Backward-angle (*u*-Channel) Physics π^0 Production at EIC

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Joint postdoc at W&M and JLab EIC Center

EICUG Early Career Workshop 2021

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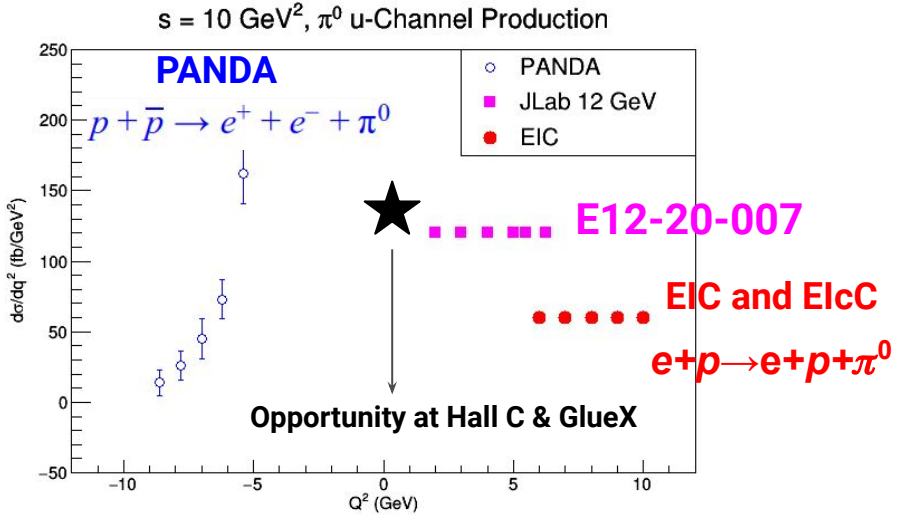
WILLIAM & MARY
CHARTERED 1693

u-Channel studies at EIC

- As postdoctoral fellow at JLab EIC Center: Development of Backward π^0 Program for EIC
  - Feasibility studies included as part of the EIC Yellow report.



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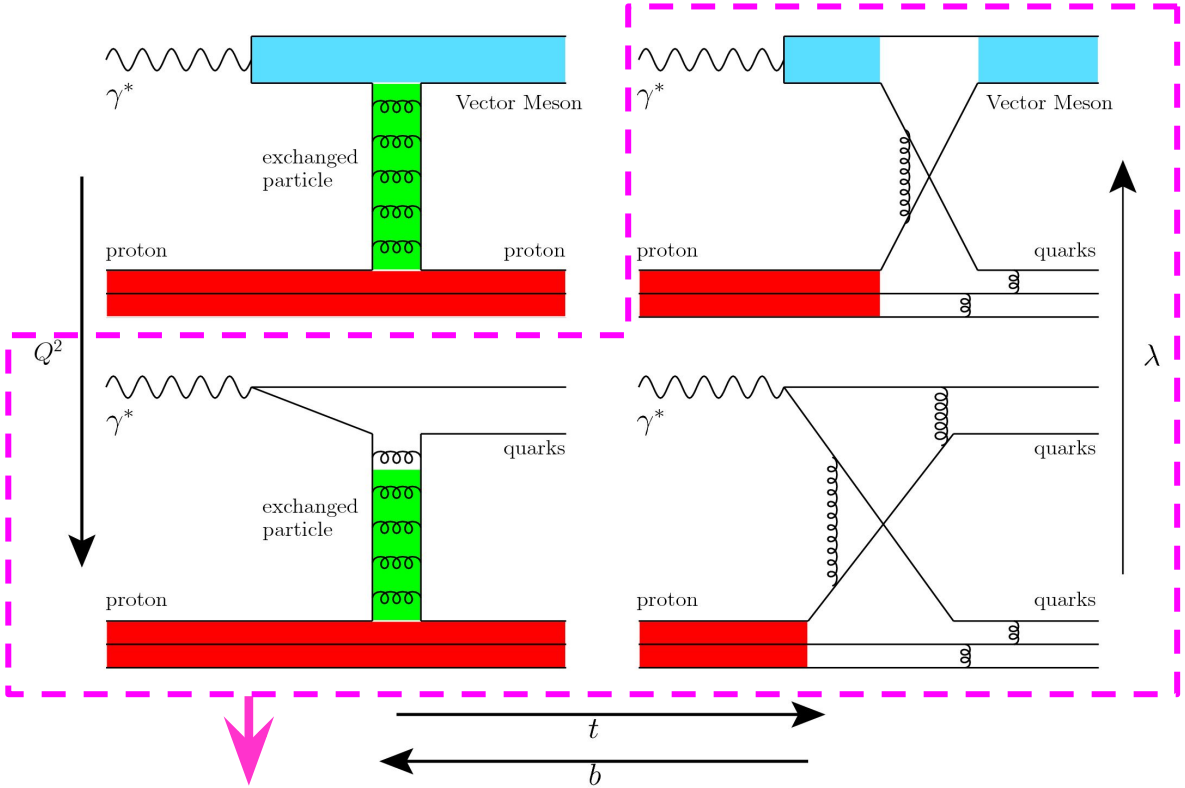
Hadronic Model: Transition (Evolution) of Proton Structure



- **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 role does *u* play?**

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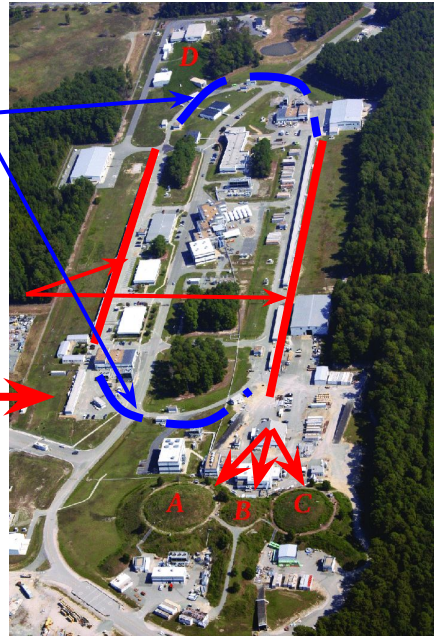
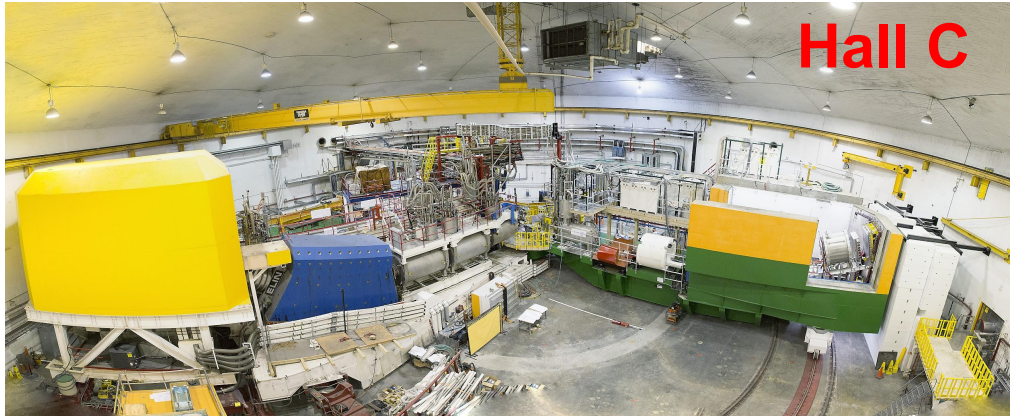
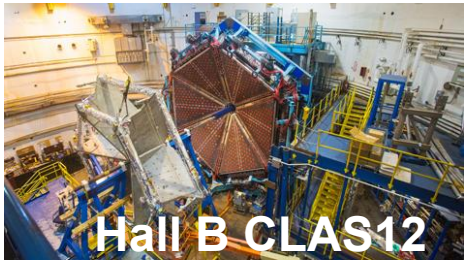
Jefferson Lab Experimental Halls at 12 GeV





- **Facility:**
  - **Two Superconducting LINAC**
- **Electron beam energy up to 12 GeV**
- **Four experimental Halls different 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.



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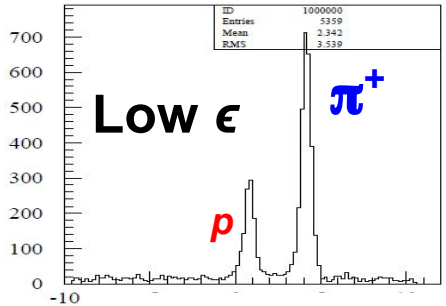
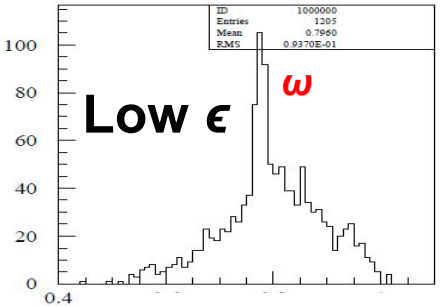
Backward-angle Observables

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

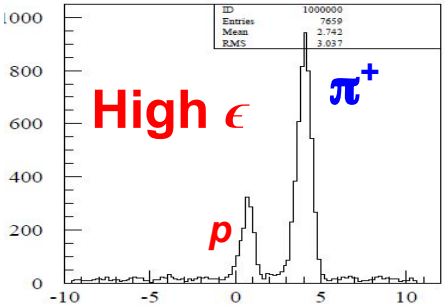
Q^2=2.45 GeV^2 **2003** 2003/07/25 08.56



