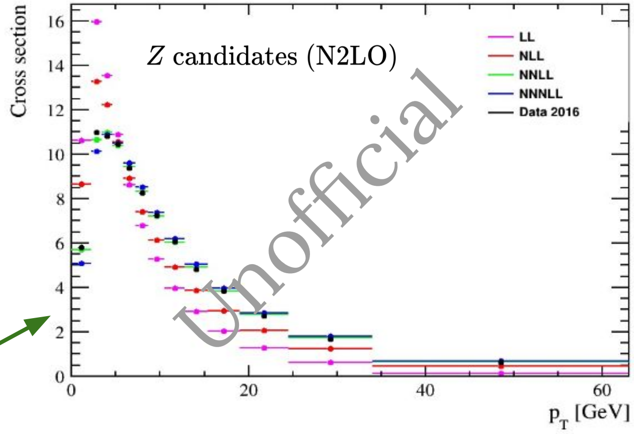


Considerations for the future

- Aim at using a single generator to describe the cross-section
- Considering to switch into more modern generators to fully describe the cross-section:
    - We expect that the difference between α_s for W and Z is reduced
    - Attempt to move to N2LO, N2LL predictions of both cross-sections
    - Partial calculations at N3LO, N3LL worth to study
    - Exploring the usage of NNPDF 4.0
- Cross-checks to be made with POWHEG + Pythia

[PRD 104 (2021 111503]

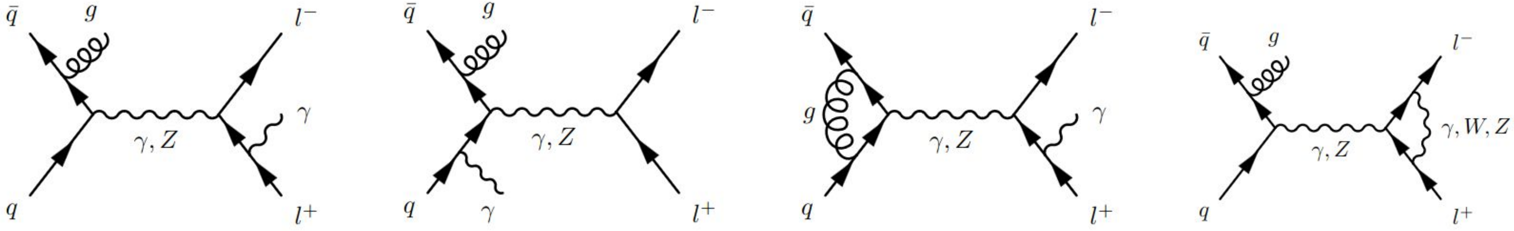




Comparison at N2LO to LHCb data from [LHCb-PAPER-2021-037] (unofficial)

Improving the simulation

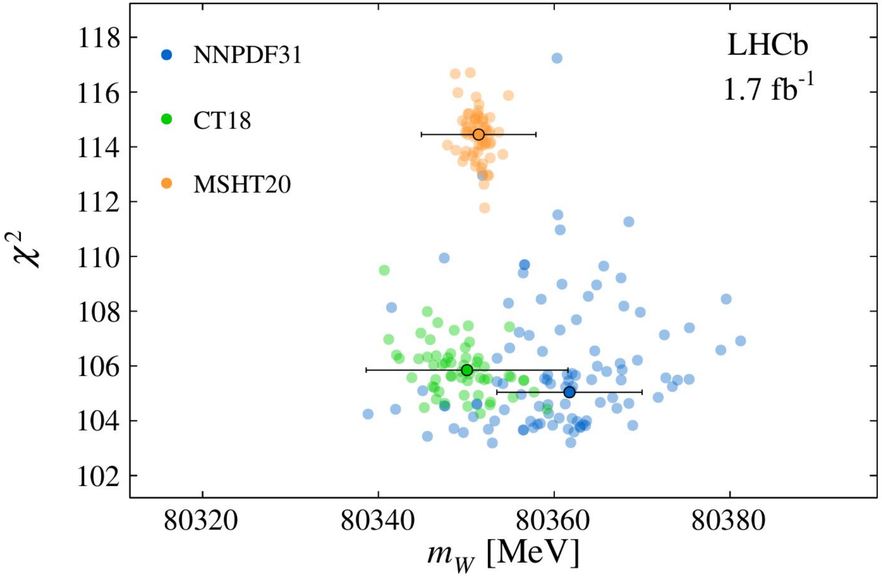
- Take advantage of the latest developments on the theory side:
    - Switch to more accurate predictors of the boson production
    - Explore new PDF sets (NNPDF 4.0)
- Change the treatment of generators/PDF sets when calculating systematic uncertainties
    - Drop known inaccurate PDF sets or combination of generators
    - Revisit the way to handle the different predictors and the order of the accuracy (NLL, NNLL, …)
- Completely revisit the QED (+FSR) modelling using POWHEG-EW: NLO(QCD) + NLO(EW)



Treatment of PDF sets

- PDFs chosen from three different recent sets
    - NNPDF3.1: [Eur. Phys. J. C 77, 663 (2017)]
    - CT18: [Phys. Rev. D 103, 014013]
    - MSHT20: Eur. Phys. J. C 81, 341 (2021)
- The result is an average of the three assuming 100% correlation

[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024]



Systematic uncertainties

[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024]

Source	**Size (MeV)**
Parton distribution functions	**9**
Total theoretical syst. uncertainty (excluding PDFs)	**17**
Transverse momentum model	11
Angular coefficients	10
QED FSR model	7
Additional electroweak corrections	5
Total experimental syst. uncertainty	**10**
Momentum scale and resolution modelling	7
Muon ID, tracking and trigger efficiencies	6
Isolation efficiency	4
QCD background	2
Statistical	**23**
Total uncertainty	**32**

Average of NNPDF3.1, CT18 and MSHT20 systematic uncertainties

Envelope of five different models

Uncertainty due to scale variations

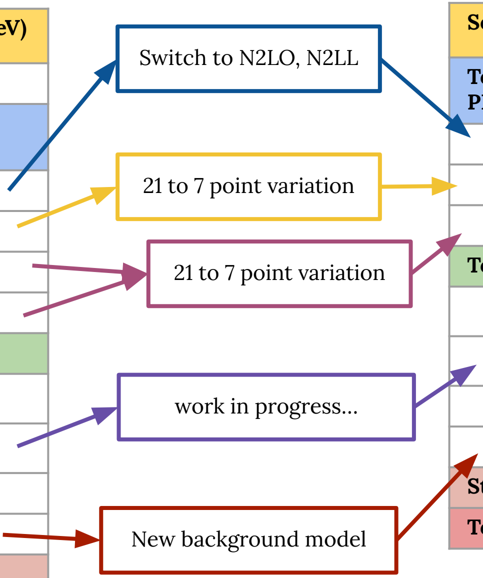
Envelope of the QED FSR from Pythia, Photos and Herwig. Additional correction from POWHEG-EW

Reducing the systematic uncertainties

[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024] (supplementary)

Source	**Size (MeV)**
Parton distribution functions	**9**
Total theoretical syst. uncertainty (excluding PDFs)	**17**
Transverse momentum model	11
Angular coefficients	10
QED FSR model	7
Additional electroweak corrections	5
Total experimental syst. uncertainty	**10**
Momentum scale and resolution modelling	7
Muon ID, tracking and trigger efficiencies	6
Isolation efficiency	4
QCD background	2
Statistical	**23**
Total uncertainty	**32**

Previous result (2016)



Switch to N2LO, N2LL

21 to 7 point variation

21 to 7 point variation

work in progress...

