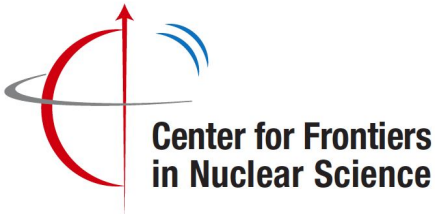
The Backward Angle (u-channel) Exclusive and Inclusive Process at 12 GeV and Future EIC

Wenliang (Bill) Li

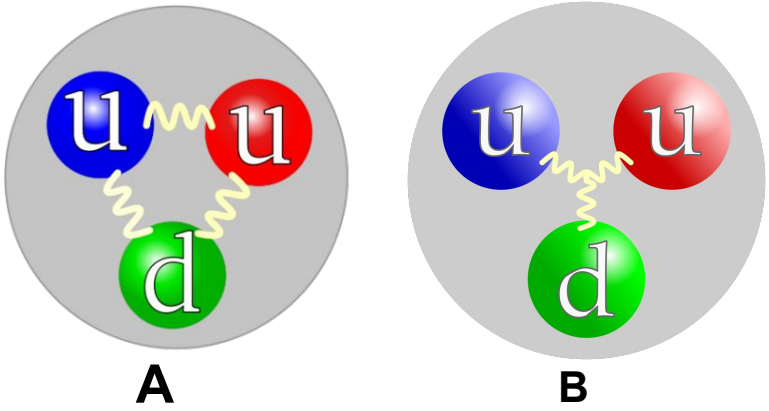
@ SPIN 2023

Sep/26/2023



Who carries the baryon number?

- **Nucleon internal structure:**



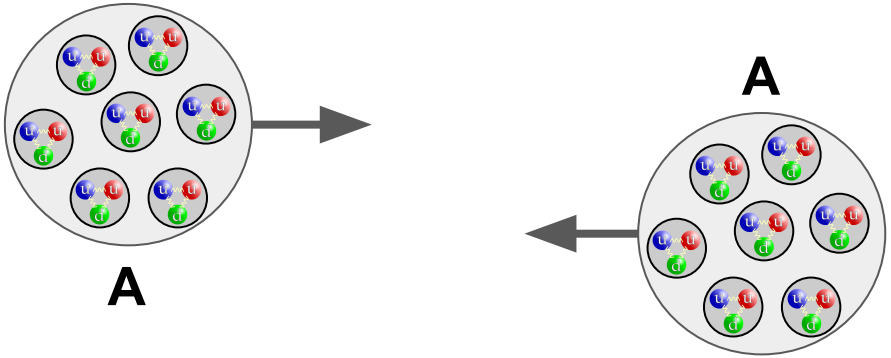
A B

Question: which one is correct?

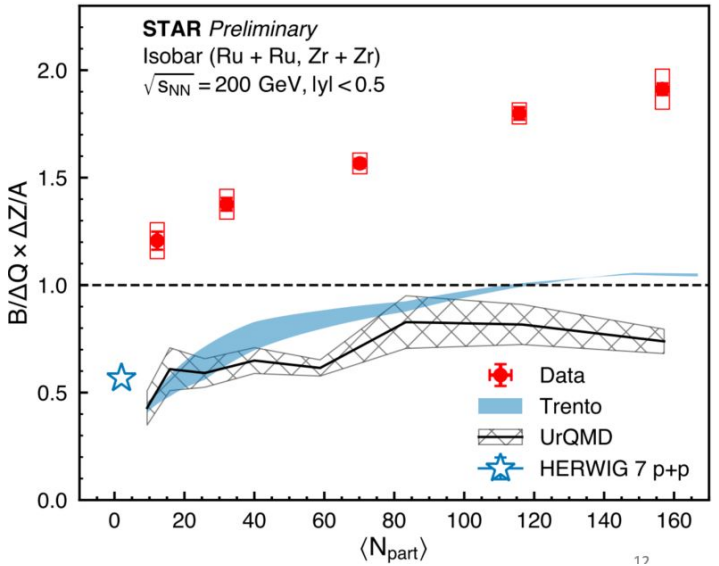
A: implies quark carries fractional baryon number

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

Probing Baryon Junction with A-A at RHIC



Tommy Tsang (KSU) for STAR, APS GHP 2023



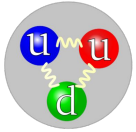
Charge vs. baryon transport in A+A collisions:

- If Valence quarks carry electric charge & baryon number:

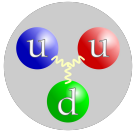
$$\frac{Z}{\text{Charge Stoppoing}} \times \frac{\text{Baryon Stopping}}{A} \cong 1$$

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

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



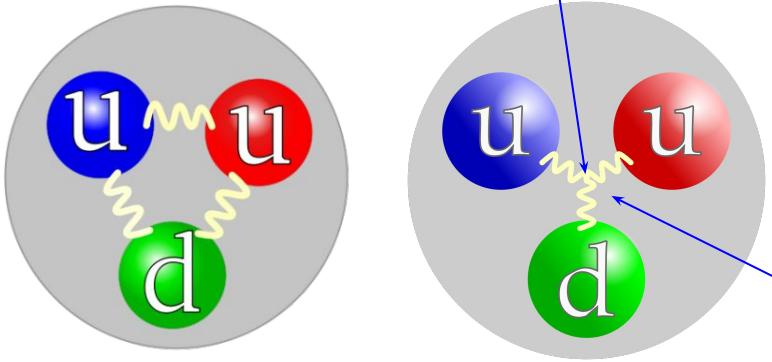
Theory: Quark Models: equal or less baryon compared to electric charge



