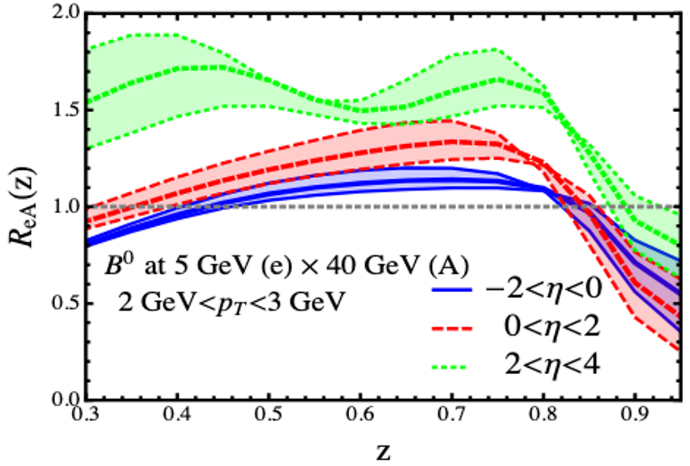
WG3
Heavy Flavor and Spectroscopy summary

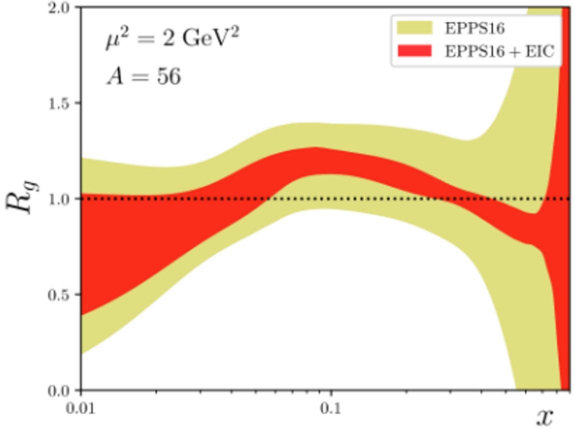
Cristiano Fanelli (MIT), Xuan Li (LANL)

IR2@EIC, March 17-19, 2021

Outline

- Heavy flavor production summary
- Spectroscopy summary
- Next steps and outlook





IR2@EIC WG3
Heavy Flavor

Convener: Xuan Li (LANL)

Speakers:

Ivan Vitev (LANL)

Open heavy flavor and quarkonium physics at the EIC

Christian Weiss (Jefferson Lab)

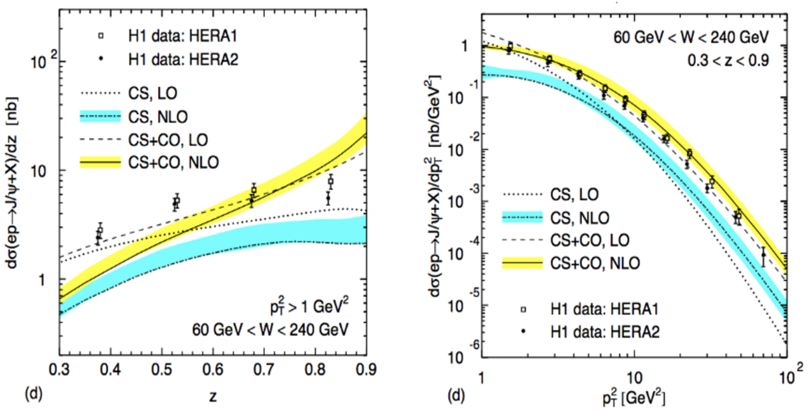
Heavy flavor production and reconstruction at EIC at lower CM energies

Open heavy flavor and quarkonium physics at the EIC

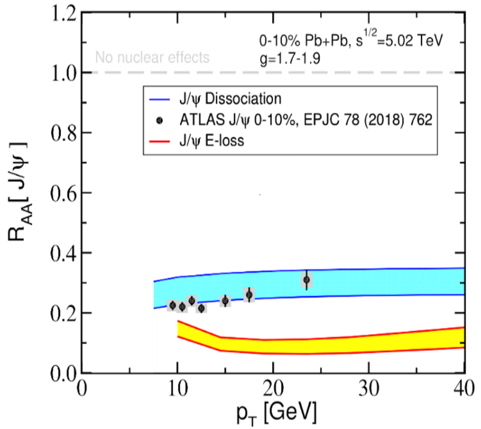
I. Vitev (LANL)

- Recent theoretical developments have achieved good descriptions of the HERA, RHIC and LHC data.

