Far-Forward Detectors @ the EIC

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NuSTEAM/NuPUMAS @ BNL
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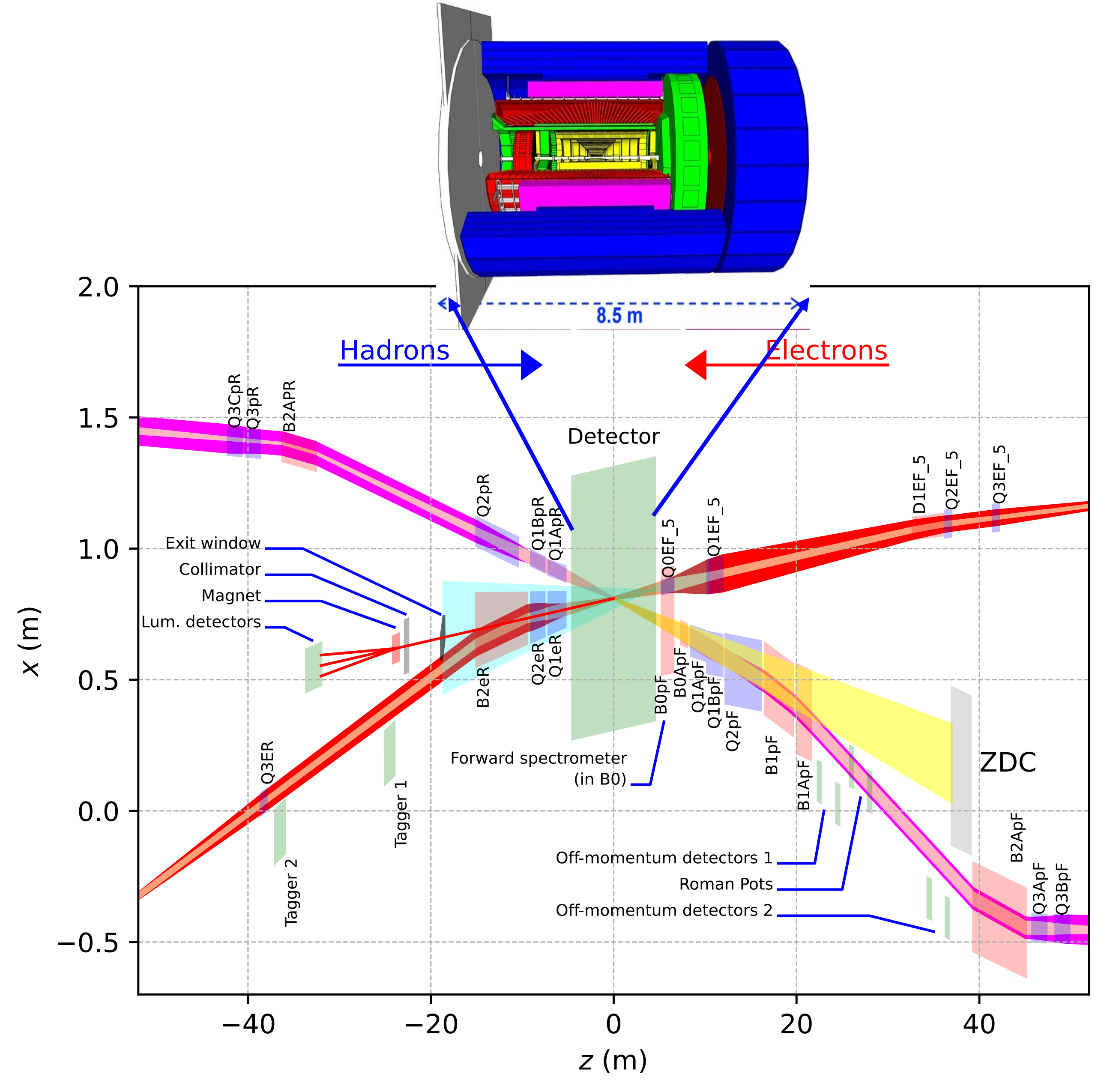
Electron Ion Collider

Brookhaven National Laboratory · Jefferson Lab · U.S. Department of Energy, Office of Science

EIC Detector 1 – IP6

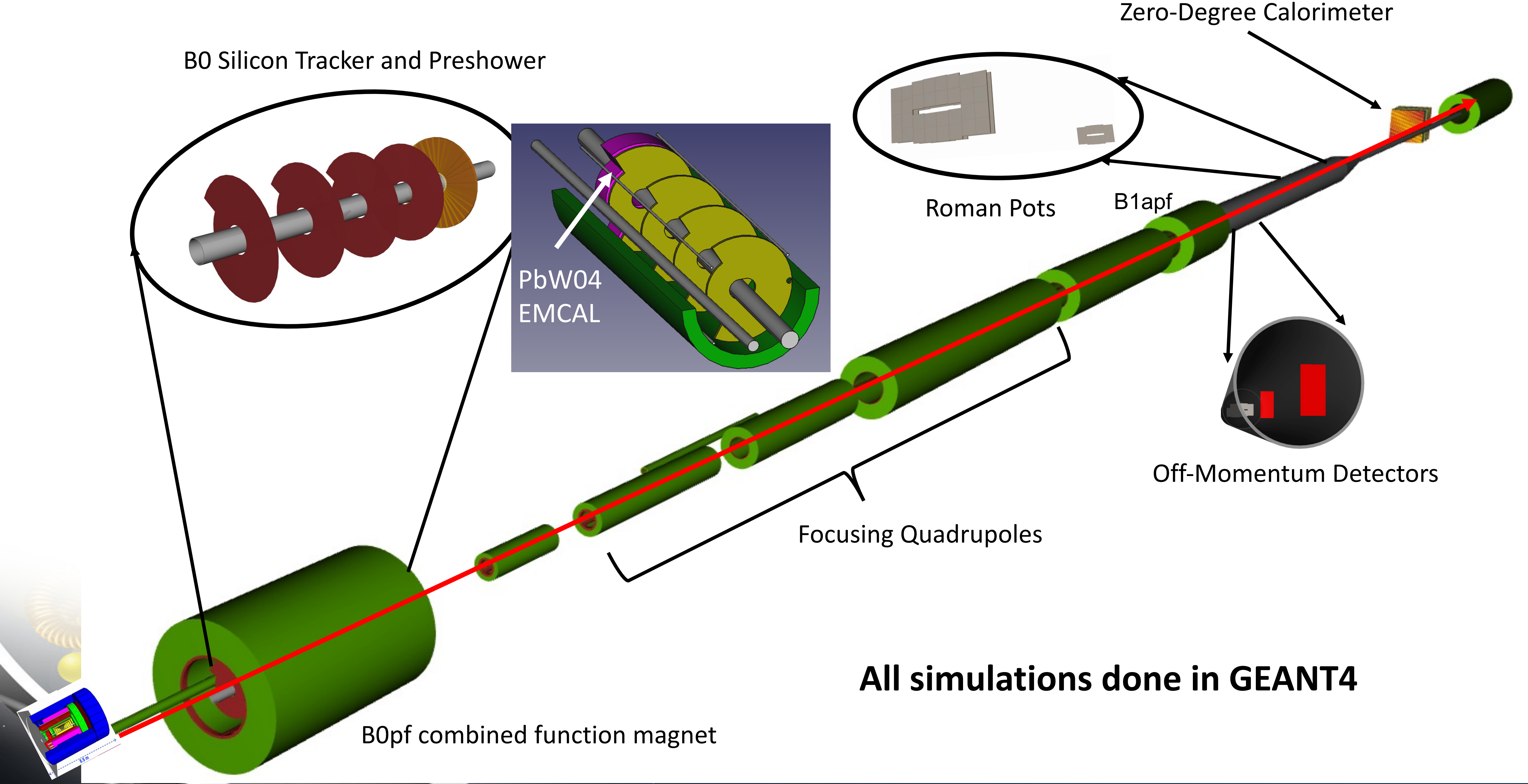


- In addition to the central detector → detectors integrated into the beamline on both the hadron-going (**far-forward**) and electron-going (**far-backward**) direction.
  - Requires special considerations for the machine-detector interface.

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

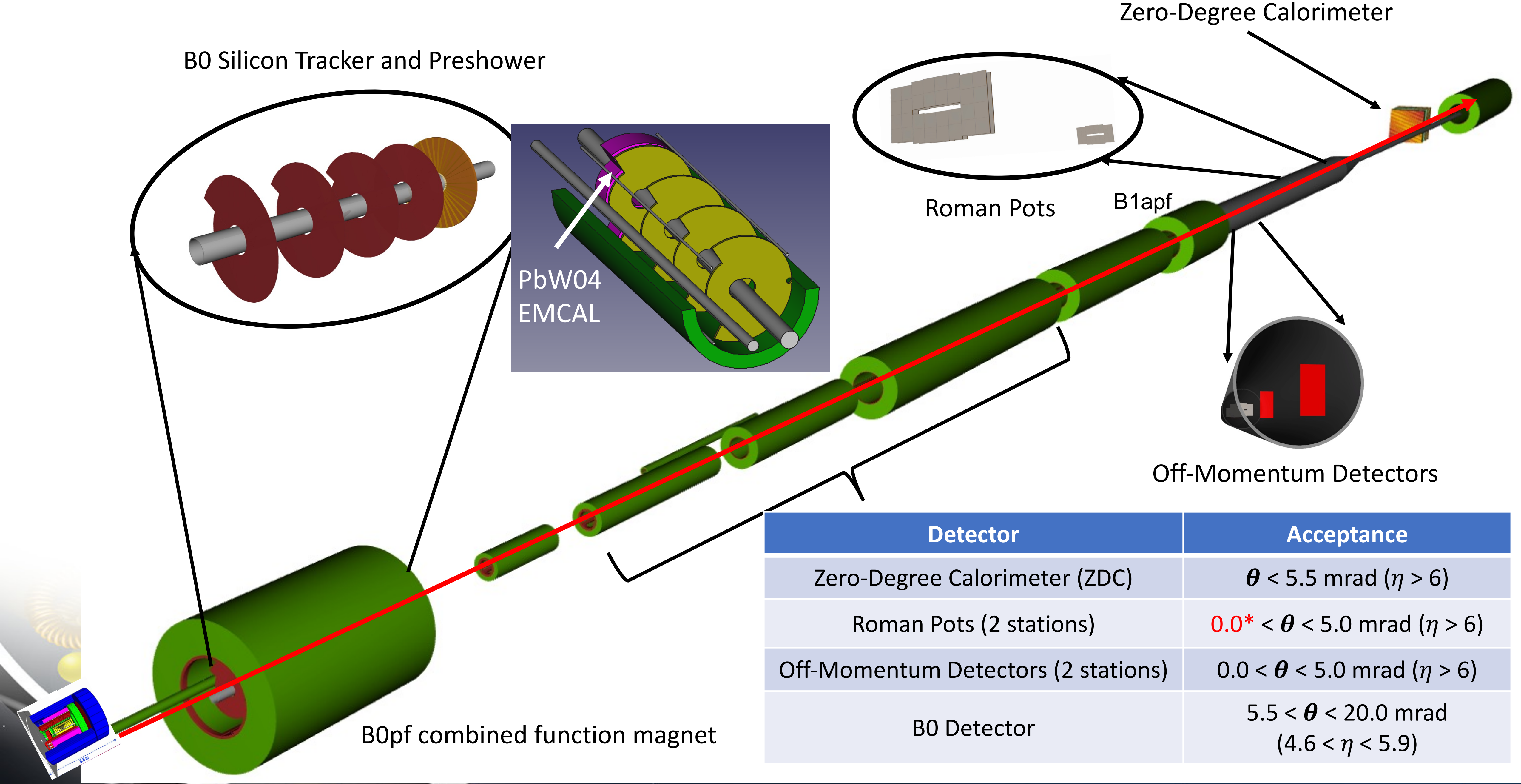
We will focus on the detector setup for IP6, but I will discuss what we gain with IP8 at the end.

The Far-Forward Detectors



All simulations done in GEANT4

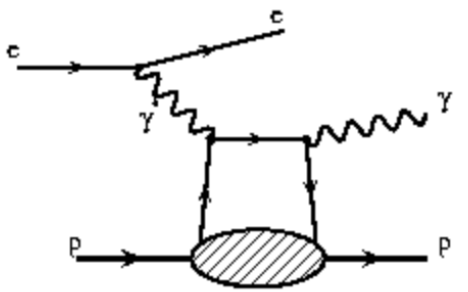
The Far-Forward Detectors



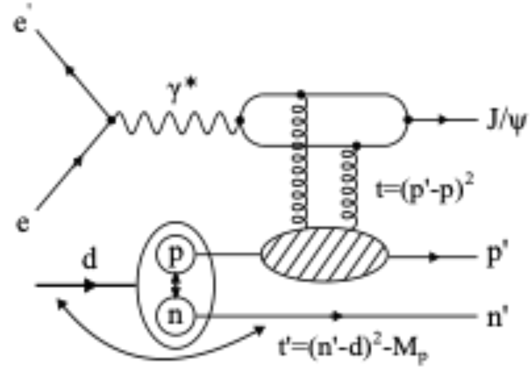
Detector	Acceptance
Zero-Degree Calorimeter (ZDC)	$\theta < 5.5$ mrad ($\eta > 6$)
Roman Pots (2 stations)	0.0* $< \theta < 5.0$ mrad ($\eta > 6$)
Off-Momentum Detectors (2 stations)	$0.0 < \theta < 5.0$ mrad ($\eta > 6$)
B0 Detector	$5.5 < \theta < 20.0$ mrad ($4.6 < \eta < 5.9$)

Far-Forward Processes at the EIC

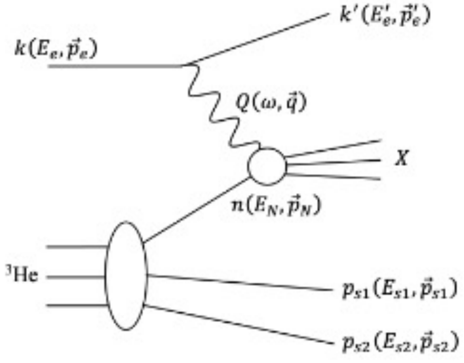
e+p DVCS



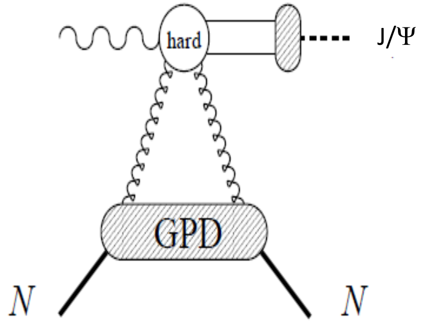
e+d exclusive J/Psi with p/n tagging



e+He3 spectator tagging

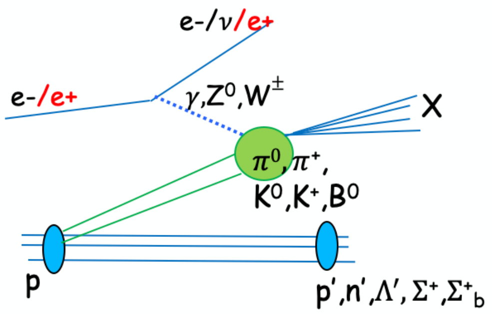


coherent/incoherent J/ψ production in e+A

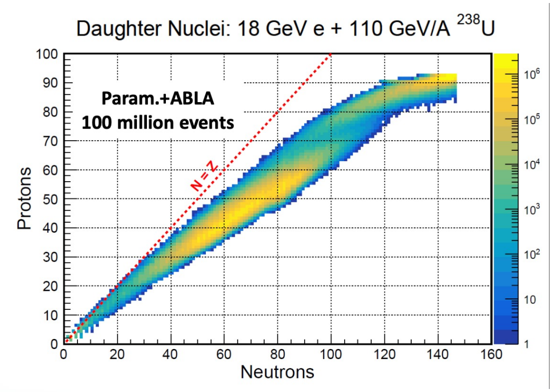


Meson structure:

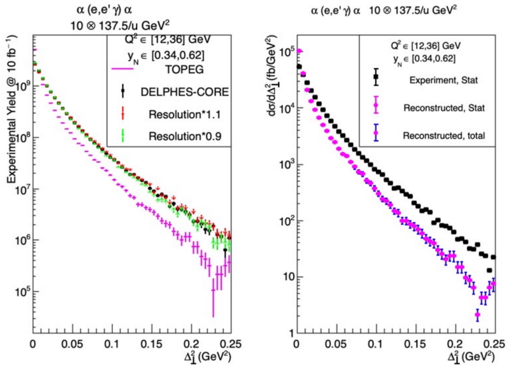
- ep→ (π) →e' n X
- $\Lambda \rightarrow p\pi^{-}$ and $\Lambda \rightarrow n\pi^{0}$



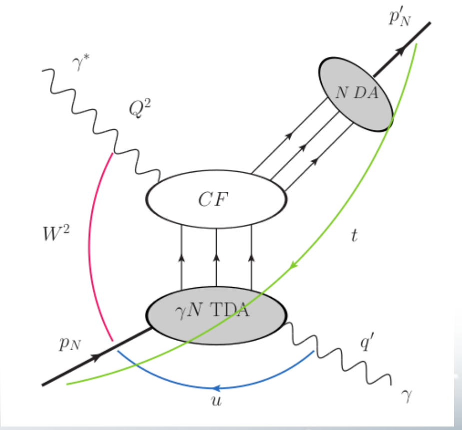
Rare isotopes



e+He4 DVCS



u-channel backward exclusive electroproduction



...and MANY more!

Far-Forward Processes at the EIC

- Physics channels require tagging of **charged hadrons** (protons, pions) or **neutral particles** (neutrons, photons) at **very-forward rapidities ($\eta > 4.5$).**
- Different final states require tailored detector subsystems.

…and MANY more!

Far-Forward Processes at the EIC

- Physics channels require tagging of **charged hadrons** (protons, pions) or **neutral particles** (neutrons, photons) at **very-forward rapidities ($\eta > 4.5$).**
- Different final states require tailored detector subsystems.
- Various collision systems (e.g. e+p, e+d, e+Au) provide unique challenges.
- Placing of far-forward detectors uniquely challenging due to presence of machine components, space constraint, apertures, etc.

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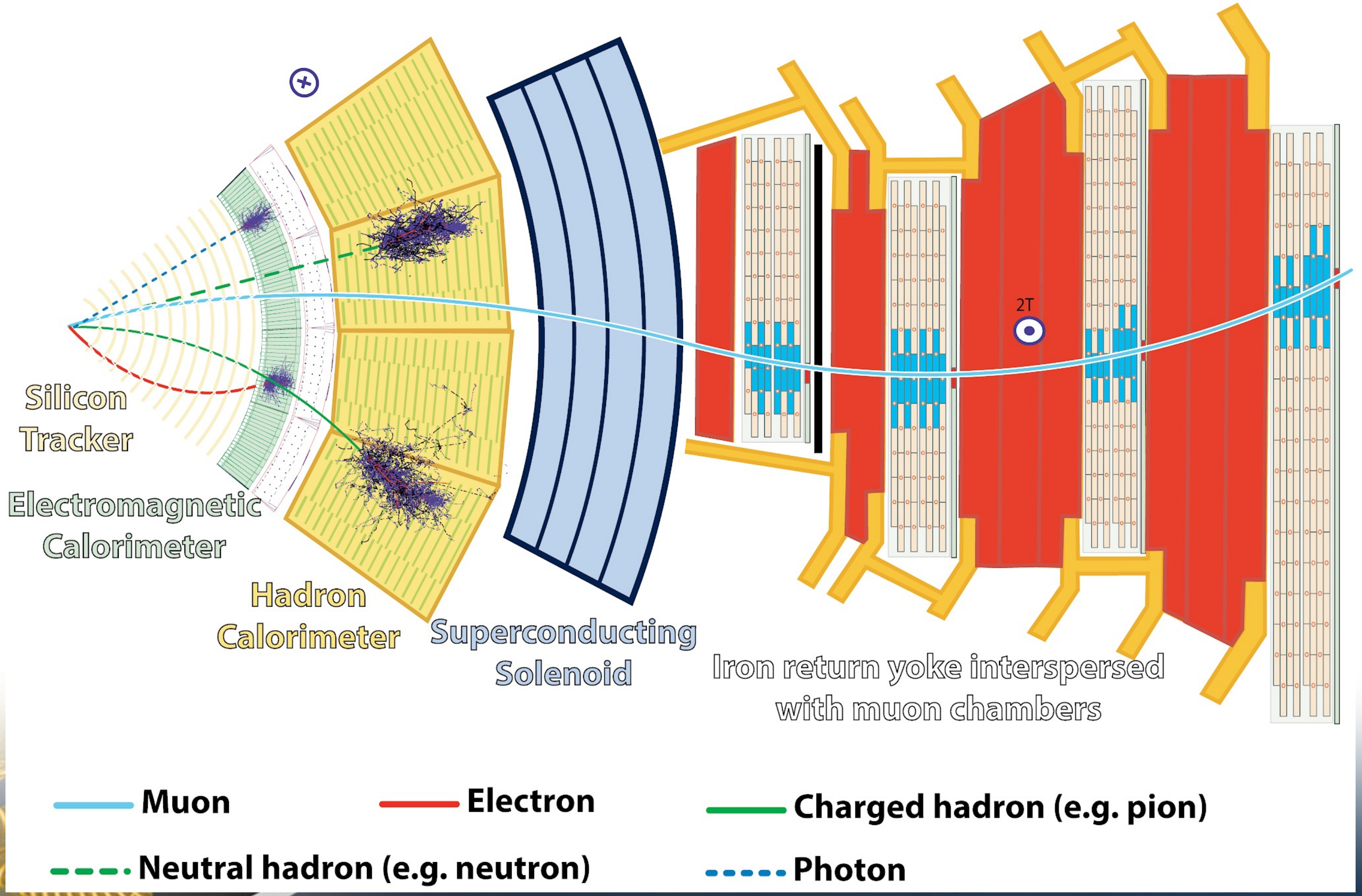
- Physics channels require tagging of **charged hadrons** (protons, pions) or **neutral particles** (neutrons, photons) at **very-forward rapidities** **($\eta > 4.5$).**
- Different final states require tailored detector subsystems.
- Various collision systems (e.g. e+p, e+d, e+Au) provide unique challenges.
- Placing of far-forward detectors uniquely challenging due to presence of machine components, space constraint, apertures, etc.
- Conceptual design and basic studies to establish requirements complete – we are moving on toward full engineering design!

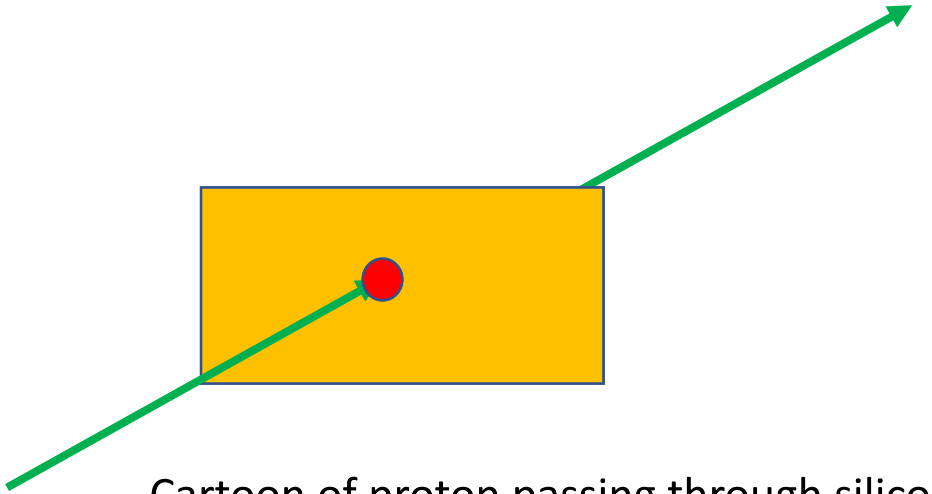
Some general comments about simulations

- Detector simulations carried out using GEANT (GEometry ANd Tracking) – a well-developed code package used to simulate particle interactions with matter.

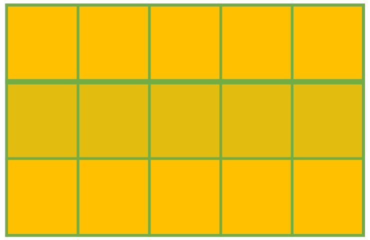


Some general comments about simulations

- Once particle + matter simulations are complete, need to be converted to useful form → digitization.
- Digitization takes the information the GEANT produces, and turns it into a mimicked signal in your simulated detector.

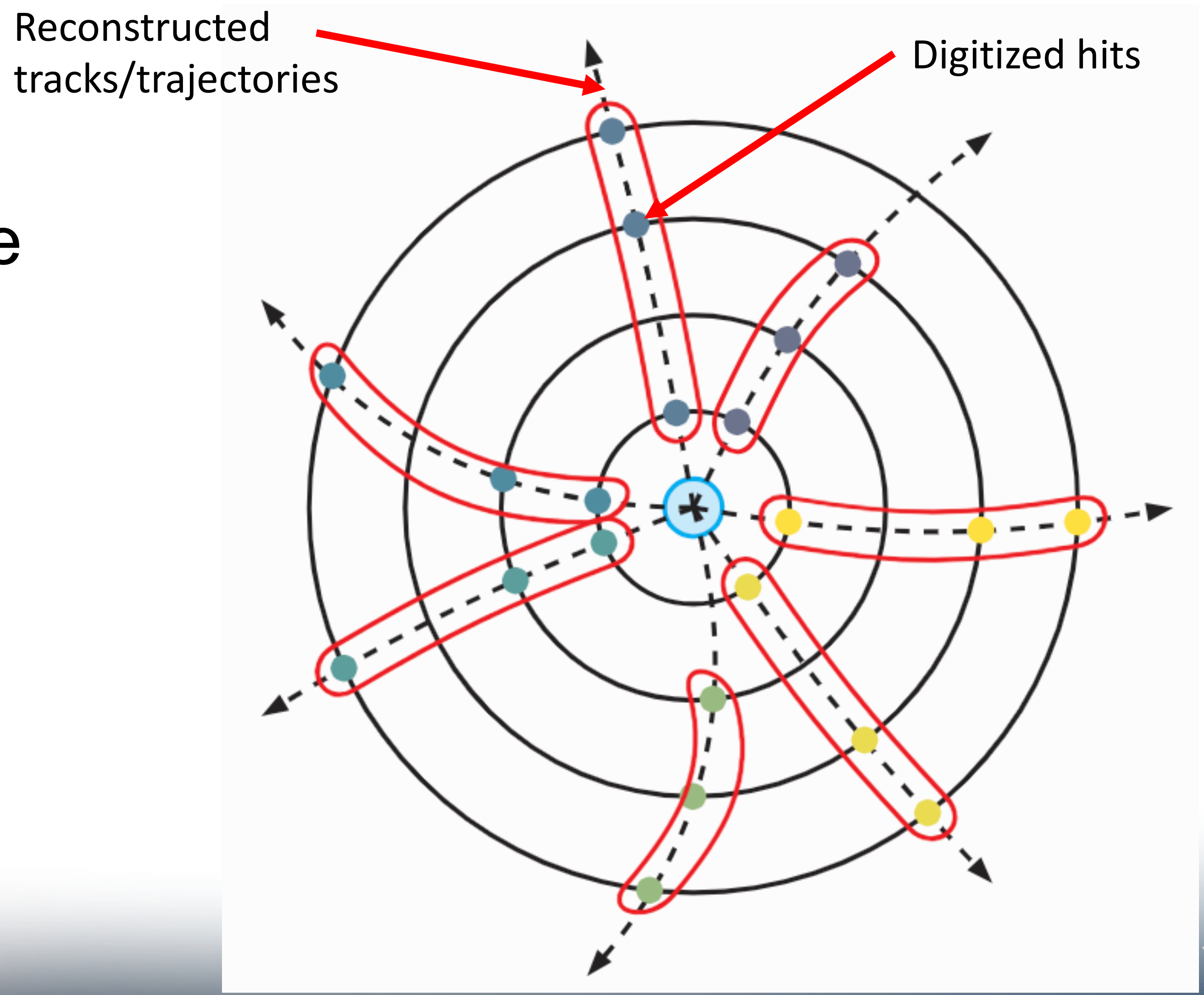


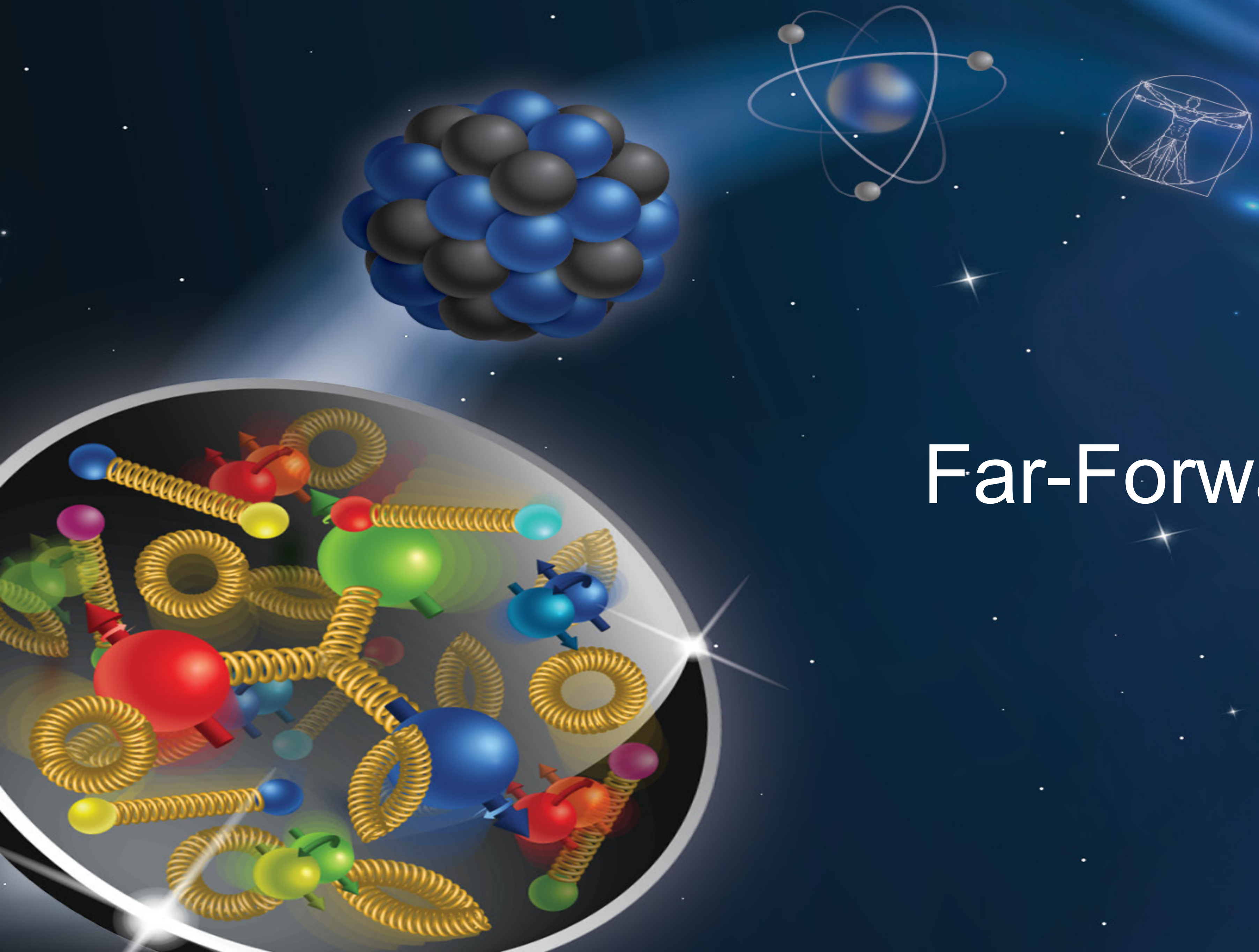
Cartoon of proton passing through silicon plane, and depositing a bit of energy.



