Backward-angle u-Channel π^0 Production Update

Wenliang (Bill) Li
on behalf of
Justin Stevens, Garth Huber, **Bernard Pire*, Lech Szymanowski*, Kirill Semenov-Tian-Shansky***

4/June/2020

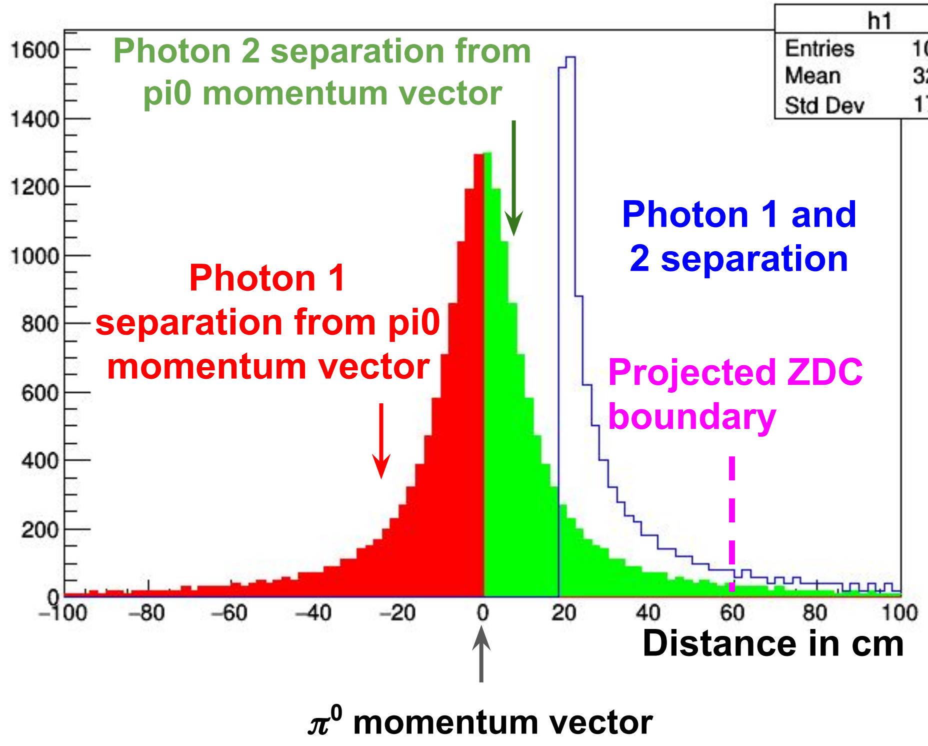
Outline

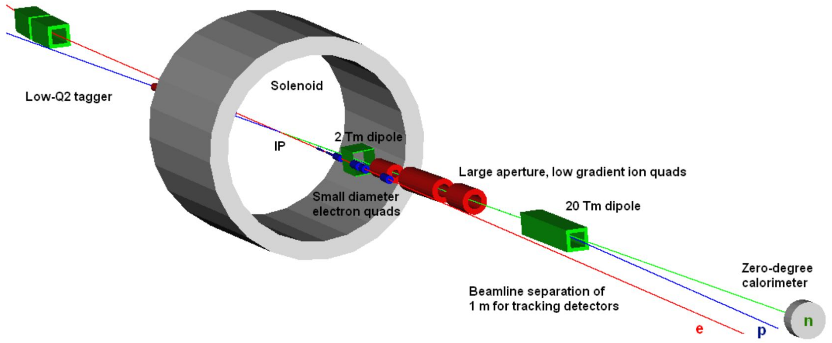
- Last pre-full simulation feasibility update

- Answers to some questions:
    - Will photon reach ZDC and where?
    - Rough detection efficiency
    - Detector constrains
    - Physics background (to our best knowledge)

- Lund files for the simulation is ready to go

Photons at the ZDC (Before Pavia meeting)



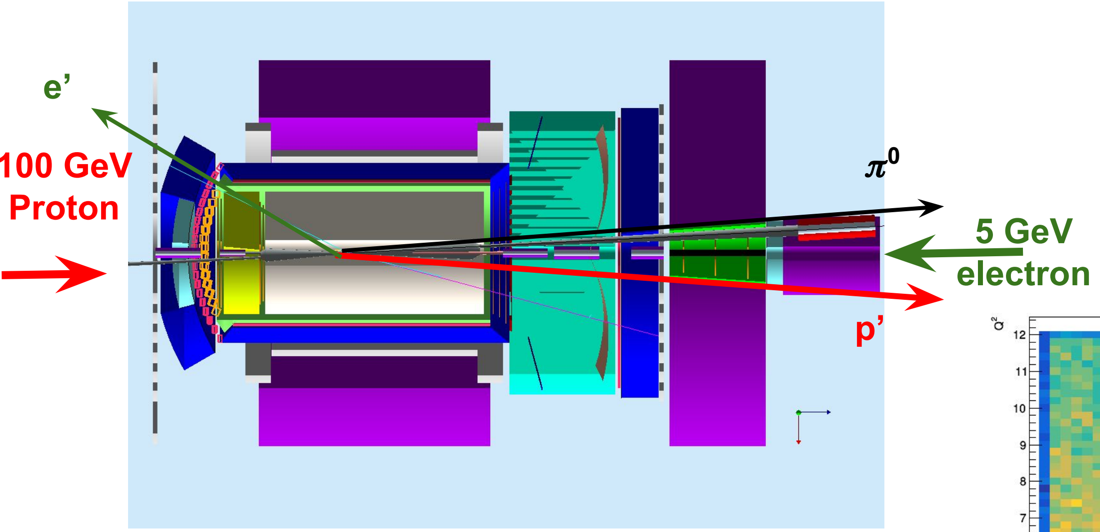


- 10000 pairs of decayed photons created isotropically from 0-180 degrees in the π^0 rest mass frame

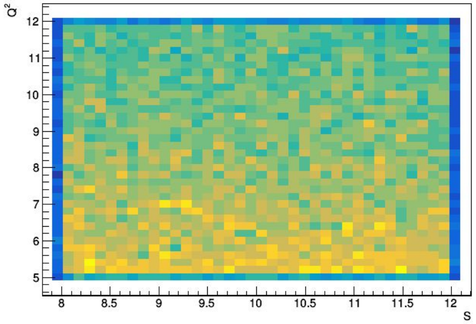
- Assuming IR-ZDC distance: 32 meters
  - Minimum two photon separation: ~19 cm
  - Separation distribution max: 22 cm

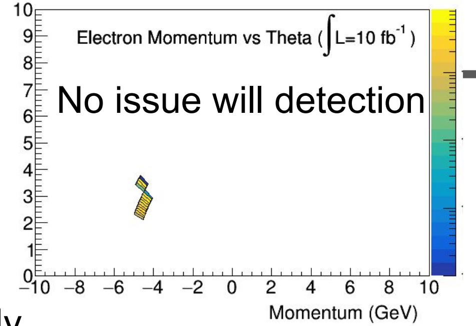
- ZDC calorimeter size and block size?
  - ZDC size 60 cm x 60 cm.
  - Even 4cm x 4cm in block size would be sufficient for π^0 :)
  - There is +-5 mrad

