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Studying hadronization in the nuclear medium with heavy flavor production at the future Electron Ion Collider

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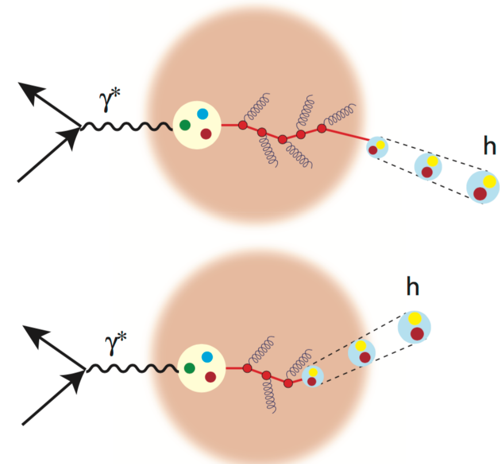
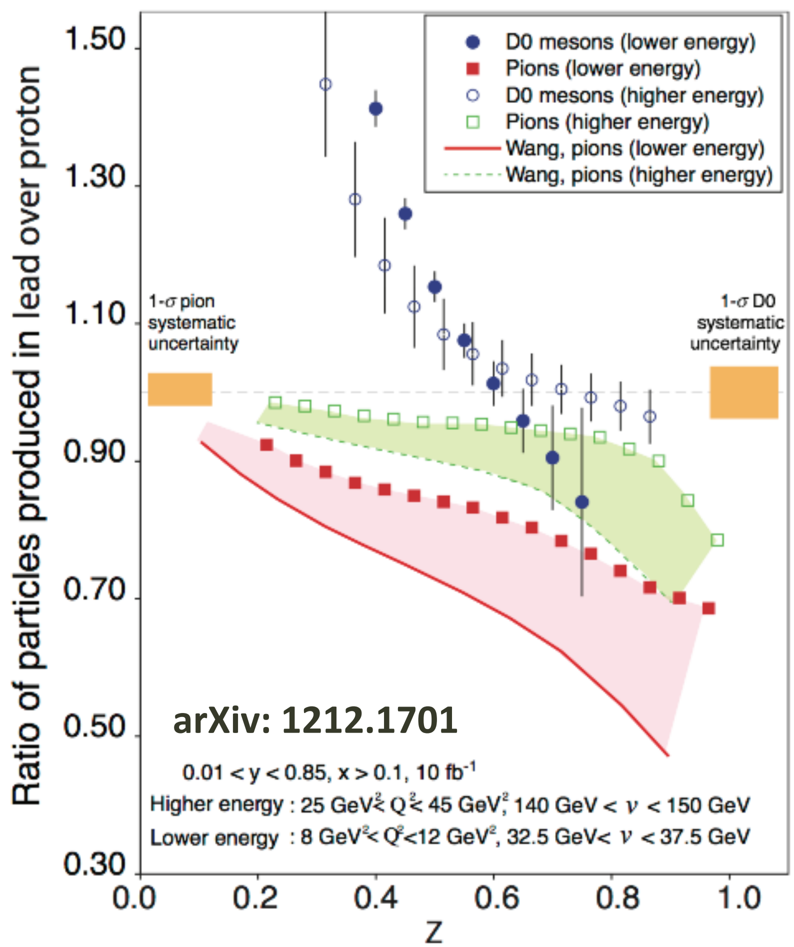
RNC Group Meeting, 11/17/2022

Motivation

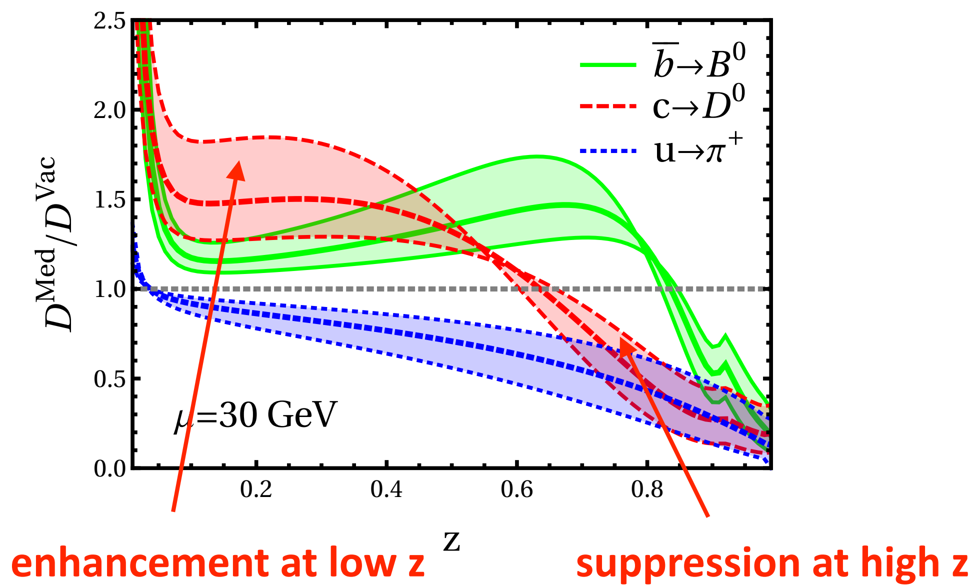
- **Study nuclear modification of (light and) heavy hadron production in different eA systems**
  - **Hadronization scale**
  - **Energy loss mechanism inside nucleus**



Interesting to also look at Λ_c (modification on parton level or hadron level or mixed?)



