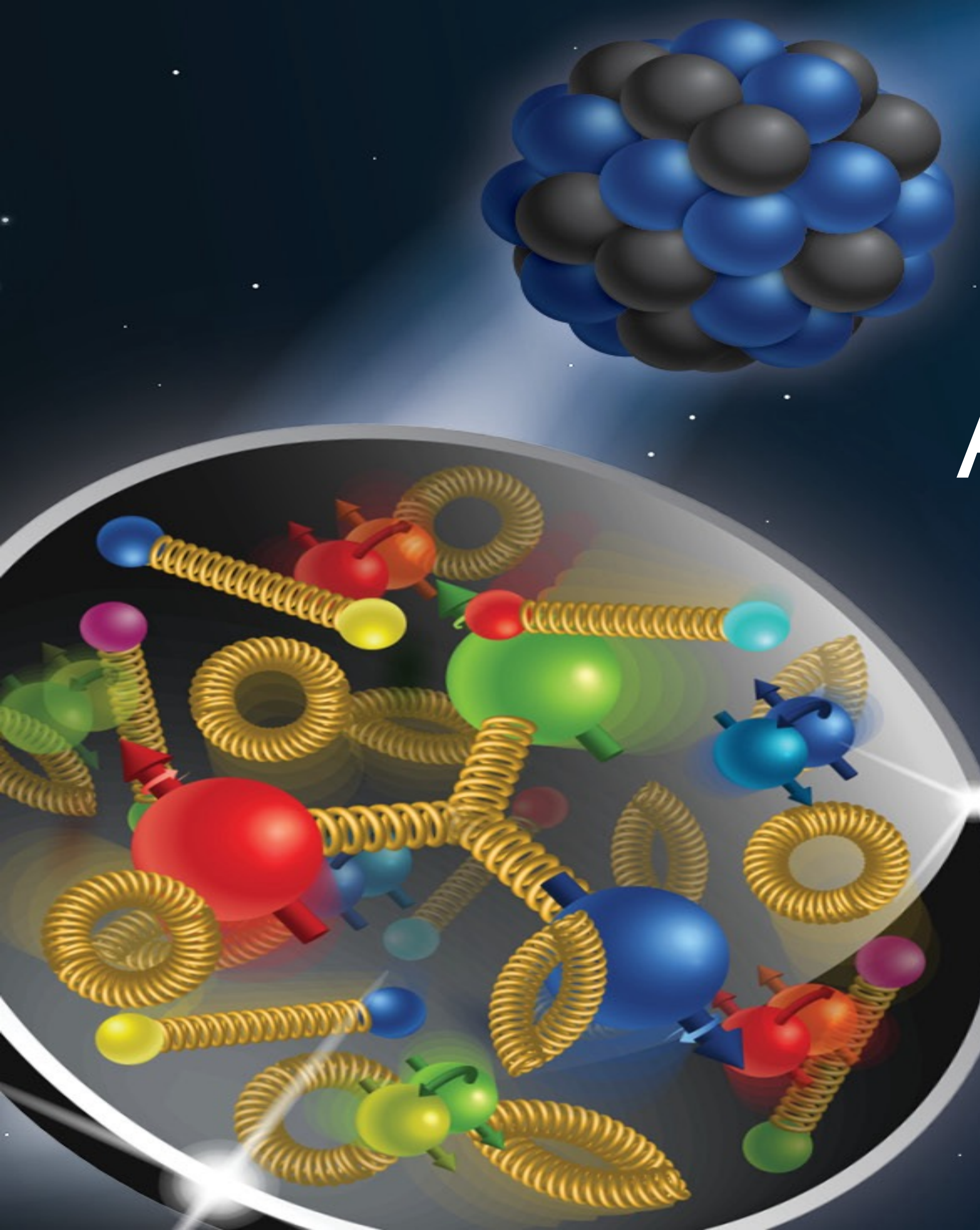


AC-LGAD for the Far-Forward Detectors at the EIC

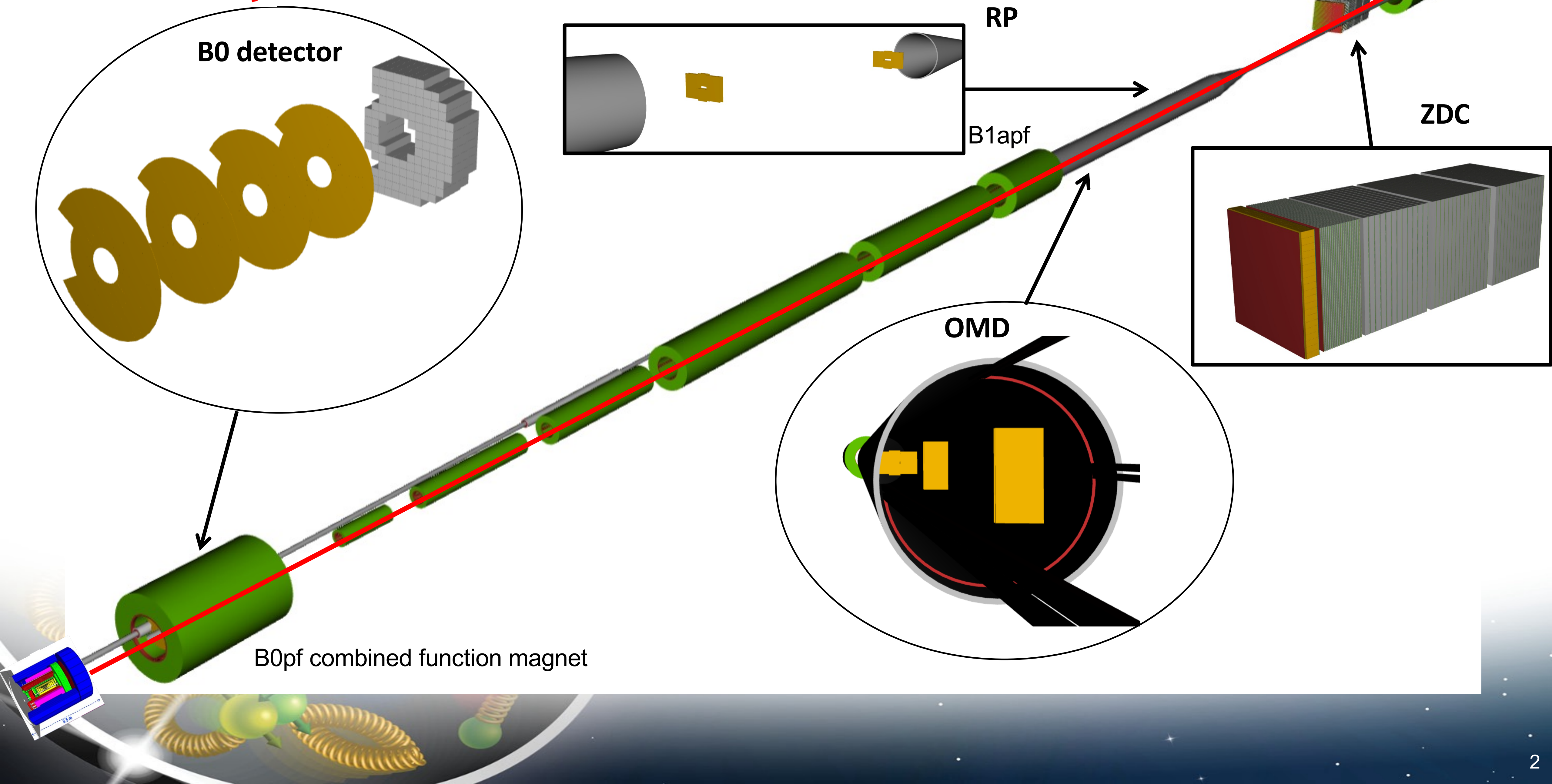
Alex Jentsch (BNL)

ePIC Collaboration Meeting

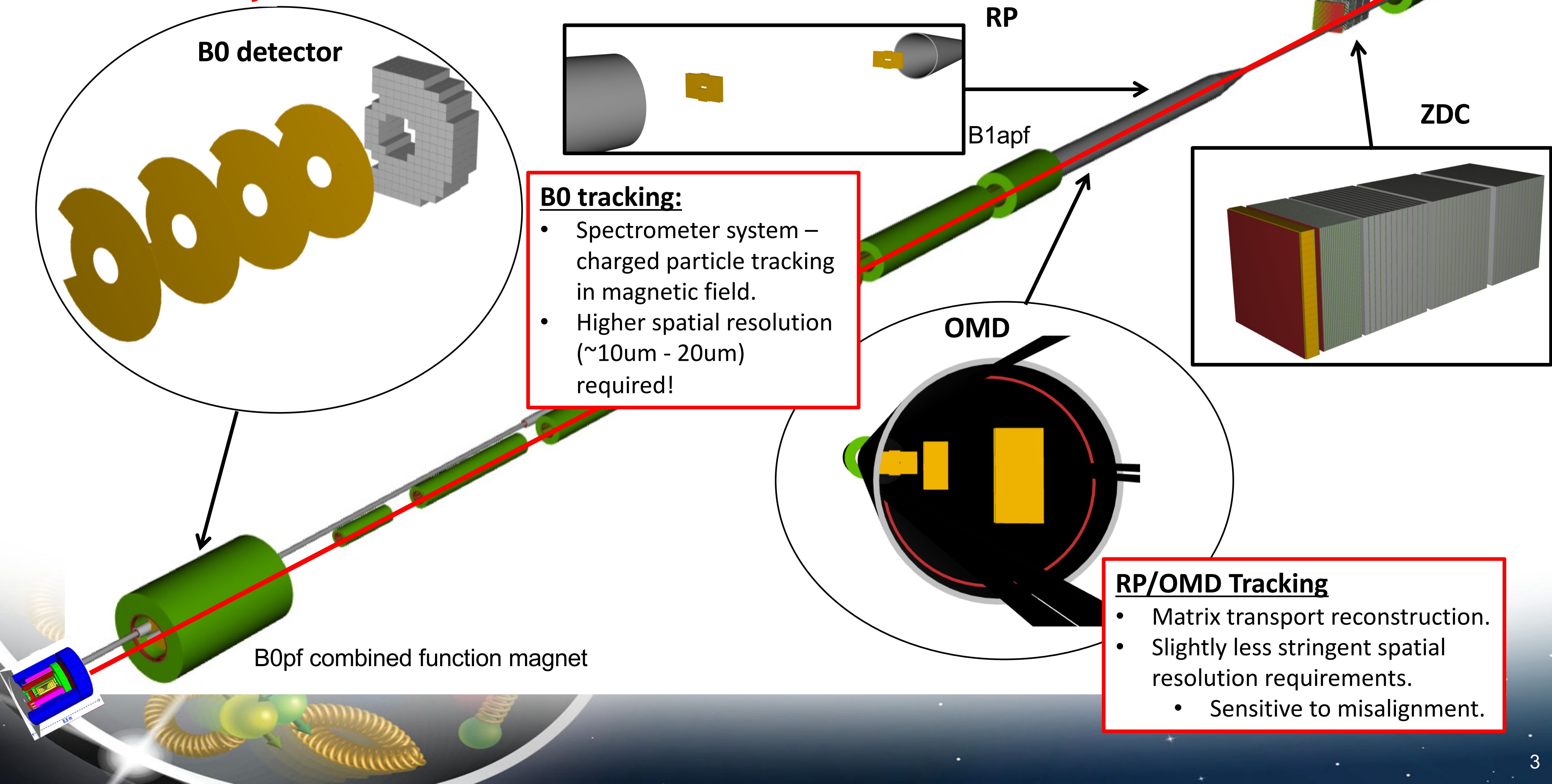
AC-LGAD Parallel Session

January 9th, 2023

The ePIC Far-Forward Detectors



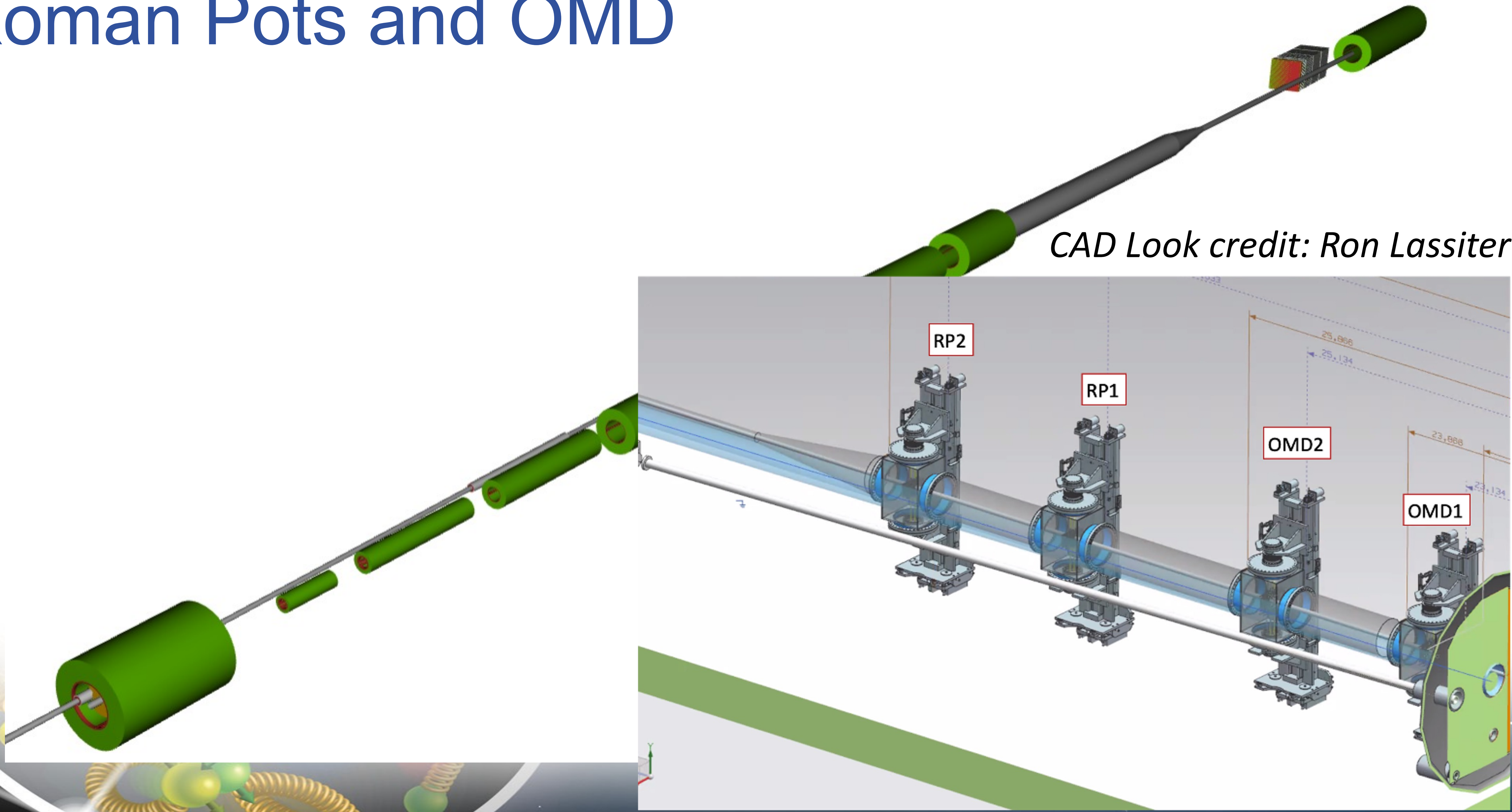
The ePIC Far-Forward Detectors



B0 tracking:
- Spectrometer system – charged particle tracking in magnetic field.
- Higher spatial resolution (~10um - 20um) required!

