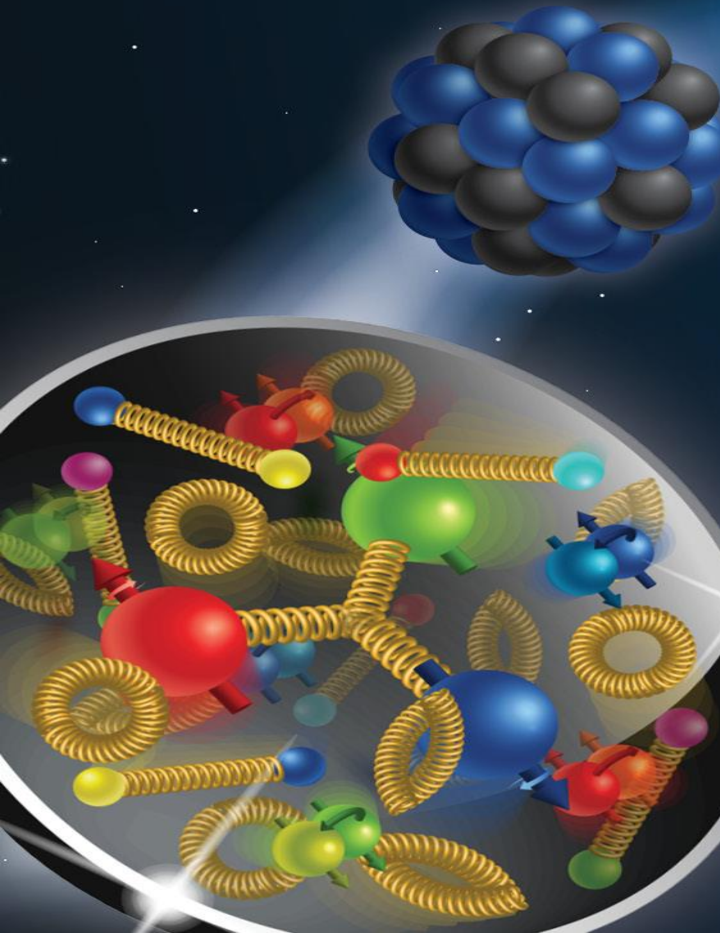


Far-Forward Detector (FFWD) Working Group Update

Michael Pitt (Ben Gurion University of the Negev)

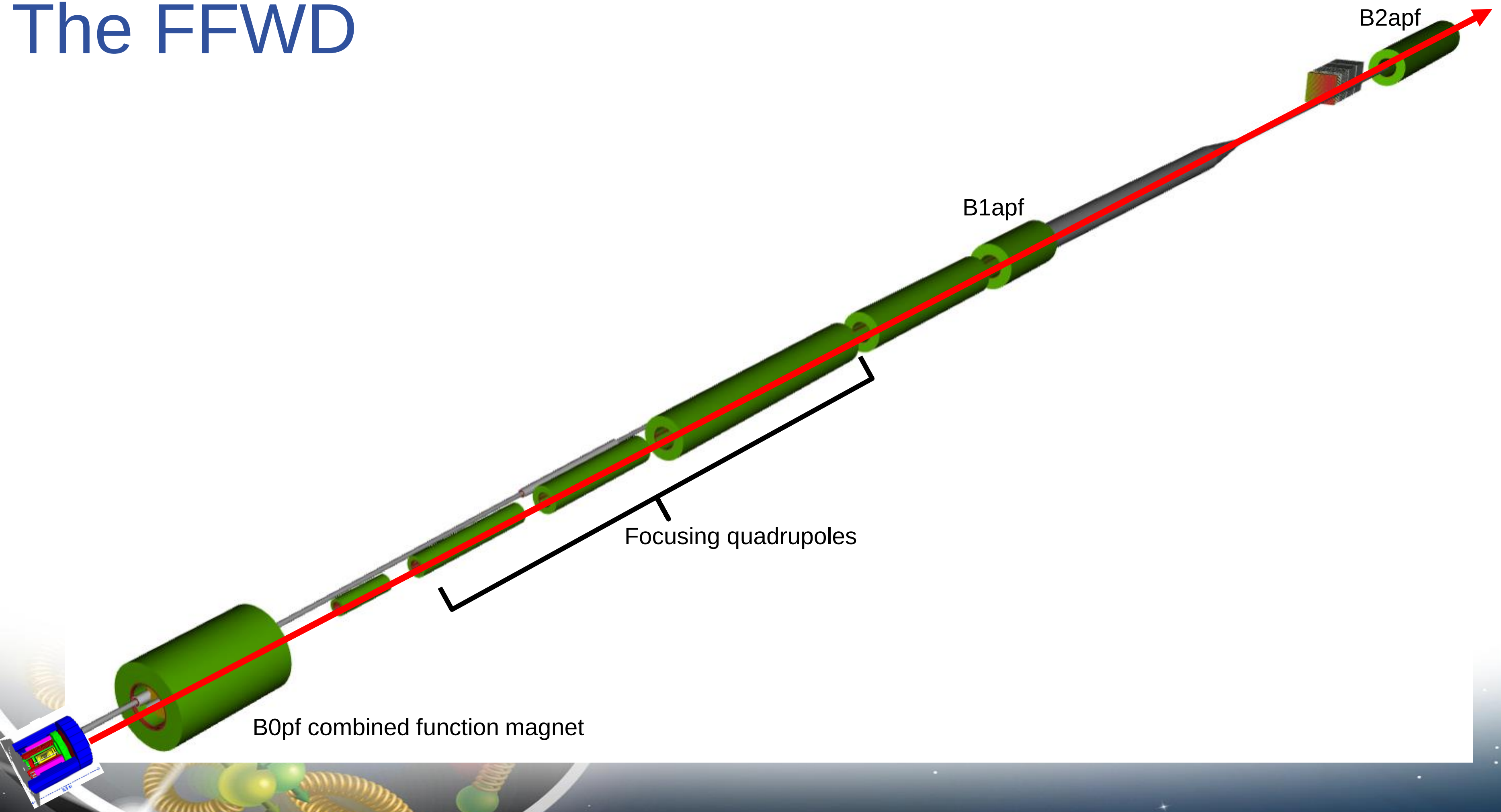
For the ePIC Far-Forward DWG

EIC UG Annual Meeting: July 23rd – 31st , 2023

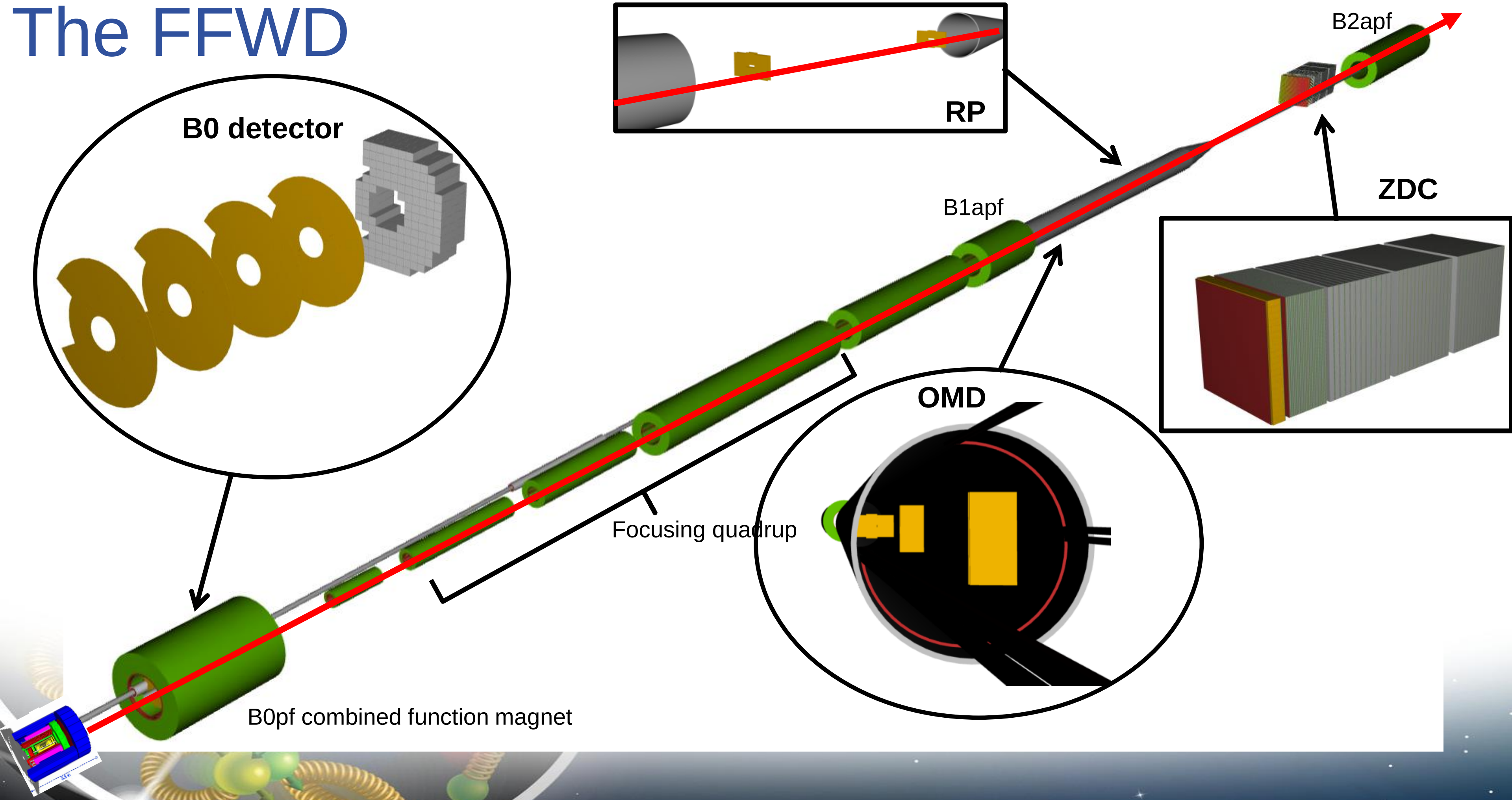
Warsaw, Poland

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

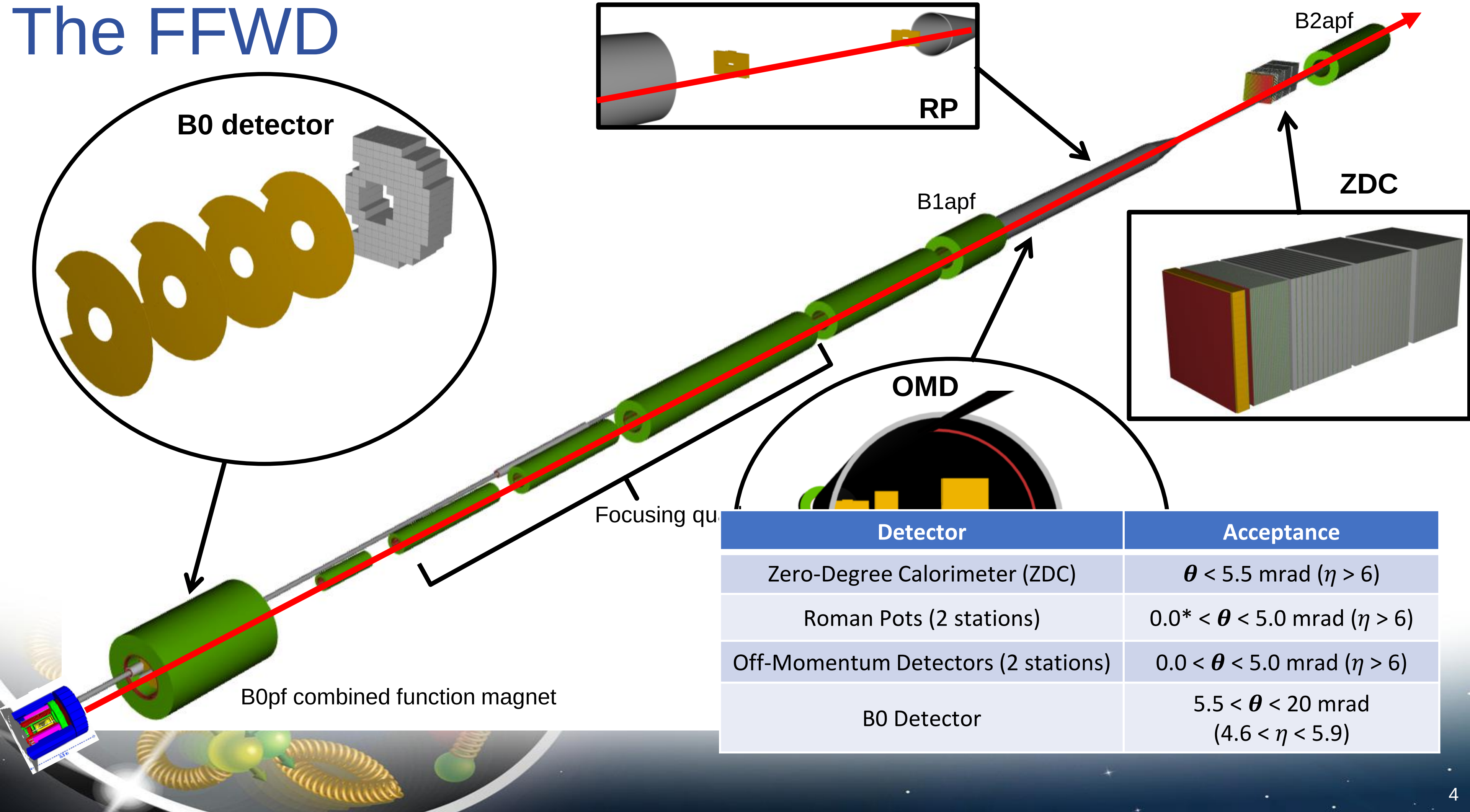
The FFWD


B2apf
B1apf
Focusing quadrupoles
B0pf combined function magnet

The FFWD


B0 detector
RP
B2apf
ZDC
B1apf
OMD
Focusing quadrup
B0pf combined function magnet

The FFWD



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 mrad (4.6 < η < 5.9)

