Heavy flavor production at the EIC

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EST. 1943

In collaboration with H.T. Li and I. Vitev, 2007.10994

Opportunities of Heavy Flavor at the EIC
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Outline

- Motivation
- NLO QCD corrections to light/heavy flavor production in e+p
- Calculation of heavy flavor production in e+A collision
- Understanding the cold nuclear matter modification
- Conclusion

Study Goals at the EIC

- Precise determination of PDFs of charm/ bottom quark

  see talks of Pavel and Vadim

- Precisely study the fragmentation functions for light/heavy flavors

  see talks of Ingo and William

- To understand the nuclear medium effects on hadron production

  e.g. energy loss mechanisms by comparing measurements between e+p and e+A

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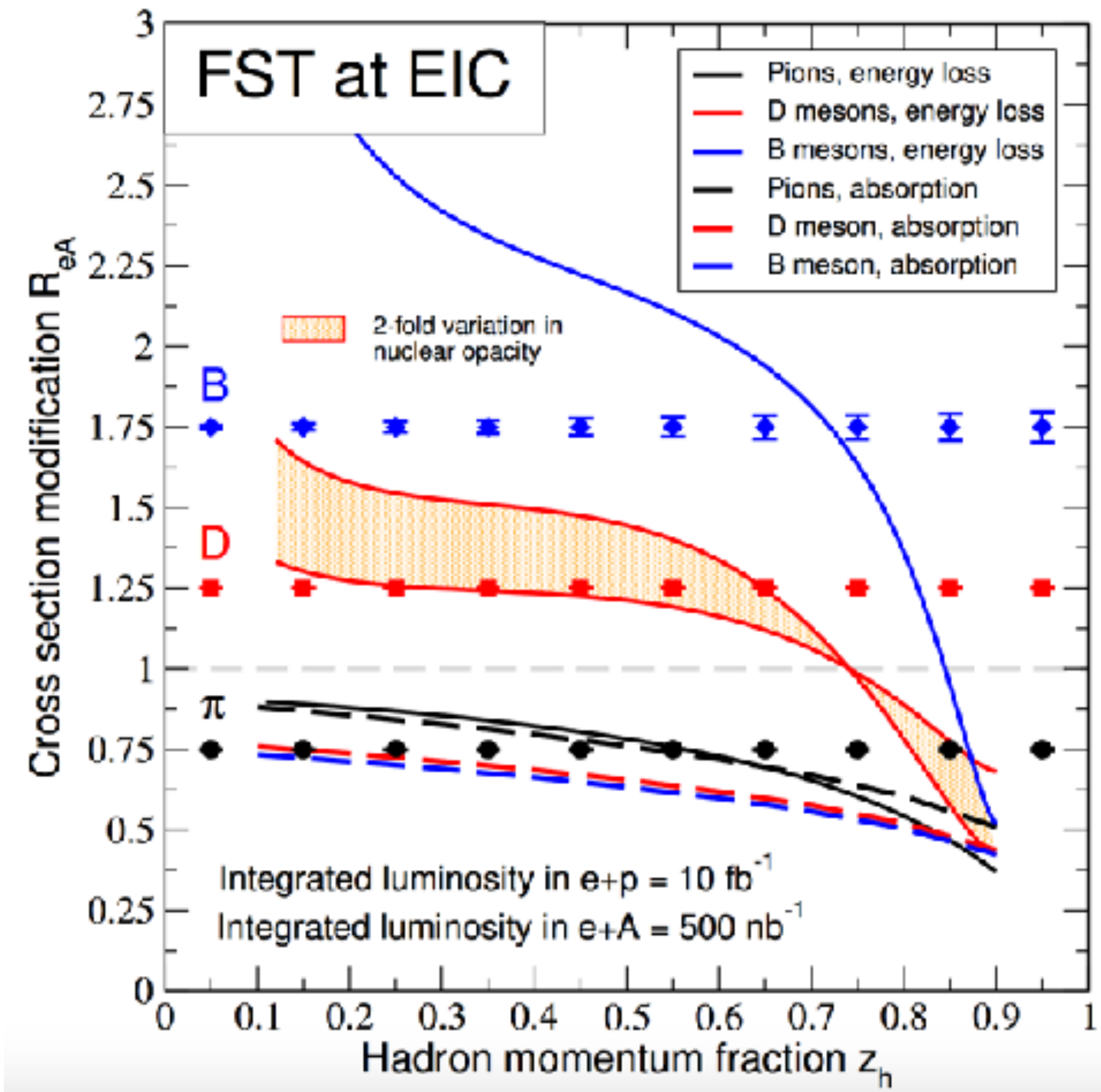
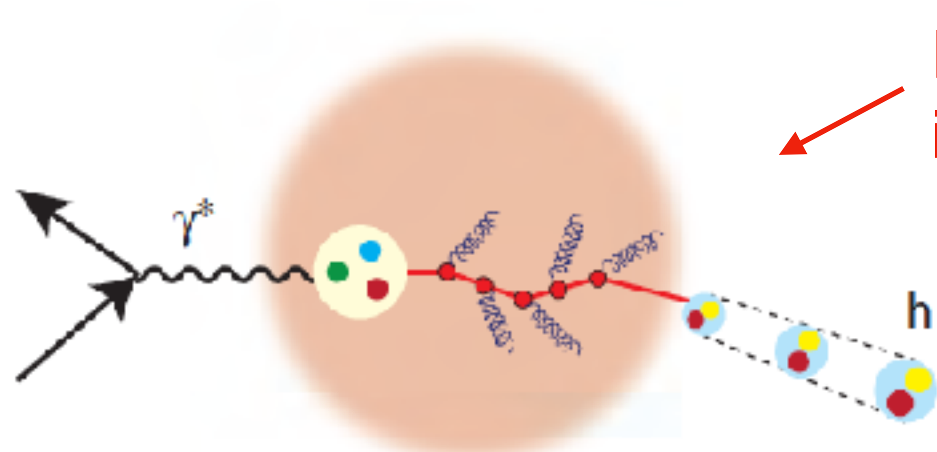


Pictures of Hadronization

- Shed light on the picture of hadronization, differentiate between energy loss and hadron absorption

