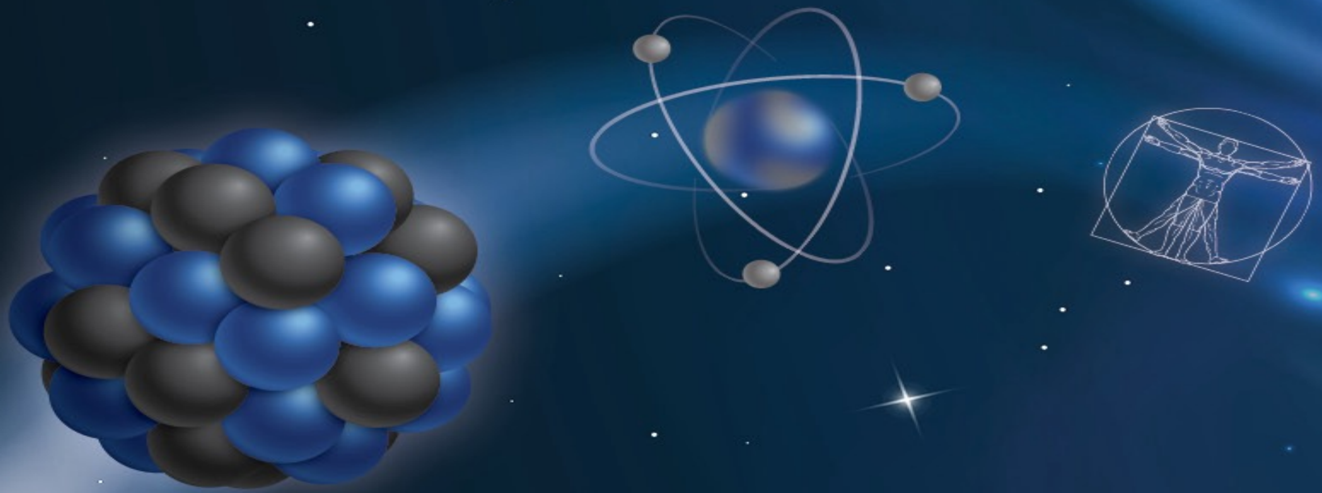
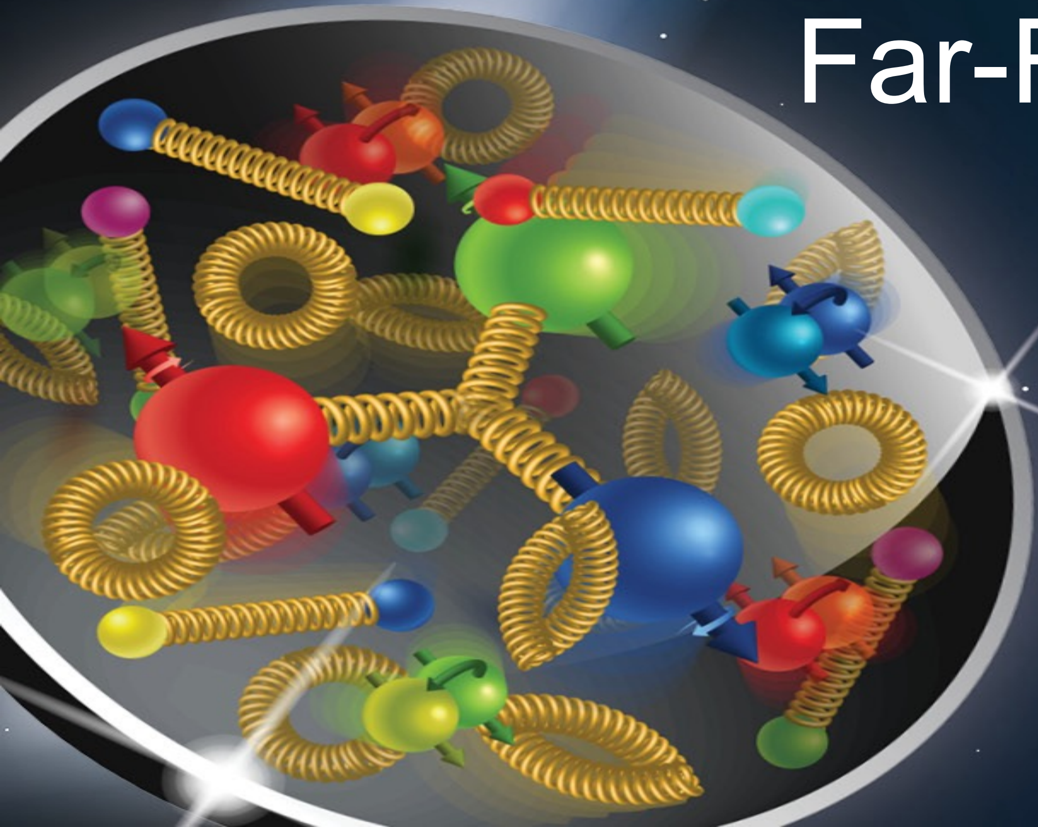




Far-Forward Detectors at the EIC

Alex Jentsch (Brookhaven National Laboratory)

For the ePIC Collaboration

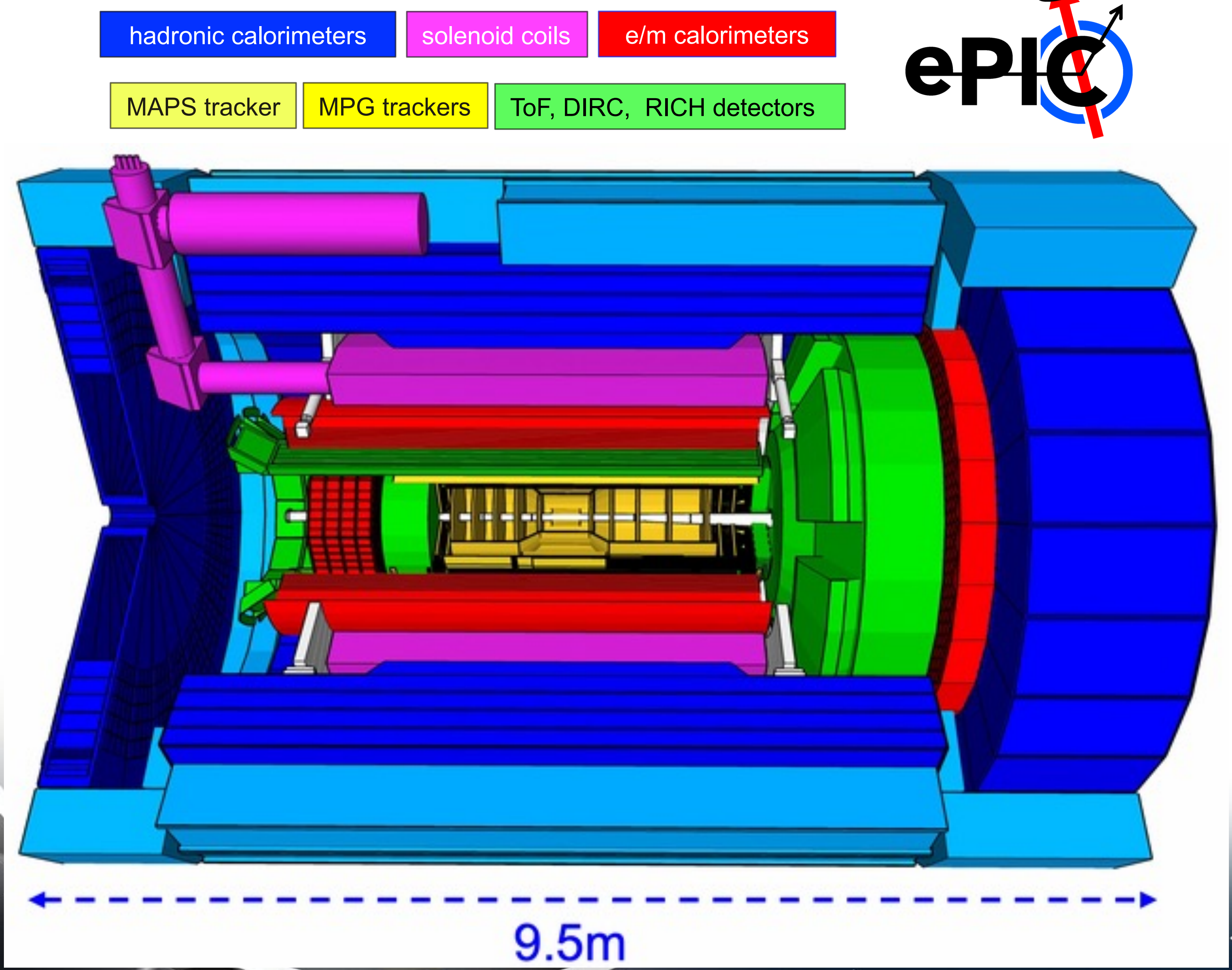
Toward Improved Hadron Femtography in Hard Exclusive Reactions

August 7th -11th , 2023

Jefferson Lab, Newport News, VA

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

What is meant by Far-Forward?



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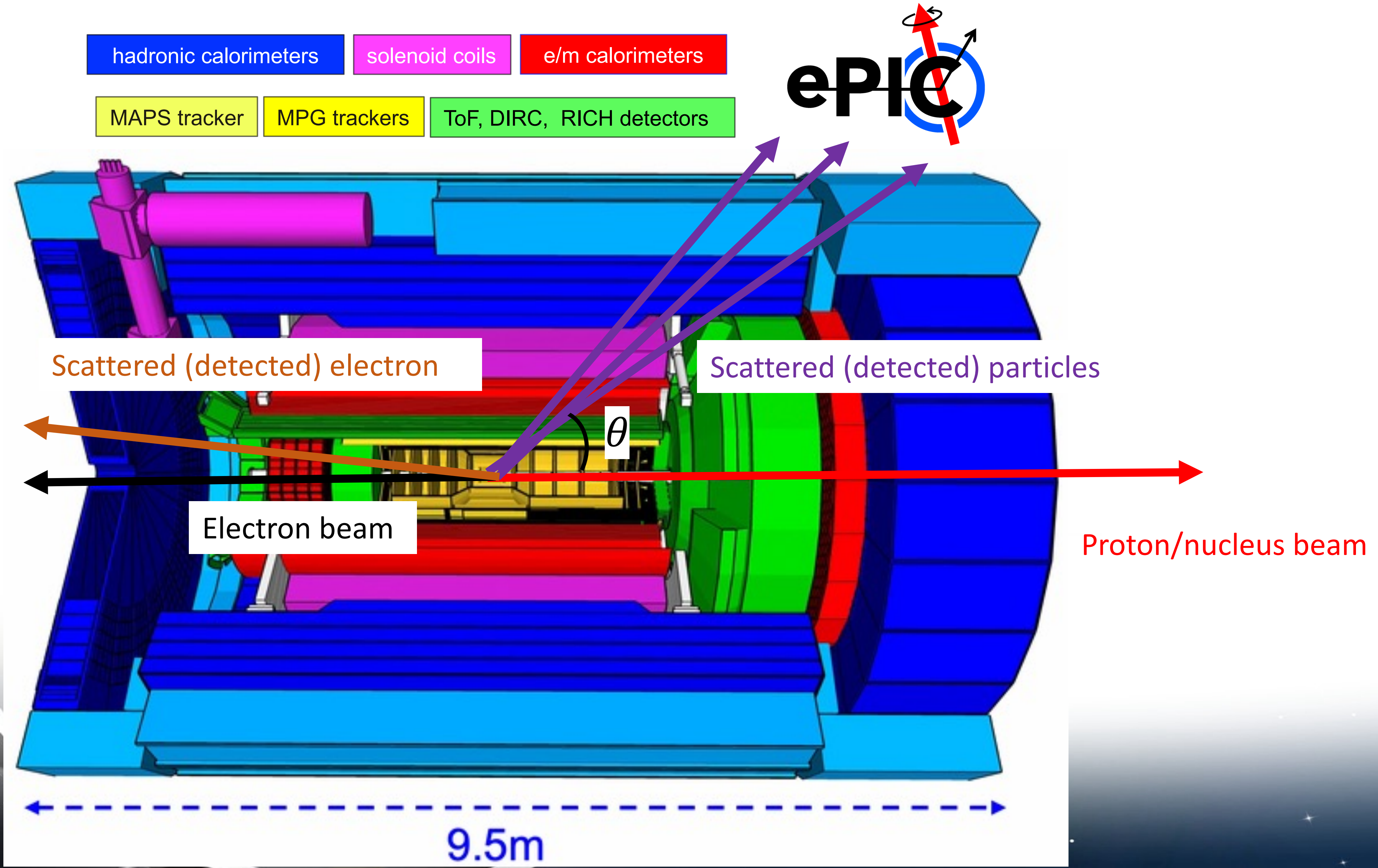
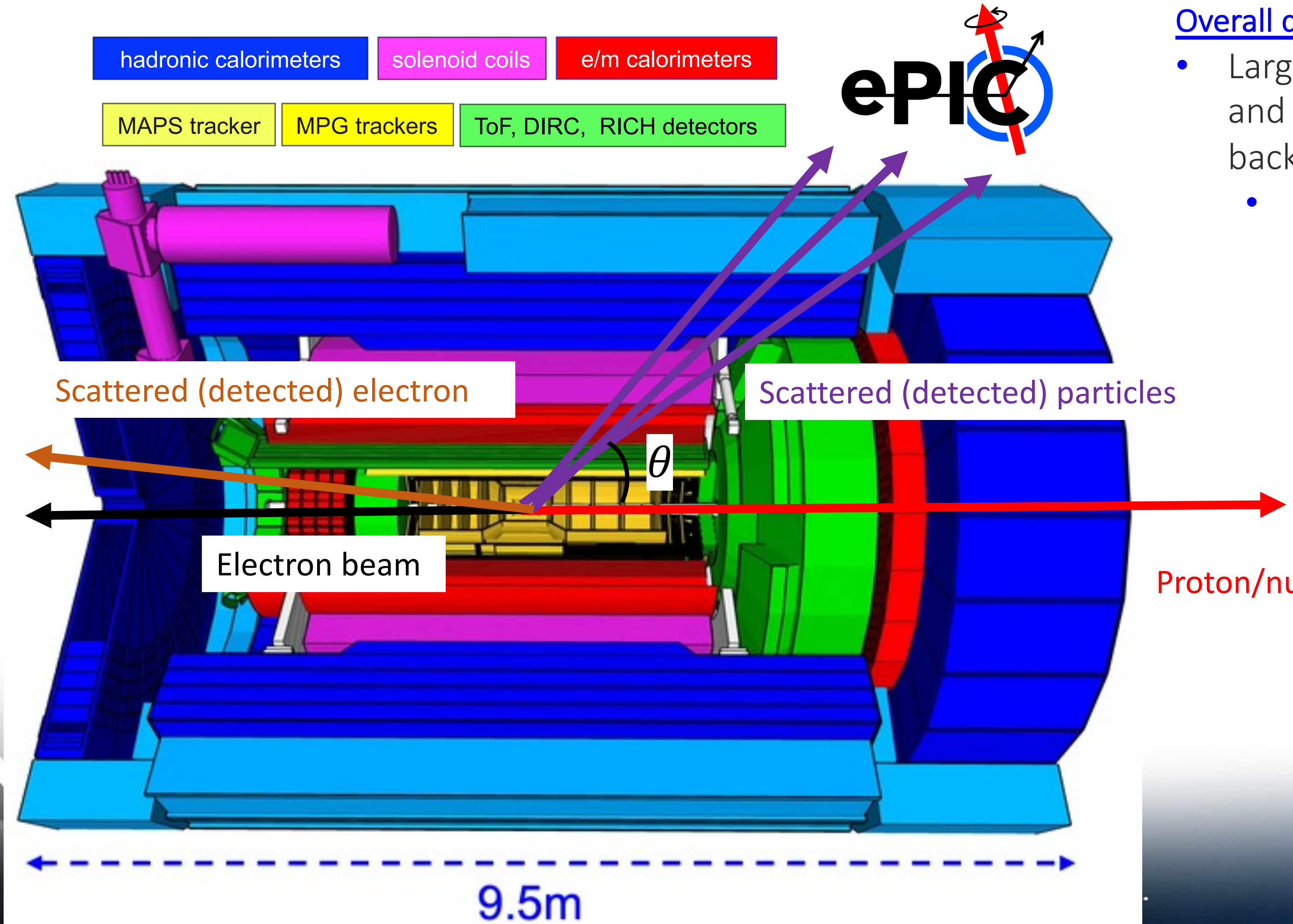


What is meant by Far-Forward?



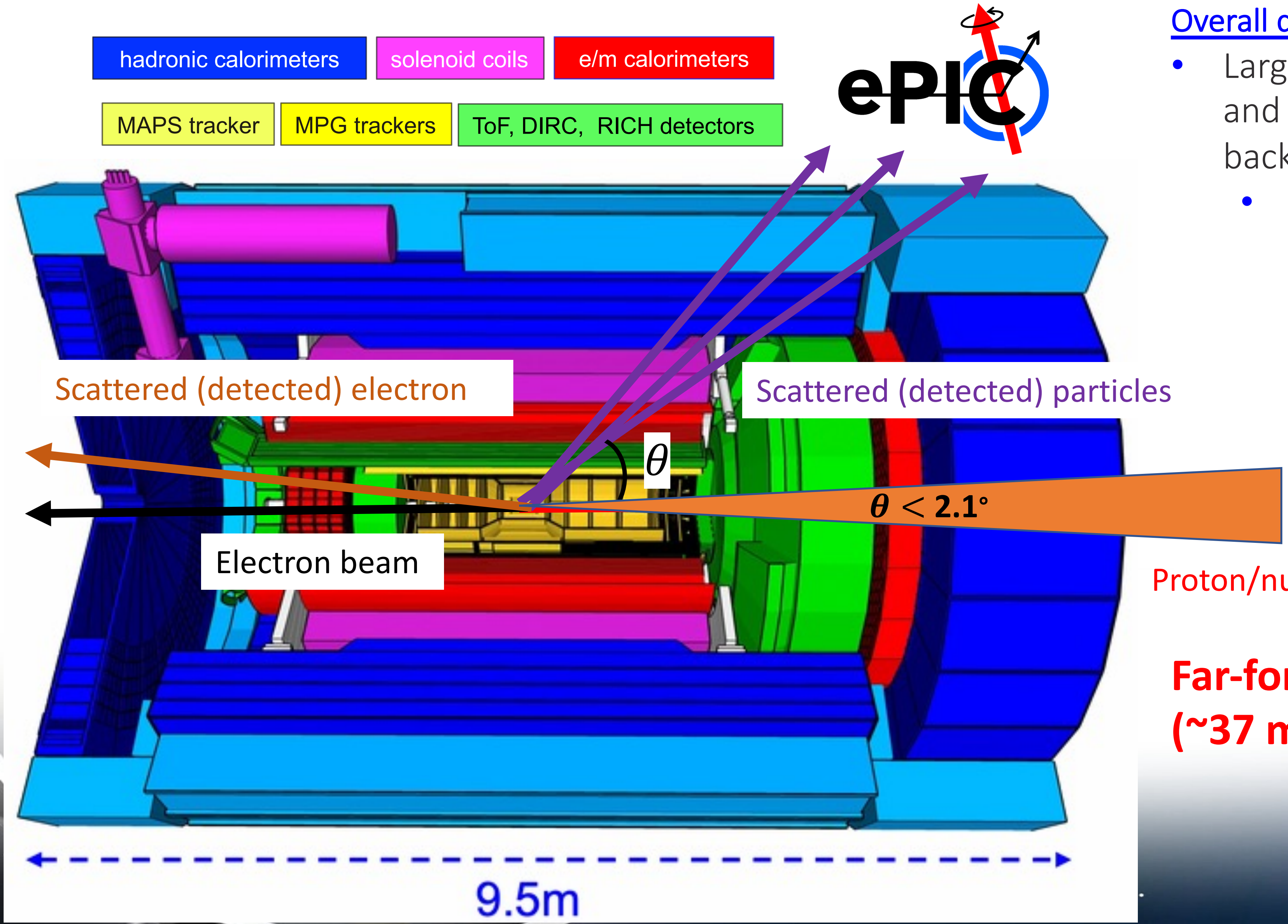
Overall detector requirements:

- 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 $2.1^{\circ} < \theta < 90^{\circ}$

$$\eta = -ln(tan(\theta/2))$$

pseudorapidity

What is meant by Far-Forward?



Proton/nucleus beam

<u>Overall detector requirements:</u>

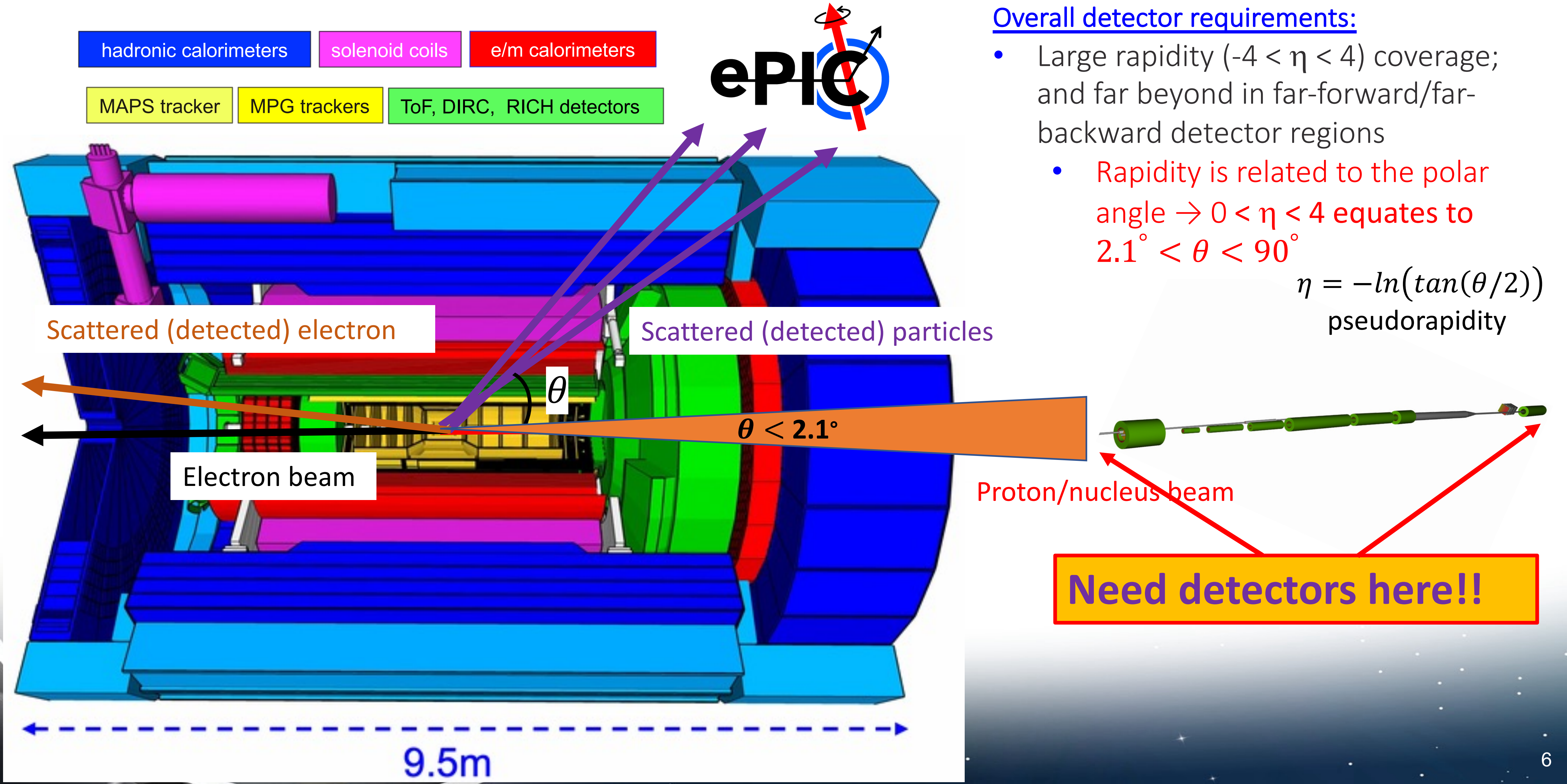
- Large rapidity (-4 < η < 4) coverage; and far beyond in far-forward/far-backward detector regions
  - Rapidity is related to the polar angle → **0 < η < 4 equates to** $2.1^{\circ} < \theta < 90^{\circ}$

$$\eta = -ln\left(tan(\theta/2)\right)$$

pseudorapidity

Far-forward here means $\theta < 2.1°$ (~37 mrad)

What is meant by Far-Forward?



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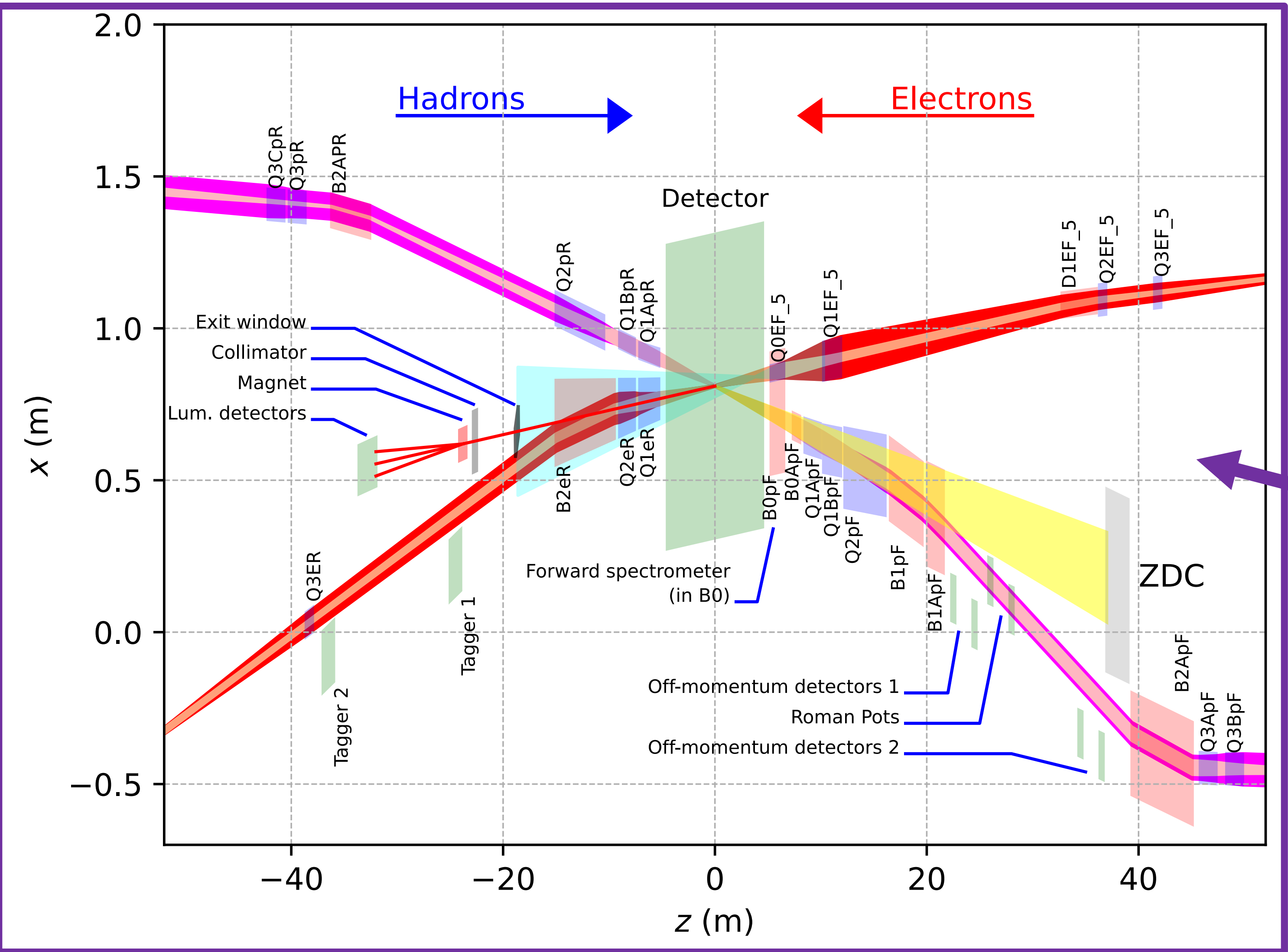
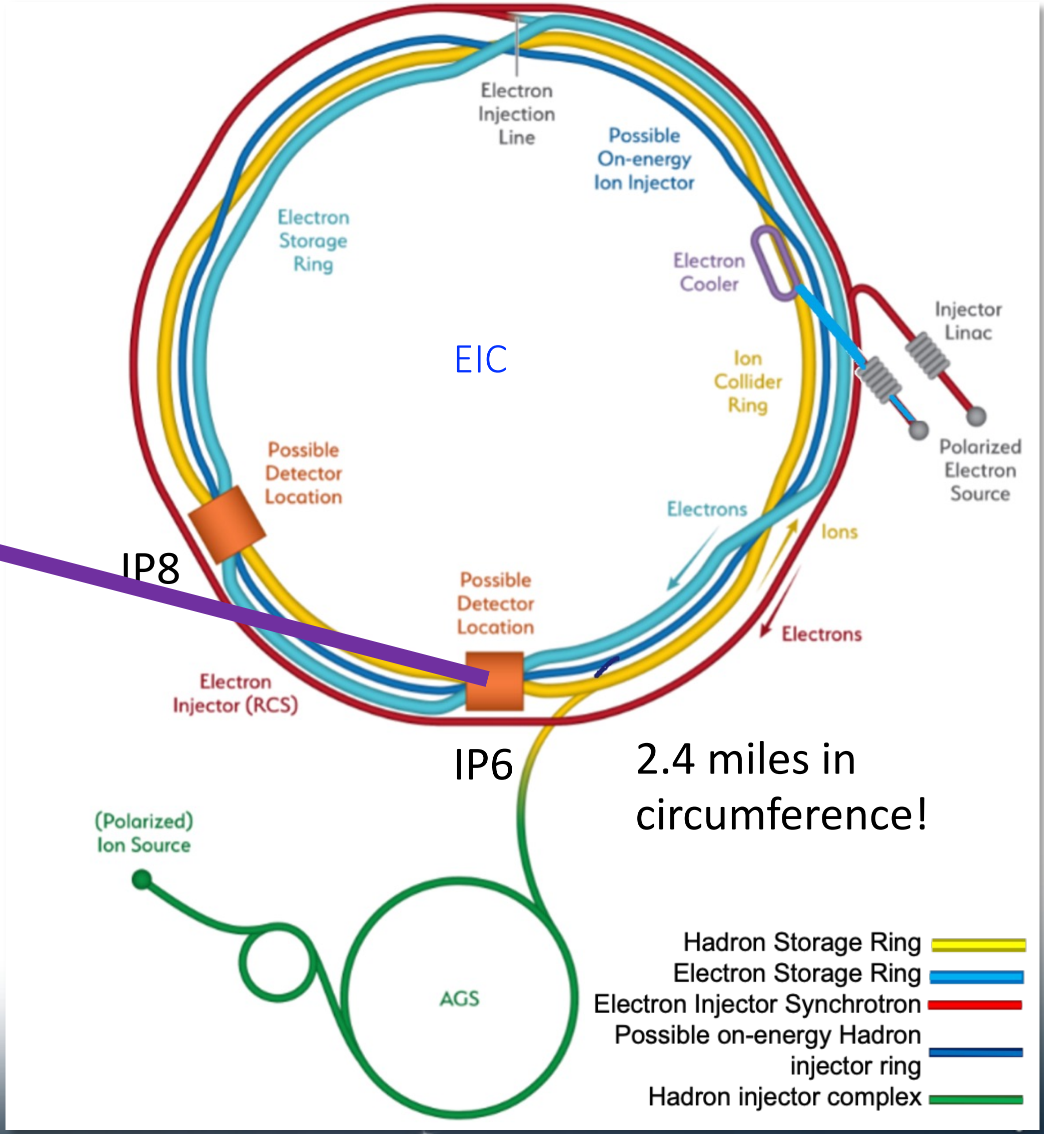
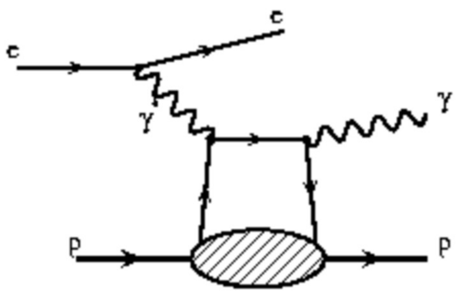
pseudorapidity


Hadrons
Electrons
Detector
Q3CpR
Q3pR
B2APR
Q2pR
Q1BpR
Q1ApR
Q0EF_5
Q1EF_5
D1EF_5
Q2EF_5
Q3EF_5
Exit window
Collimator
Magnet
Lum. detectors
B2eR
Q2eR
Q1eR
B0pF
B0ApF
Q1ApF
Q1BpF
Q2pF
B1pF
B1ApF
ZDC
Q3ER
Tagger 2
Tagger 1
Forward spectrometer
(in B0)
Off-momentum detectors 1
Roman Pots
Off-momentum detectors 2
B2ApF
Q3ApF
Q3BpF
x (m)
z (m)
2.0
1.5
1.0
0.5
0.0
−0.5
−40
−20
0
20
40

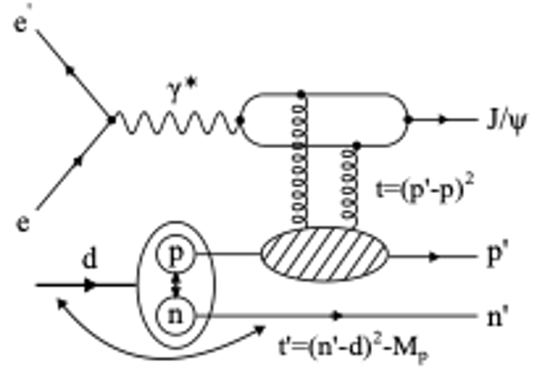

Electron
Injection
Line
Possible
On-energy
Ion Injector
Electron
Storage
Ring
Electron
Cooler
Injector
Linac
EIC
Ion
Collider
Ring
Polarized
Electron
Source
Possible
Detector
Location
Electrons
Ions
IP8
Possible
Detector
Location
Electrons
Electron
Injector (RCS)
IP6
2.4 miles in
circumference!
(Polarized)
Ion Source
AGS
Hadron Storage Ring
Electron Storage Ring
Electron Injector Synchrotron
Possible on-energy Hadron
injector ring
Hadron injector complex

(some) Far-Forward Processes at the EIC

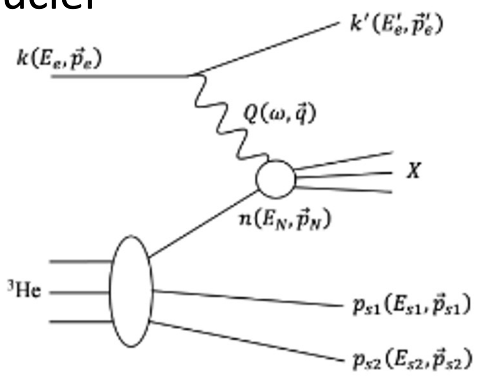
e+p DVCS



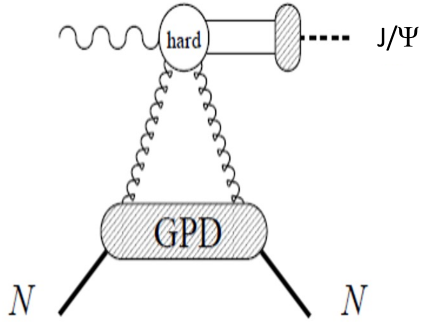
e+d exclusive J/Psi with p/n tagging



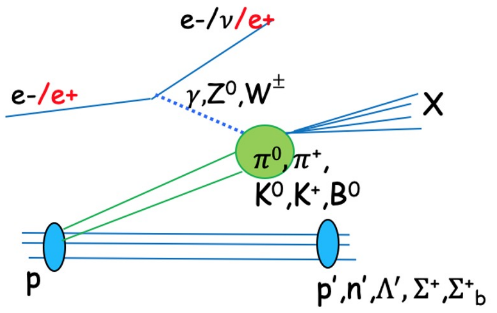
spectator tagging in light nuclei



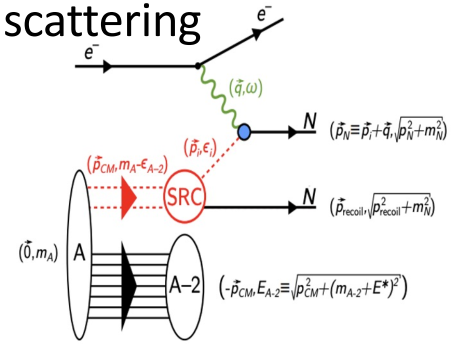
coherent/incoherent J/ψ production in e+A



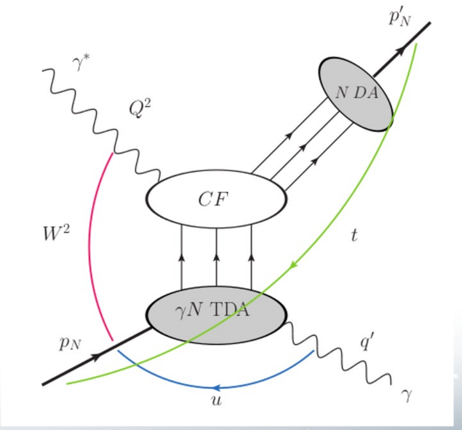
Sullivan process



Quasi-elastic electron scattering



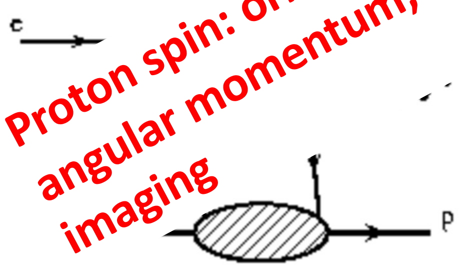
u-channel backward exclusive electroproduction



…and MANY more!