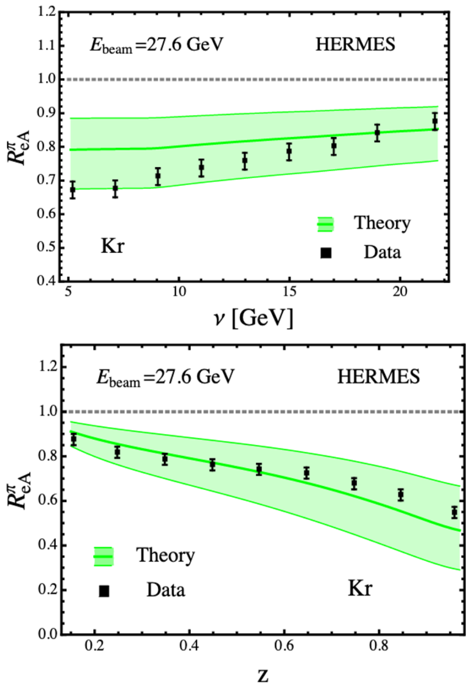
H1 photoproduction



J/ψ at LHC



HERMES π R_{eA}



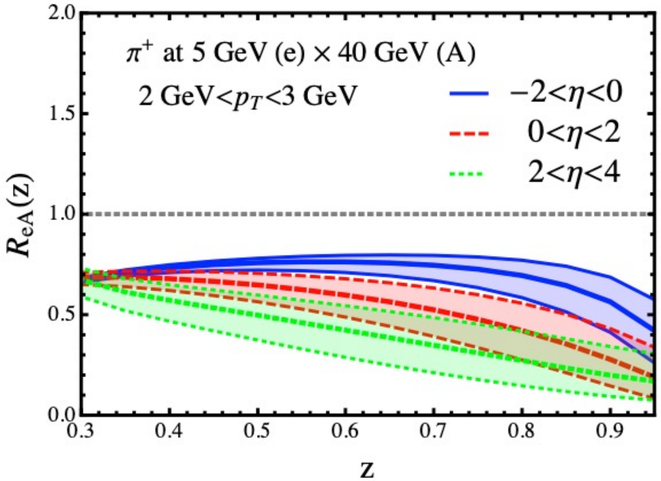
- Extension to the EIC heavy flavor studies have been done with NLO corrections.

Open heavy flavor and quarkonium physics at the EIC

I. Vitev (LANL)

- The nuclear modification factor of hadrons at the EIC provide a good approach to the hadronization process in the nuclear medium.

$$R^{\pi}_{eA}(\nu, Q^2, z) = \frac{\left.\frac{N^{\pi}(\nu,Q^2,z)}{N^{e}(\nu,Q^2)}\right|_A}{\left.\frac{N^{\pi}(\nu,Q^2,z)}{N^{e}(\nu,Q^2)}\right|_D}$$



w/ NLO corrections

H. Li et al . (2020)

- Forward rapidity measurements in small center of mass collisions at the EIC are predicted to observe largest nuclear suppression. Reference for the IR2 physics developments.

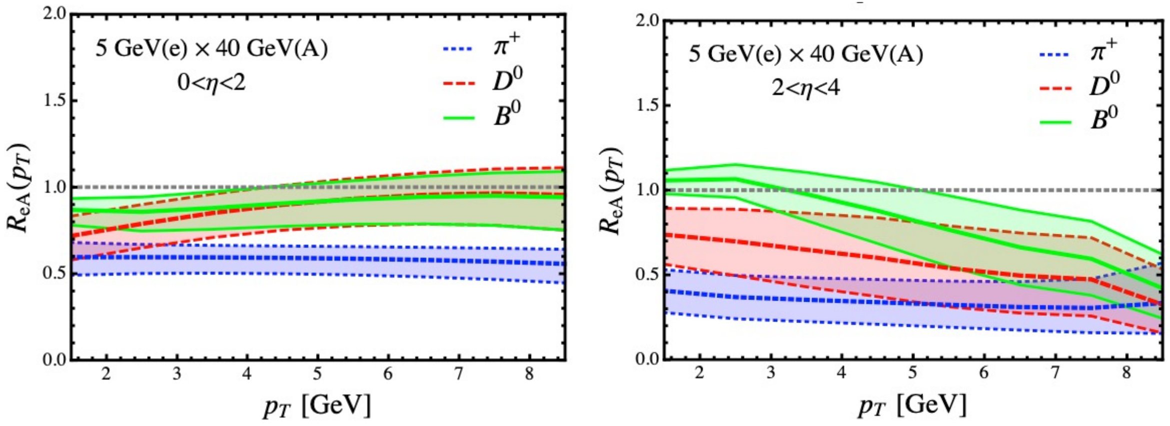
Open heavy flavor and quarkonium physics at the EIC

I. Vitev (LANL)

- Modification of heavy meson vs p_T, pseudorapidity and center of mass energies.

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

Normalization is selected to minimizing the initial-state PDF effects.



- Forward rapidity HF hadrons experience the largest nuclear effects.

