Update on IP-8 Simulation: EIC Detector-II Meeting Slides t calculation with Wan's IP-8 study

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2023/12/18

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

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2023/12/19

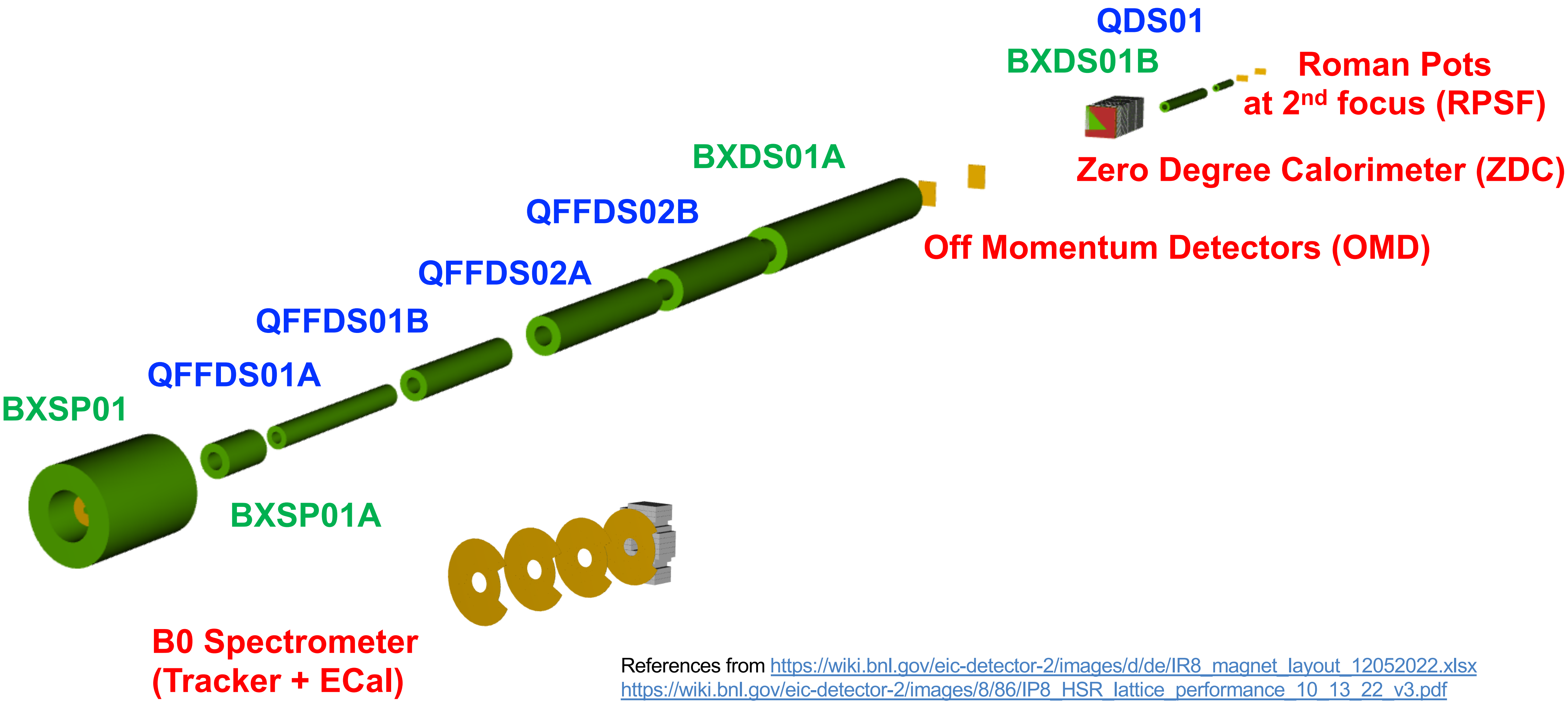
Introduction

- 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 processes
  - Separate coherent from incoherent process
    - 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

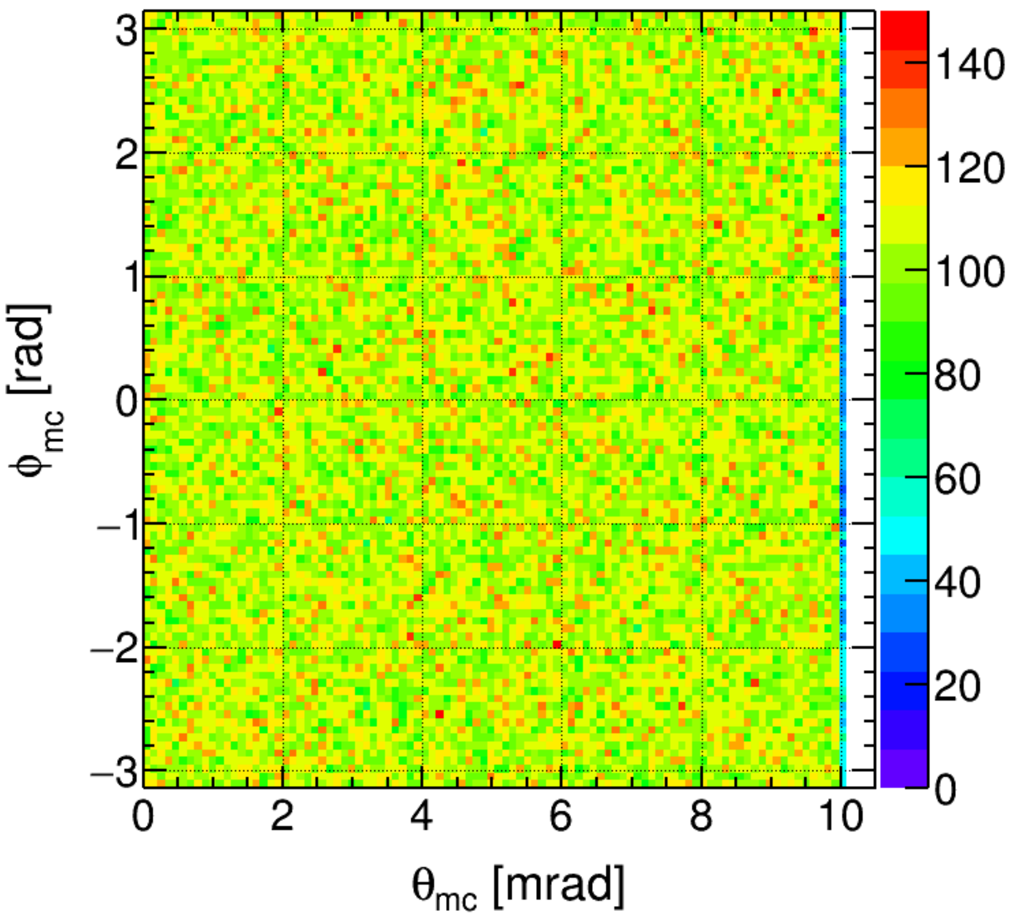
Approach – Detector Acceptance

- **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**

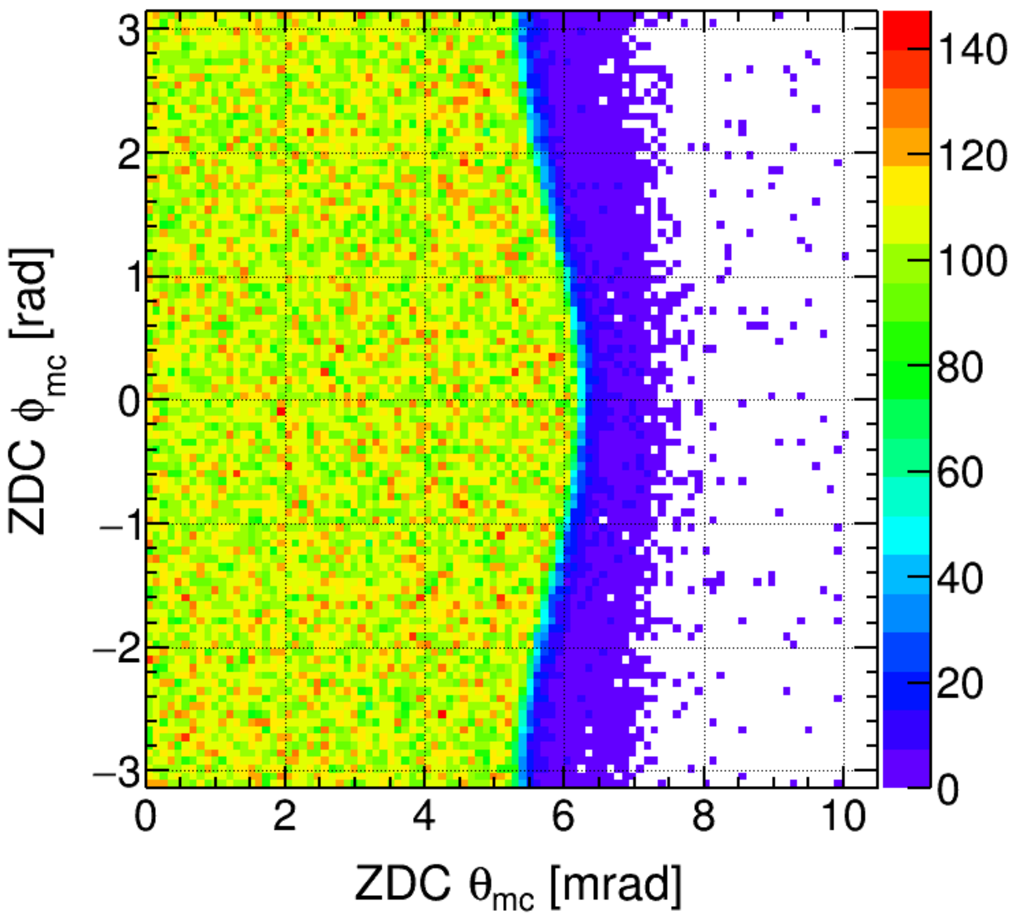
Zero Degree Calorimeter

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

Generated



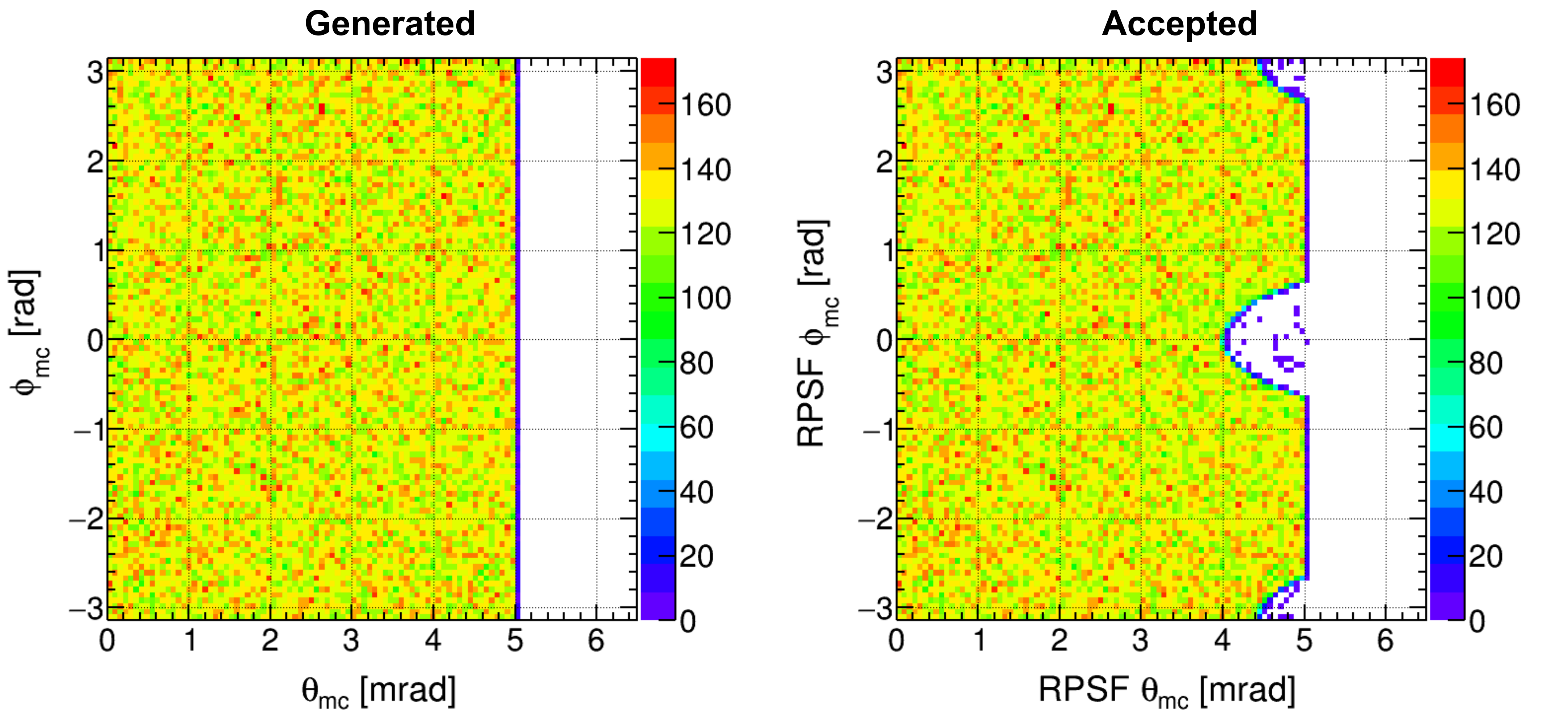
Accepted



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)

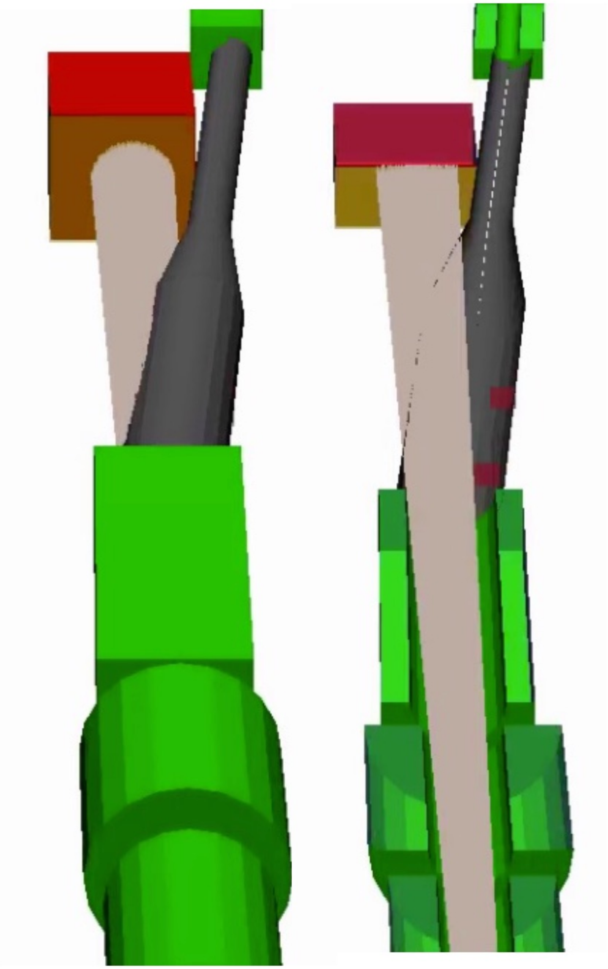
Clipping occurs in quadrupoles for protons

