Far Forward Detector Simulations: The Story So Far

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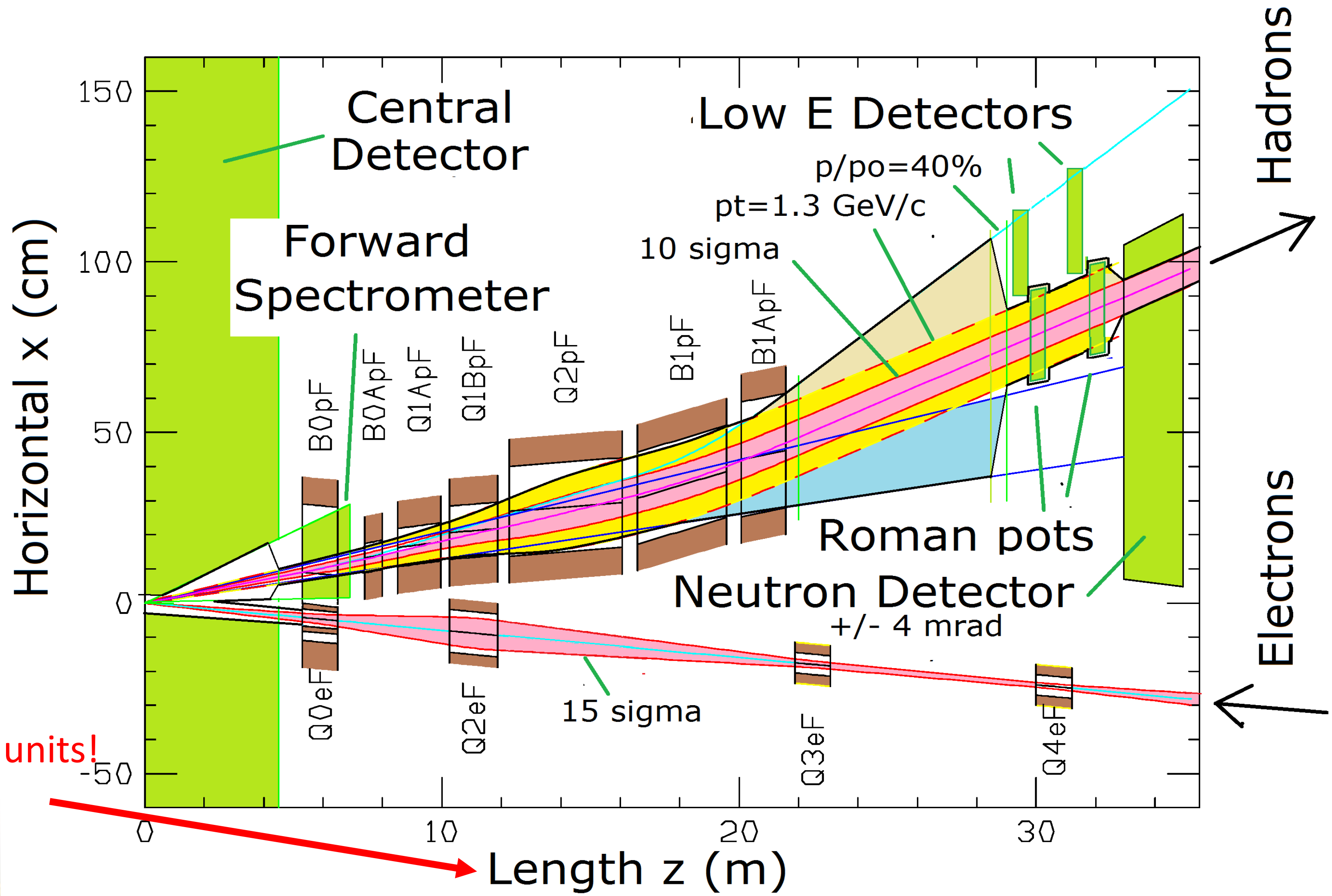
U.S. DEPARTMENT OF ENERGY | Office of Science

Simulation Goals

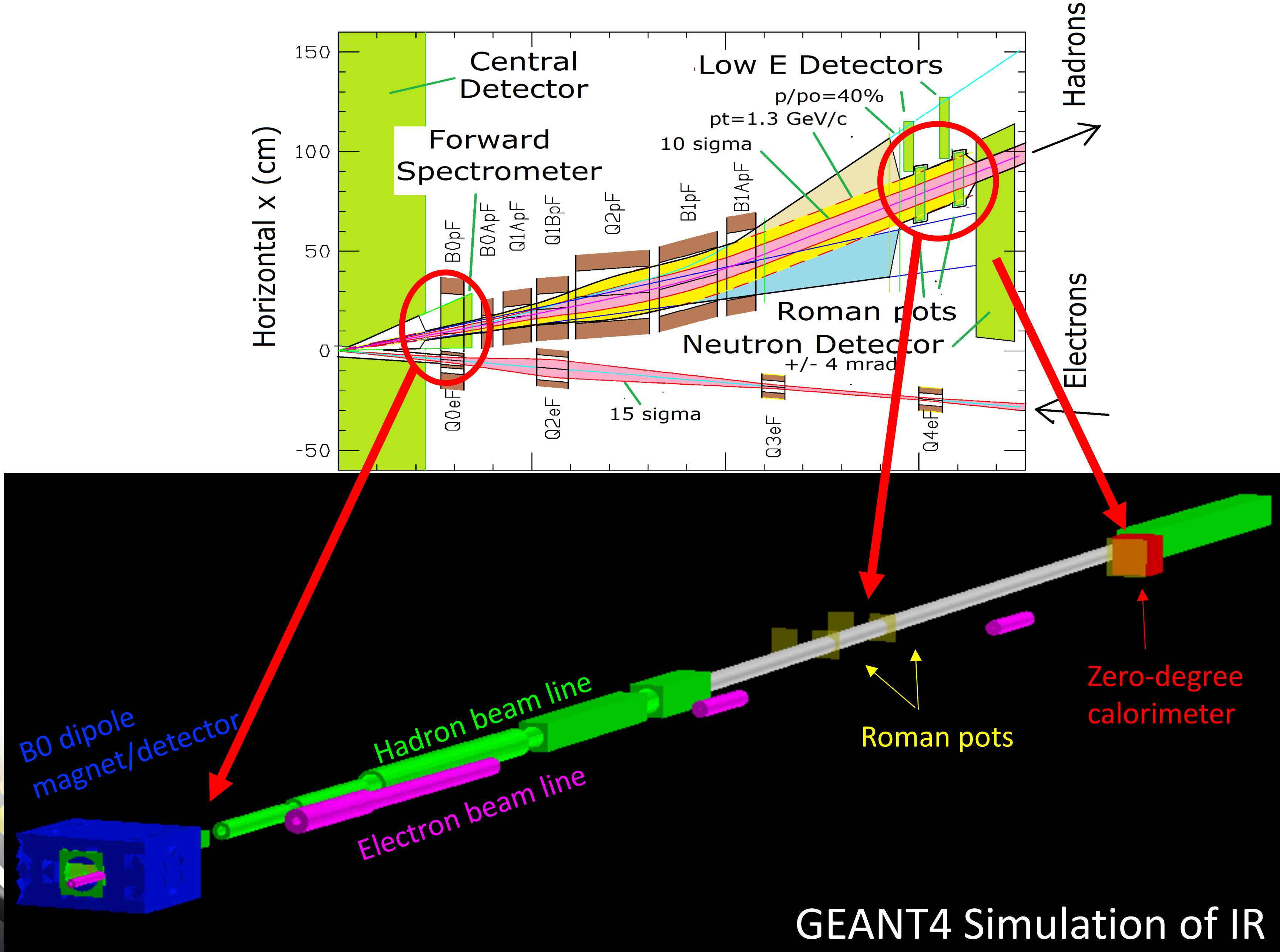
- Establish baseline detector acceptance.
- Understand various sources of smearing of reconstructed momentum.
  - Beam effects, sensor pixel size, etc.
- These studies have influenced the IR design and the choice of sensor technology to be pursued for the far-forward physics program (see eRD24 for the Roman Pots sensor R&D).

IR Layout for EIC @ BNL detector



Note the different units!

