Exclusive u-channel π^0 Electroproduction From Hall C to EIC

Wenliang (Bill) Li

On behalf of the spokespersons and authors of E12-20-007
at
Hall C Collaboration Meeting
18/Jan/2020

WILLIAM & MARY
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Jefferson Lab

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Outline

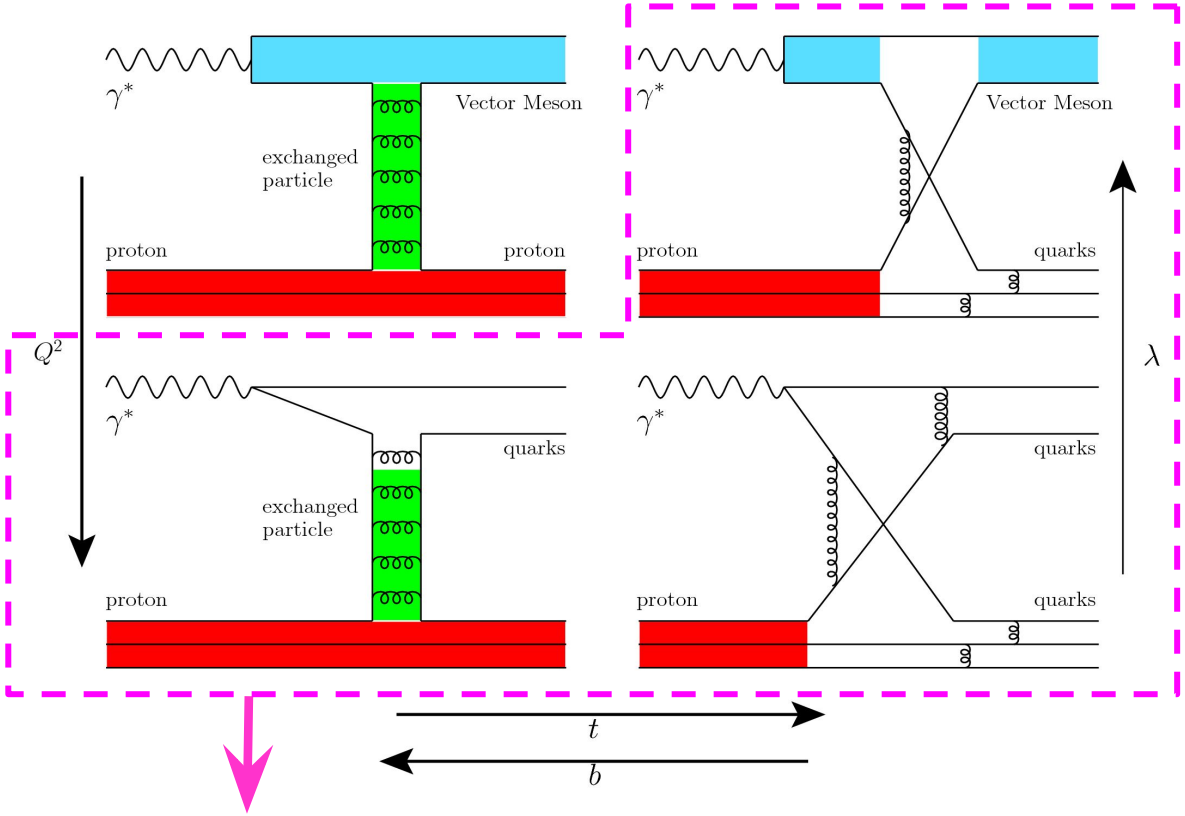
- **Introducing the backward angle physics:**
  - Summary on past studies
  - Theory perspective

- **E12-20-007:**
  - Experimental objectives
  - Experimental configuration requirements

- **Synergy of E12-20-007 to other programs**

- **Future outlook**

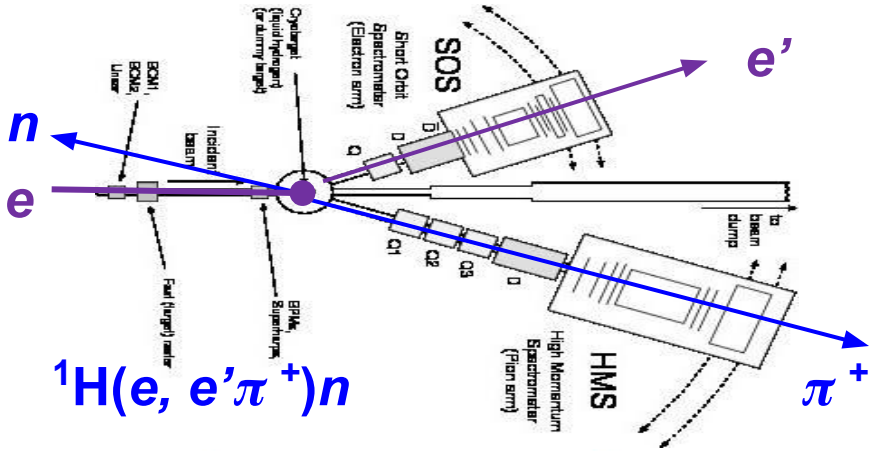
Hadronic Model: Transition (Evolution) of Proton Structure

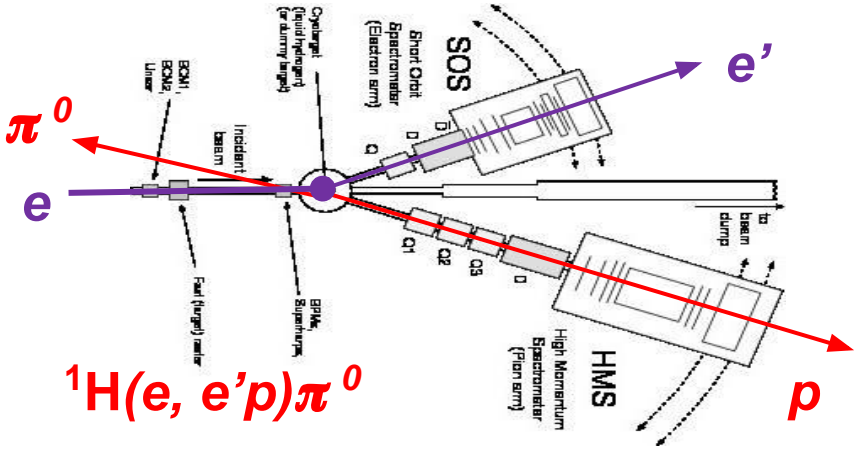


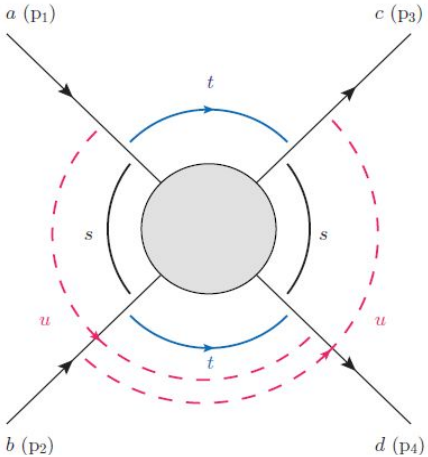
Evolution of the Proton Structure

- 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

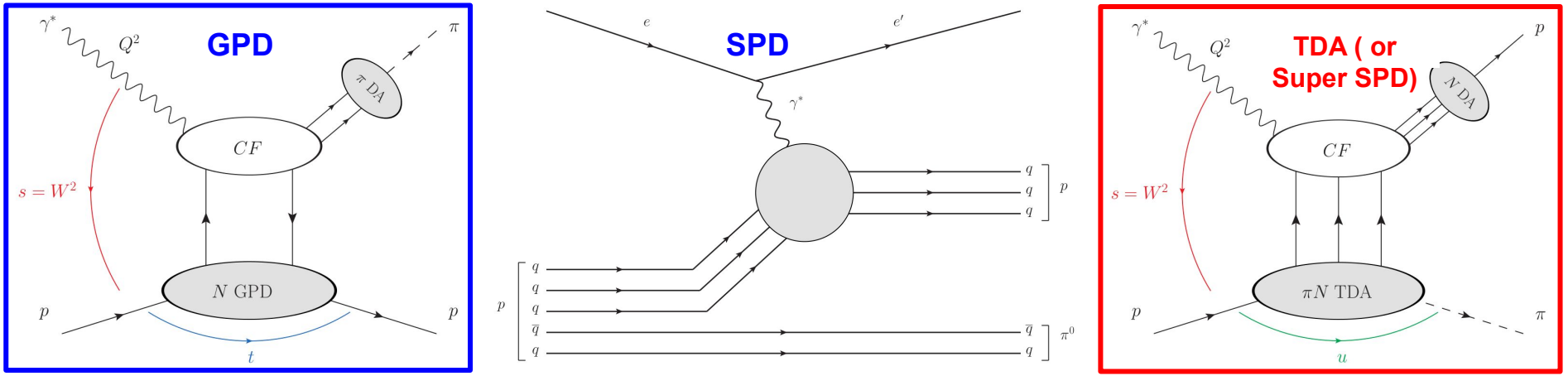






- **Fπ-2 charged π form factor experiment (E01-004)**
  - Standard HMS and SOS (e) configuration
- **Primary reaction for Fpi-2**
  - ***t*-channel π^+ production: ^{1}H(*e, e'*π^+)*n***
- **If one were to study π^0 during the 6 GeV era**
  - ***u*-channel π^0 production: ^{1}H(*e,e'p*)π^0**
- **Nature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

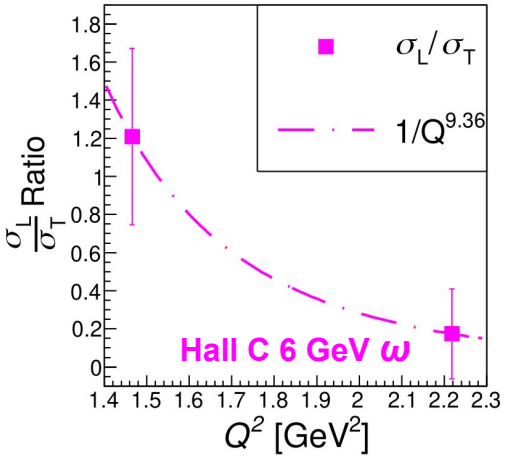


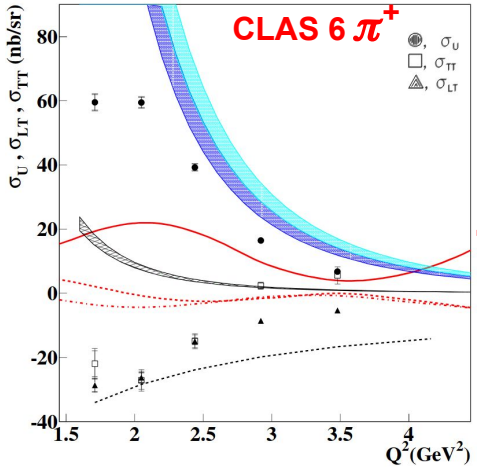
$-t_{min}$ $-t \approx -u$ $-t_{max}$

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





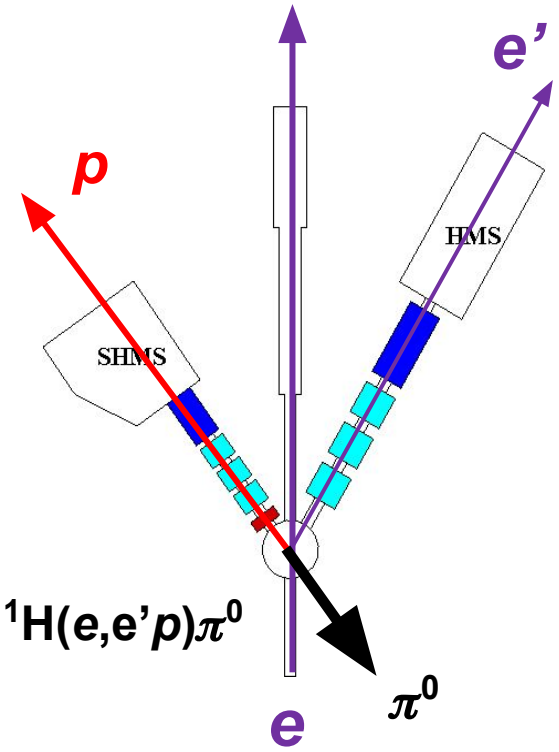
Two qualitative predictions from TDA:

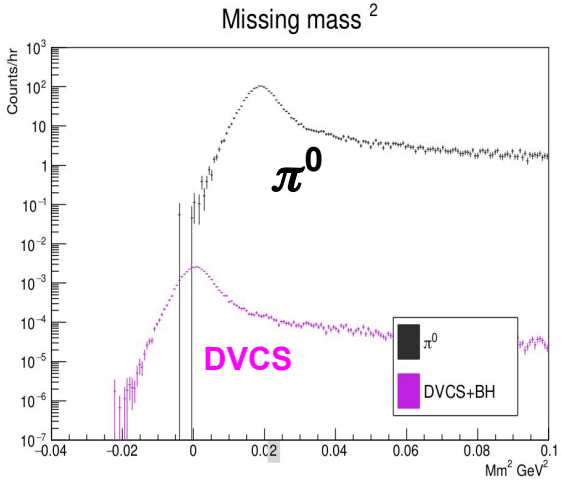
- $\sigma_T > \sigma_L$, $\sigma_L \sim 0$
- $\sigma_T \sim 1/Q^8$ scaling behavior

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

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

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:

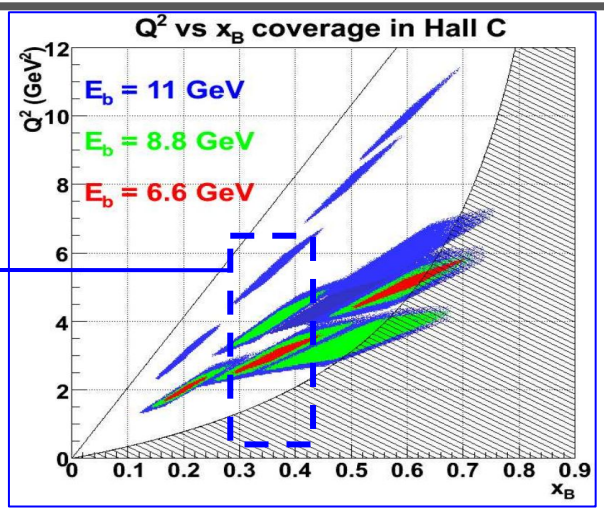
- **Q^2 coverage: $2.0 < Q^2 < 6.25$ GeV^2, at x=0.36 and W > 2 GeV**
  L/T separated cross section @ Q^2= 2, 3, 4 and 5 GeV^2.
- *u* coverage: $0 < -u' + 0.5 < 0.5$ GeV^2
- **Additional *W* scaling check @ Q^2 = 2 GeV^2**
- **Additional Q^2 scaling check @ Q^2 = 6.25 GeV^2**

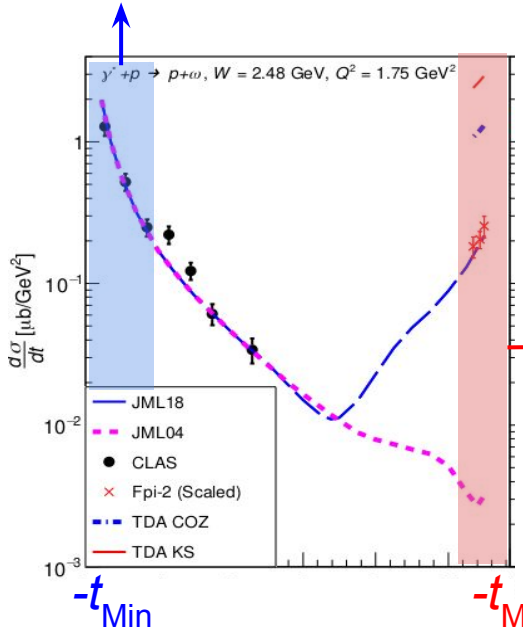
Objective 1: Backward-angle Peaks

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

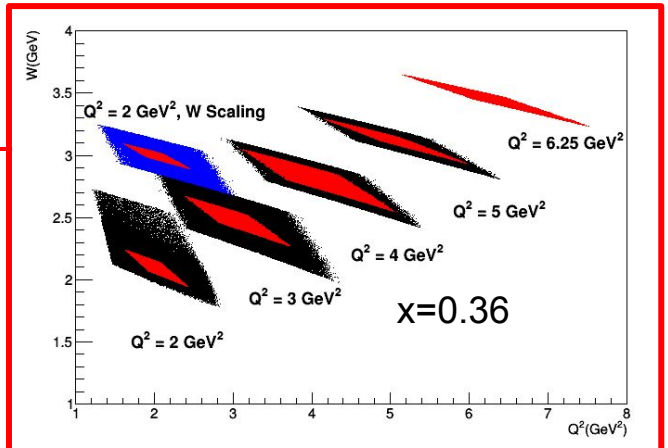
- E12-13-010 NPS experiment provide low *-t* L/T separated cross section

E12-13-010 NPS Experiment

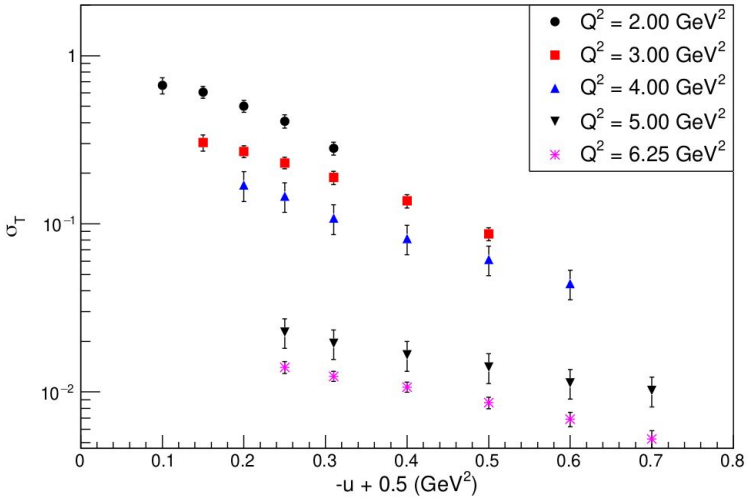




This proposal



Objective 2: *u*-dependence



Objective 2: u-dependence of the separated cross section

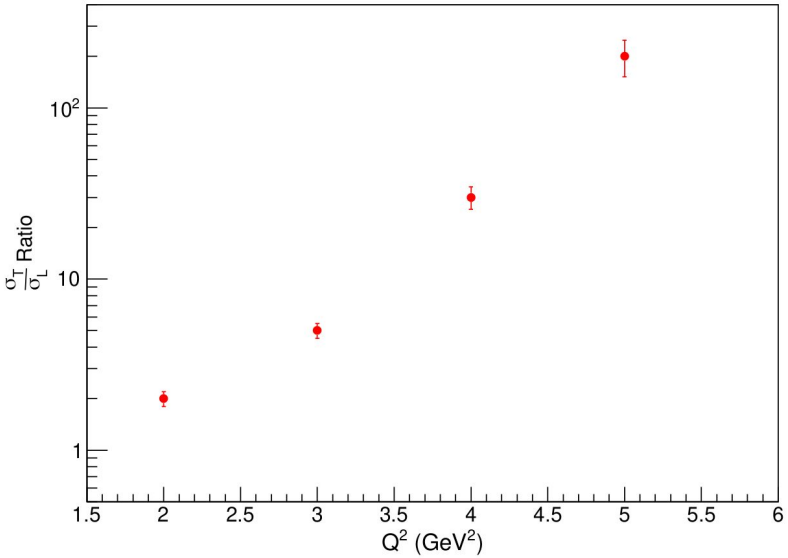
- **Extracting -u dependence of the unseparated cross section and interaction radius:**

