PAC 48 Presentation: PR12-20-007 Backward-angle Exclusive π^0 Production Above the Resonance Region

Wenliang (Bill) Li,

On behalf of the spokespersons and all authors of PR12-20-007

WILLIAM & MARY
CHARTERED 1693

Jefferson Lab

12/Aug/2020

PR12-20-007 Collaborator List

Wenliang (Bill) Li, Justin Stevens, David Armstrong, Todd Averett, Andrew Hurley, Lydia Lorenti, Arkaitz Rodas and Amy Schertz
College of William and Mary, Williamsburg, VA, USA
Garth Huber, Muhammad Junaid, Stephen Kay, Vijay Kumar, Zisis Papandreou, Dilli Paudyal, and Ali Usman
University of Regina, Regina, SK Canada
Kirill Semenov-Tian-Shansky
National Research Centre Kurchatov Institute: Petersburg Nuclear Physics Institute, RU-188300 Gatchina, Russia
Bernard Pire
CPHT, CNRS, Ecole Polytechnique, IP Paris, 91128-Palaiseau, France
Lech Szymanowski
National Centre for Nuclear Research (NCBJ), 02-093 Warsaw, Poland
Alexandre Camsonne, Jian-Ping Chen, Silviu Covrig Dusa, Filippo Delcarro, Markus Diefenthaler, Dave Gaskell, Ole Hansen, Doug Higinbotham, Astrid Hiller Blin, Mike McCaughan, Brad Sawatzky, and Greg Smith
Jefferson Lab, Newport News, Virginia, USA

Arthur Mkrtchyan, Vardan Tadevosyan, Hakob Voskanyan, and Hamlet Mkrtchyan
A. Alikhanyan National Science Laboratory (Yerevan Physics Institute), Yereven, Armenia
Stefan Diehl, Eric Fuchey, and Kyungseon Joo
University of Connecticut, Mansfield, Connecticut, USA
Werner Boeglin, Mariana Khachatryan, Pete E. Markowitz, and Carlos Yero
Florida International University, Miami, Florida, USA
Moskov Amaryan, Florian Hauenstein, and Charles Hyde
Old Dominion University, Norfolk, VA, USA
Gabriel Niculescu and Ioana Niculescu
James Madison University, Harrisonburg, Virginia, USA
Paul King and Julie Roche
Ohio University, Athens, Ohio, USA

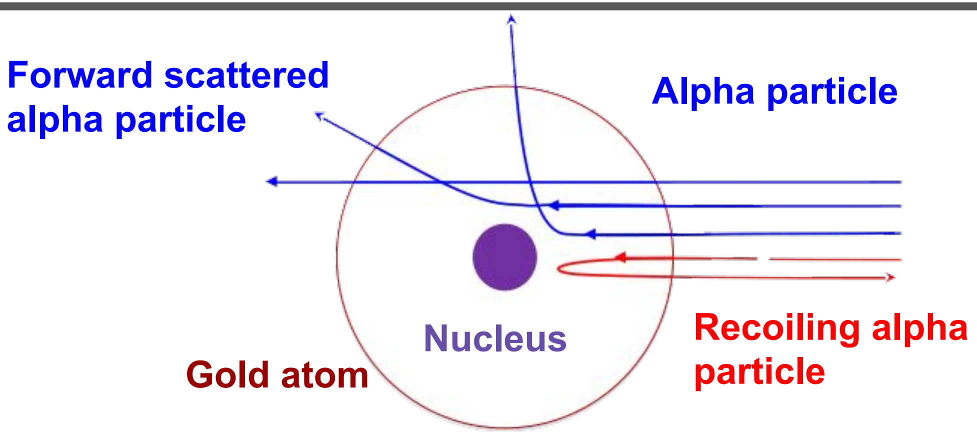
Darko Androic
University of Zagreb, Zagreb , Croatia
Konrad Aniol
California State University, Los Angeles, California, USA
Marie Boer
Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA
Wouter Deconinck
University of Manitoba, Winnipeg, Manitoba, Canada
Maxime Defurne
CEA, Universite Paris-Saclay, Gif-sur-Yvette, France
Mostafa Elaasar
Southern University at New Orleans, New Orleans, Louisiana, USA
Cristiano Fanelli
Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

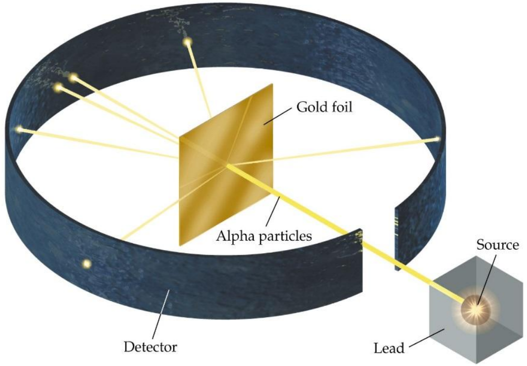
Stuart Fegan
University of York, Heslington, York, UK
Carlos Ayerbe Gayoso
Mississippi State University, Starkville, MS, USA
Narbe Kalantarians
Virginia Union University, Richmond, VA, USA
Daniel Lersch
Florida State University, Tallahassee, Florida, USA
Rafayel Paremuzyan
University of New Hampshire, Durham, New Hampshire, USA
Kijun Park
Hampton University Proton Therapy Institute, Hampton, Virginia, USA
Igor Strakovsky
The George Washington University, Washington, DC, USA

Outline

- Quick introduction into the u-channel physics
- Four Experimental objectives
- Experimental detail

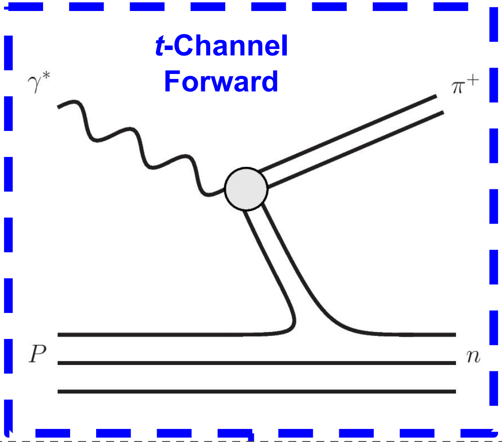
Forward and Backward-angle Scattering off Atoms

