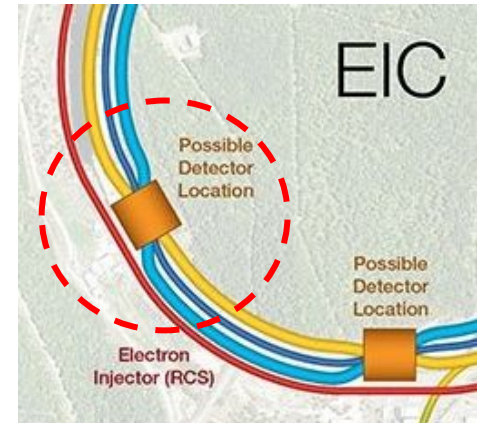
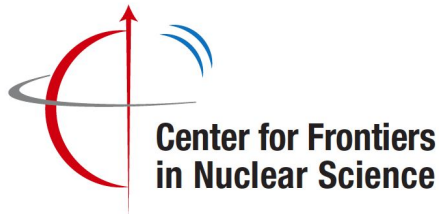


Opportunities with a 2nd EIC detector at IP8

Wenliang (Bill) Li, @ 2nd workshop on advancing the understanding of non-perturbative QCD using energy flow

Nov 6, 2023



Why do we need a 2nd detector ?

Needed to unlock the full discovery potential of the EIC

- Implies a general-purpose collider detector able to support the full EIC program
- **Cross checks** of key results are essential!

Complementary design features (to ePIC)

- Combined systematics (as for H1 and ZEUS)
- Phase-space coverage
- The EIC will have high statistics, uncertainties for the envisioned measurements will be systematics limited.

New physics opportunities

- Take advantage of much-improved near-beam hadron detection enabled by a 2nd focus,
- Impacts, for instance, exclusive / diffractive physics; greatly expands the ability to measure recoiling nuclei and fragments from nuclear breakup.
- New ideas beyond the NAS and Yellow Report scope (EW and BSM)?

Opinions on the 2nd Detector

- Two documented opinion pieces on the subject:



Opinion 1: Rolf Ent and Richard Milner et. al. for EICUG SC

JLAB-PHY-23-3761

Motivation for Two Detectors at a Particle Physics Collider

Paul D. Grannis* and Hugh E. Montgomery†
(Dated: March 27, 2023)

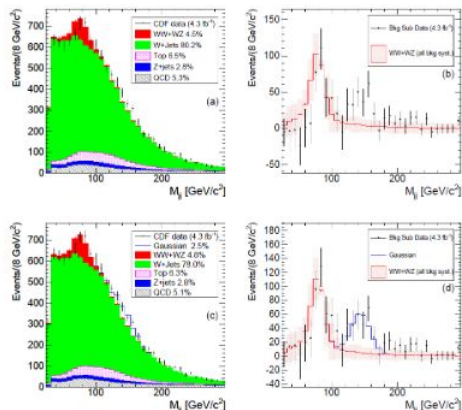
It is generally accepted that it is preferable to build two general purpose detectors at any given collider facility. We reinforce this point by discussing a number of aspects and particular instances in which this has been important. The examples are taken mainly, but not exclusively, from experience at the Tevatron collider.

Opinion 2: P. Grannis and H. Montgomery

Good cases were made for both nuclear and particle physics experiment

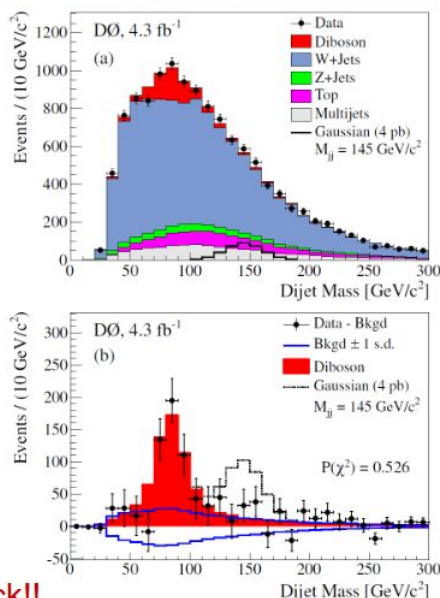
Prime Example of Cross Check Power

144 GeV Resonance? No!



- 2011 CDF study of dijet mass distributions in W + jets measurement.
- Statistically significant (p-value $7.6 \cdot 10^{-4}$, 3.2σ) excess
- Fit to extra Gaussian with width scaled to dijet resolution \rightarrow mass 144 ± 5 GeV, $\sigma_{BR} = 4$ pb.

Crosscheck!!



- 2011 DØ study gives no excess, with likelihood of 145 GeV resonance of $\sigma_{BR} = 4$ pb of $8 \cdot 10^{-6}$ Rejection 4.3σ , 95% CL UL 1.9 pb

- A talk given by H. Montgomery: <https://indico.cern.ch/event/1238718/sessions/495759/>
 - Result verification
 - Mass determination
 - Veto false signals
- A slide stolen from Mont's talk at EICUG 2023 on vetoing false signal
- My person take: EIC carries the potential for discovery level physics: **would anyone believe our result without cross-check?**

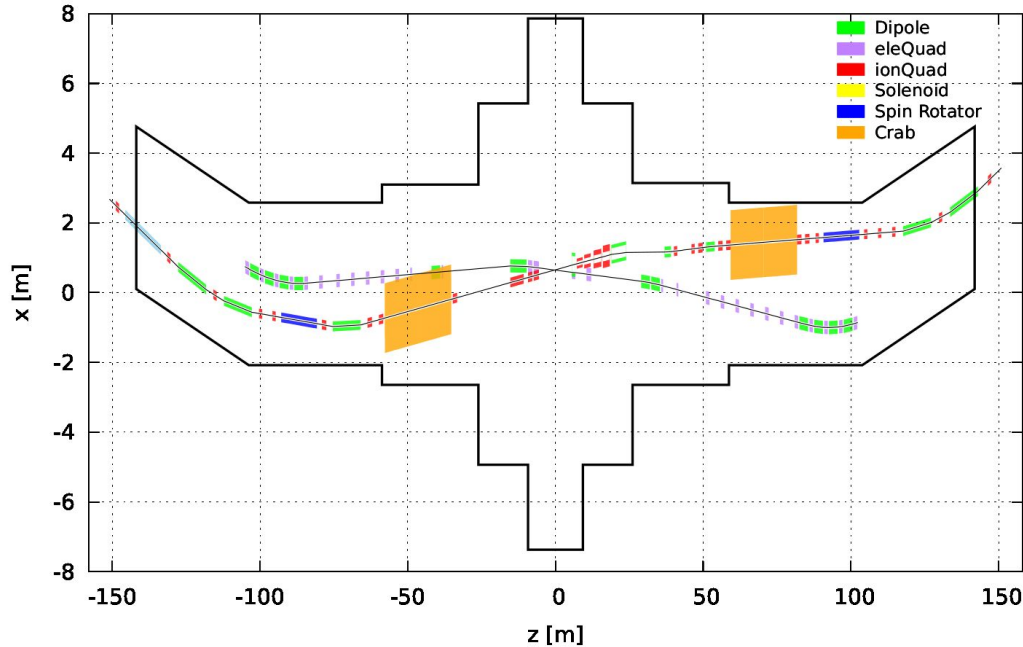
Organization and Effort to date

- **A detector 2 WG under EIC User Group**
 - Group Page: <https://eicug.github.io/content/wg.html#detector-iiip8-group>
 - Physics sub-WG
 - Detector sub-WG
 - **Conveners:** Klaus Dehmelt (CFNS/SBU), Charles Hyde (ODU), Sangbaek Lee (ANL), Simonetta Liuti (UVA), Pawel Nadel-Turonski (CFNS/SBU), Bjoern Schenke (BNL), Ernst Sichtermann (LBL), Thomas Ullrich (BNL), Anselm Vossen (Duke/JLab)
 - **General mailing list:** eic-det2-l@lists.bnl.gov
 - **Convener mailing list:** eic-det2-conveners-l@lists.bnl.gov
 - **Software coordinators:** Kong (zhoudunming@bnl.gov), Bill (wenliang.li@stonybrook.edu)
- **Meetings:**
 - Preparation meeting (SBU CFNS):
 - <https://indico.bnl.gov/event/17693/>
 - **1st International Workshop on A 2nd Detector for the EIC (Temple U.)**
 - <https://indico.bnl.gov/event/18414/>
 - **EICUG 2023 (Warsaw, Poland)**
 - <https://indico.cern.ch/event/1238718/>

