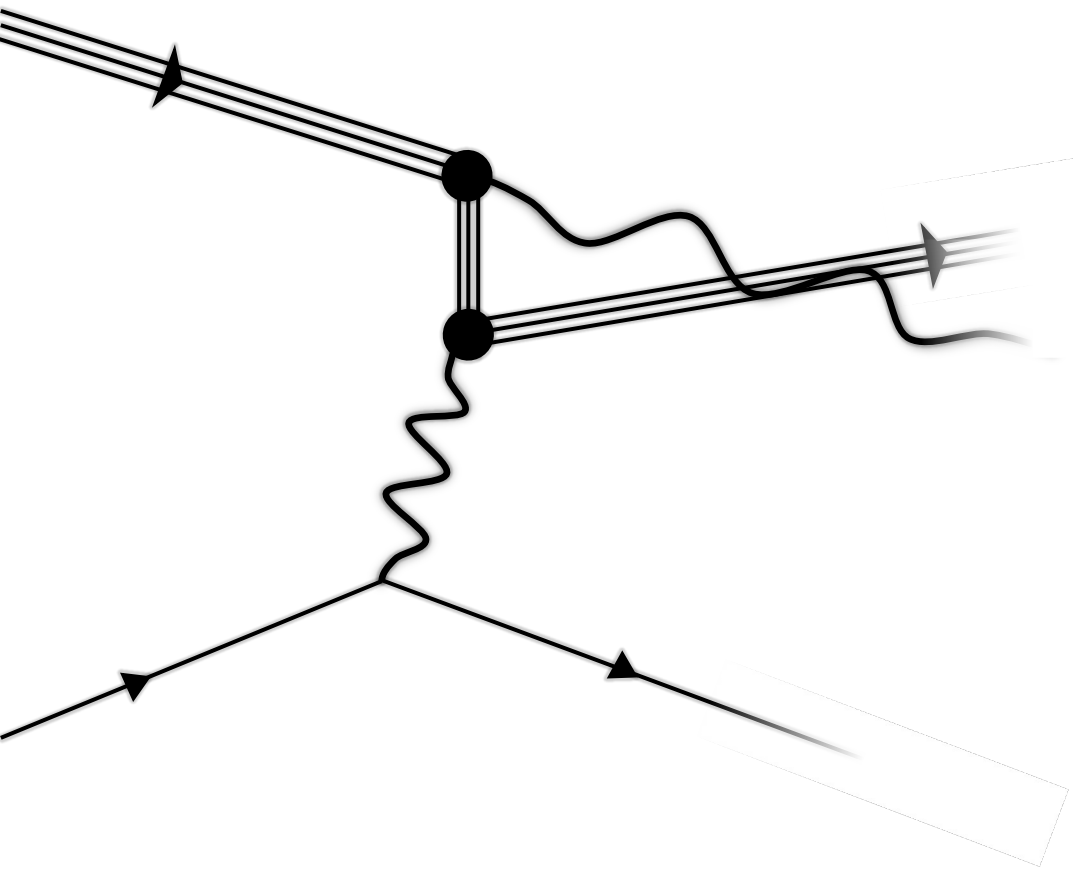


Thoughts on Interpreting u-channel Cross Sections

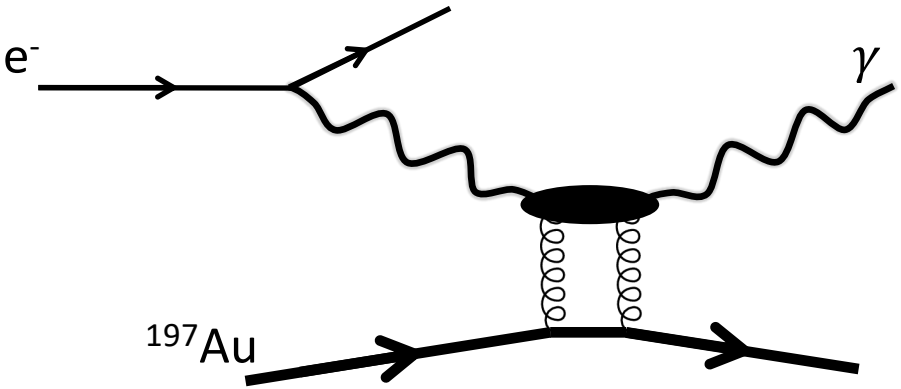
Zachary Sweger

University of California Davis

Supported in part by

Imaging Nuclei/nucleons at the Electron-Ion Collider (EIC)

- Scattering mediated by virtual photon at EIC
- Image nucleus by scattering photon off of nucleus' "gluon cloud"



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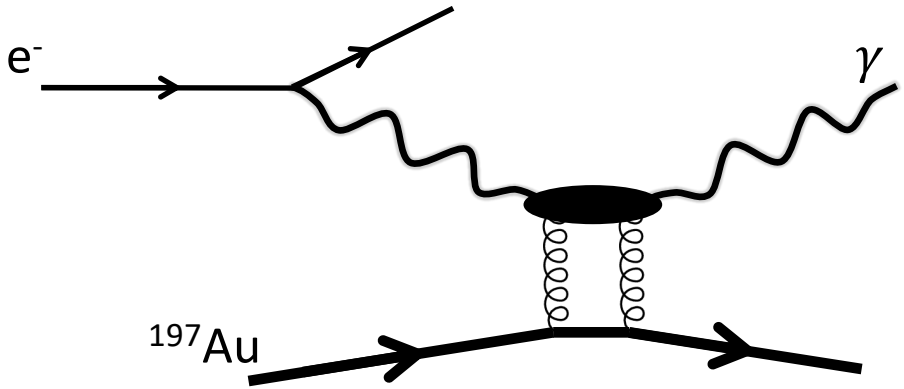

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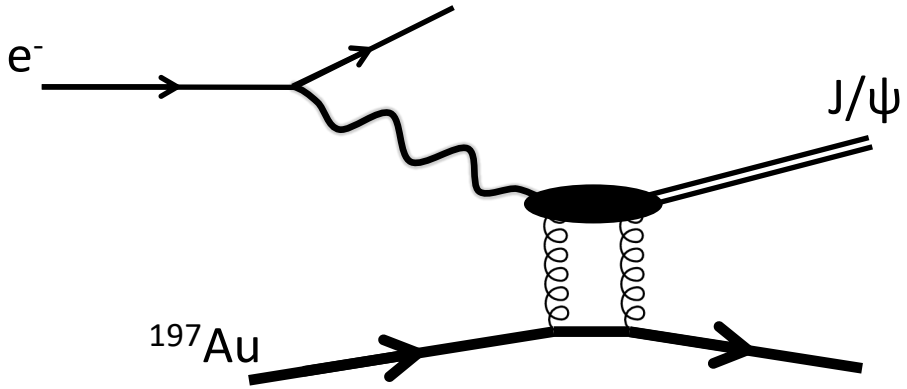

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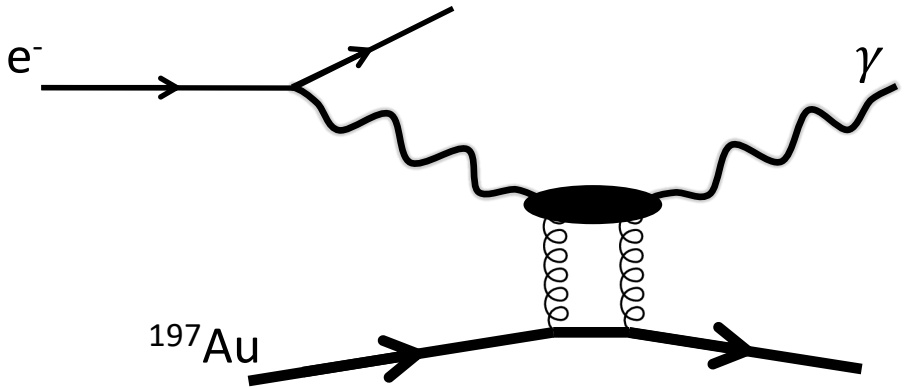

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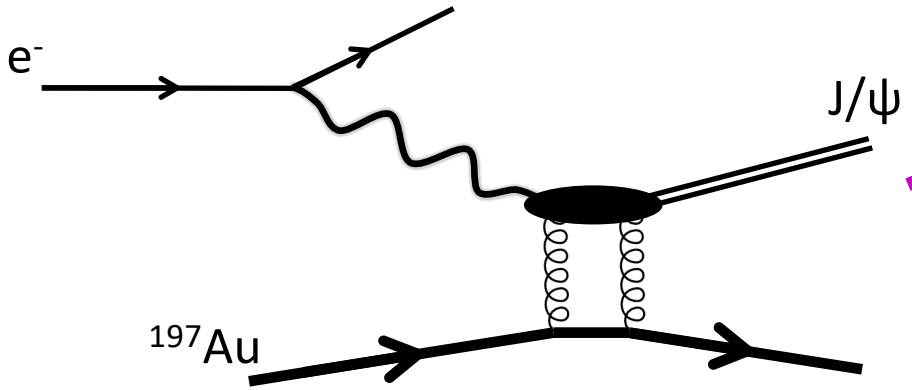
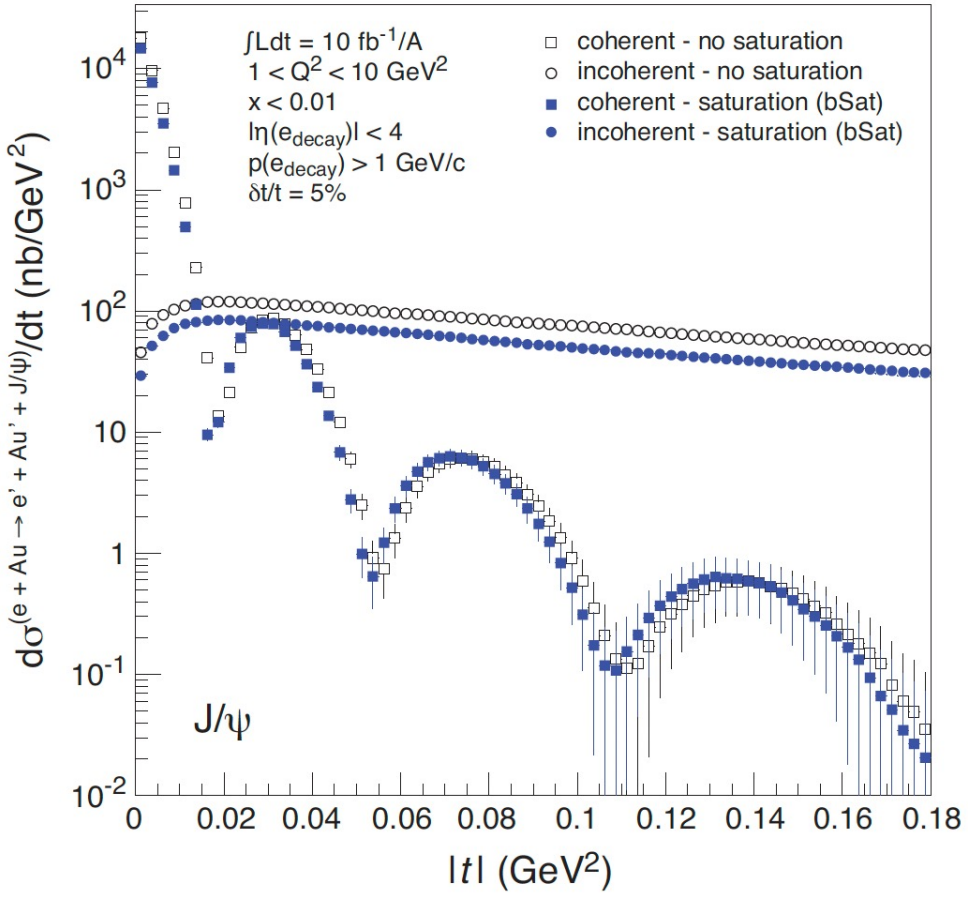