Data: More baryon transported to central rapidity than electric charge

Looking for Baryon Junction via Exclusive u-Channel Processes

- **Which proton it more correct?**

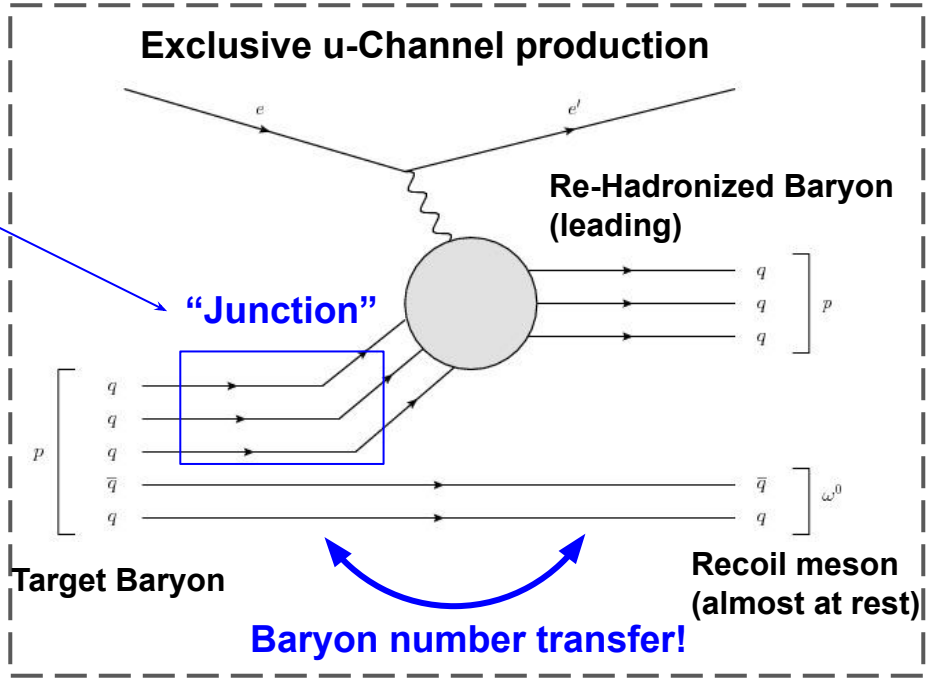


A **B**

A: implies quark carries fractional baryon number

B: **a "Junction" like structure**

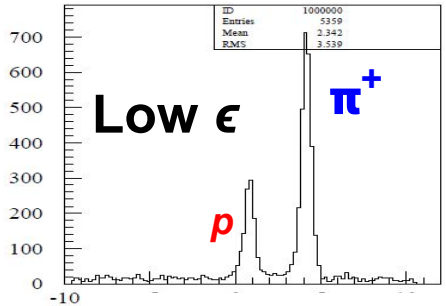
- **How do we probe this in JLab 12 GeV?**
  - May be. If manage to force the transfer of baryon number in the target and recoil particles, then Yes.

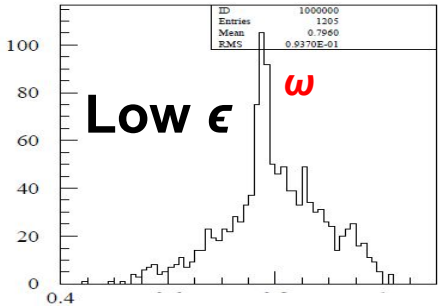


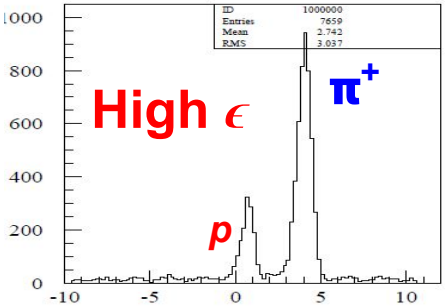
Gifted Backward-angle Observables

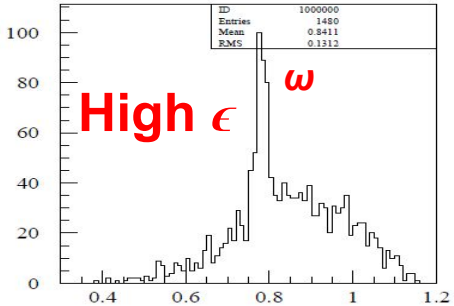
- **Fpi-2 (E01-004) 2003**
  - Spokesperson: **Garth Huber, Henk Blok**
  - Standard HMS and SOS (e) configuration
  - **Electric form factor of charged π** through exclusive π production
- **Primary reaction for Fpi-2**
  - **H(*e*, *e'* π^+)*n***
- **In addition, the experiment fortuitously received**
  - ***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



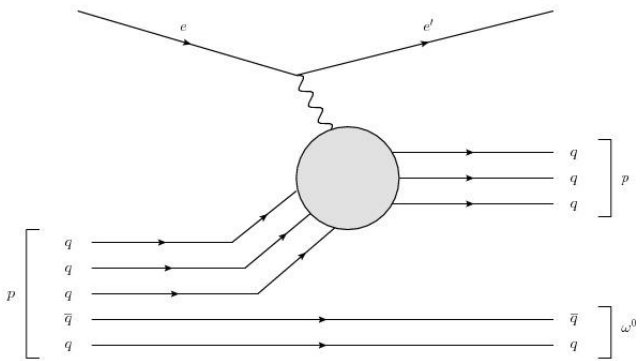




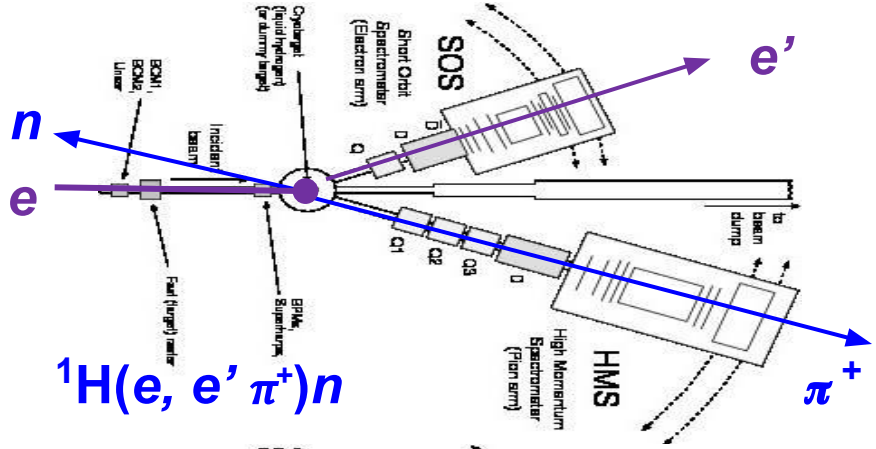


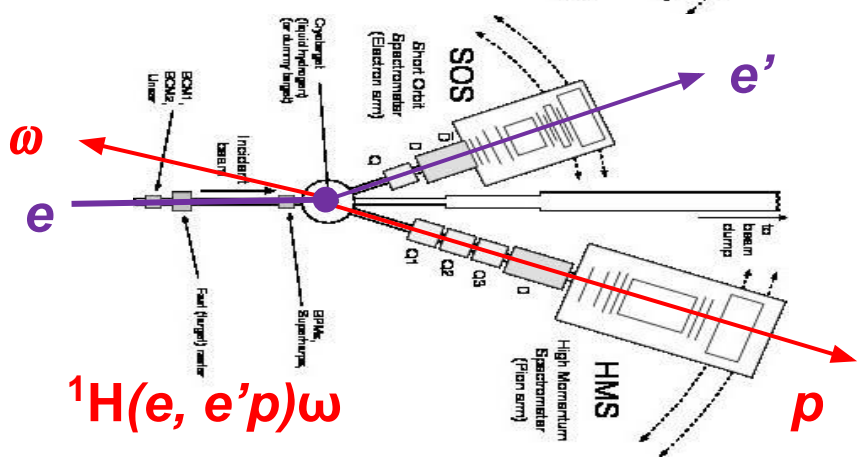
t-Channel π^+ vs *u*-Channel ω Electroproduction

