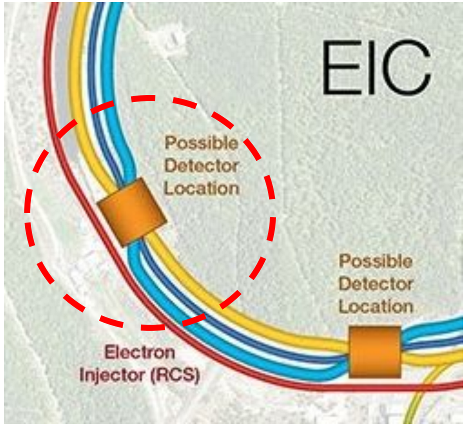
Opportunities with a 2nd EIC detector at IP8

Wenliang (Bill) Li, on behalf of the 2nd detector WG
@ RHIC & AGS Annual Users' Meeting

Aug 4, 2023



Center for Frontiers in Nuclear Science
Stony Brook University

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)

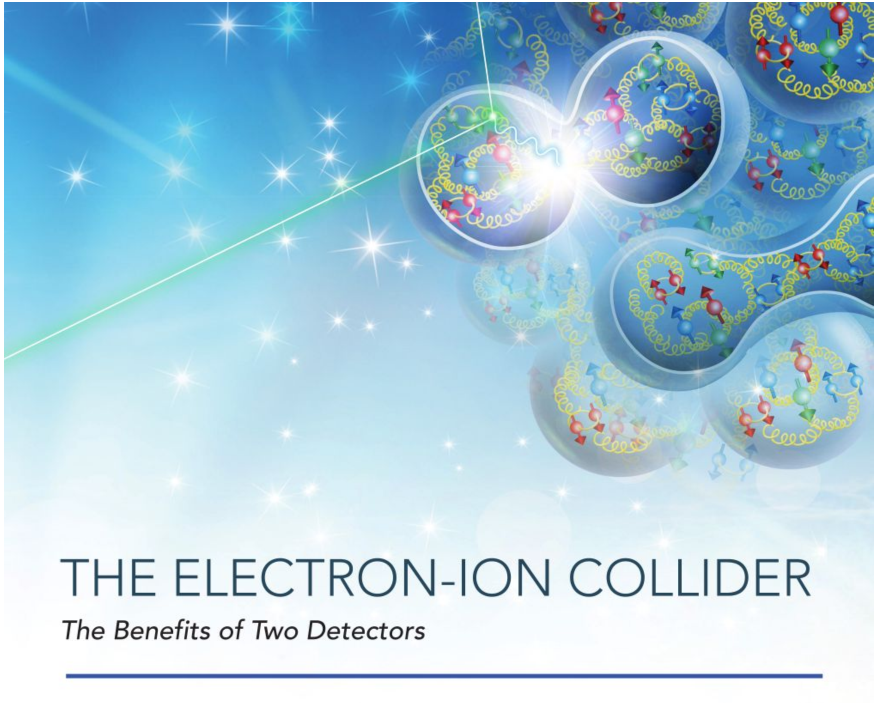
- Combined systematics (as for H1 and ZEUS)
- Phase-space coverage
- The EIC will high statistics, uncertainties for the envisioned measurements will be systematics limited.

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 el. 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)

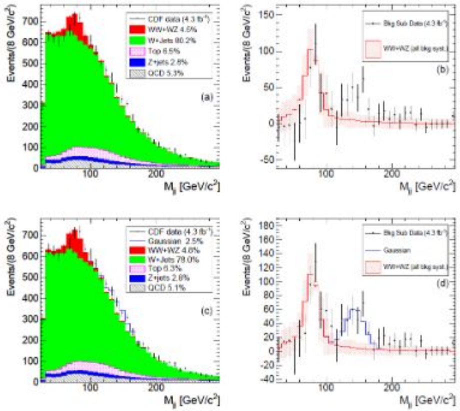
It is generally accepted that it is preferable to build two general purpose detectors at any given collider facility. We reinforce this point by discussing a number of aspects and particular instances in which this has been important. The examples are taken mainly, but not exclusively, from experience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

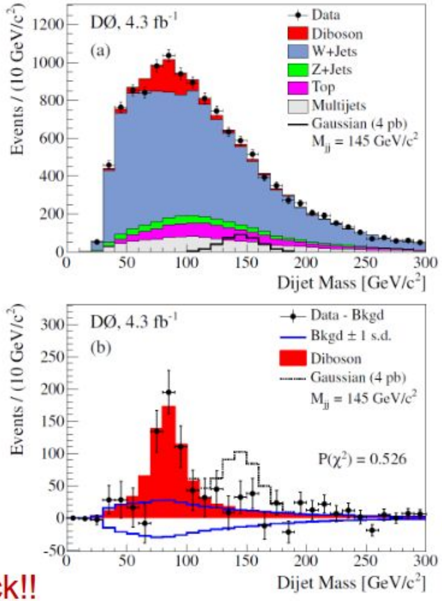
Opinion 2: P. Grannis and H. Montgomery

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 10^{-4}, 3.2 σ) excess
- Fit to extra Gaussian with width scaled to dijet resolution→ mass 144+- 5 GeV, σ.BR = 4 pb.

Crosscheck!!

- 2011 DØ study gives no excess, with likelihood of 145 GeV resonance of σ.BR= 4 pb of 8. 10^{-6} Rejection 4.3 σ, 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

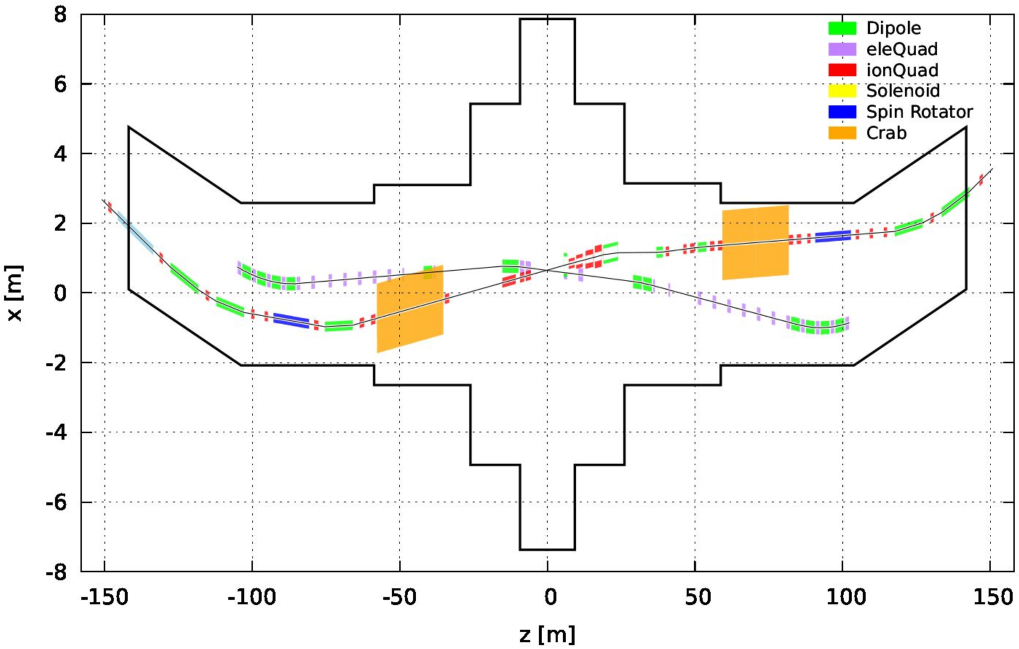
- **A detector 2 WG under EIC User Group**
  - **Group Page:** https://eicug.github.io/content/wg.html#detector-iiip8-group
  - **Physics sub-WG**
  - **Detector sub-WG**
  - **Conveners:** Klaus Dehmelt (CFNS/SBU), Charles Hyde (ODU), Sangbaek Lee (ANL), Simonetta Liuti (UVA), Pawel Nadel-Turonski (CFNS/SBU), 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
- **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.

