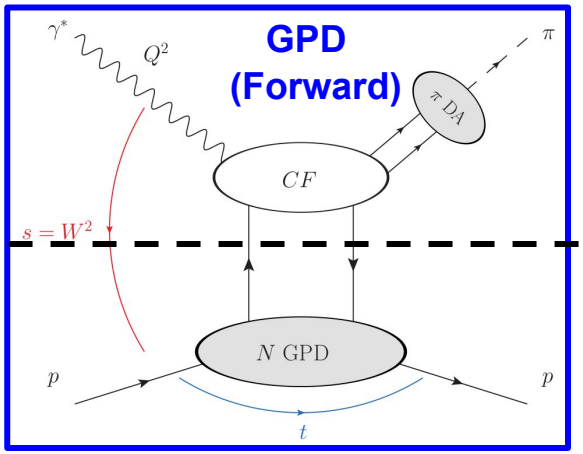
Diffractive & Tagging meeting on Dec 9th 2021

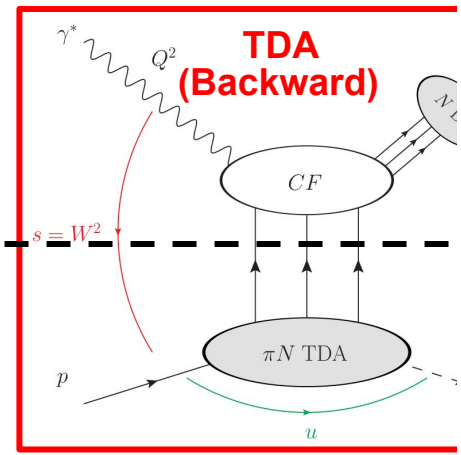
Wenliang (Bill) Li

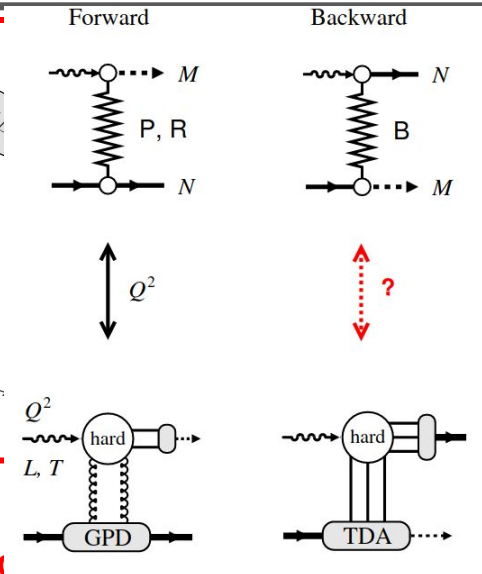
GPD, SPD and TDA (Hard Structure)

Hard structure

Soft structure





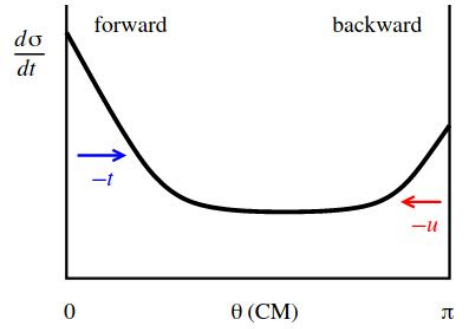


By **X. Ji et al.** in 1997

Description to the unseen si

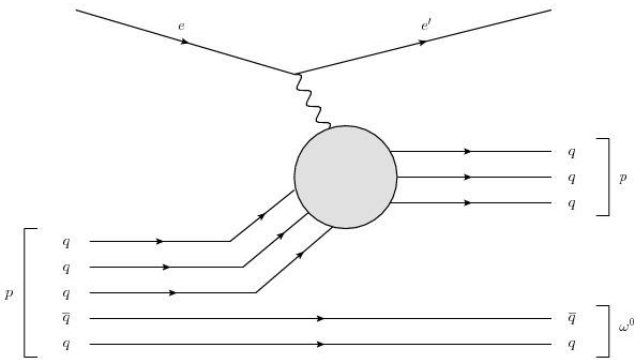
Complete description of Nucleon

- **GPD**: It is extracted predominantly based in the forward angle observables.
- **TDA**: meson-nucleon Transition Distribution Amplitude (TDA) only accessible through backward (u-channel) meson production.

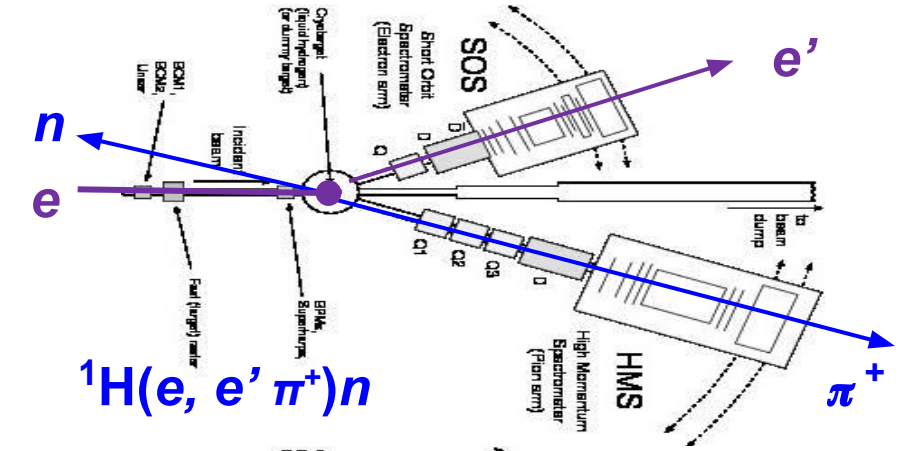


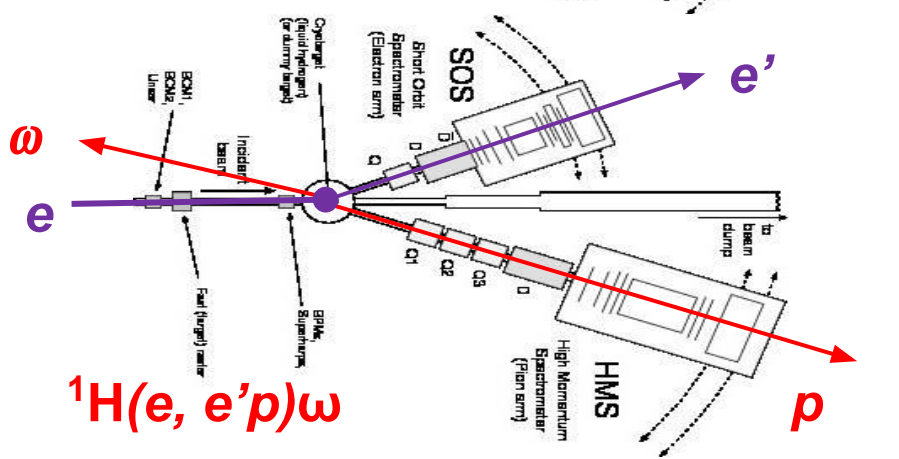
t-Channel π^+ vs u-Channel ω Production

- **Primary reaction for Fpi-2**
  - **H(e, e' π^+)n**
  - **n (940 MeV)**
  - **π^+ (140 MeV)**
- **Unexpected reaction:**
  - **H(e,e' p)ω**
  - **p (940 MeV)**
  - **ω (783 MeV)**



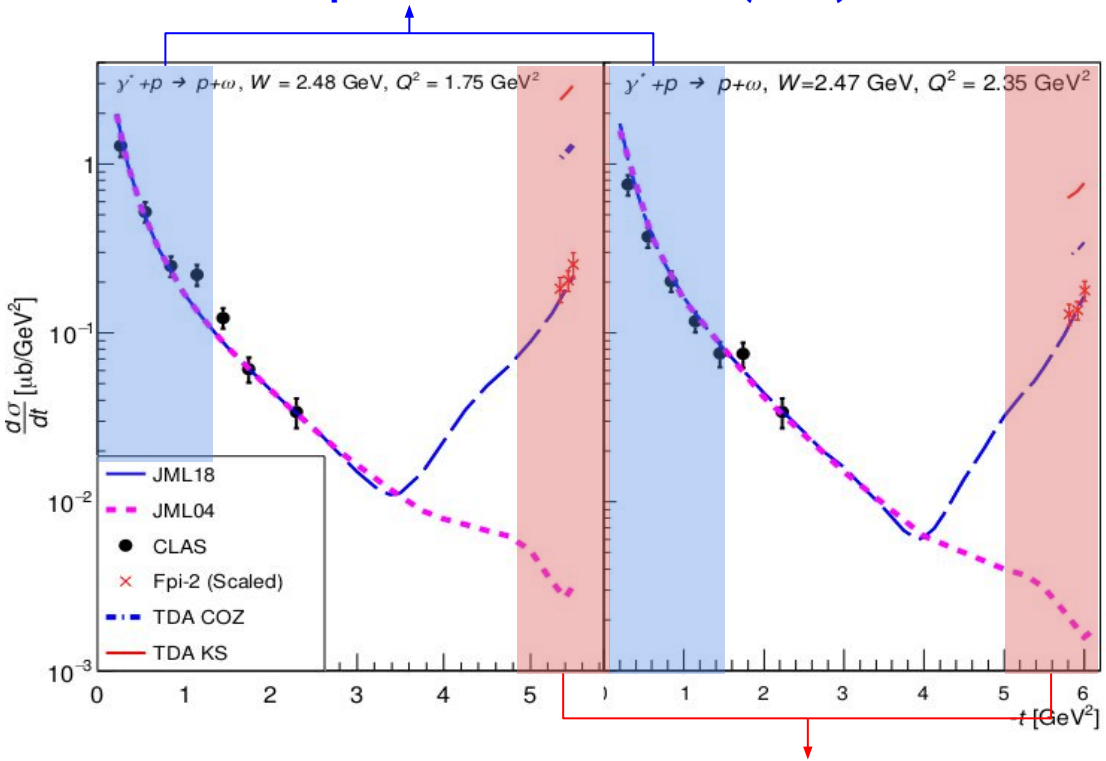
Mark Strikman & Christian Weiss: A proton being knocked out of a proton process



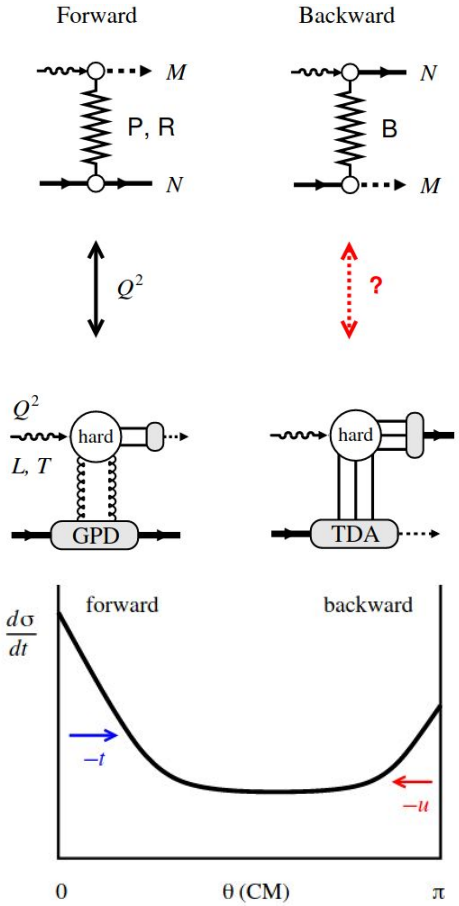


Results on Backward Angle Electroproduction

Forward ω electroproduction from CLAS 6 *(2004)*

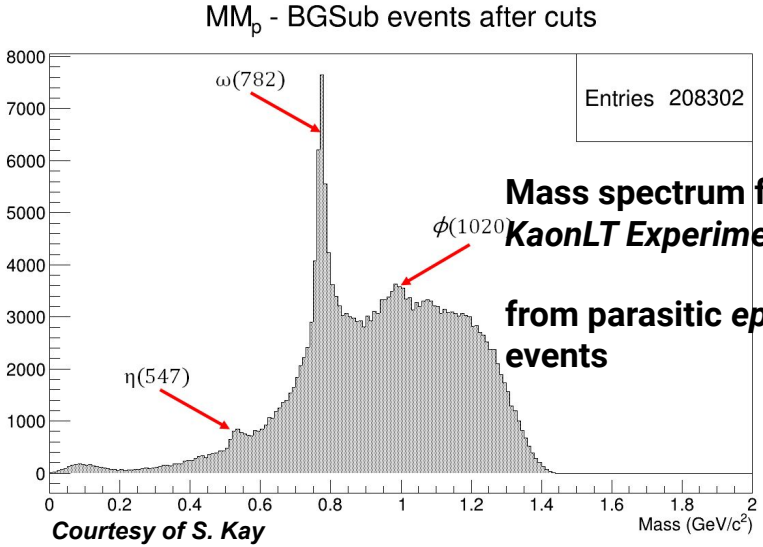


Backward angle ω electroproduction *(2017)*



Question: *u*-channel peaks for other processes?

- **Is there a u-channel peak for other processes?**
  - **Answer: Yes**
- **Evidences:**
  - 6 GeV pioneering analysis efforts from Hall C and CLAS 6
  - Parasitic data from 12 GeV Hall C experiments



Courtesy of S. Kay

Mass spectrum from 12 GeV *KaonLT Experiment 2020*

from parasitic *ep* coincidence events

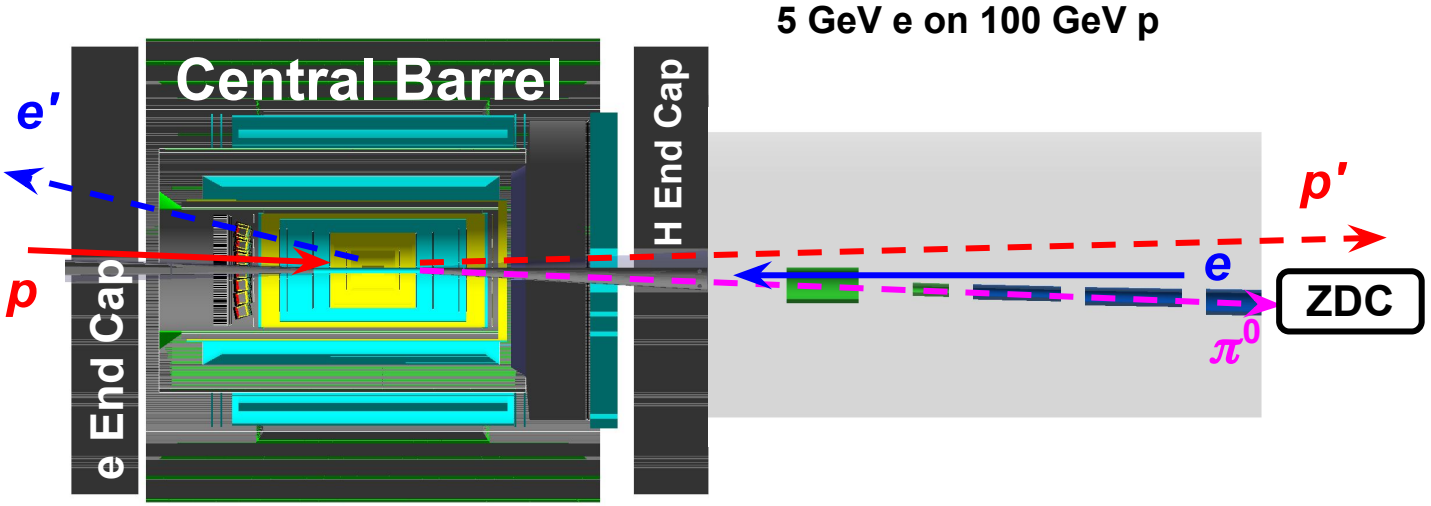
	$\sigma_T > \sigma_L$	$1/Q^8$ Scaling
π^0		
π^+		✓✓
π^-		
K^0		
$K^\pm$		
η	✓	✓
ρ		
ω	✓✓	✓
η'	✓	✓
ϕ	✓	✓
VCS		

Confirmed!
By CLAS6 π^+

Parasitic Hall C Study

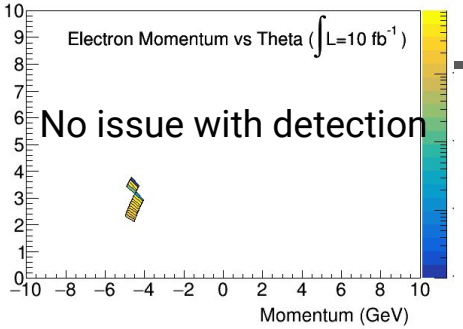
Confirmed! By Hall C 6 GeV ω

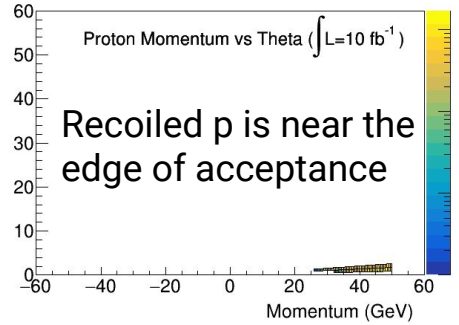
u-Channel Meson Production Setup

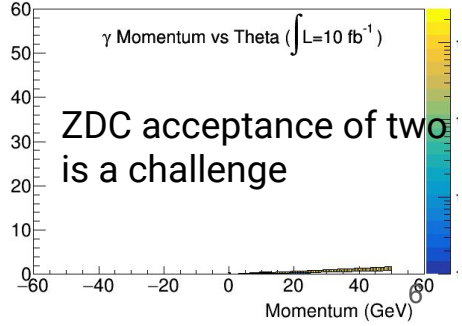


Q^2 (GeV^2)	W (GeV)	x_B	$\theta_{e'}$ (deg)	$\eta_{e'}$	$P_{e'}$ (GeV)	$\theta_{p'}$ (deg)	$\eta_{p'}$	$P_{p'}$ (GeV)	θ_{π^0} (deg)	η_{π^0}	P_{π^0} (GeV)	$-t$ (GeV^2)	$-u$ (GeV^2)
6.2	3.19		152	1.39	5.31	-1.84	4.13	43.40	1.43	4.38	56.29	14.84	-0.37
7.0	3.19		150	1.32	5.35	-1.92	4.09	45.50	1.43	4.38	54.12	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

e' p' π^0







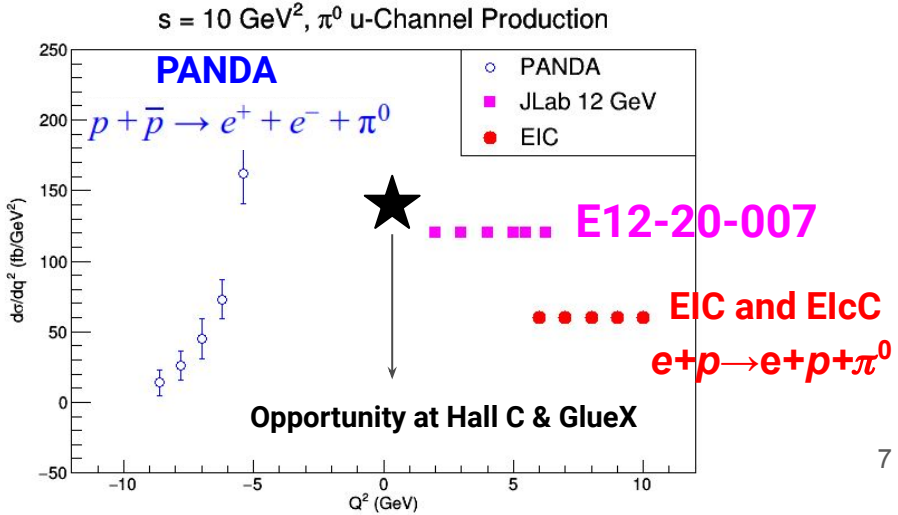
u-Channel studies at EIC

7.4 Understanding Hadronization

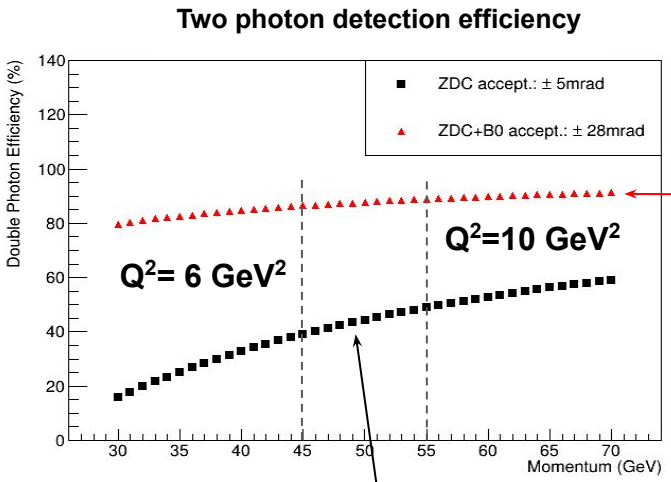
There is great potential also in studying **new particle production mechanisms** such as exclusive backward *u*-channel production. Given its high luminosity the EIC may be able to discover fundamental QCD particle production processes with low cross sections such as via hard (perturbative) C-odd three gluon exchange.

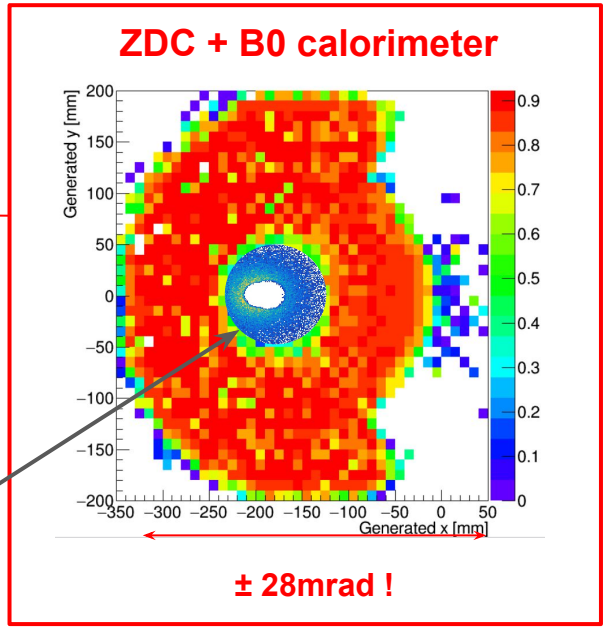
EIC YELLOW REPORT

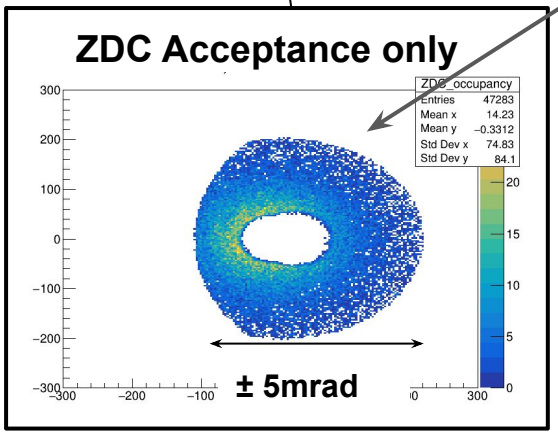
- **As postdoctoral fellow at JLab EIC Center: developed Backward π^0 program for EIC**
  - Offers synergy to other planned data set
  - Feasibility studies included as part of the EIC Yellow report (published last week)



Enhanced acceptance and resolution with B0 calorimeter

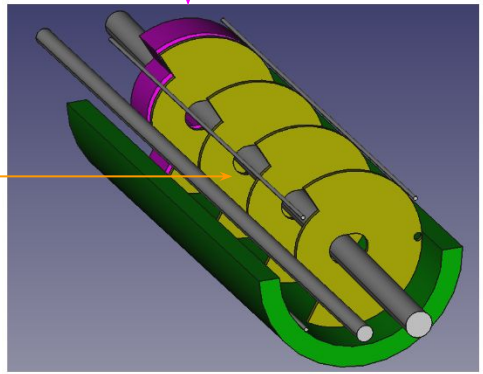






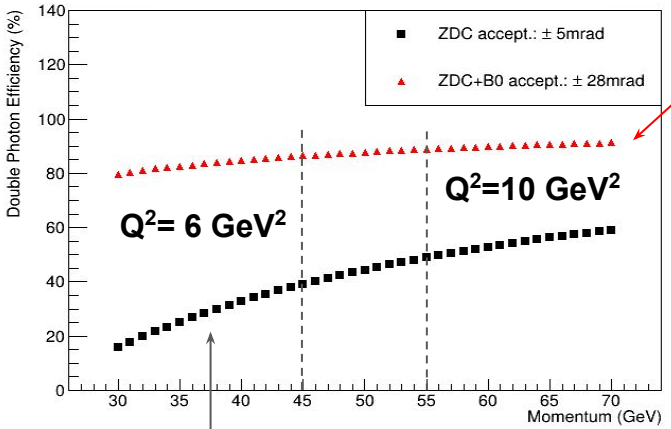
B0 Calorimeter

B0 Trackers



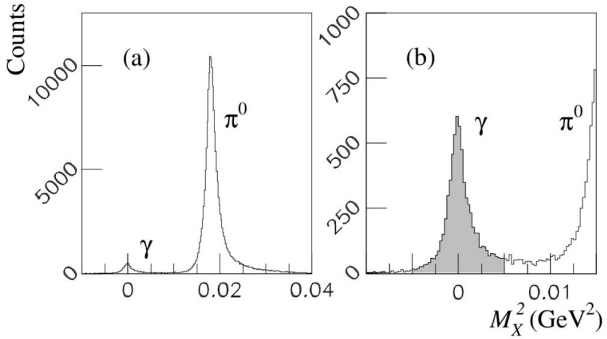
Enhanced acceptance and resolution with B0 calorimeter

Two photon detection efficiency



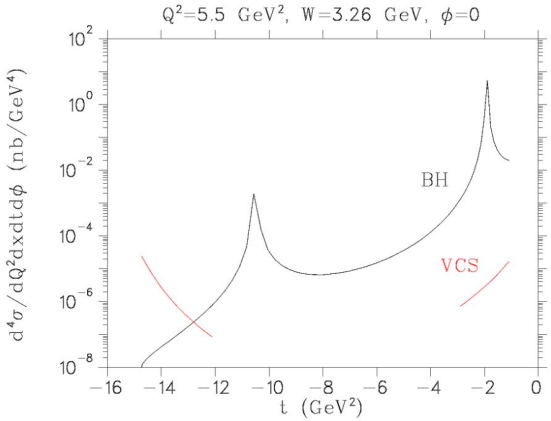
Only u-Channel π^0 is possible

u-Channel DVCS is a possible!



