Hall A/C Collaboration meeting

PR12-20-007: Backward-angle Exclusive pi0 Production Above the Resonance Region

Wenliang (Bill) Li,
A postdoc at William and Mary

On behalf of all authors of PR12-20-007

18/July/2020

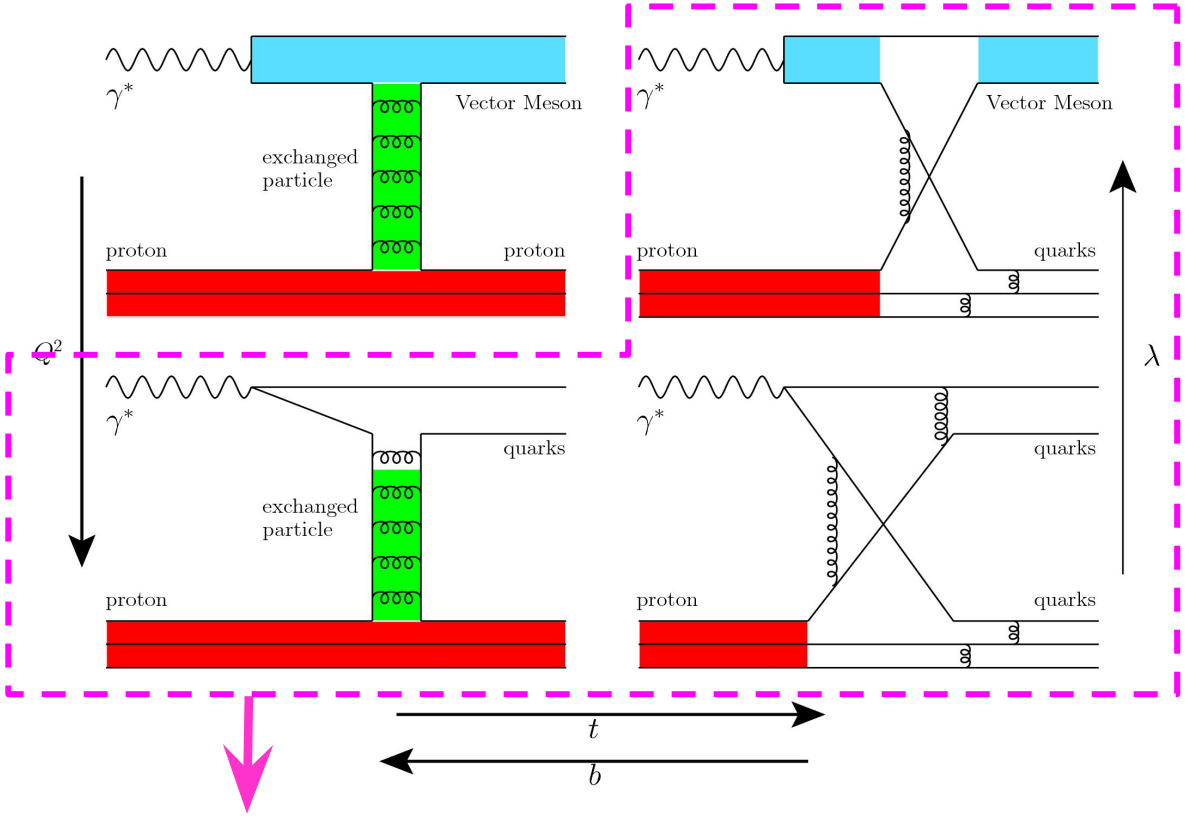
Outline

- **Introducing the backward angle physics:**
  - Summary on past studies
  - Theory perspective

- **Experimental objectives**

- **Experimental configuration requirements**
  - Equipment
  - PID
  - Suggested Hardware Improvement

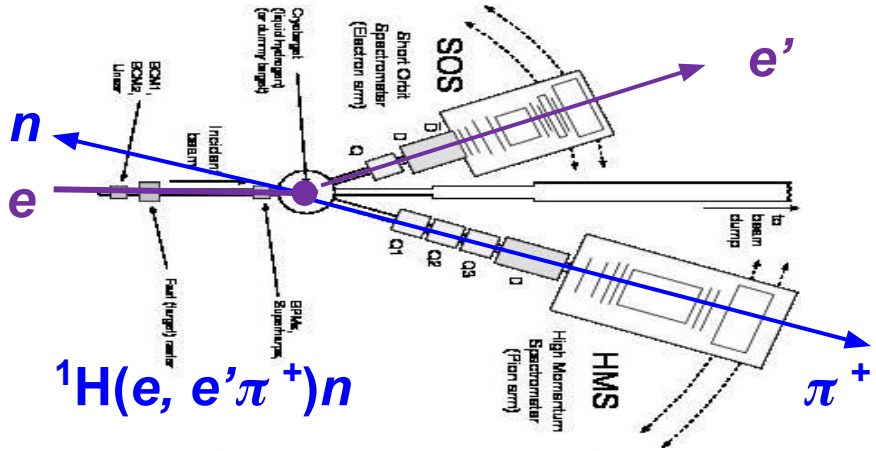
Hadronic Model: Transition (Evolution) of Proton Structure

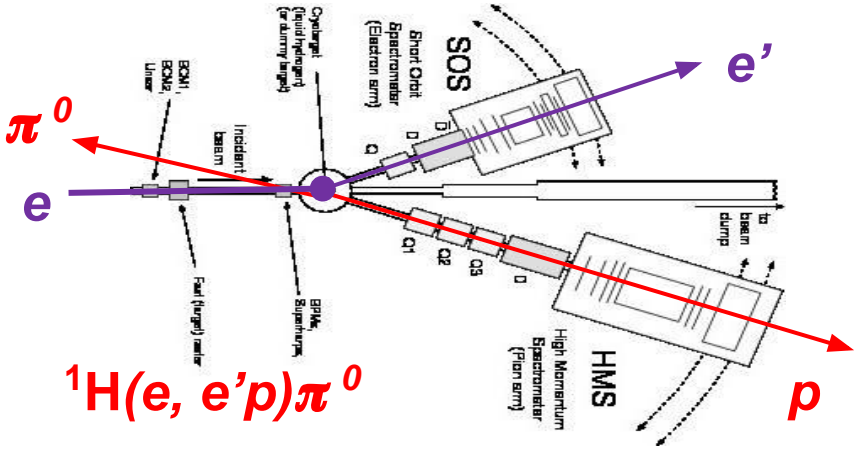


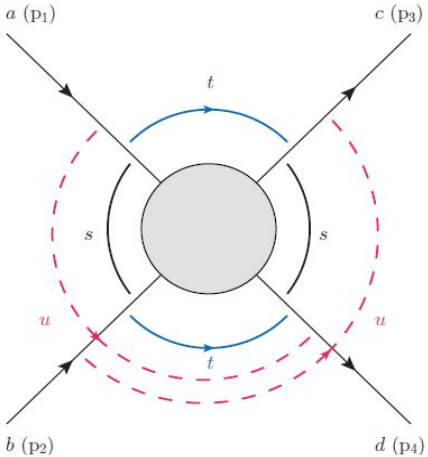
Evolution of the Proton Structure

- 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 about ***u***? Any role?

t-Channel π^+ vs *u*-Channel π^0 Production

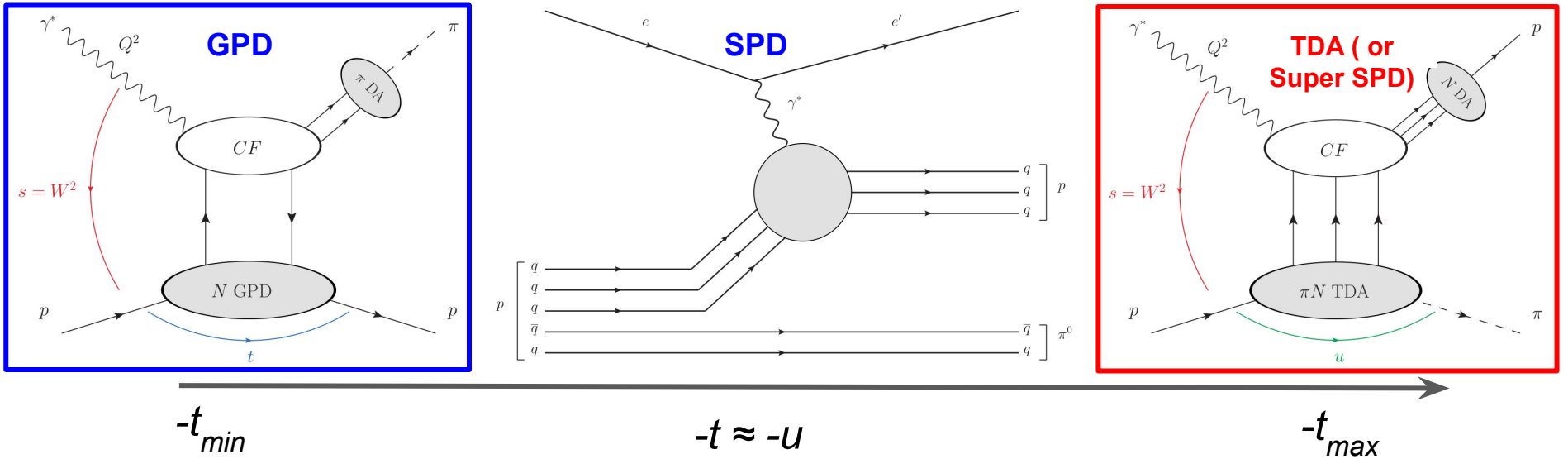






- **Fπ-2 charged π form factor experiment (E01-004)**
  - Standard HMS and SOS (e) configuration
- **Primary reaction for Fpi-2**
  - ***t*-channel π^+ production: ^{1}H(*e, e'*π^+)*n***
- **If one were to study π^0 during the 6 GeV era**
  - ***u*-channel π^0 production: ^{1}H(*e,e'p*)π^0**
- **Nature give us u-channel : ^{1}H(*e,e'p*)ω, instead**
- **Kinematics coverage**
  - ***W*= 2.21 GeV, Q^2=1.6 and 2.45 GeV^2**

GPD, SPD and TDA (Hard Structure)

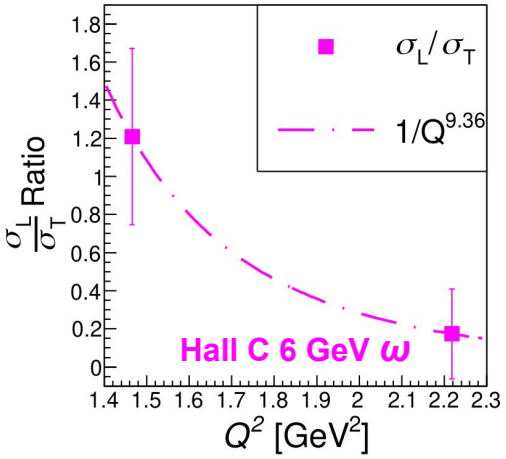


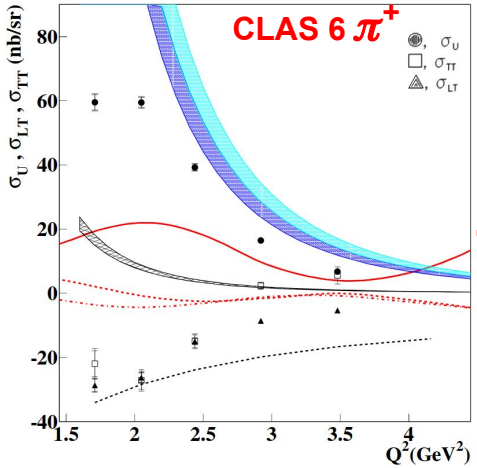
$-t_{min}$ $-t \approx -u$ $-t_{max}$

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





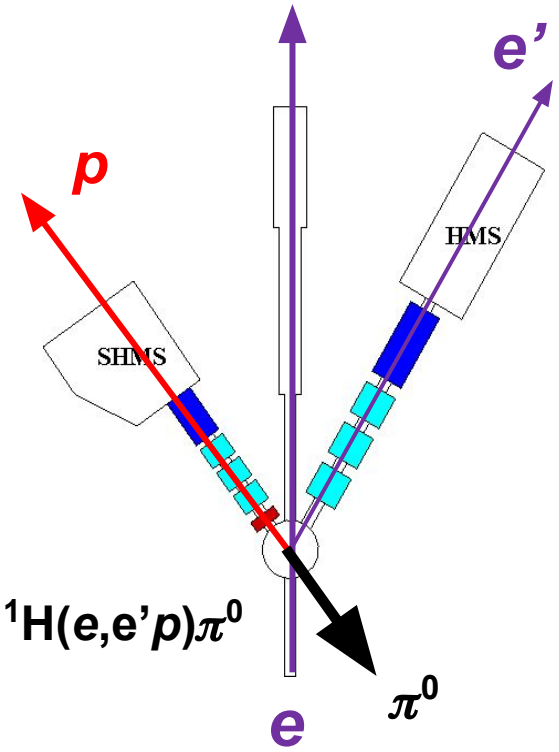
Two qualitative predictions from TDA:

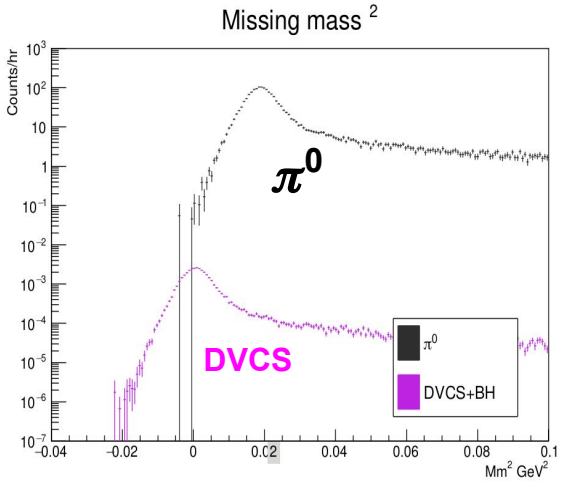
- $\sigma_T \sim 1/Q^8$ scaling behavior
- $\sigma_T > \sigma_L$, $\sigma_L \sim 0$

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

- **Stage 0: find *u*-channel peaks for all mesons (12 GeV). This proposal**
- **Stage 1: test TDA predictions (12 GeV). This proposal.**
- Stage 2: extractions of TDAs

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:

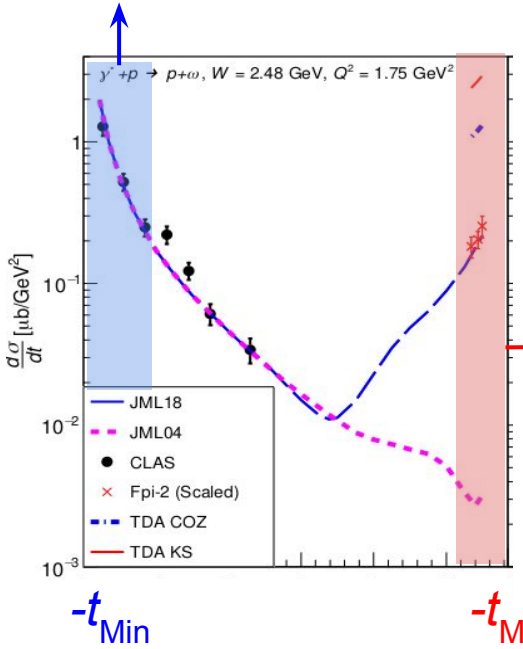
- **Q^2 coverage: $2.0 < Q^2 < 6.25$ GeV^2, at x=0.36 and W > 2 GeV**
  L/T separated cross section @ Q^2= 2, 3, 4 and 5 GeV^2.
- *u* coverage: $0 < -u' + 0.5 < 0.5$ GeV^2
- **Additional *W* scaling check @ Q^2 = 2 GeV^2**
- **Additional Q^2 scaling check @ Q^2 = 6.25 GeV^2**