Aspirational goals for a 2nd EIC detector

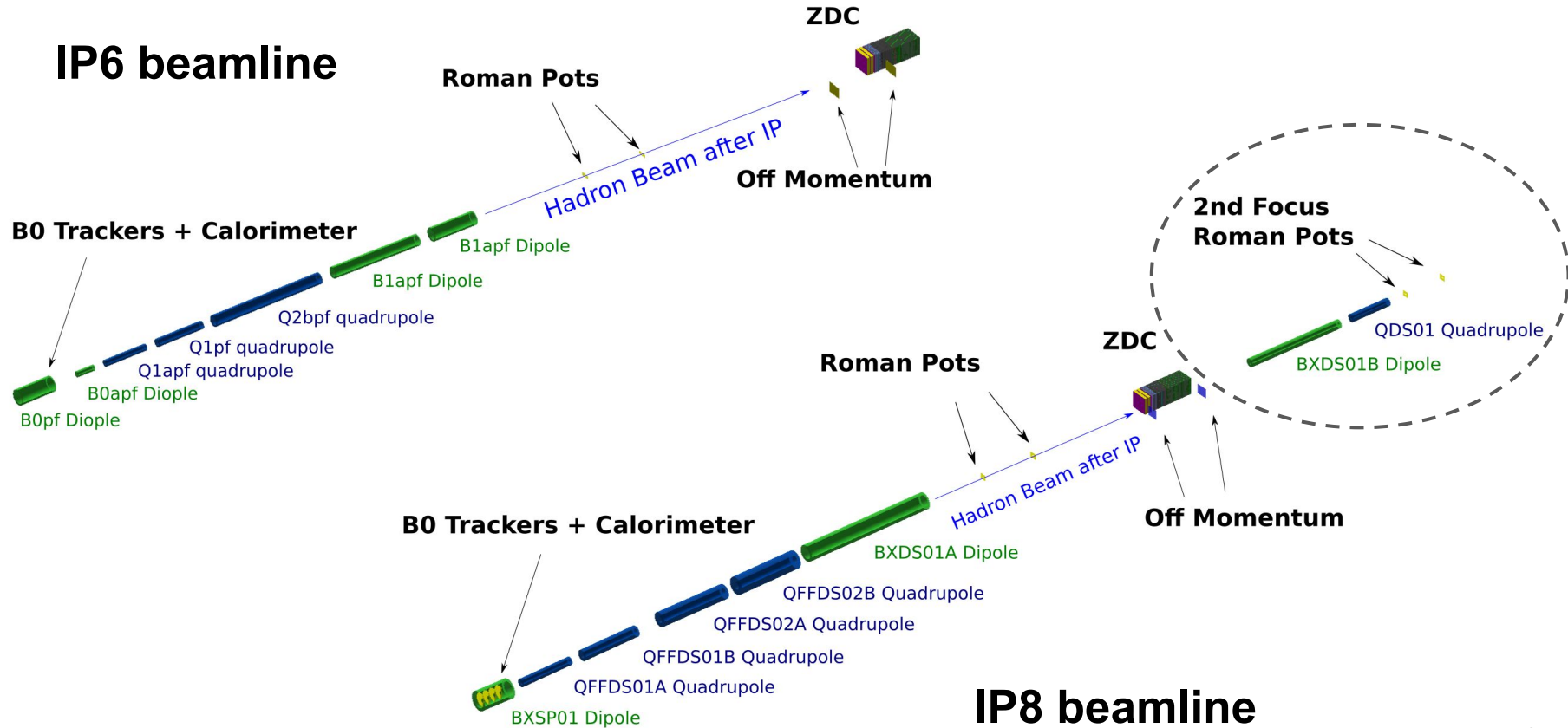
- **MAGNETIC FIELD** – Solenoid field up to 3T, allowing for high resolution momentum reconstruction for charged particles.
- **EXTENDED COVERAGE** for precision electromagnetic calorimetry – important for DVCS on nuclei.
- **MUONS** – enhanced muon ID (not only MIPs) in the barrel and (possibly) backward region.
- **BACKWARD HADRONIC CALORIMETER** – Low-x physics, reconstruction of current jets in the approach to saturation.
- **SECONDARY FOCUS** – tagging for nearly all ion fragments and extended acceptance for low-pT/ low-x protons. Enables detection of short-lived rare isotopes.

Official Project Information

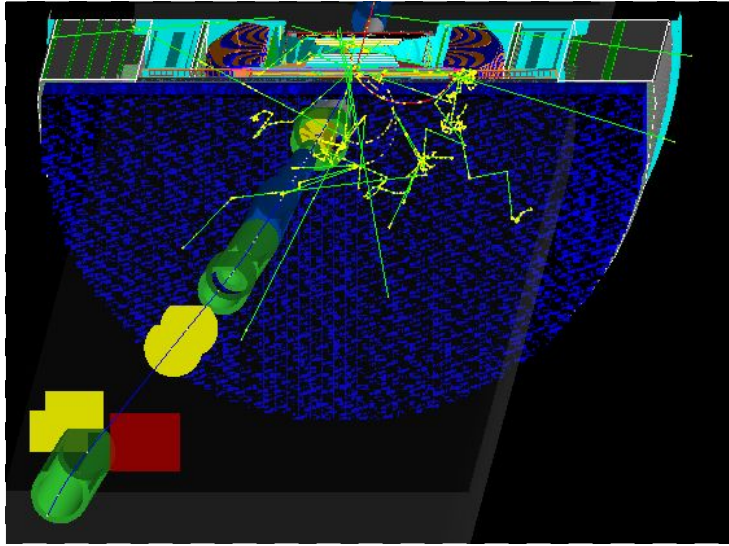


- e-p crossing angle 35 mRad
- A short space allocated for the central detector
 - Less space than ePIC
 - Hard decision needs to be made to meet the design goal (backward angle PID)
- Official Public Information: https://wiki.bnl.gov/eic-detector-2/index.php?title=Project_Information
 - Contact person: Bamunuvita Gamage (randika@jlab.org)
 - Further optimization is needed! (See example in later slides)

IP6 vs IP8: Similar But Different

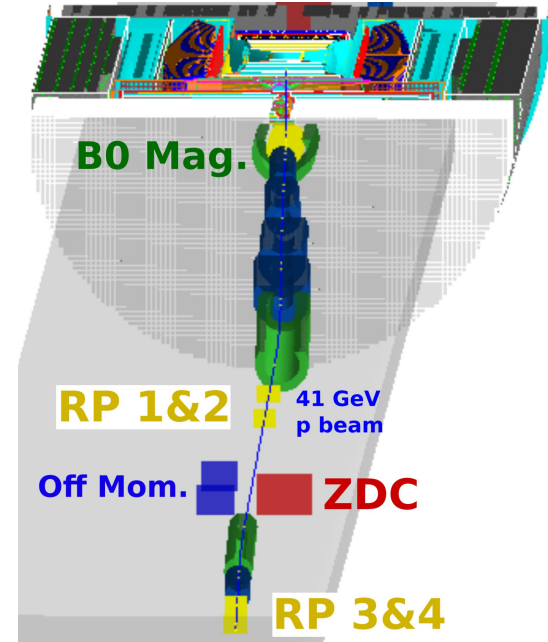


IP6 vs IP8: similar but different



IP6:

- 25 mrad e+p crossing angle
- ZDC Acceptance: -4.5 to +5.5

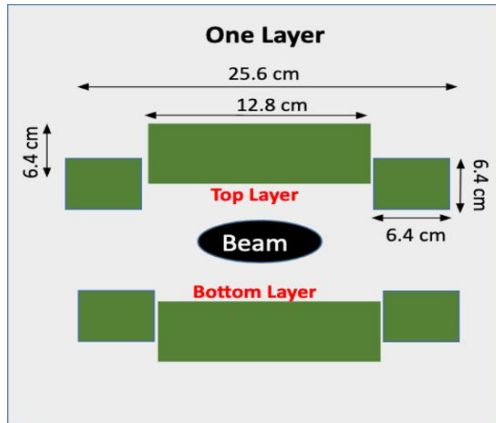
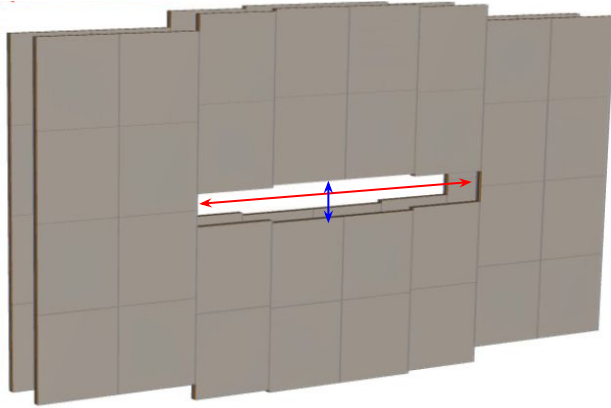


IP8:

- 35 mrad e+p crossing angle
- Second focus
- ZDC Acceptance: +-5

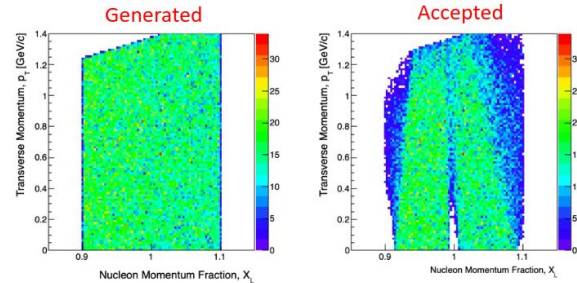
Roman Pots

Image by A. Jentsch, BNL



- **Primary consideration:**
 - Slit opening 10σ wider than the beam width.

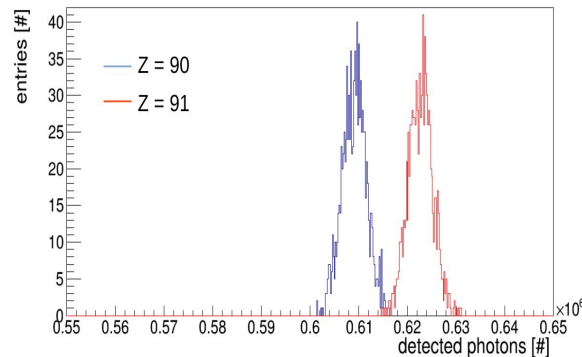
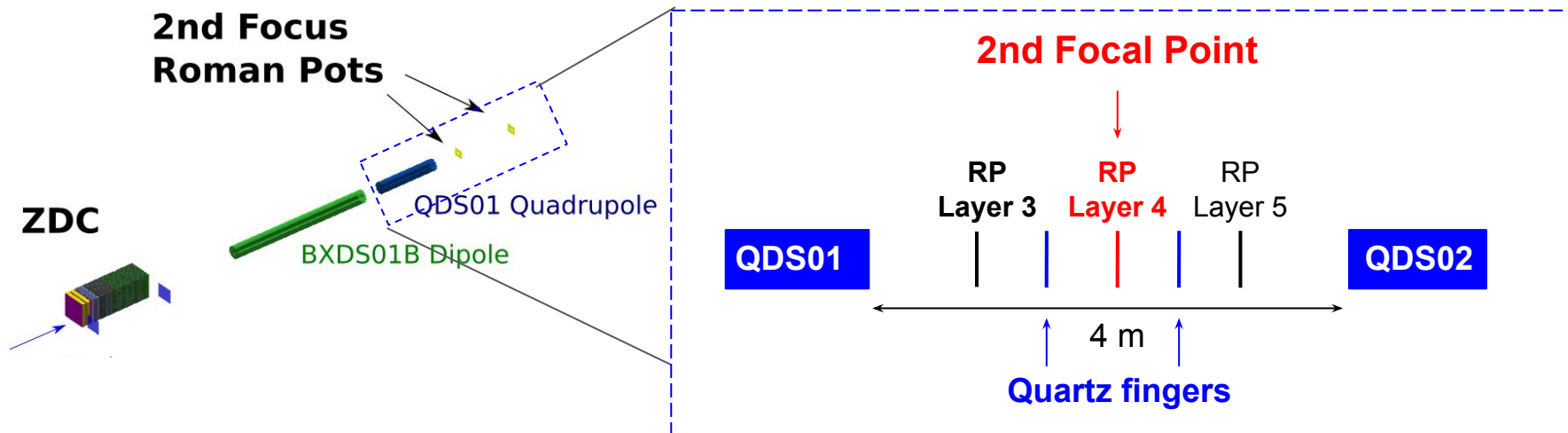
	Slit width	Slit height
IP6 RP 1&2	8.8 cm	1.2 cm
IP8 1&2	6.2 cm	0.8 cm
IP8 3&4 (2nd focus)	0.7 cm	0.2 cm