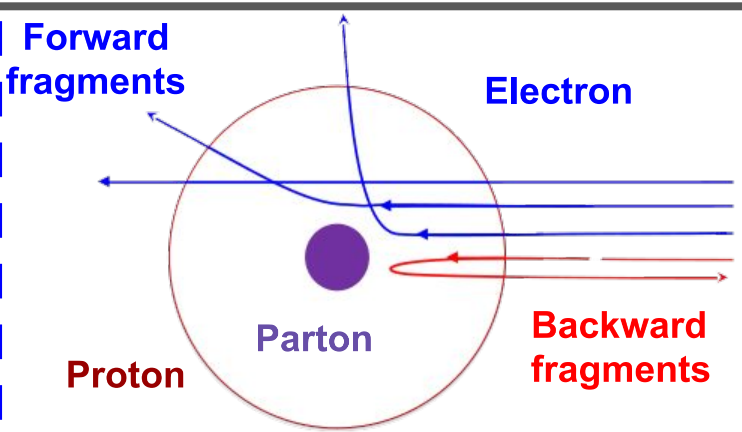


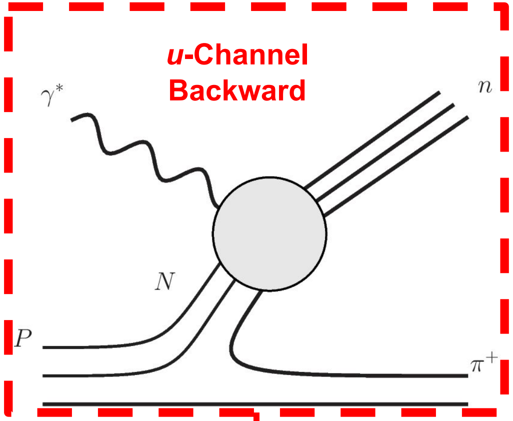


- **Forward scattered alpha particle: extracting the interaction radius of the nucleus and mapping out the transverse structure of the atom (mostly empty)**
- **Recoiling alpha particle: stiffness of the “point-like” structure.**
- Full structure must incorporate both forward angle and backward angle observables.

Forward and Backward-angle Photoproduction

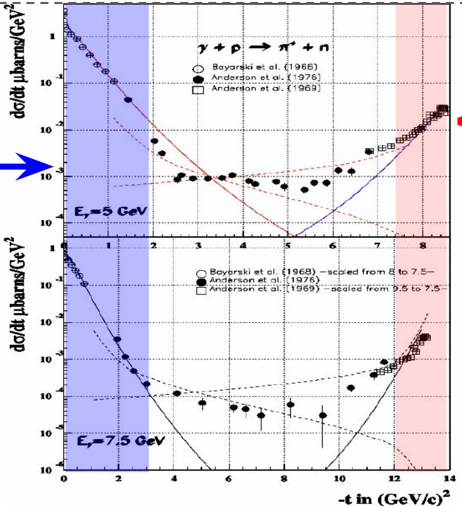






Meson pole contribution

Baryon pole contribution



u_{min} : 180° emitted meson and the *q*-vector

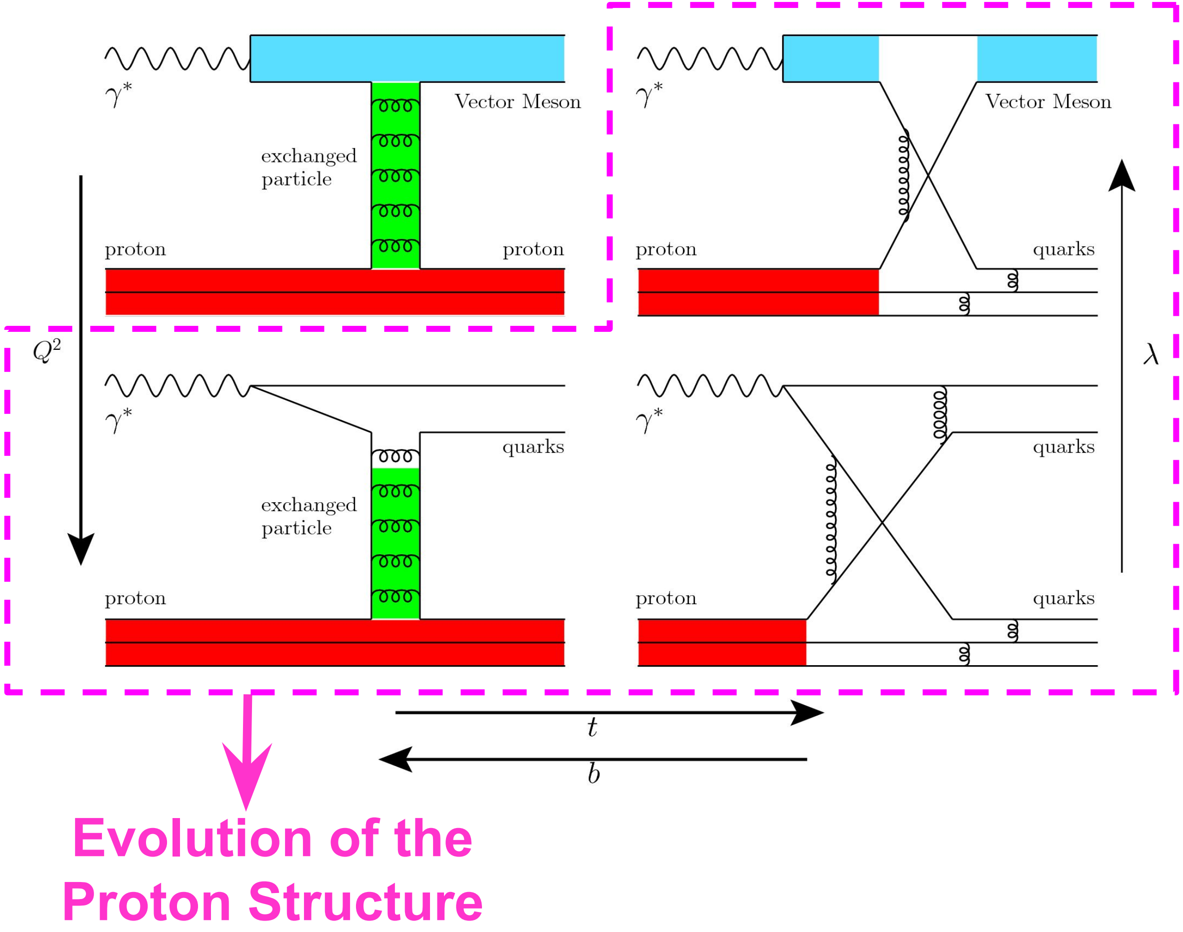
t_{min} : 0° emitted meson and the *q*-vector

Transition:

Soft structure→Hard structure→Soft structure

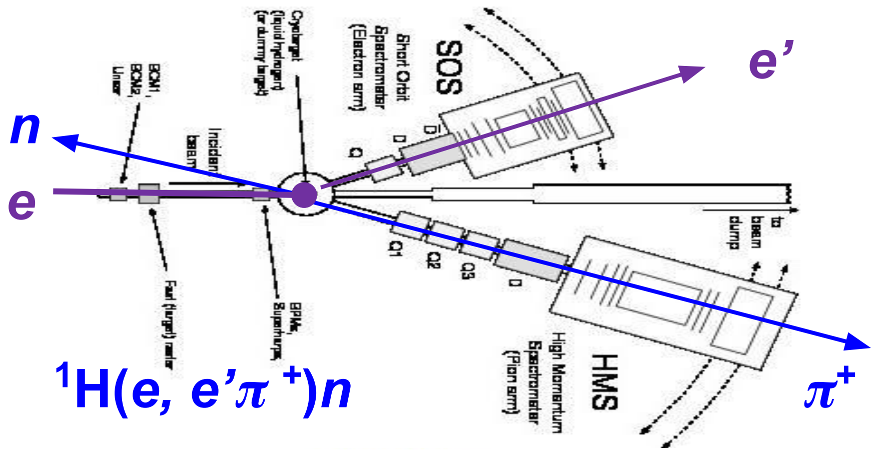
M. Guidal, J.-M. Laget, and M. Vanderhaeghen.
*Physics Letters B*400(1): 6 – 11, 1997.

