Backward (u-Channel) DVCS

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@ Hadron Femtography Workshop 2023

Aug/6/2023

Center for Frontiers in Nuclear Science

Stony Brook University

Outline

- **Revisit 6 GeV *u*-Channel data**
- **What are we probing?**
  - **A GPD like framework on backward proton structure (nucleon-photon Transition Distribution Amplitudes)**
  - **Are we probing the Baryon junction? [New Content]**
- **Experimental road map from JLab12 to EIC**
  - **Hall C**
    - A triple coincidence experiment
    - **Or do we even need a detector? [New Content]**
  - **CLAS 12 and SoLID [New Content]**
    - **Must map out -t distribution!**
  - **u-Channel DVCS at EIC (see nice presentation from Alex Jenstch)**

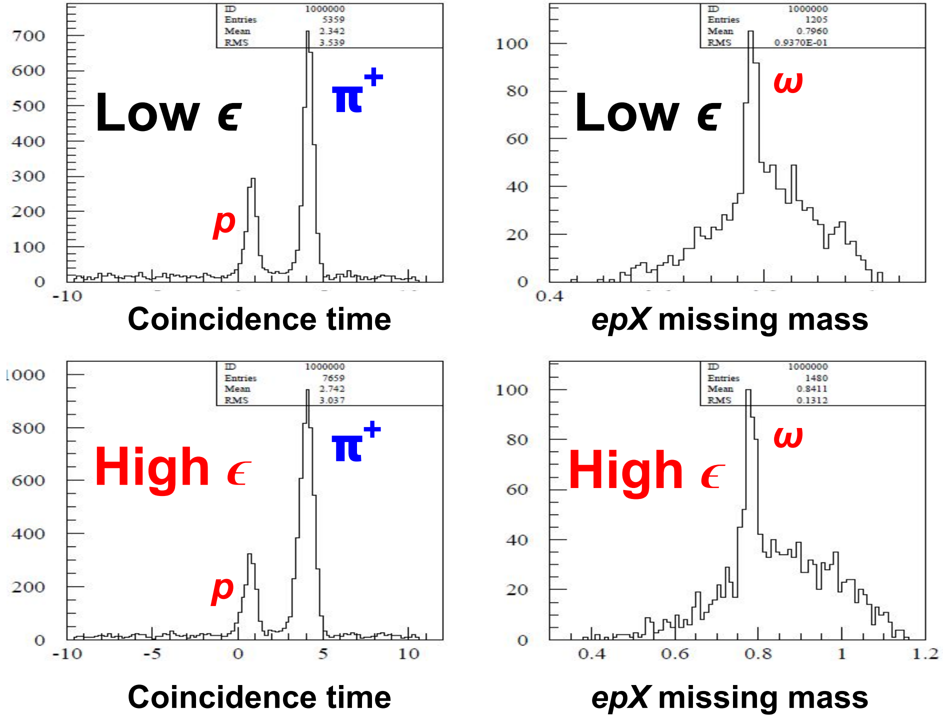
FREE!

Gifted Backward-angle Observables

- **Fpi-2 (E01-004) 2003**
  - Spokesperson: **Garth Huber, Henk Blok**
  - Standard HMS and SOS (e) configuration
  - **Electric form factor of charged π** through exclusive π production
- **Primary reaction for Fpi-2**
  - **H(*e, e' π^+*)*n***
- **In addition, the experiment fortuitously received**
  - ***p(e,e' p)ω***
- **Kinematics coverage**
  - ***W*= 2.21 GeV, Q^2=1.6 and 2.45 GeV^2**
  - Two ϵ settings for each Q^2

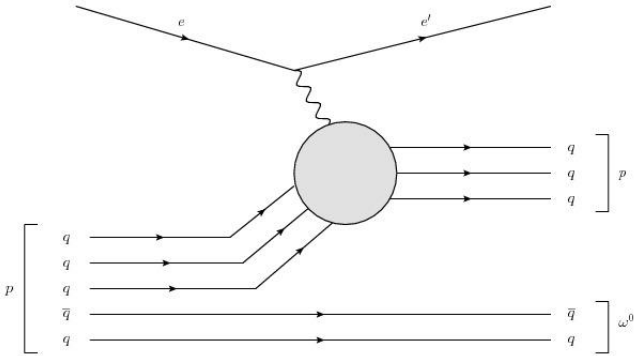
Q^2=2.45 GeV^2 2003

2003/07/25 08.56

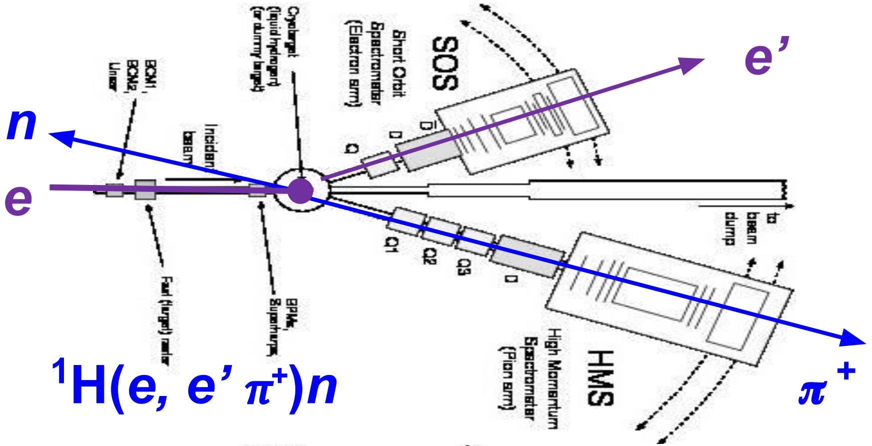


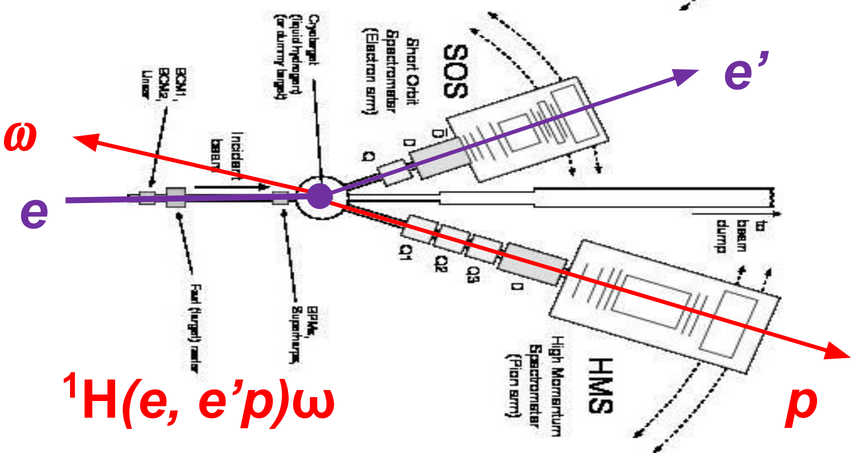
t-Channel π^+ vs *u*-Channel ω Electroproduction

- **Primary reaction for Fpi-2**
  - H(*e, e' π^+*)*n*
  - *n* (940 MeV)
  - π^+ (140 MeV)
- **Unexpected reaction:**
  - H(*e,e' p*)ω
  - p (940 MeV)
  - ω (783 MeV)



Mark Strikman & Christian Weiss: A proton being knocked out of a proton process

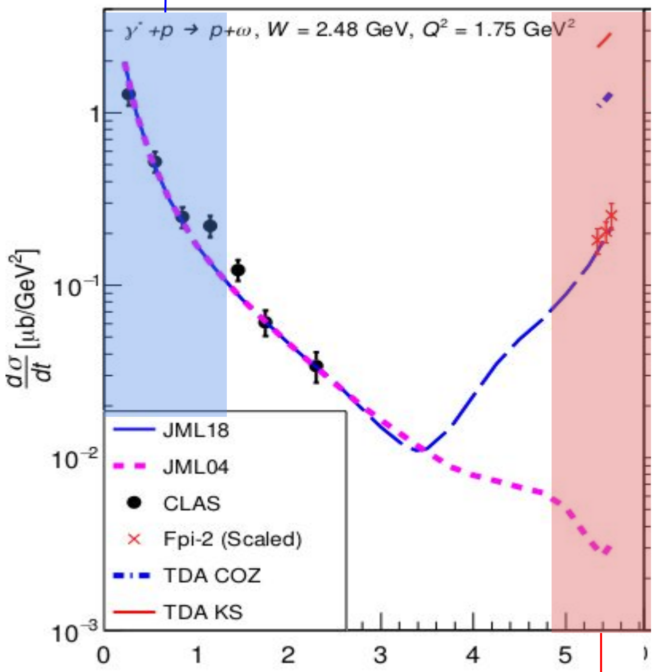




Two Key Discoveries from Fpi-2 ω Analysis

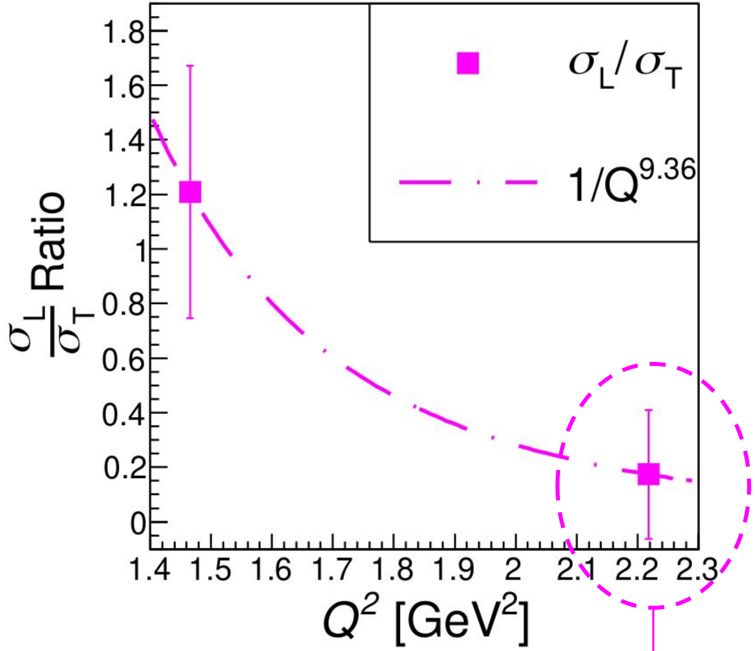
Discovery 1: Unexpected large *u*-Channel peak

Forward ω electroproduction from CLAS 6 *(2004)*



Backward angle ω electroproduction *(2017)*

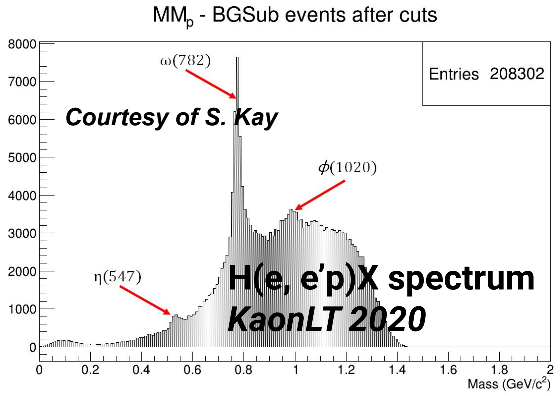
Discovery 2: $\sigma_T > \sigma_L$, $\sigma_L \sim 0$

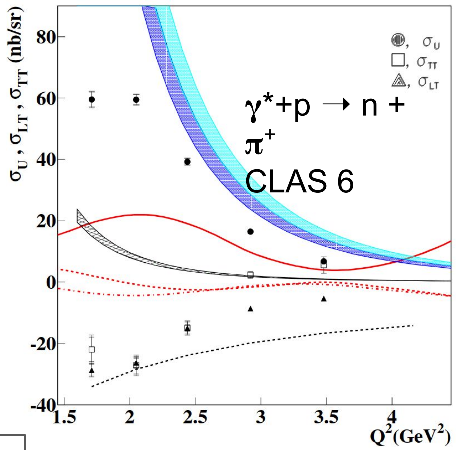


$$\frac{\sigma_T}{\sigma_L} \sim 0 \text{ at } Q^2 = 2.2\,\text{GeV}^2$$

Therefore, $\sigma_T > \sigma_L$

Question: Are there *u*-channel peaks for other processes? Yes!





	$\sigma_T > \sigma_L$	$1/Q^8$ Scaling
π^0	○	○
π^+		✓✓
π^-		
K^0		
$K^\pm$		
η	✓	✓
ρ		
ω	✓✓	✓
η'	✓	✓
ϕ	✓	✓
J/ψ		
DVCS		

Approved proposal

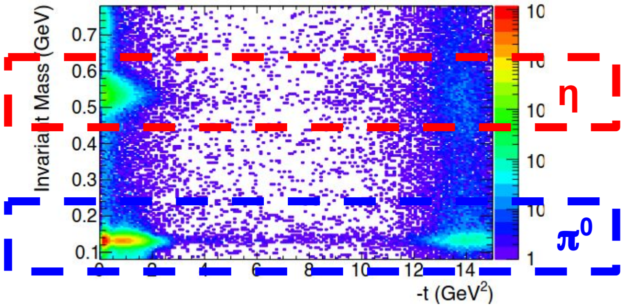
Confirmed! By CLAS6

Confirmed!

Hall C GlueX

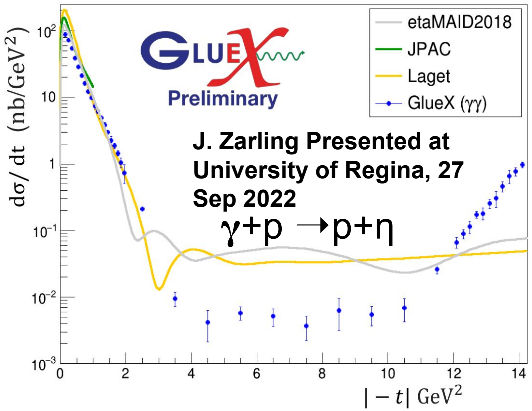
GlueX mass vs -t Phasespace

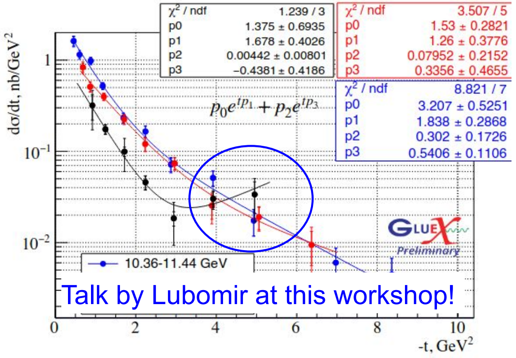
t-channel u-channel



By J.R. Stevens, at u-channel Physics workshop, 2020

$E_\gamma = 8.25 \pm 0.25$ GeV





Probing the *u*-channel observables

- **We can't enter EIC era without systematically study u-channel interactions! (Will expand on this)**
- **Only one approved experiment by PAC**

