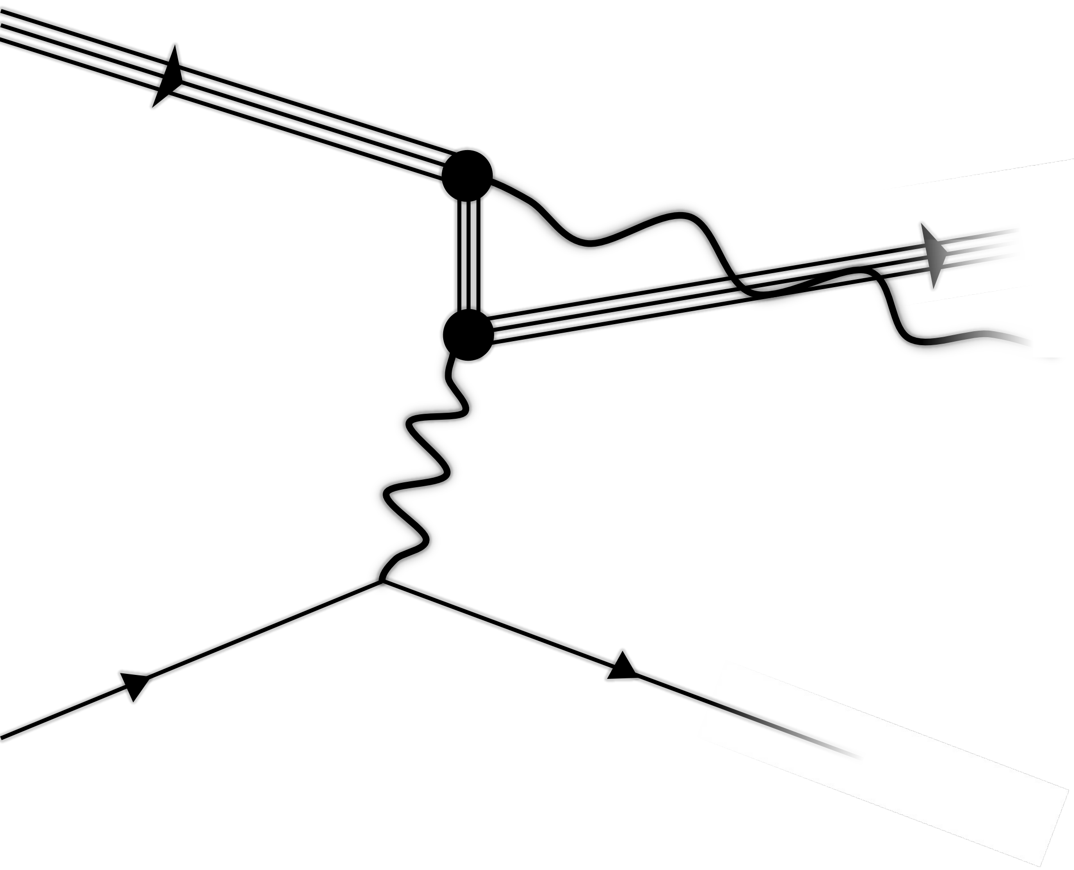

Modeling u-channel DVCS at the EIC

Zachary Sweger

University of California, Davis

Supported in part by

Forward and Backward Compton Scattering

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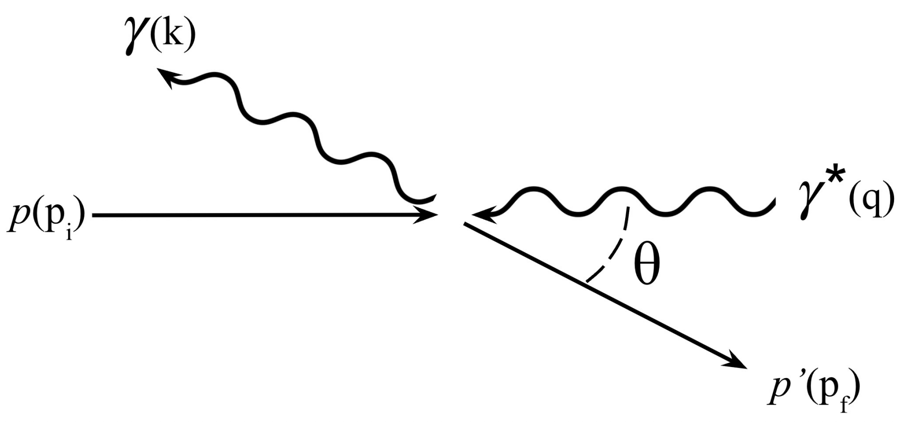
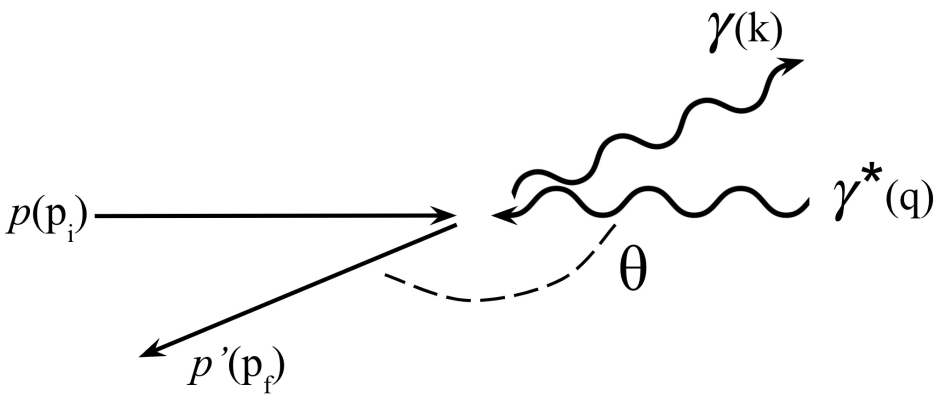
Forward Compton Scattering (COM Frame)



Glancing collision, small momentum transfer

Backward Compton Scattering (COM Frame)



Backscattering, large momentum transfer

Backwards (u-channel) Compton Scattering

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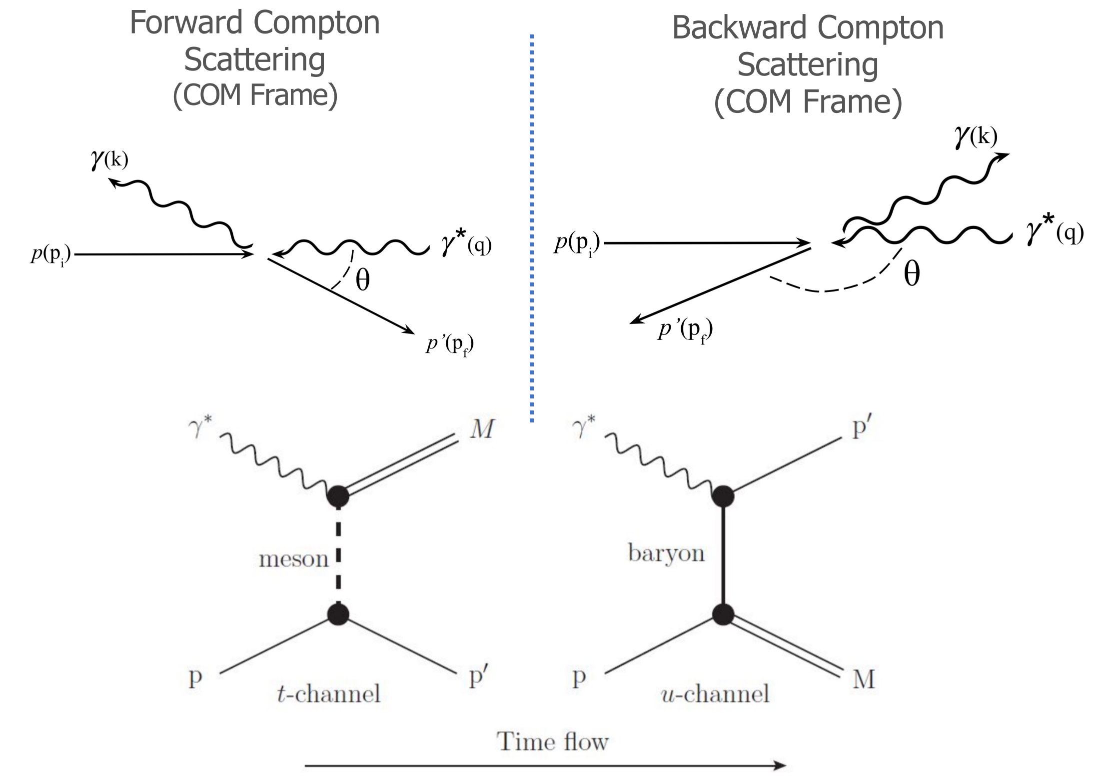
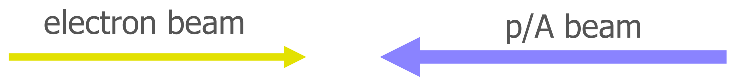