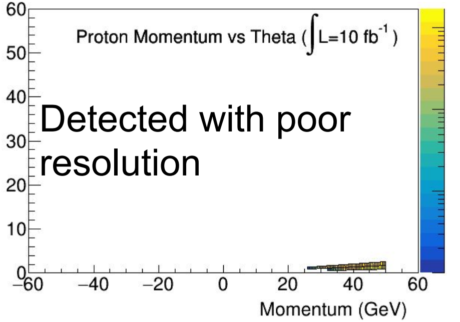
U-channel Meson Production Setup

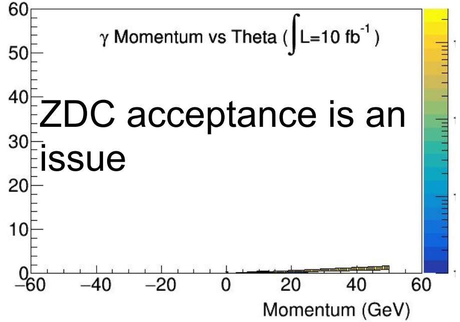


Q^2 vs S intentionally constraint





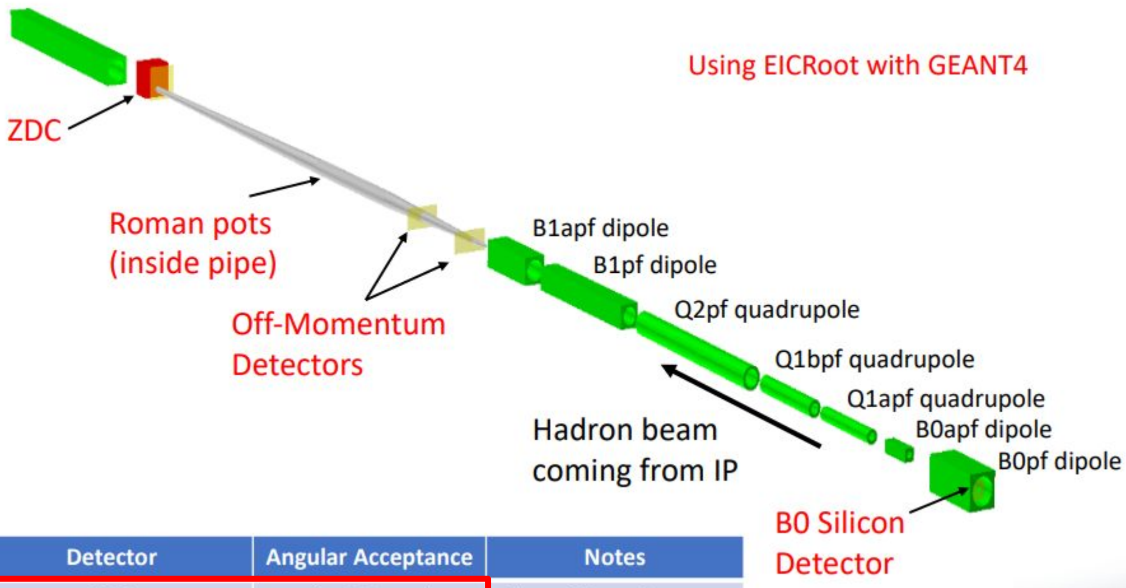




Q^2 (GeV^2)	W (GeV)	x_B	$\theta_{e'}$ (deg)	$\eta_{e'}$	$P_{e'}$ (GeV)	$\theta_{p'}$ (deg)	$\eta_{p'}$	$P_{p'}$ (GeV)	θ_{π^0} (deg)	η_{π^0}	P_{π^0} (GeV)	$-t$ (GeV^2)	$-u$ (GeV^2)
6.2	3.19		152	-1.39	5.31	-1.84	4.13	43.40	1.43	4.38	56.29	14.84	-0.37
7.0	3.19		150	-1.32	5.35	-1.92	4.09	45.50	1.43	4.38	54.12	16.19	-0.39
8.2	3.19		148	-1.24	5.40	-1.85	4.12	49.74	1.43	4.38	49.84	16.80	-0.42
9.3	3.19		146	-1.19	5.46	-1.92	4.09	51.90	1.43	4.38	47.60	18.19	-0.44
10.5	3.19		144	-1.12	5.52	-1.94	4.07	54.96	1.43	4.38	44.50	19.32	-0.47

From Pavia Meeting

Central Integration – Beam Pipe



Detector	Angular Acceptance	Notes
ZDC	$\theta < 5.5$ mrad	About 4.0 mrad at $\varphi \sim \pi$
Roman Pots	$0.0 < \theta < 5.0$ mrad	Need 10σ cut.
Off-Momentum Detectors	$0.0 < \theta < 5.0$ mrad	Roughly $.4 < x_L < .6$
B0 Sensors	$5.5 < \theta < 20.0$ mrad	Still need to optimize.

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

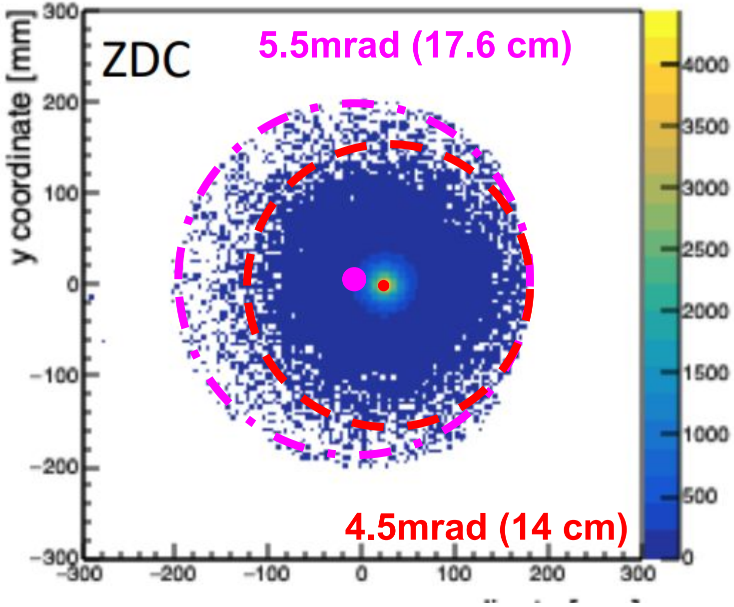
Slide from Alex Jentsch

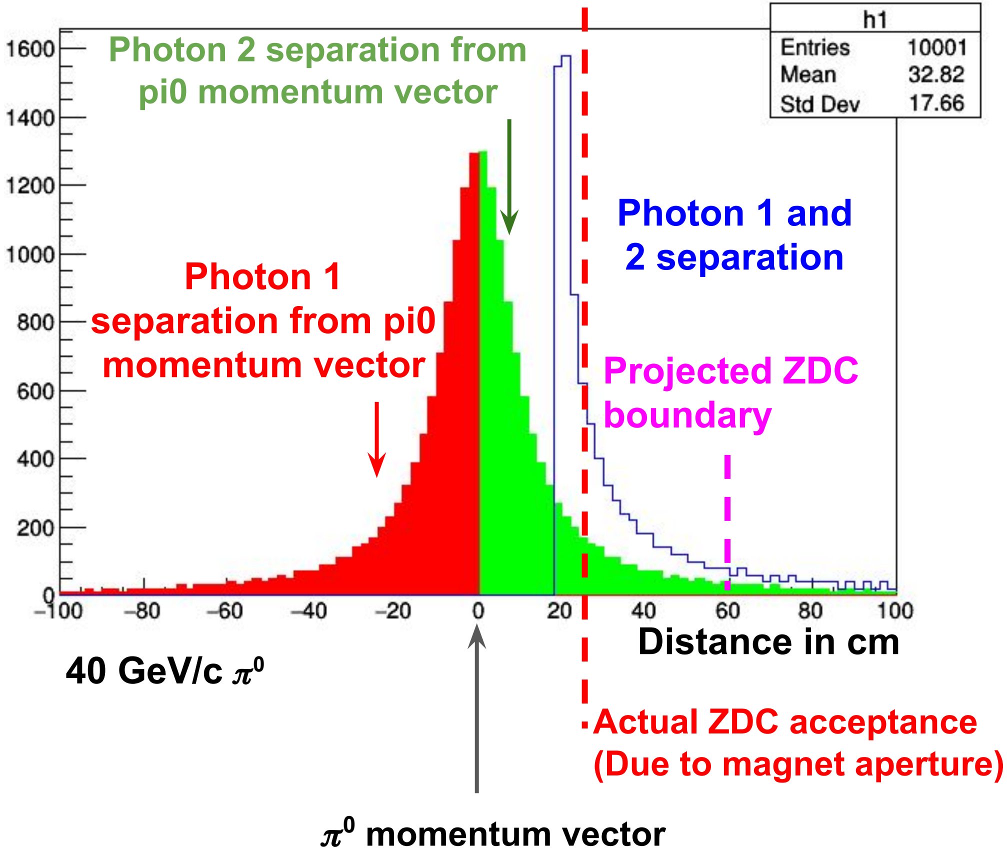
4

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?

U-channel Meson Production (After Pavia Meeting)

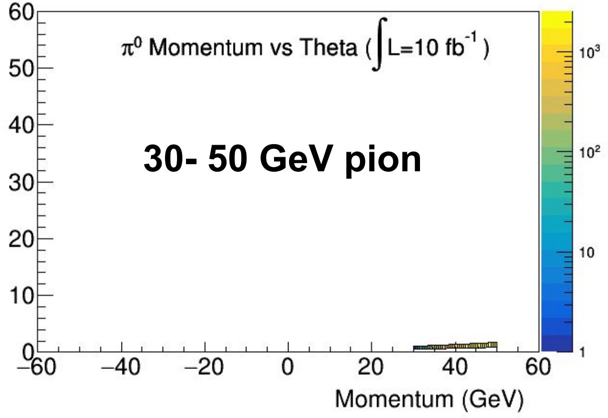


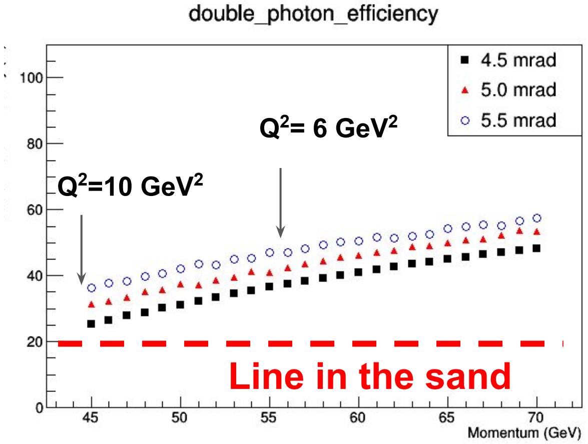


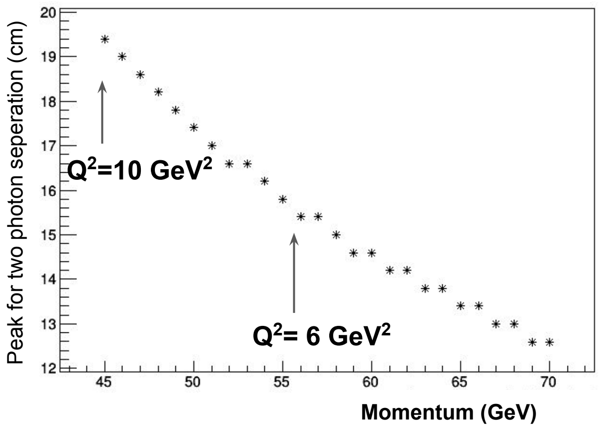
DVCS simulation with deuterium, spectating neutron distribution on ZDC, from Alex

