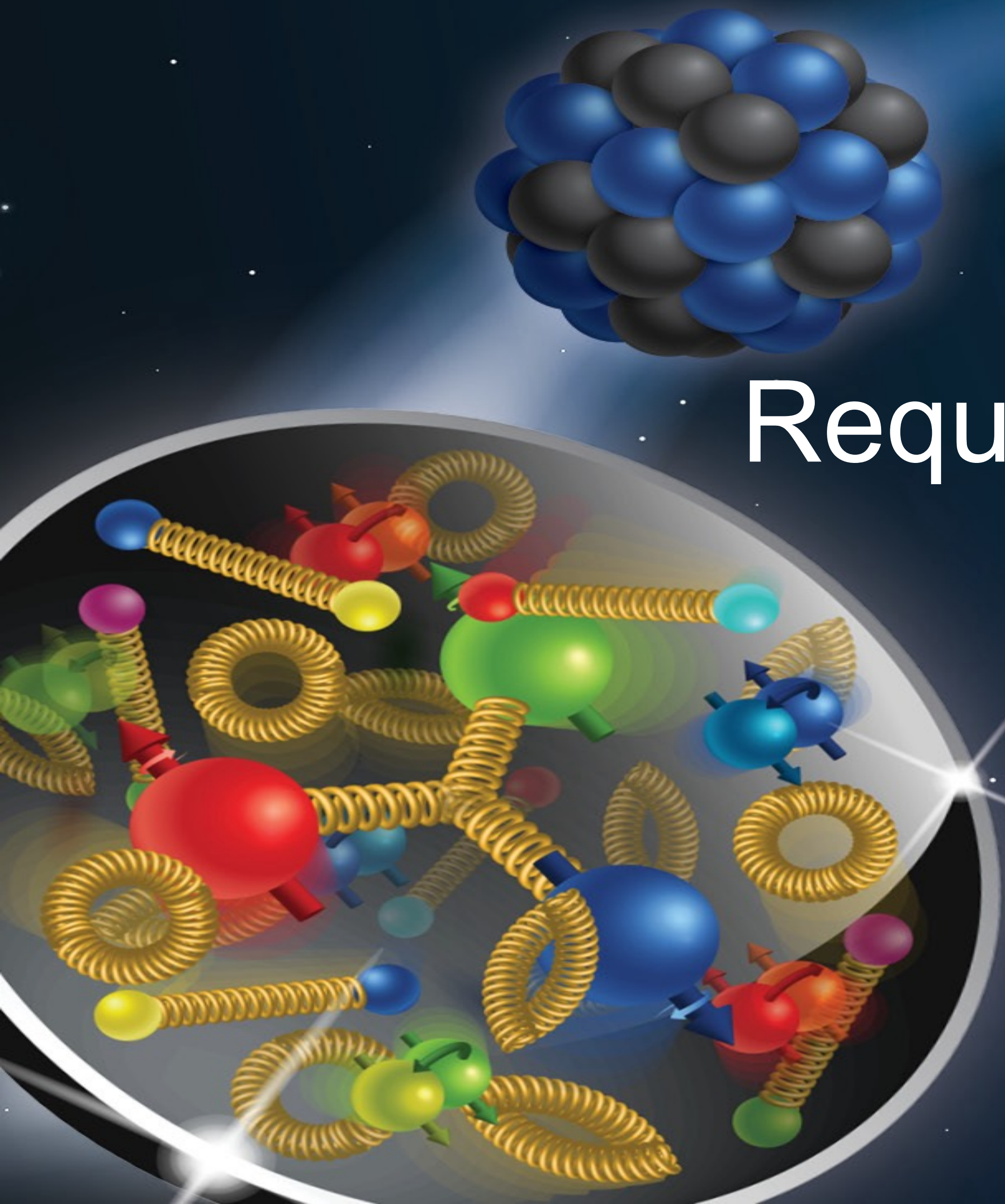


Requirements for the Roman Pots Detectors at the EIC

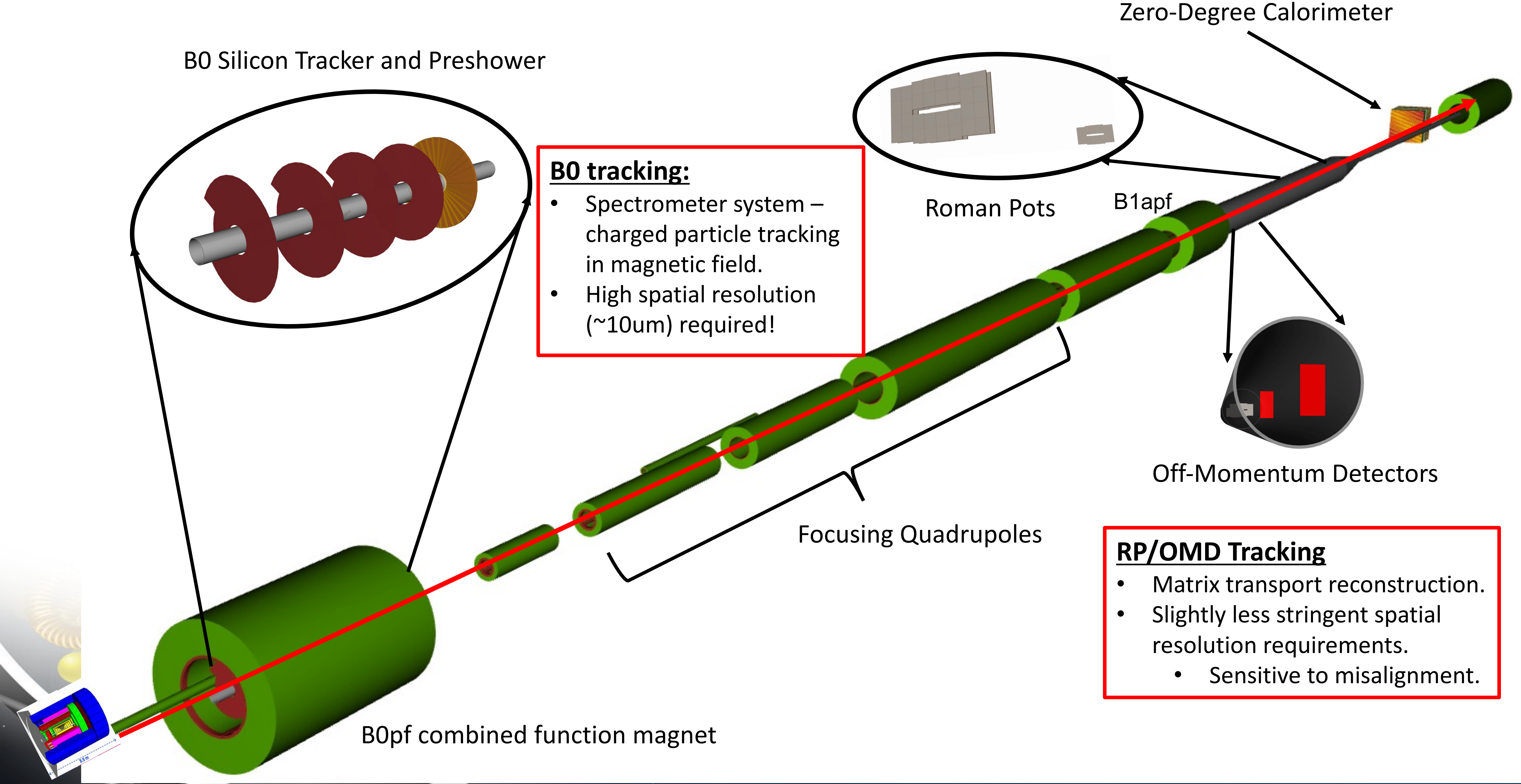
Alex Jentsch (BNL)

eRD112 Meeting

June 29th, 2022

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

The Far-Forward Detectors



<u>B0 tracking:</u>

- Spectrometer system – charged particle tracking in magnetic field.
- High spatial resolution (~10um) required!

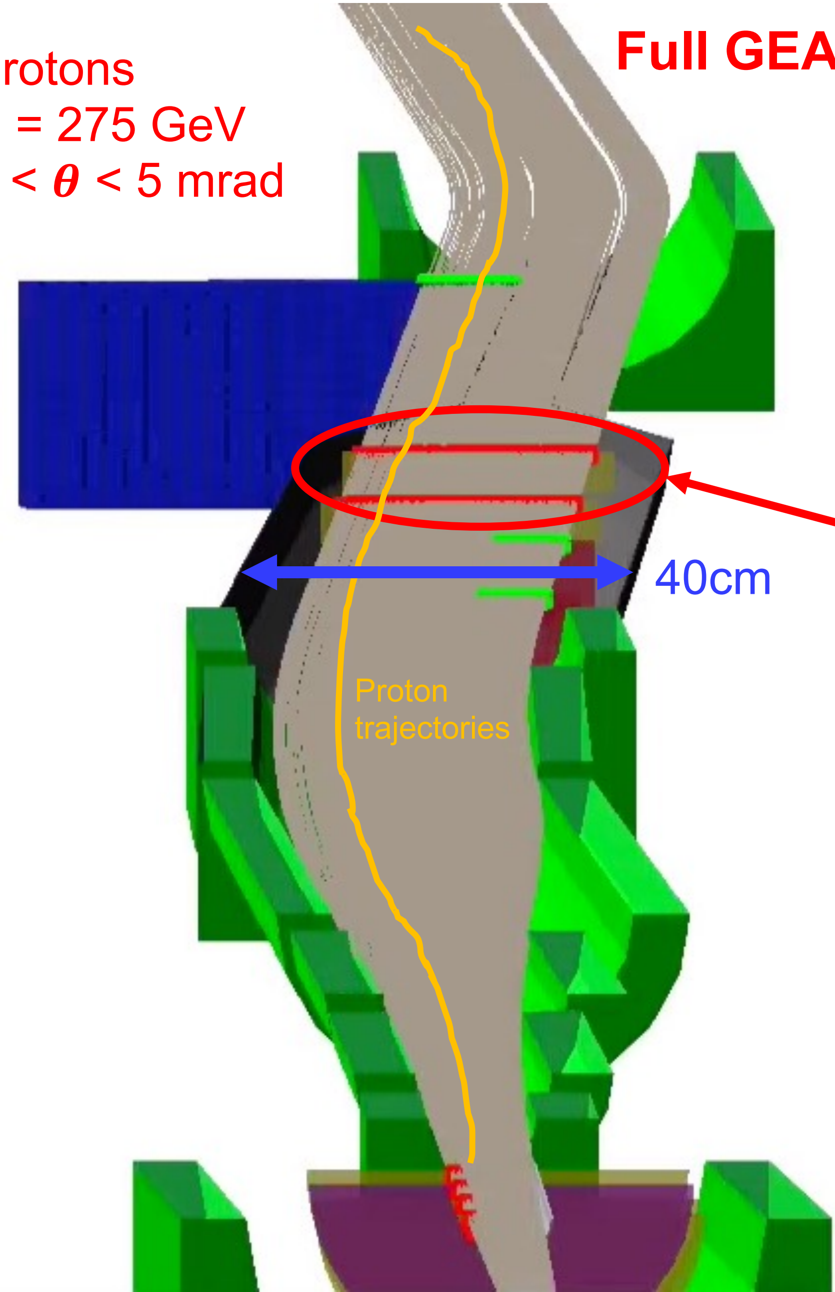
<u>RP/OMD Tracking</u>

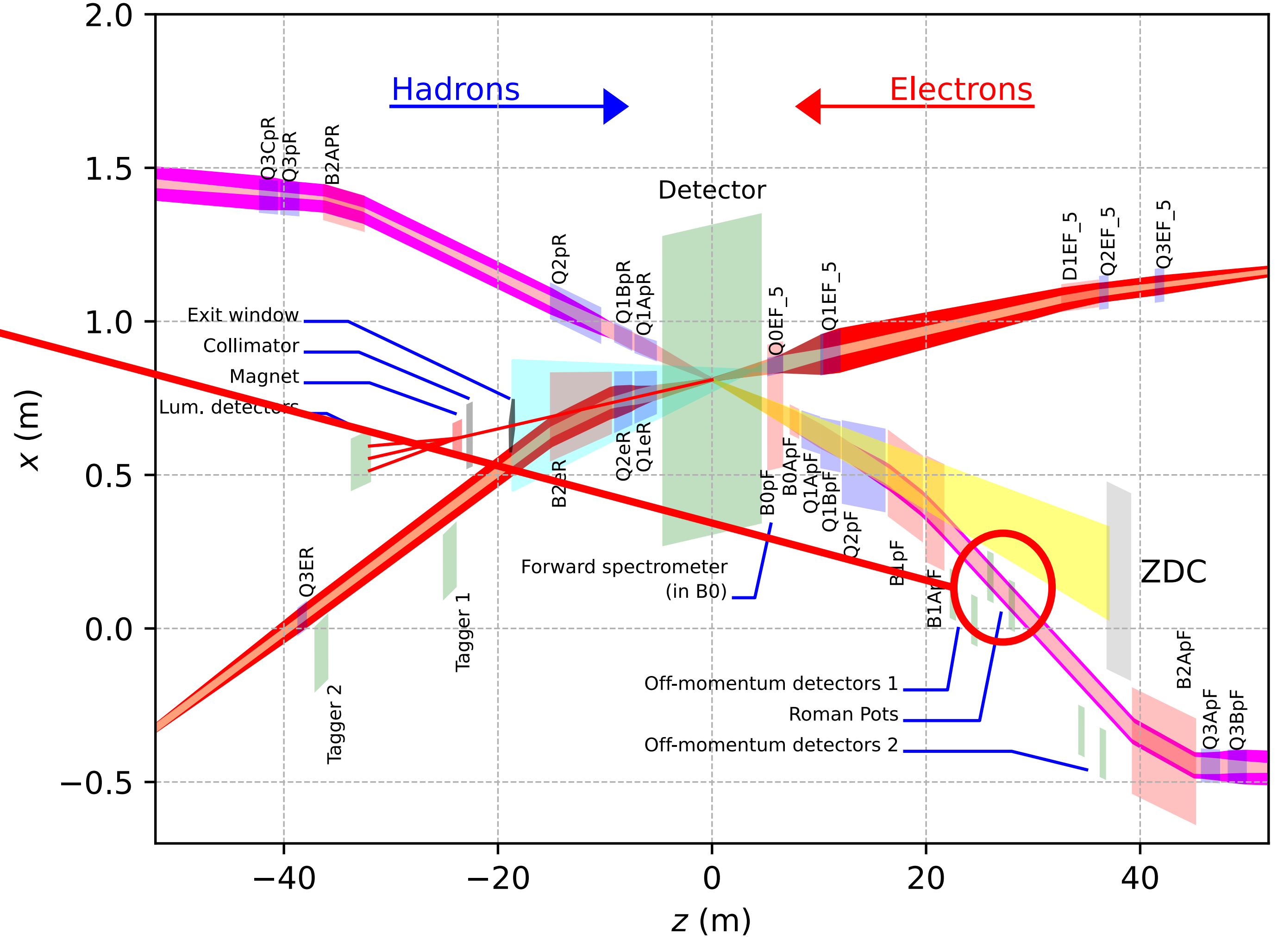
- Matrix transport reconstruction.
- Slightly less stringent spatial resolution requirements.
    - Sensitive to misalignment.

