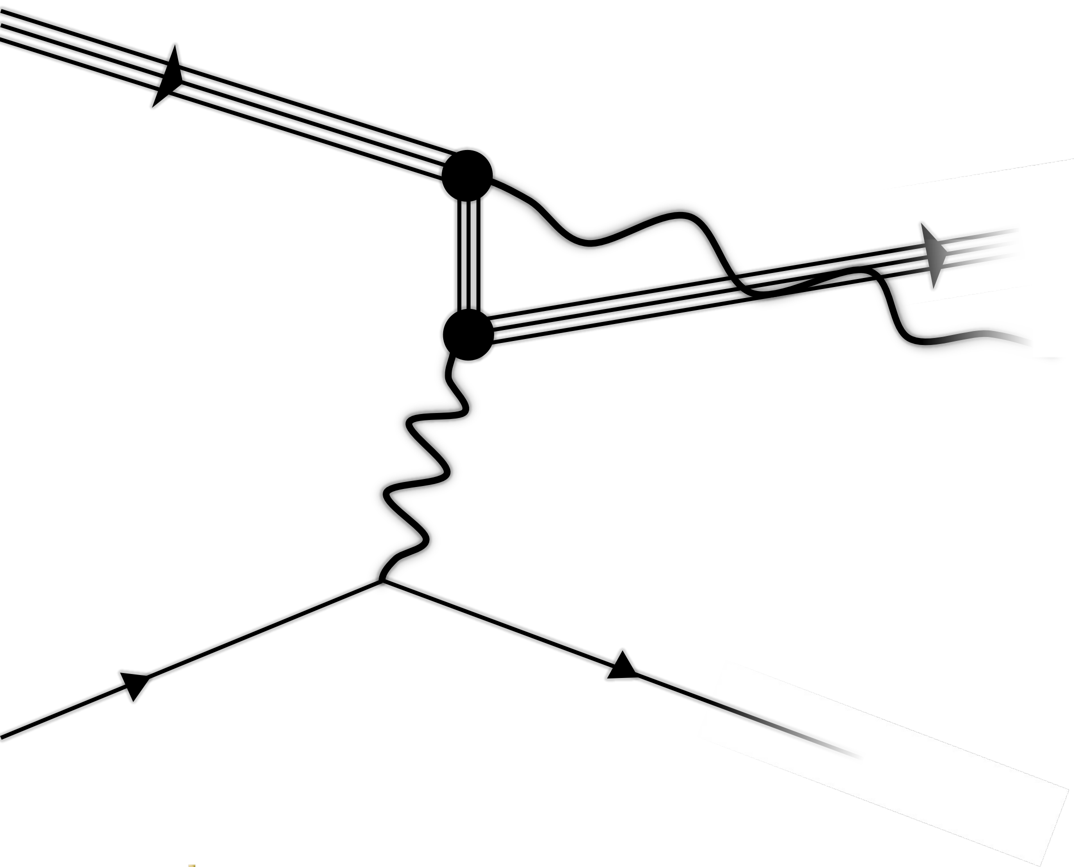


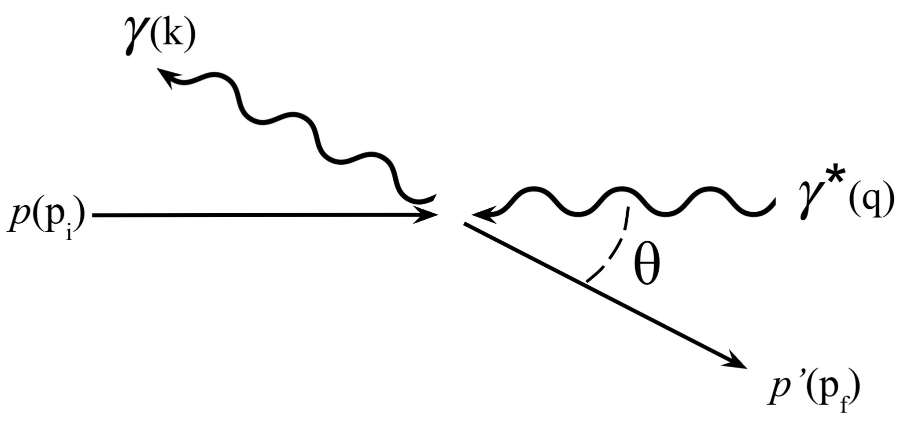
Update on Backward-Angle (u-channel) VCS and DVCS