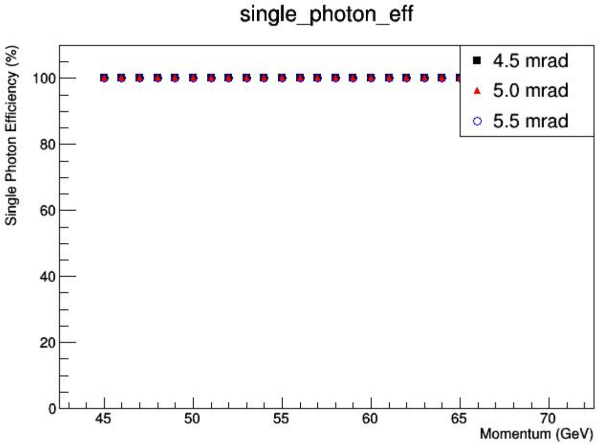
Slight shift in -u' will give us larger coverage.

Impact to the efficiency









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

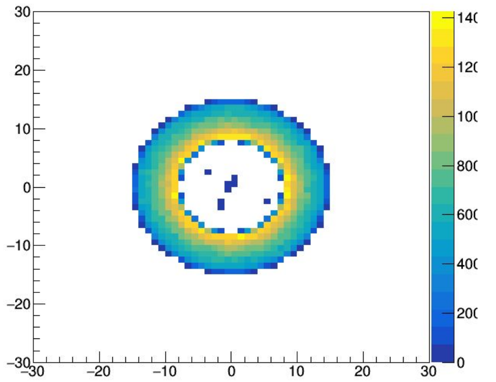
Physics background (to our current best knowledge)

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

2 γ hit parttern

40 GeV/c π^0

4.5 mrad acceptance

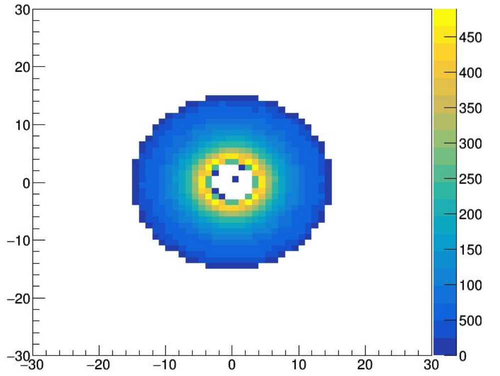


- Single photon case:
  - Primary reaction: e+p-> e'+p' + π^0
  - Ideal expected trigger: e'+p'+ γ
  - Physis background: DVCS, eta, Λ->n+π^0
  - Less than ideal trigger: e'+γ
  - Background: many many possibility

2 γ hit parttern

60 GeV/c π^0

4.5 mrad acceptance



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

Conclusion

- U-channel π^0 (2gamma) will be on ZDC at specific location and we conclude it is possible to reconstruct this reaction.

- Full simulation will provide further detail including realistic efficiency, PID, signal/background estimation, etc.

- Lund file for both pi0 and two-photon scenario are ready to go
  - For detector experts to study acceptance
  - PID study (myself)

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?

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

Confirmed! Q^2=2.45 GeV

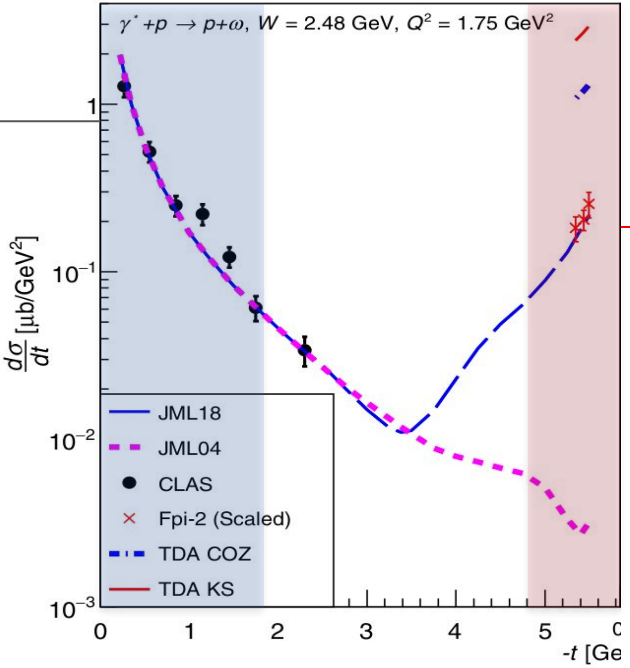
Upcoming PAC 48 proposal

Thank you

Advertisement:

- The first *u*-channel physics workshop will be held at JLab in September 21-22.
  - Event page: https://www.jlab.org/conference/BACKANGLE
  - Indico page: https://www.jlab.org/indico/event/375

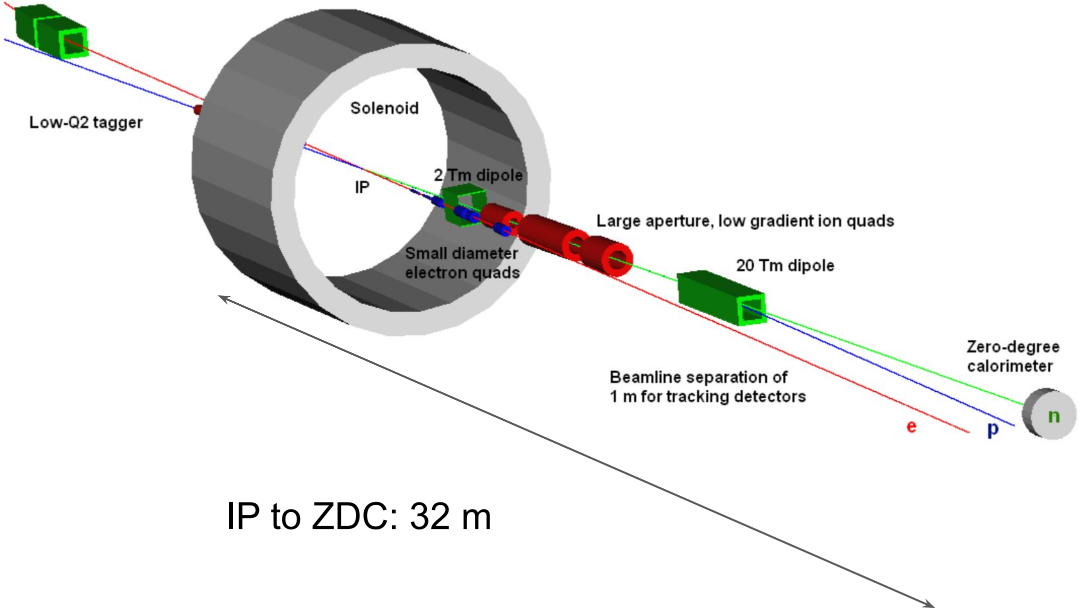
***t*-channel**



***u*-channel**

Result on *u*-channel omega production, Phys. Rev. Lett. 123, 182501

Photons at the ZDC



- IP to ZDC distance: ~ 30m
- Q^2=10.5 GeV^2, π^0 momentum=44.5 GeV
  - Lifttime = 8.4×10^{-17} s
  - Beta = 0.99999 c
  - Decay at the IP
- Assume IP-ZDC distance: 32 meters
- Where do two photons end up on the ZDC?

