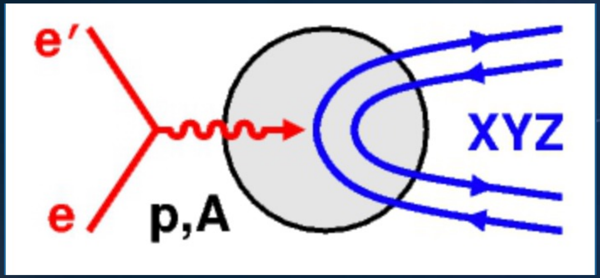
Far-Forward Detectors and Capabilities for Meson Spectroscopy



Alex Jentsch (BNL)

ajentsch@bnl.gov

Exotic Heavy-Meson Spectroscopy and Structure with the EIC

August 15th-18th, 2022

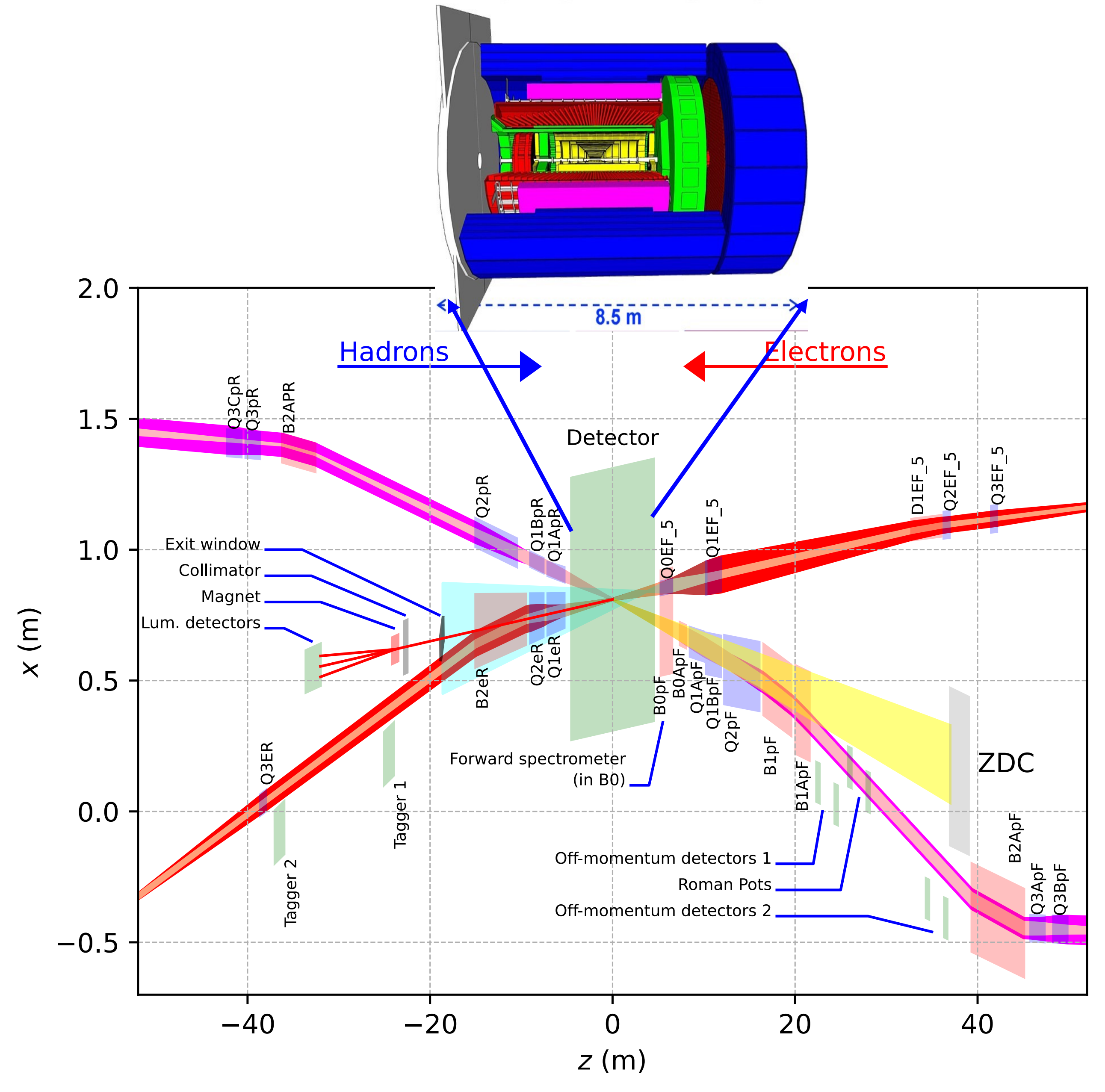
Stony Brook University

BROOKHAVEN NATIONAL LABORATORY

Jefferson Lab

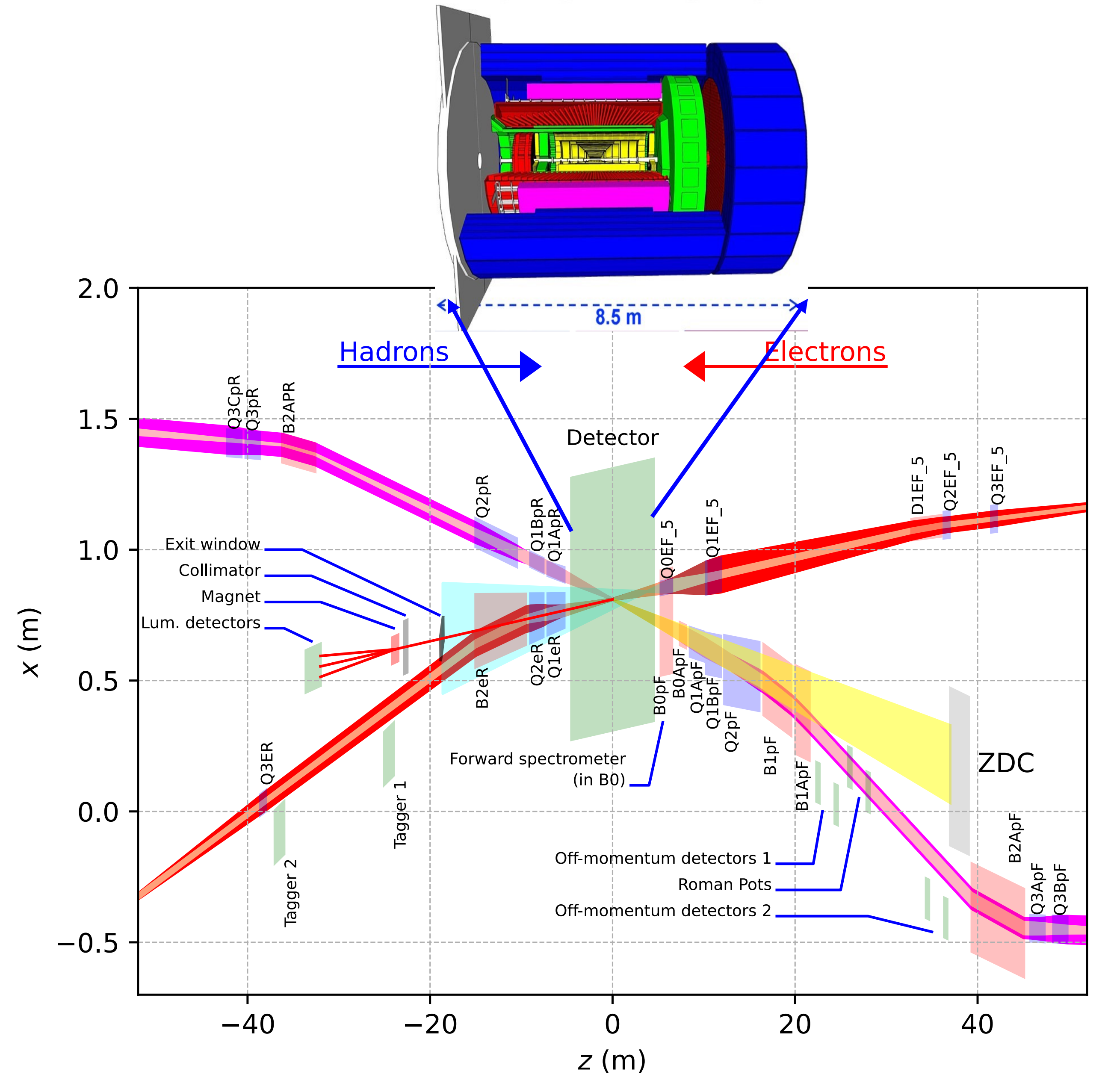
U.S. DEPARTMENT OF ENERGY | Office of Science

The EPIC Detector



- In addition to the central detector → detectors integrated into the beamline on both the hadron-going (**far-forward**) and electron-going (**far-backward**) direction.
  - Requires special considerations for the machine-detector interface.

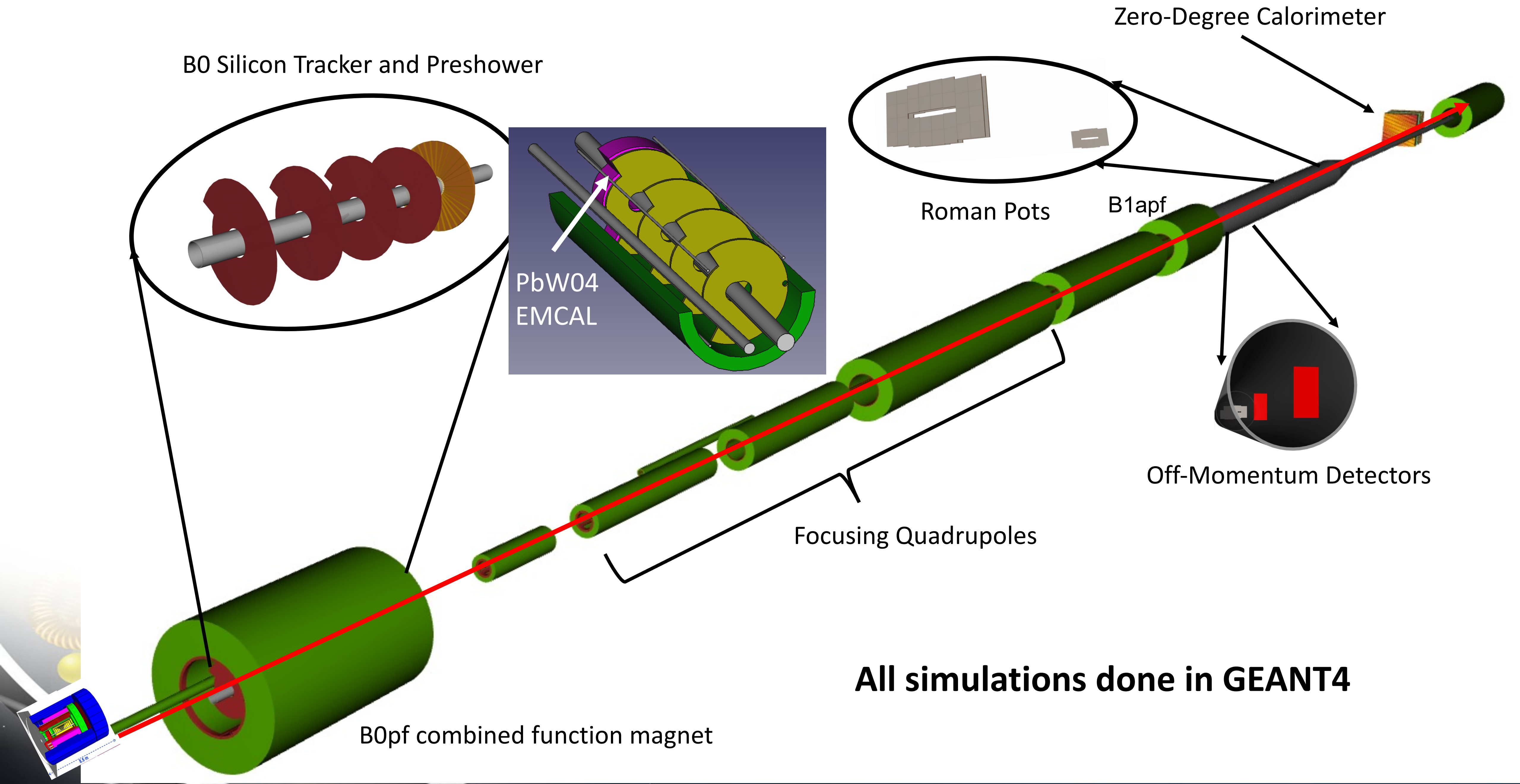
The EPIC Detector



- In addition to the central detector → detectors integrated into the beamline on both the hadron-going (far-forward) and electron-going (**far-backward**) direction.
  - Requires special considerations for the machine-detector interface.

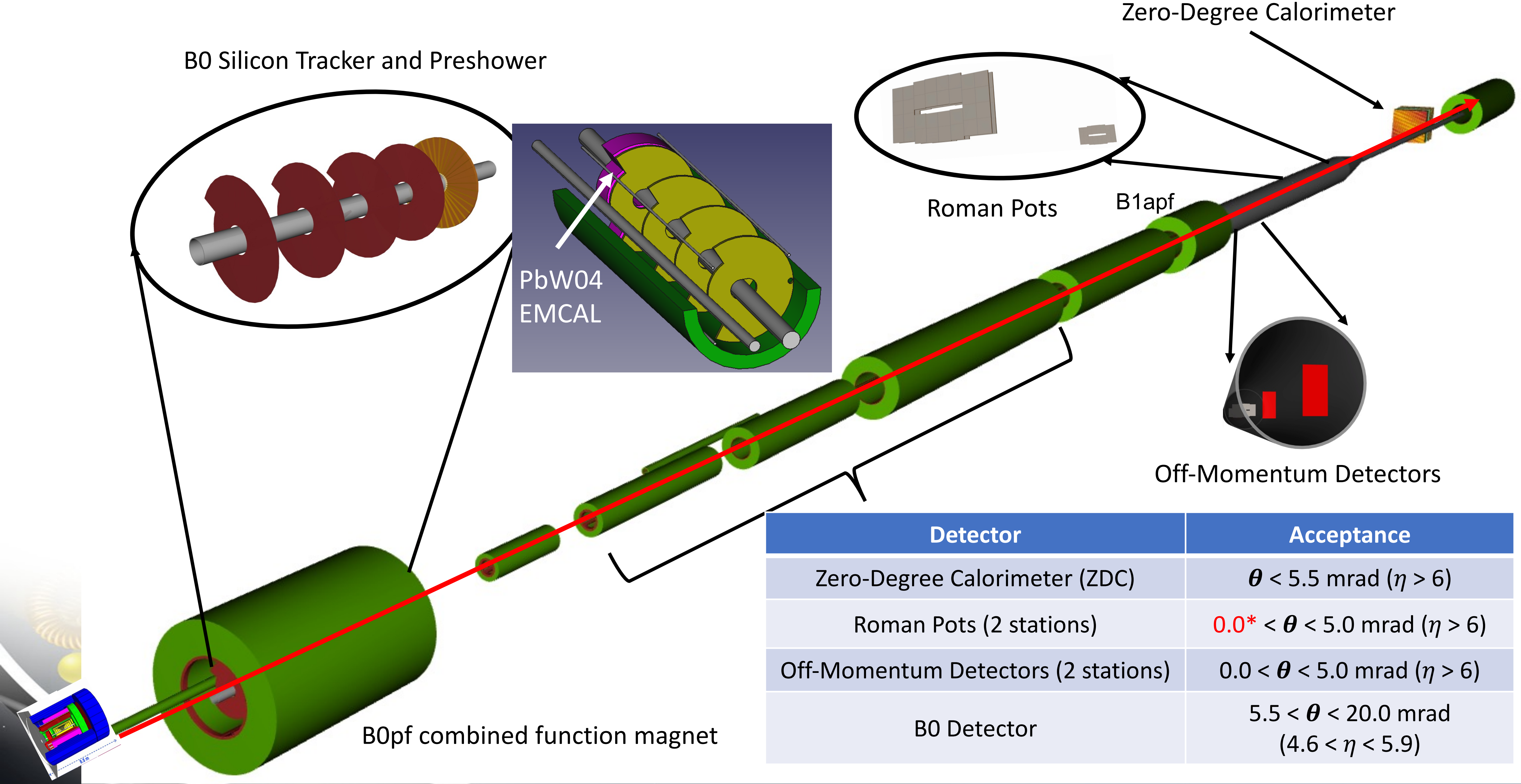
The far-forward system functions almost like an independent spectrometer experiment at the EIC!

The Far-Forward Detectors

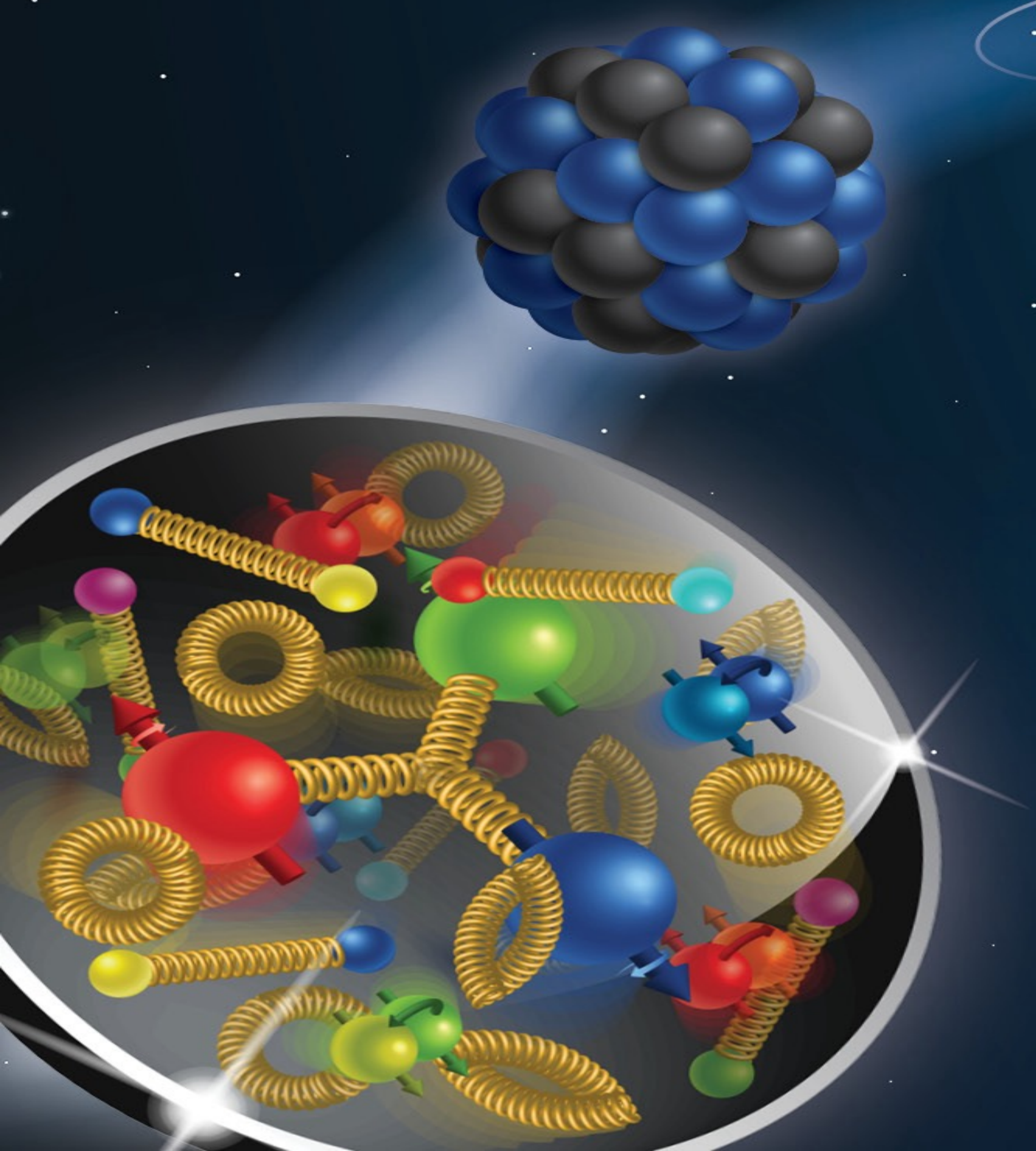


All simulations done in GEANT4

The Far-Forward Detectors

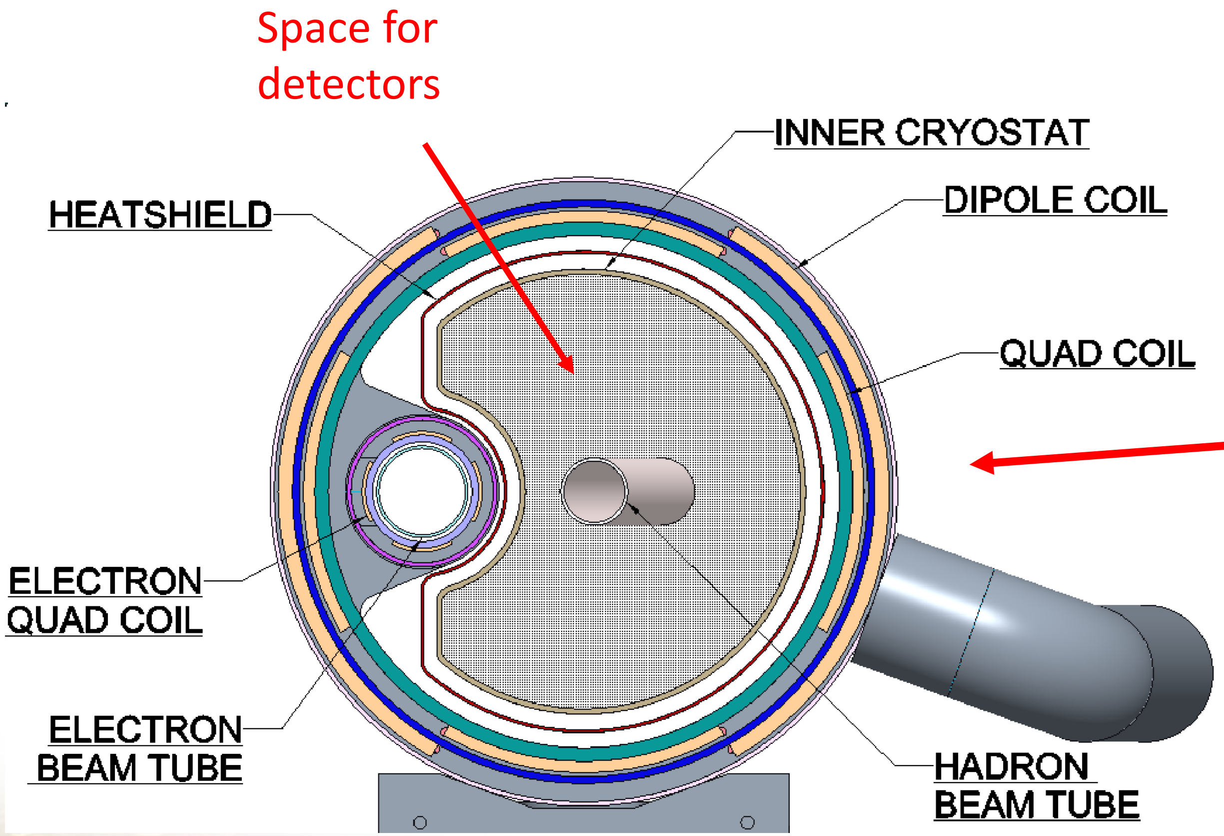


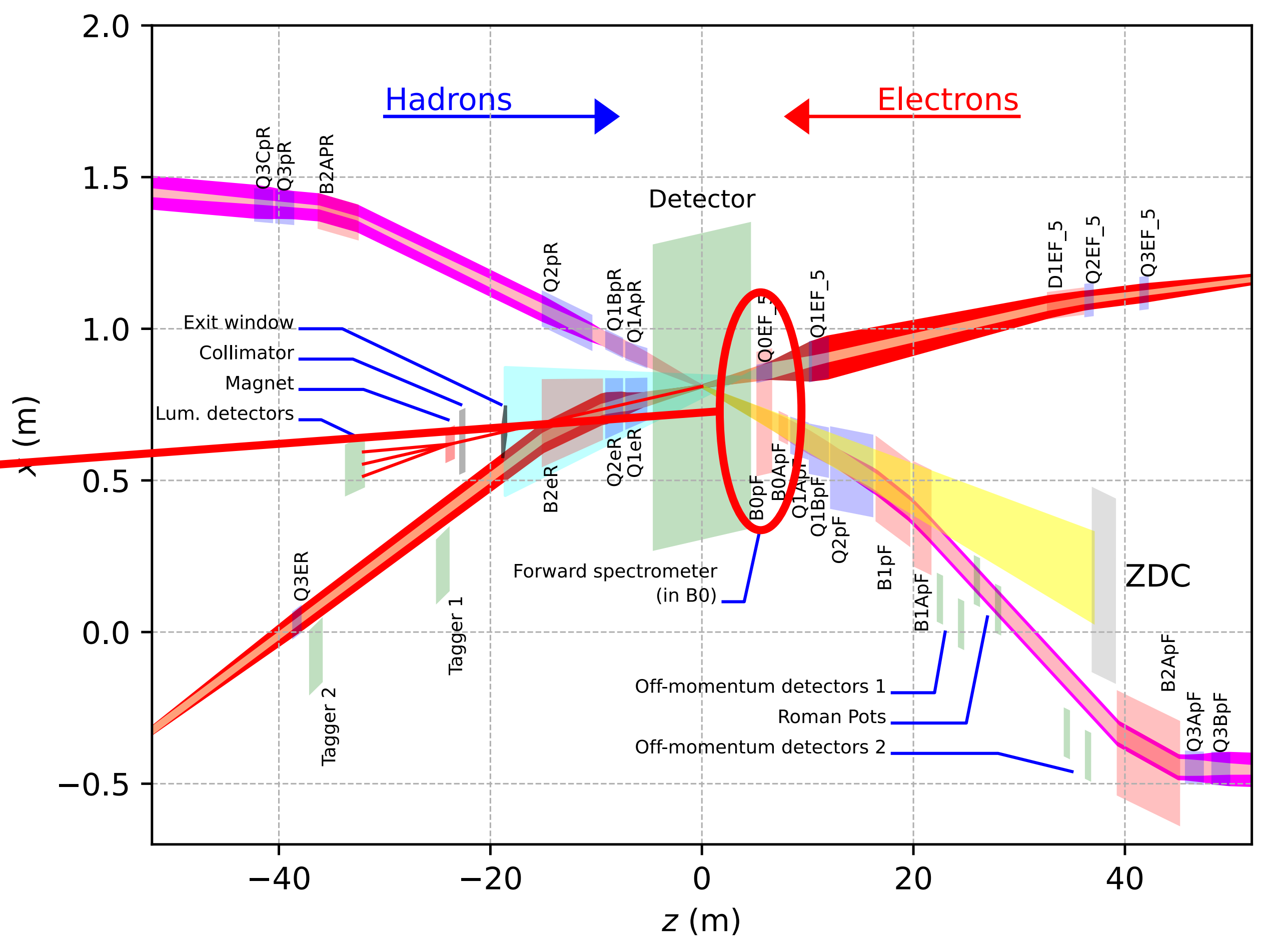
Detector	Acceptance
Zero-Degree Calorimeter (ZDC)	θ < 5.5 mrad (η > 6)
Roman Pots (2 stations)	0.0* < θ < 5.0 mrad (η > 6)
Off-Momentum Detectors (2 stations)	0.0 < θ < 5.0 mrad (η > 6)
B0 Detector	5.5 < θ < 20.0 mrad (4.6 < η < 5.9)