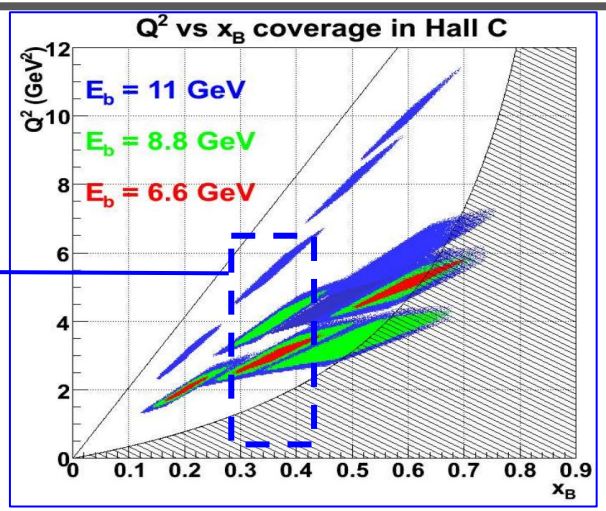
Objective 1: Backward-angle Peaks

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

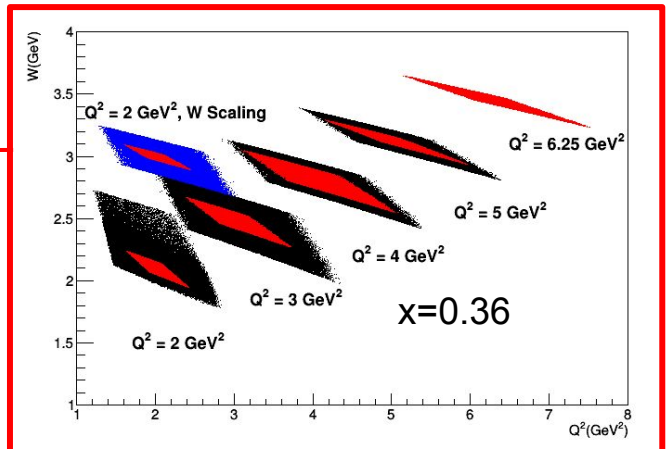
- E12-13-010 NPS experiment provide low *-t* L/T separated cross section

E12-13-010 NPS Experiment

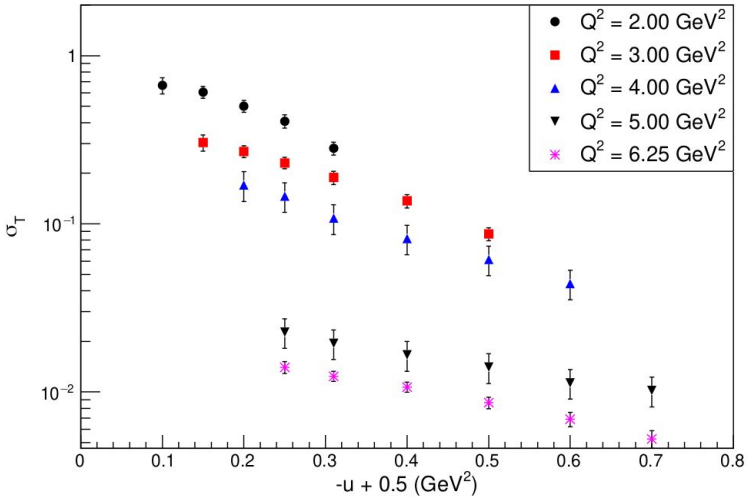




This proposal



Objective 2: *u*-dependence



Objective 2: u-dependence of the separated cross section

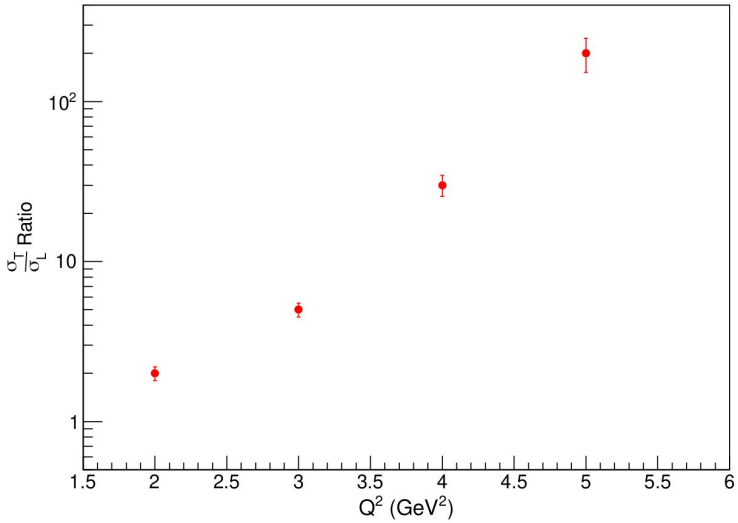
- **Extracting -u dependence of the unseparated cross section and interaction radius:**

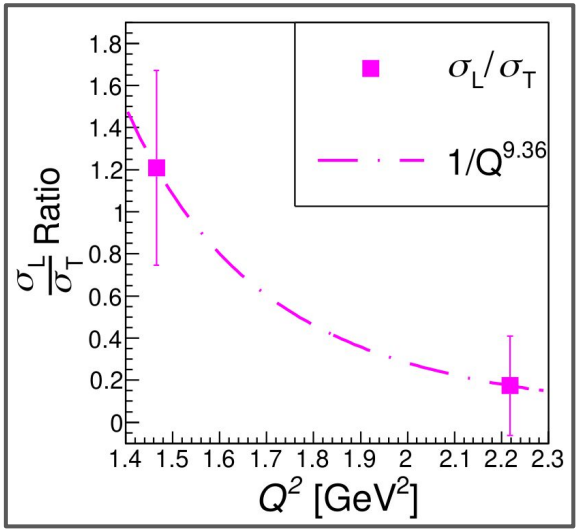
$$\sigma = Ae^{-b \cdot |u|}, \qquad r_{int} = \sqrt{b}\,\hbar\, c$$

- **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 $\sigma_T > \sigma_L$

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



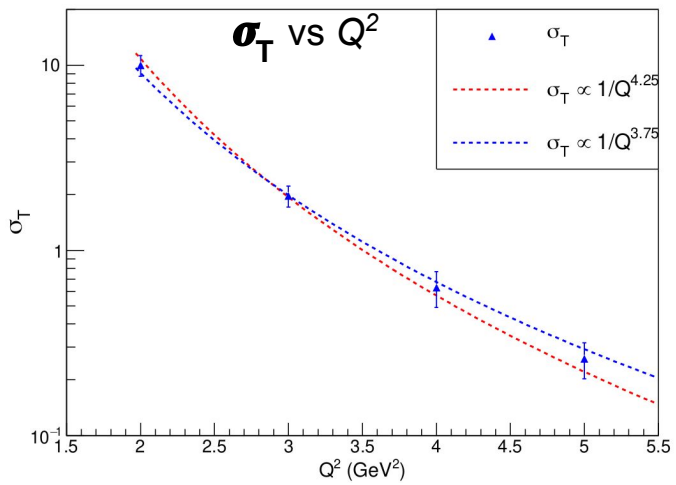


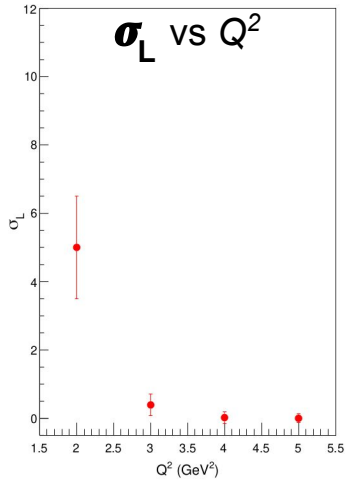
L/T ratio vs Q^2 (6 GeV F_π-2 experiment)

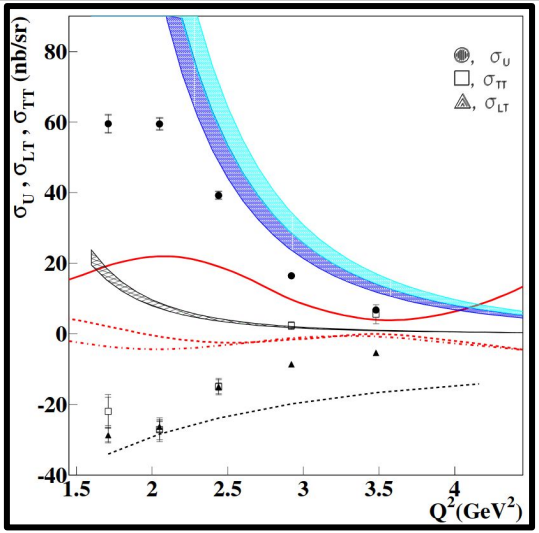
L/T Separated Cross section

- **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







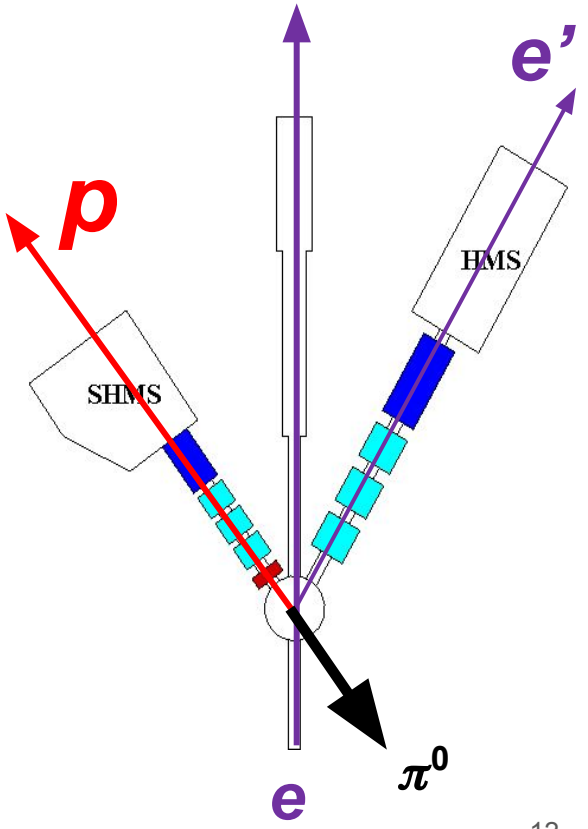
σ vs Q^2 (CLAS 6 result)

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.
- Experiment designed to $(Q^2)^n$, $3.75 < n < 4.25$

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**



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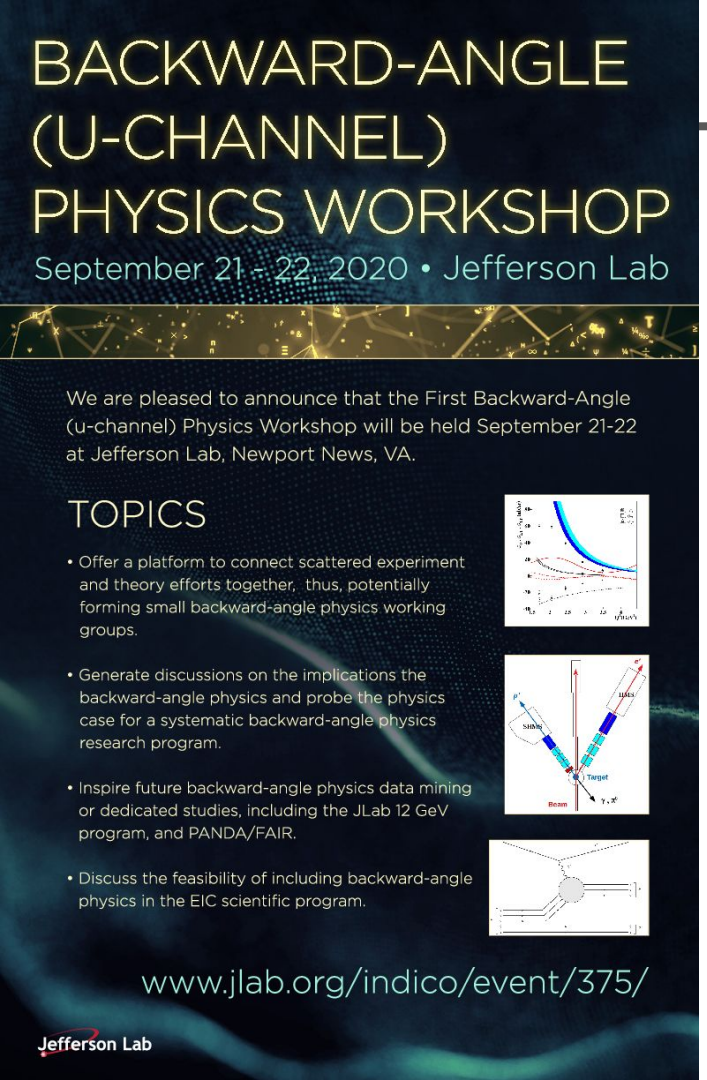


Thanks you and Advertisement

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**

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)

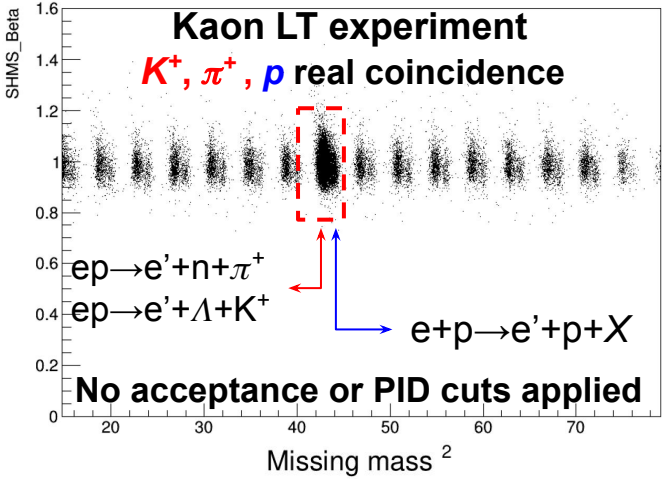
- **NGC installation (for electron detection setting)**
- HGC: 1 atm vetoing π and *K*
- Aerogel: n=1.0003 tray for proton ID (threshold cut at 3 p.e.)

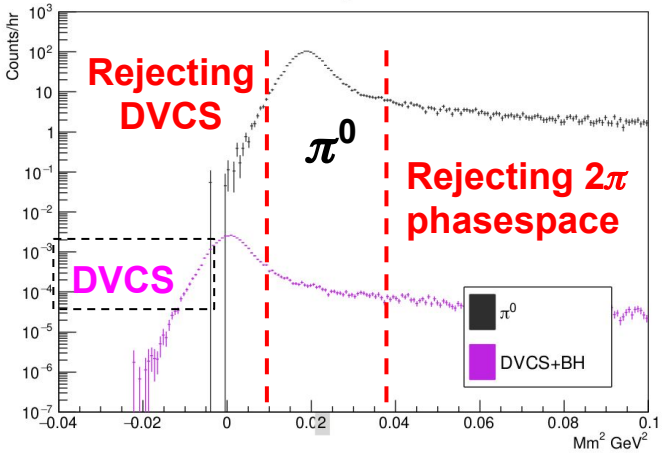
SHMS β vs Coincidence timing structure:

- Coincidence timing is the primary method for the proton

Primary Physics Background

- DVCS is a small contribution





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

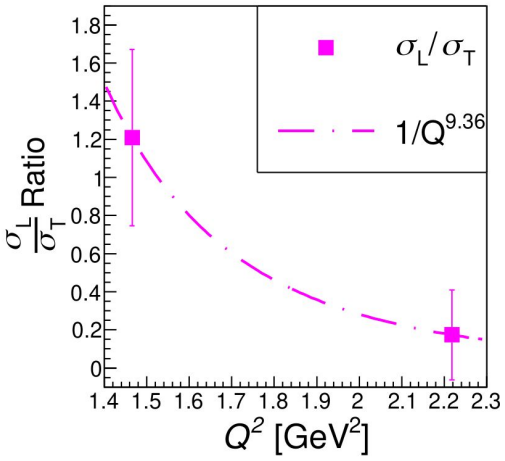
- **Correlated (scale) cross section is comparable to the F-π-2-ω analysis**
- **Uncorrelated (pt-to-pt) is much smaller since ^{1}H(e,e'p)π^0 is a 'clean' channel**

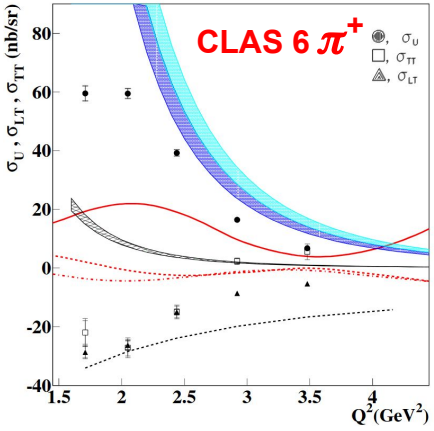
Beam Time Estimation

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}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

- All listed time includes 10% dummy target data taking
- Heep study is included
- Optics study at high HMS momentum setting (P_{HMS}=5 GeV) planned to check for the saturation effect