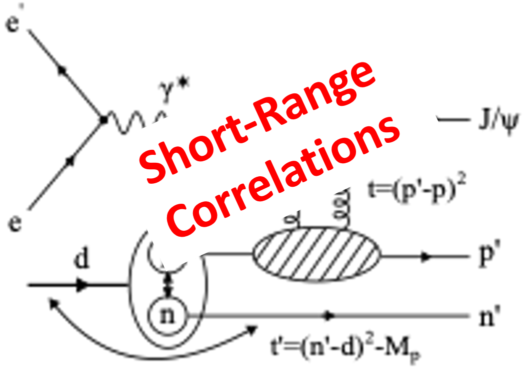
(some) Far-Forward **Physics** at the EIC

e+p DVCS



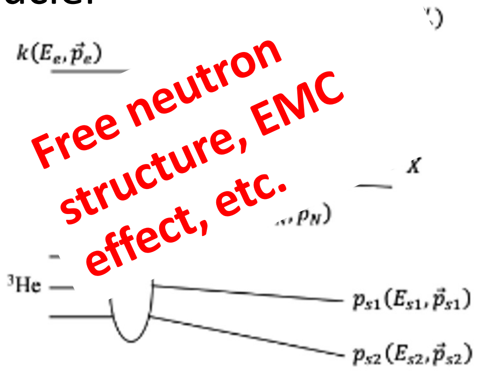
Proton spin: orbital angular momentum; imaging

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



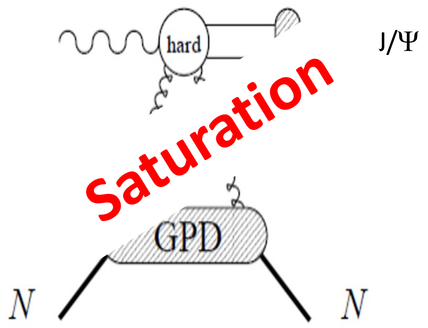
Short-Range Correlations

spectator tagging in light nuclei



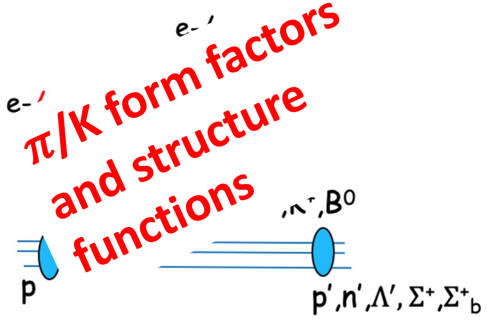
Free neutron structure, EMC effect, etc.

coherent/incoherent J/ψ production in e+A



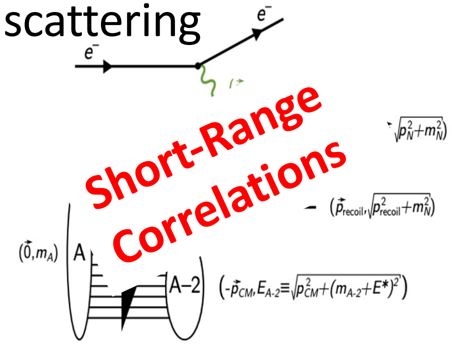
Saturation

Sullivan process



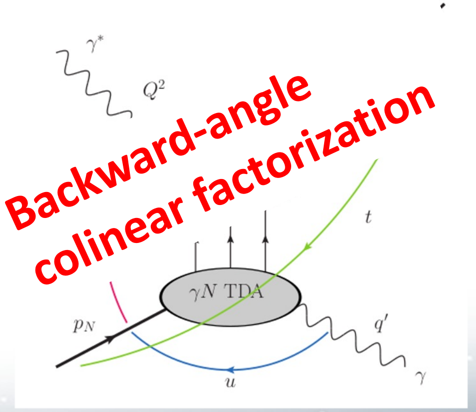
π/K form factors and structure functions

Quasi-elastic electron scattering



Short-Range Correlations

u-channel backward exclusive electroproduction



Backward-angle colinear factorization

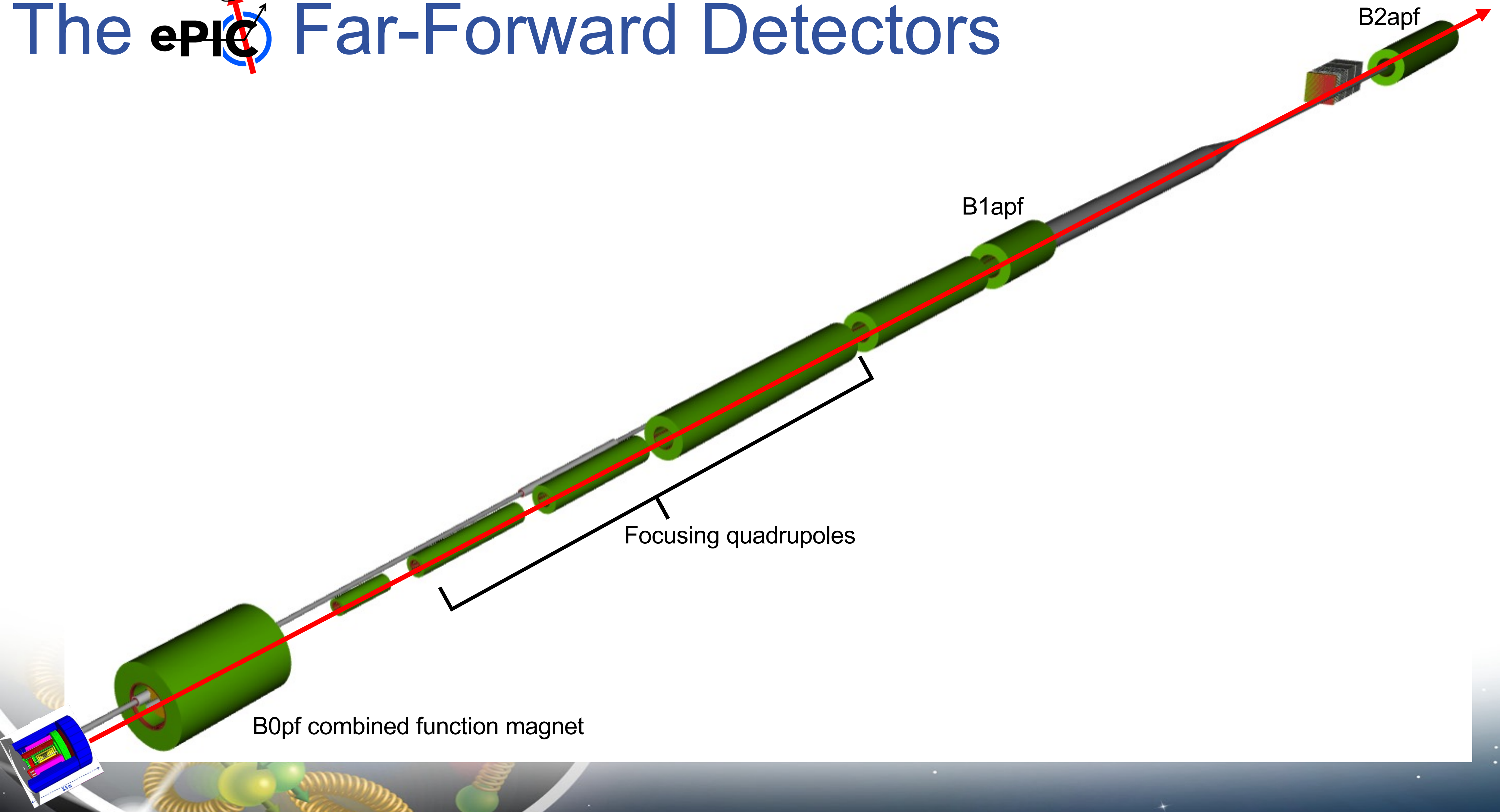
[1] Z. Tu, A. Jentsch, et al., Physics Letters B, (2020)
[2] I. Friscic, D. Nguyen, J. R. Pybus, A. Jentsch, *et al.*, Phys. Lett. B, **Volume 823**, 136726 (2021)
[3] W. Chang, E.C. Aschenauer, M. D. Baker, A. Jentsch, J.H. Lee, Z. Tu, Z. Yin, and L.Zheng, Phys. Rev. D **104**, 114030 (2021)
[4] A. Jentsch, Z. Tu, and C. Weiss, Phys. Rev. C **104**, 065205, (2021) **(Editor's Suggestion)**

…and MANY more!

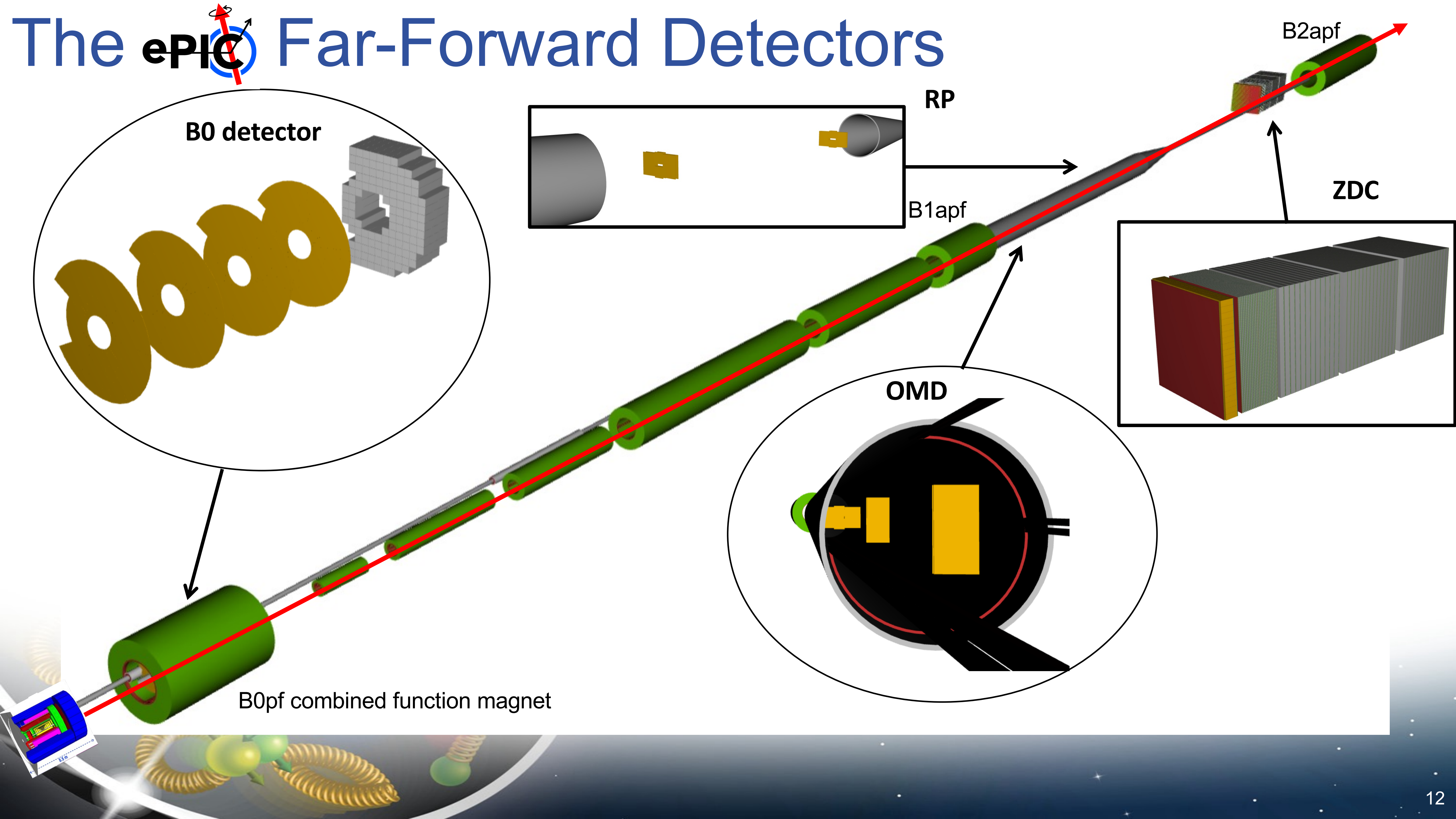
(some) Far-Forward **Physics** at the EIC

- Physics channels require tagging of **charged hadrons** (protons, pions) or **neutral particles** (neutrons, photons) at **very-forward rapidities ($\eta > 4.5$).**
- Different final states $\longrightarrow$ tailored detector subsystems.
- Various beams and energies (h: 41, 100-275 GeV, e: 5-18 GeV; e+p, e+d, e+Au, etc.).
- Placing and operation of far-forward detectors uniquely challenging due to integration with accelerator.

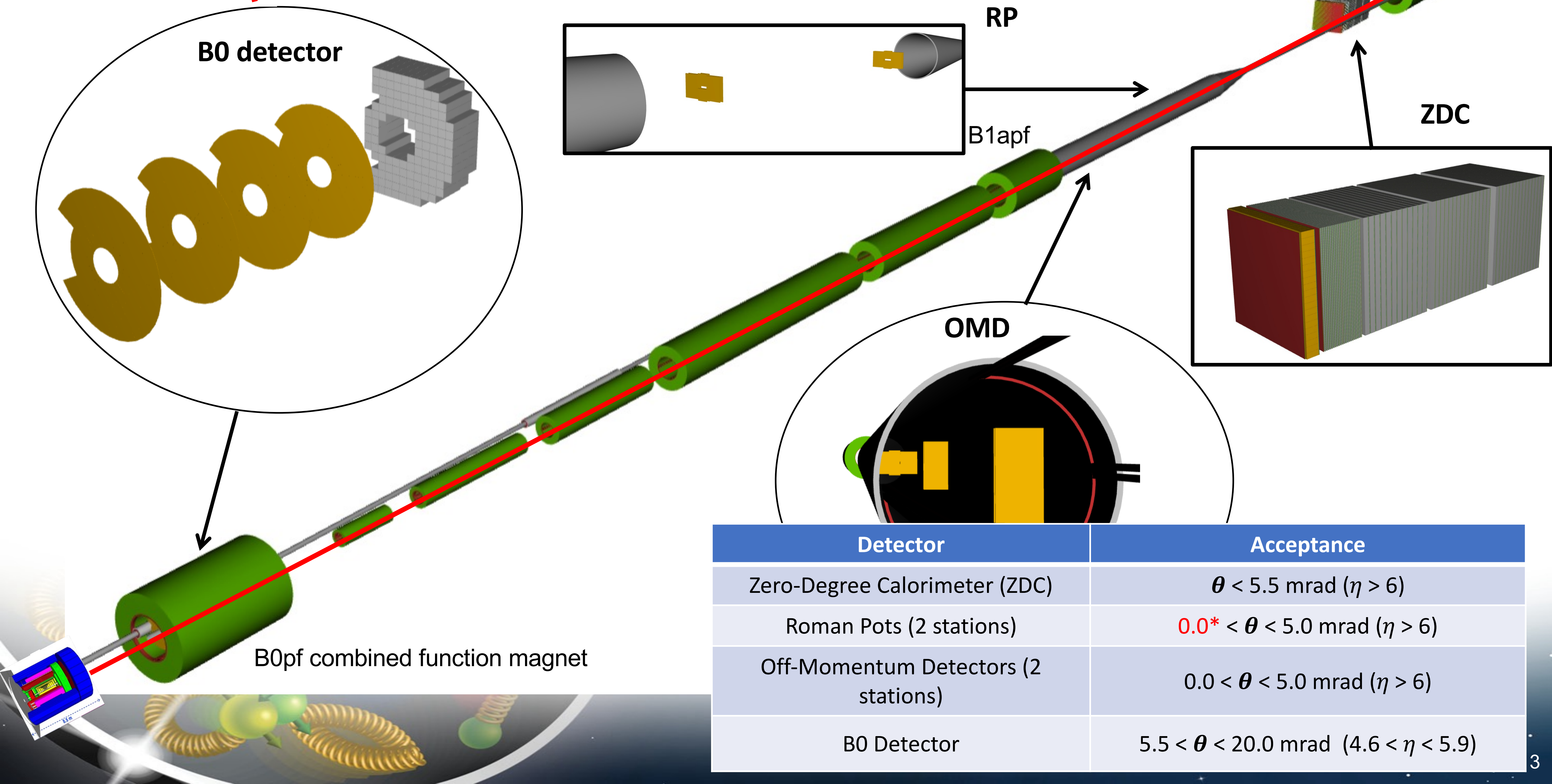
The ePIC Far-Forward Detectors



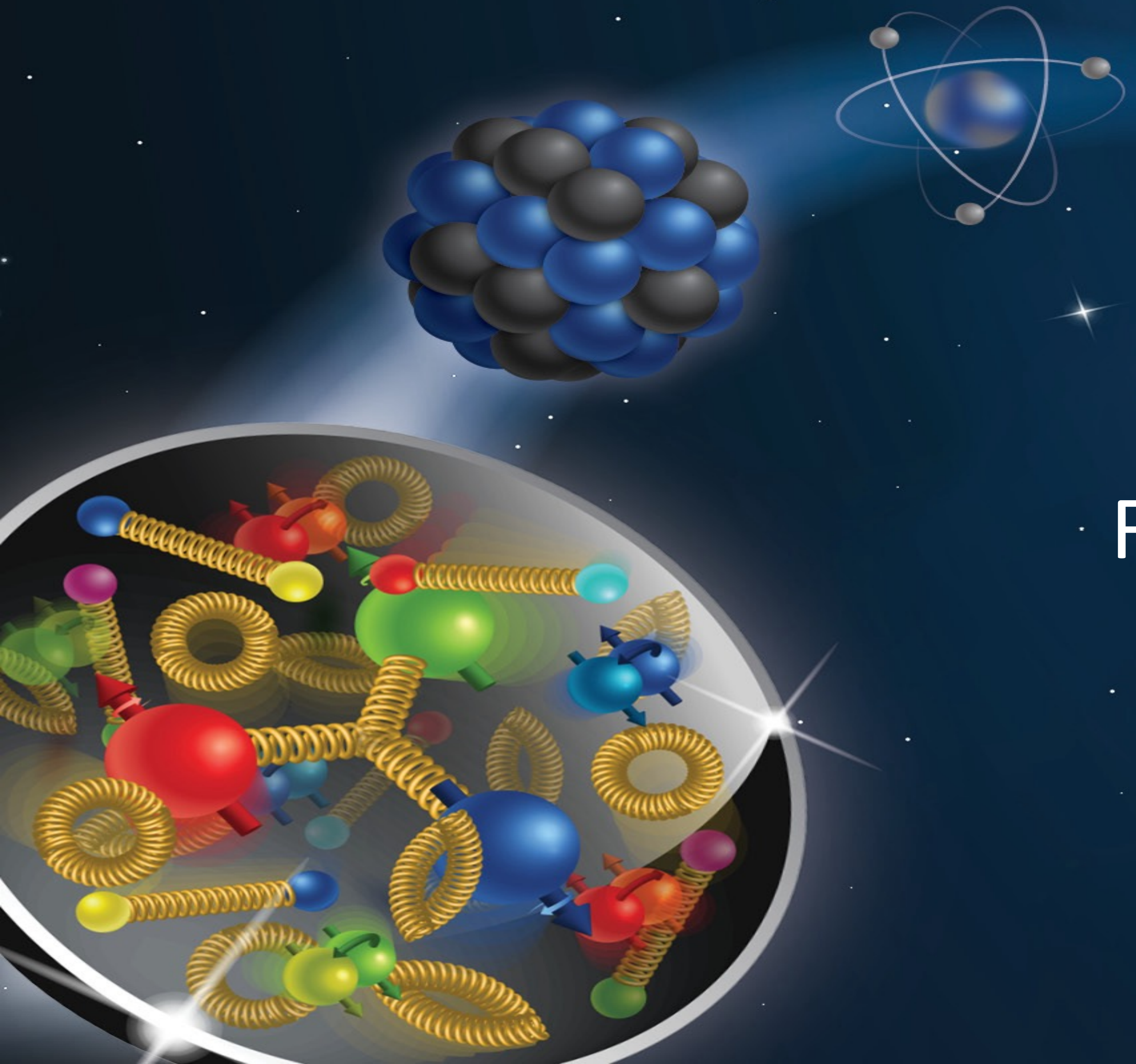
The ePIC Far-Forward Detectors



The ePIC Far-Forward Detectors



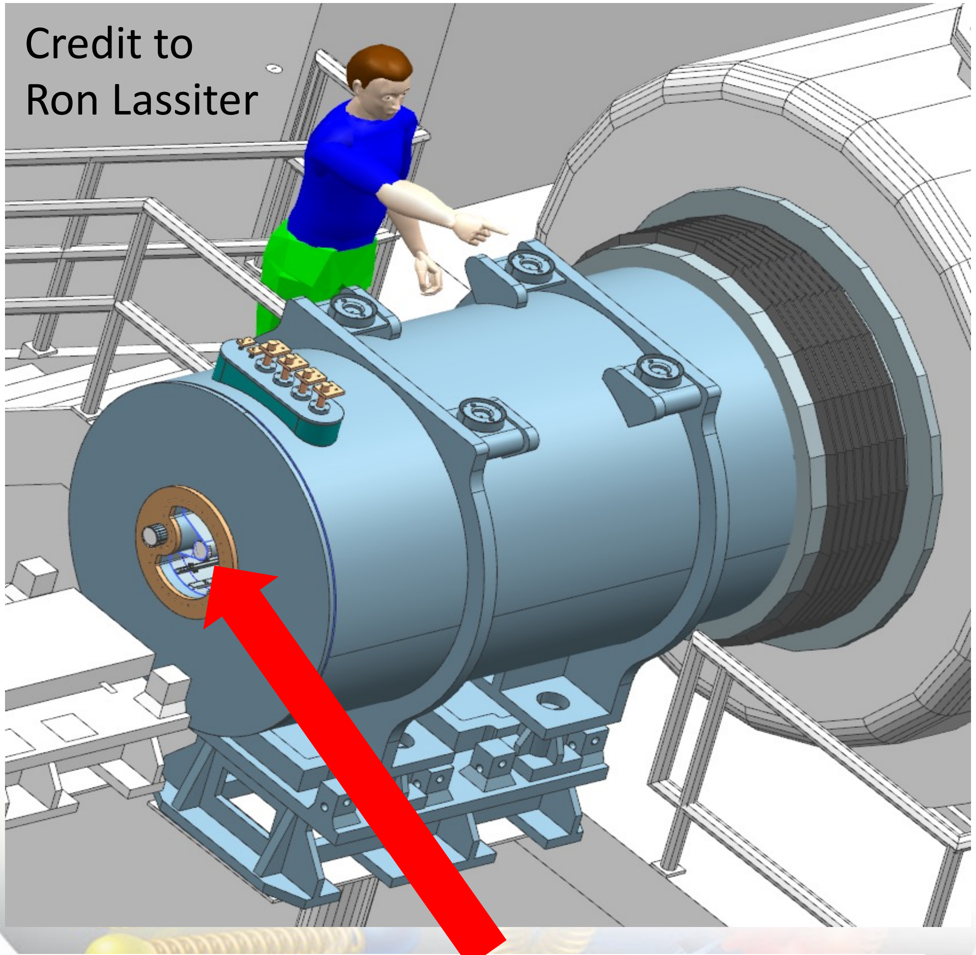
Detector	Acceptance
Zero-Degree Calorimeter (ZDC)	θ < 5.5 mrad (η > 6)
Roman Pots (2 stations)	0.0* < θ < 5.0 mrad (η > 6)
Off-Momentum Detectors (2 stations)	0.0 < θ < 5.0 mrad (η > 6)
B0 Detector	5.5 < θ < 20.0 mrad (4.6 < η < 5.9)



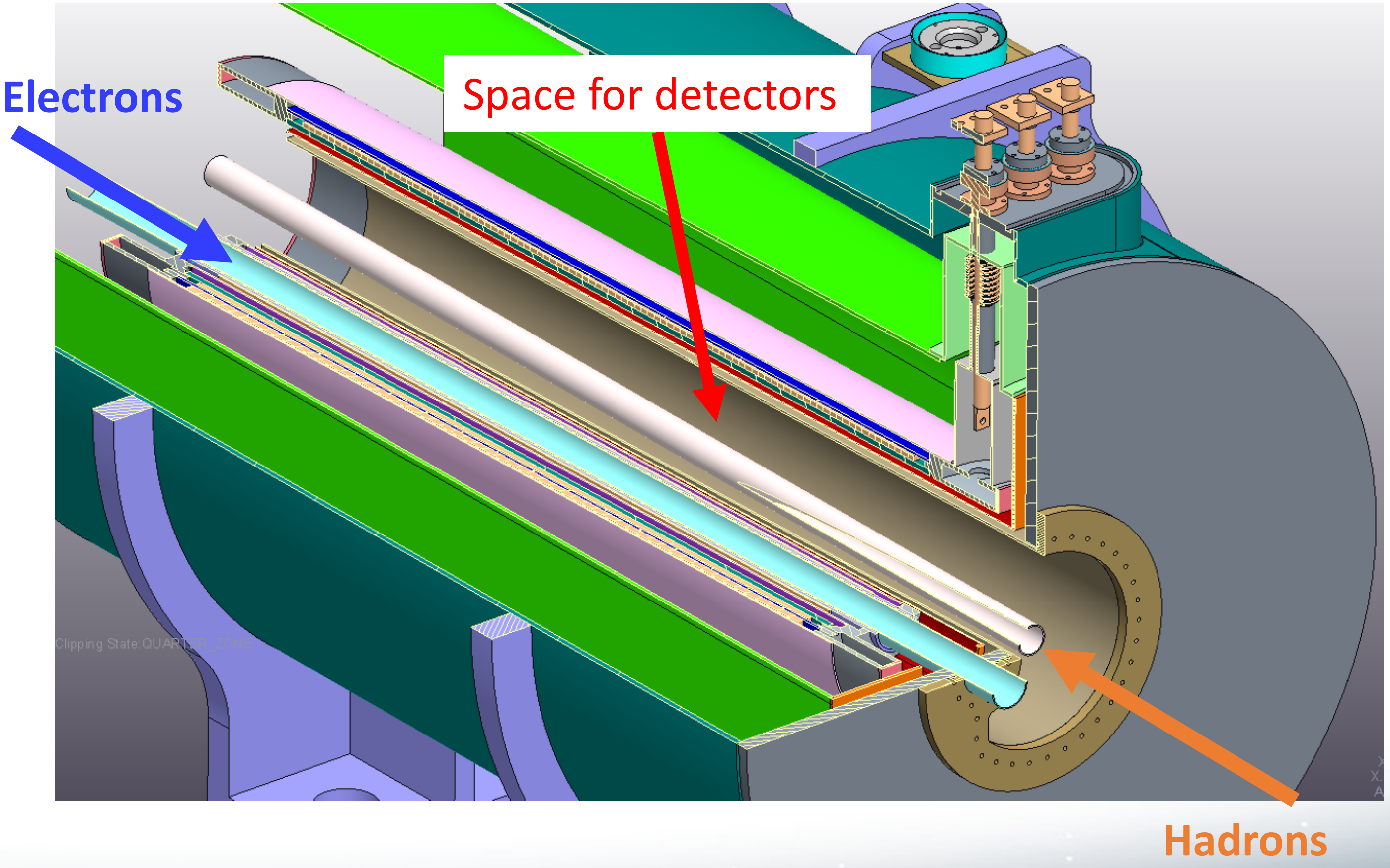
Far-Forward Detector Subsystems

B0 Detectors

- Detector subsystem embedded in an accelerator magnet.



This is the opening where the detector planes will be inserted



B0 Detectors

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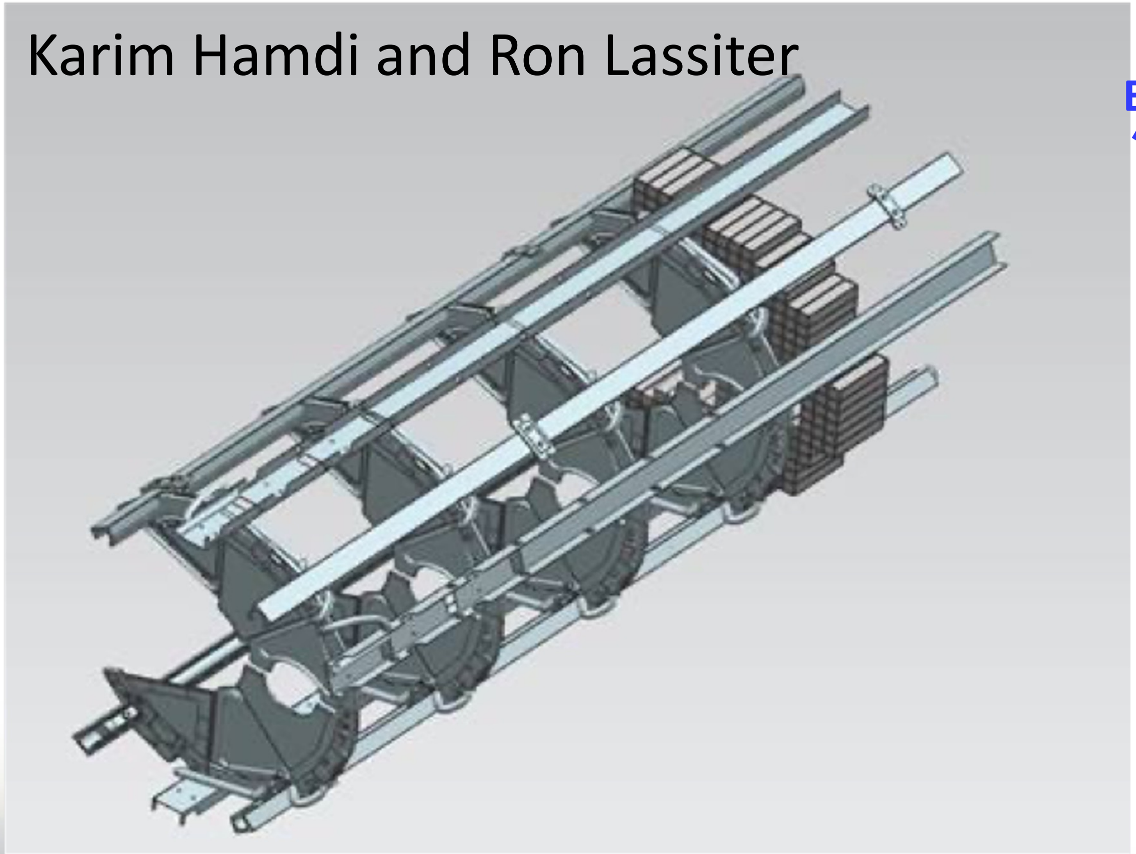
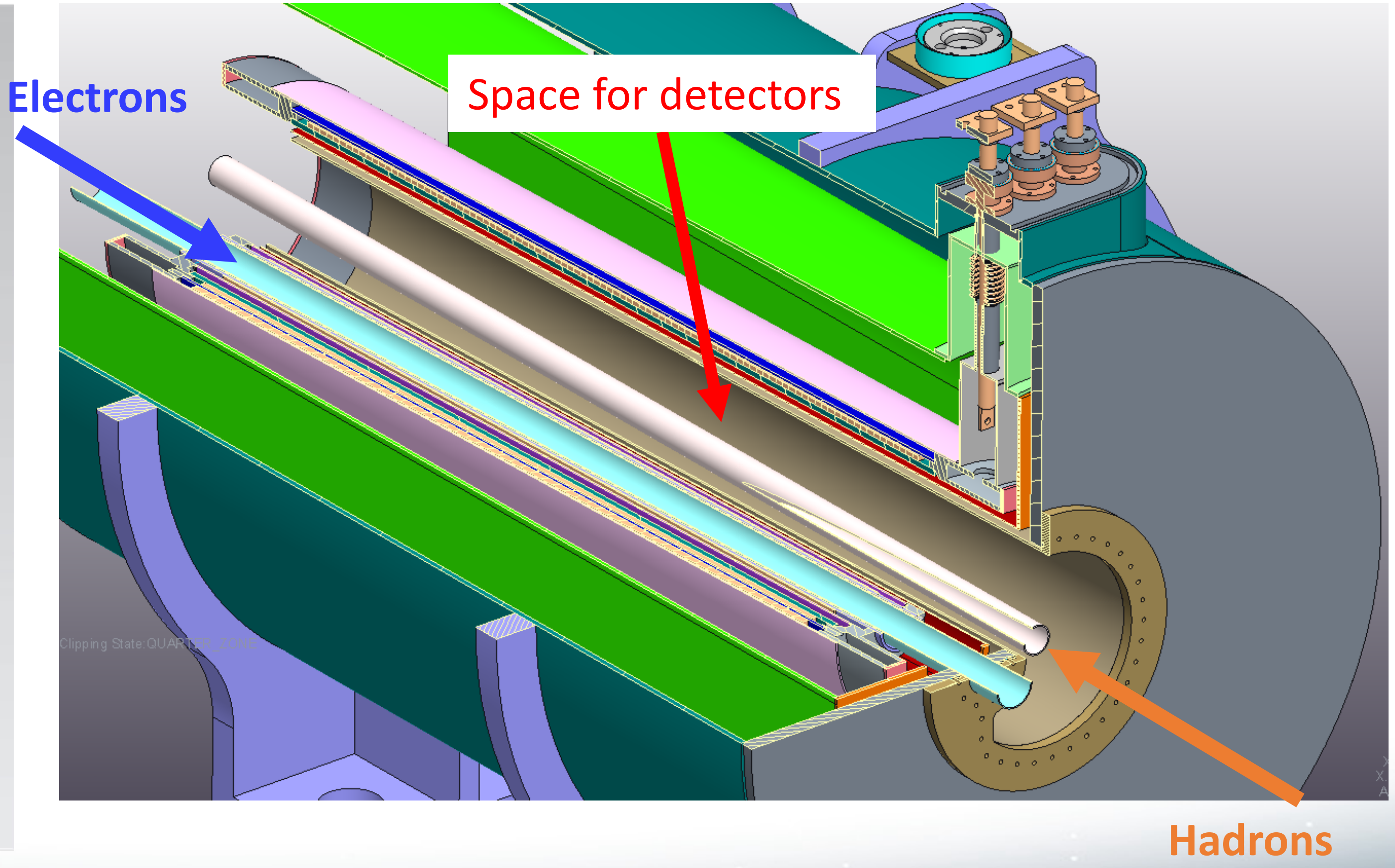
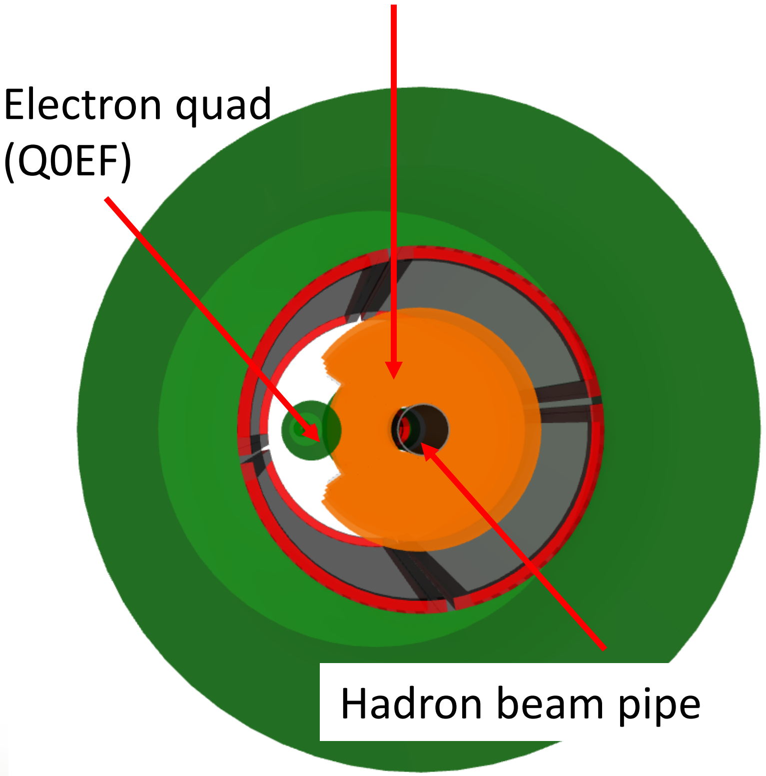
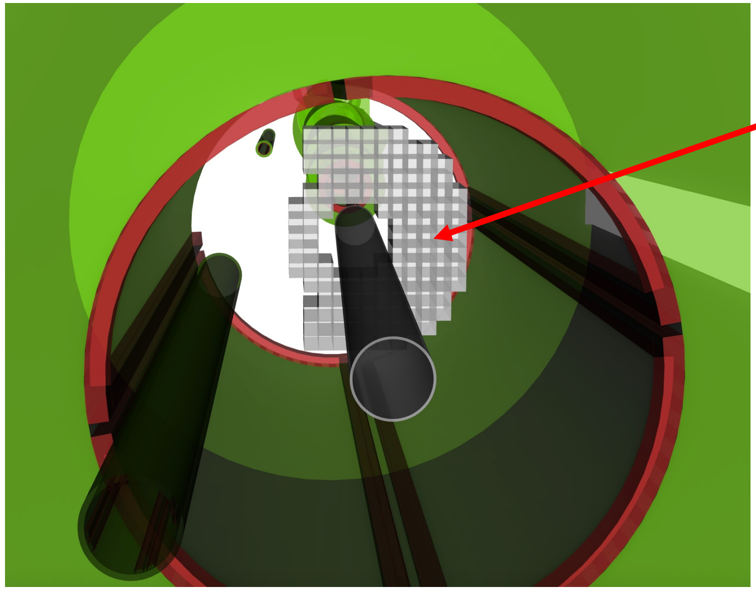




B0 Tracking and EMCAL Detectors



ePIC DD4HEP Simulation



$PbWO_4$/LYSO EMCAL (behind tracker)

- <u>**Technology choices:**</u>
  - **Tracking: 4 layers AC-LGADs**
  - **PbWO4 or LYSO EMCAL.**

- <u>**Status**</u>
  - ✓ **Used to reconstruct charged particles and photons.**
    - ✓ **Acceptance: 5.5 < θ < 20.0 mrad on one side, up to 13mrad on the other.**
    - ✓ **Focus now is on readout, new tracking software, and engineering support structure.**
  - ✓ **Stand-alone simulations have demonstrated tracking resolution.**
    - https://indico.bnl.gov/event/17905/
    - https://indico.bnl.gov/event/17622/

B Detectors

CAD Look credit: Jonathan Smith

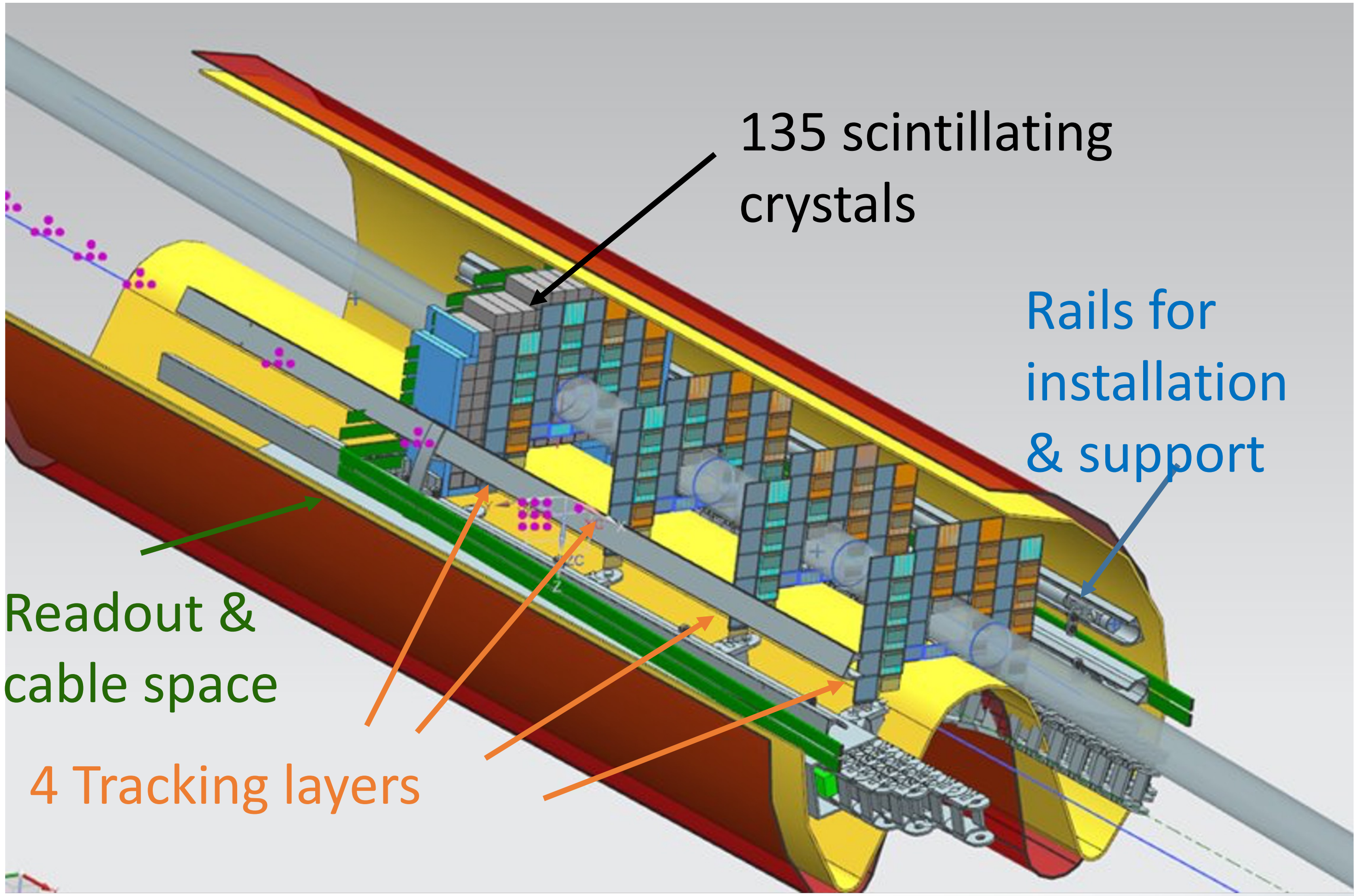
Design for two detectors is converging:

Si Tracker:

- 4 Layers of AC-LGAD → provide ~20um spatial resolution (with charge sharing) and 20-40ps timing resolution.
- Technology overlap w/ Roman pots

EM Calorimeter:

- 135 2x2x7*cm^3 LYSO crystals
- Good timing and position resolution
- Technology overlap with ZDC



* ZDC wants slightly longer crystals, ideally, we will use the same length in both detectors

BeAGLE Detectors - Simulation Studies

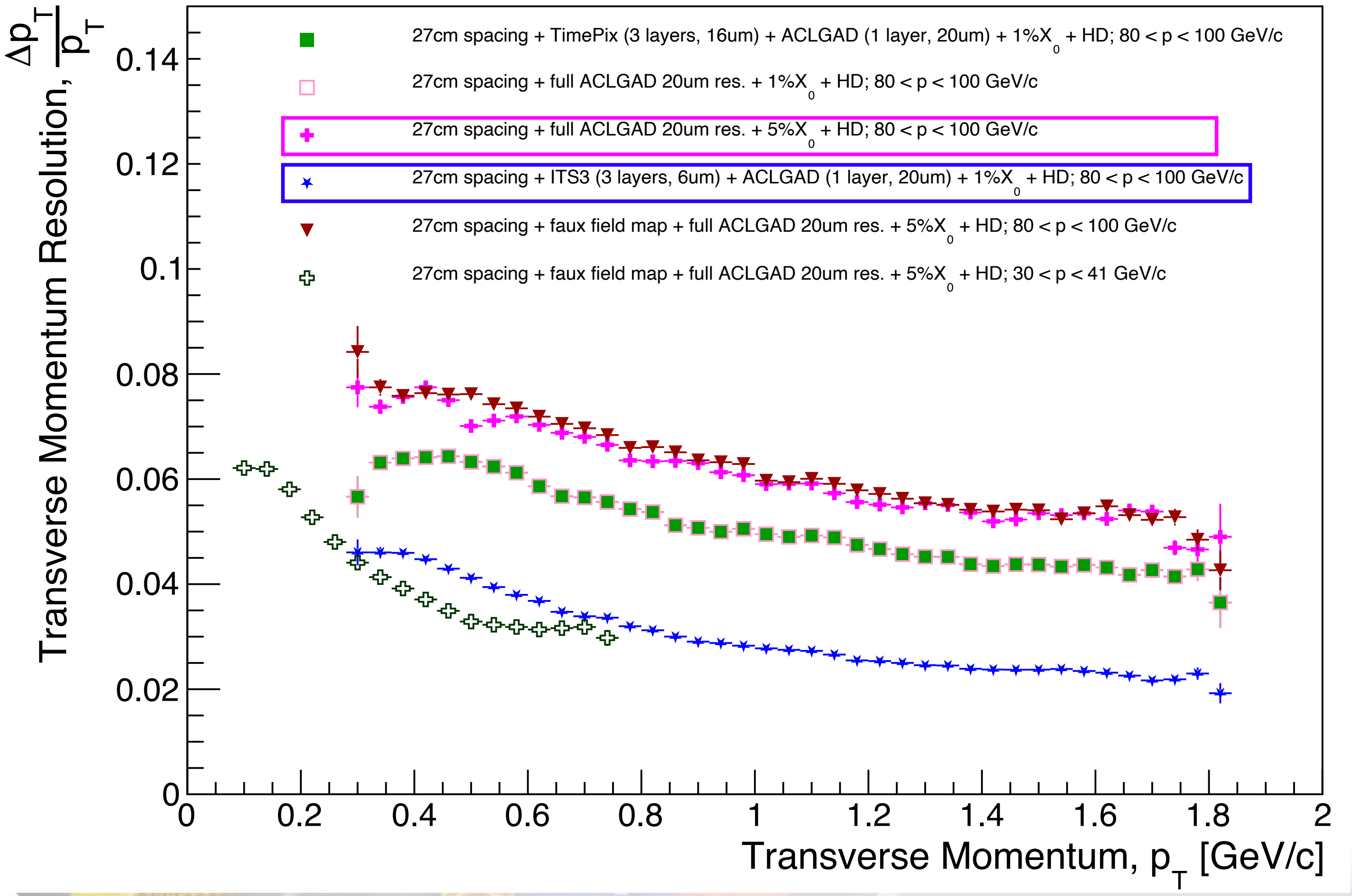
Si Tracker:

- Resolution plots made by Alex Jentsch with standalone setup (more here and here)
- ACTS Tracking (a long-standing problem) was recently solved and is implemented in the simulation (see recent Sakib R slides), we expect more results soon

EM Calorimeter:

- Caveat - studies performed with PbWO4 crystals, LYSO crystals still to be implemented in the simulation.
- General performance studies by Michael Pitt (more in FF weekly meeting)
- Sensitivity to soft photons (see Eden Mautner talk at the EICUG EC workshop early this week)

B0 Tracking - Performance



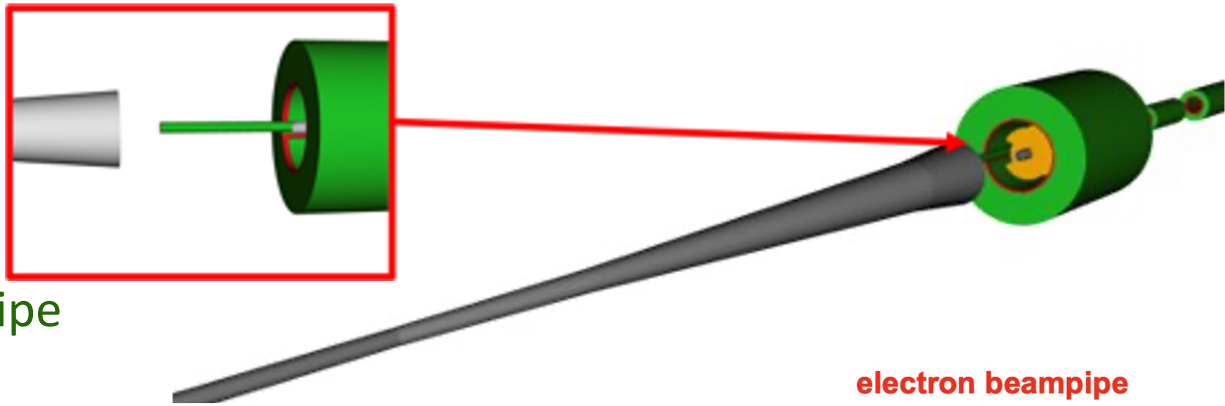
- 27cm spacing with fully AC-LGAD system and 5% radiation length may be the most-realistic option.
    - Reduced spacing (from 30cm) to make room for EMCAL.
- Needs to be looked at with proper field map and layout.
- Resolution impact on physics still being evaluated.

<u>Note:</u> momentum resolution (dp/p) is ~2-4%, depending on configuration.

B0 EMCal - Performance

- Acceptance 5.5 < θ < 23 mrad
- Very low material budget in 5 < η < 5.5

Particles within 5.5 < θ < 15 mrad don't cross the beampipe

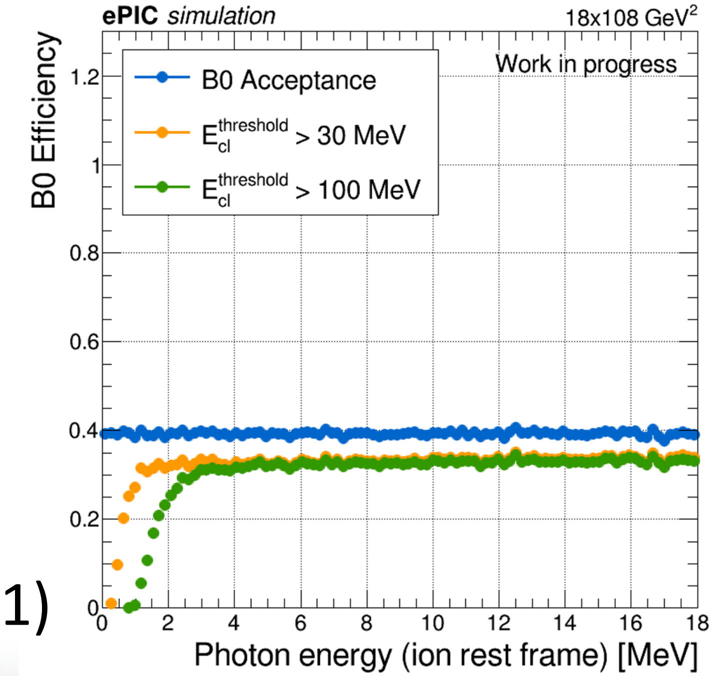


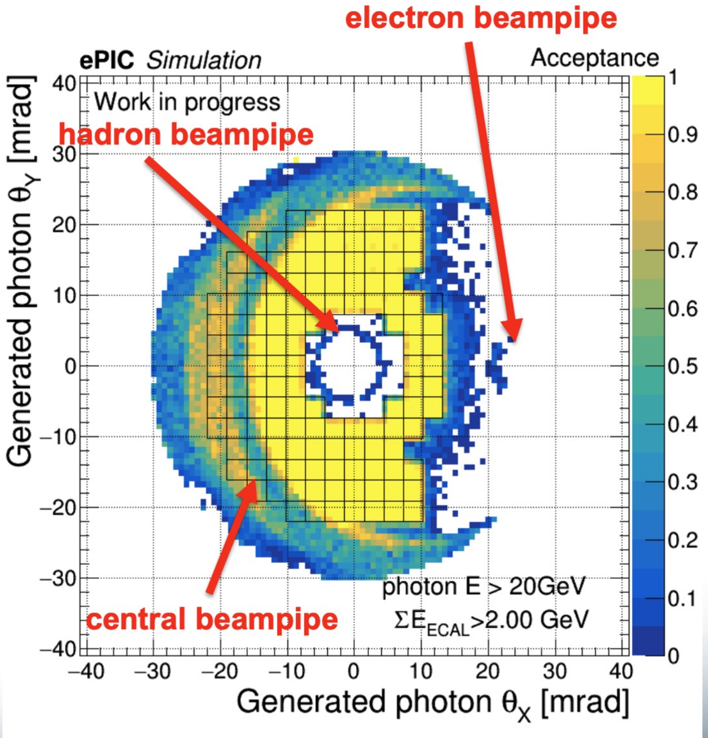
Photons:

- ➢ High acceptance in a broad energy range (> 100s MeV), including ~MeV de-excitation photons
- ➢ Energy resolution of 6-7%
- ➢ Position resolution of ~3 mm

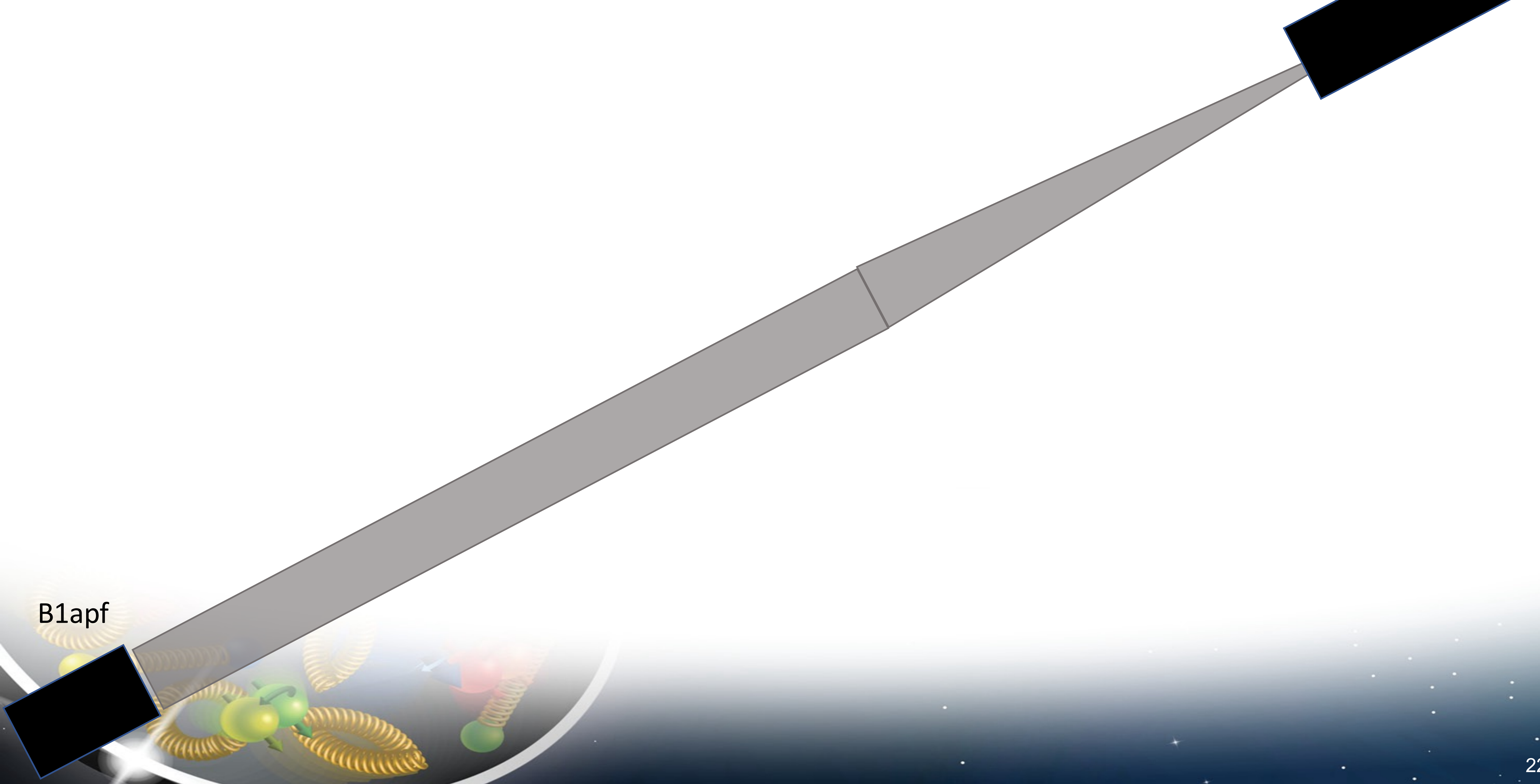
Neutrons:

- ➢ 50% detection efficiency (λ is almost 1)



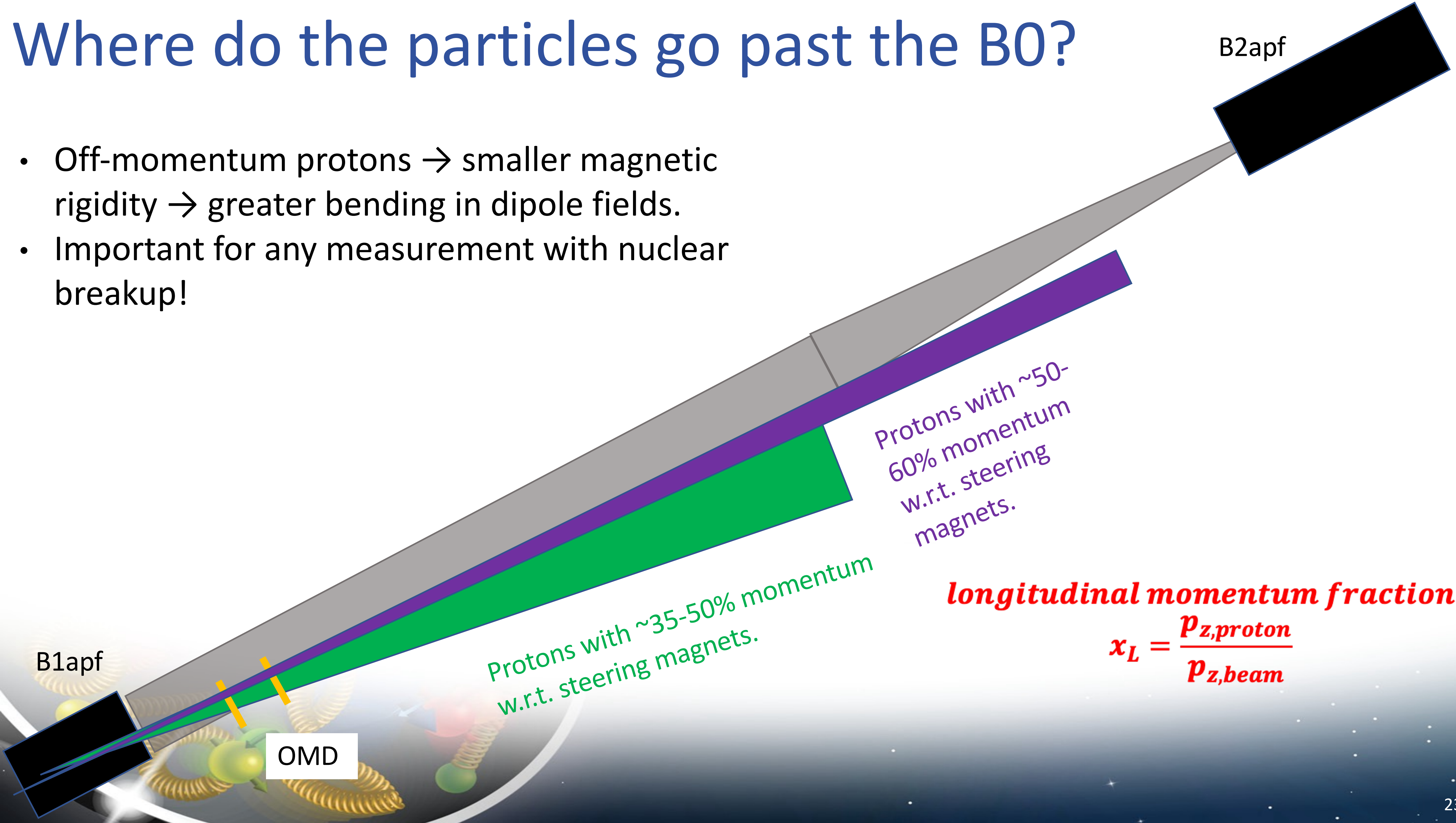


Where do the particles go past the B0?



Where do the particles go past the B0?

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



longitudinal momentum fraction

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

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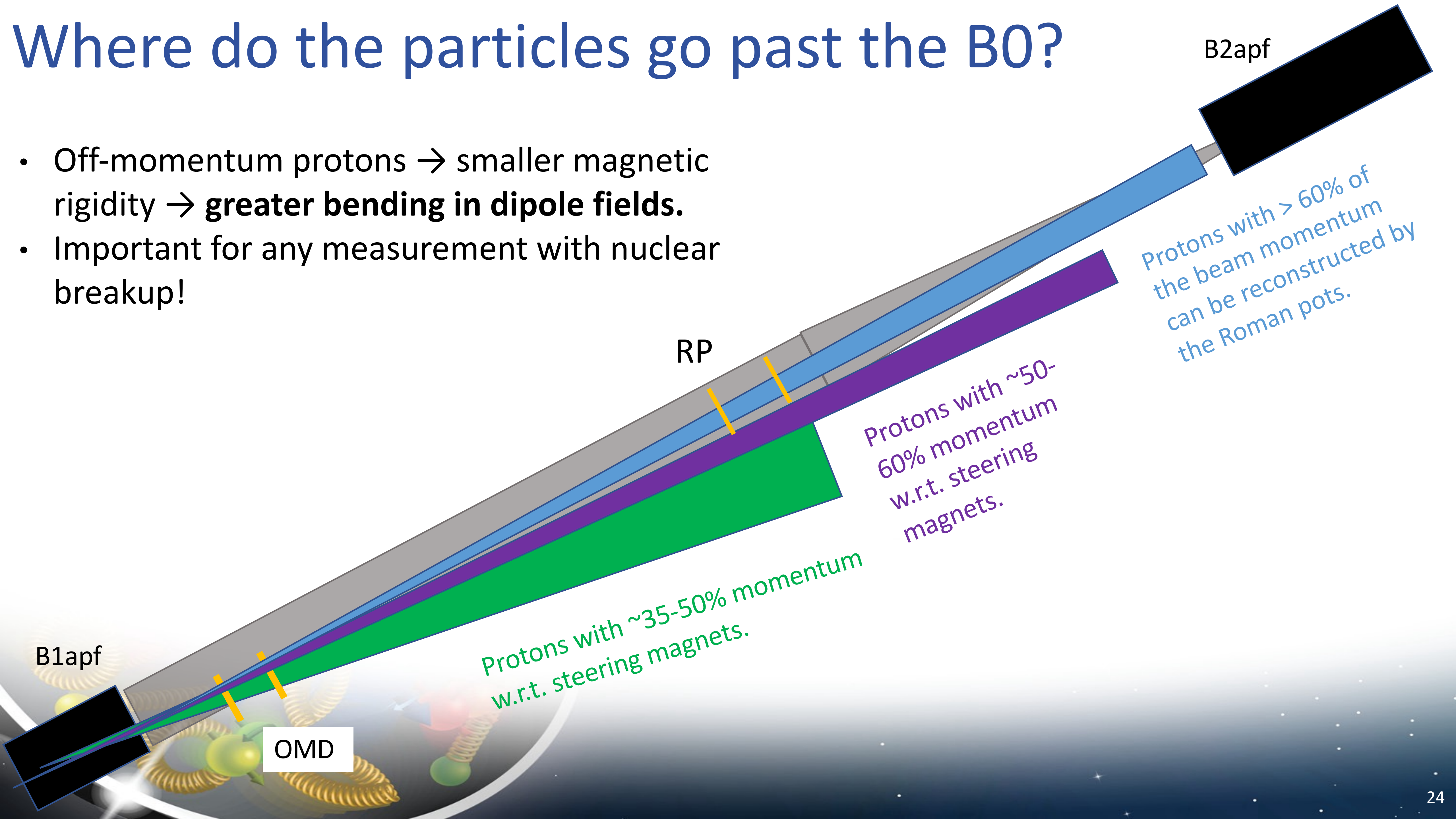

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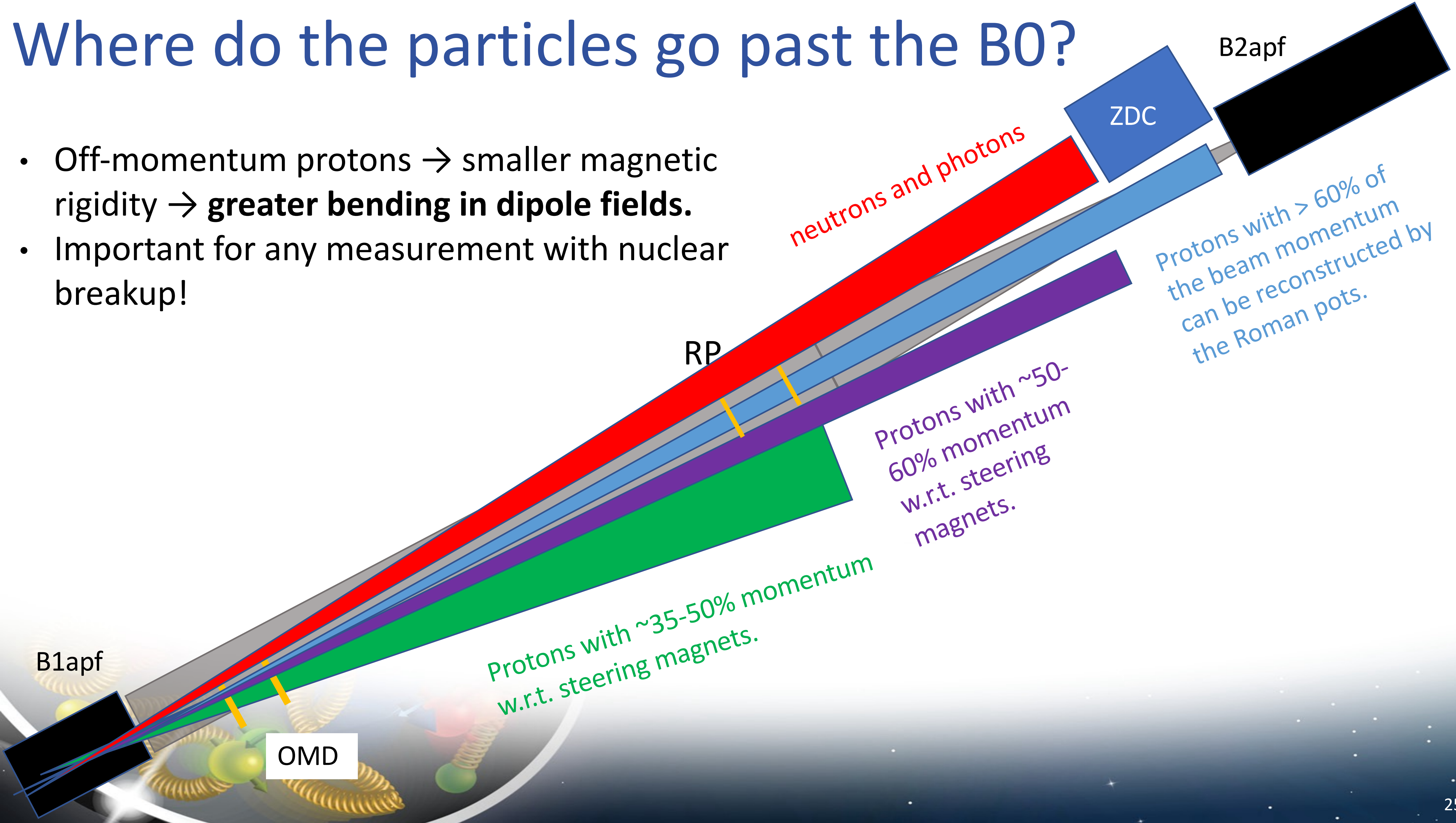
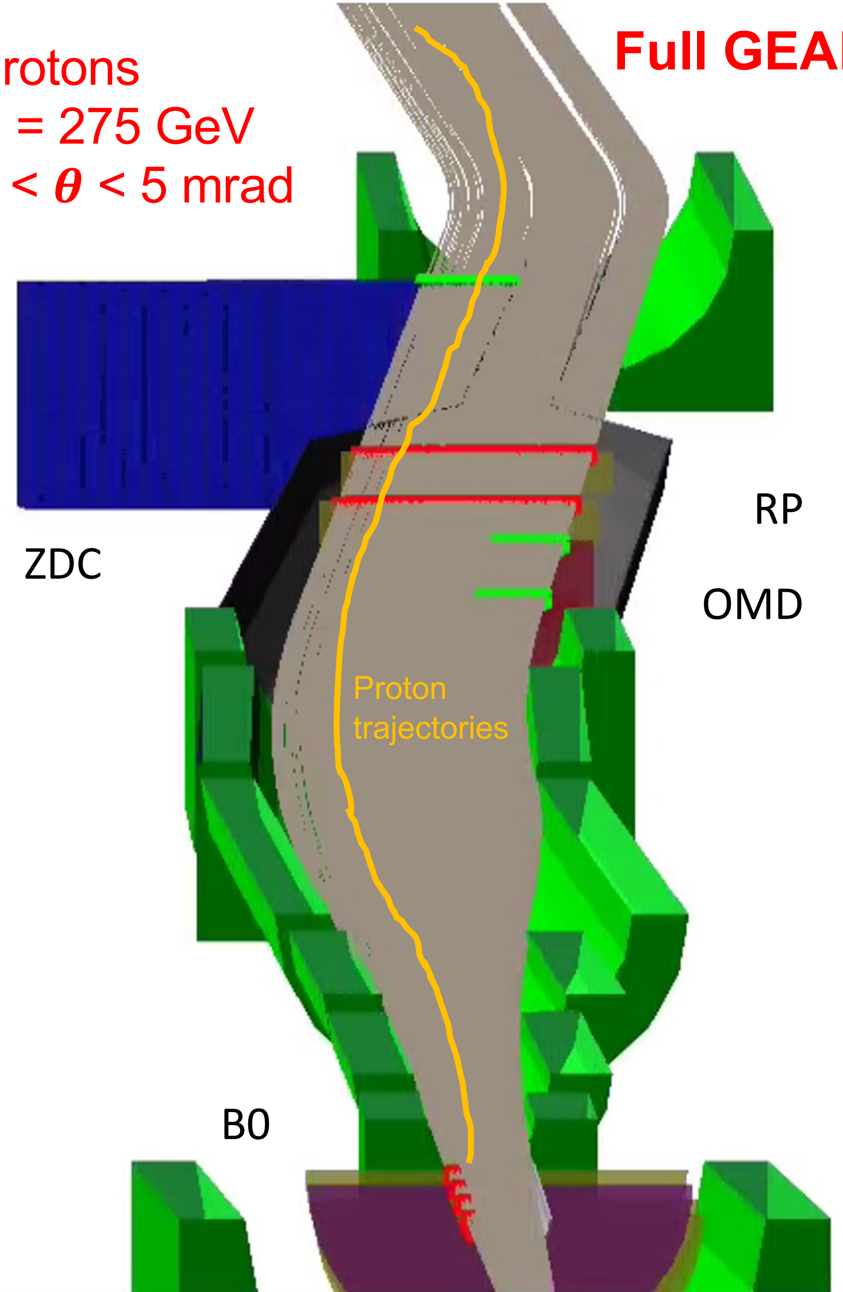


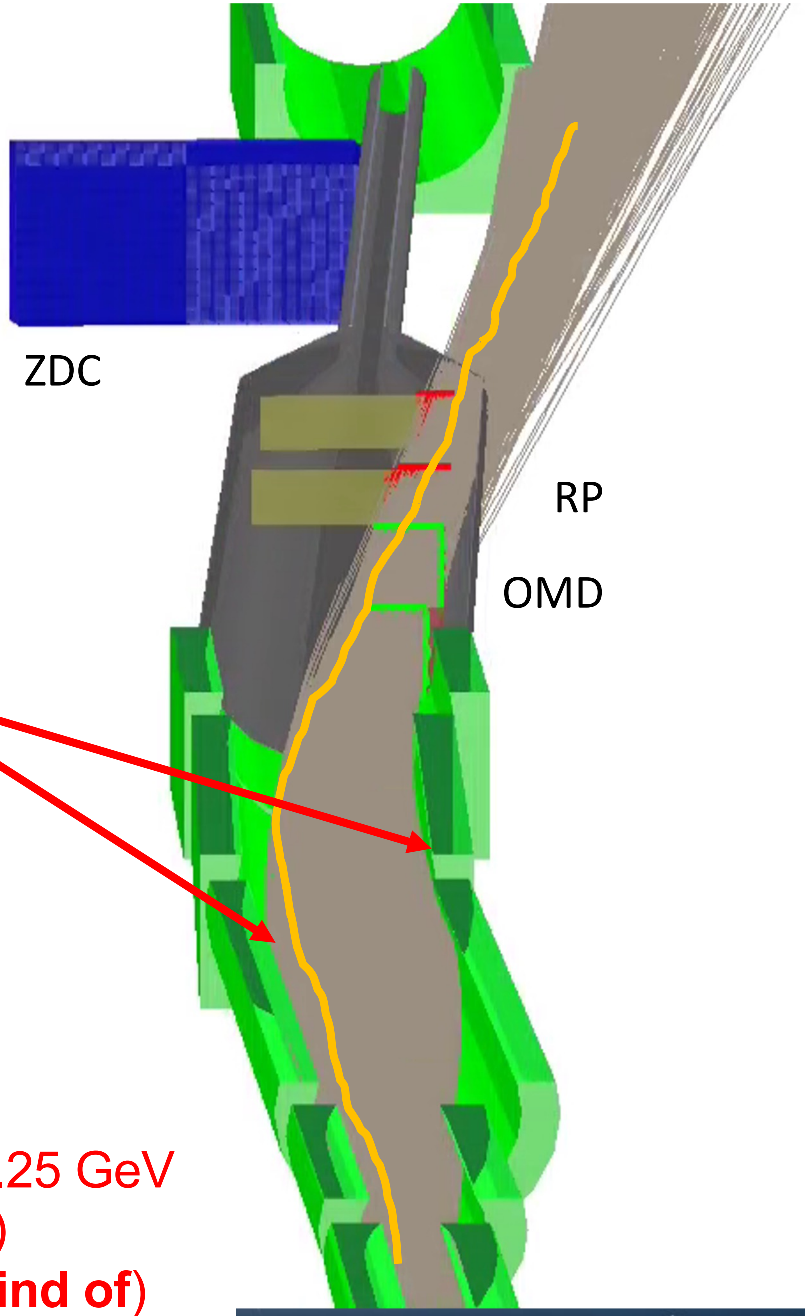
Roman Pots and OMD

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

Full GEANT4 simulation.

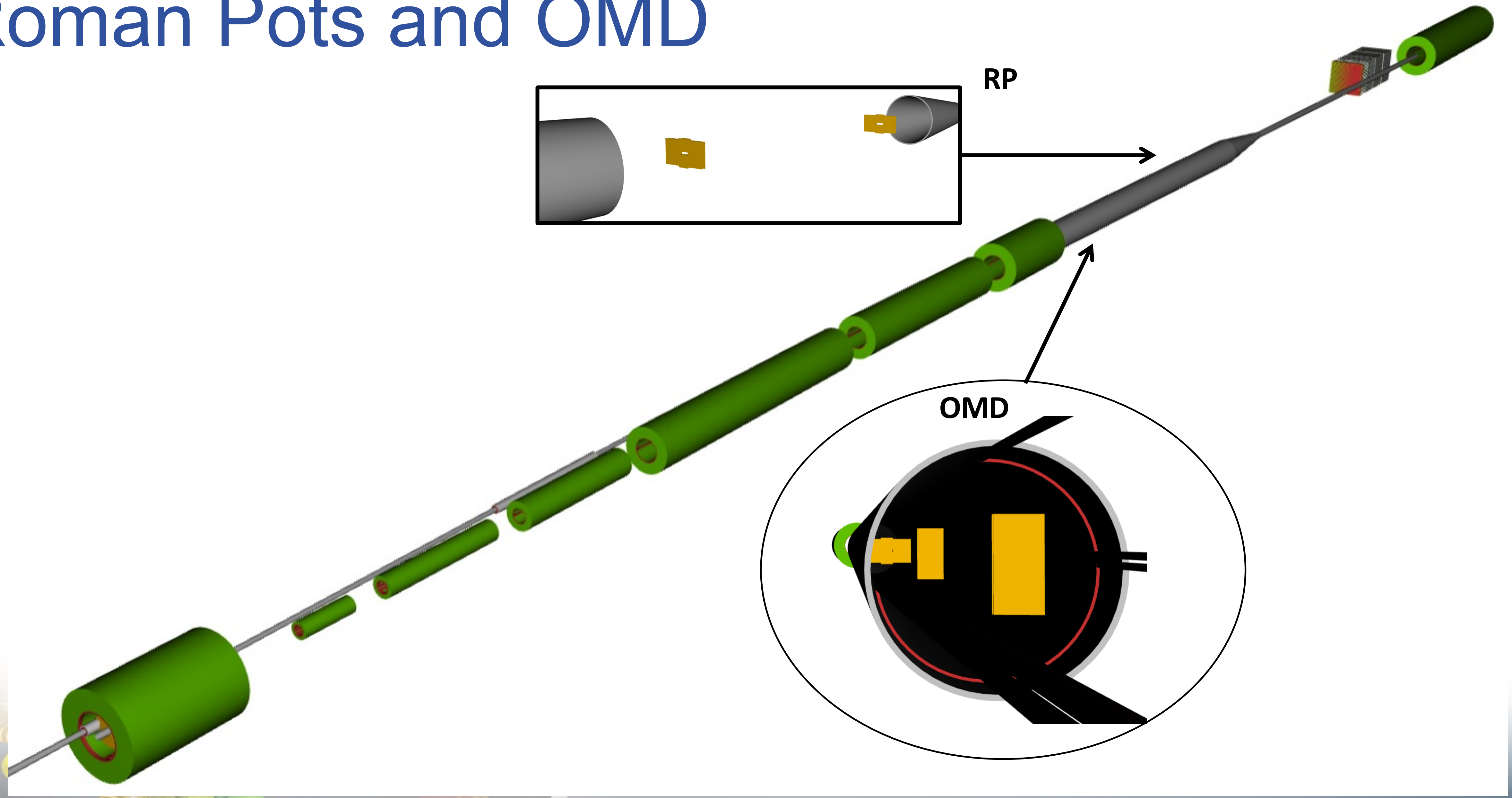


High-angle (θ > 2mrad) particles lost in aperture.