Zachary Sweger
University of California, Davis

Supported in part by

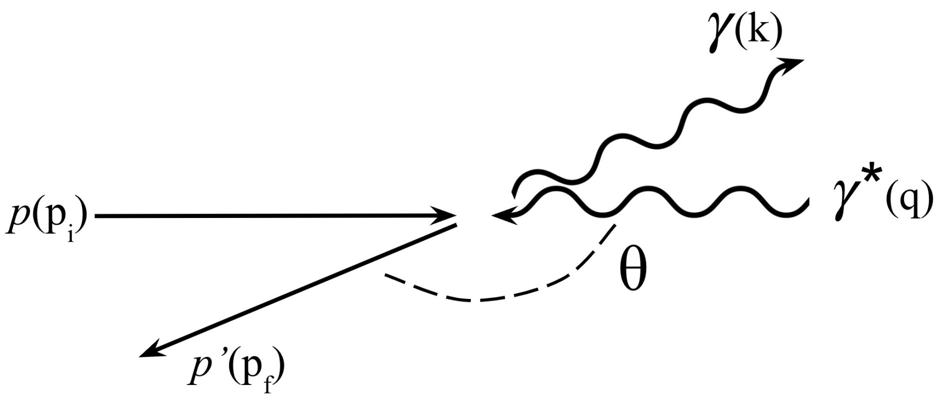
Forward and Backward Compton Scattering

Forward Compton Scattering (COM Frame)



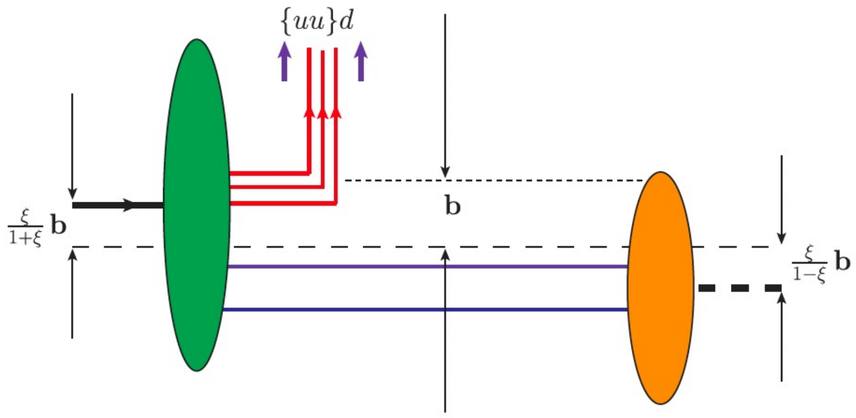
Glancing collision, small momentum transfer

Backward Compton Scattering (COM Frame)



Backscattering, large momentum transfer

Meaning of u-channel Cross Section



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?

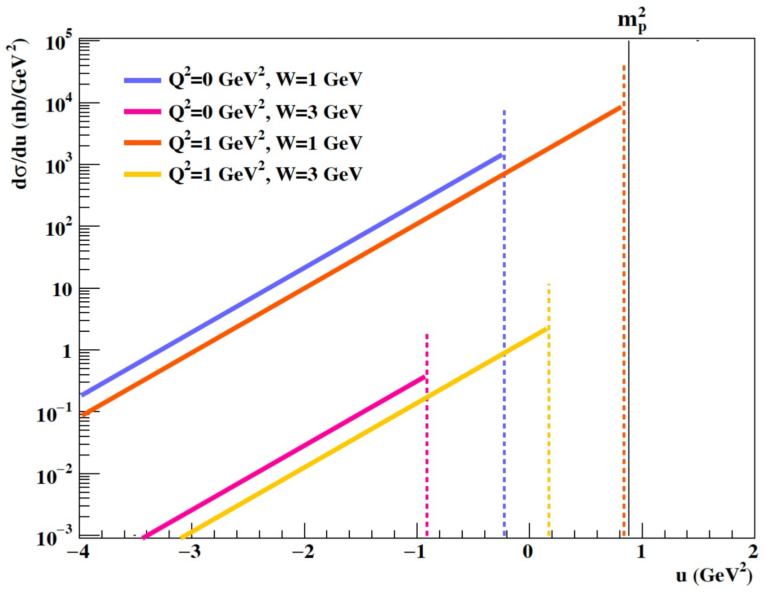
- Recent (2021) work by Pire, Shansky and Szymanowski works to formulate a similarly meaningful interpretation of the backward cross section
- In this work they argue that backward reactions provide access to the location in impact parameter space of di-quark and three-quark (shown at right) clusters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

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 simulation 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).