Kinematics table

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)
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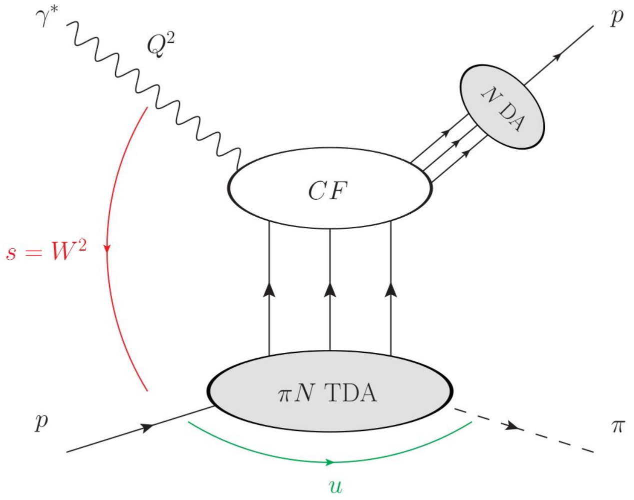
Validation of TDA or u-channel factorization scheme

- EIC L/T separation ability is unclear
- **Initial phase to study TDA at EIC: studying scaling**
  - **Low hanging fruit**
- Advance phase: Single Spin Asymmetry and Double spin Asymmetry

- **Two Postulation:**
  - **$1/Q^8$ scaling behavior**
  - **$\sigma_T > \sigma_L$, $\sigma_L \sim 0$**
- **Verified with all meson production channel**



- **$\sigma_T > \sigma_L$ will be tested at 12 GeV**

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

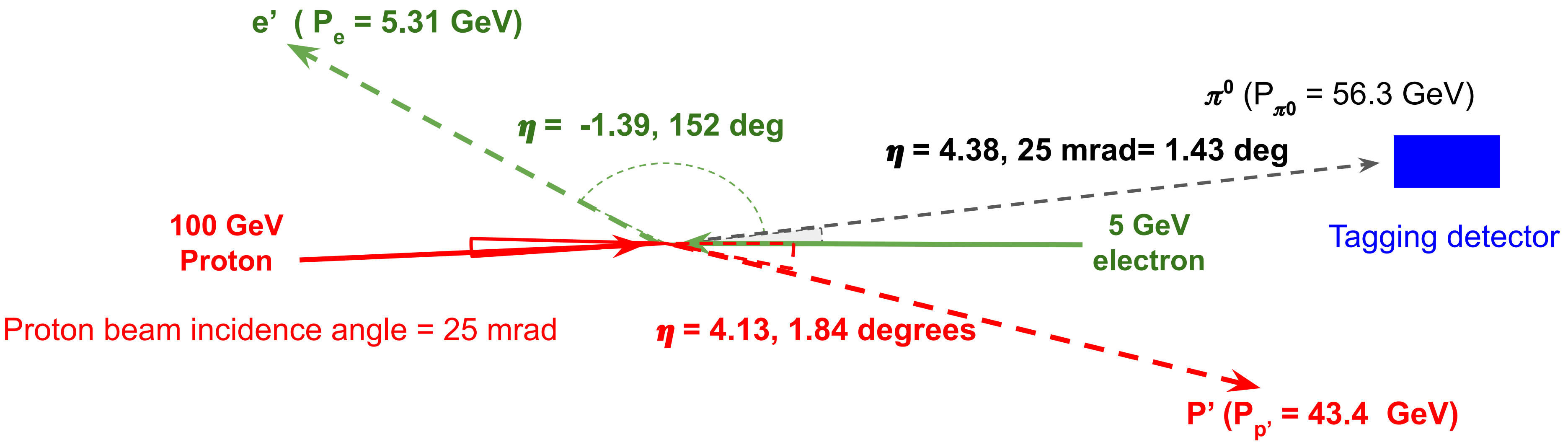
Confirmed! Q^2=2.45 GeV

Upcoming PAC 48 proposal

Others: parasitic data may be available

Simplest case 1: pi0 at 50 mrad (along p incidence angle)

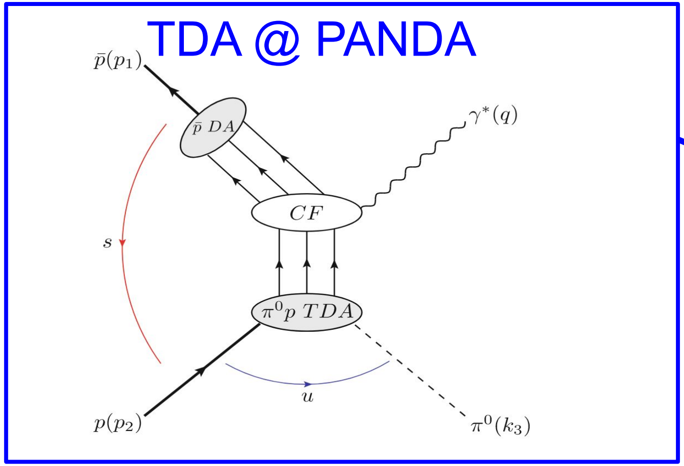
s=10 GeV^2, W= 3.13 GeV, Q^2 = 6.2 GeV^2,

