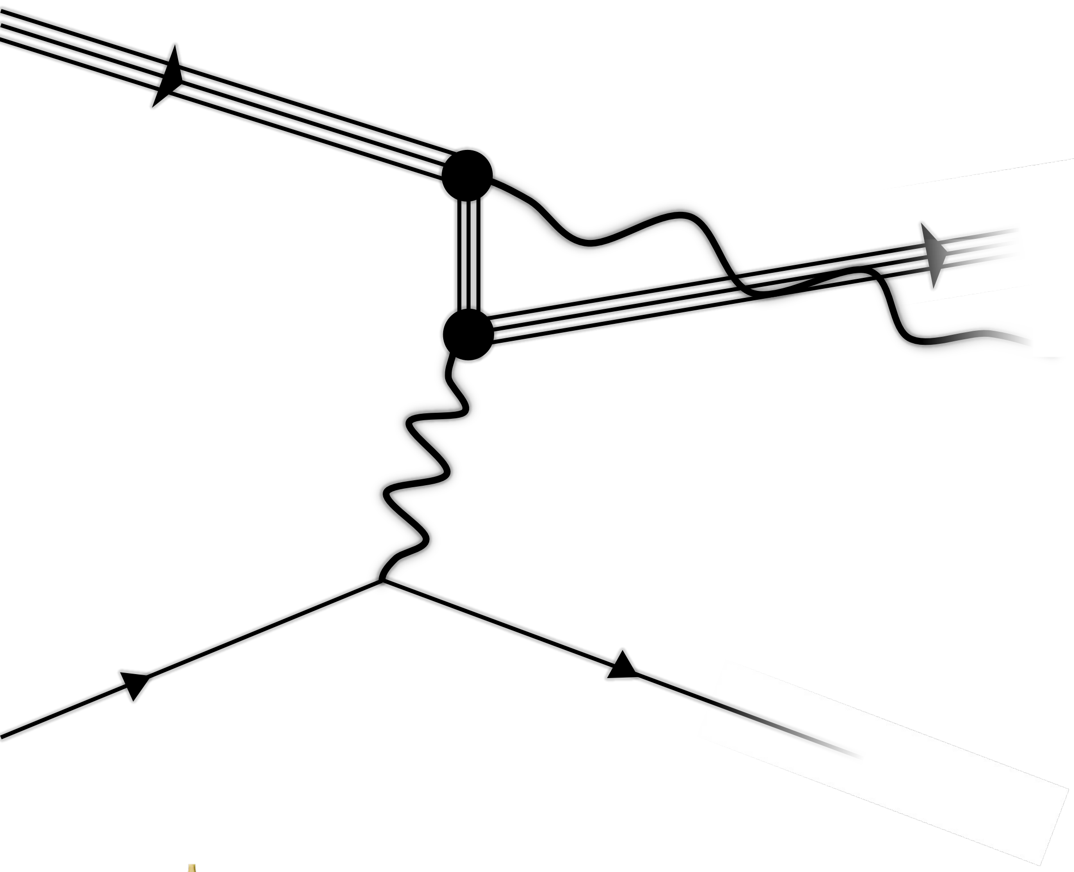

Investigation of Backward-Angle (u-channel) VCS and DVCS at the EIC

Zachary Sweger
University of California, Davis

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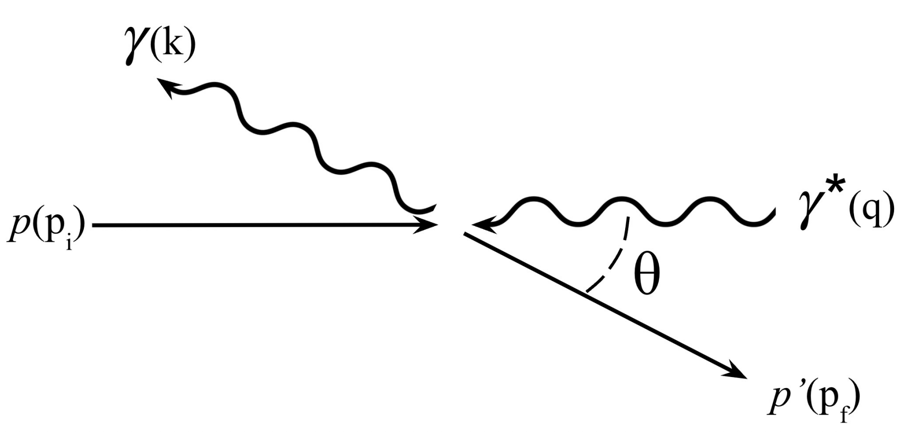
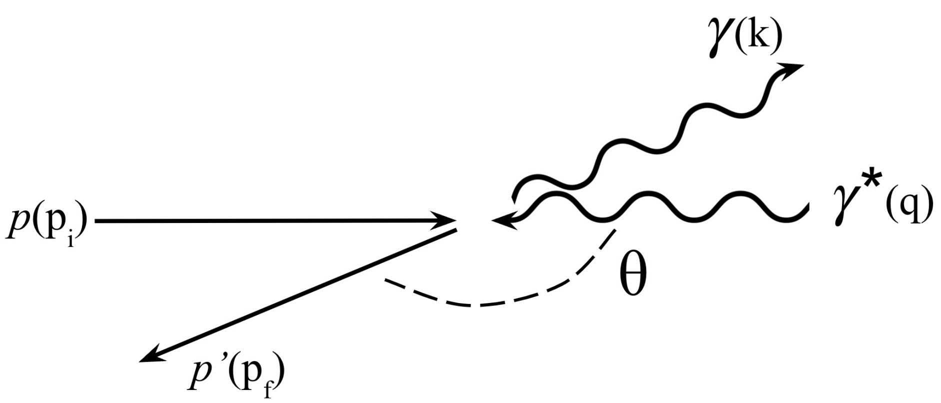
Forward and Backward Compton Scattering

