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Electroweak physics in the forward region at LHCb(*)

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Summary. — The LHCb experiment covers the forward region of proton-proton collisions and can study W and Z bosons in this phase space complementary to ATLAS and CMS, contributing to the current landscape of Electroweak (EW) Physics. Thanks to the excellent performance of the detector, the fundamental parameters of the Standard Model can be precisely measured by studying the properties of electroweak bosons. In this proceeding, an overview of the latest EW measurements at the LHCb experiment is presented. This includes the measurement of the mass of the W boson and angular coefficients of $Z \to \mu\mu$.

1. – Introduction

The Standard Model (SM) of particle physics provides a comprehensive framework for understanding matter and its subatomic interactions. While the SM successfully accounts for many fundamental interactions, it falls short in explaining several observed phenomena. Various approaches have been considered to address these gaps, including extending the SM with new particles, incorporating different symmetries, or even rethinking the entire model. This has led to extensive efforts to scrutinize the Electroweak (EW) sector of the SM, which governs electromagnetic and weak interactions among particles. High-precision measurements are crucial to identify any deviations from SM predictions, offering experimental constraints for alternative models.

The Large Hadron Collider (LHC) has seen experiments like ATLAS and CMS, which have made significant measurements in the EW sector, validating SM expectations. LHCb, originally designed for b and c hadron physics, has emerged as a valuable contributor, exploring EW and QCD properties in a phase space complementary to ATLAS and CMS. This proceeding presents the latest EW physics results from LHCb obtained analysing Run 2 data.

2. – The LHCb detector

The LHCb experiment [1] is a single-arm spectrometer in the forward region originally designed to study b and c hadron physics. It has an excellent track momentum resolution going from 0.4% at 0.5 GeV to 0.6% at 100 GeV, very good muon and electron ID

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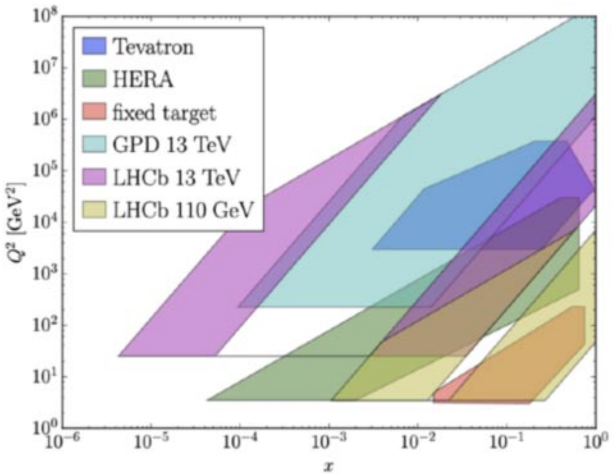

Fig. 1. – xQ^2 plane showing the acceptance of several experiments. The LHCb acceptance is shown in violet, while ATLAS and CMS acceptance ("GPD 13 TeV") are shown in light-blue.

efficiency and a good electron reconstruction system that allows for bremsstrahlung recovery. The two RICHs combined with the calorimeter system allow to perform Particle Identification (PID). It also has an excellent vertex reconstruction system, that allows to tag jets produced by b- and c-quarks by reconstructing the secondary vertex formed by tracks inside the jet cones.

Despite being designed for hadron physics, the LHCb experiment has proven itself to perform important measurements in the EW and QCD sectors, and therefore it can be considered as a General Purpose Forward Detector. At LHCb, it is possible to test perturbative QCD (pQCD) predictions in the $2 < \eta < 5$ pseudorapidity range, corresponding to the forward phase space region, which is complementary to the phase space studied by other LHC experiments such as ATLAS and CMS. Parton distribution functions (PDFs) and proton structure are therefore studied in regions not accessible by other LHC experiments, namely:

- at high x values;
- at low x values and high Q^2

where x is the longitudinal momentum fraction of the proton carried by the parton and Q^2 is the energy scale of the interaction. The regions studied by LHCb are highlighted in fig. 1.

3. – W mass measurement

The W boson mass (m_W) is directly related to the EW symmetry breaking and to other important quantities, such as the fine-structure constant α, the mass of the Z boson m_Z and the Fermi constant G_F through the relation