The Far-Forward Detectors collaboration

Detector Subsystem Lead (DSSL): Alex Jentsch

Control Account Manager
Yulia Furletova

B0 DSSTC:
Zvi Citron

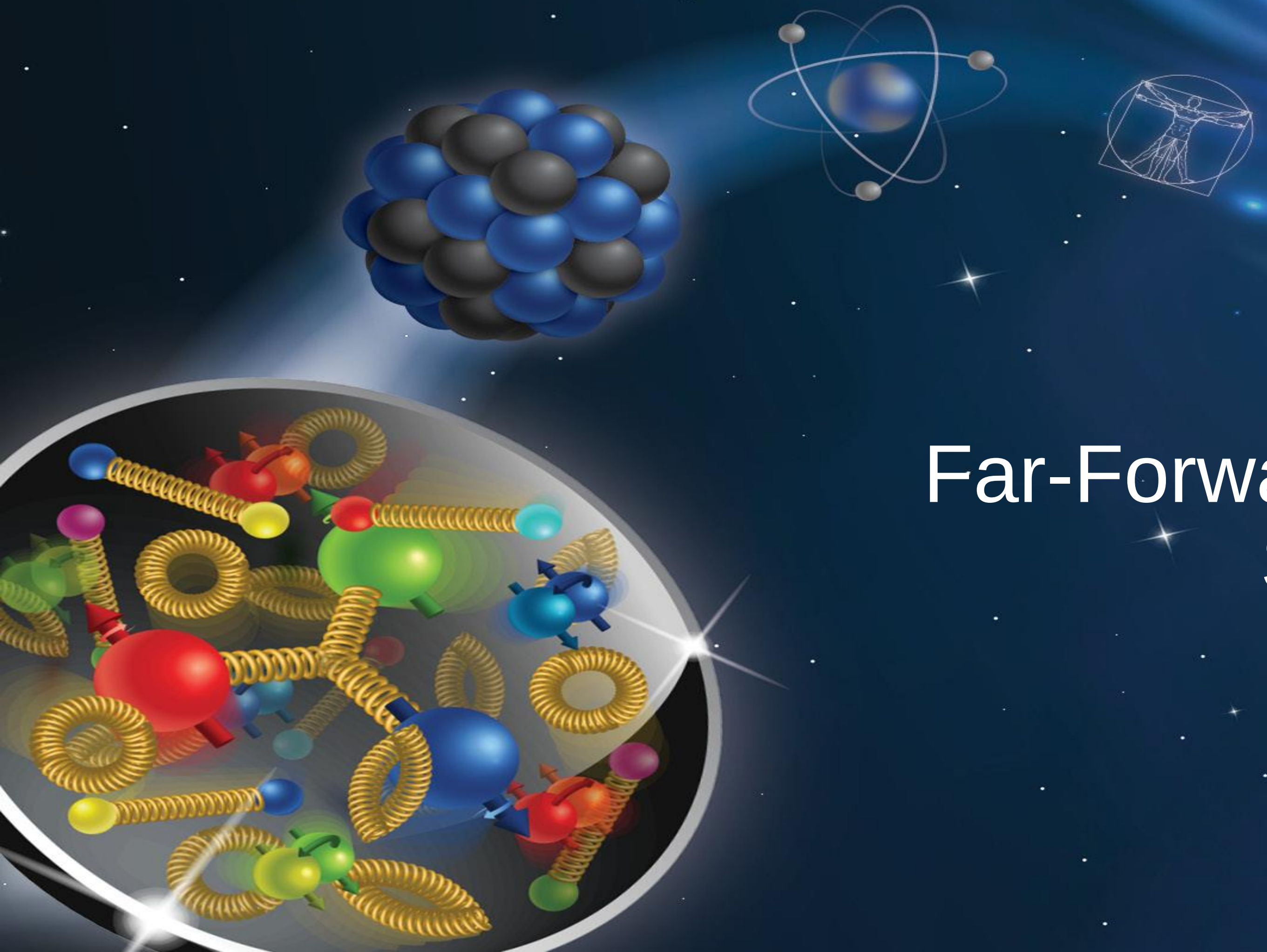
- Tel Aviv University, Israel
- Hebrew University of Jerusalem, Israel
- Ben Gurion University of the Negev, Israel

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



Far-Forward Detector Subsystems

B0 Detectors - What's New

CAD Look credit: Jonathan Smith

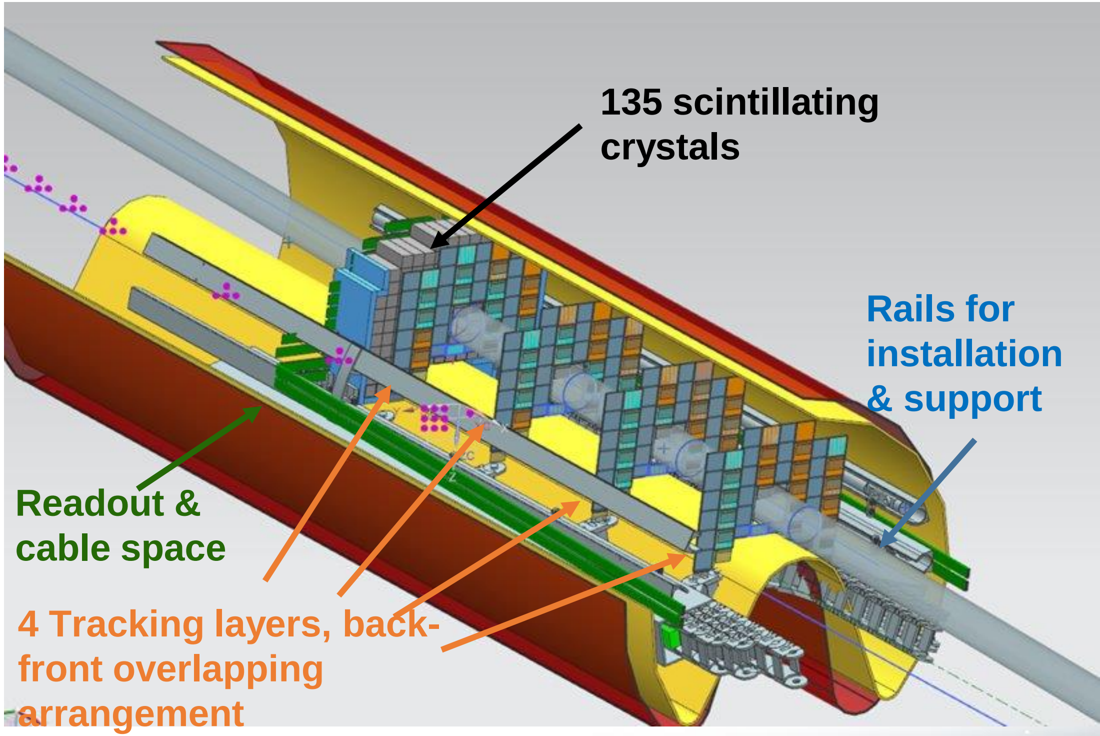
Design for two detectors is converging:

Si Tracker:

- 4 Layers of **AC-LGAD**
- Great timing capabilities
- Sufficient position resolution by utilizing charge sharing
- 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

B0 Detectors - Simulation Studies

B0 reconstuction is available in EICRecon

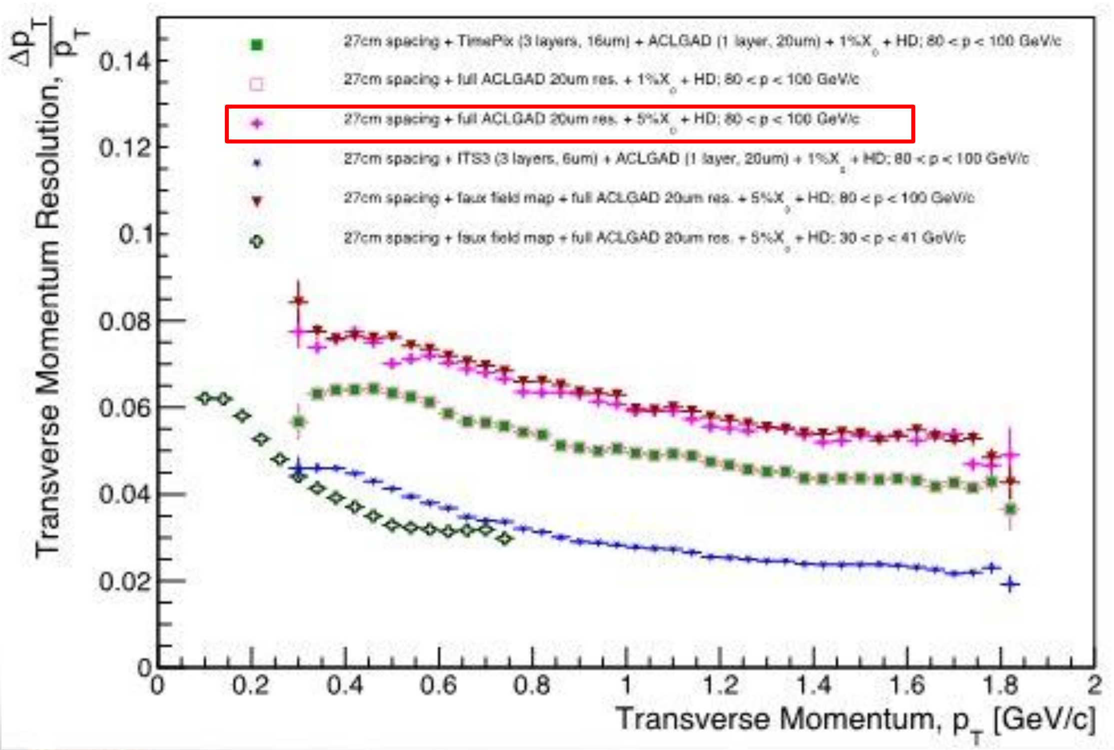
Si Tracker:

- Resolution plots made by Alex J 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 (more in Michael P. talk at the FF weekly meeting)
- Sensitivity to soft photons (see Eden M. talk at the EICUG EC workshop early this week)

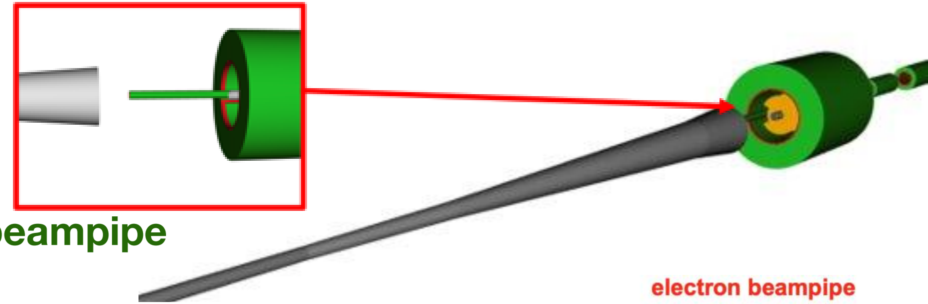
B Tracking - Performance



- 27cm spacing with fully AC-LGAD system and 5% radiation length may be the most-realistic option.
- Needs to be looked at with proper field map and layout.
- Is this resolution going to be a problem?

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

B0 EMCal - Performance



- Acceptance 5.5 < θ < 20 mrad
- Very low material budget in 5 < η < 5.5

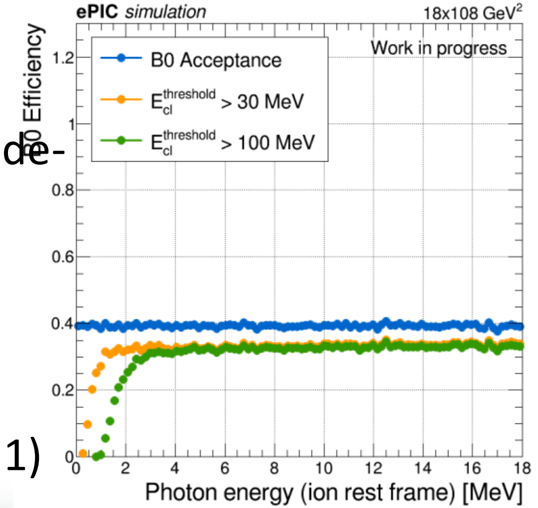
Particles within 5.5 < θ < 15 mrad don't cross the beampipe

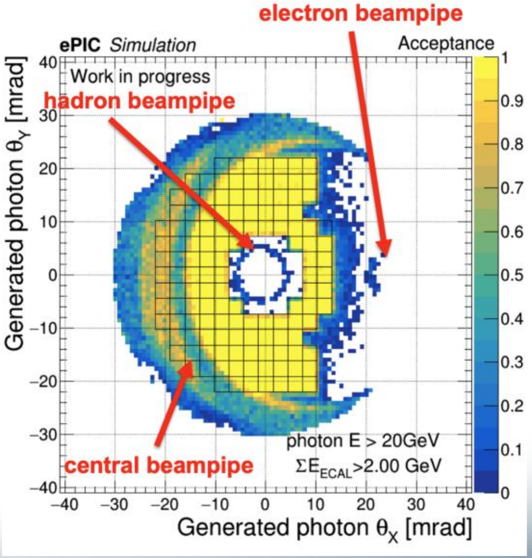
Photons:

- ➢ 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)

