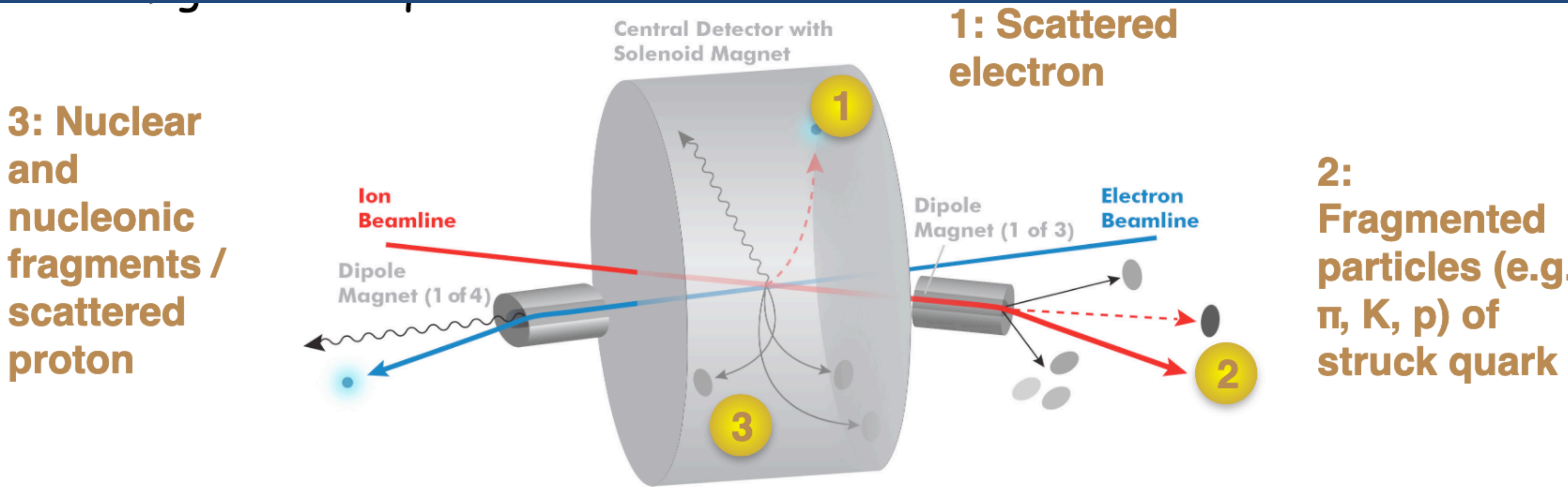
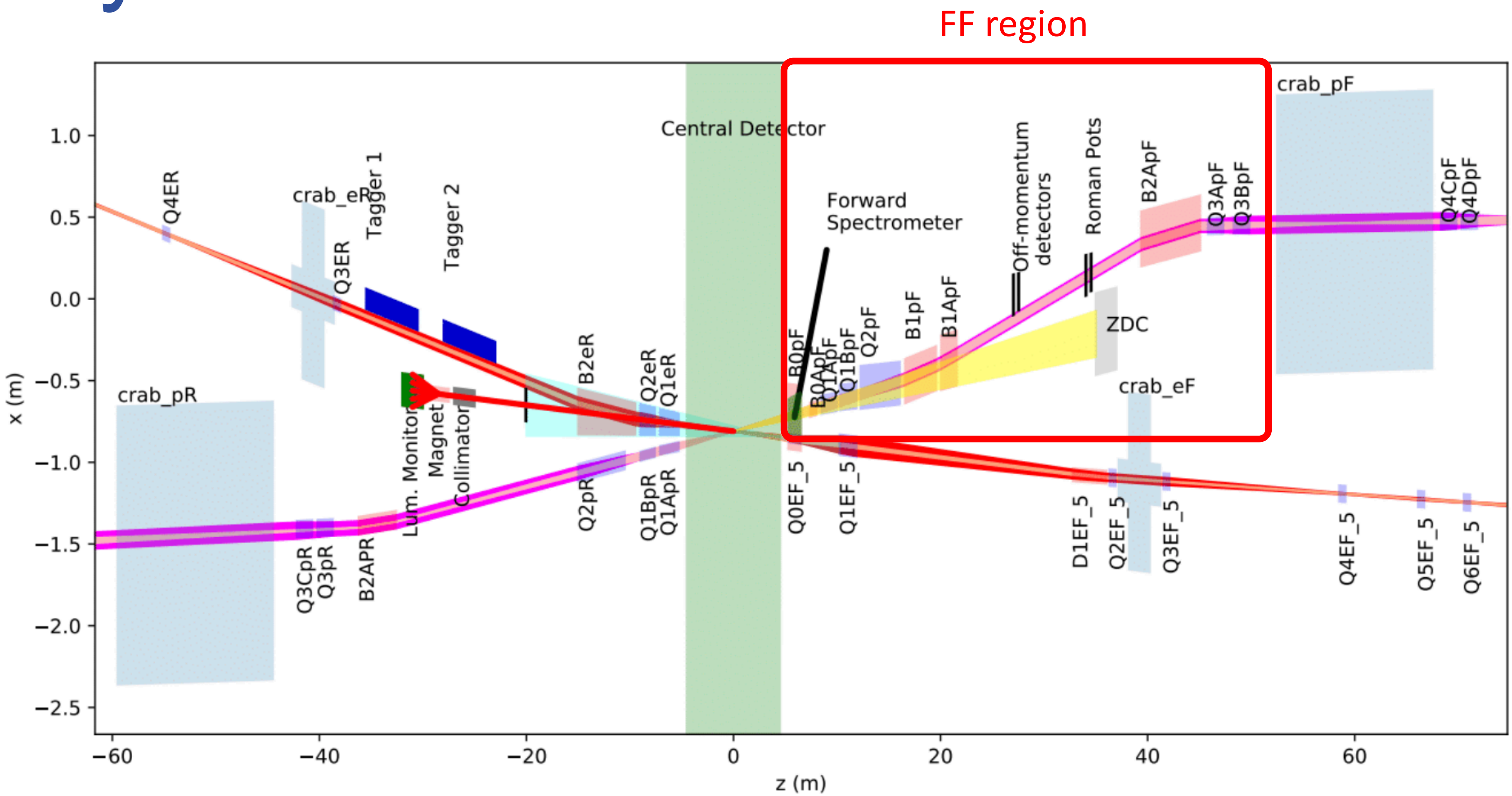
Opportunities in the Forward Region



Michael Murray
University of Kansas

Layout of Full IR

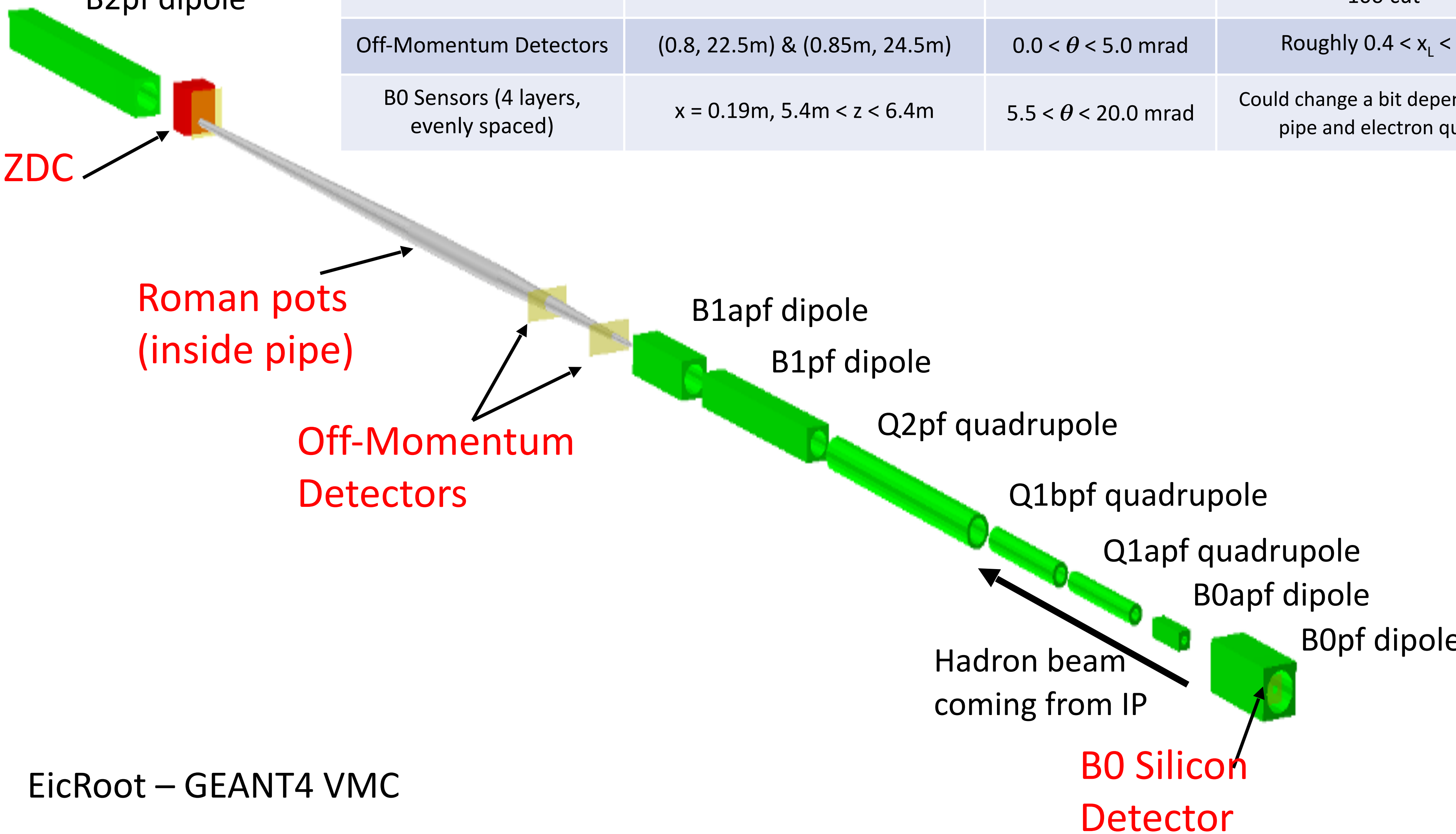


- ~9 m around the IP is reserved for the *central* detector
- But the *far forward* and *far backward* detector components are distributed along the beam line within ±35 m
- FF detectors constrained by machine design.