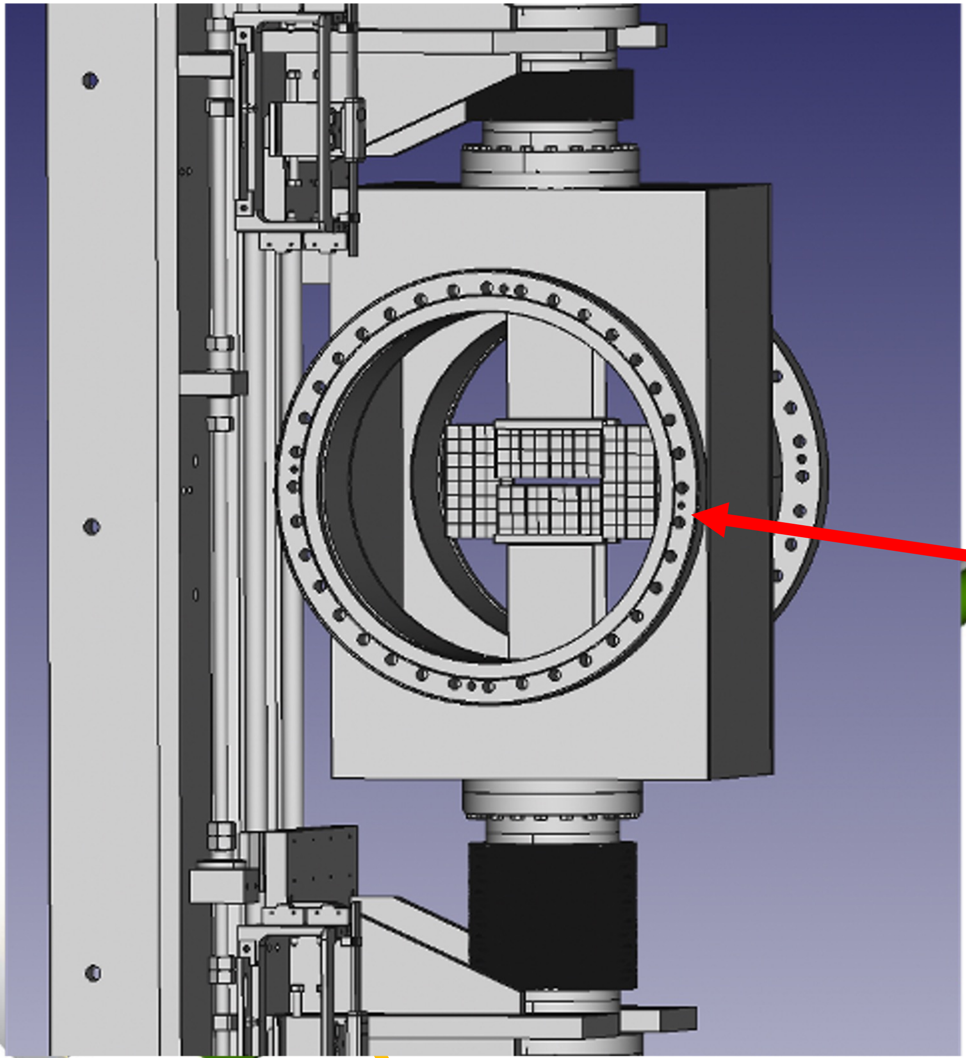
RP/OMD Tracking
- Matrix transport reconstruction.
- Slightly less stringent spatial resolution requirements.
  - Sensitive to misalignment.