Acceptance study by Alex Jentsch, see full study:

https://wiki.bnl.gov/eic-detector-2/images/8/86/IP8_HSR_lattice_performance_10_13_22_v3.pdf

A Closer Look at the 2nd Focus Area and PID



- **Z-Tagging Mini DIRC (C. Hyde)**
 - Photon counter

$$\frac{dN}{dX} \approx z^2 (0.013/\text{cm}) = \frac{106}{\text{cm}} \text{ for } z = 90$$

Golden Channels Strawman (from 1st EIC 2nd Meeting)

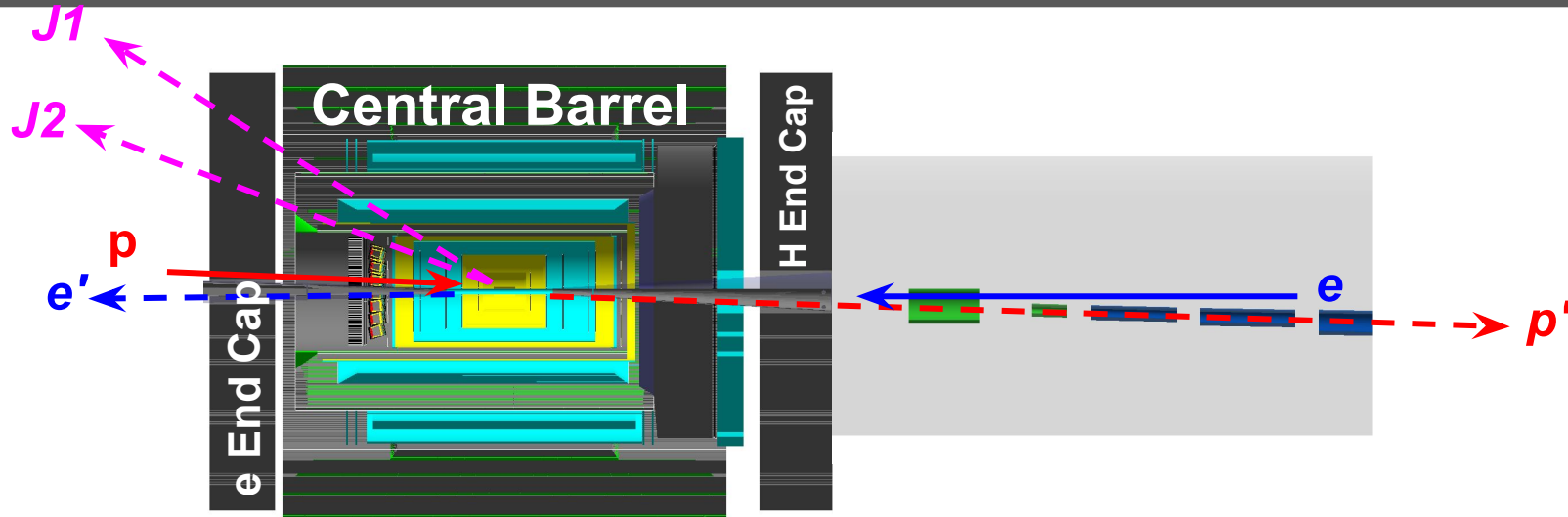
CHANNEL	PHYSICS	DETECTOR II OPPORTUNITY
Diffraction dijet	Wigner Distribution	detection of forward scattered proton/nucleus + detection of low p_T particles
DVCS on nuclei	Nuclear GPDs	High resolution photon + detection of forward scattered proton/nucleus
Baryon/Charge Stopping	Origin of Baryon # in QCD	PID and detection for low p_T $\pi/K/p$
F_2 at low x and Q^2	Probes transition from partonic to color dipole regime	Maximize Q^2 tagger down to 0.1 GeV and integrate into IR.
Coherent VM Production	Nuclear shadowing and saturation	High resolution tracking for precision t reconstruction

Target Fragmentation (see Yangting's talk)

Based original slide by R. Fatemi

- Please note that these were selected to illustrate particular opportunities
- You are most welcome to add your favorite process!

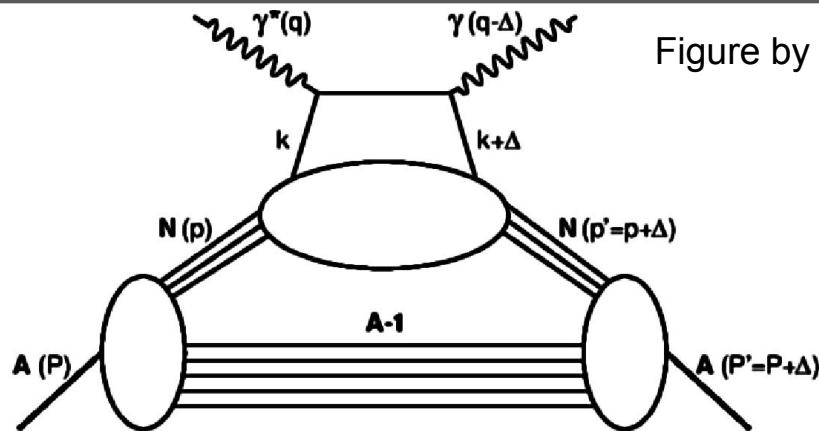
Exclusive di-jets studies (Complementarity)



- **Scattered electron (e'):** $\eta \rightarrow -\infty$, far backward region, low Q^2 tagger
- **Recoiled p :** $\eta \sim 6$, far forward region
- **Jet 1 ($J1$) and Jet 2 ($J2$):** $-3.5 < \eta < -1.5$, Central detector
- **“Complementarity”**
 - ePIC has like to have an edge over the detector 2 central detector design
 - backward HCal (ECCE design lacks backward HCal)
 - ePIC has full backward angle PID

e+Light Nuclei DVCS (Complementarity)

Figure by R. Dupré



Nuclei give control over the spin:

- Spin-0 2 GPD ; Spin-1/2 8 GPDs ; Spin-1 18 GPDs
- Half of these intervene in DVCS

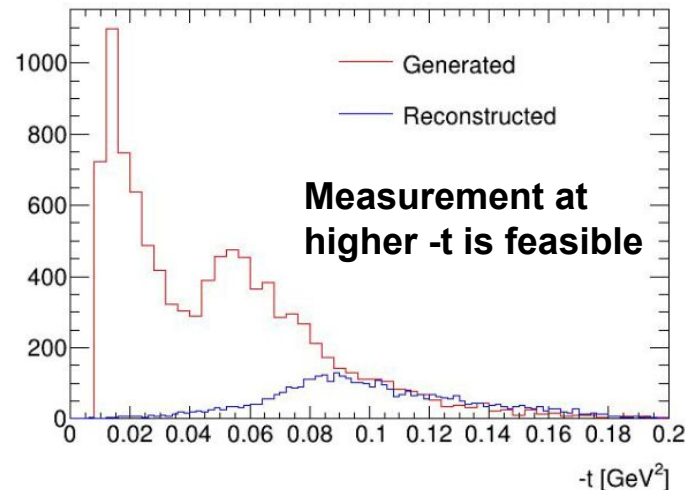
In the nucleus two processes

- Coherent and incoherent channel
- Probe the whole nucleus and the bound nucleons

A perfect tool to study the EMC effect

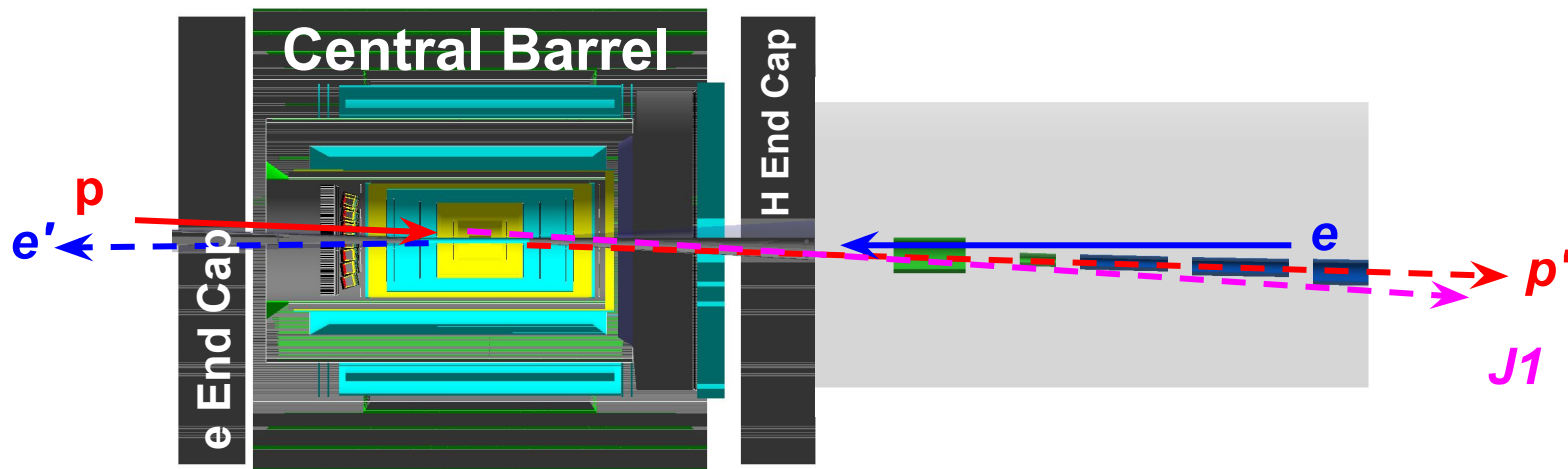
- Coherent DVCS gives access to the full nucleus
 - Including non-nucleonic degrees of freedom
- Incoherent DVCS gives access to the bound nucleon
 - To test modifications of the bound nucleon structure