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

where Δ denotes loop corrections. A high-precision measurement of the W mass is possible at LHCb and it has been performed using proton-proton collision data recorded in 2016 at $\sqrt{s} = 13$ TeV. This measurement is particularly interesting since the PDF uncertainties are anti-correlated with respect to measurements coming from ATLAS and CMS [2]: this is mainly due to the complementary angular acceptance of LHCb with respect to ATLAS and CMS, which leads to negative correlations. Therefore, a combined measurement from LHCb, CMS and ATLAS would lead to a more precise measurement, where uncertainties coming from PDFs evaluation partially cancel. In this analysis [3] the $W \to \mu\nu$ decay is considered by requiring a high-p_T muon in the LHCb acceptance, with several requirements to further reduce contamination coming from other sources of background. Data from 2016 are considered, for a total integrated luminosity of 1.6 fb^{-1}. The W boson mass m_W is extracted by a template fit to the (q/p_T) distribution from $W \to \mu\nu$ and ϕ^* from $Z \to \mu\mu$ (where $\phi^* = \tan((\pi - \Delta\phi)/2)/\cosh(\Delta\eta/2)$, with $\Delta\eta$ ($\Delta\phi$) the difference of the polar (azimuthal) angle), which is found to be:

$$m_W = 80354 \pm 23_{\text{stat}} \pm 10_{\text{exp}} \pm 17_{\text{theory}} \pm 9_{\text{PDF}}\,\text{MeV} \tag{2}$$

where each source of error is reported separately. A statistical precision of 23 MeV is reached, with a total uncertainty of 32 MeV. The result is compatible with the SM prediction from the global EW fit. A comparison to previous measurements and the latest CDF measurement is shown in fig. 2.

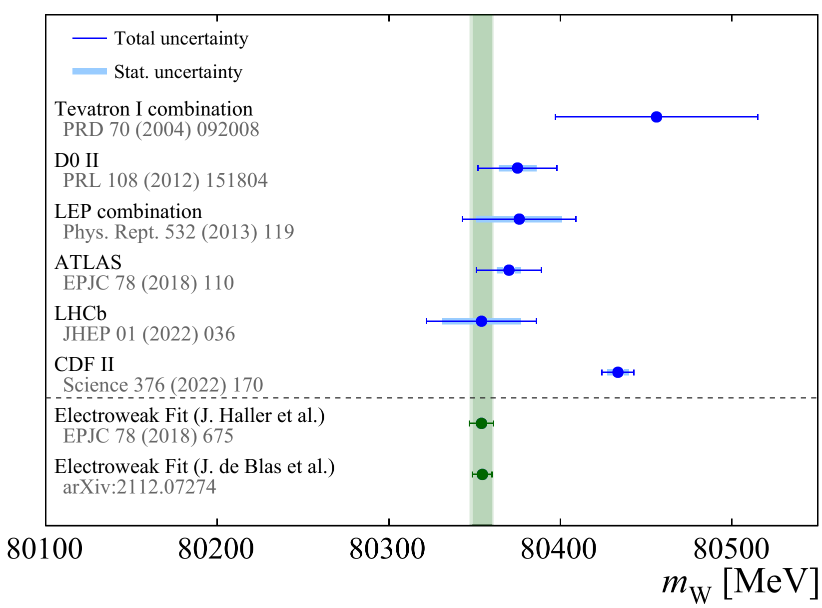

Fig. 2. – Measured value of m_W by LHCb compared to previous measurements (blue) and the EW fit (green).

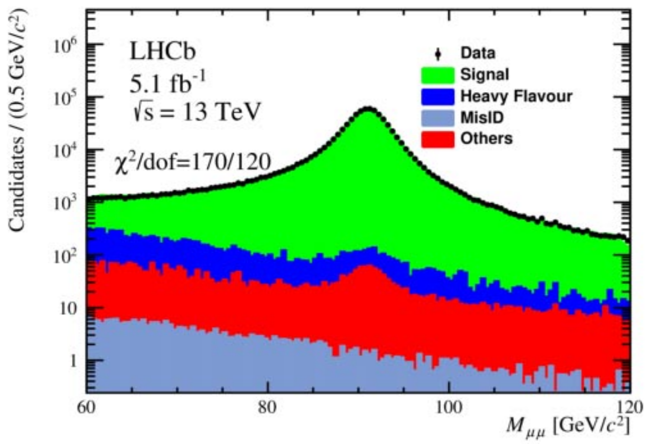

Fig. 3. – $M_{\mu\mu}$ distribution for signal ($Z \to \mu\mu$) events and background events.

4. – $Z \to \mu\mu$ cross section measurement

The measurement of the $Z \to \mu\mu$ cross section provides a stringent test of the SM. It allows to test pQCD at NNLO with an experimental precision $\mathcal{O}(1\%)$, close to the theoretical one. In this analysis [4], the whole Run 2 dataset has been analysed, with a total integrated luminosity of 5.1 fb^{-1}. The fiducial selection requires two muons to be inside the LHCb acceptance, with $p_{\mathrm{T}} > 20$ GeV and $2.0 < \eta < 4.5$, and the invariant mass of the muon system to be $60 < M_{\mu\mu} < 120$ GeV. The selection is dominated by signal events, where background events are roughly 1.5% of signal events. This is also shown in fig. 3.