Layout of Far-Forward Region

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

Detector	Detector Position (x,z)	Angular Acceptance	Notes
ZDC	(0.96m, 37.5m)	$\theta < 5.5$ mrad	About 4.0 mrad at $\varphi \sim \pi$
Roman Pots (2 stations)	(0.845m, 26m) & (0.936m, 28m)	$0.0^* < \theta < 5.0$ mrad	$0.65 < x_L < 1.0$ 10σ cut
Off-Momentum Detectors	(0.8, 22.5m) & (0.85m, 24.5m)	$0.0 < \theta < 5.0$ mrad	Roughly $0.4 < x_L < 0.6$
B0 Sensors (4 layers, evenly spaced)	x = 0.19m, 5.4m < z < 6.4m	$5.5 < \theta < 20.0$ mrad	Could change a bit depending on pipe and electron quad.

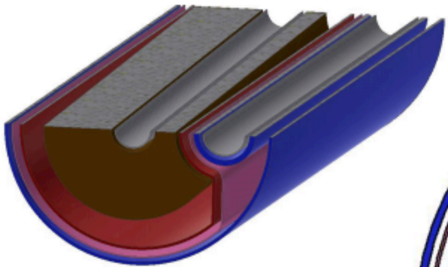


EicRoot – GEANT4 VMC

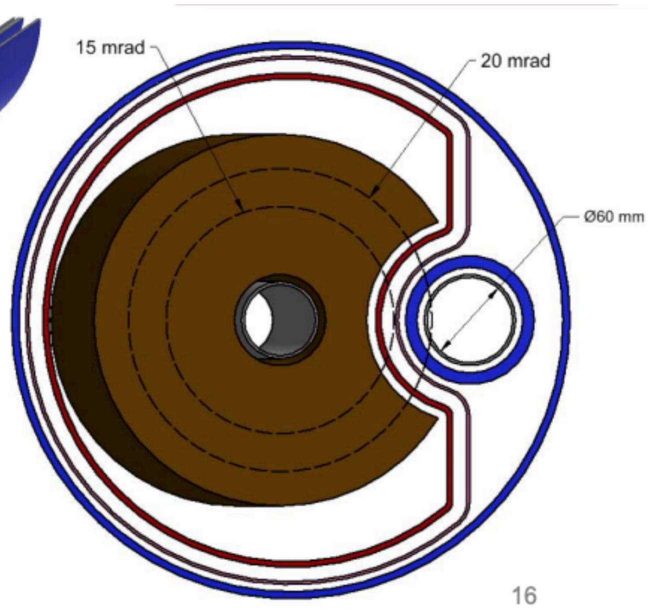
What has been simulated so far?

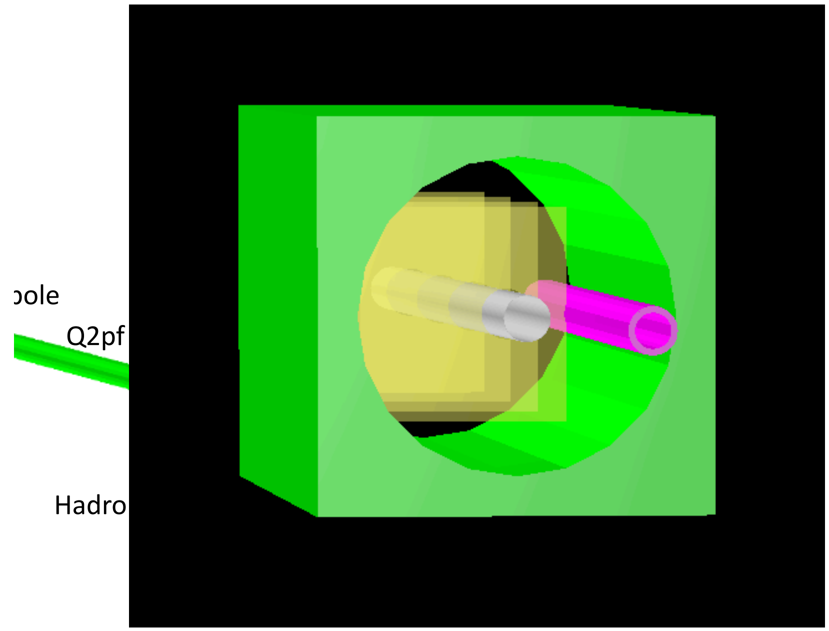
- e+p DVCS events with proton tagging.
- e+d exclusive J/Psi events with proton or neutron tagging.
- e+Au events with neutron tagging to veto breakup and photon acceptance.
- Meson structure with neutron tagging (ep $\rightarrow$ (π) $\rightarrow$ e' n X) .
- Currently in progress
  - e+He3 with spectator proton tagging
  - Meson structure with Lambda decays ($\Lambda \rightarrow$ p$\pi-$ and $\Lambda \rightarrow$ n$\pi 0$)
  - e+He4 coherent He4 tagging.

B0 Detector



Borrowed from Holger Witte.



