Notes on Nuclear PDFs

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Some notes on the nuclear PDFs.

I. INTRODUCTION

One of the effects that need to be included in the calculation of R_{AA} is that the parton distribution functions (PDFs) in Pb are different from that in the proton.

There are various parameterizations of this effect fitted to data. Two popular ones that are available in tabulated form are

1. Results from Ref. [1]. (See Ref. [2] and Ref. [3] for some more recent papers from the same group.)
2. Results from Ref. [4]. (See Ref. [5] for the first paper from this group.)

II. KINEMATICS

To set up the kinematics, we consider a collision in the center of mass coordinates of two protons (or a proton and a neutron). The energy momentum components of the protons are

$$\begin{aligned} p_1 &= (\sqrt{s}/2, 0, 0, \sqrt{s/4 - m_N^2}) && (1)\\ &\approx (\sqrt{s}/2, 0, 0, \sqrt{s}/2) && (2)\\ p_2 &= (\sqrt{s}/2, 0, 0, -\sqrt{s/4 - m_N^2}) && (3)\\ &\approx (\sqrt{s}/2, 0, 0, -\sqrt{s}/2) && (4) \end{aligned}$$

In our calculations $\sqrt{s} = 5.02\text{TeV}$.

Partons from the nucleons (at LHC energies we can assume that the two partons are gluons) carry fractions x_a and x_b of p_1 and p_2,

$$\begin{aligned} p_a &= x_a p_1 && (5)\\ p_b &= x_b p_2\ . && (6) \end{aligned}$$

In the final state, two jets with mass m_J, transverse momenta p_T, and transverse mass $m_T = \sqrt{p_T^2 + m_J^2}$ are created. Let us assume that the rapidity of one of the jets is y. Then, emergy momentum conservation gives,

$$x_b = \frac{1}{\sqrt{s}} \frac{x_a m_T \sqrt{s} \exp(-y) - m_J^2}{x_a \sqrt{s} - m_T \exp(y)}\ . \tag{7}$$

(This must be a well known expression since 1960's but I don't have a well defined reference. For now I'm referring to Ref. [6].)

We are particularly interested in small angle jets so that $m_J \sim p_T \Delta\theta \ll p_T$ at central rapidity. For these kinematics,

$$x_b = \frac{p_T x_a}{-p_T + \sqrt{s} x_a}\ . \tag{8}$$

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For the estimate of a typical hard collision, $x_b \sim x_a$ which gives the well known estimate of the dominant x,

$$x_a \approx \frac{2p_T}{\sqrt{s}} \quad . \tag{9}$$

Finally, when we calculate the parton distribution functions (gluonic), then it is a function of x ad well as the energy scale. We take the relevant energy scale to be p_T.

$$R_{\mathrm{gPb}}(p_T) = \frac{\phi_g^{\mathrm{Pb}}(x = \frac{2p_T}{\sqrt{s}}, Q = p_T)}{\phi_g^{\mathrm{p}}(x = \frac{2p_T}{\sqrt{s}}, Q = p_T)} \quad . \tag{10}$$

III. EPS09

Ref. [1] describes the fitting of

$$R_{\mathrm{g/qN}}(x, Q) = \frac{\phi_g^{\mathrm{Pb}}(x, Q)}{\phi_g^{\mathrm{p}}(x, Q)} \tag{11}$$

for partons g and q for various nuclei N.

The fitted forms are available in tabulated form at [https://www.jyu.fi/science/en/physics/research/highenergy/urhic/npdfs and are saved in the subdirectory "EPS09". The quantity of interest $R_{\mathrm{gPb}}(p_T)$ is calculated using "EPS09modified.f".

The results from the program are stored in "RgPbEPS09.dat" along with the errors.

IV. CTEQ15

Ref. [4] describes the fitting of

$$\phi_{g/q}^{\mathrm{Pb}}(x, Q) \tag{12}$$

for partons g and q for various nuclei and for protons and the ratio $R_{\mathrm{gPb}}(p_T)$ can be computed easily using Eq. 10.

The fitted forms are available in tabulated form at [https://ncteq.hepforge.org/]and are saved in the subdirectory "EPS09". The quantity of interest $R_{\mathrm{gPb}}(p_T)$ is calculated using "CalculateRgCTEQ.nb". The results are stored in "RgmidvspTCTEQ.dat", "RgdownvspTCTEQ.dat", and "RgupvspTCTEQ.dat".

V. RESULTS

The results above are read using "EPS09CTEQ15Read.nb" and plotted in Fig. 1. In Fig. 1 we show the ratio of the gluonic distribution functions in p and in Pb (Eq. 10).

We note that this ratio is slightly larger than 1 for $p_T \sim 200$GeV. For larger p_T the error bars are quite large but the results are consistent with R_{gPb} is consistent with being constant or slightly decreasing in this regime.

These results are consistent with Refs. [7, 8].

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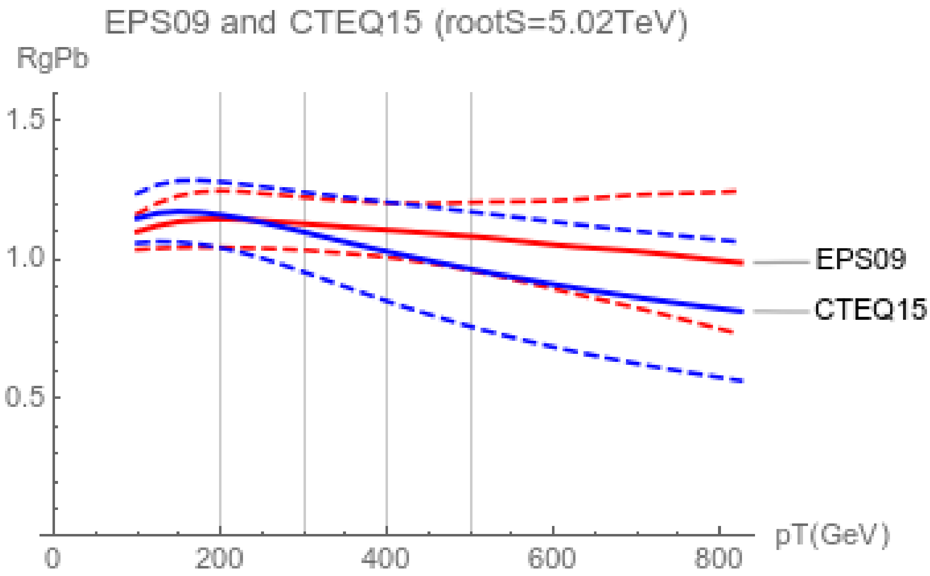

FIG. 1: Ratio of Nuclear PDFs of Pb-208 and proton as a function of p_T. $x = \frac{2p_T}{\sqrt{S}}$ (Eq. 9) and the scale of the PDFs is taken to be p_T.

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