- **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

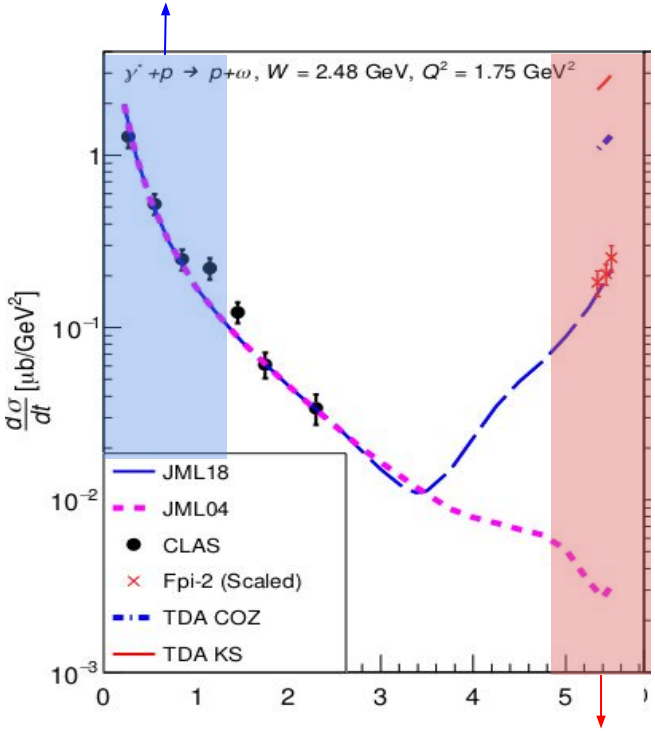




Two Key Discoveries from Fpi-2 ω Analysis

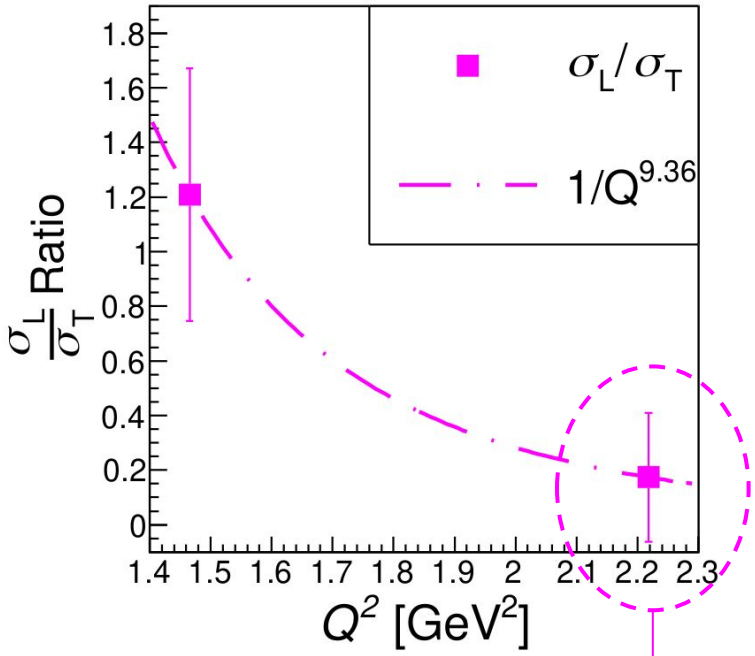
Discovery 1: Unexpected large *u*-Channel peak

Forward ω electroproduction from CLAS 6 *(2004)*



Backward angle ω electroproduction *(2017)*

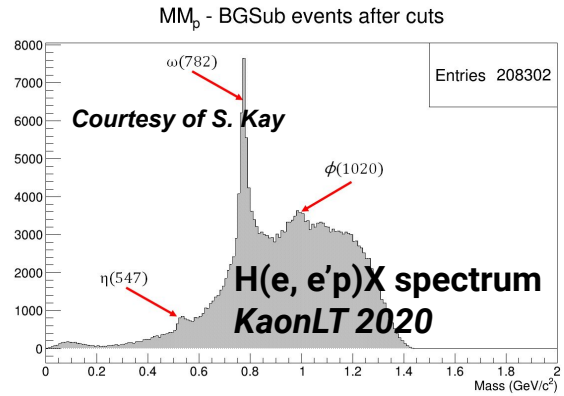
Discovery 2: $\sigma_T > \sigma_L$, $\sigma_L \sim 0$

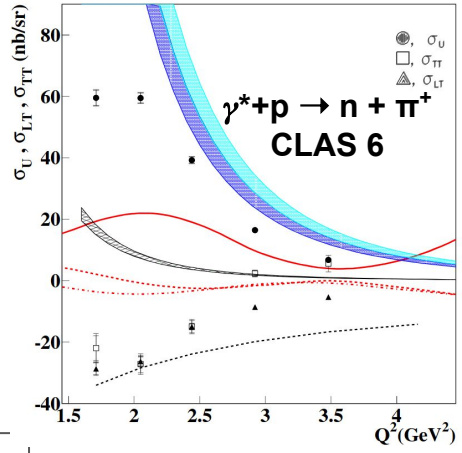


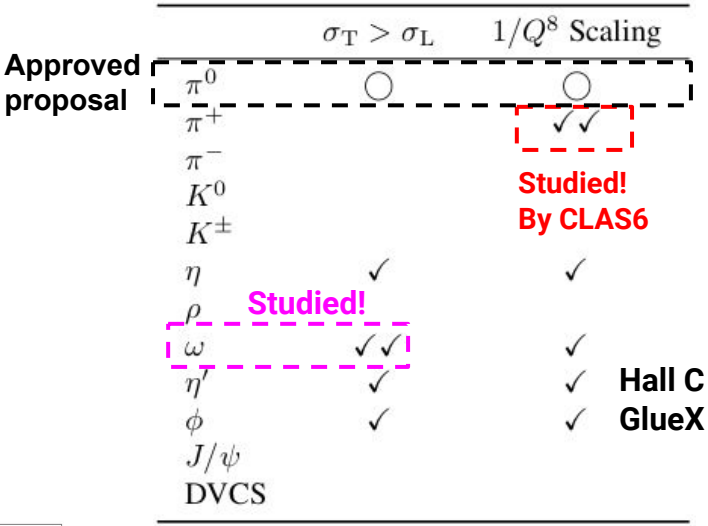
$$\frac{\sigma_T}{\sigma_L} \sim 0 \text{ at } Q^2 = 2.2\,\text{GeV}^2$$