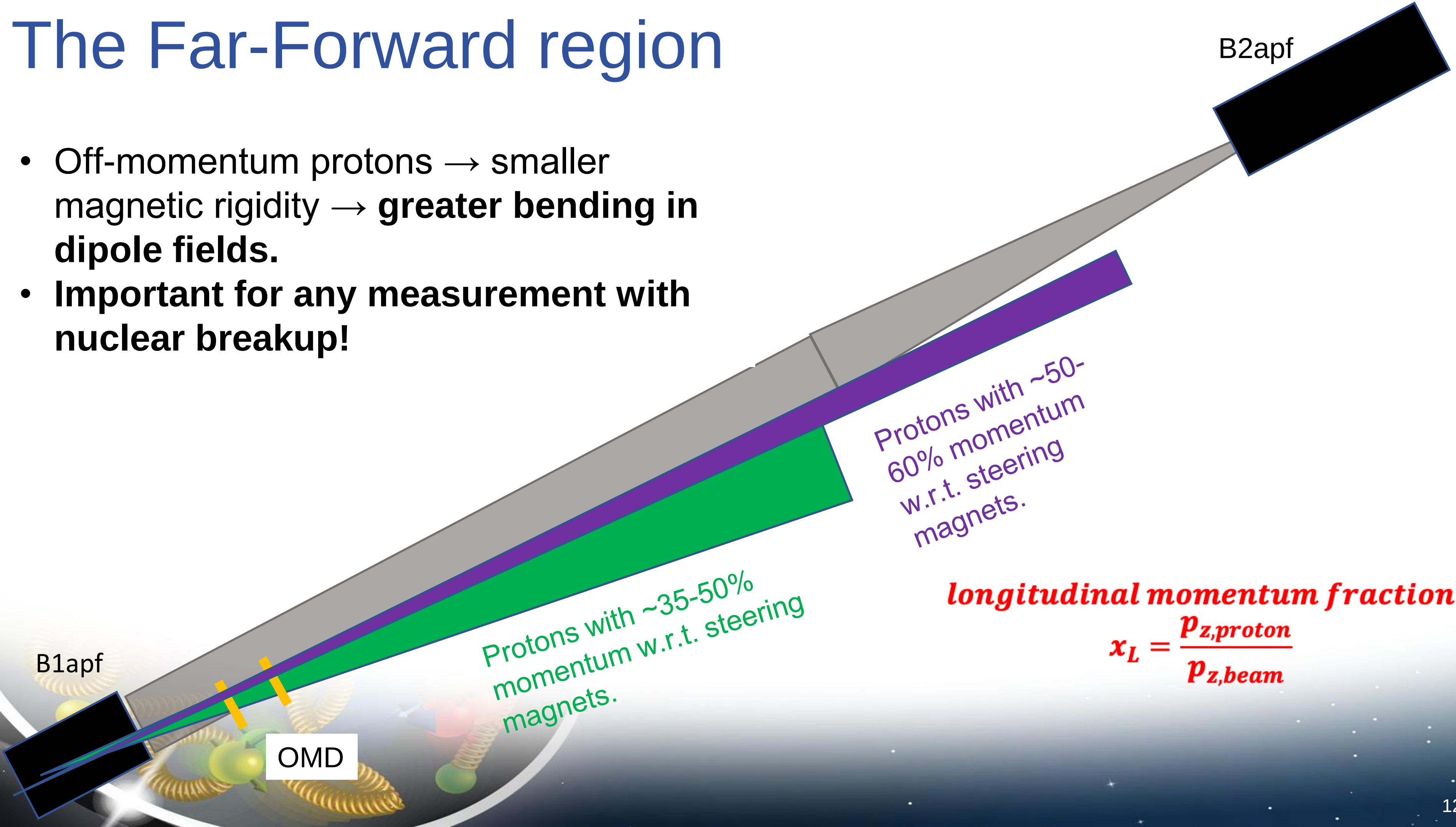




The Far-Forward region

The Far-Forward region

- 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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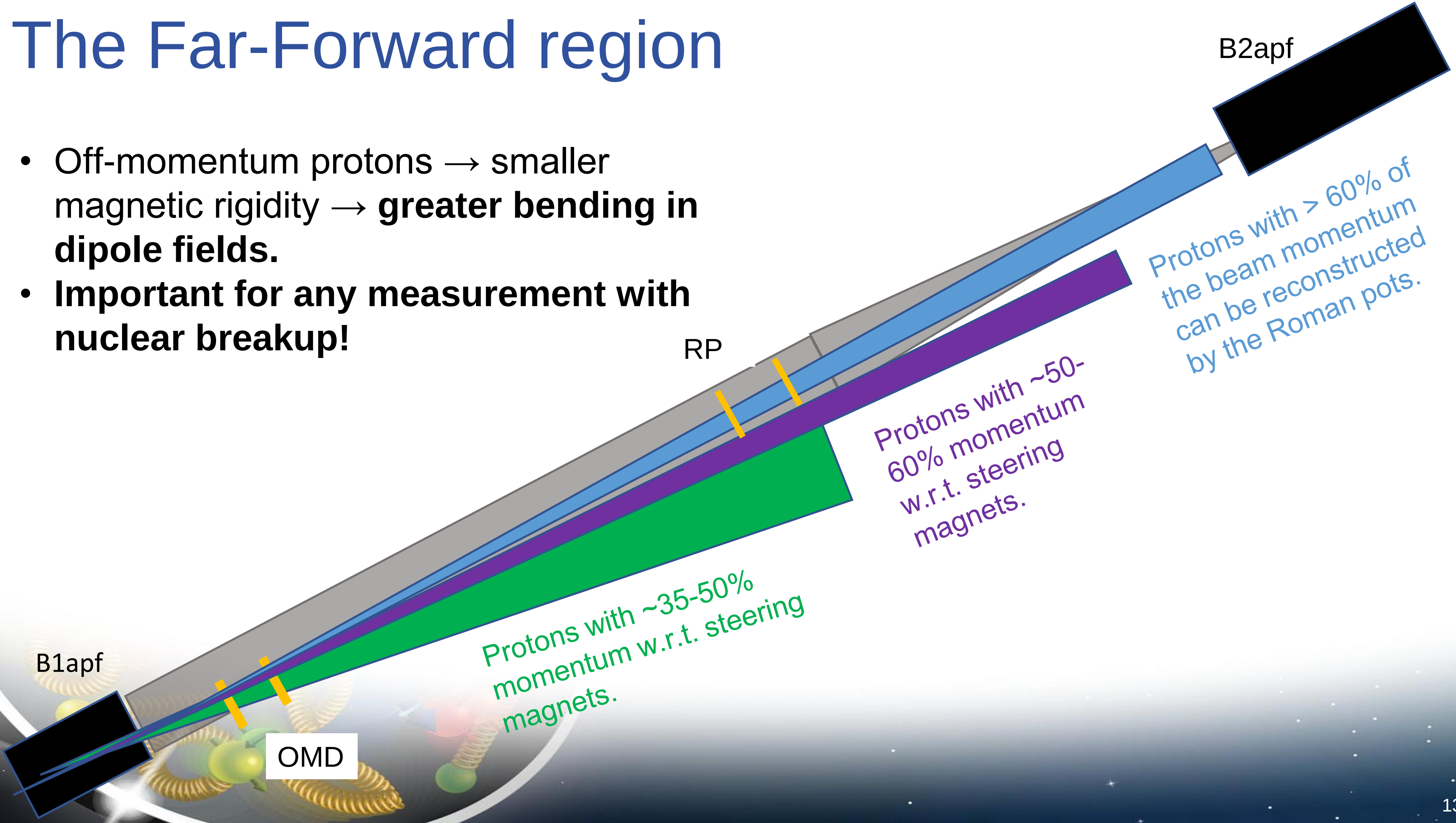

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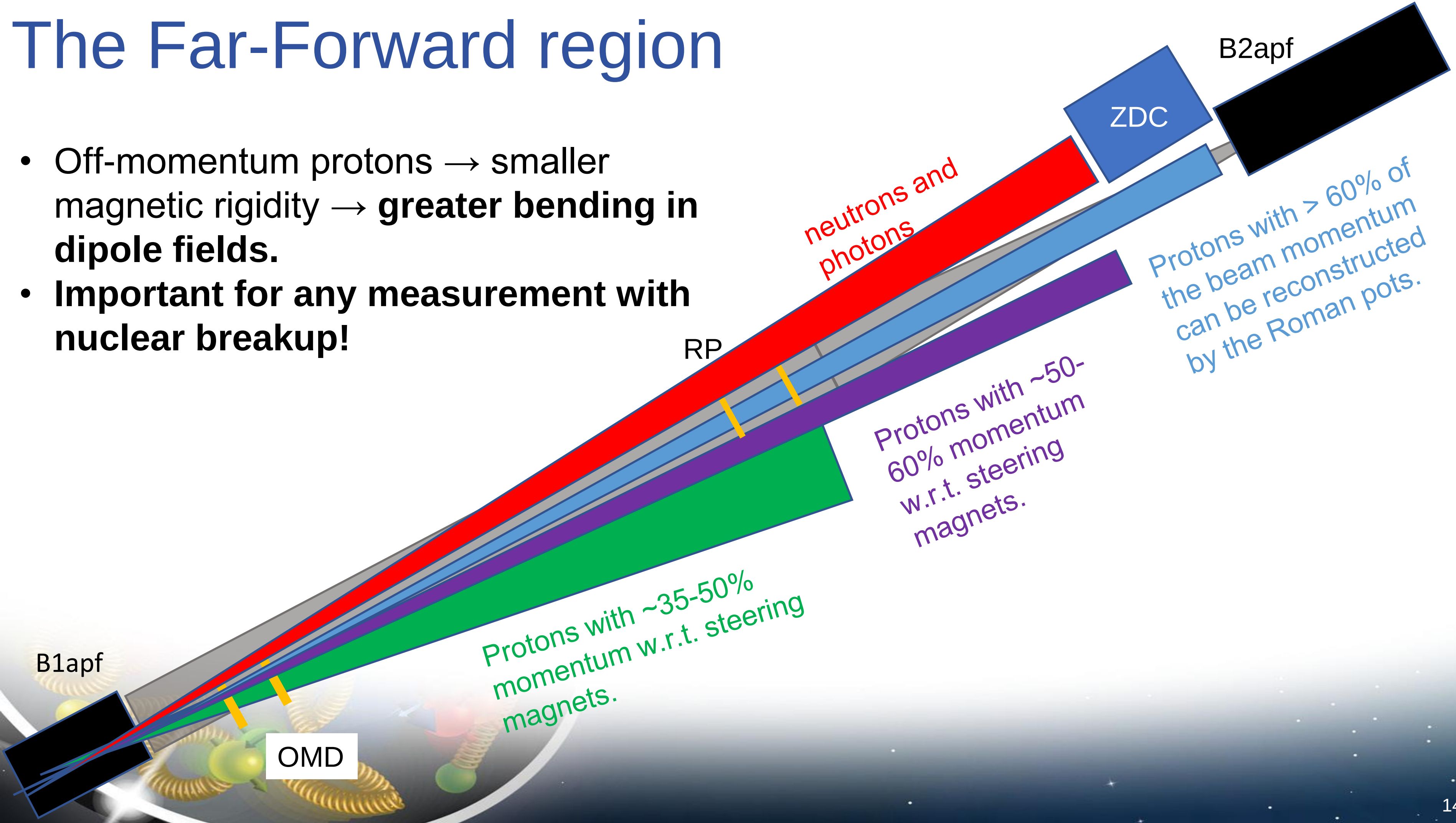
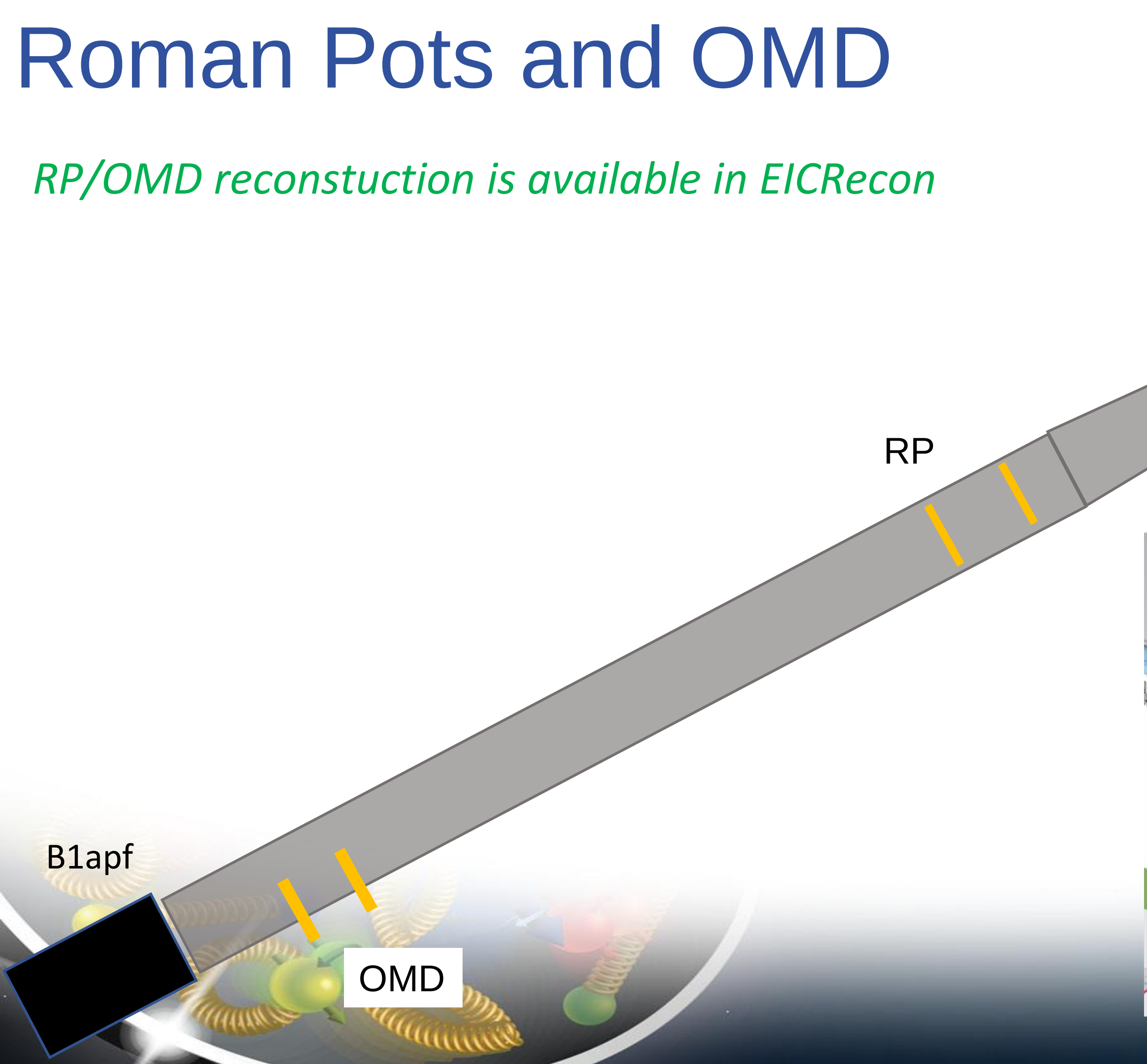
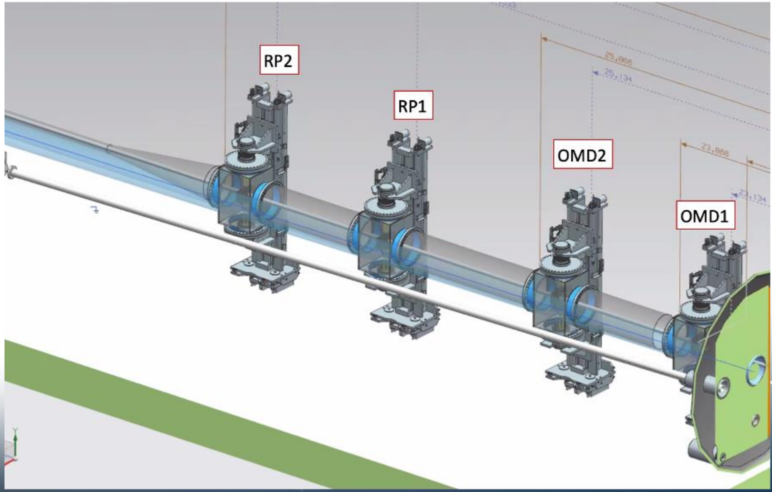