IR Layout for EIC @ BNL detector

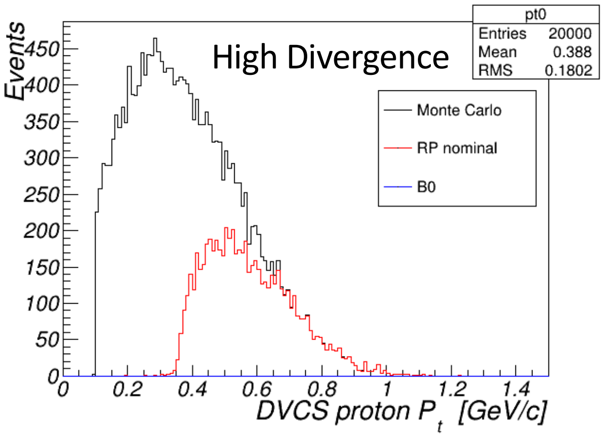


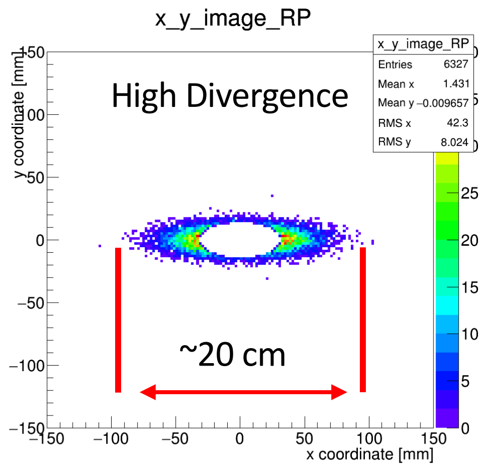
Full Simulations

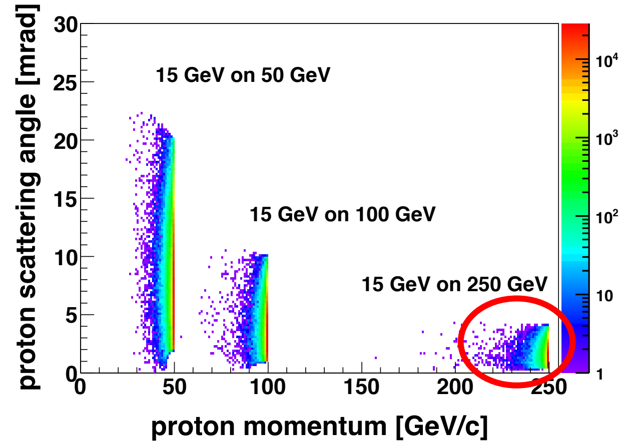
- e+p exclusive events generated using MILOU – a generator of DVCS events.
- All machine elements, magnetic fields, detectors, etc. implemented in simulation using GEANT4.
- Various beam energies considered (5(e)x41(p) GeV, 10x100 GeV, 18x275GeV)
- Effects from beam angular divergence and vertex smearing from crab cavity rotation included.

Detector Acceptance

275 GeV DVCS Proton Acceptance

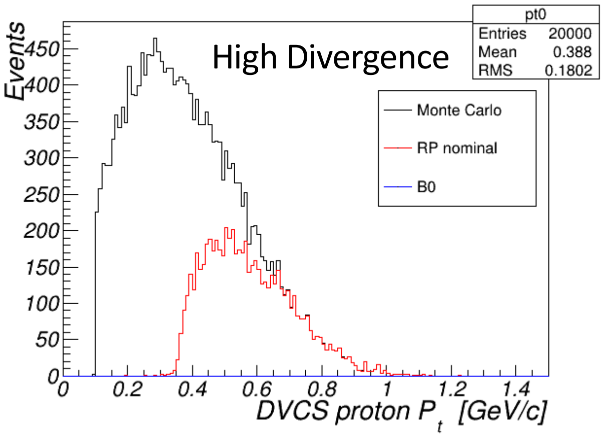


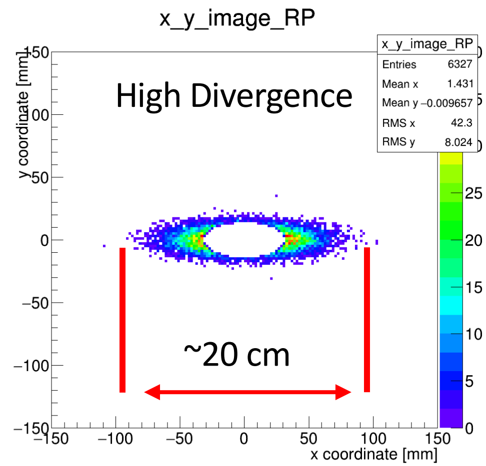


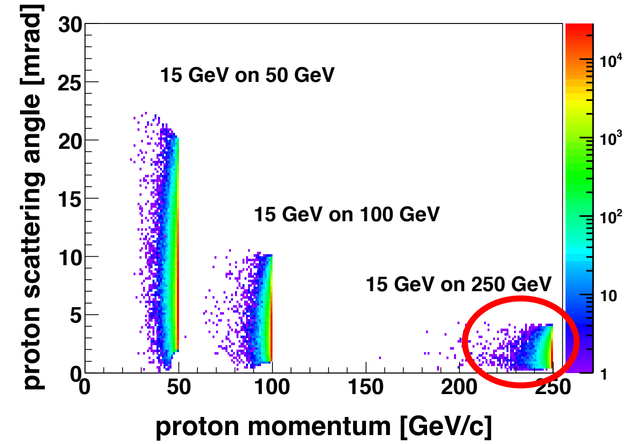


The high divergence configuration severely reduces the low p_t acceptance.

275 GeV DVCS Proton Acceptance







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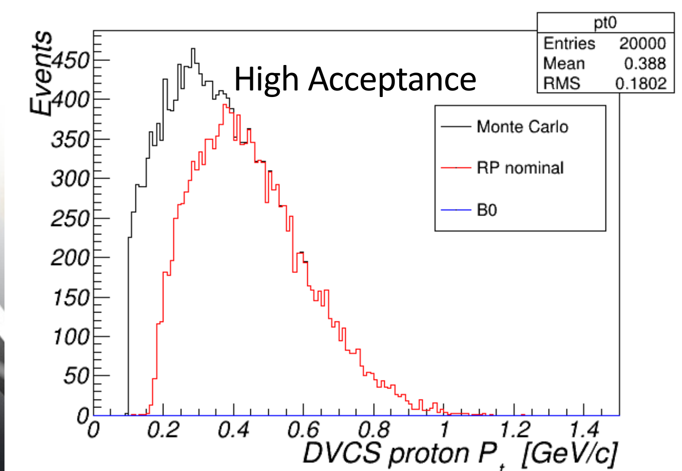
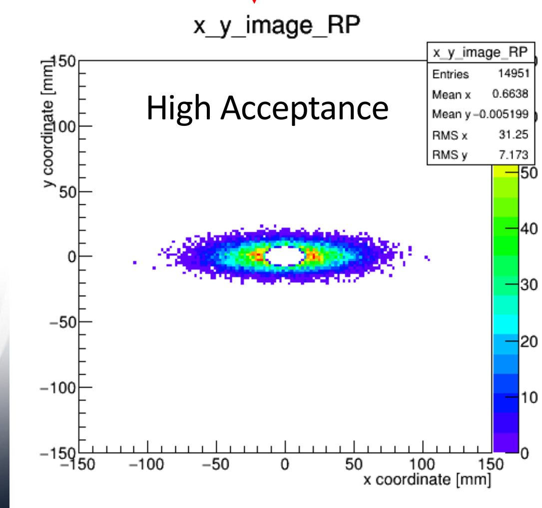
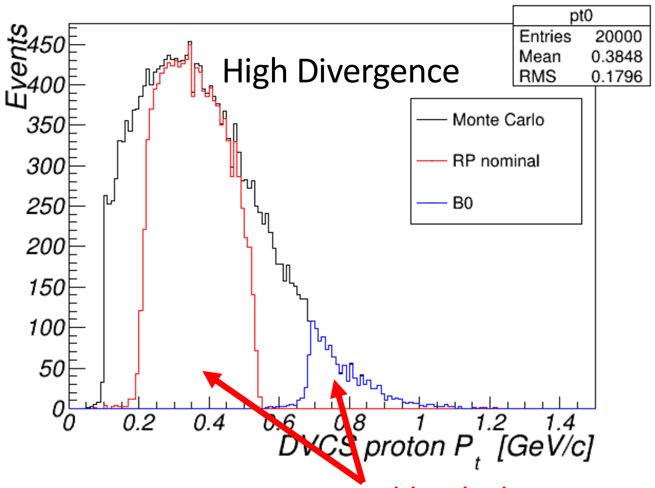
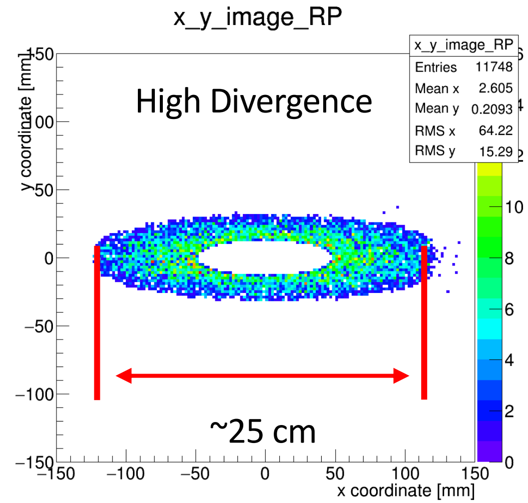