Some general comments about simulations

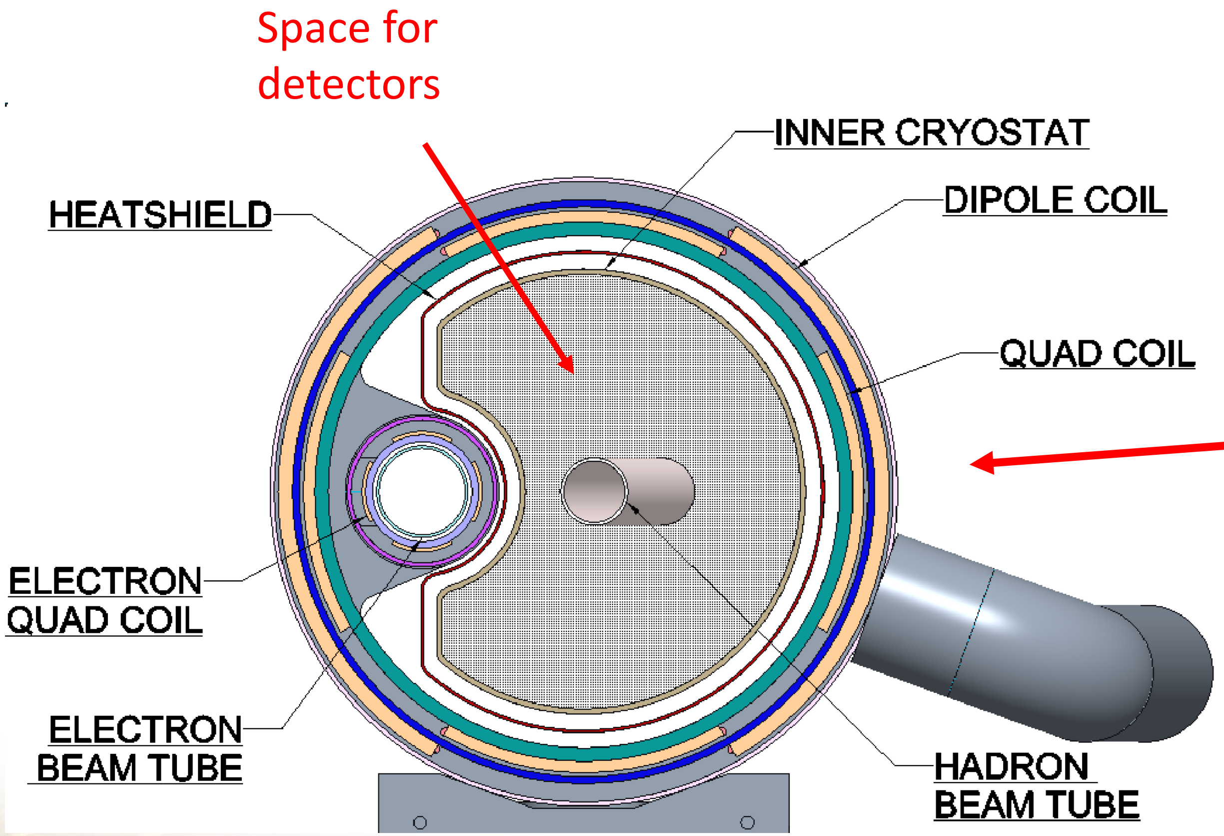
- Reconstruction is taking the digitized information and turning it into a physical quantity (e.g. energy, momentum, etc.).

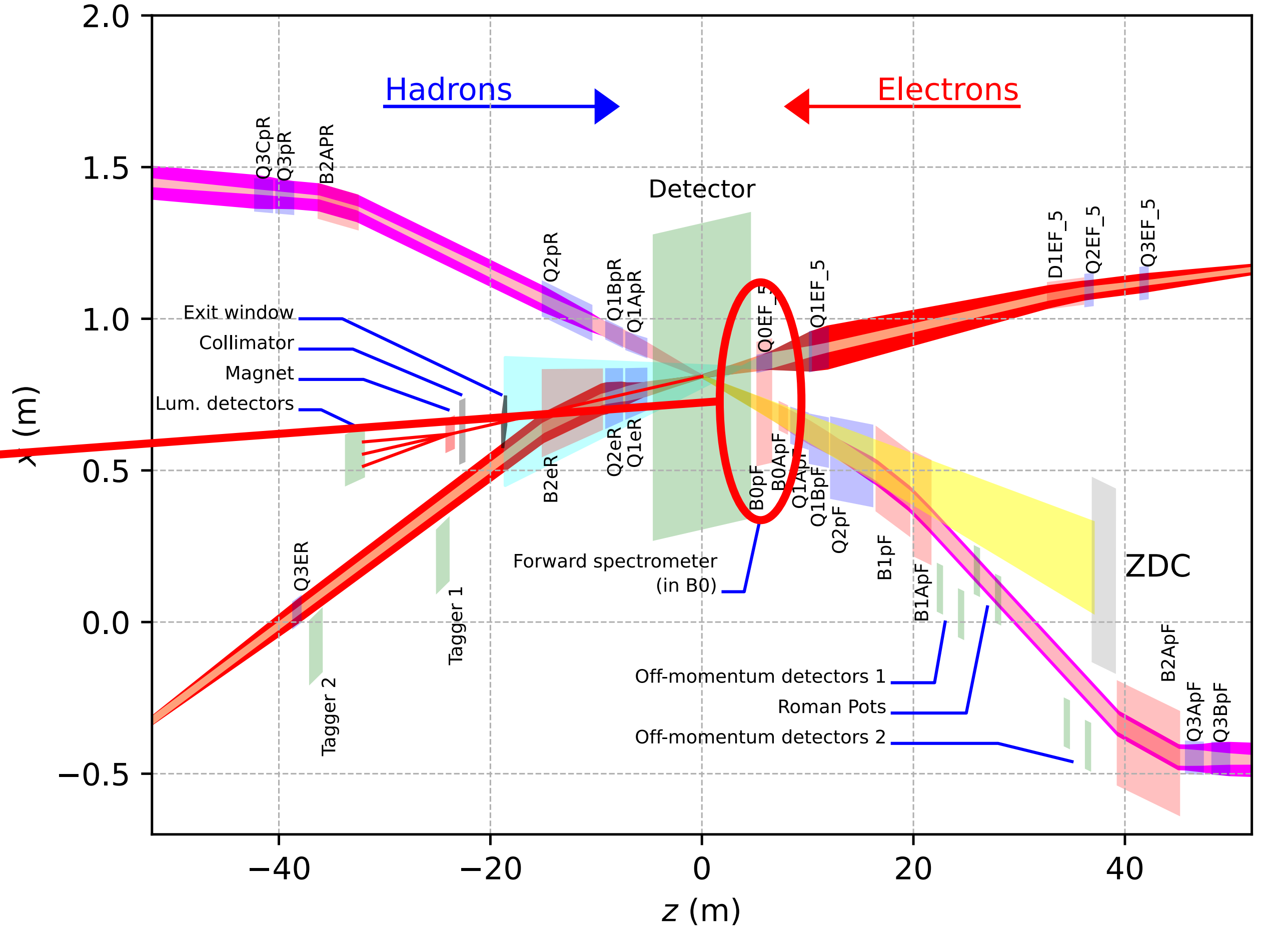




Far-Forward Detector Subsystems

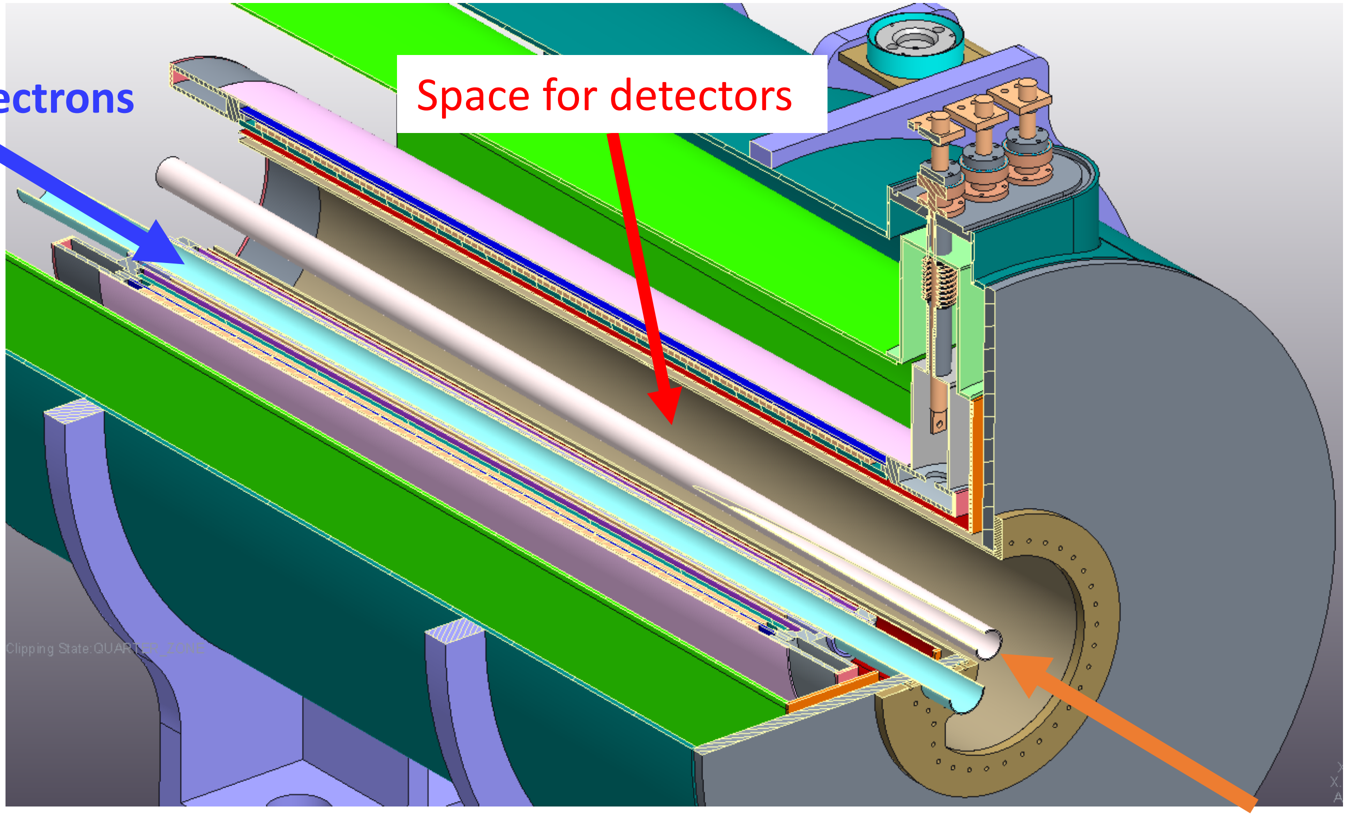
B0 Detectors

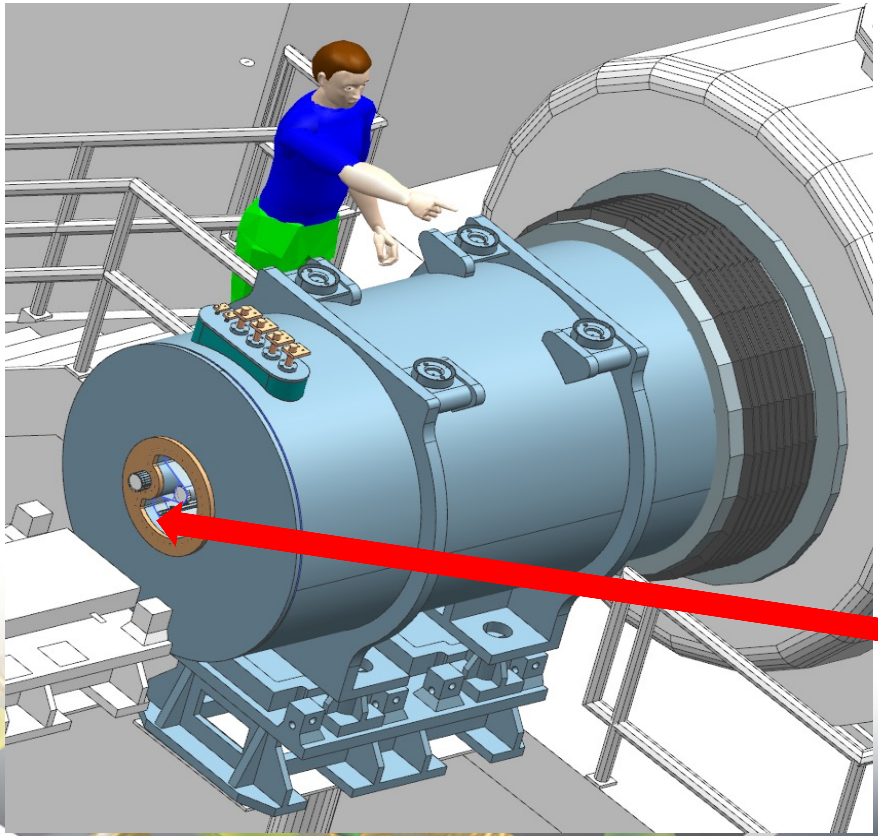




B0 Detectors

- 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).

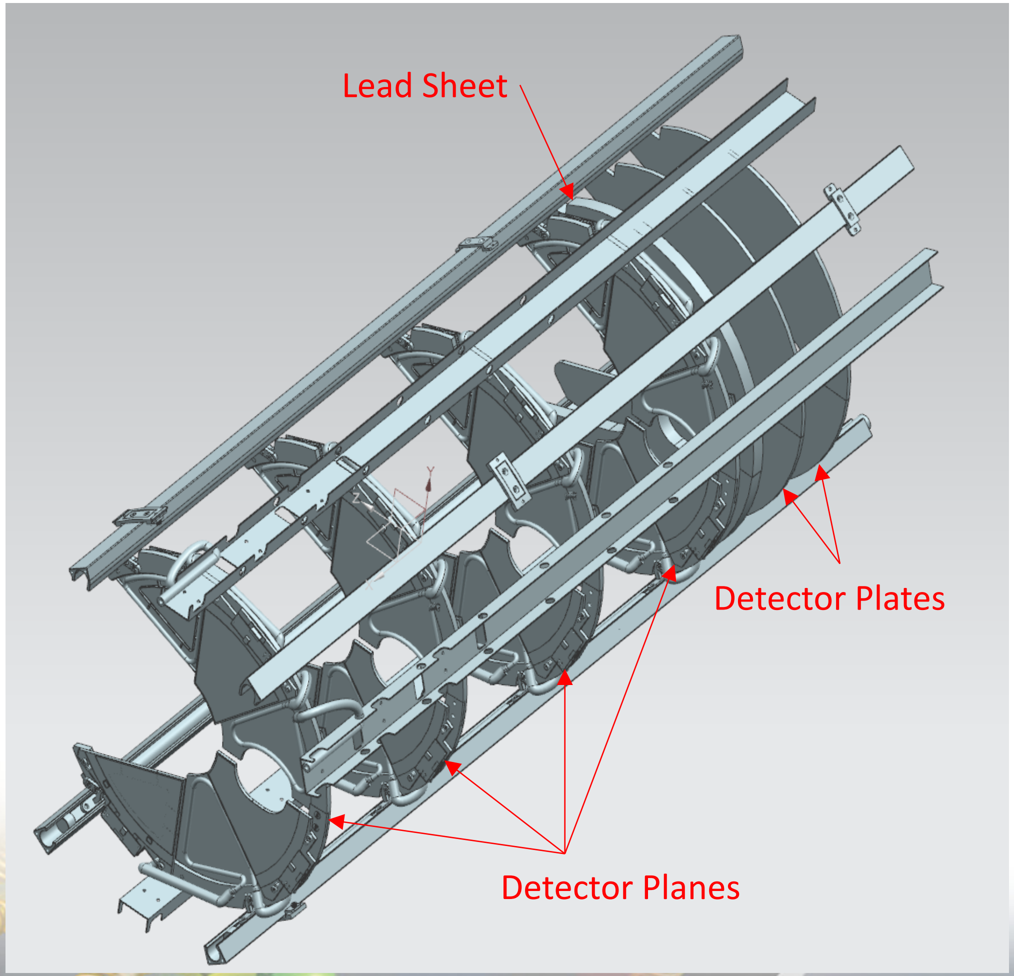




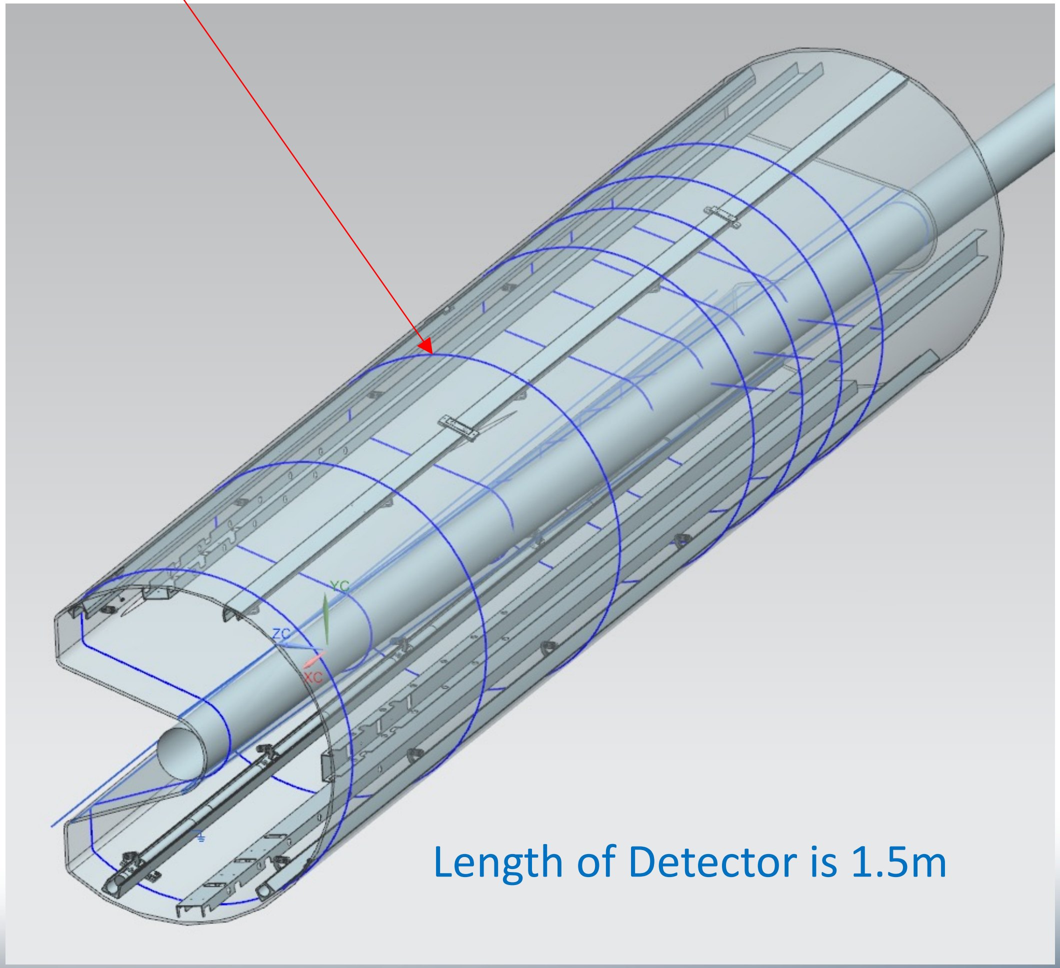
This is the opening where the detector planes will be inserted

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

B0 Detectors in CAD

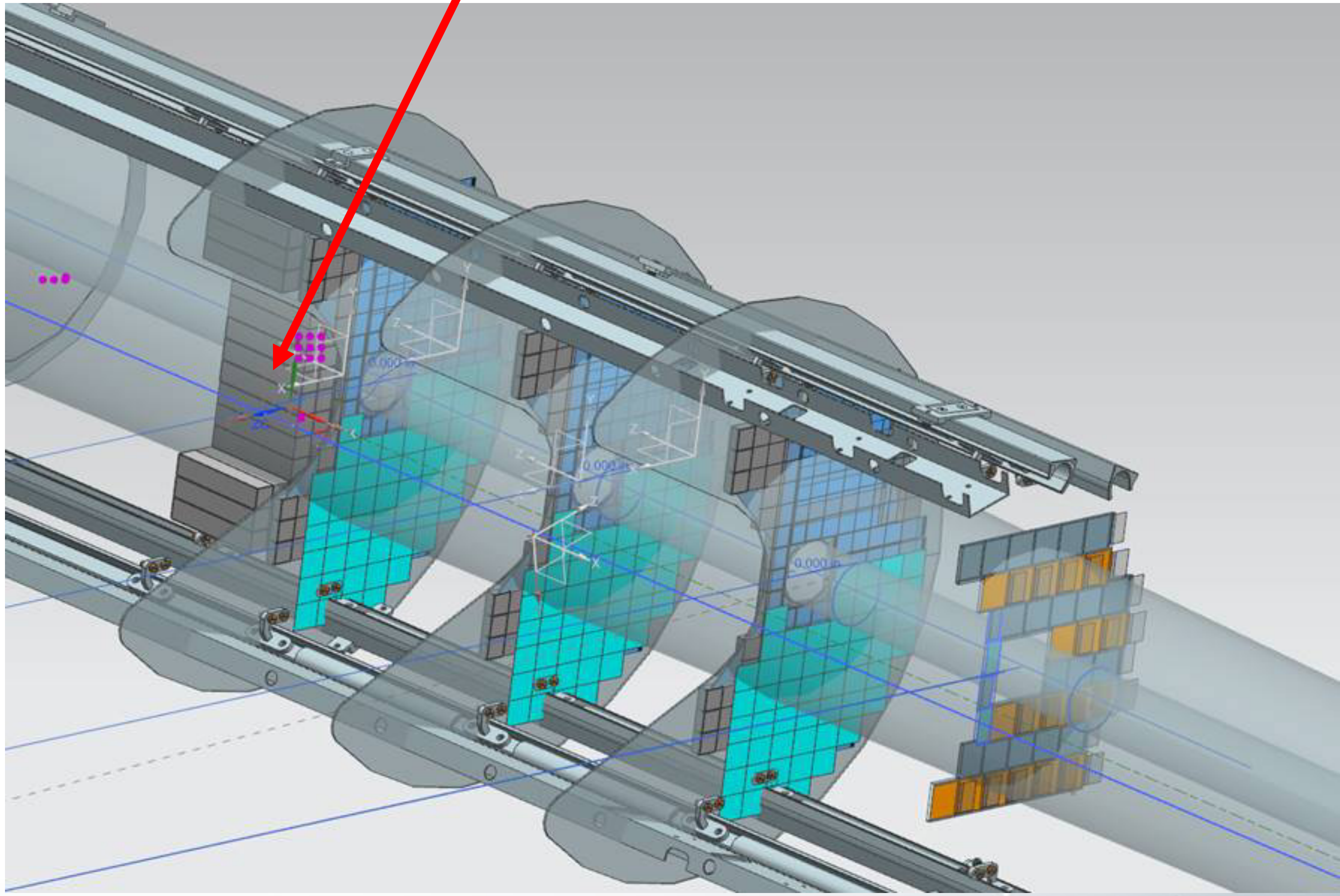


Blue lines represent where element locations are along beamline



B0 Integration

EMCAL at back of the B0pf bore

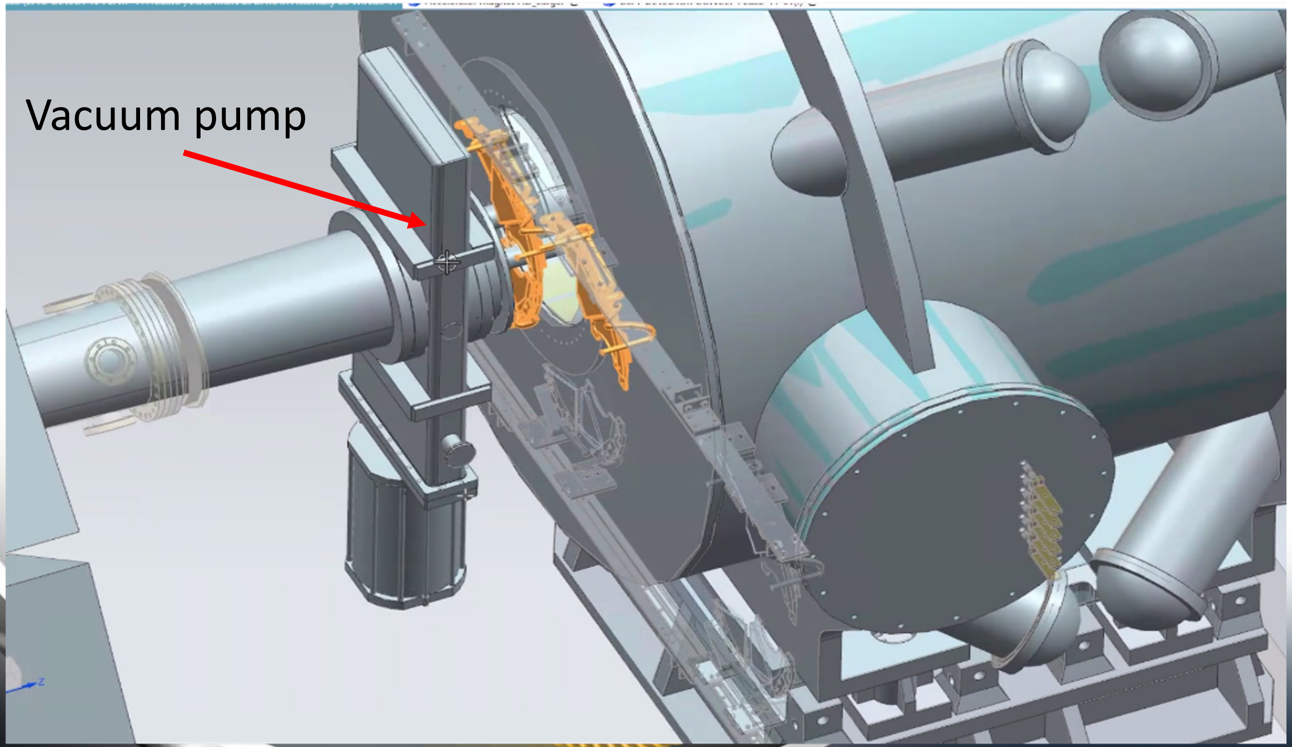


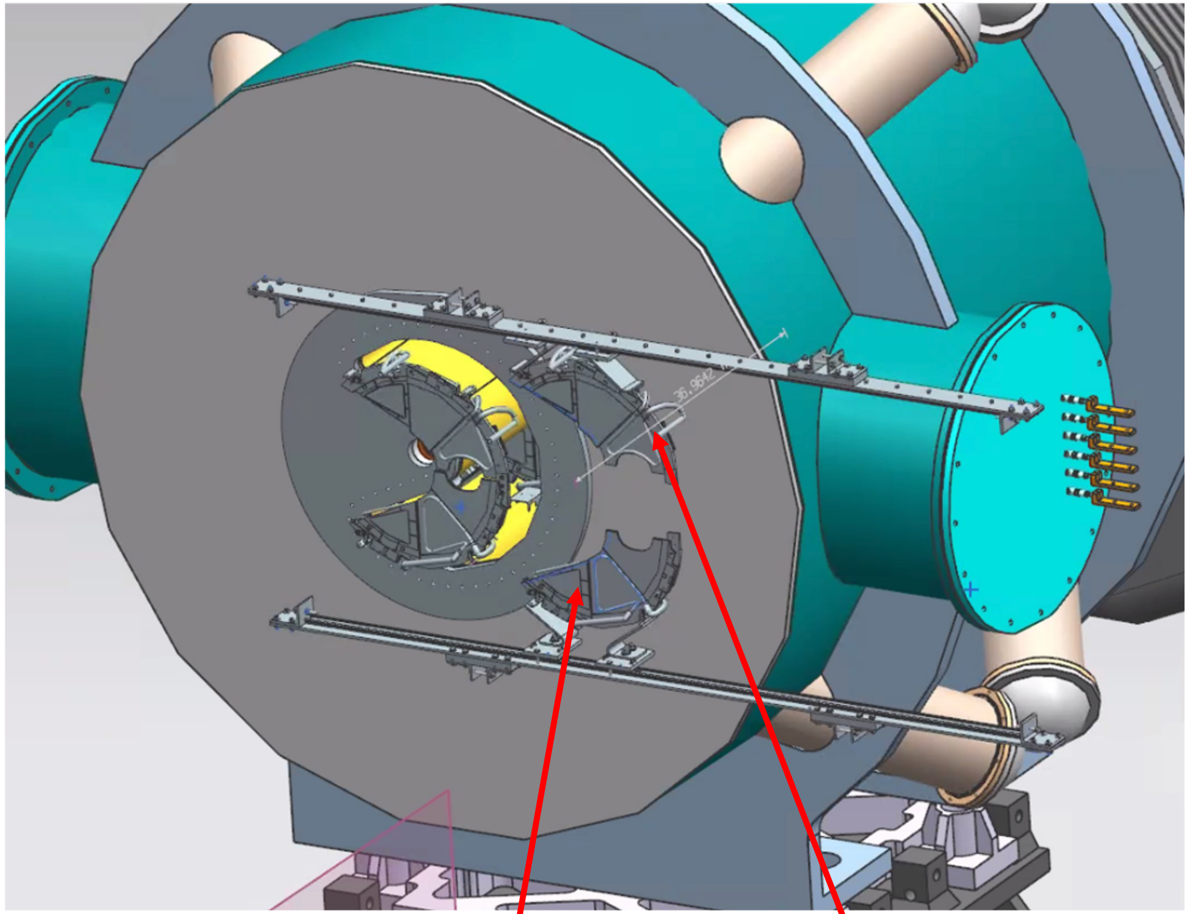
- Crystal EMCAL weight is ~50kg (for $PbWO_4$) → **support system and installation procedure for the blocks needs to be designed.**
  - Readout? → SiPMs optimal for size, but radiation loads in B0 substantial.
  - Access to B0 system requires removal of pump in front of magnet (see next slide) → not easy to simply reach in and replace PMTs.