New background model

Temptative values

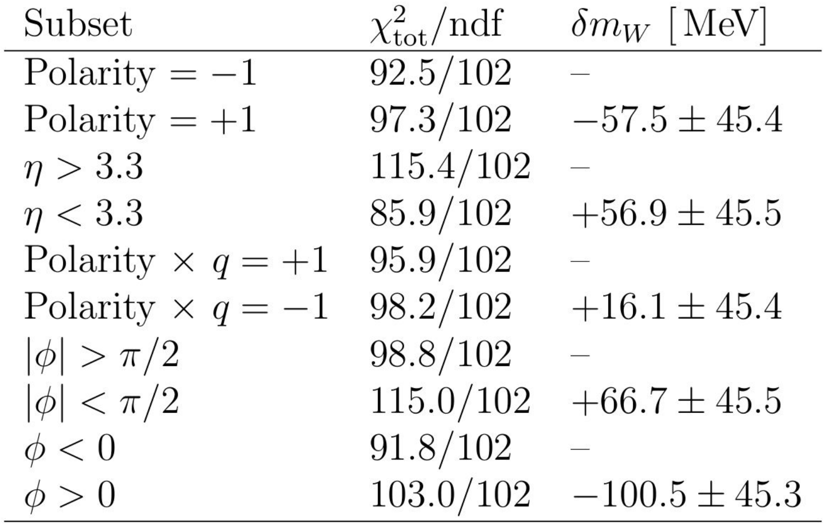
Source	**Size (MeV)**
Total theoretical syst. uncertainty (excluding PDFs)	**8**
Transverse momentum model	6
Angular coefficients	4
QED model	4
Total experimental syst. uncertainty	**8**
Momentum scale and resolution modelling	5
Muon ID, tracking and trigger efficiencies	4
Isolation efficiency	4
QCD background	2
Statistical	**14**
Total uncertainty	**18**

These are simply guesstimates of the values based on some quick calculations and due to the luminosity increase

Cross-checks

Cross-checks are vital to validate different aspects of the analysis:

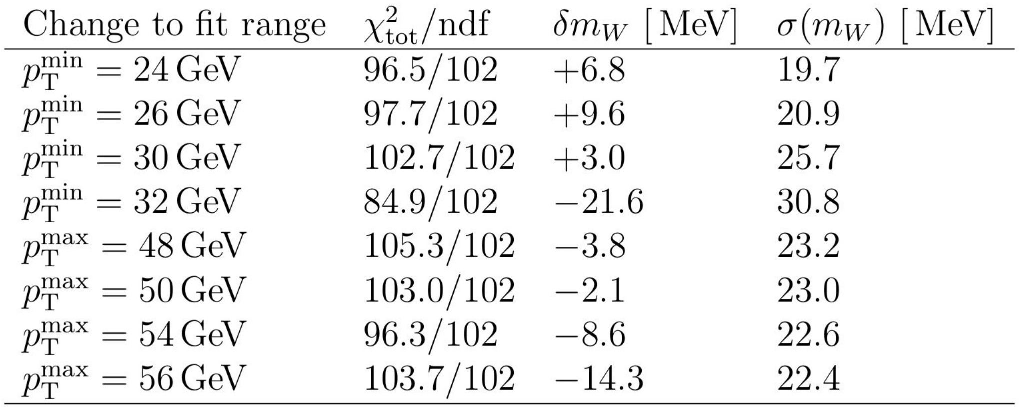
- Differences in magnet polarity
- Curvature biases in candidates bending in the same direction
- Possible detector biases in different η/φ regions
- W-like Z mass measurement, which validates the fit procedure (agreement at one standard deviation)
- Use of NNLO PDFs to test next-order effects of the PDFs (1 MeV variation)
- Separate W^+/W^- mass measurement, to study charge-dependent biases (results in agreement)



Subset	$\chi^2_{\text{tot}}/\text{ndf}$	δm_W [MeV]
Polarity $= -1$	$92.5/102$	–
Polarity $= +1$	$97.3/102$	-57.5 ± 45.4
$\eta > 3.3$	$115.4/102$	–
$\eta < 3.3$	$85.9/102$	$+56.9 \pm 45.5$
Polarity $\times\, q = +1$	$95.9/102$	–
Polarity $\times\, q = -1$	$98.2/102$	$+16.1 \pm 45.4$
$\lvert\phi\rvert > \pi/2$	$98.8/102$	–
$\lvert\phi\rvert < \pi/2$	$115.0/102$	$+66.7 \pm 45.5$
$\phi < 0$	$91.8/102$	–
$\phi > 0$	$103.0/102$	-100.5 ± 45.3

[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024] (supplementary)

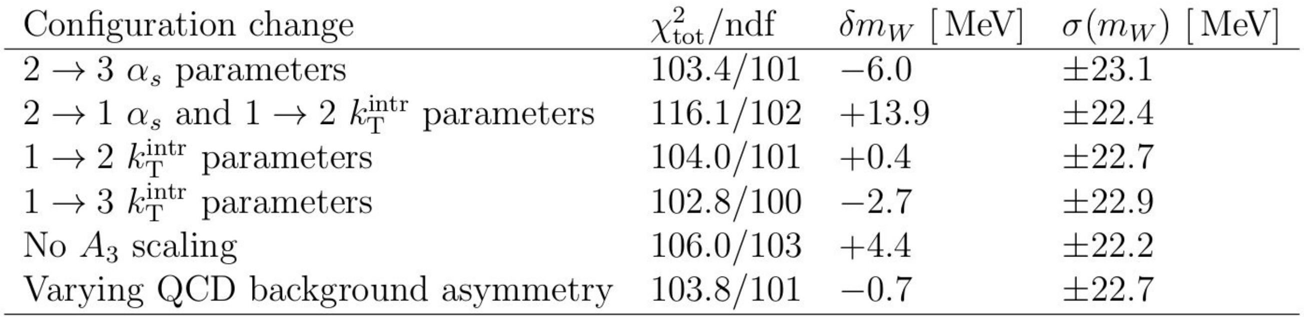
More on cross-checks



Change to fit range	$\chi^2_{\text{tot}}/\text{ndf}$	δm_W [MeV]	$\sigma(m_W)$ [MeV]
$p_{\text{T}}^{\text{min}} = 24\,\text{GeV}$	96.5/102	+6.8	19.7
$p_{\text{T}}^{\text{min}} = 26\,\text{GeV}$	97.7/102	+9.6	20.9
$p_{\text{T}}^{\text{min}} = 30\,\text{GeV}$	102.7/102	+3.0	25.7
$p_{\text{T}}^{\text{min}} = 32\,\text{GeV}$	84.9/102	−21.6	30.8
$p_{\text{T}}^{\text{max}} = 48\,\text{GeV}$	105.3/102	−3.8	23.2
$p_{\text{T}}^{\text{max}} = 50\,\text{GeV}$	103.0/102	−2.1	23.0
$p_{\text{T}}^{\text{max}} = 54\,\text{GeV}$	96.3/102	−8.6	22.6
$p_{\text{T}}^{\text{max}} = 56\,\text{GeV}$	103.7/102	−14.3	22.4