Hall A VCS experiment.
Phys. Rev. C 79 (2009) 015201

As reward, No BH in u-channel



Enhanced acceptance and resolution with B0 calorimeter

Probing the Darkside of Proton: *u*-channel Meson Production from Jefferson Lab to EIC

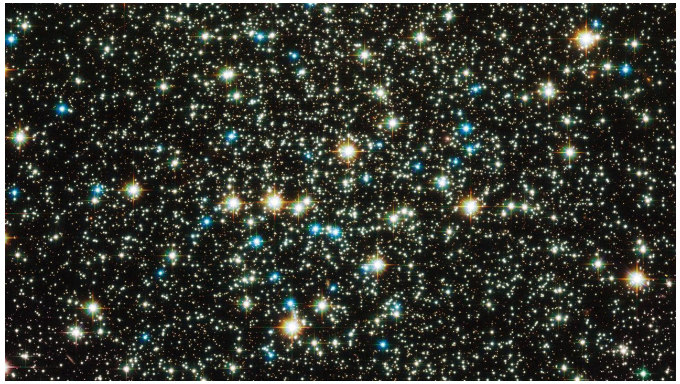
Wenliang 'Bill' Li

Joint postdoc at W&M and JLab EIC Center

Invited Colloquium at Ohio University
18/October/2021

WILLIAM & MARY
CHARTERED 1693

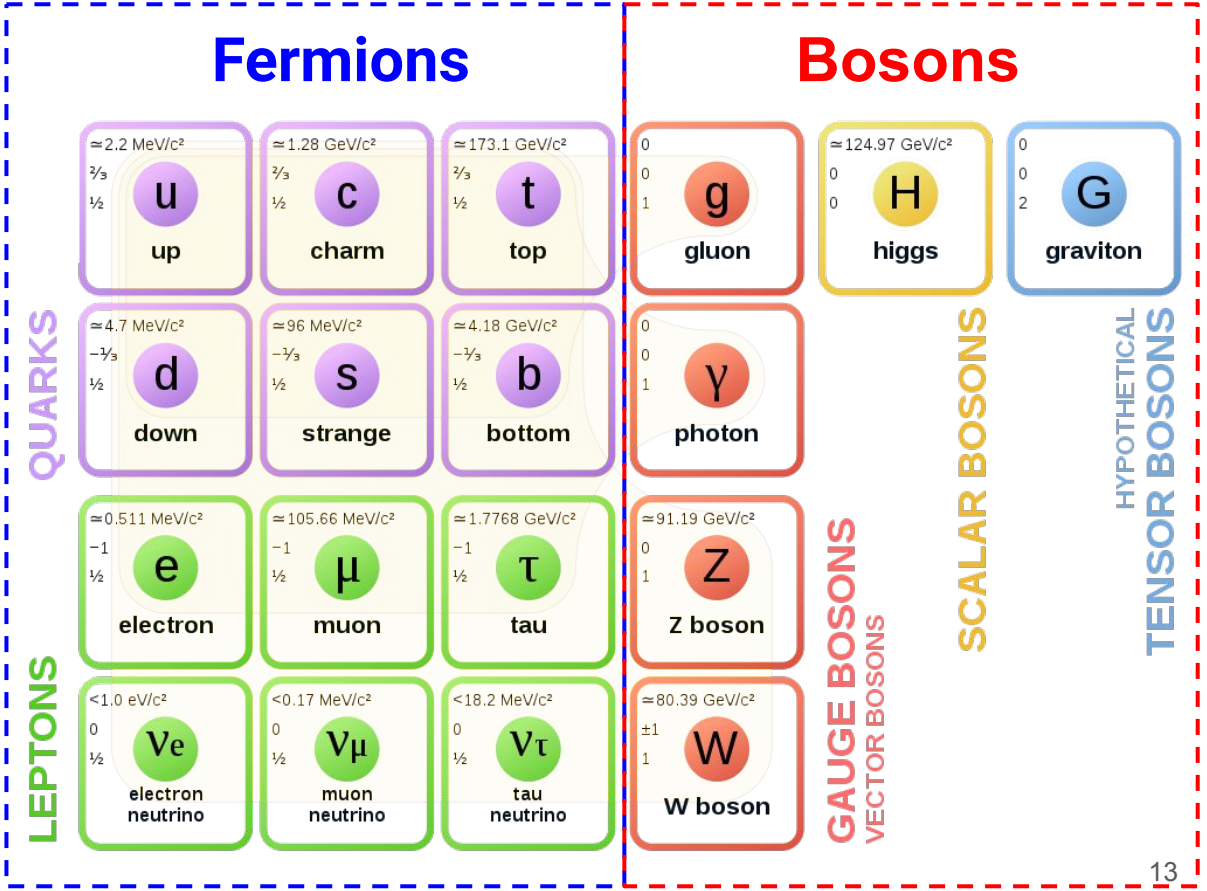
Standard Model: Simple but powerful



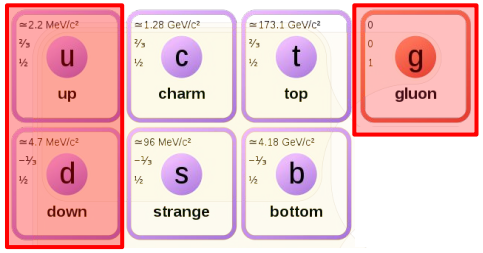
Fermions: Building blocks of known universe

Bosons: Force carriers

Higgs provide a linkage to other force carriers Z and W bosons.

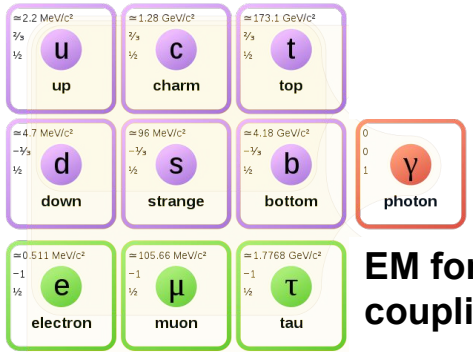


Four Fundamental Interactions of Nature

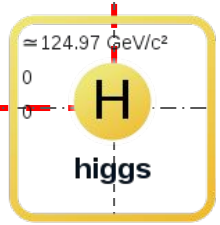


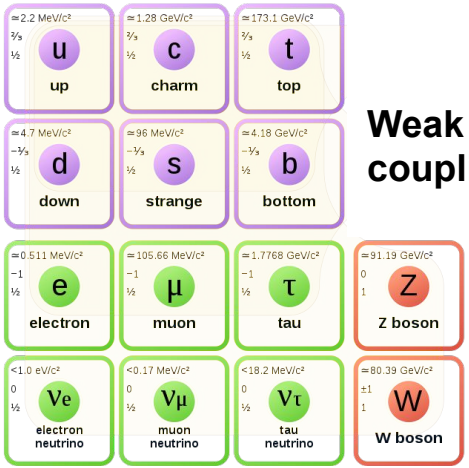
Topic of today

Strong (color) force
coupling constant $\alpha_s \sim 1$

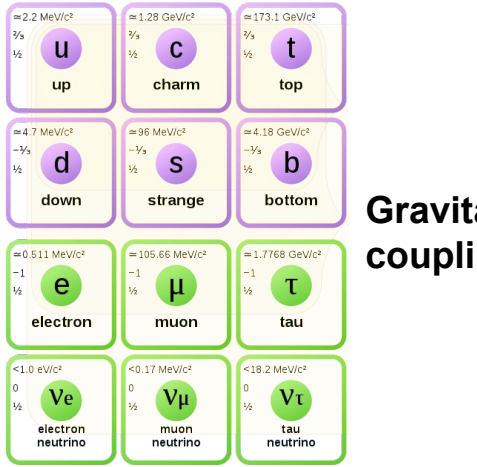


EM force:
coupling constant $\alpha_e \sim 1/137$



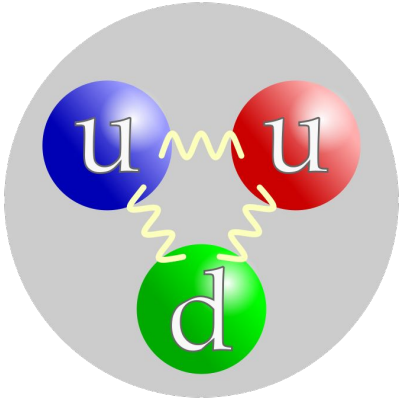


Weak force
coupling constant $\alpha_W \sim 10^{-6}$

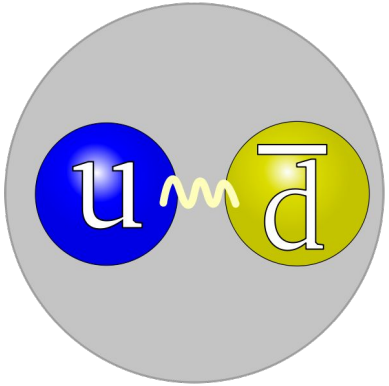


Gravitational force
coupling constant $\alpha_g \sim 10^{-45}$

Strong interaction and Particle Structure



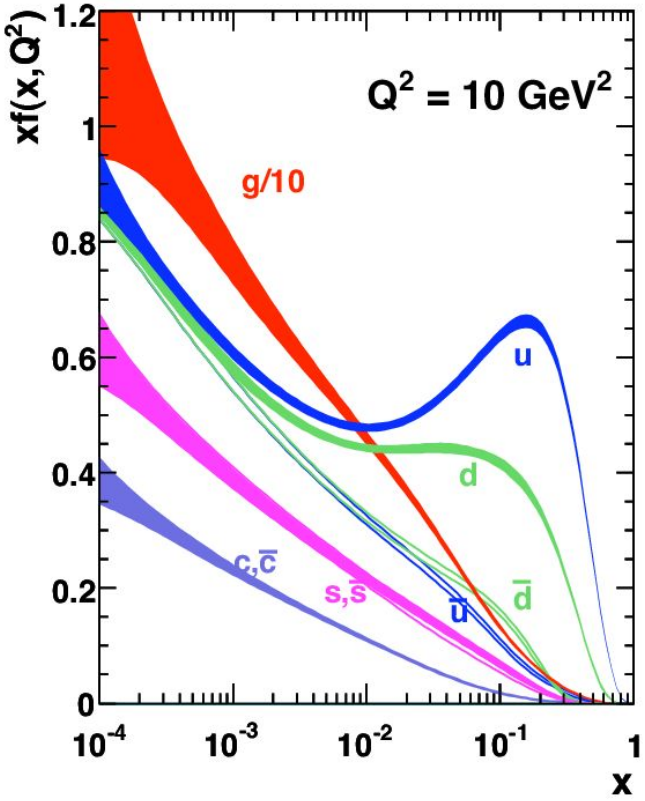
Baryons consists 3 quarks
Example: Proton (uud)

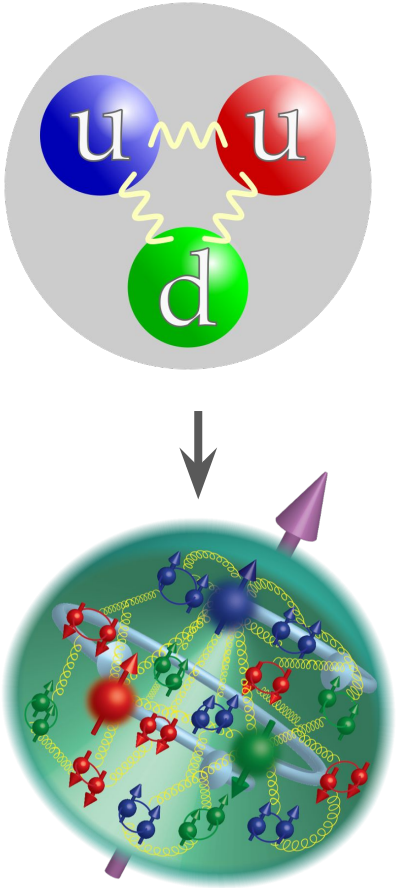


Mesons consists 2 quarks
Example: π^+

Hadrons: includes **baryons** and **mesons.**
All hadrons are color neutral
Proton and **Neutrons** are nucleons, forming the stable universe
How do quarks distribute themselves within the proton ?

Parton Distribution Function





Parton: Internal part of a proton

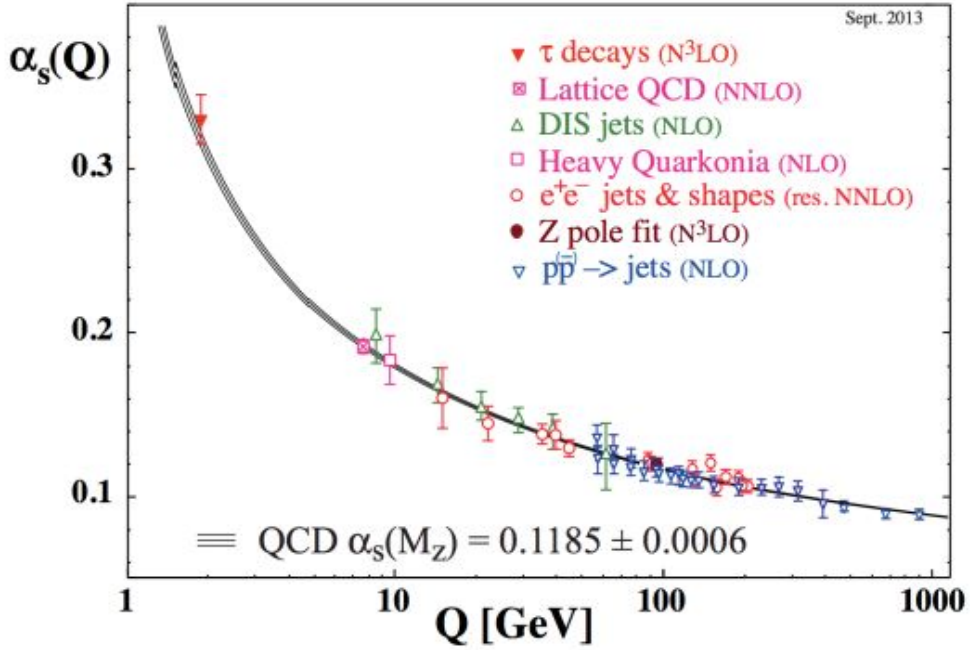
Parton distribution function is complicated! it includes:

- **Valence quark** (larger quarks)
- **Sea quark pairs** (pairs)
- **Gluons**

Proton mass: 938 MeV

Single quark mass: ~4 MeV

Strong Coupling Constant: a running constant !

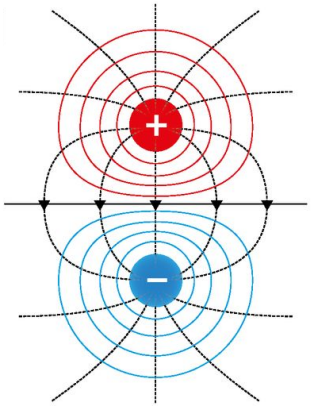


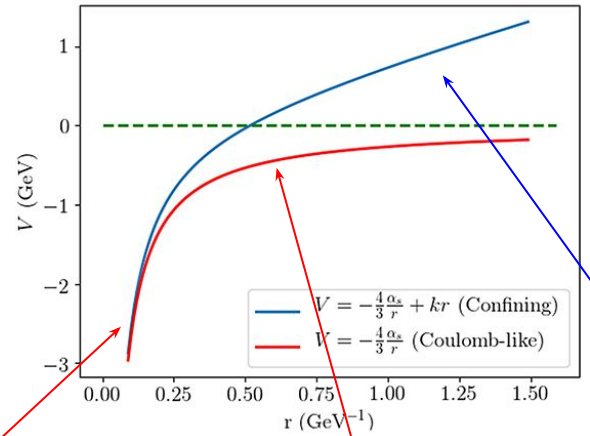
Q: Momentum exchange between the probe and struck parton

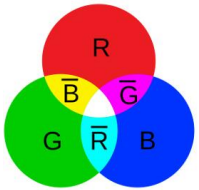
Q is equivalent to the resolving power

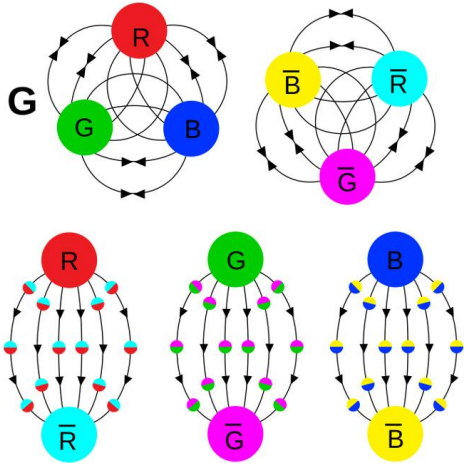
- **Strong coupling constant is not a constant!**
- **Internal structure of proton changes as the resolving power changes!**

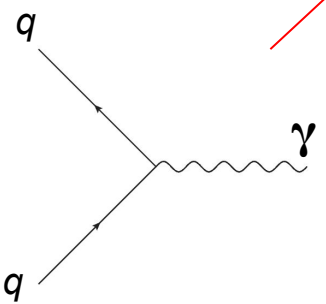
QED (Dipole Field) vs QCD (Color Field)



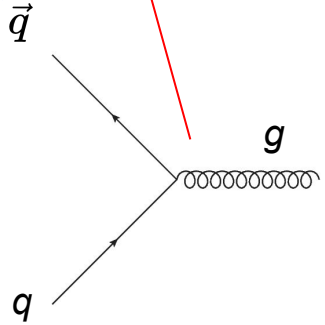




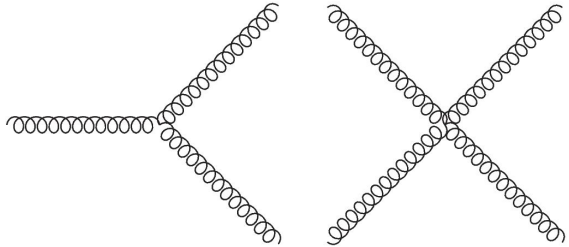




Quark-Photon interaction

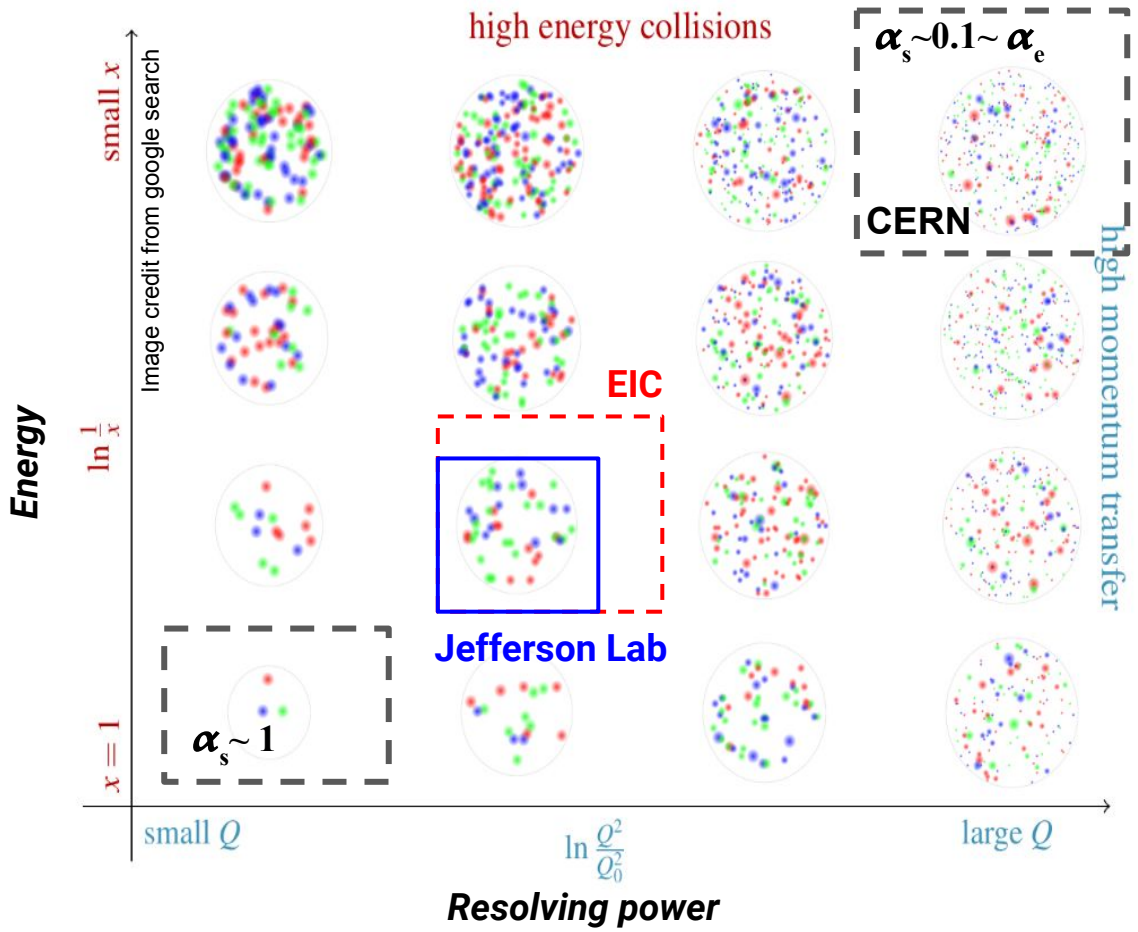


Quark-Gluon interaction



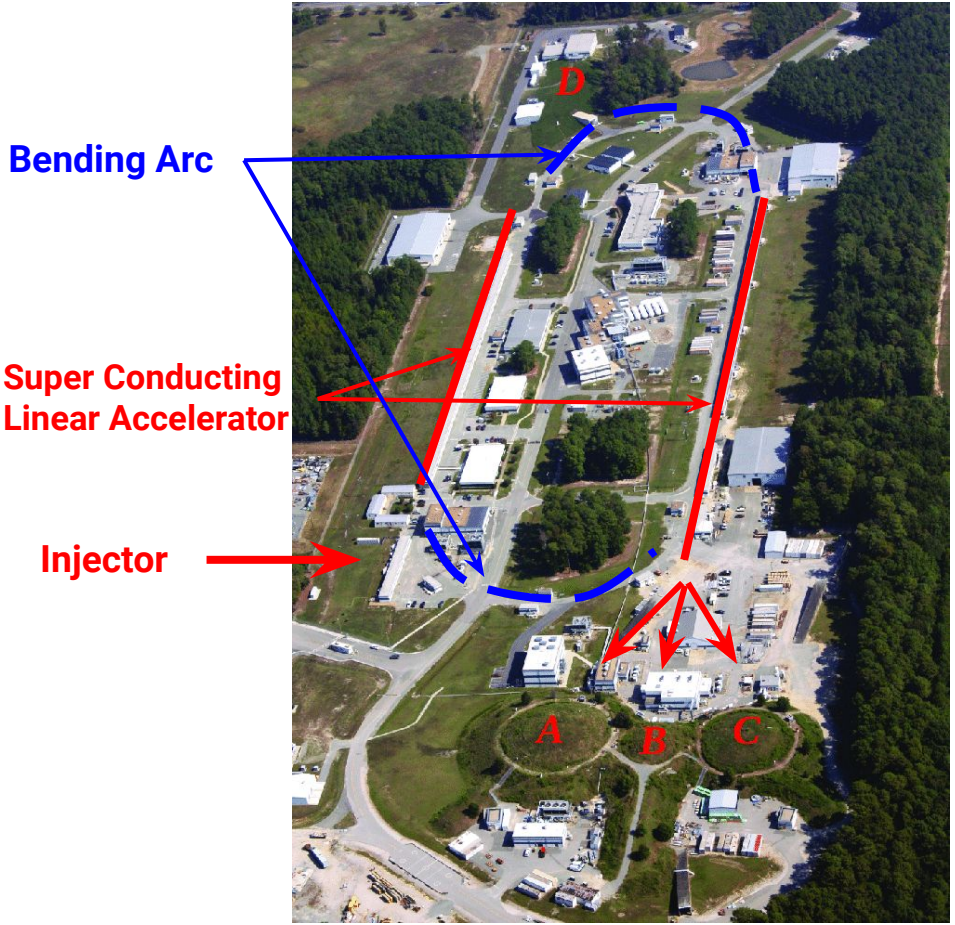
Gluon self-interactions

Dynamic Structure of the Nucleon



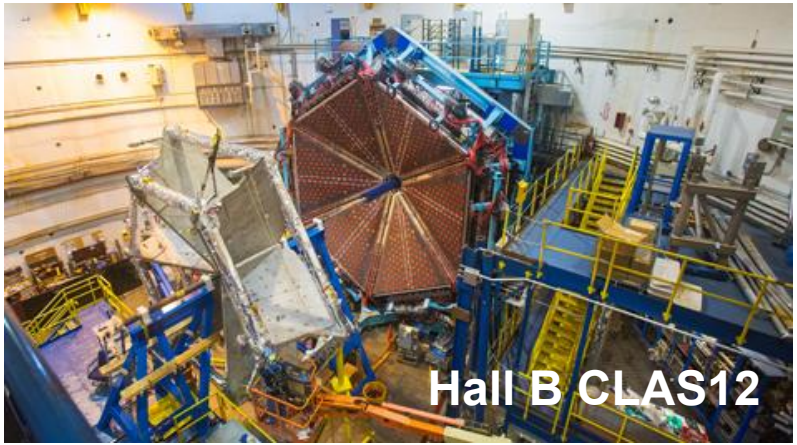
- $\alpha_s \sim 0.1 \sim \alpha_E$: Quark behaviour is described by perturbative methods; validated by CERN experiments.
- $\alpha_s \sim 1$: Not measurable
- Taking snapshots of proton structure at intermediate energy
- We need powerful theoretical tools to do the extrapolation!