B0 Integration

Ron Lassiter

- Pump in front of detector package - only 13cm of space between pump and detector.
- Not currently in DD4HEP geometry - another source of secondaries (impact to be evaluated).

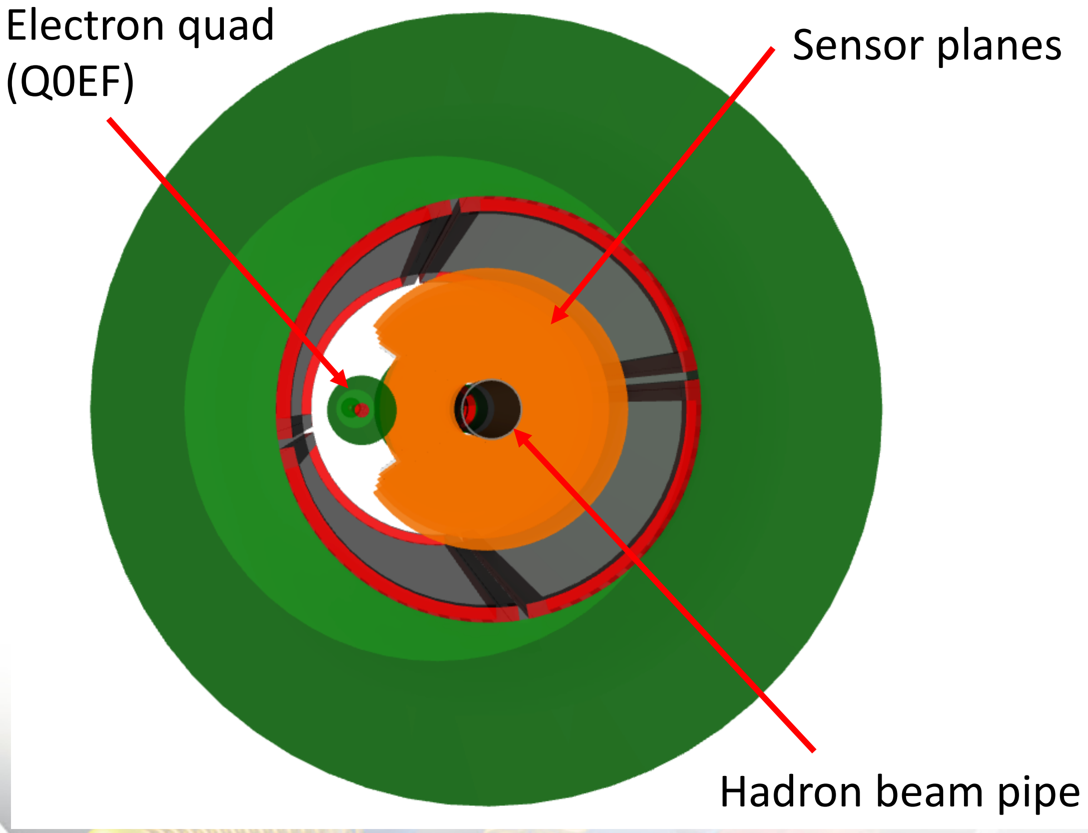




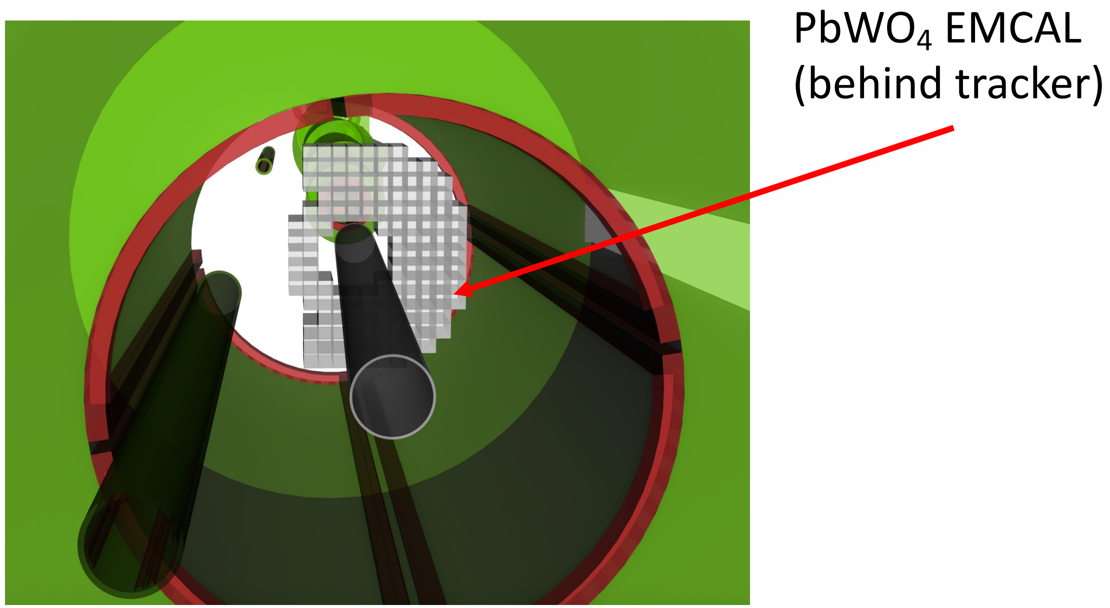
- Tracking planes separate into two pieces - top and bottom - for insertion into bore.
- Need concept for EMCAL.

B0-detectors

(5.5 < $\boldsymbol{\theta}$ < 20.0 mrad)



DD4HEP Simulation

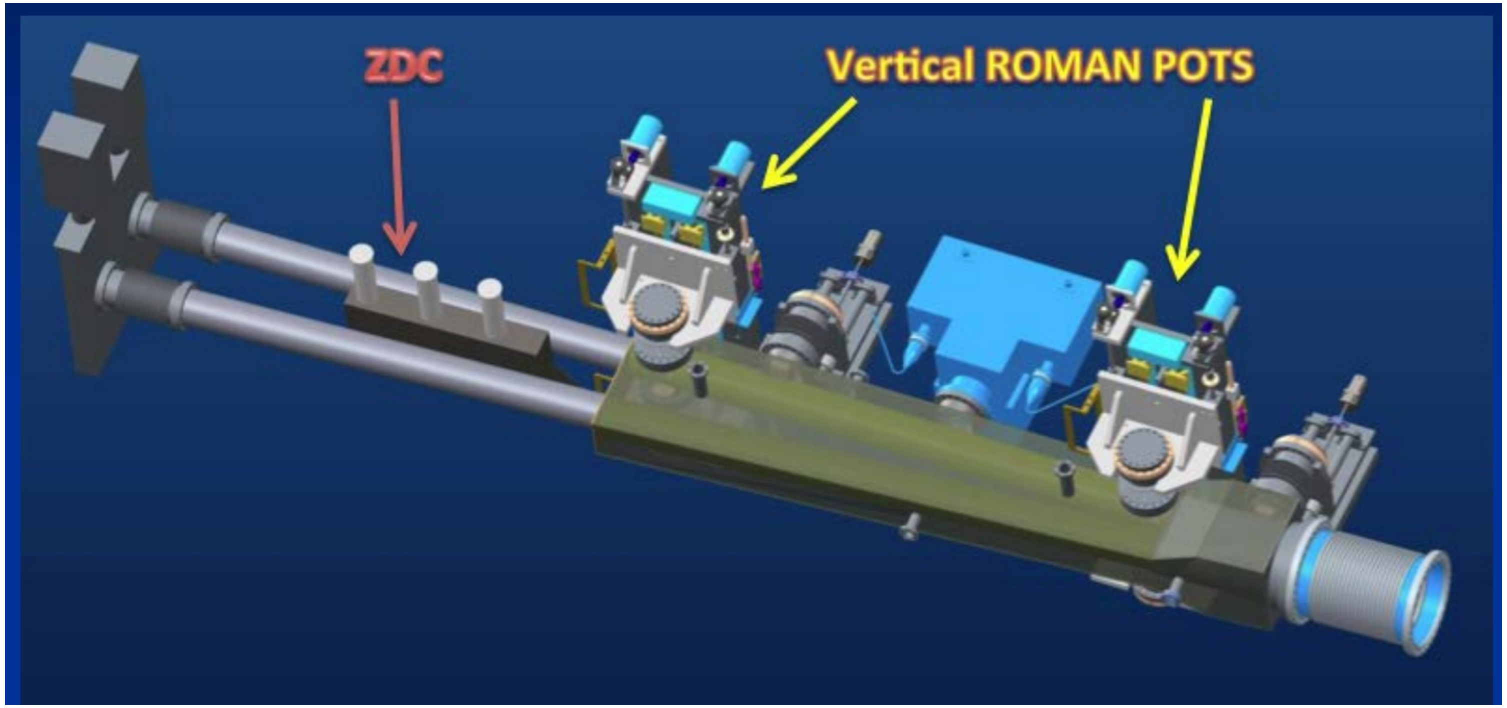


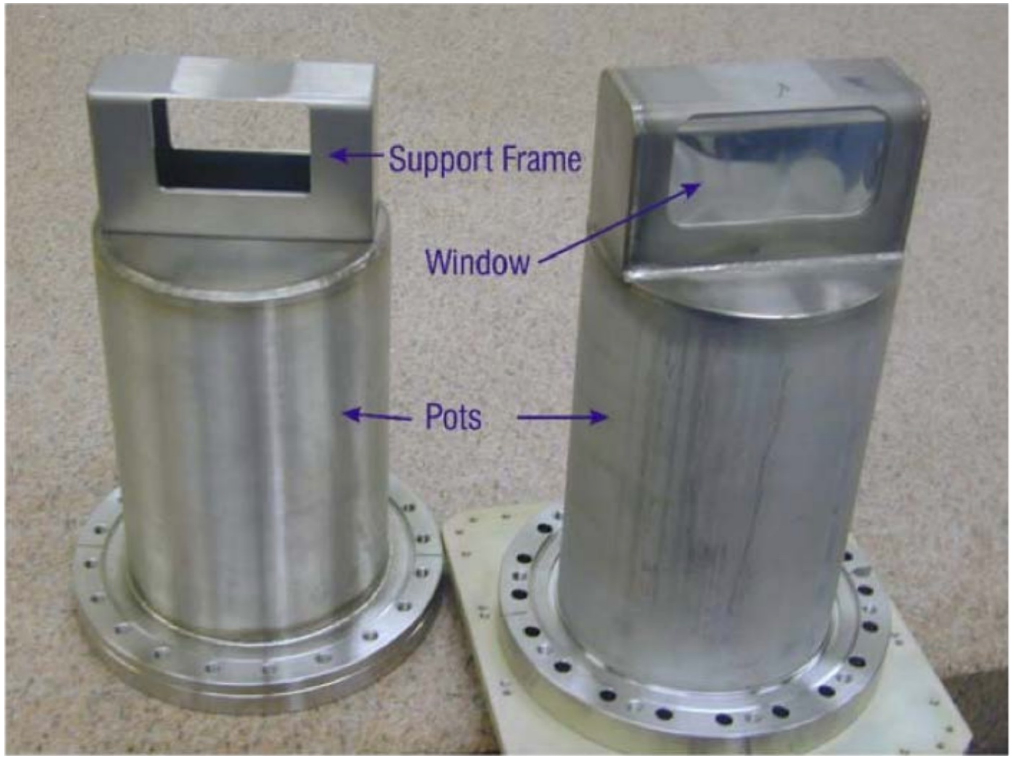
- High-precisions tracking detectors required for charged particle reconstruction.
- Tagging photons important in differentiating between coherent and incoherent heavy-nuclear scattering, and for reconstructing $\pi^0 \rightarrow \gamma\gamma$.

Roman Pots

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

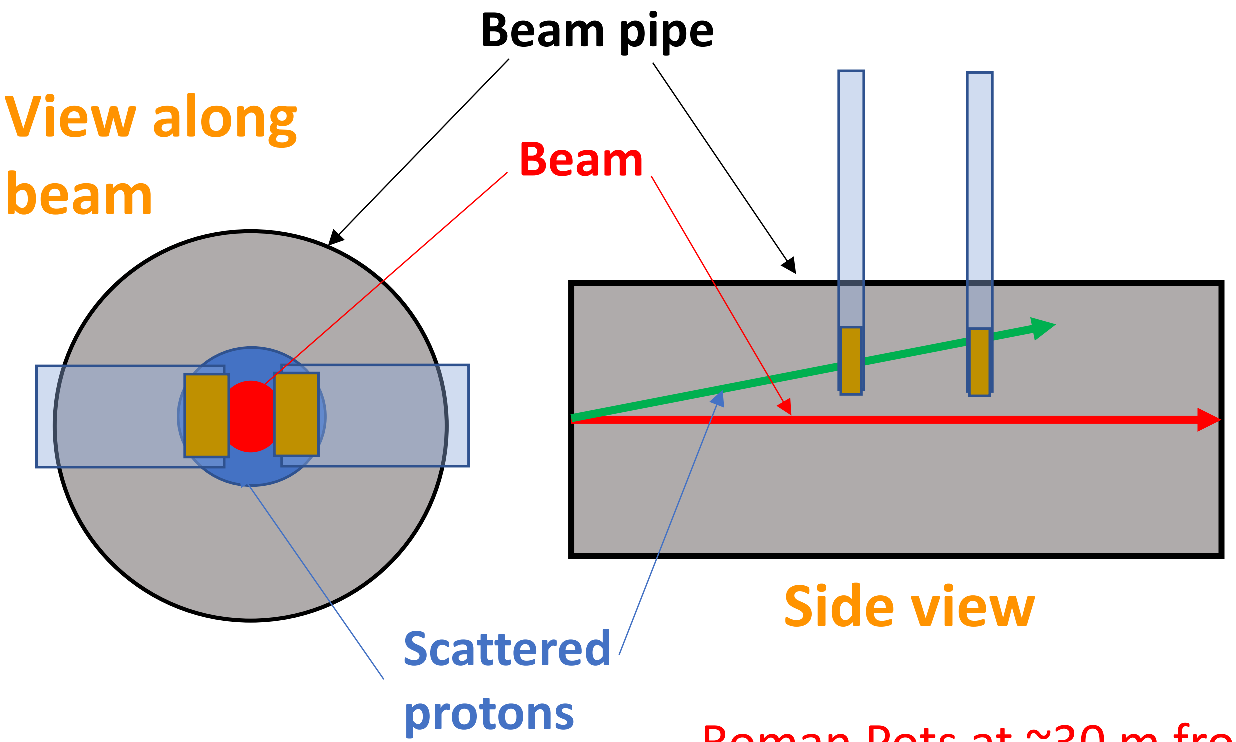
Roman Pots





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

Roman Pots



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

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

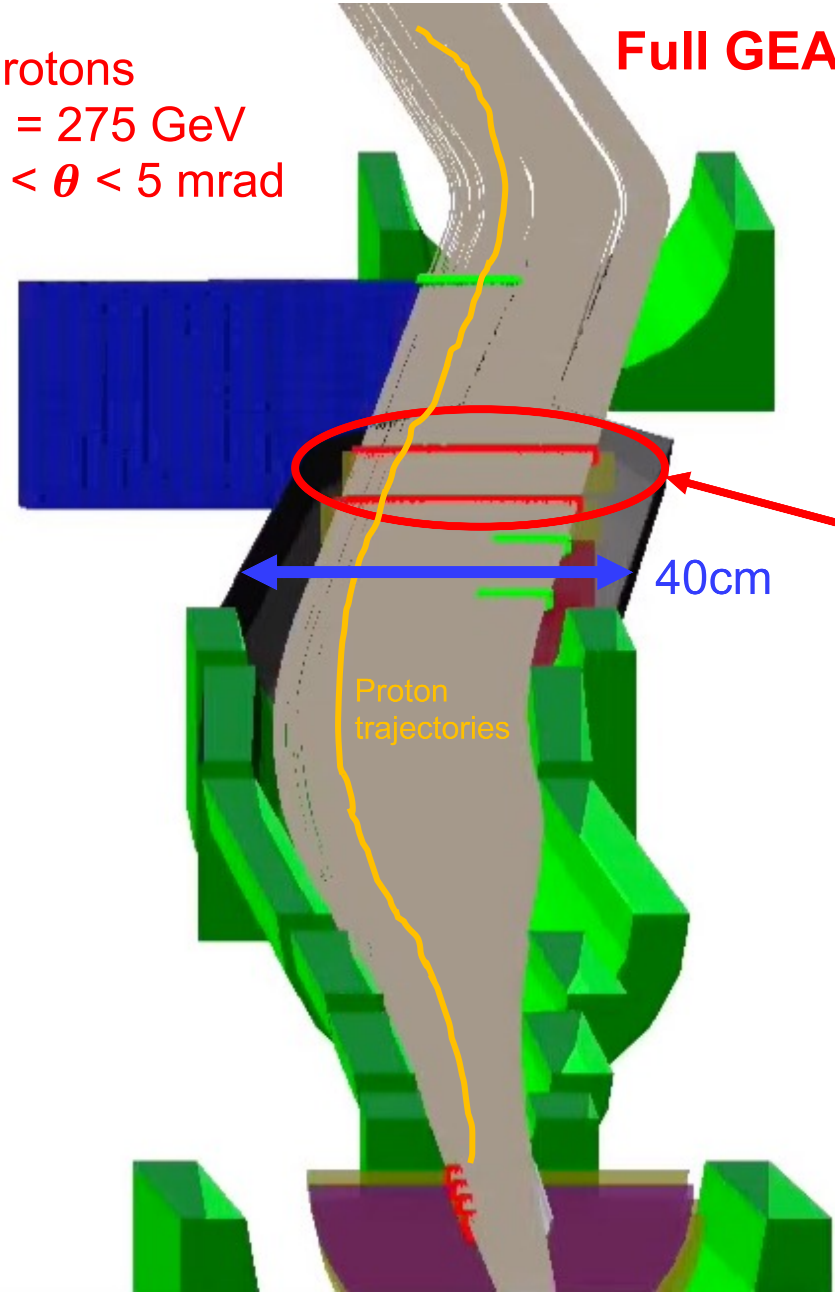
Roman Pots at ~30 m from IP → $\theta \backsim$ 0 - 5 mrad

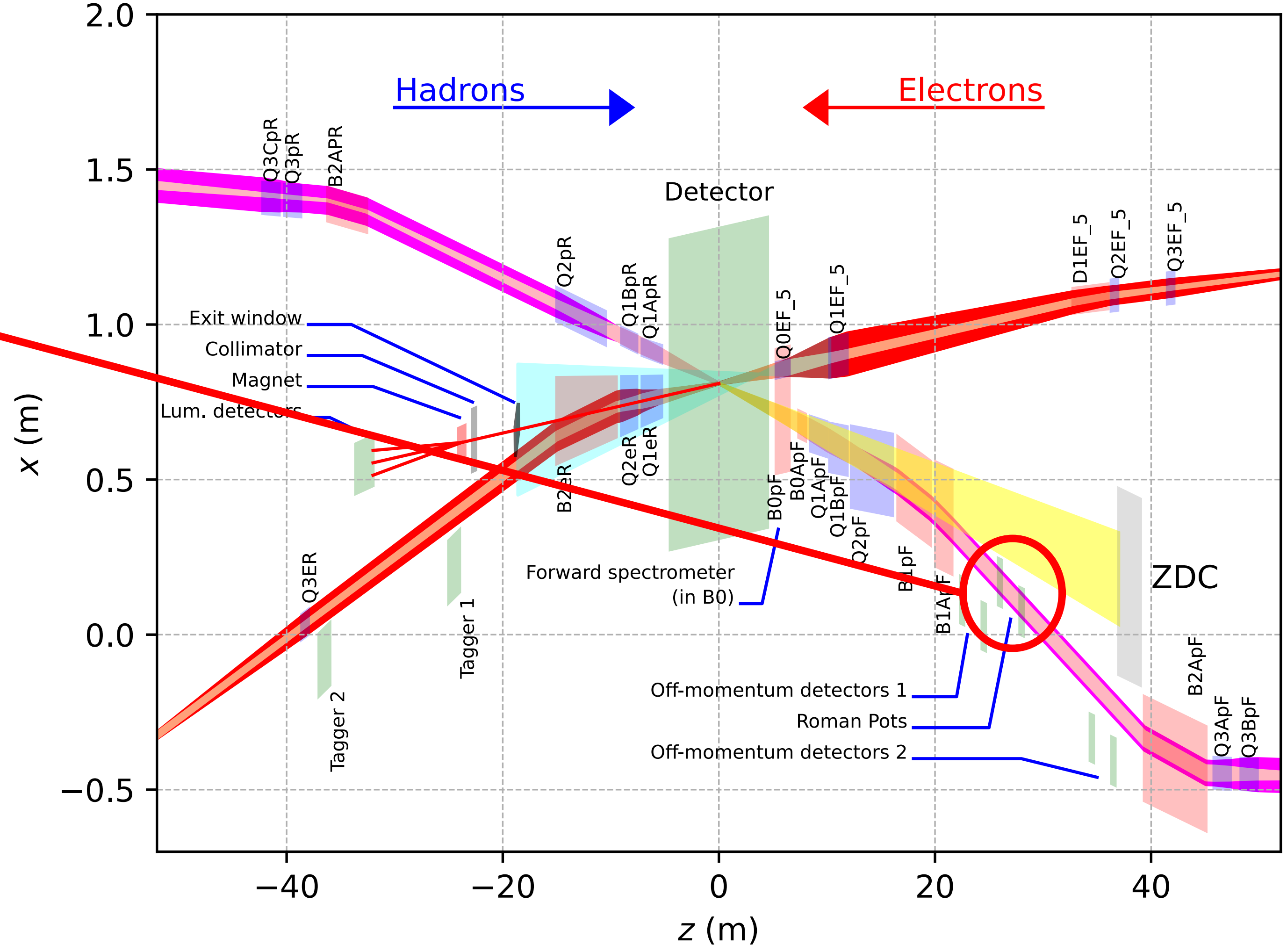
- Roman Pots are silicon sensors placed in a "pot", which is then injected into the beam pipe, tens of meters or more from the interaction point (IP).
- Momentum reconstruction carried out using matrix transport of protons through magnetic lattice.

Roman Pots @ the EIC

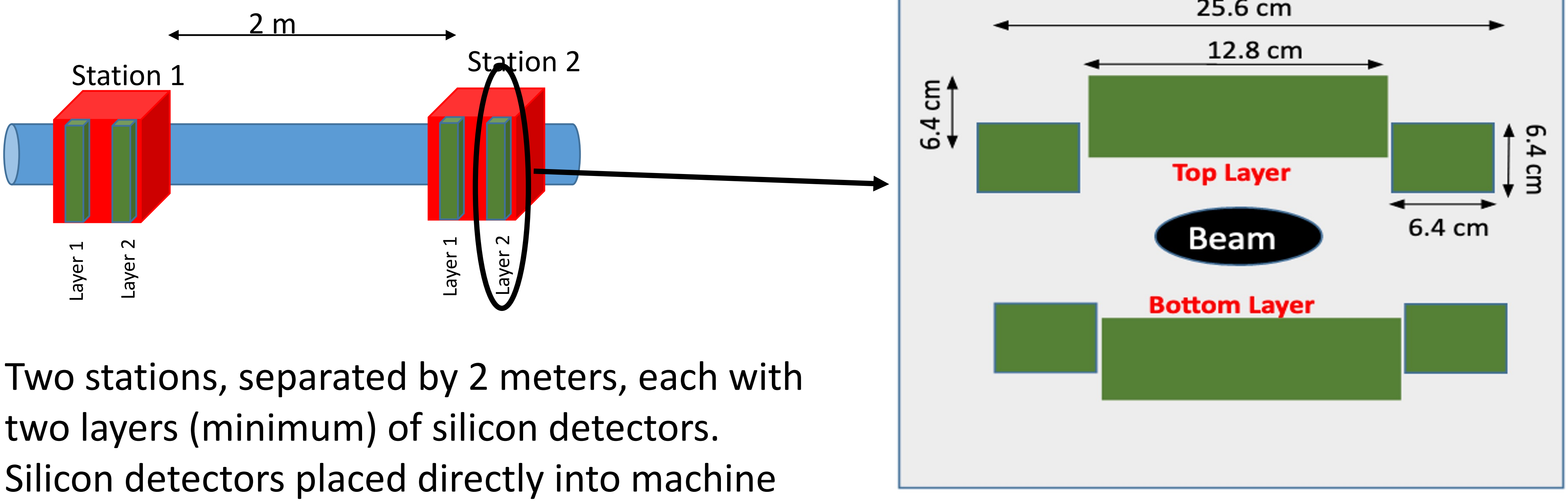
Protons
E = 275 GeV
0 < θ < 5 mrad

Full GEANT4 simulation.



