Modification of heavy flavor in e+A collisions at the EIC

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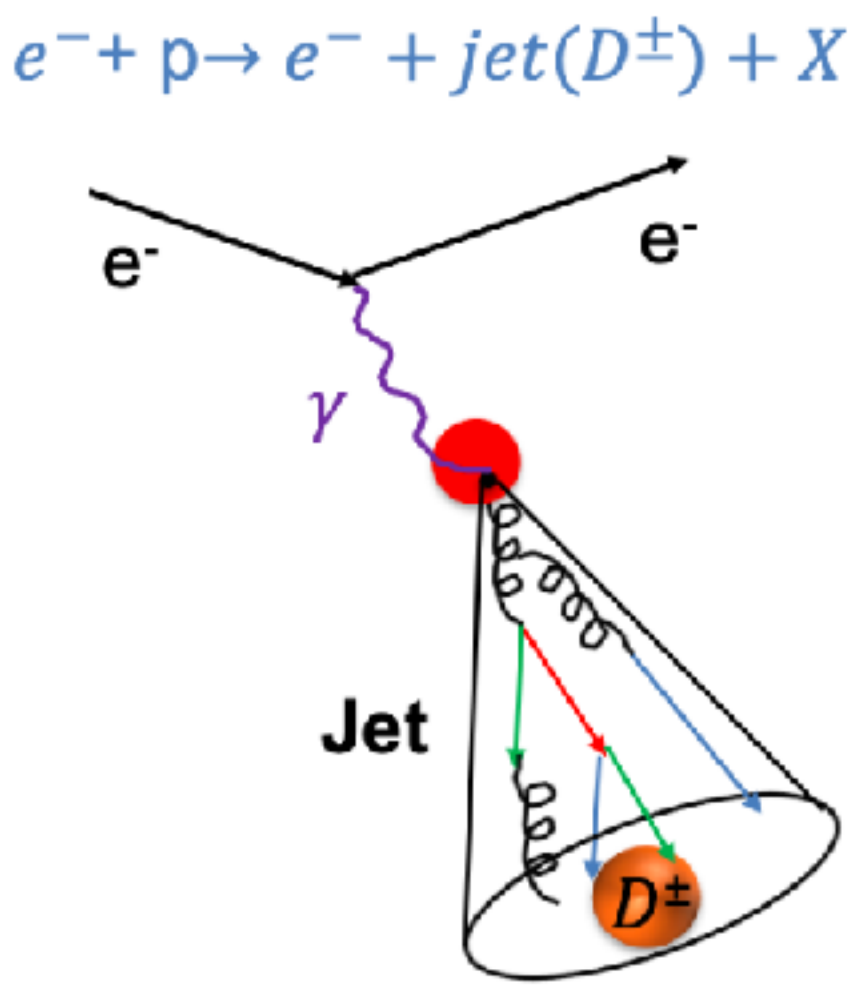
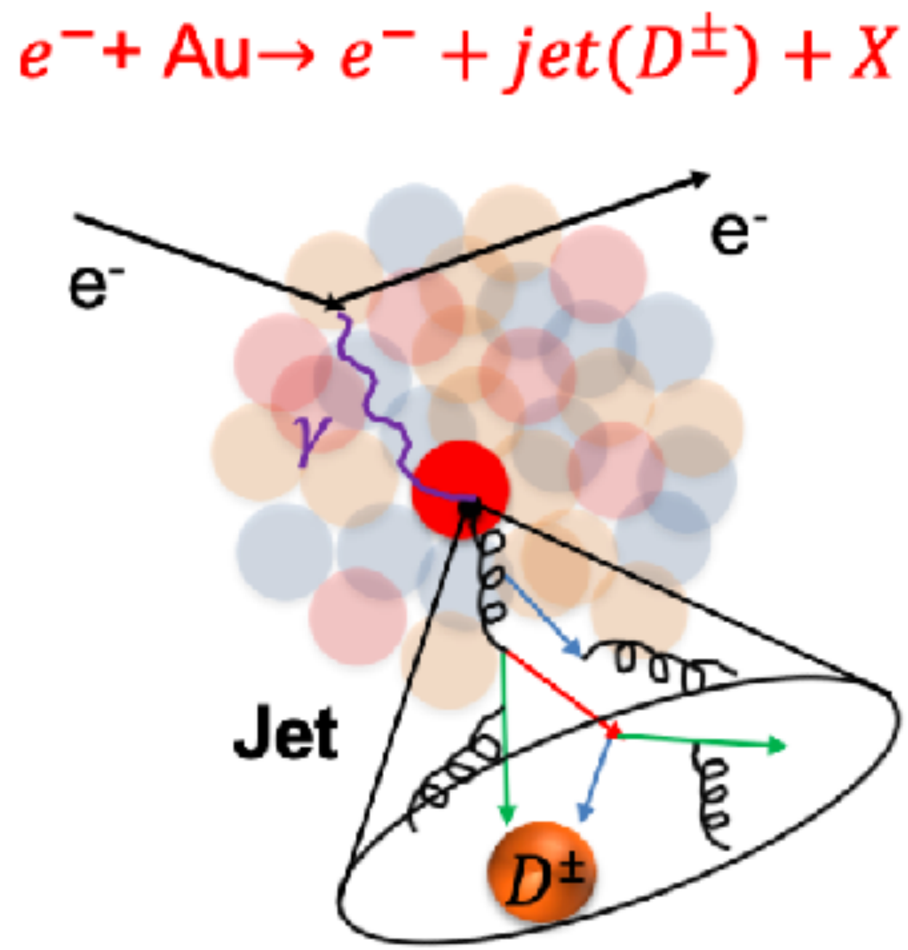
Study Goals at EIC





- **Precise determination of the initial PDFs**
- **Precisely study the fragmentation functions for light/heavy flavors**
- **To understand the nuclear medium effects on hadron production**

