

# W and Z bosons at the LHCb Upgrade Experiment with 2024 p-p collision data

Luke Grazette



Funded by  
the European Union

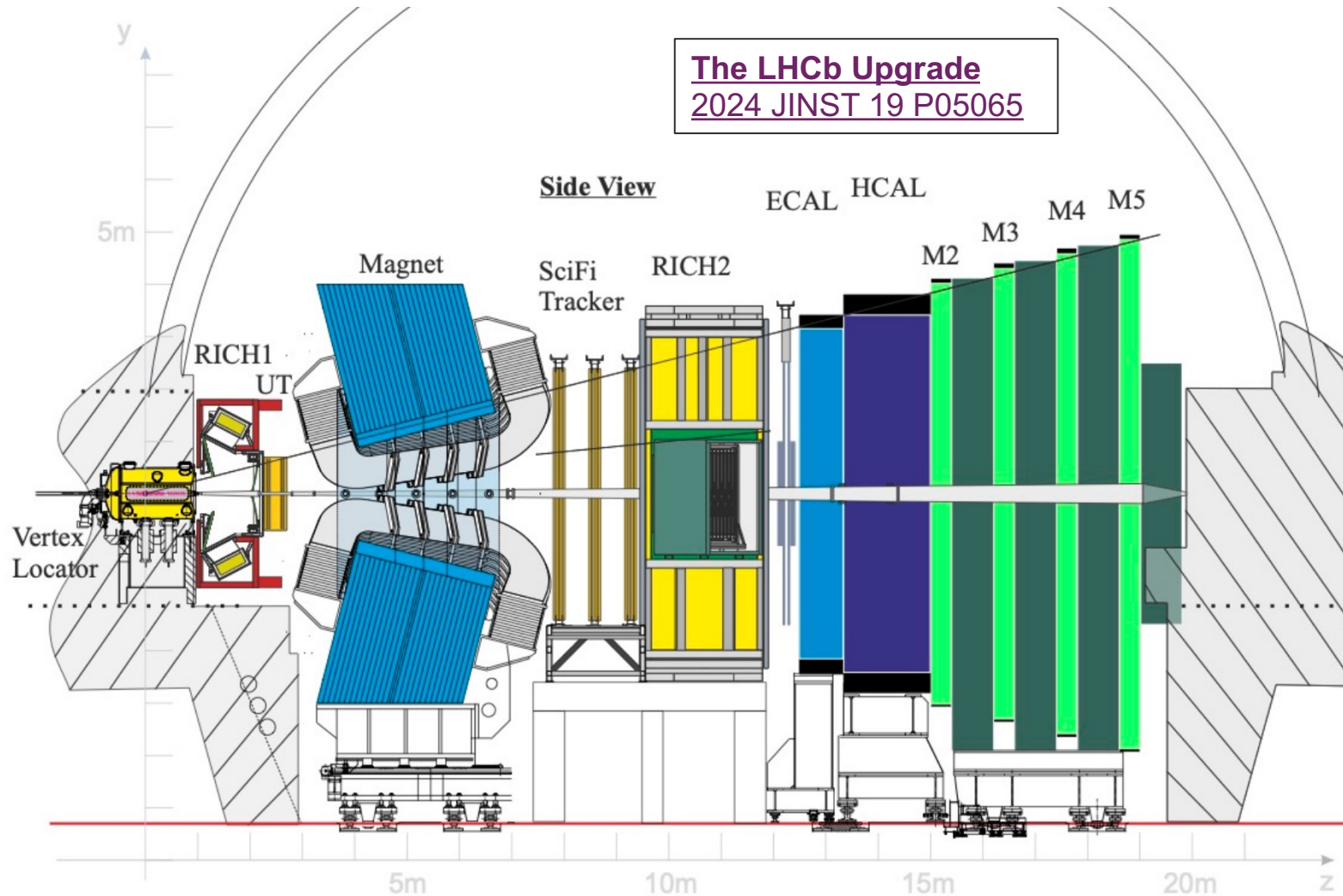


European Research Council  
Established by the European Commission

# The LHCb experiment

The Large Hadron Collider Beauty (LHCb) detector is a single-arm forward spectrometer covering approximately  $2 < \eta < 5$ .

Although the LHCb was initially designed to measure properties of particles with  $b$  and  $c$  quarks, it is also able to contribute to high-precision electroweak physics.

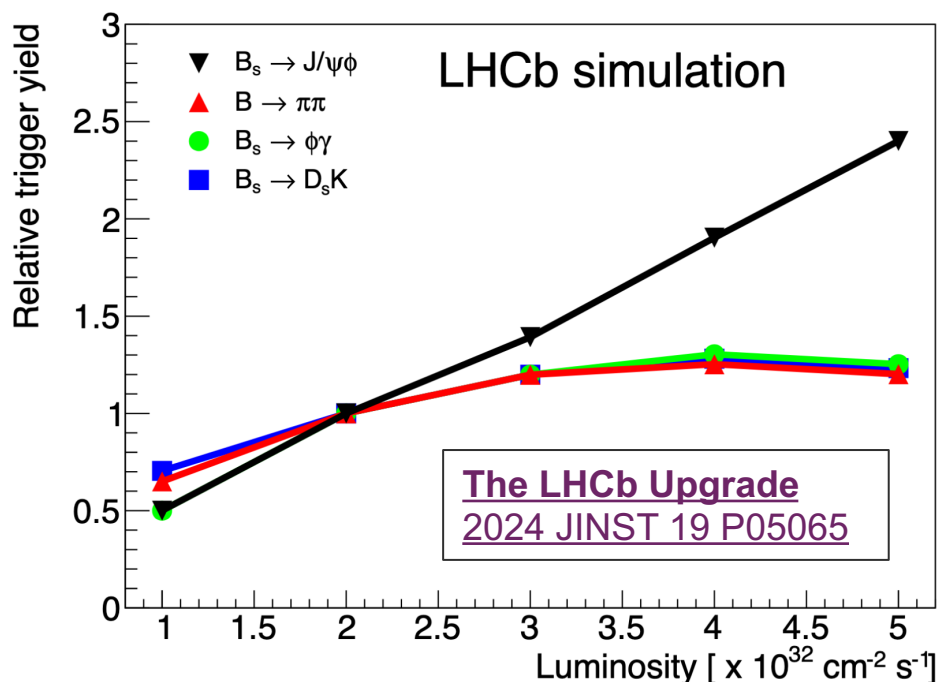


# The LHCb Upgrade

Aim: To operate at 5x the instantaneous luminosity than the previous LHCb experiment.