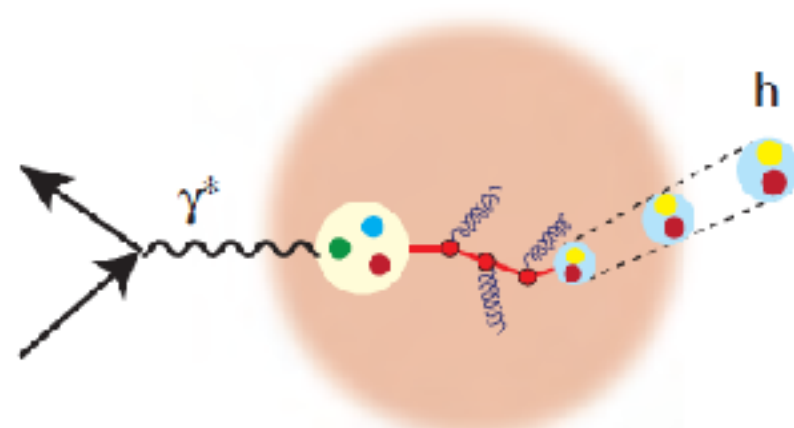
Energy loss approach



Prefer large parton energy in the nuclear rest frame

hadronization outside of the nucleus

Hadron formation and absorption



hadronization inside of the nucleus

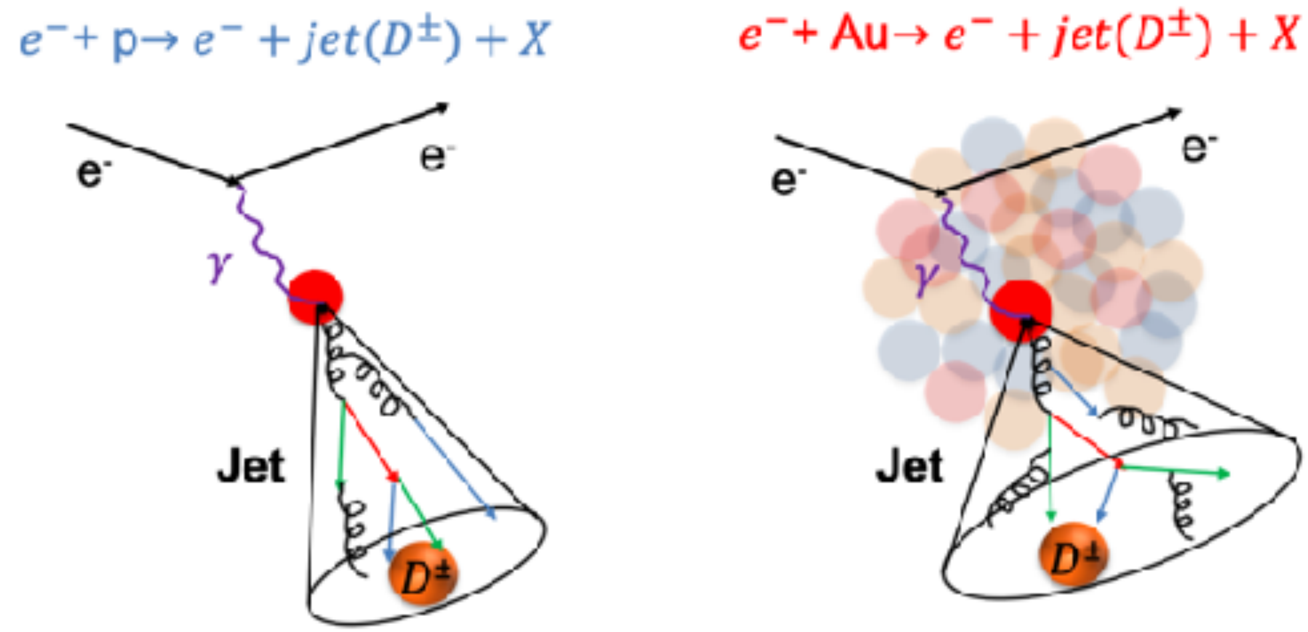
Prediction in e+p collision

- PDF sets: CT10NLO
- Fragmentation function: for light meson: HKNS

  M. Hirai et al., ’07

- Partonic cross section: analytical NLO result

  P. Hinderer et al., ’15



NLO cross section can be factorized as

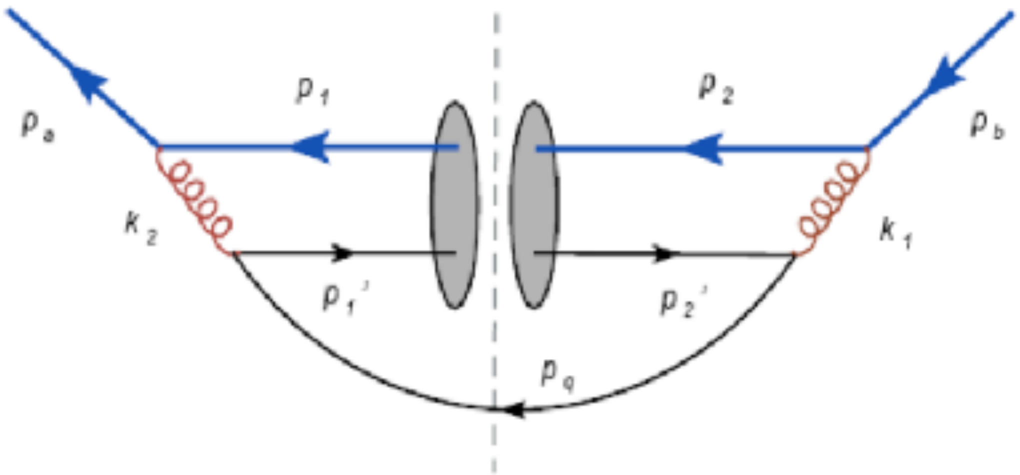
$$E_h \frac{d^3\sigma^{\ell N\to hX}}{d^3P_h} = \frac{1}{S}\sum_{i,f}\int_0^1 \frac{dx}{x}\int_0^1 \frac{dz}{z^2} f^{i/N}(x,\mu) \times D^{h/f}(z,\mu)\left[\hat{\sigma}^{i\to f} + f^{\gamma/\ell}_{\rm ren}\left(\frac{-t}{s+u},\mu\right)\hat{\sigma}^{\gamma i\to f}\right].$$

