Far-Forward Detectors @ the EIC

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NuSTEAM/NuPUMAS @ BNL
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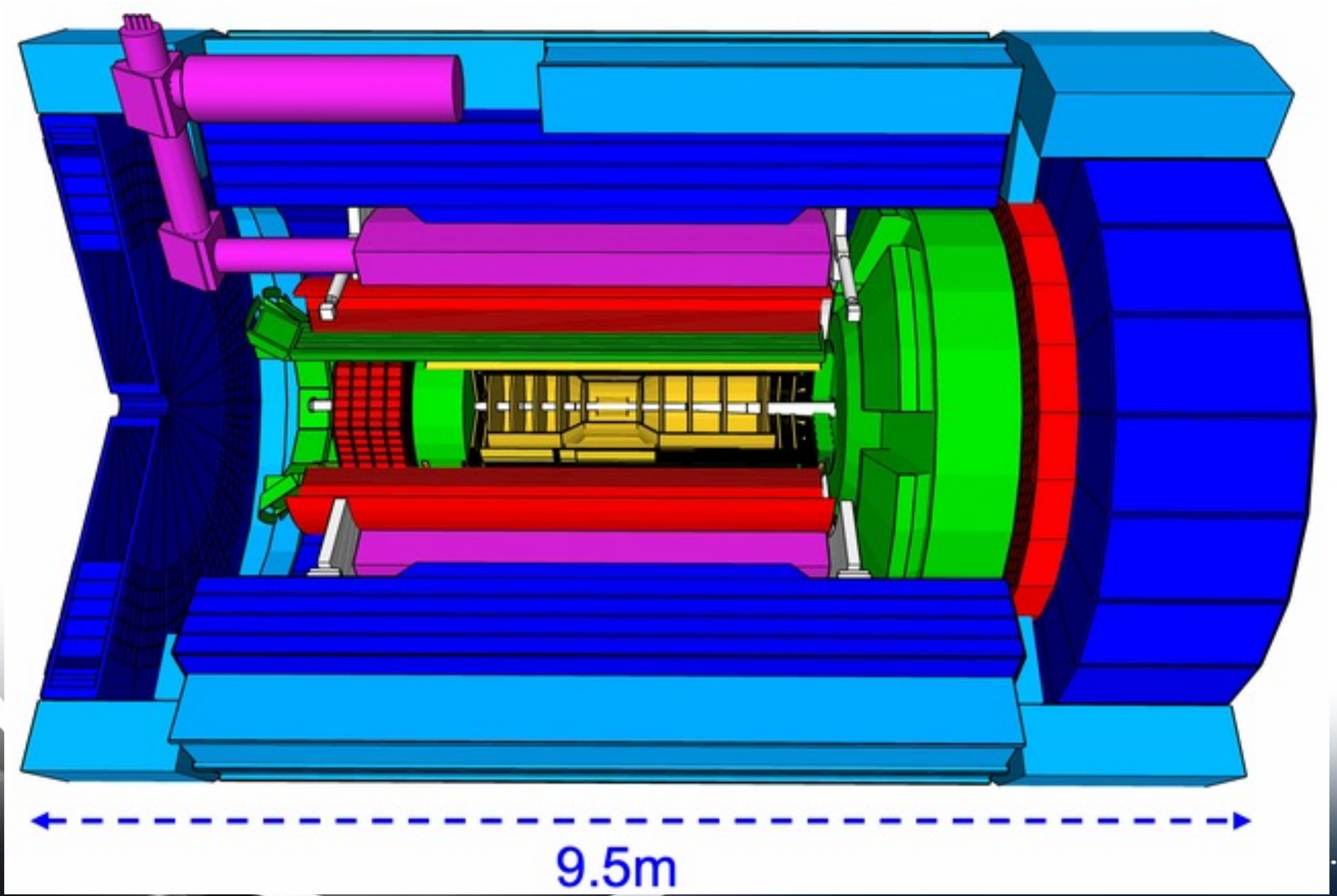
Electron Ion Collider

BROOKHAVEN NATIONAL LABORATORY   Jefferson Lab   U.S. DEPARTMENT OF ENERGY | Office of Science

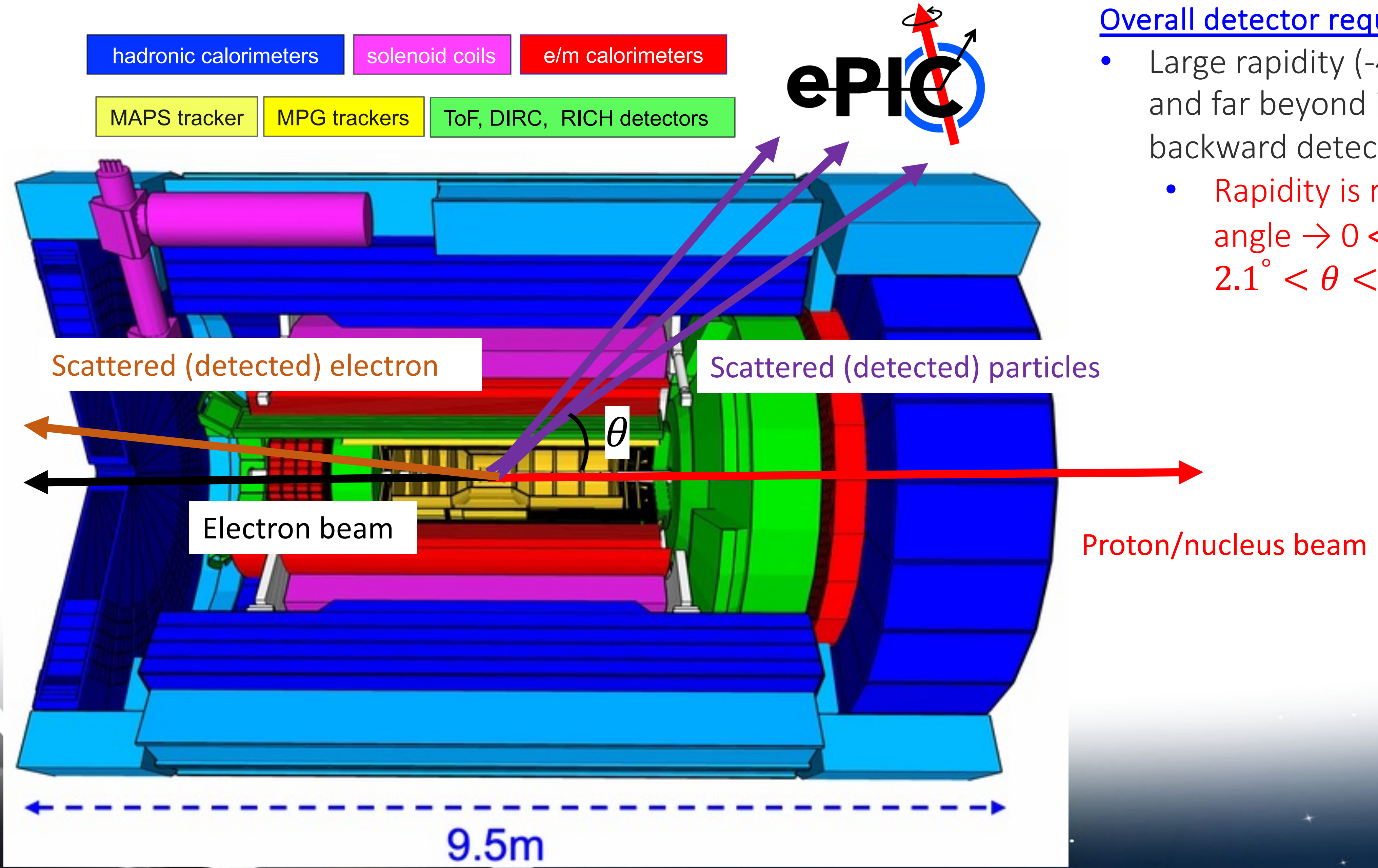
Accessing Exclusive Reactions at the EIC

hadronic calorimeters | solenoid coils | e/m calorimeters

MAPS tracker | MPG trackers | ToF, DIRC, RICH detectors



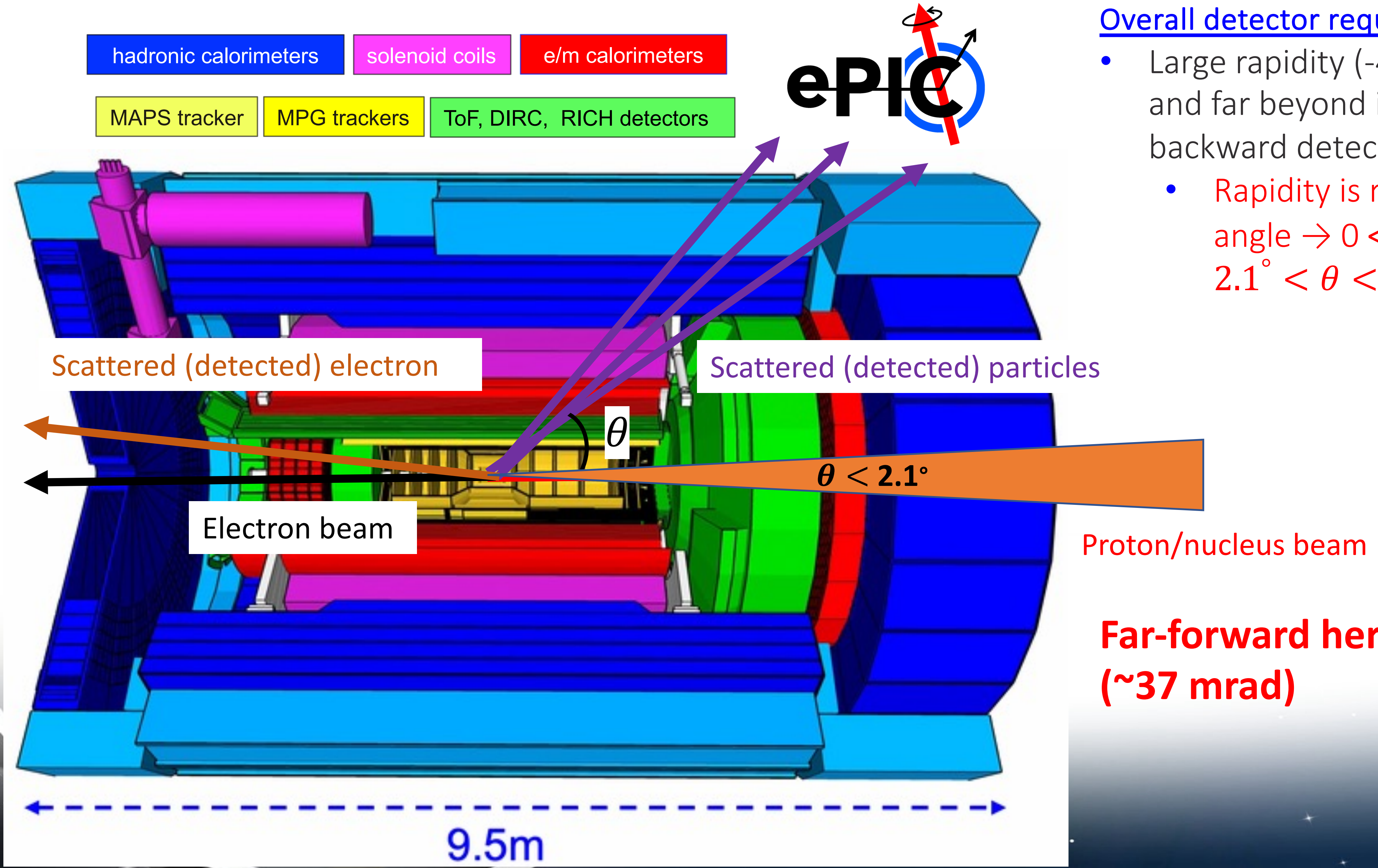
Accessing Exclusive Reactions at the EIC



<u>Overall detector requirements:</u>

- Large rapidity (-4 < η < 4) coverage; and far beyond in far-forward/far-backward detector regions
  - Rapidity is related to the polar angle → 0 < η < 4 equates to $2.1^{\circ} < \theta < 90^{\circ}$

Accessing Exclusive Reactions at the EIC



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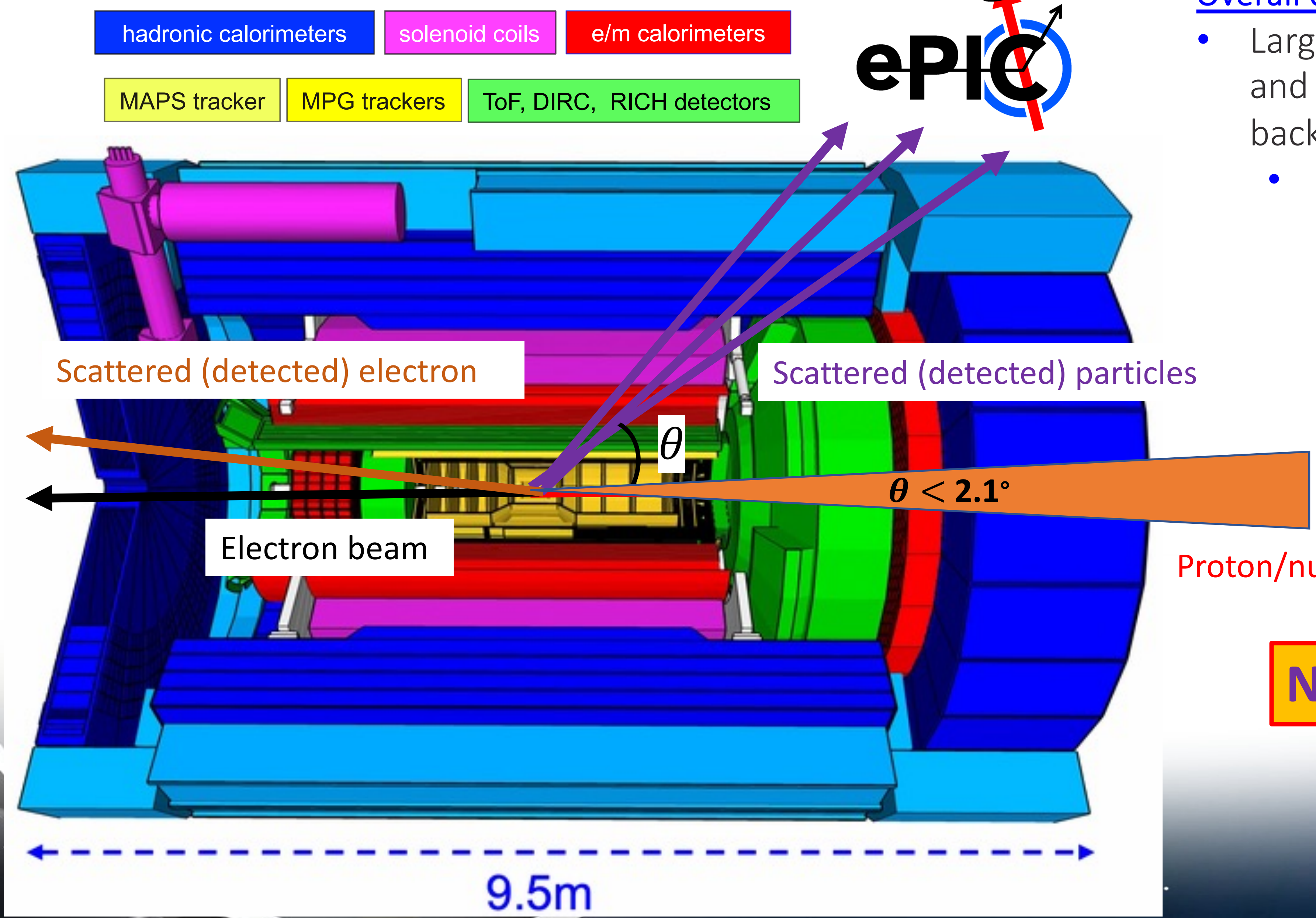
Far-forward here means $\theta < 2.1^{\circ}$ (~37 mrad)

Accessing Exclusive Reactions at the EIC



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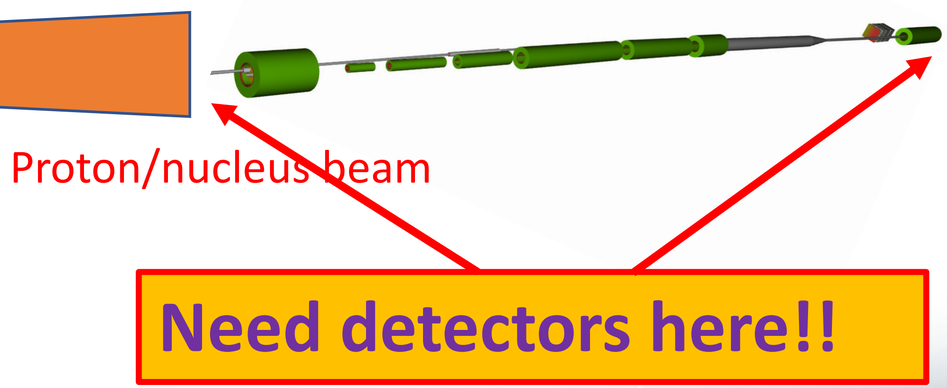
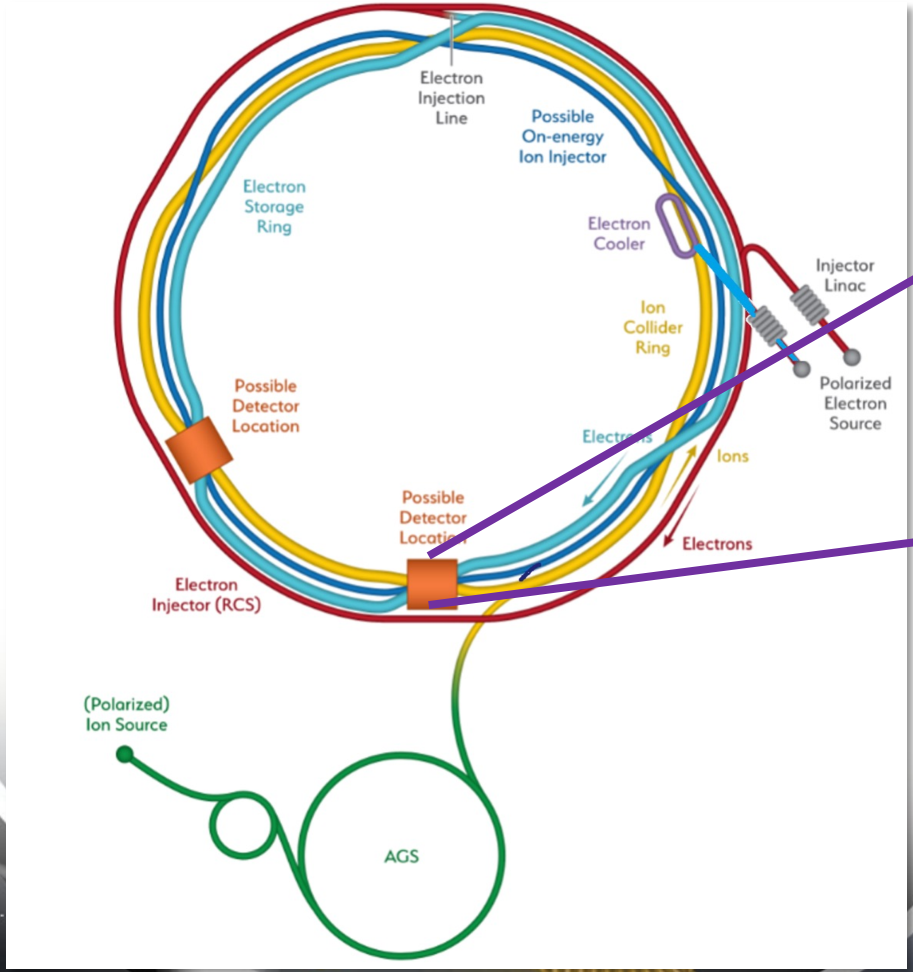
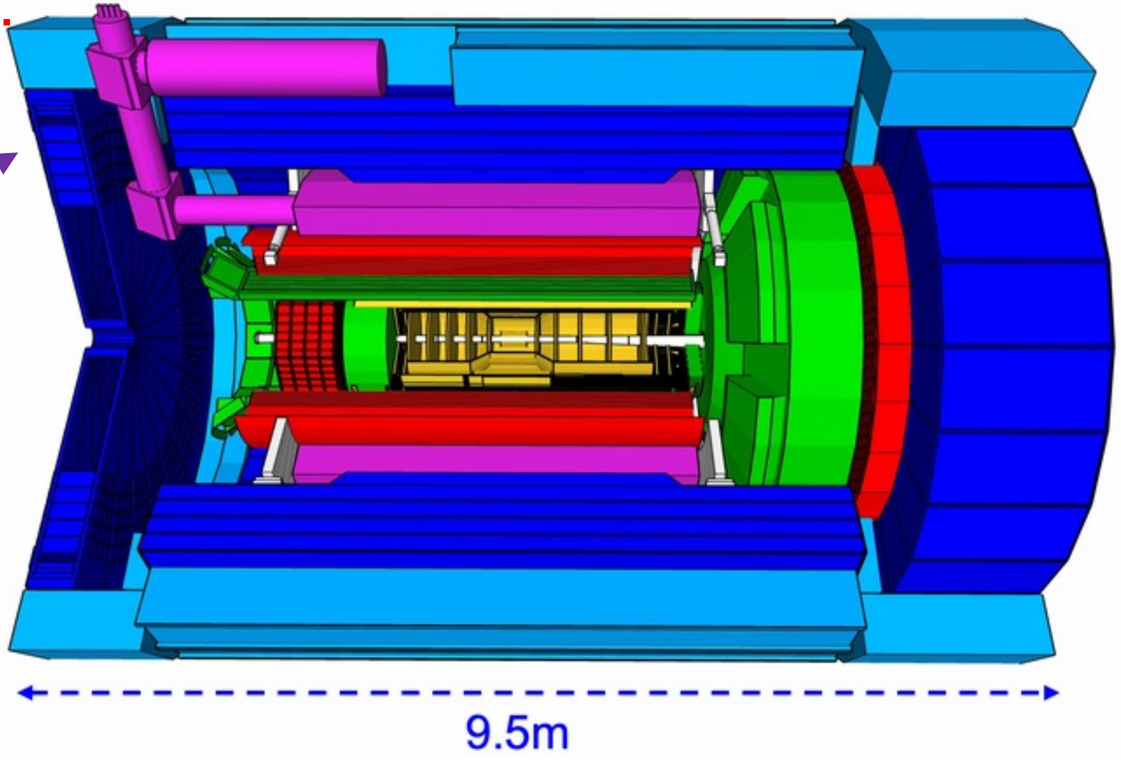


The EIC detector(s)

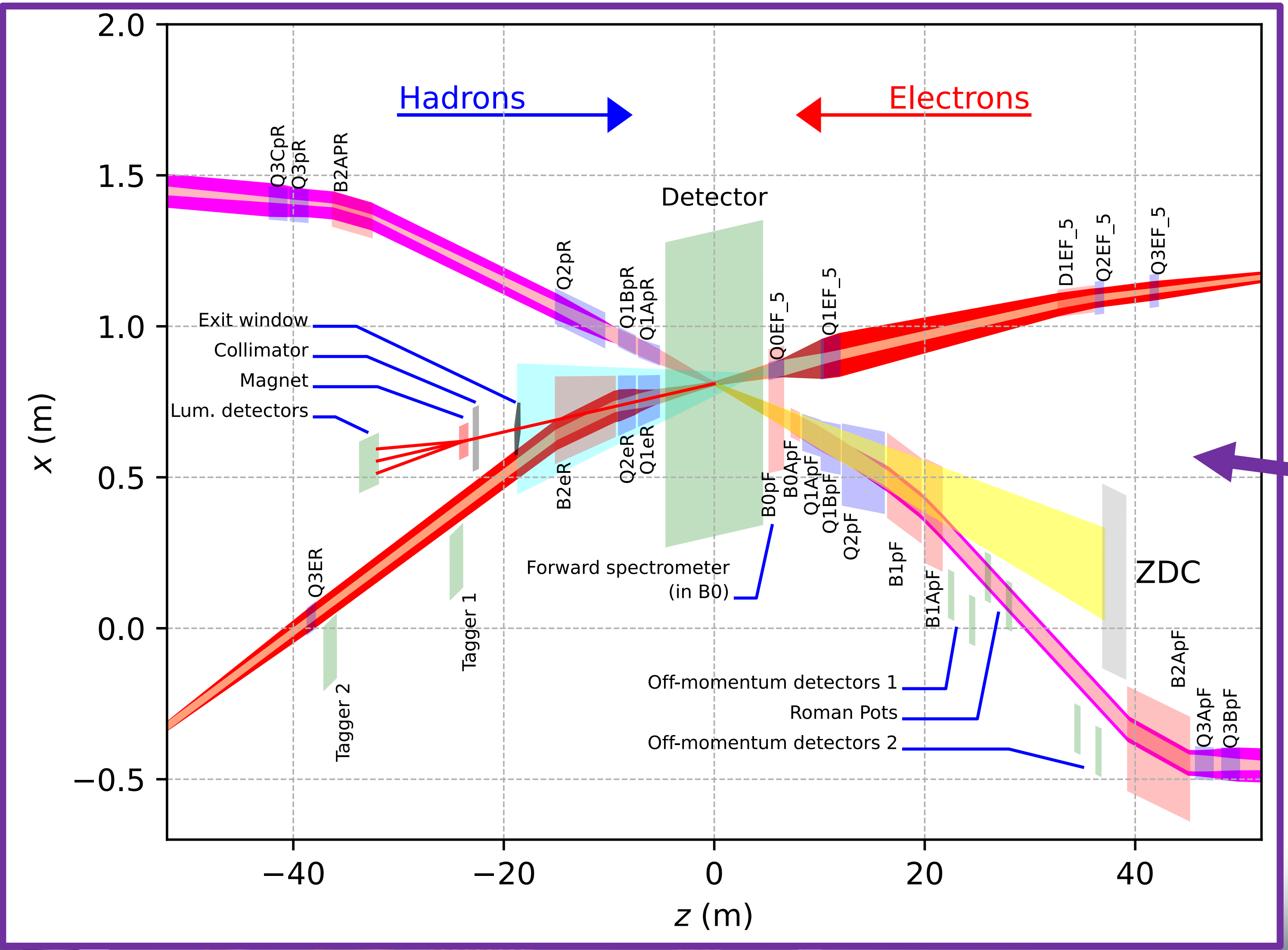
- Two interaction regions (IRs) for possible detector locations.
  - Only one IR (IP6) part of the project scope.

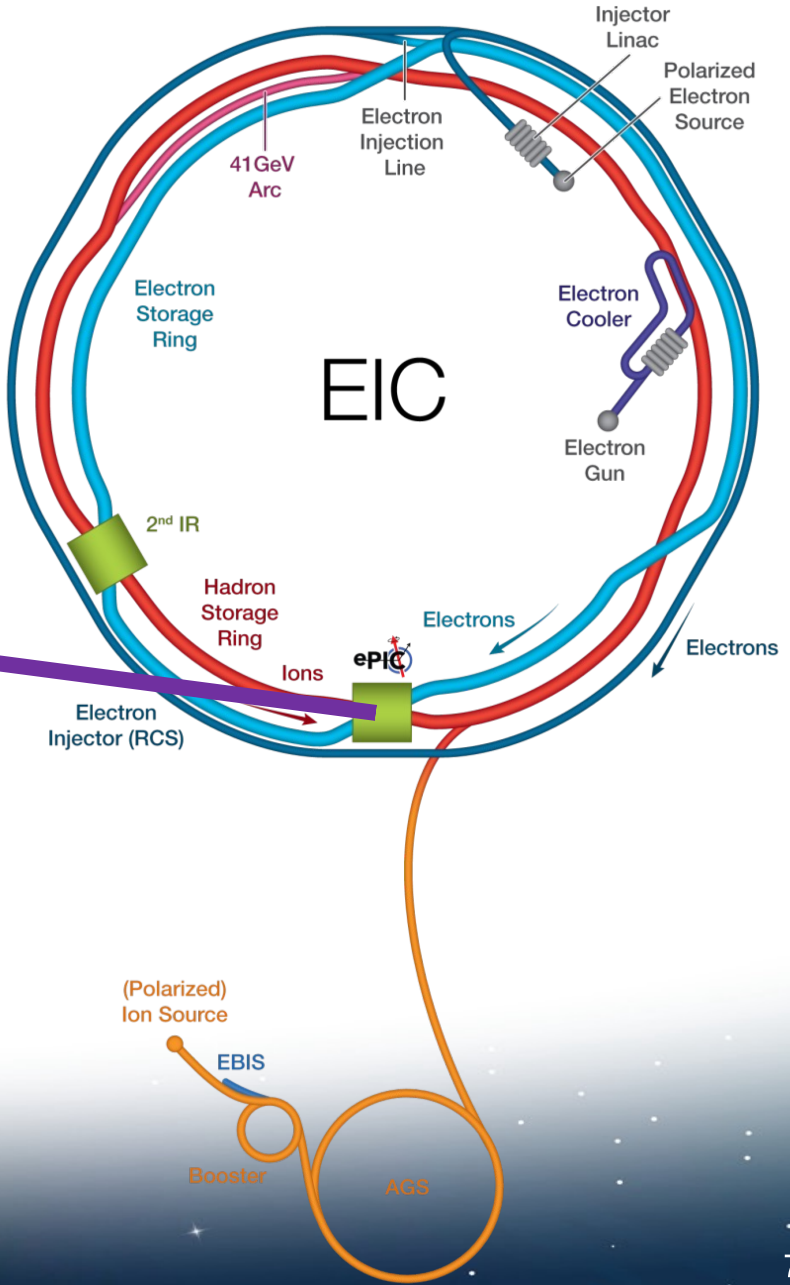




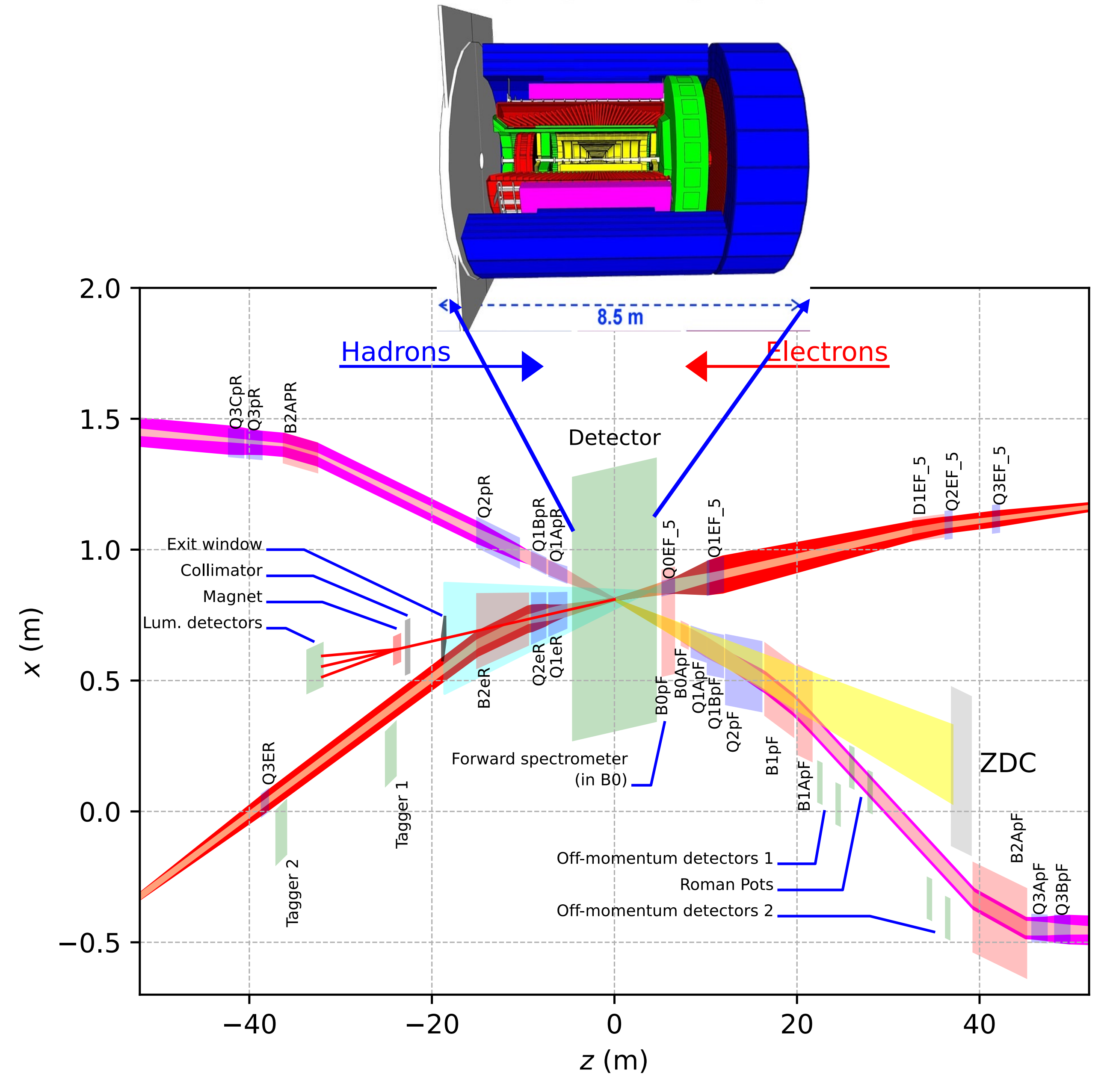
- ➢ ePIC detector based around a 1.7T solenoid magnet.
- ➢ Contains subdetectors for tracking, PID, and calorimetry.

and the full interaction region!





EIC Detector 1 – IP6

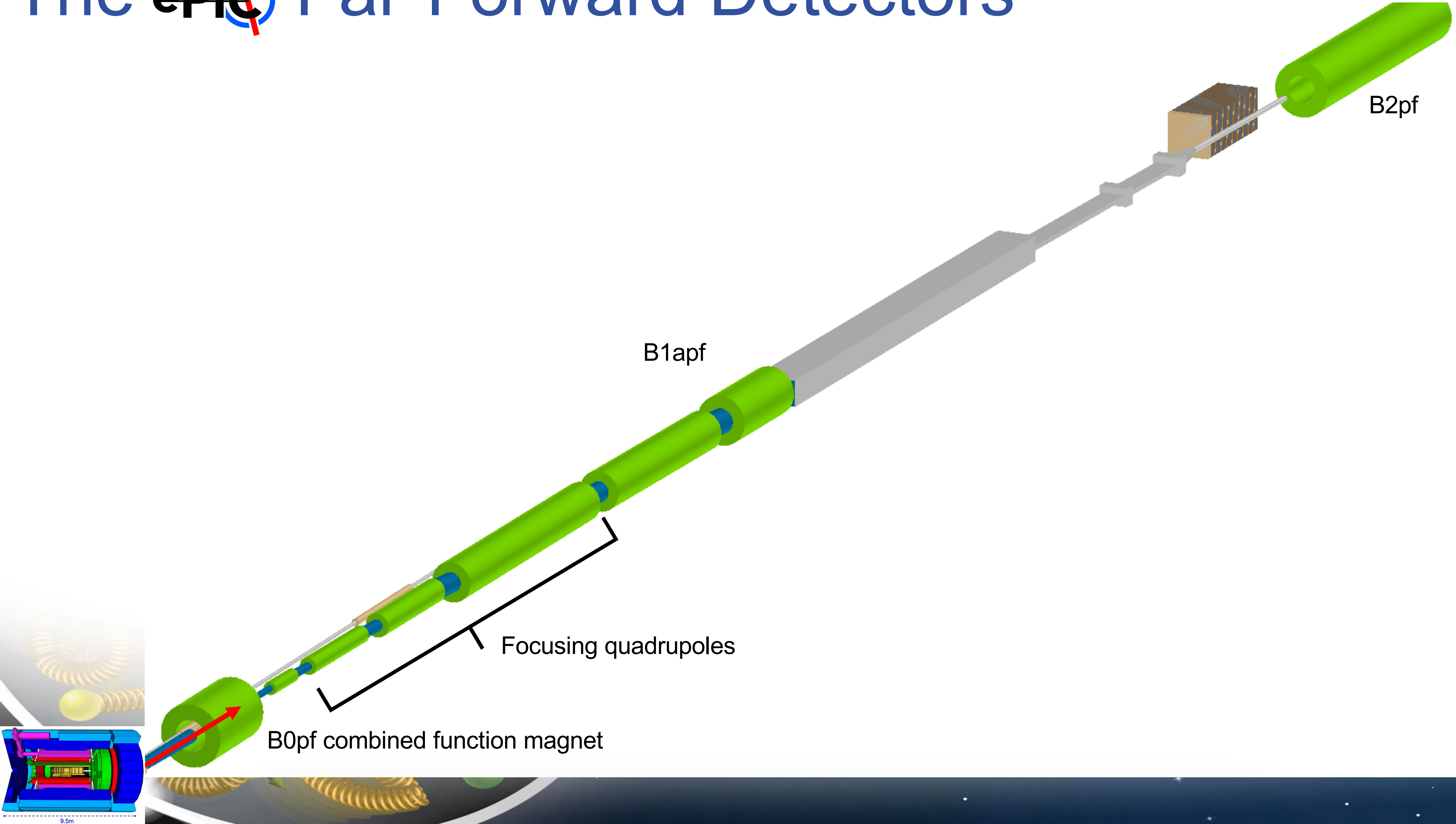


- In addition to the central detector → detectors integrated into the beamline on both the hadron-going (**far-forward**) and electron-going (**far-backward**) direction.
  - Requires special considerations for the machine-detector interface.