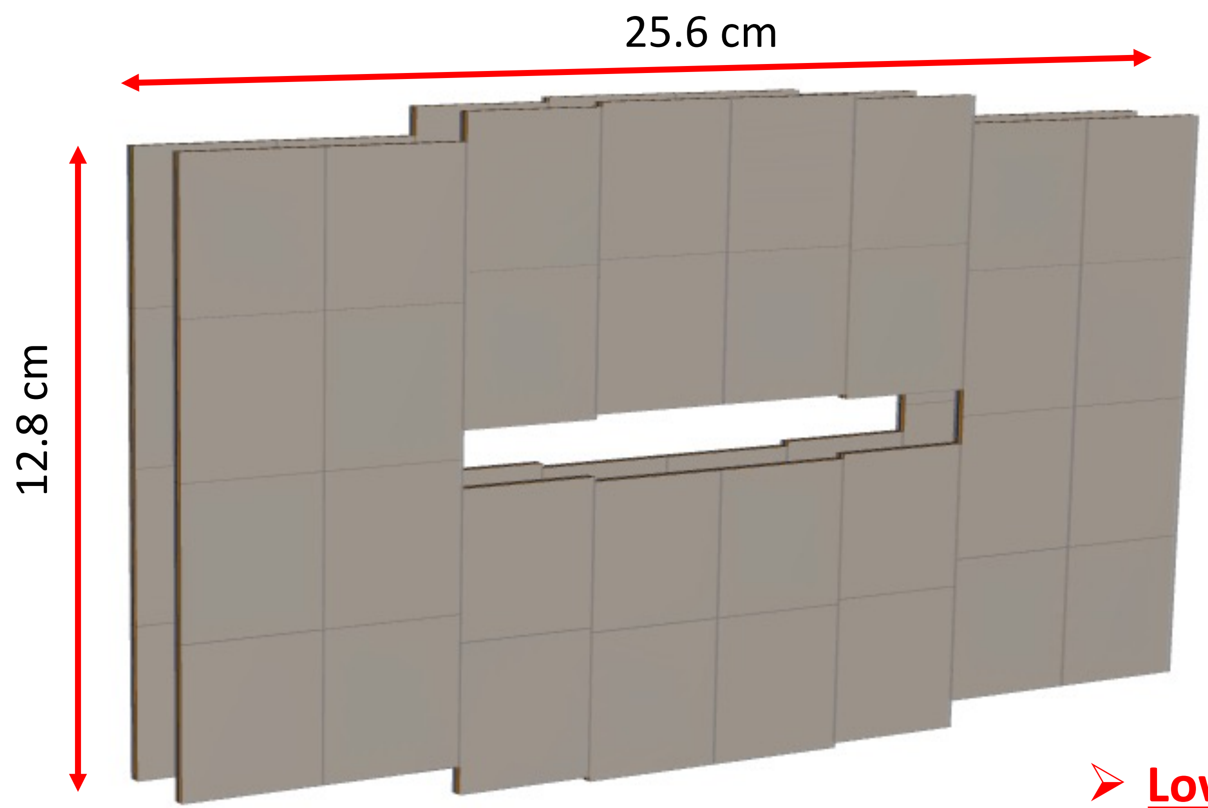


Roman "Pots" @ the EIC



- 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.

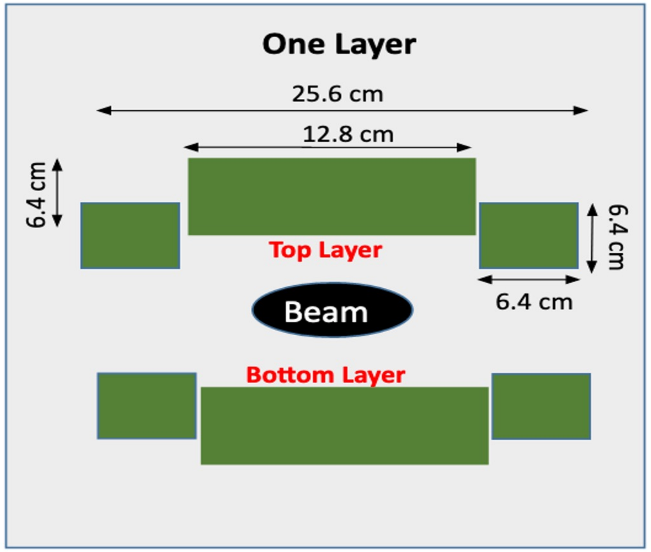
Roman “Pots” @ the EIC



DD4HEP Simulation

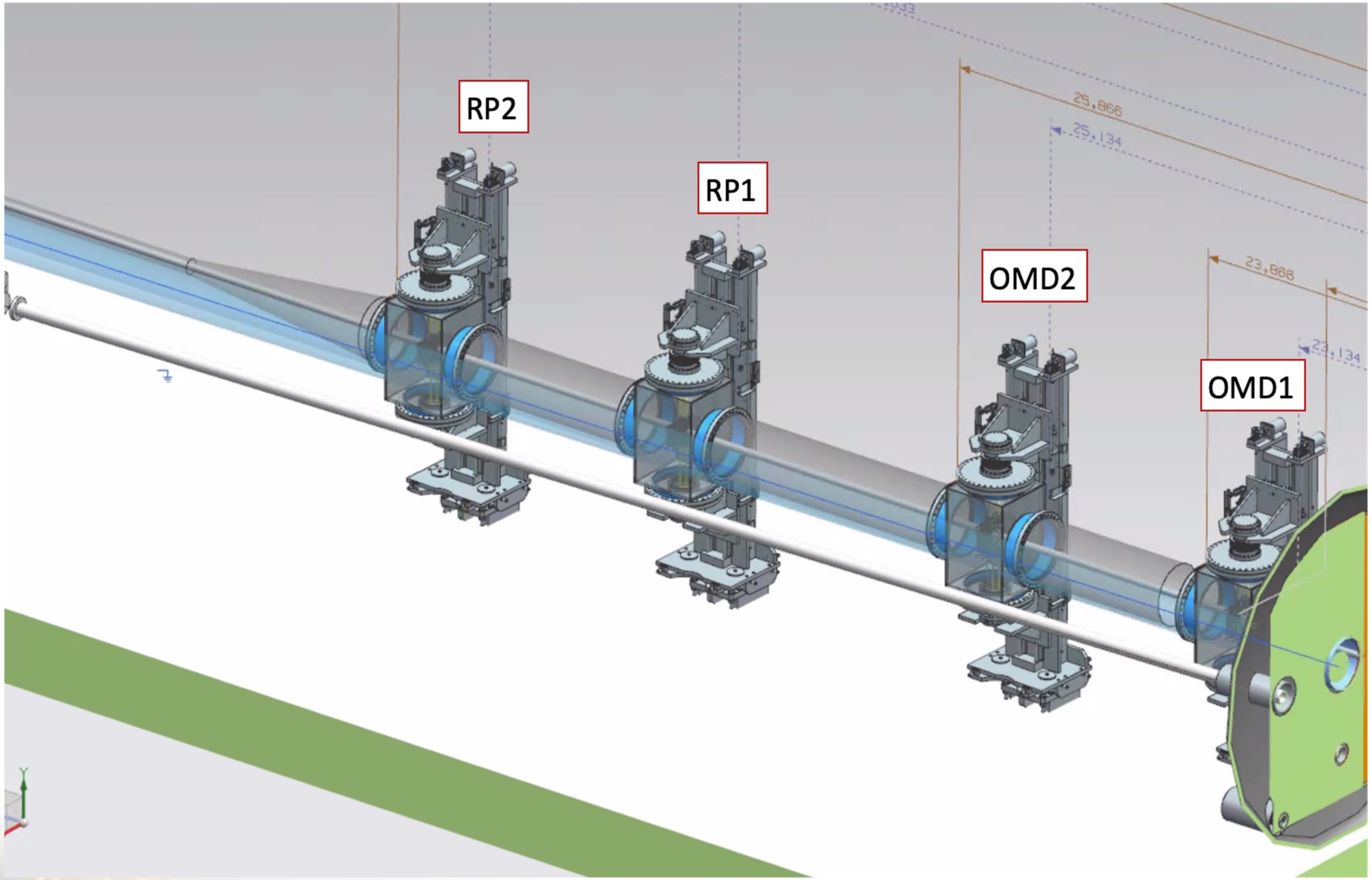
$\sigma(z)$ is the Gaussian width of the beam, $\beta(z)$ is the RMS transverse beam size.
ε is the beam emittance.

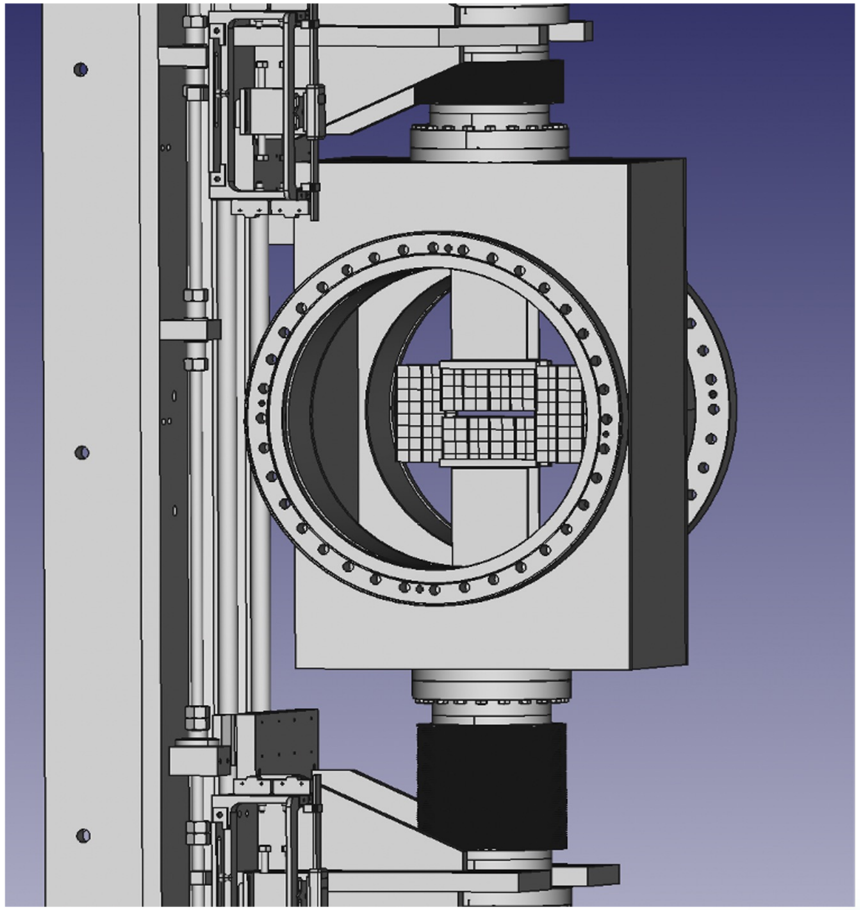
$$\sigma(z) = \sqrt{\varepsilon \cdot \beta(z))}$$



- **Low-pT cutoff determined by beam optics.**
  - **The safe distance is ~10σ from the beam center.**
  - **1$\sigma \sim$ 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*.**

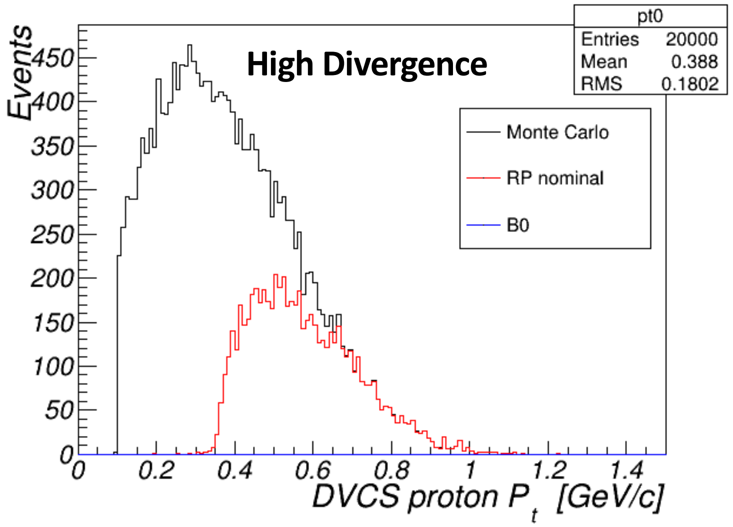
Roman “Pots” @ the EIC

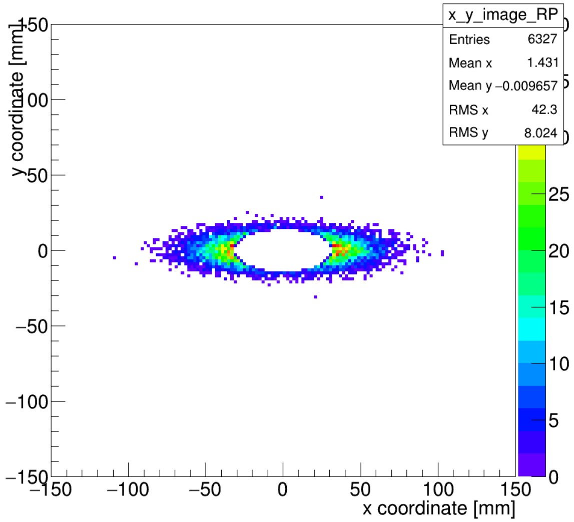


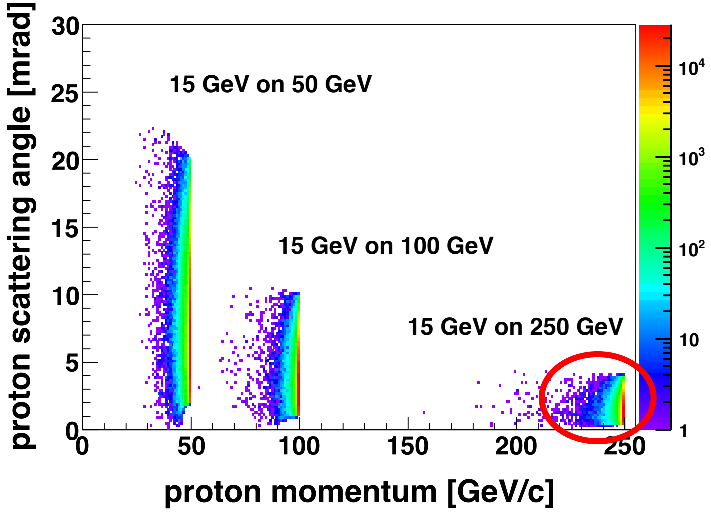


Digression: Machine Optics

275 GeV DVCS Proton Acceptance



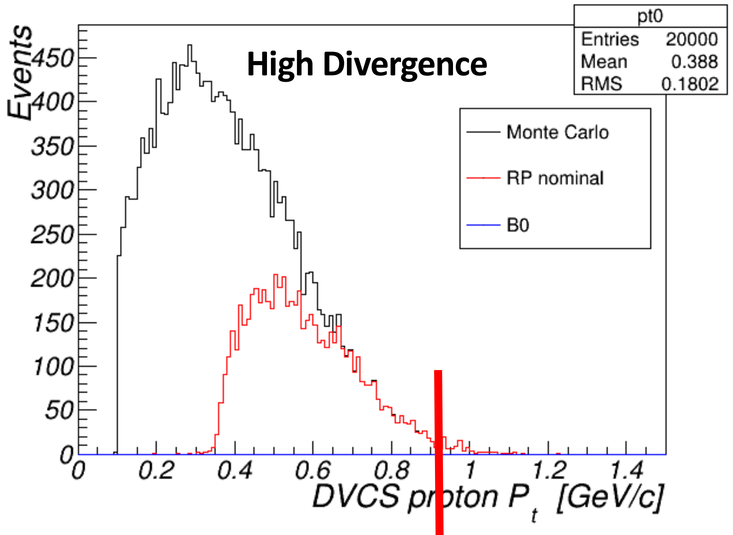


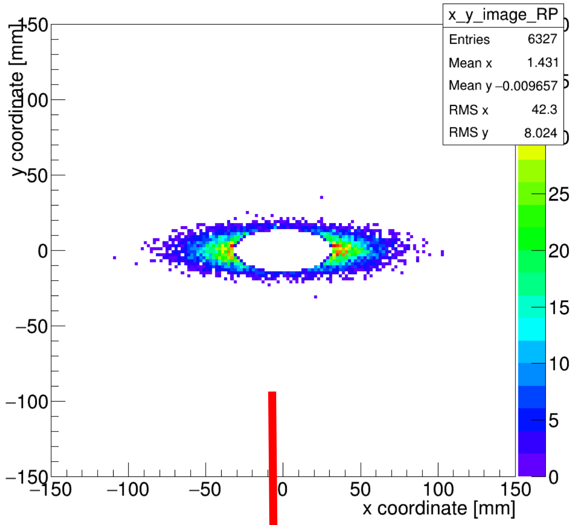


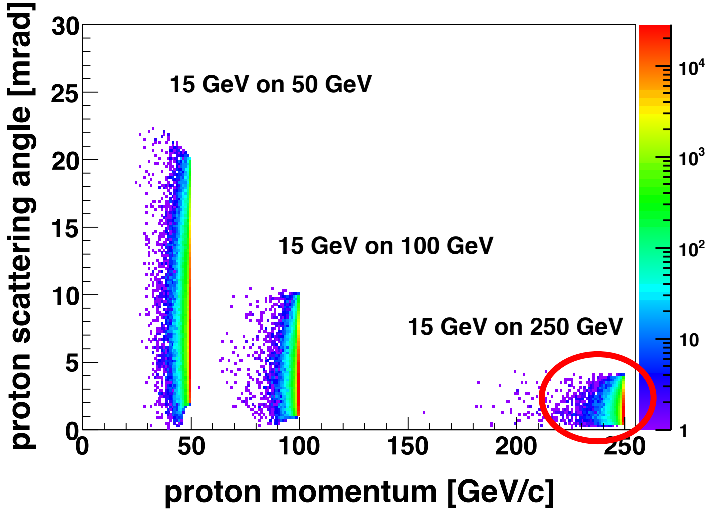
High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ ->
higher lumi., larger beam at RP

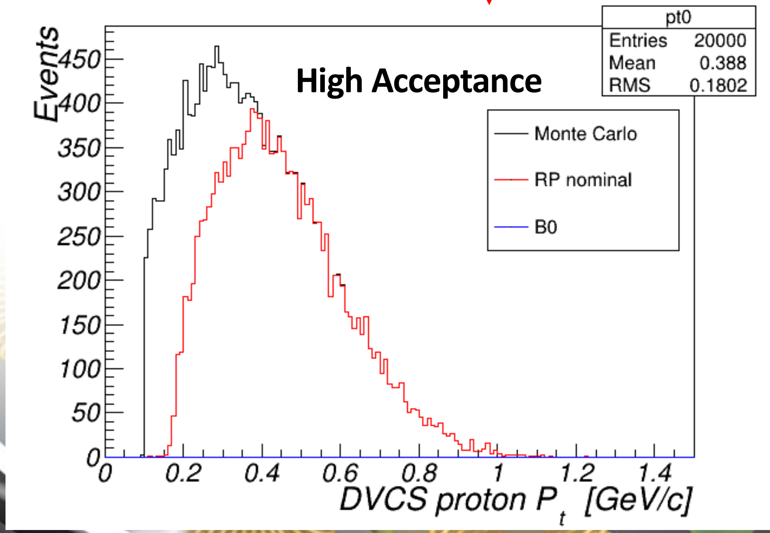
Digression: Machine Optics

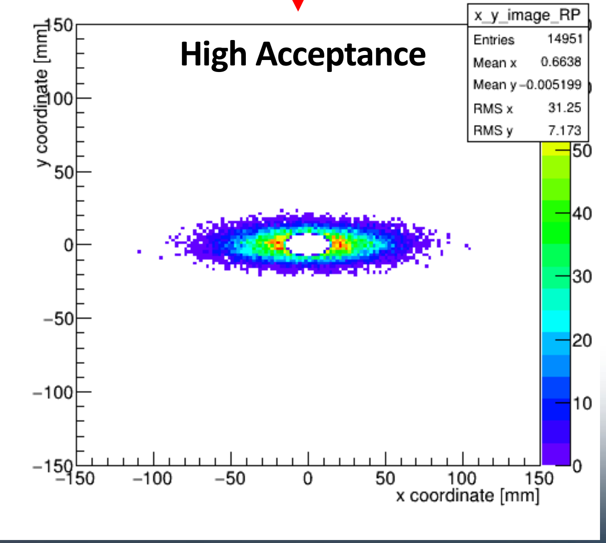
275 GeV DVCS Proton Acceptance









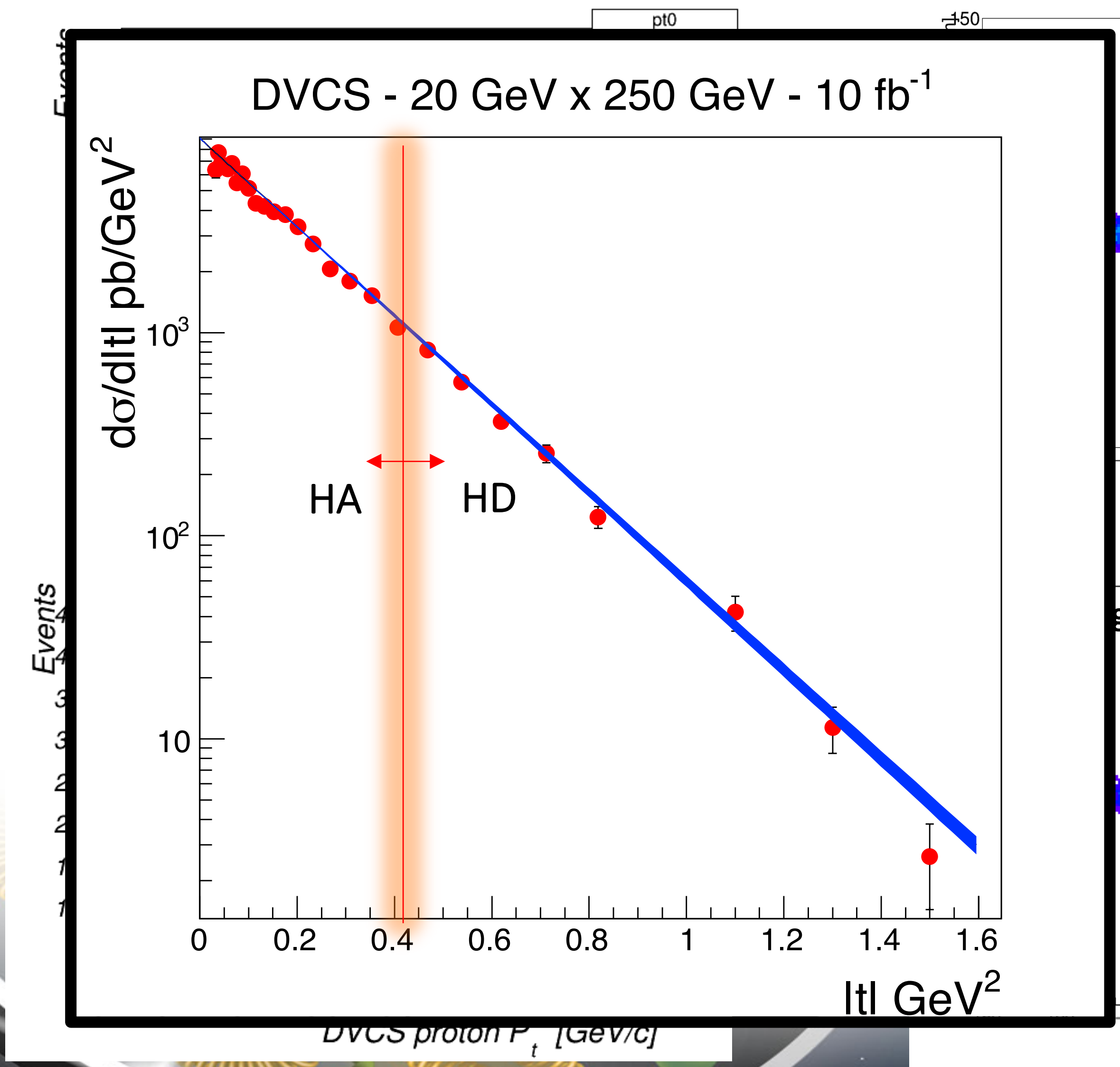


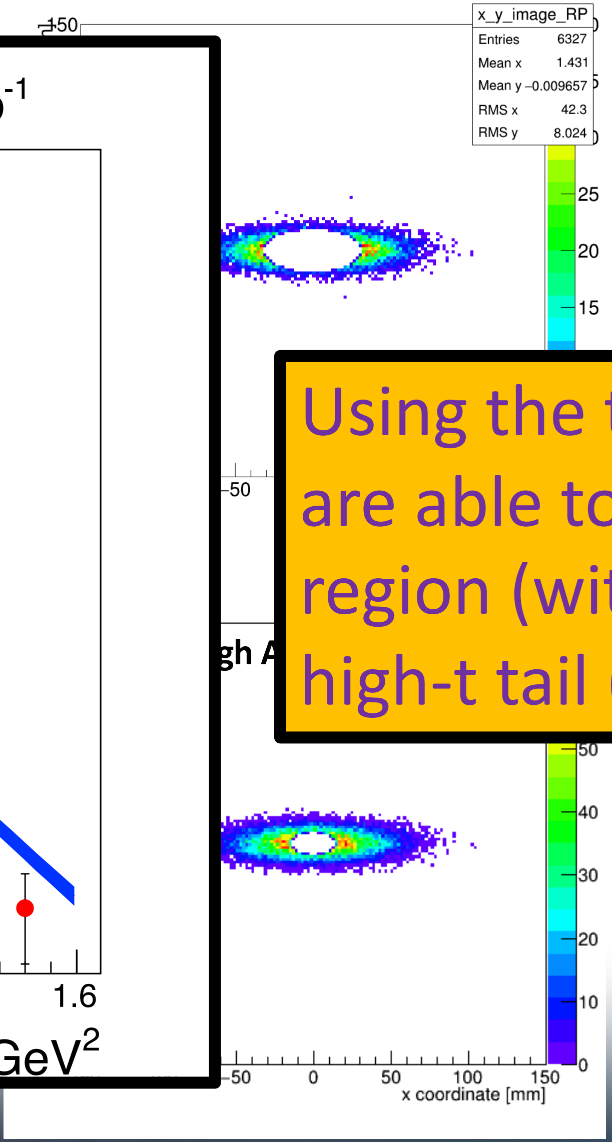
High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

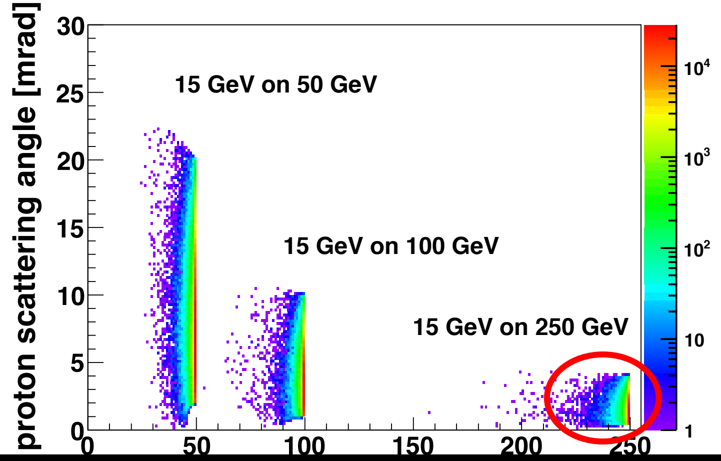
High Acceptance: larger β^* at IP, smaller $\beta(z = 30m)$ -> lower lumi., smaller beam at RP

Digression: Machine Optics

275 GeV DVCS Proton Acceptance





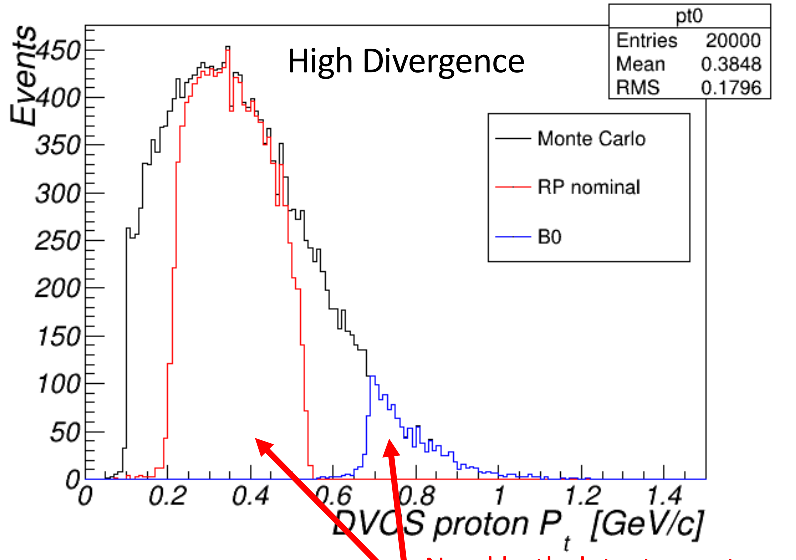


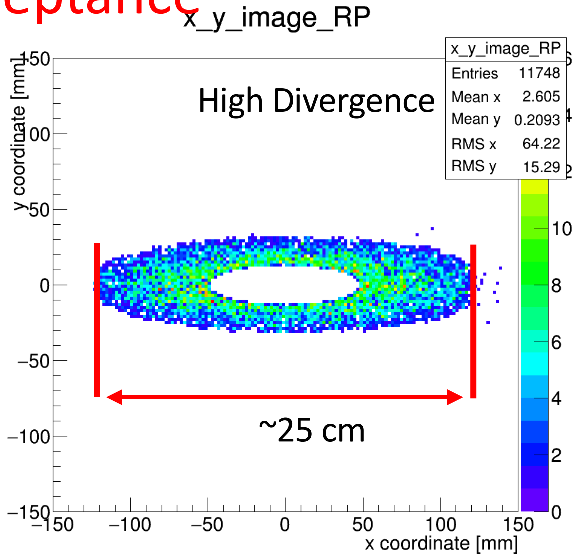
Using the two configurations, we are able to measure the low-t region (with better acceptance) and high-t tail (with higher luminosity).