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

Study Goals at EIC

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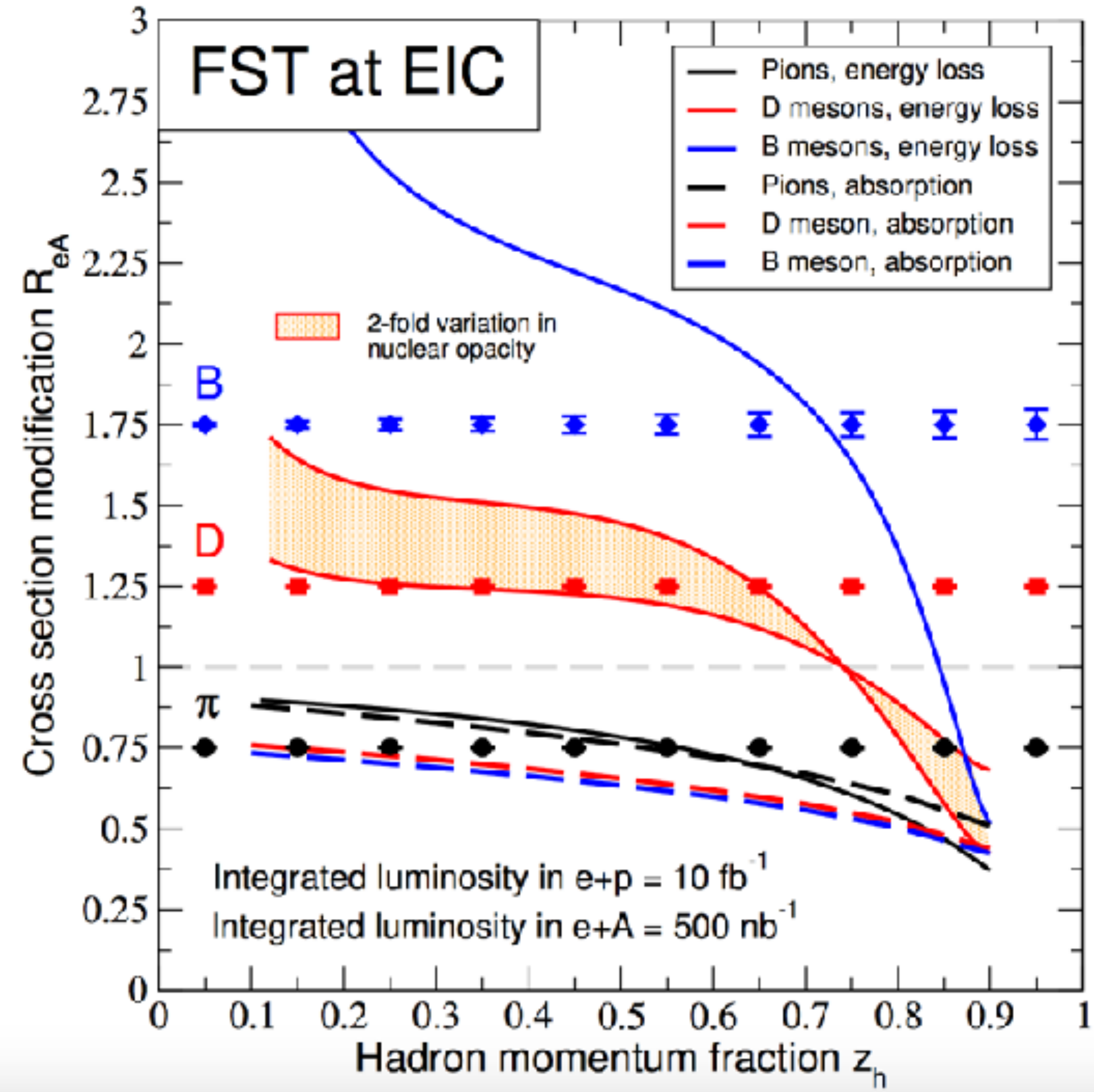
- **To understand models of nuclear modification in DIS reactions with nuclei (HERMES can not do)**
- **To see the differences of the fragmentation functions and formation times for different heavy mesons.**



The Picture of Hadronization

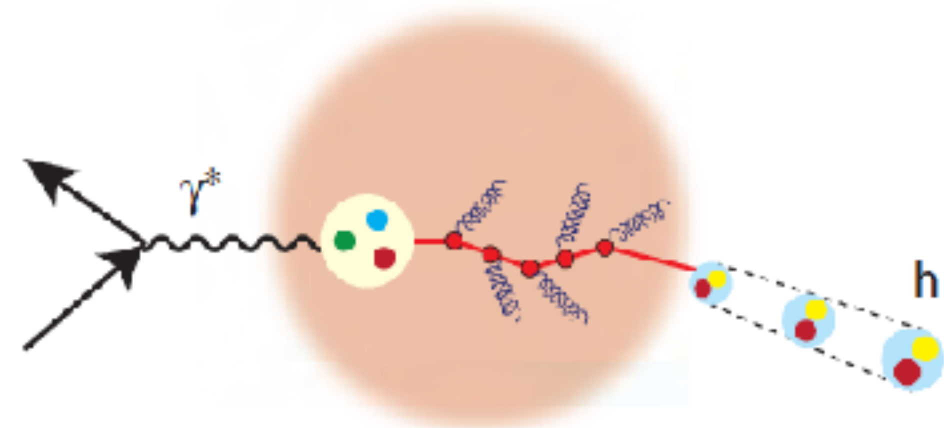
Energy loss approach

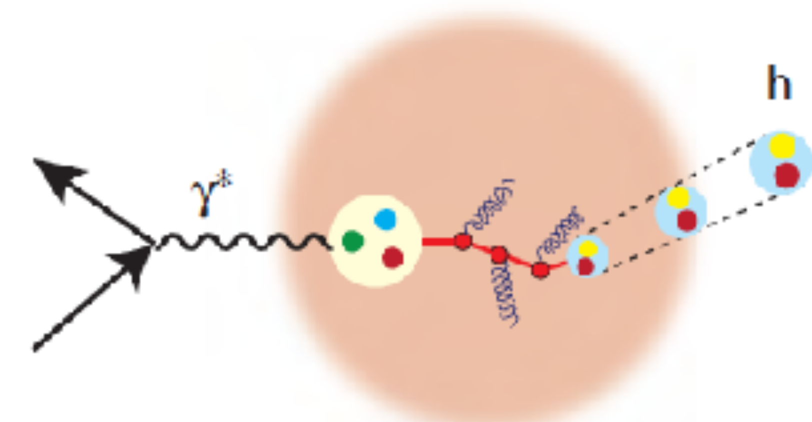
- Precluding hard splitting processes can significantly affect the accuracy of the theoretical predictions
- cannot incorporate the advances in understanding higher order calculations and resummation in the standard pQCD and SCET frameworks.

Hadron formation and absorption

- This application is intended to illustrate the effect of mass on hadronization time. Parameters chosen so that pion hadronization is inside the nucleus and the absorption cross section is chosen to reproduce light pion suppression

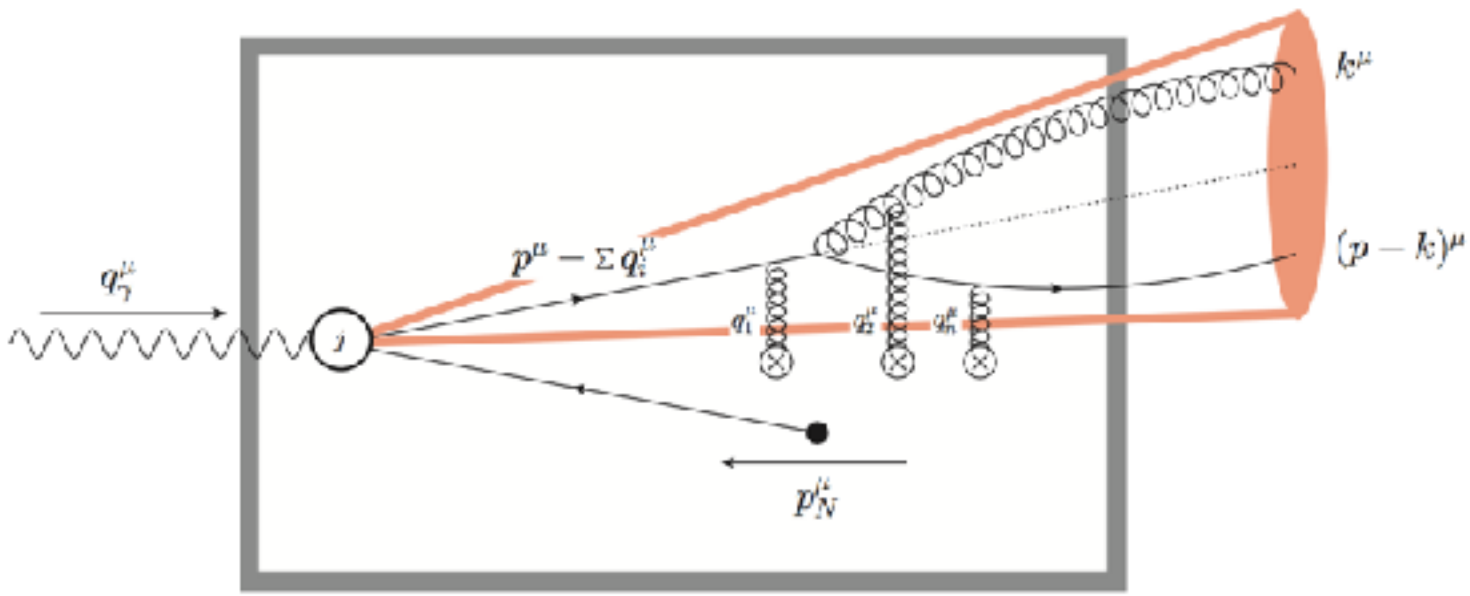
hadronization outside of the nucleus





hadronization inside of the nucleus

In-Medium Radiative Corrections



- The theoretical framework is completely general - it is applicable for both cold nuclear matter and the QGP
- This is achieved by isolating the medium in transport parameters and universal gluon-mediated interactions
- Full massless and massive in-medium splitting functions are available to first order

