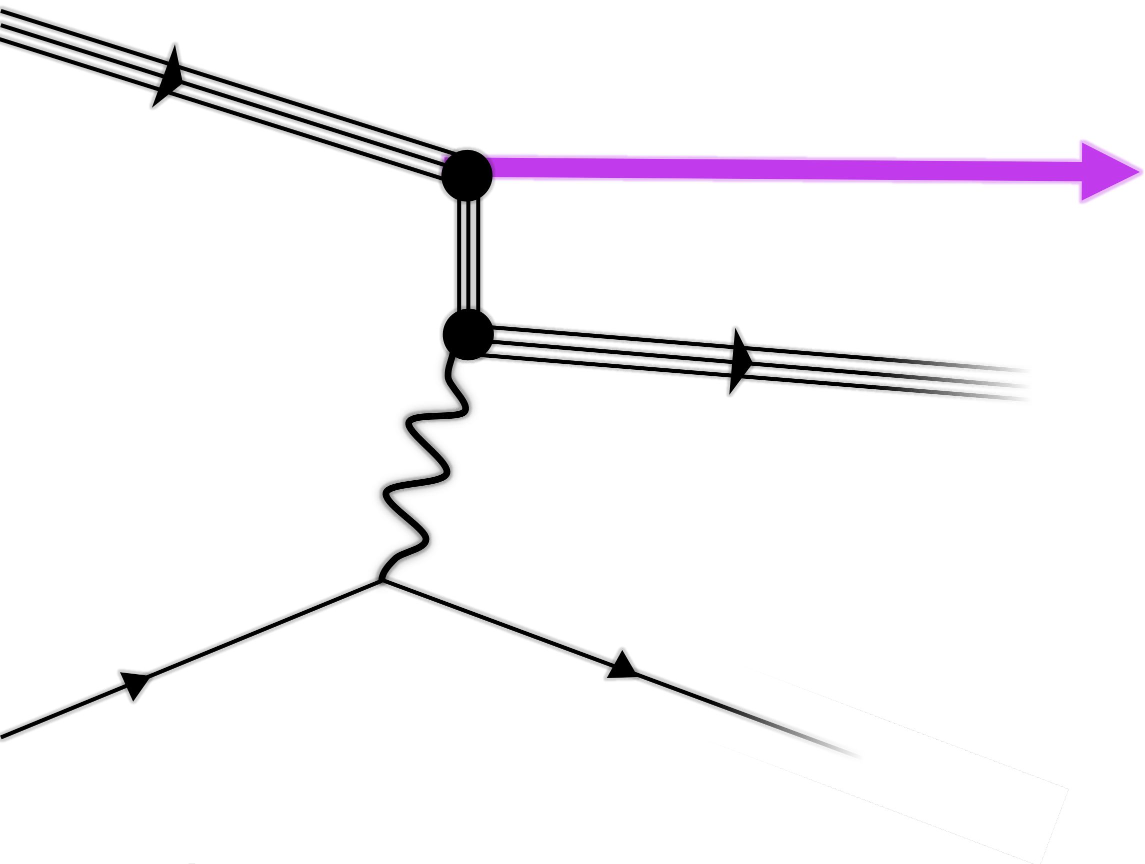

Investigation of Vector Meson Backward-Production Capabilities at the EIC

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University of California, Davis

Supported in part by

UC Davis Working with LBNL on the EIC

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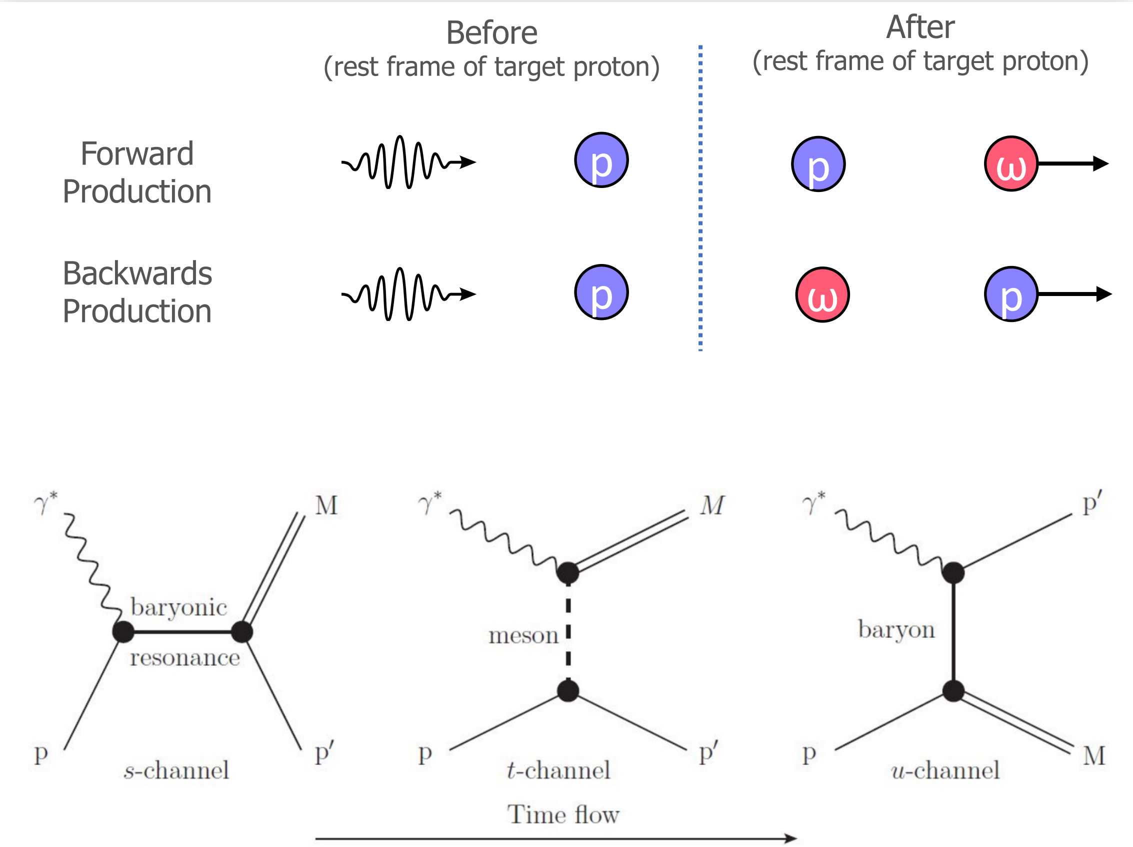
LDRD: Laboratory Directed Research and Development Program