FFs

quasi-real photon scattering

NLO hard kernel

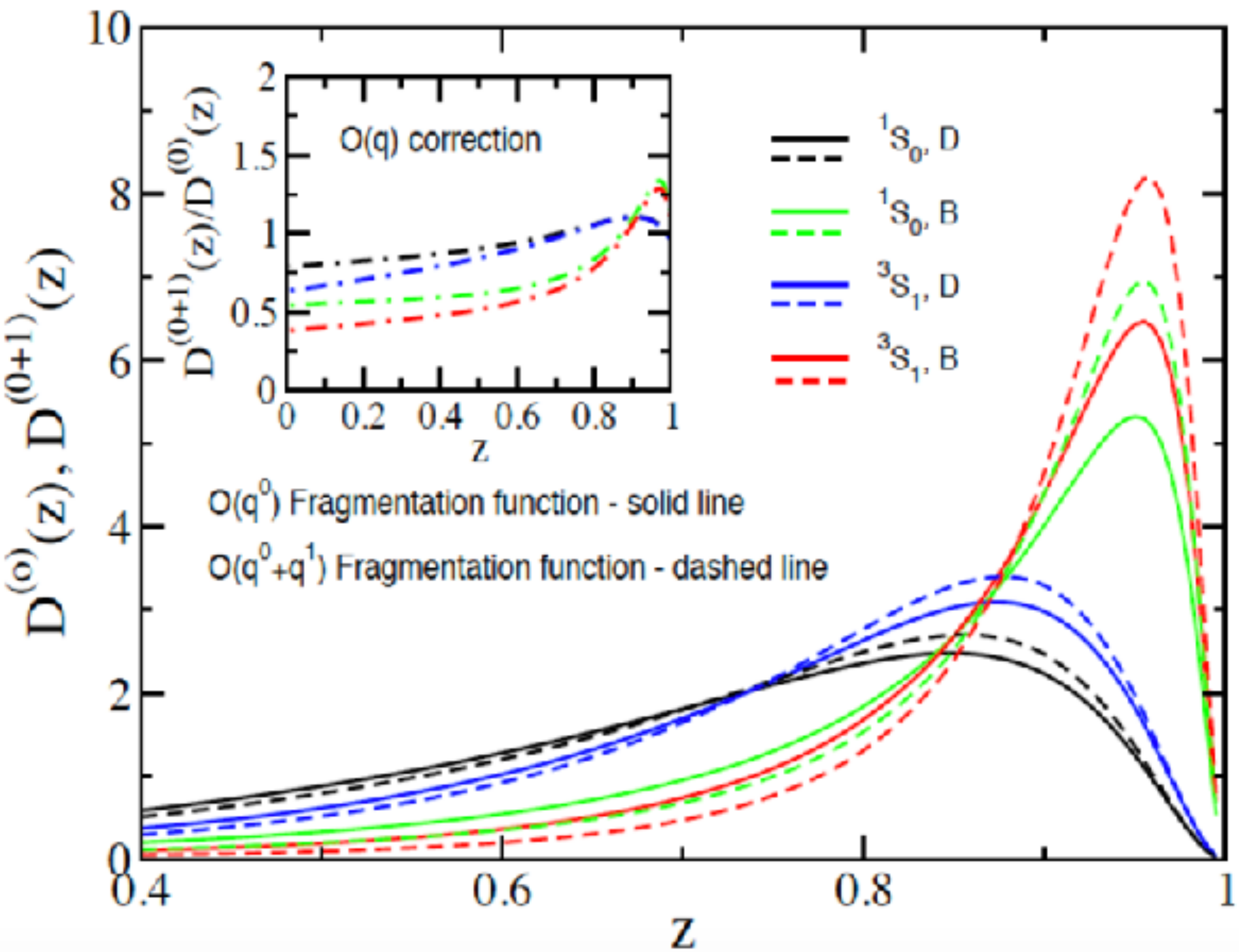
FFs for heavy flavors in vacuum



studied in HQET

Heavy quarks introduce a mass scale that allows the fragmentation function shape to be computed perturbatively

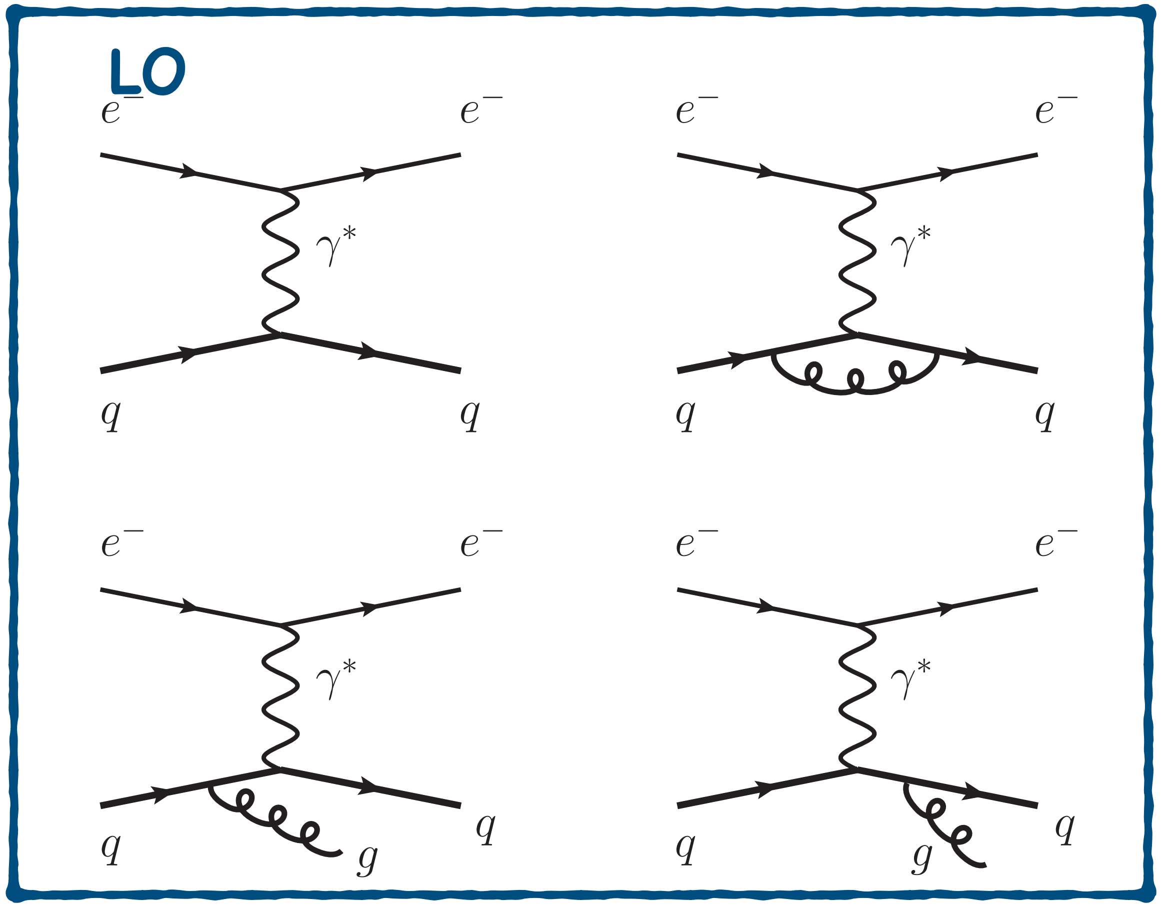
Chang et al. 1992 Braaten et al. 1995

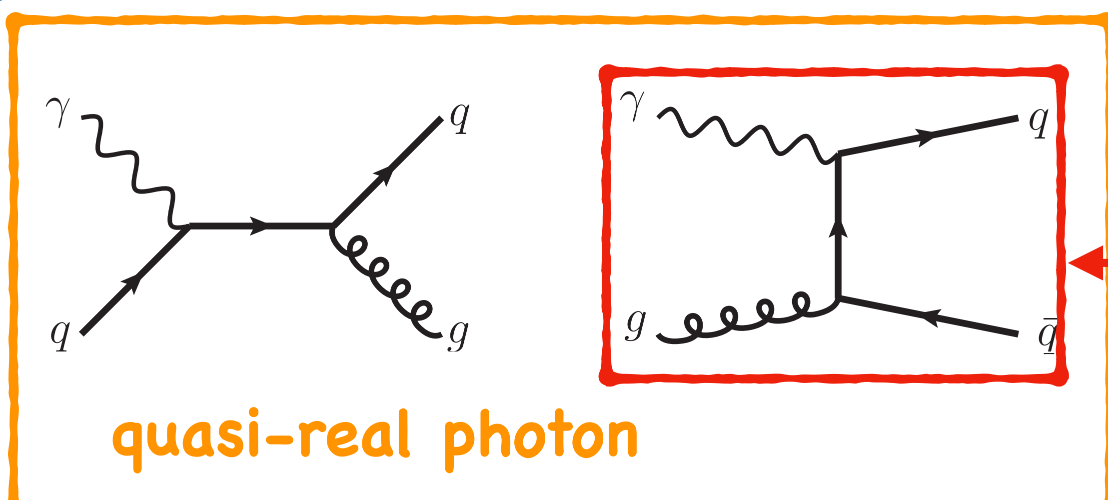


The vacuum FFs are used as input boundary conditions to determine the FFs in Medium

Partonic cross section at NLO

P. Hinderer et al., '15





$$E_h \frac{d^3\sigma^{\ell N\to hX}}{d^3P_h} = \frac{1}{S}\sum_{i,f}\int_0^1 \frac{dx}{x}\int_0^1 \frac{dz}{z^2} f^{i/N}(x,\mu) \times D^{h/f}(z,\mu)\left[\hat{\sigma}^{i\to f} + f_{\rm ren}^{\gamma/\ell}\left(\frac{-t}{s+u},\mu\right)\hat{\sigma}^{\gamma i\to f}\right].$$