See the talk from SANGBAEK LEE for detector and technology:
https://indico.bnl.gov/event/18938/contributions/79086/attachments/48890/83343/EIC_2nd_det_tech_rhic_ags_ug_2023.pdf

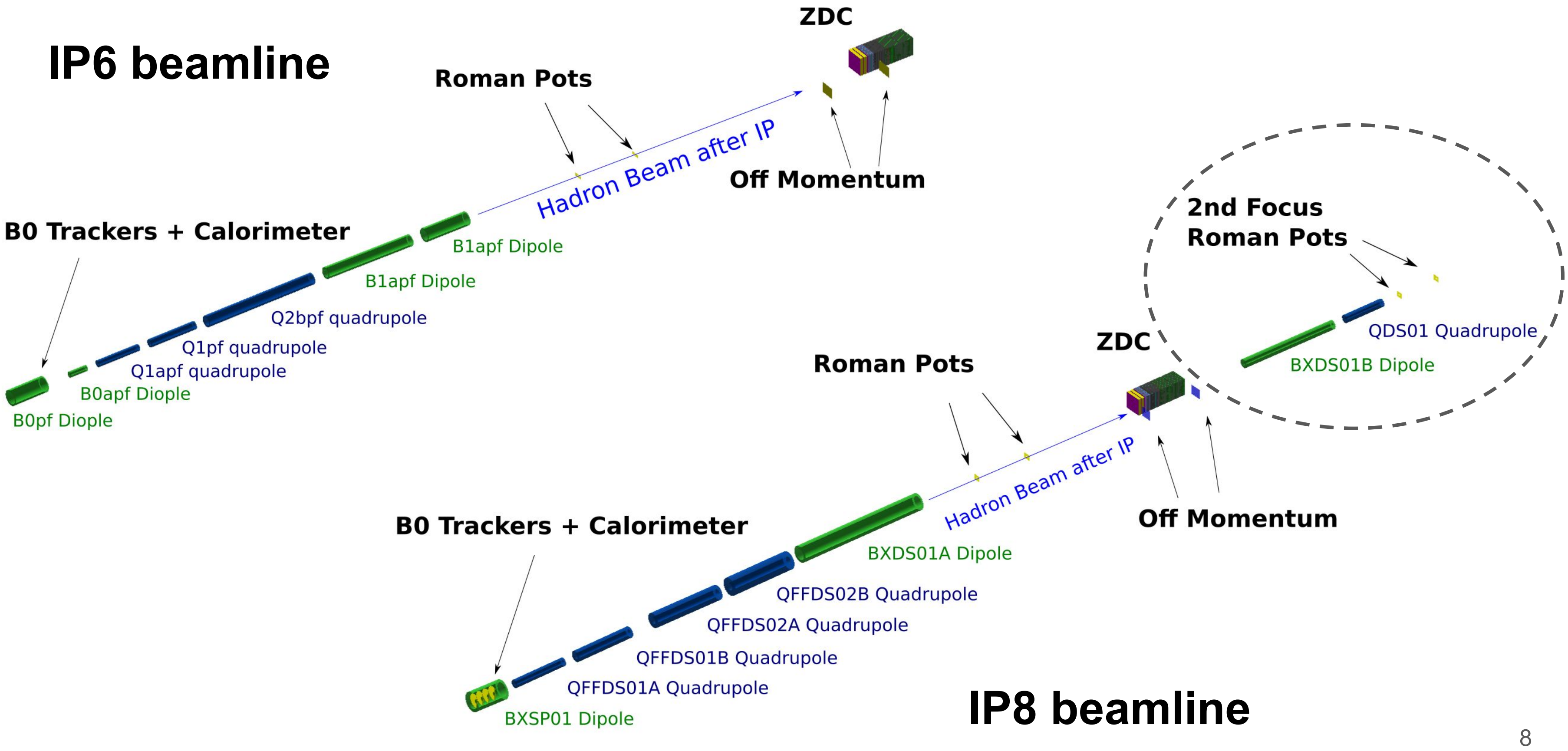
Official Project Information



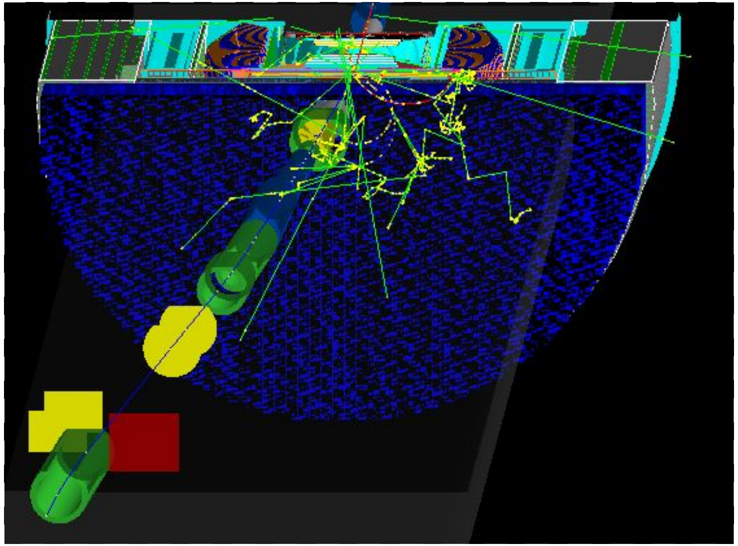
- **e-p crossing angle 35 mRad**
- **A short space allocated for the central detector**
  - **Less space than ePIC**
  - **Hard decision needs to be made to meet the design goal (backward angle PID)**

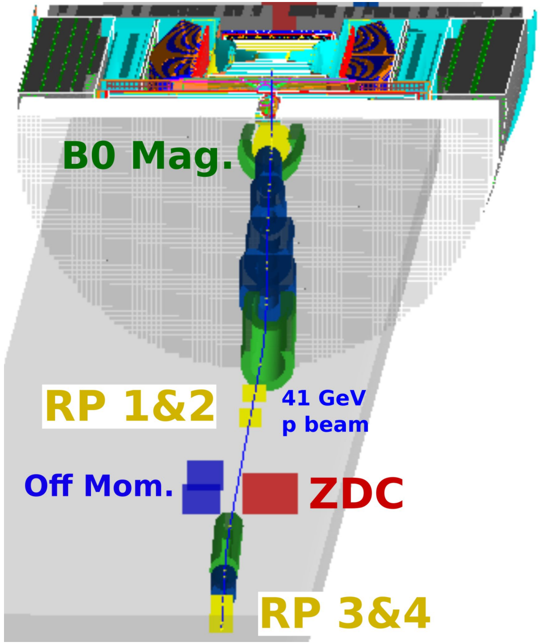
- **Official Public Information:** https://wiki.bnl.gov/eic-detector-2/index.php?title=Project_Information
  - Contact person: Bamunuvita Gamage (randika@jlab.org)
  - Further optimization is needed! (See example in later slides)

IP6 vs IP8: Similar But Different



IP6 vs IP8: similar but different





IP6:

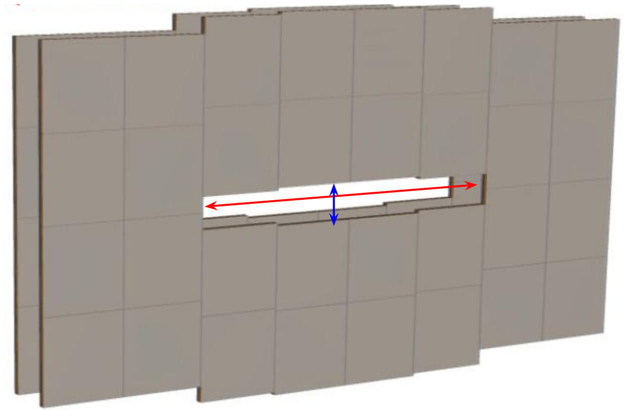
- 25 mrad e+p crossing angle
- ZDC Acceptance: -4.5 to +5.5

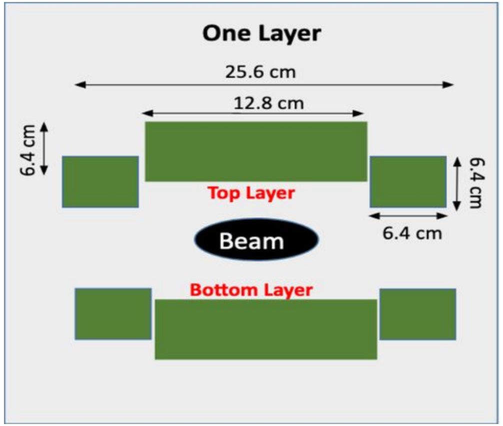
IP8:

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

Roman Pots

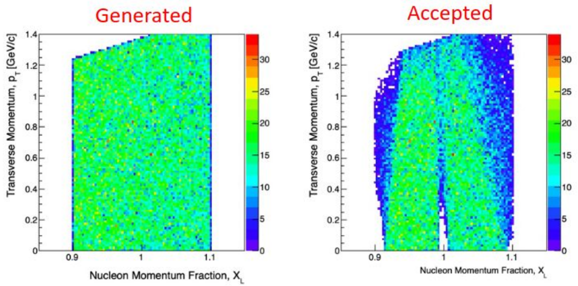
Image by A. Jentsch, BNL





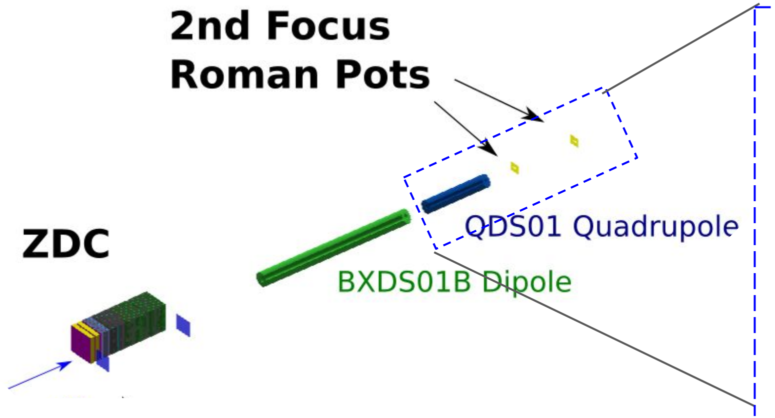
- **Primary consideration:**
  - Slit opening 10σ wider than the beam width.