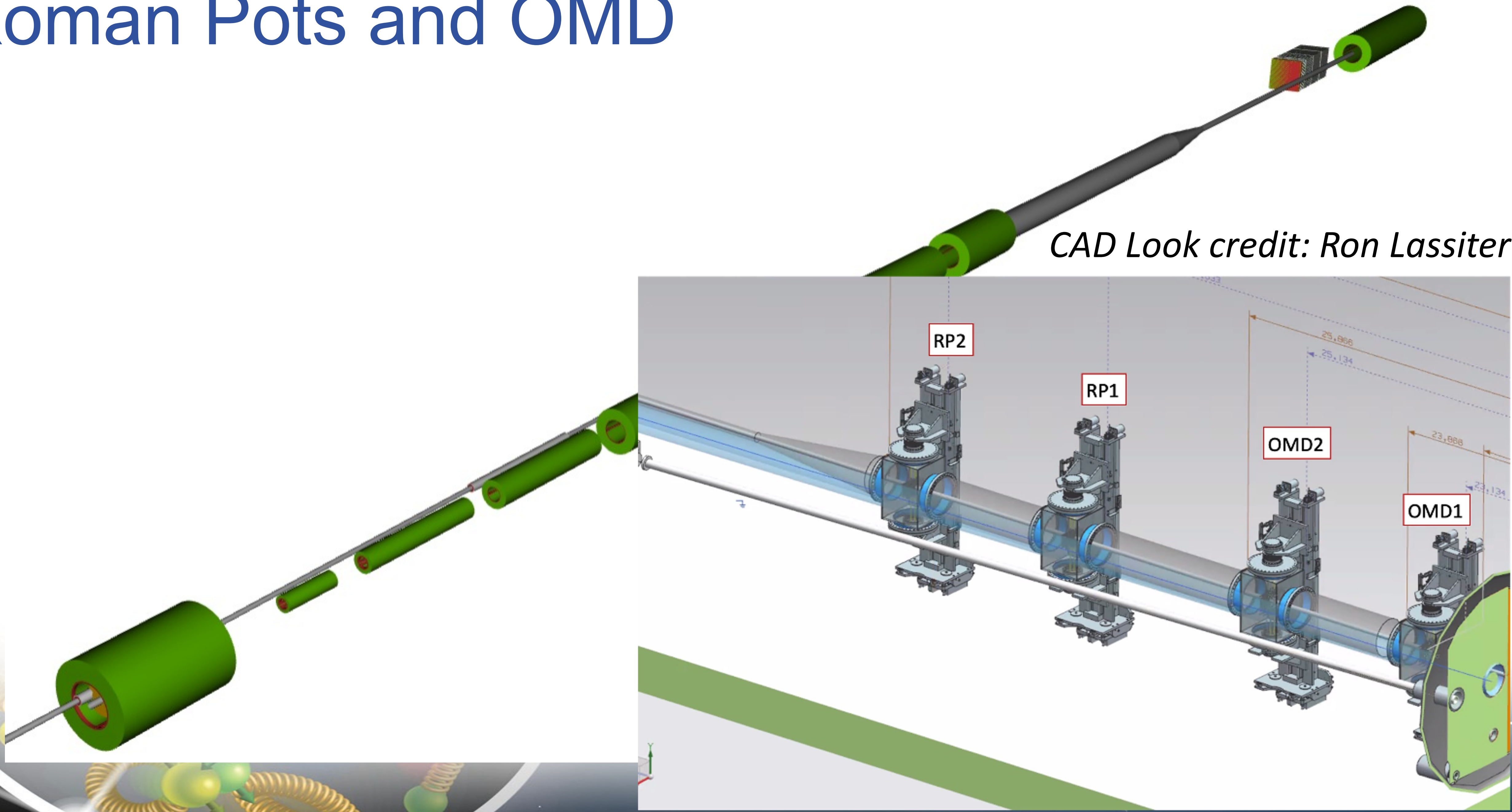


Protons
123.75 < E < 151.25 GeV
(45% < xL < 55%)
0 < $\boldsymbol{\theta}$ < 5 mrad (**kind of**)

Roman Pots and OMD

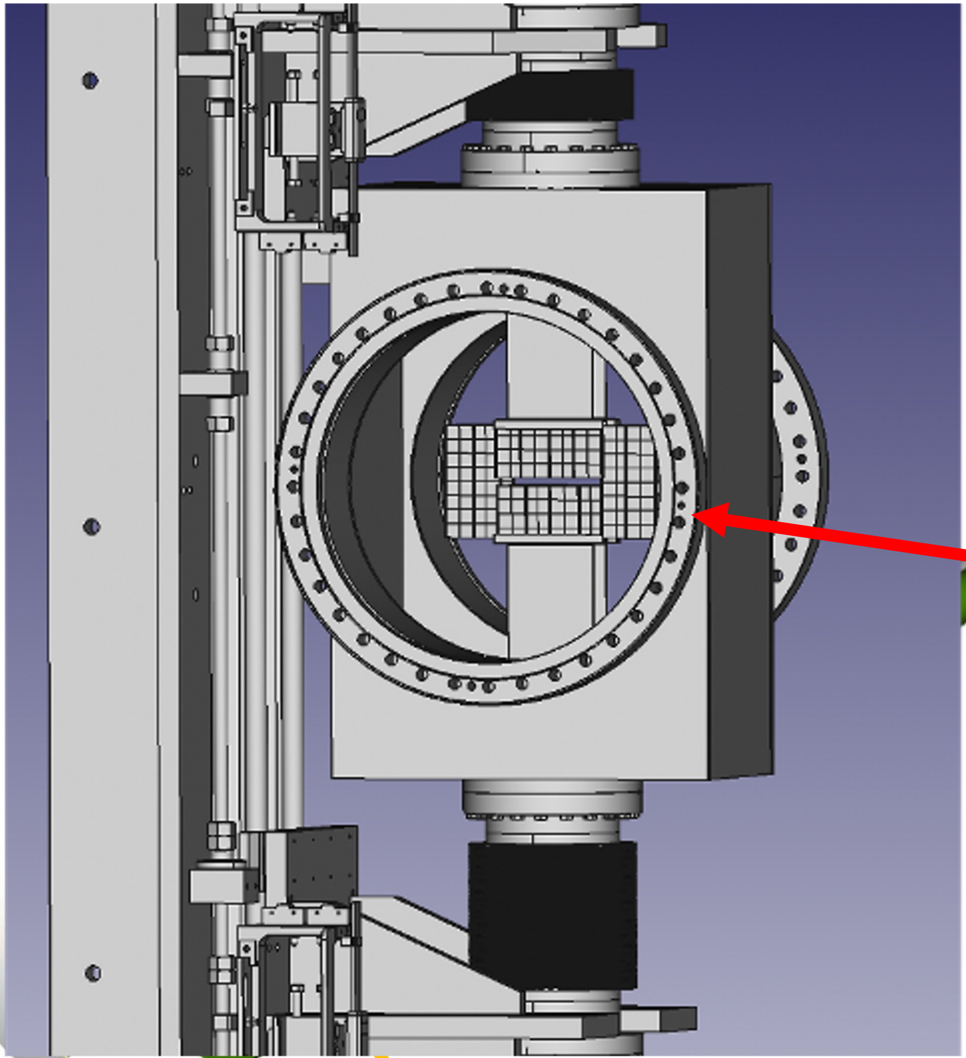


Roman Pots and OMD

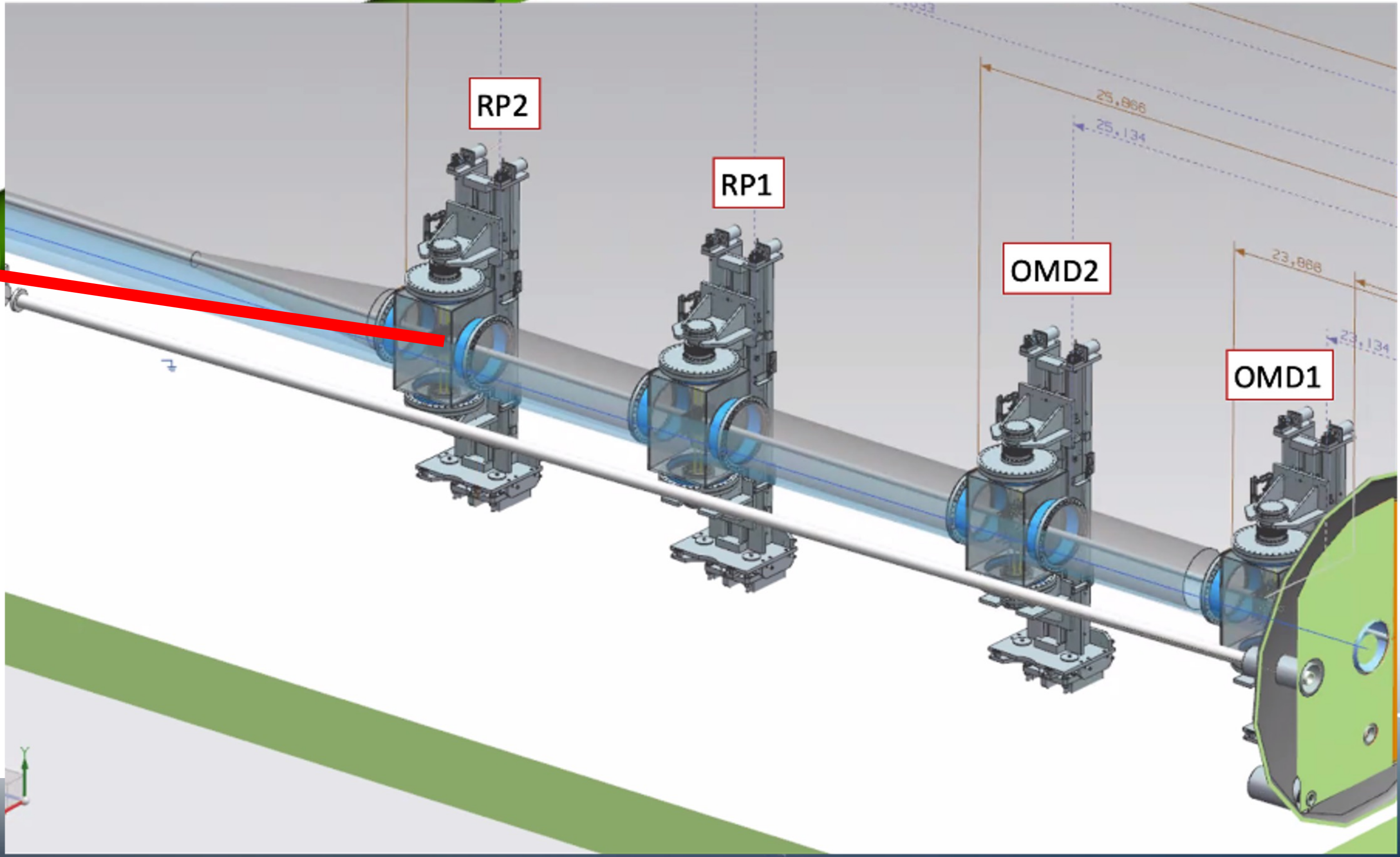


CAD Look credit: Ron Lassiter

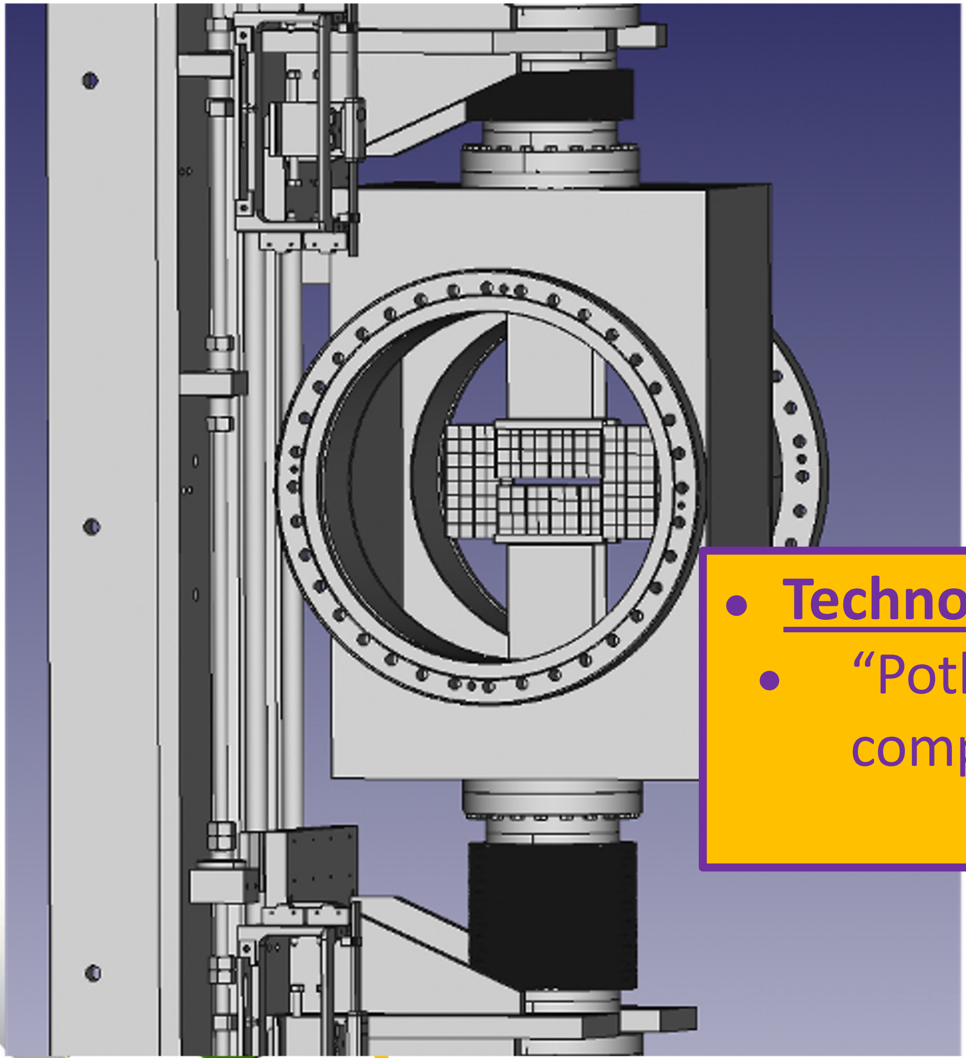
Roman Pots and OMD

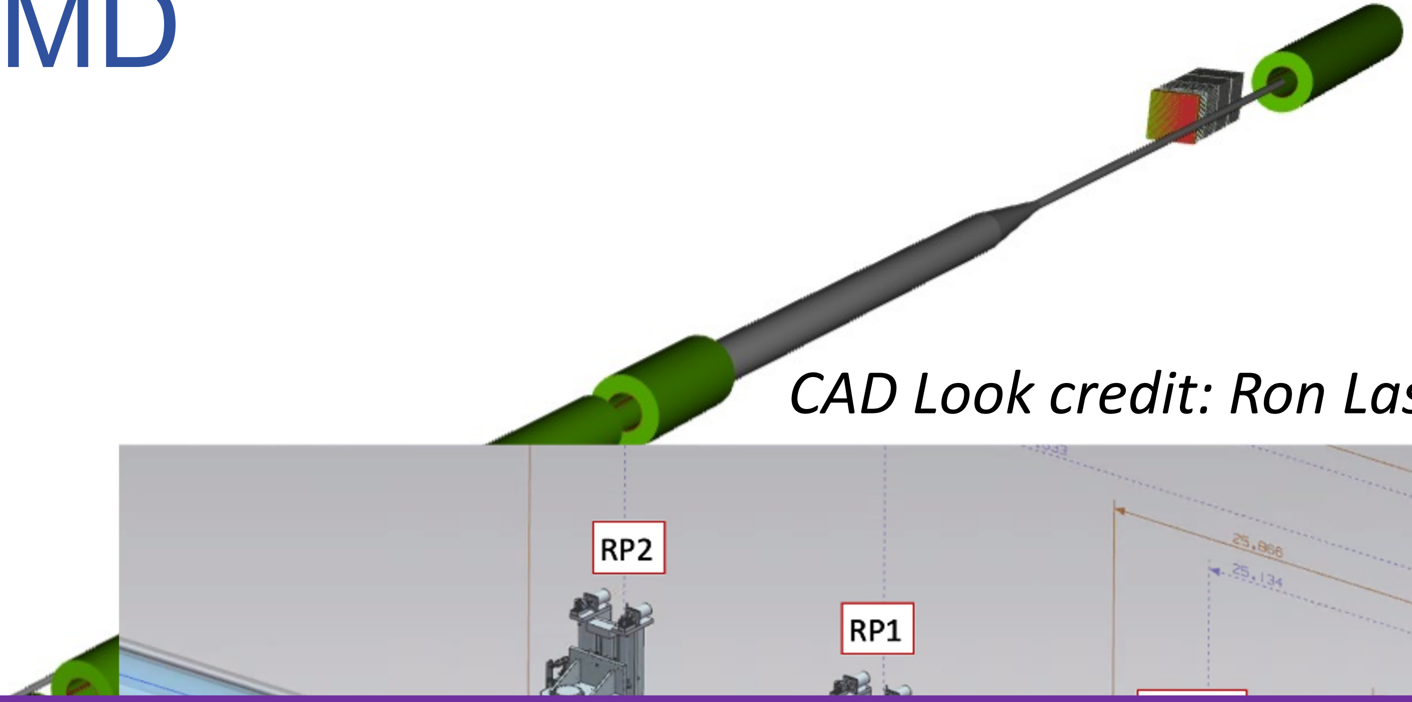


CAD Look credit: Ron Lassiter

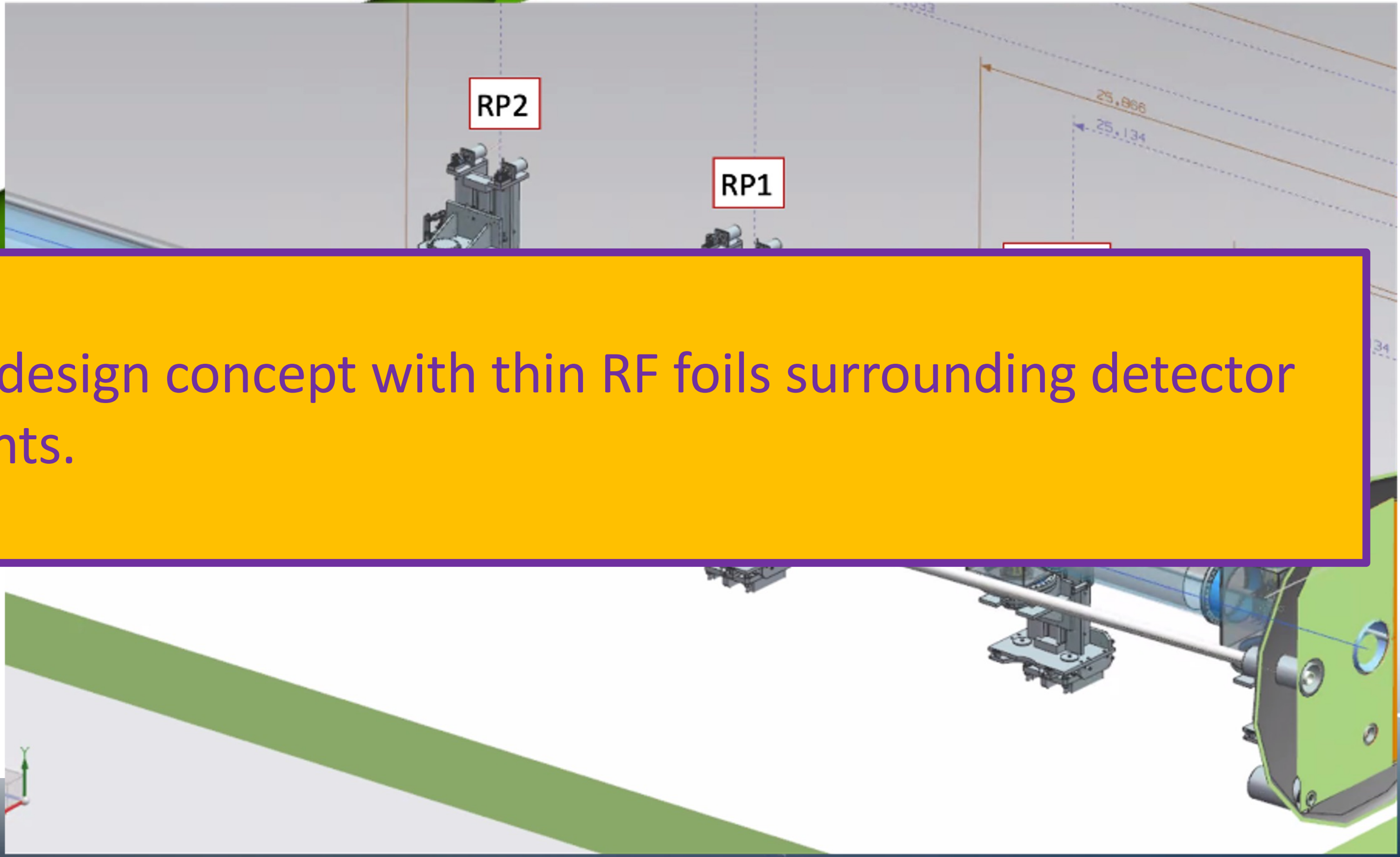


Roman Pots and OMD



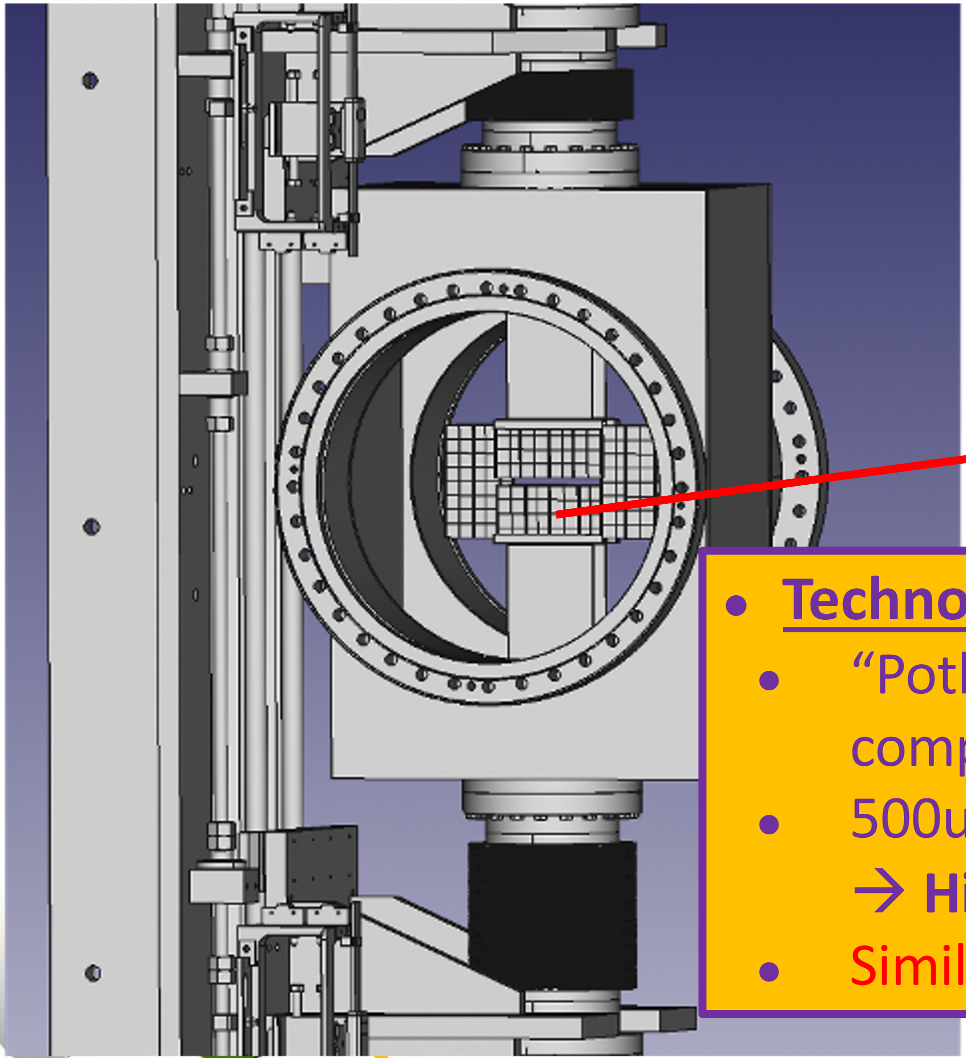


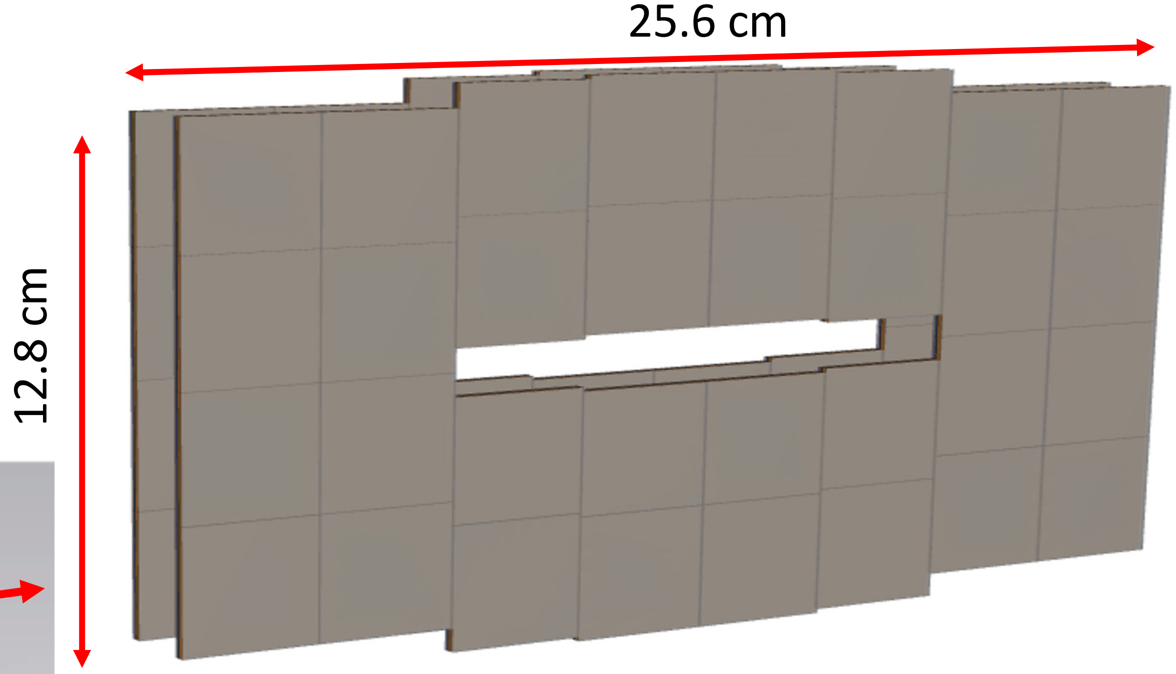
CAD Look credit: Ron Lassiter



- <u>**Technology**</u>
  - “Potless” design concept with thin RF foils surrounding detector components.

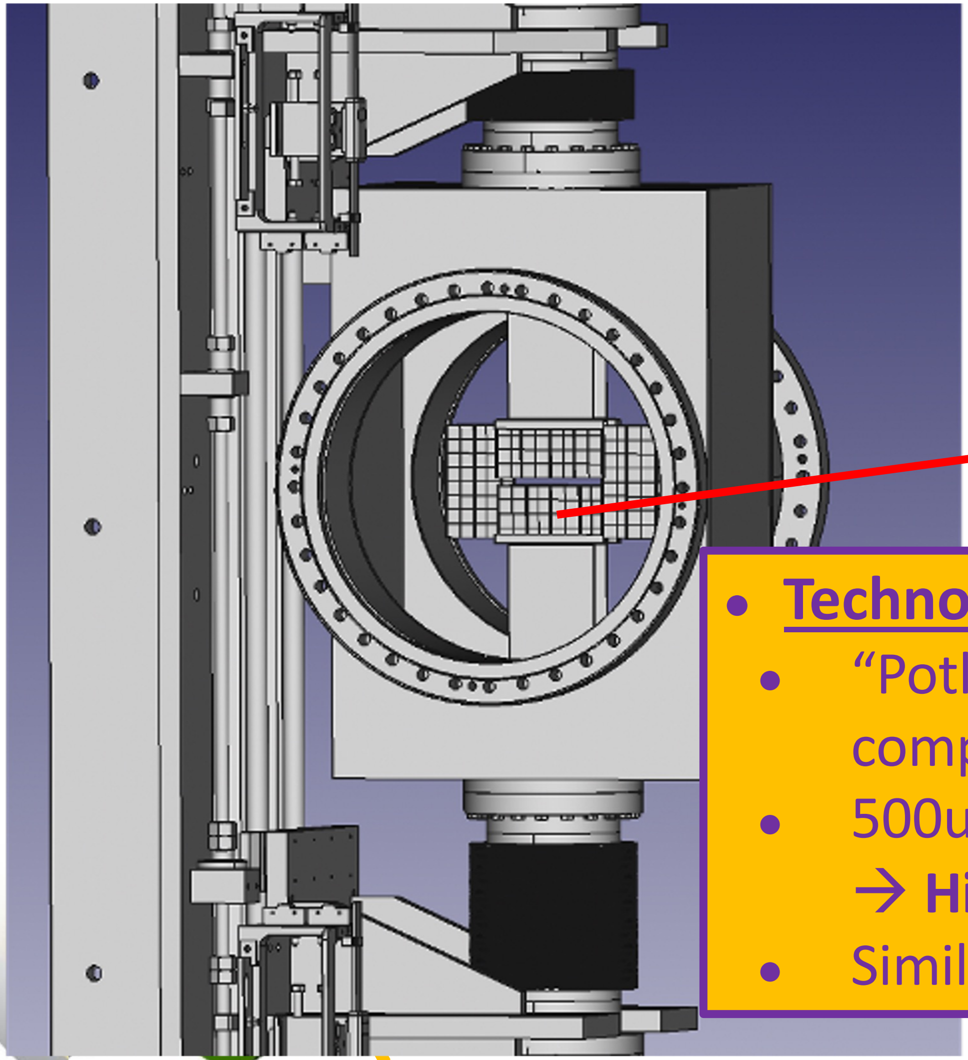
Roman Pots and OMD

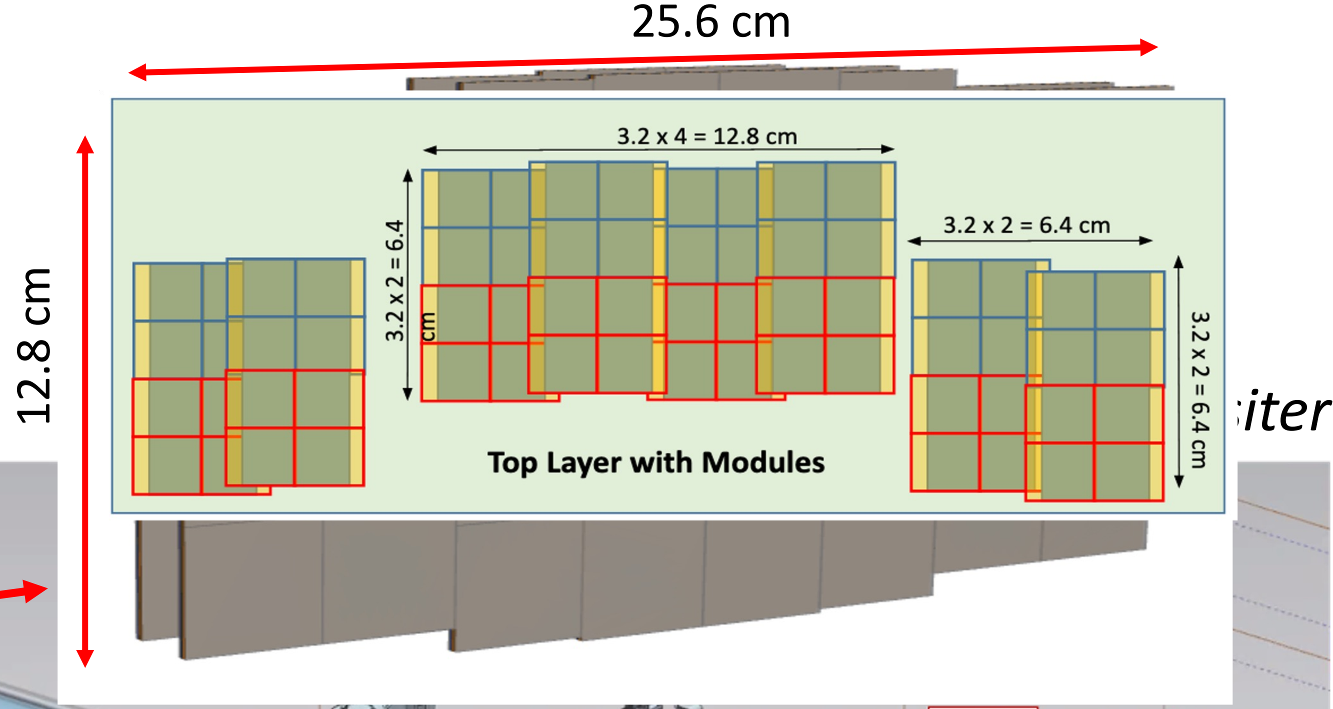




- **Technology**
  - "Potless" design concept with thin RF foils surrounding detector components.
  - 500um, **pixilated AC-LGAD sensor**, with 30-40ps timing resolution → **High-precision space and time information!**
  - Similar concept for the OMD, just different active area and shape.

Roman Pots and OMD





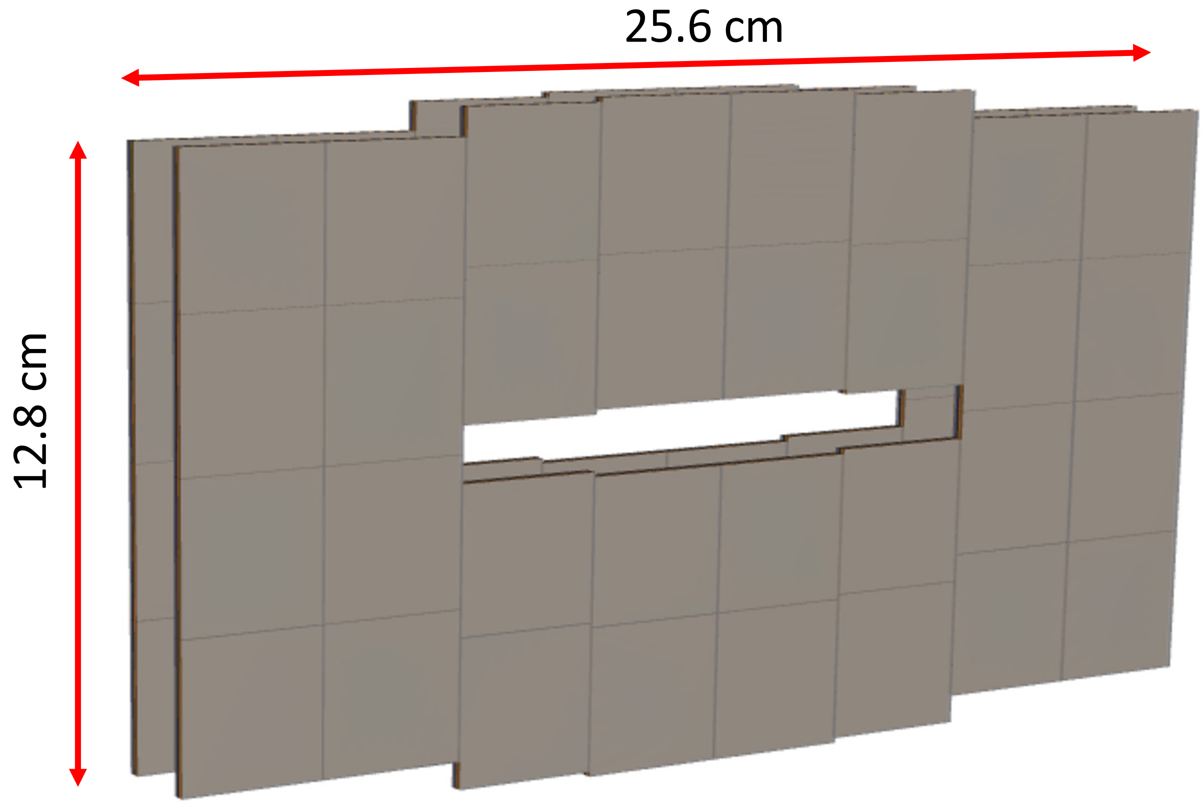
- <u>**Technology**</u>
  - "Potless" design concept with thin RF foils surrounding detector components.
  - 500um, **pixilated AC-LGAD sensor**, with 30-40ps timing resolution → **High-precision space and time information!**
  - Similar concept for the OMD, just different active area and shape.

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

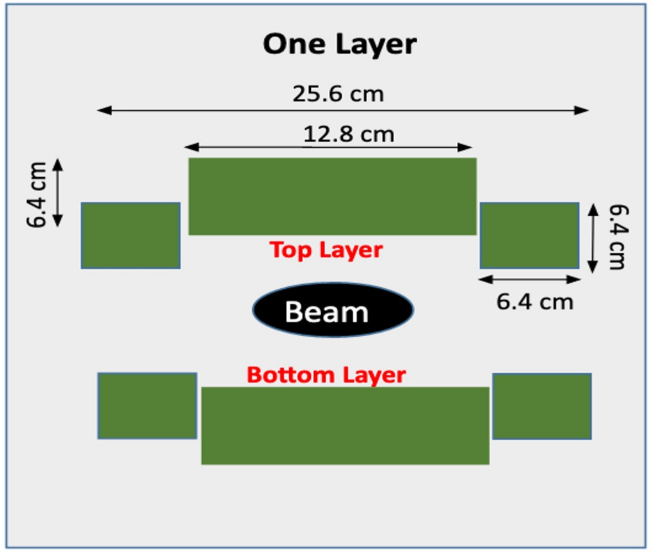
Roman "Pots" @ the EIC

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

$$\sigma_{x,y} = \sqrt{\beta(z)_{x,y}\epsilon_{x,y} + \left(D_{x,y}\frac{\Delta p}{p}\right)^2}$$



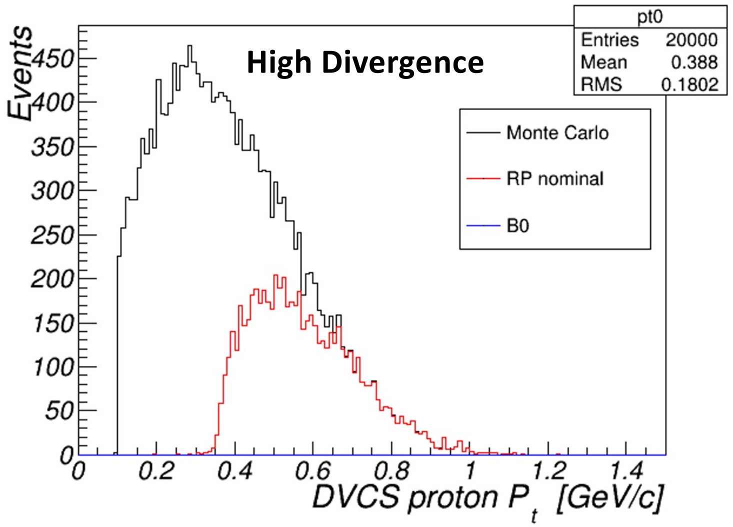
DD4HEP Simulation

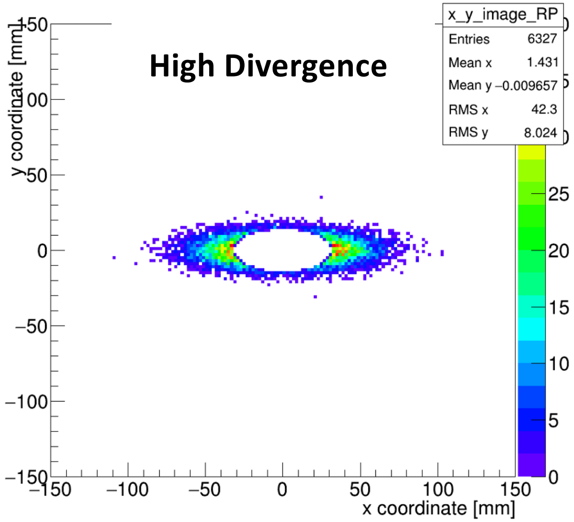


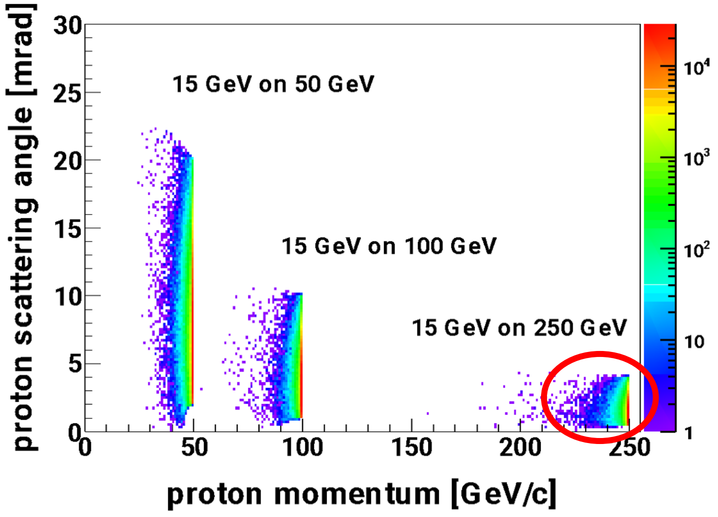
- **<u>Low-pT cutoff determined by beam optics.</u>**
  - **The safe distance is ~10σ from the beam center.**
  - **$1\sigma \sim 1$mm**
- **These optics choices change with energy, but can also be changed within a single energy to maximize *either acceptance at the RP, or the luminosity.***

Digression: Machine Optics (IP6)

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 (IP6)

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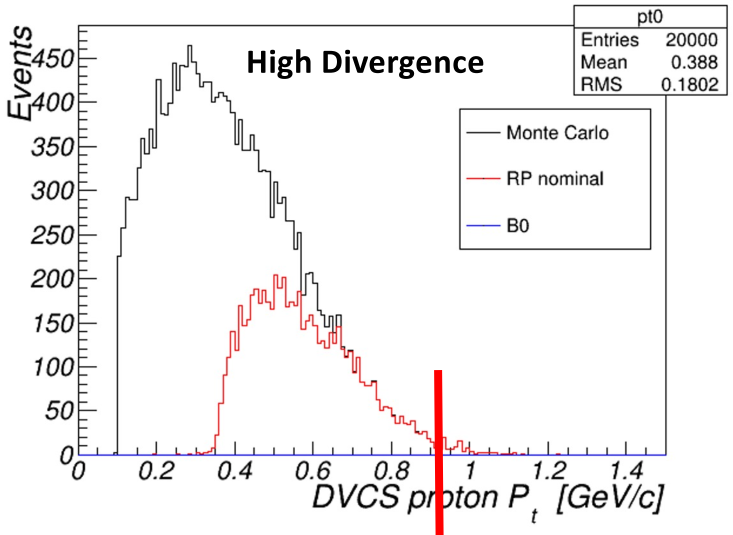