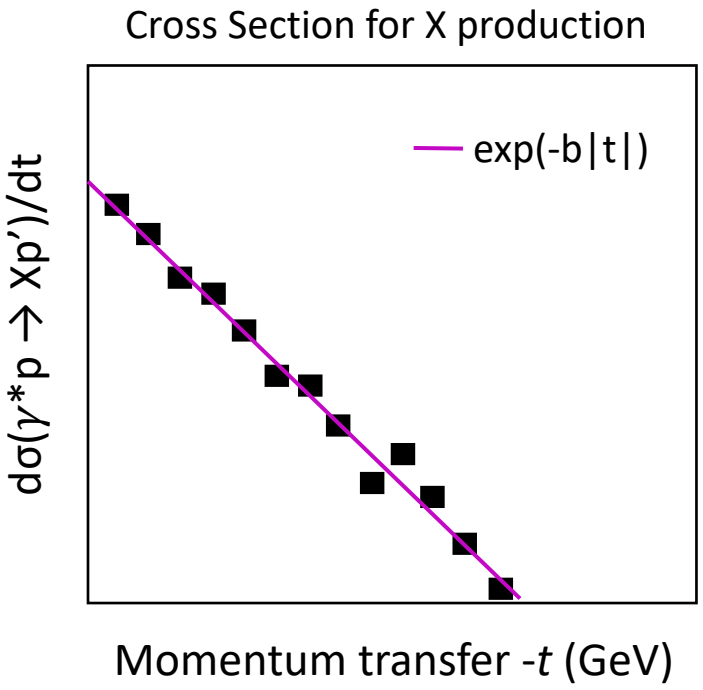
EIC White Paper (2012)



Transforming Forward (ep→e'p'X) Cross Section

Forward cross sections → nucleon form factors

- We measure meson/photon production Xsec vs momentum transfer t



Transforming Forward (ep→e'p'X) Cross Section

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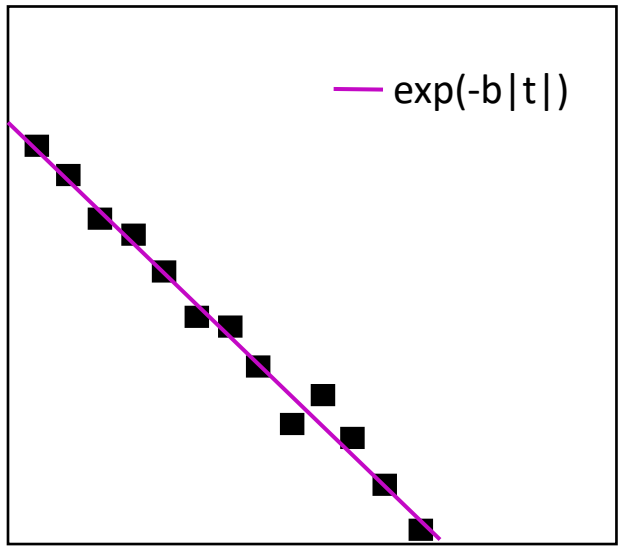
Forward cross sections → nucleon form factors

- We measure meson/photon production Xsec vs momentum transfer t
- By transforming this in the transverse plane, we can map transverse distribution of partons within proton (or nucleus)

Cross Section for X production



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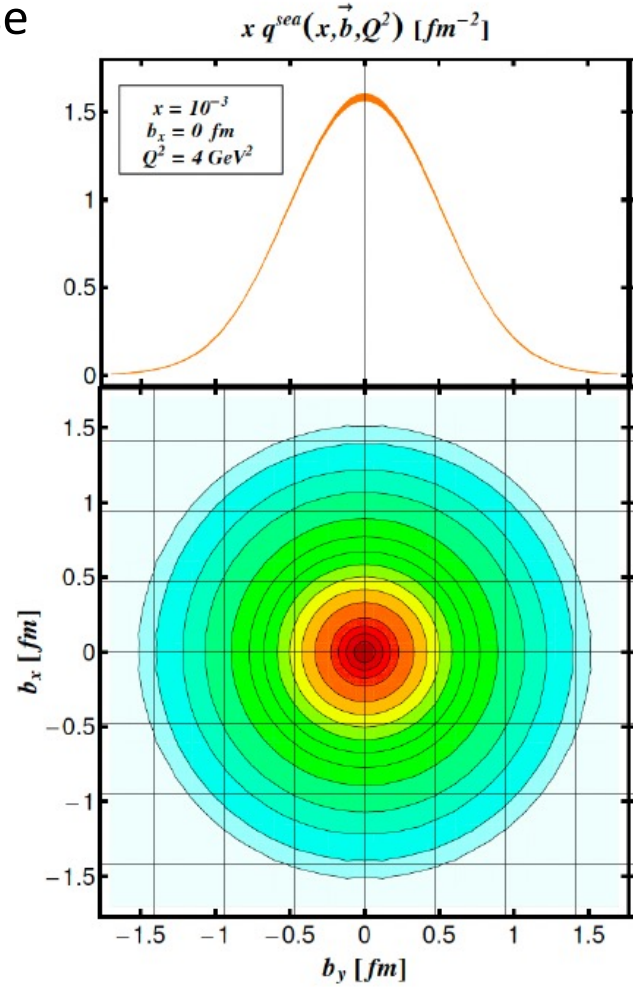
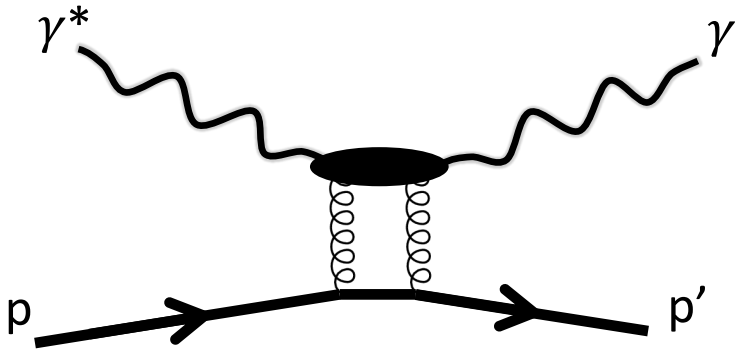


EIC Yellow Report (2021)

Meaning of Backward Cross Section

Forward scattering off proton's gluon field



Backward Xsecs → partonic correlations and baryon number?

- Forward production maps parton distributions within proton/nucleus

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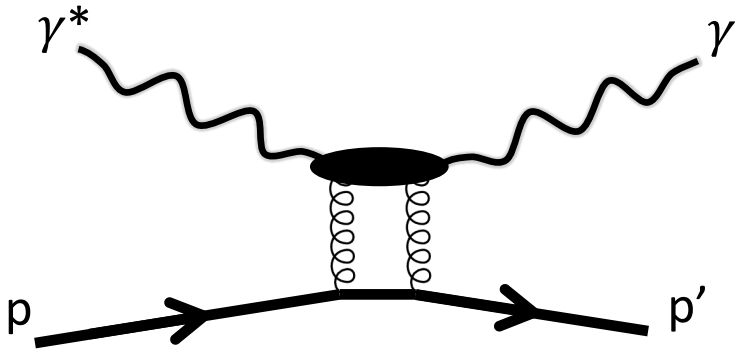
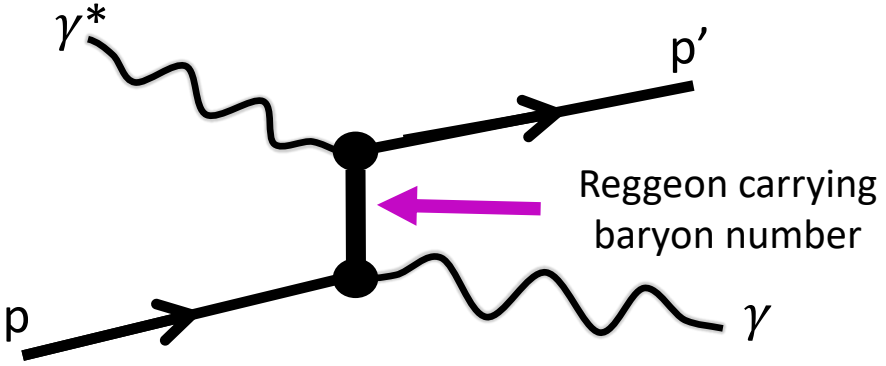


Backward scattering off proton's… baryon number?
gluon junction?
di-quark clusters?



Backward Xsecs → partonic correlations and baryon number?