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 ePIC Far-Forward Detectors



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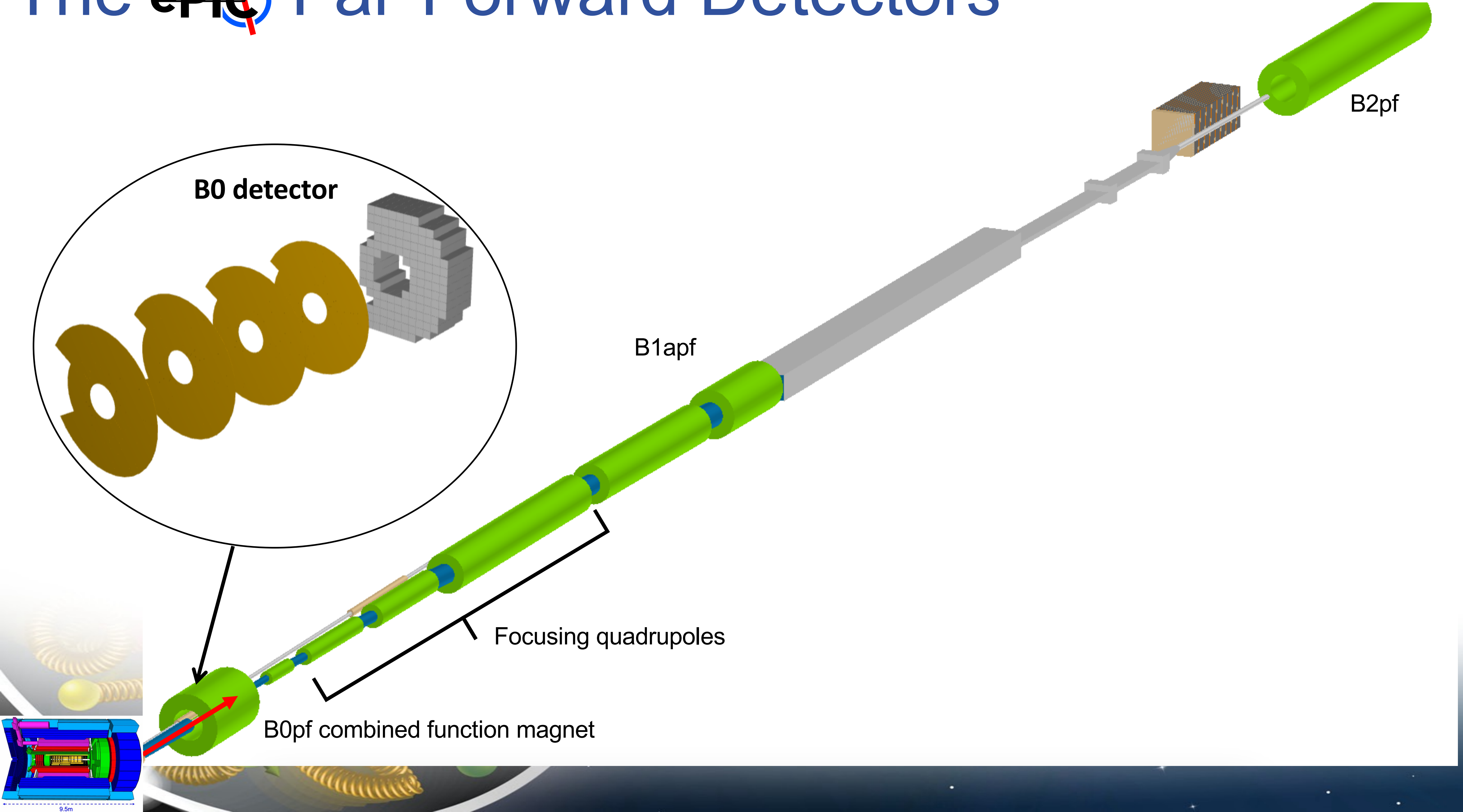

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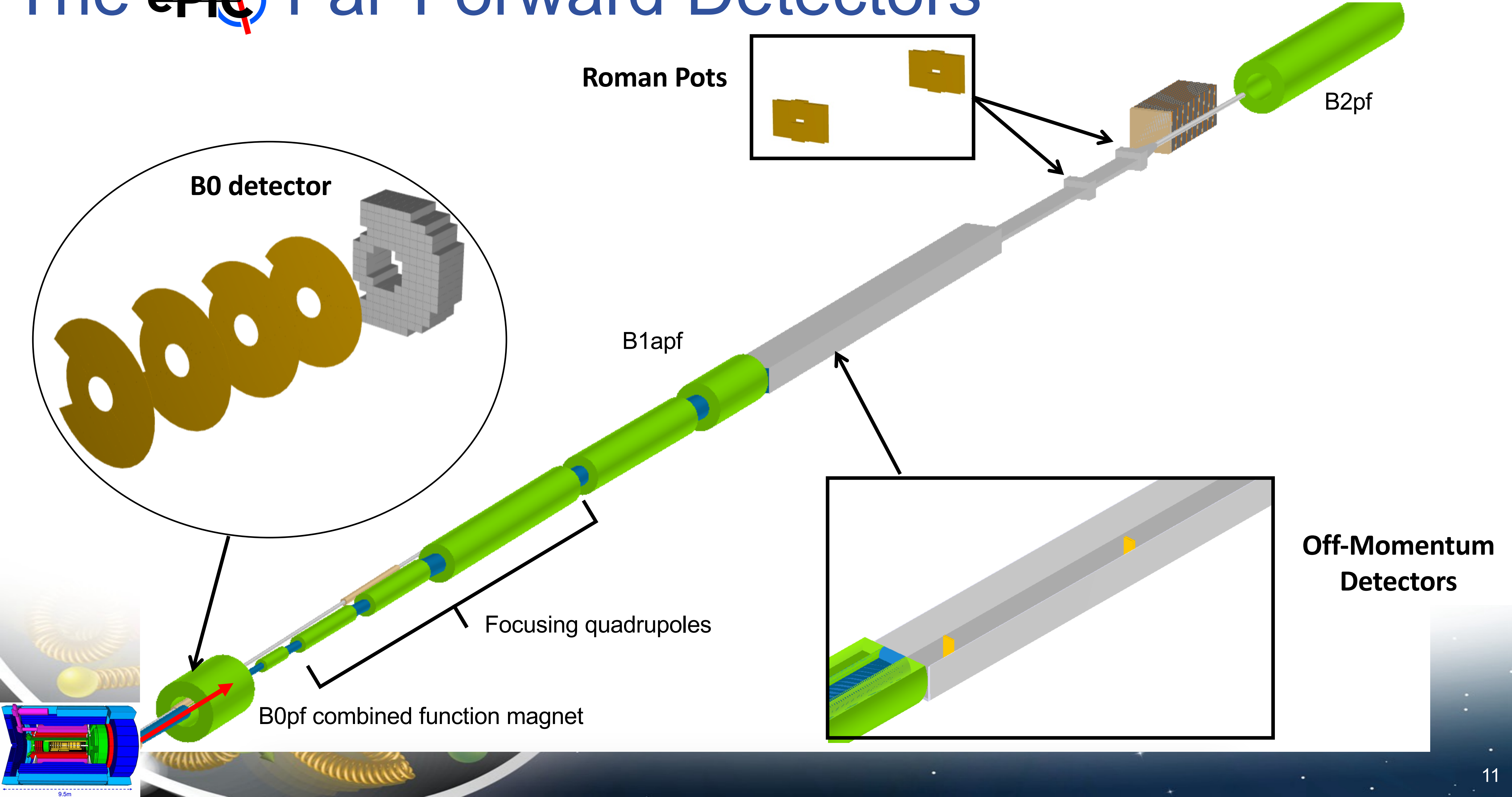

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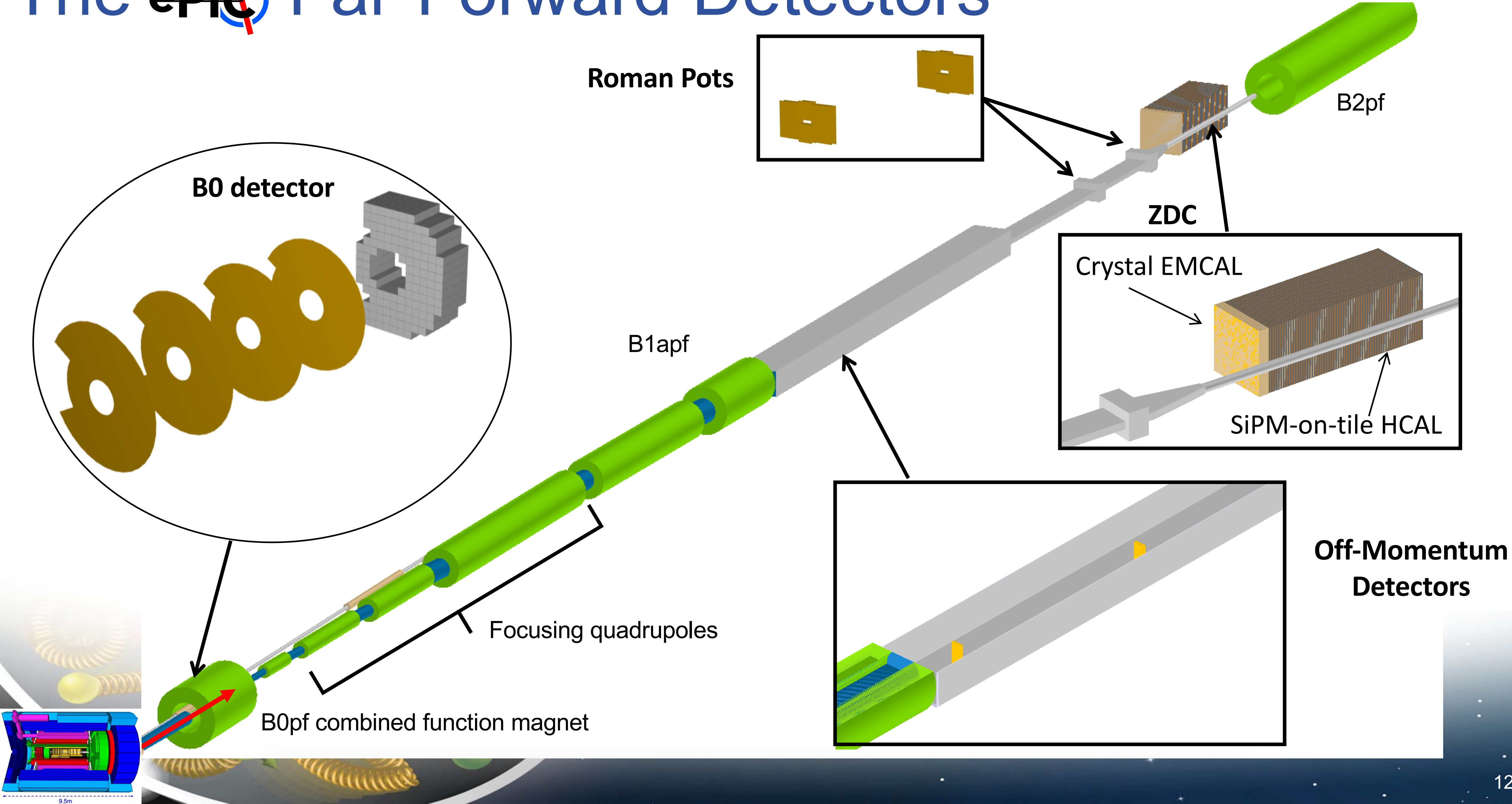

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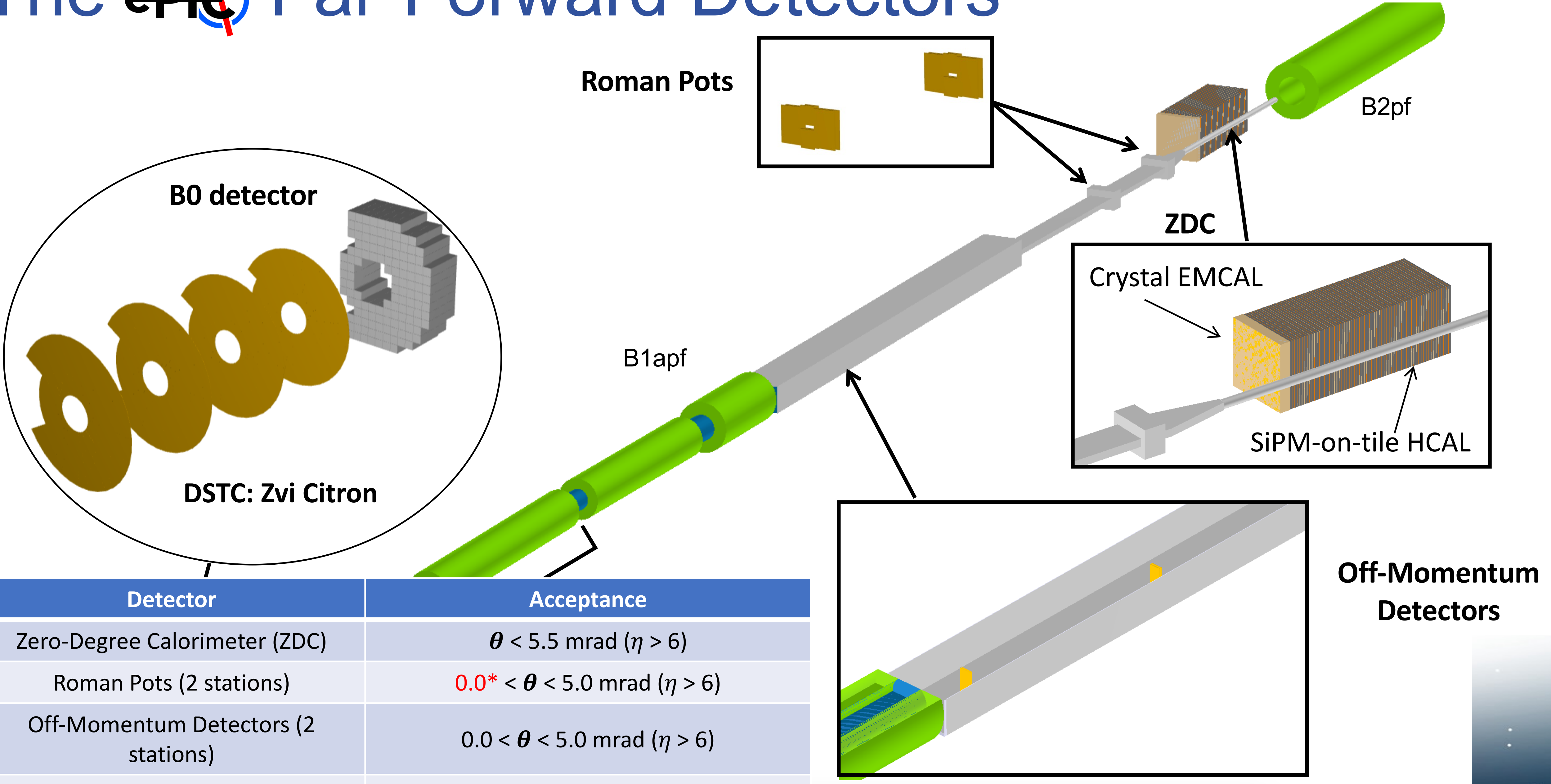
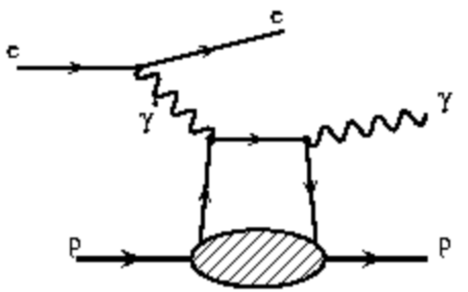


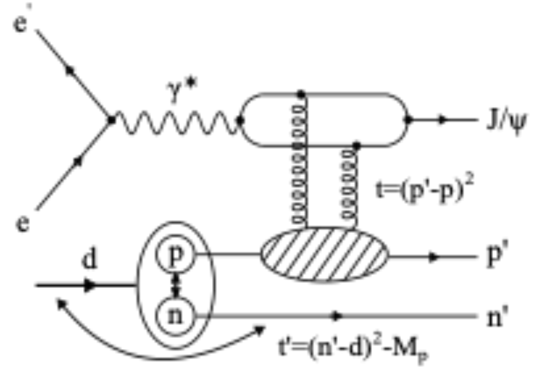
Detector	Acceptance
Zero-Degree Calorimeter (ZDC)	$\theta < 5.5$ mrad ($\eta > 6$)
Roman Pots (2 stations)	0.0* $< \theta < 5.0$ mrad ($\eta > 6$)
Off-Momentum Detectors (2 stations)	$0.0 < \theta < 5.0$ mrad ($\eta > 6$)
B0 Detector	$5.5 < \theta < 20.0$ mrad ($4.6 < \eta < 5.9$)

Far-Forward Processes at the EIC

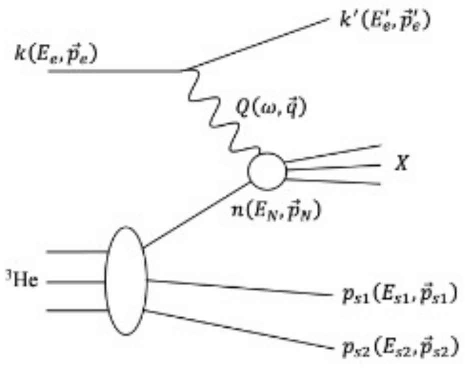
e+p DVCS



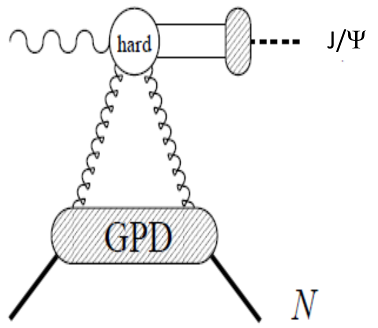
e+d exclusive J/Psi with p/n tagging



e+He3 spectator tagging

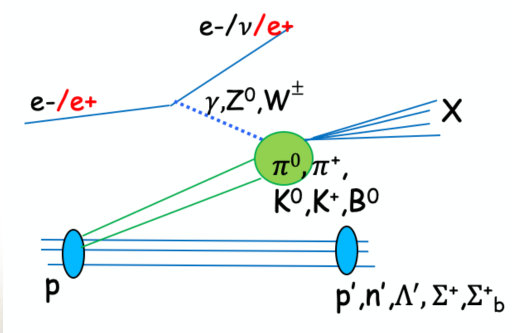


coherent/incoherent J/ψ production in e+A

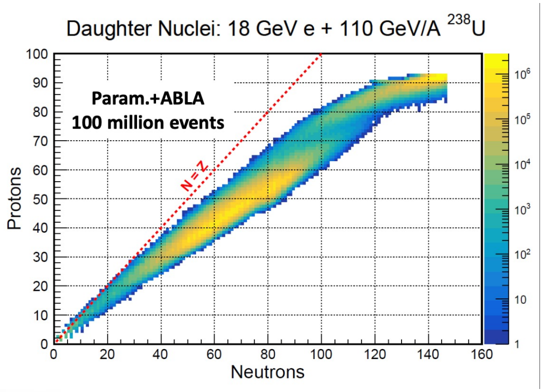


Meson structure:

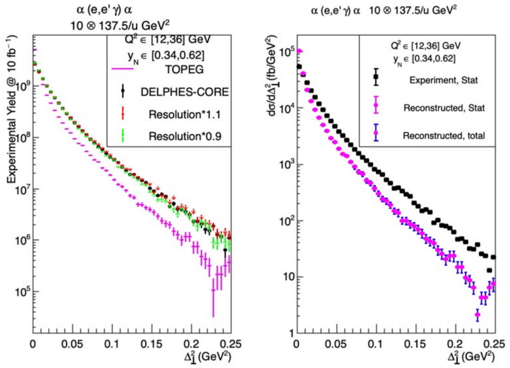
- ep→ (π) →e' n X
- Λ →pπ^- and Λ → nπ^0



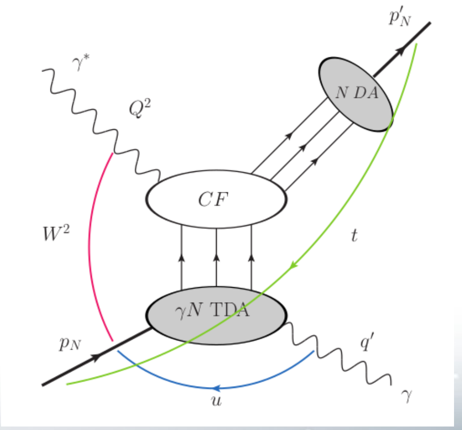
Rare isotopes



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.

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- 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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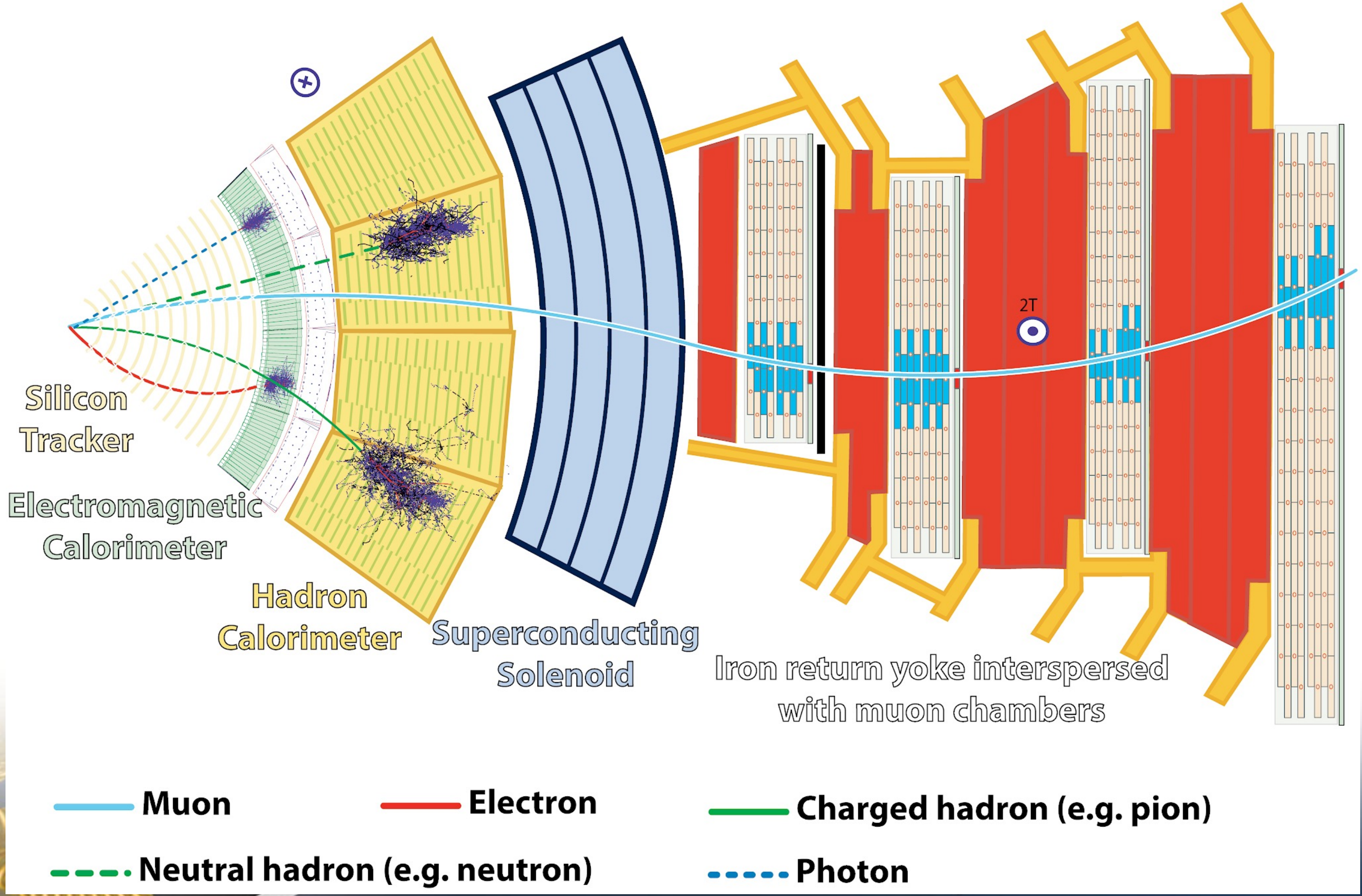
- Physics channels require tagging of **charged hadrons** (protons, pions) or **neutral particles** (neutrons, photons) at **very-forward rapidities** $(\boldsymbol{\eta > 4.5})$.
- Different final states require tailored detector subsystems.
- Various collision systems (e.g. e+p, e+d, e+Au) provide unique challenges.
- Placing of far-forward detectors uniquely challenging due to presence of machine components, space constraint, apertures, etc.
- Full engineering design underway, and detector R&D wrapping up toward construction of first test articles.

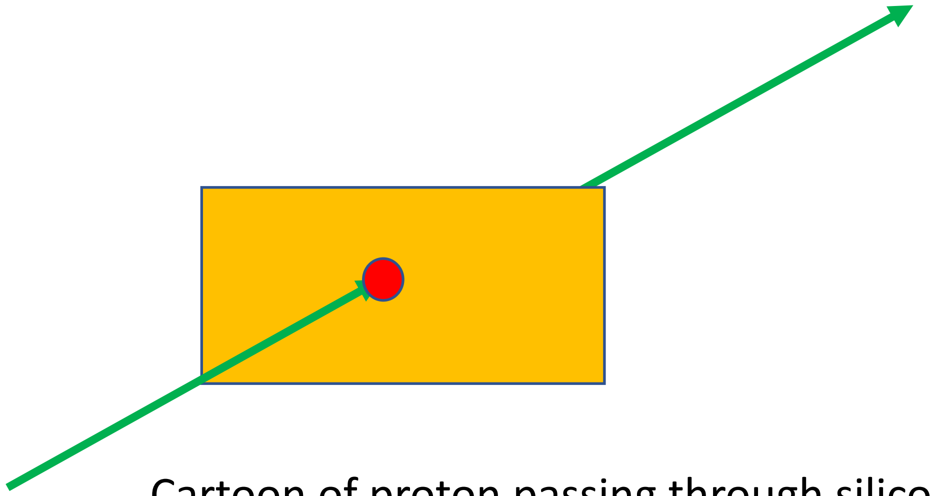
Some general comments about simulations

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

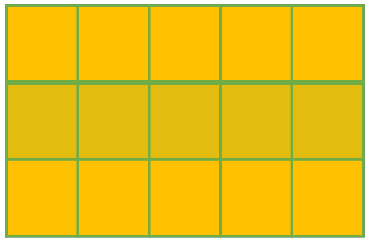


Some general comments about simulations

- 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.

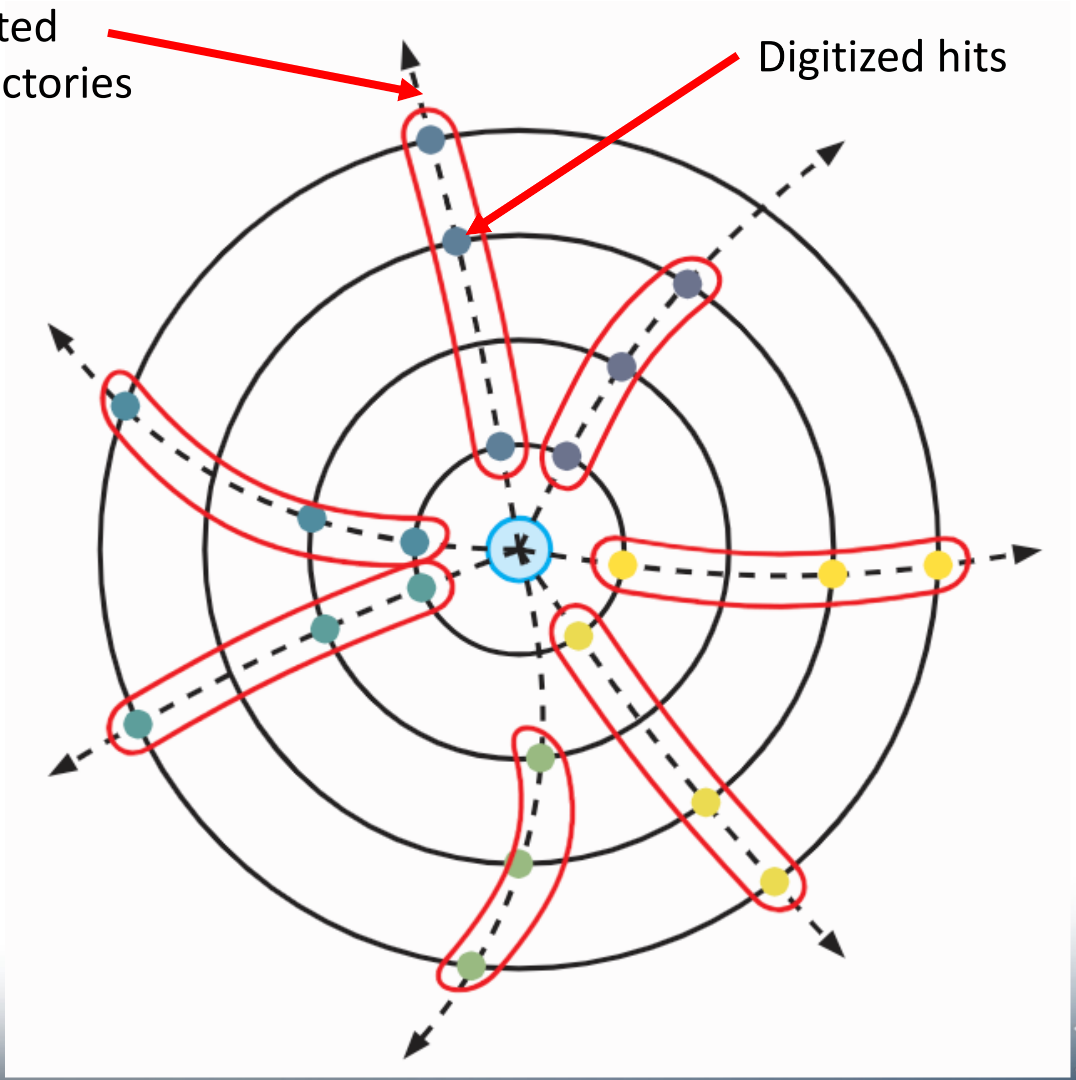


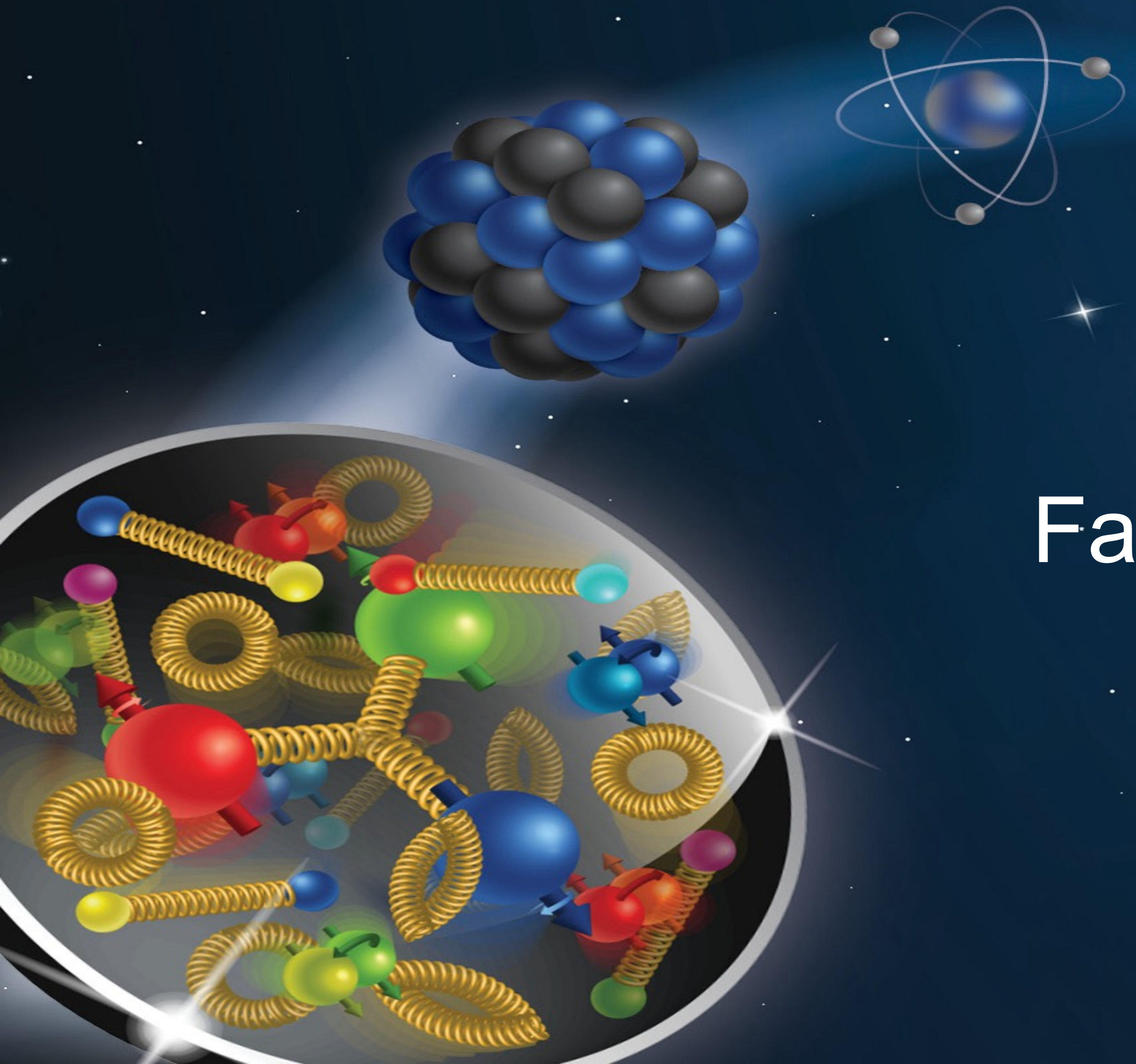
Cartoon of proton passing through silicon plane, and depositing a bit of energy.



Some general comments about simulations

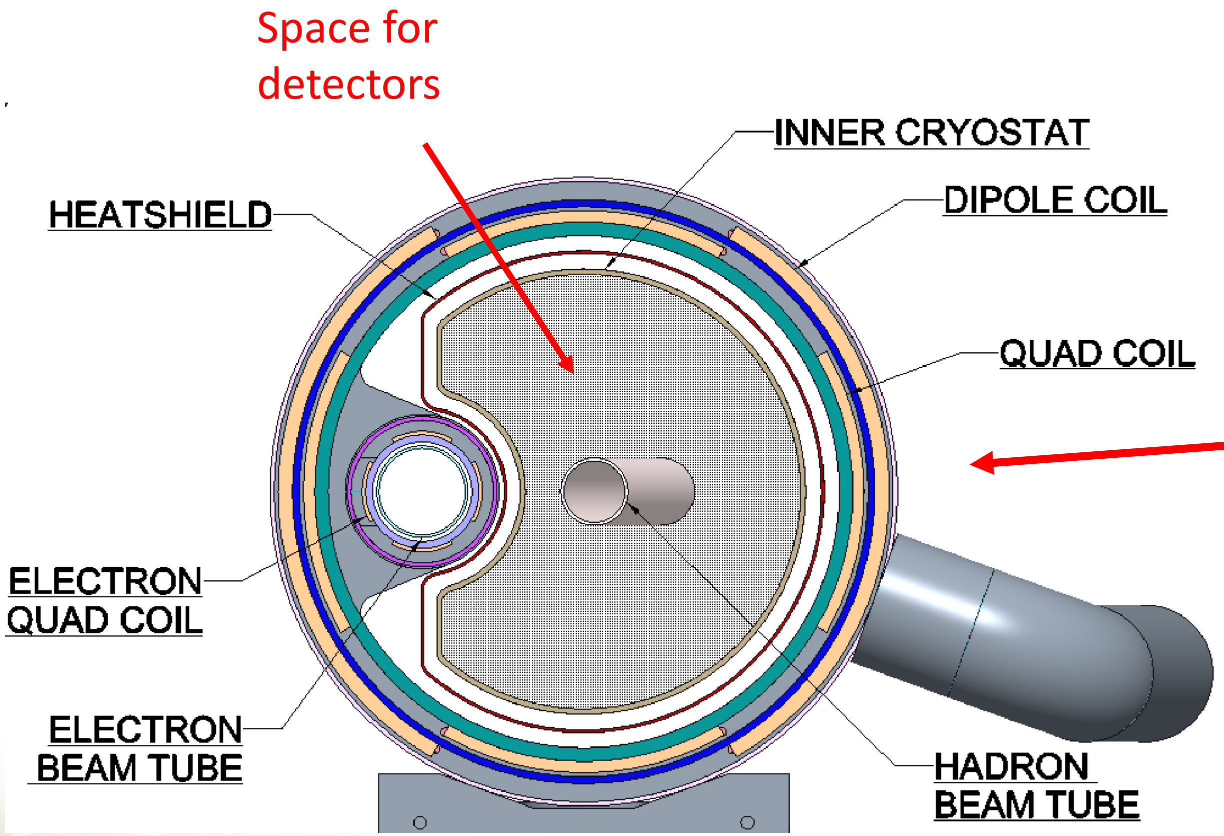
- Reconstruction is taking the digitized information and turning it into a physical quantity (e.g. energy, momentum, etc.).