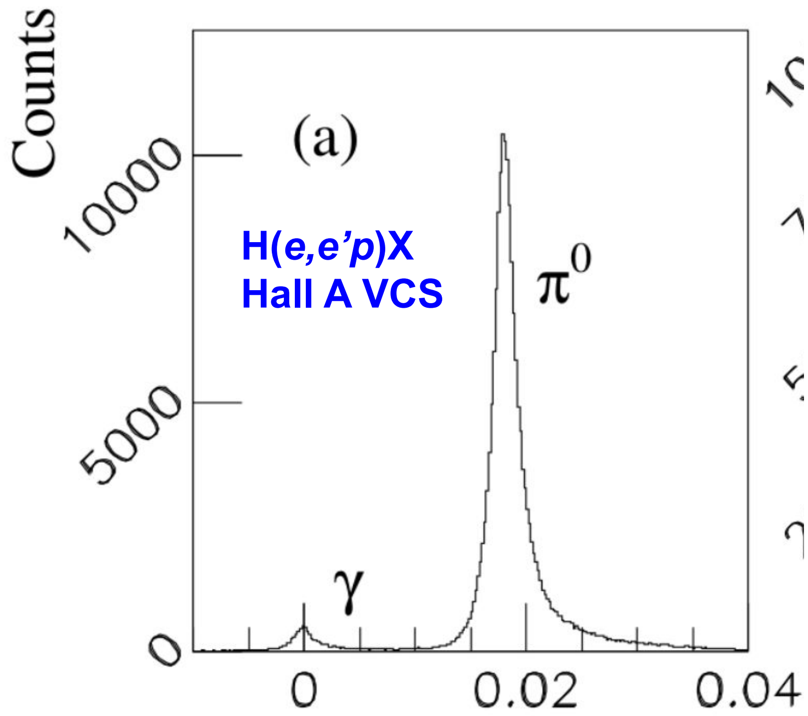
	Backward-angle Peak Seen?	Big Mac Interest Index
π^0	**E12-20-007** → ○	Boring and Not Interesting!
π^+	**CLAS 6** → ✓✓	
π^-		
K^0		
$K^\pm$		
η	✓	
ρ		
ω	**Hall 6 Fpi2** → ✓✓	
η'	✓	
ϕ	✓	
DVCS	□	May be

"Free" data from KaonLT and PionLT (η, ρ, ω, η', ϕ)

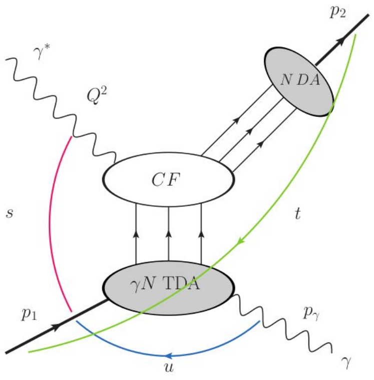
← **Dave Mack's** opinion to gauge the level of interest

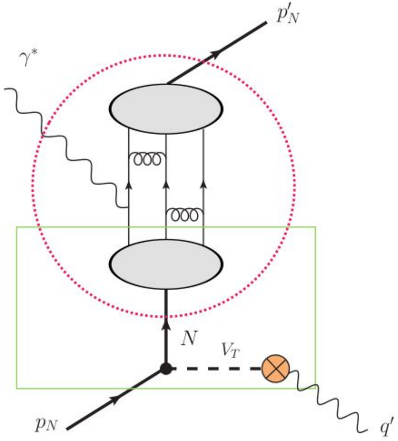
DVCS → Our focus today

Why there is a non-zero *u*-Channel DVCS



Observed at a lower ***W*** and ***Q***^{2}

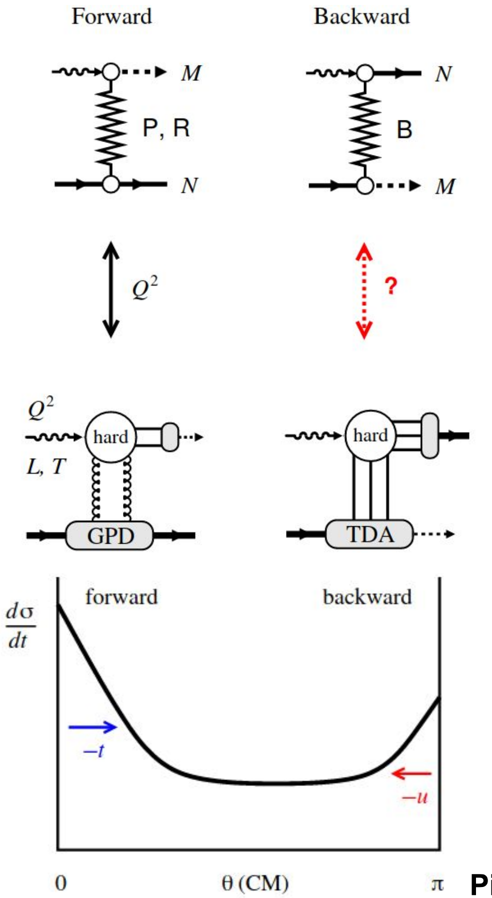




- **Left: experimental evidence of existence of VCS events**
- **Top: Hall C u-Channel ω combined with the VDM can be used to estimate the rate**
  - **1/10 of the forward DVCS cross section**

https://arxiv.org/abs/hep-ex/0406062

A Systematic Approach on *u*-Channel Meson Electroproduction



- Soft Exchange Mechanism: Regge Approach

- A hard exchange mechanism: GPD-like Approach

- Baryon Junction Model? [New]

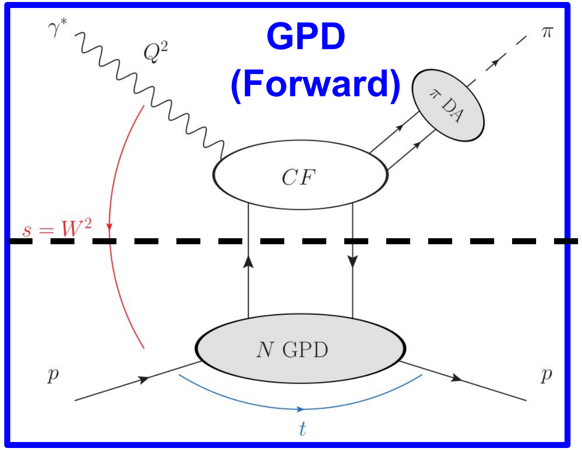
Picture from C. Weiss

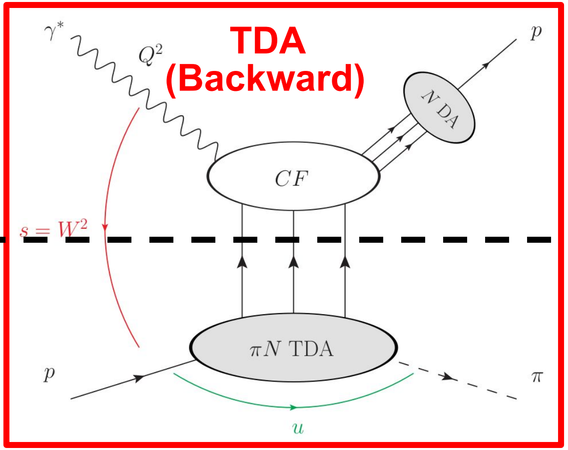
GPD and TDA (Hard Structure Approach)

Hard structure

Soft structure

By **X. Ji et al.** in 1997





Collinear factorization

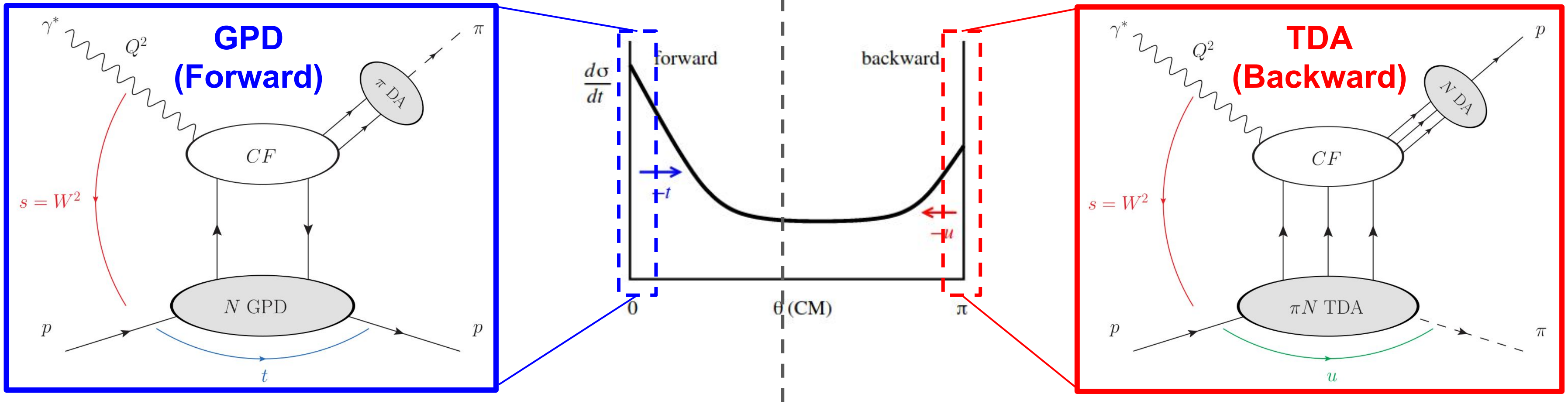
Developed by **B. Pire**, **L. Szymanowski** and **K Semenov-Tian-Shansky** in 2005

Description to the unseen side of proton

Complete description of Nucleon

- **GPD**: It is extracted predominantly based in the forward angle observables.
- **TDA**: meson-nucleon Transition Distribution Amplitude (TDA) only accessible through backward (*u*-channel) meson production.

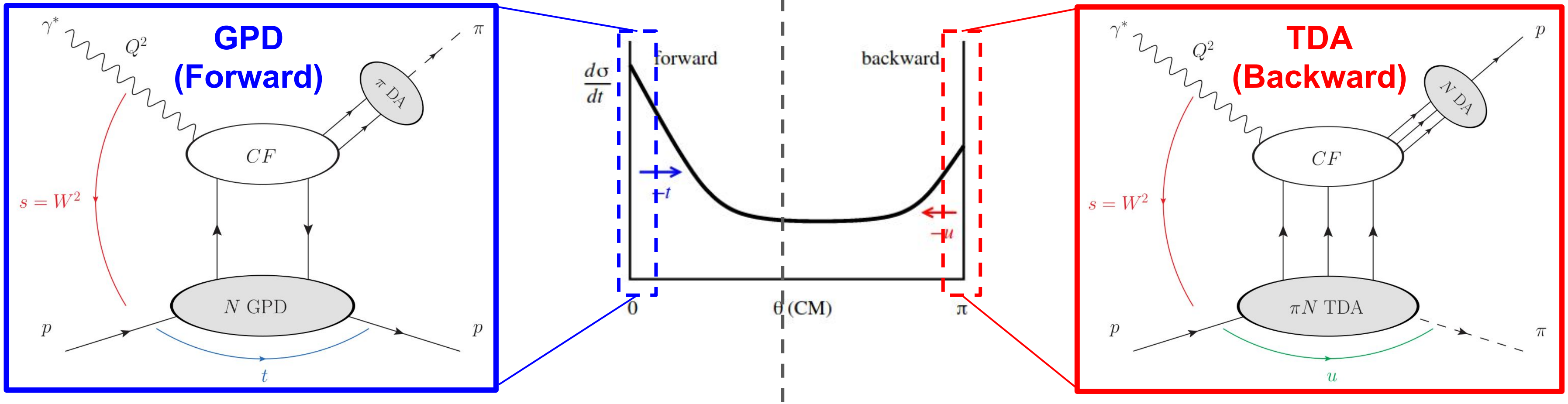
GPD vs TDA Fact sheet 2



- **Factorization: Q^2→large, $-t$ →small**
- **Systematically study forward DVCS & DVMP**
- **Factorization indicator:**
    - **$\sigma_L >> \sigma_T$**
    - **$d\sigma_L/dt \propto 1/Q^6$**
- **Factorization conclusion results from most meson production channels.**

- **Factorization: Q^2→large, $-u$→small ($-t$→large)**
- **Systematically study backward DVCS & DVMP?**
- **Factorization indicator:**
    - **$\sigma_T >> \sigma_L$**
    - **$d\sigma_T/dt \propto 1/Q^{10}$ ($d\sigma_T/d\Omega \propto 1/Q^8$)**
- **Factorization conclusion results from most meson production channels.**

GPD vs TDA Fact sheet 3



- **Formalism: four compact structures**

$$\int_{-1}^{1} dx H_q(x,\xi,t) = F_1^q(t), \quad \int_{-1}^{1} dx E_q(x,\xi,t) = F_2^q(t),$$

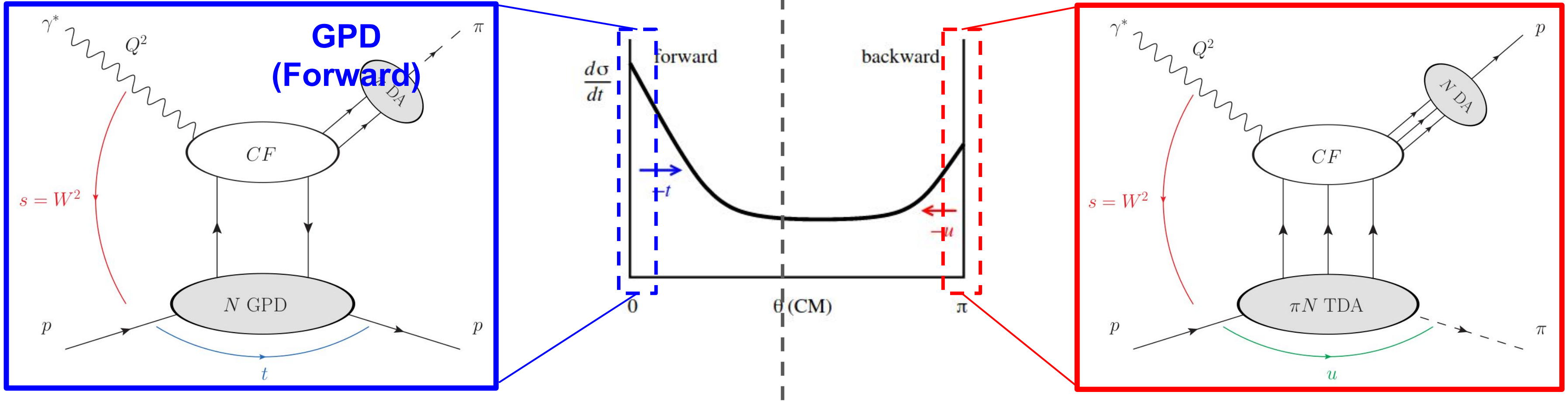
$$\int_{-1}^{1} dx \tilde{H}_q(x,\xi,t) = G_A^q(t), \quad \int_{-1}^{1} dx \tilde{E}_q(x,\xi,t) = G_P^q(t),$$

- **Formalism: experimentalist friendly, directly linked to cross section (example later)**

$$H_{s.f.}^{\pi N} = \{V_{1,2}^{\pi N}, A_{1,2}^{\pi N}, T_{1,2,3,4}^{\pi N}\}$$ π↔p TDAs

$$H_{s.f.}^{\gamma N} = \left\{V_{1\varepsilon}^{\gamma N}, A_{1\varepsilon}^{\gamma N}, T_{1\varepsilon,\,2\varepsilon}^{\gamma N}\right\}$$ γ↔p TDAs

GPD vs TDA Fact sheet 4



Cons:

- **Only consider *t*-Channel σ peak (ignores *u*-channel σ peaks)**
- **No direct experimental access to GPD, intermediate theory framework is needed, Compton Form Factor is required.**

$$\mathcal{F} = \int_{-1}^{+1} dx\, F(x,\xi,t) \left(\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon} \right)$$

$$\tilde{\mathcal{F}} = \int_{-1}^{+1} dx\, \tilde{F}(x,\xi,t) \left(\frac{1}{\xi - x - i\epsilon} + \frac{1}{\xi + x - i\epsilon} \right)$$

$$F = H, E\ ,\ \tilde{\mathcal{F}} = \tilde{\mathcal{H}}, \tilde{\mathcal{E}},\ F = H, E,\ \tilde{F} = \tilde{H}, \tilde{E}.$$

Cons:

- **Only consider *u*-Channel σ peak (ignores *t*-channel σ peaks)**
- **Require Empirical Nucleon Distribution Amplitude as input, example**
  - **KS:** King and Sachrajda nucleon wave functions parameterization
  - **COZ:** Chernyak, Ogloblin and I. R. Zhitnitsky nucleon wave functions parameterization

TDA Meson Production Cross Section

- Unpolarized exclusive meson production cross section for π^0:

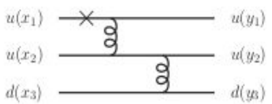
$$\frac{d^2\sigma_T}{d\Omega_\pi} = |\mathcal{C}^2| \frac{1}{Q^6} \frac{\Lambda(s, m^2, M^2)}{128\,\pi^2 s(s - M^2)} \frac{1+\xi}{\xi} \left(|\mathcal{I}|^2 - \frac{\Delta_T^2}{M^2}|\mathcal{I}'|^2\right)$$

$$\mathcal{I} = \int \left(2\sum_{\alpha=1}^{7} T_\alpha + \sum_{\alpha=8}^{14} T_\alpha \right)$$

$$\mathcal{I}' = \int \left(2\sum_{\alpha=1}^{7} T'_\alpha + \sum_{\alpha=8}^{14} T'_\alpha \right)$$

First expansion is shown as an example

$$\Delta^2 \equiv u$$

α		T_α	T'_α
1		$\frac{-Q_u(2\xi)^2[(V_1^{p\pi^0} - A_1^{p\pi^0})(V^p - A^p) + 4T_1^{p\pi^0}T^p + 2\frac{\Delta_T^2}{M^2}T_4^{p\pi^0}T^p]}{(2\xi - x_1 - i\epsilon)^2(x_3 - i\epsilon)(1-y_1)^2 y_3}$	$\frac{-Q_u(2\xi)^2[(V_2^{p\pi^0} - A_2^{p\pi^0})(V^p - A^p) + 2(T_2^{p\pi^0} + T_3^{p\pi^0})T^p]}{(2\xi - x_1 - i\epsilon)^2(x_3 - i\epsilon)(1-y_1)^2 y_3}$

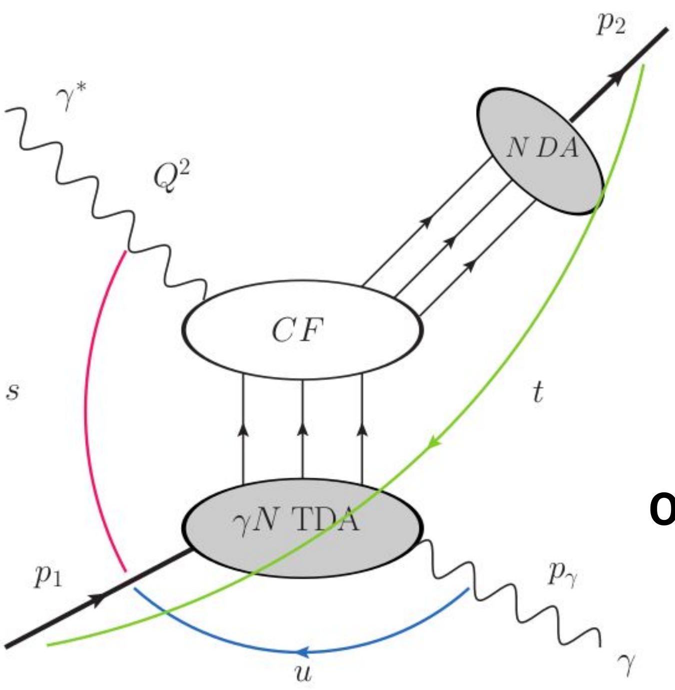
Red dashed boxes: TDAs
Blue dashed boxes: Nucleon DAs
Green box: *u*

CZ N-DA parameterization

$$V^p(x_i) = \varphi_{as}[11.35(x_1^2 + x_2^2) + 8.82x_3^2 - 1.68x_3 - 2.94],$$
$$A^p(x_i) = \varphi_{as}[6.72(x_2^2 - x_1^2)],$$
$$T^p(x_i) = \varphi_{as}[13.44(x_1^2 + x_2^2) + 4.62x_3^2 + 0.84x_3 - 3.78],$$

J. P. Lansberg, B. Pire, K. Semenov-Tian-Shansky, L. Szymananovski, Phys. Rev. D 85, 054021, 201

Backward-angle DVCS



- Matrix element directly proportional to:

$$H^{\gamma N}_{s.f.}(x,\,\xi_u,\Delta^2) = H^{\gamma N}_{s.f.}(x,\,\xi_u) \times G(\Delta^2) \qquad \Delta^2 \equiv u$$

$$H^{\gamma N}_{s.f.} = \left\{ V^{\gamma N}_{1\varepsilon},\, A^{\gamma N}_{1\varepsilon},\, T^{\gamma N}_{1\varepsilon,\,2\varepsilon} \right\}$$ γ↔p TDAs

u-slope Transition Form Factor

Objectives:

- **Offering the strongest evidence to validate TDA factorization**
  - **Proving $\sigma_T > \sigma_L$ and demonstrating $\sigma_T \propto 1/Q^8$**
  - **Help model development by offering experimental constraints**

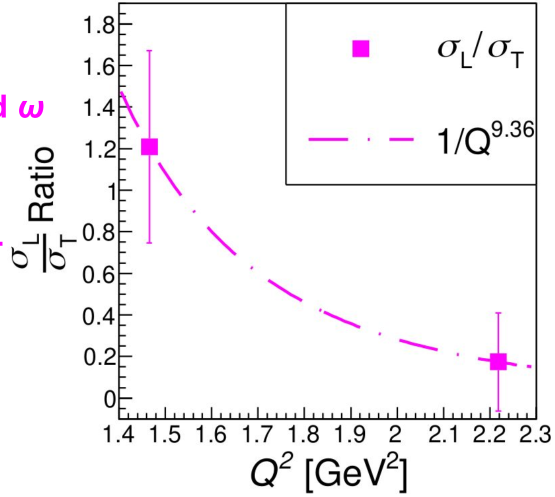
- **Data contain unique (complementary) information what is not described by GPD**

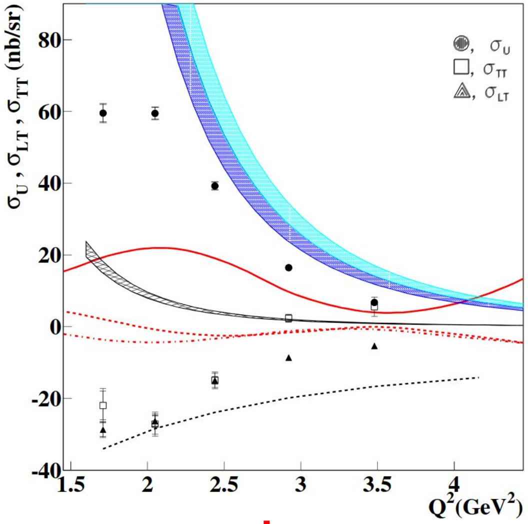
How do We Know TDA is not crazy? (Evidences)

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

K. Park et al. (CLAS), Phys. Lett.B780, 340(2018)

Hall C 6 GeV Backward ω (My analysis, 2017)





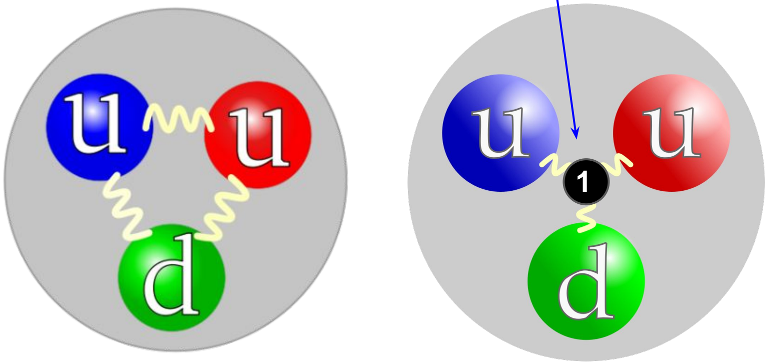
CLAS 6 backward π^+ production, (K. Park el. al, 2018)

Two qualitative predictions from TDA:

- $\sigma_T > \sigma_L$, $\sigma_L \sim 0$
- $\sigma_T \sim 1/Q^8$ **scaling behavior**
- ***u*-Channel DVCS would be the most direct evidence.**
- ***u*-Channel TCS should also be a interesting observable**

Looking for Baryon Junction via Exclusive u-Channel Processes

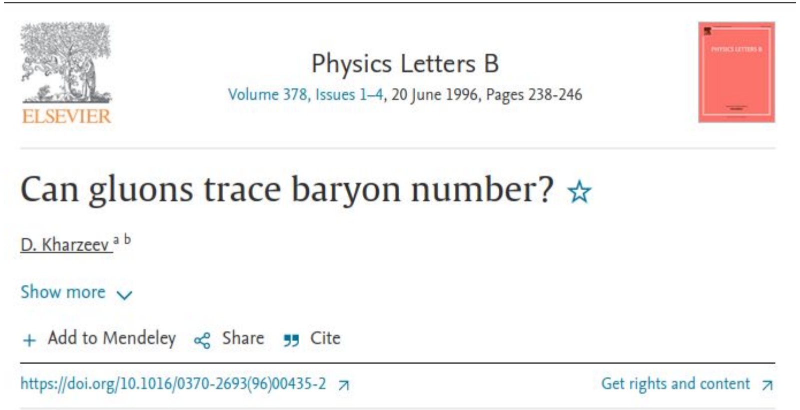
- **Which proton it more correct?**



A **B**

A: implies quark carries fractional baryon number

B: existence of a **"Junction" like structure** that carries the baryon number. (D. Kharzeev, https://arxiv.org/abs/nucl-th/9602027, 1996)



Physics Letters B
Volume 378, Issues 1–4, 20 June 1996, Pages 238-246

Can gluons trace baryon number? ☆

D. Kharzeev [a b]

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https://doi.org/10.1016/0370-2693(96)00435-2

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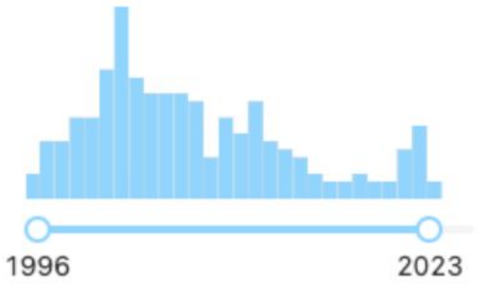
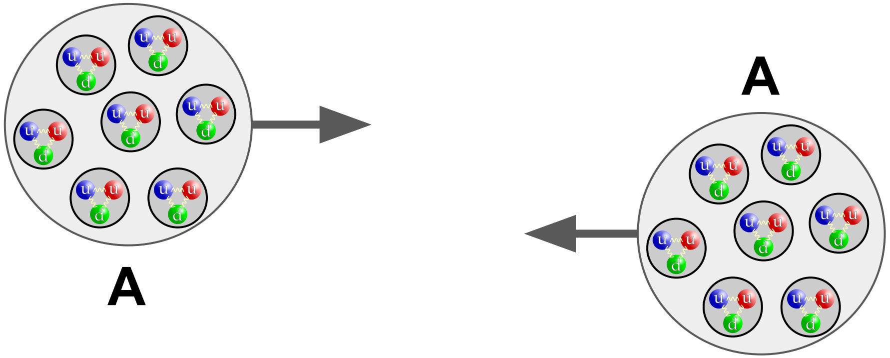
D. Kharzeev, Physics Letters B **378**, 238-246 (1996)
"Can gluons trace baryon number?"



Borrowed from slide from Xu,
https://indico.bnl.gov/event/18414/contributions/76065/attachments/47619/80734/xzb2EIC2D_05172023v2pdf.pdf

Probing Baryon Junction with A-A at RHIC



Charge vs. baryon transport in A+A collisions:

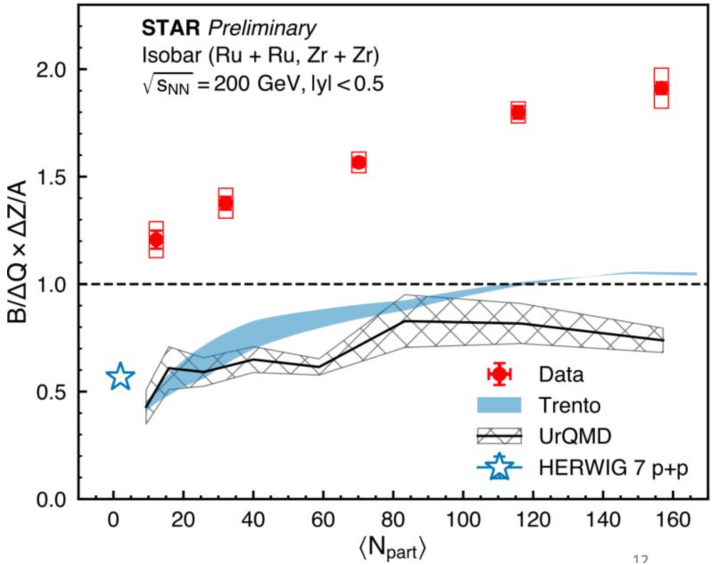
- If Valence quarks carry electric charge & baryon number:

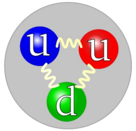
$$\frac{Z}{\text{Charge Stoppoing}} \times \frac{\text{Baryon Stopping}}{A} \cong 1$$

- If valence quarks carry electric charge & junctions cary baryon number

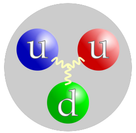
$$\frac{Z}{\text{Charge Stoppoing}} \times \frac{\text{Baryon Stopping}}{A} > 1$$

Tommy Tsang (KSU) for STAR, APS GHP 2023





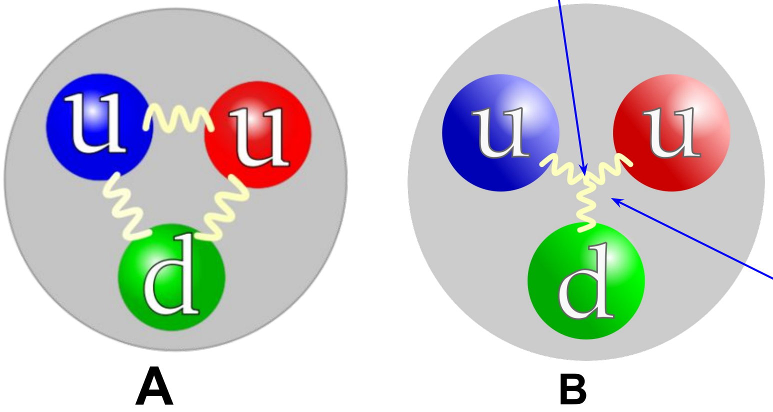
Theory: Quark Models: equal or less baryon compared to electric charge



Data: More baryon transported to central rapidity than electric charge

Looking for Baryon Junction via Exclusive u-Channel Processes

- **Which proton it more correct?**

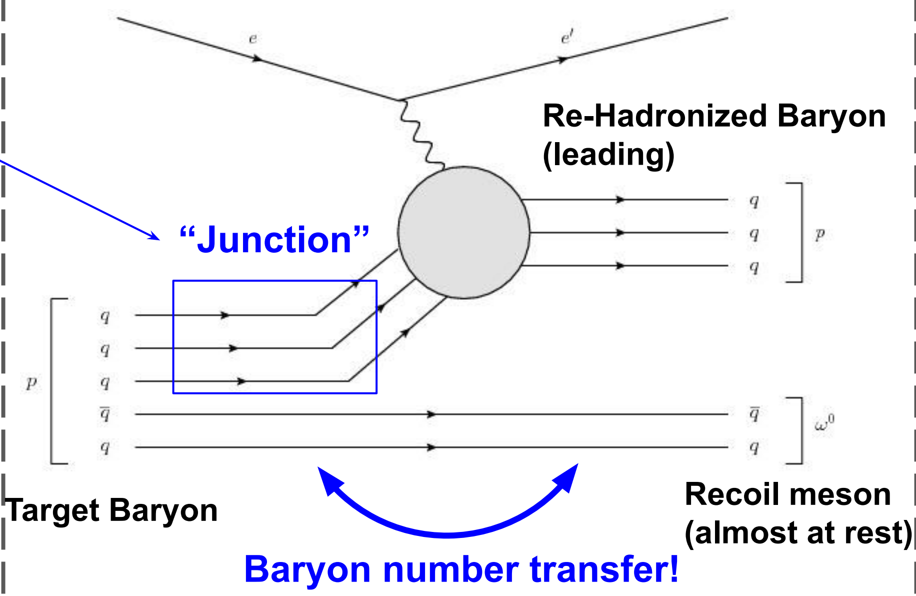


A: implies quark carries fractional baryon number

B: existence of a **“Junction” like structure** that carries the baryon number. (D. Kharzeev, https://arxiv.org/abs/nucl-th/9602027, 1996)

- **How do we probe this in JLab 12 GeV?**
  - Can we directly probe the “junction” structure?
  - May be. If manage to force the transfer of baryon number in the target and recoil particles, then Yes.