Open heavy flavor and quarkonium physics at the EIC

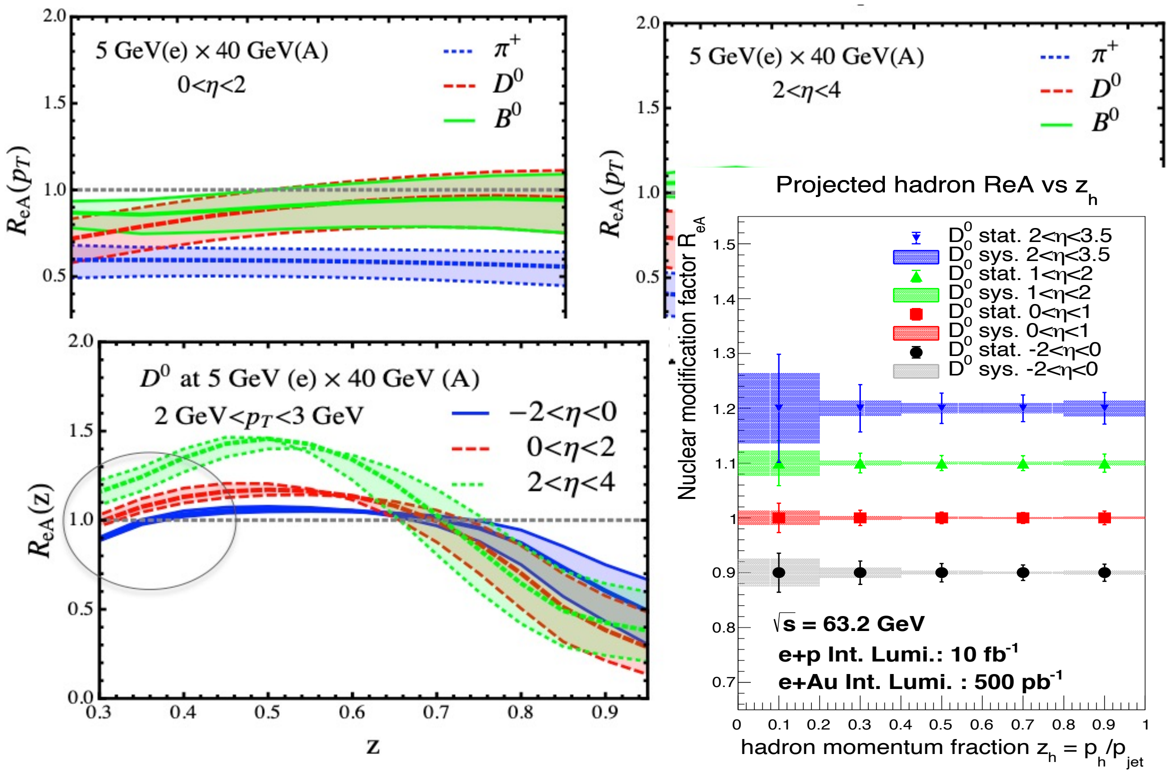
I. Vitev (LANL)

- Modification of heavy meson vs p_T, pseudorapidity and center of mass energies.

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

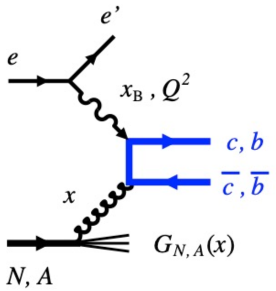
Normalization is selected to minimizing the initial-state PDF effects.

- The difference in the suppression pattern of π, D and B mesons can characterize the in-medium evolution.



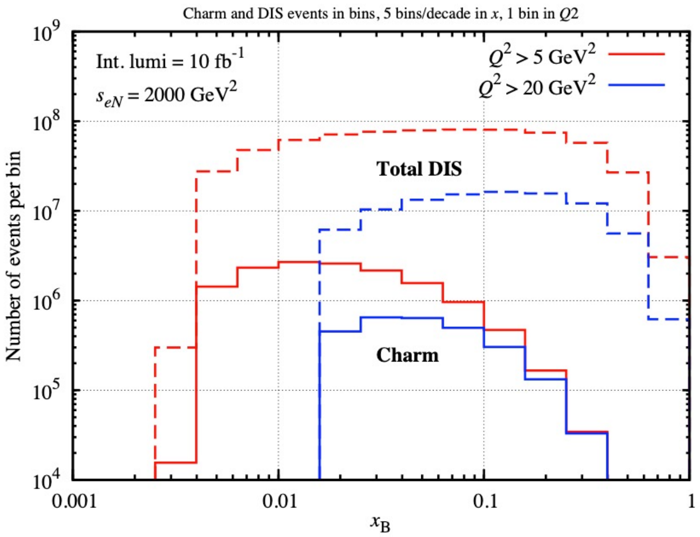
Open heavy flavor production and reconstruction with EIC at lower CM energies

C. Weiss (JLab)



- Open heavy flavor production at the EIC serves as a gluon probe as the LO process is photon-gluon fusion.

