A study of initial state quark energy loss in fixed target proton induced nuclear collisions

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Introduction

Relativistic heavy ion collision is the only tool to produce the deconfining phase of QCD matter in the laboratory. In elementary proton-proton collisions, we know about the interaction between qcd color degrees of freedom quarks and gluons which are collectively called partons. To understand the outcome of high energy heavy ion collision, the most important thing is to pin down the initial stages of such collisions. The two most dominant initial-state effects before such collisions take place are attributed in nuclear effect through parton distribution functions and the energy loss by the fast partons traversing large distance through the cold nucleus. The modification of parton distribution functions when it is immersed in the nuclei known as the nuclear effect. Due to multiple scattering with the target nucleon and QCD breamstrahhlung, the partons inside the projectile loss a major fraction of its momentum which is the initial state parton energy loss effect.

In literature there are two type of experimental process are employed to study the quark energy loss in cold nucleus. The first one is semi inclusive deep inelastic scattering by the lepton on nuclei to study the final state quark energy loss and the other one is Drell-Yan reaction in hadron-nucleus collision to look into the quark energy loss in initial state. Hadron induced Drell-Yan process is very good probe to quantify the incoming quark energy loss because the produced leptons are weakly interact with the partons present in cold nuclear matter. NA3 and NA10 collaborations from CERN and E772 ,E866 and E906 experiments at Fermilab have measured Drell-Yan differential cross-section ratio of different target nucleus bombarded with same hadron.

The main goal of this work to estimate incoming quark energy loss in cold nuclear matter from the analysis of Drell-Yan differential data. And the energy loss value with path length is useful to study the cold nuclear matter(CNM) effect in the production of J/ψ if it is used as a signal of QCD deconfining state QGP.

Brief Theoretical formalism for differential cross section in nuclear Drell-Yan reaction

In the Drell-Yan process,the leading order (LO) in perturbation theory is the quark-antiquark annihilation into lepton pair $q\bar{q} \to l^+l^-$. The invariant mass M of the lepton pair is set by the center-of-mass energy of $q\hat{q}$ collision$\sqrt{\hat{s}} = (x_1 x_2 s)^{1/2}$ where x_1 and x_2 are the momentum fraction carried by the projectile and the target parton respectively. The lepton pair production cross section in hadron-nucleus collisions can be obtained from the convolution of differential partonic cross-section with the parton distribution functions in the incident hadron h and target nucleus A. With neglecting the incoming quark energy loss in cold nuclear matter ,the differential annihilation cross-section with feynmann variable $x_F = (x_1 - x_2)$ in the hadron-nucleus reaction is written as

$$\frac{d\sigma^(hA)}{dx_F} = K\frac{8\pi\alpha_{em}^2}{9s(x_1+x_2)}\sum_f e_f^2 \int \frac{dM}{M} \times \left[q_f^h(x_1,M^2)\bar{q}_f^A(x_2,M^2) + \bar{q}_f^h(x_1,M^2)q_f^A(x_2,M^2)\right] \quad (1)$$

where K is the higher order correction ,α_{em} is the fine structure constant ,the sum is carried out over the light flavor $f = u, d, s$ of charge e_f. And $q_f^{h(A)}(x, M^2)$ and $\bar{q}_f^{h(A)}(x, M^2)$ are the quark and anti-quark distribution function in the hadron (nucleon in the nucleus A) with Bjorken variable x and M^2 virtual photon propagator mass .

After considering the quark energy loss in the target nuclei , the incident quark momentum fraction can be shifted from $x_1^{'} = x_1 + \Delta x_1$to x_1 at the point of fusion where $\Delta x_1 = \Delta E_q/E_{beam}$. Combining both the shadowing and initial state energy loss ,the Drell-Yan cross section in pA collision can be written as ,