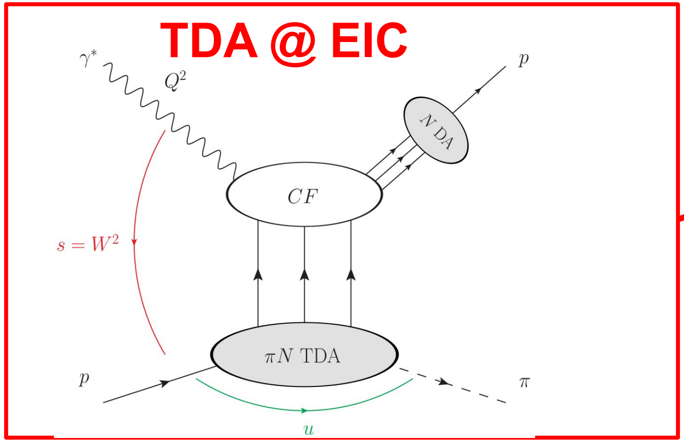


-t = 14.84 GeV^2

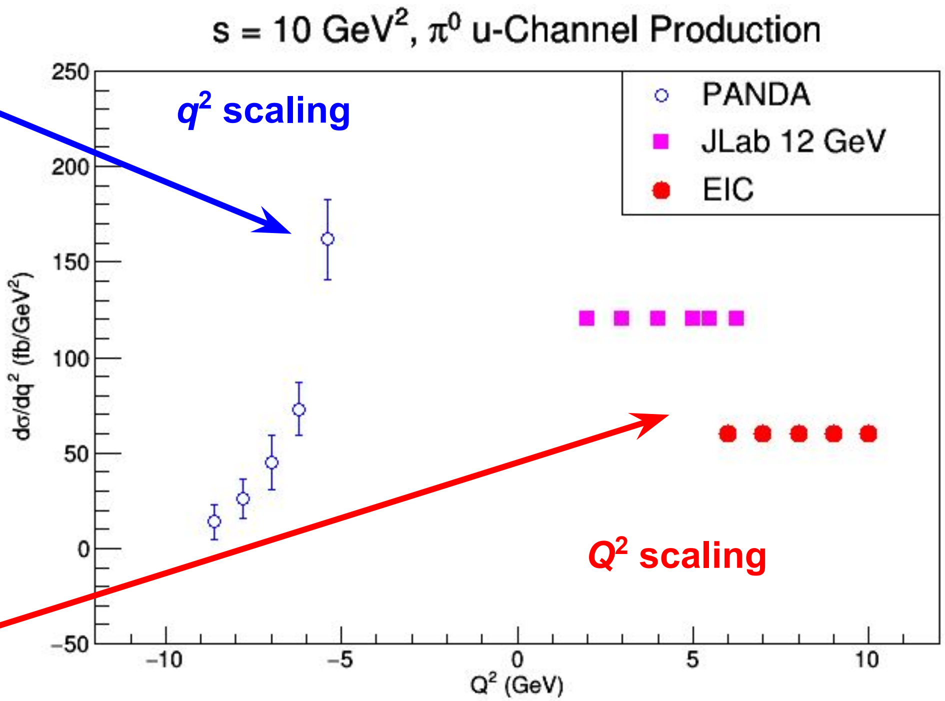
-u = -0.37 GeV^2

Q^2 (space-like) and q^2 (time-like) Scaling

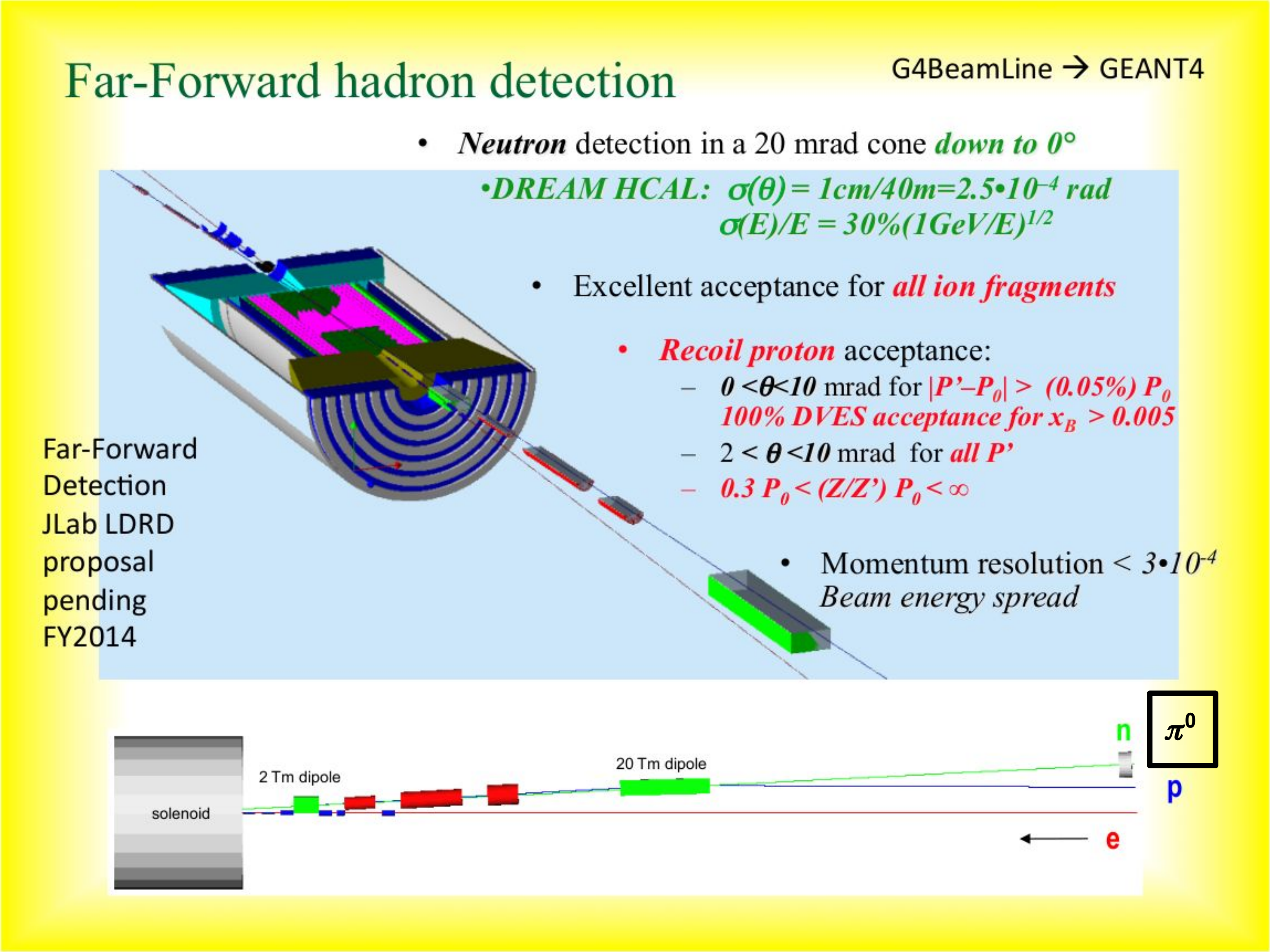




The PANDA Collabration, Eur. Phys. J. A (2015) 51: 107



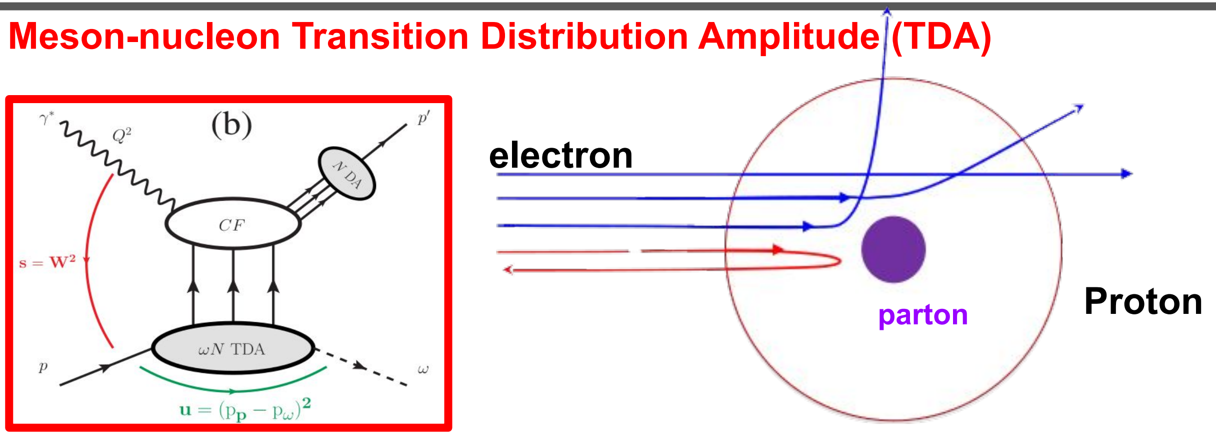
Same TDAs for PANDA and EIC, the ultimate universality check

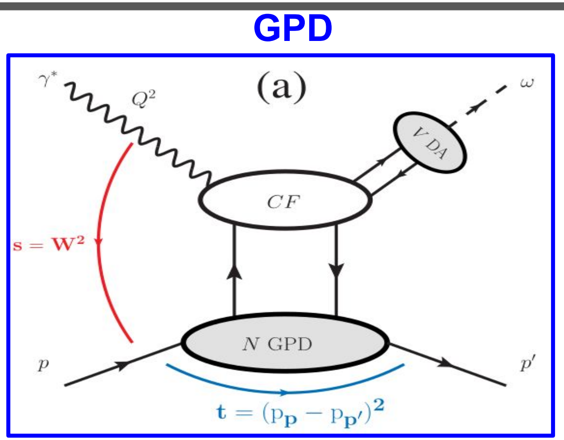


- π^0 acceptance into the foward tagging detector should be similar to recoiled neutron:
    - Maximum: 20 mrad cone down to 0 deg
- π^0 momentum ?
- Resolution needed to resolve the π^0-> 2 gamma ?

Old slides from Charles Hyde

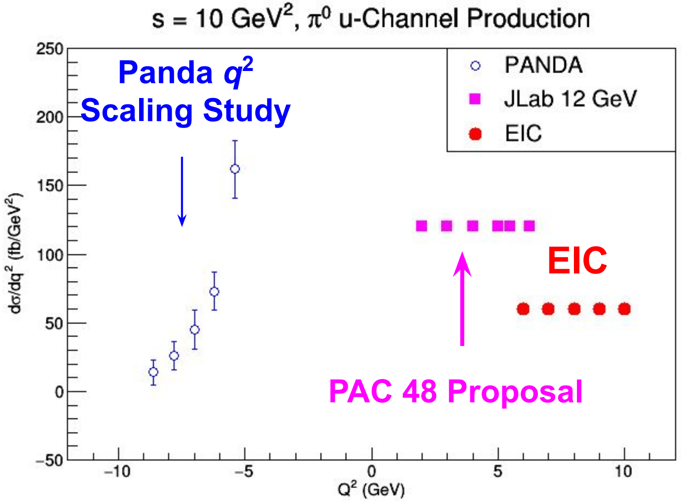
Backward-angle structure of Proton



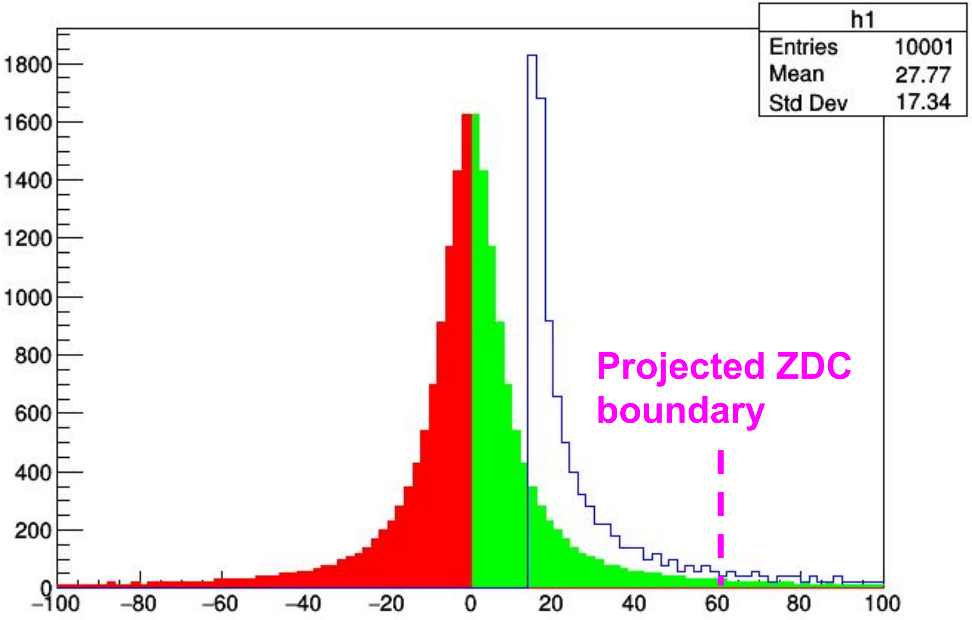


- **Complete description of Nucleon:**
  - GPD = Hadron tomography of the proton
  - TDA = tomography of partonic distributions in the nucleon --> meson and vice versa transitions probed in the backward angle kinematics

- **Two Postulation of TDA:**
  - $1/Q^8$ scaling behavior
  - $\sigma_T > \sigma_L$, $\sigma_L \sim 0$