Therefore, $\boldsymbol{\sigma_T > \sigma_L}$

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

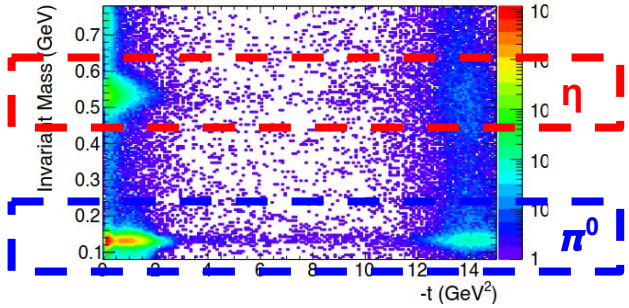






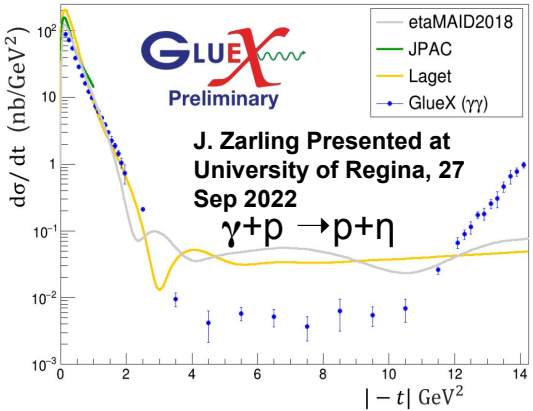
GlueX mass vs -t Phasespace

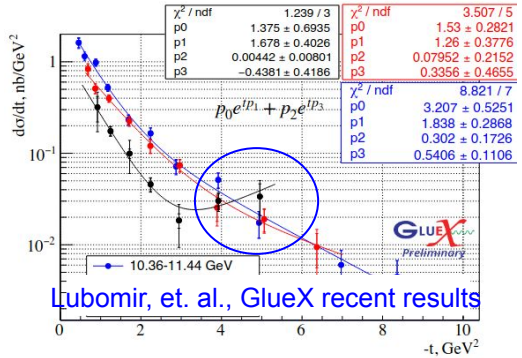
t-channel u-channel



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

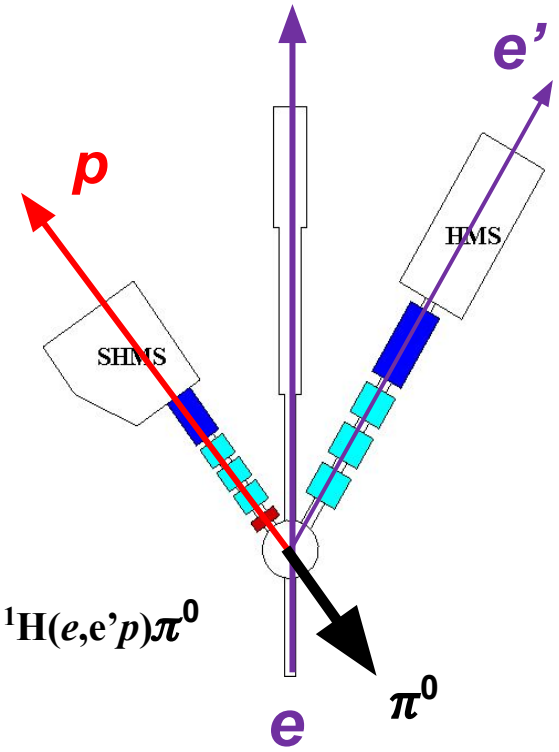
$E_\gamma = 8.25 \pm 0.25$ GeV

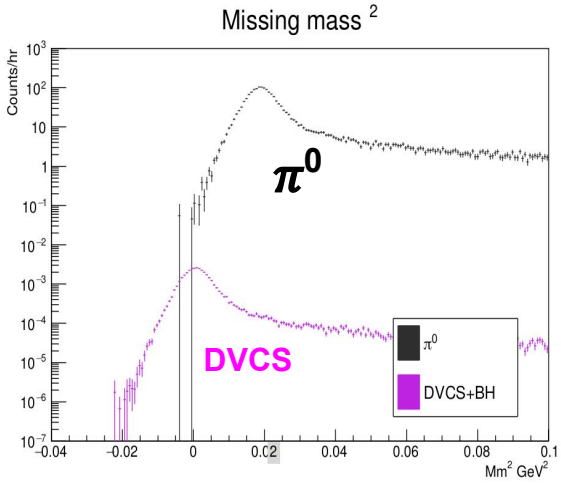




Lubomir, et. al., GlueX recent results

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



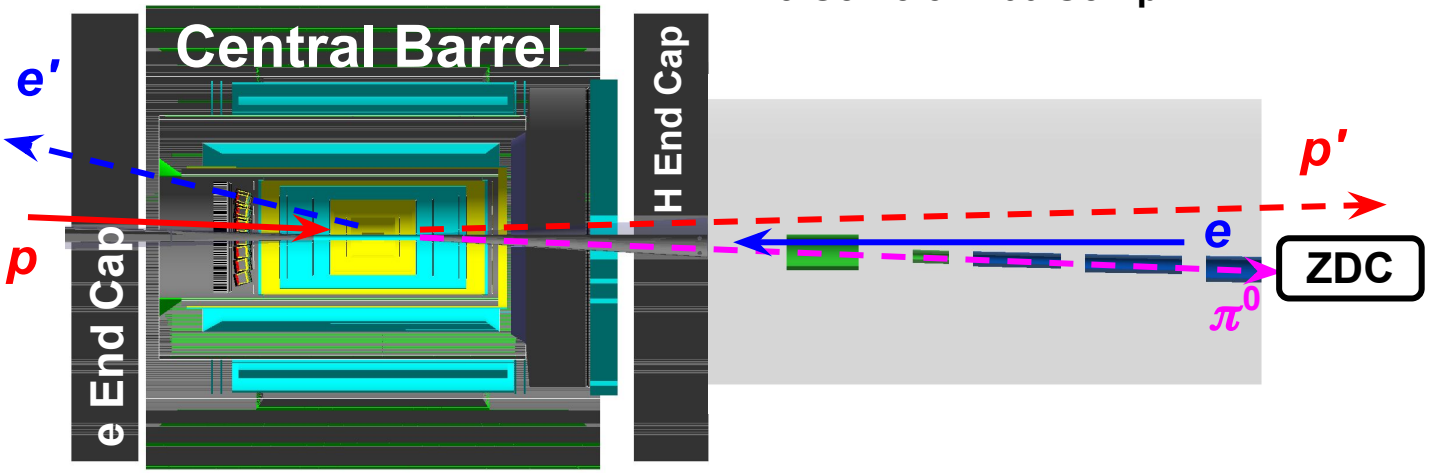


Q^2 GeV^2	W GeV	ϵ	x	θ_{pq} Degree
2.0	3.00	0.32	0.20	-3, 0
		0.79	0.20	-2.8, 0, +3
2.0	2.11	0.52	0.36	-3, 0, +3
		0.94	0.36	-3, 0, +3
3.0	2.49	0.54	0.36	-3, 0, +3
		0.86	0.36	-3, 0, +3
4.0	2.83	0.56	0.36	-3, 0, +3
		0.73	0.36	-3, 0, +3
5.0	3.13	0.26	0.36	-3, 0
		0.55	0.36	-3, 0, +3
6.25	3.46	0.27	0.36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

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

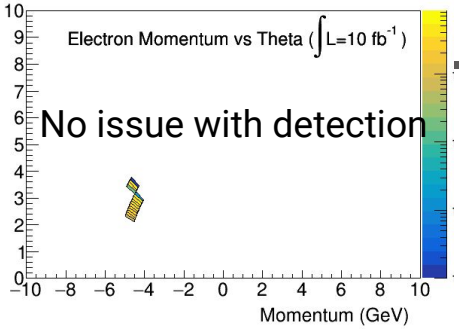
- **Q^2 coverage: $2.0 < Q^2 < 6.25$ GeV^2, at x=0.36 and W > 2 GeV L/T separated cross section @ Q^2= 2, 3, 4 and 5 GeV^2.**