Roman Pots @ the EIC

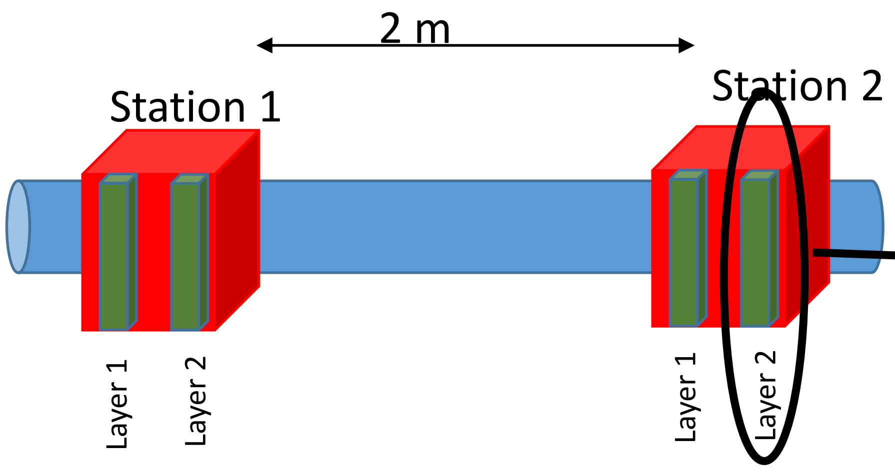
Protons
E = 275 GeV
$0 < \theta < 5$ mrad

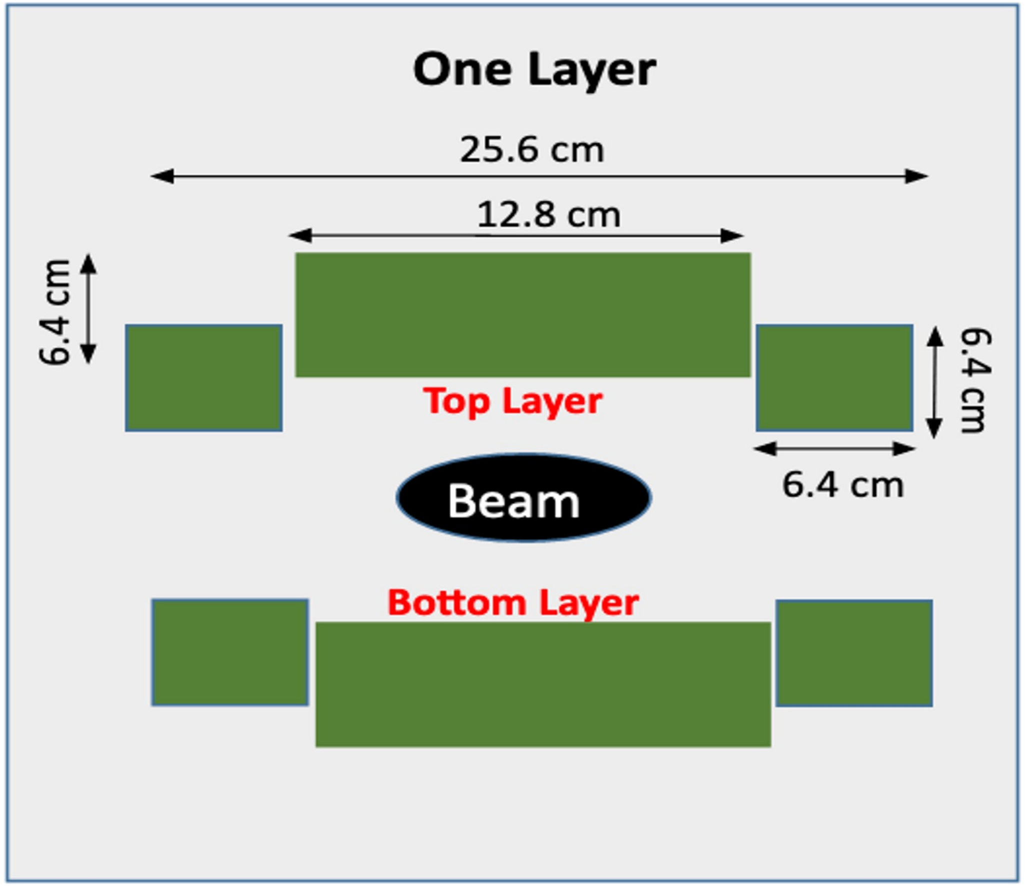
Full GEANT4 simulation.





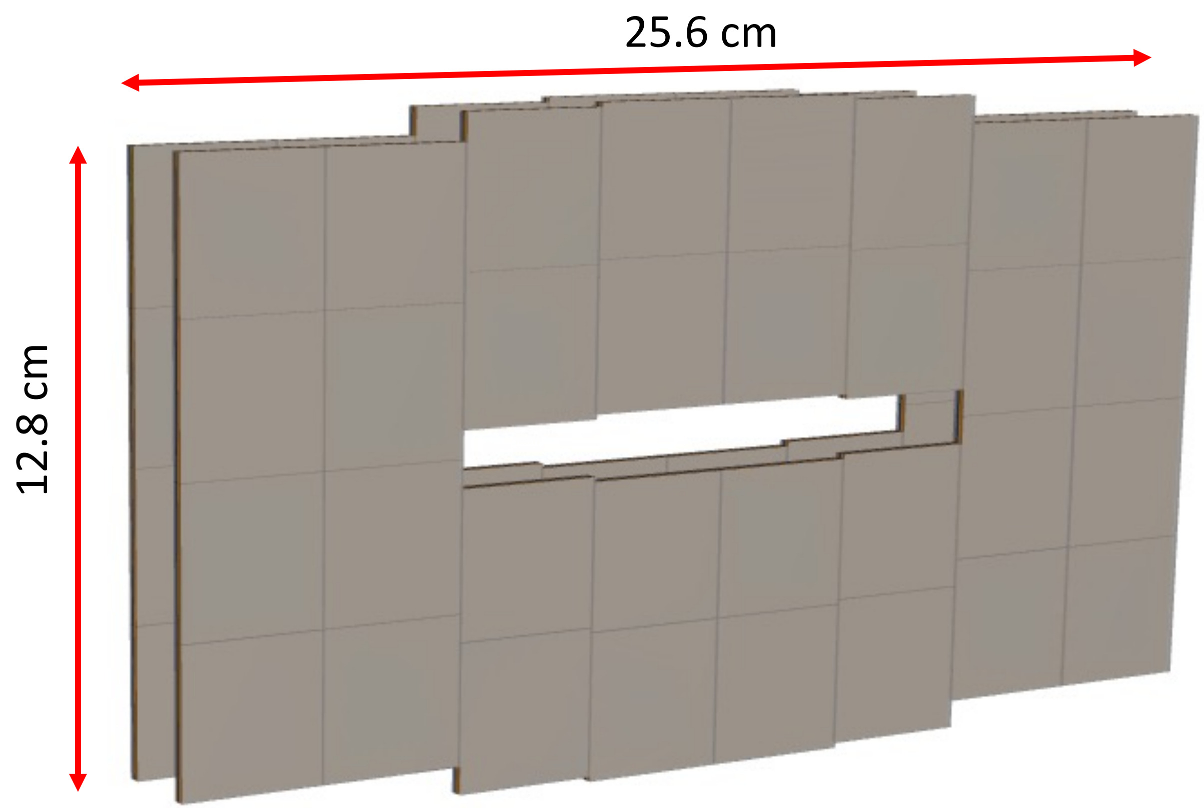
Roman "Pots" @ the EIC



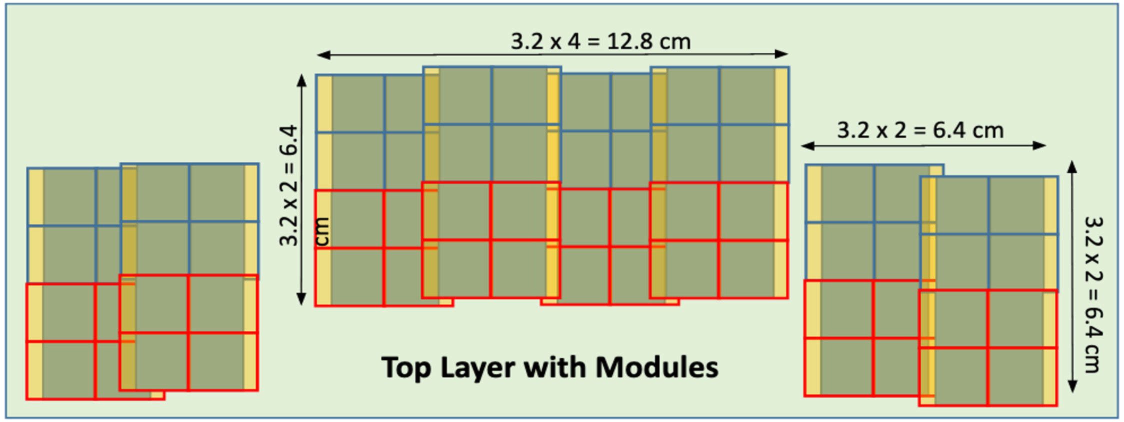


- Two stations, separated by 2 meters, each with two layers (minimum) of silicon detectors.
- Silicon detectors placed directly into machine vacuum!
  - Allows maximal geometric coverage!
- Need space for detector insertion tooling and support structure.

Roman "Pots" @ the EIC

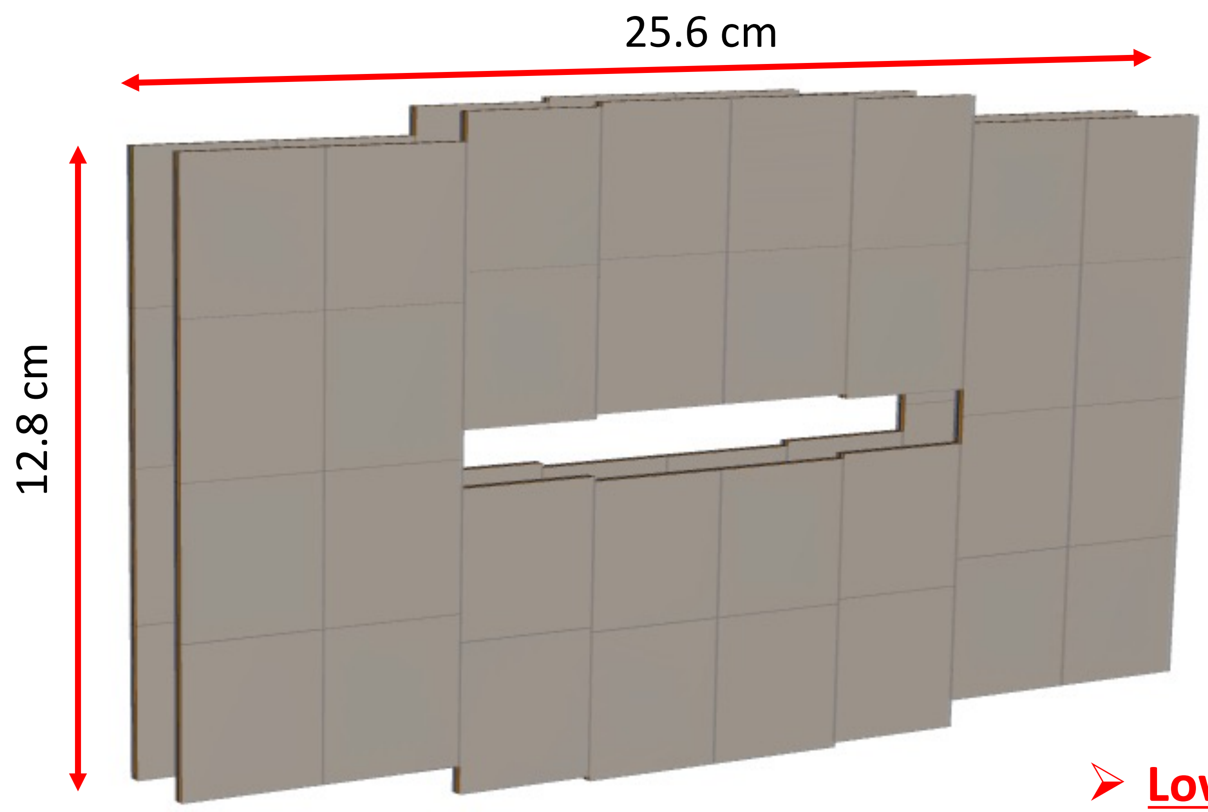


DD4HEP Simulation



- AC-LGAD sensor provides both fine pixilation (<140um spatial resolution), and fast timing (~35ps).
- **"Potless" design concept with thin RF foils surrounding detector components.**
  - **Under design/evaluation.**