Clipping on Acceptance of Far-Forward

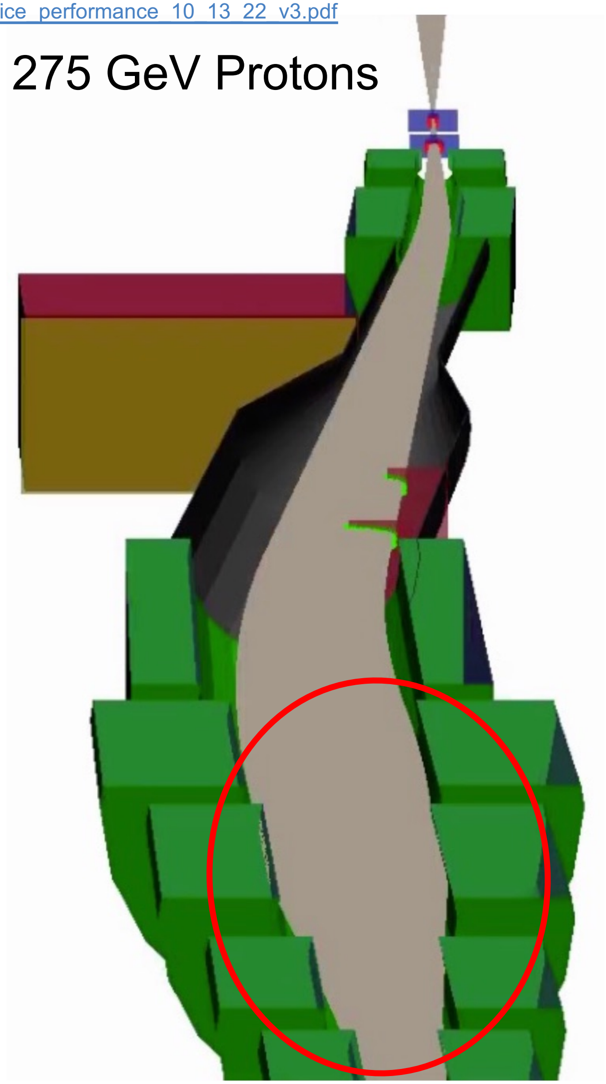
Kindly Provided by Alex Jentsch using EicRoot Simulation Event Display

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

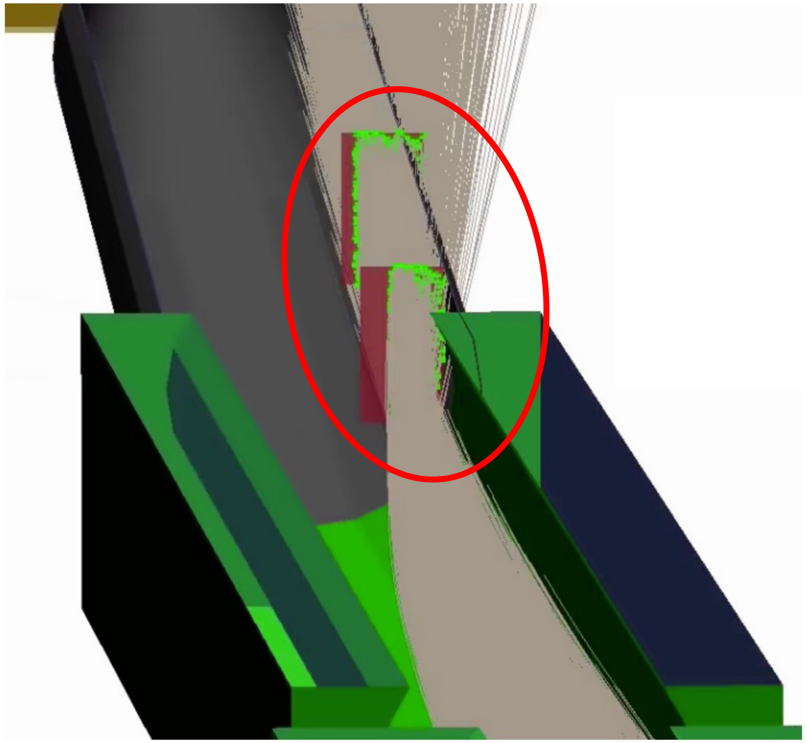
275 GeV Neutrons



275 GeV Protons



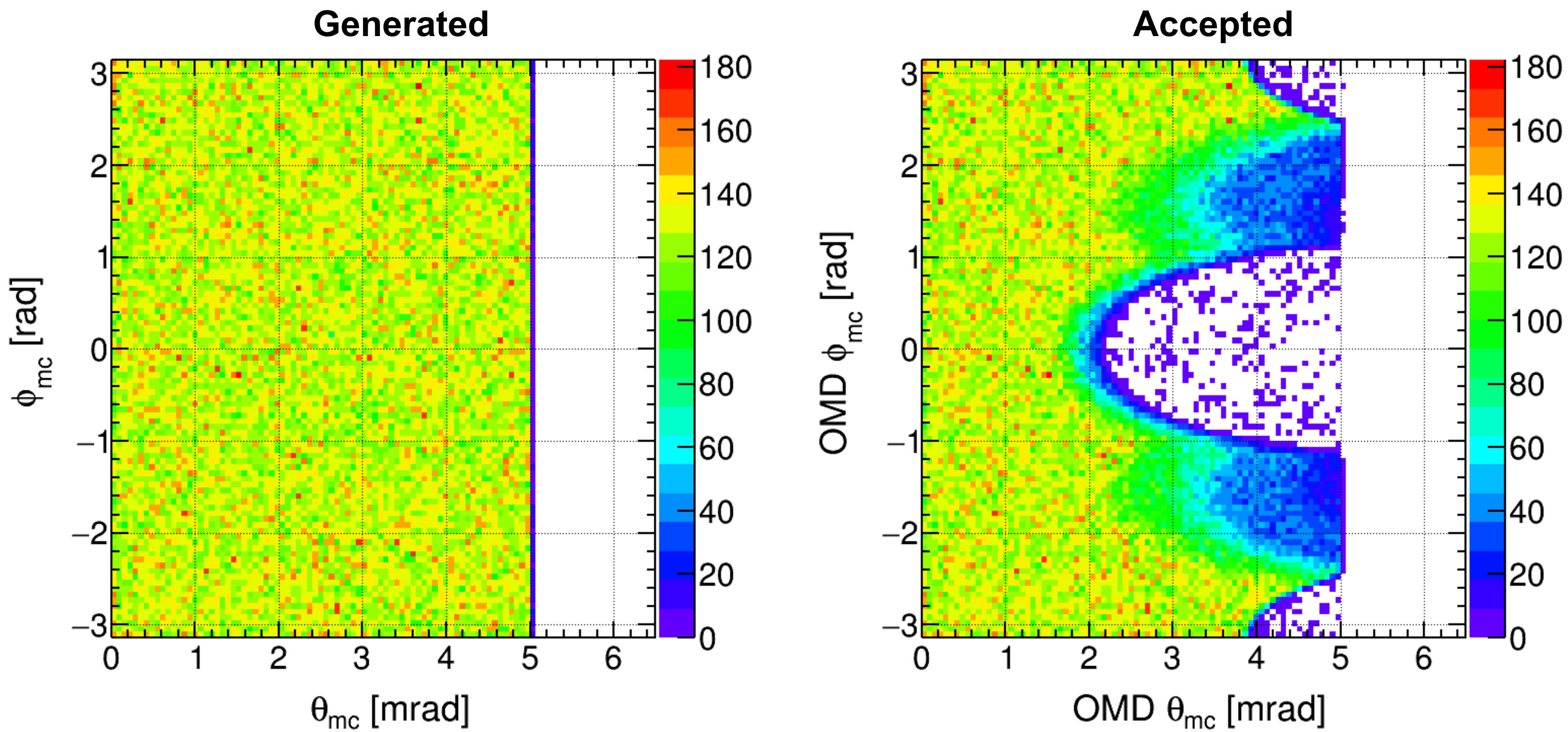
123.75 – 151.25 GeV Protons



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

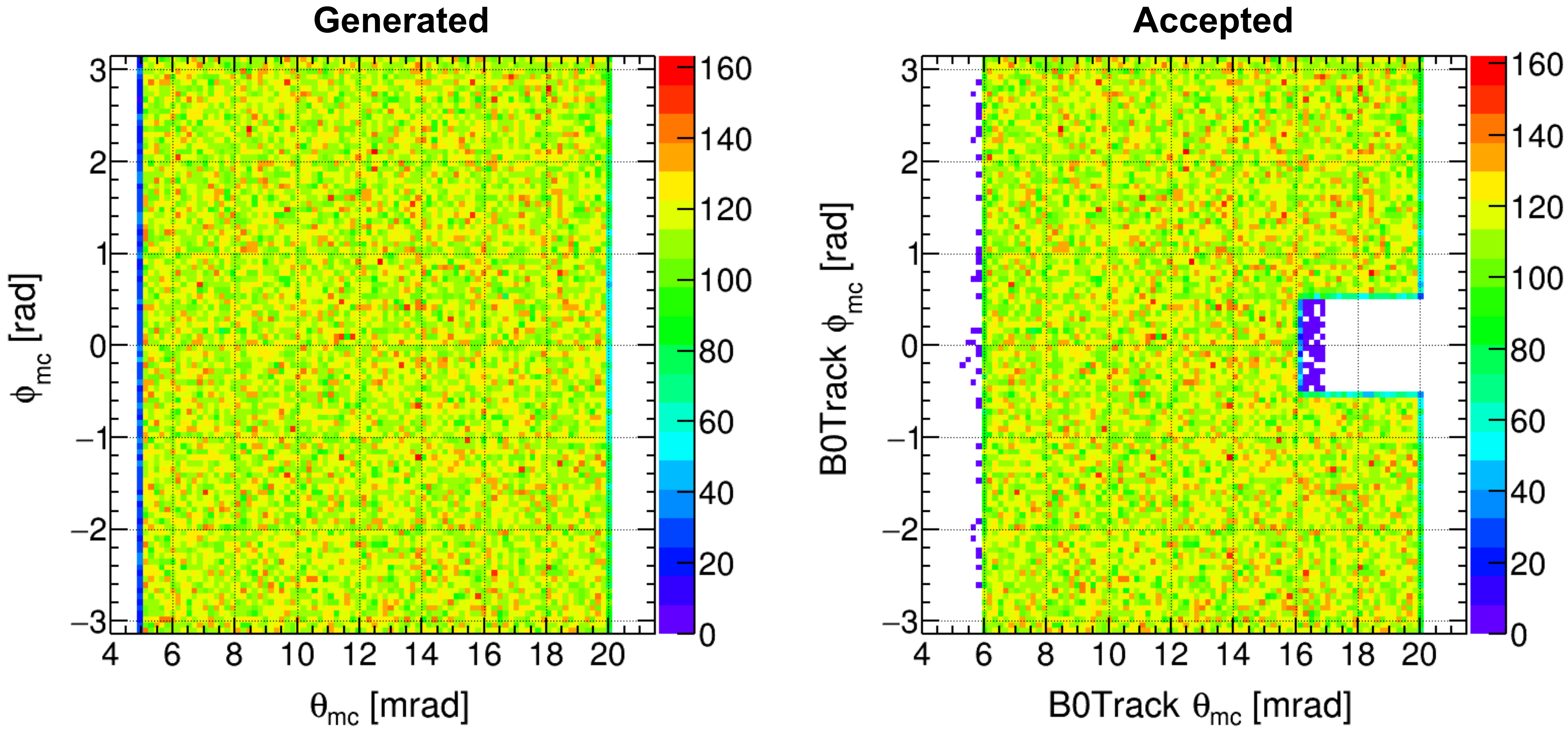


About 67.42 % events were accepted

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 **pT acceptance at B0 and RPSF**
- Used simulated **ep DVCS* 1M** events each
  - Three beam energy combinations: ep 18×275, 10×100, and 5×41 GeV^2
- Passed through **afterburner IP-8 ep high divergence** configuration
  - IP-8 crossing angle (35 mrad) and IP-6 ep high divergence beam effects based on **EIC CDR table 3.3**
- **Accepted events for scattered protons <u>reconstruction purpose</u>**
  - 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 @ IP8 RPSF**

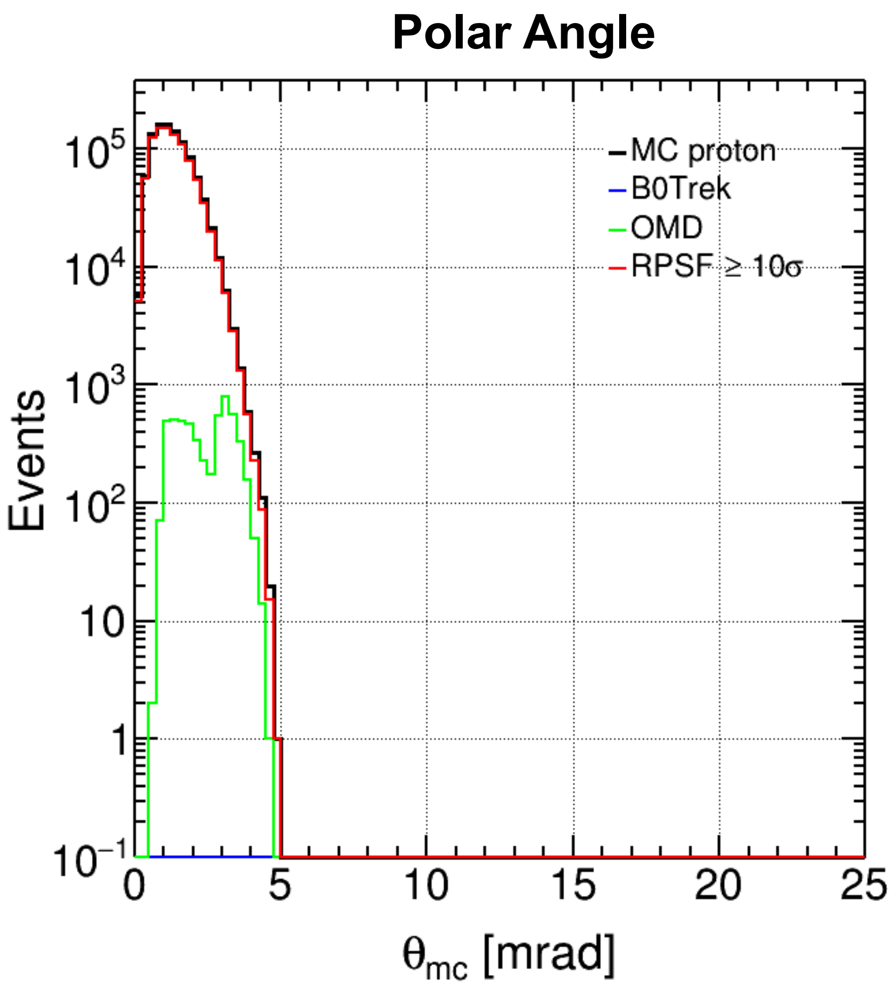
*S3/eictest/EPIC/EVGEN/EXCLUSIVE/DVCS/18x275/DVCS.3.18x275.hepmc | *S3/eictest/EPIC/EVGEN/EXCLUSIVE/DVCS/10x100/DVCS.1.10x100.hepmc
*S3/eictest/EPIC/EVGEN/EXCLUSIVE/DVCS/5x41/DVCS.2.5x41.hepmc