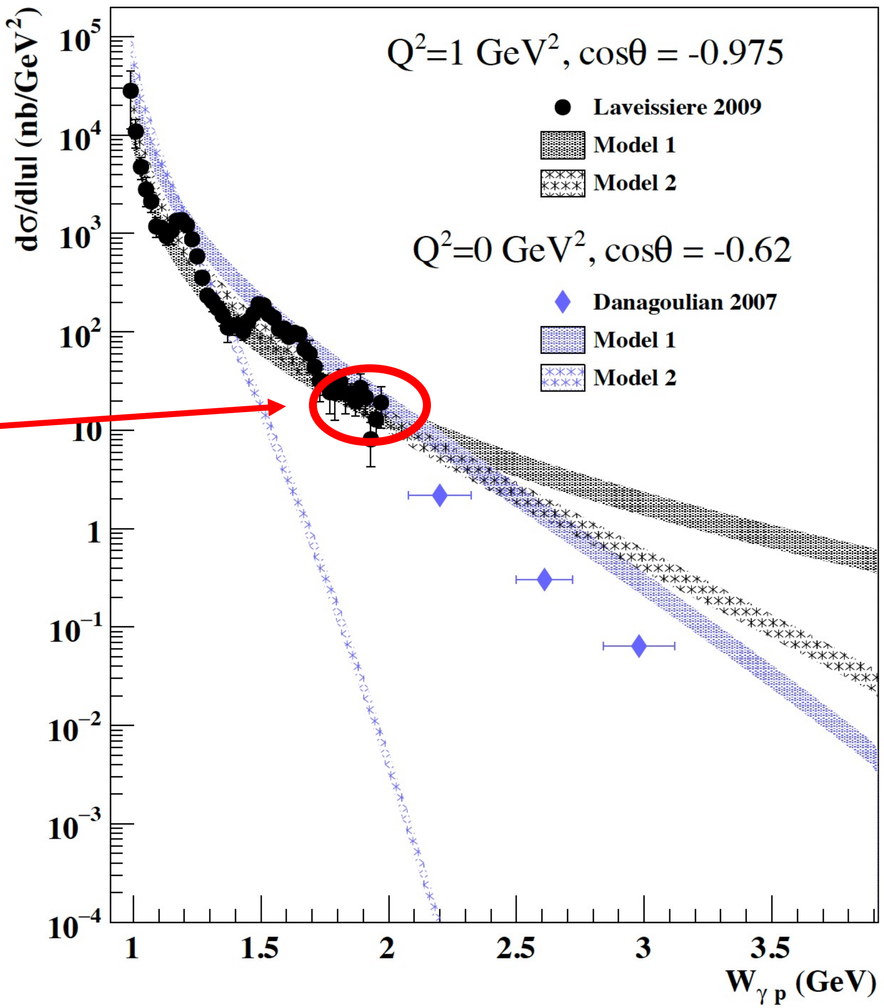
Full Cross Section Behavior

- We've developed a model of the form:

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

- 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
  - Λ^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

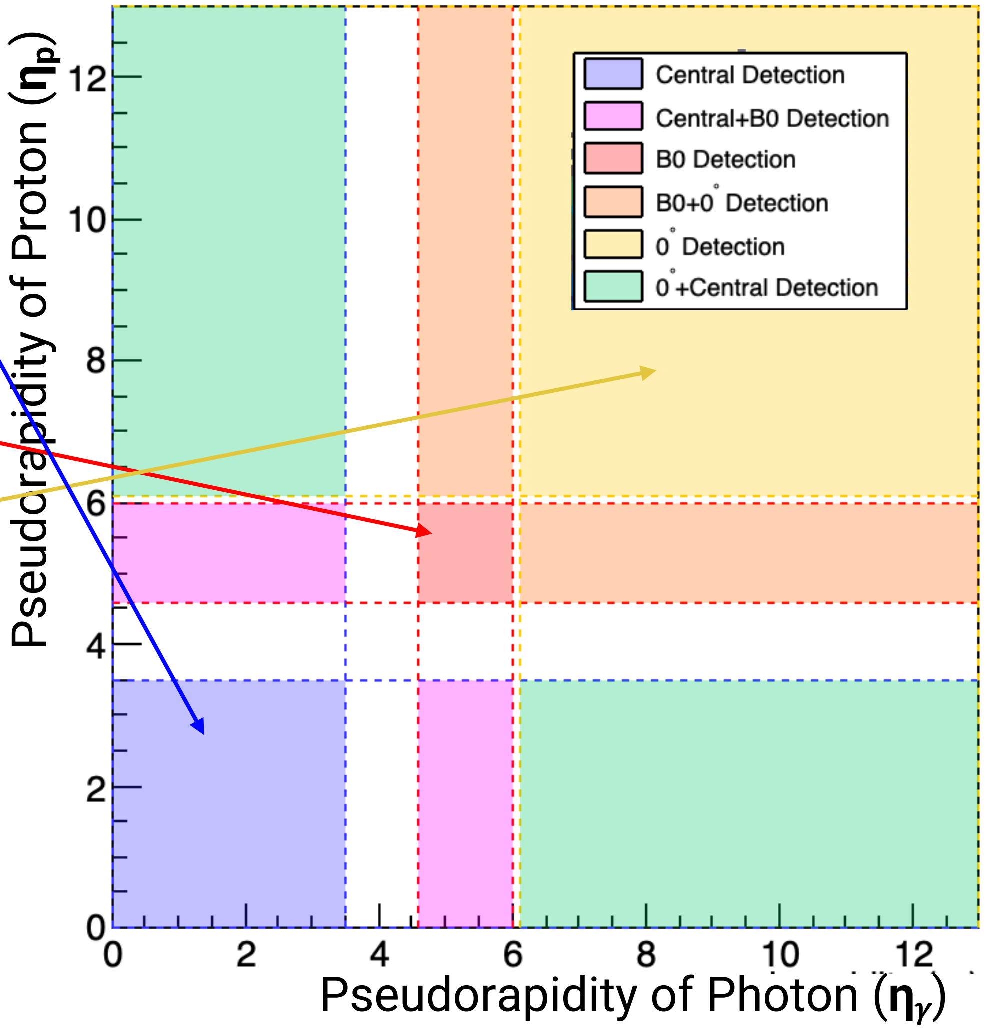


G. Laveissi`ere et al., *Physical Review C 79 (2009), 10.1103/physrevc.79.015201*.
A. Danagoulian et al. (Jefferson Lab Hall A Collaboration), *Phys. Rev. Lett. 98, 152001 (2007)*