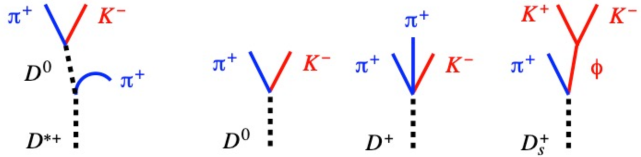
- Charm production rates drop rapidly at large x_B.
- Charm production rates ~ 10^5 at x_B ~0.1 (int. lumi. 10 fb^{-1}).
- Charm/DIS ratio ~ 2-3% at x_B ~0.1.
- Defines the charm reconstruction needs.



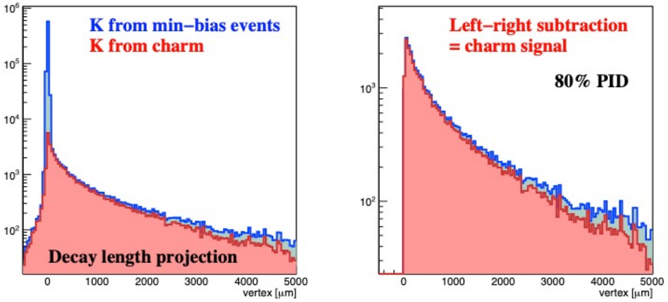
Open heavy flavor production and reconstruction with EIC at lower CM energies

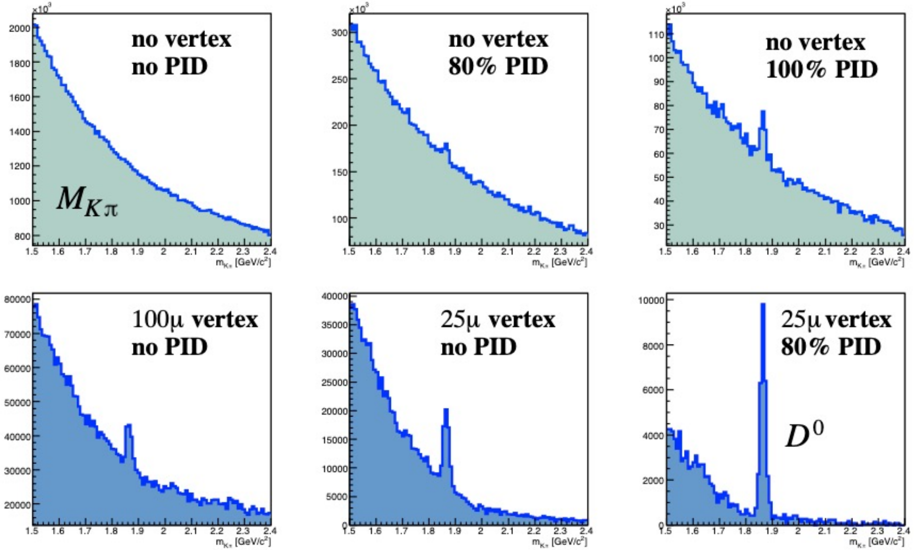
C. Weiss (JLab)

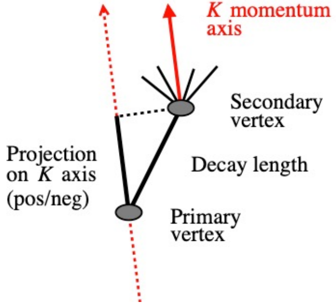
- Charm reconstruction.
  - ➢ Exclusive method:



  - ➢ Inclusive method:





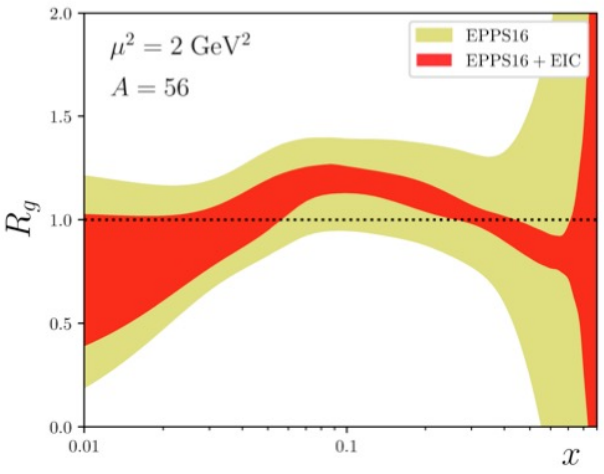


PID and vertexing is critical to realize these measurements!