Contributions to VM production from Mandelstam variables. Wenliang (Bill) Li (William and Mary). GPD Workshop at Stony Brook University



Forward region

Backward region

Forward vs Backward Compton Scattering

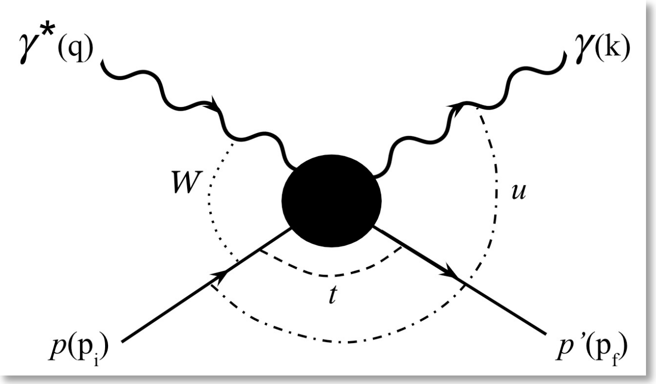
- Forward Production
  - t-channel: low Mandelstam t, high u
  - γ produced in backwards (e^--going) direction
  - Proton continues in forward direction
- Backwards Production
  - u-channel: low Mandelstam u, high t
  - γ produced in forwards (p-going) direction
  - Proton shifted many units in rapidity

Kinematics

- CS can be parameterized in terms of:
  - Q^2 ← when Q^2 is large, this is deeply-virtual CS (DVCS)
  - $W = \sqrt{s} = \sqrt{(p+q)^2}$
  - $|t| = |(p-p')^2|$
  - $|u| = |(p-k)^2|$
  - θ_{CM}
  - ϕ

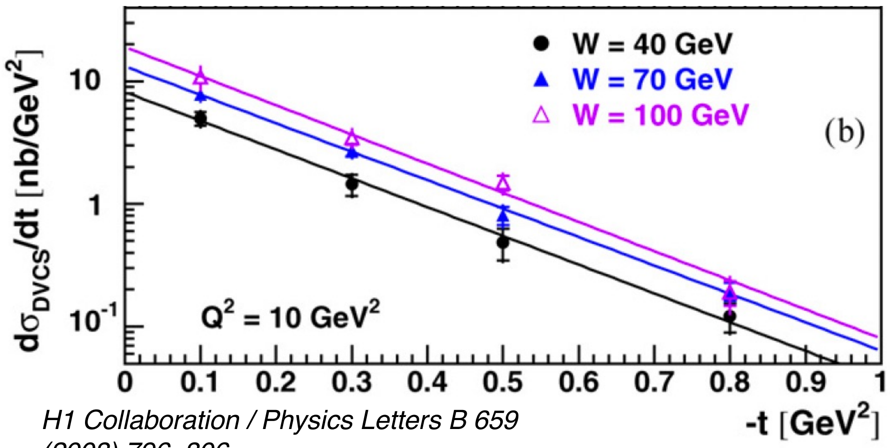
} *t*, *u*, and θ each parameterize mom. transfer in reaction. Only one needed.

← ϕ is rotation of γp plane relative to γ*e$^-$ plane



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

A u-channel Peak?



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

Typical Description of DVCS cross section

- Cross section at fixed Q^2 and W is typically modeled using an exponential: $e^{-b|t|}$
- This cross section encodes information about the proton GPDs in impact-parameter space
- So why care about cross section at very high $|t|$?

A u-channel Peak?

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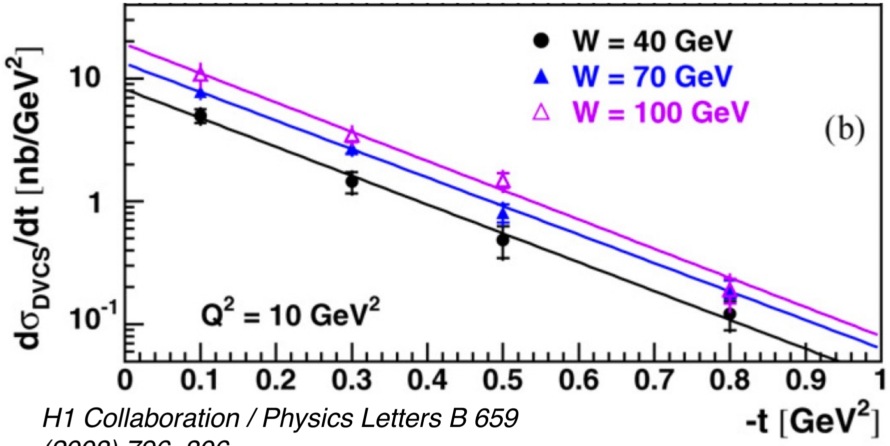

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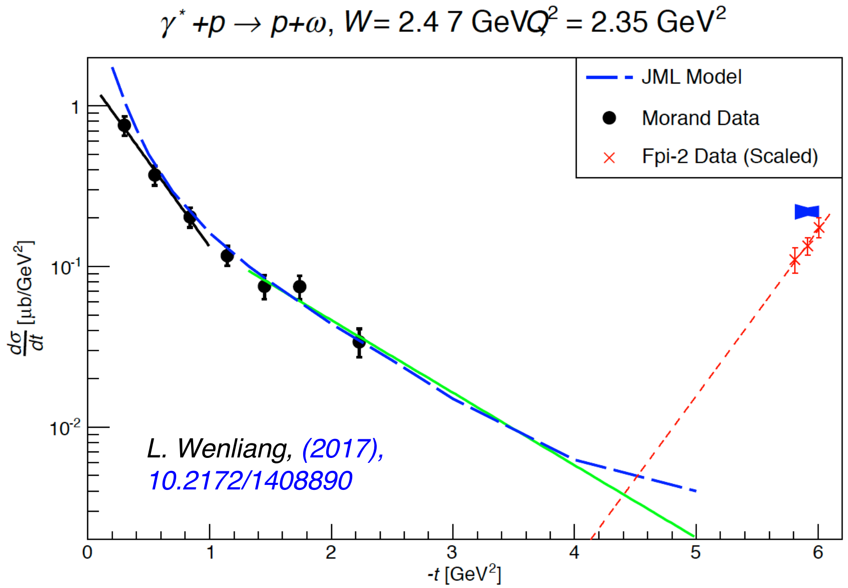
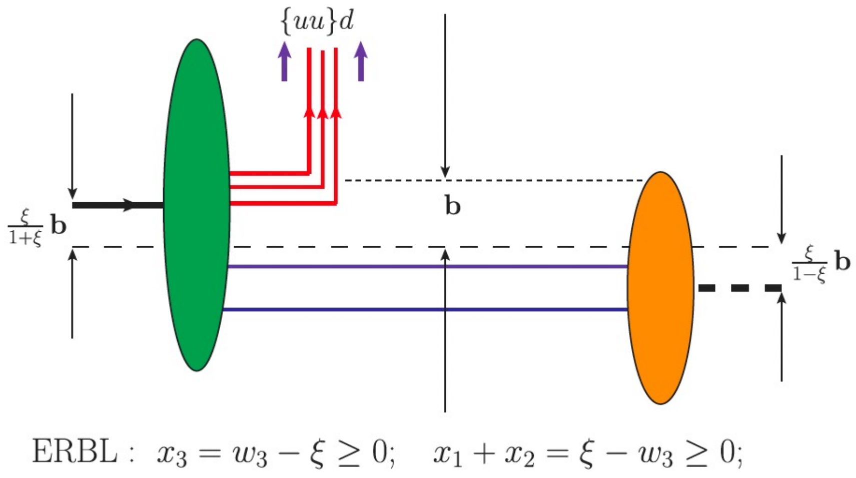
- So why care about cross section at very high $|t|$?

Non-trivial Behavior at High t

- Photon production (CS) cross sections should not be wildly different from vector-meson production
- Cross sections for mesons have exponential drop-off with $|t|$, BUT also an exponential rise at the highest $|t|$ values
- This is from u-channel contributions which may also be expected in (D)VCS



Meaning of u-channel Cross Section

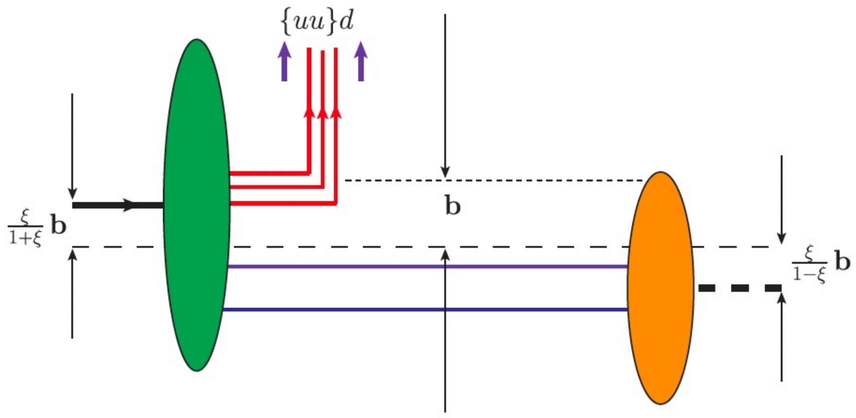


B. Pire, K. Semenov-Tian-Shansky, and L. Szymanowski, Phys. Rept. 940, 1 (2021), arXiv:2103.01079 [hep-ph].

Backward DVCS cross section → partonic correlations and baryon number?