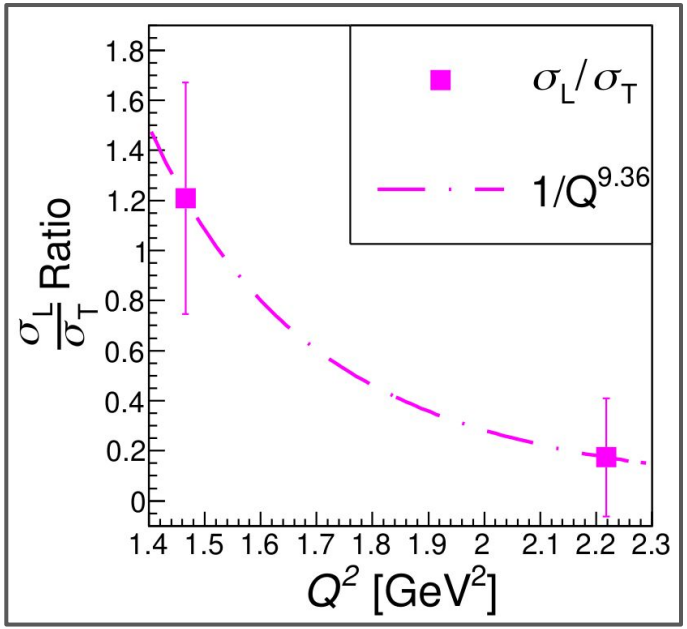
$$\sigma = Ae^{-b \cdot |u|}, \qquad r_{int} = \sqrt{b}\,\hbar\, c$$

- **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)



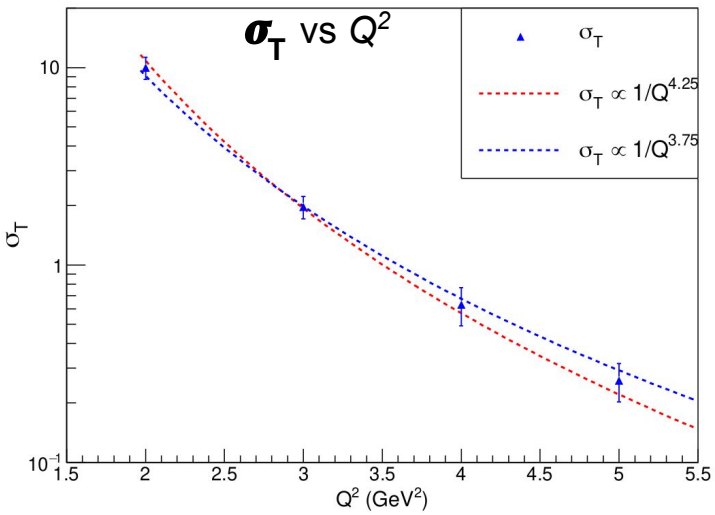


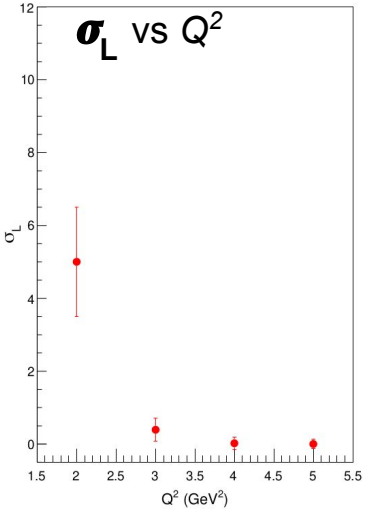
L/T ratio vs Q^2 (6 GeV F_π-2 experiment for ω)

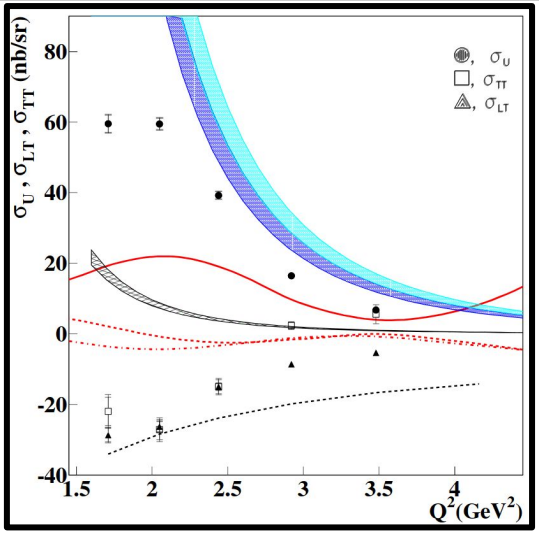
L/T Separated Cross section

- **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, $\sigma_T \propto 1/Q^8$







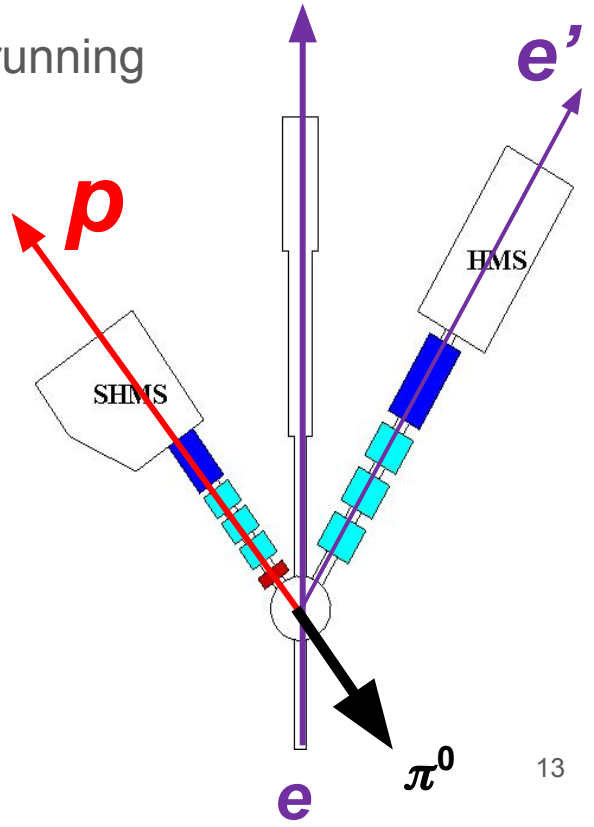
σ vs Q^2 (CLAS 6 π^+ result)

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 $(Q^2)^n$, $3.75 < n < 4.25$

Requirements

- PAC has approved 29 days of beam (requested 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**



PAC 48 Result on E12-20-007

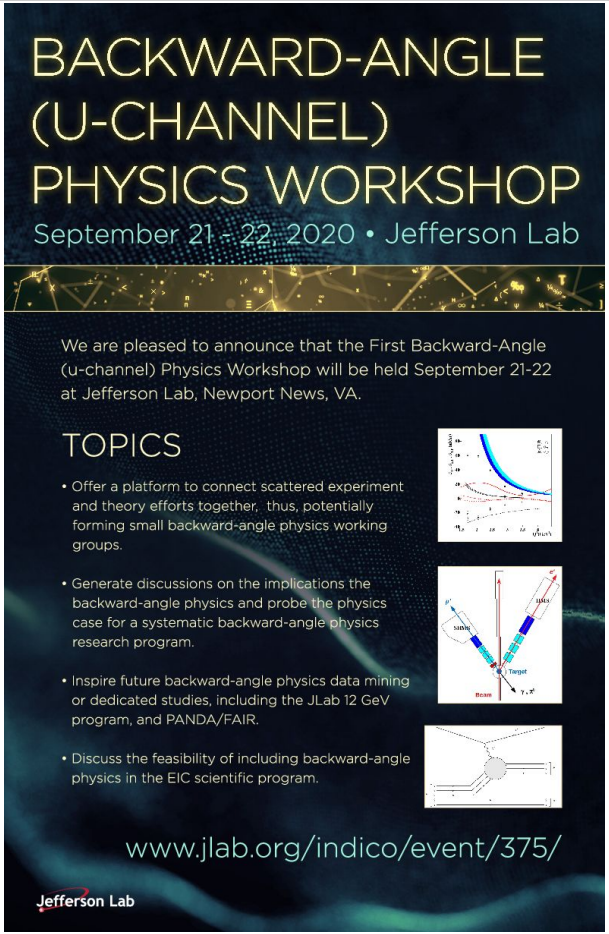
- **PAC decision:**
  - Experiment fully approved for 29 PAC days with B rating
  - Projected beam time: 48 days

- **PAC comments:**
  - The exploration of backward pion electroproduction is feasible, and JLab is an ideal venue at which to perform it.

- **Issues:**
  - Minimum achievable SHMS (5.5 degrees) and HMS (10.5 degrees) angles
  - Conflictive theory in TAC recommendations from 2018 and 2020.

- **We are very pleased with the outcome:**
  - **Approval of E12-20-007 (first dedicated u-channel study) symbolizes u-channel measurement as a concept are accepted within the community despite weakness in theory.**

u-channel Process Workshop held in September 2020



- **Workshop participation:**
  - 20 contributed talks, 2 discussion sessions.
  - Number of individual Participants throughout: 51
- **Objectives:**
  - Connect scattered experiment and theory efforts
  - Discussions on systematic backward-angle physics research program.
  - Inspire future backward-angle physics studies.
- **A workshop whitepaper summarized the workshop outcome is under preparation**

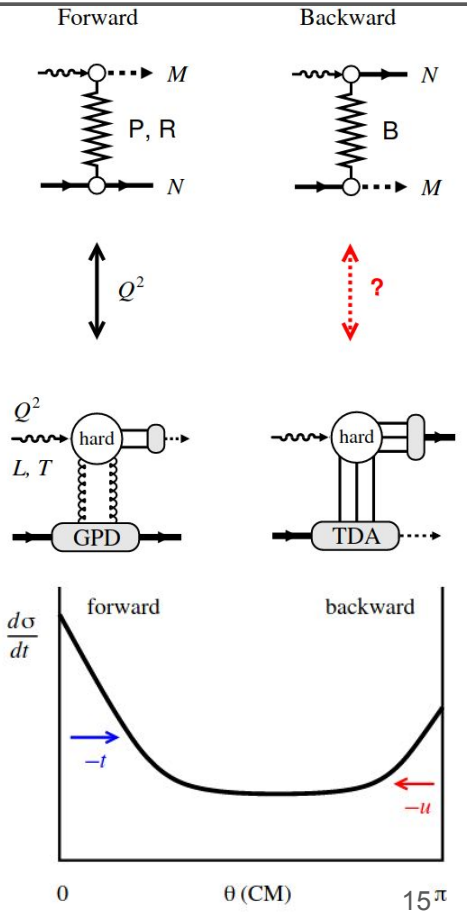
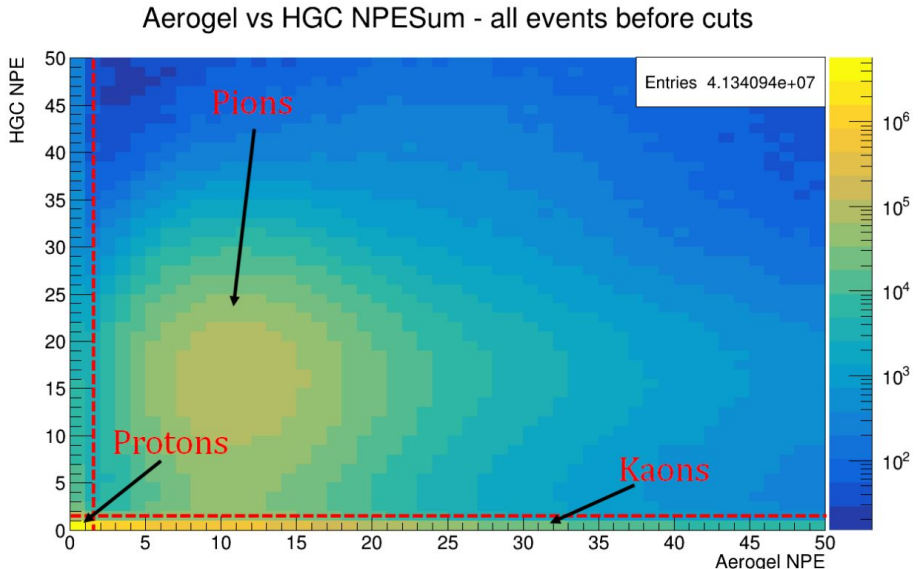
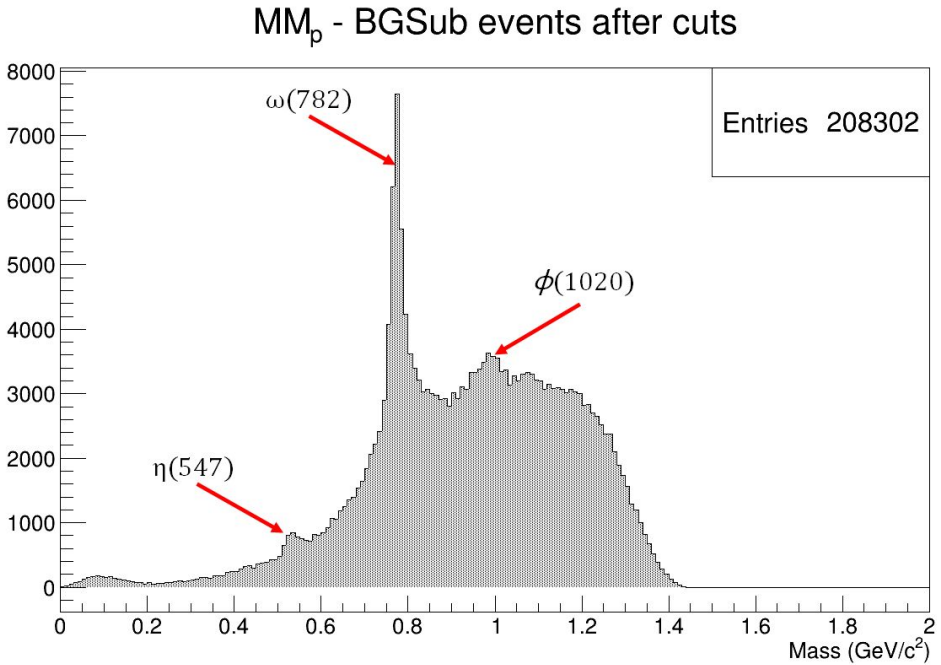


Image credit to Christian Weiss

More u-channel studies from other Hall C Experiments

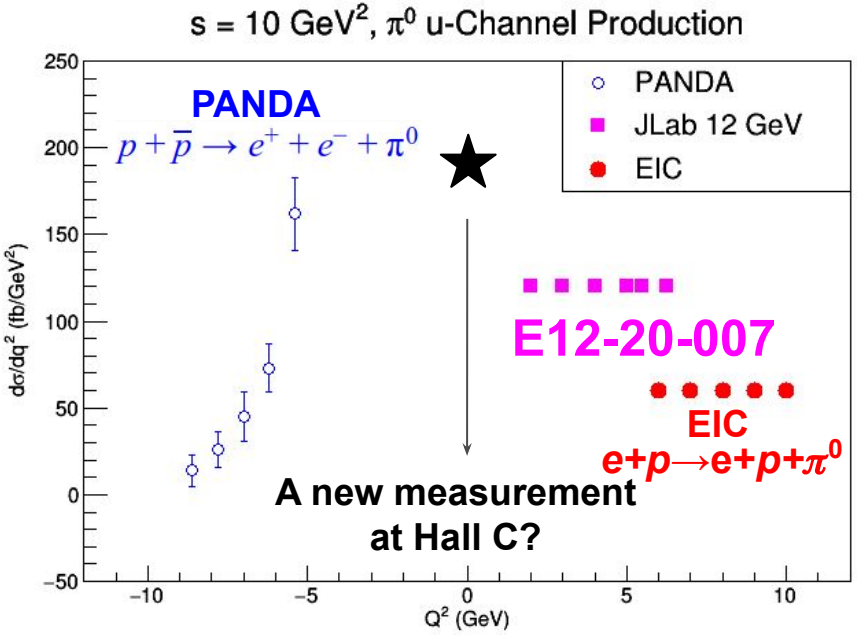
- **Missing mass reconstruction of ep events from Kaon LT experiment showing resonance peaks for multiple meson productions**





