Update on EIC 2nd detector study with Far-Forward Acceptance and Vetoing Efficiency

Jihee Kim (jkim11@bnl.gov)

2023/12/05

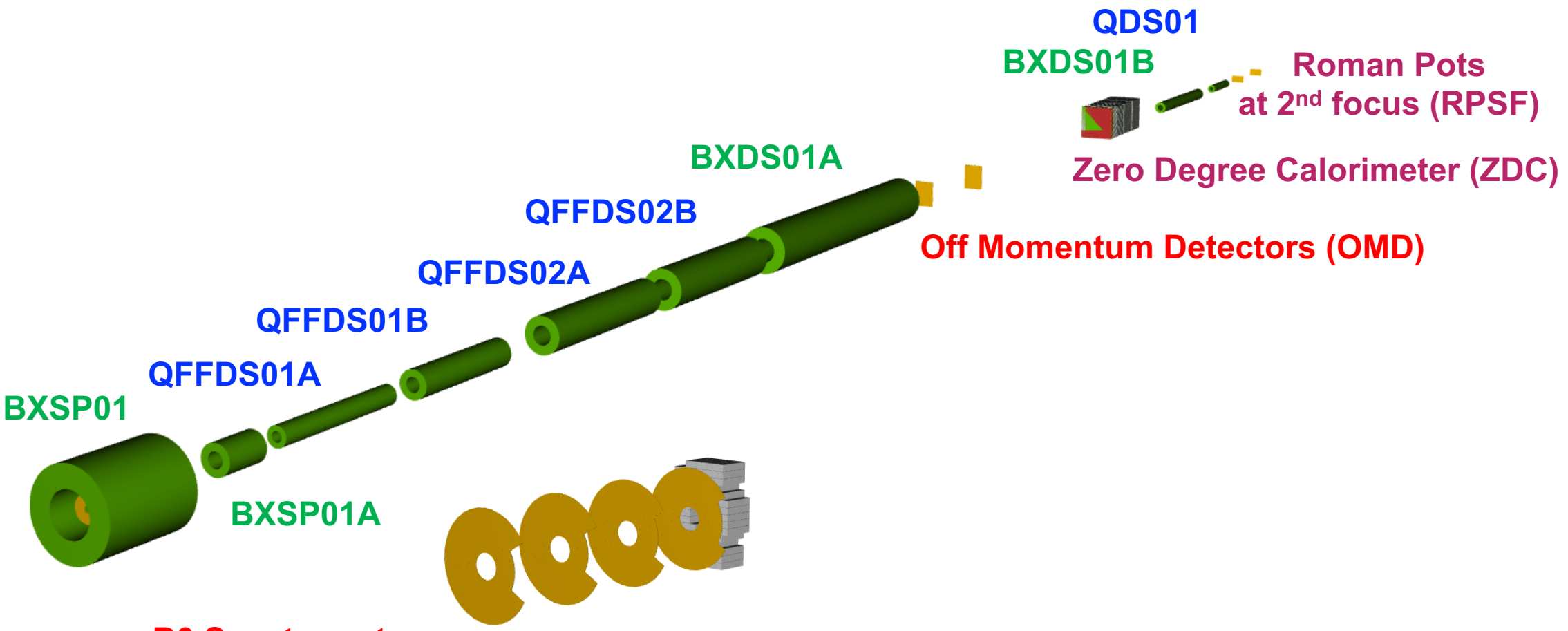
Introduction

- One of golden channels for EIC Detector-2 LDRD program
  - Study exclusive processes to access transverse spatial structure and fluctuations of gluons in target
  - Experimentally, measured spectra in vector meson production contain sum of coherent and incoherent process
  - Separate coherent and incoherent processes
    - By tagging nuclear fragments using far-forward detectors, understand background of coherent vector meson productions (ex. J/ψ)
- Looking into more details on
  - Far-forward detector acceptance
  - pT acceptance of scattered protons
  - Vetoing efficiency for incoherent events

IP-8 Far-Forward Layout

pre-conceptual design

Implemented in **IP-8 Forward Hadron Lattice** and IP-6 detector configuration



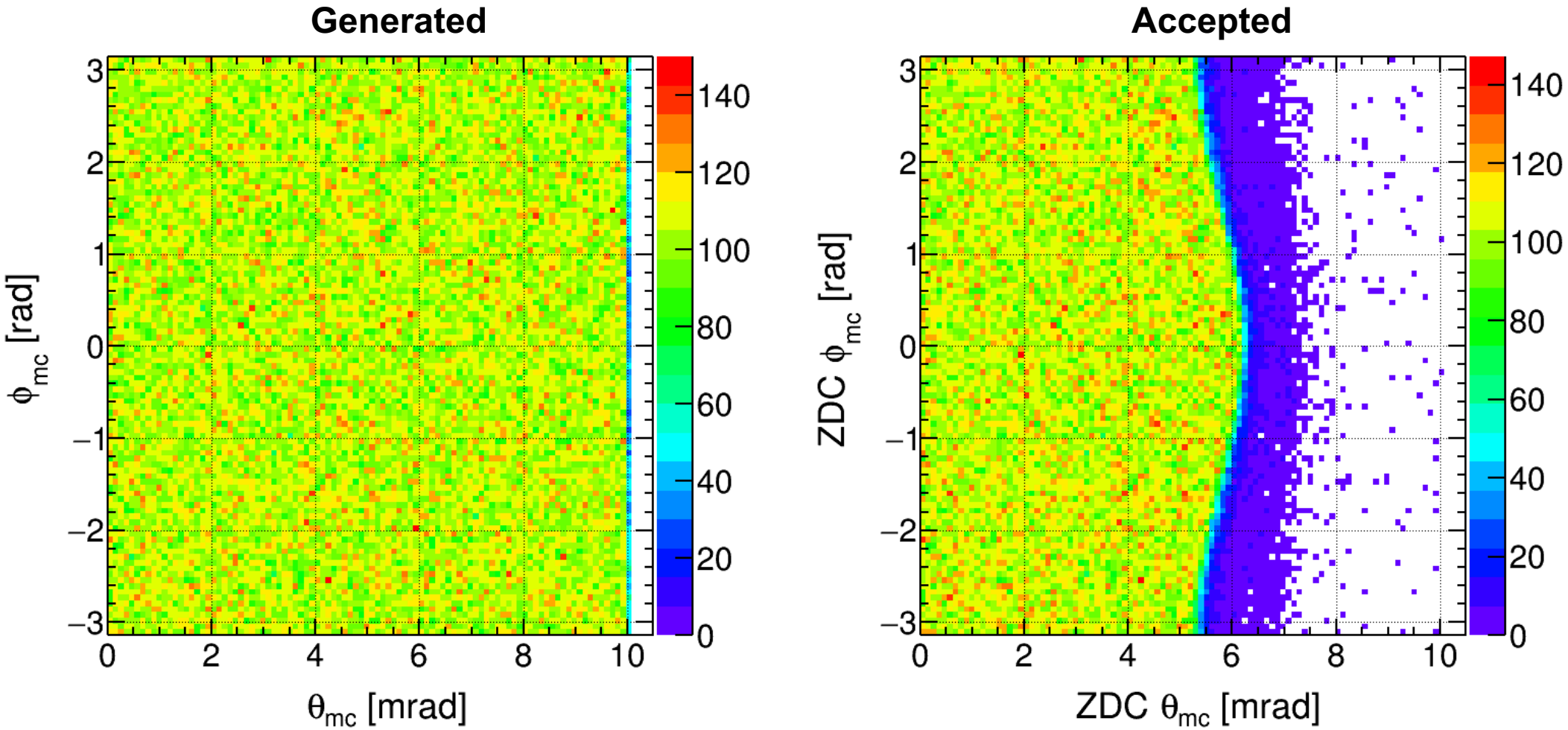
References from https://wiki.bnl.gov/eic-detector-2/images/d/de/IR8_magnet_layout_12052022.xlsx
https://wiki.bnl.gov/eic-detector-2/images/8/86/IP8_HSR_lattice_performance_10_13_22_v3.pdf

Approach – Detector Acceptance

- **Far-Forward region**
  - Particles with $\boldsymbol{\theta}$ **< ~ 37 mrad (2.1°)**
  - **Tag charged hadrons** (protons) or **neutral particles** (neutrons, photons)
  - IP8 has larger crossing angle (35 mrad) and secondary focus far downstream
- **Single particle simulation**
  - **B0 Tracker + Calorimeter** for detecting protons and photons
    - Proton energy: 80 GeV < E_p < 120 GeV and **5 < $\boldsymbol{\theta}_{MC}$ < 20 mrad**
  - **Off-Momentum Detector** for detecting protons from nuclear breakup
    - Proton energy: 123.75 GeV (45%) < E_p < 151.25 GeV (55%) and **0 < $\boldsymbol{\theta}_{MC}$ < 5 mrad**
  - **Zero Degree Calorimeter** for detecting photons and neutrons
    - Neutron energy: E_n = 275 GeV (***$\boldsymbol{\theta}_{MC}$ < 10 mrad**)
  - **Roman Pot at Secondary Focus** for detecting charged particles from nuclear breakup
    - Proton energy: E_p = 275 GeV and **0 < $\boldsymbol{\theta}_{MC}$ < 5 mrad**

Zero Degree Calorimeter

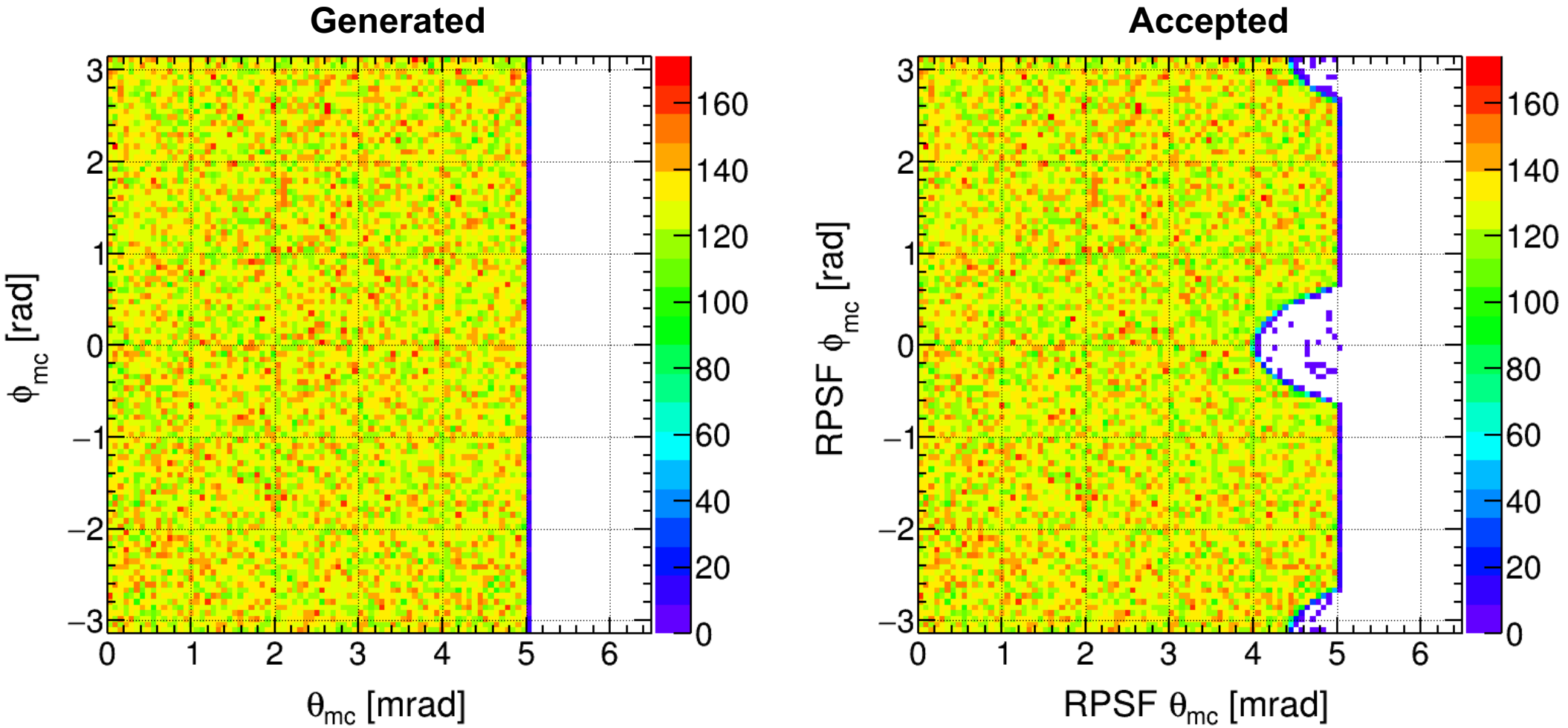
Single Neutron
E = 275 GeV
$0 < \theta_{MC} < 10$ mrad



About 99.98 % events were accepted (θ_{MC} upto 5 mrad)

Roman Pots at Secondary Focus

Single Proton
E = 275 GeV
$0 < \theta_{MC} < 5$ mrad



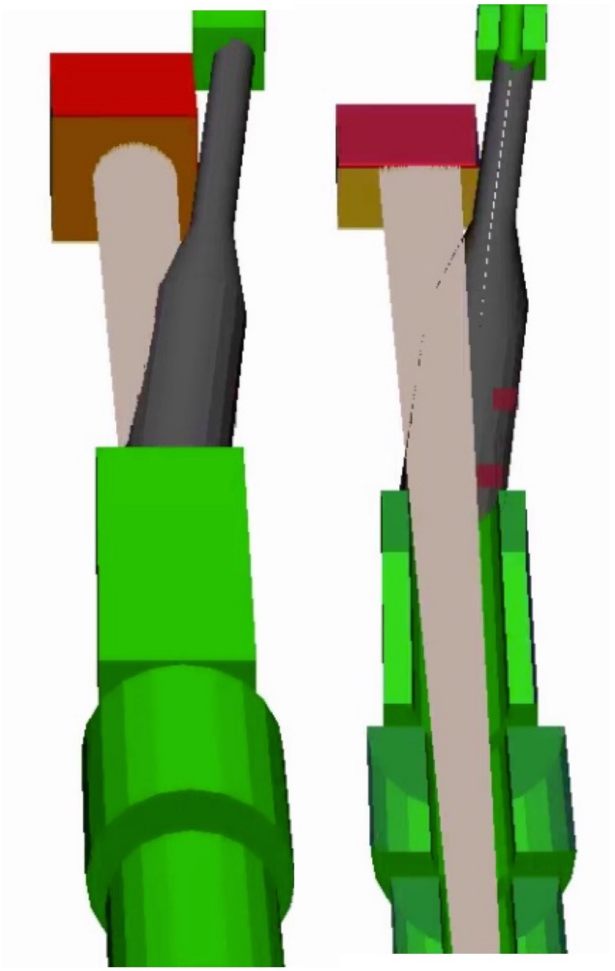
About 95.4 % events were accepted and observed losses at higher theta (polar angle)
Clipping occurs in quadrupoles for protons