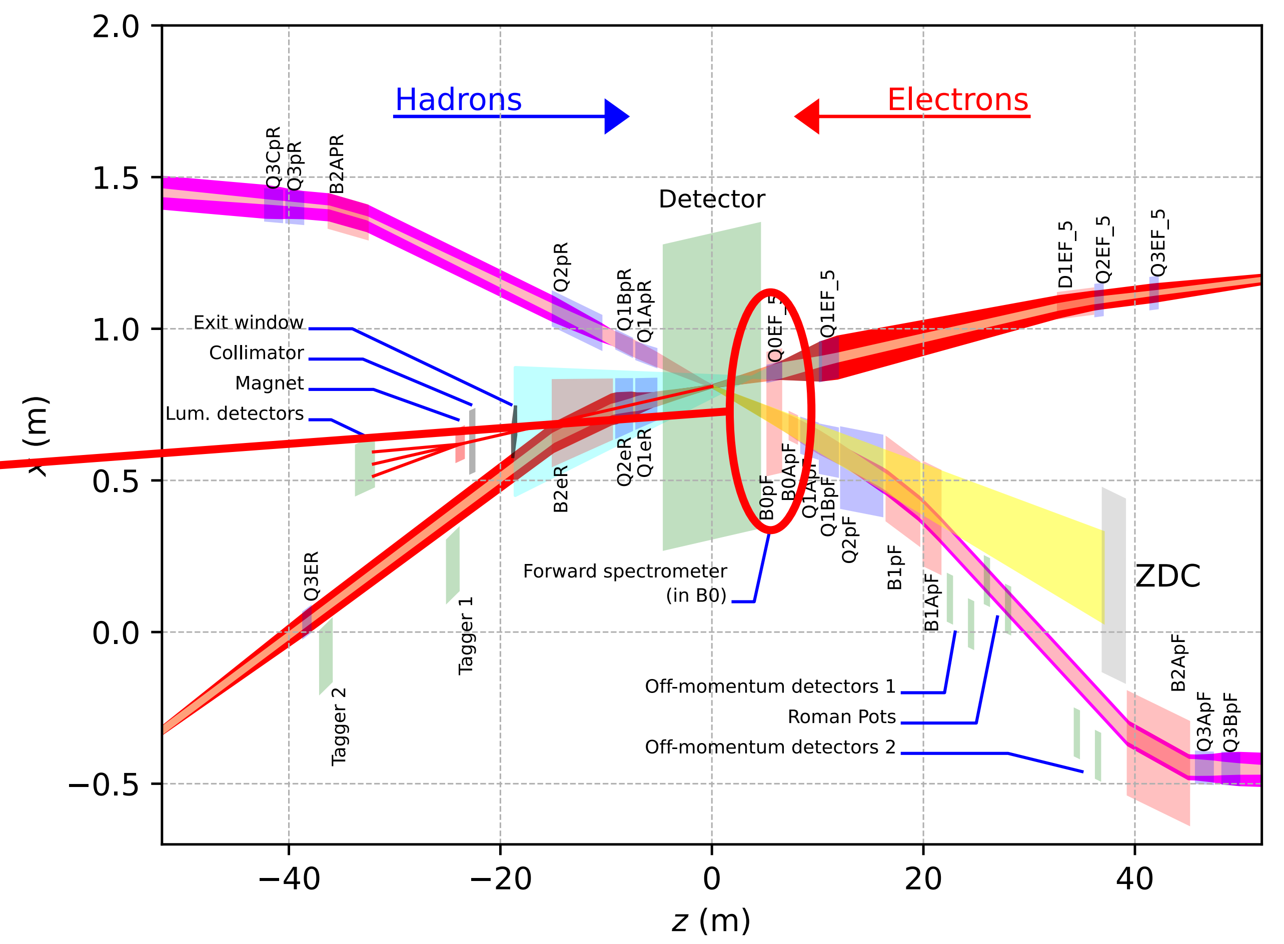




Far-Forward Detector Subsystems

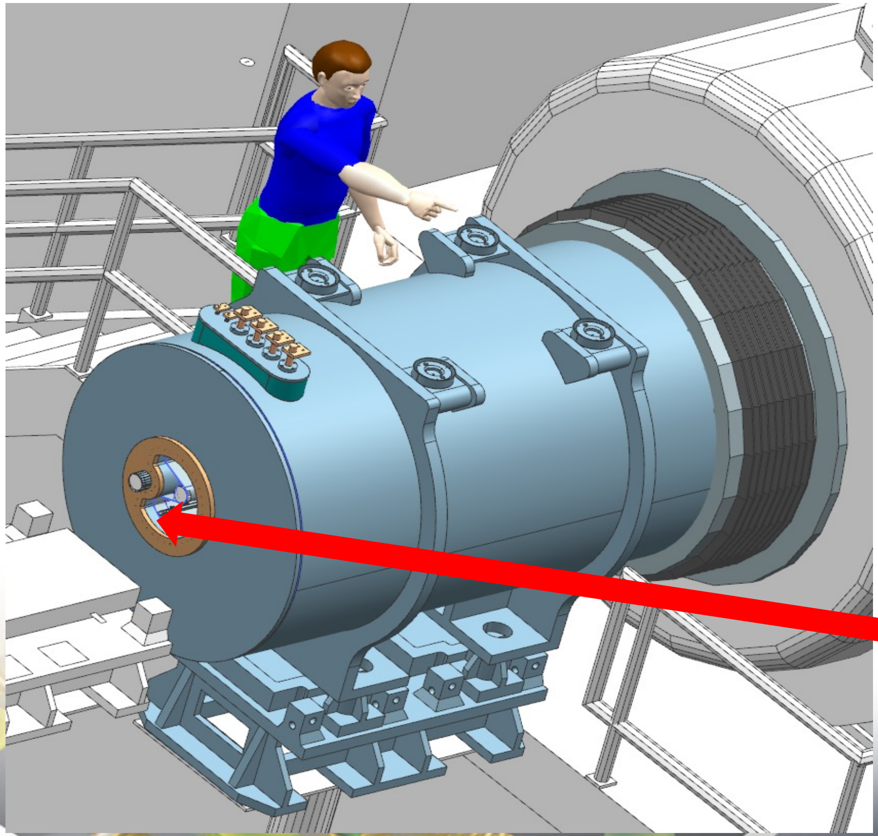
B0 Detectors



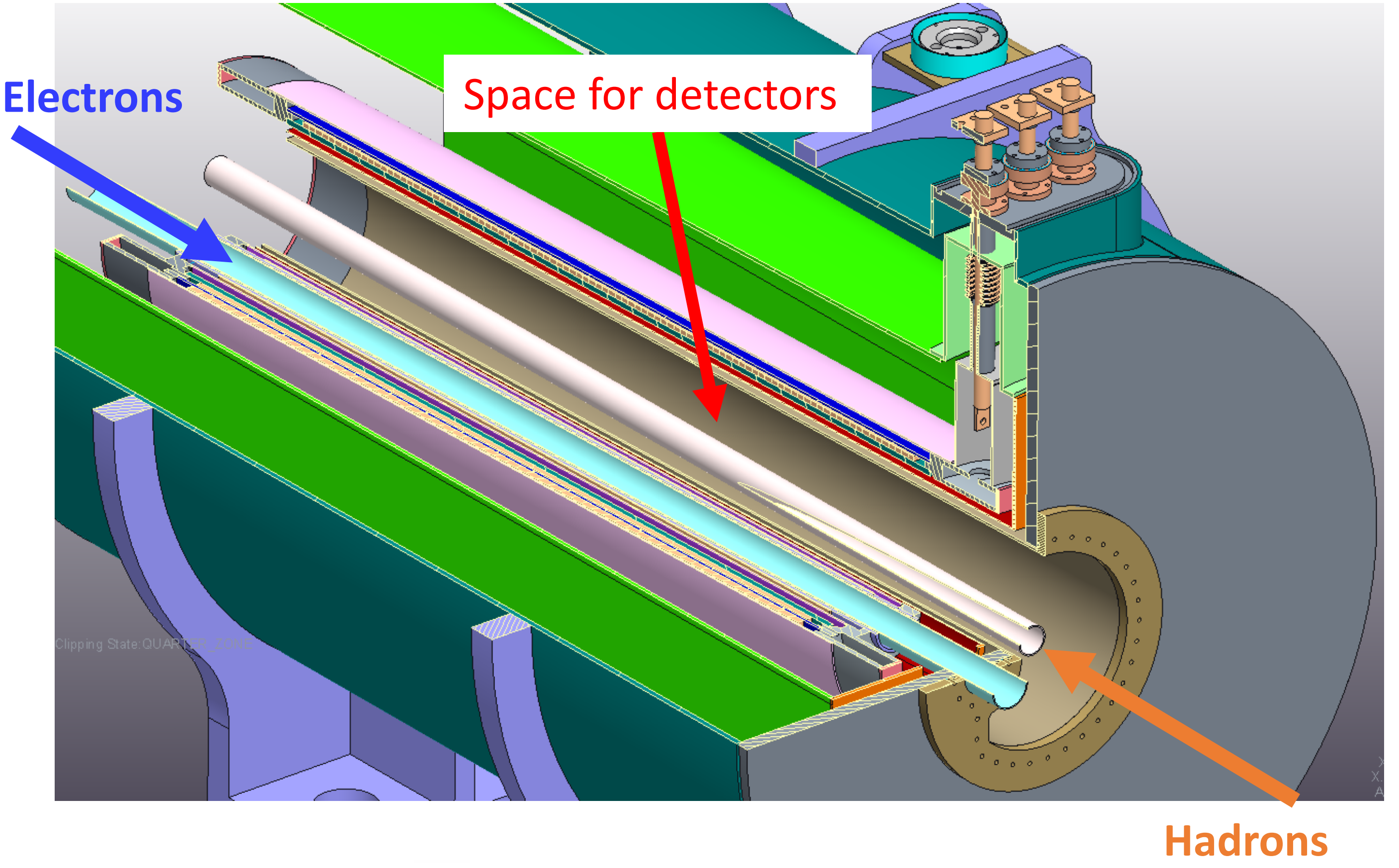


B0 Detectors

- 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).

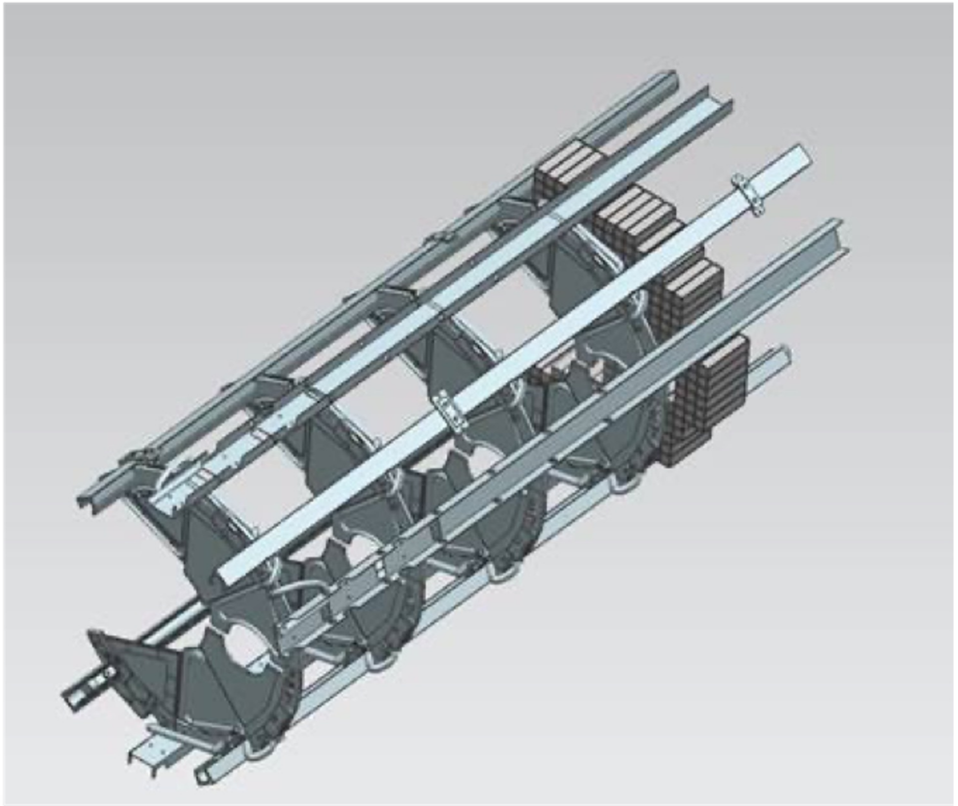


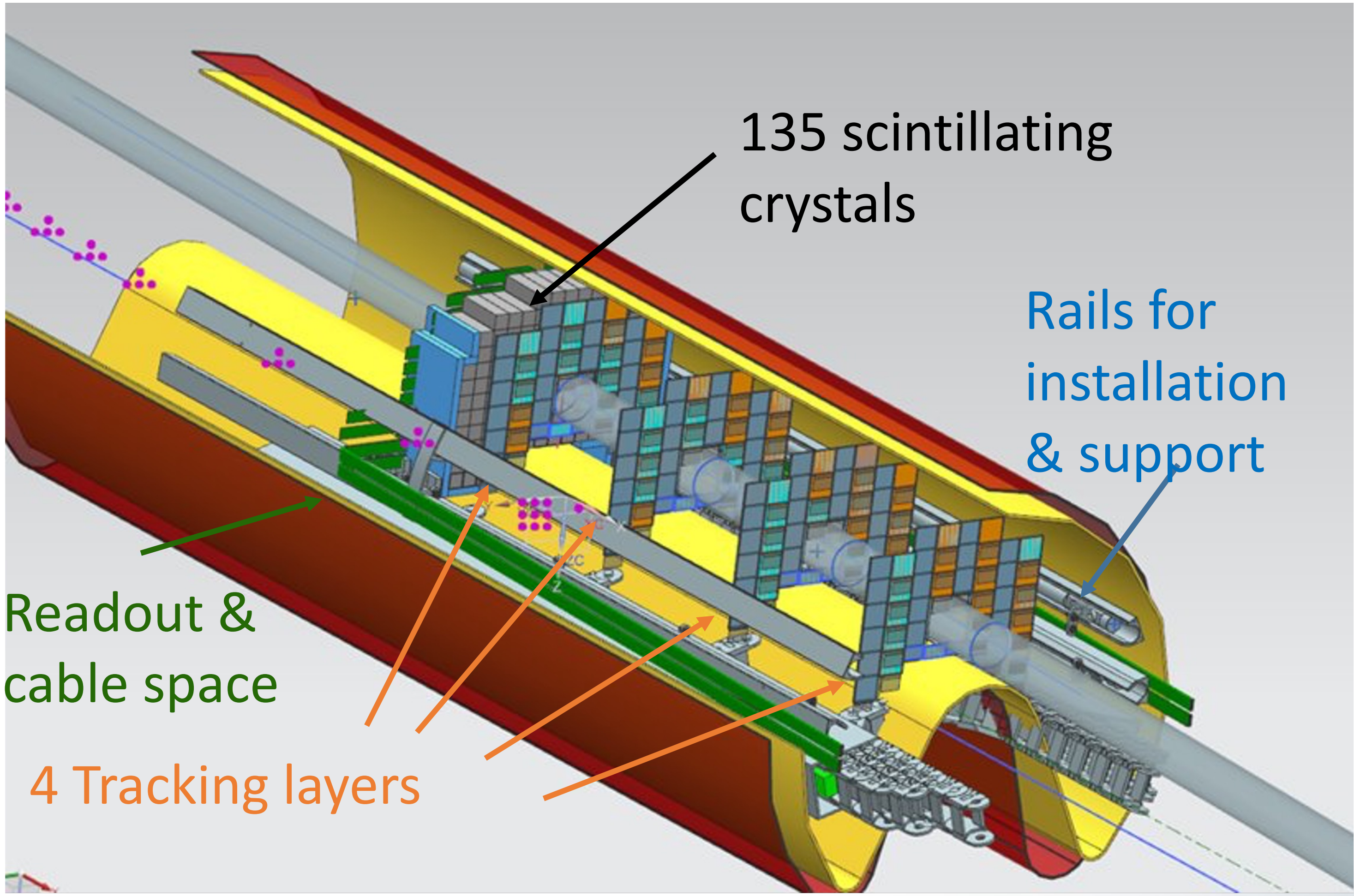
This is the opening where the detector planes will be inserted



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

B0 Detectors in CAD

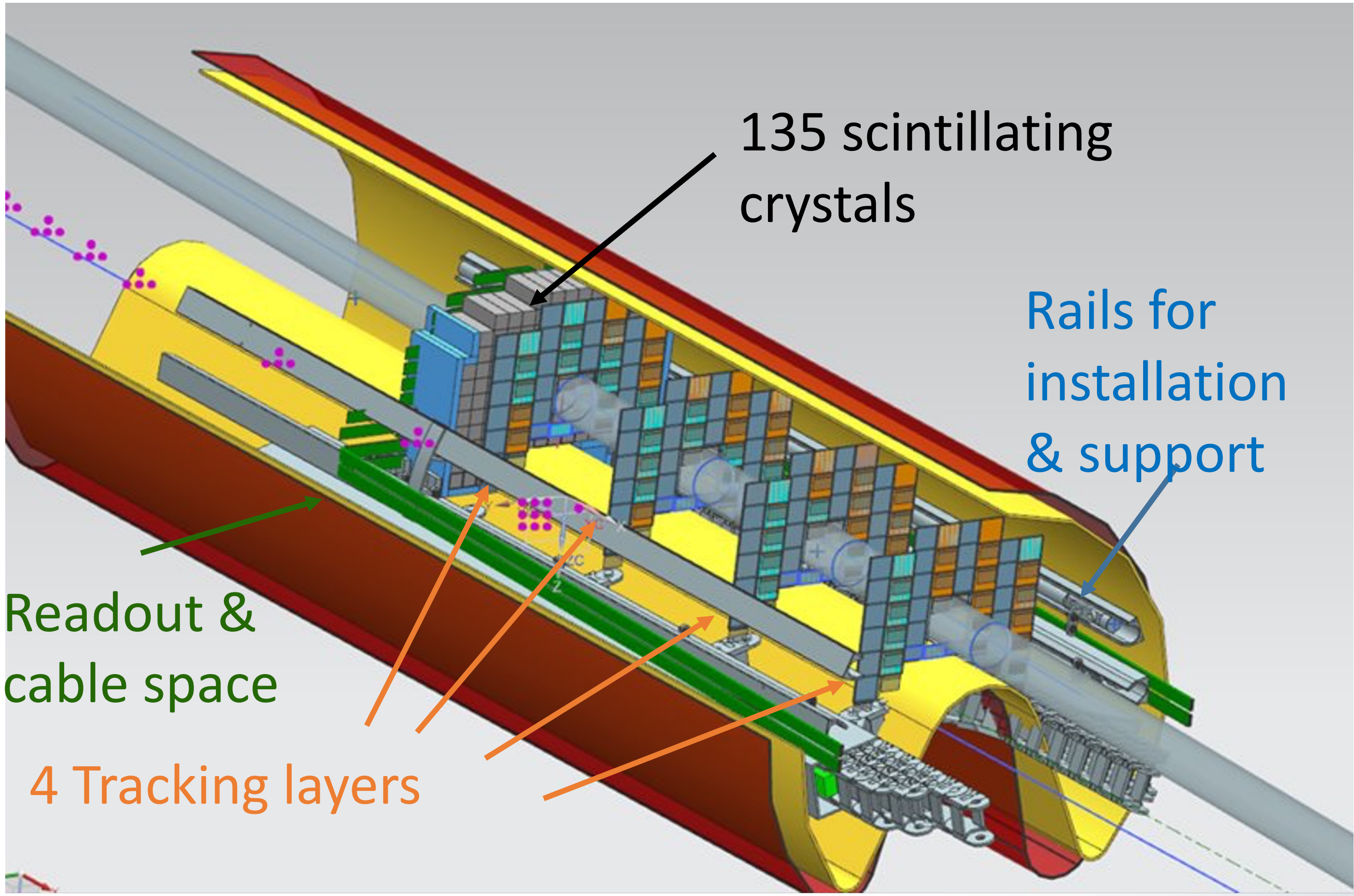




B0 Tracking and EMCAL Detectors

CAD Look credit: Jonathan Smith

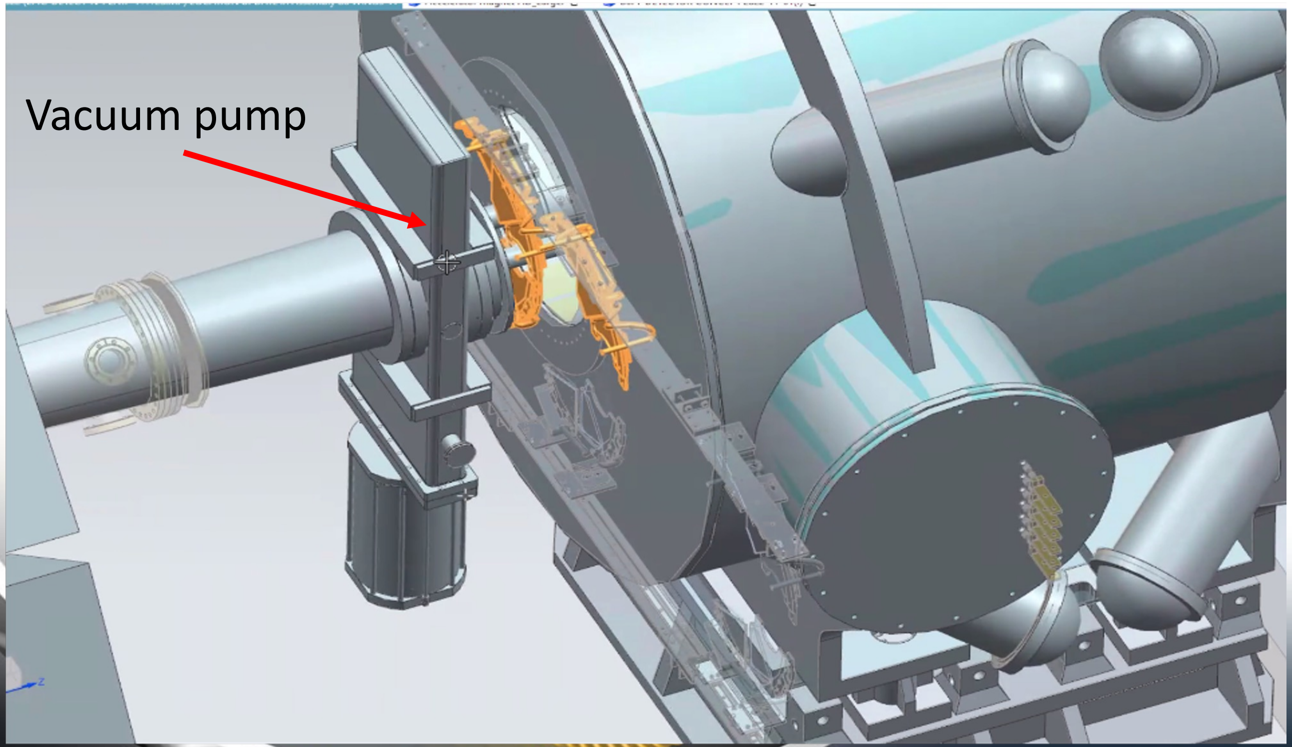
- Tracker uses a new silicon technology – AC-LGADs.
  - Allows for high-precision spatial and timing measurement!
- EMCAL uses either PbWO4 crystals or LYSO.
  - Tagging photons important in differentiating between coherent and incoherent heavy-nuclear scattering, and for reconstructing $\pi^0 \rightarrow \gamma\gamma$.
  - **Space is a major concern here – Installation of large detector into accelerator magnet highly non-trivial!**

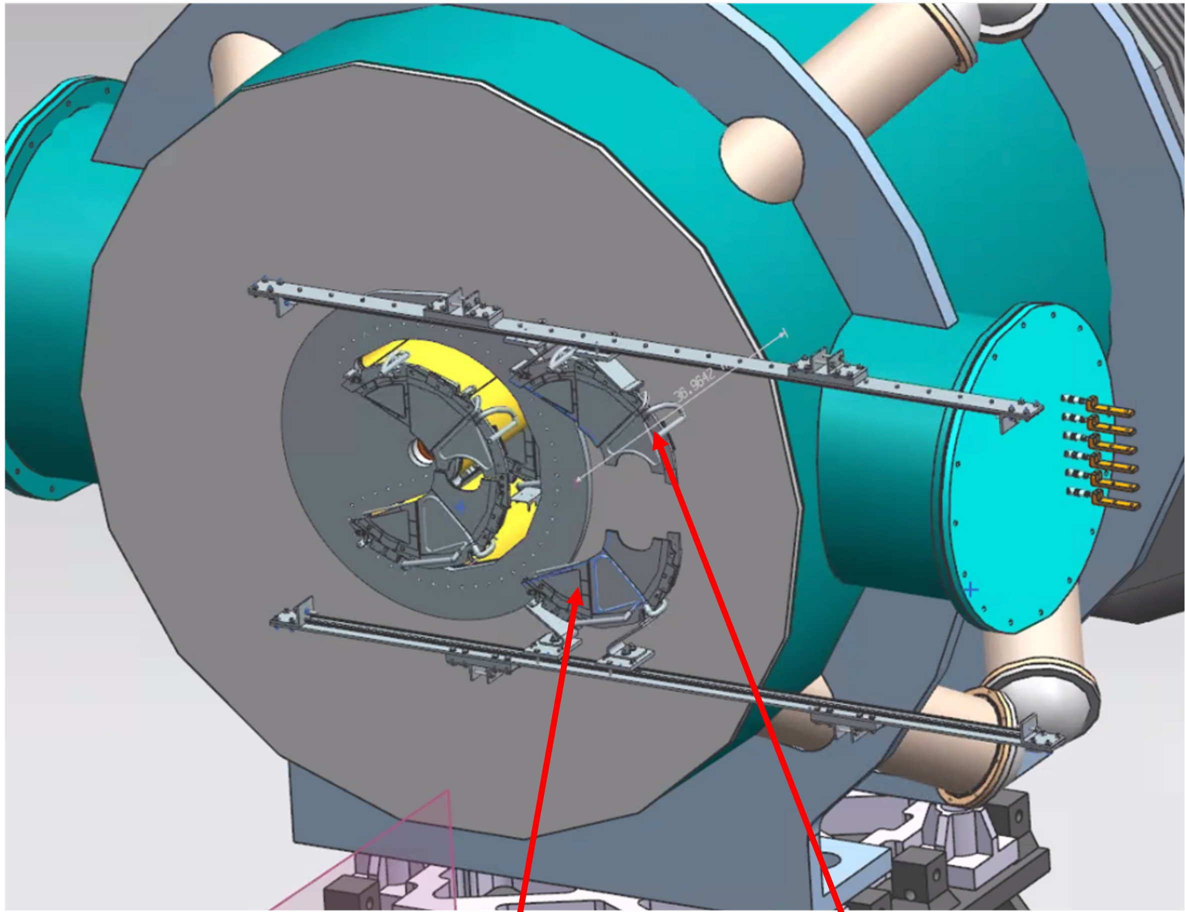


B0 Integration

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).

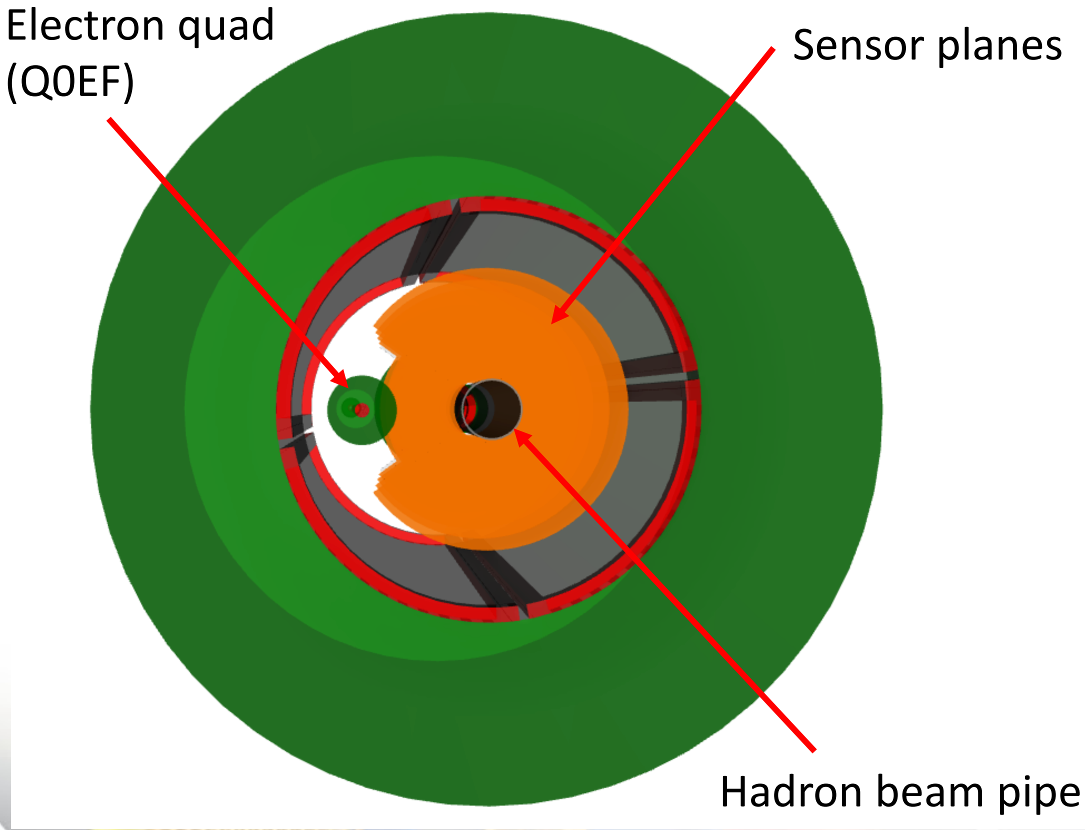


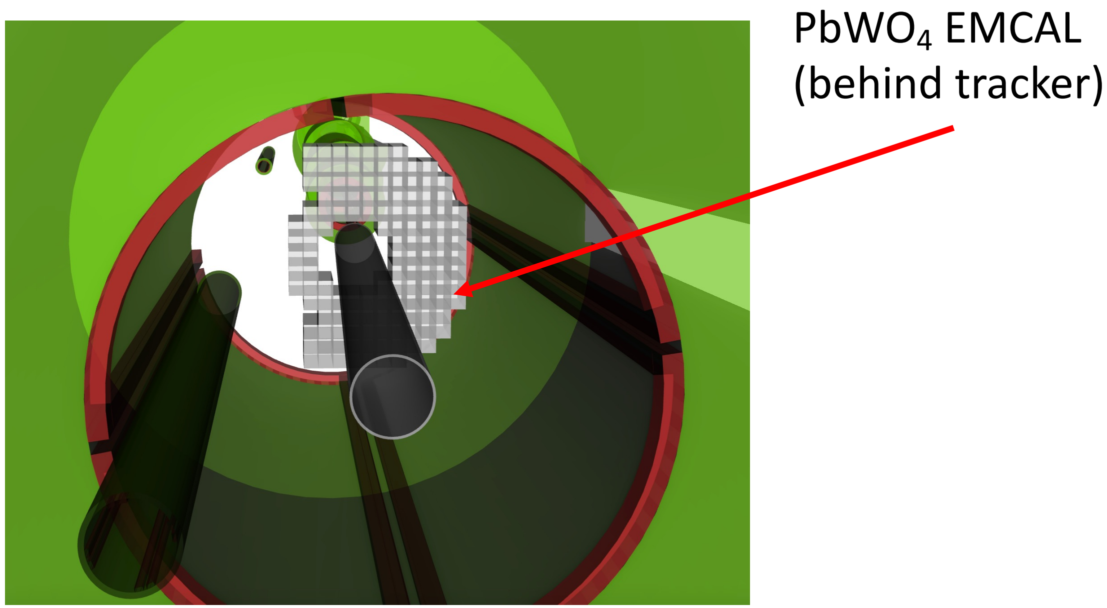


- Tracking planes separate into two pieces - top and bottom - for insertion into bore.
- Need concept for EMCAL.