arXiv: 2007.1099



Nuclear modification in eA

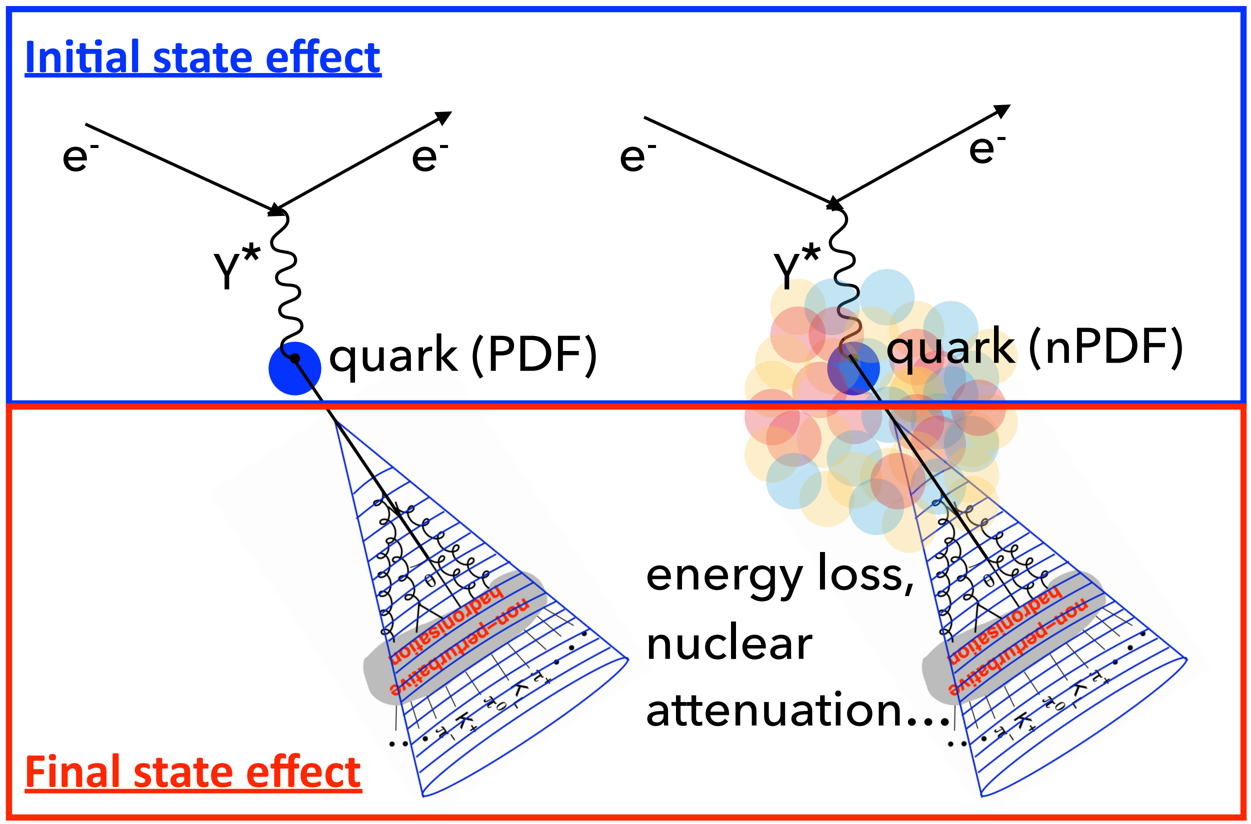
- Disentangle the intial state and final state effect

$$R_{eA}(x,Q^2,z) = \frac{\left(\frac{N^h(x,Q^2,z)}{N^e(x,Q^2)}\right)_{e+A}}{\left(\frac{N^h(x,Q^2,z)}{N^e(x,Q^2)}\right)_{e+p}} = \frac{\frac{N^h(x,Q^2,z)_{e+A}}{N^h(x,Q^2,z)_{e+p}}}{\frac{N^e(x,Q^2)_{e+A}}{N^e(x,Q^2)_{e+p}}}$$

arXiv: 0704.3270

Fractional energy of the final state hadron z: $z = \frac{P\cdot p}{P\cdot q} = \frac{E_h}{\nu}$ (nucleus rest frame)

Cancel out initial state effect



Nuclear modification in eA

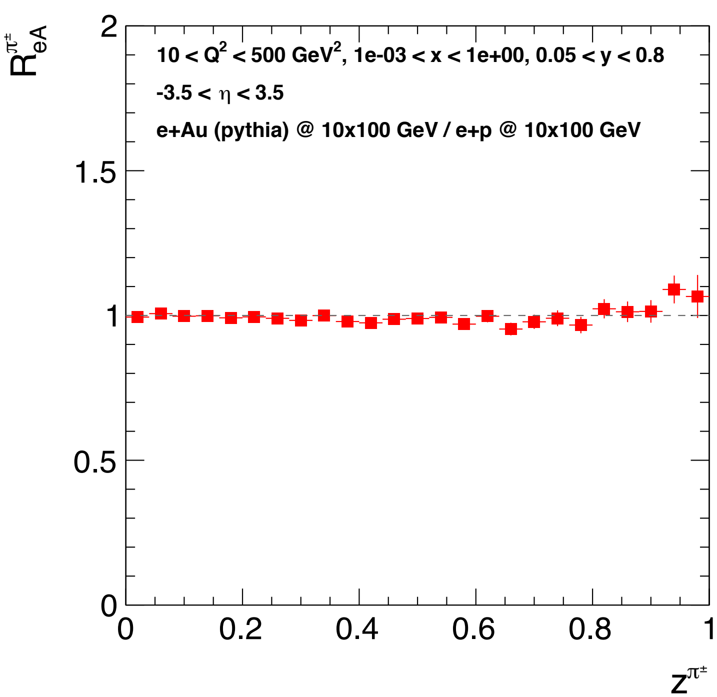
- **Disentangle the intial state and final state effect**

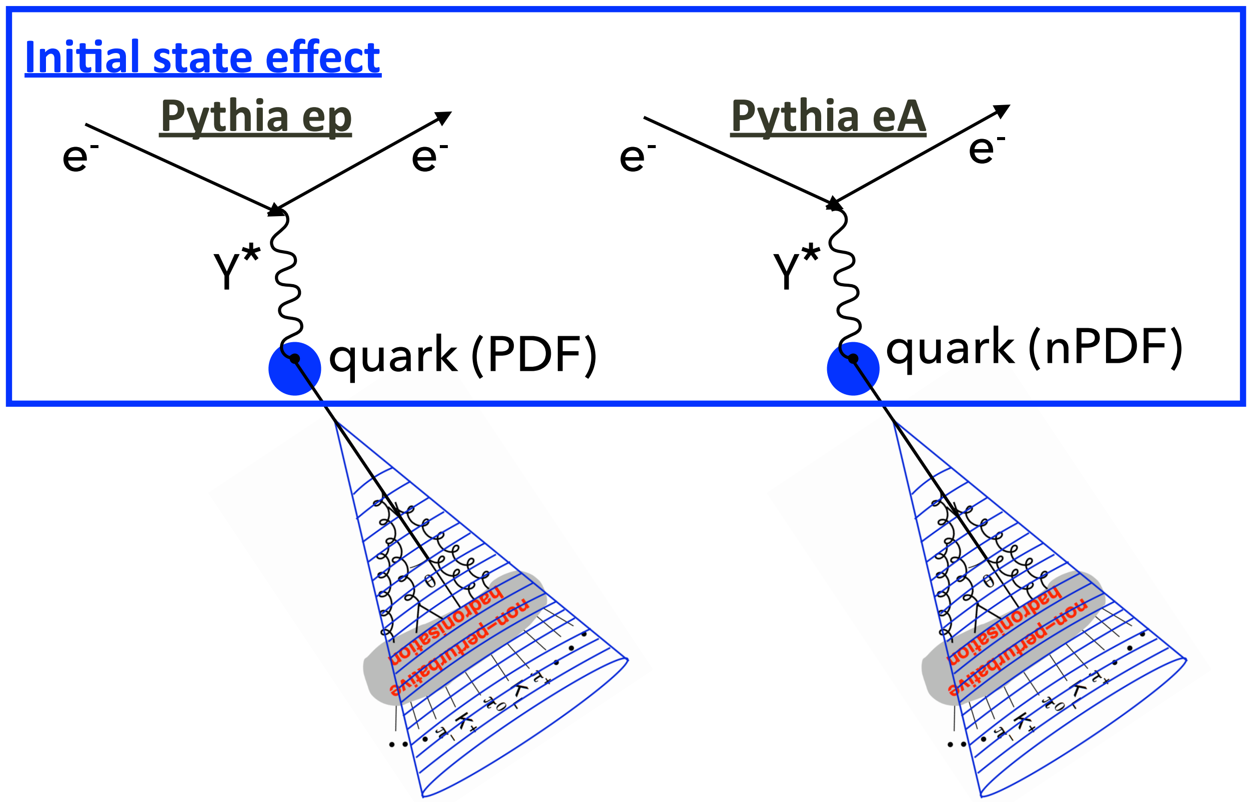
$$R_{eA}(x, Q^2, z) = \frac{\left(\frac{N^h(x,Q^2,z)}{N^e(x,Q^2)}\right)_{e+A}}{\left(\frac{N^h(x,Q^2,z)}{N^e(x,Q^2)}\right)_{e+p}} = \frac{\frac{N^h(x,Q^2,z)_{e+A}}{N^h(x,Q^2,z)_{e+p}}}{\frac{N^e(x,Q^2)_{e+A}}{N^e(x,Q^2)_{e+p}}}$$

