u-Channel Physics Observables at Future CLAS

Wenliang 'Bill' Li (SBU, W&M, Jlab EIC^2),
Stefan Diehl (Justus Liebig University Giessen, UCONN)
Kijun Park (HUPTI)

March/28/20221
@ JFuture Workshop

WILLIAM & MARY
CHARTERED 1693

Center for Frontiers
in Nuclear Science

Stony Brook
University

EIC Center at Jefferson Lab

JUSTUS-LIEBIG-
UNIVERSITÄT
GIESSEN

HAMPTON UNIVERSITY
PROTON THERAPY INSTITUTE

Outline

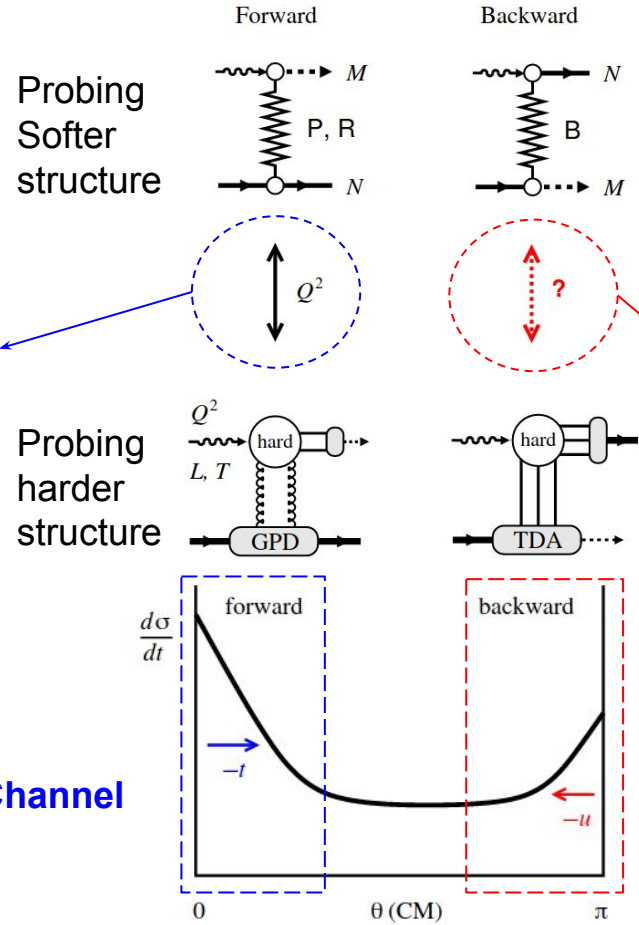
- **Important CLAS 6 measurements on *u*-Channel Physics**

- **Thoughts on future CLAS 12 upgrades and opportunities**
  - **u-Channel π^0 and DVCS @ CLAS 12**
  - **u-Channel J/ψ @ CLAS 24**
  - **u-Channel Beam Spin Asymmetry**

- **J/ψ electroproduction at CLAS 24**

Probing Soft-Hard Transition through Hard meson production

Current experimental evidence suggest Collinear factorization is marginal at JLab 12 GeV kinematics



Could the early scaling of Collinear factorization happen at Q^2 at a few GeV^2 (~2 GeV^2) ?

Two evidence showing the transition:

1. CLAS6 u-Channel π^+
2. Hall C u-Channel ω

We need to further pursue u-Channel meson production studies

***t*-Channel**

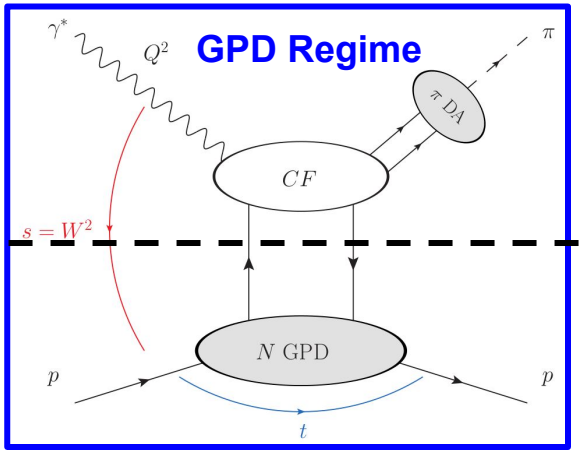
***u*-Channel**

Courtesy of Christian Weiss

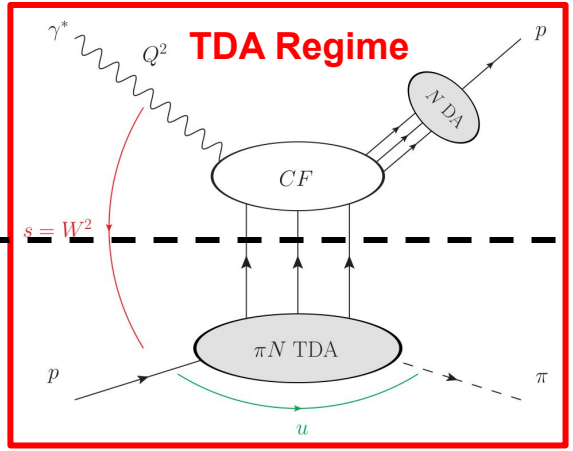
GPD and TDA (Hard Structure)

Hard structure

Soft structure



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



Collinear factorization

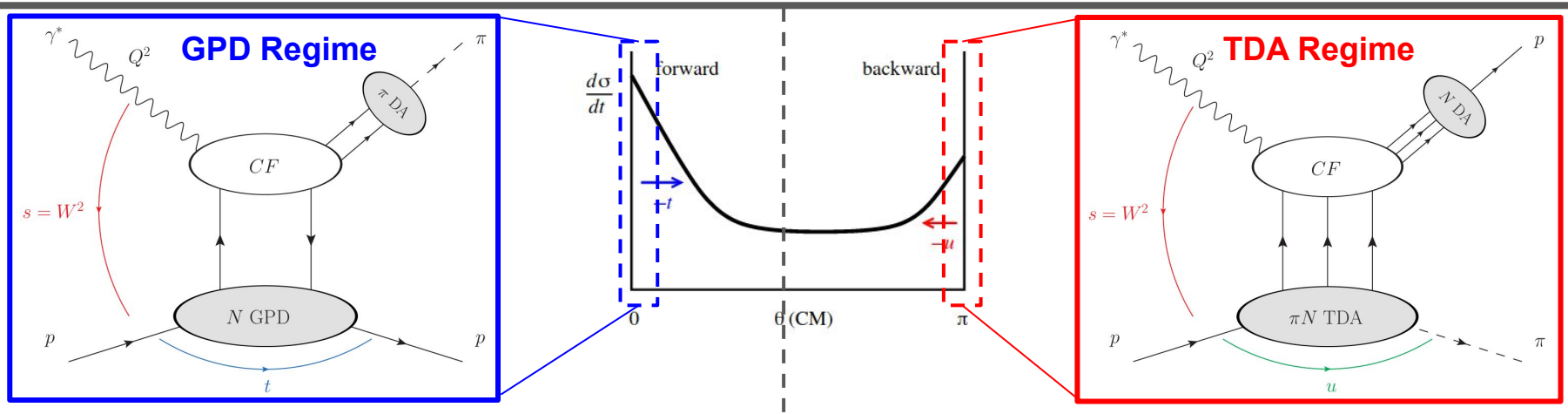
Developed by **B. Pire**, **L. Szymanowski** and **K Semenov-Tian-Shansky** in 2000