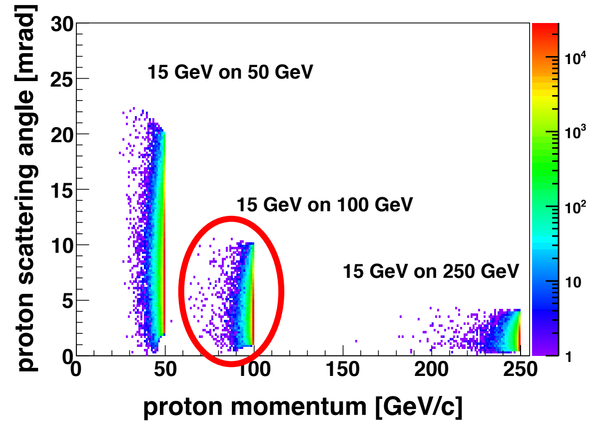


100 GeV DVCS protons



Need both detector systems together here!





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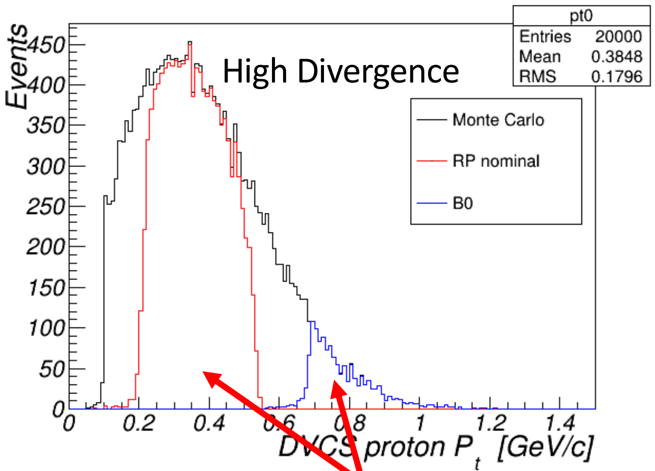

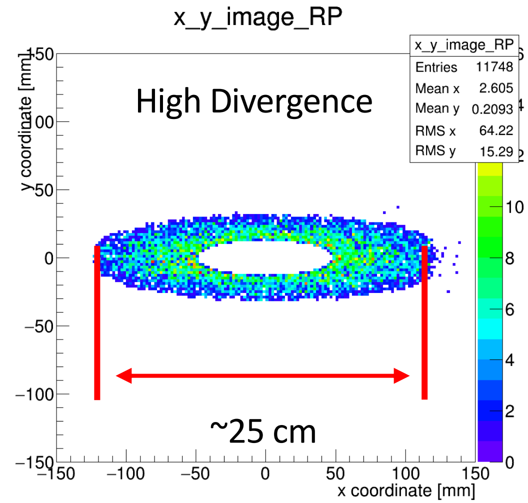

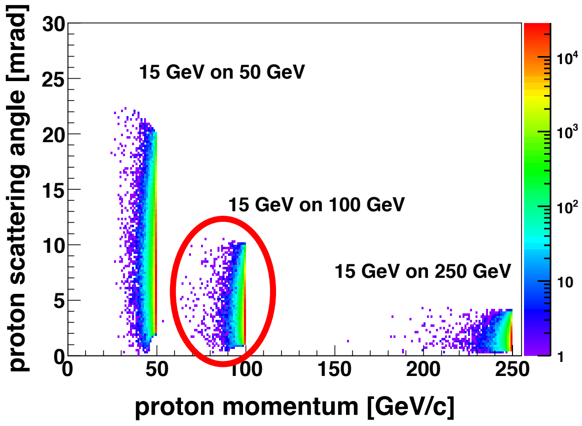

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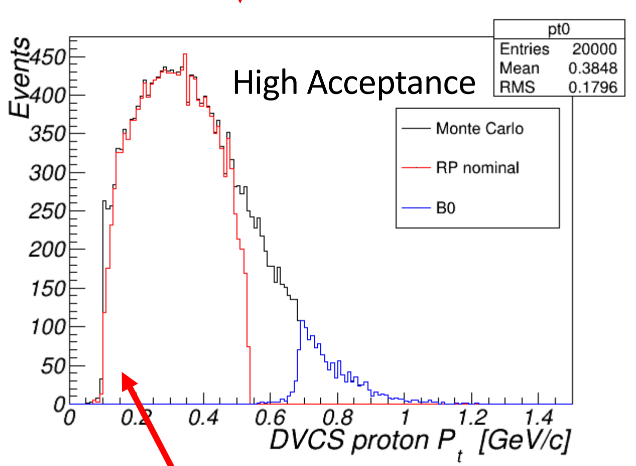
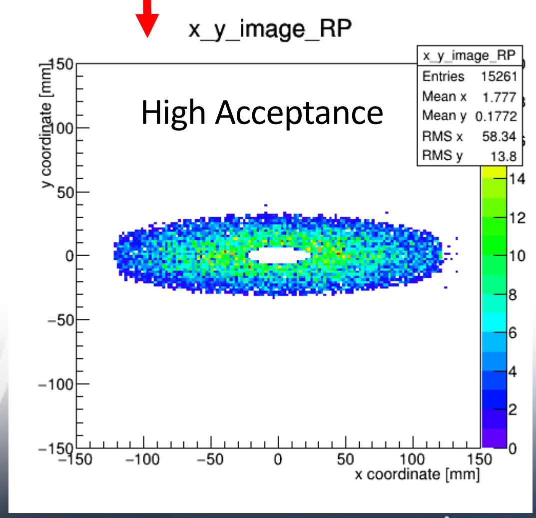
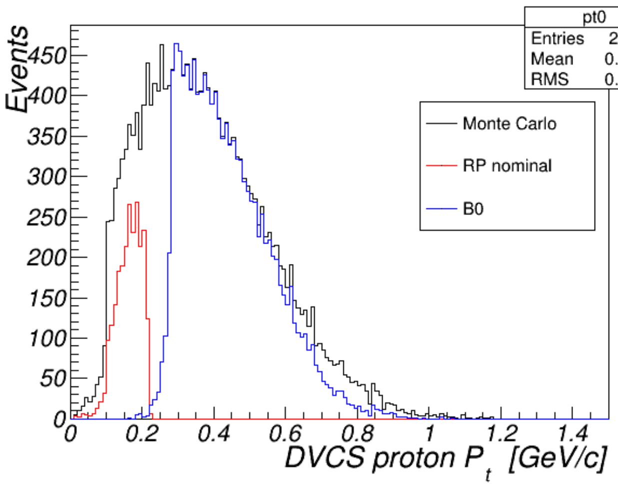
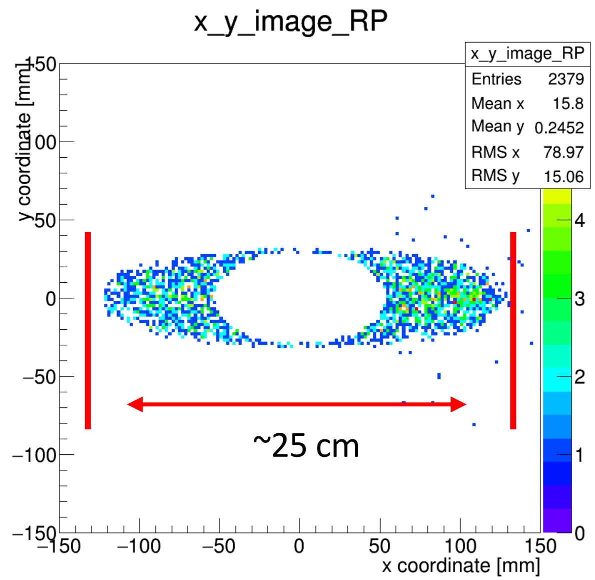


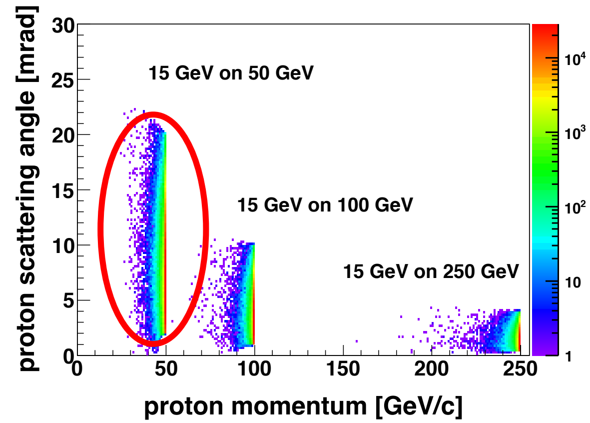


Improves low p_t acceptance.