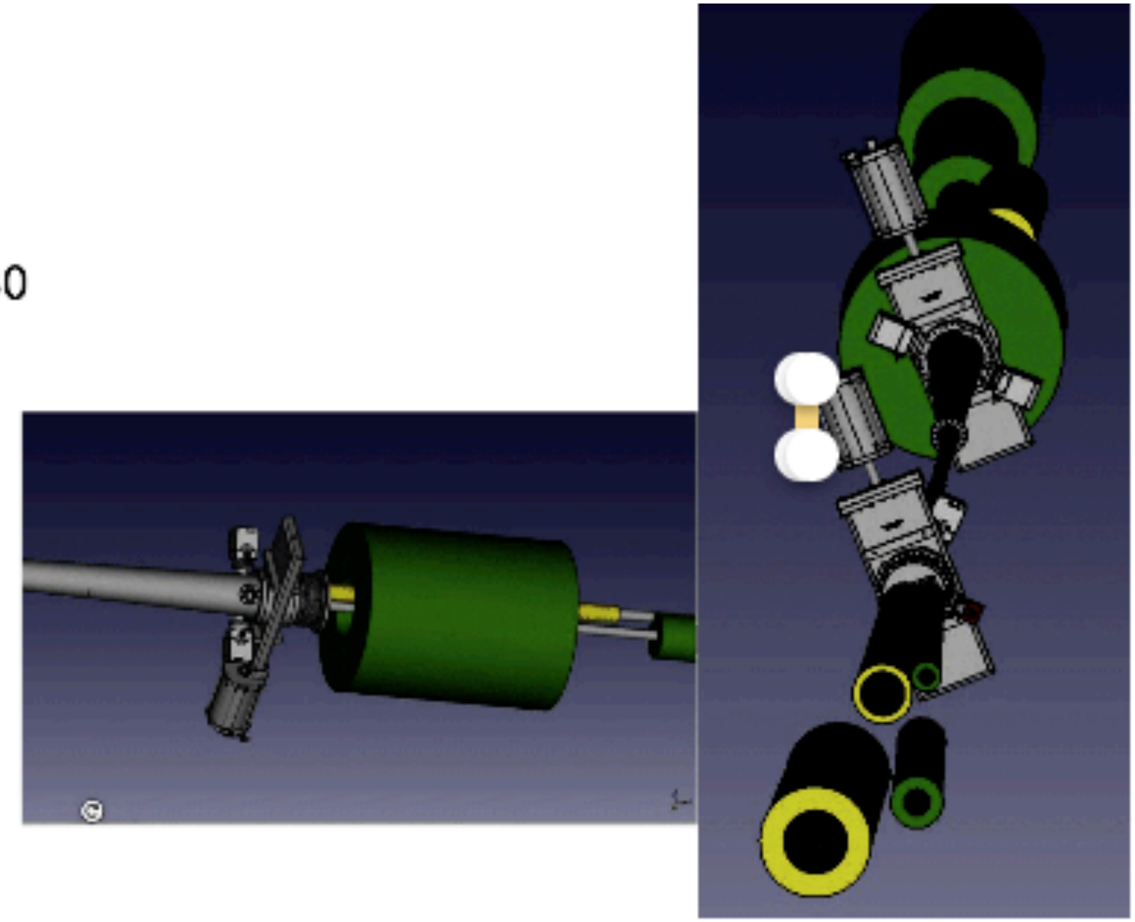


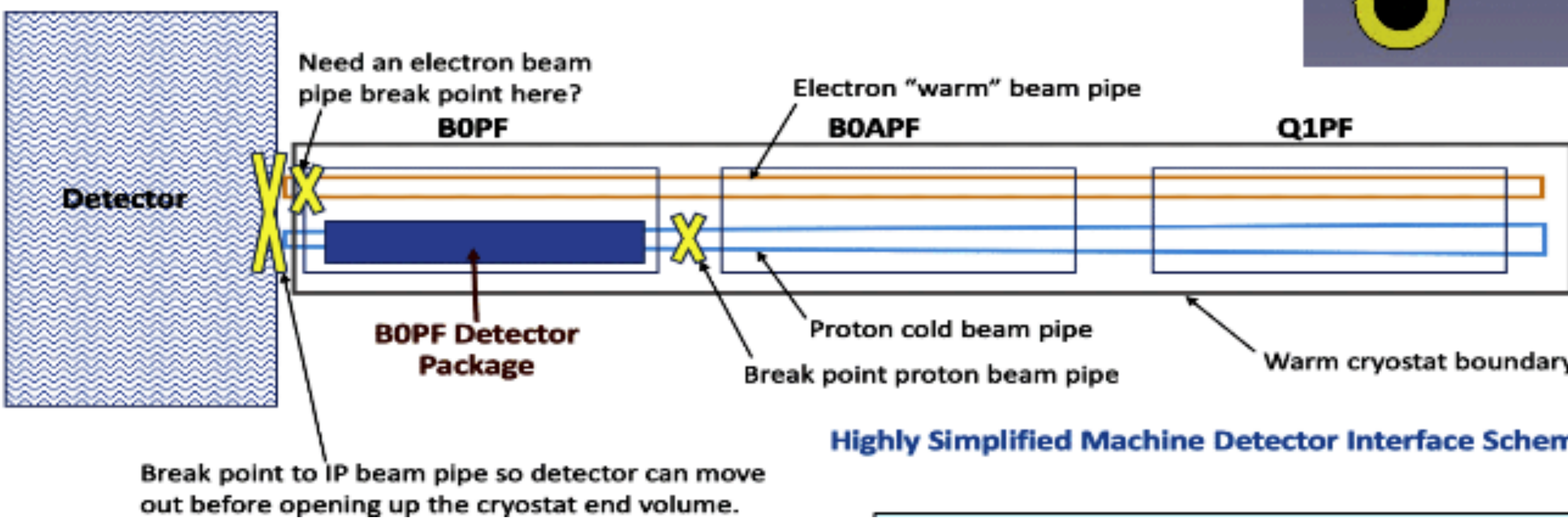
<u>B0 detector</u>

- Acts as a conventional spectrometer – allowing for tracking of charged particles in a dipole field.
- Can also be used for photon detection with pre-shower.
- 1.2 meters of total available longitudinal space – potential space for both a silicon tracker and EMCAL.
- Detects particles that are scattered with high enough angle to leave the beam pipe.
- Limitations include beam pipe size and spatial asymmetry.

B0 integration

- HCAL and vacuum pumps in front of B0 tracker => high background area
- Possible additional sub-detectors are: Pre-shower or EMCAL after B0 tracker for photons detection.
- Detector maintenance



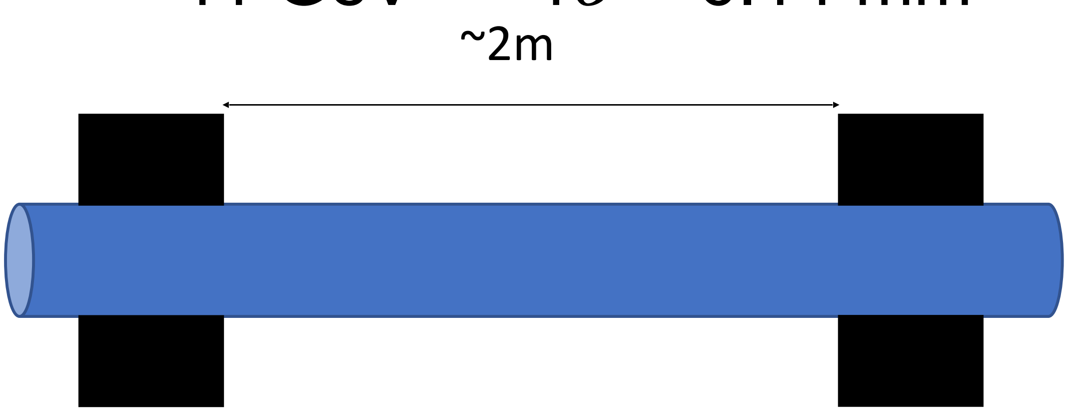


Highly Simplified Machine Detector Interface Schematic

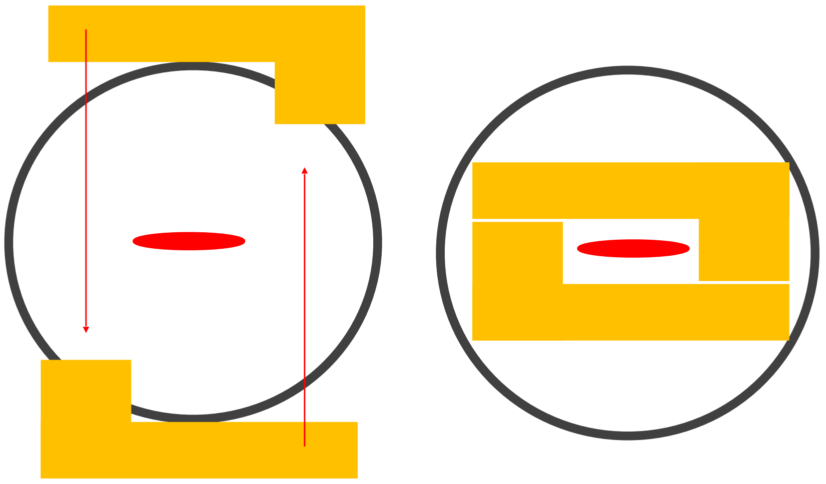
Roman Pots

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

- $\beta(z)$ is the RMS transverse beam size.
  - $\sigma(z)$ is the Gaussian width of the beam, ε is the emittance.
- General rule of thumb is to keep Roman Pot sensors at $\sim 10\sigma$ distance from beam to limit exposure.
  - 275 GeV – 1σ = 1.79 mm (HA) / 3.58 mm (HD)
  - 100 GeV – 1σ = 2.45 mm (HA) / 5.13mm (HD)
  - 41 GeV – 1σ = 6.14 mm

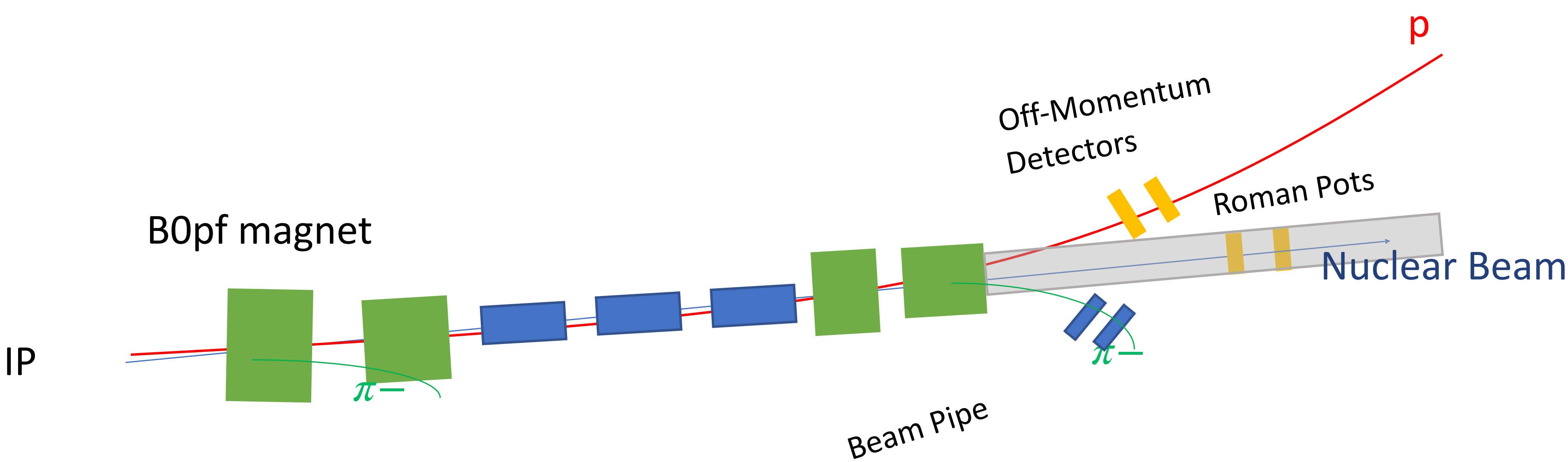


10σ cut places a limit on low-p_T acceptance.



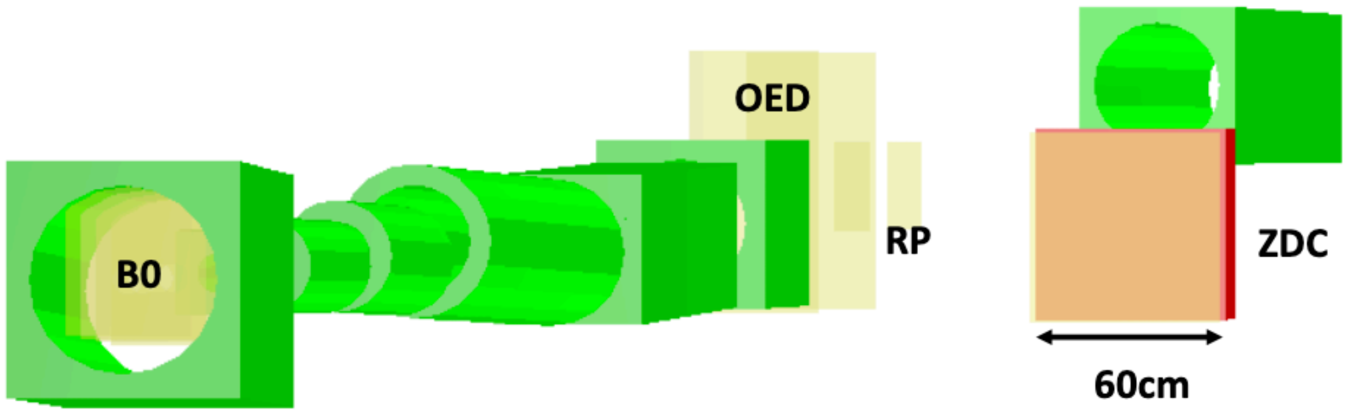
Off-Momentum Detectors

- Needed for measuring protons from nuclear breakup.
- Another set of sensors on the other side can be used to detect negative pions from lambda decay.