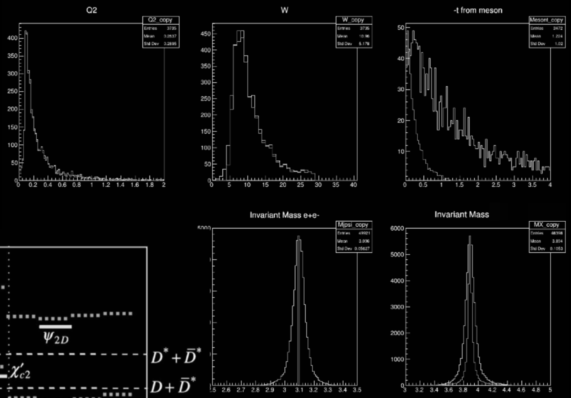
Open heavy flavor production and reconstruction with EIC at lower CM energies

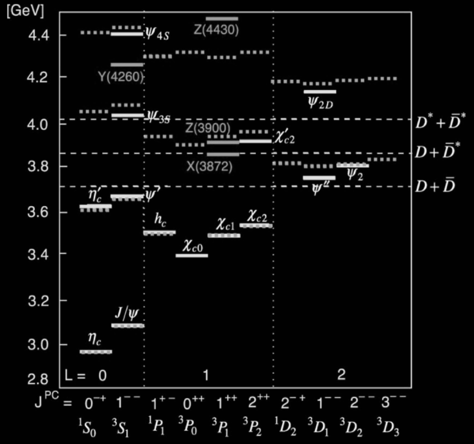
C. Weiss (JLab)

- Charm measurements at the EIC can constrain the gluon anti-shadowing and EMC effect.
- EIC enables HF production/reconstruction at x_B>0.1.
- Suggested further studies:
  - Use of differential charm cross sections for PDF analysis.
  - Charm reconstruction with high-p_T pairs – rare but distinct events, double tag.
  - Beauty production and reconstruction.
  - HF photoproduction using low-Q^2 electron tagger.

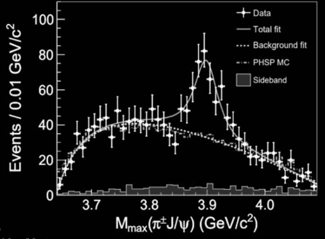


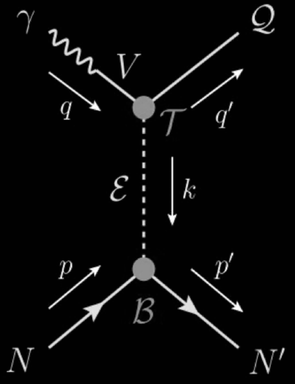
IR2@EIC Spectroscopy





BESIII [Phys. Rev. Lett. 110, 252001 (2013)]





Convener:
C. Fanelli (MIT)

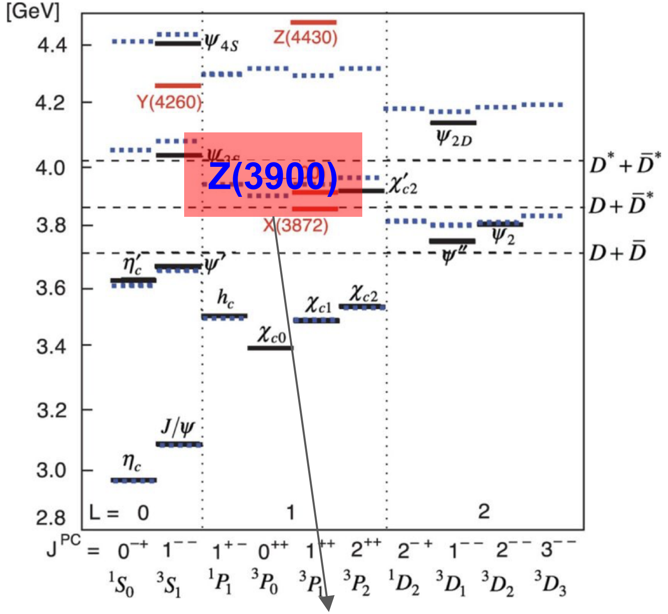
Speakers:
D. Winney (IU,JPAC),
Exotic Spectroscopy at the EIC

D. Glazier (Glas.),
EIC Smear Simulations of XYZ Production

Exotic Spectroscopy at the EIC

D. Winney (IU, JPAC)

- Comprehensive overview of XYZ and new results based on JPAC, Phys. Rev. D **102**, 114010
- Plethora of quarkonium-like states observed since 2003 not fitting conventional qqbar models, ambiguous interpretation (multi-quark resonances, hadronic molecules, hadrocharmonia, kinematic effects, etc).
- E.g., Z(3900), see right, confirmed by BESIII and Belle in 2013. Exotic nature, but precise structure still unknown.
- The XYZ not seen so far in photo-induced reactions, **EIC can provide independent confirmation** of their existence.
- Direct photo-production is an **ideal laboratory for spectroscopy**!
    - Constrained kinematics, precise determination of production mechanism, no triangle rescattering, etc.