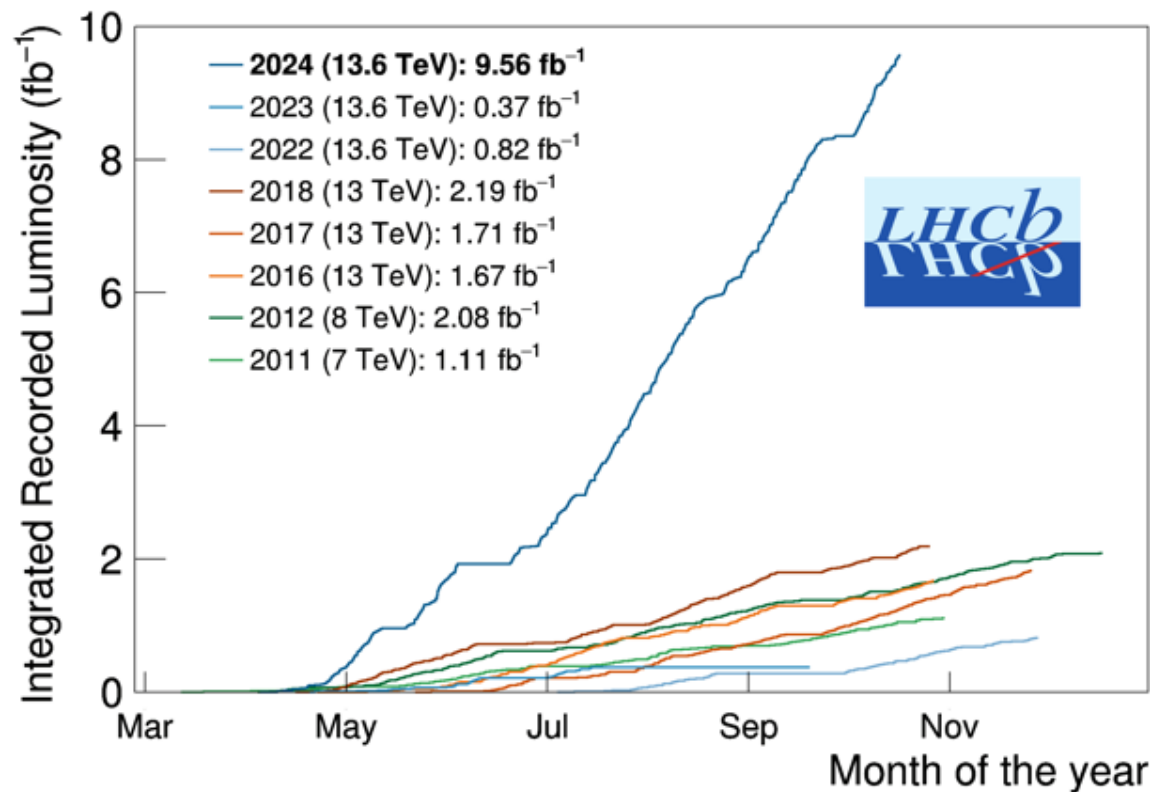
The old trigger (below) would have **saturated** and required a redesign

-> resulted in a novel fully-software trigger



Result:

Collected more data than ever before in 2024 and performed data-taking while operating at design luminosity



[lhcb outreach]: end-of-successful-proton-proton-collision-data-taking-period

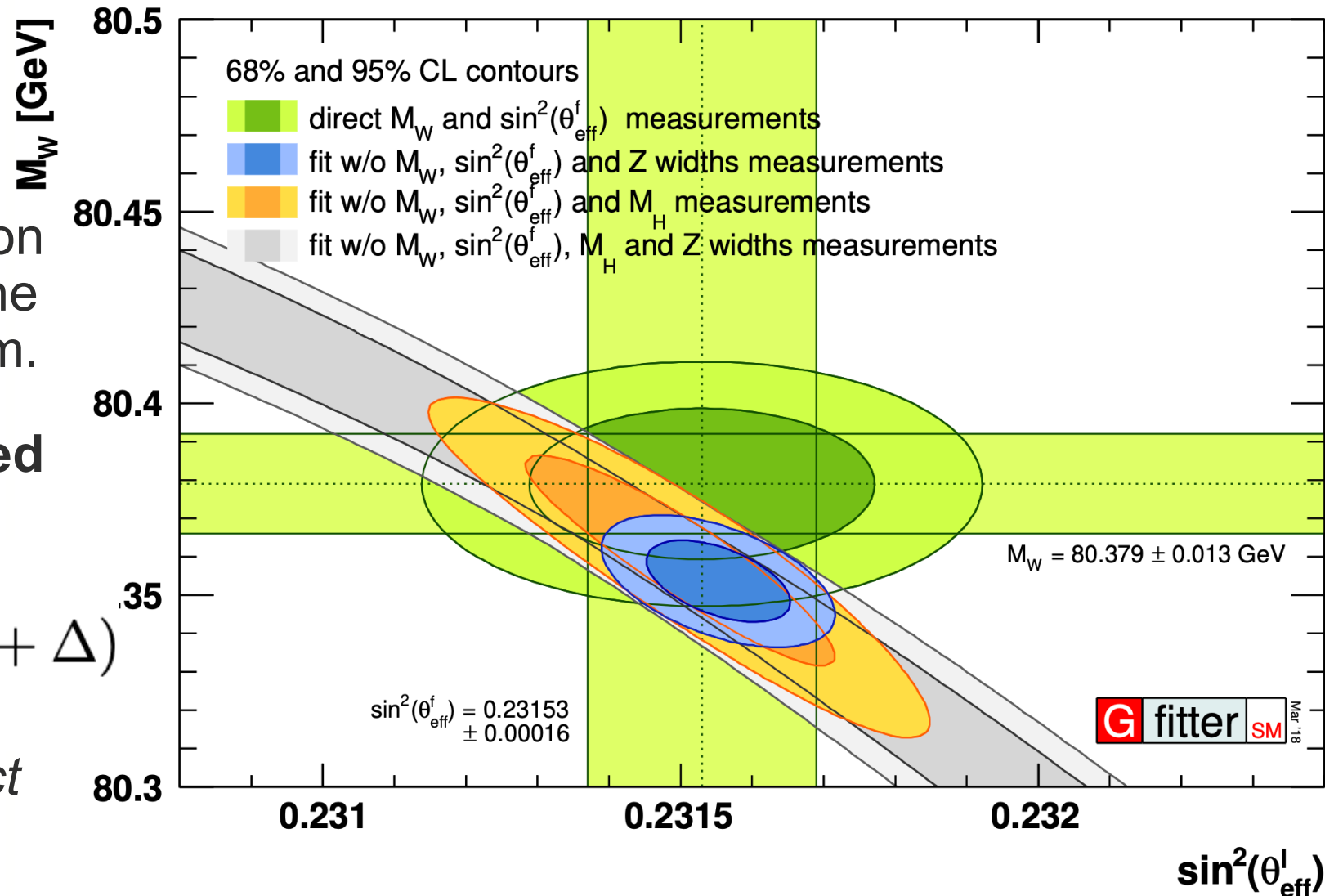
# EW physics

EW physics is a core foundation of the SM, directly related to the SSB and the Higgs mechanism.

The EW parameters are **related** in the SM.