- Forward DVCS maps parton distributions within proton
- Recent (2021) work by Pire et al. works to formulate a similarly meaningful interpretation of the backward cross section
- They argue backward reactions provide access to the location in impact parameter space of di-quark and three-quark (shown at right) clusters

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].

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"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."

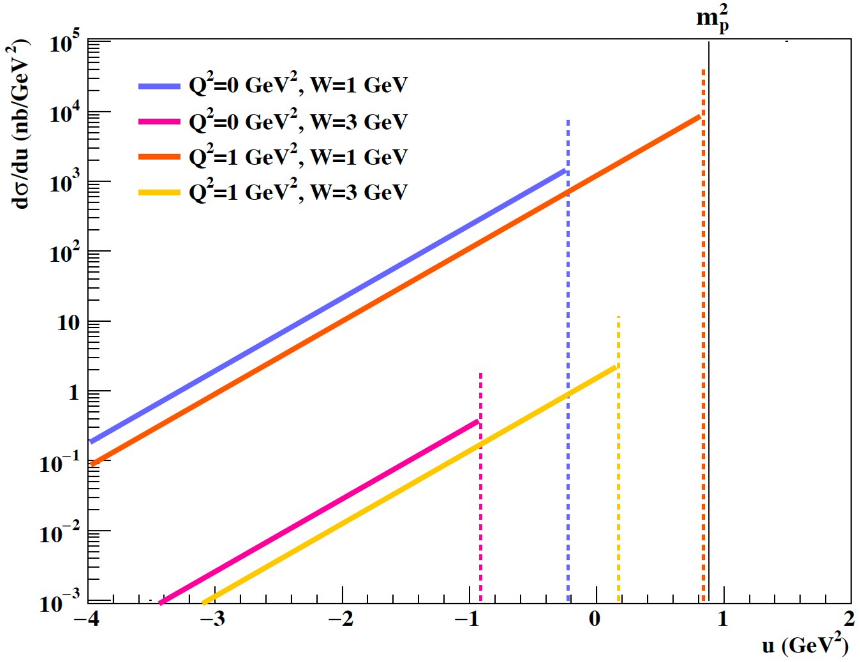
Our Backward DVCS Model: u-Dependence

Modeling u-channel DVCS

- We presuppose peak at backward angles ($u=u_0$) as seen in meson production
- **The strategy: exploit similarities to t-channel**

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

- D has not been measured for backward DVCS, so for our models we test values measured for backward vector-meson 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).

Our Backward DVCS Model: W-Dependence

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Modeling W-Dependence

- Backward physics is dominated by Regge-exchange trajectories for which the cross sections typically scale as $W^{-\alpha}$
- 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)*.

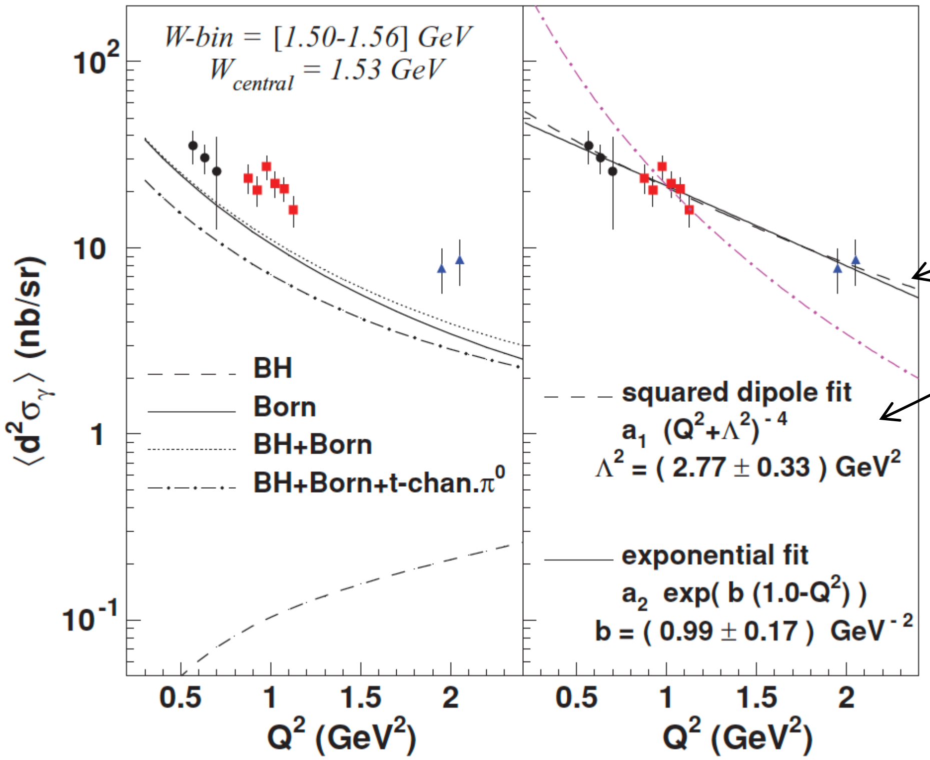
$$\frac{d\sigma}{du}(W,u) \sim \frac{1}{(W^2 - m_p^2)^2} \exp(-D|u - u_0|)$$

Our Backward DVCS Model: Q^2-Dependence

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.



Full Cross Section Behavior

- We combine these contributions to yield the form:

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

- 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)

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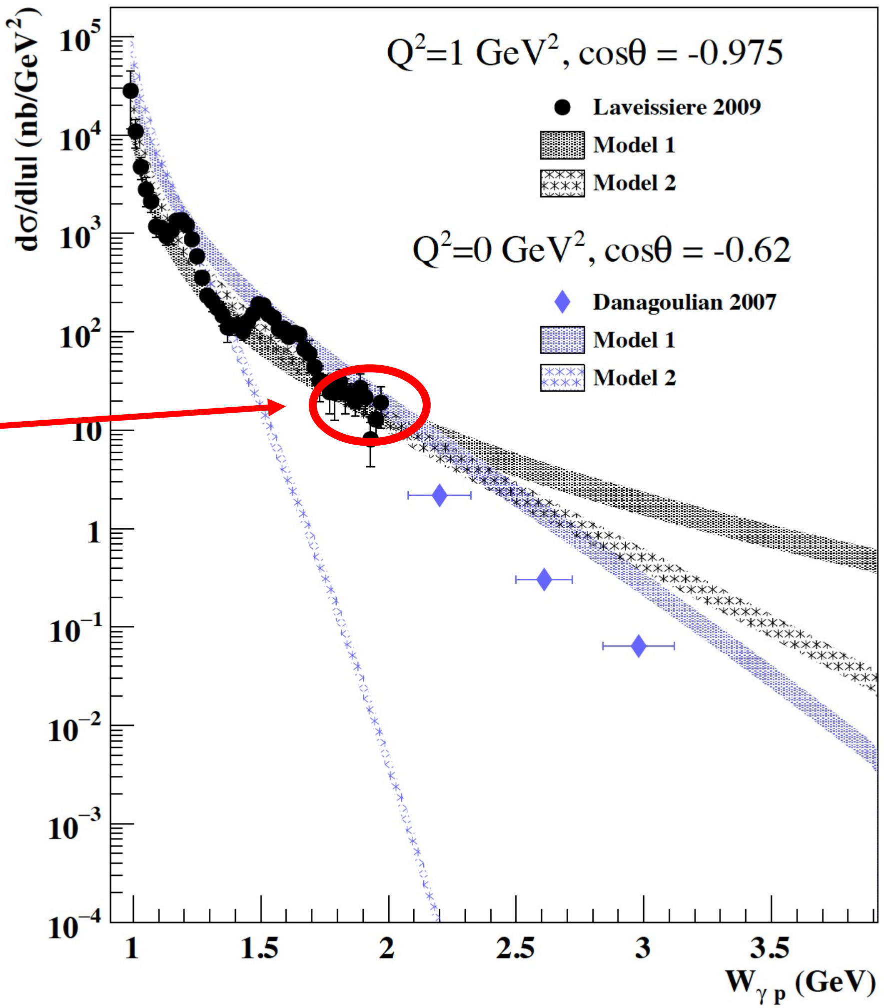
- Where
  - Λ^2 = 2.77 GeV^2
  - Model 1: D = 2.4 GeV^{-2}, A = 32 μb/GeV^2
  - Model 2: D = 21.8 GeV^{-2}, A = 65 μb/GeV^2