Higher momentum is better



- Q^2 = 6.2 GeV, π^0 momentum=56.29 GeV
- Minimum two photon separation: ~15 cm
- Separation distribution max: 16 cm

Next step

- Photon study PID study (from neutron) in **fast smear** and and **full EIC simulation**

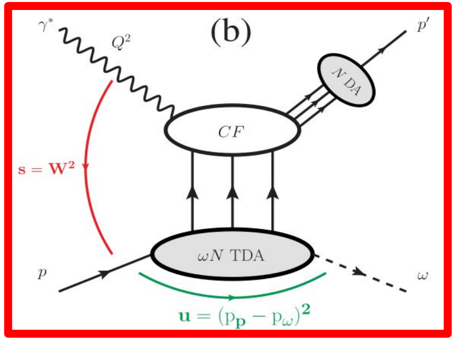
- Awaits for the physics TDA model/calculation from Bernard, Lech and Kirill

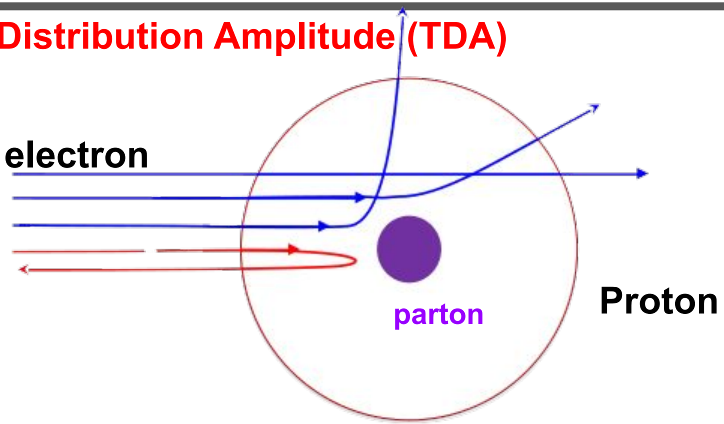
- Similar backward angle studies on
  - η (planning)
  - ω (in progress)
  - π^+ (speculating)

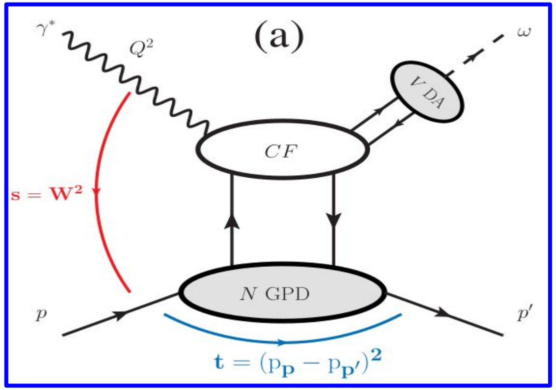
Backward-angle structure of Proton

Meson-nucleon Transition Distribution Amplitude (TDA)

GPD







- Complete description of Nucleon
    - GPD = Hadron tomography of the proton
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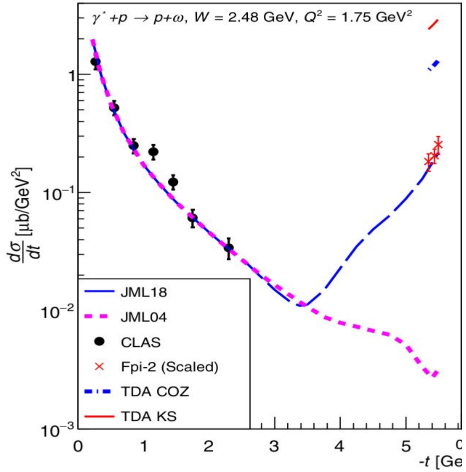
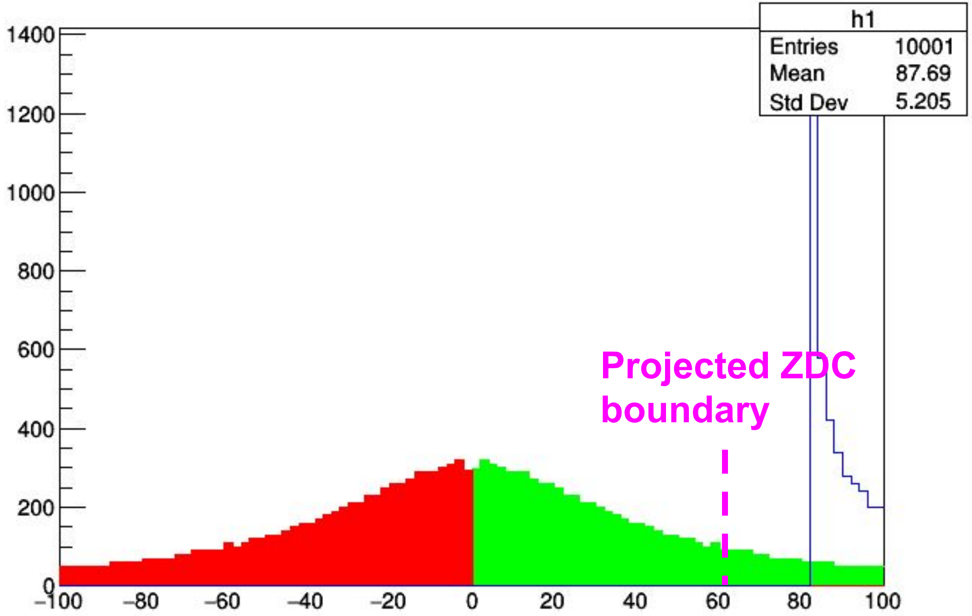
-



η decay on ZDC



- s=10 GeV^2, Q^2=10 GeV^2, η momentum = 42GeV
- Impossible for ZDC with 60 cm x 60 cm size at 32 m
- Still worth studying as it contribute to single photon background
- Possibility for end-cap detector? Need to study, same of for ω

In this Update

- Kinematics changed to focus on Q^2<10 GeV^2
- Corrected and adjusted
  - Proton incidence angle 50 mrad-> 25 mrad
  - Pi0 constrained to +-10 mrad from proton incidence angle
- Photon detection in ZDC
  - Position and angle expectation
- **Question to experts and convenors**

Question to experts and convenors

- Are there any plot to generate to demonstrate kinematics coverage?

- Plots to show detector constraints.

Backup

Kinematics Table

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)
6.0	3.19												
12.0	3.19												
18.0	3.19		134	-0.86	5.91	-2.53	49.89	66.3	2.86	4.60	32.74	26.98	-0.55
24.0	3.19												
30.0	3.19												
36.0	3.19												

50 mrad

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)
6.0	3.19												
12.0	3.19												
18.0	3.19		134	-0.86	5.91	-3.02	3.63	55.63	2.00	4.05	43.45	25.92	0.50
24.0	3.19												
30.0	3.19												
36.0	3.19												

35 mrad

In this Update

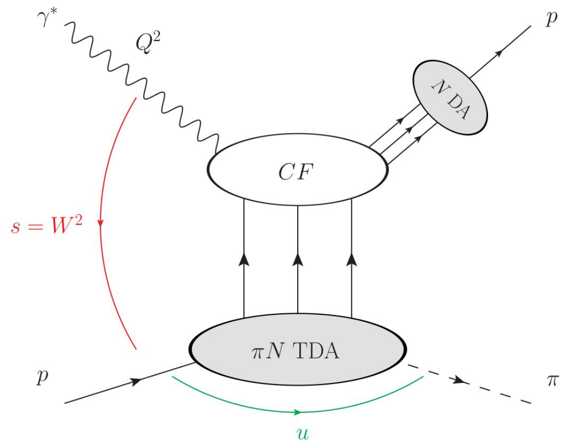
- Short information on the backward-angle (u-channal) meson production

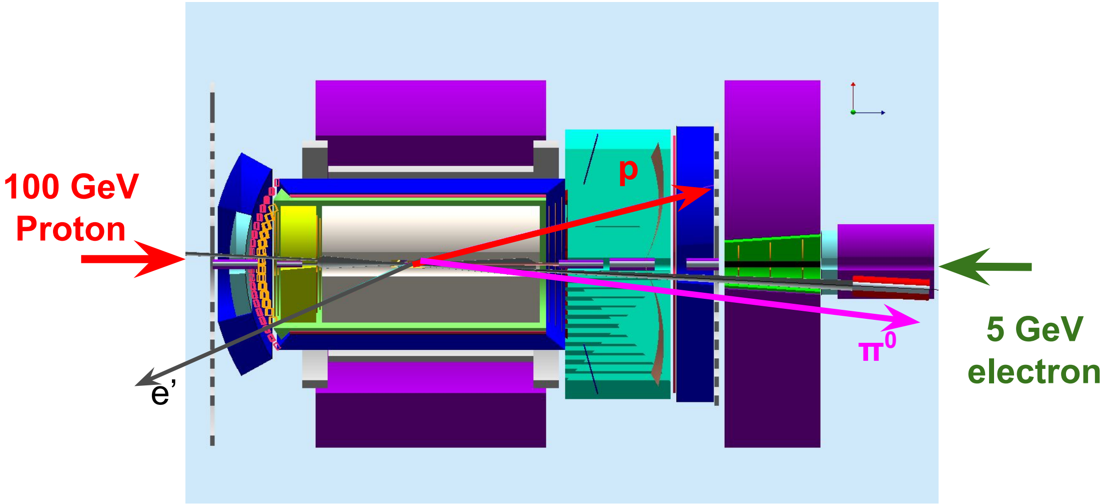
- U-channel pi0 production in EIC
    - Where particles go?
    - Kinematics
    - Produced pi0 momentum distribution