Detectors of Interest For u-channel Production

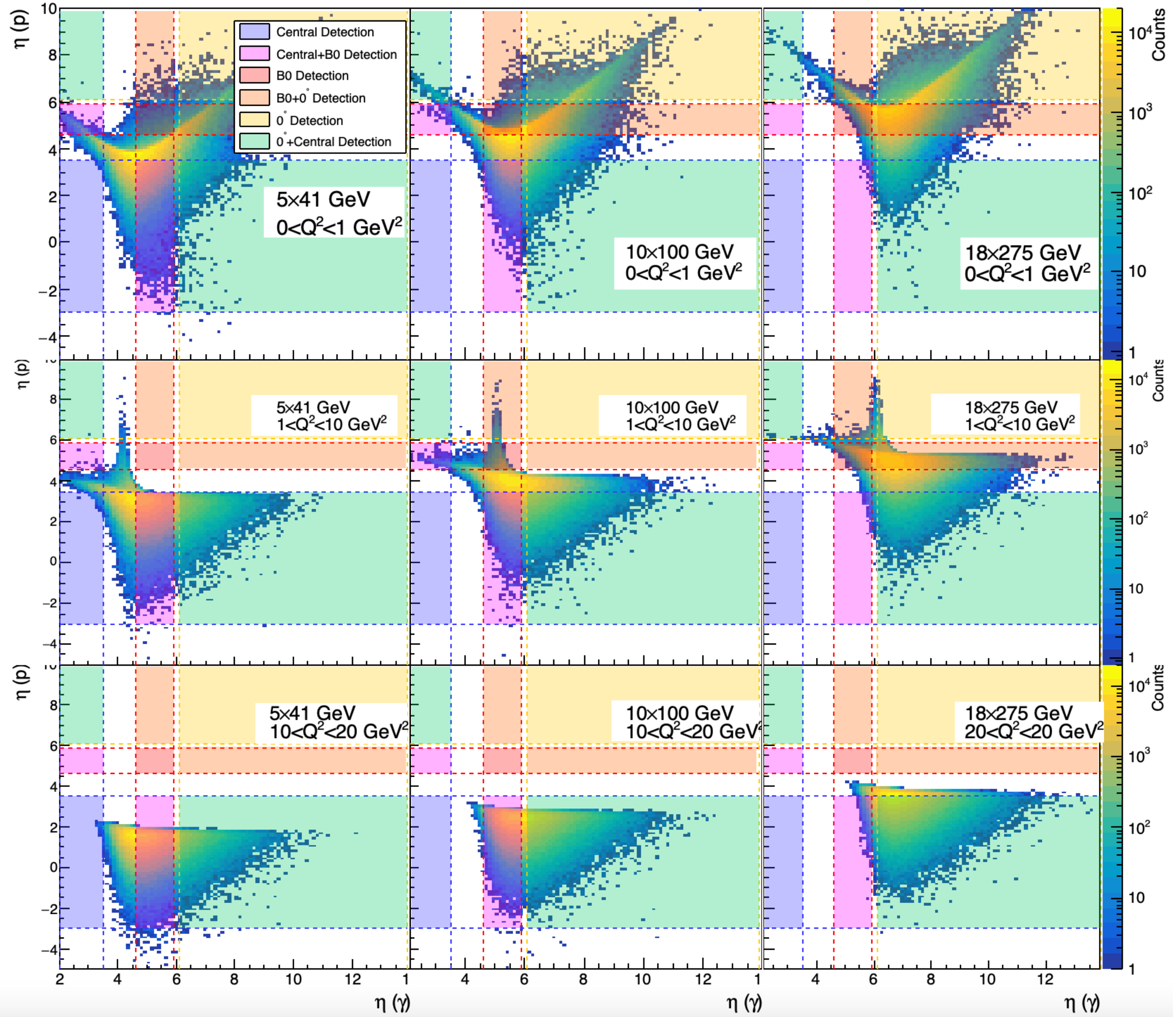
There are three detector regions of interest for backwards production

- Central Region (endcap & barrel): $|\eta| < 3.5$
  - ✓ Charged-particle tracking
  - ✓ Electromagnetic calorimetry
- B0 Magnets: $4.6 < \eta < 6.0$
  - ✓ Charged-particle tracking
  - ? Electromagnetic calorimetry
- Zero-degree Detection: $\eta > 6.215–5.991$
  - ✓ Roman Pots: Charged-particle tracking
  - ✓ ZDC: Electromagnetic calorimetry