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

-> Compare *direct* and *indirect* measurements to **test the SM**



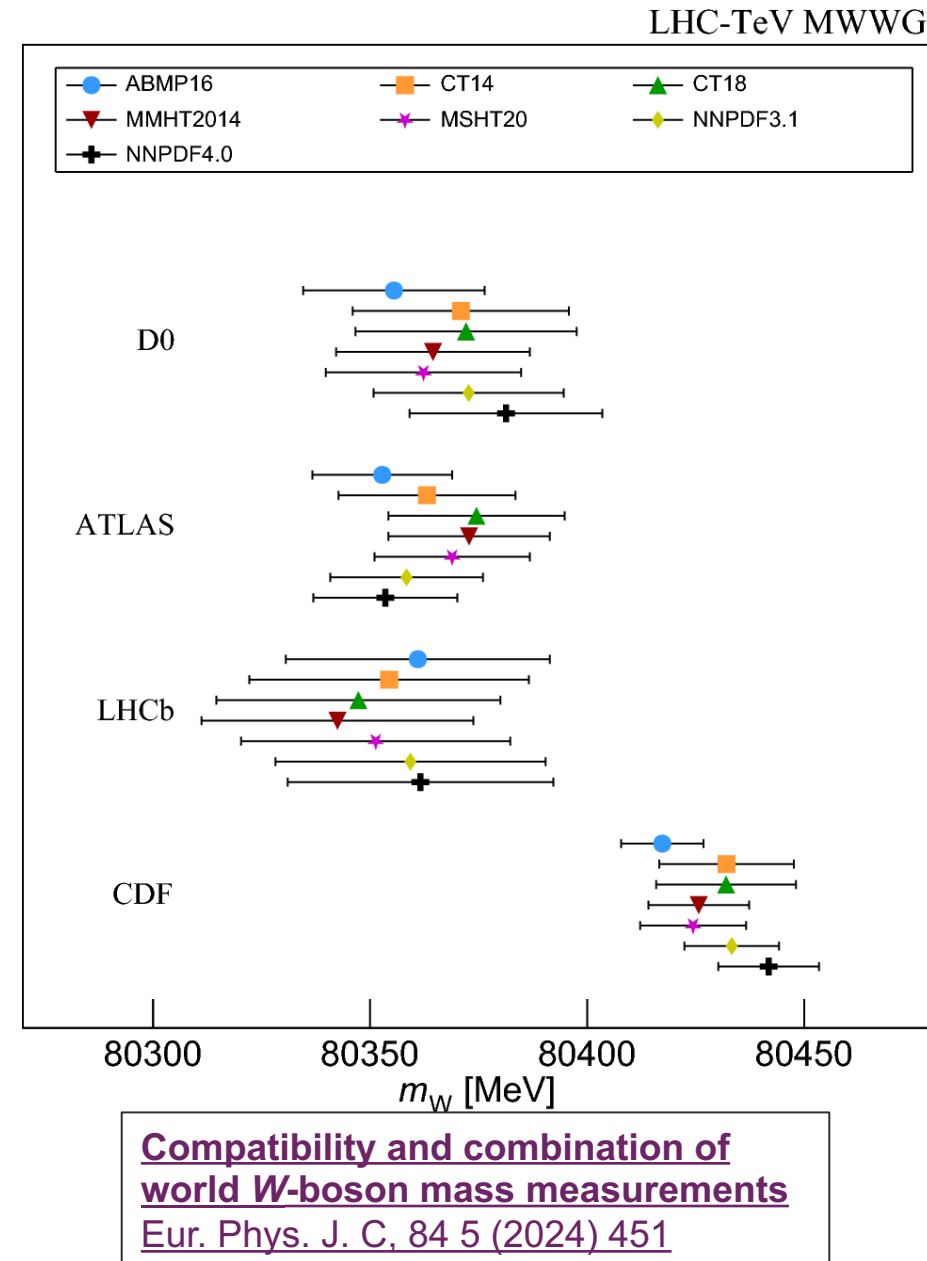
The global electroweak fit at NNLO and prospects for the LHC and ILC.  
*Eur. Phys. J. C* **74**, 3046 (2014)

# LHCb's potential in EW physics

Due to LHCb's unique acceptance:

- $W$  and  $Z$  cross-sections provides **complimentary constraints** to PDFs with ATLAS/CMS
- **Anticorrelation** in PDF systematic uncertainties in measurements of  $m_W$  between LHCb and ATLAS/CMS  
-> improves global combinations

\* The uncertainties around the parton distribution functions (PDFs) of the proton affects the boson  $p_T$  modelling.



# This analysis: W and Z cross-sections at 13.6 TeV

Measure production of  $W^\pm$  and  $Z$  bosons in proton-proton collisions at the LHCb via their muonic decay channels using a **subsection of the LHCb Upgrade data**. (~2 /fb of data collected in **Autumn of 2024**).

- Theoretically interesting to measure cross-section at new centre-of-mass energy ( $\sqrt{s} = 13.6$  TeV) with LHCb's acceptance.
- Evaluates high- $p_T$  performance in the LHCb Upgrade detector through the calibrations/efficiencies/modelling etc.

# EW analyses framework

Supports O(10) EW analyses *simultaneously*, O(20) people contributing, with 3 publications so far.

- **Shared tools**, accessed per analysis via configurations and snakemake workflows
- Via gitlab's continuous-integration, all **tools and active analyses are regression tested**

## ***This analysis:***

First analysis of LHCb Upgrade data using this framework. -> ***lays foundation*** for these shared tools/workflows to be used for future measurements.

## **NB:**

The measurements of  $m_W$ ,  $\theta_{\text{eff}}^l$ ,  $m_Z$  are ***statistically limited with the legacy dataset***

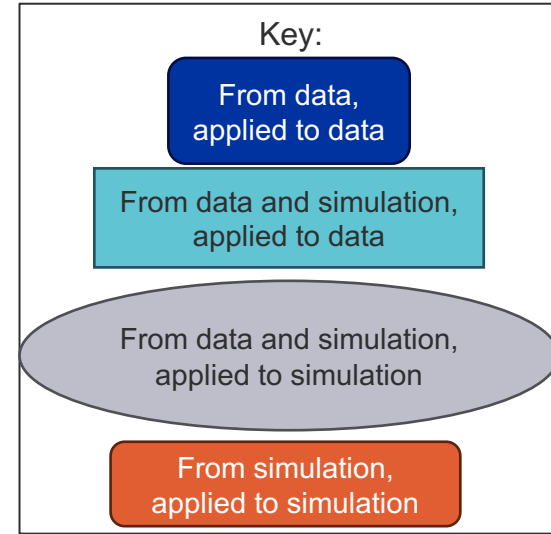
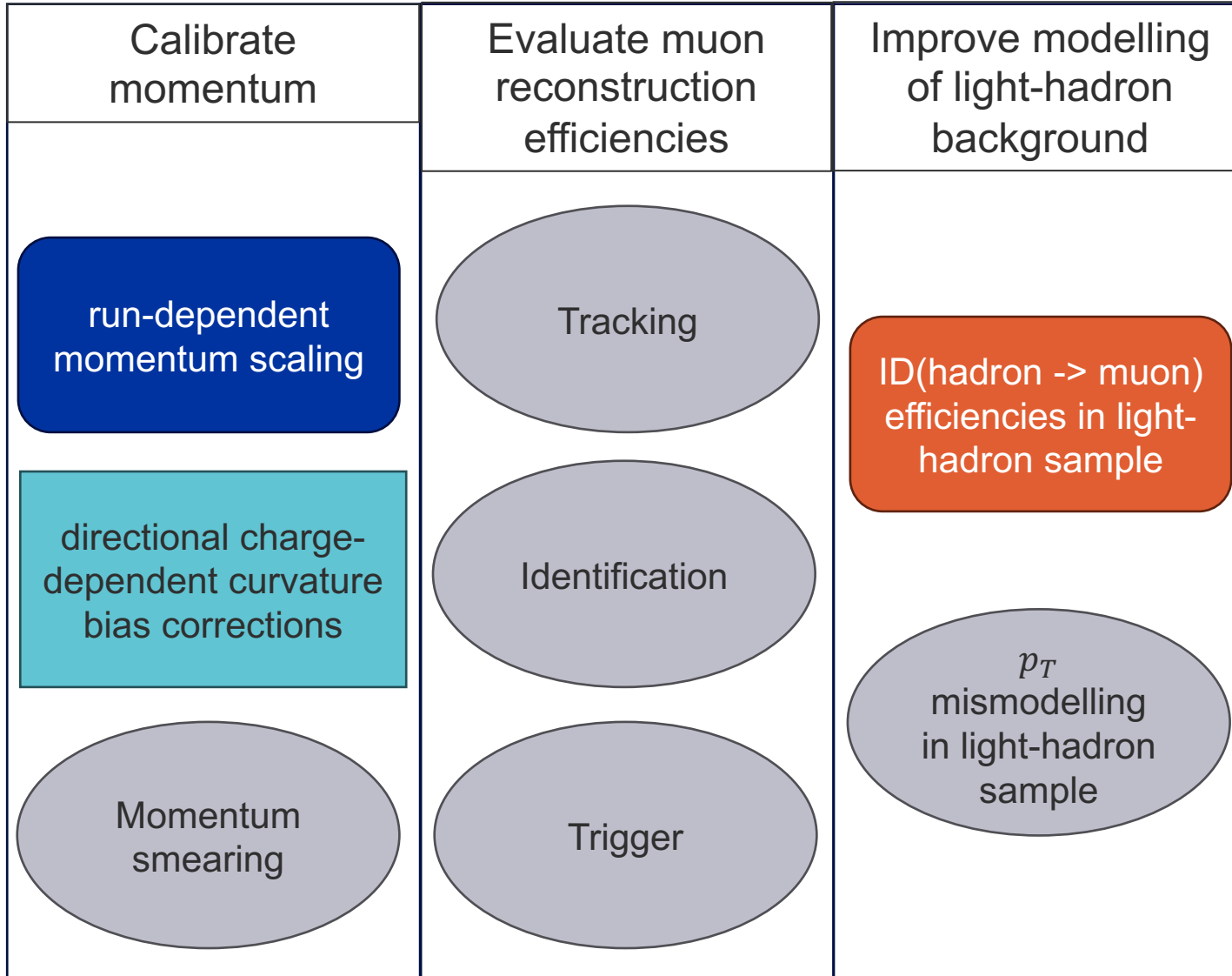
### test