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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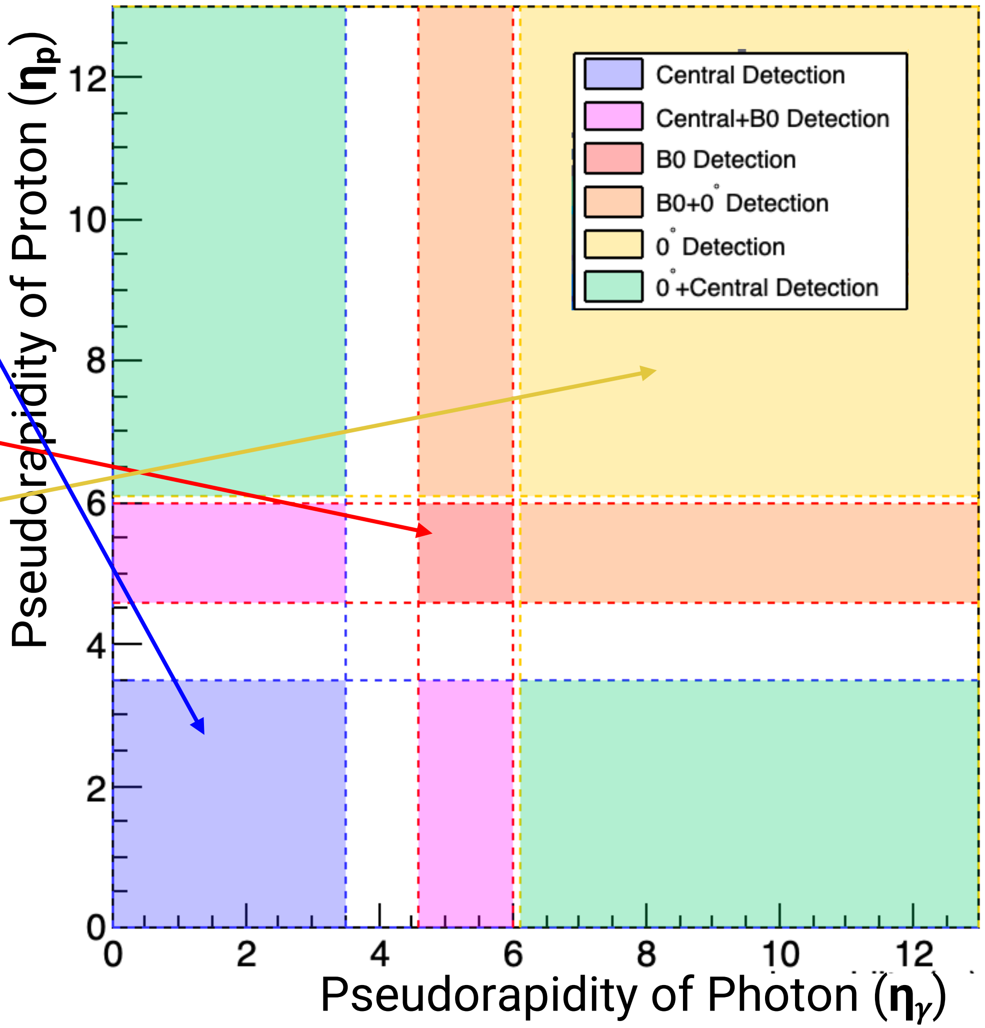
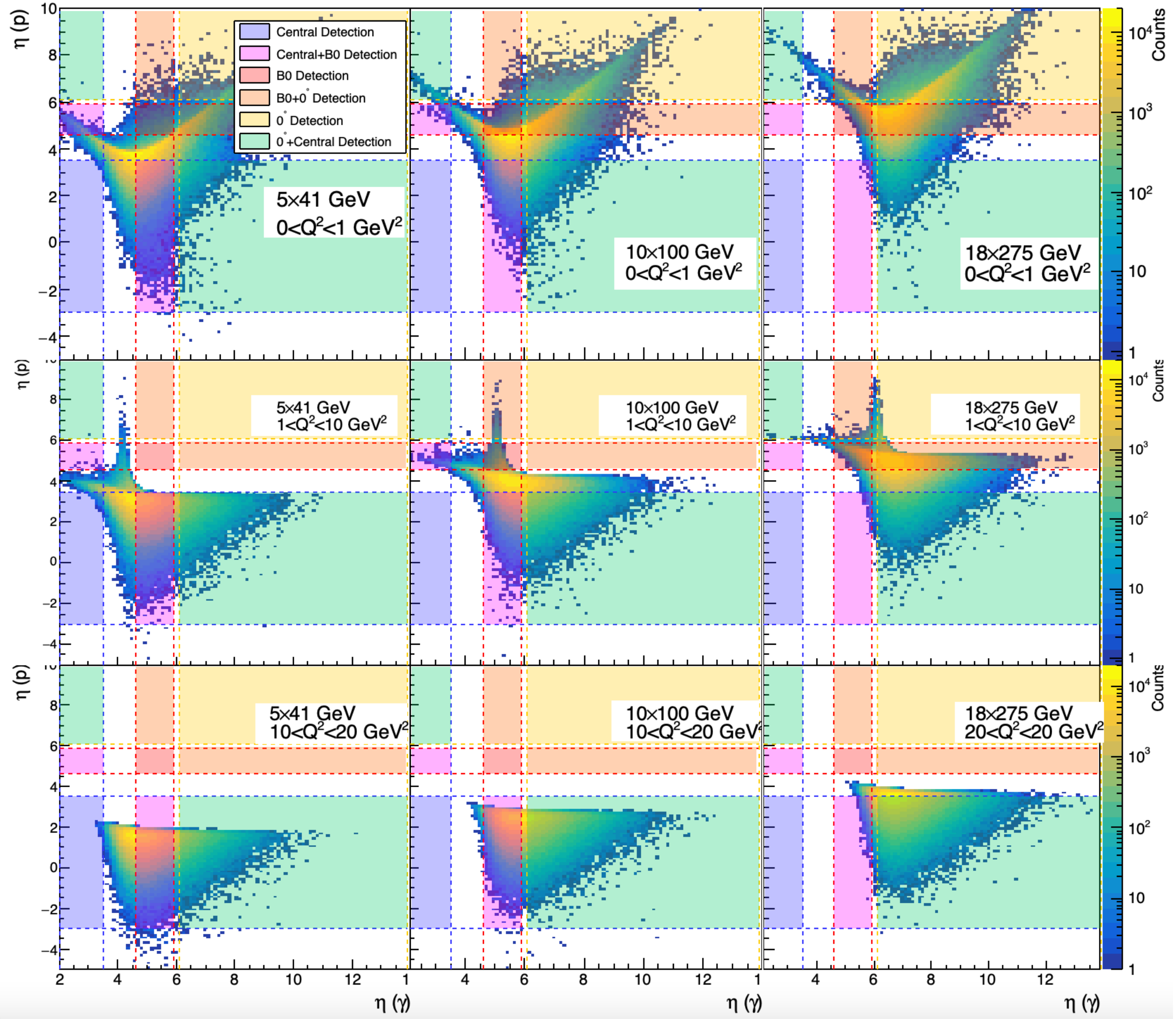
There are three detector regions of interest for backwards production

- Central Region (endcap & barrel): $|\eta| < 3.5$
  - ✓ 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

- Used Model 1 with W > 2 GeV
- Low collision energies: photon lands in B0 and ZDC
- ZDC is critical at high energies
- At low Q^2 proton is mostly in B0
- At high Q^2, proton is almost exclusively in central detector region