arXiv: 0704.3270

Cancel out initial state effect

- nPDF effect cancelled out well for light flavor hadrons





Nuclear modification in eA

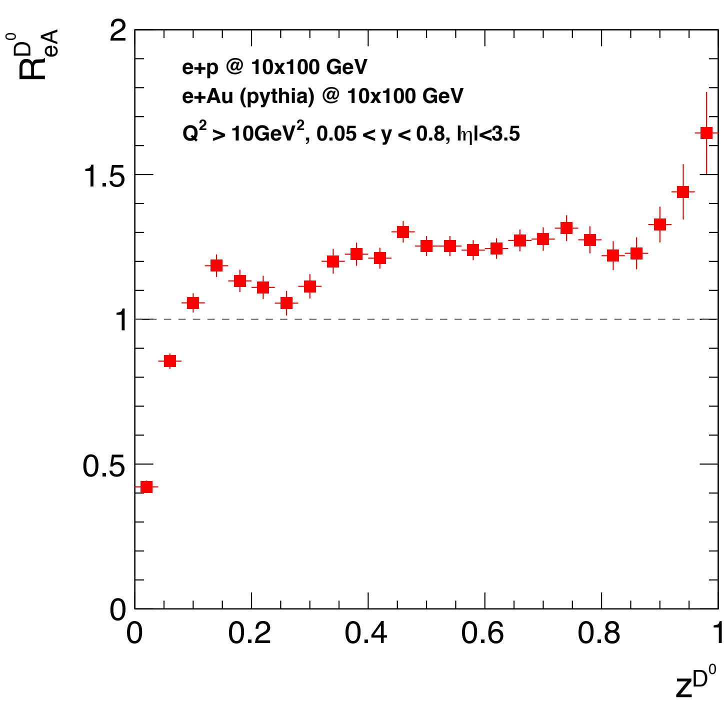
- Disentangle the intial state and final state effect

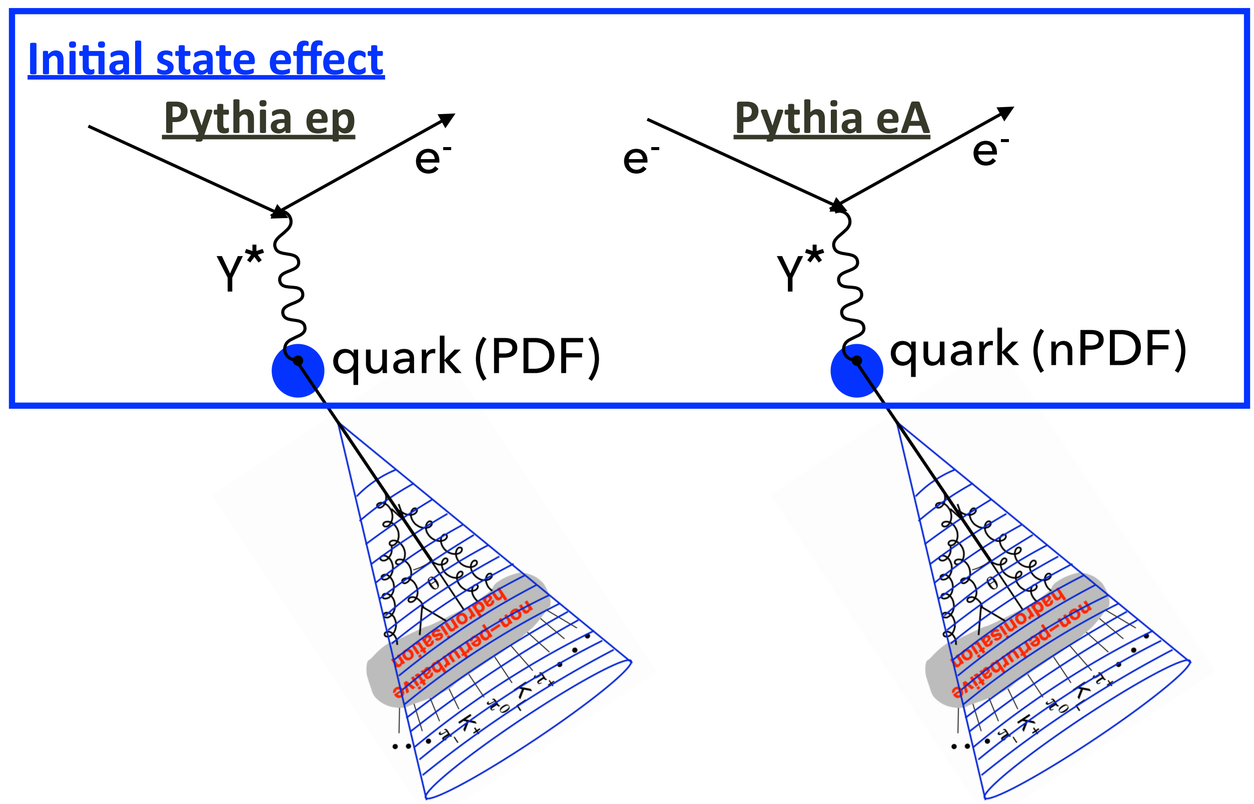
$$R_{eA}(x, Q^2, z) = \frac{\left(\frac{N^h(x,Q^2,z)}{N^e(x,Q^2)}\right)_{e+A}}{\left(\frac{N^h(x,Q^2,z)}{N^e(x,Q^2)}\right)_{e+p}} = \frac{\frac{N^h(x,Q^2,z)_{e+A}}{N^h(x,Q^2,z)_{e+p}}}{\frac{N^e(x,Q^2)_{e+A}}{N^e(x,Q^2)_{e+p}}}$$

arXiv: 0704.3270

Cancel out initial state effect

- nPDF effect **NOT** cancelled out for heavy flavor hadrons





Nuclear modification in eA

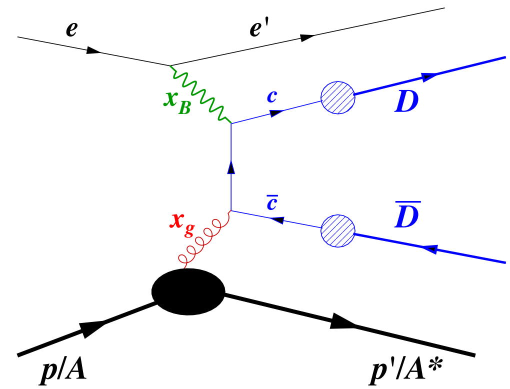
- Disentangle the intial state and final state effect

$$R_{eA}(x,Q^2,z) = \frac{\left(\frac{N^h(x,Q^2,z)}{\cancel{N^e(x,Q^2)}}\right)_{e+A}}{\left(\frac{N^h(x,Q^2,z)}{\cancel{N^e(x,Q^2)}}\right)_{e+p}} = \frac{\frac{N^h(x,Q^2,z)_{e+A}}{N^h(x,Q^2,z)_{e+p}}}{\frac{N^{c\bar{c}}(x,Q^2)_{e+A}}{N^{c\bar{c}}(x,Q^2)_{e+p}}} \neq \frac{\frac{N^h(x,Q^2,z)_{e+A}}{N^h(x,Q^2,z)_{e+p}}}{\frac{N^e(x,Q^2)_{e+A}}{N^e(x,Q^2)_{e+p}}}$$