- 5-flavor scheme is used
- gluon contribution is small at the EIC
- heavy flavor production is sensitive to c/b quark PDFs

dominant in heavy flavor production

Prediction in e+p collision

		5 GeV×40 GeV		10 GeV×100 GeV		18 GeV×275 GeV	
p_T^h [GeV]		[2 ,3]	[5 ,6]	[2 ,3]	[5 ,6]	[2 ,3]	[5 ,6]
π^+	LO	5.3×10^6	24260	1.4×10^7	3.0×10^5	2.9×10^7	9.6×10^5
	NLO	1.1×10^7	69473	2.8×10^7	6.1×10^5	5.6×10^7	1.9×10^6
D^0	LO	1.4×10^6	3242	8.6×10^6	89952	3.1×10^7	6.6×10^5
	NLO	3.7×10^6	8536	2.1×10^7	2.1×10^5	7.2×10^7	1.5×10^6
B^0	LO	3.7×10^5	1171	2.4×10^6	28413	9.0×10^6	2.0×10^5
	NLO	1.1×10^6	3333	6.2×10^6	72329	2.1×10^7	4.7×10^5

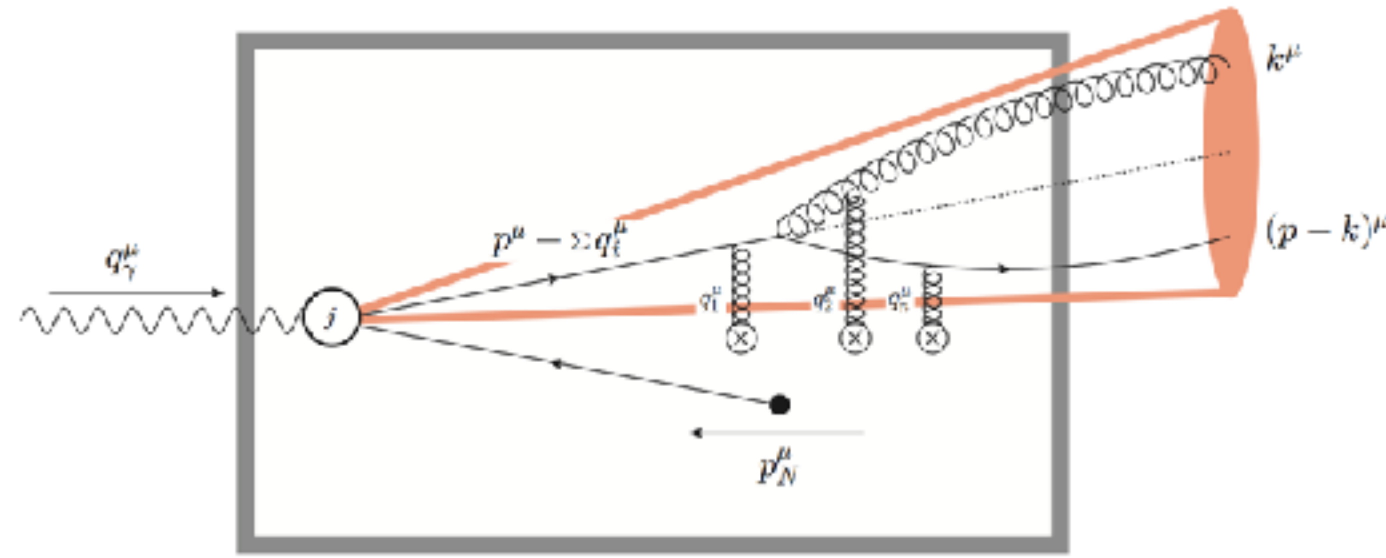
The hadron pseudo-rapidity in the interval [-2, 4]

Used a integrated luminosity of 10 fb^-1 (1-year EIC running)

- NLO correction is significant: K-factor 1.5 to 2.5
- Quasi-photon scattering contributes 40%-50% to NLO corrections
- Larger radiative corrections are pronounced at lower CM energies and forward rapidities

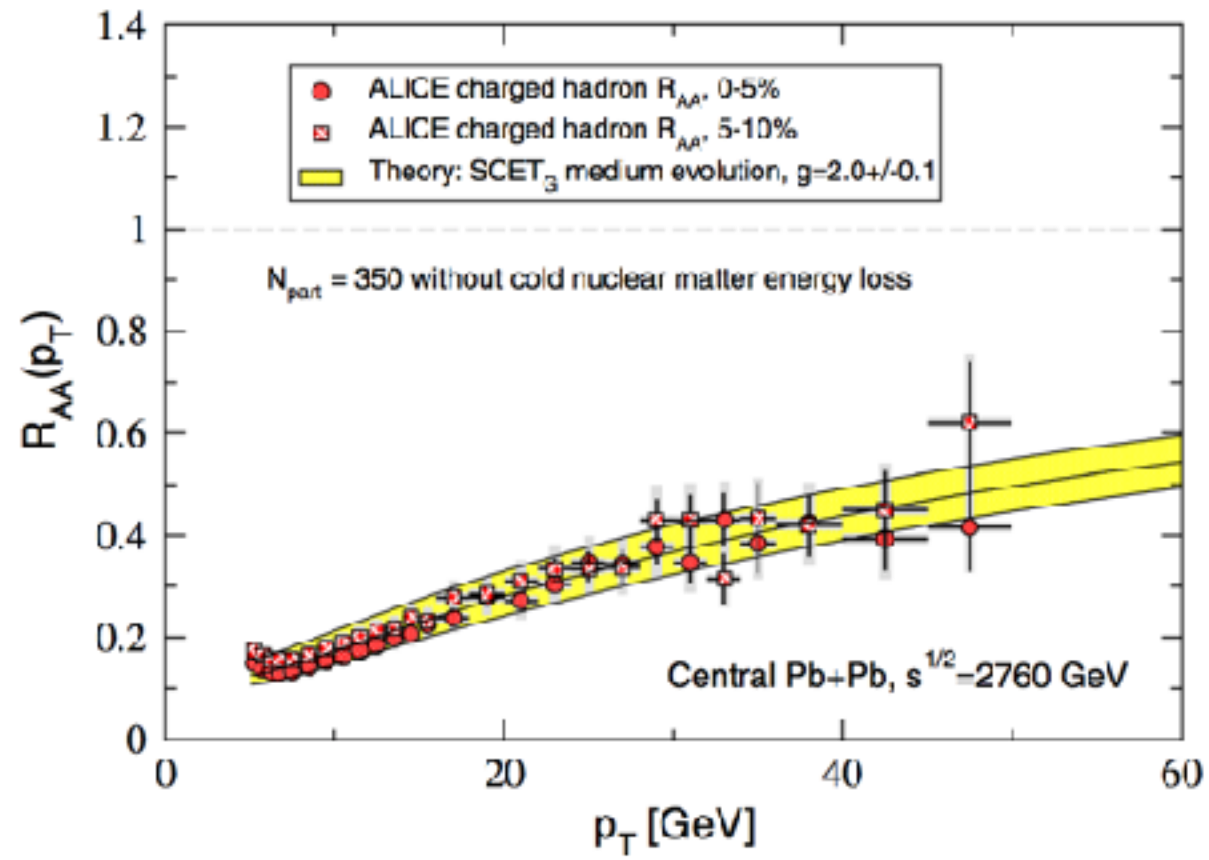
In-Medium Radiative Corrections

- The theoretical framework is completely general - it is applicable for both cold nuclear matter and the QGP