41 GeV DVCS protons



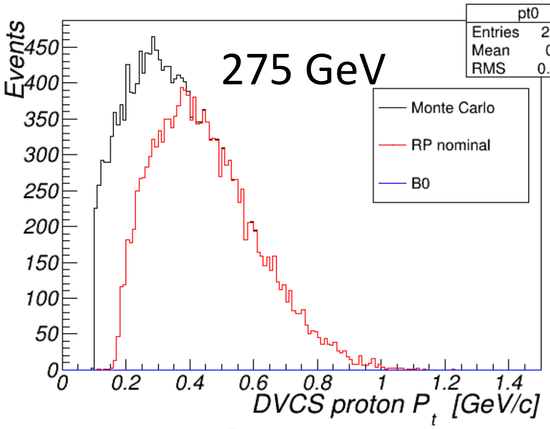


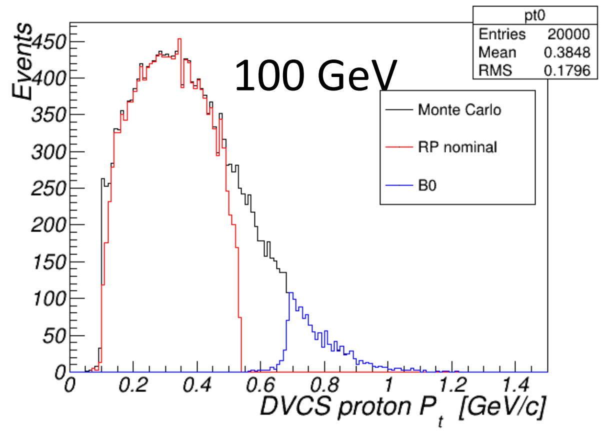


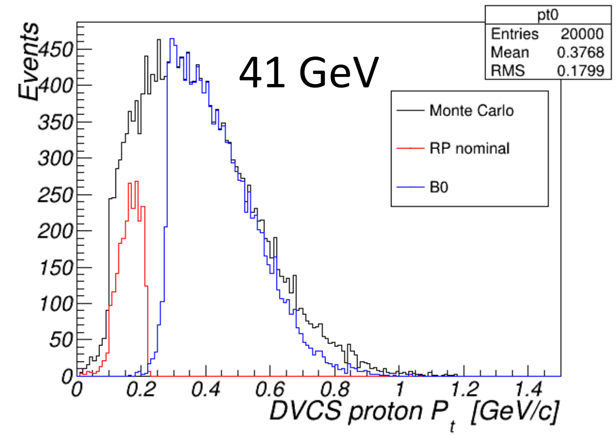
- Only one beam configuration for now.
- Acceptance gap still observed.
- Lower acceptance at high p_t.
- B0 plays largest role at this beam energy.

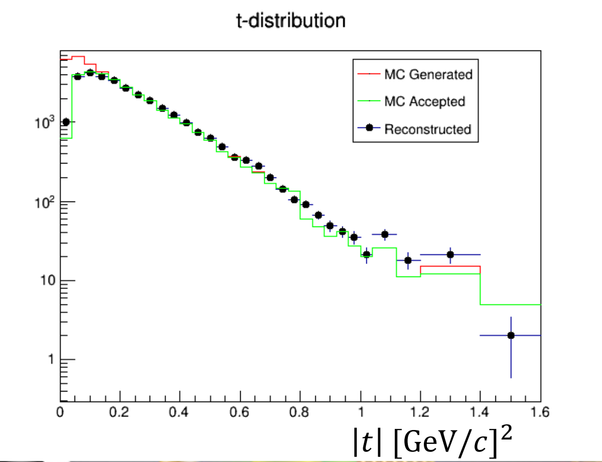
Proton Acceptance Summary

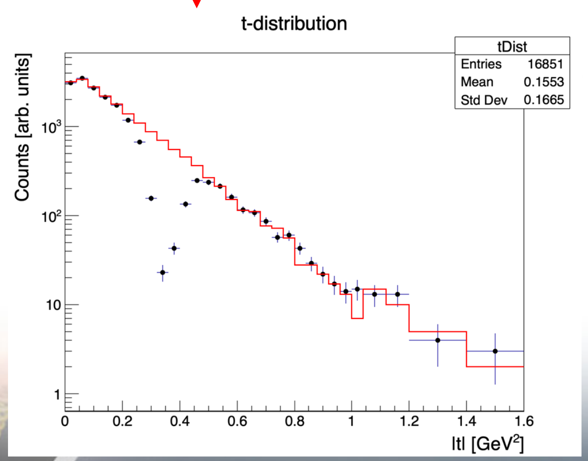
High acceptance only.

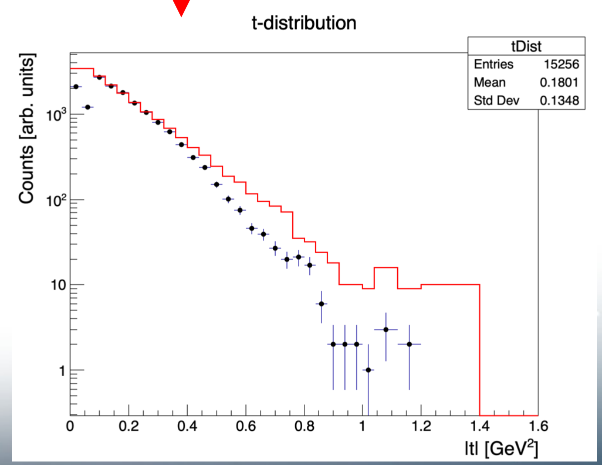








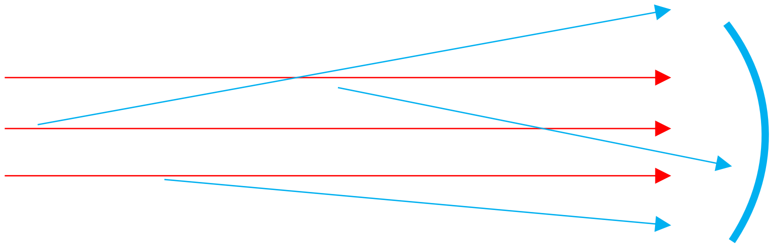




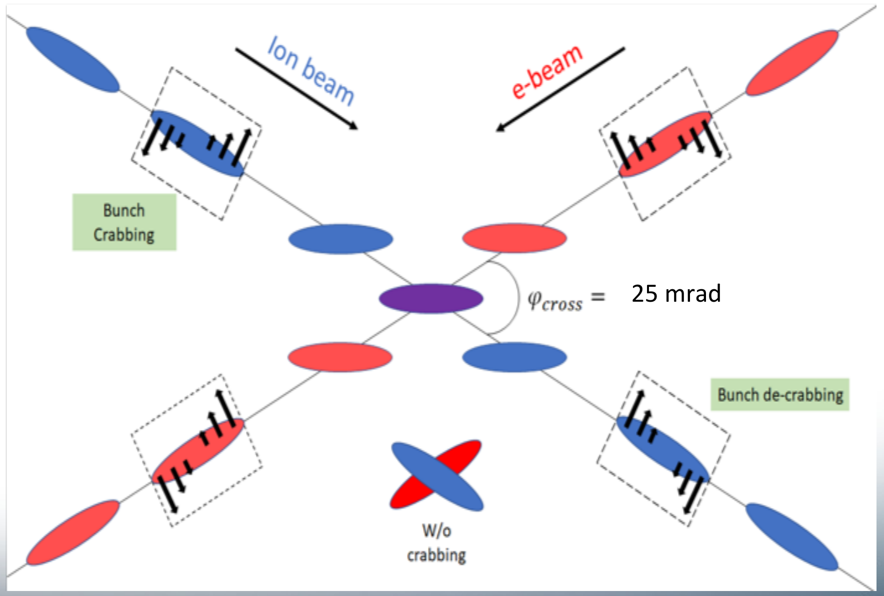
Momentum Resolution

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.