Plots provided by S. Kay

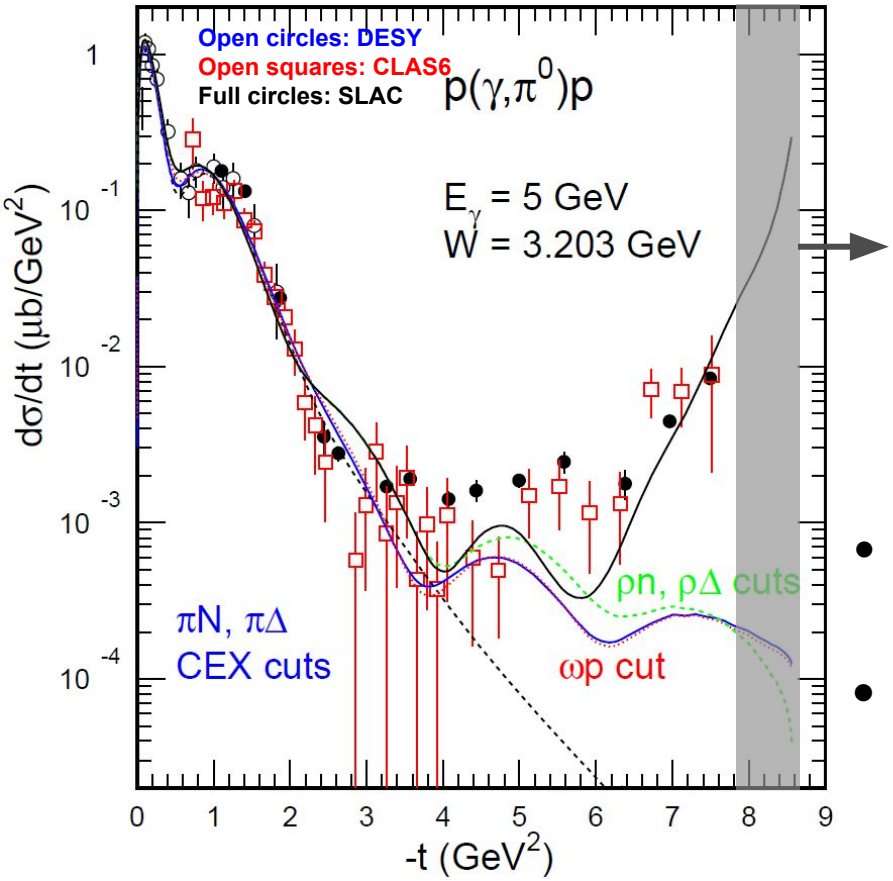
Prospect of *u*-channel π^0 at s=10 GeV^2

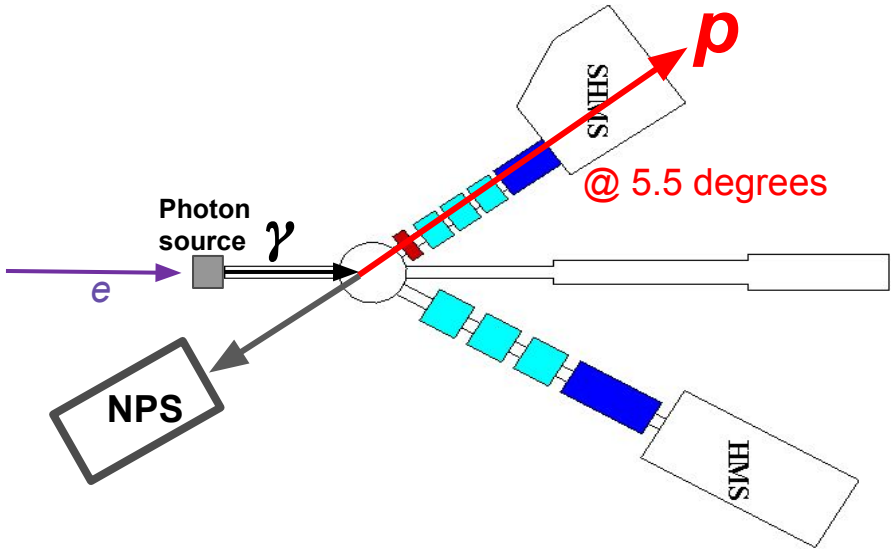


- **PANDA**
  - **proton anti-proton annihilation**
- **JLab 12 GeV: E12-20-007**
  - **^{1}H(e,e'p)π^0, a simple measurement**
- **Future Electron-ion Collider (EIC)**
  - e-p collision: **e+p→e+p+π^0**
  - L/T separation not required if **σ_T>>σ_L, is demonstrated by E12-20-007**
- **Real photon**
  - no *u*-channel data available
  - See next slide

π^0 Production Measurement via Real Photon

L.M. Laget, Progress in Particle and Nuclear Physics 111 (2020) 103737





- **p(γ, π^0)p study as function of -*t*, s~10 GeV**
  - Open question: would the γ* extrapolate to the real photon point?
- **a *u*-channel peak is anticipated real photon**
  - No measurement available yet, possible GlueX measurement
  - Precursor of u-channel DVCS

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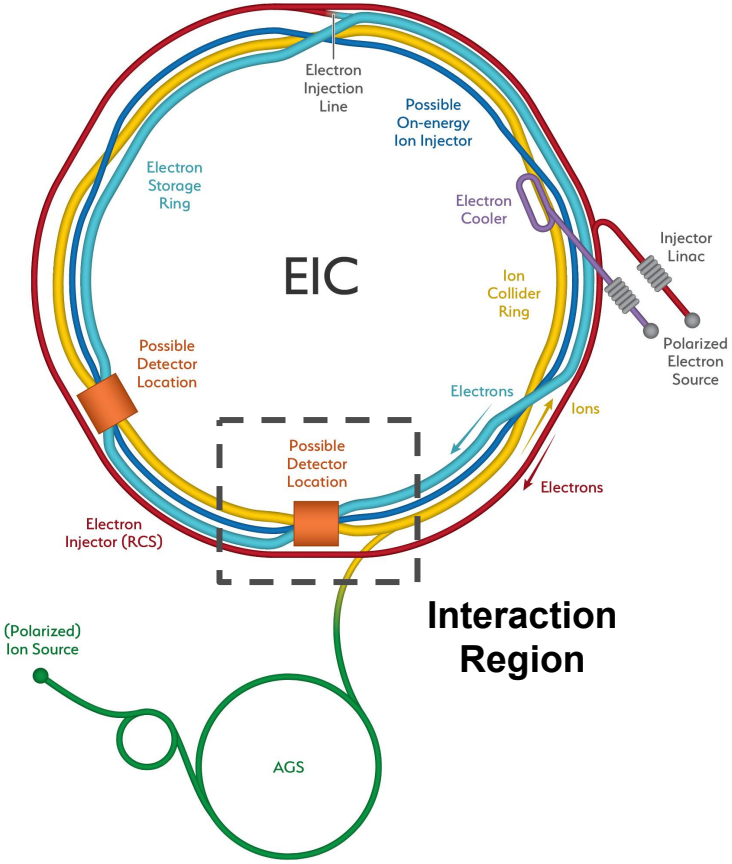
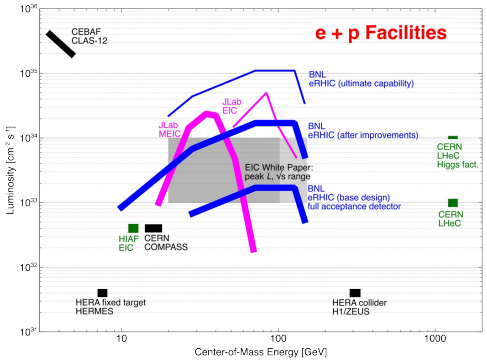
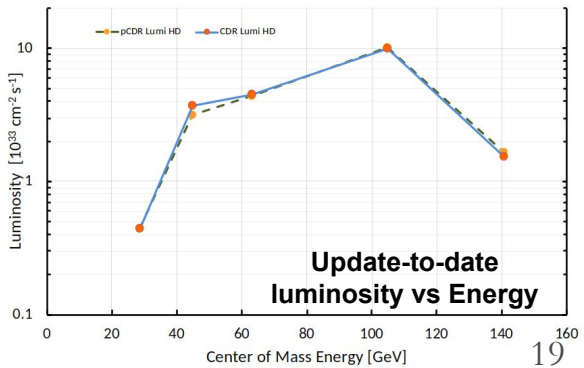
BNL-EIC Project

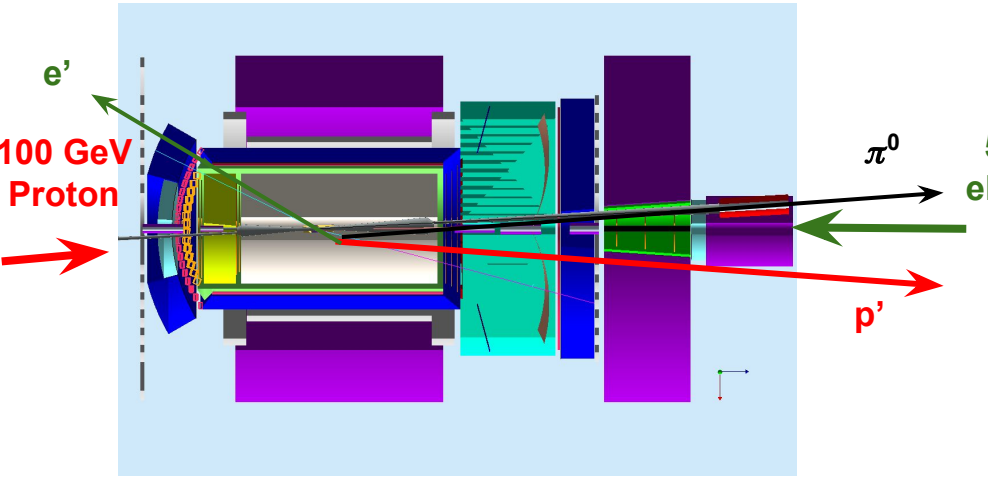


- **Next generation Electron-Ion Collider (EIC)**
  - Current consists of 1 interaction region (IR)
  - Luminosity with 100 GeV p on 5 GeV e: 10 x10^{33} $cm^{-2}s^{-1}$
- **Project location:**
  - Brookhaven National Lab (BNL), NY
- **Project information:**
  - CD-0 approved ~ $2 B
  - Completion in ~10-15 years

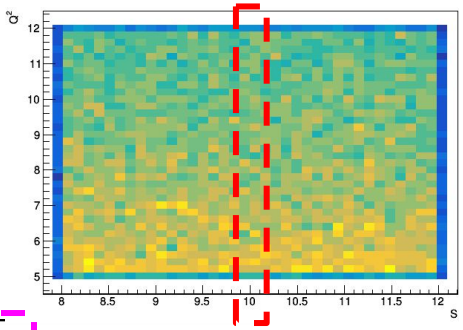


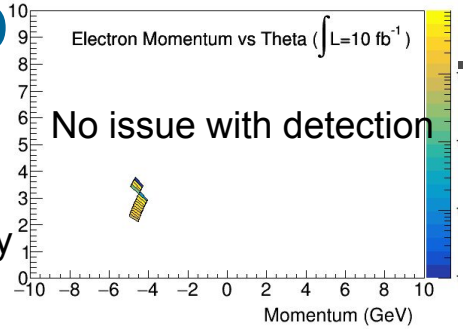


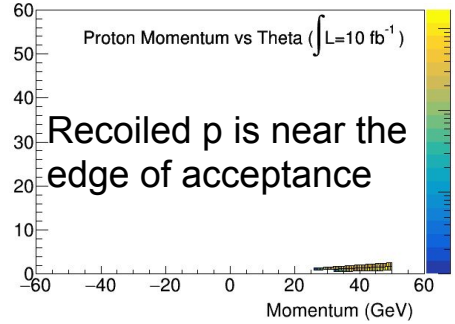
U-channel Meson Production Setup

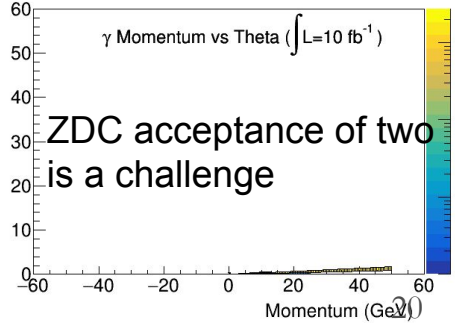


Q^2 vs S intentionally constrained









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

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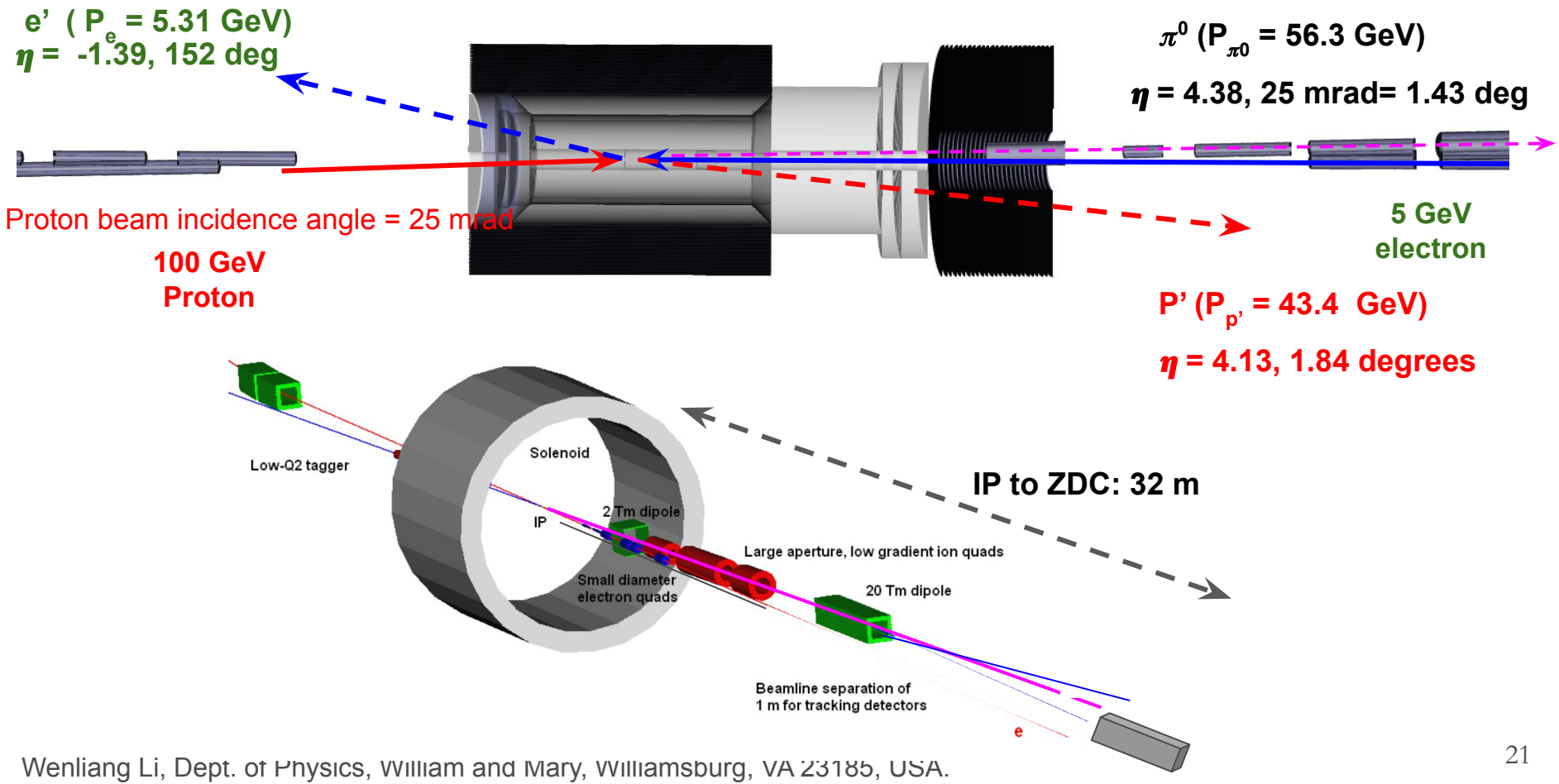
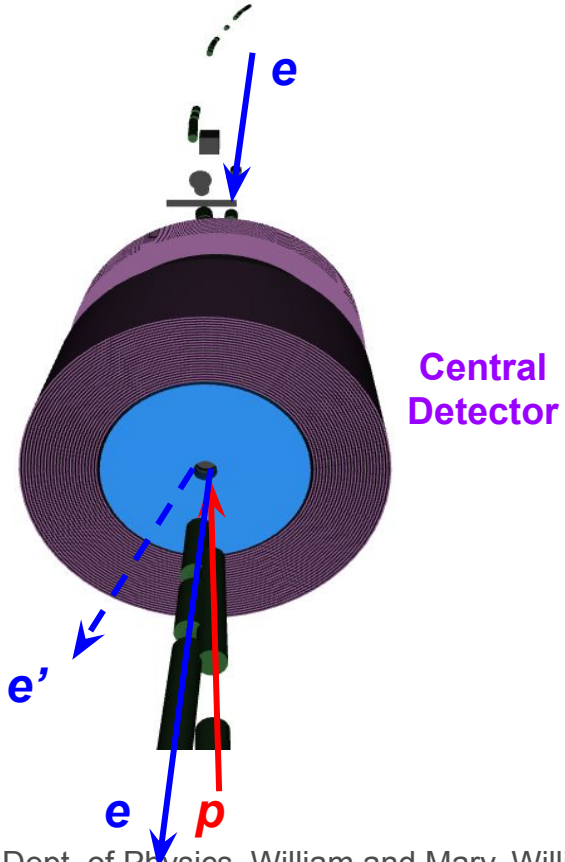
Interaction picture