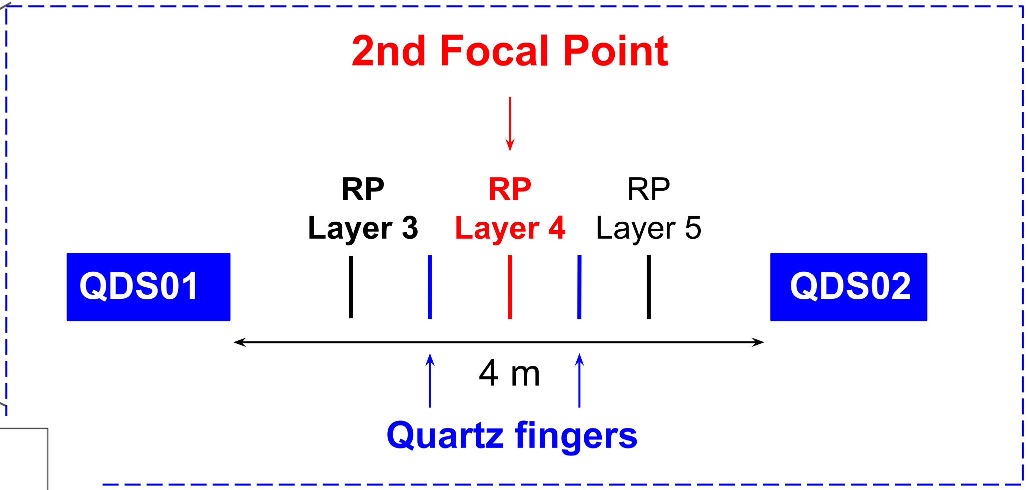
	Slit width	Slit height
IP6 RP 1&2	8.8 cm	1.2 cm
IP8 1&2	6.2 cm	0.8 cm
IP8 3&4 (2nd focus)	0.7 cm	0.2 cm

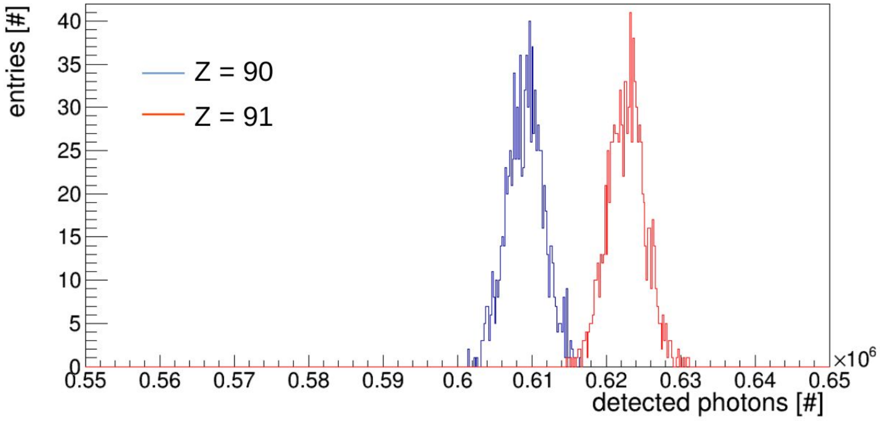


Acceptance study by Alex Jentsch, see full study: https://wiki.bnl.gov/eic-detector-2/images/8/86/IP8_HSR_lattice_performance_10_13_22_v3.pdf

A Closer Look at the 2nd Focus Area and PID







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

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

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

CHANNEL	PHYSICS	DETECTOR II OPPORTUNITY
Diffractive 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

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)

5D Image $\quad$ **GTMDs** $(x, \vec{k}_\perp, \Delta)$

$\Delta = 0$ $\qquad\qquad$ $\int d^2\vec{k}_\perp$

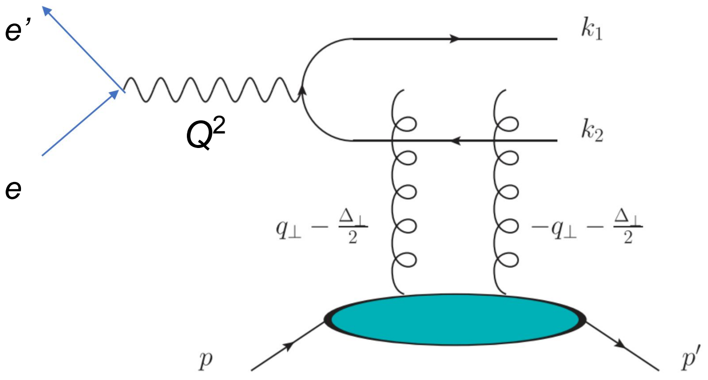
3D $\quad$ **TMDs** $(x, \vec{k}_\perp)$ $\qquad\qquad$ **GPDs** (x, Δ)

$\Delta = 0$ $\qquad\qquad$ $\int dx$

1D $\quad$ **PDFs** (x) $\qquad\qquad$ **FFs** (Δ)

GTMDs contain new physics (beyond TMDs & GPDs)

Study by S. Bhattacharya, Y. Hatta, et. al.

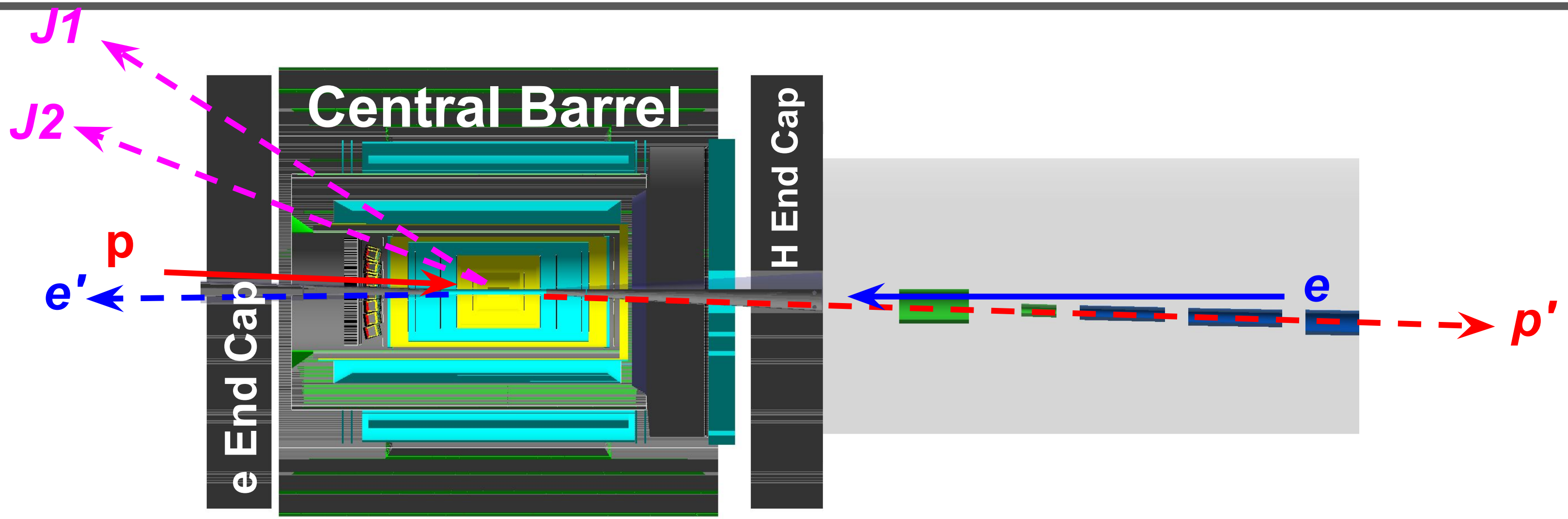


$$d\sigma \approx \underbrace{\sin(\phi_{P_\perp} - \phi_{\Delta_\perp})}_{\text{Sinusoidal angular modulation}} \underbrace{L_g(x)}_{\text{OAM}} \int d^2q_\perp\, q_\perp^2\, \underbrace{O(x, q_\perp)}_{\text{“Odderon”}}$$

- $d\sigma$ is sensitivity to the gluon Orbital Angular Momentum
- GTMDs are “disentangled” through suitable linear combination of Polarization Observables

https://indico.bnl.gov/event/18414/contributions/76076/attachments/47574/80665/hatta.pdf
https://indico.cern.ch/event/853361/contributions/3588898/attachments/1972525/3281710/Shohini_Quarkonia_2020.pdf

Exclusive di-jets studies (Complementarity)



- **Scattered electron (e'):** $\eta \rightarrow -\infty$, far backward region, low Q^2 tagger
- **Recoiled *p*:** η ~ 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)