- ✓ tools:general
- ✓ tools:momentum-calibration
- ✓ tools:process-tuples-run2
- ✓ tools:process-tuples-run3
- ✓ tools:qcd-reweighting
- ✓ tools:tracked\_result\_evolution
- ✓ tools:unit
- ✓ tools:variations

### analyses

- ✓ 24c1\_xsec
- ✓ 2024\_main\_result
- ✓ AI
- ✓ LFU
- ✓ LFU\_new\_fitter
- ✓ W\_xsec\_13TeV
- ✓ W\_xsec\_dpt
- ✓ WeakMixing
- ✓ all
- ✓ bblite
- ✓ mW:main
- ✓ mW\_rec:2016
- ✓ mW\_rec:main
- ✓ mZ
- ✓ qasym

# Analysis Workflow



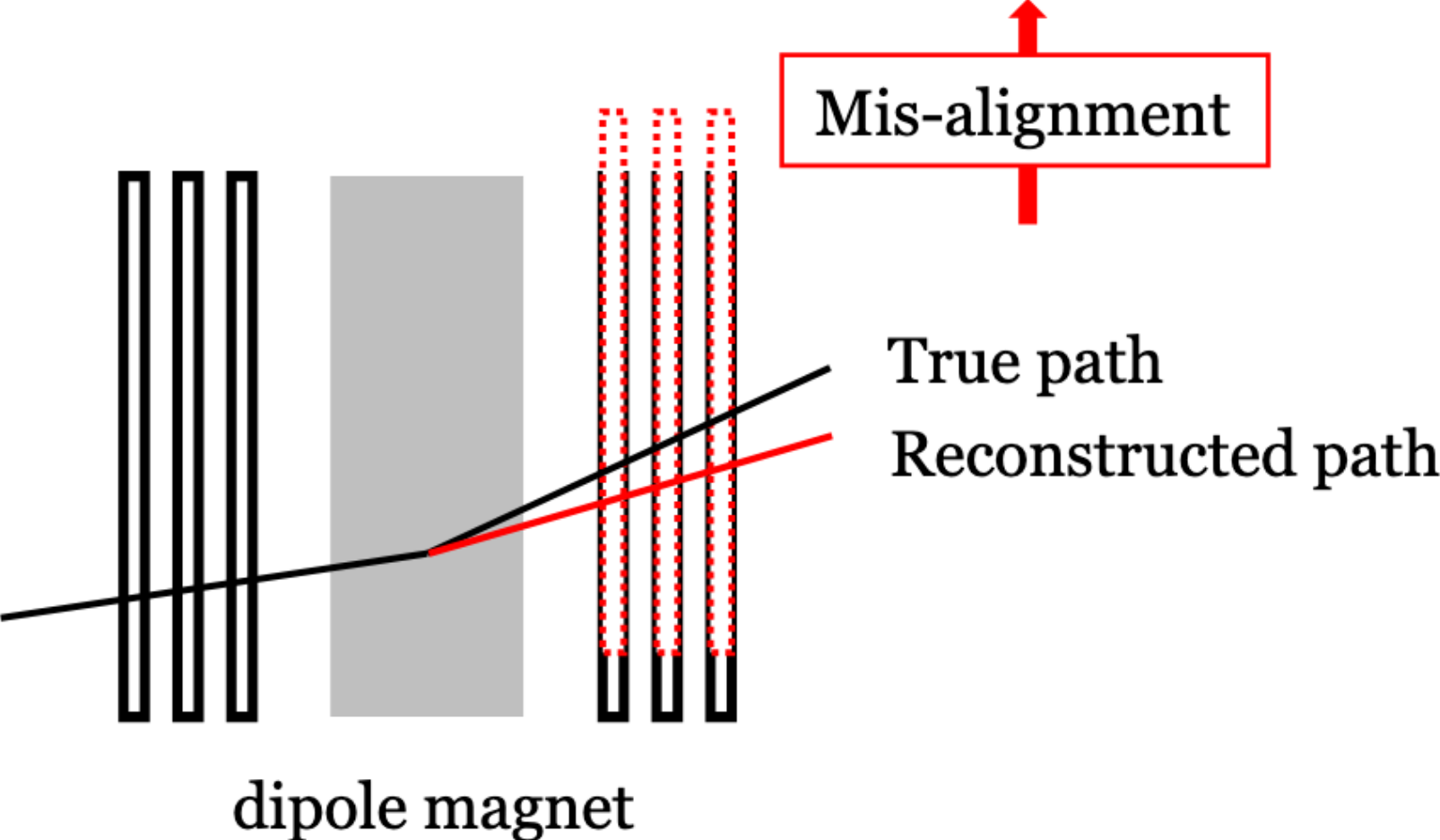
- Extract yield
- evaluate cross-section

# Charge-dependent curvature biases

Global misalignments can cause charge-dependent curvature biases

$$\delta(\phi, \eta): \frac{q}{p_{REAL}} = \frac{q}{p_{RECO}} + \delta$$

However! High- $p_T$  tracks like those for **electroweak muons are particularly susceptible to these effects.**



# The pseudomass

The *pseudomass*, is an estimator of the dimuon mass using *limited information*

Specifically:

- $Z \rightarrow \mu^+ \mu^-$  samples
- use limited information from one of the muons, then switch and recalculate

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

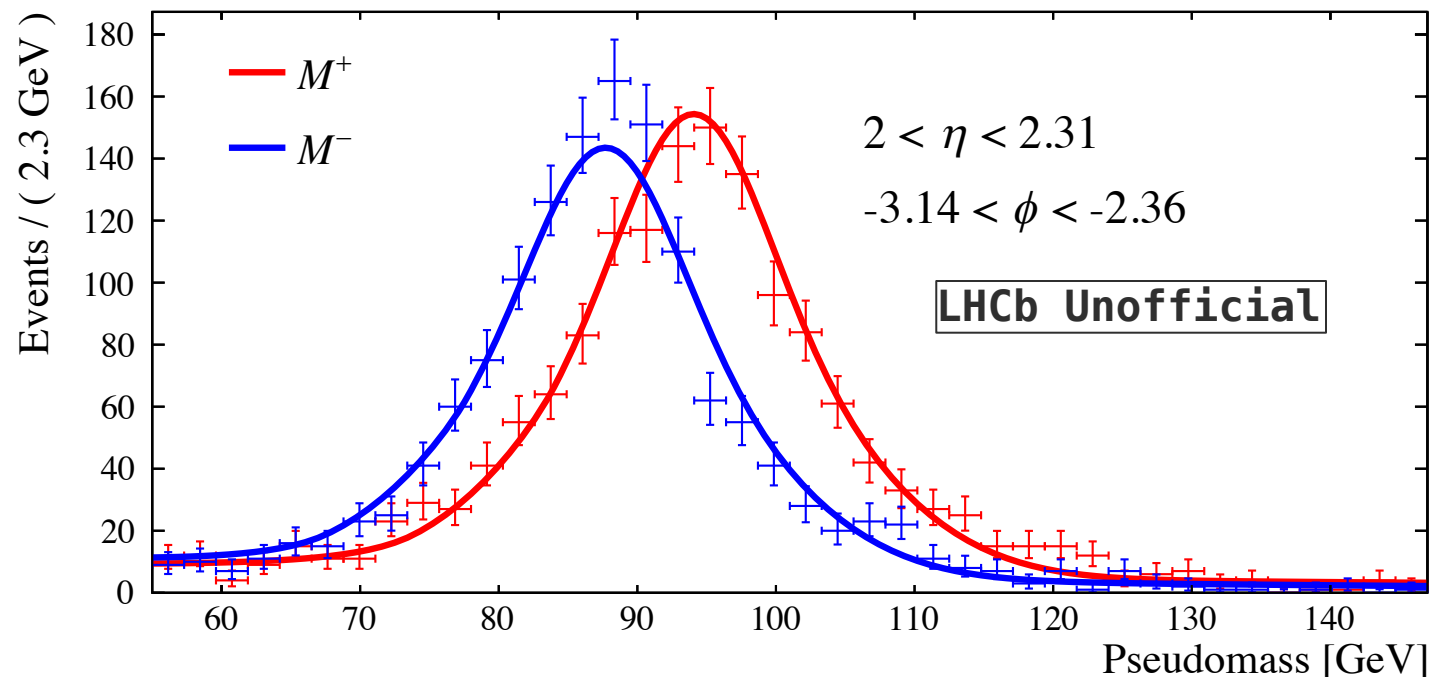
**The bias,  $\delta(\phi, \eta)$  is directly related to distance between the means of the two pseudomass peaks.**