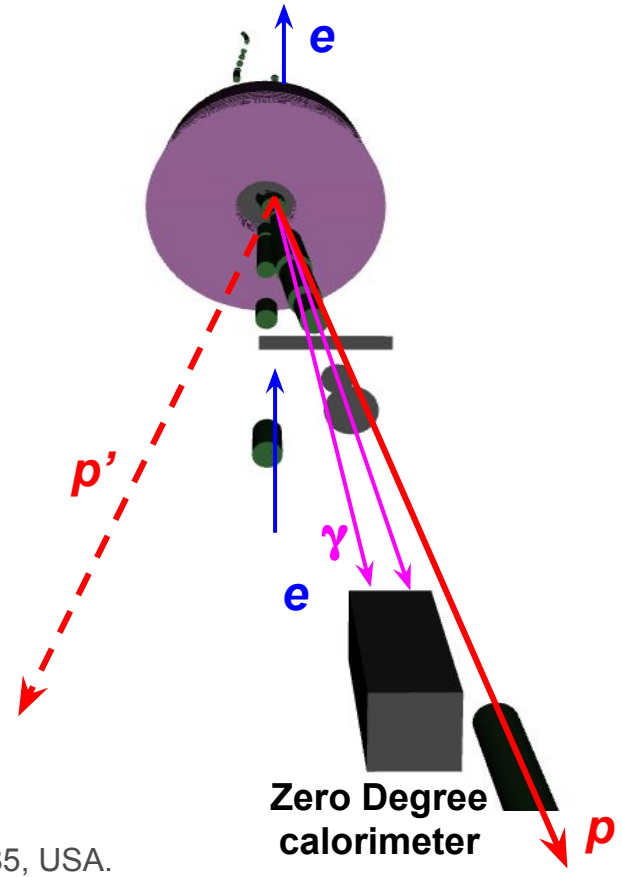


Visualizing u-channel π^0

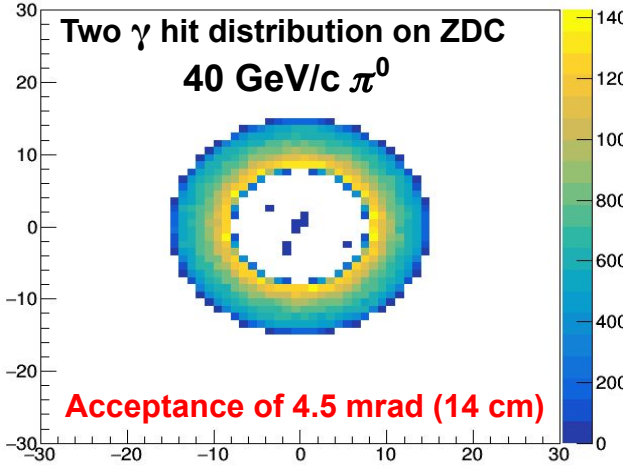
Incoming proton perspective

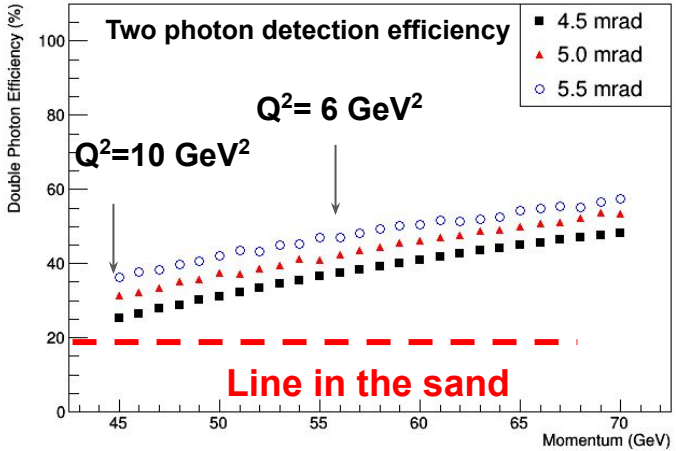


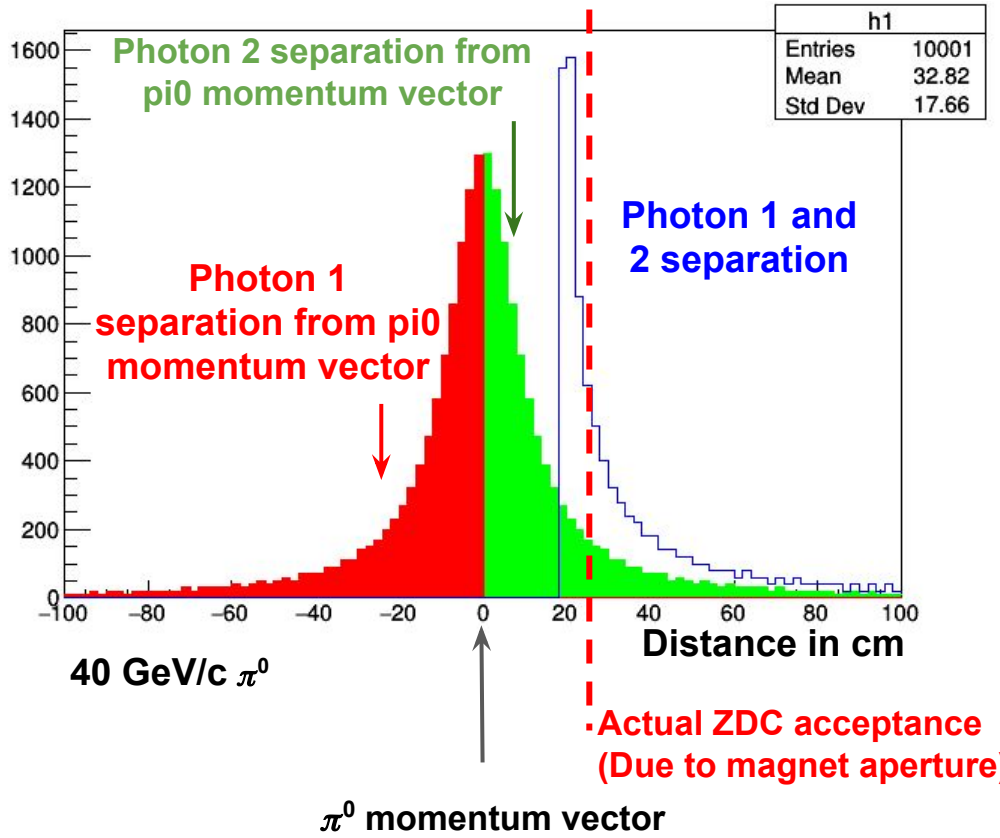
Incidence electron perspective



Realistic ZDC Acceptance (through magnets Aperture)







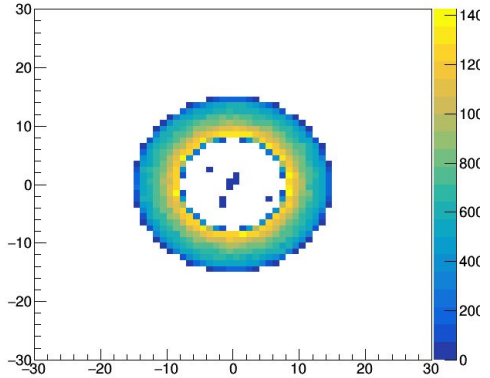
Physics background (to our current best knowledge)

- 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

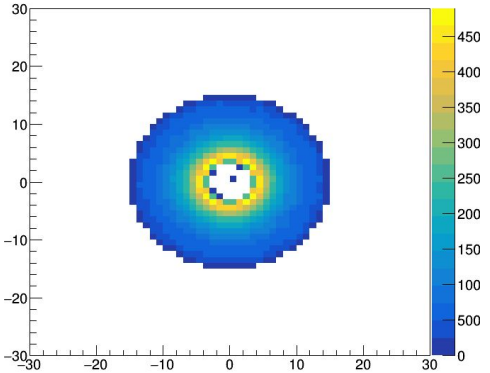


- Single photon case:
  - Primary reaction: e+p-> e'+p' + π^0
  - Ideal expected trigger: e'+p'+ γ
  - Physics background: DVCS, eta, Λ->n+π^0
  - Less than ideal trigger: e'+γ
  - Background: many many possibility

2 γ hit pattern

60 GeV/c π^0

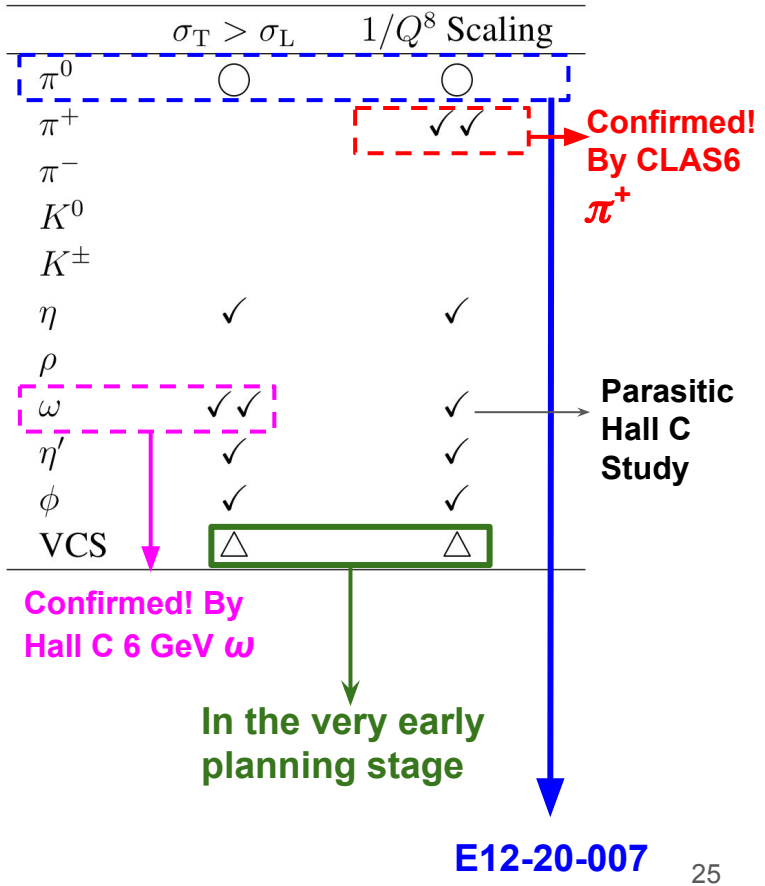
4.5 mrad acceptance



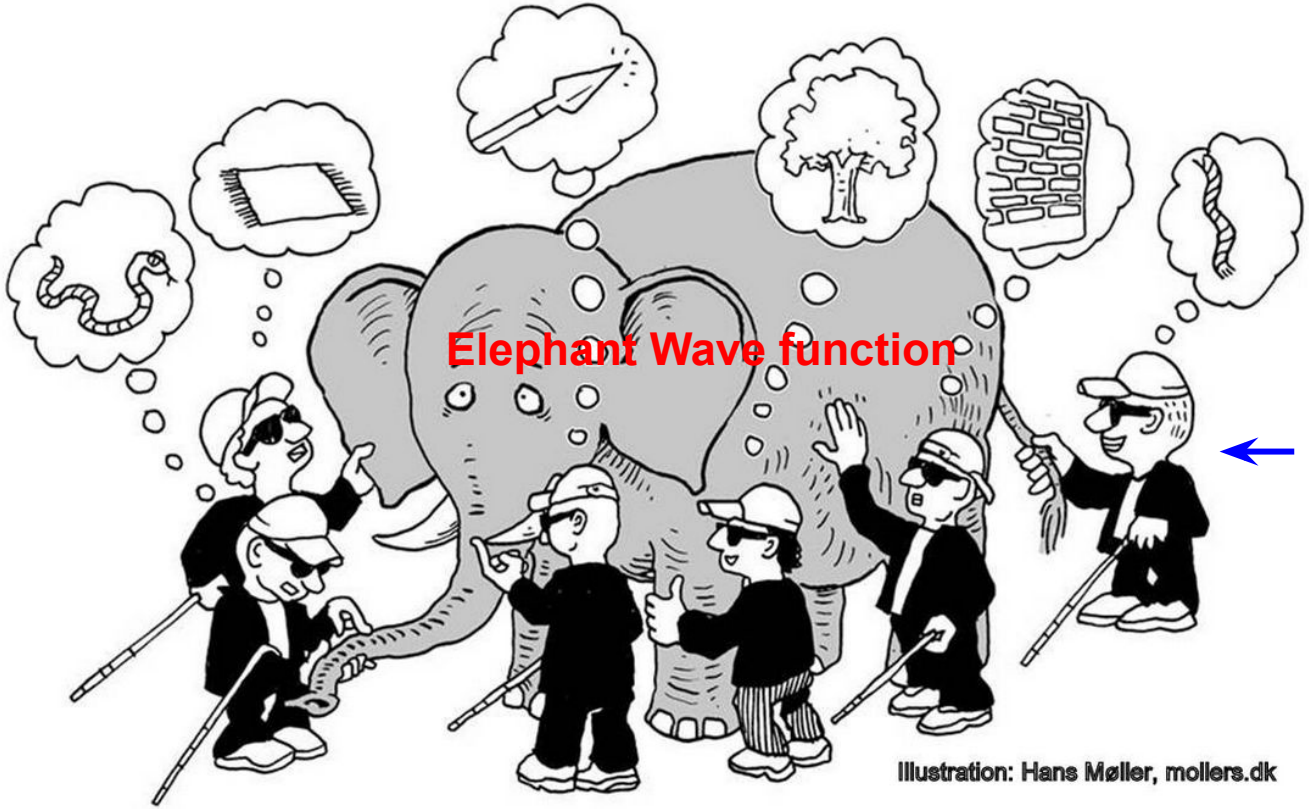
- We can use the double photon event to normalize the single photon events

Summary

- PR12-20-007 is the first dedicated u-channel study (symbolic meaning)
- There is a possibility of systematic u-channel studies in Hall C
- Preliminary study shown u-channel π^0 exclusive production progress naturally into the EIC era.

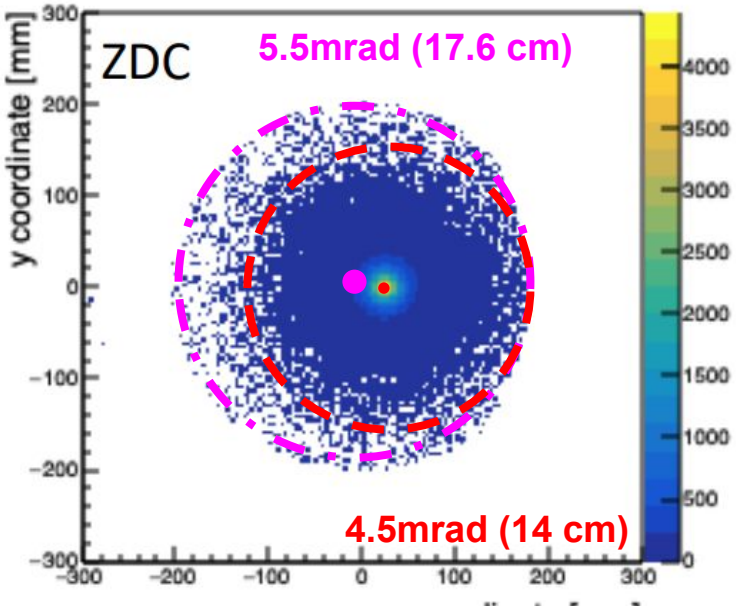


Thank you for your attention!



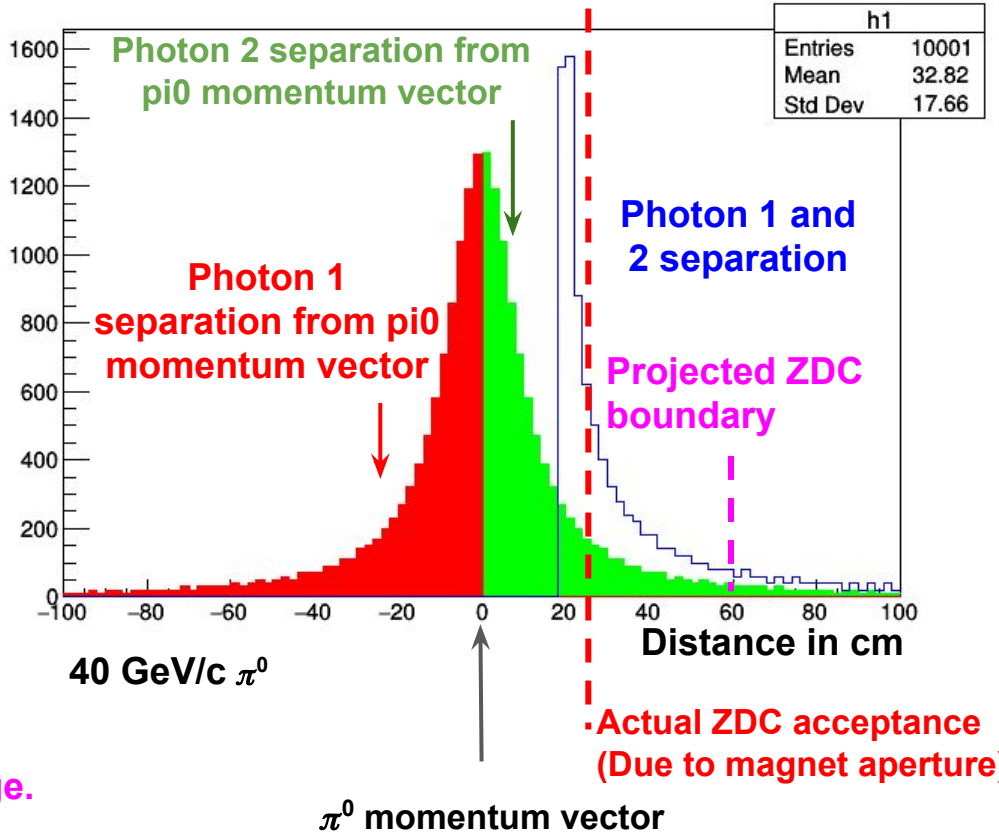
Backups

Realistic ZDC Acceptance (through magnets Aperture)

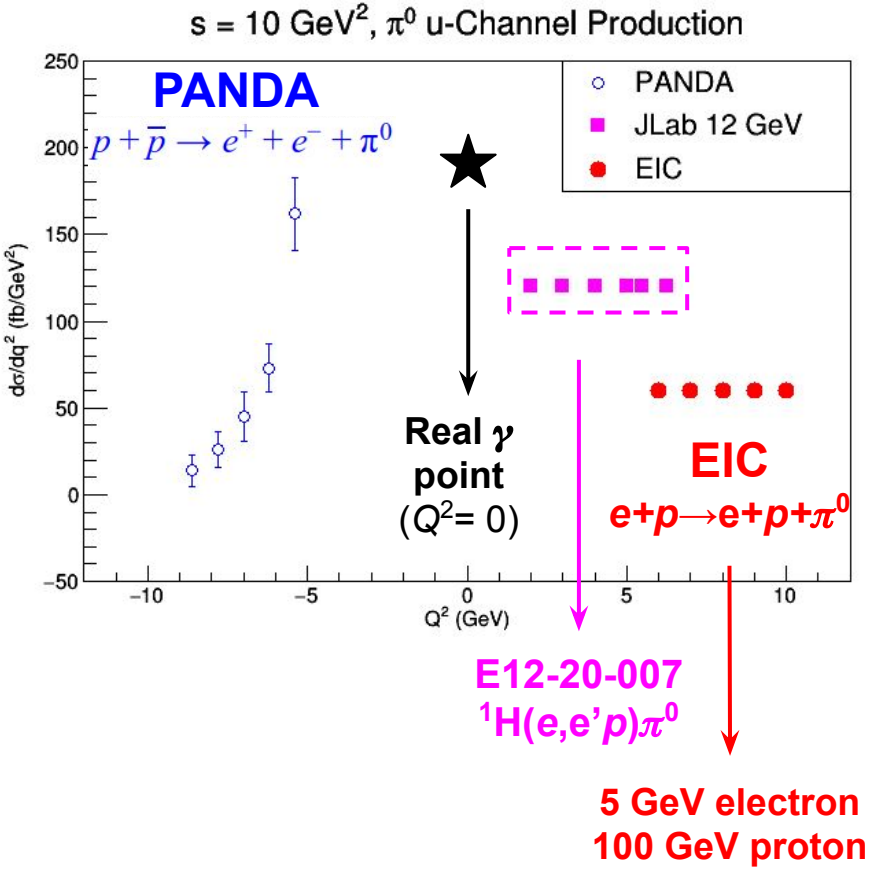


DVCS simulation with deuterium, spectating neutron distribution on ZDC, from Alex

A slight shift in -u' will give us larger coverage.