- Forward production maps parton distributions within proton/nucleus
- Recent (2021) work by Pire et al. formulates a similarly meaningful interpretation of backward cross sections
- They argue backward reactions may map transverse distribution of quark clusters and baryon number

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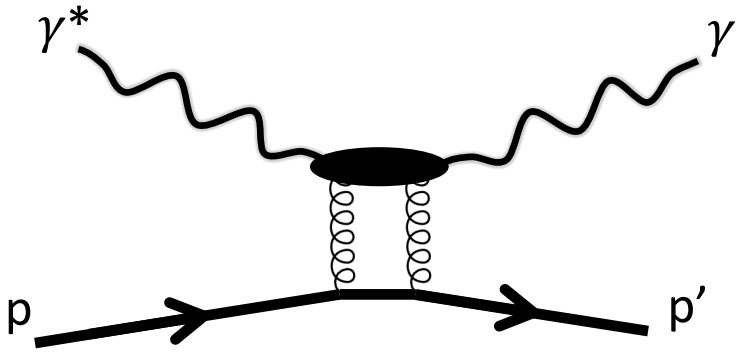

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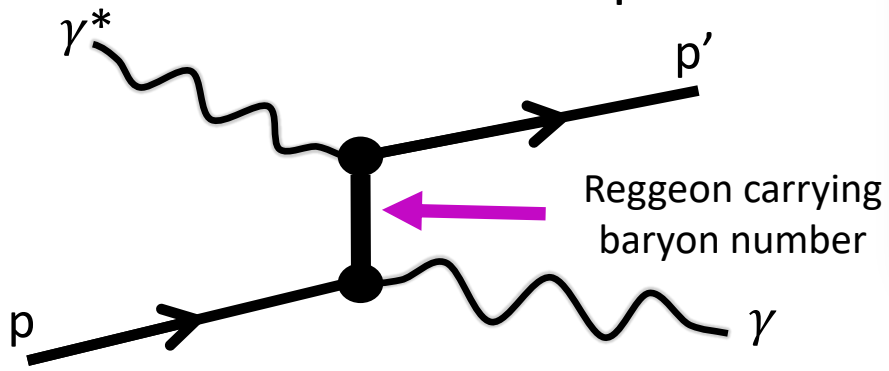


"baryon-to-meson (and baryon-to-photon) TDAs share common features both with baryon DAs and with GPDs and encode a conceptually close physical picture. They characterize partonic correlations inside a baryon and give access to the momentum distribution of the baryonic number inside a baryon. Similarly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

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

u-Channel DVCS and π^0 at the EIC

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:**

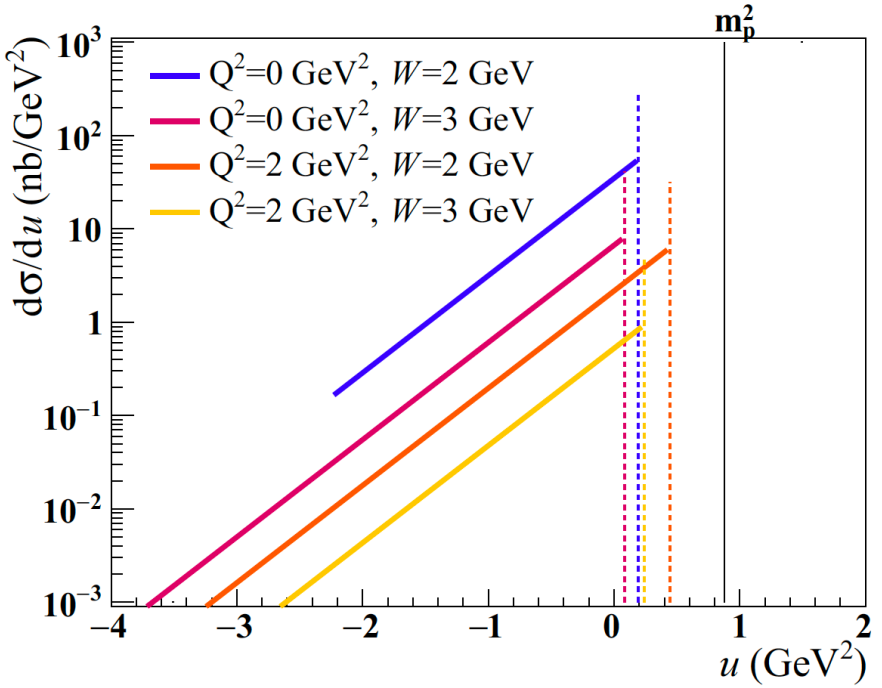
Our Backward DVCS Model: u-Dependence

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**

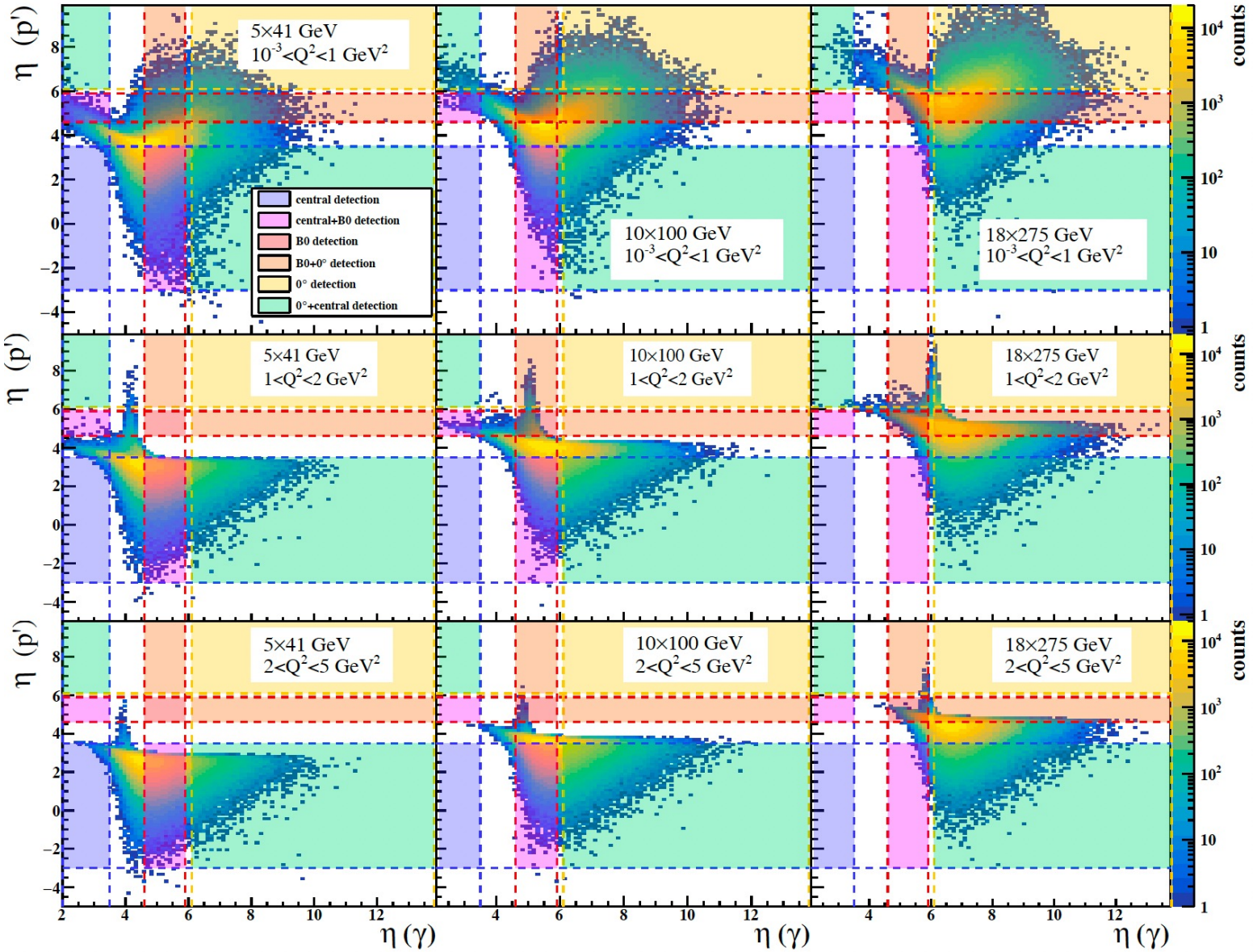
$$\frac{d\sigma}{dt}(t) \sim \exp(-B|t-t_0|) \longrightarrow \frac{d\sigma}{du}(u) \sim \exp(-D|u-u_0|)$$

- D has not been measured for backward DVCS, so for our models we test values measured for backward vector-meson production
- W, Q^2 dependencies discussed in more detail in our paper: *Phys. Rev. C 108, 055205 (2023).*



Backward DVCS Acceptances

- Low collision energies: photon lands in B0 and ZDC
- ZDC is critical at high energies
- At low Q^2 proton is often in B0
- At high Q^2, proton is almost exclusively in central detector region



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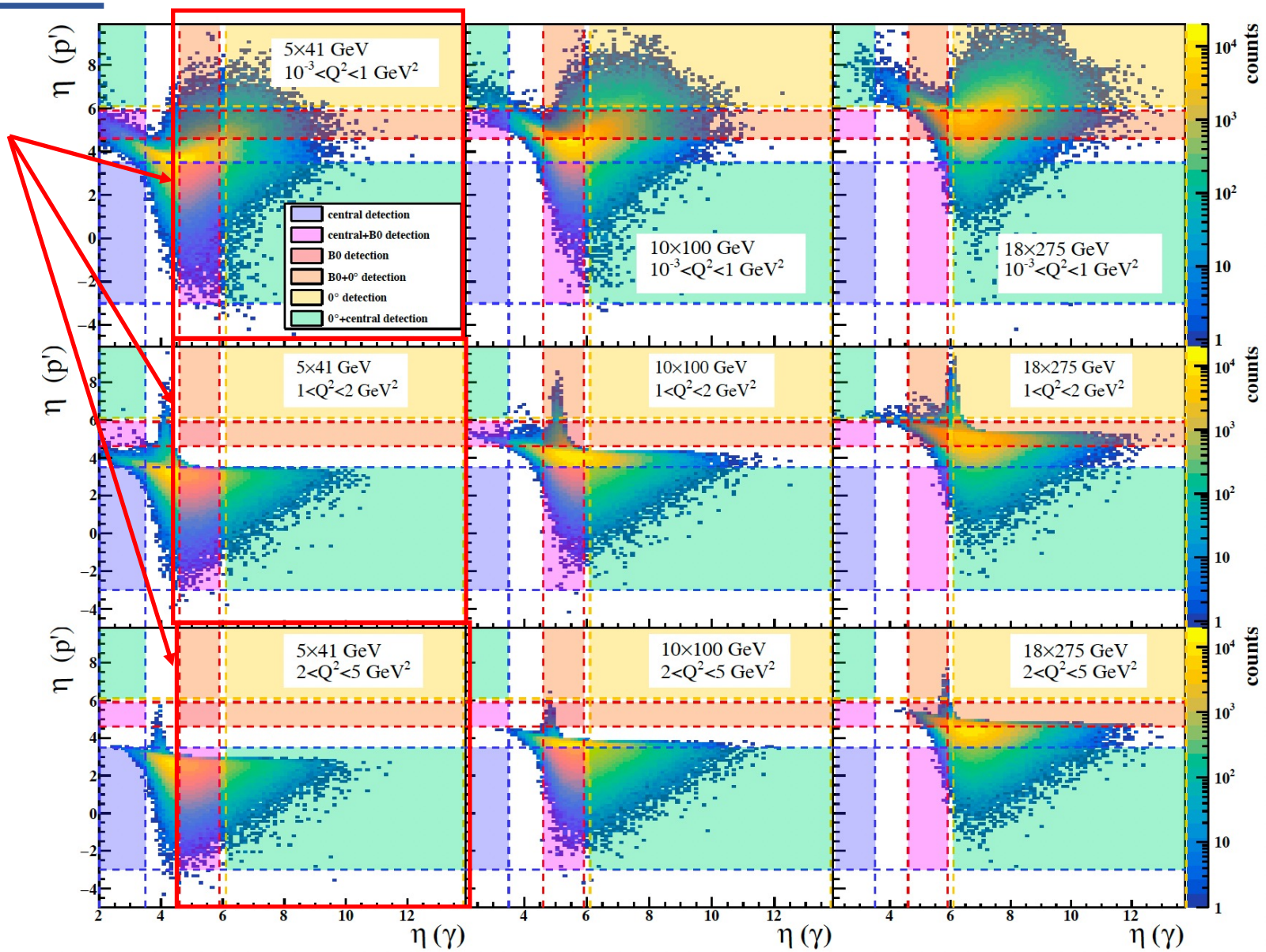

