u-Channel Physics Observables at Future JLab 20+ Program

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 Opportunities with JLab Energy and Luminosity Upgrade In Trento, Italy
 Stony Brook University

Outline

- 6 and 12 GeV u-Channel Physics studies
- JLab 20+ Upgrades and opportunities
 - Probing u-Channel π^0 and DVCS LT separation (JLAB Unique)
 - Probing u-Channel π^0 and DVCS @ CLAS 12 with backward calorimetry upgrade.
 - Volker's question: 0-150° coverage enough?
 - u-Channel J/ ψ LT separation (JLAB Unique)

Gifted Backward-angle Observables

• Fpi-2 (E01-004) 2003

FREE!

- 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
 - $W= 2.21 \text{ GeV}, Q^2=1.6 \text{ and } 2.45 \text{ GeV}^2$
 - Two ϵ settings for each Q^2



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

• Primary reaction for Fpi-2

- H(e, e' π^+)n
- o n (940 MeV)
- \circ π^+ (140 MeV)

• Unexpected reaction:

- Η(e,e' p)ω
- p (940 MeV)
- ο *ω* (783 MeV)



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



Results on Backward Angle Electroproduction

Forward ω electroproduction from CLAS 6 (2004)



- Topic of my Ph.D
- Analysis: 2013-2017
- Results published in *Phys. Rev. Let.* (2019)
- The magnitude of u-Channel peak is surprisingly large

Backward angle ω electroproduction (2017)

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



Probing Soft-Hard Transition through Hard meson production



GPD at Large -t is not a new thing



GPD at large -t is not a new thing

- Off-forward parton distributions (Ji in 1996) https://arxiv.org/pdf/hep-ph/9603249.pdf
- Non-forward Parton Distribution (Radyushkin in 1997) https://arxiv.org/pdf/hep-ph/9704207.pdf
- Skewed Parton Distribution (Radyushkin in 2000) https://arxiv.org/abs/hep-ph/0011383
- Skewed Distribution Amplitude (Frankfurt & Strikman in 1999) https://arxiv.org/pdf/hep-ph/9901429.pdf
- TDA (Bernard, Lech) https://arxiv.org/pdf/hep-ph/0411387.pdf

GPD and TDA (Hard Structure)



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

forward



- Factorization: $Q^2 \rightarrow$ large, $-t \rightarrow$ small, $-t/Q^2 \sim 0$
- Systematically study forward DVCS & DVMP
- Factorization indicator:
 - σ_L >> σ_T
 - dσ_L/dt ∝ 1/Q⁶
- 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:
 - σ_T >> σ_L

backward

θ(CM)

- $d\sigma_T/dt \propto 1/Q^{10} (d\sigma_T/d\Omega \propto 1/Q^8)$
- Factorization conclusion results from most meson production channels.

Wishlist/dos before EIC starts for u-Channel Observables

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Addressing some questions

- JLab 20+ Upgrades and opportunities
 Brobing u Channel P and DVCS IT
 - Probing u-Channel π⁰ and DVCS LT separation (JLAB Unique)
 - Probing u-Channel π⁰ and DVCS @ CLAS
 12 with backward calorimetry upgrade.
 - Volker's question: Is the 0-150° coverage enough?
 - u-Channel J/ψ LT separation (JLAB Unique)

	$\sigma_{\rm T} > \sigma_{\rm L}$	$1/Q^8$ Scaling				
π^0	0	0				
π^+		\checkmark				
π^{-}						
K^0						
K^{\pm}						
η	\checkmark	\checkmark				
ρ		1				
ω	~~	~				
η	v	V				
$\frac{\varphi}{I/2}$	v	v				
DVCS						

u-Channel Opportunities at CLAS 12 (Presented in Messina Workshop)



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 GeV². 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



Conclusion 1:

- 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.