Early look at ePIC layout, study reported by G. Penman (Glasgow University)

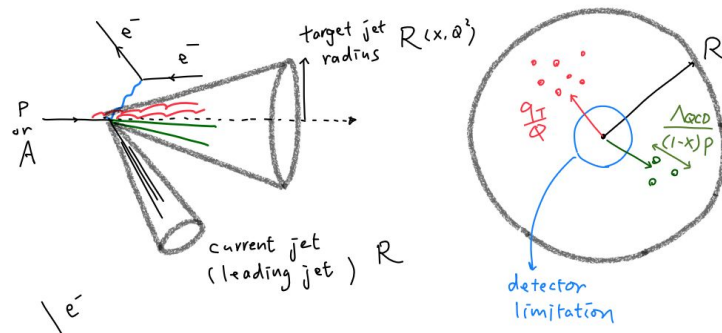


Why ePIC has difficulty for this measurement?

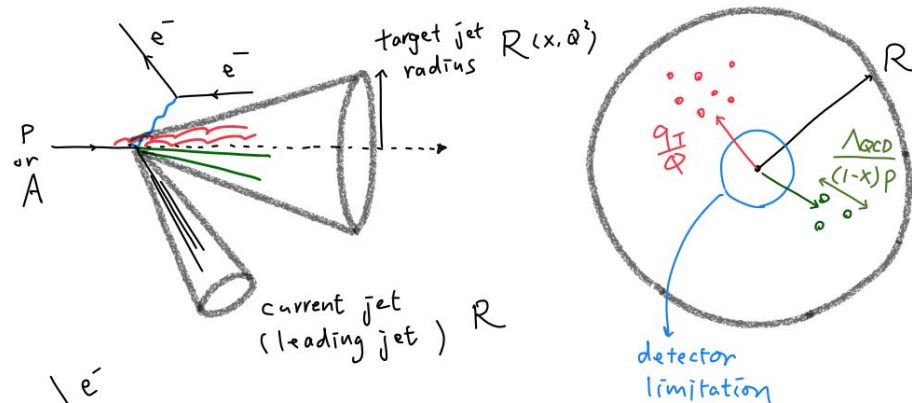
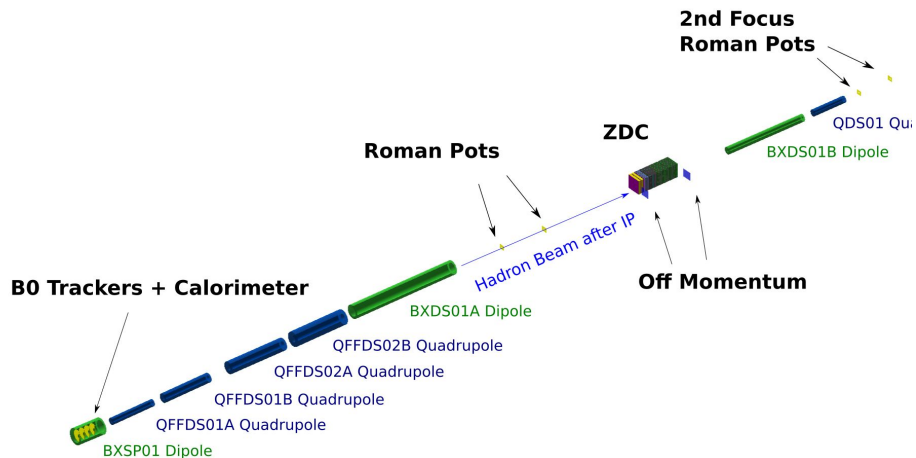
Target Jet Fragmentation



Yang-Ting,
https://indico.cfnssbu.physics.sunysb.edu/event/110/contributions/206/attachments/68/91/CFNS_2023.pdf

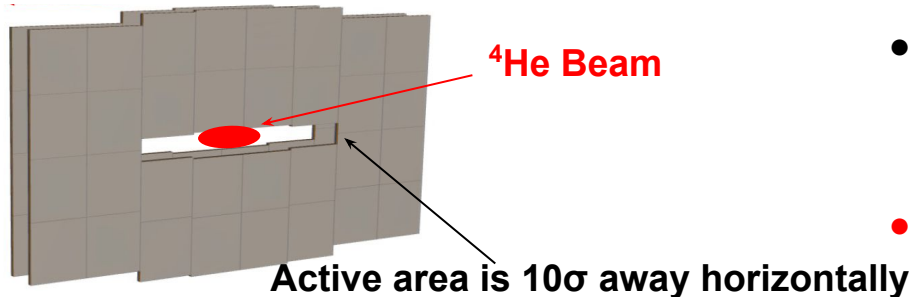
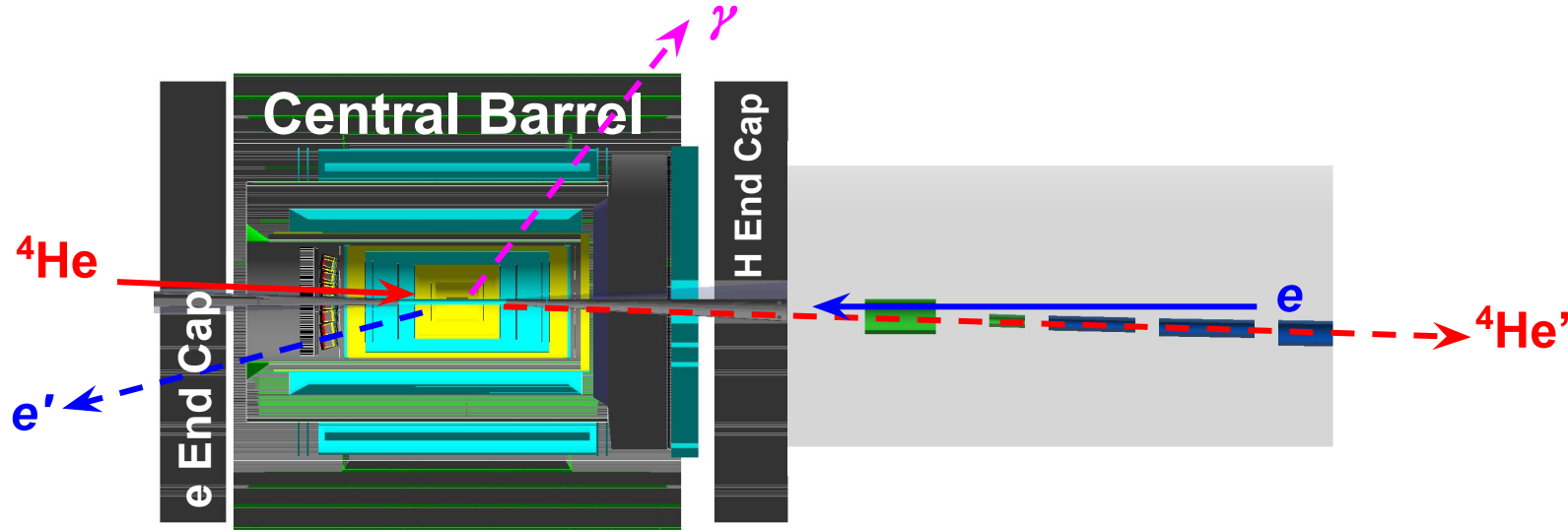


Target Jet Fragmentation



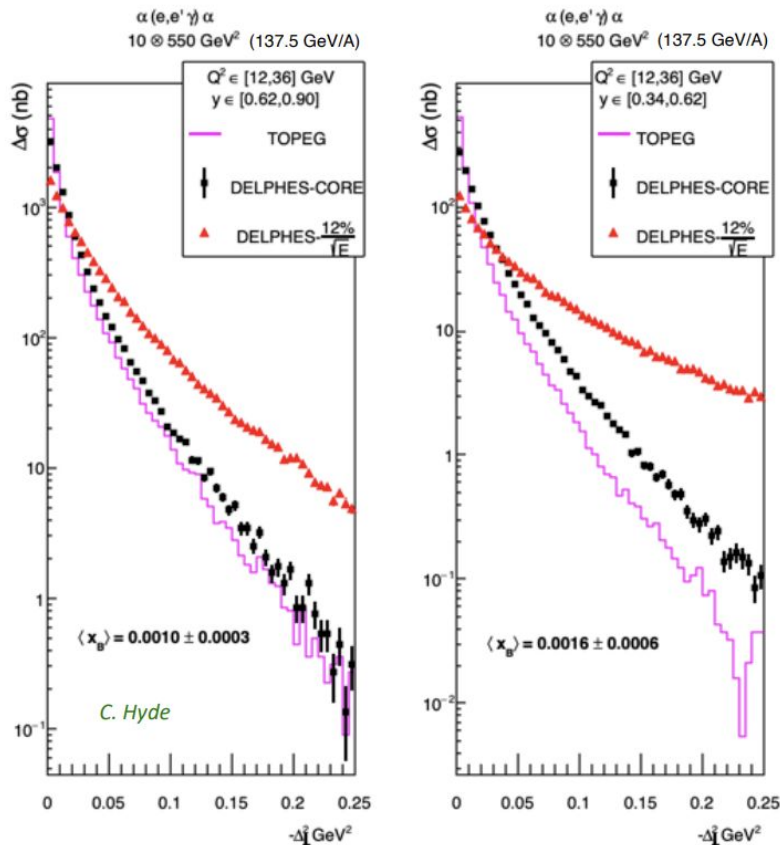
- Far Forward HCal, and EM Cal ± 28 mRad
- Neutral Tagging: ± 5 mRad
- Beam Hadron tagging: 2nd focus
- Tracking