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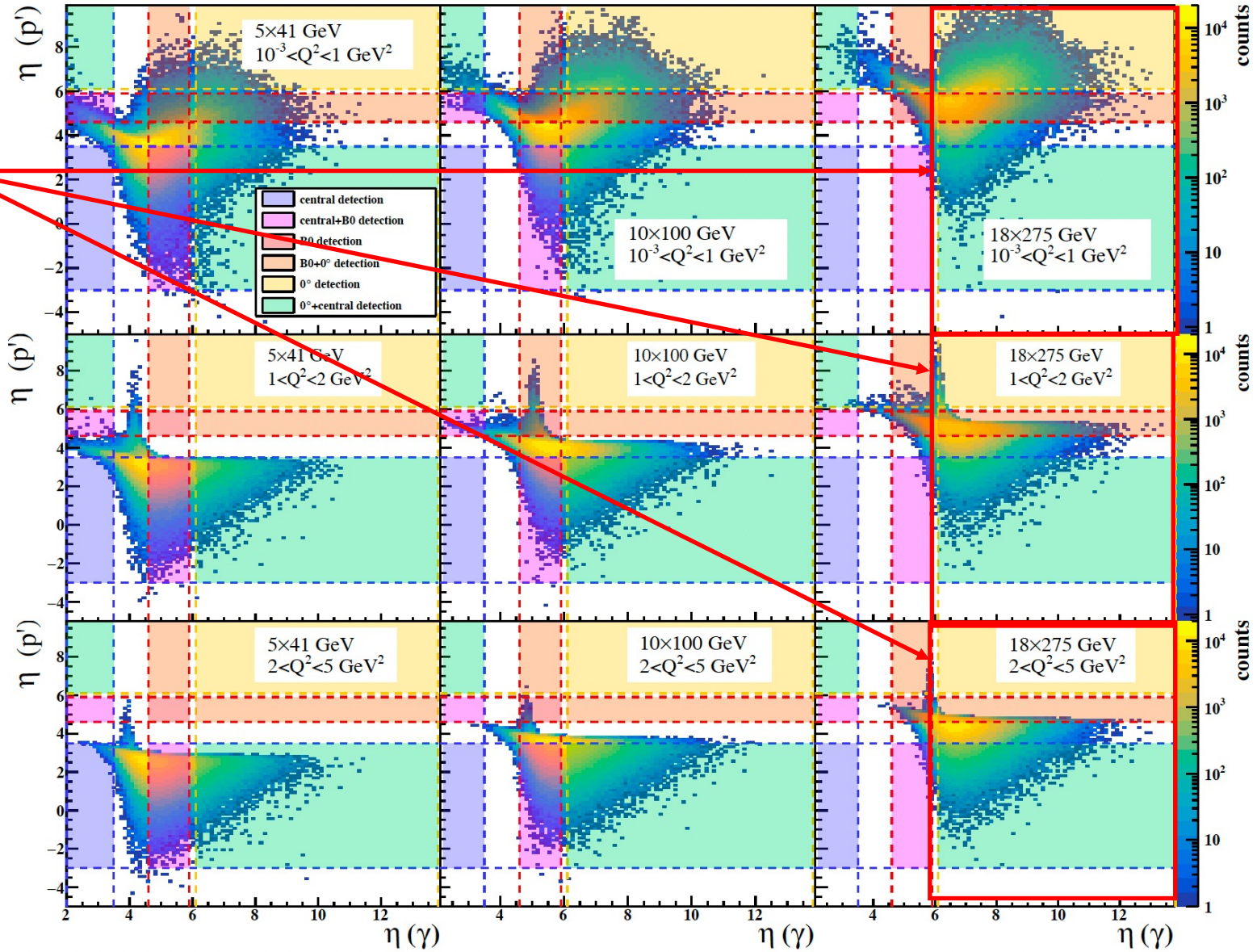

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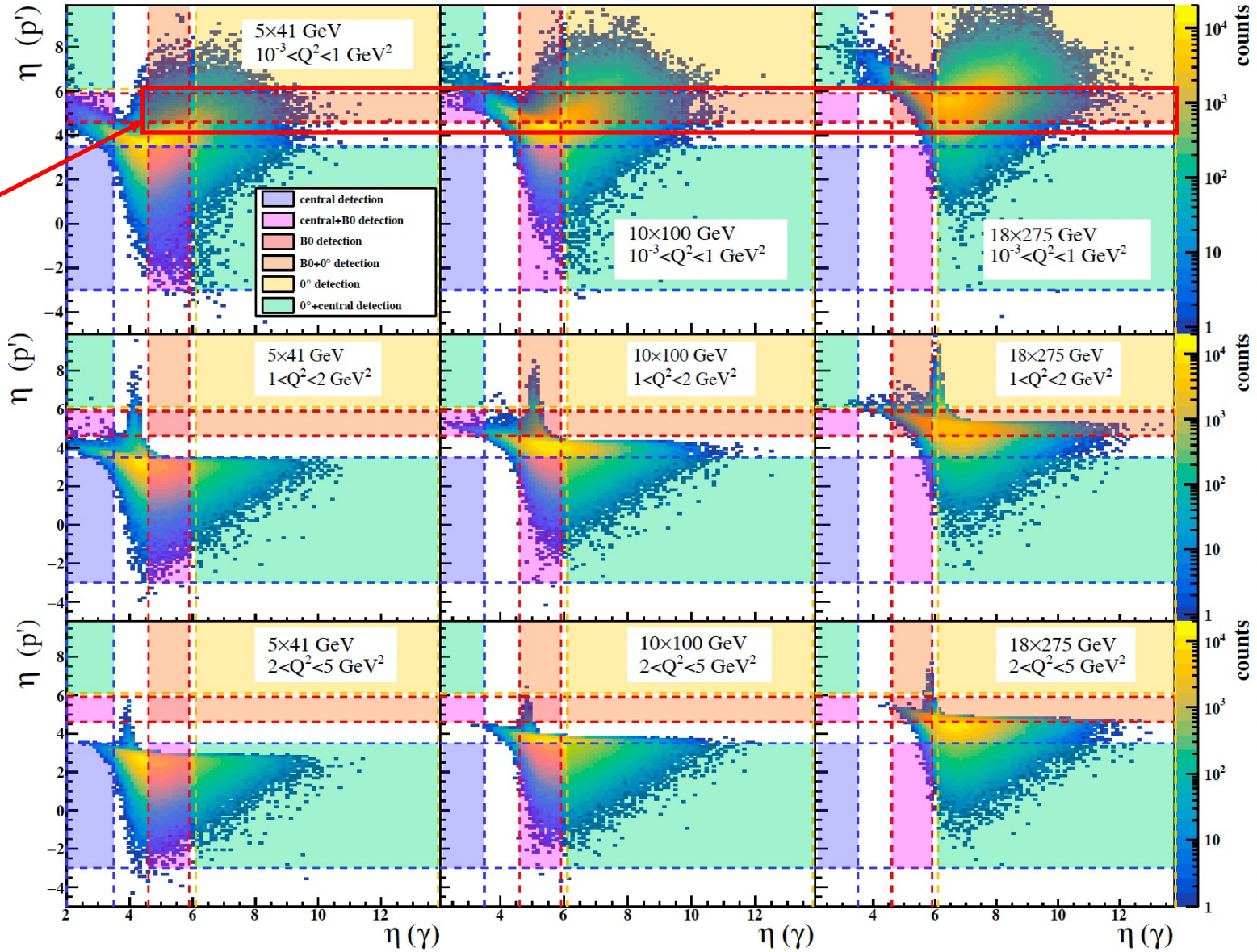