Validation of TDA Factorization Scheme





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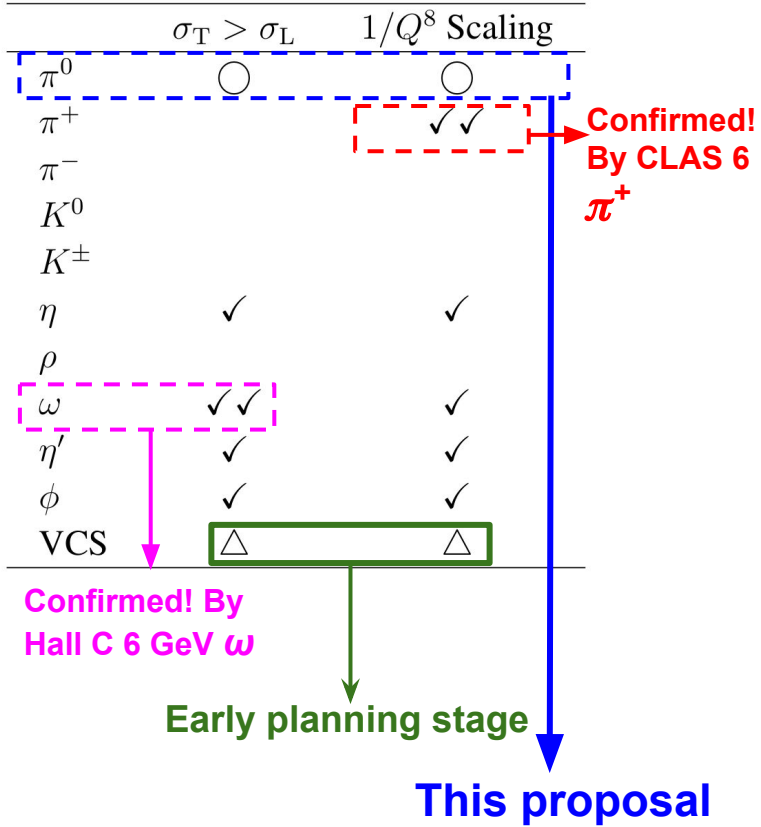


□: parasitic data may be available

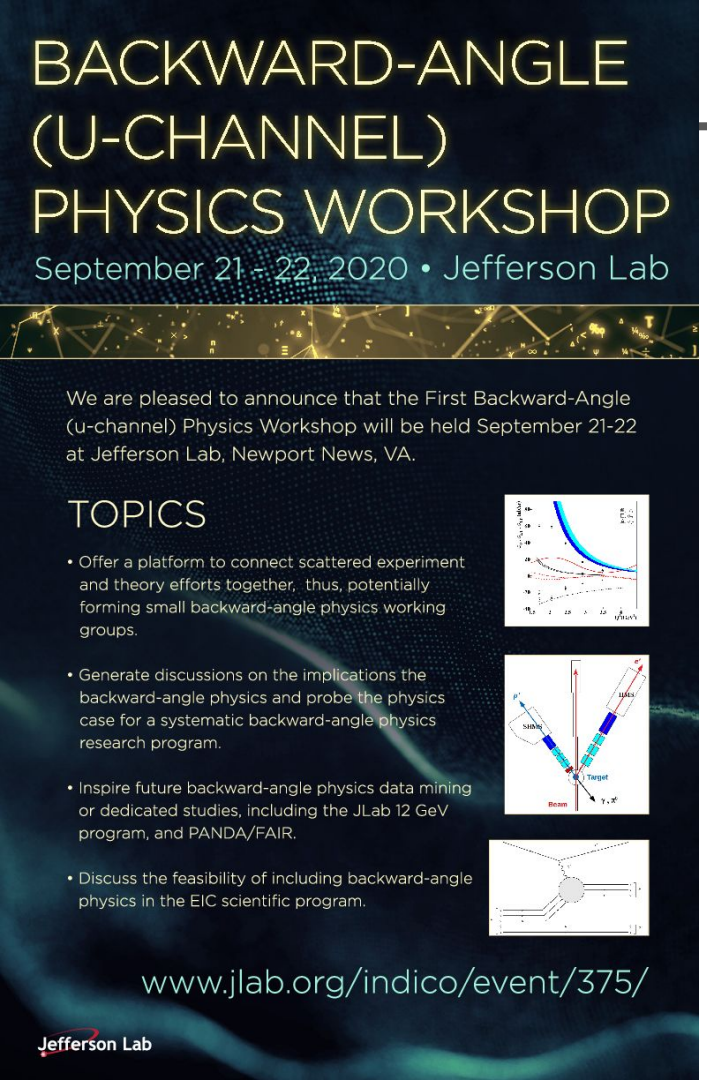
Summary

- **PR12-20-007 is the first dedicated u-channel study (symbolic meaning)**

- **Proposal experiment utilizes standard Hall C SHMS+HMS configuration**
  - **Includes Moller polarimeter**

- **Requires 29.4 PAC days at standard accelerator gradient during the time of running**

- **Study the backward-angle factorization scheme for the ^{1}H(e,e'p)π^0.**
  - **$\sigma_T > \sigma_L$**
  - **$\sigma_T \propto 1/Q^8$ Scaling**



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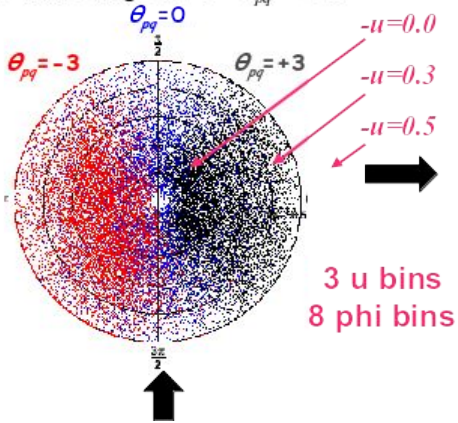
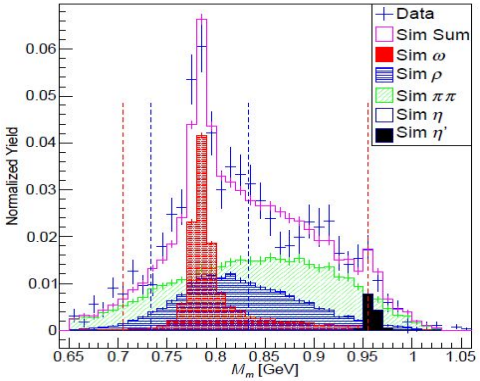
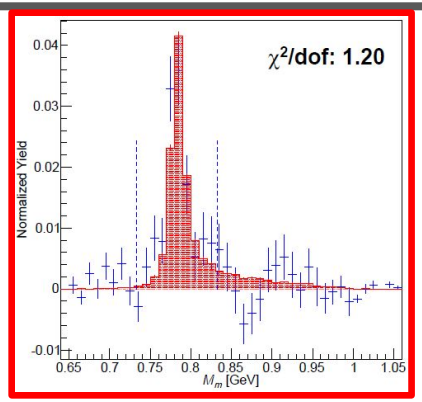
Backup slides

Iterative Procedure for L/T Separation

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





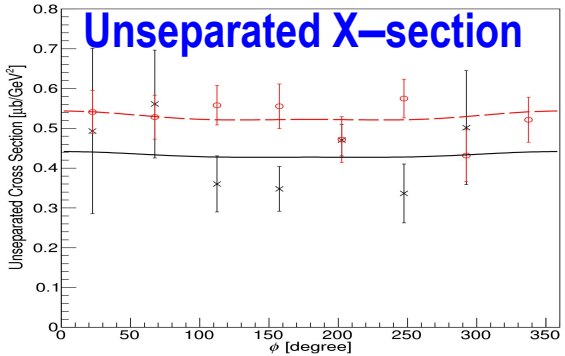


$$R = \frac{Y_{Exp} - Y_{\rho\ sim} - Y_{Xspace\ sim}}{Y_{\omega\ sim}}$$

Combine ratios for settings together, propagating errors accordingly.

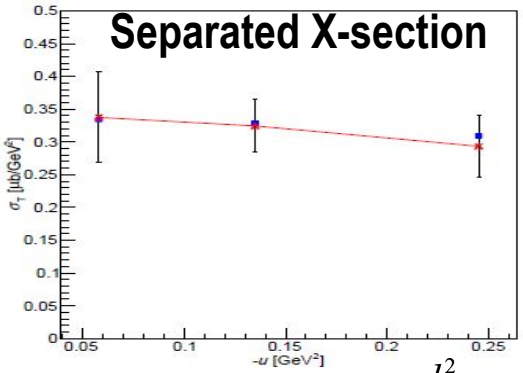
$$\frac{d^2\sigma}{dtd\varphi}_{EXP} = R\frac{d^2\sigma}{dtd\varphi}_{SIMC}$$

Empirical Model



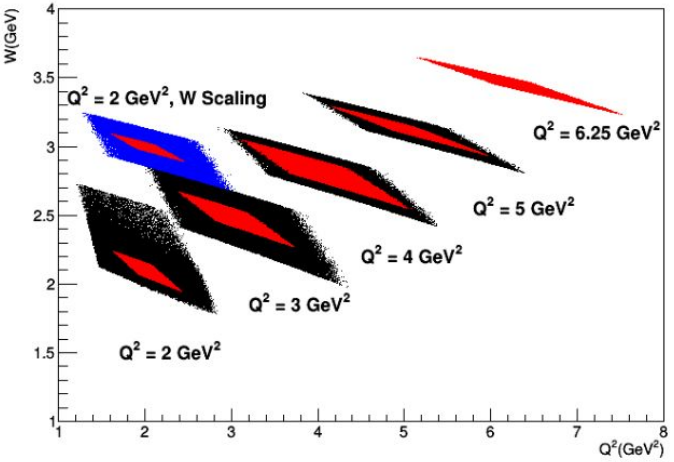
Extract L,T,LT,TT via simultaneous fit

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



π^0 Measurement Kinematics

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



^{1}H(*e, e'p*) Elastic Kinematics

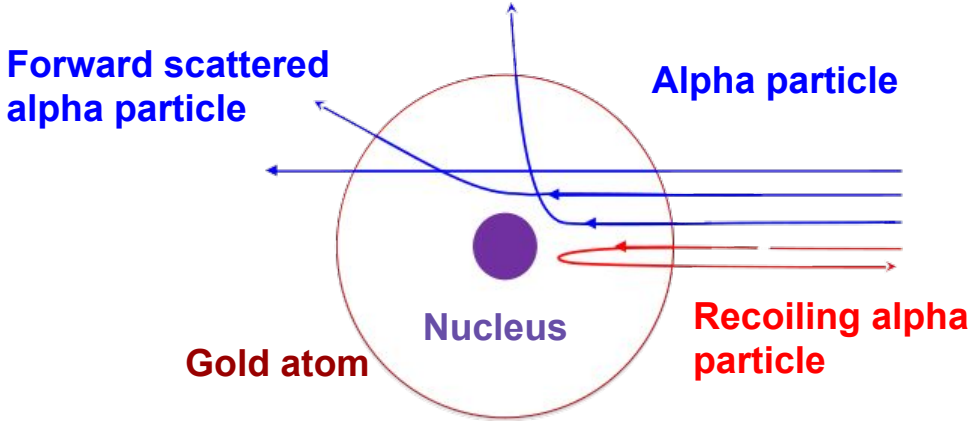
E_{beam} (GeV)	Q^2 (GeV^2)	θ'_e (deg)	p'_e (GeV)	θ_p (deg)	p_p (GeV)	Coincidence Rate (Hz)	Time (Hours)
4.4^+	2.34^+	23.70^+	3.15^+	39.95^+	1.97^+	371	1
4.4^*	2.68^*	25.15^*	2.97^*	37.12^*	2.17^*	251	1
6.6^+	4.18^+	21.95^+	4.37^+	32.69^+	3.03^+	30	1
6.6^+	3.00^+	17.35^+	5.00^+	39.21^+	2.36^+	170	1
6.6^*	3.00^*	17.35^*	5.00^*	39.21^*	2.36^*	323	1
6.6^*	1.32^*	1.55^*	5.90^*	53.43^*	1.345^*	4500	1
8.8^*	1.61^*	8.70^*	7.94^*	51.71^*	1.53^*	3272	1
8.8^*	4.32^*	15.80^*	6.50^*	34.77^*	3.10^*	0.8	4
10.9^*	1.99^*	7.80^*	9.84^*	49.30^*	1.76^*	167	1

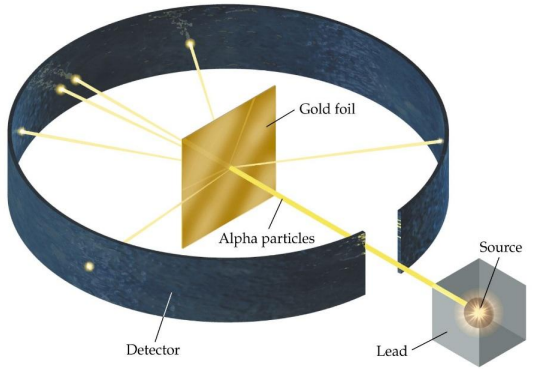
Differences to Approved/Completed Hall A/C Measurements

- VCS Experiment at Hall A: E93-050
- VCS Experiment at Hall C: E12-15-001
-

Backup slides

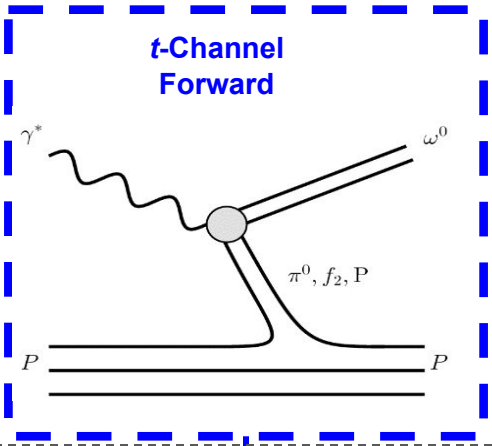
Backward-angle structure of Atom

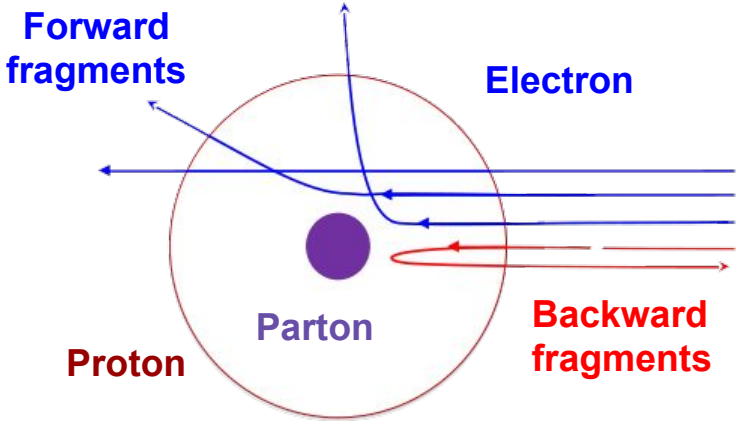


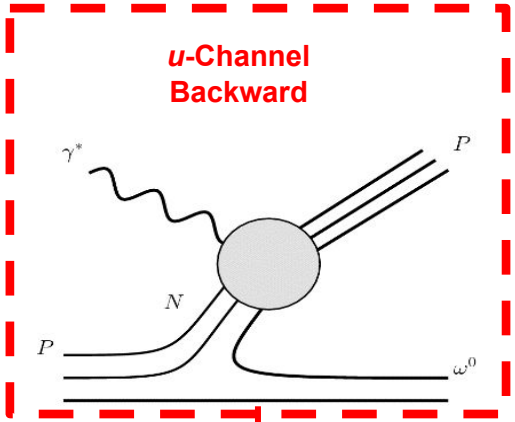


- **Forward scattered alpha particle: extracting the interaction radius of the nucleus and mapping out the transverse structure of the atom (mostly empty)**
- **Recoiling alpha particle: stiffness of the "point-like" structure.**
- Full structure must incorporate both forward angle and backward angle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