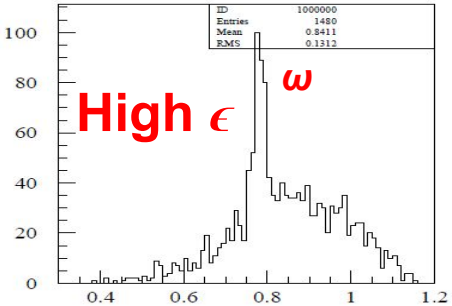
Coincidence time



***epX* missing mass**



Coincidence time



***epX* missing mass**

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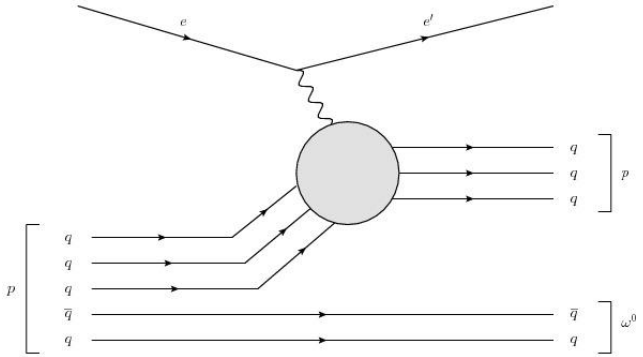
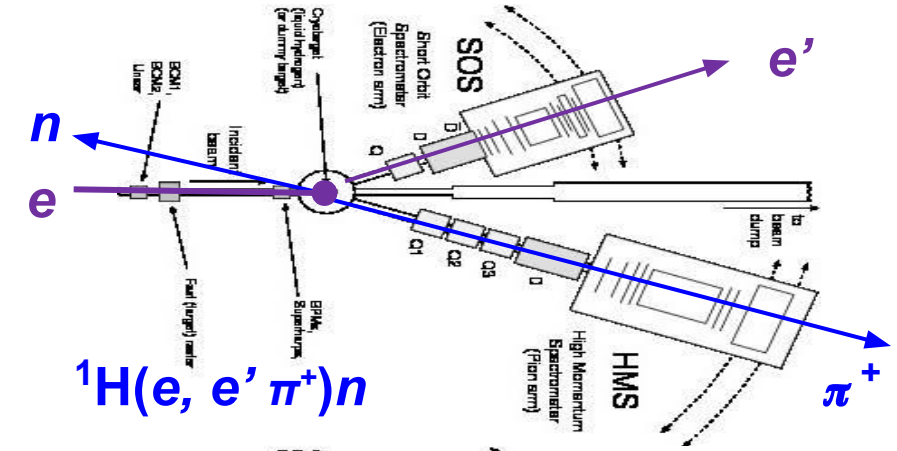
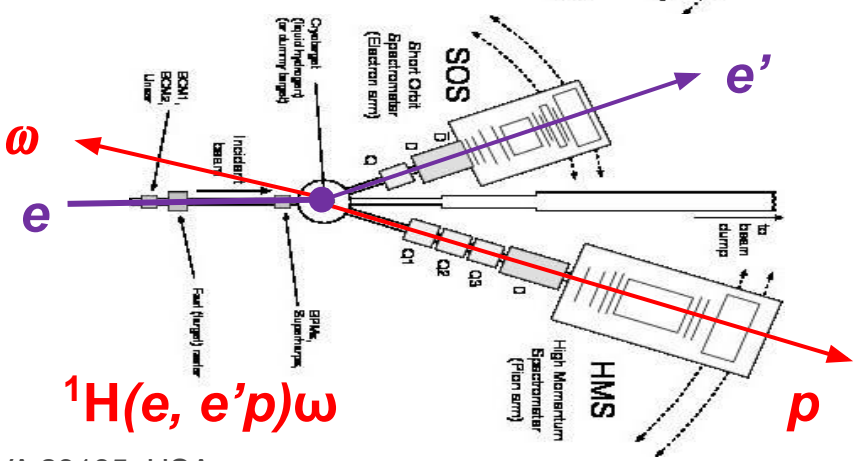
t-Channel π^+ vs *u*-Channel ω Production

- **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





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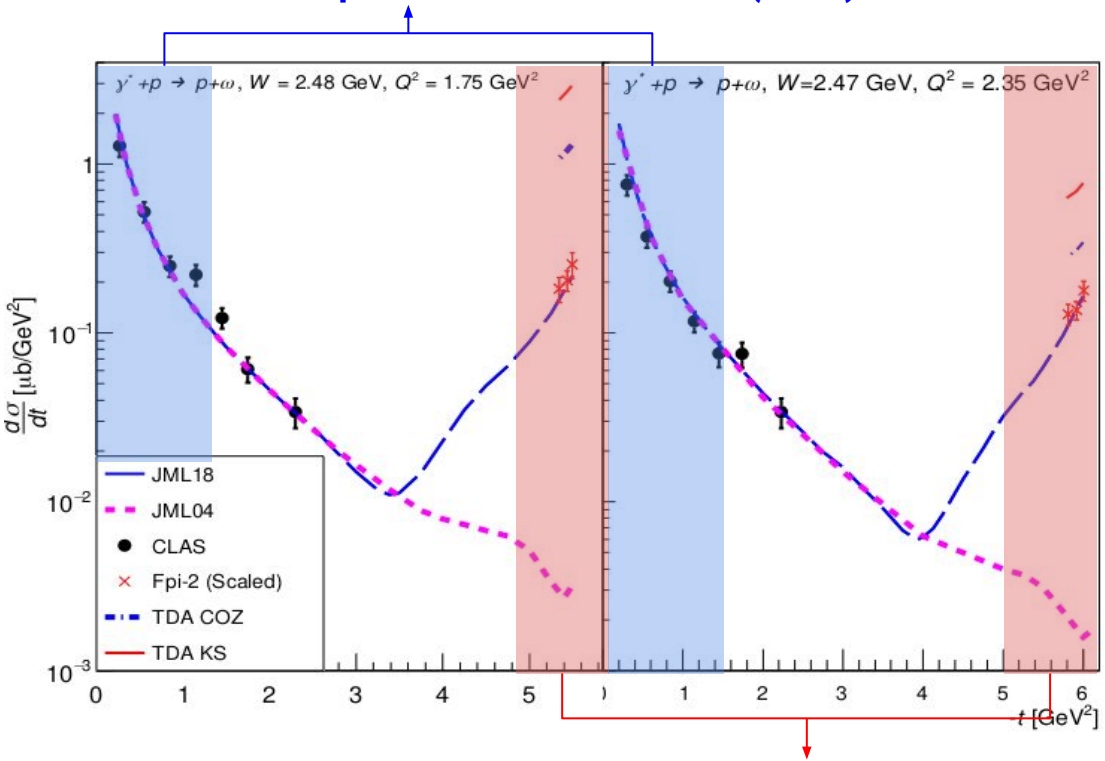
Results on Backward-angle Electroproduction

Forward ω electroproduction from CLAS 6 *(2004)*



Backward angle ω electroproduction *(2017)*

- **Analysis: *2013-2017***
- **Topic of my Ph.D - Results published in *Phys. Rev. Let. (2019)* https://doi.org/10.1103/PhysRevLett.123.182501**
- **The magnitude of *u*-channel peak is surprisingly large**

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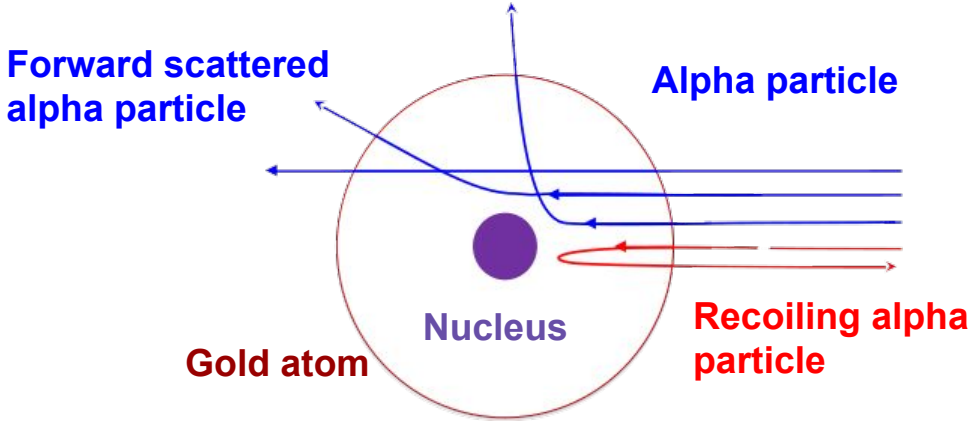
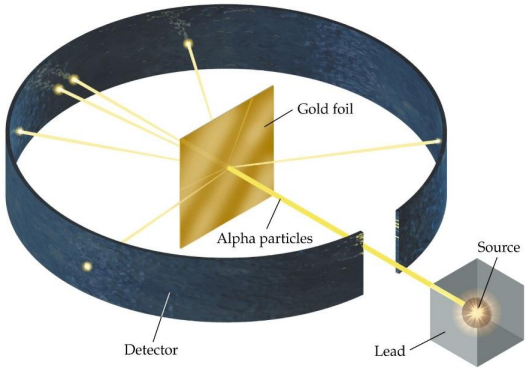
Forward and Backward-angle Scattering off Atoms





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

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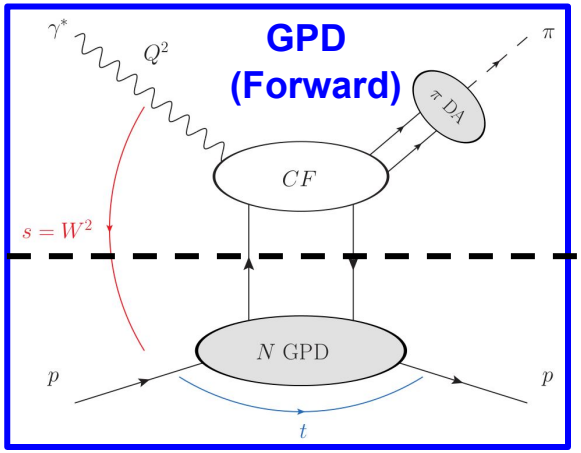
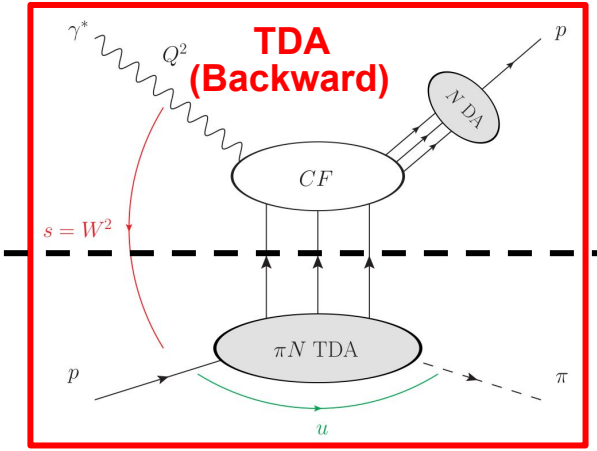
GPD, SPD and TDA (Hard Structure)