Forward Compton Scattering (COM Frame)



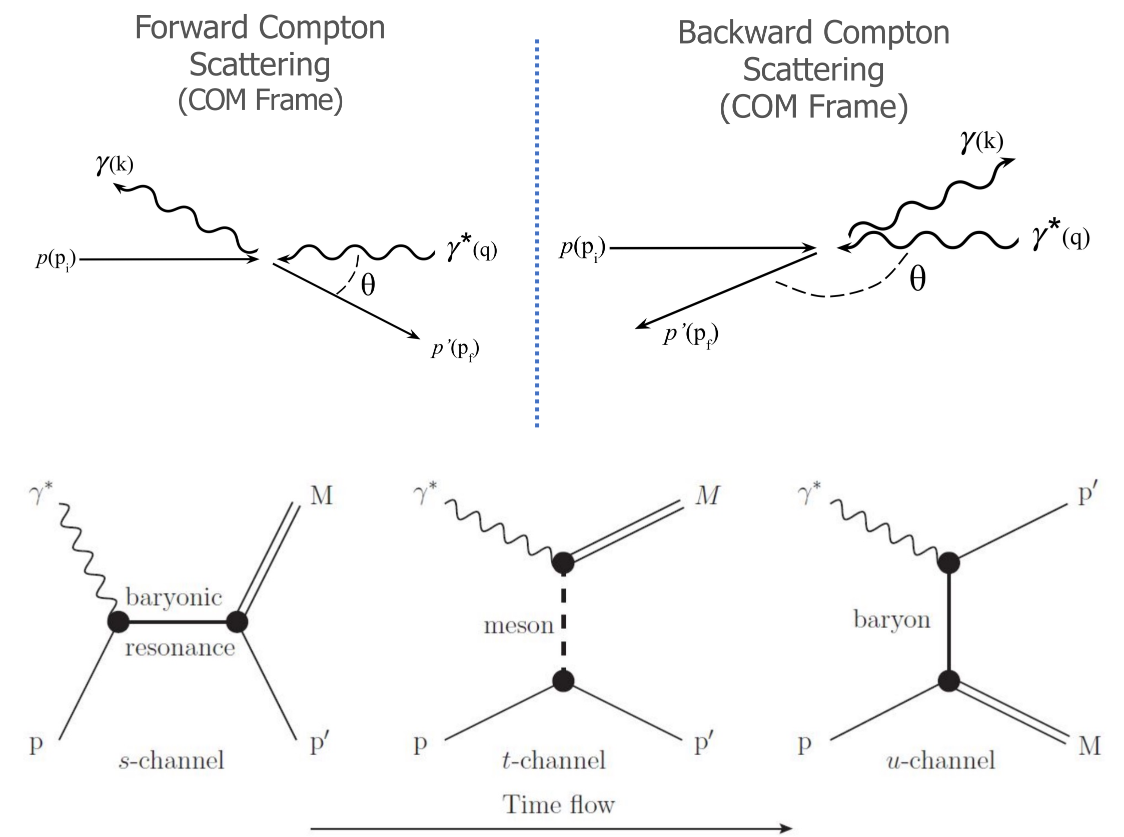
Glancing collision, small momentum transfer

Backward Compton Scattering (COM Frame)

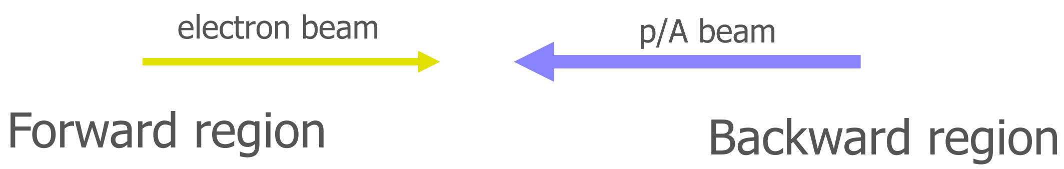


Backscattering, large momentum transfer

Backwards (u-channel) Compton Scattering



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



Forward vs Backward DVCS

- Forward Production
  - t-channel: low Mandelstam t, high u
  - Momentum transfer to target is small
  - γ 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 to target is large
  - γ produced in forwards (p-going) direction
  - Proton shifted in many units in rapidity

Kinematics

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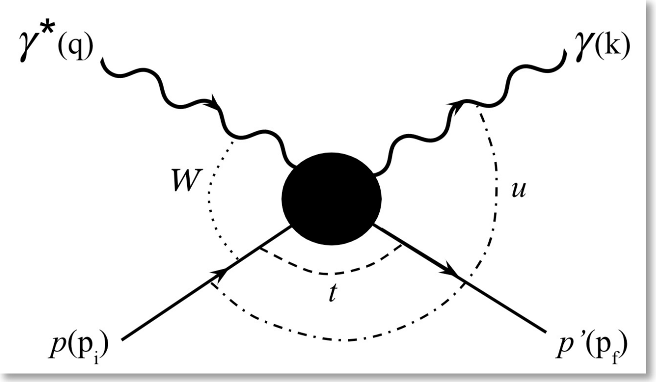
- DVCS can be parameterized in terms of
  - Q^2
  - $W = \sqrt{s} = \sqrt{(p+q)^2}$
  - $|t| = |(p-p')^2|$
  - $|u| = |(p-k)^2|$
  - θ_{CM}
  - ϕ