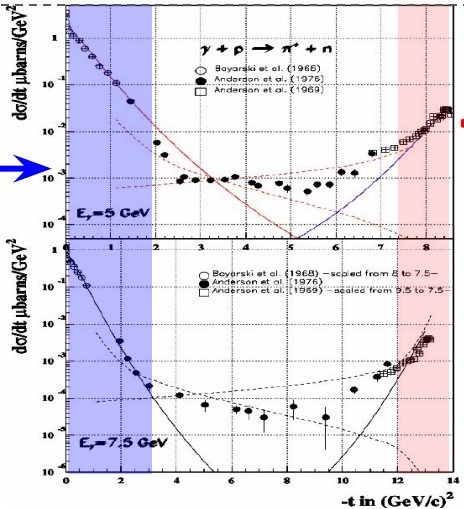
Structure of Proton







Meson pole contribution

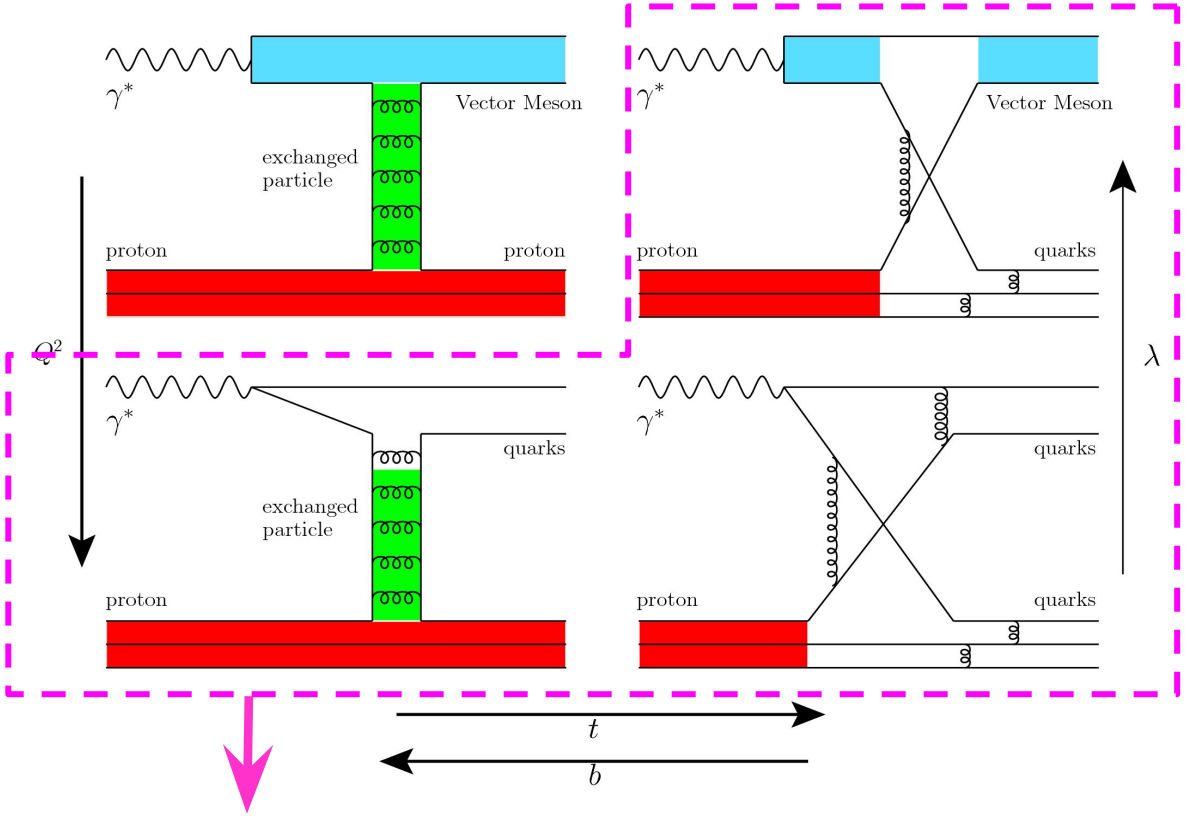


Baryon pole contribution

Transition:
Soft structure→Hard structure→Soft structure

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

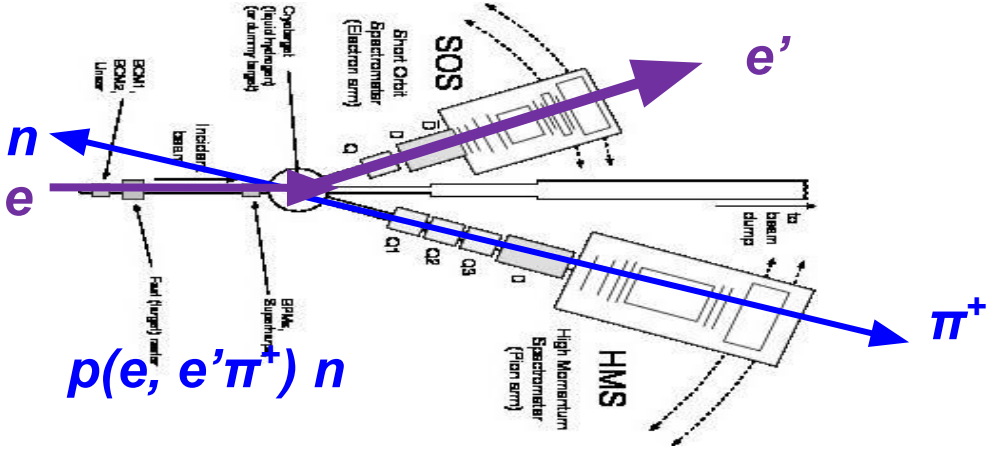
Hadronic Model: Transition (Evolution) of Proton Structure

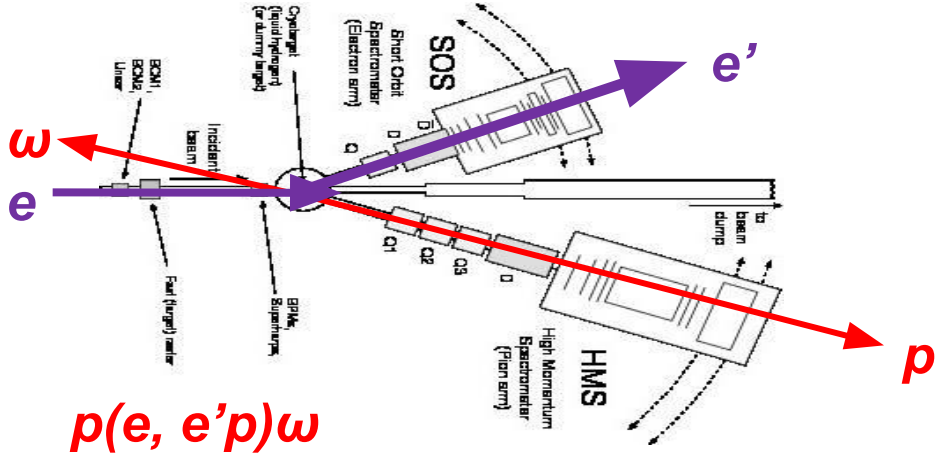


Evolution of the Proton Structure

- 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 about ***u***? Any role?

t-Channel π vs *u*-Channel ω^0 Production

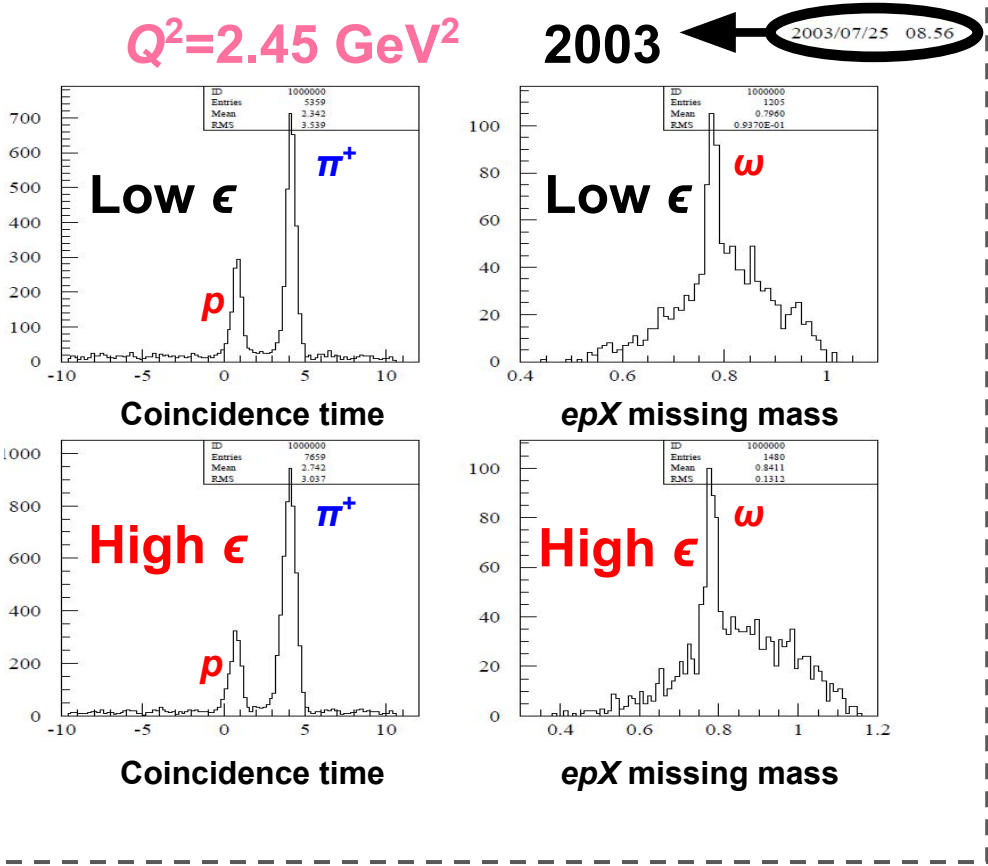


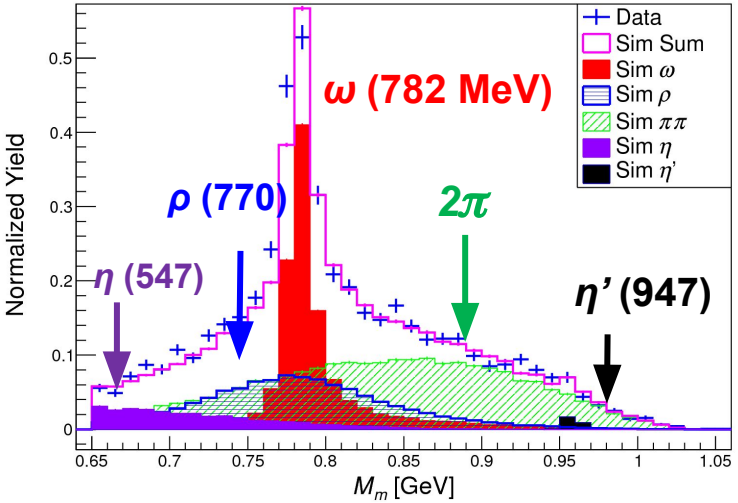


- **Fpi-2 (E01-004) 2003**
  - Spokesperson: **Garth Huber, Henk Blok**
  - Standard HMS and SOS (e) configuration
  - **Electric form factor of charged π** through exclusive π production
- **Primary reaction for Fpi-2**
  - $p(e, e' \pi^+)n$
- **In addition, we have for free**
  - $p(e,e' p)\omega$
- **Kinematics coverage**
  - W= 2.21 GeV, Q^2=1.6 and 2.45 GeV^2
  - Two ϵ settings for each Q^2
- **LT Separation!**

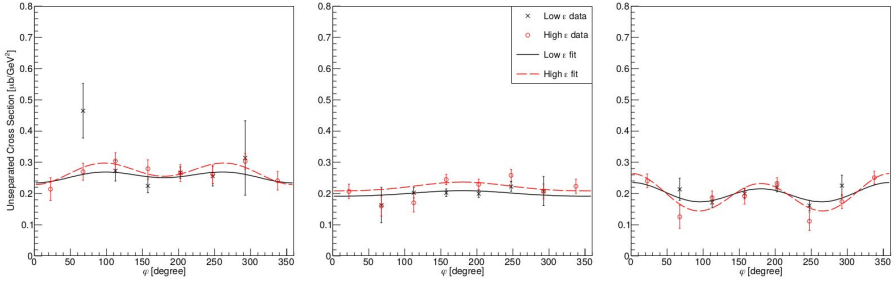
Backward Angle ω Electroproduction from 6 GeV Era

Q^2=2.45 GeV^2 2003



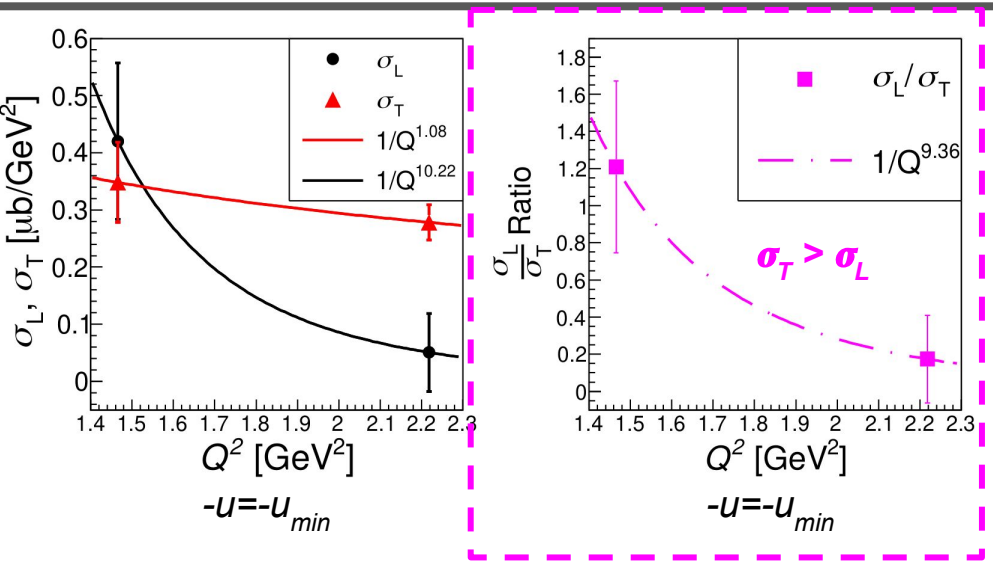


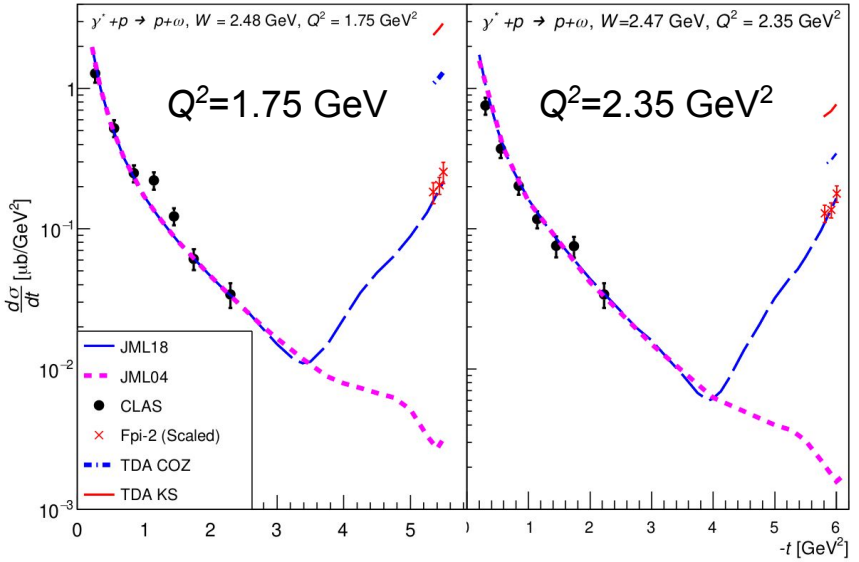
Q^2=2.45 GeV^2



(a) $-u \leq 0.19$ GeV^2 (b) $0.19 < -u \leq 0.30$ GeV^2 (c) $0.30 < -u \leq 0.50$ GeV^2

Backward Angle ω Electroproduction from 6 GeV Era

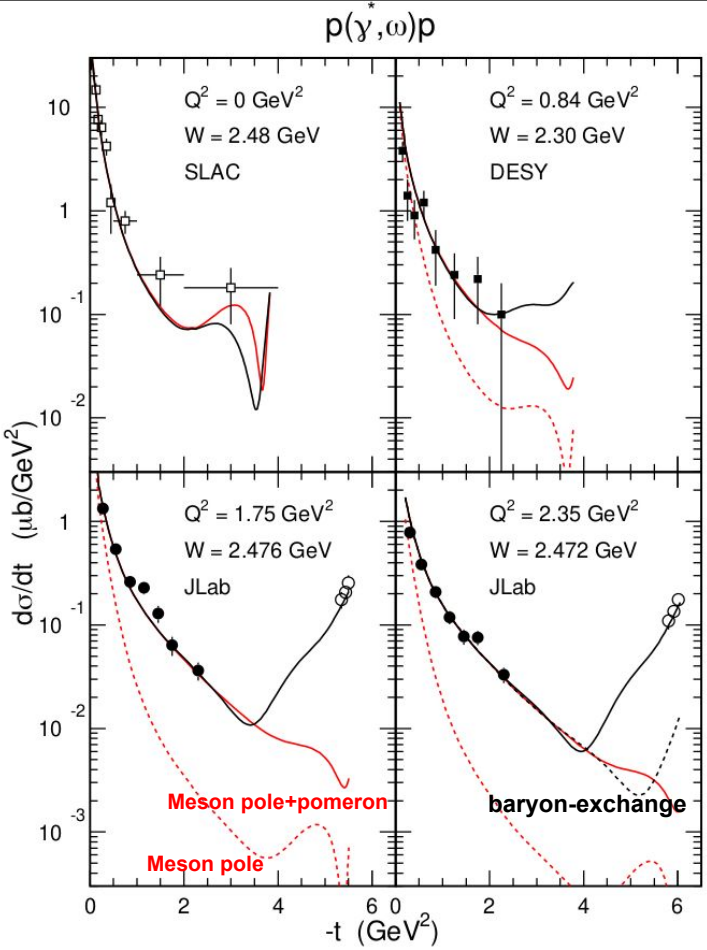




Phys. Rev. Lett. 123 (2019) 182501

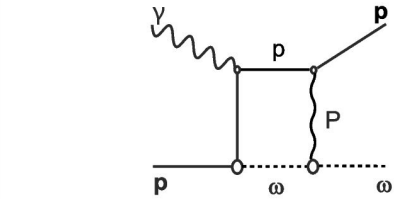
- Key observation:
  - $\boldsymbol{\sigma_L}$ dropped significantly as question of Q^2, as a result: $\boldsymbol{\sigma_T > \sigma_L}$ observed at Q^2 ~2.35 GeV^2
  - Sharp u-channel ω Electroproduction peaks are observed at both 1.75 and 2.35 GeV^2
  - Forward-backward ratio is 10:1!