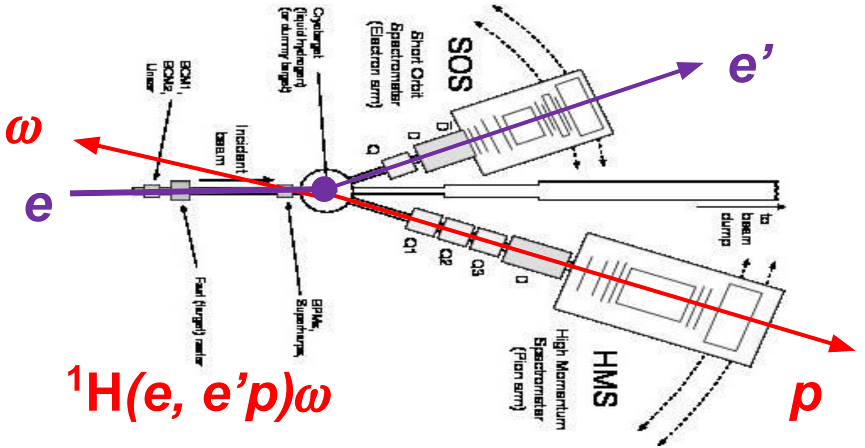
Hadronic Model: Transition (Evolution) of Proton Structure

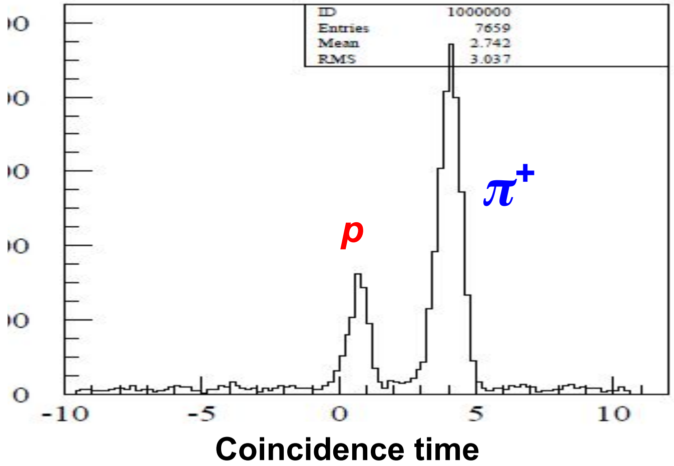


- **Physical parameters:**
  - *x*, *W* (or *s*), ***Q^2***, ***t***, ***u***
- ***x* Evolution:**
  - Parton momentum fraction: 0.2-0.3 valence quark distribution is pronounced
- ***W* Evolution:**
  - Dictate if a process is in the resonance region
- ***Q^2* Evolution:**
  - Wavelength of the probe,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

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

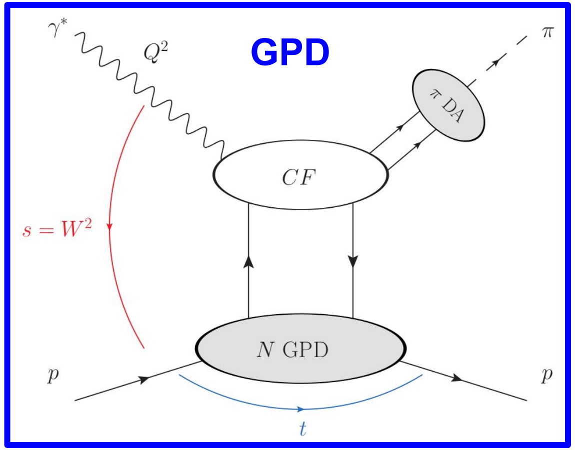


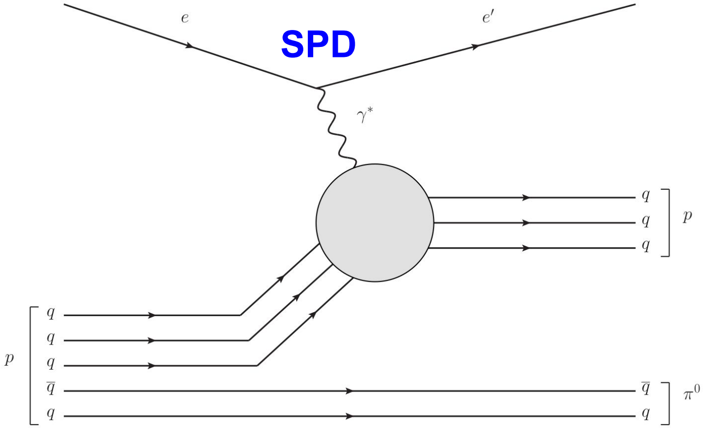


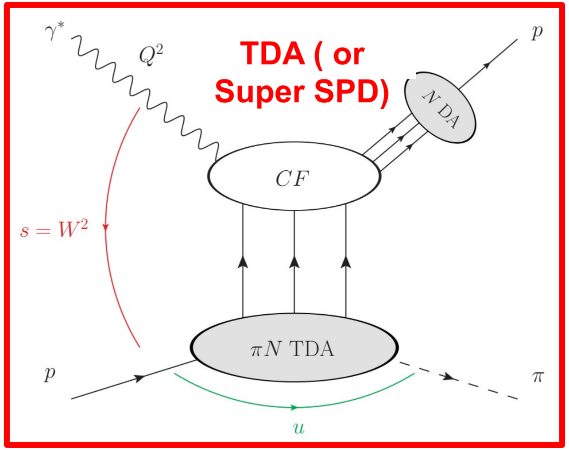


- **Fπ-2 charged π form factor experiment (E01-004)**
  - Standard HMS and SOS (e) configuration
- **Primary reaction for Fpi-2**
  - ***t*-channel π^+ production: ^{1}H(*e*, *e'*π^+)*n***
- **Nature gives us *u*-channel : ^{1}H(*e*,*e'p*)ω**
- **Kinematics coverage**
  - ***W*= 2.21 GeV, Q^2=1.6 and 2.45 GeV^2**

GPD, SPD and TDA (Hard Structure)