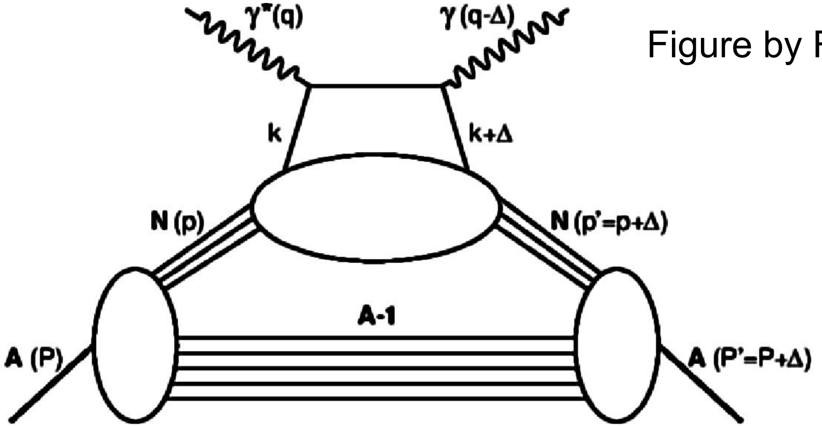


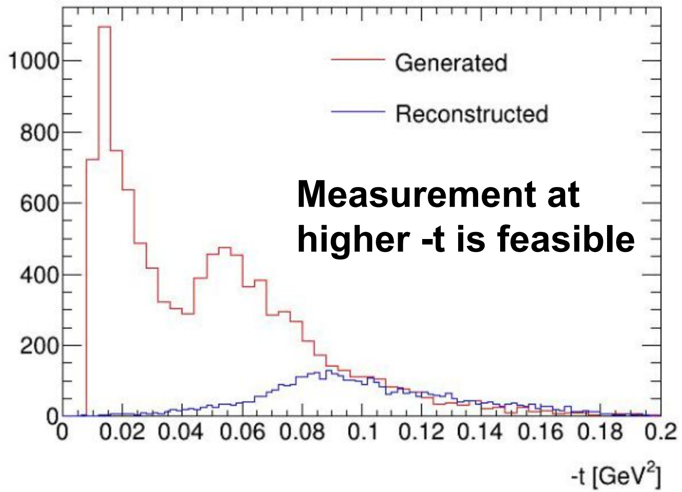
Figure by R. Dupré

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

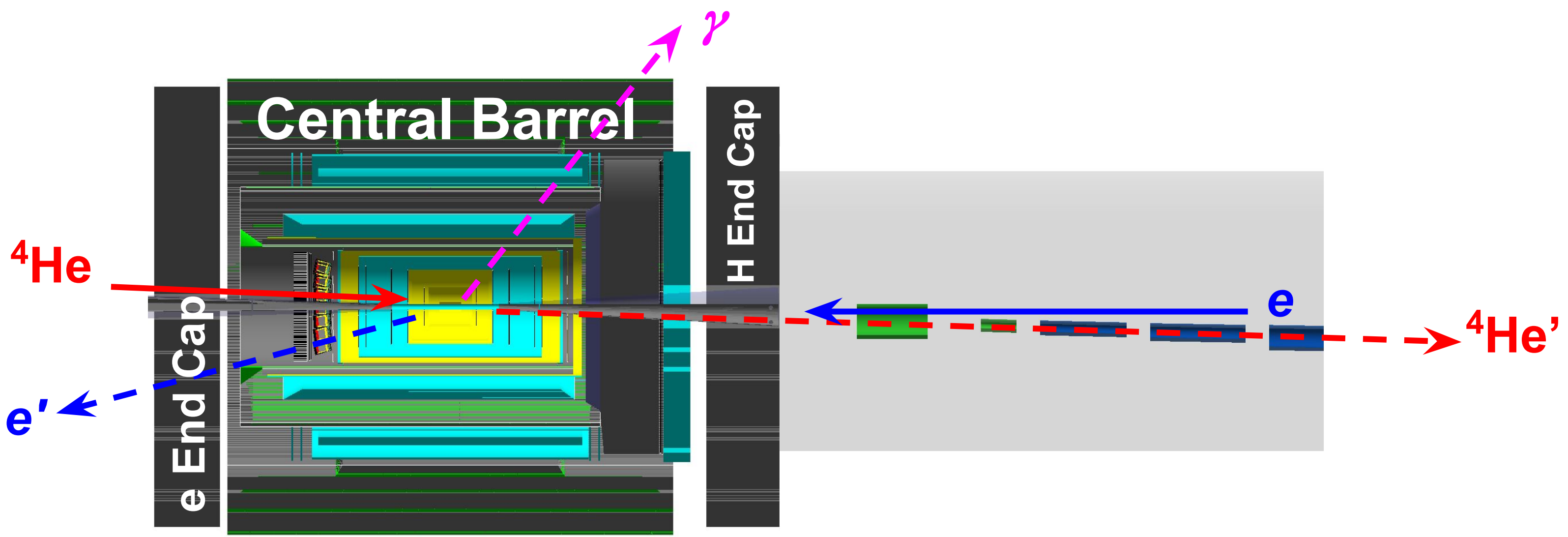
A perfect tool to study the EMC effect
- Coherent DVCS gives access to the full nucleus
  - Including non-nucleonic degrees of freedom
- Incoherent DVCS gives access to the bound nucleon
  - To test modifications of the bound nucleon structure

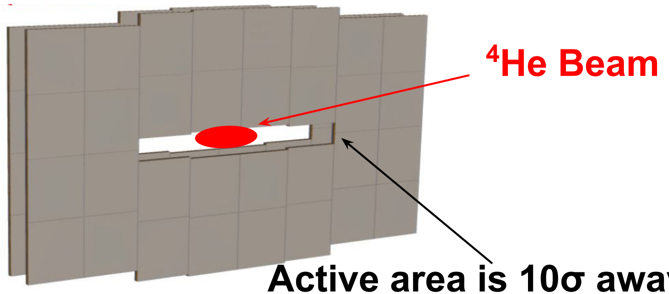
Early look at ePIC layout, study reported by G. Penman (Glasgow University)



Why ePIC has difficulty for this measurement?

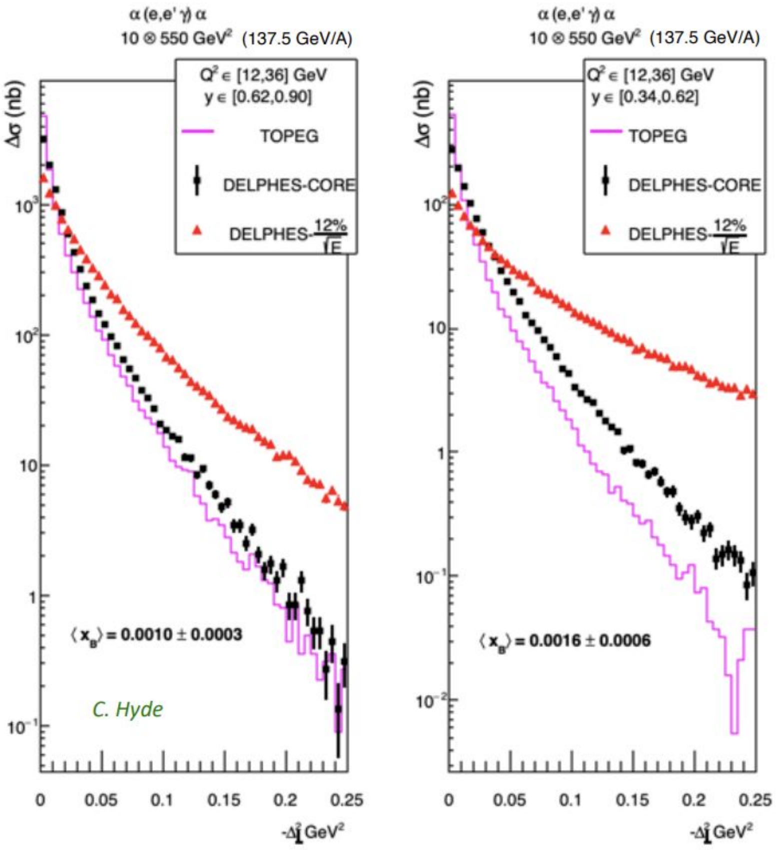
Exclusive e+^{4}He DVCS (Complementarity)





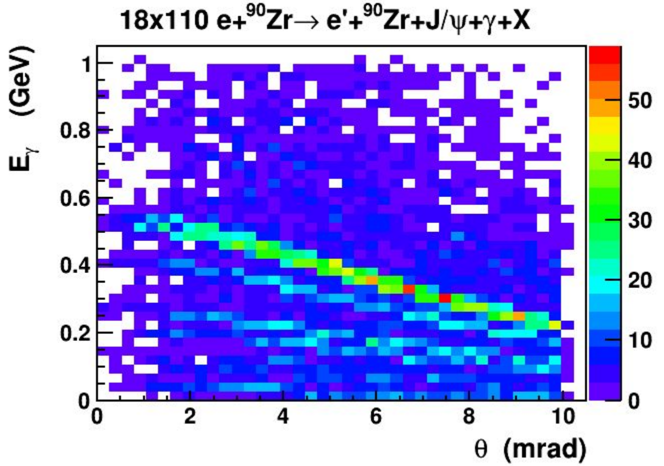
- Gluon exchange (specially at low Q^2) induced a "gentle tap" will not deflect interacted ^{4}He (at low -t) to be detected by the Roman Pots
- 2nd focus will significantly improve the -t