Roman Pots and OMD

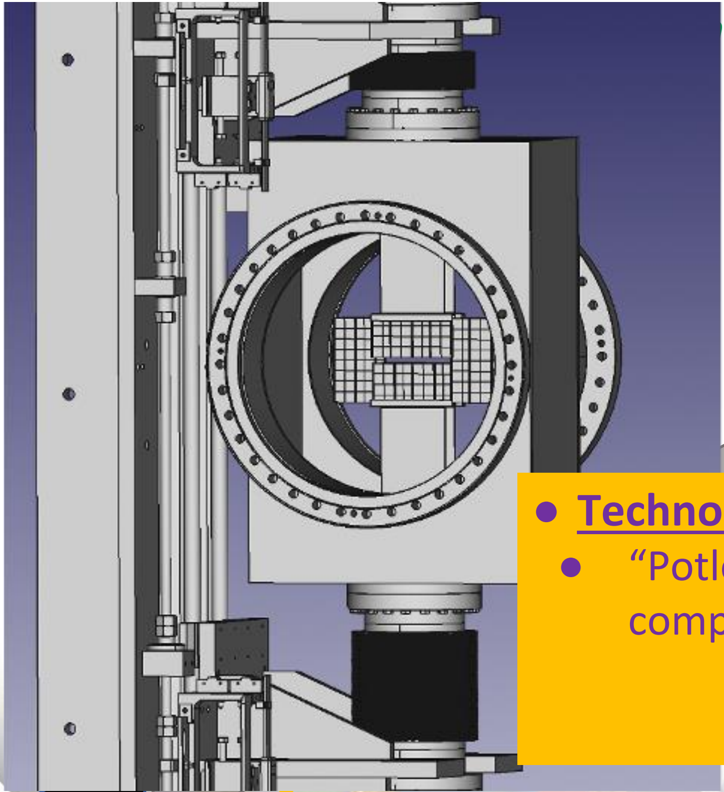
RP/OMD reconstuction is available in EICRecon

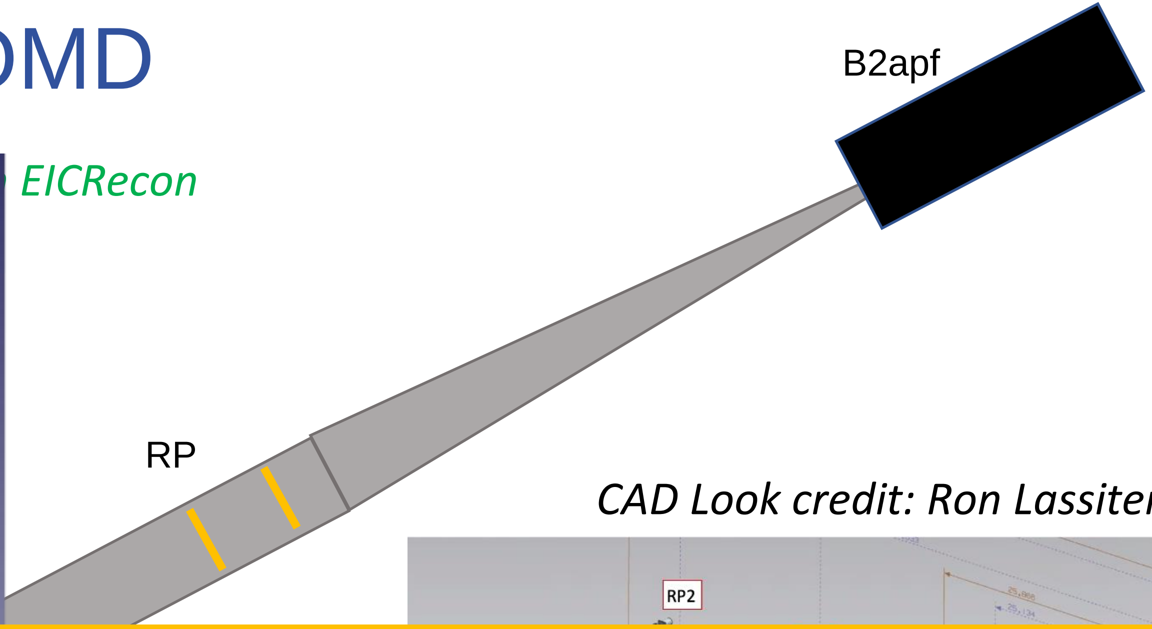


CAD Look credit: Ron Lassiter



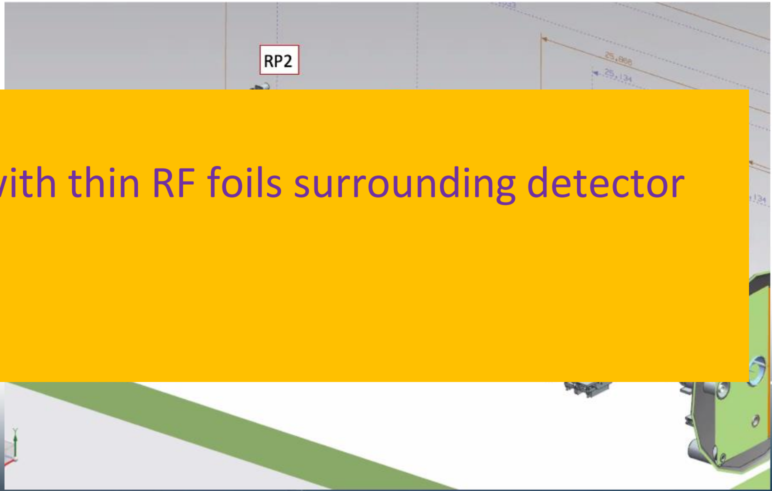
Roman Pots and OMD





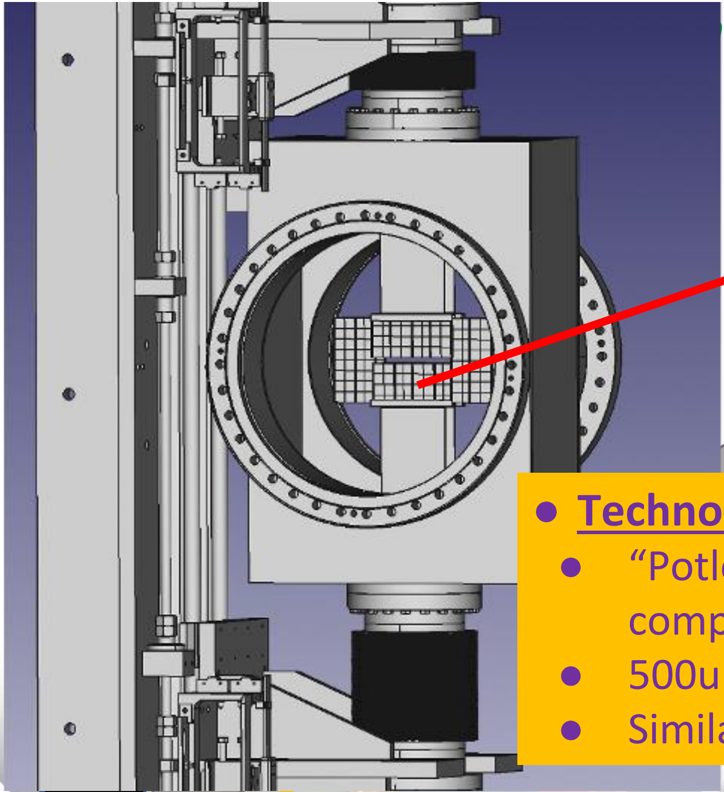
EICRecon

CAD Look credit: Ron Lassiter



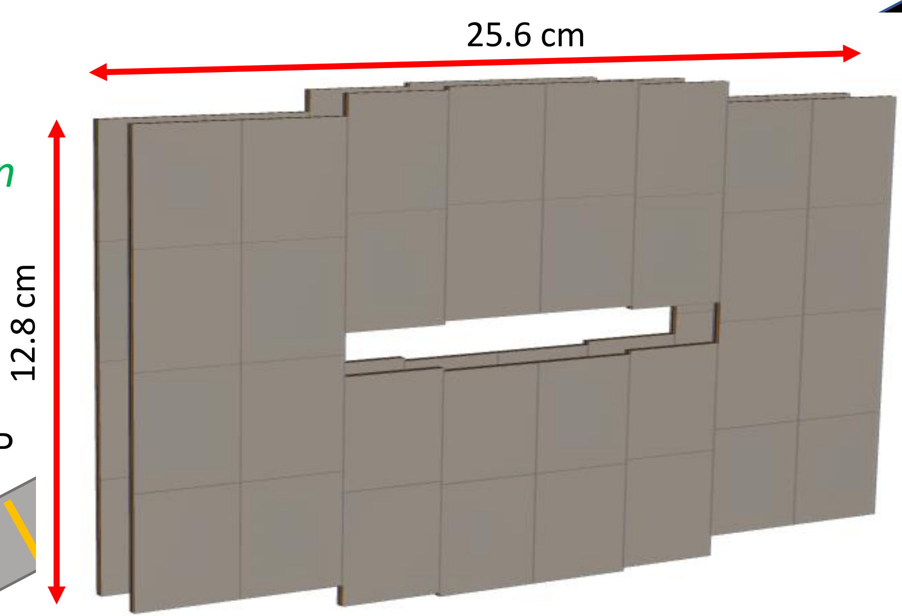
- **Technology**
  - "Potless" design concept with thin RF foils surrounding detector components.

Roman Pots and OMD



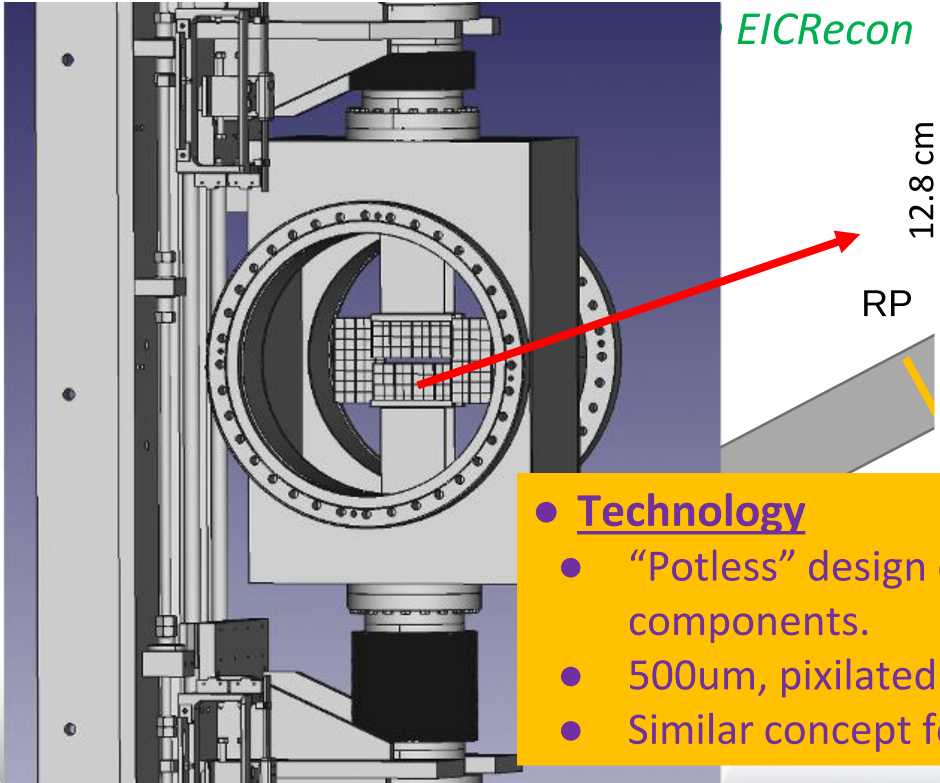
EICRecon

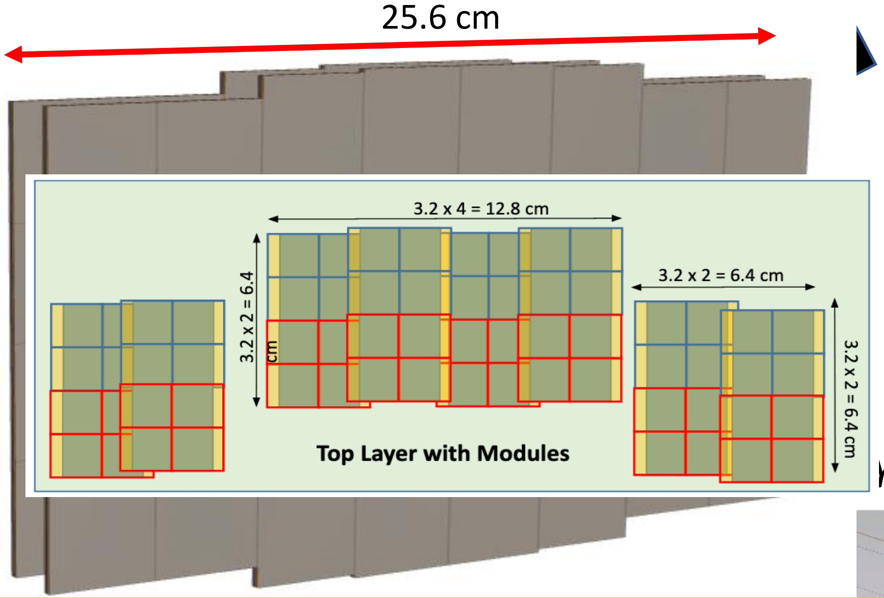
RP



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

Roman Pots and OMD



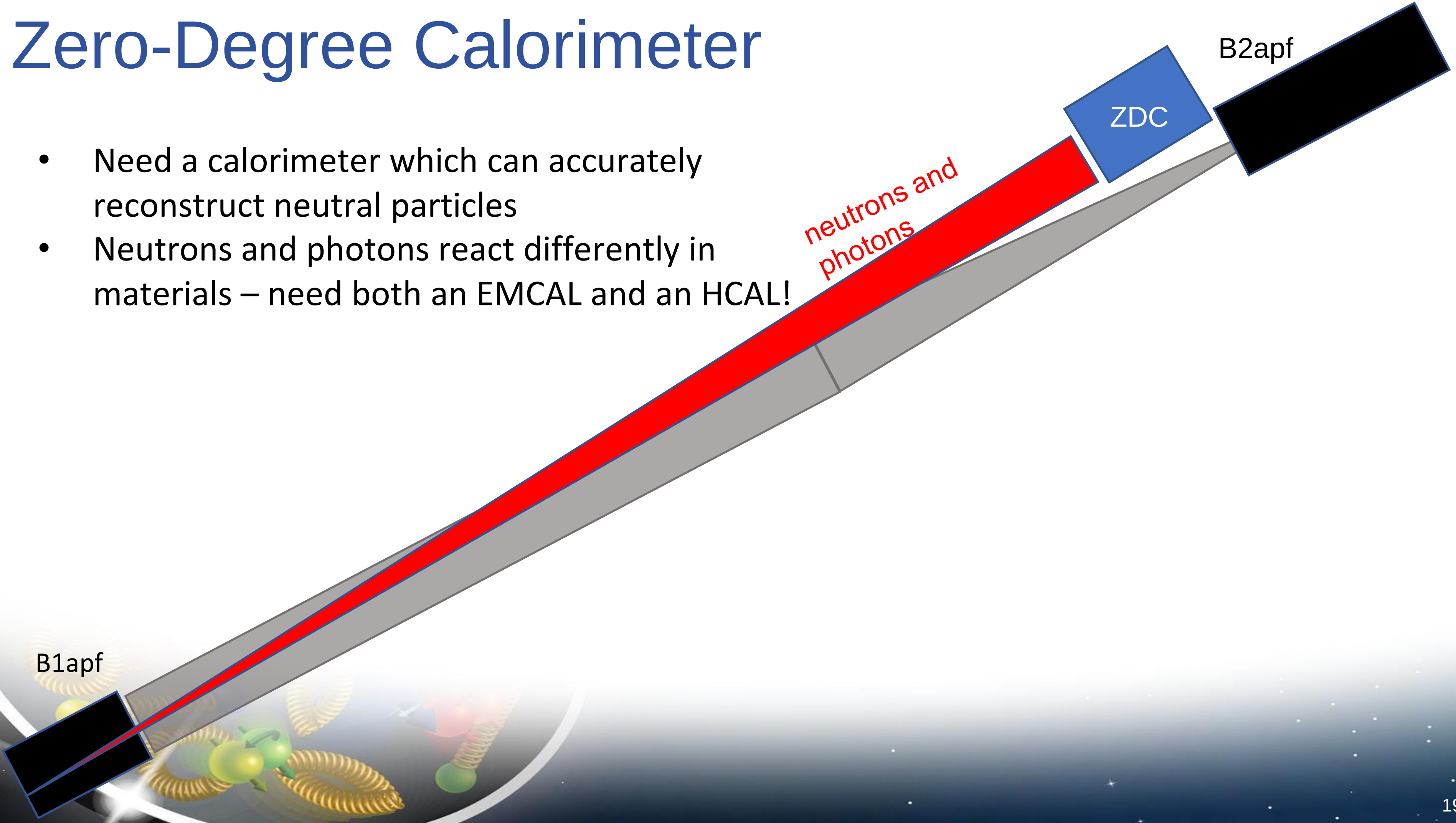


- **Technology**
  - "Potless" design concept with thin RF foils surrounding detector components.
  - 500um, pixilated AC-LGAD sensor, with 30-40ps timing resolution.
  - Similar concept for the OMD, just different active area and shape.