$-t_{min}$ → $-t_{max}$

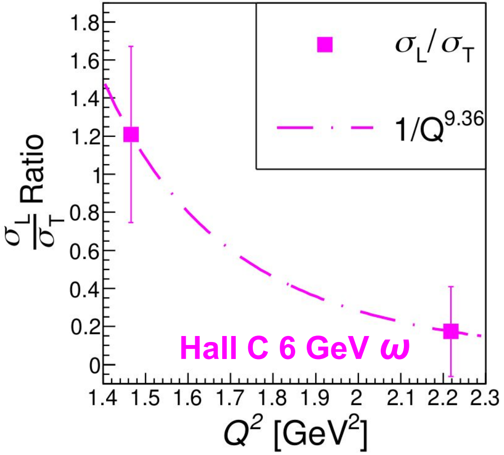
$-t \approx -u$

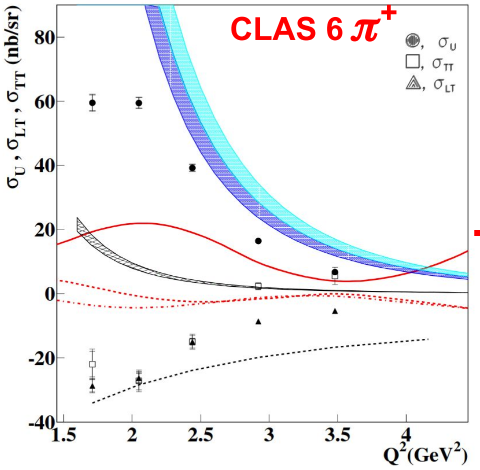
$-u_{max}$ ← $-u_{min}$

Complete description of Nucleon

- **GPD**: is like a hadron tomography of the proton. It is extracted predominantly based the forward angle observables.
- **SPD**: Skewed Parton Distribution. Discovered Frankfurt and Strikman in 2003. Hadron tomography of the proton at large skewness. At extreme skewness, known as the **Super SPD**.
- **TDA**: meson-nucleon Transition Distribution Amplitude (TDA), similar to super SPD. Rediscovered by B. Pire, and L Szymanowski and K Semenov-Tian-Shansky.. Tomography of partonic distributions in the nucleon --> meson and vice versa transitions probed in the backward angle kinematics

Validation of TDA Factorization Scheme





Two qualitative predictions from TDA:

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

Three phases of validating TDA with JLab 12 GeV meson electroproduction :

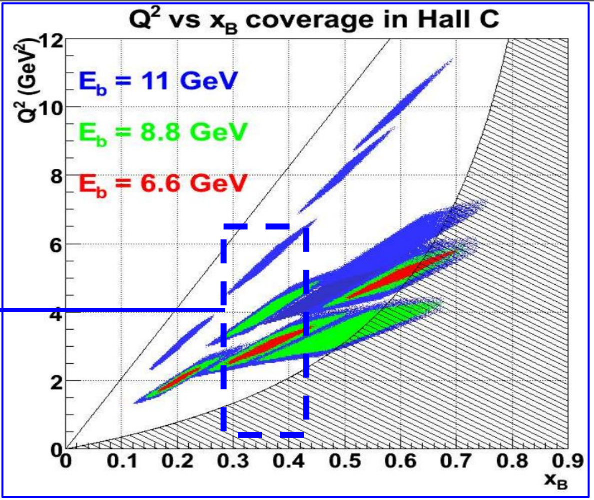
- **Stage 0: find *u*-channel peaks for all mesons (12 GeV), experimental objective #1 and #2.**
- **Stage 1: test TDA predictions (12 GeV), experimental objective #3 and #4.**
- Stage 2: extractions of TDAs

All four objectives are described in the next few slides

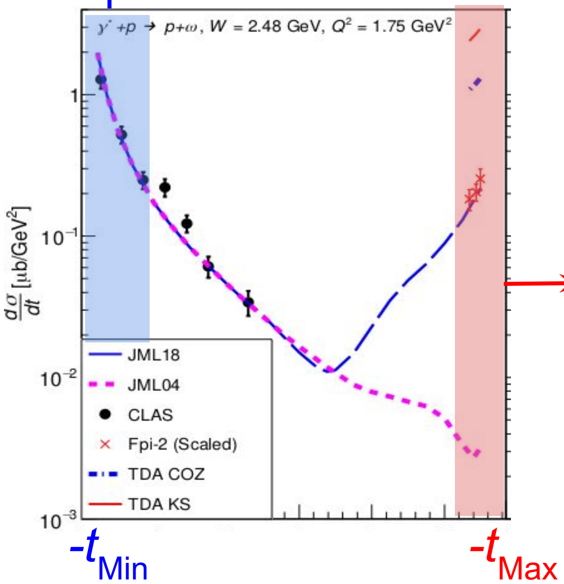
Objective 1: Backward-angle Peaks (Stage 0)

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

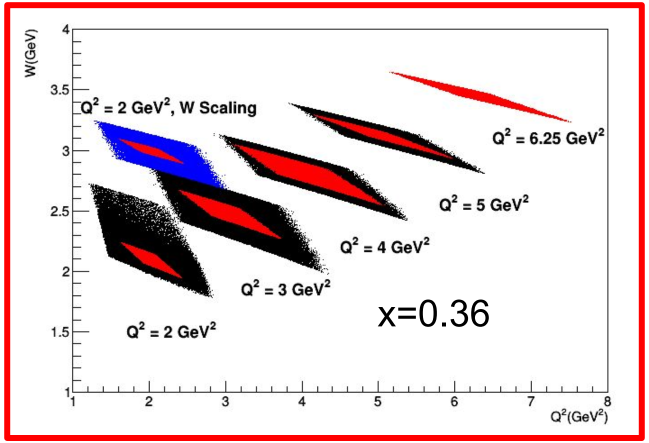
- π^0 is relatively clean channel with great community interests
- E12-13-010 NPS experiment provide low *-t* L/T separated cross section



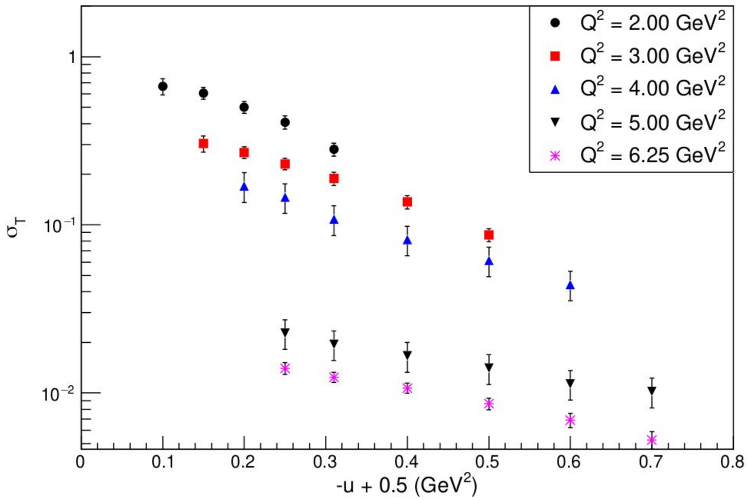
E12-13-010 NPS Experiment



This proposal



Objective 2: *u*-dependence (Stage 0)