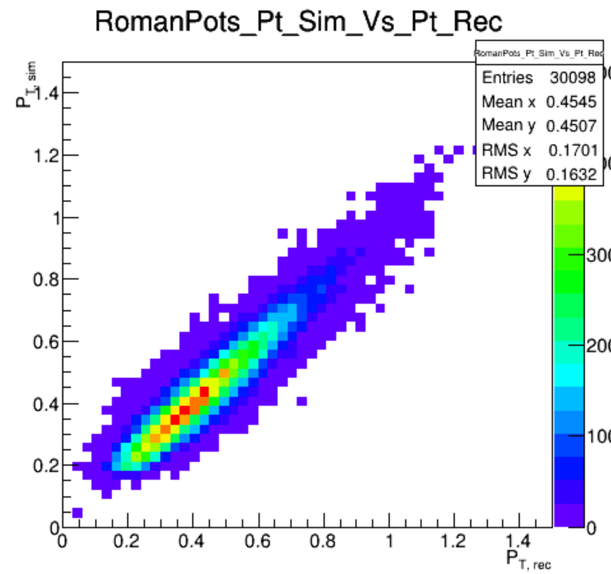
- Crab cavity rotation
  - Can perform rotations of the beam bunches in 2D.
  - Used to account for the luminosity drop due to the crossing angle – allows for head-on collisions to still take place.



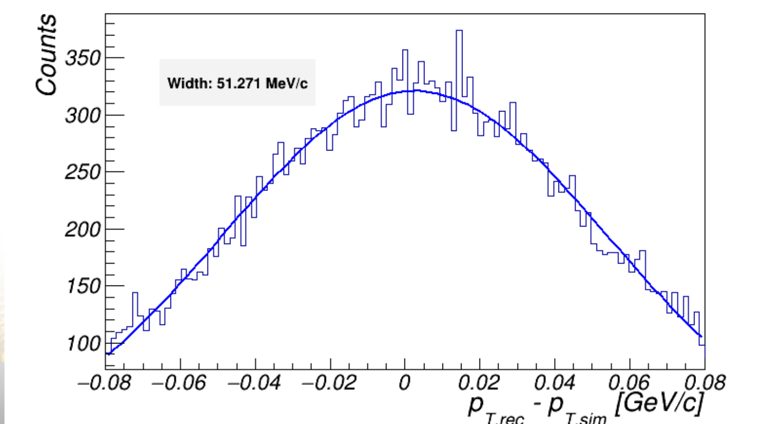
These effects introduce smearing in our momentum reconstruction.

Momentum Resolution – 275 GeV

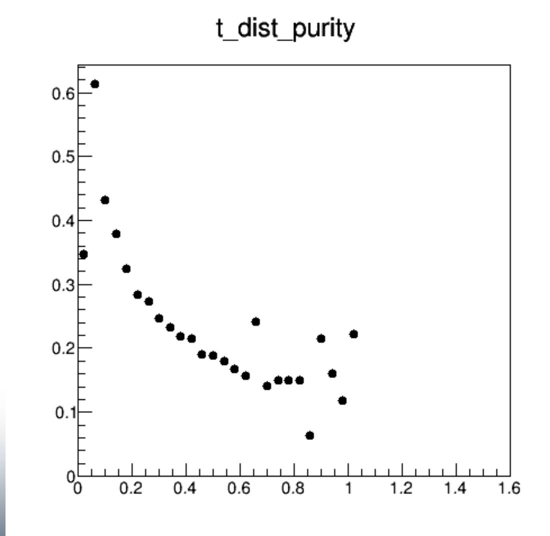
- Beam angular divergence -> $\Delta p_t \sim 40$ MeV/c
- Finite pixel size on sensor -> $\Delta p_t \sim 3$ MeV/c to 25 MeV/c [55um x 55um to 1.3mm x 1.3mm].
- Vertex smearing from crab rotation-> $\Delta p_t \sim 20$ MeV/c – removable with precise (~35ps) timing.



Timing calculated by requiring isolating PV to within 1cm of the 10cm hadron bunch length. timing ~ 1cm/c ~ 35ps



$$purity = \frac{N_{gen} - N_{out}}{N_{gen} - N_{out} + N_{in}}$$



Total (worse-case): $\Delta p_t \sim 50$ MeV/c.

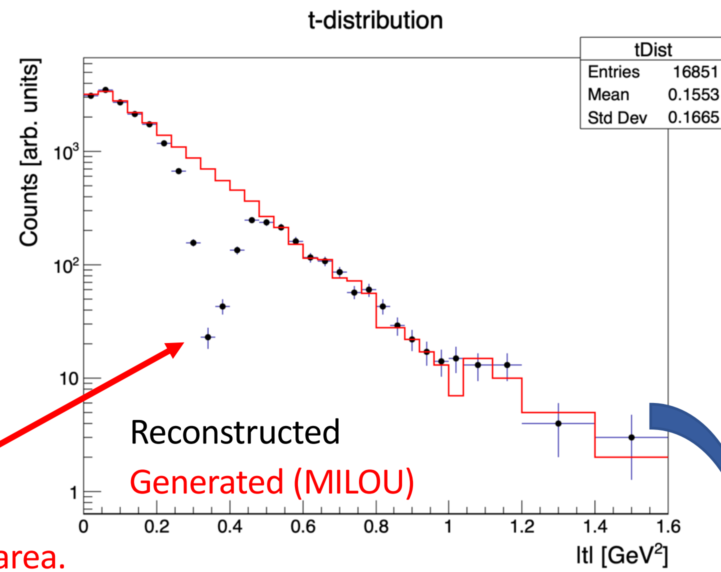
Momentum Resolution – 100 GeV

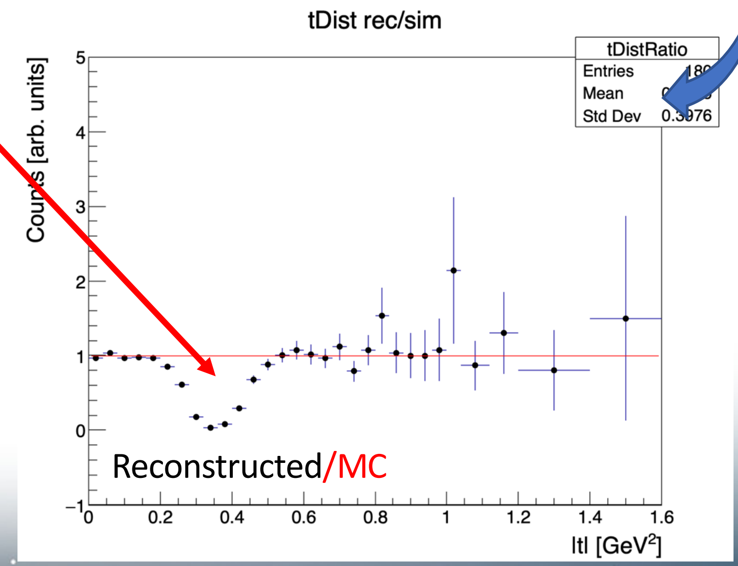
	Ang Div.	20um pxl	55um pxl	500um pxl	Vtx Smear
Roman Pots Δp_t [MeV/c]	22	-	-	10	9
B0 Δp_t [Mev/c]	25	17	38	-	20

