Heavy meson tomography of cold nuclear matter at the EIC

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

EIC Opportunities for Snowmass
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Study Goals at the EIC

- Precise determination of PDFs of charm/ bottom quark

- Precisely study the fragmentation functions for light/heavy flavors

- To understand the nuclear medium effects on hadron production

  e.g. hadronization patterns by comparing measurements between e+p and e+A

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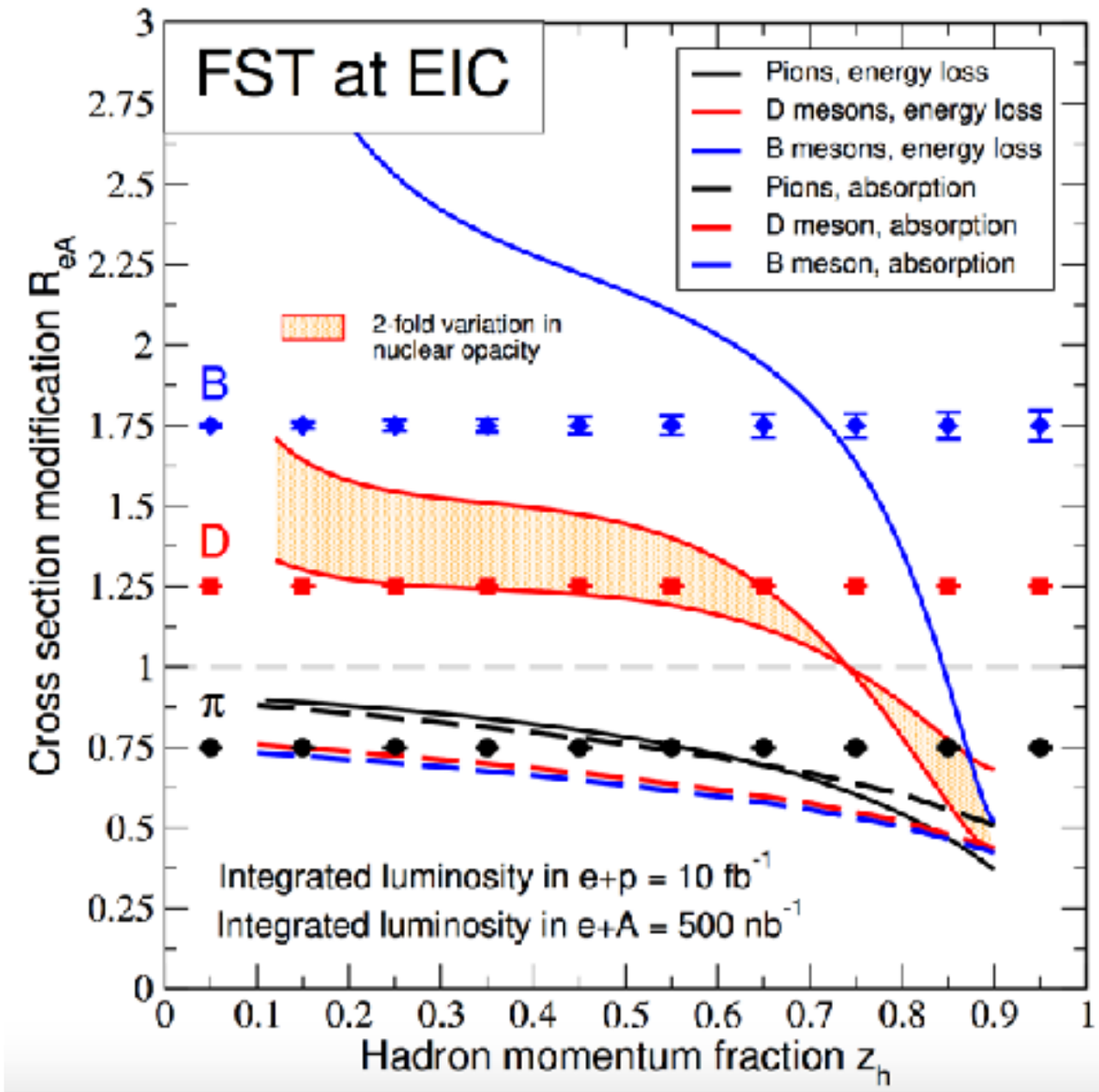
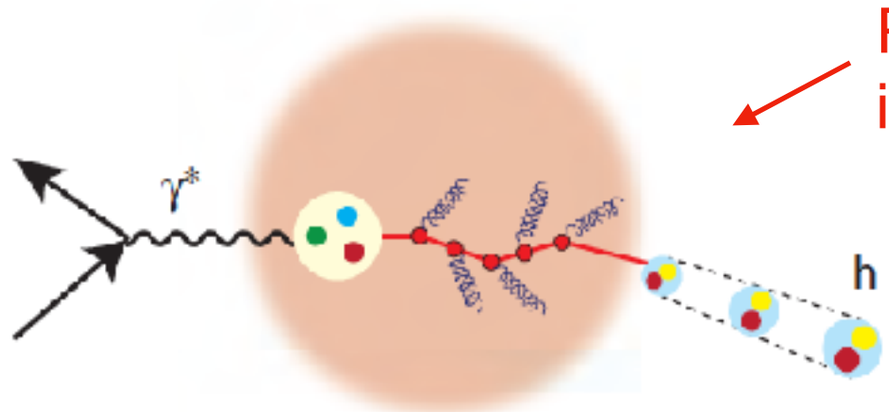