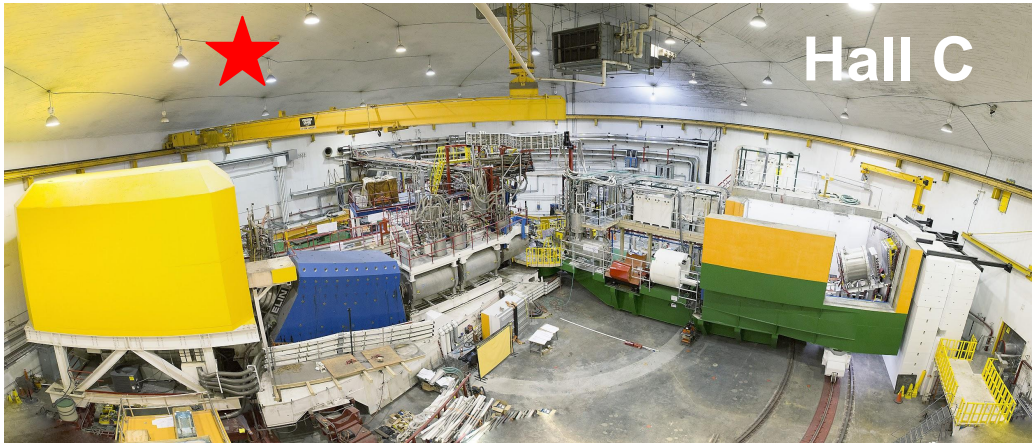
Jefferson Lab



- **Facility cost: $ 2B**
  - Two Superconducting LINAC
  - Four experimental Halls
  - Electron beam energy up to 12 GeV
  - Duty cycle~99%
- **Annual operating budget: ~$200 M**
  - 95% is electricity cost
- **Peak Power Consumption: 1.2 M Watts**
  - Ford-class aircraft carriers A1B reactor effective output
- **Standard 6 month/year operation**
  - **Electricity cost per day** to run experiments: **$ 800K**

Jefferson Lab Experimental Halls at 12 GeV

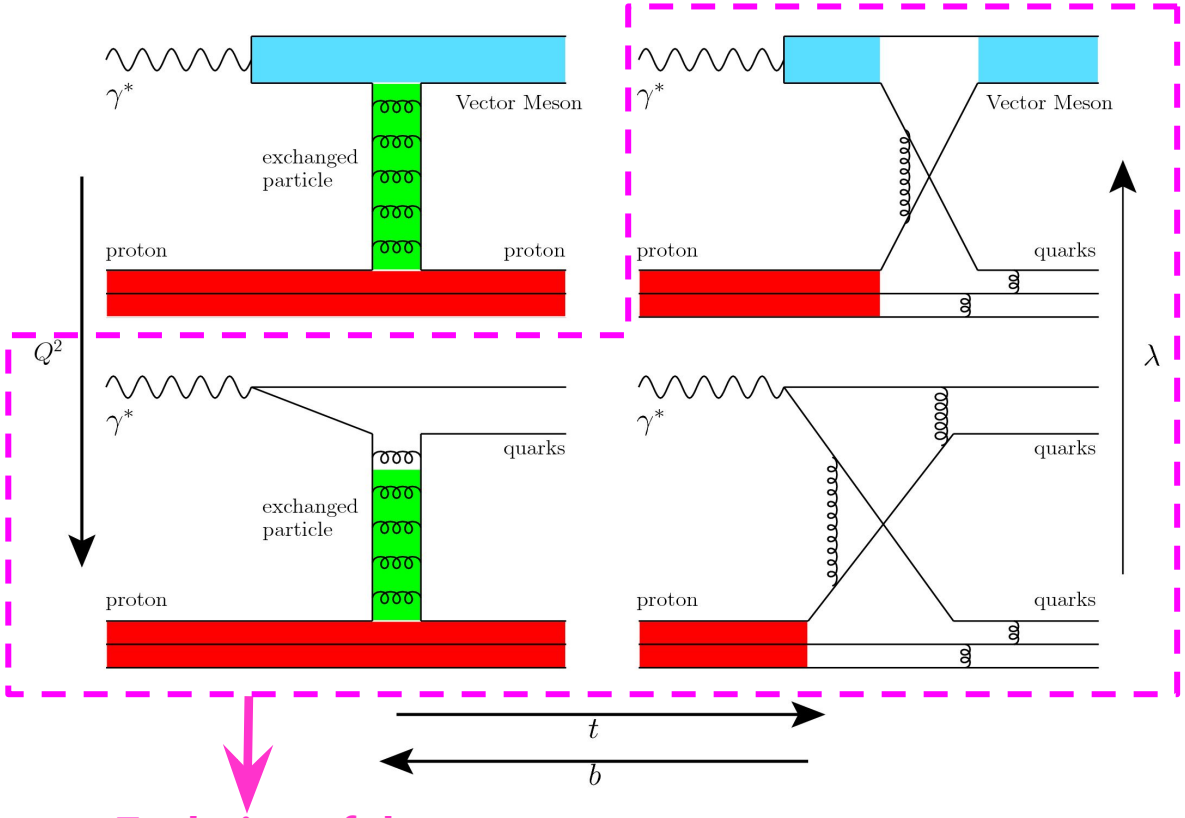




Each Experimental Hall carry unique scientific objectives:

- **Hall A: upgrading, not shown**
- **Hall B: low lumi. beam, large acceptance. Study multiple interactions simultaneously.**
- **Hall C: High Res. Spectrometers. High intensity beam. Study nucleon structure, LT separation.**
- **Hall D: photon beam, large acceptance.**

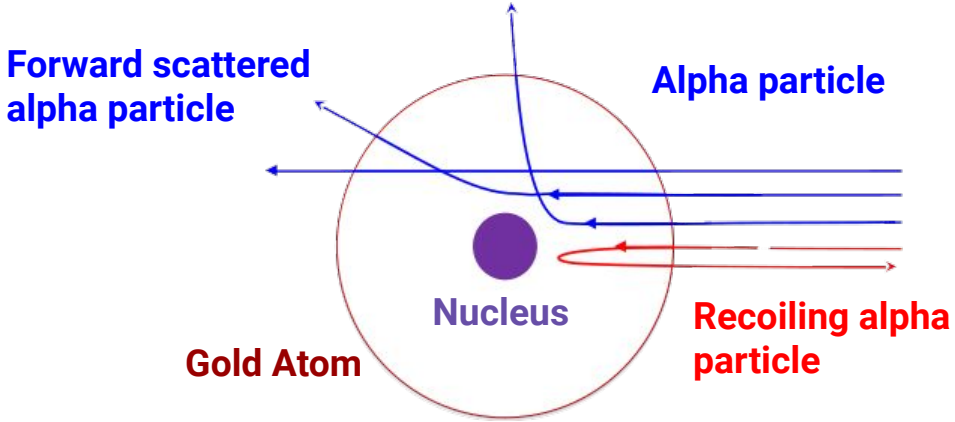
Hadronic Model: Transition (Evolution) of Proton Structure

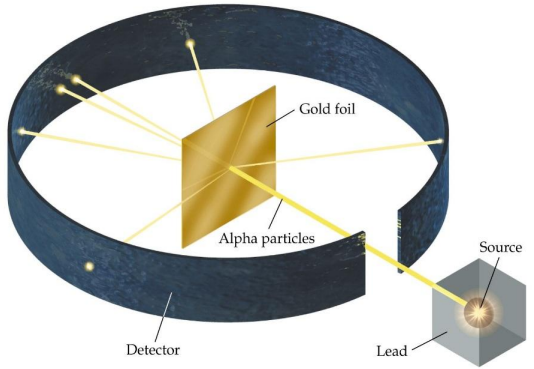


Evolution of the Proton Structure

- 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

Probing Full Structure of Atom

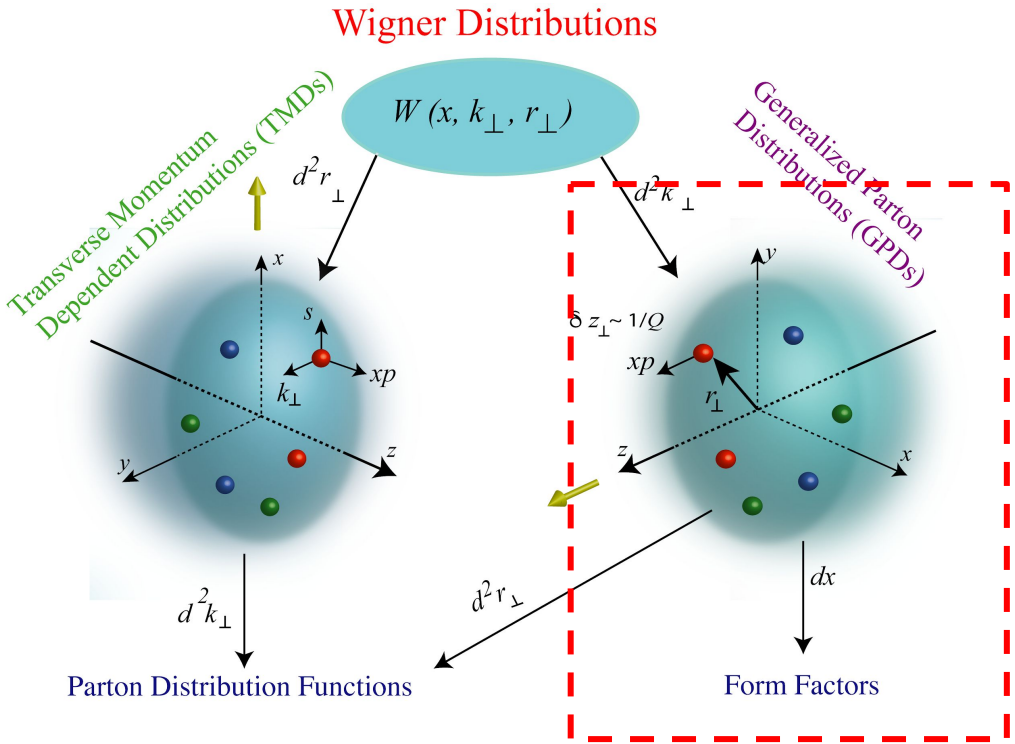




- Forward scattered alpha particle: extracting the interaction radius of the nucleus and mapping out the transverse structure of the atom (mostly empty)
- Recoiling alpha particle: stiffness of the “point-like” structure.
- Full structure = forward angle + backward angle observables.

Modern Description of Nucleon Structure

Picture credit to https://www.phy.anl.gov/qcd2019

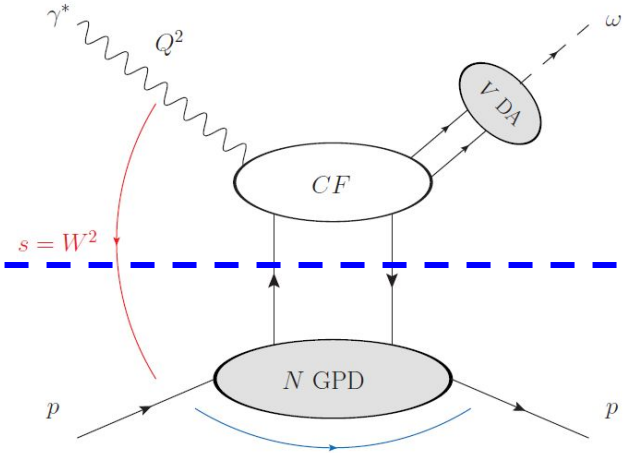


- **Wigner distribution:**
  - Complete of momentum and position information
- **Generalized Parton Distribution (GPDs):**
  - Integrated over all momentum operators
  - Complete position information of quarks inside nucleon
  - Directly translate to charge nucleon distribution
- **Transverse Momentum Distribution (TMDs):**
  - Integrated over all space
  - Complete Momentum information of quarks inside nucleon

3D structure = Computed tomography of proton

Generalized Parton Distribution

Interaction with hard structure calculable



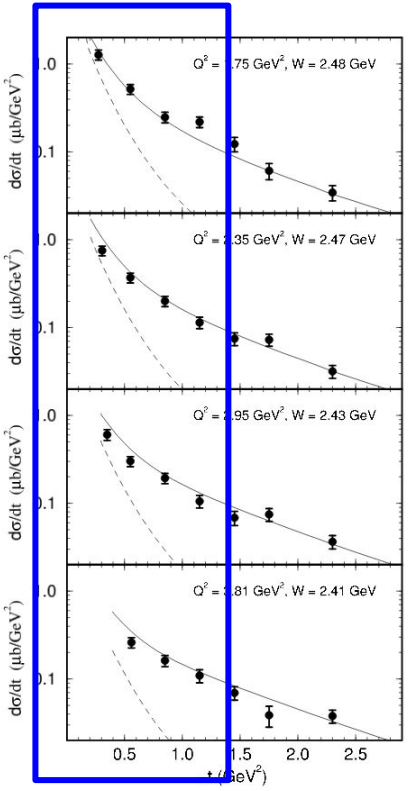
Deep exclusive ω electroproduction

Hard structure

Soft structure

Collinear factorization

forward = small -t



- **Proton structure is divided into Hard and Soft structures:**
  - Hard structure is calculable by perturbative methods
  - Framework uses Hard structure information to **extrapolate to the Soft structure**
- **Condition for Factorization Scheme:**
  - **At sufficiently large momentum transfer**
  - **Produced meson fragments scatter to extreme forward.**
    - Framework ignores the structure information from backward-angle interactions
- **Question: missing the description for backward structure of proton?**

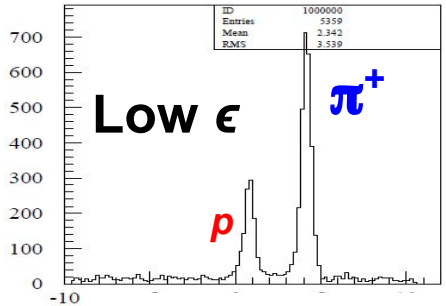
Gifted Backward-angle Observables

- **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**
  - **H(*e*, *e'* π^+)*n***
- **In addition, the experiment fortuitously received**
  - ***p*(*e*,*e'* *p*)ω**
- **Kinematics coverage**
  - ***W*= 2.21 GeV, Q^2=1.6 and 2.45 GeV^2**
  - Two ϵ settings for each Q^2

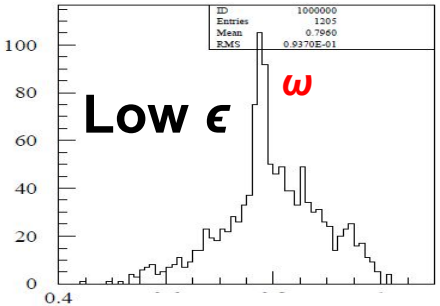
Q^2=2.45 GeV^2

2003

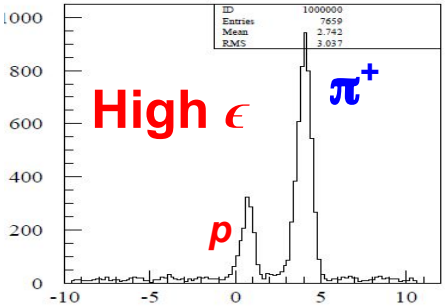
2003/07/25 08.56



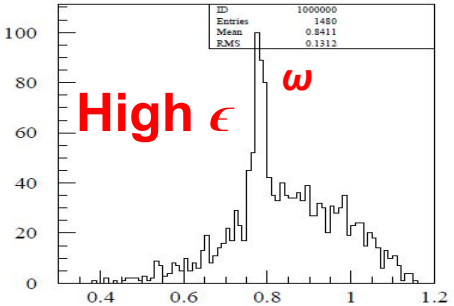
Coincidence time



***epX* missing mass**



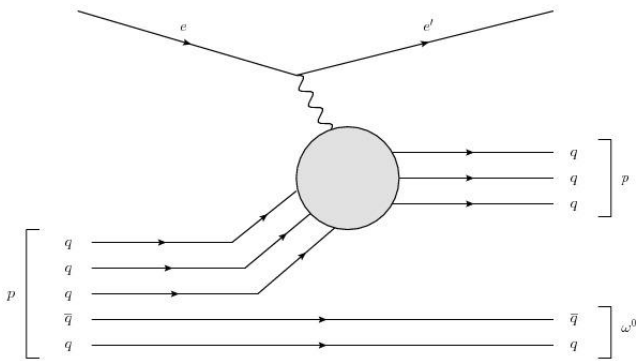
Coincidence time



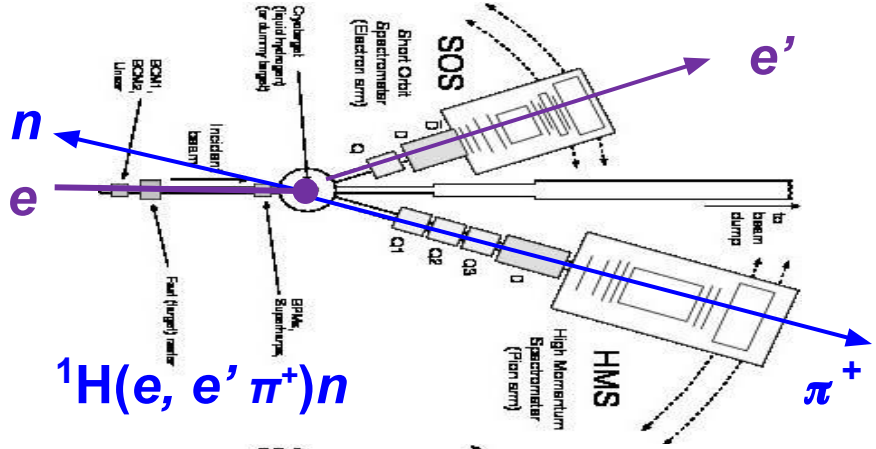
***epX* missing mass**

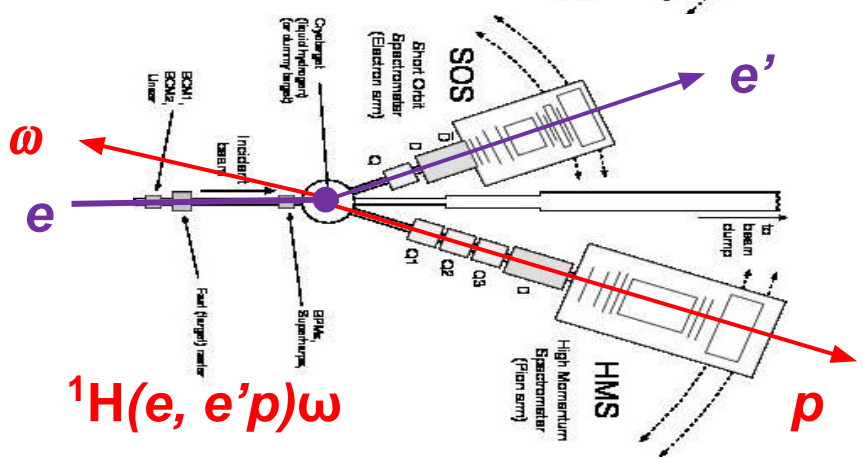
t-Channel π^+ vs u-Channel ω Production

- **Primary reaction for Fpi-2**
  - $H(e, e'\pi^+)n$
  - n (940 MeV)
  - π^+ (140 MeV)
- **Unexpected reaction:**
  - $H(e,e'p)\omega$
  - p (940 MeV)
  - ω (783 MeV)



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

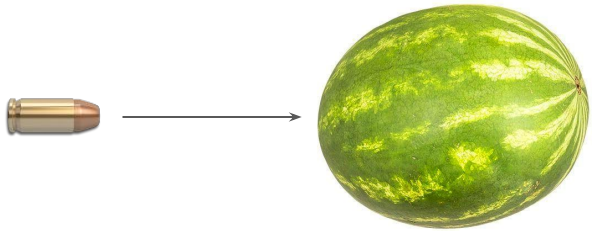




Forward and Backward Fragmentation of a Watermelon

Before interaction

e + H



n (940 MeV)

Remains at target position

H(*e*, *e'* π^+)*n*

After interaction

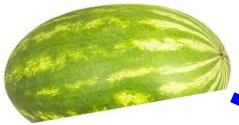
***t*-channel**

π^+(140 MeV)

ω (782 MeV)

Remains at target position

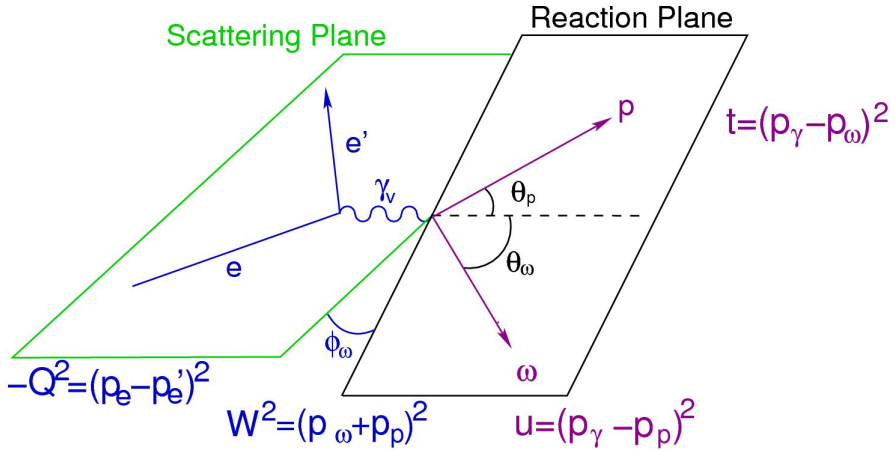
***u*-channel**



p (938 MeV)

H(*e*,*e'* *p*)*ω*

The Rosenbluth Separation



Virtual-photon polarization:

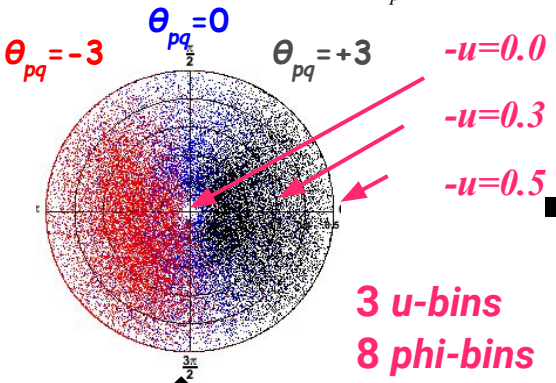
$$\varepsilon = \left(1 + 2\frac{(E_e - E_{e'})^2 + Q^2}{Q^2}\tan^2\frac{\theta_{e'}}{2}\right)^{-1}$$

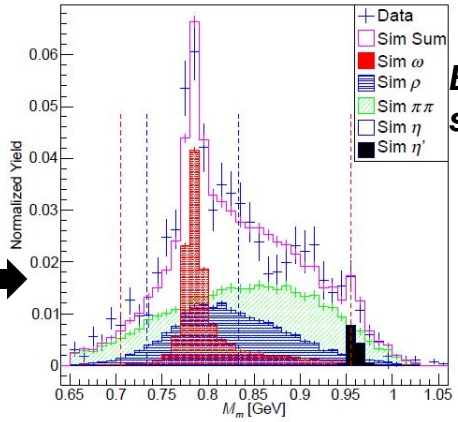
$$2\pi\frac{d\sigma}{dtd\phi} = \varepsilon\frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi + \varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi$$

- **Rosenbluth Separation requirements:**
  - Separate measurements at different ε (virtual photon polarization)
  - All Lorentz invariant physics quantities: Q^2, W, t, u, remain constant
  - Beam energy, scattered e angle and virtual photon angle will change as the result, thus event rates are dramatically different

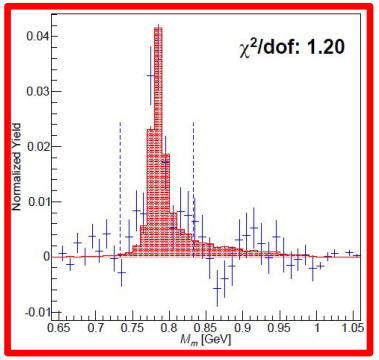
Iterative Procedure (Recipe) to a LT Separation

Improve ϕ coverage by taking data at multiple HMS angles, -3°< θ_p <+3°.