Objective 2: u-dependence of the separated cross section

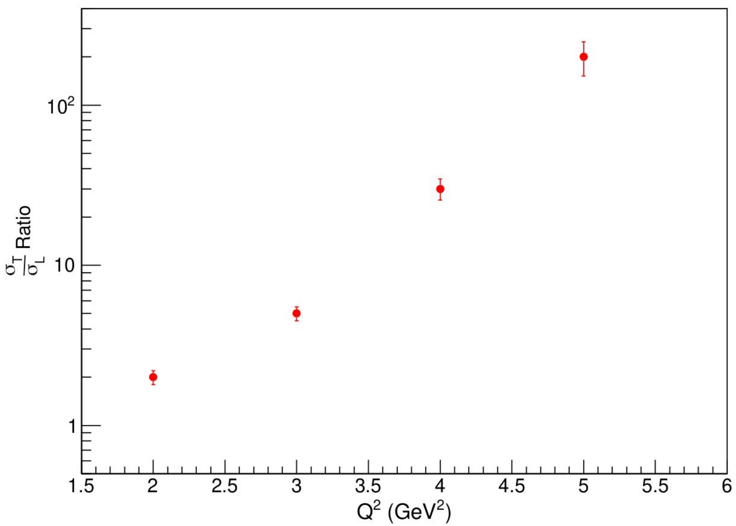
- **Extracting -u dependence of the unseparated cross section and interaction radius:**

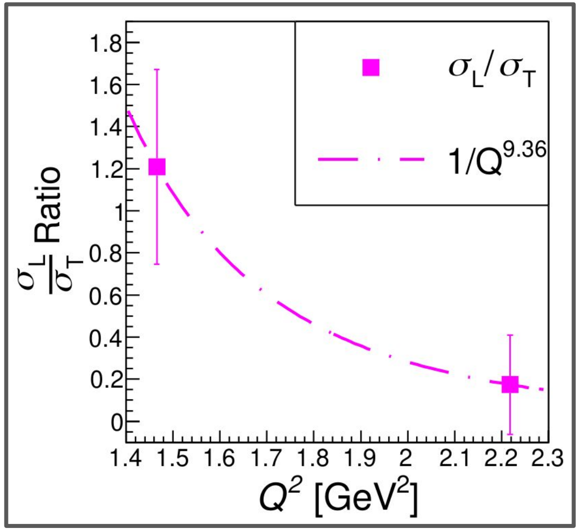
$$\sigma_T = Ae^{-b\cdot|u|}, \quad r_{int} = \sqrt{b}\,\hbar\, c$$

- **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.)

Objective 3: TDA Prediction #1 $\sigma_T > \sigma_L$ Stage(1)

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



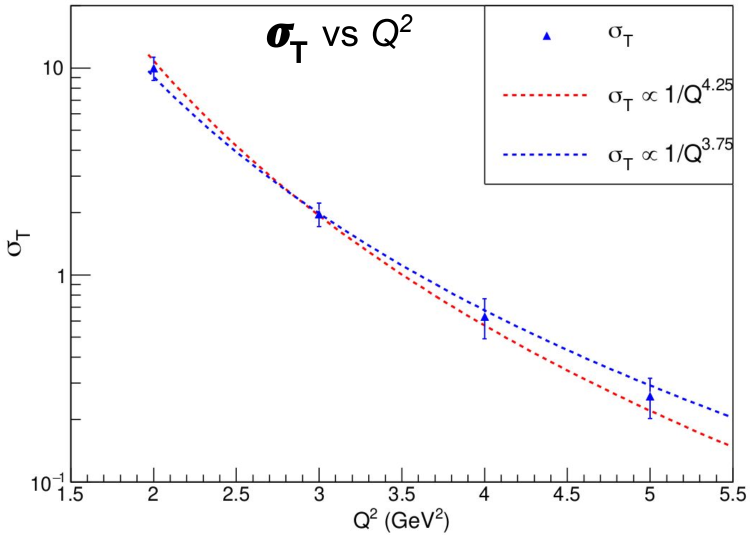


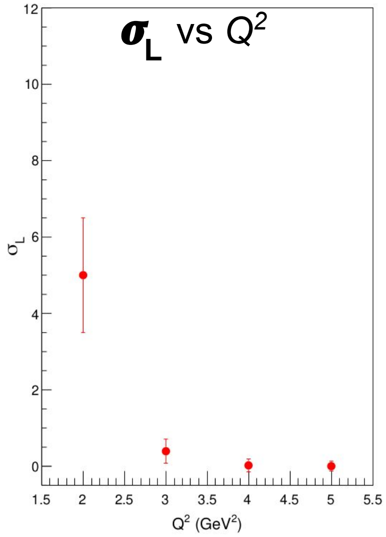
L/T ratio vs Q^2 (6 GeV F_π-2 experiment)

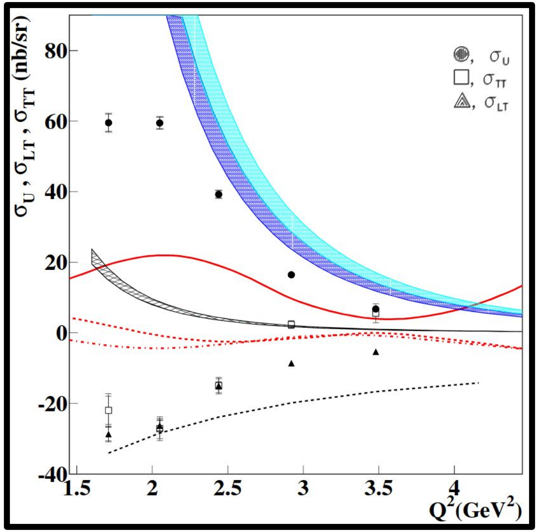
L/T Separated Cross section

- **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 $\sigma_T/\sigma_L > 10$ at $Q^2 = 5$ GeV^2**

Objective 4: TDA Prediction #2, $\sigma_T \propto 1/Q^8$ Scaling (Stage 1)