Exclusive $e+^4\text{He}$ DVCS (Complementarity)



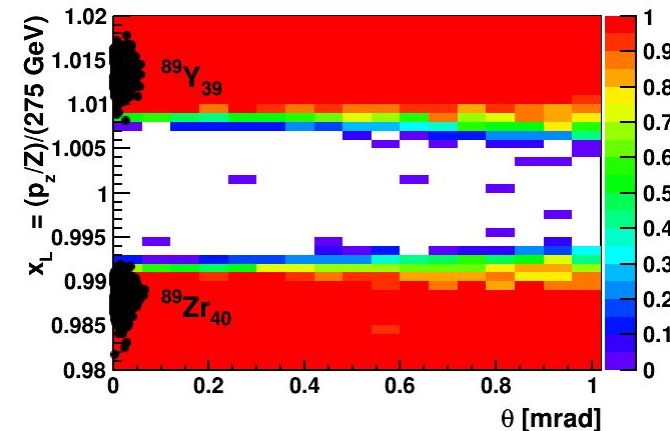
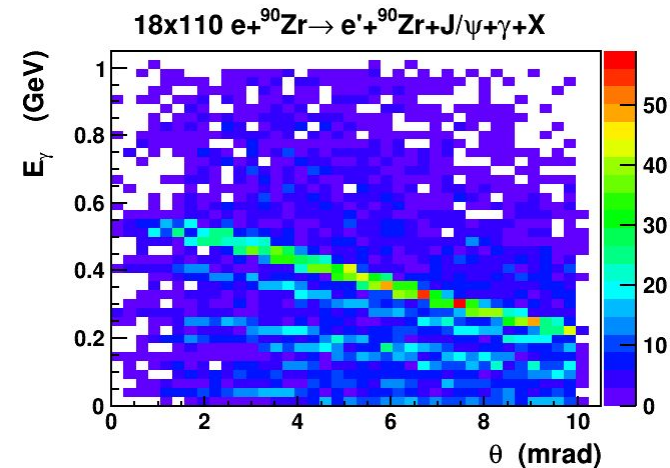
- Gluon exchange (specially at low Q^2) induced a “gentle tap” will not deflect interacted ^4He (at low $-t$) to be detected by the Roman Pots
- **2nd focus will significantly improve the $-t$**

$e+{}^4\text{He}$ DVCS at IP8

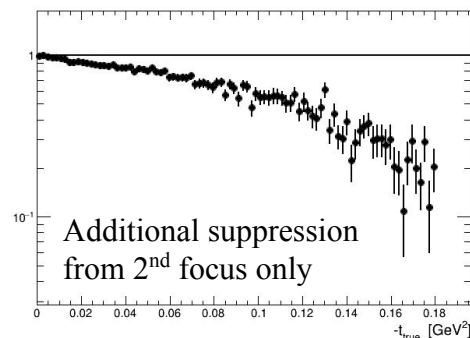
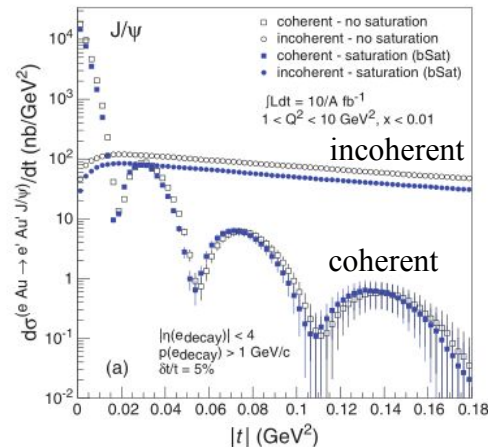


- For light nuclei, the 2nd focus enables detection with essentially 100% acceptance down to $p_T = 0$
- The study on the left shows the importance of the photon energy resolution of the barrel EMcal
 - PbWO4 with 1-2% resolution
 - ePIC's GlueX-like EMcal would fall in-between the PbWO4 (black) and 12% (red) points.

Vector Meson Production via Coherent diffractive Process with ^{90}Zr



- Extended forward photon detection is synergetic with the 2nd focus in IR8.
- ^{90}Zr is ideal for benchmarking:
 - The ability to tag A-1 nuclei in the 2nd focus and detect a large fraction of nuclear photons has the potential to significantly improve the suppression of incoherent backgrounds in coherent diffraction.
 - The photon detection will also help to distinguish reactions where the final nucleus was in the ground state or an excited state.
 - The figures on the left show the photons and A-1 fragments from ^{90}Zr
 - The figures on the right show the additional suppression at high t from the 2nd focus

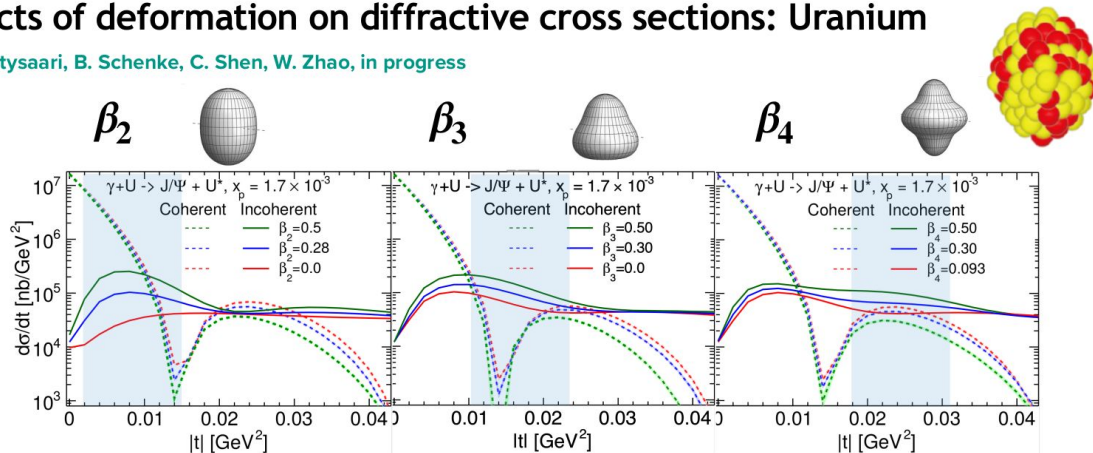


Study by M. Baker and others

Vector Meson Production via Coherent diffractive Process

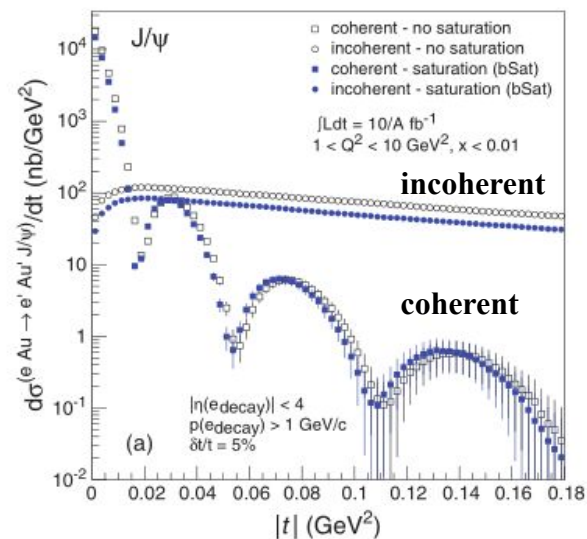
Effects of deformation on diffractive cross sections: Uranium

H. Mäntysaari, B. Schenke, C. Shen, W. Zhao, in progress

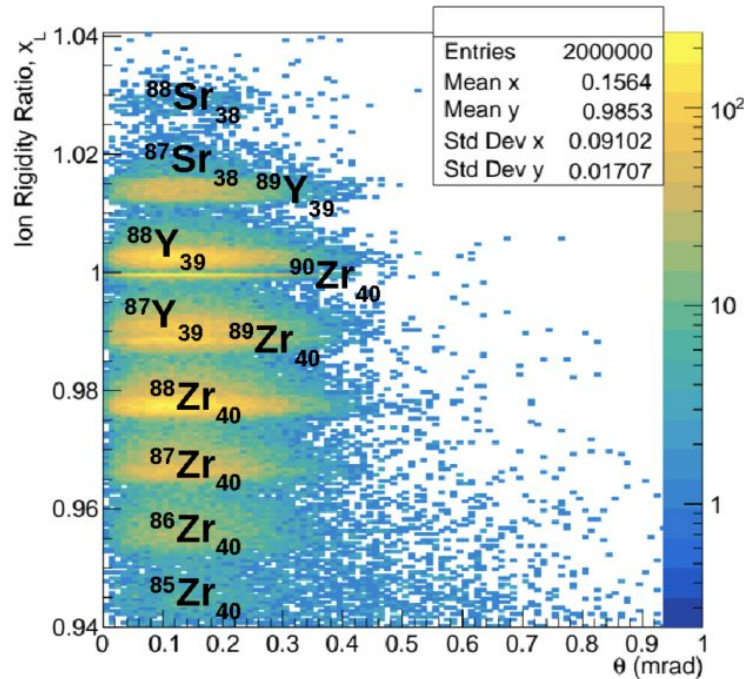


- **Diffractive Processes (no color exchange)**
 - Dips: “glumpiness” of gluon.
 - Coherent and incoherent: shape of heavy nuclei.