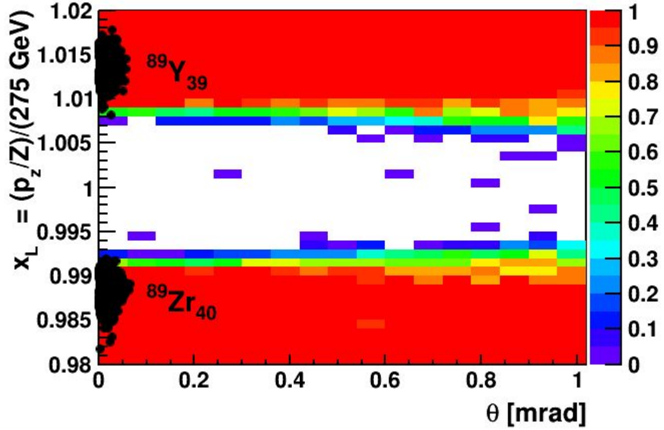
e+^{4}He DVCS at IP8



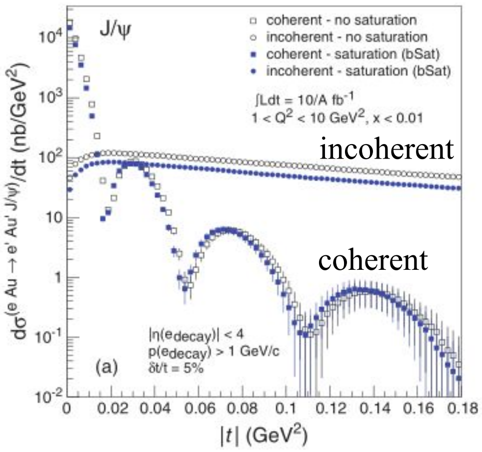
- For light nuclei, the 2nd focus enables detection with essentially 100% acceptance down to $p_T = 0$
- The study on the left shows the importance of the photon energy resolution of the barrel EMcal
    - PbWO4 with 1-2% resolution
    - ePIC's GlueX-like EMcal would fall in-between the PbWO4 (black)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

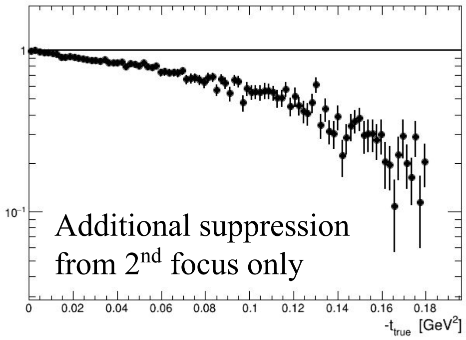
Vector Meson Production via Coherent diffractive Process with ^{90}Zr





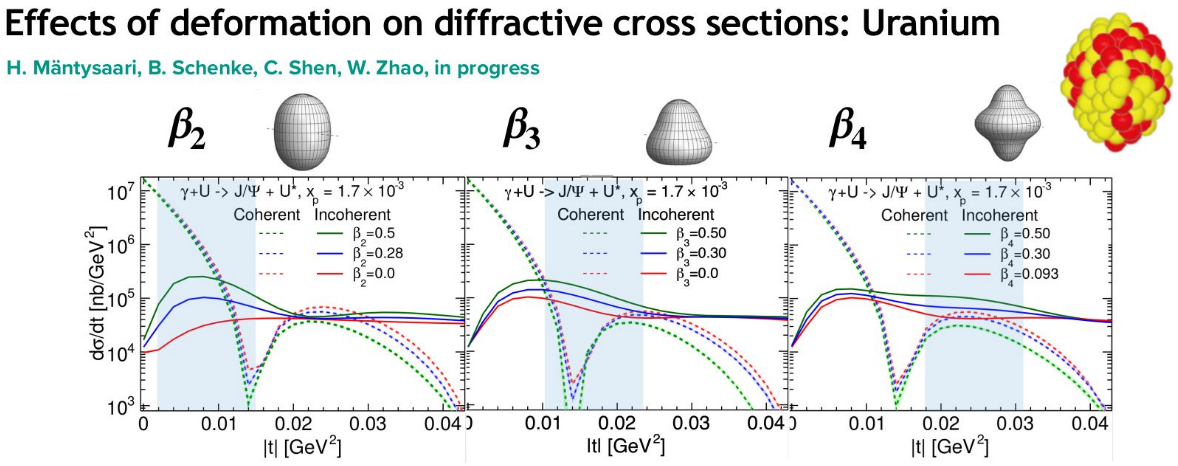
- Extended forward photon detection is synergetic with the 2nd focus in IR8.
- ^{90}Zr is ideal for benchmarking:
  - The ability to tag A-1 nuclei in the 2nd focus and detect a large fraction of nuclear photons has the potential to significantly improve the suppression of incoherent backgrounds in coherent 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



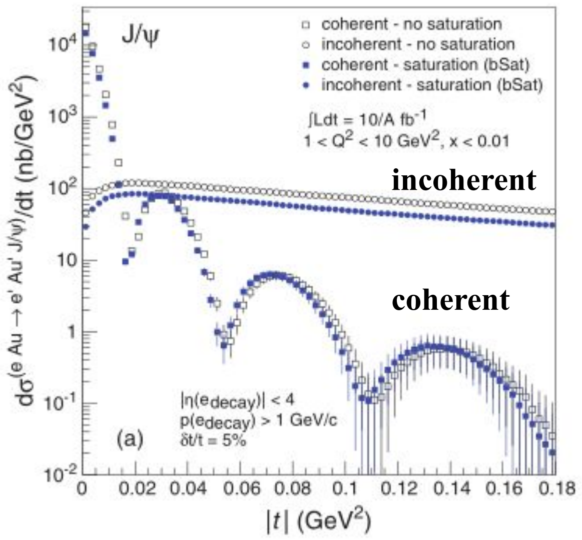


Study by M. Baker and others

Vector Meson Production via Coherent diffractive Process



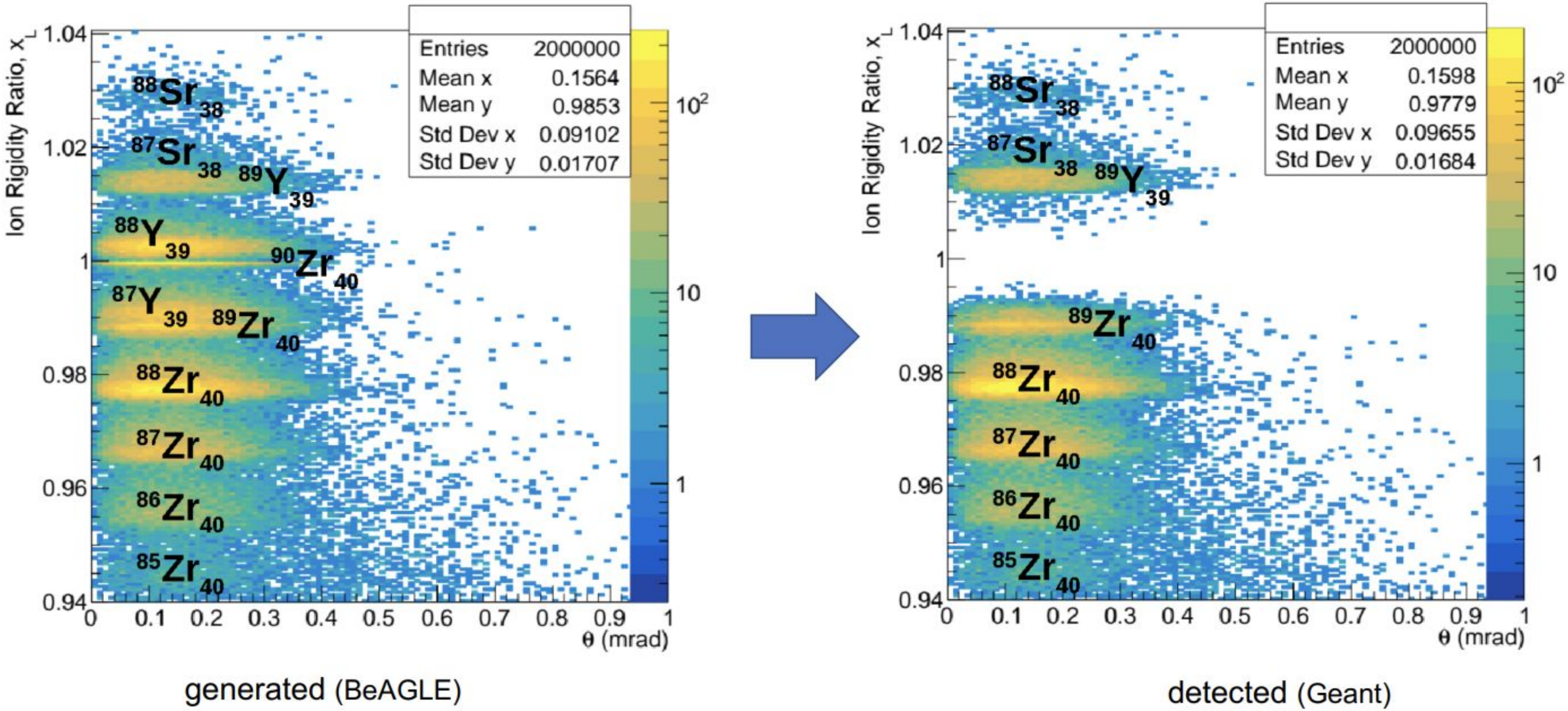
Simulations of coherent diffraction with ^{90}Pb