B0-detectors

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





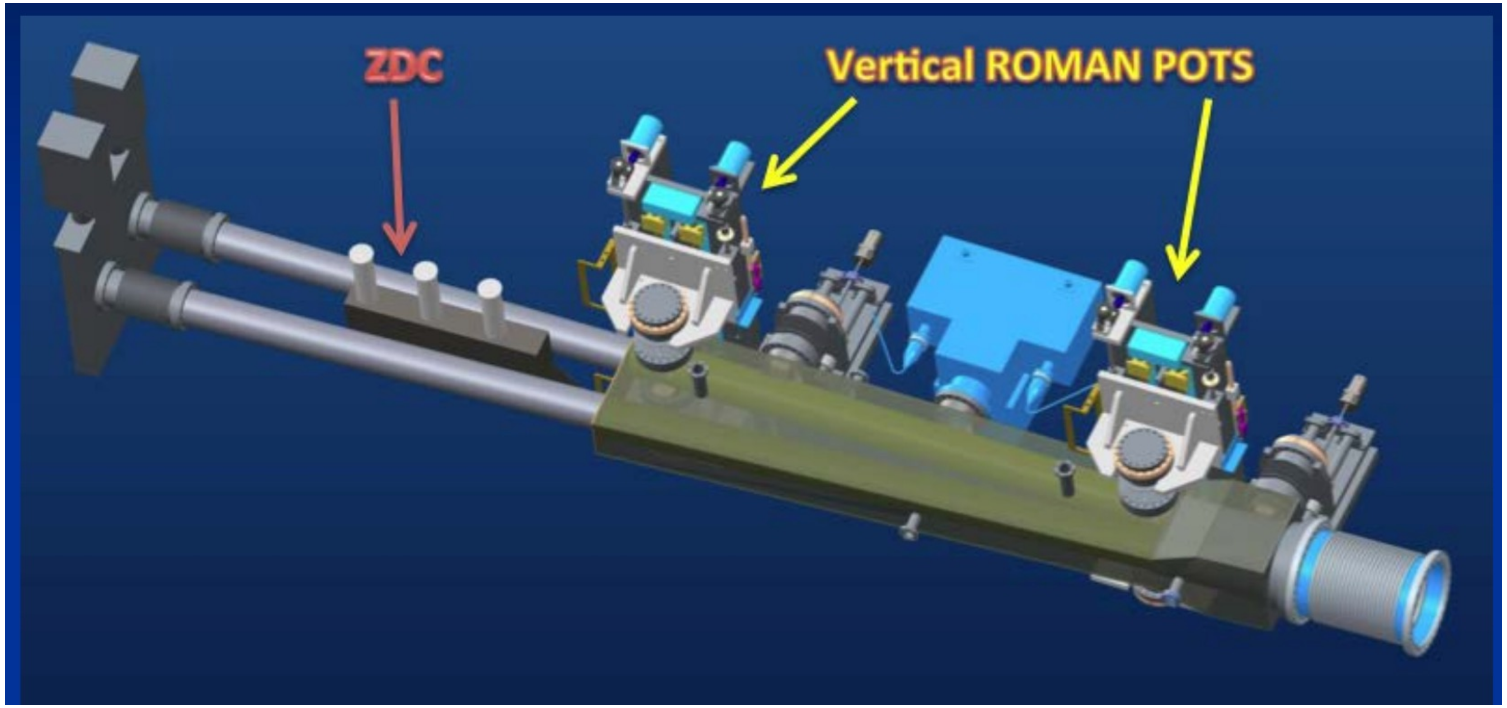
DD4HEP Simulation

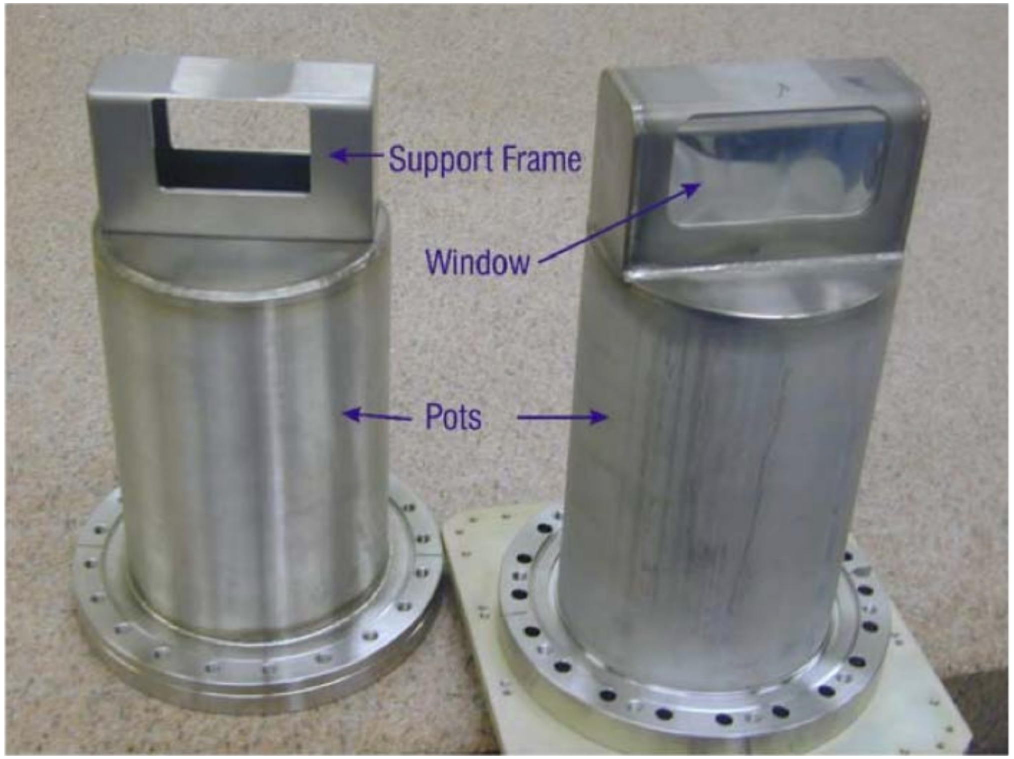
- High-precisions tracking detectors required for charged particle reconstruction.
- Tagging photons important in differentiating between coherent and incoherent heavy-nuclear scattering, and for reconstructing $\pi^0 \rightarrow \gamma\gamma$.

Roman Pots

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

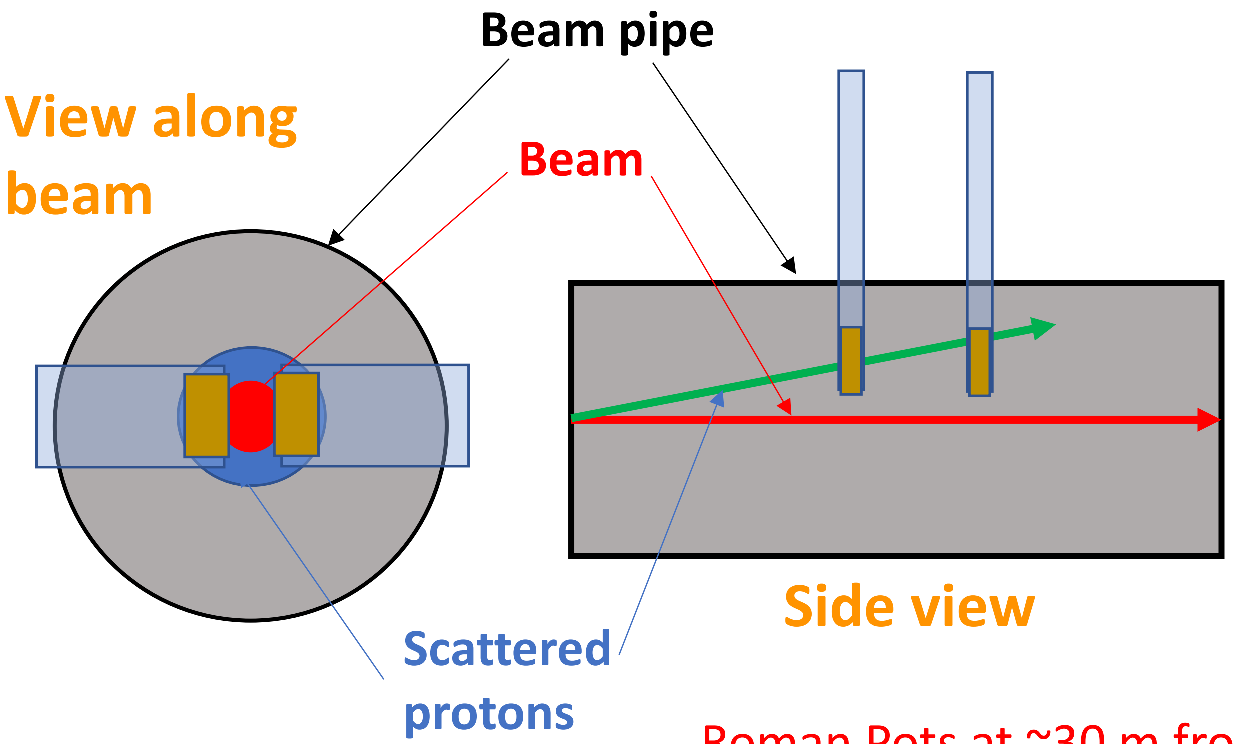
Roman Pots





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

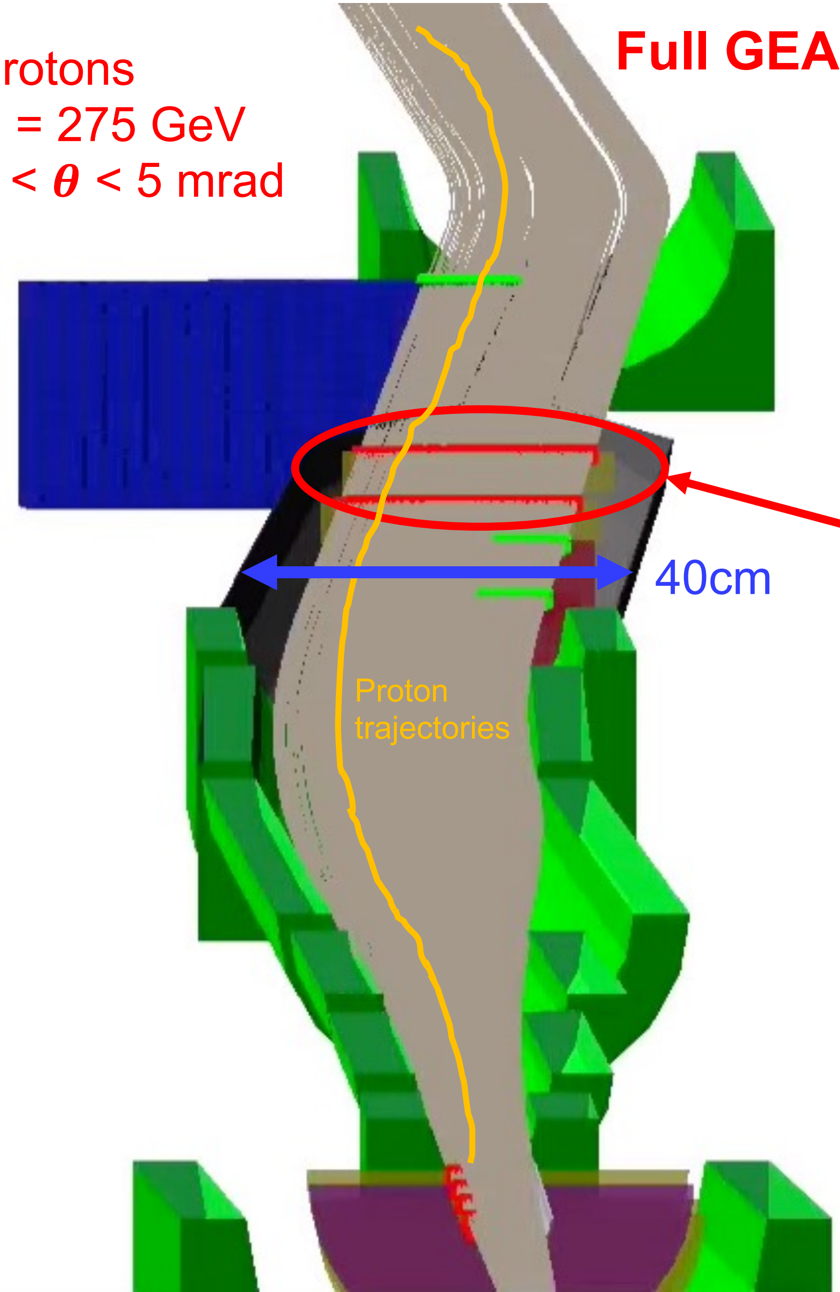
Roman Pots at ~30 m from IP → $\theta \backsim$ 0 - 5 mrad

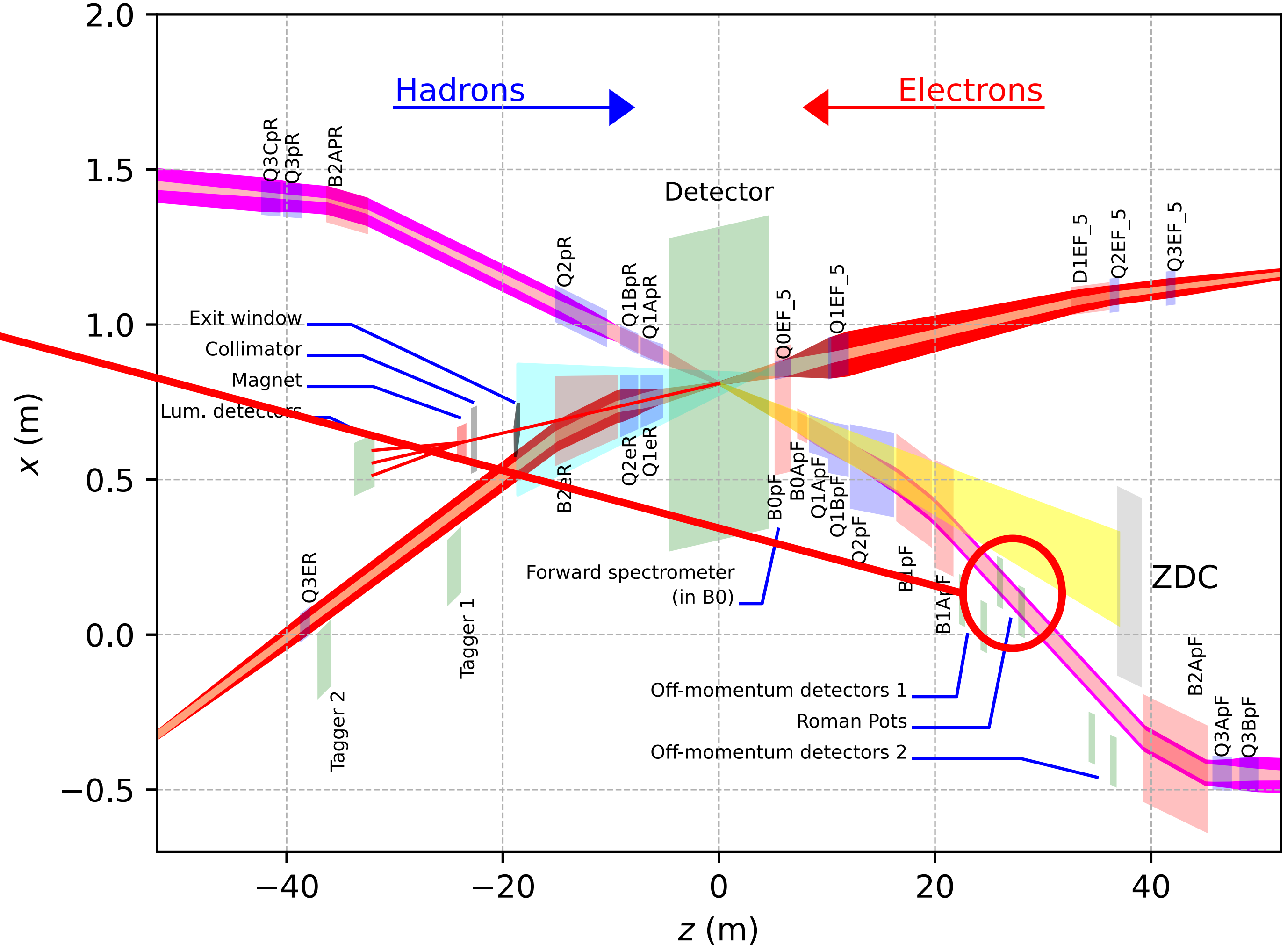
- Roman Pots are silicon sensors placed in a "pot", which is then injected into the beam pipe, tens of meters or more from the interaction point (IP).
- Momentum reconstruction carried out using matrix transport of protons through magnetic lattice.

Roman Pots @ the EIC

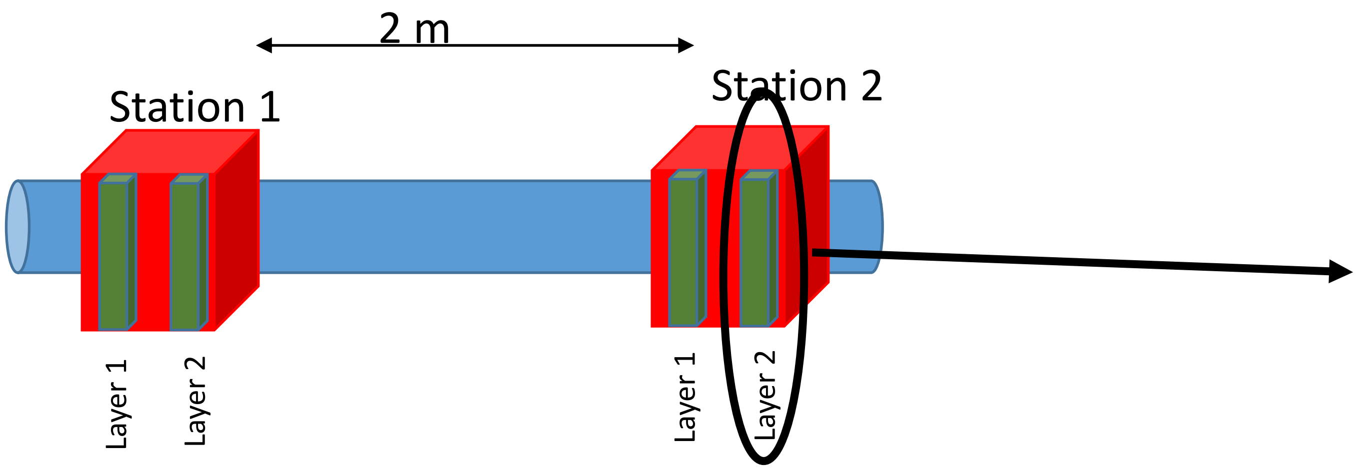
Protons
E = 275 GeV
$0 < \theta < 5$ mrad

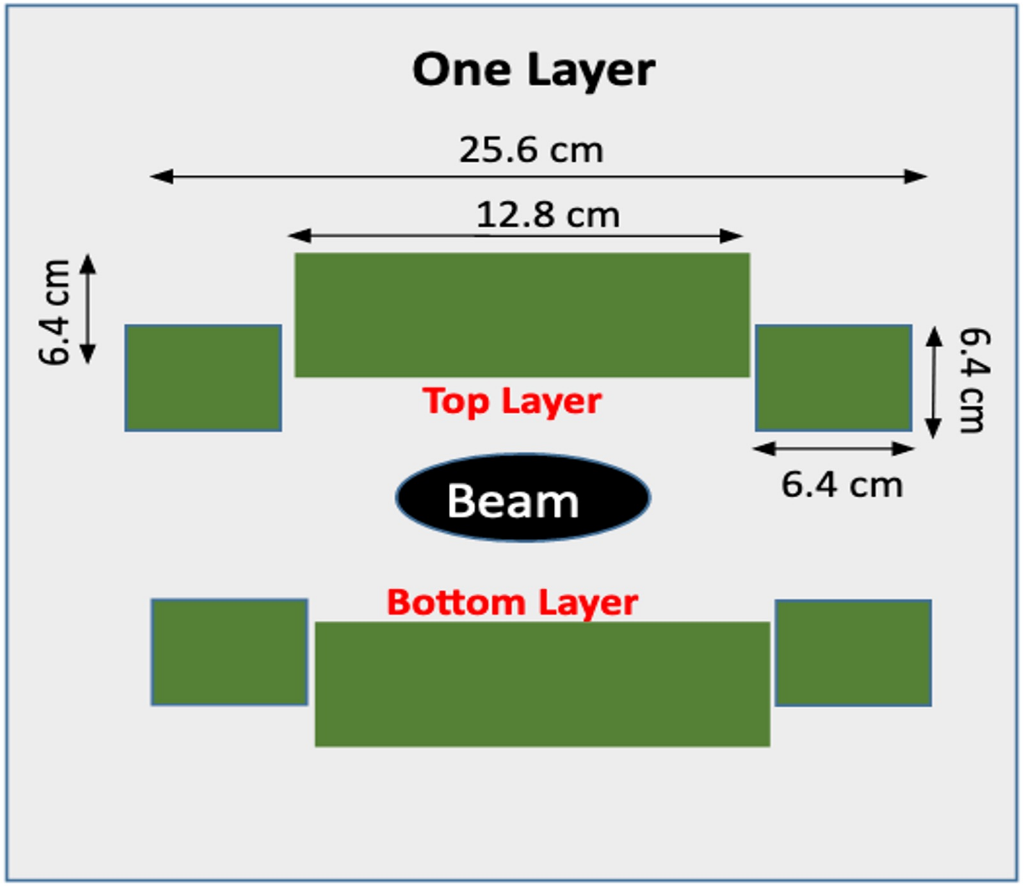
Full GEANT4 simulation.





Roman “Pots” @ the EIC



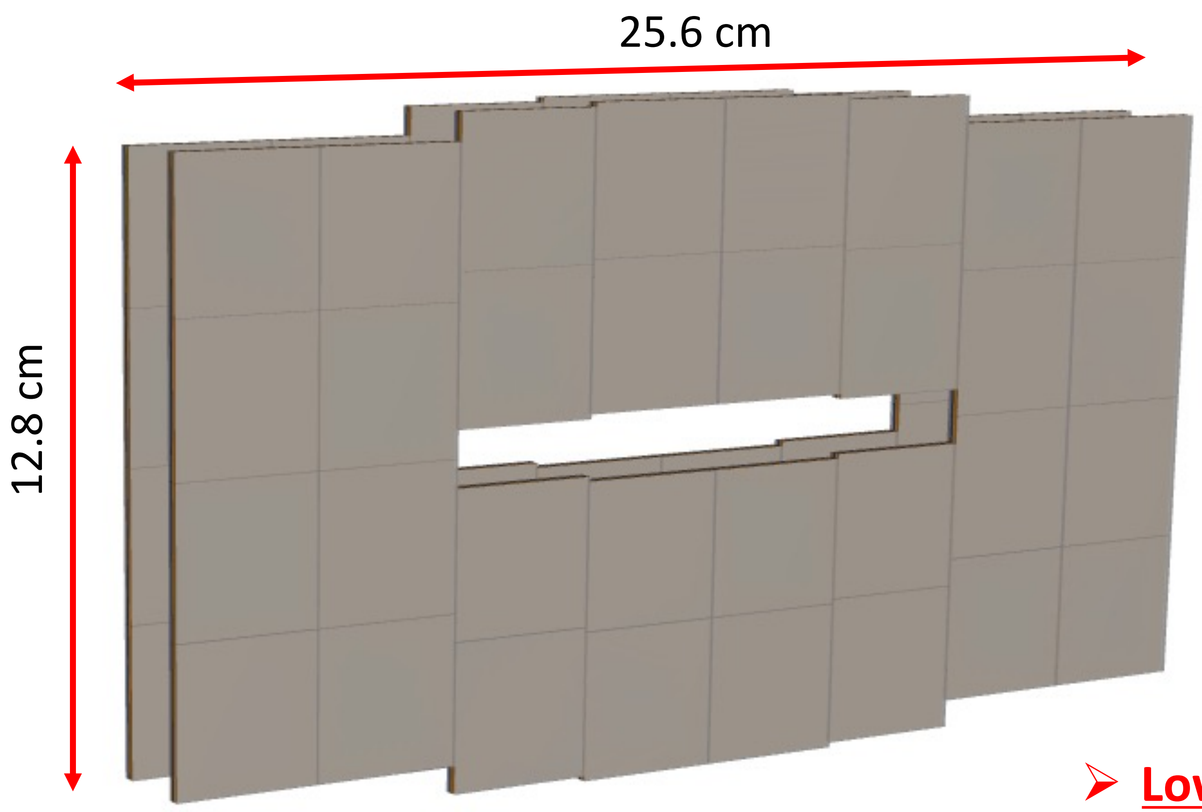


- Two stations, separated by 2 meters, each with two layers (minimum) of silicon detectors.
- Silicon detectors placed directly into machine vacuum!
  - Allows maximal geometric coverage!
- Need space for detector insertion tooling and support structure.

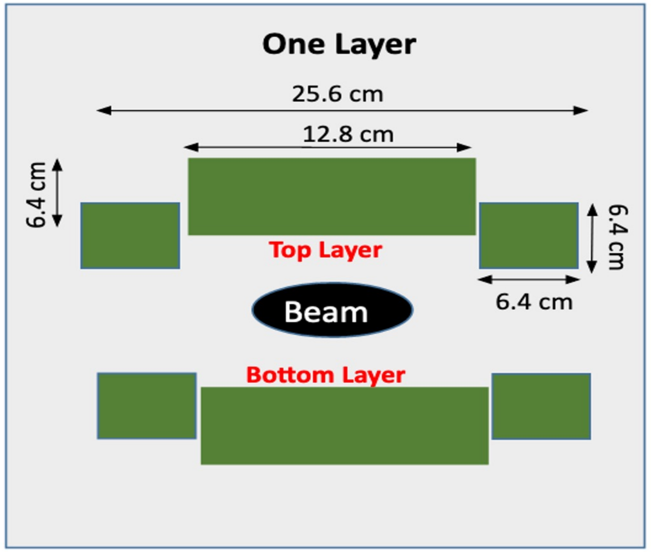
Roman "Pots" @ the EIC

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

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

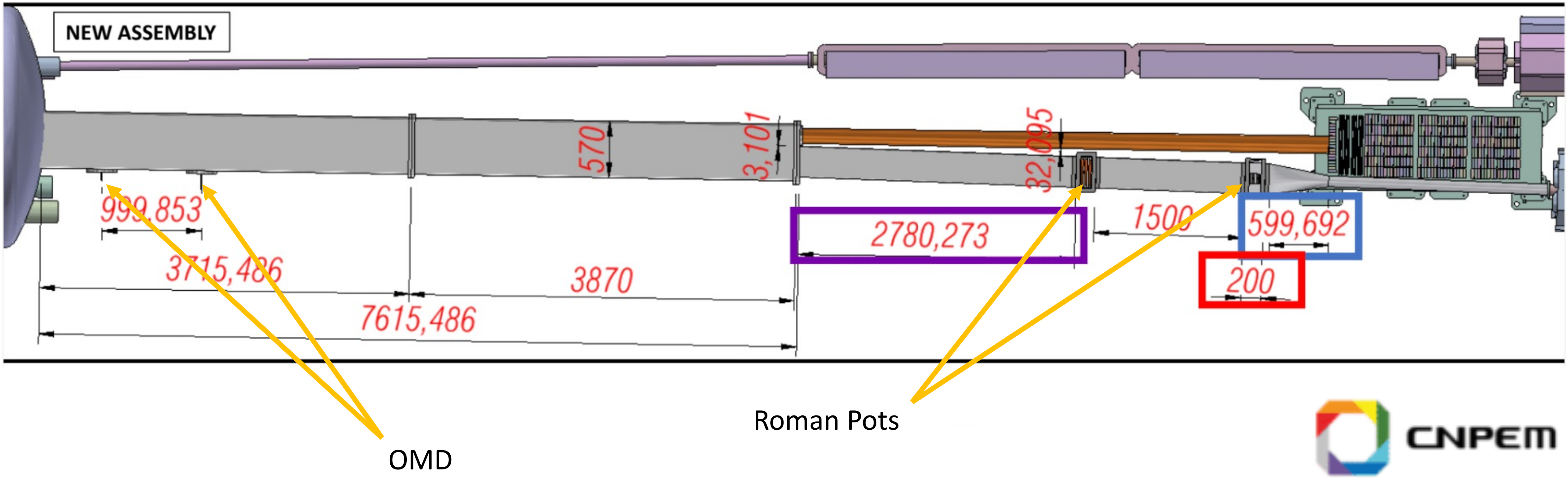


DD4HEP Simulation



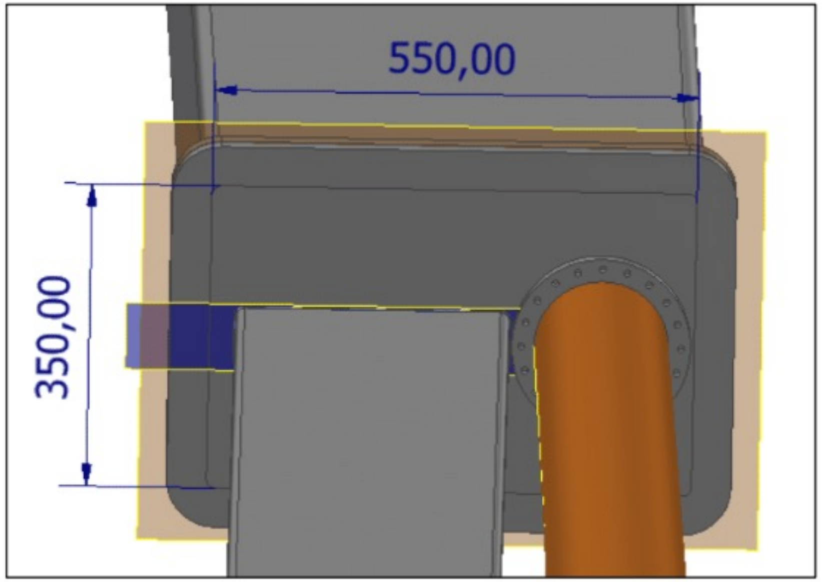
- **<u>Low-pT cutoff determined by beam optics.</u>**
  - **The safe distance is ~10σ from the beam center.**
  - **1σ ~ 1mm**
- **These optics choices change with energy, but can also be changed within a single energy to maximize *either acceptance at the RP, or the luminosity.***

Preliminary CAD drawings of RP and OMD Supports and Magnet Cryostats



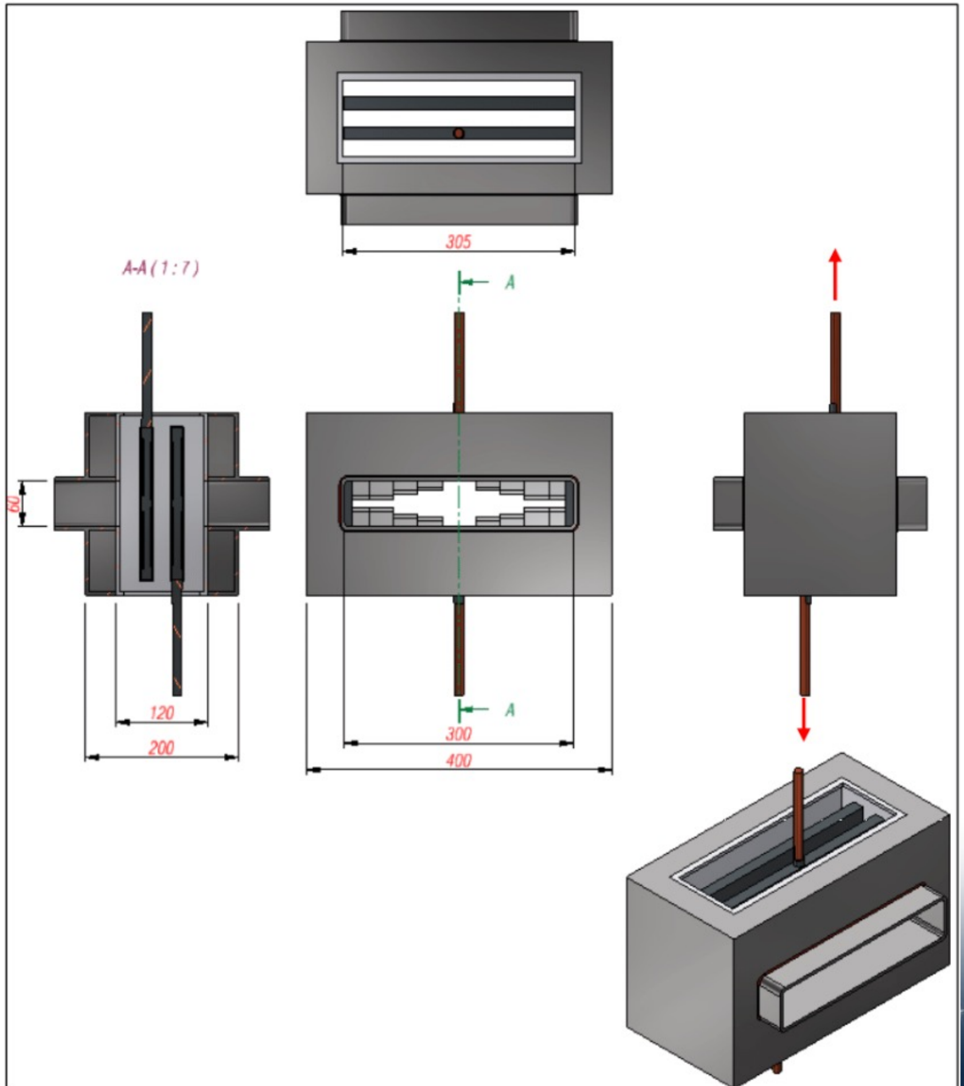
Preliminary CAD drawings of RP and OMD Supports and Magnet Cryostats

New 550x350 mm inner dimensions chamber



Transition region from larger beam pipe containing OMD to smaller pipe containing RP (left) and exit window for neutrals (right).

New Concept



Scattering chamber design for RP sensor packages.

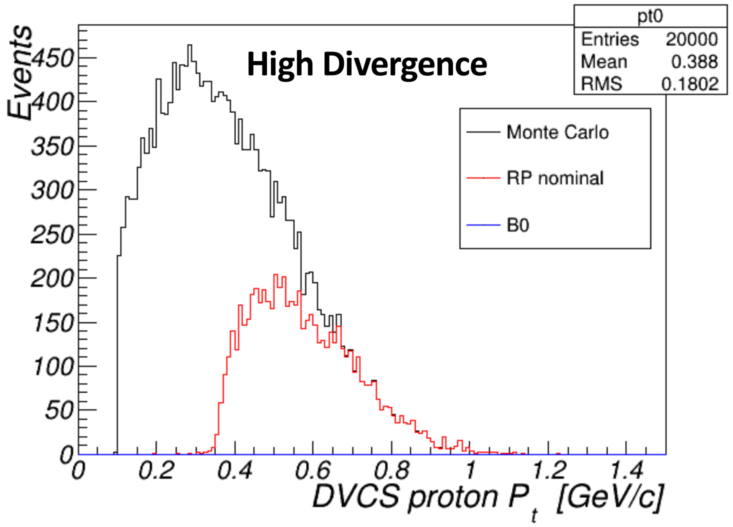
CNPEM

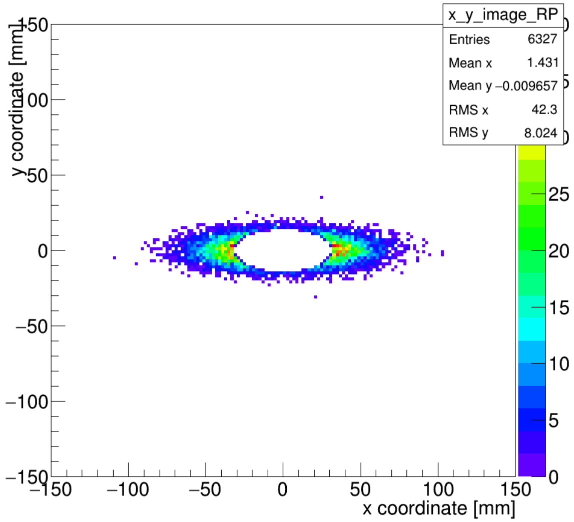
MINISTRY OF SCIENCE TECHNOLOGY AND INNOVATION

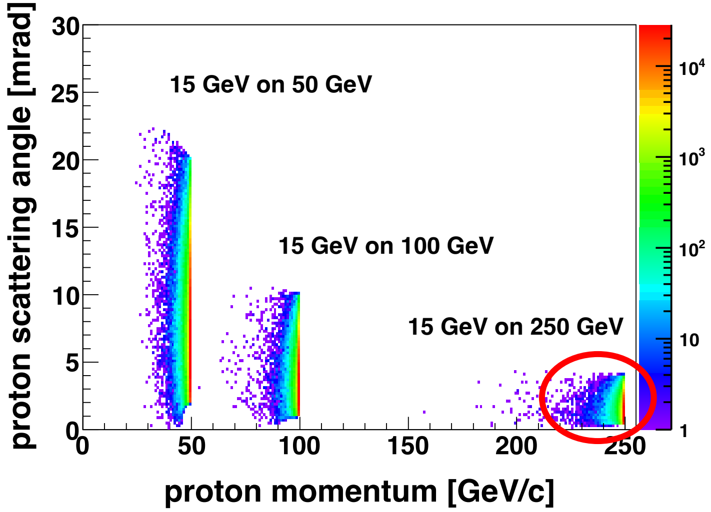
BRAZILIAN GOVERNMENT
BRASIL
UNITING AND REBUILDING

Digression: Machine Optics

275 GeV DVCS Proton Acceptance



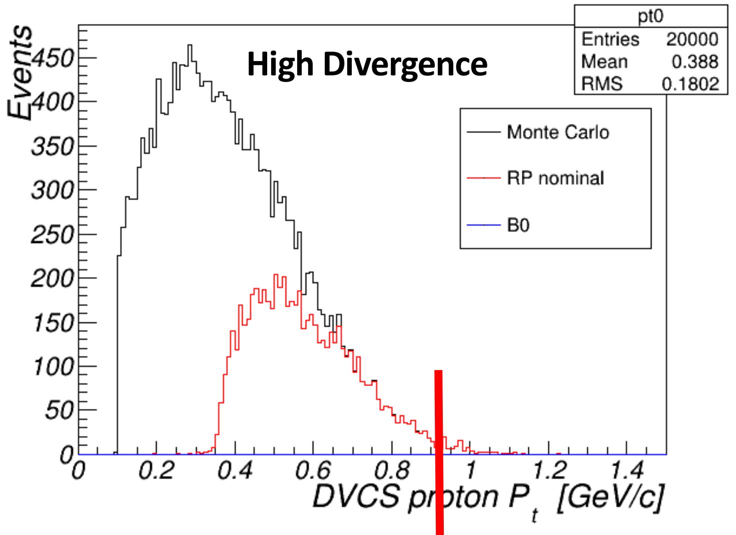


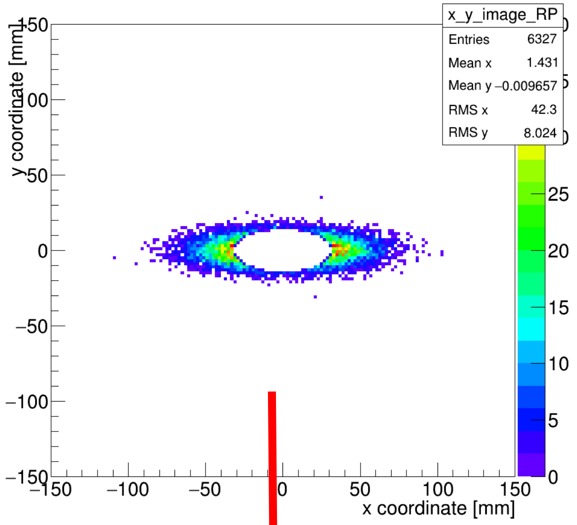


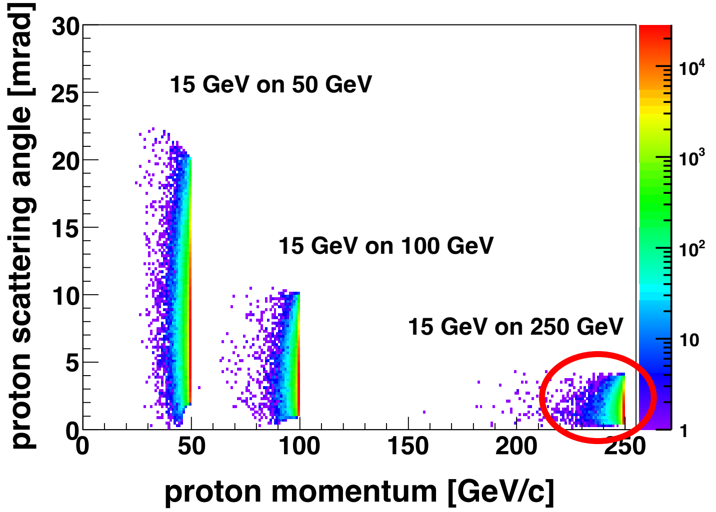
<u>High Divergence:</u> smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