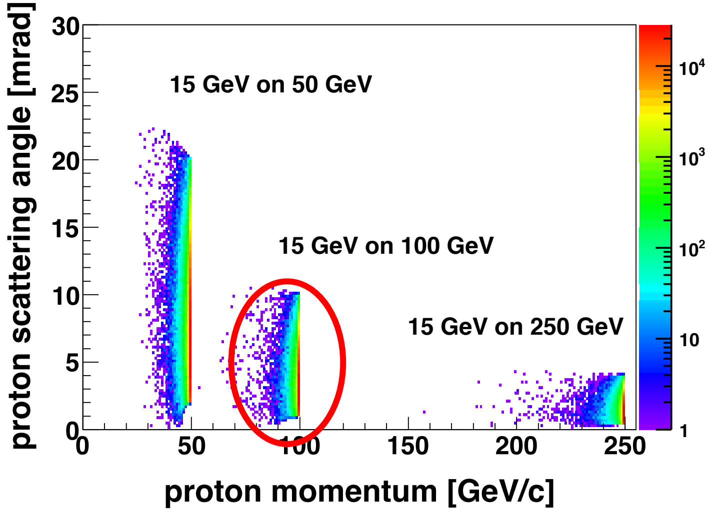
<u>High Acceptance:</u> larger β^* at IP, smaller $\beta(z = 30m)$ -> lower lumi., smaller beam at RP

Digression: Machine Optics

100 GeV DVCS Proton Acceptance



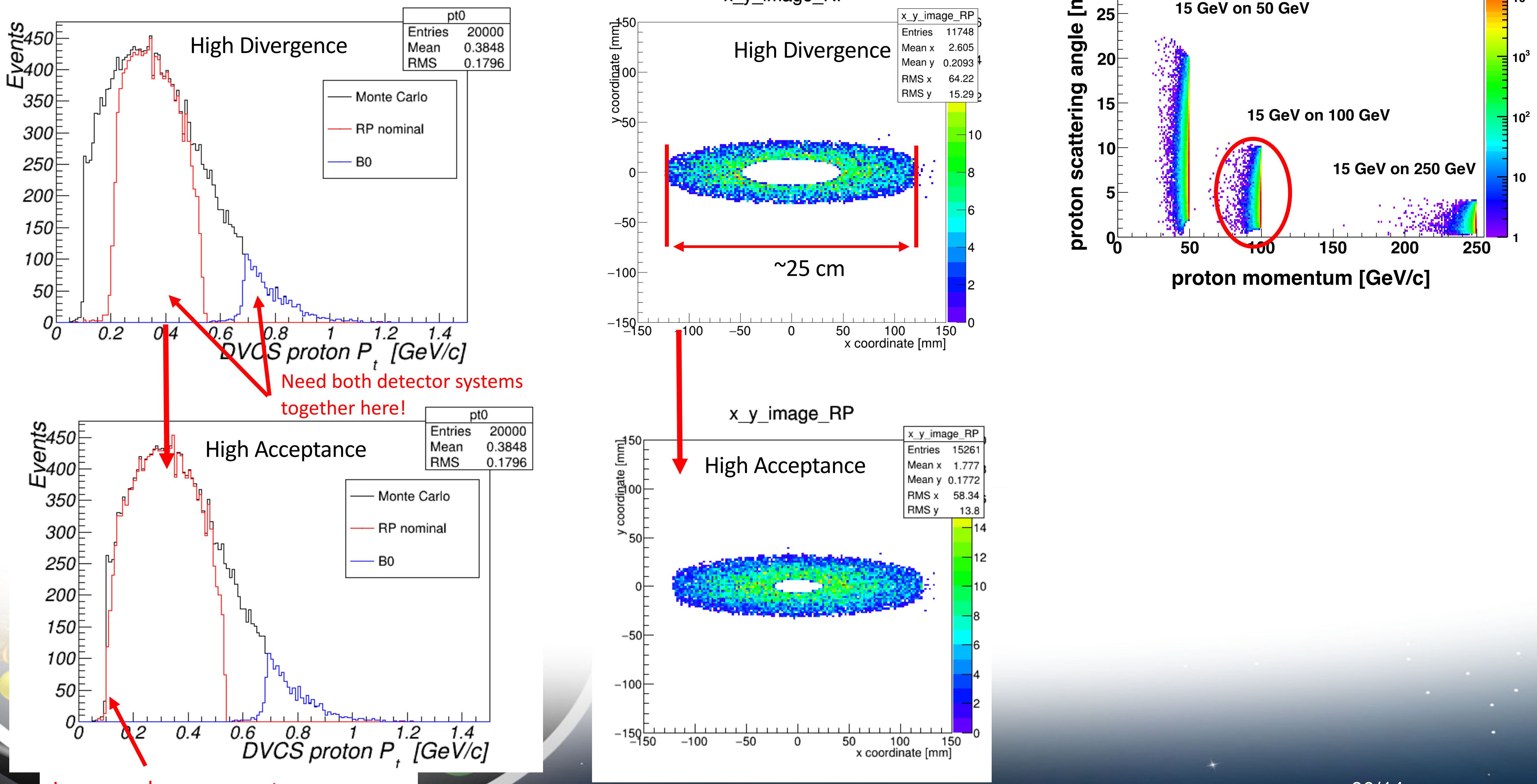




Need both detector systems together here!

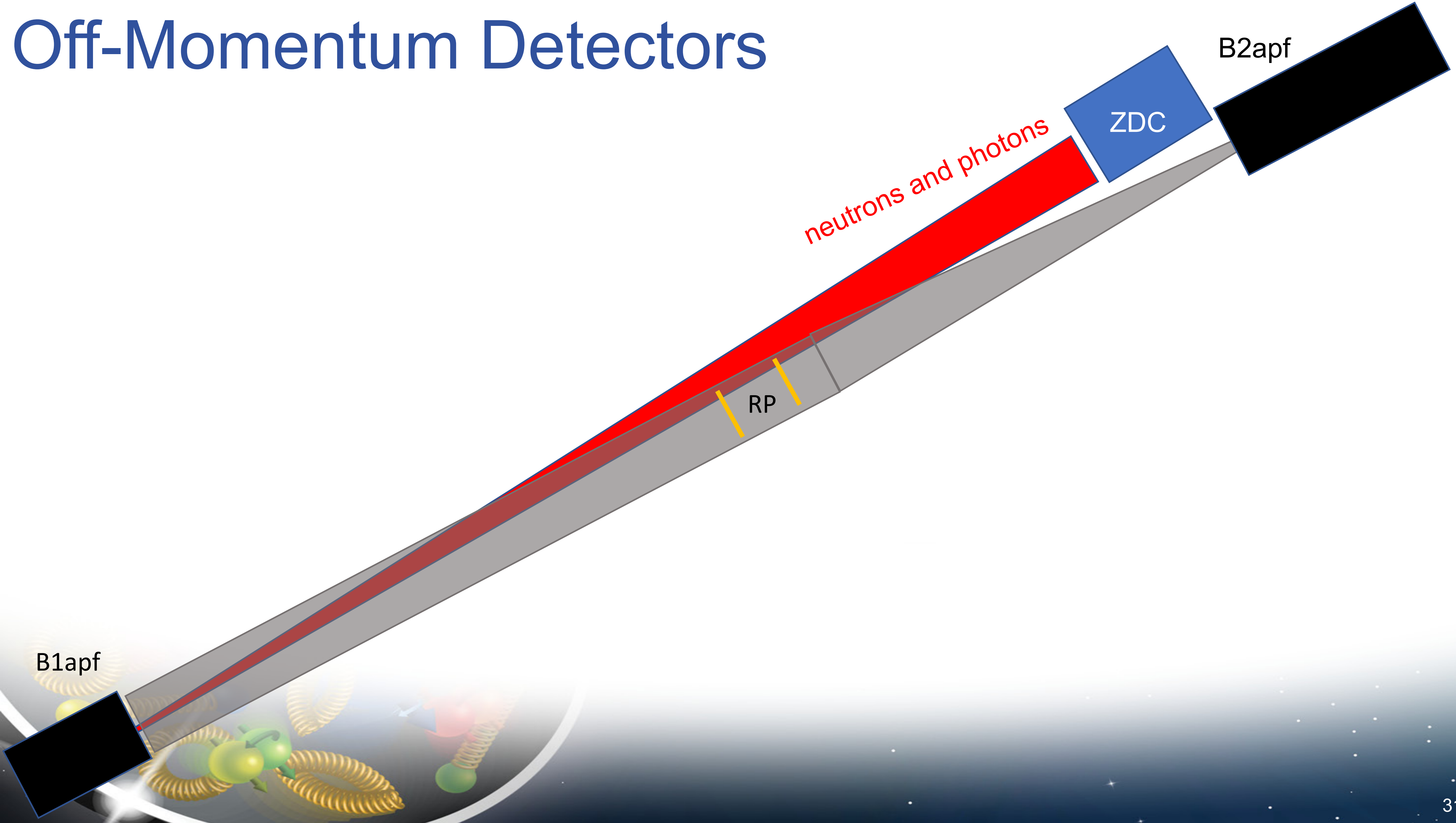
Digression: Machine Optics

100 GeV DVCS Proton Acceptance



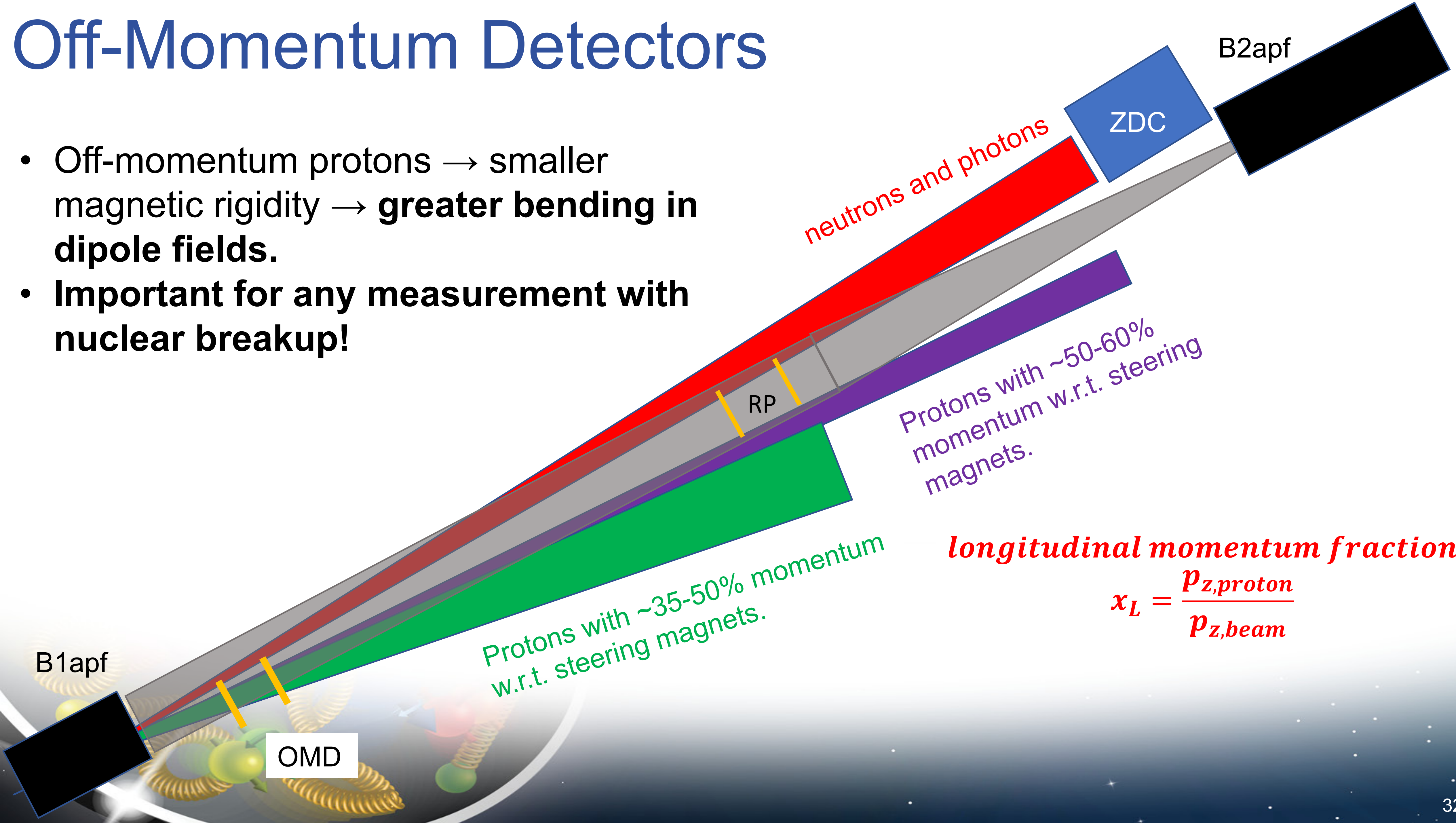
Improves low p_t acceptance.

Off-Momentum Detectors



Off-Momentum Detectors

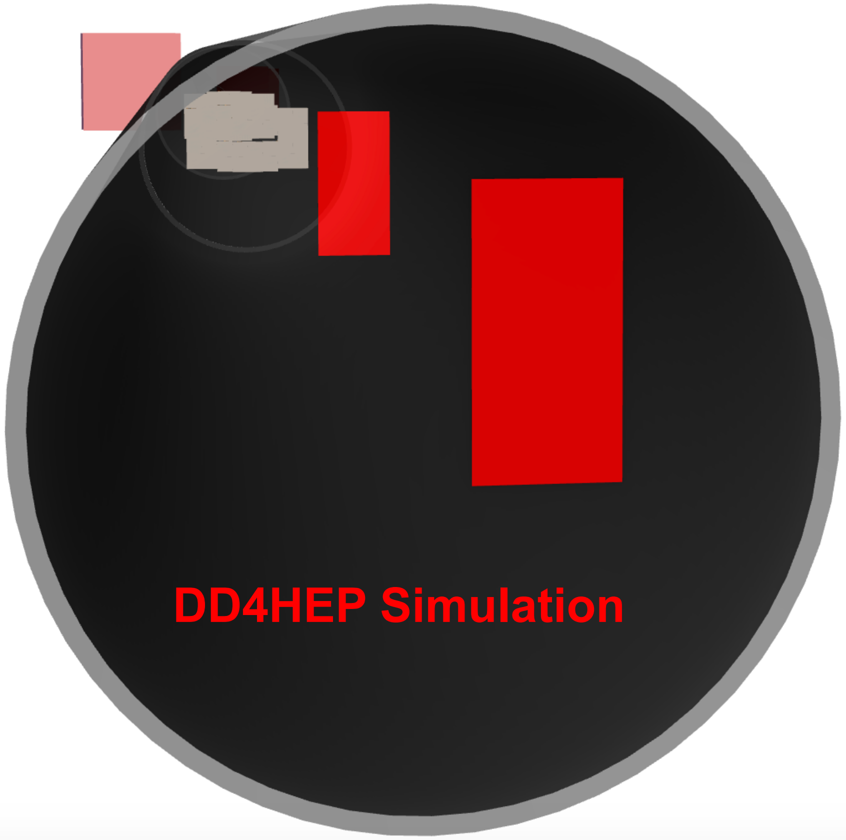
- Off-momentum protons → smaller magnetic rigidity → **greater bending in dipole fields.**
- **Important for any measurement with nuclear breakup!**



longitudinal momentum fraction

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

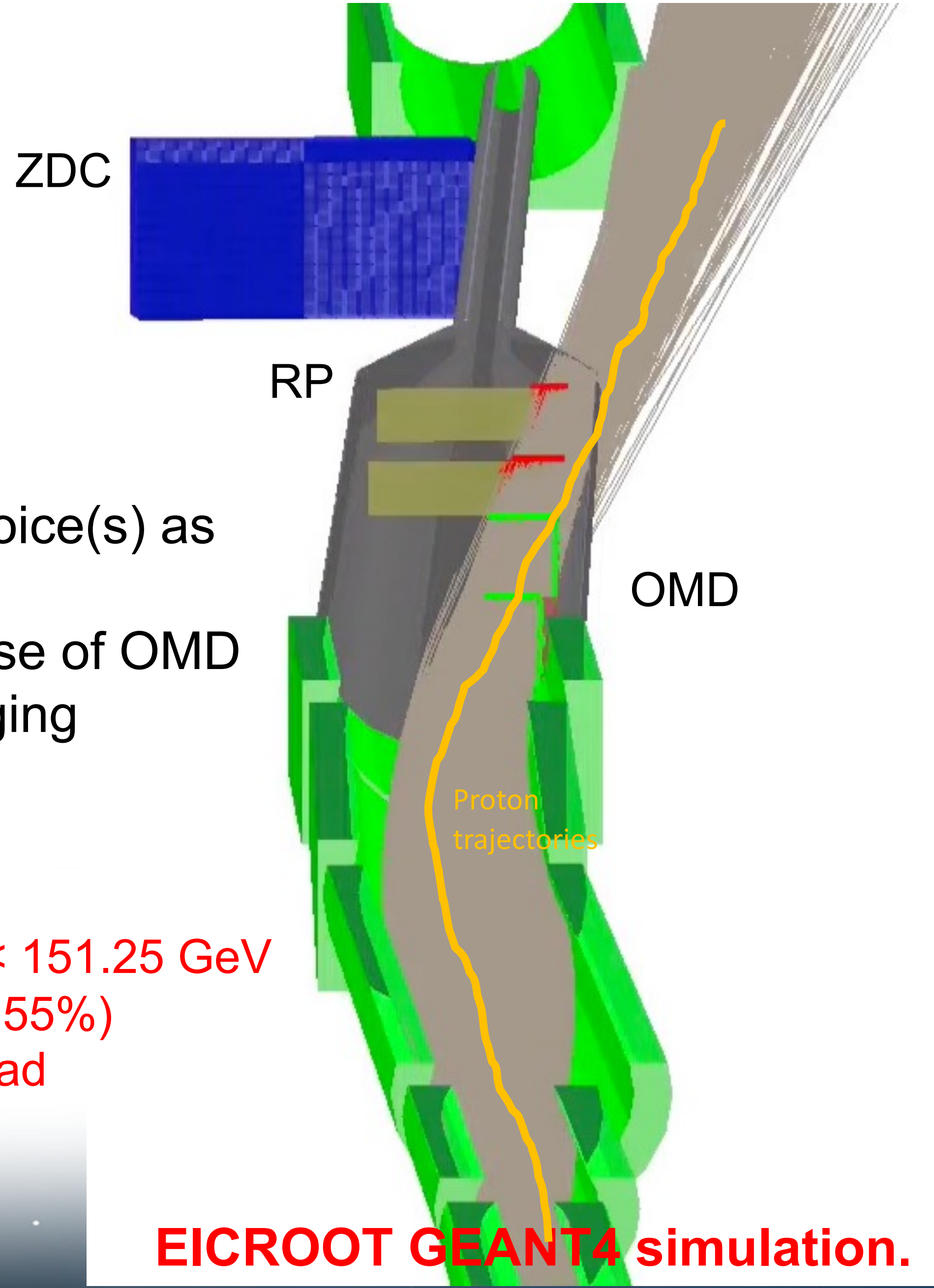
Off-Momentum Detectors



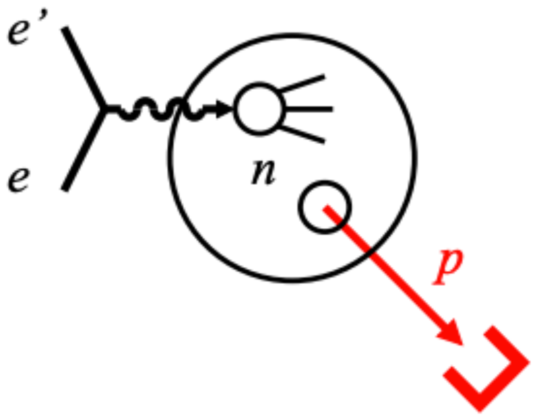
Off-momentum detectors implemented as horizontal ”Roman Pots” style sensors.

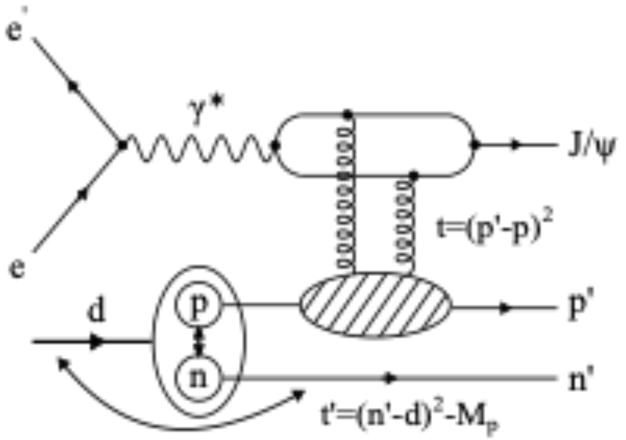
- Same technology choice(s) as for the Roman Pots.
- Need to also study use of OMD on other side for tagging negative pions.

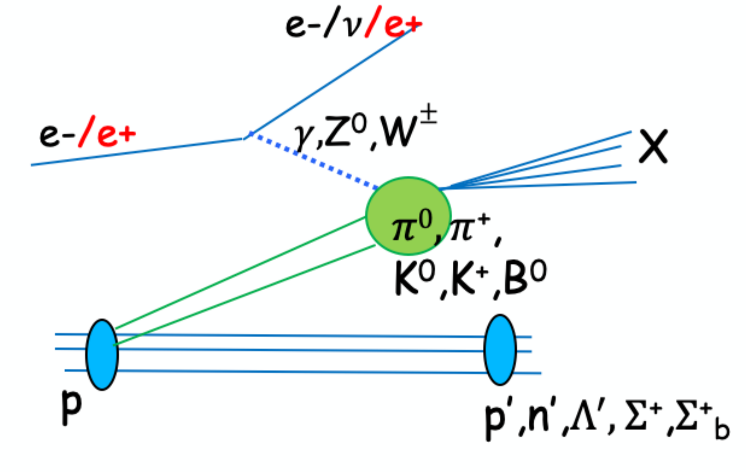
Protons
123.75 < E < 151.25 GeV
(45% < xL < 55%)
0 < θ < 5 mrad

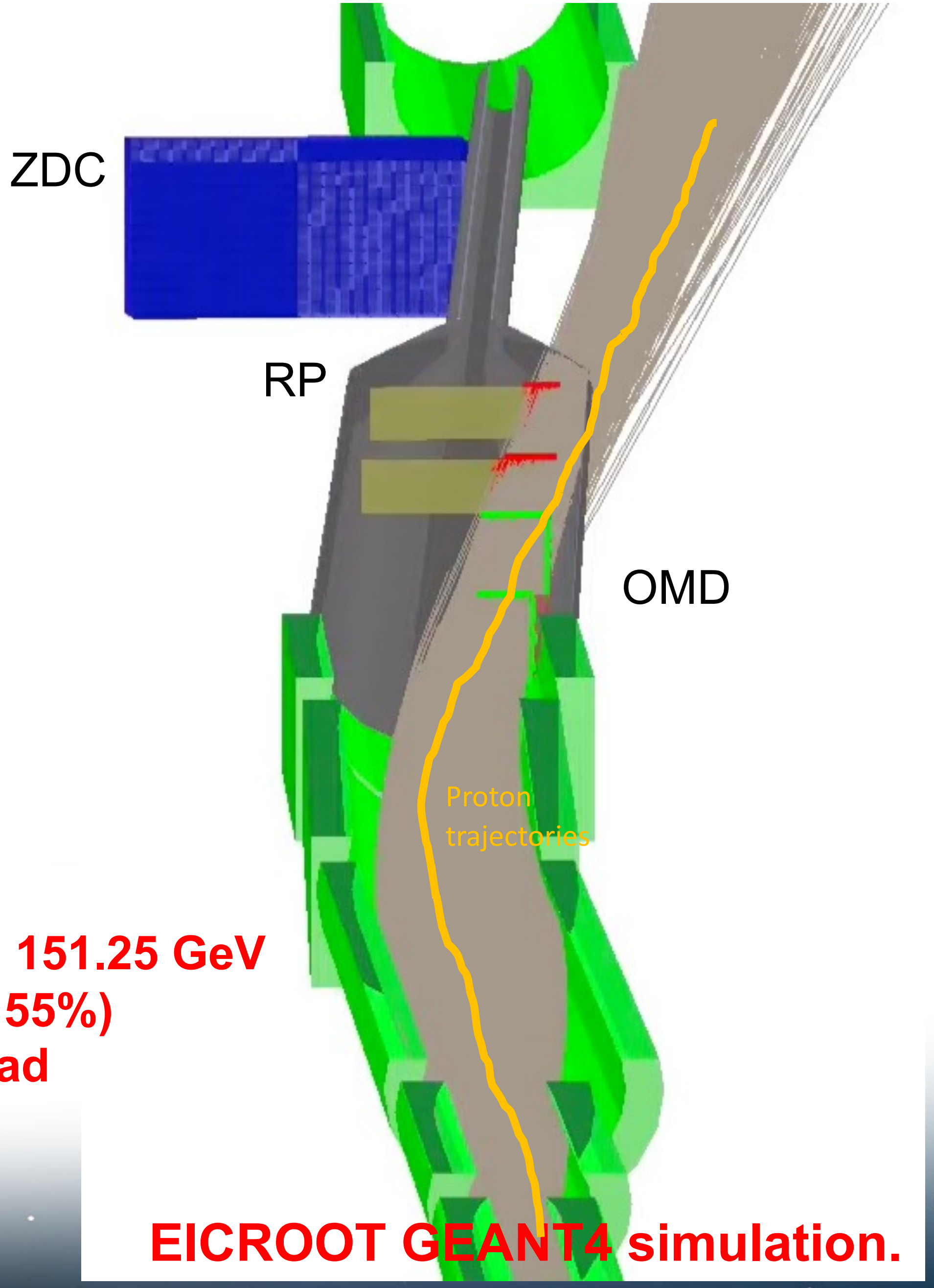


Off-Momentum Detectors





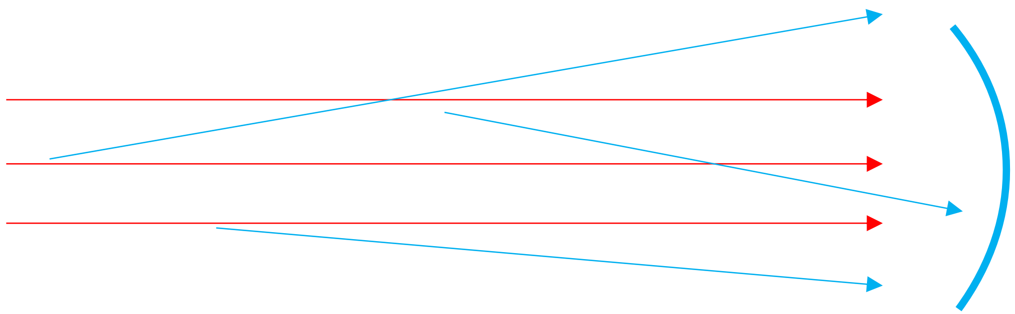




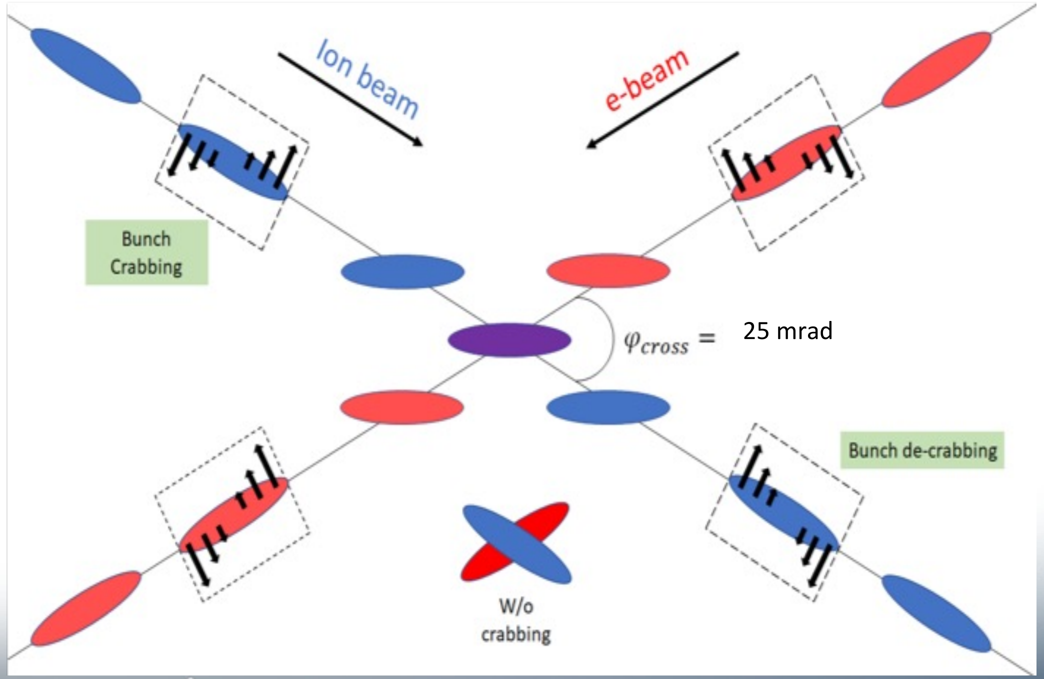
Protons
123.75 < E < 151.25 GeV
(45% < xL < 55%)
0 < θ < 5 mrad

Digression: particle beams

- Angular divergence
  - Angular “spread” of the beam away from the central trajectory.
  - Gives some small initial transverse momentum to the beam particles.