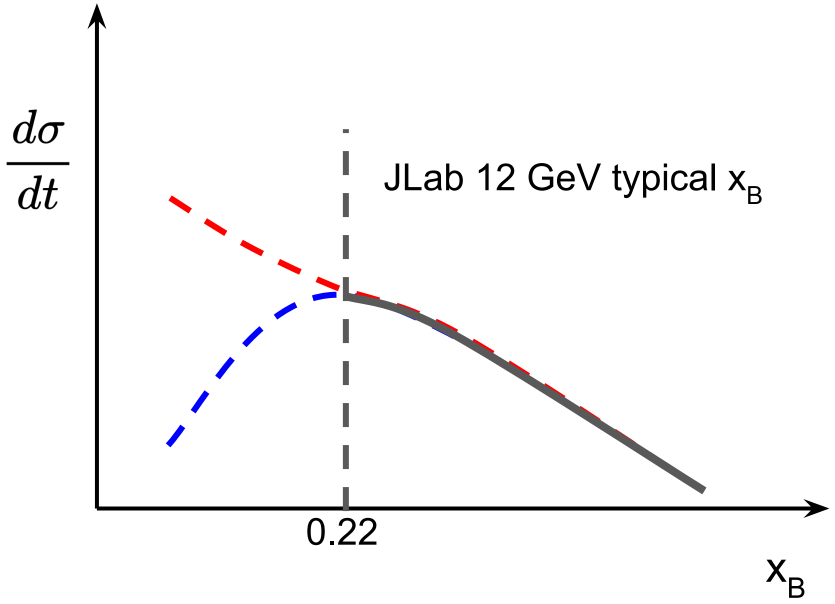
Exclusive u-Channel production



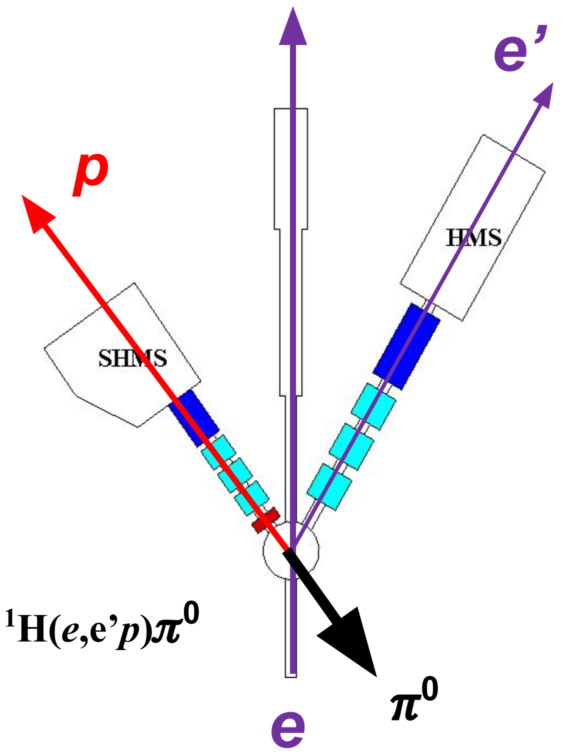
Probing Baryon Junction Via Charge Stopping

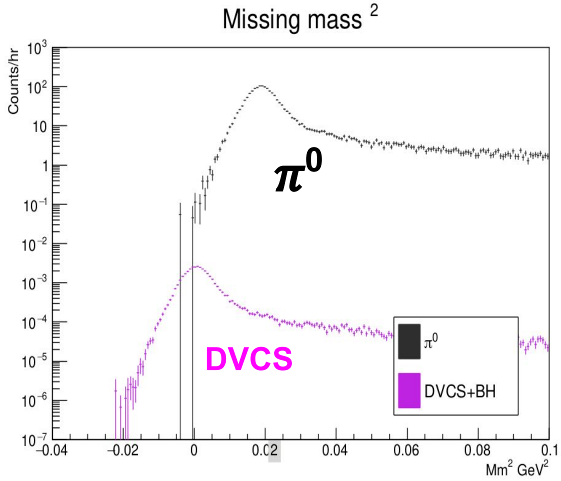
- **How do we know if we are probing the "junction"? Hypostasis**
  - **Junctions**: are construct of gluons: **Junction u-Channel cross section enhancement**
  - **No junction: u-Channel cross section suppressed valence quark contribution**

- **The JLab and EIC data are equally critical to test the hyposased x_B**



E12-20-007 Backward-angle $^1H(e,e'p)\pi^0$



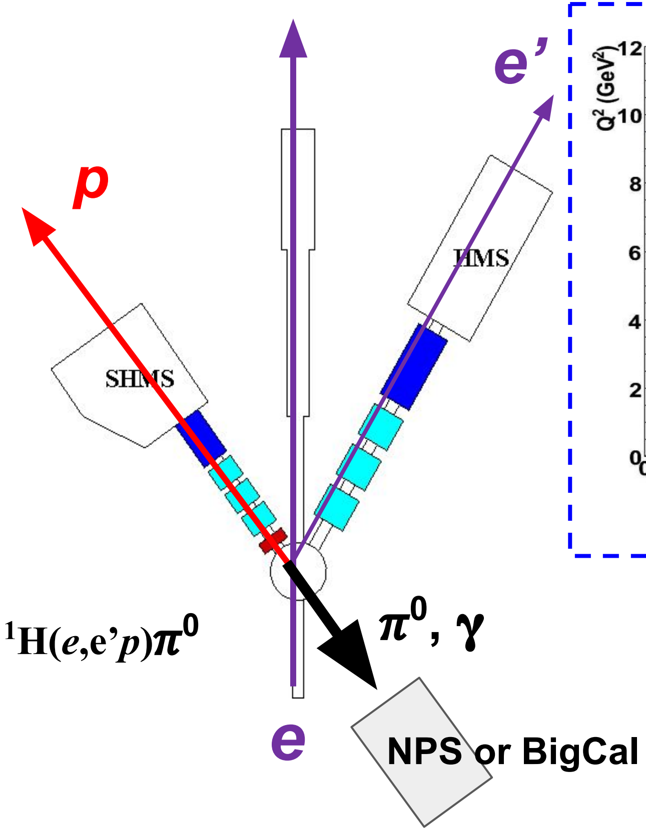


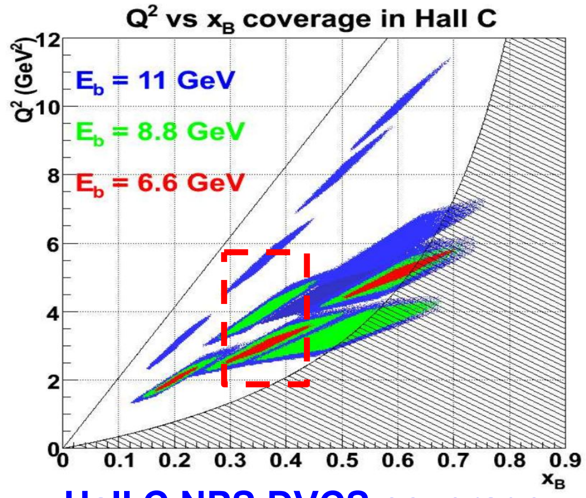
Q^2 GeV^2	W GeV	ϵ	x	θ_{pq} Degree
2.0	3.00	0.32	0.20	-3, 0
		0.79	0.20	-2.8, 0, +3
2.0	2.11	0.52	0.36	-3, 0, +3
		0.94	0.36	-3, 0, +3
3.0	2.49	0.54	0.36	-3, 0, +3
		0.86	0.36	-3, 0, +3
4.0	2.83	0.56	0.36	-3, 0, +3
		0.73	0.36	-3, 0, +3
5.0	3.13	0.26	0.36	-3, 0
		0.55	0.36	-3, 0, +3
6.25	3.46	0.27	0.36	0

First dedicated *u*-channel electroproduction study above the resonance region:

- **Q^2 coverage: $2.0 < Q^2 < 6.25$ GeV^2, at x=0.36 and W > 2 GeV L/T separated cross section @ Q^2= 2, 3, 4 and 5 GeV^2.**
- **u coverage: $0 < -u' + 0.5 < 0.5$ GeV^2**
- **Additional W scaling check @ Q^2 = 2 GeV^2**
- **Additional Q^2 scaling check @ Q^2 = 6.25 GeV^2**

Proposing A Triple Coincidence measurement: ^{1}H(e,$e'p\gamma$)





Hall C NPS DVCS coverage

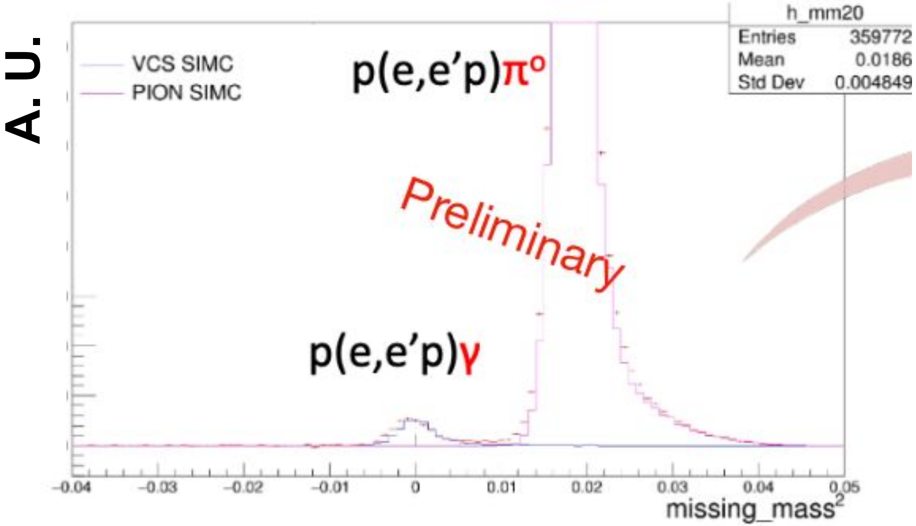
Q^2 GeV^2	W GeV	ϵ	x	θ_{pq} Degree
2.0	2.11	0.52	0.36	-3, 0, +3
		0.94	0.36	-3, 0, +3
3.0	2.49	0.54	0.36	-3, 0, +3
		0.86	0.36	-3, 0, +3
4.0	2.83	0.56	0.36	-3, 0, +3
		0.73	0.36	-3, 0, +3
5.0	3.13	0.26	0.36	-3, 0
		0.55	0.36	-3, 0, +3

First Triple Arm coincidence measurement?

- HMS + SHMS + NPS (or BigCal)
- Need NPS to detect: 200-500 MeV γ
- L/T separated cross section $2 < Q^2 < 5$ GeV^2, at x=0.36 and W > 2 GeV
- u coverage: $0 < -u' + 0.5 < 0.5$ GeV^2

~200-500 MeV Real Photon

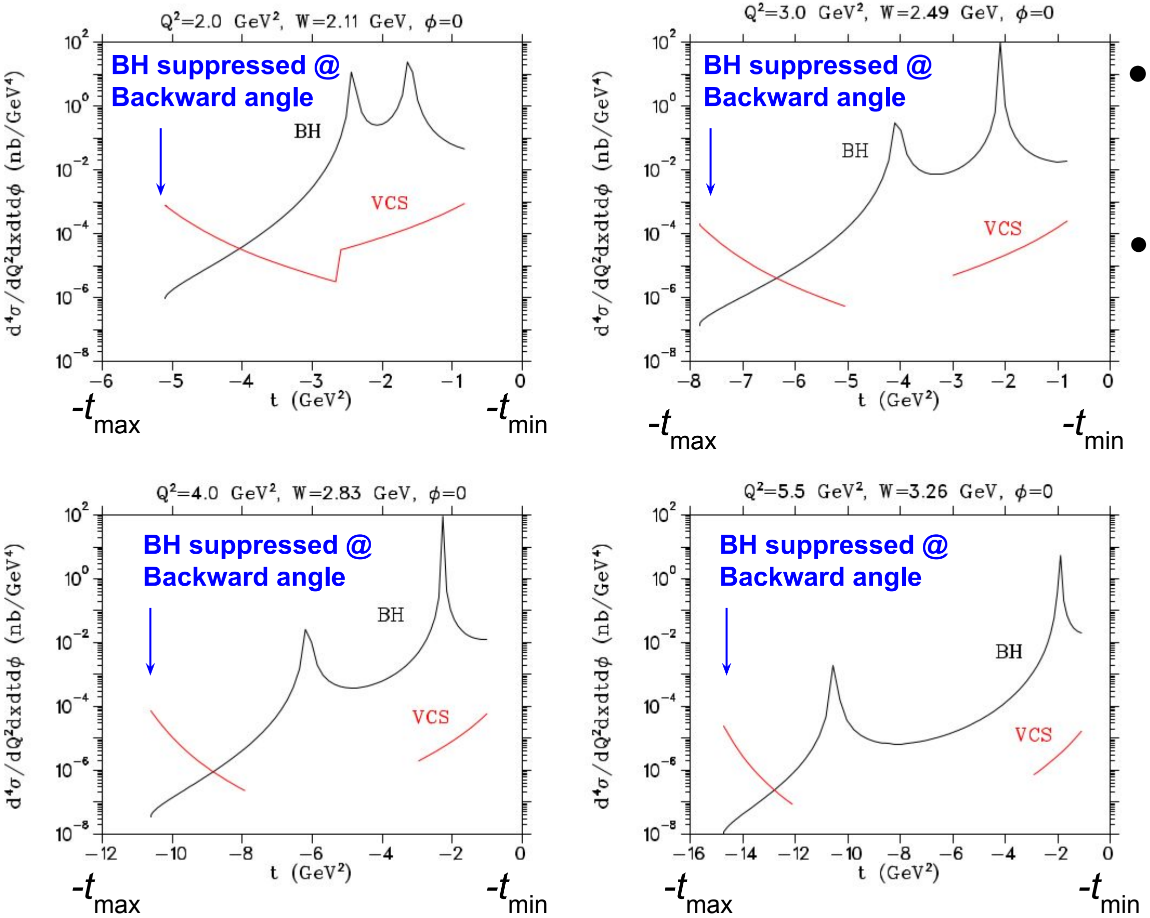
How We Really Need a Triple Coincidence Measurement?



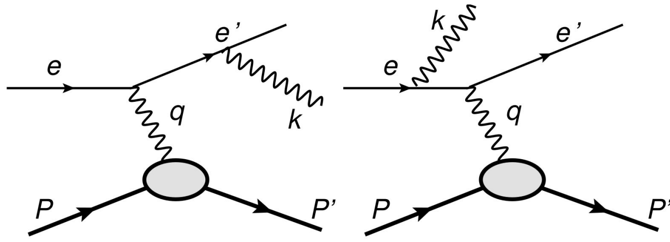
H. Rahimtula,el. al., Hall C VCS experiment

- **Recent 12 GeV VCS measurement revealed HMS+SHMS might be sufficient in extracting the u-Channel DVCS peak**
- **SImulation study is needed!**
- **We might not need a triple coincidence experiment.**
- **SHMS+HMS coincidence for a lot longer!**

No Bethe-Heitler in *u*-Channel Kinematics



- **Bethe-Heitler suppressed in $-t \sim -t_{Max}$ or $-u \sim -u_{Min}$**
  - **Used the classic BH description**
- **BH don't associate with the nucleon structure**
  - **Highly suppressed in the u-channel kinematics due to forward going electron momentum**



Vented by Andrei !