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

A 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.
  - Prediction #1: the transverse cross section dominate over the longitudinal, $\sigma_T >> \sigma_L$
  - Prediction #2: classic $\sigma \propto 1/Q^8$ scaling behavior

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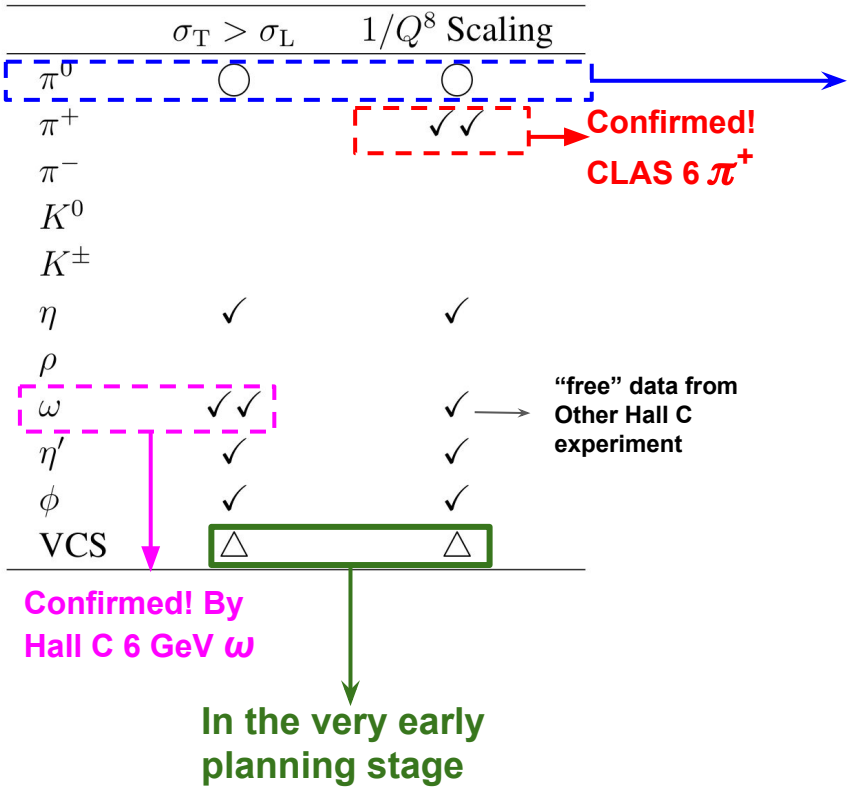
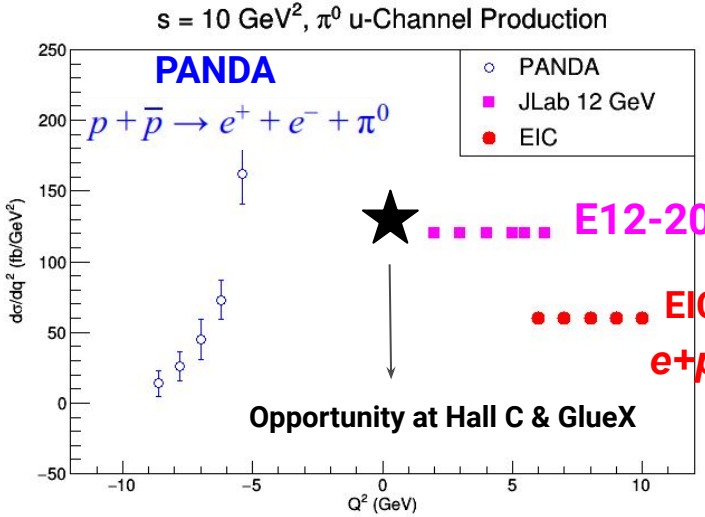
Systematically studying TDA





- Study of u-channel π^0 is only a beginning
- *u*-channel ω at EIC *see Z. Sweger's talk
- Other mesons also need to be studied

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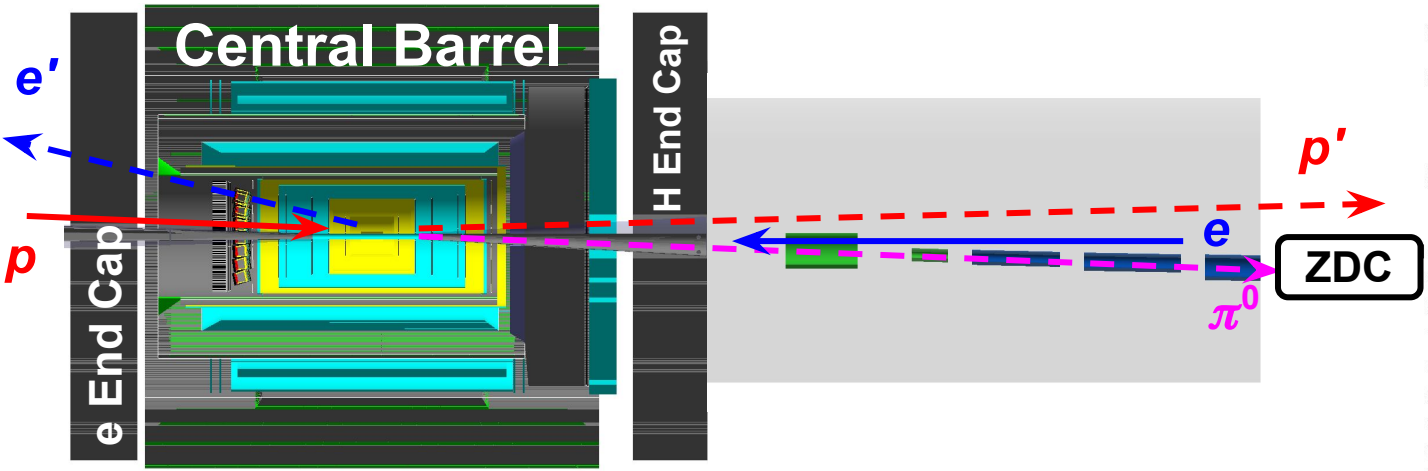
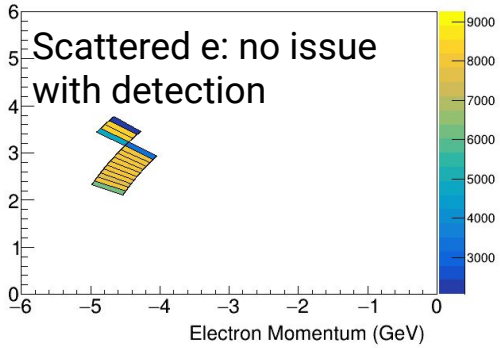
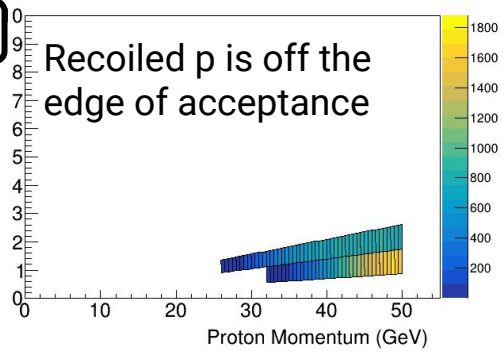
u-Channel Meson Production Setup

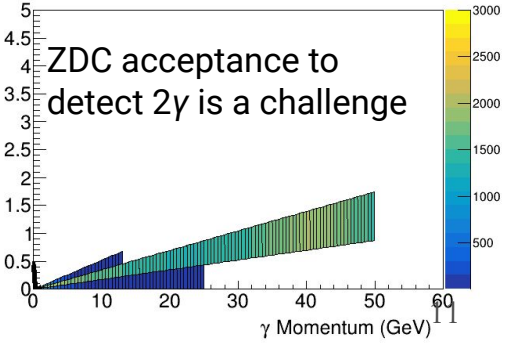


Q^2 (GeV^2)	W (GeV)	x_B	$\theta_{e'}$ (deg)	$\eta_{e'}$	$P_{e'}$ (GeV)	$\theta_{p'}$ (deg)	$\eta_{p'}$	$P_{p'}$ (GeV)	θ_{π^0} (deg)	η_{π^0}	P_{π^0} (GeV)	$-t$ (GeV^2)	$-u$ (GeV^2)
6.2	3.19		152	1.39	5.31	-1.84	4.13	43.40	1.43	4.38	56.29	14.84	-0.37
7.0	3.19		150	1.32	5.35	-1.92	4.09	45.50	1.43	4.38	54.12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