Pictures of Hadronization

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

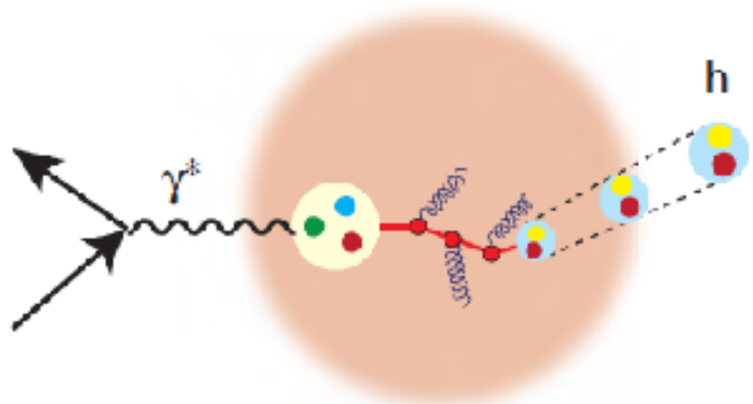
Energy loss approach



Prefer large parton energy in the nuclear rest frame

hadronization outside of the nucleus

Hadron formation and absorption



hadronization inside of the nucleus

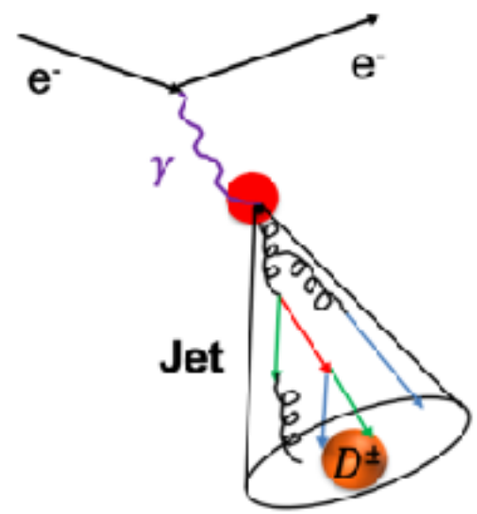
Prediction in e+p collision

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

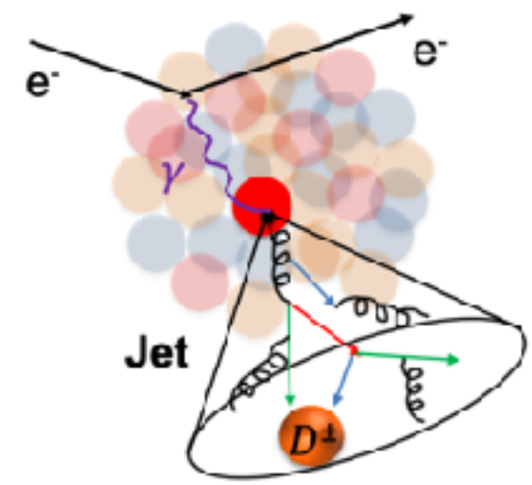
  M. Hirai et al., '07
- Partonic cross section: analytical NLO result