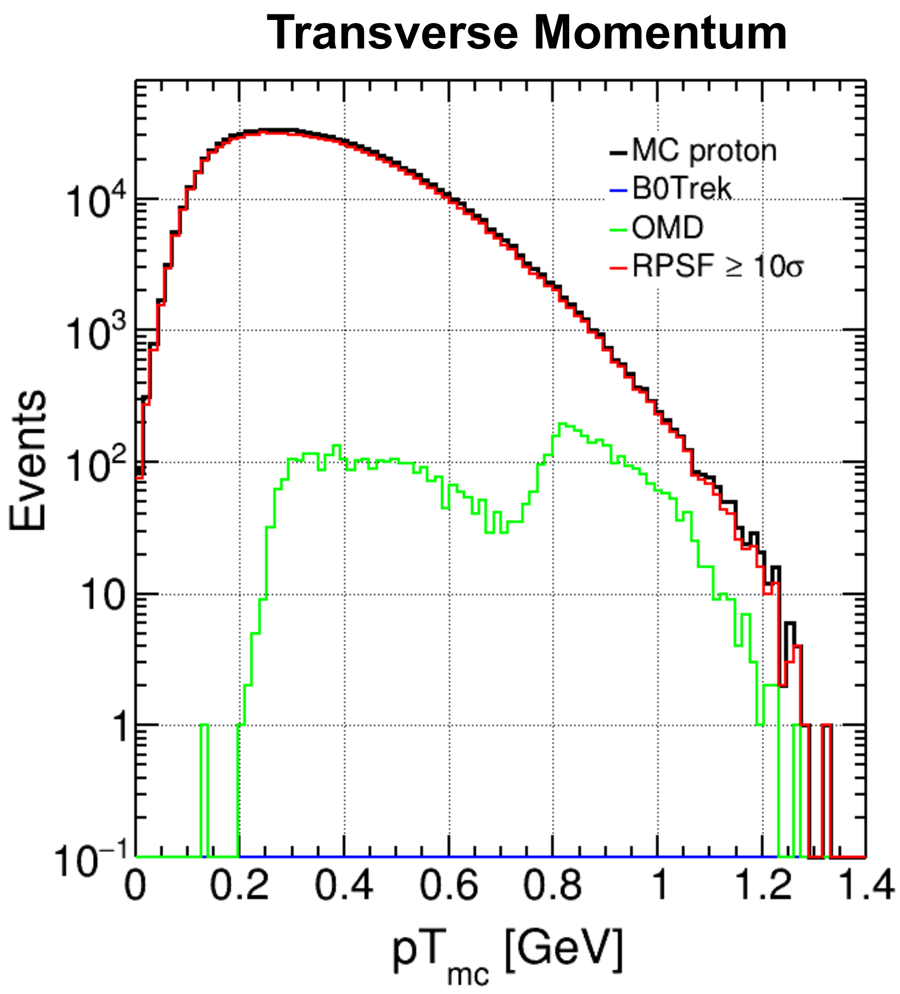
W/O Beampipe at B0

DVCS 18 GeV on 275 GeV

Log Scale

*Each histogram fills individually





MC
B0
OMD
RPSF

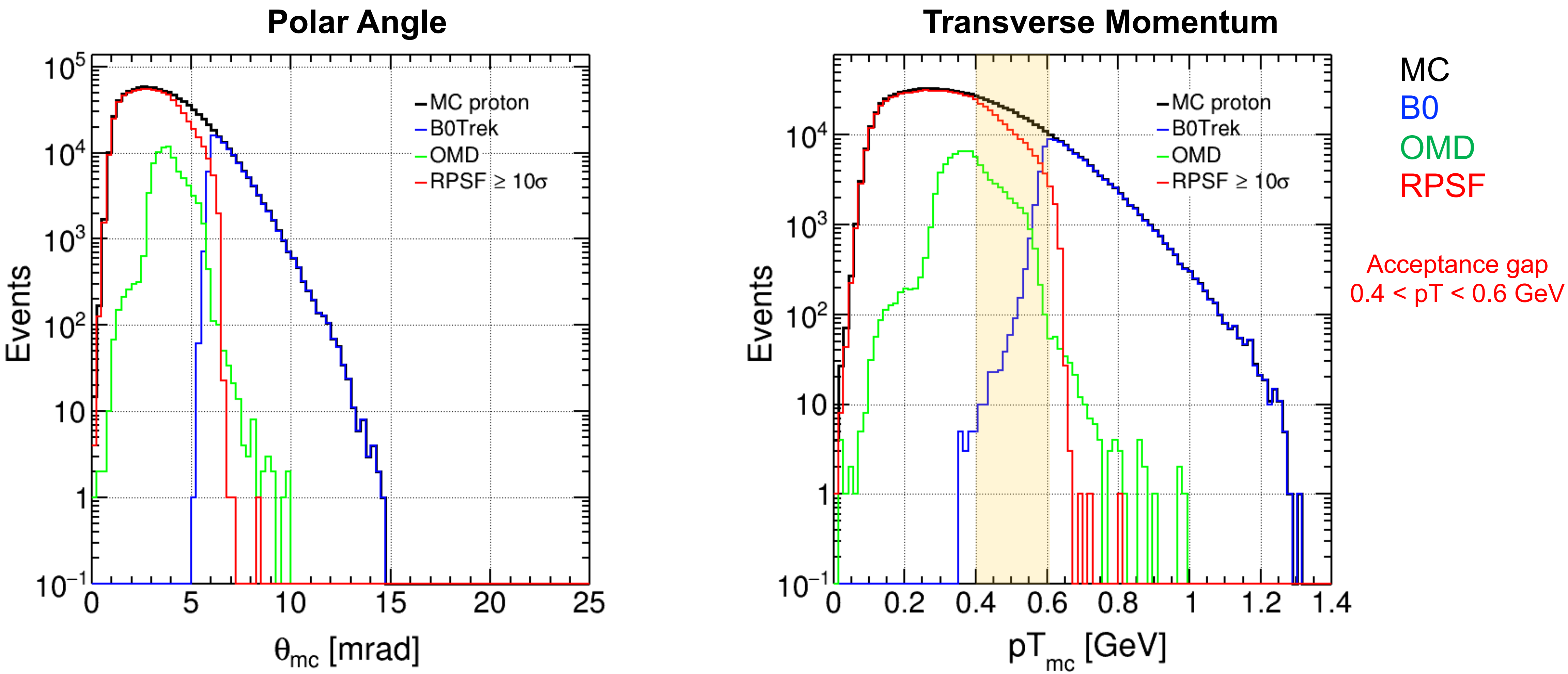
Scattered protons are very forward (< 5 mrad), measured in **Roman Pot at secondary focus**
(**93.33 %** events **accepted** with 10σ safe distance cut based on **ep 18 GeV on 275 GeV β @ IP-8 RPSF**)

W/O Beampipe at B0

DVCS 10 GeV on 100 GeV

Log Scale

*Each histogram fills individually



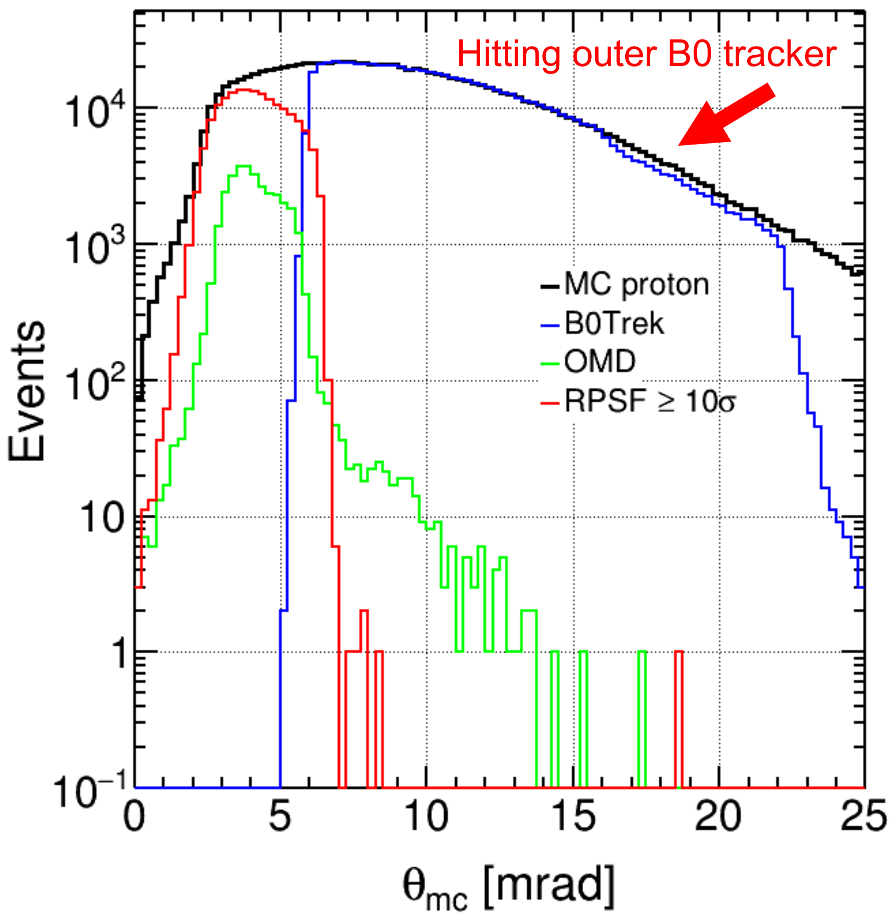
Scattered protons measured in **both B0 and *Roman Pot at secondary focus** (**10.89 %** **and** **77.71 %** events **accepted** with 10σ safe distance cut based on **ep 10 GeV on 100 GeV** β **@ IP-8 RPSF**)

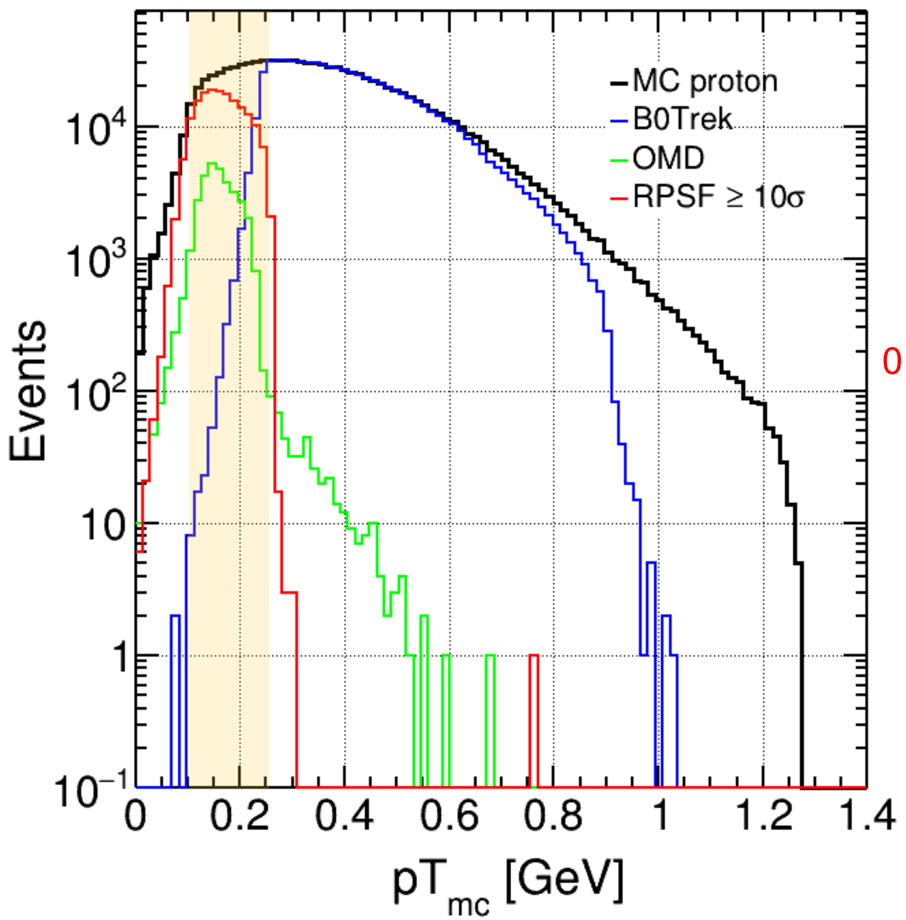
W/O Beampipe at B0

DVCS 5 GeV on 41 GeV

Log Scale

*Each histogram fills individually





MC
B0
OMD
RPSF

Acceptance gap
$0.1 < pT < 0.25$ GeV

Scattered protons measured in **both *B0 and Roman Pot at secondary focus** (**70.62 %** and **16.87 %** events **accepted** with 10σ safe distance cut based on **ep 5 GeV on 41 GeV β @ IP-8 RPSF**)

Approach – Beampipe Impact Study at B0

- How to estimate beampipe size: **15(20)σ-distance** based on **IP-6 beam parameters**
  - **Transverse beam size (σ)** is defined as

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

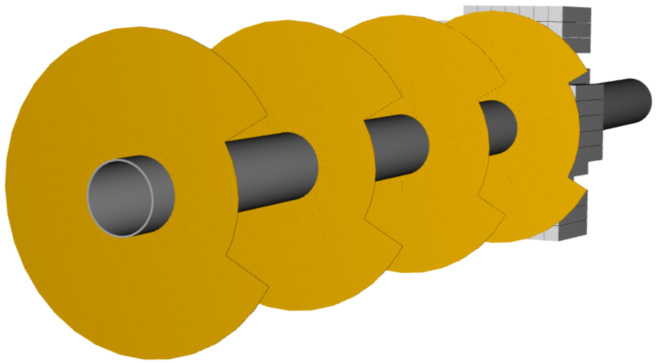
where ϵ : Emittance at z=0, **β : Beta function at z=B0** , D : Momentum dispersion at z=B0, $\frac{\Delta p}{p}$: Momentum spread at z=0

18 GeV on 275 GeV	**σ_{1x} [mm] σ_{1y} [mm]**	**σ_{15x} [mm] σ_{15y} [mm]**	**σ_{20x} [mm] σ_{20y} [mm]**
IP-6 ep High Divergence	0.96747121 0.95916659	**14.512068 14.387499**	19.349424 19.183332

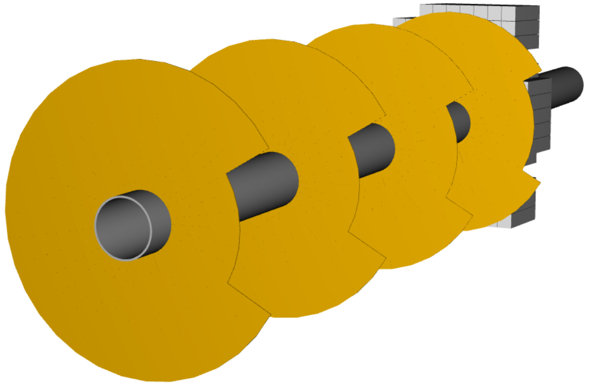
18 GeV on 110 GeV	**σ_{1x} [mm] σ_{1y} [mm]**	**σ_{15x} [mm] σ_{15y} [mm]**	**σ_{20x} [mm] σ_{20y} [mm]**
IP-6 eAu	1.4987997 1.8261984	**22.481996 27.392976**	29.975994 36.523968