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

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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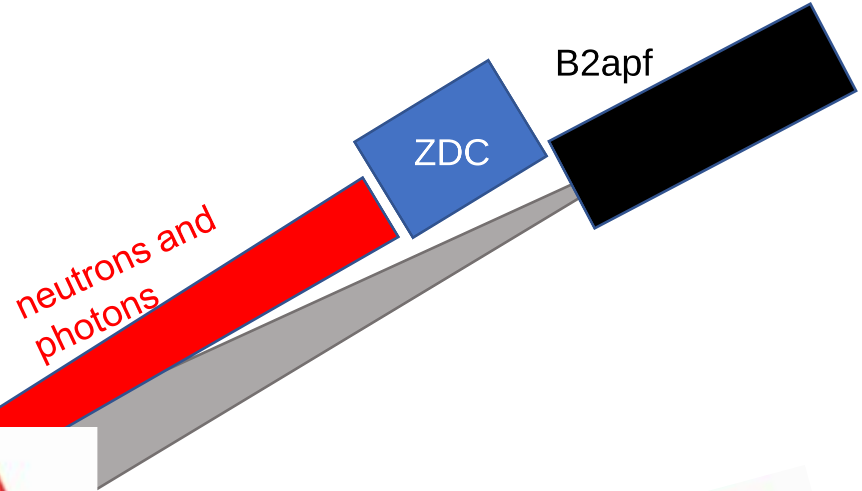
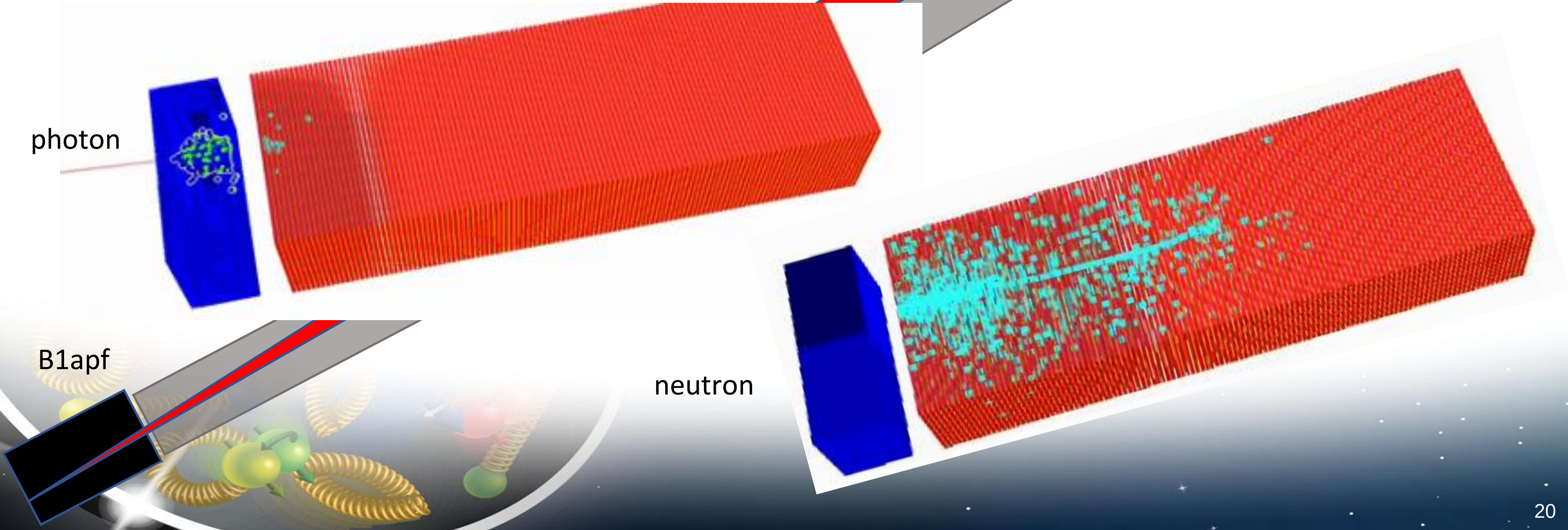
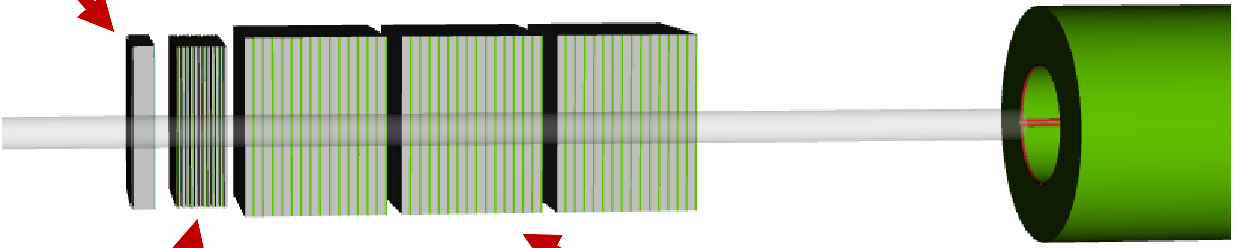




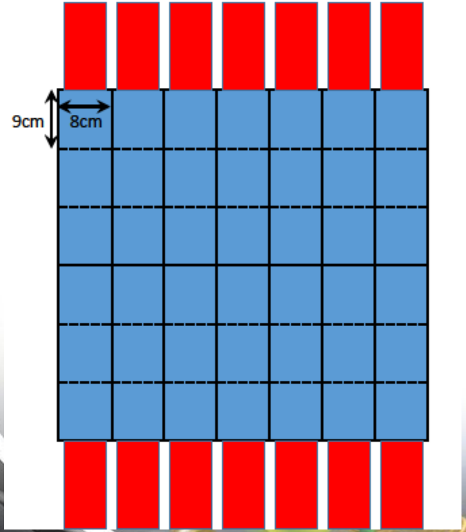
ZDC - What's New

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

Overall length within 2m limit



Readout setup from top & bottom

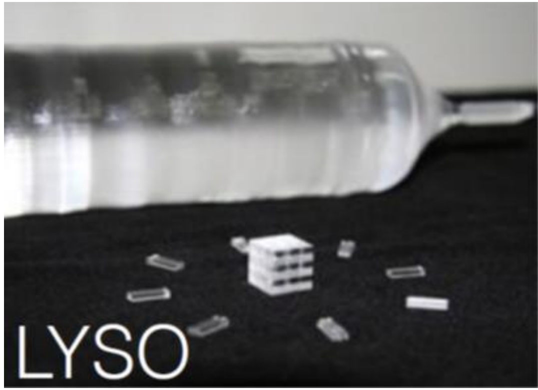


- W-Si imagine calorimeter
  - Smaller lateral dimension (x, y) = (56, 54) cm.
  - Smaller number of layers $1X_0 \times 22 \rightarrow 2X_0 \times 12$ layers

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

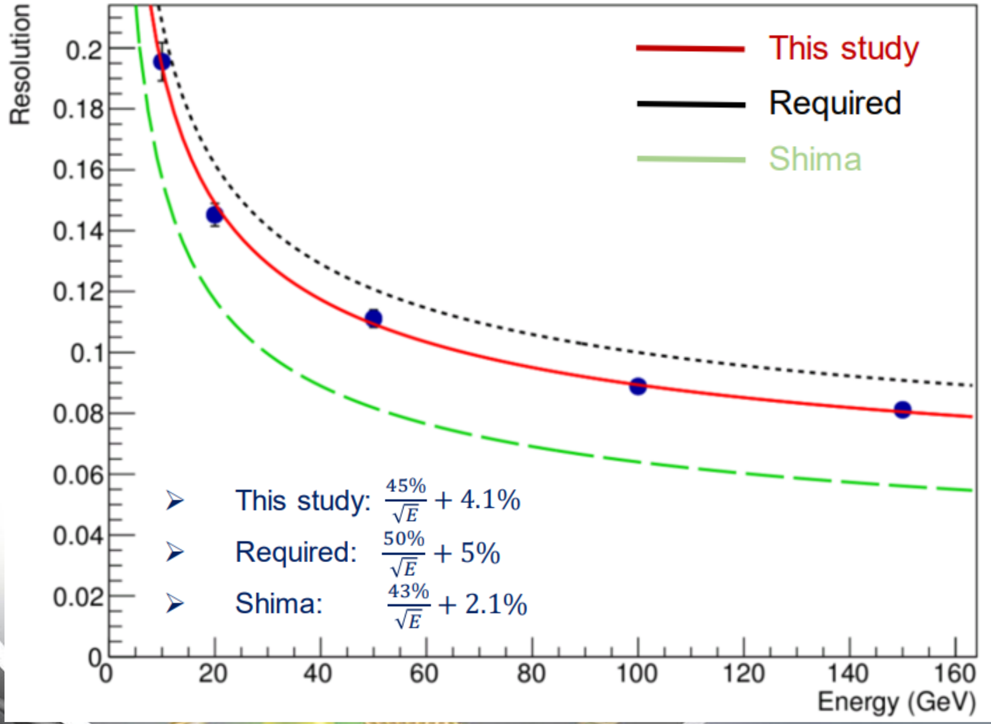
ZDC - What’s New

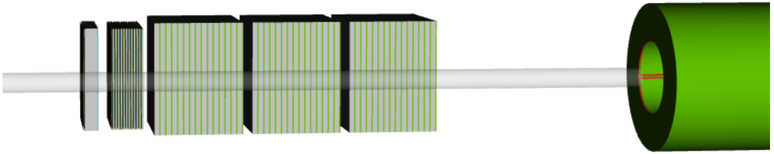
- ECAL: PbWO4 vs LYSO
  - LYSO crystal by Taiwan group (from CMS)
    - More light yield
    - More table for radiation
    - But higher cost
  - Cooperation with B0 ECAL started
- HCAL
  - Korea group
  - Dual-readout calorimeter



ZDC – Performance

Po-Ju Lin at FFD Working meeting

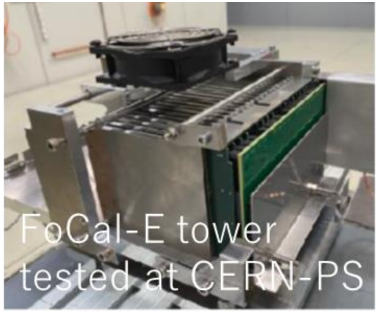




- Energy resolution in the new design acceptable → Optimization, test of different ideas within the size limit.
- Next steps:
  - Implementation of reconstruction
  - Position resolution & shower development studies in place for the imaging part of the HCAL

ZDC - Tests

- ALICE FoCal-E test beam @ Tohoku-ELPH & CERN-PS/SPS
  - ➢ p-sub sensor, HGCROC v2 for
  - ➢ Clear MIP peaks observed for almost all
  - ➢ Reaching full depletion voltage around 300 V
- Neutron irradiation test @ RIKEN-RANS
  - ➢ Sensor, photodetectors, chips, cables
  - ➢ Up to ~10^{14} neutrons/cm^2
- Crystal calorimeter
  - ➢ PbWO4 vs LYSO
  - ➢ Small prototype to be tested & evaluated @ Tohoku-ELPH in this winter



Summary and Takeaways

- All FF detector acceptances and detector performance are well-understood with currently available information.
  - **Numerous impact studies have been done!**
- Detector review is planned ~December 2023, ideal technology choices are identified, along with suitable alternate designs for risk mitigation.

Summary and Takeaways

- All FF detector acceptances and detector performance are well-understood with currently available information.
    - **Numerous impact studies have been done!**
- Detector review is planned ~December 2023, ideal technology choices are identified, along with suitable alternate designs for risk mitigation.
- More realistic engineering considerations need to be added to simulations as the design of IR vacuum system and magnets progresses toward CD-2/3a
    - Lots of experience in performing these simulations, so this work will progress rapidly as engineering design matures.
    - Already well-established communication between detector and physics parties and the EIC machine development group ⇒ Crucial for success!!!