- Checks with alternative binning schemes/fit ranges
- Modify the number of nuisance parameters

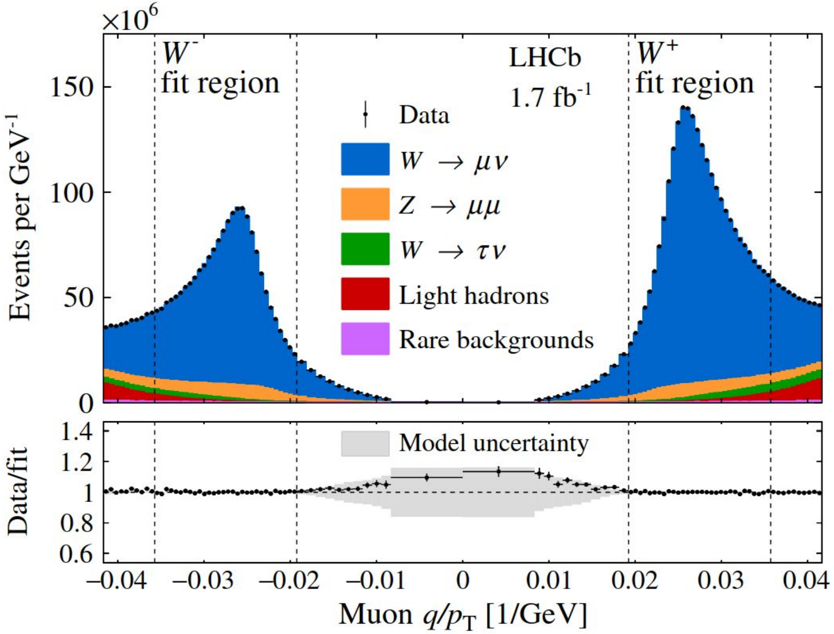
[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024] (supplementary)

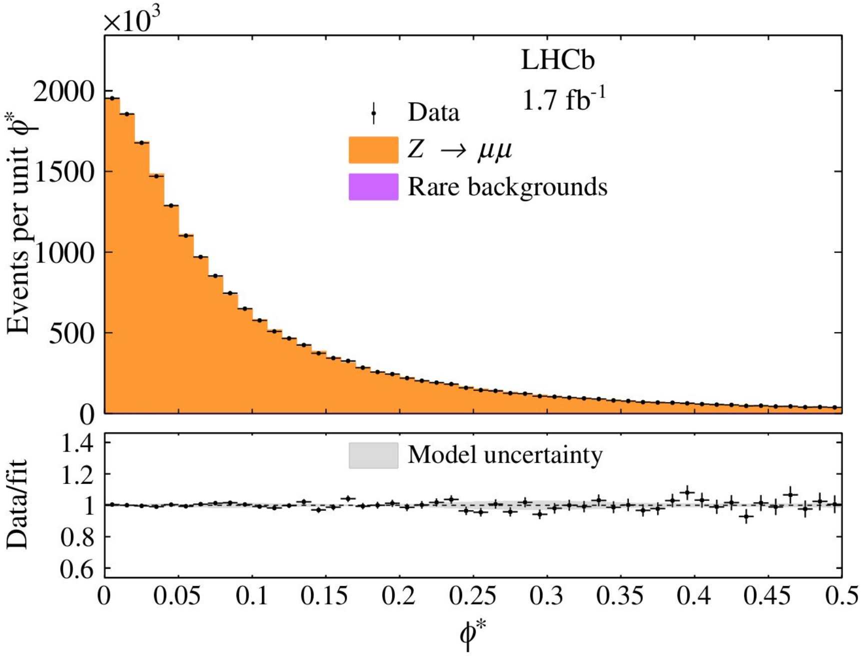


Configuration change	$\chi^2_{\text{tot}}/\text{ndf}$	δm_W [MeV]	$\sigma(m_W)$ [MeV]
$2 \to 3$ α_s parameters	103.4/101	−6.0	±23.1
$2 \to 1$ α_s and $1 \to 2$ $k_{\text{T}}^{\text{intr}}$ parameters	116.1/102	+13.9	±22.4
$1 \to 2$ $k_{\text{T}}^{\text{intr}}$ parameters	104.0/101	+0.4	±22.7
$1 \to 3$ $k_{\text{T}}^{\text{intr}}$ parameters	102.8/100	−2.7	±22.9
No A_3 scaling	106.0/103	+4.4	±22.2
Varying QCD background asymmetry	103.8/101	−0.7	±22.7

Fit to extract the W mass

[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024]