Roman Pots and OMD

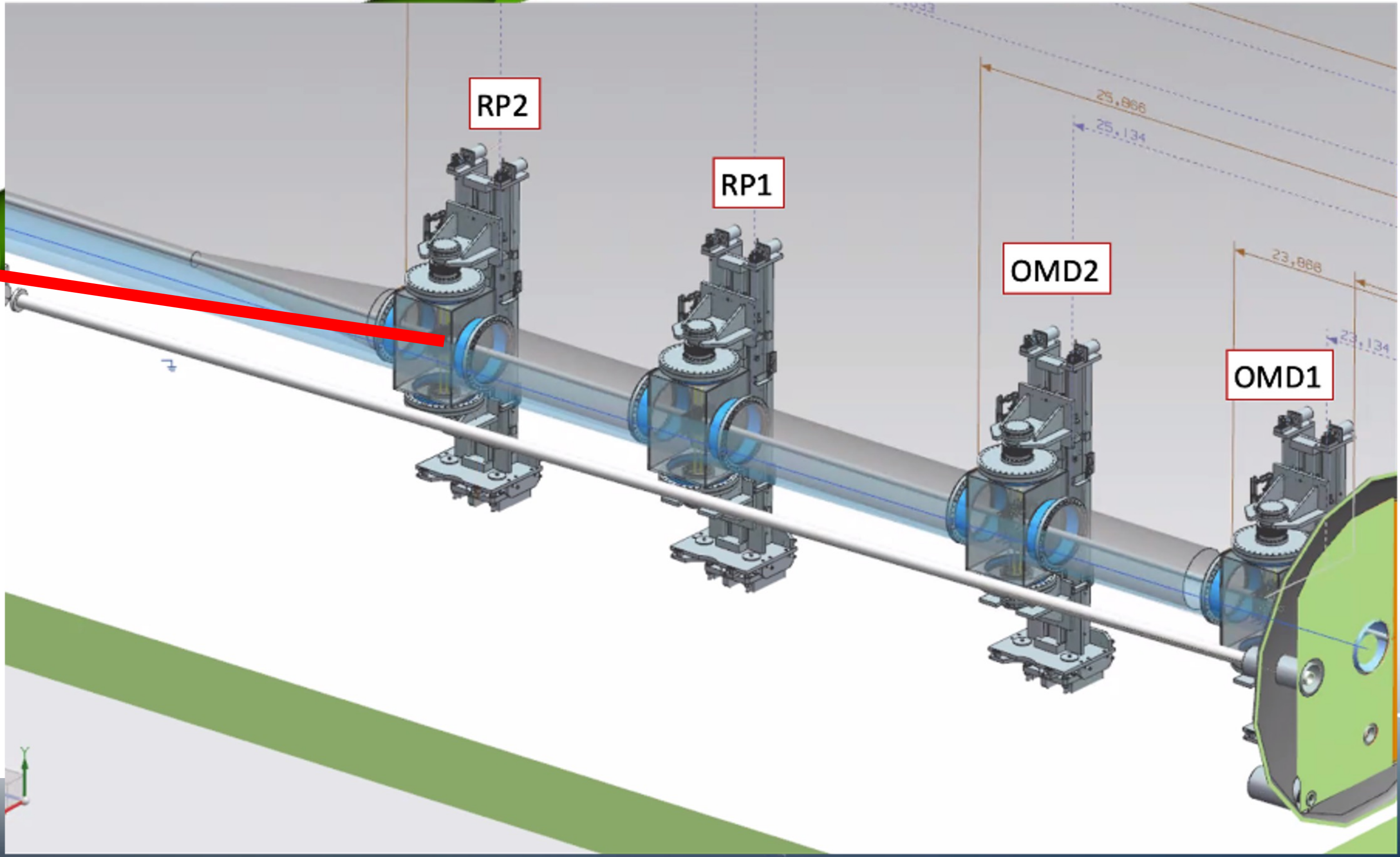


CAD Look credit: Ron Lassiter

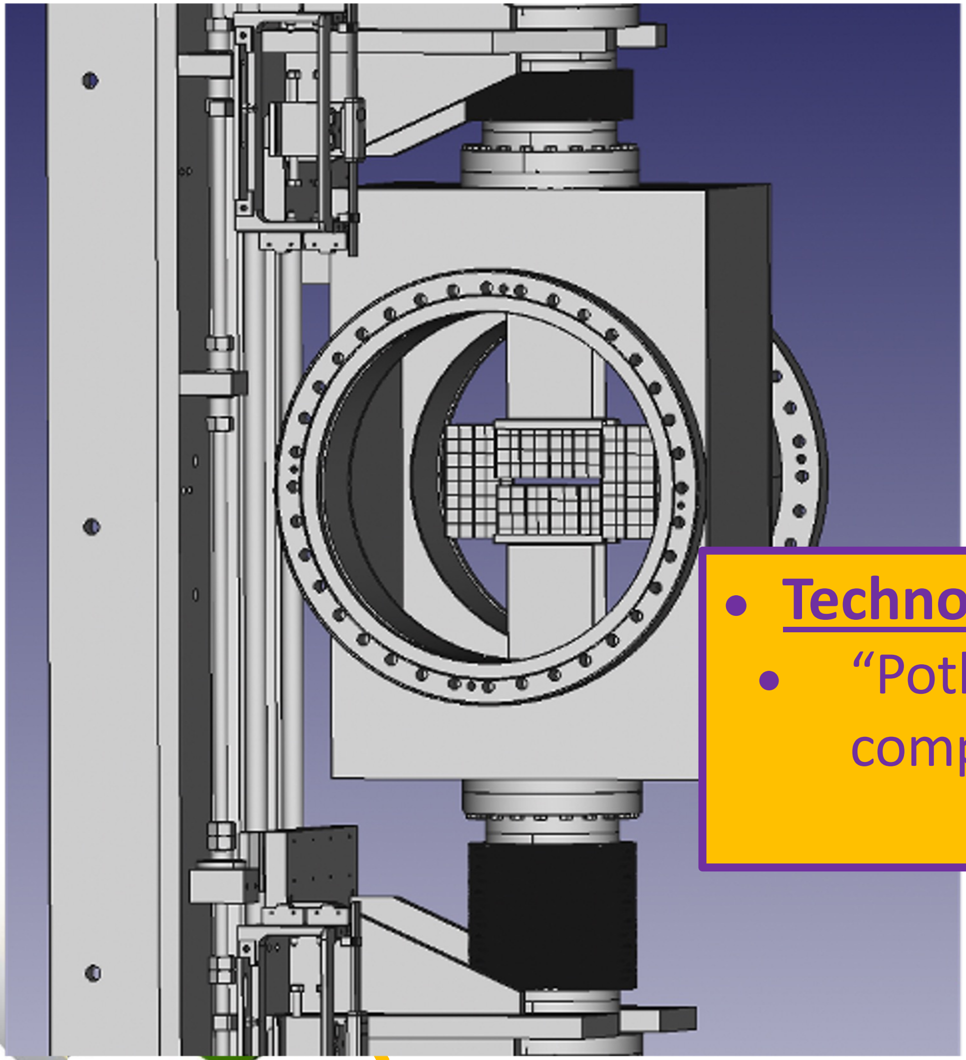
Roman Pots and OMD

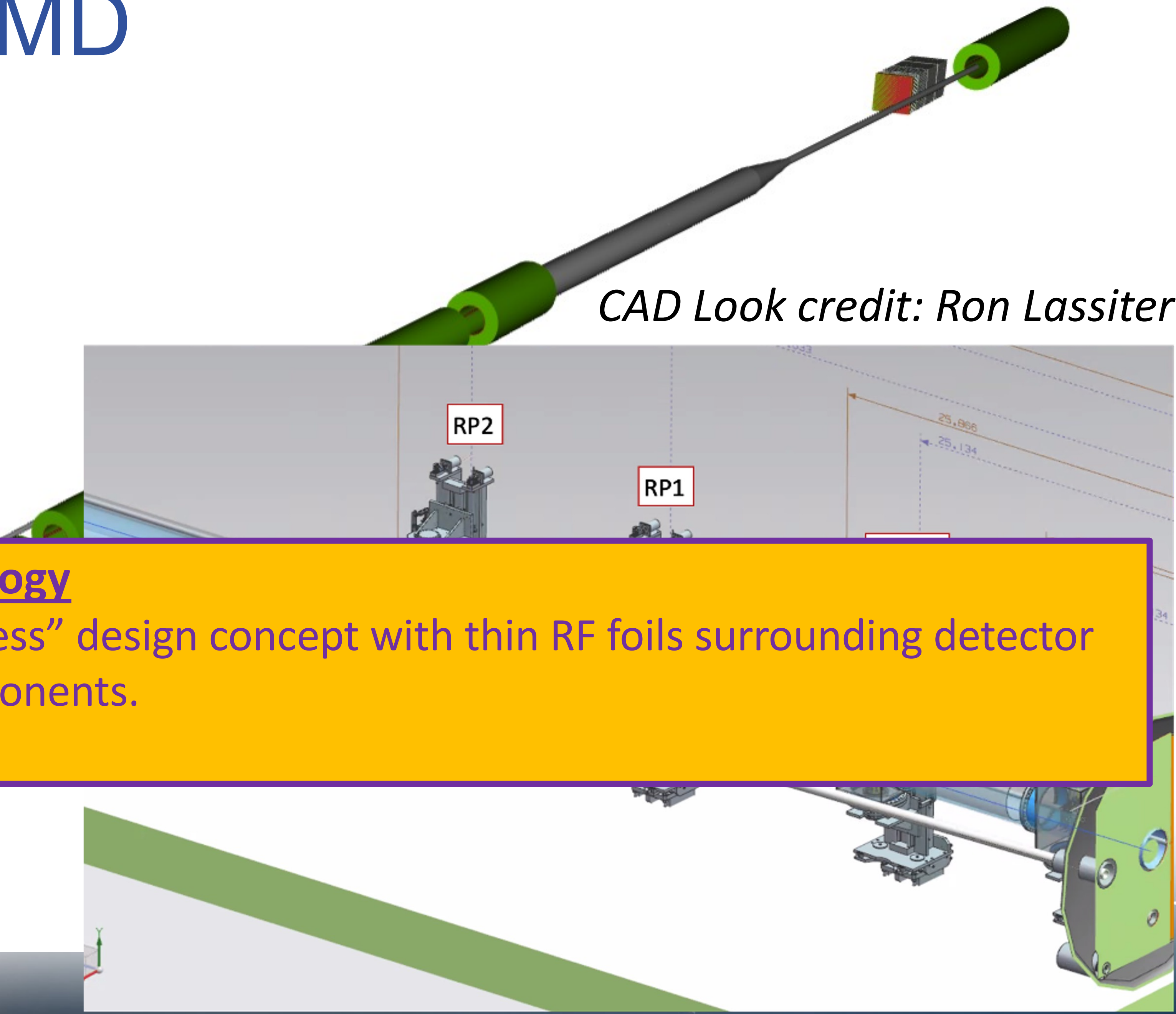


CAD Look credit: Ron Lassiter



Roman Pots and OMD

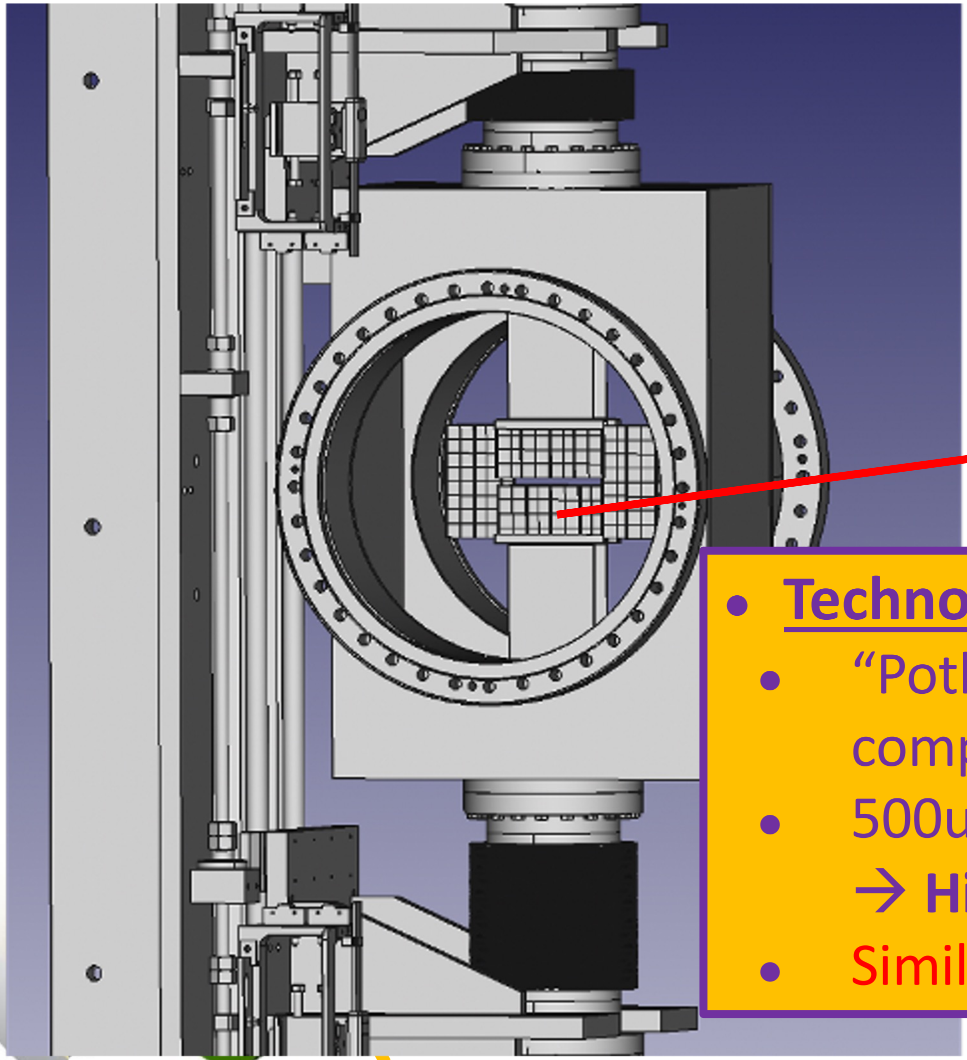


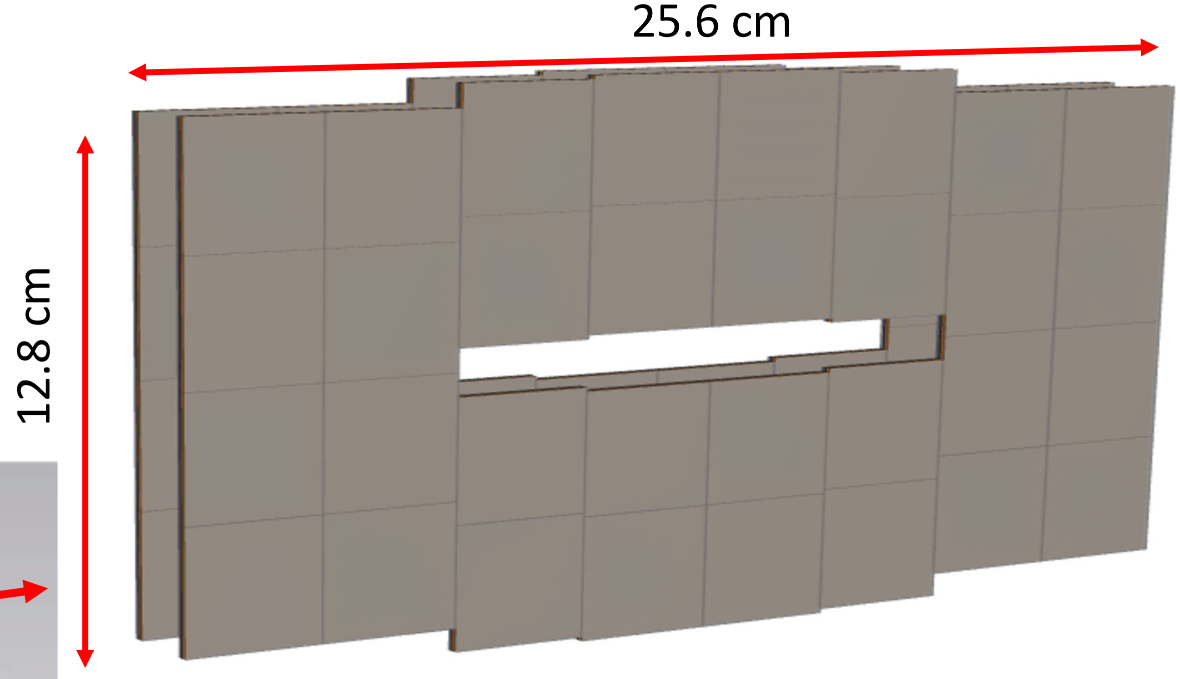


CAD Look credit: Ron Lassiter

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

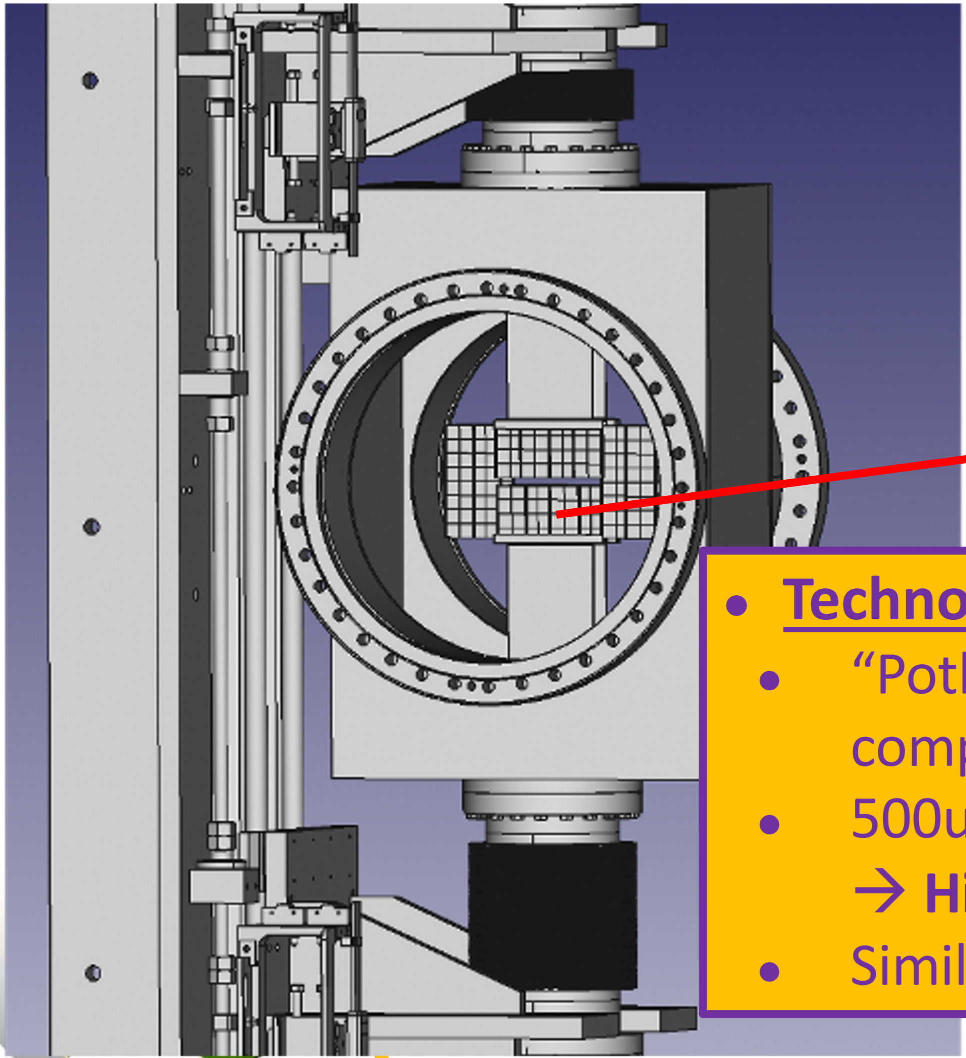
Roman Pots and OMD

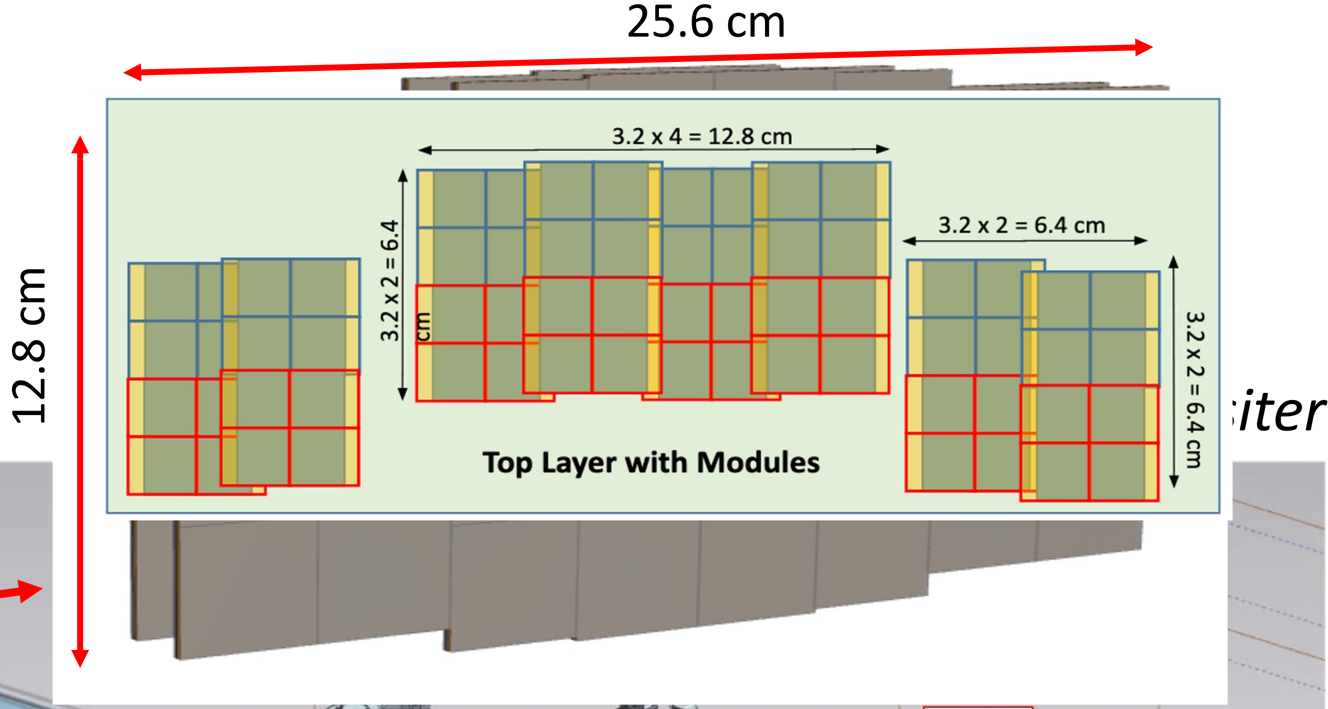




- **Technology**
  - "Potless" design concept with thin RF foils surrounding detector components.
  - 500um, **pixilated AC-LGAD sensor**, with 30-40ps timing resolution → **High-precision space and time information!**
  - Similar concept for the OMD, just different active area and shape.

Roman Pots and OMD



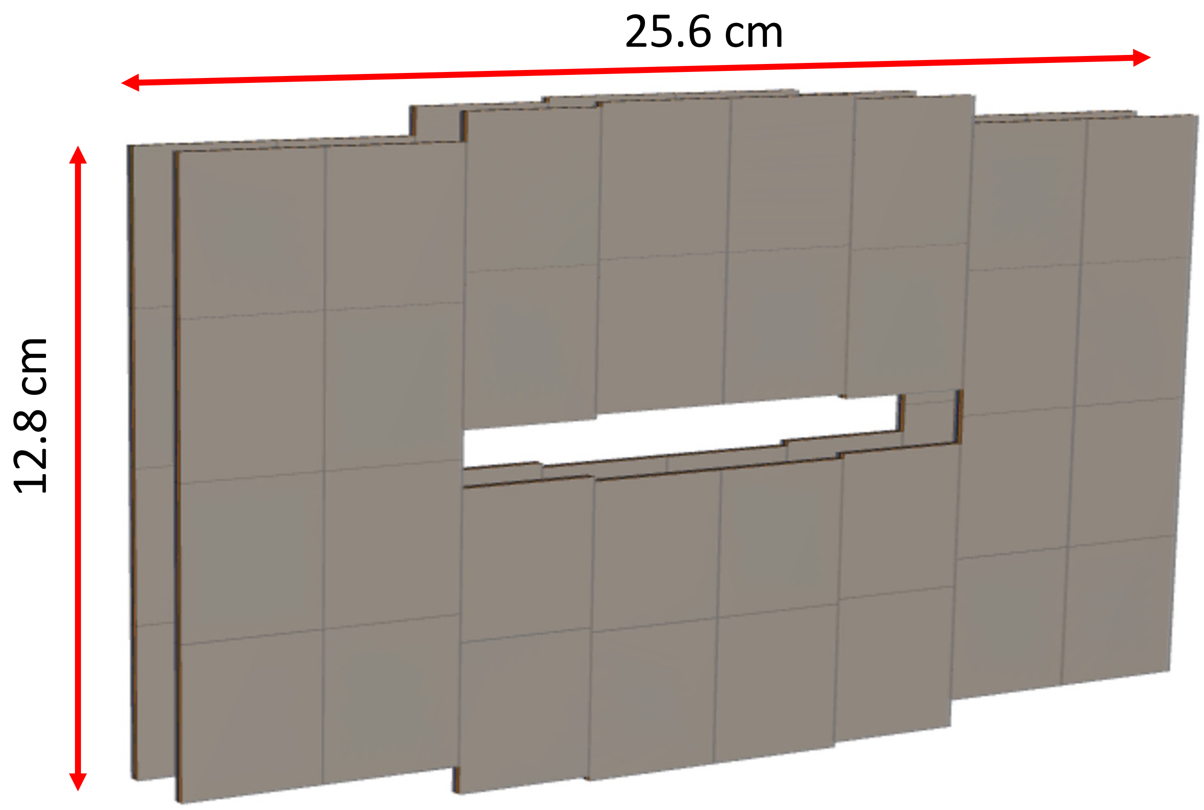


- **Technology**
  - "Potless" design concept with thin RF foils surrounding detector components.
  - 500um, **pixilated AC-LGAD sensor**, with 30-40ps timing resolution → **High-precision space and time information!**
  - Similar concept for the OMD, just different active area and shape.

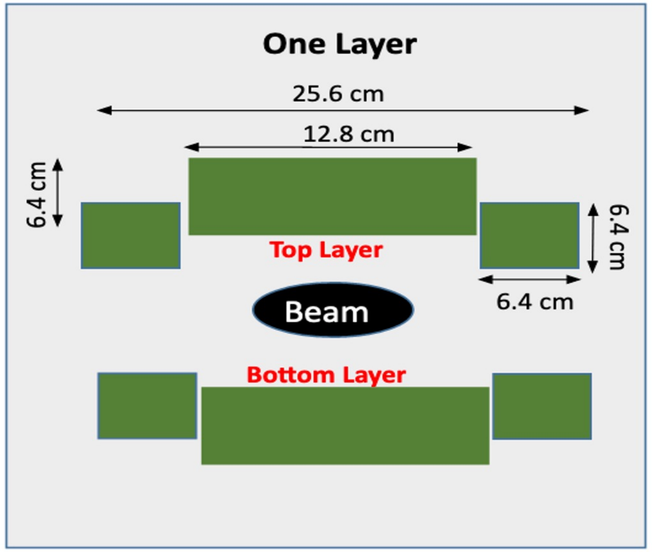
More engineering work is currently underway to optimize the layout, support structure, cooling, and movement systems for inserting the detectors into the beamline.

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.



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

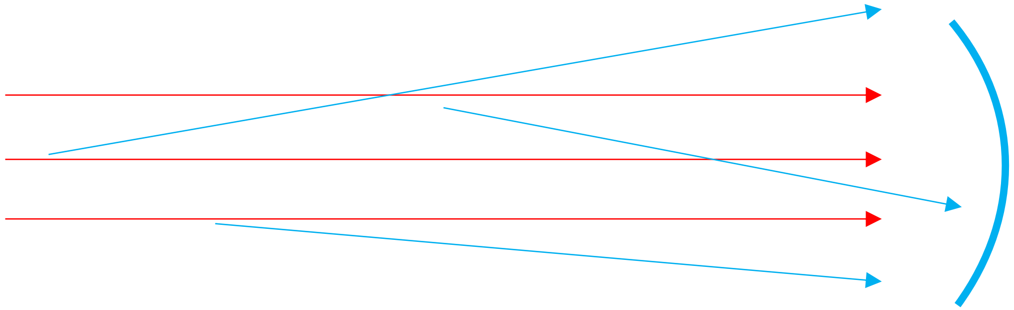


DD4HEP Simulation

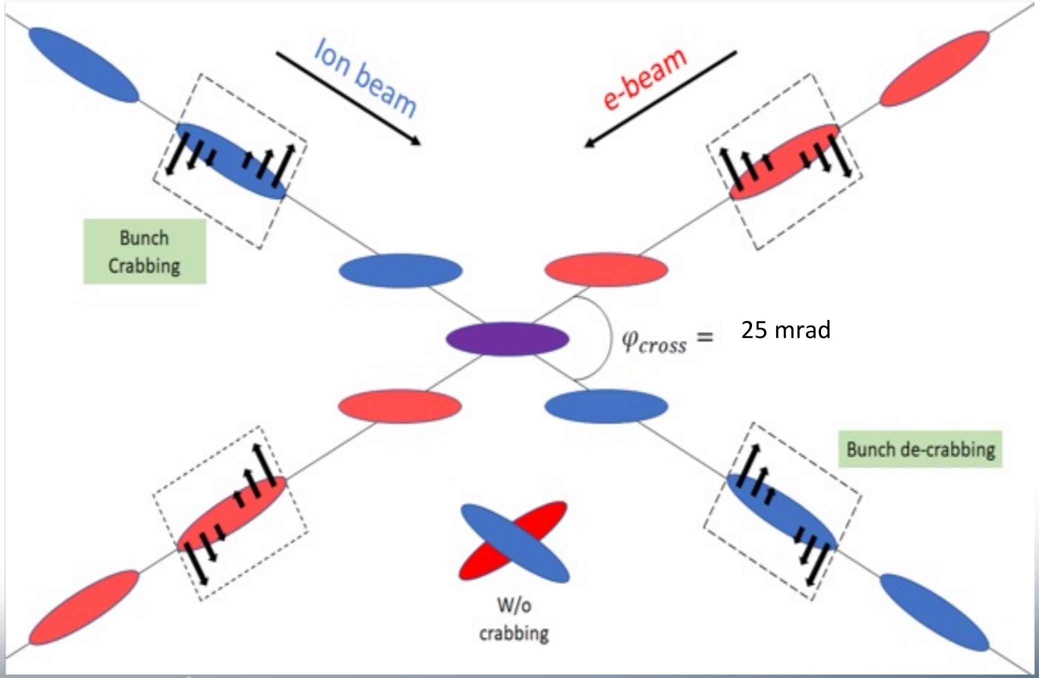
- **Low-pT cutoff determined by beam optics.**
  - **The safe distance is ~10σ from the beam center.**
  - **1σ ~ 1mm**
- **These optics choices change with energy, but can also be changed within a single energy to maximize *either acceptance at the RP, or the luminosity.***

Digression: particle beams

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



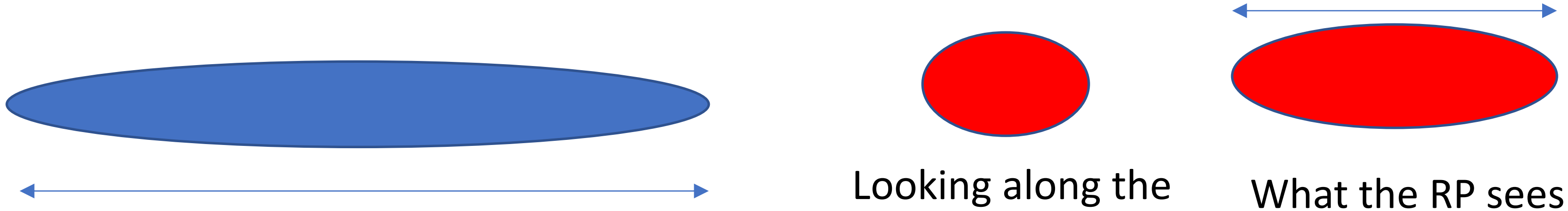
- Crab cavity rotation
  - Can perform rotations of the beam bunches in 2D.
  - Used to account for the luminosity drop due to the crossing angle – allows for head-on collisions to still take place.