- ***u* coverage: 0 < -*u*' +0.5 < 0.5 GeV^2**
- **Additional *W* scaling check @ Q^2 = 2 GeV^2**
- **Additional Q^2 scaling check @ Q^2 = 6.25 GeV^2**

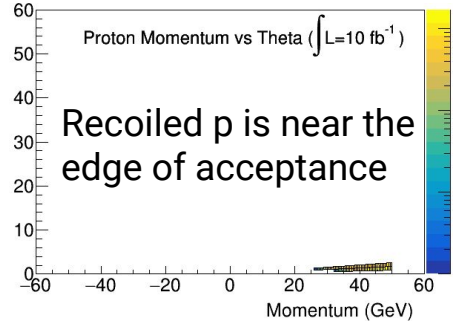
u-Channel Meson Production Setup at EIC

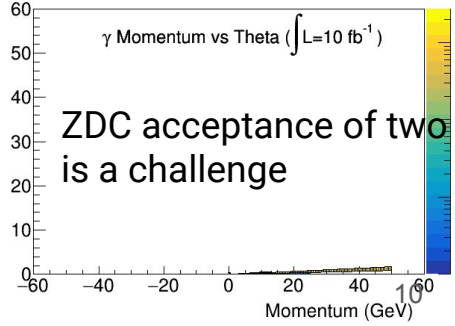


Q^2 (GeV^2)	W (GeV)	x_B	$\theta_{e'}$ (deg)	$\eta_{e'}$	$P_{e'}$ (GeV)	$\theta_{p'}$ (deg)	$\eta_{p'}$	$P_{p'}$ (GeV)	θ_{π^0} (deg)	η_{π^0}	P_{π^0} (GeV)	$-t$ (GeV^2)	$-u$ (GeV^2)
6.2	3.19		152	1.39	5.31	-1.84	4.13	43.40	1.43	4.38	56.29	14.84	-0.37
7.0	3.19		150	1.32	5.35	-1.92	4.09	45.50	1.43	4.38	54.12	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







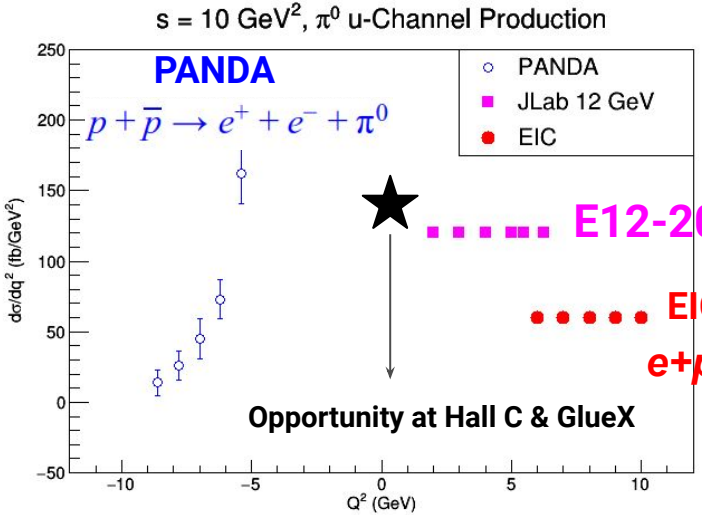
u-Channel studies at EIC

7.4 Understanding Hadronization

There is great potential also in studying **new particle production mechanisms** such as exclusive backward *u*-channel production. Given its high luminosity the EIC may be able to discover fundamental QCD particle production processes with low cross sections such as via hard (perturbative) C-odd three gluon exchange.