Beampipe thickness = 2 mm
Beampipe material = Beryllium

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



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



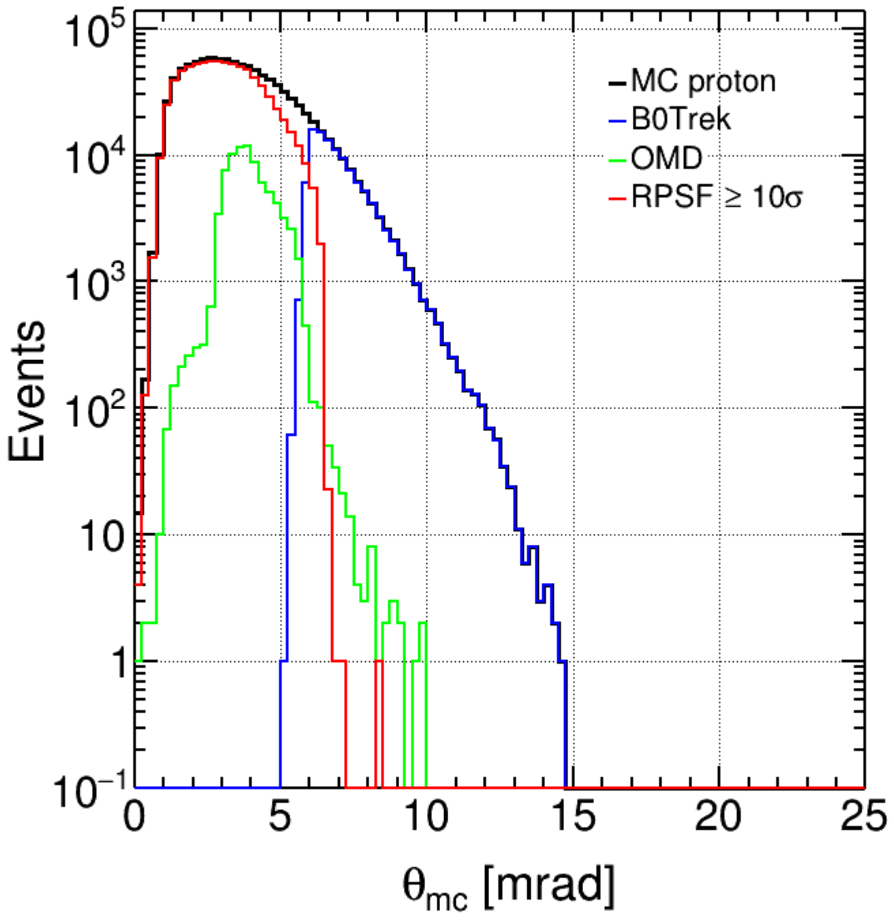
W/O Beampipe at B0

DVCS 10 GeV on 100 GeV

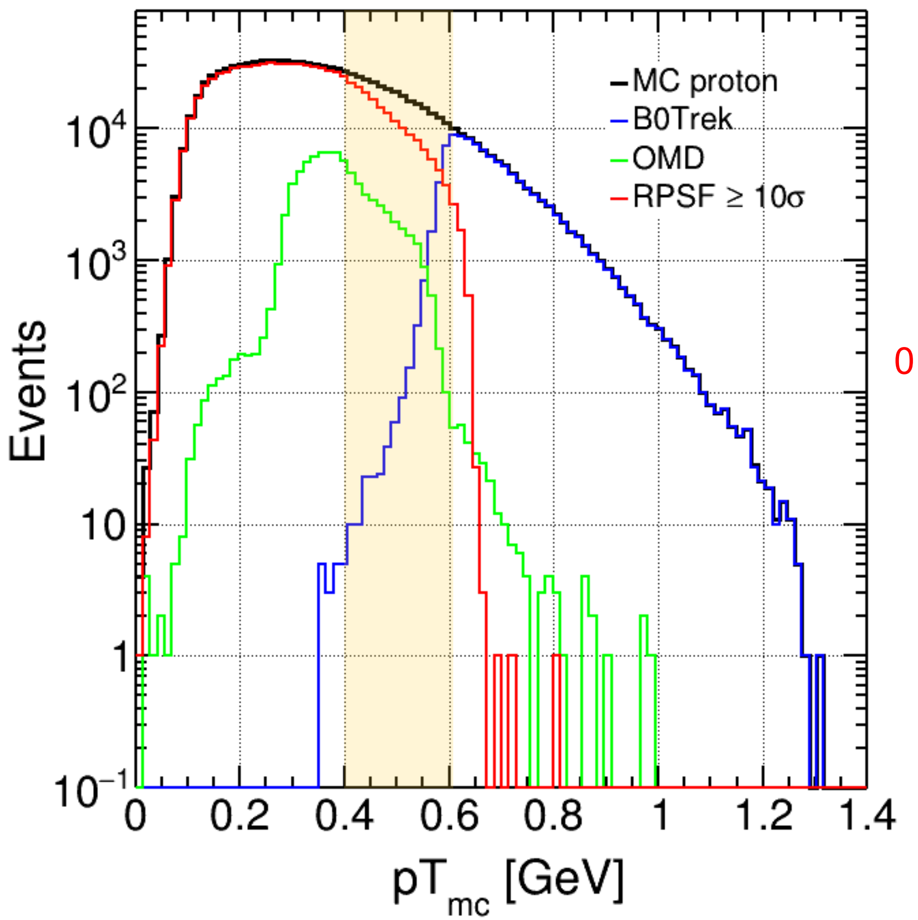
Log Scale

*Each histogram fills individually

Polar Angle



Transverse Momentum



MC
B0
OMD
RPSF

Acceptance gap
$0.4 < pT < 0.6$ GeV

Scattered protons measured in **both B0 and *Roman Pot at secondary focus** (**10.89 %** and **77.71 %** events **accepted** with 10σ safe distance cut based on **ep 10 GeV on 100 GeV β @ IP-8 RPSF**)

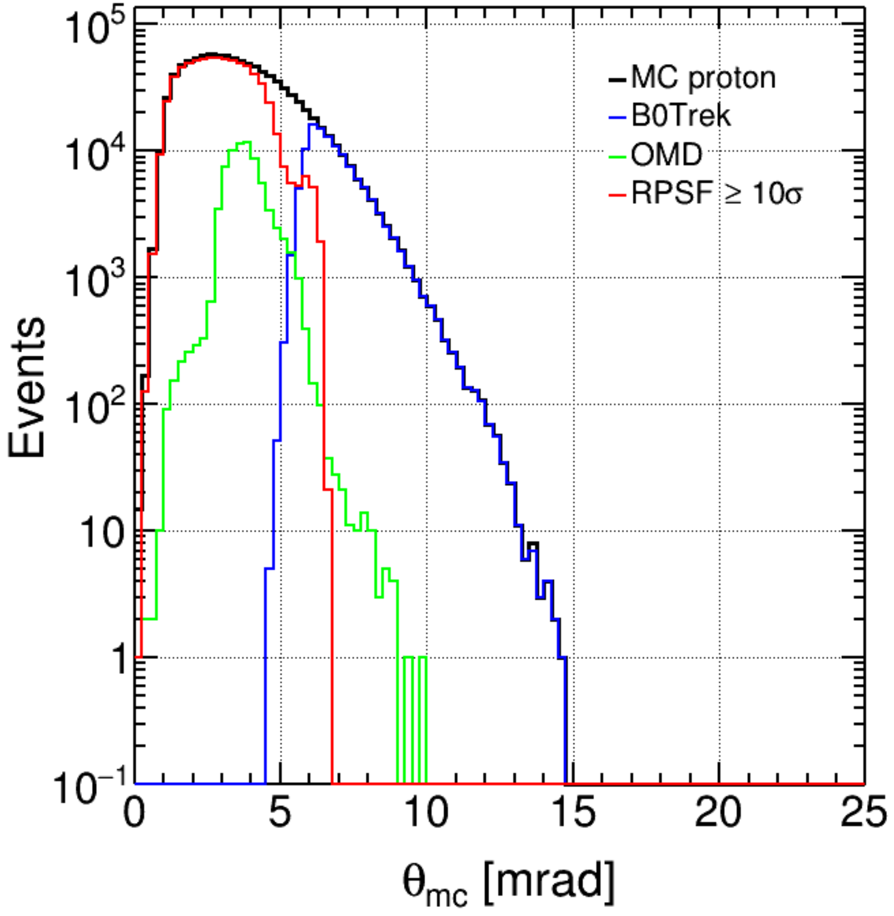
W/ Beampipe ($r_{B0\ tracker\ inner} = r_{beampipe\ outer}$ = 3.5 cm) at B0

DVCS 10 GeV on 100 GeV

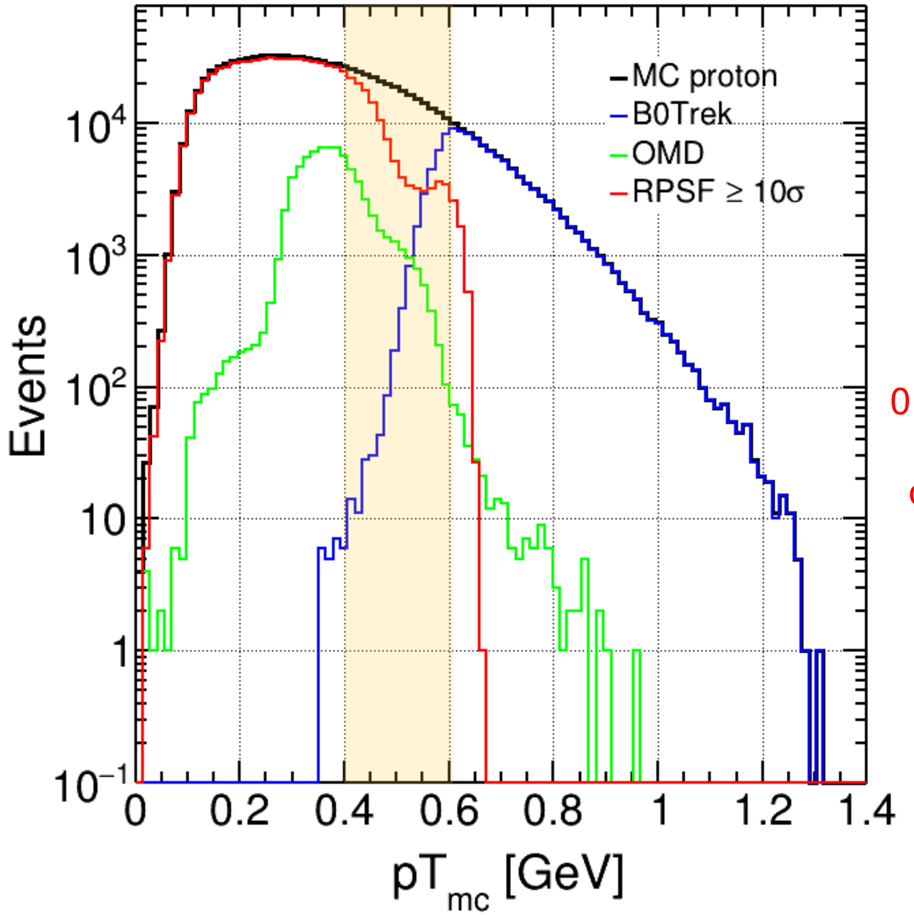
Log Scale

*Each histogram fills individually

Polar Angle



Transverse Momentum



MC
B0
OMD
RPSF

Acceptance gap stays SAME 0.4 < pT < 0.6 GeV, But acceptance drops quite steep

Scattered protons measured in **both B0 and *Roman Pot at secondary focus** (**12.01 %** and **73.32 %** events **accepted** with 10σ safe distance cut based on **ep 10 GeV on 100 GeV β @ IP-8 RPSF**)

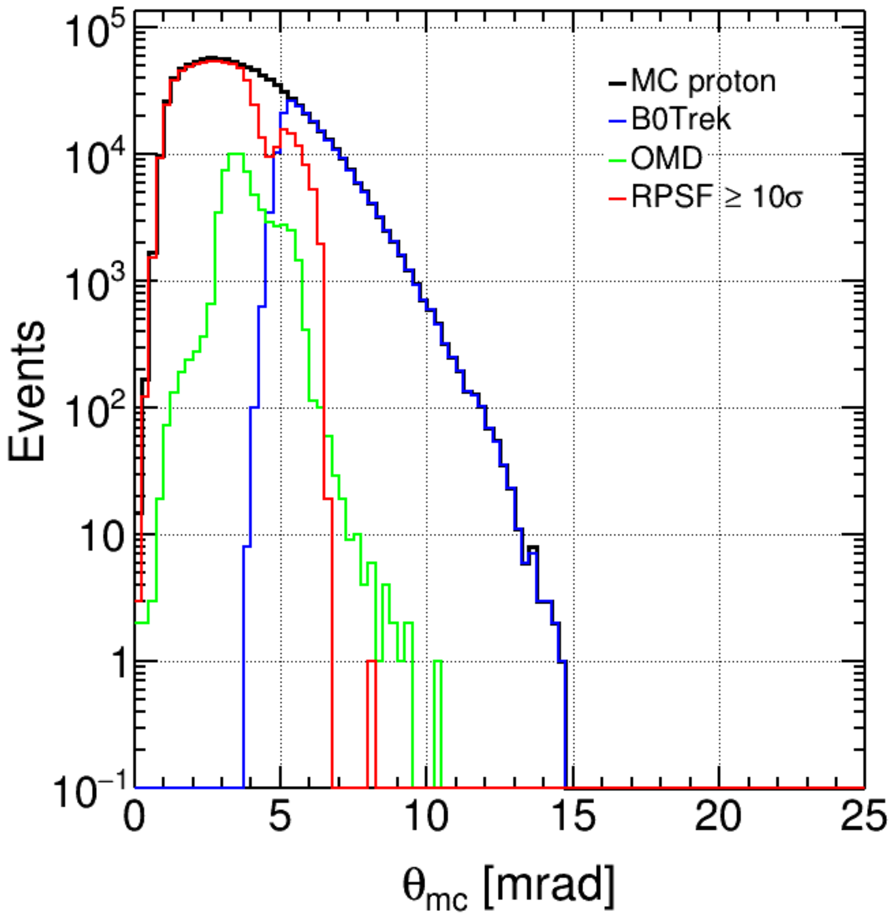
W/ Beampipe ($r_{B0\ tracker\ inner} = r_{beampipe\ outer}$ = 3.0 cm) at B0