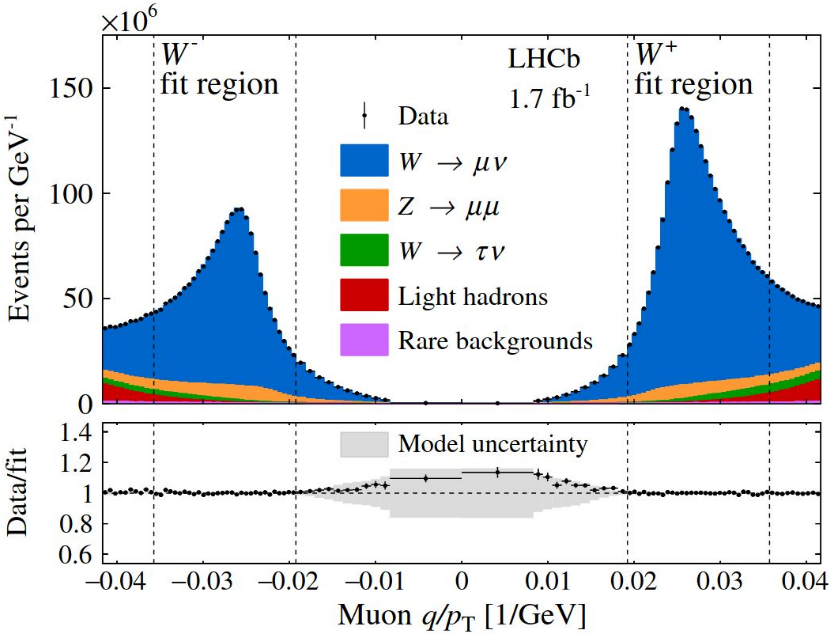


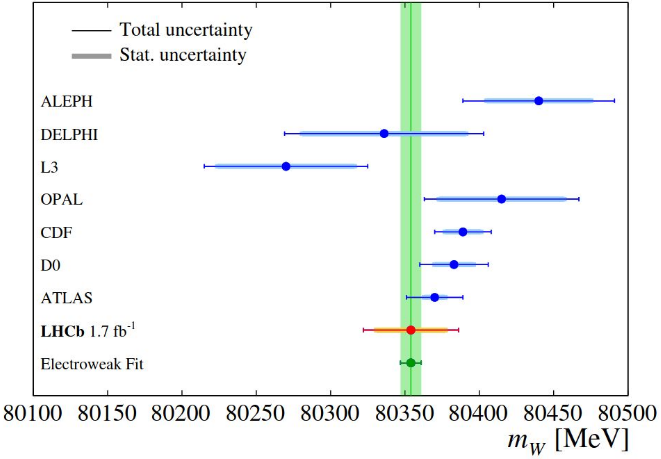
- 5D-weighted likelihood fit using the Beeston-Barlow approach (m_W, p_T, y, ϑ, ϕ)
- Fit simultaneously W and Z data
- Floating: W, Z and QCD background yields, m_W, $\alpha_s(W)$, $\alpha_s(Z)$, intrinsic k_T and A_3

The result

[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024]

- Measurement of the W mass using 2016 data
- Published on January 2022
- Shows the LHCb capabilities of doing high-precision measurements





$$m_W = 80354 \pm 23_{\text{stat}} \pm 10_{\text{exp}} \pm 17_{\text{theory}} \pm 9_{\text{PDF}}\ \text{MeV}$$

Towards a combination of the measurements

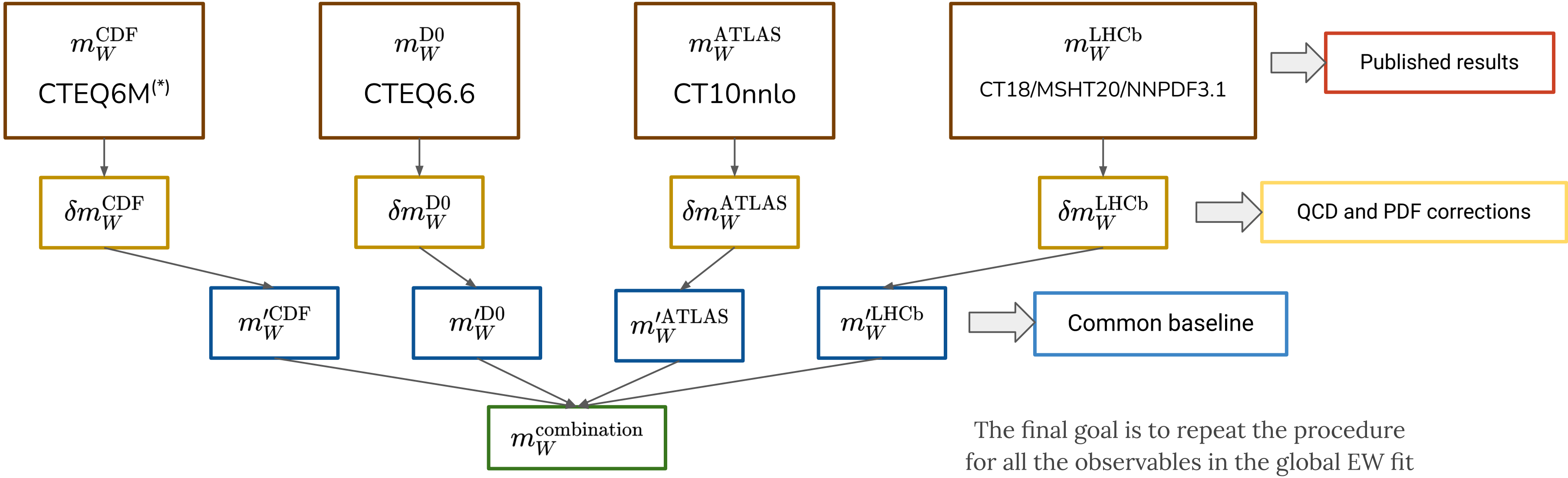
Comparison of uncertainties

Uncertainties in MeV			
Experiment	CDF (old/new)	ATLAS (old/new)	LHCb
Statistical	12 / 6.4	7.2 / 4.9	23
Momentum scale	7 / 3.0	8.4 / 6.8	7
Efficiency	(none) / 0.4	5.0 / 4.0	7
Background	3 / 3.3	4.6 / 2.4	2
QED	4 / 2.7	5.7 / 6.0	9
Modelling (unpol.)	5 / 2	5.9 / 3.5	11
Modelling (angular)	(none) / (none)	5.8 / 3.5	10
PDFs	10 / 3.9	9.0 / 7.7	9
Total systematic	15 / 6.9	17.2 / 15.5	22
Total	19 / 9.4	18.7 / 16.3	32

Towards a combination of all the measurements

Combining W mass measurements is not straightforward:

- Measurements are provided at different orders in QCD predictions
- Each experiment gives the results for different PDF sets
- The results are correlated among experiments (e.g. LHCb and ATLAS)



m_W^{CDF} CTEQ6M(*)

m_W^{D0} CTEQ6.6

m_W^{ATLAS} CT10nnlo

m_W^{LHCb} CT18/MSHT20/NNPDF3.1

Published results

δm_W^{CDF} δm_W^{D0} $\delta m_W^{\text{ATLAS}}$ δm_W^{LHCb}

QCD and PDF corrections

$m_W'^{\text{CDF}}$ $m_W'^{\text{D0}}$ $m_W'^{\text{ATLAS}}$ $m_W'^{\text{LHCb}}$

Common baseline

$m_W^{\text{combination}}$

The final goal is to repeat the procedure
for all the observables in the global EW fit

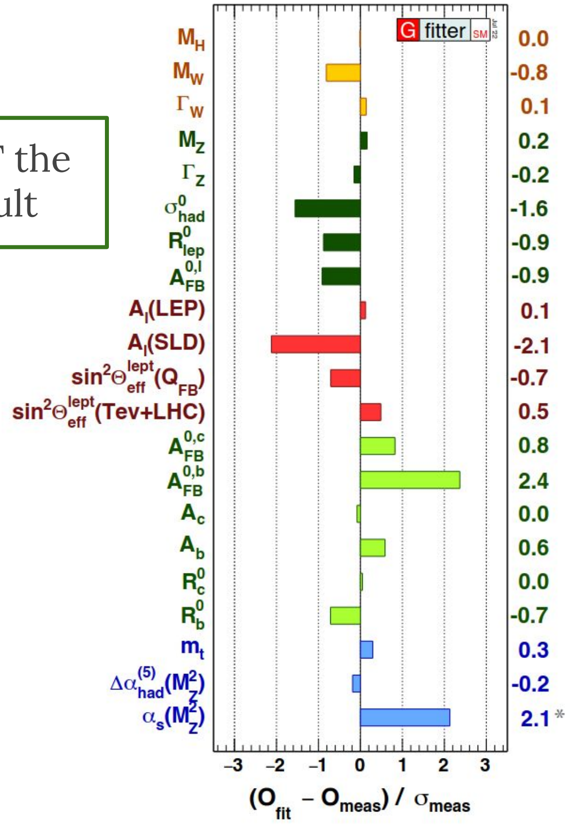
Towards a combination of the measurements