  P. Hinderer et al., '15

$e^- + \mathrm{p} \to e^- + jet(D^\pm) + X$



$e^- + \mathrm{Au} \to e^- + jet(D^\pm) + X$



NLO cross section can be factorized as

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

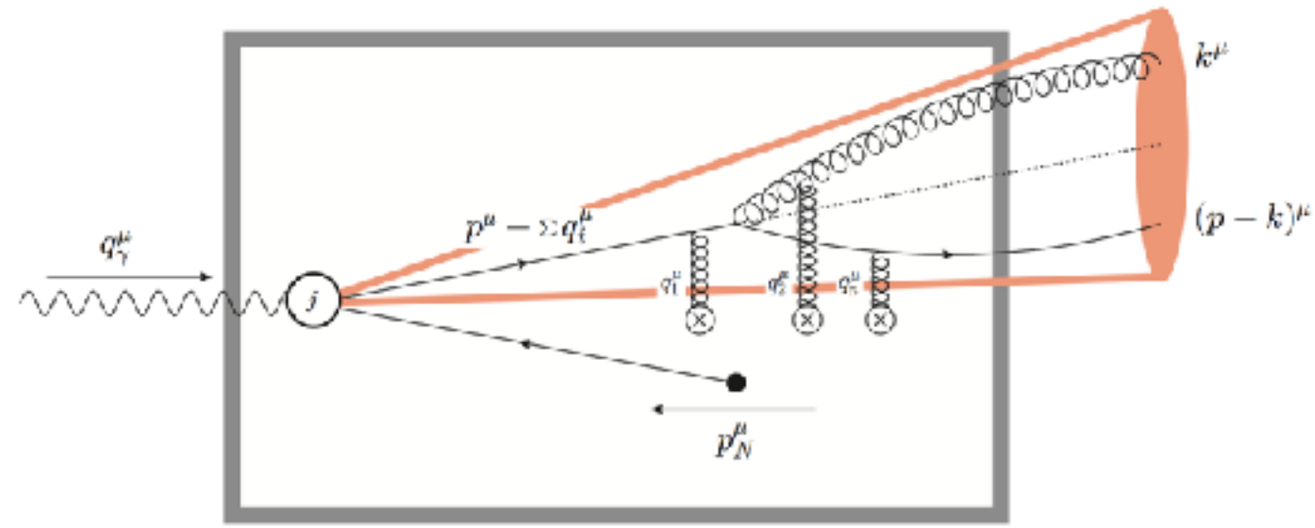
FFs

NLO hard kernel

quasi-real photon scattering

In-Medium Radiative Corrections

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

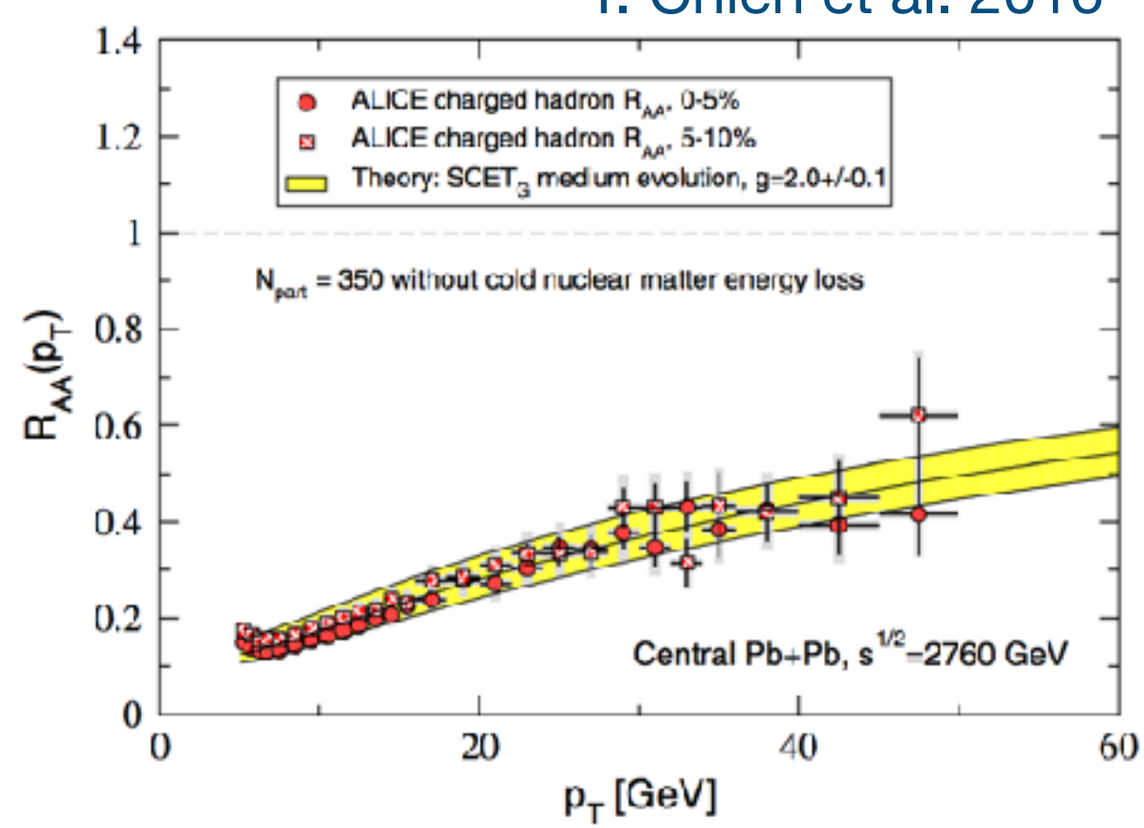


- Parton energy loss calculations can be regarded as a special soft-gluon emission limit of the general QCD evolution framework

successfully applied in QGP medium

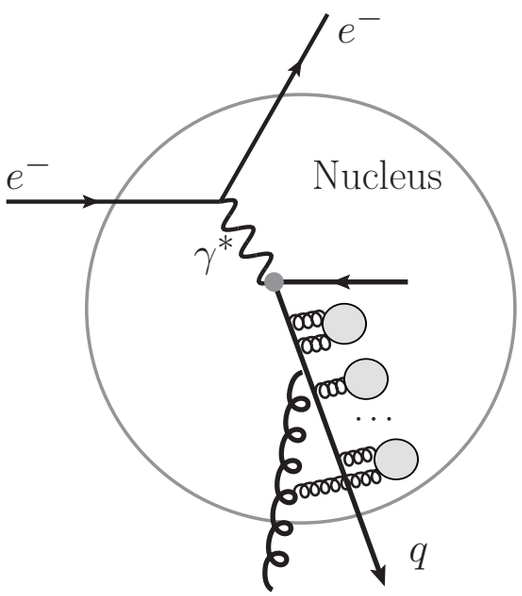
$$R_{AA}(p_T) = \frac{d\sigma^h_{AA}/dyd^2p_T}{\langle N_{\rm coll}\rangle d\sigma^h_{pp}/dyd^2p_T}$$