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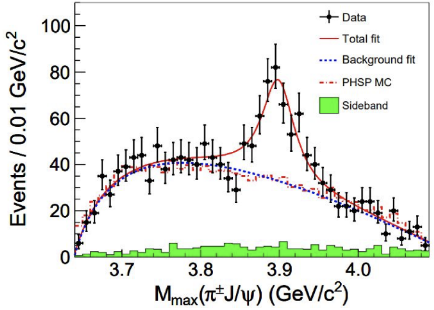
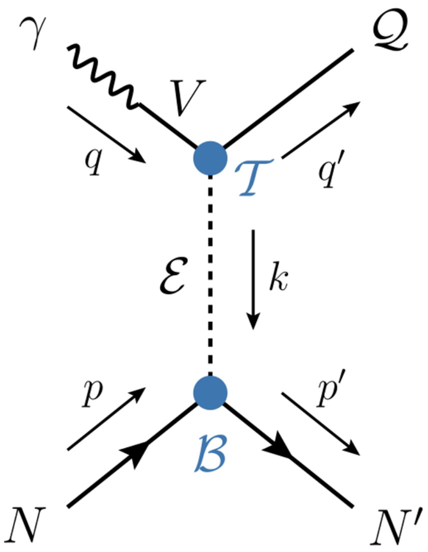


Exotic Spectroscopy at the EIC

D. Winney (IU, JPAC)



- At the energies of interest, the process is dominated by photon fragmentation
- Photoproduction of a quarkonium like meson via an exchange of Ɛ in the t-channel. Q is the heavy quarkonium-like meson.
- Photon couplings fixed by observed decay widths and VMD. Bottom coupling from other reactions.

Necessary distinction between production near-threshold (lowest spin exchange dominate) and high-energy (Regge amplitudes), see next slide.

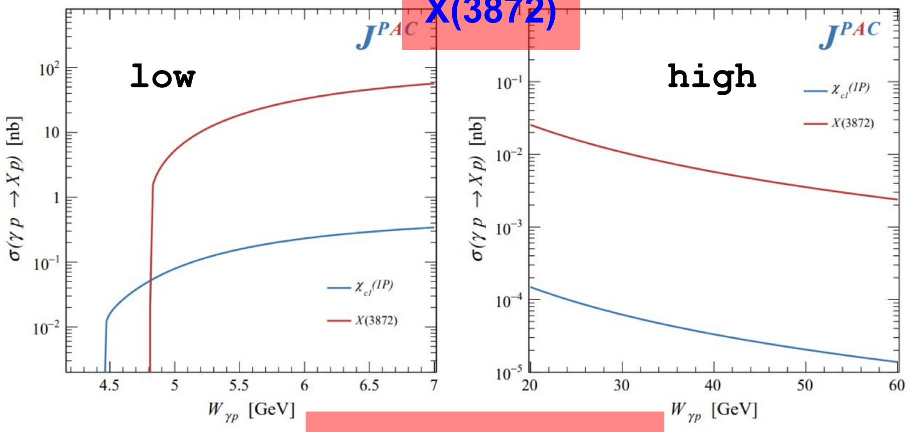
For Z π^+ exchange with V=J/ψ, Y(nS); for X(3872) vector exchange; for Y(4260) vector states produced via diffractive Pomeron exchange.

The work includes also electroproduction via Primakoff of X off nuclei A, where the exchanged photon is quasi-real. Not covered in the talk, only mentioned in the Q&A session.