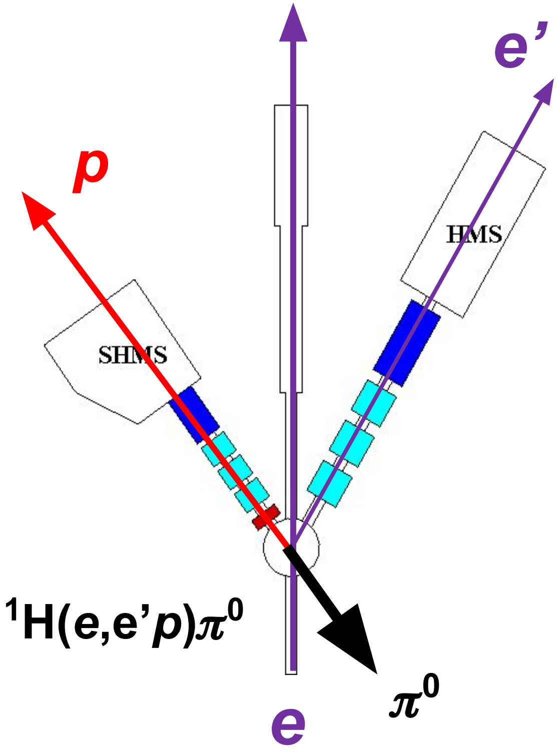


σ vs Q^2 (CLAS 6 result)

L/T Separated Cross section

- TDA predicts $\sigma_T \propto 1/Q^8$.
- TDA predicts $\sigma_L \sim 0$, not a leading order leading twist contribution effect.
- Experimental beam time planned to determine $(Q^2)^n$, $3.75 < n < 4.25$

Proposal: PR12-20-007 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: $|u_{min}| < |u| < |u_{min}| +0.5$ GeV^2
- **Additional W scaling check @ Q^2 = 2 GeV^2**
- **Additional Q^2 scaling check @ Q^2 = 6.25 GeV^2**

Theory TAC Report

Direct quote from the theory TAC report

- “This proposal will provide the needed information to verify how hard scattering interactions play a role in backward exclusive production, confirming early indications that this may happen starting at values of $Q^2 > 3$ GeV^2”

- “Should this not be the case, and soft, non-perturbative interaction play a non-negligible or dominant role, the envisioned model-independent measurements are likely to encourage the development of non perturbative methods, that at present seem limited to hadronic modeling”

- “Either way, this experiment should enable an initial study of the soft-hard mechanism transition, and **spur further theoretical and experimental activity**.”

Particle Identification

HMS as *e* arm (most settings)

- Standard *e* PID, HGC < 1 atm various pressure
- Aerogel: n=1.0011 tray for proton ID (for electron detection setting)

SHMS as proton arm (most settings)

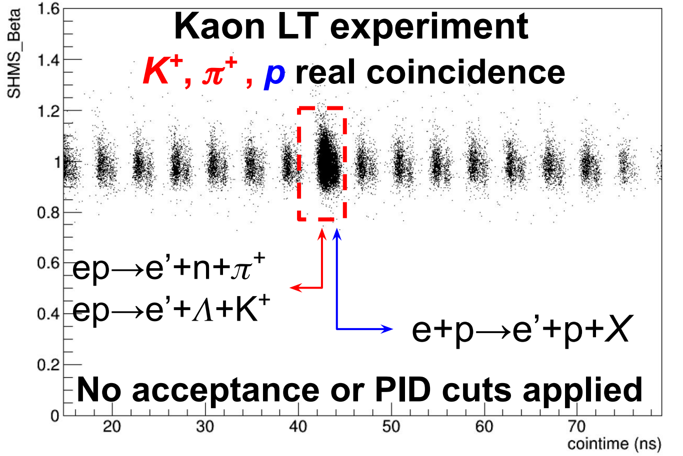
- **NGC installation (for electron detection setting)**
- HGC: 1 atm vetoing π and *K*
- Aerogel: n=1.0003 tray for proton ID (threshold cut at 3 p.e.)

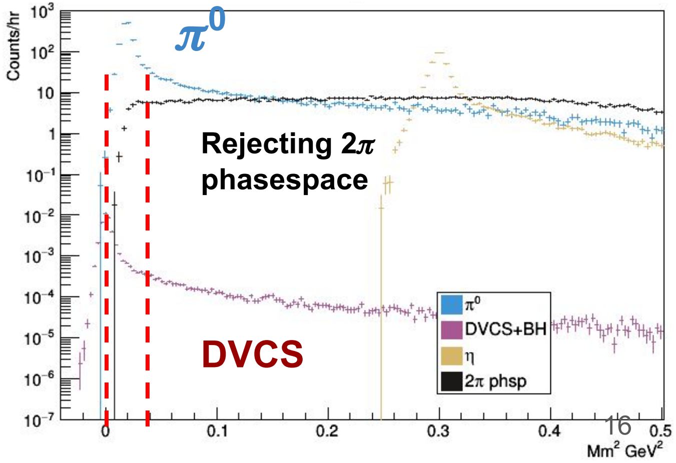
SHMS β vs Coincidence timing structure:

- Coincidence timing is the primary method for the proton

Primary Physics Background

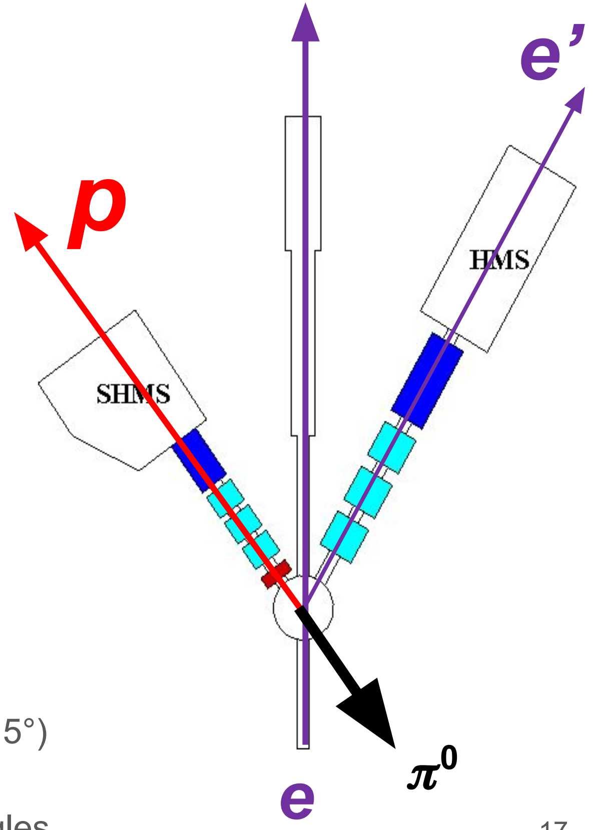
- Two pion exchange phasespace
- DVCS





Requirement

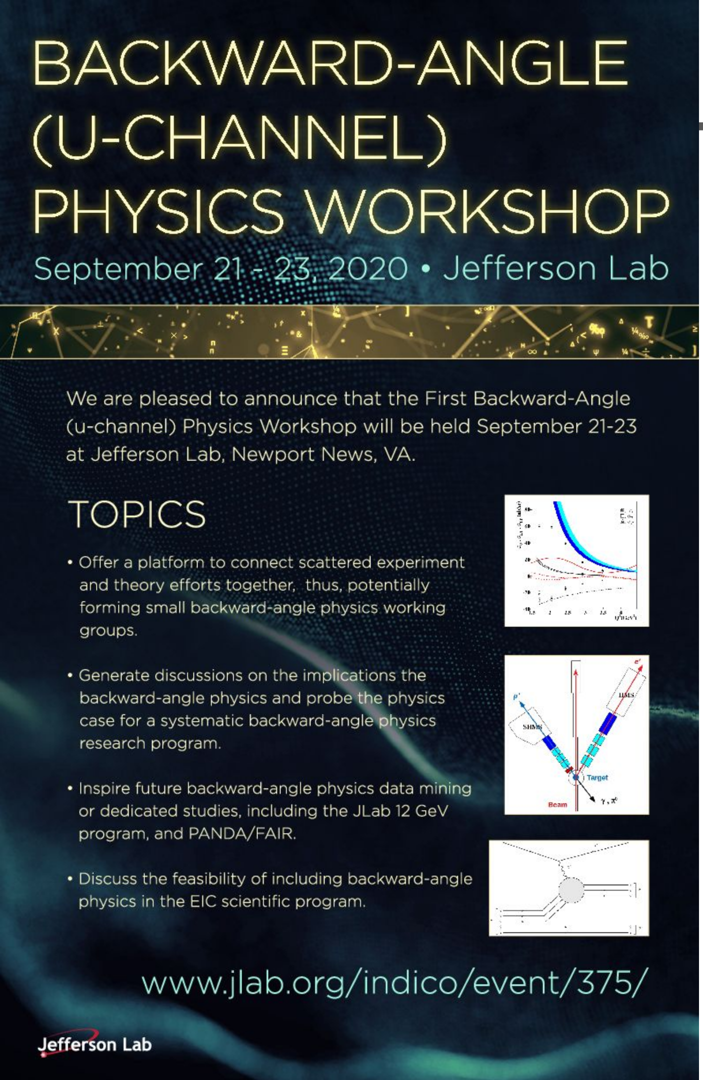
- PAC Days request: **29.4 days**
- Beam request: standard beam tune during the time of running with standard polarization
- **Equipment refurbishment:**
  - **HMS Aerogel PMT Replacement (new request)**
  - **SHMS Aerogel tray of n=1.0003 (already planned)**
- **Special detector configuration:**
  - **Installing NGC for SHMS**
  - **SHMS aerogel tray n=1.0003**
  - **HMS aerogel tray n=1.0011**
  - **Using Moller polarimeter**
- **Experimental TAC report**
  - Minimum required SHMS angle (design spec): 5.5° (5.5°)
  - Minimum required HMS angle (design spec): 10.5° (10.5°)
  - Minimum required HMS-SHMS separation (design specs): 18.0° (17.5°)
  - **These are required by Fpi-12 measurement at Hall C in 2021.**
  - We will re-tune our kinematics to match the minimum achievable angles.



Beam Time Request - Hall C

Q^2 (GeV^2)	W (GeV)	ϵ	E_{Beam} [Pass] (GeV)	Physics Rate (per Hour)	Background Rate (per Hour)	PAC Time (Hours)	PAC Time (Days)
2.0	2.11	0.52	4.4 [2]	140	0.01	33	1.4
		0.94	10.9 [5]	500	0.05	10	0.4
2.0	3.00	0.32	6.6 [3]	14	<0.01	66	2.8
		0.79	10.9 [5]	73	<0.01	27	1.1
3.0	2.49	0.54	6.6 [3]	60	<0.01	60	2.5
		0.86	10.9 [5]	140	0.01	27	1.1
4.0	2.83	0.56	8.8 [4]	40	<0.01	60	2.5
		0.73	10.9 [5]	80	<0.01	40	1.7
5.0	3.31	0.26	8.8 [4]	4	<0.01	132	5.5
		0.55	10.9 [5]	11	<0.01	47	2.0
6.25	3.46	0.36	10.9 [5]	2.63	<0.01	88	3.7
Subtotal						590	24.6
$^1\mathrm{H}(e, e'p)$						28	1.2
E_{Beam} change						52	2.2
Optics study						4	0.2
E_{Beam} Polar.						32	1.3
Total Time						706	29.4

- Time estimate include 10% for the dummy target running
- 70 uA current for all LH_2 measurement settings
- One shift per energy change (three energy change in total), 22 hours is the overhead when changing momentum setting, angle, polarity and detector pressure
- HMS momentum saturation study needed
- Beam polarization measurement needed. One shift per energy change.



Thanks you and Advertisement

Backward angle Physics workshop: Sep 21st-23rd, 2020

JLab event Page: https://www.jlab.org/conference/BACKANGLE

Indico page: https://www.jlab.org/indico/event/375

- **The workshop have representatives from all four halls, from JLab 6, 12 GeV, PANDA and EIC**
- **u-channel electroproduction (Hall A, B, C) examples at 12 GeV**
- **u-channel photoproduction (Hall B, D) examples at 12 GeV**
- **Theory perspective:**
  - Meson-Nucleon Transition Distribution Amplitude
  - Photon-nucleon together with meson-nucleon TDAs
  - Skewed Parton Distribution
  - *u*-channel Regge Approach
- **Future perspective of u-channel physics**
  - *u*-channel π^0 production at EIC
  - Studying TDA with pp → e+e−π^0 at the PANDA Experiment
- **A summary white paper is planned: outlining the JLab 12 GeV to EIC u-channel physics strategy**

Backup Slides

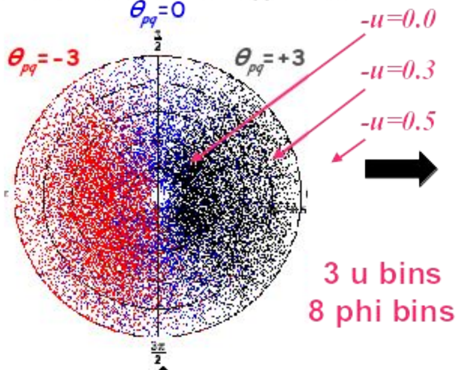
Error Budget

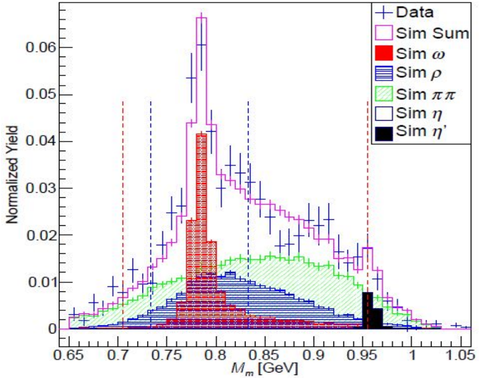
Correction	Uncorrelated (Pt-to-Pt) (%)	ϵ Uncorrelated u Correlated (%)	Correlated (scale) (%)
SHMS+HMS Tracking		0.6	1.2
SHMS+HMS Triggers		0.1	
SHMS/HMS Detectors			0.2
Target Thickness		0.2	0.8
CPU Live Time		0.2	
Electronic Live Time		0.2	
Coincidence Blocking			0.2
Beam charge		0.5	0.5
PID		0.2	
Acceptance	0.6	0.6	1.0
Proton Interaction			1.0
Radiative Corrections		0.3	1.5
Kinematics Offset	0.4	1.0	
Model Dependence	0.7		
π^0 Total	1.0	1.4	2.5
F_π-2-ω Total	2.9	1.9	2.7