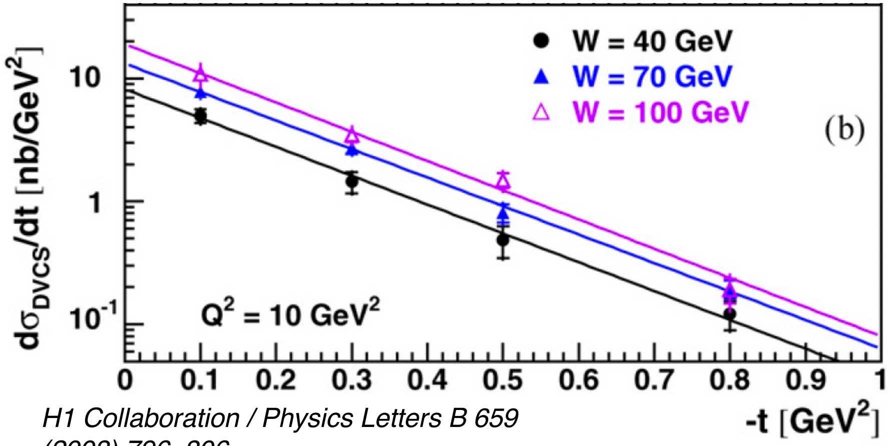
t, *u*, and θ all parameterize the momentum transfer in the reaction. Only one is needed in the cross section



ϕ describes rotation of γp plane relative to γ^*e^- plane. This is a polarization observable, but does not affect rapidity distributions that we're studying

$$\frac{d^4\sigma[ep \to e'p'\gamma]}{dQ^2 dW d\phi dt} = \Gamma(Q^2, W)\frac{d^2\sigma[\gamma^* p \to p'\gamma]}{d\phi dt}(Q^2, W, \phi, t)$$

A u-channel Peak?



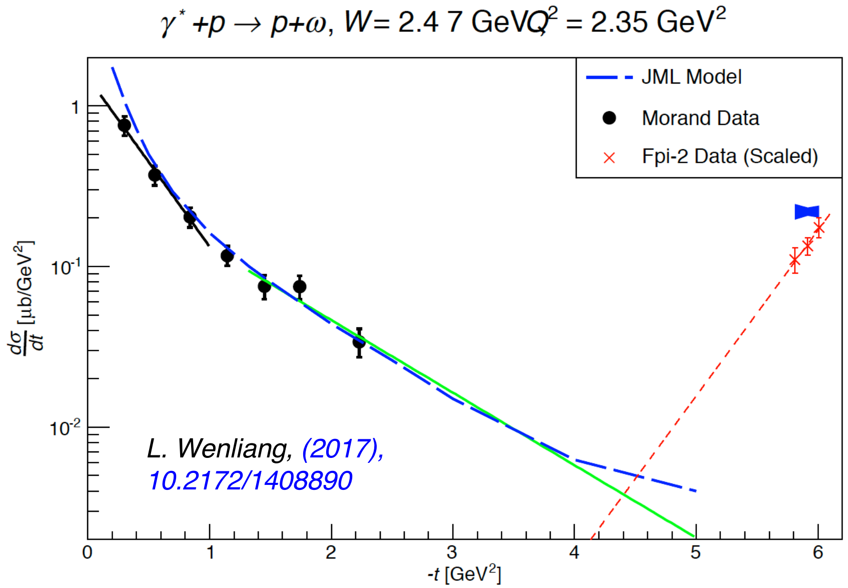
H1 Collaboration / Physics Letters B 659 (2008) 796–806

Typical Description of DVCS cross section

- Differential cross section at fixed Q^2 and W is typically modeled using an exponential of the form $e^{-b|t|}$
- The Fourier transform of this differential cross section encodes information about the proton GPDs in impact-parameter space
- So why care about cross section at very high $|t|$?

Non-trivial Behavior at High t

- We should start from the assumption that we should not expect photon production (DVCS) cross sections to be wildly different from vector-meson production cross sections (vector-meson dominance)
- Cross sections for vector (and non-vector) mesons see similar exponential drop-off in $|t|$, BUT also an exponential rise at the highest $|t|$ values
- This is from u-channel contributions which may also be expected in DVCS



Meaning of t-channel Cross Section

Yellow Report, R. Abdul Khalek et al., arXiv:2103.05419.

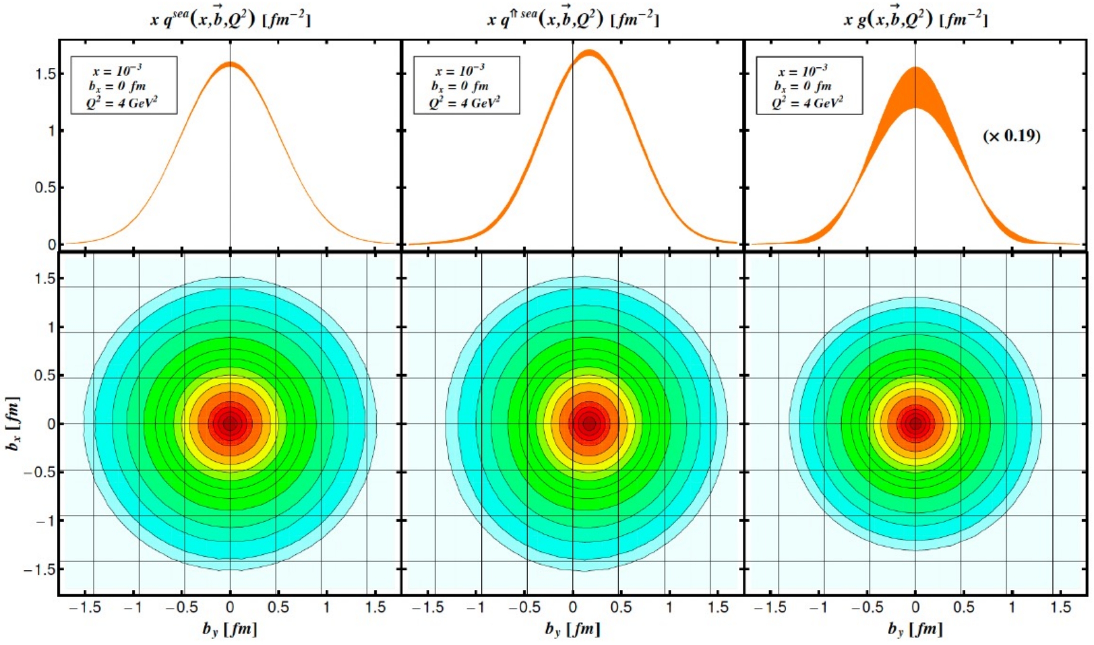
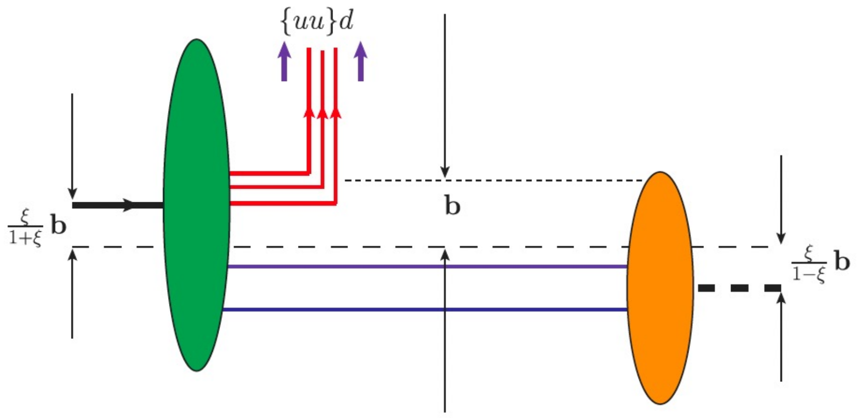