DVCS 10 GeV on 100 GeV

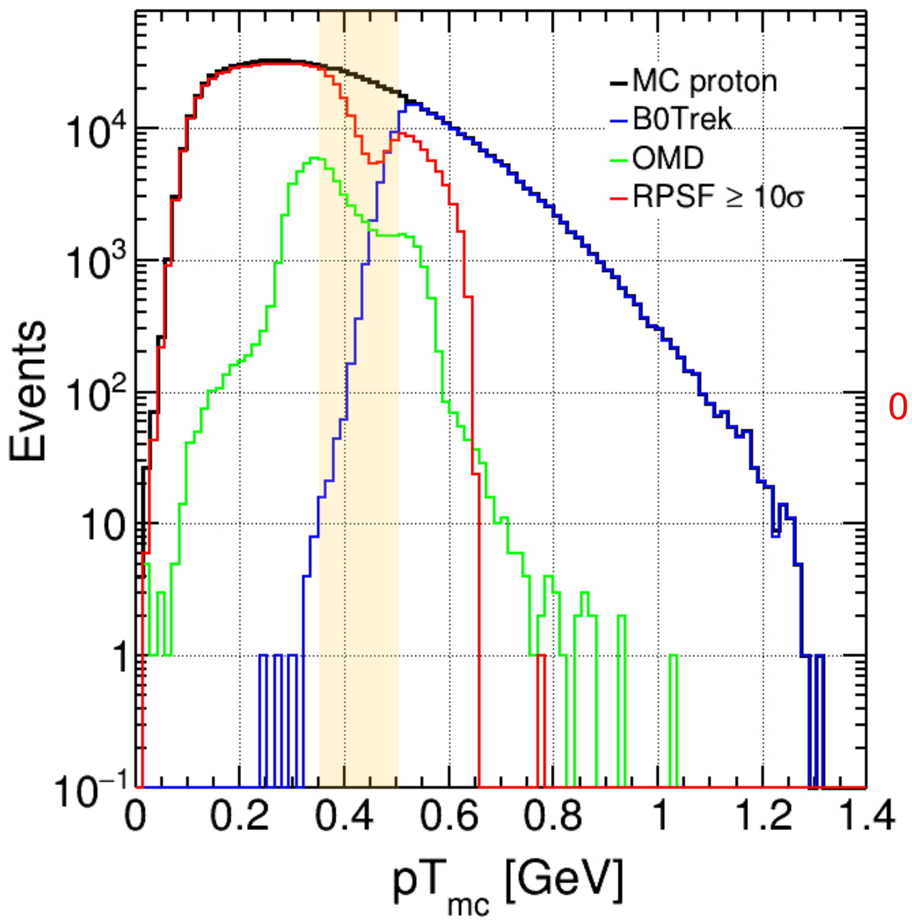
Log Scale

*Each histogram fills individually

Polar Angle



Transverse Momentum



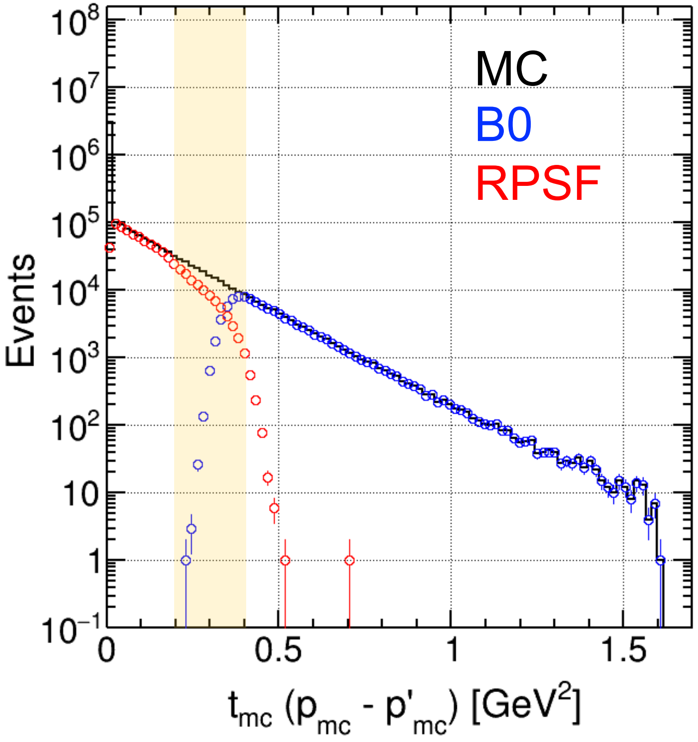
MC
B0
OMD
RPSF

Acceptance gap moves lower pT
0.35 < pT < 0.5 GeV

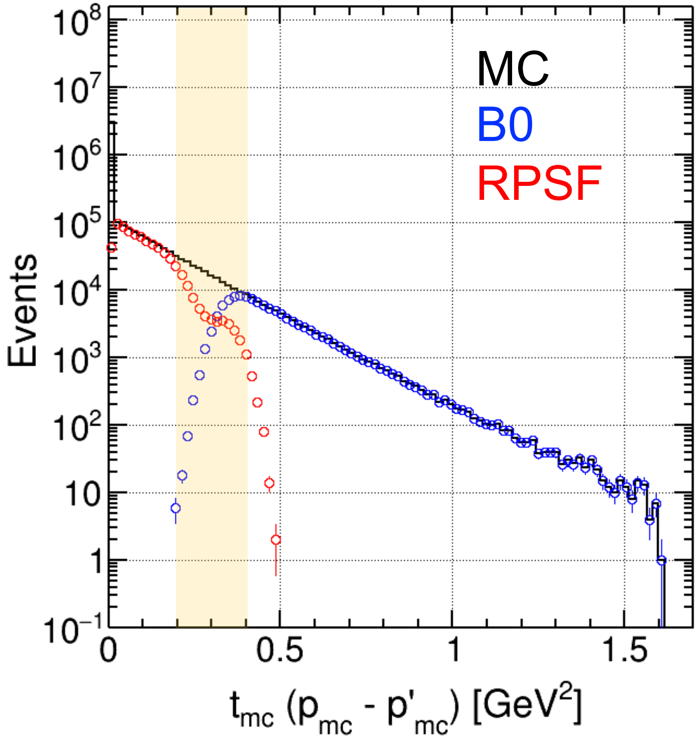
Scattered protons measured in **both B0 and *Roman Pot at secondary focus** (**21.29 %** and **69.62 %** events **accepted** with 10σ safe distance cut based on **ep 10 GeV on 100 GeV β @ IP-8 RPSF**)

DVCS 10 GeV on 100 GeV

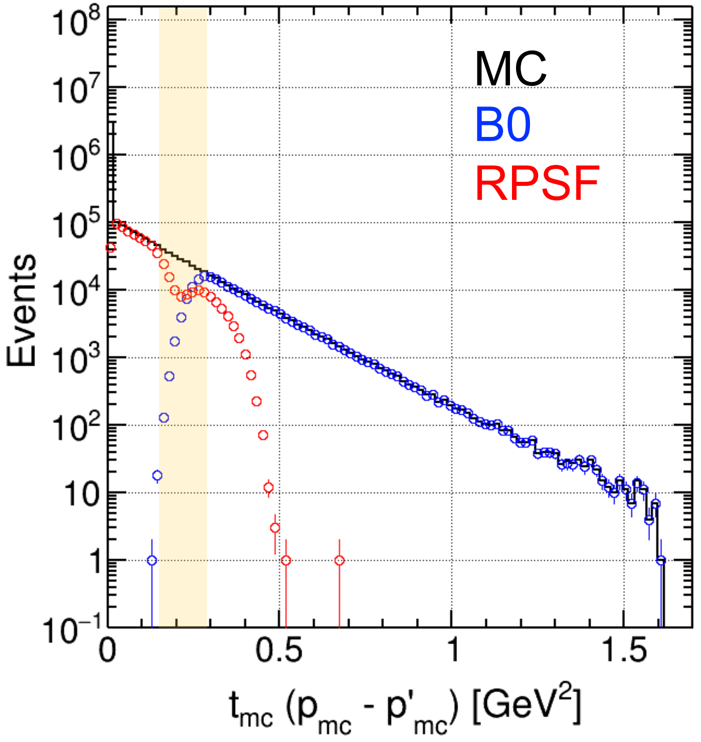
W/O Beampipe at B0



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



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



Approach – Incoherent Vetoing Efficiency

- Understand background to coherent J/ψ production
- Used **BeAGLE** ePb 18×110 GeV incoherent $J/\psi(\mu\mu)$* 801k events with 1 < Q^2 < 10
- Passed through **afterburner IP-8 eAu** configuration
  - IP-8 crossing angle (35 mrad) and IP-6 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 @ IP-8 RPSF**
  - **Transverse beam size (σ)** is defined as $\sigma_{x,y} = \sqrt{\epsilon_{x,y}\beta(z)_{x,y} + (D_{x,y}\frac{\Delta p}{p})^2}$ where ϵ : Emittance at z=0, **β : Beta function at z=RPSF** , D : Momentum dispersion at z=RPSF, $\frac{\Delta p}{p}$: Momentum spread at z=0
- **Tagged events for nuclear breakups <u>tagging purpose</u>**
  - 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**

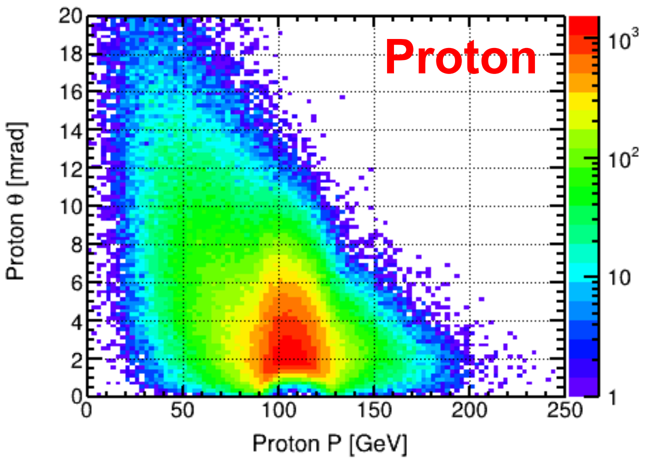
*S3/eictest/EPIC/EVGEN/EXCLUSIVE/DIFFRACTIVE_JPSI_ABCONV/BeAGLE/ePb_18x108.41_tau10_B1.1_Jpsi_highstats/ePb_18x108.41_tune3_tau10_B1.1_extracted_Jmu_1.hepmc

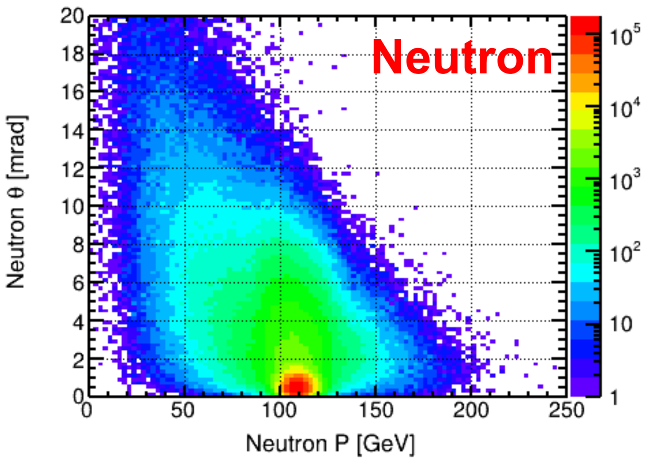
Nuclear Breakups Distribution

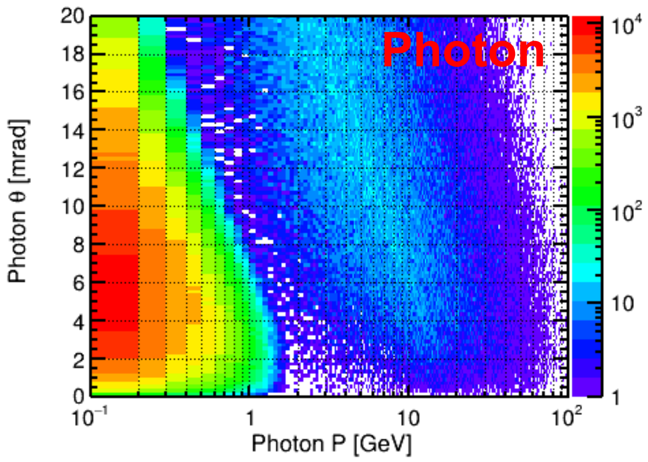
BeAGLE 18x110 GeV^2
Incoherent events
$ePb \rightarrow e' + J/\psi(\mu\mu) + X$

	Nuclear Breakups at Final State	Number of Events
Generated Level	**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 %

