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Electroweak measurements at LHCb with the calorimeter upgrade

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Summary. — The LHCb experiment covers the forward region of proton-proton collisions, and it can improve the current electroweak landscape by studying W and Z bosons in this phase space complementary to ATLAS and CMS. Thanks to the excellent detector performance, fundamental parameters of the Standard Model can be precisely measured by studying the properties of the electroweak bosons. In this communication, an overview of the wide LHCb electroweak measurement program will be presented. The proposal of a new calorimeter for LHCb will be also presented: this calorimeter could enhance the performance on electroweak boson measurements in the High Luminosity LHC era, by precisely measuring the energy of electrons and hadronic jets in a high pile-up environment.

1. – Introduction

In the realm of Particle Physics, the electroweak theory unifies two of the four fundamental forces, namely the weak and the electromagnetic force. Precision measurements within this sector allow for the testing of the Standard Model which is able to successfully describe large part of particle interactions. However, this is not true for some phenomena that we observe, and some tensions persist between theoretical predictions and experimental data. Therefore, it is even more important to explore and constrain the Standard Model, and to search for signs of New Physics. To address these challenges, the Large Hadron Collider (LHC) aims at conducting precision measurements of electroweak bosons through its experiments, notably ATLAS and CMS, exploiting their high luminosity and acceptance. While LHCb was originally designed to study b and c hadrons, it was demonstrated that it can offer a unique perspective on electroweak physics. In this article, the possibilities of LHCb experiment regarding electroweak measurements are presented, both in the current state and in the future of Upgrade II with the improvement of the electromagnetic calorimeter, which will be also described.

2. – LHCb detector

LHCb [1] is an experiment originally designed to study b and c hadrons in the forward region of proton-proton collisions. The detector apparatus is a single-arm spectrometer with an angular coverage from 10 to 300 mrad and it extends longitudinally along the beam direction. Thanks to its great performances in terms of hit efficiency and momentum resolution and its angular acceptance, LHCb can participate to Electroweak measurements also with a new contribution. Its pseudorapidity coverage is $2 < \eta < 5$ (where $\eta = -\ln(\tan(\theta/2))$ and θ is the polar angle with respect to the beam direction), complementary to the one of ATLAS and CMS, therefore LHCb can study the proton structure in the regions of high x and low x and high Q^2, where x is the momentum fraction of the parton and Q^2 is the squared energy transfer during the scattering. Figure 1 shows those regions covered by LHCb compared to other experiments, it is noticeable that the region at low x is completely unexplored and so it constitutes a great asset for LHCb.

3. – Electroweak measurements

LHCb significantly contributes to electroweak measurements by studying the production of W and Z bosons in leptonic channels. This plays an important role in advancing our understanding of fundamental particles and their interactions due to their relation with some other important quantities such as lepton charge asymmetry or $\sin\theta_W$. Also, its involvement in the computation of W mass is of great importance in the physics landscape since recent measurements seem to deviate from the expected value from electroweak fit. LHCb measurement is compared to other experiments and to theoretical fit and PDG average in fig. 2 [2]. This result is compatible with the Electroweak fit, although the statistical uncertainty of 32 MeV is not yet quite competitive compared to ATLAS (19 MeV). With Run 2 dataset, LHCb aims to improve it further to 10 MeV by increasing the statistics of proton collisions and by including the $W \to e\nu$ channel available with future upgrades mentioned in the section below.

Beyond leptonic channels, LHCb explores W and Z production in association with jets, contributing to the investigation of the complex structure of the proton. The re-

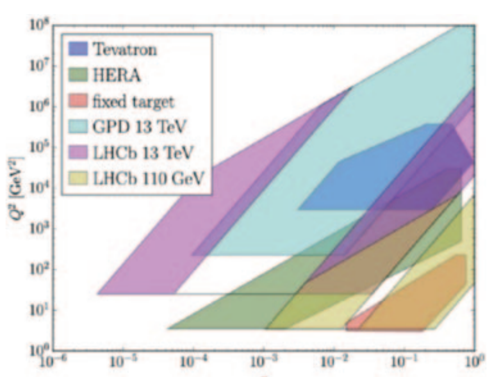

Fig. 1. – x-Q^2 plane showing the acceptance of several experiments. The LHCb acceptance is shown in violet [3].

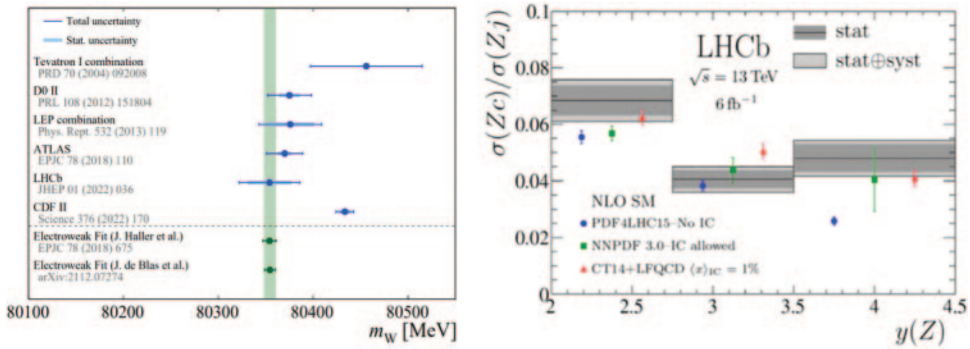

Fig. 2. – Left: the measured value of m_W by LHCb compared to previous measurements (blue) and the EW fit (green). Right: results for $R = \sigma(Zc)/\sigma(Zj)$ with respect to Z boson rapidity $y(Z)$ and comparison with NLO SM predictions without IC (blue), with the charm component PDF shape allowed to vary and therefore allowing for IC (green) and LFQCD predictions for IC with a mean momentum fraction of 1% (red).

sults are in overall agreement with Standard Model expectations when cross-sections are computed using the muonic decay channels $W \to \mu\nu$ and $Z \to \mu\mu$, together with their ratio and leptonic charge asymmetry [4].