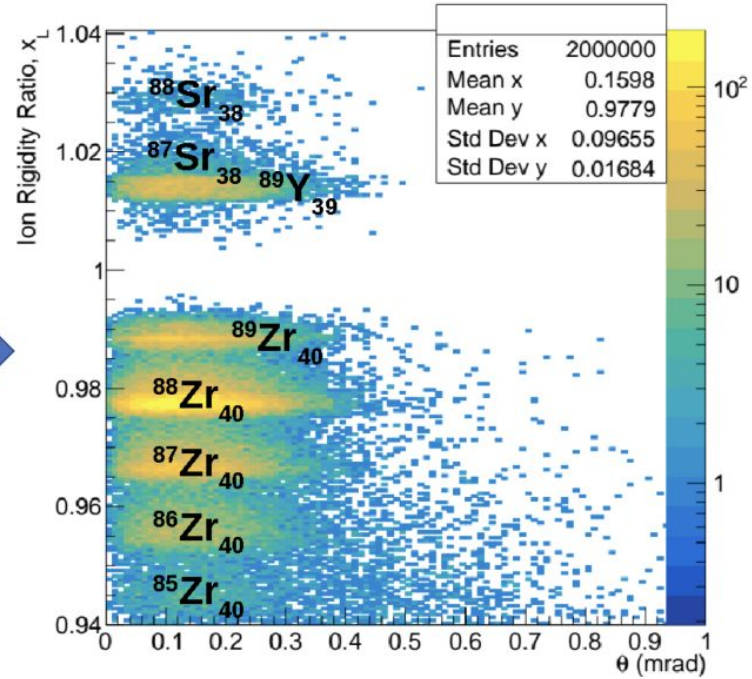
Simulations of coherent diffraction with ^{90}Pb



A-1 tagging with 2nd focus using a ^{90}Zr beam



generated (BeAGLE)



detected (Geant)

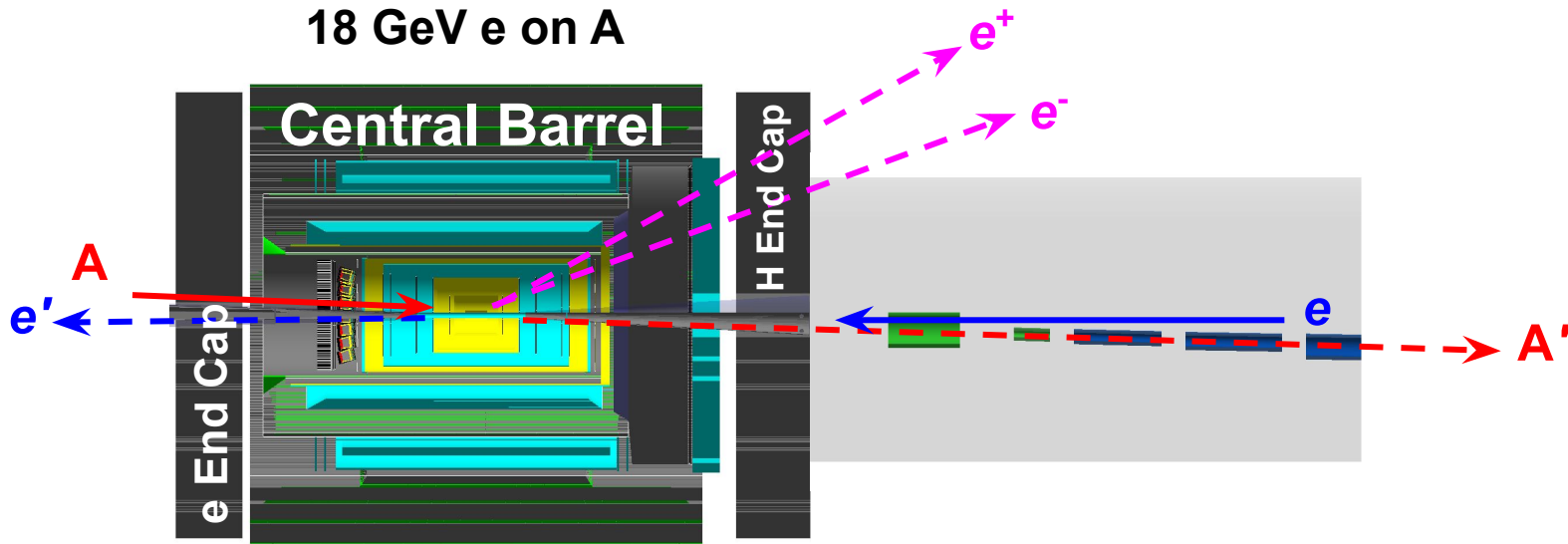
A similar study will be completed on Uranium

<https://arxiv.org/abs/2208.14575>

Study by Mark Baker

Exclusive Vector Meson production

18 GeV e on A

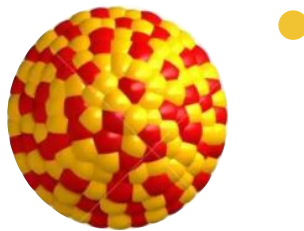


- **Scattered electron (e'):** $\eta \rightarrow -\infty$, far backward region, low Q^2 tagger
- **Decayed $J/\psi \rightarrow e^+e^-$:** $-1.5 < \eta < 3.5$, Central detector
- **Recoiled A (A'):** $\eta \sim 6$, far forward region

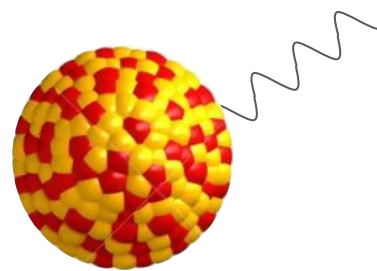
What does A' do In the Beam Pipe? (Opportunities)



A'



Neutron Evaporation



Gamma de-excitation

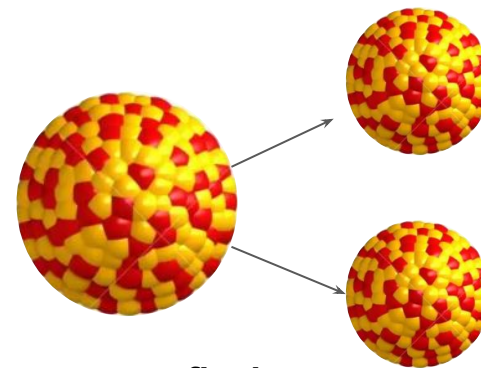
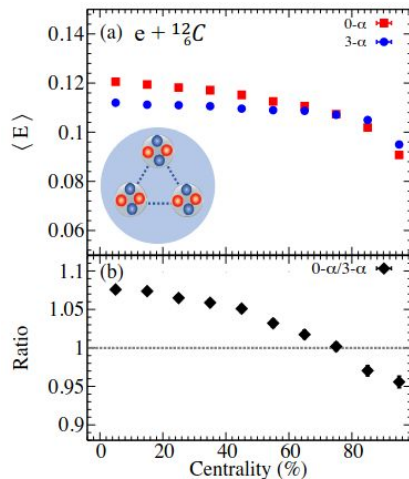
- **eA Diffractive study, forward detector must:**
 - Tag A'
 - Veto events due to neutron evaporation and gamma de-excitation

A' Decay is not all bad !



Neutron Evaporation

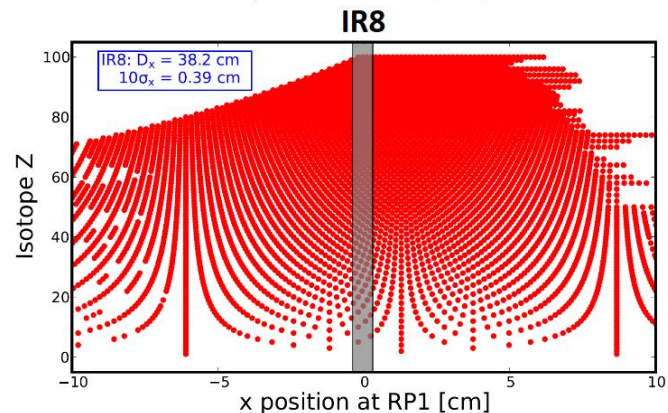
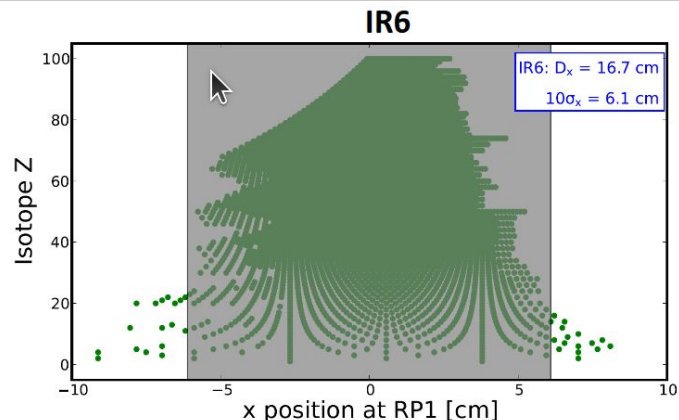
- Evaporated neutron energy deposition study by N. Magdy, J. Jia, et. al.



fission

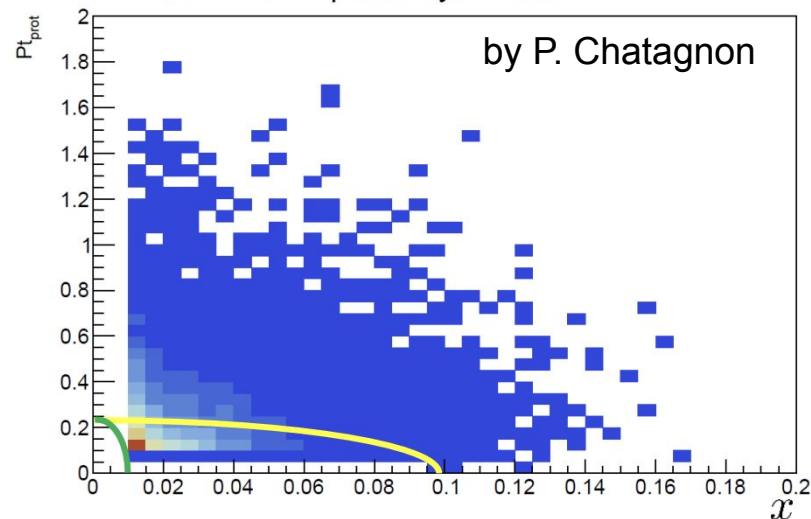
- Direct measurement of final nuclei, including rare isotopes, and associated de-excitation gamma photons study by B. Moran, et. al.