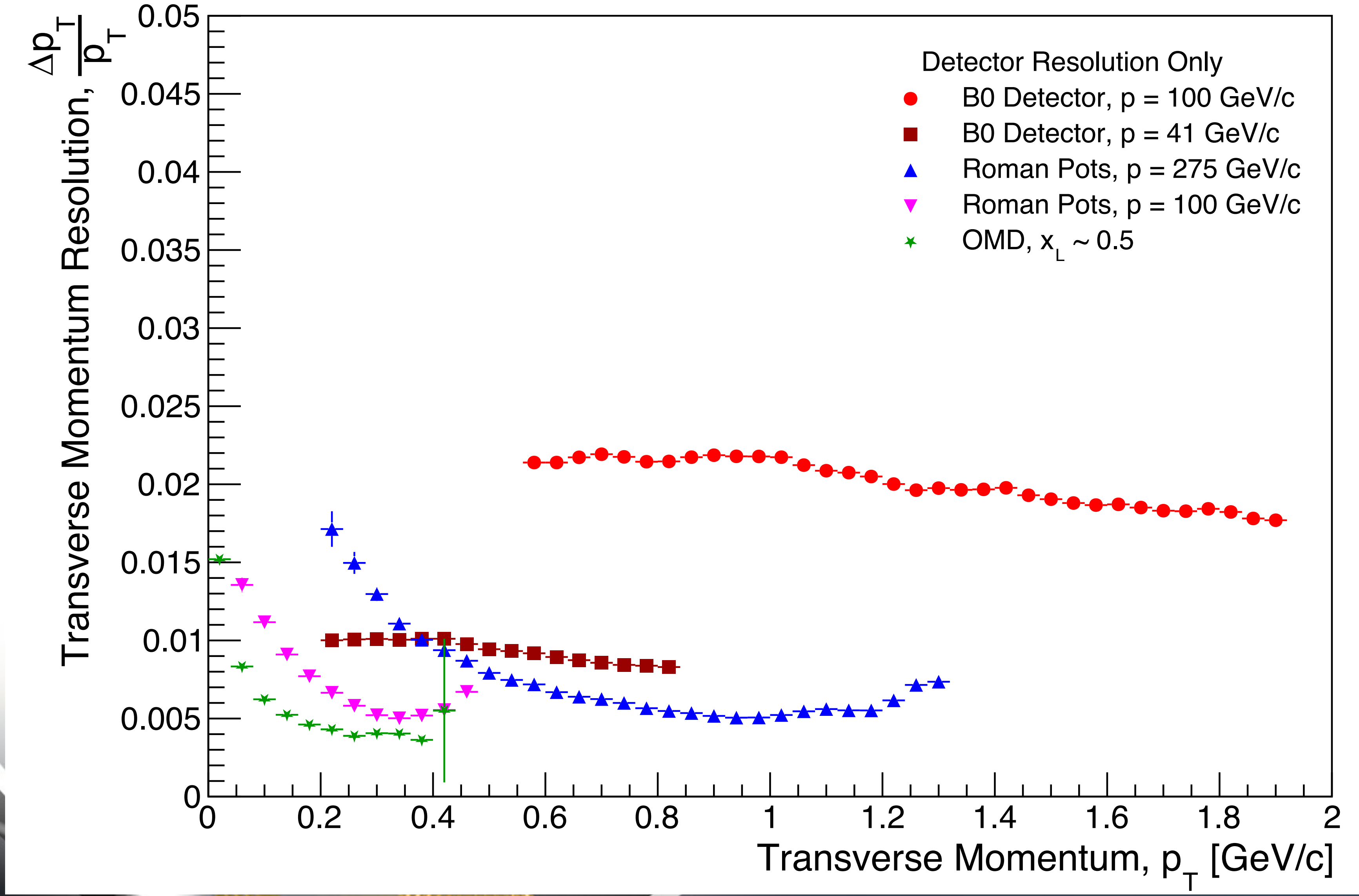


- Crab cavity rotation
  - Can perform rotations of the beam bunches in 2D.
  - Used to account for the luminosity drop due to the crossing angle – allows for head-on collisions to still take place.



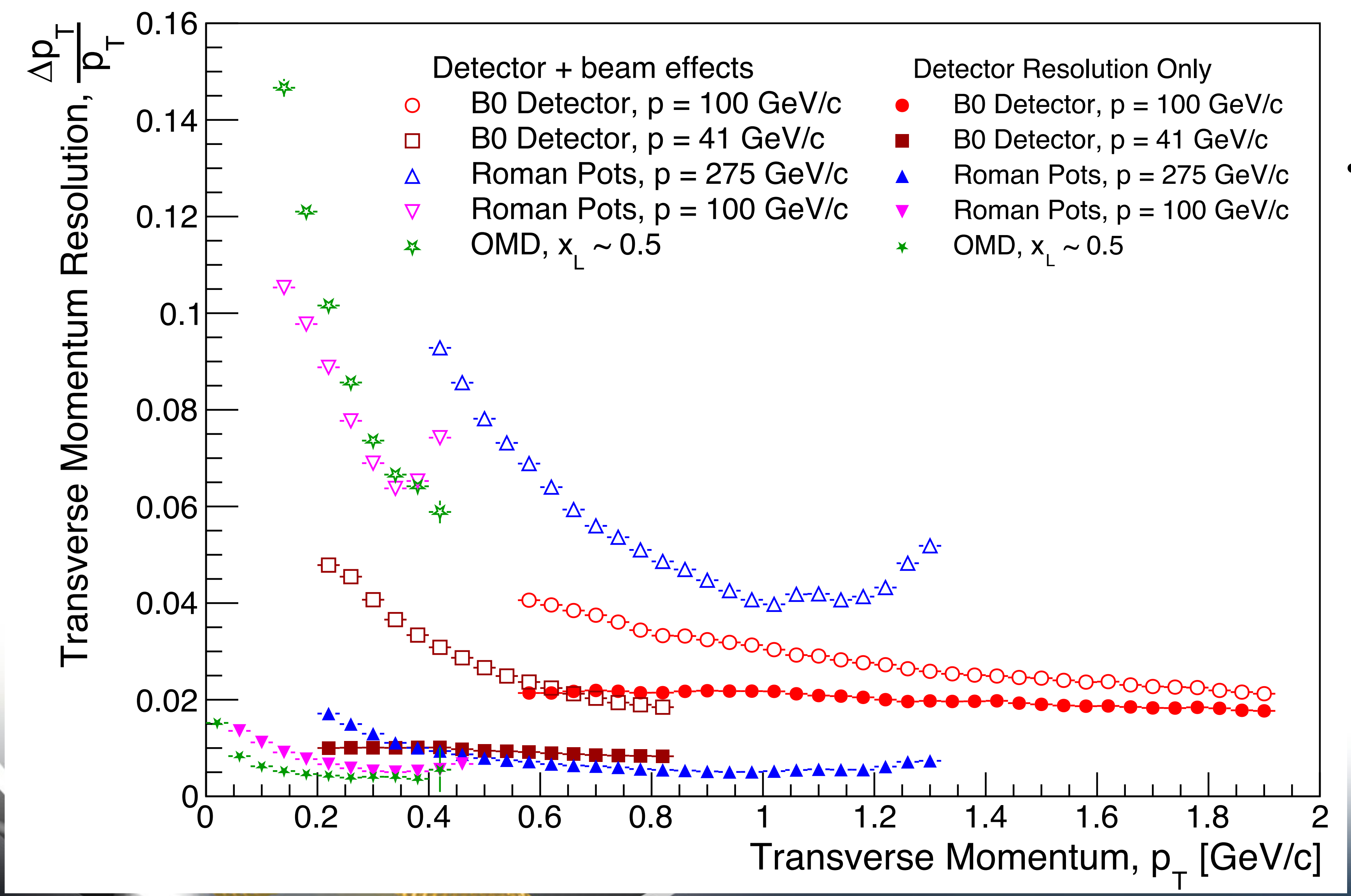
These effects introduce smearing in our momentum reconstruction.

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!

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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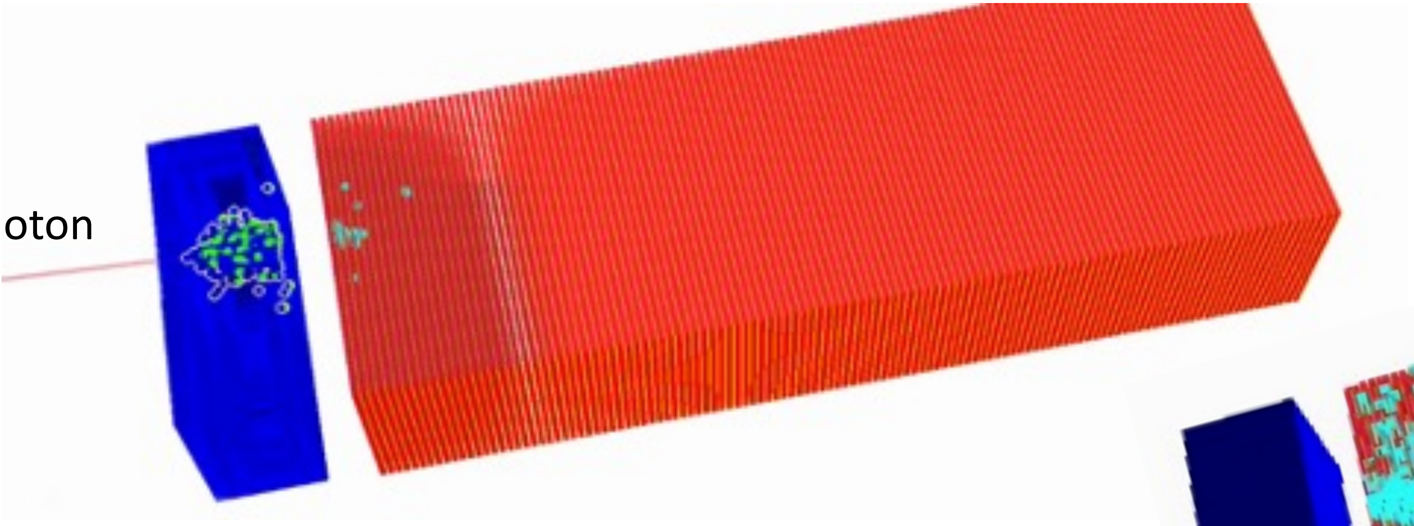
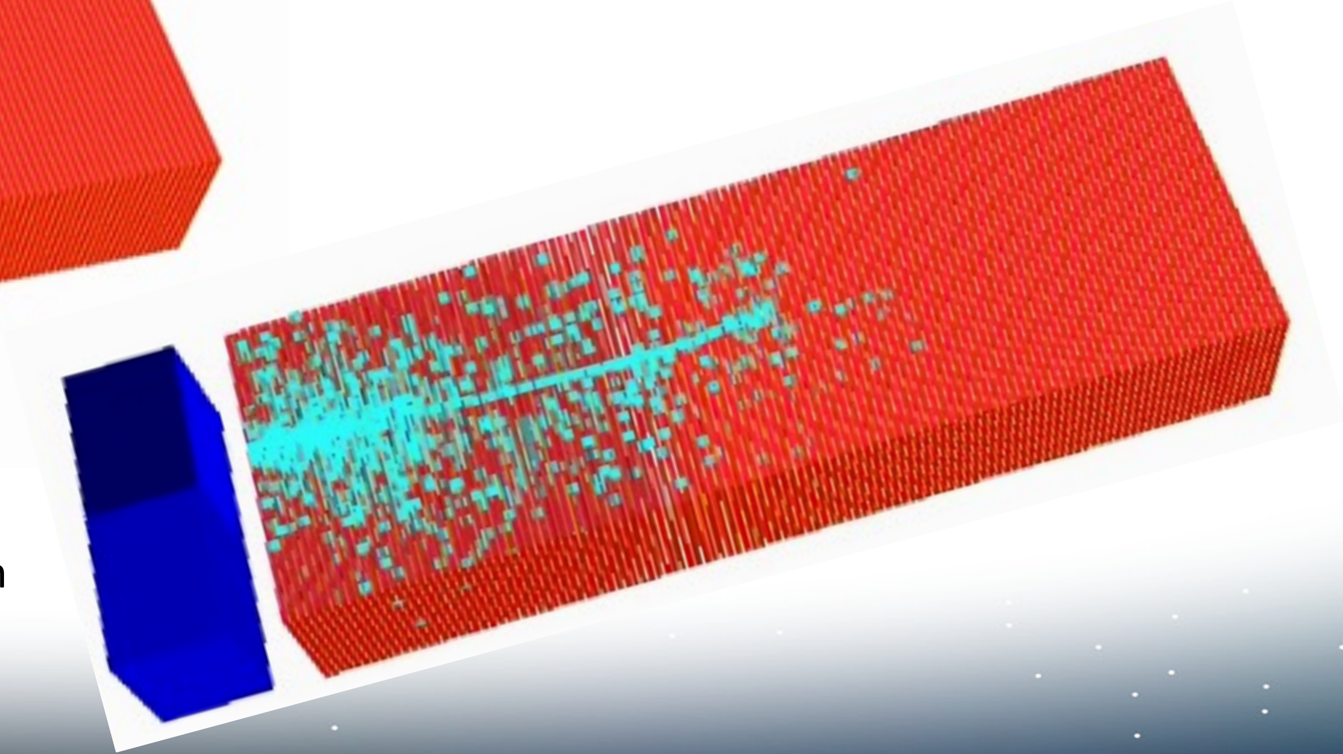
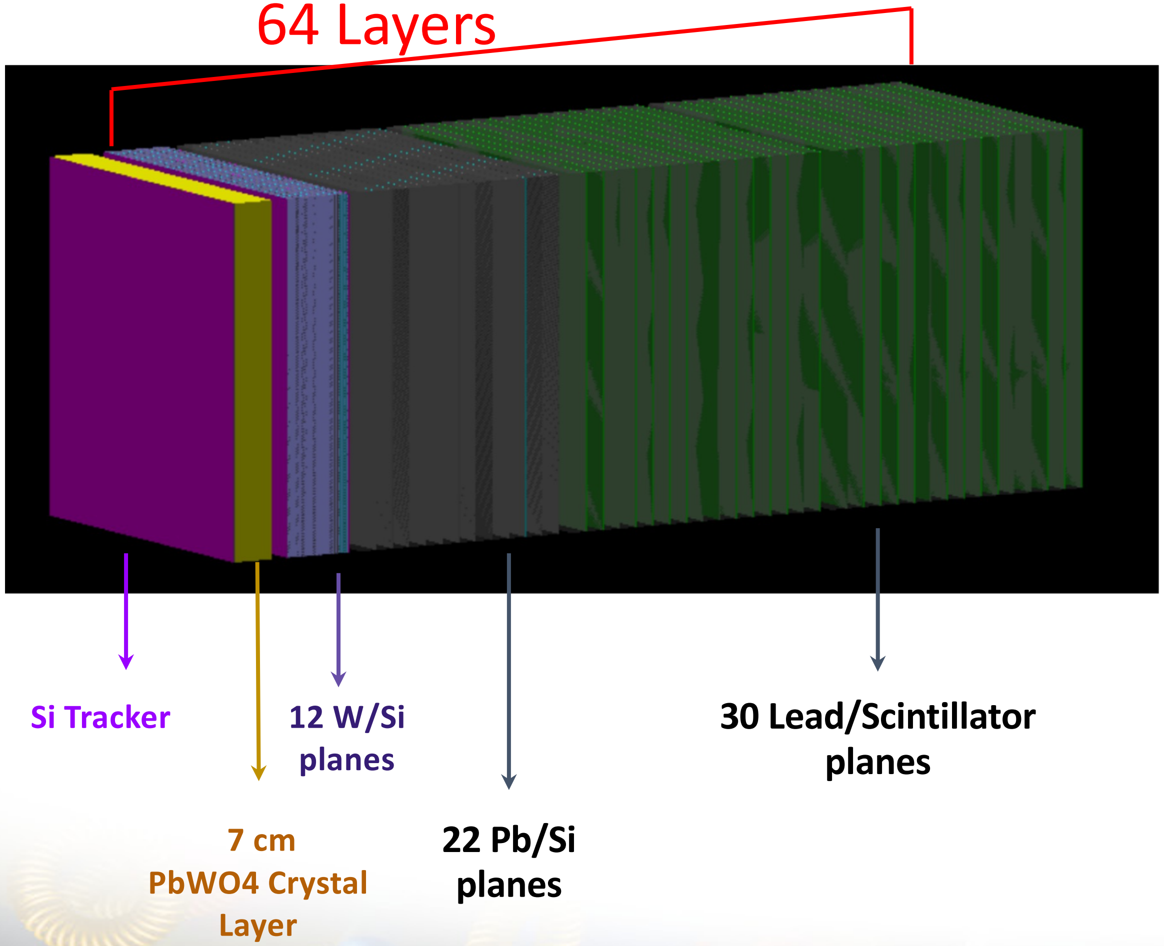
photon



neutron



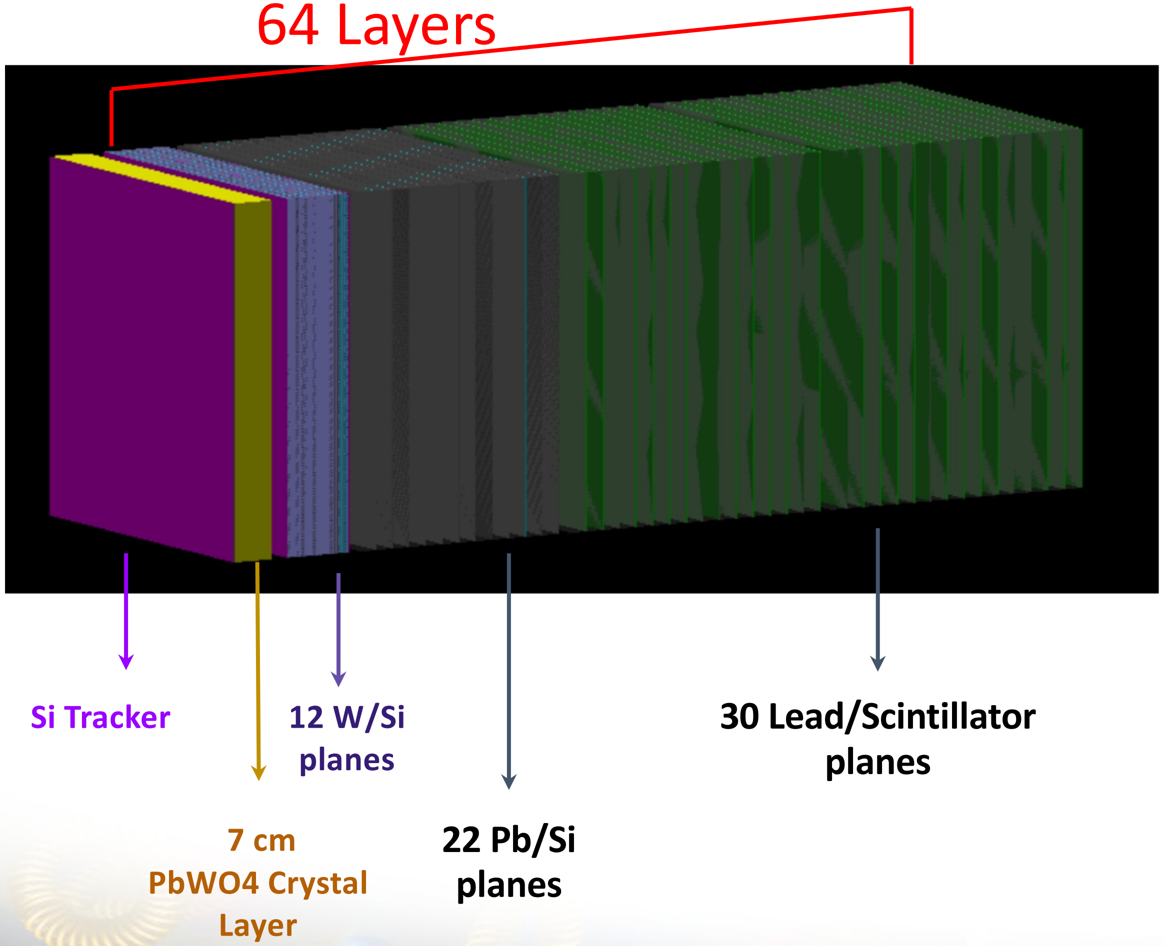
Zero-Degree Calorimeter



- **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)**

Credit to Shima Shimizu (Kobe U. , Japan)

Zero-Degree Calorimeter



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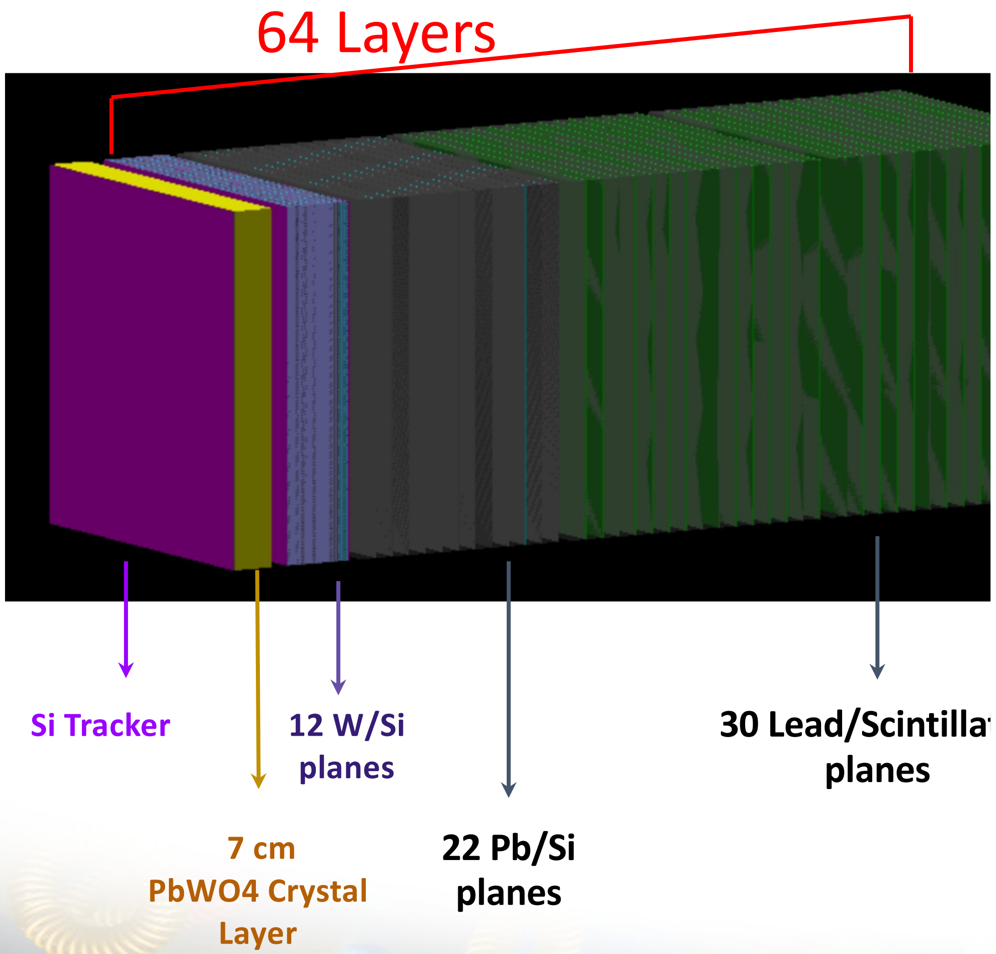
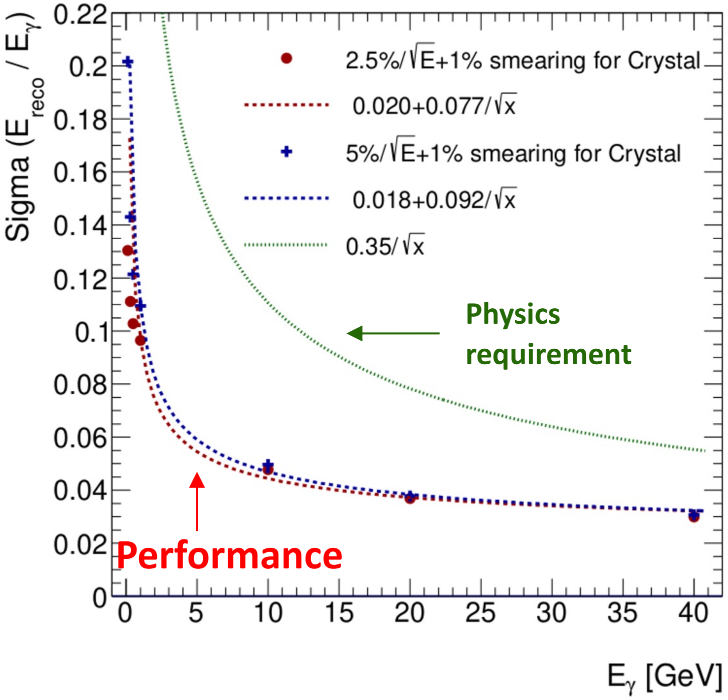
  - **Full reconstruction of photons (EMCAL) and neutrons (HCAL)**

- 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!