EIC YELLOW REPORT

- **Backward π ^{0} program for EIC**



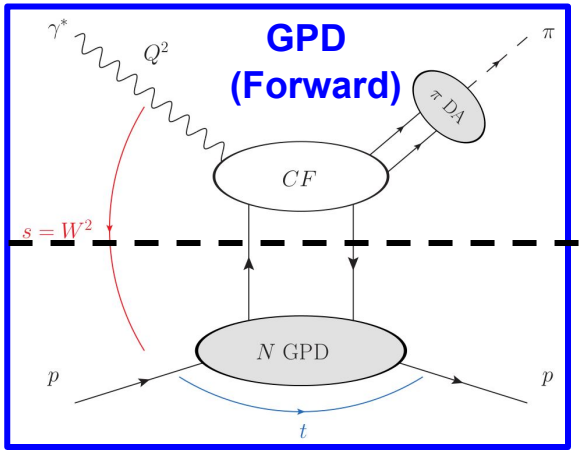
- **Recent u-Channel EIC publication:**
  - ***Backward-angle (u-Channel) production at an electron-ion collider,*** **D. Cebra, Z. Sweger, S. Klein, et. al., PhysRevC.106.015204**
  - **Modeling Backward-Angle (u-channel) Virtual Compton Scattering at an Electron-Ion Collider, Z. Sweger, S. Klein, et. al., https://arxiv.org/abs/2308.10478**

GPD and TDA (Hard Structure Approach)

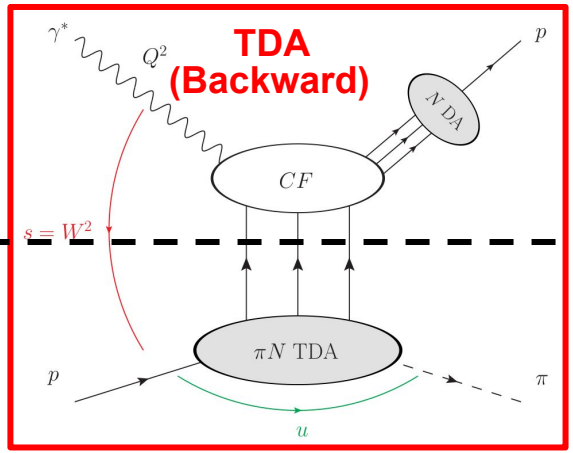
Hard structure

Soft structure

Collinear factorization



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



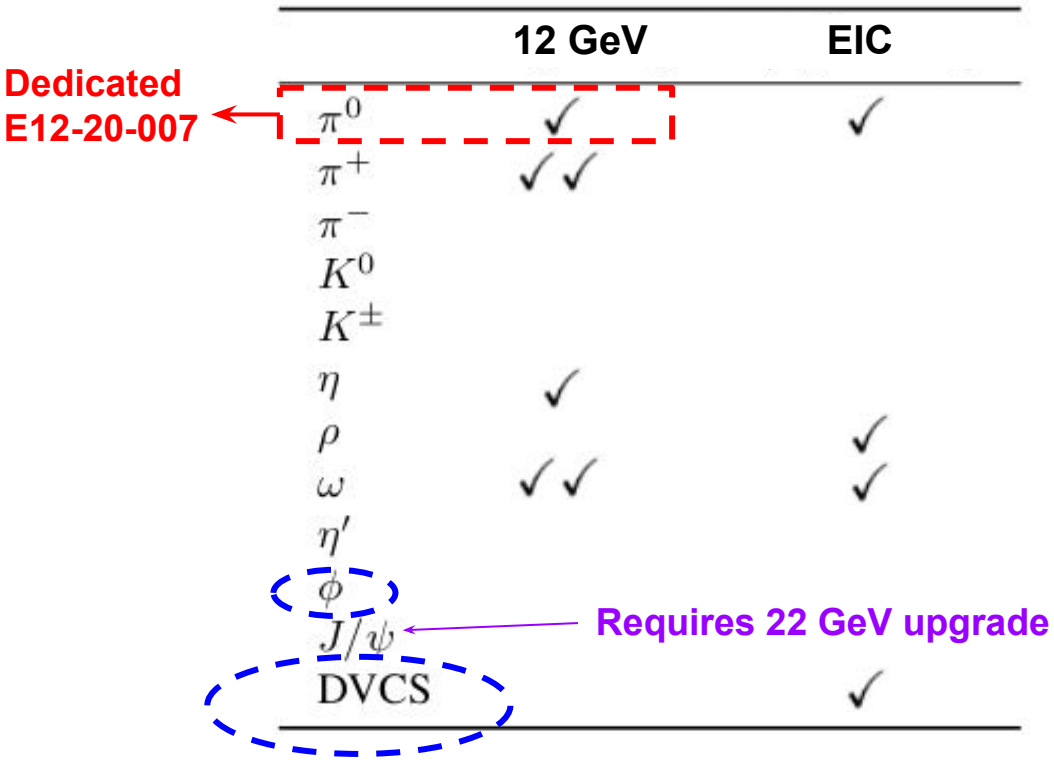
Developed by **B. Pire**, **L. Szymanowski** and **K Semenov-Tian-Shansky** in 2005

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.

u-Channel Exclusive Electroproduction



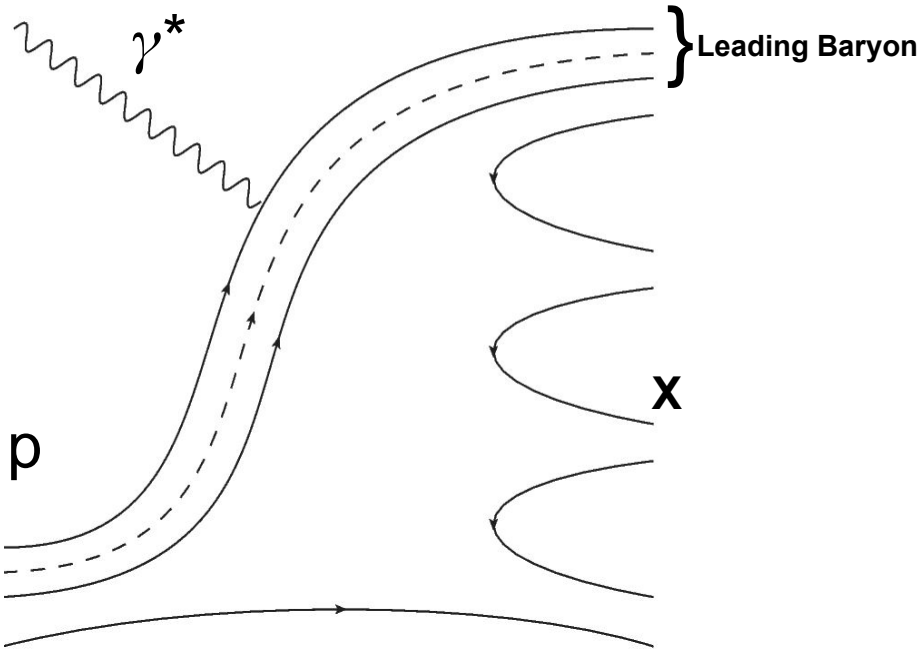
- We are good shape with the exclusive productions! :D

✓✓ Data already available

✓ Studies planned

Large community interests, will be developed into proposal in the upcoming years

Inclusive or Semi-inclusive u-Channel processes?