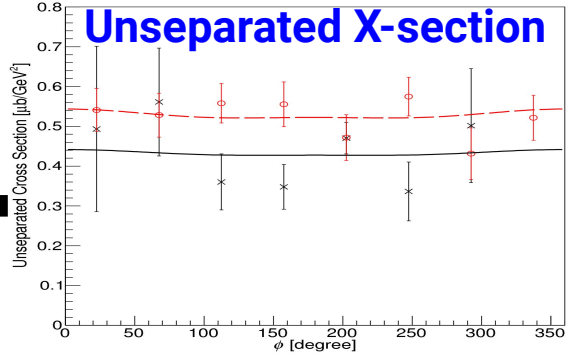
Background subtraction

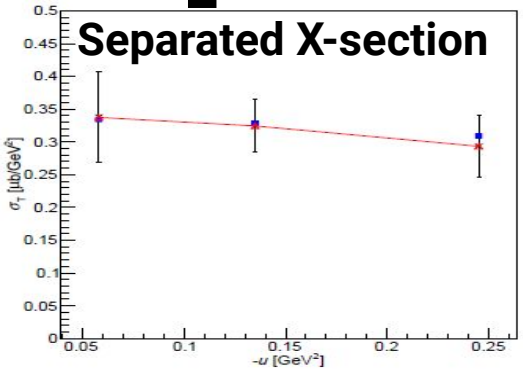


Ohio U. Grad. student Jacob Murphy is doing very similar analysis on pion Form factor.

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

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

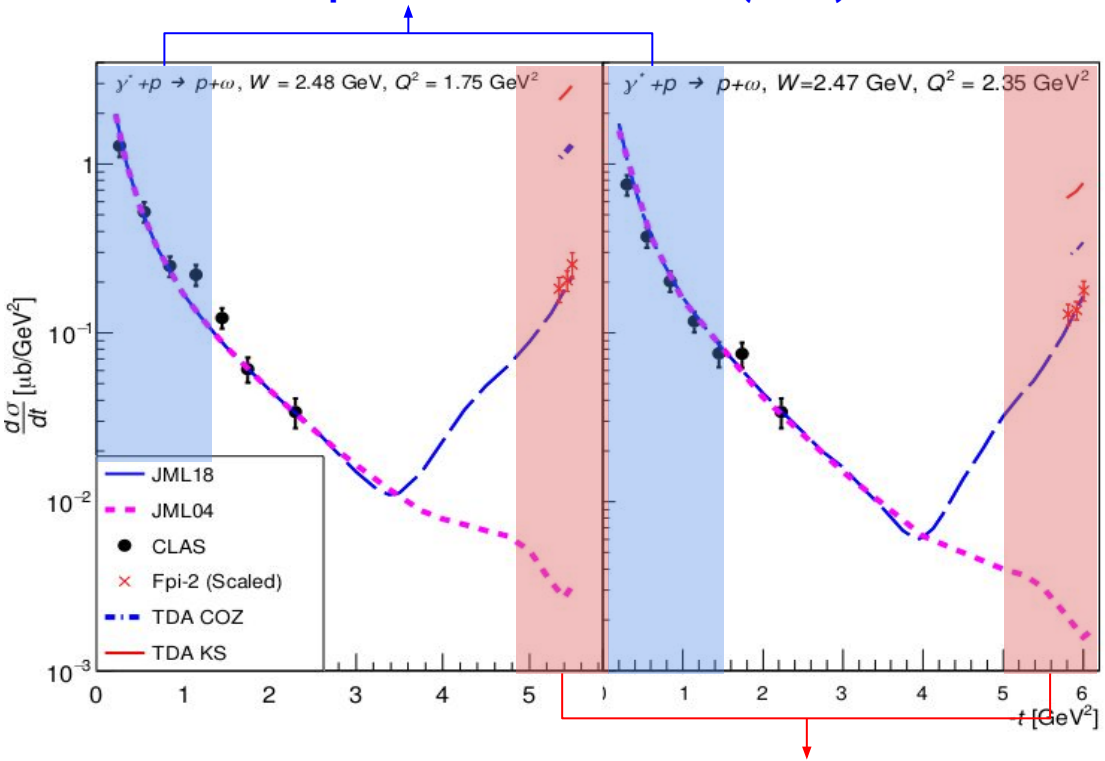
Extracting T, L, LT, TT via simultaneous fit

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

30

Results on Backward Angle Electroproduction

Forward ω electroproduction from CLAS 6 *(2004)*

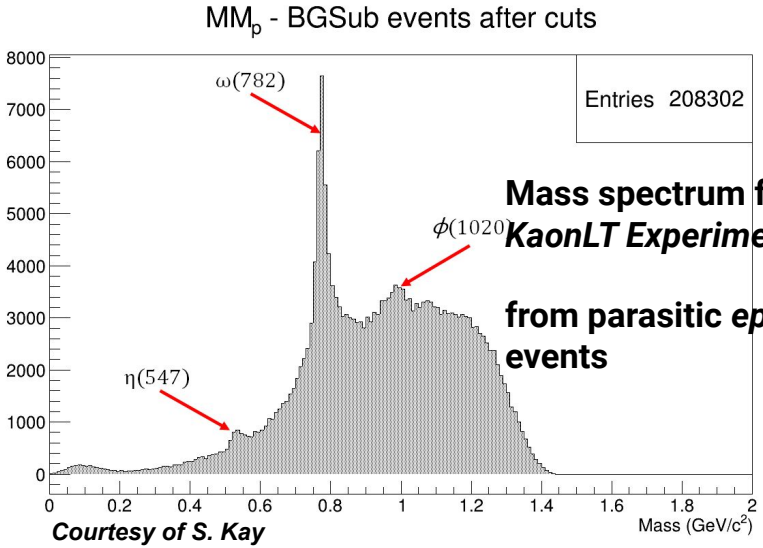


Backward angle ω electroproduction *(2017)*

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

Question: *u*-channel peaks for other processes?

- **Is there a u-channel peak for other processes?**
  - **Answer: Yes**
- **Evidences:**
  - 6 GeV pioneering analysis efforts from Hall C and CLAS 6
  - Parasitic data from 12 GeV Hall C experiments



Courtesy of S. Kay

Mass spectrum from 12 GeV *KaonLT Experiment 2020*

from parasitic *ep* coincidence events

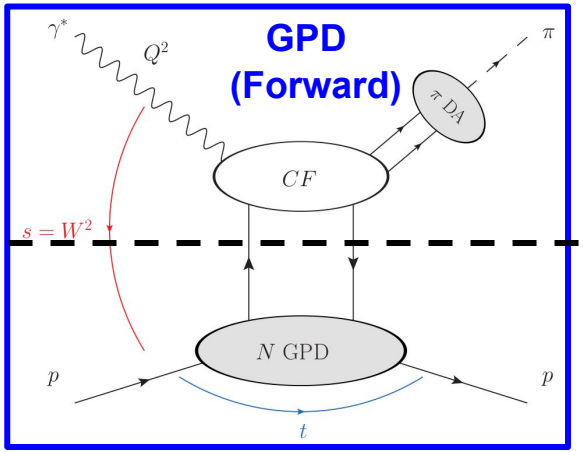
	$\sigma_T > \sigma_L$	$1/Q^8$ Scaling
π^0		
π^+		✓✓
π^-		
K^0		
$K^\pm$		
η	✓	✓
ρ		
ω	✓✓	✓
η'	✓	✓
ϕ	✓	✓
VCS		

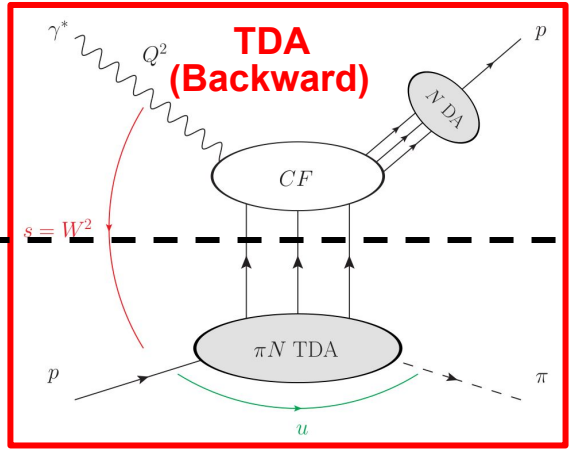
Confirmed!
By CLAS6 π^+

Parasitic Hall C Study

Confirmed! By Hall C 6 GeV ω

GPD, SPD and TDA (Hard Structure)





Hard structure

Soft structure

Collinear factorization

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

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

Description to the unseen side of proton

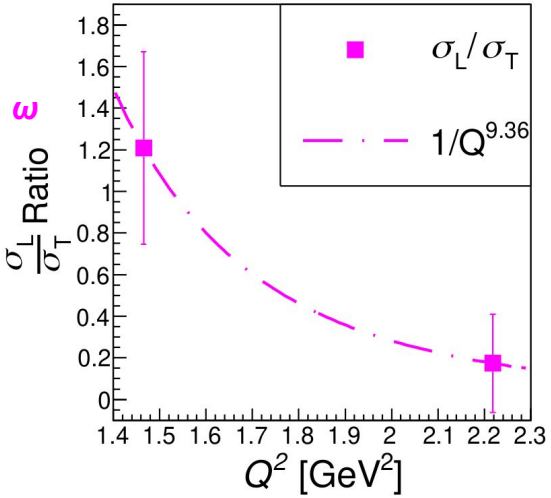
Complete description of Nucleon

- **GPD**: It is extracted predominantly based in the forward angle observables.
- **TDA**: meson-nucleon Transition Distribution Amplitude (TDA) only accessible through backward (u-channel) meson production.

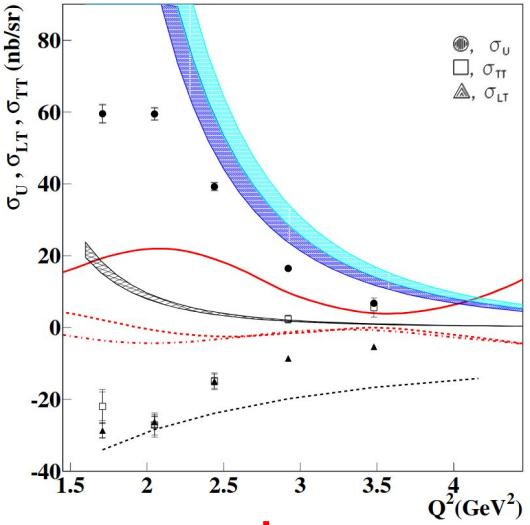
Validation of TDA Factorization Scheme

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

Hall C 6 GeV Backward ω (My analysis, 2017)



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



Two qualitative predictions from TDA:

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

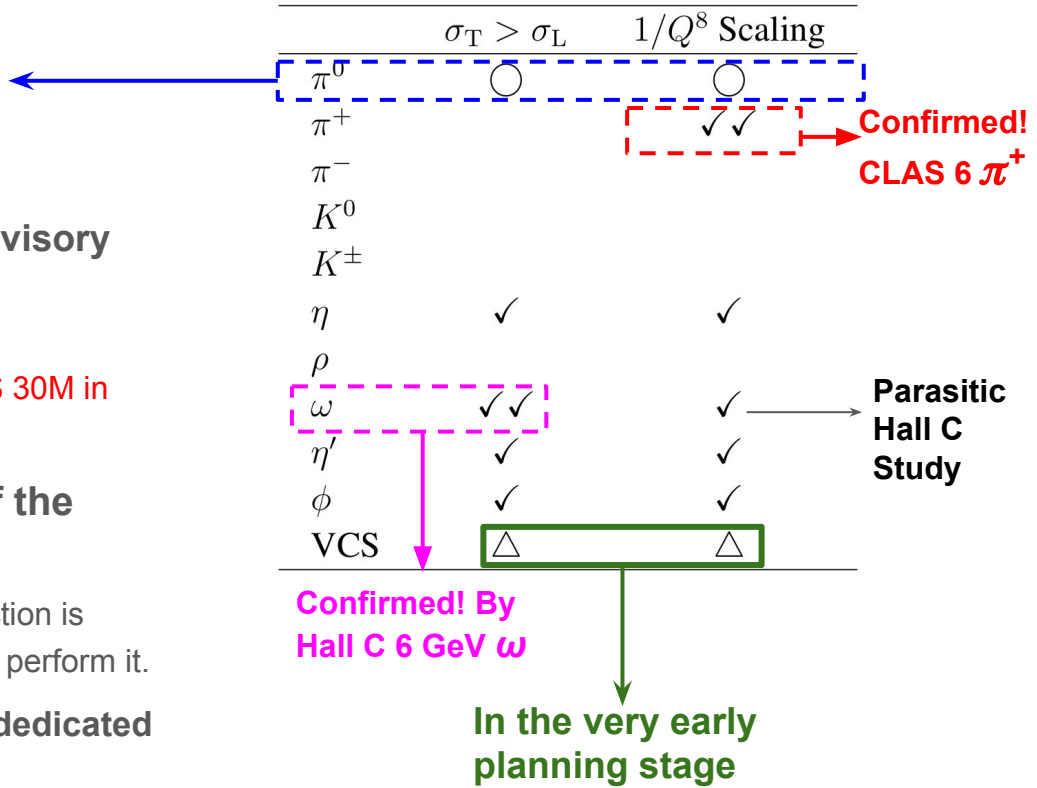
CLAS 6 backward π^+ production, (K. Park el. al, 2018)

This is the time for a dedicated backward angle study:

- **Simultaneously testing both TDA predictions**

First Dedicated Backward Angle Experiment

- **Probing backward-angle (*u*-channel) electroproduction of π^0 : E12-20-007**
  - First presented as Letter of Intent in 2018
  - Full proposal submitted in 2020
- **Received full approval by JLab Program Advisory Committee (PAC):**
  - Experiment fully approved for 29 PAC days
  - **Projected beam time: 48 days** (48 * $800k = $ 30M in electricity bill from tax payer)
- **PAC recognized the pioneering nature of the measurement**
  - The exploration of backward pion electroproduction is feasible, and JLab is an ideal venue at which to perform it.
- **Significant symbolic meaning: First approved dedicated u-channel experiment**



PR12-20-007 Collaborator List

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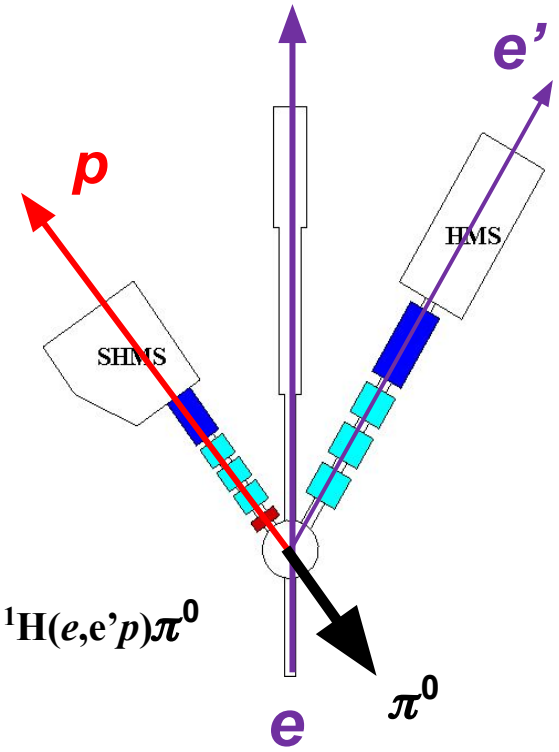
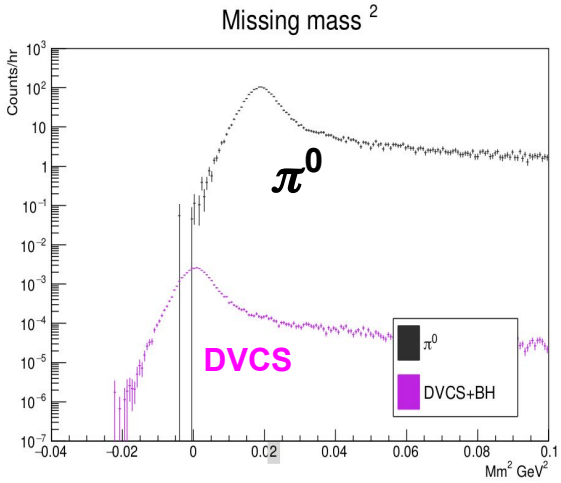
The George Washington University, Washington, DC, USA

Strong collaborators from Ohio U.

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:

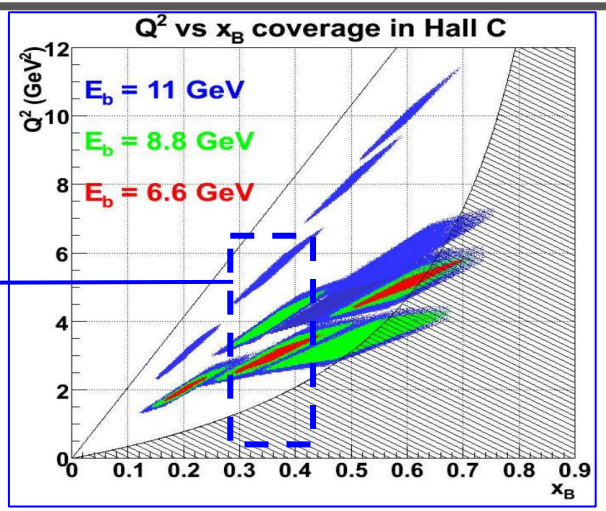
- **Q^2 coverage: $2.0 < Q^2 < 6.25$ GeV^2, at x=0.36 and W > 2 GeV L/T separated cross section @ Q^2= 2, 3, 4 and 5 GeV^2.**
- u coverage: $0 < -u' + 0.5 < 0.5$ GeV^2
- **Additional W scaling check @ Q^2 = 2 GeV^2**
- **Additional Q^2 scaling check @ Q^2 = 6.25 GeV^2**

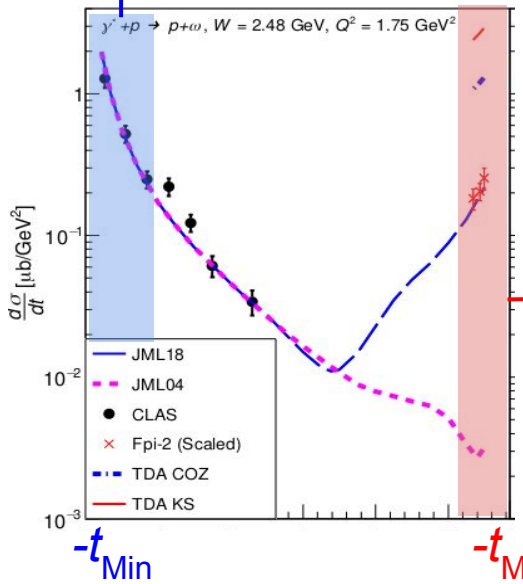
Objective 1: *Backward-angle Peaks*

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

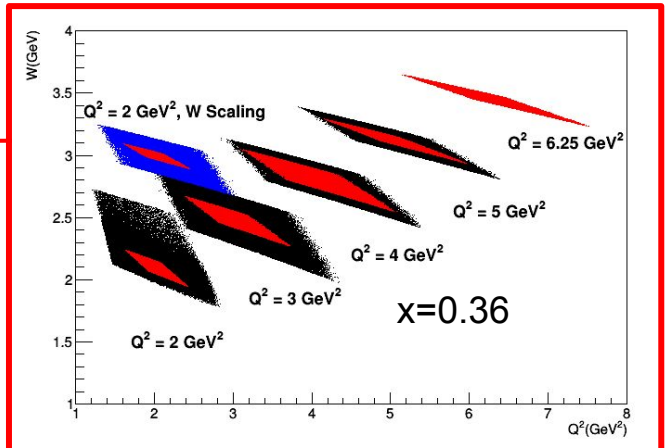
- E12-13-010 NPS experiment provides low -*t* L/T separated cross section