The Regge Approach (Soft structure)

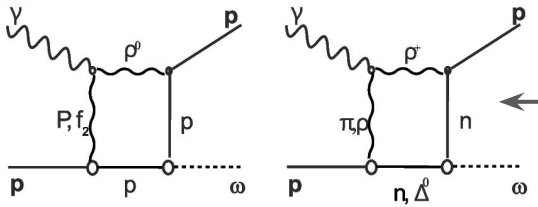


Unitarity cut in *u*-channel

Images credit to J-M. Laget



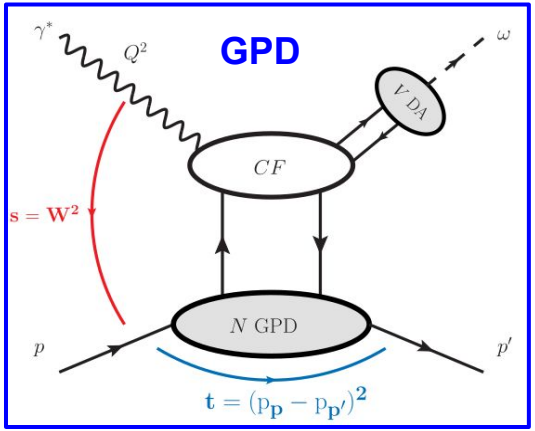
Nucleon pole Exchange diagram

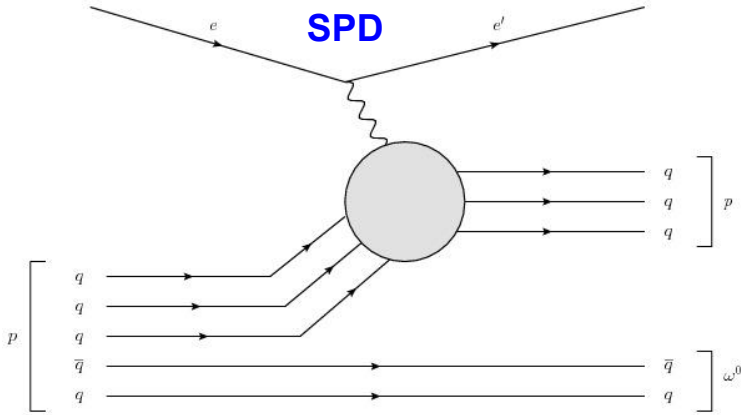


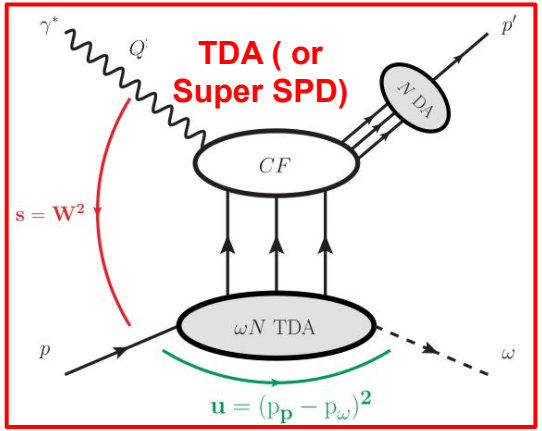
Additional ρ re-scattering within nucleon diagrams

- **Regge Study by J-M. Laget in 2018**
- **Key findings:**
  - Nucleon pole contribution along could not explain the sharply rising slope at $-t = -t_{max}$.
  - ρ re-scattering within nucleon diagrams is required
  - Work is in progress**. L/T separation study was not attempted.**
- **Another Regge effort from Be-Geel Yu is also work in progress. Attempting the L/T separation prediction.**

GPD, SPD and TDA (Hard structure)





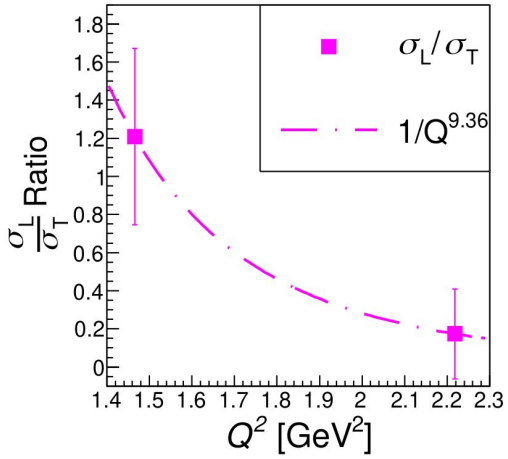


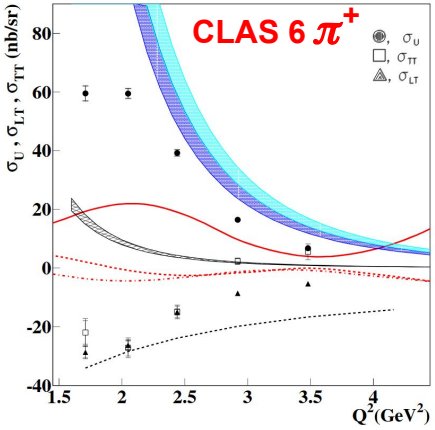
$-t_{min}$ $-t \approx -u$ $-t_{max}$

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 or *u*-Channel Factorization Scheme



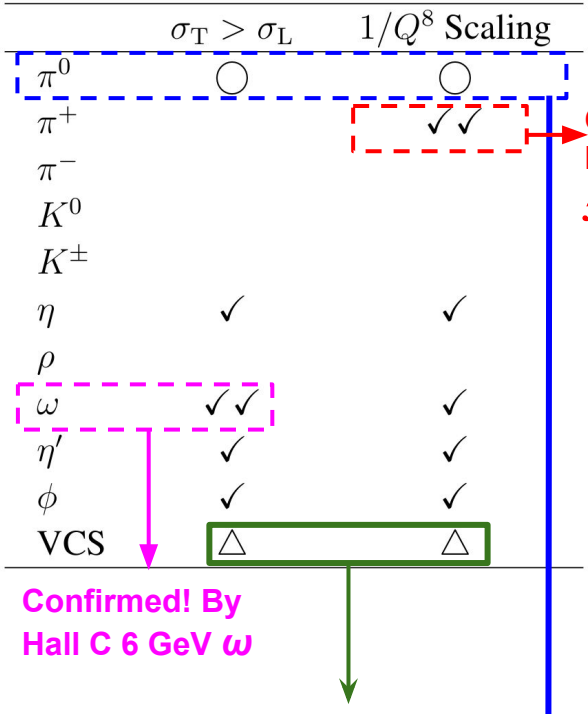


Two qualitative predictions from TDA:

- $\sigma_T \sim 1/Q^8$ 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)**
- **Stage 1: test TDA predictions (12 GeV)**
- **Stage 2: extractions of TDAs**



Others: parasitic data may be available

JSA Award List of Tasks

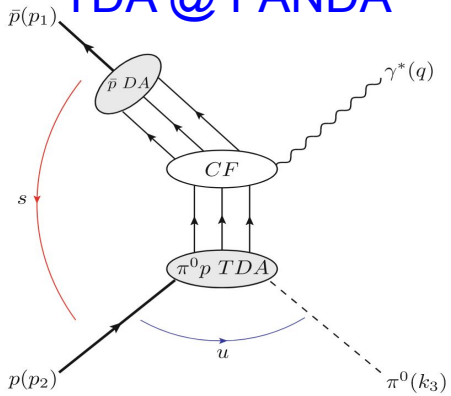
- Invite Dr. K. Semenov-Tian-Shansky (as a TDA expert) for a research visit to deepen discussion in u-channel physics
- Developing coherent and comprehensive 12 GeV strategy
  - Priorities list of prime observables: takes into account realistic constraints and available resources
  - *u*-channel DVCS: kinematics survey
  - Supporting more single pion beam spin asymmetries development from CLAS
- TDA cross section predictions 12 GeV and EIC kinematics
- Hosting first *u*-channel physics workshop

Measure of Success:

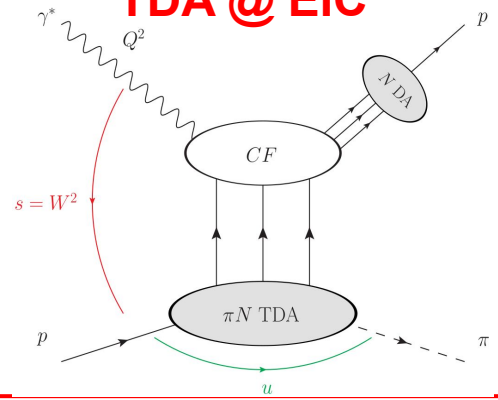
- Completing and publishing the workshop white paper on the backward angle physics strategy for JLab 12 GeV.
- Completing and publishing the EIC backward-angle π^0 feasibility study (work in progress).
- Completing the relevant section in Yellow report (work in progress).
- Presenting PAC48 proposal (submitted to PAC).

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

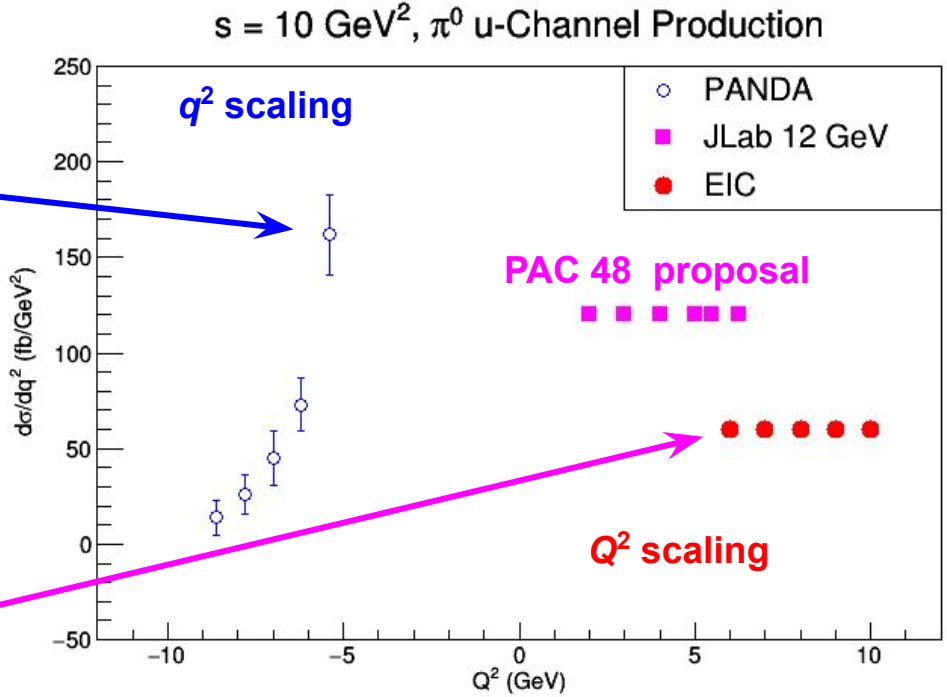
TDA @ PANDA



TDA @ EIC

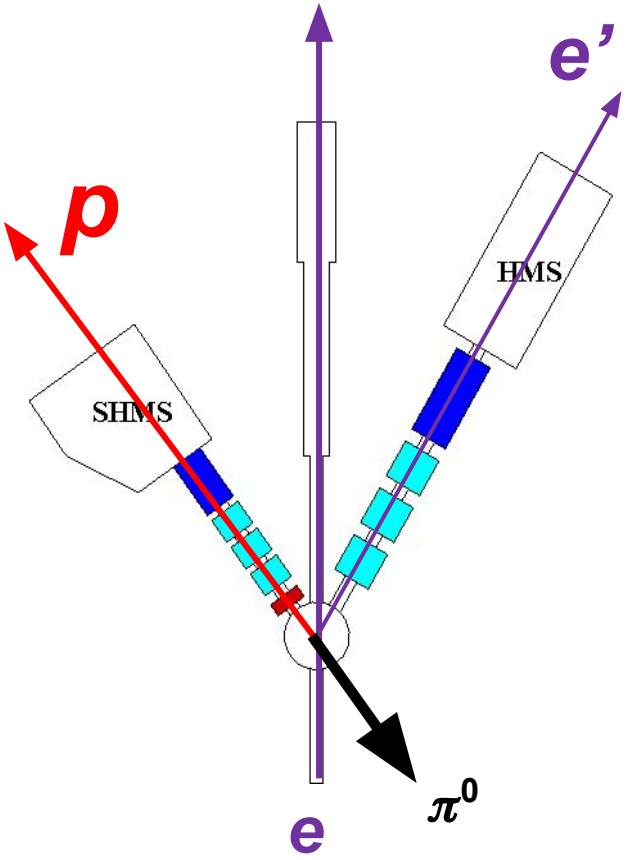


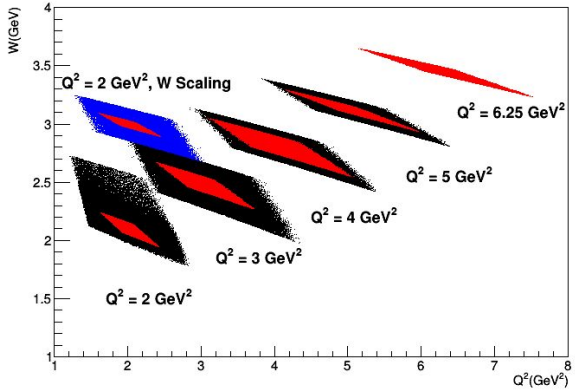
The PANDA Collaboration, Eur. Phys. J. A (2015) 51: 107

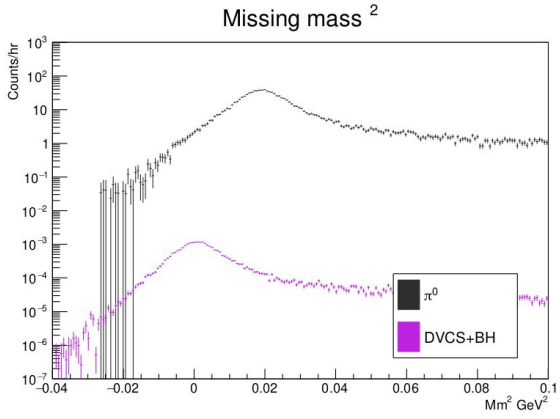


Same TDAs for PANDA and EIC, the ultimate universality check

Progress Report on PAC 48 Proposal: Backward-angle π^0







First dedicated *u*-channel electroproduction study above the resonance region: ^{1}H(*e*,*e'p*)π^0

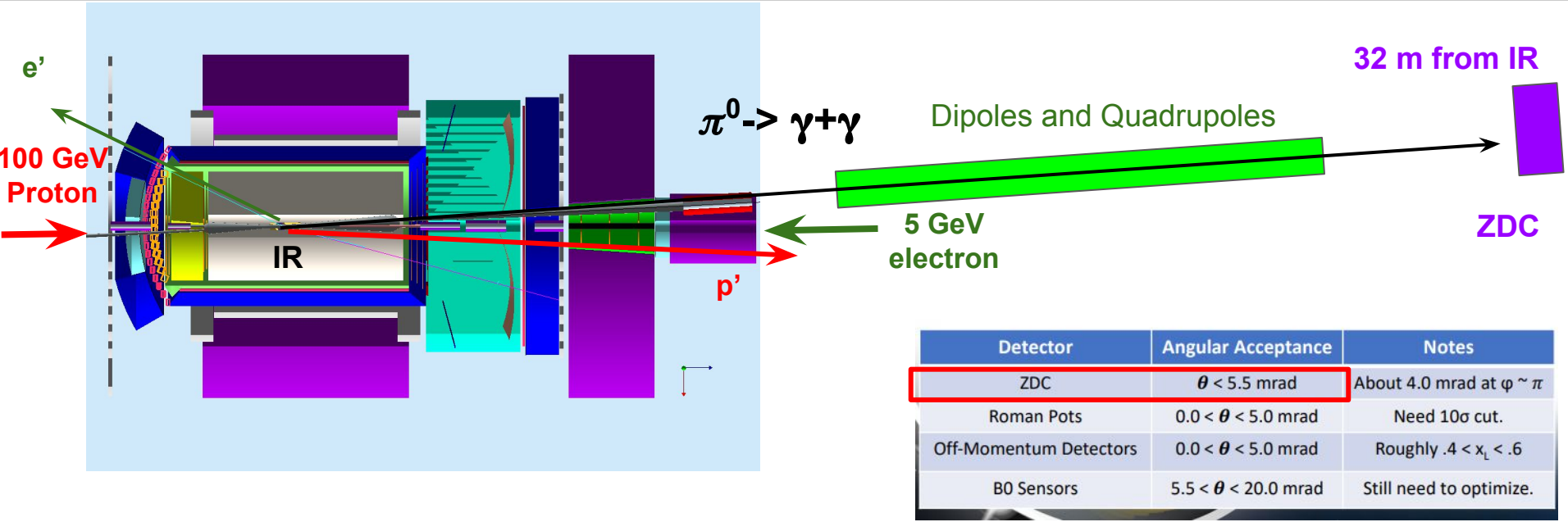
- Q^2 coverage: 2.0 < Q^2 < 6.25 GeV^2.
- *x*=0.36
- *u* coverage: 0 < -*u*' < 0.5 GeV^2

Submitted to PAC 48!