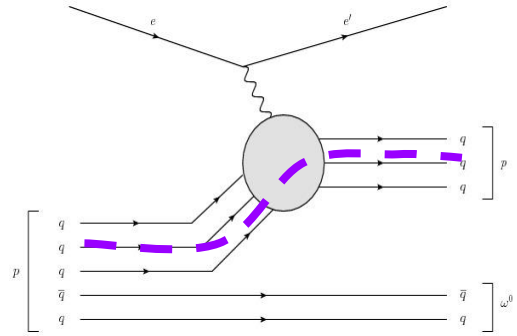


- **Interaction: e + H→e' + B + X**
  - **e(H, e'B)X**
- **B: Leading baryon**
  - Candidates: p, n, Λ, Σ
  - Small Mandelstam variable -*u*
  - Fix target: Maximum momentum gain
  - Collider: Maximum momentum loss

Semi-Inclusive u-Channel study Cases?

D. Frenklakh, Dmitri Kharzeev,
https://indico.cern.ch/event/1139644/contributions/5490519/

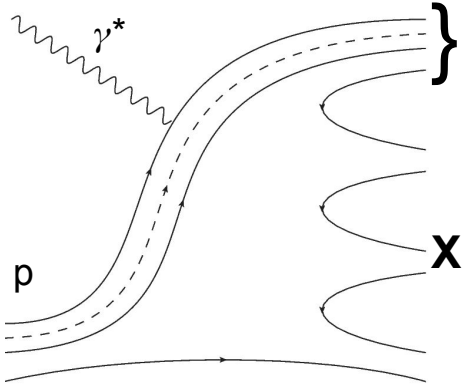
Case 0: J/3q exchange



Complicated form factor leads inconclusive exchange mechanism

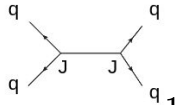
Indistinguishable exchange mechanism: 3q vs Junction (after hadronazation)

Case 1: J+2q exchange



Leading Baryon

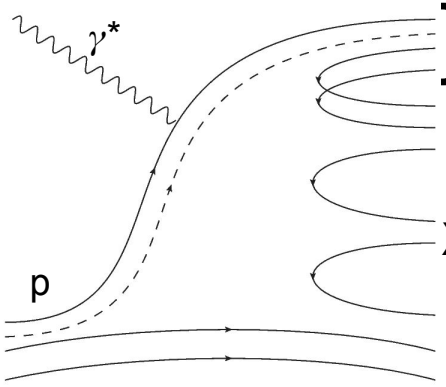
Coupling:



Regge interception: $\alpha(0) = -\frac{1}{2}$

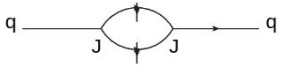
Baryon Multiplicity: $n_x = 1n^{(1)}$

Case 2: J+q exchange



Leading Baryon

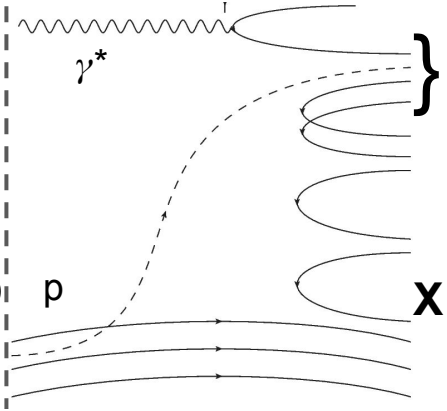
Coupling:



Regge interception: $\alpha(0) = 0$

Baryon Multiplicity: $n_x = 2n^{(1)}$

Case 3: J exchange



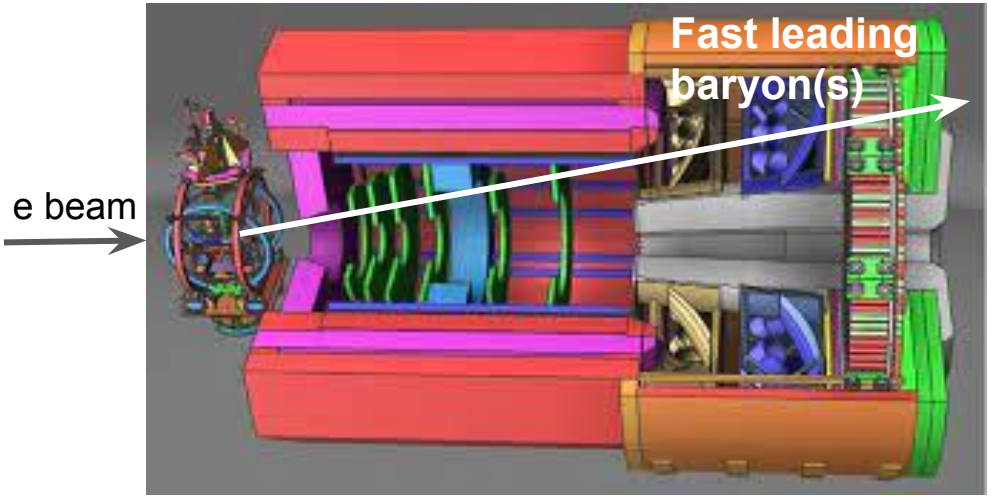
Leading Baryon

Coupling:

Regge interception: $\alpha(0) = +\frac{1}{2}$

Baryon Multiplicity: $n_x = 3n^{(1)}$

Probing u-Channel Inclusive processes during JLab 12 GeV

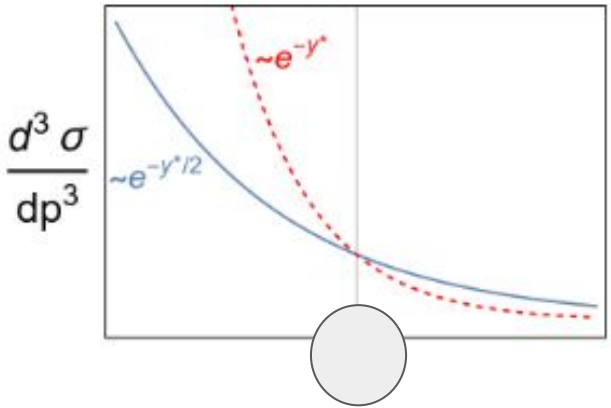


SoLID experiment is ideal venue to study the u-Channel inclusive processes !