G. Ovanesyan et al. 2011 F. Ringer et al. 2016 M. Sievert et al. 2018

- SCET-based effective theories created to solve this problem

Splitting function in Medium

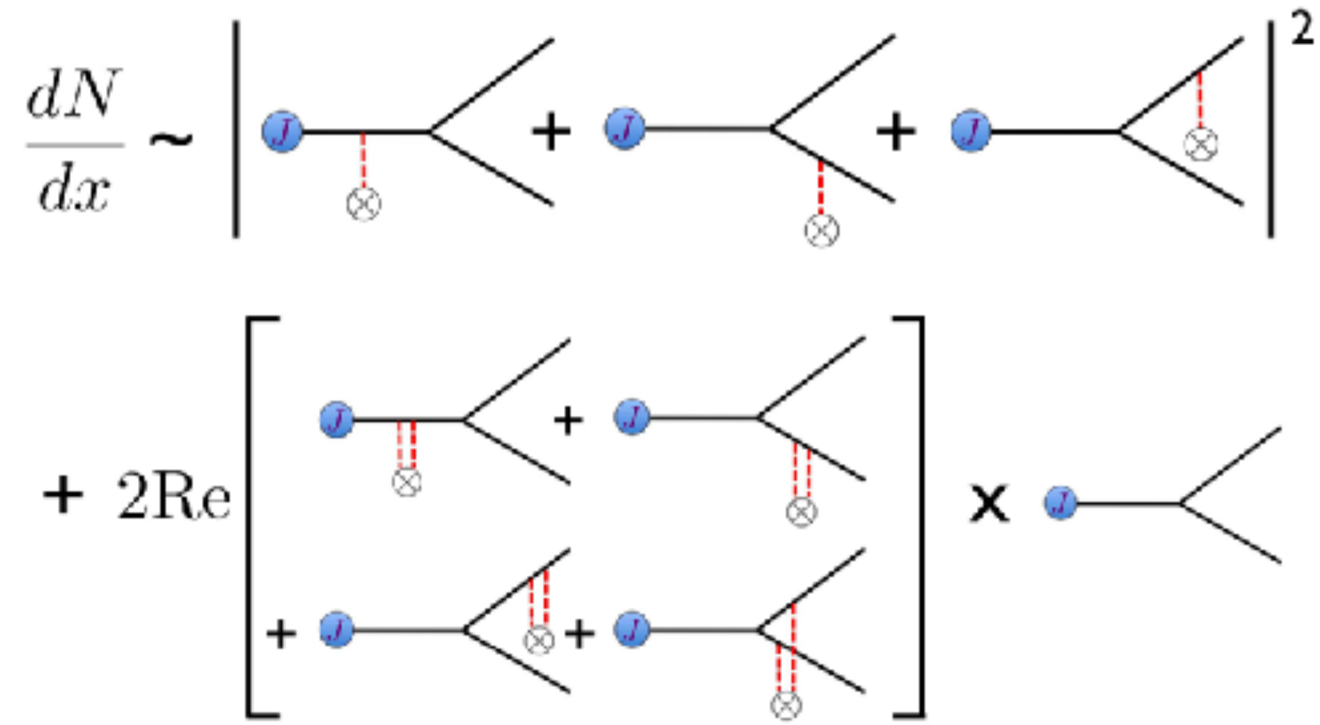
G. Ovanesyan et al. 2012

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

$$\mathcal{L}_{\mathrm{G}}(\xi_n, A_n, A_G) = \sum_{p,p'} \mathrm{e}^{-i(p-p')x} \left(\bar{\xi}_{n,p'} \Gamma^{\mu,a}_{\mathrm{qqA_G}} \frac{\bar{n}}{2} \xi_{n,p} - i \Gamma^{\mu\nu\lambda,abc}_{\mathrm{ggA_G}} (A^b_{n,p'})_\nu (A^c_{n,p})_\lambda \right) A_{\mathrm{G}\mu,a}(x).$$

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

$$S = i \int d^4x \mathcal{L}_{\mathrm{SCET_G}}$$



Red lines correspond to Glauber gluons

Phenomenological study

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

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

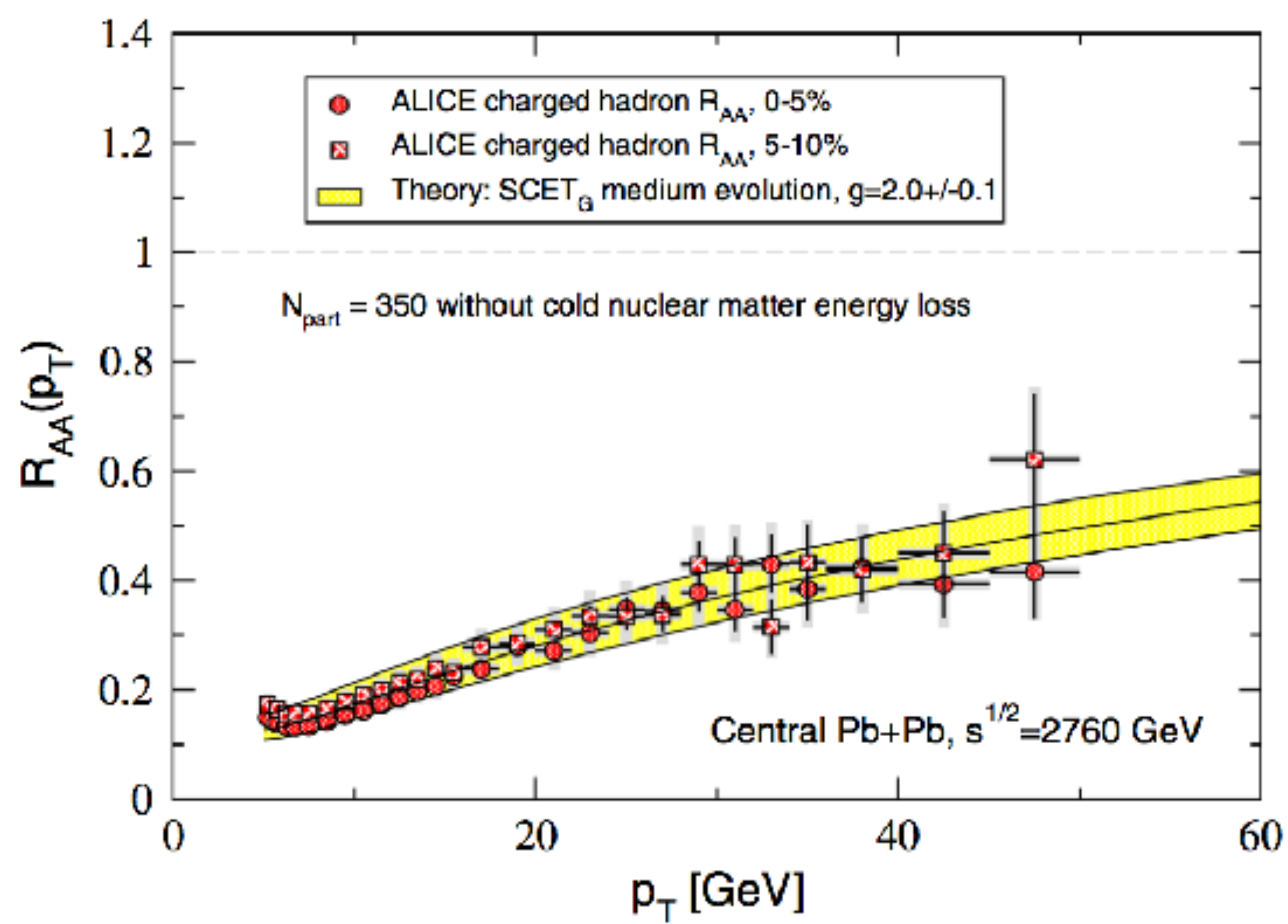
$$\frac{1}{\langle N_{\rm coll}\rangle}\frac{d\sigma^h_{AA}}{dyd^2p_T} = \sum_c \int \frac{dz}{z^2}\frac{d\hat\sigma_c^{\rm CNM}(p_{T_c}=p_T/z)}{dyd^2p_{T_c}}D^{\rm med}_{h/c}(z,Q)$$