Clipping on Acceptance of Far-Forward

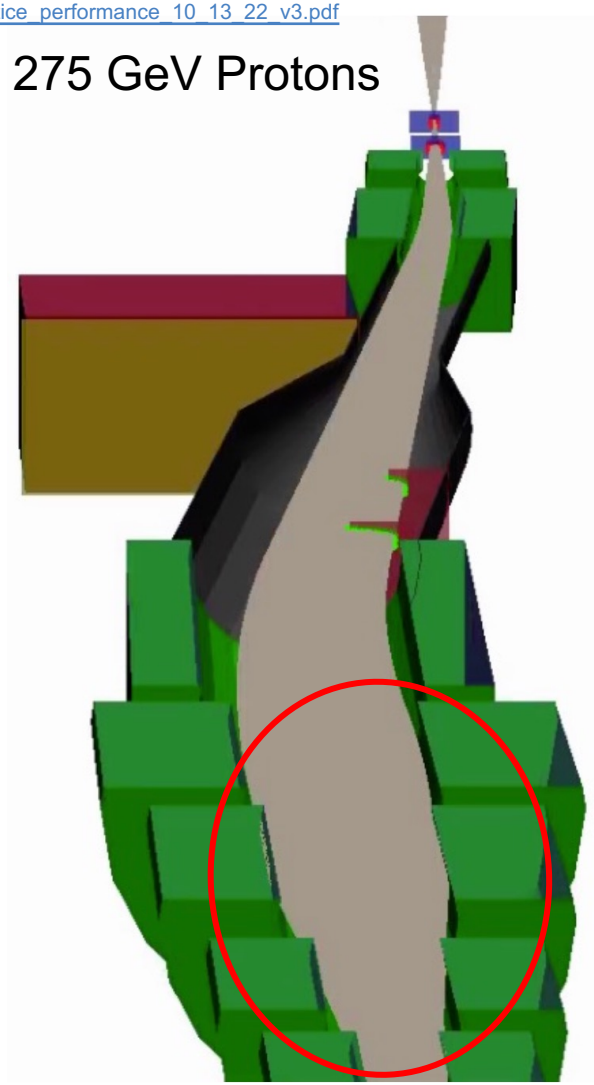
Kindly Provided by Alex Jentsch using EicRoot Simulation Event Display

Reference from https://wiki.bnl.gov/eic-detector-2/images/8/86/IP8_HSR_lattice_performance_10_13_22_v3.pdf

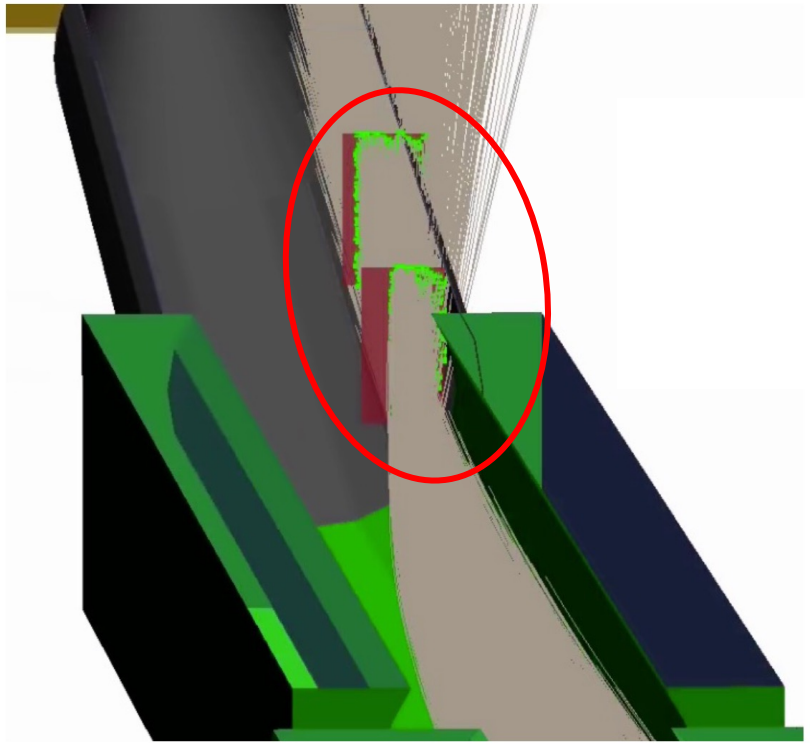
275 GeV Neutrons



275 GeV Protons



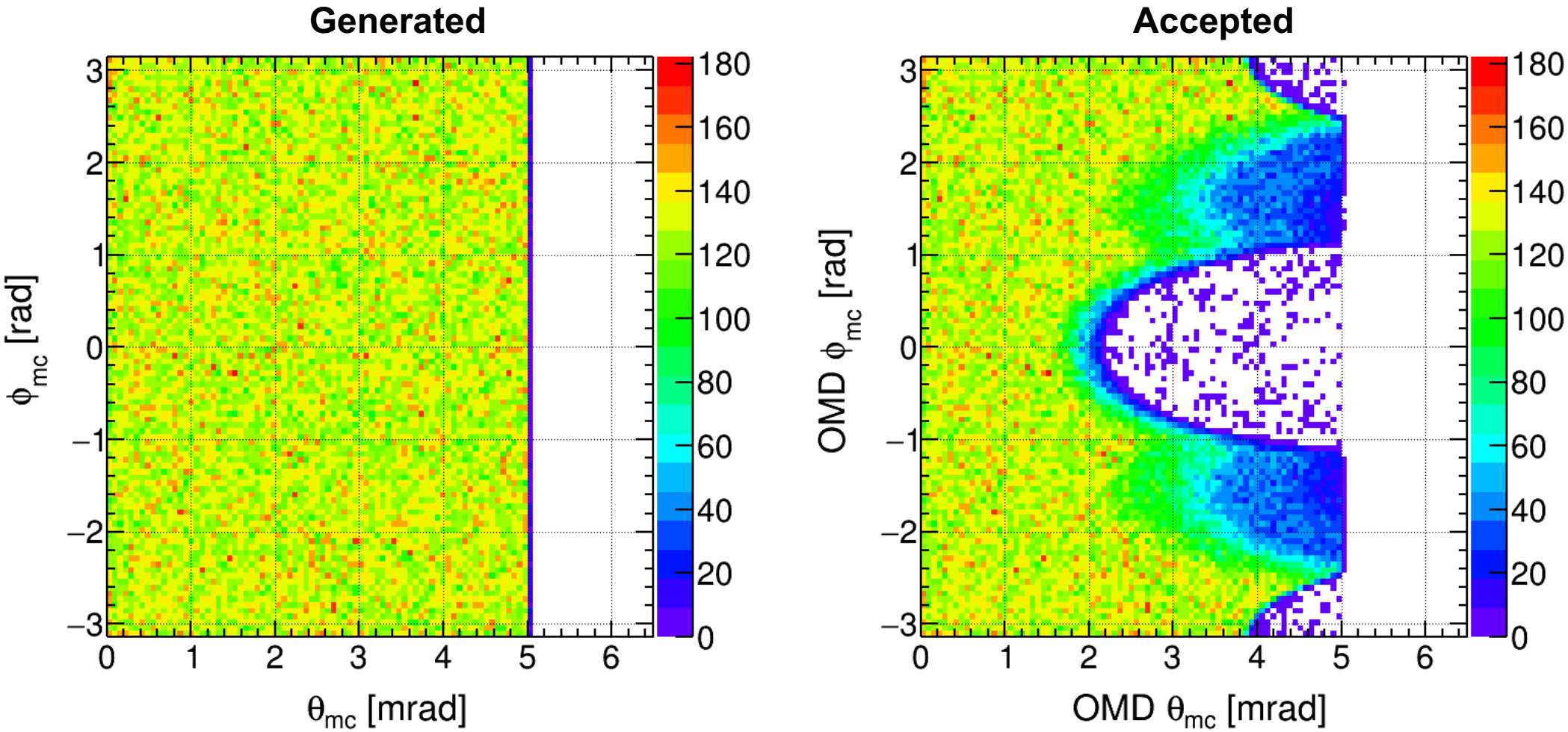
123.75 – 151.25 GeV Protons



DD4hep simulation event display was not successful…

Off Momentum Detectors

Single Proton
123.75 GeV (45%) < E < 151.25 GeV (55%)
$0 < \theta_{MC} < 5$ mrad

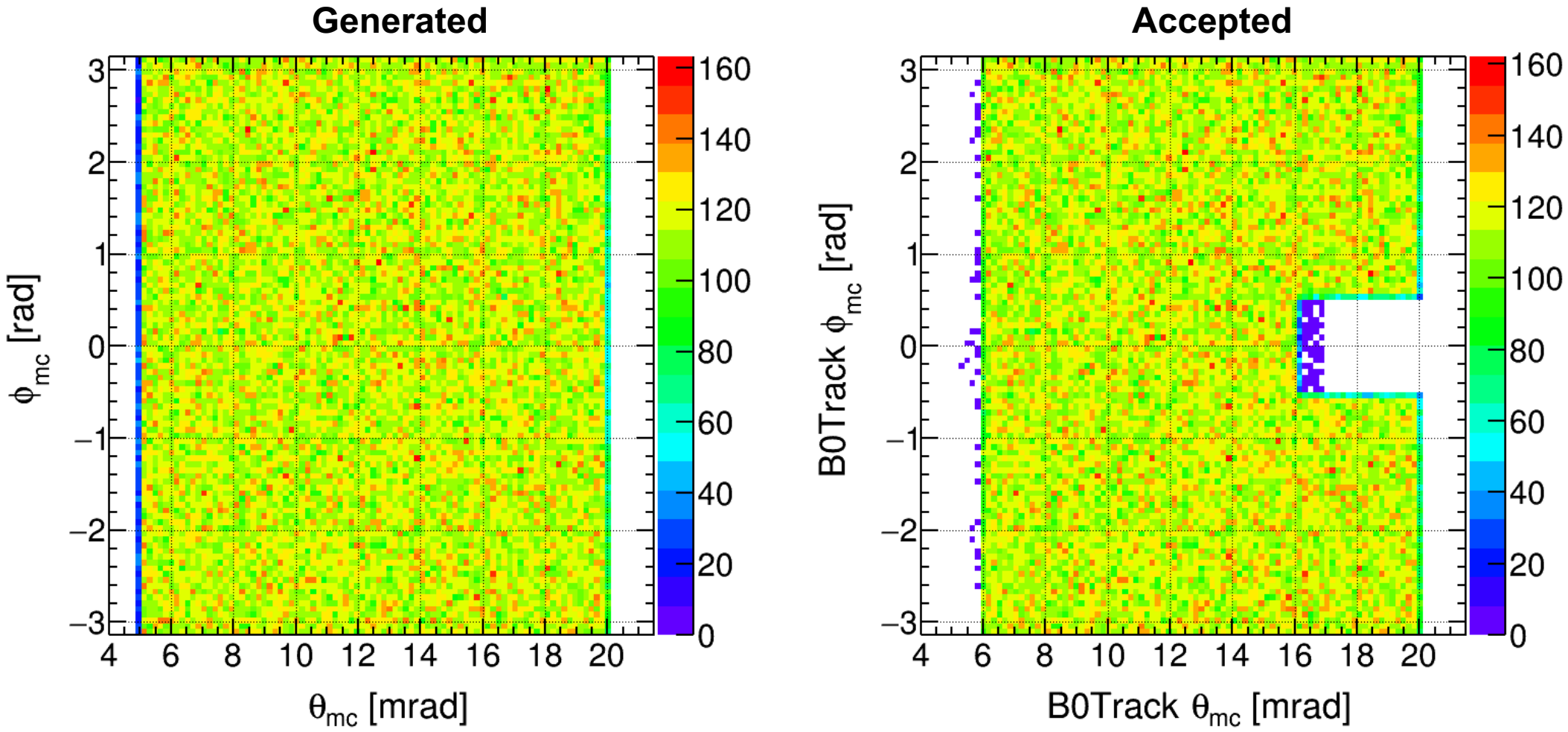


About 67.42 % events were accepted

Hadron lattice in simulation set to be 275 GeV proton and clipping occurs in quadrupoles for protons

B0 Tracker

Single Proton
80 GeV < E < 120 GeV
5 < θ_{MC} < 20 mrad



About **88.94 (93.6) %** events were **accepted requiring four layers (more than two layers)**

Approach – pT Acceptance

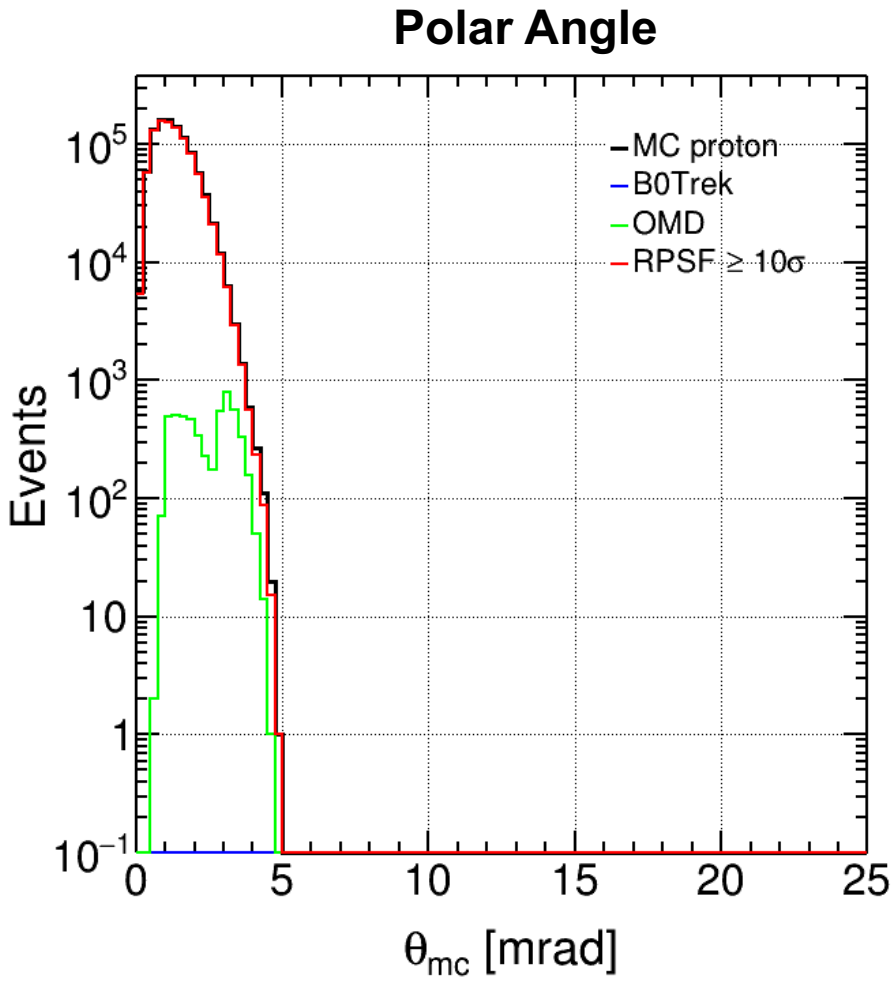
- By **tagging final-state proton**, it directly connects to **momentum transfer, t, measurement**
  - Investigate **low pT acceptance cutoffs**
- Used simulated **ep DVCS 1M** events each
  - Three beam energy combinations: ep 18×275, 10×100, and 5×41 GeV^2
    - S3/eictest/EPIC/EVGEN/EXCLUSIVE/DVCS/18x275/DVCS.3.18x275.hepmc
    - S3/eictest/EPIC/EVGEN/EXCLUSIVE/DVCS/10x100/DVCS.1.10x100.hepmc
    - S3/eictest/EPIC/EVGEN/EXCLUSIVE/DVCS/5x41/DVCS.2.5x41.hepmc
- Passed through **afterburner IP8 ep high divergence** configuration
  - IP8 crossing angle (35 mrad) and IP6 ep high divergence beam effects based on **EIC CDR table 3.3**
- **Accepted events for scattered protons *reconstruction purpose***
  - B0 tracker: **all four layers** have hits
  - OMD: **two layers** (actual four layers as redundancy) have hits
  - RPSF: **two layers** have hits > 10σ safe distance based on ***ep β @ IP6 interaction point (z = 0)***