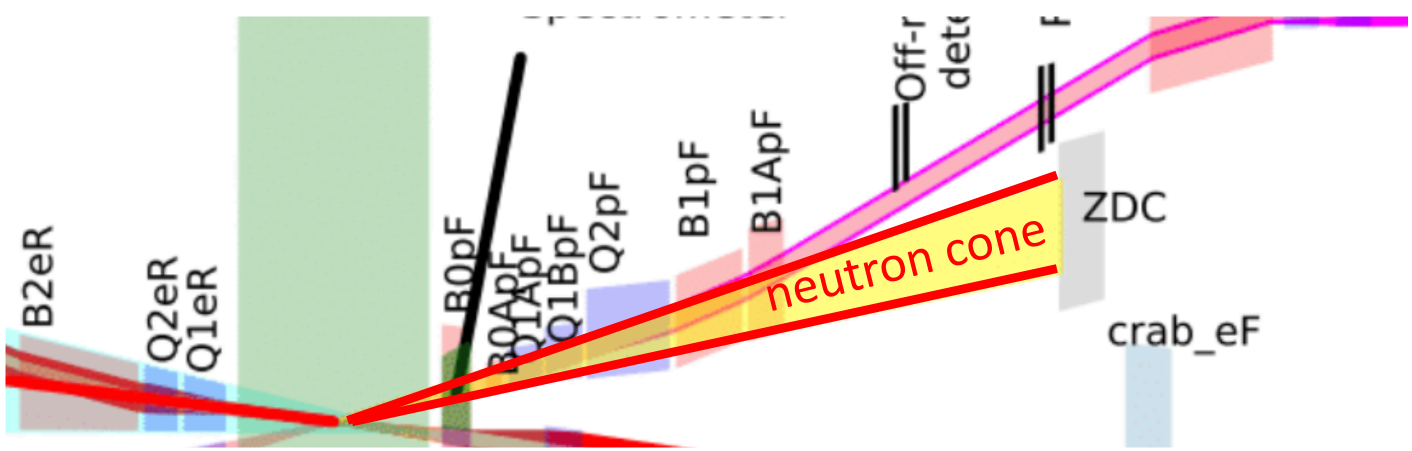


- No low-p_T cutoff - sensors are outside the beam pipe.
- Very off-momentum particles can be lost in the quads.

Zero-Degree Calorimeter (ZDC)



- For detecting neutral forward-going particles (neutrons and very low energy photons)
- Acceptance limited by bore of magnet where the neutron/ photon cone has to exit.



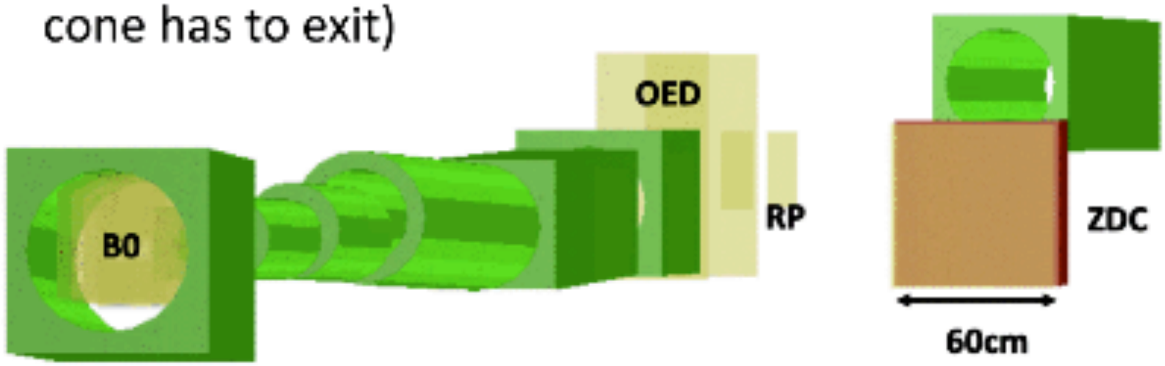
Zero-degree Calorimeter

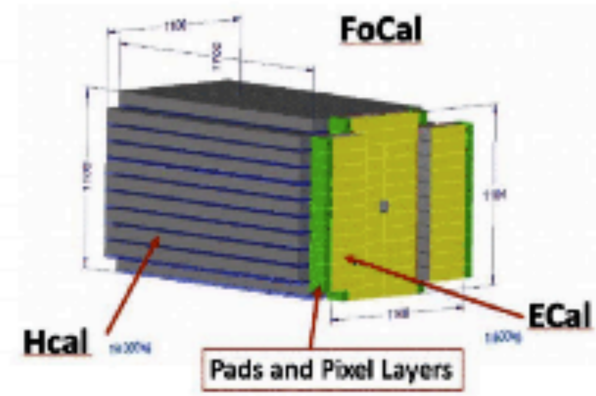
For detection of neutrons and photons

<u>Acceptance:</u>

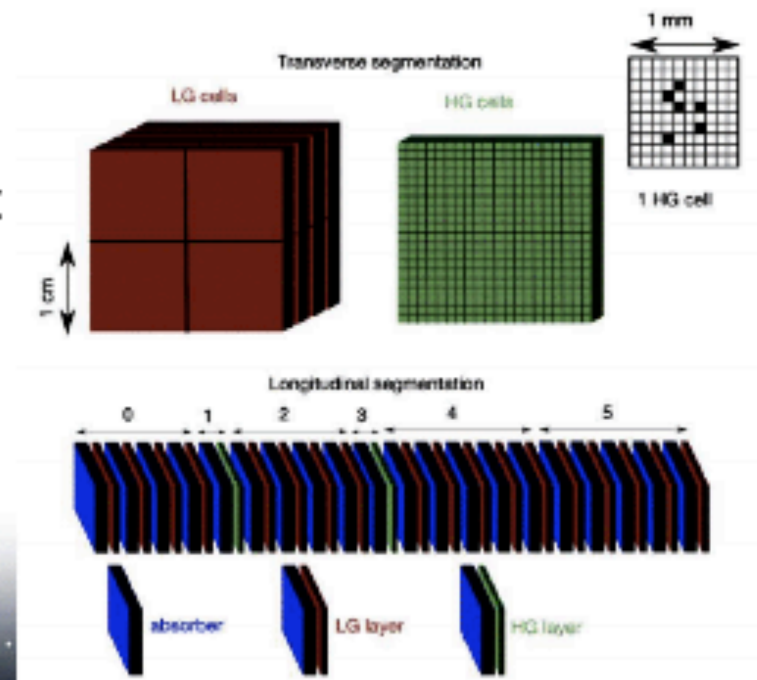
0<θ<4.5 mrad

(Limited by bore of magnet where the neutron cone has to exit)

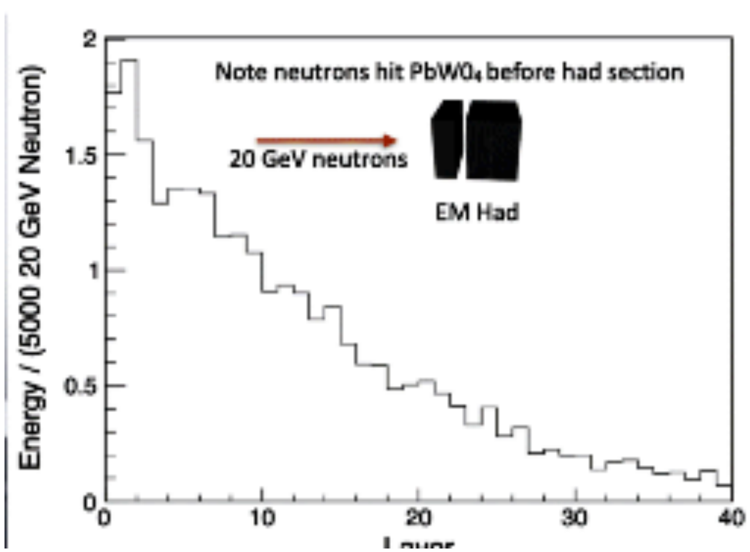




HCal: ~2K channels



- ALICE FoCal
- ATLAS/CMS ZDC



Geometric Acceptances

Neutrons:

- Assume uniform acceptance for $0<\theta<4.5$ mrad
  - Limited by bore of magnet where the neutron cone has to exit.
  - Up to 5.5 mrad on one side of the aperture.
- Resolutions (ZDC)
  - Assume an overall energy resolution of $\sigma_E/E=(50\%)/\sqrt{E} \oplus 5\%$
  - Assume angular resolution of $\sigma_\theta=(3\ \text{mrad})/\sqrt{E}$