Roman "Pots" @ the EIC

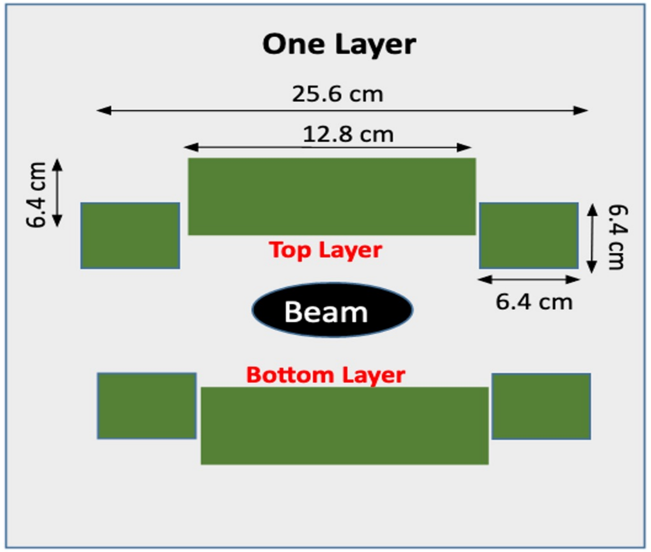


DD4HEP Simulation

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

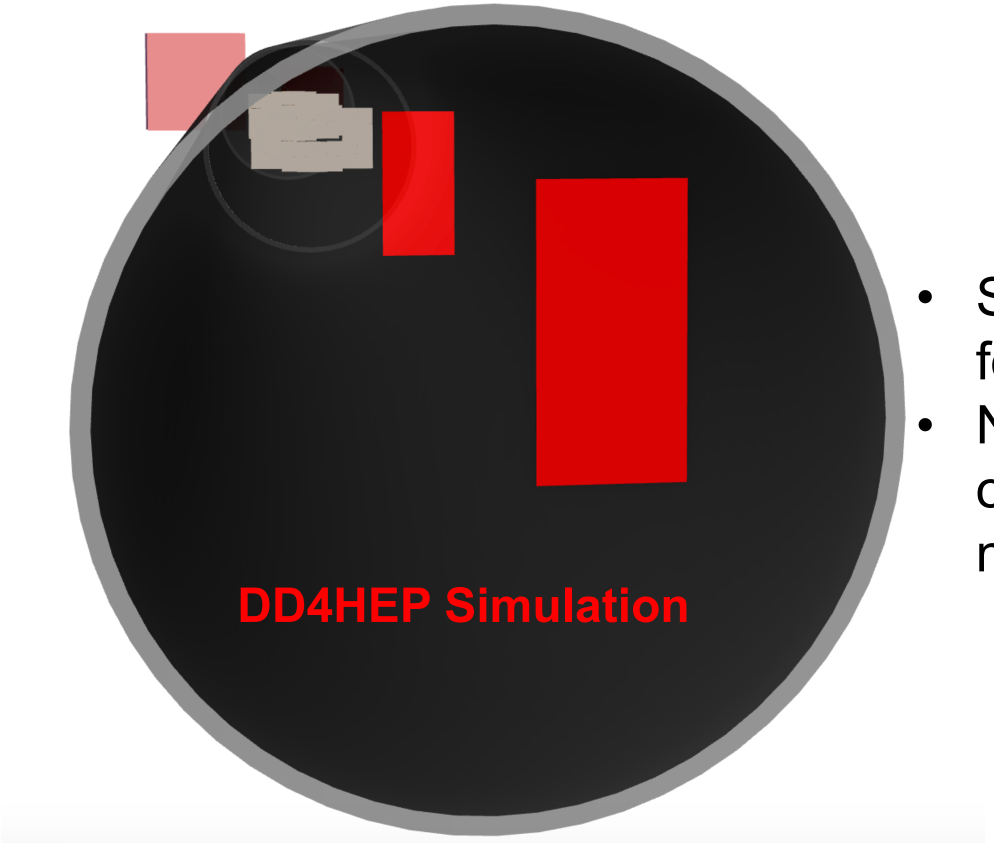
ε is the beam emittance.

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



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

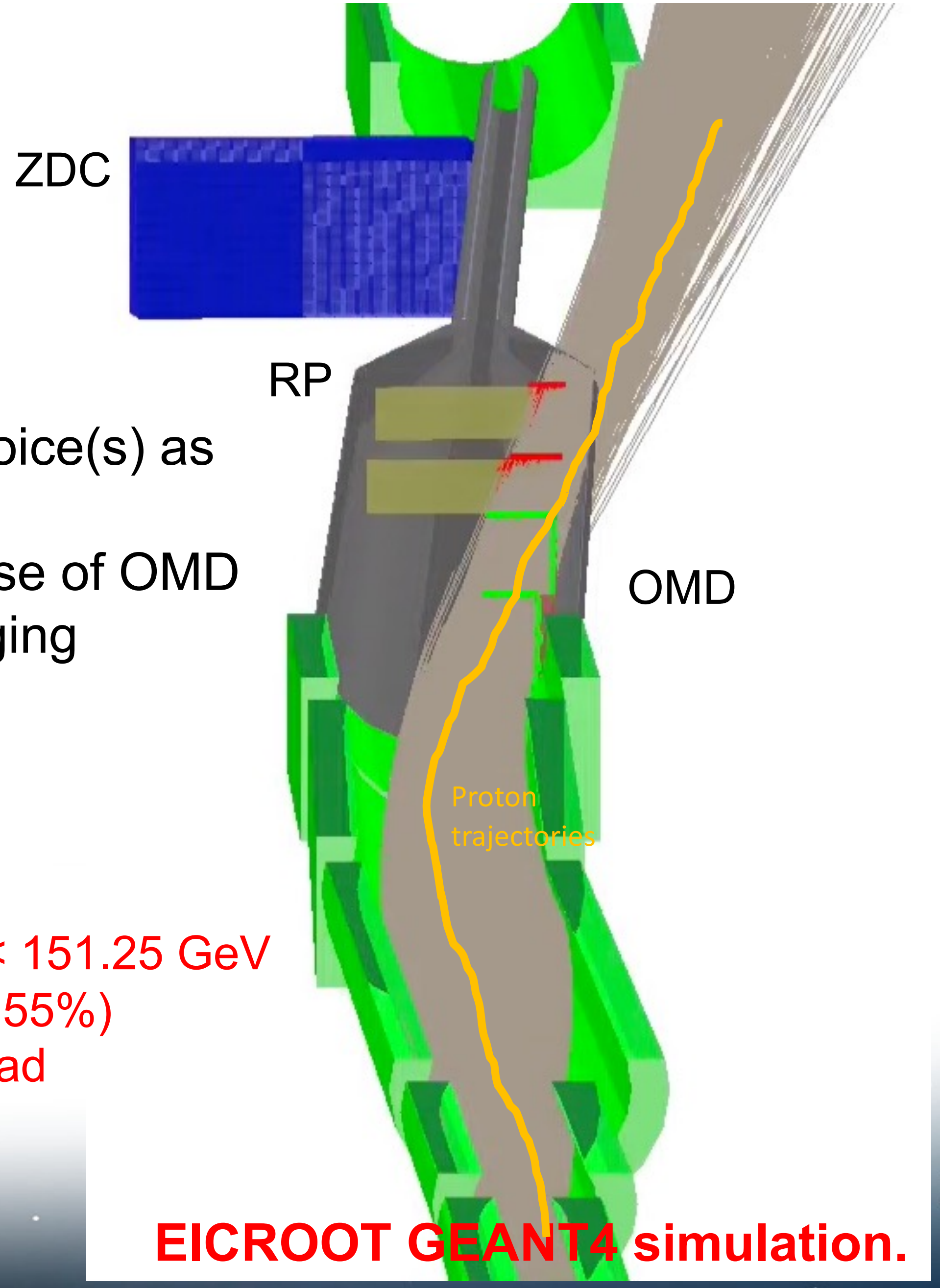
Off-Momentum Detectors



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

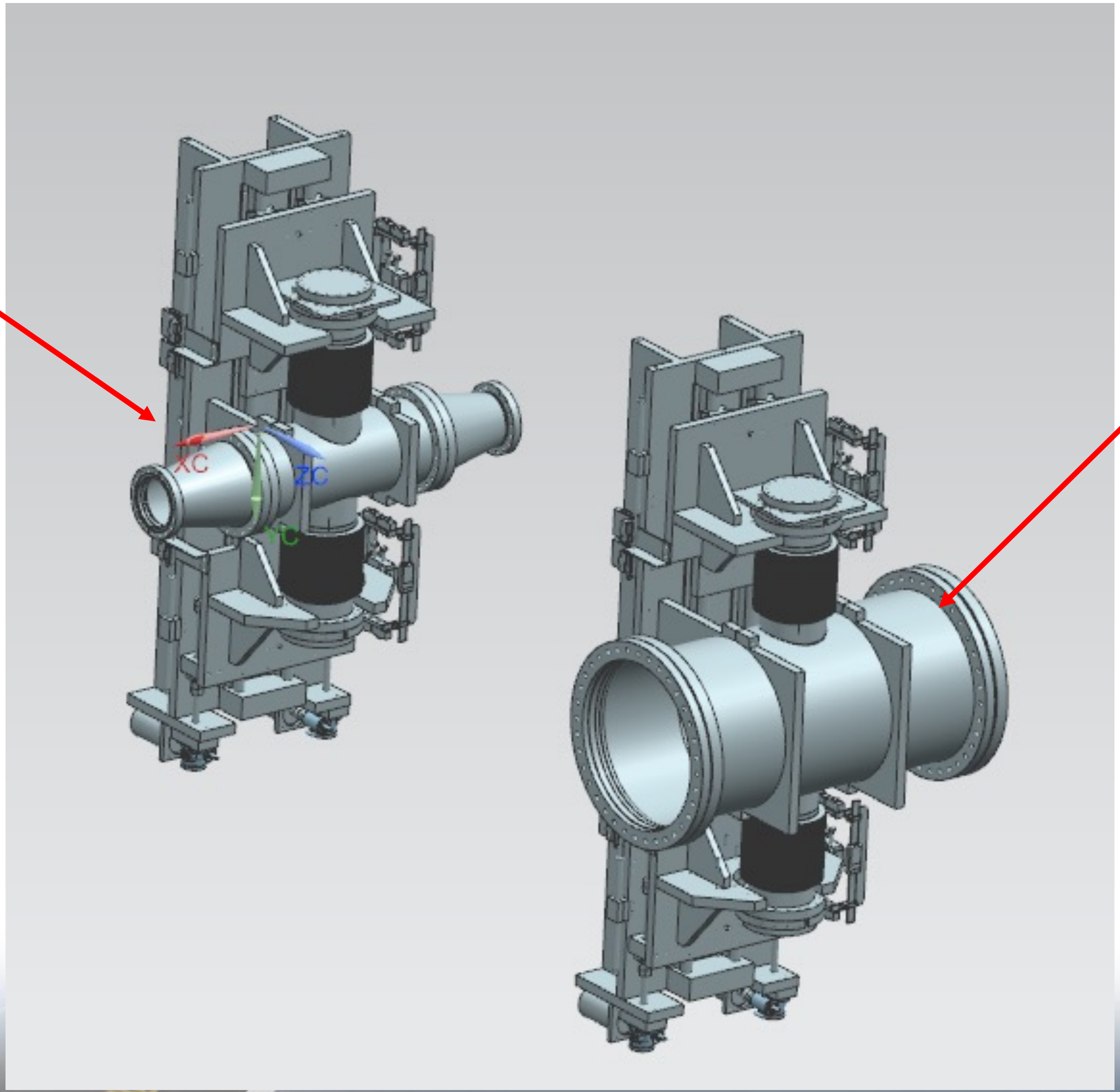
- Same technology choice(s) as for the Roman Pots.
- Need to also study use of OMD on other side for tagging negative pions.