Y. Chien et al. 2016



Evolution of Fragmentation Functions

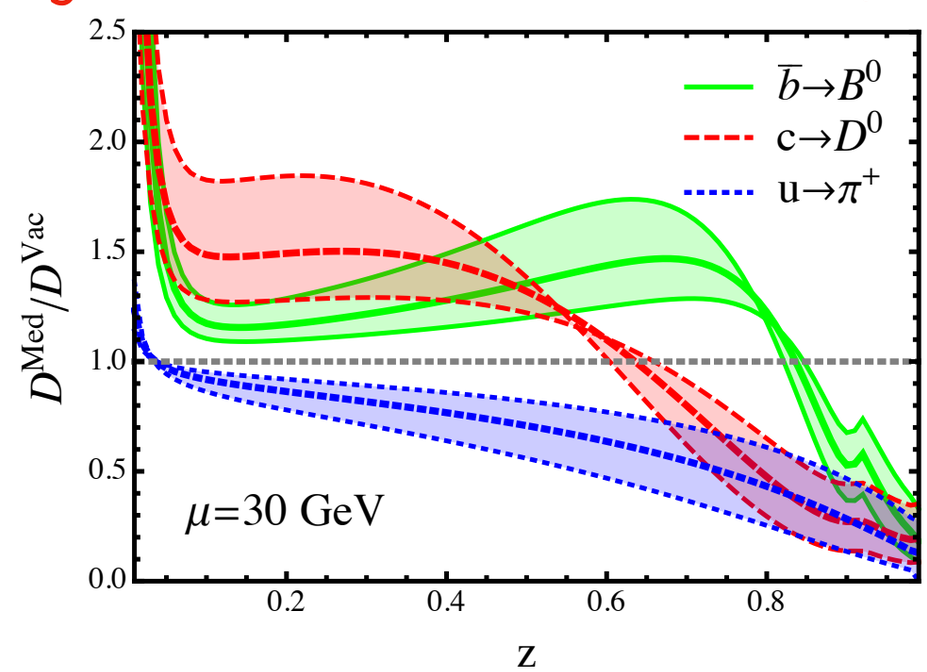
$$\frac{\mathrm{d}D_{h/q}(z,Q)}{\mathrm{d}\ln Q} = \frac{\alpha_s(Q)}{\pi}\int_z^1 \frac{\mathrm{d}z'}{z'}\left[P^{\mathrm{full}}_{q\to qg}(z',Q;\beta)D_{h/q}\left(\frac{z}{z'},Q\right) + P^{\mathrm{full}}_{q\to gq}(z',Q;\beta)D_{h/g}\left(\frac{z}{z'},Q\right)\right]$$



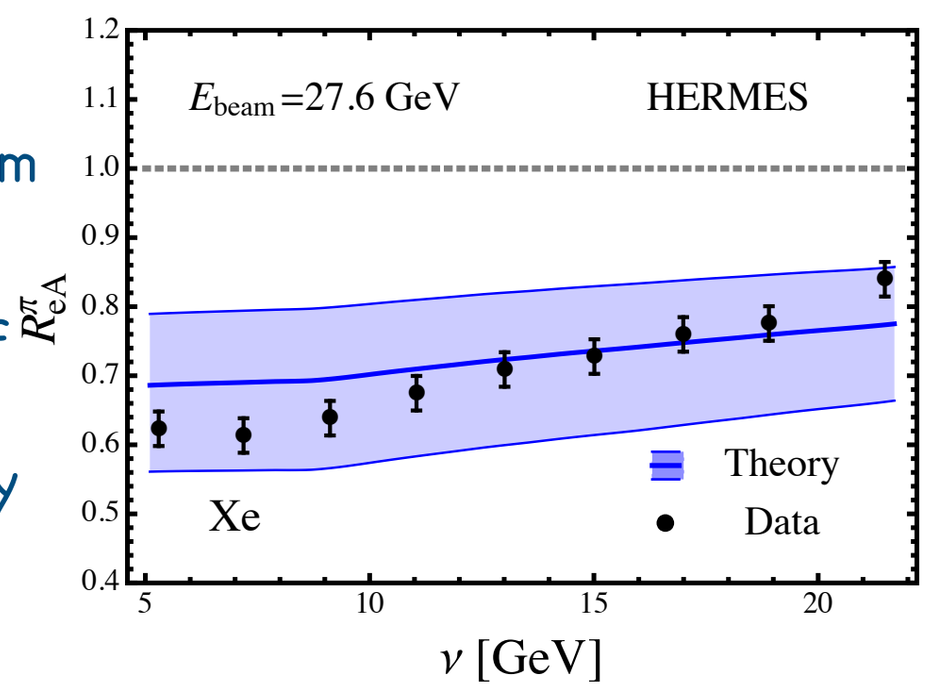
$$P_i^{\mathrm{full}}(x,\boldsymbol{k}_\perp;\beta) = P_i^{\mathrm{vac}}(x) + P_i^{\mathrm{med}}(x,\boldsymbol{k}_\perp;\beta)$$

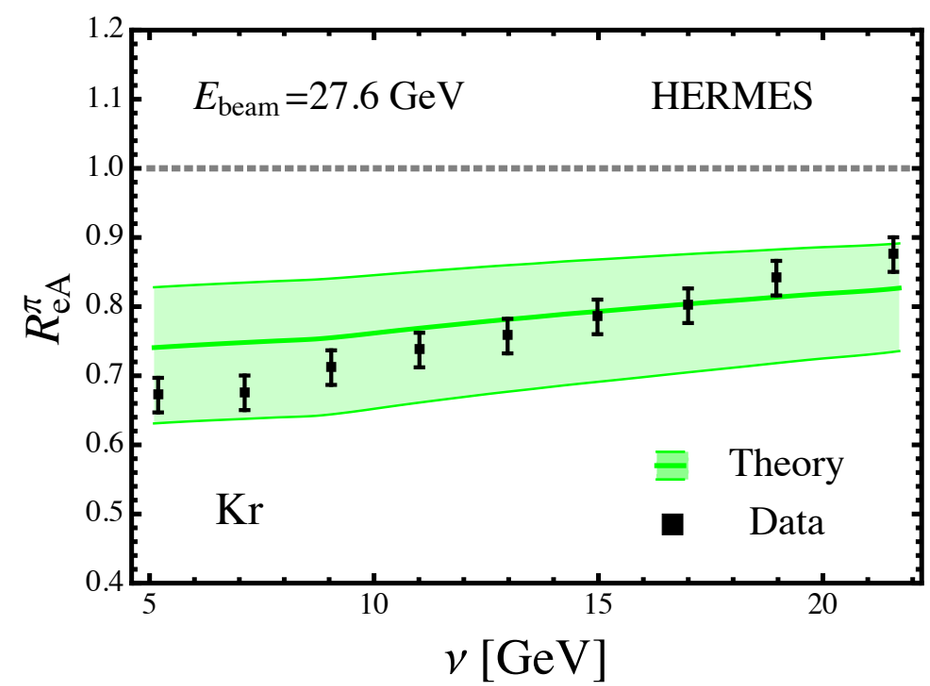
- In-Medium Splitting functions are derived based on SCET$_G$
- Significant Enhancement at small z for heavy flavors