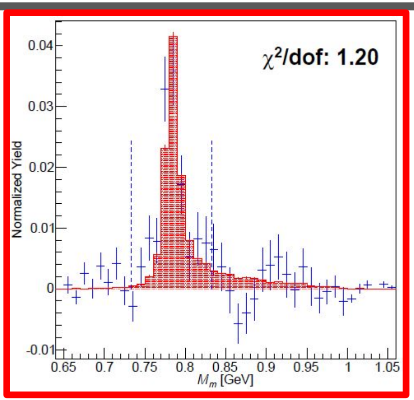
- **Correlated (scale) cross section is comparable to the F-π-2-ω analysis**
- **Uncorrelated (pt-to-pt) is much smaller since ^{1}H(e,e'p)π^0 is a 'clean' channel**

Iterative Procedure for L/T Separation

Improve φ coverage by taking data at multiple HMS angles, $-3^{o} < \theta_{pq} < +3^{o}$.





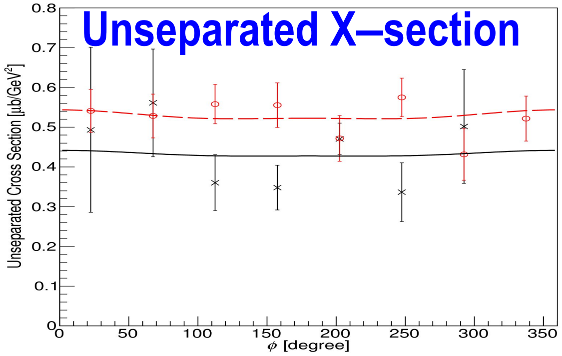


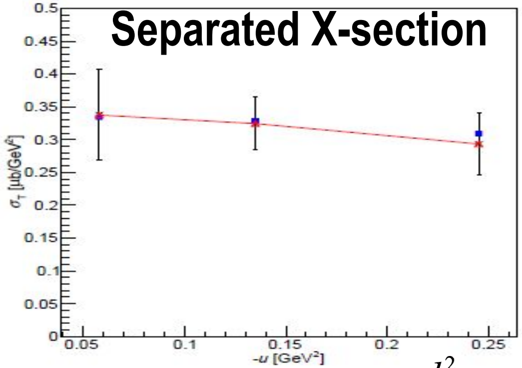
$$R = \frac{Y_{Exp} - Y_{\rho\ sim} - Y_{Xspace\ sim}}{Y_{\omega\ sim}}$$

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



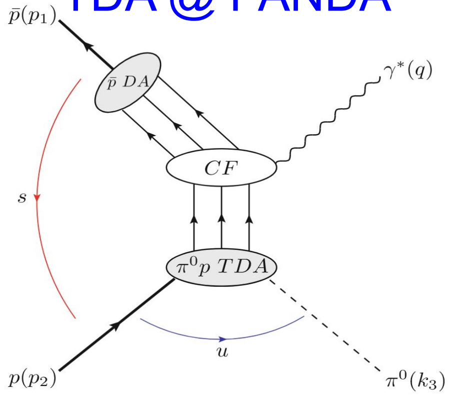


Extract L,T,LT,TT via simultaneous fit

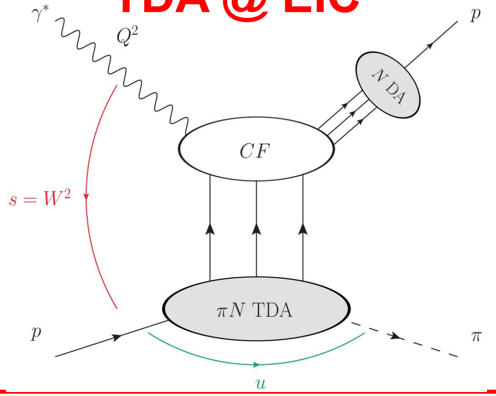
$$2\pi\frac{d^2\sigma}{dtd\phi} = \varepsilon\frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi + \varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi$$

JLab 12 GeV to EIC Transition: *u*-channel π^0 production

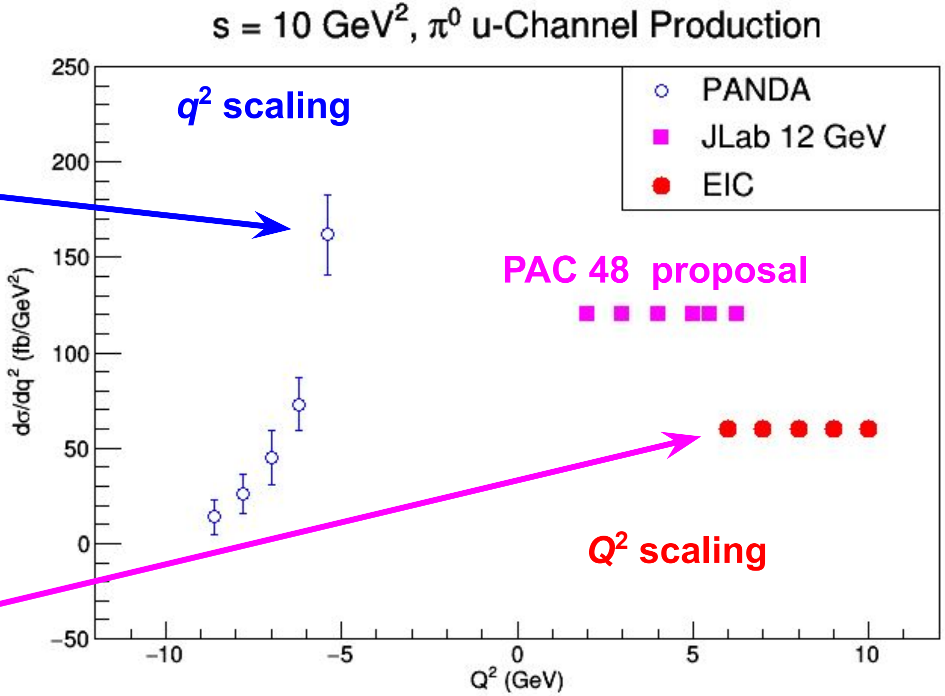
TDA @ PANDA



TDA @ EIC



The PANDA Collaboration, Eur. Phys. J. A (2015) 51: 107



Same TDAs for PANDA and EIC, the ultimate universality check