E12-13-010 NPS Experiment



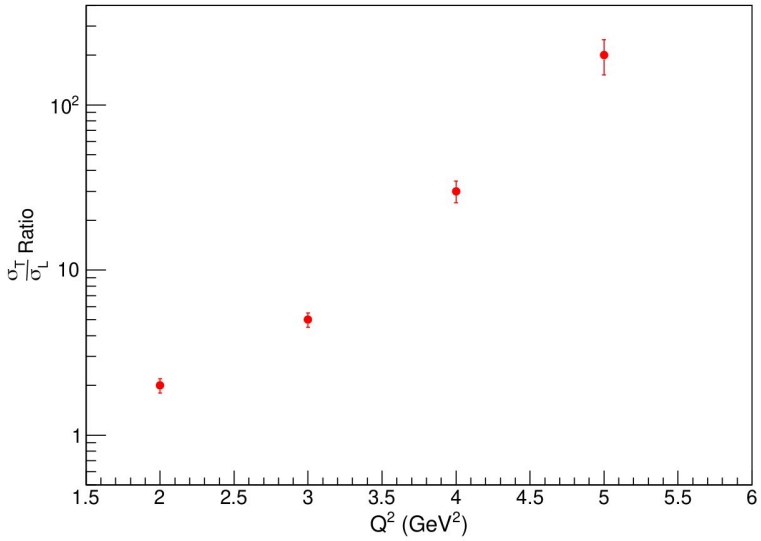


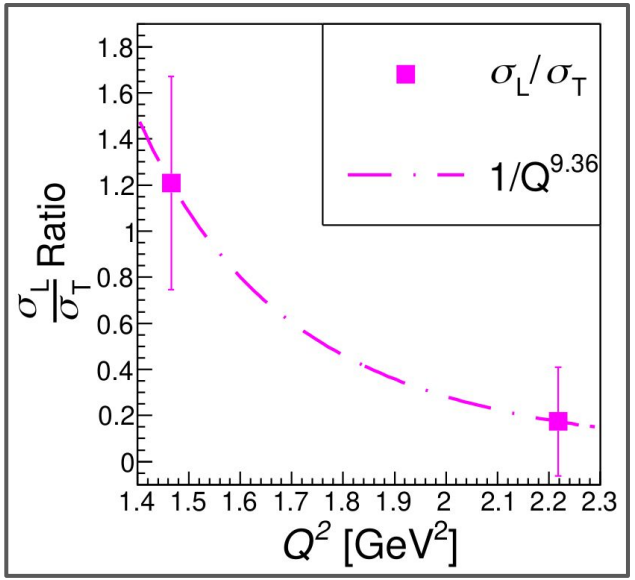
This proposal



Objective 2: *TDA Prediction #1* $\sigma_T > \sigma_L$

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



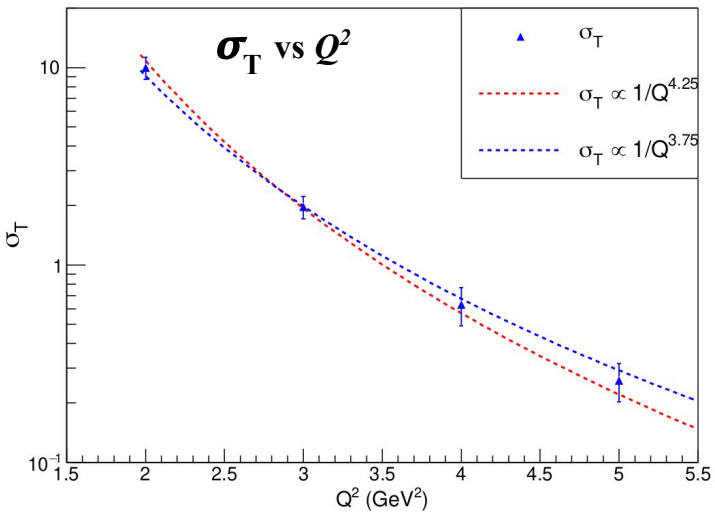


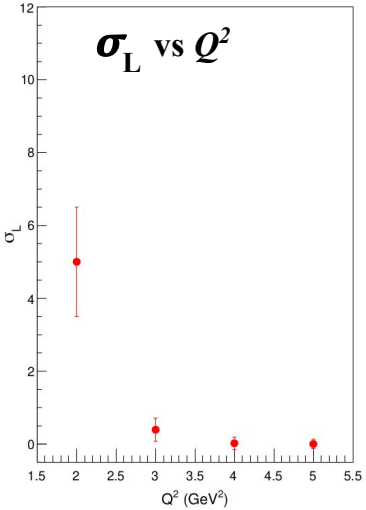
L/T ratio vs Q^2 (6 GeV F_π-2 experiment for ω)

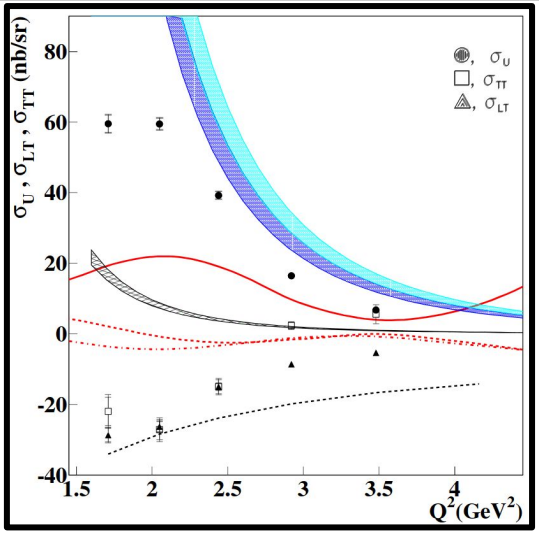
Objective 3: L/T Separated Cross section

- 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 3: *TDA Prediction #2,* $\sigma_T \propto 1/Q^8$ *Scaling*





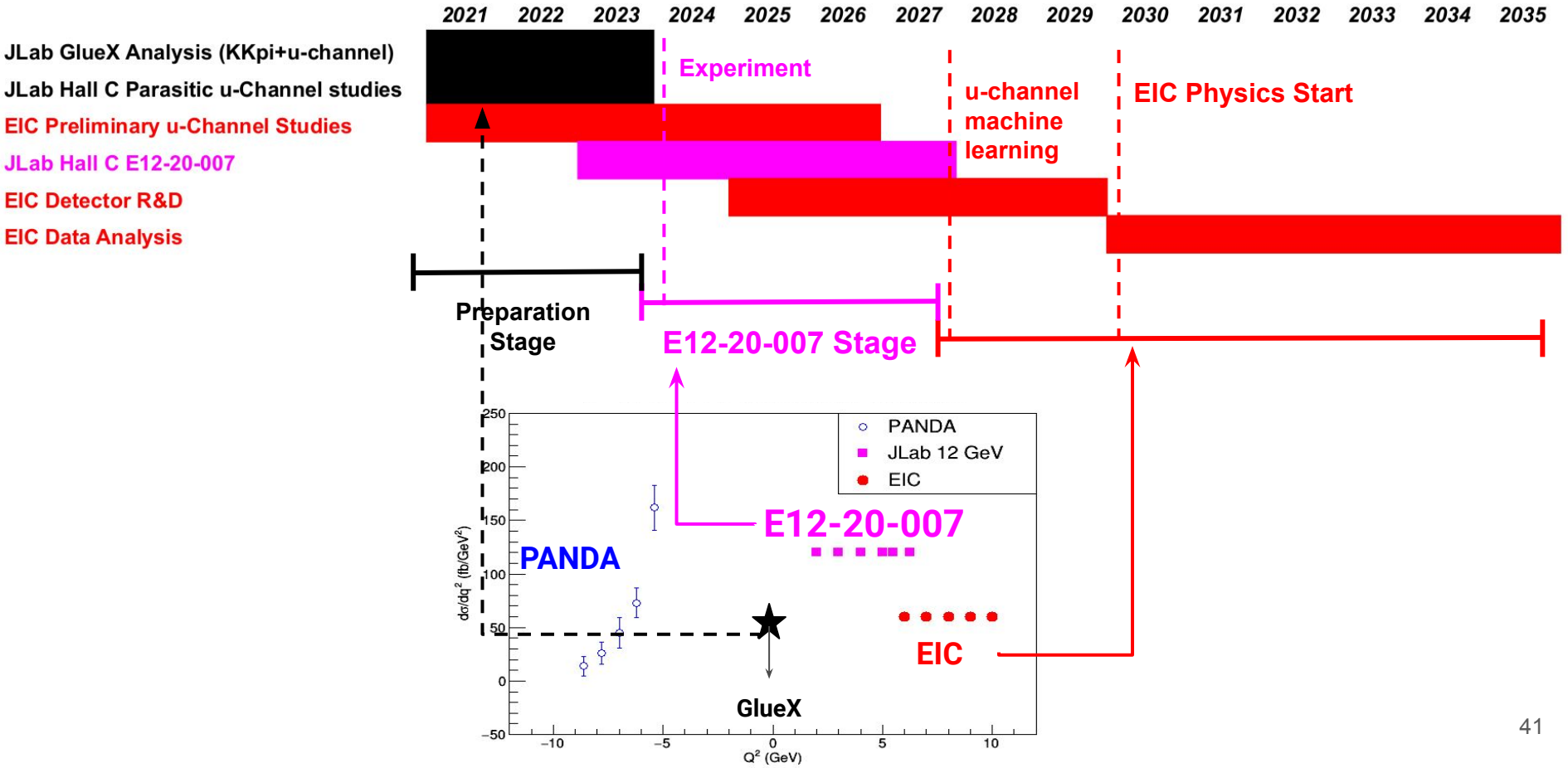


σ vs Q^2 (CLAS 6 π^+ result)

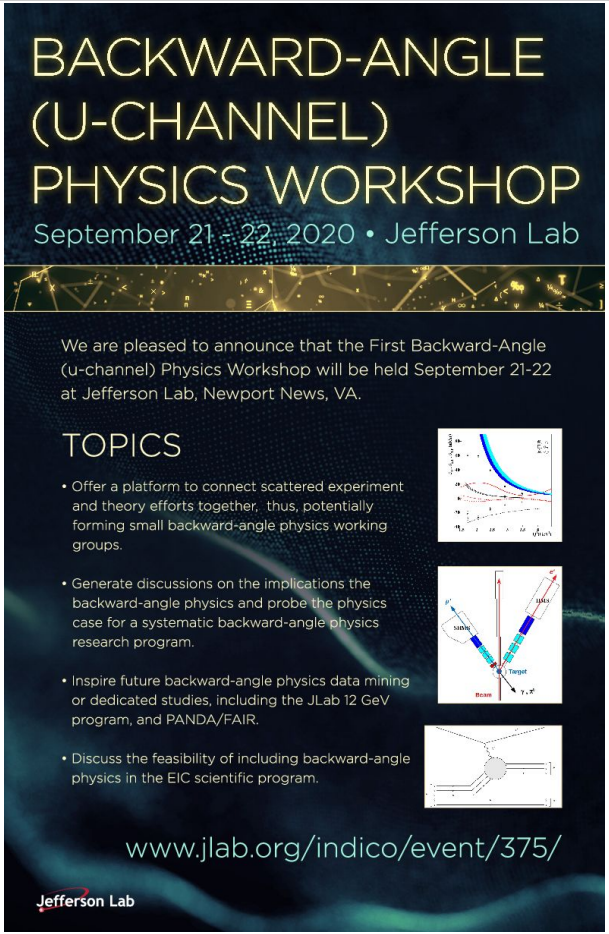
Objective 4: L/T Separated Cross section

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

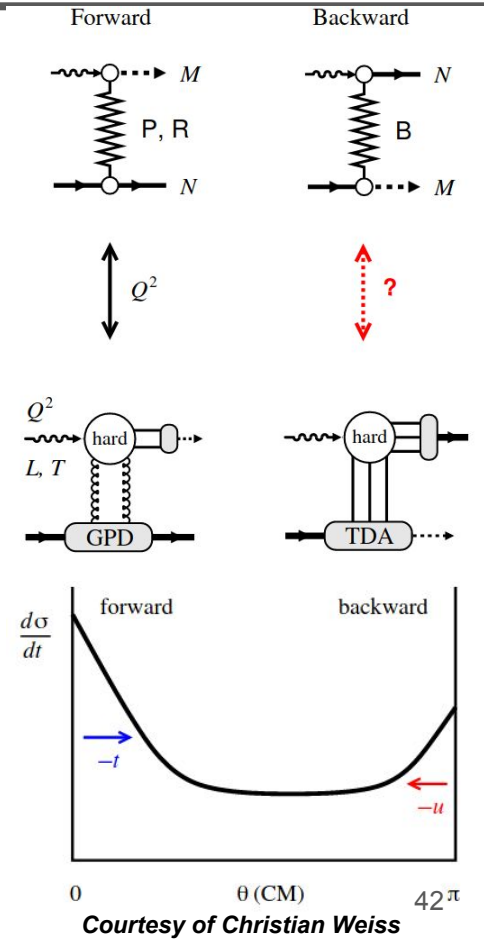
Research Plan: time projection JLab to EIC



u-channel Process Workshop *(September 2020)*

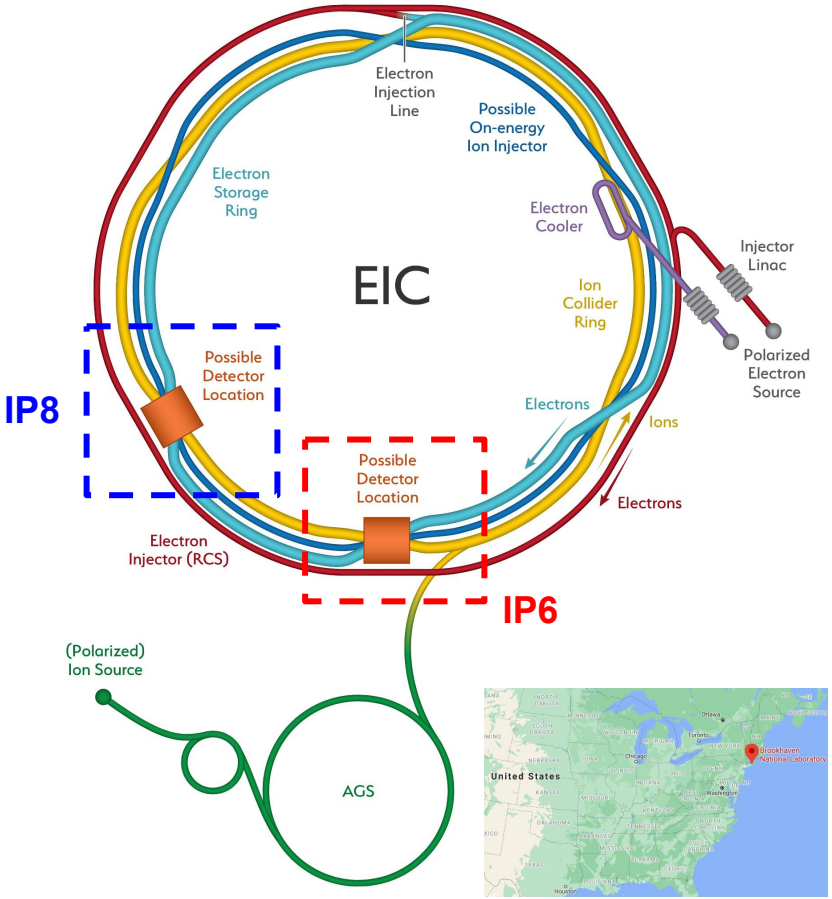


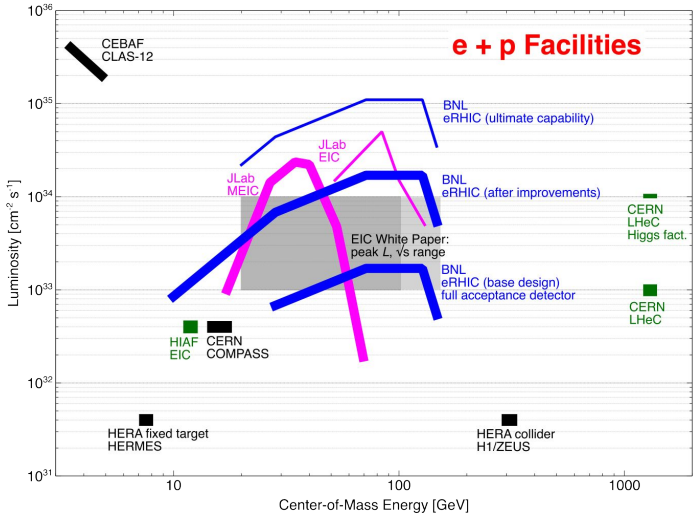
- **Workshop participation:**
  - 20 contributed talks, 2 discussion sessions.
  - Number of individual Participants: 51
- **Objectives:**
  - Connect scattered experiment and theory efforts
  - Discussions on systematic backward-angle physics research program.
  - Inspire future backward-angle physics studies.
- **A workshop whitepaper submitted for publication:**
  https://arxiv.org/pdf/2107.06748.pdf



Courtesy of Christian Weiss

Electron Ion Collider (EIC) @ BNL



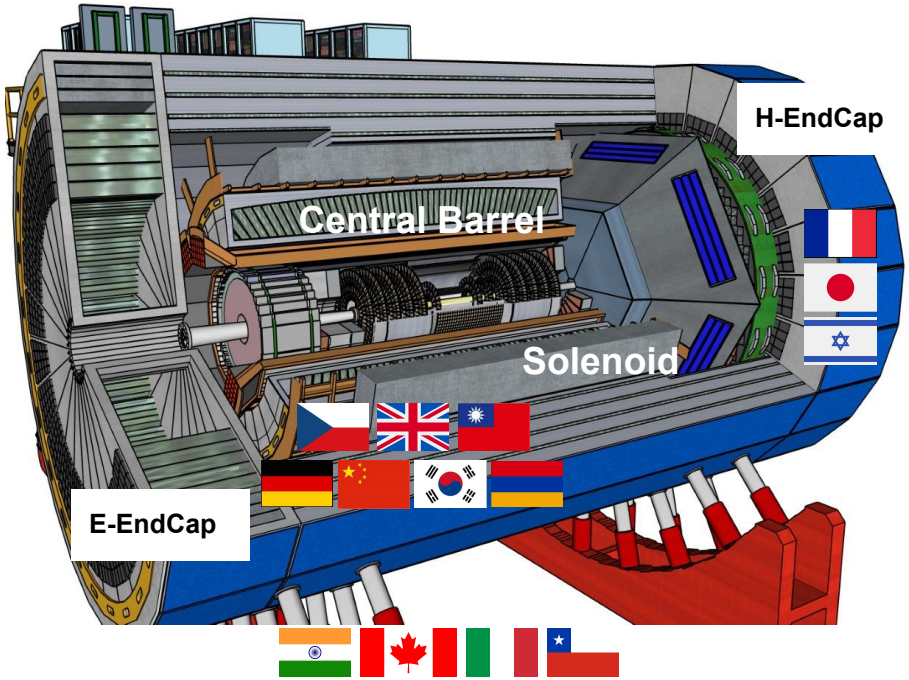


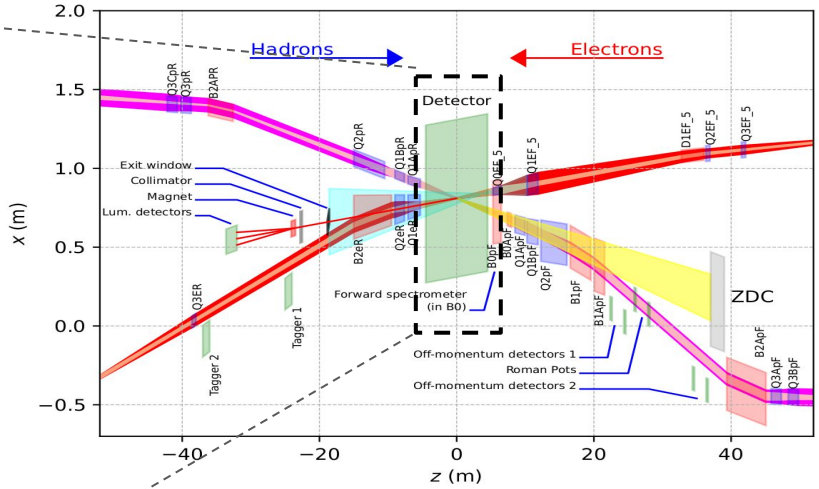
The Electron-Ion Collider (EIC) is the next generation "Dream Machine" for Nuclear Physics Research.

- Luminosity with 100 GeV p on 5 GeV e: 10 x10^{33} $cm^{-2}s^{-1}$ mi
- Project Location: Brookhaven National Laboratory (BNL), NY.
- Additional Information:
  - CD-0 approved ~ $2 B
  - Physics starts in 2031

EIC (ECCE) Detector Concept @ IP6

ECCE central detector concept





Main Features:

- Utilize babar magnet (1.4T)
- $ 200M
- A international effort
- Collaboration from ANL, ONL, JLab, LANL, LBL
- More to come!

OHIO UNIVERSITY

Ohio University if playing a major role in the early EIC project development !

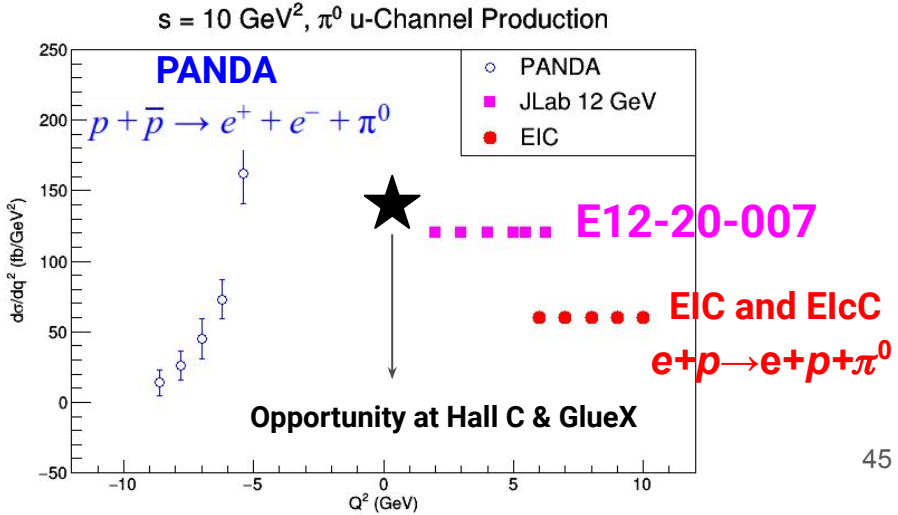
u-Channel studies at EIC

7.4 Understanding Hadronization

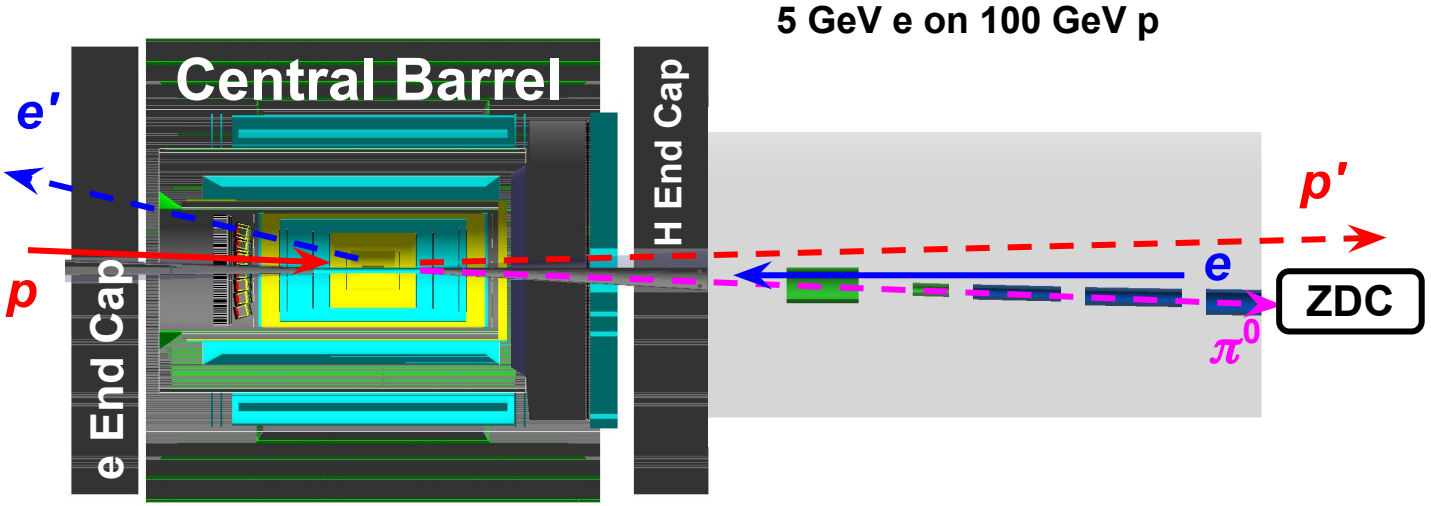
There is great potential also in studying **new particle production mechanisms** such as exclusive backward *u*-channel production. Given its high luminosity the EIC may be able to discover fundamental QCD particle production processes with low cross sections such as via hard (perturbative) C-odd three gluon exchange.