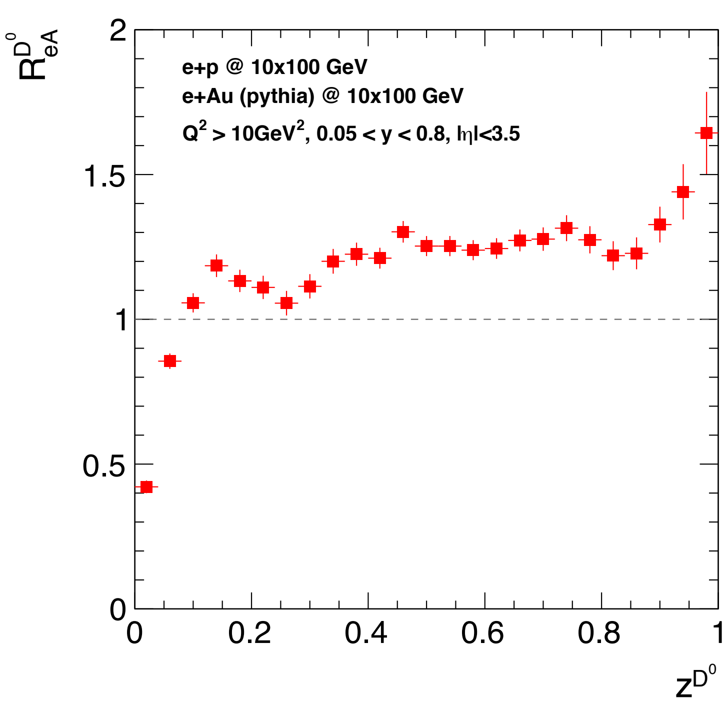
($N^e(x,Q^2) \rightarrow N^{c\bar{c}}(x,Q^2)$)

arXiv: 0704.3270

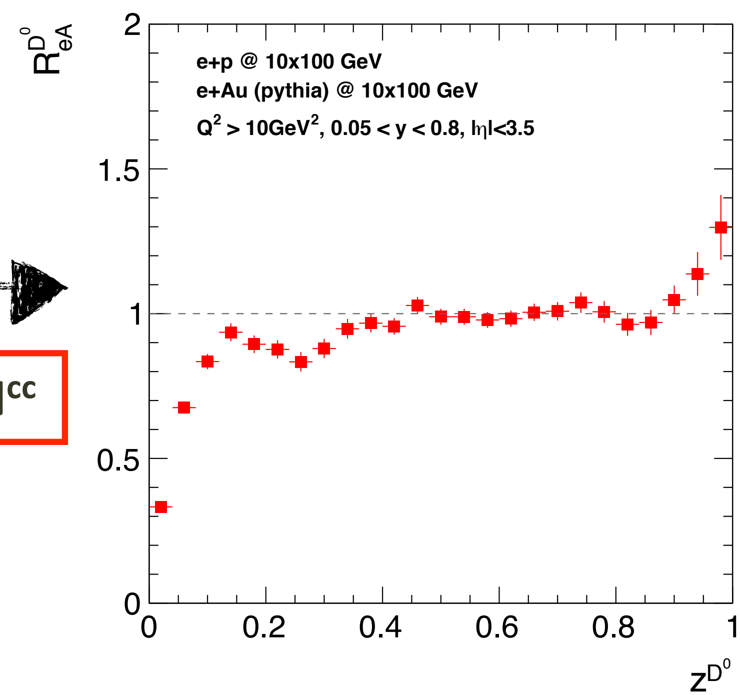
Cancel out initial state effect



- Charm cross section cancels out the initial state effect better for charm hadrons

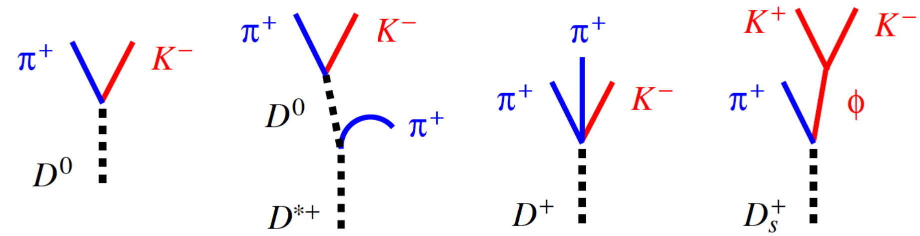


Replacing N^e by N^{cc}



Charm hadron reconstruction via hadronic decays

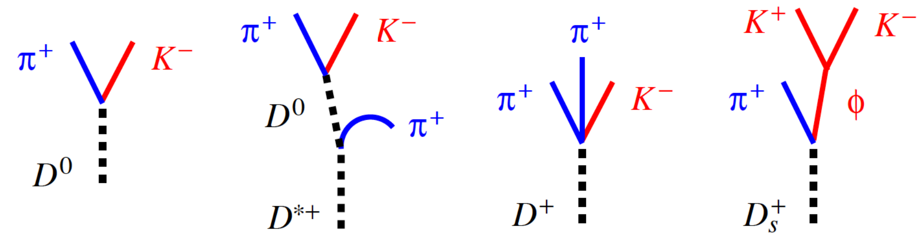
- Key of precision heavy flavor hadron reconstruction ☛ reduce the stat. err. for the signal extraction
  - ❖ High statistics (increase SG)
  - ❖ High purity (decrease BG/SG)



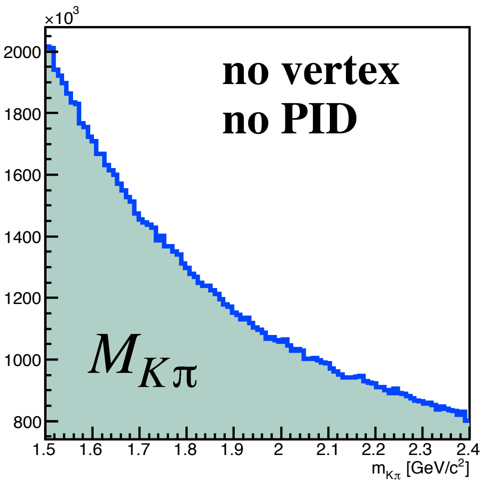
Stat. Err. = √(SG+BG)/SG = √(1/SG+BG/SG)