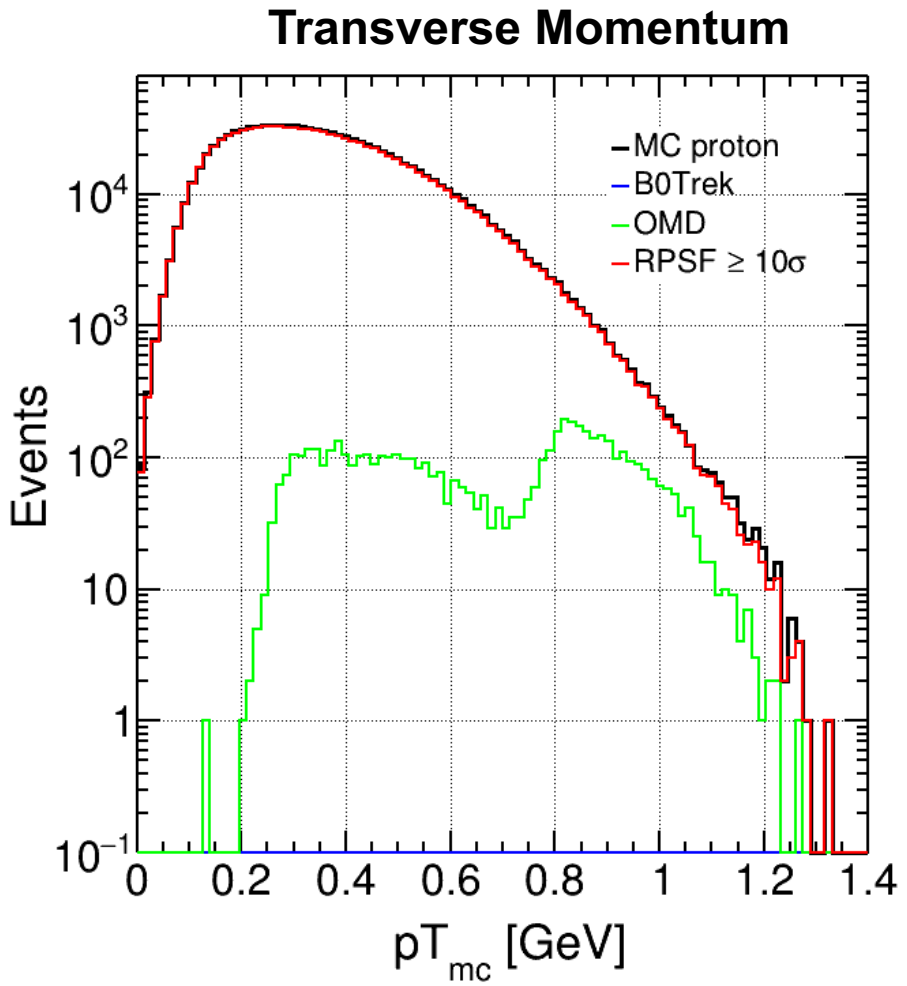
W/O Beampipe at B0

DVCS 18 GeV on 275 GeV

Log Scale

*Each histogram fills individually





MC
B0
OMD
RPSF

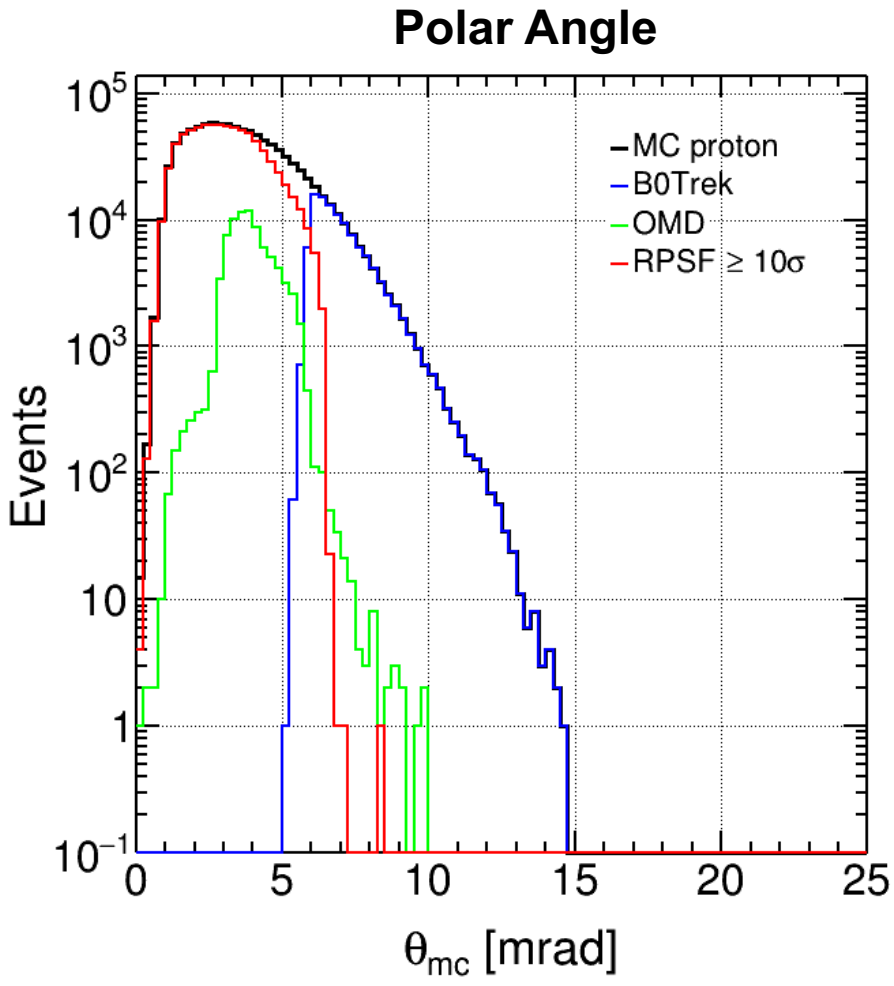
Scattered protons are very forward (< 5 mrad), measured in **Roman Pot at secondary focus** (**96.77 % events accepted** with 10σ safe distance cut based on **ep β @ IP6* (= IP8*)**)

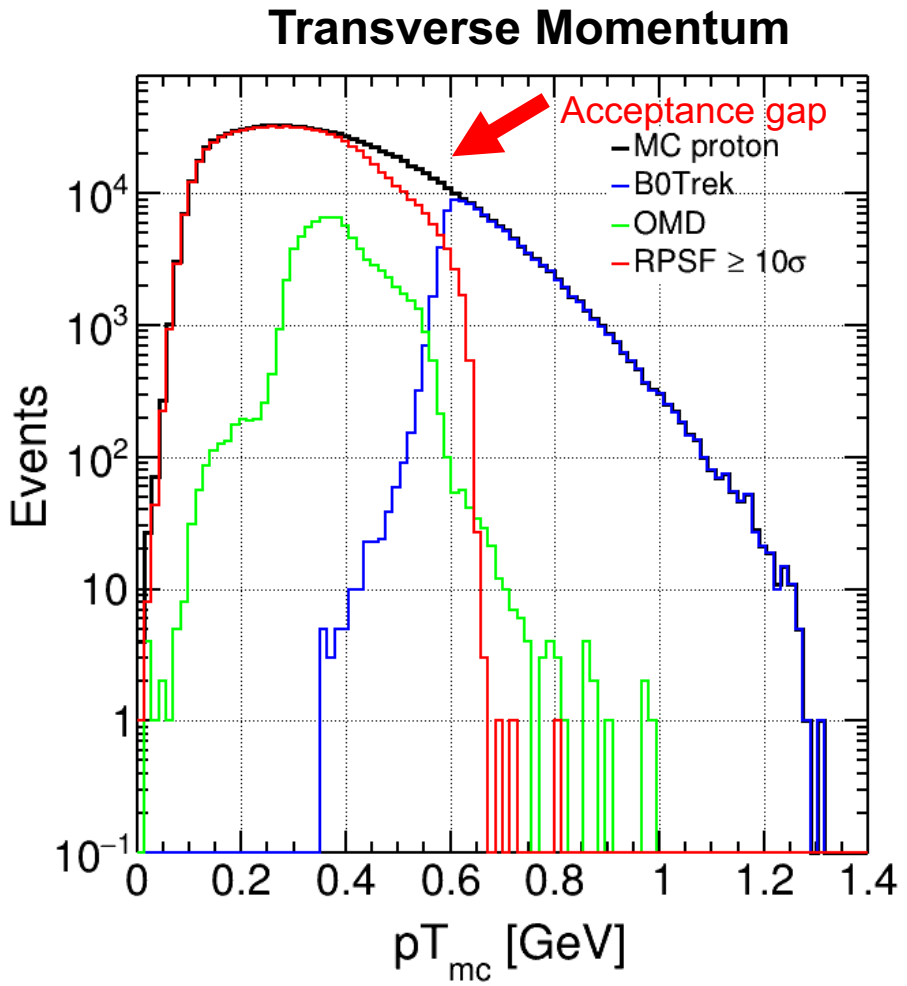
W/O Beampipe at B0

DVCS 10 GeV on 100 GeV

Log Scale

*Each histogram fills individually





MC
B0
OMD
RPSF

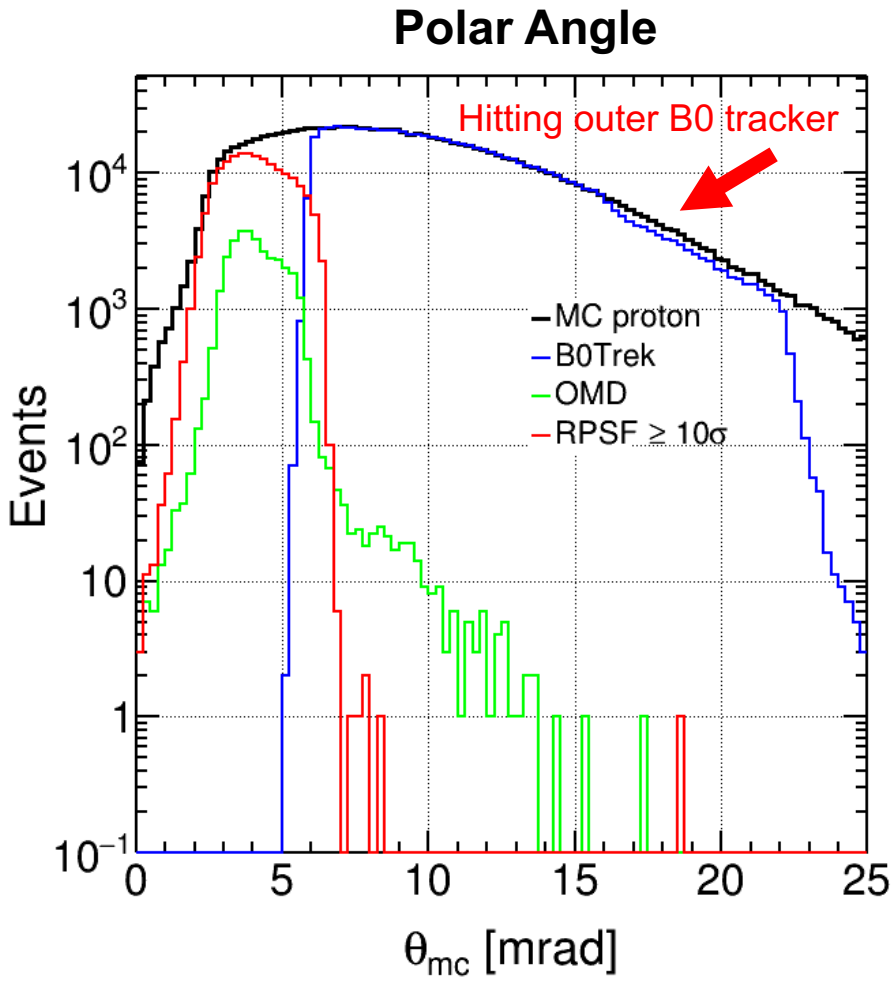
Scattered protons measured in **both B0 and *Roman Pot at secondary focus**
(**10.89 % and 79.46 % events accepted** with 10σ safe distance cut based on **ep β @ IP6* (= IP8*)**)

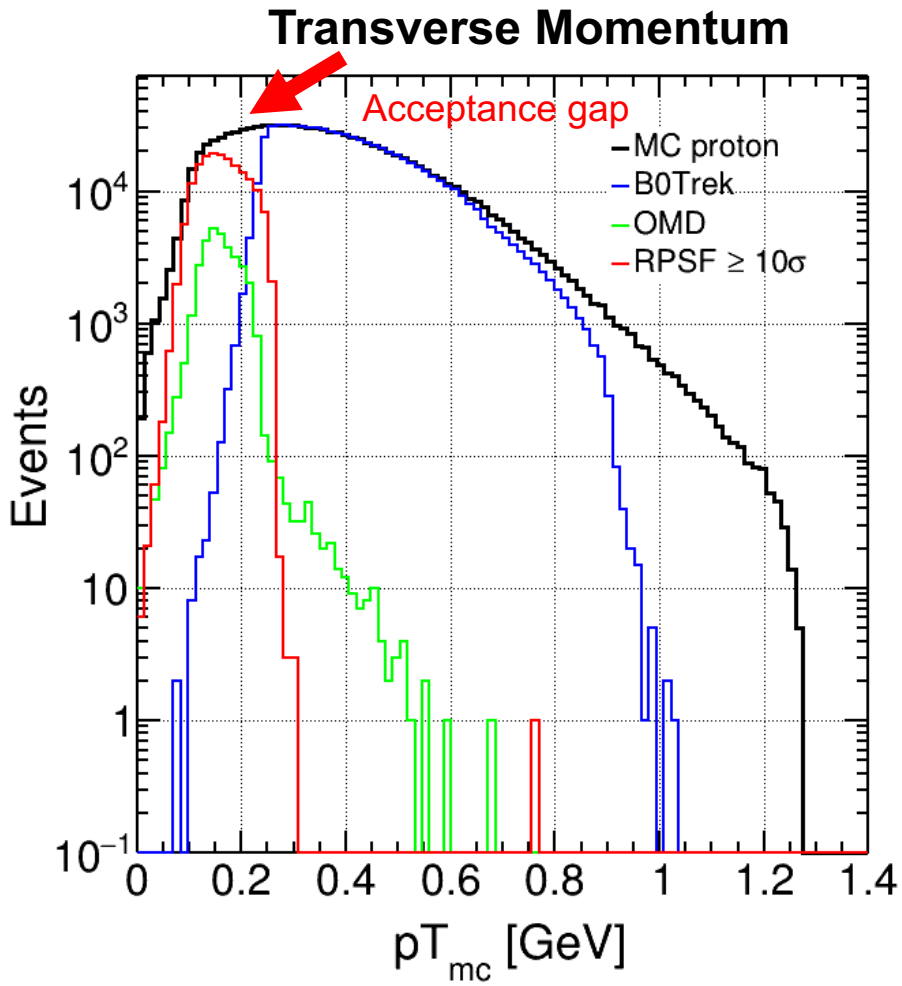
W/O Beampipe at B0

DVCS 5 GeV on 41 GeV

Log Scale

*Each histogram fills individually





MC
B0
OMD
RPSF

Scattered protons measured in **both *B0 and Roman Pot at secondary focus**
(**70.62 % and 17.00 % events accepted** with 10σ safe distance cut based on **ep β @ IP6* (= IP8*)**)