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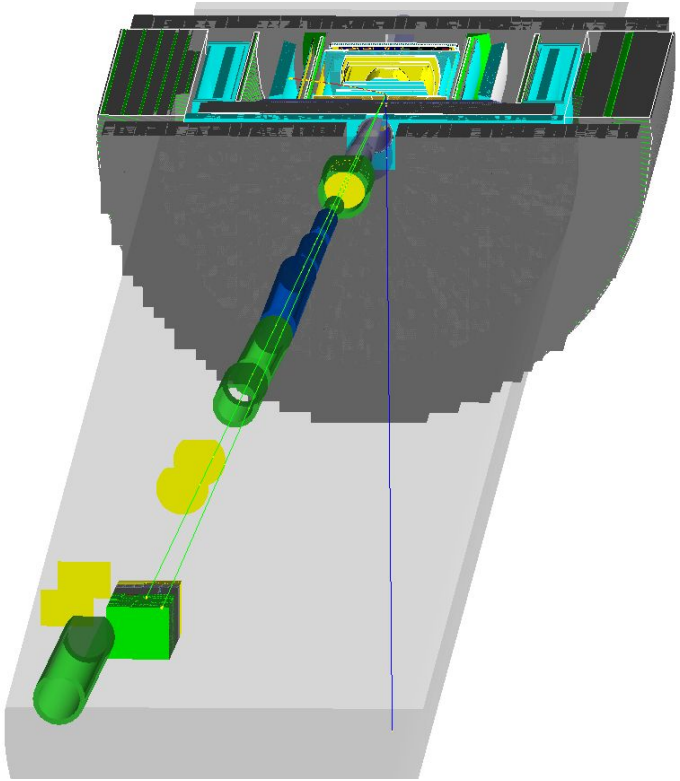
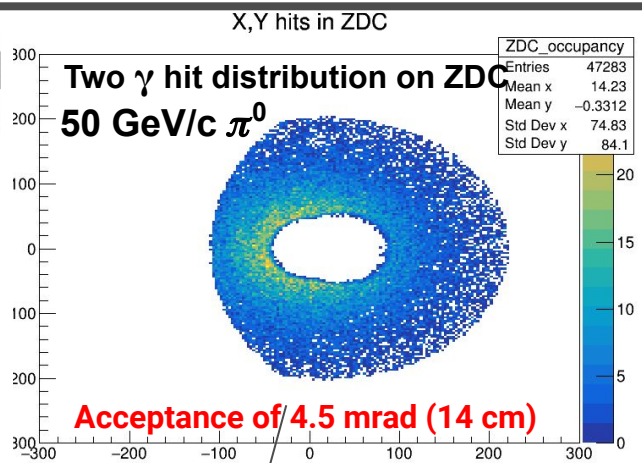
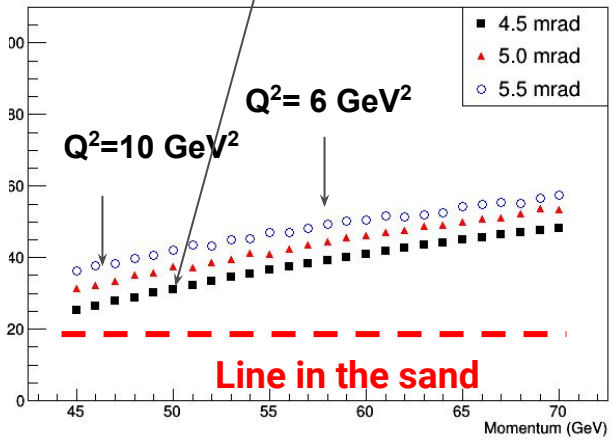
Realistic ZDC acceptance for π^0 and p detection

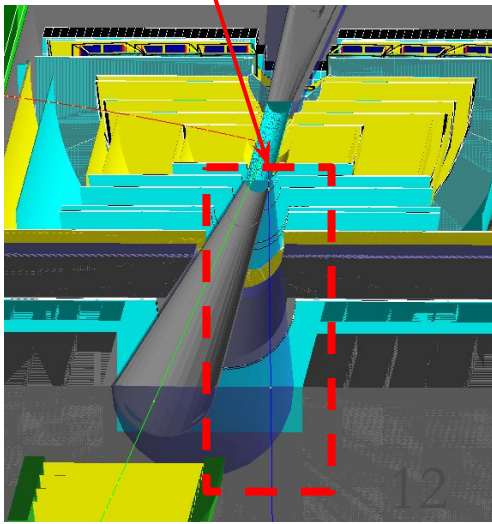


Zero Degree Calorimeter (30 m) downstream of IR

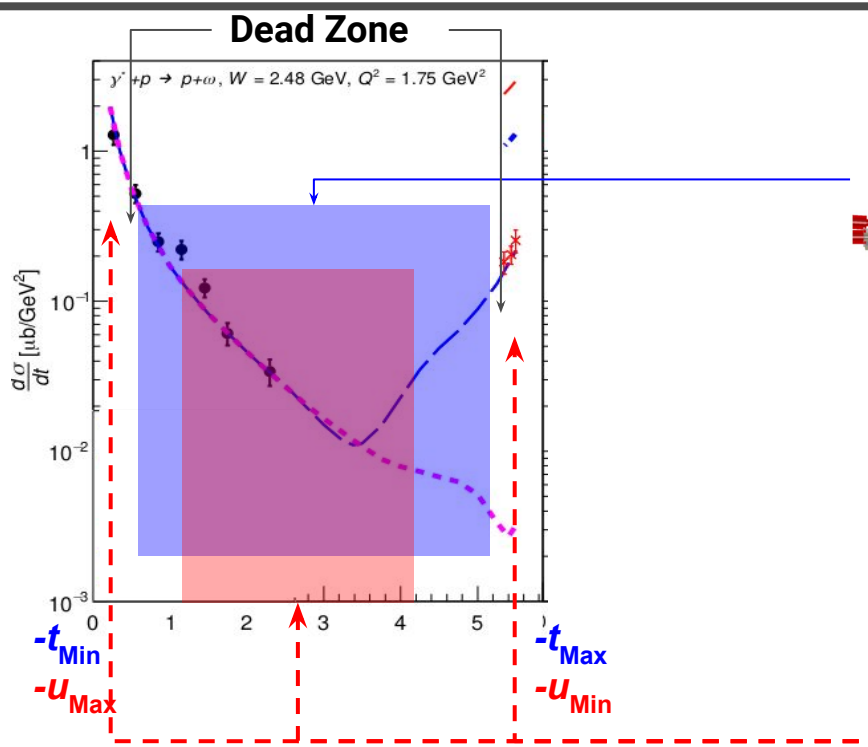


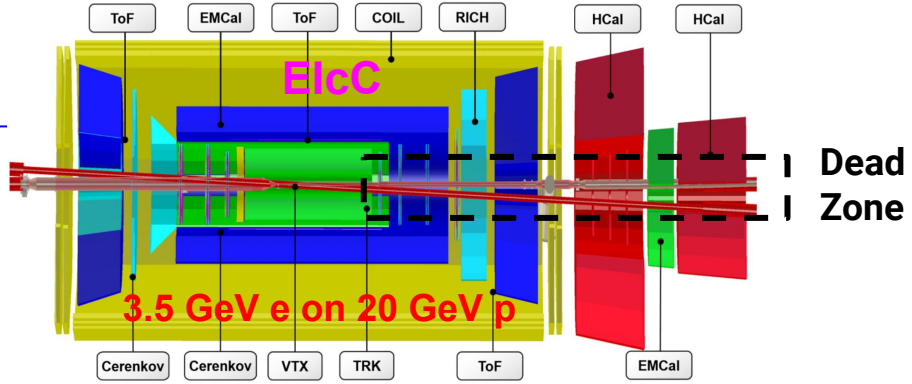


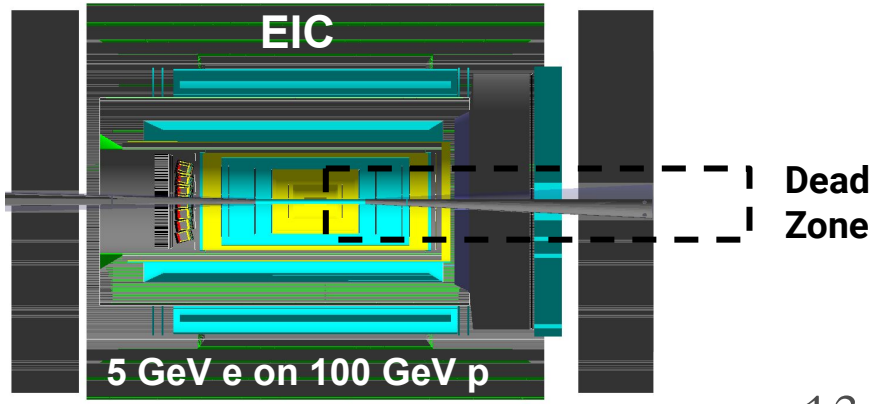
- **Forward π^0 detection**
  - **30-40% 2γ event eff.**
- **Forward p detection**
  - **Current not covered**
  - **Patching up forward EM Cal**