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

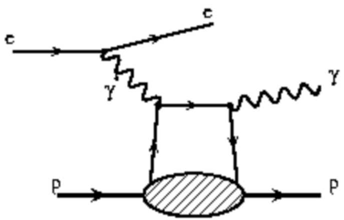
Meeting time: Tuesdays @ 9am EDT (bi-weekly, or weekly, as needed) https://indico.bnl.gov/category/407/

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

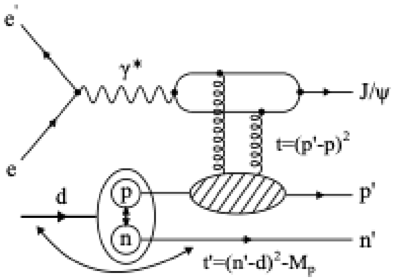
Email-list: eic-projdet-FarForw-l@lists.bnl.gov (https://lists.bnl.gov/mailman/listinfo/eic-projdet-farforw-l)

Backup

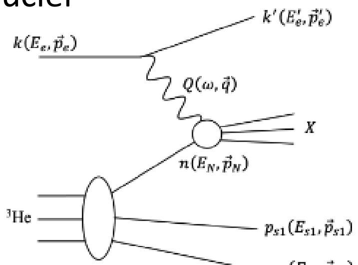
e+p DVCS



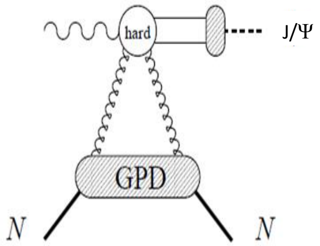
e+d exclusive J/Psi with p/n tagging



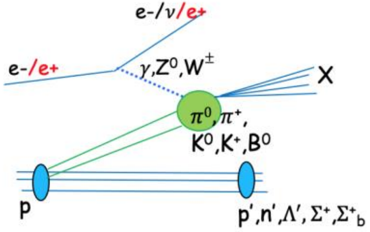
spectator tagging in light nuclei



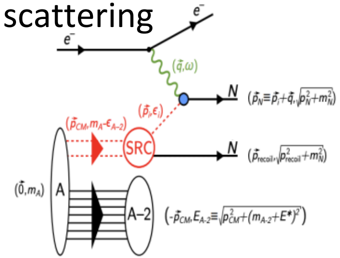
coherent/incoherent J/ψ production in e+A



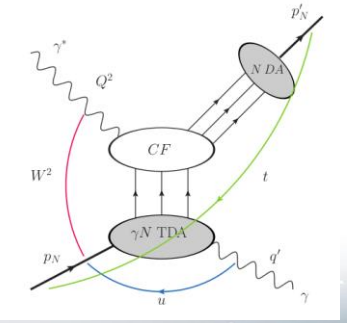
Sullivan process



Quasi-elastic electron scattering



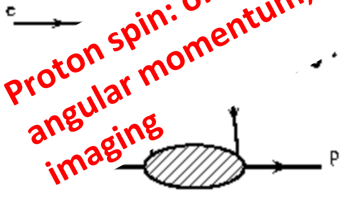
u-channel backward exclusive electroproduction



...and MANY more!

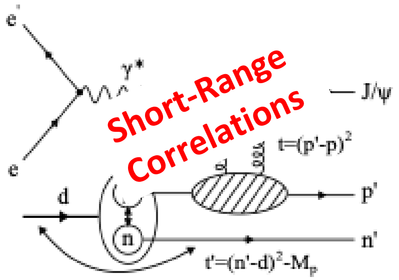
(some) Far-Forward **Physics** at the EIC

e+p DVCS



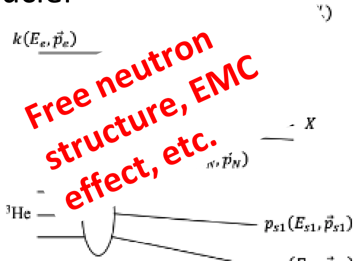
Proton spin: orbital angular momentum; imaging

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



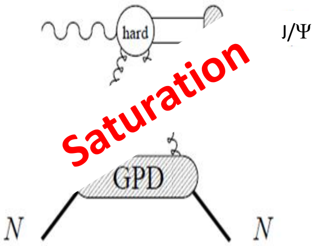
Short-Range Correlations

spectator tagging in light nuclei



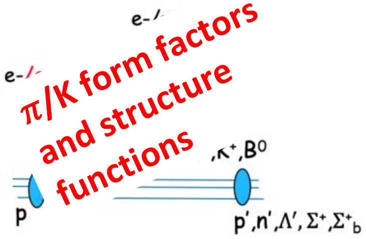
Free neutron structure, EMC effect, etc.

coherent/incoherent J/ψ production in e+A



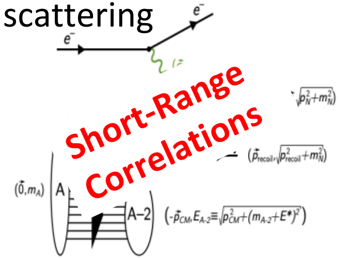
Saturation

Sullivan process



π/K form factors and structure functions

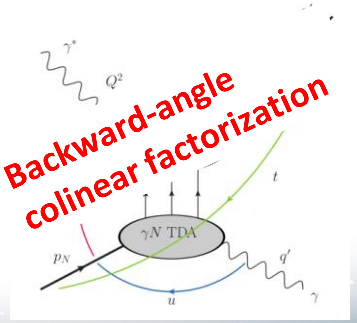
Quasi-elastic electron scattering



Short-Range Correlations

[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

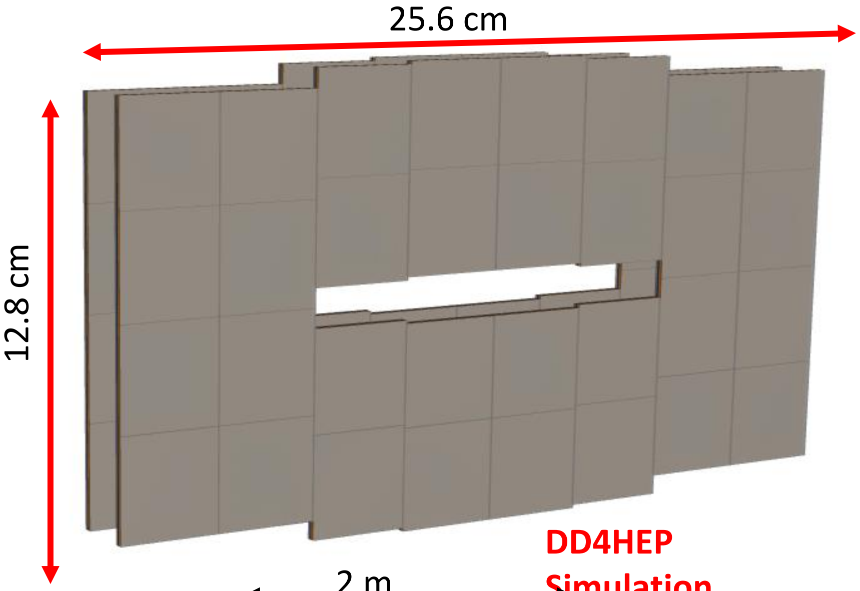


Backward-angle colinear factorization

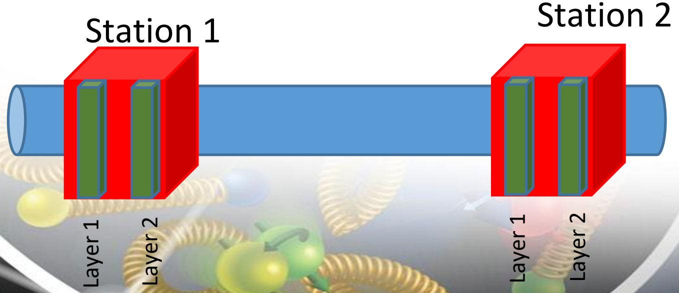
…and MANY more!

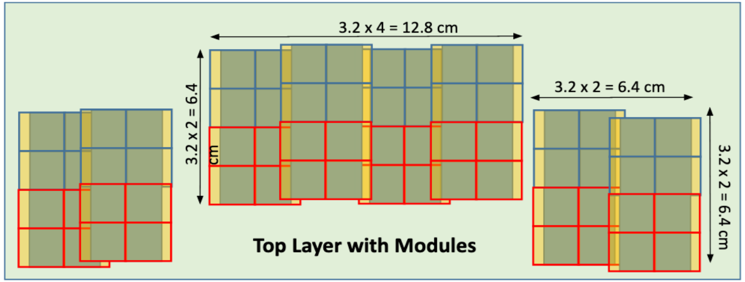
- Physics channels require tagging of **charged hadrons** (protons, pions) or **neutral particles** (neutrons, photons) at **very-forward rapidities** **($\eta > 4.5$).**
- Different final states require tailored detector subsystems.
- Various collision systems (e.g. e+p, e+d, e+Au) provide unique challenges.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

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.

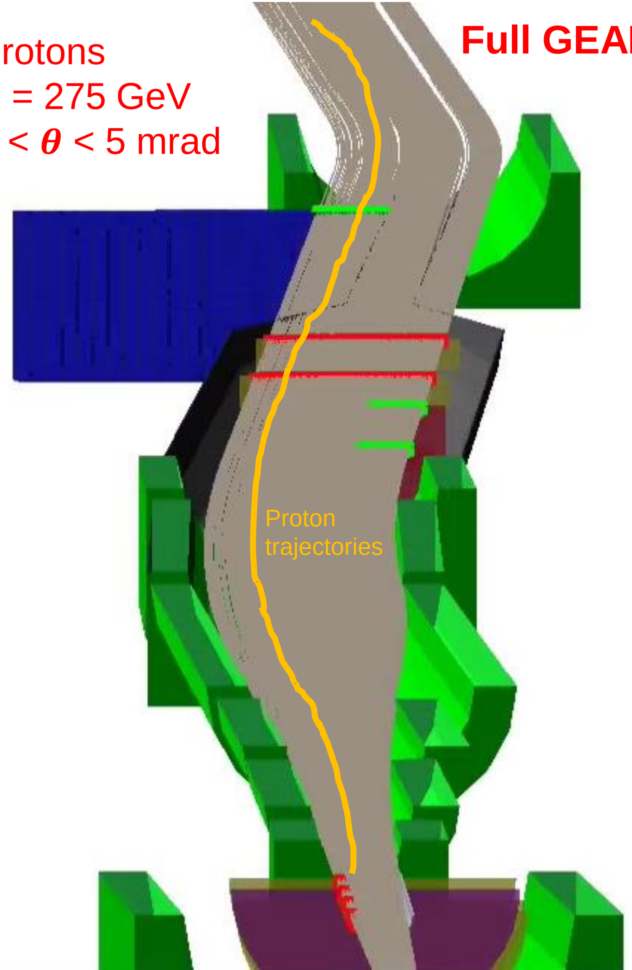
➢ **Status**
- ✓ **Acceptance: 0.0* < θ < 5.0 mrad (lower bound depends on optics).**
- ✓ **Detector directly in-vacuum a challenge for both detector and beam → impedance studies underway.**
- ✓ **Approved generic R&D to develop more-adaptive reconstruction code!**

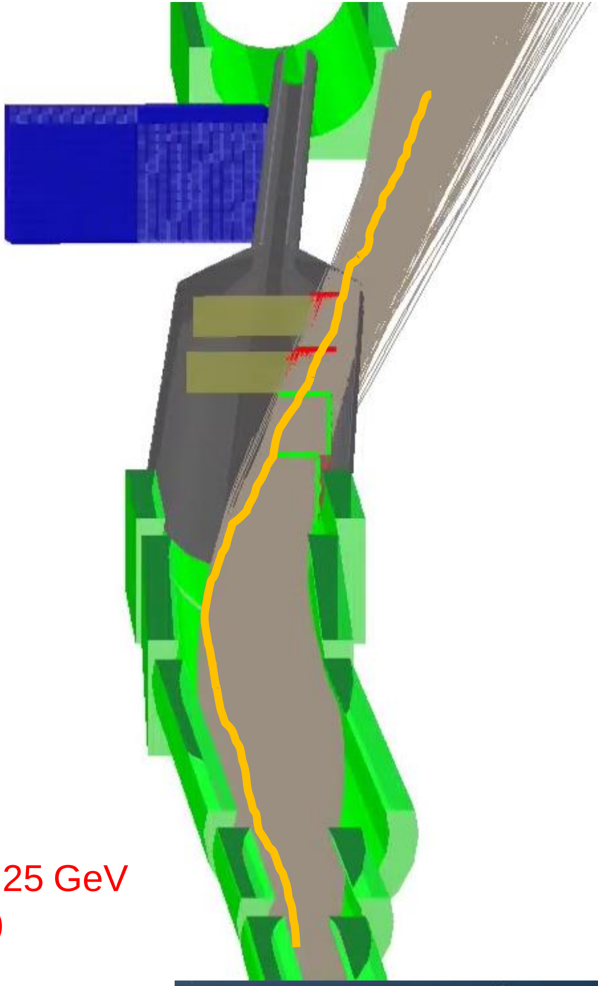
ML + Roman Pots: See talk by D. Ruth WG6; Tuesday @ 2pm

Roman Pots and OMD @ the EIC

Full GEANT4 simulation.

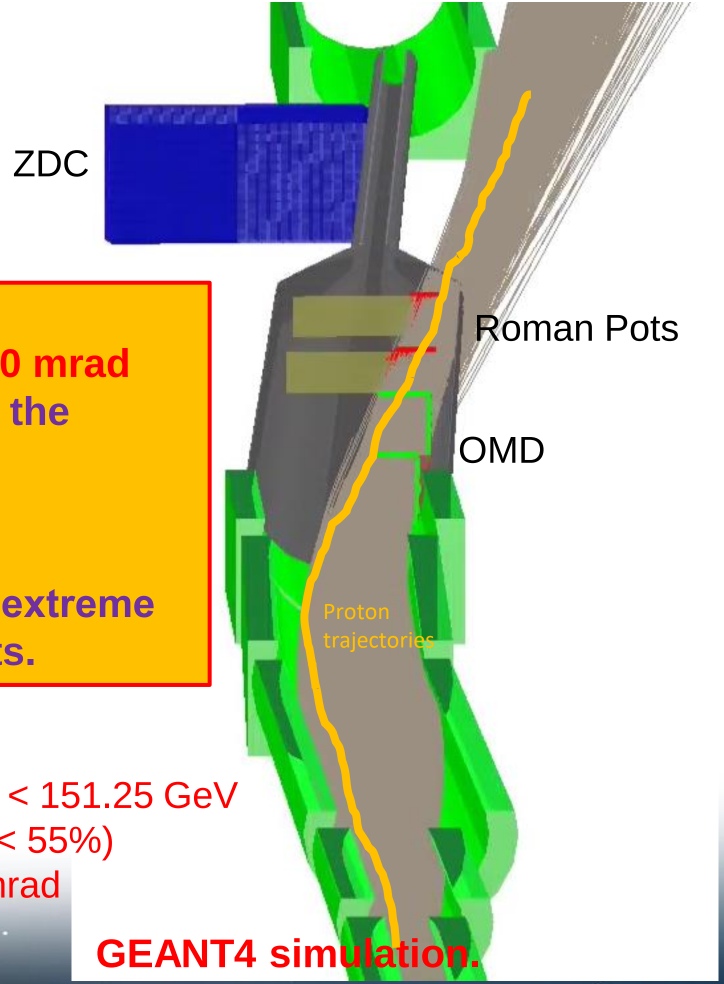
Protons
E = 275 GeV
$0 < \theta < 5$ mrad