Approach – Beampipe Impact Study at B0

- How to estimate beampipe size: **15(20)σ-distance** based on **IP6 beam parameters**
  - **Transverse beam size (σ)** is defined as

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

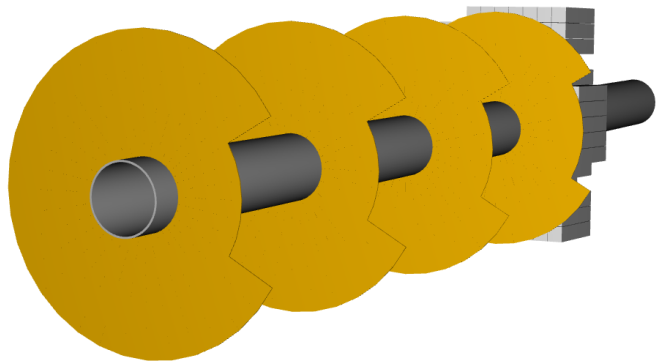
where ϵ : Emittance at z=0, $\boldsymbol{\beta}$ **: Beta function at z=B0** , D : Momentum dispersion at z=B0, $\frac{\Delta p}{p}$: Momentum spread at z=0

18 GeV on 275 GeV	σ_{1x} [mm] σ_{1y} [mm]	σ_{15x} [mm] σ_{15y} [mm]	σ_{20x} [mm] σ_{20y} [mm]
IP6 ep High Divergence	0.96747121 0.95916659	**14.512068** **14.387499**	**19.349424** **19.183332**

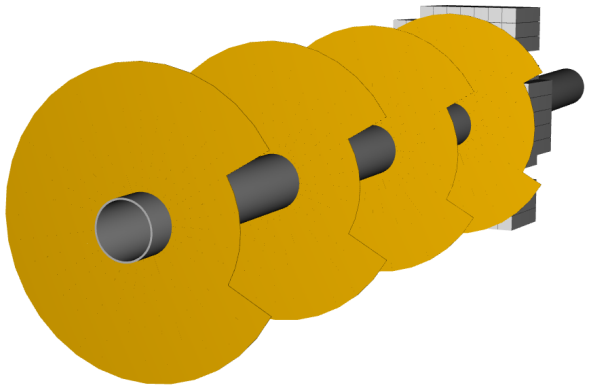
18 GeV on 110 GeV	σ_{1x} [mm] σ_{1y} [mm]	σ_{15x} [mm] σ_{15y} [mm]	σ_{20x} [mm] σ_{20y} [mm]
IP6 eAu	1.4987997 1.8261984	**22.481996** **27.392976**	**29.975994** **36.523968**

Beampipe thickness = 2 mm
Beampipe material = Beryllium

$r_{B0\ tracker\ inner}$ = 3.5 cm



$r_{B0\ tracker\ inner}$ = 3.0 cm

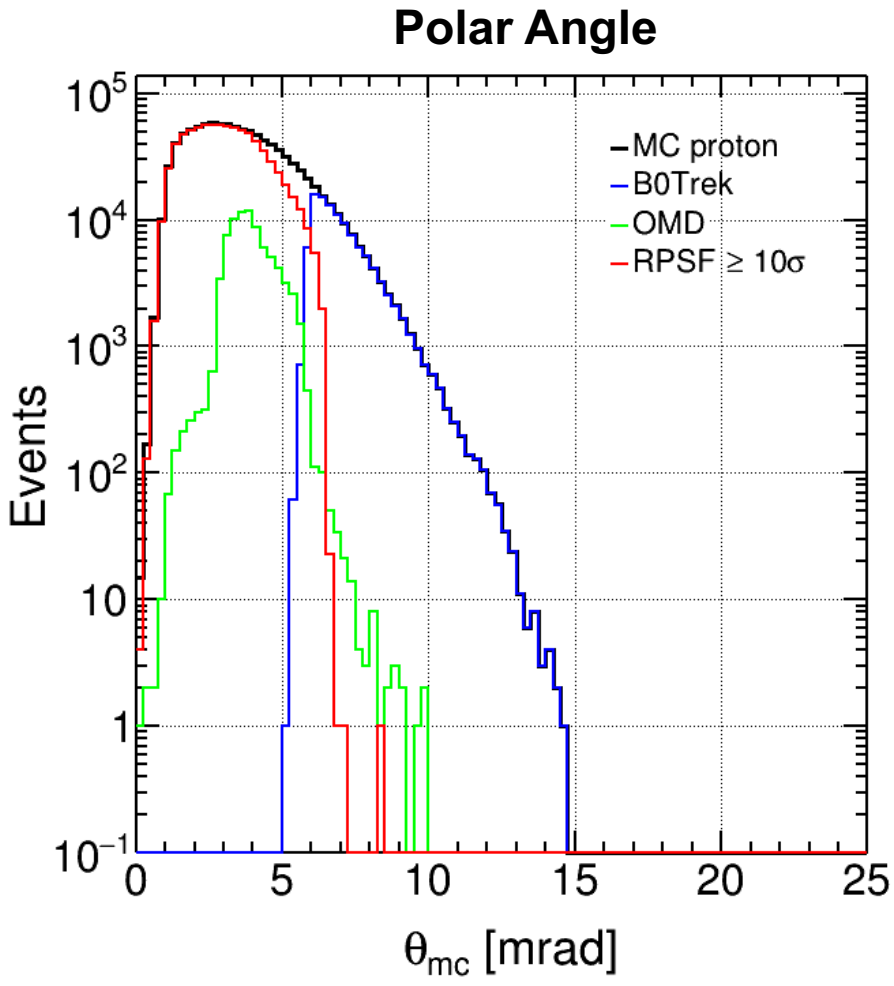


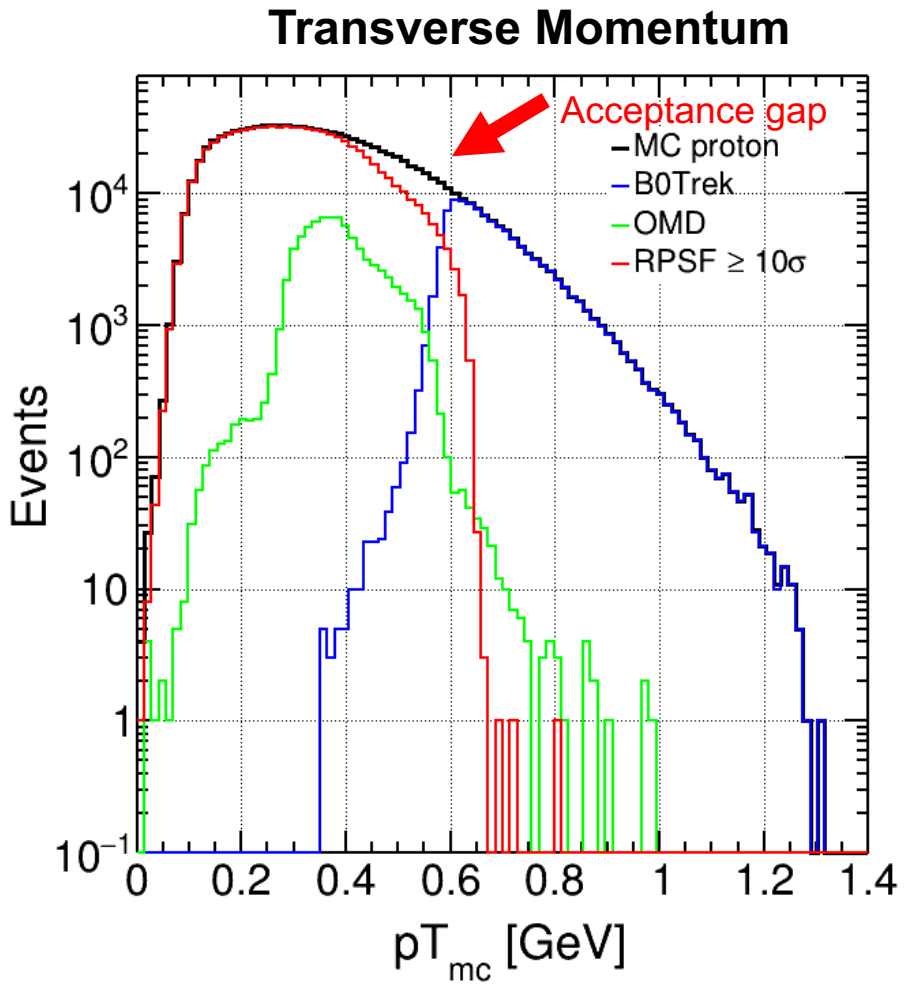
W/O Beampipe at B0

DVCS 10 GeV on 100 GeV

Log Scale

*Each histogram fills individually





MC
B0
OMD
RPSF

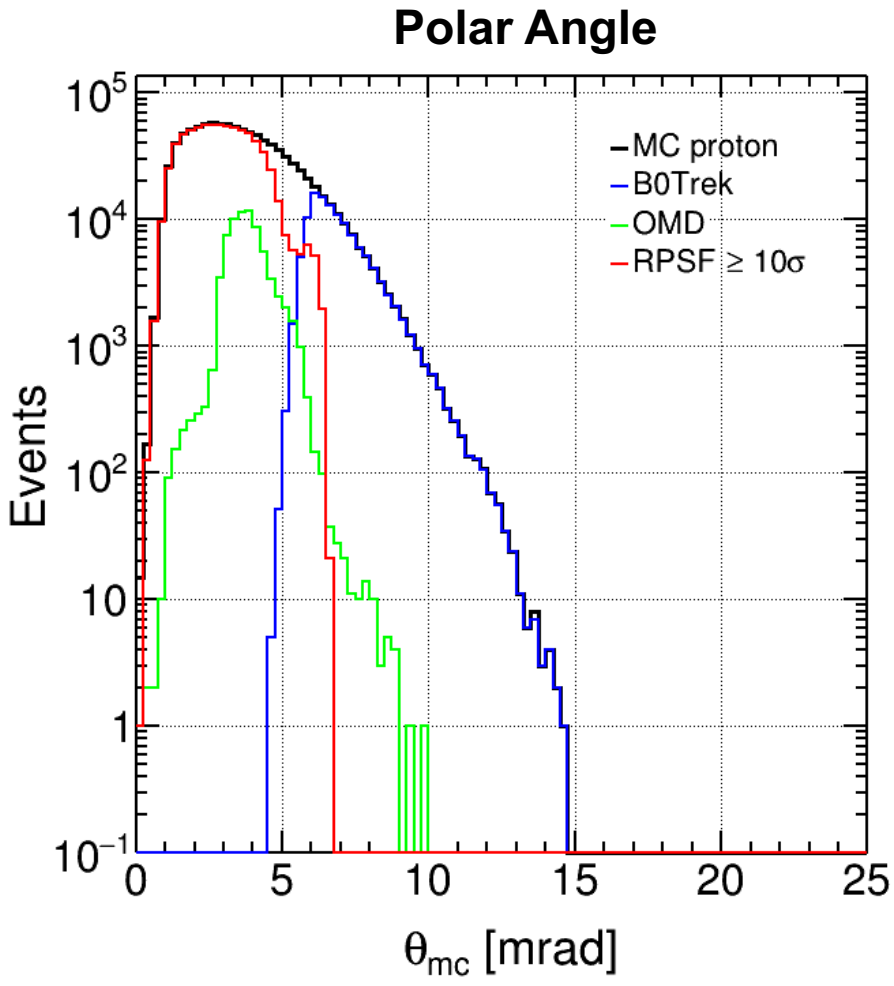
Scattered protons measured in **both B0 and *Roman Pot at secondary focus**
(**10.89 % and 79.46 % events accepted** with 10σ safe distance cut based on **ep β @ IP6* (= IP8*)**)

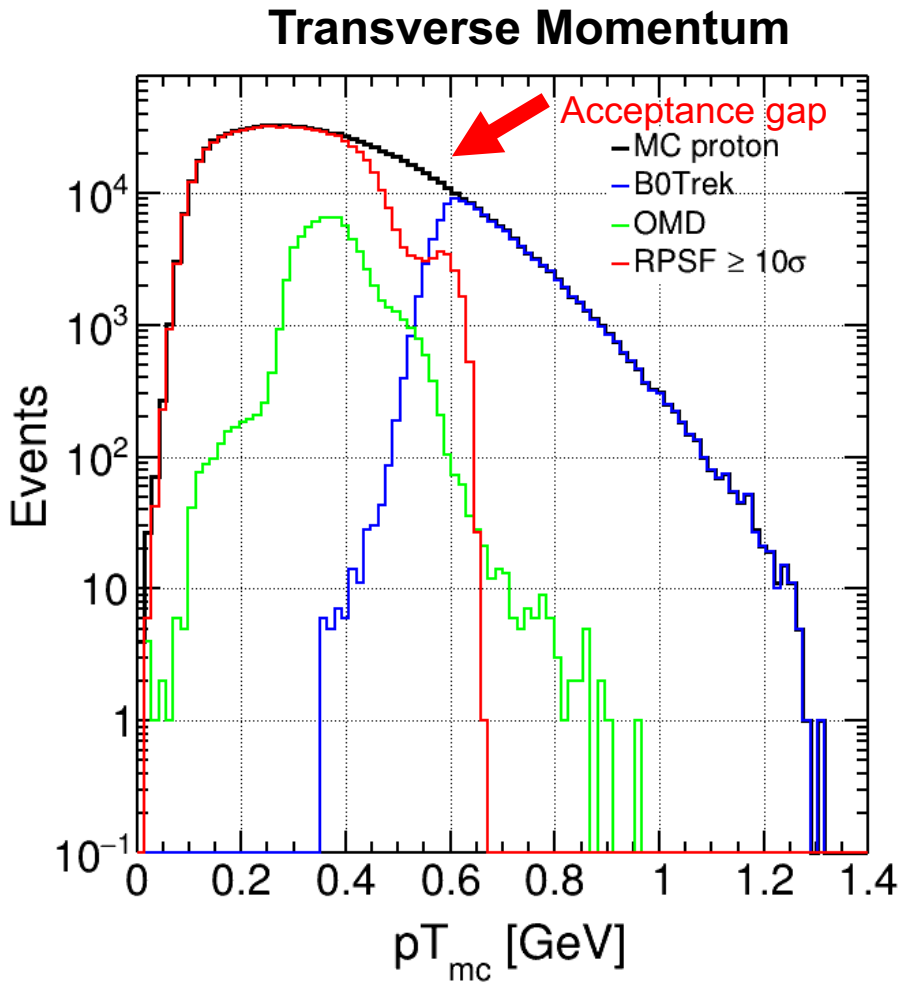
W/ Beampipe ($r_{B0\ tracker\ inner} = r_{beampipe\ outer} = 3.5$ cm) at B0