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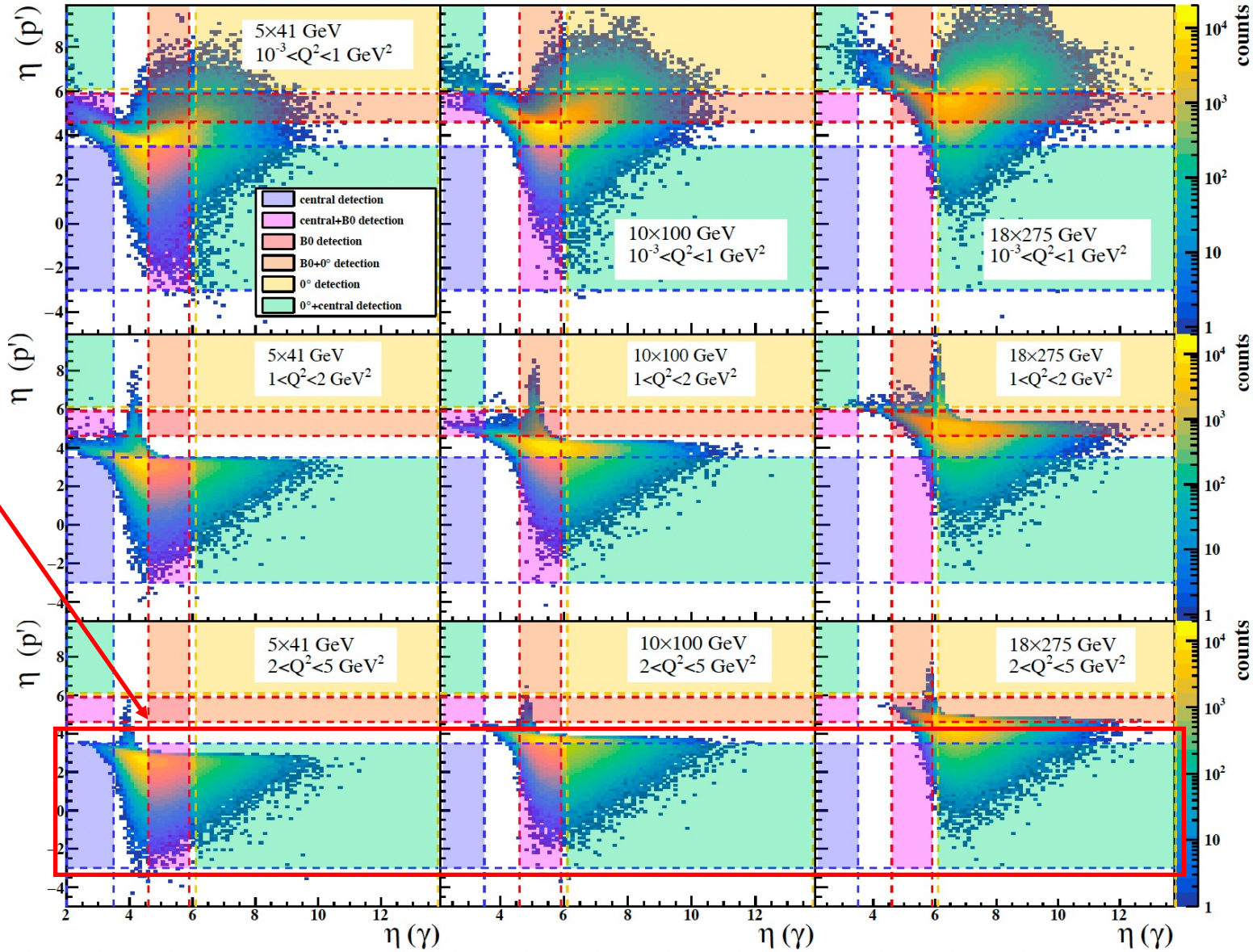
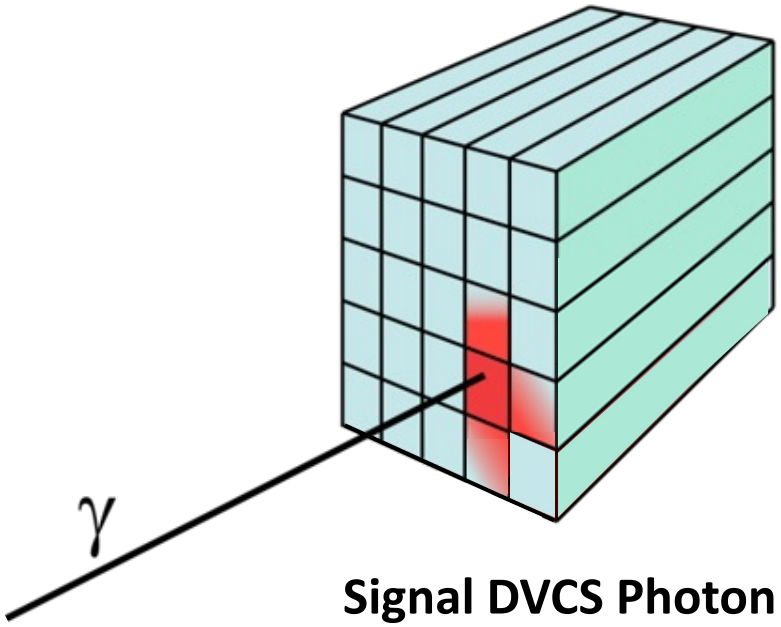
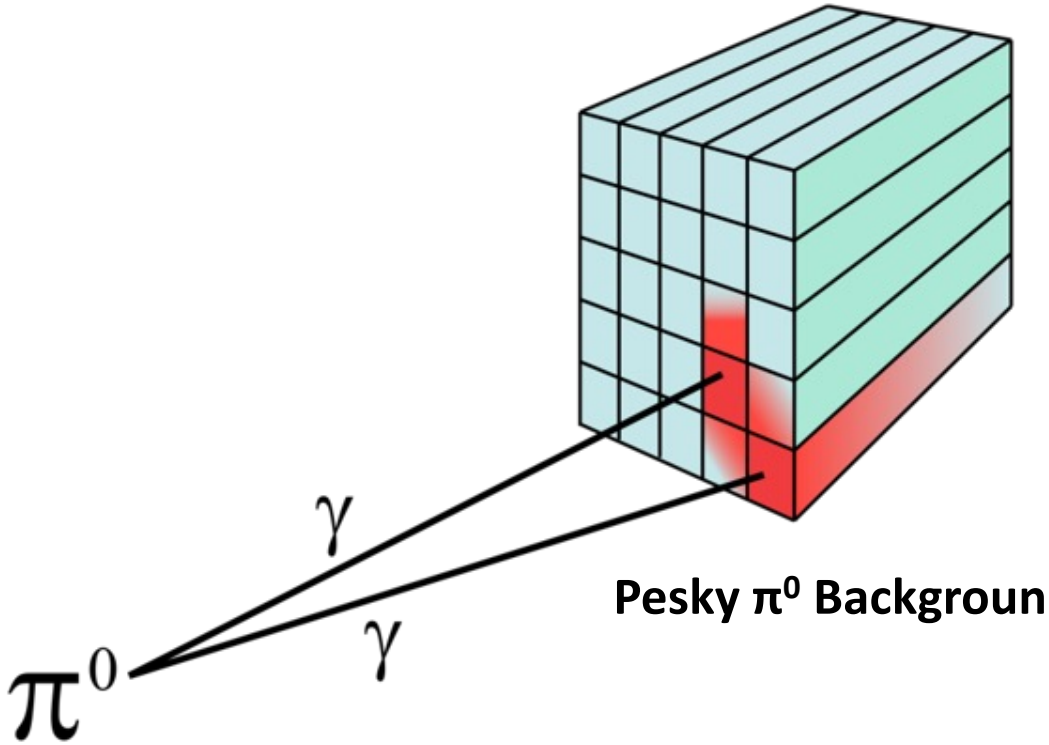


Primary Challenge: π^0 Background

- 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



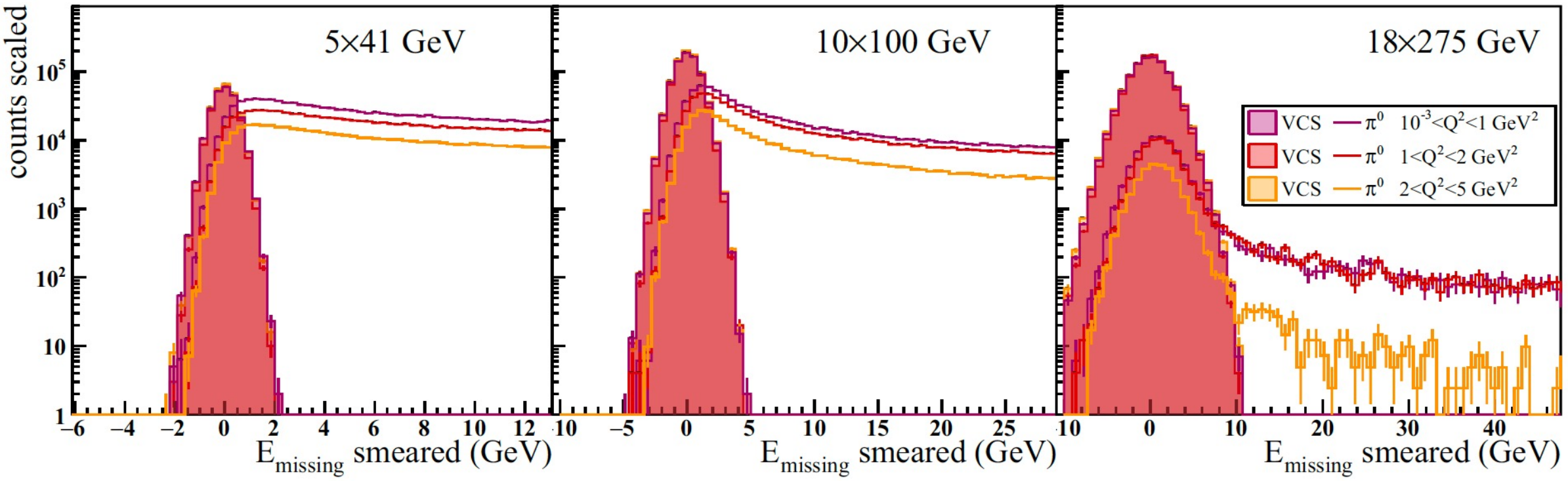
Signal DVCS Photon



Pesky π^0 Background

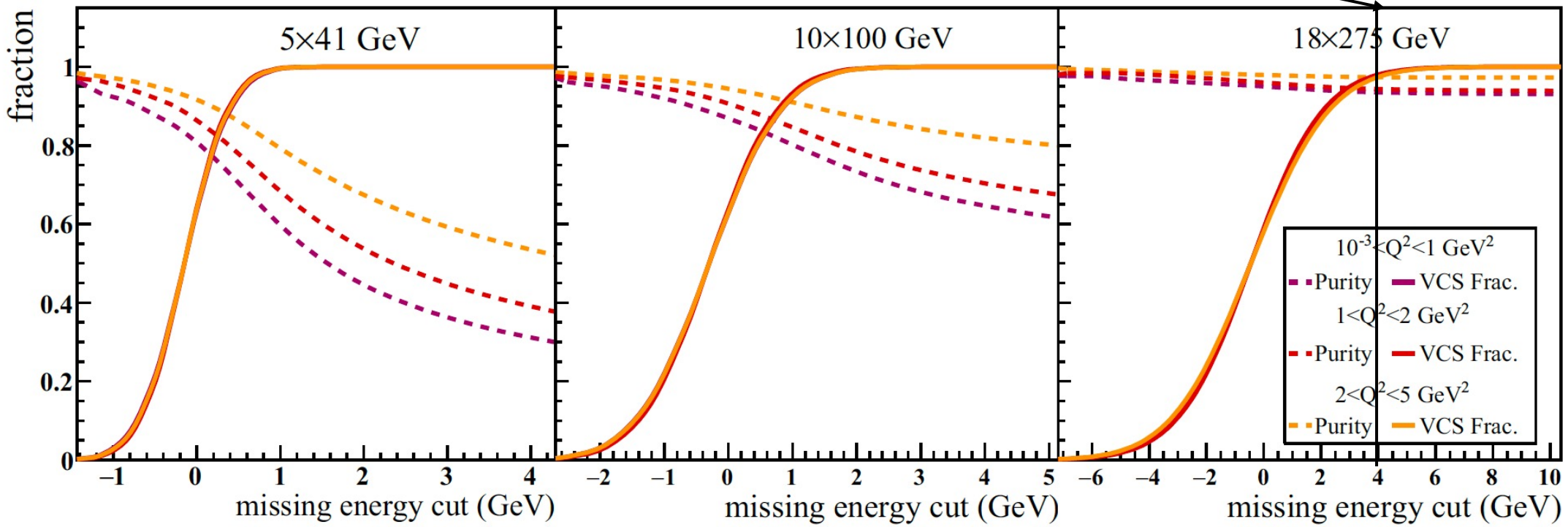
Exclusivity Cuts on π^0 Background

- Simulated effect of ZDC smearing on single-photon π^0 and Compton photons
- A missing energy cut can reduce much of the single-photon π^0 events