Far-Forward Detector Subsystems

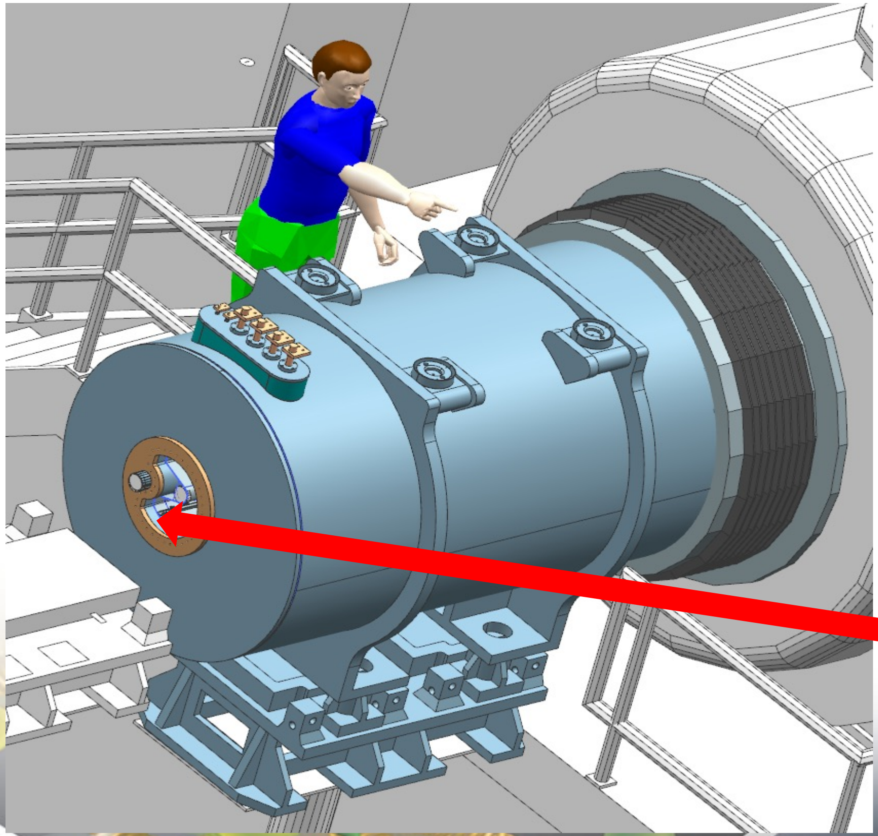
B0 Detectors

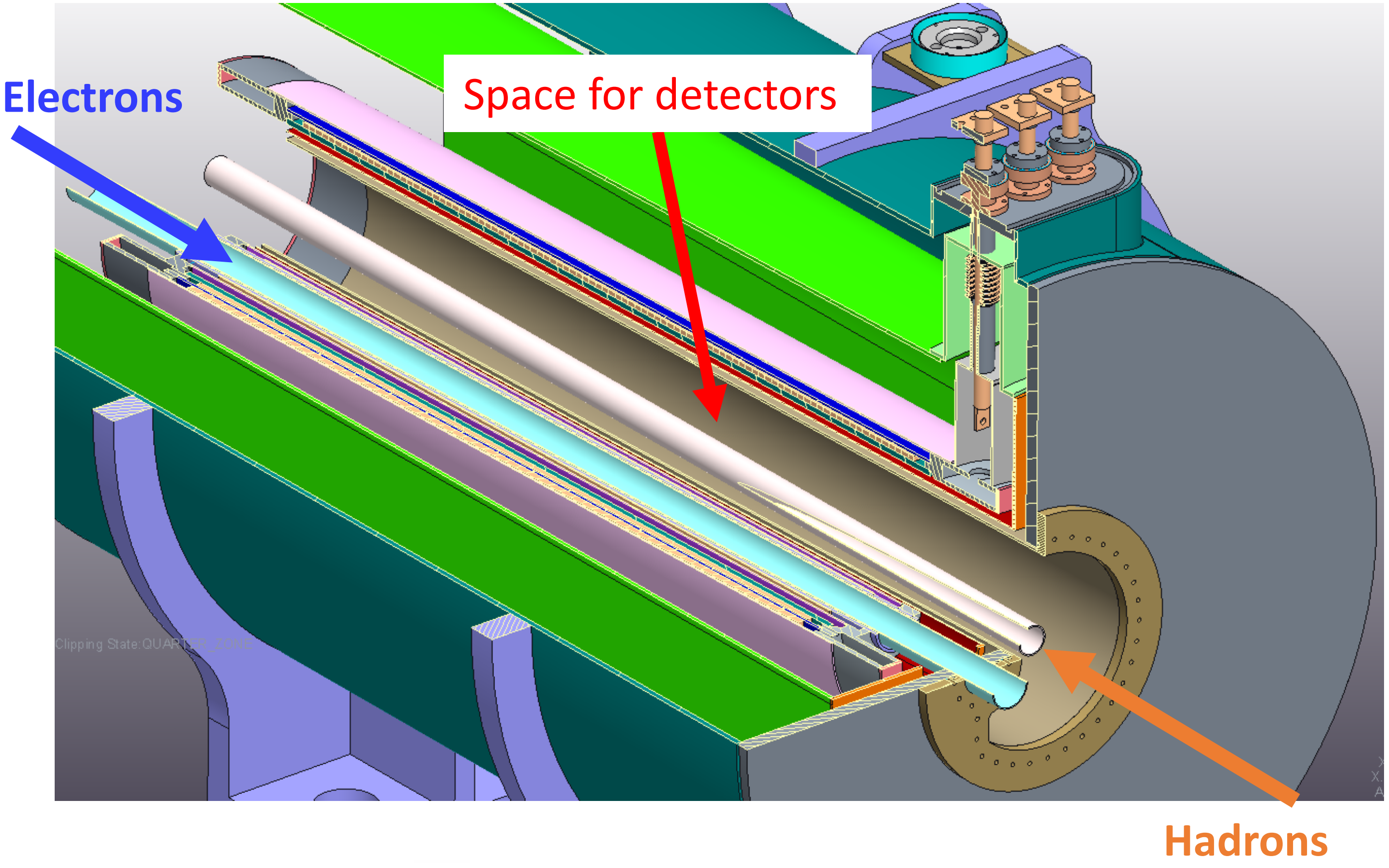




B0 Detectors

- Charged particle reconstruction and photon tagging.
  - Precise tracking (~10um spatial resolution).
  - Fast timing for background rejection and to remove crab smearing (~35ps).
  - Photon detection (tagging or full reco).



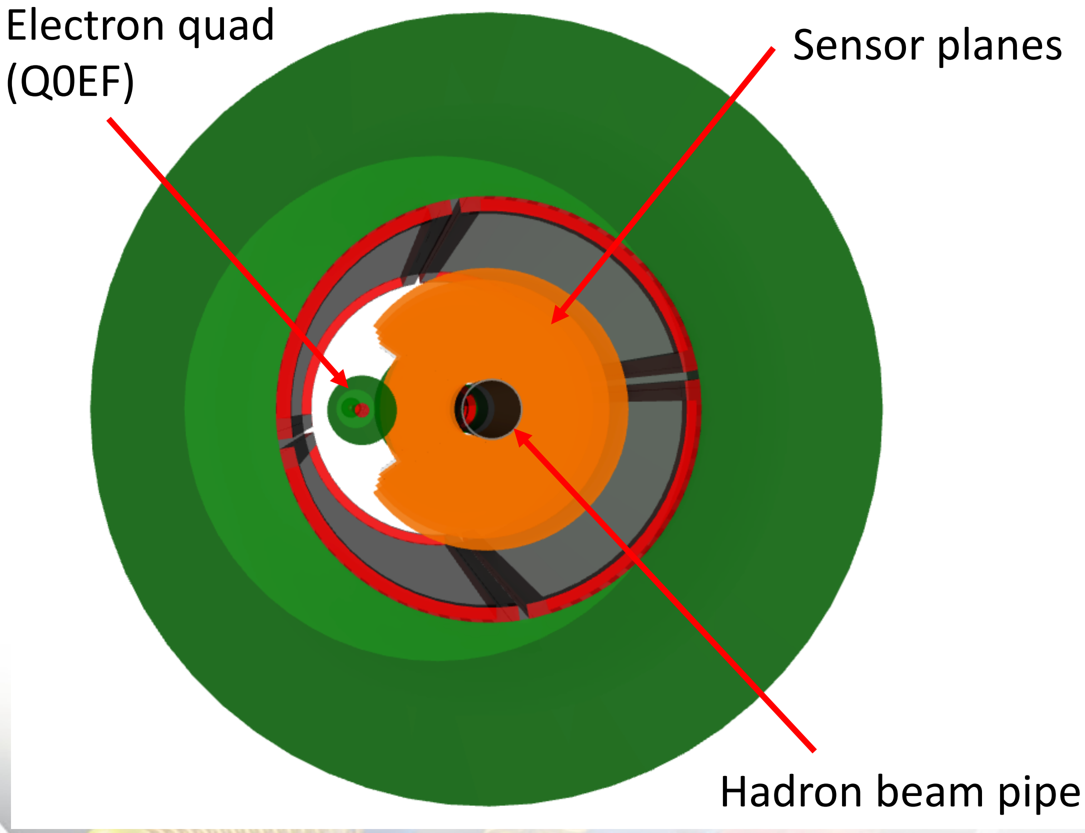


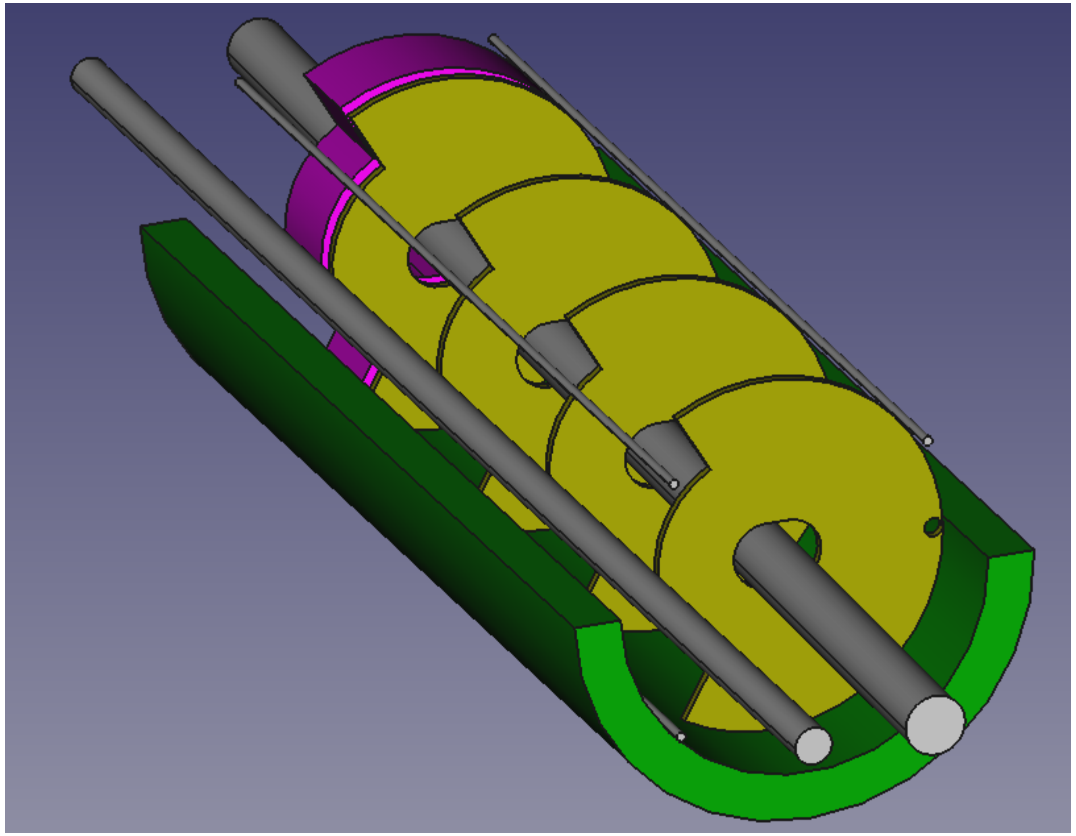
This is the opening where the detector planes will be inserted

Preliminary Parameters:
229.5cm x 121.1cm x 195cm
(Actual length will be shorter)

B0 Detectors

(5.5 < θ < 20.0 mrad)





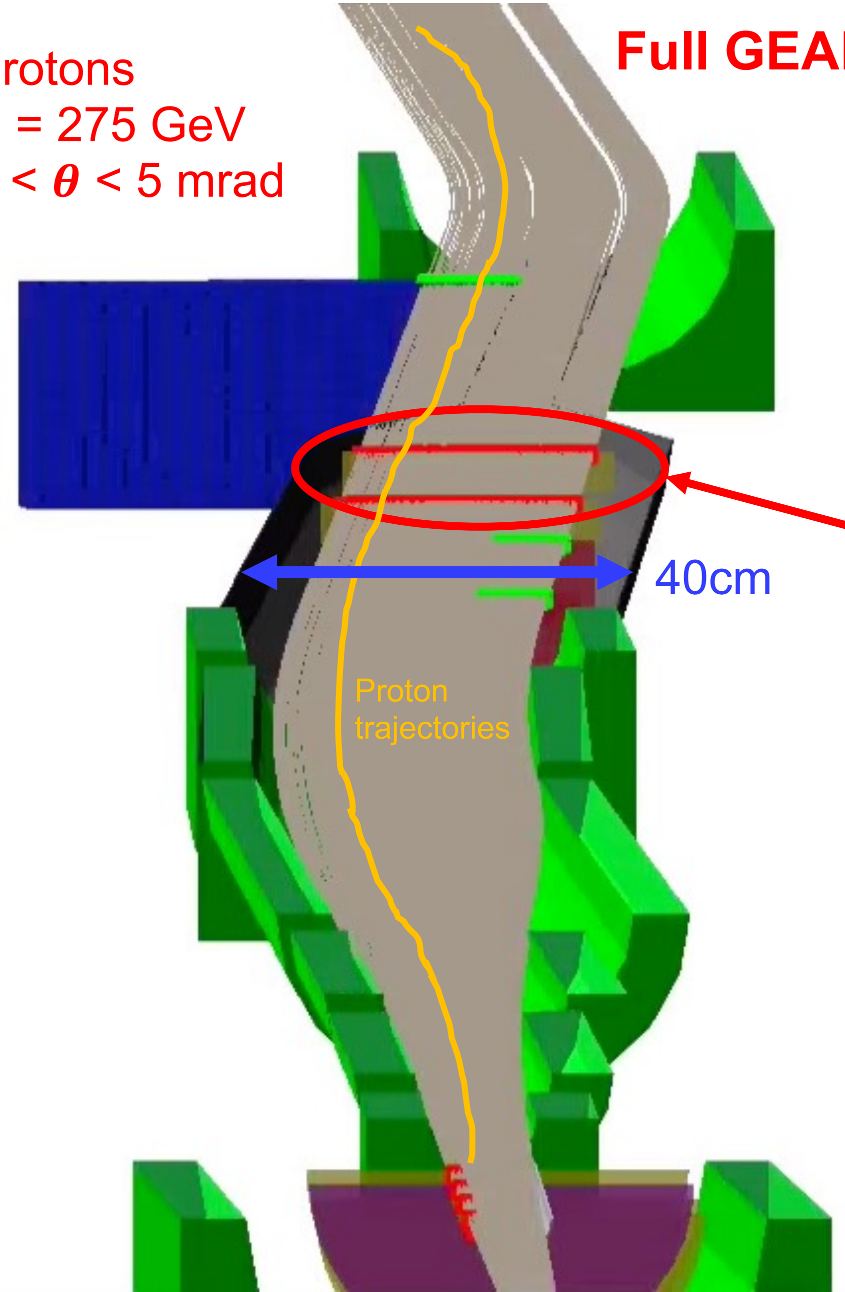
DD4HEP Simulation

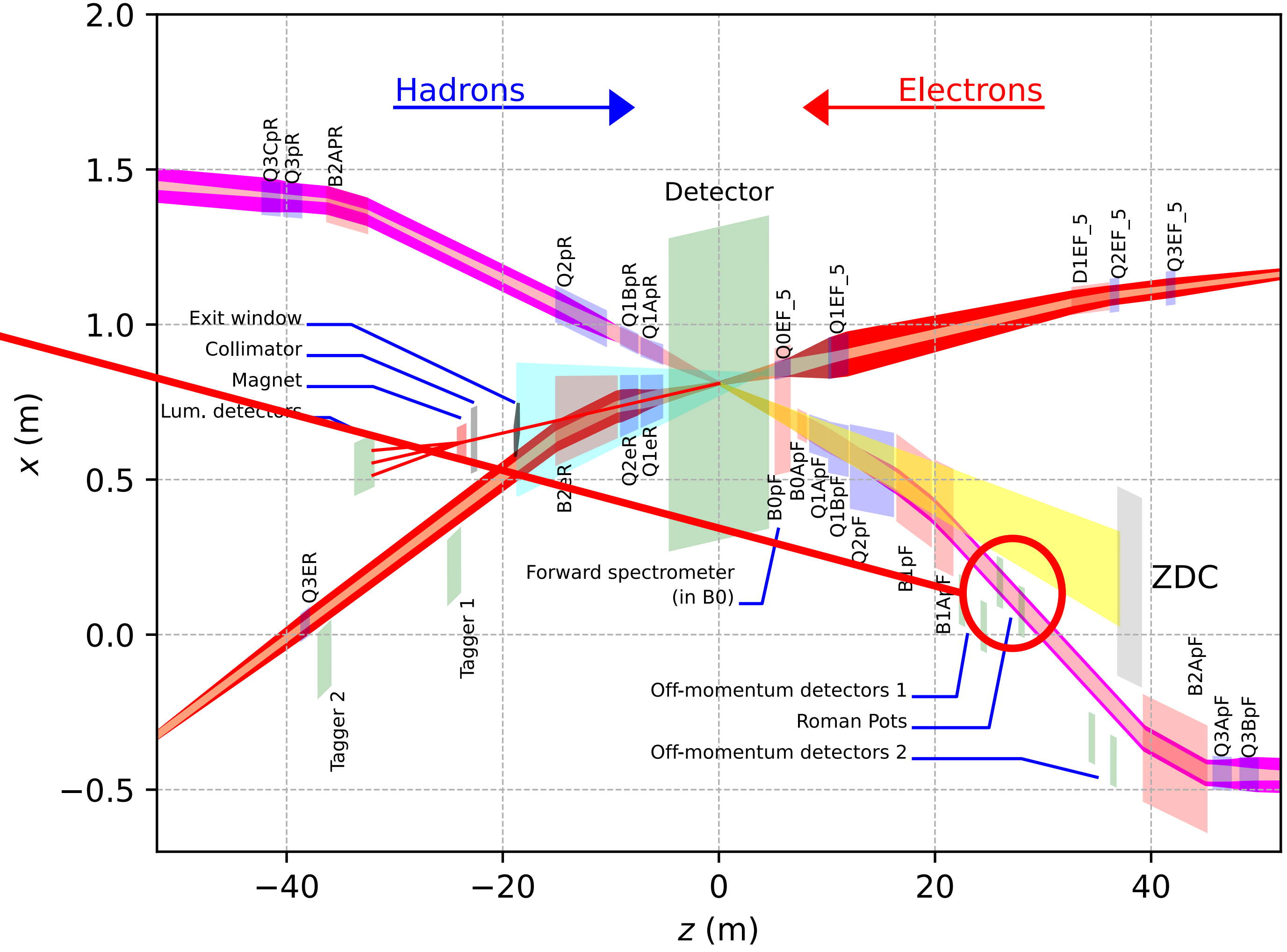
- **Technology:**
  - **Tracking: IT3 or ITS2 MAPS (3 layers) + AC-LGADs (1 layer)**
  - **PbWO4 EMCAL or silicon preshower, depending on available space in final B0pf magnet design (pending).**

Roman Pots @ the EIC

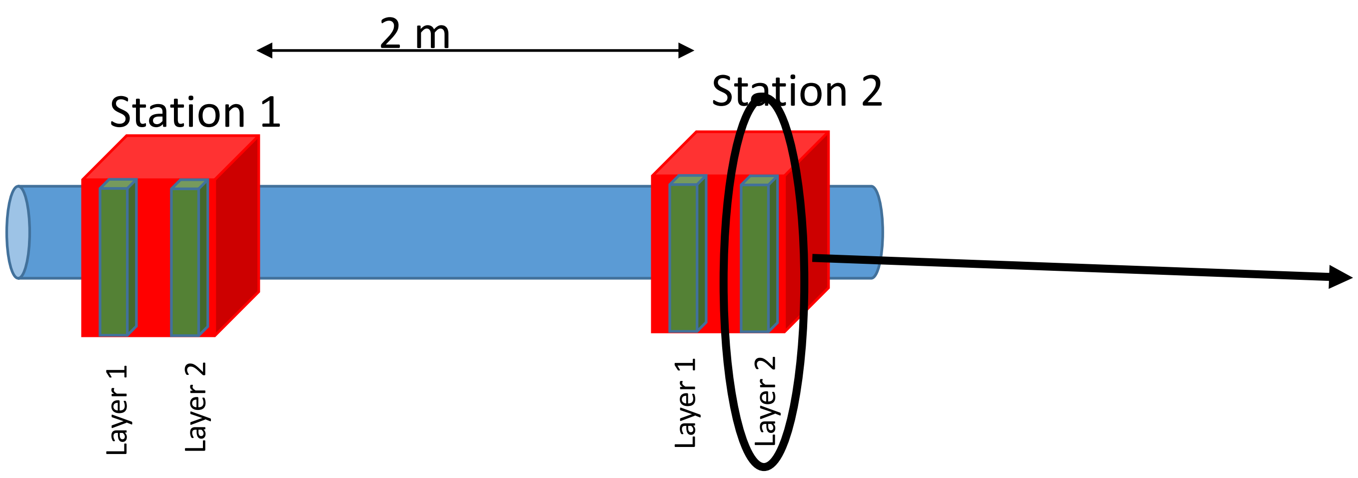
Protons
E = 275 GeV
$0 < \theta < 5$ mrad

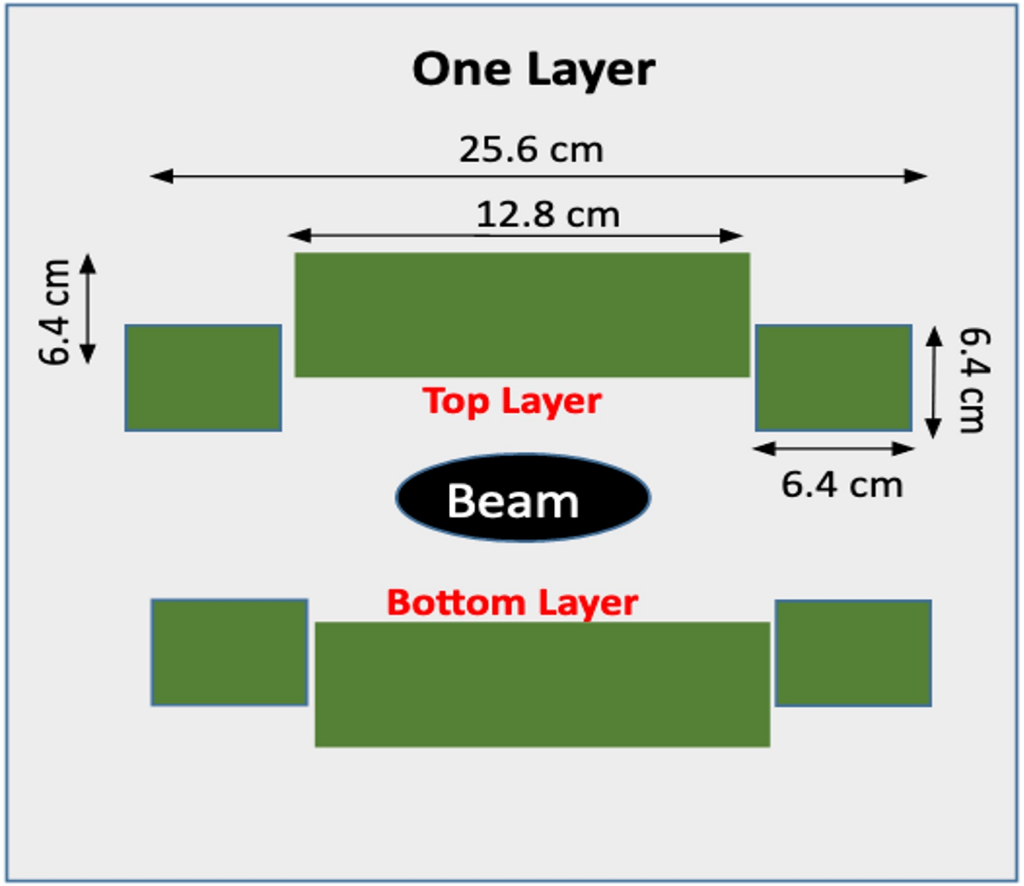
Full GEANT4 simulation.





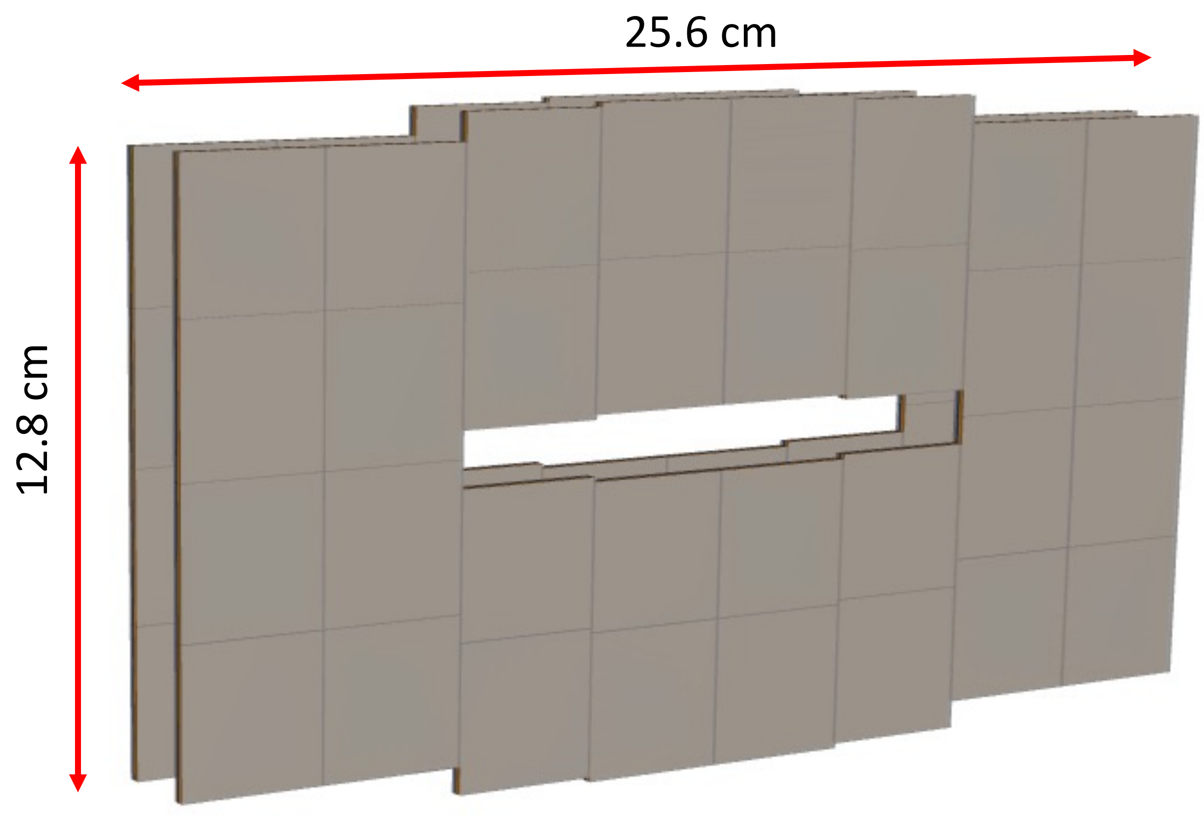
Roman "Pots" @ the EIC





- Two stations, separated by 2 meters, each with two layers (minimum) of silicon detectors.
- Silicon detectors placed directly into machine vacuum!
  - Allows maximal geometric coverage!
- Need space for detector insertion tooling and support structure.