Prospect of *u*-channel π^0 Study at s=10 GeV^2



- **PANDA**
  - **proton anti-proton annihilation**
  - **S. Diehl's talk**
- **JLab 12 GeV: E12-20-007**
  - **^{1}H(e,e'p)π^0, a simple measurement**
- **Future Electron-ion Collider (EIC)**
  - e-p collision: **e+p→e+p+π^0**
  - L/T separation not required if **$\sigma_T >> \sigma_L$, is demonstrated by E12-20-007**
- **Real photon**
  - no *u*-channel data available
  - See next slide

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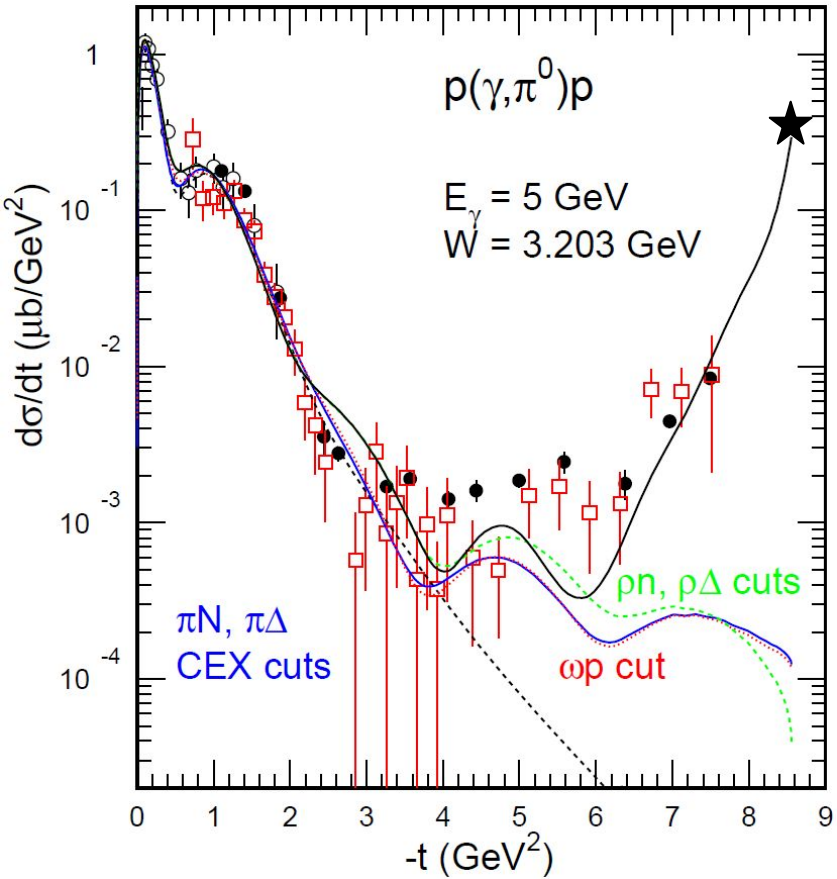
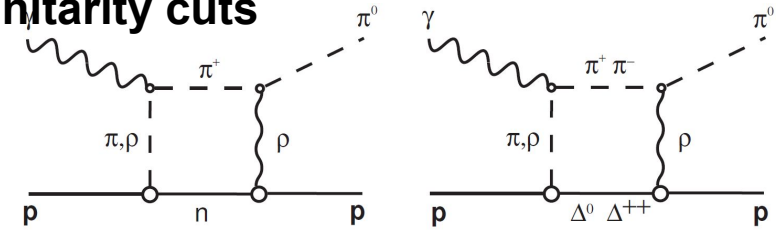
π^0 Production Measurement via Real Photon

L.M. Laget, Progress in Particle and Nuclear Physics 111 (2020) 103737



- **$p(\gamma, \pi^0)p$ study as function of $-t$, s~10 GeV^2**
  - Open circles: DESY data
  - Open squares: 6 GeV CLAS data
  - Full circles: SLAC data
- **Slide line = baryon pole + rescattering unitarity cuts**



- **a *u*-channel peak is anticipated real photon**
  - No measurement available yet
  - Open question: would the γ^* extrapolate to the real photon point?

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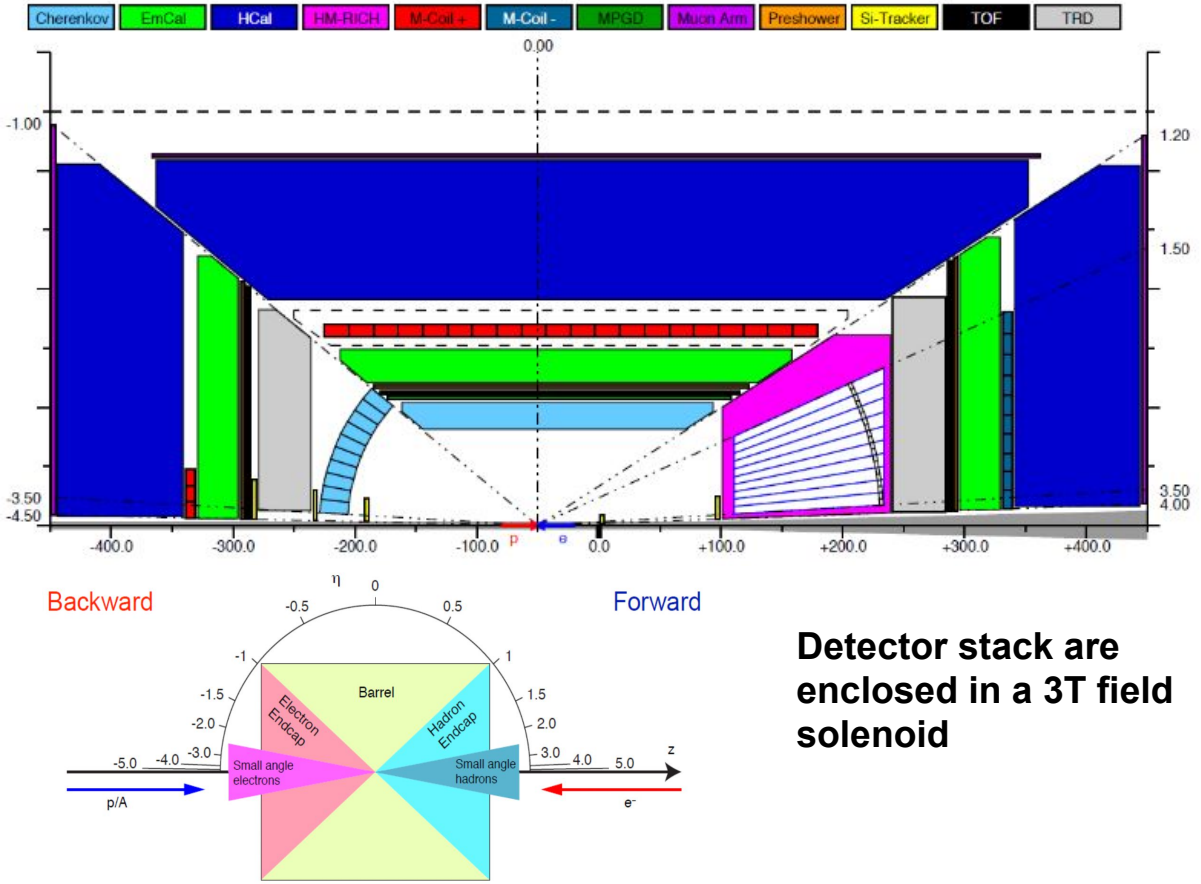
EIC Central Detector Update-to-date Concept



Detector stack are enclosed in a 3T field solenoid

Hadron End Cap

- $\eta > 1$ (~45 Degrees)
- HCal + EmCal
- RICH
- Tracking

Electron End Cap

- $\eta < -1$
- HCal+EmCal
- Tracking
- Cherenkov PID

Barrel Calorimeter

- $-1 < \eta < 1$
- Not needed for the *u*-channel
- Used as veto

Zero-degree Calorimeter (not shown)

- Expecting neutral particles

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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)

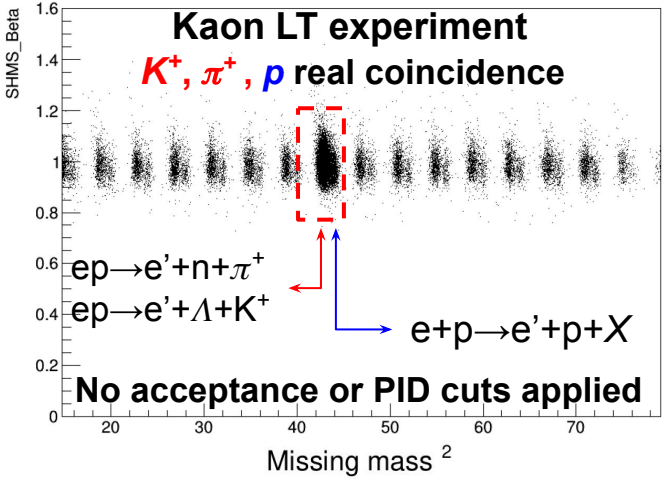
- **NGC installation (for electron detection setting)**
- HGC: 1 atm vetoing π and *K*
- Aerogel: n=1.0003 tray for proton ID (threshold cut at 3 p.e.)

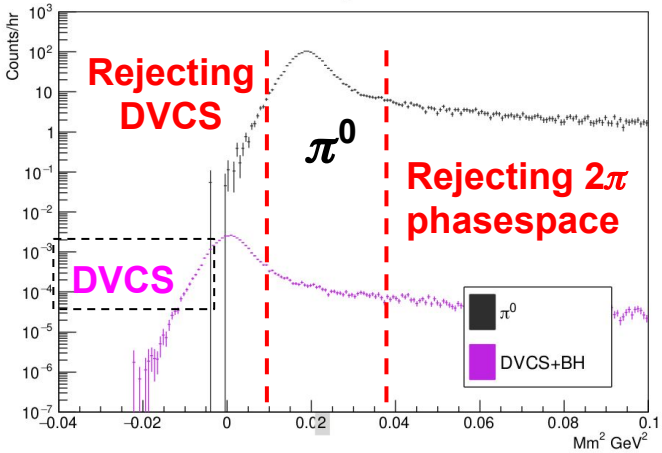
SHMS β vs Coincidence timing structure:

- 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

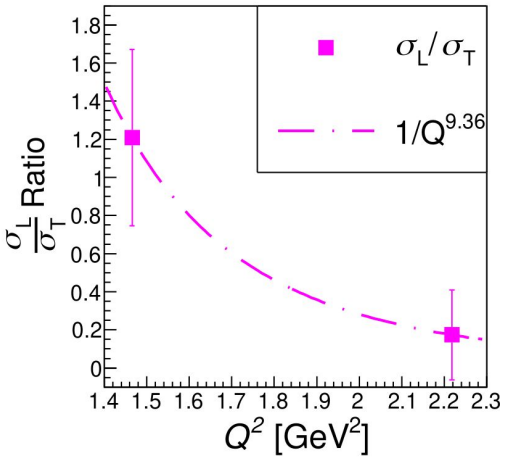
- **Correlated (scale) cross section is comparable to the F-π-2-ω analysis**
- **Uncorrelated (pt-to-pt) is much smaller since ^{1}H(e,e'p)π^0 is a 'clean' channel**

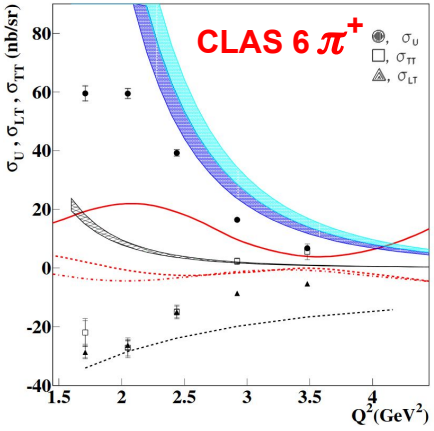
Beam Time Estimation

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
$^1\text{H}(e, e'p)$						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



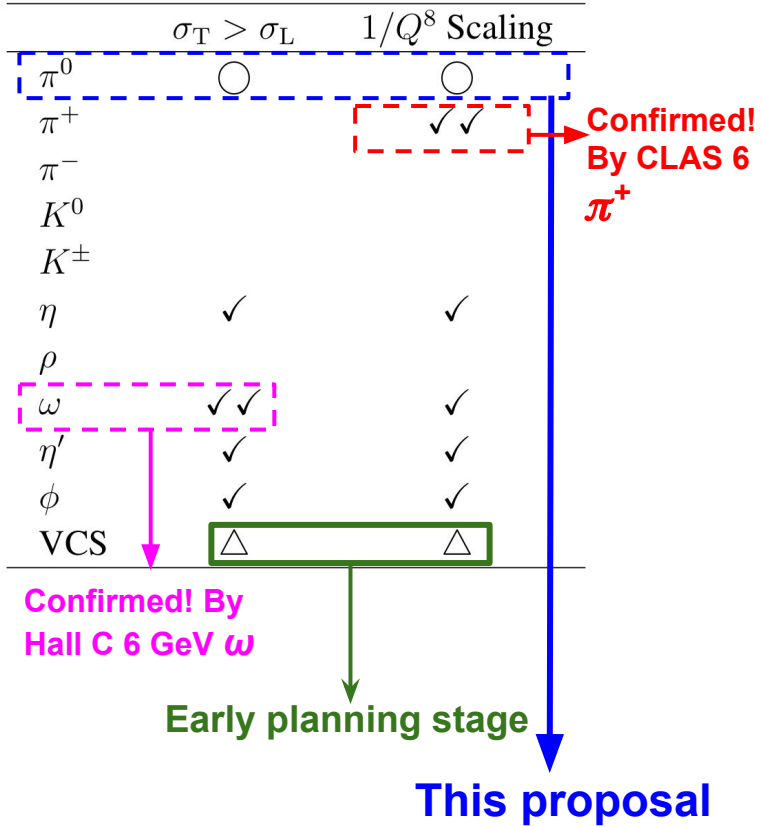


Two qualitative predictions from TDA:

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

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

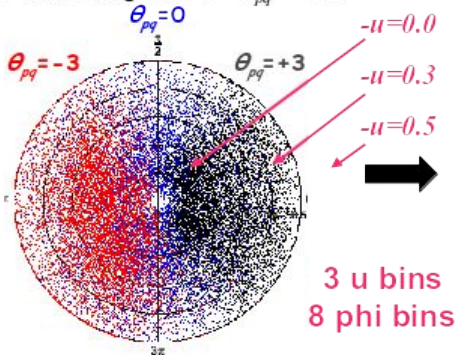
- Stage 0: find *u*-channel peaks for all mesons (12 GeV)
- Stage 1: test TDA predictions (12 GeV)
- Stage 2: extractions of TDAs

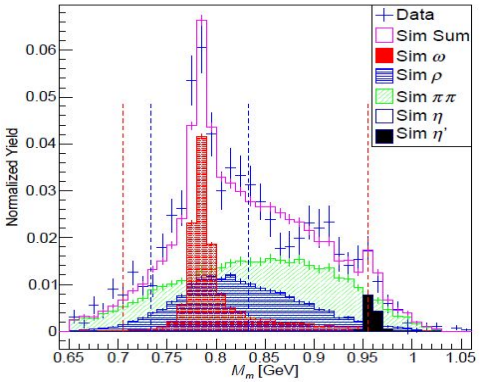


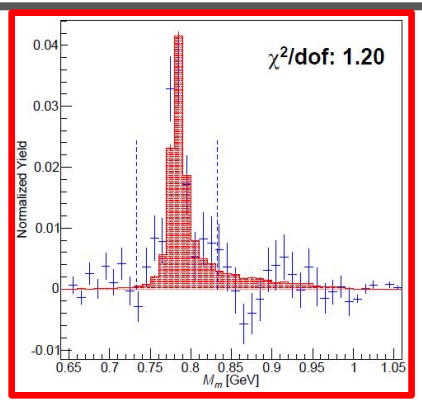
□: parasitic data may be available

Iterative Procedure for L/T Separation

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





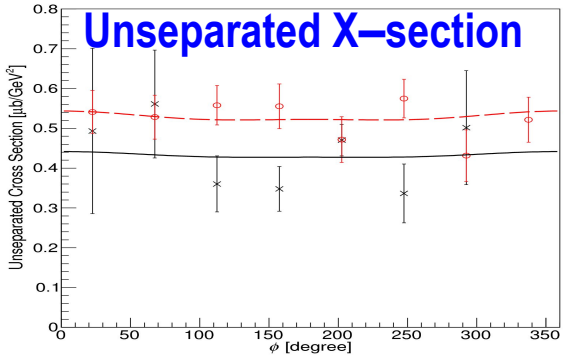


$$R = \frac{Y_{Exp} - Y_{\rho\ sim} - Y_{Xspace\ sim}}{Y_{\omega\ sim}}$$

Combine ratios for settings together, propagating errors accordingly.