Particularly interesting is the investigation into $Z + c$-jet production, where one inquires about the presence of intrinsic charm quarks in the proton. The LHCb contribution is important in this matter since the pdf linked to the existence of intrinsic charm is very well defined in its rapidity region. From the recent calculation [5] of the cross-section ratio between Z in association with c-jet and Z in association with jets, shown in fig. 2, the absence of intrinsic charm deviates from LHCb data with $> 3\sigma$ in the high rapidity region covered by the detector.

4. – Calorimeter upgrade

In the next years the LHC will start a high luminosity program (HL-LHC) where the event rate will increase significantly [6]. LHCb aims at increasing its total dataset from the current 9/fb to 300/fb of integrated luminosity, leading to enhanced measurement precision. However, this advancement comes with challenges, such as the increase in pile-up, which is expected to reach a value over 40 in Upgrade II. To address this, an upgrade to the calorimeter system is proposed.

The current calorimeter limitations involve cell saturation at only 20 GeV of transverse energy due to the dynamic range of the ADC, this leads to limitations in statistics and indirectly also to the reduced electron reconstruction precision with respect to muons. Achieving the same precision would increase statistical sensitivity and lower sistematic and statistical uncertainties, as a result of using both channels for electroweak analysis. The proposed calorimeter upgrade aims for greater granularity in the central region, new radiation-tolerant technology and new temporal measurements with a resolution of around 20 ps in order to associate calorimeter clusters to primary vertices reconstructed by the Vertex Locator. A new configuration with a rhomboidal arrangement of Shashlik and Spaghetti calorimeter (SpaCal) modules was chosen to follow the radiation distribution on ECAL, with the most inner SpaCal modules withstanding an anticipated

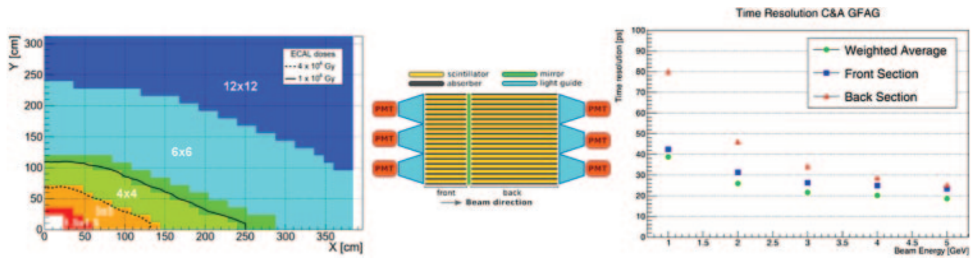

Fig. 3. – Left: first optimisation of ECAL regions and cell sizes for Upgrade II with the SpaCal/Shashlik option following the radiation dose [6]. Middle: schematic side view of the SpaCal configuration. Right: time resolution of the GFAG SpaCal cells obtained using the front cell, the back one, and the inverse-variance weighted average of the two.

radiation dose of 1 MGy. The temporal measurements will employ a double-sided readout system in all the modules.

Figure 3 shows the structure of the new technology, SpaCal, with longitudinal scintillating fibers in a dense absorber material, which solves the issues of granularity and radiation tolerance. It is also possible to see that the requirement on temporal resolution is satisfied, in particular fig. 3 shows the results for SpaCal prototype with garnet crystal fibers of Gadolinium Fine Aluminum Gallate (GFAG) [7].

5. – Conclusions

In conclusion, the LHCb experiment's unique acceptance in the forward region and its remarkable detector performance have positioned it as a valuable contributor to electroweak measurements and therefore it can be considered as a General Purpose Forward Detector. Vector bosons production in leptonic channels and in association with jets, together with the measurement of W mass, shows agreement with Standard Model expectations, with the only constraint being low statistics and consequently greater uncertainties. Moreover, the study of Z boson production in association with c-jet highlights the importance of LHCb, since the possibility to prove the presence of an intrinsic charm component in the proton is directly linked to the high rapidity region covered by the detector. Lastly, the proposed calorimeter upgrade is an important step in preparing for the High Luminosity LHC era, ensuring the precision and reliability needed for future discoveries in the electroweak sector, allowing LHCb to be competitive with other experiments by including also decay channels with electrons in the analysis.

REFERENCES

[1] LHCb Collaboration (Aaij R. *et al.*), *JINST*, **3** (2008) S08005.
[2] LHCb Collaboration (Aaij R. *et al.*), *JHEP*, **36** (2022) 36.
[3] Boettcher T. *et al.*, *Phys. Rev. D*, **93** (2016) 074008.
[4] LHCb Collaboration (Aaij R. *et al.*), *JHEP*, **05** (2016) 131.
[5] LHCb Collaboration (Aaij R. *et al.*), *Phys. Rev. Lett.*, **128** (2022) 082001.
[6] LHCb Collaboration, CERN-LHCC-2018-027 (2018).
[7] An L. *et al.*, *Nucl. Instrum. Methods A*, **1045** (2023) 167629.