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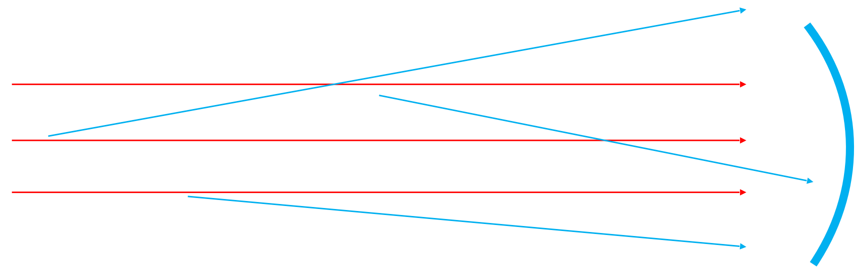
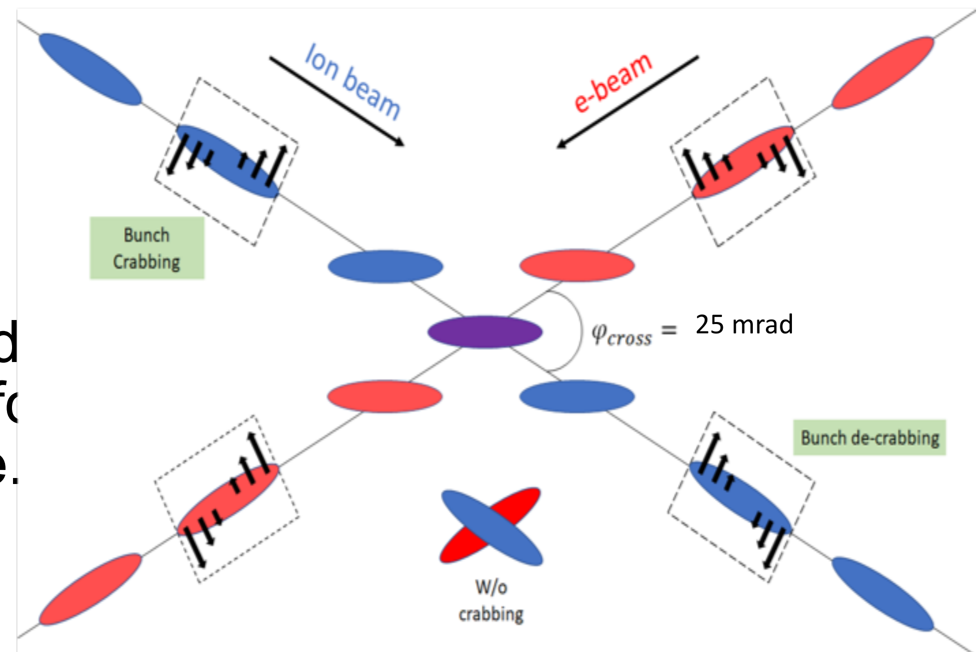
Protons:

- Assume uniform acceptance for $6 < \theta < 13$ mrad (20mrad on the other side) – "B0 spectrometer"
- For protons with p_z/(beam momentum) > 0.6 – "Roman pots"
  - 275 GeV: Assume uniform acceptance for $0.5<\theta<5.0$ mrad
  - 100 GeV: Assume uniform acceptance for $0.2<\theta<5.0$ mrad
  - 41 GeV: Assume uniform acceptance for $1.0<\theta<4.5$ mrad
- For protons with $0.25<p_z$/(beam momentum)<0.6 – "Off-momentum Detectors"
- Assume uniform acceptance for $0.0<\theta<2.0$ mrad
- for $2.0<\theta<5.0$ mrad, only accepted for $|\varphi|>1$ radian
- Resolutions (silicon reconstruction with transfer matrix or conventional tracking).
  - pt ~ 3% for pt > 550 MeV/c, p ~ 0.5%

Resolution: Smearing Contributions



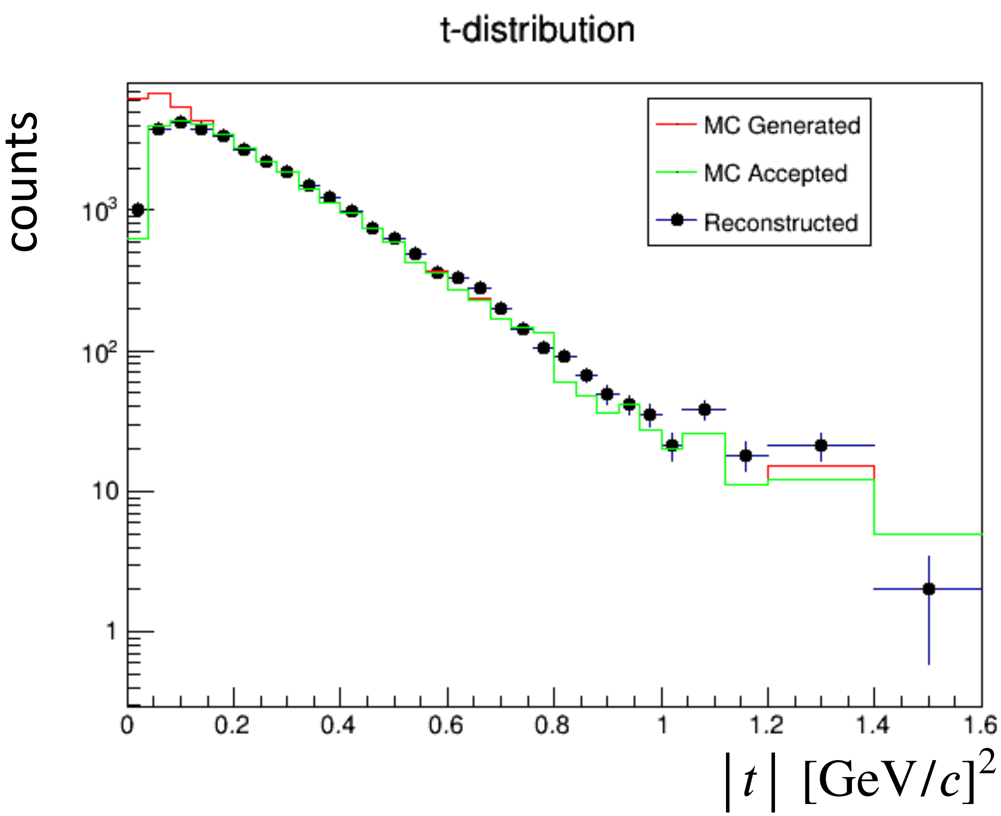
- Angular divergence
  - Angular “spread” of the beam away from the central trajectory.
  - Gives some small initial transverse momentum to the beam particles.
- Crab cavity rotation
  - Can perform rotations of the beam bunches in 2D.
  - Used to account for the luminosity d due to the crossing angle – allows fo head-on collisions to still take place.
- Detector Choices
  - Pixel size, transfer matrix, etc.

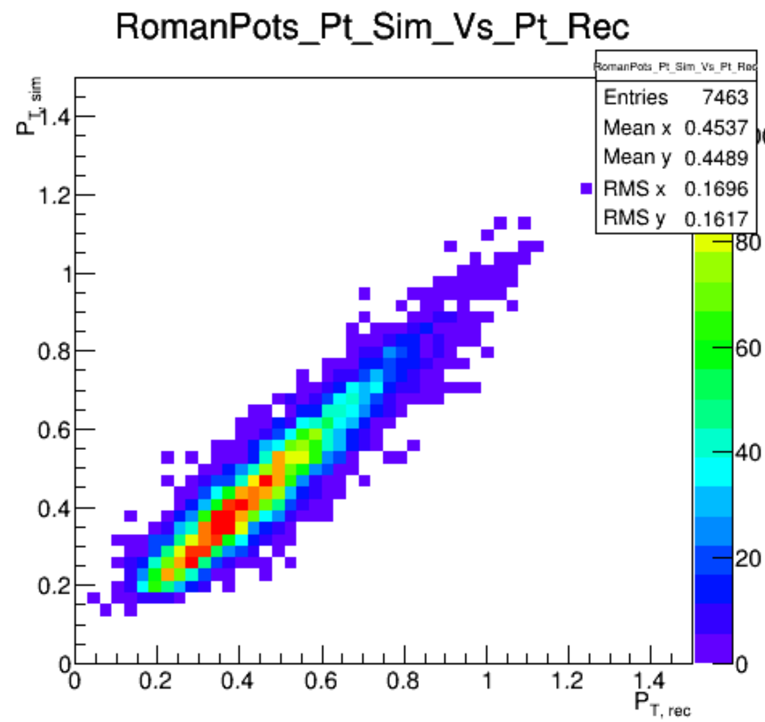


These effects introduce smearing in our momentum reconstruction.

DVCS Snapshot – 275 GeV

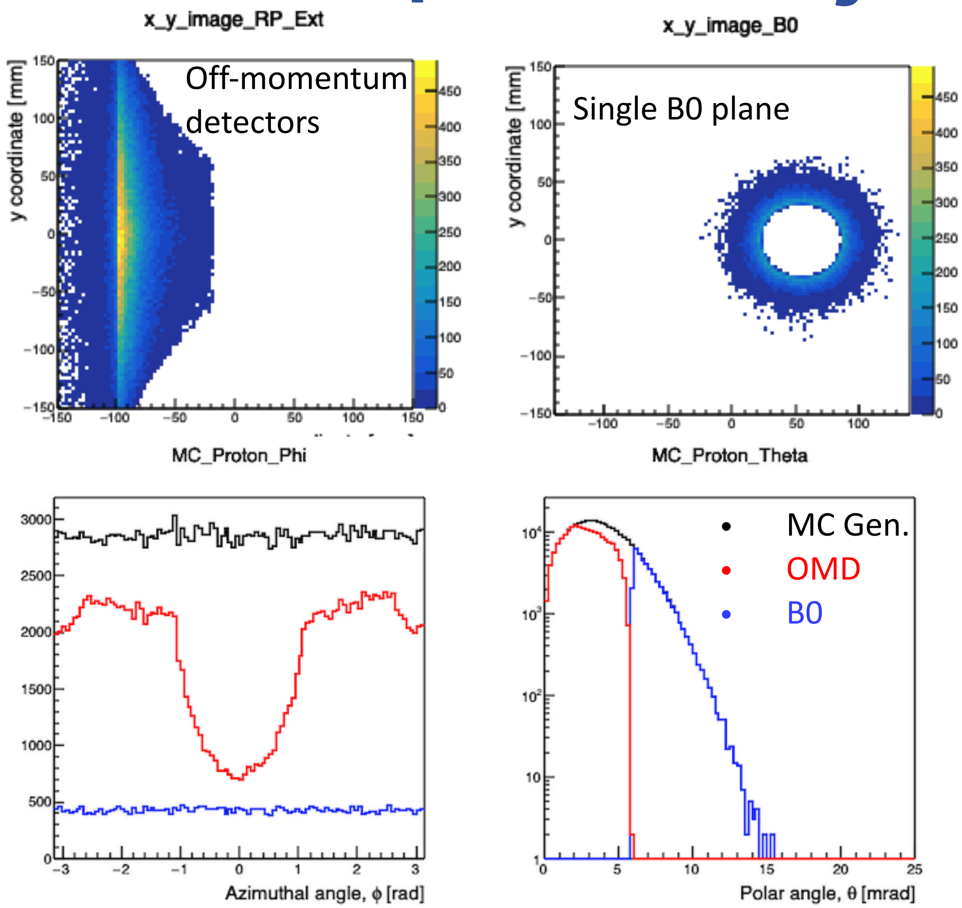
- Reconstruction includes all smearing effects.
- Bin migration present, but the slope can still be accurately extracted.