Objective:

- **Study soft-hard transition**
- **Validating TDA**

Progress Report on *u*-channel π^0 @ EIC

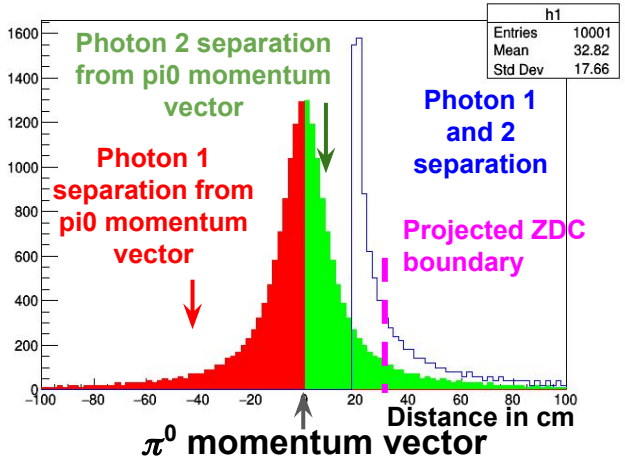


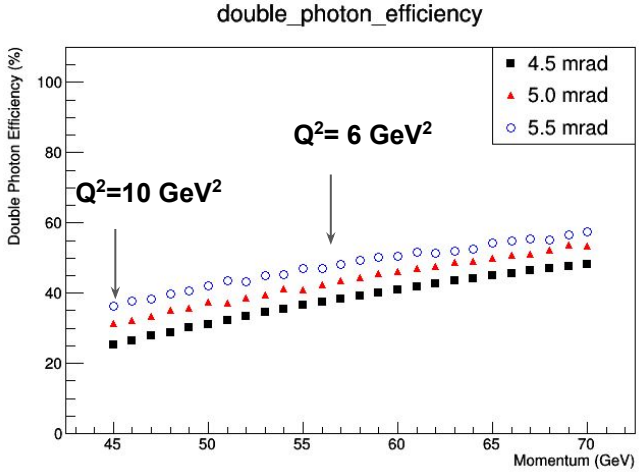
Detector	Angular Acceptance	Notes
ZDC	θ < 5.5 mrad	About 4.0 mrad at φ ~ π
Roman Pots	0.0 < θ < 5.0 mrad	Need 10σ cut.
Off-Momentum Detectors	0.0 < θ < 5.0 mrad	Roughly .4 < x_L < .6
B0 Sensors	5.5 < θ < 20.0 mrad	Still need to optimize.

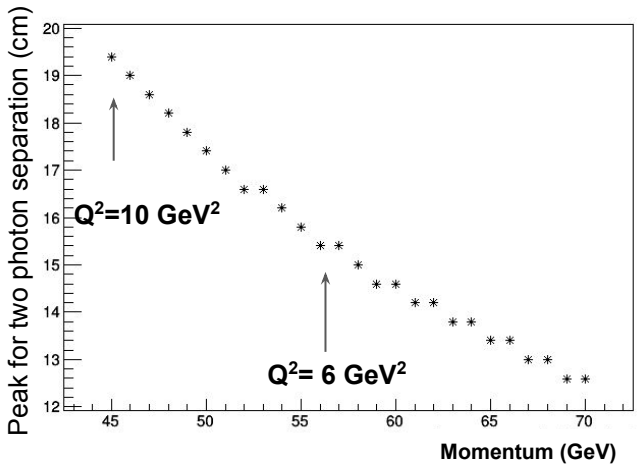
Q^2 (GeV^2)	W (GeV)	x_B	$\theta_{e'}$ (deg)	$\eta_{e'}$	$P_{e'}$ (GeV)	$\theta_{p'}$ (deg)	$\eta_{p'}$	$P_{p'}$ (GeV)	θ_{π^0} (deg)	η_{π^0}	P_{π^0} (GeV)	$-t$ (GeV^2)	$-u$ (GeV^2)
6.2	3.19		152	-1.39	5.31	-1.84	4.13	43.40	1.43	4.38	56.29	14.84	-0.37
7.0	3.19		150	-1.32	5.35	-1.92	4.09	45.50	1.43	4.38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

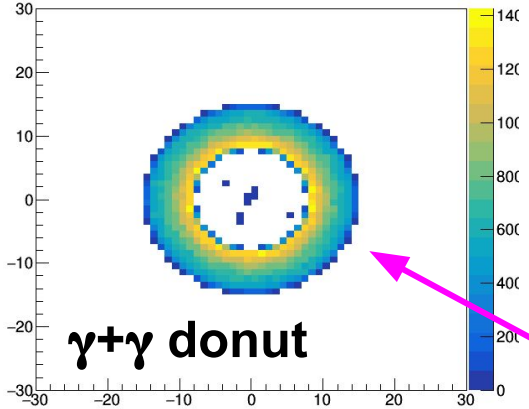
u'=0 GeV

Progress Report on *u*-channel π^0 @ EIC









Preliminary conclusion:

- *u*-channel π^0 at EIC with current design is a feasible measurement
- Ideal expected trigger: e'+p'+ 2 γ, is very clean with very little background, with reduced efficiency
- **Next step: process to full geant4 simulation**

The EIC fellowship award will help completing the YR and feasibility studies

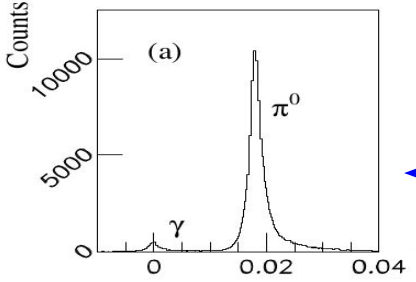
ZDC 2 γ hit pattern @ 40 GeV/c π^0 4.5 mrad acceptance

Progress Report: First *u*-channel Physics Workshop

- **Thanks to the support from JLab, JSA and William & Mary, workshop is on track for September 21st-23rd, 2020.**
  - **Indico page of the workshop: 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 examples at 12 GeV**
    - Backward DVCS (Hall **B**, **C**)
    - CLAS 12 single pion spin asymmetry (Hall **B**)
    - U-channel meson production (omega, rho, phi) production from Kaon LT experiment (Hall **C**)
  - **u-channel photoproduction examples at 12 GeV**
    - Timelike Compton scattering (Hall **B**, **C** and **D**)
    - Wide angle compton scattering (Hall **C**)
    - ω Photoproduction off Proton Target at Backward Angles (Hall **D**)
    - Σ-K+ Photoproduction at Backward Angle at GlueX Experiment (Hall **D**)
    - ω Photoproduction off Proton Target at Backward Angles (Hall **D**)
  - **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**

A Lesson from the Past

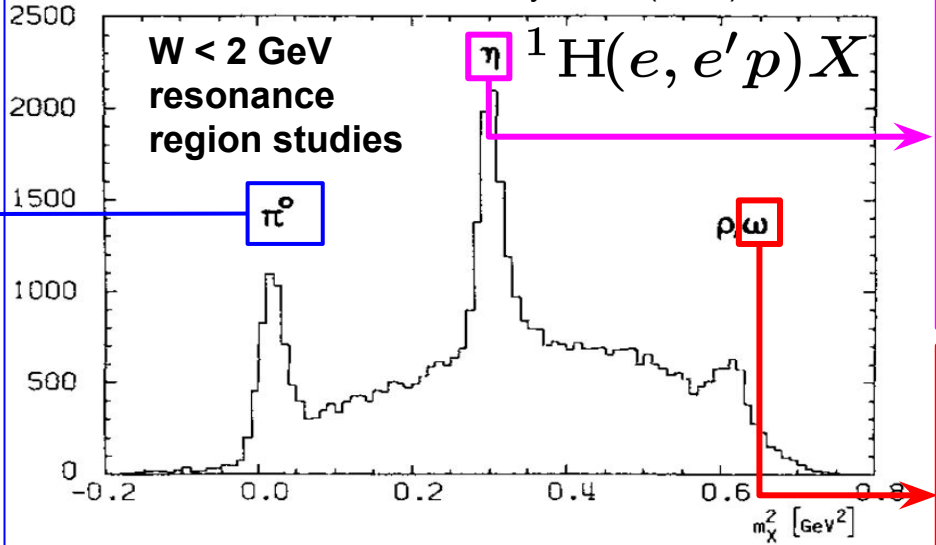
G. Laveissière et al. Phys. Rev. C 79, 015201 (2004)



Hall A VCS: E93-050

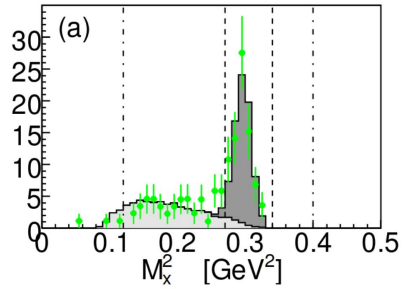
Hall C VCS: E12-15-001

F. W. Brasse et. al. Z. Phys. C22 (1984) 33



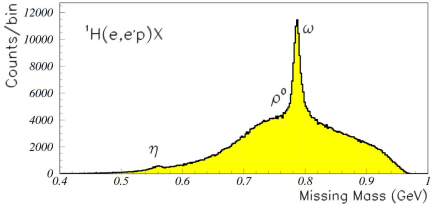
***u*-channel meson spectral at DESY spectrometer experiment from 1984**

M. Dalton et al. Phys. Rev. C 80, 015205 (2008)



Hall C E01-002

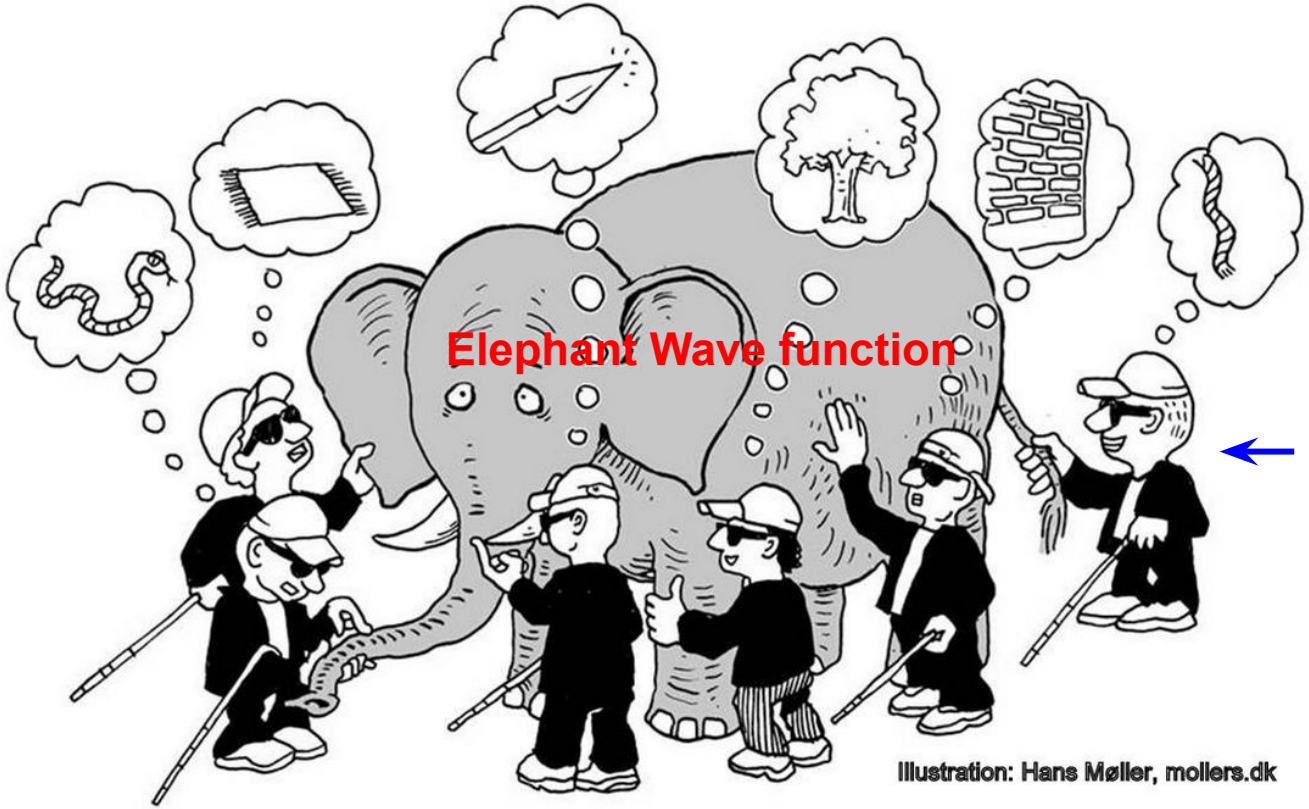
P. AmbrozwiczPhys. Rev. C 70, 035203 (2004)



Hall C E91-016

- Now is the time to resurrect u-channel meson productions at 12 GeV kinematics and future EIC.
- **Goal of our activity: to inspire a wave of backward-angle physics measurements**

Thank you for your attention!