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)**

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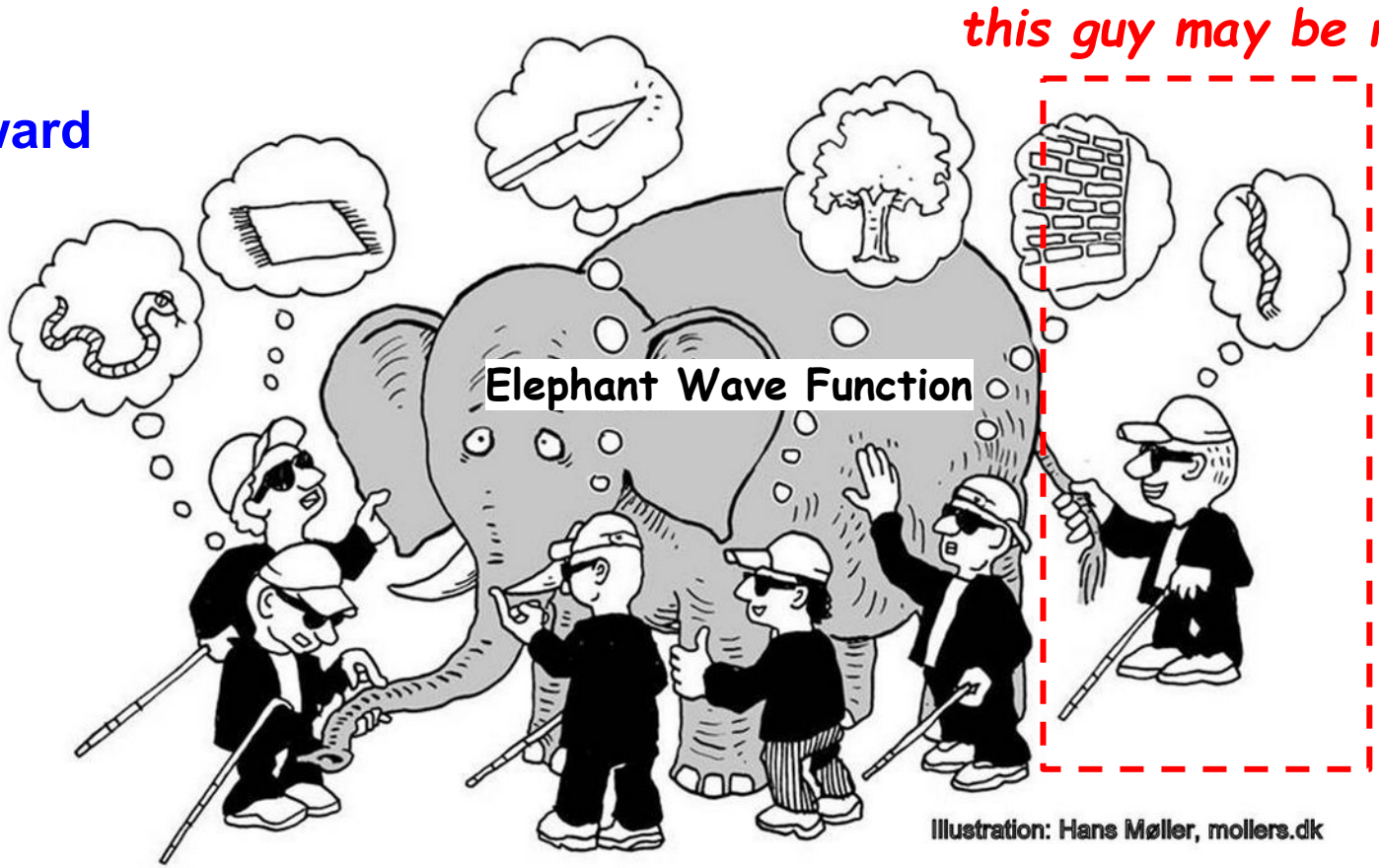
Thank You! ..and Let's explore *u*-channel Physics together!



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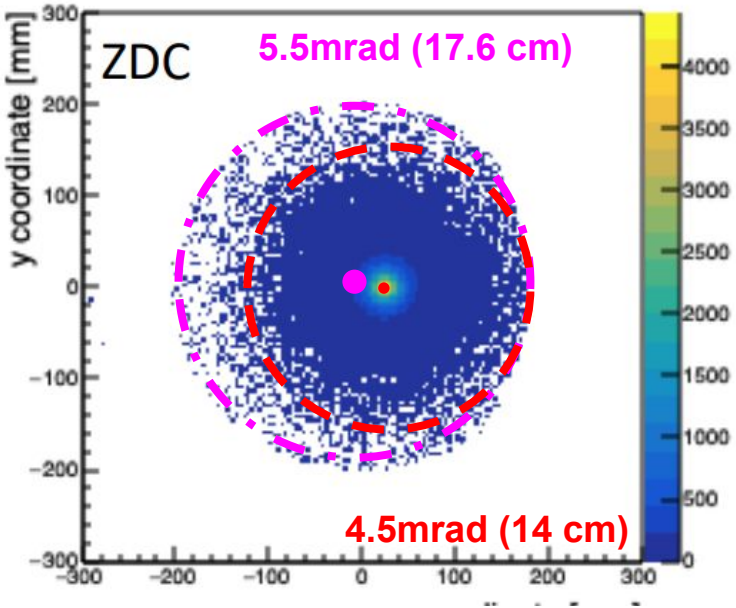
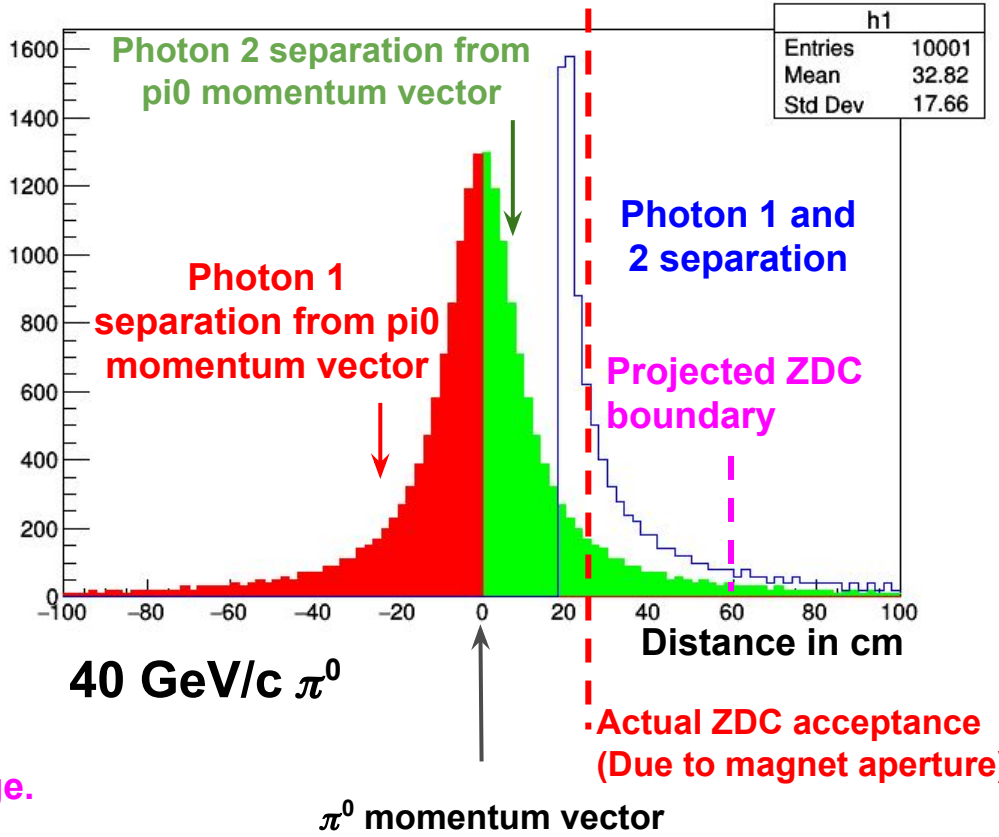
Realistic ZDC Acceptance (through magnets Aperture)



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

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



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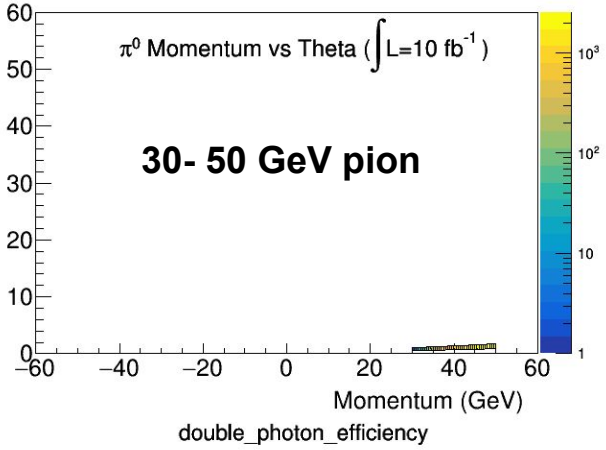
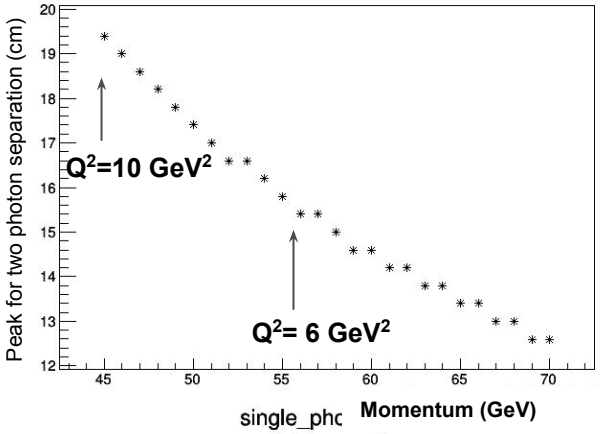
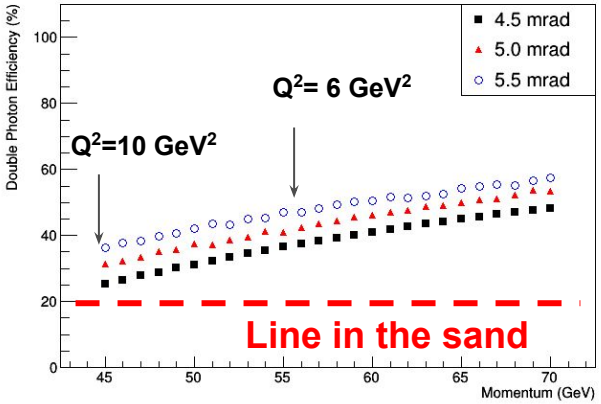
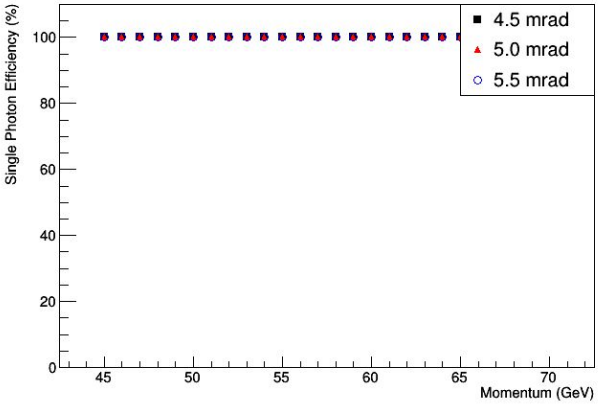
$\pi^0 \rightarrow 2\gamma$ Detection at ZDC