- The most difficult part is transporting the results to a common ground:
    - **D0**: `ResBos CP` (N2LO, N2LL) with `CTEQ66` PDFs (NLO)
    - **CDF**: `ResBos C` (NLO, N2LL) with `CTEQ6M` PDFs (NLO)
    - **ATLAS**: `POWHEG + Pythia8` (NLO + PS) combined with `DYTurbo` for A_i (N2LO) with `CT10` PDFs (N2LO)
    - **LHCb**: `POWHEG + Pythia8` (NLO + PS) combined with `DYTurbo` for A_i (N2LO) and averaging `NNPDF 3.1`, `MSHT20` and `CT18` PDFs (NLO)
- Preliminary results are now under review of the different collaborators (LHC-Tevatron)

Variation of the global EW fit with the CDF II result

Borrowed from Roman Kogler (ICHEP 2022)

WITHOUT the CDF result



(*) comparison to PDG value, not included in fit as input parameter

WITH the CDF result

largest pull in M_W (80.3817 GeV)

would shift M_Z up by 1.3σ

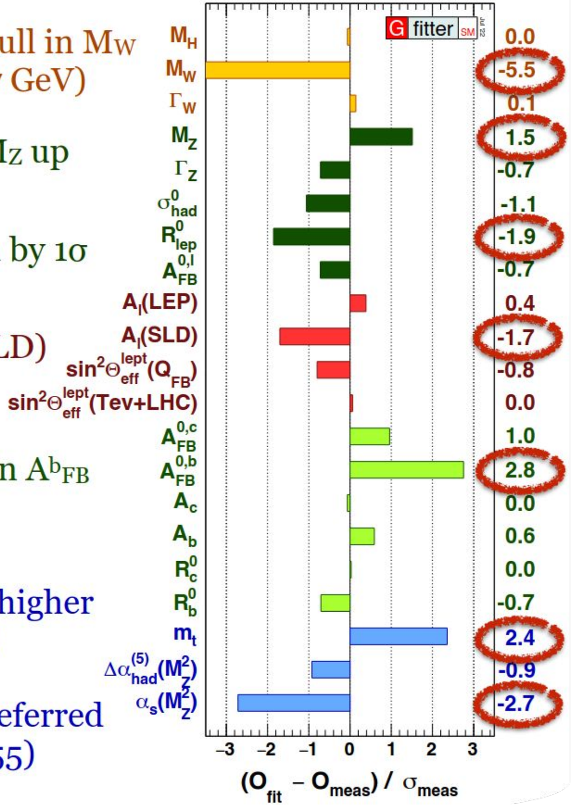
R^0_{lep} down by 1σ

Smaller pull in A_ℓ(SLD)

Larger pull in A^b_{FB}

m_t preferred higher (174.07 GeV)

$\alpha_s(M_Z)$ preferred low (0.1155)



Final remarks

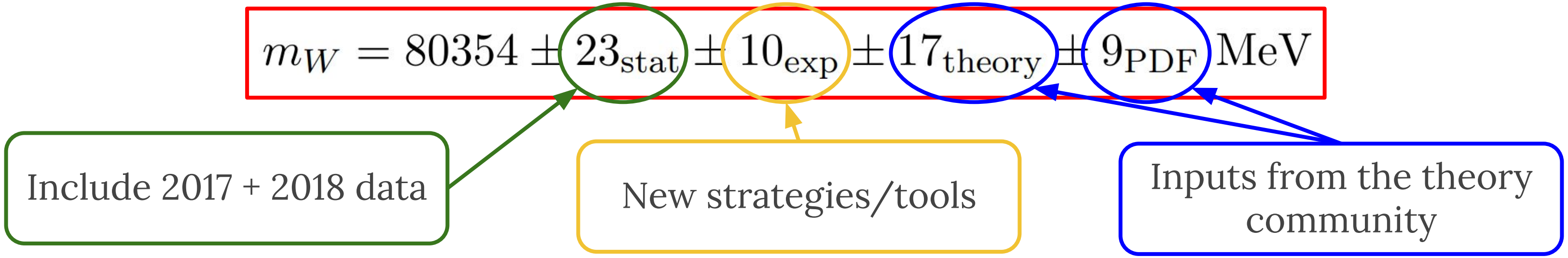
Is including 2017 and 2018 data straight-forward?

- It is straight-forward, but we must ask ourselves the following questions:
    - Can we optimize any part of the analysis strategy?
    - Can we use any of the new options available in the market?
    - Are there ways to make the result more accessible/easy to use for people outside the collaboration?
- The result using 2016 data shows the capabilities of the LHCb detector to contribute to this measurement, but it is worth re-considering our strategy before studying the full Run 2 data sample

Target sensitivity:

$$\sigma^{\text{Run 2}}_{\text{stat.}} \sim 14\,\text{MeV}$$

$$\sigma^{\text{Run 2}}_{\text{total}} \sim 20\,\text{MeV}$$



$$m_W = 80354 \pm 23_{\text{stat}} \pm 10_{\text{exp}} \pm 17_{\text{theory}} \pm 9_{\text{PDF}}\,\text{MeV}$$

Include 2017 + 2018 data

New strategies/tools

Inputs from the theory community

A few notes on reproducibility

- Reproducibility is one of the main pillars of science
- Some fields are currently facing a crisis, leading to unpublished dead-ends, low research efficiency, biases, … (see [Is there a reproducibility crisis in science?]())
- HEP data is hard to reproduce:
  - Unfeasible to fully mimic the experimental conditions
  - Data can not be retriggered
  - Expertise on old tools and data-taking conditions decays over time
- However, things improve drastically at the analysis level (i.e. after basic data-processing)

Versioned, tagged, reproducible analyses

The central W mass measurement at LHCb, together with other EW analyses is reproducible from the basic ROOT files in 20-45 min with 18 cores