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.

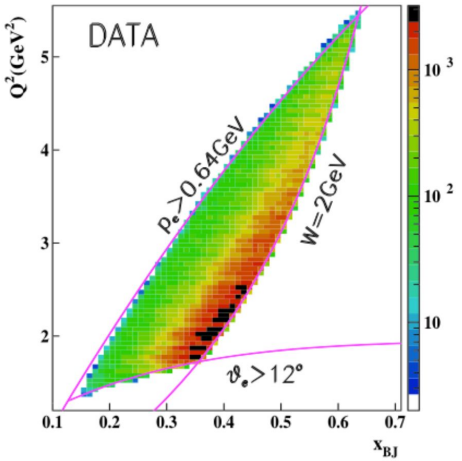
GPD vs TDA Diagrams

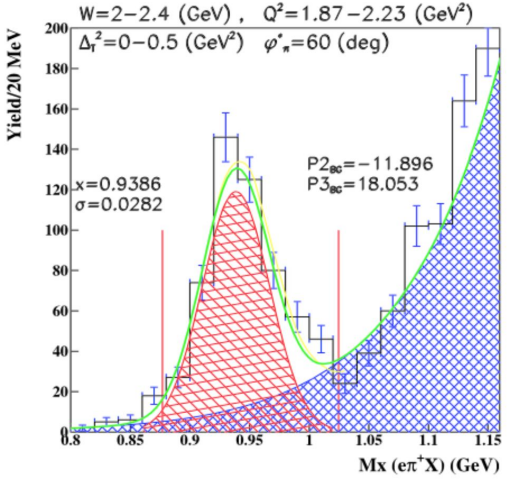


- Factorization: $Q^2 \rightarrow$ large, $-t \rightarrow$ small, $-t/Q^2 \sim 0$
- Systematically study forward DVCS & DVMP
- Factorization indicator:
  - $\sigma_L >> \sigma_T$
  - $d\sigma_L/dt \propto 1/Q^6$
- Factorization conclusion results from most meson production channels.

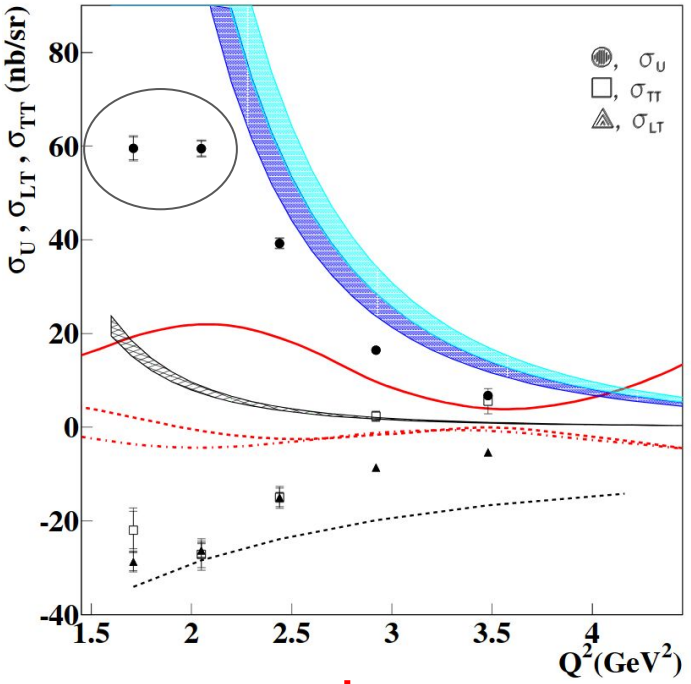
- Factorization: $Q^2 \rightarrow$ large, $-u \rightarrow$ small, $-u/Q^2 \sim 0$
- Systematically study backward DVCS & DVMP?
- Factorization indicator:
  - $\sigma_T >> \sigma_L$
  - $d\sigma_T/dt \propto 1/Q^{10}$ ($d\sigma_T/d\Omega \propto 1/Q^8$)
- Factorization conclusion results from most meson production channels.

CLAS 6 Backward π^+ Electroproduction





Key 6 GeV CLAS result #1



CLAS u-Channel π^+ electroproduction

- At Q^2 data start to track Q^2 scaling prediction at Q^2>2 GeV^2

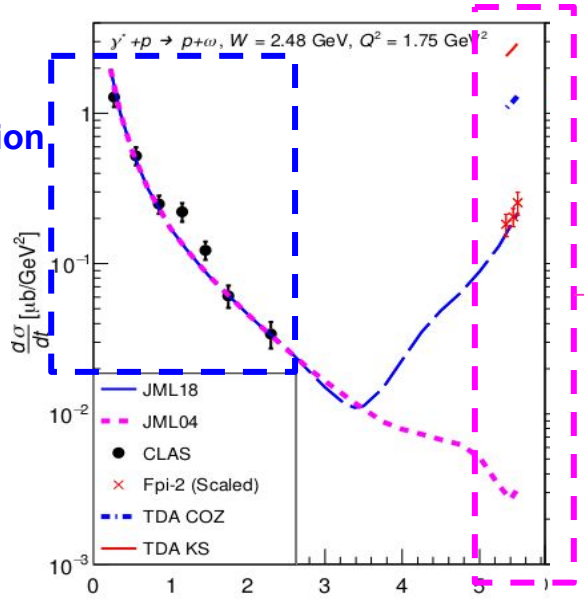
Two qualitative predictions from TDA:

- $\sigma_T > \sigma_L$, $\sigma_L \sim 0$
- $\sigma_T \sim 1/Q^8$ scaling behavior

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

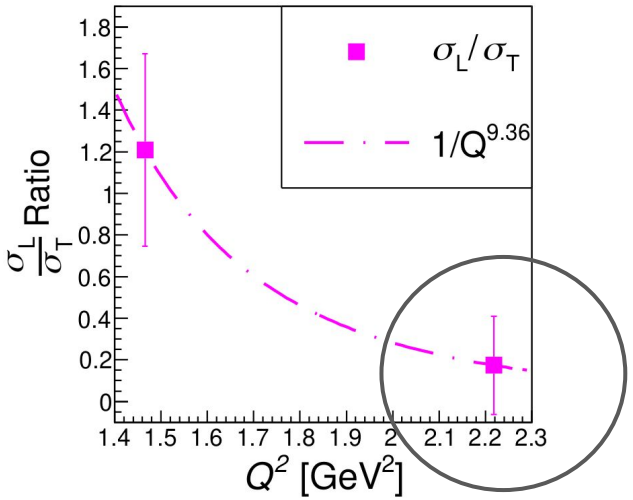
Validation of TDA Factorization Scheme

CLAS 6 ω electroprorduction



Hall C ω L/T study

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



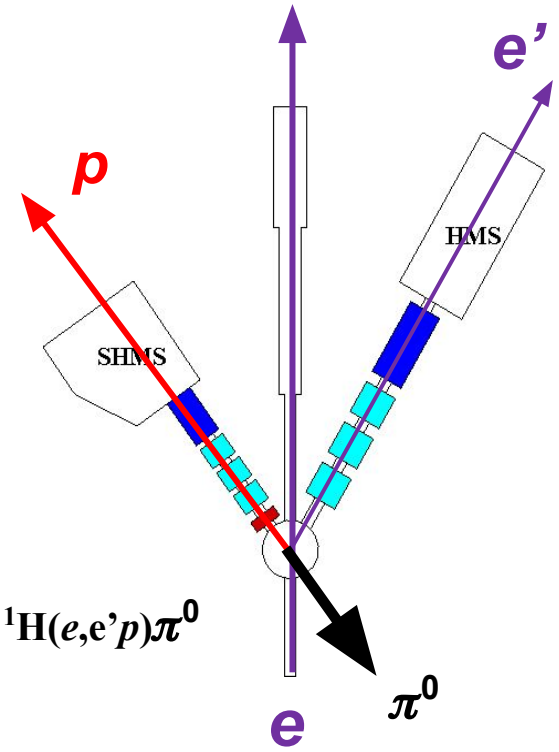
$\sigma_T > \sigma_L$ at $Q^2 \sim 2.2$ GeV^2

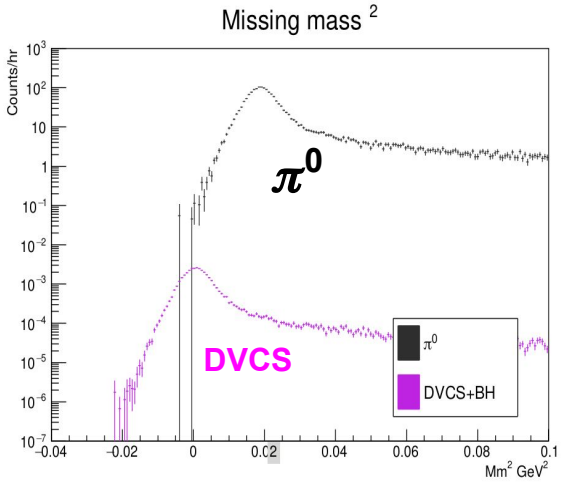
Two qualitative predictions from TDA:

- $\sigma_T > \sigma_L$, $\sigma_L \sim 0$
- $\sigma_T \sim 1/Q^8$ scaling behavior

A new measurement needed to simultaneously study TDA

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



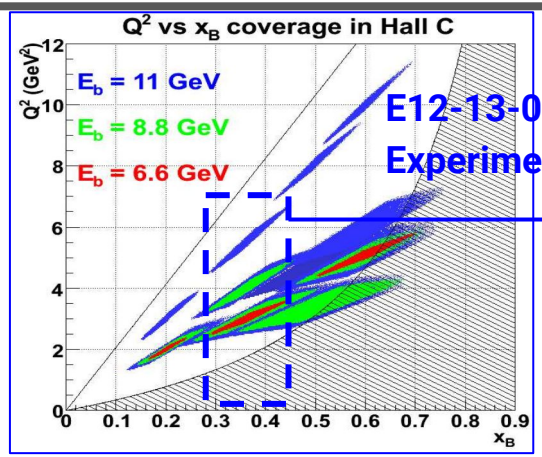


Q^2 GeV^2	W GeV	ϵ	x	θ_{pq} Degree
2.0	3.00	0.32	0.20	-3, 0
		0.79	0.20	-2.8, 0, +3
2.0	2.11	0.52	0.36	-3, 0, +3
		0.94	0.36	-3, 0, +3
3.0	2.49	0.54	0.36	-3, 0, +3
		0.86	0.36	-3, 0, +3
4.0	2.83	0.56	0.36	-3, 0, +3
		0.73	0.36	-3, 0, +3
5.0	3.13	0.26	0.36	-3, 0
		0.55	0.36	-3, 0, +3
6.25	3.46	0.27	0.36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

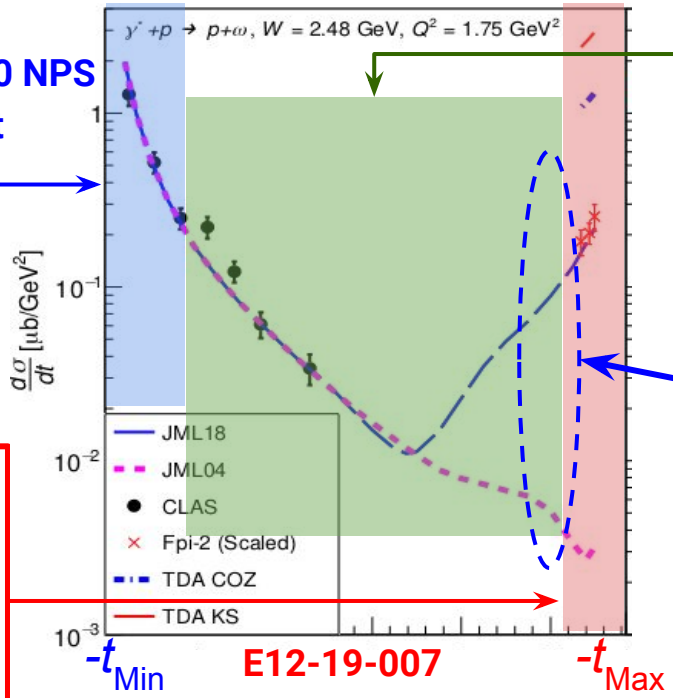
First dedicated *u*-channel electroproduction study above the resonance region:

- **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**

A Complete -*t* Evolution Backward-angle Peaks

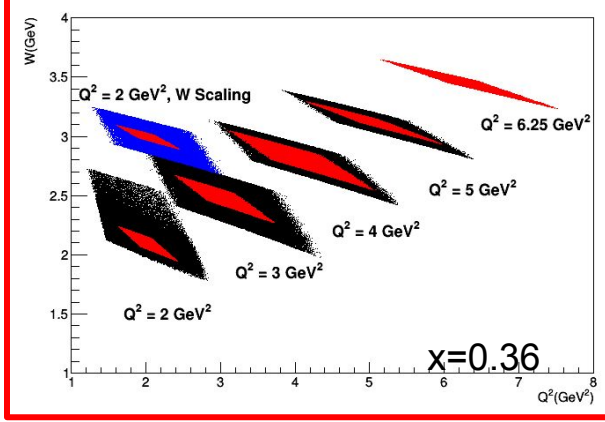


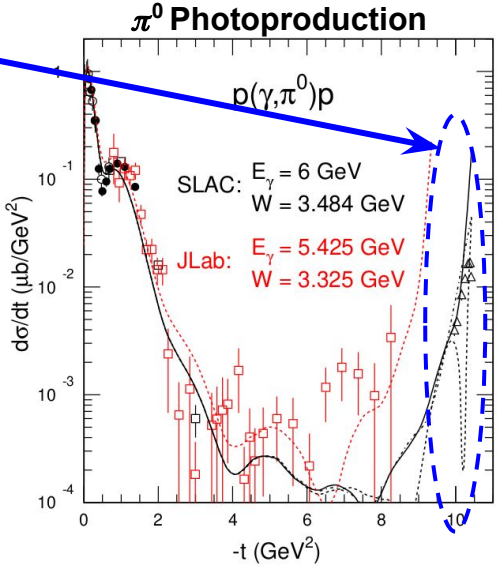
E12-13-010 NPS Experiment



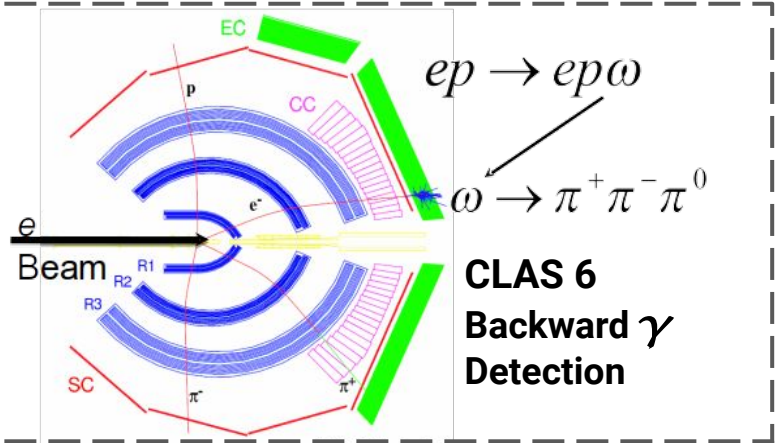
CLAS Only!
With a future upgrade to enhance the backward (large angle) photon detection. (See next slide).

Observing dips?





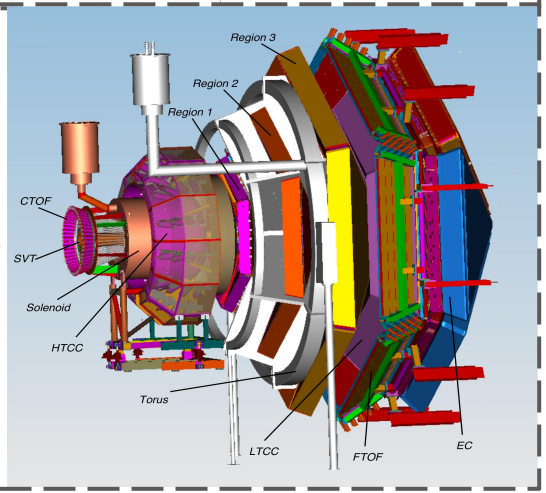
u-Channel Opportunities at CLAS 12



CLAS 6
Backward γ Detection

CLAS 12
No backward γ Detection capability

e beam →

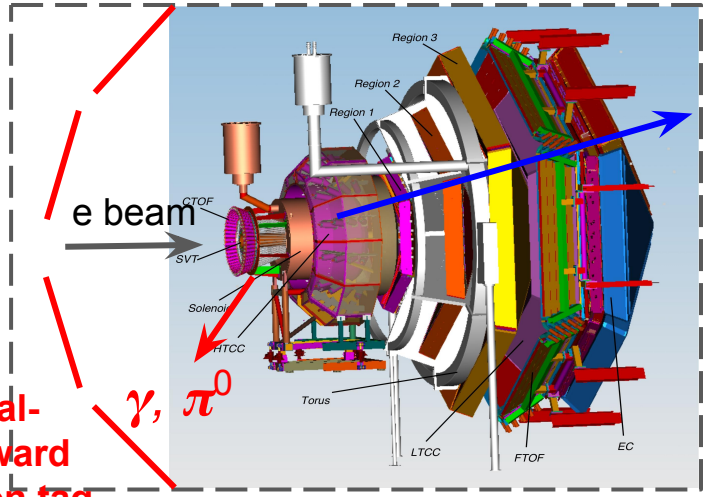


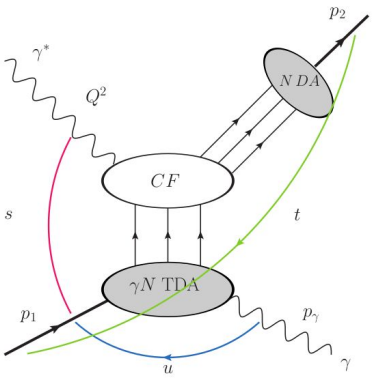
Harvesting u-channel meson production cross section at near u_{min} kinematics at Hall B CLAS12 (expert opinion by S. Diehl)