$$\frac{d\sigma^h_{pp}}{dyd^2p_T} = \sum_c \int \frac{dz}{z^2}\frac{d\hat\sigma_c(p_{T_c}=p_T/z)}{dyd^2p_{T_c}}D^{\rm vac}_{h/c}(z,Q)$$

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

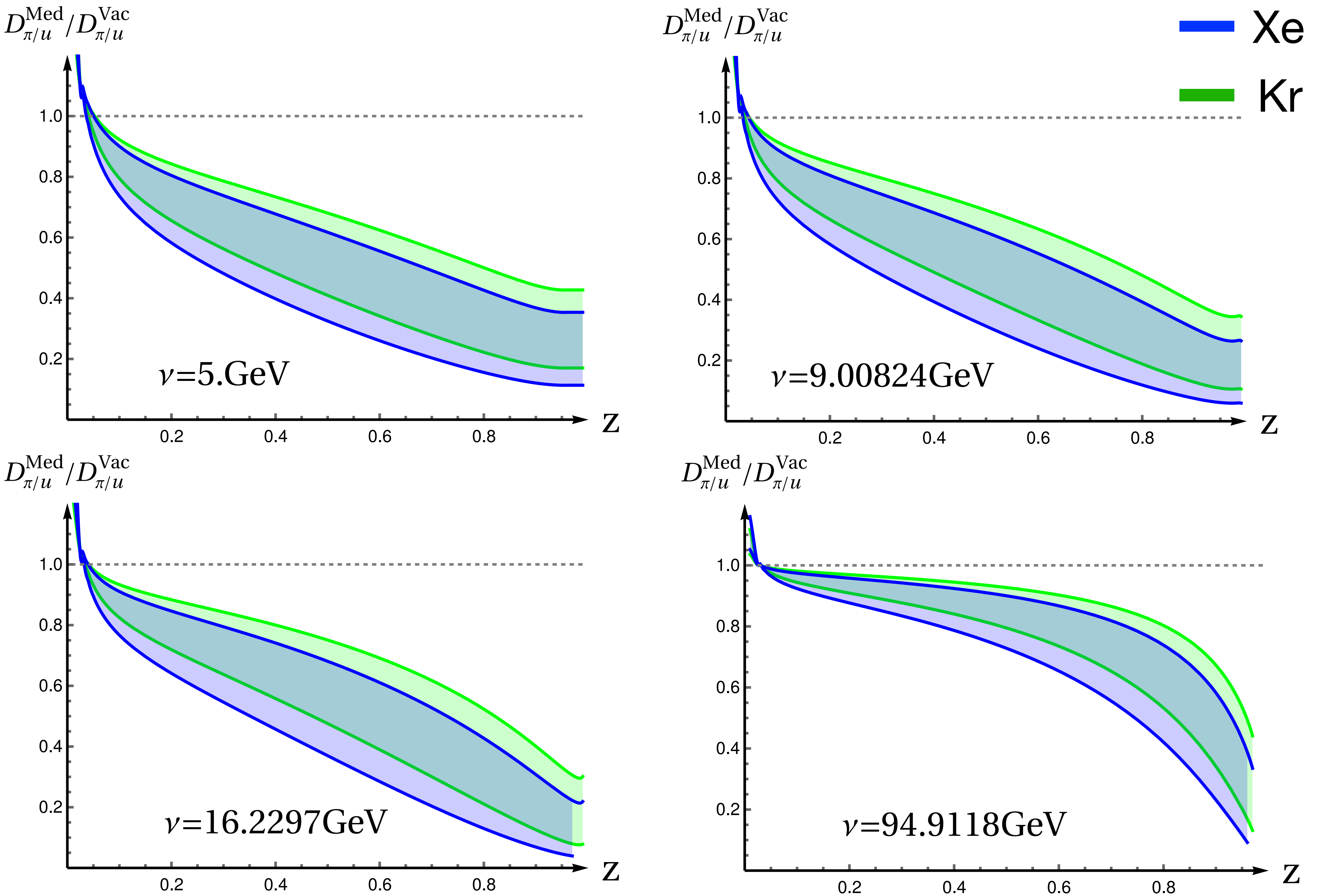
successfully explains data!

Y. Chien et al. 2016



- Take into account the full-x effects in the medium, including flavor changing processes
- parton energy loss calculations can be regarded as a special soft-gluon emission limit of the general QCD evolution framework