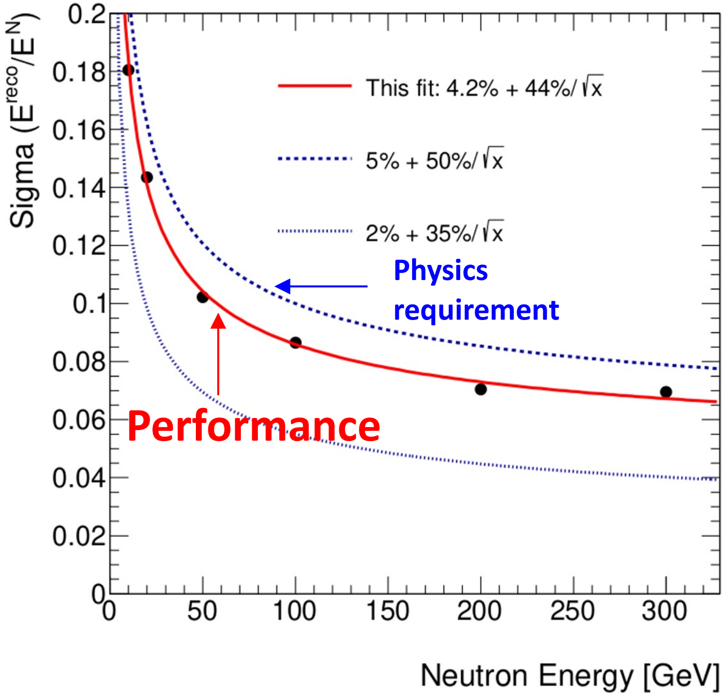
Zero-Degree Calorimeter



Photon energy resolution

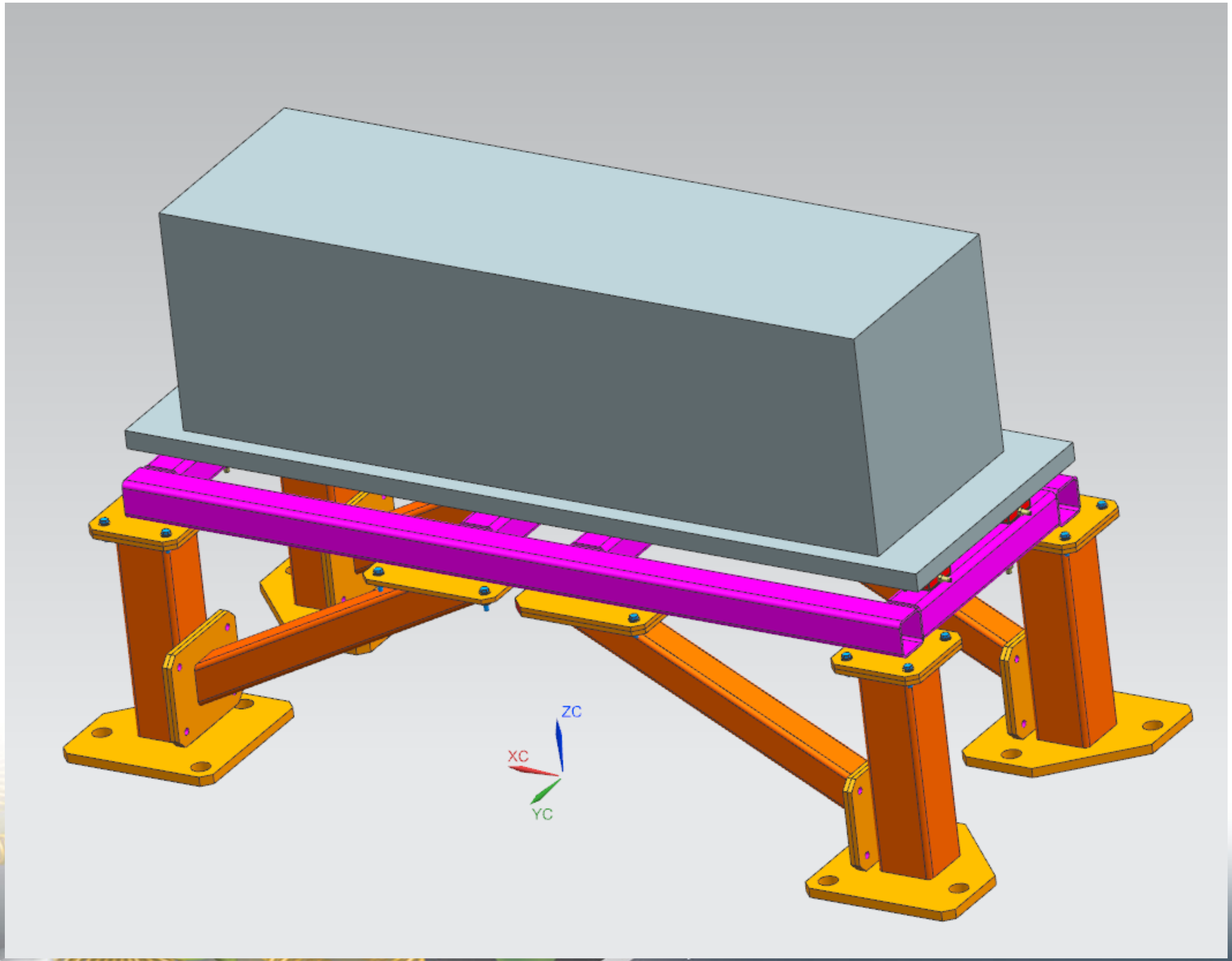


Neutron energy resolution



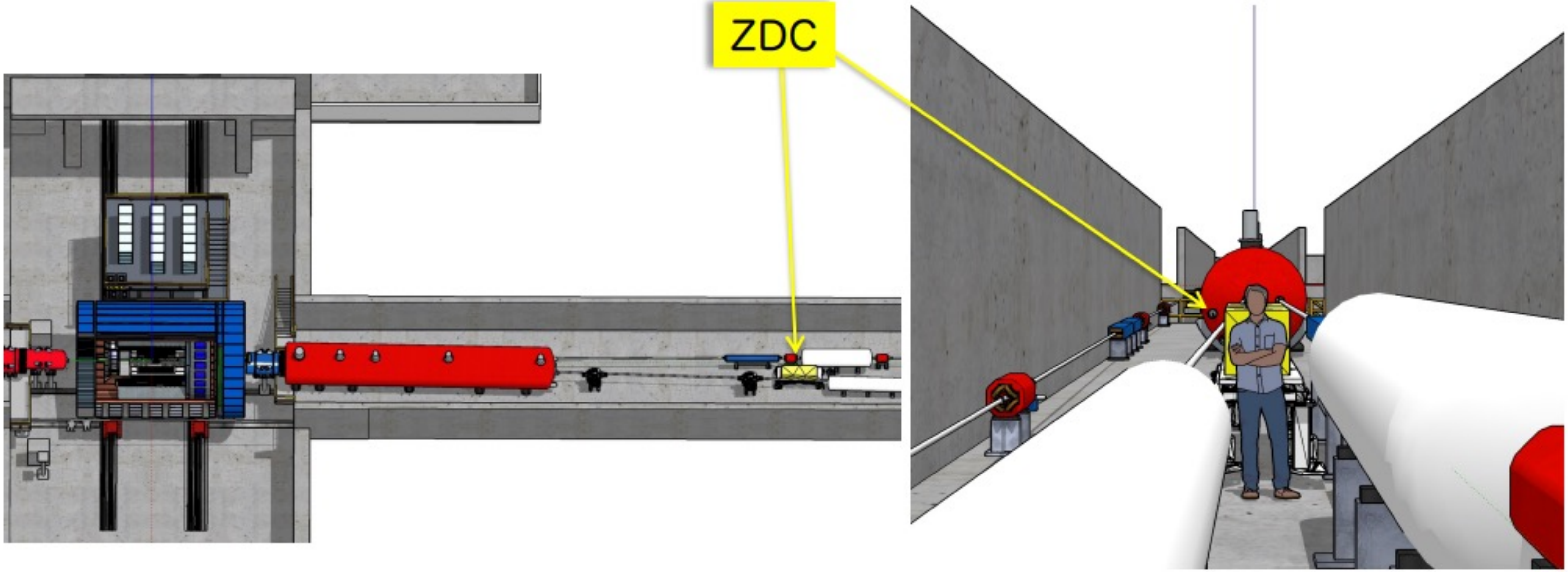
Credit to Shima Shimizu (Kobe U. , Japan)

Zero-Degree Calorimeter with Stand



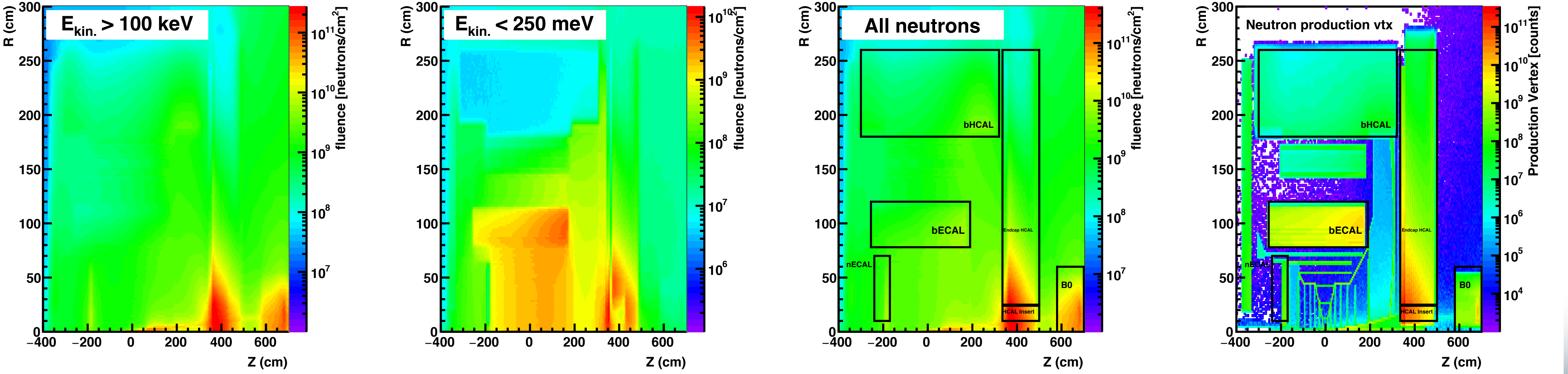
Preliminary Design of Zero--Degree Calorimeter with full support structure.

Zero-Degree Calorimeter



Understanding the support material is critical

- Support material provides interference for particles to make it to their respective detectors.
- Serves as a source for "secondary" particle production – can cause radiation damage to detectors.



Neutron radiation produced from e+p collisions at 10x275 GeV. →
Most of the neutrons produced via interaction with the material!

Summary and Takeaways

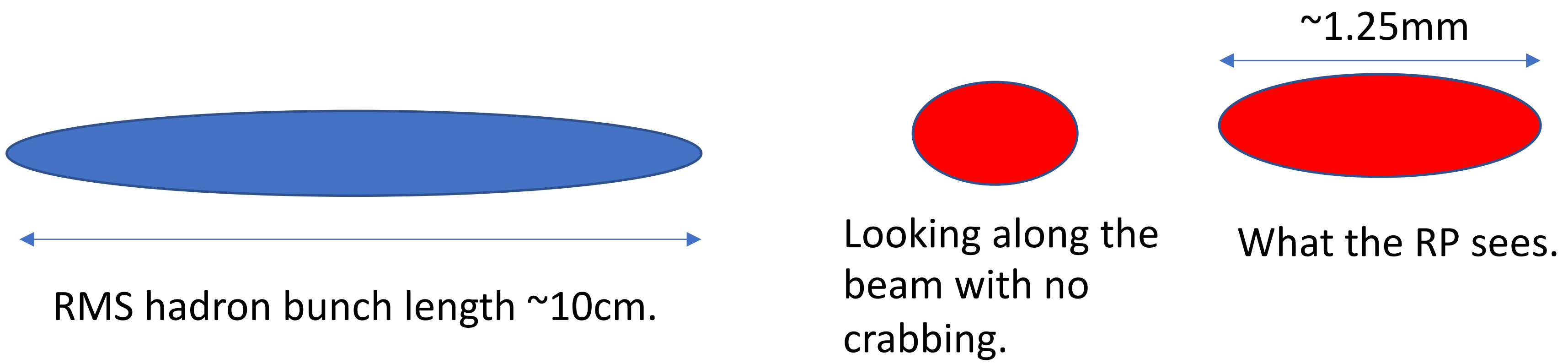
- All FF detector acceptances and detector performance well-understood with currently available information.
  - Numerous impact studies done!
    - Yellow Report, Detector proposals, and stand-alone impact studies.
  - Final technology choices identified, along with suitable alternate designs for risk mitigation.
- More realistic engineering considerations need to be added to simulations as design of IR vacuum system and magnets progresses toward CD-2/3a.
  - Lots of experience in performing these simulations, so this work will progress rapidly as engineering design matures.
  - Already well-established line of communication between detector and physics parties and the EIC machine/IR development group ⇒ Crucial for success!!!

Email me if you have any questions: ajentsch@bnl.gov

Backup

Momentum Resolution – Timing

For exclusive reactions measured with the Roman Pots we need good timing to resolve the position of the interaction within the proton bunch. But what should the timing be?



- Because of the rotation, the Roman Pots see the bunch crossing smeared in x.
- Vertex smearing = 12.5mrad (half the crossing angle) * 10cm = **1.25 mm**
- If the effective vertex smearing was **for a 1cm bunch**, we would have **.125mm** vertex smearing.
- The simulations were done with these two extrema and the results compared.

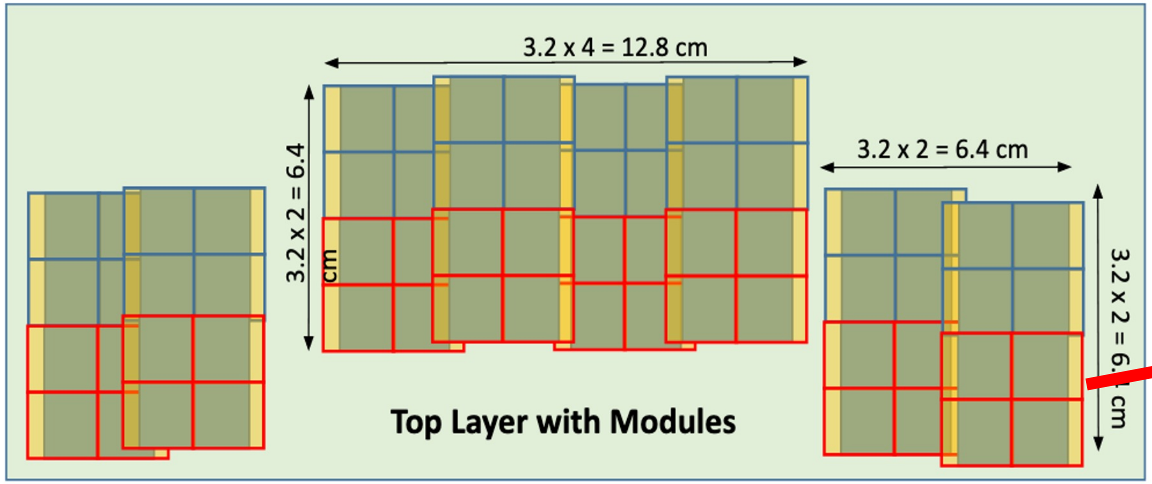
> ➢ **From these comparisons, reducing the effective vertex smearing to that of the 1cm bunch length reduces the momentum smearing to negligible from this contribution.**
> ➢ **This can be achieved with timing of ~ 35ps (1cm/speed of light).**

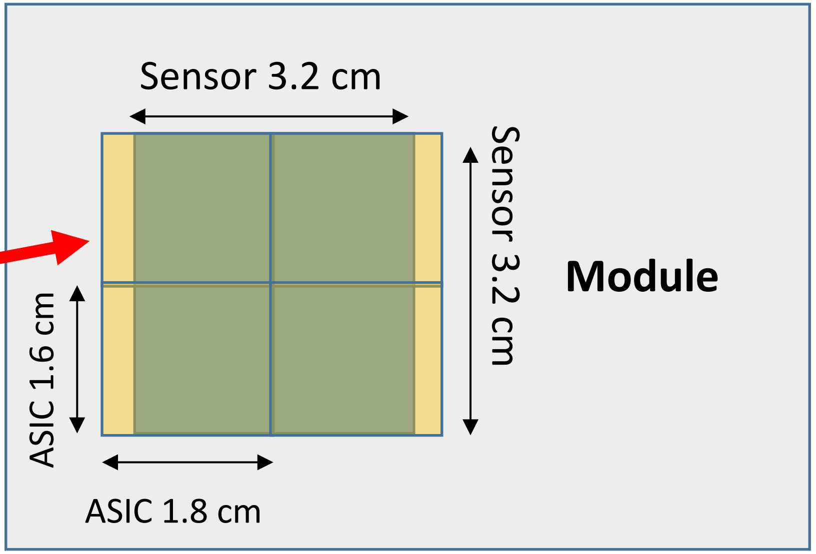
Roman Pots

- Active sensor area very large (26cm x 13cm).
- “Potless” design could make better use of space.
- With AC-LGADS + ALTIROC ASIC, current estimates of power dissipation around 400-500 watts for entire subsystem, so roughly 100 watts/layer.
    - With potless design, leveraging experience from LHCb VELO for cooling would allow for cooling of the electronics within the vacuum.
- Support structure only to be placed between hadron pipe and wall to avoid interference with the ZDC.

Roman Pots

- Updated layout with current design for AC-LGAD sensor + ASIC.





- Current R&D aimed at customizing ASIC readout chip (ALTIROC) for use with AC-LGADs.

ASIC size	ASIC Pixel pitch	# Ch. per ASIC	# ASICs per module	Sensor area	# Mod. per layer	Total # ASICs	Total # Ch.	Total Si Area
1.6x1.8 cm^2	500 μm	32x32	4	3.2x3.2 cm^2	32	512	524,288	1,311 cm^2

Momentum Resolution – Comparison

- The various contributions add in quadrature (this was checked empirically, measuring each effect independently).

$$\Delta p_{t,total} = \sqrt{(\Delta p_{t,AD})^2 + (\Delta p_{t,CC})^2 + (\Delta p_{t,pxl})^2}$$

Angular divergence

Primary vertex smearing from crab cavity rotation.

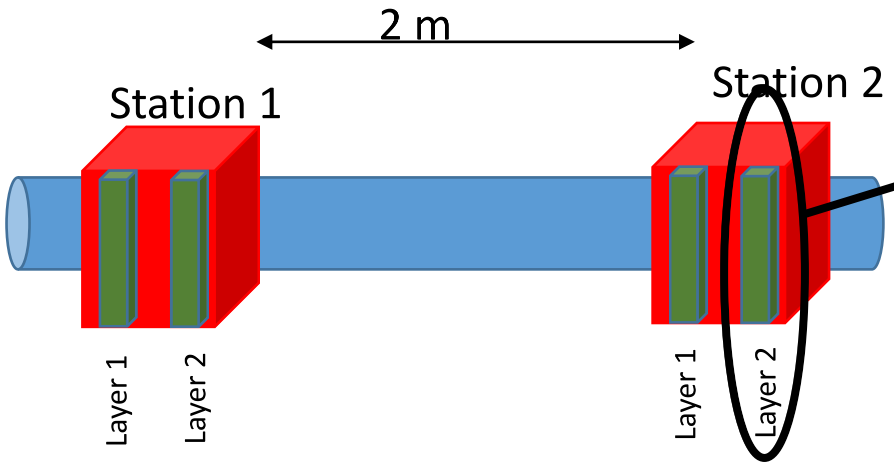
Smearing from finite pixel size.

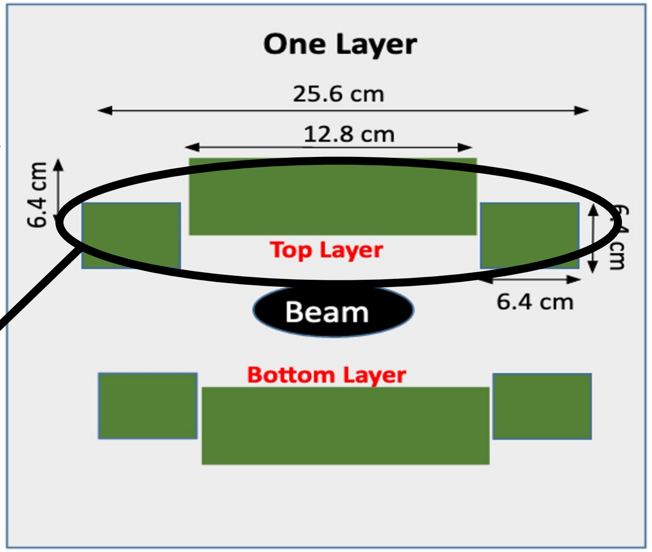
	Ang Div. (HD)	Ang Div. (HA)	Vtx Smear	250um pxl	500um pxl	1.3mm pxl
$\Delta p_{t,total}$ [MeV/c] - 275 GeV	40	28	20	6	11	26
$\Delta p_{t,total}$ [MeV/c] - 100 GeV	22	11	9	9	11	16
$\Delta p_{t,total}$ [MeV/c] - 41 GeV	14	-	10	9	10	12

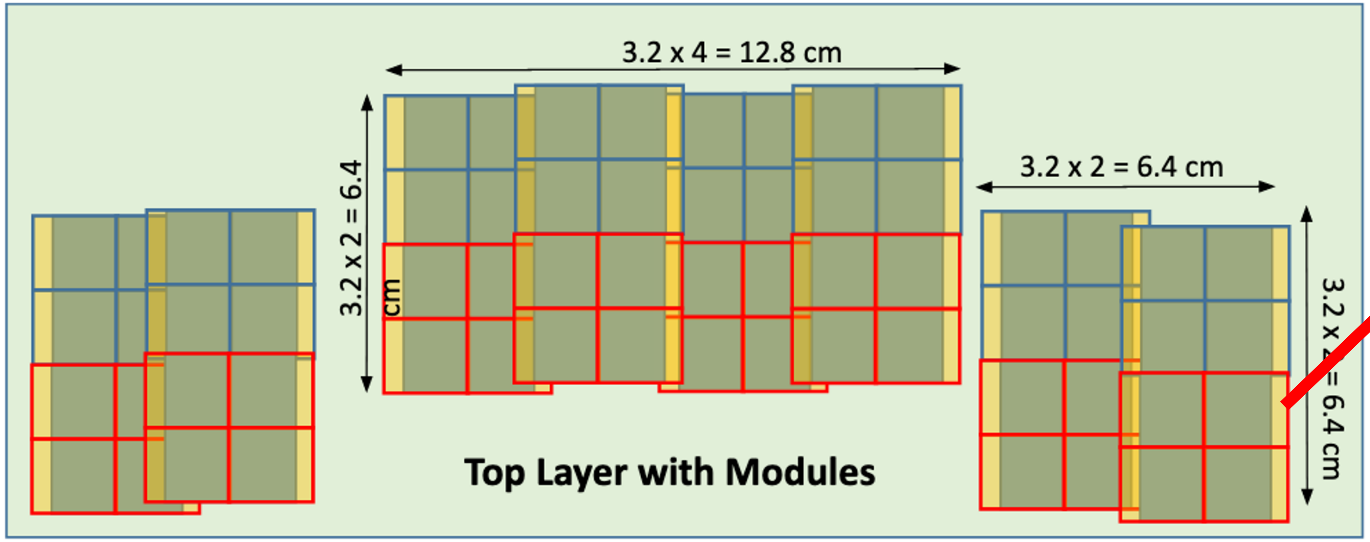
- **Beam angular divergence**
  - Beam property, can't correct for it – sets the lower bound of smearing.
  - Subject to change (i.e. get better) – beam parameters not yet set in stone
- **Vertex smearing from crab rotation**
  - Correctable with good timing (~35ps)
- **Finite pixel size on sensor**
  - 500um seems like the best compromise between potential cost and smearing

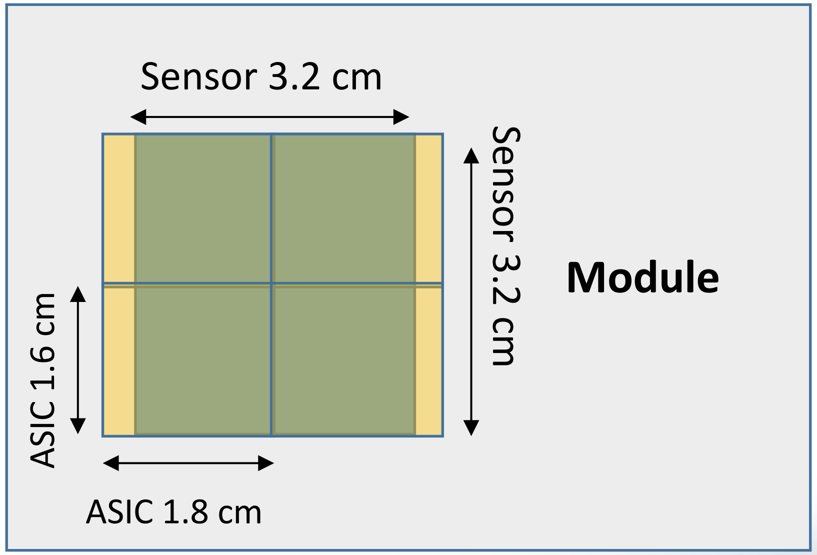
Roman Pots @ the EIC

- Updated layout with current design for AC-LGAD sensor + ASIC.







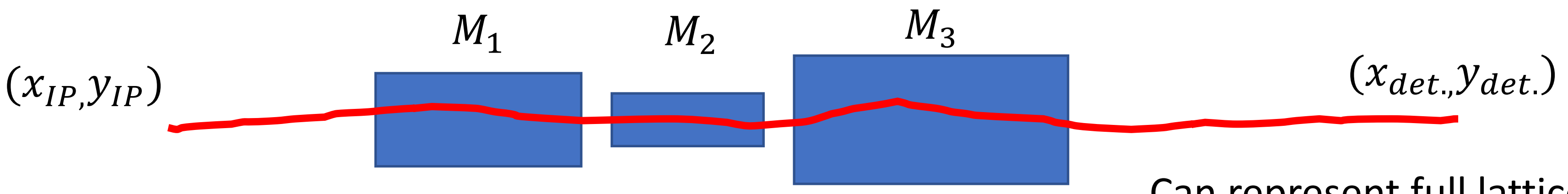


- Current R&D aimed at customizing ASIC readout chip (ALTIROC) for use with AC-LGADs.

Based on eRD24 R&D work.

Momentum Reconstruction with Roman Pots

- Use a matrix which describes the transport of a charged particle trajectory through the magnet lattice.
  - Matrix unique for different positions along the beam-axis (s)!
  - Transforms coordinates at detectors (position, angle) to original IP coordinates.
  - Proper usage assumes a reference orbit – all calculations MUST be done in that coordinate system!



$$M_{transfer} = M_1 M_2 M_3 \ldots$$

Can represent full lattice with a single "transfer matrix" (also called "transfer map").

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

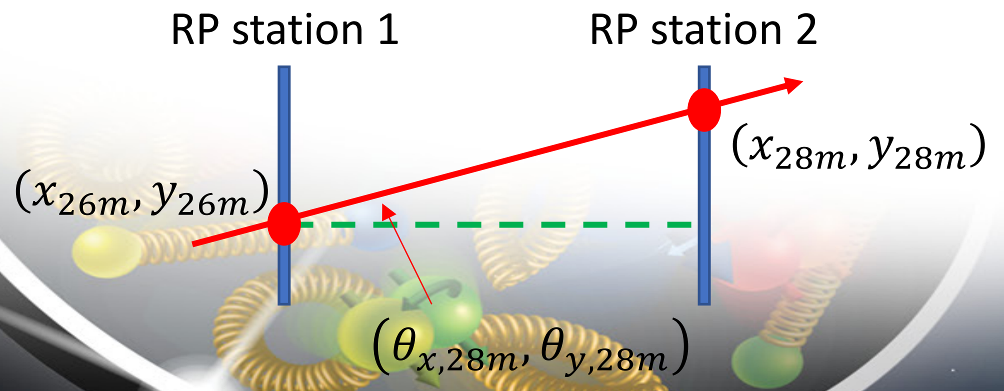
x_0, y_0: Position at Interaction Point
Θ^*_x, Θ^*_y: Scattering Angle at IP
x_D, y_D : Position at Detector
Θ^x_D, Θ^y_D : Angle at Detector

Momentum Reconstruction with Roman Pots

From BMAD!

$$\begin{pmatrix} 1.88481537 & 28.96766544 & 0.0000 & 0.0000 & 0.0000 & 0.24906255 \\ -0.02114673 & 0.20555261 & 0.0000 & 0.0000 & 0.0000 & -0.03322467 \\ 0.0000 & 0.0000 & -2.25541901 & 3.78031509 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & -0.17782524 & -0.14532313 & 0.0000 & 0.0000 \\ 0.05735551 & 1.01363652 & 0.0000 & 0.0000 & 1.0000 & 0.02568709 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000 \end{pmatrix} \begin{pmatrix} x_{ip} \\ \theta_{xip} \\ y_{ip} \\ \theta_{yip} \\ z_{ip} \\ \Delta p/p \end{pmatrix} = \begin{pmatrix} x_{28m} \\ \theta_{x,28m} \\ y_{28m} \\ \theta_{y28m} \\ z_{28m} \\ \Delta p/p \end{pmatrix}$$

- Able to benchmark transport through lattice using machine codes, and comparing with what GEANT produces (e.g. what we calculate ”by hand” with GEANT).
    - The machine magnet code is called MAD-X or BMAD.
- **Question: what happens when our measured trajectory deviates too much from the reference orbit?**



$$(1.88)x_{ip} + (28.97)\theta_{xip} + (0.249)\frac{\Delta p}{p} = x_{28m}$$

... Etc.

$$(-0.0211)x_{ip} + (0.206)\theta_{xip} + (-0.033)\frac{\Delta p}{p} = \theta_{x,28m}$$

Momentum Reconstruction with Roman Pots

From BMAD!

$$\begin{pmatrix} 1.88481537 & 28.96766544 & 0.0000 & 0.0000 & 0.0000 & 0.24906255 \\ -0.02114673 & 0.20555261 & 0.0000 & 0.0000 & 0.0000 & -0.03322467 \\ 0.0000 & 0.0000 & -2.25541901 & 3.78031509 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & -0.17782524 & -0.14532313 & 0.0000 & 0.0000 \\ 0.05735551 & 1.01363652 & 0.0000 & 0.0000 & 1.0000 & 0.02568709 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000 \end{pmatrix} \begin{pmatrix} x_{ip} \\ \theta_{xip} \\ y_{ip} \\ \theta_{yip} \\ z_{ip} \\ \Delta p/p \end{pmatrix} = \begin{pmatrix} x_{28m} \\ \theta_{x,28m} \\ y_{28m} \\ \theta_{y28m} \\ z_{28m} \\ \Delta p/p \end{pmatrix}$$

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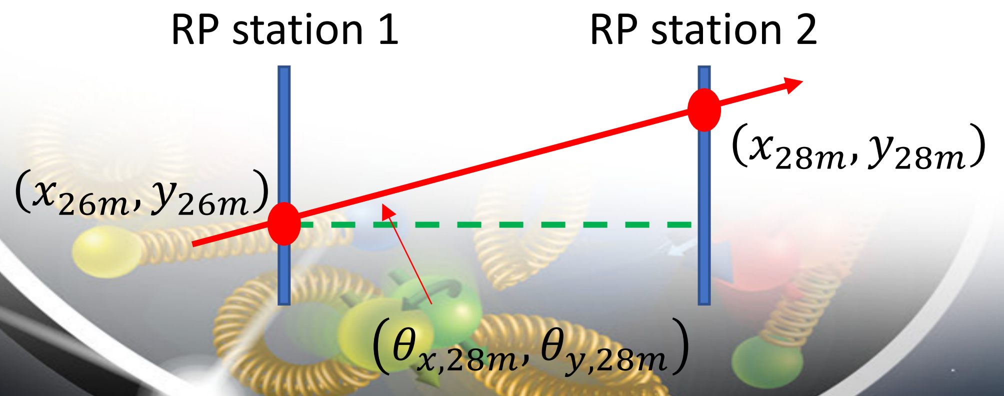


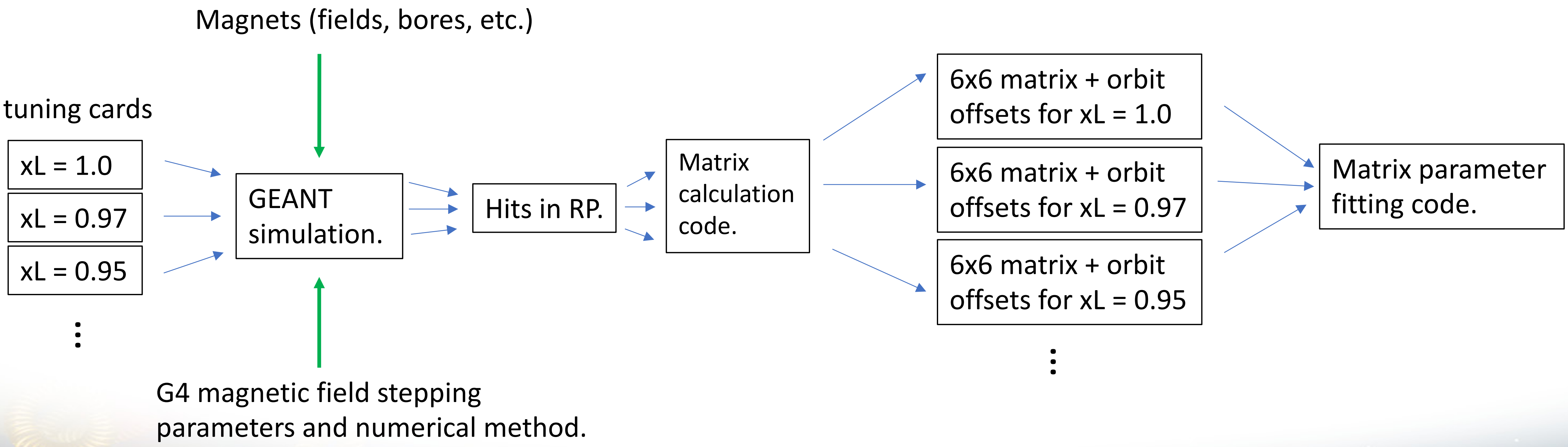
longitudinal momentum fraction

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

For a 275 GeV beam, a 270 GeV proton has an xL of 0.98.