Figure 7.46: Impact parameter distributions at $x = 0.001$ and $Q^2 = 4\,\text{GeV}^2$ for unpolarized sea quarks in an unpolarized proton (left), a transversely polarized proton (middle), and for unpolarized gluons in an unpolarized proton (right), obtained from a combined fit to the HERA collider data and EIC pseudodata [23]. Top row: IPDs at fixed $b_x = 0$ as a function of $b = b_y$. Bottom row: density plots of IPDs in the (b_x, b_y)-plane.

Forward DVCS cross section → proton GPDs

- Differential cross section as a function of t encodes information about proton GPDs
- GPDs can be translated into an impact-parameter description of the proton via a Fourier transform in t
- Thus the forward DVCS cross section is meaningfully related to the parton structure of the proton

Meaning of u-channel Cross Section



$$\text{ERBL}: \quad x_3 = w_3 - \xi \geq 0; \quad x_1 + x_2 = \xi - w_3 \geq 0;$$

B. Pire, K. Semenov-Tian-Shansky, and L. Szymanowski, Phys. Rept. 940, 1 (2021), arXiv:2103.01079 [hep-ph].

Backward DVCS cross section → partonic correlations and baryon number?

- Recent (2021) work by Pire, Shansky and Szymanowski works to formulate a similarly meaningful interpretation of the backward cross section
- In this work they argue that backward reactions provide access to the location in impact parameter space of di-quark and three-quark (shown at right) clusters
- In backward reactions the baryon number follows these clusters to form a "new" baryon

"baryon-to-meson (and baryon-to-photon) TDAs share common features both with baryon DAs and with GPDs and encode a conceptually close physical picture. They characterize partonic correlations inside a baryon and give access to the momentum distribution of the baryonic number inside a baryon. Similarly to GPDs, TDAs – after the Fourier transform in the transverse plane – represent valuable information on the transverse location of hadron constituents."

Our Backward DVCS Model: u-Dependence

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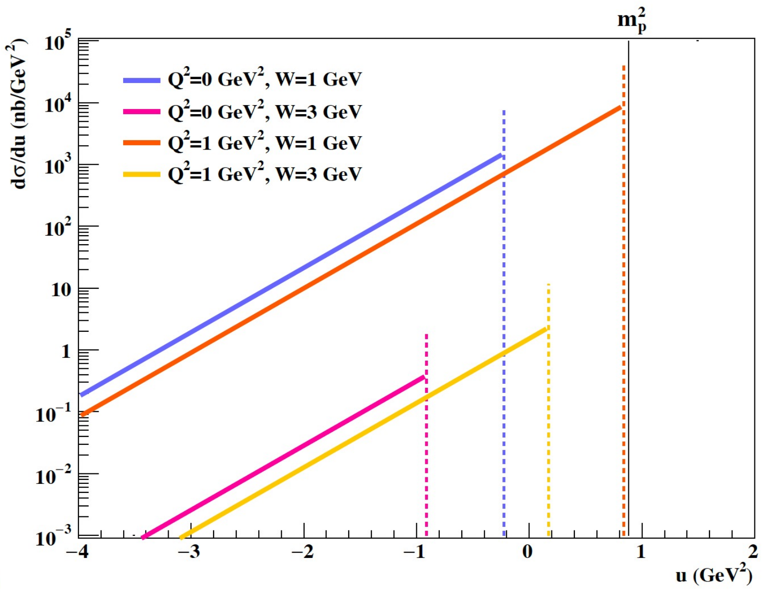
Modeling u-channel DVCS

- We presuppose a peak at backward angles ($u=u_0$) as is seen in meson production
- EIC will provide an opportunity to measure this peak if it exits, a task that is challenging in fixed-target experiments due to the softness of the photons produced
- **The strategy: exploit similarities to t-channel**



$$\frac{d\sigma}{dt}(t) \sim \exp(-B|t-t_0|) \longrightarrow \frac{d\sigma}{du}(u) \sim \exp(-D|u-u_0|)$$

- B and D are related to the size of production region which differs in t and u channels due to role of meson vs baryon exchange trajectories
- D has not been measured for backward DVCS, so for our models we test values measured for backward ω production

L. Wenliang, (2017), 10.2172/1408890.

D. Cebra, Z. Sweger, X. Dong, Y. Ji, and S. R. Klein, Phys. Rev. C 106, 015204 (2022).

Modeling *W*-Dependence

- Backward physics is dominated by Regge-exchange trajectories for which the cross sections typically scale with $W^{-\alpha}$ where $\alpha>0$
- In our backward ω/ρ paper, we used a data-driven $(W^2\text{-}m_p^2)^{-2.4}$ dependence

D. Cebra, Z. Sweger, X. Dong, Y. Ji, and S. R. Klein, Phys. Rev. C 106, 015204 (2022).

- Several sources suggest rough $(W^2\text{-}m_p^2)^{-2}$ scaling which is what we start from.