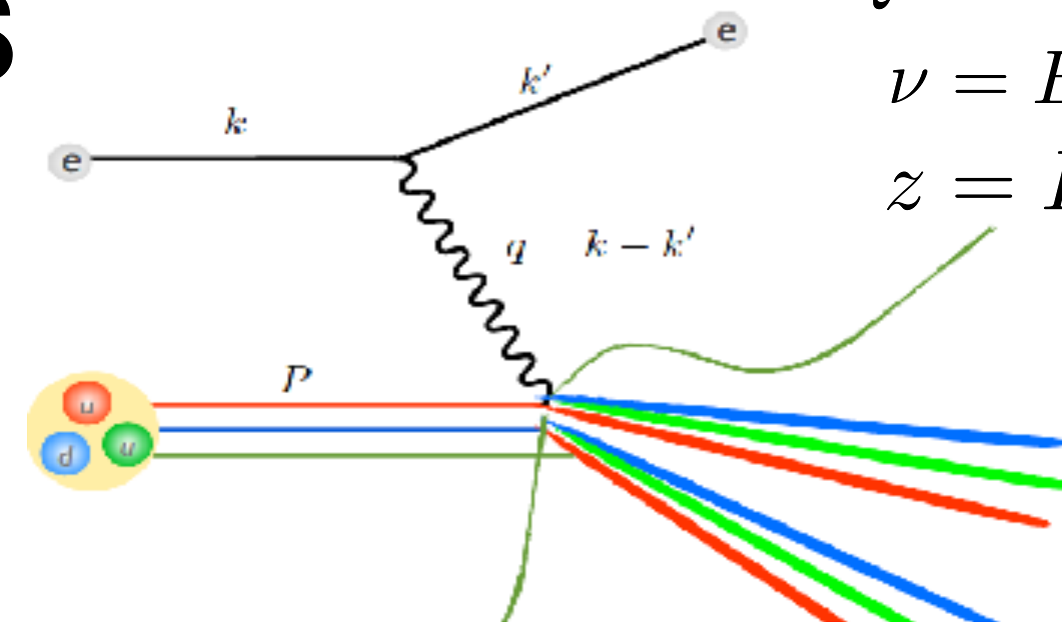
FFs for light flavors in nuclear matter



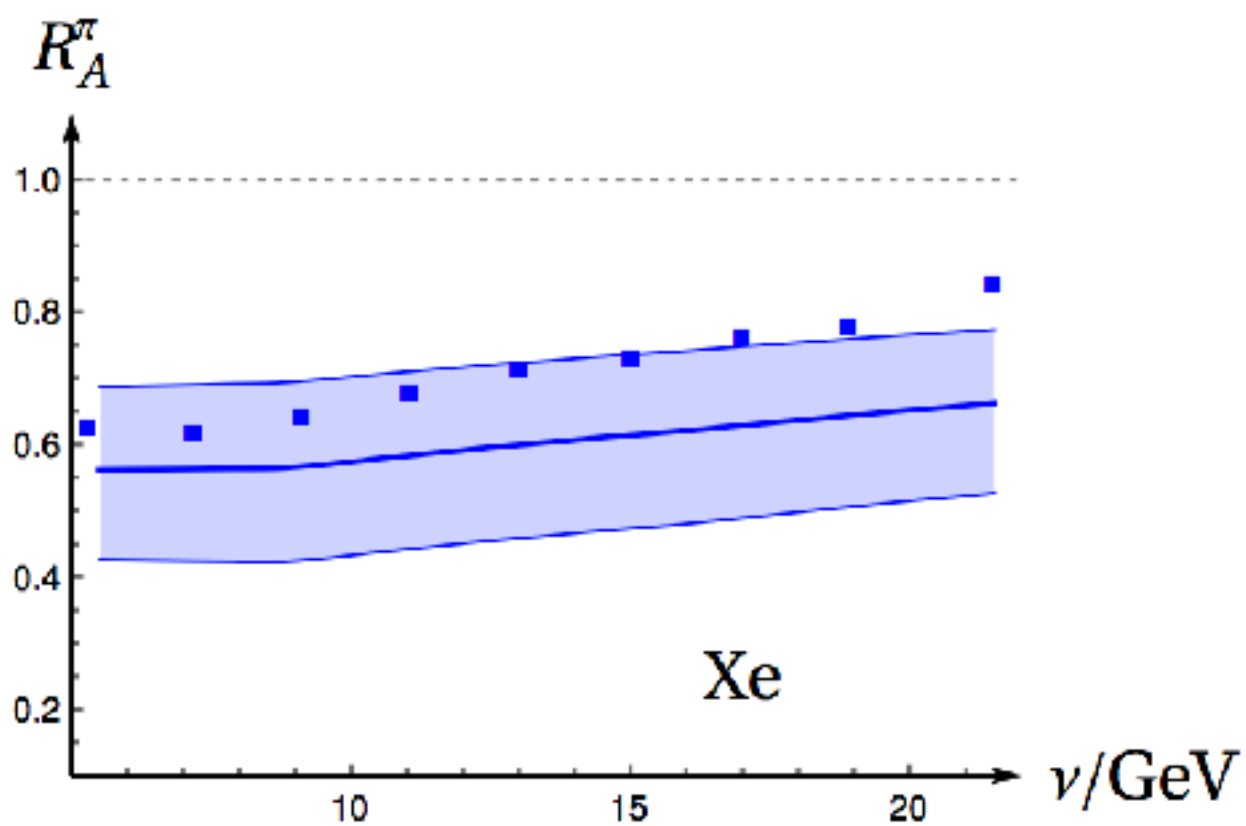
Medium evolutions from vacuum FFs with HKNS data

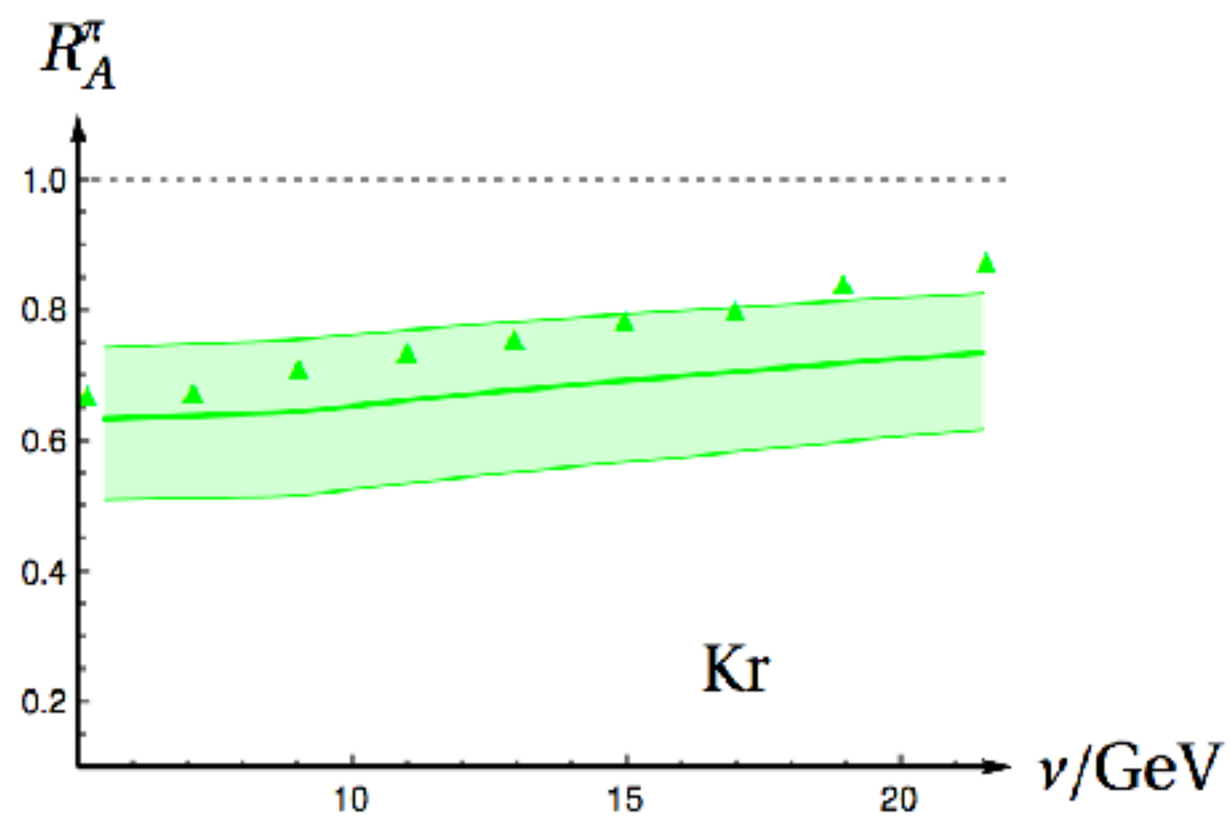
Predictions in SIDIS

$$Q^2 = -q^2$$
$$\nu = E - E'$$
$$z = E_h/\nu$$



$$R_A^h(\nu, Q^2, z, p_t^2) = \frac{\left(\frac{N^h(\nu,Q^2,z,p_t^2)}{N^e(\nu,Q^2)}\right)_A}{\left(\frac{N^h(\nu,Q^2,z,p_t^2)}{N^e(\nu,Q^2)}\right)_D}$$