- FY21 LDRD call for proposals stresses high-impact research areas
- Colleagues at RNC (LBNL) and UC Davis nuclear group write joint proposal for a collaborative effort to study backwards vector-meson and forward upsilon production at the EIC
- This proposal won approval by lab director and progress started last June
- Project culminated in a paper that was just accepted to PRC (10.1103/PhysRevC.106.015204)

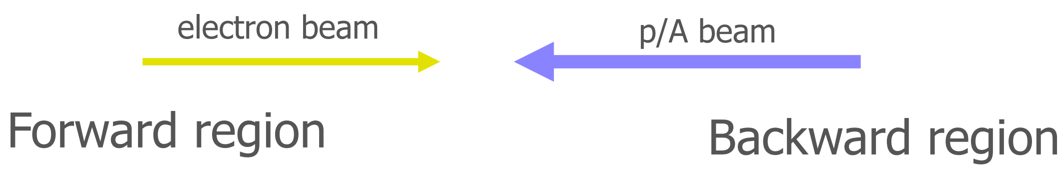
LBNL+UCD Outlook

- Joint efforts in progress on continued eSTARlight development
- I plan on continuing work with Spencer Klein, Xin Dong, and Yuanjing Ji on developing models for simulations of interesting physics channels at the EIC

Backwards (u-channel) Production



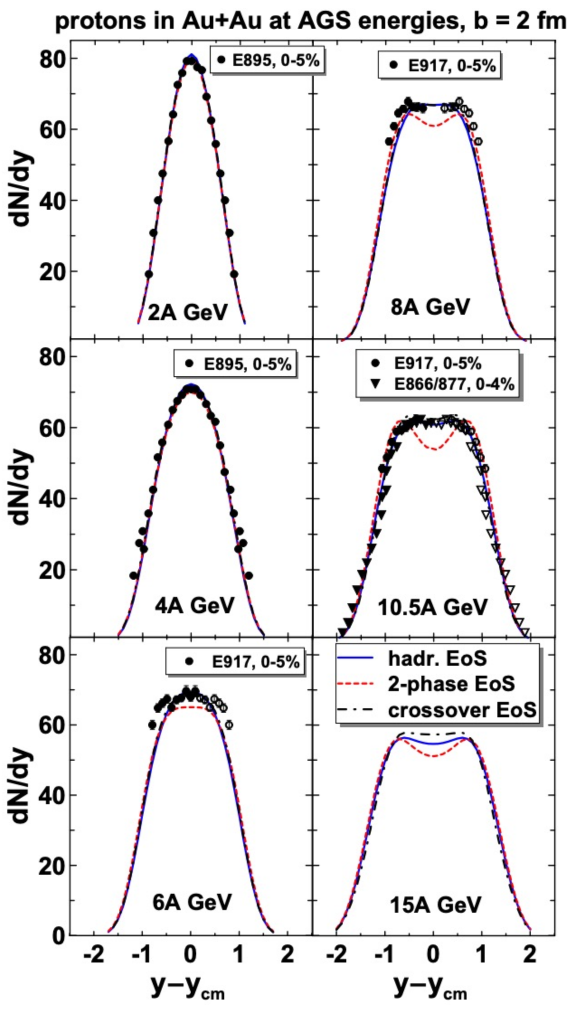
Contributions to VM production from Mandelstam variables. Wenliang (Bill) Li (William and Mary). GPD Workshop at Stony Brook University



Forward vs Backwards Production

- Forward Production
  - t-channel: low Mandelstam t, high u
  - Momentum transfer from target is small
  - VM is produced in backwards (e^--going) direction
  - Proton in forward direction
    - Proton rapidity only slightly modified
- Backwards Production
  - u-channel: low Mandelstam u, high t
  - Momentum transfer from target is large
  - VM produced in forwards (p-going) direction
  - Proton in backwards direction
    - Proton shifted many units in rapidity
  - Similarities with stopping in heavy ion collisions

u-channel Physics and Baryon Stopping



Net-proton rapidity distributions at AGS compared with three distinct models of EoS

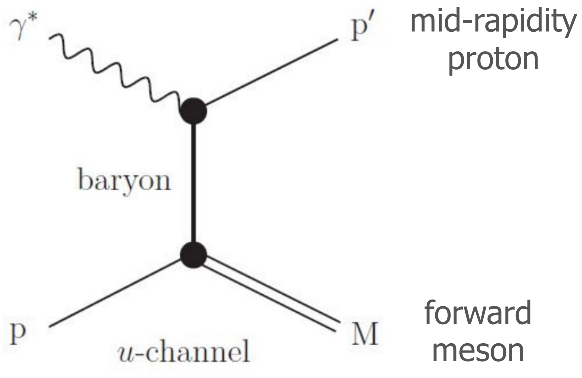
Stopping in Heavy-Ion Collisions

- Baryons participating in a collision can be shifted many units in rapidity
- Generally more collisions → more stopping
- Models of stopping using various equations of state indicate sensitivity to EoS
  - Onset of deconfinement may be probed by baryon stopping
  - **Understanding behavior of midrapidity baryons as a function of energy is critical** (see left)