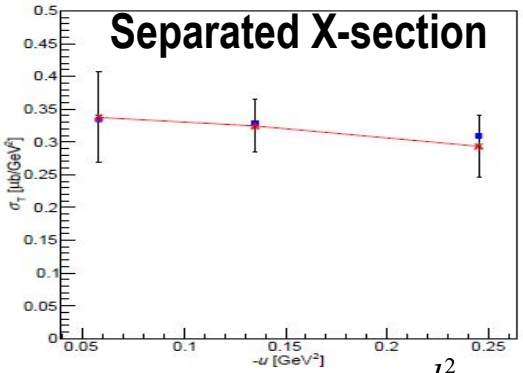
$$\frac{d^2\sigma}{dtd\varphi}_{EXP} = R\frac{d^2\sigma}{dtd\varphi}_{SIMC}$$

Empirical Model



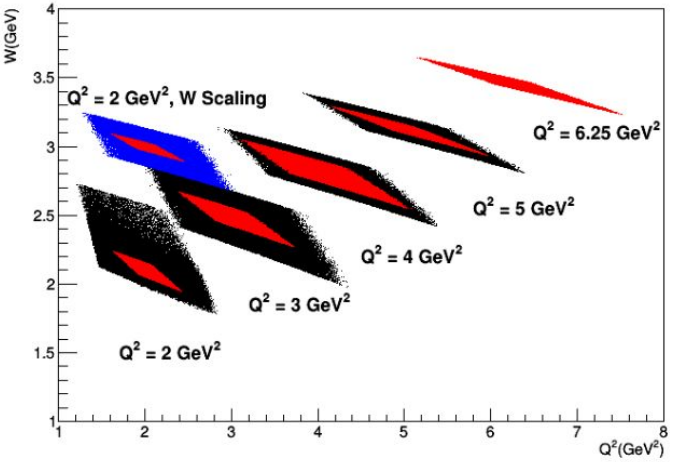
Extract L,T,LT,TT via simultaneous fit

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



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

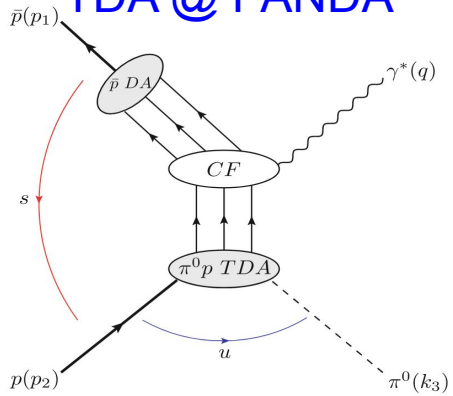


^{1}H(*e, e'p*) Elastic Kinematics

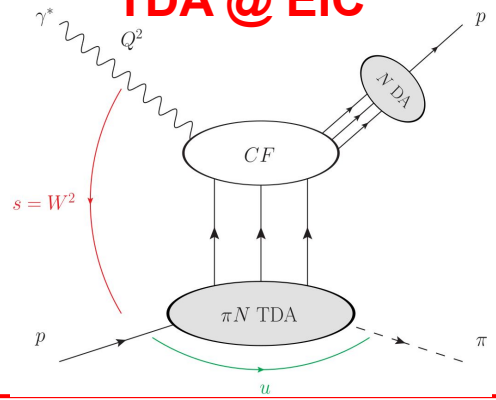
E_{beam} (GeV)	Q^2 (GeV^2)	θ'_e (deg)	p'_e (GeV)	θ_p (deg)	p_p (GeV)	Coincidence Rate (Hz)	Time (Hours)
4.4^+	2.34^+	23.70^+	3.15^+	39.95^+	1.97^+	371	1
4.4^*	2.68^*	25.15^*	2.97^*	37.12^*	2.17^*	251	1
6.6^+	4.18^+	21.95^+	4.37^+	32.69^+	3.03^+	30	1
6.6^+	3.00^+	17.35^+	5.00^+	39.21^+	2.36^+	170	1
6.6^*	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

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

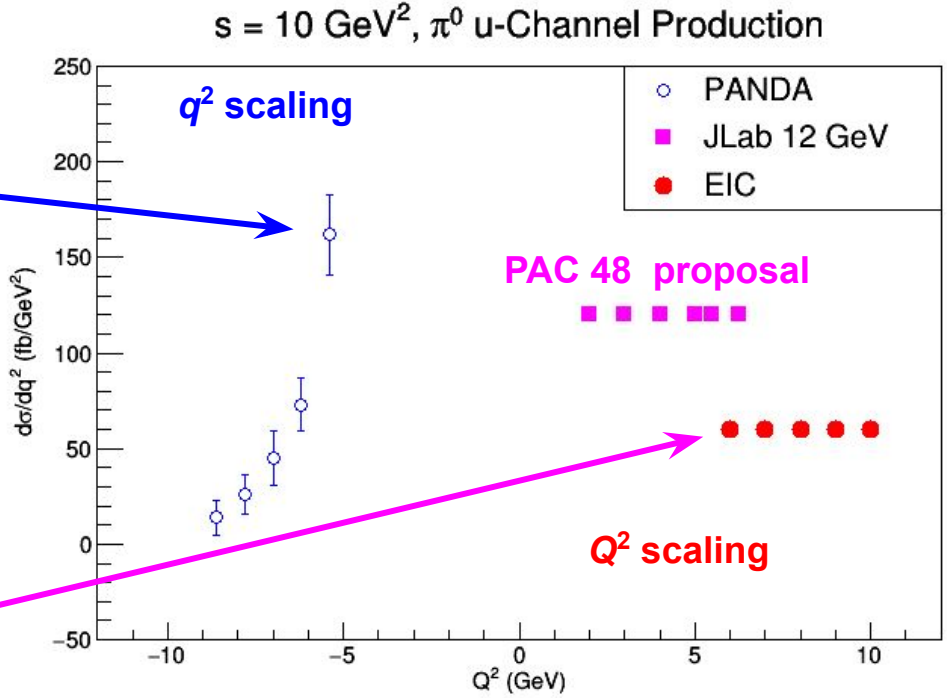
TDA @ PANDA



TDA @ EIC

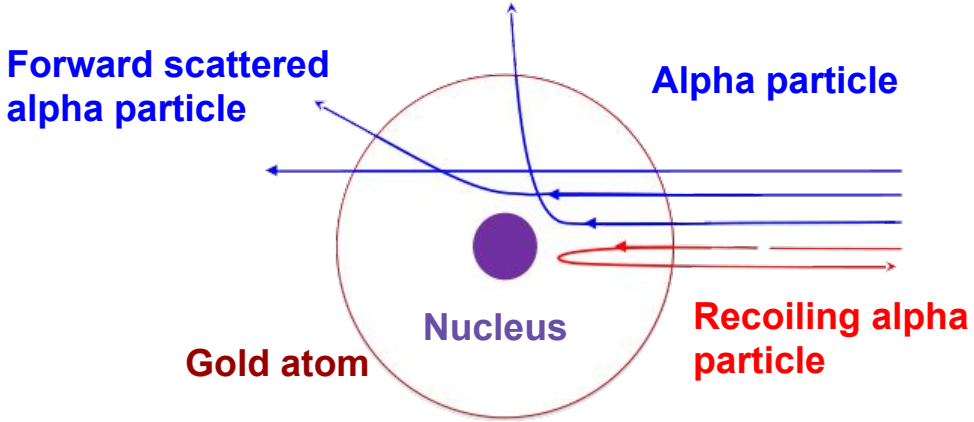


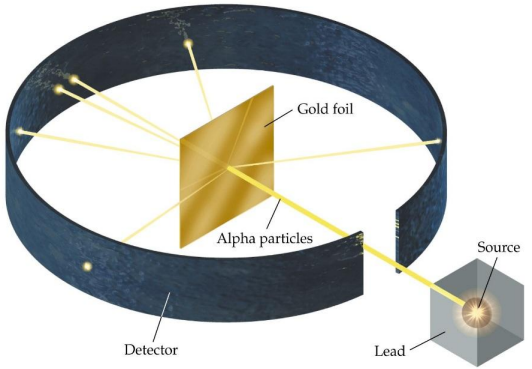
The PANDA Collaboration, Eur. Phys. J. A (2015) 51: 107



Same TDAs for PANDA and EIC, the ultimate universality check

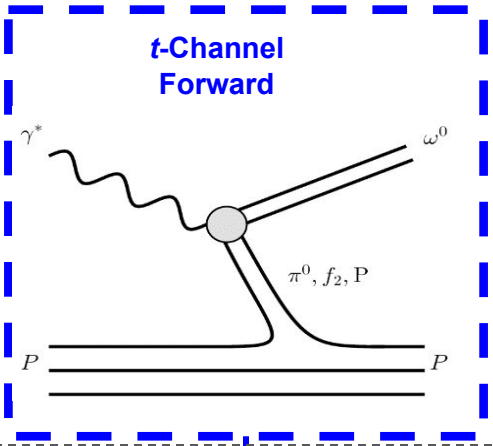
Backward-angle structure of Atom

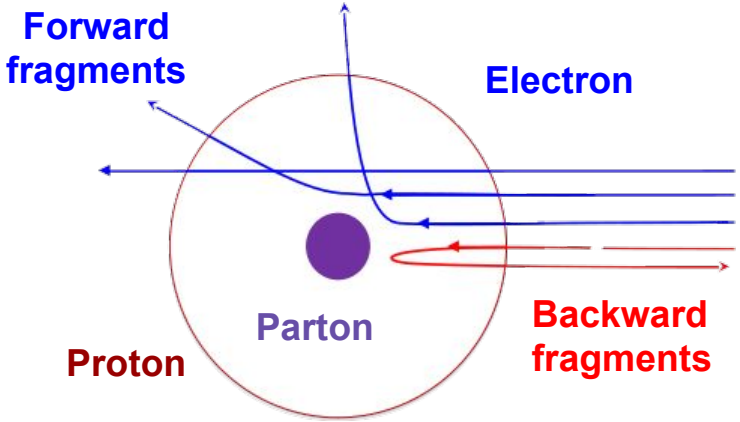


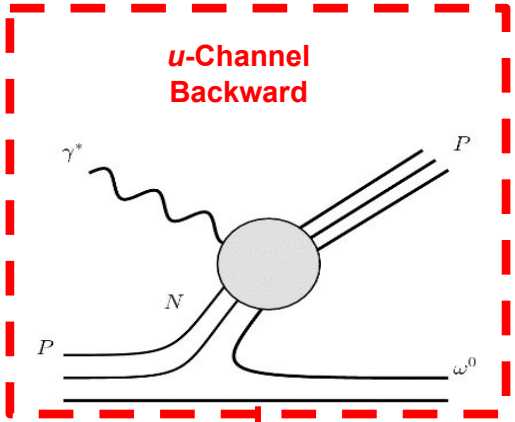


- **Forward scattered alpha particle: extracting the interaction radius of the nucleus and mapping out the transverse structure of the atom (mostly empty)**
- **Recoiling alpha particle: stiffness of the "point-like" structure.**
- Full structure must incorporate both forward angle and backward angle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

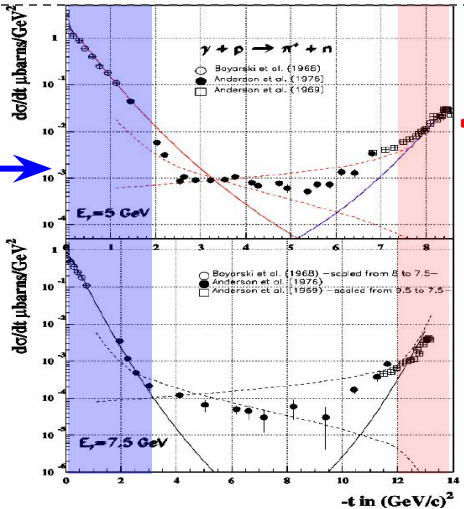
Structure of Proton







Meson pole contribution

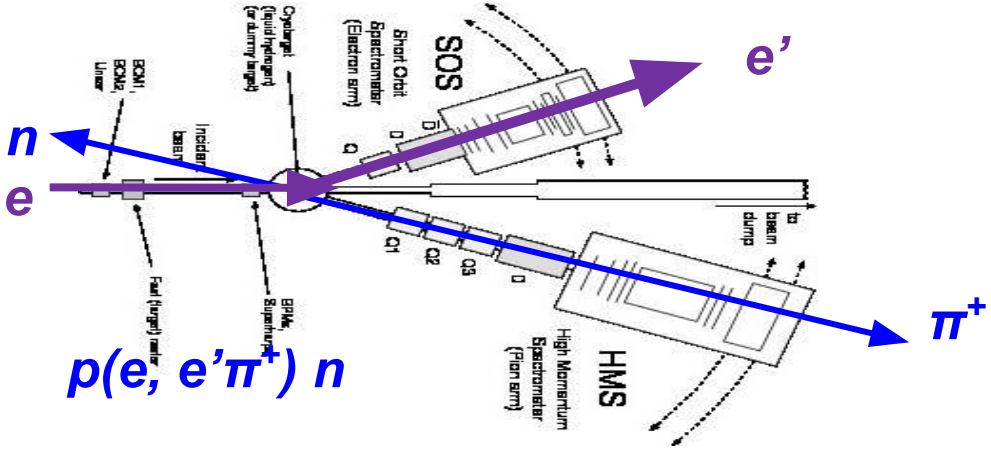


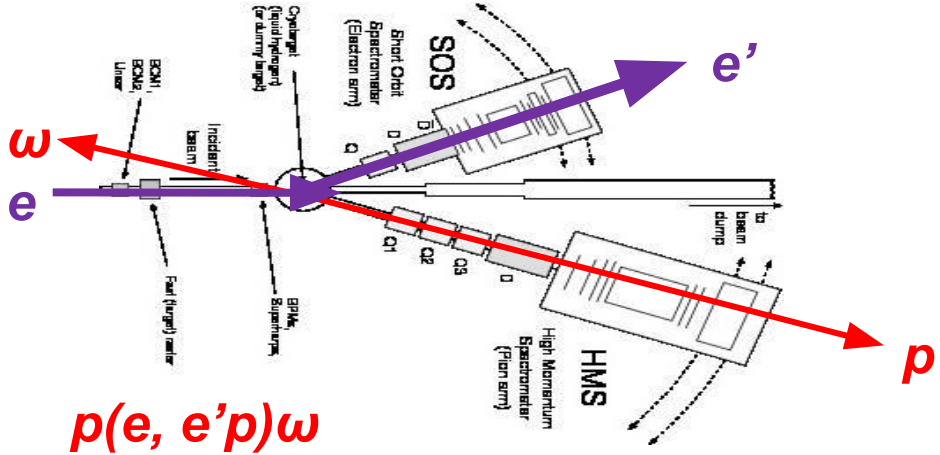
Baryon pole contribution

Transition:
Soft structure→Hard structure→Soft structure

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

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



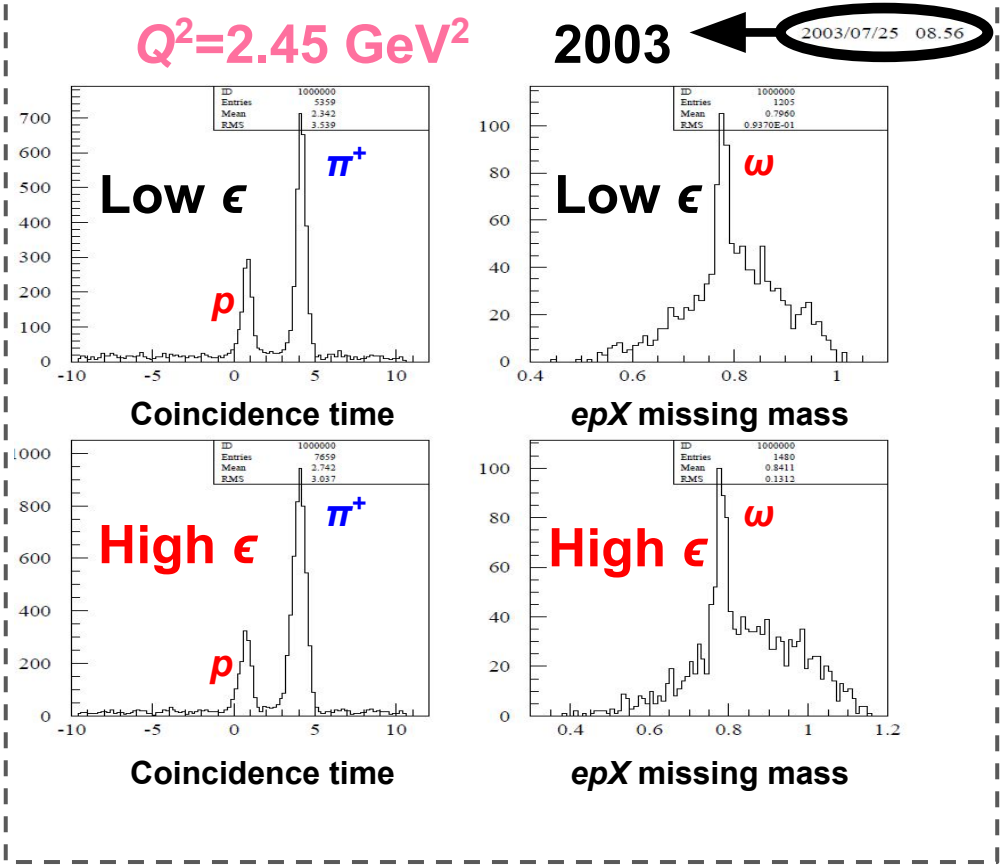


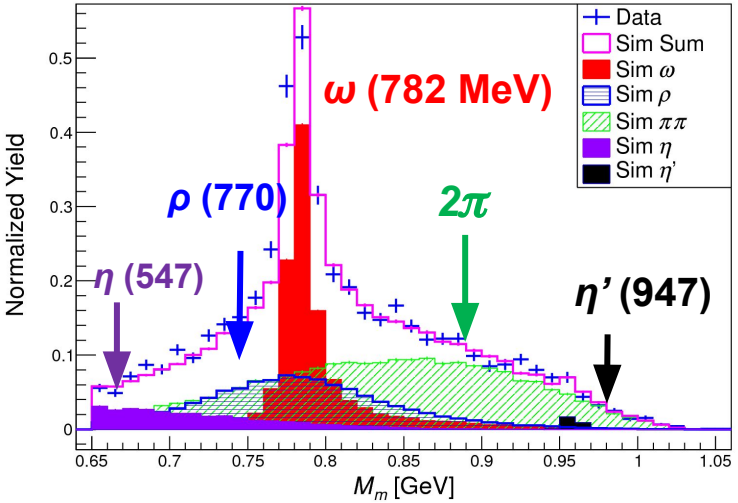
- **Fpi-2 (E01-004) 2003**
  - Spokesperson: **Garth Huber, Henk Blok**
  - Standard HMS and SOS (e) configuration
  - **Electric form factor of charged π** through exclusive π production
- **Primary reaction for Fpi-2**
  - $p(e, e' \pi^+)n$
- **In addition, we have for free**
  - $p(e,e' p)\omega$
- **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