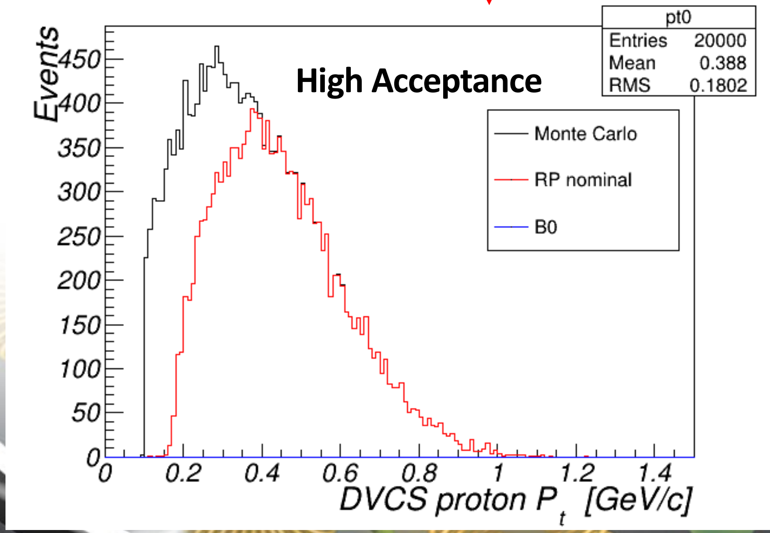
Digression: Machine Optics

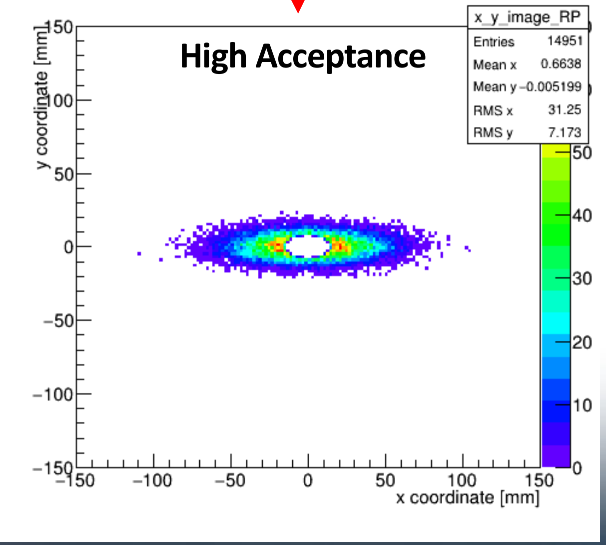
275 GeV DVCS Proton Acceptance









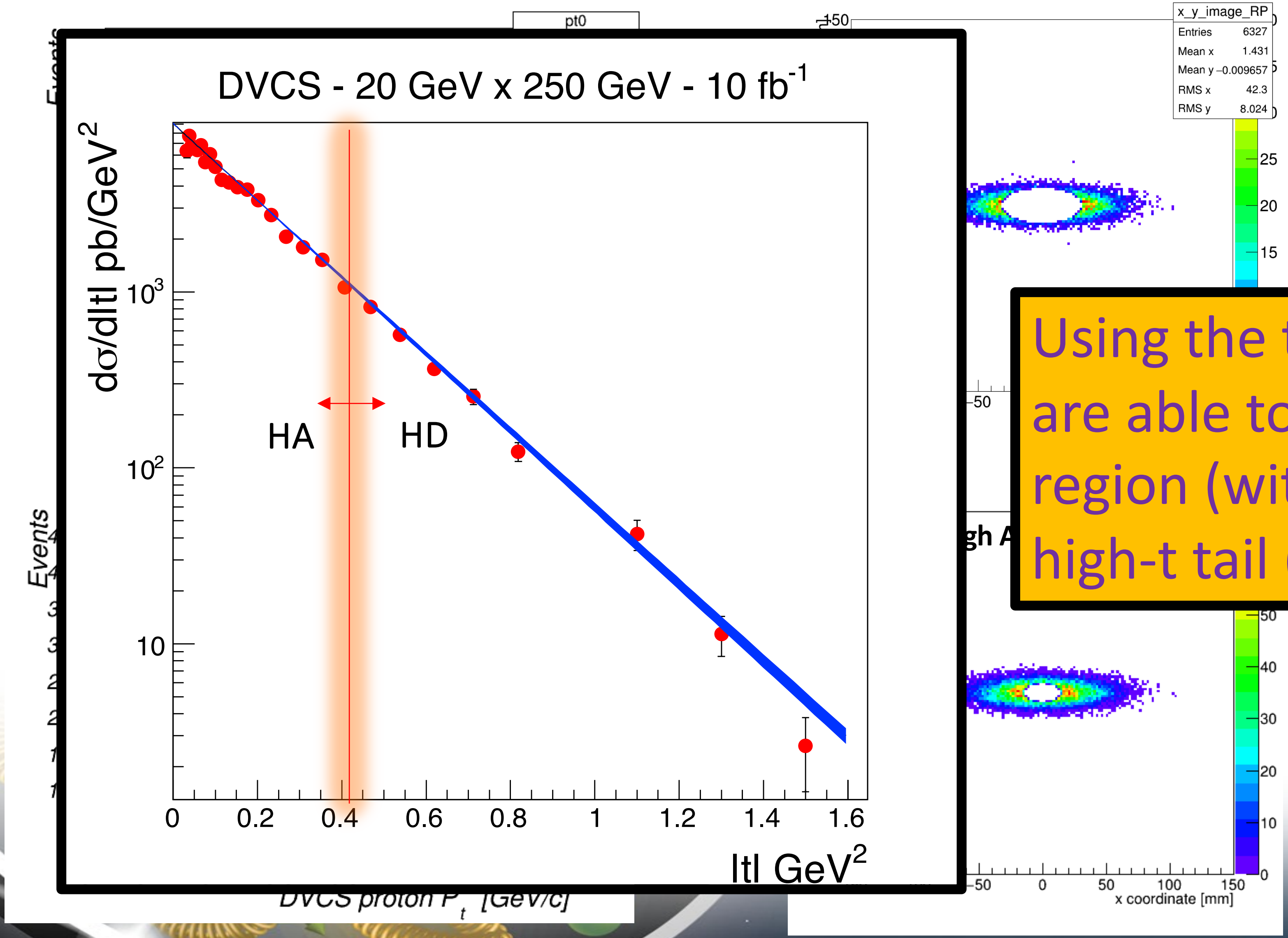


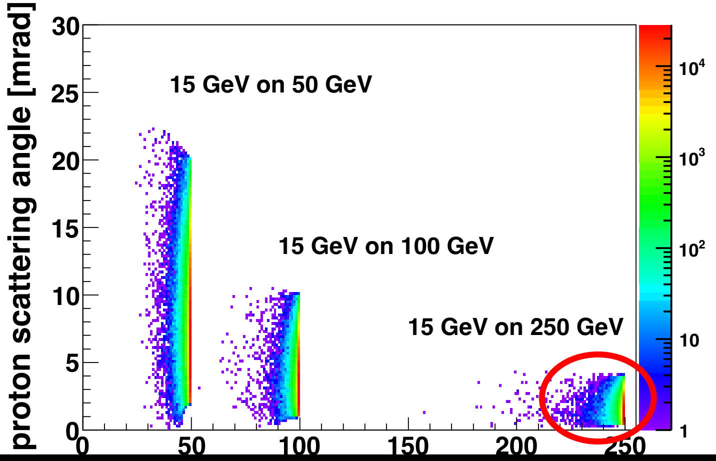
High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

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

Digression: Machine Optics

275 GeV DVCS Proton Acceptance



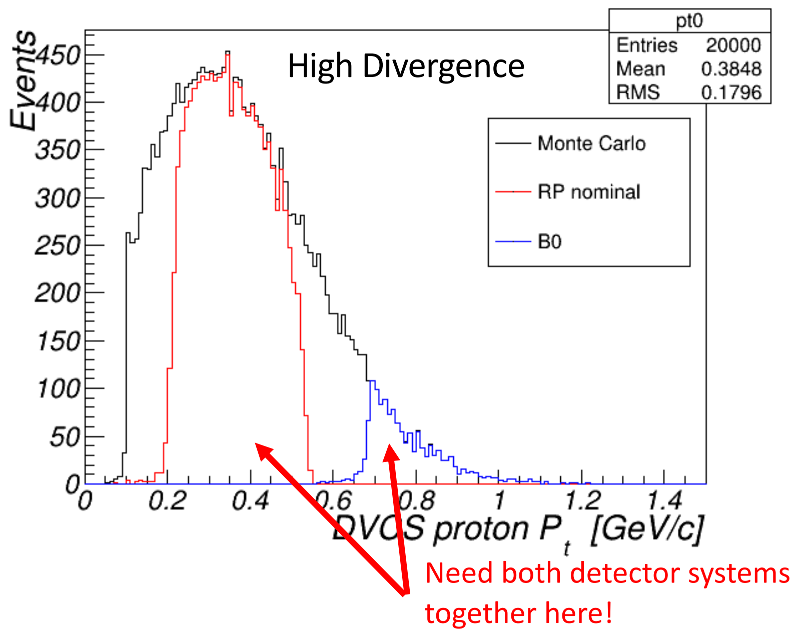


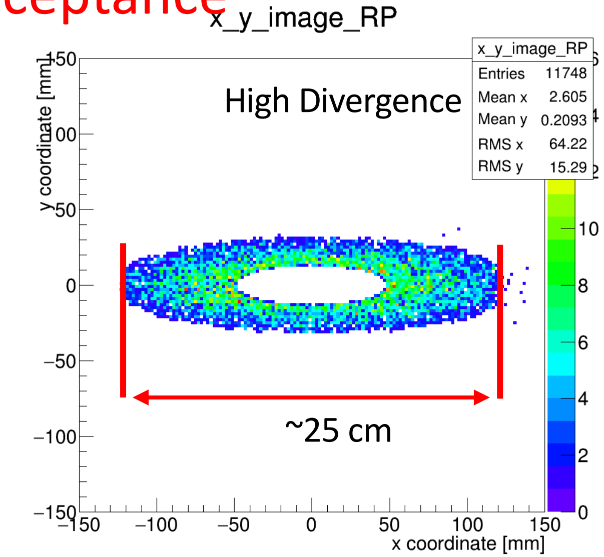
Using the two configurations, we are able to measure the low-t region (with better acceptance) and high-t tail (with higher luminosity).

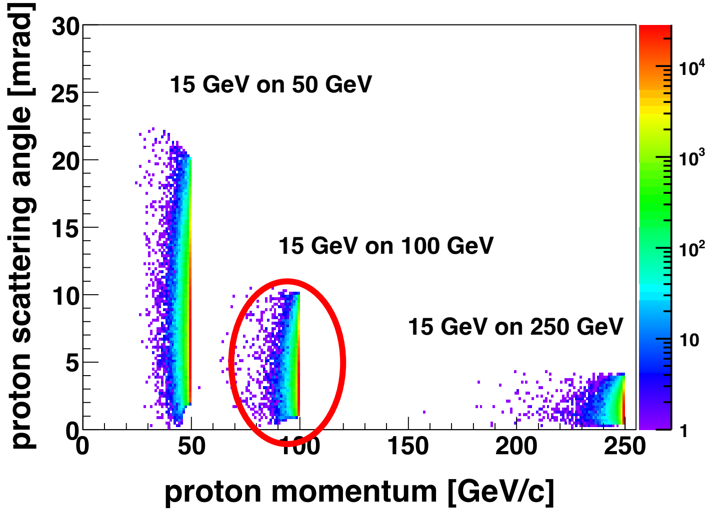
<u>High Acceptance:</u> larger β^* at IP, smaller $\beta(z = 30m)$ -> lower lumi., smaller beam at RP

Digression: Machine Optics

100 GeV DVCS Proton Acceptance

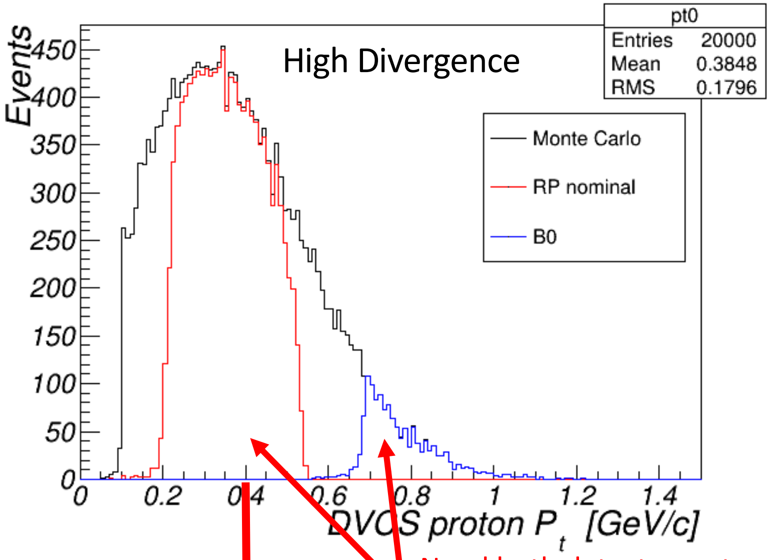


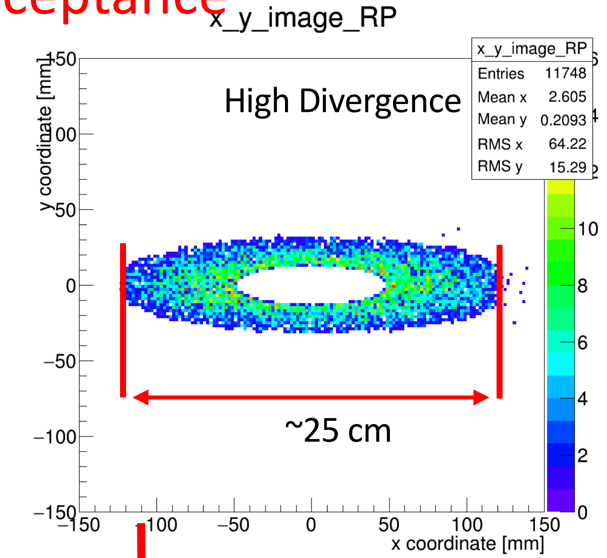


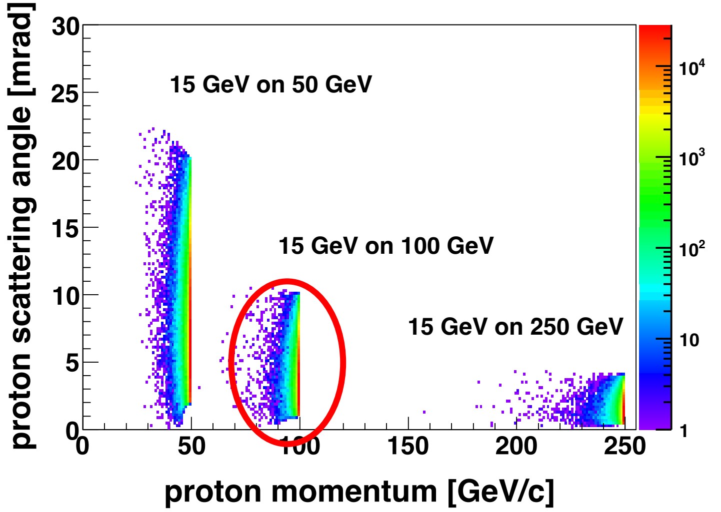


Digression: Machine Optics

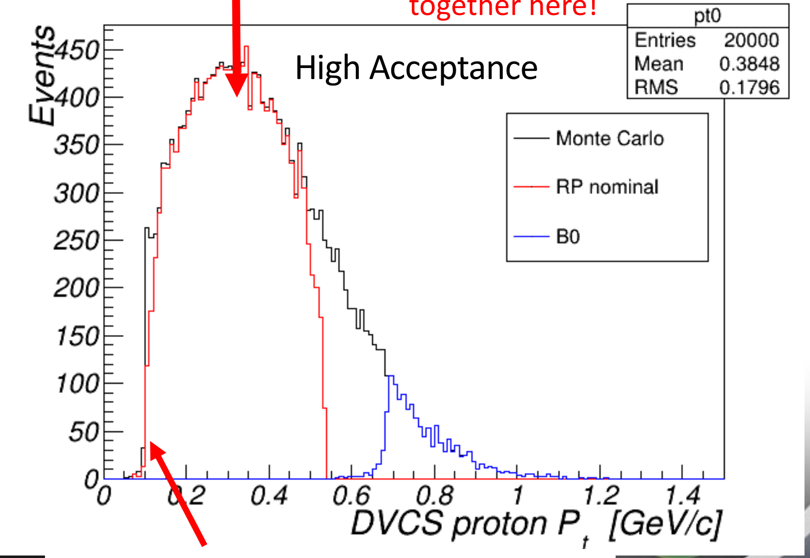
100 GeV DVCS Proton Acceptance

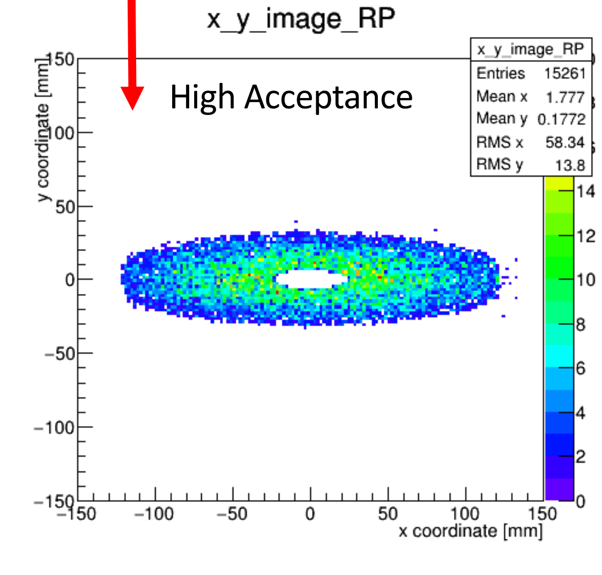






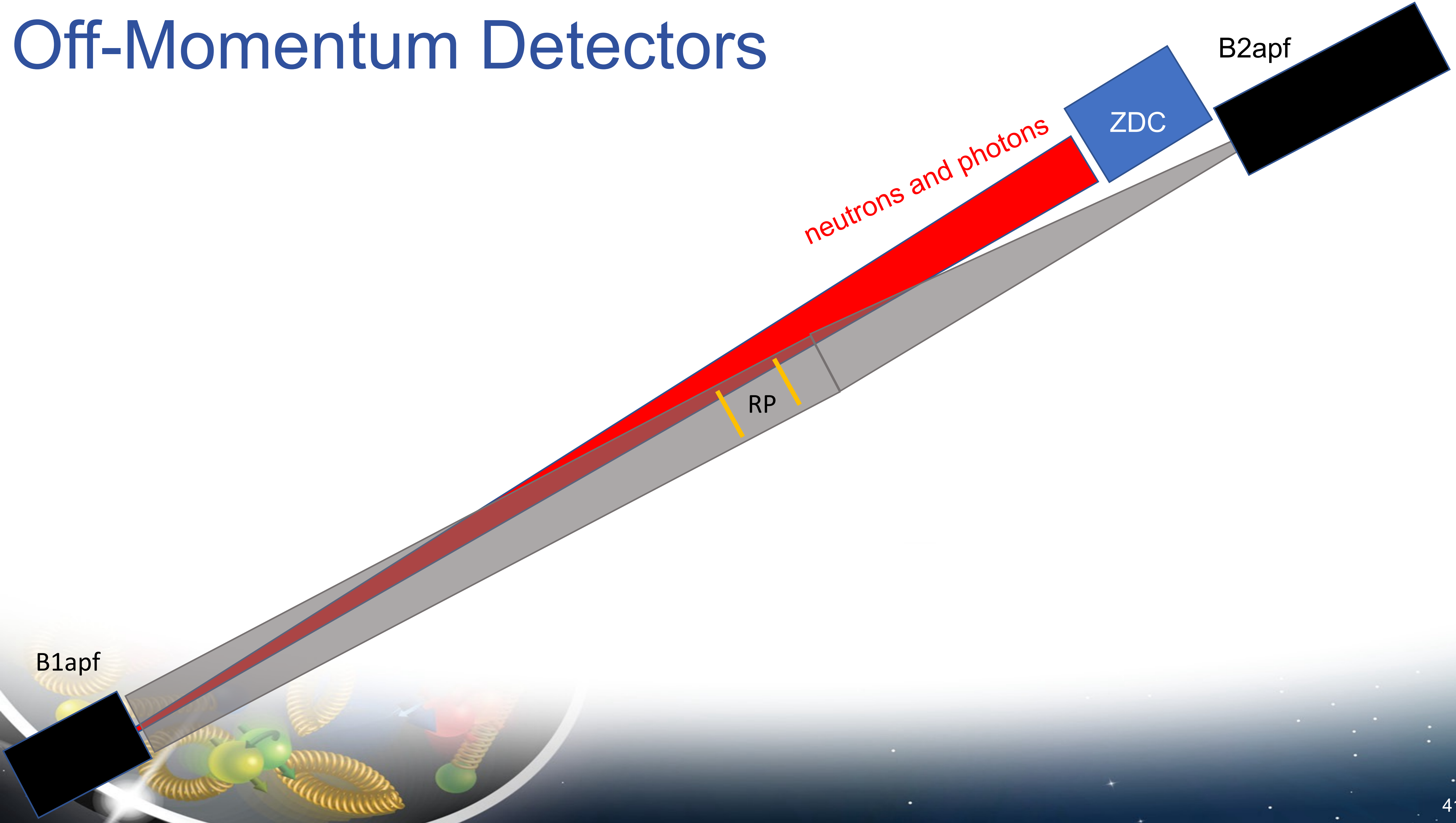
Need both detector systems together here!





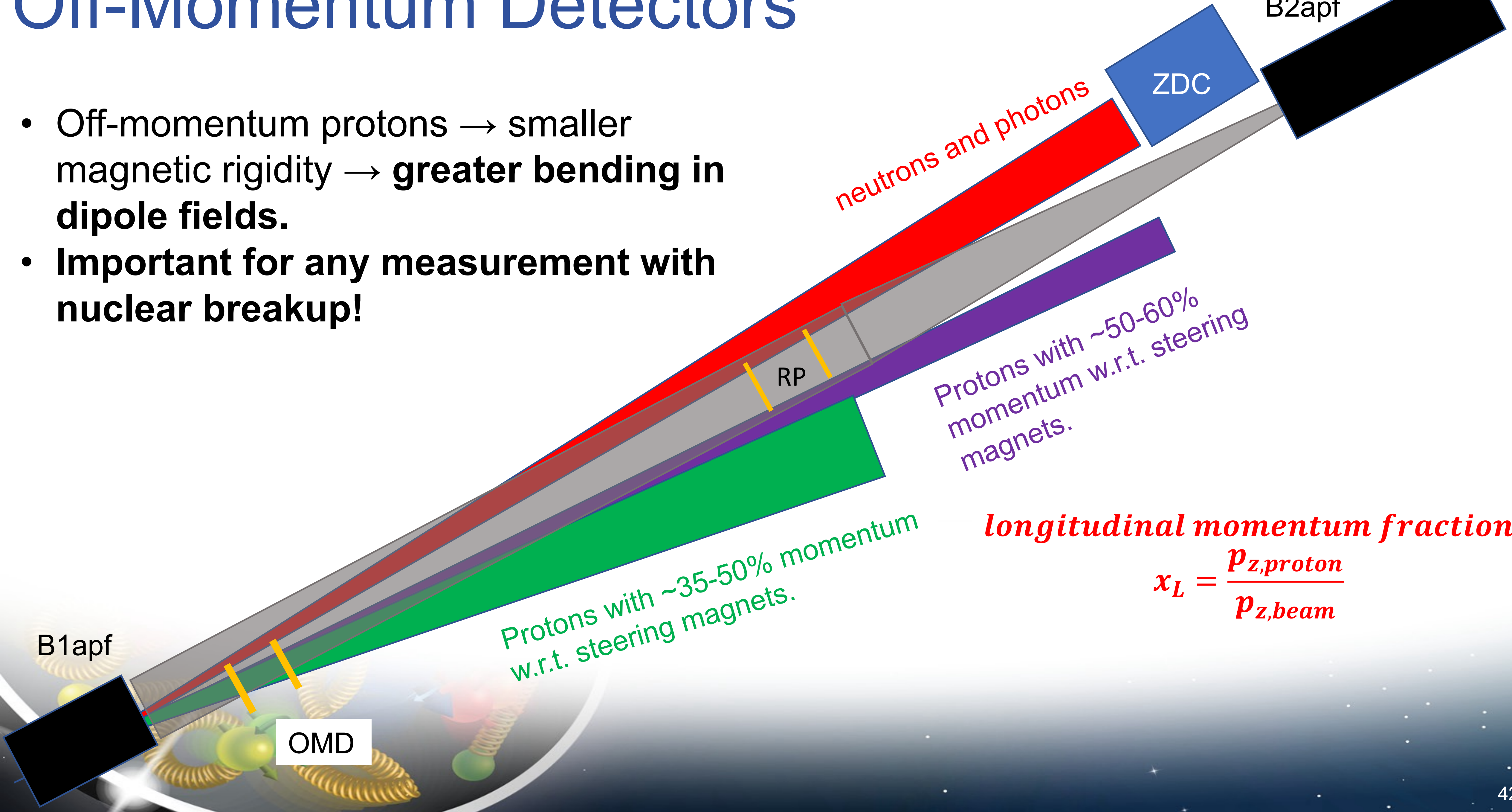
Improves low p_t acceptance.

Off-Momentum Detectors



Off-Momentum Detectors

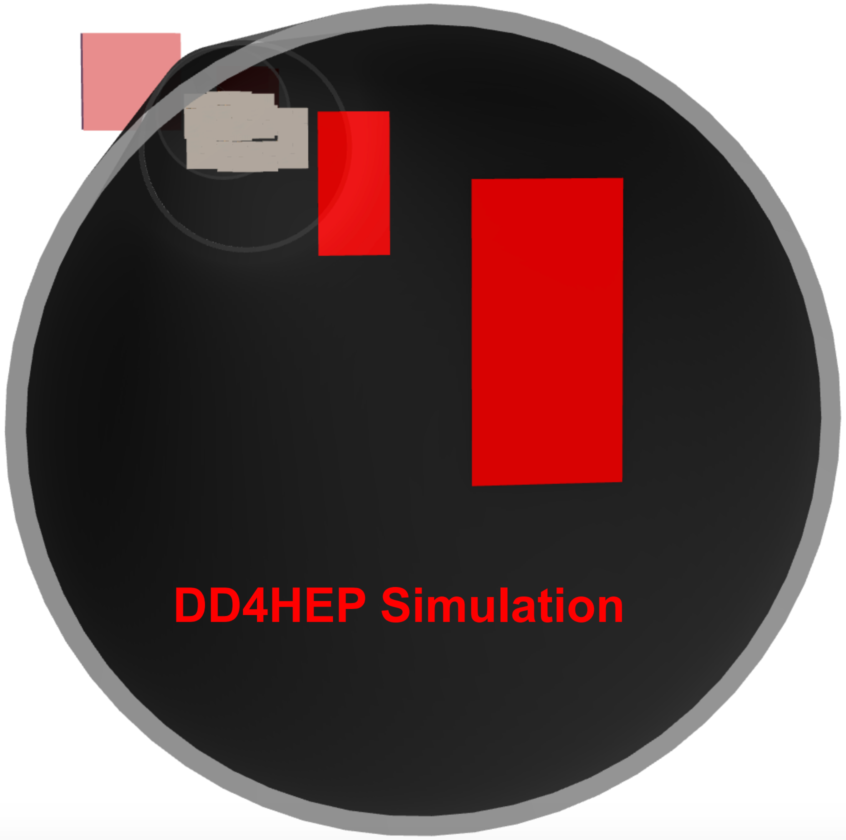
- Off-momentum protons → smaller magnetic rigidity → **greater bending in dipole fields.**
- **Important for any measurement with nuclear breakup!**



longitudinal momentum fraction

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

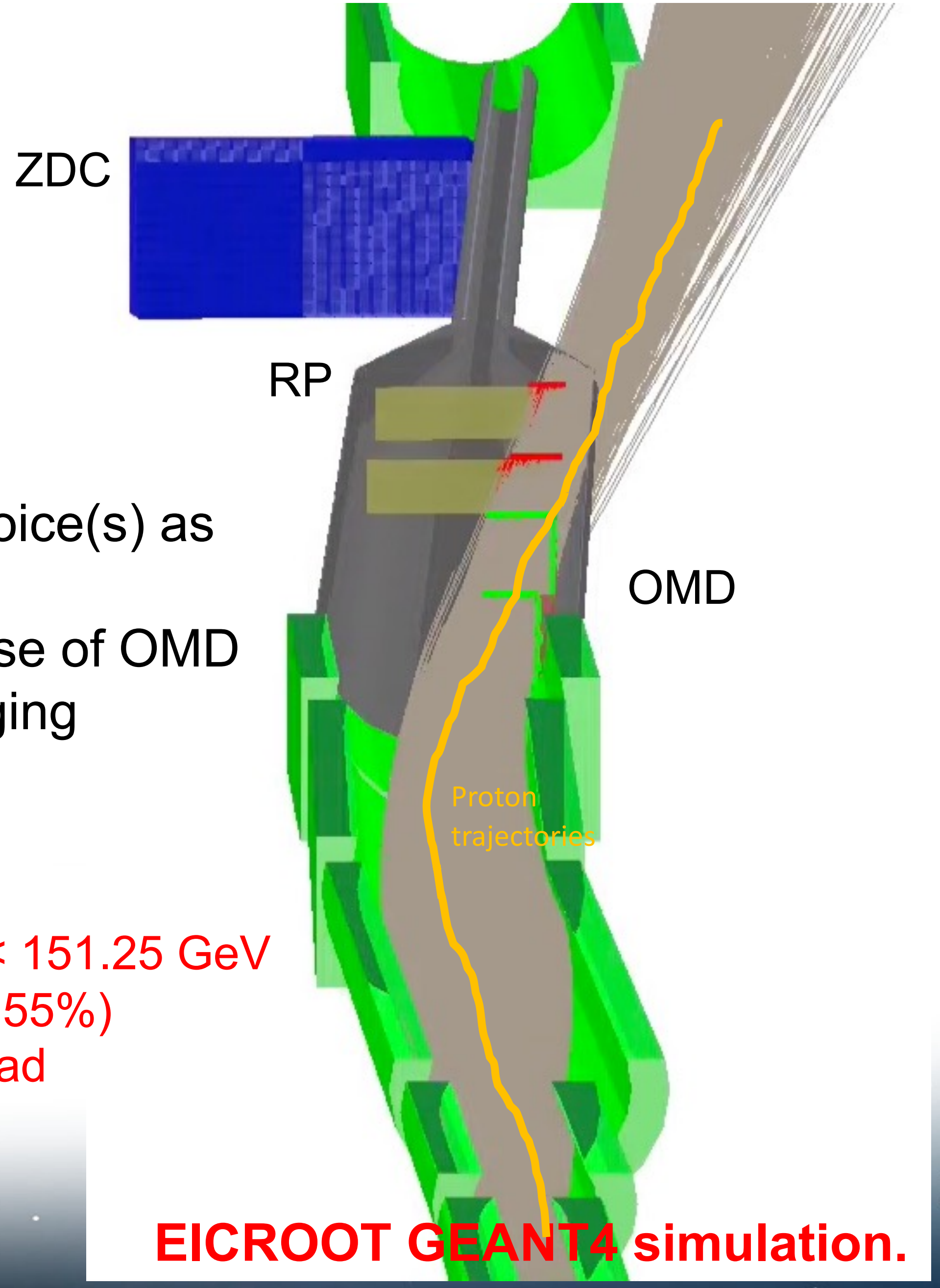
Off-Momentum Detectors



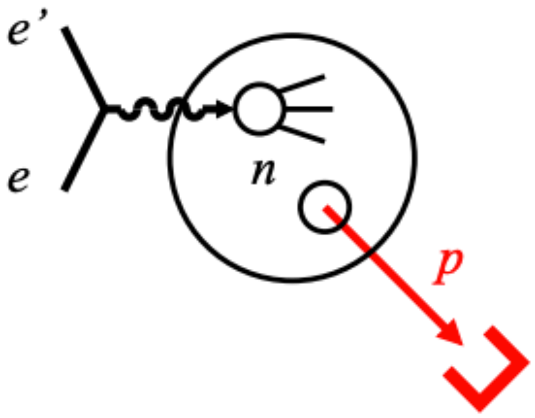
Off-momentum detectors implemented as horizontal ”Roman Pots” style sensors.

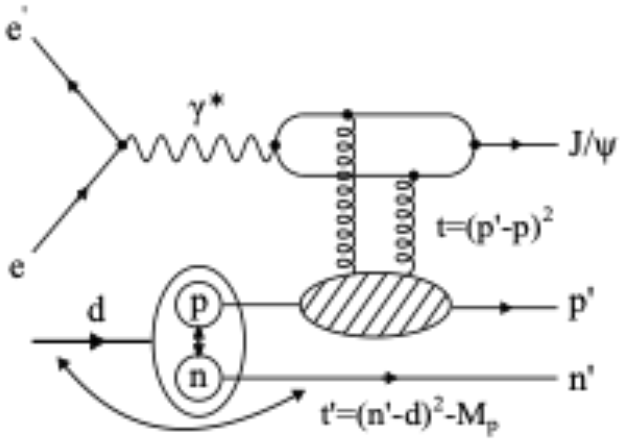
- Same technology choice(s) as for the Roman Pots.
- Need to also study use of OMD on other side for tagging negative pions.