Yu.B. Ivanov. Phys Lett B, Vol 721, Issues 1–3, 2013, 123-130, ISSN 0370-2693

Stopping in ep collisions

- Single collision causes large momentum transfer
- u-channel mechanism is not well-understood as a function of energy
- ep collision is simple system for studying midrapidity proton behavior in absence of deconfinement and hot QCD effects
- **This gives us a better understanding of mechanisms contributing to baryon stopping in larger systems**



u-channel proton stopping in ep collision

u-channel Physics and Baryon Stopping

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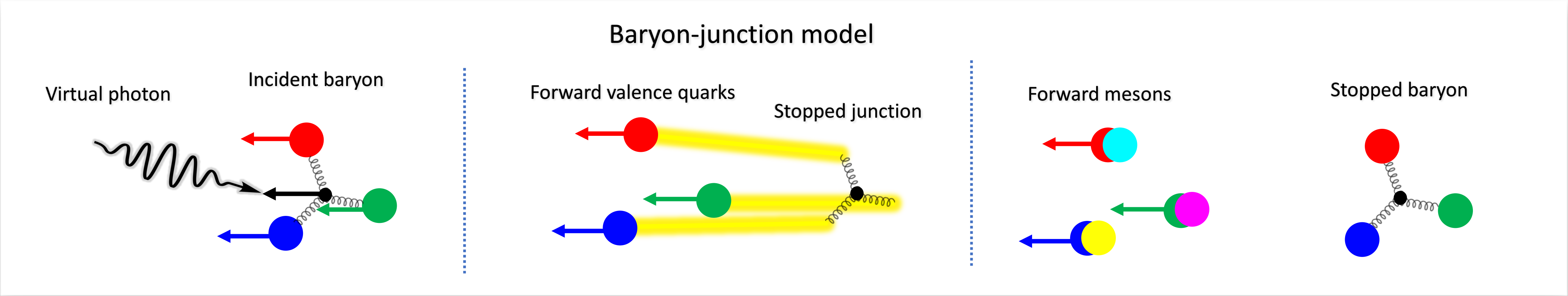
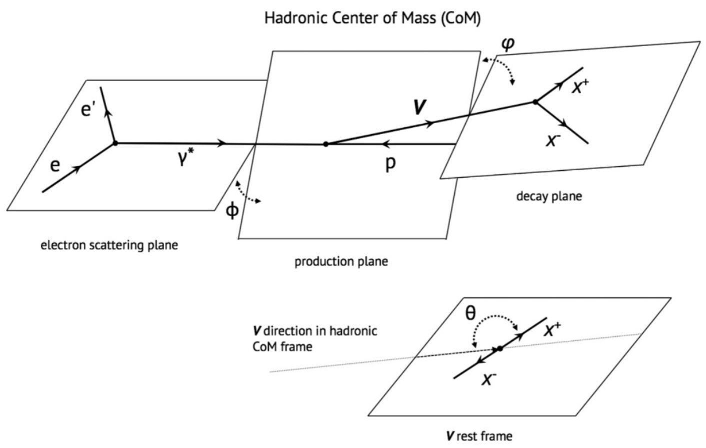
How can a 275 GeV proton undergo this large momentum transfer and remain intact?

- Is there enough time available in a collision for all the quarks to "know" that a collision has occurred?

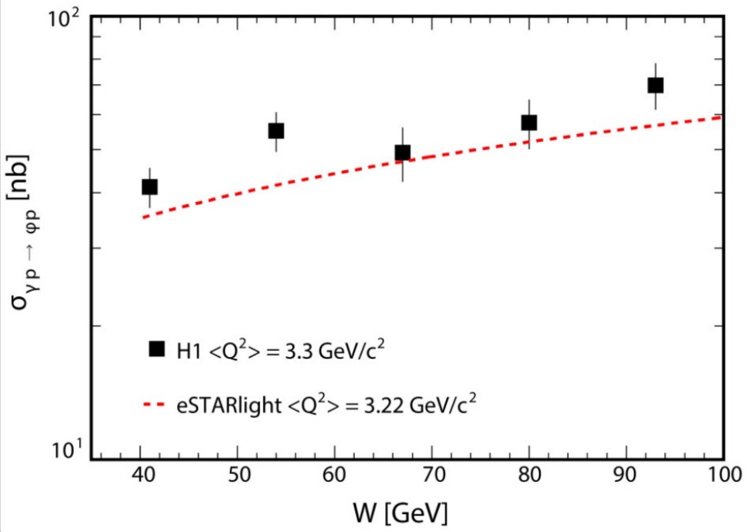
Kharzeev, Phys.Lett. B378 (1996) 238-246, arXiv:nucl-th/9602027

- Is there a connection to the baryon-junction model (BJM)?
- The BJM posits that baryon number is not just carried by valence quarks
- In BJM, baryon number is also carried by a non-perturbative configuration of gluons. These gluons can be easily stopped in a collision





Kinematics of VM production and decay in eSTARlight



Benchmarking eSTARlight against HERA data. Michael Lomnitz and Spencer Klein. Phys. Rev. C **99**, 015203 – Published 11 January 2019

eSTARlight

Background on eSTARlight

- Models VM production in electron-ion collisions at finite photon virtuality
  - ➢ Includes a variety of vector mesons (ρ, ρ’, ω, J/ψ, ψ(2S), ϒ)
  - ➢ Wide range of COM energies
  - ➢ Simulates final-state particle kinematics
- Complete kinematics simulations at variable energies make this a useful tool for informing detector design for EIC
- Variable photon virtuality (Q^2) allows predictions of production cross section scaling with Q^2

$$\sigma(eA \rightarrow eAV) = \int \frac{dW}{W} \int dk \int dQ^2 \frac{d^2 N_\gamma}{dk\, dQ^2} \sigma_{\gamma^* A \rightarrow VA}(W, Q^2)$$

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Modeling u-channel Production

C. Ayerbe Gayoso et al. Progress and Opportunities in Backward angle (u-channel) Physics. Eur. Phys. J. A (2021). arXiv:2107.06748

- eSTARlight has been modified include backward production!
- **The strategy: exploit similarities to t-channel**

$$\frac{d\sigma}{dt} \sim e^{-Bt} \longrightarrow \frac{d\sigma}{du} \sim e^{-Cu}$$

- Scaling depends on the meson produced
- B and C relate to size of production region which differs in t and u channels due to role of meson vs baryon exchange trajectories
- Effect of photon virtuality estimated with similar behavior to t-channel

$$\sigma_{\gamma^* p \to \omega p}(W, Q^2) = \sigma_{\gamma^* p \to \omega p}(W, Q^2 = 0)\left(\frac{M_\omega^2}{M_\omega^2 + Q^2}\right)^n$$

- Assumption based on data from HERA forward-production (a source of uncertainty)
- Rates: Forward production: predicted rate ~(billion events)/10^7s

