Probing photonic content of the proton using photon-induced dilepton production in $p + Pb$ collisions at the LHC

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Abstract

We propose a new experimental method of validating photon PDF of the proton at LHC energies.

1. Introduction

A significant fraction of proton-proton collisions at the LHC involves quasi-real photon interactions, where the photons are emitted by both protons. The proton-proton collision is then transformed into a photon-photon interaction and the protons are deflected at small angles. At LHC energies, these reactions occur at energies well beyond the electroweak energy scale. They offer an interesting field of research linked to photon-photon interactions, where the available effective luminosity is small, relative to parton-parton interactions, but is compensated by better known initial conditions and usually simpler final states.

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2. Formalism

2.1. Elastic vertices

In this work we are only interested in the elastic vertices on the nucleus side.

We recall, that for the proton, we can express the photon flux through the electric and magnetic form factors $G_E(Q^2)$ and $G_M(Q^2)$ of the proton:

$$W_T^{\rm el}(M_X^2,Q^2)=\delta(M_X^2-m_p^2)\,Q^2G_M^2(Q^2)\,,\,W_L^{\rm el}(M_X^2,Q^2)=\delta(M_X^2-m_p^2)4m_p^2G_E^2(Q^2)\,. \quad (1)$$

The contribution to the photon flux is then again obtained by contracting

$$\frac{p^\mu p^\nu}{s^2}\,W_{\mu\nu}^{\rm el}(M_X^2,Q^2)=\delta(M_X^2-m_p^2)\Big[\Big(1-\frac{z}{2}\Big)^2\,\frac{4m_p^2G_E^2(Q^2)+Q^2G_M^2(Q^2)}{4m_p^2+Q^2}+\frac{z^2}{4}G_M^2(Q^2)\Big] \quad (2)$$

For the nucleus, we follow [1], and replace

$$\frac{4m_p^2G_E^2(Q^2)+Q^2G_M^2(Q^2)}{4m_p^2+Q^2}\longrightarrow Z^2F_{\rm em}^2(Q^2)\,. \quad (3)$$

We neglect the magnetic form factor in the following. (It even rigorously vanishes for spinless nuclei.)

For the ^{208}Pb nucleus, we use the realistic formfactor from the STARLIGHT MC.

$$F_{\rm em}(Q^2)=\frac{3}{(QR_A)^3}\Big\{\sin(QR_A)-QR_A\cos(QR_A)\Big\}\frac{1}{1+a^2Q^2}\,. \quad (4)$$

Here

$$R_A=1.1A^{1/3}\,{\rm fm}\,,\,a=0.7\,{\rm fm},\,Q=\sqrt{Q^2}\,. \quad (5)$$

Therefore we obtain the elastic flux

$$\mathcal{F}_{\gamma^*\leftarrow A}^{\rm el}(z,\boldsymbol{q})=\frac{Z^2\alpha_{\rm em}}{\pi}\,(1-z)\,\Big(\frac{\boldsymbol{q}^2}{\boldsymbol{q}^2+z(M_X^2-m_A^2)+z^2m_A^2}\Big)^2\,F_{\rm em}^2(Q^2)\,. \quad (6)$$

For ^{208}Pb the charge is $Z=82$.

3. Fiducial selection and possible background sources

We start with applying minimum transverse momentum requirement of 4 GeV to both muons. This requirement is imposed to ensure high lepton reconstruction and triggering efficiency in the ATLAS and CMS experiments during LHC's p+Pb runs **??**. Moreover, due to limited acceptance of the detectors, each muon is required to have pseudorapidity (η_ℓ) that satisfies $|\eta_\ell|<2.5$ condition.

Our calculations are carried out for a minimum dilepton invariant mass $m_{\ell\ell}=10$ GeV. Such a choice is due to removal of possible contamination from $\Upsilon(\to\ell\ell)$ photoproduction process.

Possible background for this process

4. Results with collinear photon PDF

5. Results including photon transverse momentum

6. Discussion

7. Summary

References

[1] Budnev, V. M., Ginzburg, I. F., Meledin, G. V., Serbo, V. G., 1975. The two photon particle production mechanism. Physical problems. Applications. Equivalent photon approximation. Phys. Rept. 15, 181.

[2] Chatrchyan, S., et al., 2012. Exclusive photon-photon production of muon pairs in proton-proton collisions at $\sqrt{s} = 7$ TeV. JHEP 1201, 052.