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



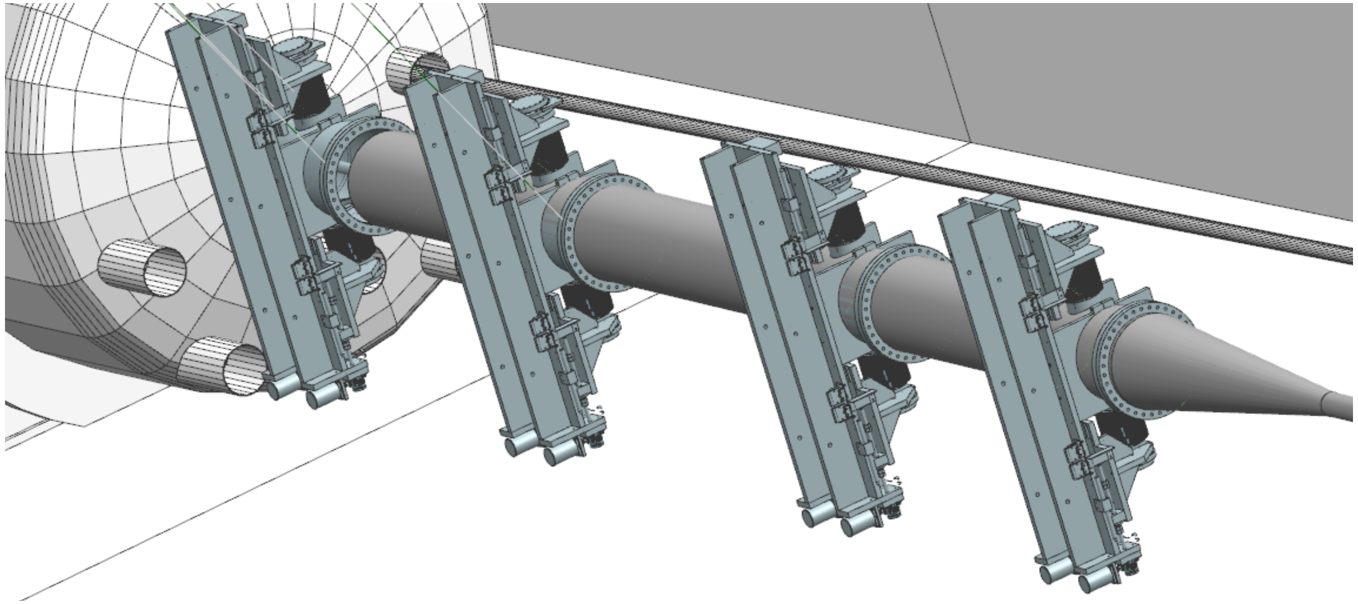
Roman Pots and Off-Momentum Detectors

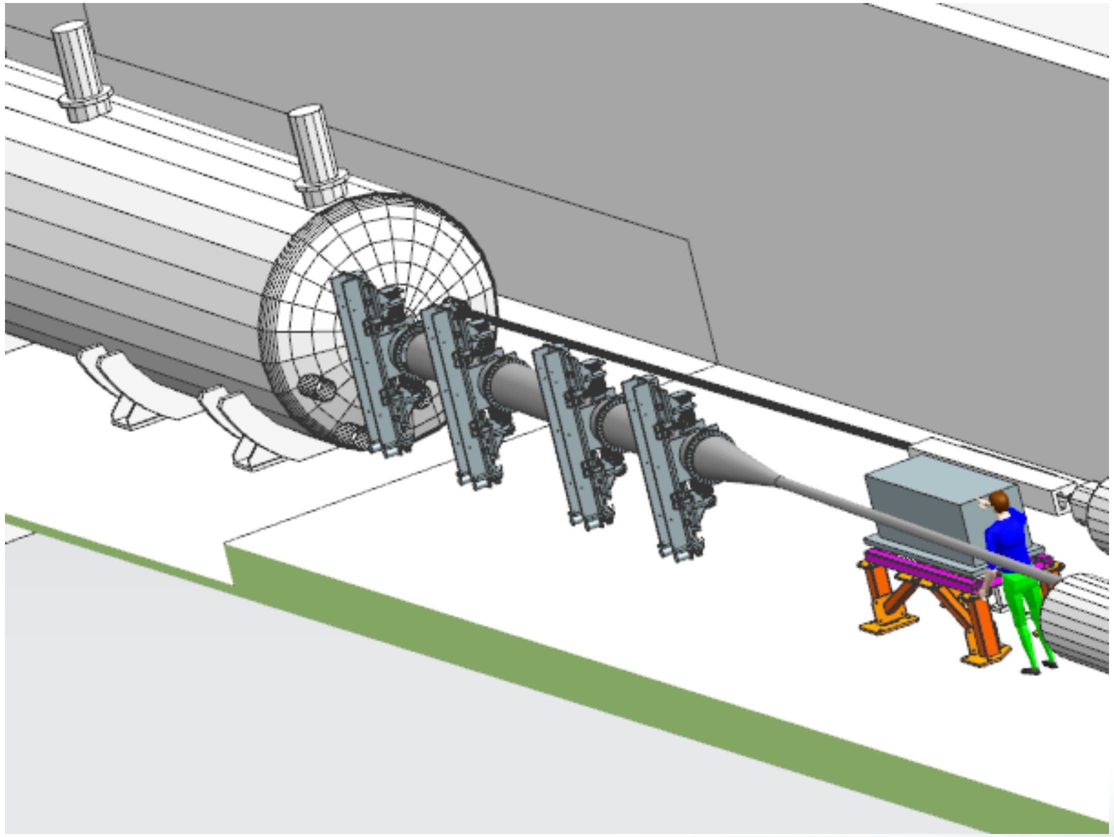
Initial step file inspired by STAR



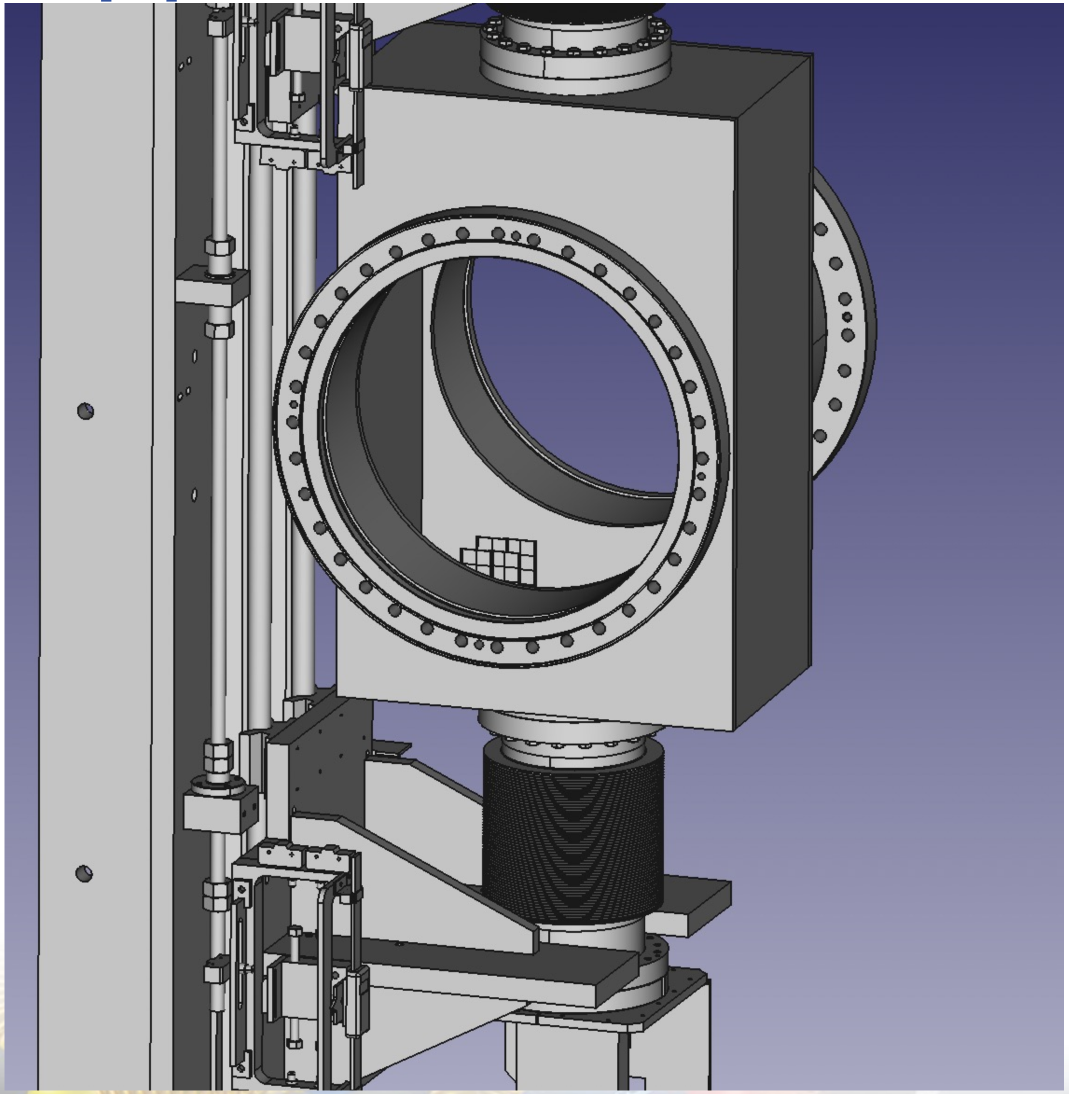
Updated model in NX with different beamtube size

Preliminary CAD drawings of RP and OMD Supports and Magnet Cryostats

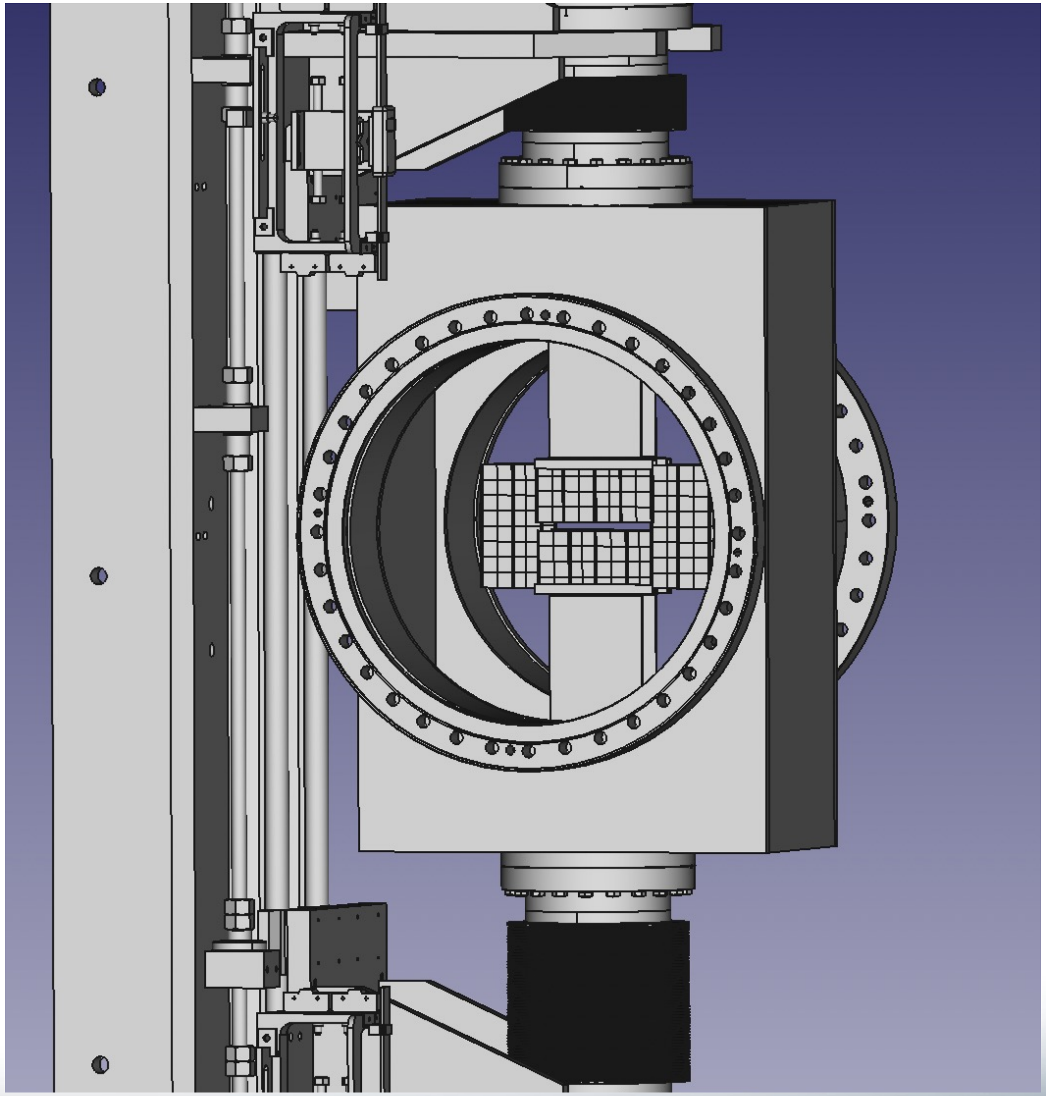




Support and Insertion System



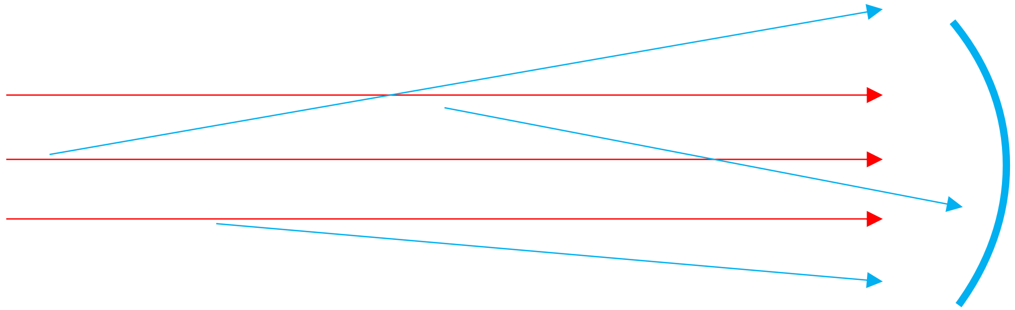
Home or “park” position (out of beam path).