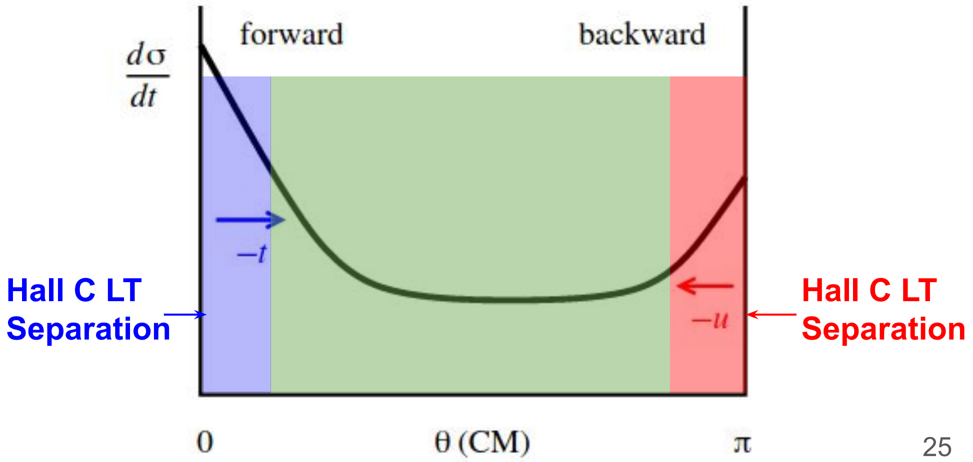
What can we do at JLab 12 GeV?

Hall C

- L/T separation offers the best theory constraints.
- High Luminosity of Hall C allows the measurement (low cross section) to be completed faster.
- Last chance in our lifetime to attempt this measurement.

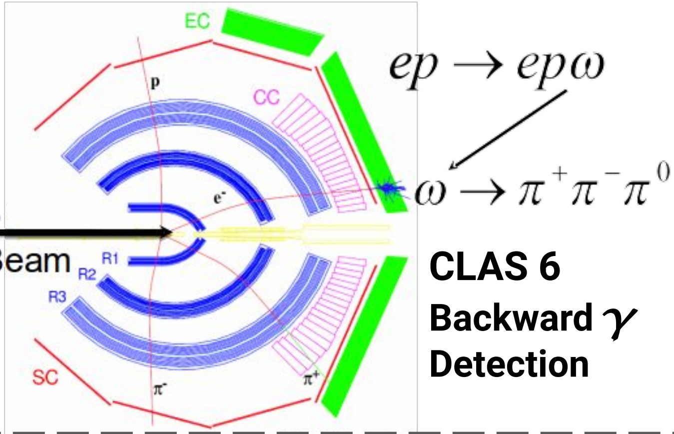
CLAS12 and SoLID

- Full -t distribution
- Large phasespace coverage
- An upgrade needed



u-Channel Opportunities at CLAS 12

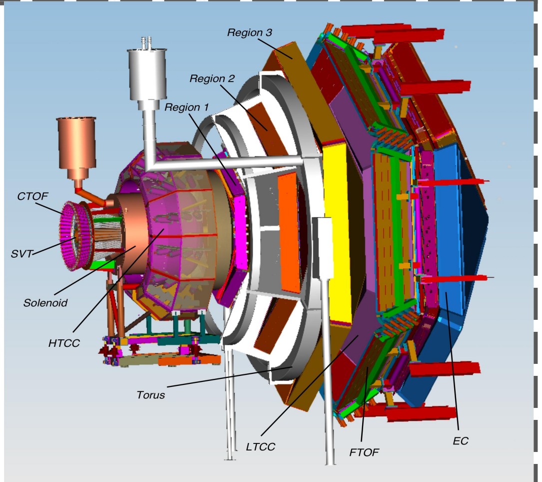
Morand et al., Eur. Phys. J. A24, 445 (2005)



CLAS 6
Backward γ Detection

CLAS 12
No backward γ Detection capability

e
beam



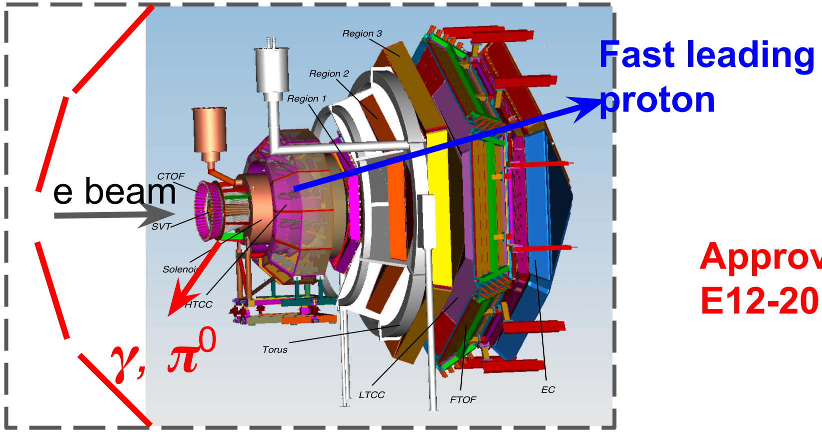
Harvesting u-channel meson production cross section at near u_{min} kinematics at Hall B CLAS12 (expert opinion by S. Diehl)

- **π^0: good acceptance for $-t$ of 5-6 GeV^2. u-channel measurements not possible.**
- **π^+**: full coverage of the *t* and *u* acceptance.
- **$\rho/\omega \rightarrow \pi^+\pi^-$**: decay well measured, full coverage of the *t* and *u* acceptance.
- **$\phi \rightarrow K^+K^-$**: full coverage of the t and u acceptance, very limited statistics at small *u*.

Greatly appreciate Stefan Diehl for these insights and Marco for providing guidance on implementation for the near future

Possibility to address *u*-channel π^0 issue in the near future? Question from Messina Workshop: Will a coverage extending to 150° be enough?

u-Channel DVCS at CLAS 12 with upgrade



Central-backward Photon tag

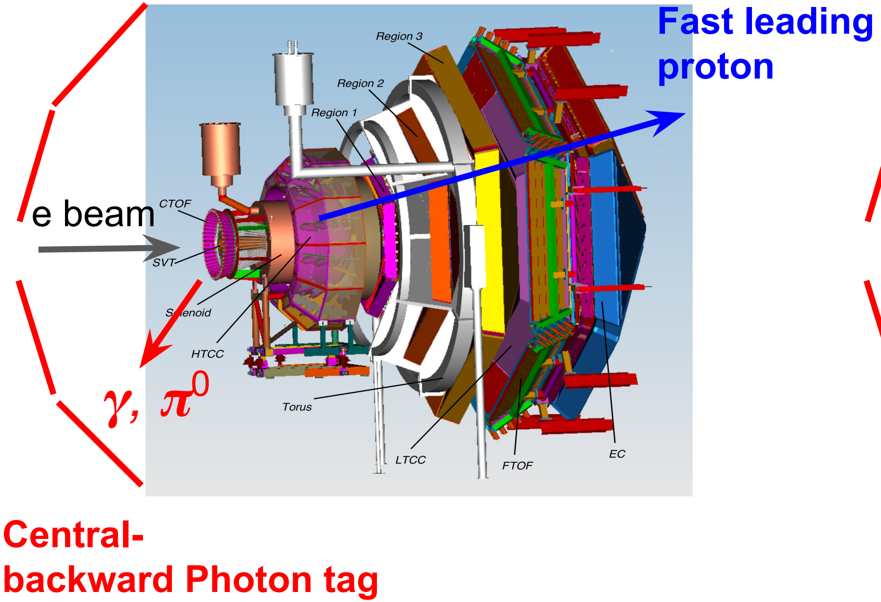
Approved E12-20-007

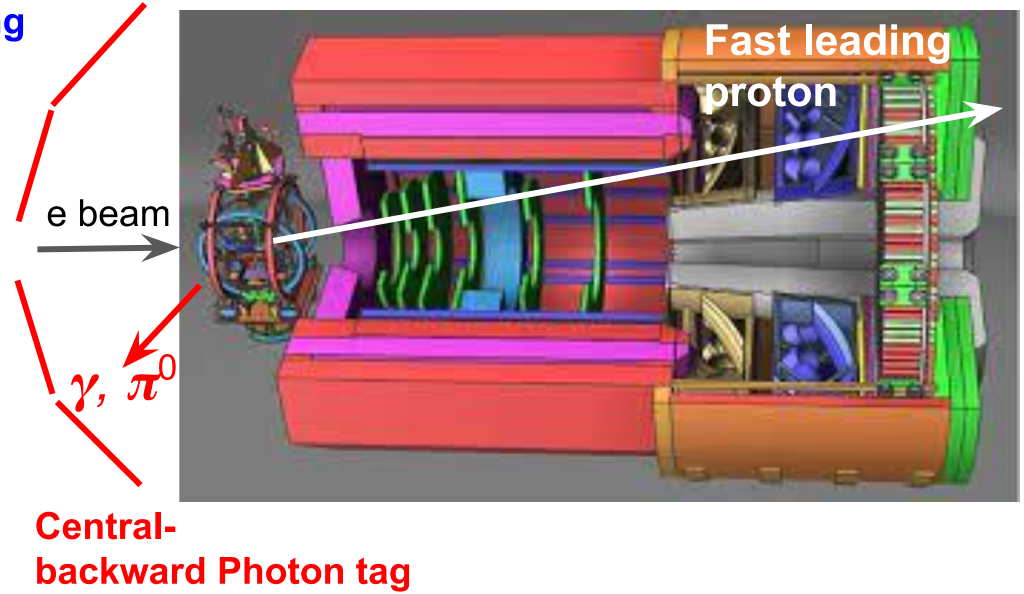
Q^2 (GeV^2)	W (GeV)	x_B	E_{Beam} (GeV)	ϵ	θ_{HMS} (deg)	P_{HMS} (GeV/c)	θ_{SHMS} (deg)	P_{SHMS} (GeV/c)	θ_{pq} (deg)	$-t$ (GeV^2)
2.0	2.11	0.36	4.4*	0.52*	13.71*	3.51*	−32.60*	−1.44*	−3.0, 0, +3.0	5.05*
			10.9*	0.94*	21.54*	3.51*	−8.72*	−7.94*	−3.0, 0, +3.0	5.05*
2.0	3.00	0.20	6.60	0.32	29.01	−1.21	−6.03	5.90	−3.0, 0	9.45
			10.90	0.79	10.47	−5.51	−10.34	5.90	−2.84, 0, +3.0	9.45
3.0	2.49	0.36	6.60	0.54	26.50	−2.17	−11.70	5.00	−3.0, 0, +3.0	7.79
			10.90	0.86	11.80	−4.37	−16.20	5.00	−3.0, 0, +3.0	7.79
4.0	2.83	0.36	8.80	0.56	22.89	−2.89	−10.35	6.50	−3.0, 0, +3.0	10.56
			10.90	0.73	15.59	−4.99	−12.39	6.50	−3.0, 0, +3.0	10.56
5.0	3.13	0.36	8.80	0.26	37.36	−1.38	−6.23	8.00	−3.0, 0	13.37
			10.90	0.55	20.90	−3.48	−9.24	8.00	−3.0, 0, +3.0	13.37
6.25	3.46	0.36	10.90	0.27	34.18	−1.66	−5.59	9.84	0	16.78

Conclusion:

- **A coverage at 170° is needed to match Hall C LT separated cross section points.**
- DVCS will be much easier than π°, assuming CLAS could reject single photon pion events.

Tagging *u*-Channel DVCS with SoLID



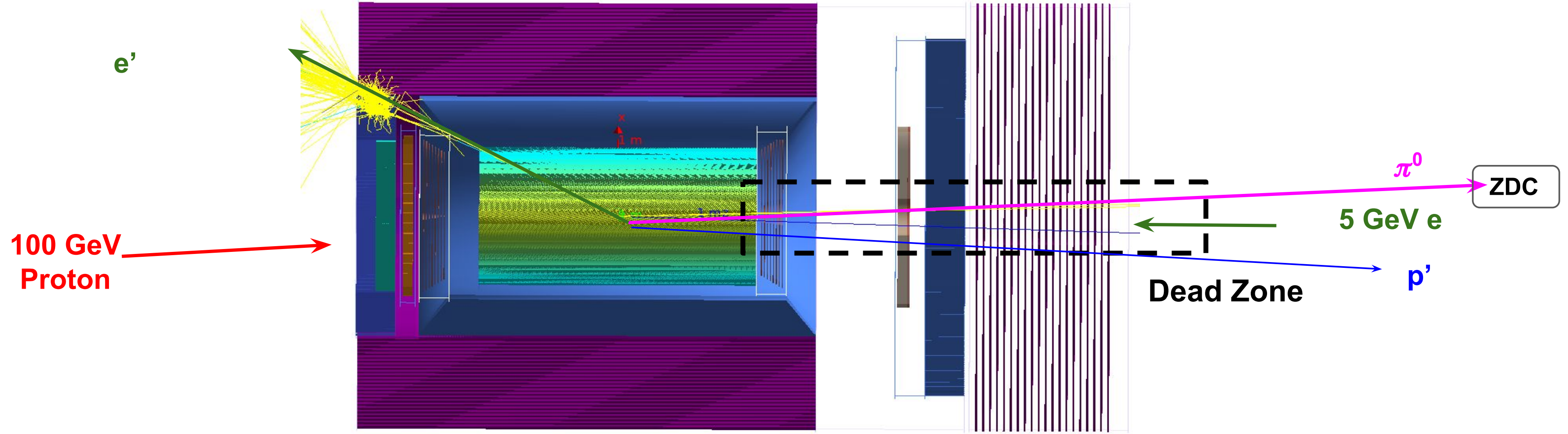


- **If the CLAS 12 GeV backward tagging of DVCS is a reality, the same tagging system can be applied to the SoLID!**

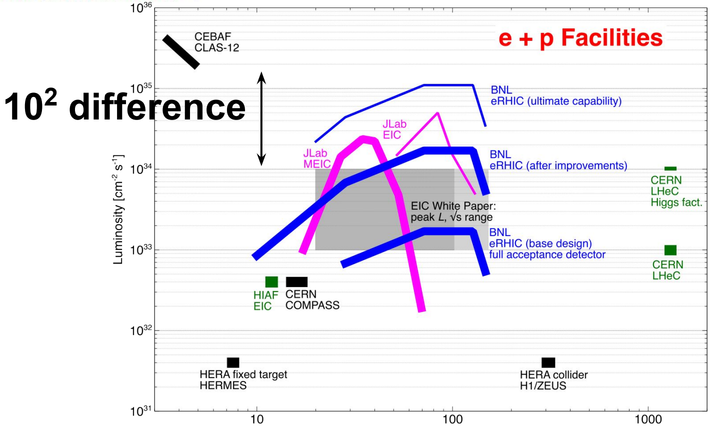
Thank you for your attention!

Thank the organizers for a fantastic and well organized workshop!