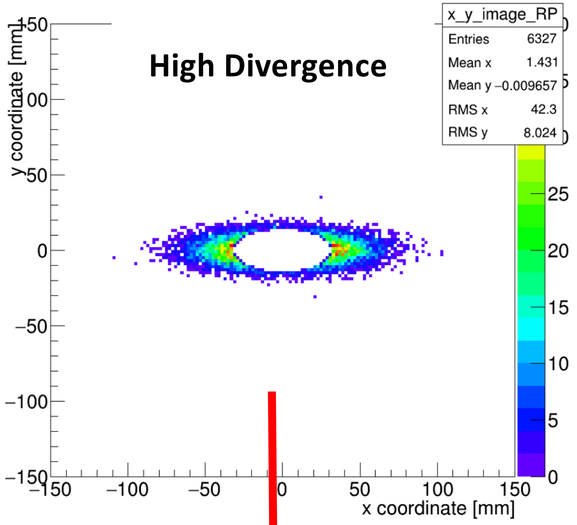

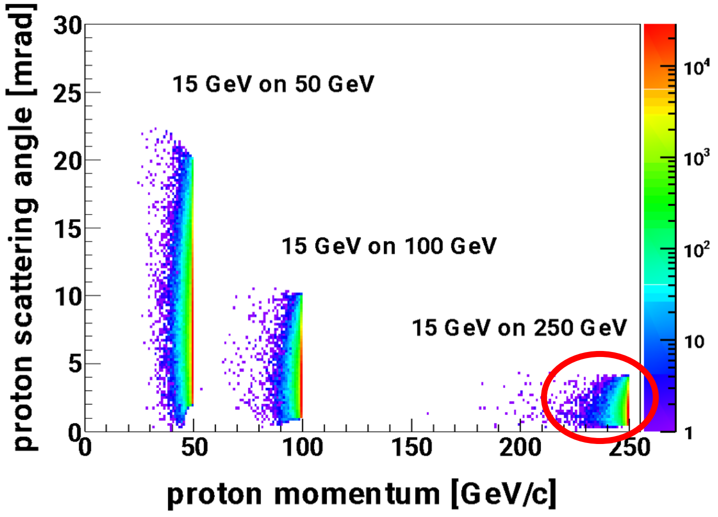

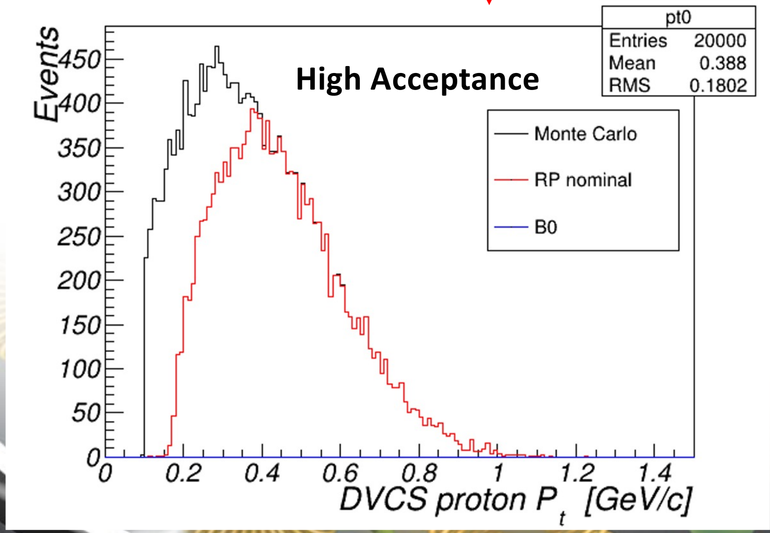

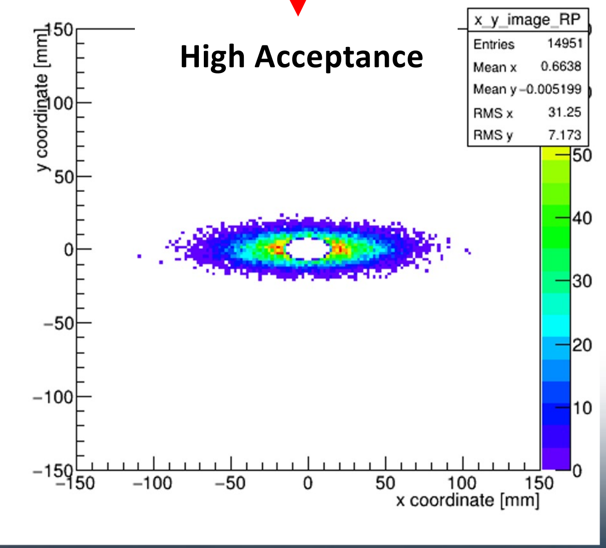

High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

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

Digression: Machine Optics (IP6)

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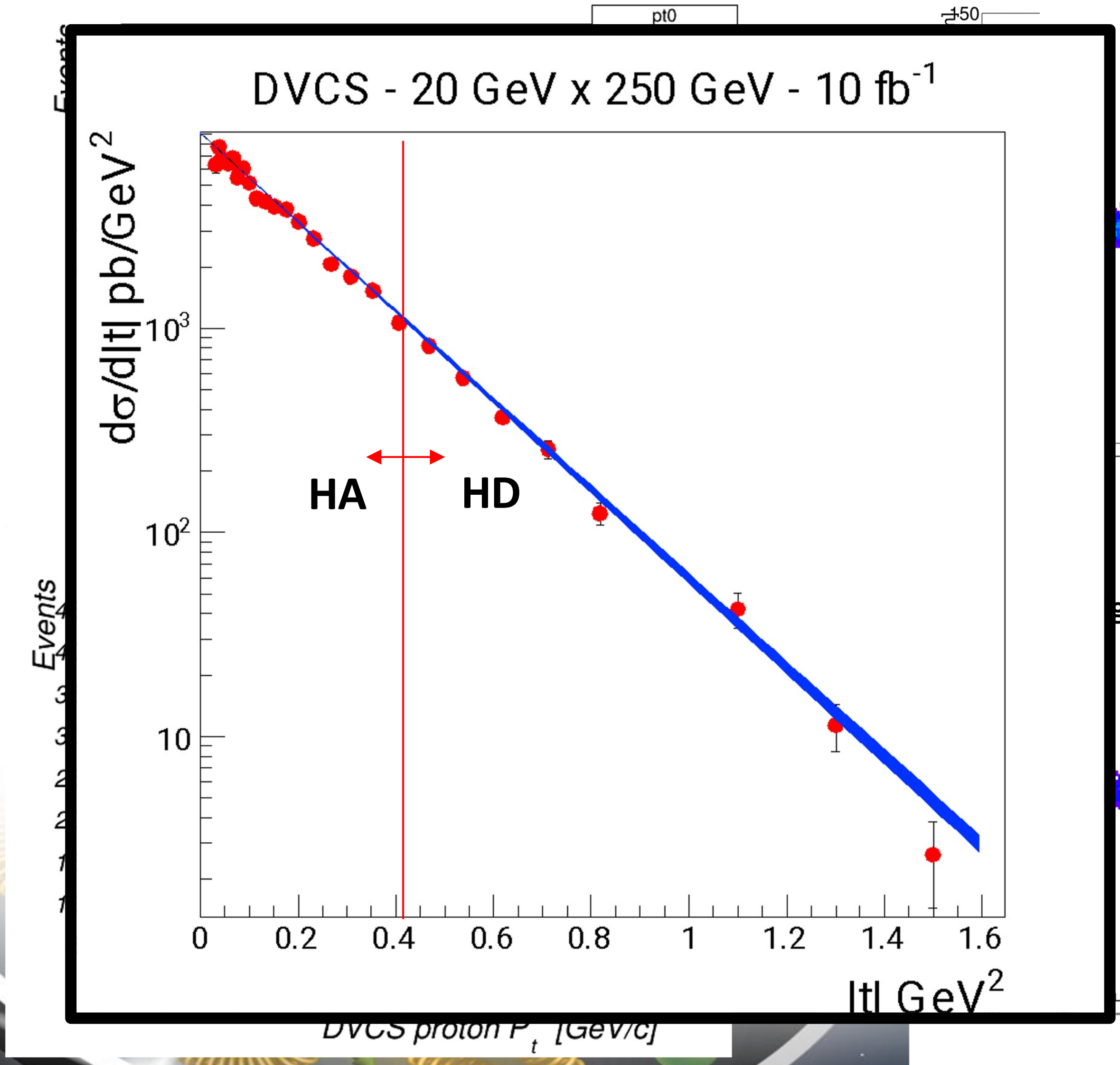
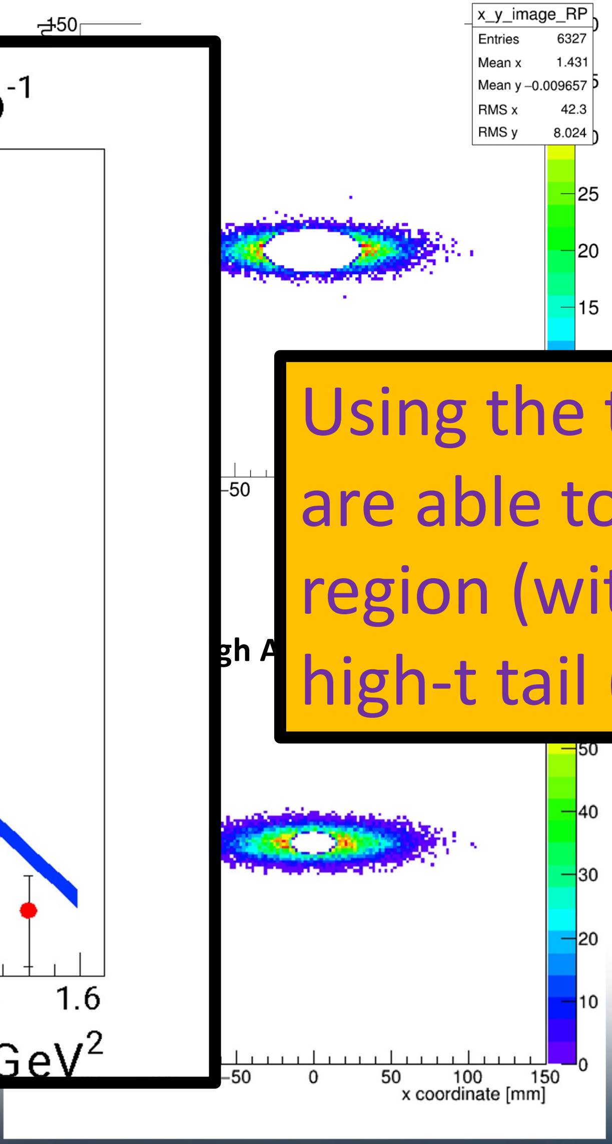
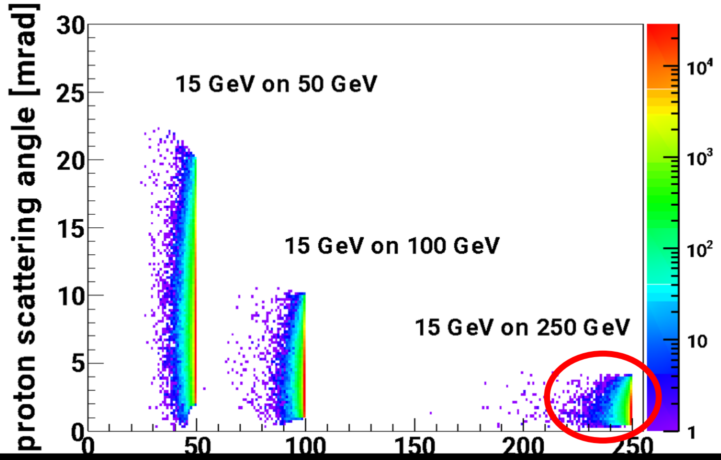




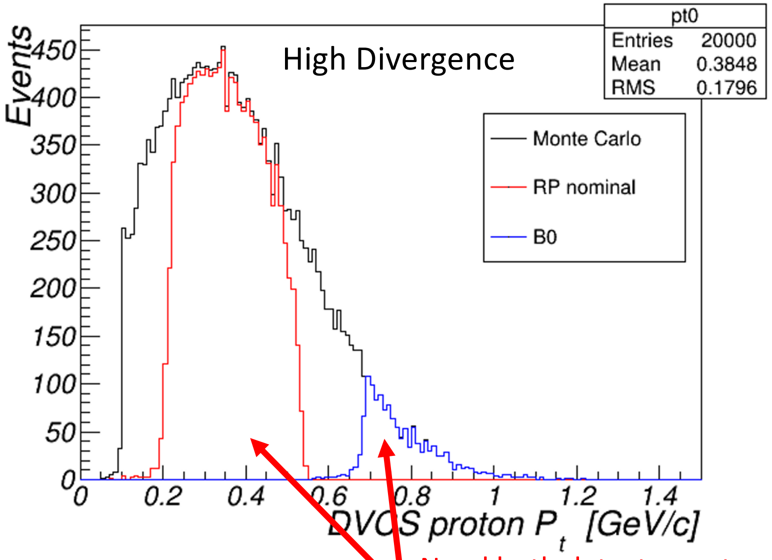


Using the two configurations, we are able to measure the low-t region (with better acceptance) and high-t tail (with higher luminosity).

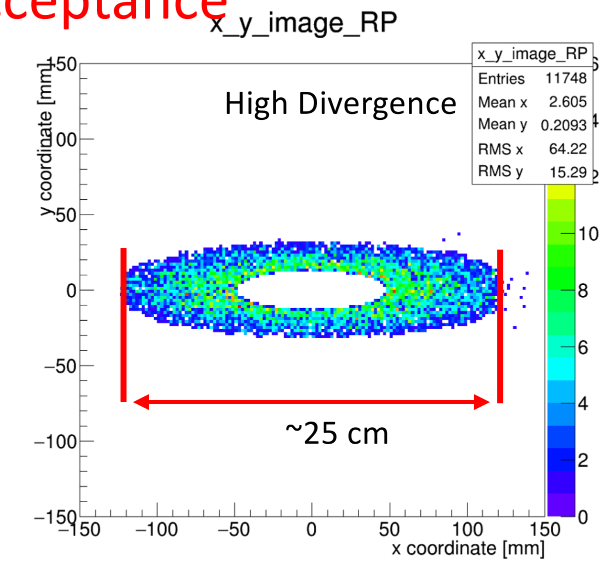
High Acceptance: larger β^* at IP, smaller $\beta(z = 30m)$ -> lower lumi., smaller beam at RP

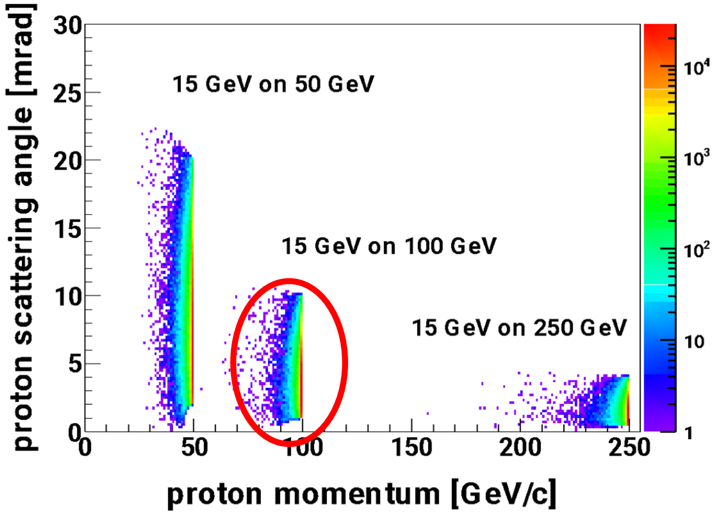
Digression: Machine Optics (IP6)

100 GeV DVCS Proton Acceptance



Need both detector systems together here!





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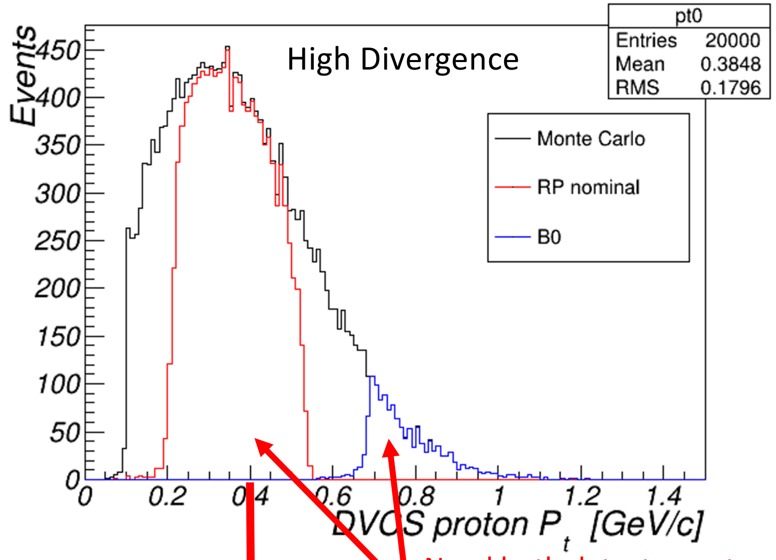

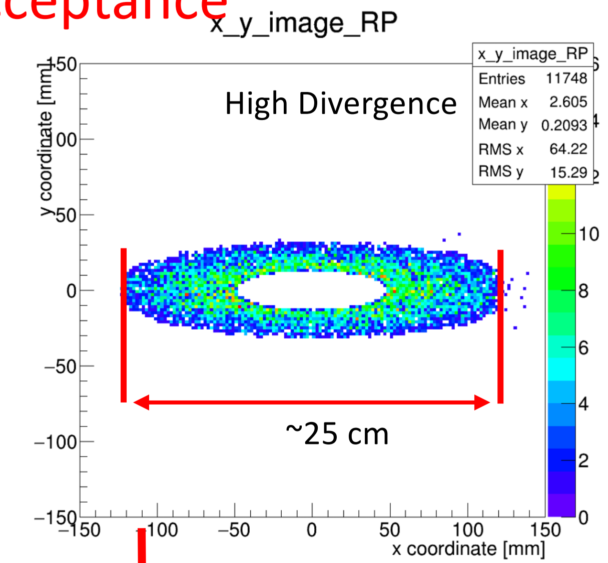

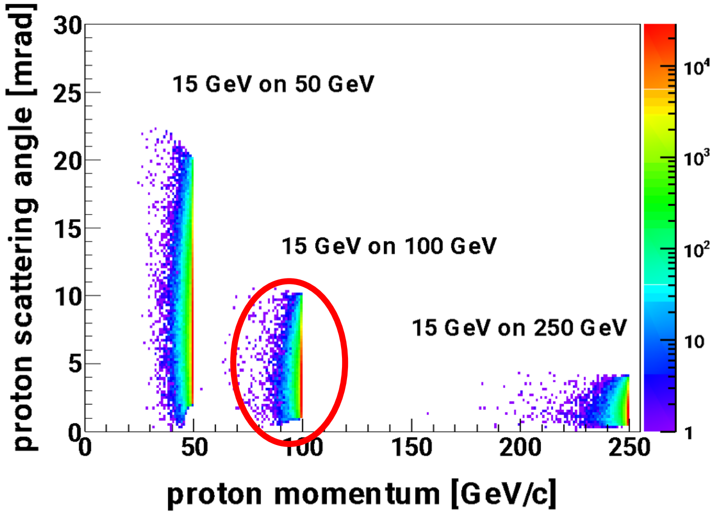

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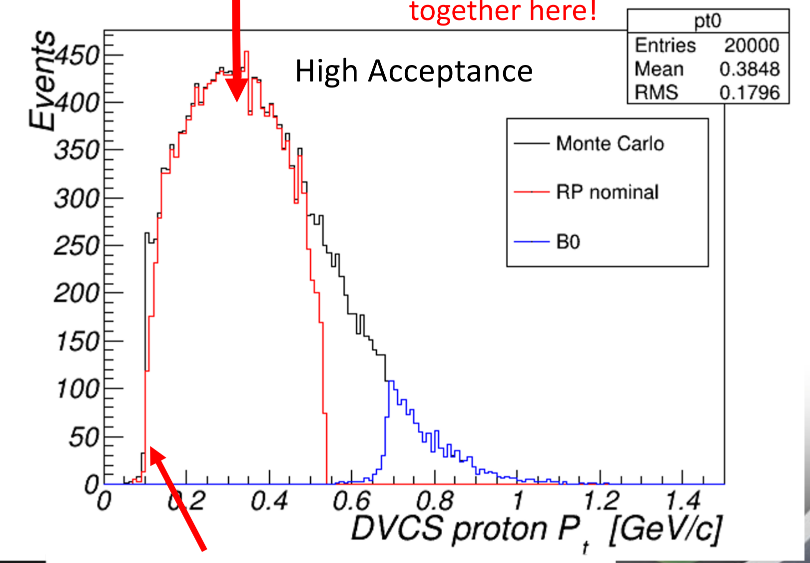
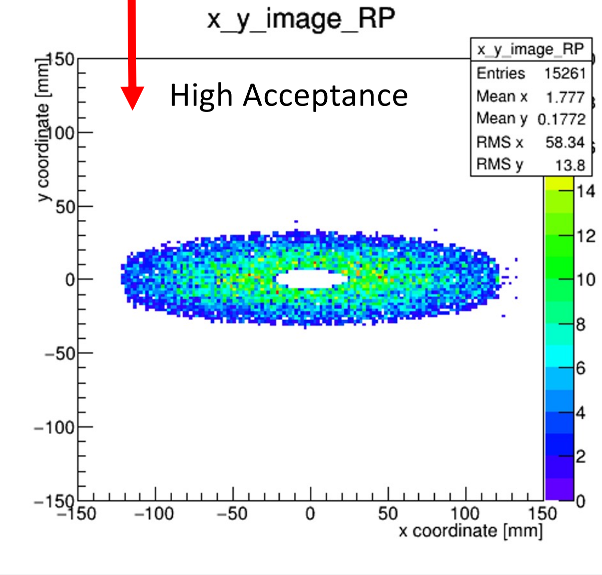
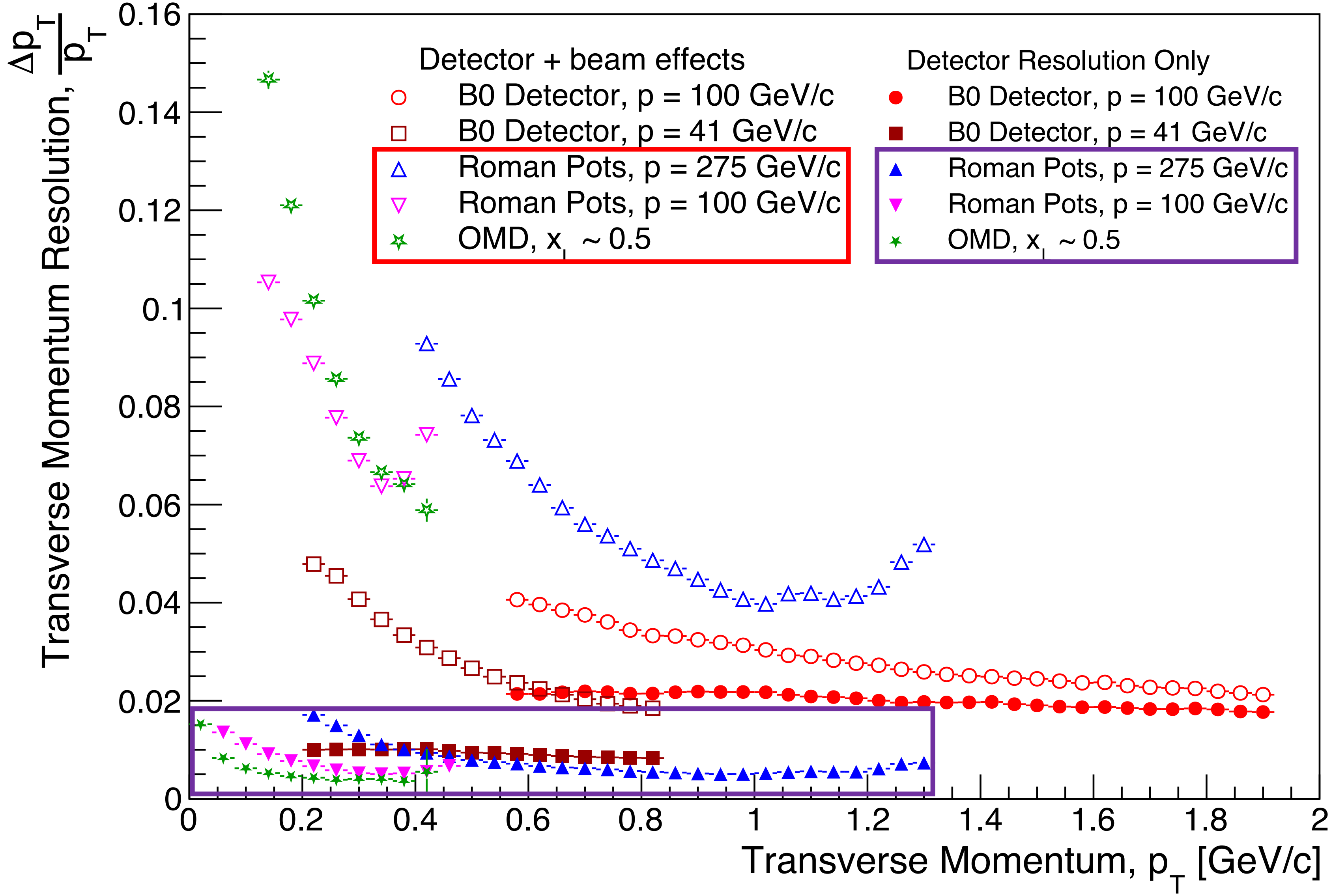




Improves low p_t acceptance.

Summary of Detector Performance

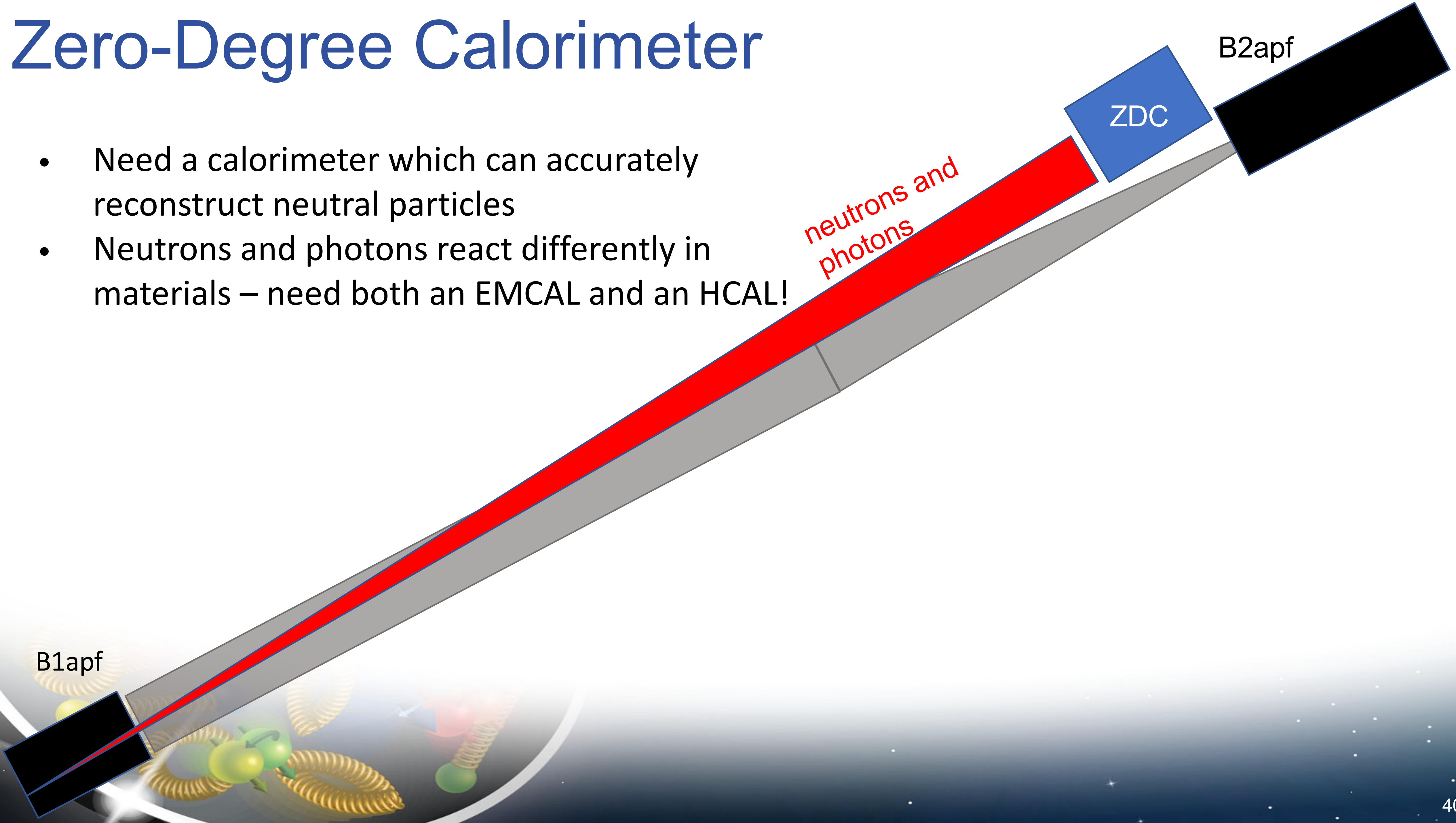


- All beam effects included!
  - Angular divergence.
  - Crossing angle.
  - Crab rotation/vertex smearing.

Beam effects the dominant source of momentum smearing!

Zero-Degree Calorimeter

- Need a calorimeter which can accurately reconstruct neutral particles
- Neutrons and photons react differently in materials – need both an EMCAL and an HCAL!



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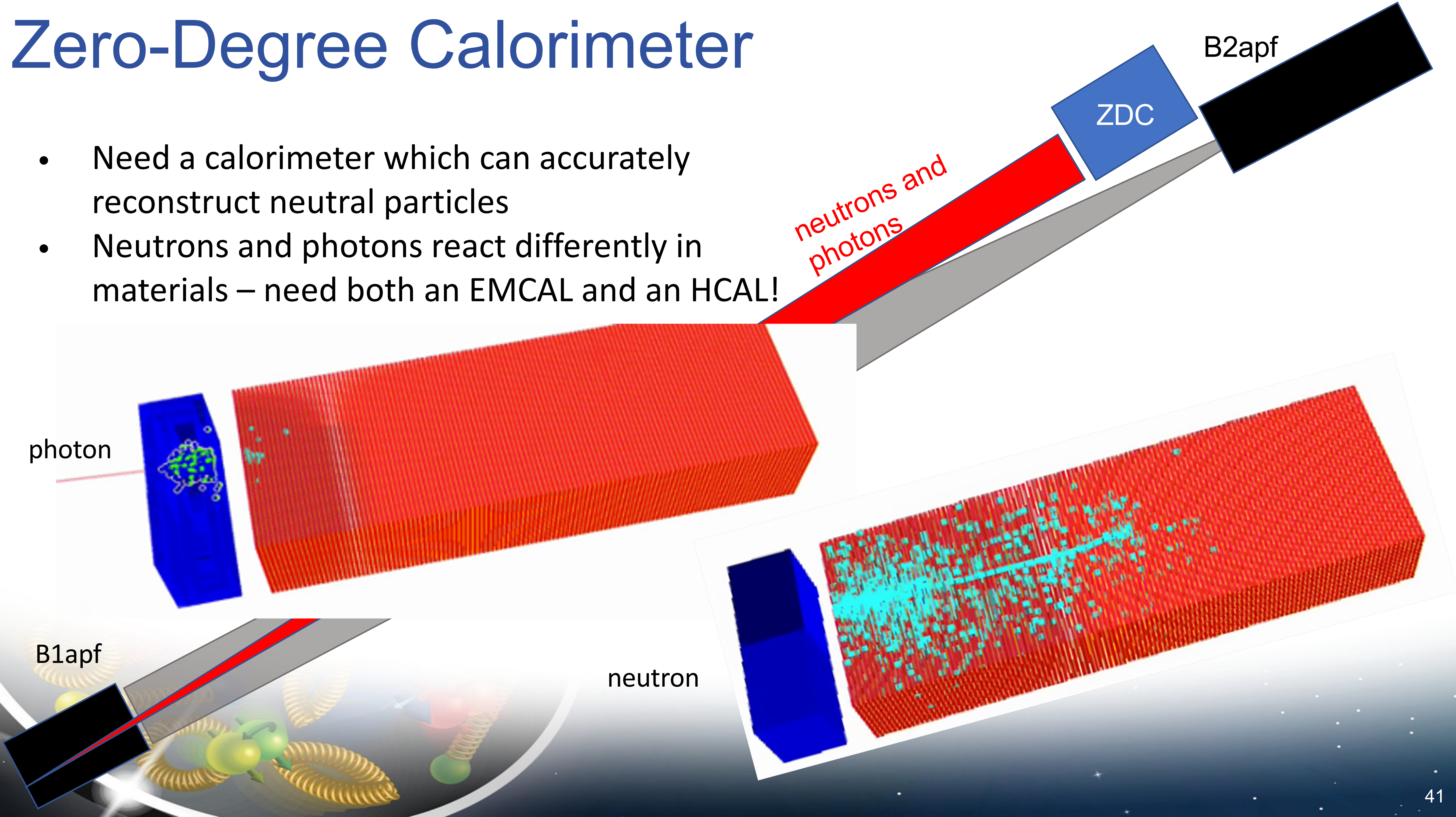
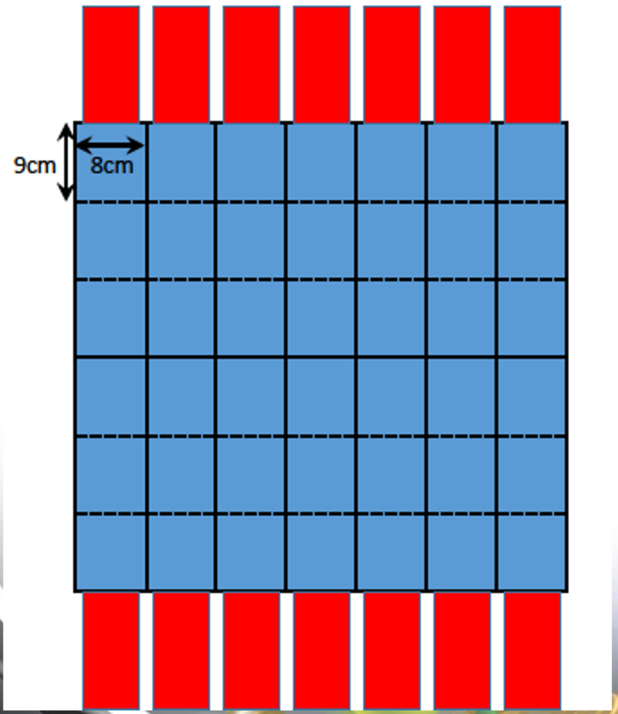


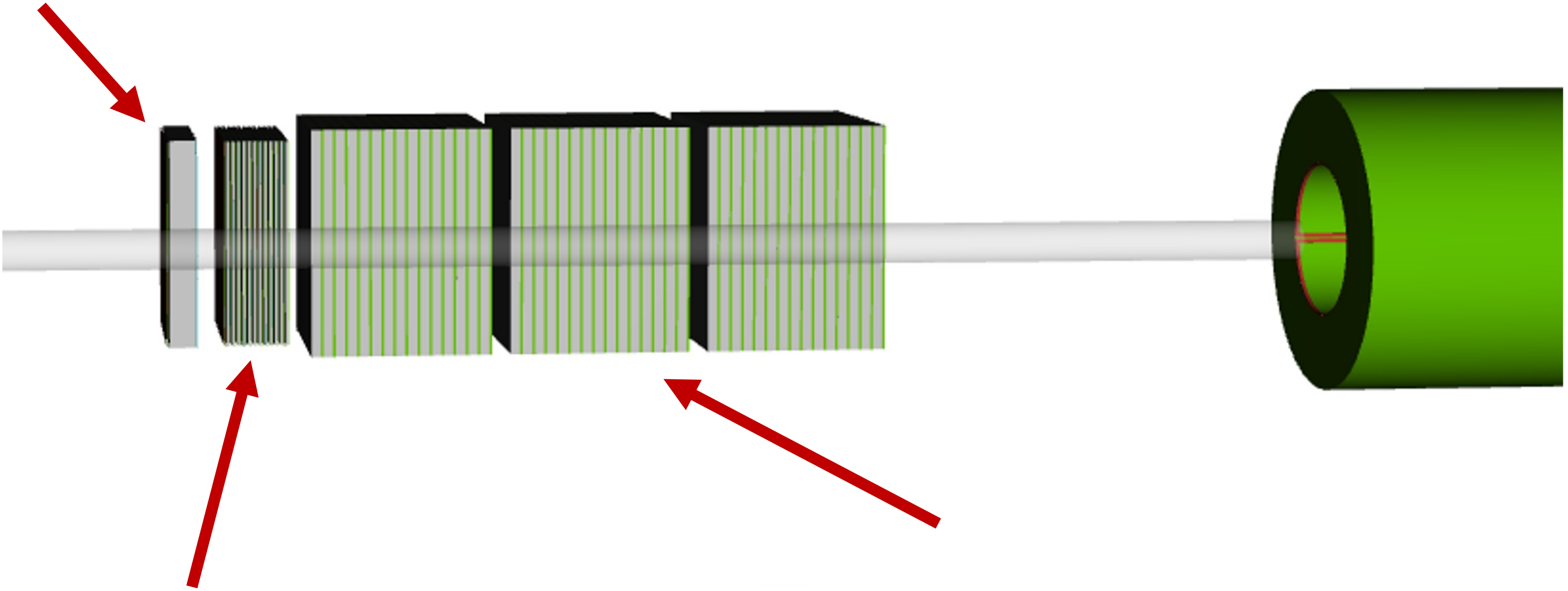
ZDC - What's New

- 1st Silicon & crystal calorimeter (PbWO4 or LYSO):
  - Smaller lateral dimension (x, y) = (56, 54) cm.