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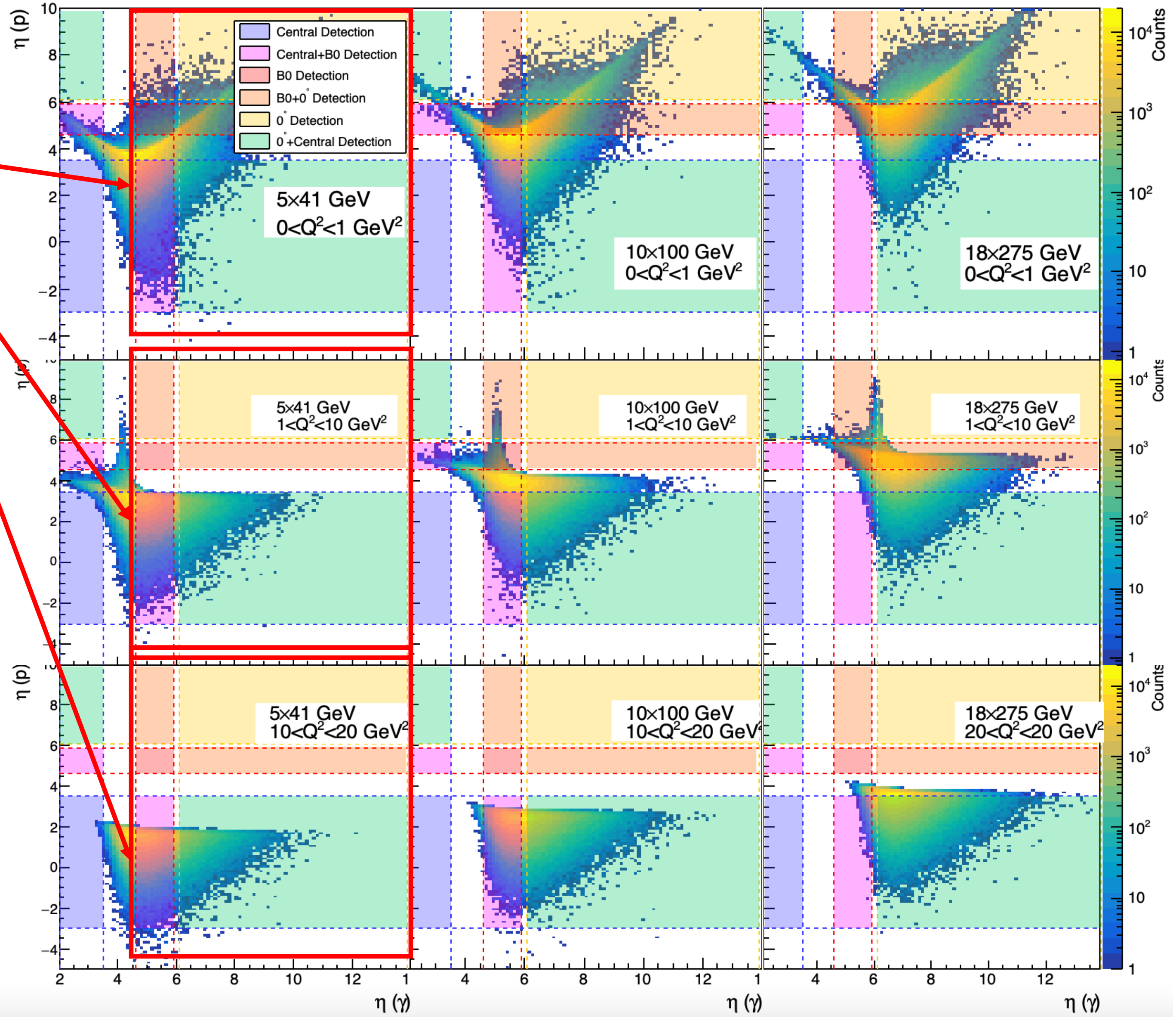

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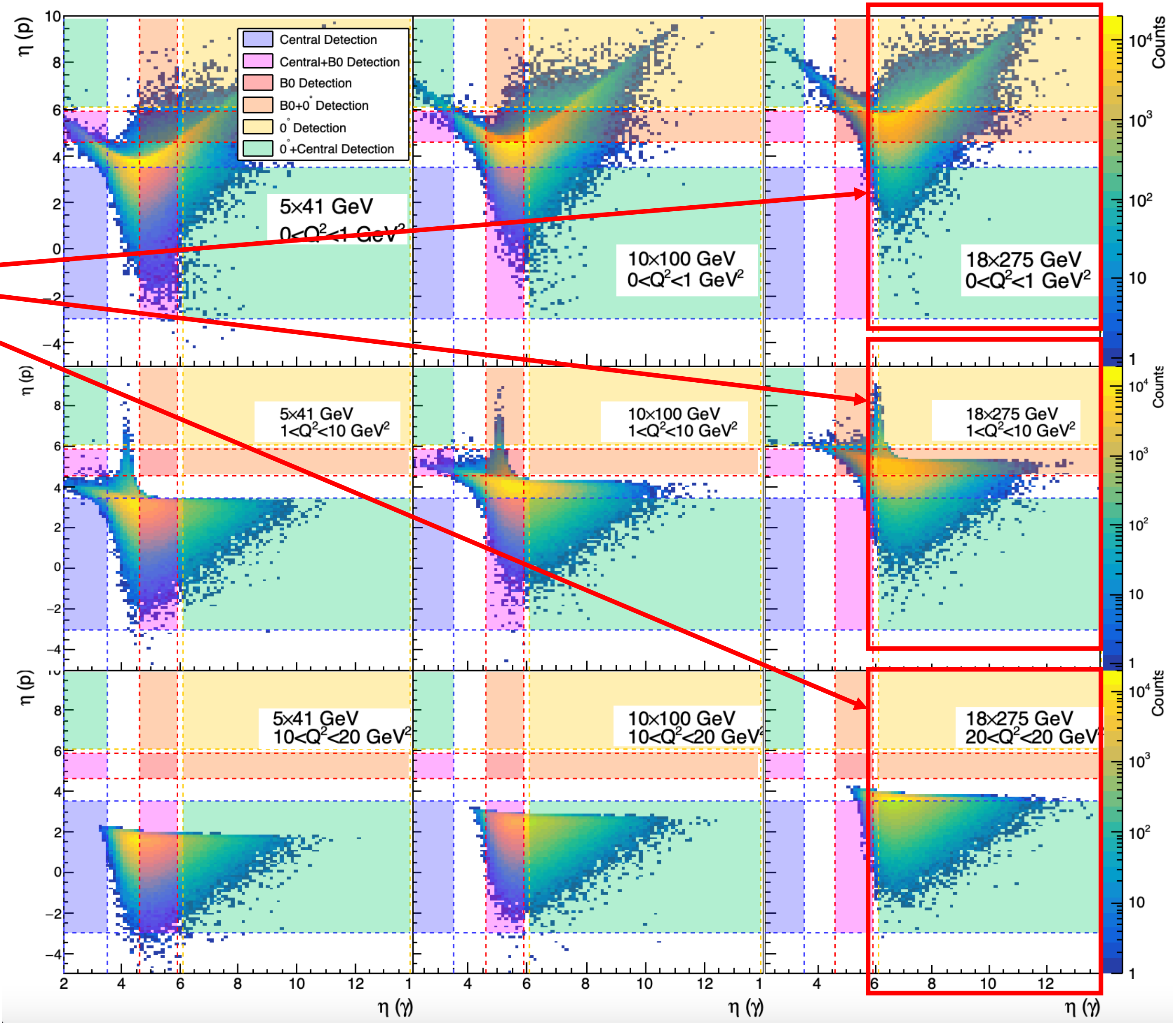

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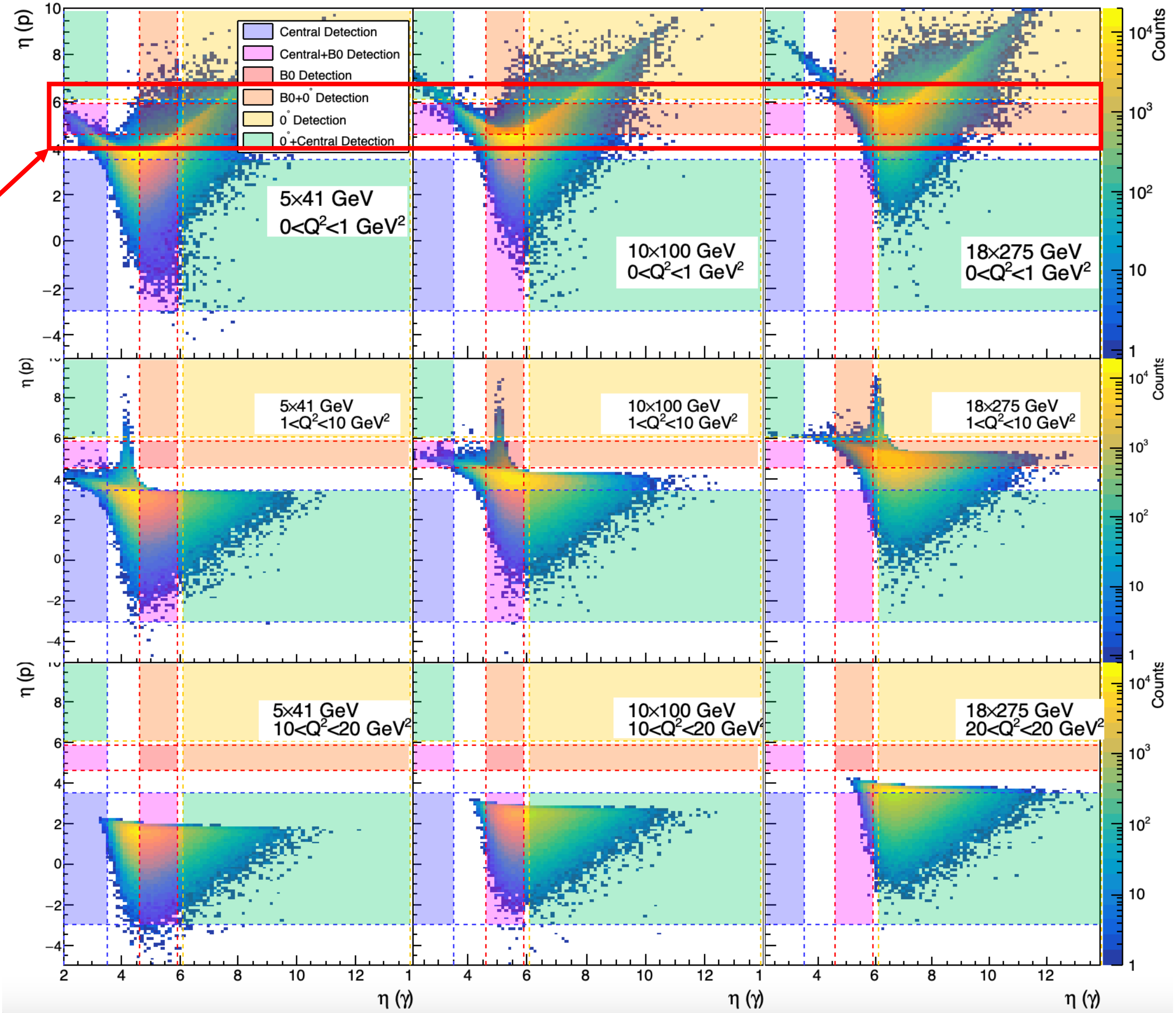