Global misalignments can cause charge-dependent curvature biases

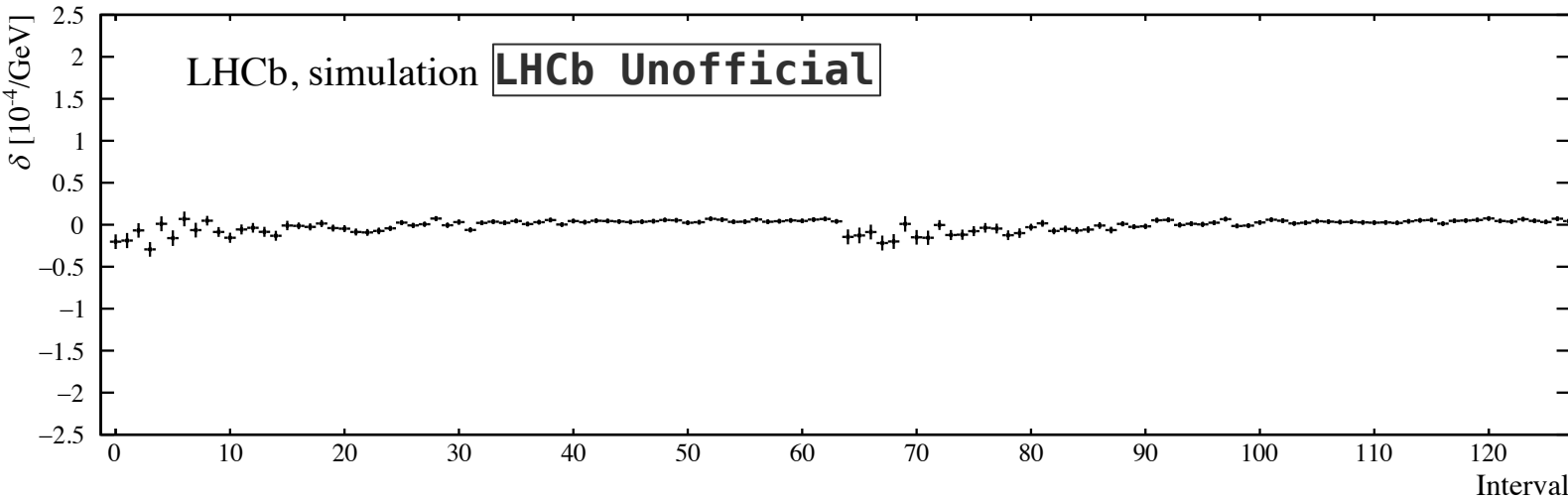
$$\delta(\phi, \eta): \frac{q}{p_{REAL}} = \frac{q}{p_{RECO}} + \delta$$

## Curvature-bias corrections using a pseudomass method

R. Aaij et al 2024 JINST 19 P03010

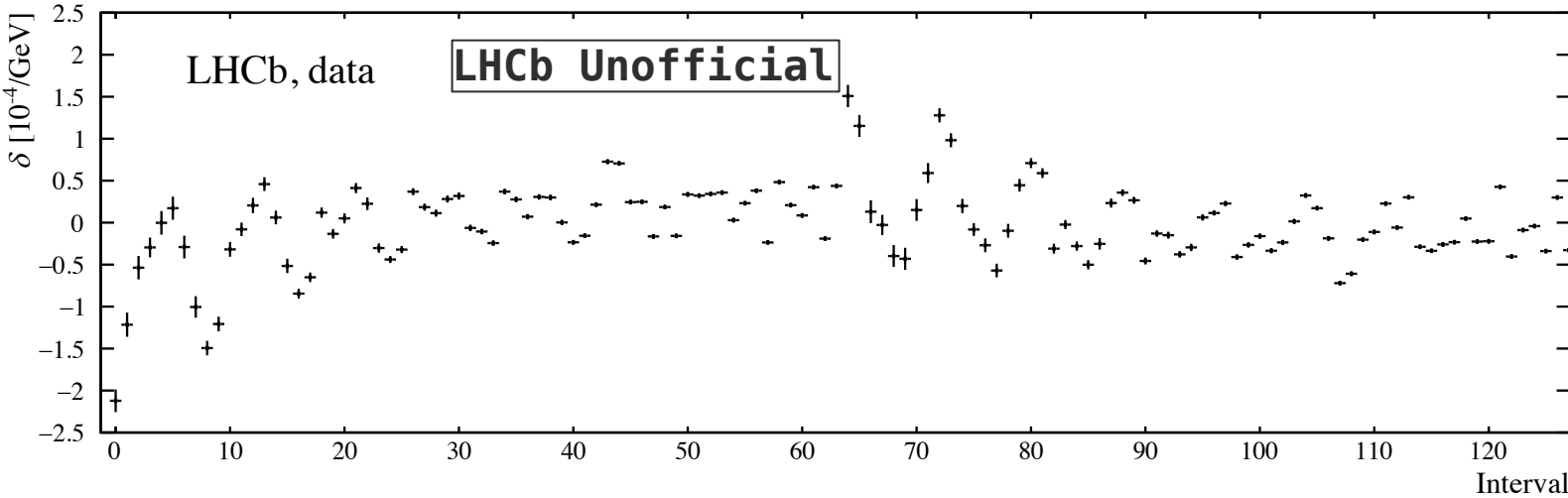


# Charge-dependent curvature biases



x-axis is flattened bins of  $\mu_\phi$ ,  $\mu_\eta$  and magnet polarity

Expected very small variations in MC



Much larger variations in data -> suggestive of real misalignments

Apply a correction of  $\delta_{\text{data}} - \delta_{\text{sim}}$  to the muons in data