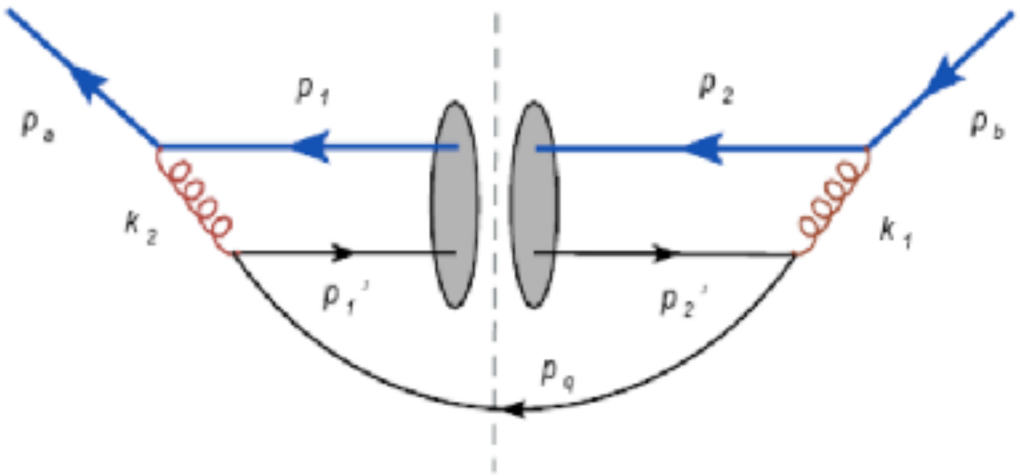


Kinematic constrains: $Q^2 > 1\text{GeV}^2$ $\quad y = \nu/E < 0.85$

$$\sqrt{2M\nu + M^2 - Q^2} > 2\text{GeV}$$

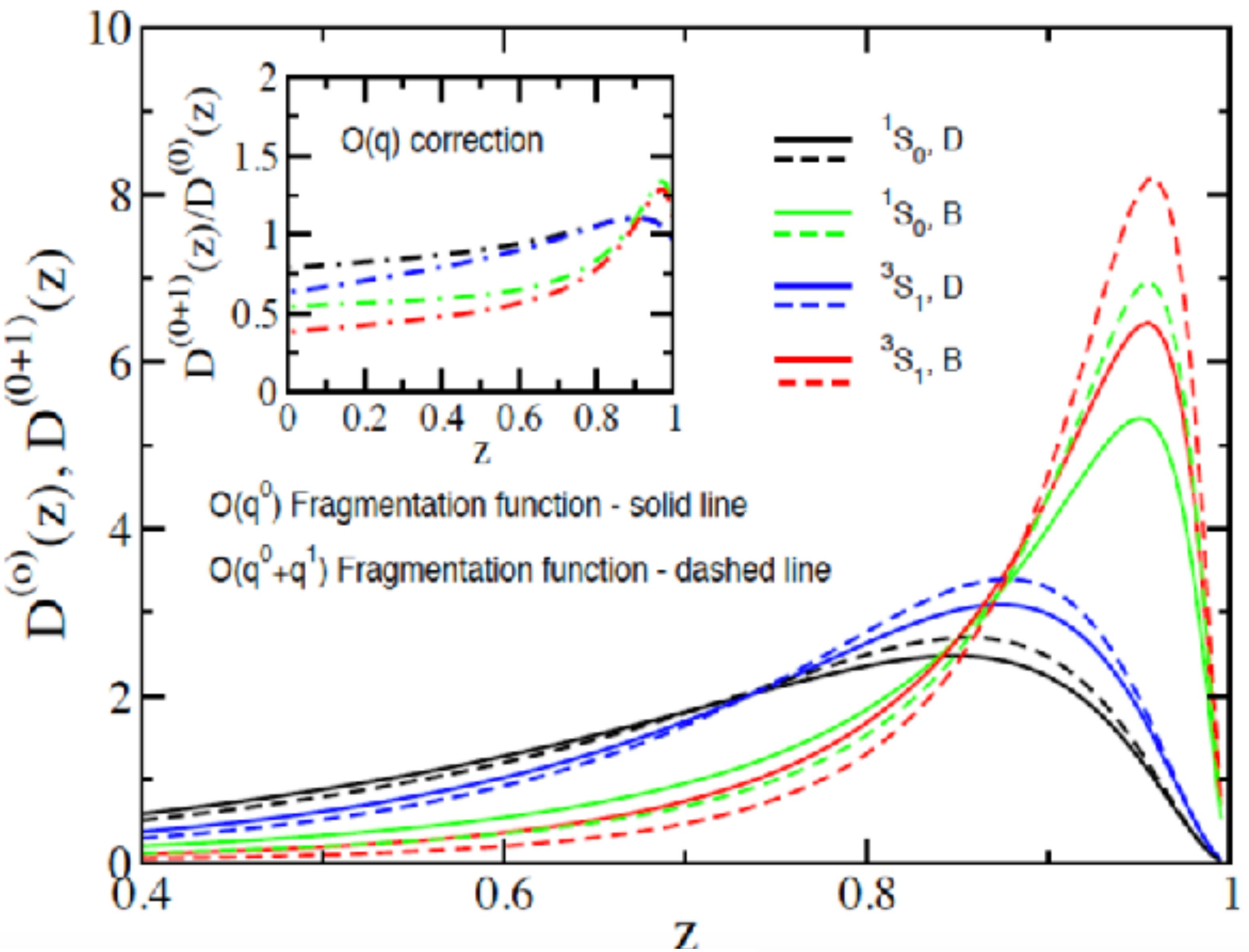
- **Well consistent with measurement of HERMES** 0704.3270

FFs for heavy flavors in vacuum



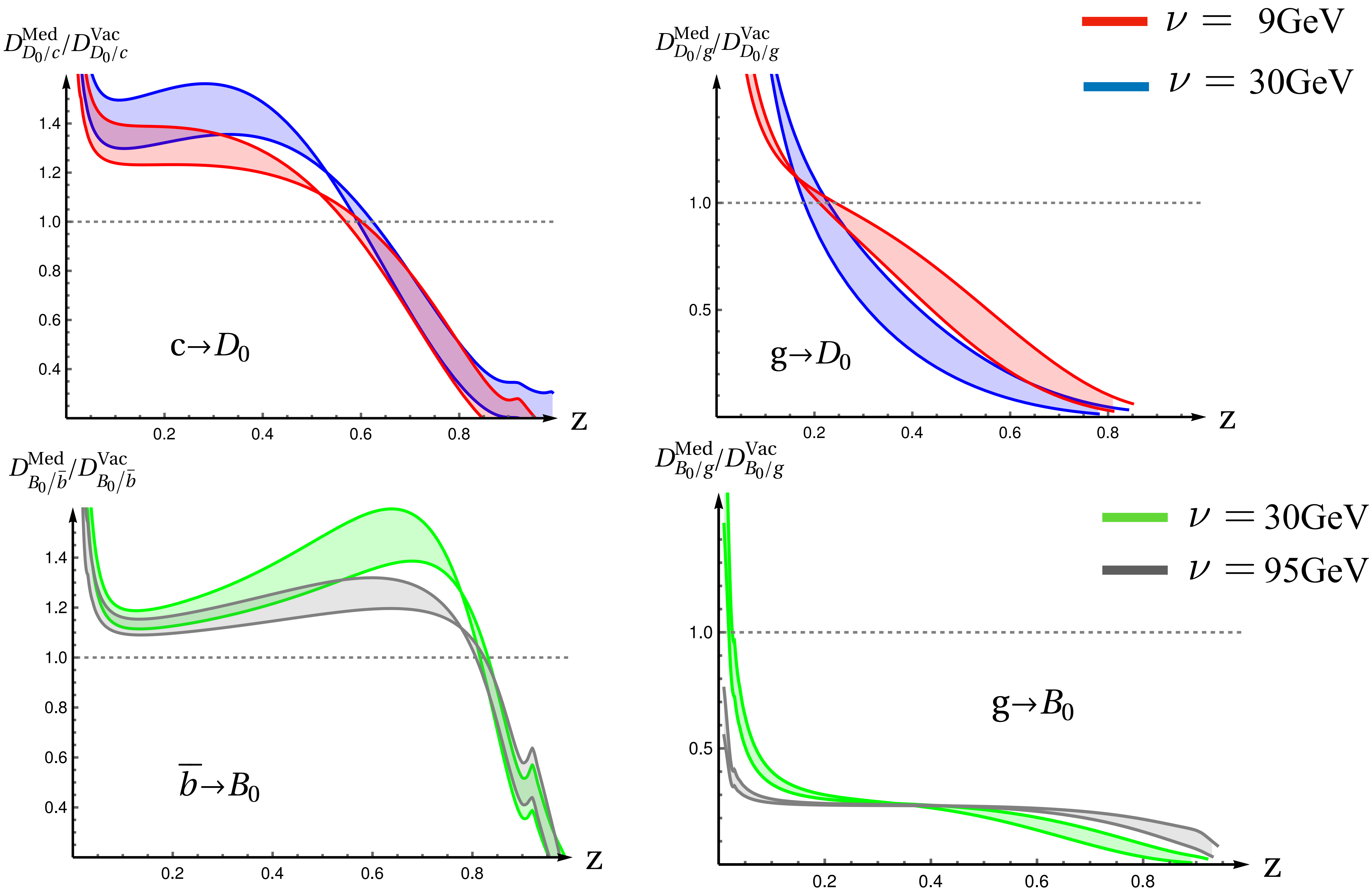
Heavy quarks introduce a mass scale that allows the fragmentation function shape to be computed perturbatively