Fragmentation Function In Medium (Au)



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



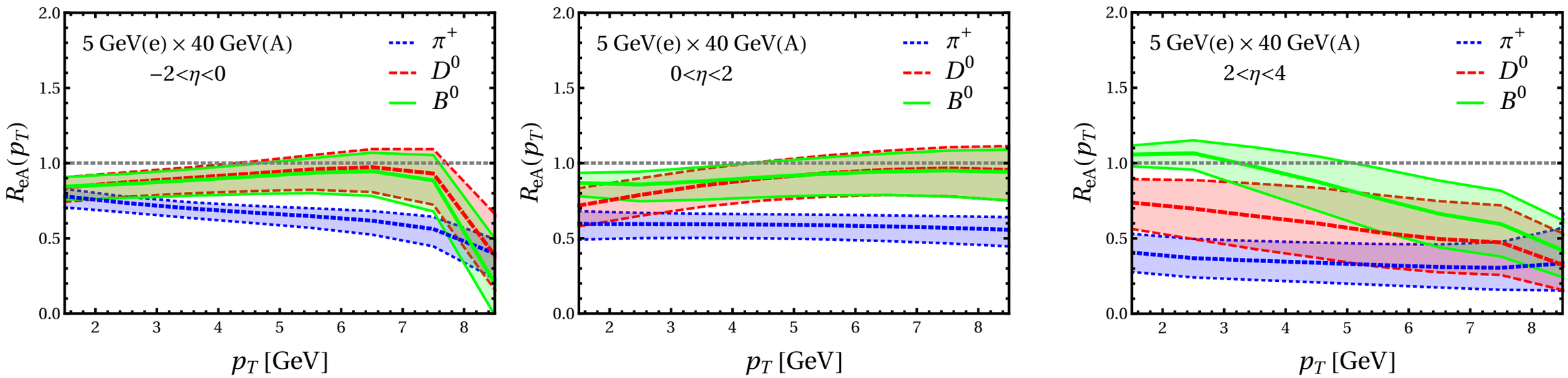


Hadron production at the EIC

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

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

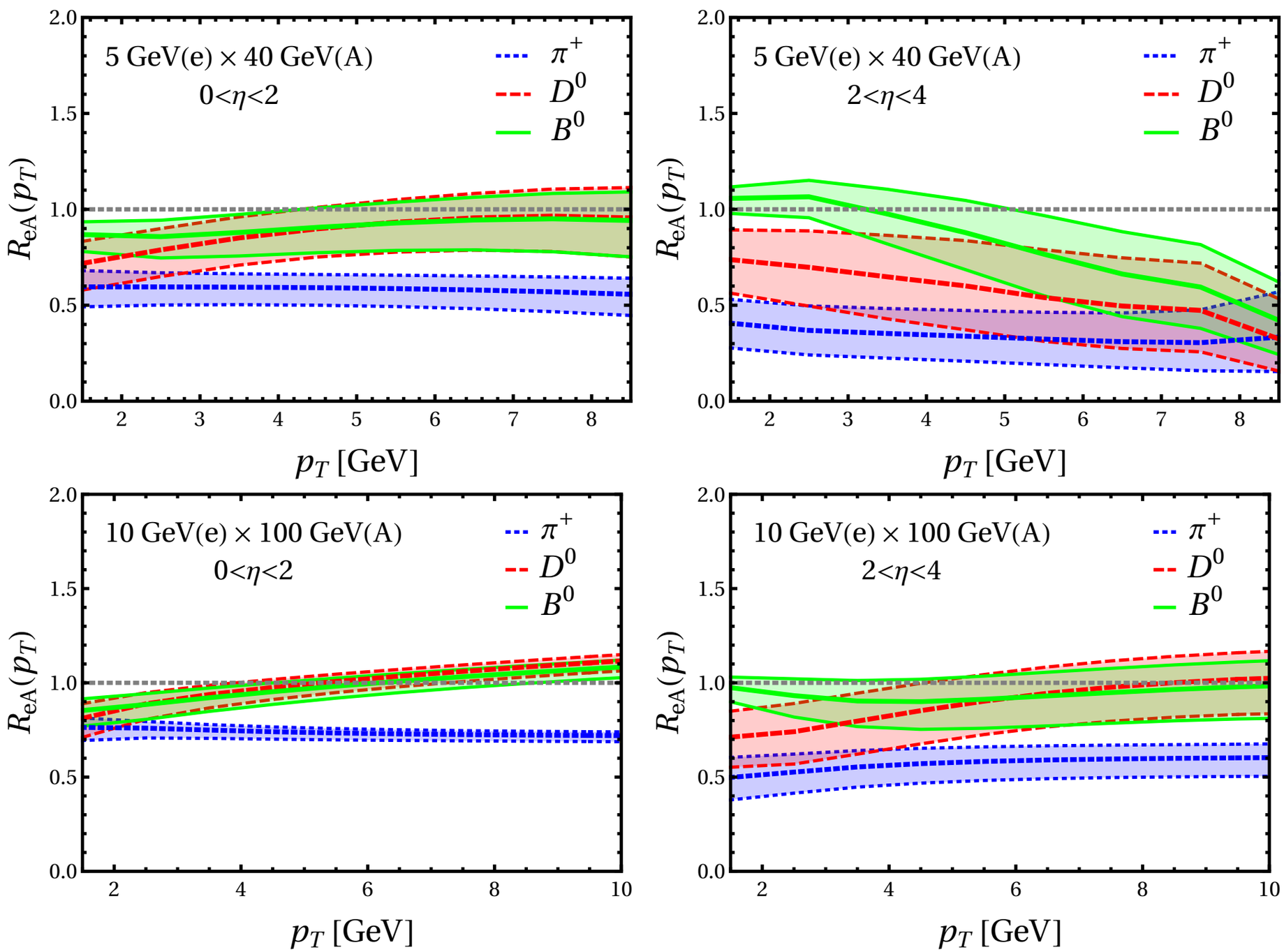
use the cross section of inclusive jet production for normalization that minimizes the effect of nuclear PDFs