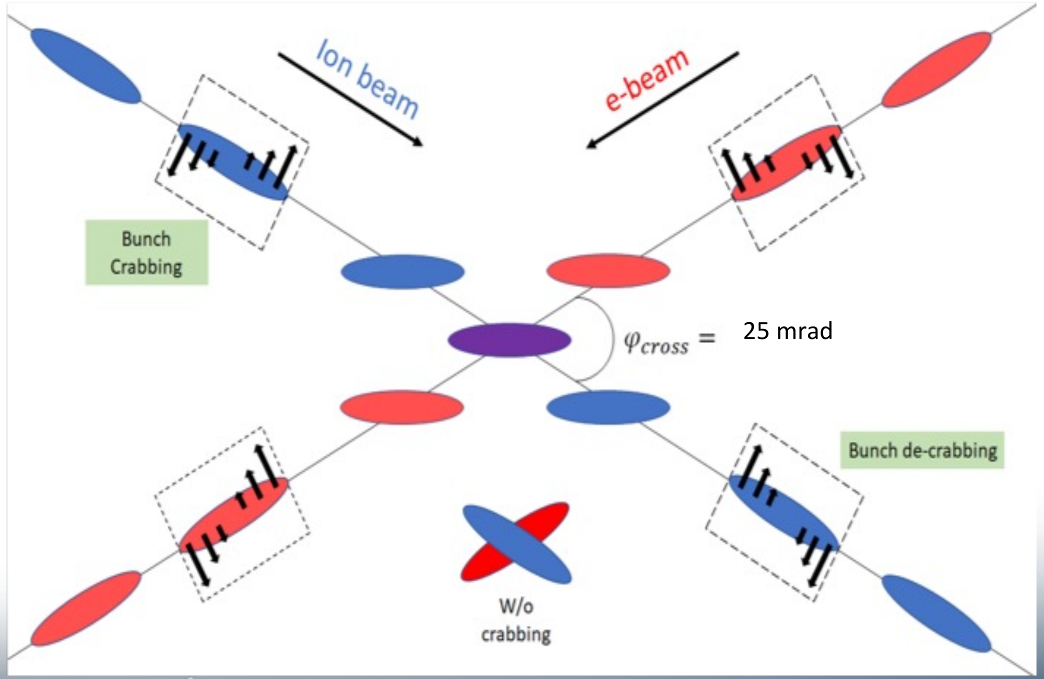


Data taking (e.g. 10Sigma) position.

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.

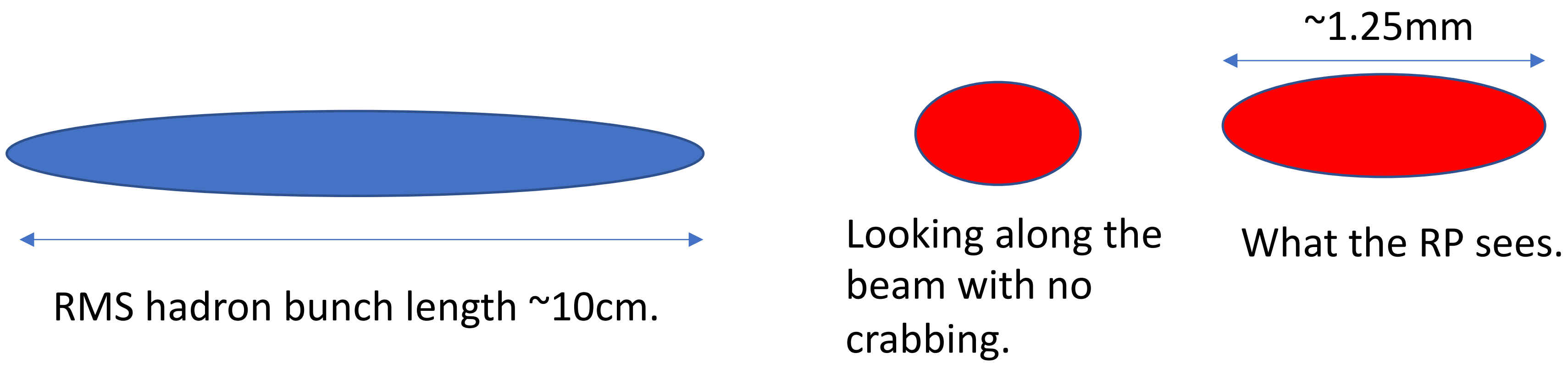




These effects introduce smearing in our momentum reconstruction.

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).**

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.

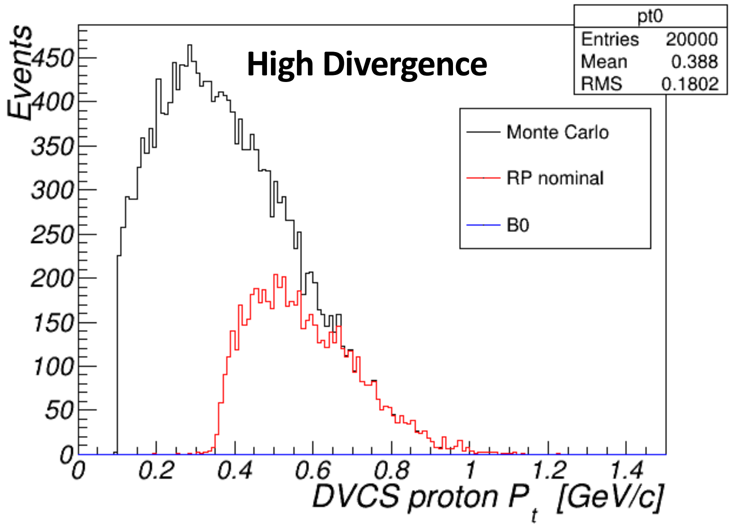
Smearing from finite pixel size.

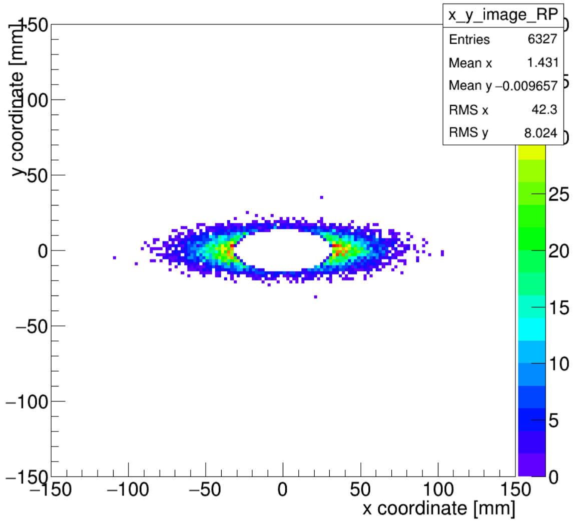
	Ang Div. (HD)	Ang Div. (HA)	Vtx Smear	250um pxl	500um pxl	1.3mm pxl
$\Delta p_{t,total}$ [MeV/c] - 275 GeV	40	28	20	6	11	26
$\Delta p_{t,total}$ [MeV/c] - 100 GeV	22	11	9	9	11	16
$\Delta p_{t,total}$ [MeV/c] - 41 GeV	14	-	10	9	10	12

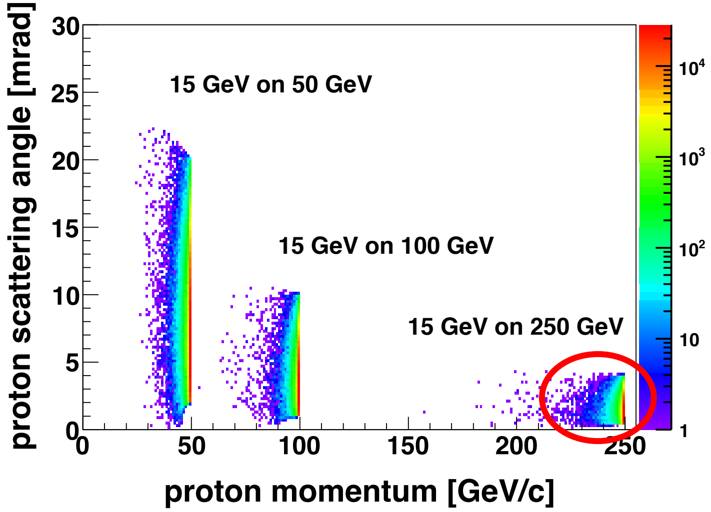
- **Beam angular divergence**
  - Beam property, can't correct for it – sets the lower bound of smearing.
  - Subject to change (i.e. get better) – beam parameters not yet set in stone
- **Vertex smearing from crab rotation**
  - Correctable with good timing (~35ps)
- **Finite pixel size on sensor**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

Digression: Machine Optics

275 GeV DVCS Proton Acceptance



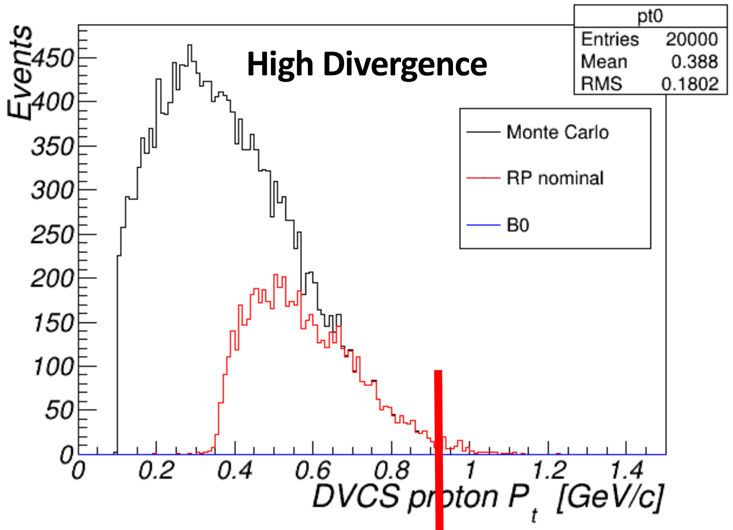


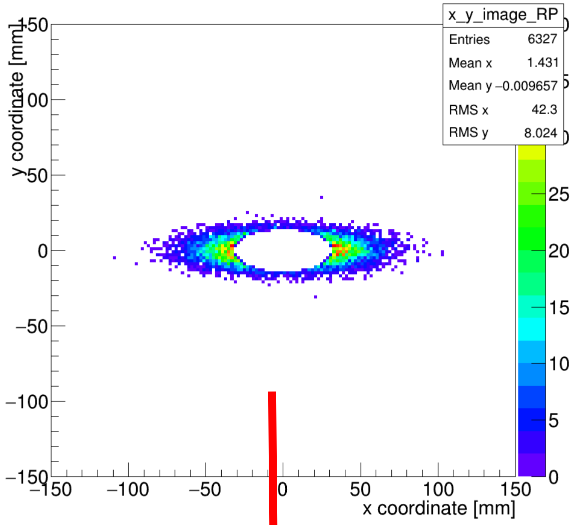


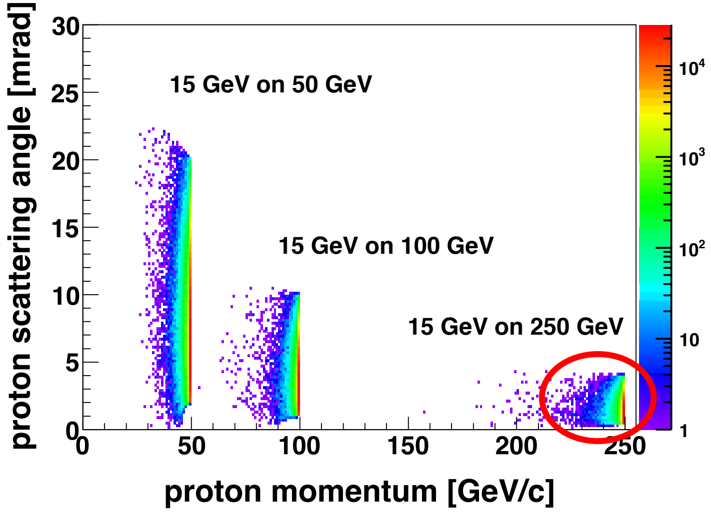
High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

