EW Physics in the Forward Region

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on behalf of the LHCb Collaboration

Workshop on the physics of HL-LHC, and perspectives at HE-LHC.
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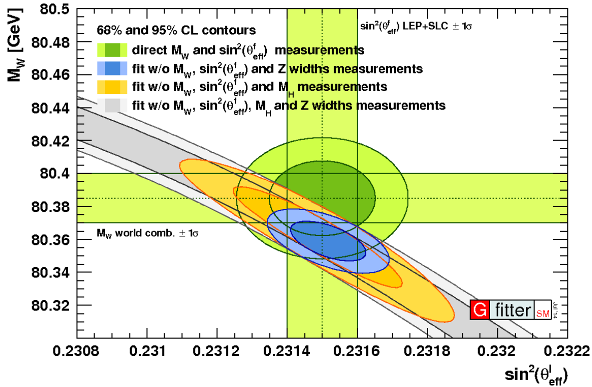
Outline

This talk will address what LHCb can do in EW physics in the HL-LHC era, focusing on selected topics:

1. LHCb Phase-II upgrade
2. Effective leptonic weak mixing angle measurement, $\sin^2\theta_{\text{eff}}^{\text{lept}}$
3. W mass measurement, m_W



Eur.Phys.J.C(2014)74

LHCb Phase-II upgrade

LHCb Phase-II upgrade

LHCb is increasingly used as a general physics measurements in the forward region, complementary to the GPDs (General Purpose Detector; e.g., ATLAS, CMS).

Table 1.1: Summary of LHCb *pp* data taking and running conditions for the current experiment, the Phase-I and Phase-II Upgrades. The future years of data taking will be interrupted by Long Shutdowns 2, 3, 4 and 5, currently scheduled to take place in 2019-2020, 2024-2026, 2030 and 2034, respectively [22].

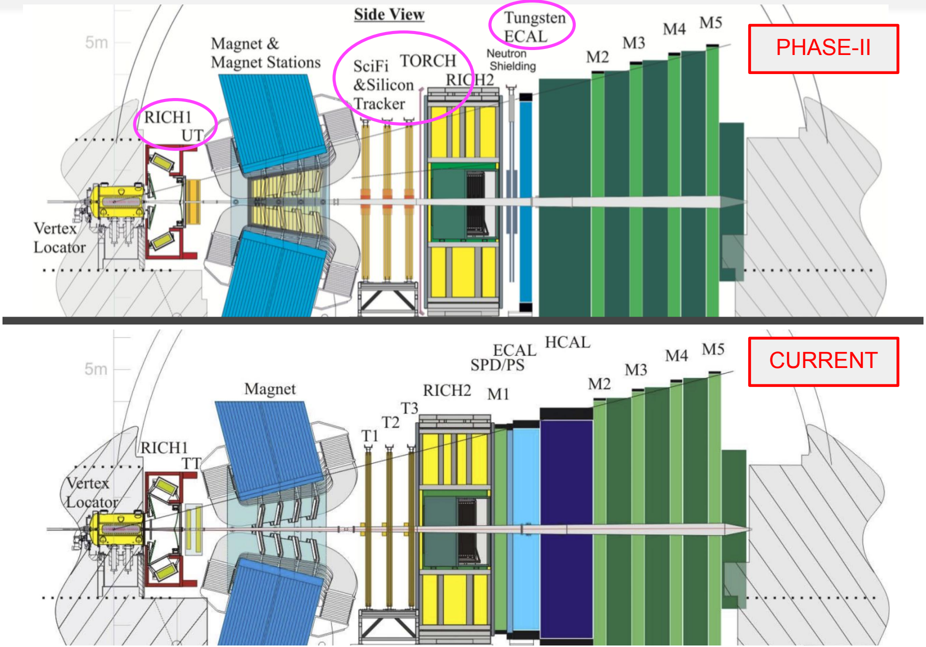
	LHC Run	Period of data taking	Maximum $\mathcal{L}$ $[\text{cm}^{-2}\text{s}^{-1}]$	Cumulative $\int \mathcal{L}\,dt$ $[\text{fb}^{-1}]$
Current detector	1 & 2	2010–2012, 2015–2018	4×10^{32}	8
Phase-I Upgrade	3 & 4	2021–2023, 2026–2029	2×10^{33}	50
Phase-II Upgrade	5 $\rightarrow$	2031–2033, 2035 $\rightarrow$	2×10^{34}	300

Main challenges from HL-LHC:

- Mean number of interactions ($\sim$ 2-3 $\rightarrow$ 50)
- Particle multiplicities
- Radiation damage

*[CERN-LHCC-2017-003] Expression of Interest for a Phase-II LHCb Upgrade

Detector upgrade



An opportunity to improve current subdetector limitations, and taking full advantage of HL-LHC!