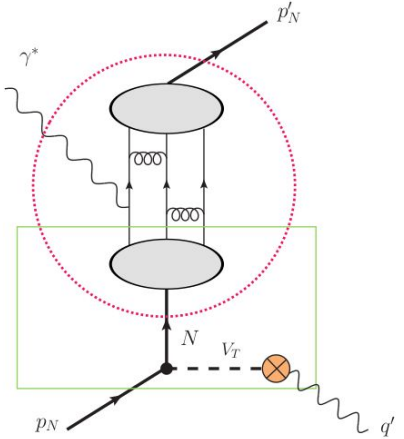
- **π^0: good acceptance for -*t* of 5-6 GeV^2. u-channel measurements not possible.**
- **π^+:** full coverage of the *t* and *u* acceptance.
- **$\rho/\omega \rightarrow \pi^+\pi^-$:** decay well measured, full coverage of the *t* and *u* acceptance.
- **$\phi \rightarrow K^+K^-$:** full coverage of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

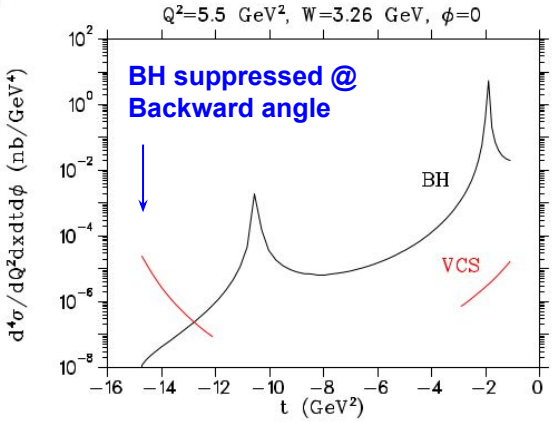
Possibility to address *u*-channel π^0 issue in the near future?

u-Channel DVCS at CLAS 12 with Upgrade



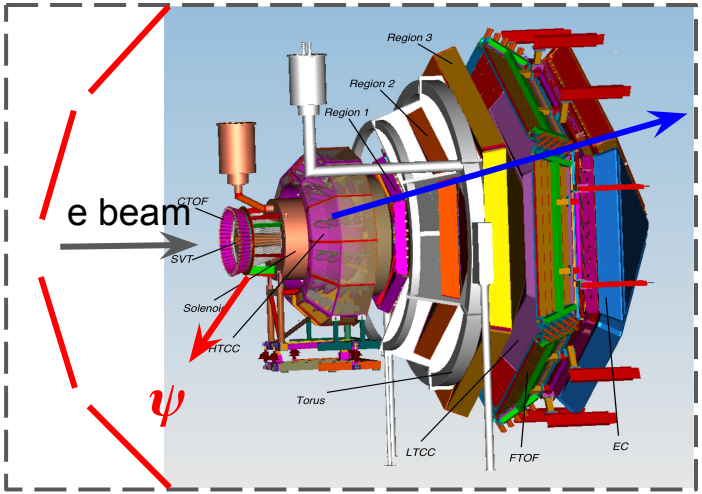






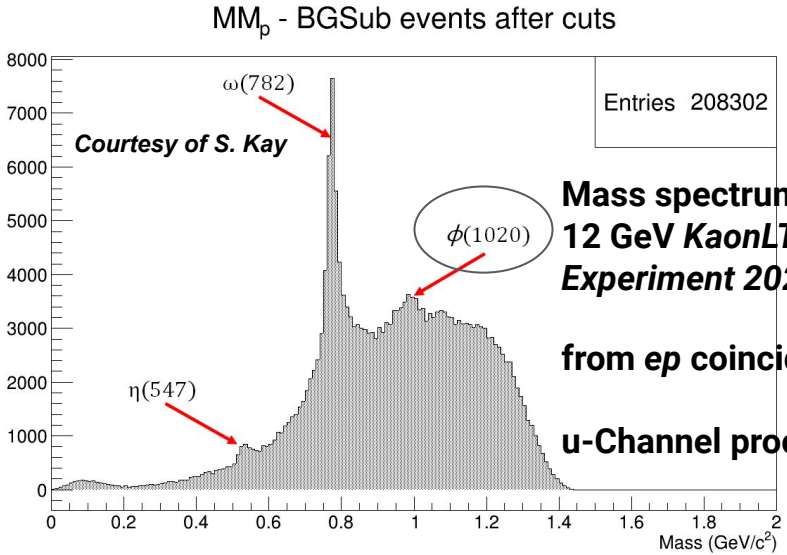
- **u-Channel Benefit feasibility:**
  - **BH is highly suppressed at the backward angle**
  - **Hall C u-Channel ω combined with the VDM can be used to estimate the rate**
  - **Large acceptance and luminosity at CLAS12 is the best value to study complete -t evolution**

u-Channel J/ψ at CLAS 24



Fast leading proton

Central-backward dilepton tag



Mass spectrum from 12 GeV *KaonLT Experiment 2020*

from *ep* coincidence

u-Channel processes

J/$\psi\rightarrow e^+e^-$ and J/$\psi\rightarrow\mu^+\mu^-$

- **JLab 24 GeV (potential 10x luminosity) open new possibilities for u-Channel meson productions: e+p→e'p'J/ψ**
  - Probing intrinsic cc-bar content of the target nucleon at the valence quark region.
  - Rate projection could be done based on the t-Channel J/ψ production process
  - Di-lepton capability needs to be investigated.