# Effect on $M_{\mu\mu}$

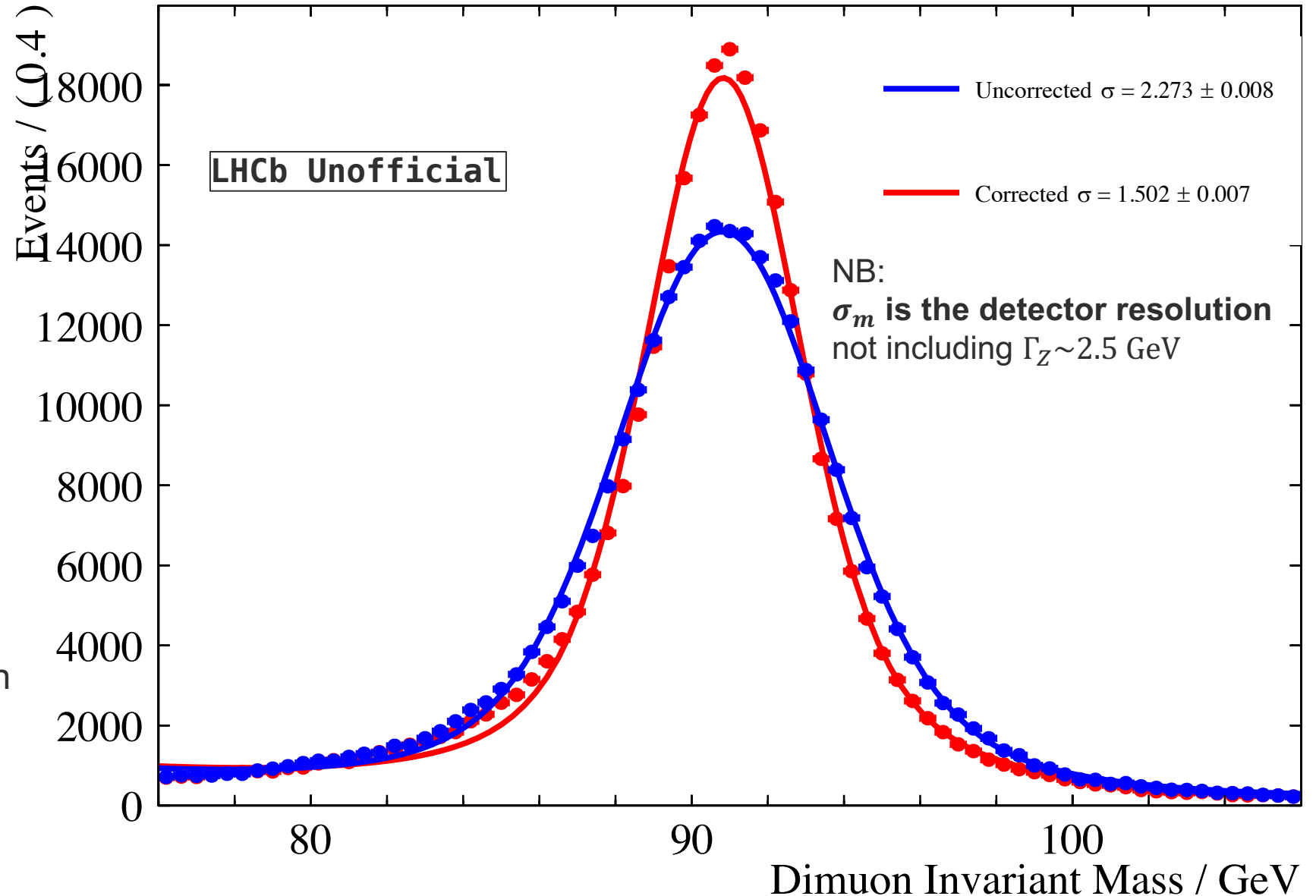
Effect on dimuon Z:

$$\frac{\sigma_m}{m} : 2.5\% \rightarrow 1.6\%$$

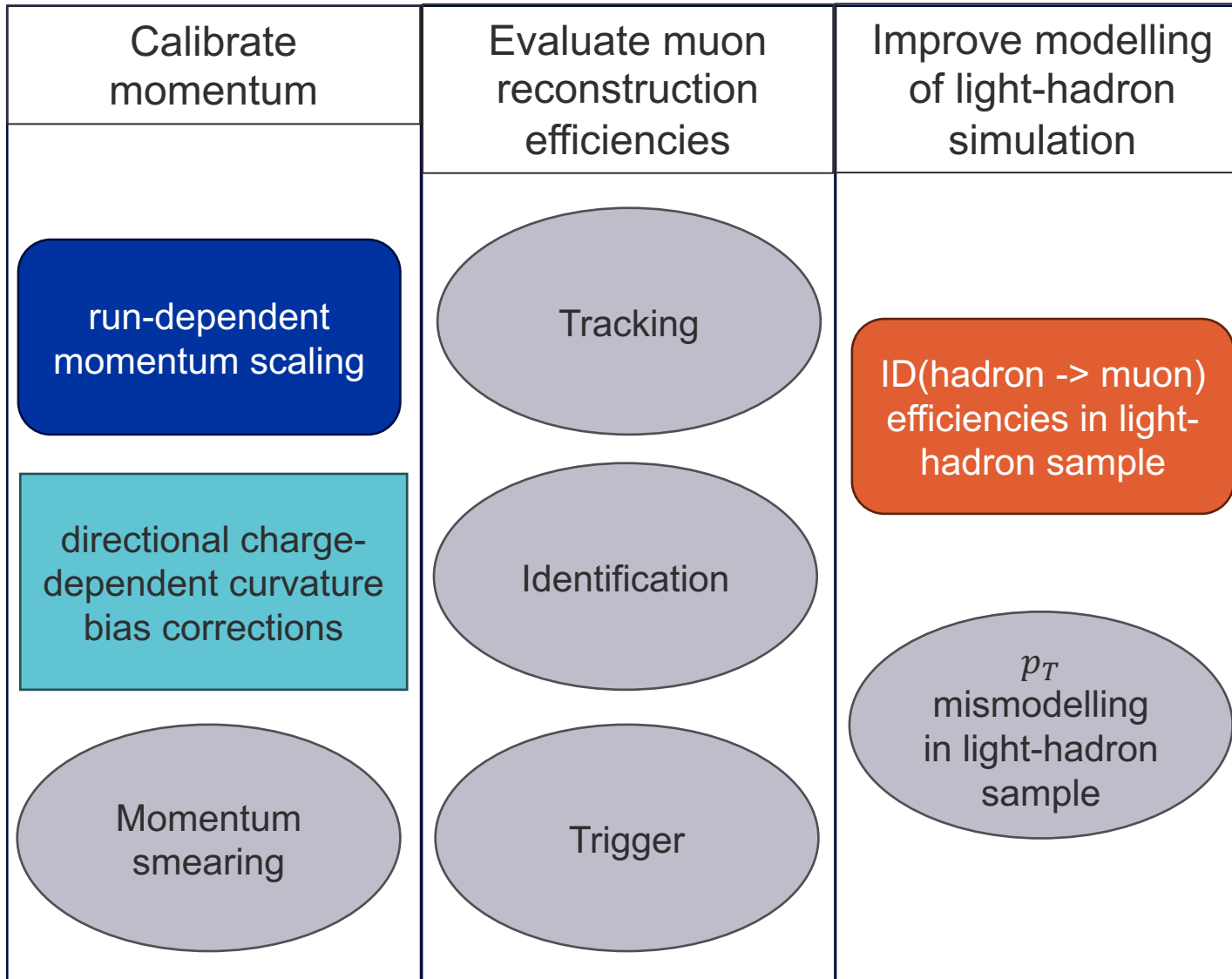
Nearing Run2-like detector resolution with the offline calibration ( $\frac{\sigma_m}{m} \sim 1.5\%$ )!

The muons from  $W, Z$  are particularly sensitive to this due to their high  $p_T$ .