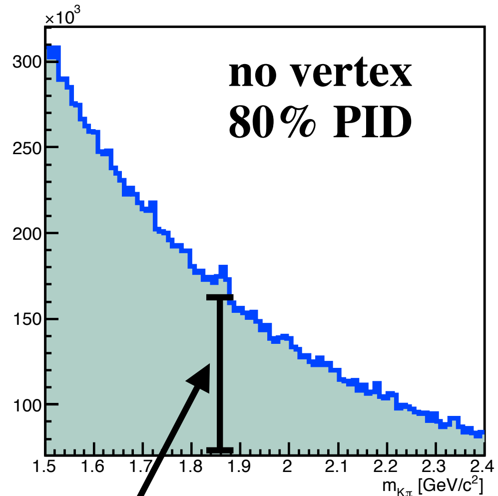
Charm hadron reconstruction via hadronic decays

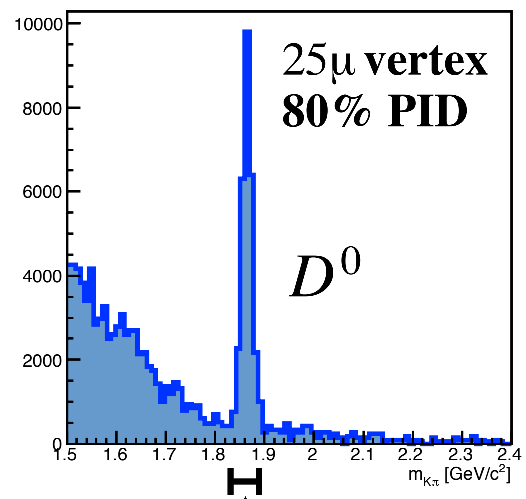
- Key of precision heavy flavor hadron reconstruction ☛ reduce the stat. err. for the signal extraction
  - High statistics (increase SG)
    - High luminosity + good detector acceptance
  - High purity (decrease BG/SG)



Stat. Err. = √(SG+BG)/SG = √(1/SG+BG/SG)







Particle	cτ
D^0	123 μm
$D^{\pm}$	312 μm
B^0	456 μm
$B^{\pm}$	491 μm
Λ_c	60 μm

arXiv: 1610.08536

Reduce the comb. bkg. level

Reduce the integration window

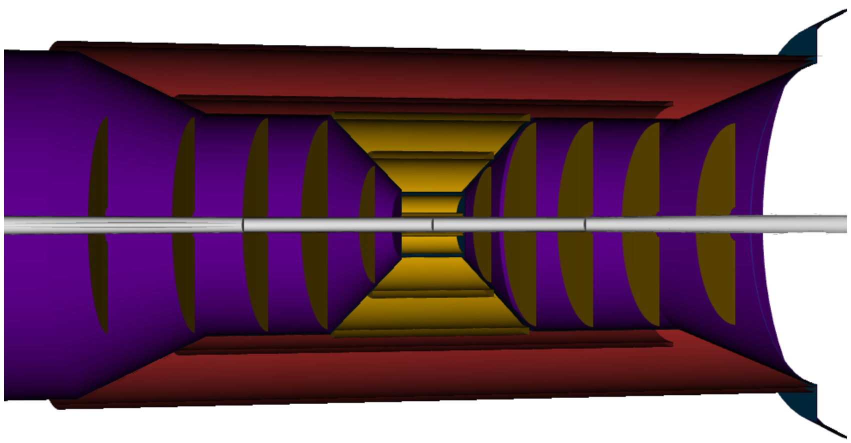
Reduce BG/SG

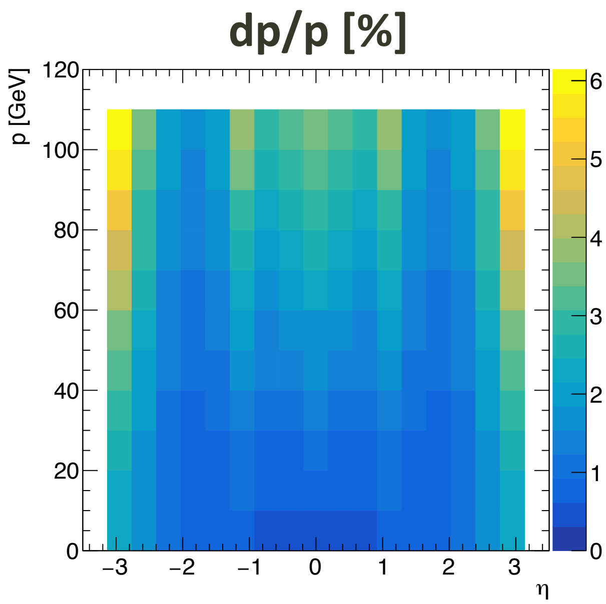
- Good π/K/p seperation power
- Good pointing resolution
- Good momentum resolution

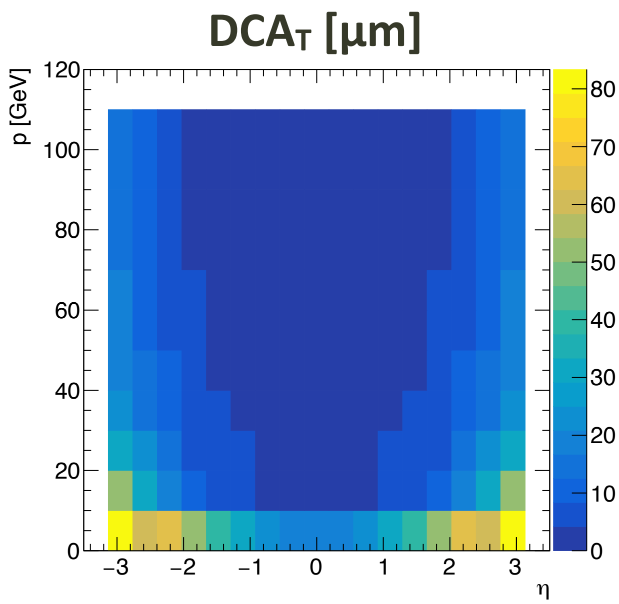
Analysis framework

- Reconstruct D^0 from $K\pi$, Λ_c from $K\pi p$ with analysis selections
  - Include realistic detector responses
  - Project statistical uncertainty to EIC luminosity

- Single track smearing (both p and vertex) using parameters from a fast simulation package with the baseline tracking system of the ePIC detector
  - The parameters in the tracking fast simulation are bench-marked against GEANT-based full simulation