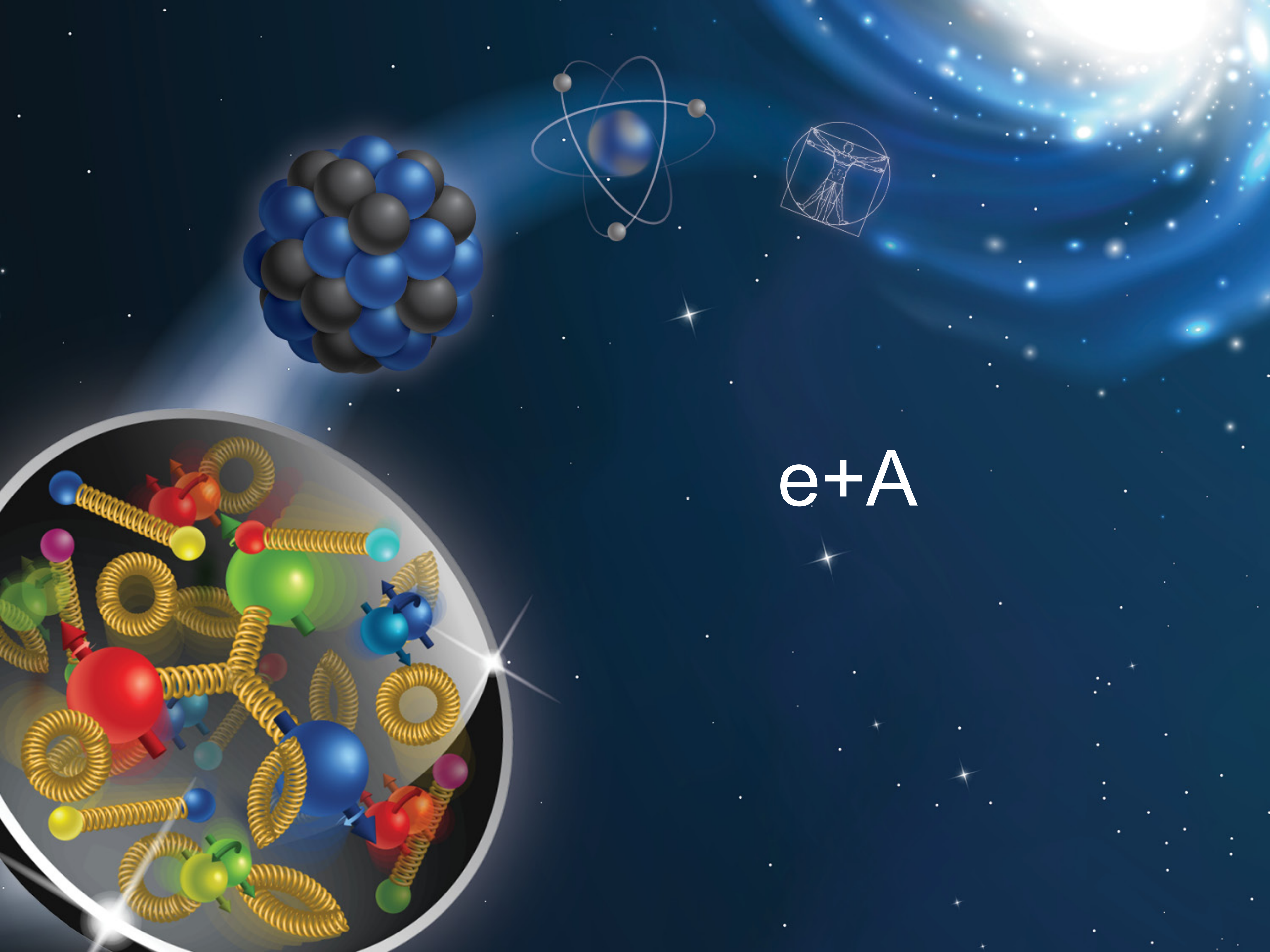
- Total:
  - RP: $\Delta p_t \sim 23$ MeV/c (worst case)
  - B0: $\Delta p_t \sim 26$ MeV/c (20 um pixels)
- |t|-reconstruction requires combined Roman Pots and B0 information.
- Still allows reconstruction of |t|-dist since data points exist on both sides of gap.

Since the angular divergence has a smaller effect on the resolution at this energy, the larger pixels could become a significant impact on the total resolution.

Acceptance “grey” area.

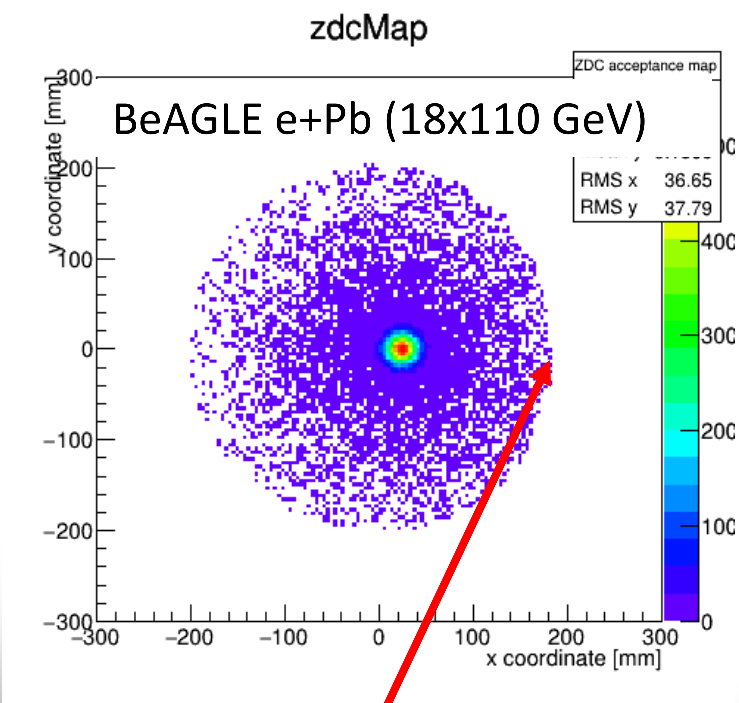




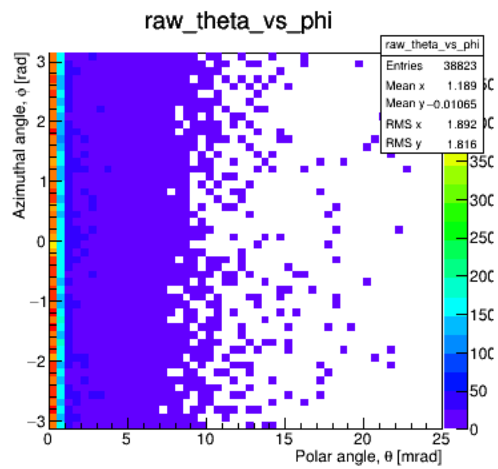

e+A

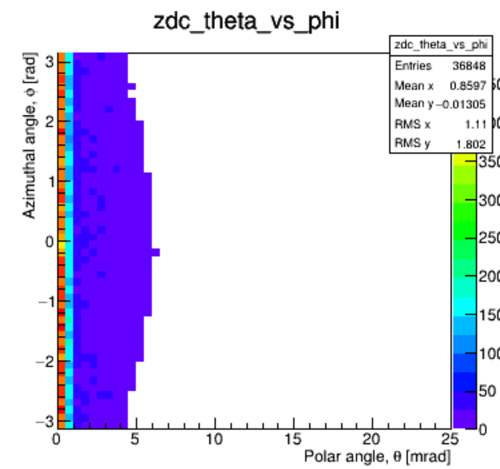
Zero-Degree Calorimeter (ZDC)

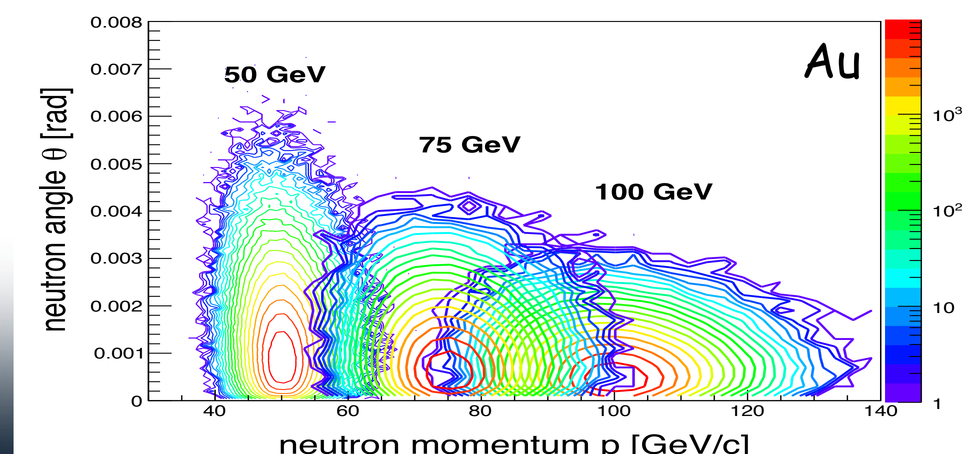
- Used to detect neutrons from incoherent nuclear breakup reactions.
  - Space constraints need to be obeyed.



Neutrons hitting inside of aperture!