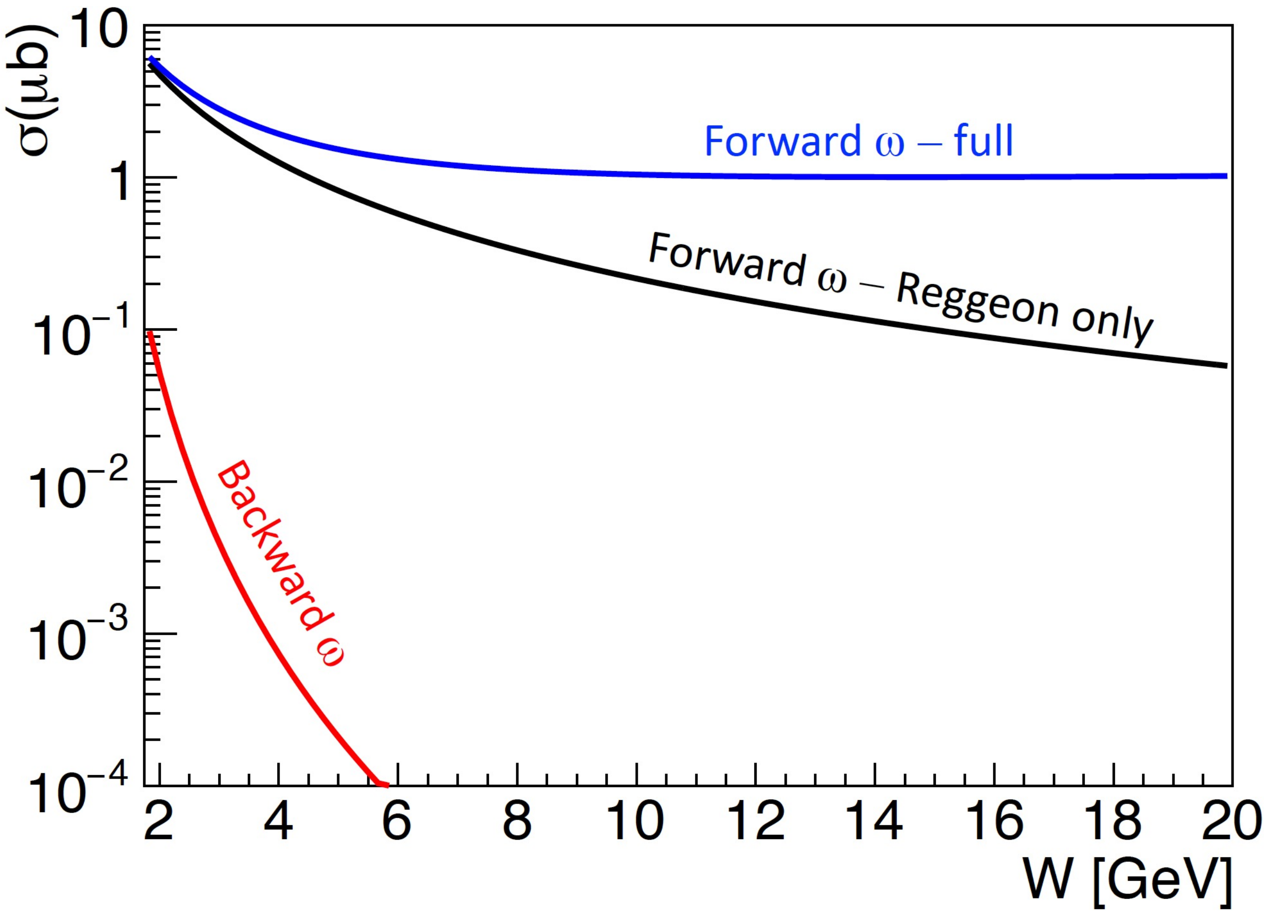
  Backward production: predicted rate ~(10 million events)/10^7s

F.D. Aaron et al. (H1), JHEP 05, 032 (2010)

- This model was developed by Aaron Stanek (LBNL) and implemented by Samuel Heppelmann (UC Davis)

Backward Production Cross Section in eSTARlight

- The cross section for backward production as a function of the center-of-mass energy of the photon+proton system is lower, affecting our expected statistics



Cebra et al. Backward-Angle (u-channel) Production at an Electron-Ion Collider arXiv:2204.07915

Vector Mesons Channels of Interest at EIC

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ω Neutral Decay Channel

- $\omega \rightarrow \pi^0\gamma_{primary} \rightarrow \gamma\gamma\gamma_{primary}$ (8.3%) is fully calorimetric
- Data exists from JLab for benchmarking eSTARlight
- Spin of backward-produced ω still under discussion. In forward-production, ω has same polarization as photon. This polarization is being compared against unpolarized ω in u-channel
- We need far-forward electromagnetic calorimetry

ρ^0 2-Pion Decay Channel

- $\rho^0 \rightarrow \pi^+ \pi^-$ (100%)
- Expected to have similar behavior to ω
- Spin of backward-produced ρ still under discussion. Taken to be unpolarized for now
- We need far-forward charged-particle tracking