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

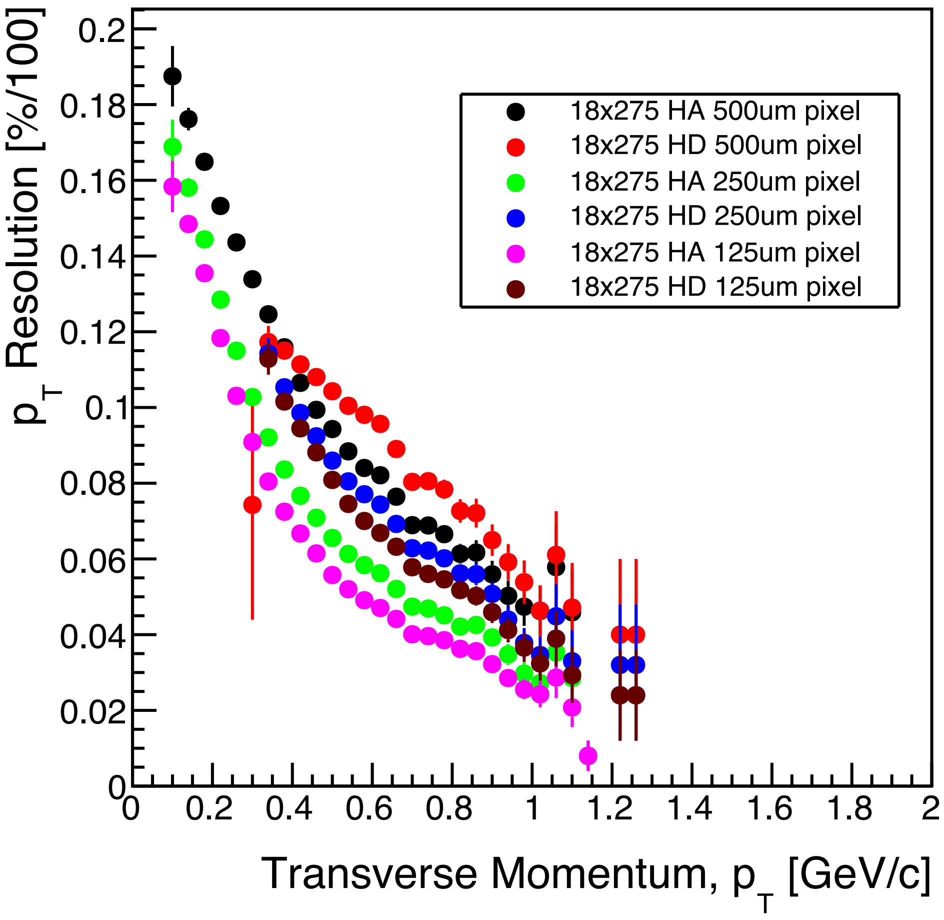
Primary vertex smearing from crab cavity rotation.

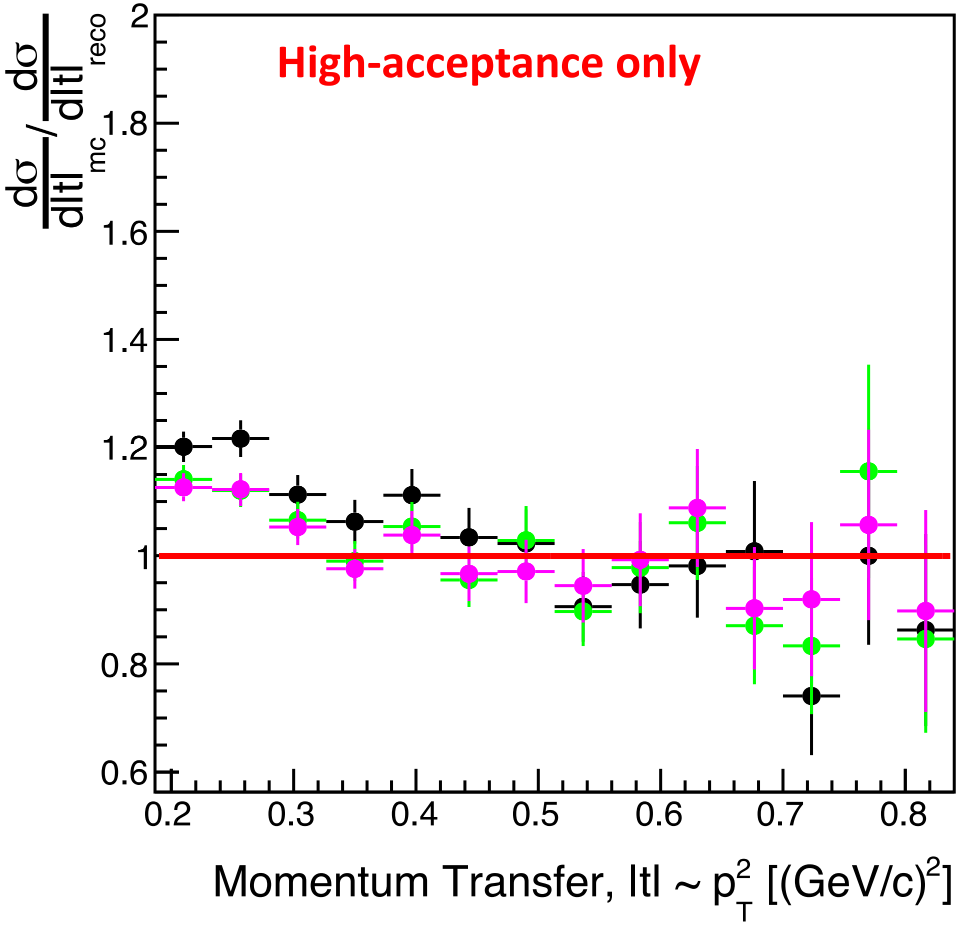
Smearing from finite pixel size.

	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

Detailed RP Momentum Resolution - 18x275 GeV





- 500um = no charge sharing
- 250um = charge sharing, x2 improvement
- 125um = charge sharing, x4 improvement

- 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.

Detector Resolution Summary

- Modern studies support basic idea of eRD24 studies.
  - 500um pixels can do the job.
    - Beam effects the larger impact for RP/OMD reconstruction.
  - Expecting x2 improvement (super-conservative minimum) in (pixel size)/Sqrt(12) – reduces slope distortion in t-distribution.
- 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.

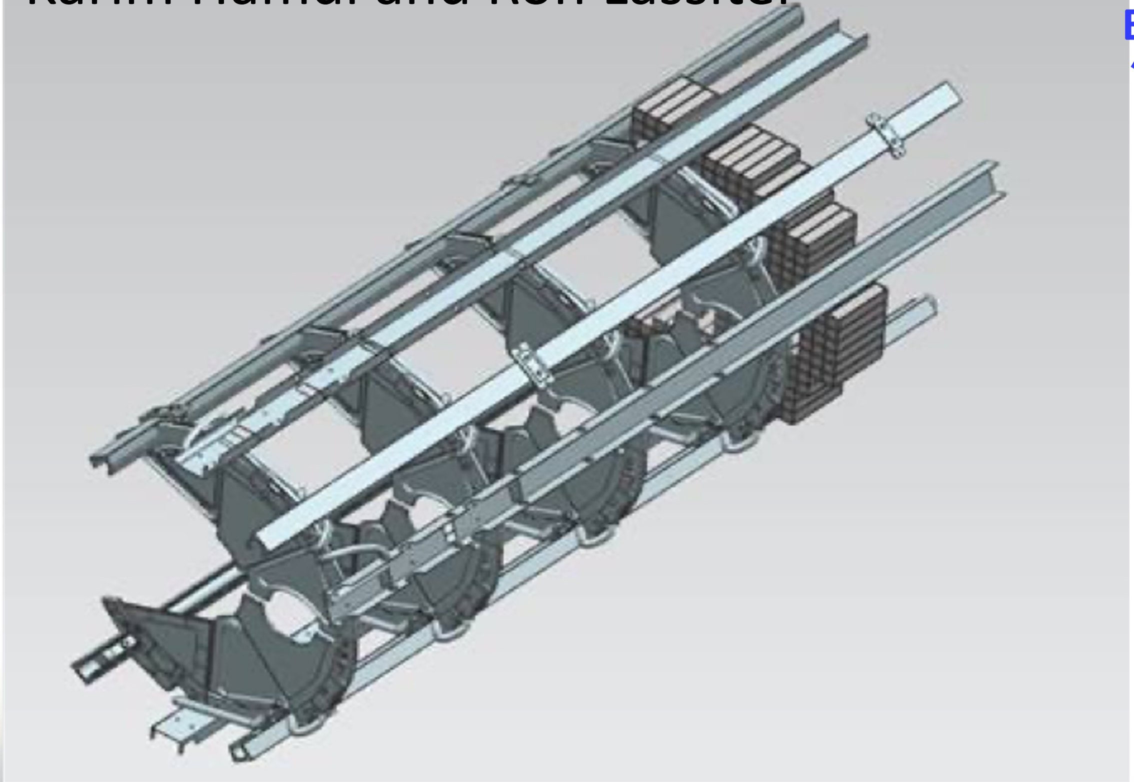
What about the B0 tracker?

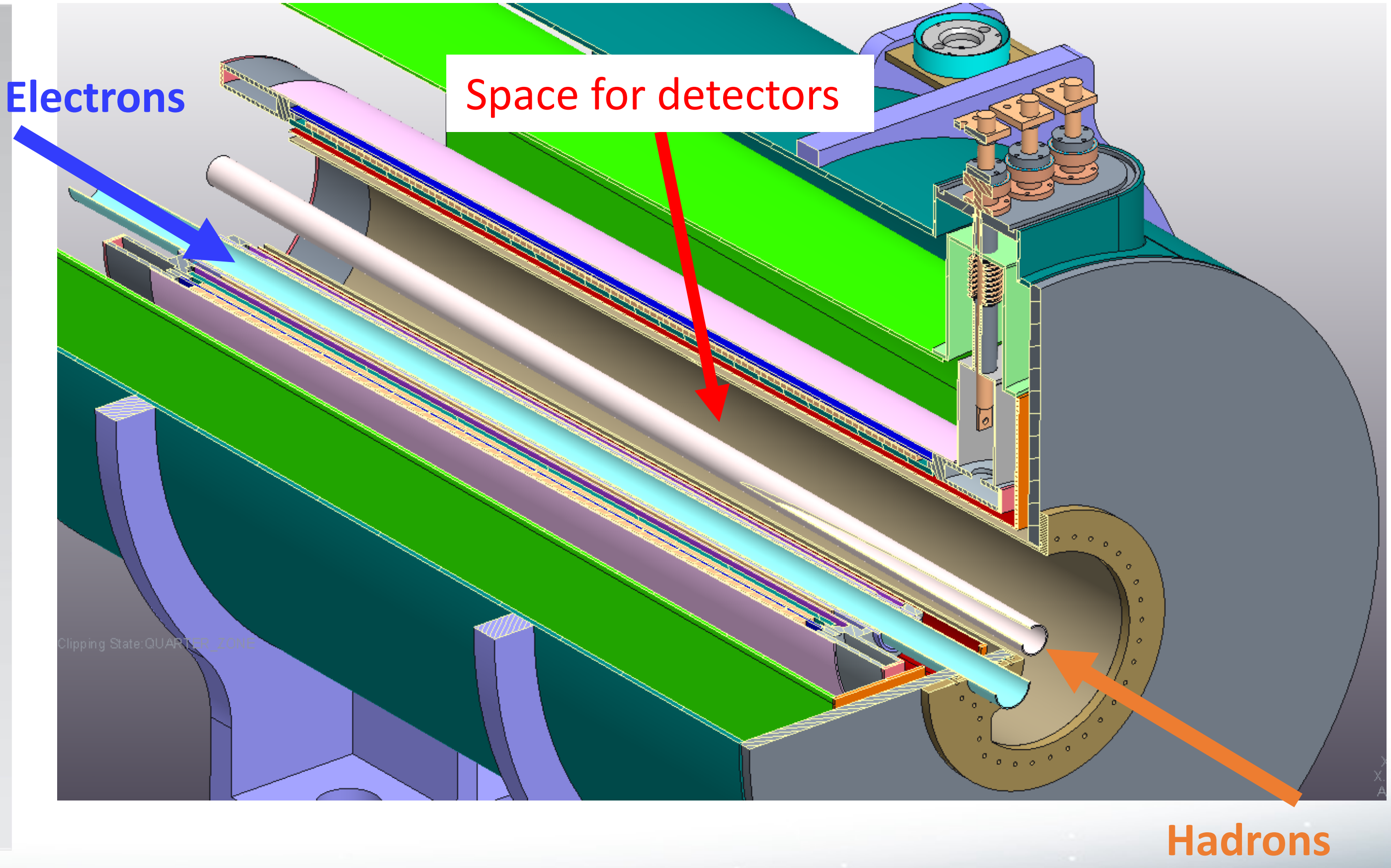
- Originally planned to use ITS3 (3 layers) + AC-LGAD (1 layer) to get 5-10um spatial resolution, combined with precise timing of AC-LGADs.
- Long integration window for ITS3 sensors a major problem for the high occupancy environment of the B0 tracker.
  - https://wiki.bnl.gov/EPIC/index.php?title=Background
- Looking at AC-LGADs as an option for the full subsystem → will the worsening of the spatial resolution be tolerable?
  - Beam tests demonstrate AC-LGADs achieving ~ 20um spatial resolution with charge sharing: https://indico.bnl.gov/event/19471/

B0 Detectors

- Detector subsystem embedded in an accelerator magnet.