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

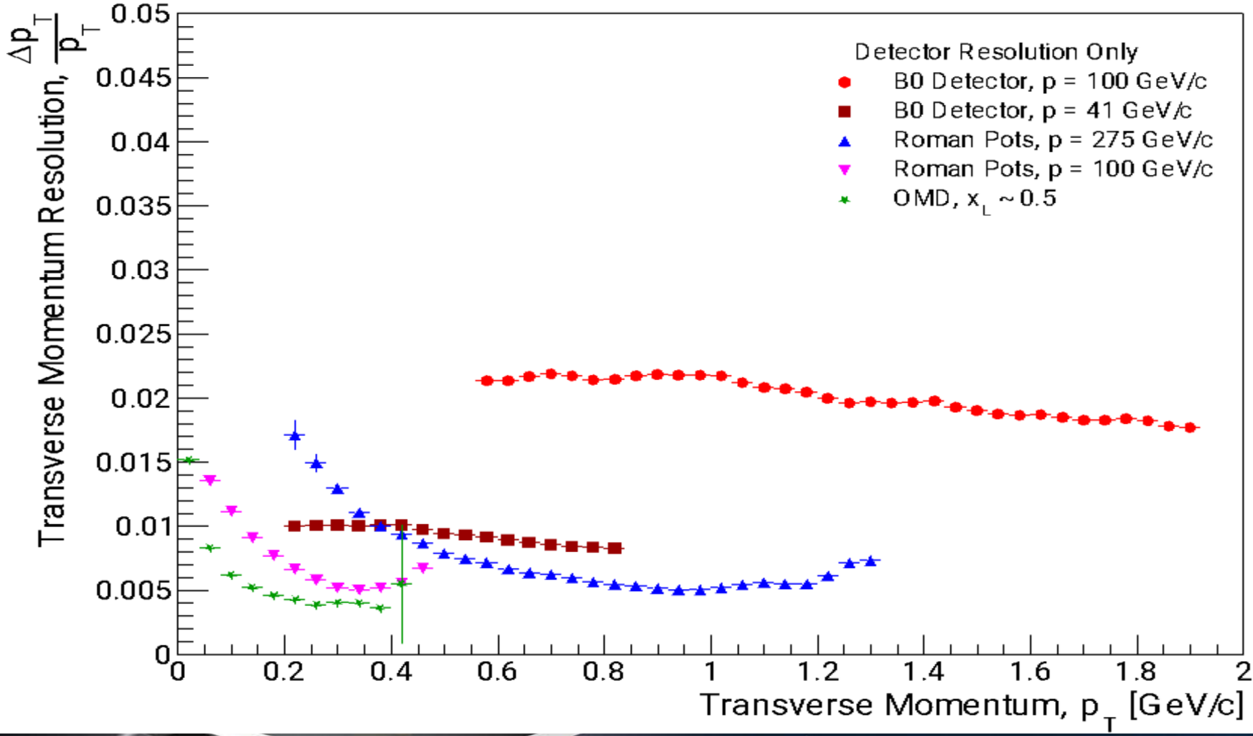
- **Status**
  - ✓ **Acceptance: 0.0 < θ < 5.0 mrad**
  - ✓ **Same technology as for the Roman Pots.**
  - ✓ **Even more-challenging reconstruction with off-momentum particles → extreme orbit path in the magnets.**

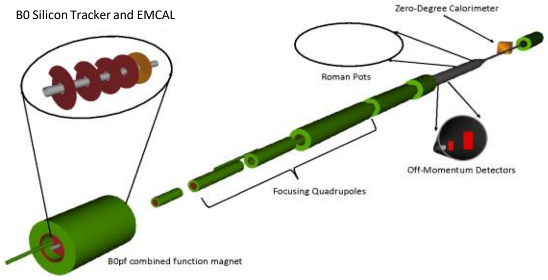


Off-momentum detectors implemented as horizontal "Roman Pots" style sensors.

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

Summary of Detector Performance (Trackers)

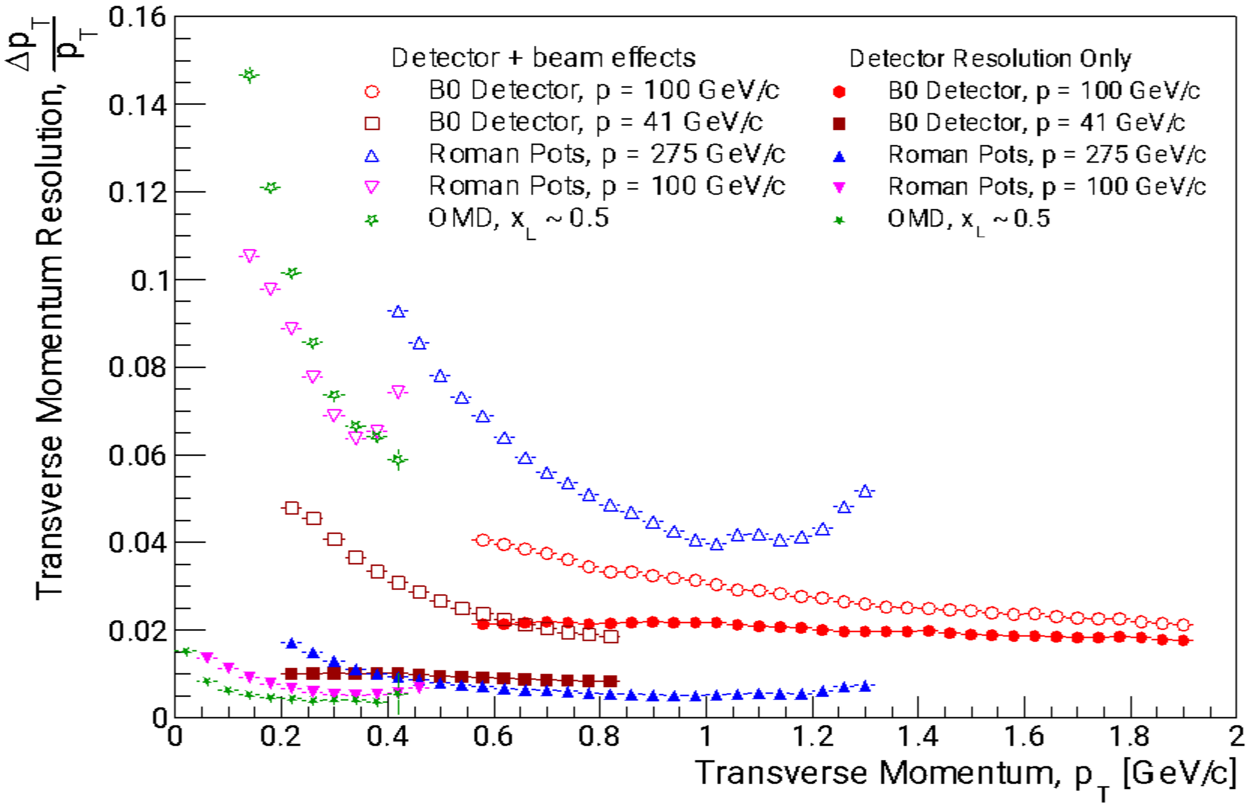


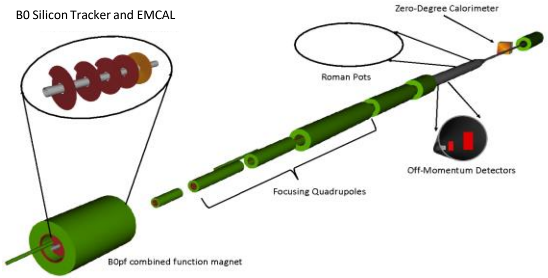


- Includes realistic considerations for pixel sizes and materials
  - Work needed on support structure.
- Roman Pots/OMDs suffer from additional smearing due to improper transfer matrix reconstruction.

ML + Roman Pots: See talk by D. Ruth WG6; Tuesday @ 2pm

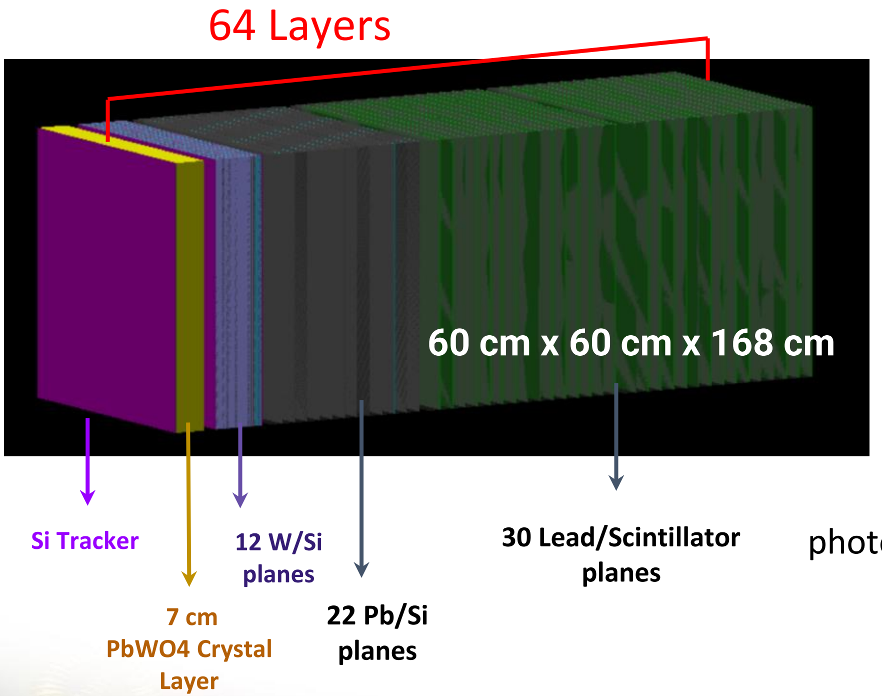
Summary of Detector Performance (Trackers)



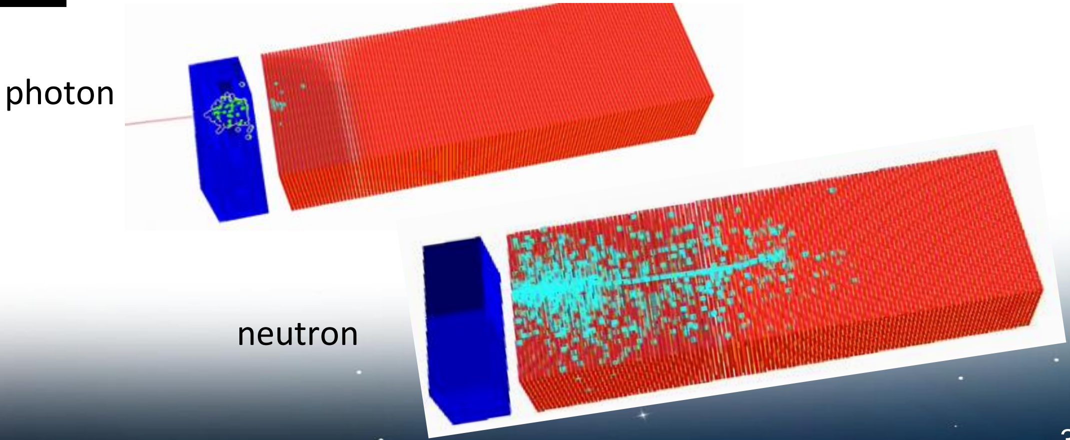


- All beam effects included!
  - Angular divergence.
  - Crossing angle.
  - Crab rotation/vertex smearing.

Beam effects the dominant source of momentum smearing!



- **Status**
  - ✓ 30 m from IR
  - ✓ Detect spectator neutrons (HCAL) & photons (EMCAL)
  - ✓ Acceptance: +4.5 mrad, -5.5mrad (aperture limits)
  - ✓ Position resolution ~1.3mm at 40 GeV
  - ✓ Meets requirements from Yellow Report.
  - ✓ Lots of work to do on shower reconstruction with imaging layers.



Roman Pots

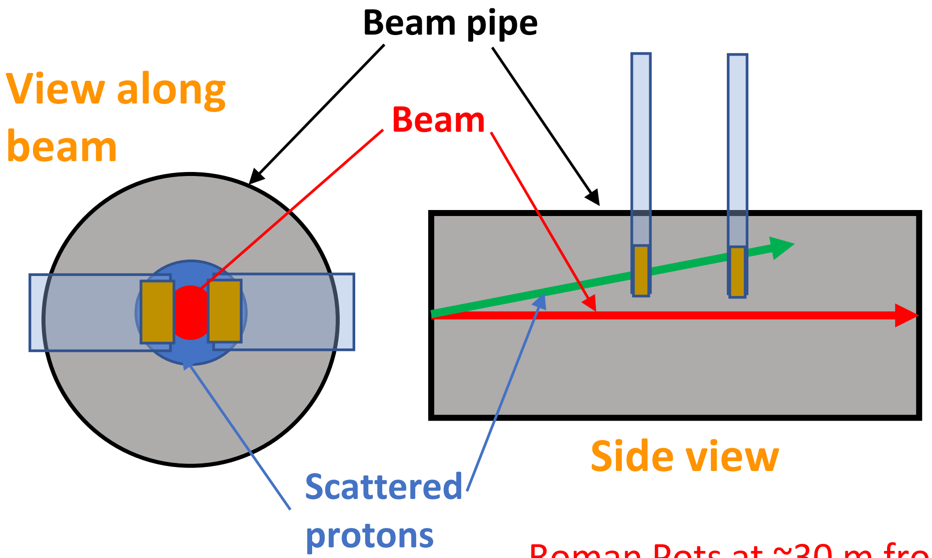
$$\begin{pmatrix} x_D \\ \Theta_D^x \\ y_D \\ \Theta_D^y \end{pmatrix} = \begin{pmatrix} a_{11} & L_{eff}^x & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & L_{eff}^y \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix} \begin{pmatrix} x_0 \\ \Theta_x^* \\ y_0 \\ \Theta_y^*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

x_0, y_0: Position at Interaction Point

Θ^*_x, Θ^*_y: Scattering Angle at IP

x_D, y_D : Position at Detector

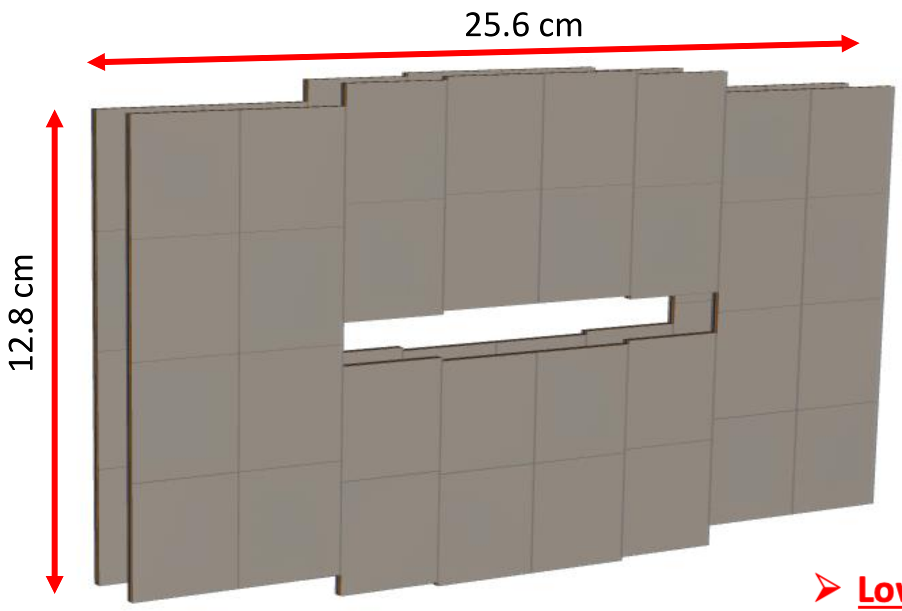
Θ^x_D, Θ^y_D : Angle at Detector



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.