- 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

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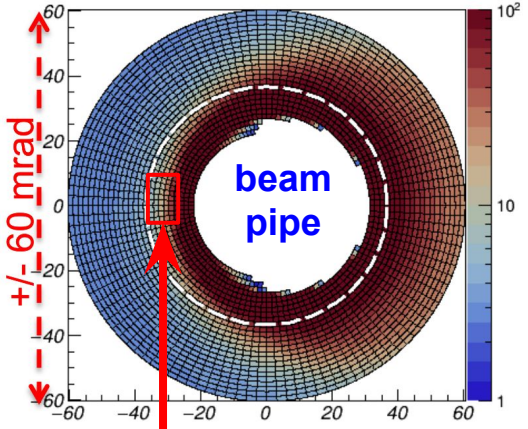
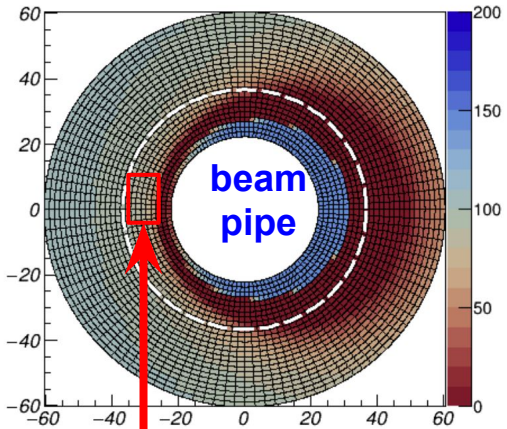
Recoil Proton Detection

Figures created by Alexander Kiselev

Material in acceptance, [%]



Max space available for Si tracker, [cm]



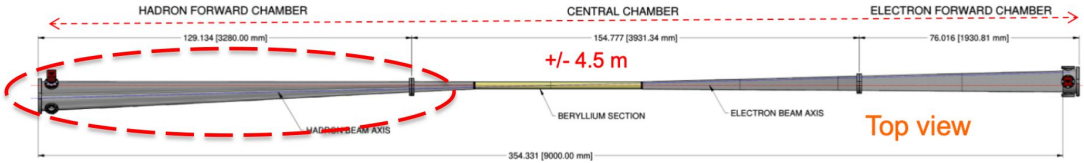
Recoiled *p* detection region $|\eta| < 4.15$

White Circle: $|\eta| = 4.0$

$\|\eta\| = 3.00$	$\|\eta\| = 3.50$	$\|\eta\| = 4.00$	$\|\eta\| \sim 4.38$	$\|\eta\| = 4.50$
~99.5 mrad	~60.4 mrad	~36.6 mrad	25.0 mrad	~22.2 mrad

Proton End Cap constrain

- Recoiled proton $|\eta| < 4.13$
- Limited detector acceptance near the incidence electron and outgoing proton beam pipe
- Preliminary assessment: Acceptance is feasible with reduced efficiency, further simulation work is required.



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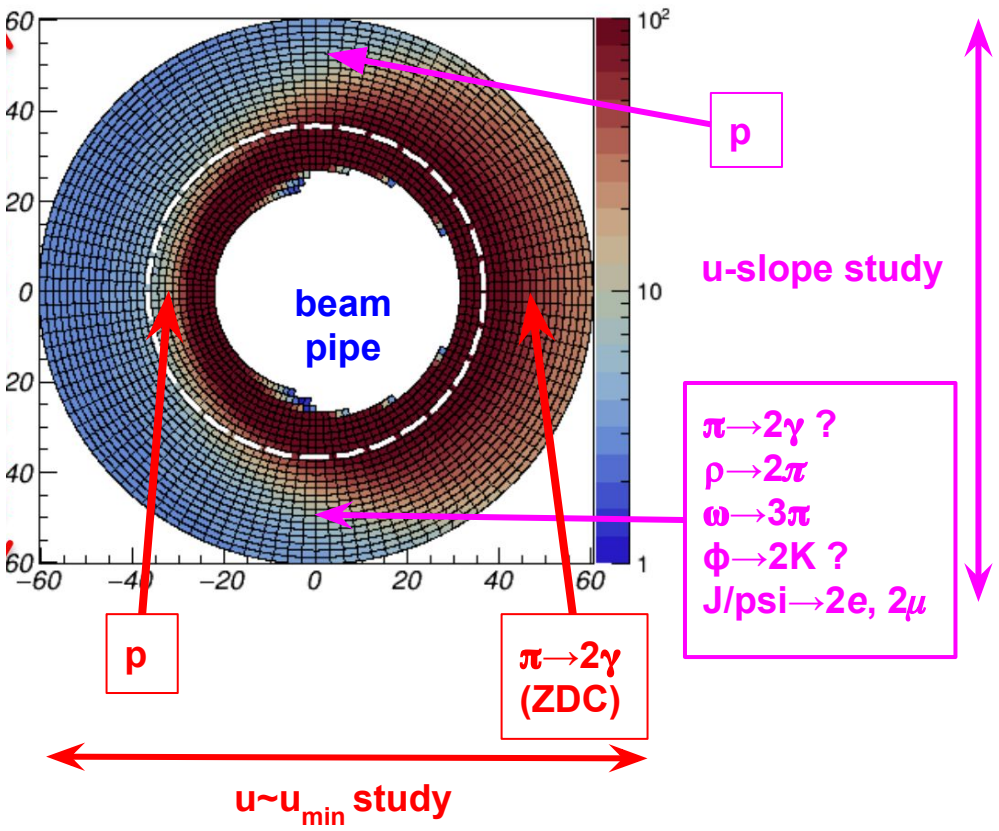
u-channel Meson Study from Hadron End Point of View



Figures created by Alexander Kiselev

- u~u_{min} study of π^0 exclusive production
  - To be documented in YR Section 2
- u-slope study
  - Inspired by the workshop
  - To be documented in YR Section 7
- Detection requirements (YR Section 8)
  - u~u_{min} study is finalized
  - u-slope study to be studied
- **I would like to contribute to the ZDC placement and optimizing the detector stack of the Hadron End Cap at for high η**
- 2nd IR Complementarity
- All studies will be done using g4e inside escalate

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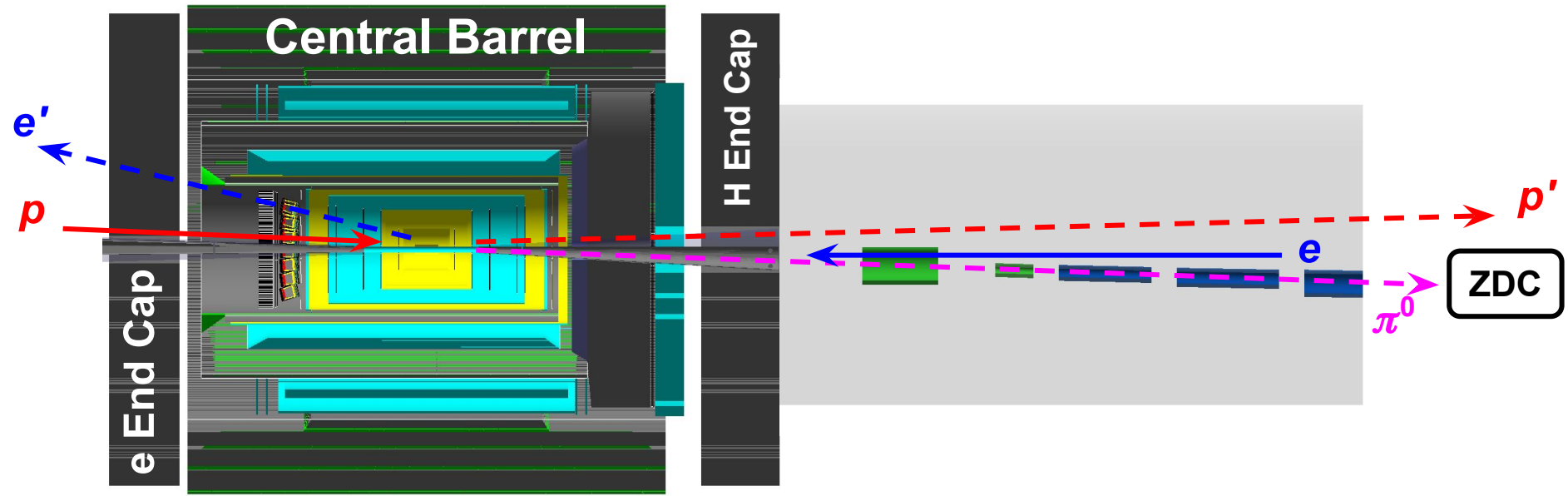