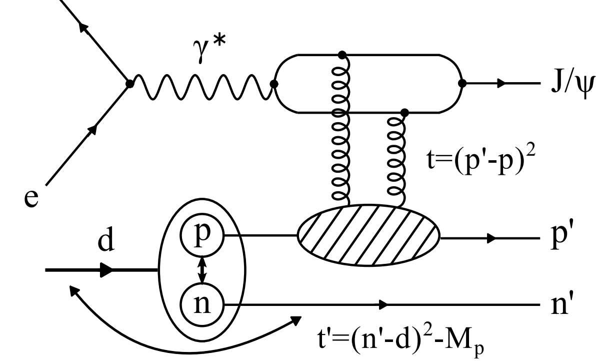
e+d -> p + n + j/Psi

arXiv:2005.14706

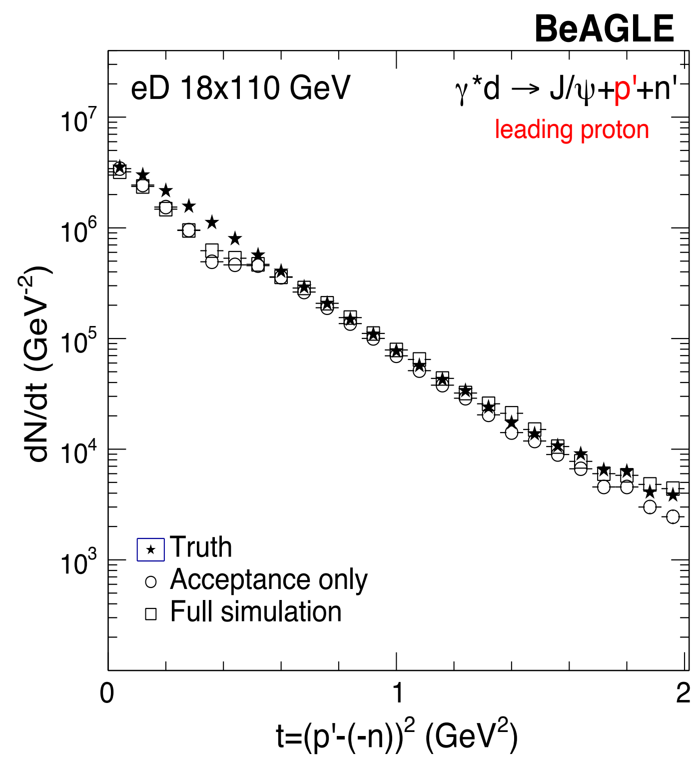


Neutron spectator/leading proton case.

Particular process in BeAGLE: incoherent diffractive J/psi production off bounded nucleons.



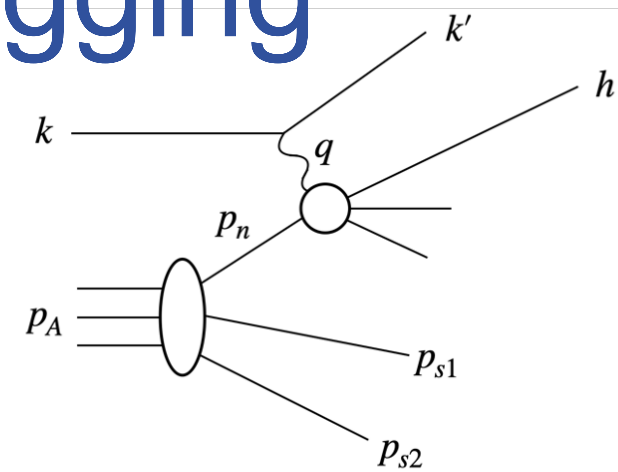
18x110GeV



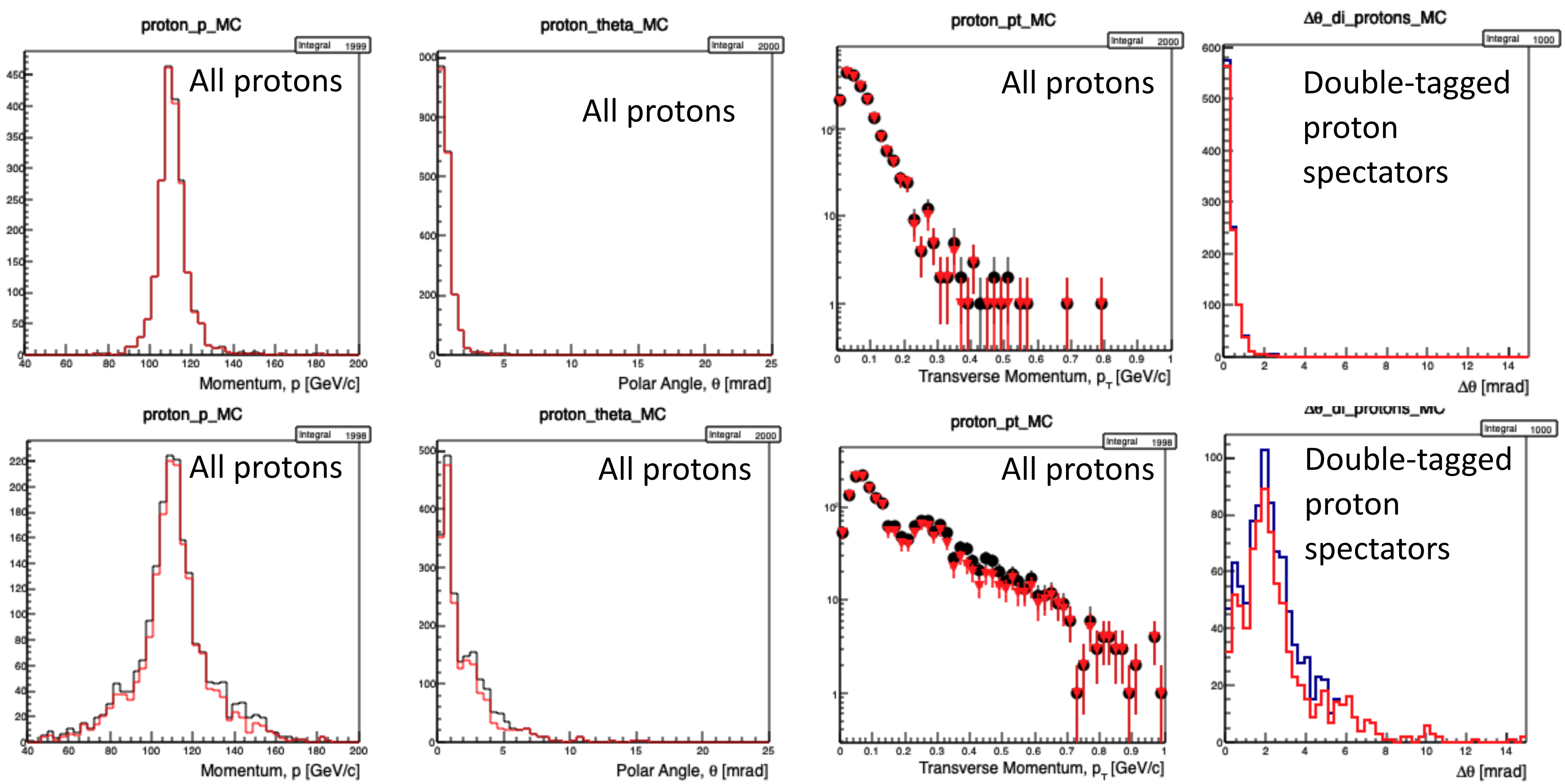
Good timing is assumed here (i.e. vertex smearing removed). If this contribution was not removed, the slope would be distorted.

t-reconstruction using double-tagging (both proton and neutron). Takes advantage of combined B0 + off-momentum detector coverage.

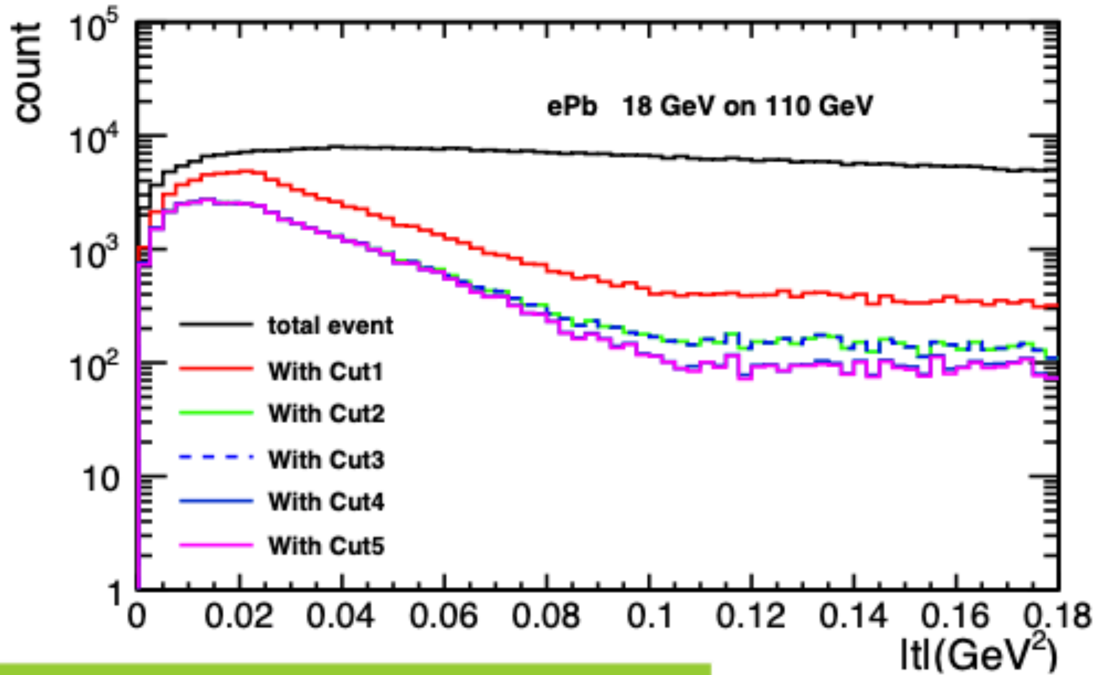
e+³He spectator proton tagging



- Acceptance looks good for double tagging the protons.
- More detailed study underway.
    - Top row: 10x110GeV/n BeAGLE DIS
    - Bottom row: 10x110 GeV/n SRC



e+Pb Collisions in BeAGLE



The impact of the different detectors is studied by adding one requirement / cut after the other.