- Parton energy loss calculations can be regarded as a special soft-gluon emission limit of the general QCD evolution framework

Y. Chien et al. 2016



successfully applied in QGP medium

$$R_{AA}(p_T) = \frac{d\sigma^h_{AA}/dyd^2p_T}{\langle N_{\rm coll}\rangle d\sigma^h_{pp}/dyd^2p_T}$$

Splitting function in Medium

G. Ovanesyan et al. 2012

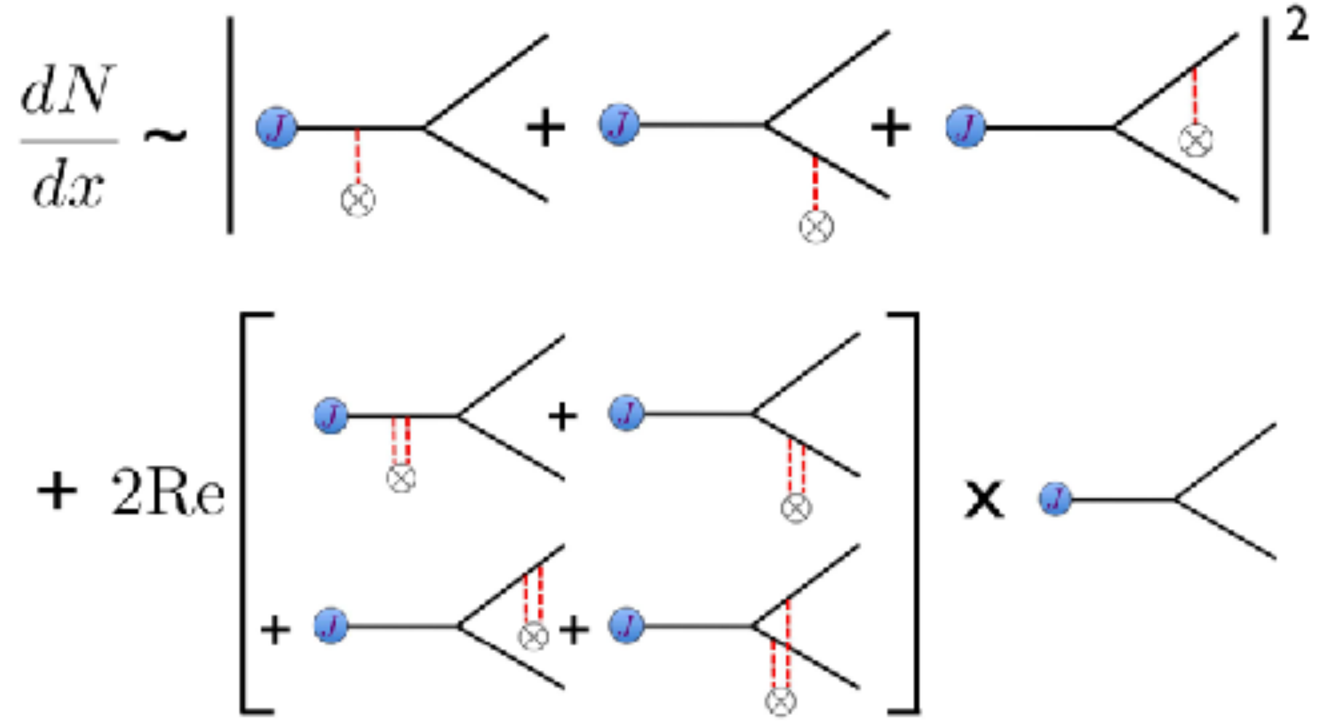
cross checked by 1807.03799

$$\mathcal{L}_{\text{SCET}_\text{G}}(\xi_n, A_n, A_G) = \mathcal{L}_{\text{SCET}}(\xi_n, A_n) + \mathcal{L}_\text{G}(\xi_n, A_n, A_G),$$

$$\mathcal{L}_\text{G}(\xi_n, A_n, A_G) = \sum_{p,p'} \text{e}^{-i(p-p')x}\left(\bar{\xi}_{n,p'}\Gamma^{\mu,a}_{\text{qqA}_\text{G}}\frac{\bar{\not n}}{2}\xi_{n,p} - i\Gamma^{\mu\nu\lambda,abc}_{\text{ggA}_\text{G}}(A^b_{n,p'})_\nu (A^c_{n,p})_\lambda\right)A_{\text{G}\mu,a}(x).$$

$$A_{q\to qg} = \langle q(p)g(k)|T\text{e}^{iS}\bar{\chi}_n(x_0)|q(p_0)\rangle,$$
$$A_{g\to gg} = \langle g(p)g(k)|T\text{e}^{iS}\mathcal{B}^{\lambda c}(x_0)|g(p_0)\rangle,$$
$$A_{g\to q\bar{q}} = \langle q(p)\bar{q}(k)|T\text{e}^{iS}\mathcal{B}^{\lambda c}(x_0)|g(p_0)\rangle,$$
$$A_{q\to gq} = \langle g(p)q(k)|T\text{e}^{iS}\bar{\chi}_n(x_0)|q(p_0)\rangle,$$