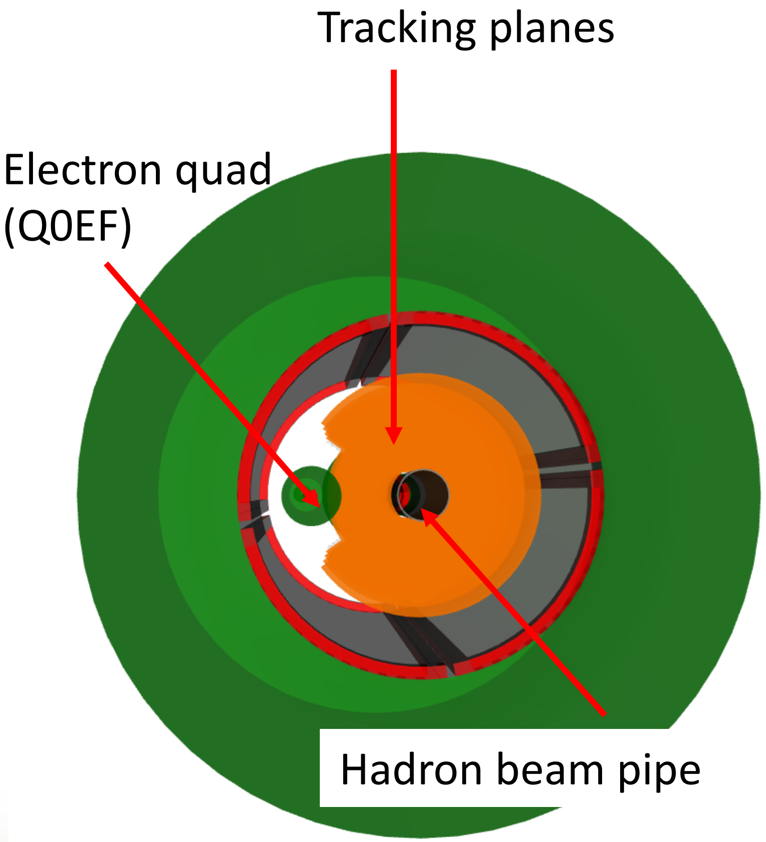
Karim Hamdi and Ron Lassiter



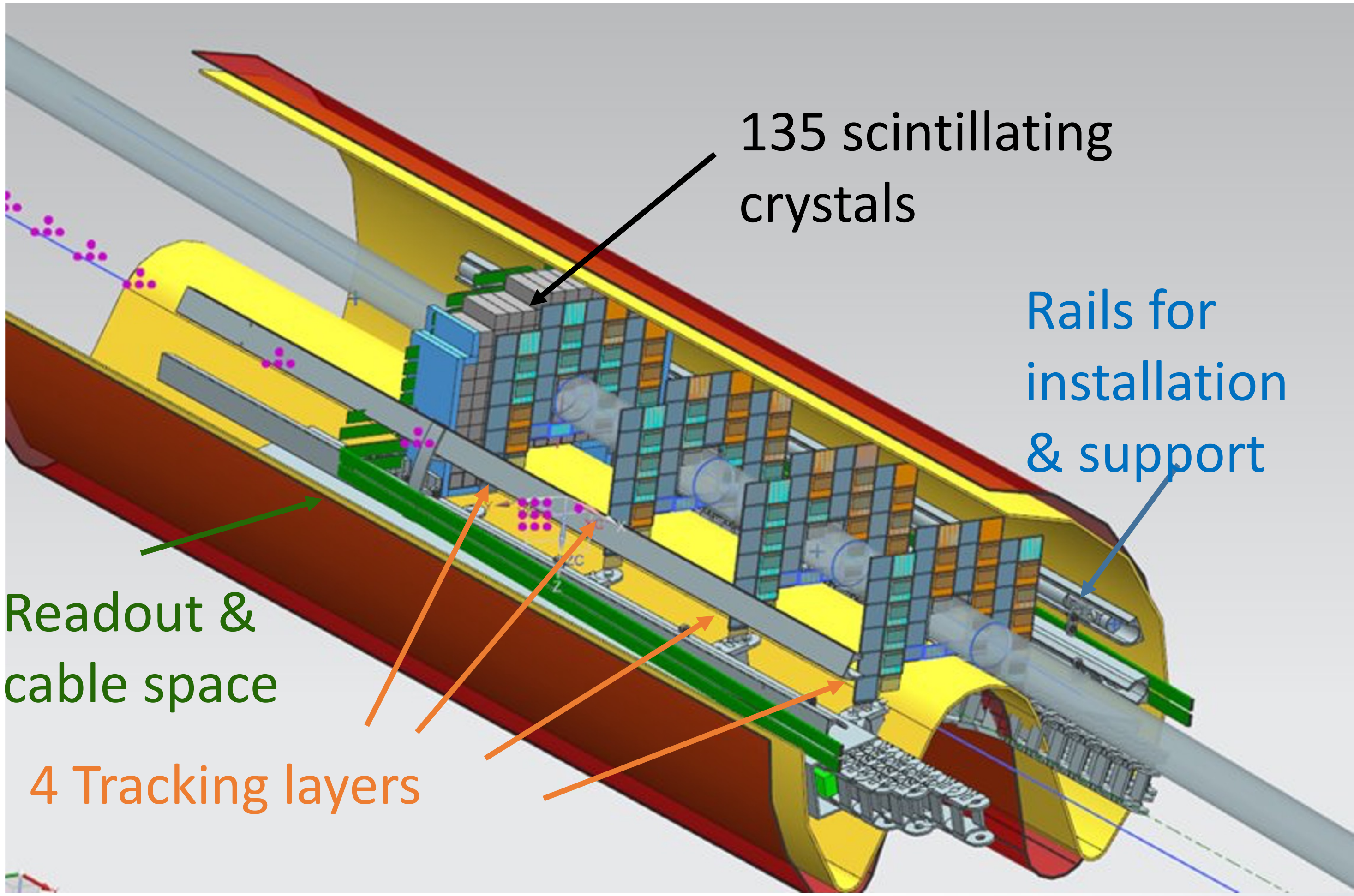


B0 Tracking and EMCAL Detectors

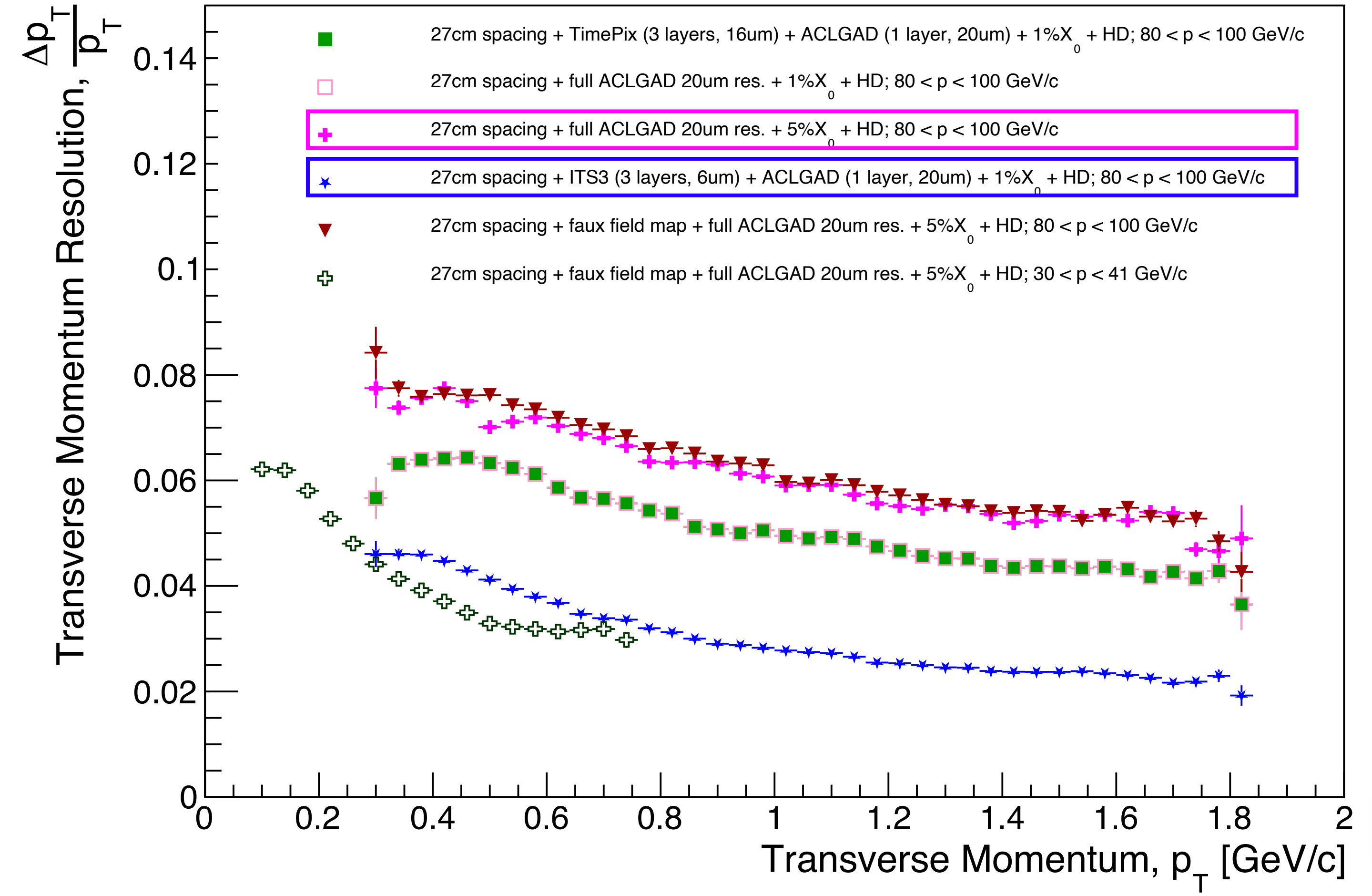
CAD Look credit: Jonathan Smith



ePIC DD4HEP Simulation

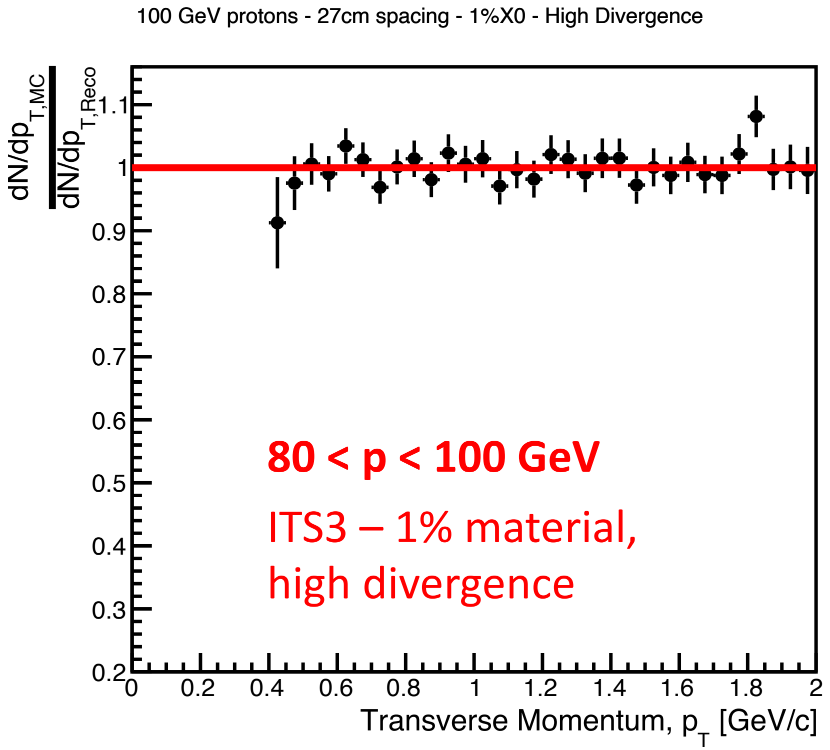


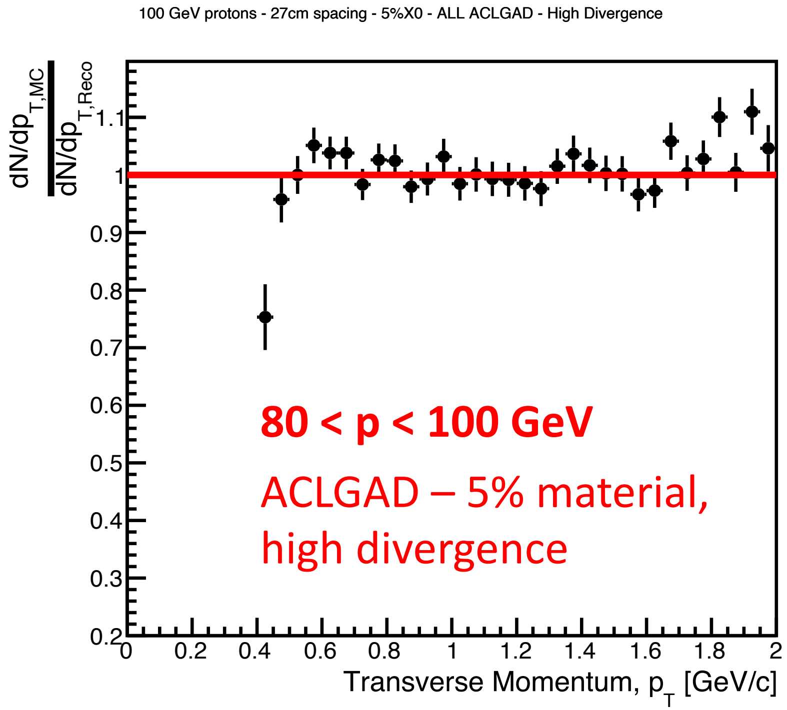
B0 tracking: new technology + material assumptions (first tests last Summer)



- 27cm spacing with fully AC-LGAD system and 5% radiation length may be the most-realistic option.
  - Constant & uniform magnetic field for tracker.
- **<u>Note:</u>** p resolution is ~ 2-4%, depending on configuration.

B0 tracking: Impact on pT spectra



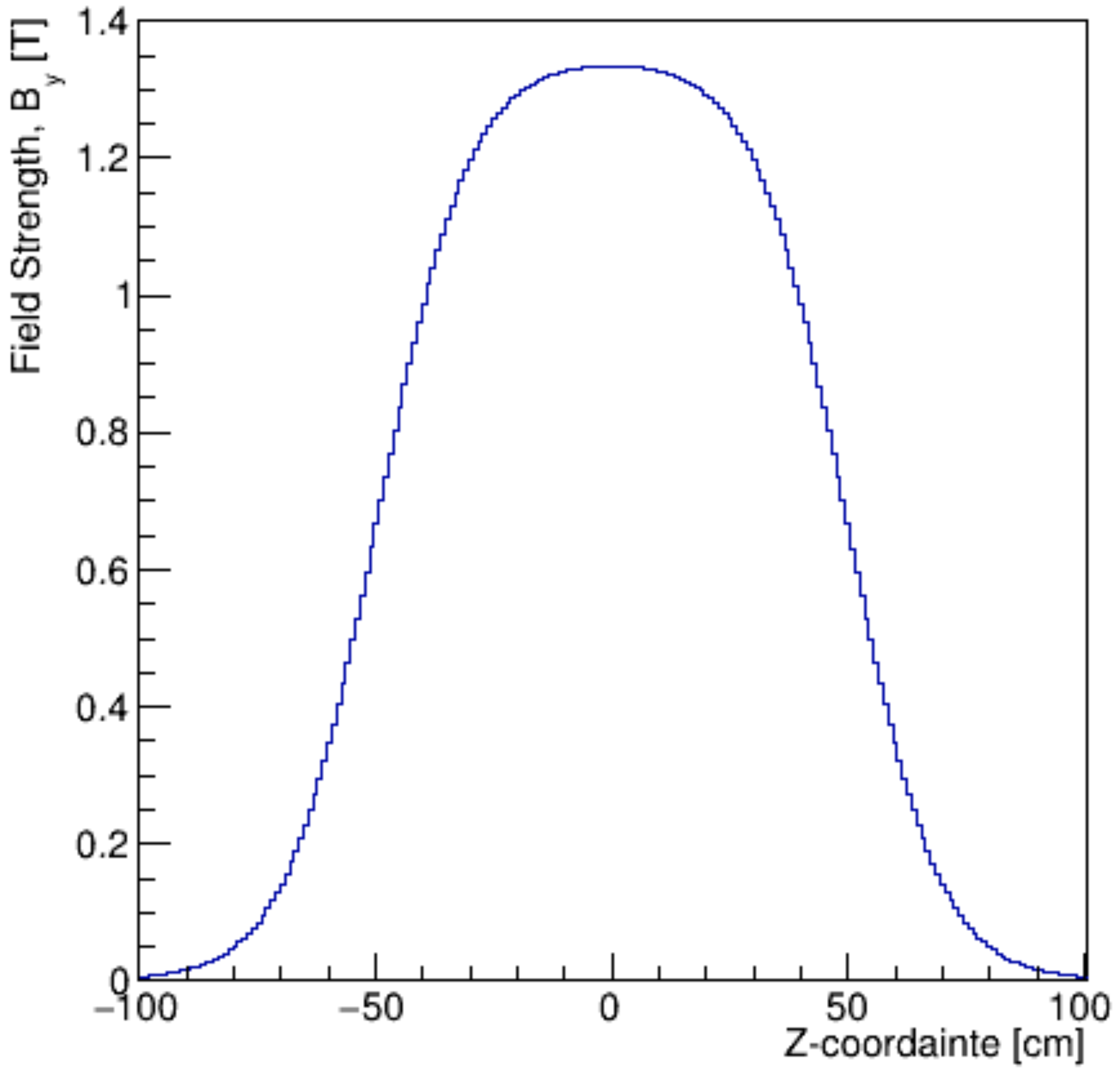


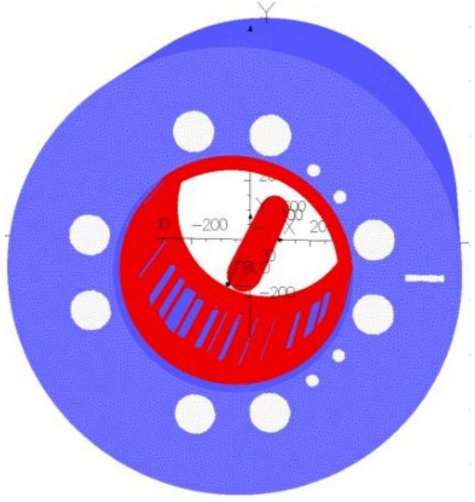
- Full study: https://indico.bnl.gov/event/19620/
- Information passed to PWG in early June.

Recent update: B0 Field Map

- Previous studies done with constant, uniform dipole + quadrupole fields.
- Studies now moving forward with correct field map in the B0.
  - Information pulled from here:
    - https://wiki.bnl.gov/EPIC/images/e/ef/12212022_-_Set_up_to_do_3D_field_map.pdf
    - https://wiki.bnl.gov/EPIC/images/1/1b/B0_field_map_23dec2022.txt.zip
- Map given in 1cm steps → lots of information for the detector simulations, reduced to 10cm steps in z for processing.
  - Fully implemented in DD4HEP, but not merged into main repo (still need to study use of field map with the rest of the FF magnets before making it the standard).
  - ✓Field lines then rotated and translated to correct simulation coordinate system.
  - ✓Field values checked at various locations to ensure correct usage.