Г												
	${f T}_{inc}$ MeV	${ m T}_e^* { m MeV}$	$ heta_e^*$ deg	ϵ	−t GeV/c	$ heta_q$ deg	P_p MeV/c	$\begin{array}{c} \theta_{pq} \\ \mathrm{deg} \end{array}$	P_m MeV/c	$\begin{array}{c} \theta_{mq} \\ \mathrm{deg} \end{array}$	−u GeV/c	x
				Q_{no}^2	$m_{inal} = 10$	0 GeV ²	$W_{nominal} =$	3.3 Ge	V			
JLab 20+	13400	2736.945	30.266	0.356	19.558 19.236	-7.126	11321.616 11149.540	0.0 2.0	-199.53 -389.66	180 93.04	-0.4465 -0.1247	0.4998
	17800	7136.946	16.128	0.6682	19.558 19.236	-10.268	11321.616 11149.540	0.0 2.0	-199.53 -389.66	180 93.04	-0.4465 -0.1247	0.4998
				Q_{no}^2	$m_{inal} = 12$	$2 \mathrm{GeV}^2$	$W_{nominal} =$	3.1 Ge	V			
	13400	2353.26	35.926	0.2987	20.337 19.925	-6.851	11738.124 11518.003	0.0 2.0	-160.97 407.38	180 99.35	-0.5053 -0.0935	0.5789
	17800	6753.261	18.178	0.6363	20.337 19.925	-10.486	11738.124 11518.003	0.0 2.0	-160.97 407.38	180 99.35	-0.5053 -0.0935	0.5789
]					

u-Channel DVCS at Hall C



An Example Study for u-Channel Exclusive π^0



EIC and ElcC cannot provide L/T separated cross sections. The scaling test alone is insufficient to validate factorization

u-Channel DVCS at CLAS 12 with Upgrade



J/psi Electroproduction in the *u*-Channel Kinematics at 20+



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J/psi Production in the *u*-Channel Kinematics at Hall C



Summary on J/psi production in the *u*-Channel kinematics



• 22 GeV is the only venue could do traditional L/T separation measurement. In the *u*-Channel kinematics.

• Issues and improvements:

- HMS momentum is 10-20% too low (10 GeV would be ideal), Currently at 7.4 GeV
- HMS minimum rotation angle is too large (5° would be ideal), currently 10°
 - Horizontal bender. (similar to the angle used by SHMS) ~ \$25 M
 - Spectrum magnets is an option? (Hall A 6 GeV era)

Thank You for an inspiring Workshop!



Backup slides

GPD vs TDA Fact sheet 3



• Formalism: four compact structures

$$\begin{split} &\int_{-1}^{1} dx H_q(x,\xi,t) = F_1^q(t), \quad \int_{-1}^{1} dx E_q(x,\xi,t) = F_2^q(t), \\ &\int_{-1}^{1} dx \tilde{H}_q(x,\xi,t) = G_A^q(t), \quad \int_{-1}^{1} dx \tilde{E}_q(x,\xi,t) = G_P^q(t), \end{split}$$

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

$$H^{\pi N}_{s.f.} = \{V^{\pi N}_{1,2}, A^{\pi N}_{1,2}, T^{\pi N}_{1,2,3,4}\} \quad \pi {\leftrightarrow} \mathsf{p} \, \mathsf{TDAs}$$

$$H_{s.f.}^{\gamma N} = \left\{ V_{1arepsilon}^{\gamma N}, A_{1arepsilon}^{\gamma N}, \, T_{1arepsilon,\,2arepsilon}^{\gamma N}
ight\}$$
 γ \leftrightarrow p TDAs

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TDA Meson Production Cross Section



J. P. Lansberg, B. Pire, K. Semenov-Tian-Shansky, L. Szymananovski, Phys. Rev. D 85, 054021, 2011

Testing Nuclear Color Transparency at JLab



Moving freely (within nuclei) due to CT

New way of Testing Nuclear Color Transparency

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

Predicted nuclear CT via ¹²C(e,e'p)X π^0



Observation of CT will add strong evidence invalidating TDA

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

CLAS 6 Backward Beam Spin Asymmetry Result



Key 6 GeV CLAS result #2

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 $\sigma_{\rm LT}$ indication sudden change of production mechanism
- Similar study at 12 GeV will be done for π^+ , ρ/ω , ϕ



Testing Nuclear Color Transparency via u-Channel meson Production





A Complete -t Evolution Backward-angle Peaks



u-Channel J/ ψ at CLAS 24



Central-backwa dilepton tag

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

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

CLAS 6 Backward π^+ Electroproduction



Validation of TDA Factorization Scheme



A new measurement needed to simultaneously study TDA

E12-20-007 Backward-angle 1 H(*e*,*e*'*p*) π^{0}

 π^0

e



- Q² coverage: 2.0 < Q² < 6.25 GeV², at x=0.36 and W > 2 GeV L/T separated cross section @ Q²= 2, 3, 4 and 5 GeV².
- *u* coverage: 0 < -*u*' +0.5 < 0.5 GeV²
- Additional W scaling check @ Q² = 2 GeV²
- Additional Q^2 scaling check @ Q^2 = 6.25 GeV²