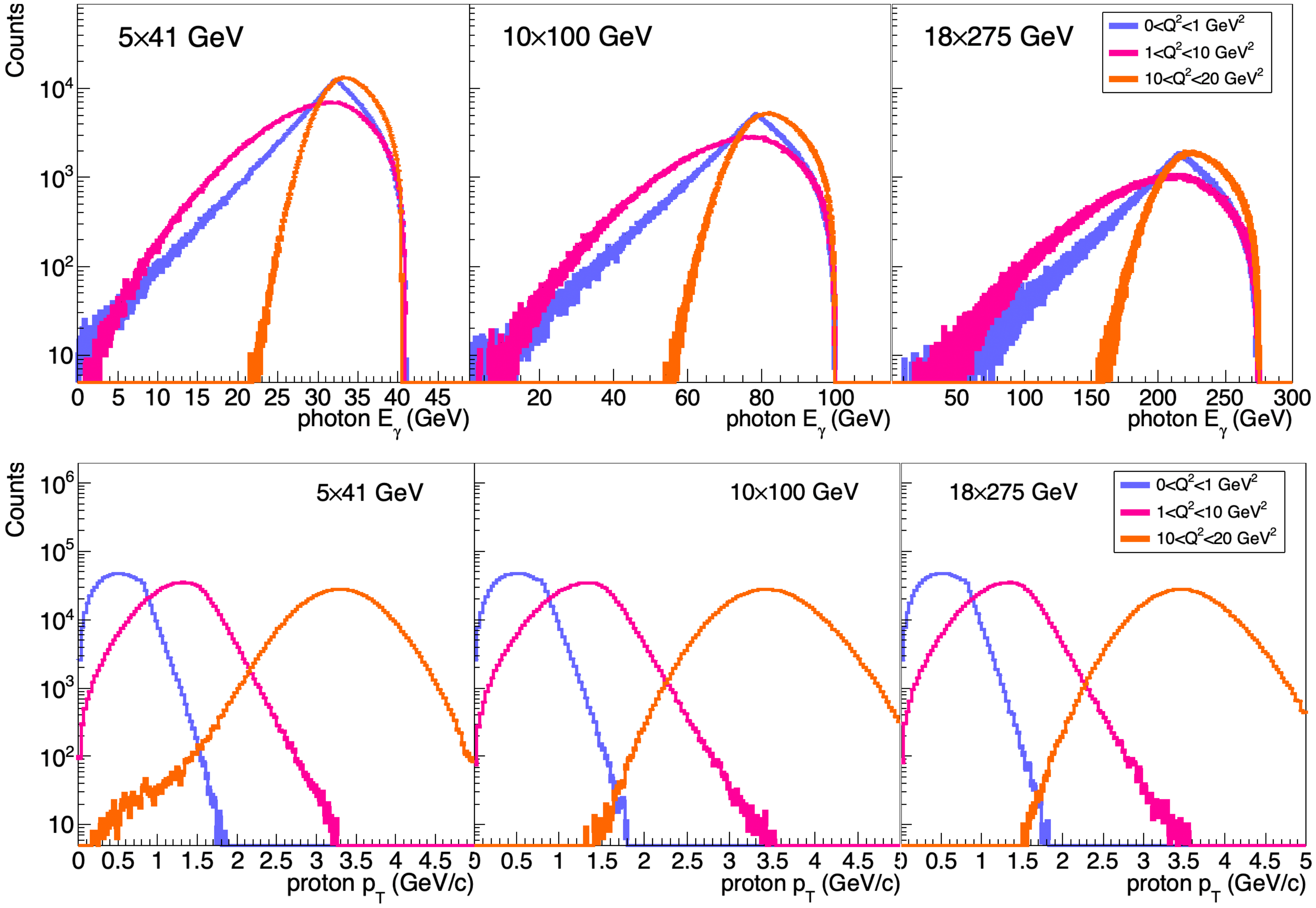
Backward DVCS Acceptances

- These simulations used Model 2 for W > 2 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



Kinematics of Final-State Particles

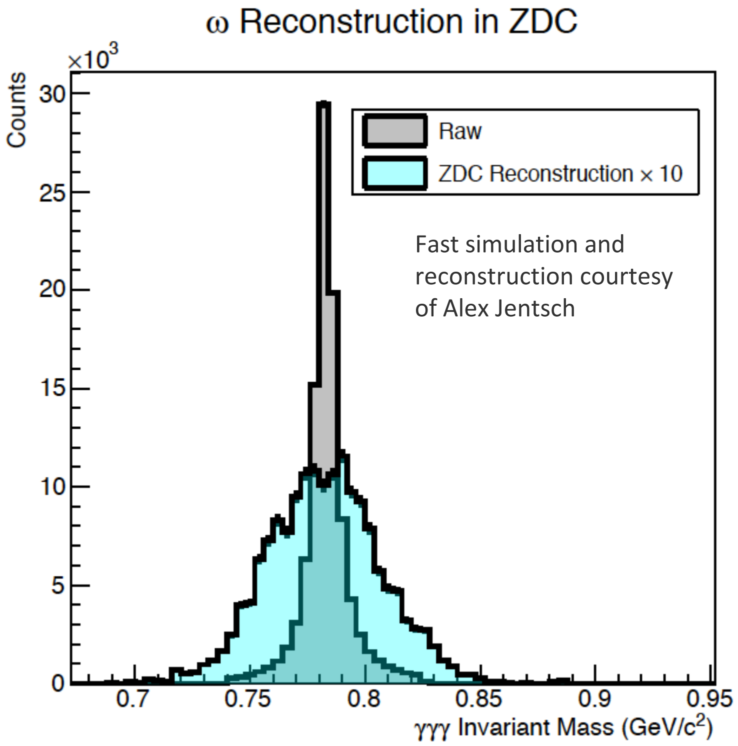
- Final-state photons in the B0 and ZDC will be between 10 and 275 GeV
- Protons from low-Q^2 events will have low pT
- Moderate pT for high-Q^2 events will aid detection but the potentially rapid drop-off of the cross section with Q^2 may prevent this