B0 Field Map



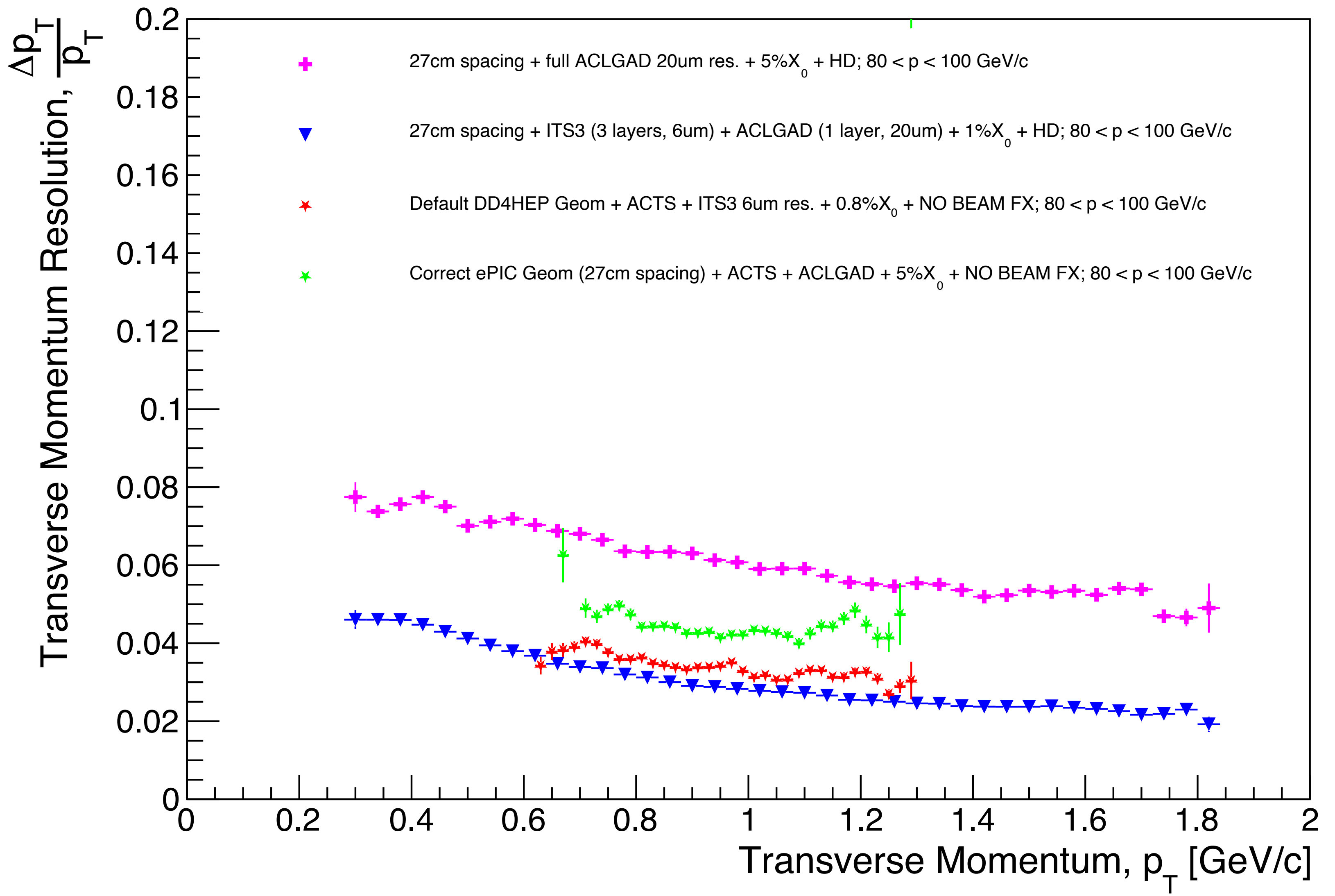


```
e-beam @ +34 mm and hadrons @ -126 mm
(neglecting 25 mrad angle) in this model

Z=0 is center of the magnet @ 6.4m
```

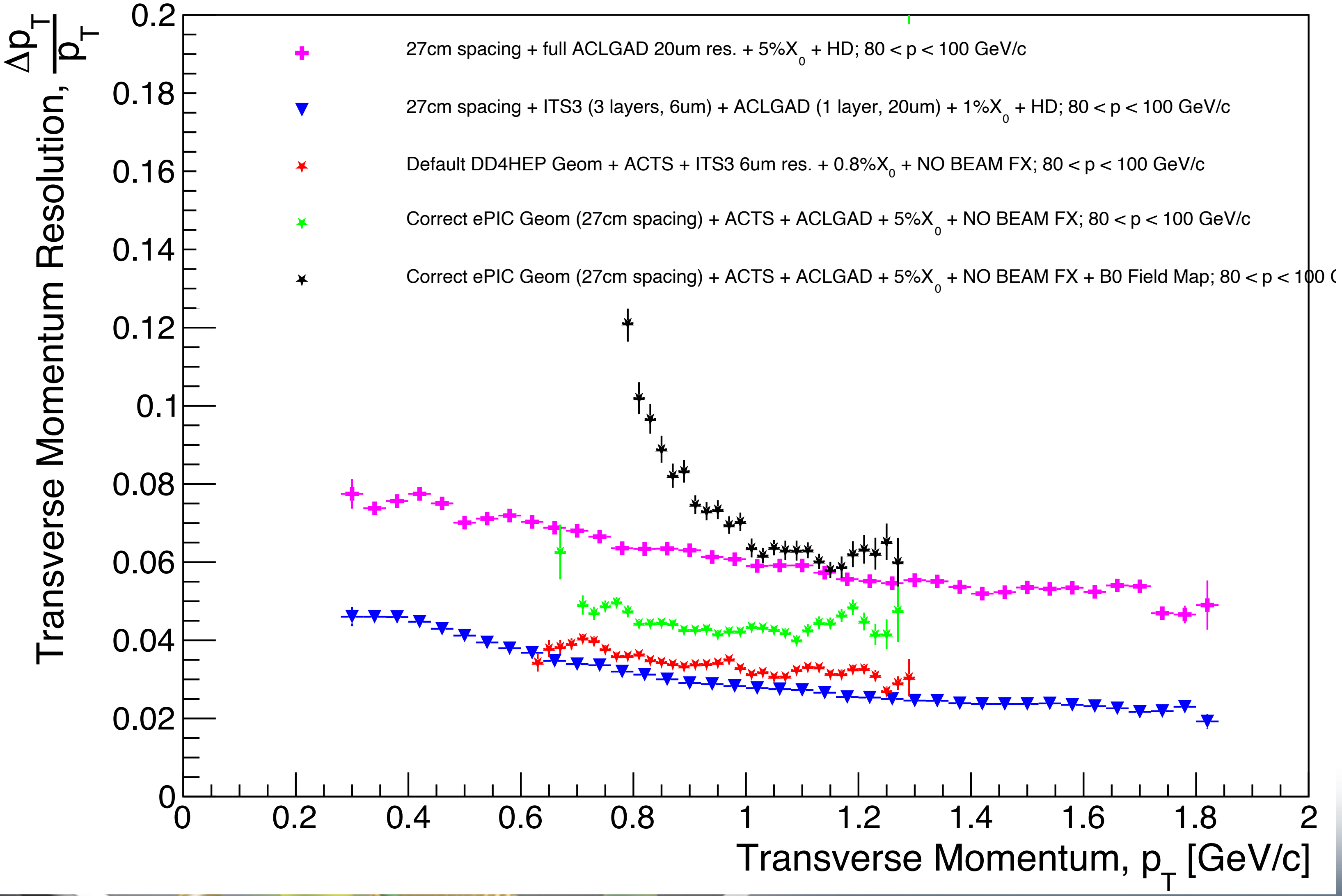
- X = -126 mm, y = 0 mm (before rotation and shift to fit along beamline).
  - By field strength along the hadron beam.
  - Gaussian field shape!

B0 Tracking - Performance



- All of these assume constant dipole + quadrupole field through entire 1.2m long magnet volume.
- Green/Red assume 6 to 13 mrad cone of 80 to 100 GeV protons.
  - Aiming at ~symmetric portion of acceptance, conservative case for the tracking performance (100 GeV protons are very rigid)

B0 Tracking - Performance



- Black: tracker shifted away from IP by 10cm.
- Assume 6 to 13 mrad cone of 80 to 100 GeV protons.
- Need to understand how charge sharing + spatial resolution is affected by radiation dose.

Detector Summary

- **Roman Pots:**
  - ~26cm x 10cm x 4 layers = 524k channels
- **Off-Momentum Detectors:**
  - ~10cm x 20cm x 4 layers = 295k channels
- **B0 Tracker System:**
  - “Pac-man” disks ~ 370 cm^2 per layer; 4 layers = 606k channels

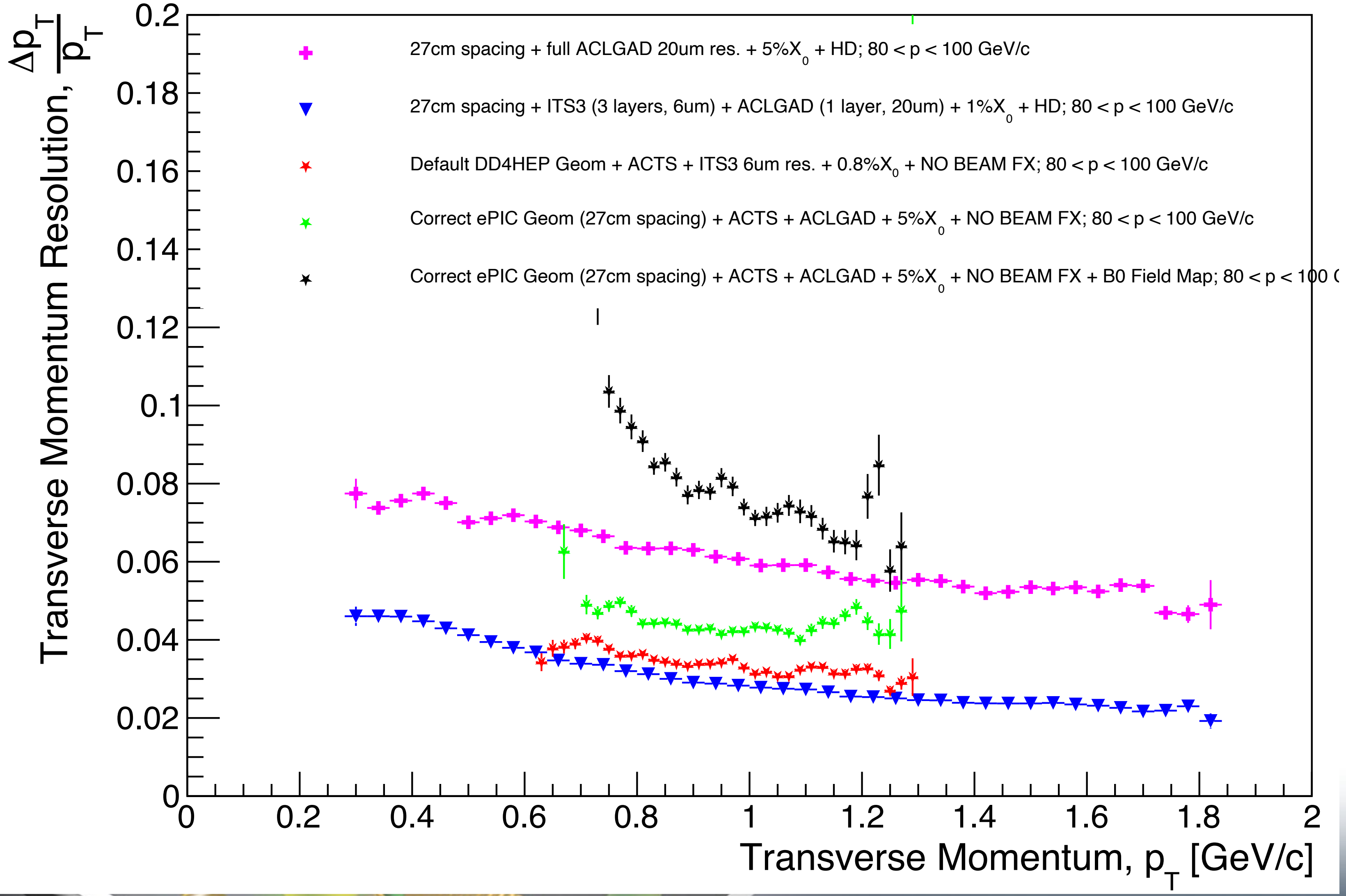
- Expected power consumption is 1-2 mW/channel – not a major issue for the B0, requires special considerations to cool vacuum-based detectors.

Summary

- Roman Pots (and Off-Momentum Detectors) requirements met by AC-LGADs.
  - Pixel size and timing requirement came from original studies and defined the present concept.
- B0 was only recently (Summer 2023) switched to fully AC-LGAD from the original ITS3 + AC-LGAD approach.
  - Relies heavily on charge/signal sharing spatial resolution improvements to meet physics goals.
  - Degradation of spatial resolution with radiation damage a possible concern which needs to be studied.

Backup

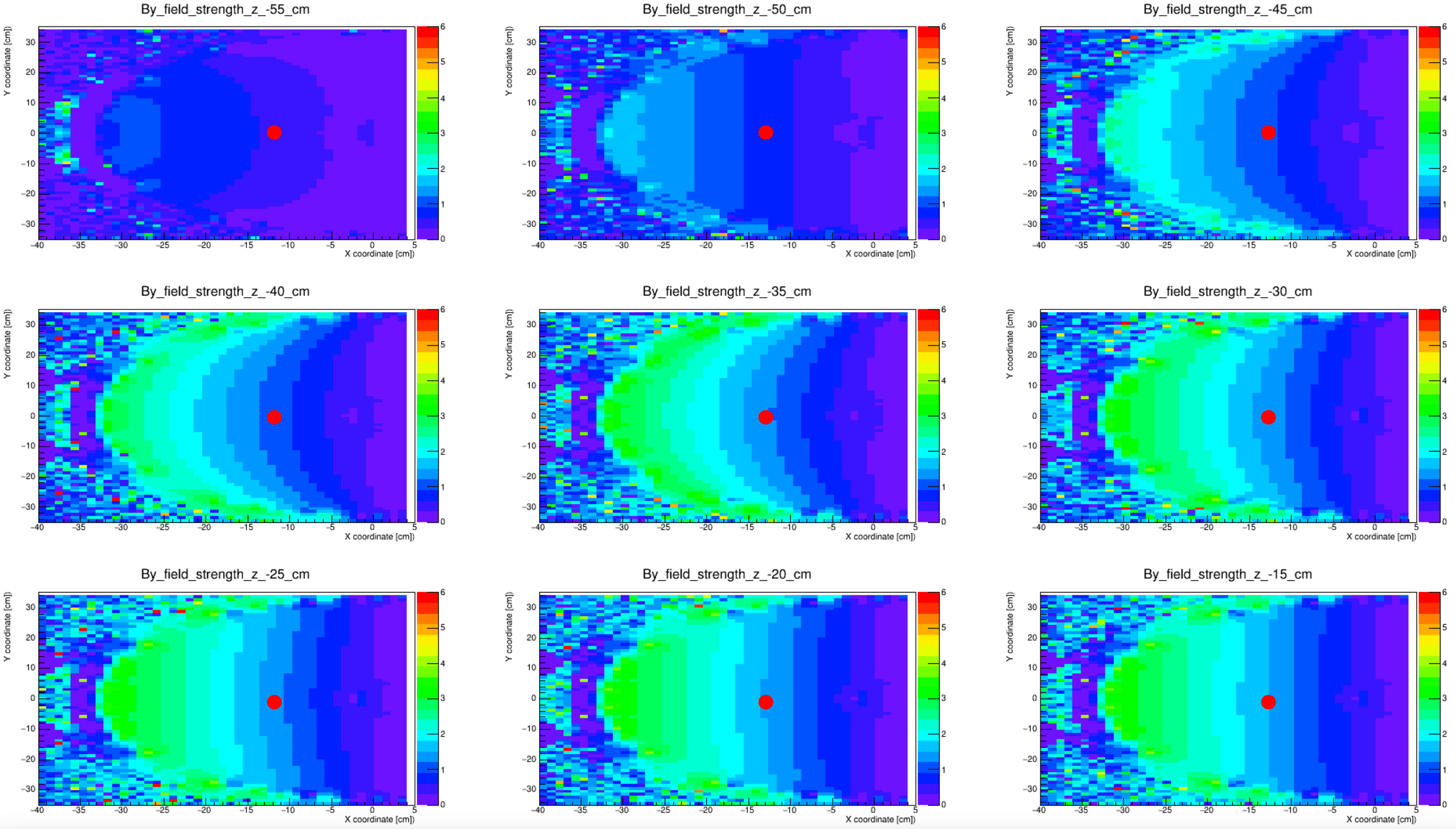
B0 Tracking - Performance



- Black: field map with nominal geometry (plane separation and central location).
- Assume 6 to 13 mrad cone of 80 to 100 GeV protons.