The measurement is performed in the whole fiducial region and differentially as a function of the rapidity y and the p_{T} of the Z boson. The main source of systematic uncertainty comes from the luminosity evaluation. The results are compared with different generators (POWHEG, ResBos and FEWZ), and for different different choices of the PDF sets. Good agreement is found between results and theoretical expectations, and this measurement provides the most precise measurement of $Z \to \mu\mu$ cross section in the forward region.

5. – Measurement of $Z \to \mu\mu$ angular coefficients

Starting from the same fiducial selection described in the previous analysis, it is possible to measure the polarization of the Z boson by measuring the kinematics of the muons coming from its decay. In this analysis [5], the whole Run 2 dataset has been analysed, with a total integrated luminosity of 5.1 fb^{-1}. The $Z \to \mu\mu$ decay is represented in the Collins-Soper [6] reference frame: in this way, the cross section can be described differentially as a function of θ and ϕ, respectively the polar and the azimuthal angle, with different angular coefficients A_i, which describes the QCD mechanisms of the process at different orders. Figure 4 shows the results of the coefficients A_i as function of the p_{T} of the Z boson, for different generators. The main source of systematic uncertainty comes from the limited simulated samples used to perform the analysis. The behaviour

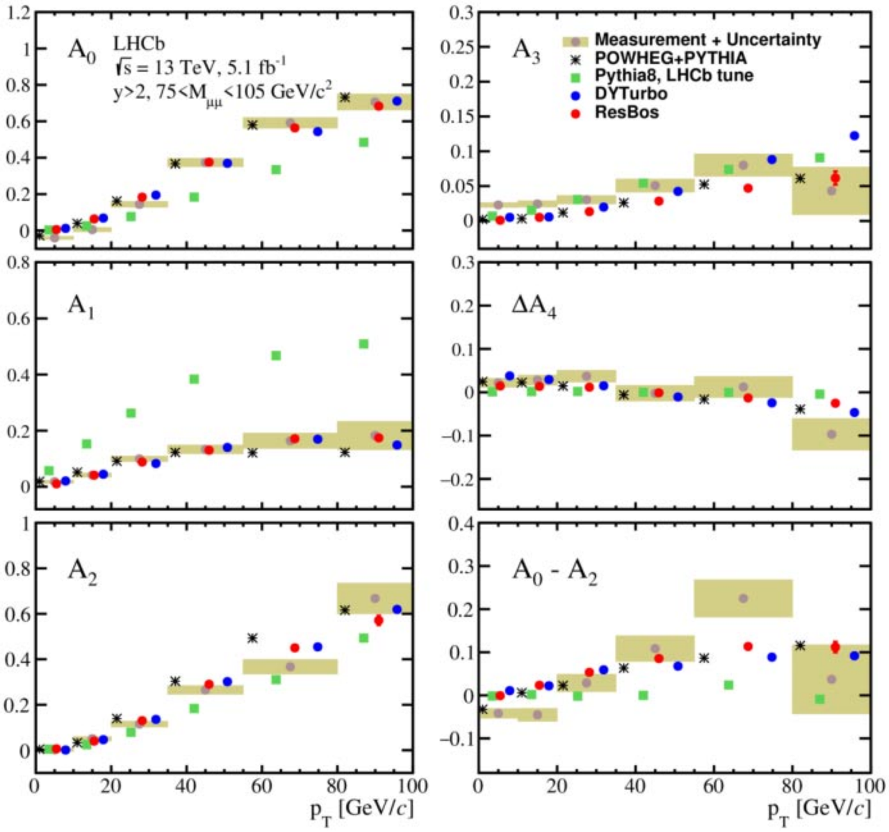

Fig. 4. – Measured angular coefficients A_i as function of the p_{T} of the Z boson, and comparison with theoretical expectations from different generators.

of A_0 and A_1 is not well described by Pythia8. Moreover, the Lam-Tung [7] relation ($A_0 = A_2$) is not verified, confirming previous results obtained by ATLAS and CMS. This study provides the first measurements of $Z \to \mu\mu$ angular coefficients.

6. – Conclusions

The LHCb experiment is able to perform measurements in a phase-space region complementary to other experiments. While originally designed to study flavour physics, it is now a General Purpose Detector that is able to perform interesting measurements in the EW and QCD sectors. The recent EW measurements presented here show the ability of the LHCb experiment to test the SM and constrain PDFs in a $x - Q^2$ region not accessible by other experiments. Several analyses are ongoing, particularly targeting the production of vector bosons in association with jets: these studies will further constrain PDFs, particularly in the high x range. Finally, in the future, with an important increase in luminosity and the upgrade of all the sub-detectors [8], the LHCb experiment will continue to play a fundamental role in the EW physics sector.

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