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

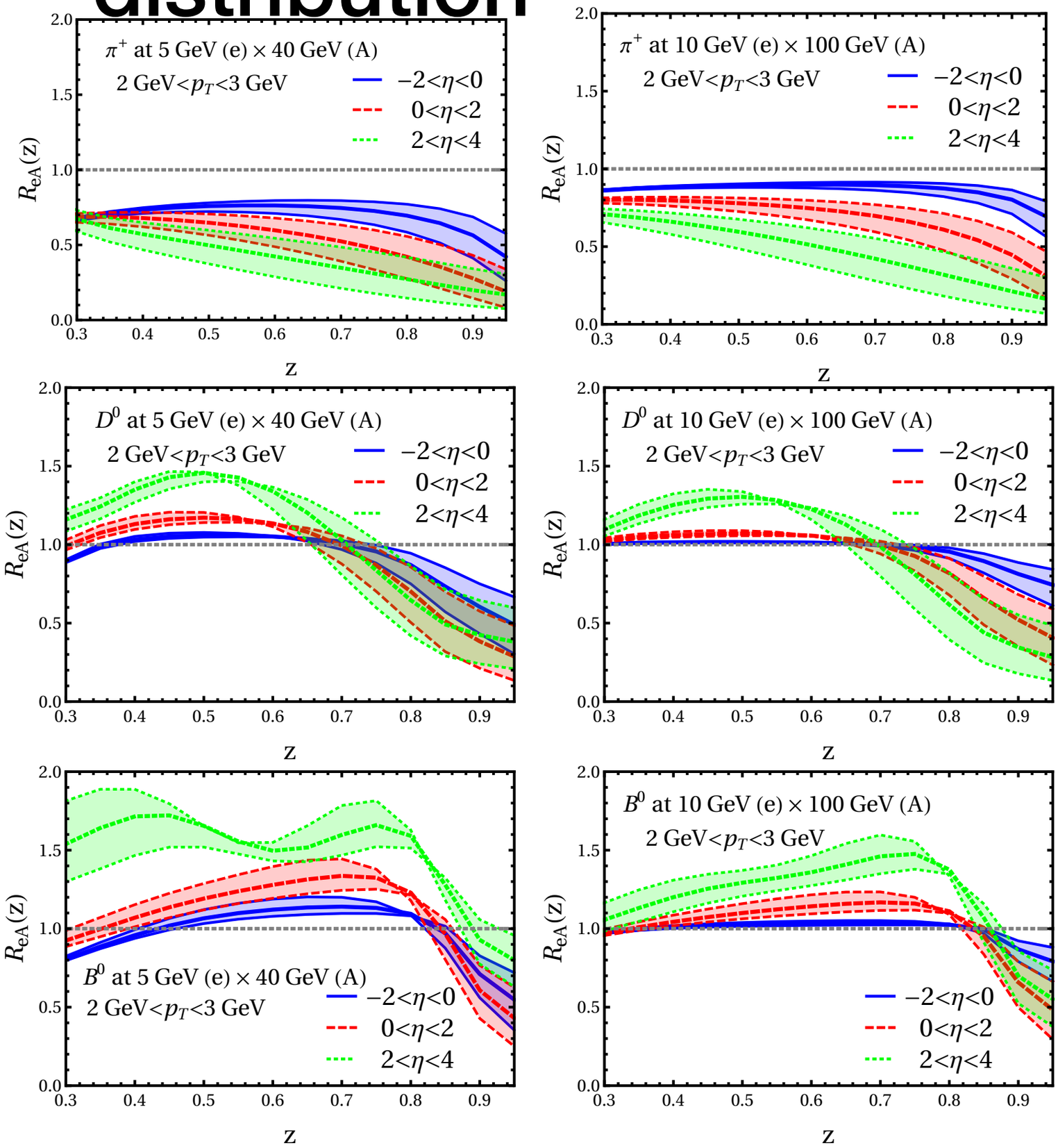
result of Landau-Pomeranchuk-Migdal (LPM) Effect