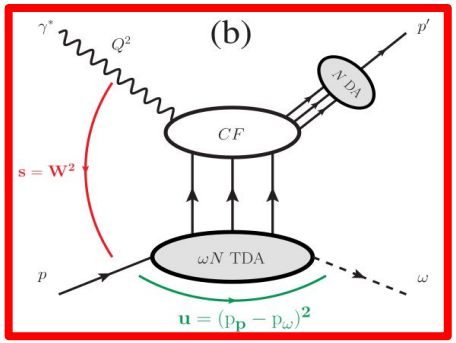
Thank you for the supports

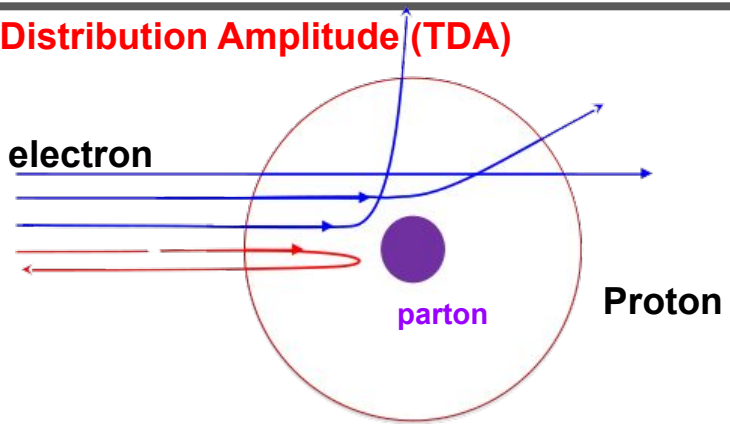
- **Gratitude to the JSA, JLUO award selection committee,**
- **Gratitude to Garth and Justin guidance, advance and support**
- **Gratitude to the TDA theorist: Bernard, Lech and Kirill, and assistance from JLab theory center: Christian**
- **Thanks to my Hall A/C, CLAS TDA working group and Hall D colleagues**
- **My people from the postdocs and graduate students community**
- **Great support from William and Mary Physics department**

Backup

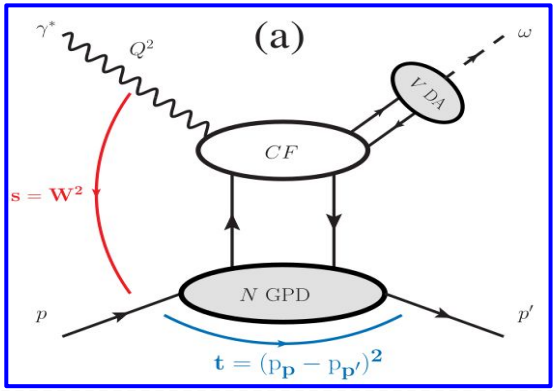
Backward-angle structure of Proton

Meson-nucleon Transition Distribution Amplitude (TDA)



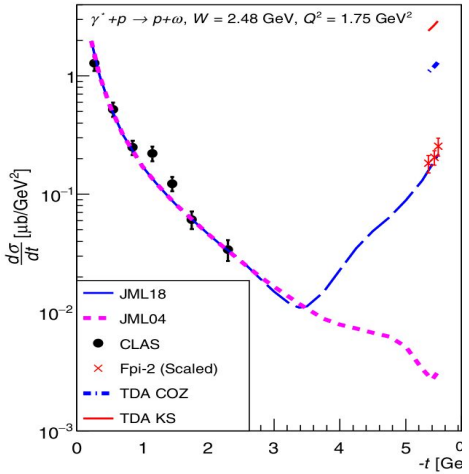


GPD



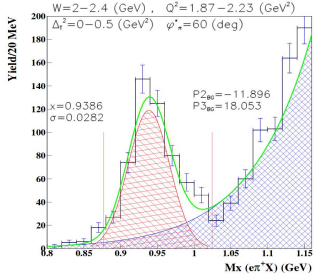
- Complete description of Nucleon
  - GPD = Hadron tomography of the proton
  - TDA = tomography of partonic distributions in the nucleon --> meson and vice versa transitions probed in the backward angle kinematics

- Backward-angle cross section is not 0!
  - backward angle cross section is 1/10 of the forward angle cross section at observed Q^2



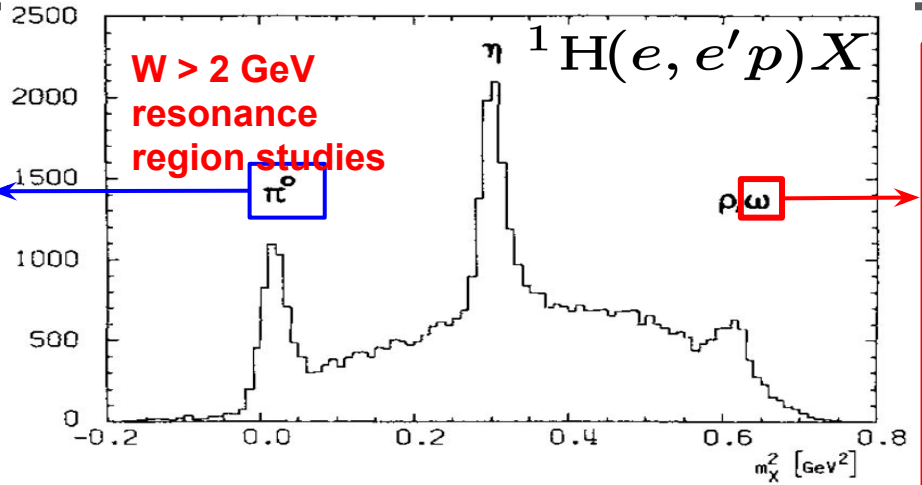
6 GeV Backward Angle Physics at W > 2 GeV

Charged Pion Production from CLAS 6

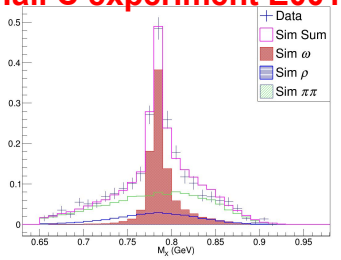


^{1}H(e, e'π$^+$)X

- **Q^2 Scaling**



Hall C experiment E001-004

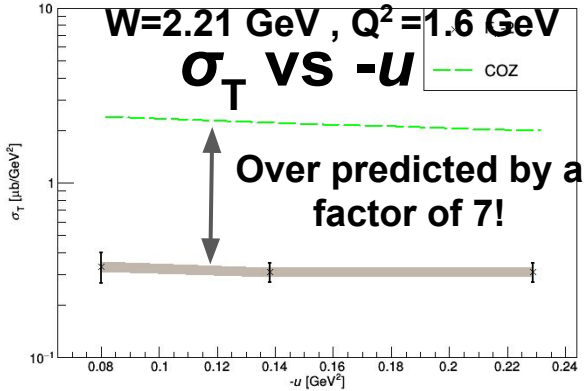


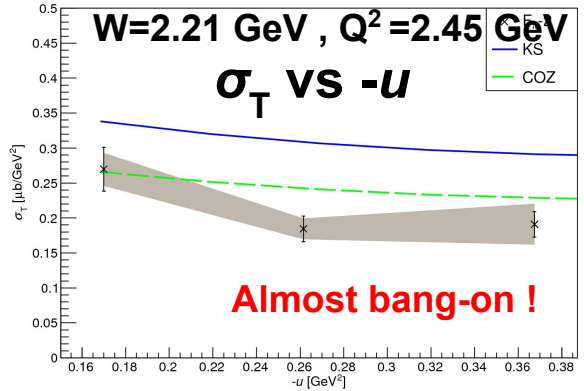
^{1}H(e, e'p)X

- **Parasitic data**
- **Full L/T separation**

- **Backward angle physics in this talk: backward angle physics above the resonance region (W>2 GeV^2)**
- ***u'* -> u_{min}, $t > Q^2$**
- **A systematic backward angle physics program:**
  - **JLab 6 -> JLab 12 -> EIC**

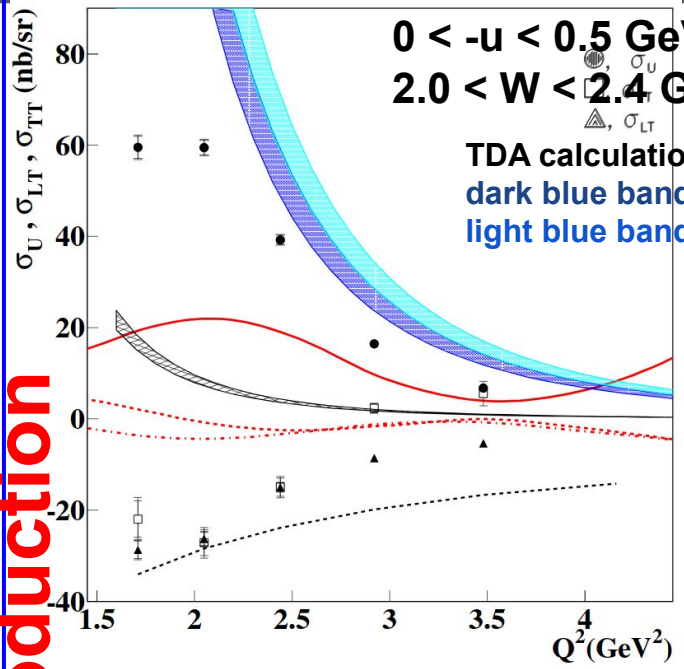
Comparison to TDA calculation





TDA Calculation by B. Pire, K. Semenov, L. Szymanowski, Private Communication. (2015)

Hall C Omega Production

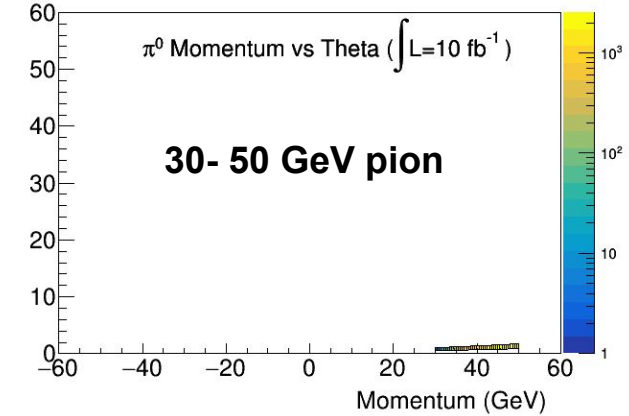


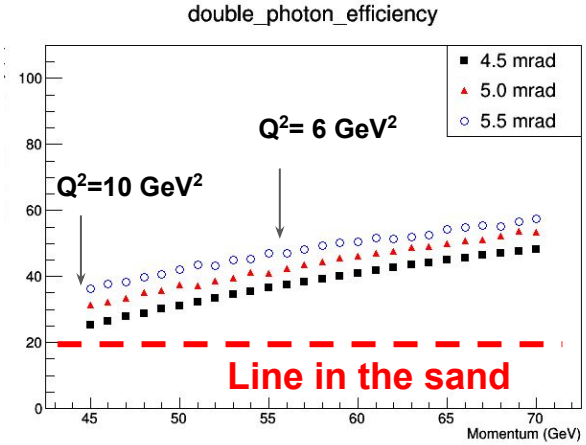
Hall B charged π production

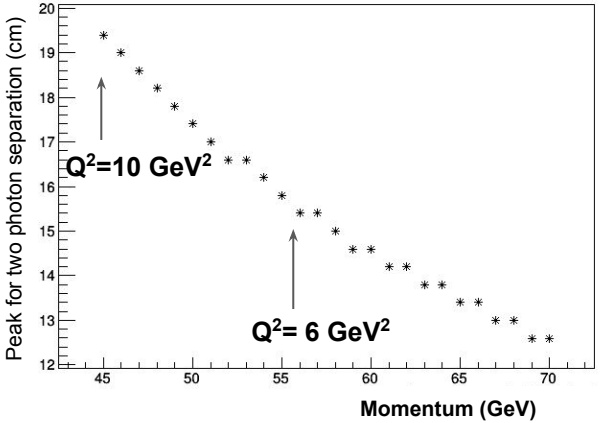
K. Park et. al,Physics Letters B
Volume 780, 10 May 2018, Pages 340-345, (2017)

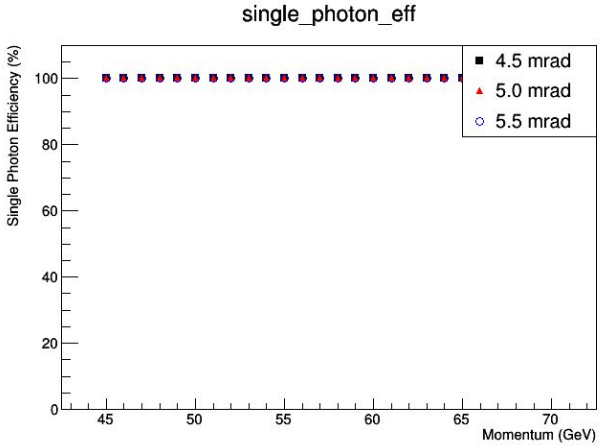
Indication of early TDA scaling !?

Impact to the efficiency









- Double photon efficiency for the nominal π^0 event is larger than 20%
- Detector (magnetic aperture) constrains:
  - Fixing center of the neutral particle at ZDC
  - Ensuring largest possible symmetrical acceptance

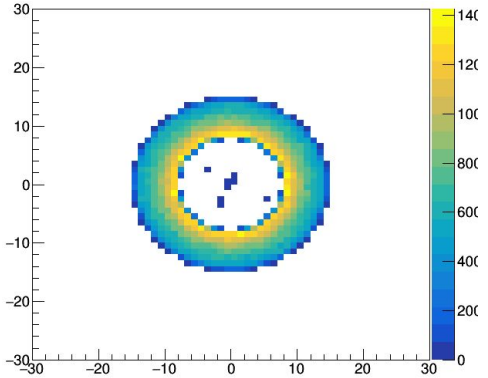
Physics background (to our current best knowledge)

- Double photon case:
  - Primary reaction: e+p-> e'+p' + π^0
  - Ideal expected trigger: e'+p'+ 2 γ
  - Physics background: none
  - Less than ideal trigger: e'+2 γ
  - Background: Λ->n+π^0

2 γ hit pattern

40 GeV/c π^0

4.5 mrad acceptance

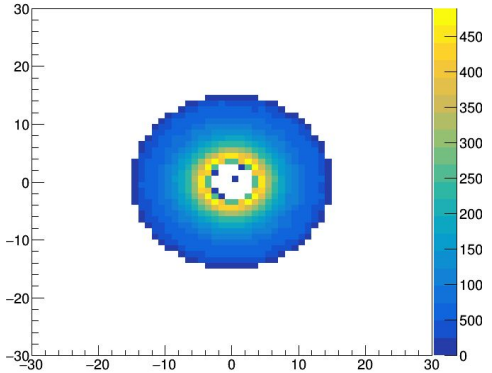


- Single photon case:
  - Primary reaction: e+p-> e'+p' + π^0
  - Ideal expected trigger: e'+p'+ γ
  - Physics background: DVCS, eta, Λ->n+π^0
  - Less than ideal trigger: e'+γ
  - Background: many many possibility

2 γ hit pattern

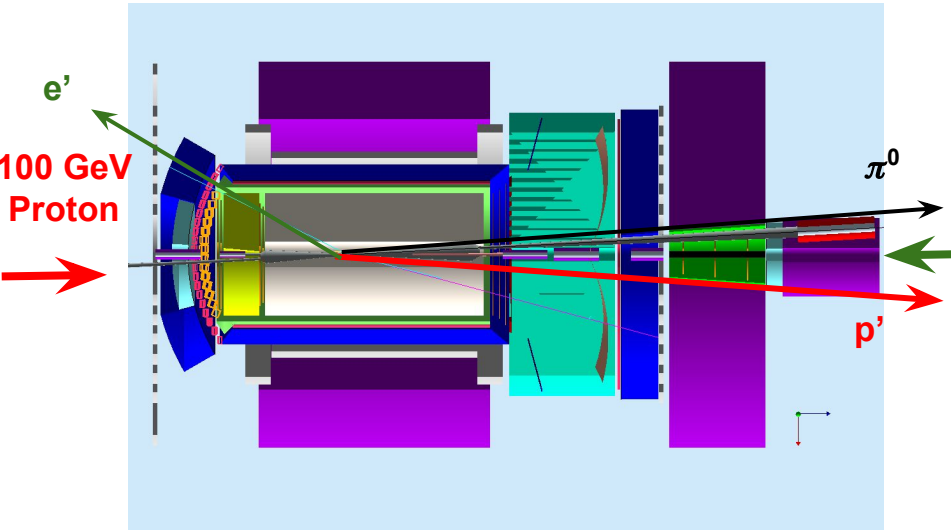
60 GeV/c π^0

4.5 mrad acceptance

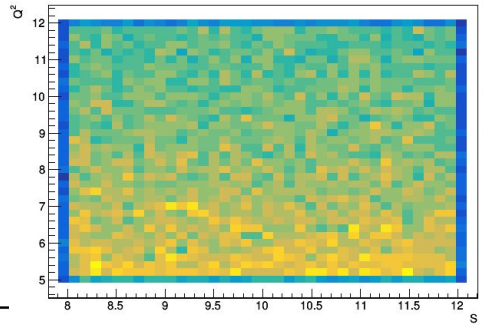


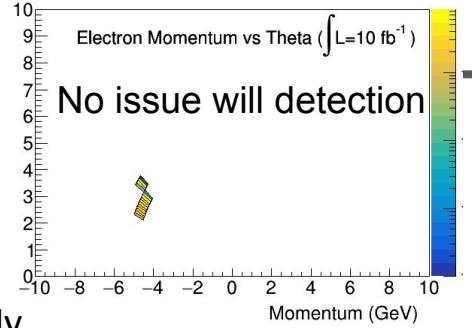
- We can use the double photon event to normalize the single photon events