Primary Challenge: π^0 Background

- Backward π^0 production is expected to be ~100-1000 stronger than backward CS
- We need to be able to resolve the one-photon from CS from the two photons from the π^0 decay
- ZDC is made of segmented PbWO4 towers with 2cm transverse size
- ZDC is ~35m downstream of IP
- If the two photons from the π^0 have an opening angle of 0.3mrad, these should land in different towers

- When processing our backward $\omega \rightarrow \pi^0\gamma$ events, Alex Jentsch was able to use fast simulations of the ZDC to reconstruct the ω with reasonable efficiency
- In those samples, the photons typically had a separation of >1mrad, resulting in them landing in distinct towers
- It remains to be seen what the separation will be for backward π^0 production since these will have a larger energy than the π^0s produced from ω decay
- In the coming weeks I will be looking into this problem and considering whether TMVA may be used to separate the events



Next

- Investigate Q^2-dependence of photon-polarized cross section
- Generate π^0 and γ samples with the same energy to test ZDC's ability to resolve single high-energy photons vs two-photons from π^0
- There is potential for detecting backward DVCS in UPCs prior to EIC
  - ❑ working on simulating what this would look like
- Our backward DVCS model is still under development
- Continue writing paper

Thank you for your attention!

zwsweger@ucdavis.edu

Backup Slides

Backwards (u-channel) Compton Scattering

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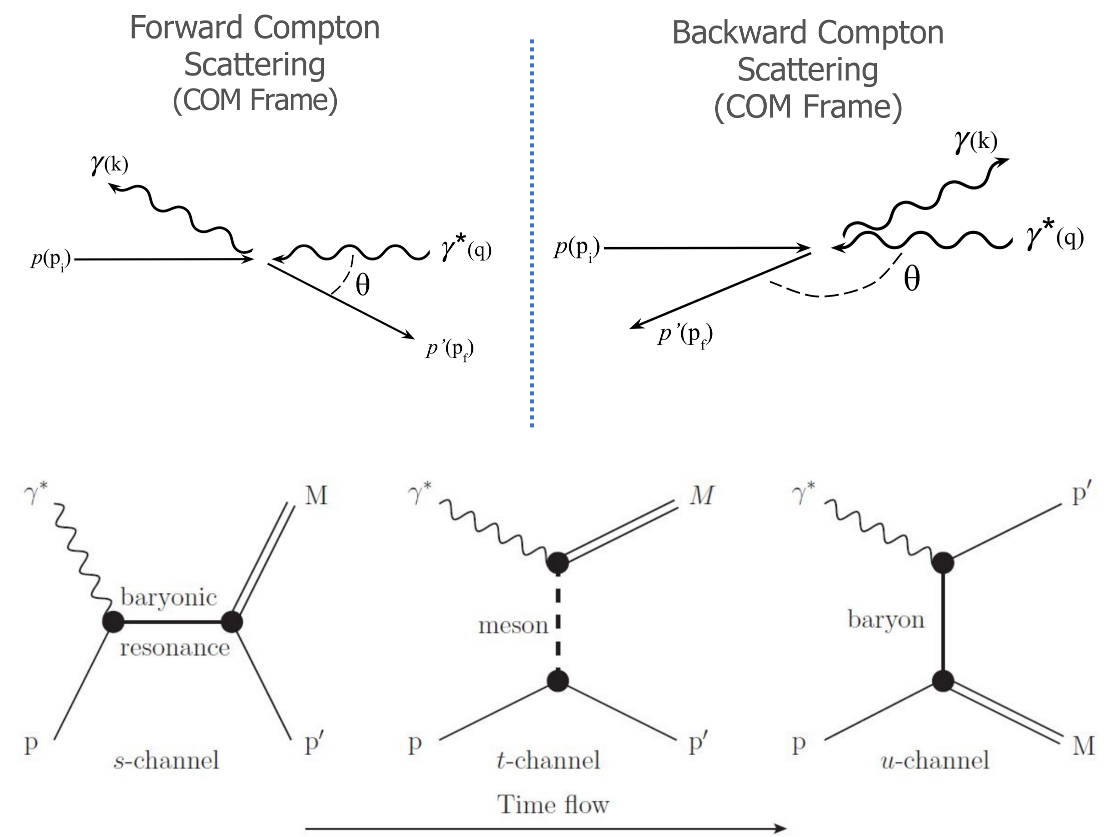
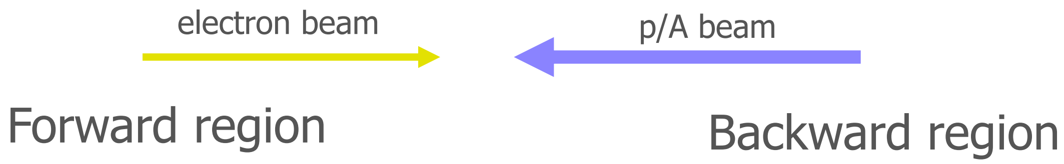