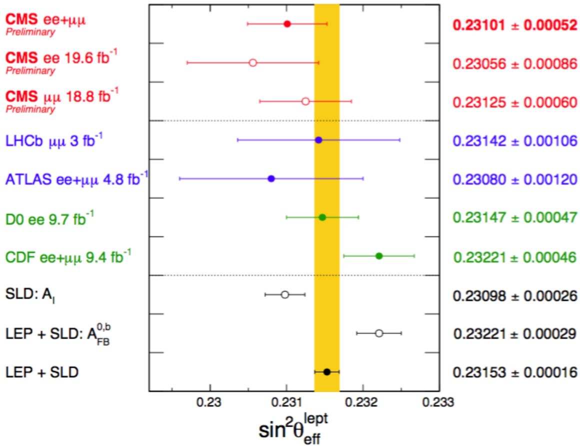
Weak mixing angle measurement; $\sin^2\theta^{\text{lept}}_{\text{eff}}$

Weak mixing angle measurement

Crucial consistency test of SM.

$\sin^2\theta_{\text{eff}}^{\text{lept}}$; effective leptonic weak mixing angle, via $Z \to ll$ decay.

At LHC, currently the best limit is from CMS*, followed by LHCb†.

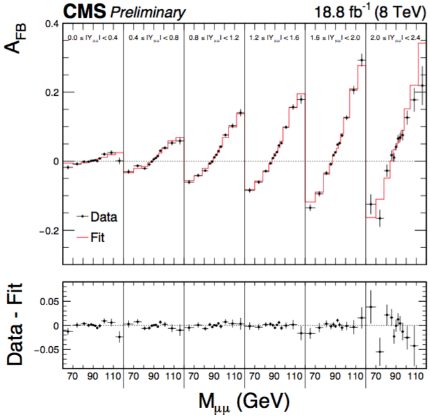


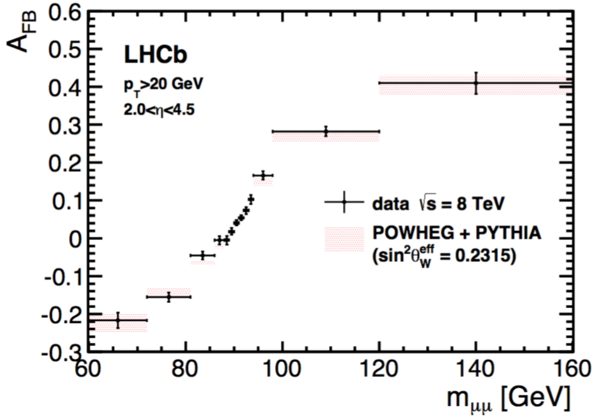
*[CMS-PAS-SMP-16-007] Measurement of the weak mixing angle with the forward-backward asymmetry of Drell-Yan events at 8 TeV

†[JHEP 1511(2015) 190] Measurement of the forward-backward asymmetry in $Z/\gamma* \to \mu^-\mu^+$ decays and determination of the effective weak mixing angle

Why this measurement is interesting at LHCb

The sensitivity of $A_{\rm FB}$ (forward-backward asymmetry, $\frac{N_F - N_B}{N_F + N_B}$) to $\sin^2\theta_{\rm eff}^{\rm lept}$ is greater at large rapidities of Z boson (produced predominantly from $u\bar{u}, d\bar{d}$).





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Improvement

Current LHCb result (7+8 TeV):

$$\sin^2\theta^{\text{lept}}_{\text{eff}} = 0.23142 \pm 0.00073(\text{stat}) \pm 0.00052(\text{exp}) \pm 0.00056(\text{theory})$$

Several uncertainties improvements are expected:

- Statistical uncertainty ($3 \to 300\,\text{fb}^{-1}$ at HL-LHC) will be very promising.

Period	Yield	Statistical Sensitivity (naïve scaling) $\sin^2\theta^{eff}_{lept}$ / 10^{-5}
End of Run 2	700k	50
End of Run 3	7M	20
300/fb	40M	7

Naïve scaling
Naïve scaling

- Experimental uncertainty, currently dominated by momentum scale, could also be reduced as more calibration sample accumulated, as well as improved analysis technique (e.g., event weighing*).
- The measurement could also be made with electron channel.
- Theoretical uncertainty will have a very impact role!

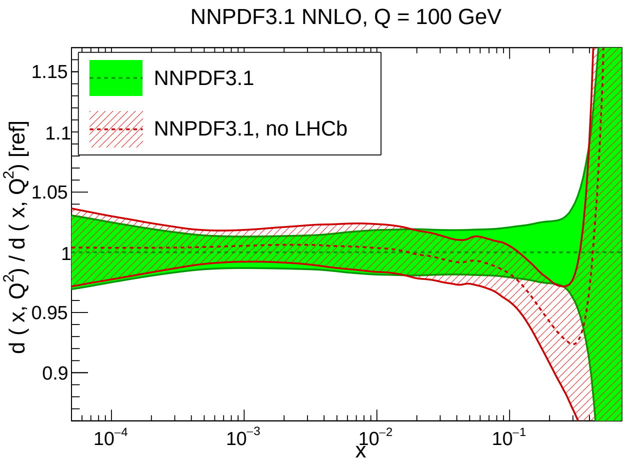
*[Eur.Phys.J.C67:321-334,2010] A simple event weighting technique for optimizing the measurement of the forward-backward asymmetry of Drell-Yan dilepton pairs at hadron colliders

Impact of theoretical uncertainty

Progress in differential cross-section measurements at LHCb helps contraining the PDF at large-x, as seen in the recent NNPDF3.1 release. The uncertainty decreases up to a factor of 2.