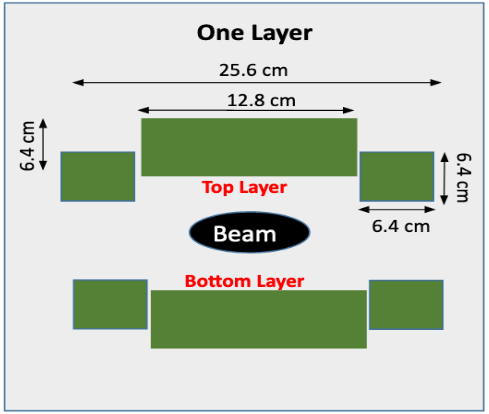
Roman "Pots" @ the EIC



DD4HEP
Simulation

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

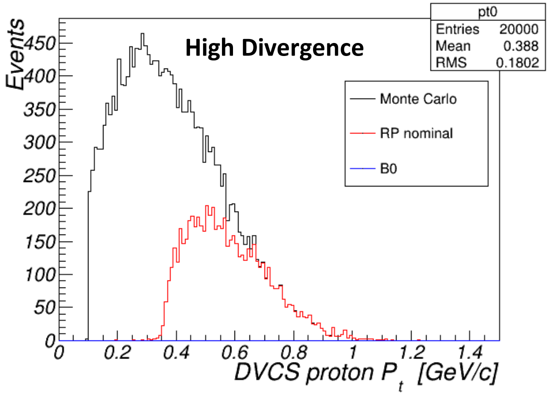
$$\sigma(z) = \sqrt{\varepsilon \cdot \beta(z}$$

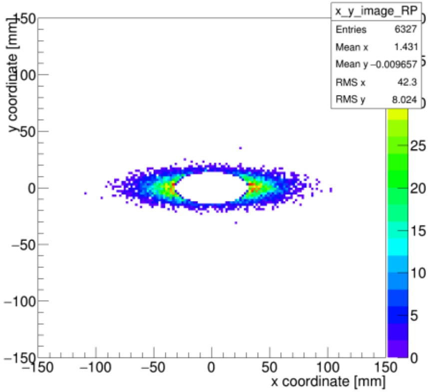


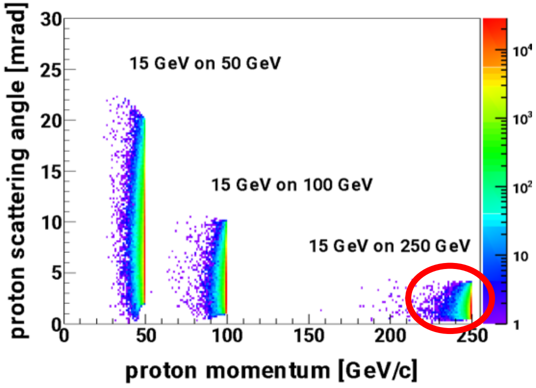
- <u>**Low-pT cutoff determined by beam optics.**</u>
  - **The safe distance is ~10σ from the beam center.**
  - **1σ ~ 1mm**
- **These optics choices change with energy, but can also be changed within a single energy to maximize *either acceptance at the RP, or the luminosity*.**

Digression: Machine Optics

275 GeV DVCS Proton Acceptance



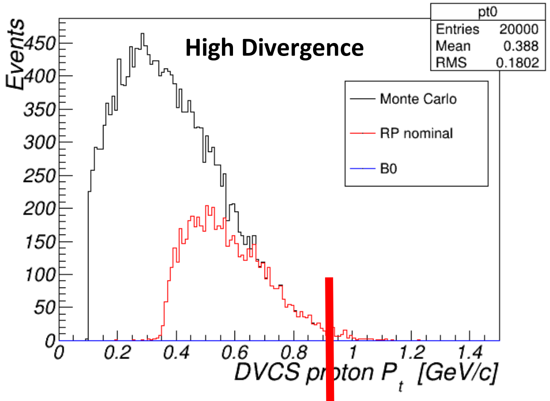


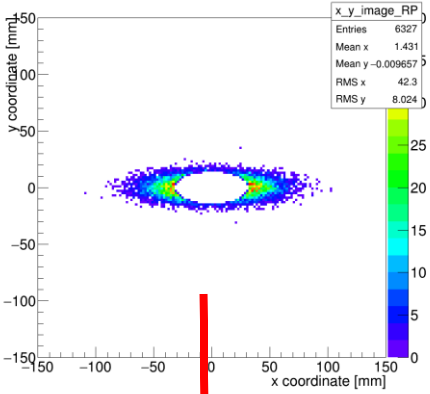


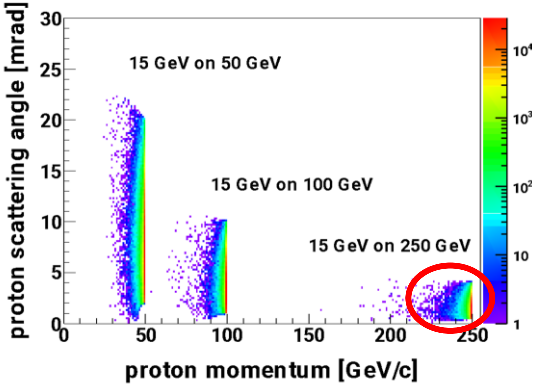
High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

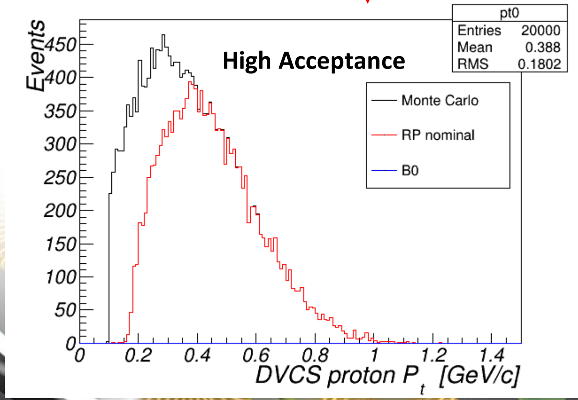
Digression: Machine Optics

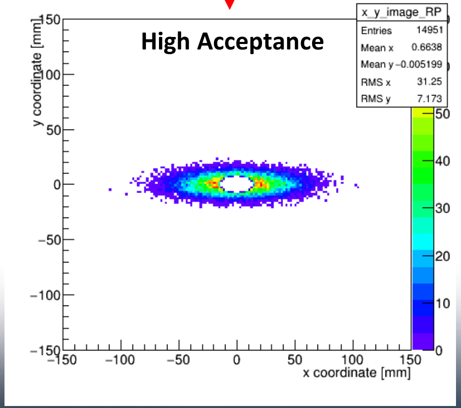
275 GeV DVCS Proton Acceptance









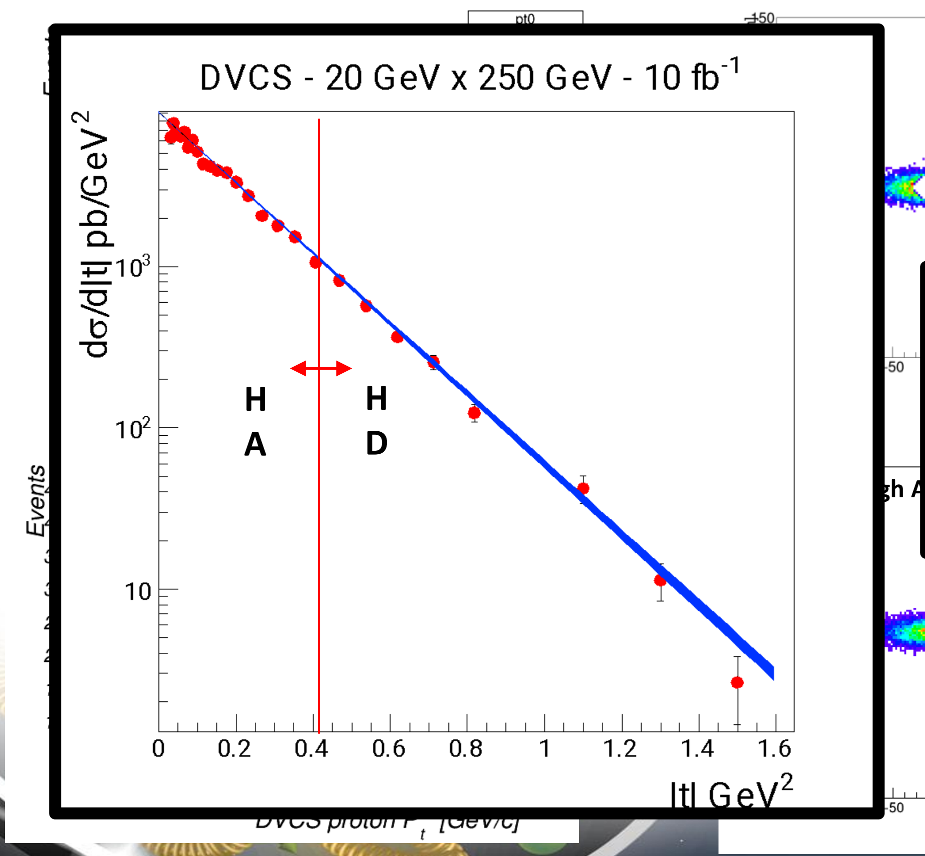


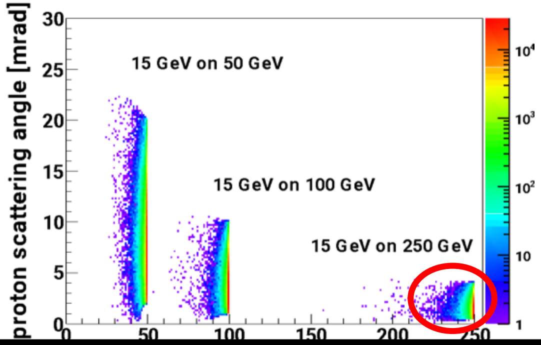
High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

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

Digression: Machine Optics

275 GeV DVCS Proton Acceptance



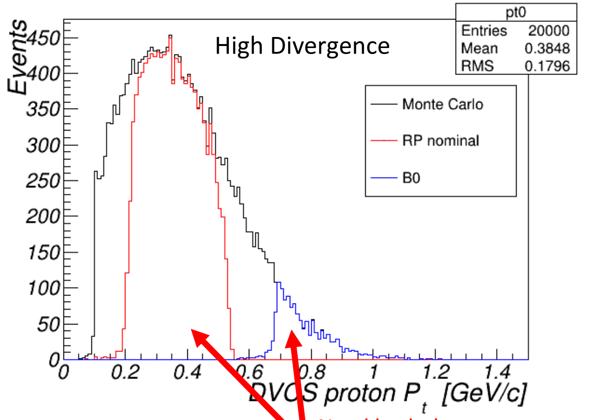


Using the two configurations, we are able to measure the low-t region (with better acceptance) and high-t tail (with higher luminosity).

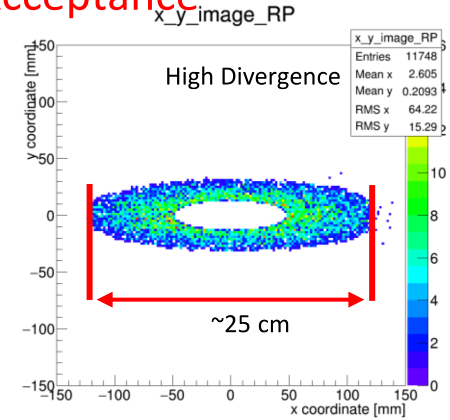
High Acceptance: larger β^* at IP, smaller $\beta(z = 30m)$ -> lower lumi., smaller beam at RP

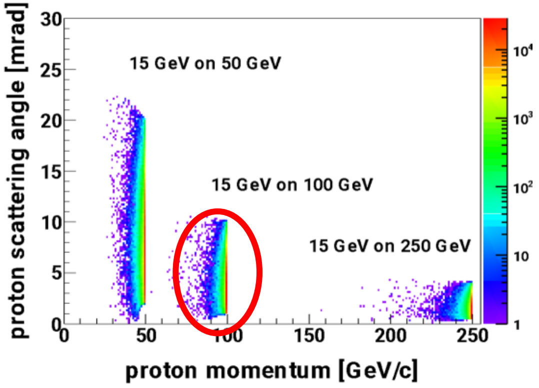
Digression: Machine Optics

100 GeV DVCS Proton Acceptance



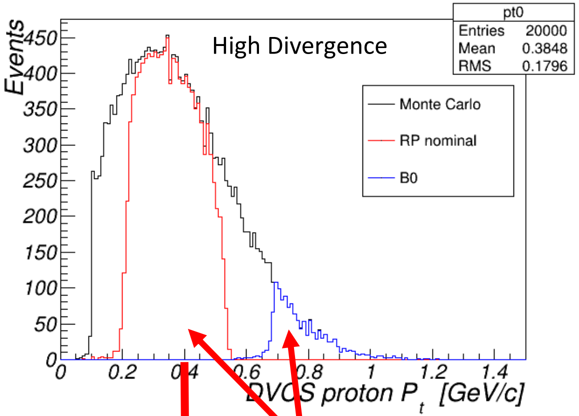
Need both detector systems together here!





Digression: Machine Optics

100 GeV DVCS Proton Acceptance



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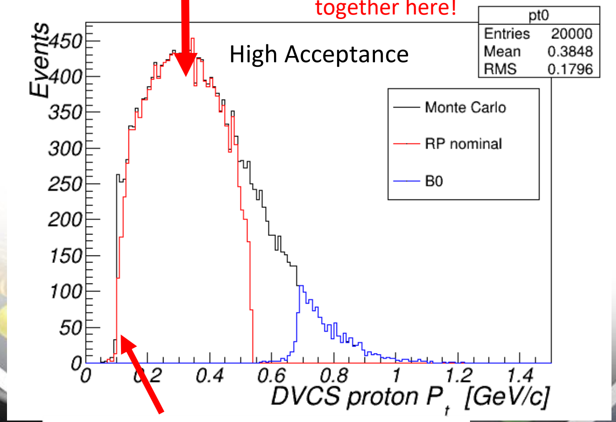

Improves low p_t acceptance.