G. Laveissi`ere et al., Physical Review C 79 (2009), 10.1103/physrevc.79.015201.

S. J. Brodsky, F. J. Llanes-Estrada, and A. P. Szczepaniak, Phys. Rev. D 79, 033012 (2009).

W. B. Li et al. (Jefferson Lab Fπ Collaboration), Phys. Rev. Lett. 123, 182501 (2019).

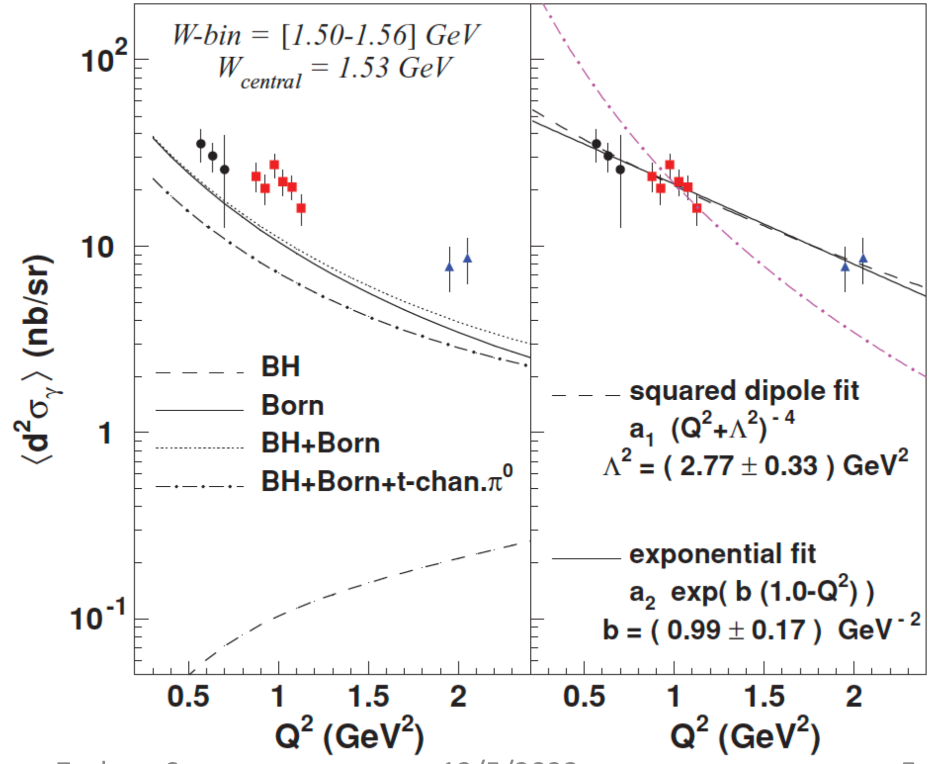
$$\frac{d\sigma}{du}(W,u) \sim \frac{1}{(W^2 - m_p^2)^2} \exp(-D|u-u_0|)$$

Our Backward DVCS Model: Q^2-Dependence

Backward VCS in Resonance Region

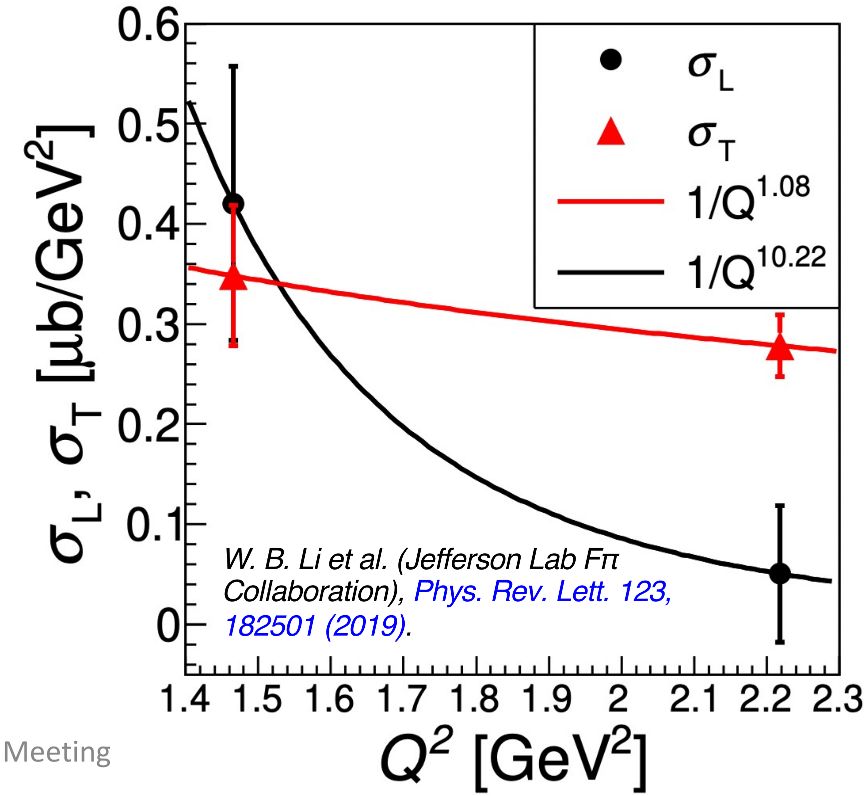
- There is some limited data available for this
- For backward VCS in the resonance region, JLab measured $(Q^2+2.77\ \text{GeV}^2)^{-4}$ dependence