Roman “Pots” @ the EIC



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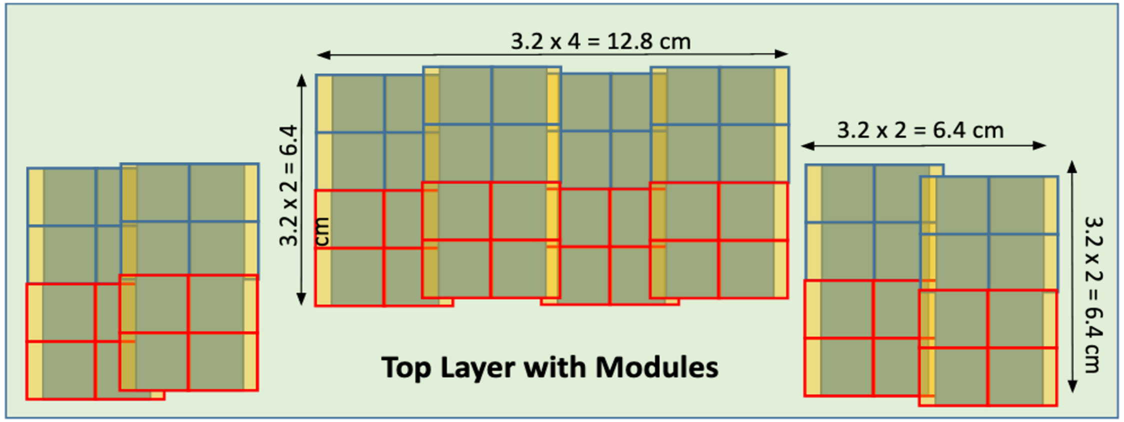
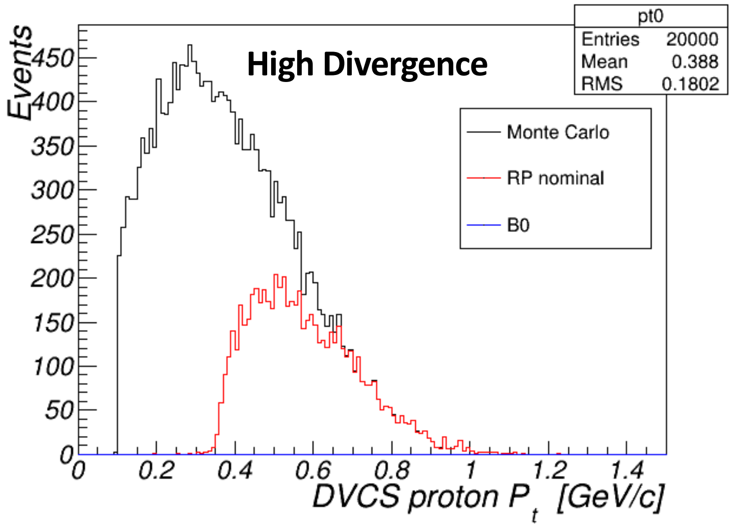
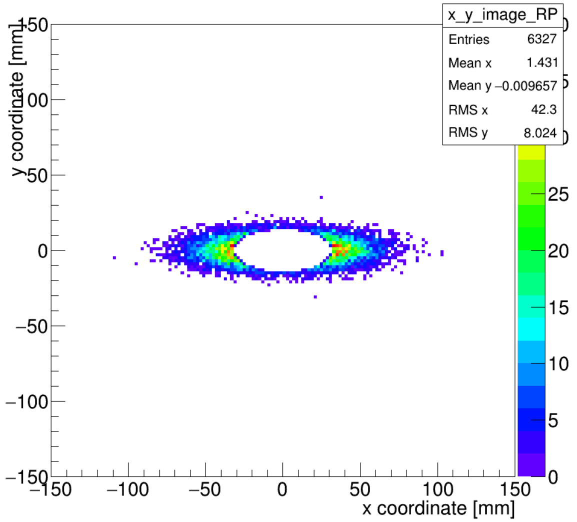


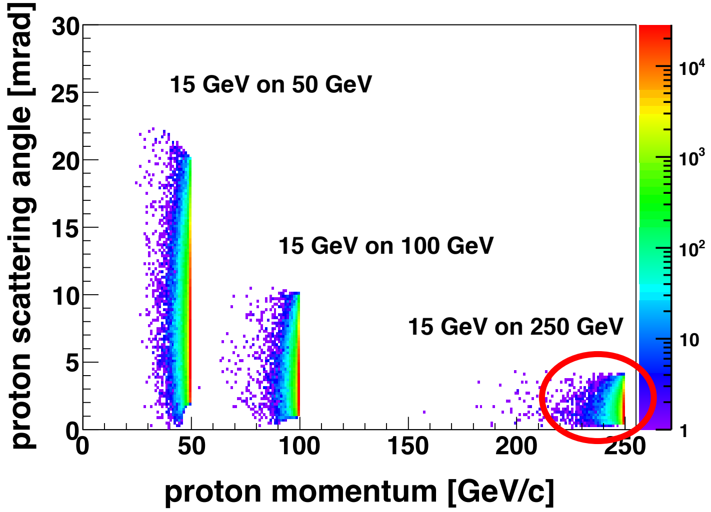
- **Technology**
  - 500um, pixilated AC-LGAD sensor, with 30-40ps timing resolution.
  - “Potless” design concept with thin RF foils surrounding detector components.

Digression: Machine Optics

275 GeV DVCS Proton Acceptance







<u>High Divergence:</u> smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

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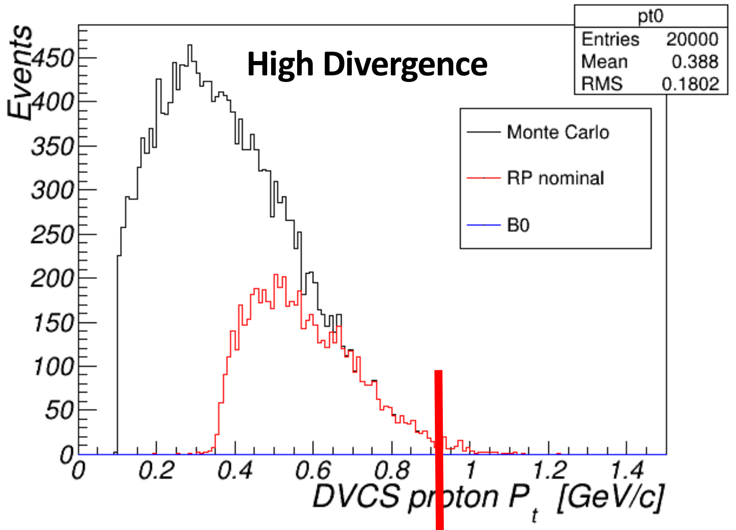

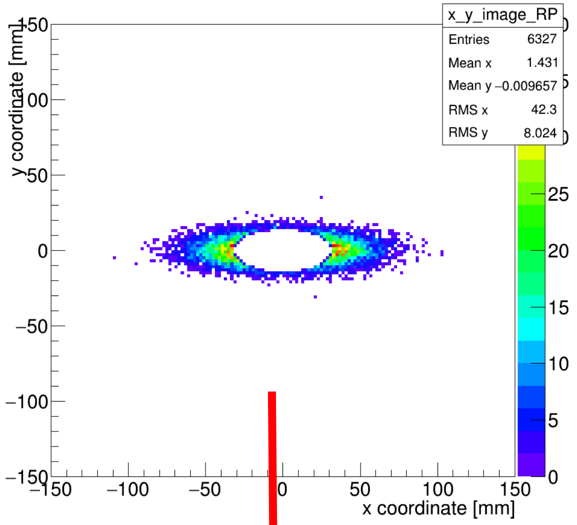

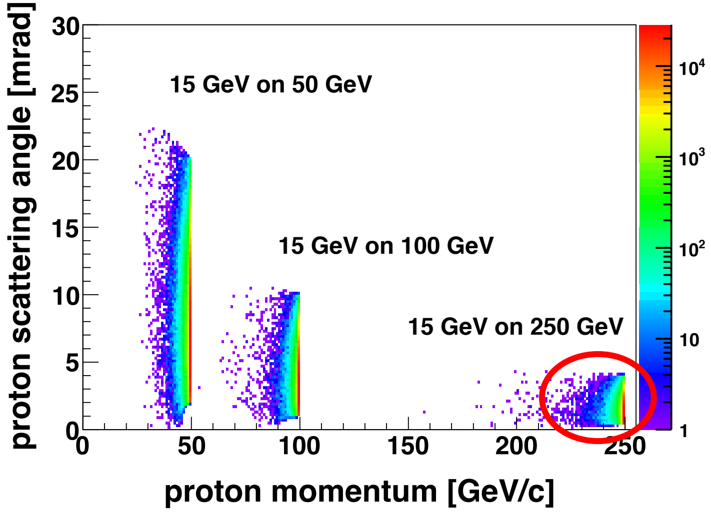

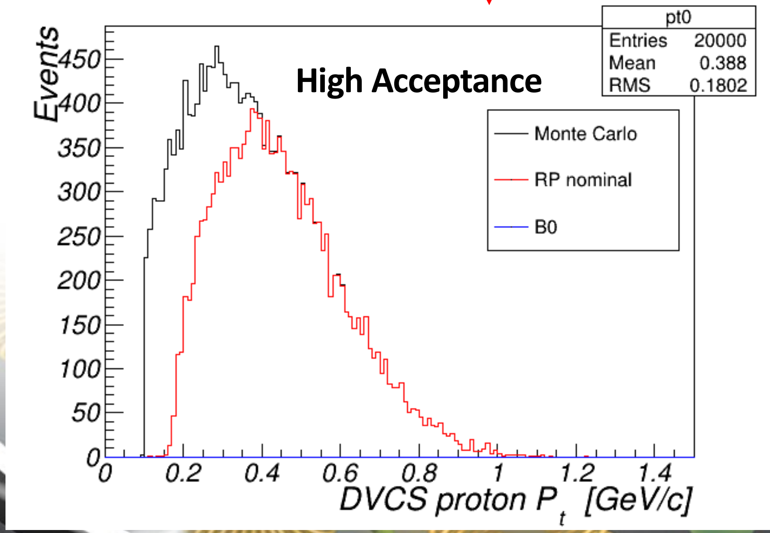

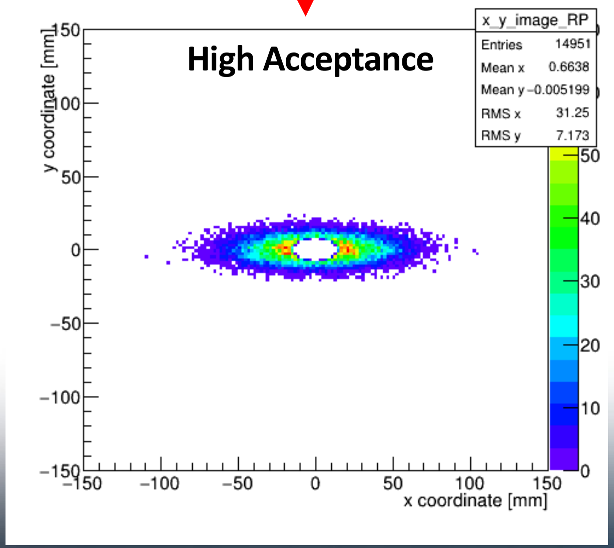

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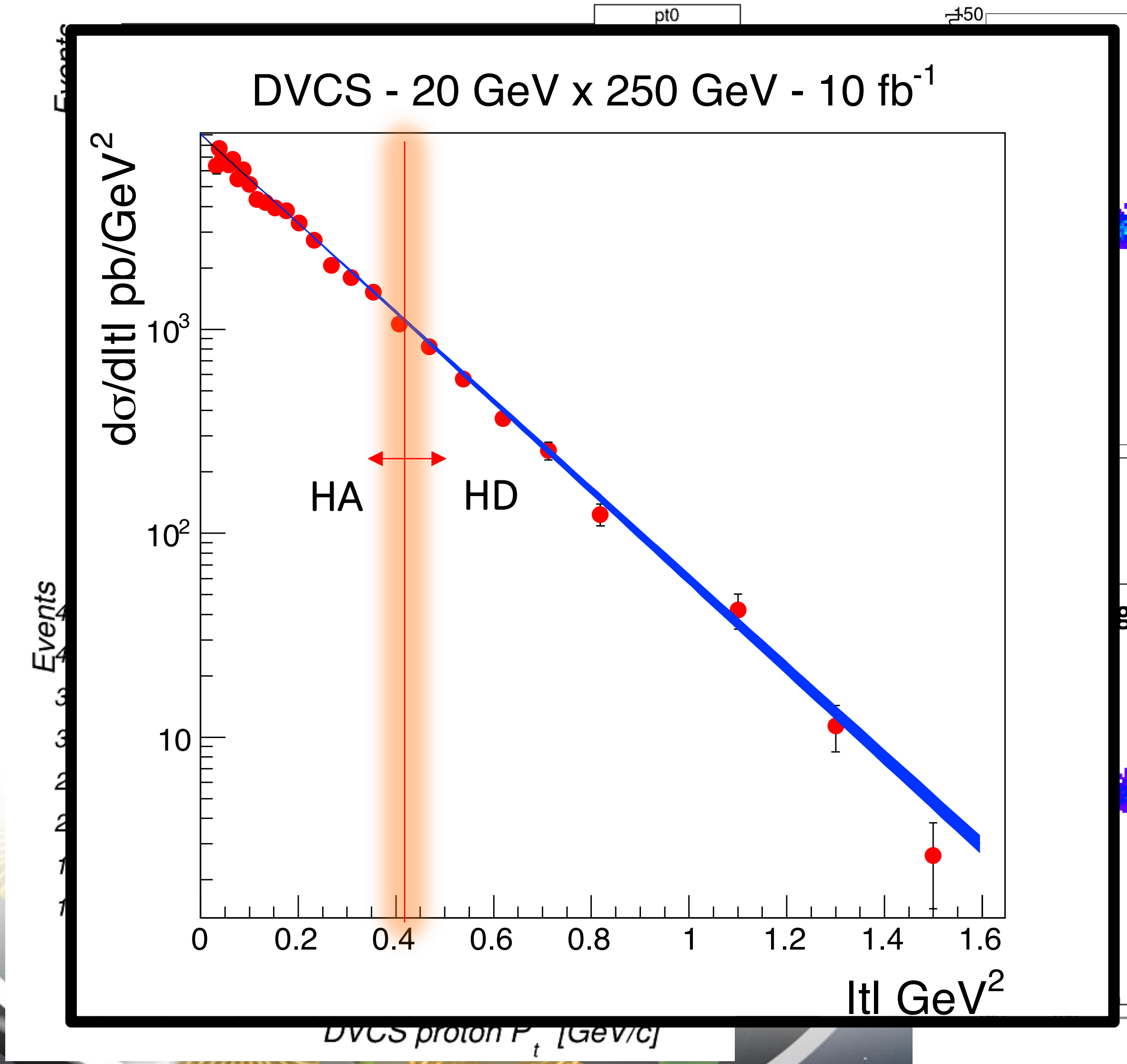
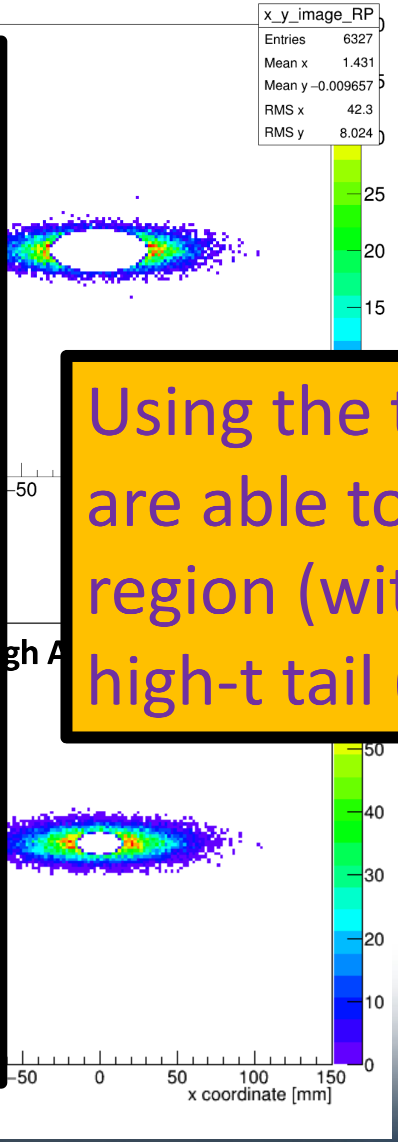
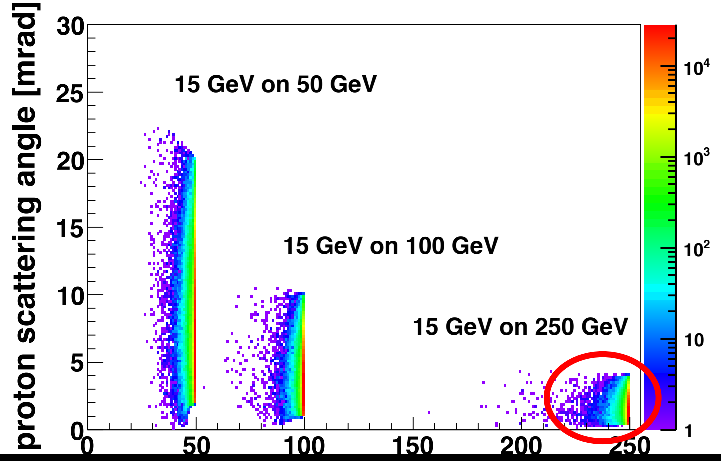


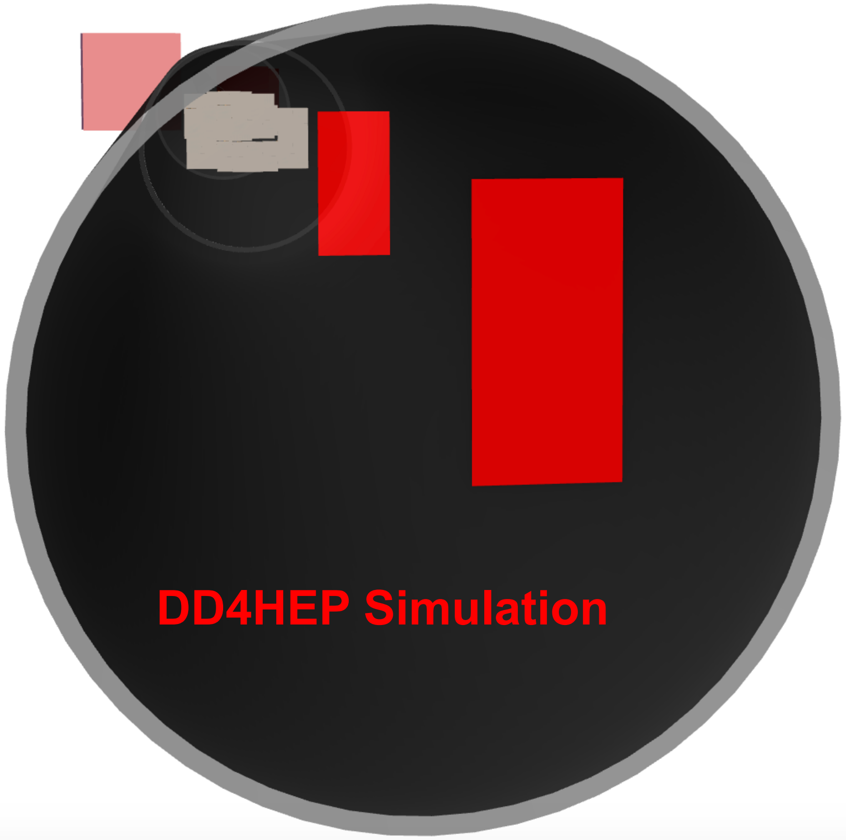




Using the two configurations, we are able to measure the low-t region (with better acceptance) and high-t tail (with higher luminosity).

High Acceptance: larger β^* at IP, smaller $\beta(z=30m)$ -> lower lumi., smaller beam at RP

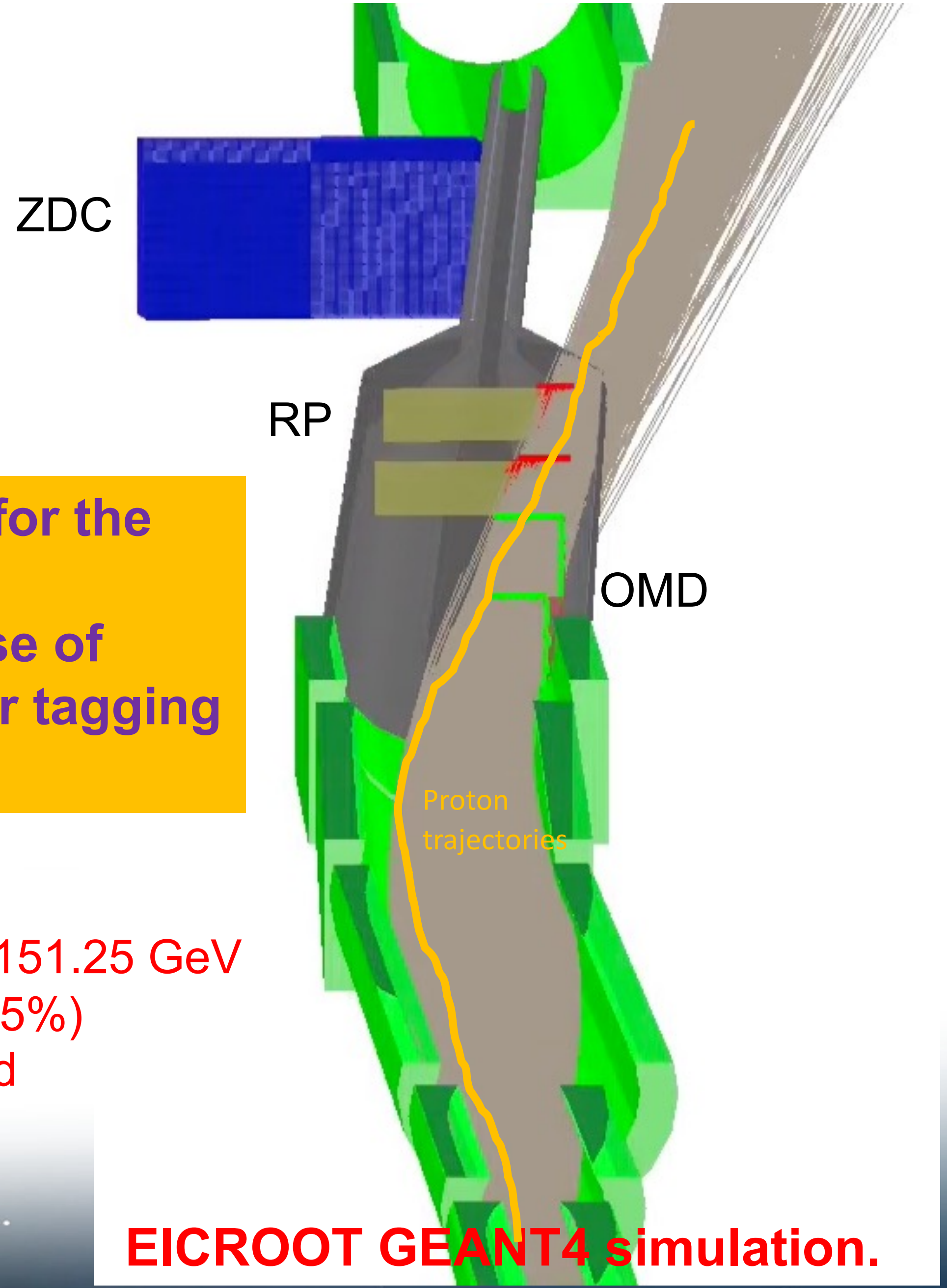
Off-Momentum Detectors



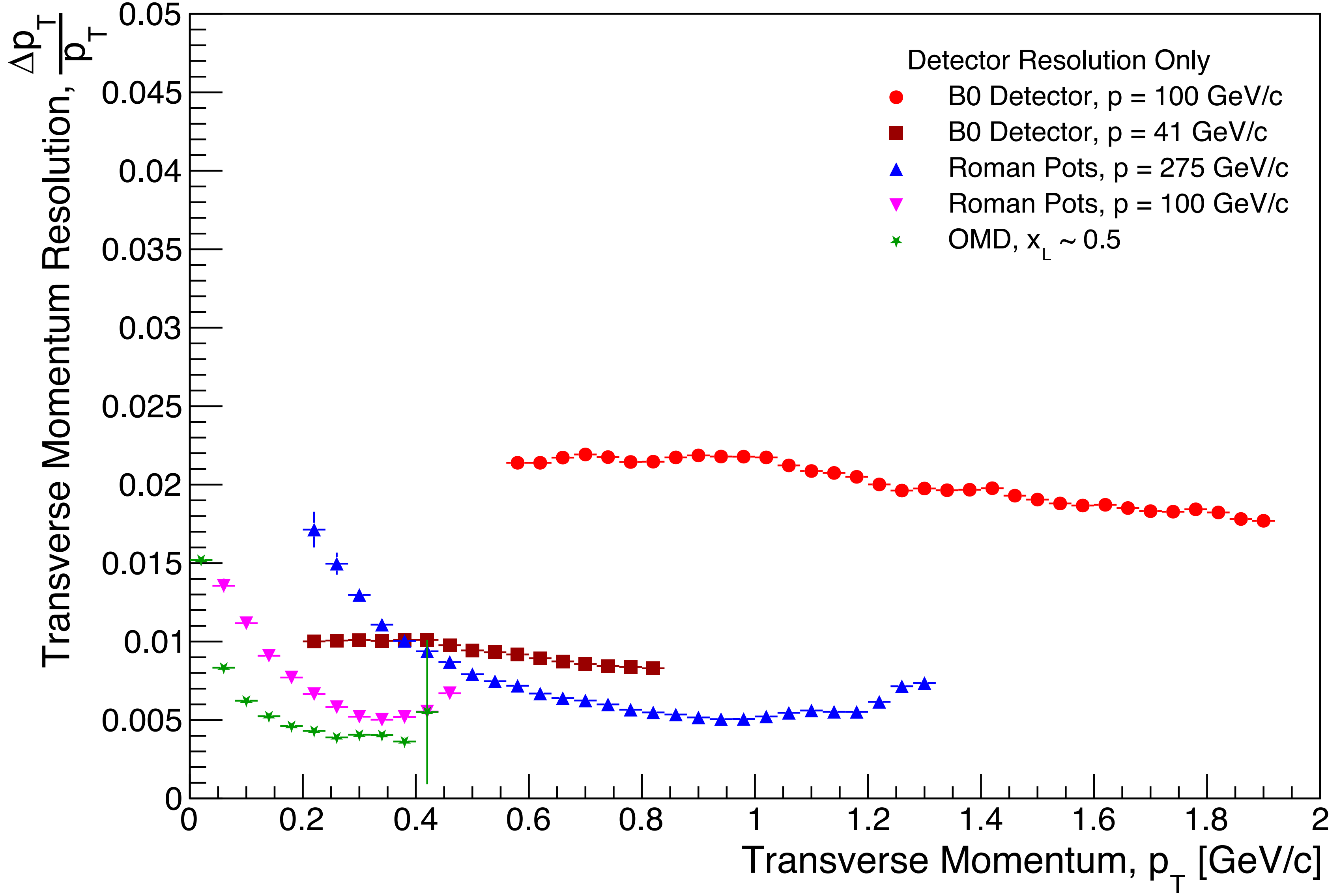
Off-momentum detectors implemented as horizontal "Roman Pots" style sensors.