Cut1:
- no neutron in ZDC

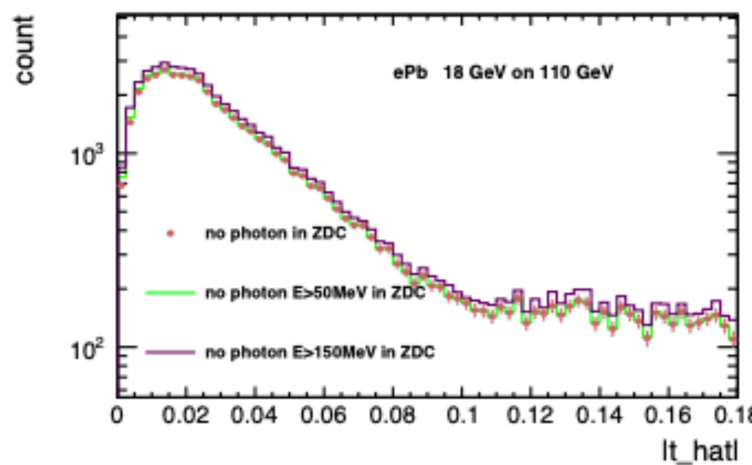
Cut2 :
- Cut1 + no photon ***E>50MeV*** in ZDC

Cut3:
- Cut2 + no proton in Roman Pots

Cut4:
- Cut3 + no proton in off-energy detector

Cut5:
- Cut4 + no proton in B0

Survived event count	
Total events	1000000
Cut1	132127
Cut2	66101
Cut3	66099
Cut4	61487
Cut5	55792



The survived events count after Cut2 with different energy cut on photon:

Survived event count	
E>150 MeV	71773
E>50MeV	66101
E>0 MeV	65278

Wan Chang

Lambda Decays

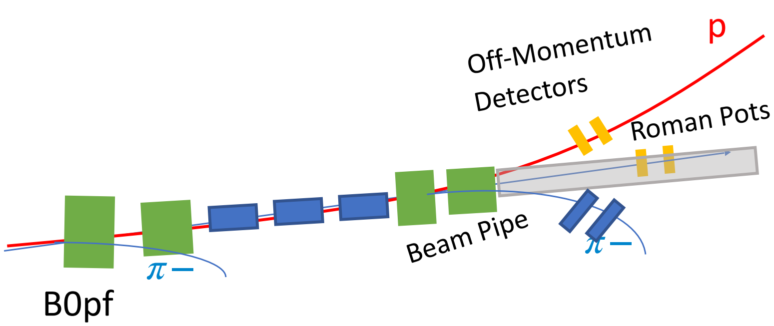
Example (10x100 GeV): ~100% detection for protons from Lambda. Significant loss $\pi-$ along the beam line (FFQs) due to low momentum of those pions.

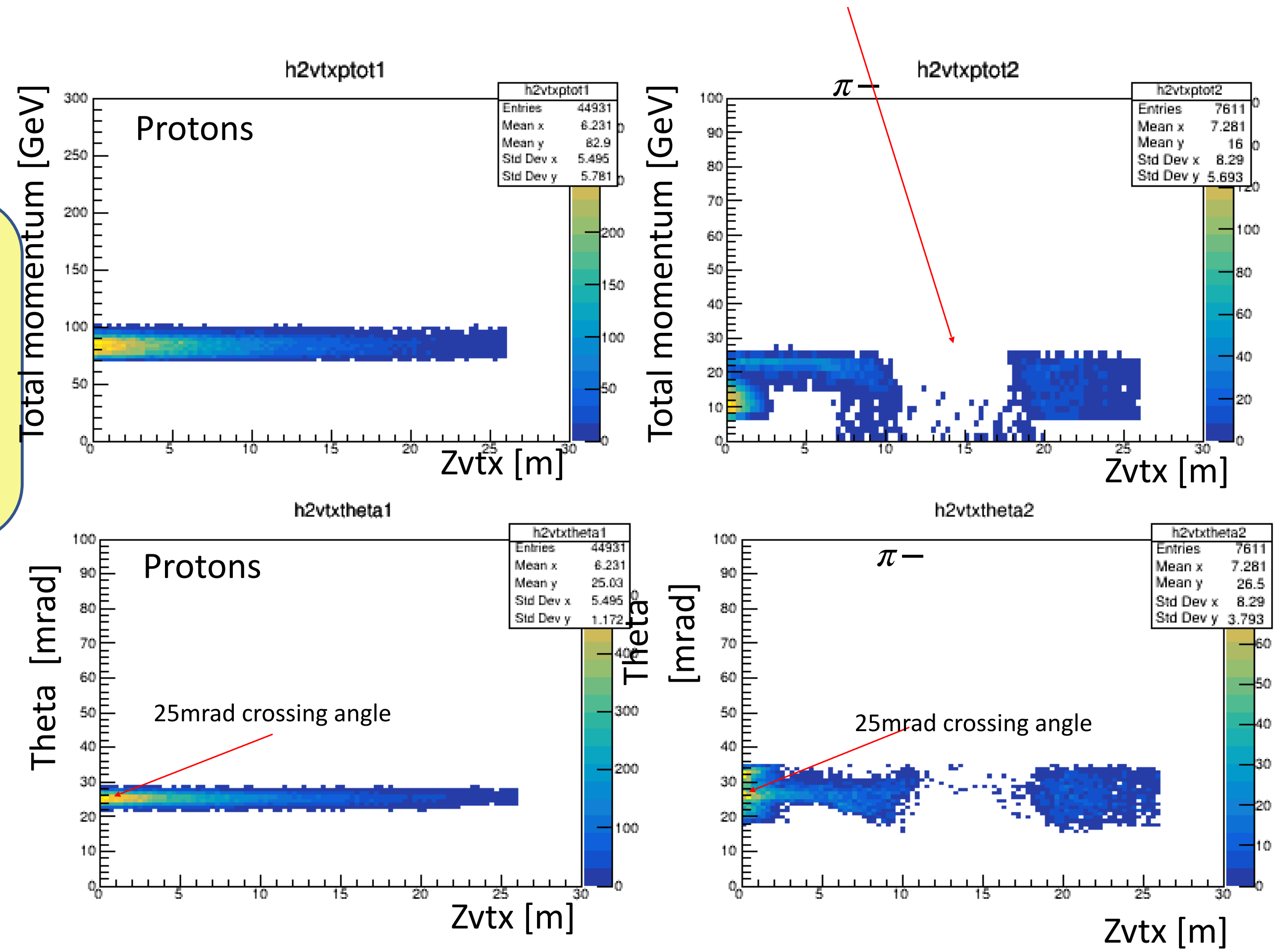
e p -> (K) -> e' + Λ + X

↳ p + $\pi-$(Br~64%)

↳ n+ $\pi 0$ (Br ~36%)

- ➢ Detecting Lambda's decays in the target fragmentation area is very hard, due to very large decay length (meters).
- ➢ Would require in addition detection of negative charged particles (pi-) at the OFF-mom