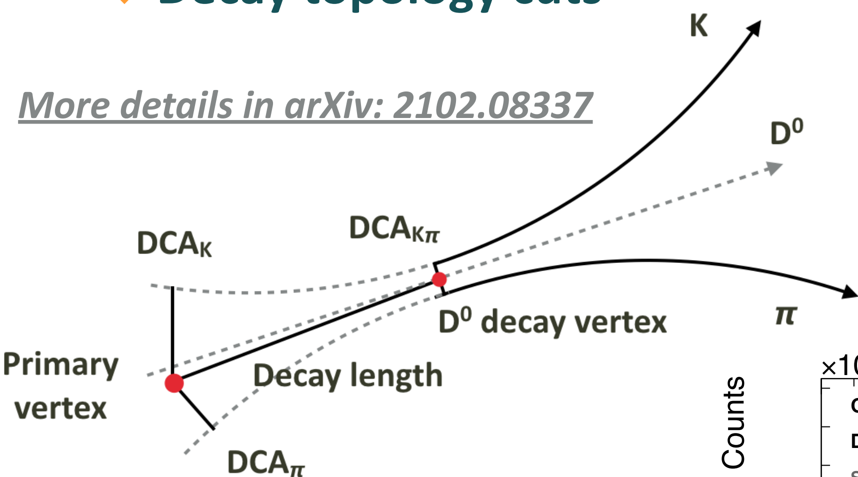


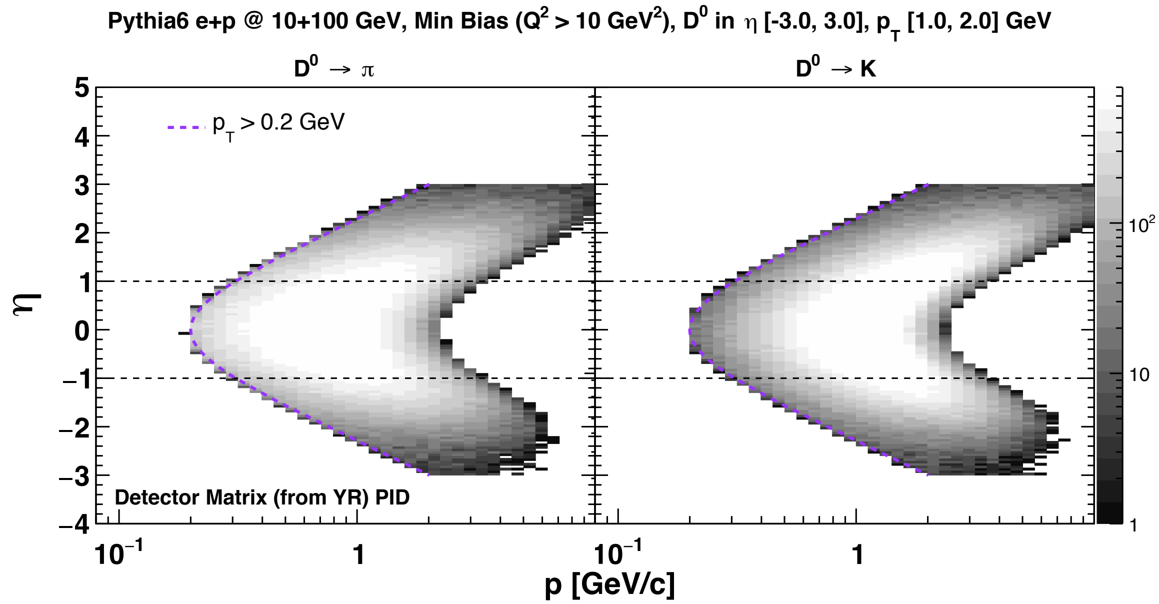


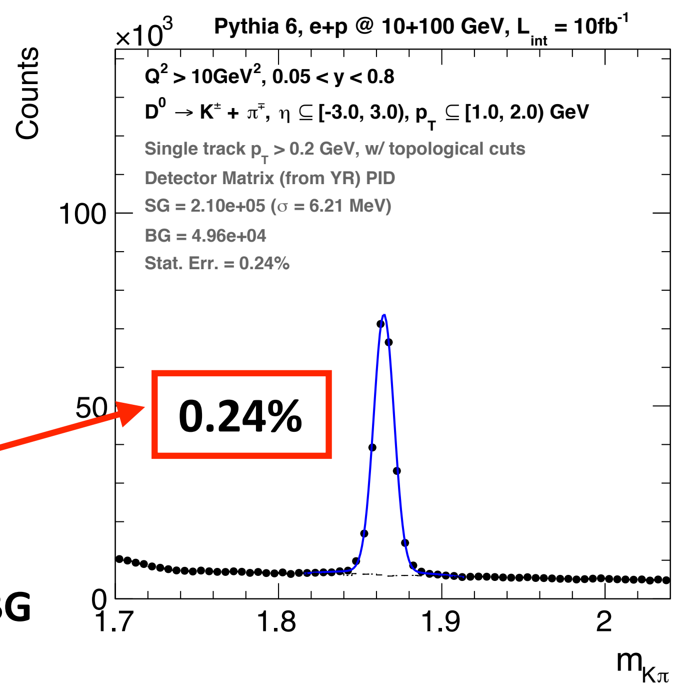
Measurement of D^0

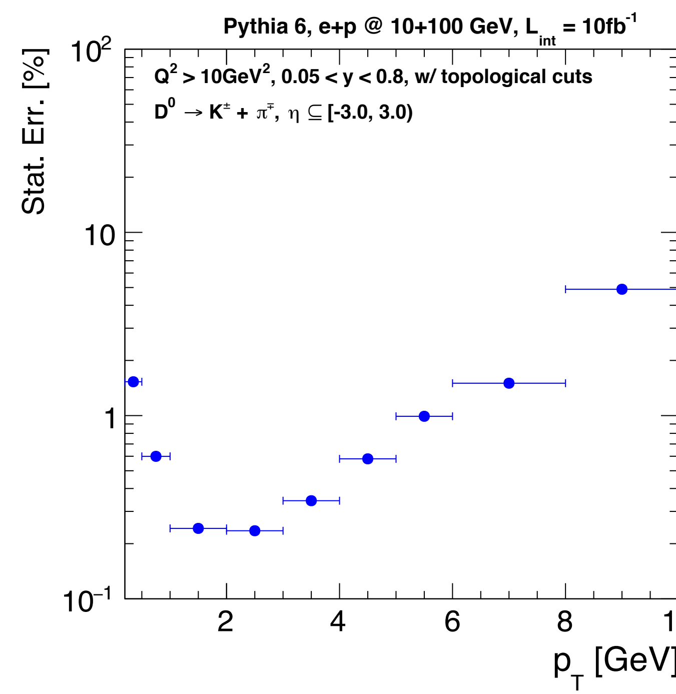
- D^0 selection
  - $p_T > 0.2$GeV
  - Identified π/K
  - Decay topology cuts

More details in arXiv: 2102.08337









Stat. Err. = sqrt(SG+BG)/SG
= sqrt(1+BG/SG)/sqrt(SG)