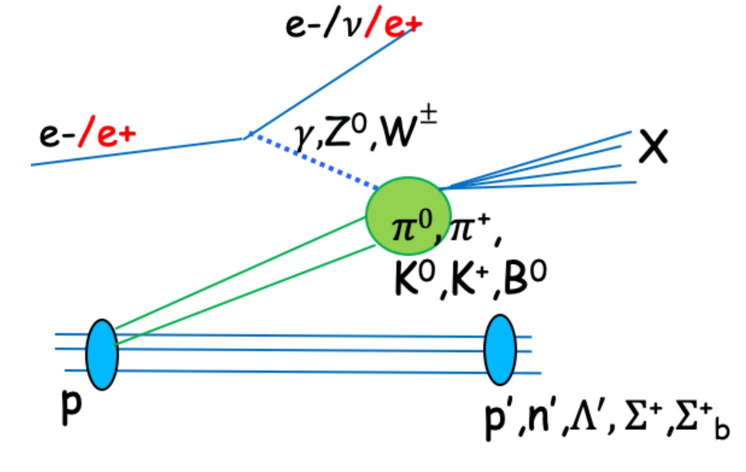
Protons
123.75 < E < 151.25 GeV
(45% < xL < 55%)
0 < θ < 5 mrad

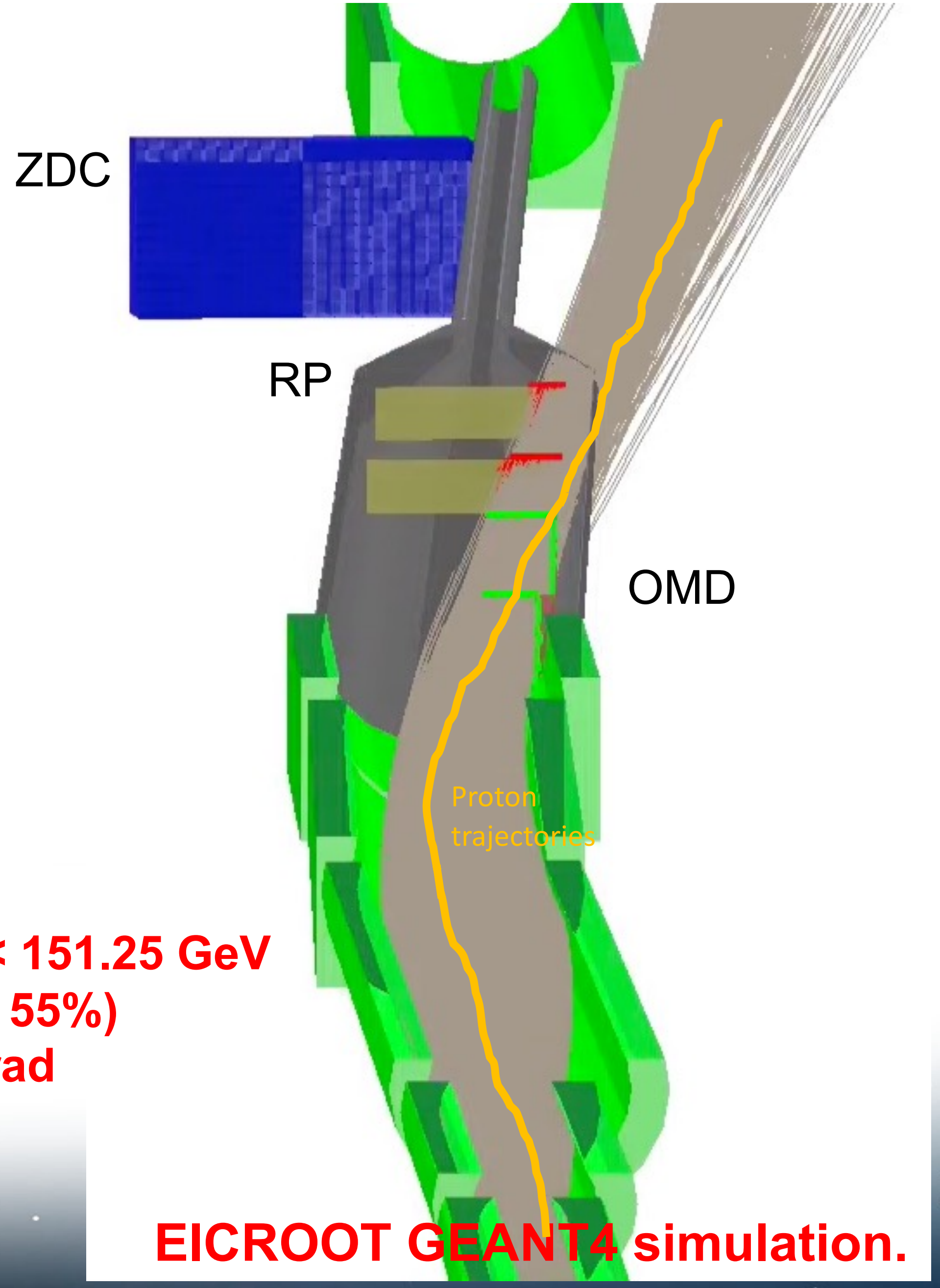


Off-Momentum Detectors





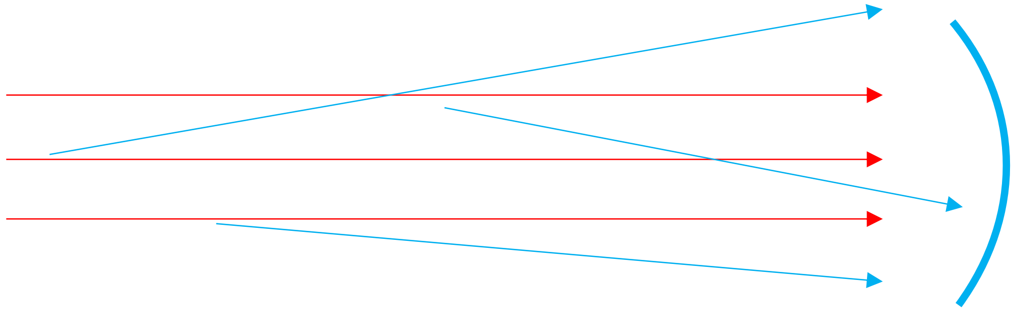




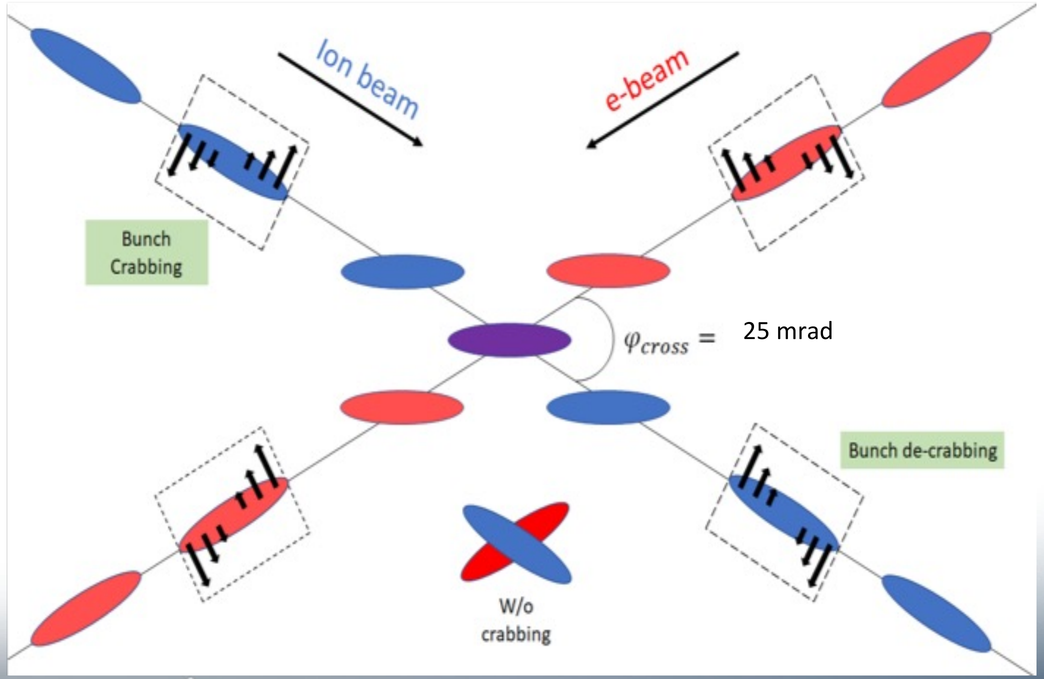
Protons
123.75 < E < 151.25 GeV
(45% < xL < 55%)
0 < θ < 5 mrad

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.

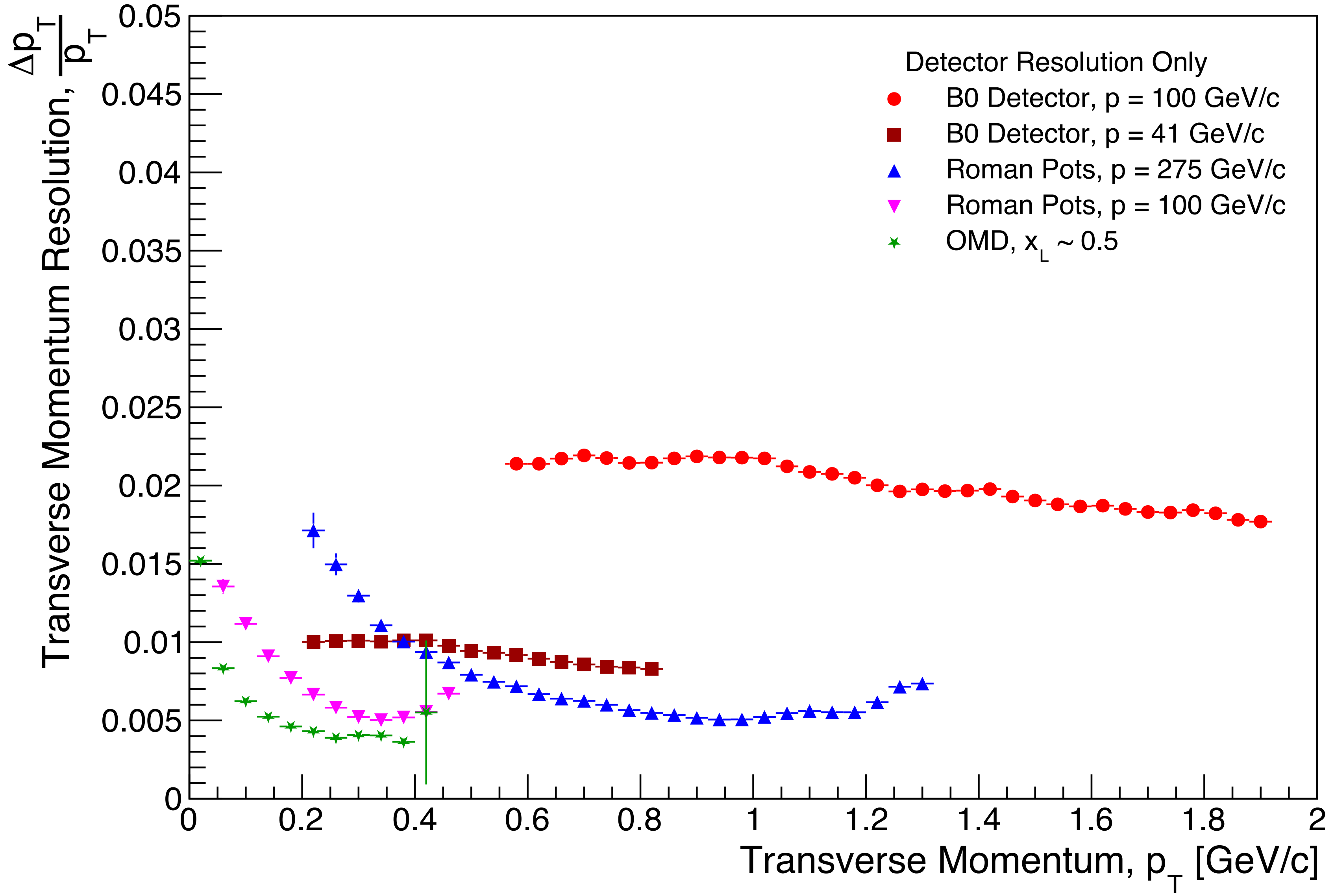


- Crab cavity rotation
  - Can perform rotations of the beam bunches in 2D.
  - Used to account for the luminosity drop due to the crossing angle – allows for head-on collisions to still take place.



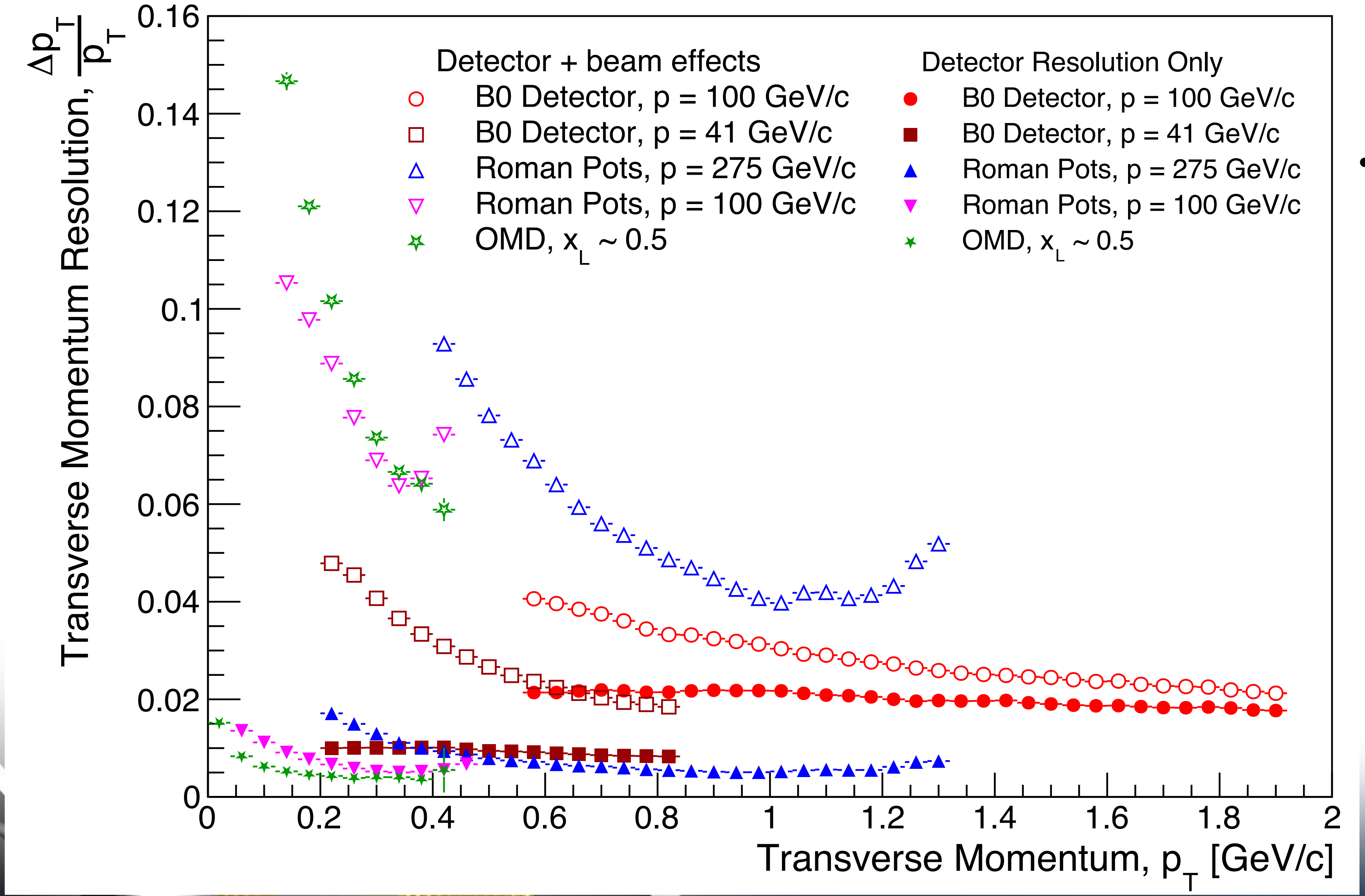
These effects introduce smearing in our momentum reconstruction.

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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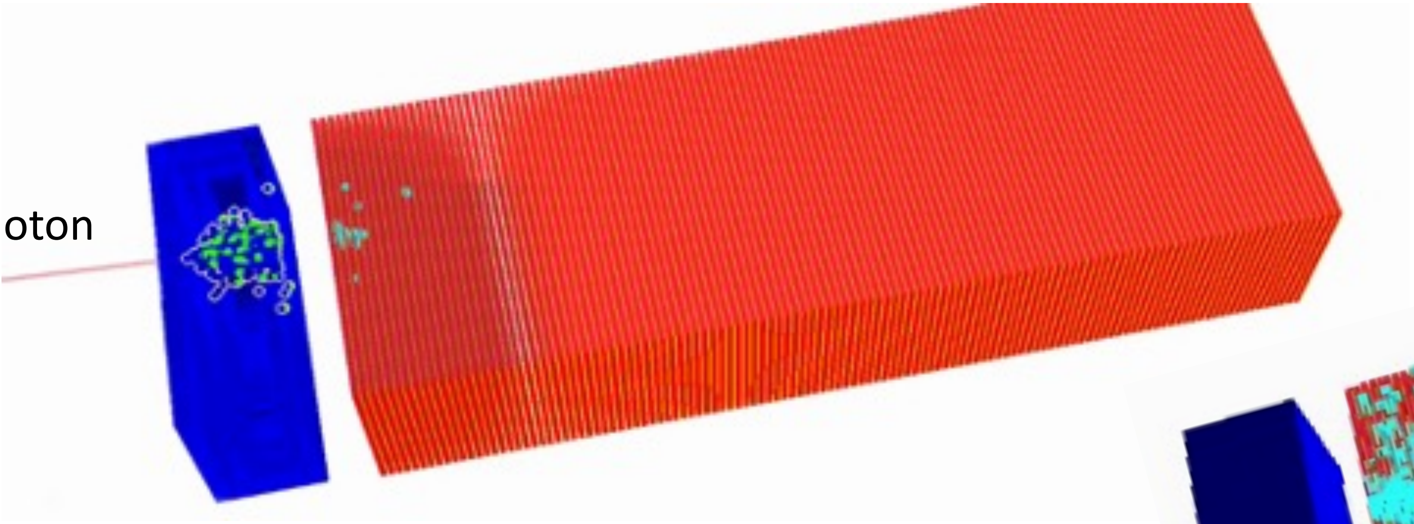
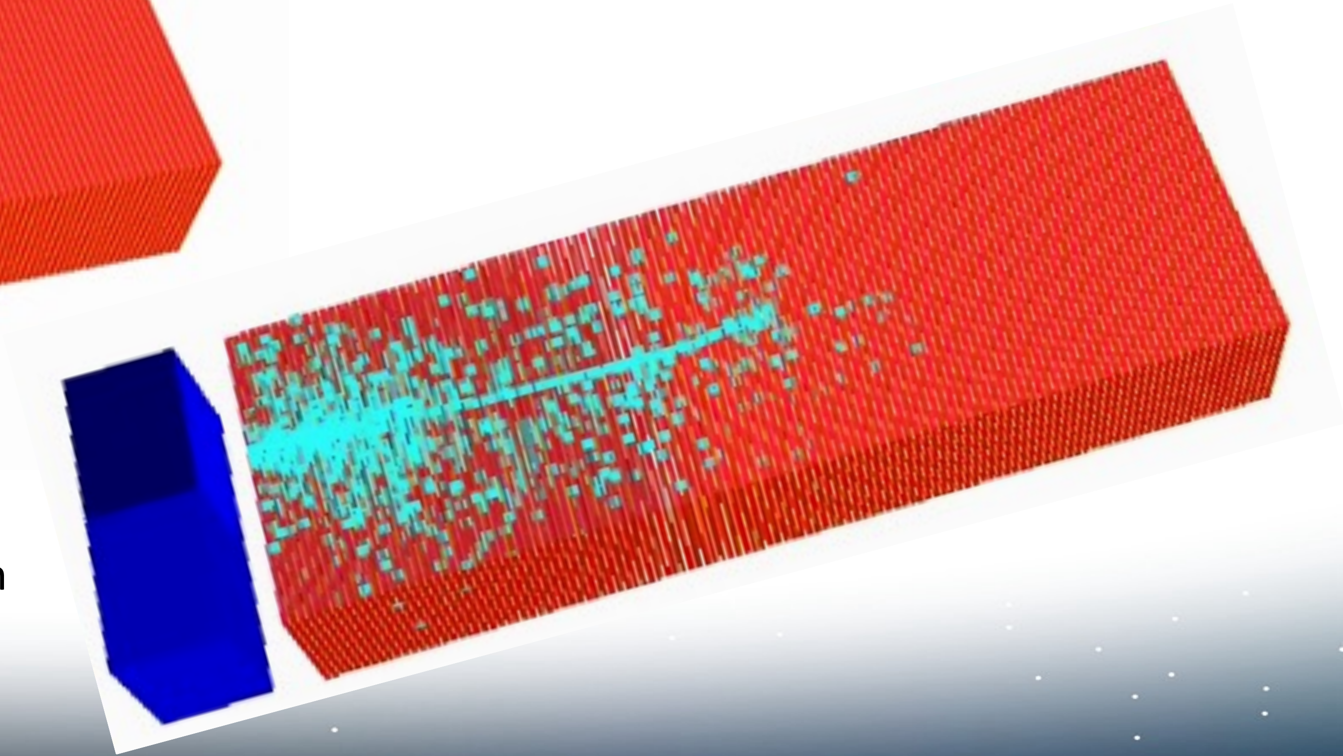
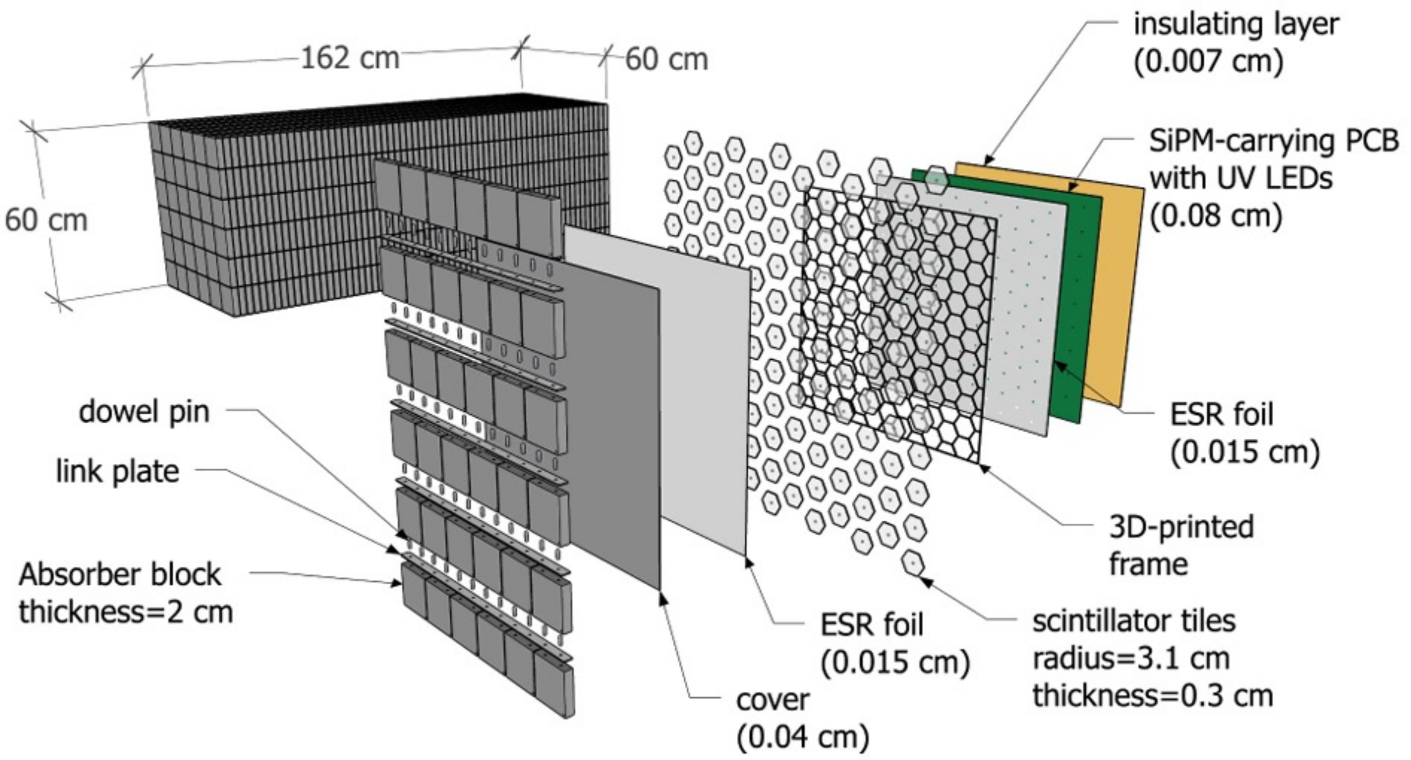
photon

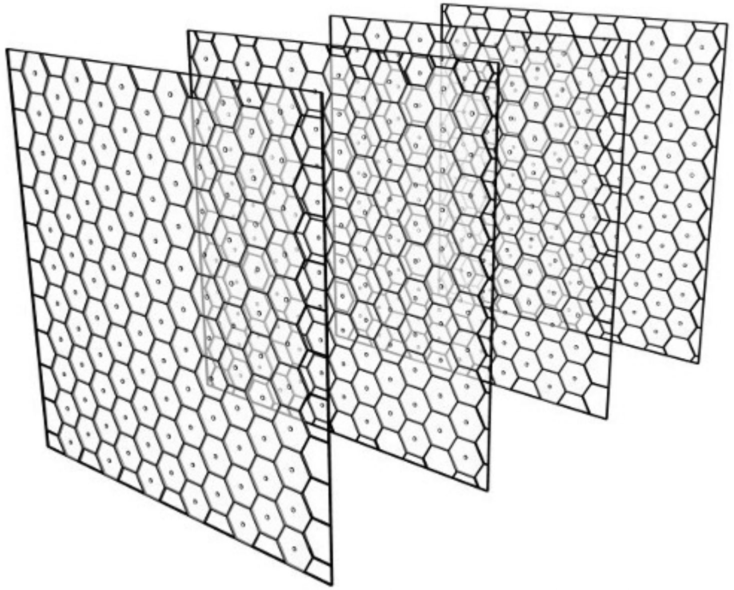


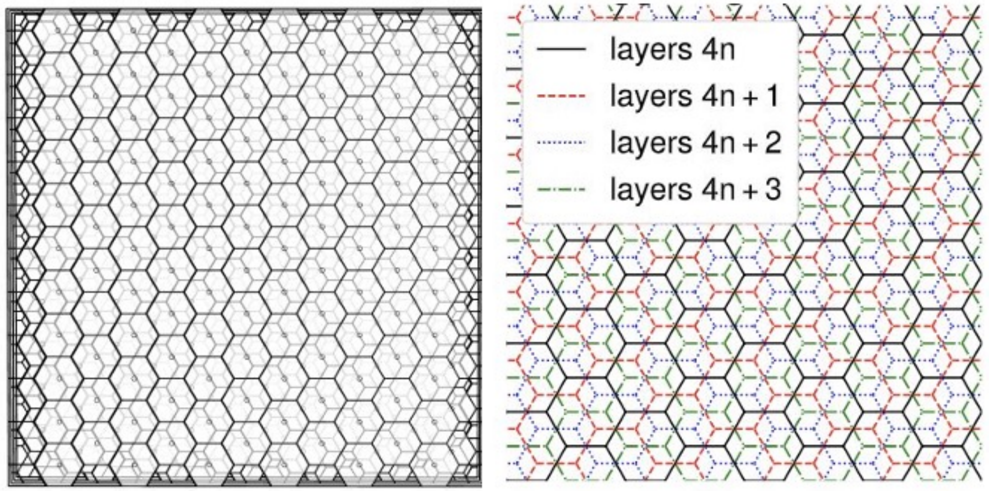
neutron



Hadronic Calorimeter – SiPM-on-Tile

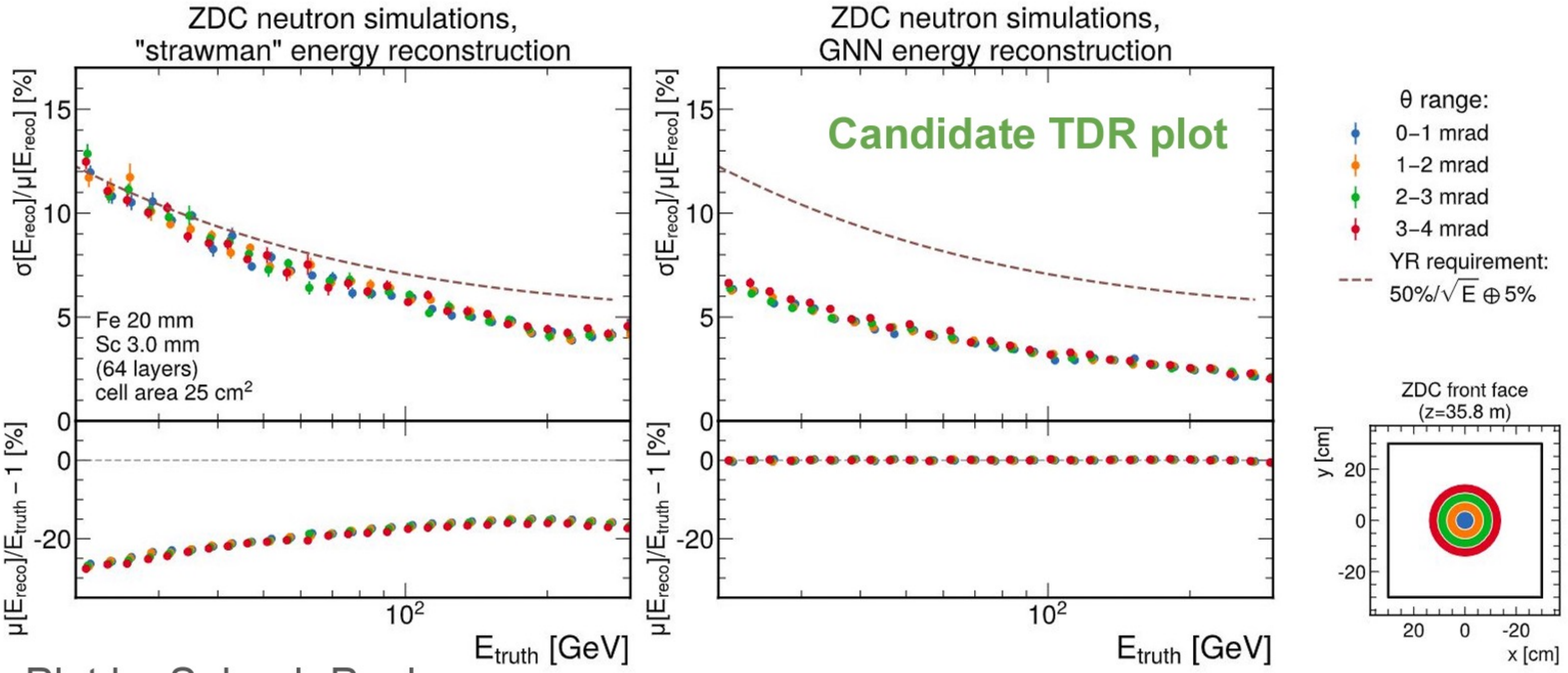






Staggered design described in
"Leveraging staggered tessellation for enhanced spatial resolution in high-granularity calorimeters" [NIMA 1060 (2024) 169044]

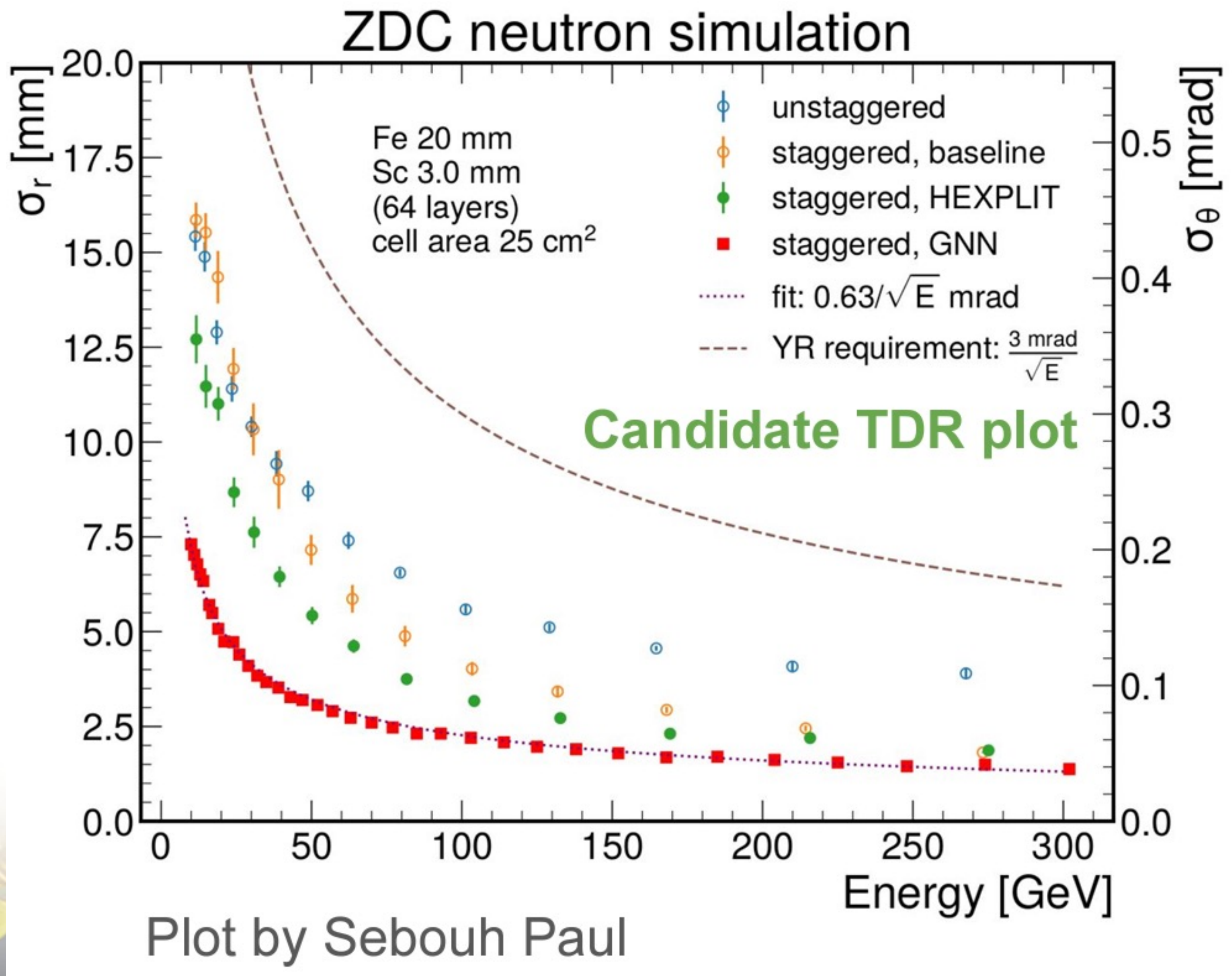
Hadronic Calorimeter – SiPM-on-Tile



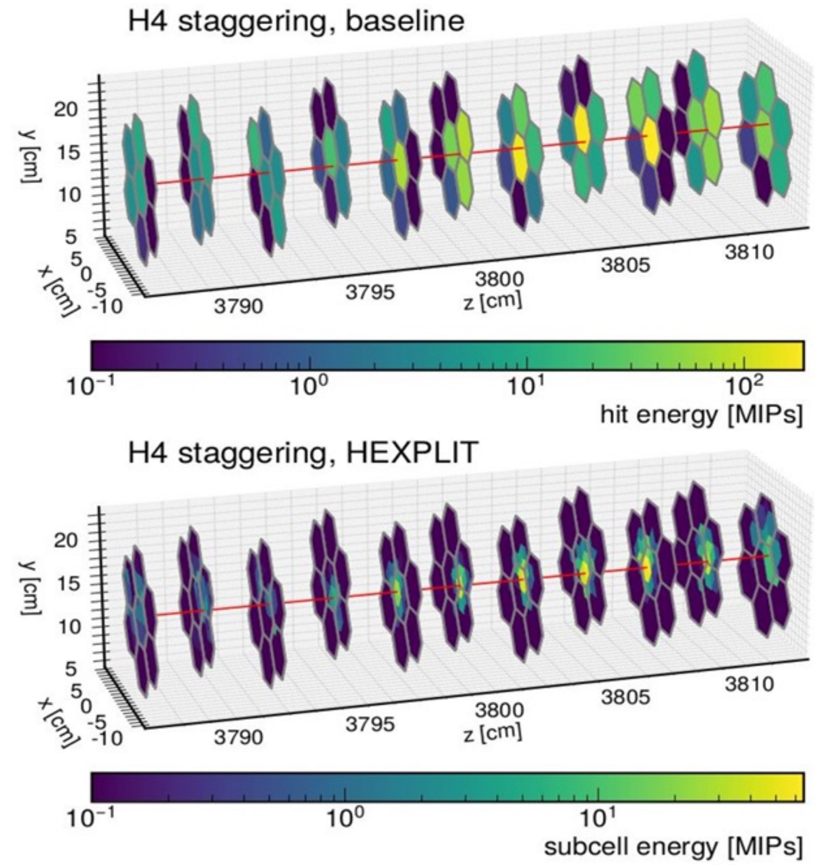
Plot by Sebouh Paul

Hadronic Calorimeter – SiPM-on-Tile

Position Resolution

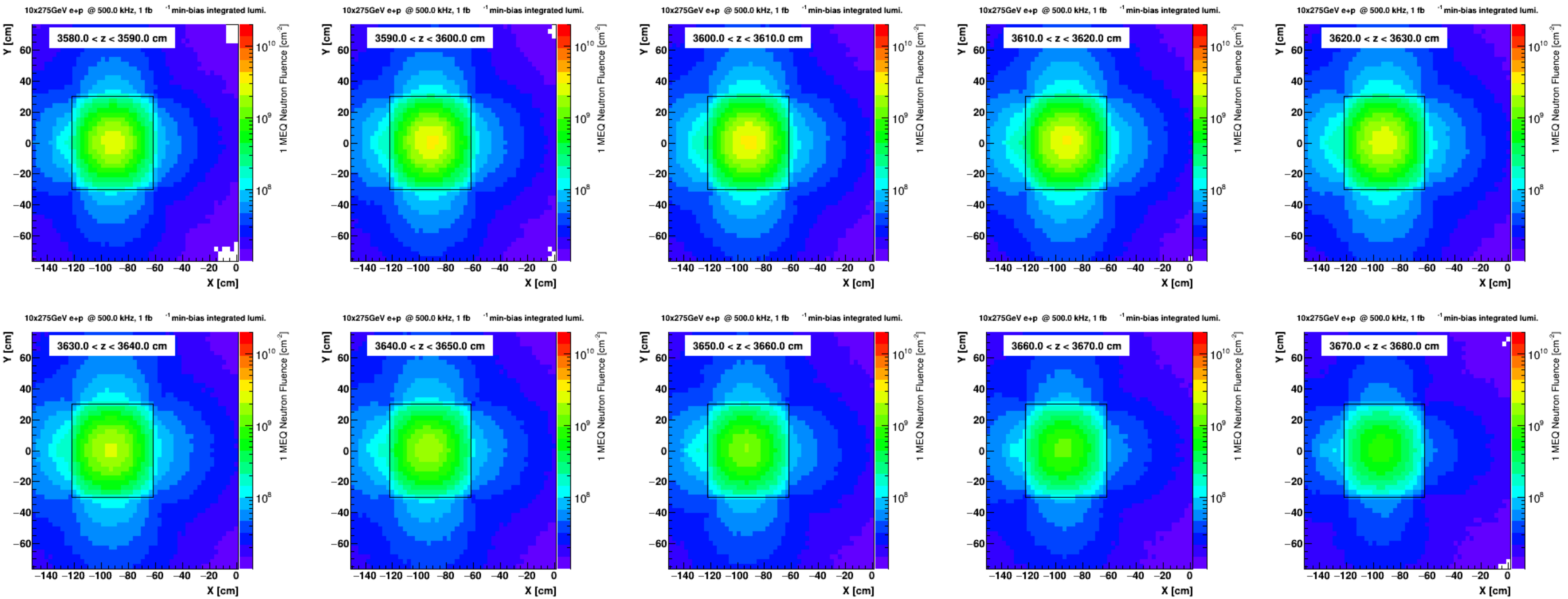


HEXPLIT design and algorithm described in *"Leveraging staggered tessellation for enhanced spatial resolution in high-granularity calorimeters"* NIMA 1060 (2024) 169044