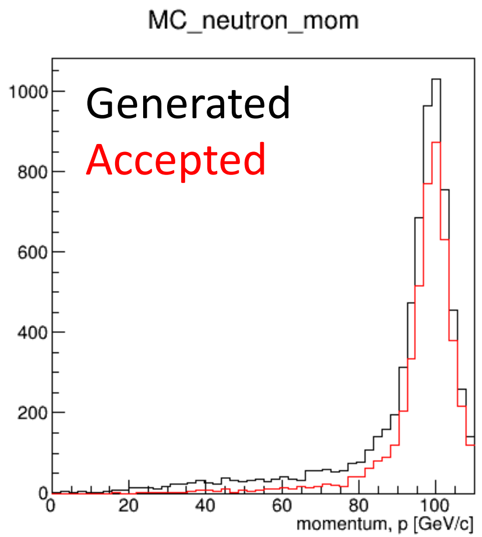


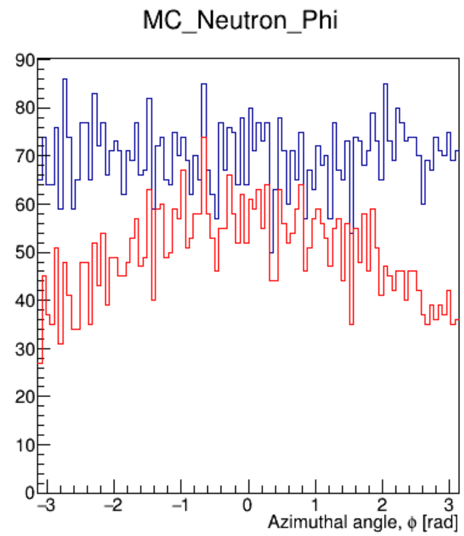


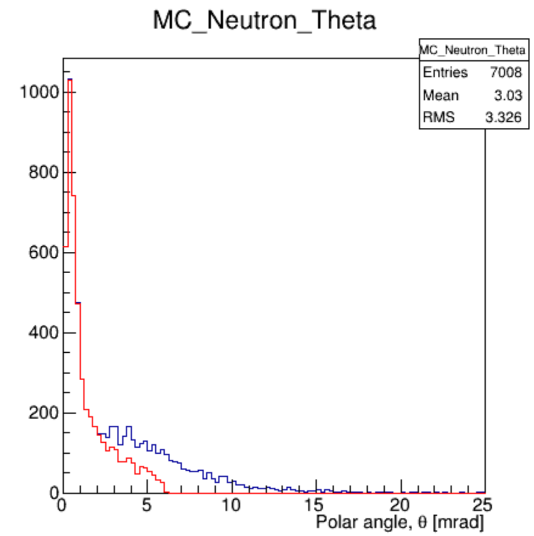
Light Nuclei (e+D)

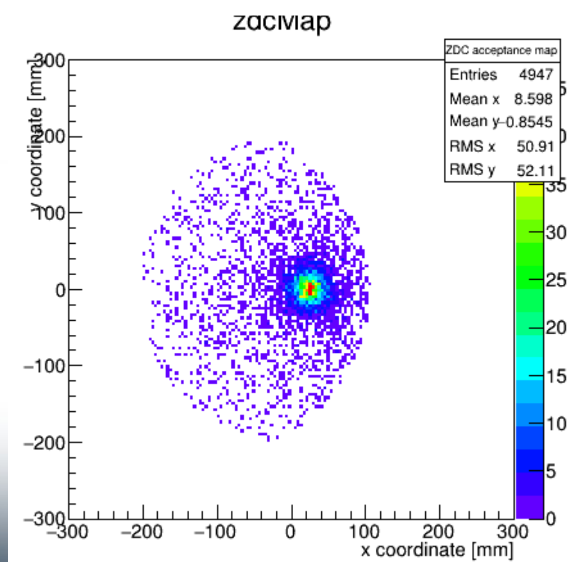
- Acceptance studies are underway for light nuclei.
- BeAGLE is being used for these tests.
  - Many thanks to Mark Baker for the event sample!
- Only one energy right now (18 GeV (e)x100 GeV/n (A)).
- These are preliminary studies – we neglect angular divergence, which has no effect on acceptance (only on momentum resolution).

Light Nuclei(e+D) - Neutrons









- Only neutrons close to beam momentum accepted.
- Aperture limits acceptance to ~ 0-5mrad.

Summary of Simulation Findings

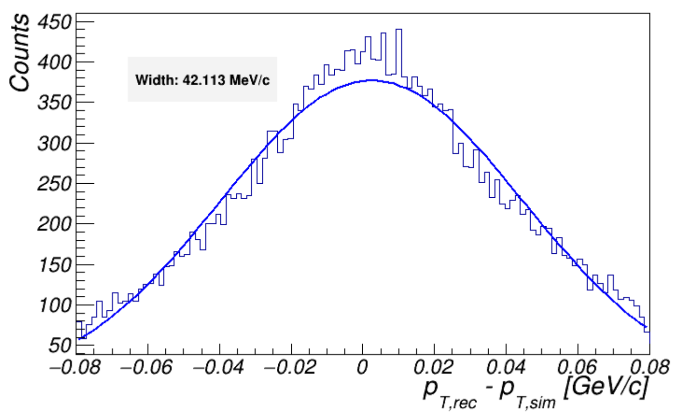
- The EIC Roman Pots will require an *active sensor area of ~25cm x 10cm.*
- The beam angular divergence sets the lower bound for achievable smearing – *other controllable effects should be kept well-below contribution from divergence.*
- Having precise timing ~35ps allows for precise determination of z-position of collision relative to the center of the bunch.
- The B0 sensors will need to have much smaller pixels than the Roman Pots.

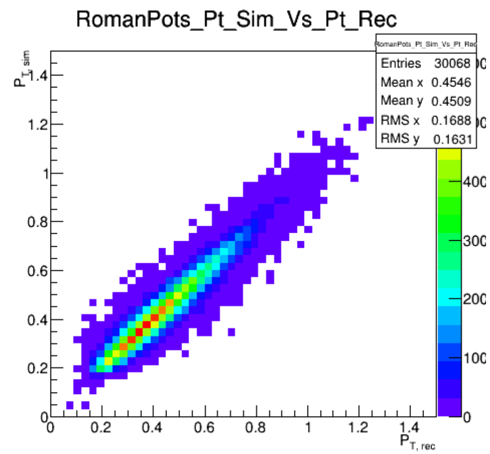
Next Steps

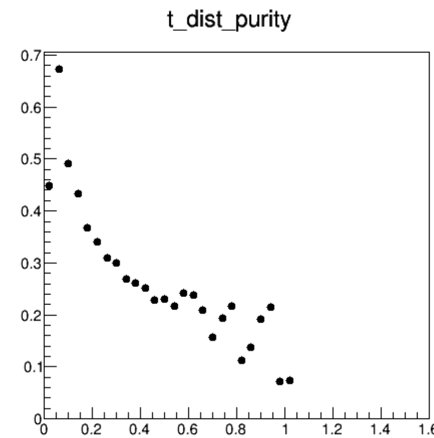
- Study of beam+gas backgrounds and beam+machine backgrounds. (ongoing)
  - Still need vacuum system design for the simulations to be credible.
- Still need to study many processes in detail.
  - e+A exclusive events (e.g. DVCS with light nuclei)
    - No MCEG for this?
  - e+A nuclear breakup with extra sensors for dp/p ~ 40% (started – ongoing)
- There is much more to do!