EIC YELLOW REPORT

- **As postdoctoral fellow at JLab EIC Center: developed Backward π^0 program for EIC**
  - Offers synergy to other planned data set
  - Feasibility studies included as part of the EIC Yellow report (published last week)

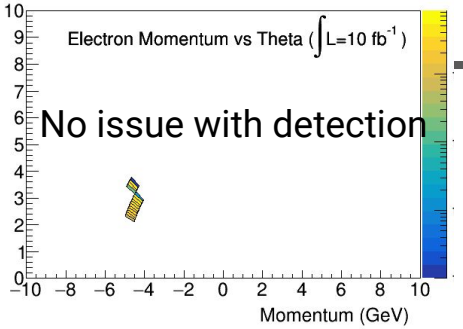


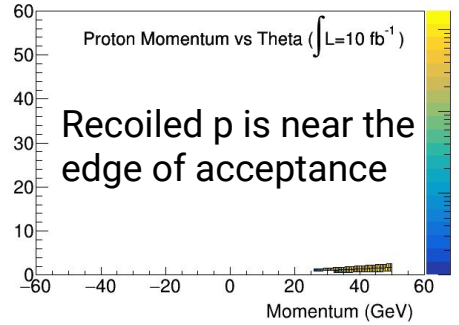
u-Channel Meson Production Setup

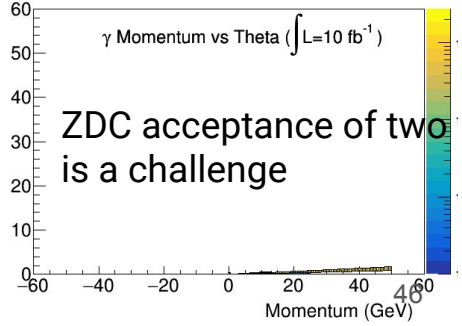


Q^2 (GeV^2)	W (GeV)	x_B	$\theta_{e'}$ (deg)	$\eta_{e'}$	$P_{e'}$ (GeV)	$\theta_{p'}$ (deg)	$\eta_{p'}$	$P_{p'}$ (GeV)	θ_{π^0} (deg)	η_{π^0}	P_{π^0} (GeV)	$-t$ (GeV^2)	$-u$ (GeV^2)
6.2	3.19		152	1.39	5.31	-1.84	4.13	43.40	1.43	4.38	56.29	14.84	-0.37
7.0	3.19		150	1.32	5.35	-1.92	4.09	45.50	1.43	4.38	54.12	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

e' p' π^0



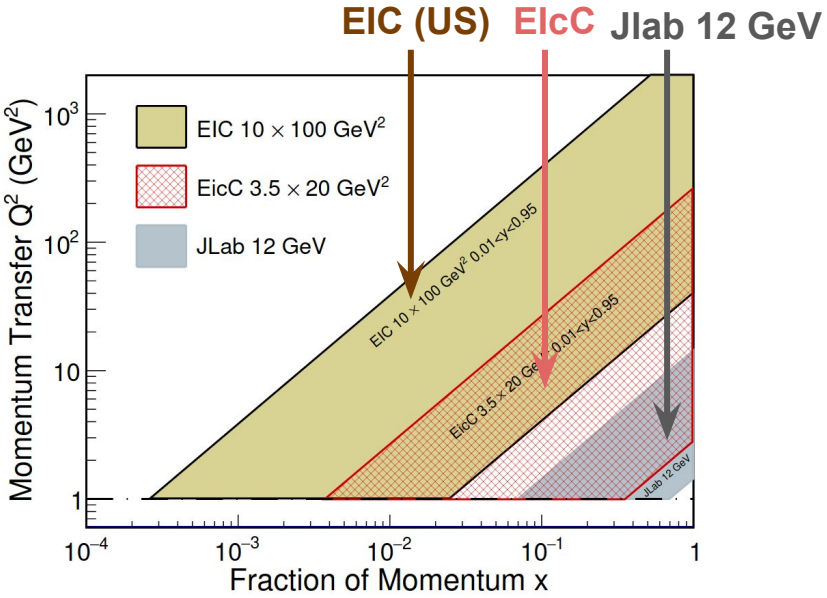


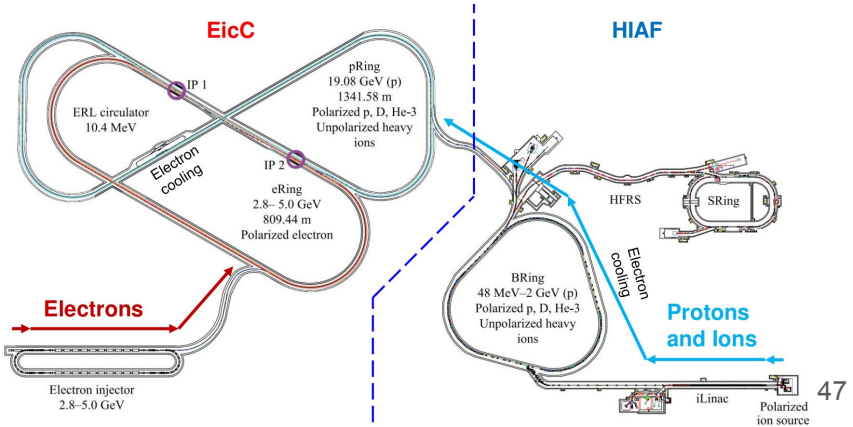


u-channel π^0 at EIC in China (EicC):

The Electron-Ion Collider in China (EicC):

- **Nominal energy: 3.5 GeV e on 20 GeV proton**
- **Luminosity reaches 10^{33} cm^{-2} s^{-1} (comparable to EIC)**
- **Physics ready by 2031**
- **Is EicC competitor to the EIC?**





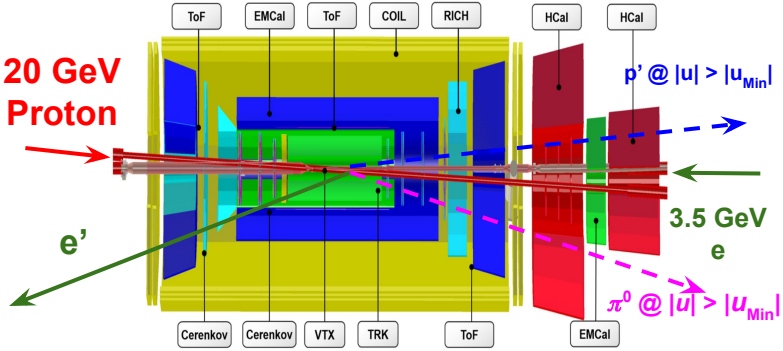
Kinematics Table for $u = u_{min}$, $s = 10$ GeV^2

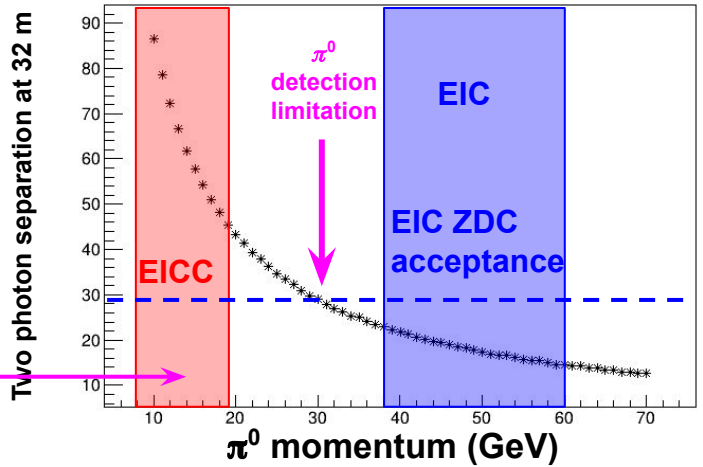
	e'			p'			π^0			
Q^2 (GeV^2)	$\theta_{e'}$ (deg)	$\eta_{e'}$	$P_{e'}$ (GeV)	$\theta_{p'}$ (deg)	$\eta_{p'}$	$P_{p'}$ (GeV)	θ_{π^0} (deg)	η_{π^0}	P_{π^0} (GeV)	P_γ (GeV)
3.4	150	1.31	3.62	15.00	2.03	5.83	2.86	3.69	13.99	7.00
4.7	145	1.15	3.71	14.26	2.07	7.13	2.86	3.69	12.61	6.31
6.2	140	1.10	3.81	14.13	2.09	8.26	2.86	3.69	11.39	5.70
8.0	135	0.88	3.93	13.91	2.10	9.97	2.86	3.69	10.05	7.02

Gaining Momentum!

Much more comfortable ! No special attention needed

Momentum causing acceptance issue

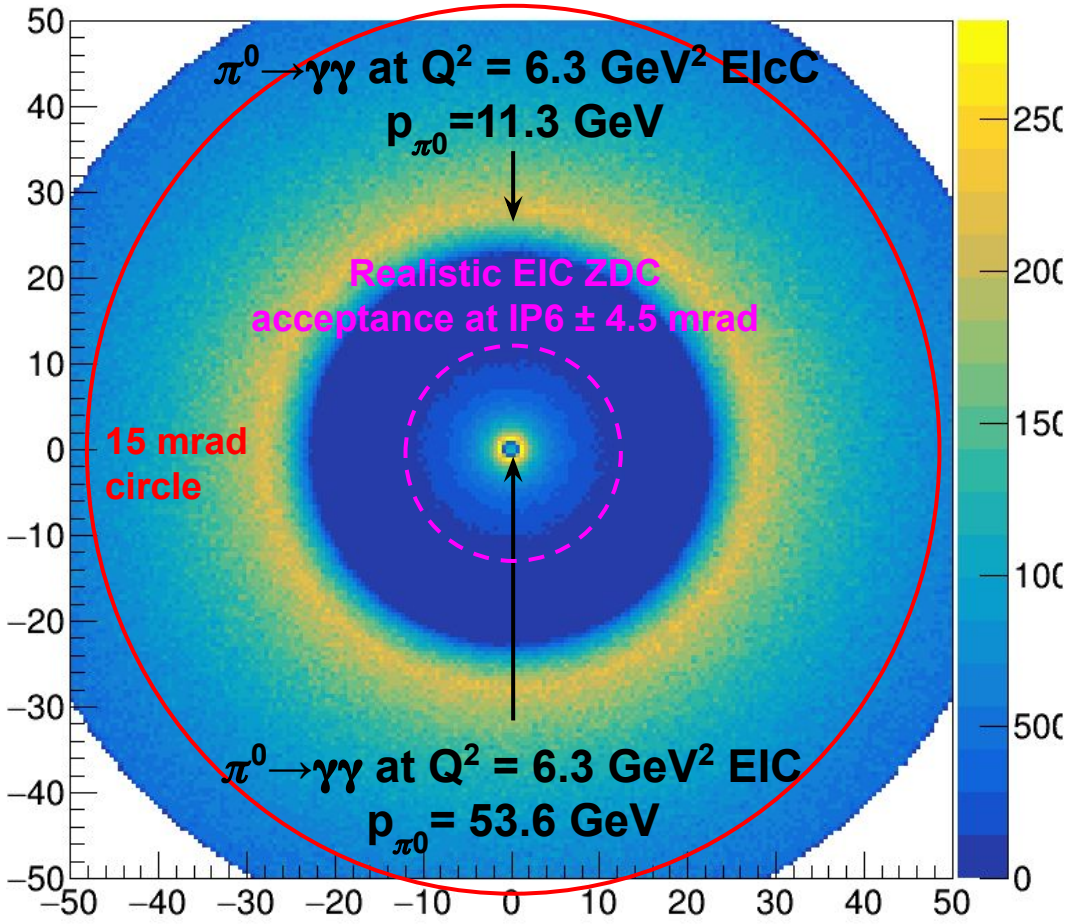




Viable observable

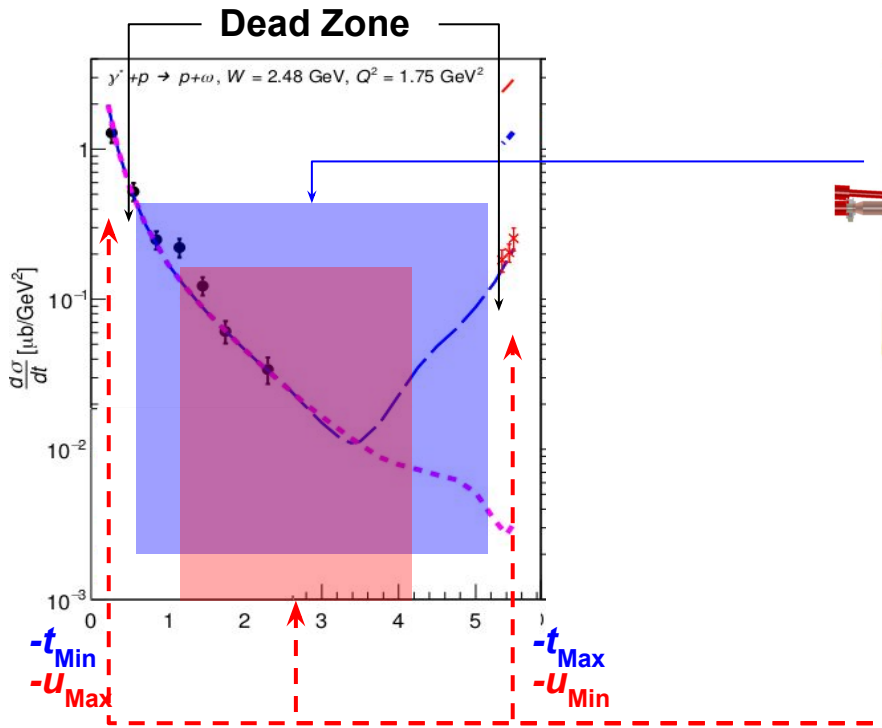
- Not completely exclusive **(ep, e'p'γ) γ**
- Huge backgrounds!

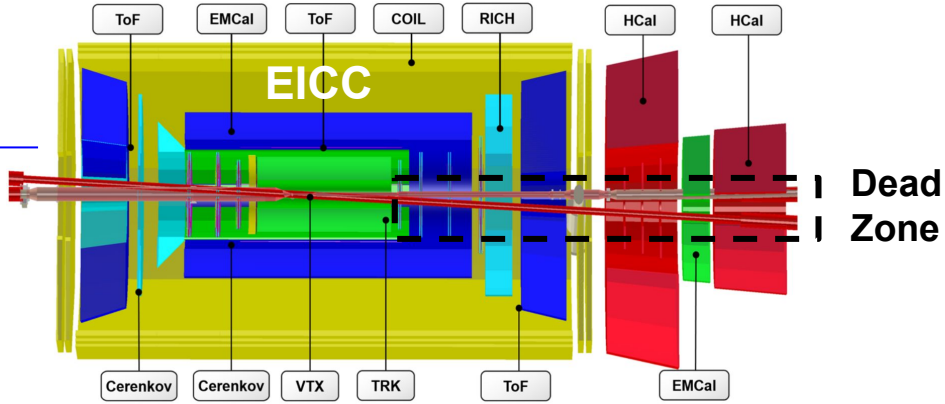
Why ZDC is less important for *u*-Channel π^0 at EIcC

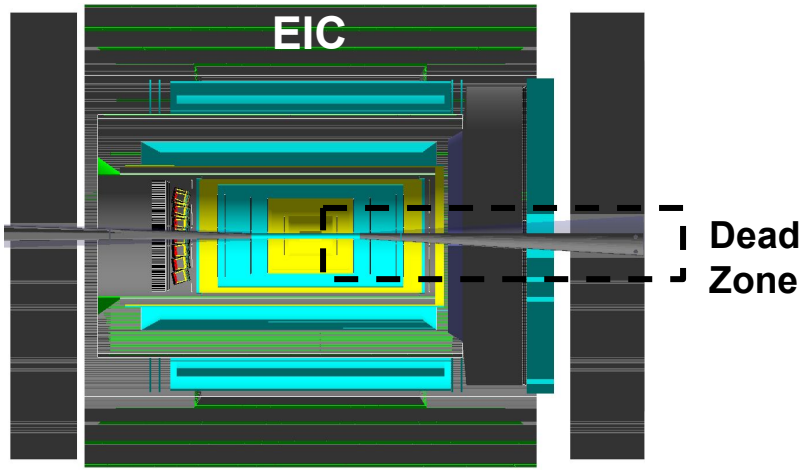


- At Q^2 = 6.3 GeV^2 , s = 10 GeV.
  - EIC: $\pi^0 \rightarrow \gamma\gamma$ ($p_{\pi 0}$= 53.6 GeV)
  - EicC: $\pi^0 \rightarrow \gamma\gamma$ ($p_{\pi 0}$= 11.3 GeV)
- **Assumption**: ZDC is at 30m from IR.
- **Conclusion:** ZDC acceptance at EicC must exceed ± 15mrad.
- **Recommendation:** minimized the the ZDC acceptance and reduce the dead zone near the beamline.

EIC and EicC Complementarity



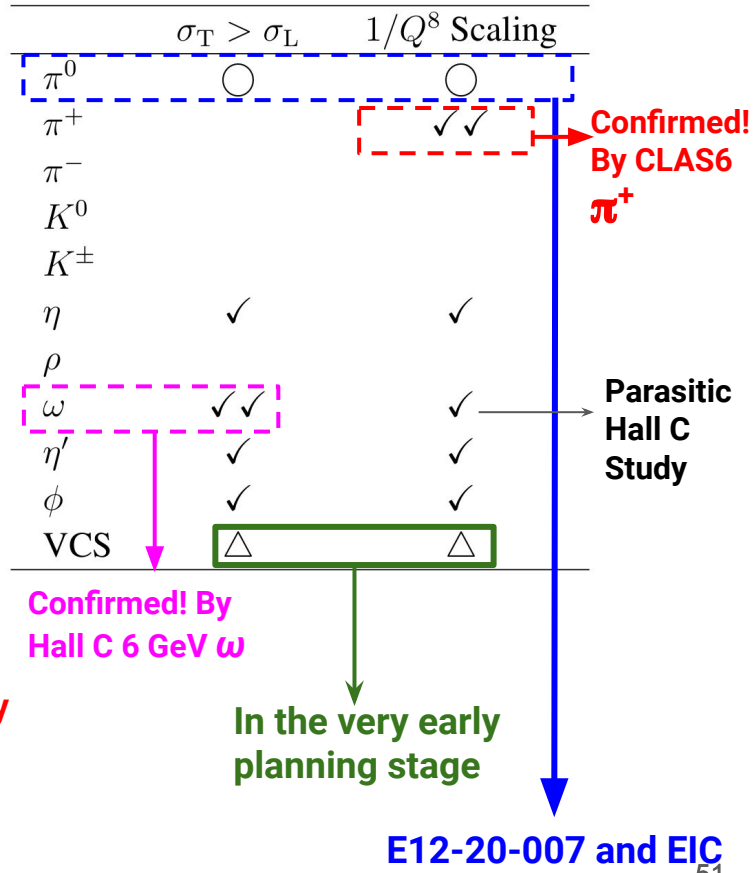




- EIC and EICC should be designed to avoid common dead zone overlap in phasespace. Studies needed
- Angular dependence asymmetry study is possible (needed to extract TDAs)

Timeline Recap of Events in Backward Proton Structure Study

- 2000: TDA framework first published
- 2003: JLab 6 GeV experiment collected parasitic ω and π
- 2017: u-Channel ω analysis completed (my graduation)
- 2018:
  - CLAS u-Channel π^+ published
  - u-Channel π^0 letter of intent submitted to JLab PAC
- 2019: u-Channel ω result published
- 2020:
  - CLAS 6 u-channel π^0 Beam Spin Asymmetry result published
  - u-Channel π^0 full proposal approved by PAC
  - JSA Post-doctoral Award given to *u*-channel programs
  - JLab EIC fellowship awarded to investigate *u*-channel π^0 at EIC
  - First u-channel physics workshop was hosted
- 2021 (present): EIC yellow report published with *u*-channel π^0 study
- 2025: Experiment E12-20-12 runs at Hall C
- 2031: Physics start at EIC and EIcC, data available for u-channel π^0

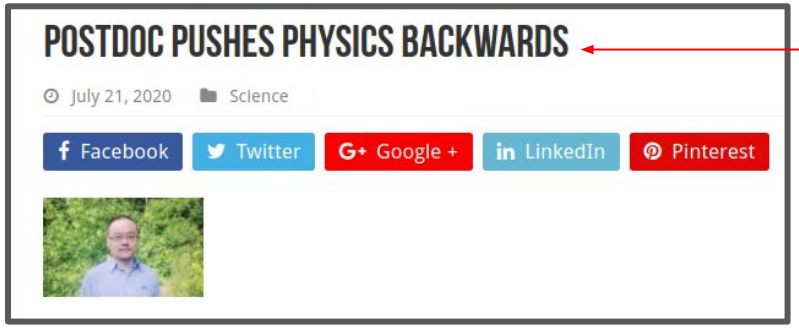


Summary

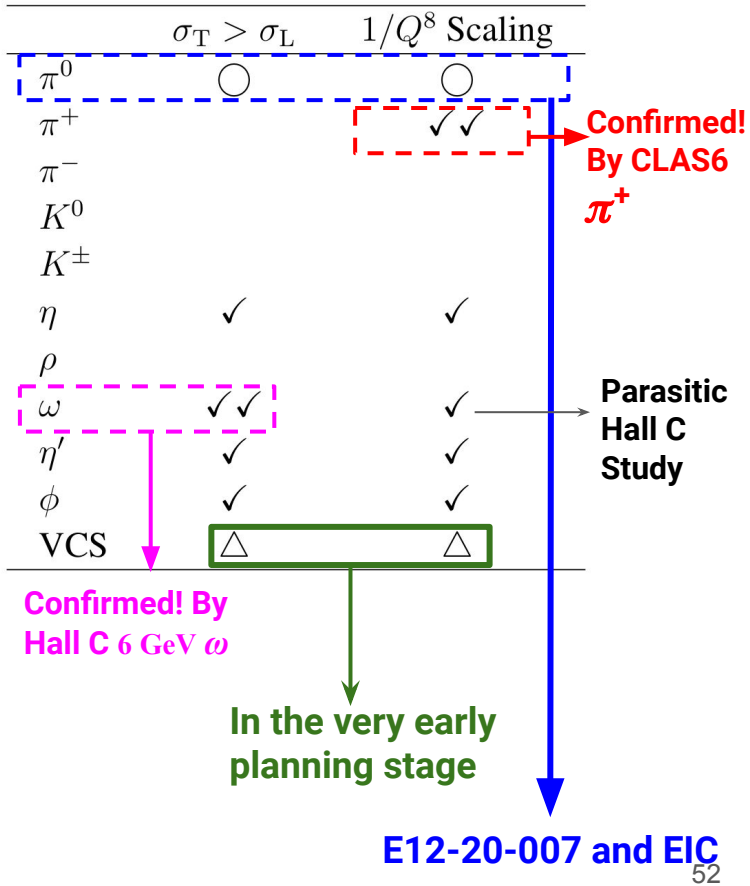
We are introducing a new path to probe the unseen side of a nucleon

In 10 years:

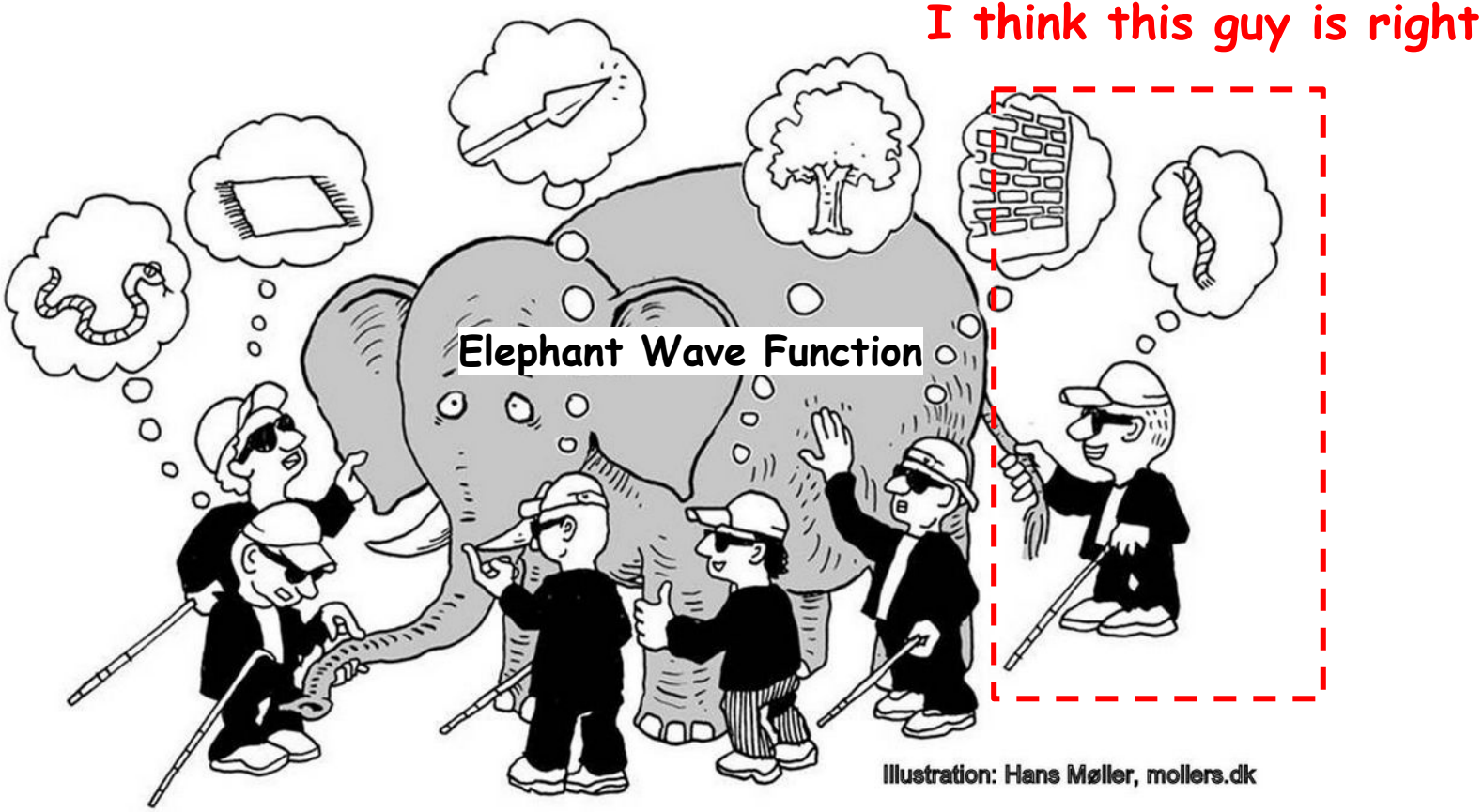
- **Together to push backward angle physics forward**
- To guide and inspire more young scientists to study this dark side of proton.