94.53 % of events have **neutrons** in nuclear breakups



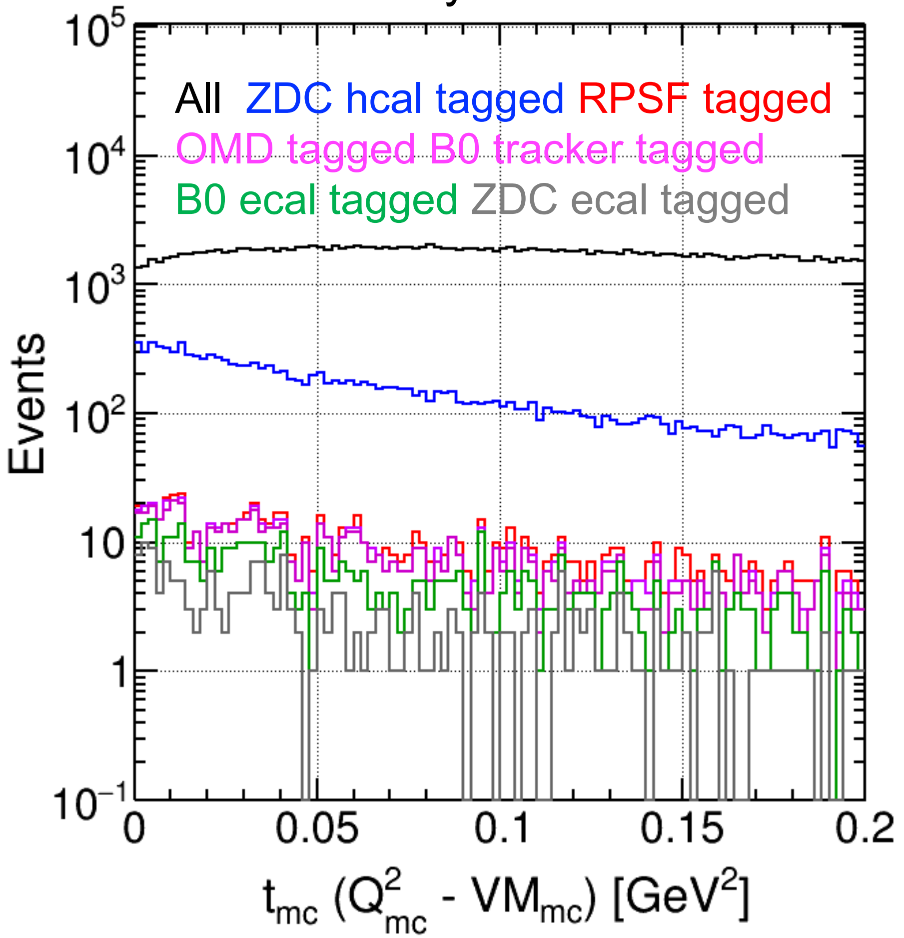




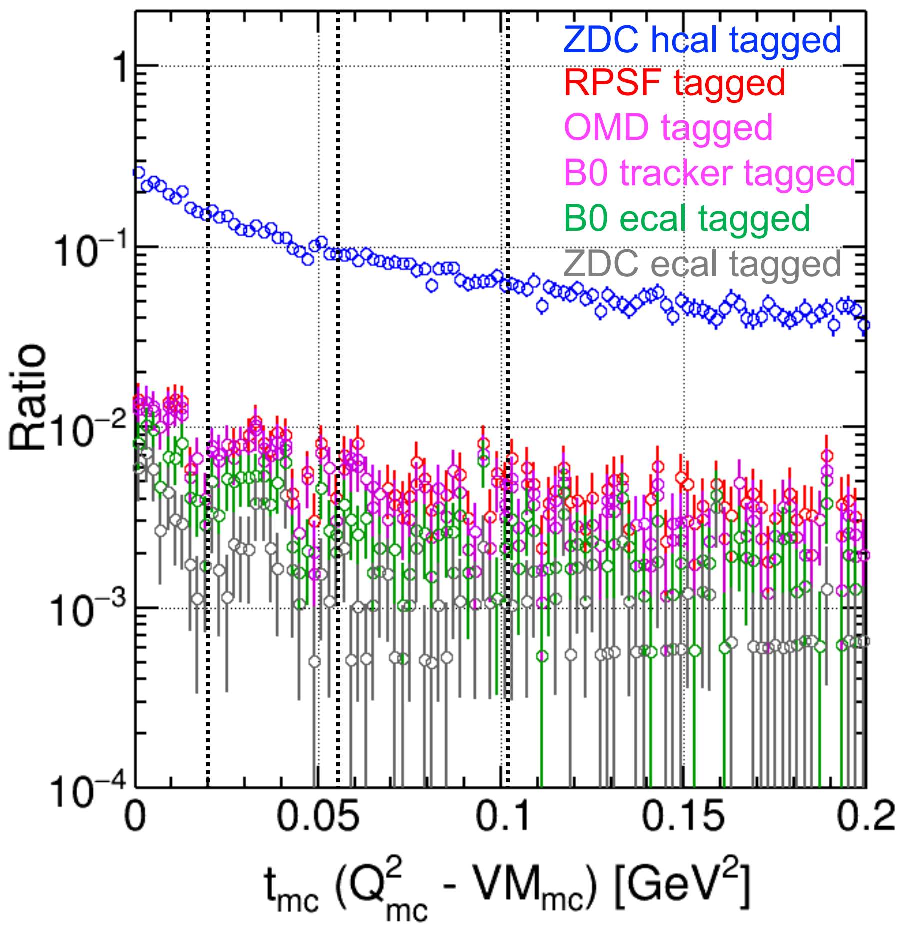
t distribution

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

Veto inefficiency for incoherent events



Coherent diffractive minima

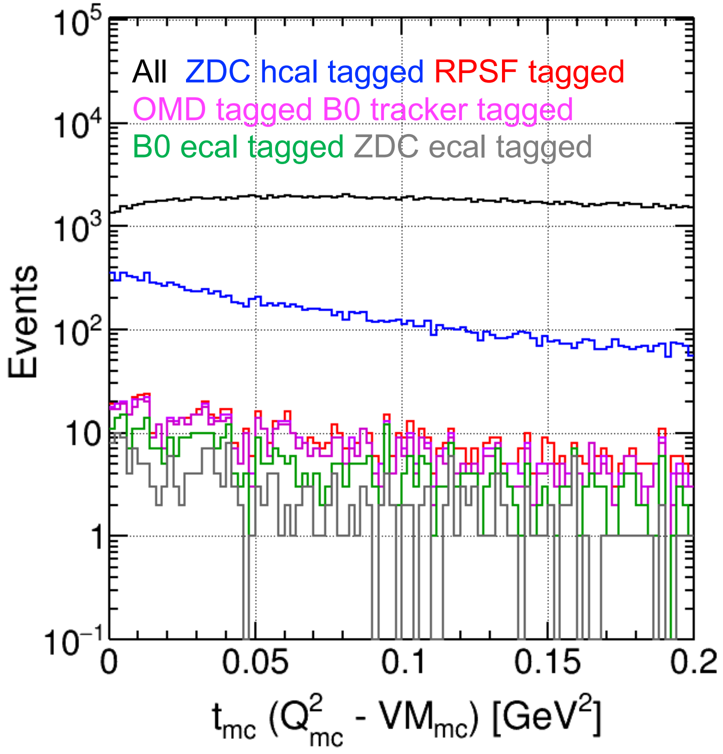


Found to be enough to suppress incoherent contribution at three minima
Vetoing efficiency is about 99.99%

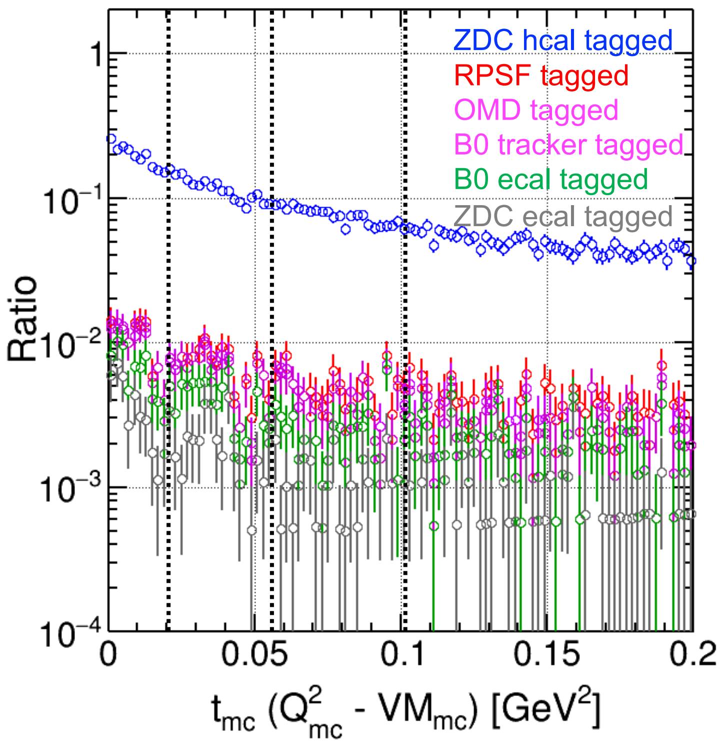
t distribution

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

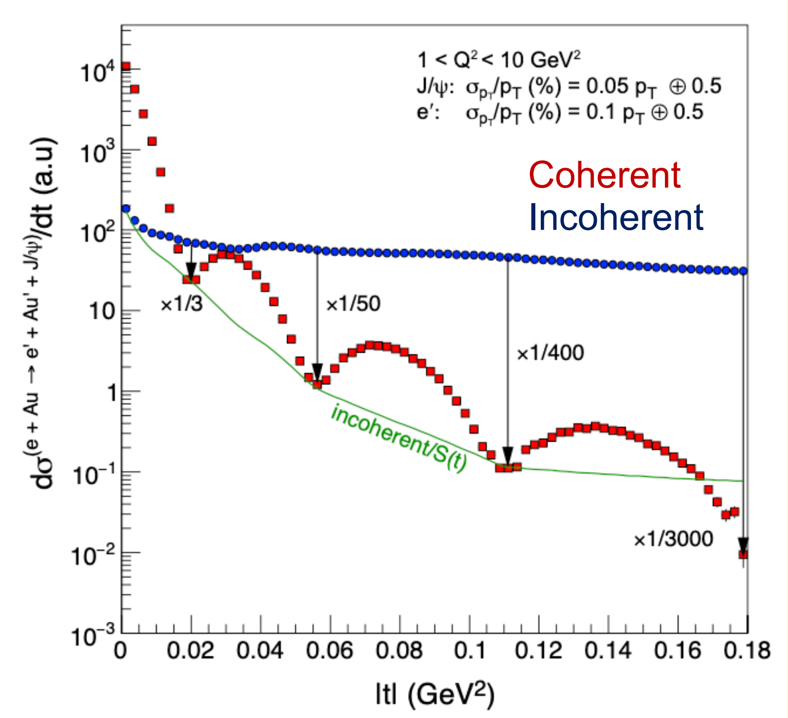
Veto inefficiency for incoherent events



Coherent diffractive minima



Reference from EIC YR p.352



At position of third diffractive minimum, rejection factor for incoherent event better than 400:1 must be achievable

Found to be enough to suppress incoherent contribution at three minima
Vetoing efficiency is about 99.99%

Remaining Events

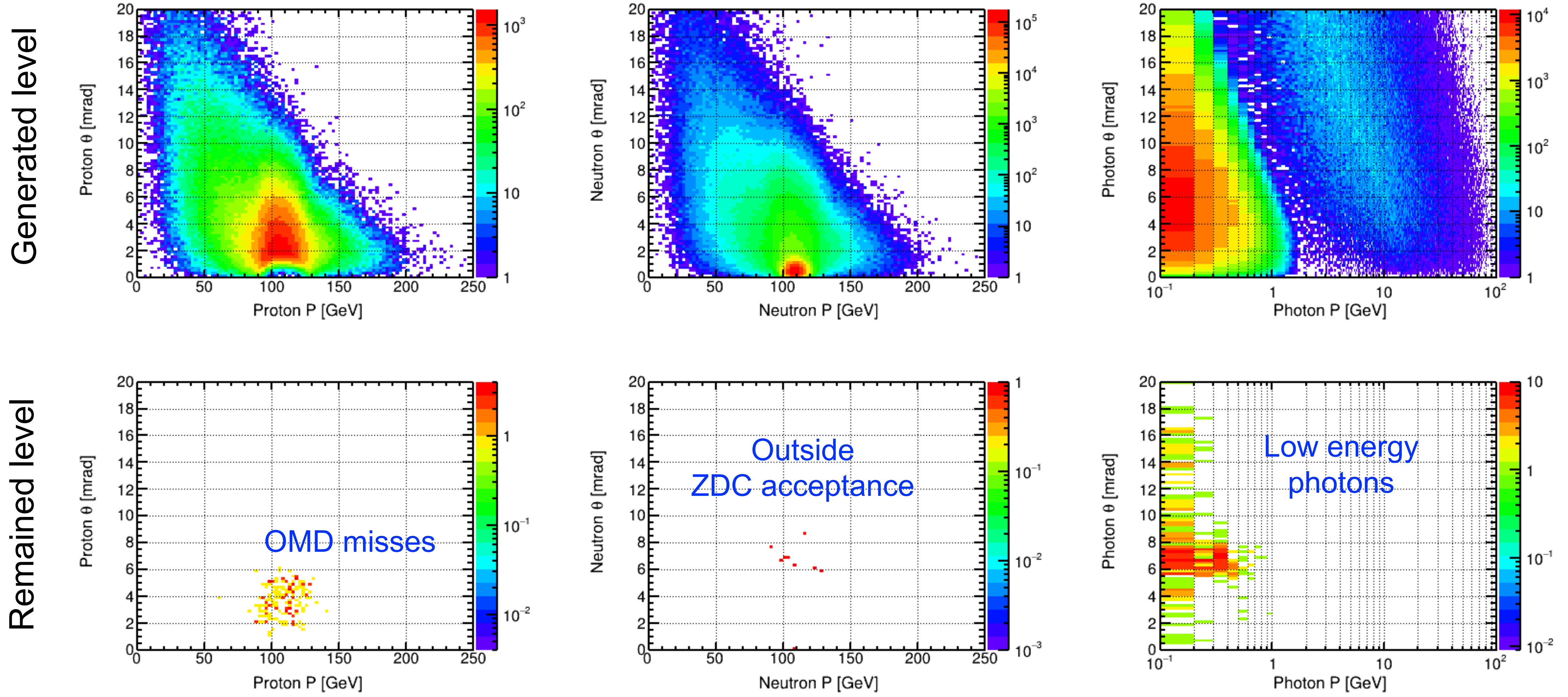
BeAGLE 18x110 GeV^2
Incoherent events
$ePb \rightarrow e' + J/\psi(\mu\mu) + X$

Veto Selections	Surviving Events
All events	801,464
Events with one scattered electron identified and $\lvert\eta_{J/\psi}\rvert < 4$	711,795 (100.0 %)
ZDC HCAL tagged	41,751 (5.86559 %)
+ RPSF tagged	2,785 (0.391264 %)
+ OMD tagged	2,484 (0.348977 %)
+ B0 tracker tagged	1,994 (0.280137 %)
+ B0 ecal tagged	1,257 (0.176596 %)
+ ZDC ECAL tagged	589 (**0.0827485 %**)

With 10σ safe distance cut based on ***eAu β @ IP-8 RPSF***
589 of 801,464 events were NOT vetoed

Remaining Events

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



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)
  - Acceptance and things can change as this is still pre-conceptual design (magnets, space, etc)
- Using exclusive DVCS events, understanding acceptance gap in pT between B0 and RPSF
  - 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 IP-6 and IP-8
- Using BeAGLE incoherent events, evaluating vetoing power to understand background to coherent events with $1 < Q^2 < 10$ and $t < 0.2$
  - Used more realistic beam optics for IP8 ep(eAu) especially for secondary focus
  - Vetoing power reaches $\sim 10^{-3}$ at three coherent diffractive minima