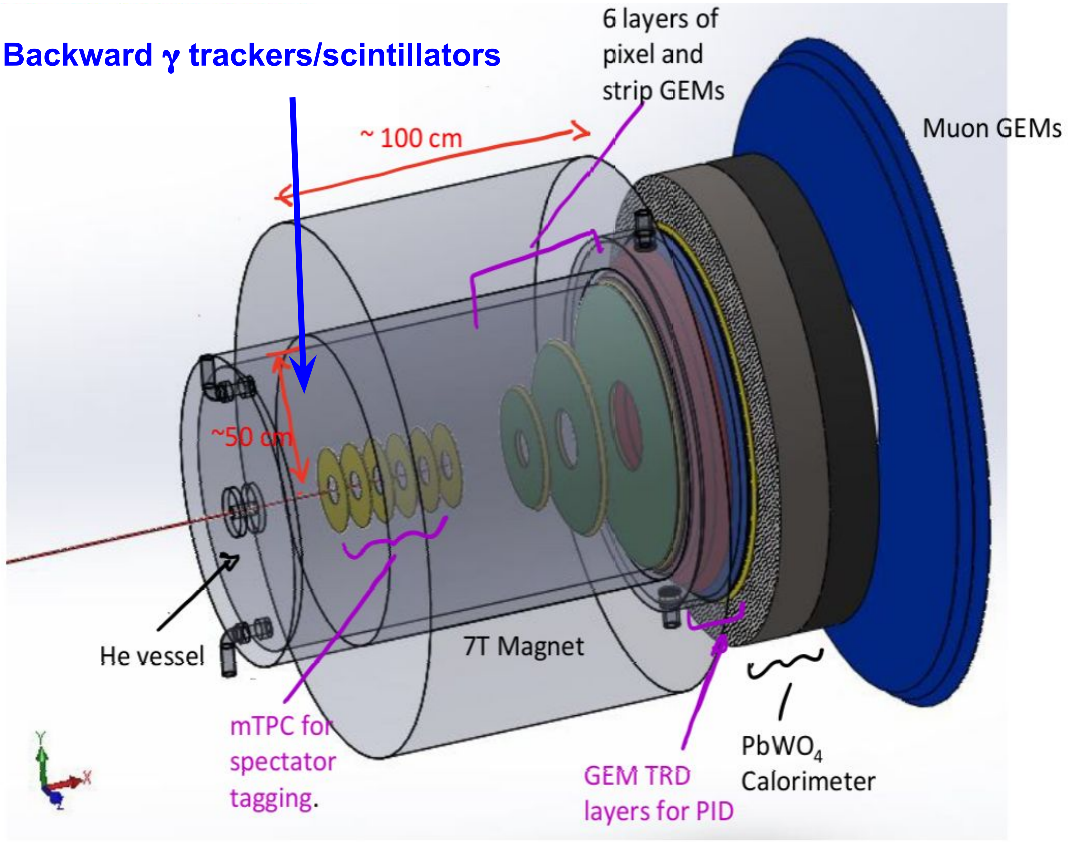
u-channel DVCS at EIC?



- **u-Channel DVCS is feasible measurement**
  - **kinematics and acceptance**
- **Could EIC reproduce the resolution of SHMS+HMS+NPS ? To ensure exclusivity?**
- **How do we do π^0/γ separation?**
- EIC luminosity 100 less than CEBAF
  - Will never collect enough data to do L/T separation



Nilanga's High Luminosity Spectrometer: study is needed



	$\sigma_T > \sigma_L$	$1/Q^8$ Scaling
π^0	○	○
π^+		✓✓
π^-		
K^0		
$K^\pm$		
η	✓	✓
ρ		
ω	✓✓	✓
η'	✓	✓
ϕ	✓	✓
VCS	△	△

Confirmed! By CLAS6 π^+

Parasitic Hall C Study

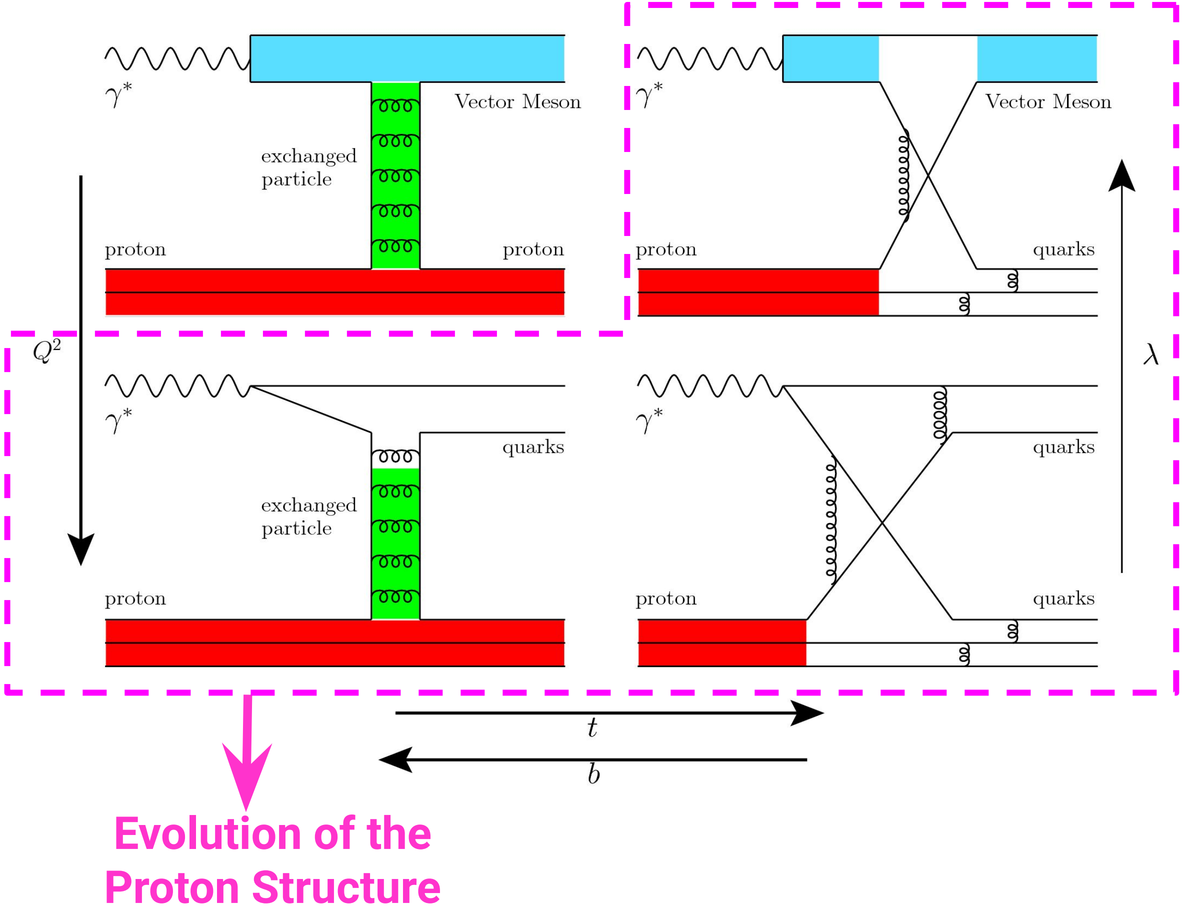
Confirmed! By Hall C 6 GeV ω

In the very early planning stage

E12-20-007 and EIC

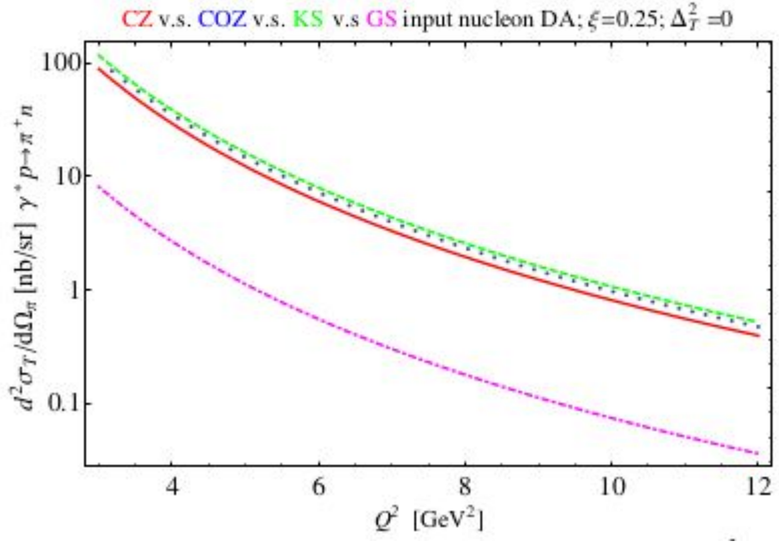
u-channel TCS?

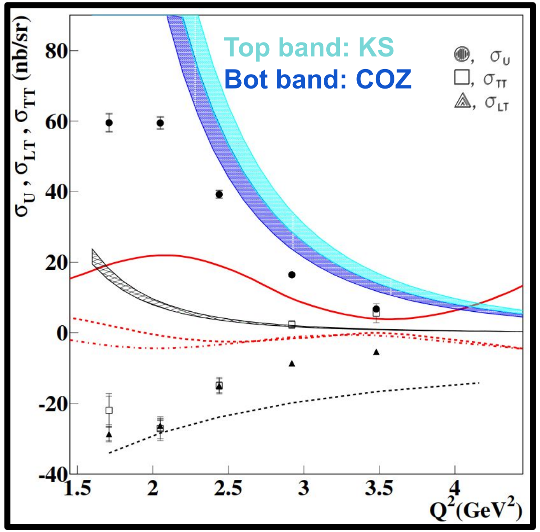
Hadronic Model: Transition (Evolution) of Proton Structure

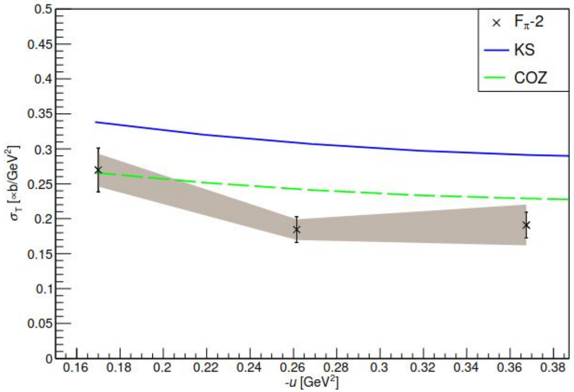


- **Physical parameters:**
  - In *x*, *W* (or *s*), ***Q***^{2}, ***t***, ***u***
- ***x* Evolution:**
  - Parton momentum fraction: 0.2-0.3 valence quark distribution is pronounced
- ***W* Evolution:**
  - Dictate if a process is in the resonance region
- ***Q***^{2} **Evolution**
  - Wavelength of the probe, or resolving power
- ***t* Evolution**
  - Inversely related to the Impact parameter b
- **What role does *u* play?**

Nucleon DA Difference

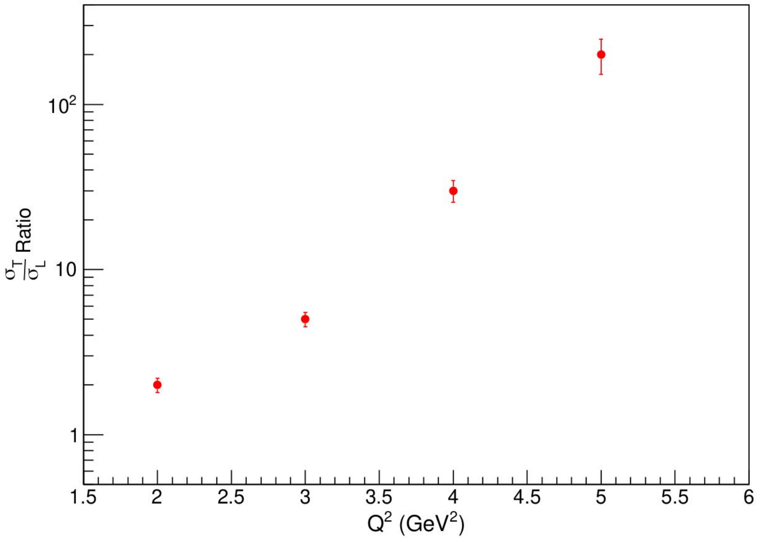


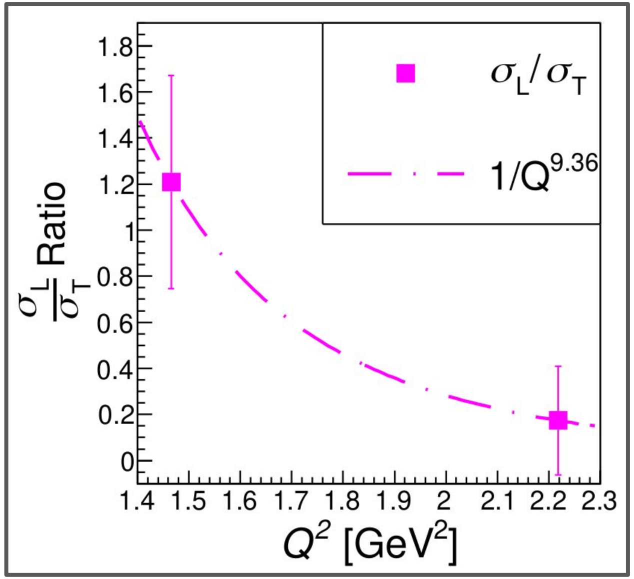




Objective 2: *TDA Prediction #1* $\sigma_T > \sigma_L$

Projected T/L ratio vs Q^2 (this proposal)



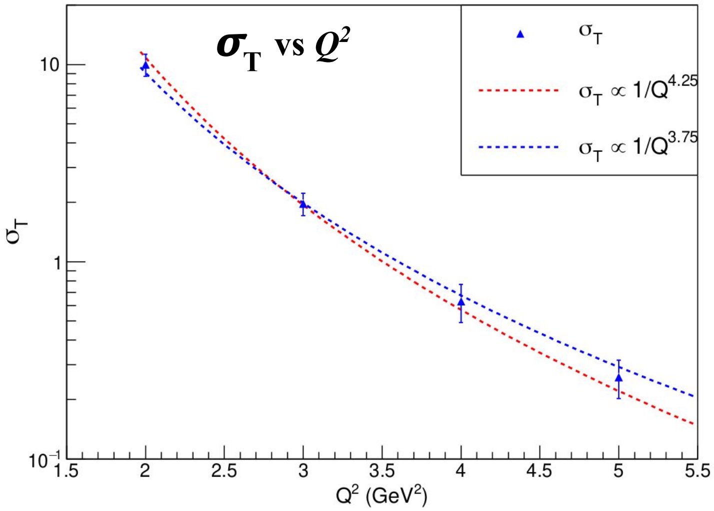


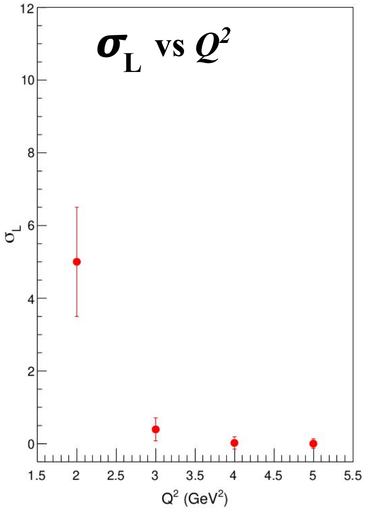
L/T ratio vs Q^2 (6 GeV F_π-2 experiment for ω)

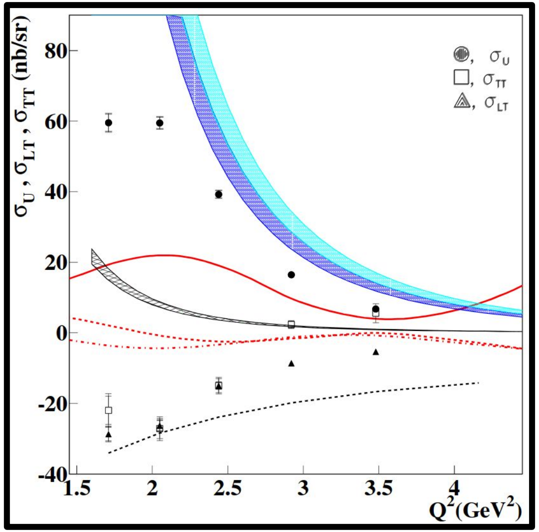
Objective 2: L/T Separated Cross section

- TDA predicts $\sigma_T > \sigma_L$
- Experimental criteria for concluding σ_T dominance: σ_T/σ_L increases as a function of Q^2 and reaches $\boldsymbol{\sigma_T/\sigma_L > 10}$ at $\boldsymbol{Q^2 = 5\ \mathrm{GeV}^2}$