No, that is not what I am doing.



Thank You!


I think this guy is right
Elephant Wave Function
Illustration: Hans Møller, mollers.dk

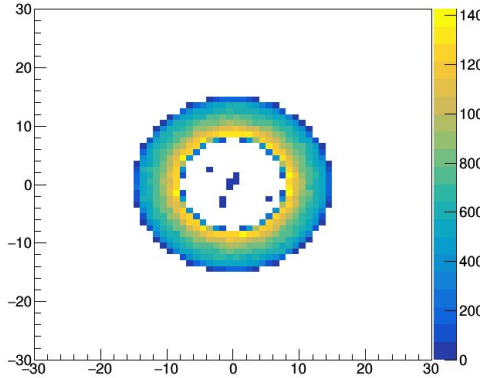
Physics background (to our current best knowledge)

- 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

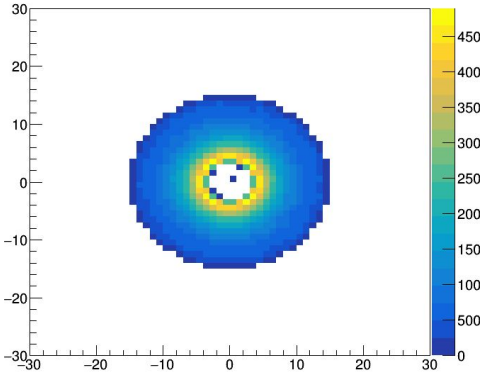


- Single photon case:
  - Primary reaction: e+p-> e'+p' + π^0
  - Ideal expected trigger: e'+p'+ γ
  - Physics background: DVCS, eta, Λ->n+π^0
  - Less than ideal trigger: e'+γ
  - Background: many many possibility

2 γ hit pattern

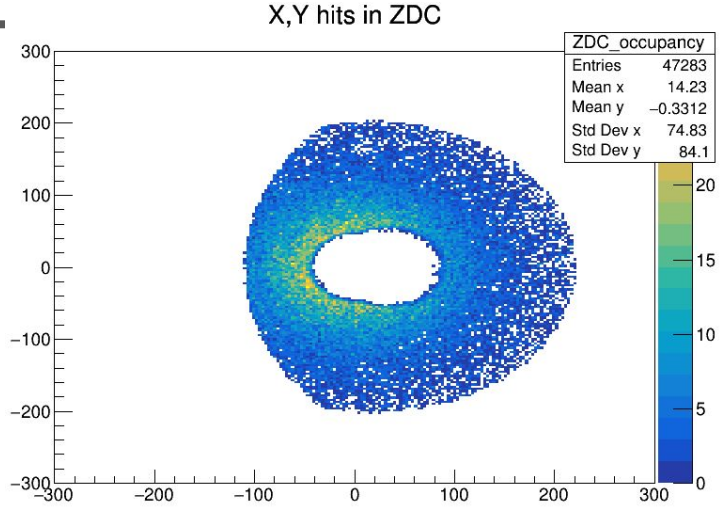
60 GeV/c π^0

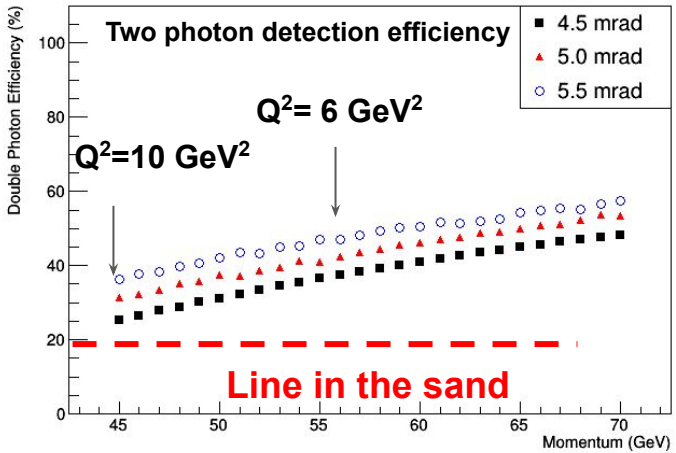
4.5 mrad acceptance

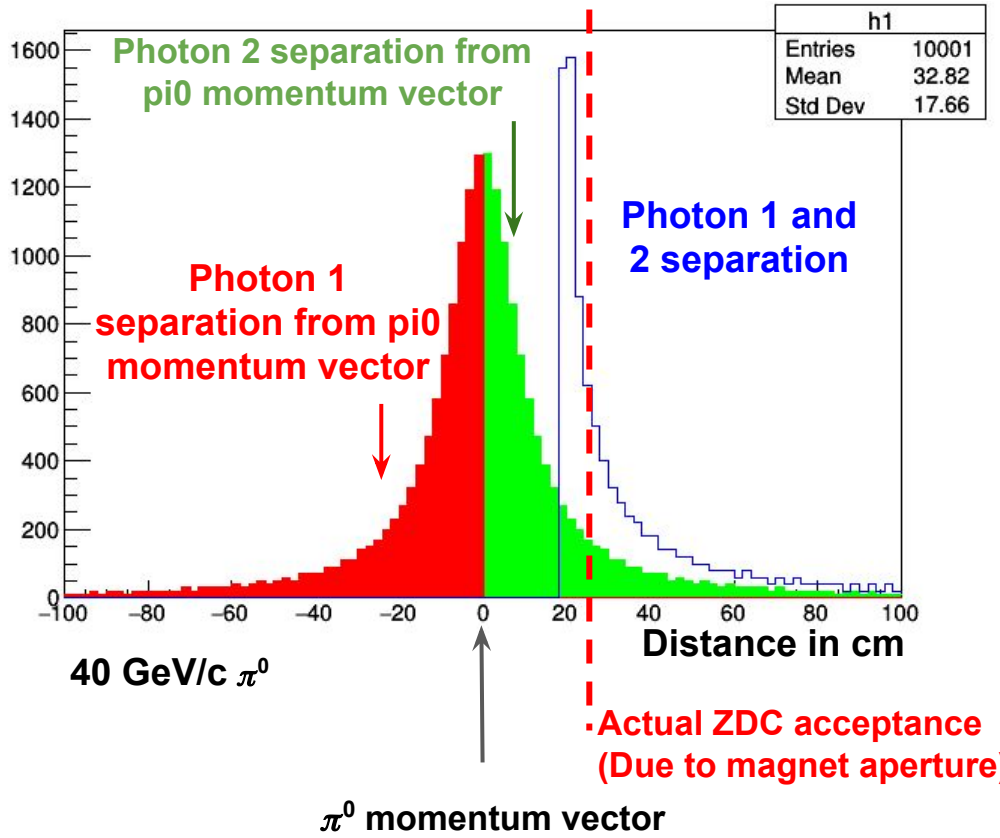


- We can use the double photon event to normalize the single photon events

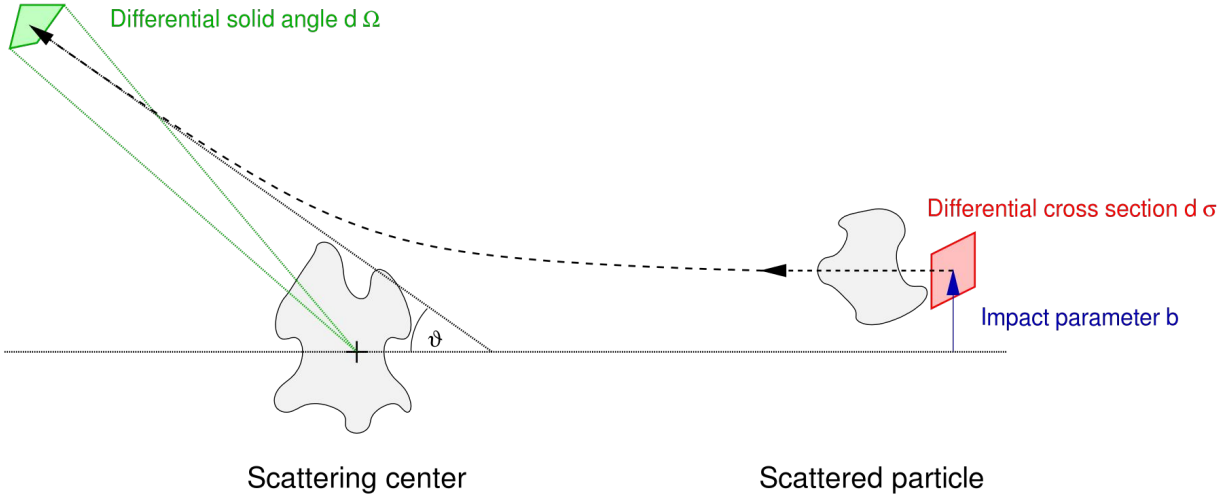
Realistic ZDC Acceptance (through magnets Aperture)



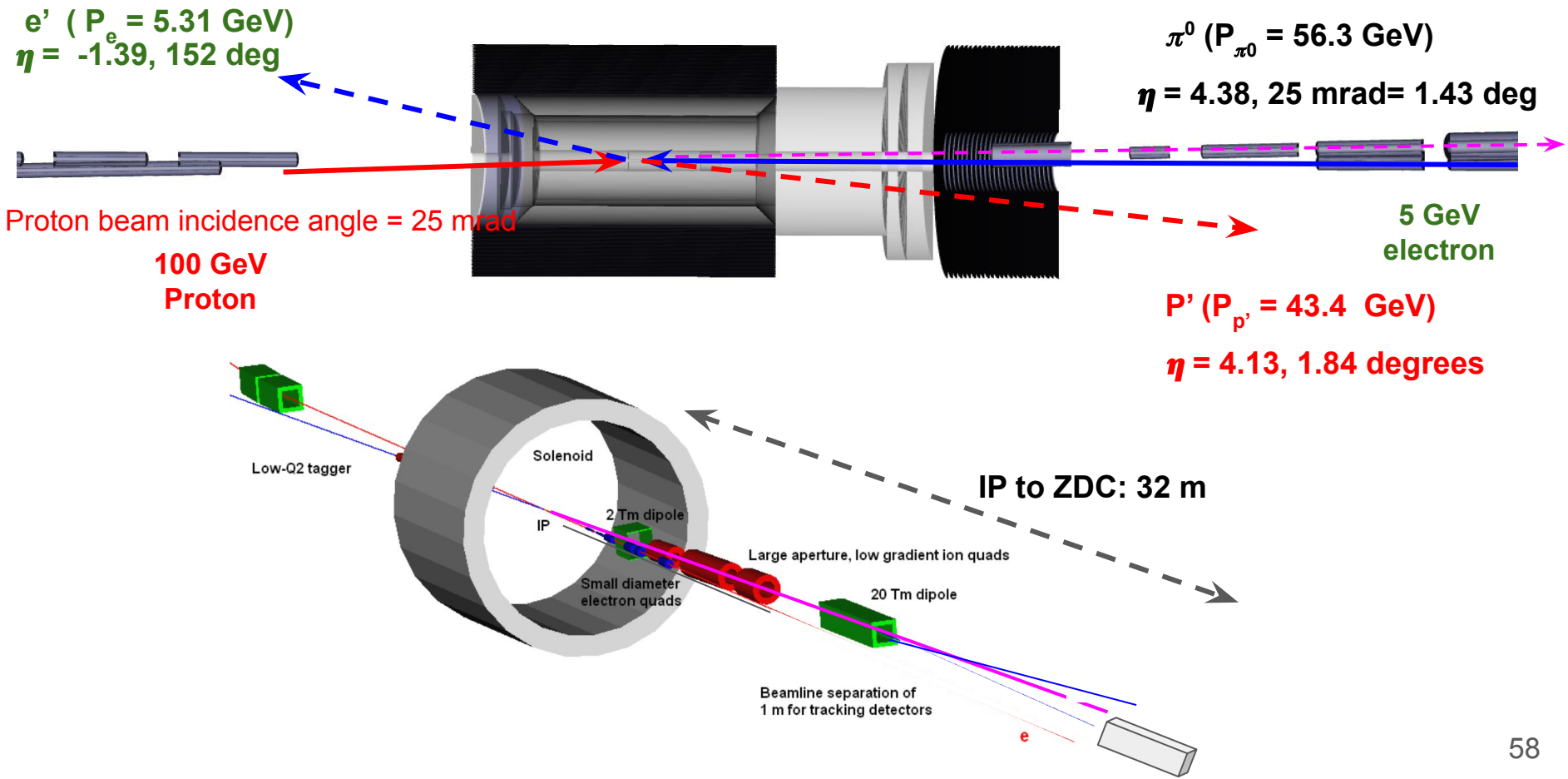




Rutherford Scattering



Interaction picture



Manpower & Funding Required to Complete E12-20-007

- **Mississippi State as leading institution for Completing E12-20-007**
  - **Man power for experiment:** Faculty members + **2 Ph.D students + 1 postdoc**
  - **Additional theory support** to achieve publication: **1 theory postdoc**
  - Other in kind contributions from other institution (Regina, W&M, etc)
- **DOE early career award:**
  - Include **2 Ph.D students + 1 Postdoc**
  - Fallback: standard DOE research grant
- **External funding:**
  - **Funding commitment from JLab Hall C** leadership for ⅓ to ½ post-doc: **~$27K**
  - ½ theory postdoc funding provided by JLab theory center ~$ 27k
  - Student/Postdoc Fellowship through JLab EIC Center
    - As 2020 recipient: 36K (salary+admin) + travel expenses
    - Student: 13K
- **A guaranteed success if the experiment adapt the existing MSU infrastructure by Dipangkar and Lamiaa !**

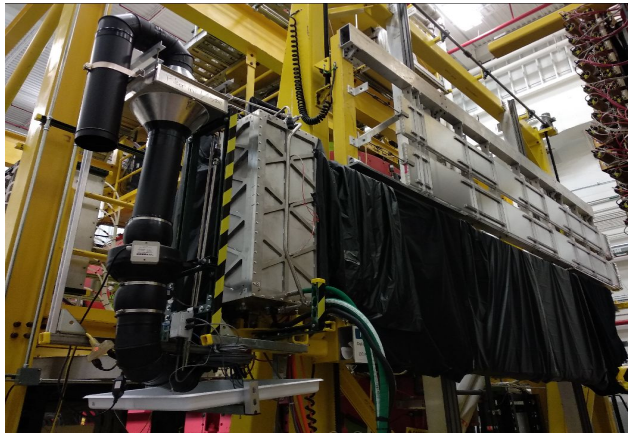
Two Cherenkov Detectors experiences and EIC R&D

Heavy Gas Cherenkov Detector Construction for JLab Hall C

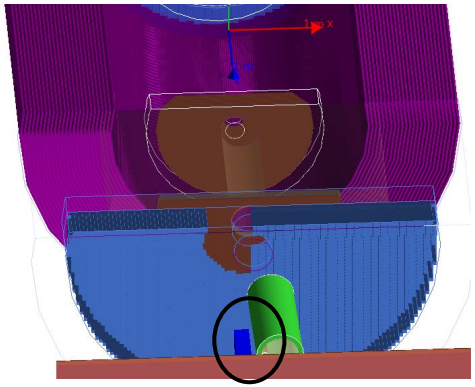
- 2009-2017
- Led by Dr. G. Huber
- My contribution: Design, prototyping, Geant4 simulation, final assembly

GlueX DIRC Detector

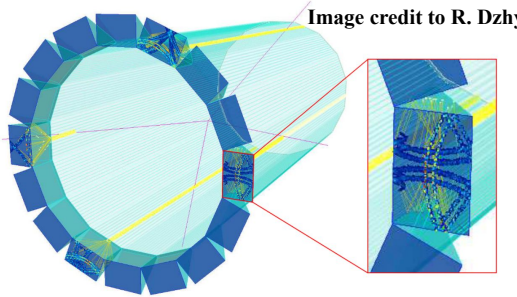
- 2017-Present
- Led by Dr. J. Stevens
- My contribution: Prototyping, final assembly, maintenance, data analysis



EIC Detector R&D

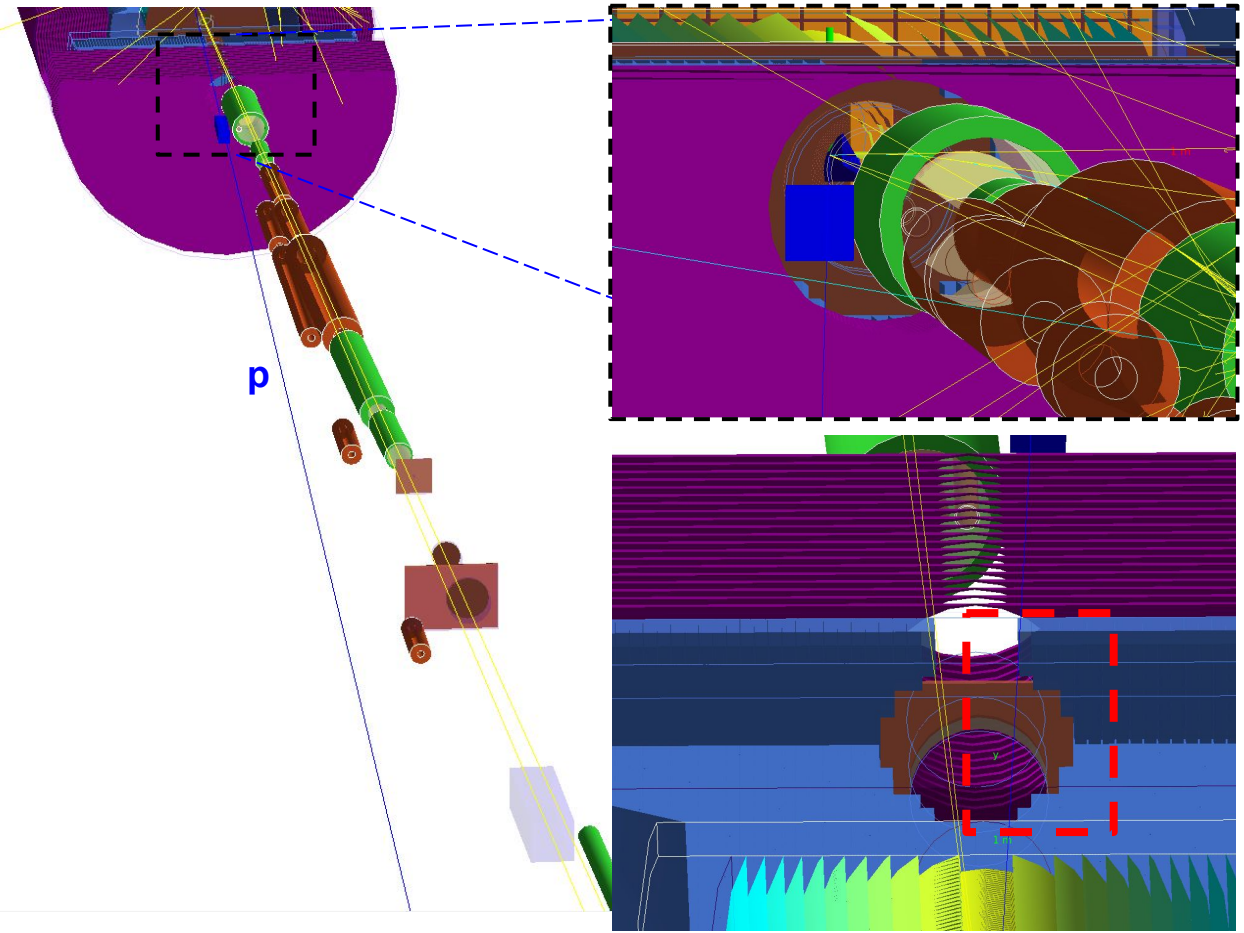


High Eta Counter for backward π^0



High-performance-DIRC: CUA,JLab, W&M, GSI (Germany), University of Hawaii, Indiana University

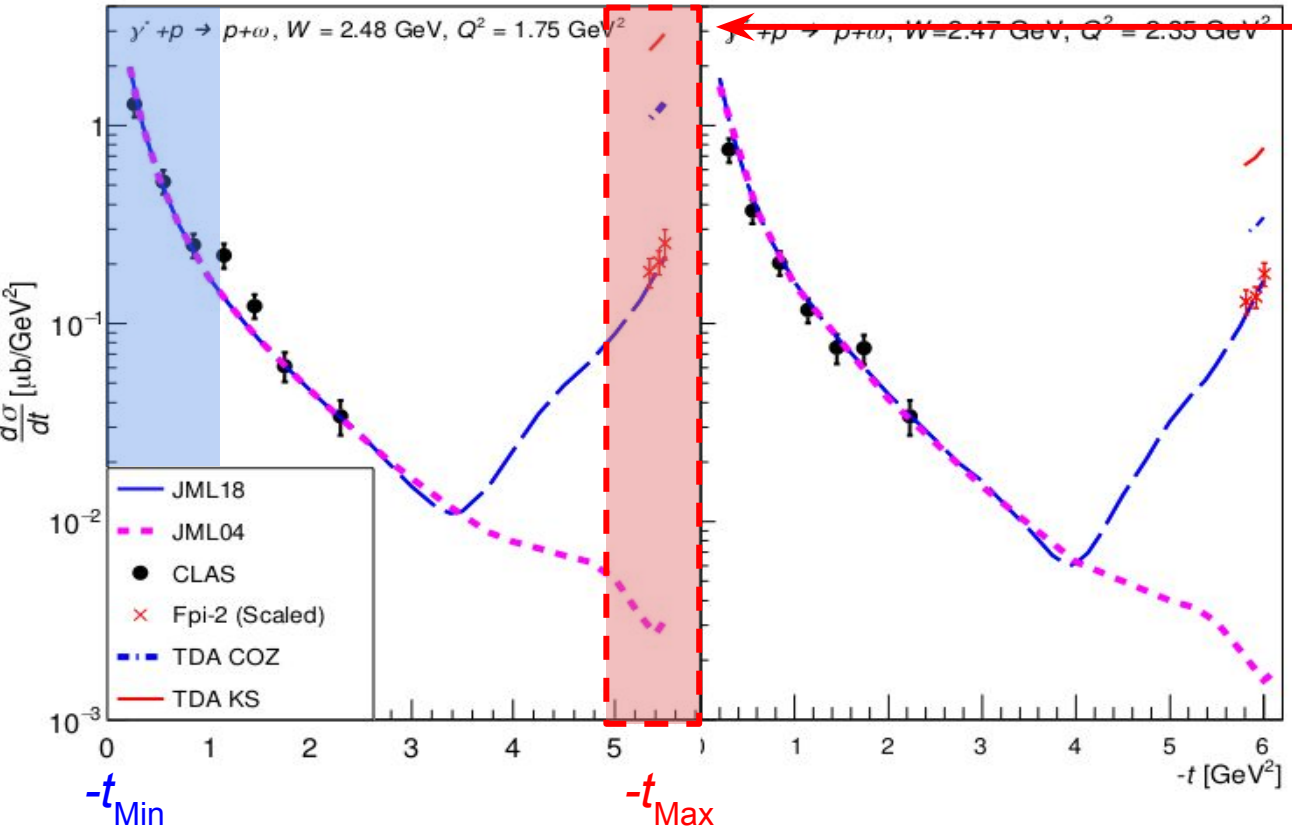
A Proton Detection Problem



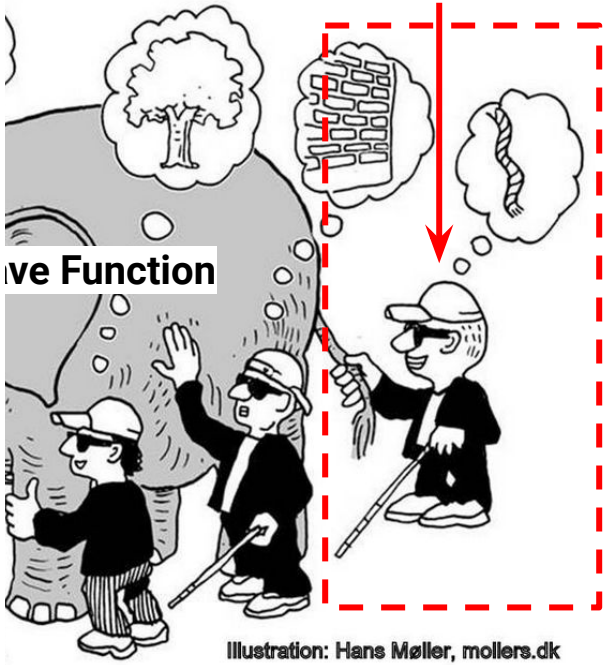
Proton detector issue!