Detectors of Interest For u-channel Production

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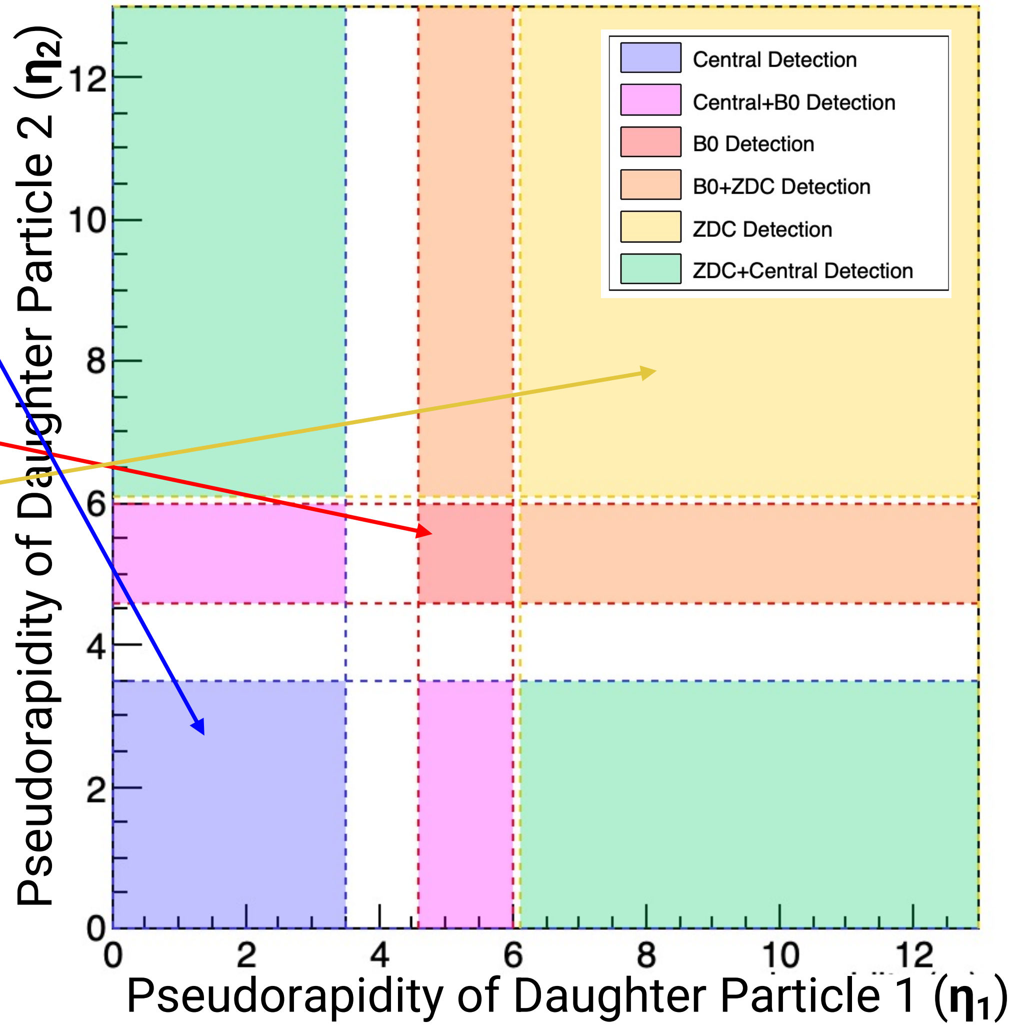
There are three detector regions of interest for backwards production

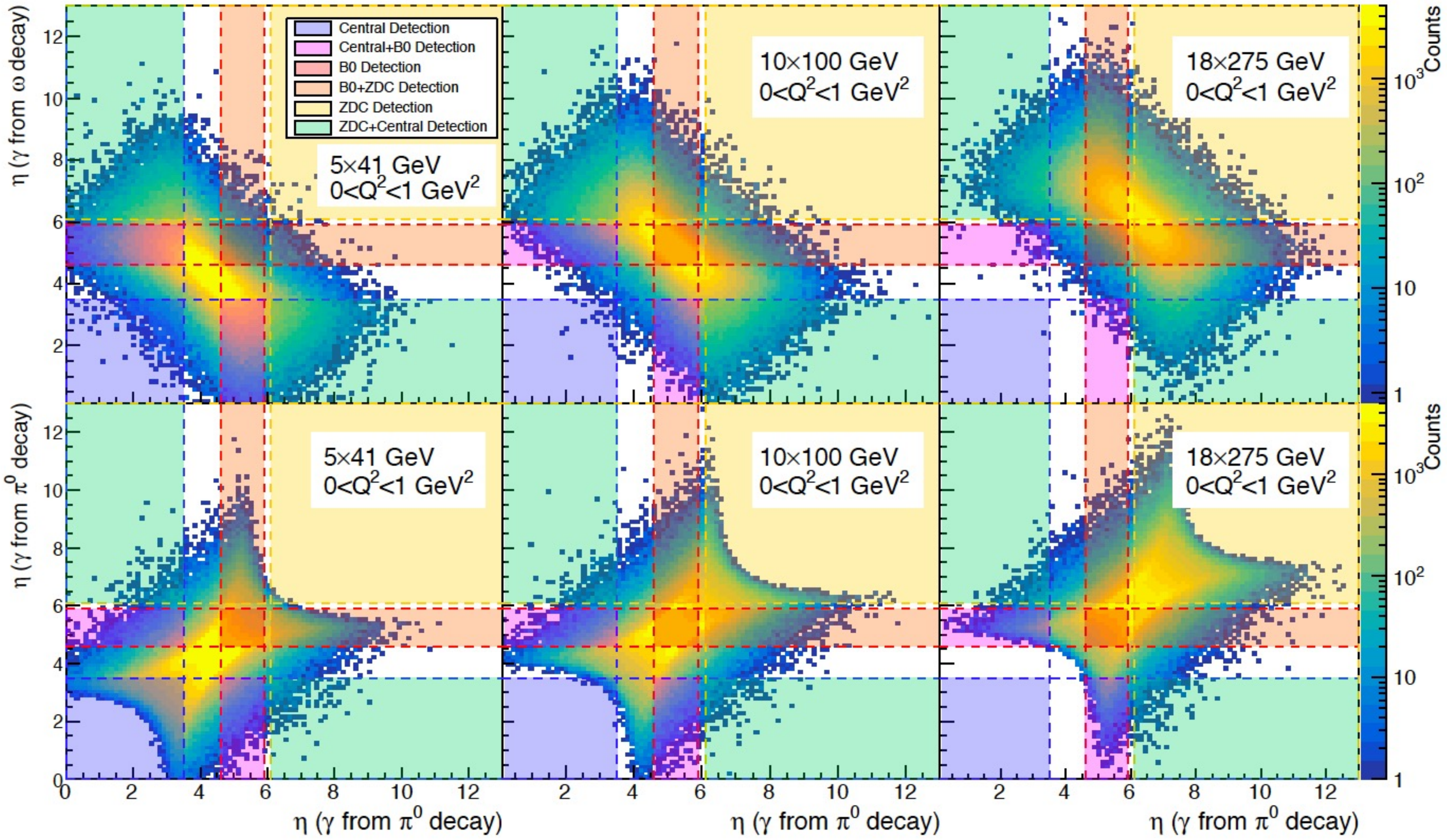
- **Central Region (endcap & barrel): |η| < 3.5**
  - ✓ **Charged-particle tracking (ρ)**
  - ✓ **Electromagnetic calorimetry (ω)**
- **B0 Magnets: 4.6 < η < 6.0**
  - ✓ **Charged-particle tracking (ρ)**
  - ? **Electromagnetic calorimetry (ω)**
- **ZDC: η > 6.215–5.991**
  - ✓ **Electromagnetic calorimetry (ω)**