Chang et al. 1992 Braaten et al. 1995



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

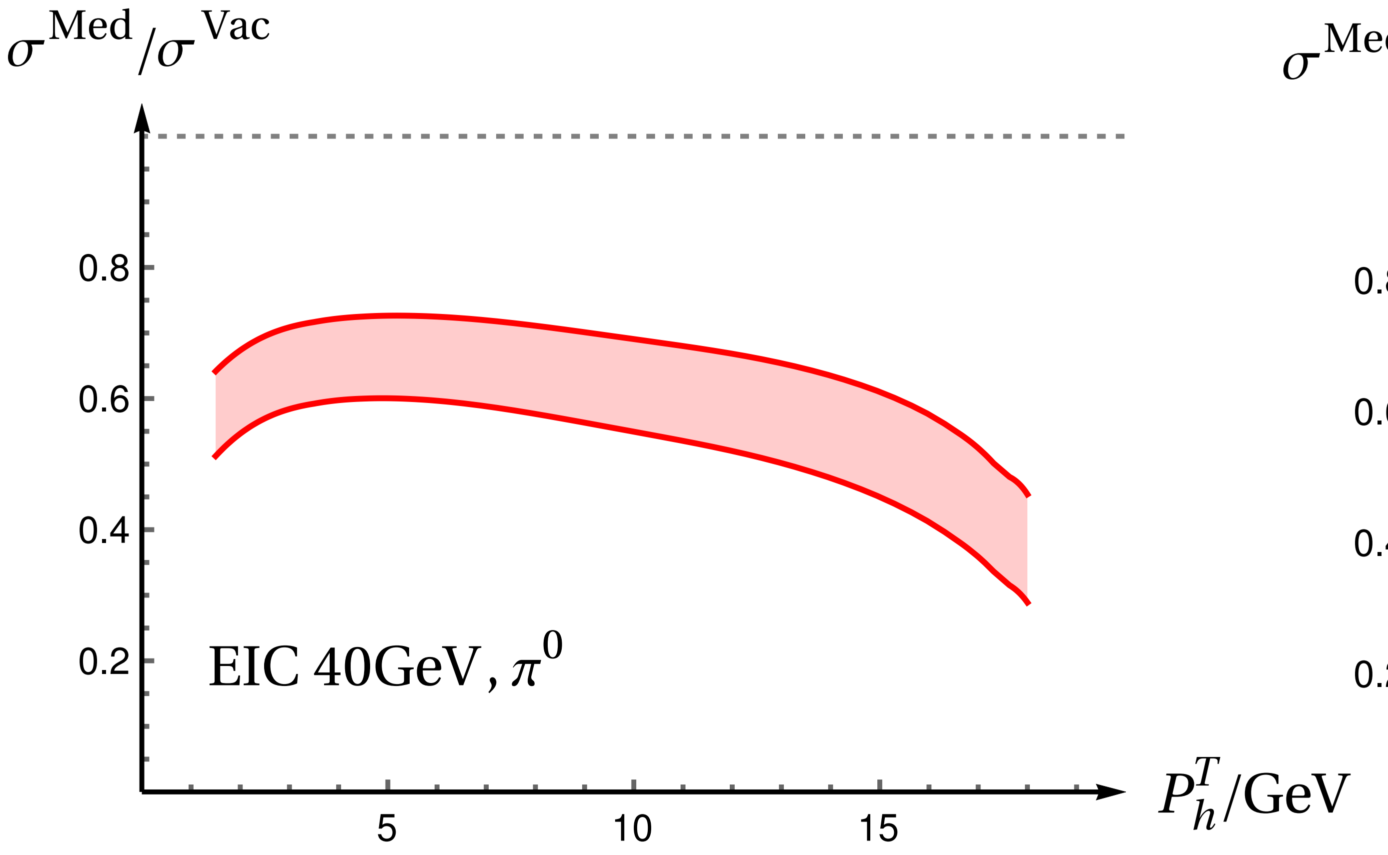
FFs for heavy flavors in Au

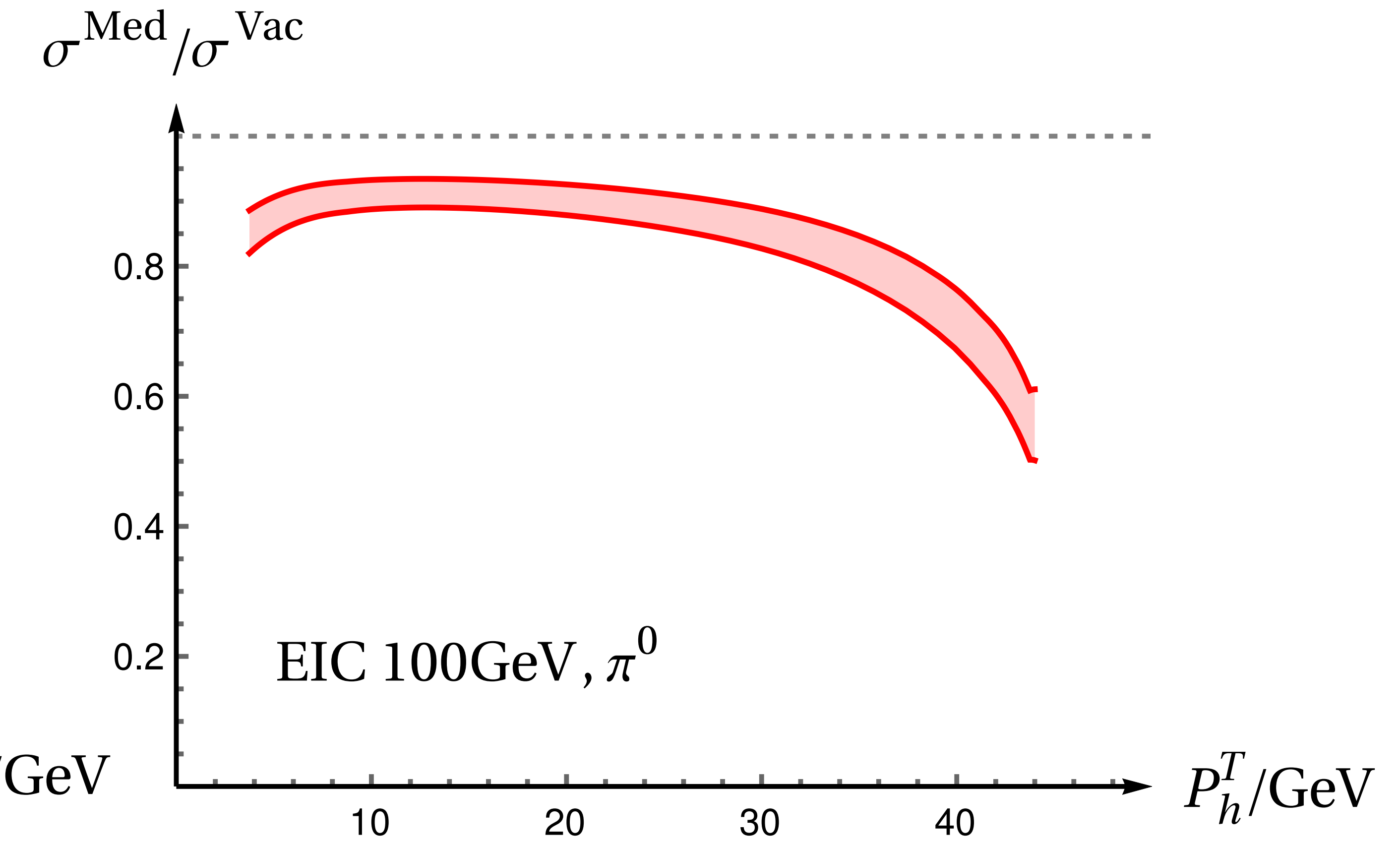


Hadron production in e+Au collision at EIC

$$E_h \frac{d^3\sigma^{\ell N \to hX}}{d^3 P_h} = \frac{1}{S}\sum_{i,f}\int_0^1 \frac{dx}{x}\int_0^1 \frac{dz}{z^2} f^{i/N}(x,\mu)\, \boxed{D^{h/f}(z,\mu)}\, \hat{\sigma}^{i\to f}(s,t,u,\mu)$$

FFs in Au medium

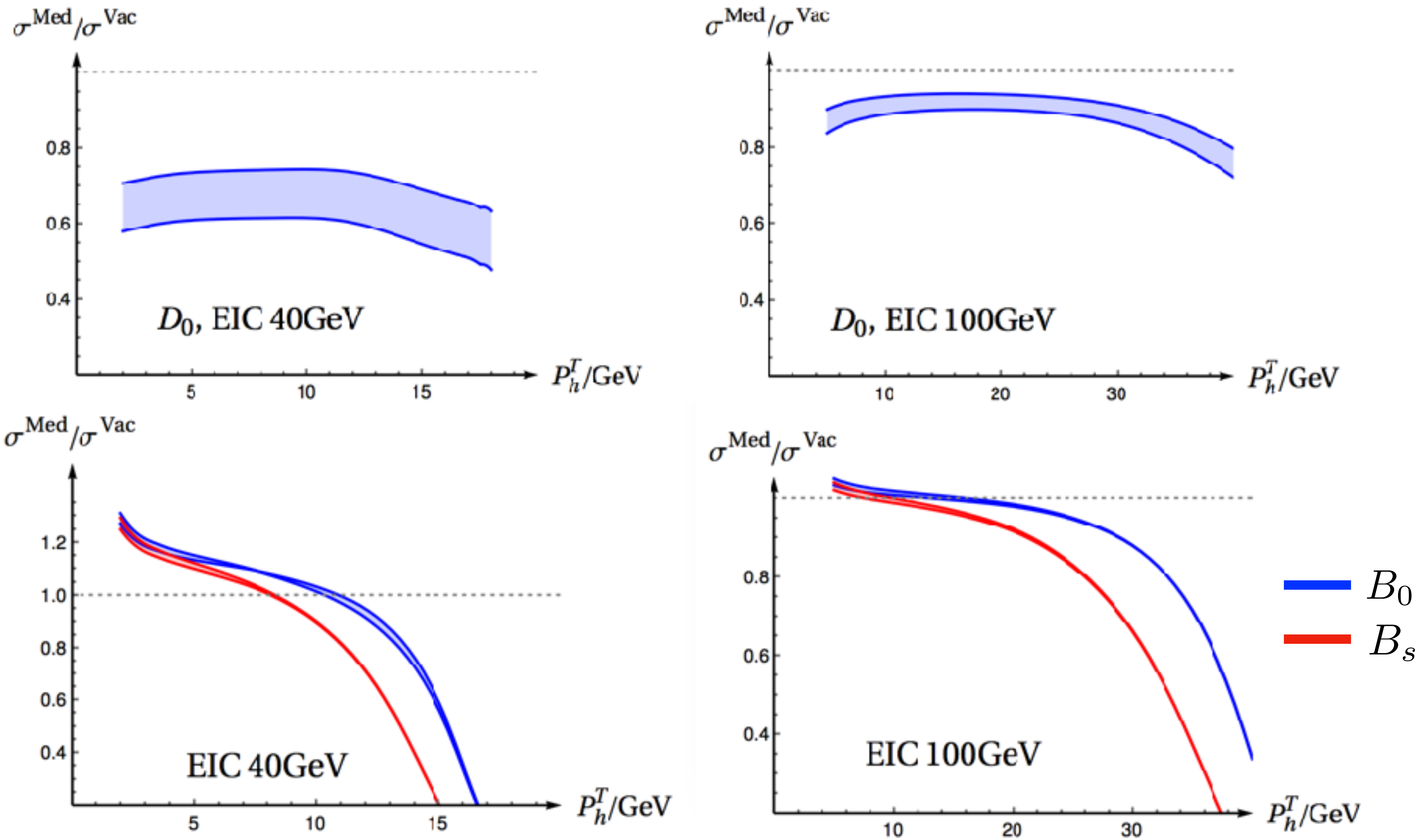




Hadron production in e+Au collision at EIC

$$E_h \frac{d^3\sigma^{\ell N \to hX}}{d^3 P_h} = \frac{1}{S} \sum_{i,f} \int_0^1 \frac{dx}{x} \int_0^1 \frac{dz}{z^2} f^{i/N}(x,\mu)\, \boxed{D^{h/f}(z,\mu)}\, \hat{\sigma}^{i\to f}(s,t,u,\mu)$$

FFs in Au medium



Hadron production in e+Au collision at EIC

- Various fragmentation functions are studied

e.g. π^0 , $\pi^\pm$, D_0 , D^+, D_s , B_0 , B^+, B_s

- Various nuclear matter are studied, e.g. Pb, Au, Cu,

- Various kinematic constrains are considered

- Generally, larger suppression by in-medium effects with small center of mass energy

Conclusion

- In-medium splitting functions is applied, which takes into account the full-x effects in the medium, including flavor changing processes
- Comparing the theoretical predictions of π^0 meson production in DIS on Kr and Xe targets with the measurements of HERMES, the results are consistent
- The QCD evolution of fragmentation functions of heavy flavors in nuclear medium are also presented. The shape of the FFs are similar with the ones from energy loss approach, but it still need to do comparison in detail.
- Hadron (π^0, D , B mesons) productions at EIC are studied by using the FFs in Au medium

Thank you for your attention!