$$S = i\int d^4x \mathcal{L}_{\text{SCET}_\text{G}}$$

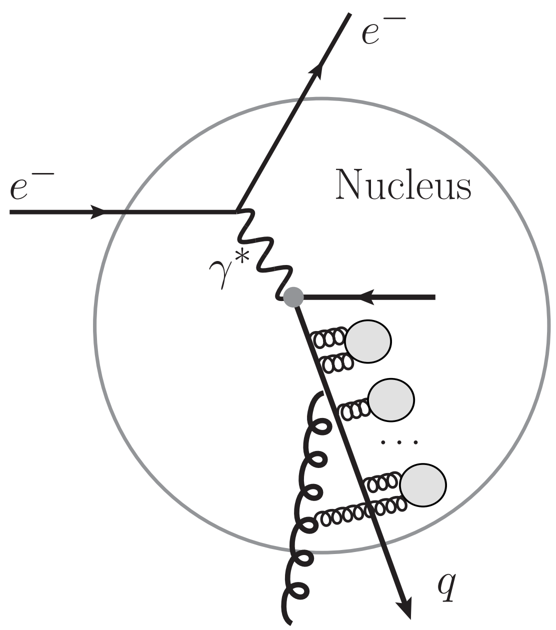


Red lines correspond to Glauber gluons

Evolution of Fragmentation Functions

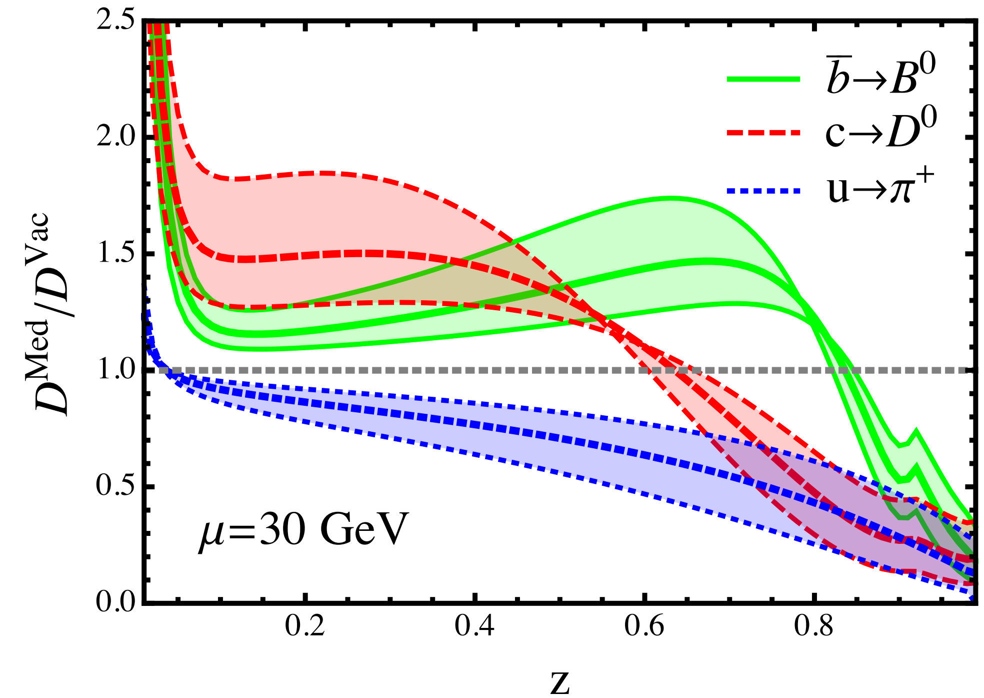
$$\frac{\mathrm{d}D_{h/q}(z,Q)}{\mathrm{d}\ln Q} = \frac{\alpha_s(Q)}{\pi}\int_z^1 \frac{\mathrm{d}z'}{z'}\left[P^{\rm full}_{q\to qg}(z',Q;\beta)D_{h/q}\left(\frac{z}{z'},Q\right) + P^{\rm full}_{q\to gq}(z',Q;\beta)D_{h/g}\left(\frac{z}{z'},Q\right)\right]$$

$$P_i^{\rm full}(x,\boldsymbol{k}_\perp;\beta) = P_i^{\rm vac}(x) + P_i^{\rm med}(x,\boldsymbol{k}_\perp;\beta)$$

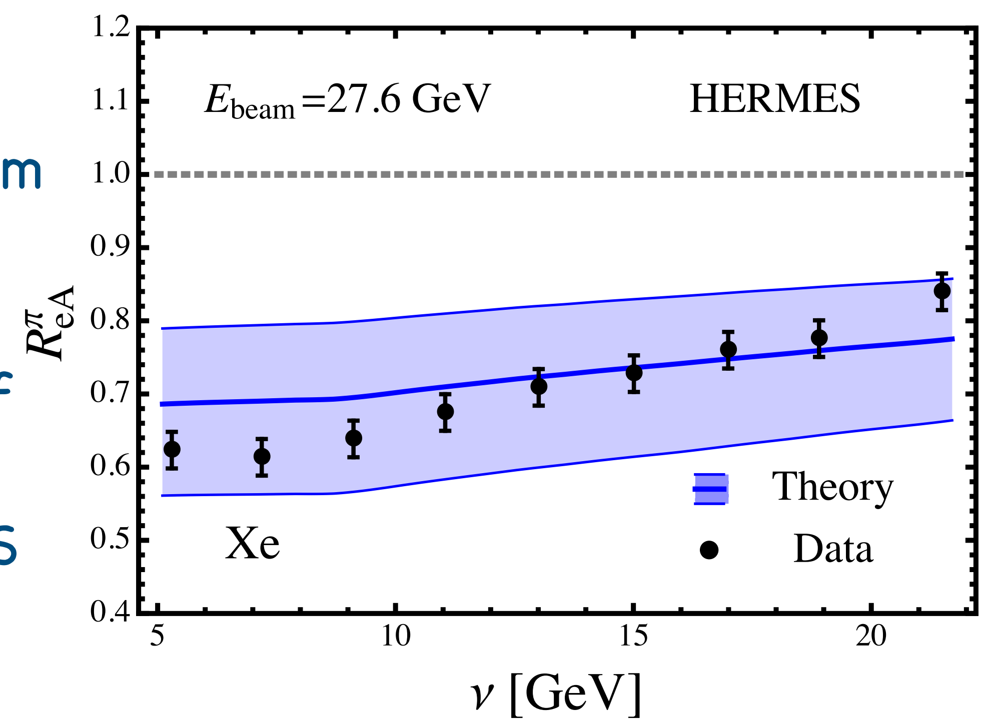


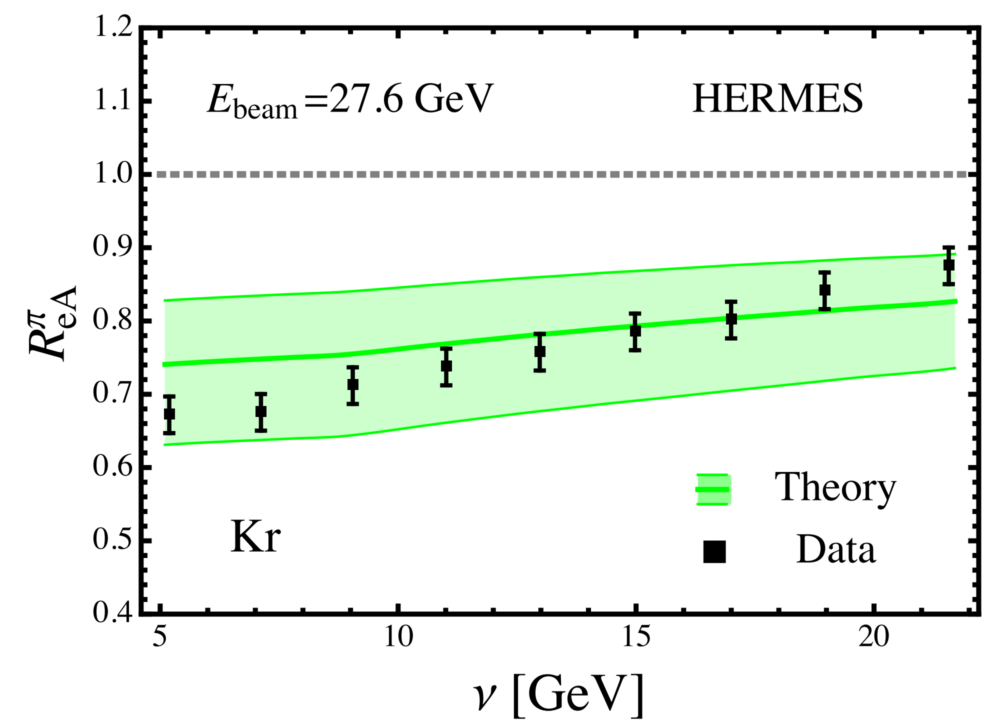
- In-Medium Splitting functions are derived based on SCETG
- Significant Enhancement at small z for heavy flavors

Fragmentation Function In Medium (Au)