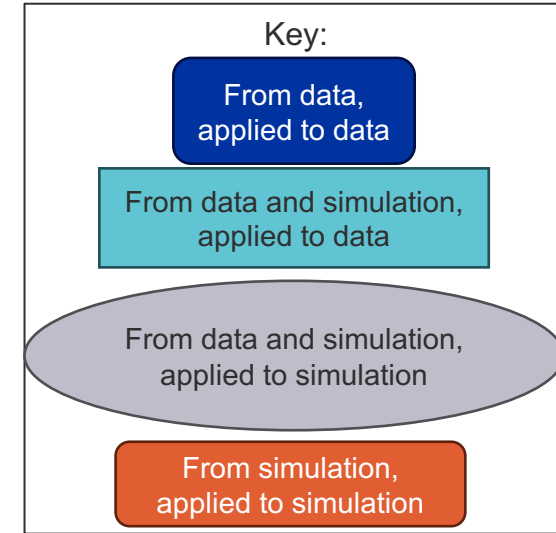
When applying the same correction to  $Y(1S)$  and  $J/\psi$  dimuon samples the improvements are marginal



# Analysis Workflow



- Extract yield
- evaluate cross-section



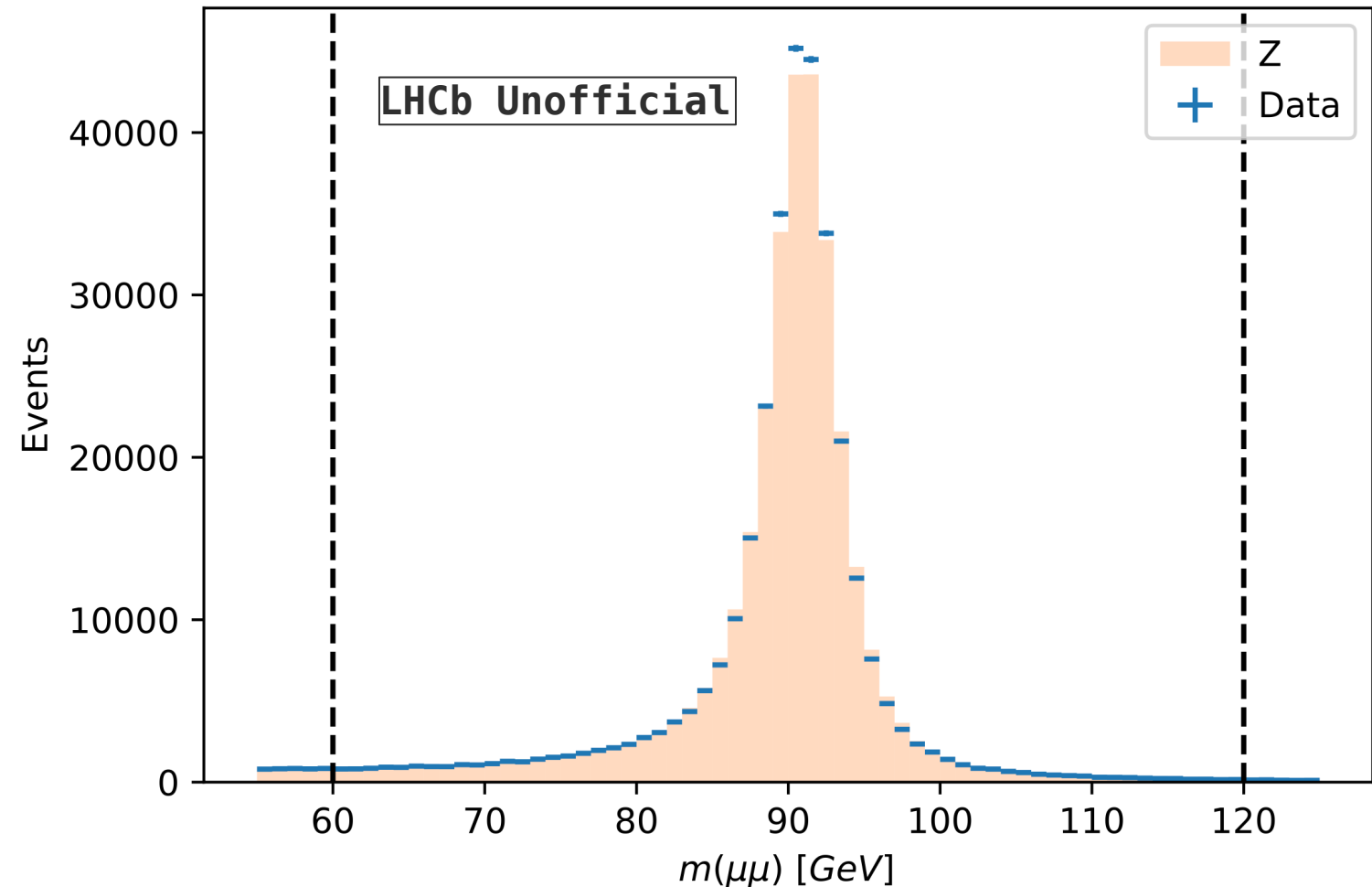
# Z Yield

$$60 < m_Z \text{ [GeV]} < 120, \quad \mu_{P_T}^{\pm} \text{ [GeV]} > 20, \quad 2.0 < \mu_{\eta}^{\pm} < 4.5$$

$$\sigma = \frac{\text{Yield}}{\text{Luminosity} \cdot \text{efficiency}}$$

High purity -> Z yield is trivial

Simply count the number of candidates in the fiducial volume



# W Yield

$$25 < \mu_{p_T} [\text{GeV}] < 55, \quad 2.2 < \mu_\eta < 4.4$$

Template fit the  $p_T$  spectrum to extract  $W \rightarrow \mu\nu$  yields

Independent fits per muon charge.

Each fit floats the yields for the W signal and the light hadron contribution.

Known single-muon backgrounds fixed with respect to the observed  $Z \rightarrow \mu^+ \mu^-$ :

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

$$W^+ \rightarrow (\tau^+ \rightarrow \mu^+ \bar{\nu}_\tau \nu_\mu) \nu_\tau + \text{c. c.}$$

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

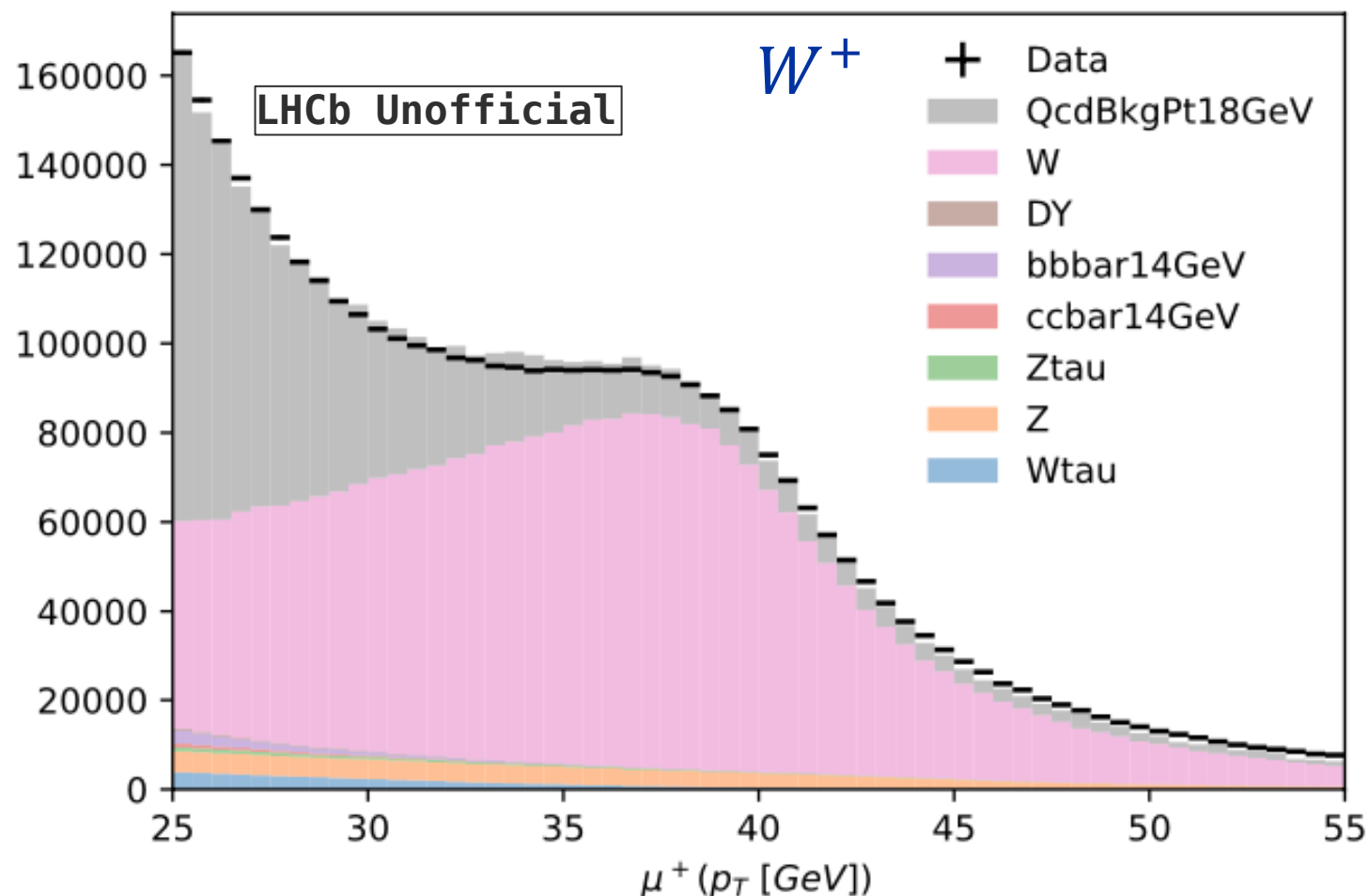
$$\text{lowmass DrellYan} \rightarrow \mu^+ \mu^-$$