G. Laveissi`ere et al., Physical Review C 79 (2009), 10.1103/physrevc.79.015201.



Backward ω Production Above Resonance

- Polarization-dependent cross section
- Q^2-dependence is much softer for transversely-polarized photons.
- Needs to be explored further in our simulations

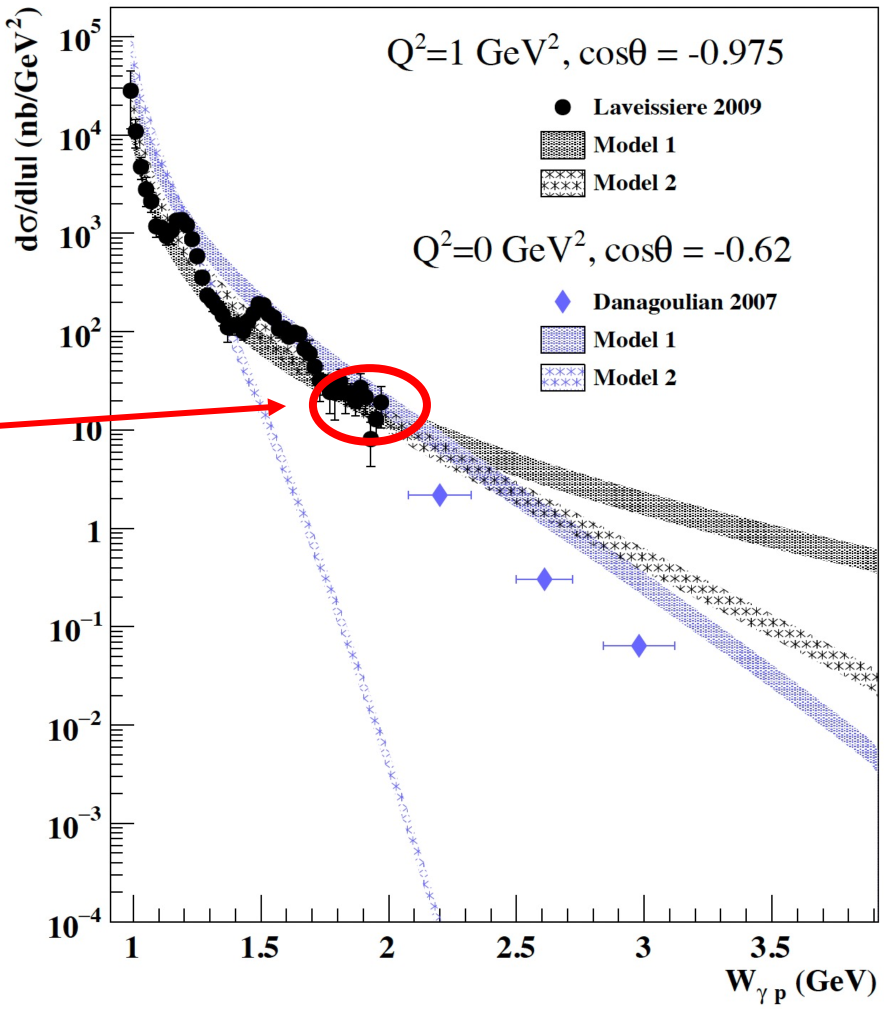


Full Cross Section Behavior

- We combine these contributions to yield the form:

$$\frac{d\sigma}{du}(Q^2, W, u) \approx \frac{A\exp(-D|u-u_0|)}{(W^2-m_p^2)^2(Q^2+\Lambda^2)^4/\text{GeV}^8}$$

- In order to anchor the amplitude, we can fit this model to 11 VCS (Q^2=1 GeV^2) data points from JLab from 1.77<W<1.96 GeV (above strong resonances)
- Where
  - $\boldsymbol{\Lambda}^2$ = 2.77 GeV^2
  - Model 1: D = 2.4 GeV^{-2}, A = 32 μb/GeV^2
  - Model 2: D = 21.8 GeV^{-2}, A = 65 μb/GeV



G. Laveissi`ere et al., Physical Review C 79 (2009), 10.1103/physrevc.79.015201.
A. Danagoulian et al. (Jefferson Lab Hall A Collaboration), Phys. Rev. Lett. 98, 152001 (2007)