- **Same technology as for the Roman Pots.**
- **Need to also study use of OMD on other side for tagging negative pions.**

Protons
123.75 < E < 151.25 GeV
(45% < xL < 55%)
0 < θ < 5 mrad

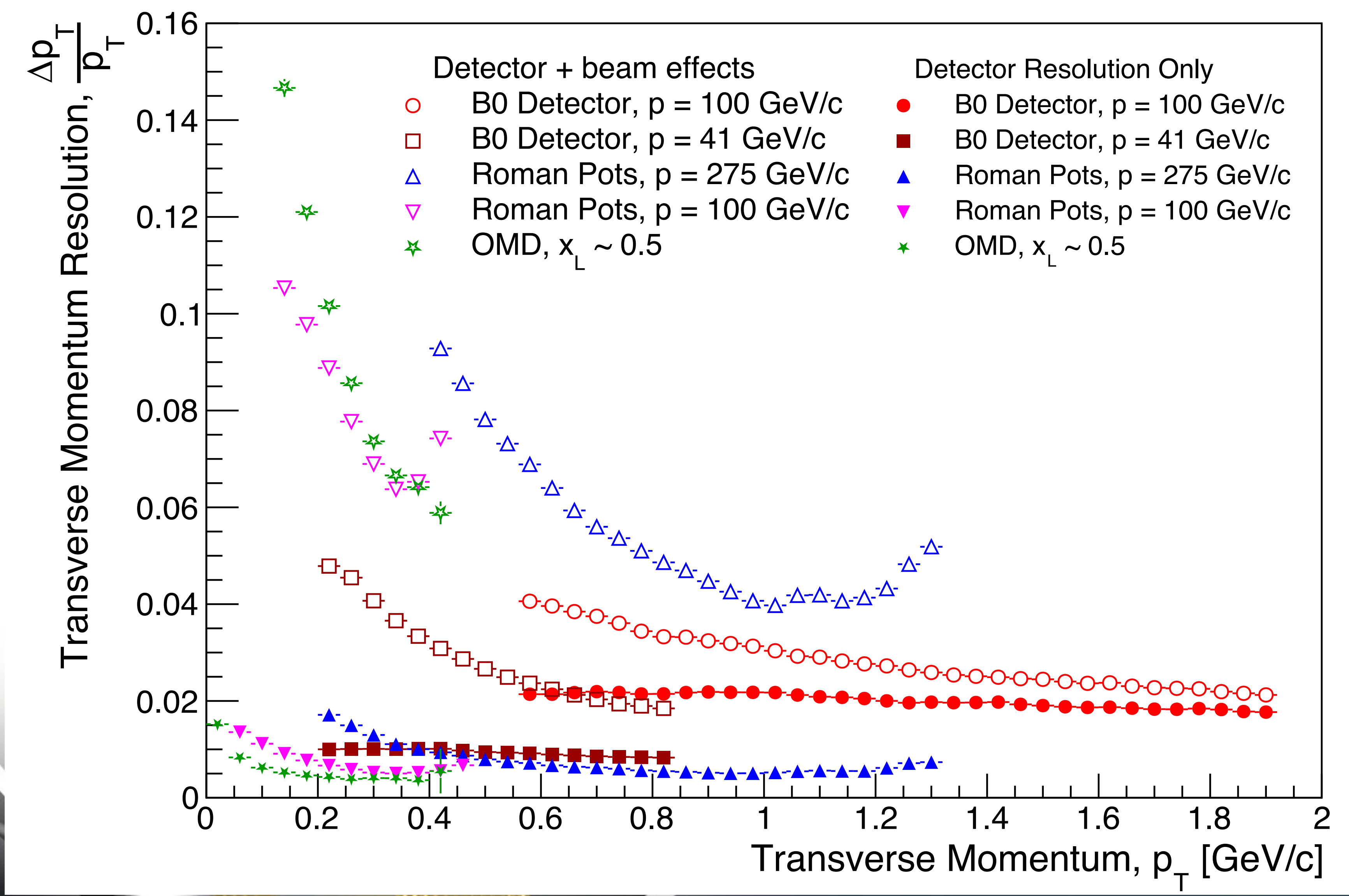


Summary of Detector Performance (Trackers)



- Includes realistic considerations for pixel sizes and materials
  - More work needed on support structure and associated impacts.
- Roman Pots and Off-Momentum detectors suffer from additional smearing due to improper transfer matrix reconstruction.
  - This problem is close to being solved!

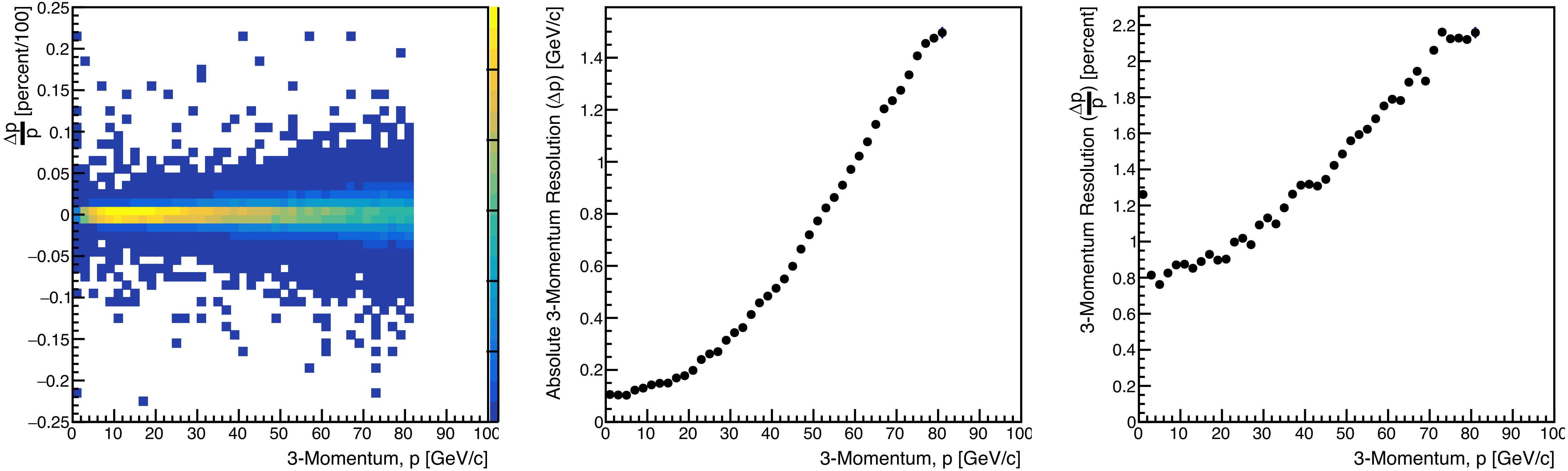
Summary of Detector Performance (Trackers)



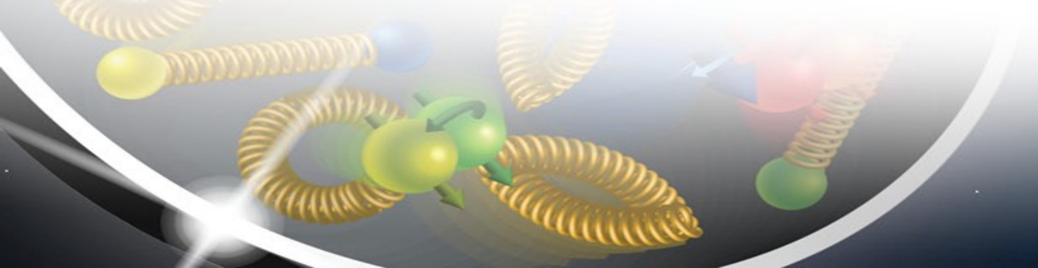
- All beam effects included!
  - Angular divergence.
  - Crossing angle.
  - Crab rotation/vertex smearing.

Beam effects the dominant source of momentum smearing!

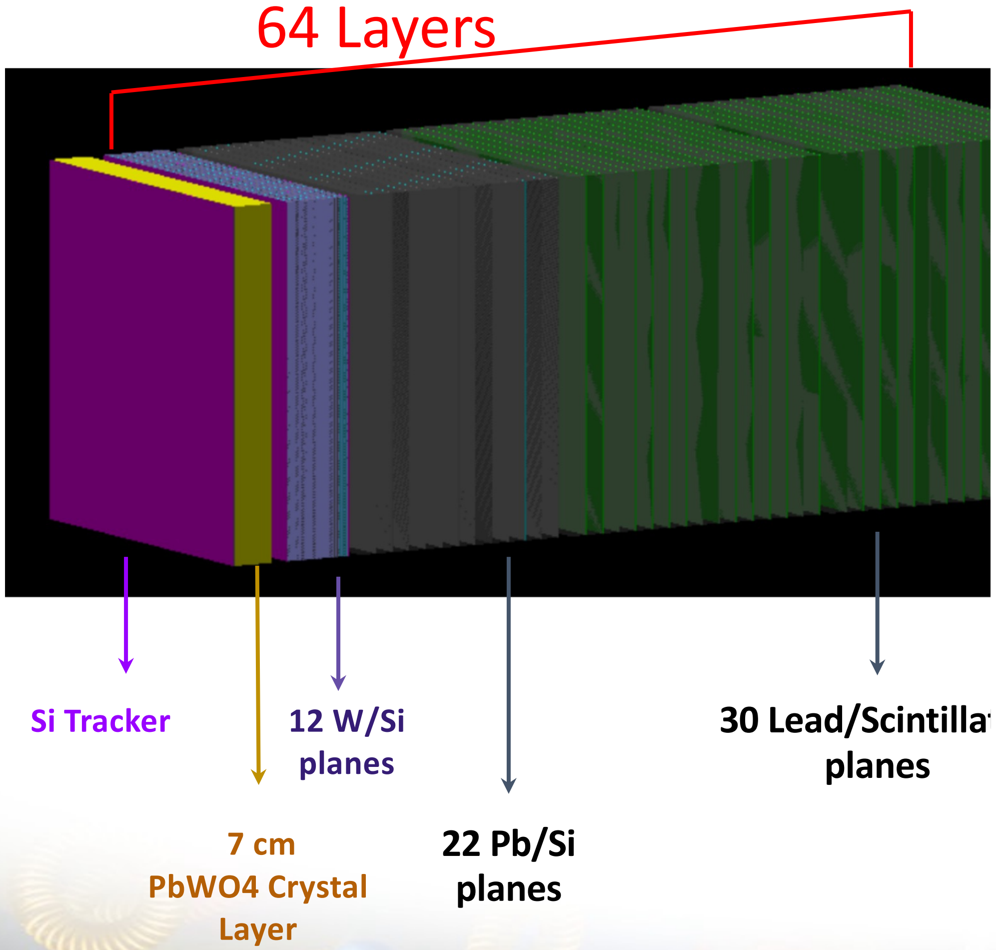
3-Momentum Resolution (B0 tracker)

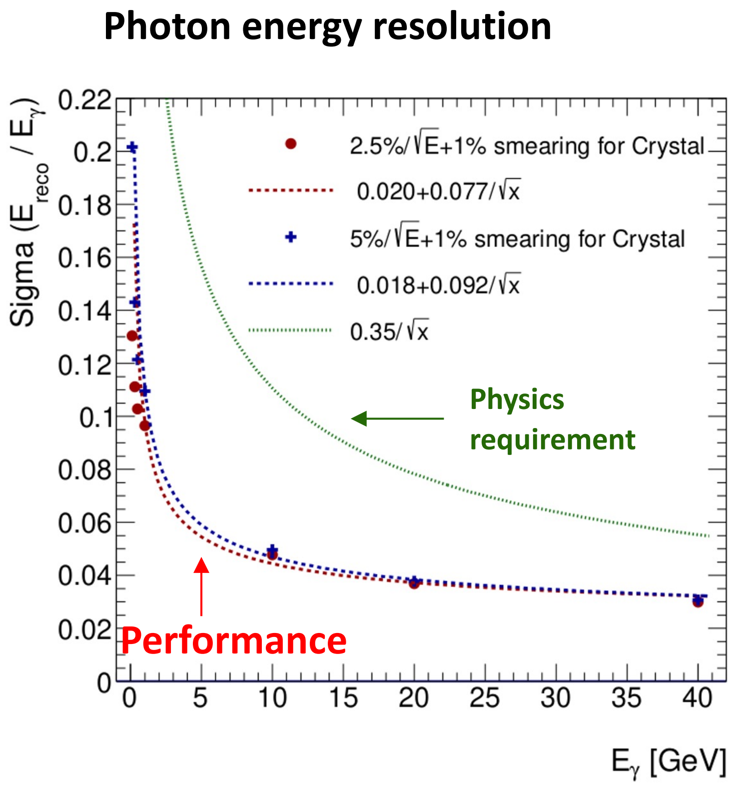


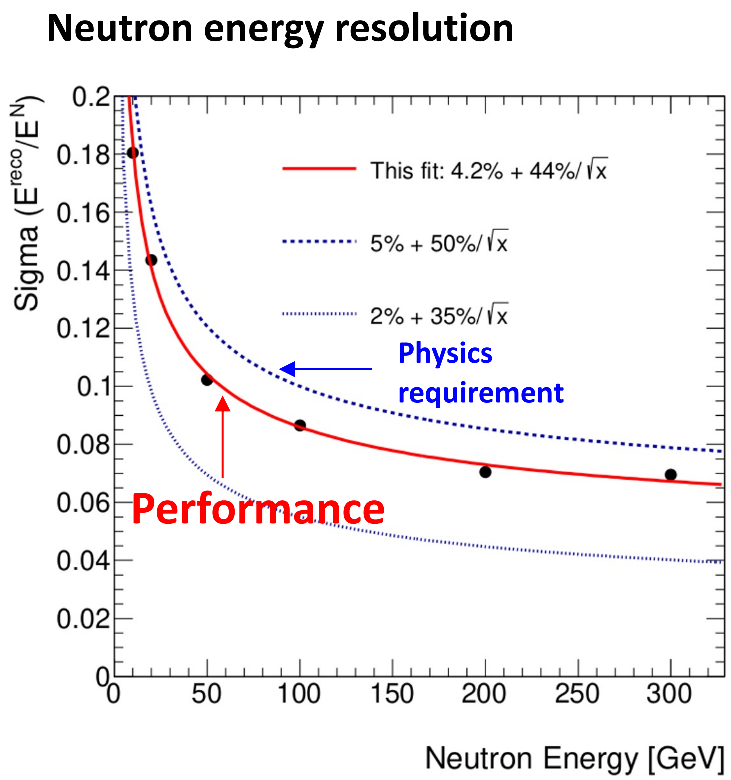
- Similar results for the RP and OMD.
  - Mostly dominated by transfer matrix inaccuracy.



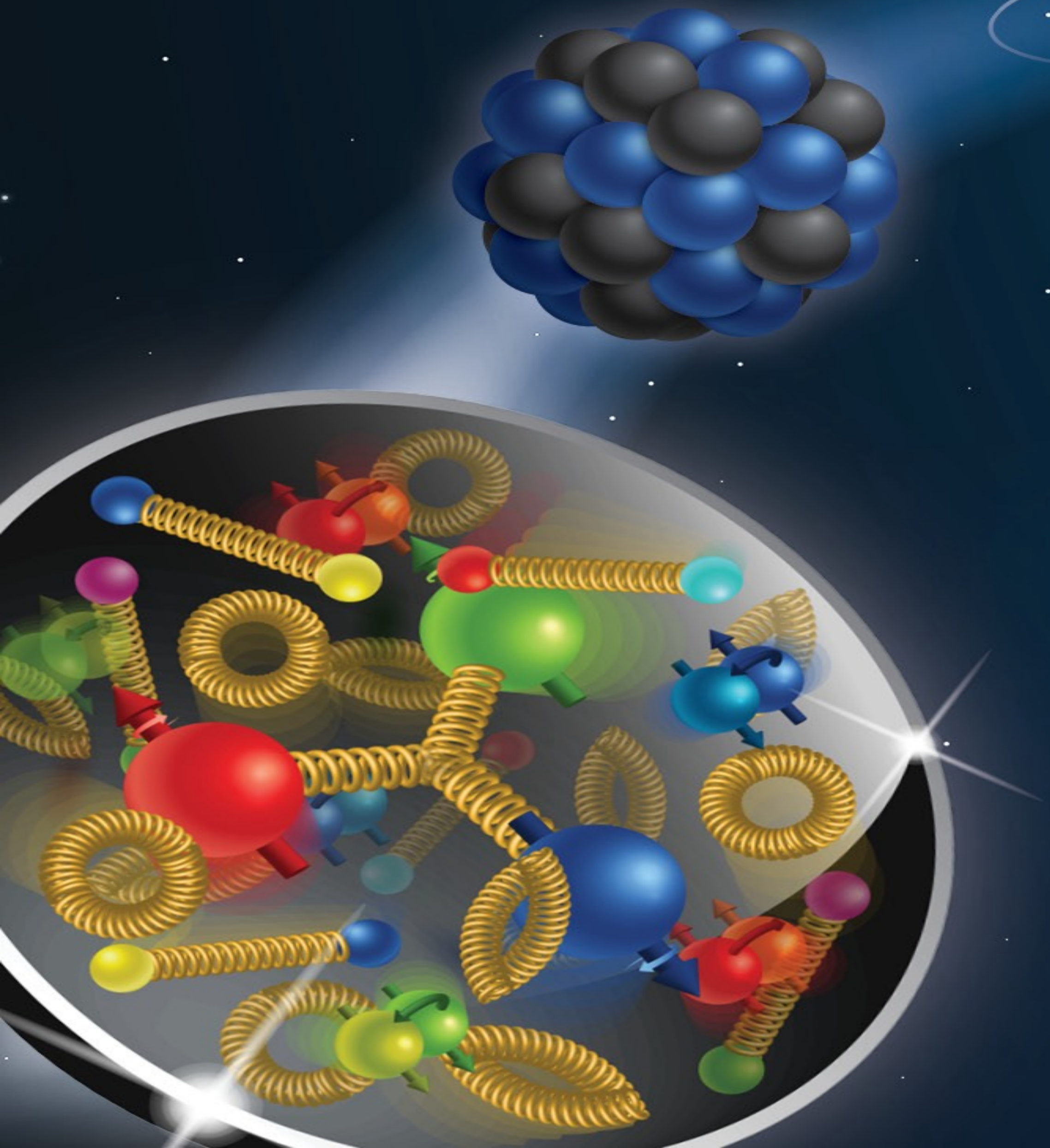
Zero-Degree Calorimeter







Credit to Shima Shimizu (Kobe U. , Japan)

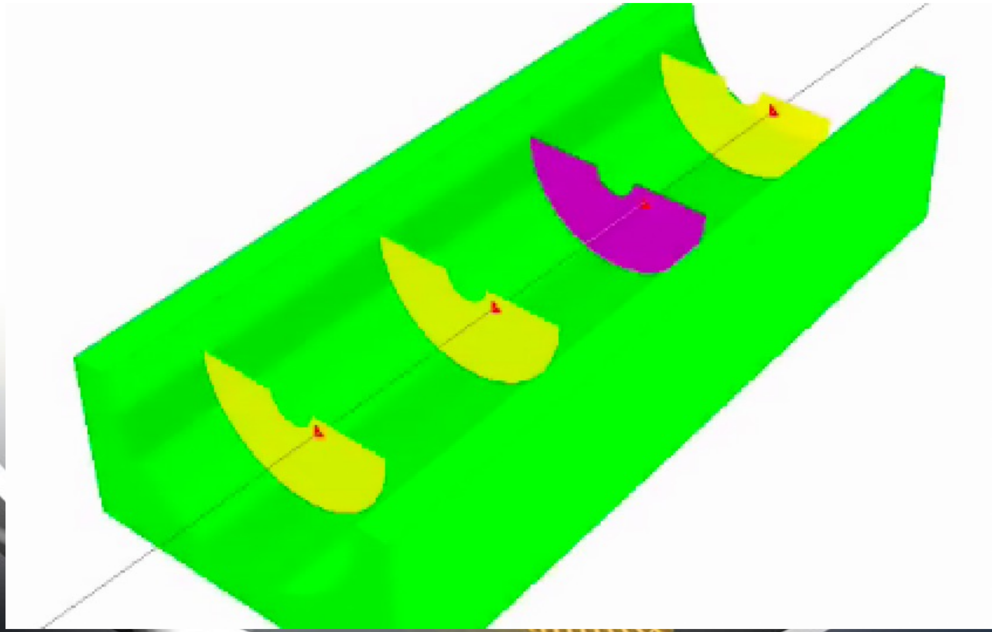


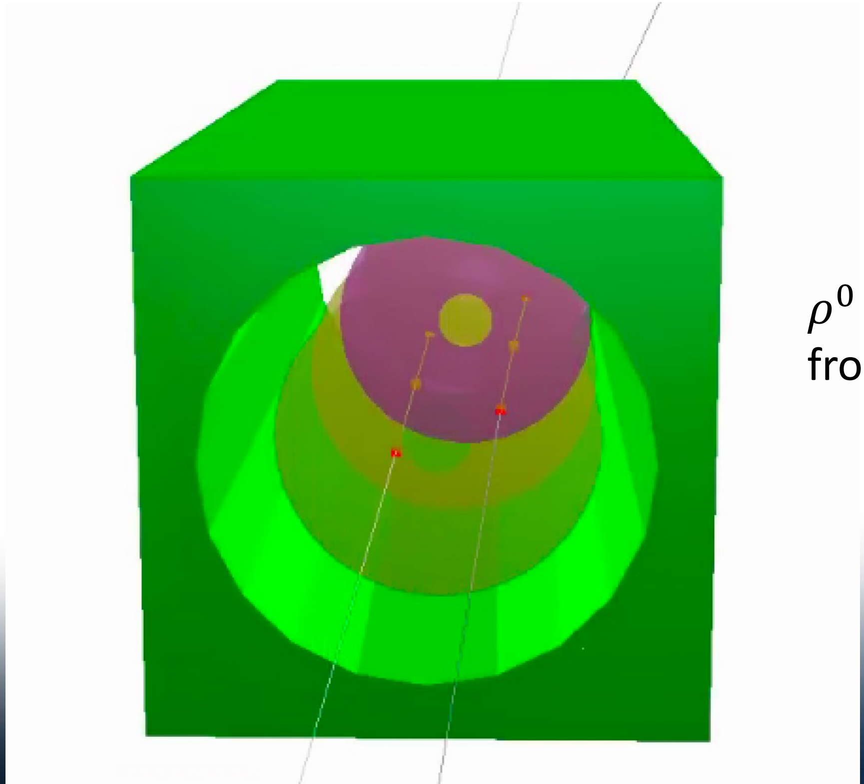
What can we do with meson and baryon decays in the FF region?

The importance of the B0 for the meson program

- Needed for measuring final states with θ > 5.5 mrad.
  - Especially important at medium and low hadron beam energies at the EIC.
- Important for incoherent vetoing in e+A (heavy nuclear) collisions.
  - Charged particles and photons.
- The B0 tracking system behaves like a normal spectrometer, so anything which decays with particles in its acceptance can be reconstructed just like in the forward tracking disks!