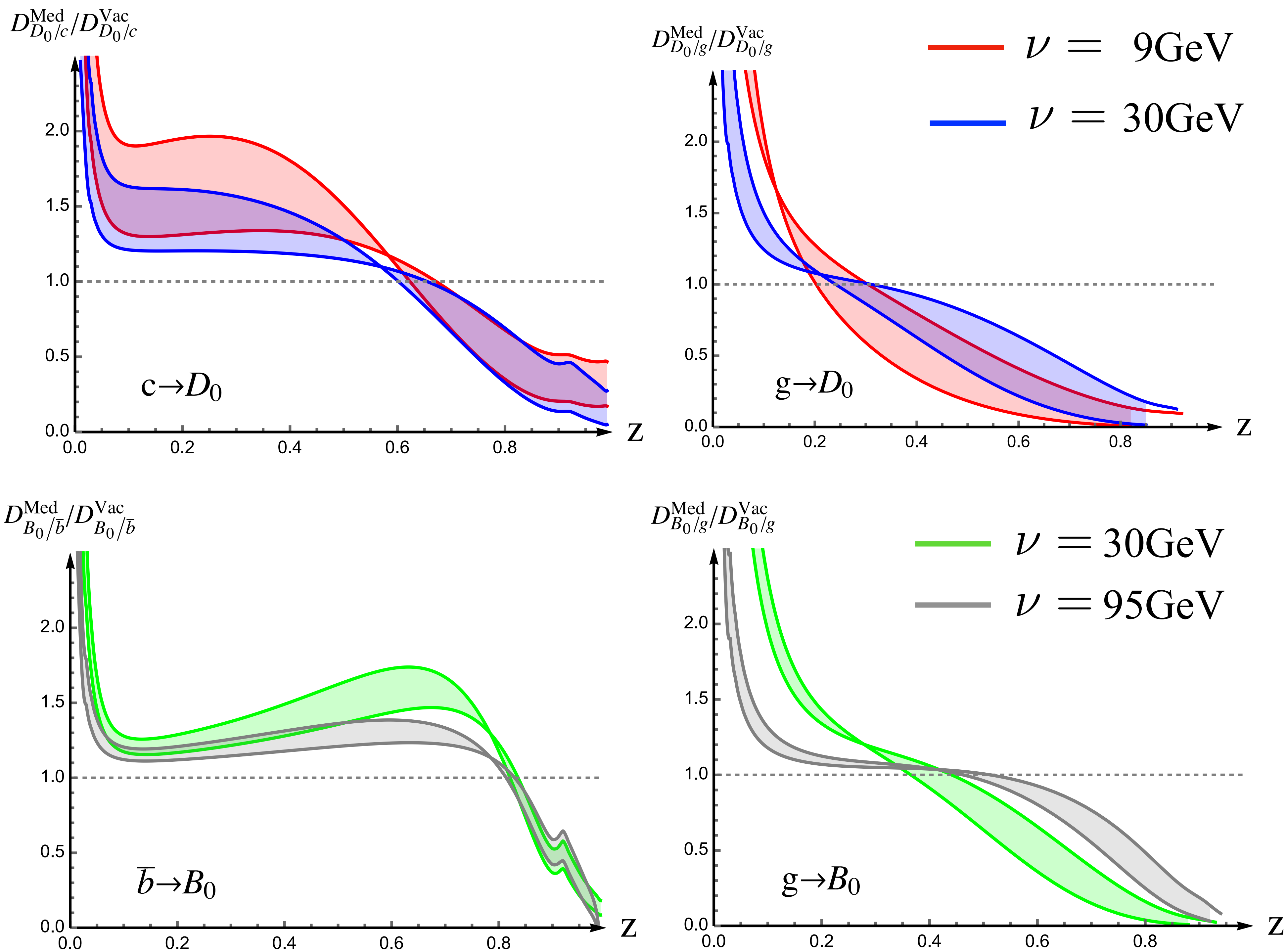
- Our description of hadronization in-medium is valid
- Transport parameter of Cold Nuclear Matter is constrained by HERMES





Fragmentation Function for HF in Au

The modification of HF channels is very different from light channels!



Significant enhancement at small and moderate value of z

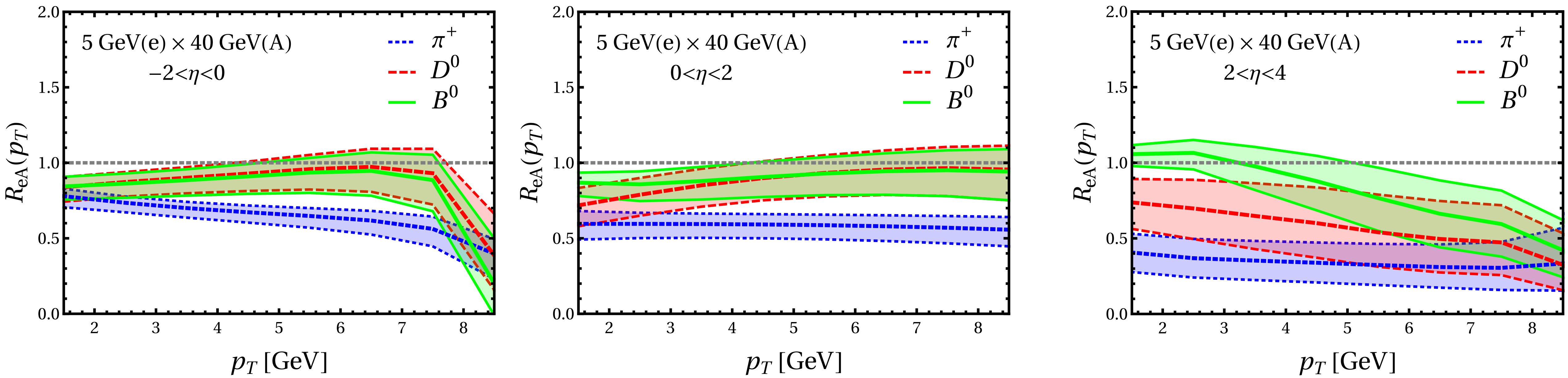
Transition from suppression to enhancement is much steeper for B meson

Hadron production at the EIC

To investigate nuclear medium effect, study the ratio of cross section in e+Au to the one in e+p

$$R^h_{eA}(p_T,\eta,z) = \frac{\left.\frac{N^h(p_T,\eta,z)}{N^{\rm inc}(p_T,\eta)}\right|_{\rm e+Au}}{\left.\frac{N^h(p_T,\eta,z)}{N^{\rm inc}(p_T,\eta)}\right|_{\rm e+p}}$$