Detectors of Interest For u-channel Production

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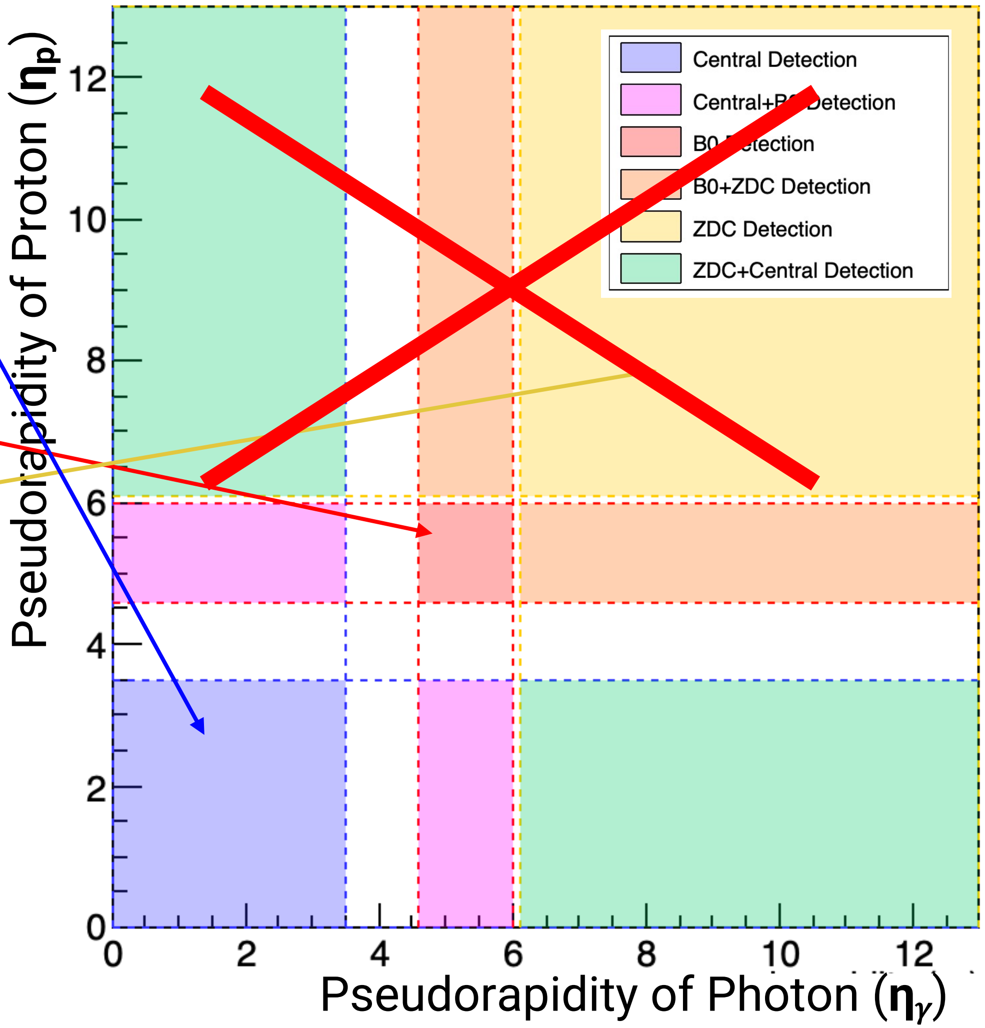
There are three detector regions of interest for backwards production

- **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)**

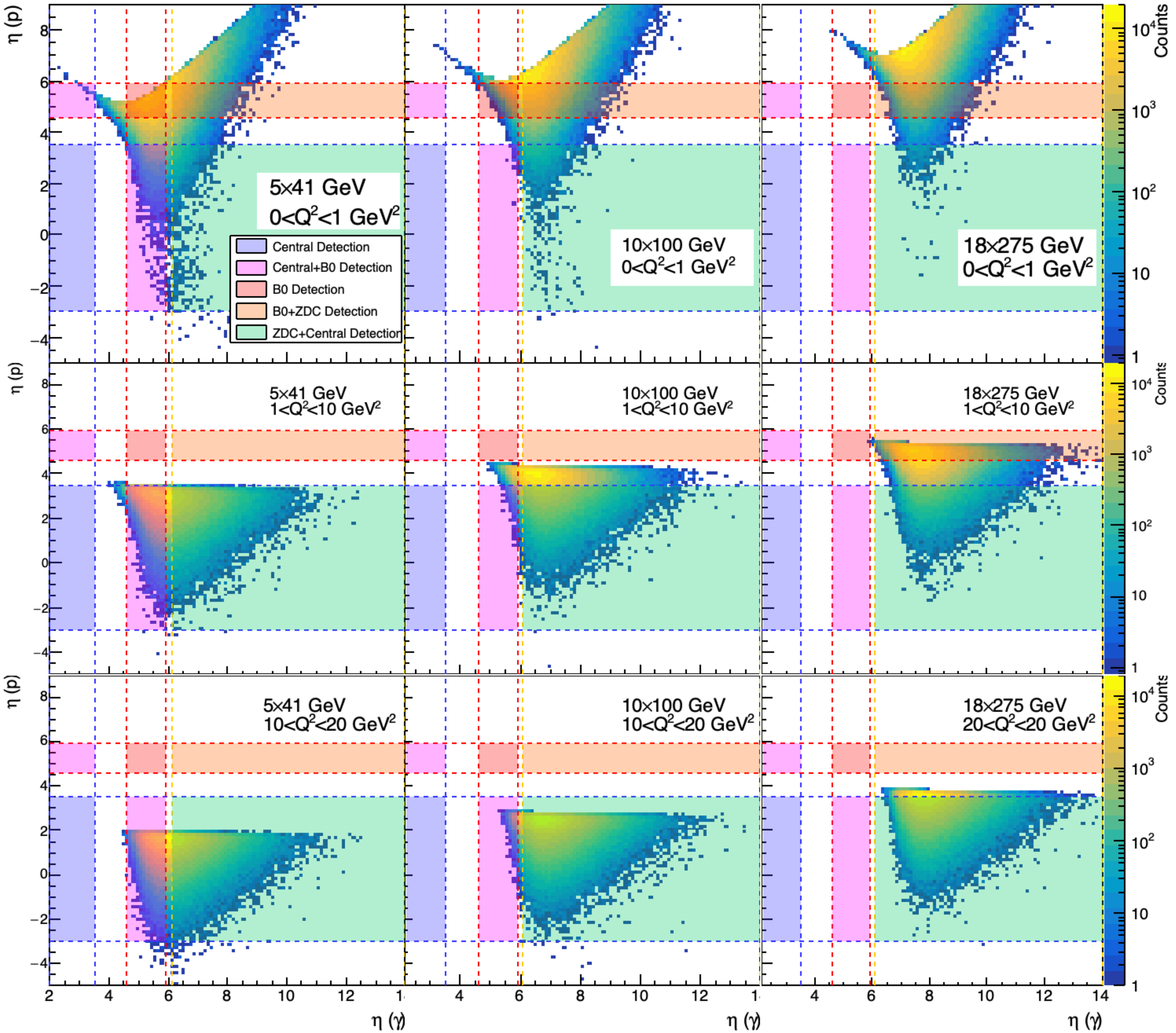


Proton may be detected in central or B0 detectors but not the ZDC. Photons may be detected in central, B0 or ZDC