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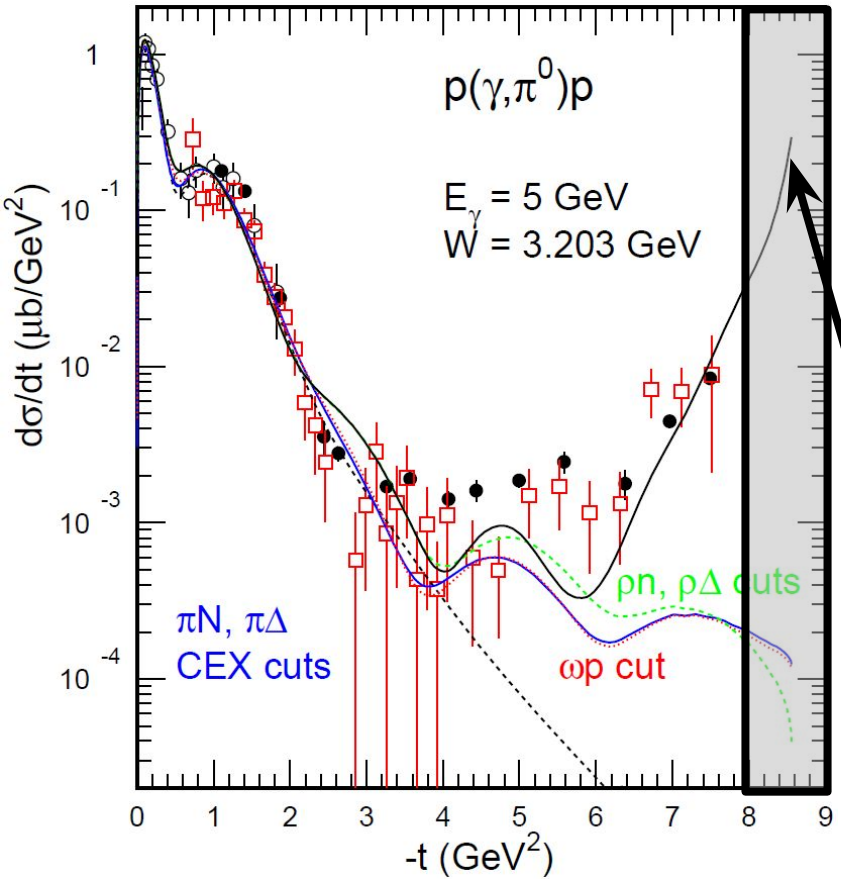
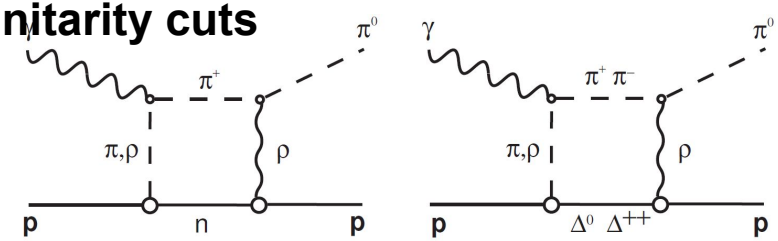
π^0 Production Measurement via Real Photon

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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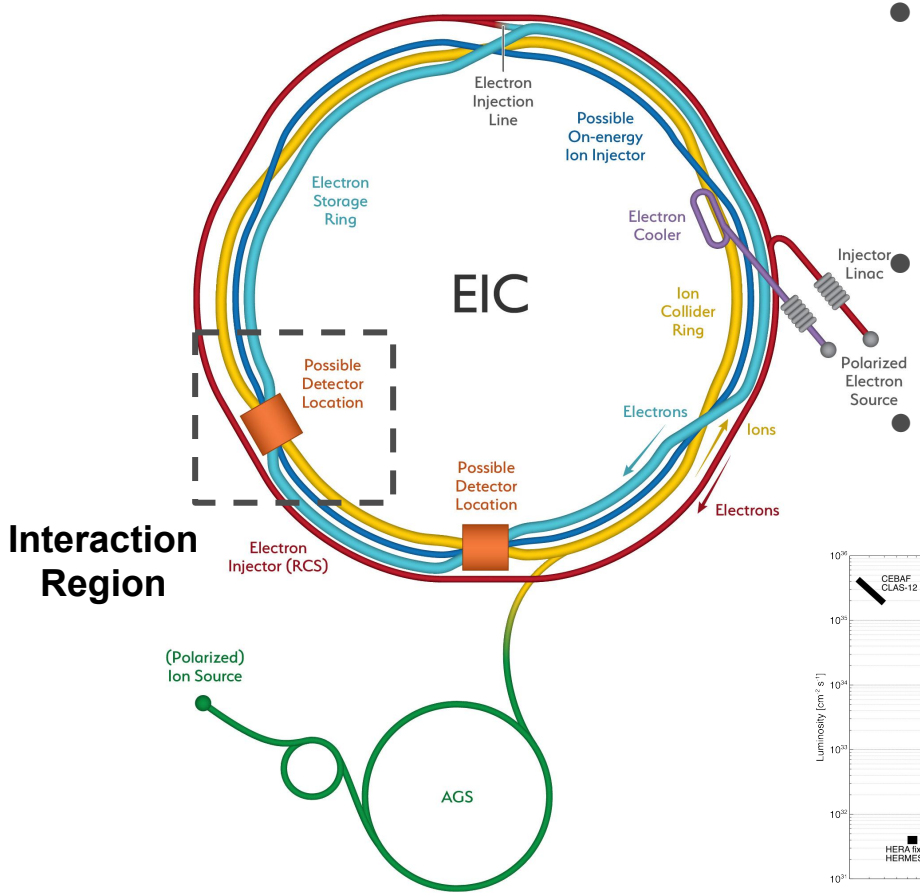
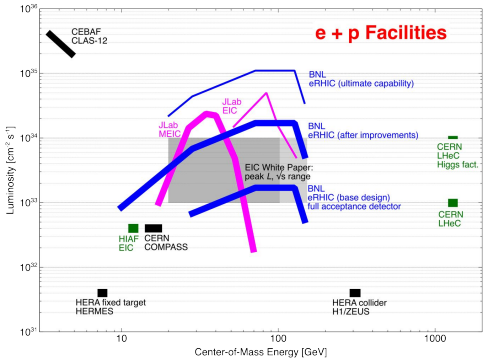
BNL-EIC Project

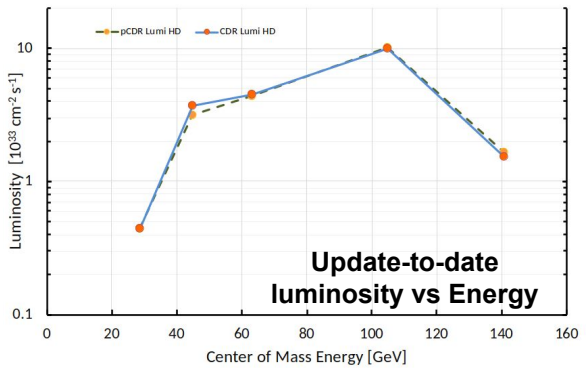


- **Next generation Electron-Ion Collider (EIC)**
  - Current consists of 1 interaction region (IR)
  - Luminosity with 100 GeV p on 5 GeV e: 10 x10^{33} $cm^{-2}s^{-1}$

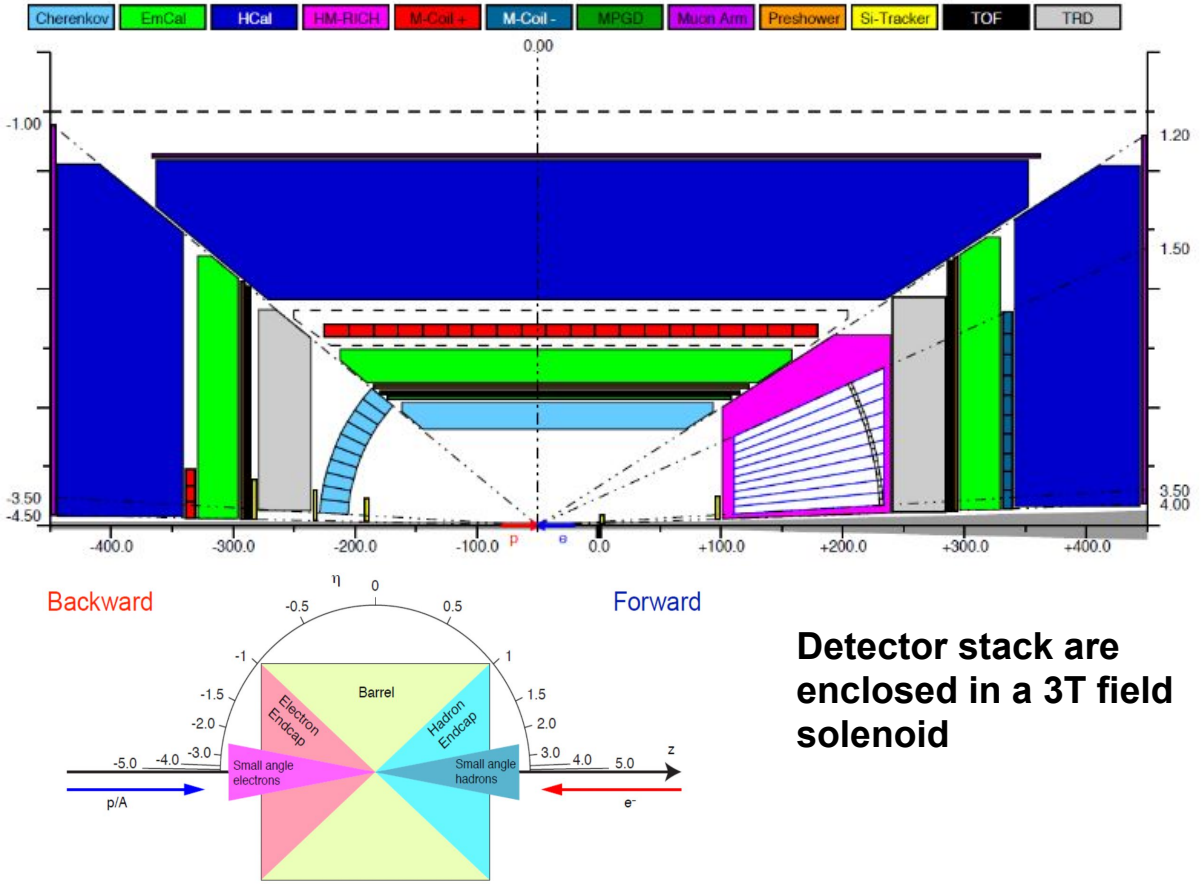
- **Project location:**
  - Brookhaven National Lab (BNL), NY

- **Project information:**
  - CD-0 approved ~ $2 B
  - Completion in ~10-15 years





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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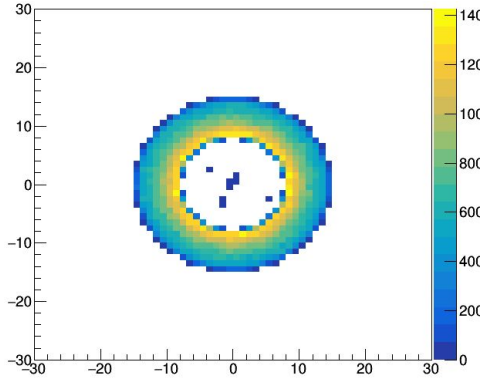
Physics background (to our current best knowledge)