GEANT simulation: 100 GeV proton





$\rho^0 \rightarrow \pi^+\pi^-$ decay
from u-channel production

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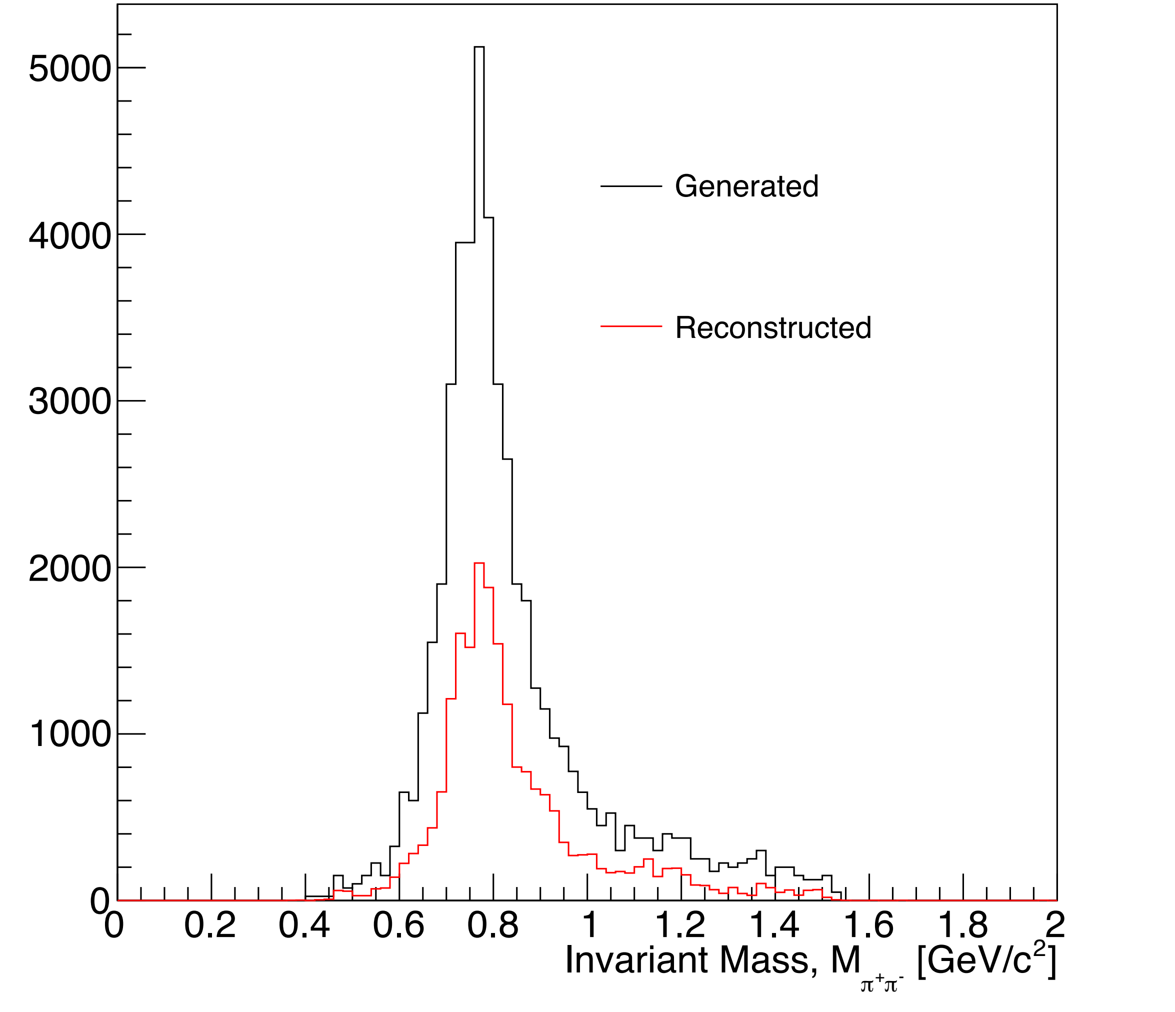
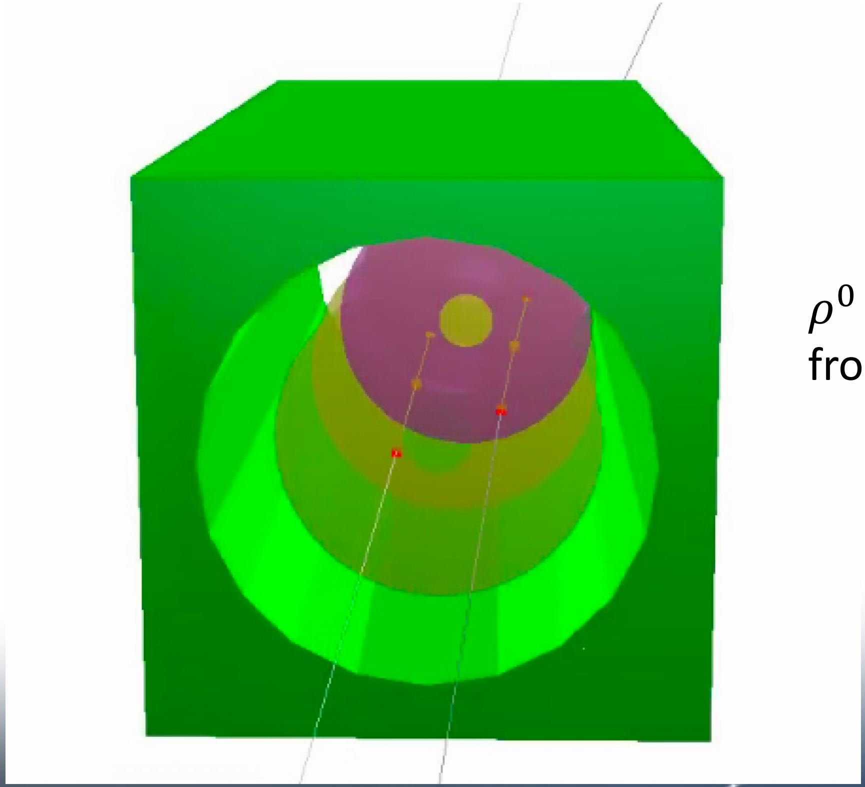


- $\rho^0 \rightarrow \pi^+\pi^-$ decay studied with eSTARLight 5x41 events (generated by Zach Sweger).
- Reconstruction performed with EicRoot.



$\rho^0 \rightarrow \pi^+\pi^-$ decay
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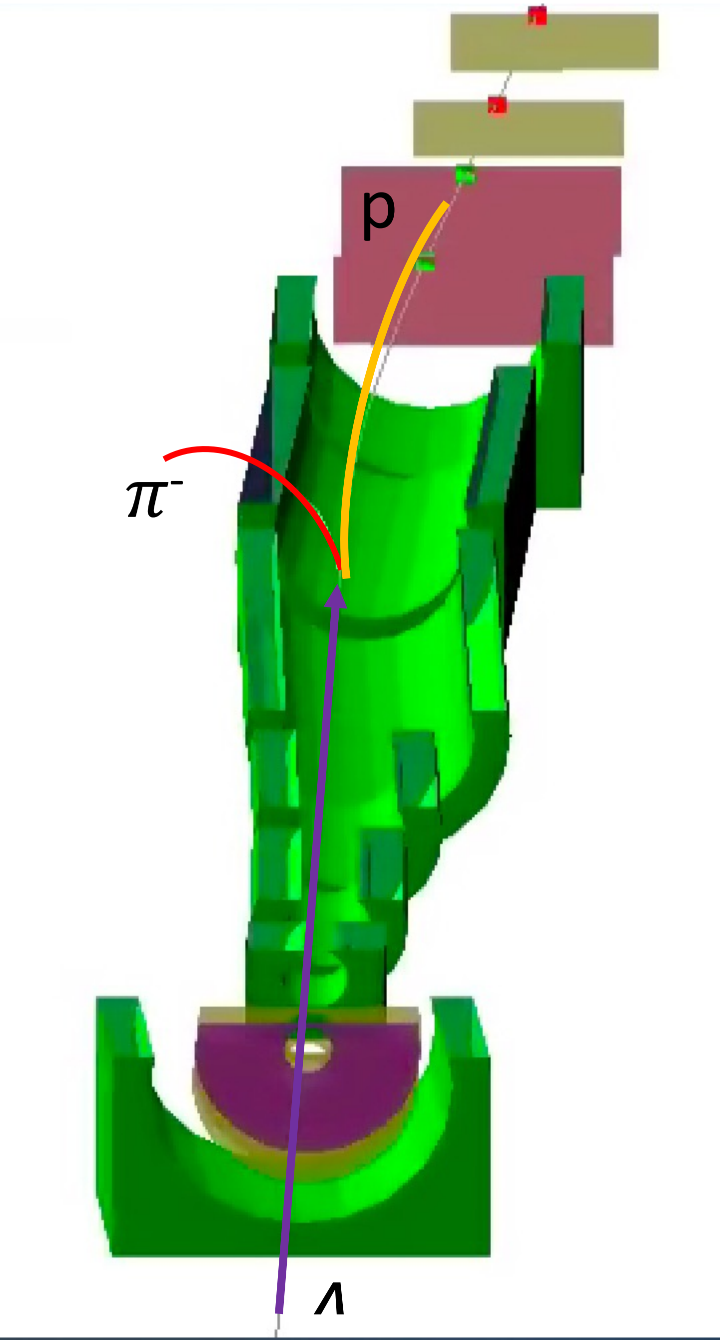
Lambda Decay (p + π^-)

- Boost causes the lambda to be able to decay 10s of meters from the IP.
  - Significant problem since reconstruction of this displaced secondary vertex within the hadron magnets is very challenging.



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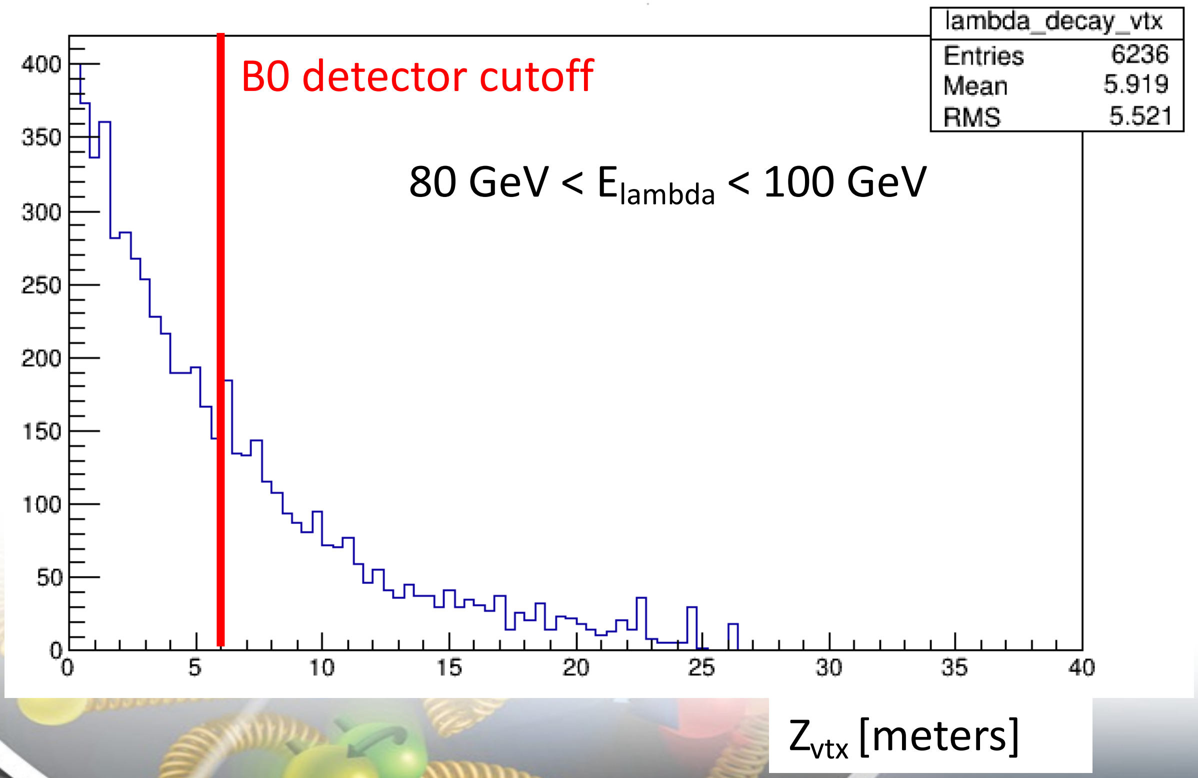

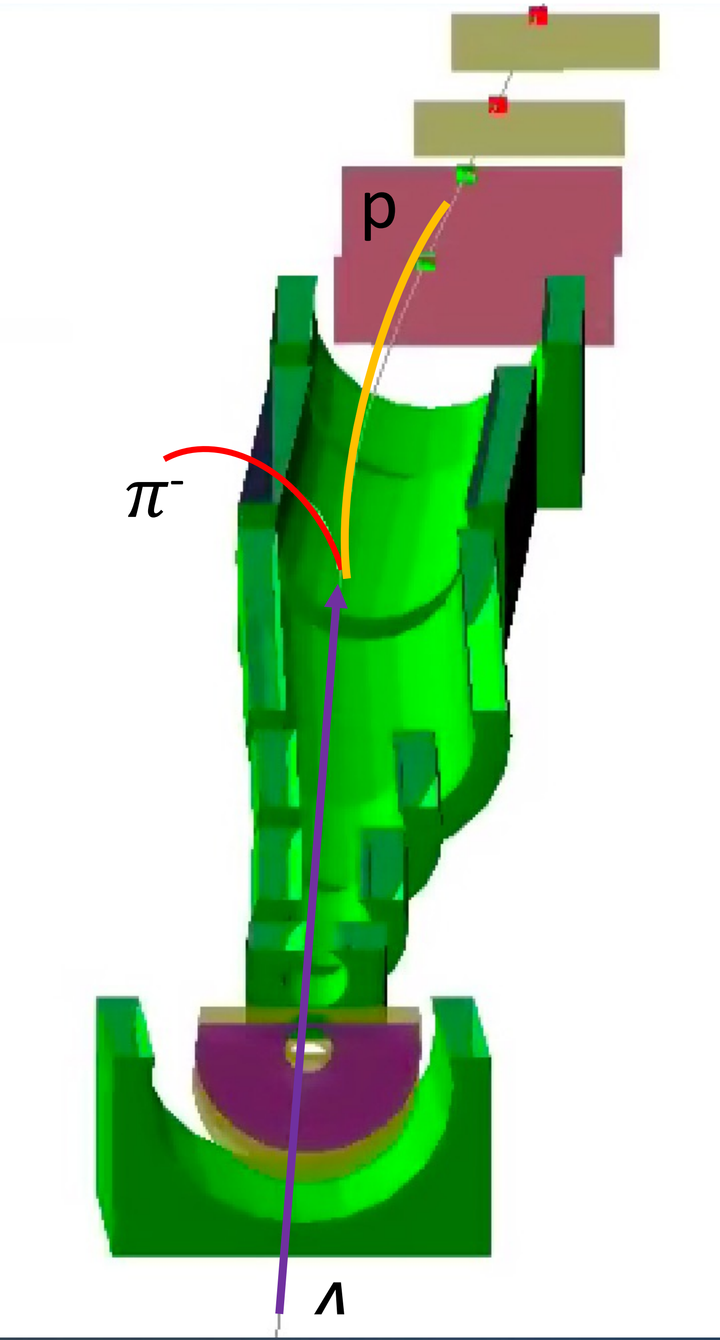

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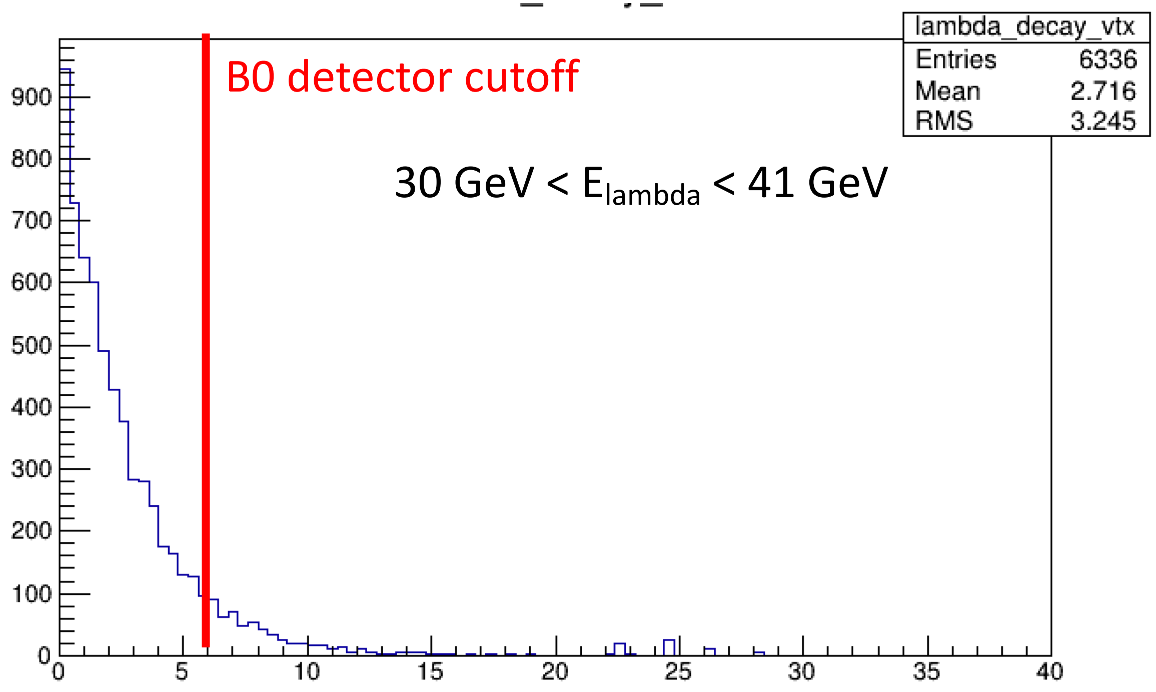
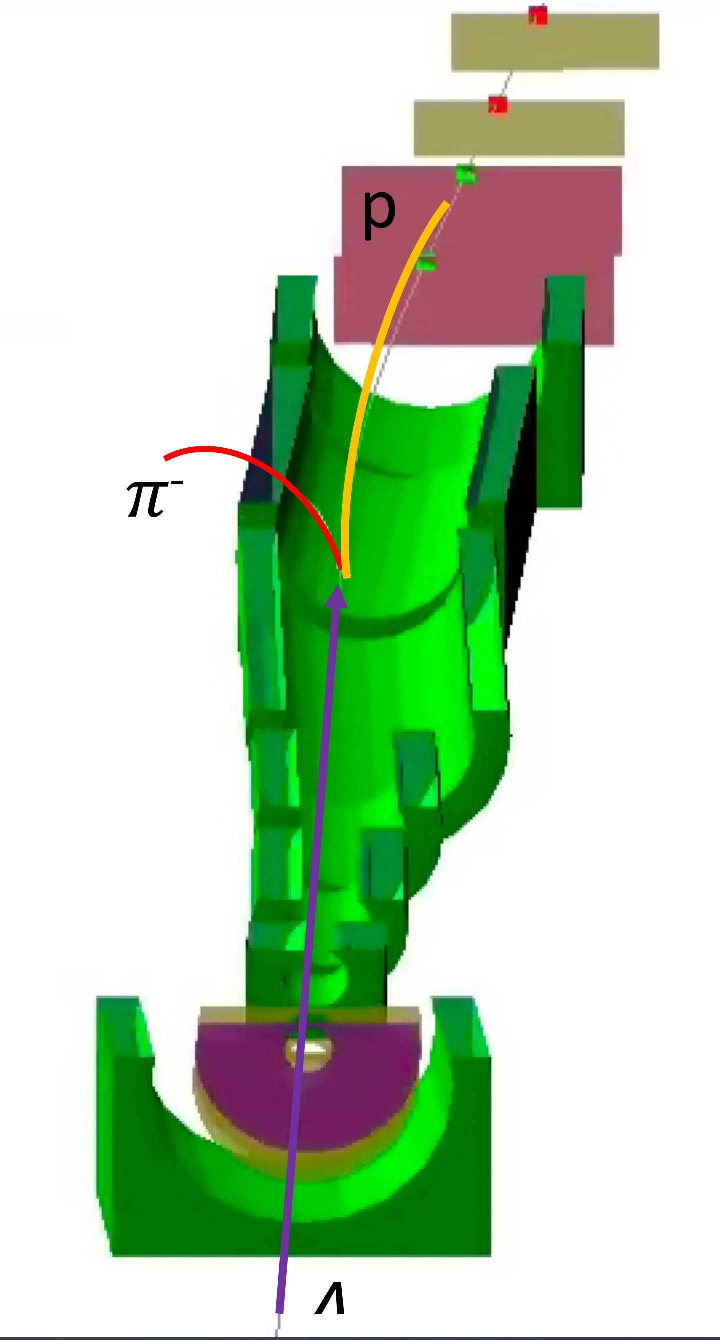


Lower beam energies help for the charged particle final state.



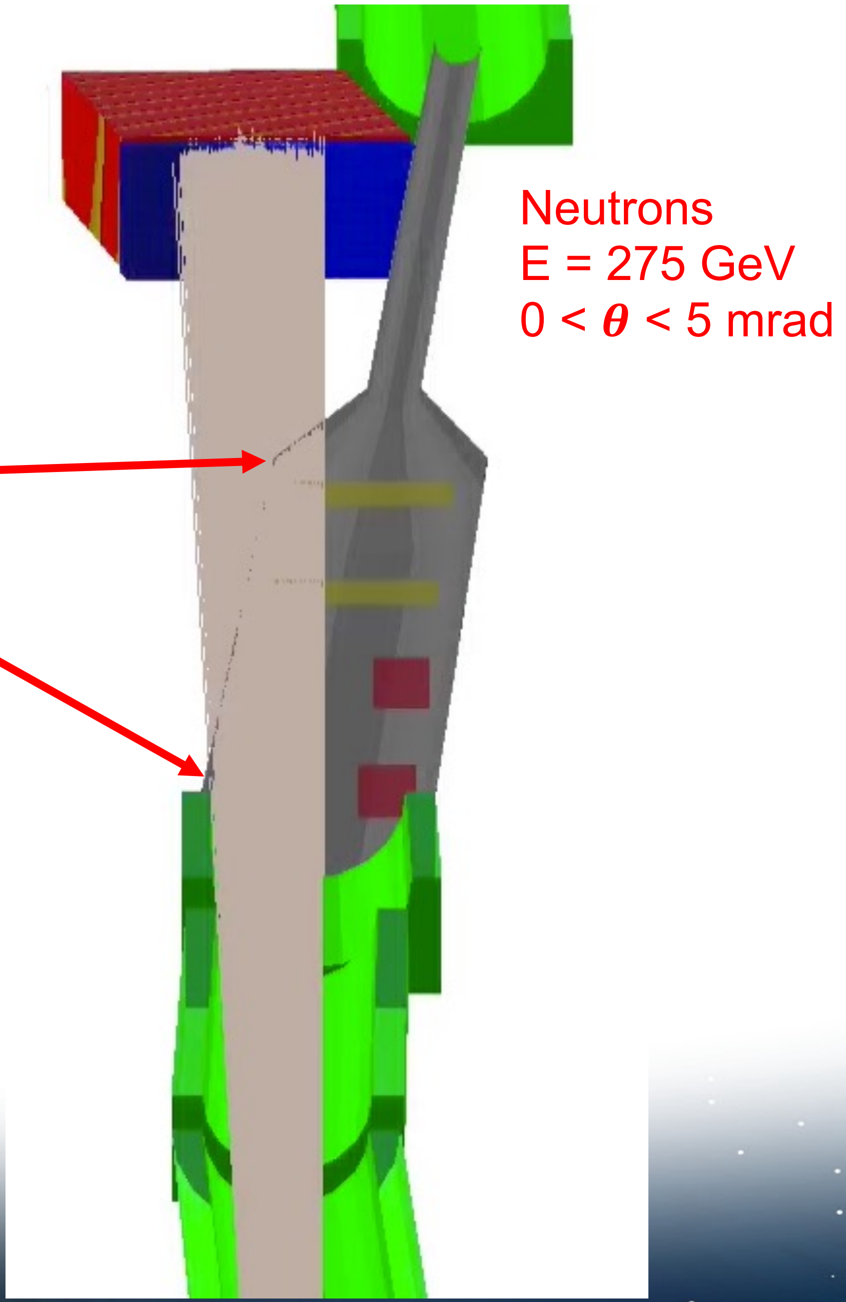
ZDC & neutral particle exit

Want to have as large an incident angle with the beam pipe as possible.

This is the problem area → shallow incident angle can increase effective material thickness by ~ factor of 10!!

This will reduce our detection efficiency beyond just the aperture limit!

- More detailed study needed as updated design becomes available.



Summary and Takeaways

- All FF detector acceptances and detector performance well-understood with currently available information.
  - **Numerous impact studies done!**
    - Yellow Report, Detector proposals, and stand-alone studies.
  - **Ideal technology choices identified, along with suitable alternate designs for risk mitigation.**

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- The NAS physics can be delivered by the FF detectors -> what else can we do with these other very important channels?
  - **How does this influence the development of IP8?**

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Email me or any other FF convener if you have any questions!

Want to get involved?? Join our meetings and learn how!

Meeting time: Tuesdays @ 9am EDT (bi-weekly, or weekly, as needed)

Indico: https://indico.bnl.gov/category/407/

Wiki: https://wiki.bnl.gov/EPIC/index.php?title=FarForward

Email-list: eic-projdet-FarForw-l@lists.bnl.gov

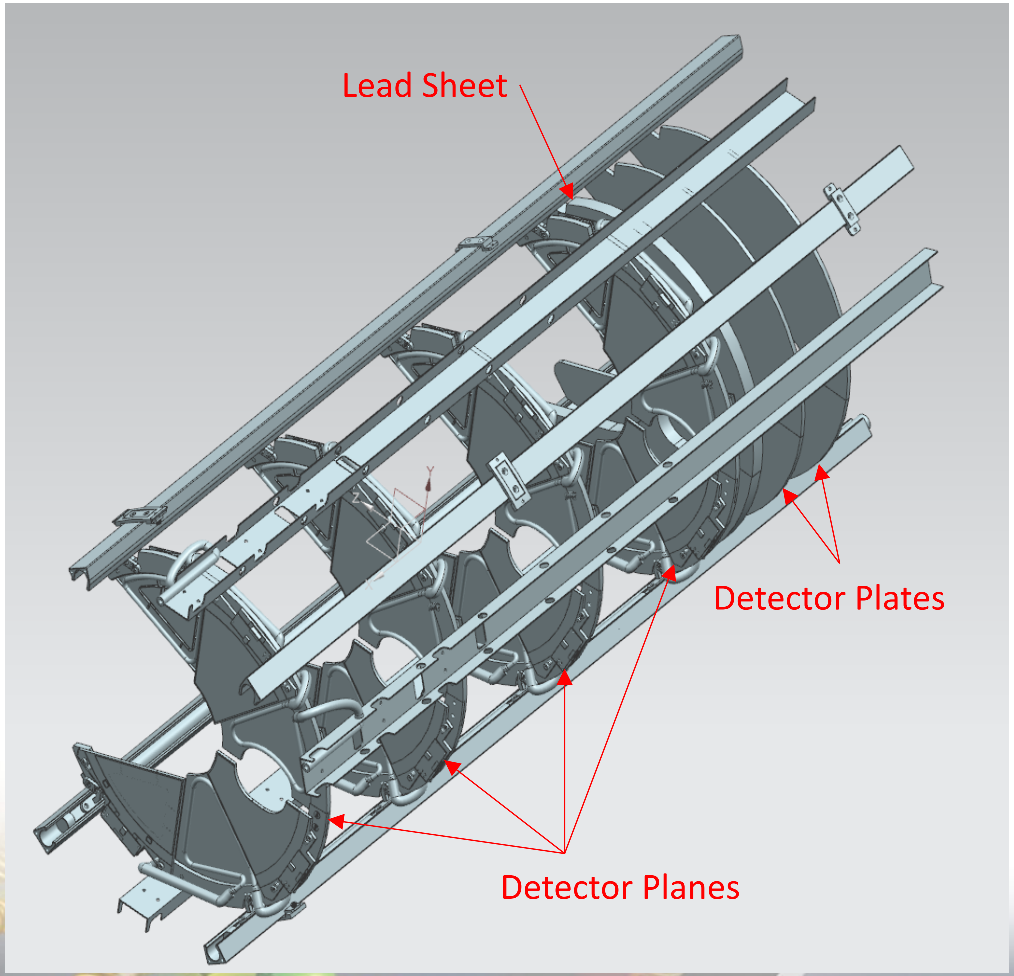
Subscribe to mailing list through: https://lists.bnl.gov/mailman/listinfo/eic-projdet-farforw-l