Comparison of 500um and 1.3mm pixels

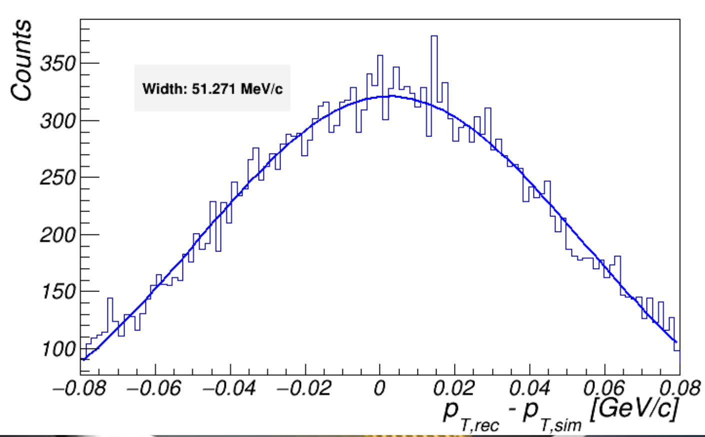
500um x 500um

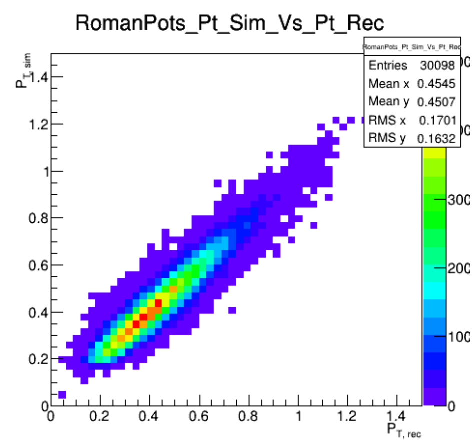


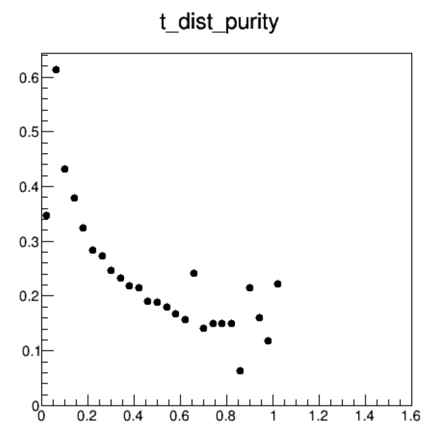




1.3mm x 1.3mm







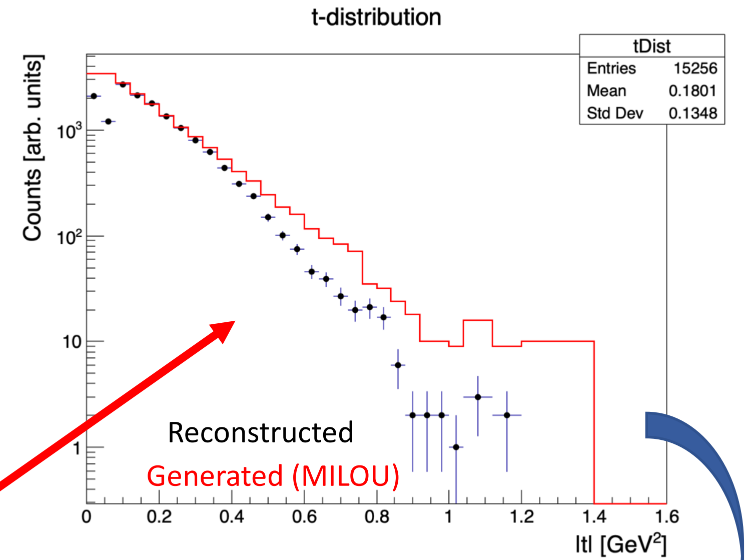
Momentum Resolution – 41 GeV

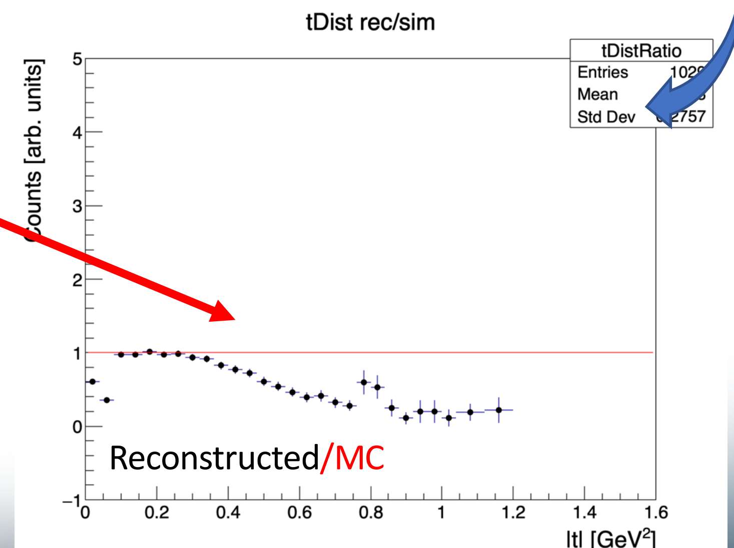
	Ang Div.	20um pxl	55um pxl	500um pxl	Vtx Smear
Roman Pots Δp_t [MeV/c]	14	N/A	N/A	10	10
B0 Δp_t [Mev/c]	17	13	25	N/A	10

- Total:
  - RP: $\Delta p_t \sim$ 15 MeV/c (worse case)
  - B0: $\Delta p_t \sim$ 18 MeV/c (20um pixels)
- |t|-reconstruction requires B0 for majority of reconstruction.

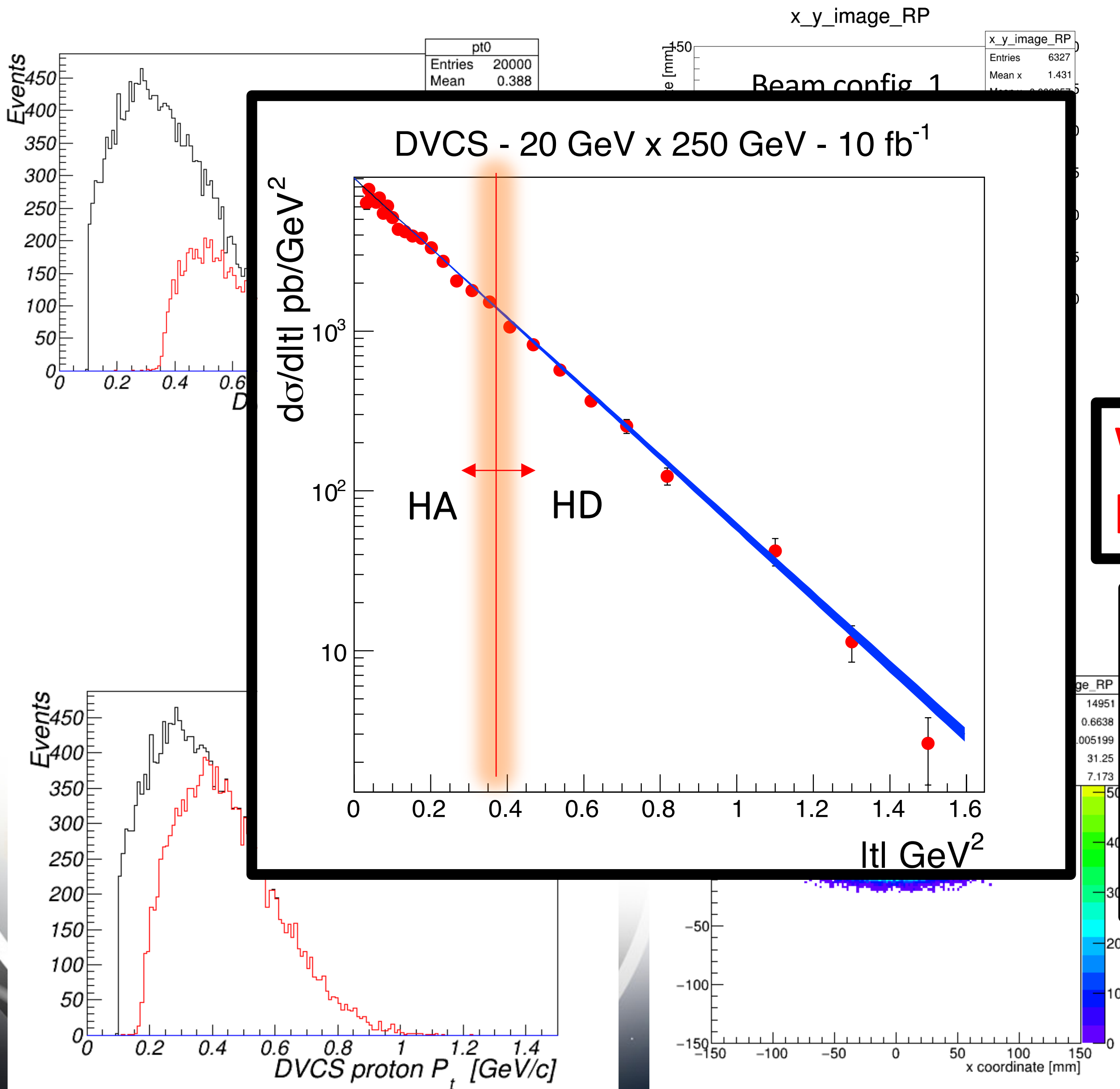
Some acceptance issues.
Optimization of B0 sensor layout in GEANT ongoing.

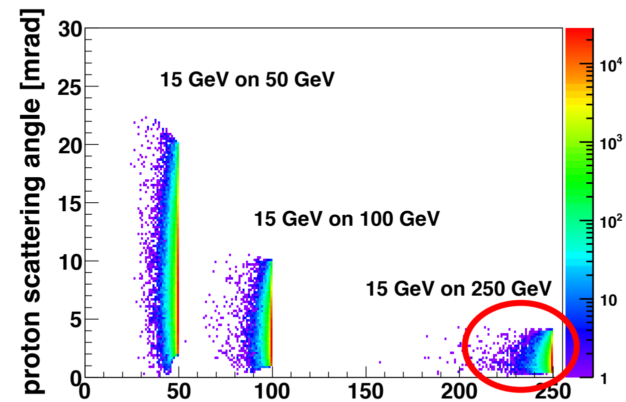
Still need to optimize the location of the detectors.





275 GeV DVCS Proton Acceptance





Why two different beam configurations?

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