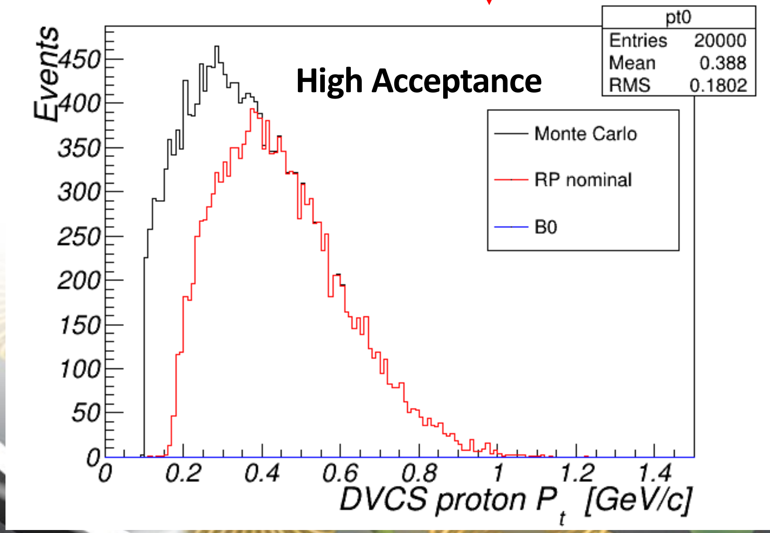
Digression: Machine Optics

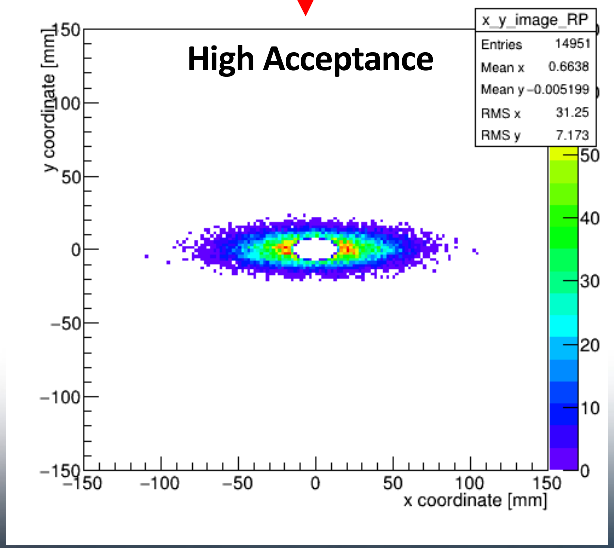
275 GeV DVCS Proton Acceptance









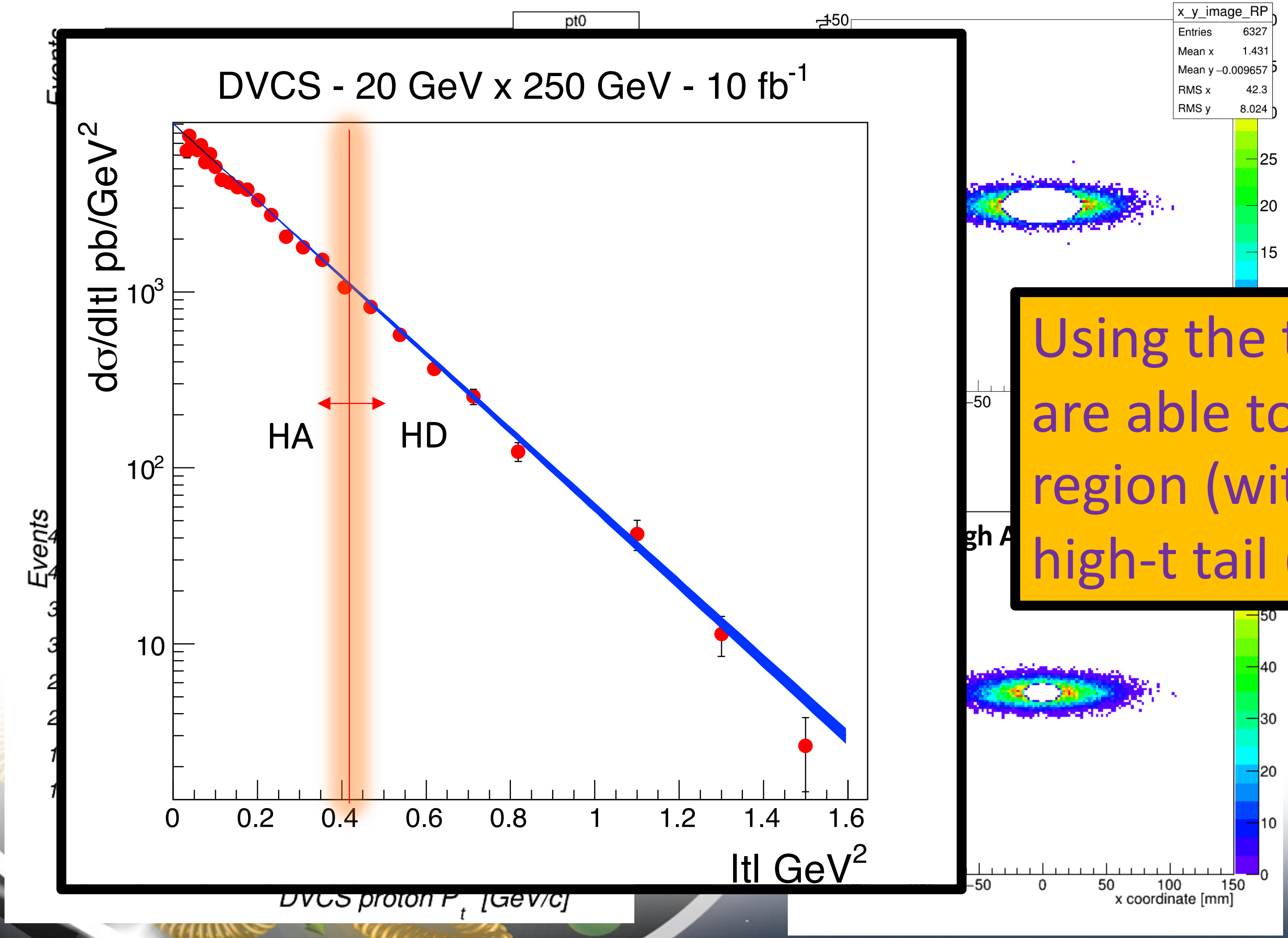


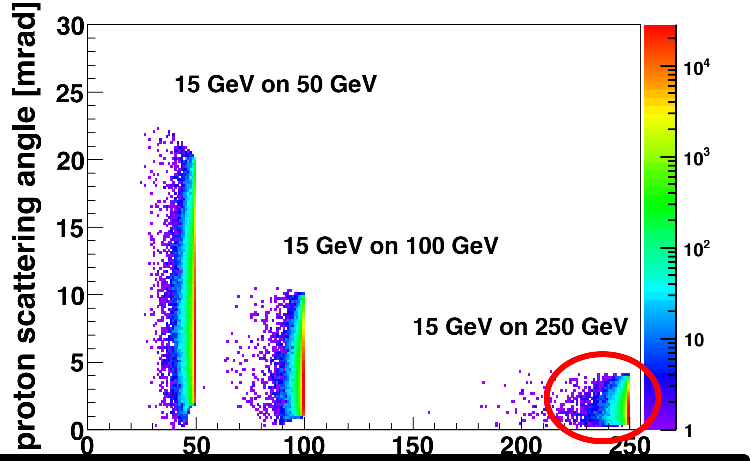
High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

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

Digression: Machine Optics

275 GeV DVCS Proton Acceptance

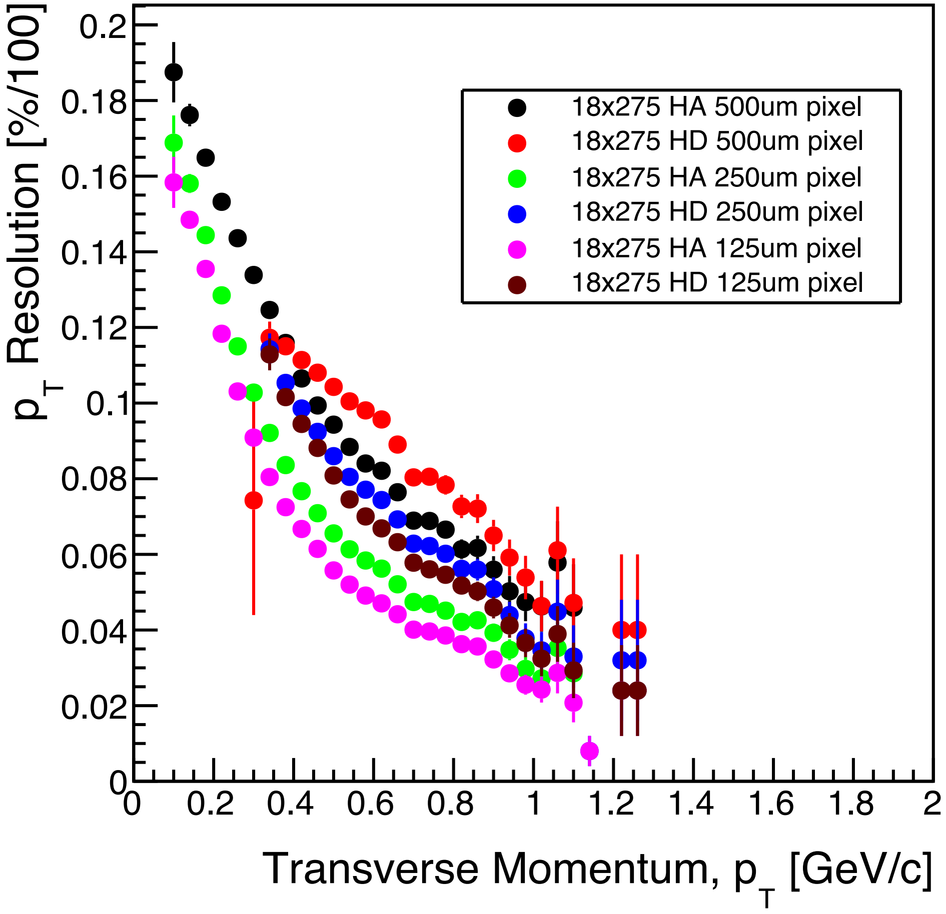


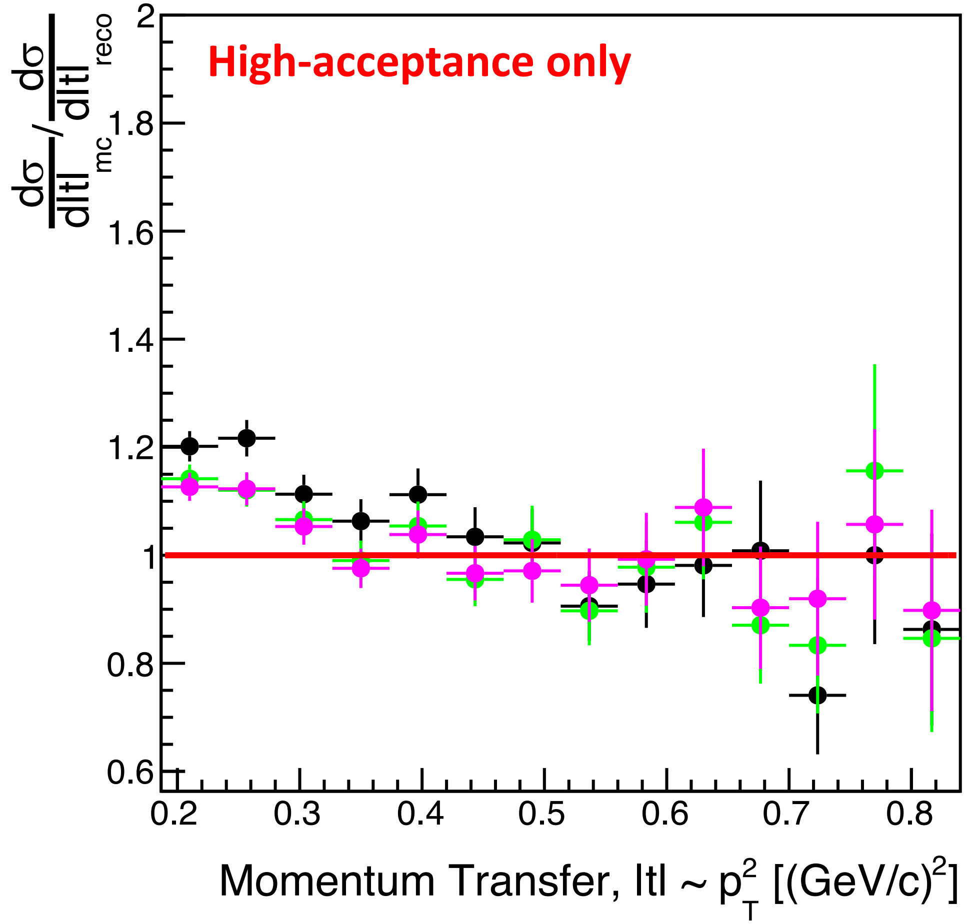


Using the two configurations, we are able to measure the low-t region (with better acceptance) and high-t tail (with higher luminosity).