EIC far-forward acceptance with and without a 2nd focus



Nuclear fragments detection at Roman Pot

TCS at the EIC - Exploratory studies



— IR6-EPIC indicative acceptance limit

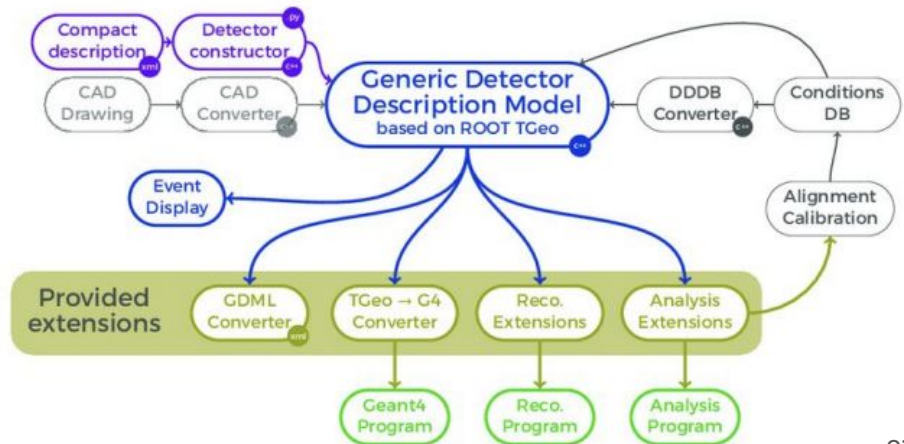
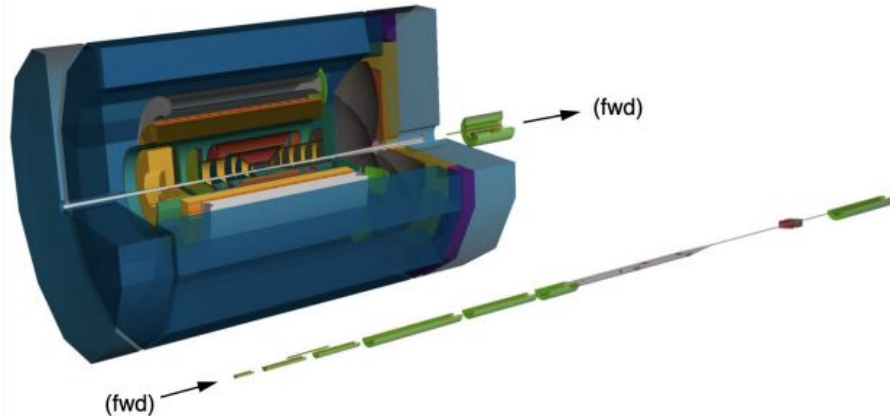
— IR8 indicative acceptance limit

**Order-of-magnitude
improvement in
forward acceptance**

Most event have a proton carrying
a large fraction of the initial
momentum and small Pt

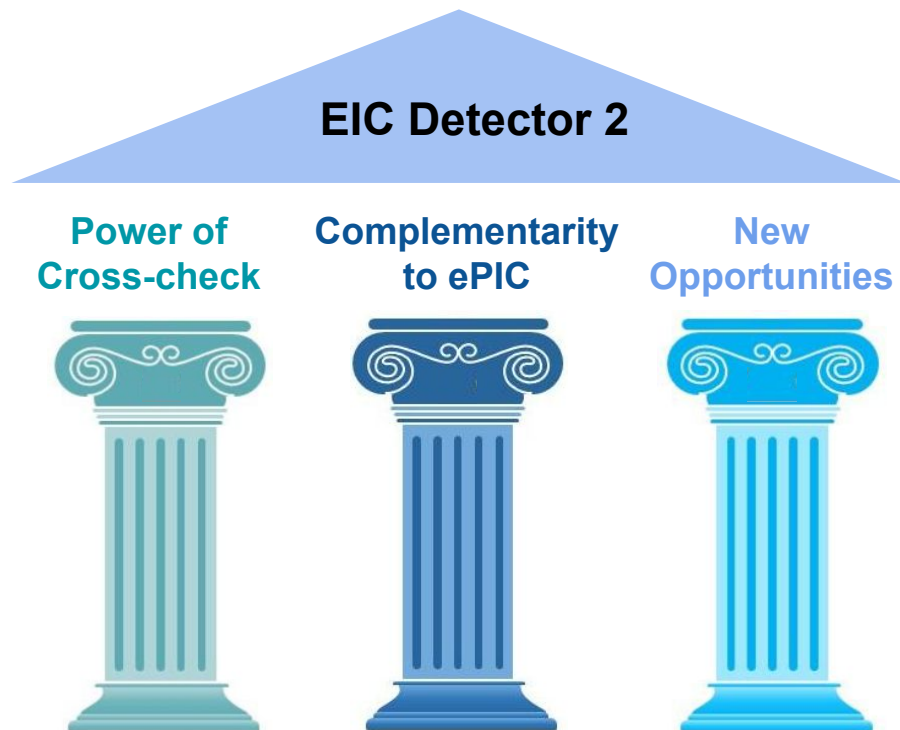
Software Tools

- **Consensus: not to reinvent the wheel at this stage**
- **Make best use of ePIC development**
 - DD4HEP as geometry description
 - Podio and EDM4hep as data model
 - EIC-recon as reconstruction
- **Detail is to be developed**



Conclusion

- **Three pillars of 2nd Detector**
 - Cross-check
 - Complementarity
 - Opportunities
- **Enthusiasm from the community with drive the project forward**
 - Your input is extremely valuable



Acknowledgement and Advertisement

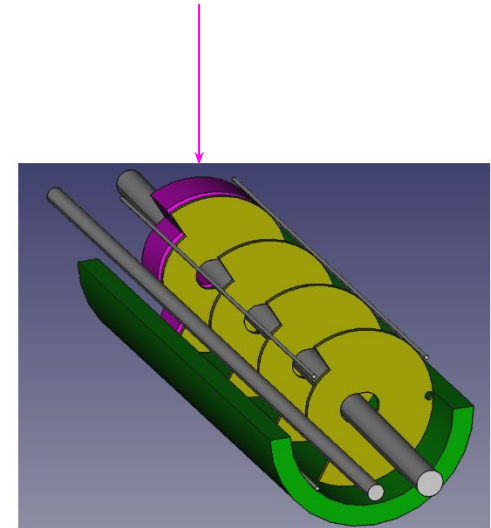
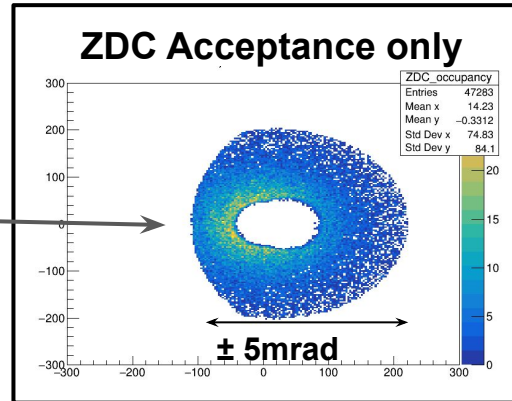
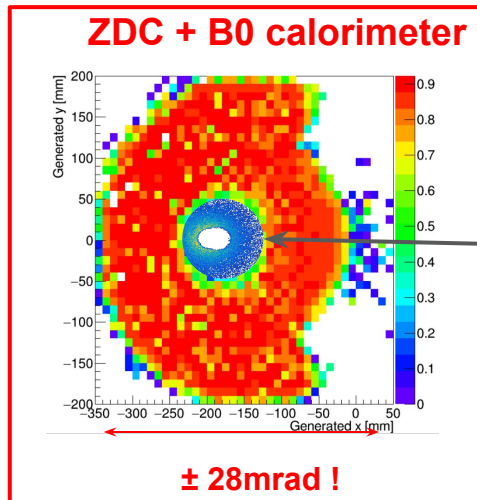
- Detector 2 is a new opportunity, require input Ξ from the community
- If you would like to share your idea, please reach out to any of the WG conveners directly:
 - <https://eicug.github.io/content/wg.html#detector-iiip8-group>

Backup

In terms of Far Forward Acceptance: B0 is the Key

- The increase to ZDC acceptance from ± 5 to ± 7 marginally increases the recoil nucleon acceptance:
 - e+p 5x41 GeV pion structure study: 20% increase in terms of nucleon detection efficiency
- Instrumentation of a full calorimeter inside B0 will significantly boost the forward acceptance: from ± 5 mrad to ± 28 mrad !
- Due to special constraints, full Calorimeter might be a “no-go”