- Our plan and timeline

Short update on the backward-angle π^0 Production

Bill and Bernard on behalf of backward meson production group

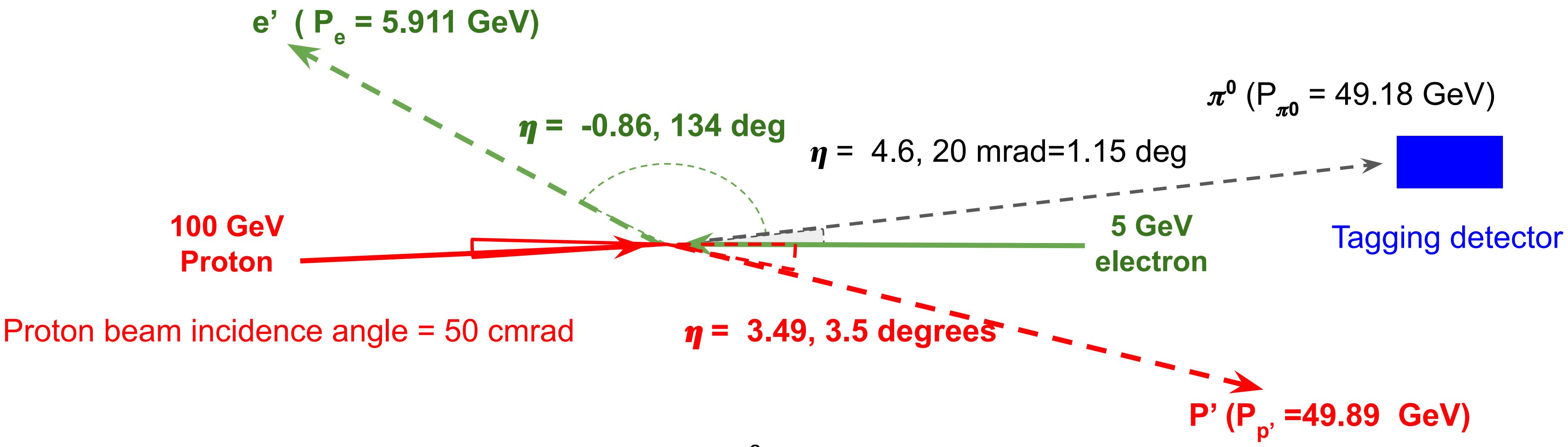




- Bill merged the EIC exclusive charged pion production generator into a C++ coding platform
- Bill is now working on this platform to make it more general (by separating the physics section of the code and make it modular)
- The same platform could be used for other processes (such as backward-angle DVCS) in the EIC
- Justin Stevens will give an update on our progress at the Temple meeting in March
- Any question or interested in helping, contact Bill: billlee@jlab.org

Simplest case: pi0 at 20 mrad

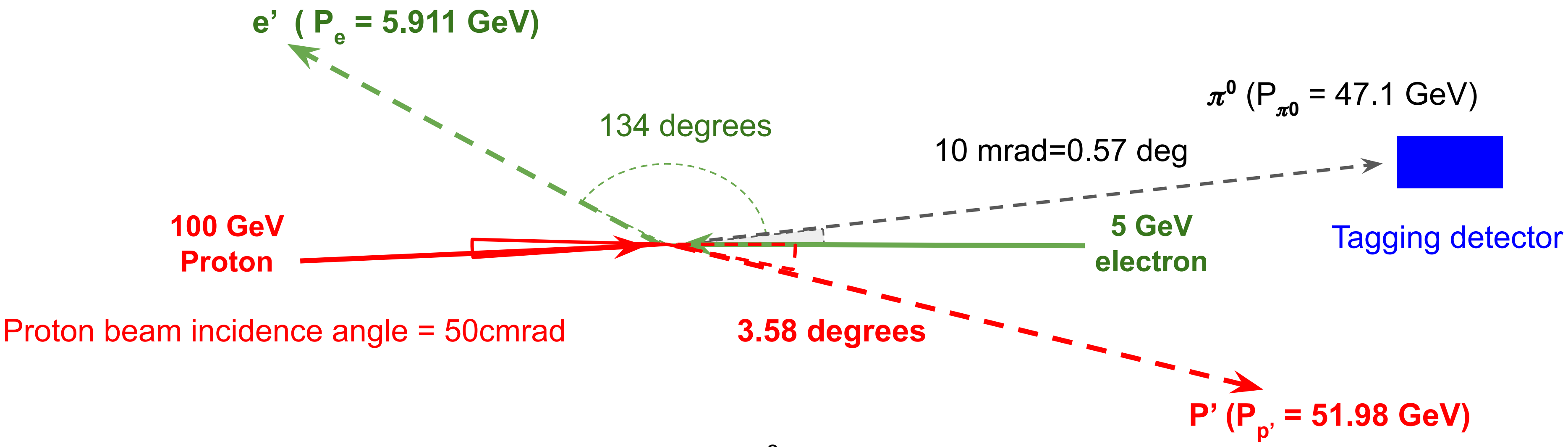
s=10 GeV^2, W= 3.13 GeV, Q^2 = 18.05 GeV^2,



-t = 22.4 GeV^2
-u = 4 GeV^2

Simplest case: pi0 at 10 mrad

$s=10\ GeV^2$, $W= 3.13\ GeV$, $Q^2 = 18.05\ GeV^2$,

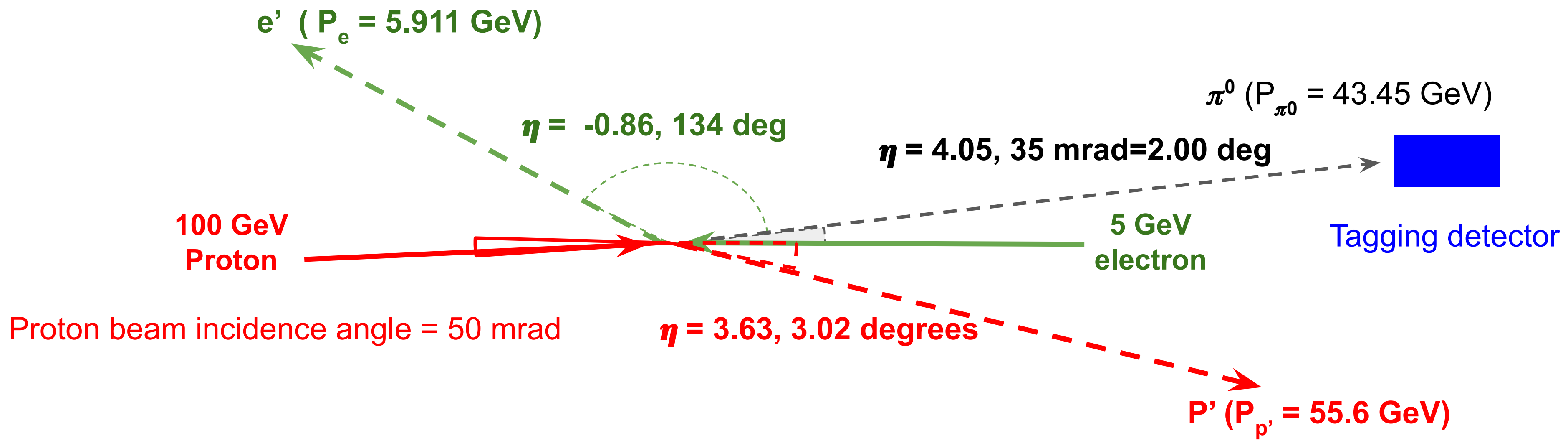


$-t = 19.33\ GeV^2$

$-u = 7.09\ GeV^2$

Simplest case 2: pi0 at 35 mrad (15 mrad from p incidence angle)

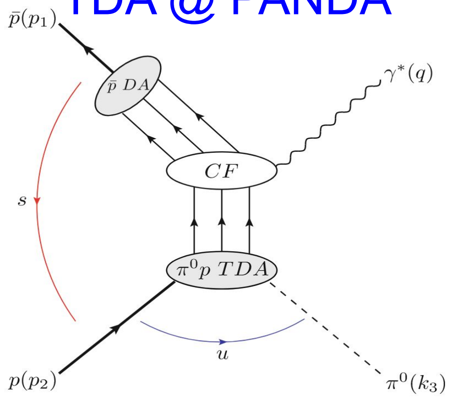
$s=10\ GeV^2$, $W= 3.13\ GeV$, $Q^2 = 18.05\ GeV^2$,