- Proton will NOT be detector due to ventilation hole!
- Blue cube: new detector dropped in to help with acceptance study
- Completing feasibility study is critical now ! (designing stage)

Probing the “dark” side of proton



I am here

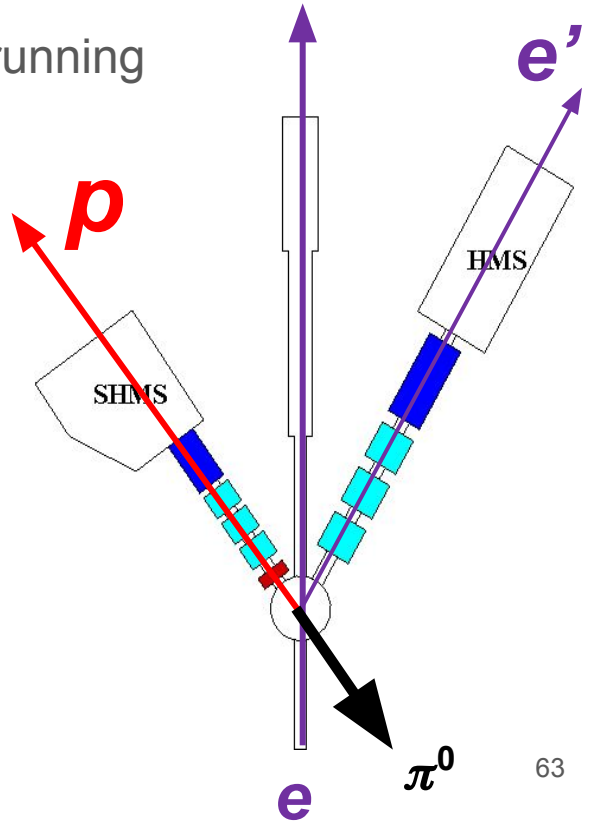


Forward → Backward

Forward → Backward

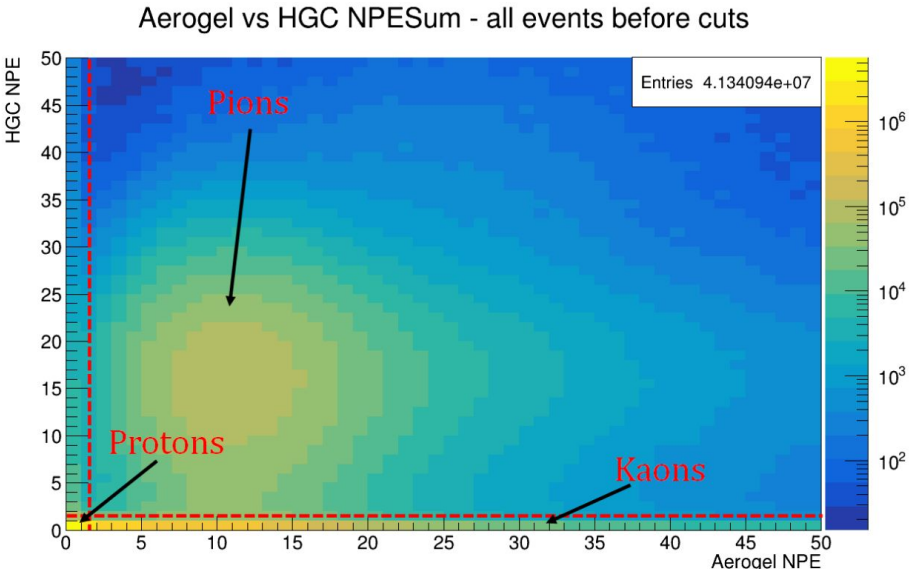
Requirements

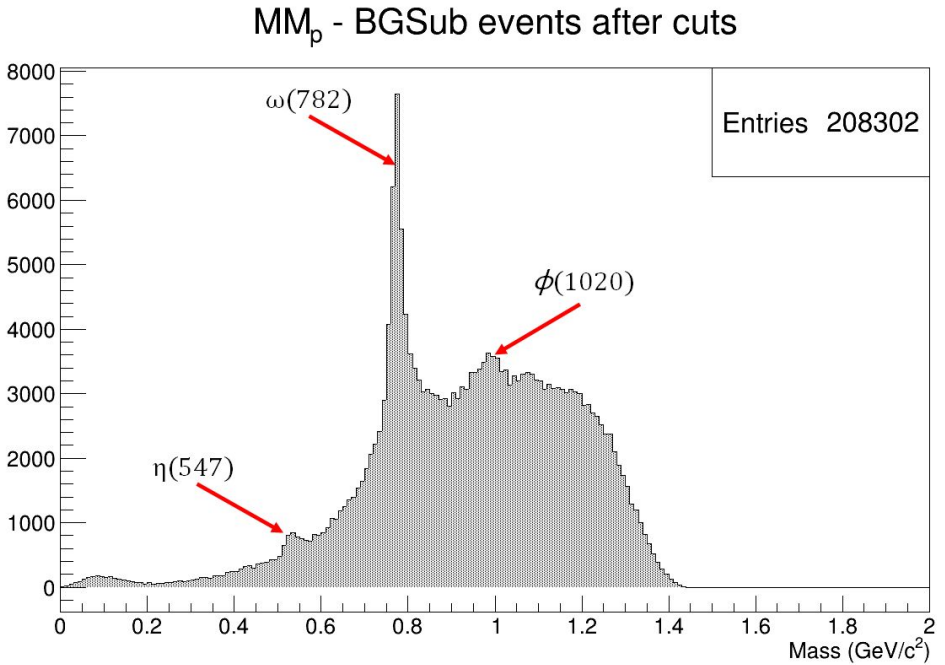
- PAC has approved 29 days of beam (requested 29.4 days)
- Beam request: standard beam tune during the time of running with standard polarization
- **Equipment refurbishment:**
  - **HMS Aerogel PMT Replacement (new request)**
  - **SHMS Aerogel tray of n=1.0003 (already planned)**
- **Special detector configuration:**
  - **Installing NGC for SHMS**
  - **SHMS aerogel tray n=1.0003**
  - **HMS aerogel tray n=1.0011**
  - **Using Moller polarimeter**



More u-channel studies from other Hall C Experiments

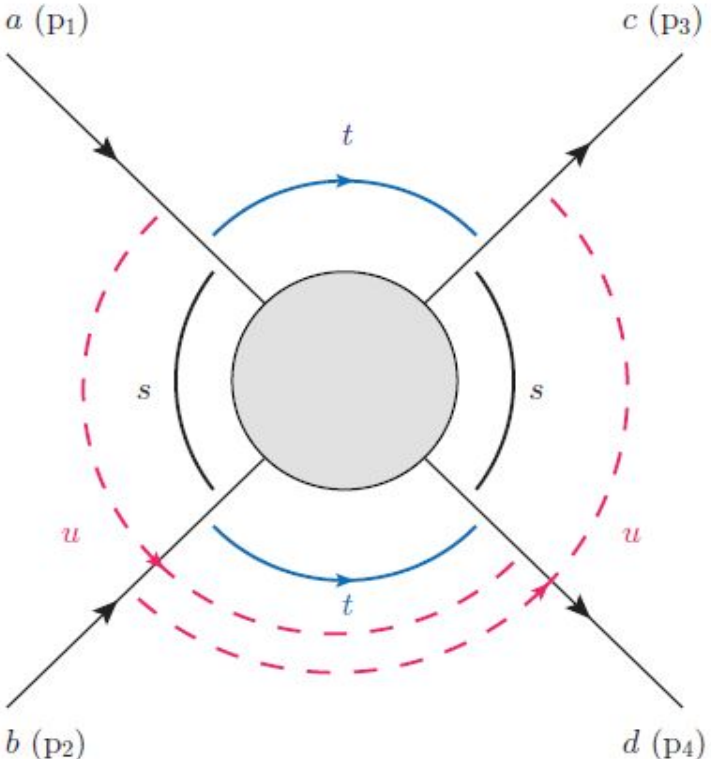
- **Missing mass reconstruction of ep events from Kaon LT experiment showing resonance peaks for multiple meson productions**





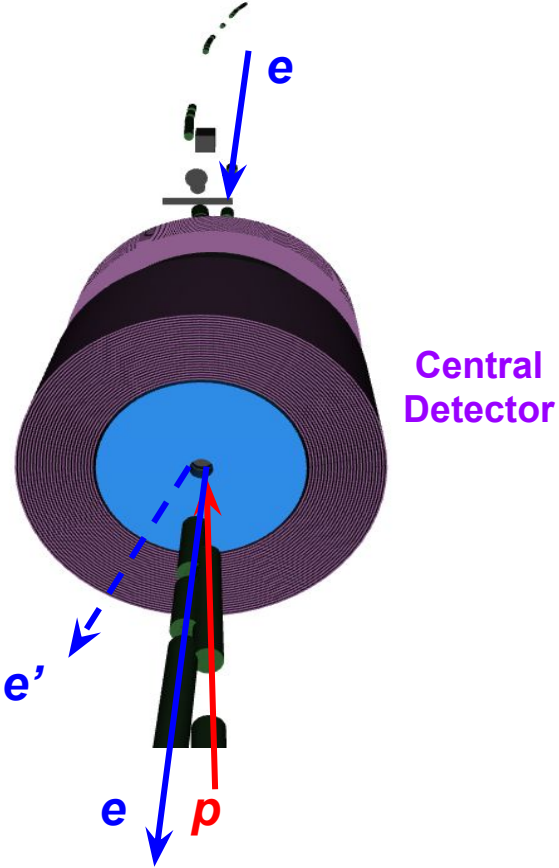
Plots provided by S. Kay

Mandelstam Variable

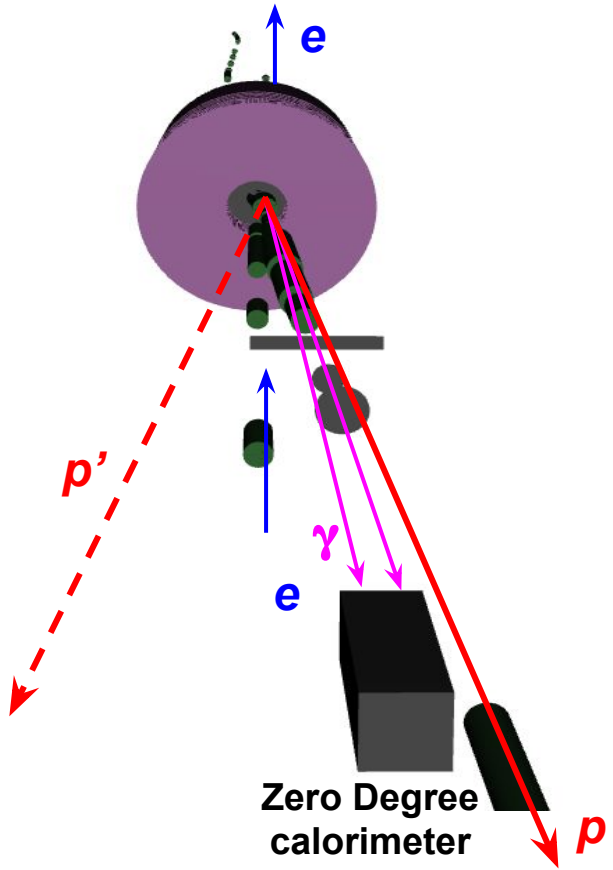


Visualizing u-channel π^0

Incoming proton perspective



Incidence electron perspective

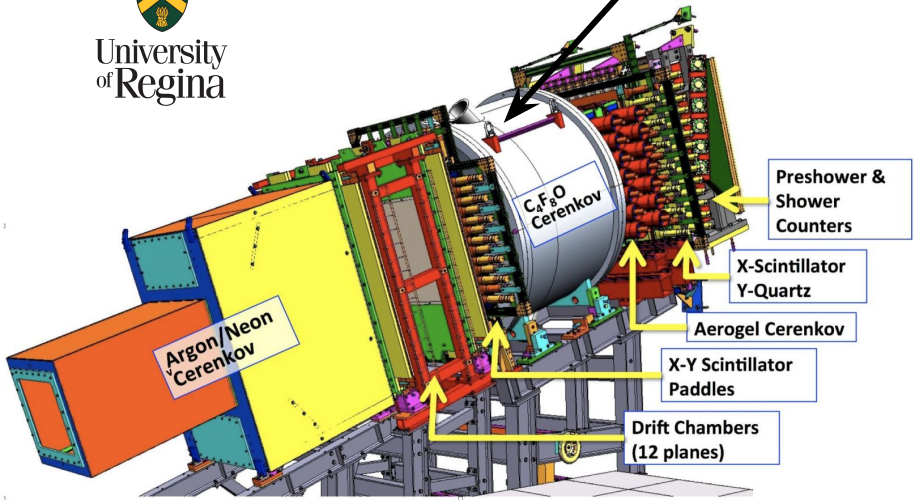


My Contribution to JLab 12 GeV: HGC and DIRC

Heavy Gas Cherenkov Detector for Hall C

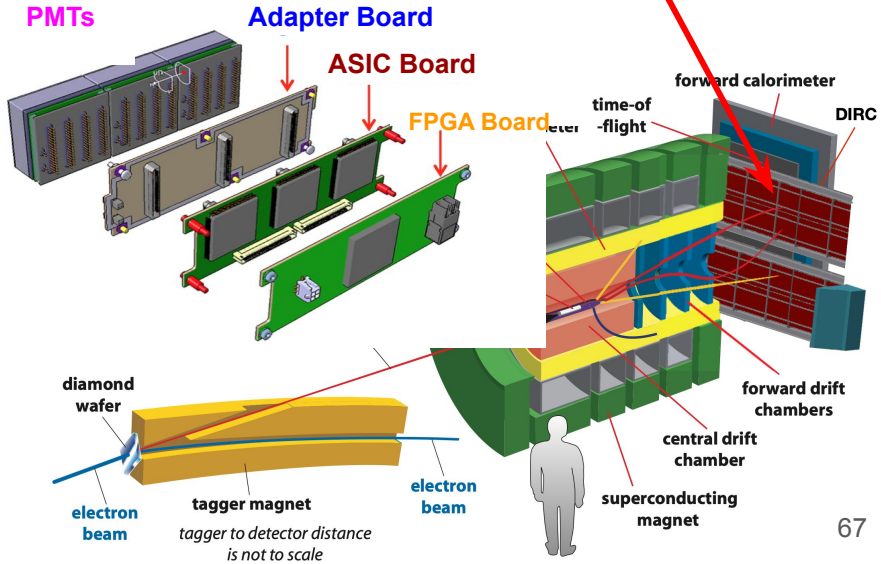
- Master Student
- 2009-2013
- Led by Dr. G. Huber (University of Regina, Canada)

University of Regina

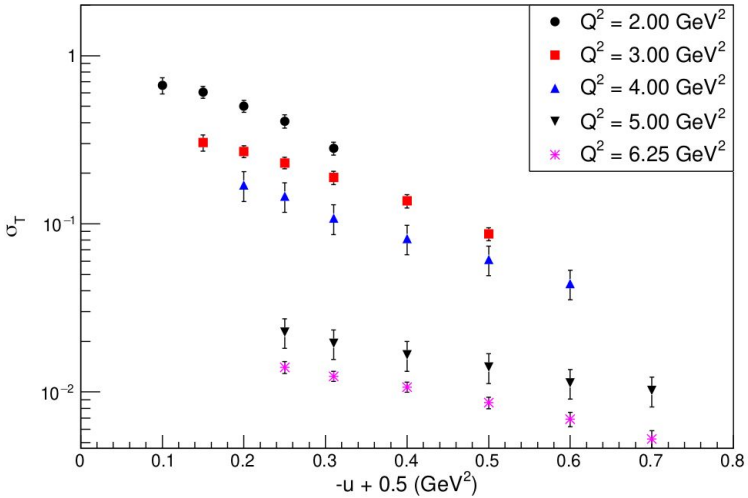


GlueX DIRC Detector for Hall D

- Postdoc
- 2017-Present
- Led by Dr. J. Stevens (W&M)



Objective 2: *u-dependence*



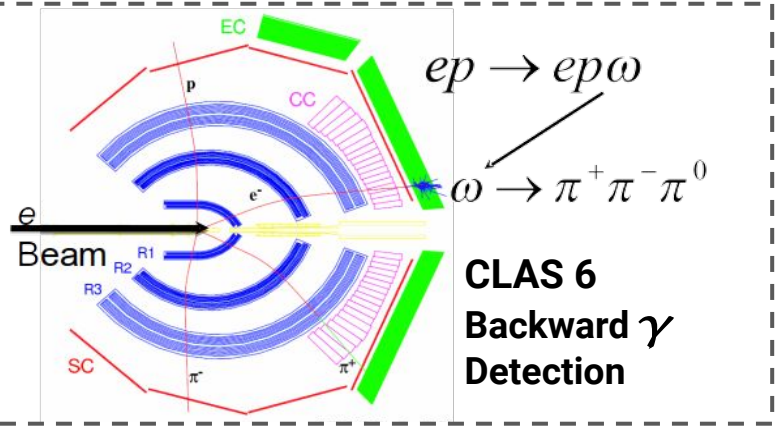
Objective 2: u-dependence of the separated cross section

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

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

- **Study of parameter r_{int} as function of Q^2, probe the proton structure transition from hadronic to partonic degrees of freedom.** (Similar to the study by Halina Abramowicz, Leonid Frankfurt, Mark Strikman, arXiv:hep-ph/9503437, 1995.)

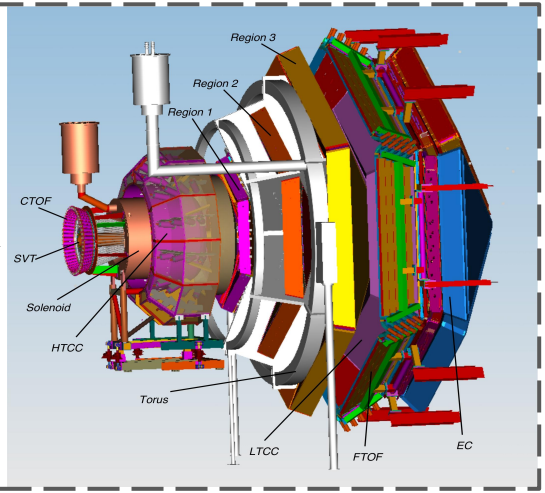
u-Channel Opportunities at CLAS 12



CLAS 6
Backward γ Detection

CLAS 12
No backward γ Detection capability

e beam →

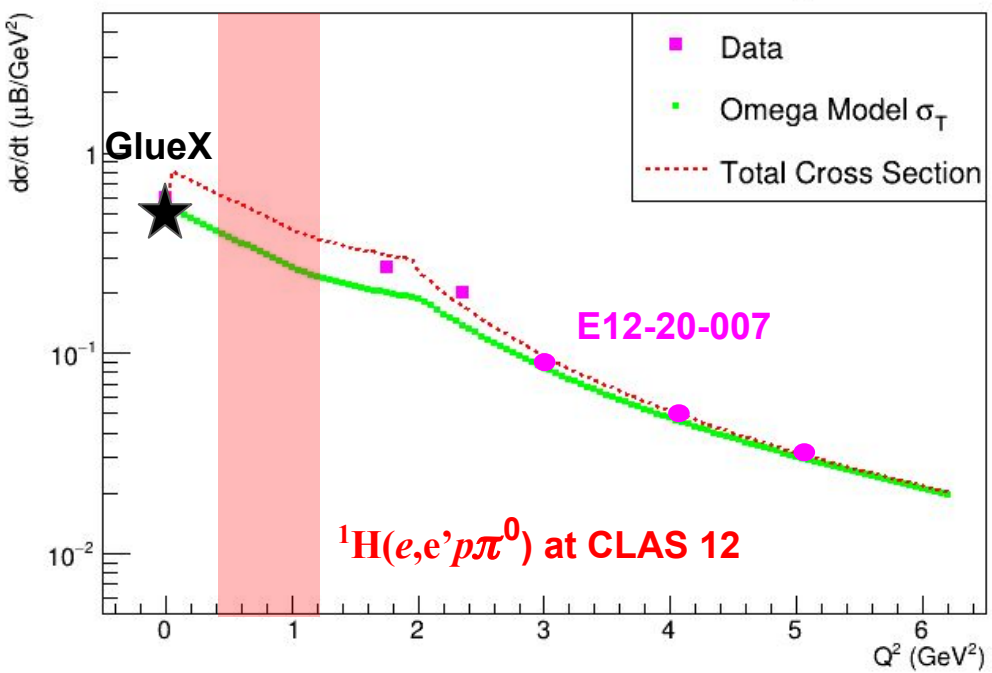


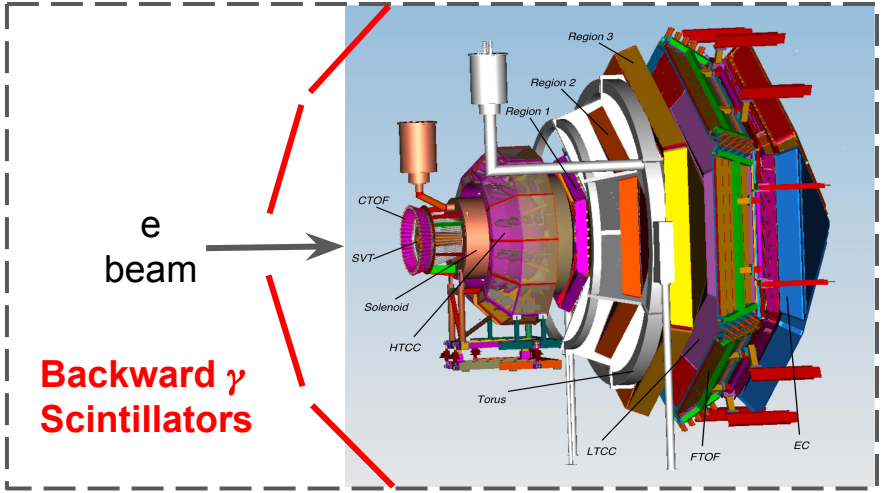
Harvesting u-channel meson production cross section at near u_{min} kinematics at Hall B CLAS 12 (consulted with S. Diehl)

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

Possibility to address *u*-channel π^0 issue?

u-Channel Opportunities at CLAS 12





- **Adding Scintillators allows u-channel π^0**
- $0 < Q^2 < 1.2$ GeV kinematics only available with CLAS 12
- Offering unique opportunity