- decrease with increasing SG
- descrease with descreasing BG

Measurement of Λ_c

- Λ_c selection
  - $p_T > 0.2$GeV
  - Identified π/K/p
  - Decay topology cuts

More details in arXiv: 2102.08337

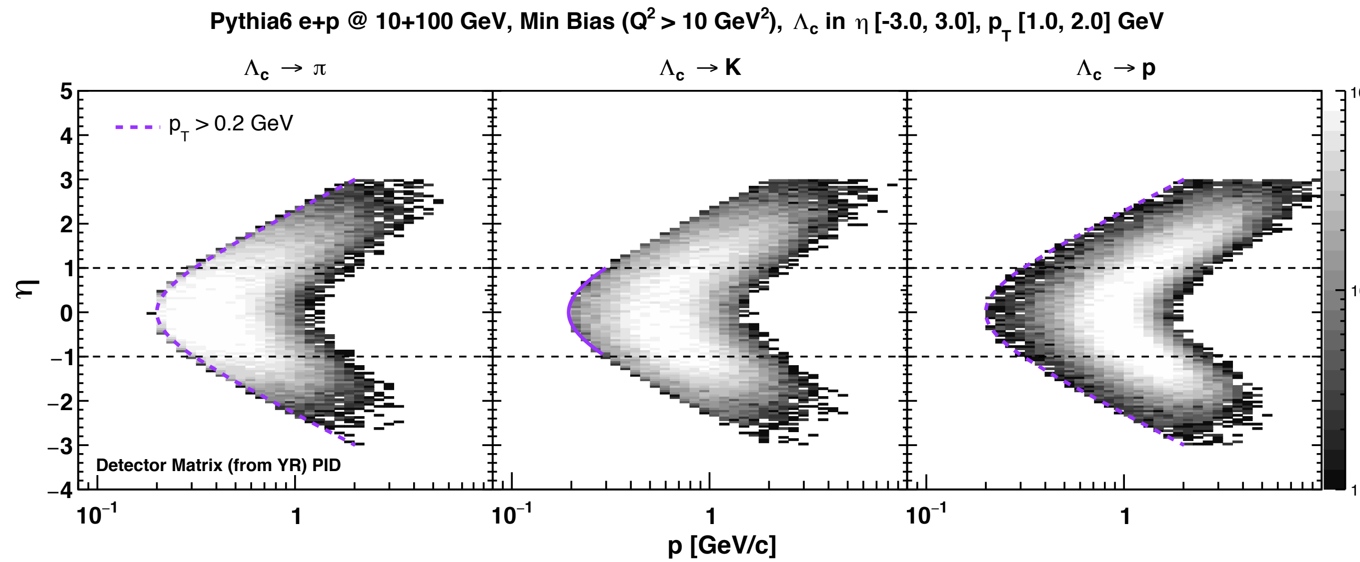
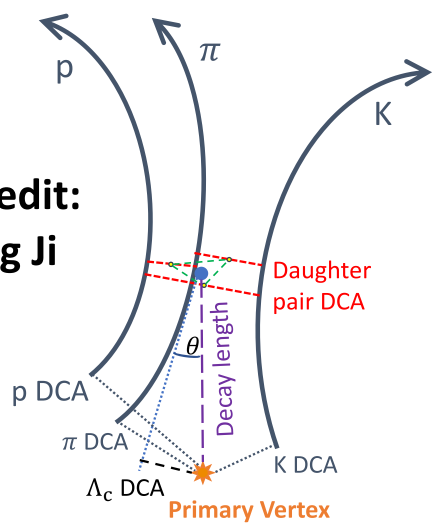
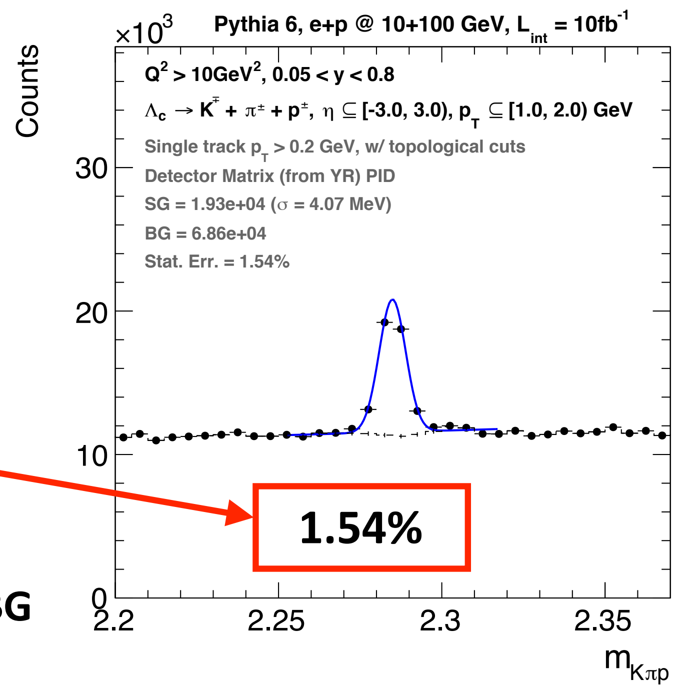
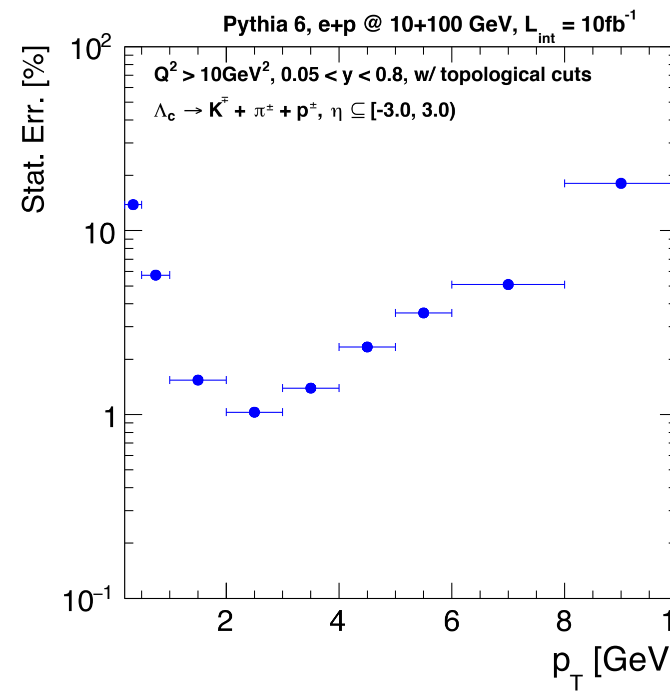


Figure credit: Yuanjing Ji







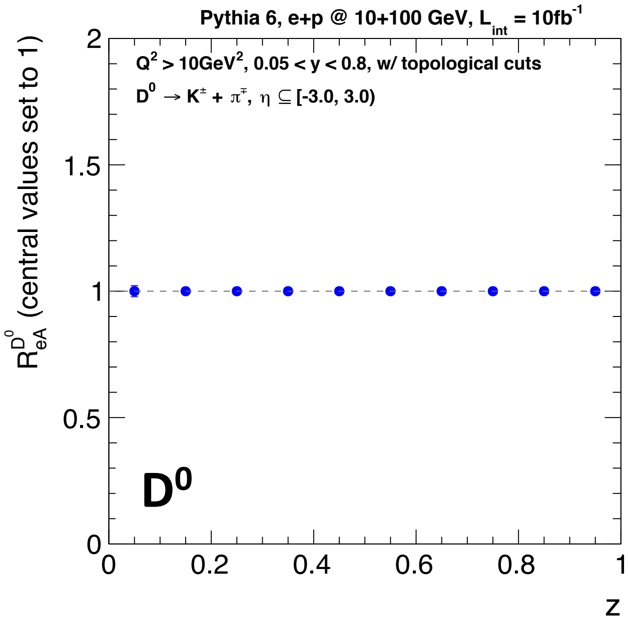
Stat. Err. = sqrt(SG+BG)/SG
= sqrt(1+BG/SG)/sqrt(SG)