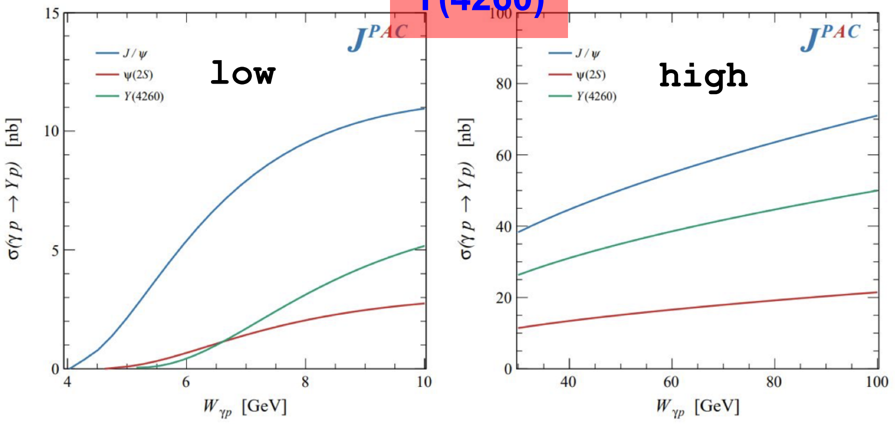
Exotic Spectroscopy at the EIC

D. Winney (IU, JPAC)

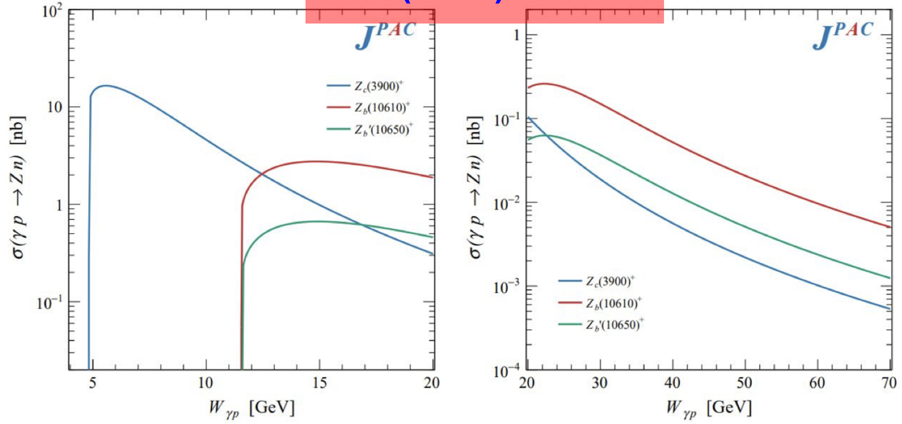
X(3872)



Y(4260)



Zc(3900)⁺ & Zb



- Lower γp invariant mass => higher cross-section for X and Z
- X: Interpolation between low and high energy regimes not straightforward
- Z: spectroscopy of Z’s possible with high-luminosity at low CM energies
- Y: Diffractive cross-section rise with energy, Y states benefit from high CM

Exotic Spectroscopy at the EIC

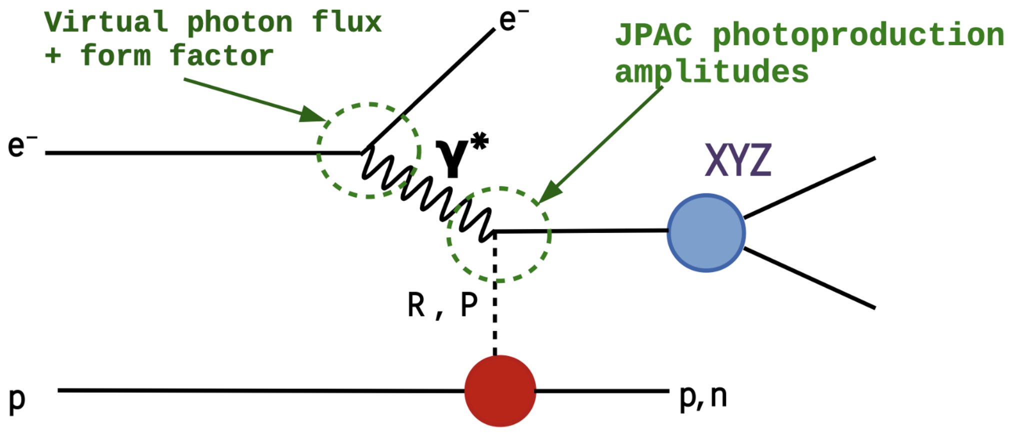
D. Winney (IU, JPAC)

- EIC offers unique opportunity to study exotics in photoproduction and complement measurements at existing facilities.
- Major takeaway is that the production of Zc and Zb benefits from a high-luminosity, low energy program at IR2, with production cross-section comparable to existing e^+e^- machines.
- Major comments/questions (Q/A part):
  - Questions about the two regimes (low and high energy) and mismatching strengths of the amplitudes for X(3872). Fixed-spin described correctly the size of the cross-section at threshold, the physical amplitude is expected to match the Regge prediction at Wγp~20 GeV.
  - Systematic uncertainties related to predictions expected to dominating. Nevertheless predictions should provide the right orders of magnitude for cross-section.
  - With regard to heavier atomic nuclei, the only studies in this regard have been for the Primakoff production of X(3872), enhanced by the atomic number.

EIC Smear Simulations of XYZ

D. Glazier (Glas.)

- Talk complementary to theory overview given by D. Winney (JPAC).
- Presented simulation results on EIC-Smear Simulations of XYZ production.
- The event generator (ElSpectro) incorporates spectroscopy into electro/photo production reactions.



