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 to validate 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.

... [3]

As the signal process does not involve the exchange of color with the photon-emitting nucleus, no significant particle production is expected in the rapidity region between the dilepton system and the nucleus. The photon-emitting nucleus is also expected to produce no neutrons because the photons couple to the entire nucleus. Thus a combination of a rapidity gap and zero neutrons in the same direction provide straightforward criteria to identify these events experimentally.

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:

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

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

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

For the nucleus, we follow [2], and replace

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

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

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

Therefore we obtain the elastic flux

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

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 can arise from inclusive lepton-pair production, e.g. from Drell–Yan [5] process. This processes would lead to disintegration of the incoming ion, and zero-degree calorimeters (ZDC) [4, 1] can be used to veto very-forward-going neutral fragments which would allow to fully reduce this background. Another background can arise from diffractive interactions, hence possibly mimicking signal topology. However, since the nucleus is a fragile object (with the nucleon binding energy of just 8 MeV) even the softest diffractive interaction will result in the emission of a few nucleons from the ion, detectable in the ZDC.

Another background category is the photon-induced process with resolved photon, i.e. $\gamma p \to Z/\gamma^* X$ reaction. Here, the rapidity gap is expected to be smaller than in the signal process due to the additional particle production associated with the "photon remnant". Any other residual contamination of this process can be controlled using dedicated region, with a dilepton invariant mass around the Z-boson mass.

4. Results with collinear photon PDF

5. Results including photon transverse momentum

6. Discussion

7. Summary

References

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