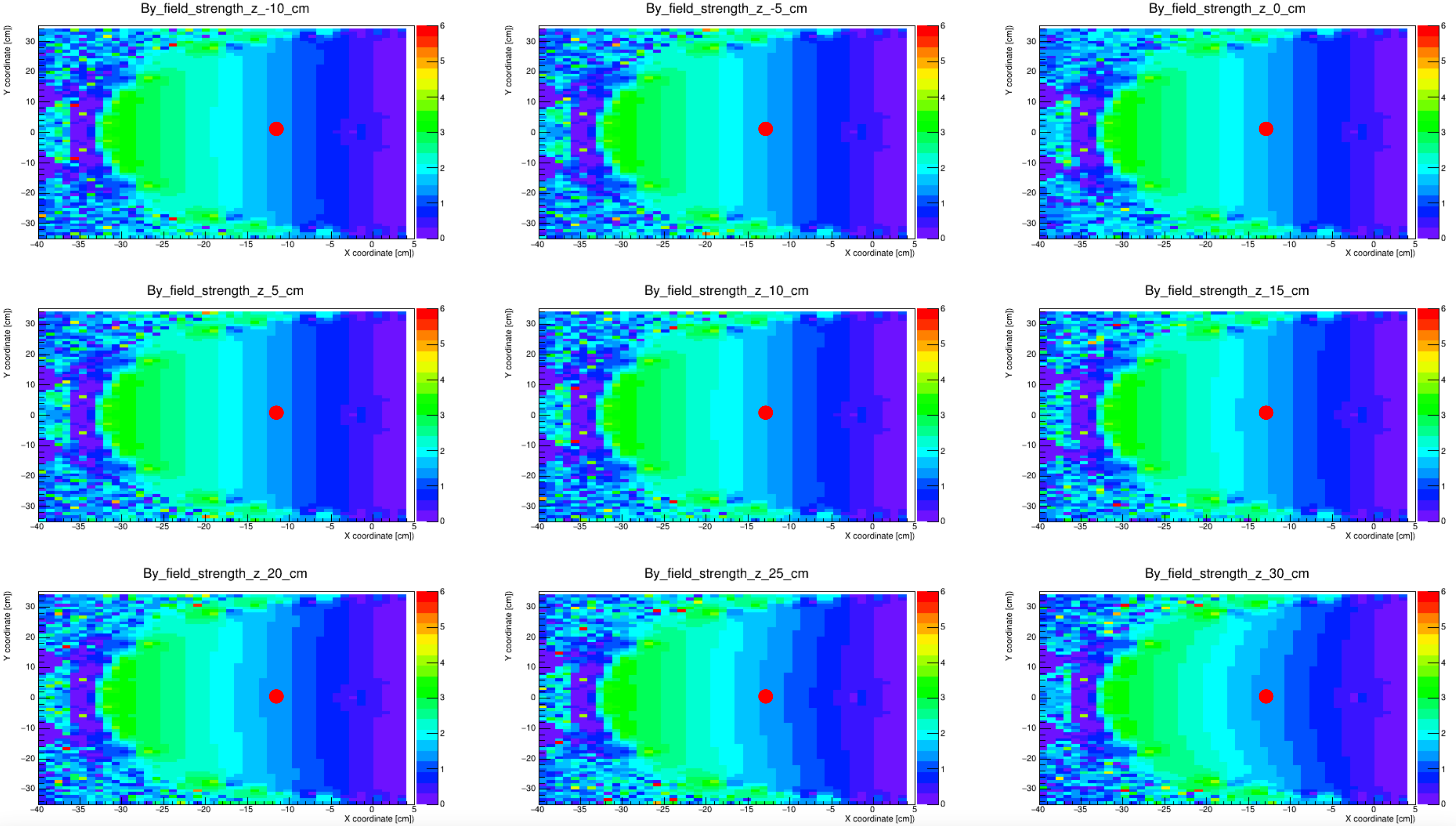
B0 Field Map

Left to right, top to bottom – increasing Z (IP to center of magnet)

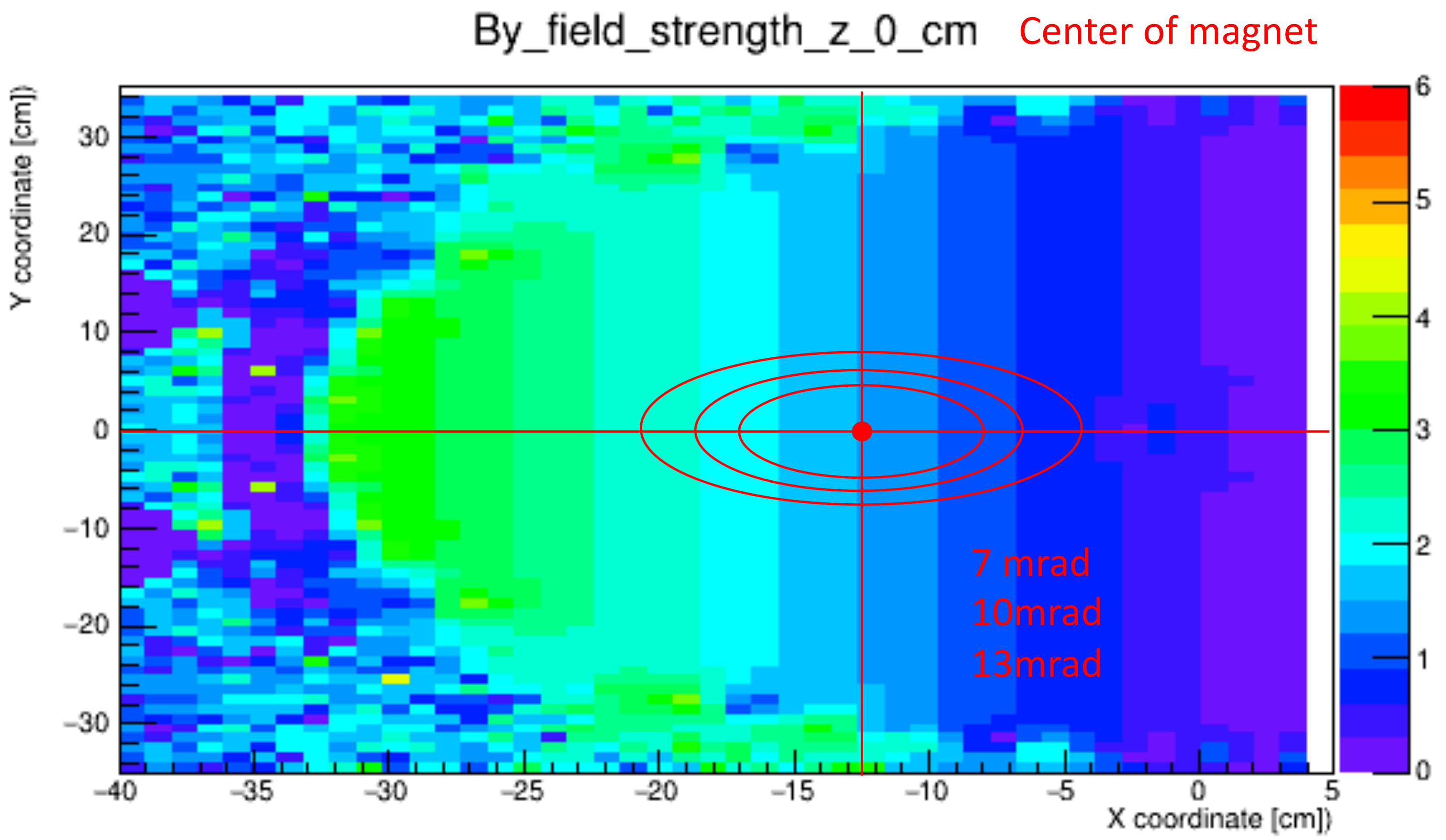


B0 Field Map

Left to right, top to bottom – increasing Z (IP to center of magnet)

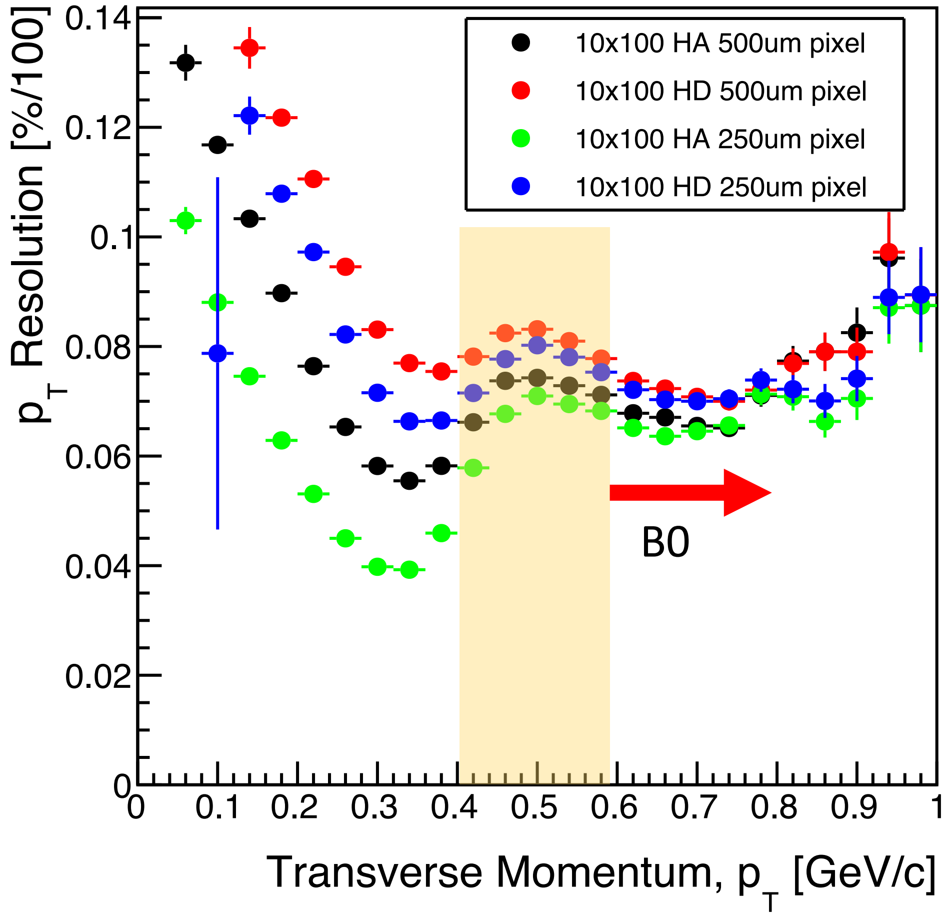


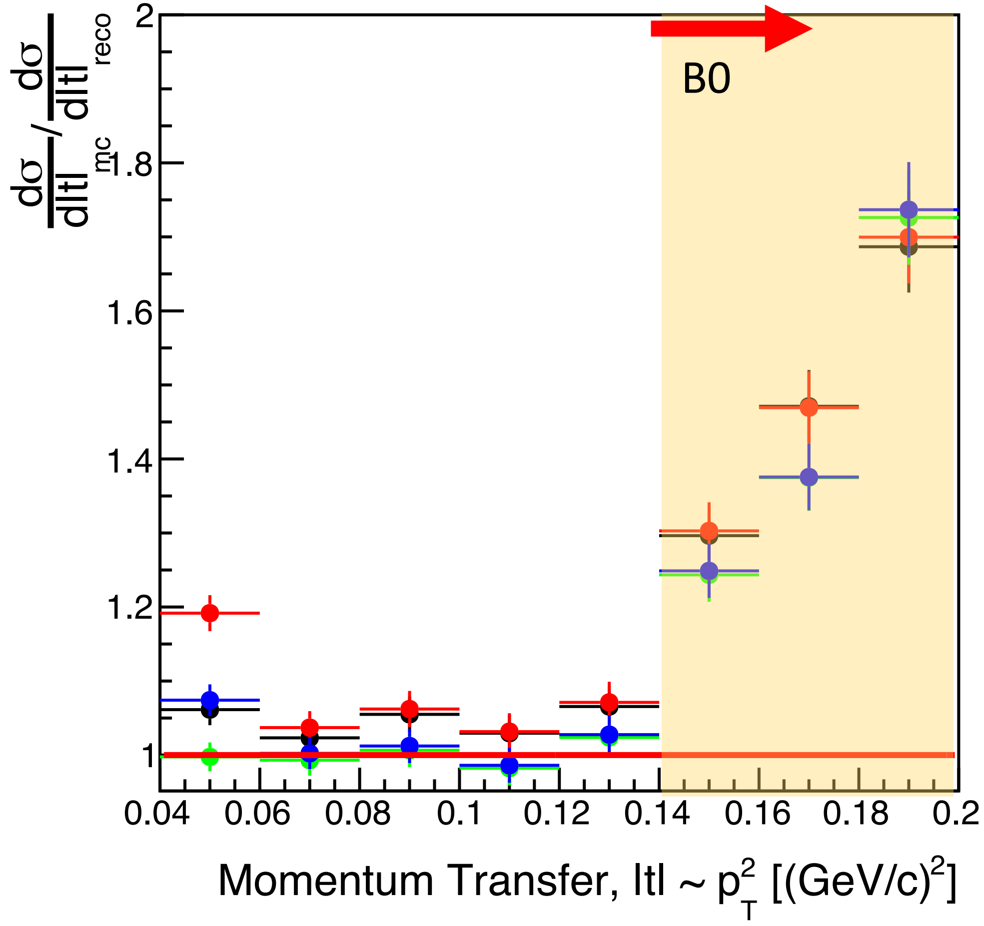
B0 Field Map



- Field seen by protons is pT/angle dependent – will add an additional smearing dependence on position within the magnetic field.

Detailed Momentum Resolution - 10x100 GeV



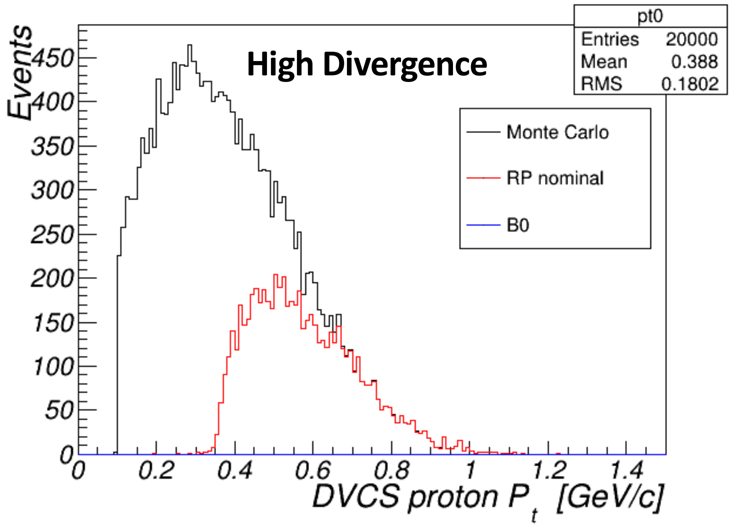


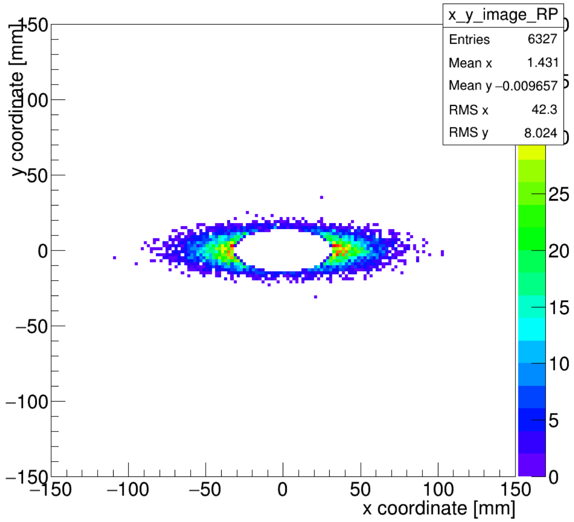
- **Yellow shaded area** is the acceptance gap between the RP and B0 detectors.
- No acceptance correction is applied here.