DVCS 10 GeV on 100 GeV

Log Scale

*Each histogram fills individually





MC
B0
OMD
RPSF

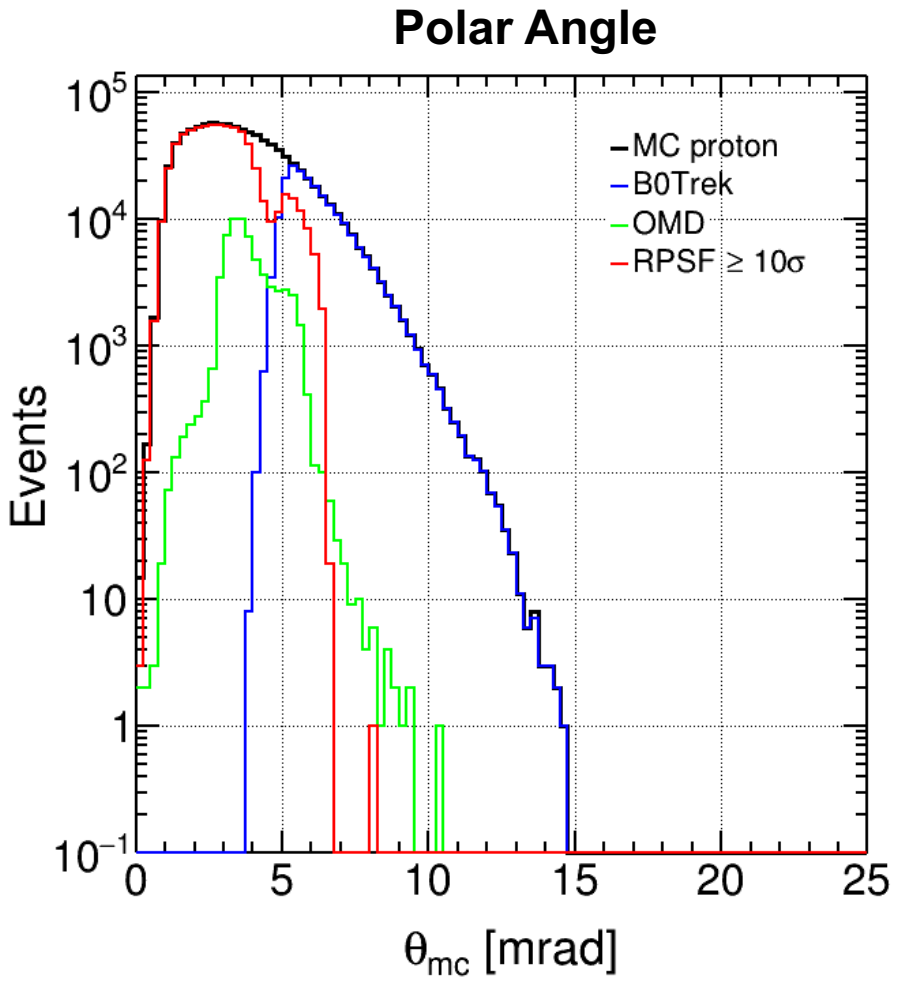
Scattered protons measured in **both B0 and *Roman Pot at secondary focus**
(**12.01 % and 75.06 % events accepted** with 10σ safe distance cut based on **ep β @ IP6* (= IP8*)**)

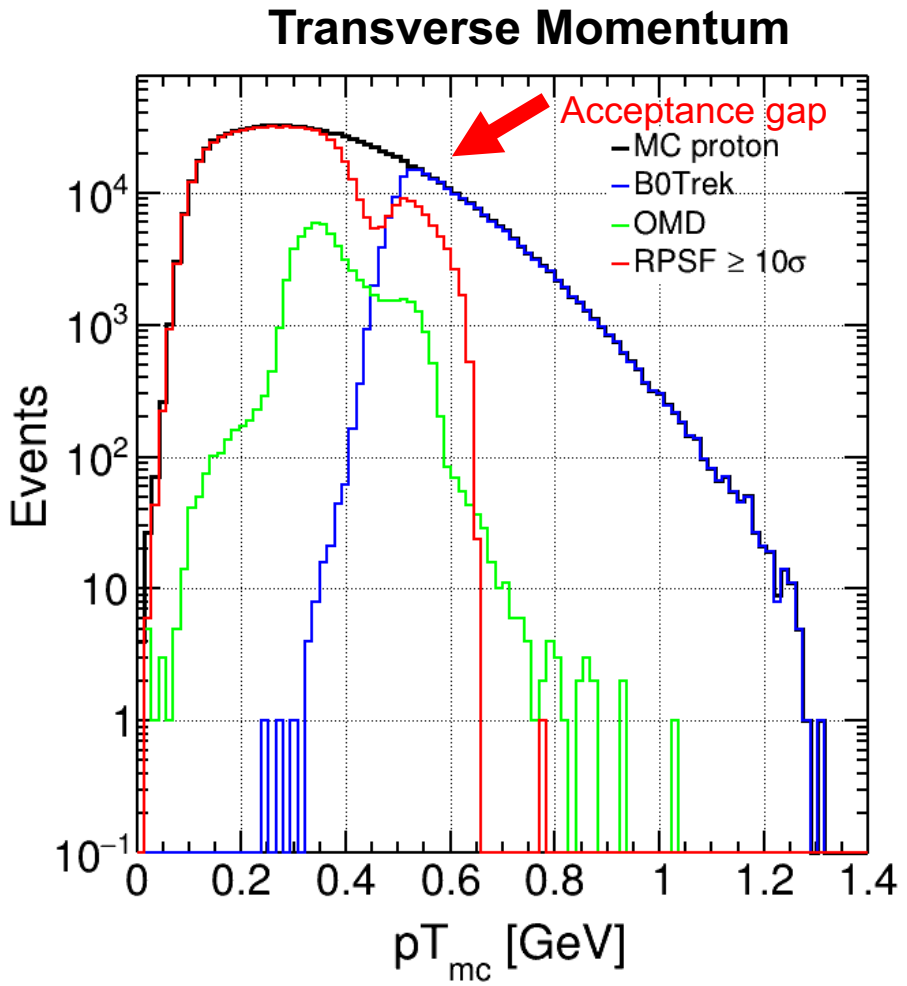
W/ Beampipe ($r_{B0\ tracker\ inner} = r_{beampipe\ outer} = 3.0$ cm) at B0

DVCS 10 GeV on 100 GeV

Log Scale

*Each histogram fills individually





MC
B0
OMD
RPSF

Scattered protons measured in **both B0 and *Roman Pot at secondary focus**
(**21.29 % and 71.30 % events accepted** with 10σ safe distance cut based on **ep β @ IP6* (= IP8*)**)

Approach – Incoherent Vetoing Efficiency

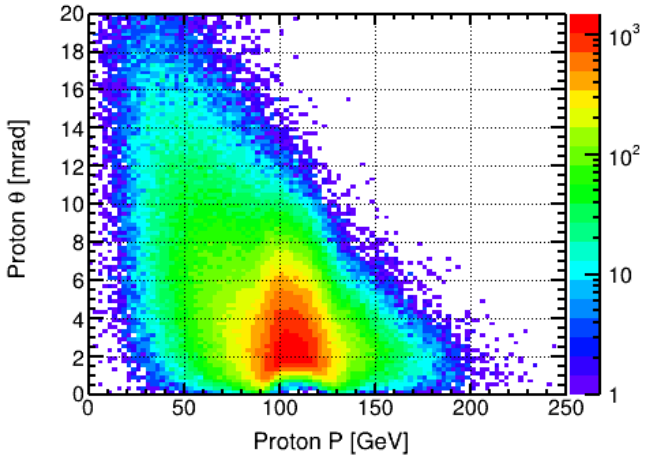
- Understand background to coherent J/ψ production
- Used simulated **BeAGLE** 801k events with **$1 < Q^2 < 10$**
  - **ePb 18×110 GeV incoherent $J/\psi(\mu\mu)$ events** $ePb \rightarrow e' + J/\psi(\mu\mu) + X$ (S3/eictest/EPIC/EVGEN/EXCLUSIVE/DIFFRACTIVE_JPSI_ABCONV/BeAGLE/ePb_18x108.41_tau10_B1.1_Jpsi_highstats/ePb_18x108.41_tune3_tau10_B1.1_extracted_Jmu_1.hepmc)
- Passed through **afterburner IP8 eAu** configuration
  - IP8 crossing angle (35 mrad) and IP6 eAu beam effects based on **EIC CDR table 3.5**
- Discarded events having **more than one electron in final state with η < -1**
- Calculated **10σ safe distance cut** based on ***eAu β IP8 RPSF***
- **Tagged events for nuclear breakups *tagging purpose***
  - ZDC Hcal: **any registered RAW hits**
  - RPSF: **one layer (closet to 2nd focus)** has registered RAW hits outside **10σ** safe distance
  - OMD: **two layers** (actual four layers as redundancy) have registered RAW hits
  - B0 Tracker: **at least two out of four layers** have registered RAW hits
  - B0 Ecal: **energy** of all hits greater than **100 MeV**
  - ZDC Ecal**: energy** of all hits greater than **100 MeV**

Nuclear Breakups Distribution

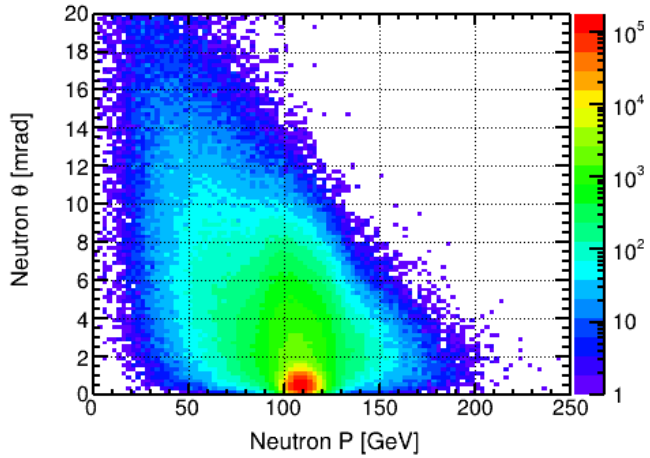
BeAGLE 18x110 GeV^2
Incoherent events
$ePb \rightarrow e' + J/\psi(\mu\mu) + X$

Generated Level	Nuclear Breakups at Final State	Number of Events
	Only Neutrons	7.55 %
	Only Protons	0.0004 %
	Only Photons	3.24 %
	Neutrons + Protons	3.28 %
	Neutrons + Photons	43.98 %
	Protons + Photons	2.24 %
	Neutrons + Protons + Photons	39.72 %