A Simplistic General Method

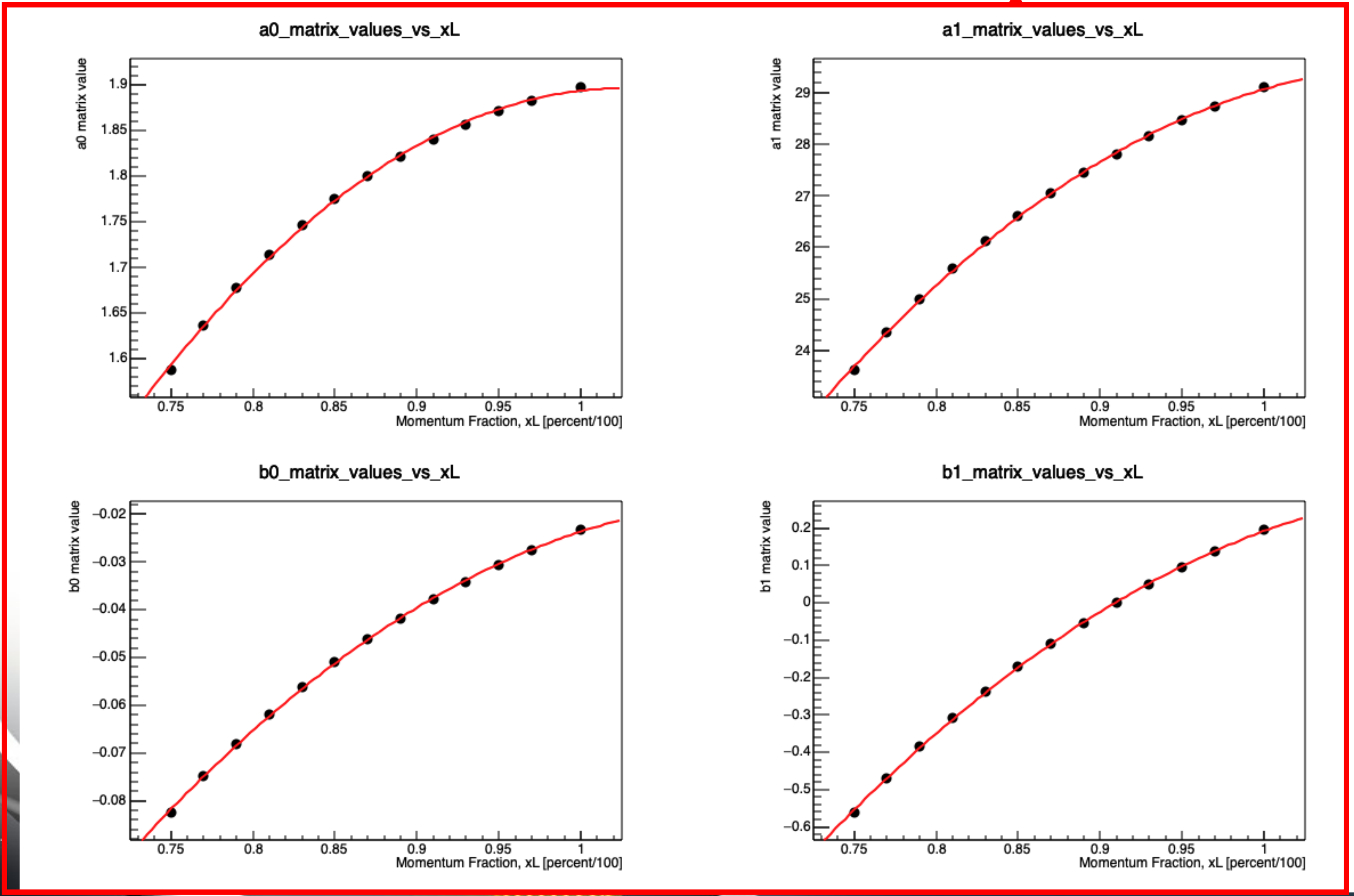
- Begin with a set of “input tuning cards” which contain many reference trajectories for calculating the matrices.



A Simplistic General Method

- Plot the 36 matrix values (and 4 offsets) as a function of xL.
- Fit the resulting plots with 2nd-degree polynomials.

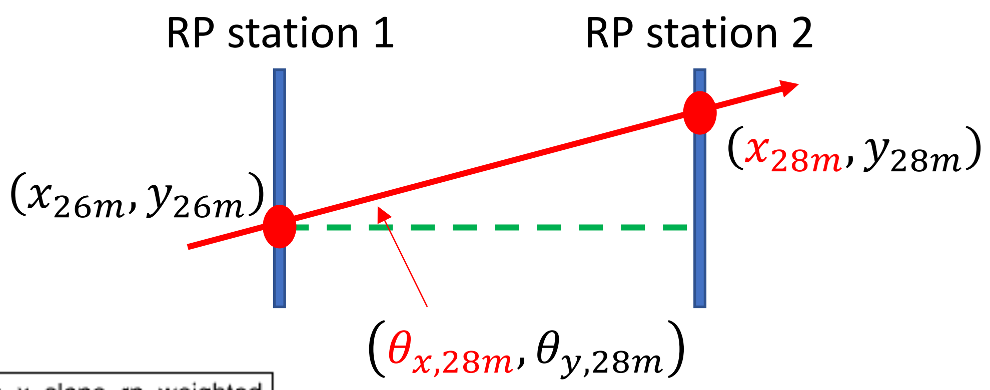
$$\begin{pmatrix} 1.88481537 & 28.96766544 & 0.0000 & 0.0000 & 0.0000 & 0.24906255 \\ -0.02114673 & 0.20555261 & 0.0000 & 0.0000 & 0.0000 & -0.03322467 \\ 0.0000 & 0.0000 & -2.25541901 & 3.78031509 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & -0.17782524 & -0.14532313 & 0.0000 & 0.0000 \\ 0.05735551 & 1.01363652 & 0.0000 & 0.0000 & 1.0000 & 0.02568709 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000 \end{pmatrix}$$

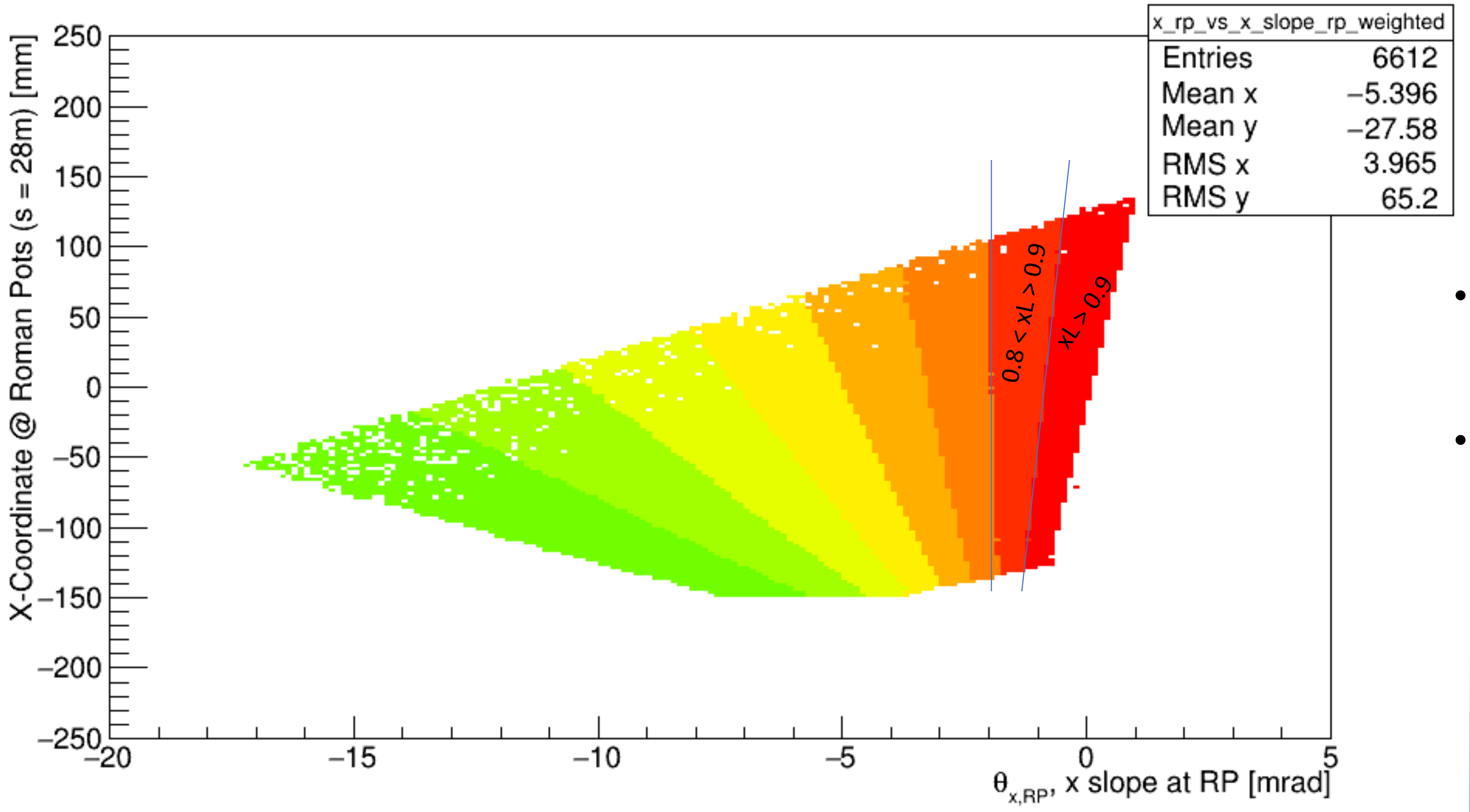


- The 40 fit functions (36 matrix parameters + 4 offsets) then represent the ingredients to calculate the needed matrix in real-time at reconstruction.
- All that is needed is a lookup table to get the xL value for an event based on the coordinates at the Roman Pots.

A Simplistic General Method

- Extract x_L value from lookup table for the $(\theta_{x,rp}, x_{rp})$ ordered pair.



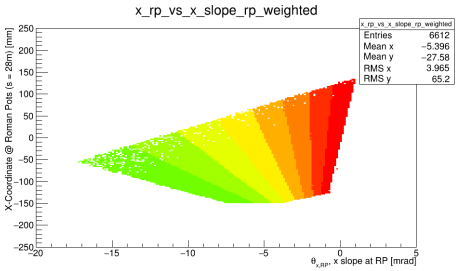


- "Chromaticity plot" serves as a lookup table to use RP coordinates to find the xL value.
- xL is then used to evaluate the correct matrix for reconstruction.

A Simplistic General Method

- Now we can “build” the correct matrix with the correct offset values for a given trajectory and perform our kinematic reconstruction.

Detector “hit” coordinates



Lookup xL

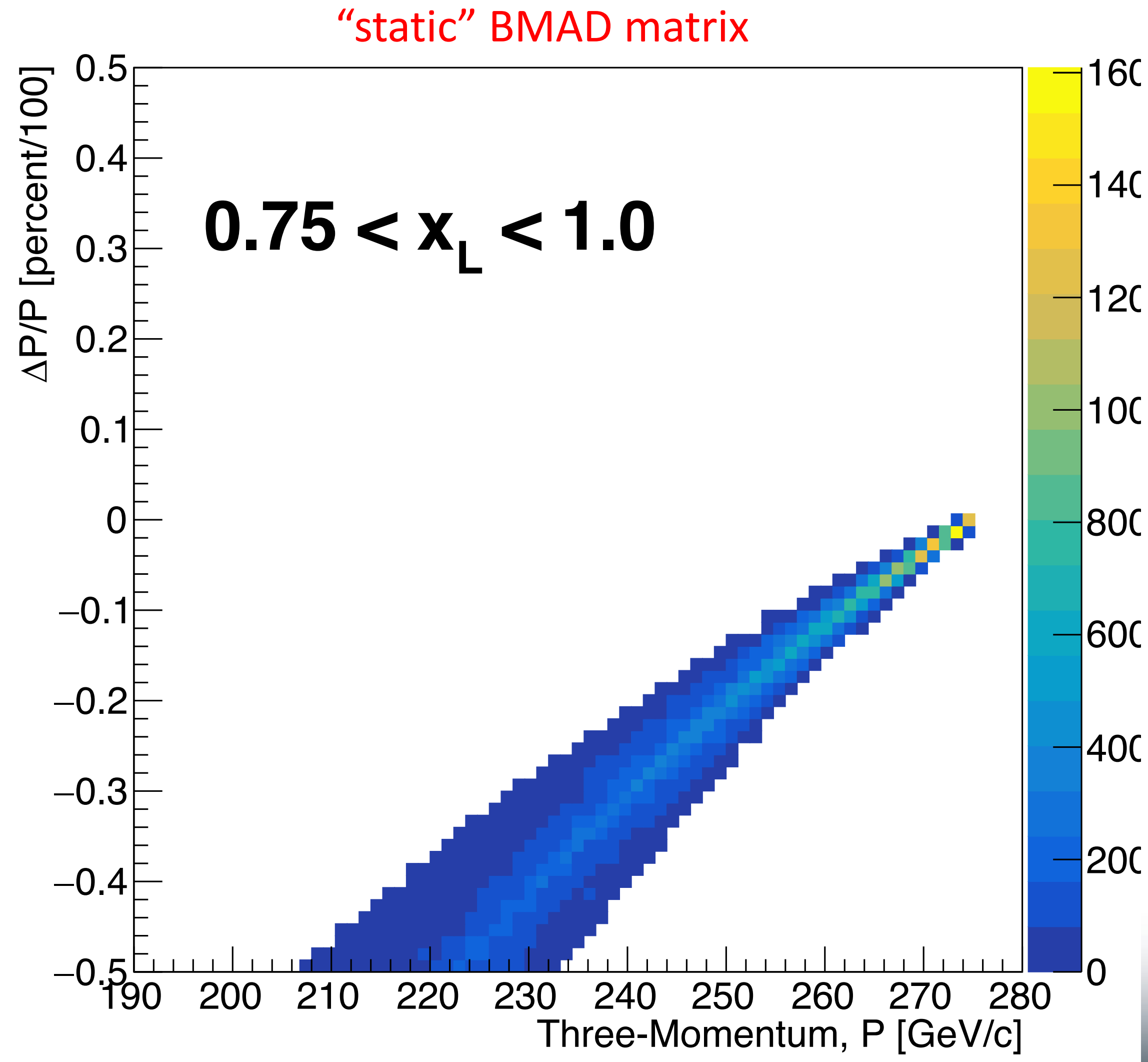
Calculate matrix parameters and offsets from fit equations.

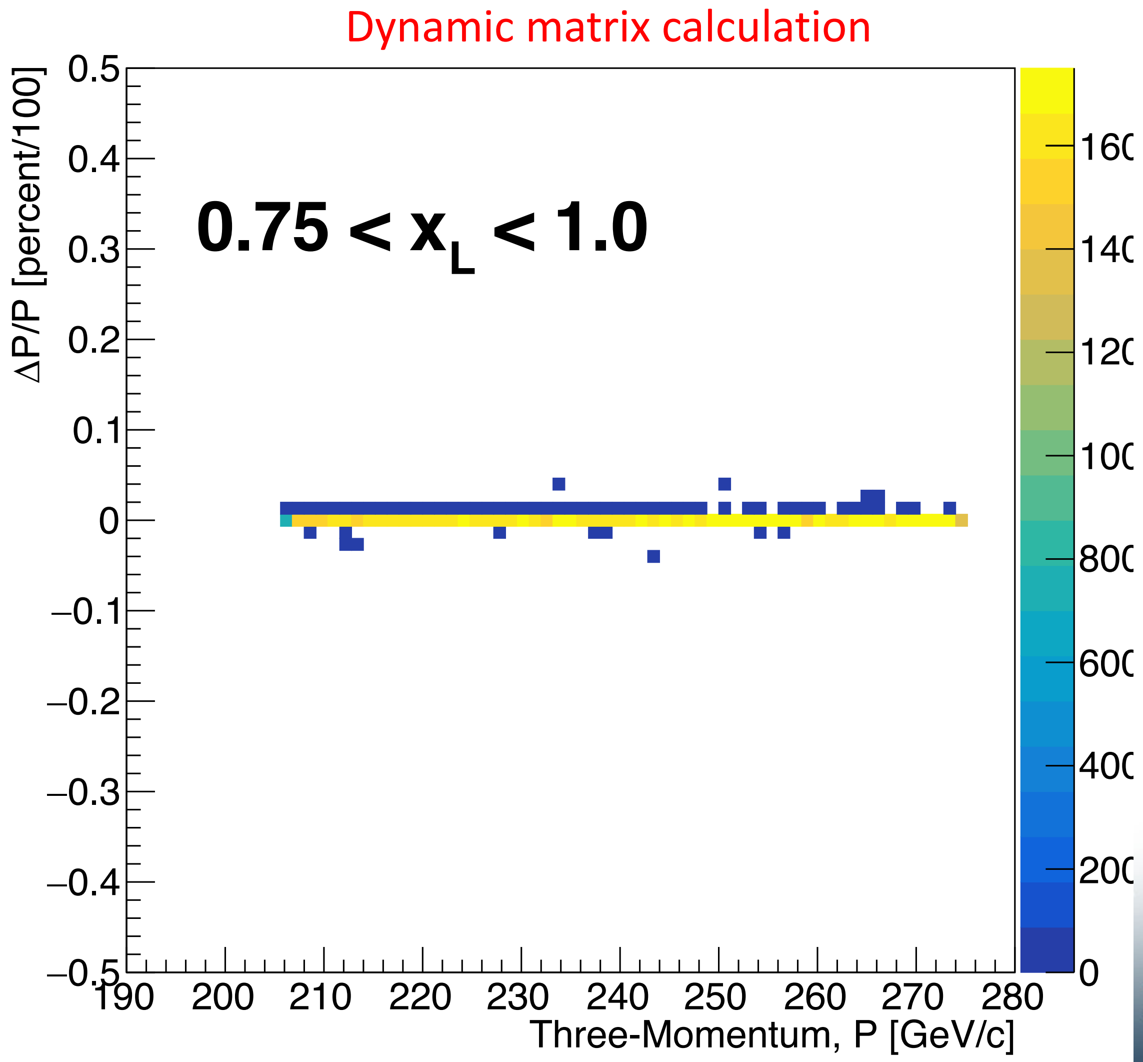
$$\begin{pmatrix} 1.88481537 & 28.96766544 & 0.0000 & 0.0000 & 0.0000 & 0.24906255 \\ -0.02114673 & 0.20555261 & 0.0000 & 0.0000 & 0.0000 & -0.03322467 \\ 0.0000 & 0.0000 & -2.25541901 & 3.78031509 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & -0.17782524 & -0.14532313 & 0.0000 & 0.0000 \\ 0.05735551 & 1.01363652 & 0.0000 & 0.0000 & 1.0000 & 0.02568709 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000 \end{pmatrix}$$

Reconstructed momentum vector.

Results - Momentum

- Comparing “static” BMAD matrix (left) with dynamic matrix calculation (right).

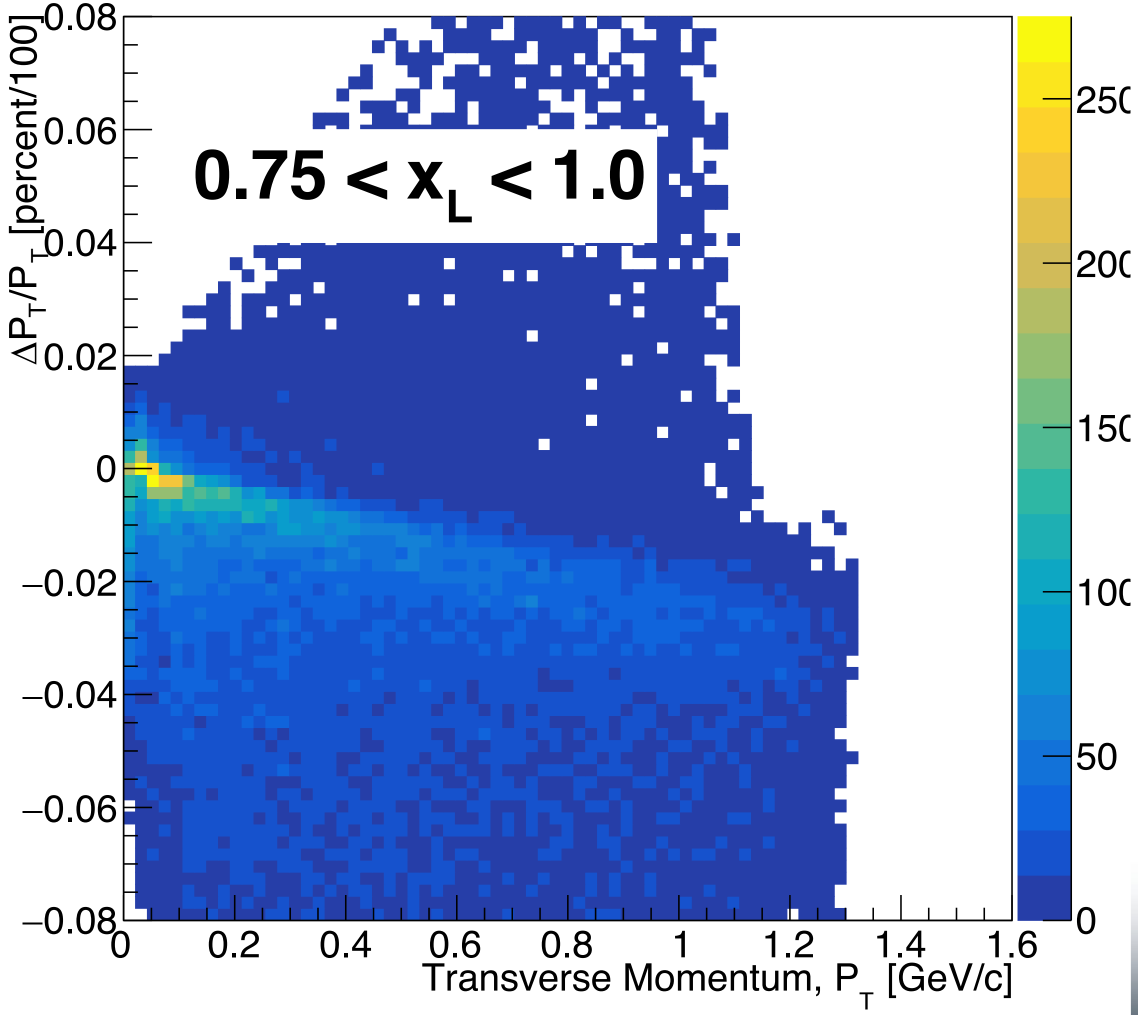




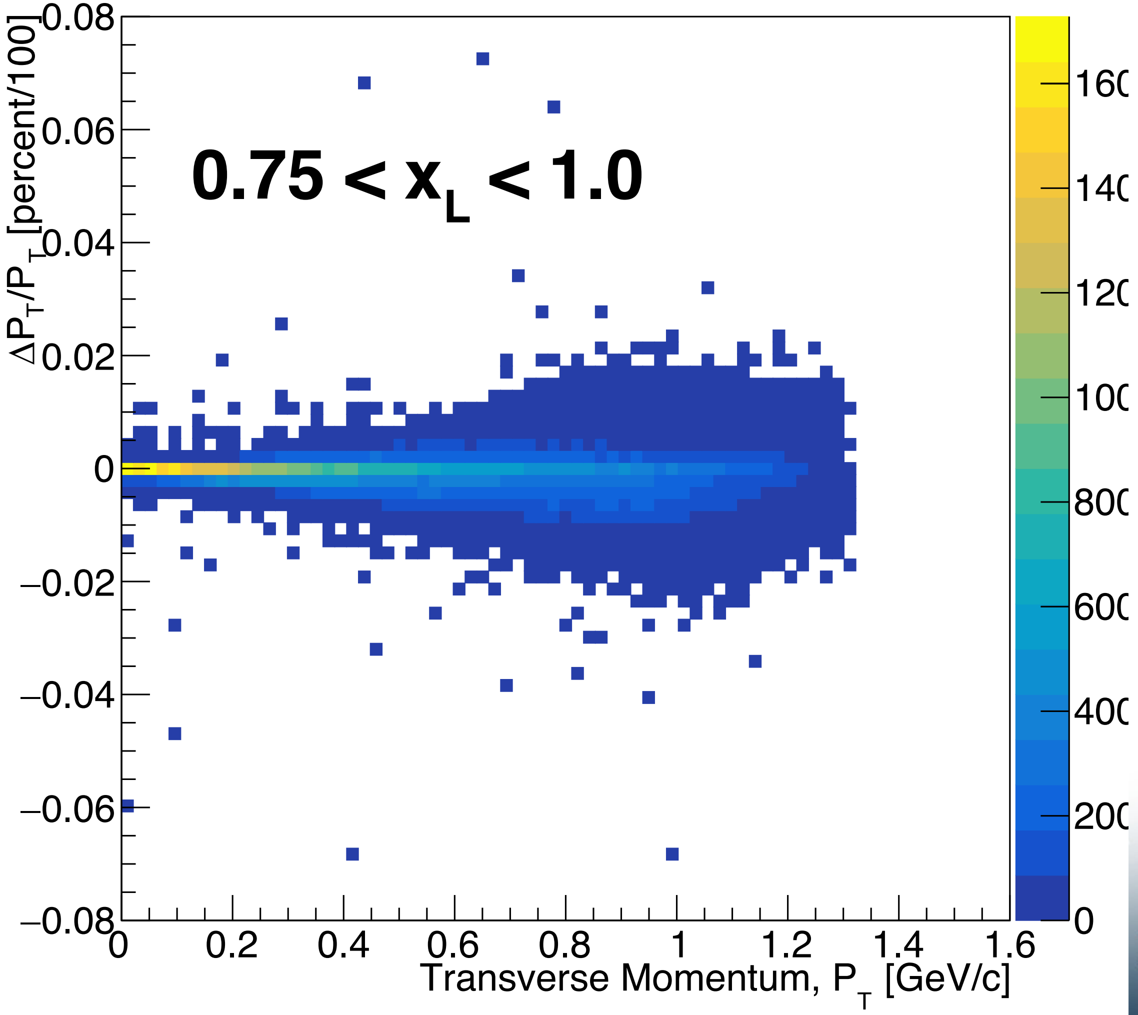
Results - pT

- Comparing “static” BMAD matrix (left) with dynamic matrix calculation (right).

“static” BMAD matrix



Dynamic matrix calculation



Some Final Comments on Reco in the RP

- The accelerator/machine folks are used to using BMAD/MAD-X → They do not know GEANT!
- As a result, we have to do our checks and studies in a common language to ensure errors/problems are caught early.
- The method presented will obviously be improved using machine learning methods, which is next on the list of things to do.