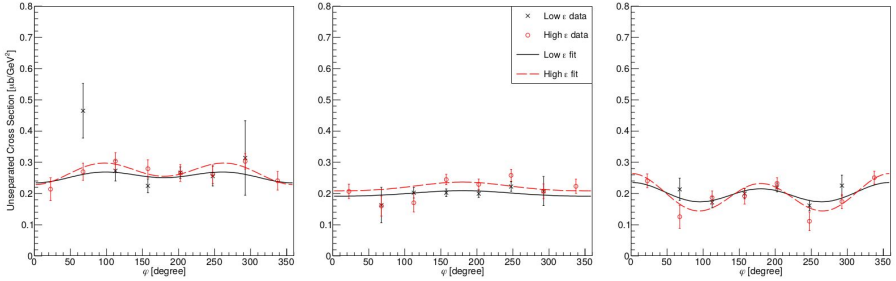
Q^2=2.45 GeV^2

2003



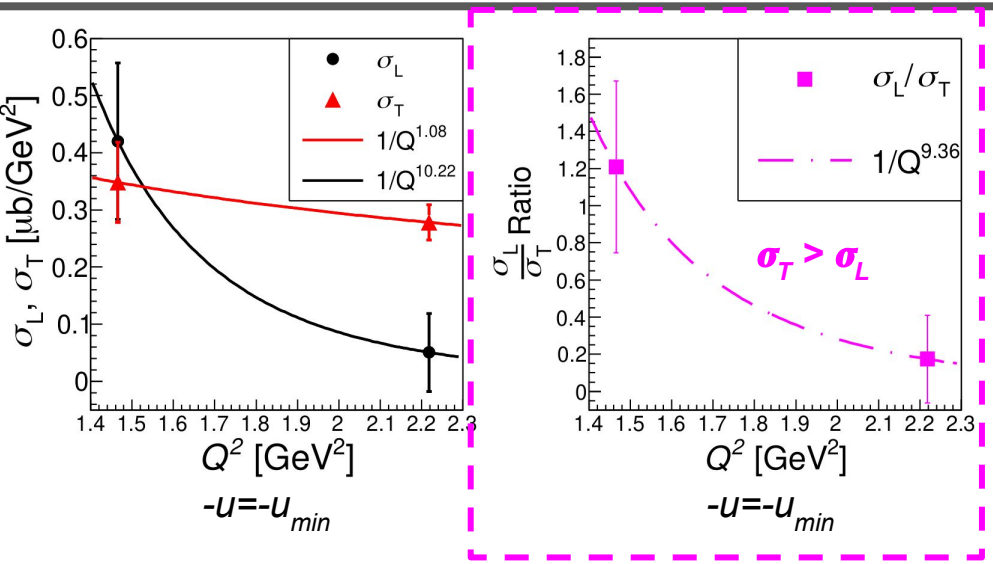


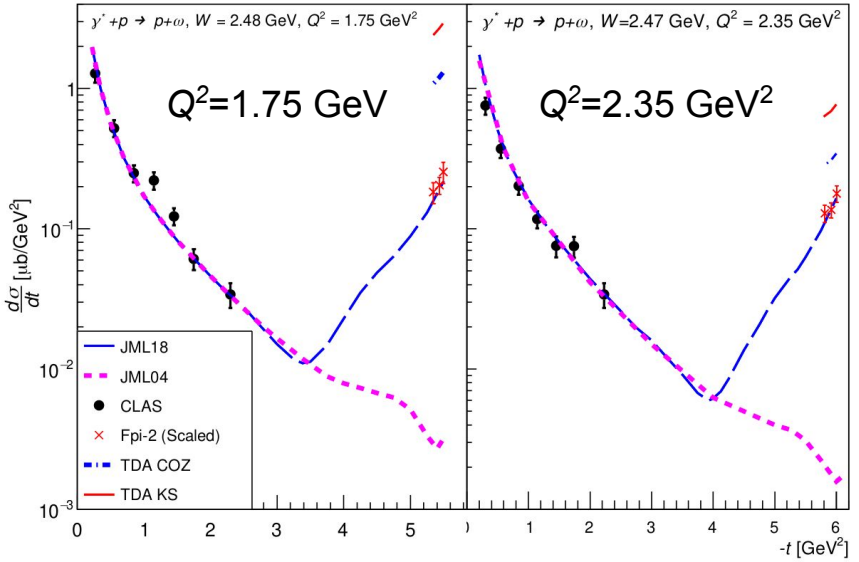
Q^2=2.45 GeV^2



(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

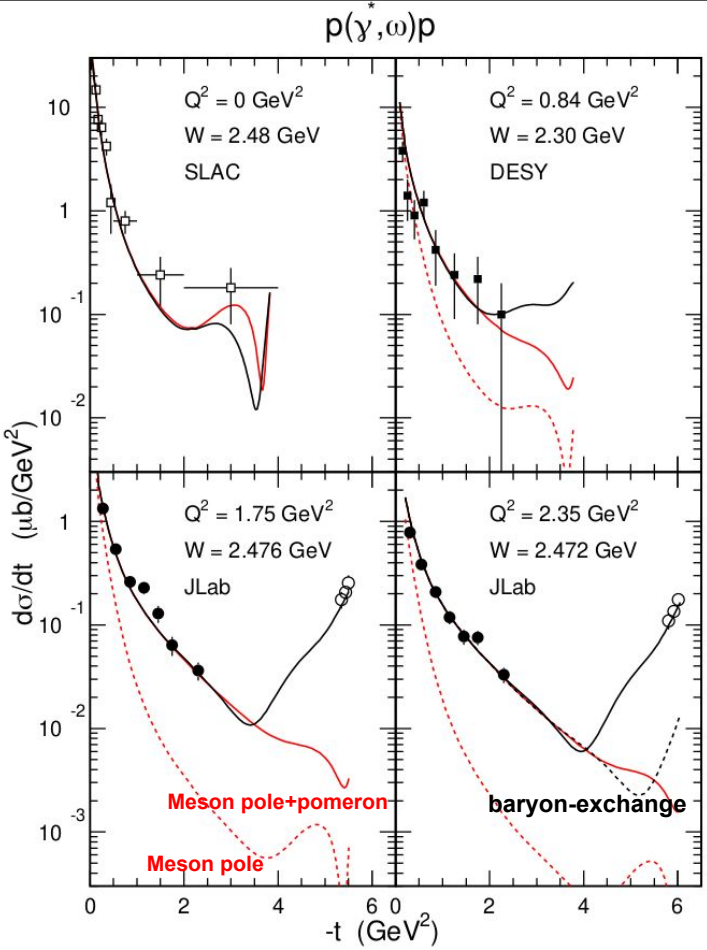




Phys. Rev. Lett. 123 (2019) 182501

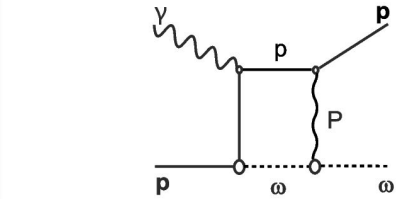
- Key observation:
  - σ_L dropped significantly as question of Q^2, as a result: $\sigma_T > \sigma_L$ observed at Q^2 ~2.35 GeV^2
  - Sharp u-channel ω Electroproduction peaks are observed at both 1.75 and 2.35 GeV^2
  - Forward-backward ratio is 10:1!

The Regge Approach (Soft structure)

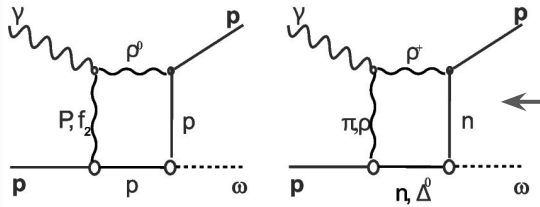


Unitarity cut in *u*-channel

Images credit to J-M. Laget



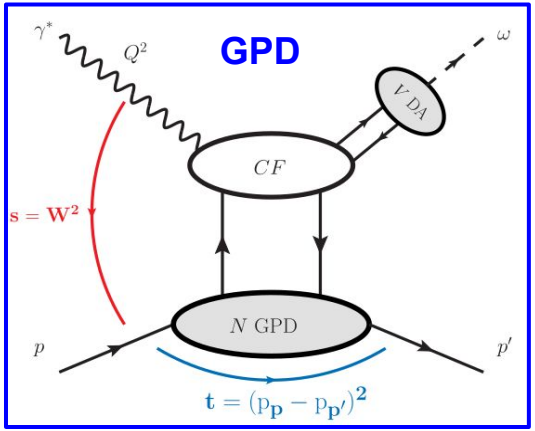
Nucleon pole Exchange diagram

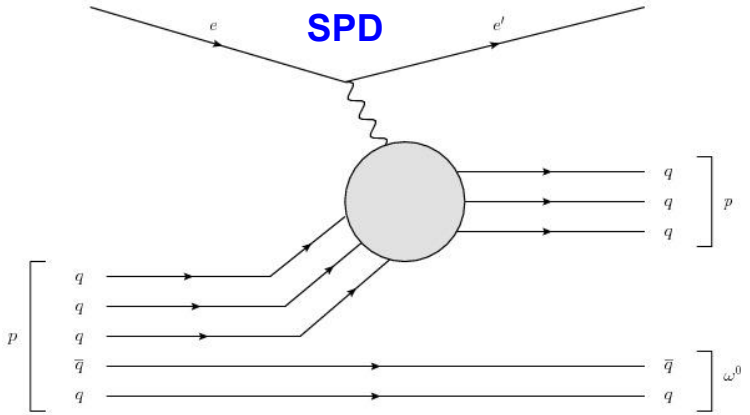


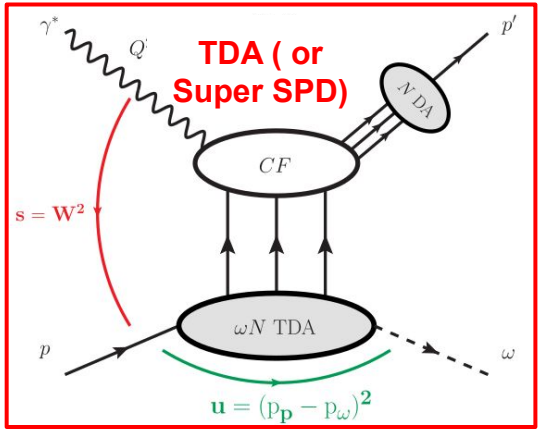
Additional ρ re-scattering within nucleon diagrams

- **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)





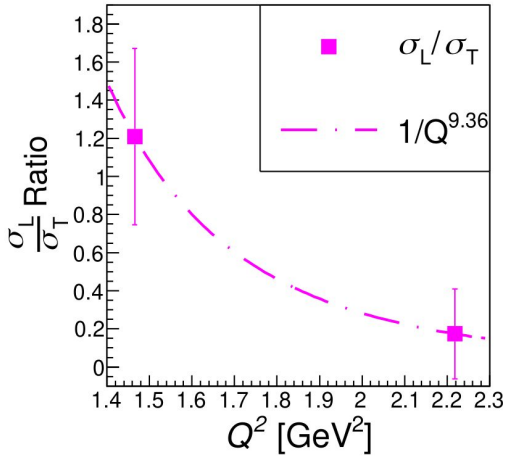


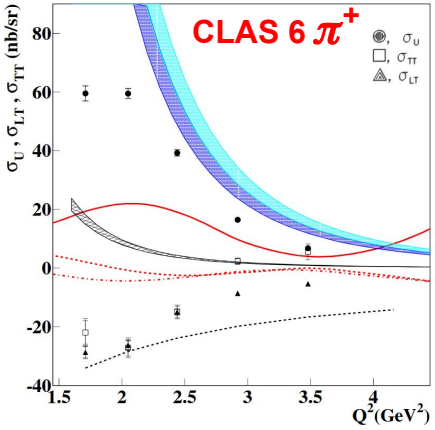
$-t_{min}$ $-t \approx -u$ $-t_{max}$

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



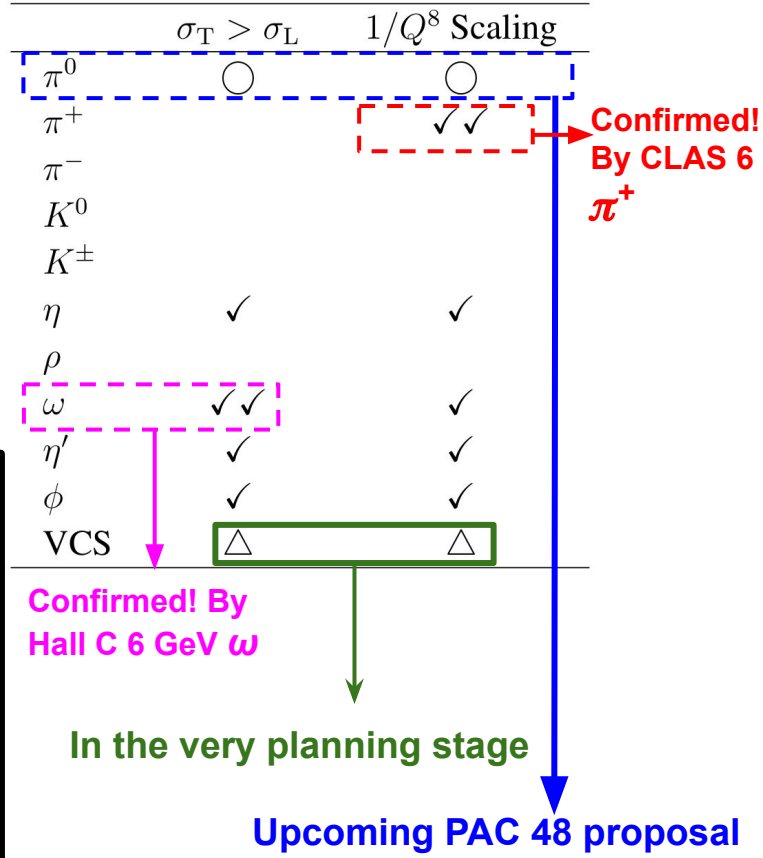


Two qualitative predictions from TDA:

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

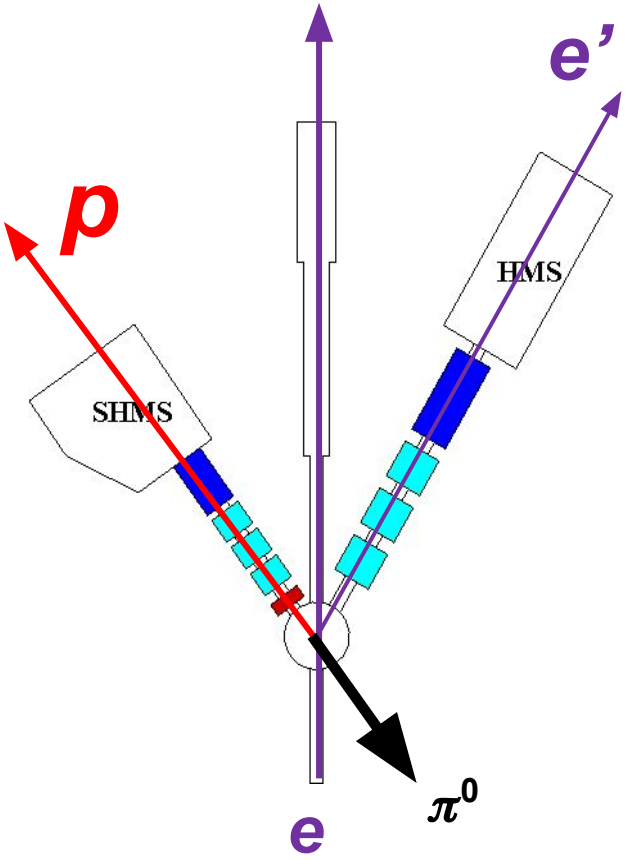
Three phases of validating TDA with JLab 12 GeV meson electroproduction :

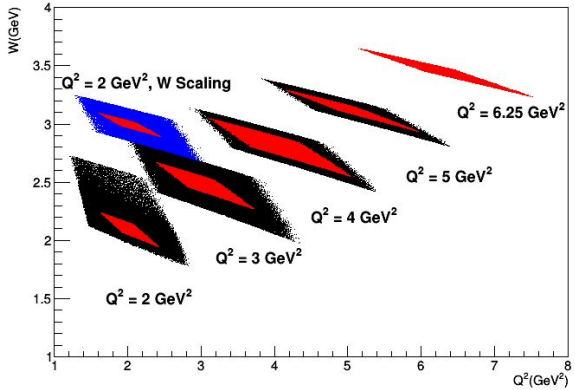
- **Stage 0: find *u*-channel peaks for all mesons (12 GeV)**
- **Stage 1: test TDA predictions (12 GeV)**
- **Stage 2: extractions of TDAs**

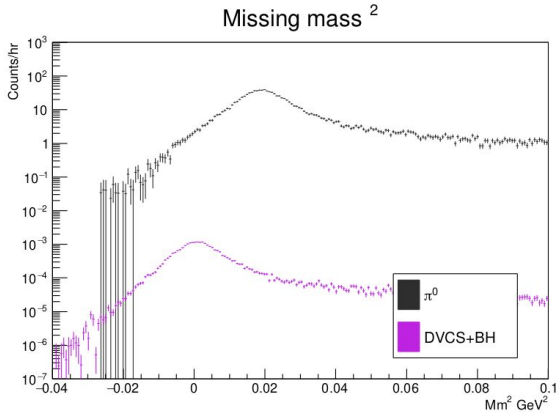


Others: parasitic data may be available

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

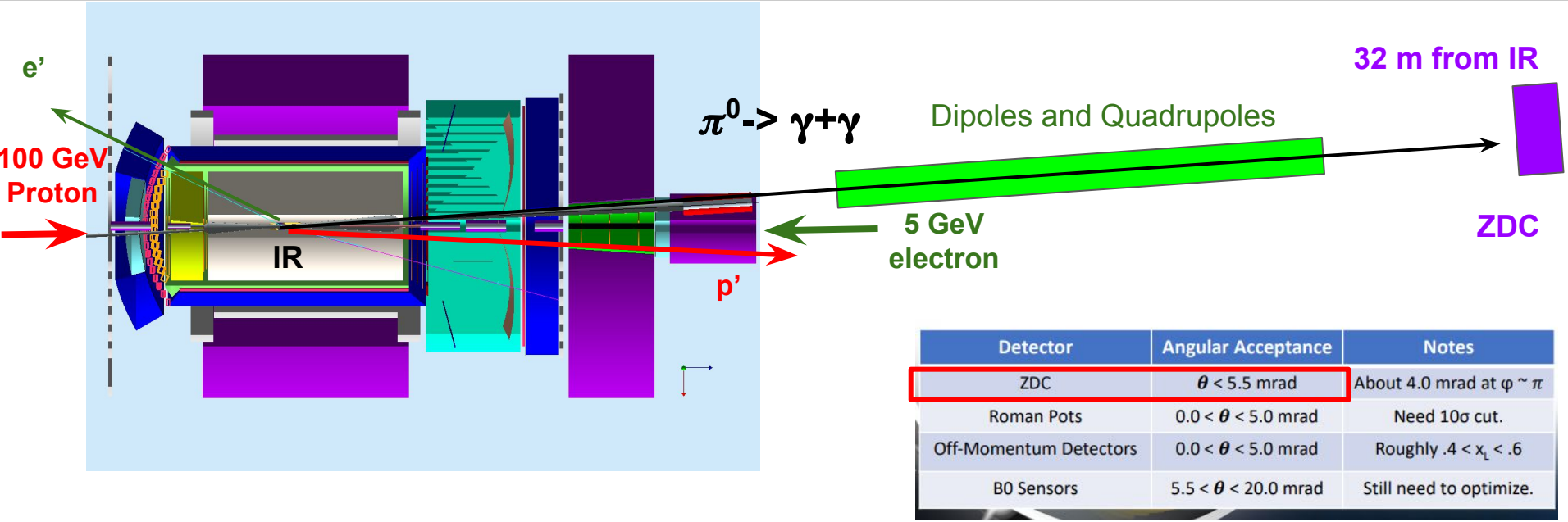
- Q^2 coverage: 2.0 < Q^2 < 6.25 GeV^2.
- *x*=0.36
- *u* coverage: 0 < -*u*' < 0.5 GeV^2

Submitted to PAC 48!