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

Further detail see Bjoern’s talk early today:
https://indico.bnl.gov/event/18938/contributions/78451/attachments/48988/83441/EICPhysics_Schenke.pdf

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

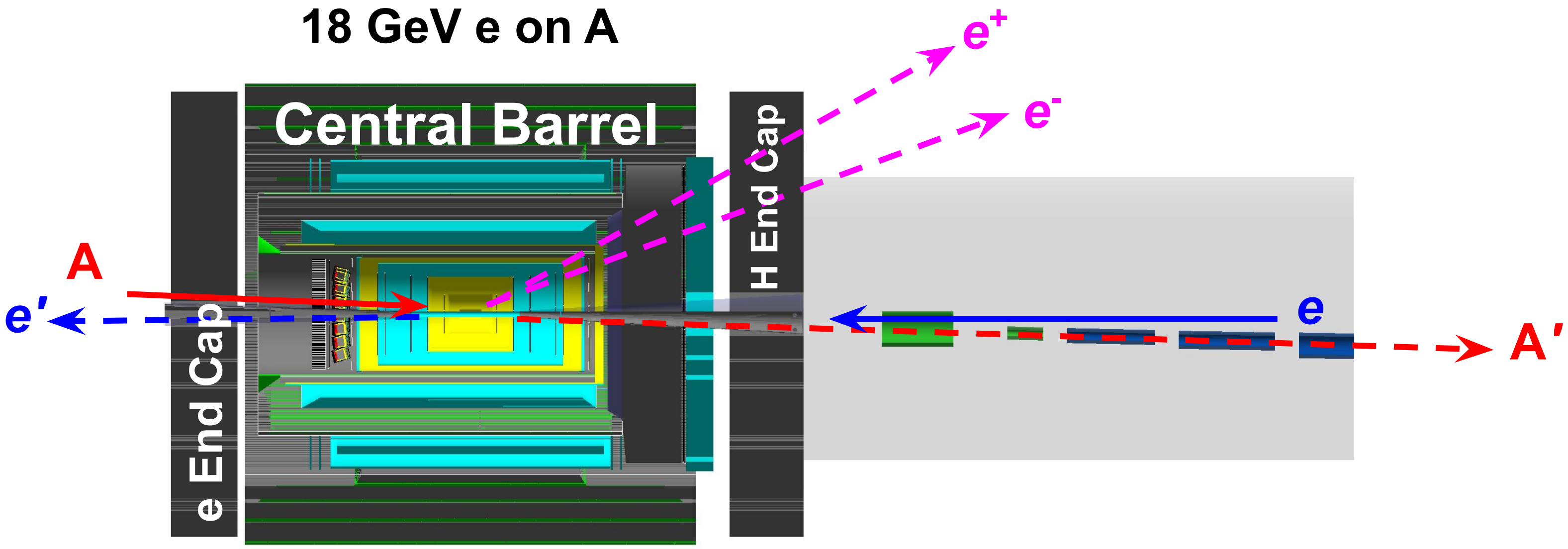


A similar study will be completed on Uranium

https://arxiv.org/abs/2208.14575

Study by Mark Baker

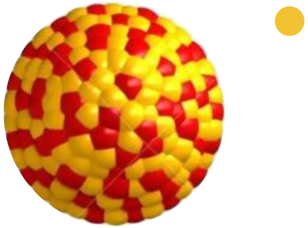
Exclusive Vector Meson production



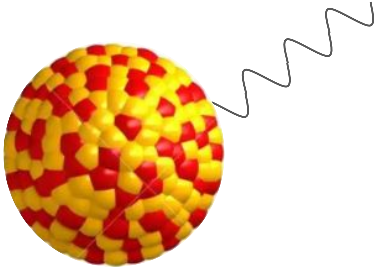
- **Scattered electron (e')**: $\eta \rightarrow -\infty$, far backward region, low Q^2 tagger
- **Decayed J/$\psi \rightarrow e^+e^-$**: $-1.5 < \eta < 3.5$, Central detector
- **Recoiled A (A')**: $\eta \sim 6$, far forward region

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

A′



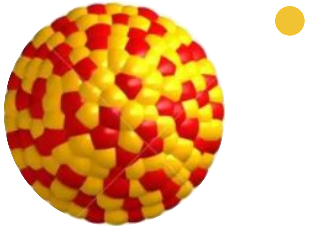
Neutron Evaporation



Gamma de-excitation

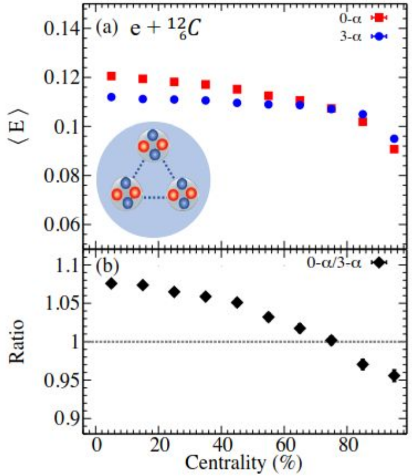
- **eA Diffractive study, forward detector must:**
  - Tag A′
  - Veto events due to neutron evaporation and gamma de-excitation

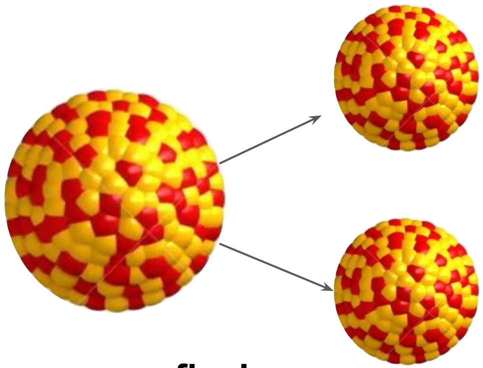
A′ Decay is not all bad !



Neutron Evaporation

- **Evaporated neutron energy deposition study by Niseem Magdy, Y. Jia, et. al.**

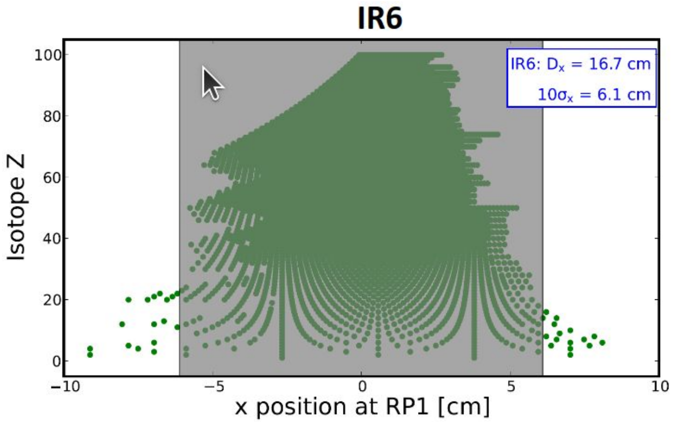


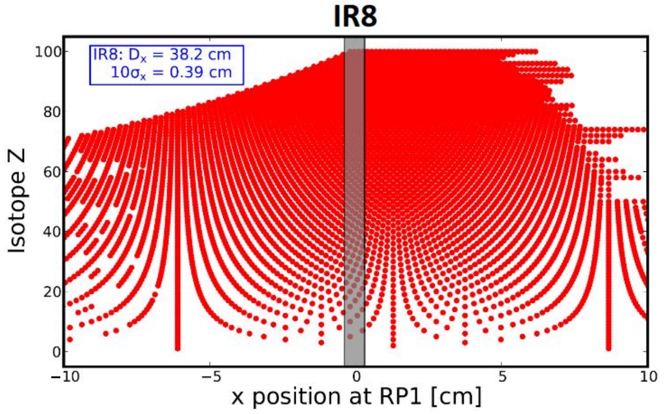


fission

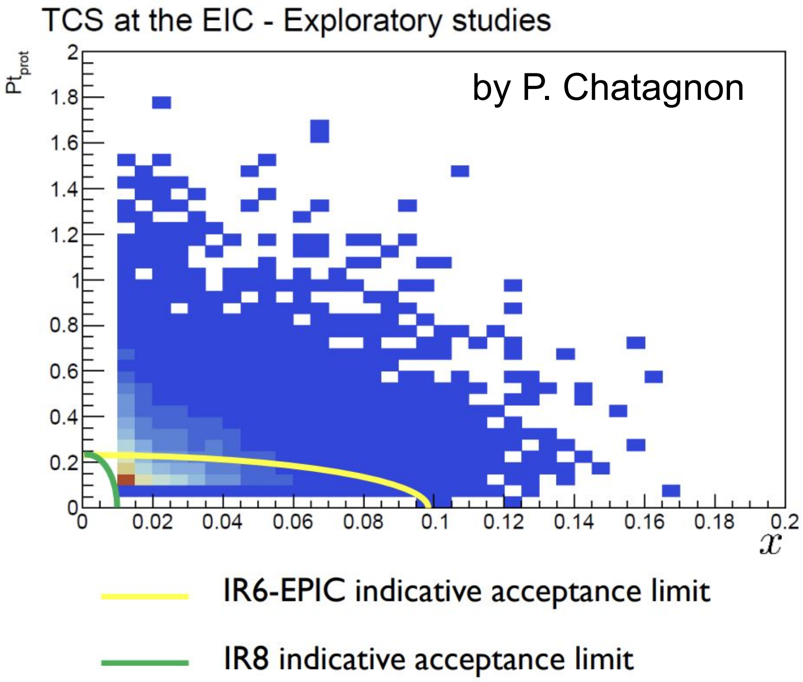
- **Direct measurement of final nuclei, including rare isotopes, and associated de-excitation gamma photons study by B. Moran, et. al.**