Objective 3: *TDA Prediction #2, $\sigma_T \propto 1/Q^8$ Scaling*







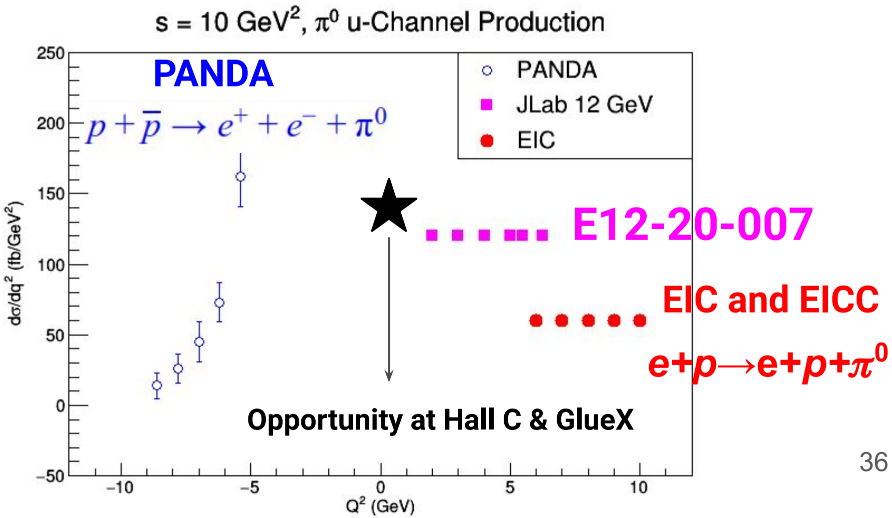
σ vs Q^2 (CLAS 6 π^+ result)

Objective 3: L/T Separated Cross section

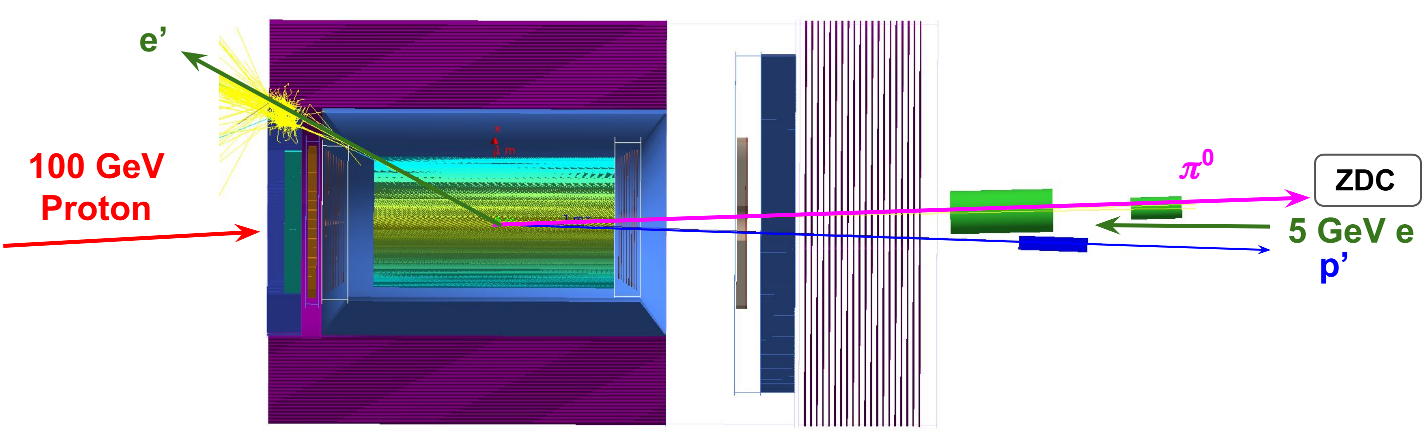
- TDA predicts $\boldsymbol{\sigma_T \propto 1/Q^8}$.
- TDA predicts $\boldsymbol{\sigma_L \sim 0}$, not a leading order leading twist contribution effect.
- Experiment designed to $\boldsymbol{(Q^2)^n}$, $3.75 < n < 4.25$

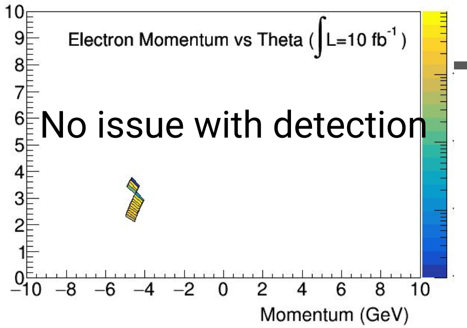
u-Channel studies at EIC

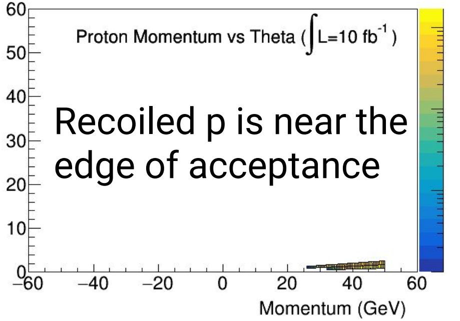
- **As postdoctoral fellow at JLab EIC Center: developed Backward π^0 program for EIC**
  - Offers synergy to other planned data set
  - Feasibility studies included as part of the EIC Yellow report (published last week)

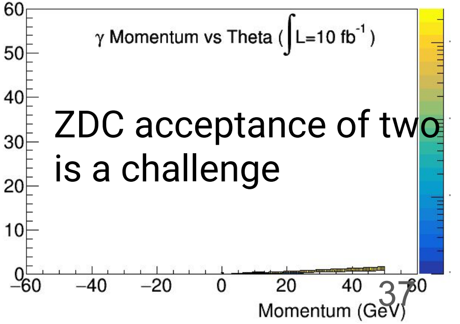


u-Channel Meson Production Setup









Q^2 (GeV^2)	W (GeV)	x_B	$\theta_{e'}$ (deg)	$\eta_{e'}$	$P_{e'}$ (GeV)	$\theta_{p'}$ (deg)	$\eta_{p'}$	$P_{p'}$ (GeV)	θ_{π^0} (deg)	η_{π^0}	P_{π^0} (GeV)	$-t$ (GeV^2)	$-u$ (GeV^2)
6.2	3.19		152	-1.39	5.31	-1.84	4.13	43.40	1.43	4.38	56.29	14.84	-0.37
7.0	3.19		150	-1.32	5.35	-1.92	4.09	45.50	1.43	4.38	54.12	16.19	-0.39
8.2	3.19		148	-1.24	5.40	-1.85	4.12	49.74	1.43	4.38	49.84	16.80	-0.42
9.3	3.19		146	-1.19	5.46	-1.92	4.09	51.90	1.43	4.38	47.60	18.19	-0.44
10.5	3.19		144	-1.12	5.52	-1.94	4.07	54.96	1.43	4.38	44.50	19.32	-0.47

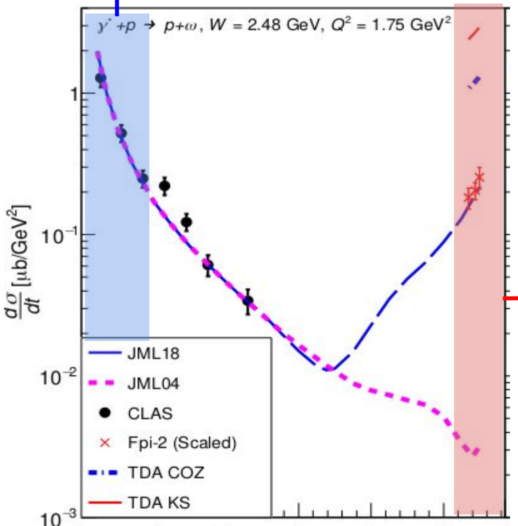
e' p' π^0

Objective 1: *Backward-angle Peaks*

Objective 1: Demonstrating the existence of the *u*-channel peaks for $H(e,e'p)\pi^0$

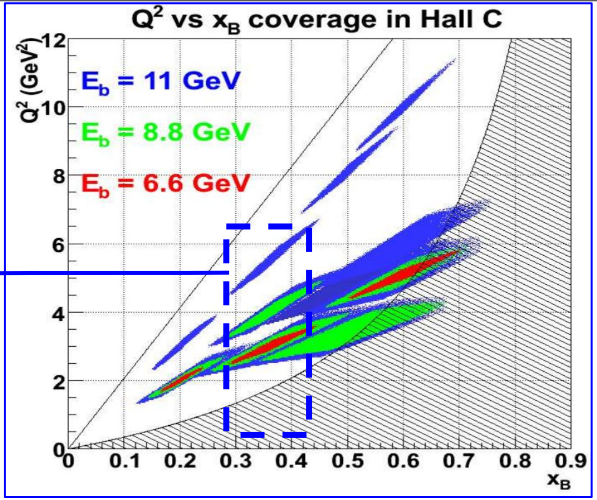
- E12-13-010 NPS experiment provides low -*t* L/T separated cross section

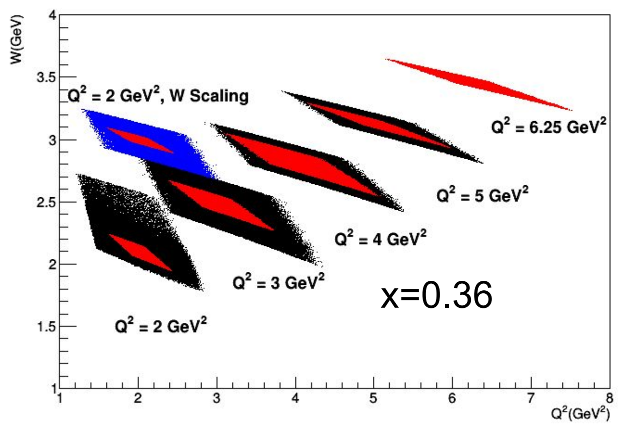
E12-13-010 NPS Experiment



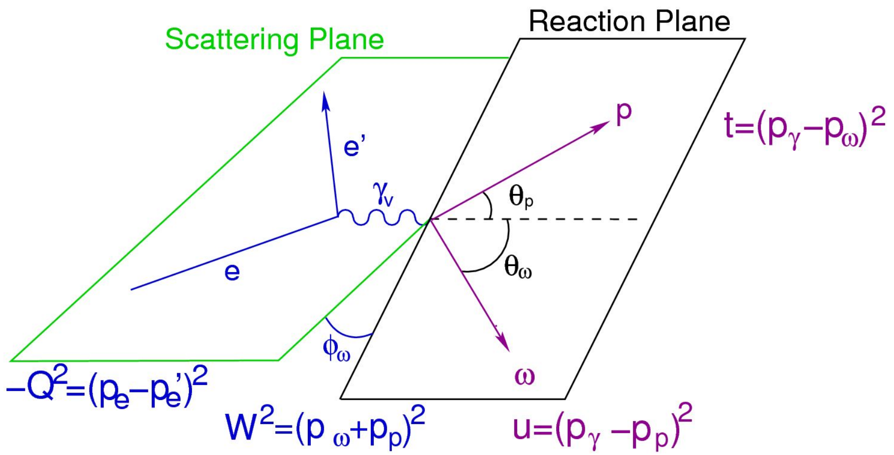
$-t_{Min}$ $-t_{Max}$

This proposal





The Rosenbluth Separation



Virtual-photon polarization:

$$\varepsilon=\left(1+2\frac{(E_e-E_{e'})^2+Q^2}{Q^2}\tan^2\frac{\theta_{e'}}{2}\right)^{-1}$$

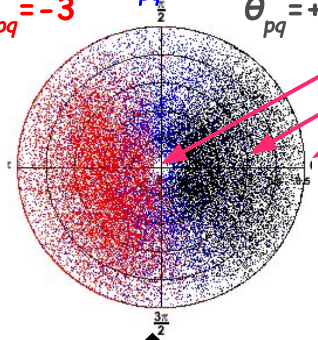
$$2\pi\frac{d\sigma}{dt\,d\phi}=\varepsilon\frac{d\sigma_L}{dt}+\frac{d\sigma_T}{dt}+\sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi+\varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi$$

- **Rosenbluth Separation requirements:**
  - Separate measurements at different ε (virtual photon polarization)
  - All Lorentz invariant physics quantities: Q^2, W, t, u, remain constant
  - Beam energy, scattered e angle and virtual photon angle will change as the result, thus event rates are dramatically different

Iterative Procedure (Recipe) to a LT Separation

Improve ϕ coverage by taking data at multiple HMS angles, -3°< θ_p<+3°.

θ_{pq}=-3 θ_{pq}=0 θ_{pq}=+3



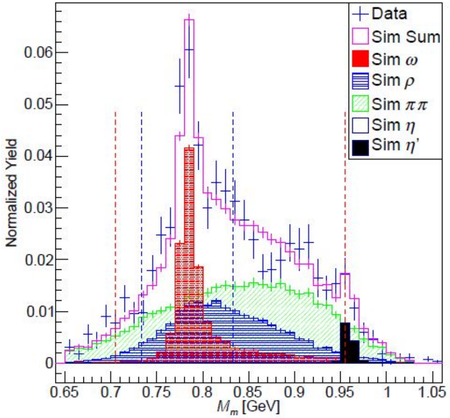
-u=0.0

-u=0.3

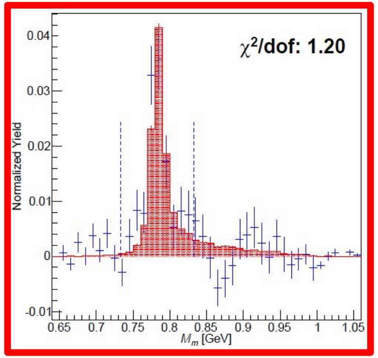
-u=0.5

3 u-bins

8 phi-bins



Background subtraction



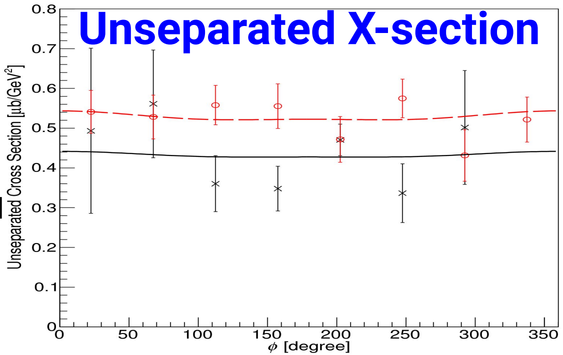
$$R = \frac{Y_{Exp} - Y_{\rho\ sim} - Y_{Xspace\ sim} - Y_{\eta\ sim}}{Y_{\omega\ sim}}$$

Combine ratios for settings together, propagating errors accordingly.

$$\frac{d^2\sigma}{dtd\varphi}_{EXP} = R\, \frac{d^2\sigma}{dtd\varphi}_{SIMC}$$

Empirical Model

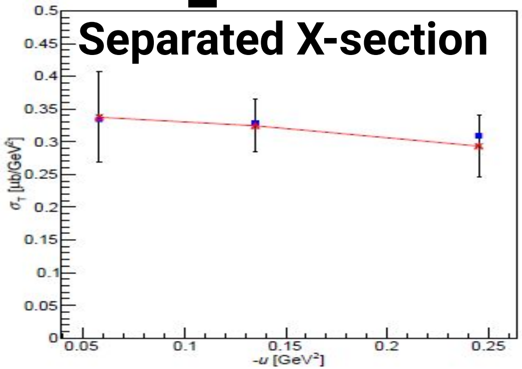
Unseparated X-section



Extracting T, L, LT, TT via simultaneous fit

$$2\pi \frac{d\sigma}{dtd\phi} = \frac{d\sigma_T}{dt} + \varepsilon \frac{d\sigma_L}{dt} + \sqrt{2\varepsilon(\varepsilon+1)} \frac{d\sigma_{LT}}{dt} \cos\phi + \varepsilon \frac{d\sigma_{TT}}{dt} \cos 2\phi$$