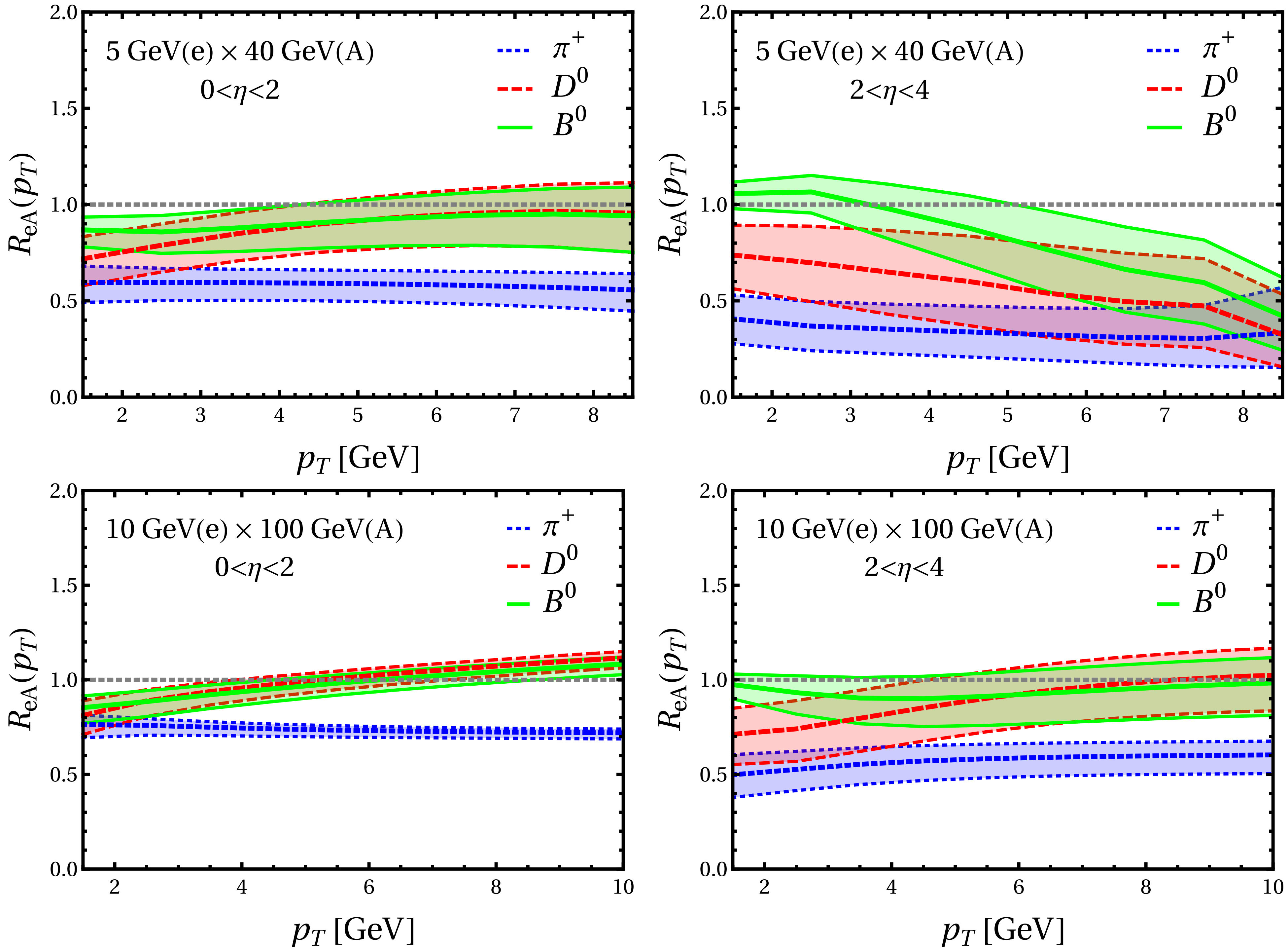
use the cross section of inclusive jet production for normalization that minimizes the effect of nuclear PDFs



Parton in forward rapidity region has lower energy in rest frame of nuclei, resulting in larger in-medium modification

result of Landau-Pomeranchuk-Migdal (LPM) Effect

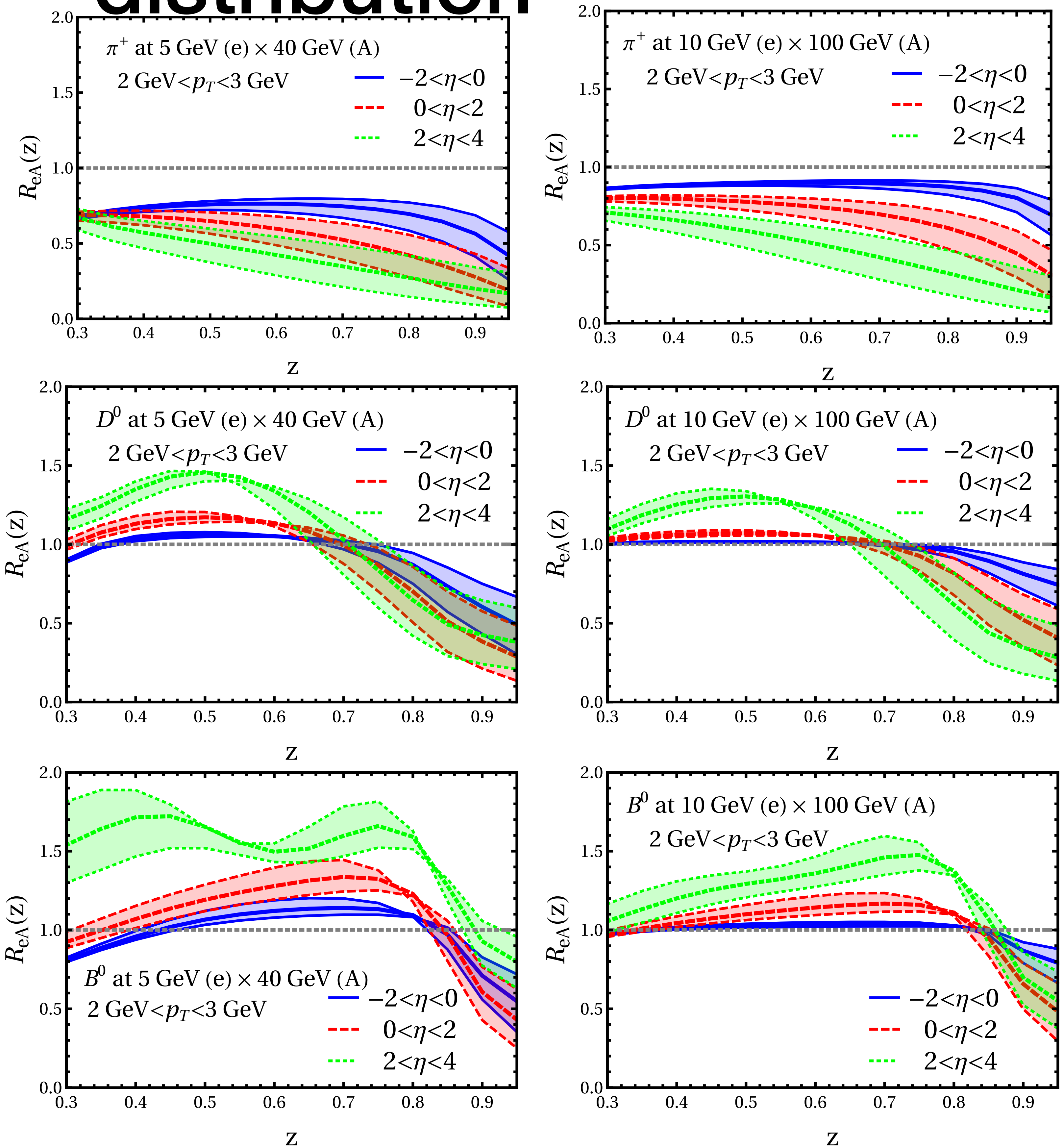
Heavy Flavor production - pT distribution



- There results highlight the suppression of light hadrons and transmission to enhancement for heavy flavor

- Lower CM energies are clearly better for the energy-loss/hadronization studies

Heavy Flavor production - fragmentation distribution



More differential v.s. z

- For light flavor, observe suppression, which can be as large as a factor of 2
- Lower energy parton in the rest frame of nuclear receives the larger medium corrections
- Cold Nuclear Matter effect is more significant in forward rapidity region at lower energy collision
- Study of in-medium effects benefits from more differential analysis !!!

Conclusion

- Hadronization plays an important role for jet and most semi-inclusive observables and affects them qualitatively and quantitatively. Its role at the EIC is not explored yet
- Larger radiative corrections are pronounced at lower CM energies and forward rapidities
- Studies of in-medium modification benefits from more differential measurements
- The clear transition from enhancement to suppression at moderate to large values of z will be a quantitative measure of parton shower formation in large nuclei.

Thank you for your attention!