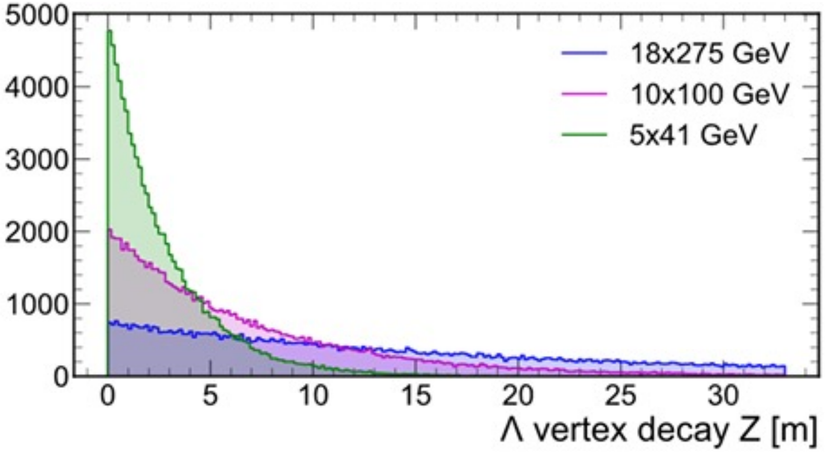
Radiation Damage from Neutrons

10cm steps through the length of the ZDC



Peak fluence @ z = 3615cm is 9.4e6 neutrons/cm^2/fb^{-1}

What about the EMCAL? (LYSO or PbWO4)

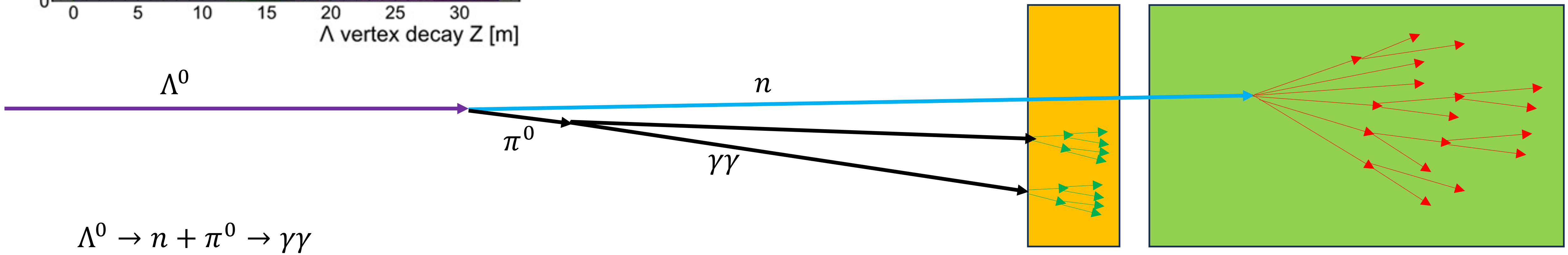


From: J Arrington *et al* 2021 *J. Phys. G: Nucl. Part. Phys.* **48** 075106

Yellow: crystal EMCAL
Blue: SiPM-on-Tile

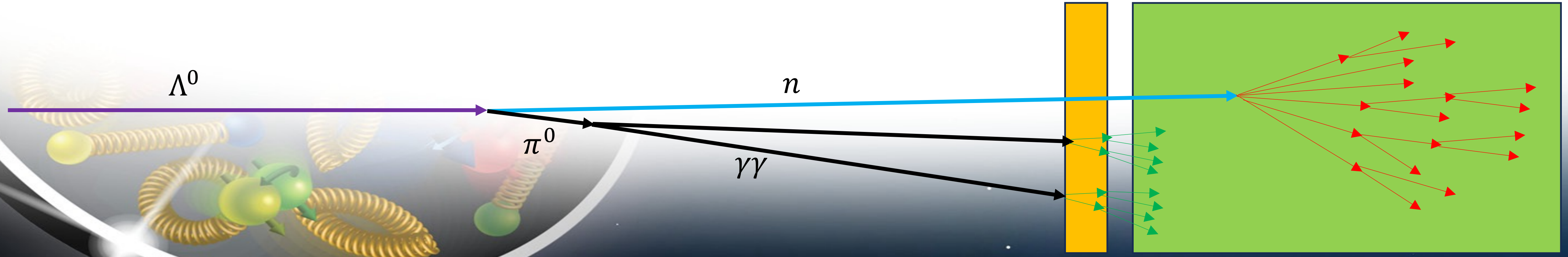
Some physics we didn't discuss yesterday – meson form factors!

Current configuration

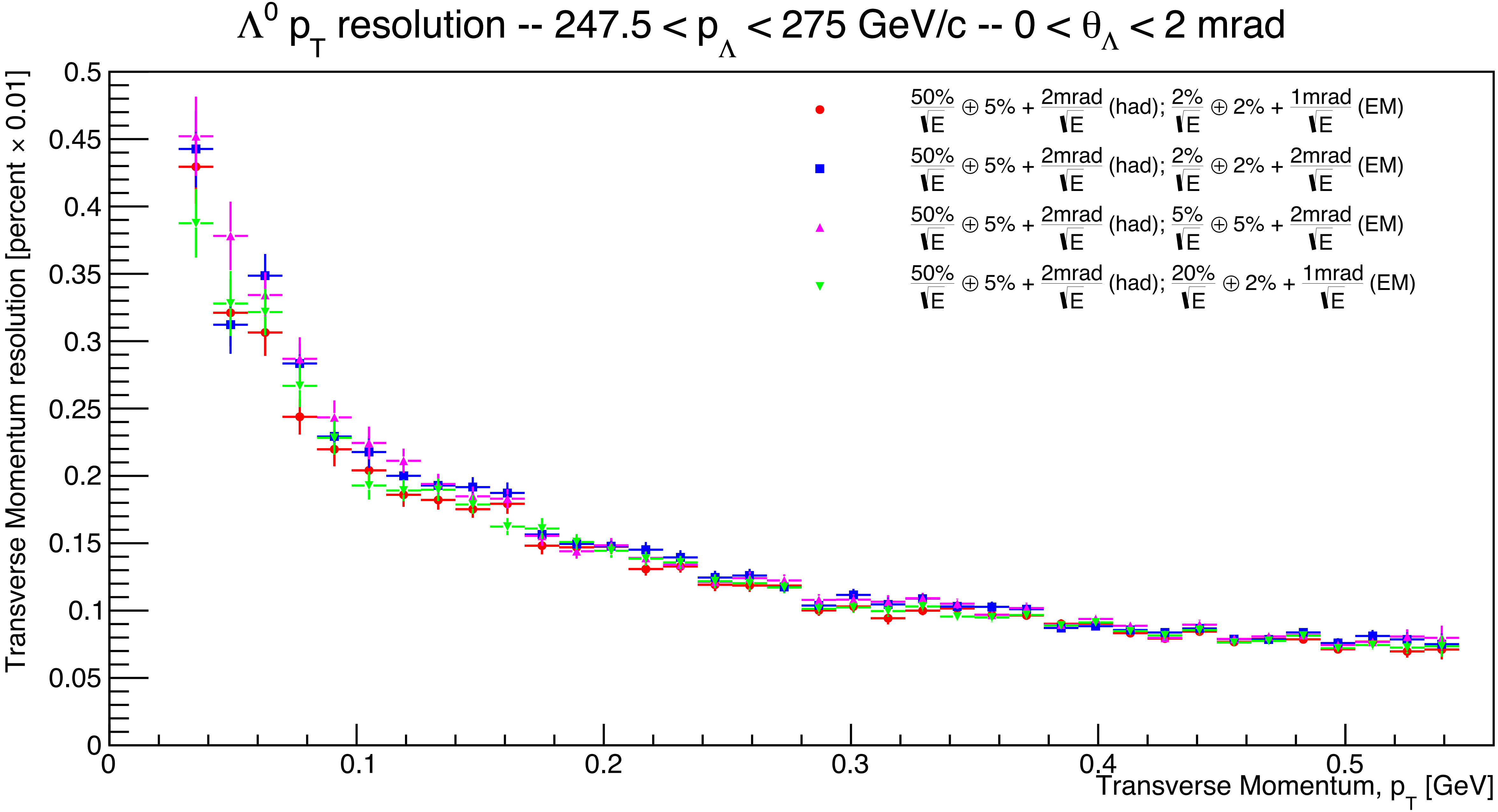


$\Lambda^0 \to n + \pi^0 \to \gamma\gamma$

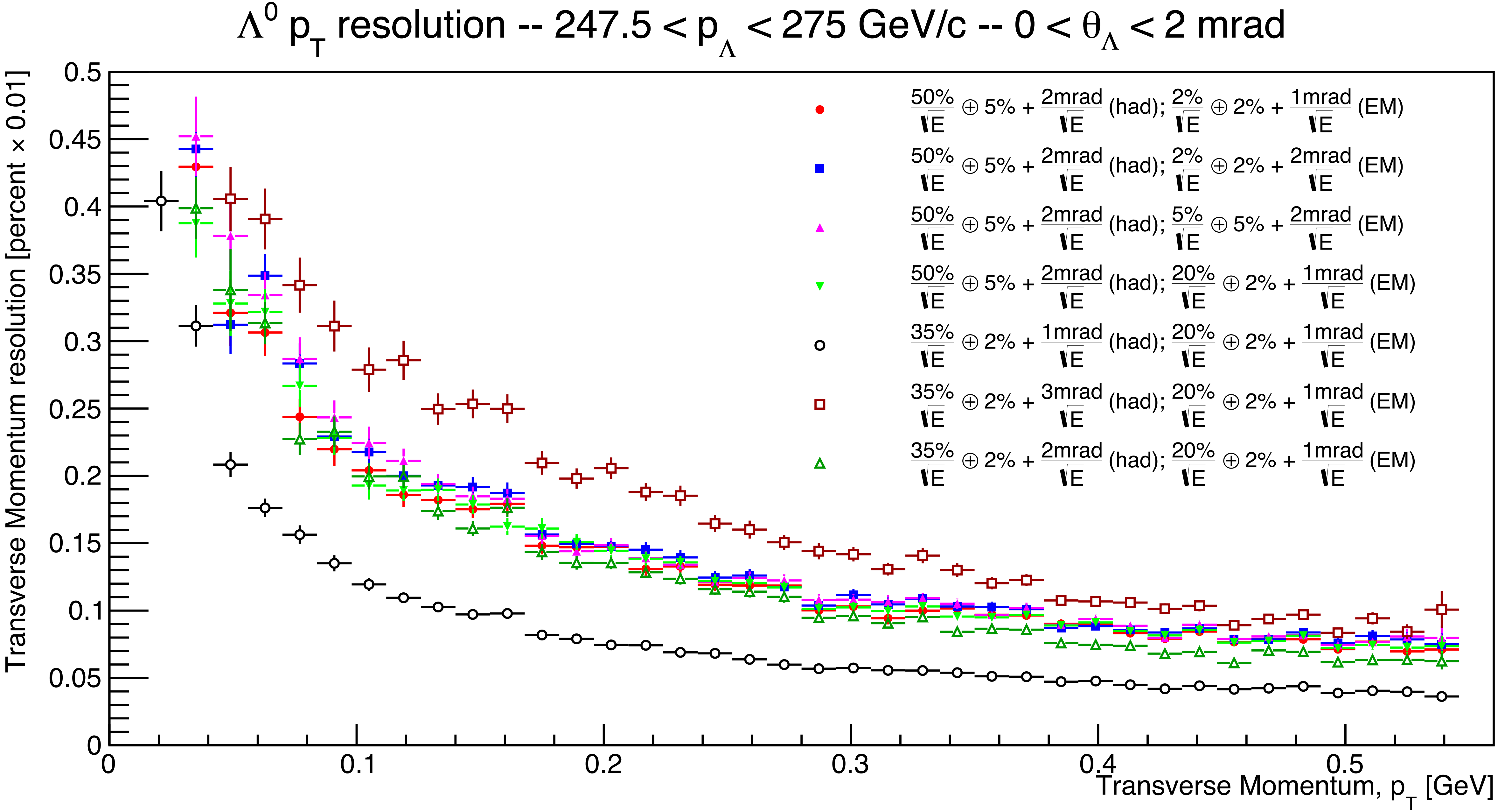
Shorter crystals



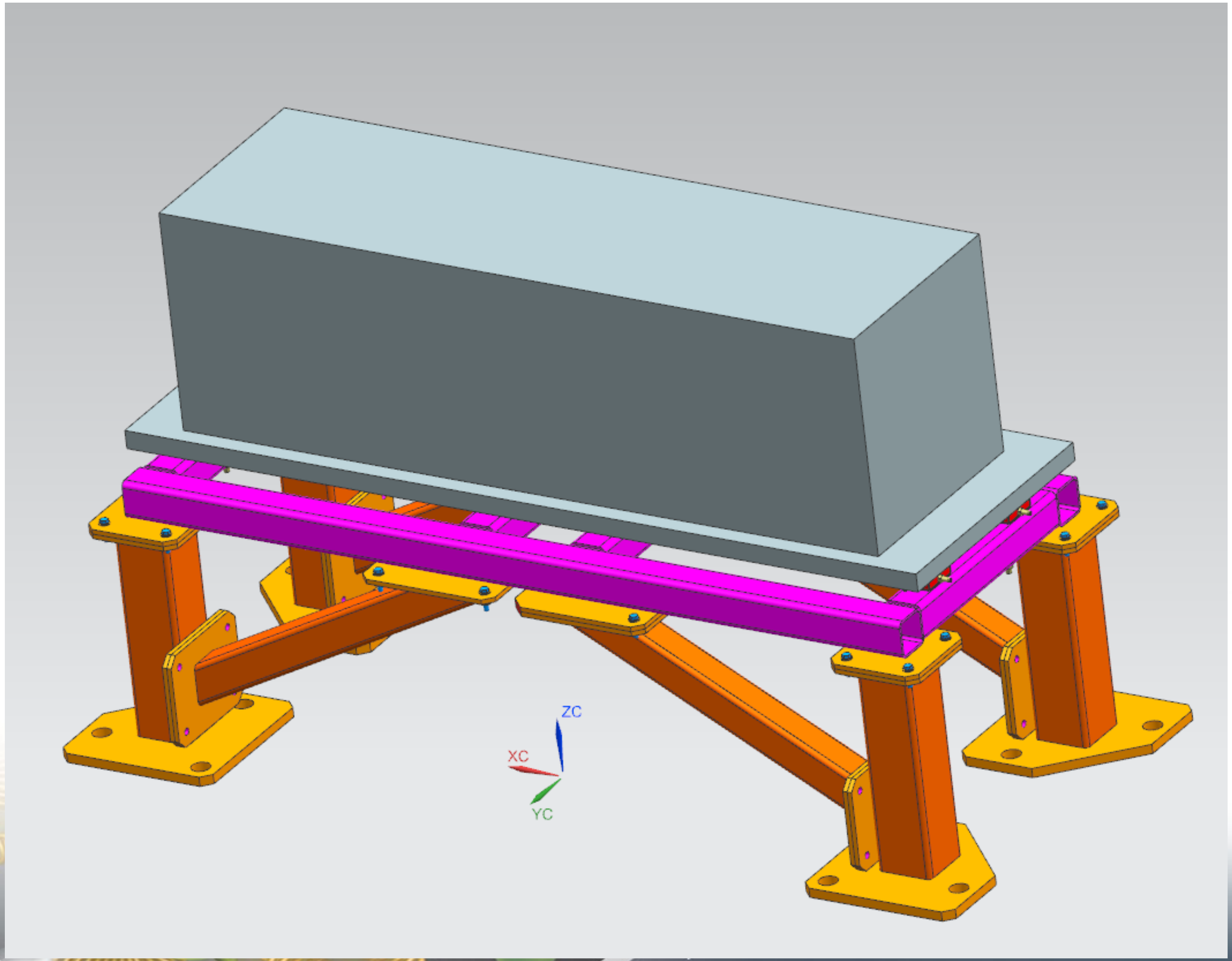
Lambda Decay Study



Lambda Decay Study

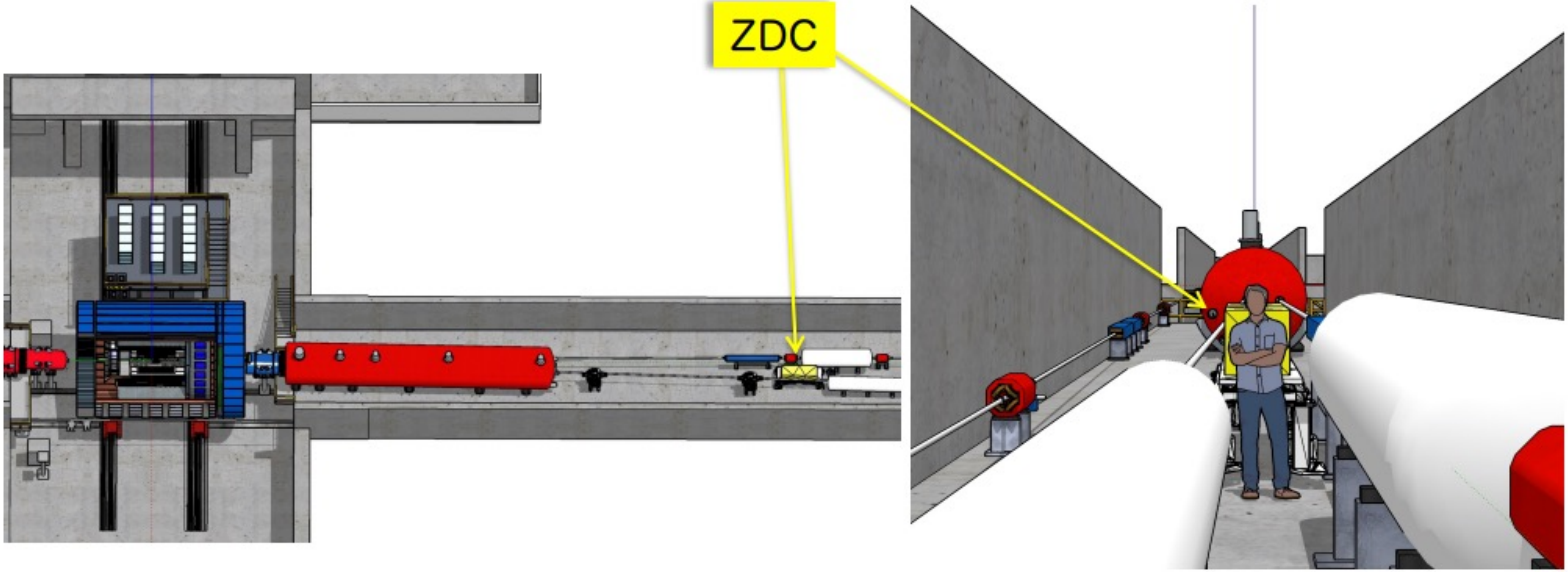


Zero-Degree Calorimeter with Stand

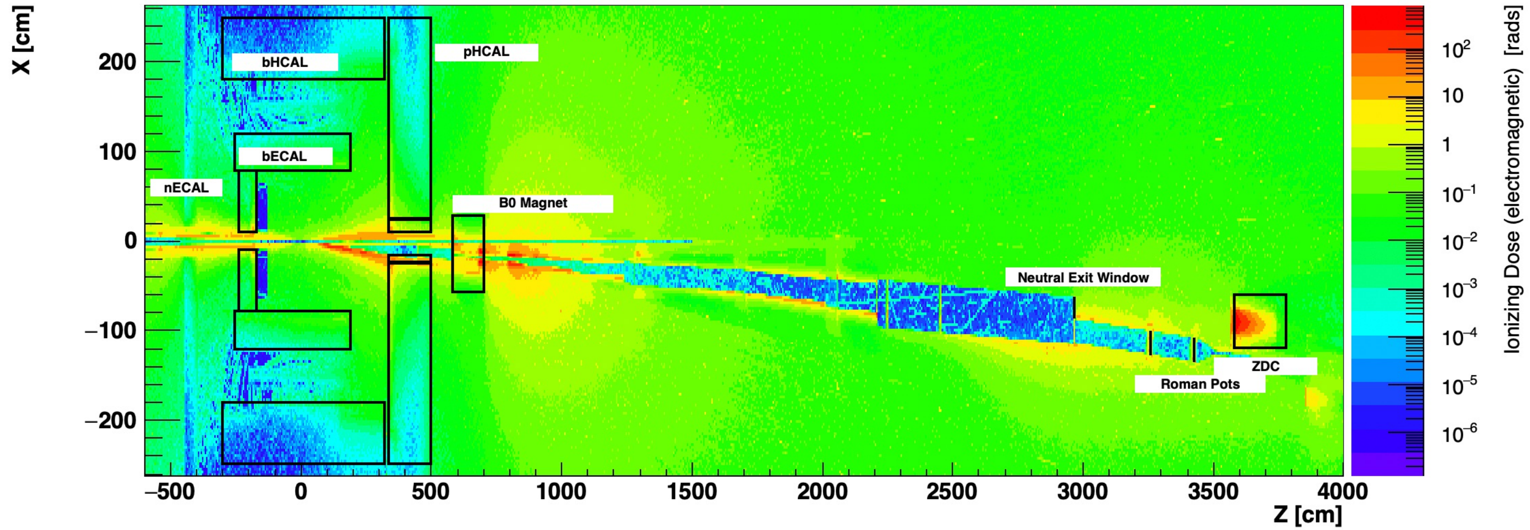


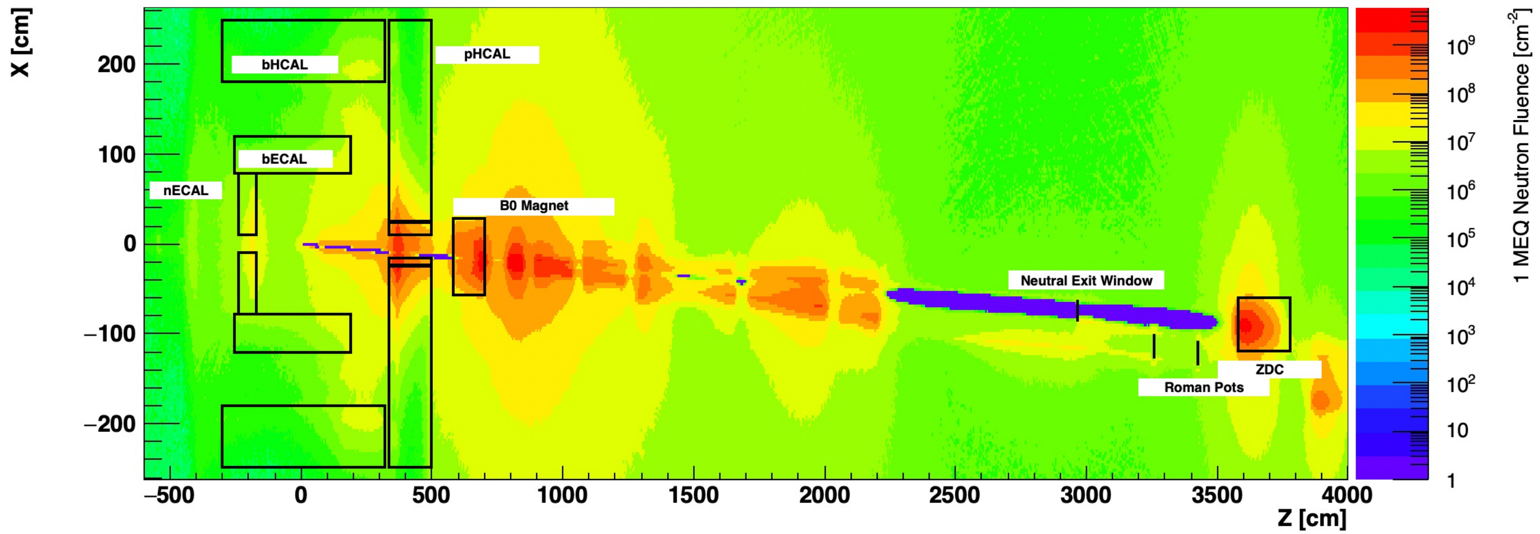
Preliminary Design of Zero--Degree Calorimeter with full support structure.

Zero-Degree Calorimeter

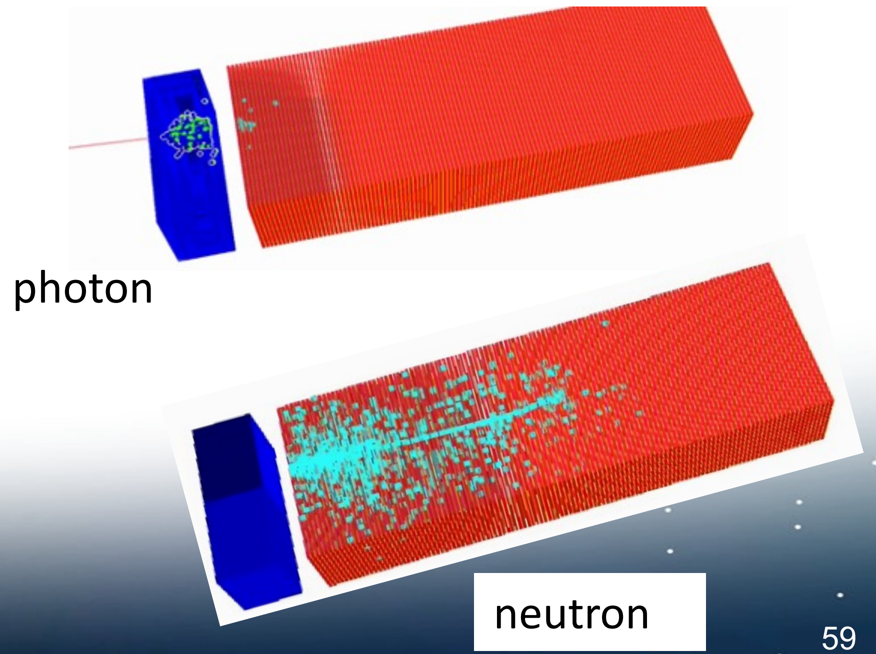


Radiation Tolerance





- Ionizing radiation will cause harm to electronics, sometimes acutely.
- Neutron radiation can cause long-term, cumulative damage to silicon, scintillator, etc.
- Have to make sure our simulations have accurate geometry – heavy metals can be a *source* of additional radiation!!



Summary and Takeaways

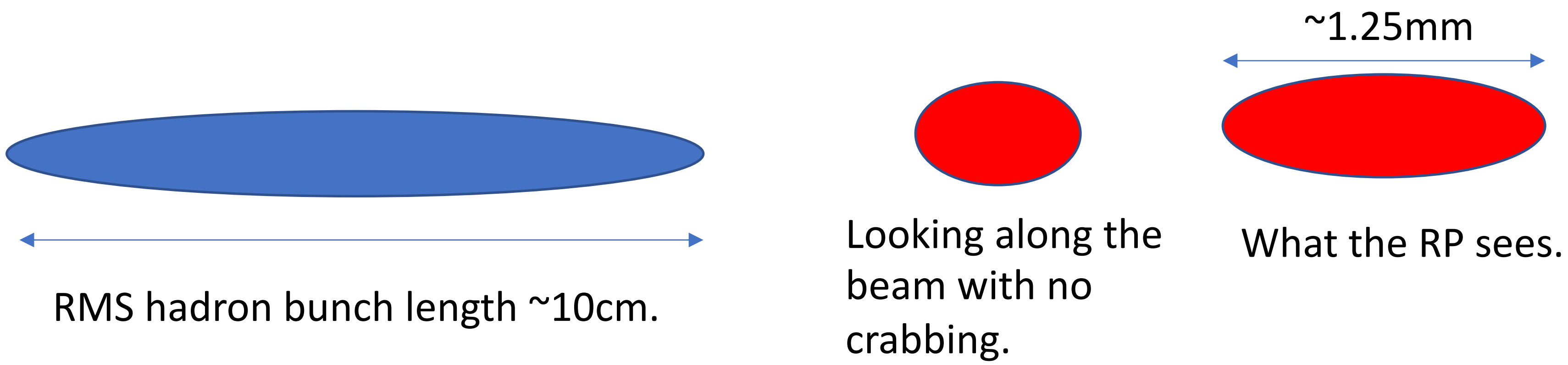
- All FF detector acceptances and detector performance well-understood with currently available information.
  - Numerous impact studies done!
    - Yellow Report, Detector proposals, and stand-alone impact studies.
  - Final technology choices identified, along with suitable alternate designs for risk mitigation.
- More realistic engineering considerations need to be added to simulations as design of IR vacuum system and magnets progresses toward CD-2/3.
  - 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.

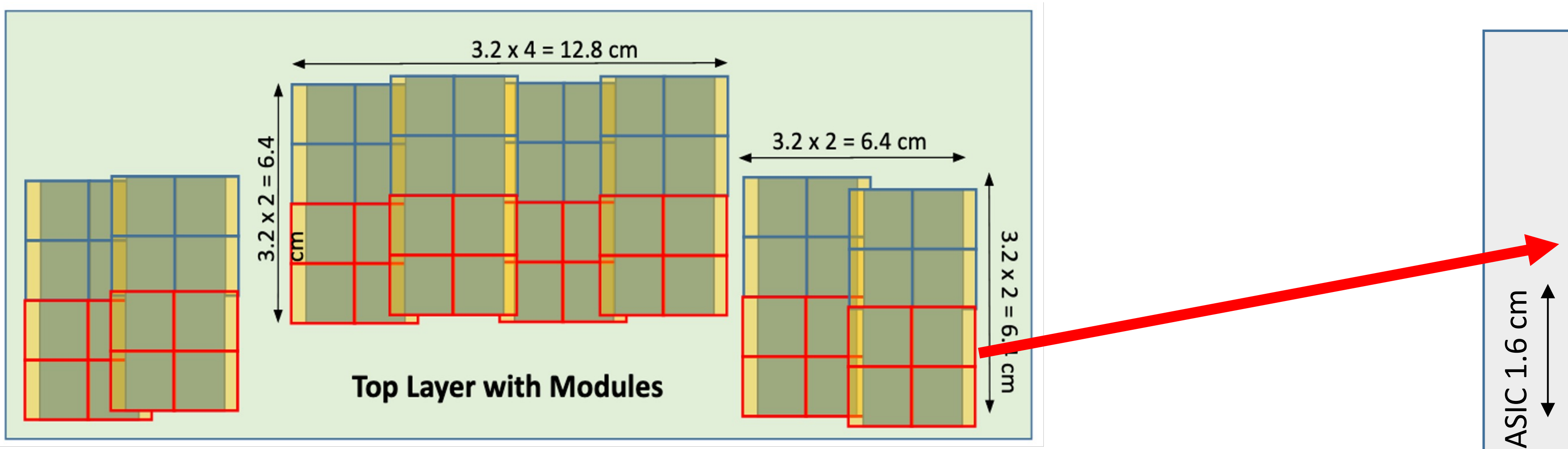
> - **From these comparisons, reducing the effective vertex smearing to that of the 1cm bunch length reduces the momentum smearing to negligible from this contribution.**
> - **This can be achieved with timing of ~ 35ps (1cm/speed of light).**

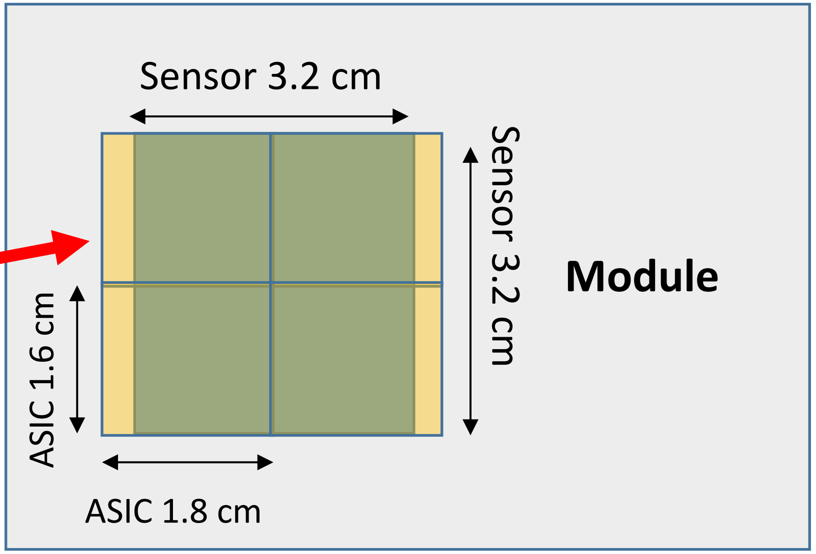
Roman Pots

- 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.

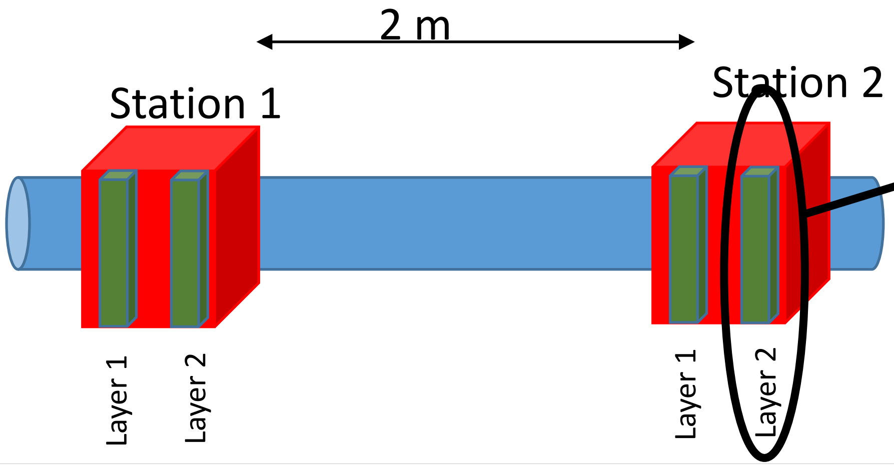
Smearing from finite pixel size.