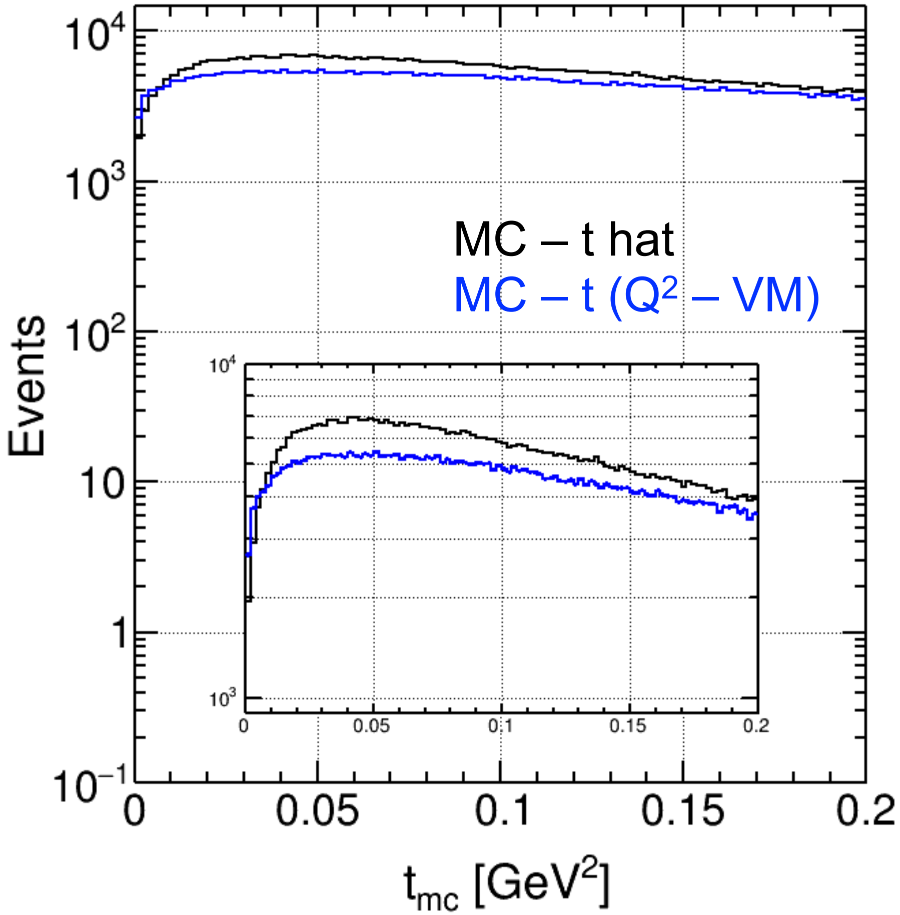
Next Steps

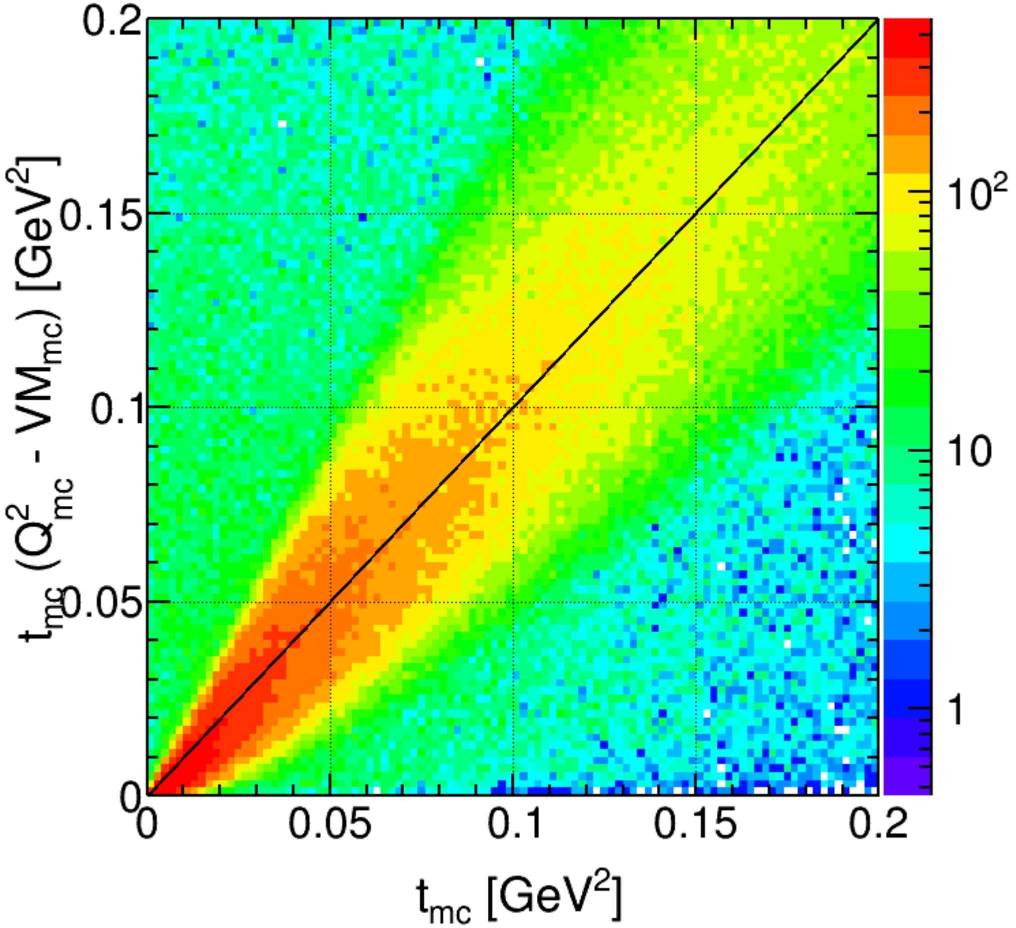
- Recently more realistic beam optics for IP-8 thanks to Randy
  - Update forward beamline – this will affect on detector acceptance
    - Coordinates of magnets and magnetic fields
    - Expect small impact in acceptance. Need to re-evaluate
    - Will include into D2EIC github repo
    - eAu lattice study coming up (so far, ep lattice study with different beam configurations)
- Look into events without beam effects
  - Current sample with beam effects has more (transverse) momentum-kick
  - Evaluate vetoing power on detector response
- Implement beampipe between OMD-ZDC-RPSF to study beampipe impact

t Calculation using Wan's Data

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

Wan's data files ("**EICTree**") in total **1.15M** events are from:
/gpfs/mnt/gpfs02/eic/wanchang/Paper_vetoing_IP8/20230910/simFiles/simulation_BeAGLE_18x110_ePb_file_*.root





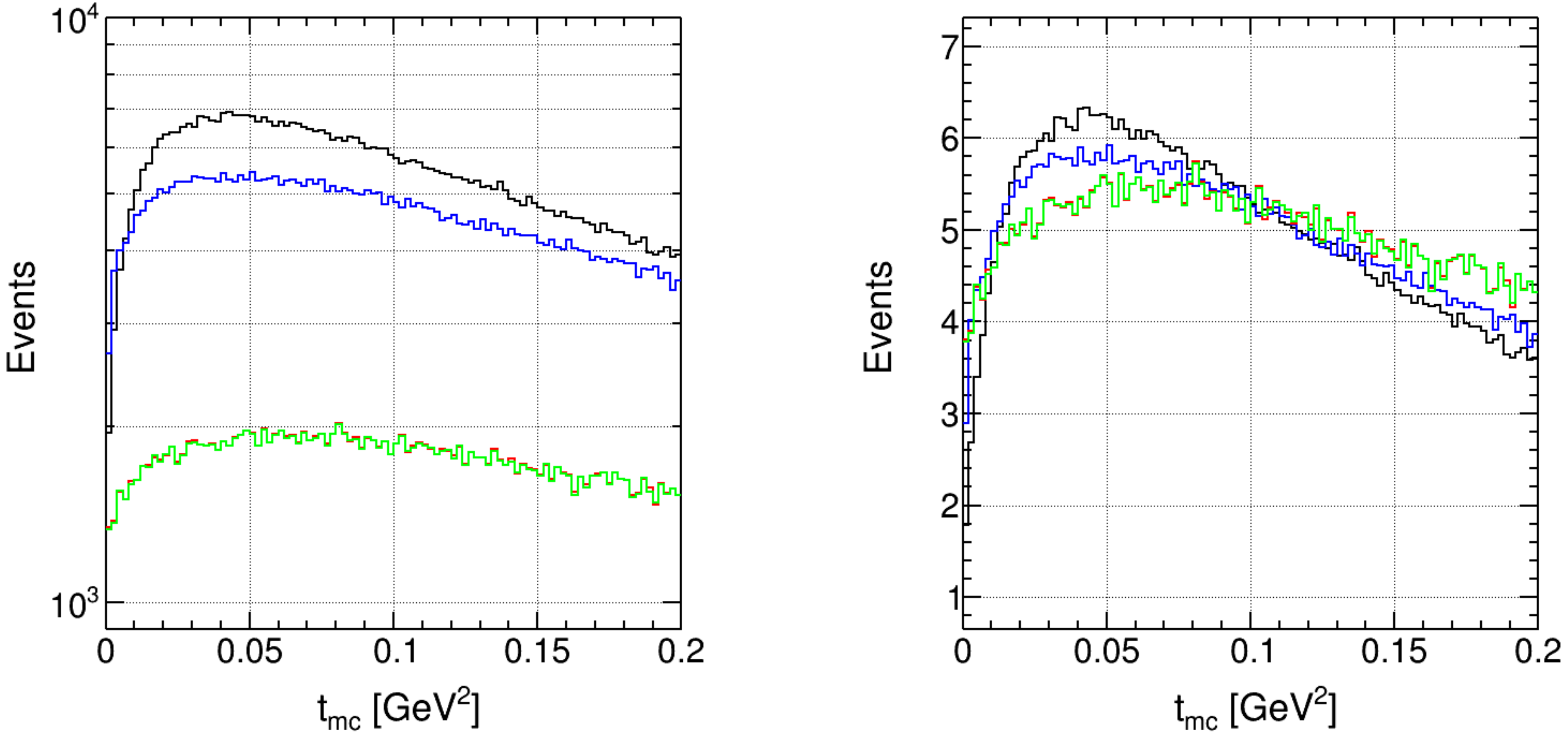
Used different t calculations (1 < Q^2 < 10 GeV^2)

- t read off from PYTHIA directly ("**t_hat**"): 1.02M events used
- t calculated from four-momentum of scattered electron and vector meson (decaying J/ψ): 0.99M events used

t Calculation

Wan data without beam effects: MC – t hat
Wan data without beam effects: MC – t (Q^2 – VM)
Jihee data with beam effects: MC – t (Q^2 – VM)
Jihee data without beam effects: MC – t (Q^2 – VM)

BeAGLE 18x110 GeV^2
Incoherent events
$ePb \rightarrow e' + J/\psi + X$
$1 < Q^2 < 10$ GeV^2

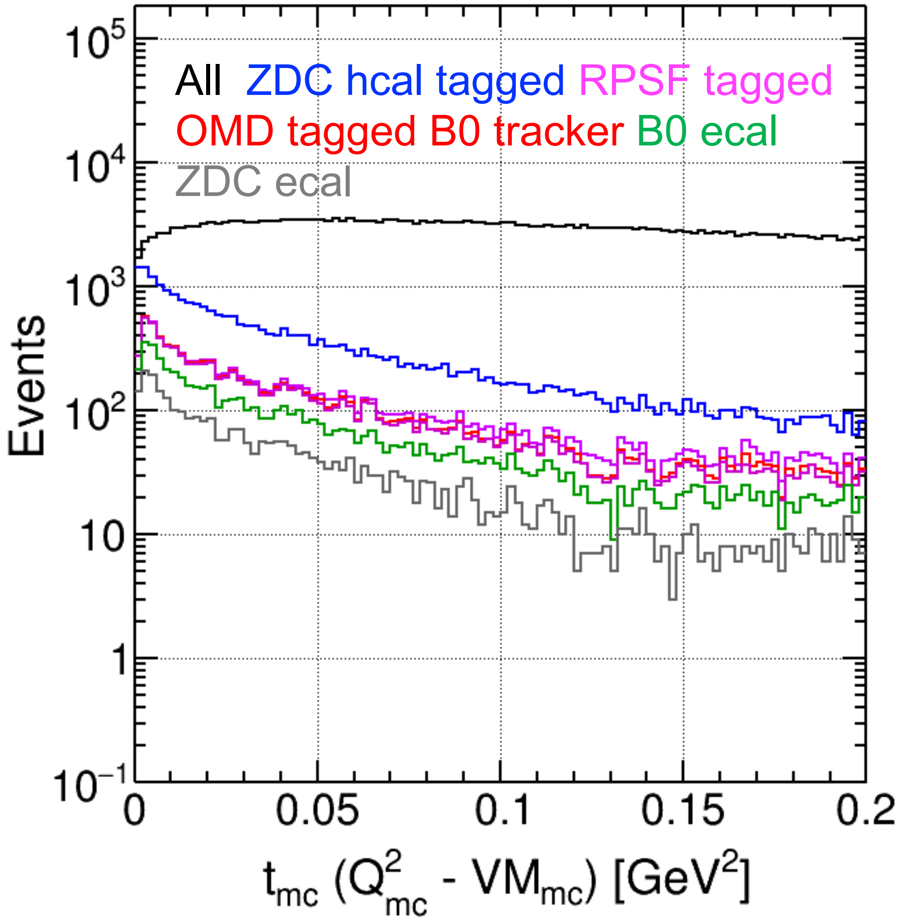


Using *final-state particles from BeAGLE hepmc file, t values are not much difference with or without beam effects.
However, vetoing power shows otherwise, very different (comparing one another on following slides #3 and 4)
*taken out crossing angle effects when calculating t with/without beam effect data

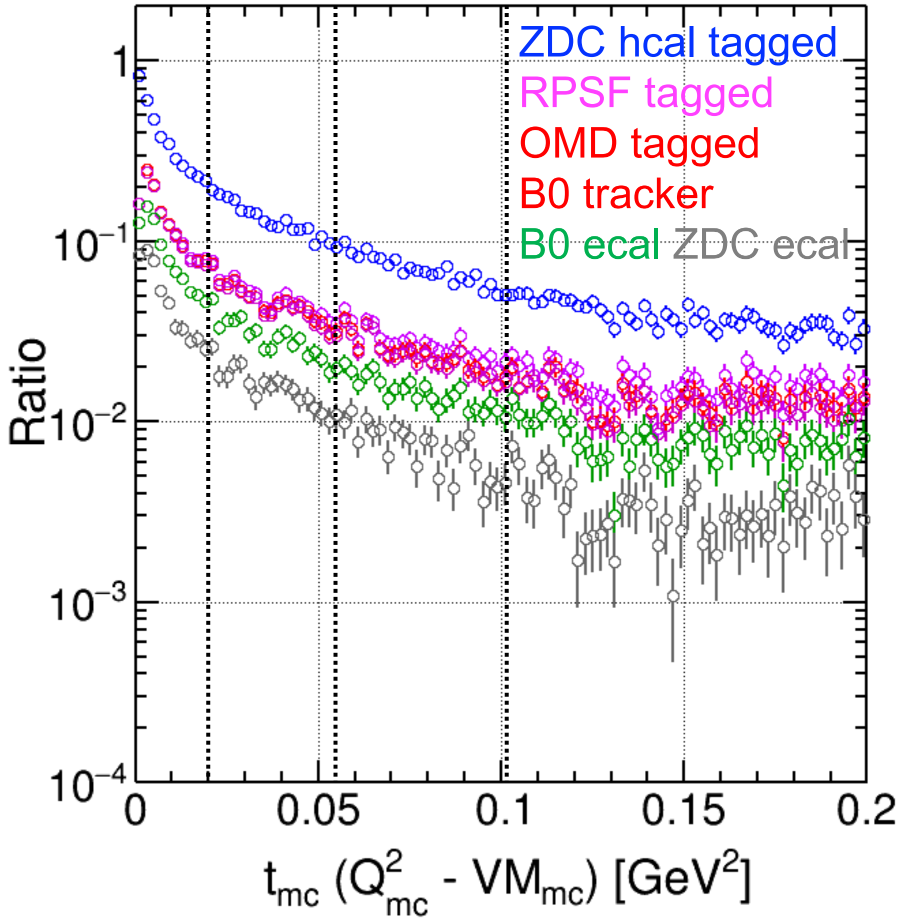
W/O Beam effects

t distribution

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



Coherent diffractive minima



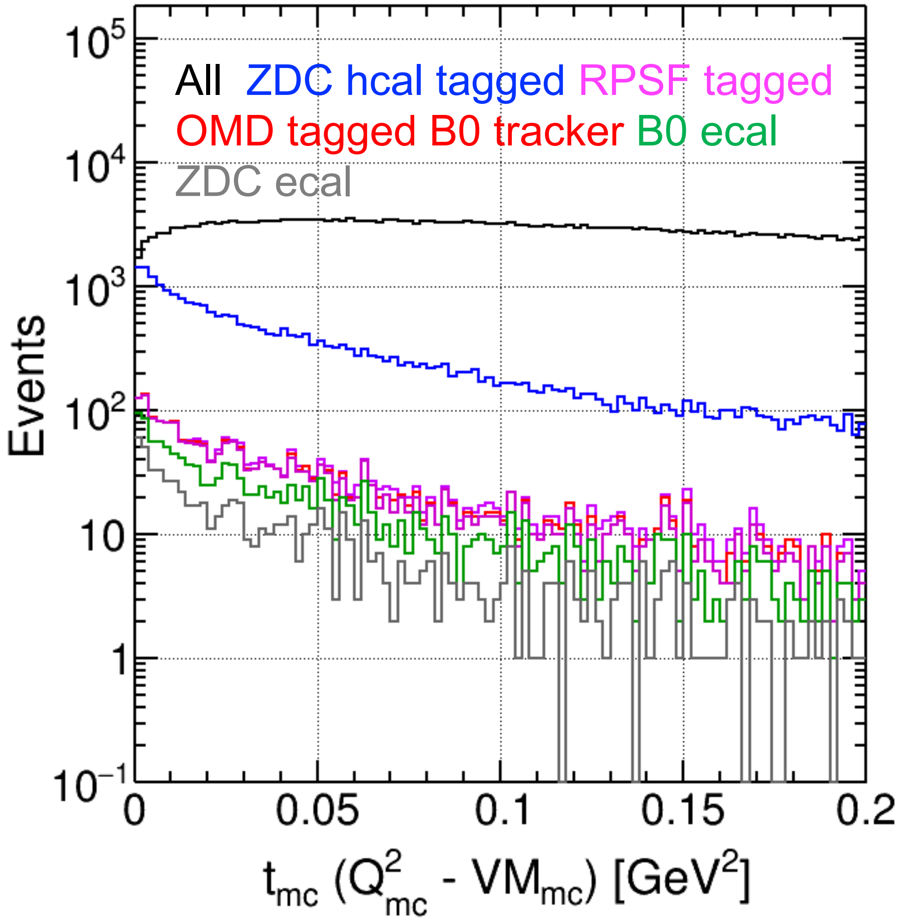
With 10σ safe distance cut based on ***exact Wan's IP8 sigma cut***