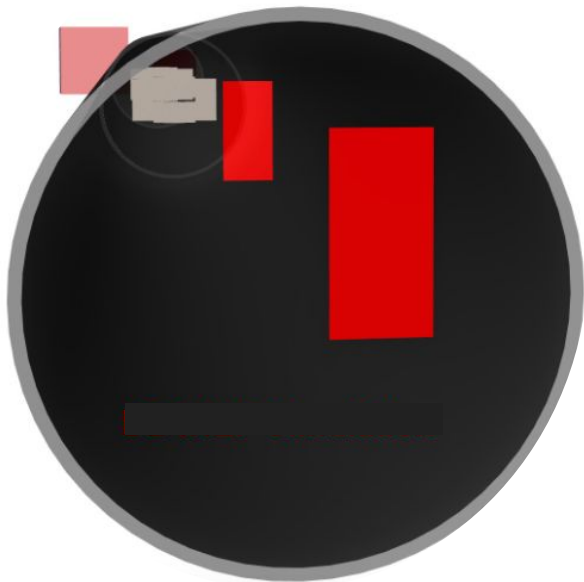
B0 Calorimeter



IP8 Forward Detector Suggestion

Detector	Acceptance	Requirement
ZDC	$\theta < 5.5 \text{ mrad } (\eta > 6)$	35%/√E ~1mm position resolution
RP 1&2	$0.0^* < \theta < 5.0 \text{ mrad } (\eta > 6)$	
RP 3&4	$0.0^* < \theta < 5.0 \text{ mrad } (\eta > 6)$	
Off Momentum	$0.0^* < \theta < 5.0 \text{ mrad } (\eta > 6)$	
B0 tracker + Calorimeter	$5.5 < \theta < 25.0 \text{ mrad}$ $(4.6 < \eta < 5.9)$	Full Calorimeter
PID at 2nd focus	$0.0^* < \theta < 5.0 \text{ mrad } (\eta > 6)$	Z tagger photon counter

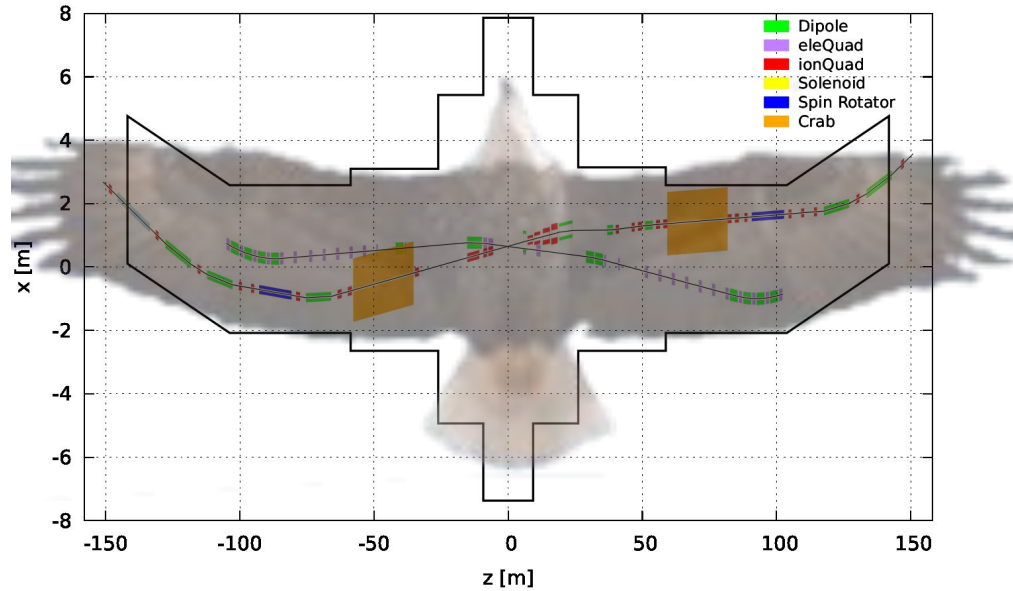
Off Momentum Tracker



- Roman pot without slits.
- Offsetted to one direction
- Protons tagging:
 - $123.75 < E < 151.25$ GeV
 - $45\% < p_{z,proton} / p_{z,beam} < 55\%$
- Tagging decay remnants from Λ or Σ

Image by A. Jentsch, BNL

Thank you for your attention!



Zero Degree Calorimeter

Image by engineers, BNL

- **ZDC**

- Sensitive to soft photon and neutron
- IP6 ZDC ± 5 mrad acceptance
- IP8 benefit from higher acceptance?

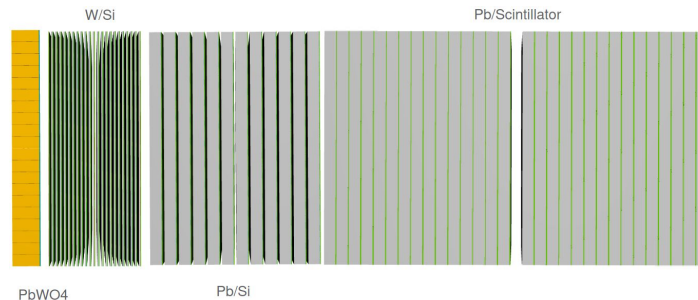


Image by D. Misra, PNNL

Ideas: Adding PID? Z-Tagging Mini DIRC Concept (C. Hyde)

2nd Focal Point

- **Z-Tagging Mini DIRC** (C. Hyde)
 - Photon counter

$$\frac{dN}{dX} \approx z^2 (0.013/\text{cm}) = \frac{106}{\text{cm}} \text{ for } z = 90$$

QDS01

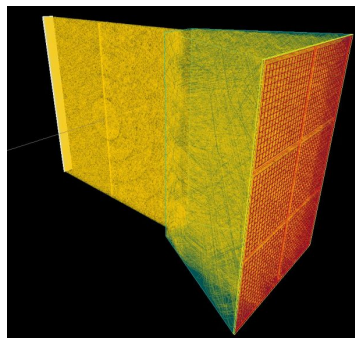
RP
Layer 3

RP
Layer 4

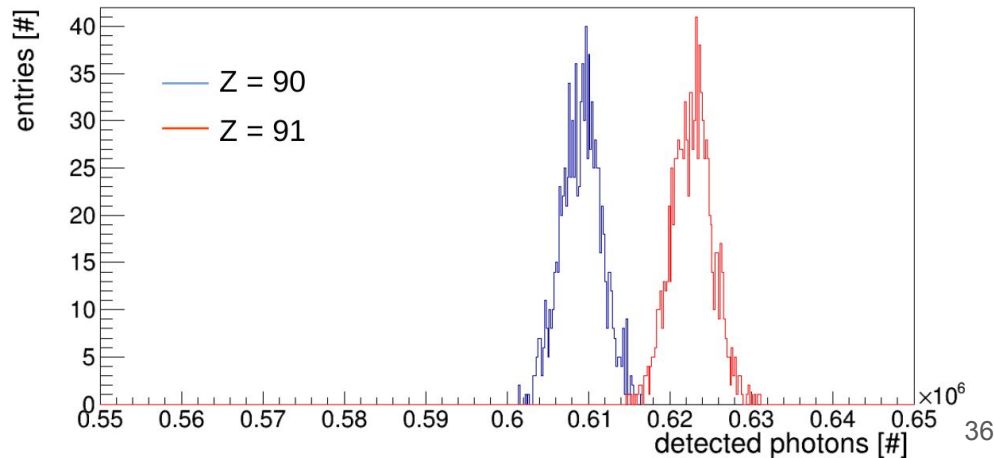
RP
Layer 5

QDS02

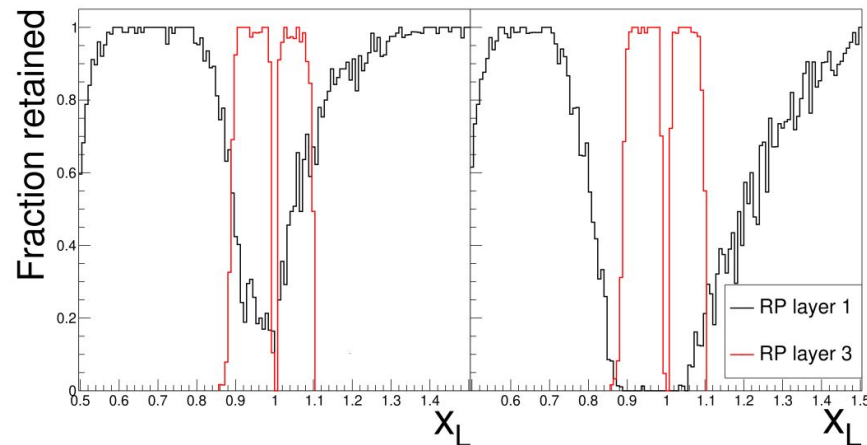
PID



Ray trace simulation by
C. Hyde and R. Dzhygadlo



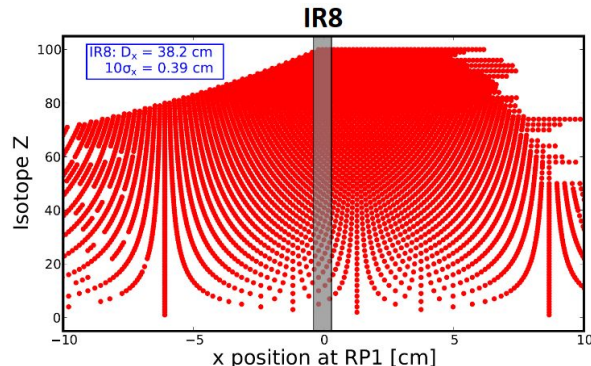
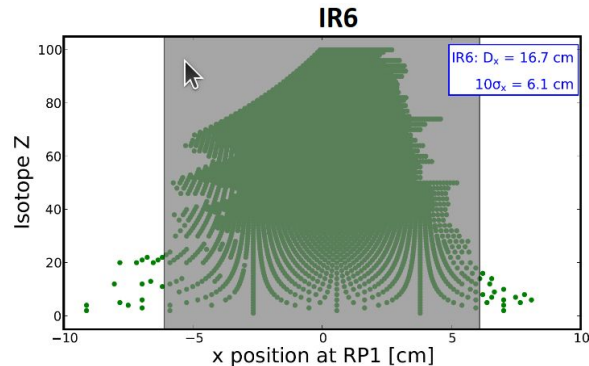
In terms of PD acceptance



Rigidity fraction of eA diffractive process:

- with 2nd focus: black + red
- without 2nd focus: black

Study by M. Baker and others



Nuclear fragments detection at Roman Pot

Study by B. Moran and others