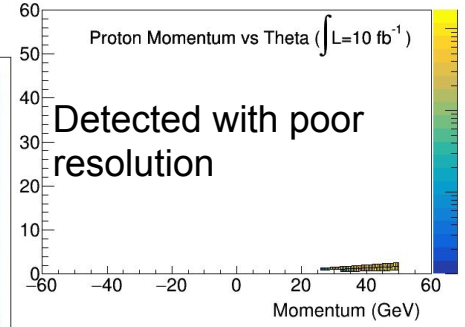
U-channel Meson Production Setup

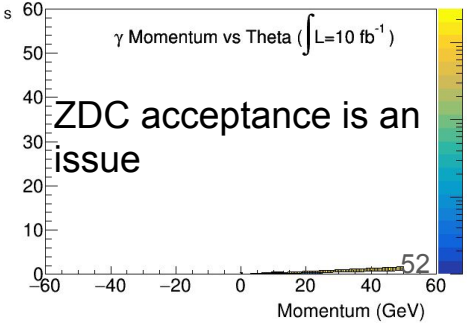


Q^2 vs S intentionally constraint







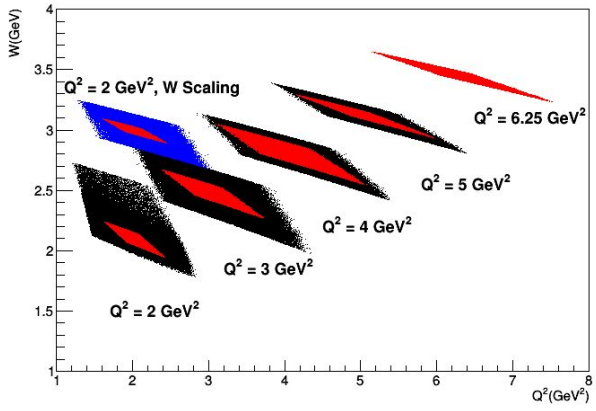


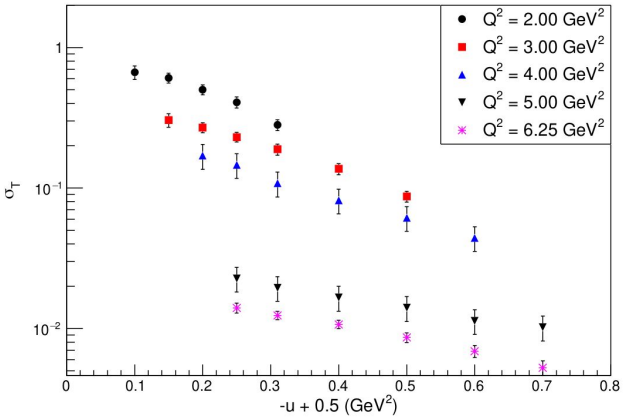
Q^2 (GeV^2)	W (GeV)	x_B	$\theta_{e'}$ (deg)	$\eta_{e'}$	$P_{e'}$ (GeV)	$\theta_{p'}$ (deg)	$\eta_{p'}$	$P_{p'}$ (GeV)	θ_{π^0} (deg)	η_{π^0}	P_{π^0} (GeV)	$-t$ (GeV^2)	$-u$ (GeV^2)
6.2	3.19		152	-1.39	5.31	-1.84	4.13	43.40	1.43	4.38	56.29	14.84	-0.37
7.0	3.19		150	-1.32	5.35	-1.92	4.09	45.50	1.43	4.38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

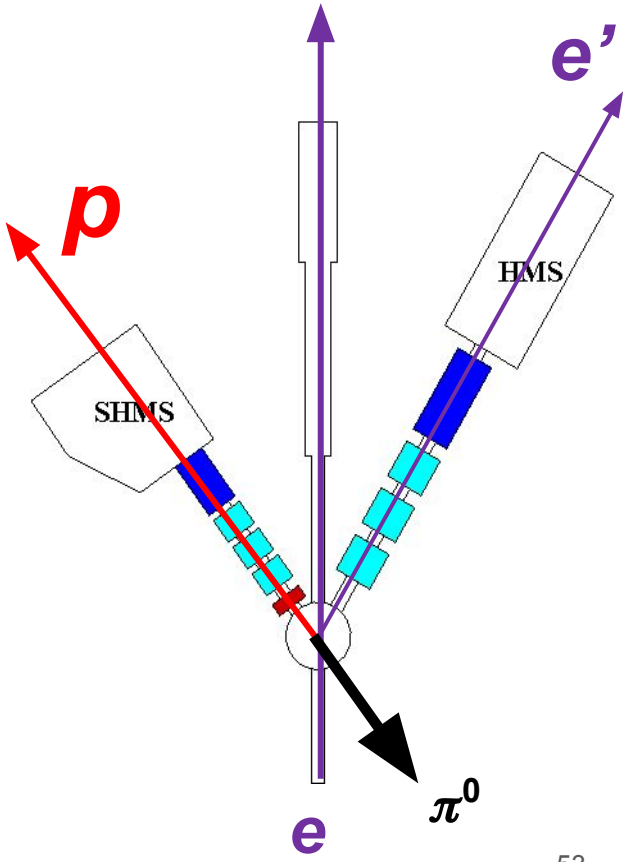
New Proposal to PAC 48 on Backward-angle π^0 Production

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

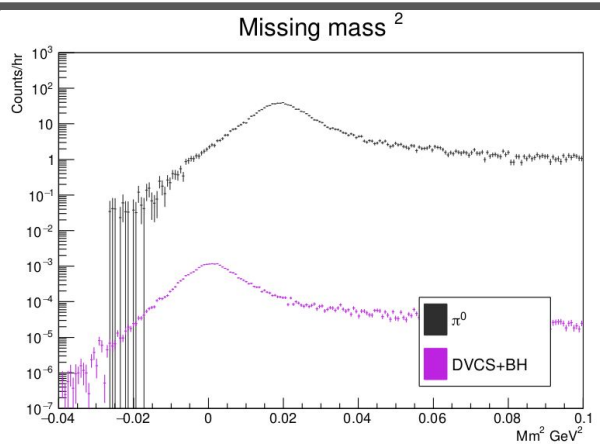
- ^{1}H(e,e'p)π^0
- Q^2 coverage: 2.0 < Q^2 < 6.25 GeV^2.
- L/T separation at Q^2 = 2.0, 3.0, 4.0 and 5.0 GeV^2
- Fixed x=0.36 for all settings
- u coverage: 0 < -u' < 0.5 GeV^2



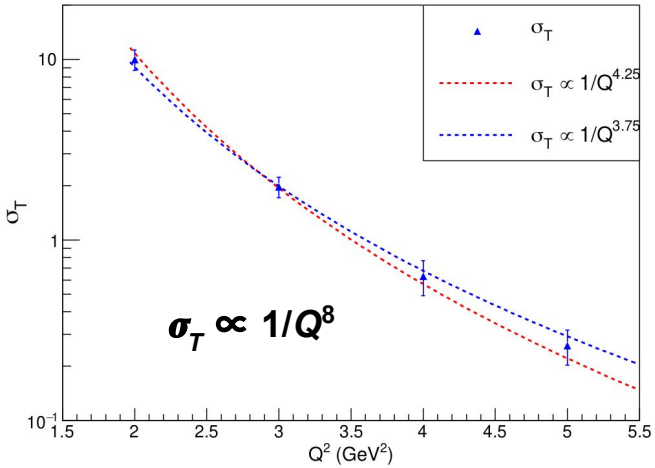


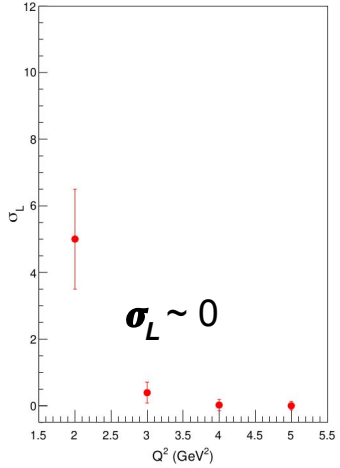


New Proposal to PAC 48 on Backward-angle π^0 Production



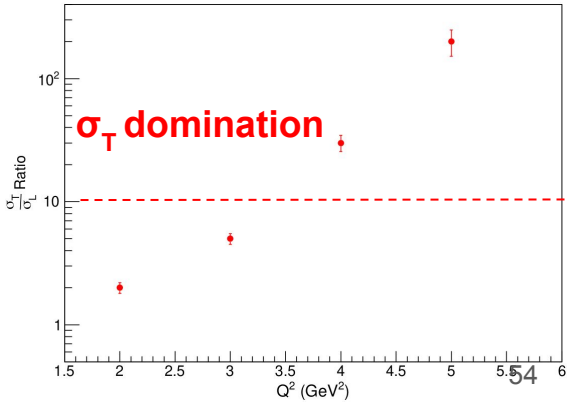
Q^2= 4 GeV^2, W=2.8 GeV, x=0.36





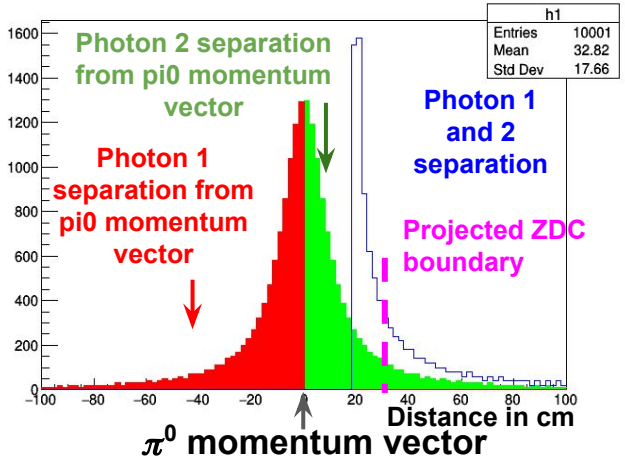
Experiment objective

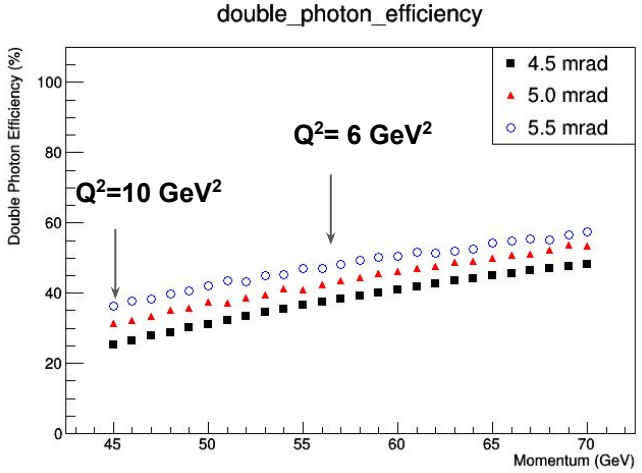
1. Demonstrate existence of u-channel peaks
2. *u*-dependence of L/T separated cross sectio
3. If peaks exist, test TDA prediction: $\sigma_T > \sigma_L$
4. If $\sigma_T > \sigma_L$, test $\sigma_T \propto 1/Q^8$

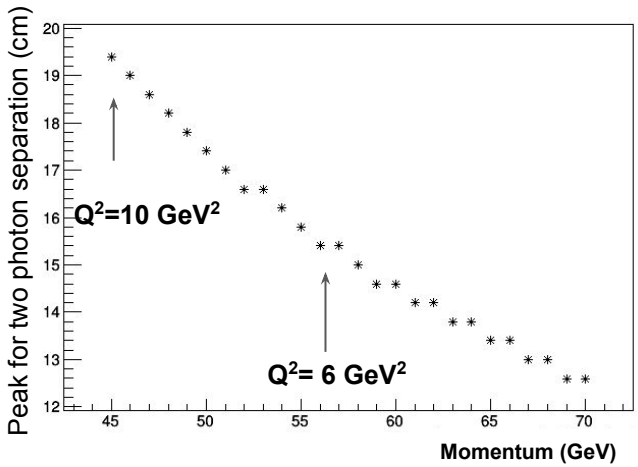


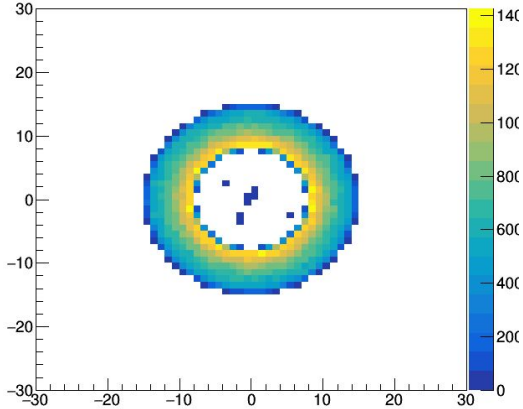
We are pleased to report the proposal was submitted to PAC 48

π^0 Events on ZDC









Preliminary conclusion:

- *u*-channel π^0 at EIC with current design is a feasible measurement
- Ideal expected trigger: e'+p'+ 2 γ, is very clean with very little background, with reduced efficiency
- **Next step: process to full geant4 simulation**

2 γ hit pattern

40 GeV/c π^0

4.5 mrad acceptance

Budget & Measure of Success

Planned Budget (in the proposal):

- Dr. Kirill Semonov-Tian-Shansky's research trip to WM
  - Accommodation: $ 3000
  - Airfare: $1600
  - Visa application: $ 800
  - Transportation: $ 600

Require re-evaluation

- Participating conferences (Bill and Kirill): 3000
- Computational equipment (storage hard drives): $ 900
- Office space is provided by WM in kind

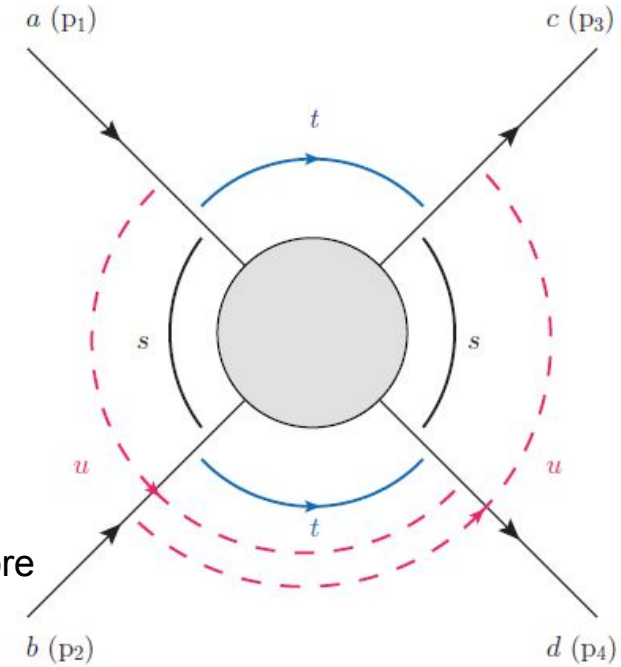
Measure of Success:

- PAC 48 proposal on backward-angle pi0 production above the resonance region (submitted to PAC).
- Hosting u-channel physics workshop and completing a white paper on the backward angle physics strategy for JLab 12 GeV.
- Completing and publishing the EIC backward-angle pi0 feasibility study (work in progress).
- Completing the pi0 u-channel pi0 production section in Yellow report (work in progress).

Mandelstam variables (*s*,*t*,*u*-Channels)

Projectile Before

Target Before



$$s = (p_1 + p_2)^2 = (p_3 + p_4)^2$$

$$t = (p_1 - p_3)^2 = (p_2 - p_4)^2$$

$$u = (p_1 - p_4)^2 = (p_2 - p_3)^2$$

- ***t***: Four-momentum-transfer squared between **target before and after interaction.**

$$\xi = 0, t \approx t_{min}, u \approx u_{max}, t < Q^2$$

- ***u***: Four-momentum-transfer squared between **virtual photon before interaction and target after interaction**

$$\xi = 1, t \approx t_{max}, u \approx u_{min}, t > Q^2$$

- ***t*-channel: *-t ~ 0*, after interaction**
  - Target: stationary,
  - Meson: forward

- ***u*-channel: *-u~0*, after interaction**
  - Target: forward
  - Meson: stationary
  - **Disclaimer: "Backward physics" is a marketing term, and it is equivalent to u-channel physics**
  - Equivalent to "extremely large momentum transfer"

List of Tasks for the JSA Award

- Knowledge exchange within in theory community (K)
  - Inspire more collaboration between local and european experts on u-channel physics
- Developing coherent and comprehensive 12 GeV strategy (K+B)
  - Priorities list of prime observables: takes into account realistic constraints and available resources (K+B)
  - *u*-channel DVCS: kinematics survey (B)
  - Supporting more single pion beam spin asymmetries development from CLAS (K)
- TDA cross section predictions 12 GeV and EIC kinematics (K)
- Hosting first *u*-channel physics workshop (B)

What channel is more important?

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

Strategy Based on TDA, SPD and Regge approach