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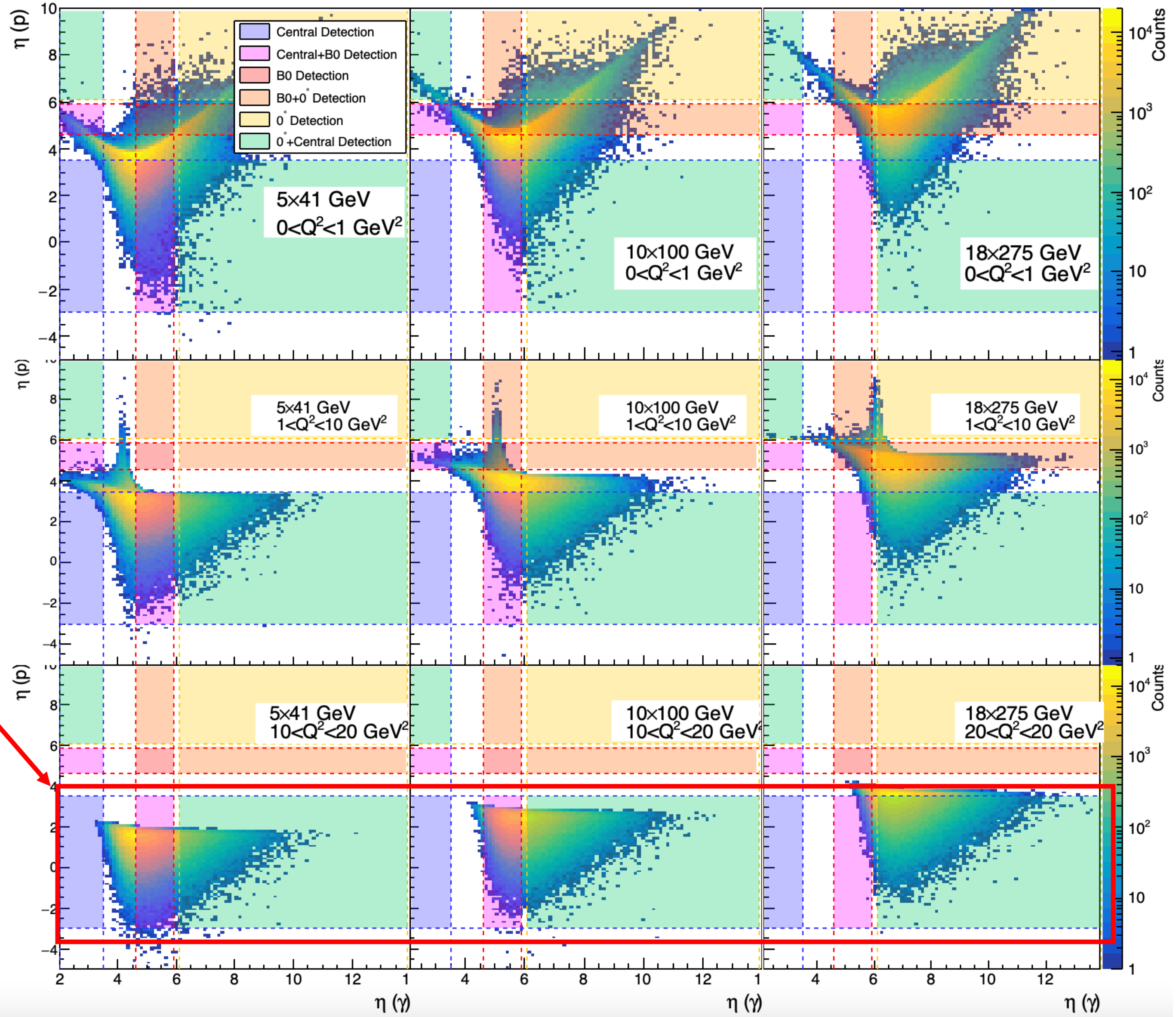
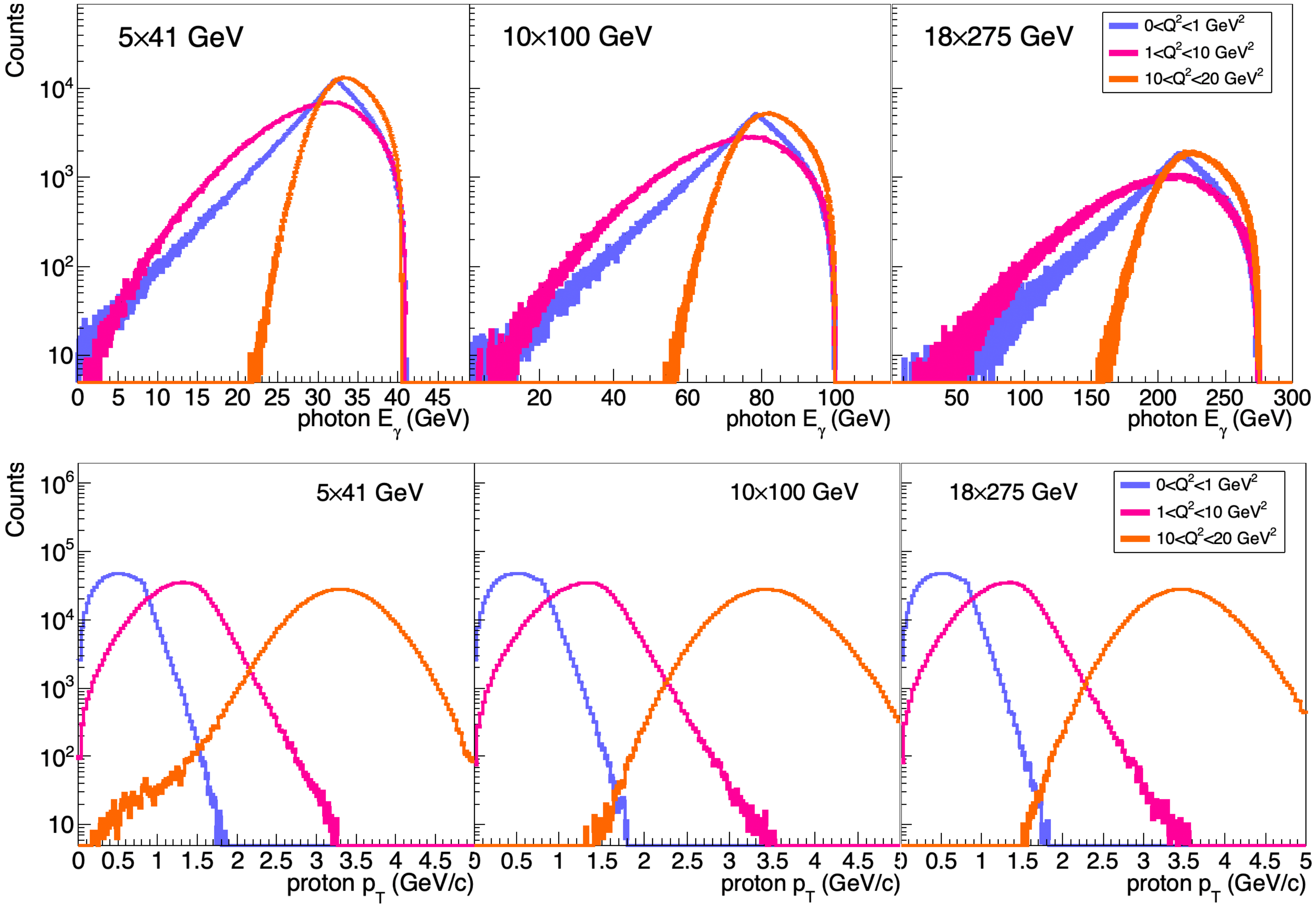