Exclusivity Cuts on π^0 Background

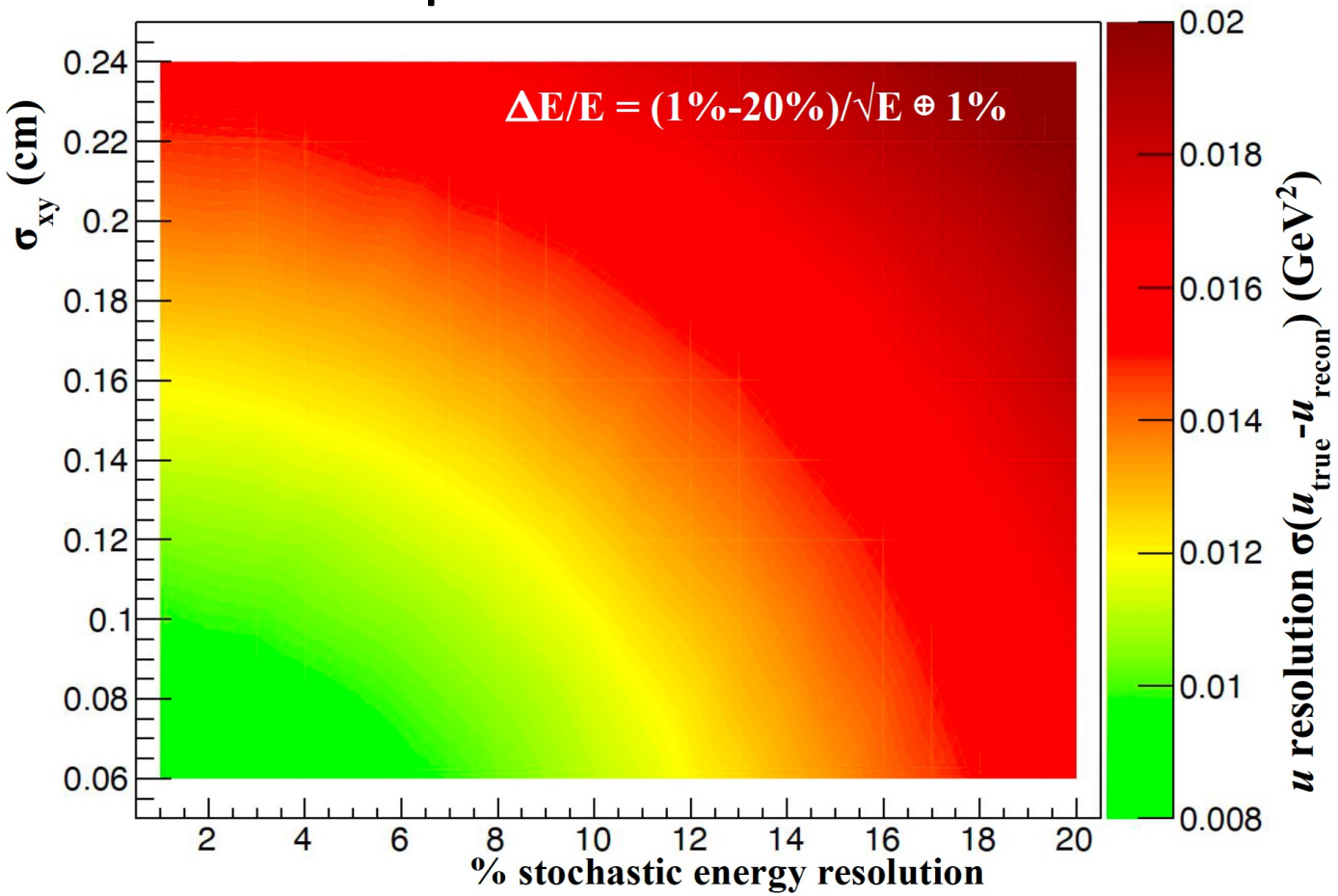
- We can simulate missing energy cut using the ZDC smearing
- For a given cut ($E_{missing}<E_{cut}$) this shows the fraction of our backward VCS signal collected
- Purity of VCS signal (dotted graphs) also plotted as a function of missing energy cut
- For example at 5×41 GeV, a cut of $E_{missing}< 1$ GeV is sufficient to collect entire signal. Any larger cut just decreases purity.
- At 18×275 GeV, a cut of $E_{missing}< 4$ GeV may collect signal with ~95% purity!



u-Channel π^0 as a Signal

- We are currently using this physics channel and our simulations to inform ZDC design
- By advising detector experts on our requirements early, we may get a ZDC which allows us to map these cross sections with high u resolution
- With good detector design, we may measure cross sections with enough resolution to be used in TDA factorization scheme

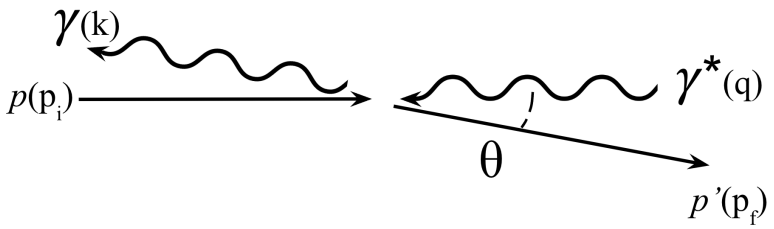
u resolution in π^0 production with expected ZDC resolutions



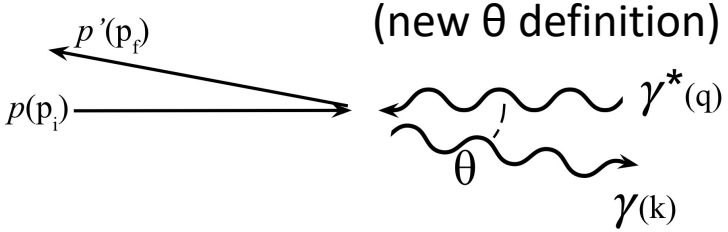
An Exploratory Study

First attempt at this transformation

t-channel: transform around t~0, θ ~0



u-channel: transform around u~0, θ~0 (new θ definition)



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

Calculate the Mandelstam *u*

$$\Delta \equiv p_{\mathcal{M}} - p_N \qquad \Delta^2 = u$$

We need $\boldsymbol{\Delta}_T$ which is conjugate to b_T

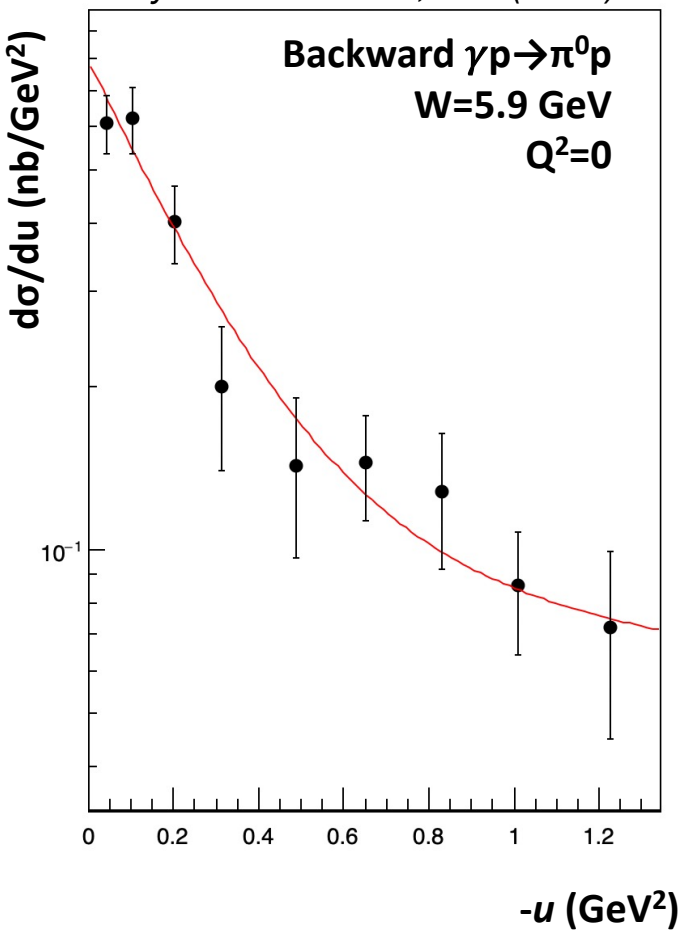
$$\Delta_T^2 = \frac{1-\xi}{1+\xi}\left(\Delta^2 - 2\xi\left[\frac{m_N^2}{1+\xi} - \frac{m_{\mathcal{M}}^2}{1-\xi}\right]\right)$$

As a first pass, I took the skewness ξ≈0, approximating any non-zero *u* contribution to come from the transverse component

Transforming Backward Cross Section

- We can do a quick fit to backward cross sections and transform distribution around $p_T \sim 0$ ($u \sim 0$)

Phys. Rev. Lett. 23, 725 (1969).