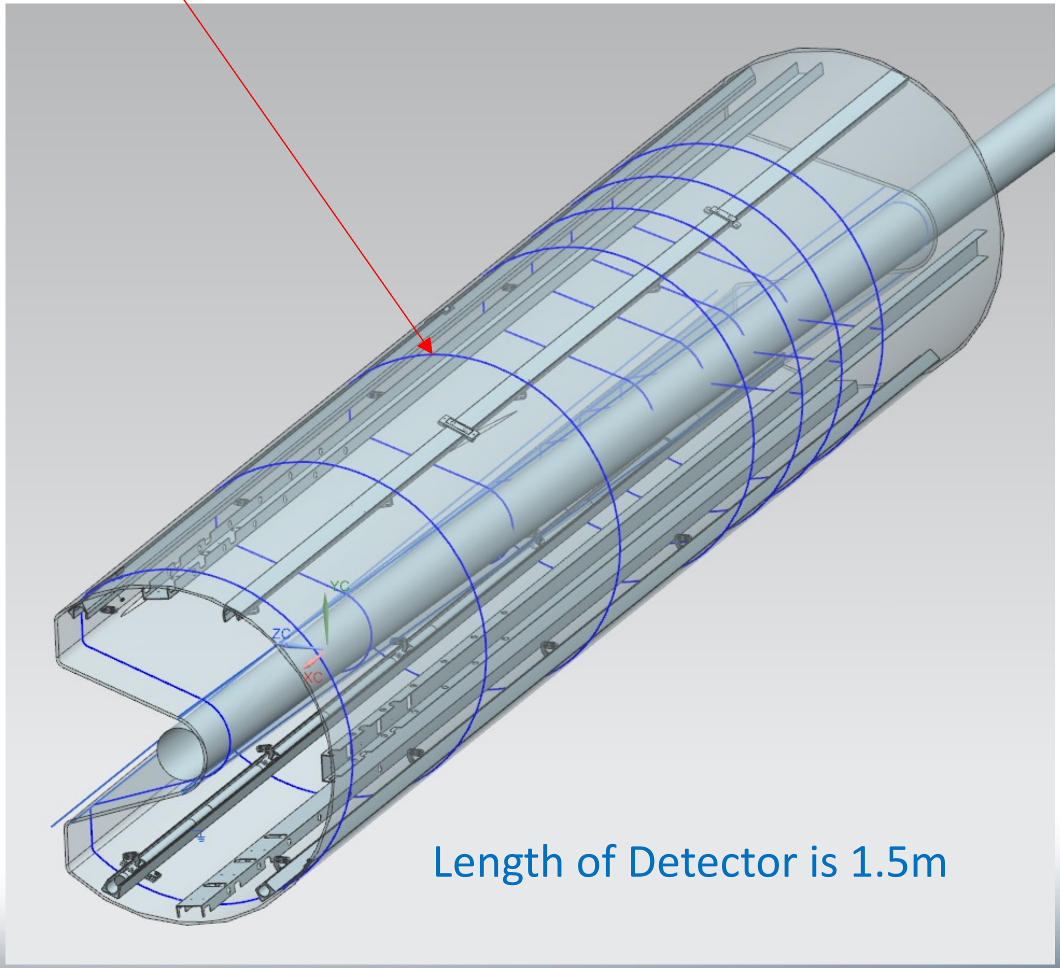
Backup

B0 Detectors in CAD

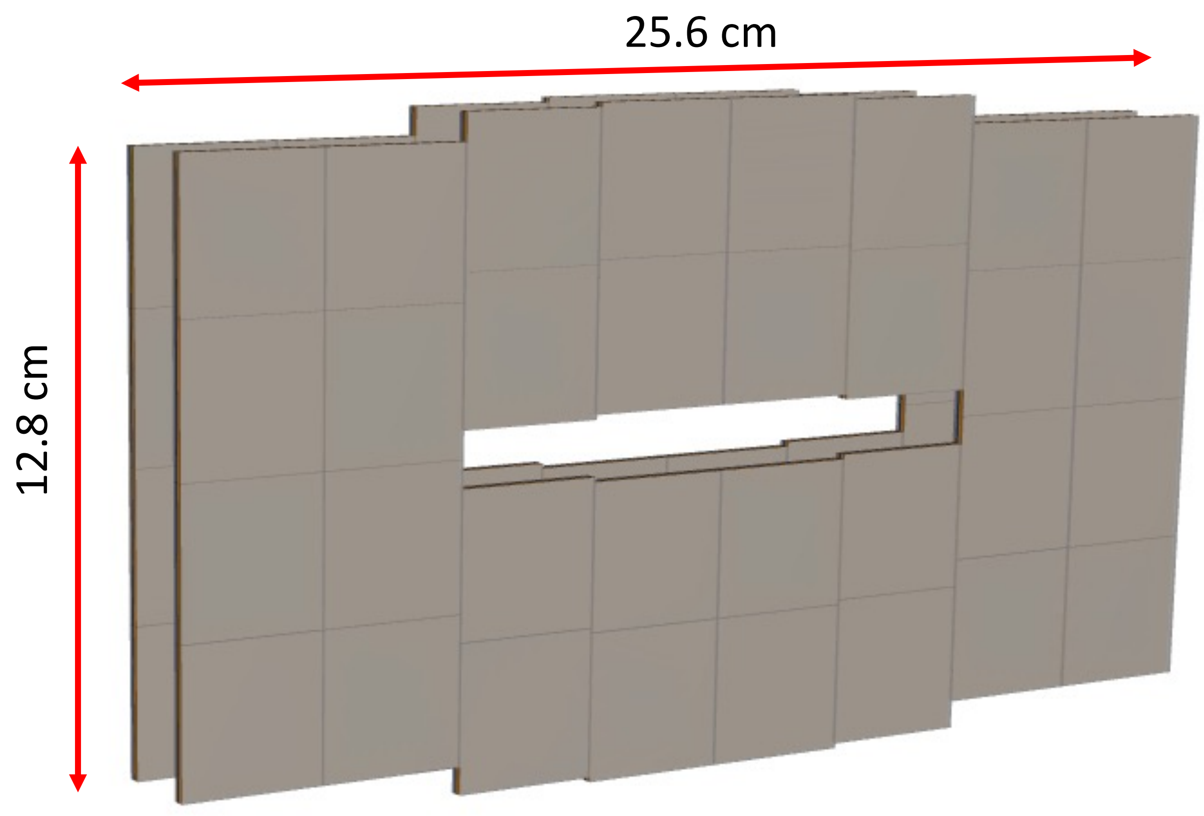
Credit: Ron Lassiter and Karim Hamdi

Blue lines represent where element locations are along beamline





Roman "Pots" @ the EIC



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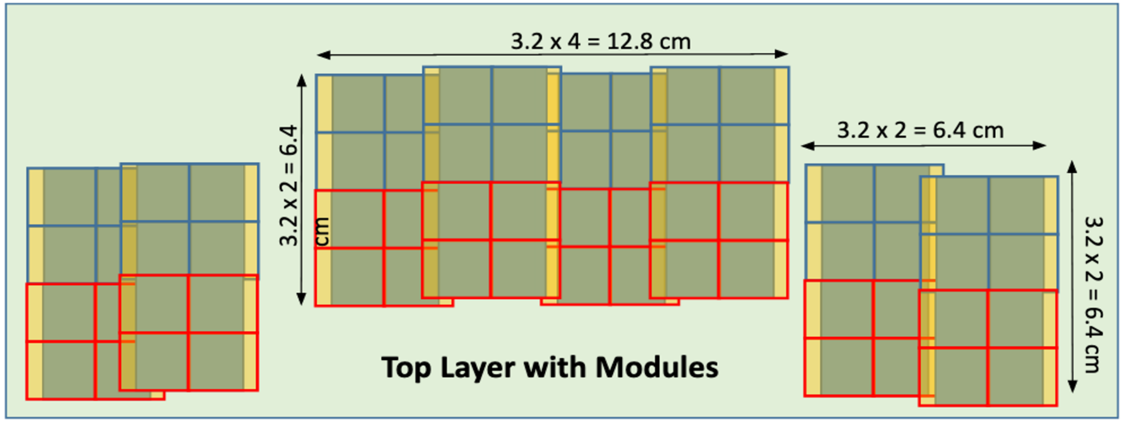


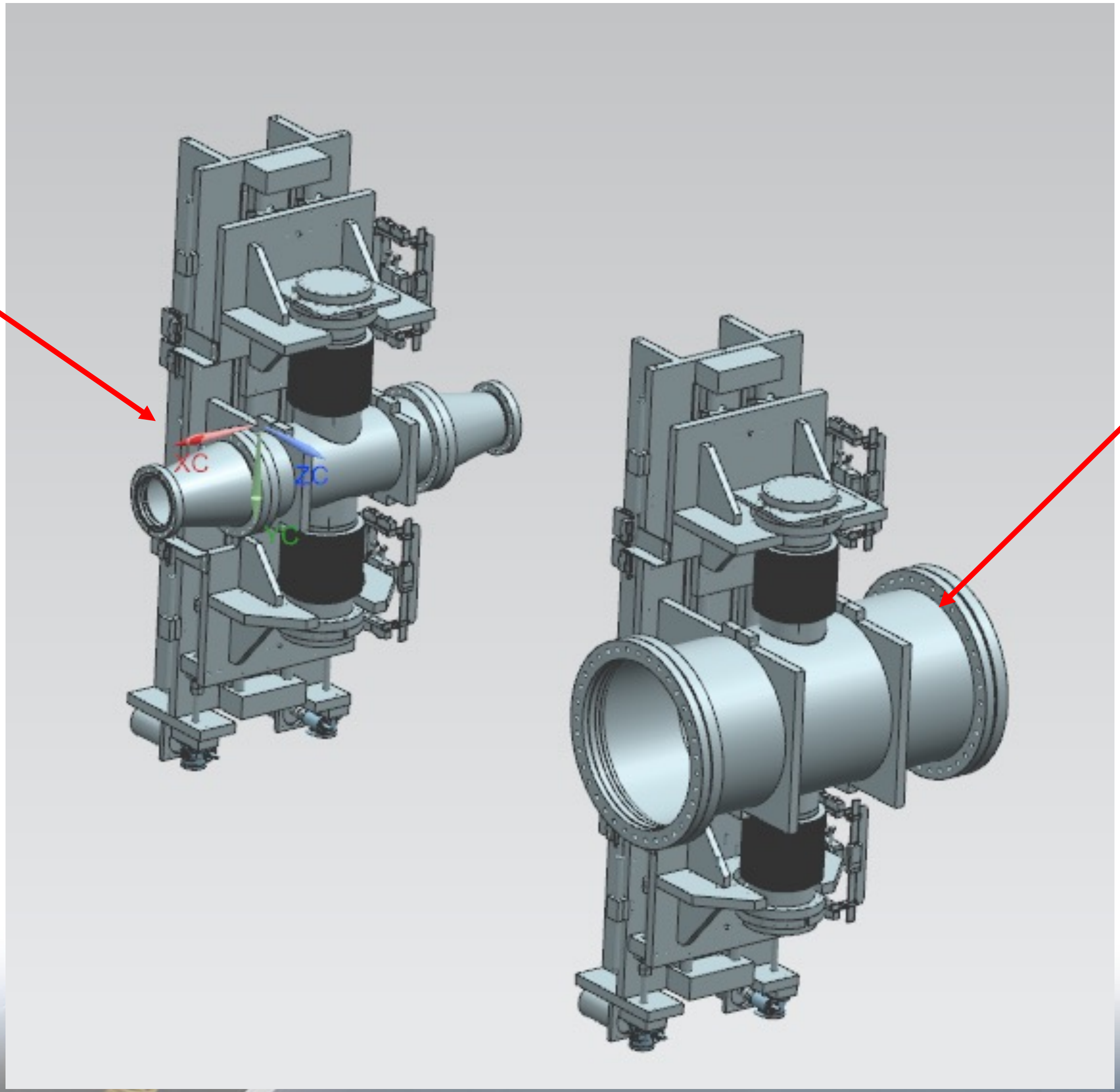
- **Technology**
  - 500um, pixilated AC-LGAD sensor, with 30-40ps timing resolution.
  - "Potless" design concept with thin RF foils surrounding detector components.

More engineering work is currently underway to optimize the layout, support structure, cooling, and movement systems for inserting the detectors into the beamline.

Roman Pots and Off-Momentum Detectors

Credit: Ron Lassiter

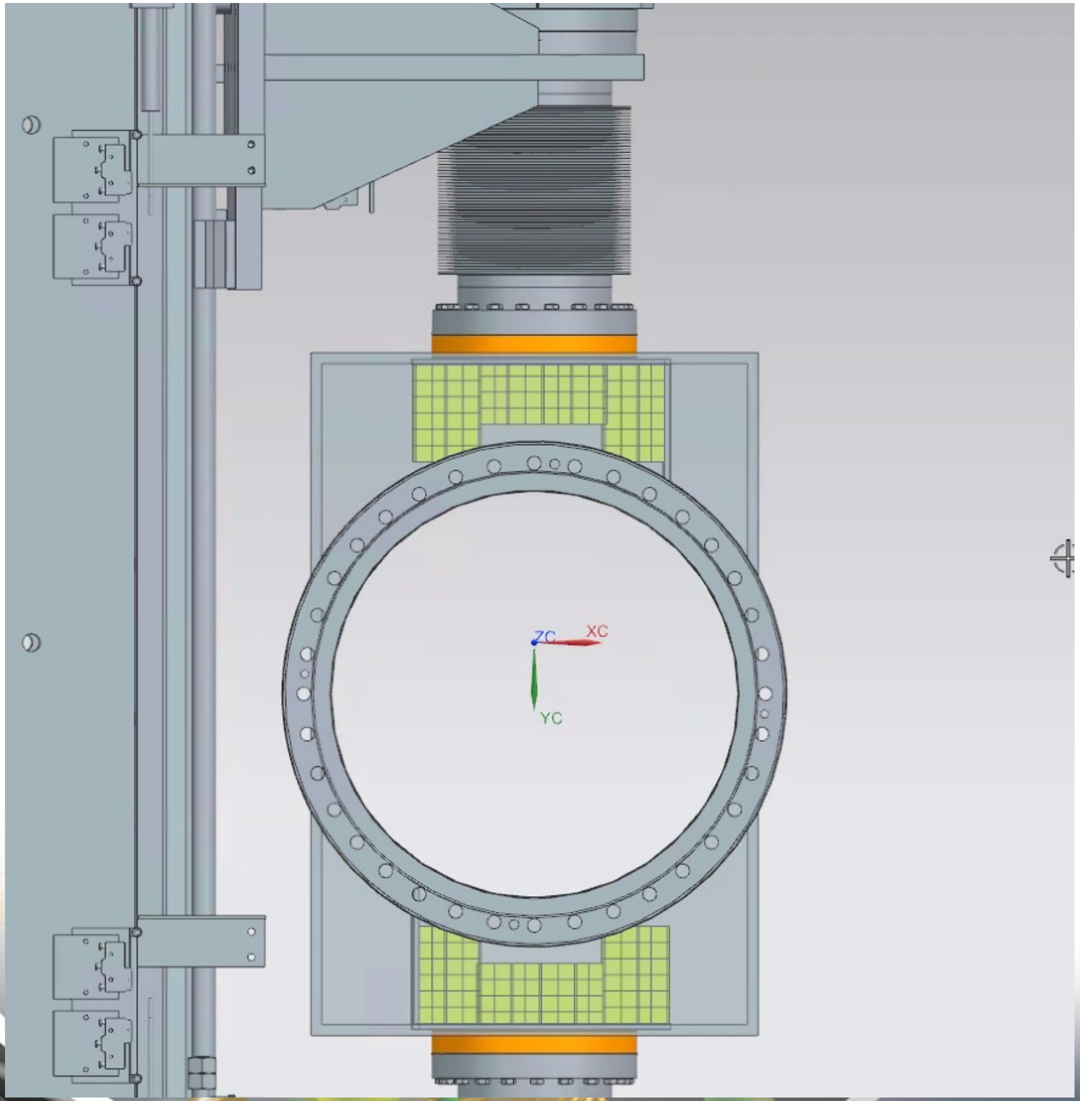
Initial step file
inspired by STAR

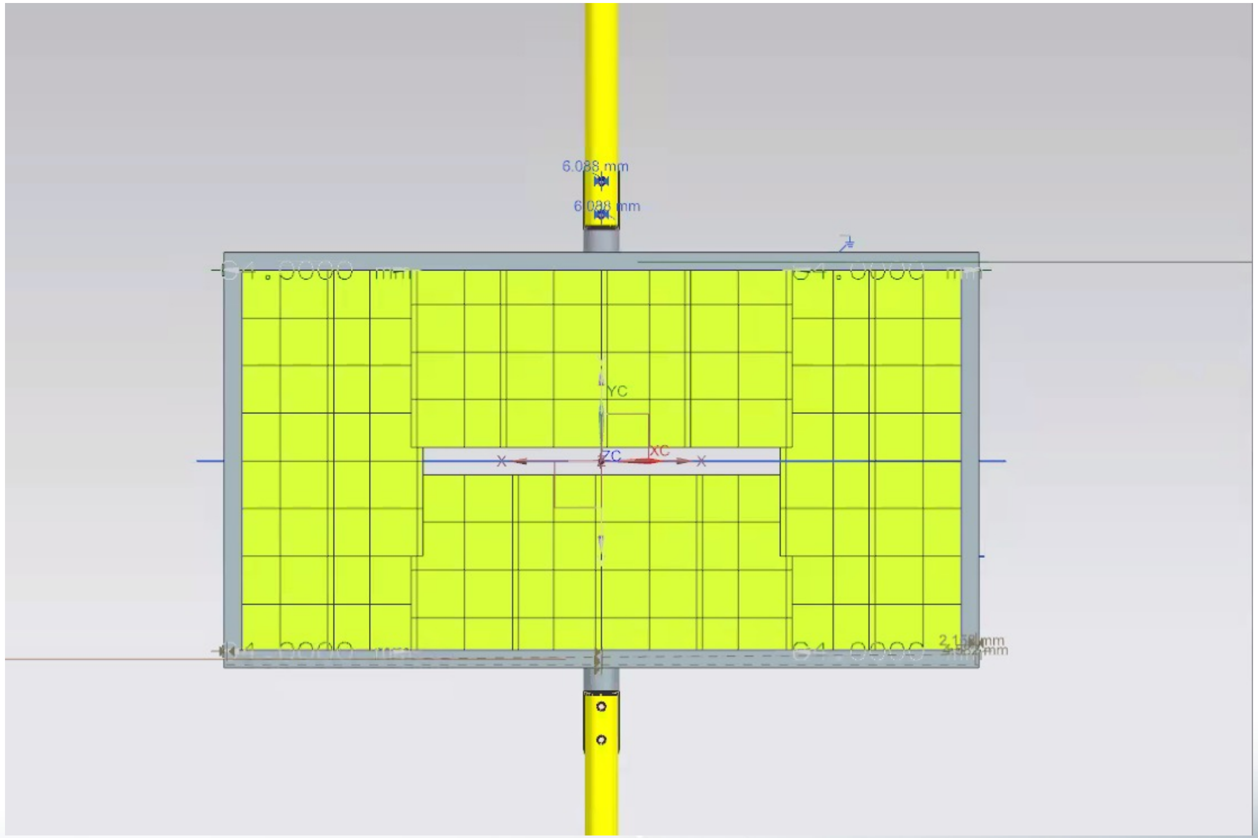


Updated model in NX with
different beamtube size

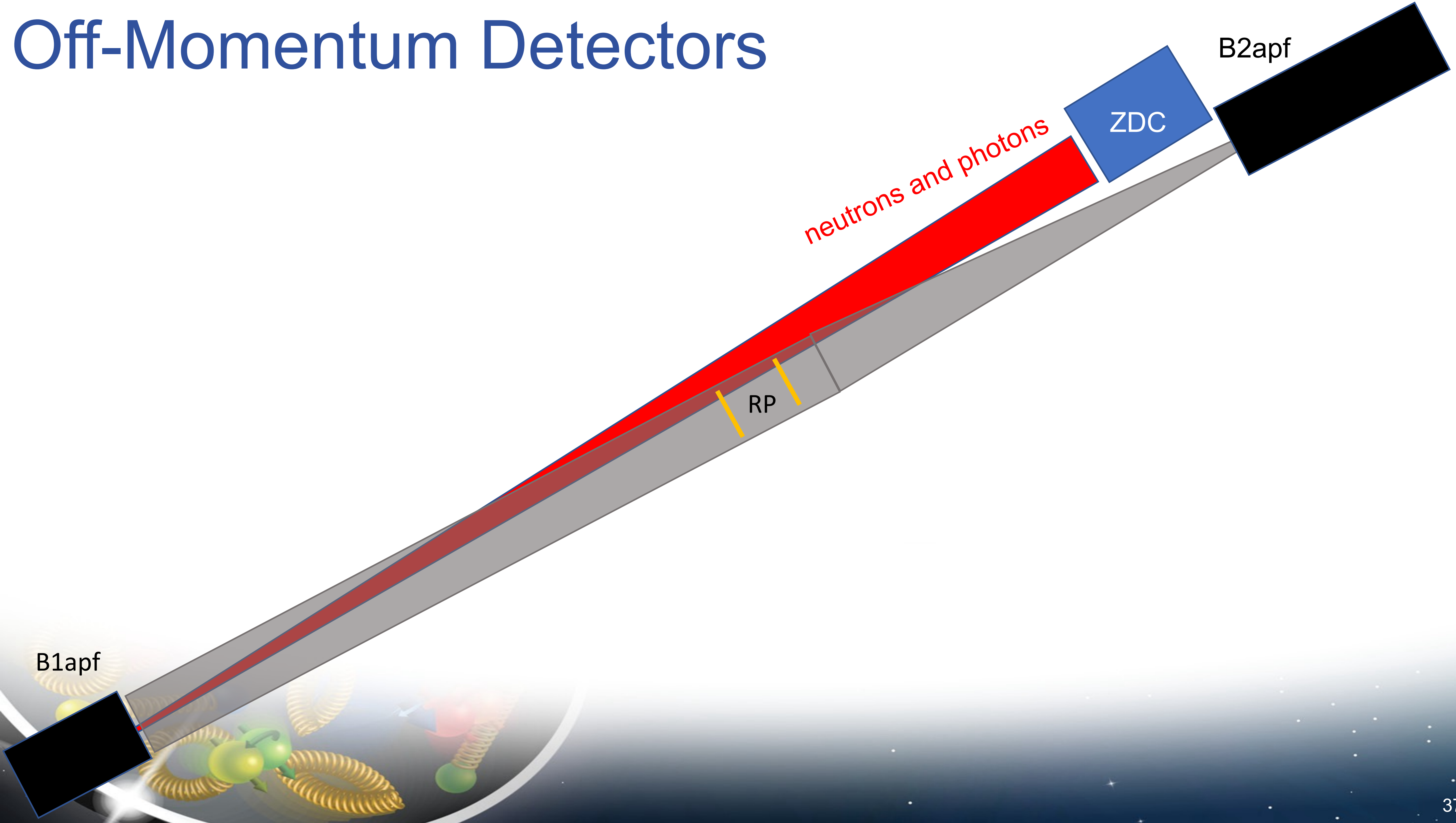
Roman Pots in CAD

Credit: Ron Lassiter



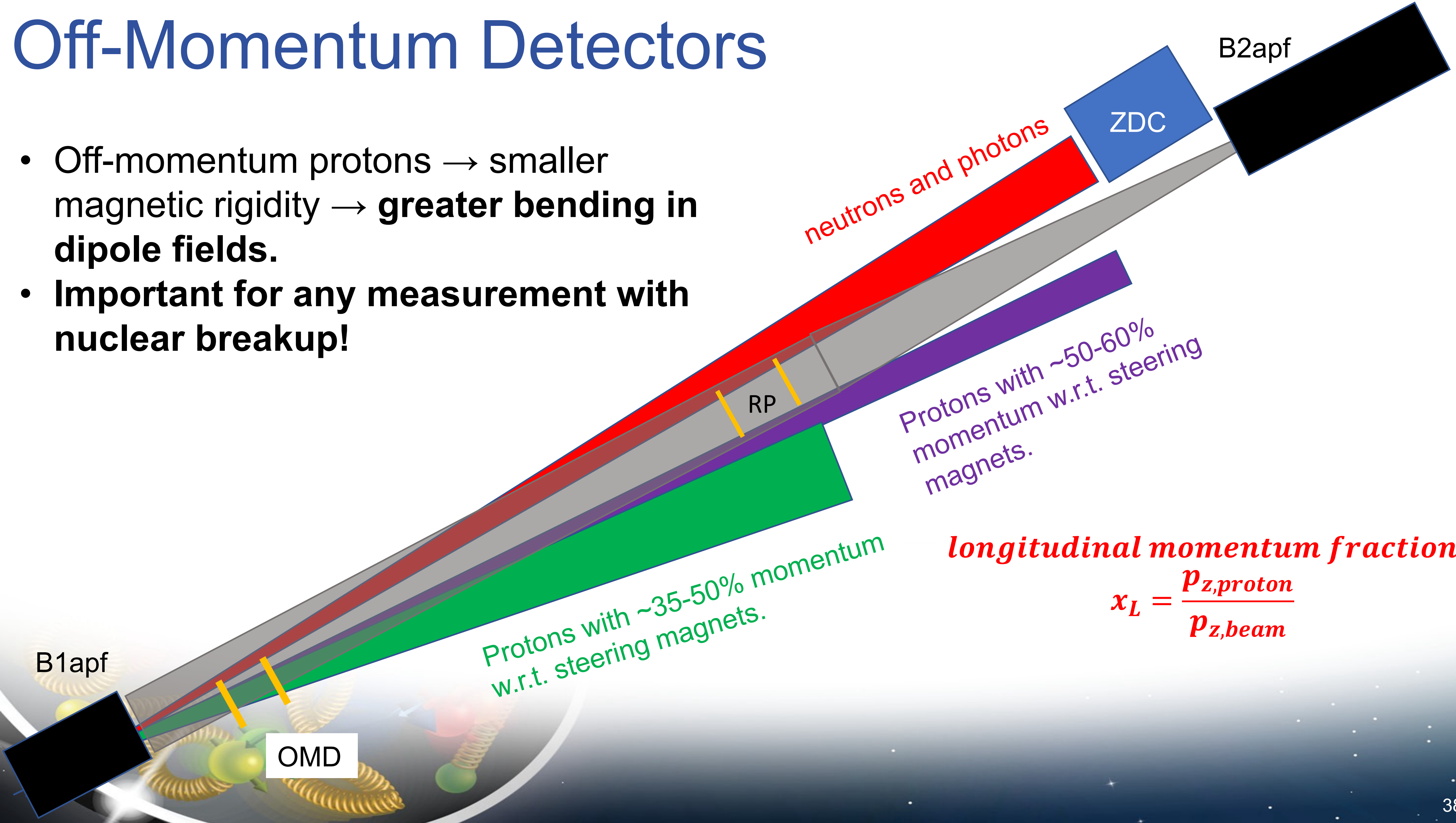


Off-Momentum Detectors



Off-Momentum Detectors

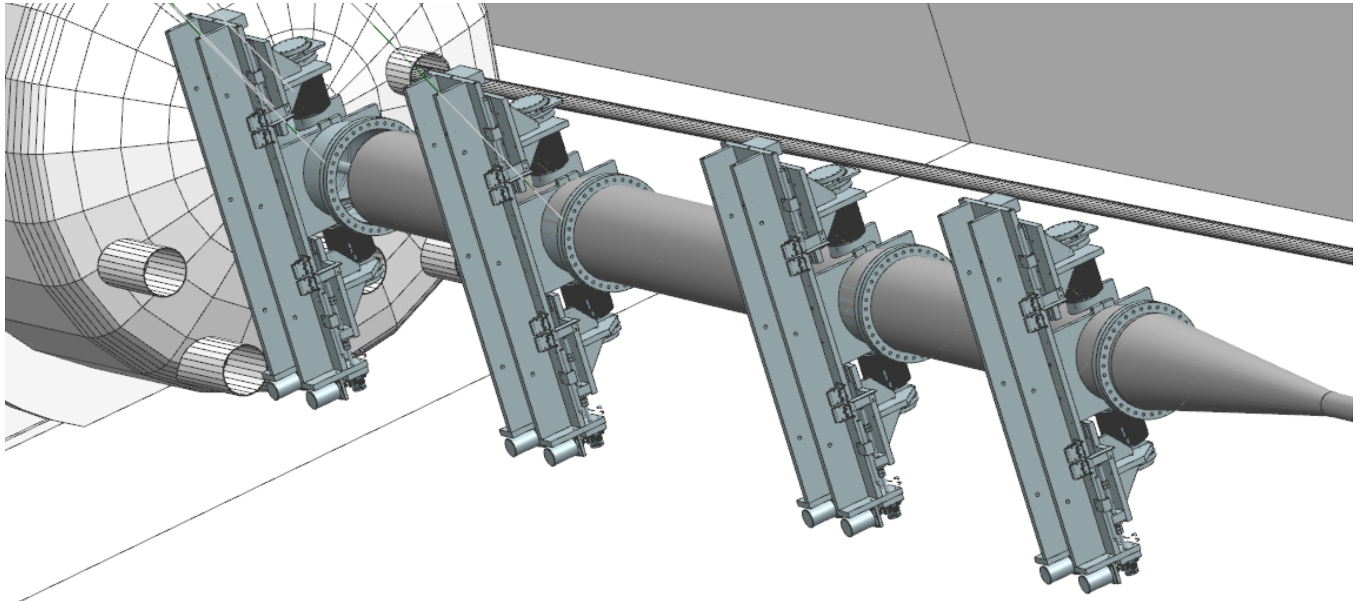
- Off-momentum protons → smaller magnetic rigidity → **greater bending in dipole fields.**
- **Important for any measurement with nuclear breakup!**