Overall length within 2m limit

Readout setup from top & bottom

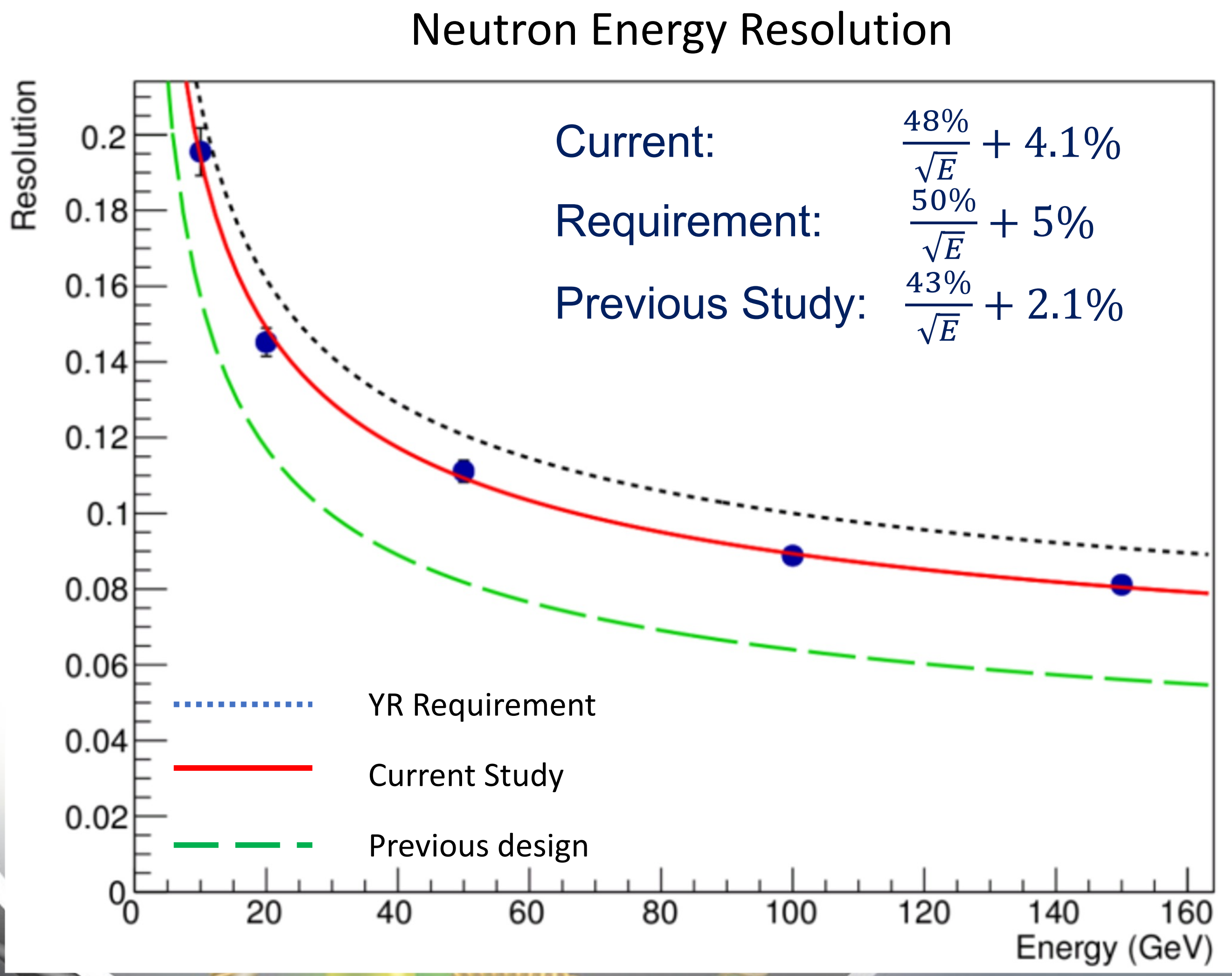


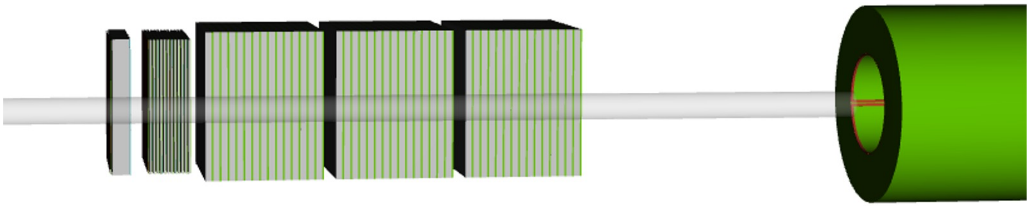


- W/Silicon Imaging EMCAL
  - Transverse size (x,y) = (56, 54) cm
  - 12 layers (~$24\chi_0$)

- Pb-Scintillator (+ fused silica)
  - Towers of 10cm x 10cm x 48cm, each module 60cm x 60cm x 48cm
  - 3 modules

ZDC - Performance



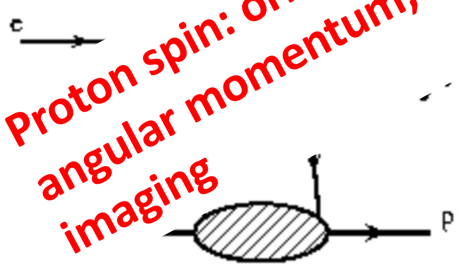


- Energy resolution in the new design acceptable → Optimization, test of different ideas within the size limit.

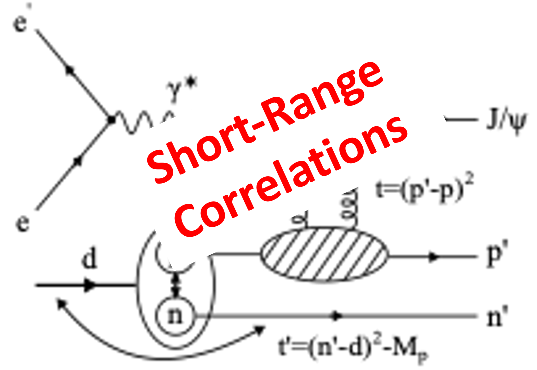
- Next steps:
  - Implementation of reconstruction
  - Position resolution & shower development study ongoing for the imaging part of HCAL

(some) Far-Forward **Physics** at the EIC

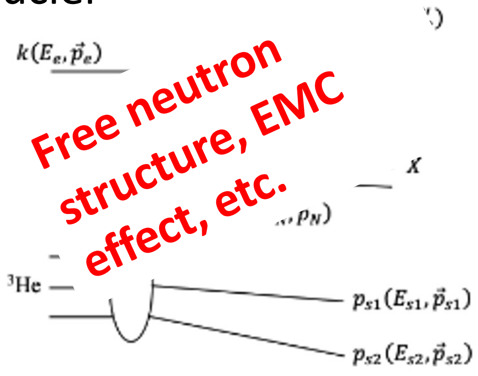
e+p DVCS



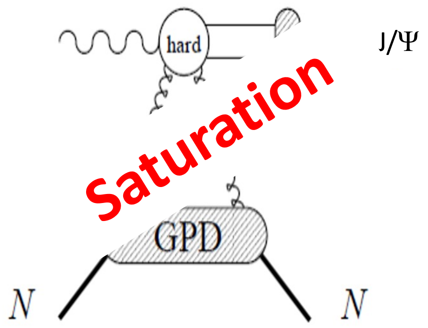
e+d exclusive J/Psi with p/n tagging



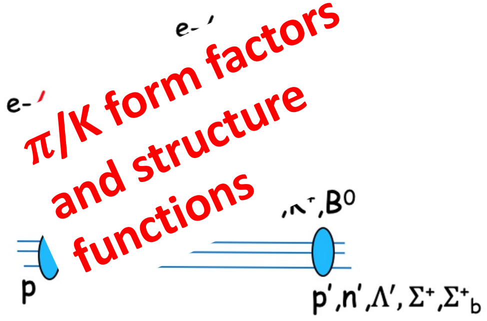
spectator tagging in light nuclei



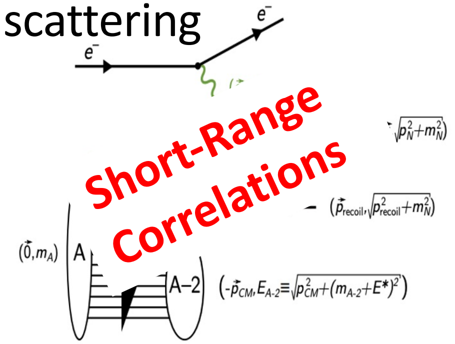
coherent/incoherent J/ψ production in e+A



Sullivan process

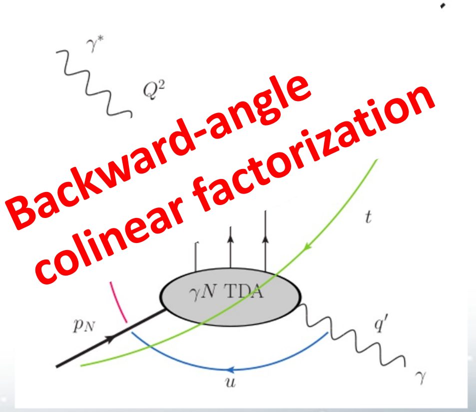


Quasi-elastic electron scattering



[1] Z. Tu, A. Jentsch, et al., Physics Letters B, (2020)
[2] I. Friscic, D. Nguyen, J. R. Pybus, A. Jentsch, *et al.*, Phys. Lett. B, **Volume 823**, 136726 (2021)
[3] W. Chang, E.C. Aschenauer, M. D. Baker, A. Jentsch, J.H. Lee, Z. Tu, Z. Yin, and L.Zheng, Phys. Rev. D **104**, 114030 (2021)
[4] A. Jentsch, Z. Tu, and C. Weiss, Phys. Rev. C **104**, 065205, (2021) **(Editor's Suggestion)**

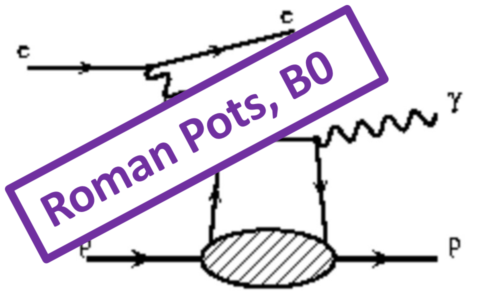
u-channel backward exclusive electroproduction



…and MANY more!

(some) Far-Forward **Physics** at the EIC

e+p DVCS



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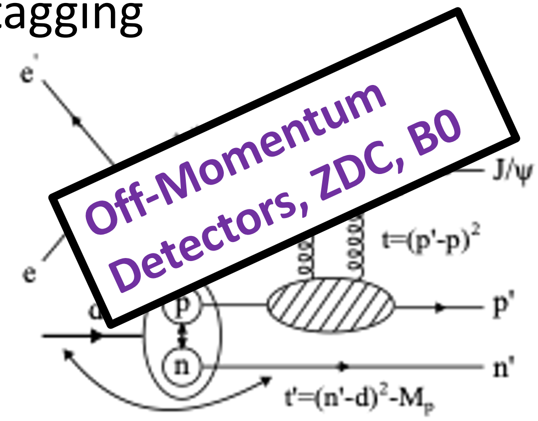

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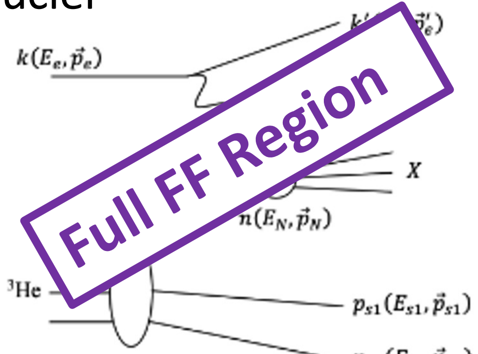
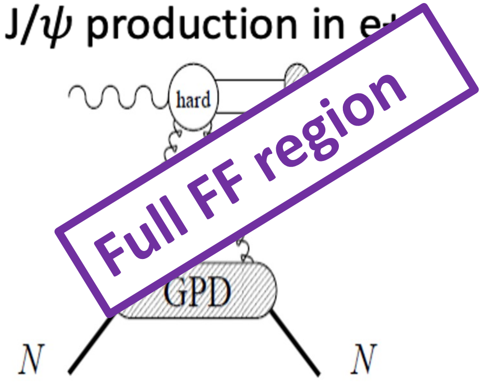


coherent/incoherent J/ψ production in e+



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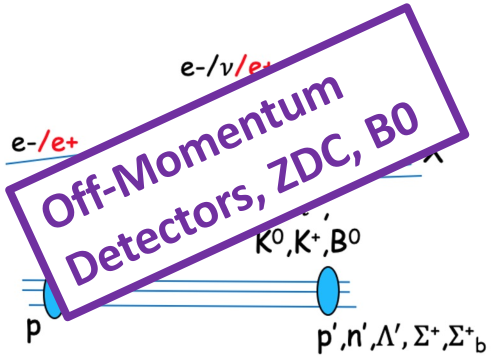

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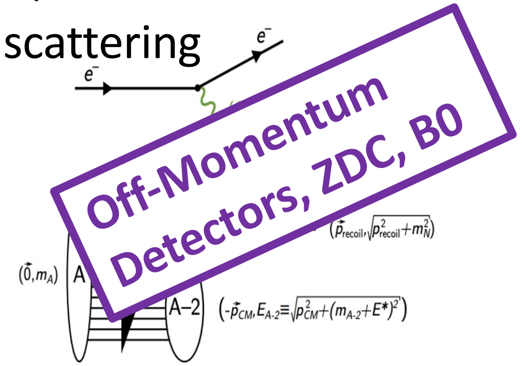

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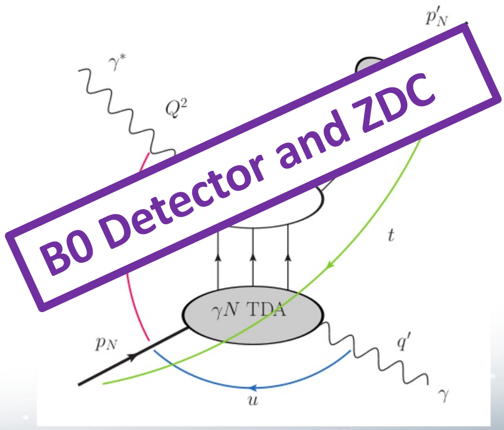

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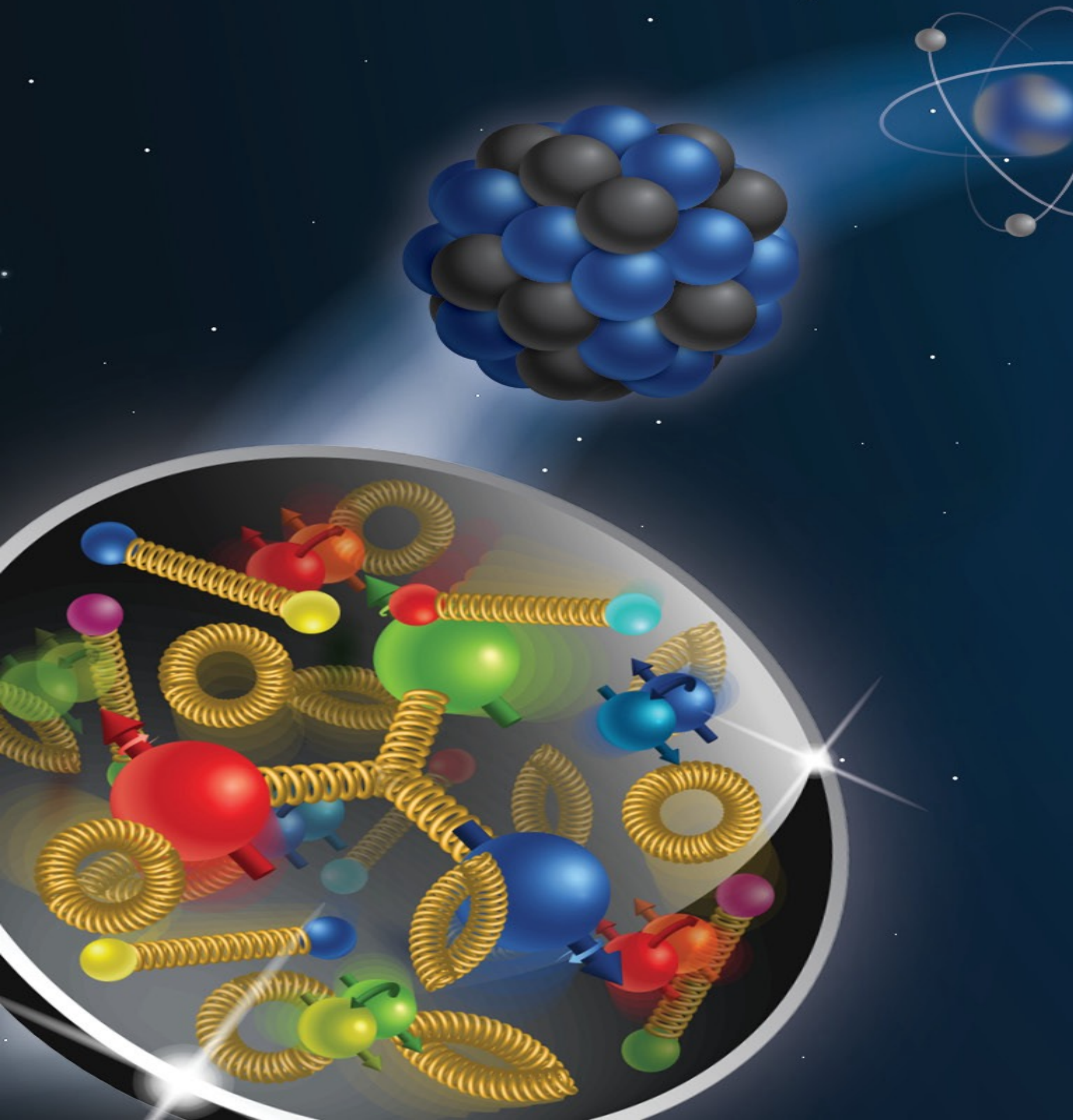
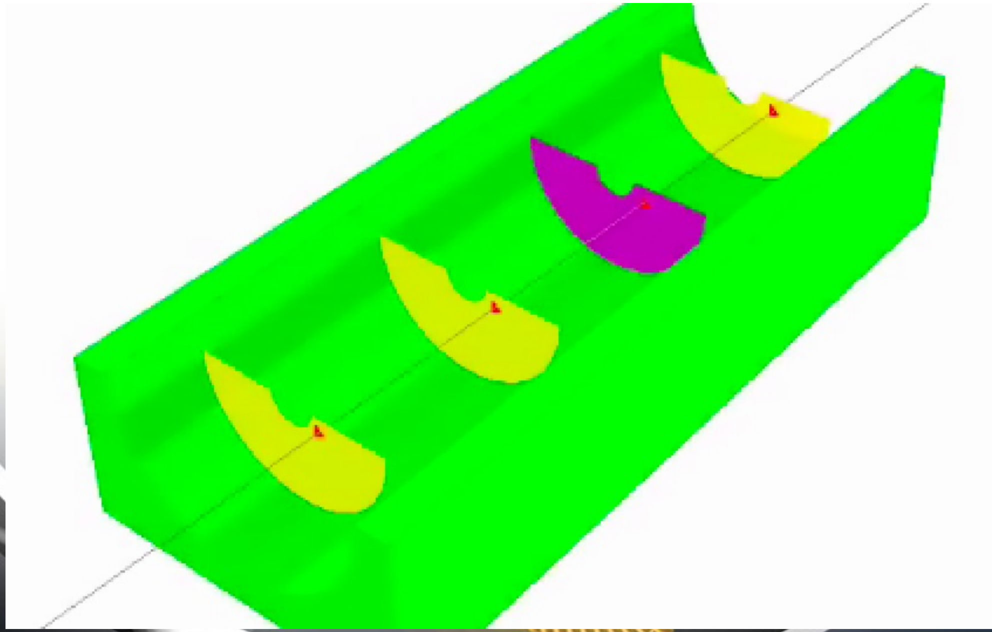


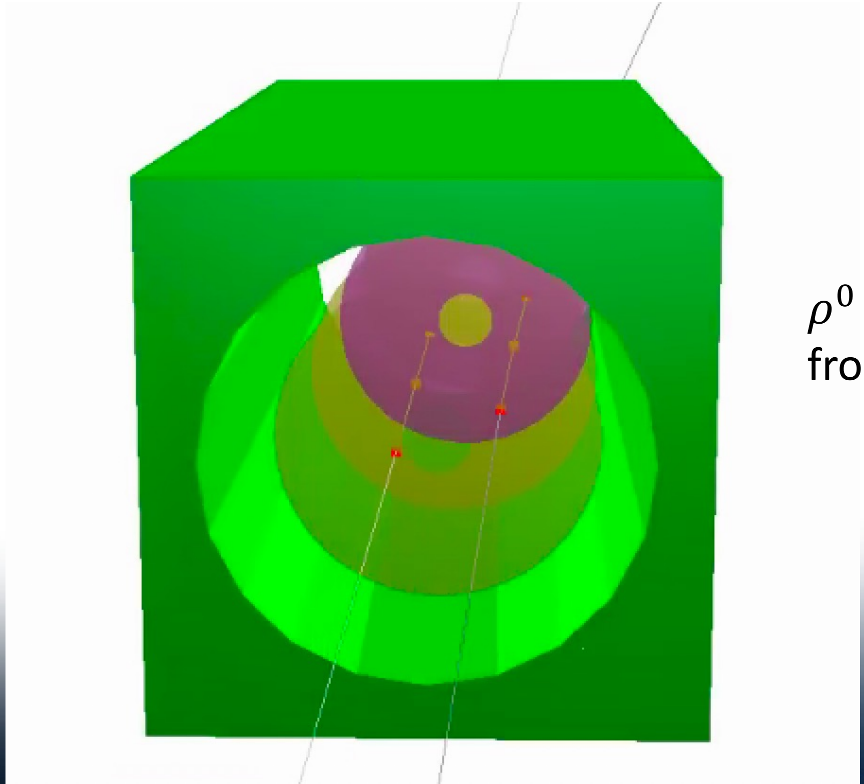
Some final comments
(by request)

The importance of the B0 for the meson program

- Needed for measuring final states with $\theta > 5.5$ 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!

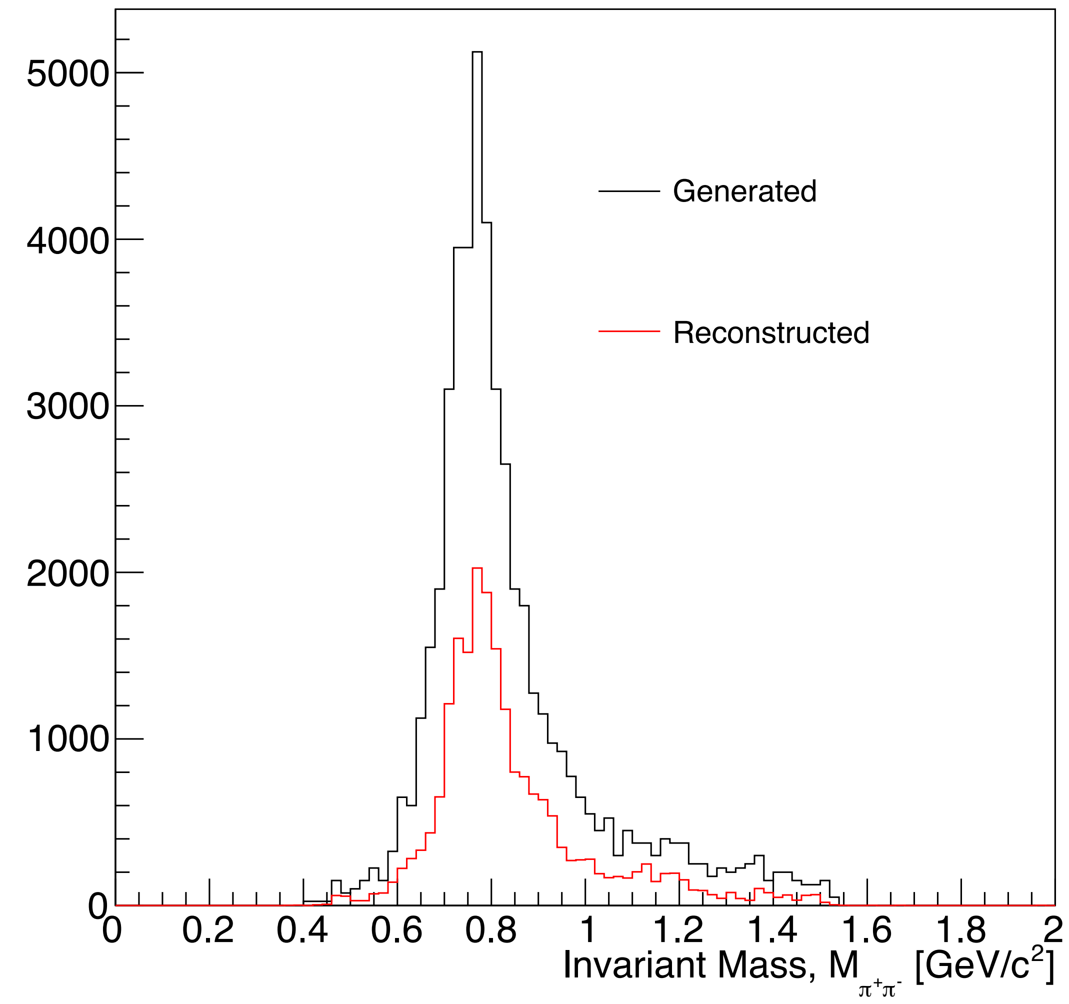
GEANT simulation: 100 GeV proton



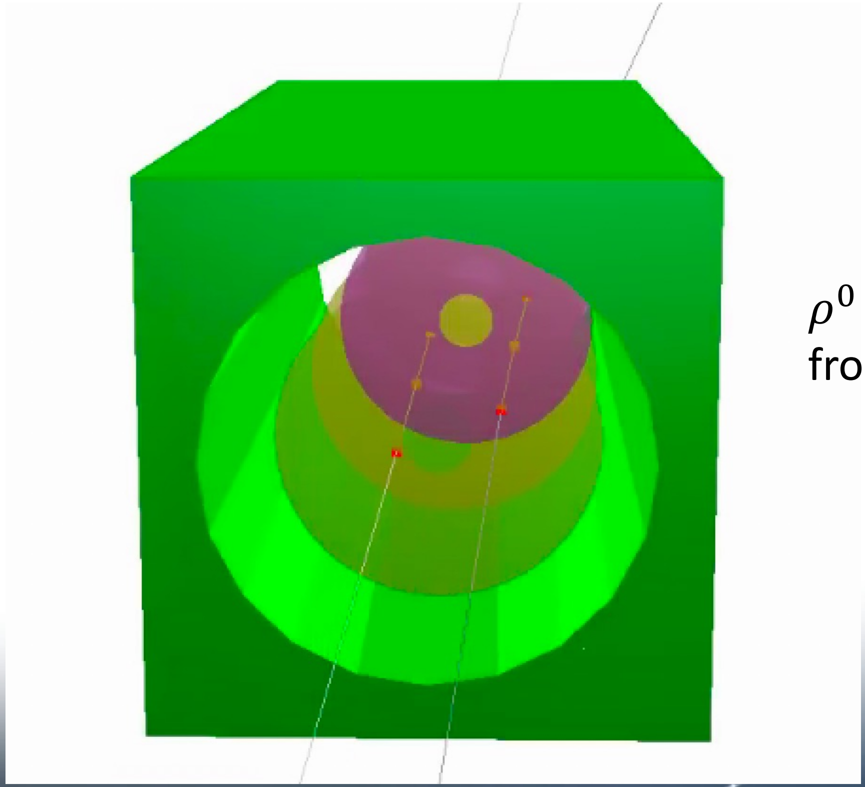


$\rho^0 \rightarrow \pi^+\pi^-$ decay
from u-channel production

The importance of the B0 for the meson program



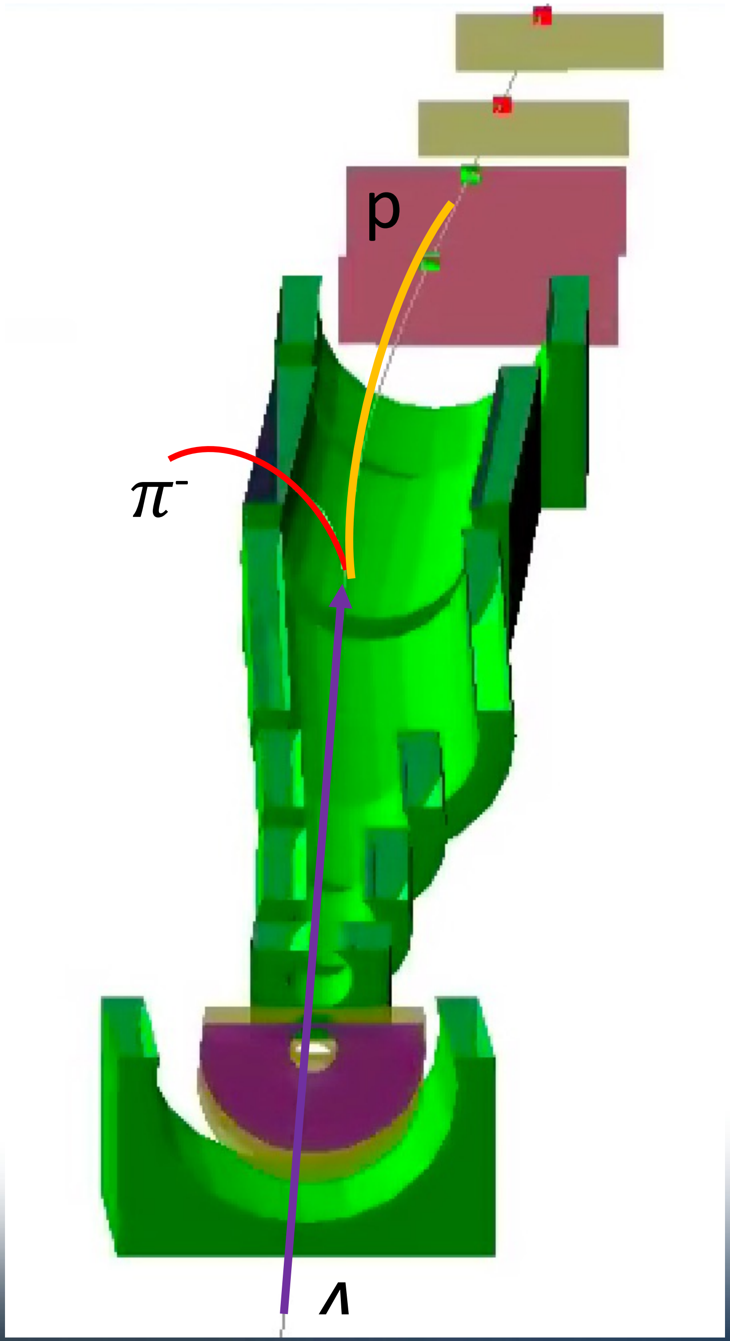
- $\rho^0 \to \pi^+\pi^-$ decay studied with eSTARLight 5x41 events (generated by Zach Sweger).
- Reconstruction performed with EicRoot.



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

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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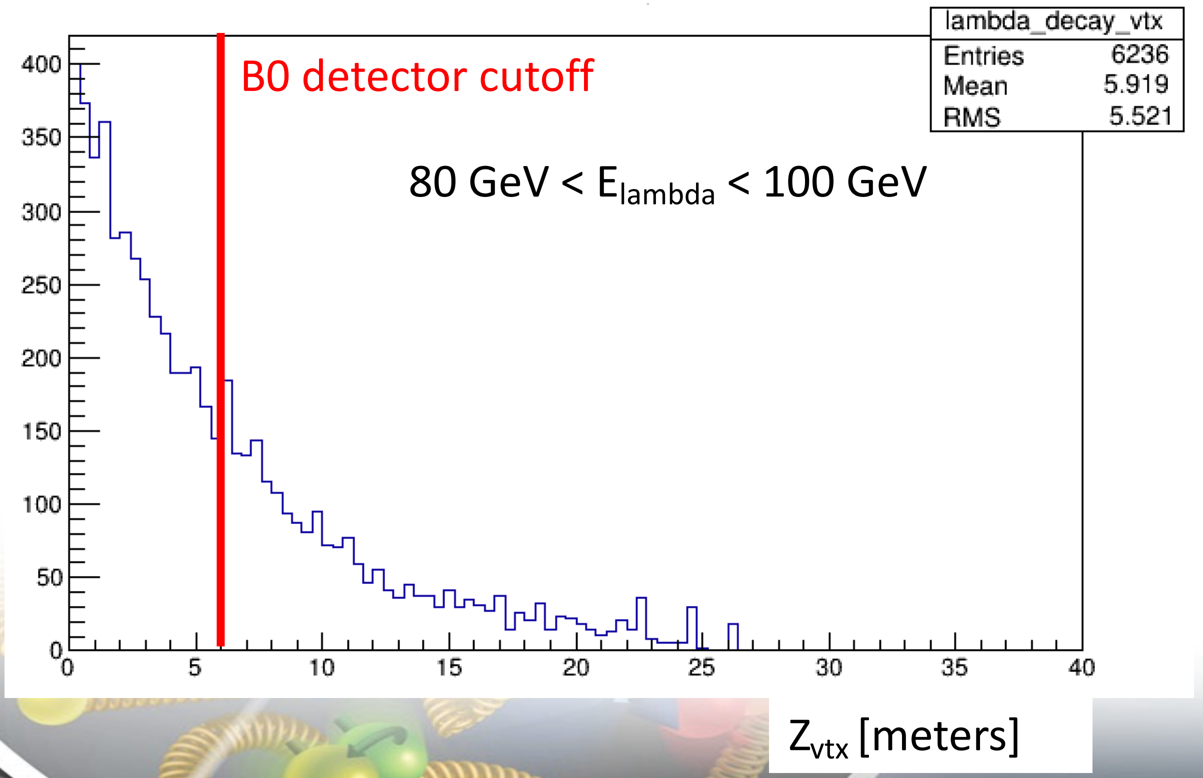

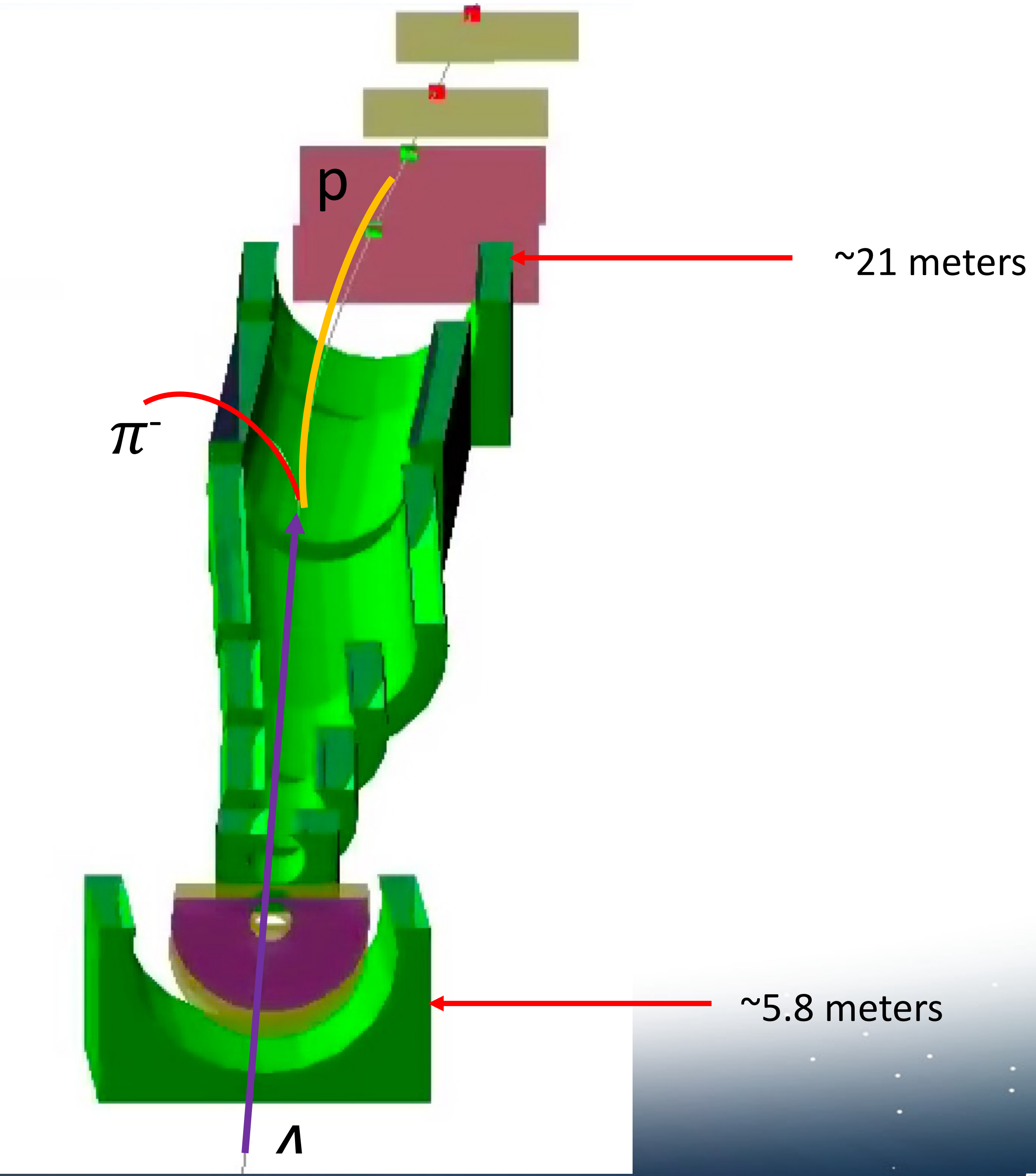

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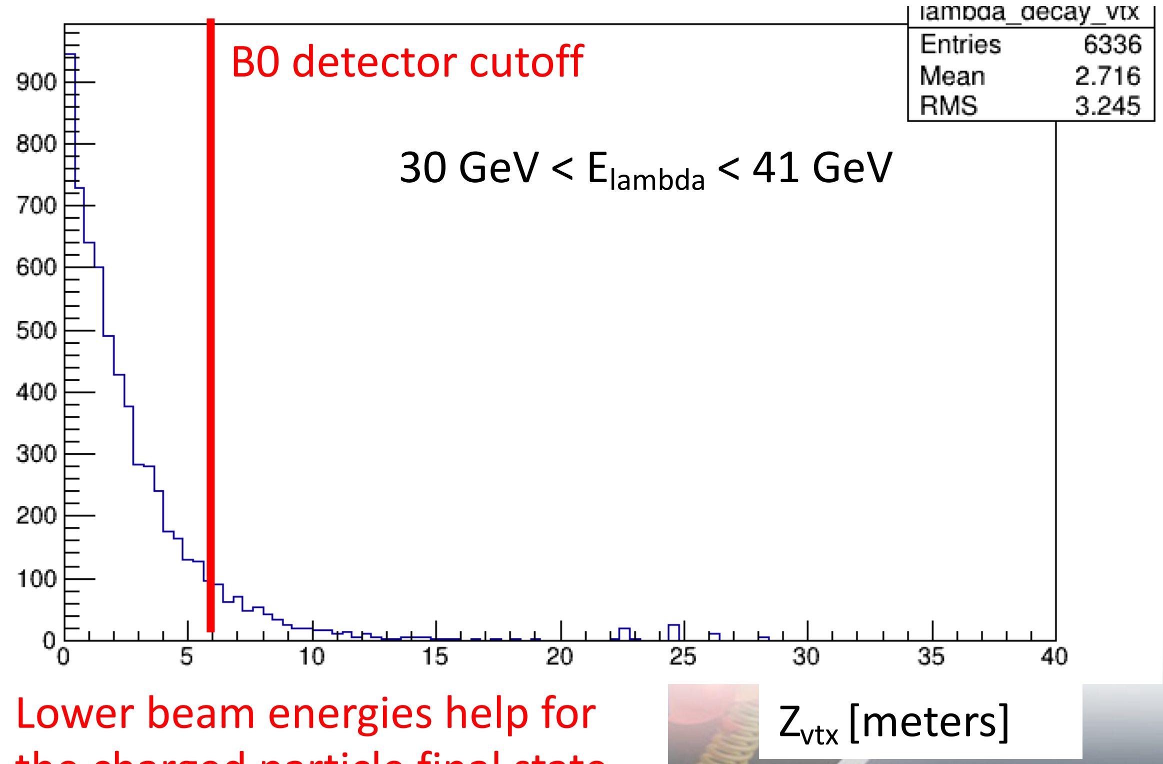
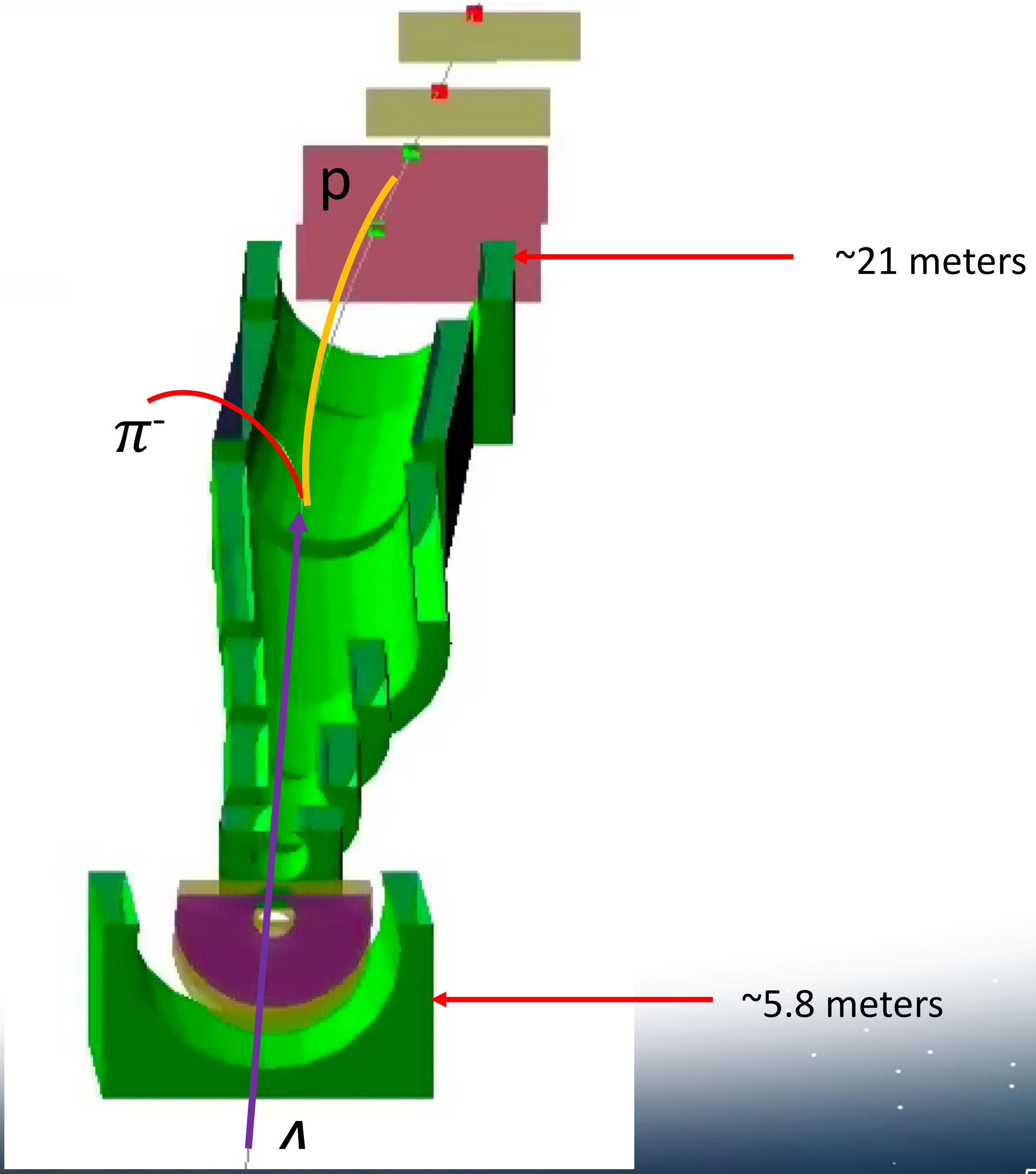