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- When we do this, we see an "object" that's much smaller than the proton

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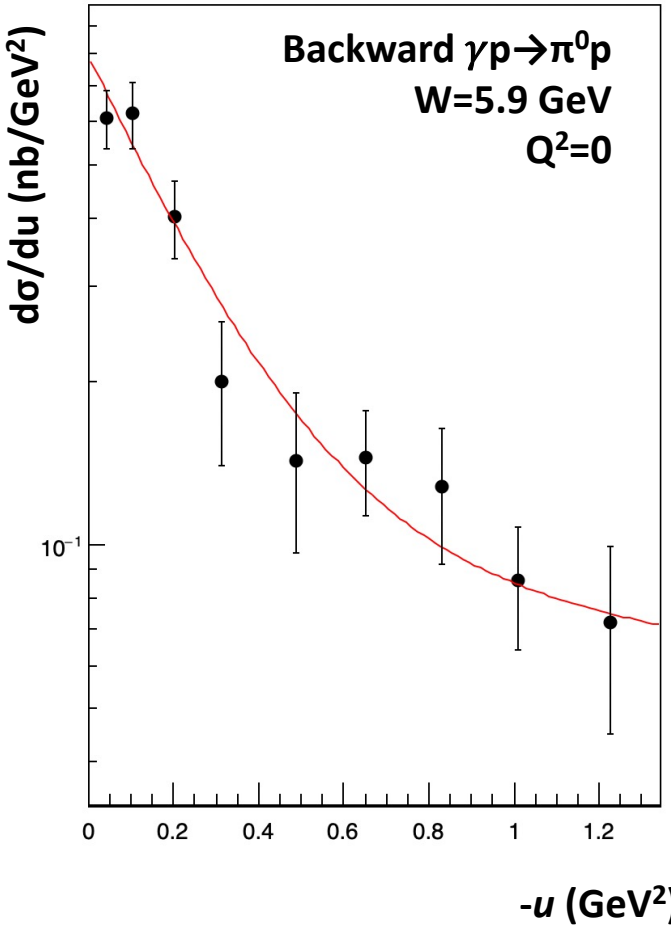

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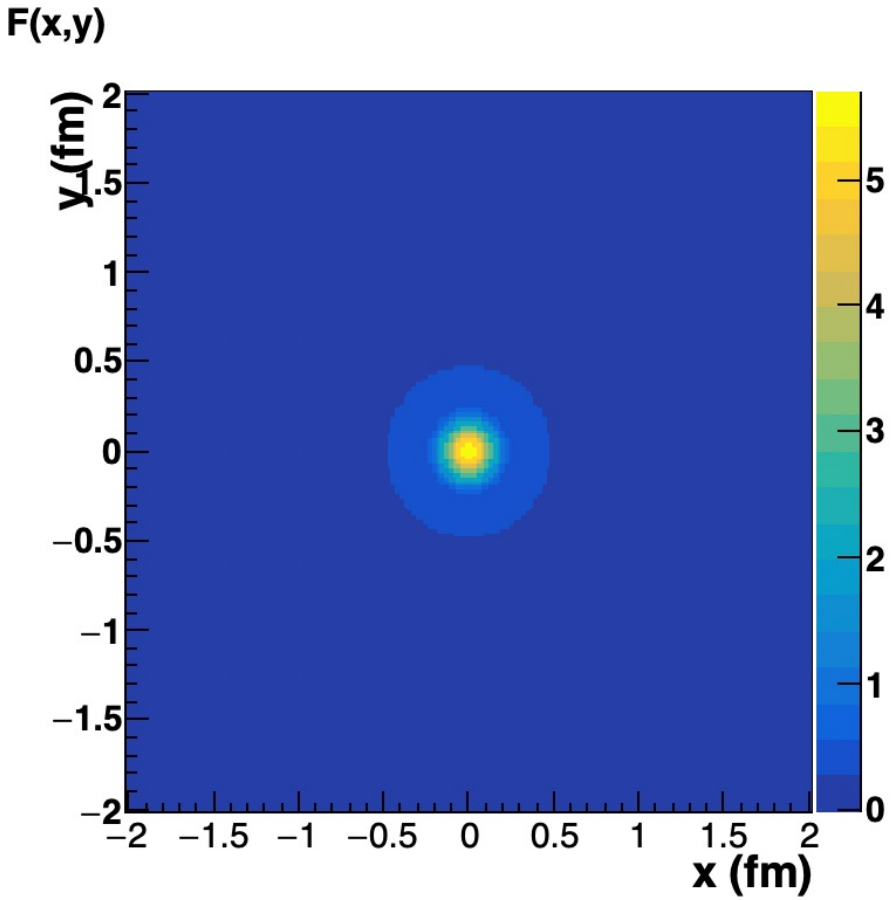

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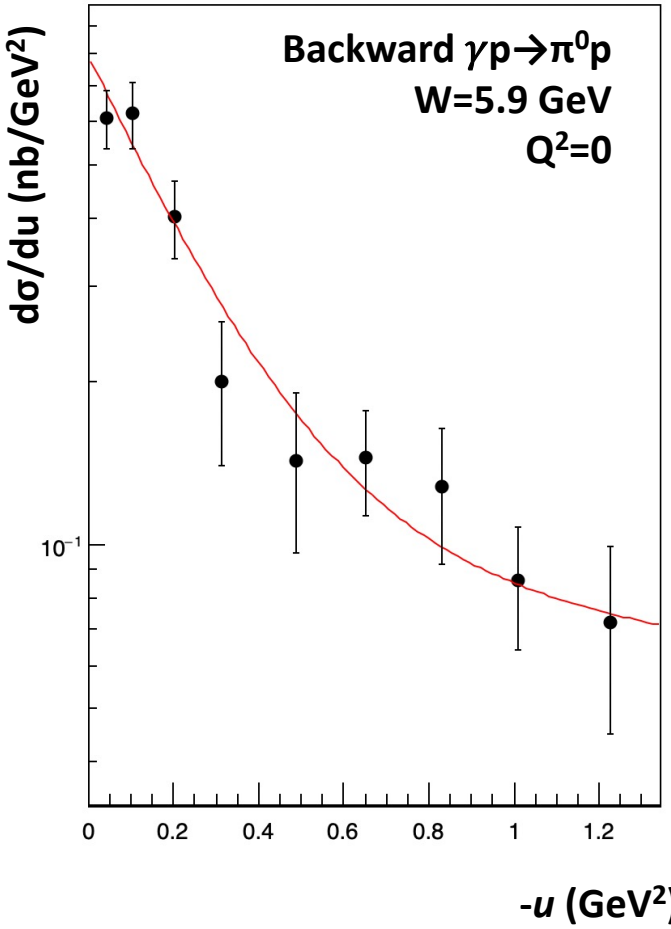

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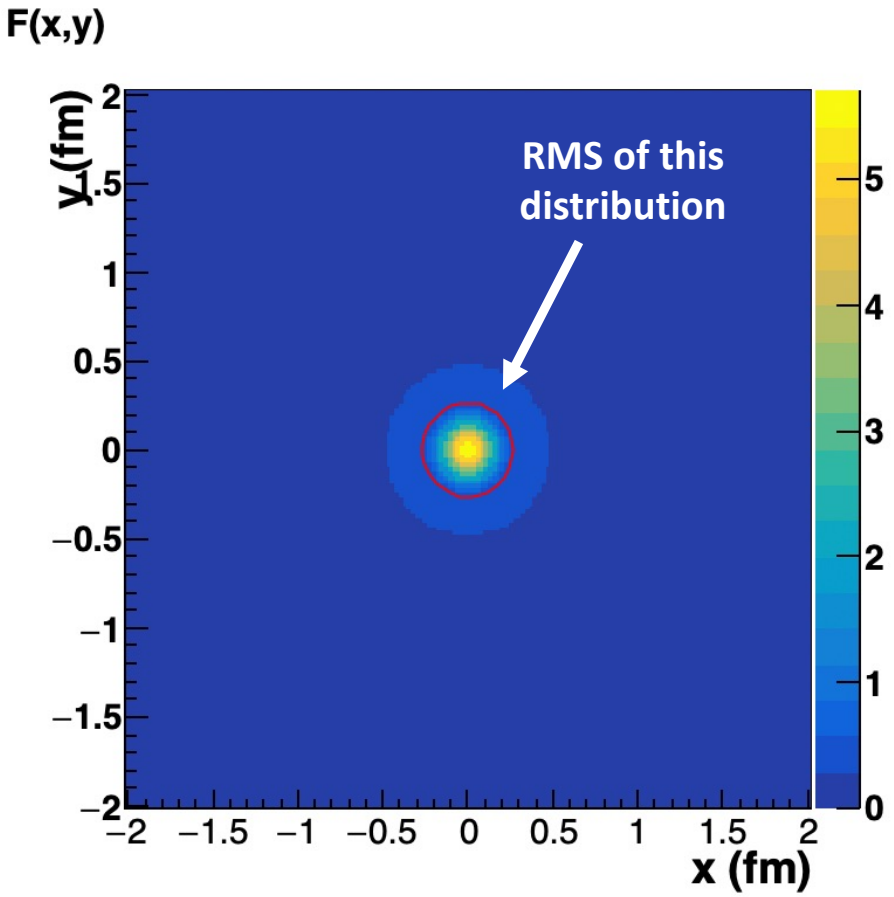

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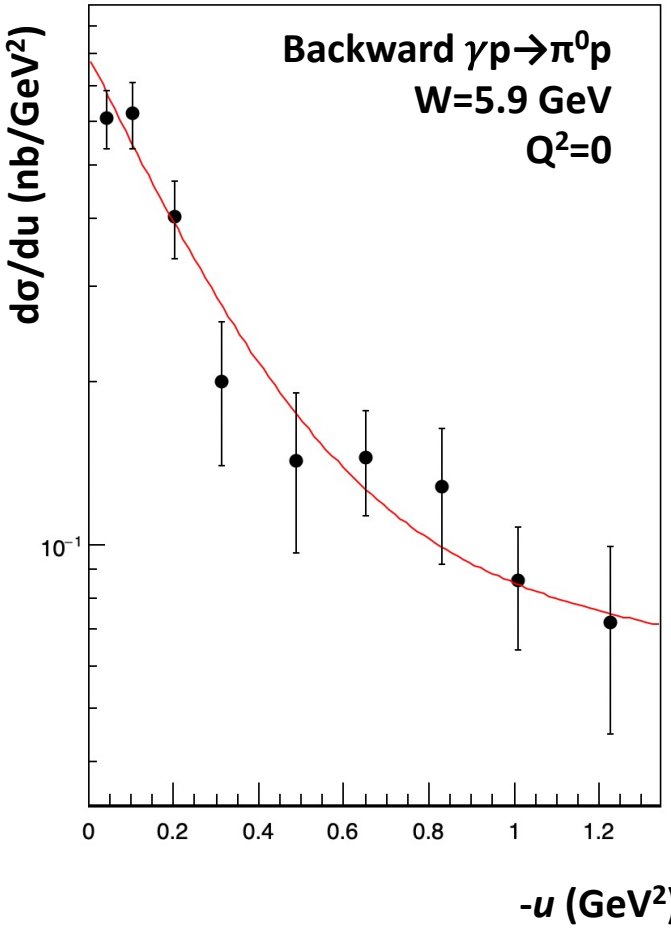