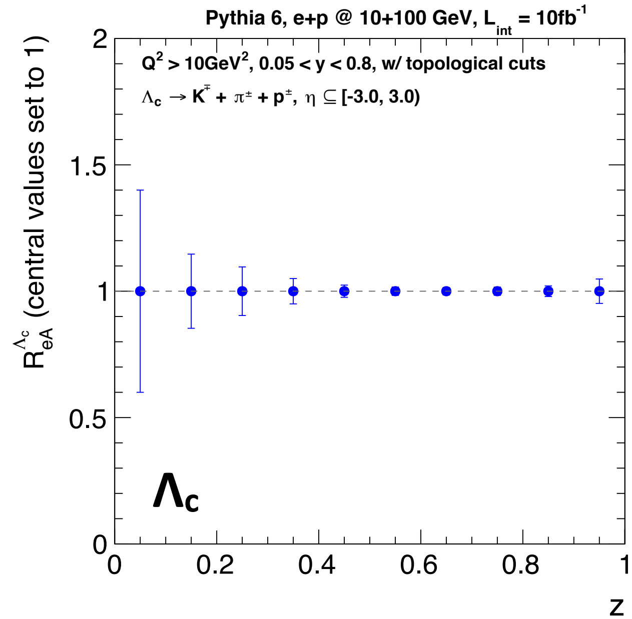
☛ decrease with increasing SG

☛ descrease with descreasing BG

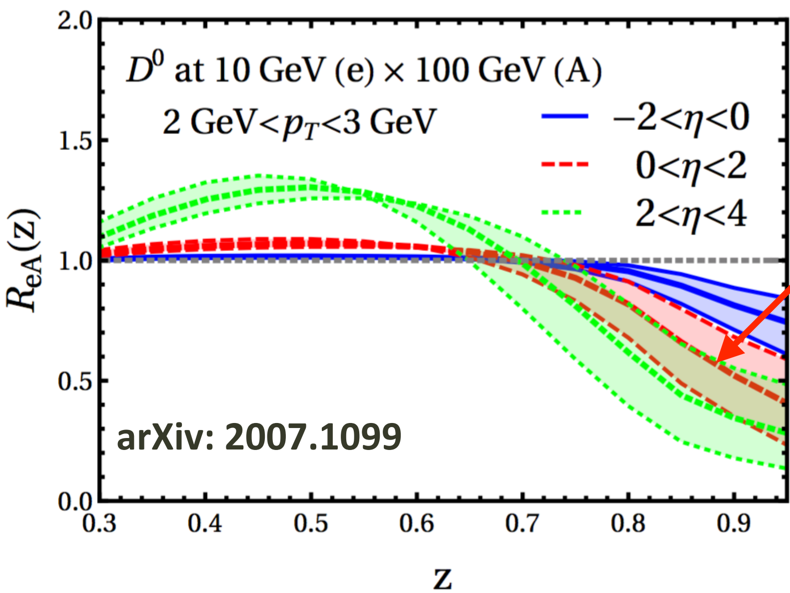
Precision and physics impact

- **Projected stat. uncertainty on R_{eA}**
  - High accuracy for D^0: <1%
  - Moderate accuracy for Λ_c: 1-10%

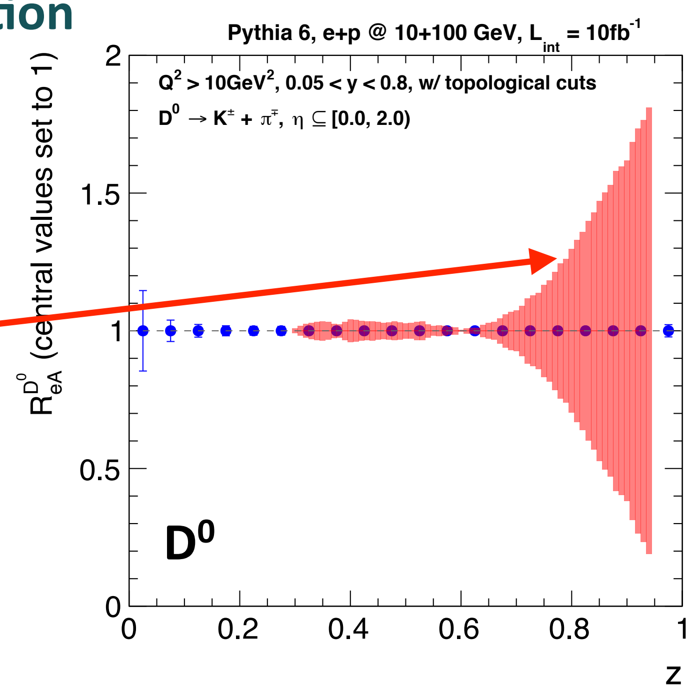




- **Compare to partonic energy loss model**
  - Constraining transport coefficient (characterize interaction strength between the parton and nuclear medium)



Transport coefficient varied by a factor of 2



Summary

- R_{eA} with projected statistical precision with realistic detector effects via fast smearing framework
  - High accuracy (<1%) for D^0 and moderate accuracy (1-10%) for Λ_c
- More differential measurements of R_{eA} as functions of x, ν and system sizes
- Compare with different models
  - More detailed comparison with the partonic energy loss model to evaluate the impact on constraining the transport coefficient in the cold nuclear matter

PRD 103.L031901

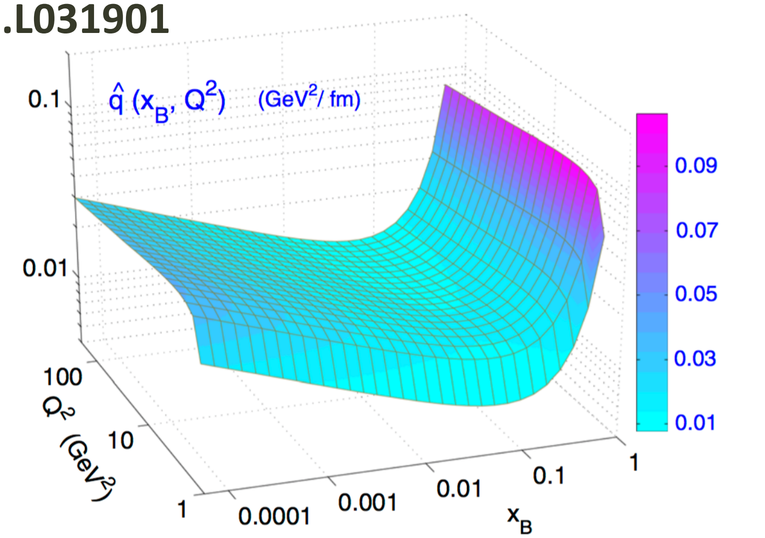


FIG. 4. The extracted $\hat{q}$ as functions of Bjorken x_B and scale Q^2, the color bar show the $\hat{q}$ values.