Long-term plans

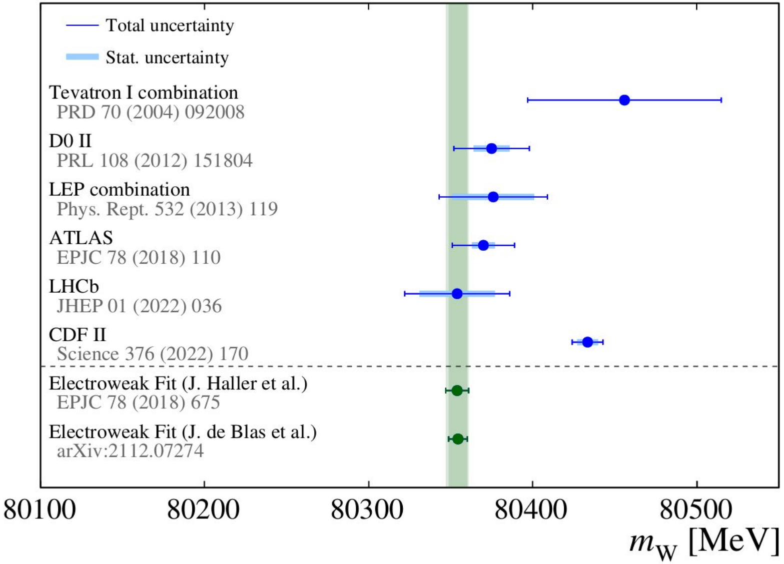
- The W mass determination at LHCb with full Run 2 data will allow to clarify the picture about this measurement
- Afterwards, LHCb can provide very useful data to further tune the generators and understand QCD and EW effects
    - Cross-sections at different energies (5 TeV, 13 TeV) of W and Z bosons
    - Drell-Yan studies
    - Weak mixing angle (forward-backward asymmetry)
    - Studies with electrons in the final state
- On Run 3, with a similar detector and analysis environment the precision will increase with the square root of the luminosity
- On Run 4 and beyond, an improved electromagnetic calorimeter system might improve the studies with electron modes at LHCb

Summary

- The W mass measurement using 2016 data is a big milestone at LHCb
- There is a huge ongoing effort to optimize the analysis and reevaluate systematic uncertainties
- Improvements on the physics modelling are strictly necessary to be competitive
    - Total and polarised cross-section
    - QED and FSR effects

$$m_W = 80354 \pm 23_{\text{stat}} \pm 10_{\text{exp}} \pm 17_{\text{theory}} \pm 9_{\text{PDF}}\ \text{MeV}$$

[LHCB-FIGURE-2022-003]



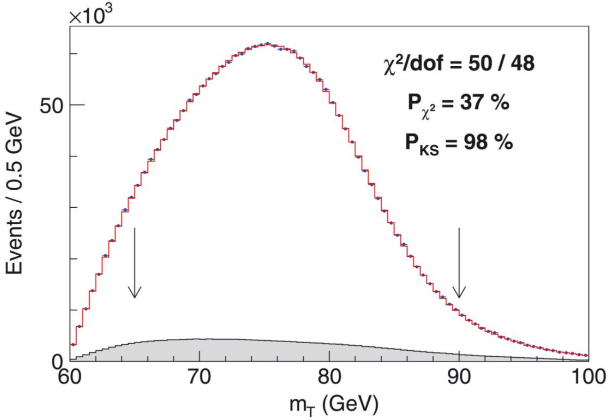
Looking forward to hearing your comments and suggestions

Thank you!

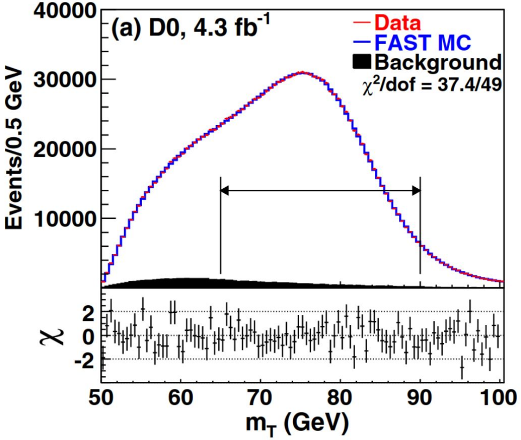
Backup

Results from other experiments

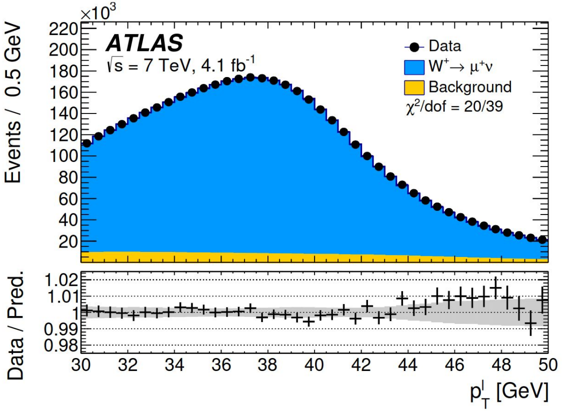
CDF: [Science 376, 170-176 (2022)] (old measurement: [PRL 108, 151803])



D0: [PRD 89, 012005]



ATLAS: [EPJC 78 (2018) 110]



$m_W = 80433.5 \pm 6.4_{\text{stat}} \pm 6.9_{\text{syst}}\text{MeV}$

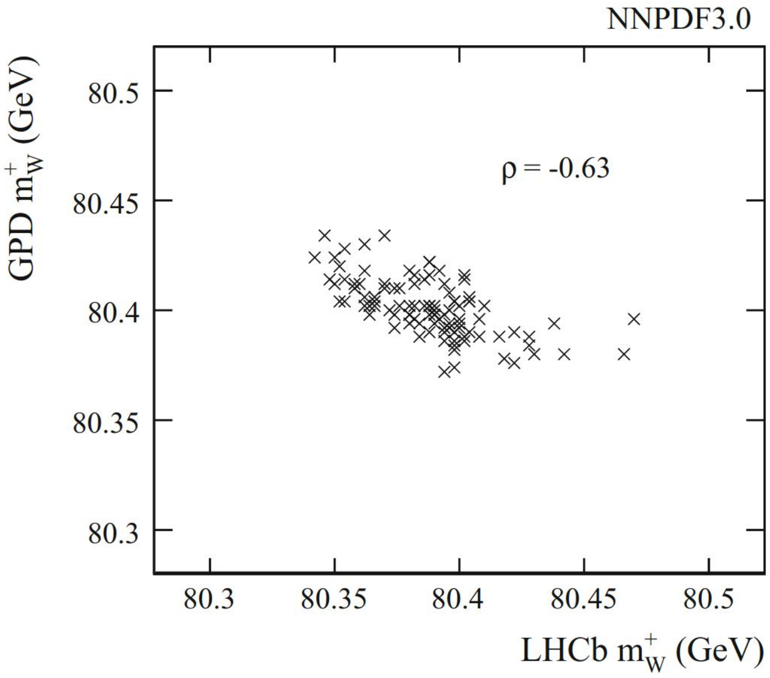
$m_W = 80367 \pm 13_{\text{stat}} \pm 22_{\text{syst}}\text{MeV}$