Contributions to VM production from Mandelstam variables. Wenliang (Bill) Li (William and Mary). GPD Workshop at Stony Brook University

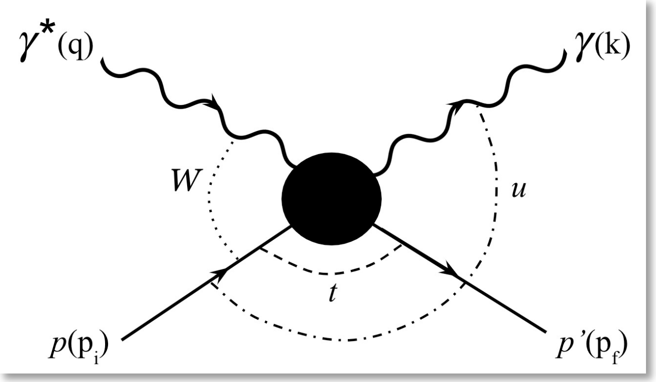


Forward vs Backward DVCS

- 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

- 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

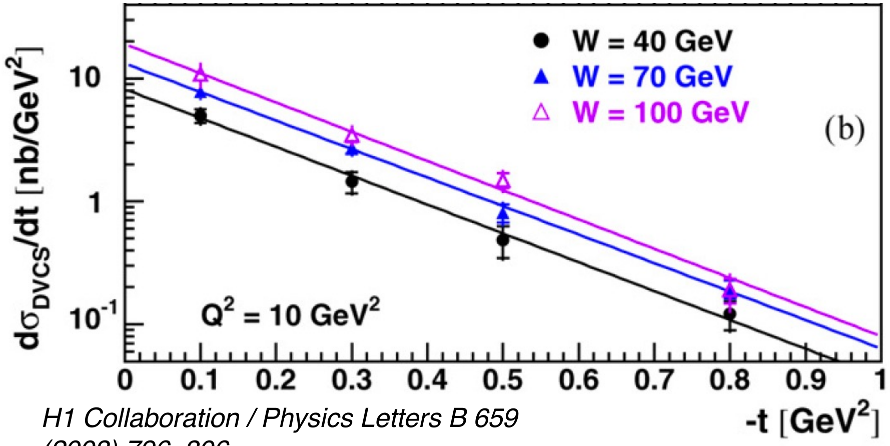


t, *u*, and θ all parameterize the momentum transfer in the reaction. Only one is needed in the cross section

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?



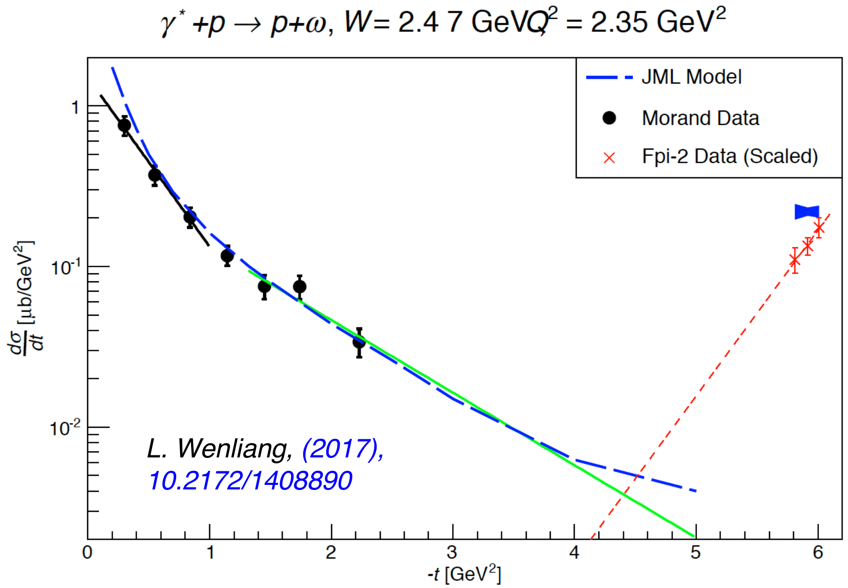
H1 Collaboration / Physics Letters B 659 (2008) 796–806

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 also have 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.