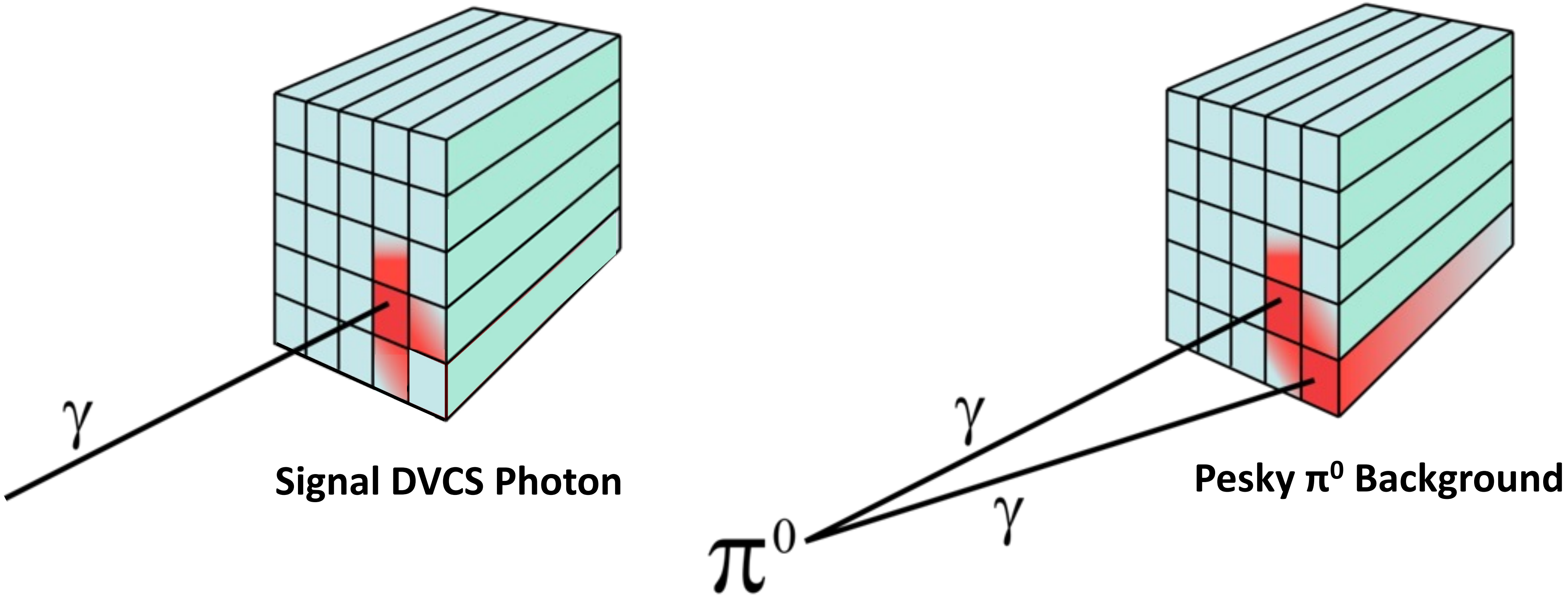
Kinematics of Final-State Particles

- Final-state photons in B0 and ZDC between 10 and 275 GeV
- Low-Q^2 events have low-pT protons
- Need to focus on detecting these due to large cross section



Primary Challenge: π^0 Background

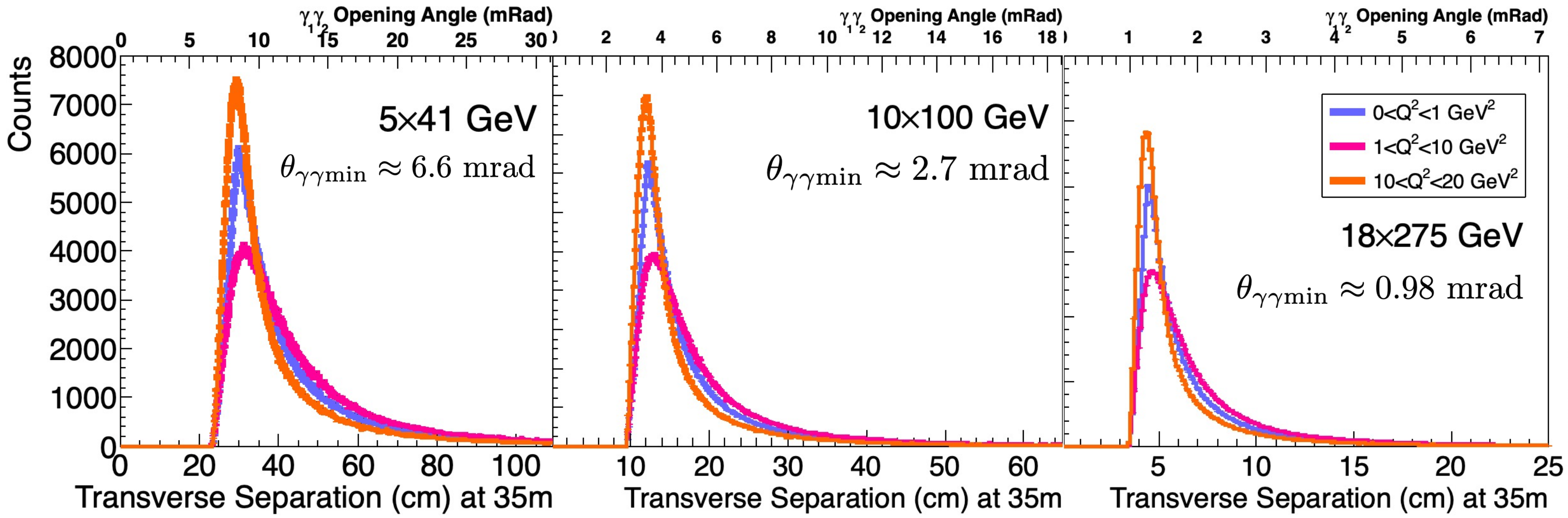
- Backward π^0s expected ~100-1000 stronger than backward CS
- Need to resolve one CS photon from two π^0 photons
- ZDC made of PbWO4 towers with 2cm transverse size
- ZDC ~35m downstream of IP



π^0 Background Photon Separation

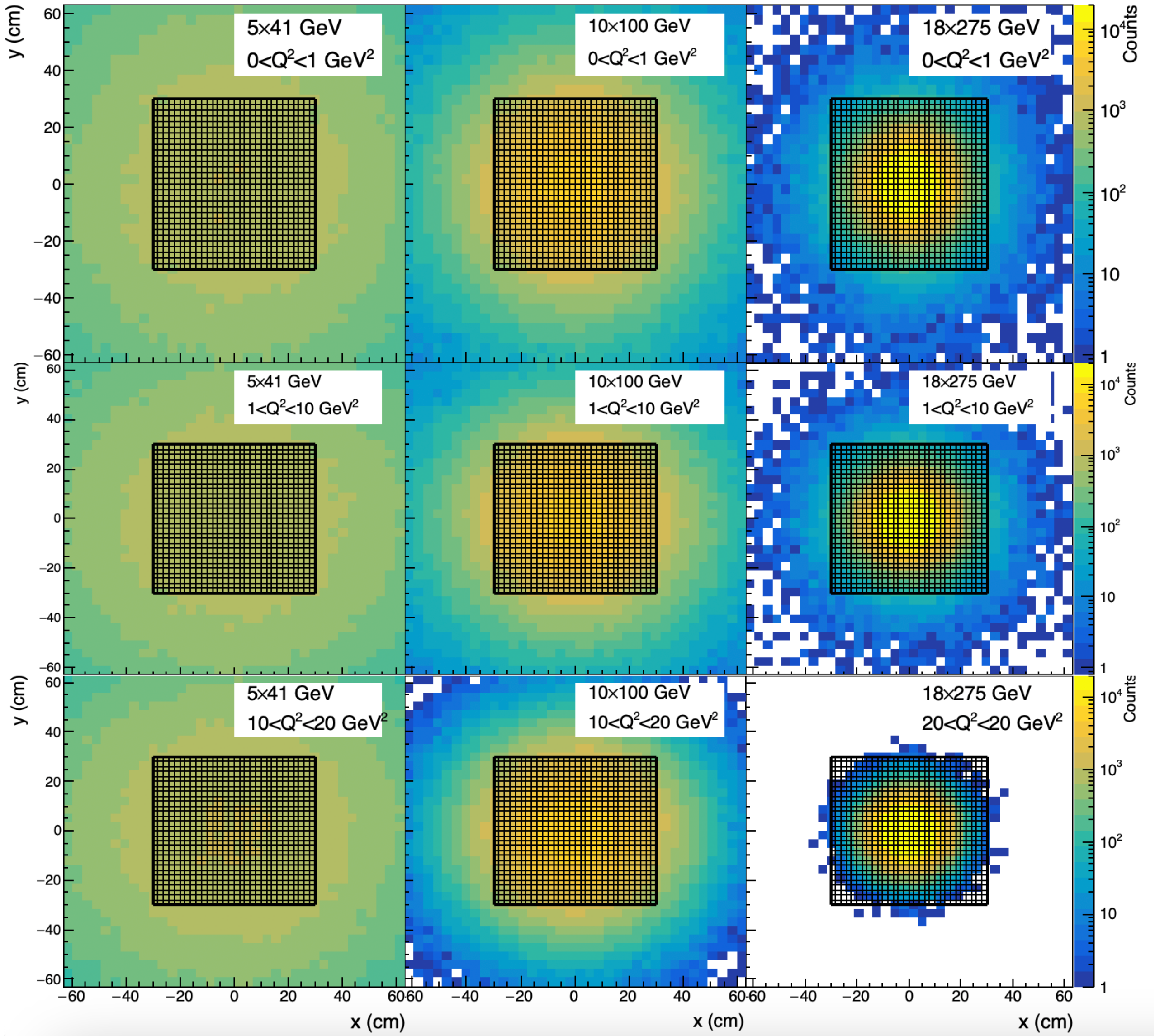
- I generated π^0s with the same kinematics as predicted DVCS photons
- Photons were well-separated
- Photons from π^0s merging in the same tower will not be the main issue