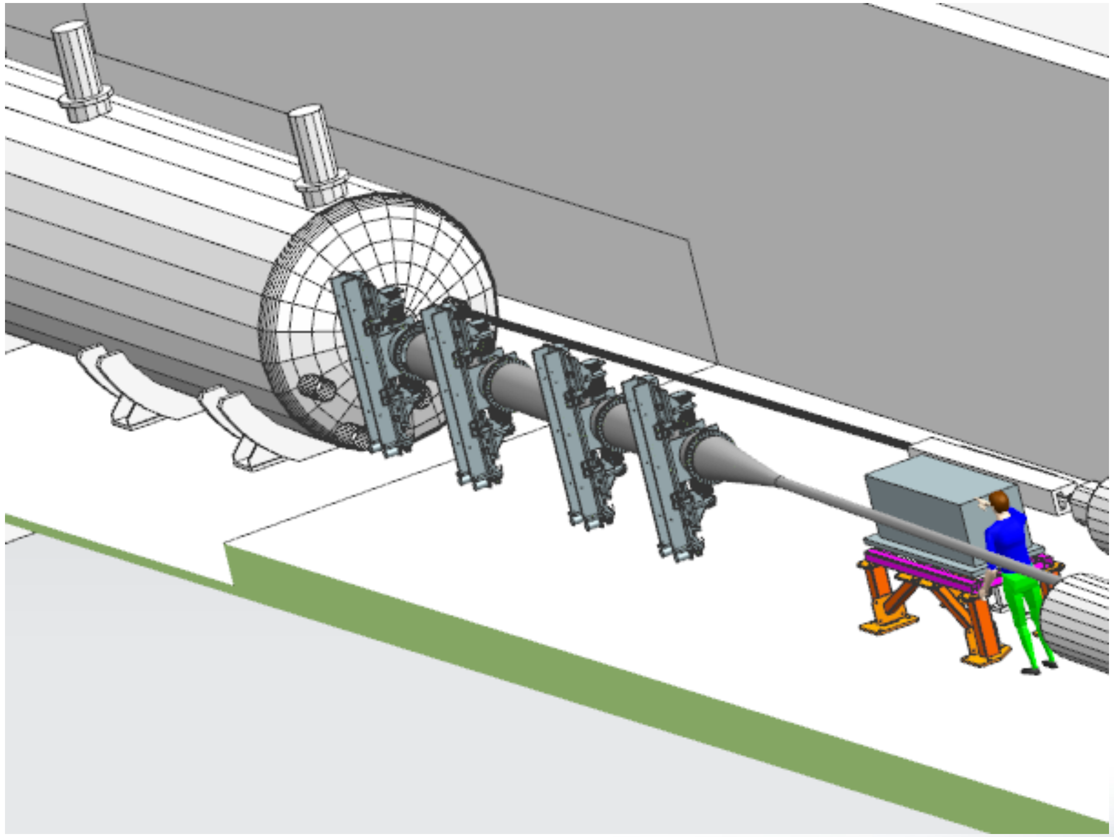


longitudinal momentum fraction

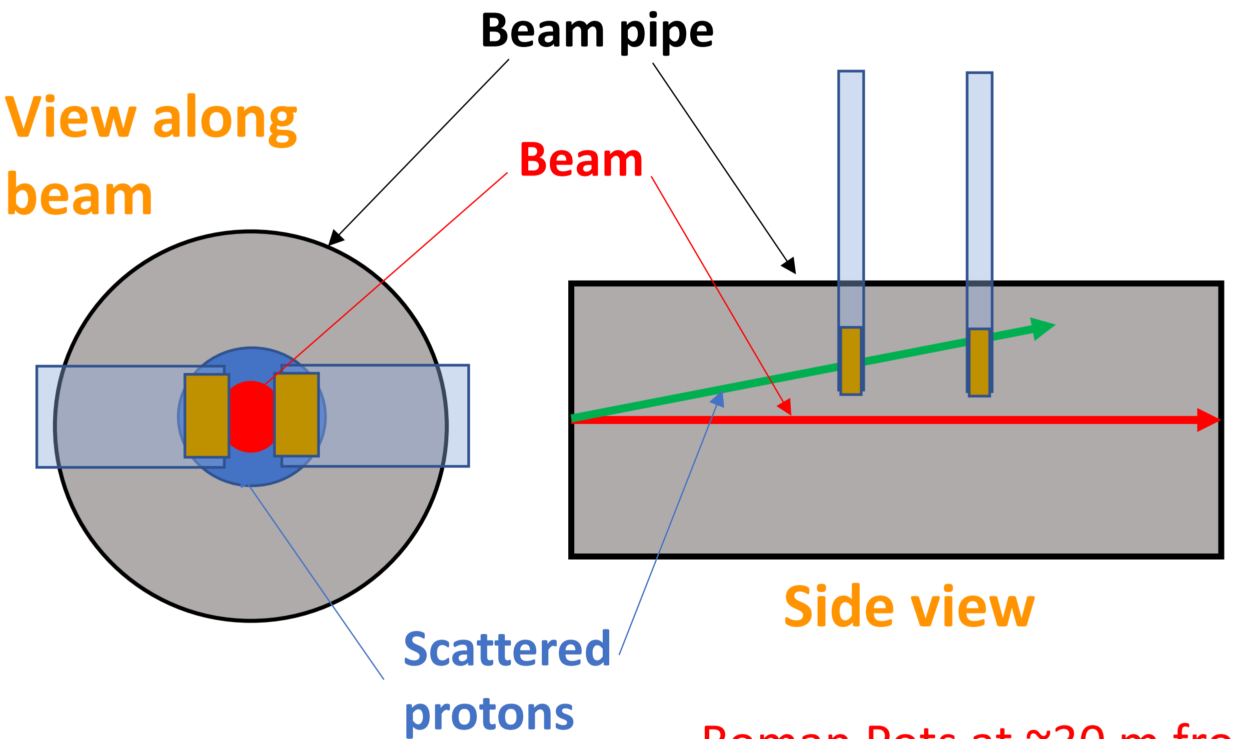
$$x_L = \frac{p_{z,proton}}{p_{z,beam}}$$

Preliminary CAD drawings of RP and OMD Supports and Magnet Cryostats





Roman Pots



$$\begin{pmatrix} x_D \\ \Theta_D^x \\ y_D \\ \Theta_D^y \end{pmatrix} = \begin{pmatrix} a_{11} & L_{eff}^x & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & L_{eff}^y \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix} \begin{pmatrix} x_0 \\ \Theta_x^* \\ y_0 \\ \Theta_y^* \end{pmatrix}$$

x_0, y_0: Position at Interaction Point

Θ^*_x, Θ^*_y: Scattering Angle at IP

x_D, y_D : Position at Detector

Θ^x_D, Θ^y_D : Angle at Detector

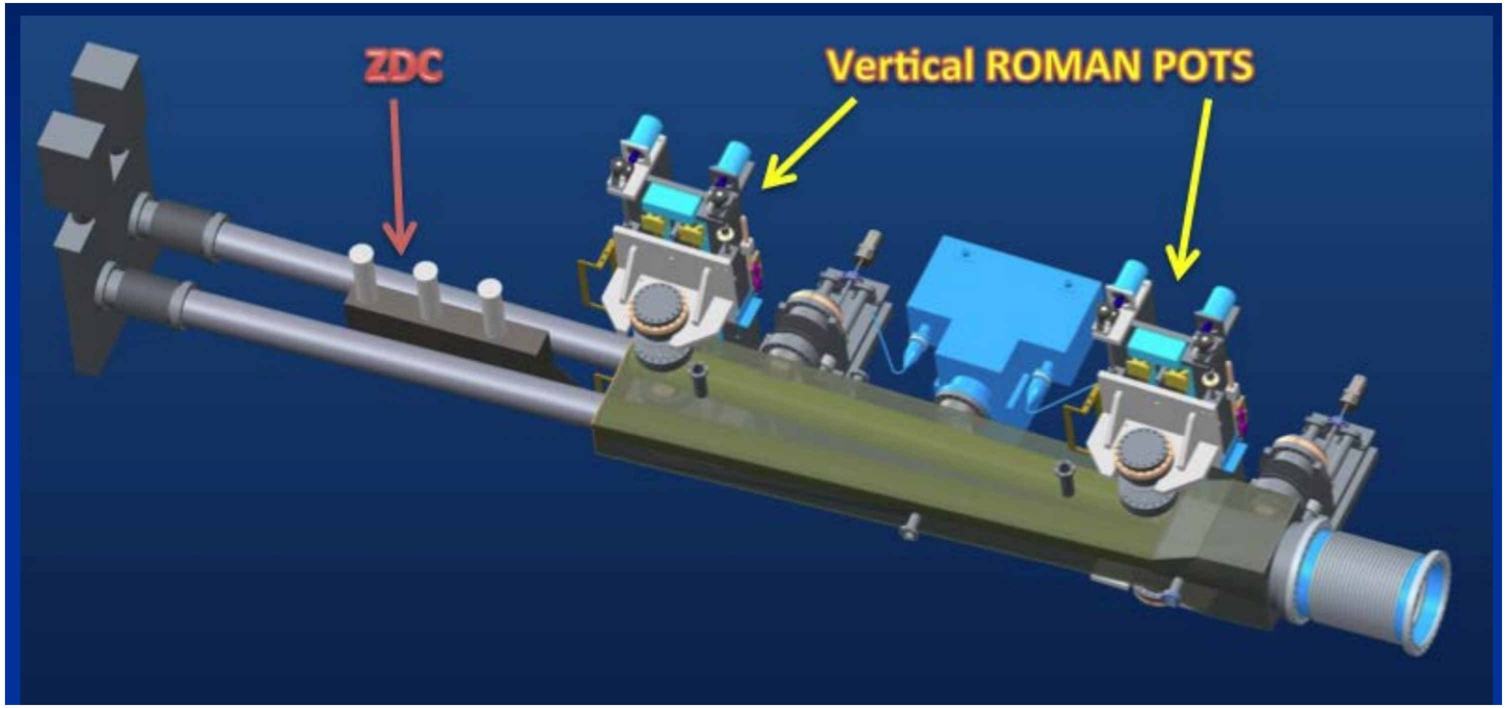
Roman Pots at ~30 m from IP → $\theta \backsim$ 0 - 5 mrad

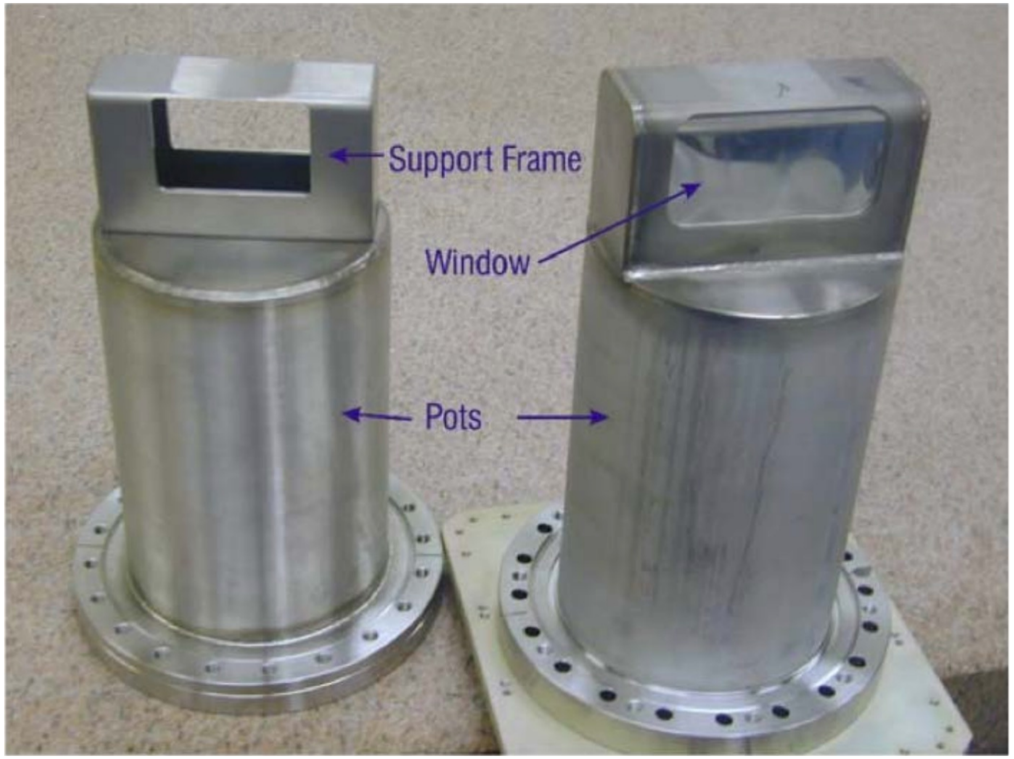
- Roman Pots are silicon sensors placed in a “pot”, which is then injected into the beam pipe, tens of meters or more from the interaction point (IP).
- Momentum reconstruction carried out using matrix transport of protons through magnetic lattice.

Roman Pots

- Place roman pottery into the particle accelerator → learn the deep mysteries of the universe?

Roman Pots



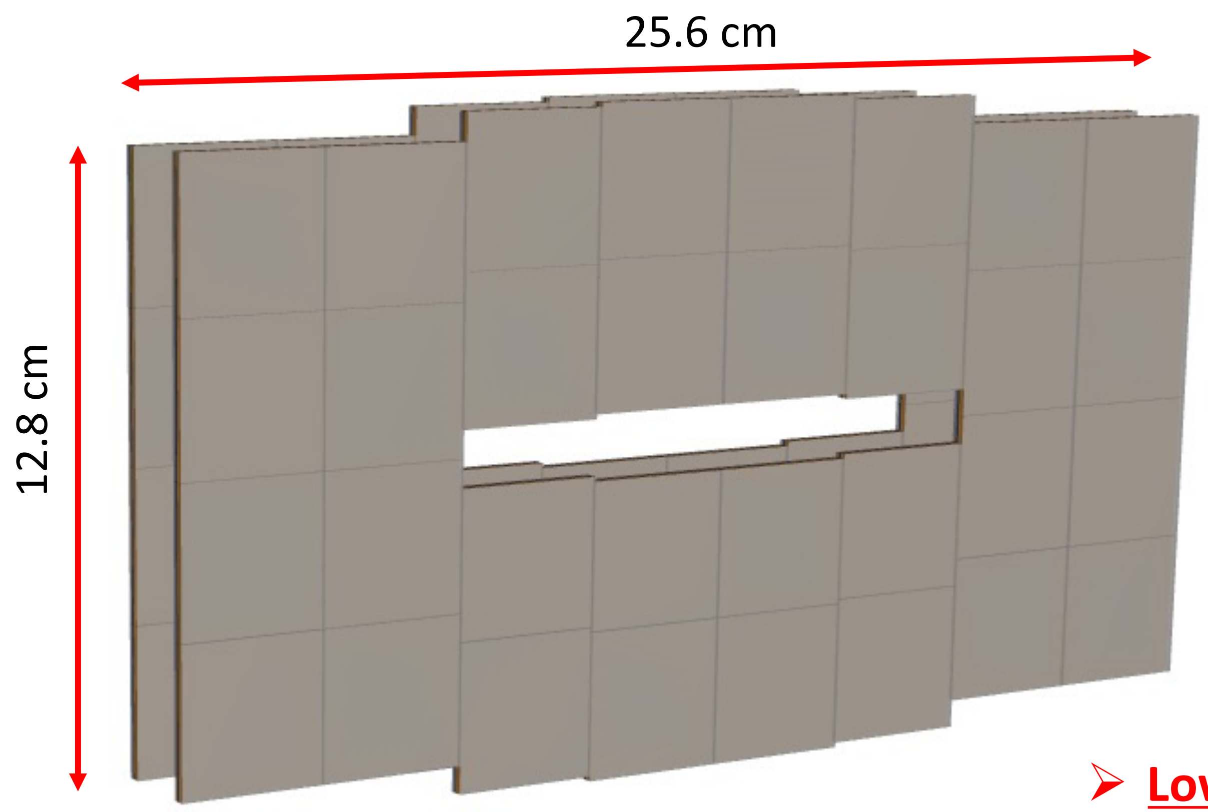


Roman pots at STAR – used to measure p+p elastic scattering.

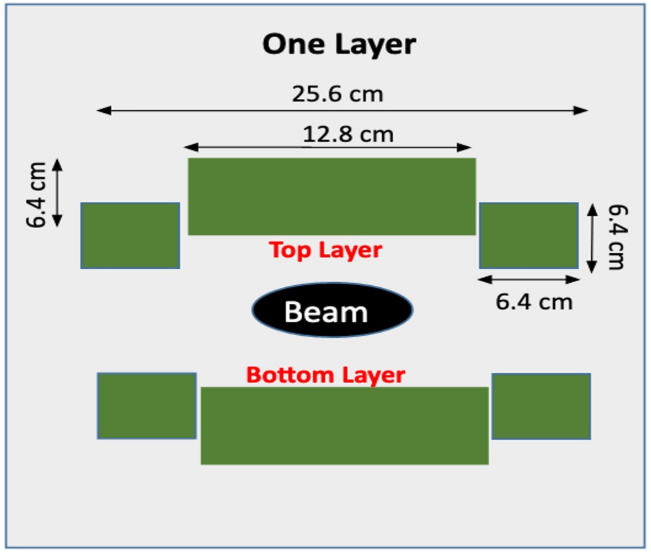
Roman "Pots" @ the EIC

$\sigma(z)$ is the Gaussian width of the beam, $\beta(z)$ is the RMS transverse beam size.
ε is the beam emittance.

$$\sigma(z) = \sqrt{\varepsilon \cdot \beta(z))}$$

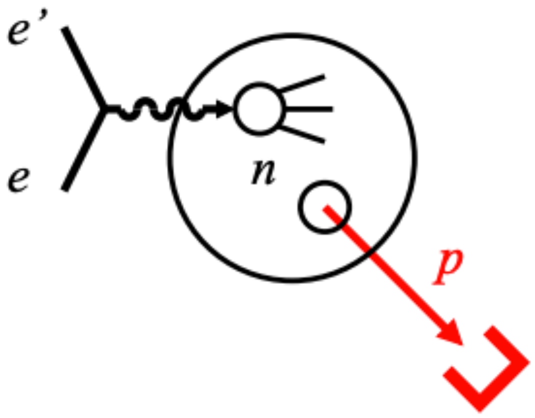


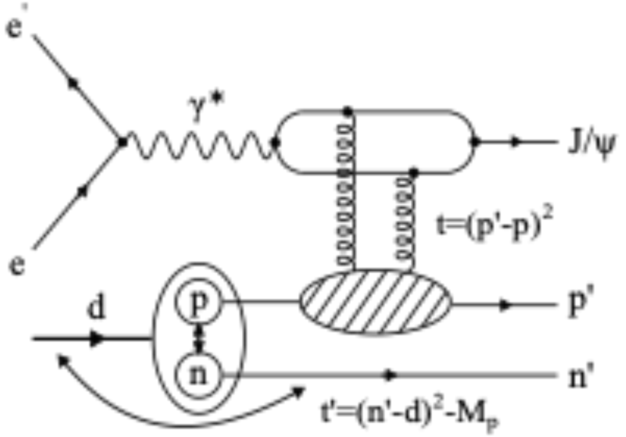
DD4HEP Simulation

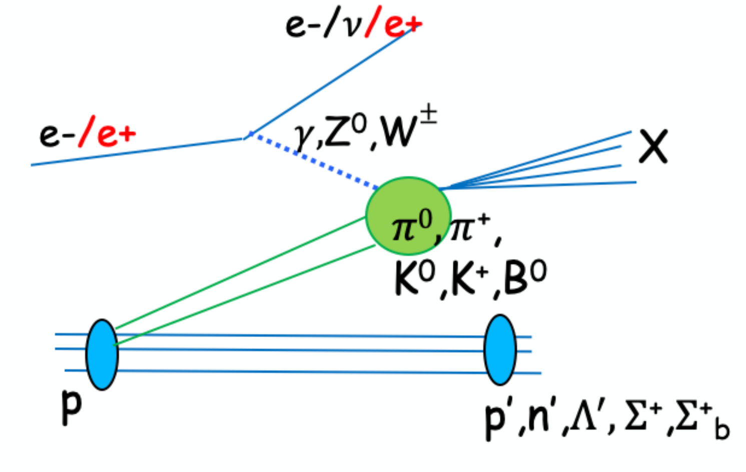


- <u>**Low-pT cutoff determined by beam optics.**</u>
  - **The safe distance is ~10σ from the beam center.**
  - **1σ ~ 1mm**
- **These optics choices change with energy, but can also be changed within a single energy to maximize *either acceptance at the RP, or the luminosity*.**

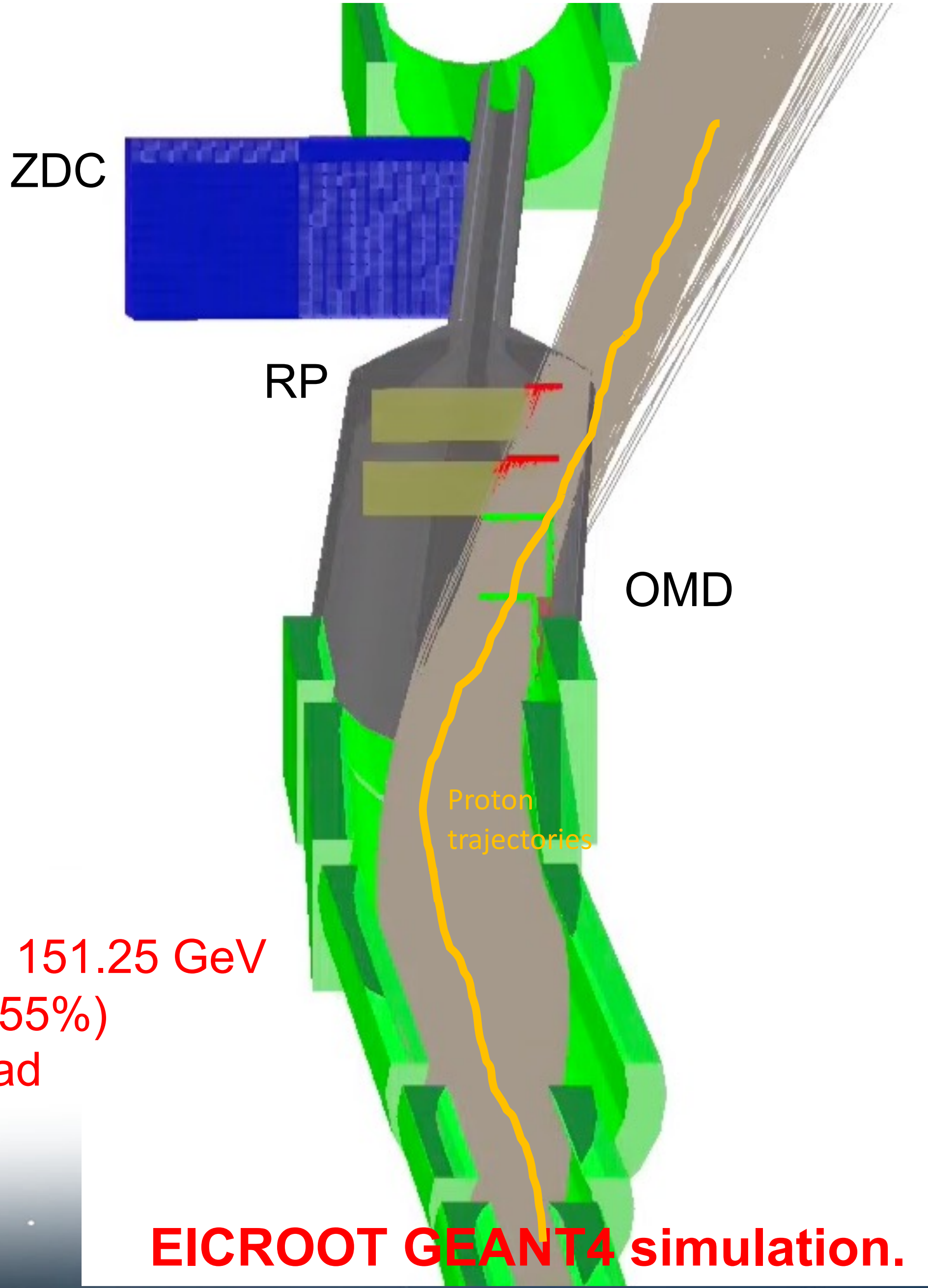
Off-Momentum Detectors





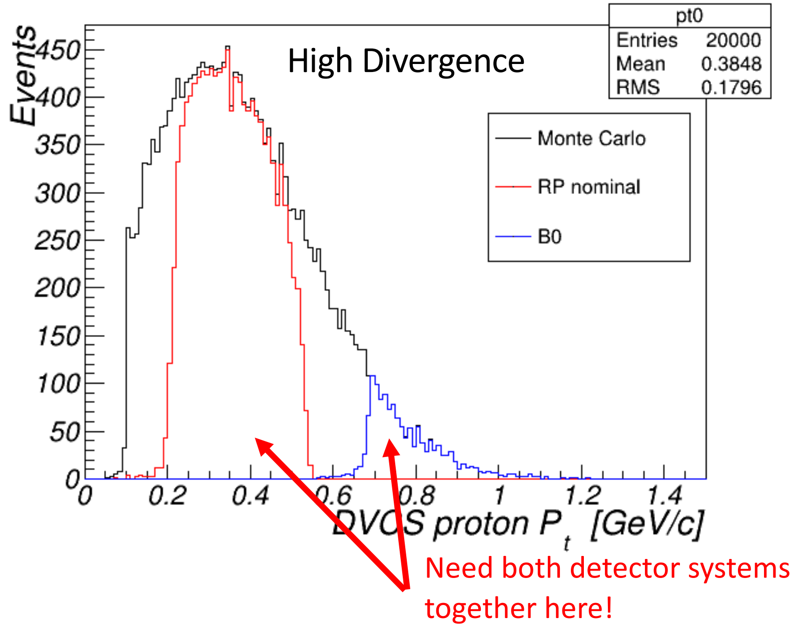


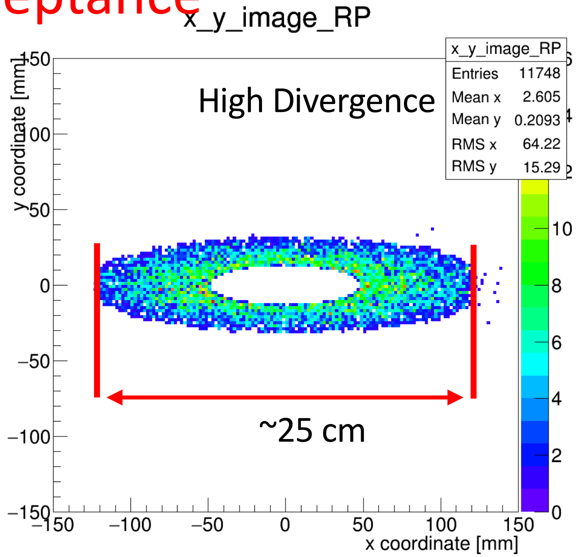
Protons
123.75 < E < 151.25 GeV
(45% < xL < 55%)
$0 < \theta < 5$ mrad