- Publication and SoLID run group proposal will soon follow

Experimental observable:

- $Q^2 \sim 1$ GeV
- High luminosity
- Detecting baryon multiplicity (Large acceptance)
- Measurement involves
  - Multiplicity
  - differential cross section as function of rapidity

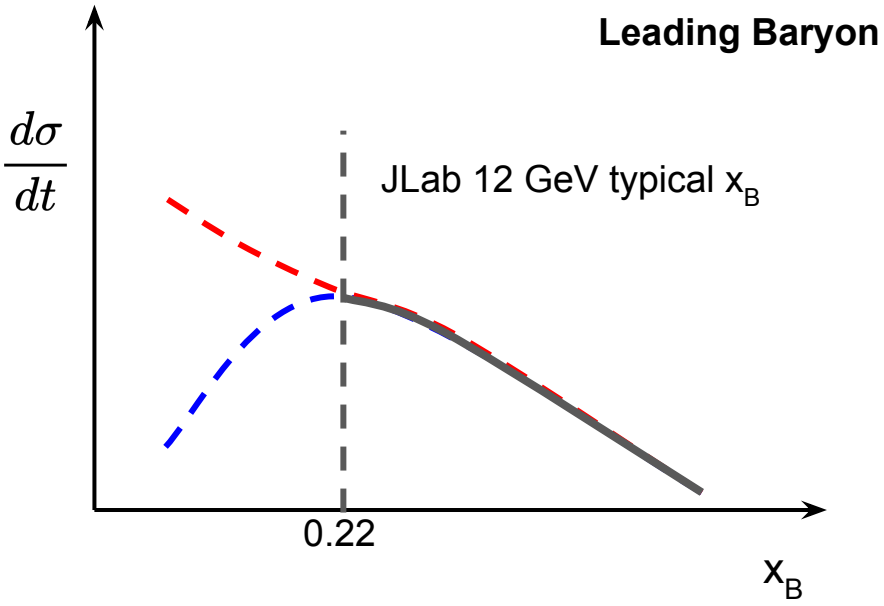


Conclusively Demonstrate the Baryon Junction Structure

- **How do we conclude the "junction"**
  - **Junctions**: are construct of gluons: **Junction -> u-Channel cross section enhancement at low x_b**
  - **No junction: u-Channel cross section suppressed -> valence quark contribution**

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

- **u-Channel inclusive program is under development**



u-Channel Beam Spin Asymmetry (CLAS 6 measurement)

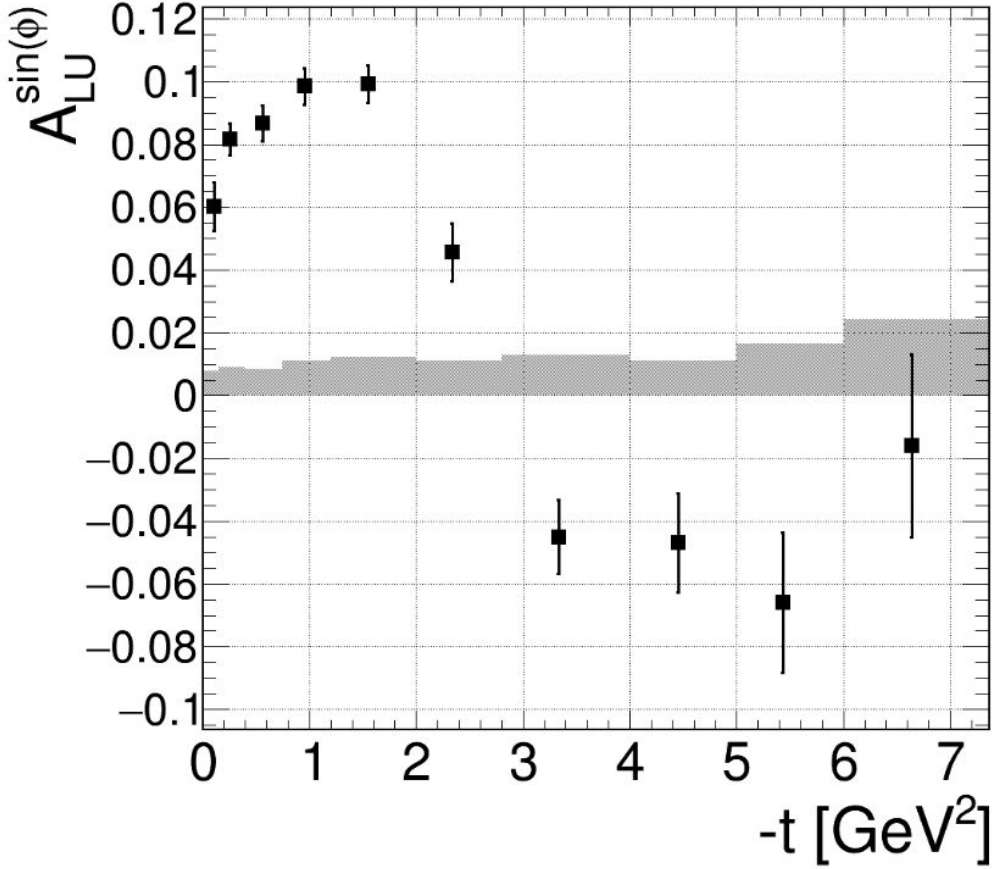
$$BSA_i = \frac{1}{P_e} \cdot \frac{N_i^+ - N_i^-}{N_i^+ + N_i^-}$$

$$A_{LU}^{\sin\phi} = \frac{\sqrt{2\epsilon(1-\epsilon)}\,\sigma_{LT'}}{\sigma_T + \epsilon\sigma_L}$$

***u*-Channel Beam Spin Asymmetry (S. Diehl, Kyungseon Joo, et. al):**

- Longitudinally polarized e beam on a unpolarized target
- Average e polarization was 75%
- **Result indicating a sudden change of sig for σ_{LT} indication sudden change of production mechanism**
- **Similar study at 12 GeV will be done for ρ/ω, ϕ**

Potential observable to map out the transition in production mechanism



S. Diehl *et al.* (CLAS Collaboration) Phys. Rev. Lett. 128, 062005

Asymmetry Result

Summary

- ***u*-Channel exclusive and inclusive DIS processes are linked to uncover the parton contributions to the baryon number**

- **Current JLab 12 GeV program is an unique opportunity to study exclusive and inclusive DIS processes.**

- **EIC is the neutral continuation to further explore the *u*-Channel DIS processes.**

- **u-Channel Spin observable could be the key to unveil transition of mechanisms.**