CLAS 6 Backward Beam Spin Asymmetry Result

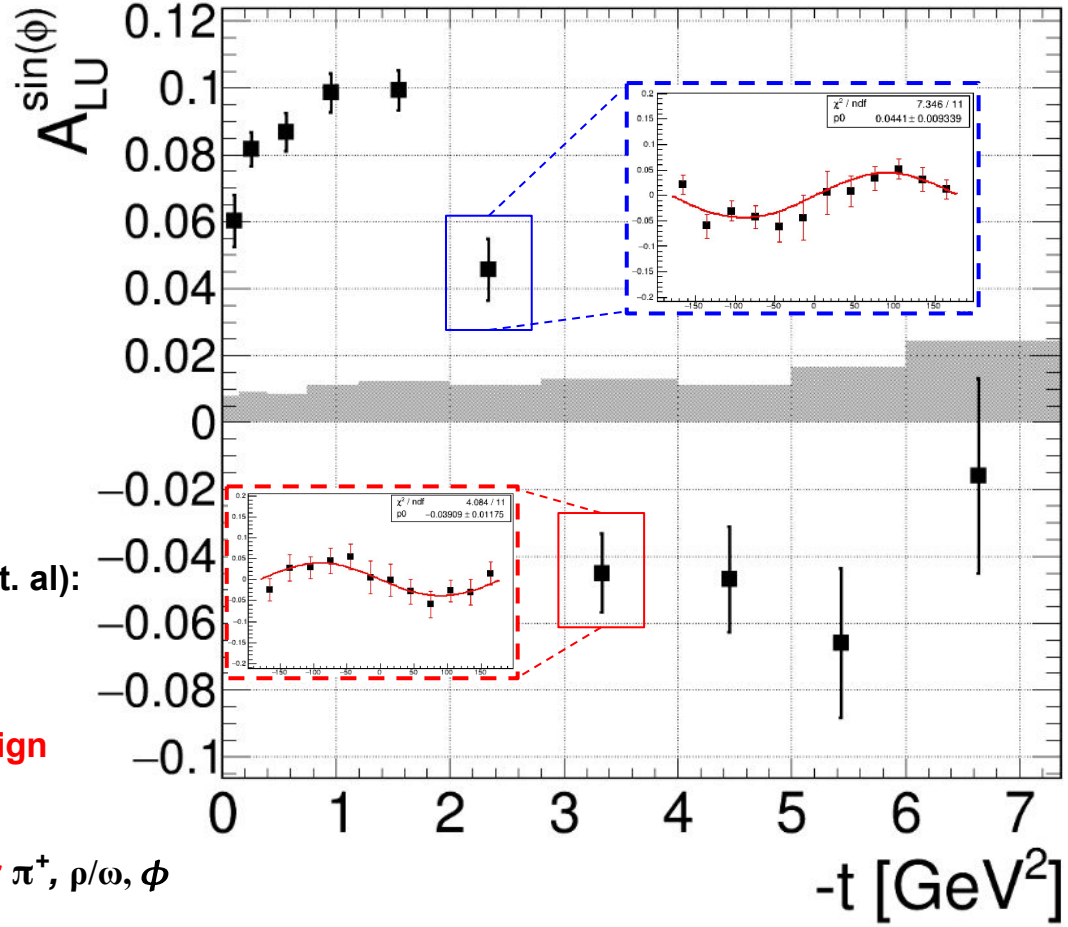
Key 6 GeV CLAS result #2

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

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

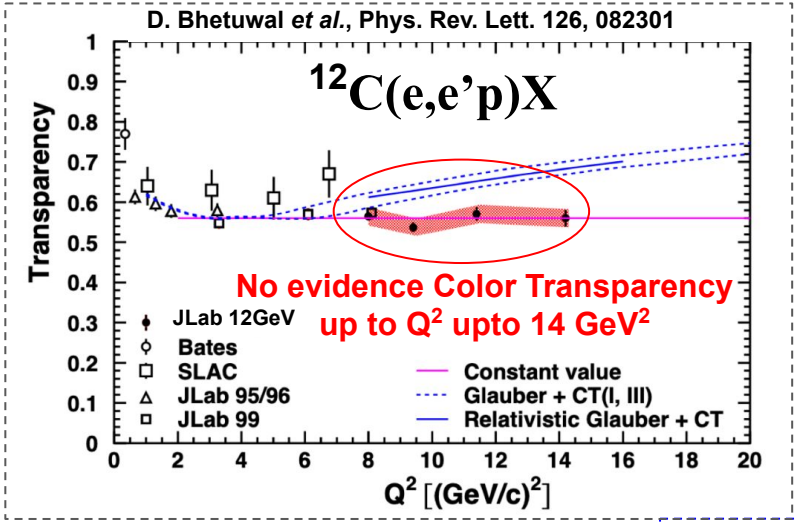
u-Channel Beam Spin Asymmetry (S. Diehl, et. al):

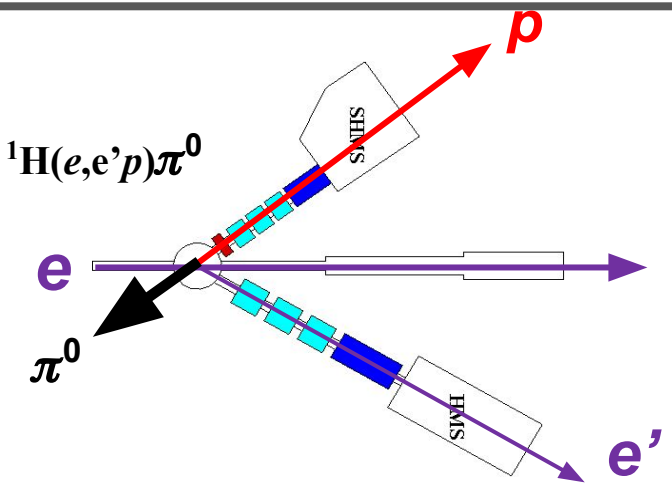
- Longitudinally polarized e beam on a unpolarized target
- Average e polarization was 75%
- **Result indicating a sudden change of sign for σ_{LT} indication sudden change of production mechanism**
- **Similar study at 12 GeV will be done for π^+, ρ/ω, ϕ**