Backward DVCS Acceptances

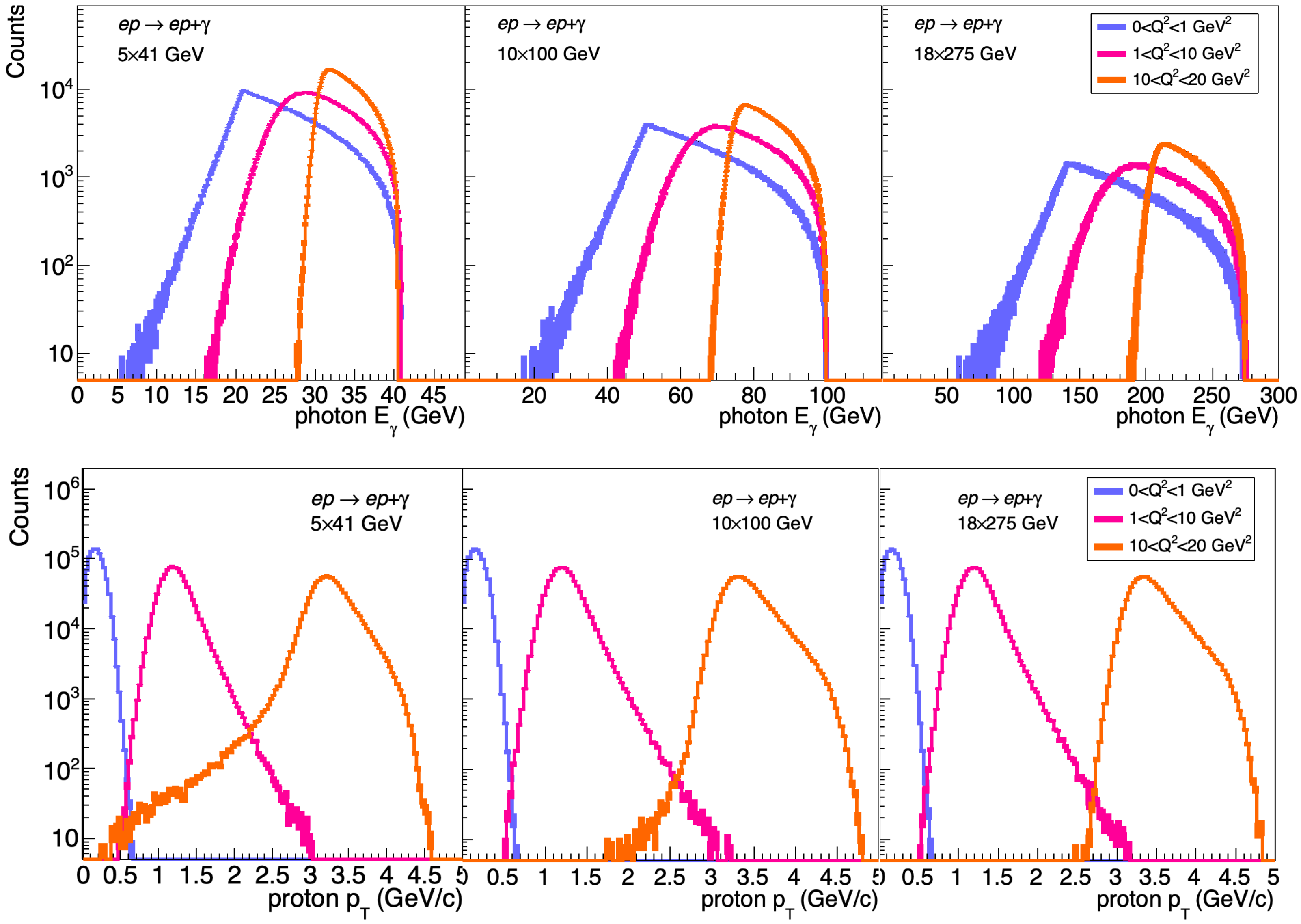
- These simulations used Model 2 for W>1.3 GeV
- At low collision energies, the photon will be seen in the B0 and ZDC
- At high energies, the ZDC is critical
- At very low Q^2, the proton will be seen mostly in the B0
- At high Q^2, the proton lands almost exclusively in the central detector region
- Geometric efficiency estimates:

Proton beam energy	$p+\gamma$ eff. $Q^2<1$	$p+\gamma$ eff. $1<Q^2<10$	$p+\gamma$ eff. $10<Q^2<20$
41 GeV w/o B0	12%	35%	44%
41 GeV w/ B0	62%	88%	86%
100 GeV w/o B0	23%	30%	97%
100 GeV w/ B0	29%	30%	97%
275 GeV w/o B0	46%	68%	68%
275 GeV w/ B0	46%	68%	68%



Kinematics of Final-State Particles

- Final-state photons in the B0 and ZDC will be between 10 and 275 GeV
- Protons from low-Q^2 events will have low pT
- Moderate pT for high-Q^2 events will aid detection but the potentially rapid drop-off of the cross section with Q^2 may prevent this



Conclusions and Outlook

- Backward production is interesting, in its own right, for encoding unique information about proton GPDs, an active and evolving topic of research
- Measurements at the EIC can improve our understanding of these u-channel mechanisms as well as their contribution to the t-channel background near-threshold
- Our backward DVCS model is still under development
- Early simulations demonstrate importance of B0 and ZDC calorimetry especially for high-energy photons.
- Next step are to
  - Finalize and compare models
  - Generate event samples for simulations
  - Write up results

Thank you for your attention!

zwsweger@ucdavis.edu