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

Detailed Momentum Resolution - 18x275 GeV

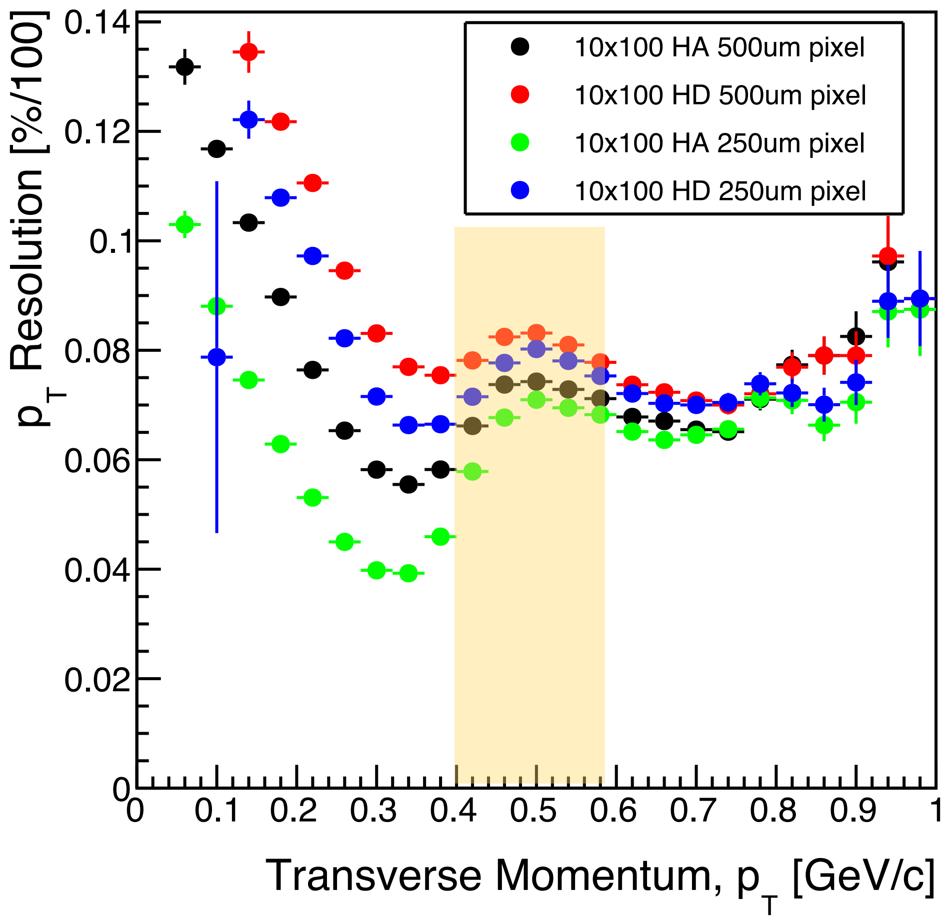


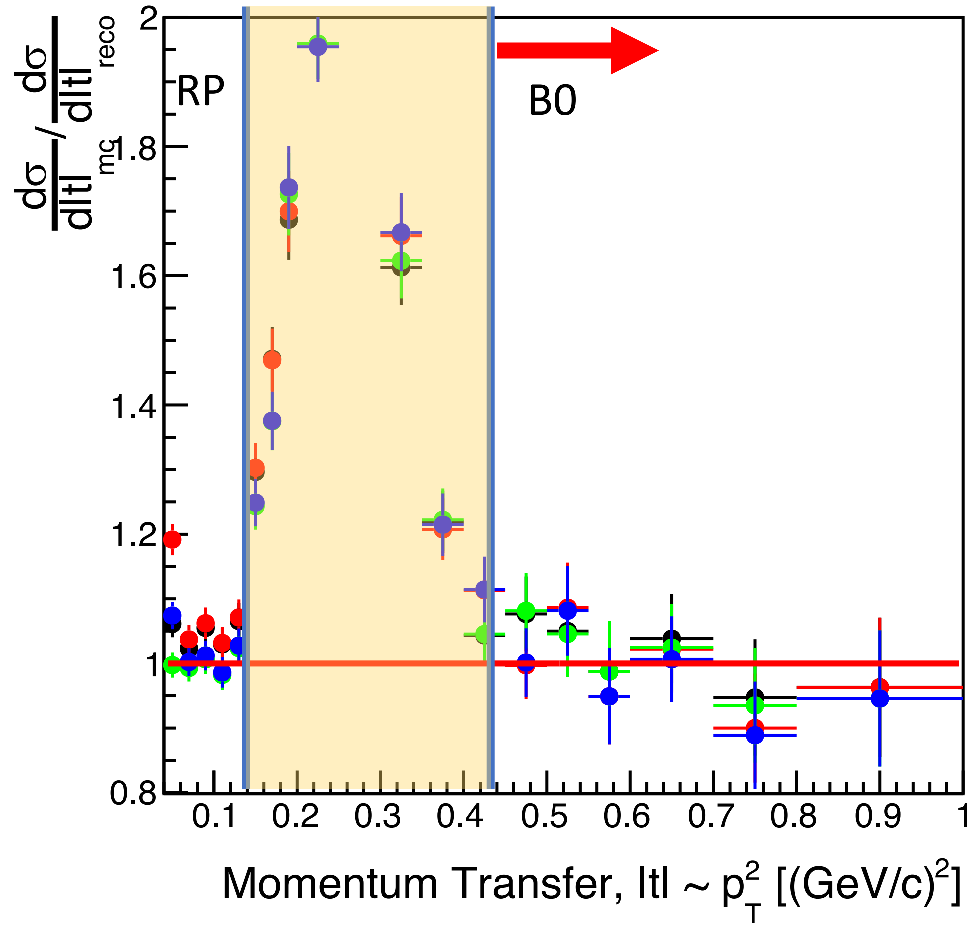


- Each case includes all beam effects.
- Updated transfer matrix reconstruction compared to eRD24.
- **Material thickness has not been evaluated in detail, but of course additional material will degrade resolution.**

- Goal is to extract slope of t-distribution.
- Ratio indicates expected capability.

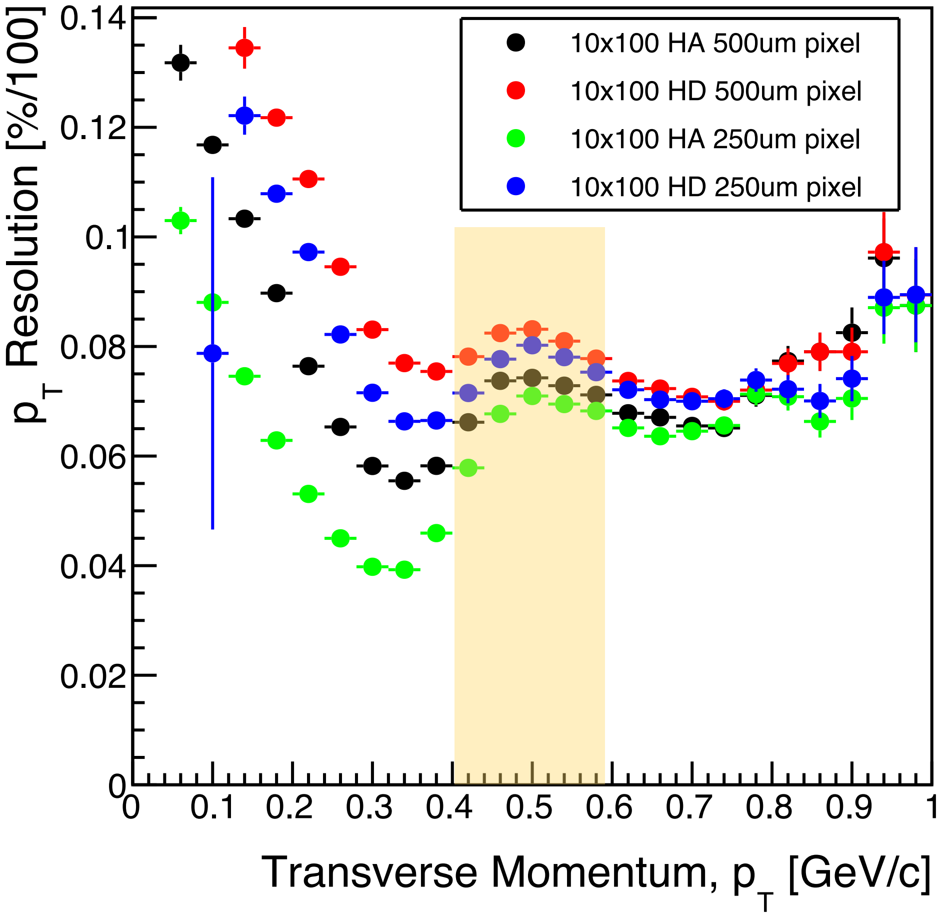
Detailed Momentum Resolution - 10x100 GeV

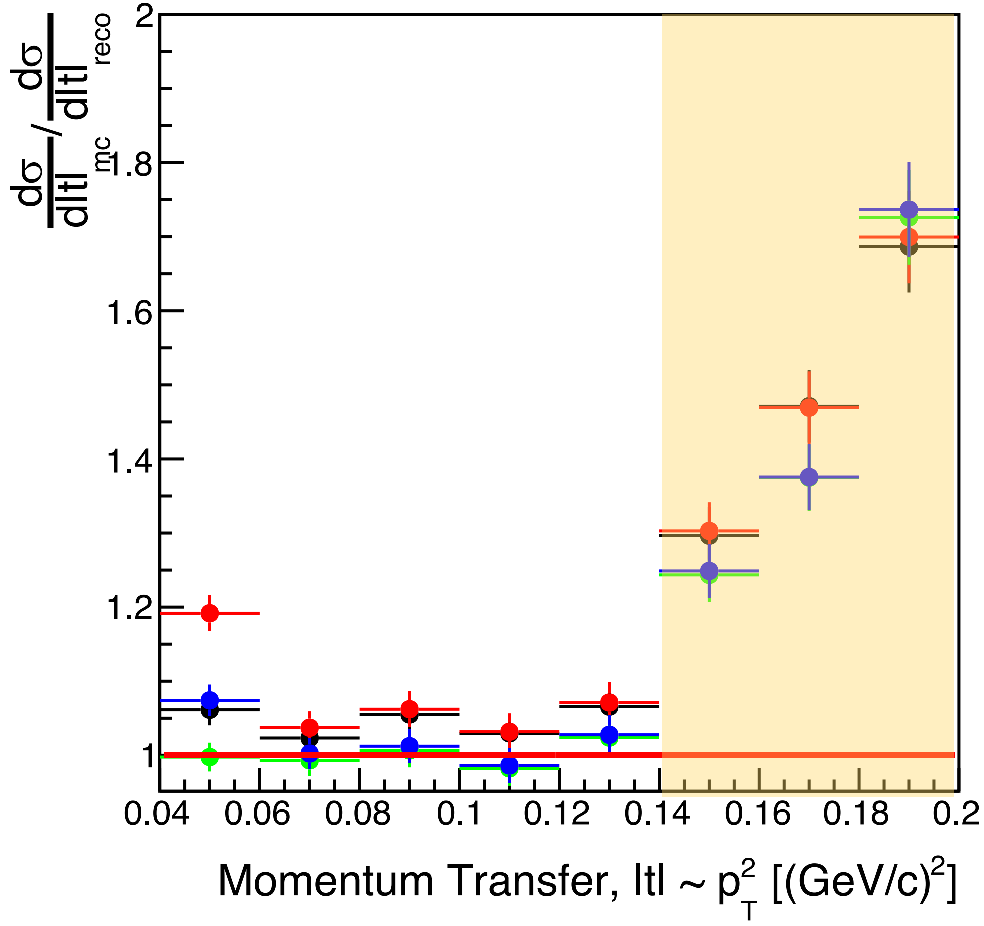




- Yellow shaded area is the acceptance gap between the detectors.
- No acceptance correction is applied here.

Detailed Momentum Resolution - 10x100 GeV





- Zoom-in to relevant RP range.
- Since angular divergence is smaller in the 100 GeV beam, the spatial resolution has a larger impact.

Detector Resolution Summary

- Modern studies support basic idea of eRD24 studies.
  - 500um pixels can do the job.
  - Expecting x2 improvement (super-conservative minimum) in (pixel size)/Sqrt(12) – reduces slope distortion in t-distribution.
  - Physics groups have not produced any further input on required performance – so we should ensure the detector choices do not hinder a possible measurement.
- Strips increase the number of needed planes x2, which increases cooling, needed space, engineering constraints, etc.
  - Strips can make background rejection much more challenging (experience of PPS @ CMS).
  - Long strips potential for RF pickup noise.
  - We have no real estimates on these things from the engineering design, so it makes it challenging to know what to include in the simulations.
  - The active area of the detectors is very large, and the whole system is directly in vacuum. Adding more planes means more services, impedance, etc.

The far-forward DWG, based on other experience implementing RP in other experiments, endorses use of pixels rather than strips.

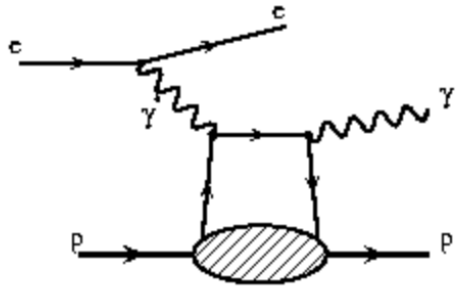
Open Questions (to you)

- Requirements for operating in vacuum?
  - e.g. cooling requirements.
- Cabling and readout?
  - The “strawman” layout is currently ~ 3cm x 3cm sensor + ASIC packages – how do we plan to read this out?
- Expected noise rates for DAQ/readout?
  - Plan to run in streaming mode like the rest of the EIC.
- How does the timing and charge sharing (spatial resolution) degrade with radiation damage?
  - We need to get better estimates for rates w.r.t. to injection/tuning as the sensors approach the beam halo.

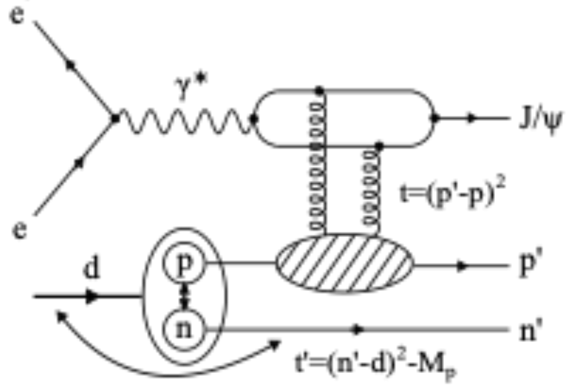
Backup

Far-forward physics at EIC

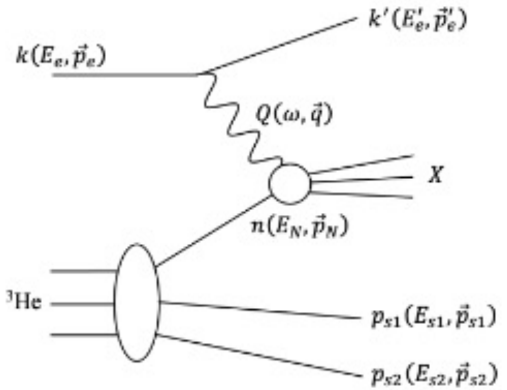
e+p DVCS with proton tagging



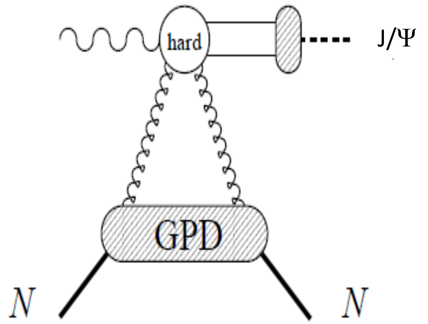
e+d exclusive J/Psi with proton or neutron tagging



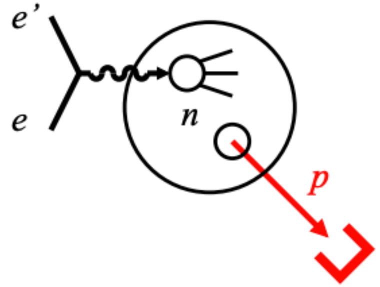
e+He3 spectator tagging



coherent/incoherent J/ψ production in e+A

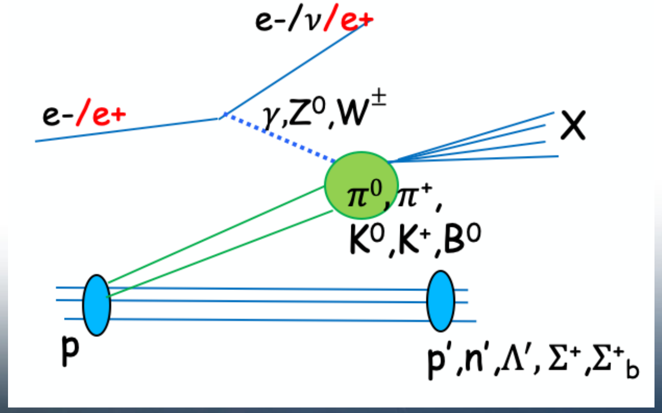


e+d DIS spectator tagging



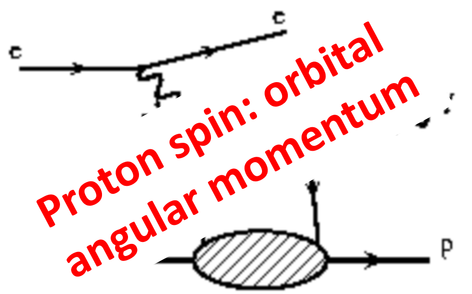
Meson structure:

- with neutron tagging (ep→ (π) →e' n X)
- Lambda decays (Λ →pπ^- and $\Lambda \to$ nπ^0)

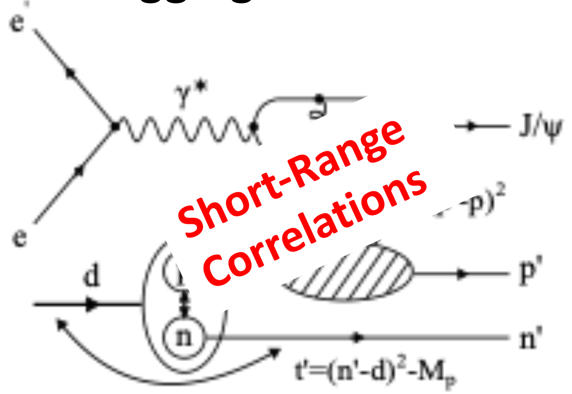


Far-forward physics at EIC

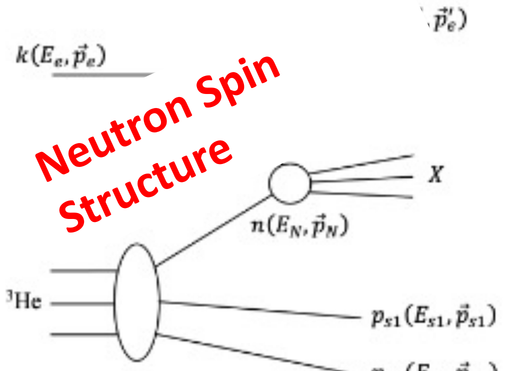
e+p DVCS with proton tagging



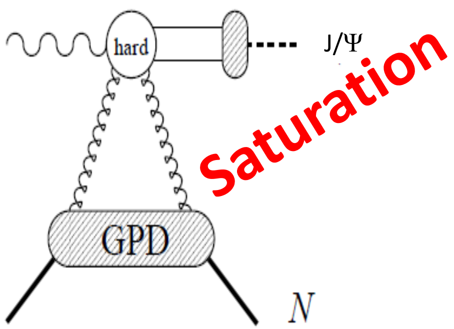
e+d exclusive J/Psi with proton or neutron tagging[1]



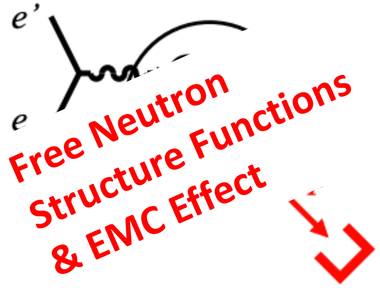
e+He3 spectator tagging[2]



coherent/incoherent J/ψ production in e+A[3]

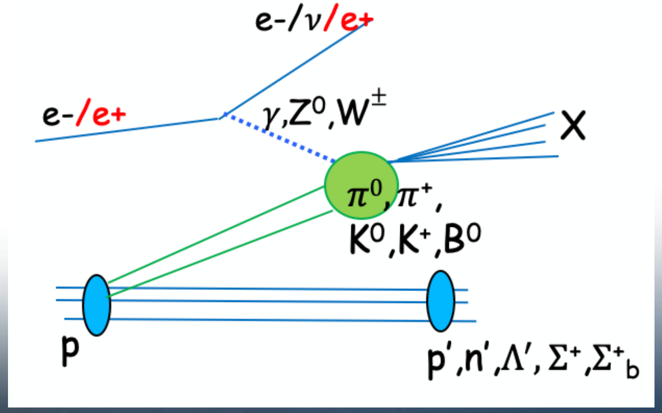


e+d DIS spectator tagging[4]



Meson structure:

- with neutron tagging (ep→ (π) →e' n X)
- Lambda decays ($\Lambda \to p\pi^-$ and $\Lambda \to n\pi^0$)



[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)**

Far-forward physics at EIC

e+p DVCS with proton tagging

e+d exclusive J/Psi with proton or

e+He3 spectator tagging[2]

- **Many detailed impact studies with full GEANT4 detector simulations carried out!**
  - **This is a non-exhaustive list!**
- **There are numerous crucial final-states which require Far-Forward detectors!!**
- **Many of these exclusive final states are crucial to the White Paper and NAS physics.**
  - **We will use e+p DVCS for the studies below.**

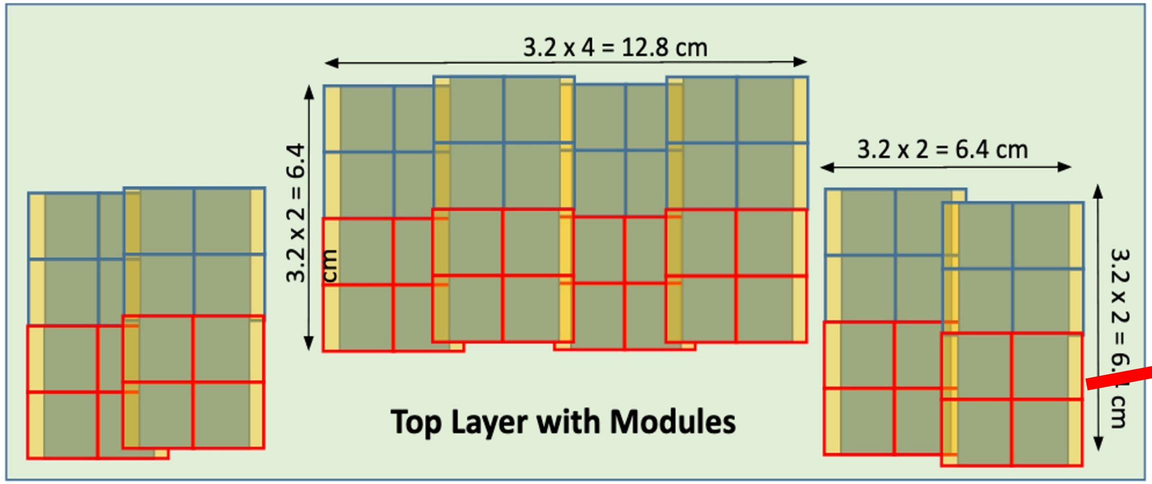
D **104**, 114030 (2021)
[4] A. Jentsch, Z. Tu, and C. Weiss, Phys. Rev. C **104,** 065205, (2021) **(Editor's Suggestion)**

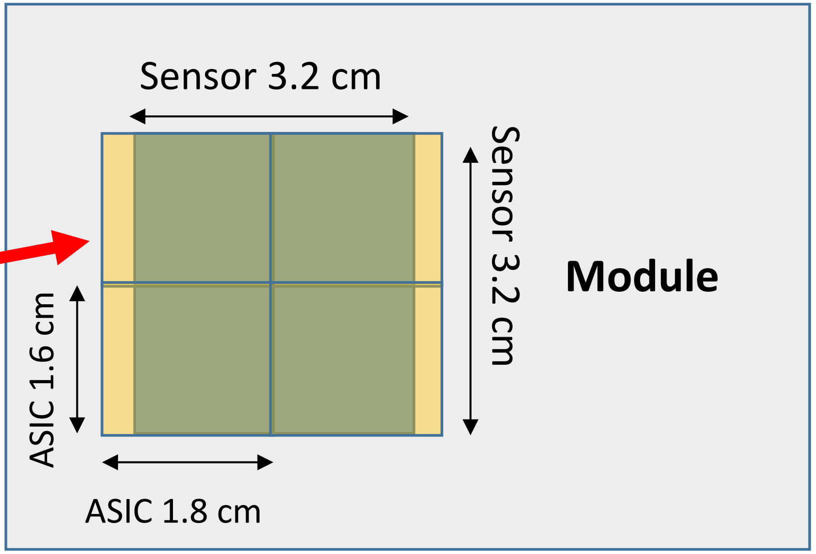
p

p',n',Λ',Σ⁺,Σ⁺b

Roman Pots

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



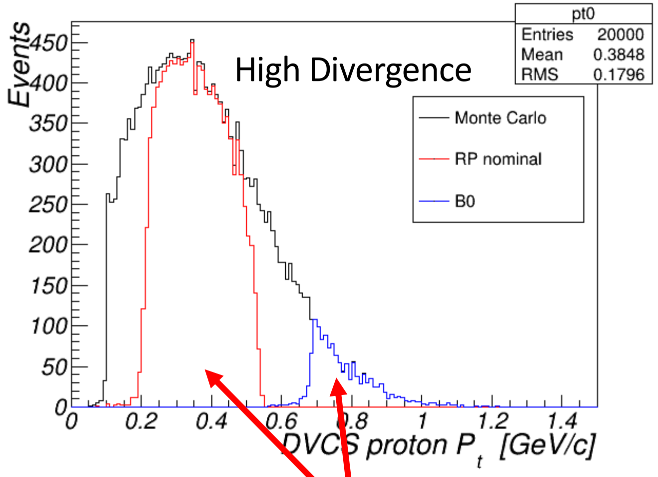


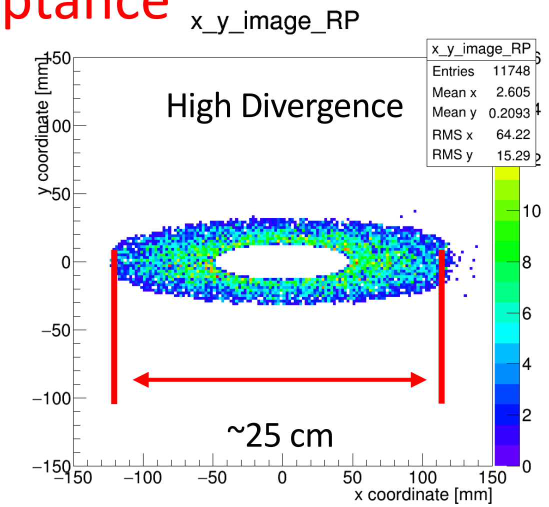
- Current R&D aimed at customizing ASIC readout chip (ALTIROC) for use with AC-LGADs.

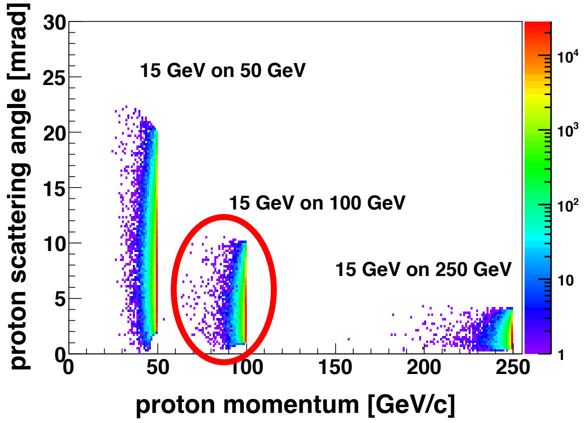
ASIC size	ASIC Pixel pitch	# Ch. per ASIC	# ASICs per module	Sensor area	# Mod. per layer	Total # ASICs	Total # Ch.	Total Si Area
1.6x1.8 cm^2	500 μm	32x32	4	3.2x3.2 cm^2	32	512	524,288	1,311 cm^2

Machine Optics: Roman Pots

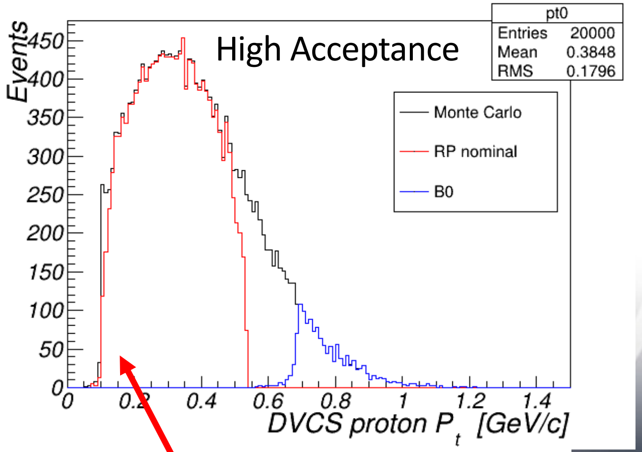
100 GeV DVCS Proton Acceptance

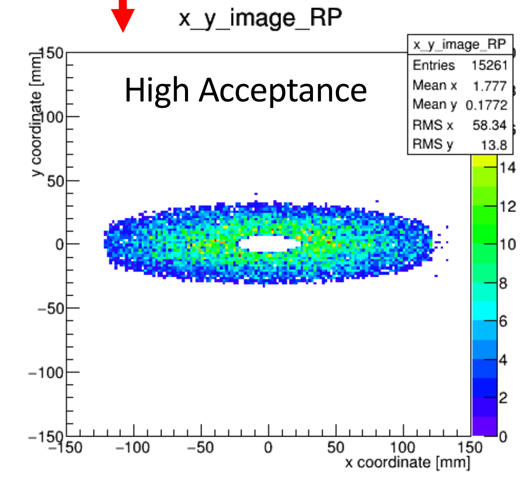






Need both detector systems together here!





Improves low p_t acceptance.