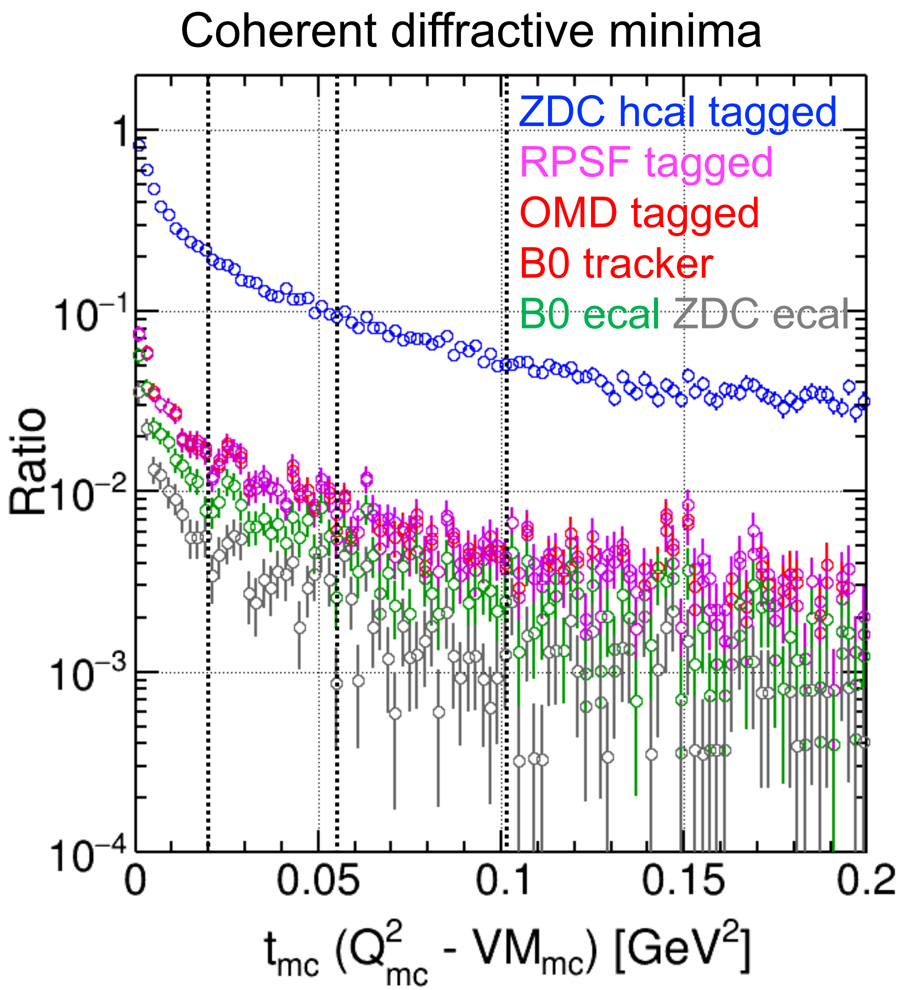
3,837 of 800,978 events were NOT vetoed (0.538 %)

W/ Beam effects

t distribution

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





With 10σ safe distance cut based on ***exact Wan's IP8 sigma cut***

886 of 800,964 events were NOT vetoed (0.12 %)

Vetoing Power Update

- Randy sent IP-8 lattice study for ep 18GeV on 275 GeV configuration

18 GeV on 110 GeV		Momentum Dispersion ($D^{secondary\ focus}$)	Emittance X (ϵ_x*) [mm]	Emittance Y(ϵ_y*) [mm]	Beta function X ($\beta_x^{secondary\ focus}$) [mm]	Beta function Y ($\beta_y^{secondary\ focus}$) [mm]	Momentum spread ($\Delta p/p$)*
IP8 eAu	Old	0.382	43.2e-6	5.8e-6	2289.454596	4538.713168	6.2e-4
	New	**0.465446718**	43.2e-6	5.8e-6	**498.013008**	**3392.376638**	6.2e-4

- Transverse beam size (σ) calculation at secondary focus

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

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

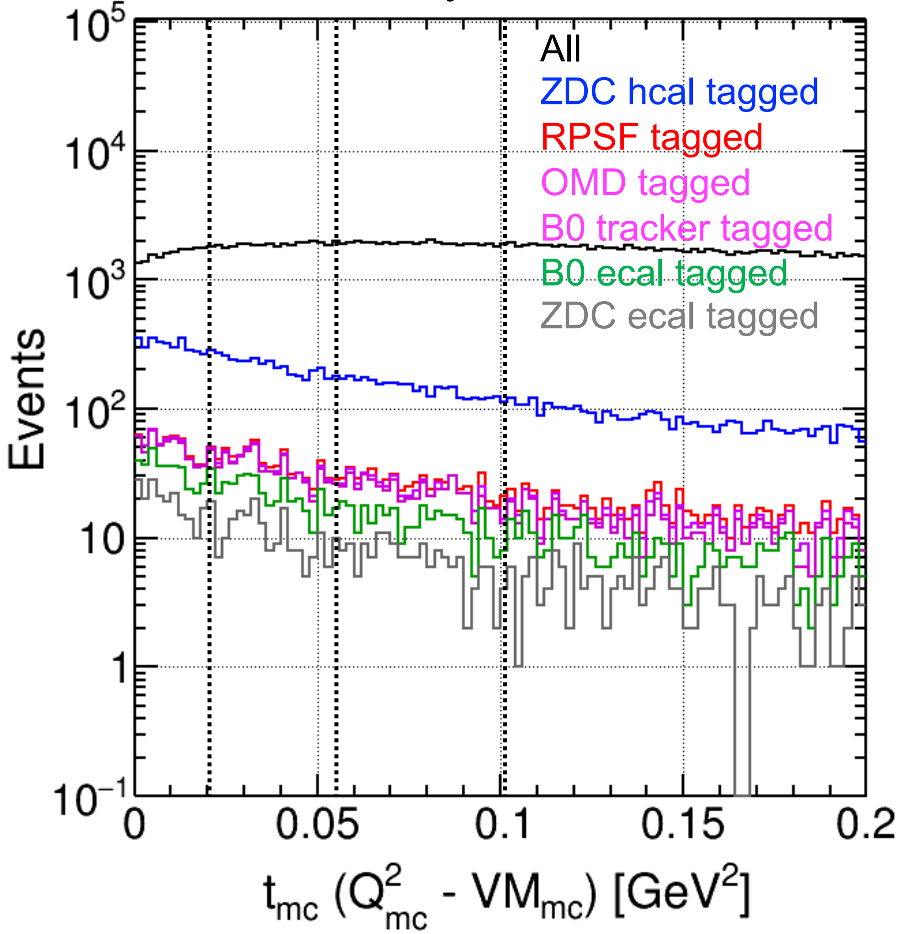
	σ_{1x}	σ_{1y}
eAu β @ IP8 RPSF (Old)	**0.314867**	**0.1629770**
Wan's IP8 Study	0.328283	0.085217
eAu β @ IP8 RPSF (New)	**0.146677**	**0.140271**

W/ Beam effects

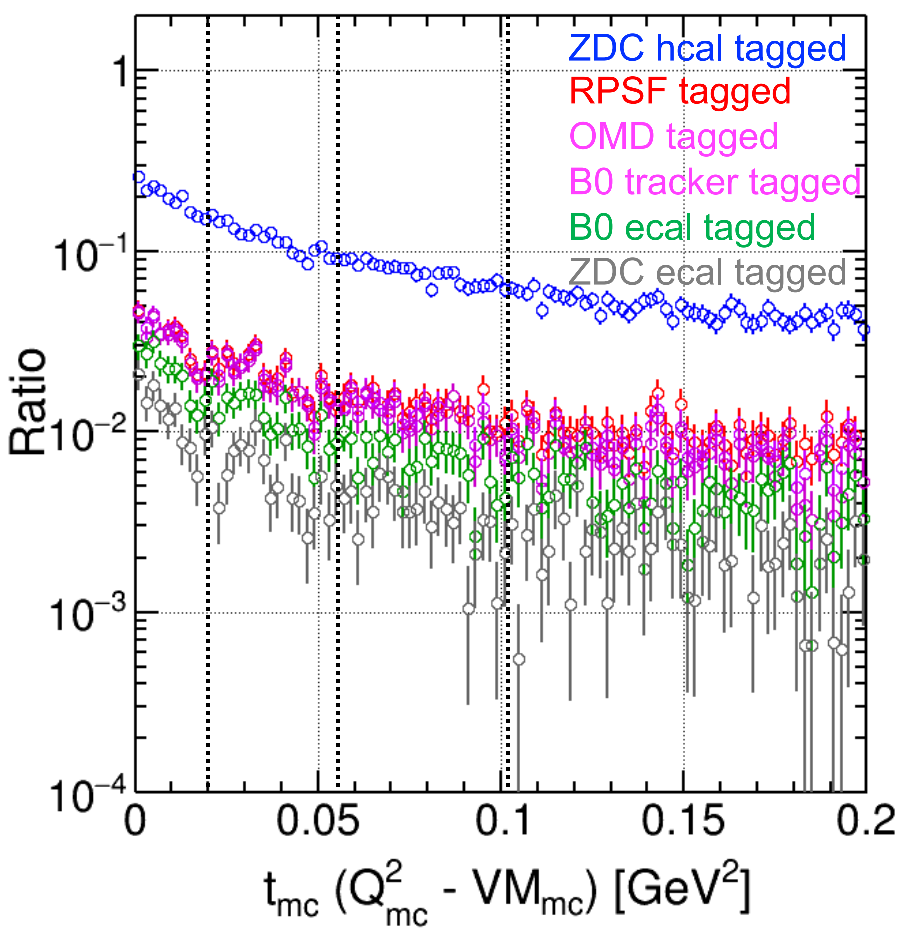
t distribution – IP-8 Old 10σ Cut

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

Veto inefficiency for incoherent events



Coherent diffractive minima



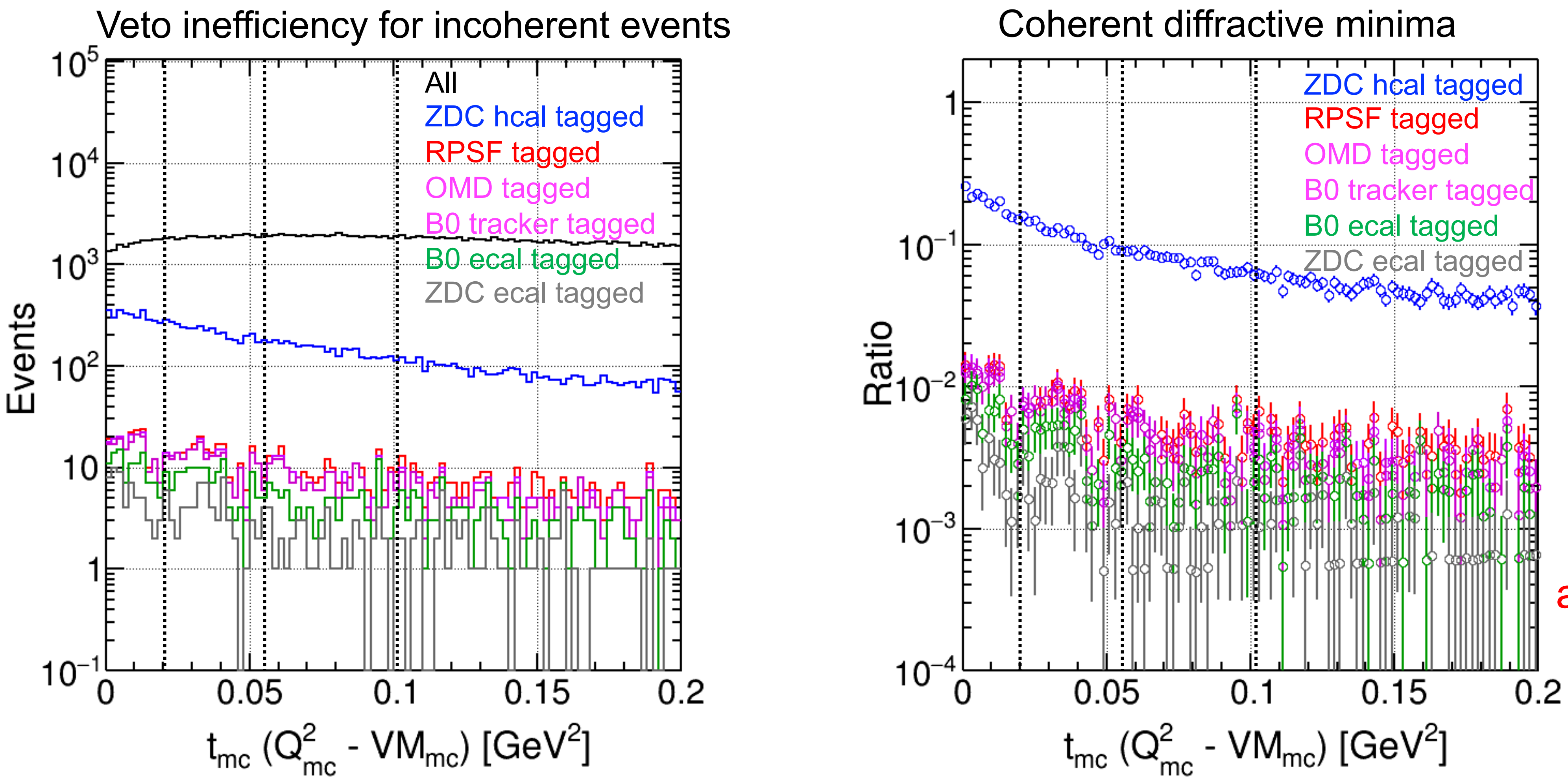
With 10σ safe distance cut based on ***old eAu @ IP-8 RPSF***

0.252 % events were NOT vetoed

W/ Beam effects

t distribution – IP-8 New 10σ Cut

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



Found to be enough to suppress incoherent contribution at three minima
Vetoing efficiency is about 99.99%

With 10σ safe distance cut based on ***new eAu @ IP-8 RPSF***

0.083 % events were NOT vetoed

Summary

- Checked different t calculations using Wan's IP-8 study data
  - Known in t difference between direct BeAGLE and final-state information
  - Using final-state particles from BeAGLE hepmc file, t values are not much difference with or without beam effects
  - However, it makes a big difference in vetoing power because **sample with beam effect has transverse momentum kicks** (making easier particle getting out of beam envelope)
- Updated vetoing power based on latest version of IP-8 lattice study
  - Momentum dispersion at secondary focus became larger, but x and y beta function values are smaller especially in x (quadrupole before secondary focus squeezes in x)
  - In transverse beam size calculation, beta function term is more dominate. Even momentum dispersion became larger, in general new 1σ safe distance is much smaller than old beam parameters
  - With latest values from IP-8 lattice study, **vetoing power is enough to suppress incoherent contribution at three minima** (vetoing efficiency is about 99.99%)