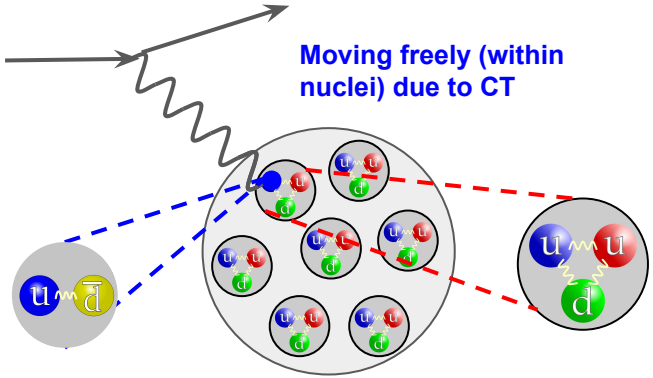


S. Diehl *et al.* (CLAS Collaboration) Phys. Rev. Lett. 128, 062005

Testing Nuclear Color Transparency via u-Channel meson Production

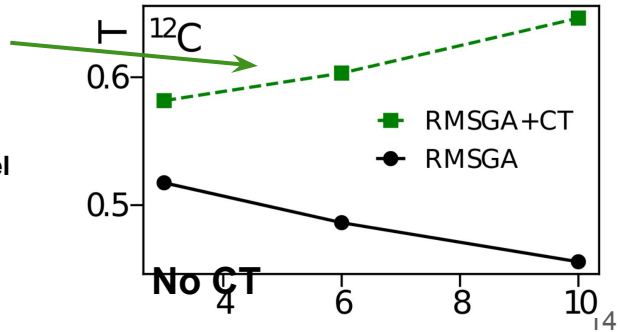




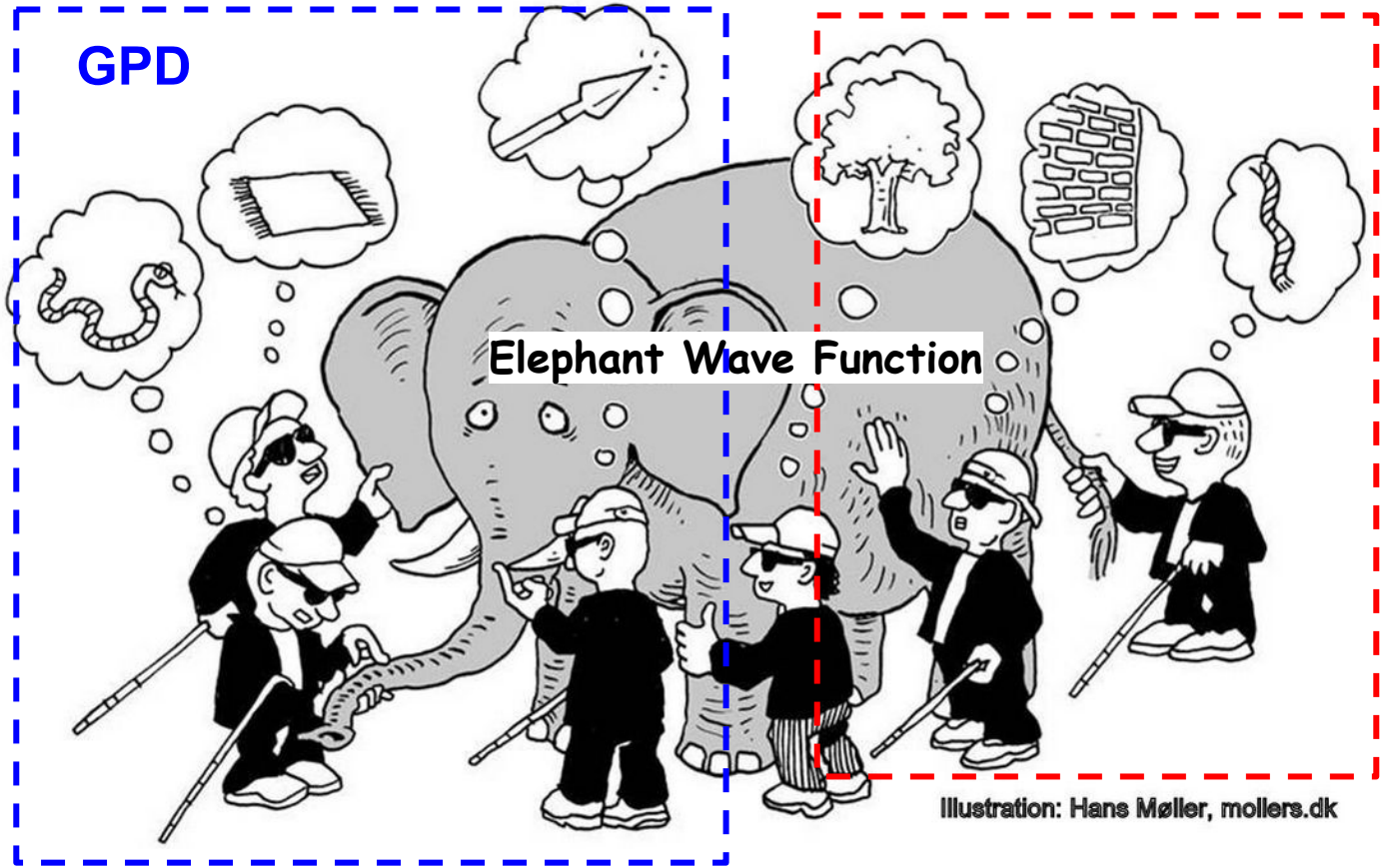


CT onset predicted
$^{12}C(e,e'p)X\pi^0$ by W. Cosyn

A new CT observable through u-Channel meson electroproduction by
G. Hube, W.B. Li, W. Cosyn, B. Pire
https://arxiv.org/abs/2202.04470



Thank You! And Our Final Thoughts

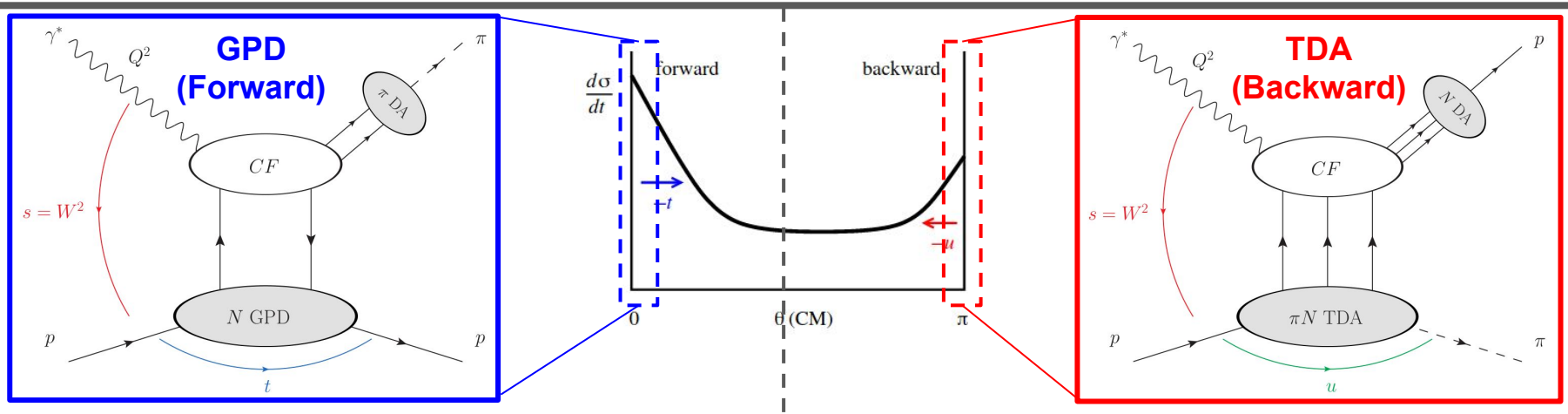


We must consider to give CLAS12 and CLAS24 with appropriate equipment to probe u-channel processes.