- 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: Δ->n+π^0

2 γ hit pattern

40 GeV/c π^0

4.5 mrad acceptance

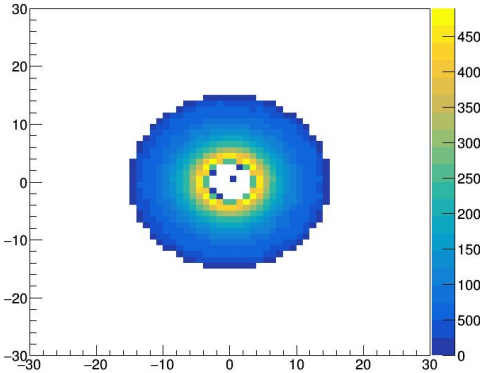


- Single photon case:
  - Primary reaction: e+p-> e'+p' + π^0
  - Ideal expected trigger: e'+p'+ γ
  - Physics background: DVCS, eta,Δ->n+π^0
  - Less than ideal trigger: e'+γ
  - Background: many possibilities

2 γ hit pattern

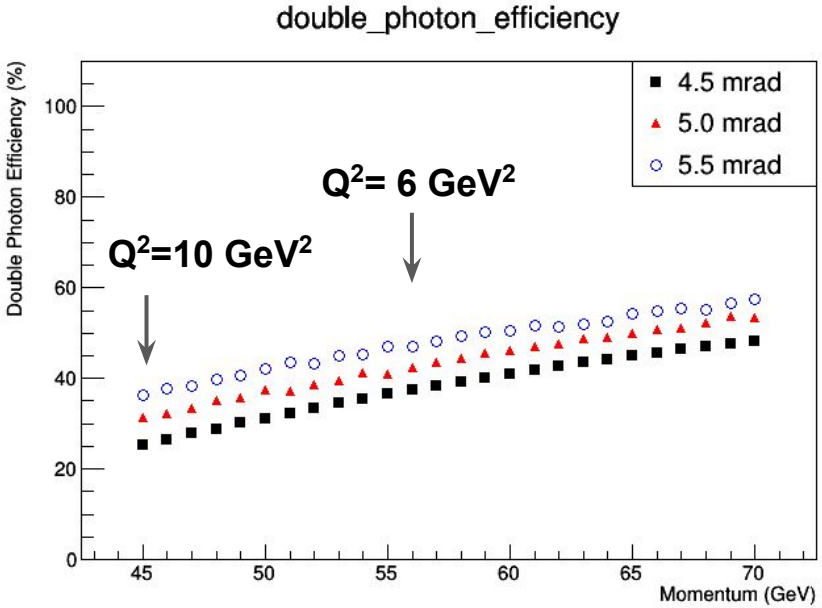
60 GeV/c π^0

4.5 mrad acceptance

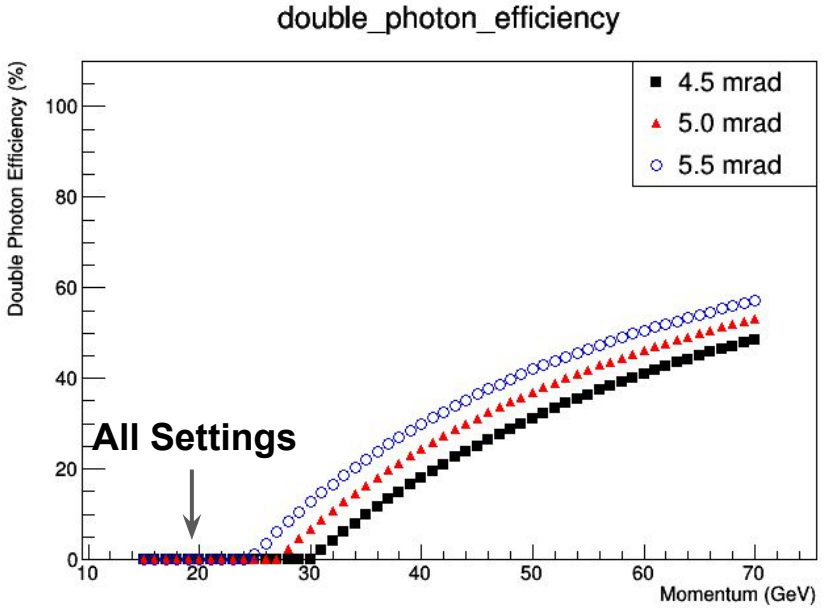


- We can use the double photon event to normalize the single photon events

EIC $e+p \rightarrow e+p+\pi^0$ for 5 GeV e on 41 GeV p



5 GeV e on 100 GeV p



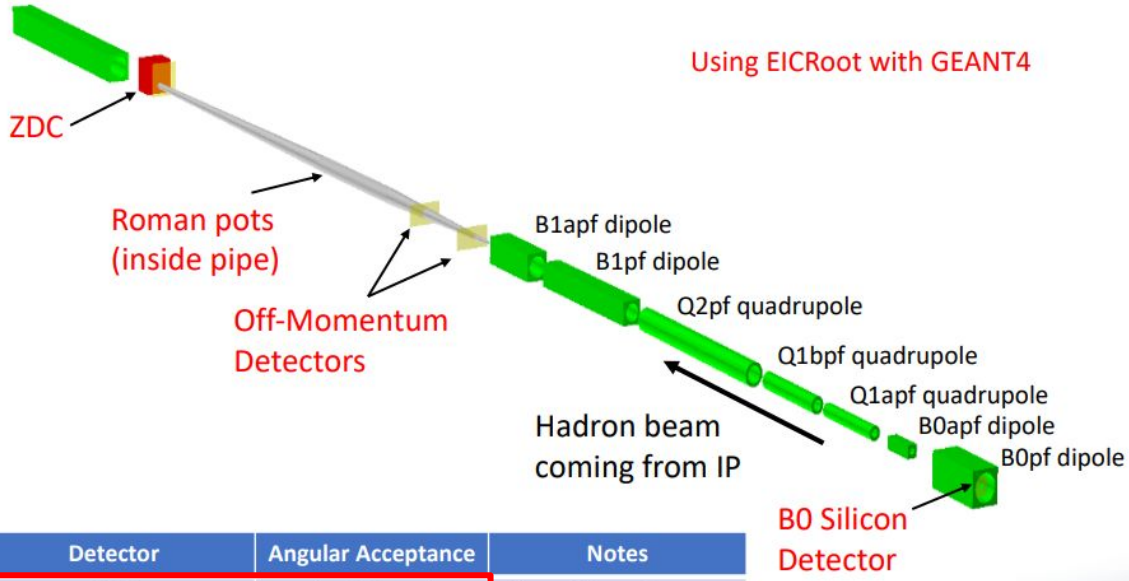
5 GeV e on 41 GeV p

Conclusion:

- No double photon detection on the ZDC!
- Proton will be at a more optimal angle
- 5 GeV e on 100 GeV p is more optimal.
- The setting configuration of 10 GeV e on 100 GeV p is similar

From Pavia Meeting

Central Integration – Beam Pipe



Detector	Angular Acceptance	Notes
ZDC	θ < 5.5 mrad	About 4.0 mrad at $\varphi \sim \pi$
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.

$$x_L = \frac{p_{z,nucleon}}{p_{z,beam}}$$

Slide from Alex Jentsch

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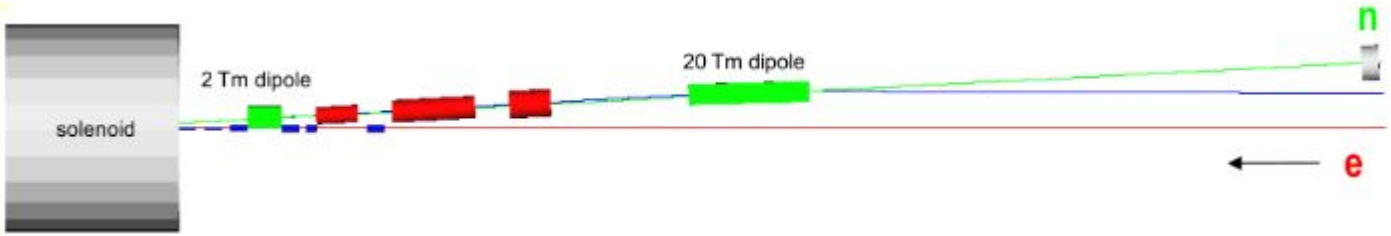
This corresponds to 17.6 cm radius circle at 32 meters from IR! much smaller than expected 60x60 cm^2 square!

What does this mean for the two photons?

Detecting a 20-50 GeV pi0



- At 20-50 GeV, π^0-> 2 gamma decay angle (between two photon) is 0.8-0.4 degree.

- Best way to detect π^0 at neutro $\sin\theta_{\max} = \frac{m_\pi}{2E_\gamma}$ we need to insert lead to slow down π^0? Resolution needed to distinguish pi0 from single photon DVCS events?

- Simulation is needed to answer these questions

- Some feedbacks and suggestions from experts:
  - Abhay: PHENIX central arm, 5 meters from IR. pi0->2photon separation at about 20 GeV. Our calorimeter granularity 2.7 cm square facing the IR.
  - Elke: In Star, ECal at 7m and separate pi0 up to 60 gev
  - Preshower to the calorimeter?

Question and Discussion

- How ready is fast-smear and full simulation for the tagging detector to perform photon/neutron PID study?
- Small angle proton detection, complications?
- Backward π^0 is just the beginning
  - Study on u-channel η, ω, π^+ is in the plan (not inclued in YR)
  - Our currently knowledge of *u*-channel physics in the DIS region almost none
    - Unknown *W* dependence (EIC possible)
    - Unknown x_B dependence (EIC + 12 GeV possible)
    - Unclear -*t* dependence (EIC possible, but required significant modification to ZDC, bigger ZDC)
    - L/T Separation possibility? (Need more study)
- More and more *u*-channel data will come out of 12 GeV, on all meson production channels
- Would be there a universality (*t*-channel and *u*-channel) effort in the EIC era?