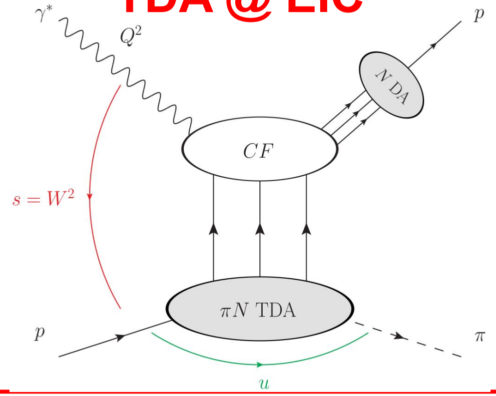
$-t = 25.92\ GeV^2$
$-u = 0.5\ GeV^2$

Q^2 (space-like) and q^2 (time-like) Scaling

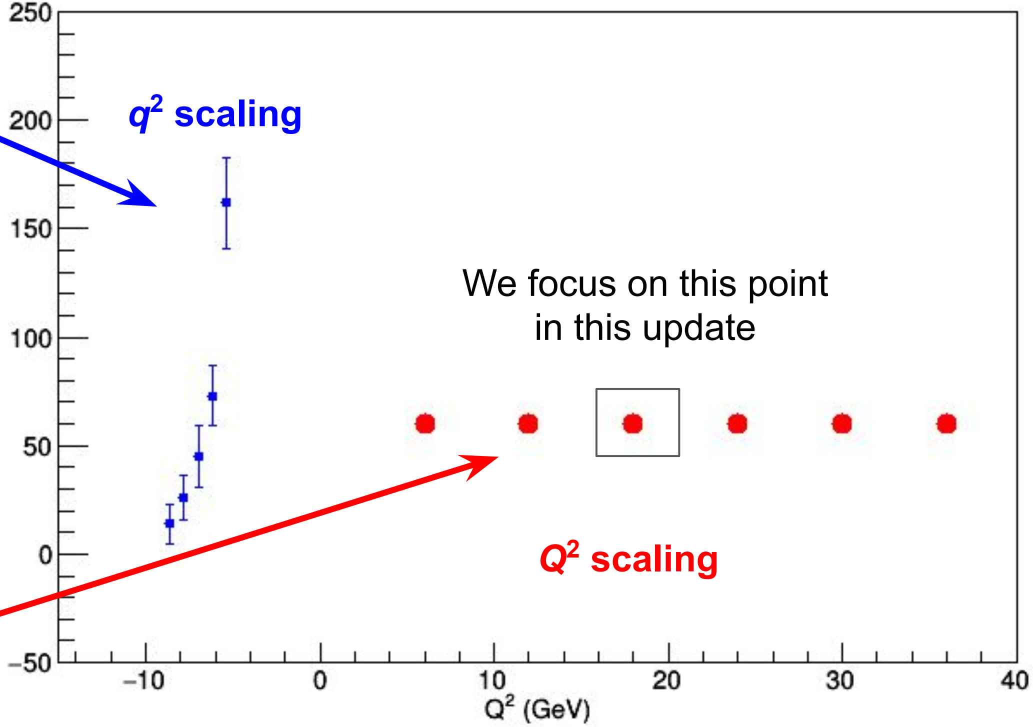
TDA @ PANDA



TDA @ EIC

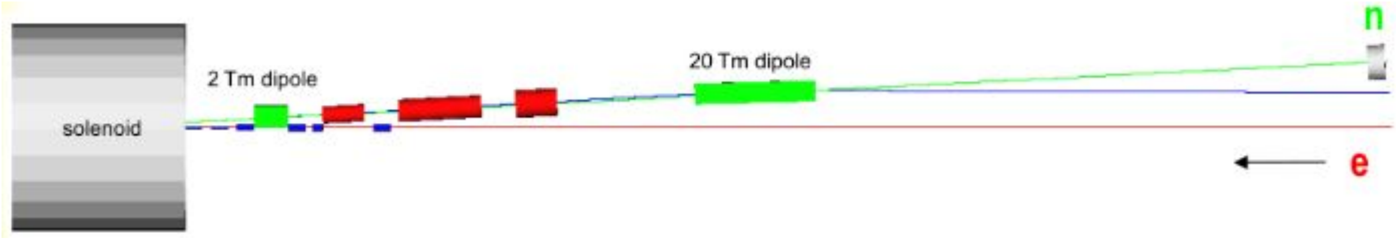


The PANDA Collaboration, Eur. Phys. J. A (2015) 51: 107



Same TDAs for PANDA and EIC, the ultimate universality check

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?

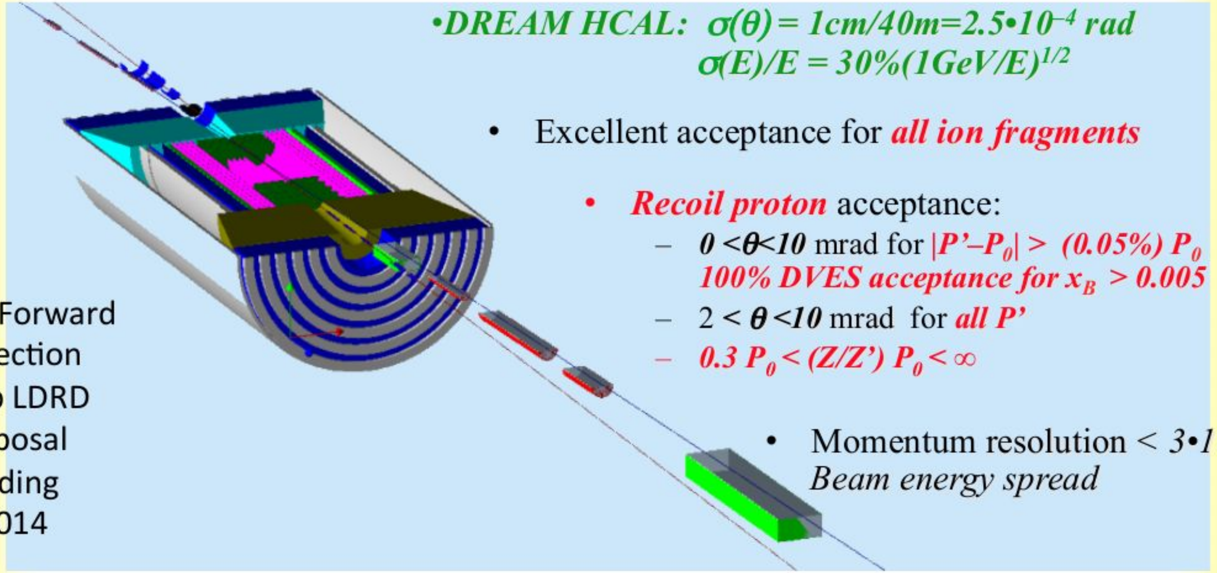
- Simulation is needed to answer these questions

- 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?

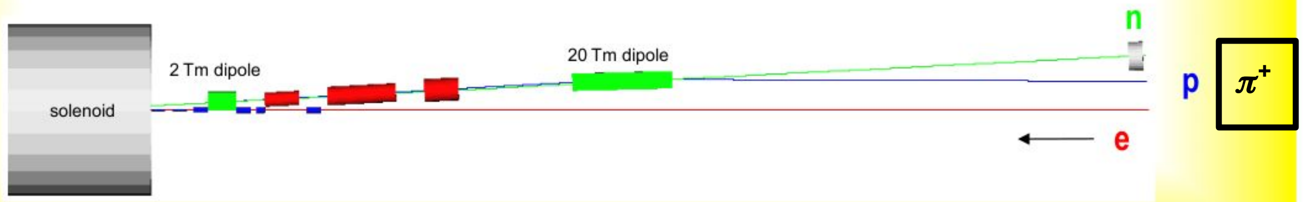
Far-Forward hadron detection

G4BeamLine → GEANT4

- ***Neutron*** detection in a 20 mrad cone ***down to 0°***
  - ***•DREAM HCAL:*** $\sigma(\theta) = 1cm/40m = 2.5 \cdot 10^{-4}$ ***rad***
    $\sigma(E)/E = 30\%(1GeV/E)^{1/2}$
- Excellent acceptance for ***all ion fragments***
- ***Recoil proton*** acceptance:
  - $0 < \theta < 10$ mrad for $|P' - P_0| > (0.05\%) P_0$
    100% DVES acceptance for $x_B > 0.005$
  - $2 < \theta < 10$ mrad for ***all P'***
  - $0.3 P_0 < (Z/Z') P_0 < \infty$
- Momentum resolution < $3 \cdot 10^{-4}$
  Beam energy spread



Far-Forward Detection JLab LDRD proposal pending FY2014



- π^+ acceptance into the foward tagging detector should be similar path to proton:
  - Maximum: 10 mrad cone down to 0 deg
- The kinematics tables are coming.

Old slides from Charles Hyde