$$b\bar{b} \rightarrow \mu$$

$$c\bar{c} \rightarrow \mu$$

Caveat:

Purity is expected to improve as the isolation information used in the analysis develops



# W&Z cross-sections

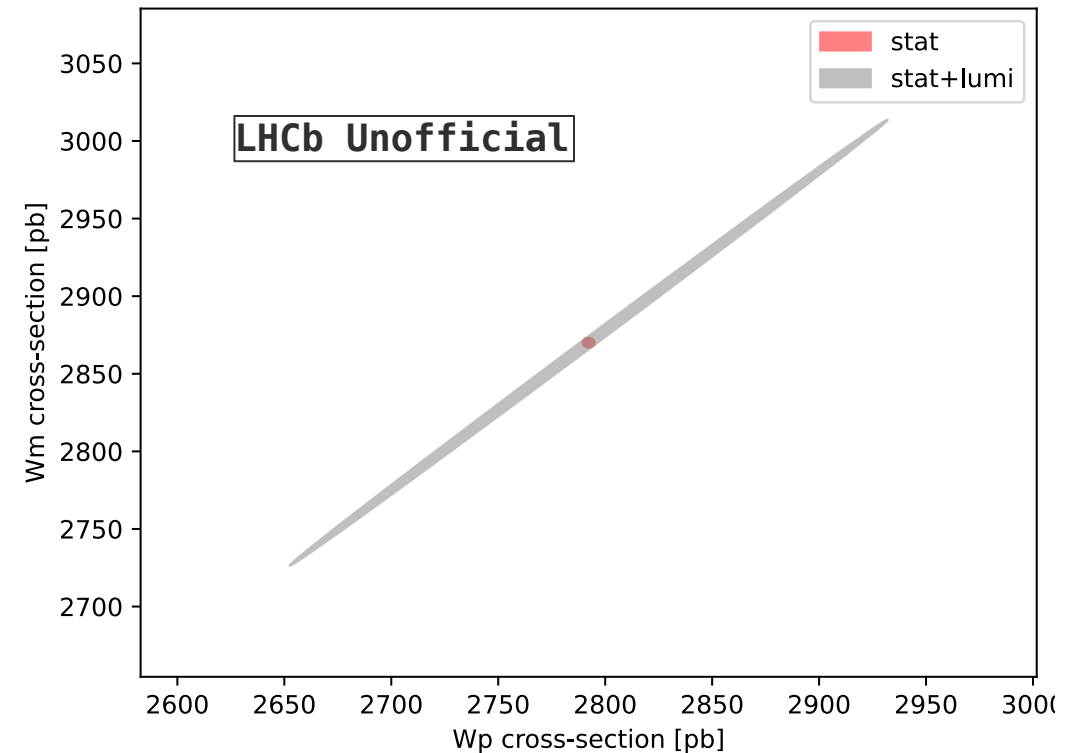
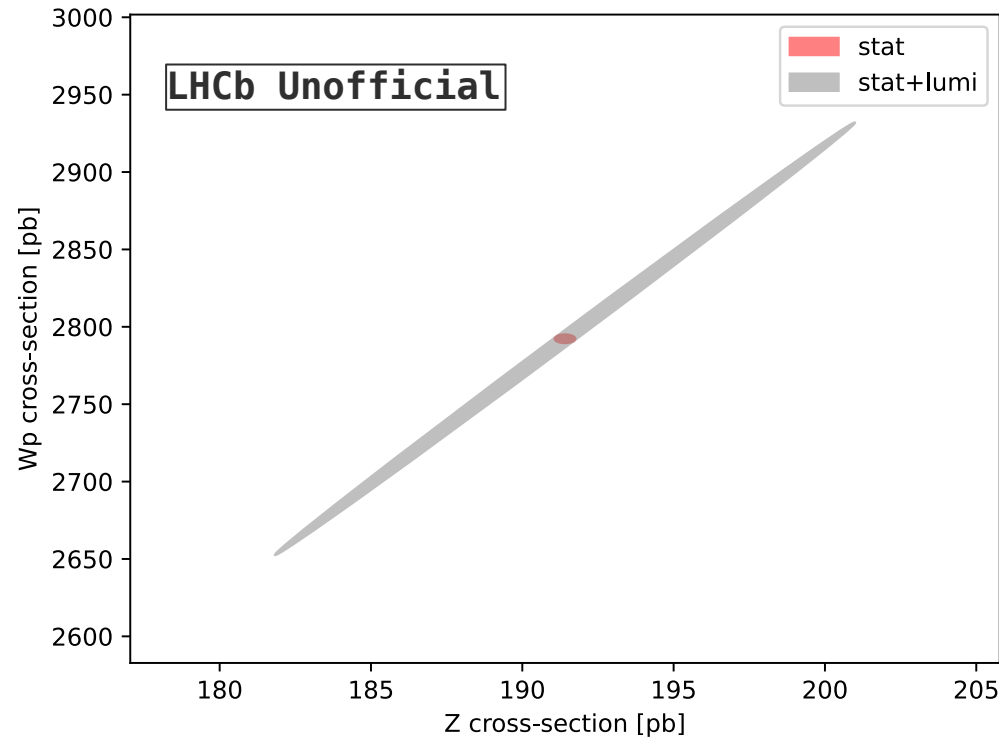
Luminosity calibration currently conservative ~5% error

LHCb's offline calibration in progress:

expected to end up similar to LHCb Run2 which had ~2%

The analysis remains of theoretical interest as a large part of the interest is in the direction along the *minor-axis*

**NB: Significant correction to the efficiencies not included yet, absolute values of cross-sections are shifted.**



# Summary

EW Physics at LHCb Upgrade is expected to have greater sensitivity as a test of the Standard Model and greater reach for potential new physics when compared to the previous LHCb.

- Much greater luminosities will be available than previously possible
- High- $p_T$  muon performance in LHCb's 2024 dataset is nearing previous performance in several calibrations, and in some cases surpassing it!

This  $W^\pm, Z$  production measurement is almost 'feature complete' and aiming to be the first electroweak measurement with the LHCb Upgrade:

- Theoretically interesting to measure cross-section at new centre-of-mass energy ( $\sqrt{s} = 13.6$  TeV) with LHCb's acceptance.
- Evaluates high- $p_T$  performance in the LHCb Upgrade detector through the calibrations/efficiencies/modelling etc.
- Lays foundation in shared framework for future EW measurements with LHCb Upgrade.