Separated X-section



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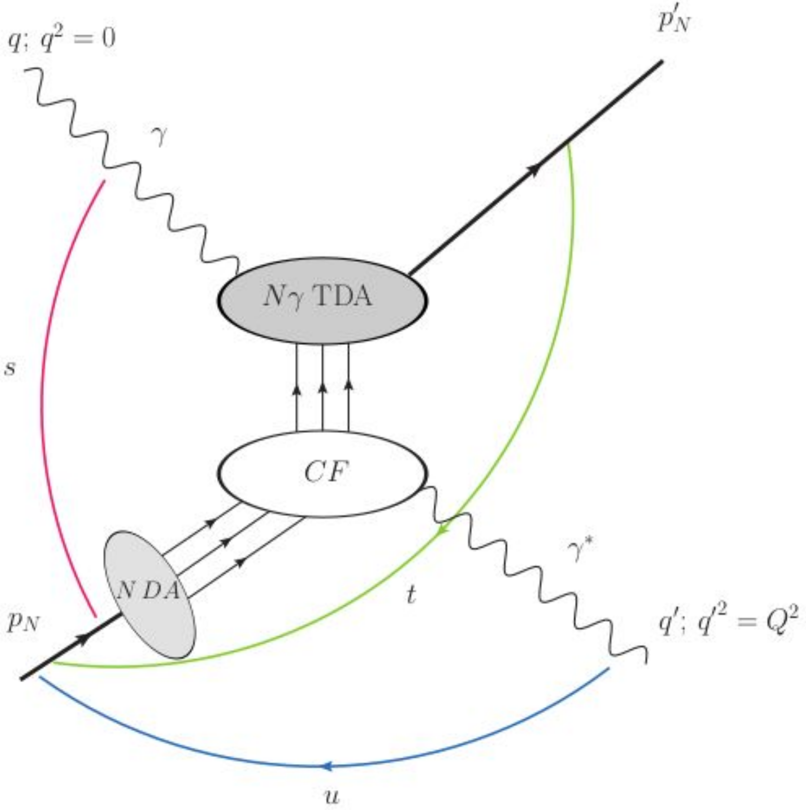
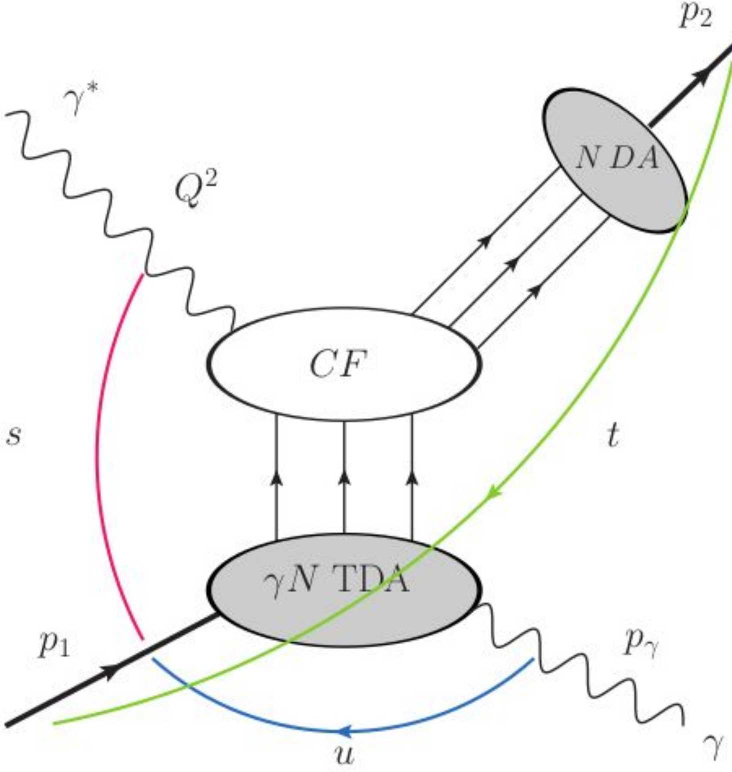
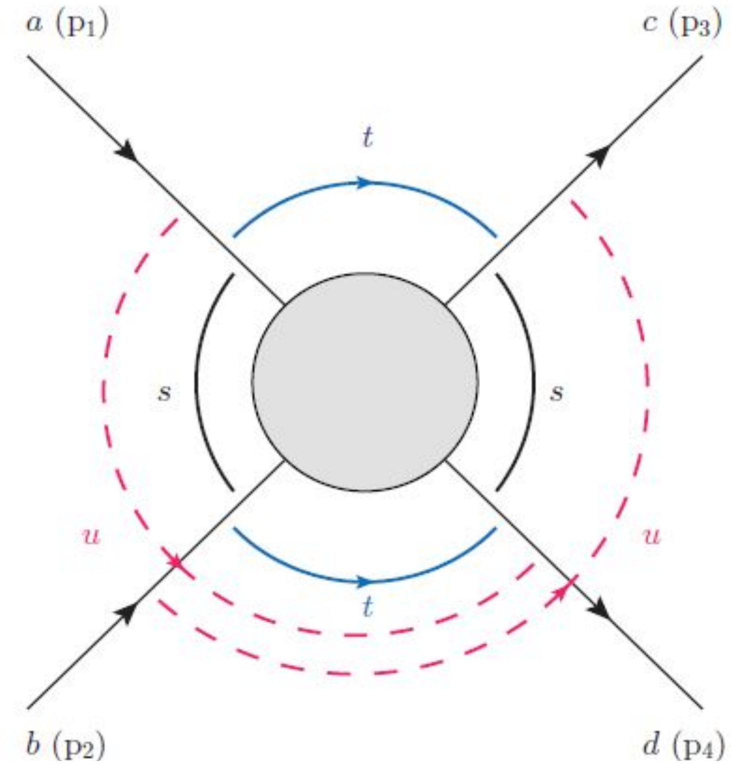
u-channel DVCS and TCS

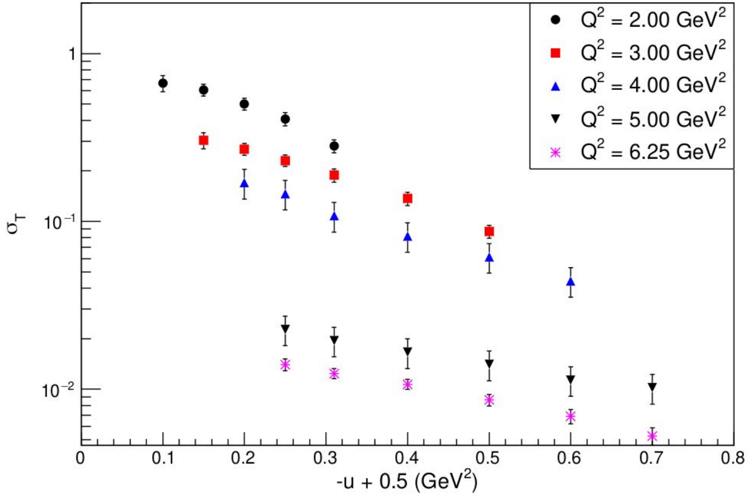




Mandelstam Variable



Objective 2: *u-dependence*



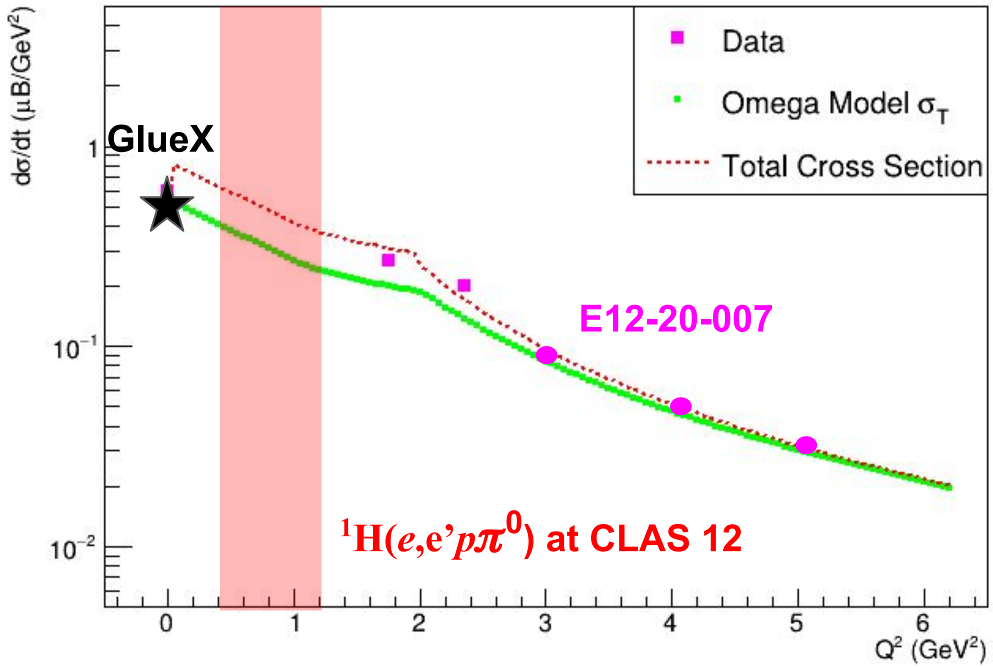
Objective 2: u-dependence of the separated cross section

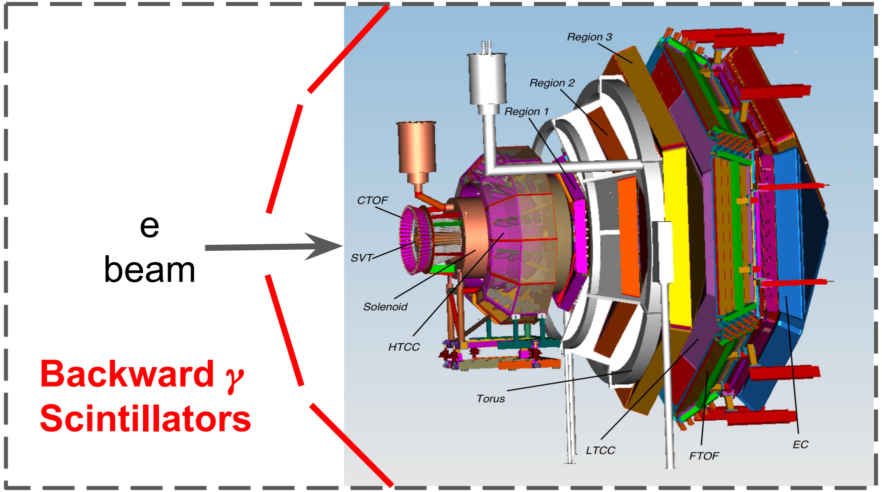
- **Extracting -u dependence of the unseparated cross section and interaction radius:**

$$\sigma = Ae^{-b \cdot |u|}, \quad r_{int} = \sqrt{b}\,\hbar\, c$$

- **Study of parameter r_{int} as function of Q^2, probe the proton structure transition from hadronic to partonic degrees of freedom.** (Similar to the study by Halina Abramowicz, Leonid Frankfurt, Mark Strikman, arXiv:hep-ph/9503437, 1995.)

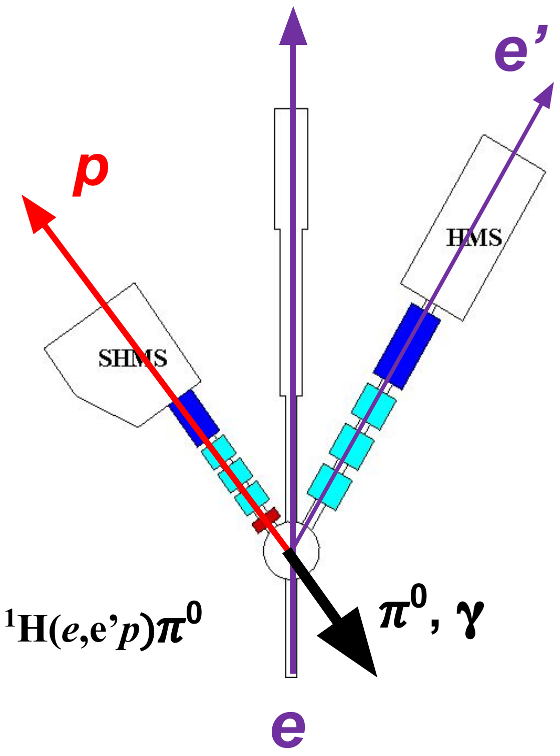
u-Channel Opportunities at CLAS 12

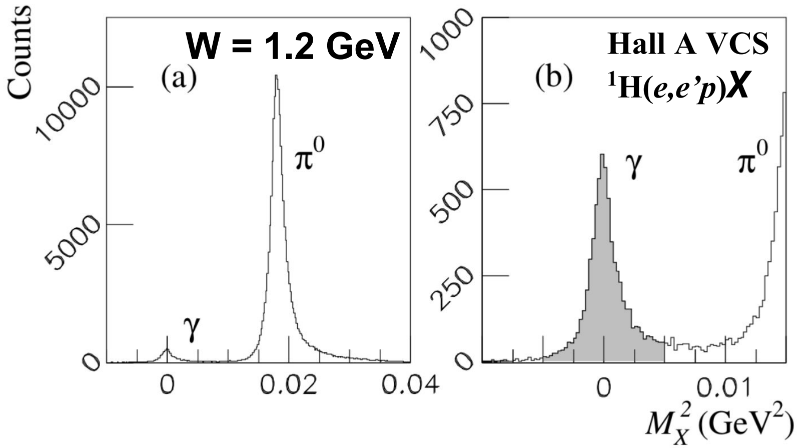




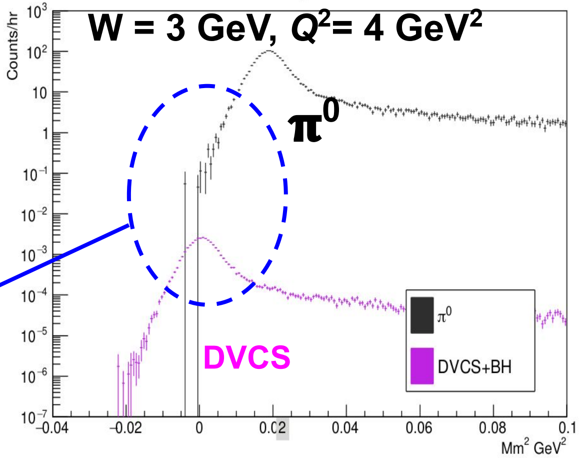
- **Adding Scintillators allows u-channel π^0**
- $0 < Q^2 < 1.2$ GeV kinematics only available with CLAS 12
- Offering unique opportunity

Past VCS and A Proposed $^1H(e,e'p\gamma)$





HRSs missing mass resolution



HMS+SHMS missing mass resolution

Not good enough to separate γ and π^0

First Dedicated Backward Angle Experiment

- **Probing backward-angle (*u*-channel) electroproduction of π^0 : E12-20-007**
  - First presented as Letter of Intent in 2018
  - Full proposal submitted in 2020
- **Received full approval by JLab Program Advisory Committee (PAC):**
  - Experiment fully approved for 29 PAC days
  - **Projected beam time: 48 days** (48 * $800k = $ 30M in electricity bill from tax payer)
- **PAC recognized the pioneering nature of the measurement**
  - The exploration of backward pion electroproduction is feasible, and JLab is an ideal venue at which to perform it.
- **Significant symbolic meaning: First approved dedicated u-channel experiment**

	$\sigma_T > \sigma_L$	$1/Q^8$ Scaling
π^0	○	○
π^+		✓✓
π^-		
K^0		
$K^\pm$		
η	✓	✓
ρ		
ω	✓✓	✓
η'	✓	✓
ϕ	✓	✓
VCS	△	△

Confirmed! CLAS 6 π^+

Parasitic Hall C Study

Confirmed! By Hall C 6 GeV ω

In the very early planning stage