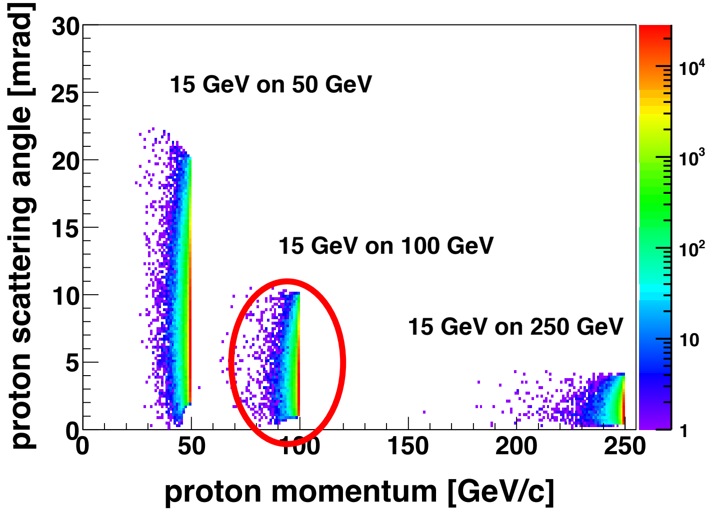


Digression: Machine Optics

100 GeV DVCS Proton Acceptance







Digression: Machine Optics

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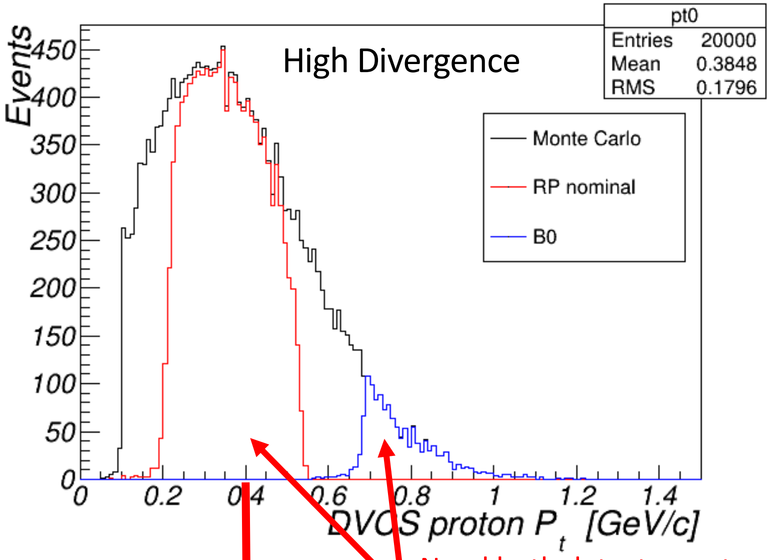
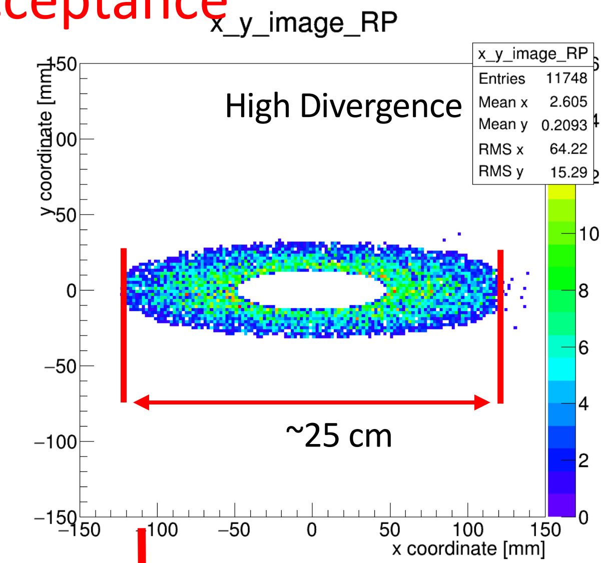
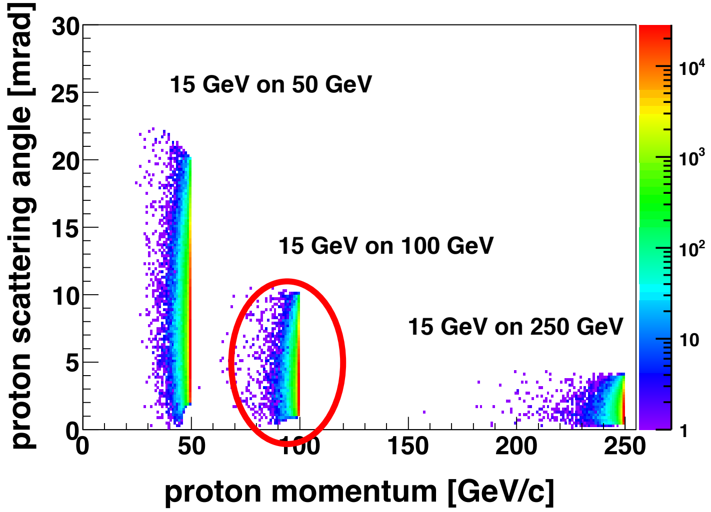
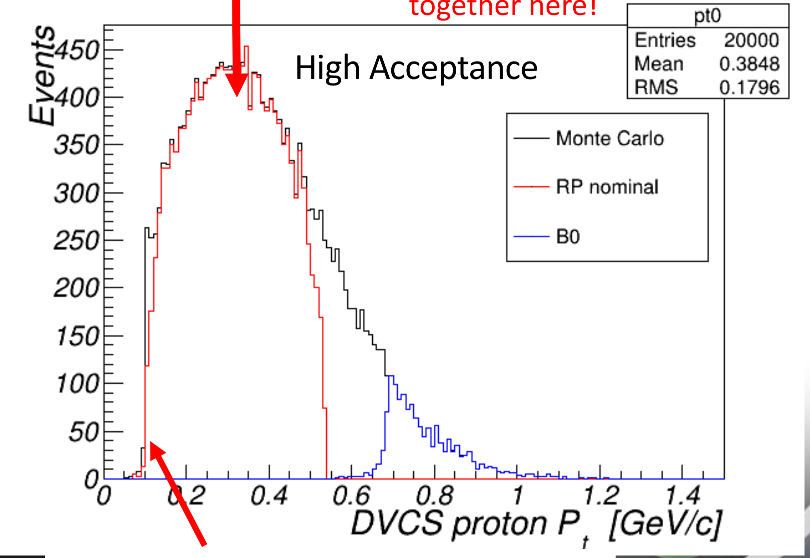
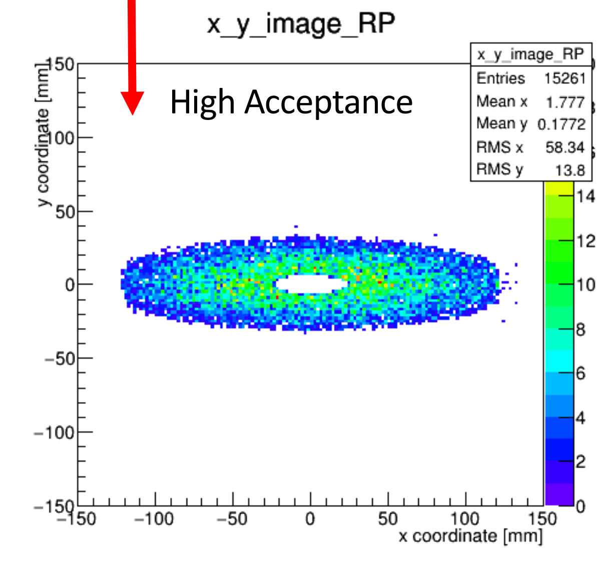






Need both detector systems together here!





Improves low p_t acceptance.

Zero-Degree Calorimeter

- Need a calorimeter which can accurately reconstruct photons and neutrons from our various final states (e.g. tagged DIS, incoherent vetoing in e+A, backward u-channel omega production).
- Neutrons and photons react differently in materials – need both an EMCAL and an HCAL!

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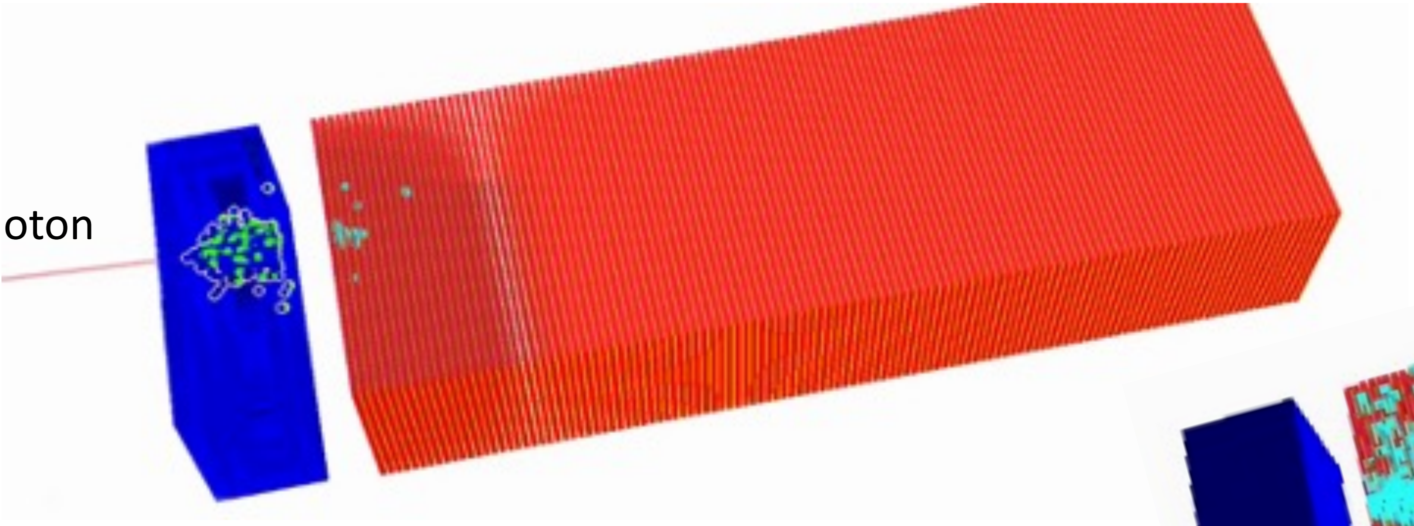
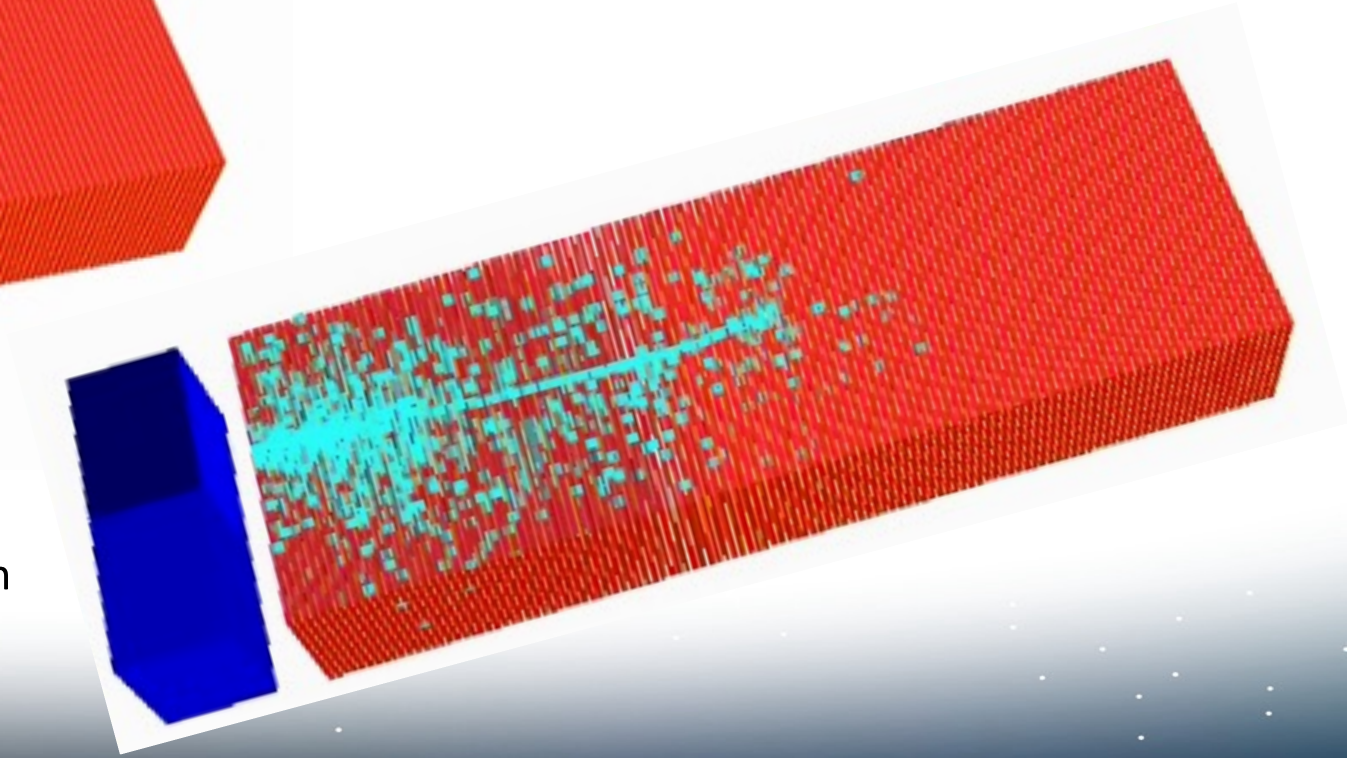
photon



neutron



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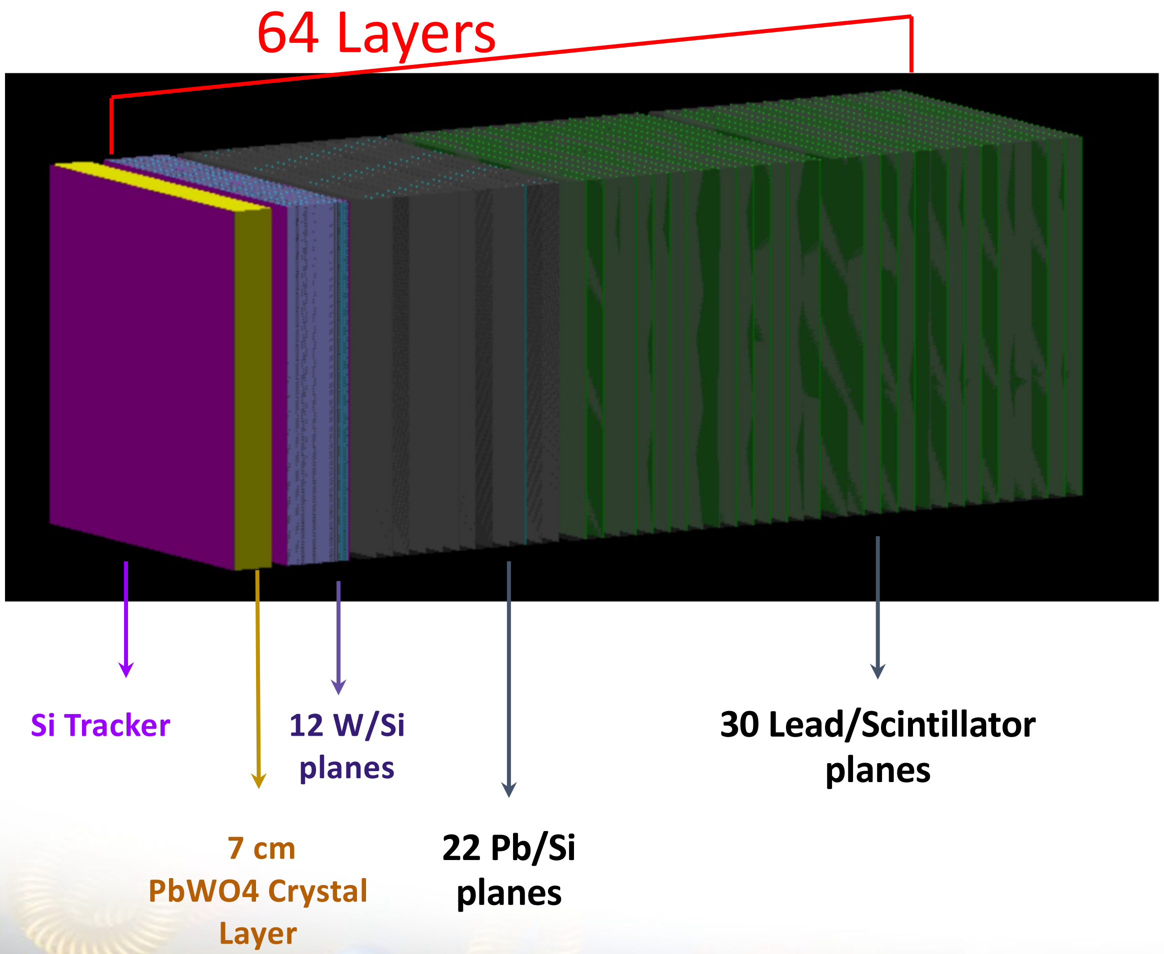

Credit to Shima Shimizu (Kobe U. , Japan)

- **Zero Degree Calorimeter (improved ALICE design):**
  - **Dimension: 60 cm x 60 cm x 168 cm**
  - **30 m from IR**
  - **Detect spectator nucleon**
  - **Acceptance: +4.5 mrad, -5.5mrad**
  - **Position resolution ~1.3mm at 40 GeV**
  - **Full reconstruction of photons (EMCAL) and neutrons (HCAL)**

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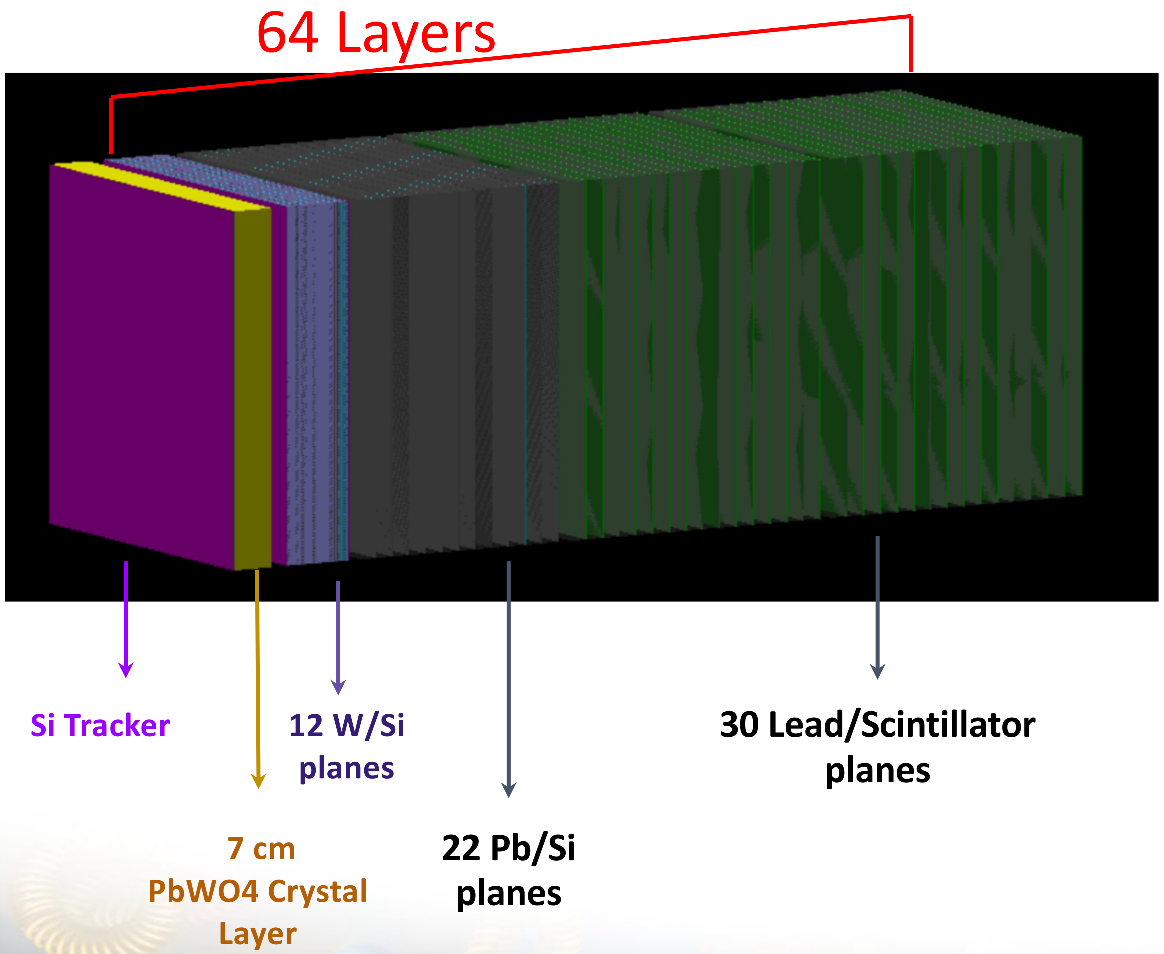

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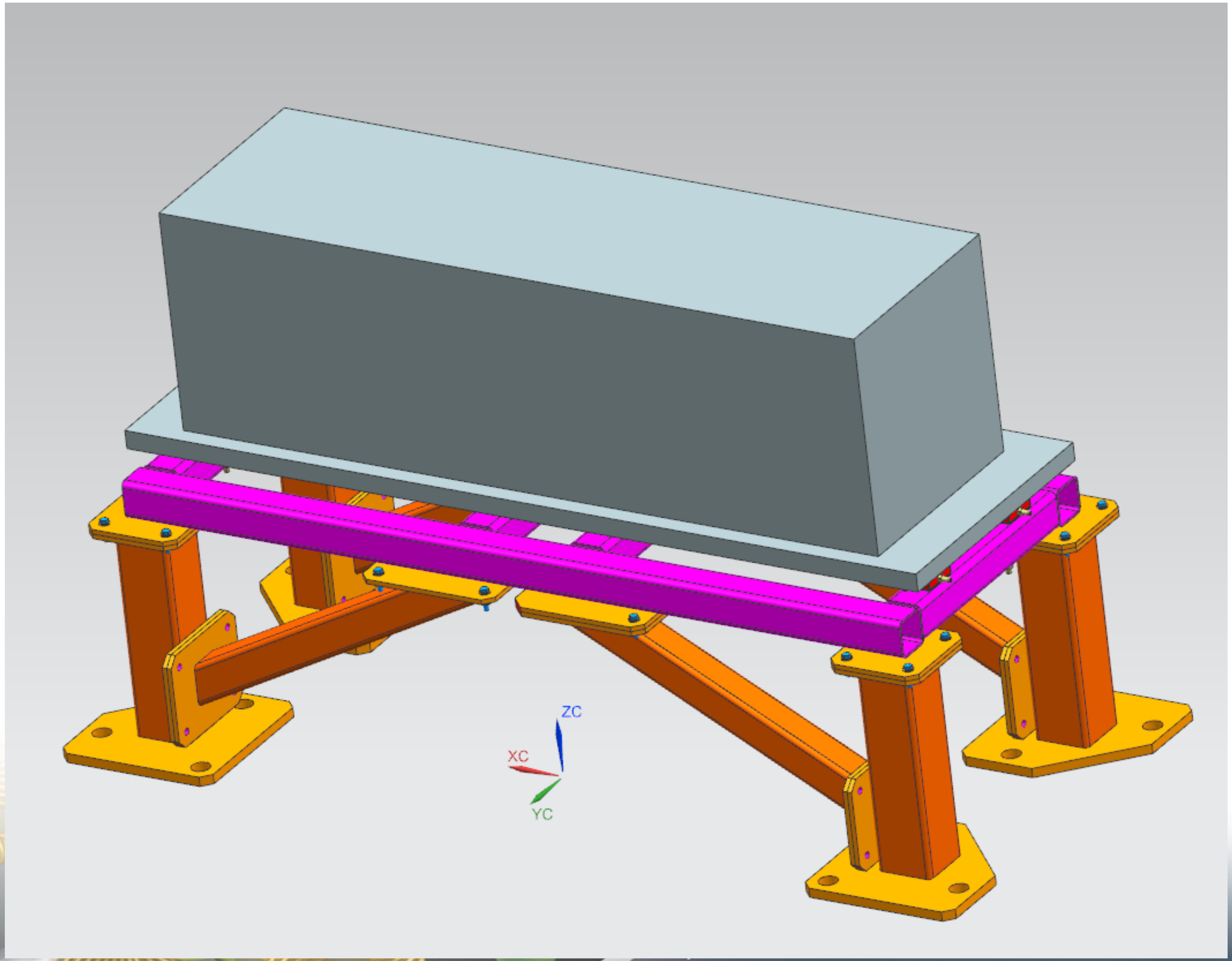
➢ Sufficient calorimeter depth (radiation lengths, X_0 for photons/electrons; nuclear interaction lengths, λ_I for neutrons/hadrons)
  - Required for good energy resolution.

➢ Granularity needed for proper reconstruction of shower.
  - Finding the center of the shower needed to provide angular resolution to get neutron transverse momentum!

Zero-Degree Calorimeter with Stand

Credit: Ron Lassiter



Preliminary Design of Zero--Degree Calorimeter with full support structure.

Zero-Degree Calorimeter