Uncertainty	average $\Delta\lvert A_{FB}^{pred}\rvert$
PDF	0.0062
scale	0.0040
α_s	0.0030
FSR	0.0016

Figure 1: Run-I theoretical uncertainty



*[arXiv:1706.00428] Parton distributions from high-precision collider data

W-boson mass measurement

W-boson mass measurement

New physics can be hiding in the m_W measurement, as direct constraint remains weaker than indirect constraint (m_Z, α, G_F)

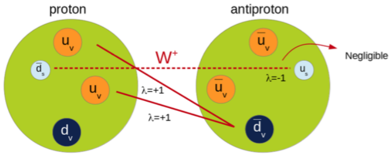
- Current world best: 80.387 ± 0.019 GeV [CDF]
- Current world average: 80.385 ± 0.015 GeV [PDG]
- Prediction in global EW fit: 80.358 ± 0.008 GeV [Eur.Phys.J.C(2014)74]

- ATLAS: 80.3695 ± 0.019 GeV [arXiv:1701.07240] $\sim$ CDF precision

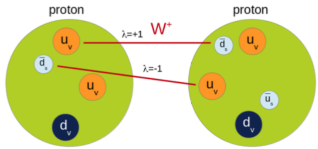
At LHC, the W mass is usually extracted from the PT(lepton) spectrum for different W mass (or m_T spectrum if available).

QCD & PDF uncertainty is dominating at the LHC

A proton-proton collider is the most challenging enviroment to measure m_W, worse compared to e+e- and proton-antiproton



In $p\bar{p}$ collisions W bosons are mostly produced in the same helicity state



In pp collisions they are equally distributed between positive and negative helicity states

Large PDF-induced W-polarisation uncertainty affecting the p_T lepton distribution

Further QCD complications

- Heavy-flavour-initiated processes
- W+, W- and Z are produced by different light flavour fractions
- Larger gluon-induced W production

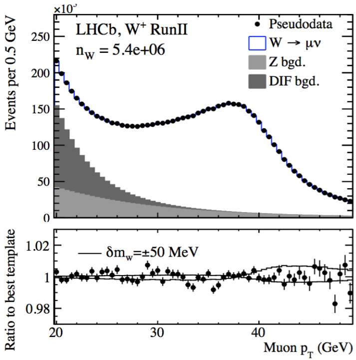
Combined categories	Value [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW Unc.	PDF Unc.	Total Unc.	χ^2/dof of Comb.
m_T-p_T^ℓ, $W^\pm$, e-μ	80369.5	6.8	6.6	6.4	2.9	4.5	8.3	5.5	9.2	18.5	29/27

*Slide from https://indico.cern.ch/event/466934/contributions/2575348

W mass at LHCb

A measurement at LHCb could achieve a statistical precision of 10 MeV (W^+) and 13 MeV (W^-) using just Run II data.

The PDF uncertainty in the forward region is anti-correlated with those used in ATLAS, CMS, such that
δm_W(GPD+LHCb) $<$ δm_W(GPD+GPD).



Careful coordination between LHC experiments
can help exploiting the complementarity!

* [Eur. Phys. J. C (2015) 75]: Prospects for improving the LHC W boson mass measurement with forward muons

Room for improvements

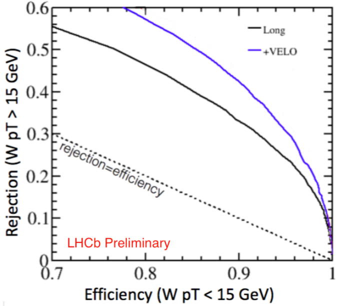
With the upgraded ECAL, the measurement could be made with the electron final state:

- uncorrelated statistical and experimental systematic uncertainties.
- improved ECAL performance, reduced bremsstrahlung (material budget before the magnet).

Restricting measurement to region where QCD is better modelled.

- This is an analysis-level improvement, with possibility to estimate a recoil opposite of $p_{\mathrm{T}}(W)$ using VELO.
- Not perfect (LHCb is not hermetic), but significant gain is possible as seen from toy study.

Can create a forward recoil or MET variable.



See also talk by W.Barter

Conclusion

- EW programme at LHCb continues to make the best use of the GPD-complimentarity, providing precision measurements and improving systematics.
- $\sin^2\theta^{\text{lept}}_{\text{eff}}$: Forward region at LHCb is very sensitive to A_{FB} measurement. The uncertainties (stat, exp, theo) are expected to continue to be reduced as it enters the HL-LHC era, up to a factor of 3.
- m_W: Constraining the uncertainty using measurement from LHCb is favorable given the QCD modelling and anti-correlated PDF uncertainty with GPD's.
- In both cases, the upgrade ECAL is anticipated to enable further exploitation in electron channel, providing orthogonal statistics.