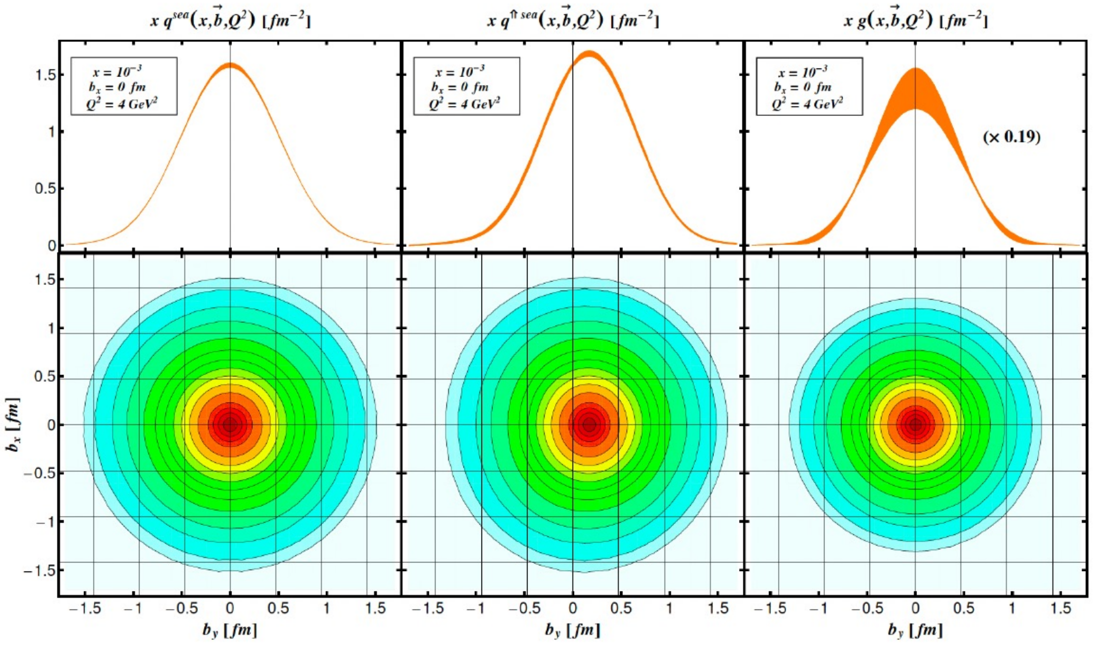


Figure 7.46: Impact parameter distributions at $x = 0.001$ and $Q^2 = 4\,\mathrm{GeV}^2$ for unpolarized sea quarks in an unpolarized proton (left), a transversely polarized proton (middle), and for unpolarized gluons in an unpolarized proton (right), obtained from a combined fit to the HERA collider 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

Our Backward DVCS Model: W-Dependence

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 $(W^2-m_p^2)^{-2.4}$ dependence

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

- Several sources suggest rough $(W^2-m_p^2)^{-2}$ 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

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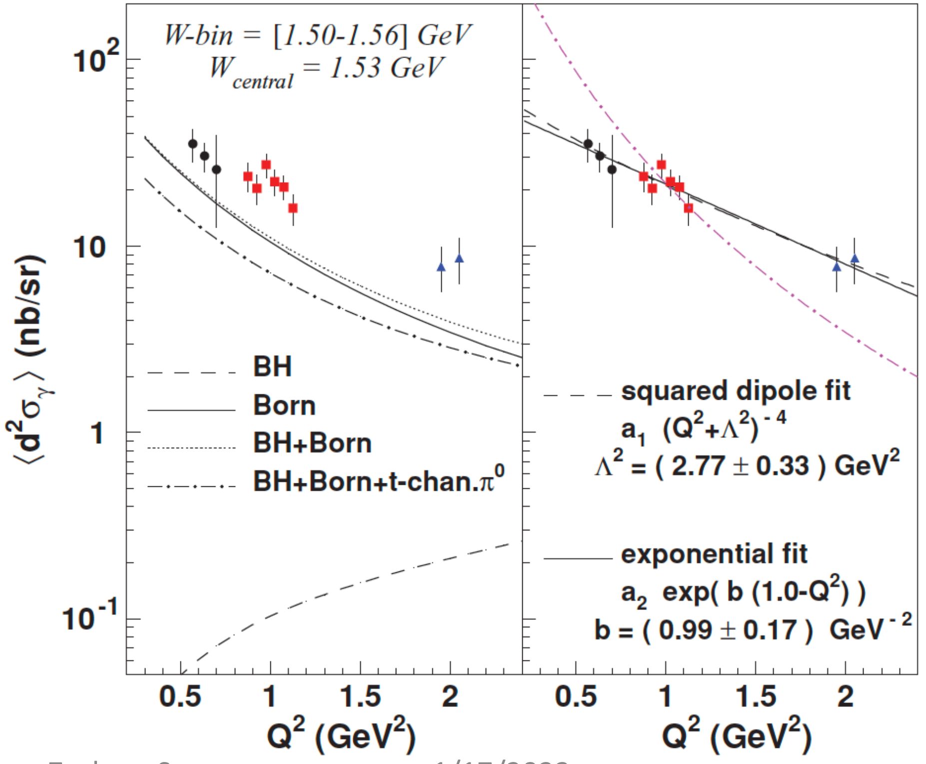
Backward VCS in Resonance Region

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