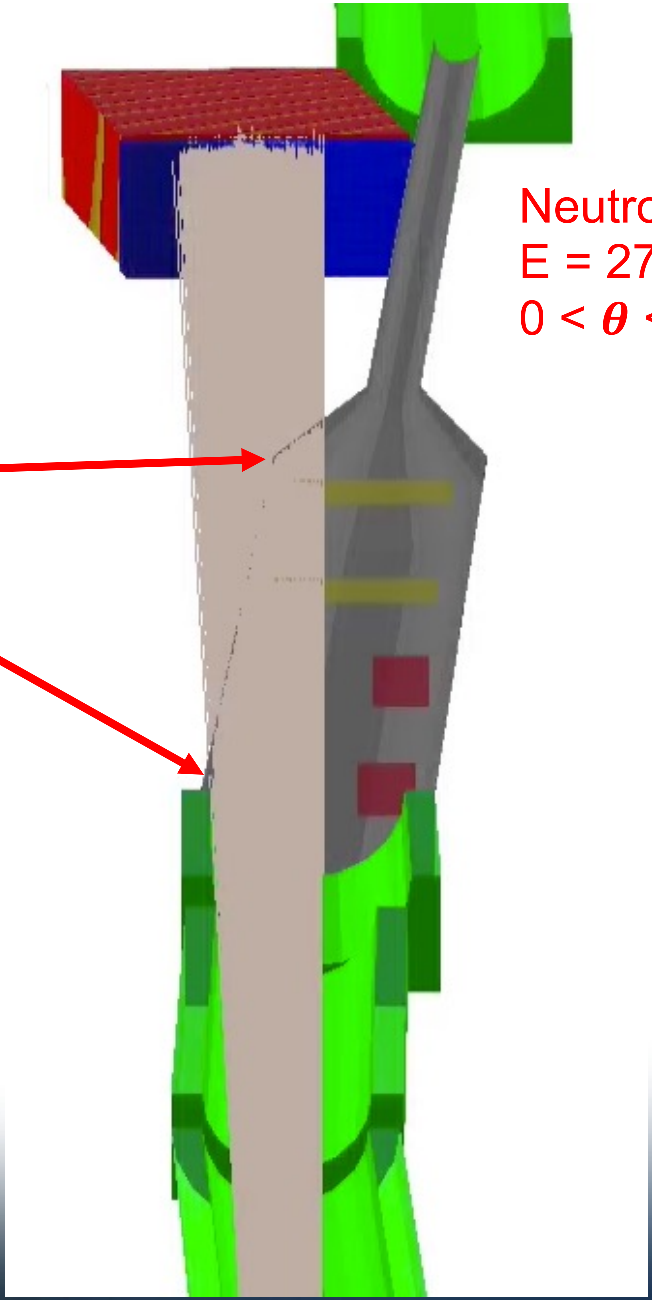
Lower beam energies help for the charged particle final state.



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!!



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

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

➢ **Updated design in-production.**

Summary and Takeaways

- Far-Forward detectors uniquely challenging in realization of ePIC!
  - Integrated with beamline → crowded area, complicated constraints on rates, beam operations, etc.
  - Trying to cover broad phase space not covered by main detector → Crucial for physics program!
  - Need to identify areas of complementarity to hone needs for IP8!
- Technologies identified for the all subsystems, and (many) simulations have been carried out → engineering design underway for CD-2/3A
- Backgrounds have been studied → more to do! (see information here)

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/eic-project-detector/index.php?title=Collaboration

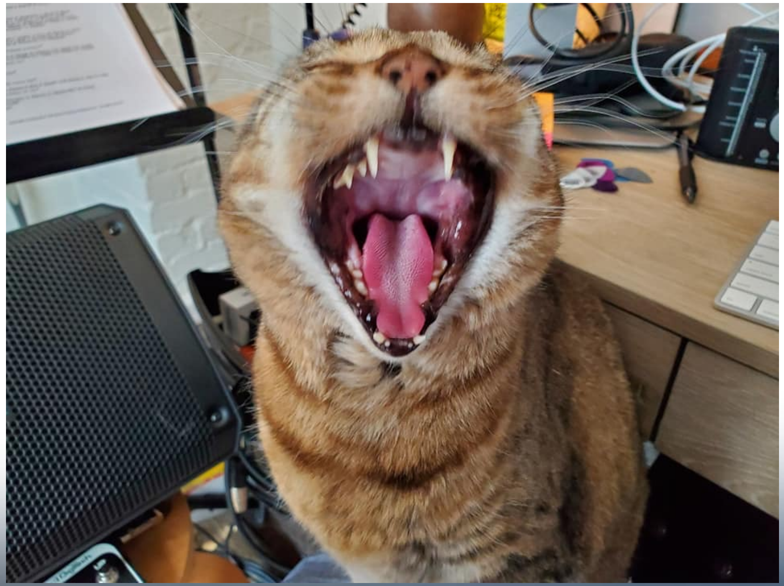
Subscribe to mailing list through: https://lists.bnl.gov/mailman/listinfo/eic-projdet-farforw-l

Thank you!

Julep

They (mostly) get along.

Lilu

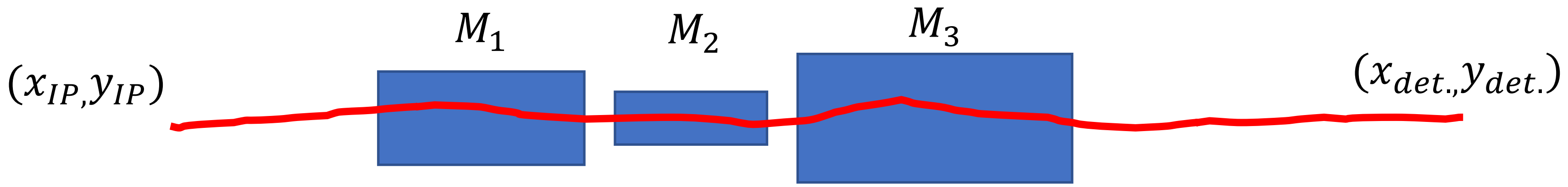


She's in a death metal band.

Backup

Preliminaries

- The EIC physics program includes reconstruction of final states with very far-forward protons, from many different possible collision systems.
  - e+p scattering, e+d/e+He3/e+A (proton(s) from nuclear breakup).
  - Produces protons with a broad range in longitudinal momentum, which then traverse the full hadron-going lattice (dipoles and quads).
- Momentum reconstruction requires *transfer matrices* to describe particle motion through the magnets.



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

$$\begin{pmatrix} x_{ip} \\ \theta_{x,ip} \\ y_{ip} \\ \theta_{y,ip} \\ z_{ip} \\ \Delta p/p \end{pmatrix} = \begin{pmatrix} a_0 & a_1 & a_2 & a_3 & a_4 & a_5 \\ b_0 & b_1 & b_2 & b_3 & b_4 & b_5 \\ c_0 & c_1 & c_2 & c_3 & c_4 & c_5 \\ d_0 & d_1 & d_2 & d_3 & d_4 & d_5 \\ e_0 & e_1 & e_2 & e_3 & e_4 & e_5 \\ f_0 & f_1 & f_2 & f_3 & f_4 & f_5 \end{pmatrix} \begin{pmatrix} x_{det.} \\ \theta_{x,det.} \\ y_{det.} \\ \theta_{y,det.} \\ z_{det.} \\ \Delta p/p \end{pmatrix}$$

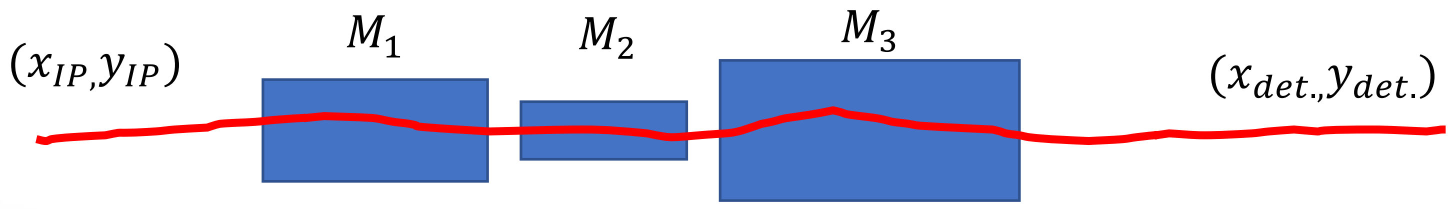
- Transforms coordinates at detectors (position, angle) to original IP coordinates.
- Matrix unique for different positions along the beam-axis!

Preliminaries

$$\begin{pmatrix} 1.88 & 28.97 & .0 & 0.0 & 0.0 & 0.25 \\ -0.0211 & 0.21 & 0.0 & 0.0 & 0.0 & -0.034 \\ 0.0 & 0.0 & -2.26 & 3.78 & 0.0 & 0.0 \\ 0.0 & 0.0 & -0.18 & -0.145 & 0.0 & 0.0 \\ 0.057 & 1.014 & 0.0 & 0.0 & 1.0 & 0.026 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 \end{pmatrix} \begin{pmatrix} x_{ip} \\ \theta_{xip} \\ y_{ip} \\ \theta_{yip} \\ z_{ip} \\ \Delta p/p \end{pmatrix} = \begin{pmatrix} x_{28m} \\ \theta_{x,28m} \\ y_{28m} \\ \theta_{y28m} \\ z_{28m} \\ \Delta p/p \end{pmatrix}$$

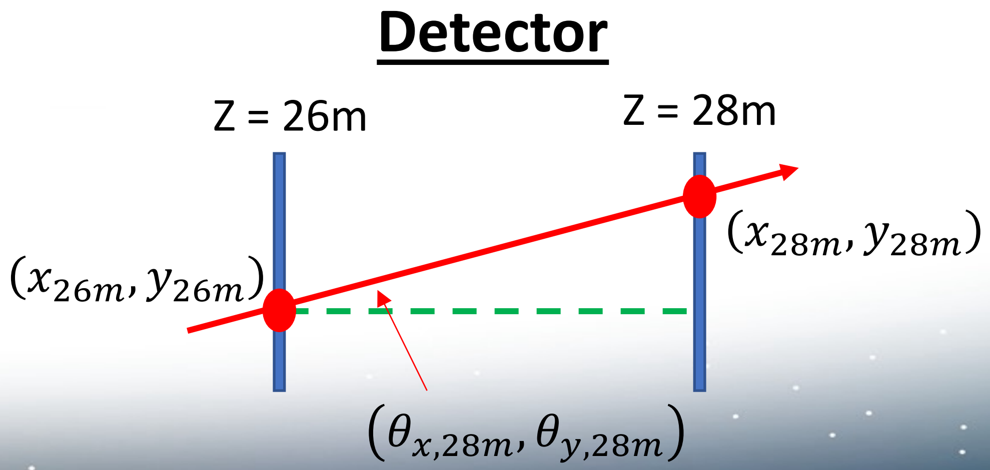
From BMAD – central trajectory 275 GeV proton

- Matrix describes how particles travel through the magnets toward the detector.



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

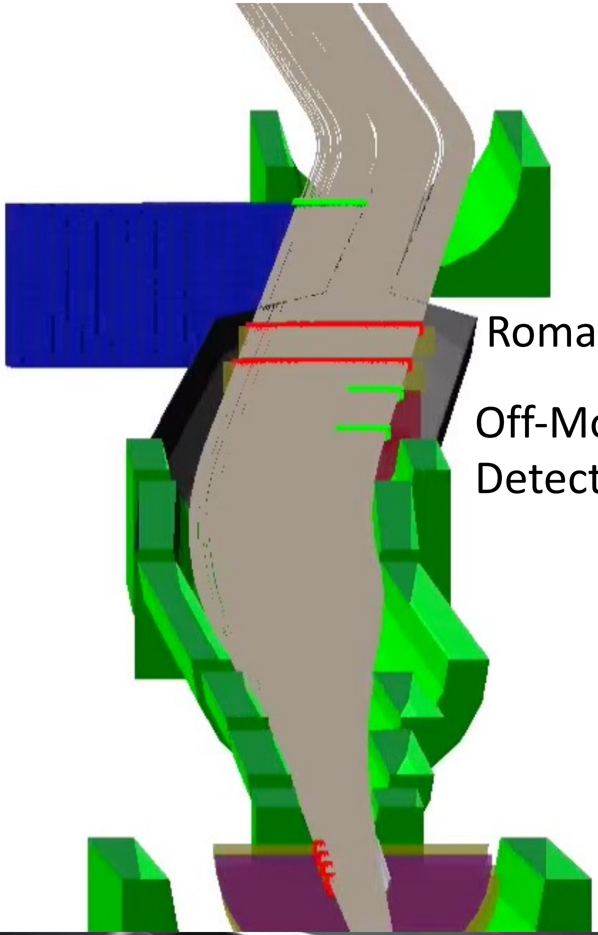
Matrix enables reconstruction of scattering information at the IP using only local hits at the detector.



The Problem

$$\begin{pmatrix} 1.88 & 28.97 & 0.0 & 0.0 & 0.0 & 0.25 \\ -0.0211 & 0.21 & 0.0 & 0.0 & 0.0 & -0.034 \\ 0.0 & 0.0 & -2.26 & 3.78 & 0.0 & 0.0 \\ 0.0 & 0.0 & -0.18 & -0.145 & 0.0 & 0.0 \\ 0.057 & 1.014 & 0.0 & 0.0 & 1.0 & 0.026 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 \end{pmatrix} \begin{pmatrix} x_{ip} \\ \theta_{xip} \\ y_{ip} \\ \theta_{yip} \\ z_{ip} \\ \Delta p/p \end{pmatrix} = \begin{pmatrix} x_{28m} \\ \theta_{x,28m} \\ y_{28m} \\ \theta_{y28m} \\ z_{28m} \\ \Delta p/p \end{pmatrix}$$

From BMAD – central trajectory 275 GeV proton



- Protons from nuclear breakup, or high-Q^2 e+p interactions → protons can have large deviations from central orbit momentum → **require unique matrices!**

longitudinal momentum fraction

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

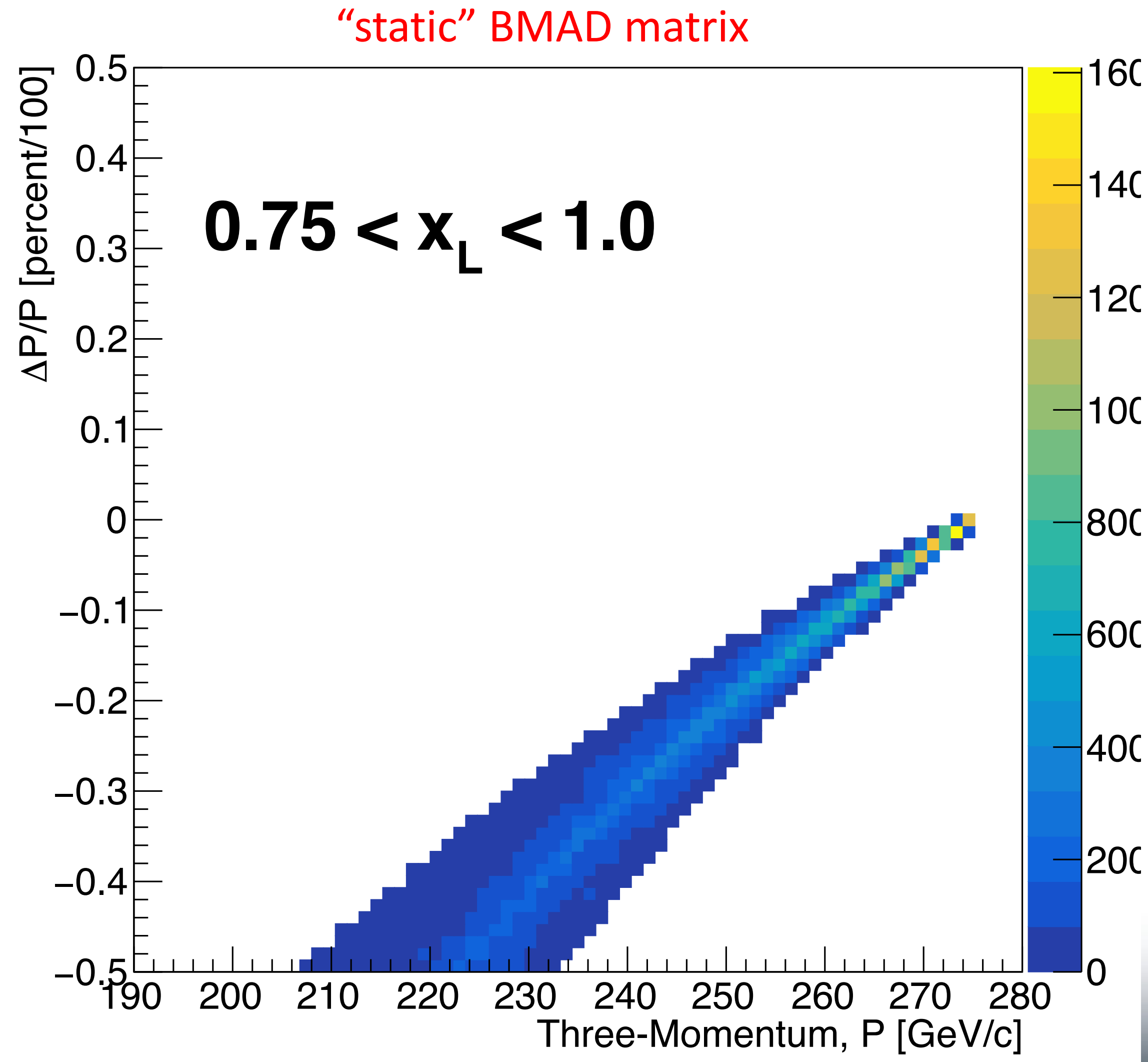
Full GEANT4 simulation.

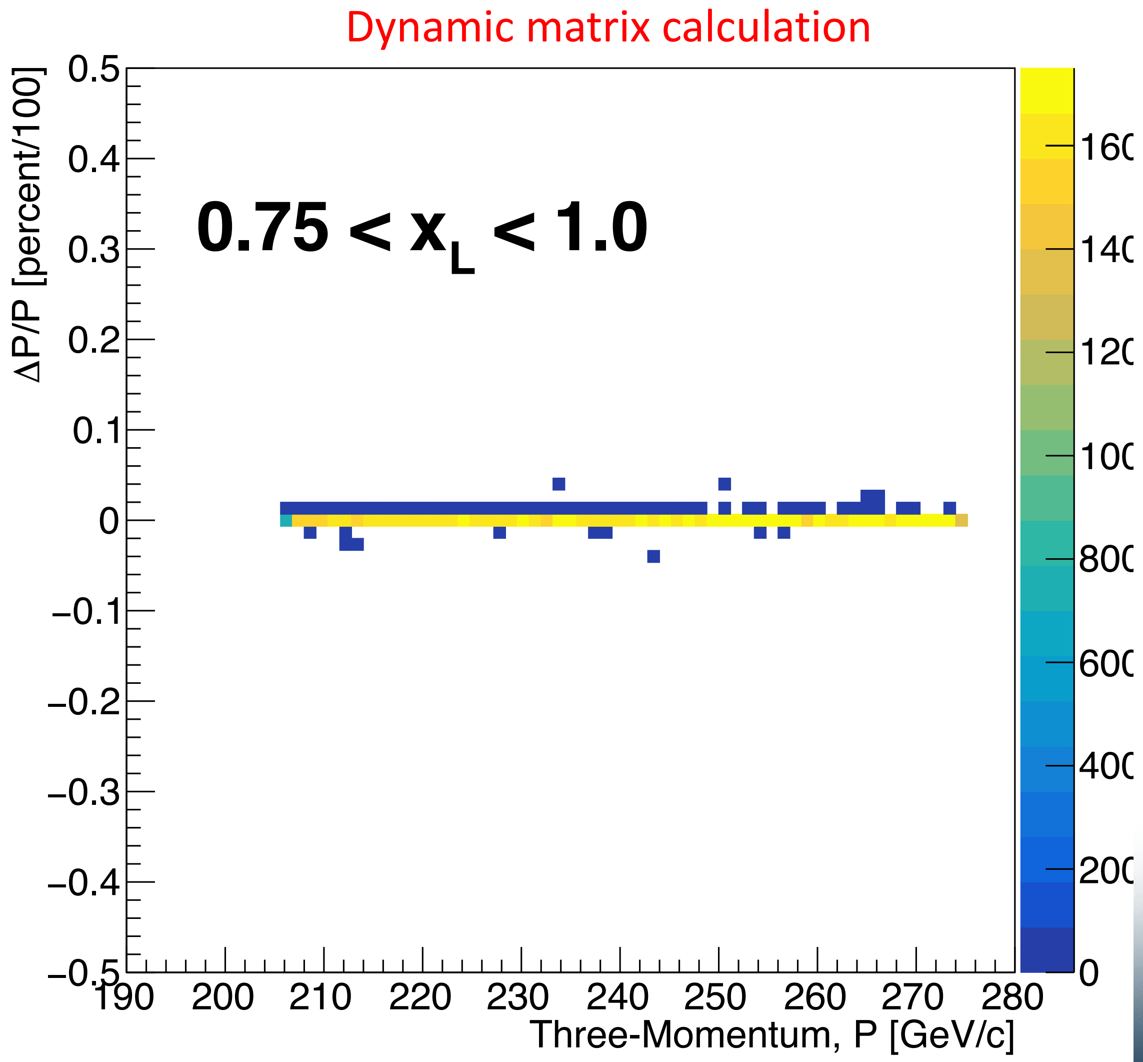
Protons
E = 275 GeV
$0 < \theta < 5$ mrad

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

Results - Momentum

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

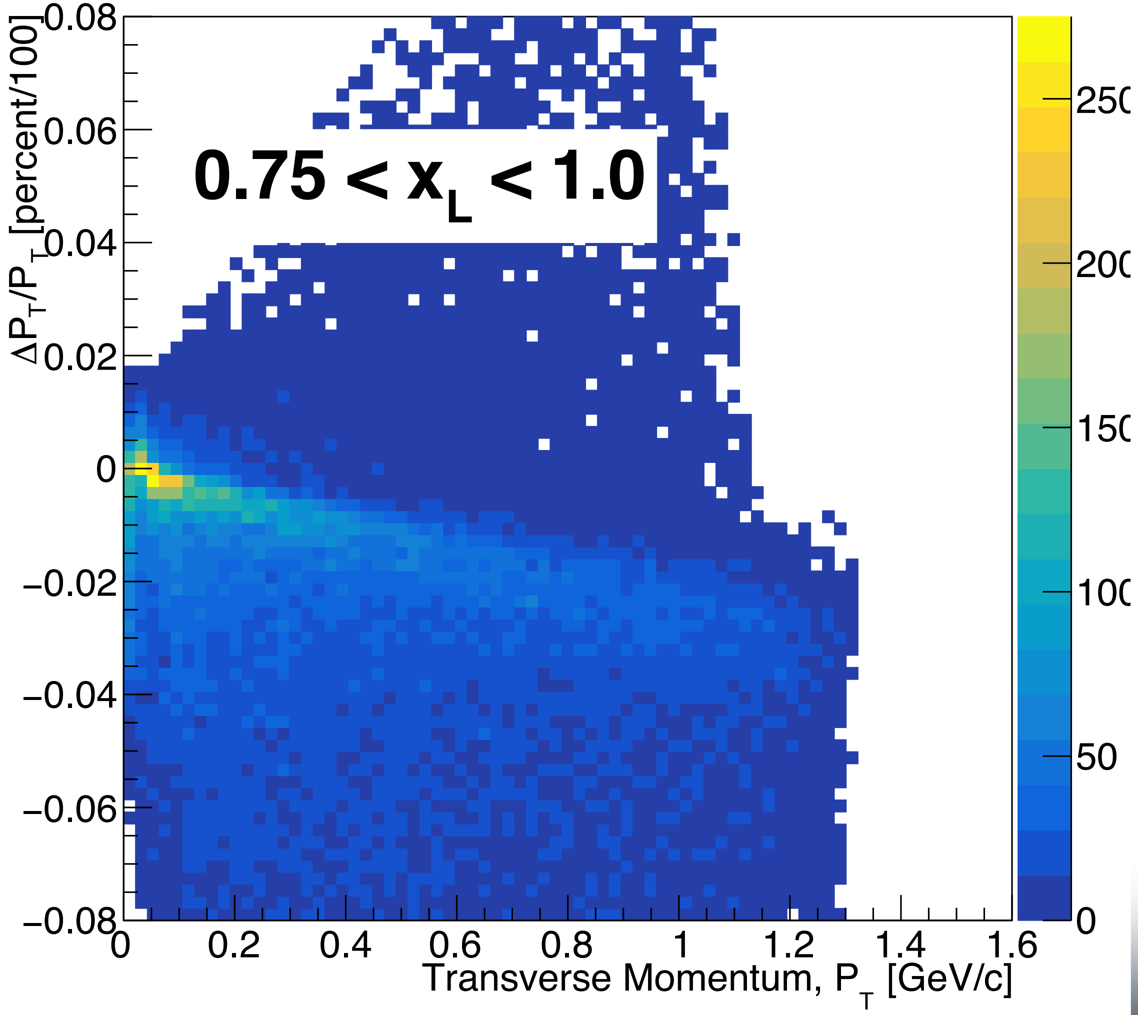




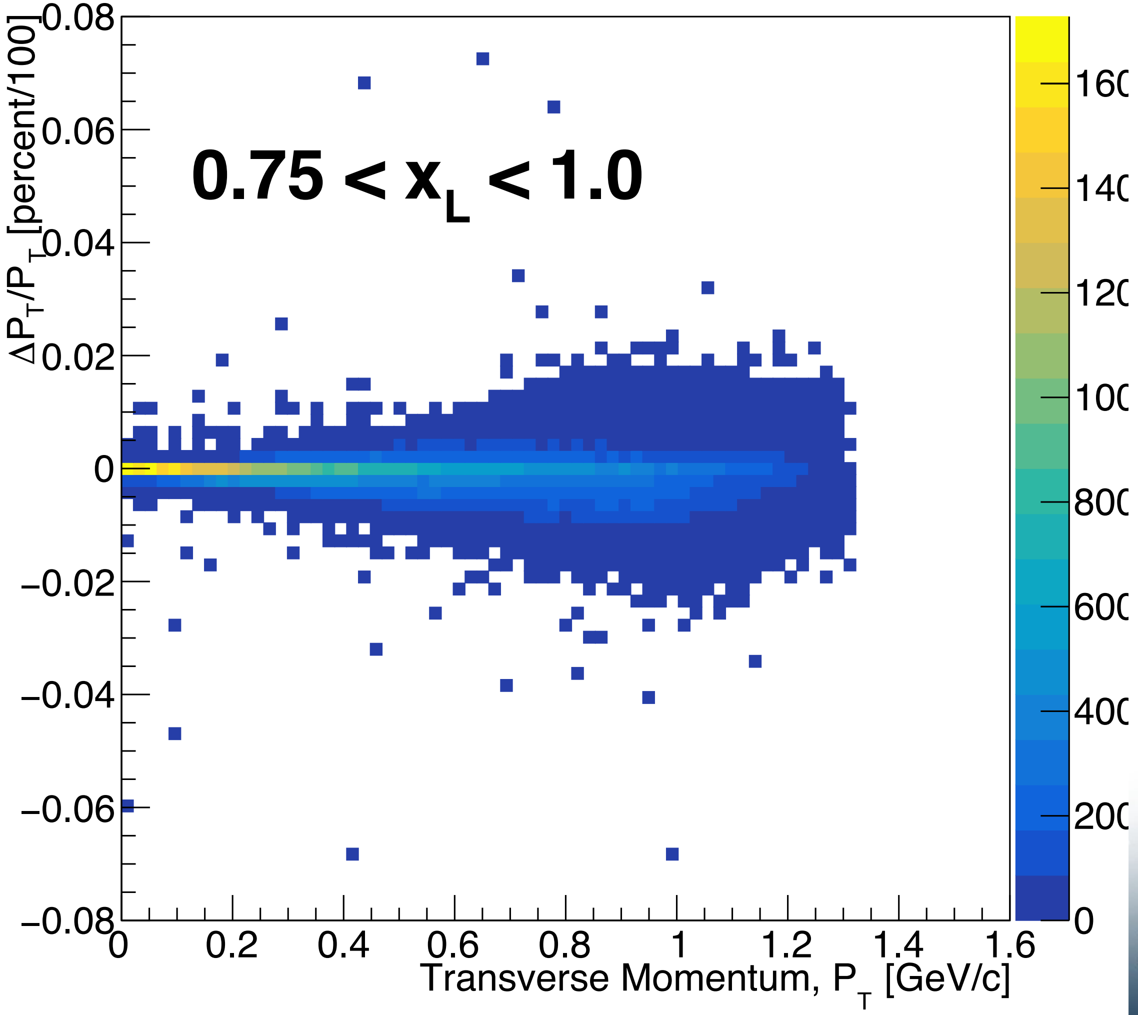
Results - p_T

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

“static” BMAD matrix



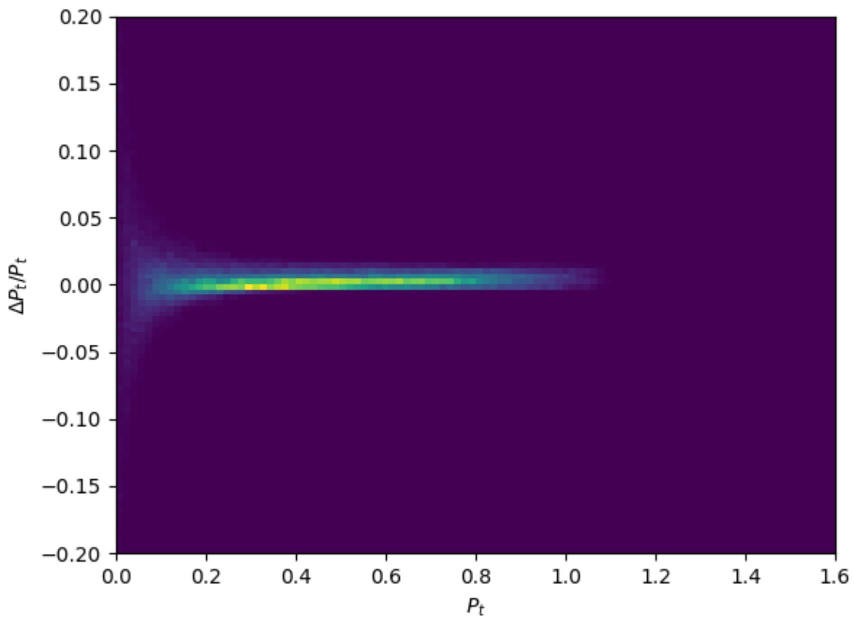
Dynamic matrix calculation

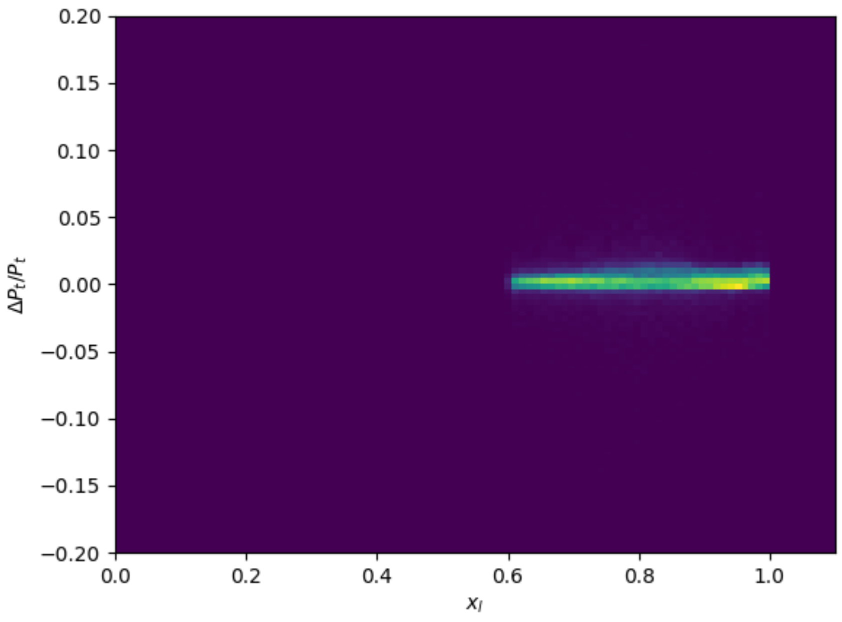


Reconstruction

- **General methods for tracking:**
  - **Matrix method (standard) → **should always have access to this to check performance.
  - **Machine learning methods → **more-general for broader set of final-state momenta.

$$\begin{pmatrix} x \\ \theta_x \\ y \\ \theta_y \end{pmatrix} \rightarrow (P_z) \qquad \begin{pmatrix} x \\ \theta_x \\ P_z \end{pmatrix} \rightarrow (P_x) \qquad \begin{pmatrix} y \\ \theta_y \\ P_z \end{pmatrix} \rightarrow (P_y)$$



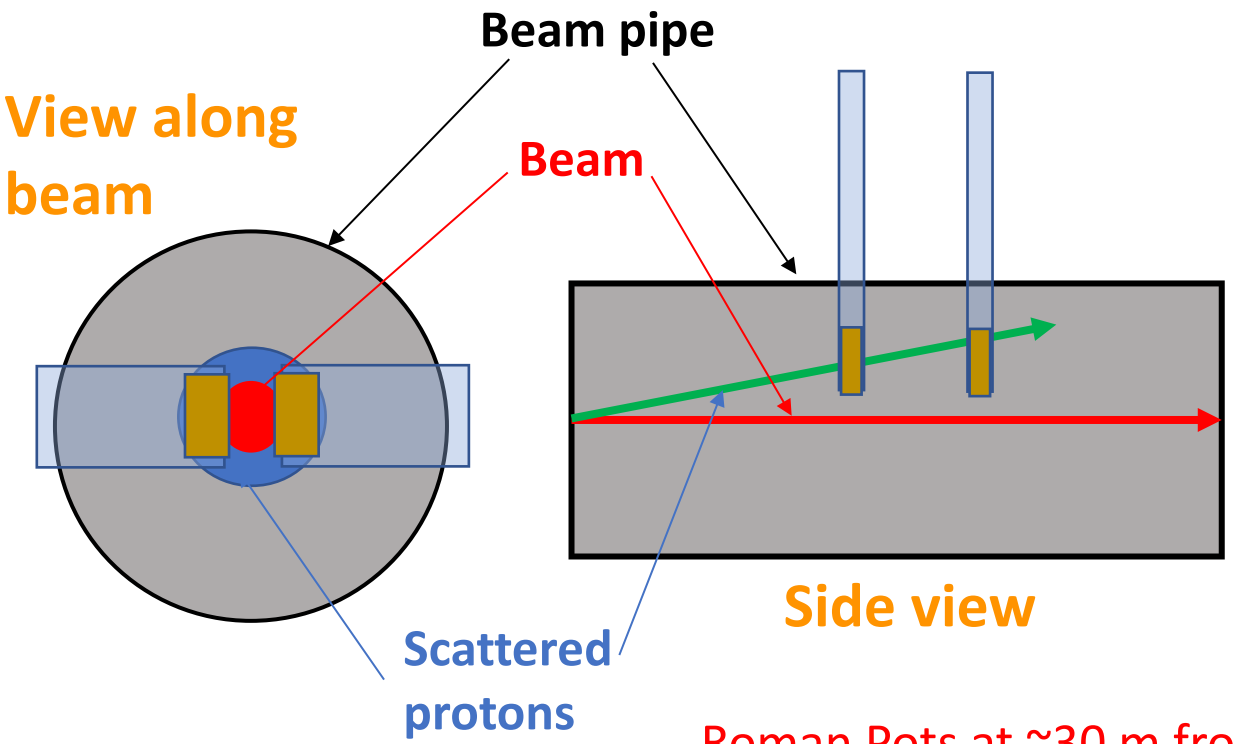


- **Framework:** PyTorch
- **Architecture:** Multi-Layer Perceptron
- **3 Independent Models:**
- **5 Hidden Layers, 128 Neurons**
- **Loss Function:** Huber Loss
- **Optimizer:** Adam
- Performance is excellent for P_z and shows little dependence on x_L
- P_t performance is good, but needs further optimization, and performance suffers at very low P_t

Progress on RP reconstruction.