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





Nuclear fragments detection at Roman Pot

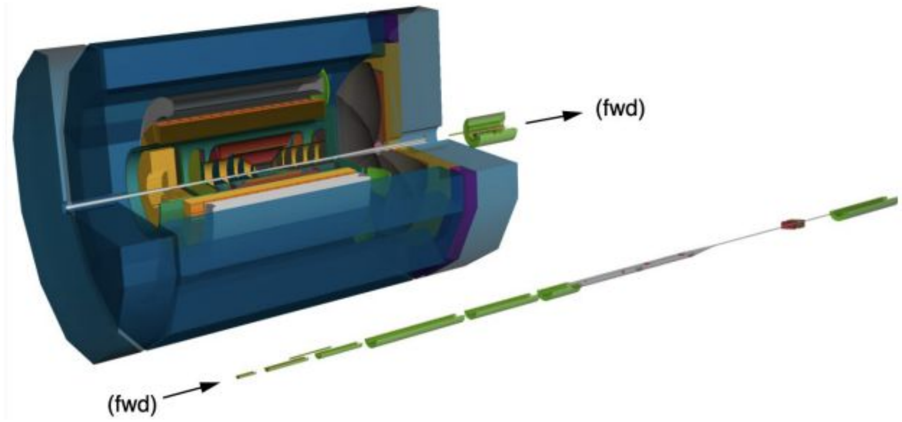


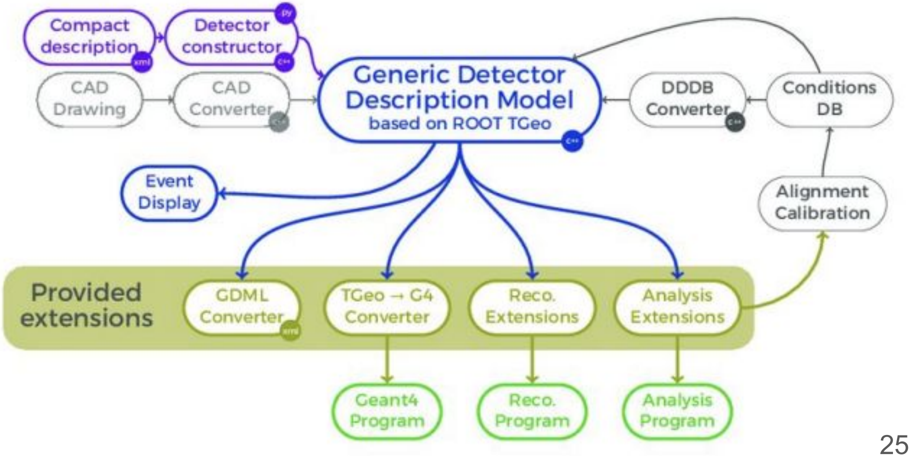
Order-of-magnitude improvement in forward acceptance

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

Software Tools

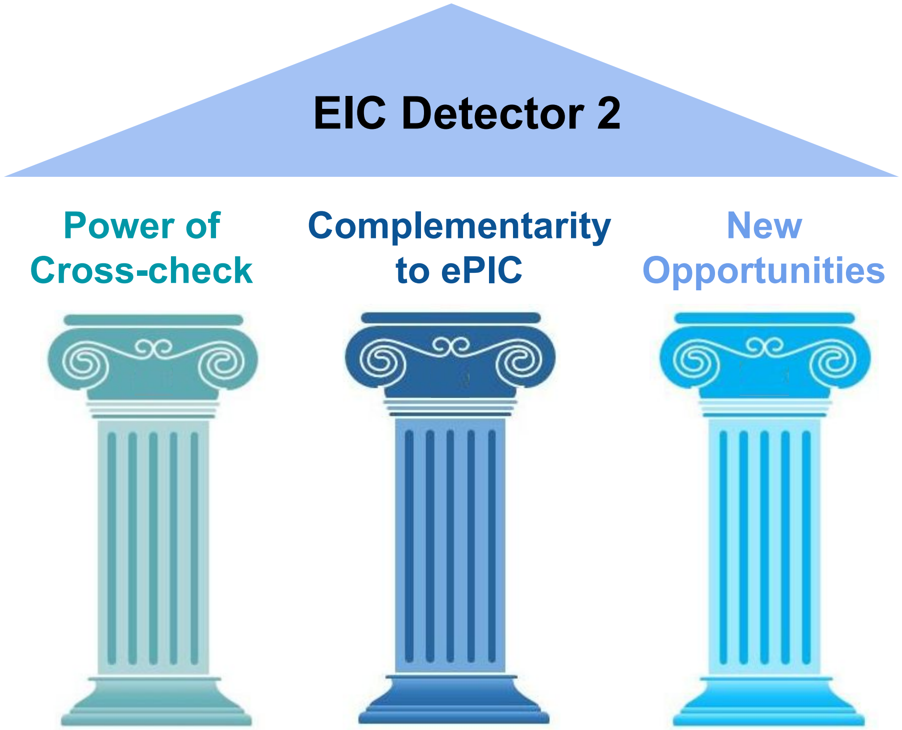
- **Consensus: not to reinvent the wheel at this stage**
- **Make best use of ePIC development**
  - DD4HEP as geometry description
  - Podio and EDM4hep as data model
  - EIC-recon as reconstruction
- **Detail is to be developed**





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三 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**

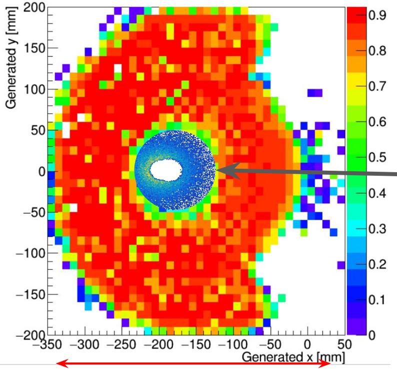
Backup

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”

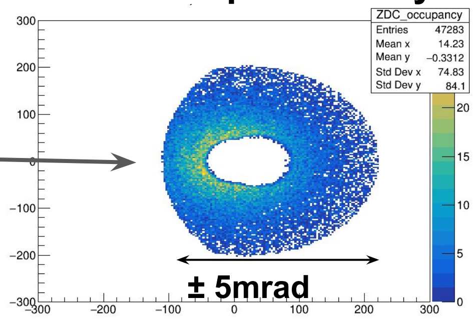
B0 Calorimeter

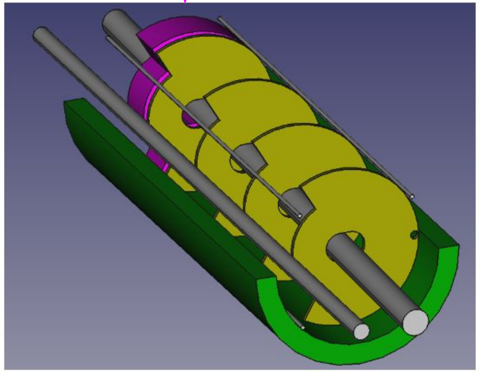
ZDC + B0 calorimeter



± 28mrad !