Backwards ω Detection

$\omega \rightarrow \pi^0\gamma_{primary} \rightarrow \gamma\gamma\gamma_{primary}$ (8.3%)

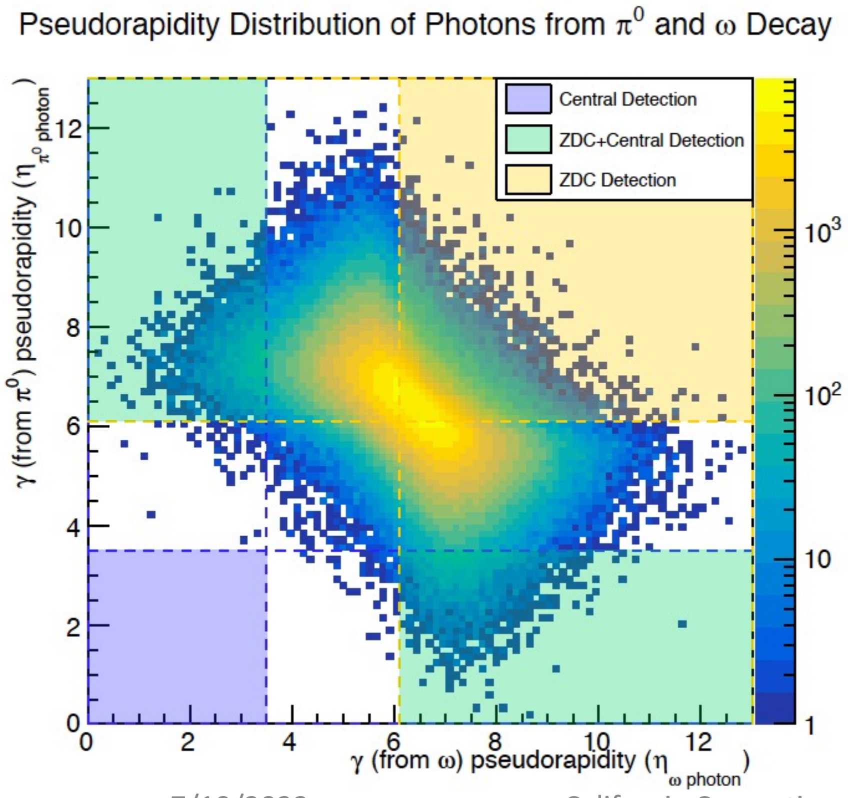
Proton beam energy	ω eff. cent.+ZDC	ω eff. cent.+B0+ZDC
41 GeV	1.4%	18%
100 GeV	1.3%	41%
275 GeV	6%	63%

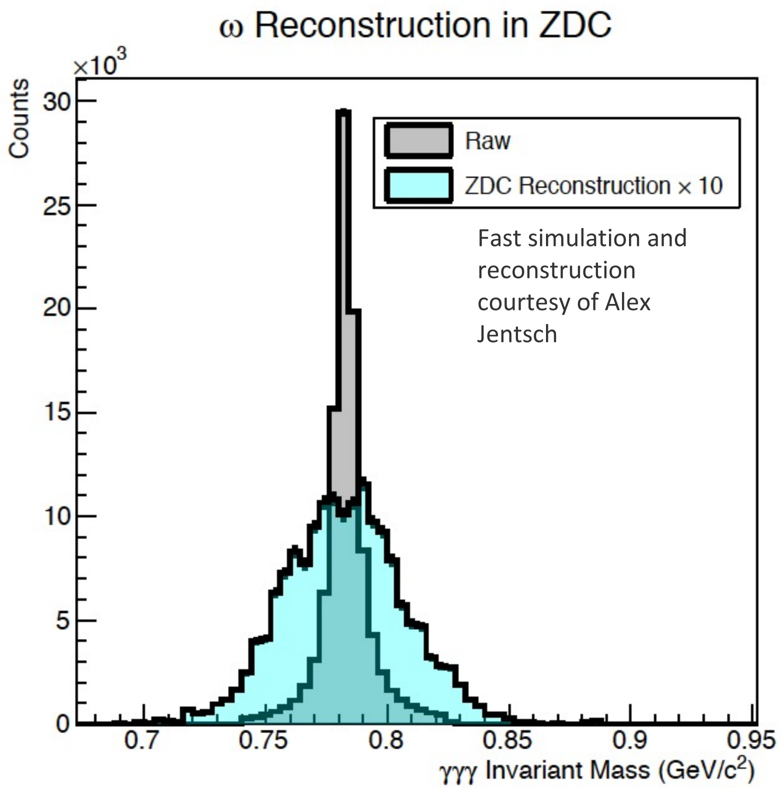


Cebra et al. Backward-Angle (u-channel) Production at an Electron-Ion Collider arXiv:2204.07915