David Ruth & Sakib Rahman

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

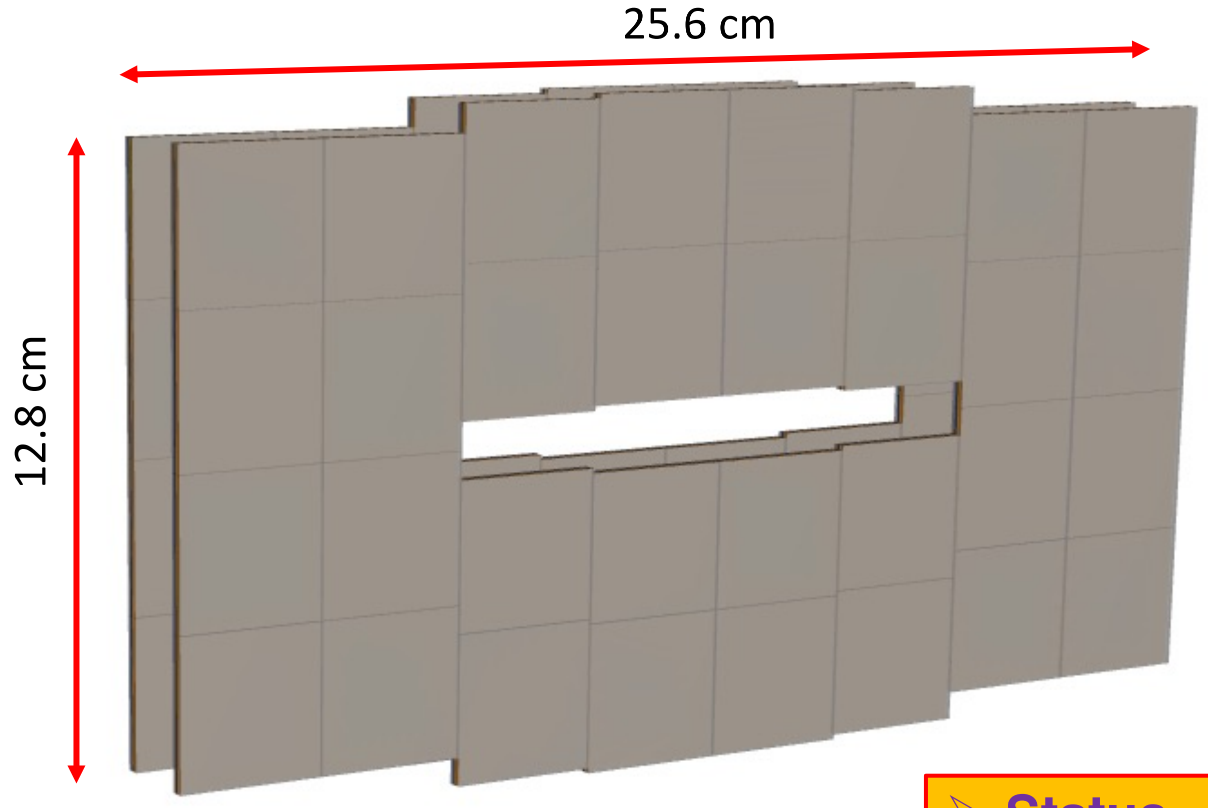
x_D, y_D : Position at Detector

Θ^x_D, Θ^y_D : Angle at Detector

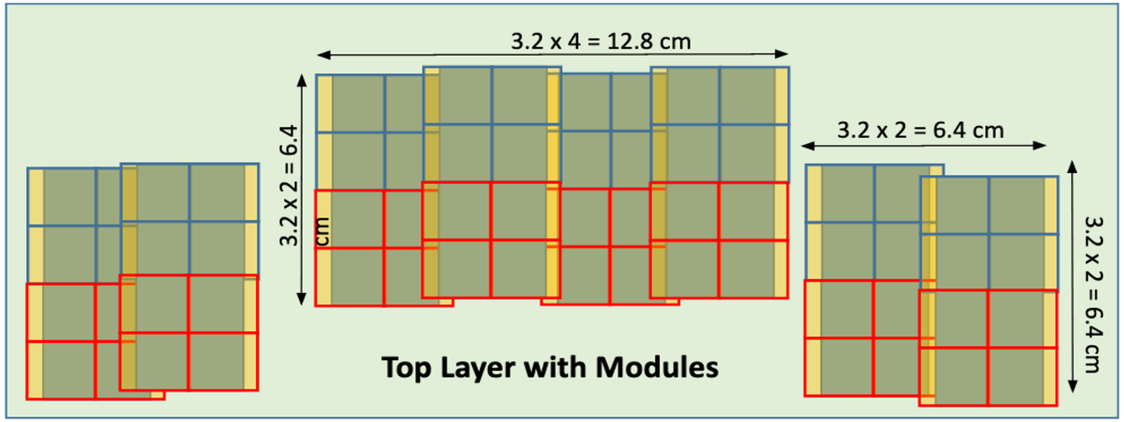
Roman Pots at ~30 m from IP → $\theta \backsim$ 0 - 5 mrad

- 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



DD4HEP Simulation



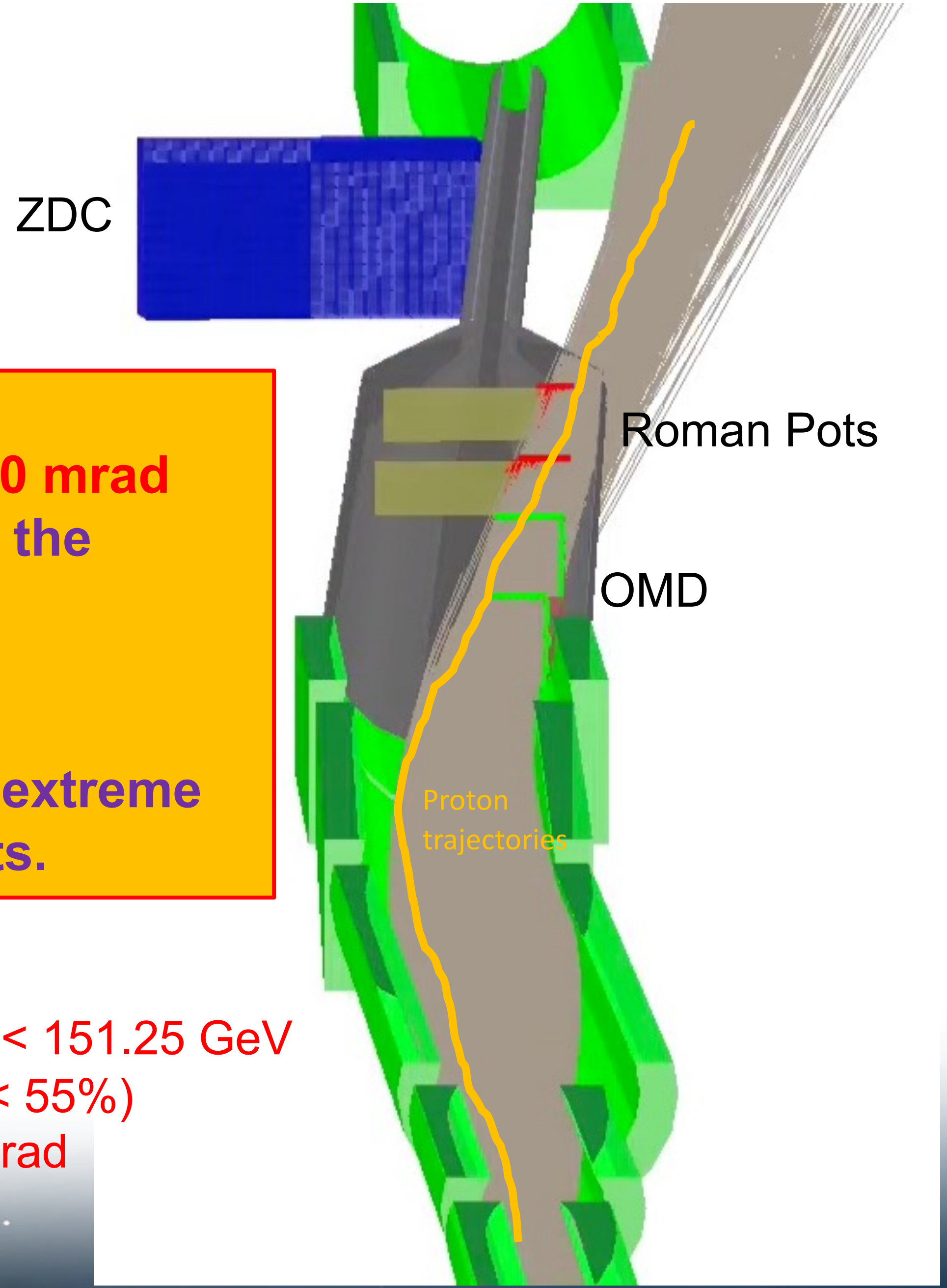
Technology

- 500um, pixilated AC-LGAD sensor provides both fine pixilation.
- "Potless" design concept with thin RF foils surrounding detector components.

- **Status**
  - ✓ **Acceptance: 0.0* < θ < 5.0 mrad (lower bound depends on optics).**
  - ✓ **Detector directly in-vacuum a challenge for both detector and beam → impedance studies underway.**
  - ✓ **Approved generic R&D to develop more-adaptive reconstruction code!**

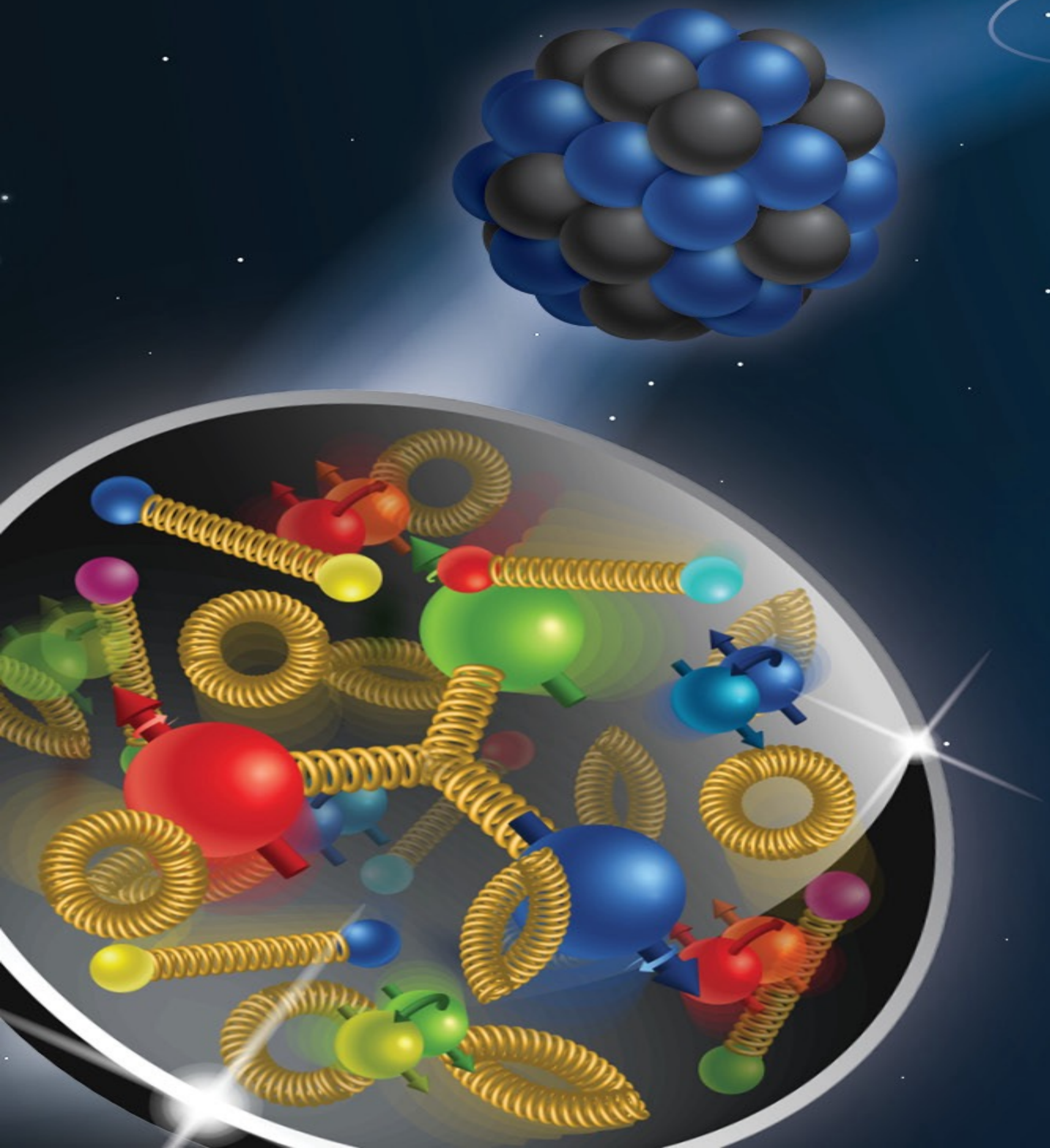
Off-Momentum Detectors

- **Status**
  - ✓ **Acceptance: 0.0 < θ < 5.0 mrad**
  - ✓ **Same technology as for the Roman Pots.**
  - ✓ **Even more-challenging reconstruction with off-momentum particles → extreme orbit path in the magnets.**



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

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



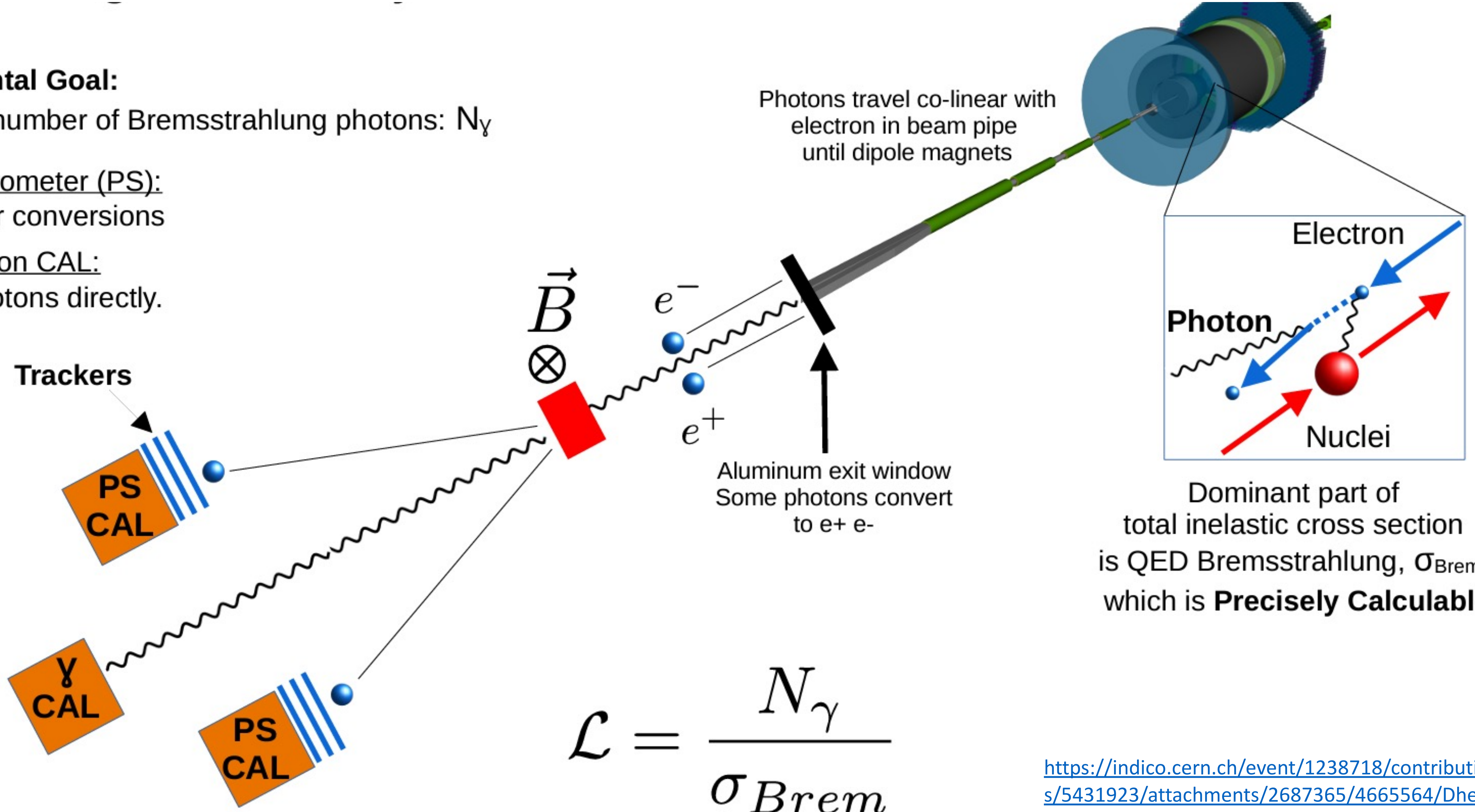
Far-Backward Detectors

Measuring Luminosity

Experimental Goal:
Count the number of Bremsstrahlung photons: N_γ

Pair Spectrometer (PS):
Counts pair conversions

Direct photon CAL:
Counts photons directly.



Dominant part of
total inelastic cross section
is QED Bremsstrahlung, σ_{Brem},
which is **Precisely Calculable**

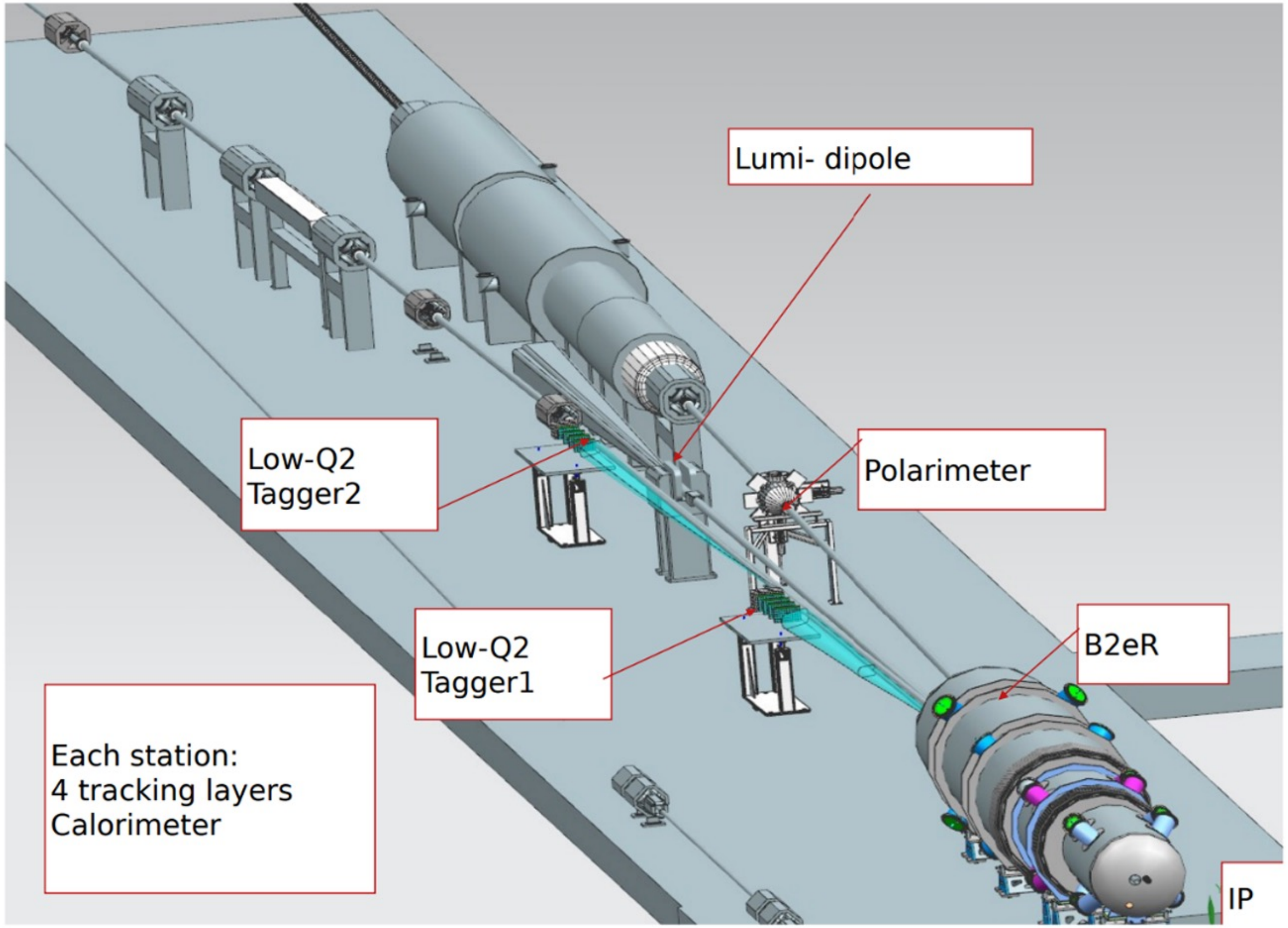
$$\mathcal{L} = \frac{N_\gamma}{\sigma_{Brem}}$$

https://indico.cern.ch/event/1238718/contributions/5431923/attachments/2687365/4665564/Dhevan_PS_ePIC_ColabMeeting_July29_2023.pdf

Slide from Dhevan Gangadharan and Nick Zachariou

Tagging Electrons at Low-Q^2

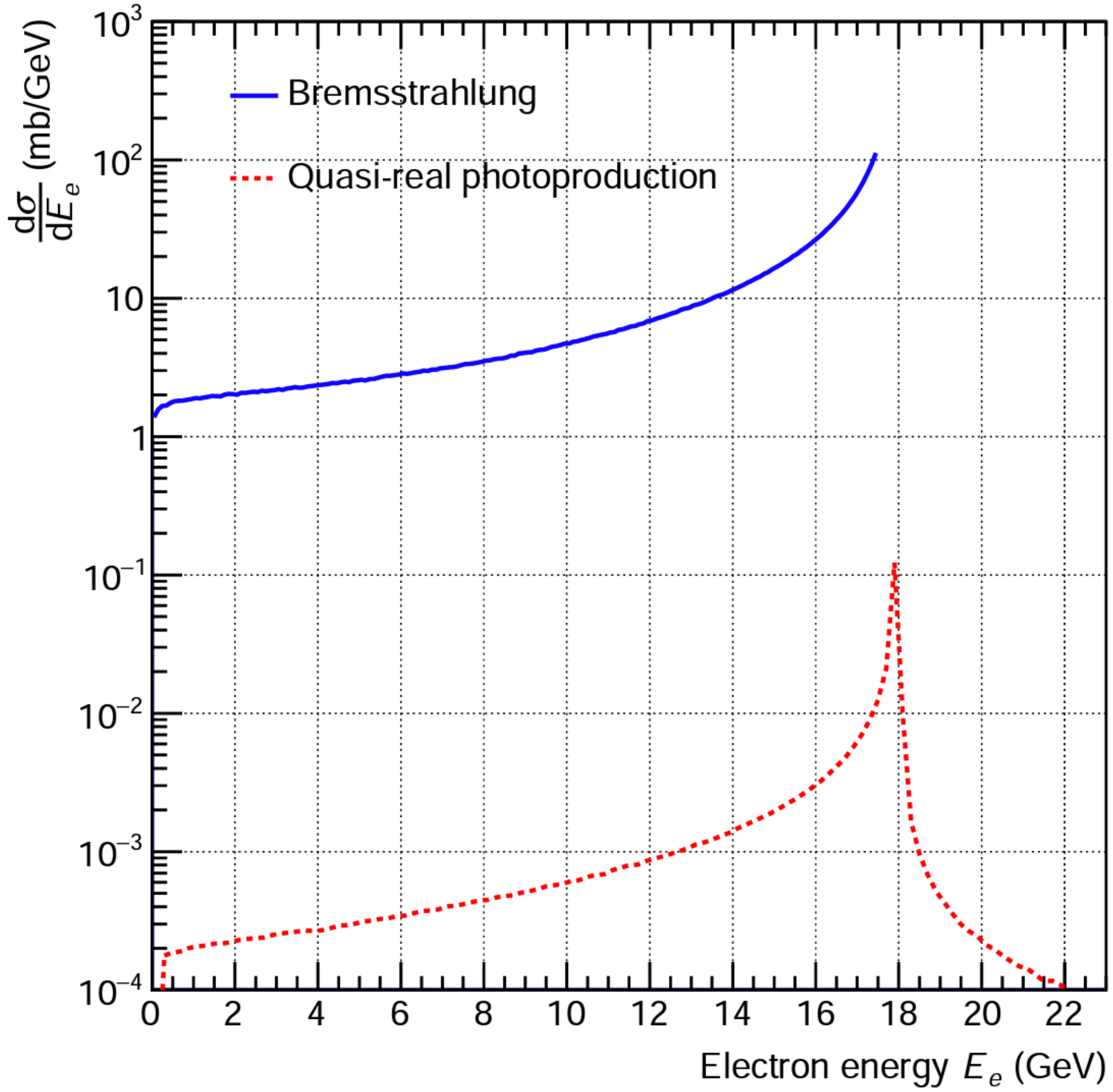
- Jaroslav Adam (Project Lead)
  `jaroslav.adam@fjfi.cvut.cz`
- Simon Gardner (Technical Lead)
  `Simon.Gardner@Glasgow.ac.uk`
- Two low-Q^2 tagger detectors along outgoing electron beam pipe
- Placed at about -20 m and -36 m from IP



Slide from Jaroslav Adam (CTU)

Tagging Electrons at Low-Q^2

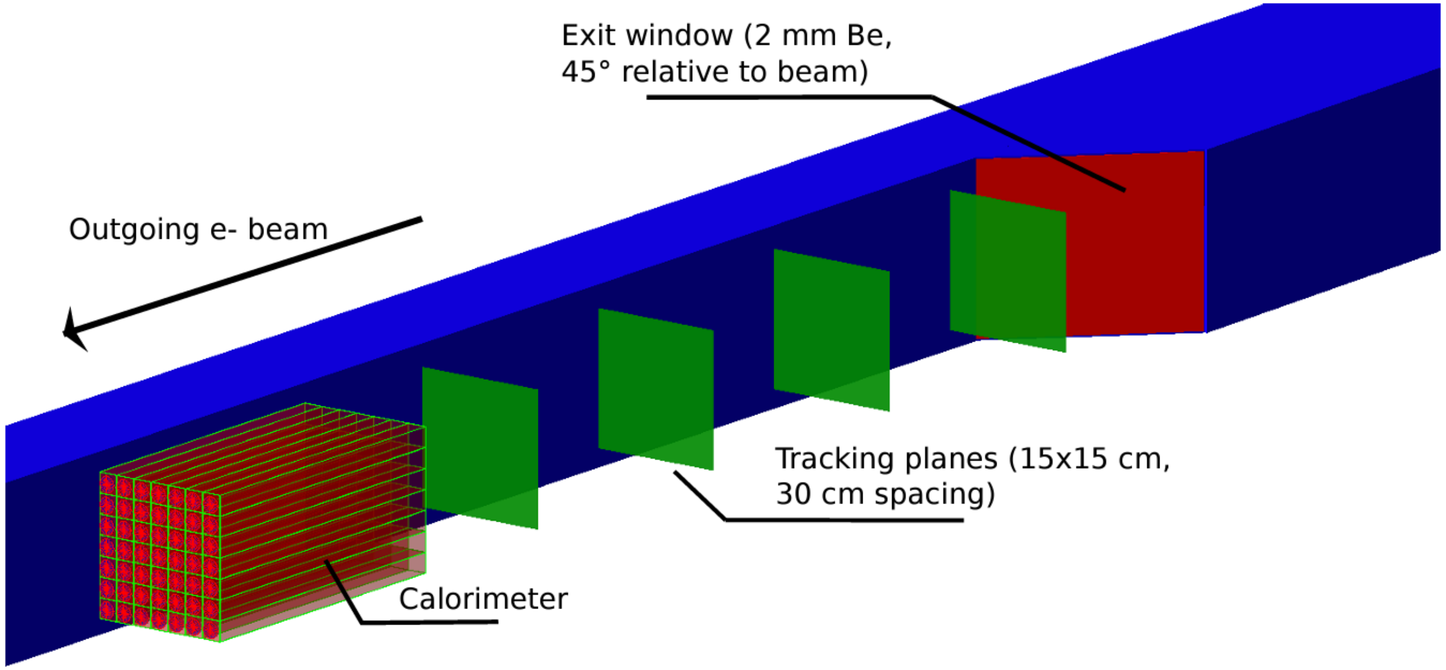
- Photoproduction in $10^{-3} \lesssim Q^2 \lesssim 10^{-1}$ GeV^2
- Scattered electrons for meson spectroscopy and exclusive pair production
- Help for luminosity measurement by coincidence with pair spectrometer
- Large background and event rates due to Bethe-Heitler bremsstrahlung – illustrated by comparing to photoproduction cross section
- The background can be mitigated by good tracking and Q^2 reconstruction

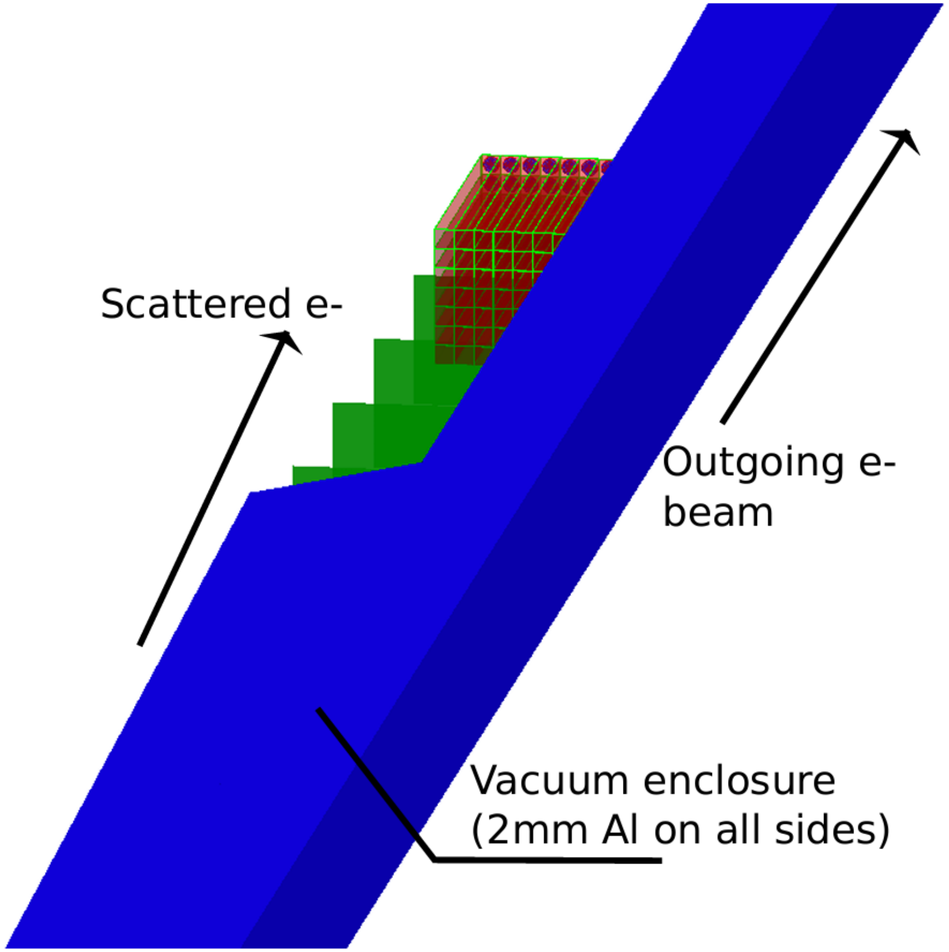


Slide from Jaroslav Adam (CTU)

Tagging Electrons at Low-Q^2

- Detectors outside beam vacuum
- Several considerations for exit window (material, thin mesh followed by 90° exit window)

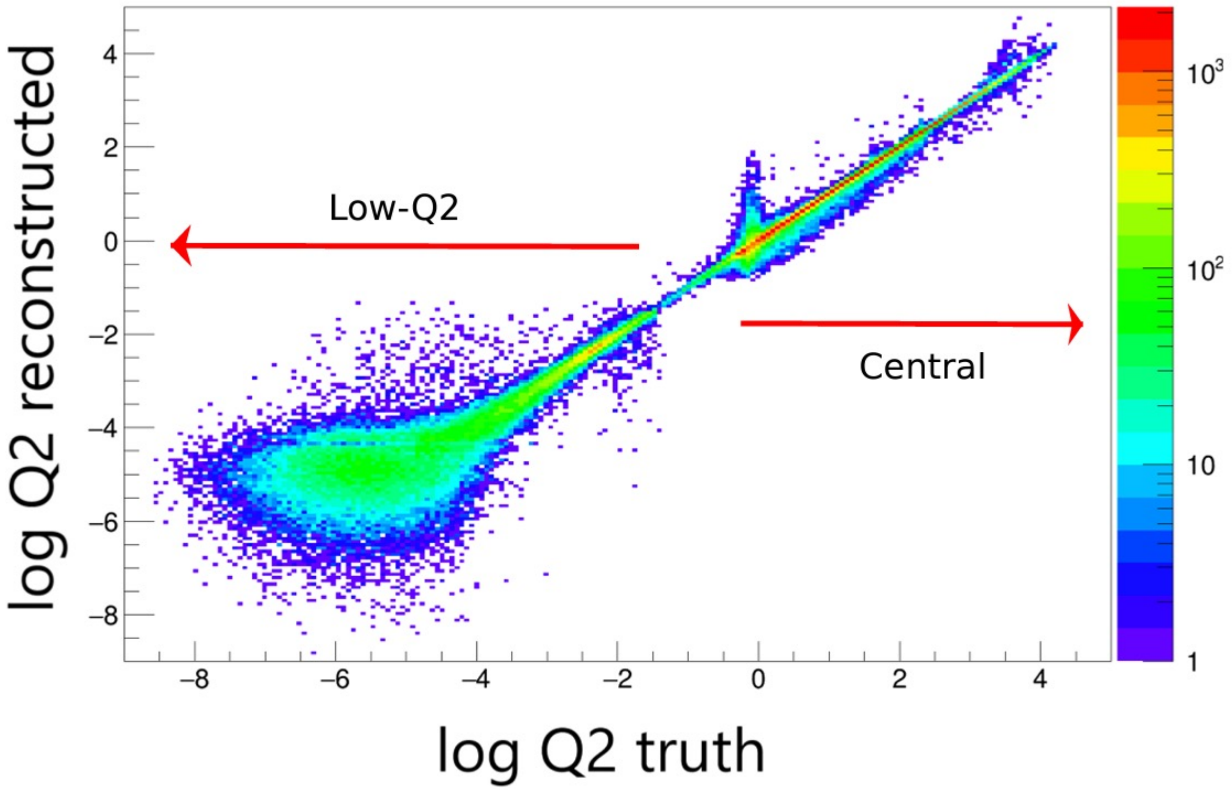




Slide from Jaroslav Adam (CTU)

Low-Q^2 Reconstruction

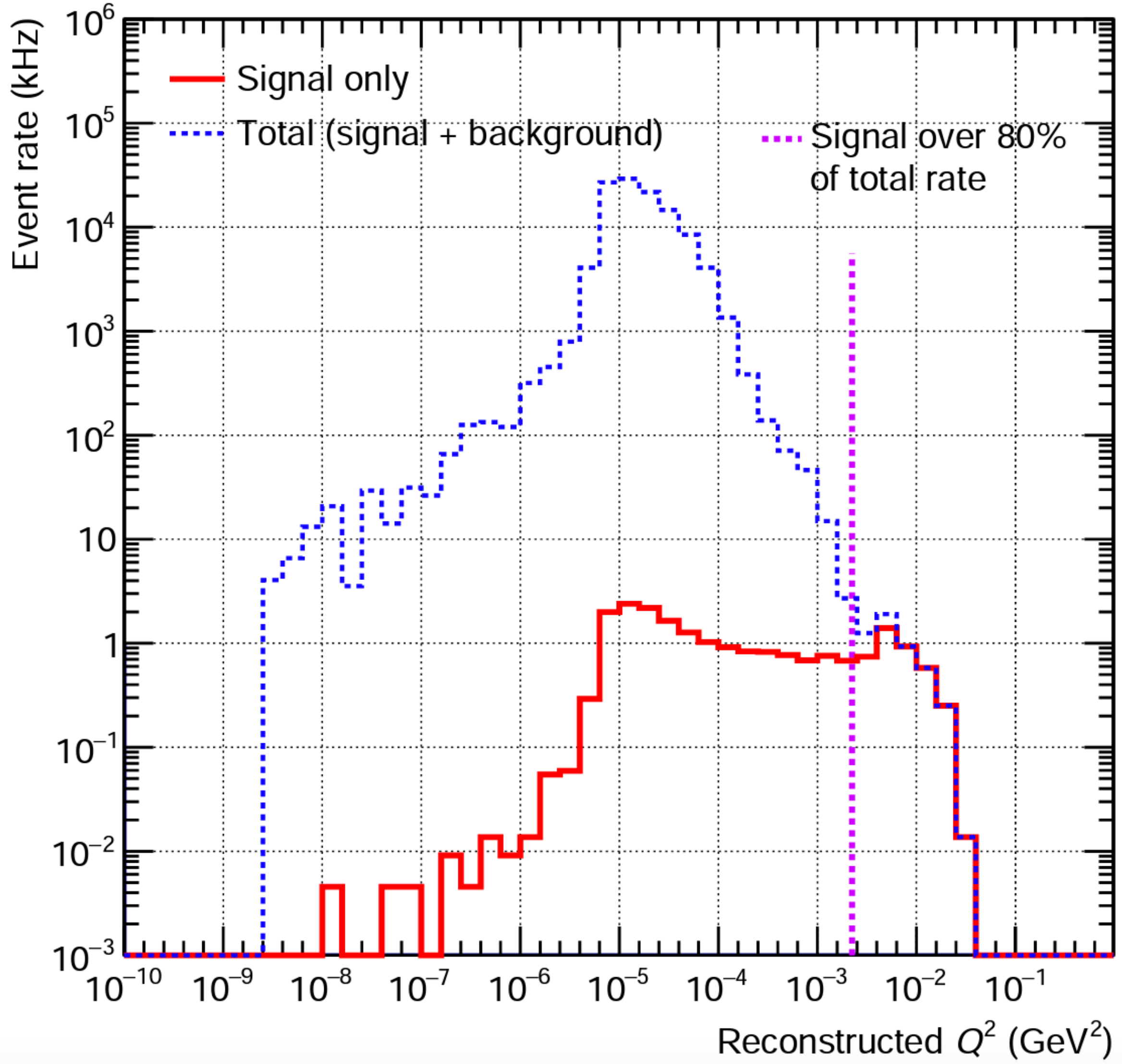
- Two different ML algorithms giving compatible results
- The algorithms connect reconstructed tracks to kinematics of original scattered electrons (energy and polar and azimuthal angle)
- Q^2 is obtained from electron energy and polar angle
- Plot shows combined reconstruction in low-Q^2 taggers and central detector



Slide from Jaroslav Adam (CTU)

Low-Q² Reconstruction

- Mixed hepmc of signal (quasi-real photoproduction) and background (Bethe-Heitler) events
- Event rates are obtained as a function of reconstructed Q^2
- Background tracks reconstruct dominantly to very low Q^2



Slide from Jaroslav Adam (CTU)

The Far-Forward Detectors collaboration

Detector Subsystem Lead (DSSL): Alex Jentsch

Control Account Manager
Yulia Furletova

B0 DSSTC:
Zvi Citron

- Tel Aviv University, Israel
- Hebrew University of Jerusalem, Israel
- Ben Gurion University of the Negev, Israel

OMD/RP DSSTC:
Alex Jentsch

- BNL, USA
- IJCLab, Orsay, France
- OMEGA, France
- IRFU/CEA-Saclay, France

ZDC DSSTC:
Yuji Goto

- RIKEN, Japan
- Kobe University, Japan
- University of Kansas, USA
- Pacific Northwest National Lab, USA
- NCU and Academia Sinica, Taiwan
- Sejong, South Korea