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



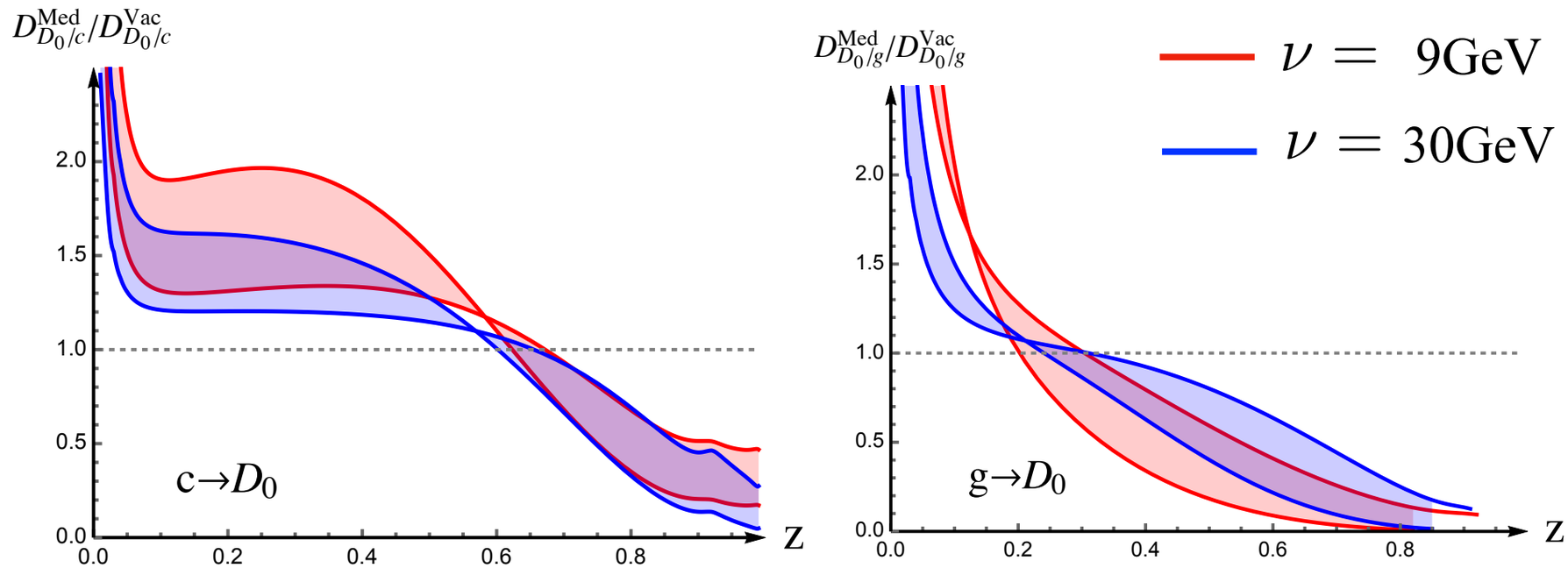
More differential v.s. z

- 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 !!!

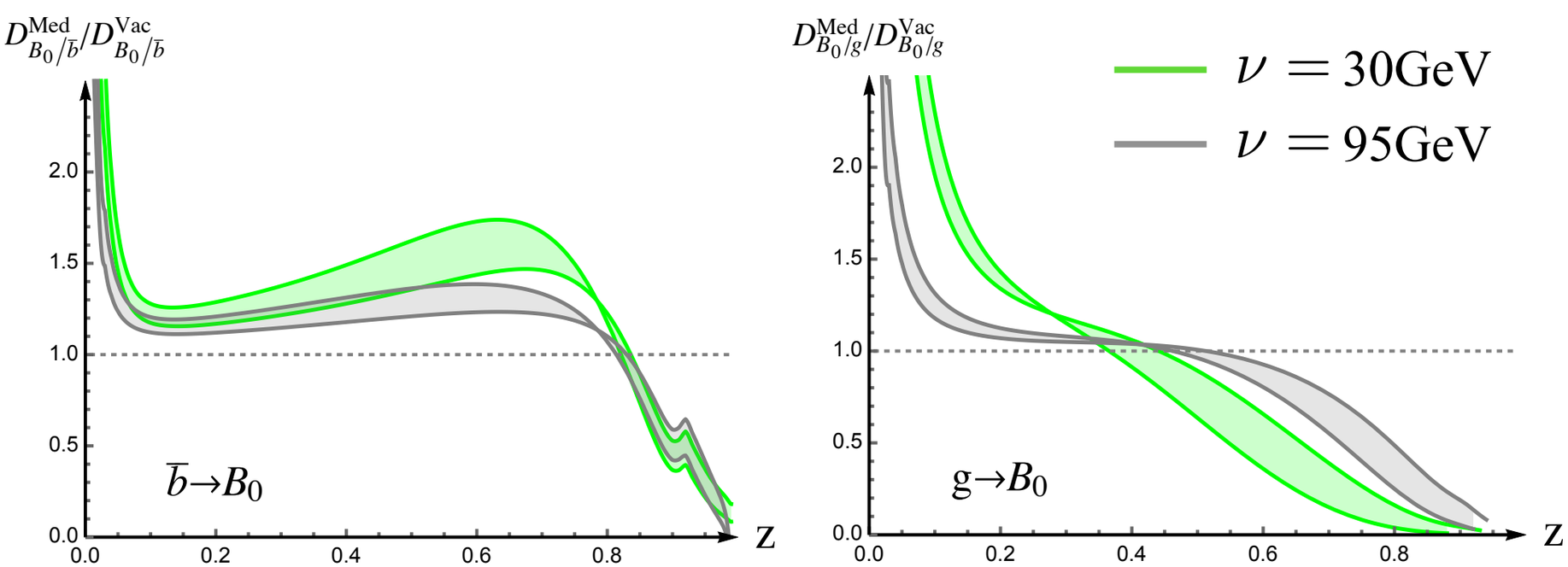
Thank you for your attention!

