Effect of neutron skin-thickness on prompt photon production at the LHC experiment

Somnath De*
Institute of Physics, Bhubaneswar, Odisha, India

Introduction

Experiments on neutron-rich nuclei have revealed that the root mean square (rms) radius of neutron distributions is larger than the rms radius of charge (proton) distributions. The difference of radii is often referred as 'neutron skin-thickness'. The parameter has particular importance in various astrophysical phenomena, equation of state of pure neutron matter, etc [1]. Recent experiments on lead (Pb^{208}_{82}) nuclei have reported the value of the parameter with very good accuracy [2, 3]. The observations suggest the matter produced in high energy peripheral Pb-Pb collisions is more neutron abundant than protons. Now the direct (prompt) photon production has been found sensitive to the isospins of the colliding nucleon pair. In order to quantify the effect of neutron skin-thickness on the elctromagnetic probes, we have studied the 'central-to-peripheral ratio'($R_{\rm cp}$) of prompt photon production for Pb-Pb collisions at the LHC energies, 2.76A TeV and 5.5A TeV [4].

Results

The 'central-to-peripheral ratio'($\rm R_{cp}$) of particle production in nucleus-nucleus (AA) collisions with impact parameter b is traditionally defined as:

$$R_{\rm cp}(p_T, b) = \frac{\frac{d^2N}{dp_T dy}/N_{\rm coll}(b)\ _{\rm central}}{\frac{d^2N}{dp_T dy}/N_{\rm coll}(b)\ _{\rm peripheral}}. \quad (1)$$

It is the ratio of particle yield in central and peripheral AA collisions, scaled with number of binary collisions ($\rm N_{coll}(b)$). The advantages of this observable are; it is routinely measured in experiment and the uncertainties in parton distribution function (pdf) almost cancels out. To this end, we discuss the direct (prompt) photon production for different centralities of Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. The effective proton (Z_{eff}) and neutron (N_{eff}) number associated with non-central collisions of impact parameter b are:

$$Z_{eff} = \frac{Z}{A}\frac{N^{AA}_{part}(b)}{2}, \quad N_{eff} = \frac{N}{A}\frac{N^{AA}_{part}(b)}{2}. \quad (2)$$

Where $N^{AA}_{part}(b)$ is number of participant nucleons calculated from optical Glauber model [6]. Z and A are the atomic number and mass number of the colliding nuclei. The prompt photon production in non-central collisions depends on these effective proton and neutron numbers. We have used a next-to leading order perturbative QCD program to evaluate the prompt photon contribution [7]. The results are shown in Fig. 1. It is found

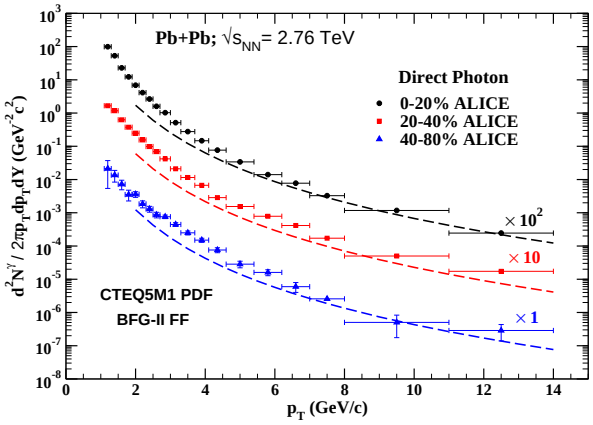

FIG. 1: Invariant yield of direct (prompt) photons for Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV for three centralities of collision. The data points are from ALICE Collaboration [5].

*Electronic address: somnath.de@iopb.res.in

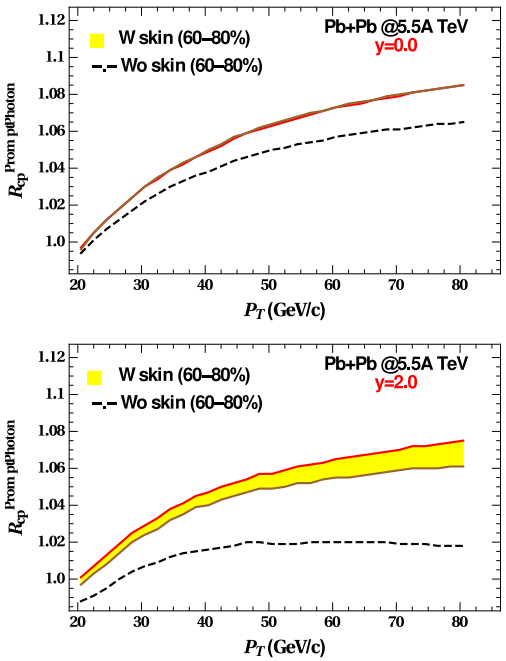

FIG. 2: The R_{cp} of prompt photon production for Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.5 TeV, with and without including neutron skin-thickness effect. The results are shown for the photon rapidities y = 0.0, 2.0.

that our model describes the data [5] well (within uncertainty) for three centralities of collision. Now introducing the neutron skin-thickness, $N_{part}^{AA}(b)$ can be factorised into four parts [4]:

$$N_{part}^{AA}(b) \approx N_{part}^{pp}(b) + N_{part}^{nn}(b) + N_{part}^{pn}(b) + N_{part}^{np}(b). \quad (3)$$

The last two terms are equal for symmetric nuclear collisions. Now each term contributes to prompt photon production in the following way:

$$Z' = \frac{N_{part}^{pp}(b)}{2}, \quad N' = \frac{N_{part}^{nn}(b)}{2};$$
$$Z'' = \frac{Z'}{A'} N_{part}^{pn}(b), \quad N'' = \frac{N'}{A'} N_{part}^{pn}(b), \quad (4)$$

where $A' = Z' + N'$. We have calculated the R_{cp} of prompt photon production, with and without accounting for the neutron skin-thickness, for the centralities of collisions: 0-10% and 60-80%. The results of 5.5A TeV center of mass energy are displayed in Fig. 2, for different photon rapidities in the p_T range 20-80 GeV/c. It is found that the ratio relatively increases by 2% at mid-rapidity ($y = 0.0$) and by 5% at forward rapidity ($y = 2.0$) while accounting for the neutron skin-thickness . The effect is more pronounced towards high p_T as the prompt photon production is sensitive to valance quark distribution there. The band shown in the results of 'W skin'depicts the uncertainty due to the error in skin-thickness parameter measured in experiment [3]. The band widens more at the lower collision energy ($\sqrt{s_{NN}}$ = 2.76 TeV) [4].
In conclusion, the neutron skin-thickness of Pb nuclei leads to observable effect in prompt photon production at the LHC experiment. However, a very accurate prompt photon data over large range of p_T would be needed to discern the difference.

Acknowledgments

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