Question to us: are we going to give-up on u-Channel study because it is too hard to understand?

Backup slides

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)**

$$H^{\pi N}_{s.f.} = \{V^{\pi N}_{1,2}, A^{\pi N}_{1,2}, T^{\pi N}_{1,2,3,4}\}$$ **π↔p TDAs**

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

TDA Meson Production Cross Section

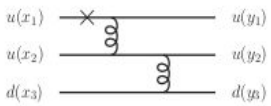
- Unpolarized exclusive meson production cross section for π^0:

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

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

First expansion is shown as an example

$\Delta^2 \equiv u$

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

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, 2011

Testing Nuclear Color Transparency at JLab

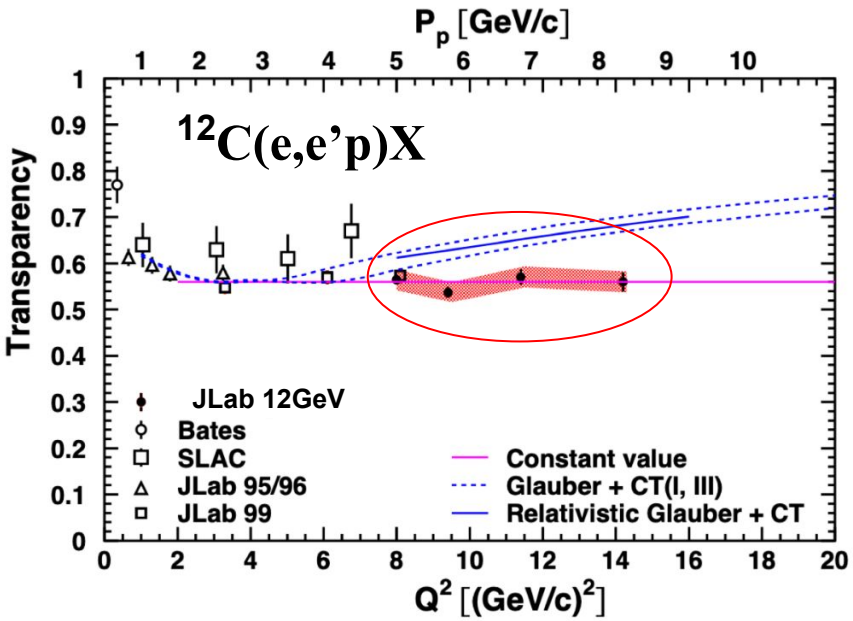
$$T = \frac{\sigma_A}{A \cdot \sigma_N}$$

(Nuclear scattering)

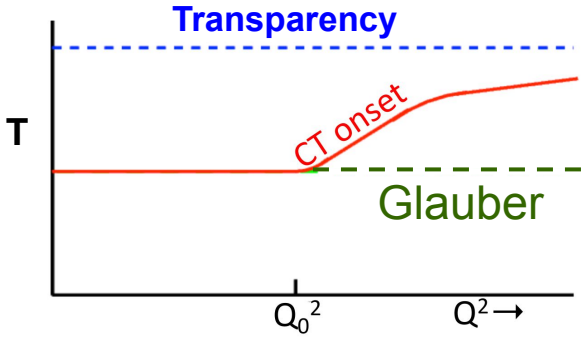
(Nucleon scattering)

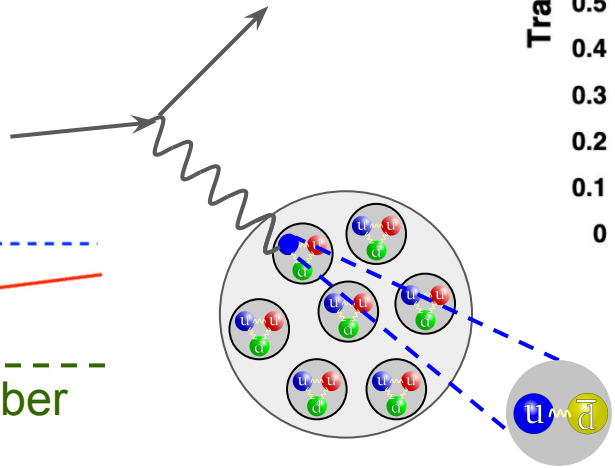
$$\sigma_A = \sigma_N A^{\alpha}$$

D. Bhetuwal *et al.*, Phys. Rev. Lett. 126, 082301



No evidence Color Transparency up to Q^2 upto 14 GeV^2



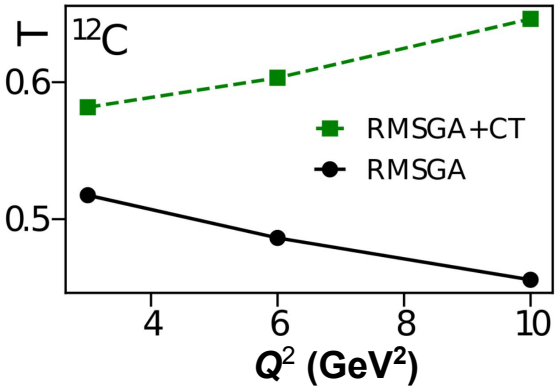


Moving freely (within nuclei) due to CT

New way of Testing Nuclear Color Transparency

- ***u*-Channel π^0 : $^{12}C(e,e'p)X\pi^0$, electroproduction to probe $^{12}C(e,e'p)X\pi^0$**
- **Two fold assumption:**
  - $\sigma_T >> \sigma_L$, thus, TDA Collinear factorization is valid.
  - Color Transparency indicate early scaling.
- No additional measurement needed for **^{12}C** as a initial test.

Predicted nuclear CT via $^{12}C(e,e'p)X\pi^0$



G. Huber, W.B. Li, W. Cosyn, B. Pire arxiv.org/abs/2202.04470

Observation of CT will add strong evidence invalidating TDA