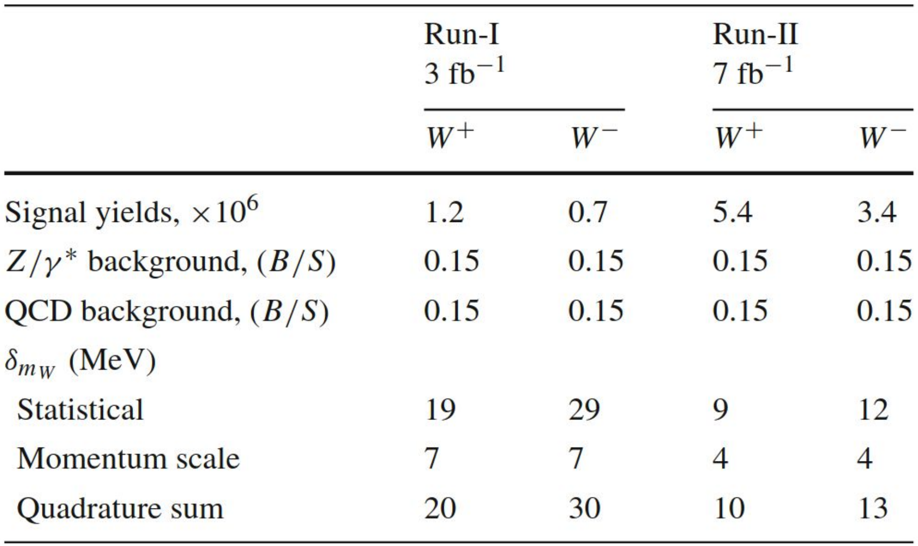
$m_W = 80370 \pm 7_{\text{stat}} \pm 11_{\text{exp. syst.}} \pm 14_{\text{theo. syst.}}\text{MeV}$

- Barrel-like detectors allow to measure missing transverse energy and the transverse mass
    - Measurement can be done measuring different quantities
- In modern experiments, a similar sensitivity can be obtained measuring the momentum of the outgoing lepton

Anti-correlation of uncertainties from PDFs

Eur. Phys. J. C 75, 601 (2015)

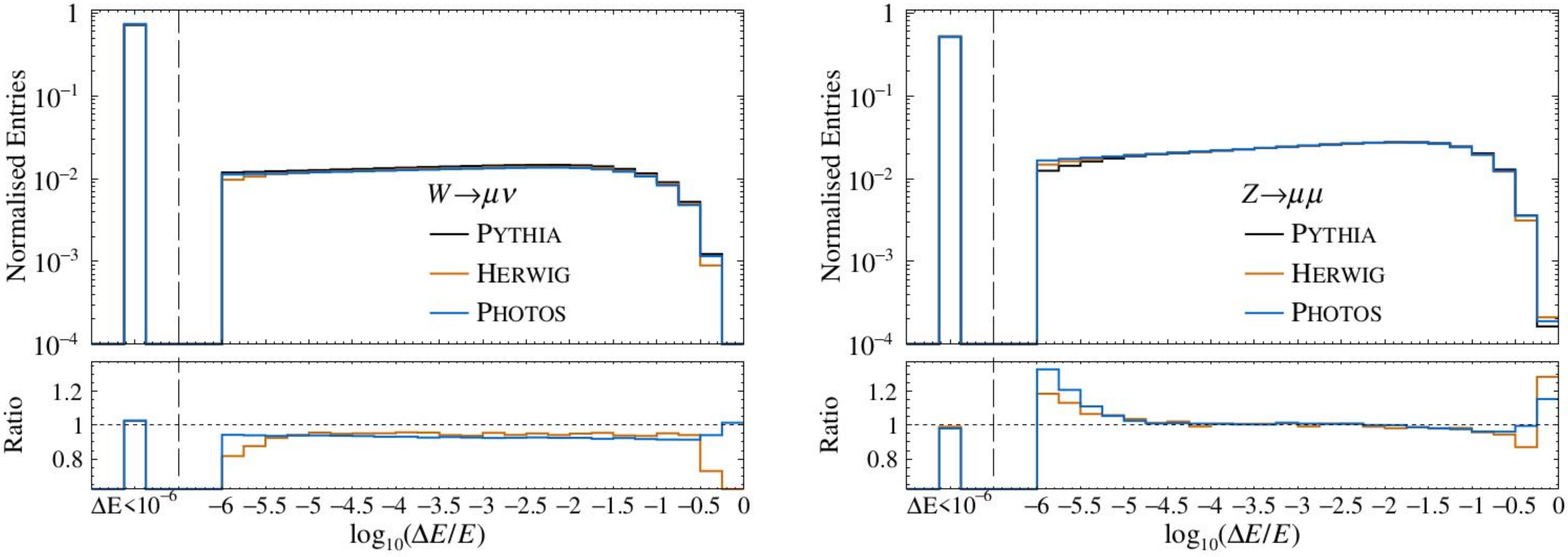




	Run-I 3 fb^{-1}		Run-II 7 fb^{-1}	
	W^+	W^-	W^+	W^-
Signal yields, $\times 10^6$	1.2	0.7	5.4	3.4
Z/γ^* background, (B/S)	0.15	0.15	0.15	0.15
QCD background, (B/S)	0.15	0.15	0.15	0.15
δ_{m_W} (MeV)				
Statistical	19	29	9	12
Momentum scale	7	7	4	4
Quadrature sum	20	30	10	13

QED corrections (2016 analysis)

[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024] (supplementary)



$$\Delta E/E = \frac{E_{\text{boson}} - E_{\text{dilepton}}^{\text{bare}}}{E_{\text{boson}}}$$