Objective:

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

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

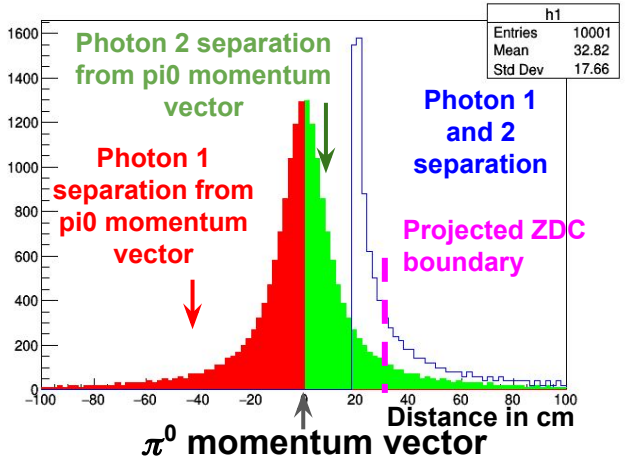


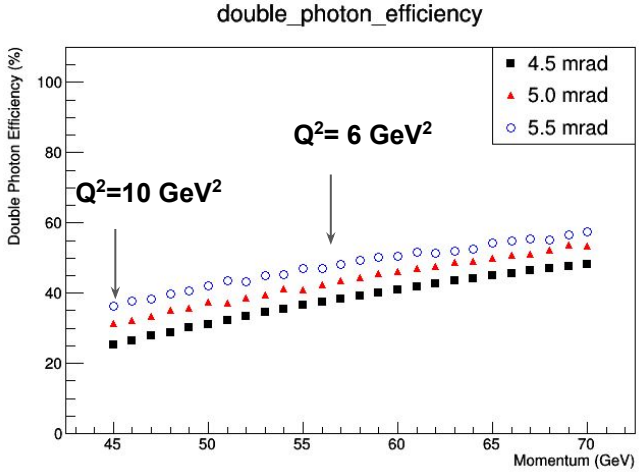
Detector	Angular Acceptance	Notes
ZDC	θ < 5.5 mrad	About 4.0 mrad at φ ~ π
Roman Pots	0.0 < θ < 5.0 mrad	Need 10σ cut.
Off-Momentum Detectors	0.0 < θ < 5.0 mrad	Roughly .4 < x_L < .6
B0 Sensors	5.5 < θ < 20.0 mrad	Still need to optimize.

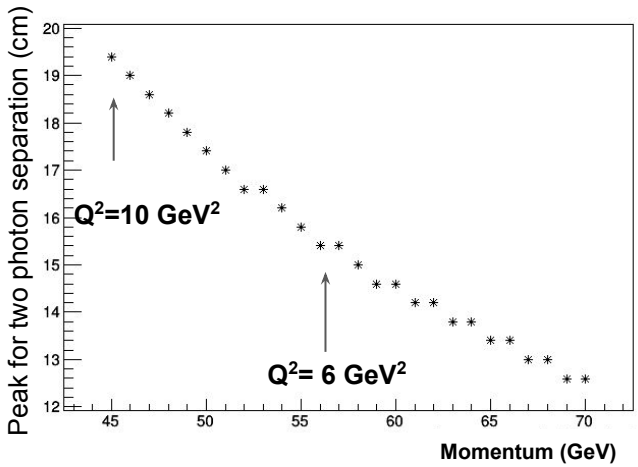
Q^2 (GeV^2)	W (GeV)	x_B	$\theta_{e'}$ (deg)	$\eta_{e'}$	$P_{e'}$ (GeV)	$\theta_{p'}$ (deg)	$\eta_{p'}$	$P_{p'}$ (GeV)	θ_{π^0} (deg)	η_{π^0}	P_{π^0} (GeV)	$-t$ (GeV^2)	$-u$ (GeV^2)
6.2	3.19		152	-1.39	5.31	-1.84	4.13	43.40	1.43	4.38	56.29	14.84	-0.37
7.0	3.19		150	-1.32	5.35	-1.92	4.09	45.50	1.43	4.38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

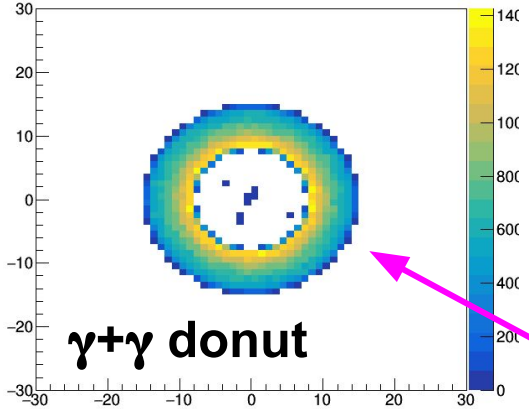
u'=0 GeV

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









Preliminary conclusion:

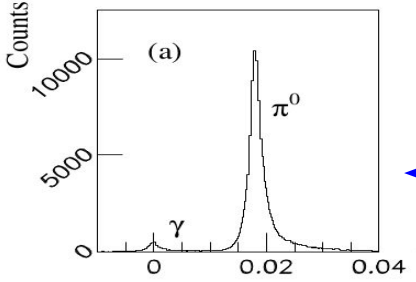
- *u*-channel π^0 at EIC with current design is a feasible measurement
- Ideal expected trigger: e'+p'+ 2 γ, is very clean with very little background, with reduced efficiency
- **Next step: process to full geant4 simulation**

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

A Lesson from the Past

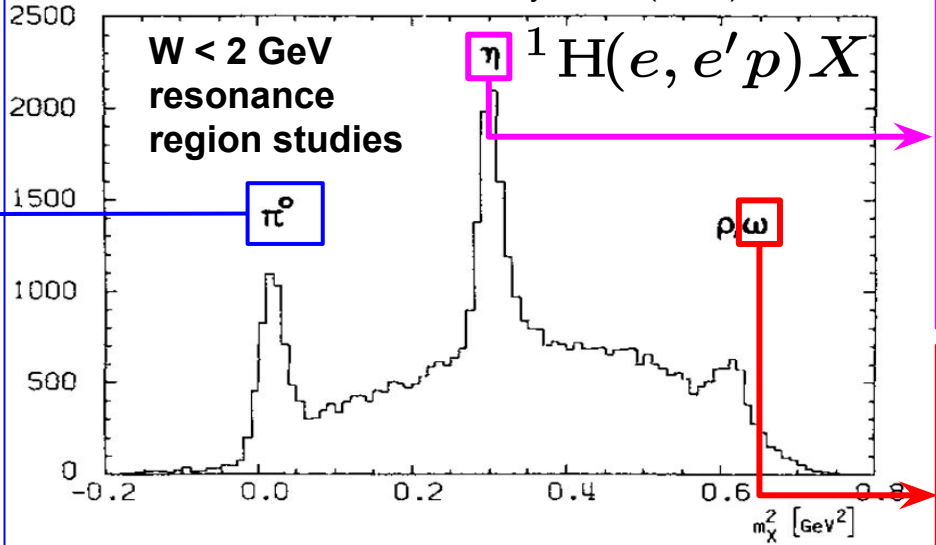
G. Laveissière et al. Phys. Rev. C 79, 015201 (2004)



Hall A VCS: E93-050

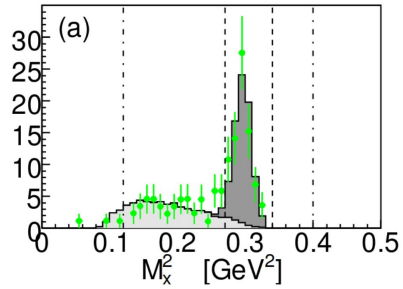
Hall C VCS: E12-15-001

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



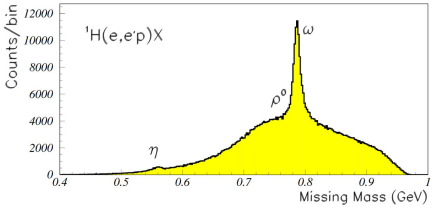
***u*-channel meson spectral at DESY spectrometer experiment from 1984**

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



Hall C E01-002

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

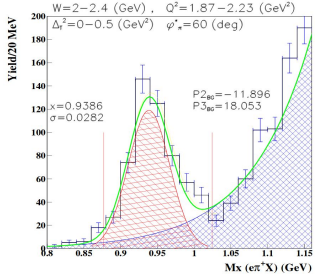


Hall C E91-016

- 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**

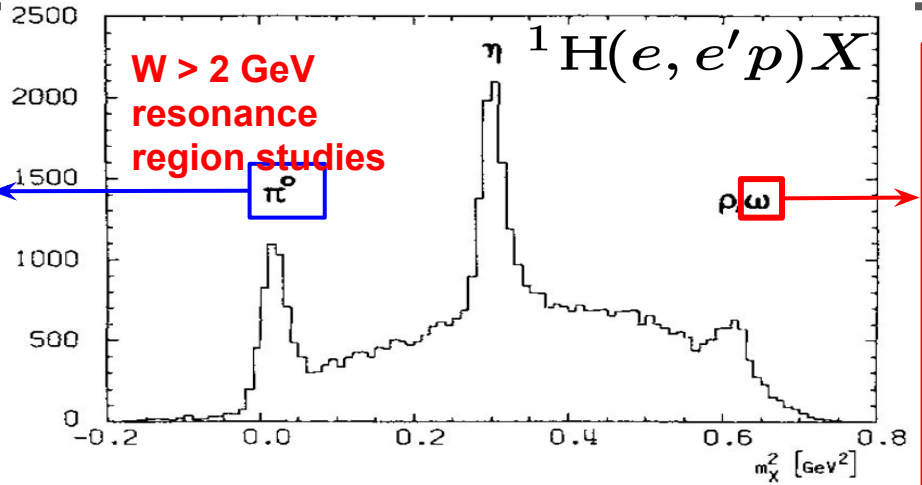
6 GeV Backward Angle Physics at W > 2 GeV

Charged Pion Production from CLAS 6

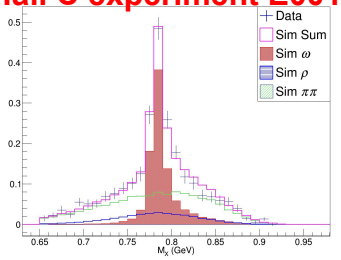


^{1}H(e, e'π$^+$)X

- **Q^2 Scaling**



Hall C experiment E001-004



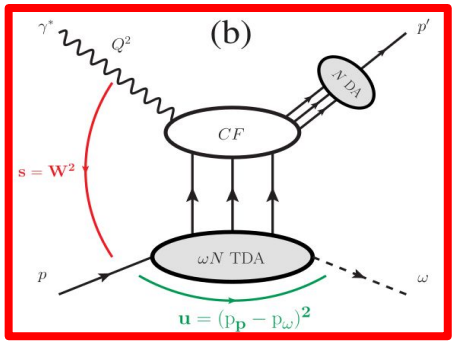
^{1}H(e, e'p)X

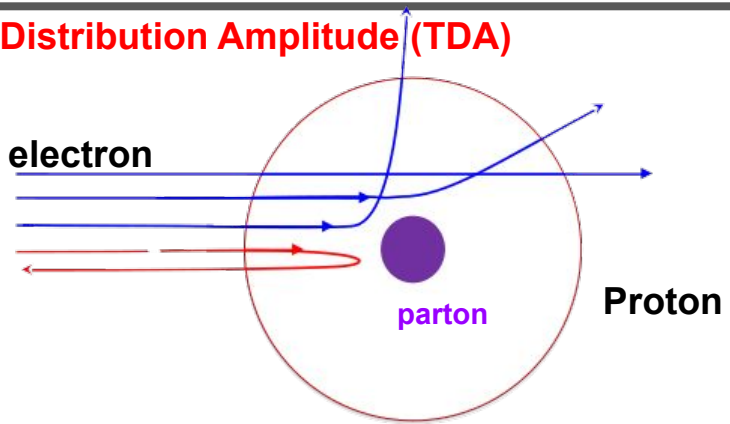
- **Parasitic data**
- **Full L/T separation**

- **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**

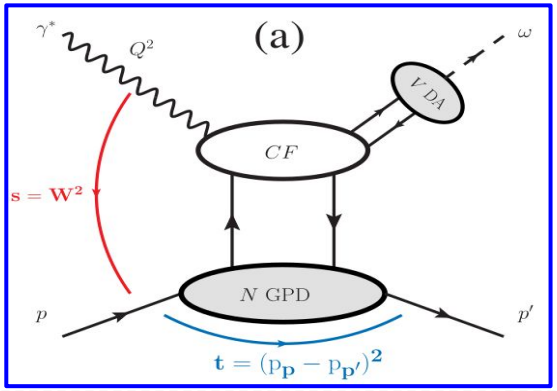
Backward-angle structure of Proton

Meson-nucleon Transition Distribution Amplitude (TDA)



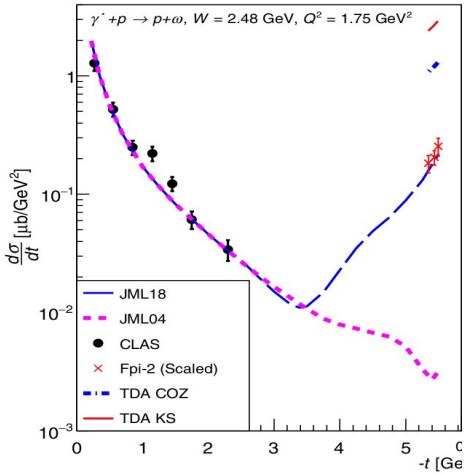


GPD

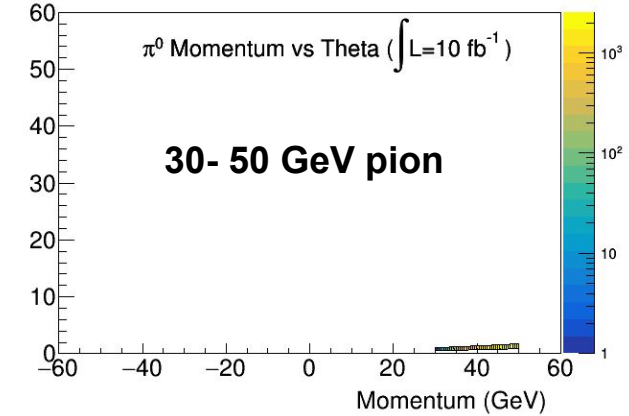


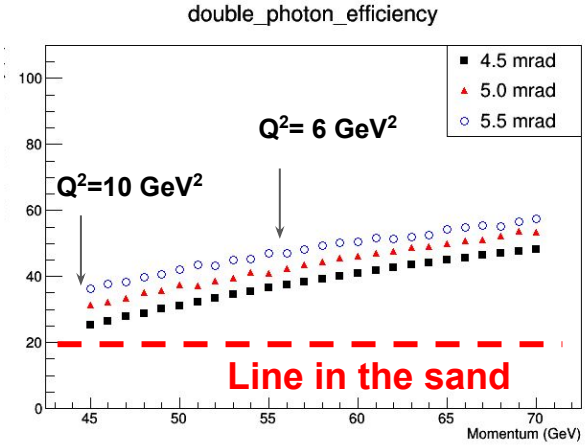
- Complete description of Nucleon
  - GPD = Hadron tomography of the proton
  - TDA = tomography of partonic distributions in the nucleon --> meson and vice versa transitions probed in the backward angle kinematics

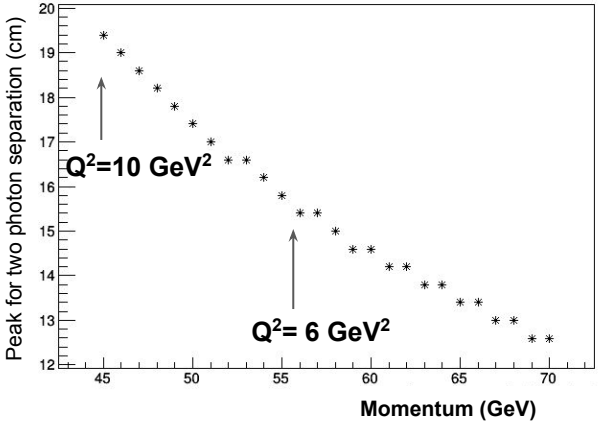
- Backward-angle cross section is not 0!
  - backward angle cross section is 1/10 of the forward angle cross section at observed Q^2

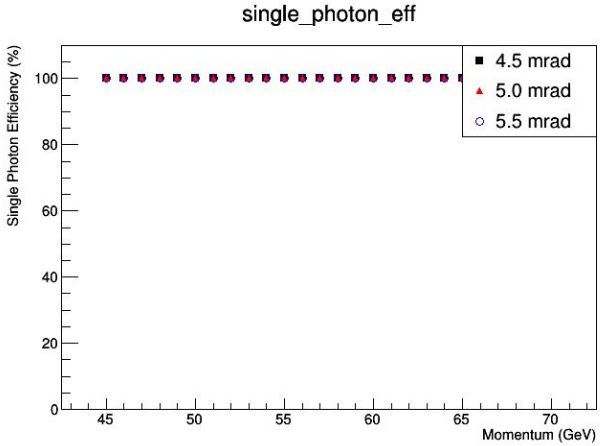


Impact to the efficiency









- 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