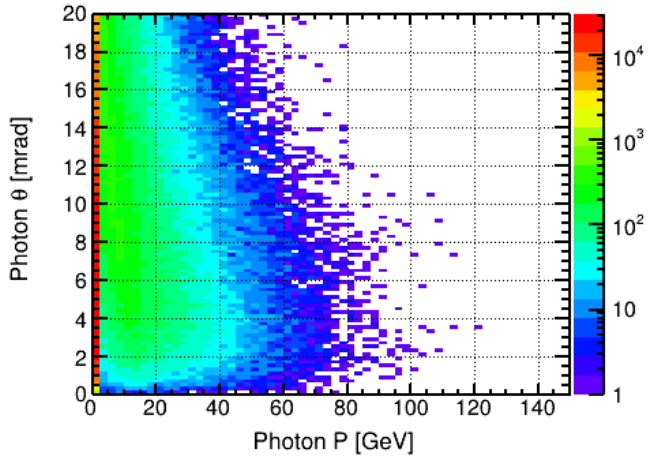
Proton



Neutron



Photon

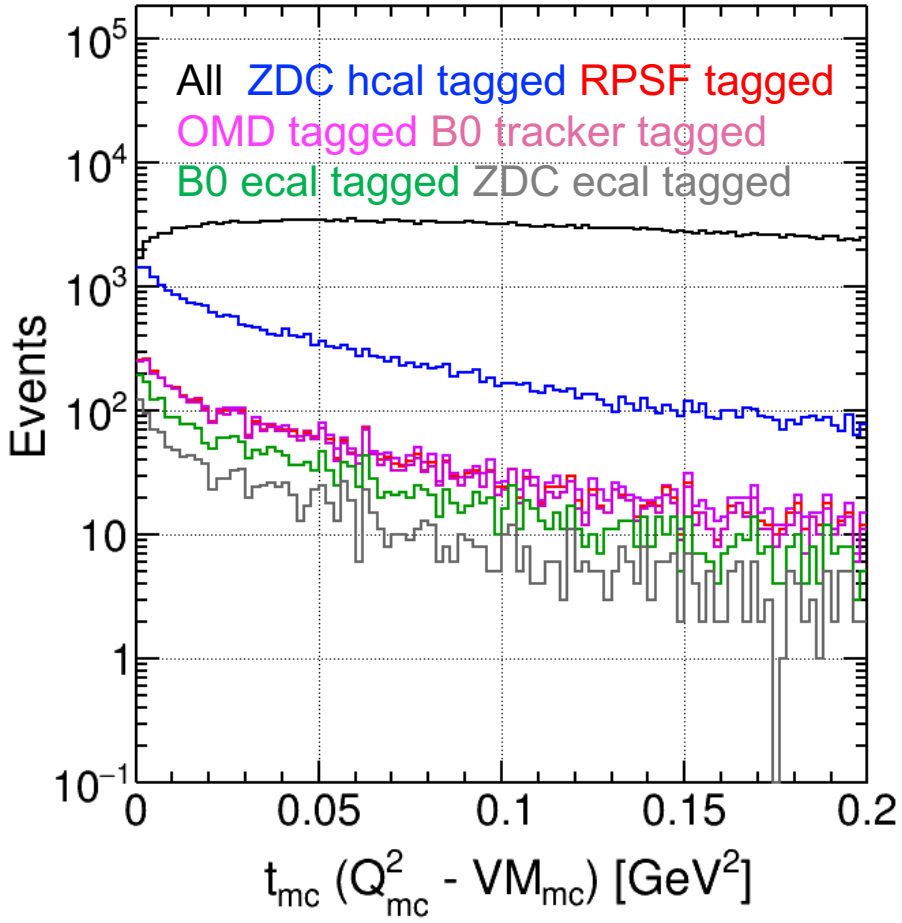


W/ Beam effects

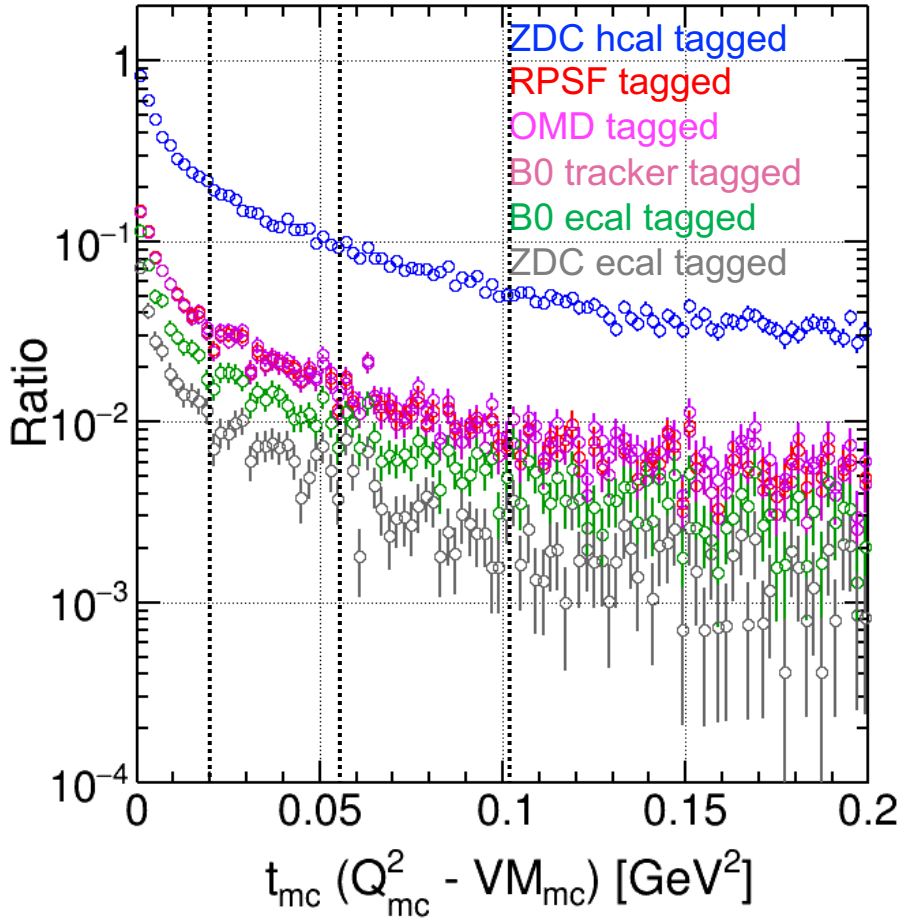
t distribution

BeAGLE 18x110 GeV^2
Incoherent events
$ePb \rightarrow e' + J/\psi(\mu\mu) + X$

Veto inefficiency for incoherent events



Coherent diffractive minima



Not yet enough to suppress incoherent contribution
Still investigating additional rejection factor to improve vetoing efficiency

W/ Beam effects

Remaining Events

BeAGLE 18x110 GeV^2
Incoherent events
$ePb \rightarrow e' + J/\psi(\mu\mu) + X$

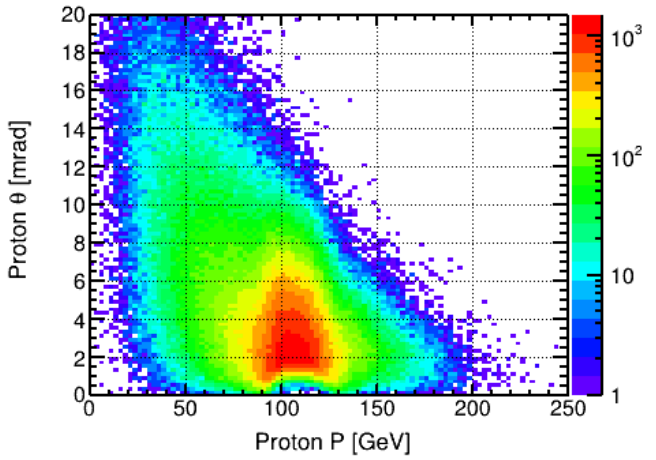
Veto Selections	Survived Events
All events	800,964
Events with one scattered electron identified	712,362 (100.0 %)
ZDC HCAL tagged	41,768 (5.86331 %)
+ RPSF tagged	7,231 (1.01507 %)
+ OMD tagged	6,781 (0.951904 %)
+ B0 tracker tagged	5,599 (0.785977 %)
+ B0 ecal tagged	3,504 (0.491885 %)
+ ZDC ECAL tagged	1,771 (0.24861 %)

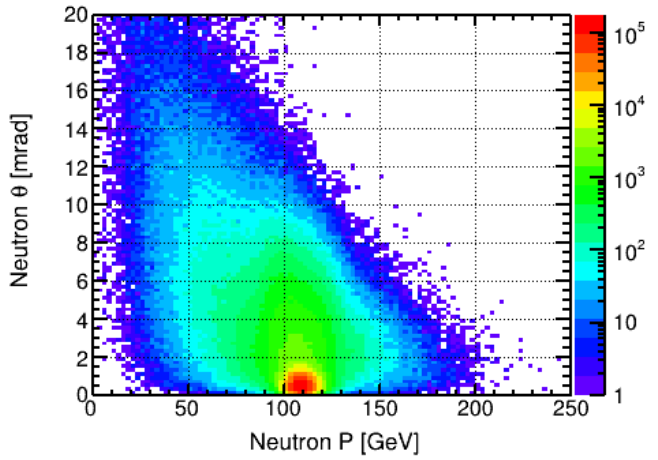
With 10σ safe distance cut based on ***ep β @ IP8 RPSF***
1,771 of 800,964 events were NOT vetoed

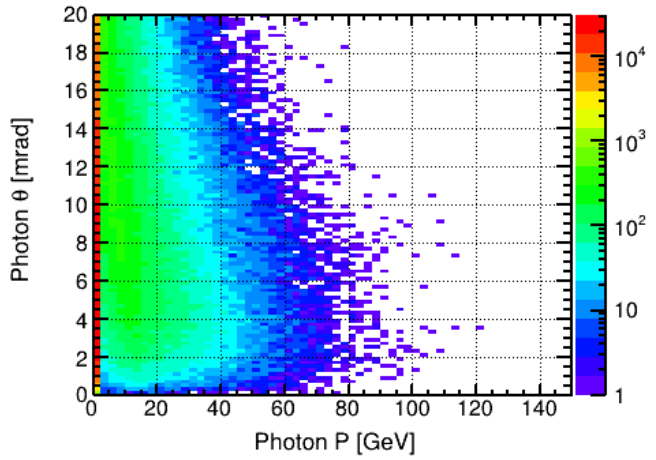
Remaining Events

BeAGLE 18x110 GeV^2
Incoherent events
$ePb \rightarrow e' + J/\psi(\mu\mu) + X$

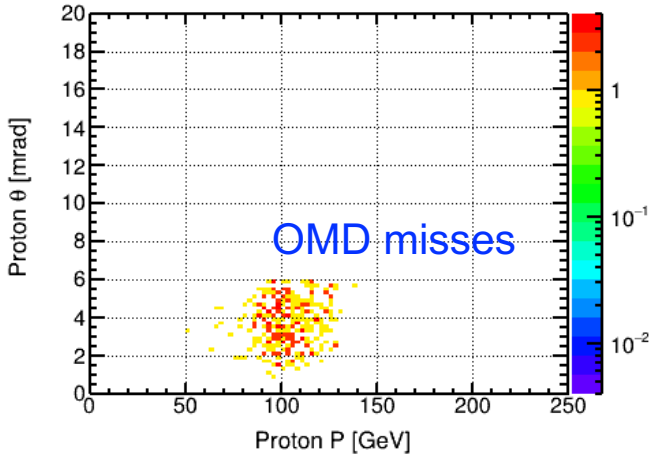
Generated level

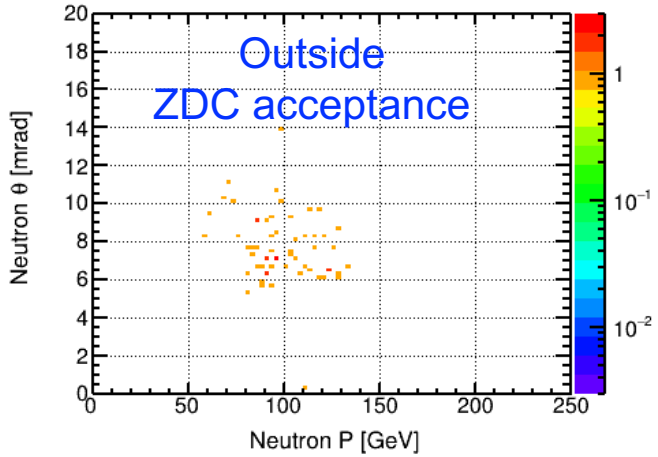


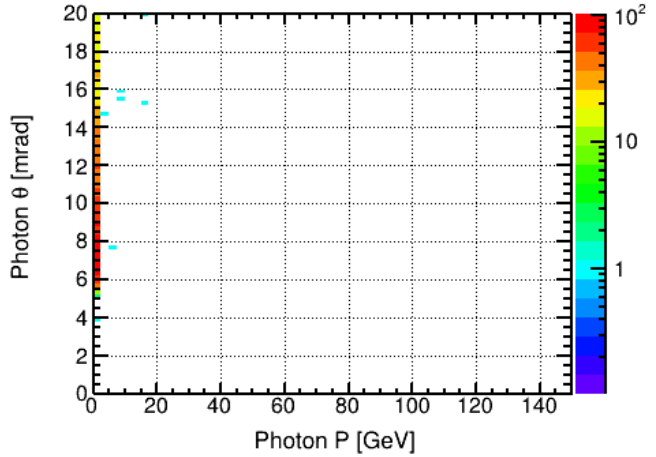




Remained level

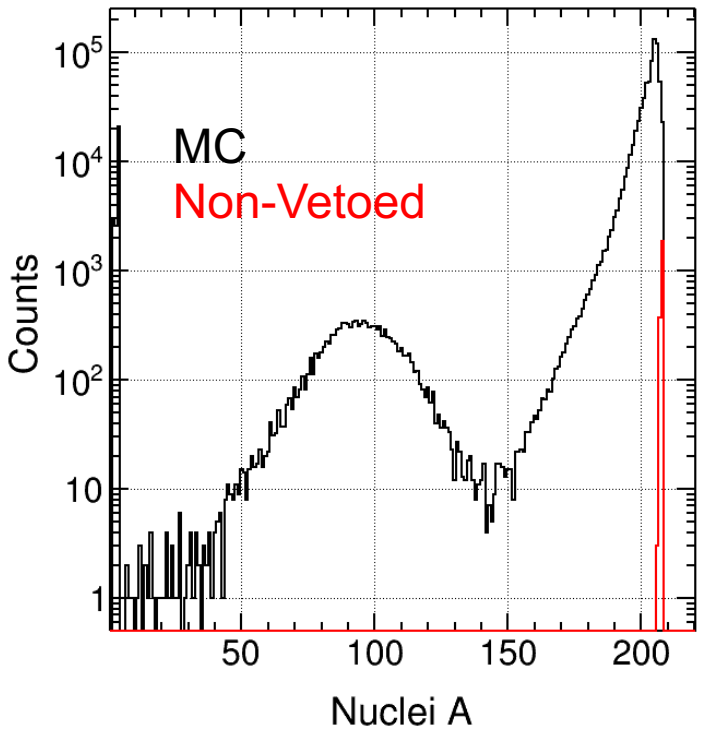


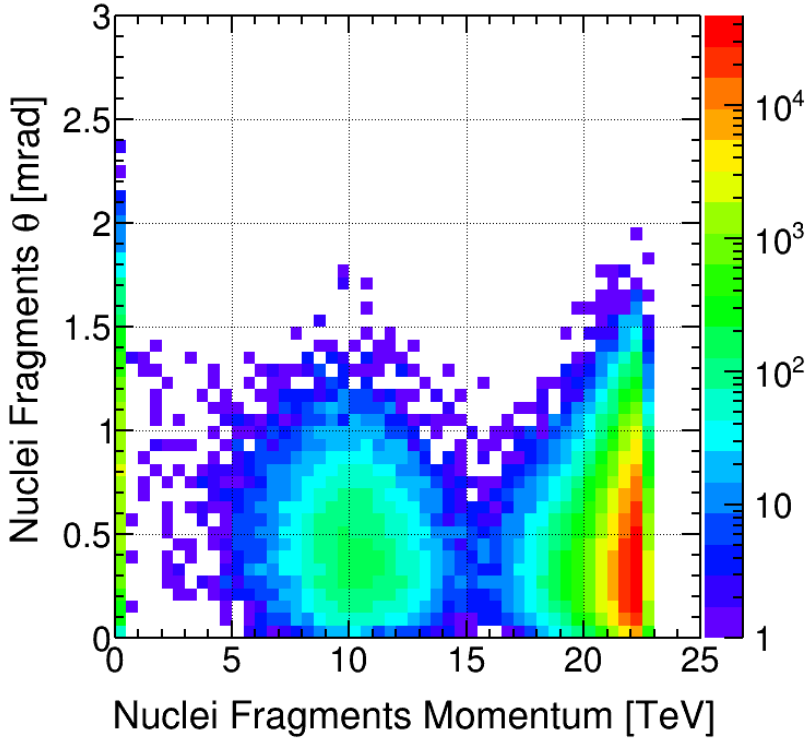


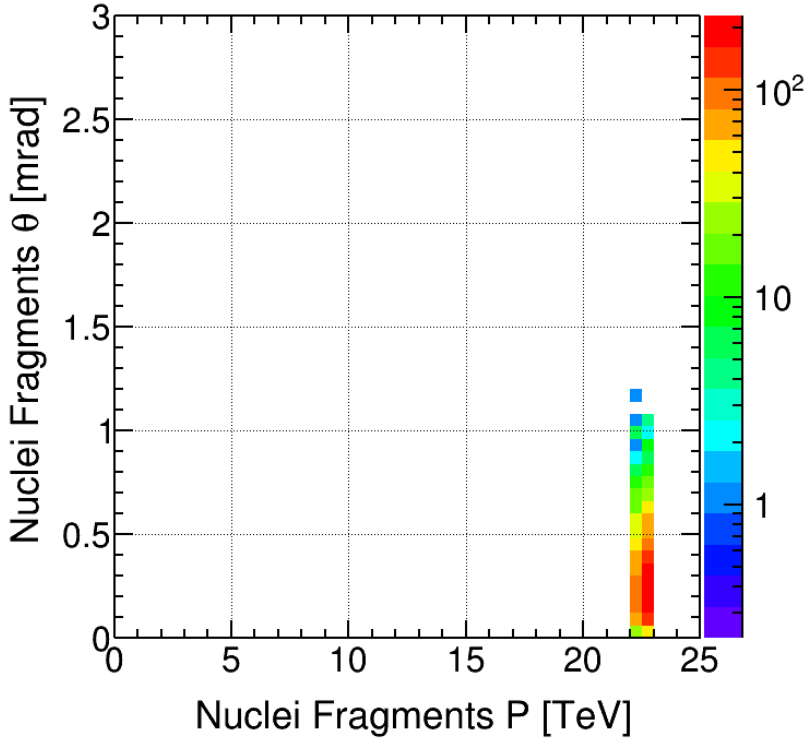


Remaining Events

BeAGLE 18x110 GeV^2
Incoherent events
$ePb \rightarrow e' + J/\psi(\mu\mu) + X$







Remaining events have higher mass nuclear remnants and low number of particles in final state