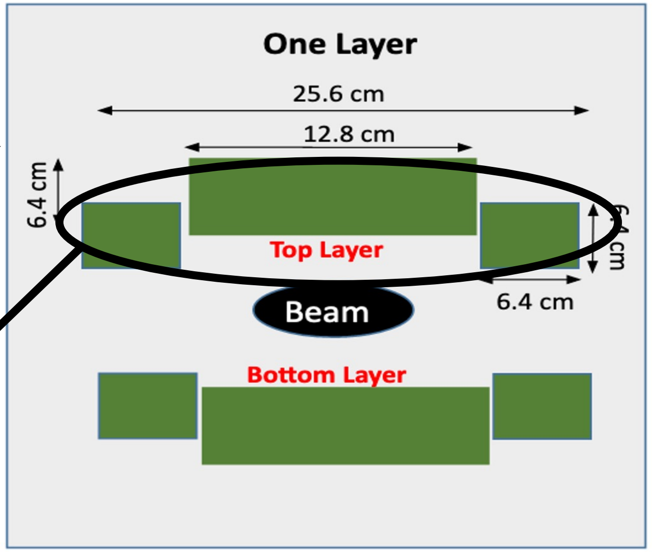
	Ang Div. (HD)	Ang Div. (HA)	Vtx Smear	250um pxl	500um pxl	1.3mm pxl
$\Delta p_{t,total}$ [MeV/c] - 275 GeV	40	28	20	6	11	26
$\Delta p_{t,total}$ [MeV/c] - 100 GeV	22	11	9	9	11	16
$\Delta p_{t,total}$ [MeV/c] - 41 GeV	14	-	10	9	10	12

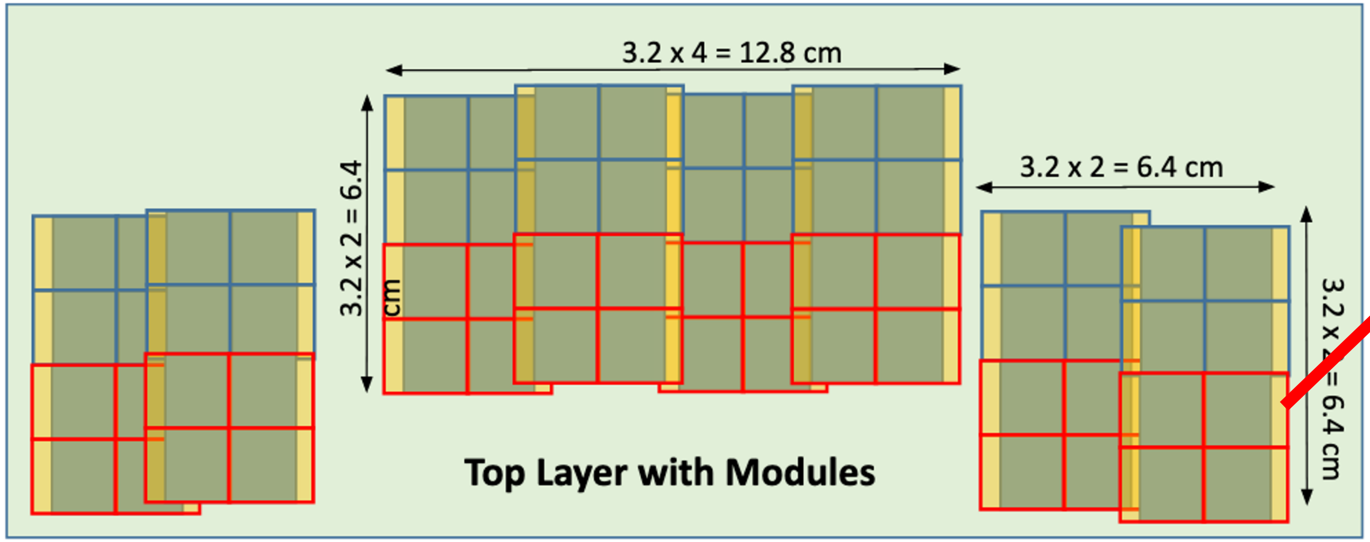
- **Beam angular divergence**
    - Beam property, can't correct for it – sets the lower bound of smearing.
    - Subject to change (i.e. get better) – beam parameters not yet set in stone
- **Vertex smearing from crab rotation**
    - Correctable with good timing (~35ps)
- **Finite pixel size on sensor**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

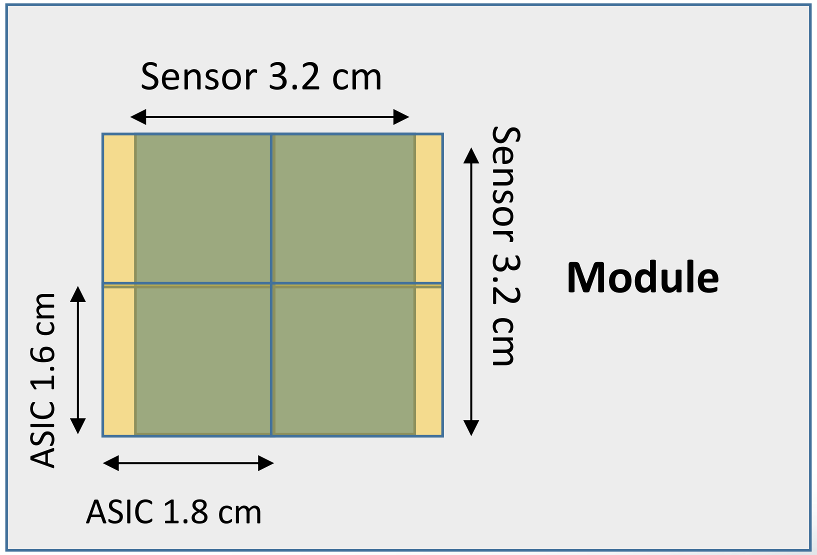
Roman Pots @ the EIC

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







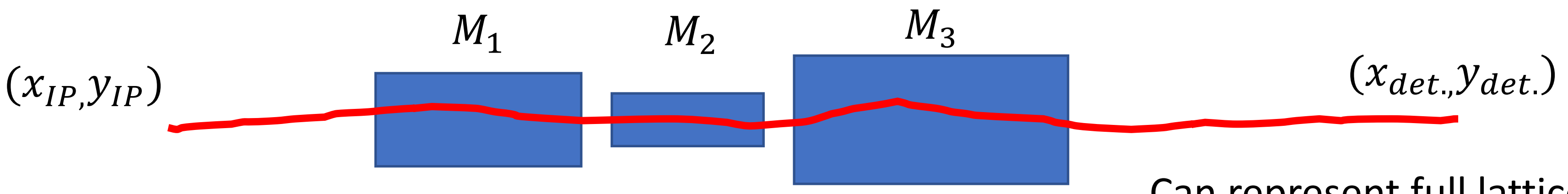


- Current R&D aimed at customizing ASIC readout chip (ALTIROC) for use with AC-LGADs.

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

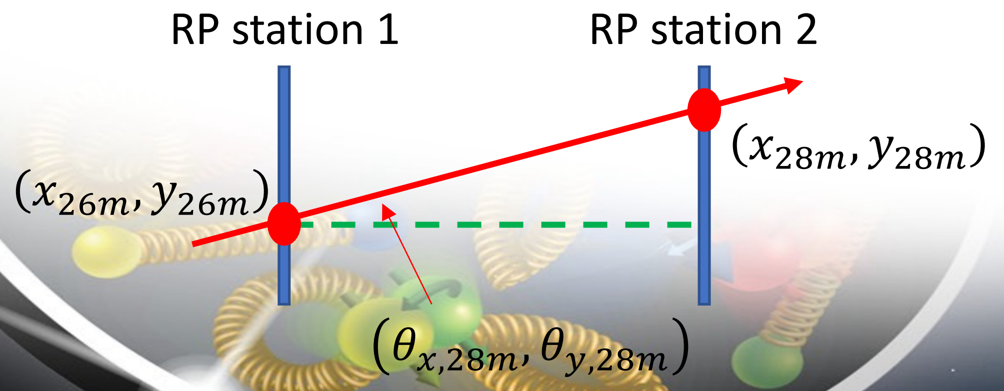
Θ^x_D, Θ^y_D : Angle at Detector

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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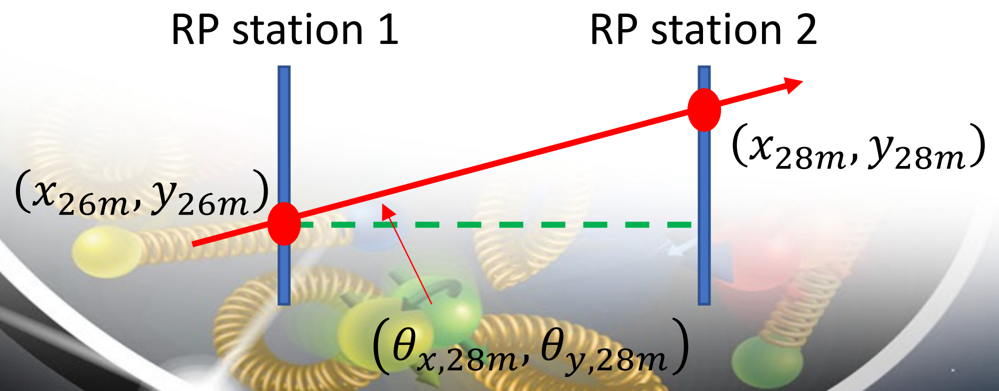
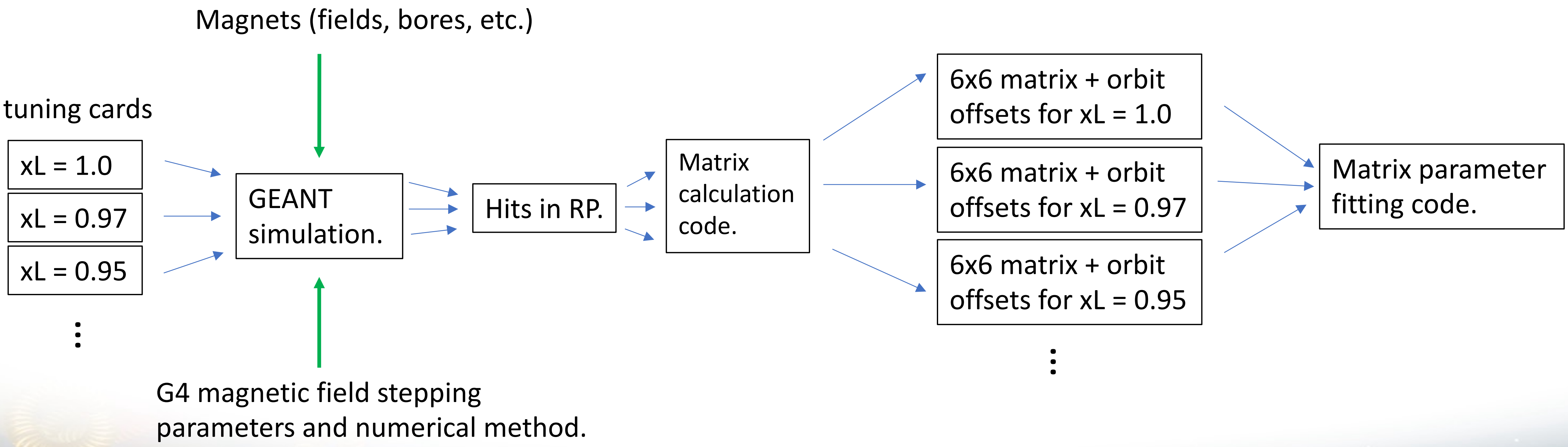


$$\textit{longitudinal momentum fraction}$$
$$x_L = \frac{p_{z,proton}}{p_{z,beam}}$$

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

A Simplistic General Method

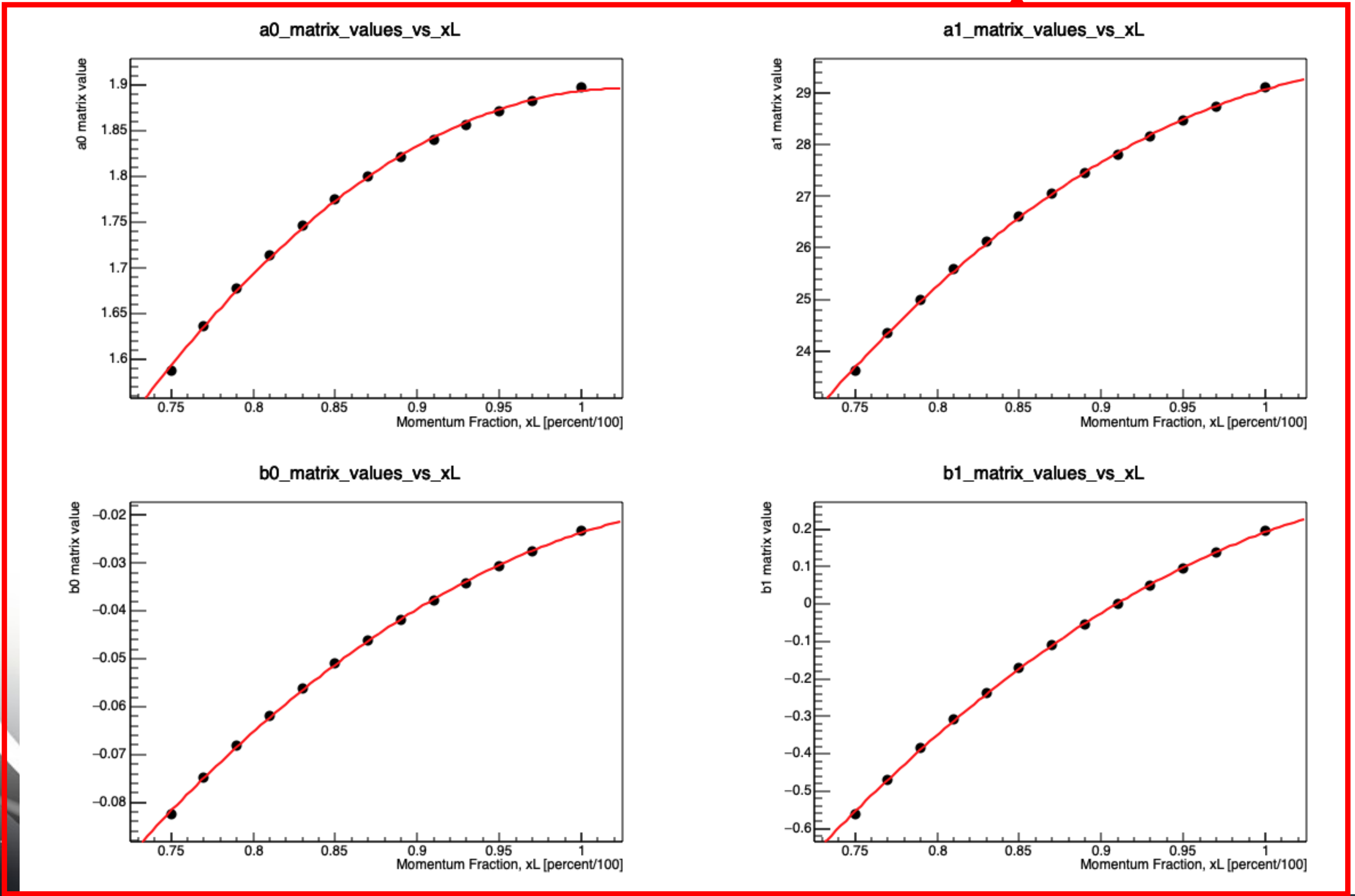
- Begin with a set of “input tuning cards” which contain many reference trajectories for calculating the matrices.



A Simplistic General Method

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

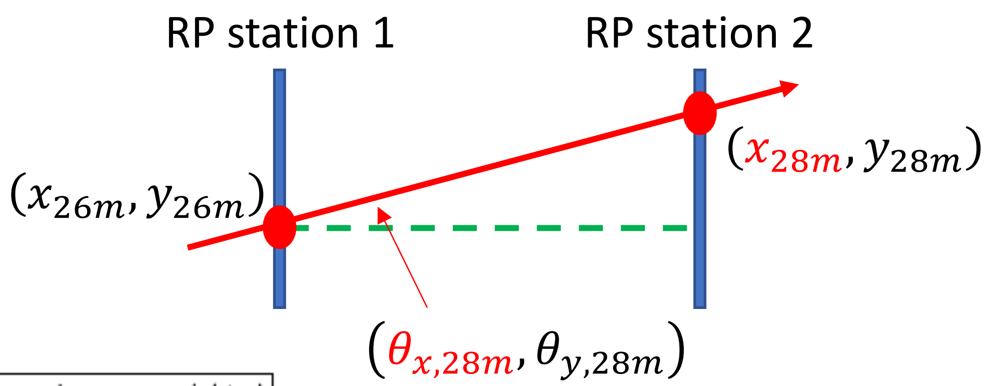
1.88481537	28.96766544	0.0000	0.0000	0.0000	0.24906255
−0.02114673	0.20555261	0.0000	0.0000	0.0000	−0.03322467
0.0000	0.0000	−2.25541901	3.78031509	0.0000	0.0000
0.0000	0.0000	−0.17782524	−0.14532313	0.0000	0.0000
0.05735551	1.01363652	0.0000	0.0000	1.0000	0.02568709
0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

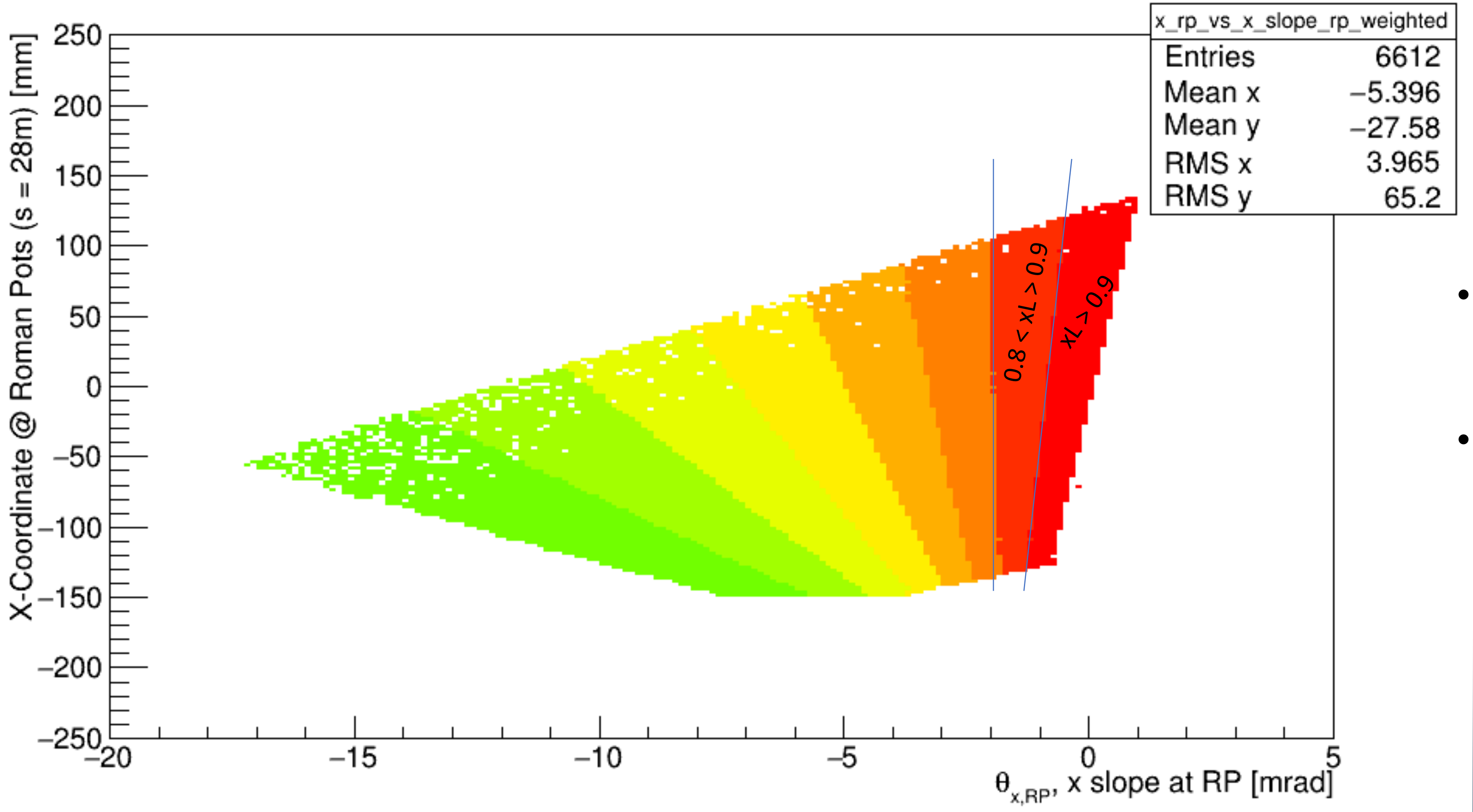


- The 40 fit functions (36 matrix parameters + 4 offsets) then represent the ingredients to calculate the needed matrix in real-time at reconstruction.
- All that is needed is a lookup table to get the xL value for an event based on the coordinates at the Roman Pots.

A Simplistic General Method

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



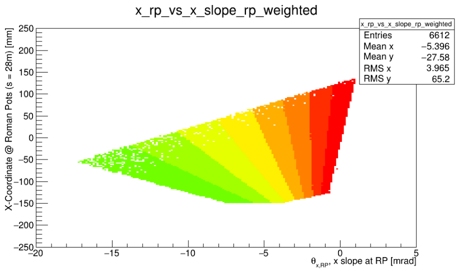


- “Chromaticity plot” serves as a lookup table to use RP coordinates to find the xL value.
- xL is then used to evaluate the correct matrix for reconstruction.

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 →



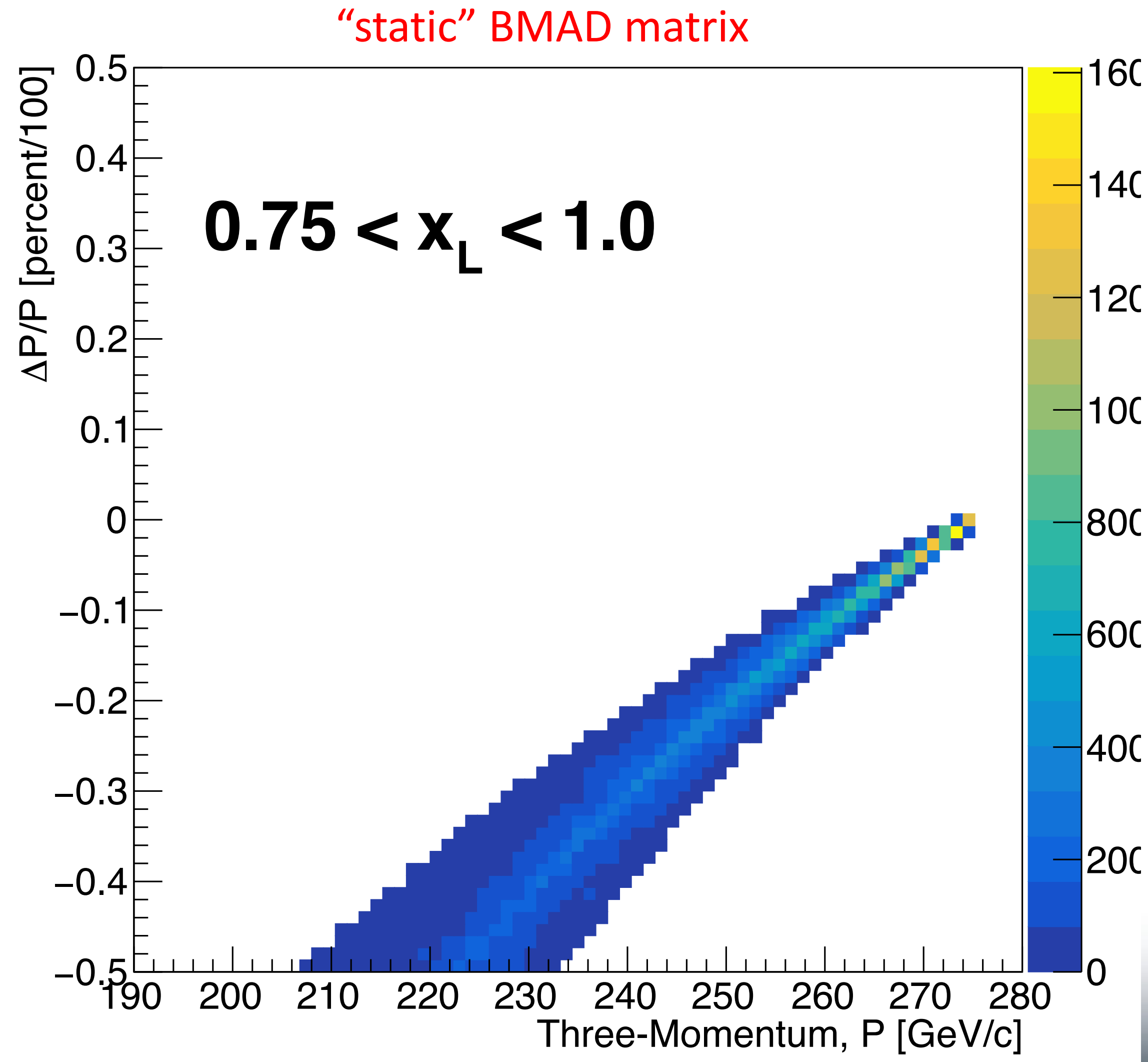
Lookup xL → Calculate matrix parameters and offsets from fit equations.

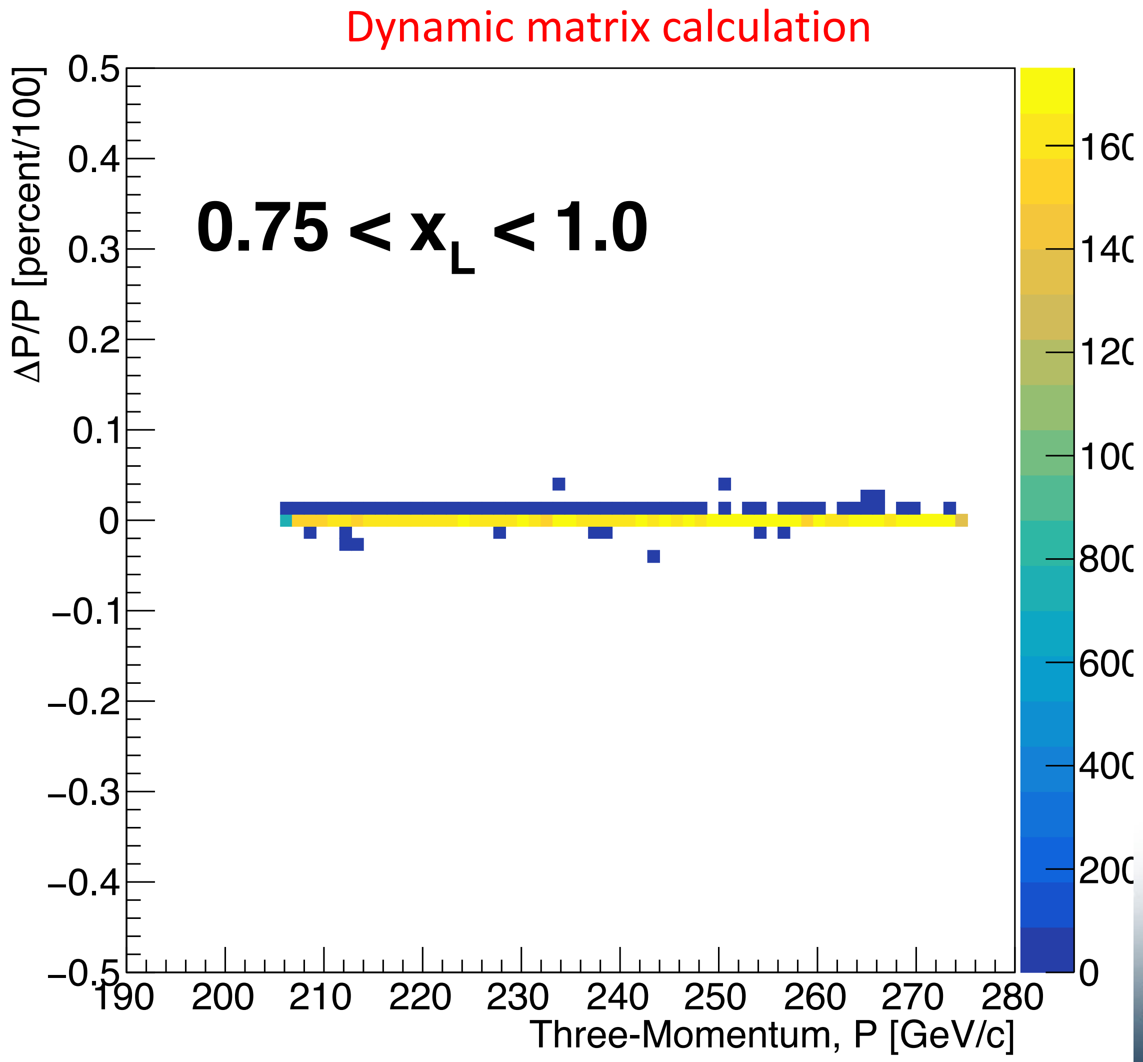
$$
\begin{pmatrix}
1.88481537 & 28.96766544 & 0.0000 & 0.0000 & 0.0000 & 0.24906255 \\
-0.02114673 & 0.20555261 & 0.0000 & 0.0000 & 0.0000 & -0.03322467 \\
0.0000 & 0.0000 & -2.25541901 & 3.78031509 & 0.0000 & 0.0000 \\
0.0000 & 0.0000 & -0.17782524 & -0.14532313 & 0.0000 & 0.0000 \\
0.05735551 & 1.01363652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

→ Reconstructed momentum vector.

Results - Momentum

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

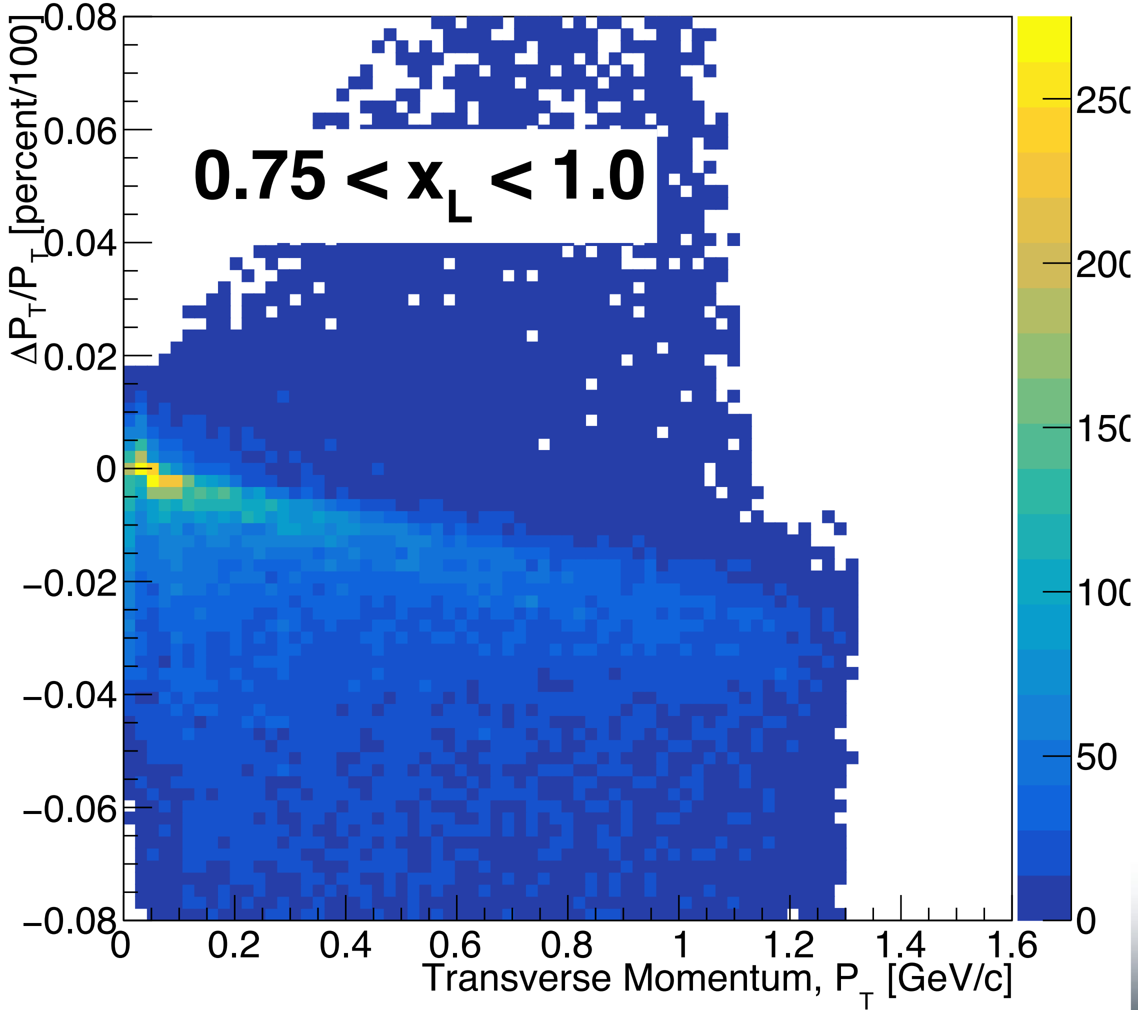




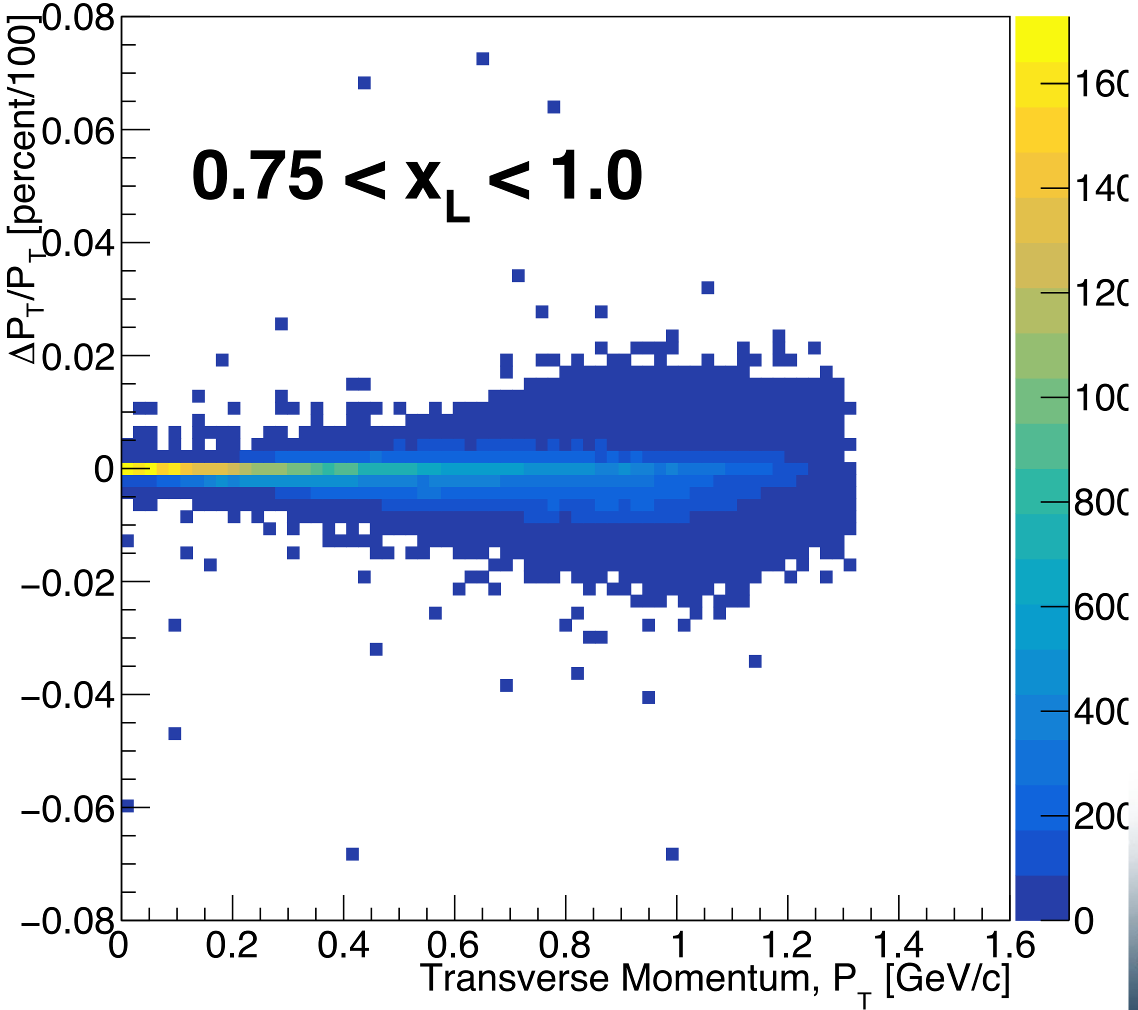
Results - pT

- 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.