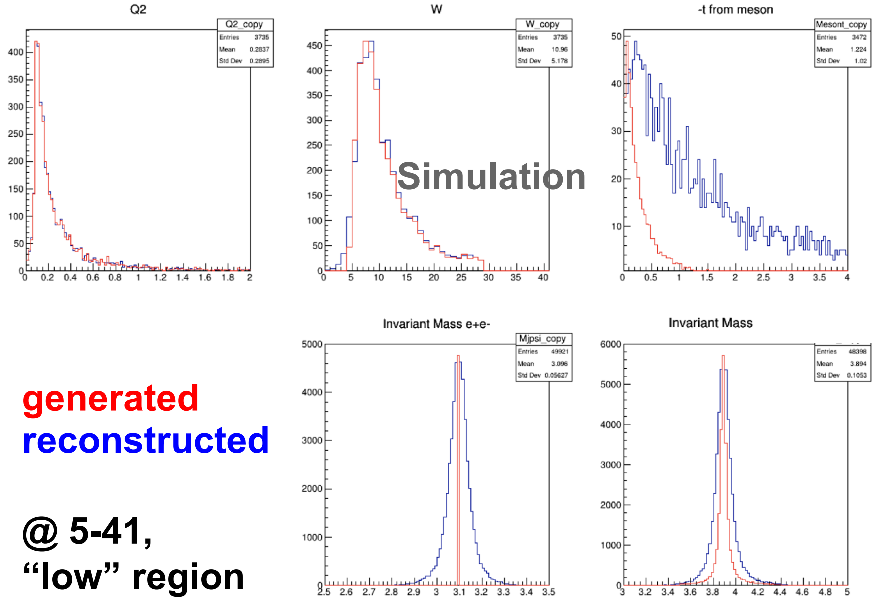
Pictorial representation of the Event Generator

- Showed preliminary analyses implementing JPAC photoproduction of X, Y, Z
- Using eic-smear for a particular experimental setting (namely, MATRIXDETECTOR_0_2_B1_5T)
- Results projected for 1 fb^{-1}, corresponding to ~11 days @ 10^{33} $cm^{-2}s^{-1}$ and yields shown for 4 settings of beam energies: 5-41, 5-100, 10-100, 18-275

EIC Smear Simulations of XYZ

D. Glazier (Glas.)

- Detailed discussion about the kinematics of the final state particles for X, Y, and Z productions.
- The Z(3900) production, for example, is characterized by e + p -> e^- + Z(3900) + n, with Z decaying in $J/\psi\pi^+$ and J/ψ decaying into e^+e^-. **Yields** (in the two regions closed to threshold and at higher energies, see D. Winney's talk, dubbed low and high) and **generated/reconstructed** distributions of these particles have been extensively discussed.



generated
reconstructed

@ 5-41,
"low" region

Model

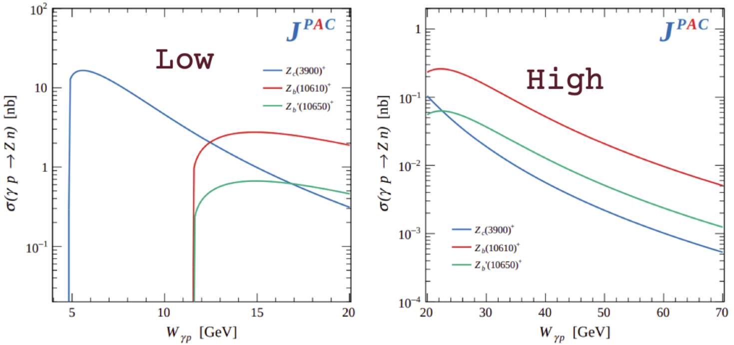


FIG. 2. Integrated cross sections for the three Z states considered. Left panel: predictions for fixed-spin exchange, which we expect to be valid up to approximately 10 GeV above each threshold. Right panel: predictions for Regge exchange, valid at high energies.

Yields

	Ngen low	NZ low	NZe- low	Ngenhigh	NZ high	NZe-high	Wmax
5-41	5.3k	4.8k	340	730	700	50	29

EIC Smear Simulations of XYZ

D. Glazier (Glas.)

- Detailed discussion about the kinematics of the final state particles for X, Y, and Z productions.
- The Z(3900) production, for example, is characterized by e + p -> e^- + Z(3900) + n, with Z decaying in $J/\psi\pi^+$ and J/ψ decaying into e^+e^-. Yields and generated/reconstructed distributions of these particles have been extensively discussed.
- Major takeaways (cf. summary):
  - Lower e beam momentum results in larger fraction of detected e' and better resolution in invariant masses.
  - Higher beam energies give larger production yields
  - An IR2 low W optimized, 5-100 beam configuration seems promising for XYZ
- Major comments/questions (Q/A part): Results shown for 1.5T. It would be interesting to test different options for the magnetic fields. - Ongoing work. Suggested to look at ep scattering for finite Q^2, allowing better bkg rejection.

Next steps and Outlook

- Request to carry out full simulation with different detector concepts and collisions energies.
- A IR2 detector with high-luminosity low energy collisions could develop a broad HF physics program at the EIC:
    - Nuclear modification of heavy flavor hadrons/jets.
    - Spectroscopy of exotic states such as X(3872), Zc(3900).