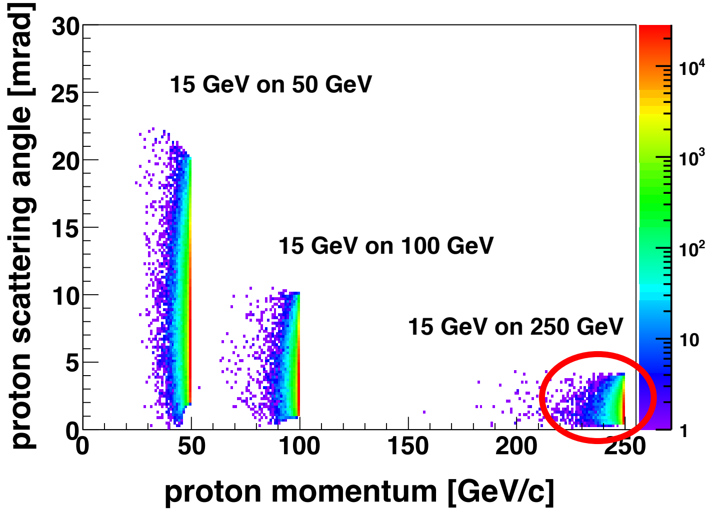
- Zoom-in to relevant RP range.
- Since angular divergence is smaller in the 100 GeV beam, the spatial resolution has a larger impact.

Digression: Machine Optics

275 GeV DVCS Proton Acceptance





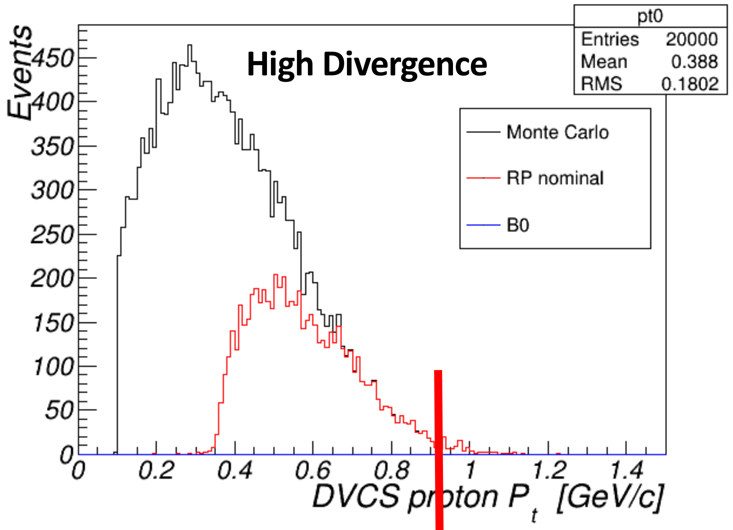


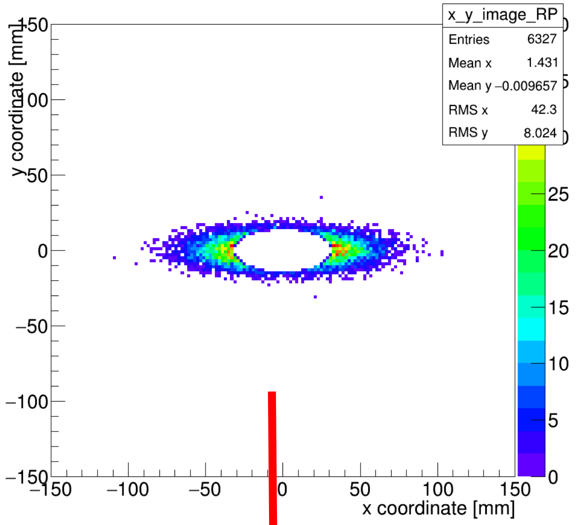
High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

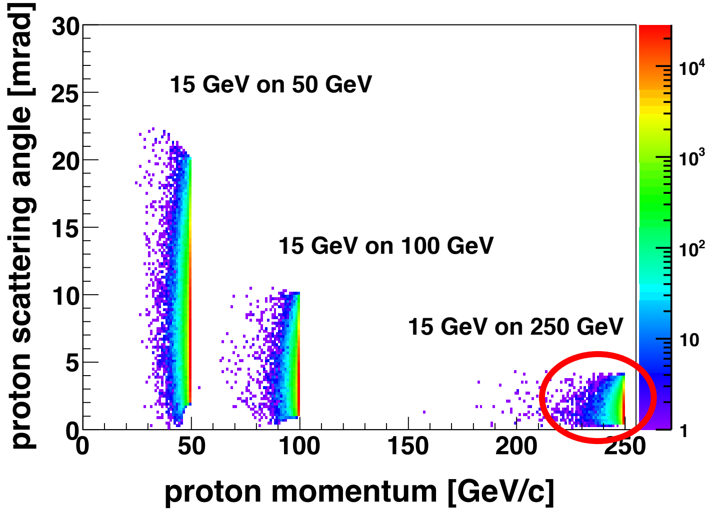
Digression: Machine Optics

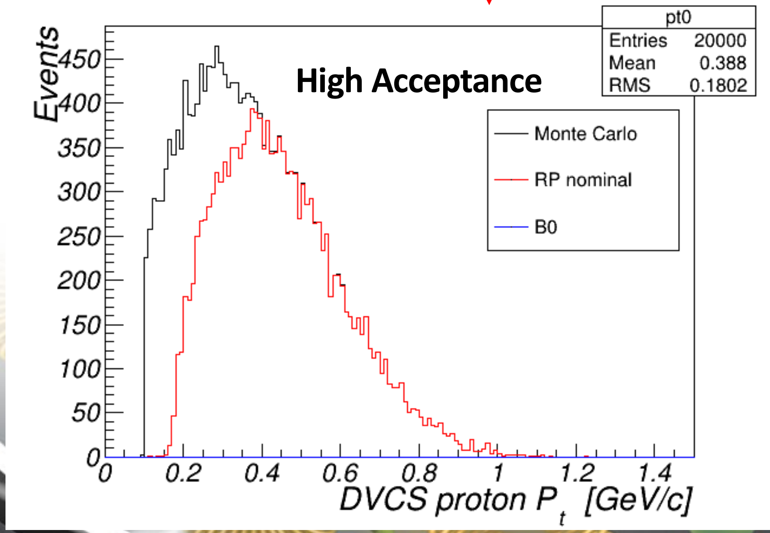
eRD24 Studies - 2020

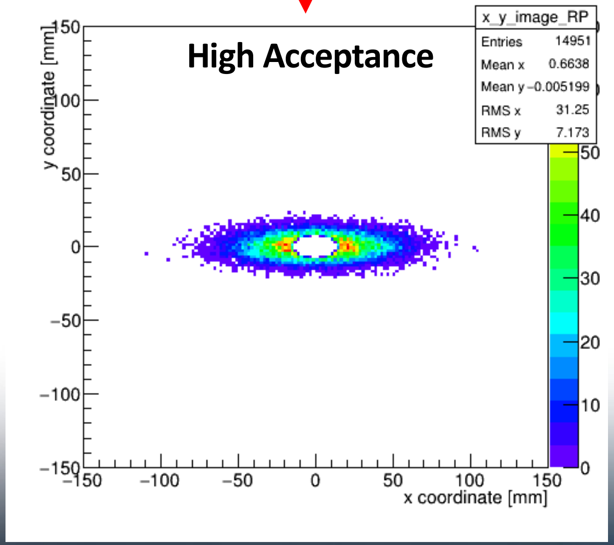
275 GeV DVCS Proton Acceptance









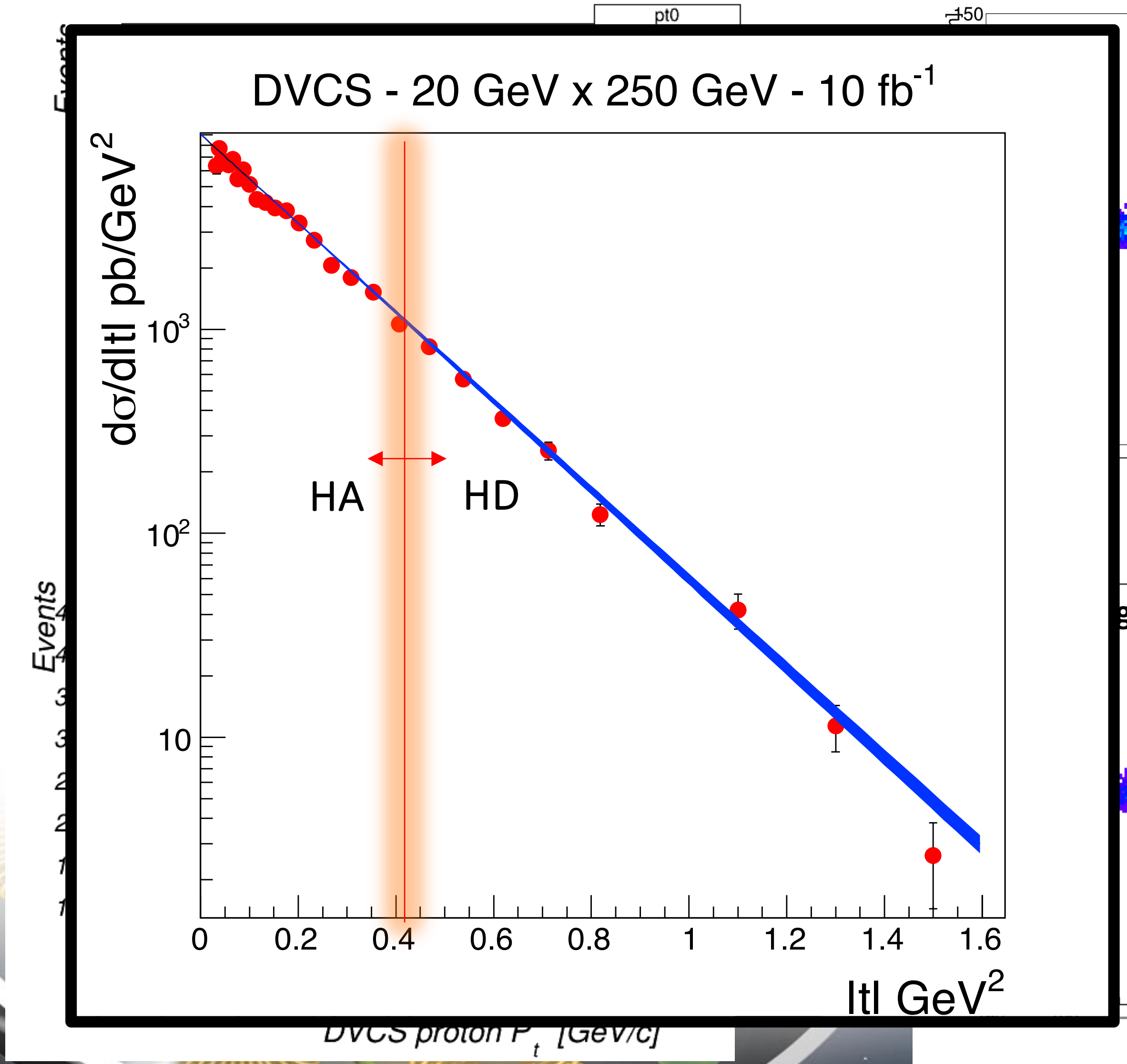


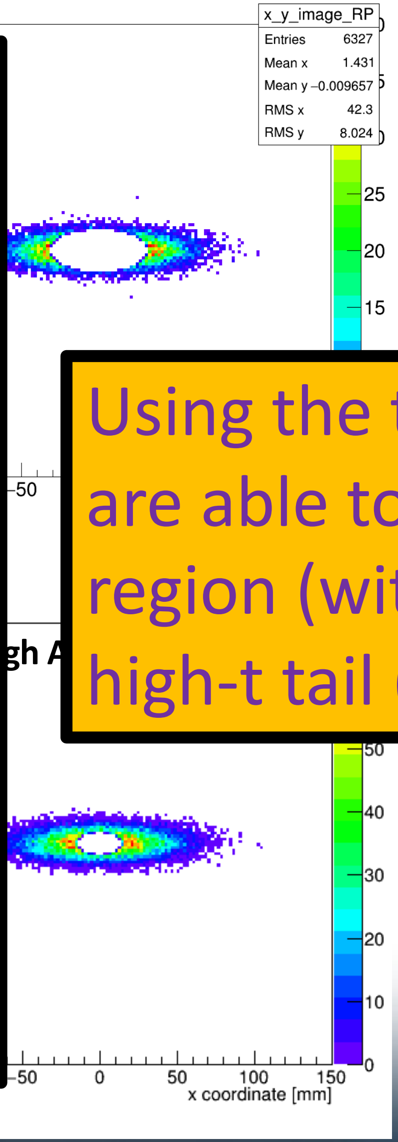
High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

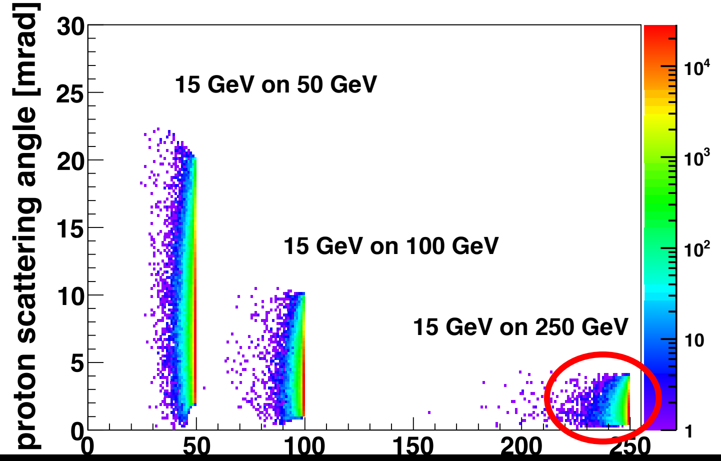
High Acceptance: larger β^* at IP, smaller $\beta(z = 30m)$ -> lower lumi., smaller beam at RP

Digression: Machine Optics

275 GeV DVCS Proton Acceptance





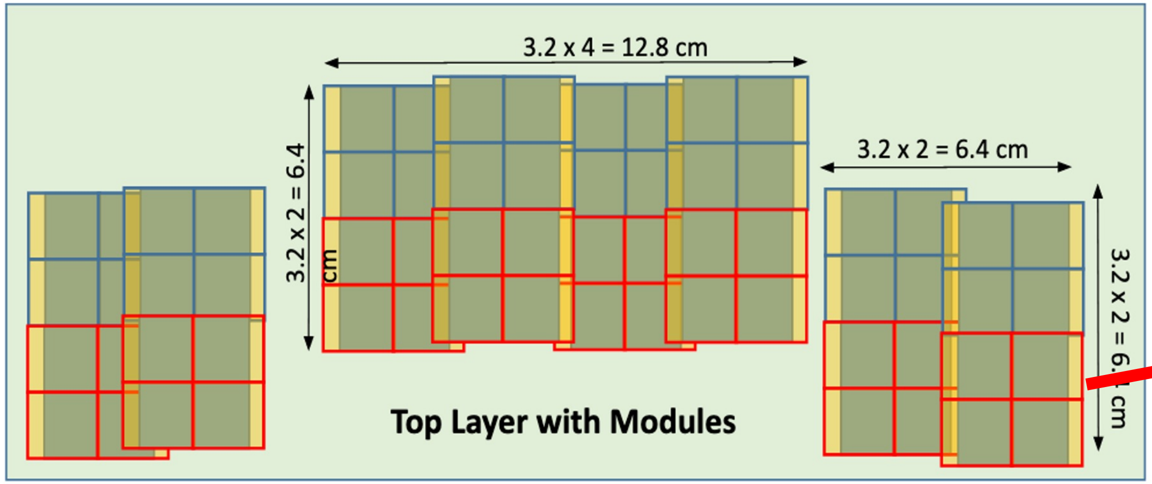


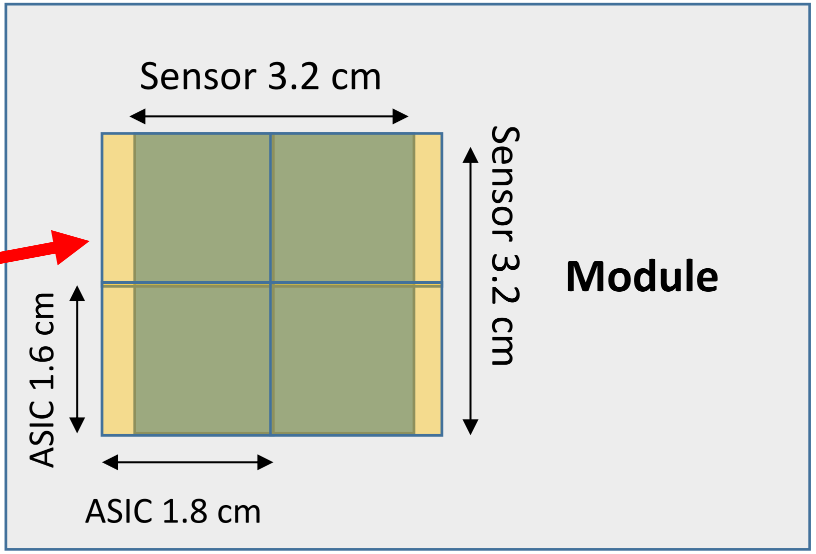
Using the two configurations, we are able to measure the low-t region (with better acceptance) and high-t tail (with higher luminosity).

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

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