Fragmentation Function for HF in Au

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

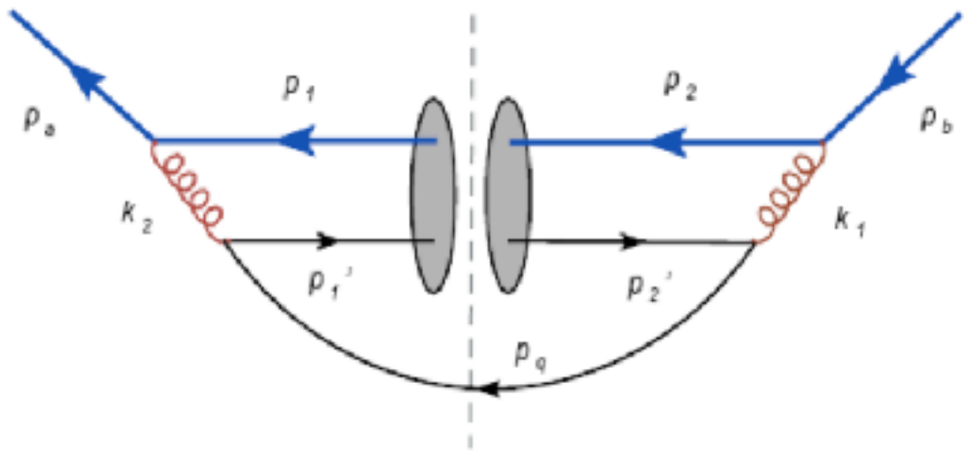


Significant enhancement at small and moderate value of z

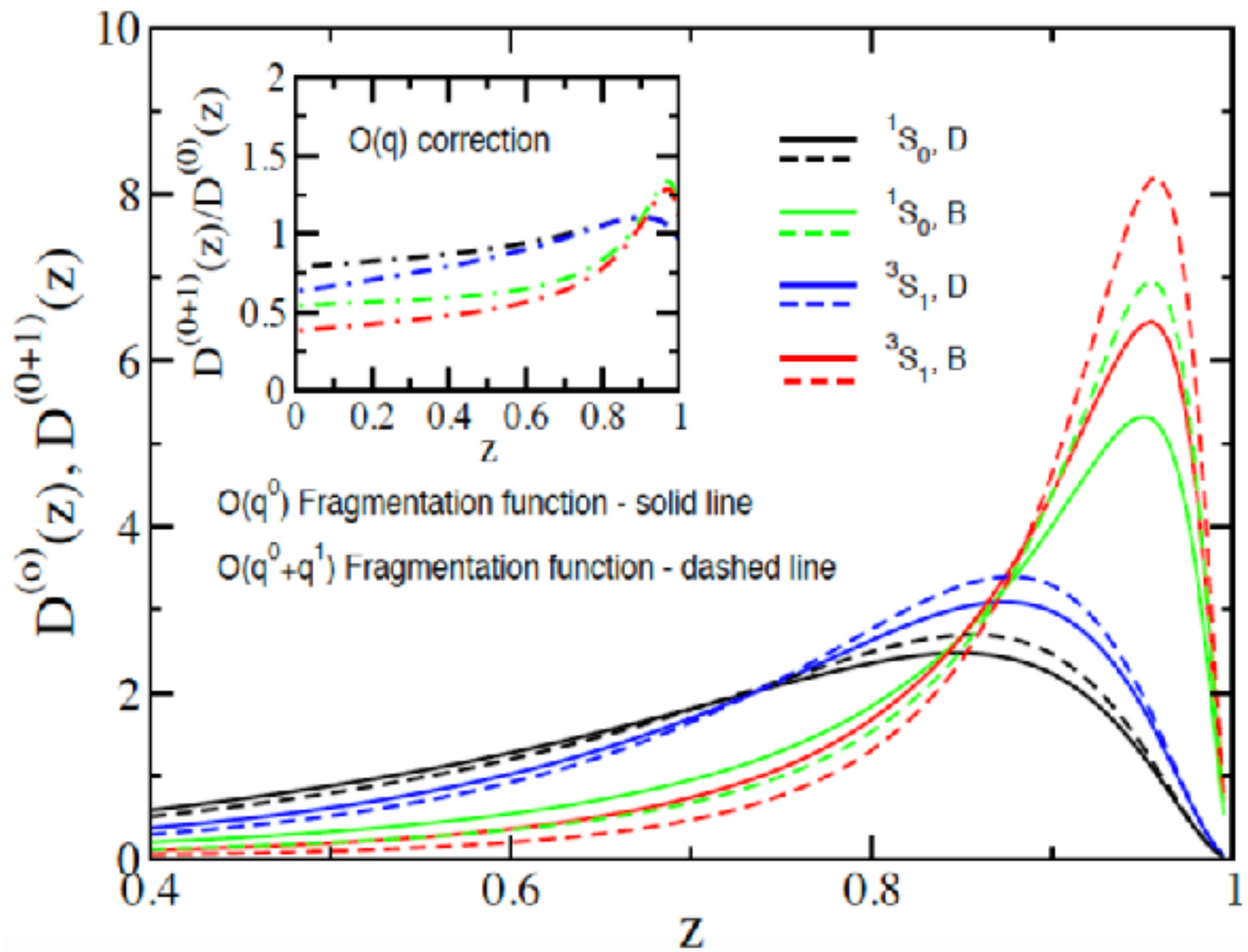


Transition from suppression to enhancement is much steeper for B meson

FFs for heavy flavors in vacuum



Chang et al. 1992 Braaten et al. 1995



studied in HQET

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

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