Number of candidates per experiment

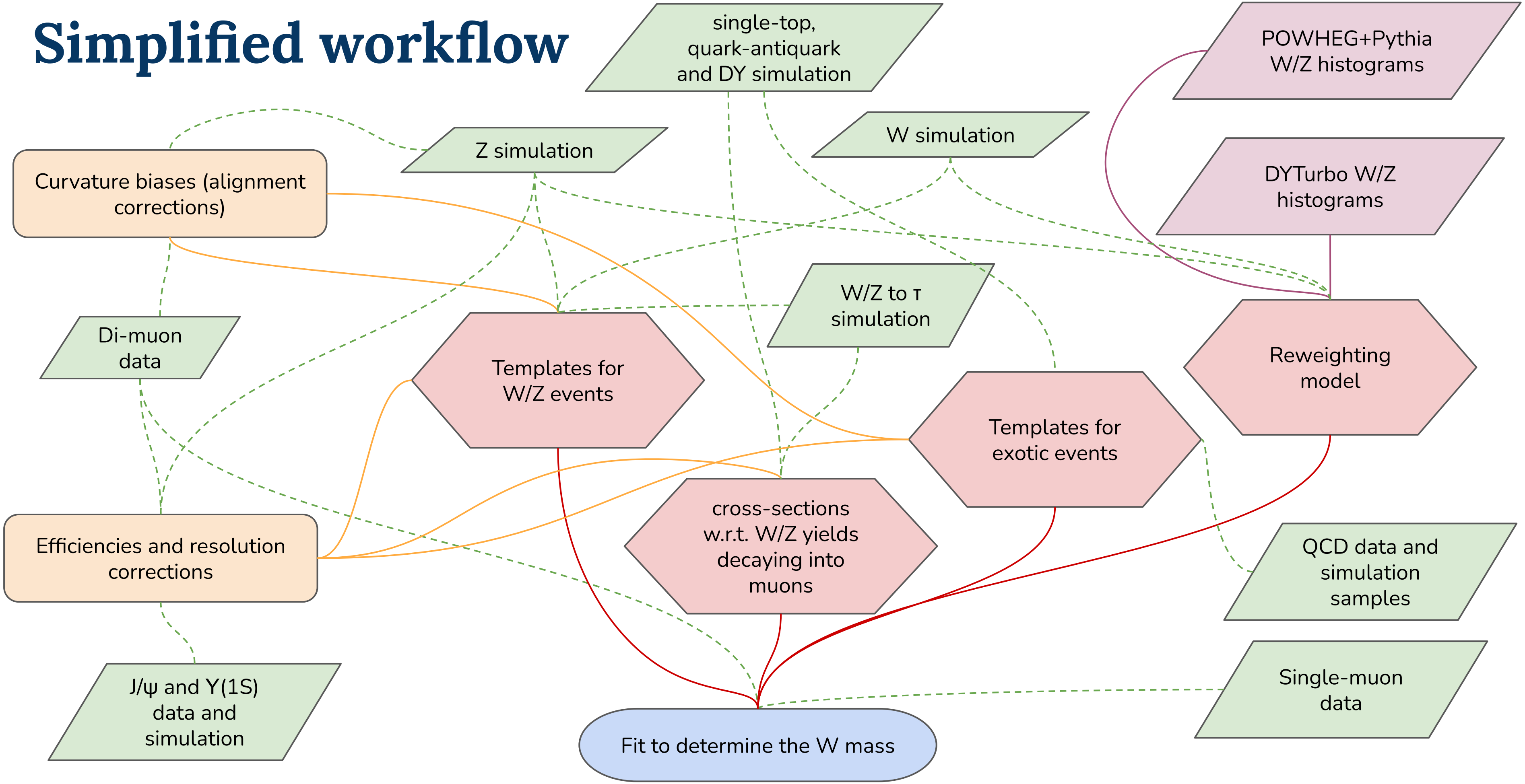
Experiment	Muon channel	Electron channel	Result (MeV)	Stat. Unc. (MeV)	Total Unc. (MeV)
ATLAS	7.8×10^6	5.9×10^6	80370	7	19
LHCb	2.4×10^6	N/A	80354	23	32
CDF-II	2.4×10^6	1.8×10^6	80433.5	6.4	9.4

ATLAS: [EPJC 78 (2018) 110]

LHCb: [JHEP 01 (2022) 036], [LHCB-PAPER-2021-024] (supplementary)

CDF: [Science, 376, 6589, (136-136), (2022)]

Simplified workflow



single-top, quark-antiquark and DY simulation

POWHEG+Pythia W/Z histograms

W simulation

Z simulation

Curvature biases (alignment corrections)

DYTurbo W/Z histograms

W/Z to τ simulation

Di-muon data

Templates for W/Z events

Reweighting model

Templates for exotic events

cross-sections w.r.t. W/Z yields decaying into muons

Efficiencies and resolution corrections

QCD data and simulation samples

Single-muon data

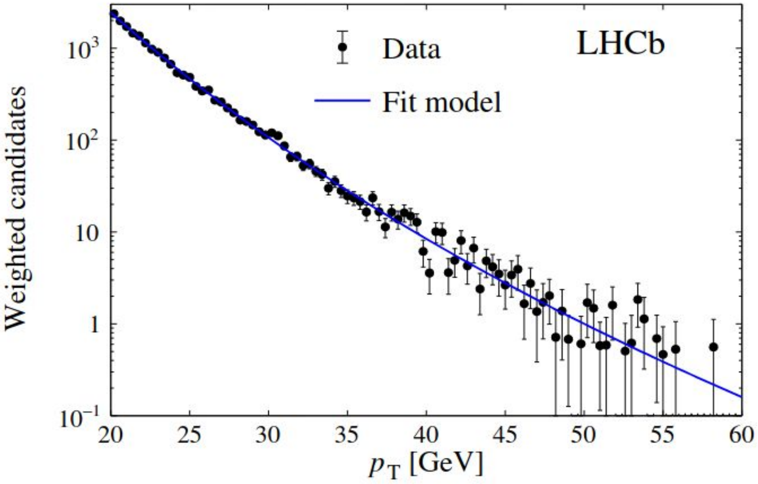
J/ψ and Υ(1S) data and simulation

Fit to determine the W mass

Towards doing an unfolded measurement

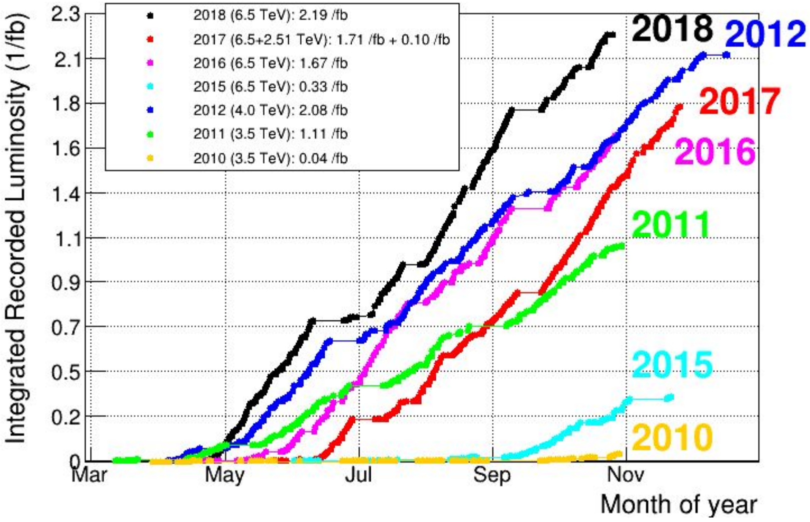
[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024]

- Ongoing studies to see if we can publish the unfolded transverse momentum distribution
- Facilitate comparing prediction and observables
- Quite challenging from the experimental point of view:
  - Must have a good control of the backgrounds (especially in the selection variables)
  - The systematic uncertainties might turn much bigger with the unfolding methods



Expected sensitivity for the full Run 2 analysis

- We expect to reduce the overall experimental uncertainty to 15 MeV
- The analysis becomes systematically dominated
  - A more careful description of the physics is necessary
- Eager to see the result of combining the measurements of all the LHC experiments



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