- Theoretical minimum opening angle: $\theta_{\gamma\gamma\text{min}} \approx 2\,\text{arctan}(m_{\pi^0}/E_p)$



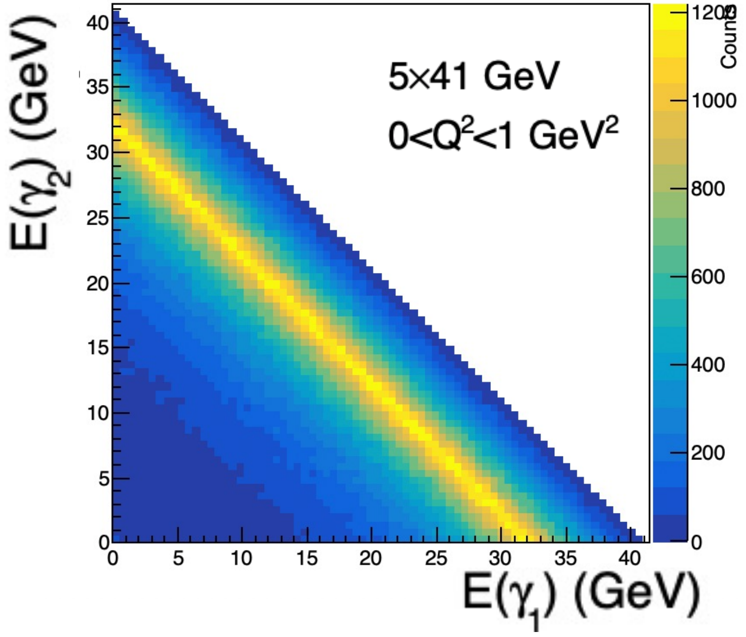
$\pi^0 \rightarrow \gamma\gamma$ CoM Distribution

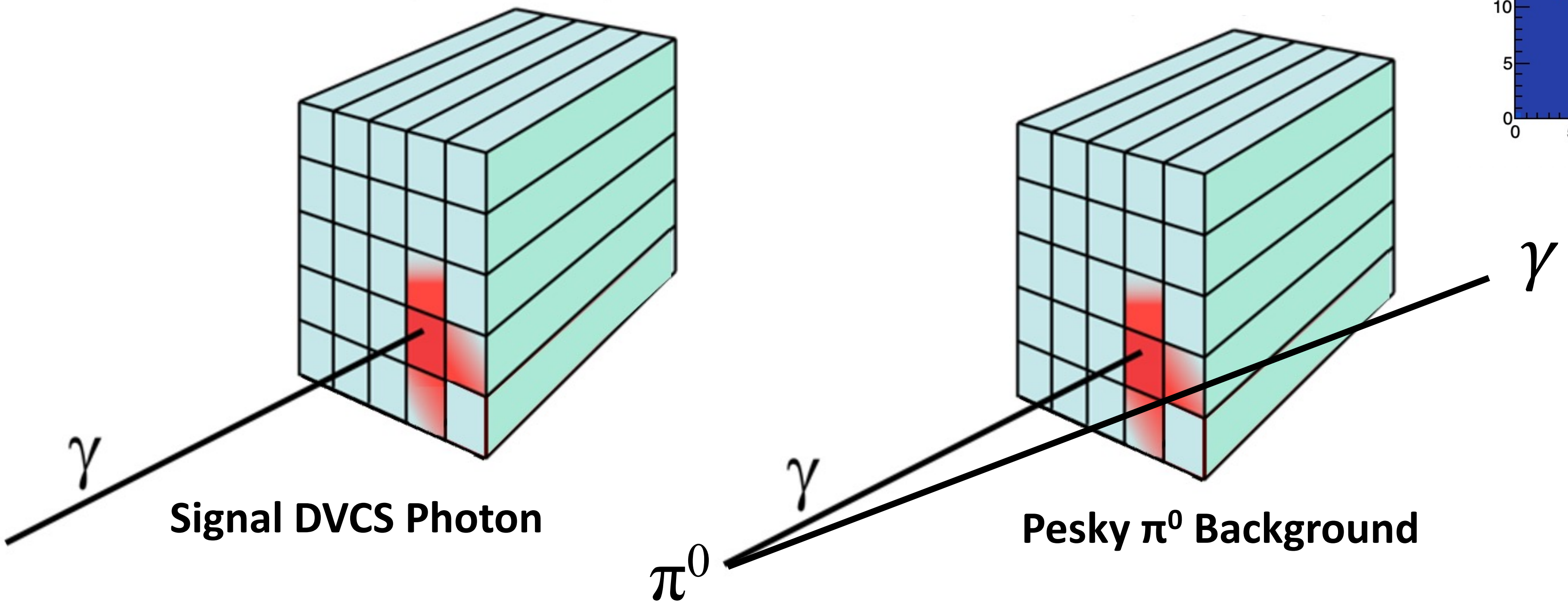
- The figure at right shows CoM distribution of $\gamma\gamma$ pairs from π^0s with the same kinematics as DVCS photons
- Overlaid on 60x60cm ZDC w/ 2x2cm towers
- At low energy and Q^2, the CoM is broad and often misses ZDC
- Taken with the previous slide, this gives an important conclusion



True Cause of $\pi^0 \to \gamma\gamma$ Background

Conclusion: the background will be dominated by events in which one of the π^0 photons carries most of the energy and the other misses the ZDC entirely. Depending on the high-energy resolution, this may easily be mistaken for backward DVCS. We need full backward π^0 simulations.





Conclusions and Outlook

- Backward production is interesting for encoding unique information about proton GPDs, an active and evolving topic of research
- Our backward DVCS model is still under development
- Early simulations demonstrate importance of B0 and ZDC calorimetry especially for high-energy photons.
- Contributions from π^0 background need to be explored in simulations
- Our team is writing a paper on backward Compton scattering so stay tuned!

Thank you for your attention!

zwsweger@ucdavis.edu

Backup Slide: Meaning of t-channel Cross Section

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

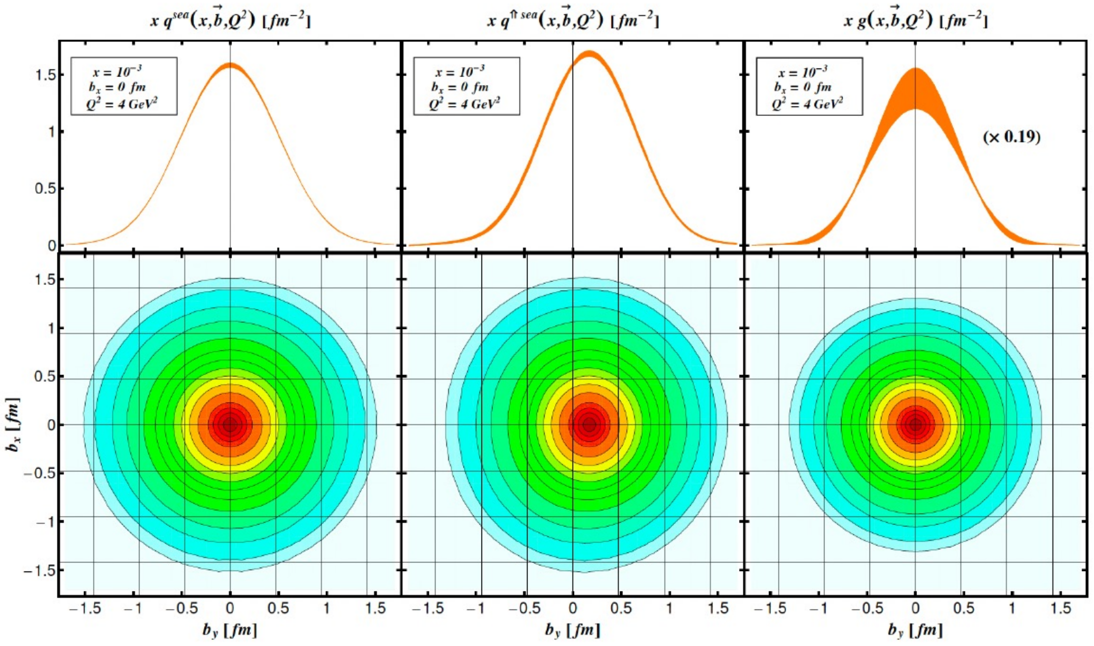


Figure 7.46: Impact parameter distributions at $x = 0.001$ and $Q^2 = 4\,\mathrm{GeV}^2$ for unpolarized sea quarks in an unpolarized proton (left), a transversely polarized proton (middle), and for unpolarized gluons in an unpolarized proton (right), obtained from a combined fit to the HERA collider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

Backup Slide: Meaning of LDEP