Backwards ω Detection

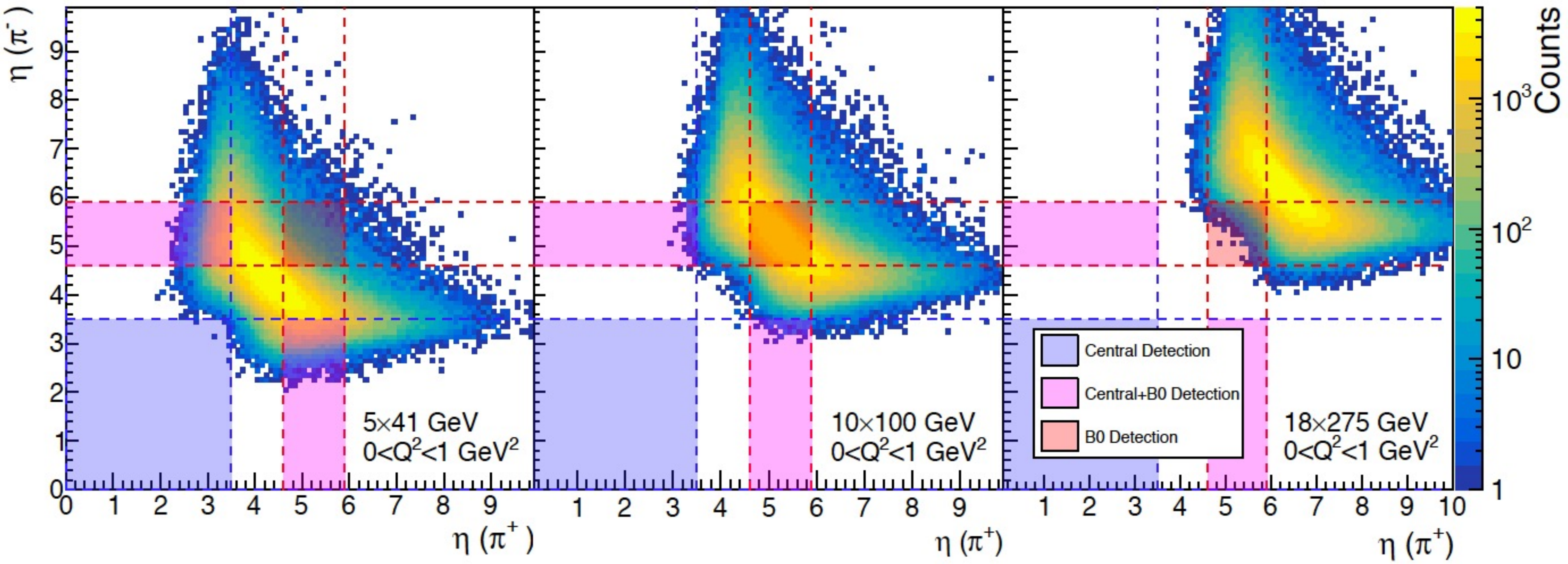
- Backward ω events at 18⨉275 GeV were simulated for the ATHENA proposal assuming no B0 calorimetry
- Simulated using a parameterization of the ZDC's acceptance and resolution
- Demonstrated that ωs could be faithfully reconstructed, but at a low (~6%) efficiency without B0 calorimeter





Backwards ρ Detection

$\rho^0 \rightarrow \pi^+ \pi^-$ (100%)