Summary

- With basic components are in-place in EIC 2nd detector DD4hep simulation, checked IP8 acceptance on each far-forward detectors (B0, OMD, ZDC, and RPSF)
- Using exclusive DVCS events, understanding acceptance gap in pT between B0 and RPSF
  - ~250 MeV for 5 GeV on 41 GeV and ~550 MeV for 10 GeV on 100 GeV
  - After adding beampipe, it has some fuzzy shape of acceptance gap since beampipe is circular shape and beam is elliptical shape and acceptance gap depends on aperture size
  - Difficult to remove acceptance gap, but complementary detector may make different acceptance gap region so that it covers all pT acceptance for scattered proton using both IP6 and IP8
- Using BeAGLE incoherent events, evaluating vetoing power to understand background to coherent events with $1 < Q^2 < 10$ and $t < 0.2$
  - Vetoing power reaches 10^{-2} at $t \sim 0.02$ coherent diffractive minima
  - Still optimizing to get better vetoing power…
  - Very helpful to have more realistic beam optics for IP8 ep(eAu) especially for secondary focus

Backup Slides

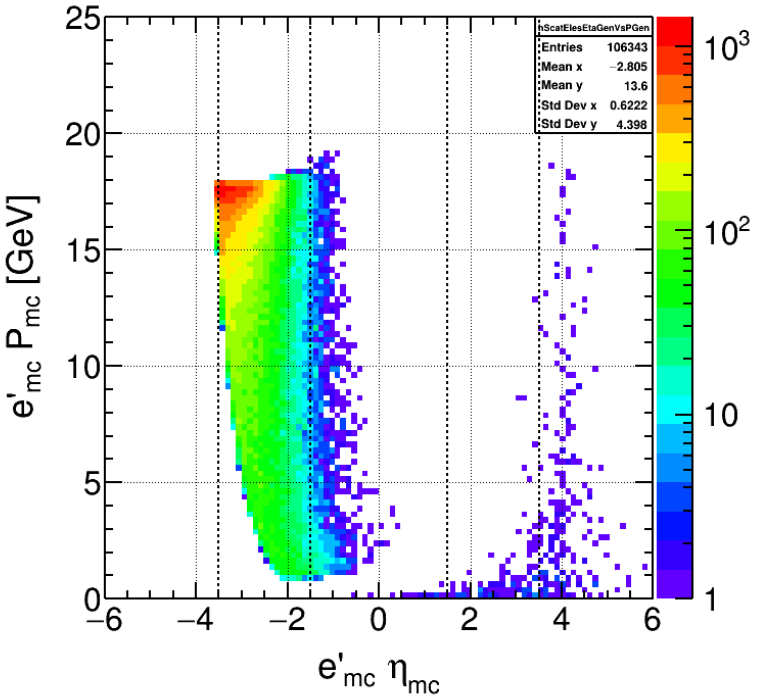
Candidates for e’

Final-state Electrons

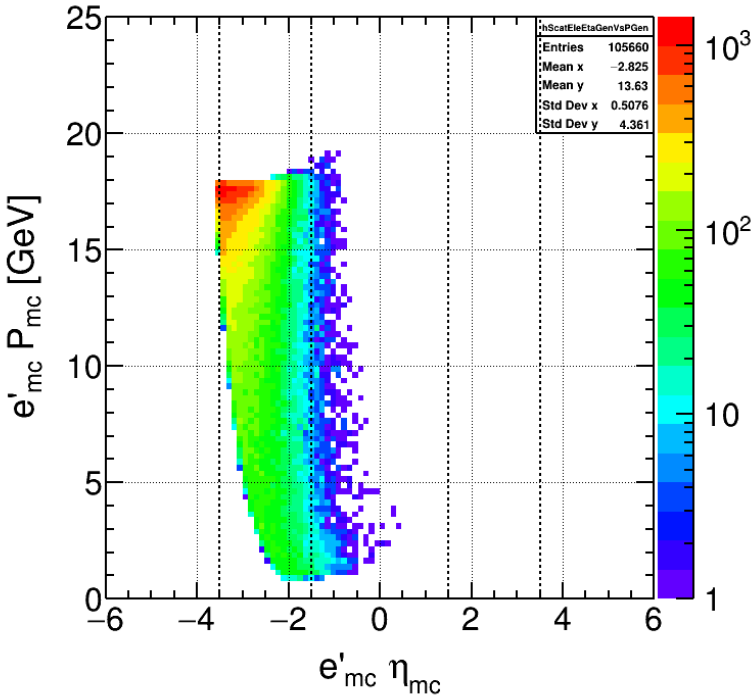
BeAGLE 18x110 GeV^2
Incoherent events
$ePb \rightarrow e' + J/\psi(\mu\mu) + X$

Within BeAGLE incoherent J/ψ events, there can be multiple electrons in final-state
If there are multiple electrons, take electron having less than -1 in rapidity
However, more than one electron heading backward (η < -1), then discard for now