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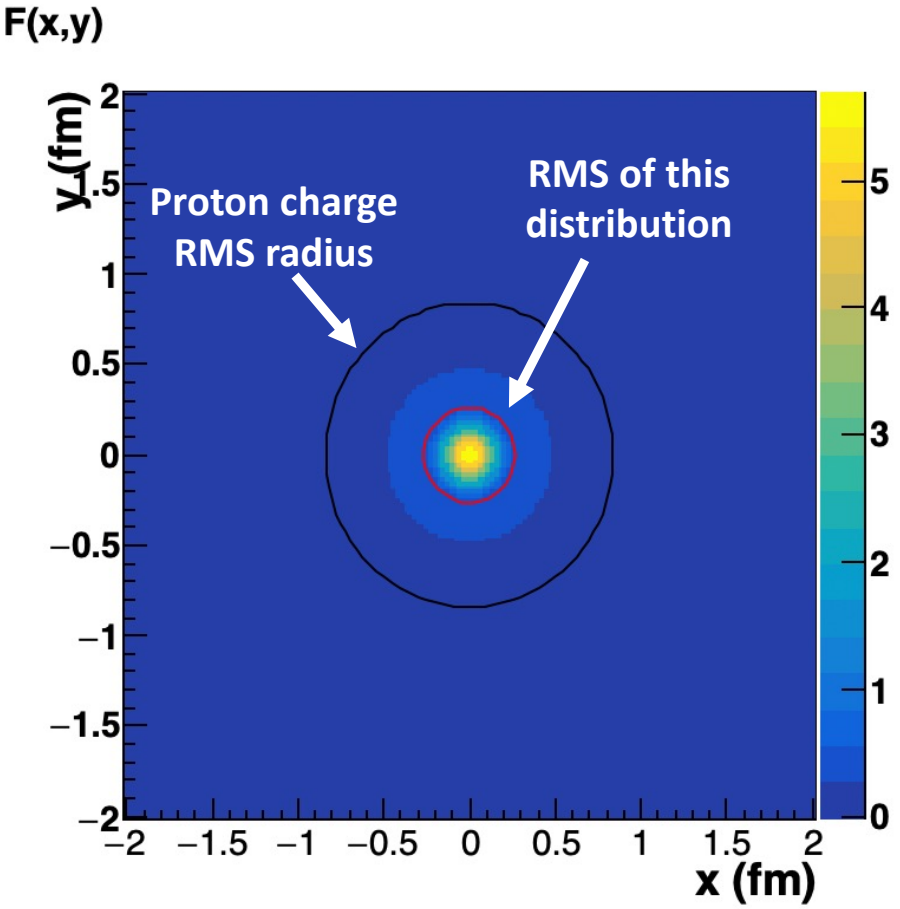

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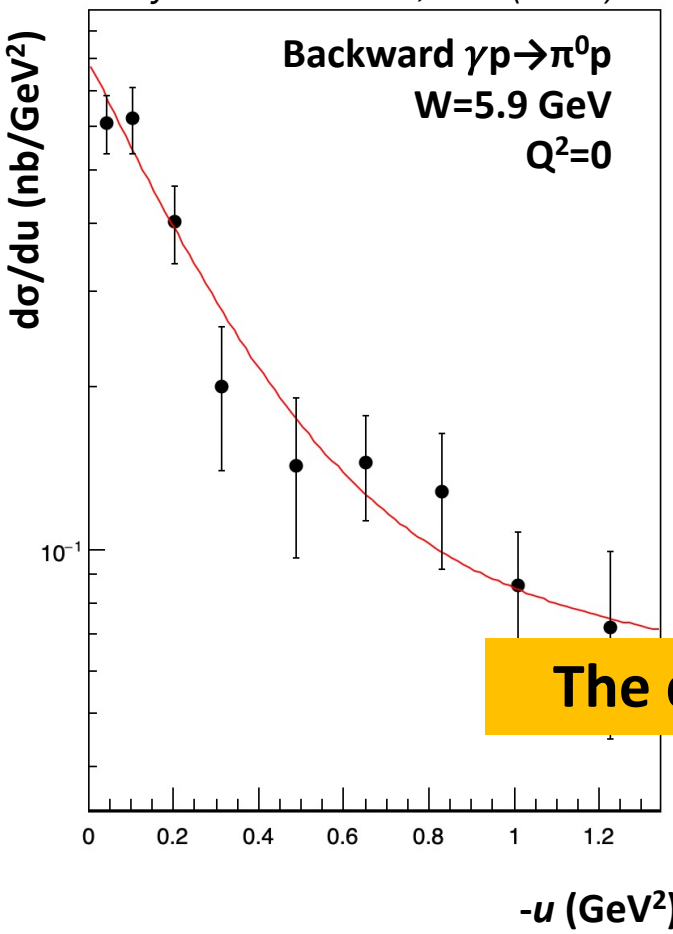

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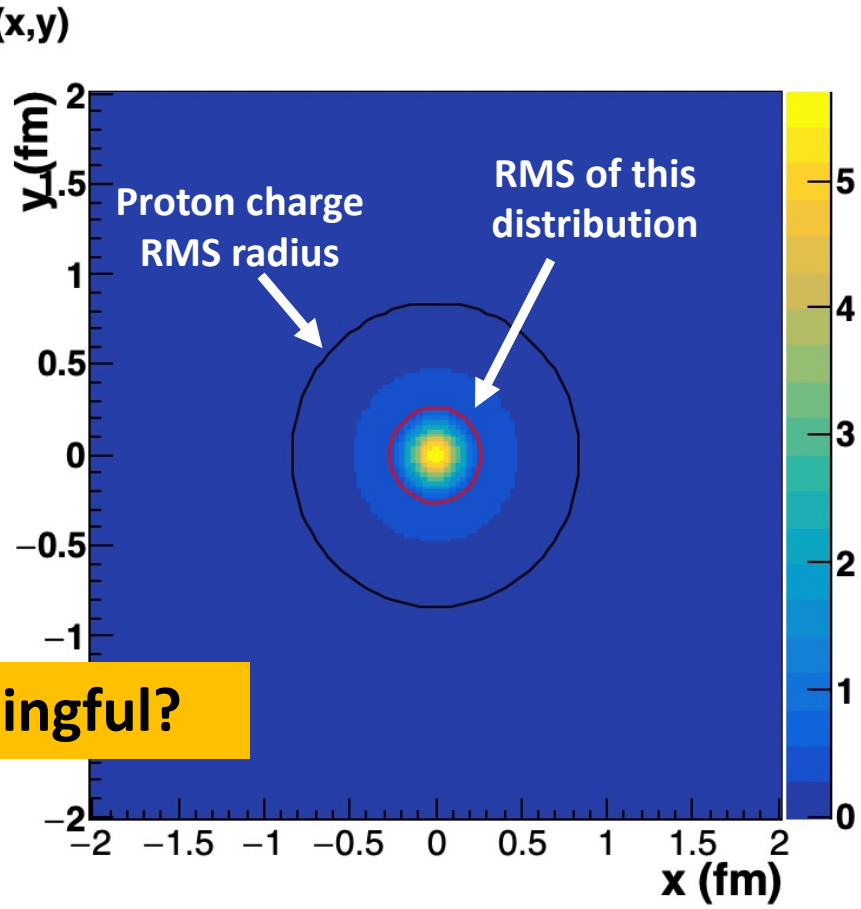

The question now: Is this "object" meaningful?

19

Prithwish

- We can do a quick fit to backward cross sections and transform distribution around p_T~0 (u~0)
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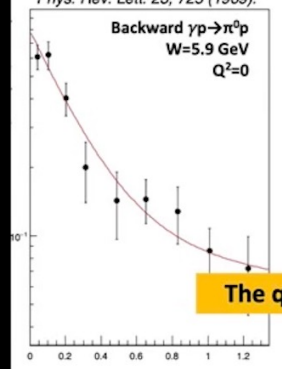
Phys. Rev. Lett. 23, 725 (1969).

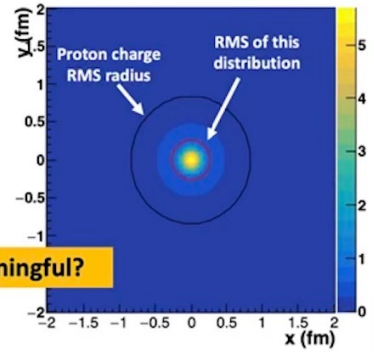
Backward $\gamma p \to \pi^0 p$
W=5.9 GeV
Q^2=0



-u (GeV^2)

$$F(b) \propto \frac{1}{2\pi} \int_0^{\sqrt{u_{max}}} dp_T p_T J_0(bp_T) \sqrt{\frac{d\sigma}{du}}$$

F(x,y)



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Zachary Sweger 4/21/23 CA Consortium for EIC Meeting 25

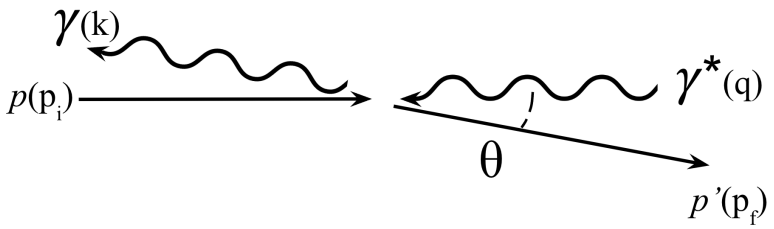
I want to know more about this

Thu, Jan 11 at 6:50 PM

Sure!

What we've learned

t-channel: transform around t~0, θ ~0



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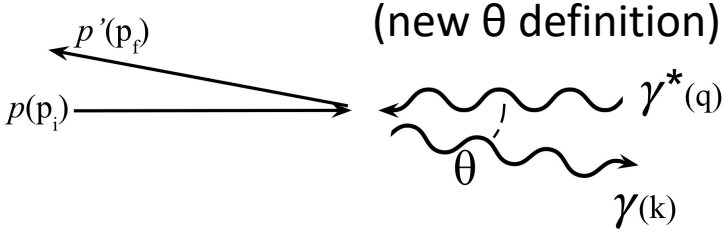

Actually it's not reasonable to assume zero skewness in the *u* channel!

t-channel: ξ→0 as θ→0

$$\xi = -\frac{(p_{N'} - p_N)\cdot n}{(p_{N'} + p_N)\cdot n}$$

u-channel: ~~ξ→0~~ as θ→0

$$\xi = -\frac{(p_{\mathcal{M}} - p_N)\cdot n}{(p_{\mathcal{M}} + p_N)\cdot n}$$

Accounting for mass differences between proton and meson, it's also not the case that u=0 at θ=0.

t-channel: t→0 as θ→0

$$t = (p_{N'} - p_N)^2$$

u-channel: ~~u→0~~ as θ→0

$$u = (p_M - p_N)^2$$

This was an exploratory study and we have a lot more to learn!

Final thoughts

- u-channel production at the EIC may provide window into baryon number transfer
- We've developed models of ω, ρ production (Cebra, *et al*. PRC 106, 015204 (2022)) and π^0, γ (Sweger *et al*. PRC 108, 055205 (2023)) and simulated these at the EIC
- u-channel cross sections potentially represent interesting spatial information about the baryon number within the nucleon
- More careful consideration of u-channel collinear factorization needed in my attempts to interpret u-channel cross sections

Thank you for your attention!

zwsweger@ucdavis.edu