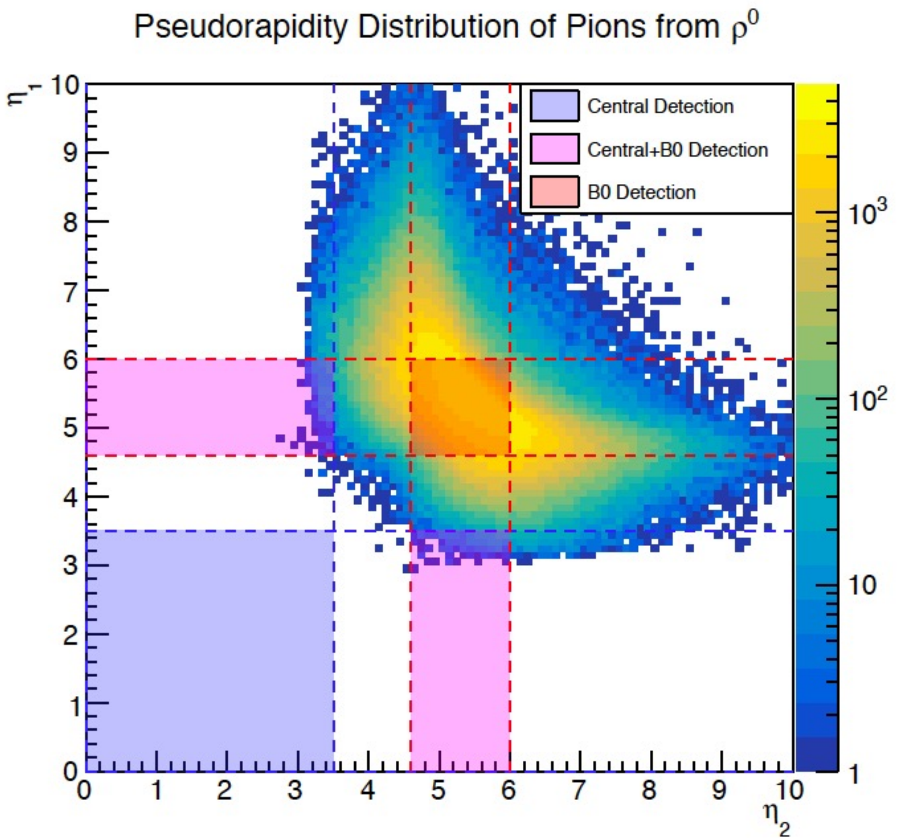


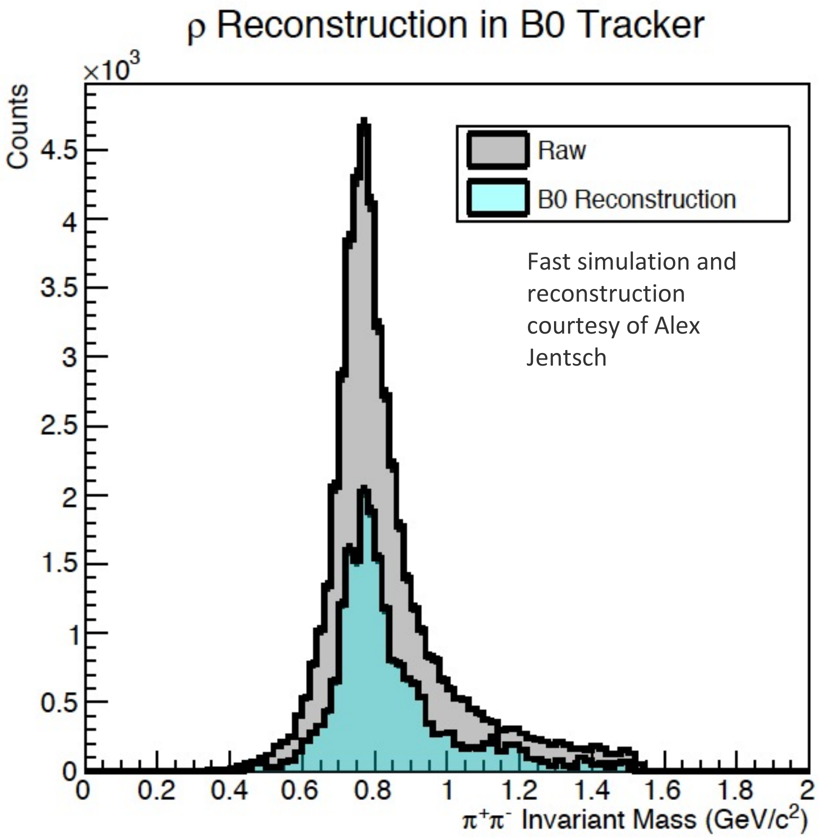
Proton beam energy	ρ eff. cent.+B0
41 GeV	13%
100 GeV	49%
275 GeV	0.7%

Cebra et al. Backward-Angle (u-channel) Production at an Electron-Ion Collider arXiv:2204.07915

Backwards ρ Detection

- Backward ρ events at 5×41 GeV were simulated for the ATHENA proposal
- B0 tracking should be the priorityfor this channel
- These too were able to be reconstructed in simulations of the B0 response





Paper on Backwards Production at EIC

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Check out our recent paper on backward-production at the EIC:
https://link.aps.org/doi/10.1103/PhysRevC.106.015204

Backward-Angle (u-channel) Production at an Electron-Ion Collider

Daniel Cebra and Zachary Sweger
University of California, Davis

Xin Dong, Yuanjing Ji, and Spencer R. Klein
Lawrence Berkeley National Laboratory Berkeley CA
(Dated: June 27, 2022)

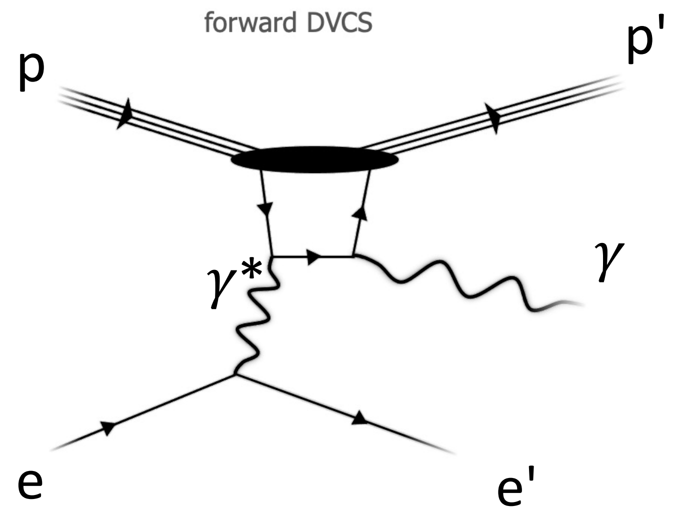
In backward photoproduction of mesons, the produced vector meson takes most of the struck nucleon momentum. The nucleon loses most of its momentum, and so is shifted several units of rapidity. Thus the Mandelstam u is small, while the squared momentum transfer t is typically large, near the kinematic limit. In a collider geometry, backward production transfers the struck baryon by many units of rapidity, in a striking similarity to baryon stopping. We explore this similarity, and point out the similarities between the Regge theories used to model baryon stopping with those that are used for backward production.

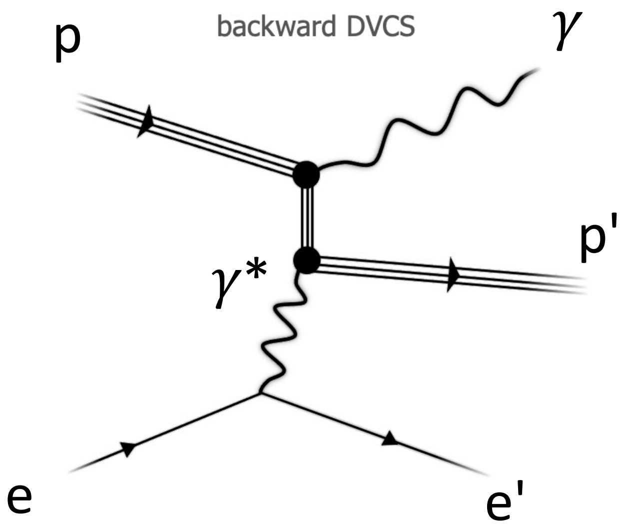
We then explore how backward production can be explored at higher energies than are available at fixed target experiments, by studying production at an electron-ion collider. We calculate the expected ep cross sections and rates, finding that the rate for backward ω production is about 1/300 that of forward ωs. We discuss the kinematics of backward production and consider the detector requirements for experimental study. We demonstrate that an experiment at the proposed U.S. Electron-Ion Collider will have the capability to detect backward-production events and may provide a test for models of stopping in high-energy ep collisions including the baryon-junction model.

Looking Forward: Backwards DVCS

Deeply Virtual Compton Scattering

- DVCS cross section is dominated by two contributions: forward and backward
- Backward DVCS is difficult in fixed-target experiments because γ is too soft, but may be detectable using forward calorimetry at EIC
- Simulating kinematics may be straightforward. Modeling the cross section will be more challenging





Conclusions and Outlook

- u-channel measurements at the EIC can improve our understanding of mechanisms involved in baryon stopping.
- Backwards ω production requires far-forward electromagnetic calorimetry and will likely prioritize ZDC calorimetry at 18×275 GeV
- Backwards ρ production requires far-forward charged-particle tracking and will most likely prioritize B0 tracking system at 10×100 GeV
- We should now move towards simulating these events in ECCE framework
- EIC will allow us to make novel backwards DVCS cross section measurements
- Priority now is developing models for this to inform experimental design and assess feasibility

Thank you for your attention!

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