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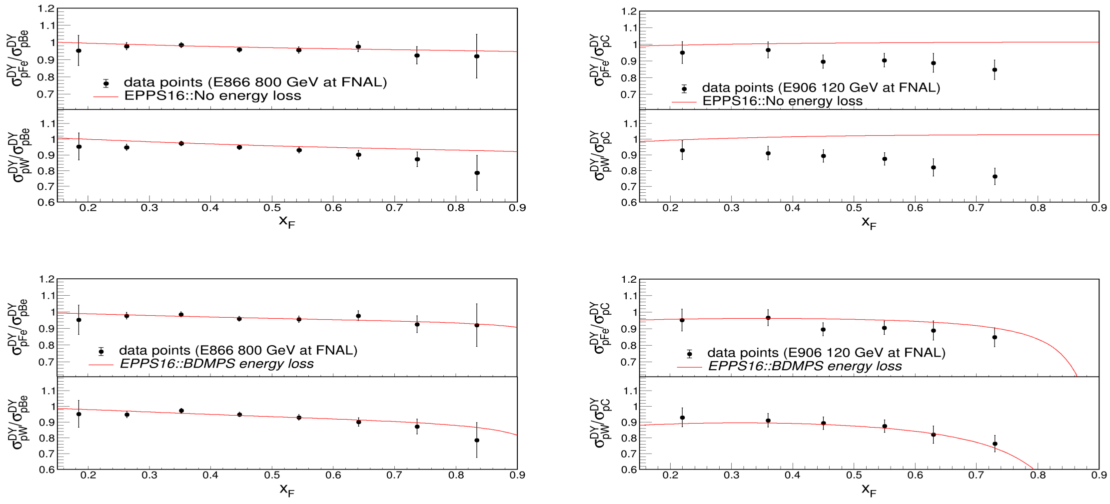

FIG. 1: Nuclear Drell-Yan cross section ratios $Fe/Be(C)$(upper)and $W/Be(C)$(lower) versus x_F .The top and bottom two plots are the E866(left), E906(right) experiments data fitted with only nuclear nPDF EPPS16 and together with nuclear nPDF EPPS16 and energy loss (BDMPS)

TABLE I: Results from simultaneous fit of Drell-Yan differential ratio with EPPS16 nPDF set from E866 and E906 collaboration data at Fermilab

Experiment	$E_{beam}(GeV)$	$\beta(GeV/fm^2)$	Pr.	χ^2/ndf
E866	800	0.097 ± 0.031	0.98	0.39
E906	120	0.072 ± 0.008	0.83	0.60

$$\frac{d\sigma^{(pA)}}{dx_F} = K\frac{8\pi\alpha^2}{9s(x_1+x_2)}\sum_f e_f^2 \int \frac{dM}{M} \times \left[q_f^p(x_1^{'}, M^2)\bar{q}_f^A(x_2, M^2) + \bar{q}_f^p(x_1^{'}, M^2)q_f^A(x_2, M^2)\right] \quad (2)$$

There are several parameterizations has been reported in literature to quantify the quark energy loss among those the latest quadratic path length dependence energy loss parameterization established by Baier et al.(BDMPS) [4] is employed in this work. Which states that energy loss is due to both the p_T broadening and the characteristic gluon radiation length so that change in momentum fraction $\Delta x_1 \approx \frac{\beta}{E_{beam}} < L >_A^2$. Where, $< L >_A$ is the average path length in the target nucleus.

Results and Discussion

We analyzed the Drell-Yan differential data from the experiments E866 [2] and E906 [3] at Fermilab. At first to see the sole effect of nuclear modification Drell-Yan differential cross-section ratio i.e. pFe/pBe(C) and pW/pBe(C) from the experiments E866(E906) at 800(120) GeV are globally fit with x_F taking use of one of the latest nPDF set EPPS16 [5] fig.(1) .Then both the energy loss as well as nuclear effect has been taken into account and repeat the same analysis fig.(1) to estimate the energy loss value which are summarised in the Table[1]. It is seen that only using nuclear effect can explain E866 experimental data but it completely fails to describe E906 Drell-Yan data.

summary

In summary we investigate the energy loss of incoming quark by Drell-Yan process in proton induced nuclear collision. It also show that only nuclear effect is unable to describe the data in higher x_F. With lowering the beam energy of the projectile hadron energy loss effect is operating significantly. The energy loss value obtained from this work will be useful in further investigating the CNM effect on J/ψ production.

References

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