All plots: accepted particles

Slide credit: Julia Furletova

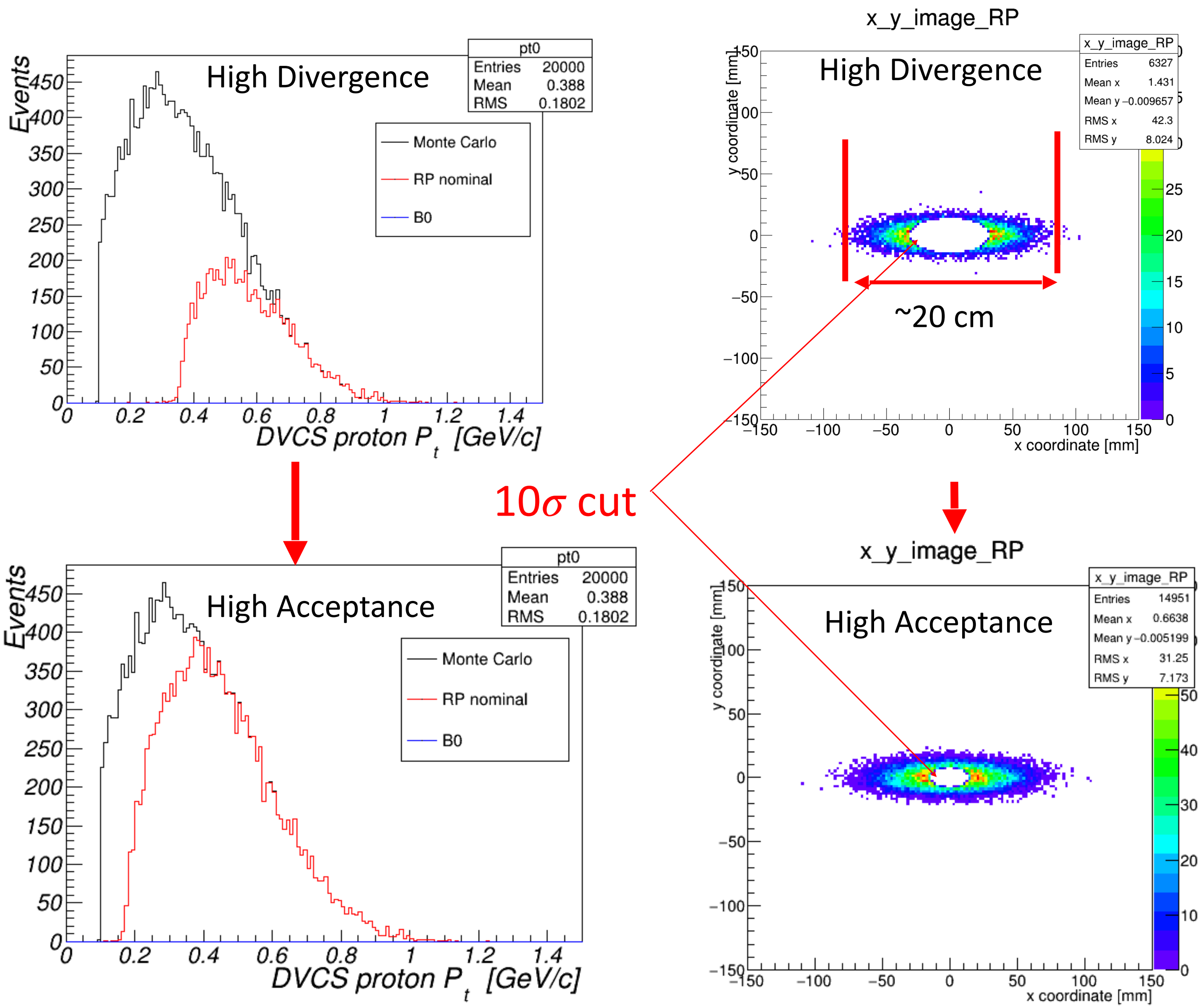
Summary

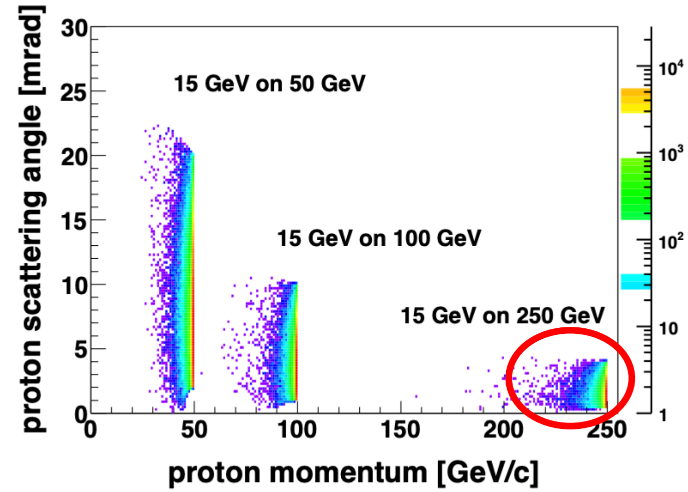
- The EIC offers great opportunities to study emergent properties of QCD
- Forward region has unique challenges, opportunities.
  - Simulations look very promising but lots of R&D needed.
- Designing and building the detectors will require collaborating groups with a wide range of capabilities.
- We would be very happy to have you join!

Backup

DVCS Snapshot – 275 GeV

- MILOU - 275 GeV DVCS Proton Acceptance
- Relevant detectors: Roman Pots and B0



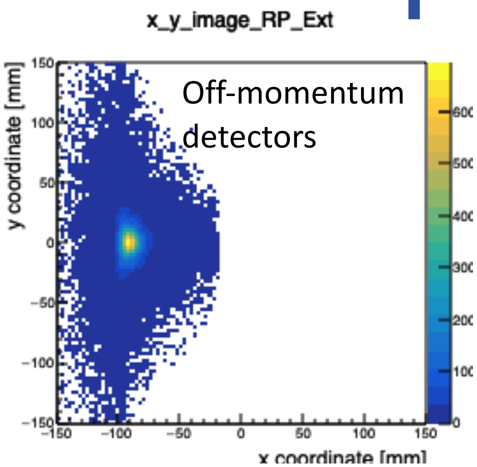


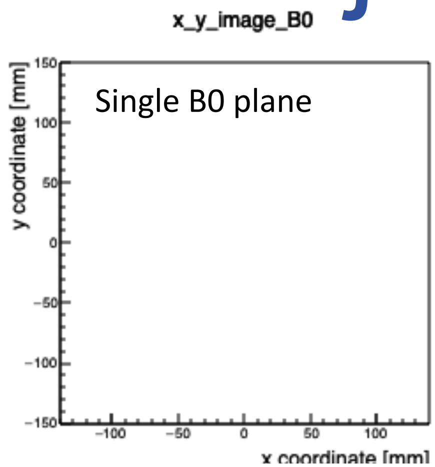
High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

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

e+d -> p + n + j/Psi

[arXiv:2005.14706](https://arxiv.org/abs/2005.14706)





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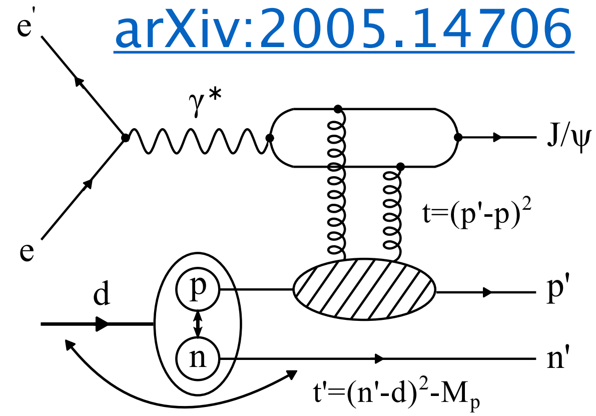
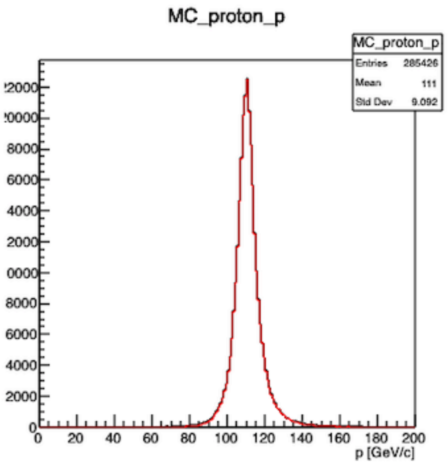
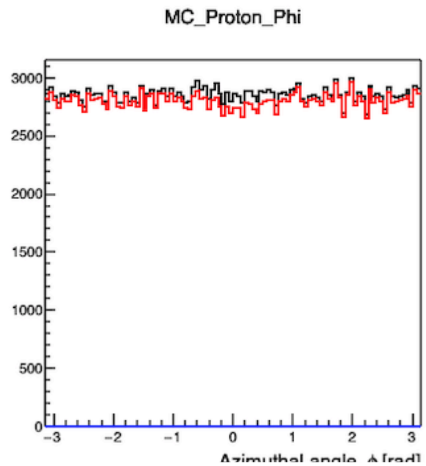
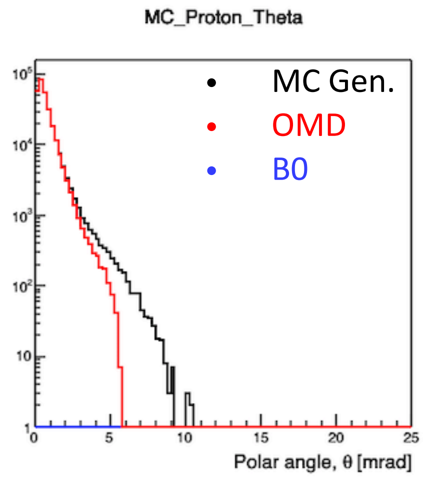


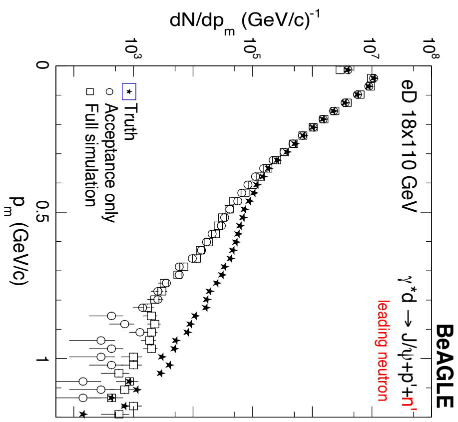
18x110GeV

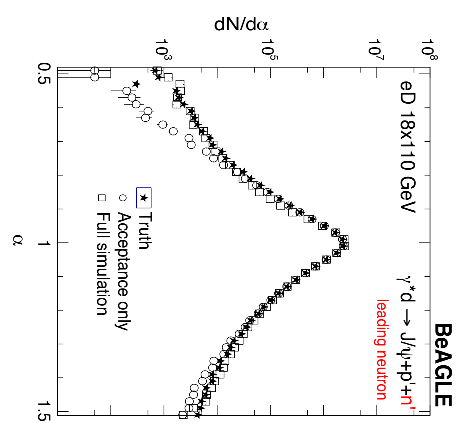






Proton spectator case.





Some examples of observables (light-cone momentum fraction, α), and missing-momentum (p_m).