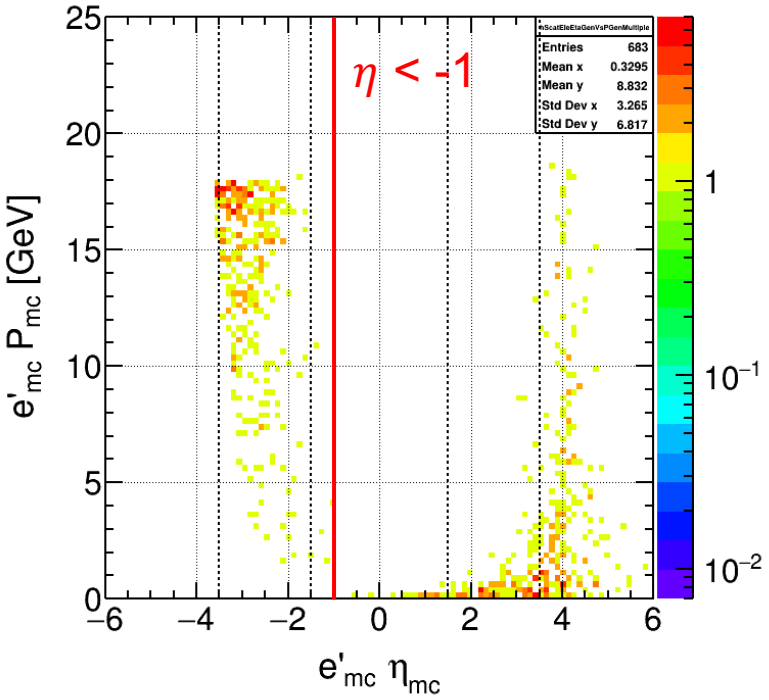
All Electrons



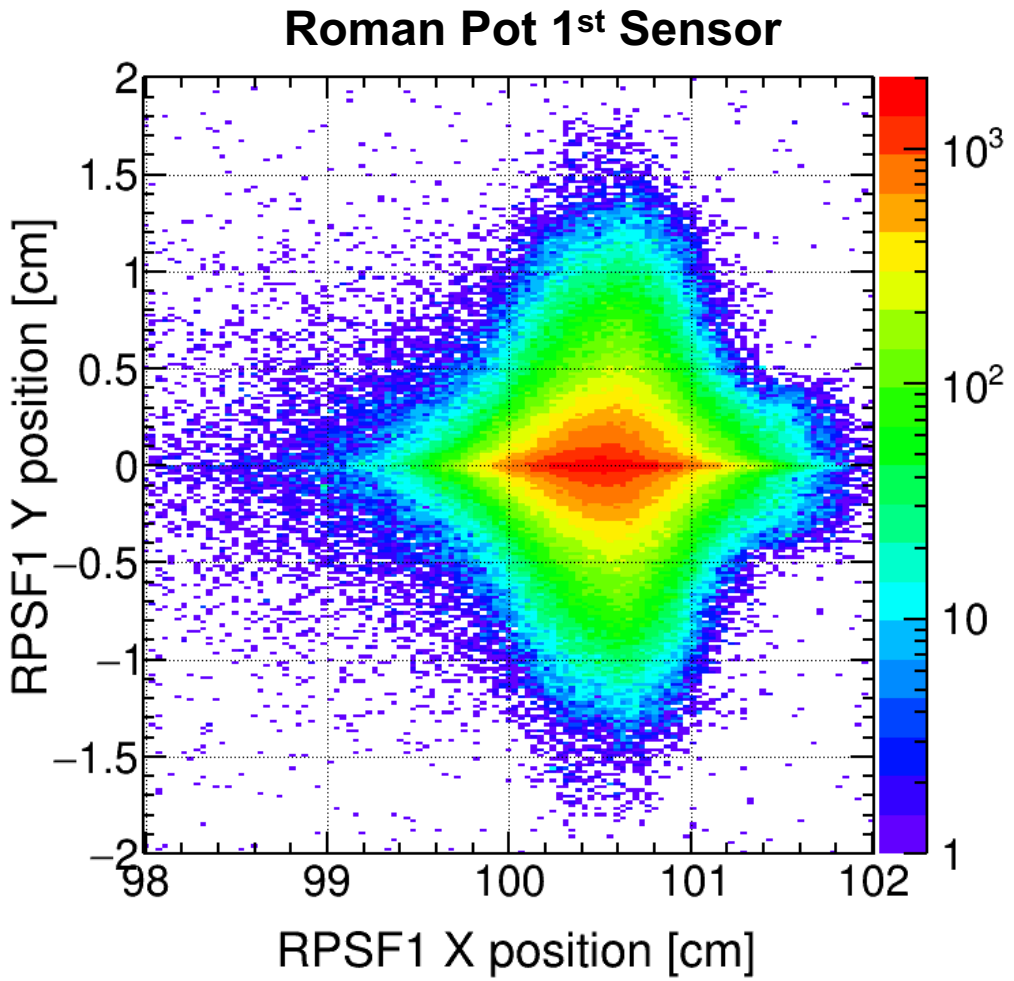
Only One Electron

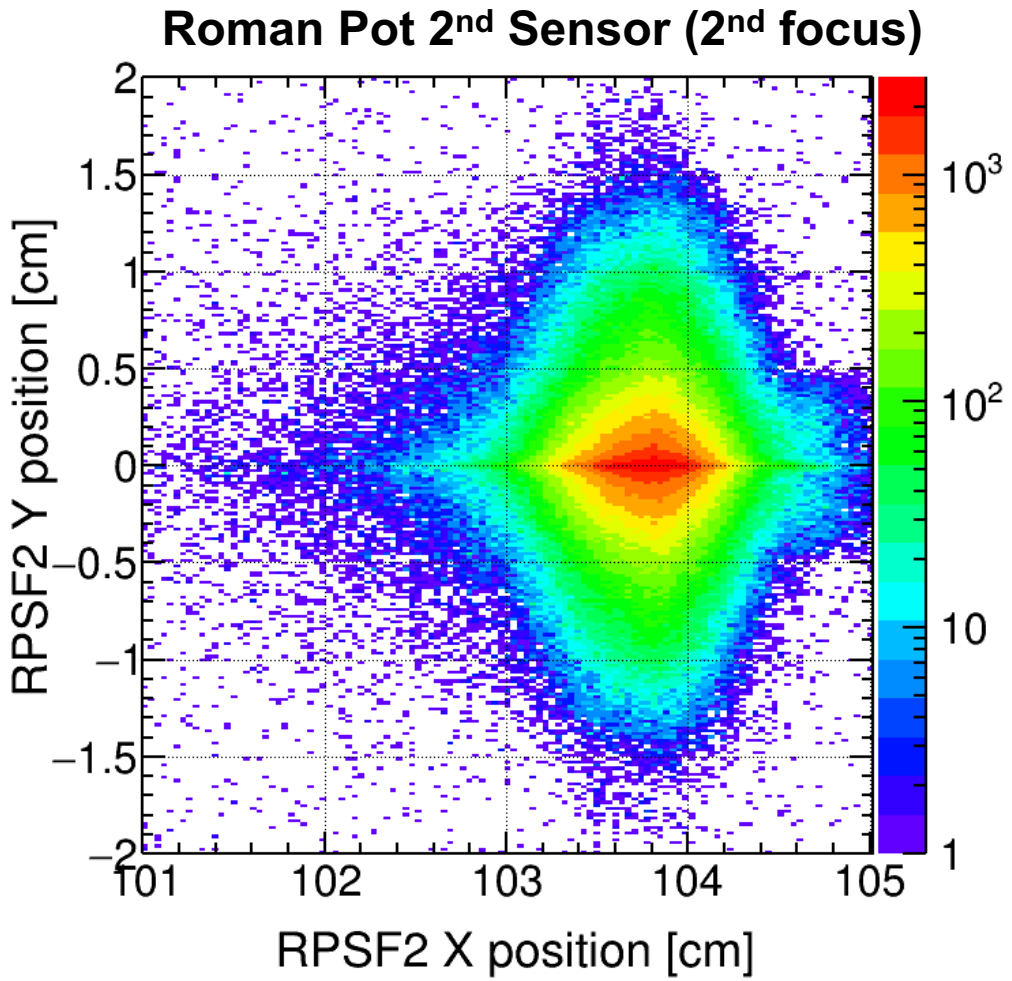


More than One Electron

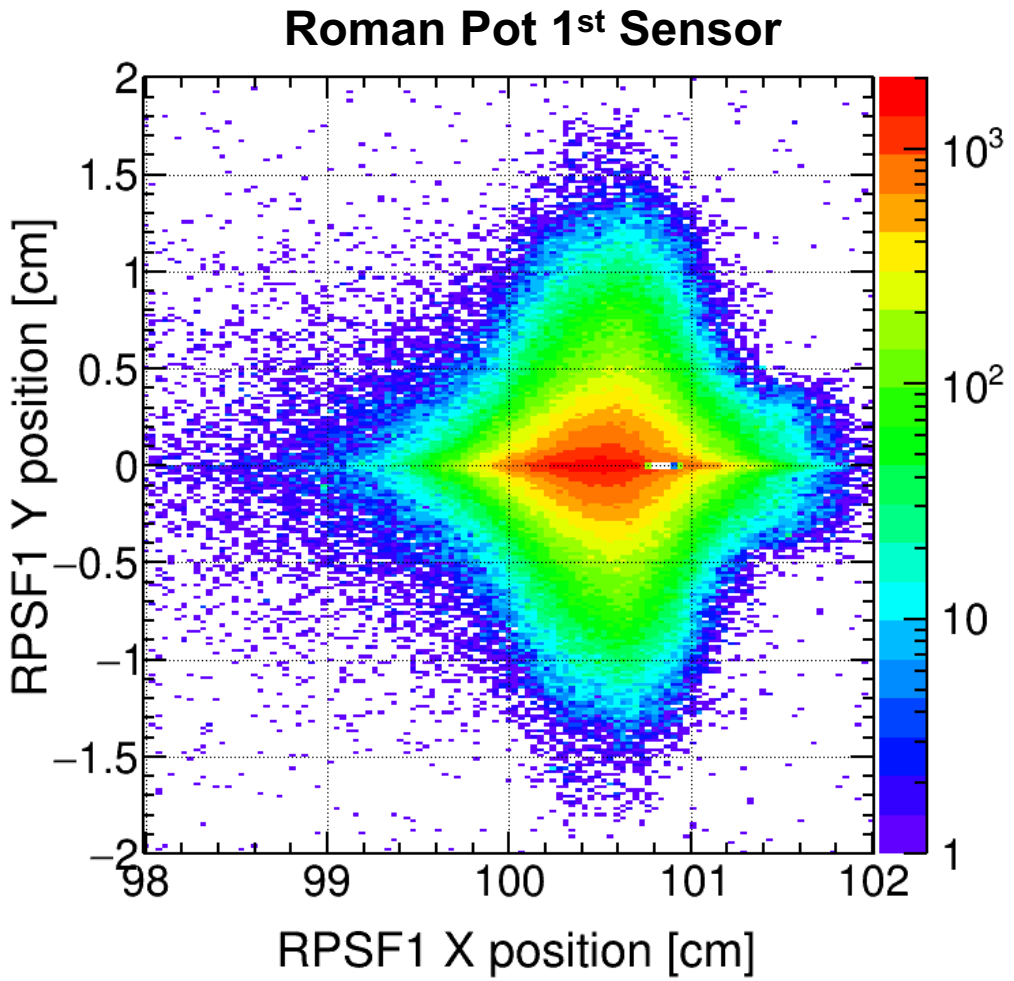


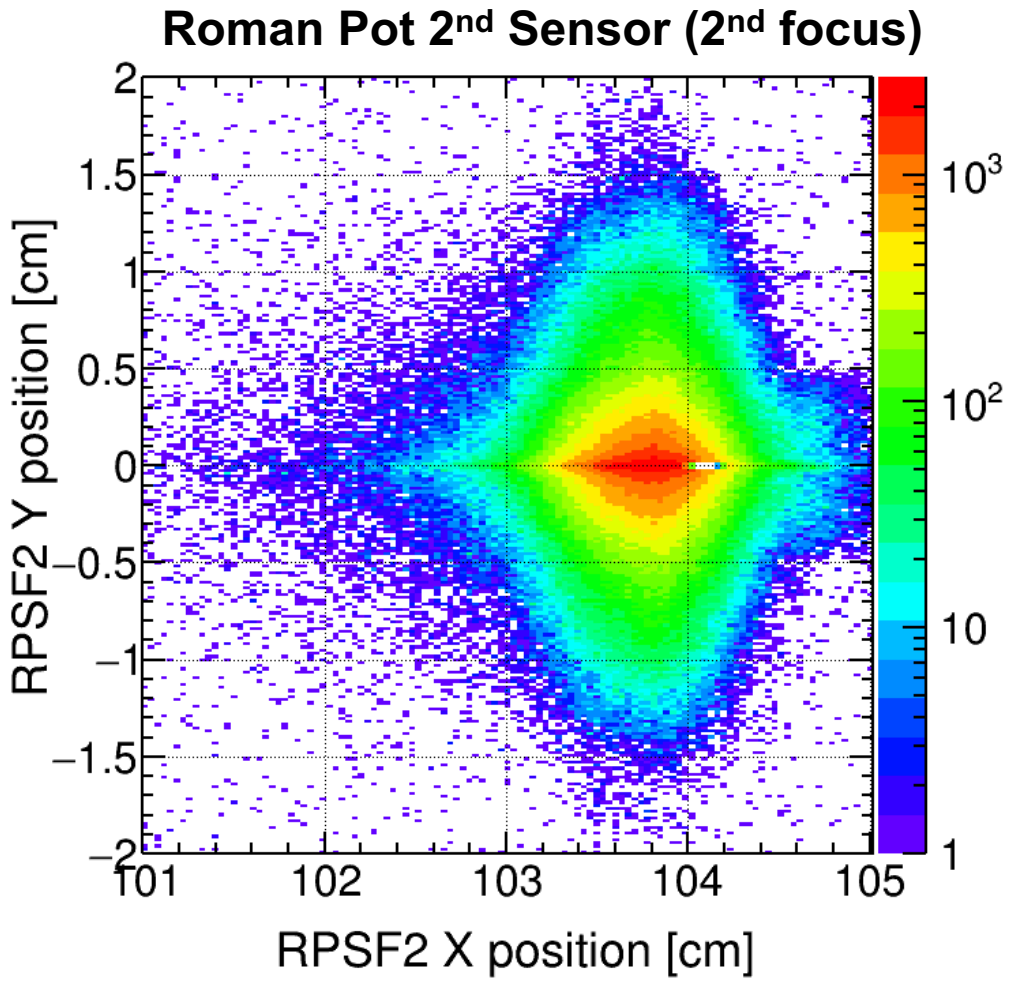
DVCS 18 GeV on 275 GeV





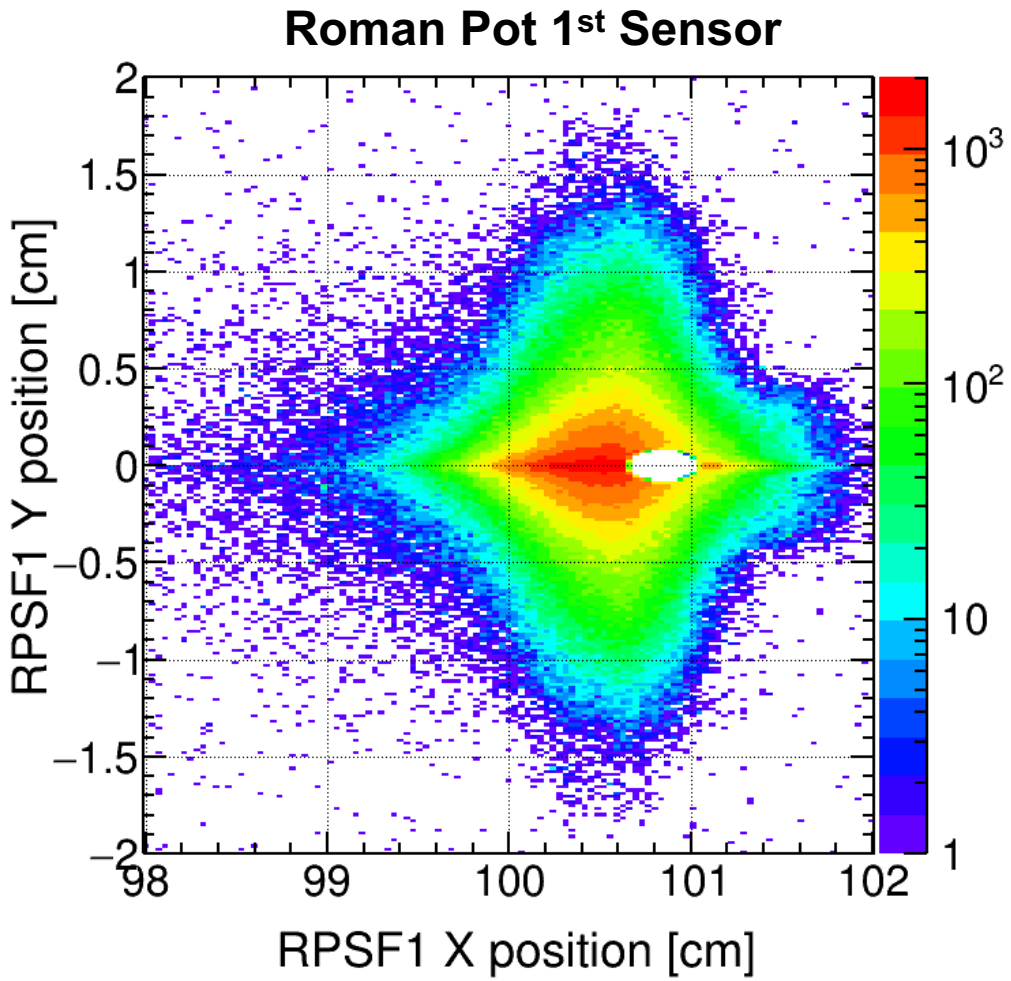
DVCS 18 GeV on 275 GeV

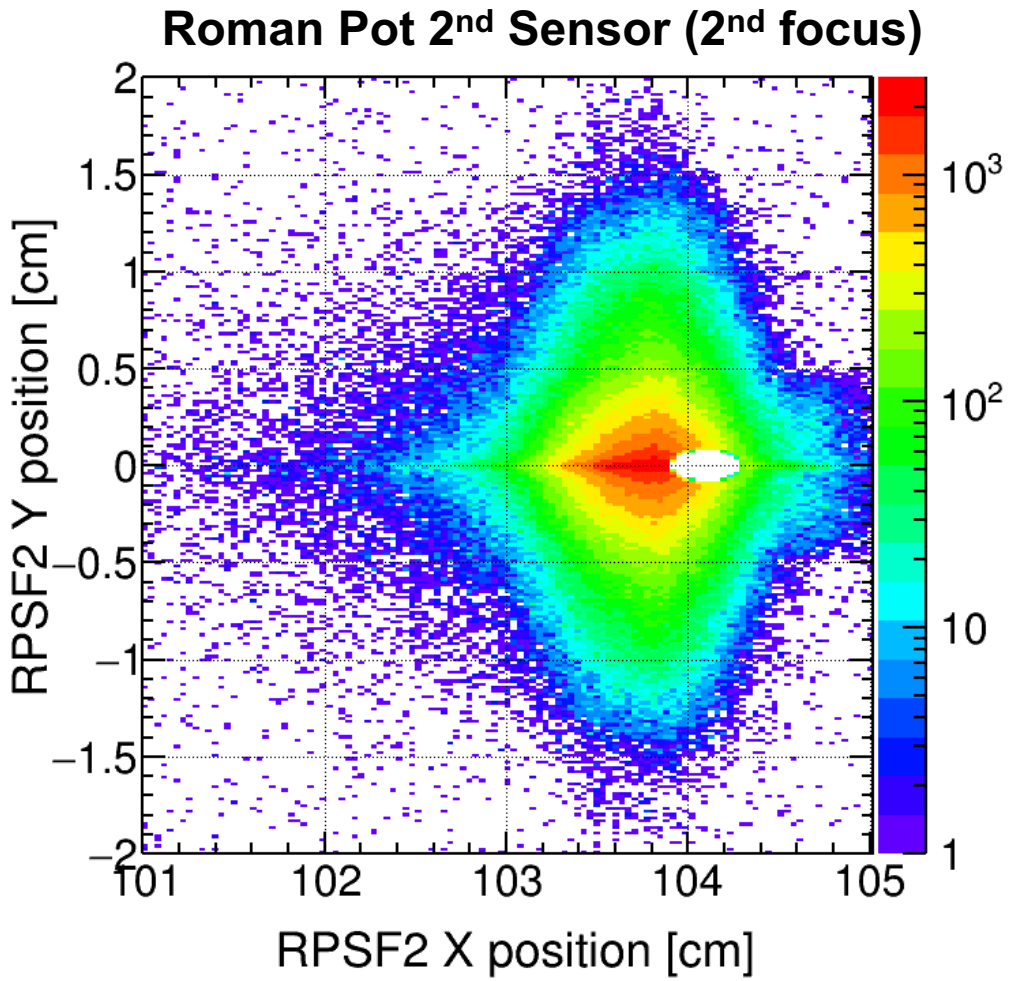




96.77 % events accepted with 10σ safe distance cut based on **ep β @ IP6**

DVCS 18 GeV on 275 GeV





86.33 % events accepted with 10σ safe distance cut based on **ep β @ IP8 RPSF**

pT Acceptance from EIC YR

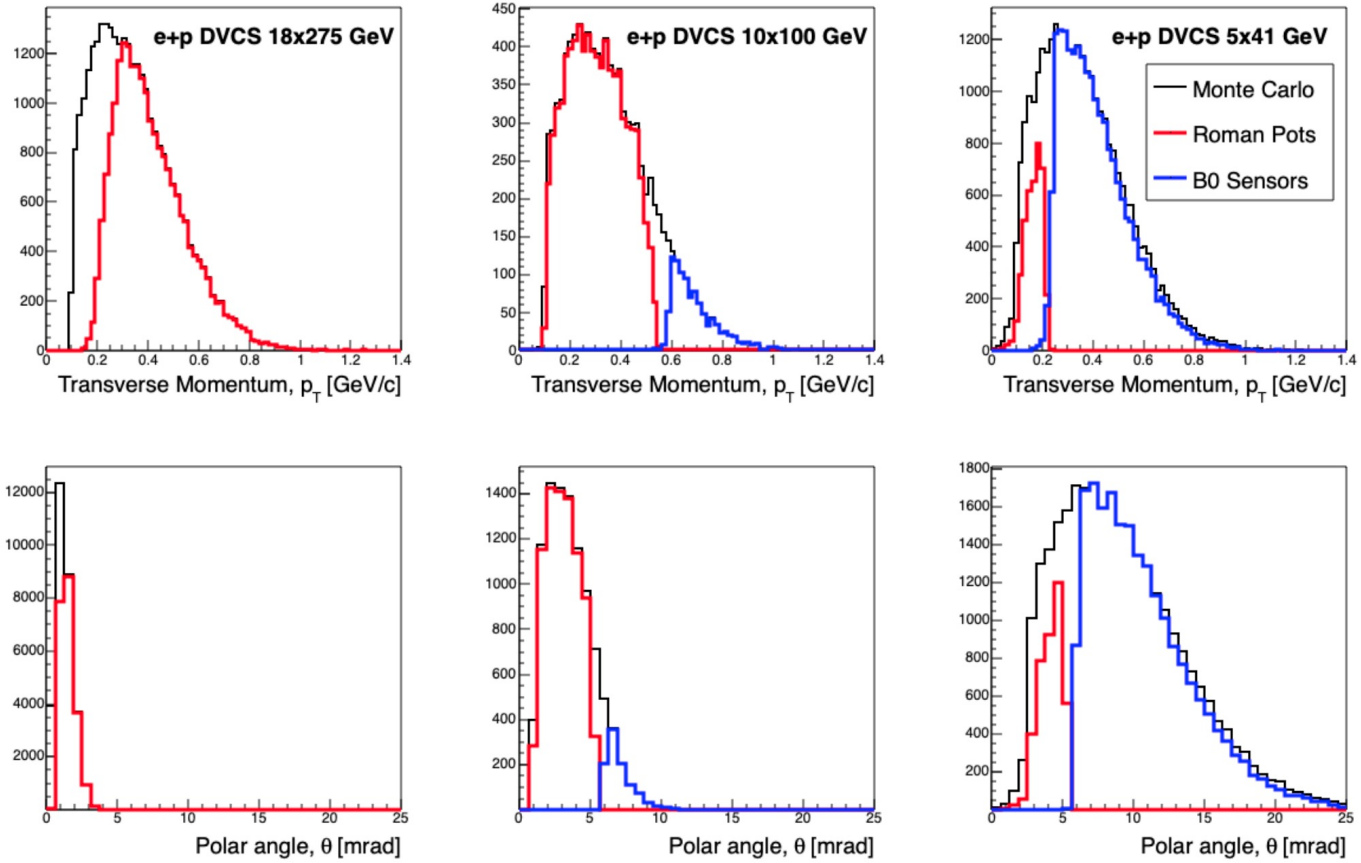


Figure 11.98: p_T (top row) and polar angle (bottom row) acceptance for three different beam energy configurations: 18x275 GeV (left), 10x100 GeV (middle), and 5x41 GeV (right). The black data in each figure represent the MC information from MILOU, the red lines are the accepted particles in the Roman Pots, and the blue lines are particles accepted in the B0 sensors.

From EIC YR p.564