ZDC Acceptance only





IP8 Forward Detector Suggestion

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

Off Momentum Tracker

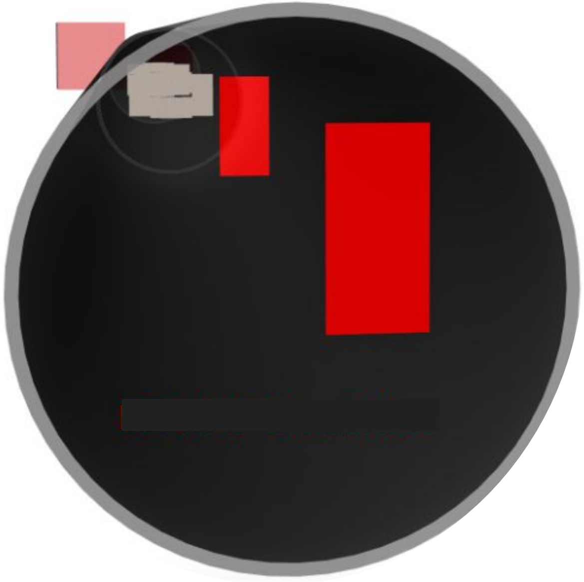
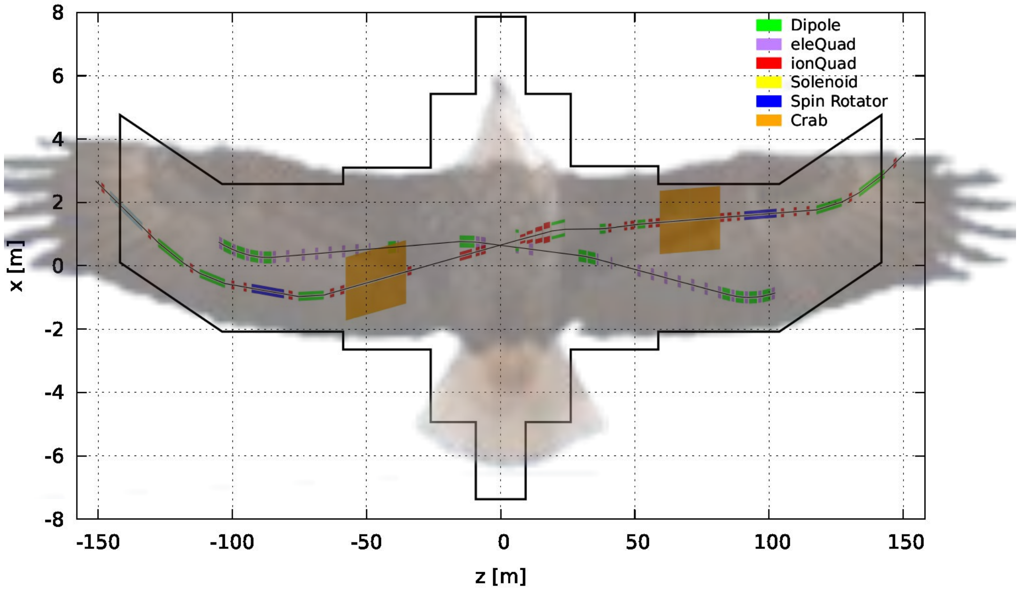


Image by A. Jentsch, BNL

- **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**

Thank you for your attention!



Zero Degree Calorimeter

Image by engineers, BNL

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

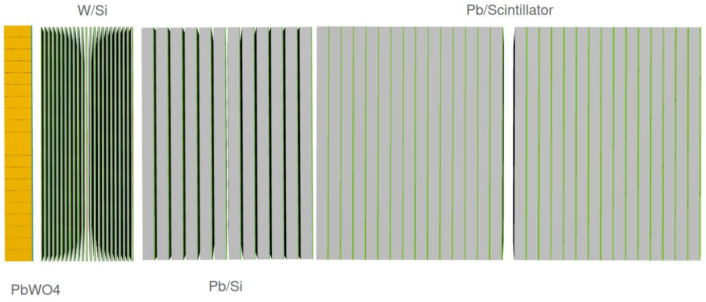
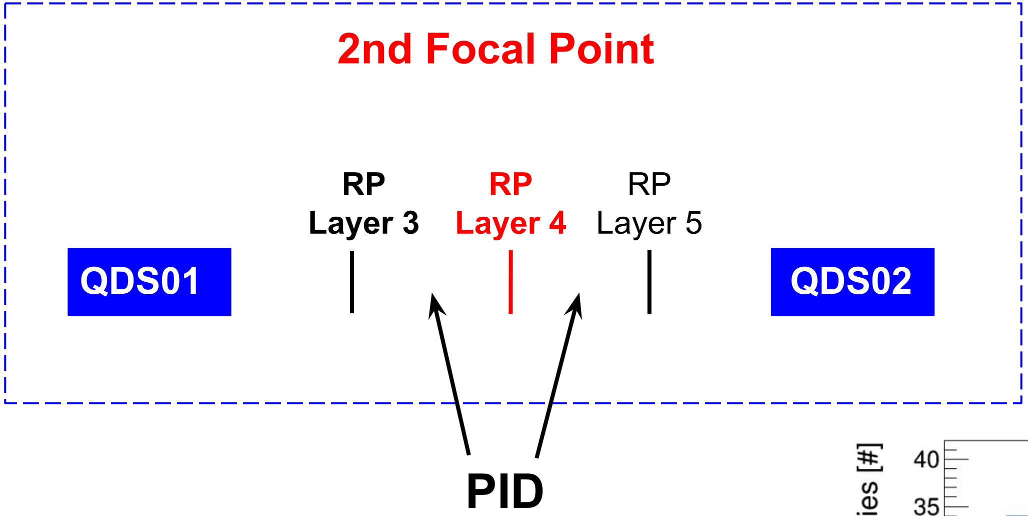


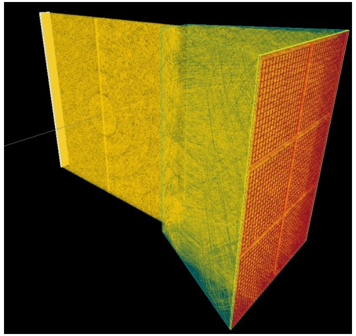
Image by D. Misra, PNNL

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

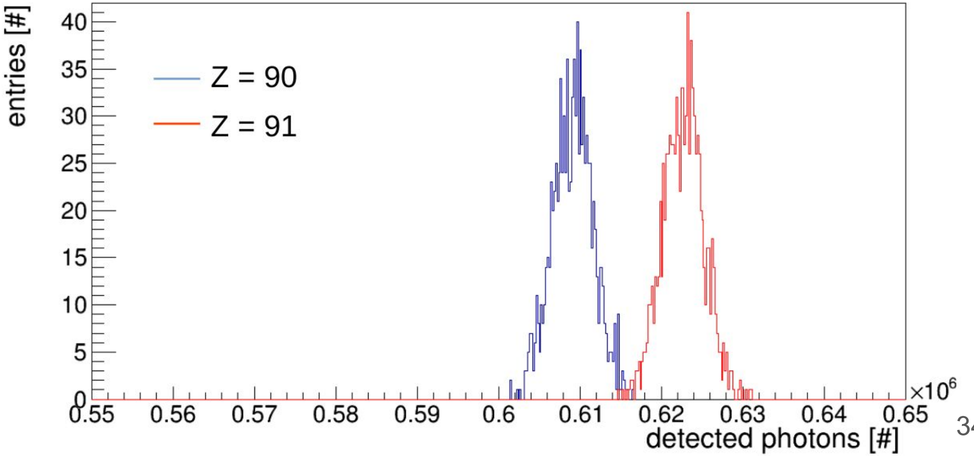


- **Z-Tagging Mini DIRC** (C. Hyde)
  - Photon counter

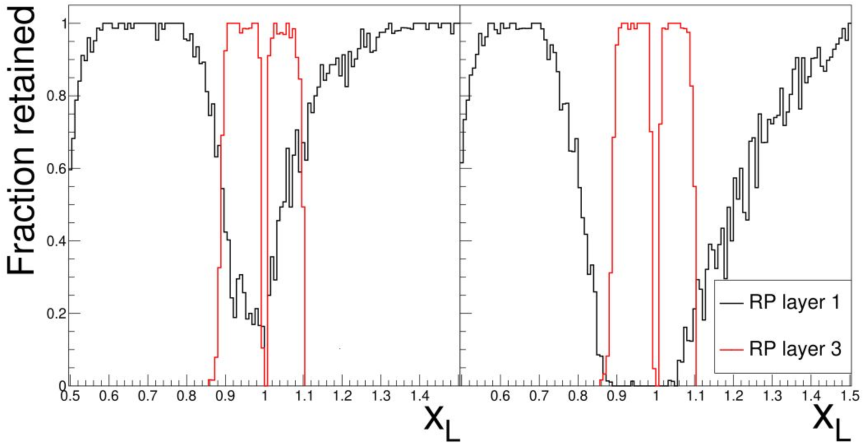
$$\frac{dN}{dX} \approx z^2\,(0.013/\mathrm{cm}) = \frac{106}{\mathrm{cm}} \text{ for } z = 90$$



Ray trace simulation by C.Hyde and R. Dzhygadlo



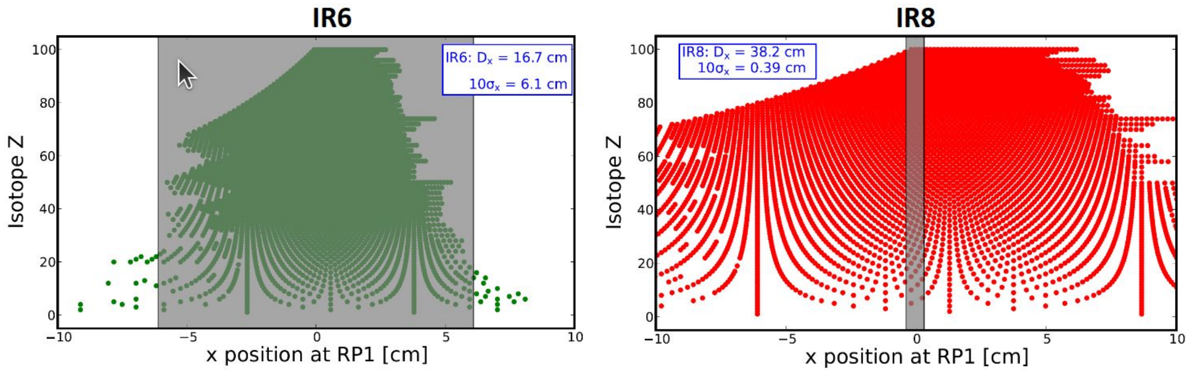
In terms of PD acceptance



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