Update on IP-8 Far-Forward Detector Simulation pT Acceptance with B0 and Vetoing Efficiency

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

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	Momentum Dispersion (D^{B0})	Emittance X (ϵ_x*) [mm]	Emittance Y(ϵ_y*) [mm]	Beta function X ($\beta_x{}^{B0}$) [mm]	Beta function Y ($\beta_y{}^{B0}$) [mm]	Momentum spread $(\Delta p/p)$*	σ_{1x} [mm] σ_{1y} [mm]	σ_{15x} [mm] σ_{15y} [mm]	σ_{20x} [mm] σ_{20y} [mm]
IP-6 ep High Divergence	8.e-4	18.e-6	1.6e-6	52000	575000	6.8e-4	0.96747121 0.95916659	**14.512068** **14.387499**	**19.349424** **19.183332**
18 GeV on 110 GeV	**Momentum Dispersion (D^{B0})**	**Emittance X (ϵ_x*) [mm]**	**Emittance Y(ϵ_y*) [mm]**	**Beta function X ($\beta_x{}^{B0}$) [mm]**	**Beta function Y ($\beta_y{}^{B0}$) [mm]**	**Momentum spread $(\Delta p/p)$***	**σ_{1x} [mm] σ_{1y} [mm]**	**σ_{15x} [mm] σ_{15y} [mm]**	**σ_{20x} [mm] σ_{20y} [mm]**
IP-6 eAu	8.e-4	43.2e-6	5.8e-6	52000	575000	6.2e-4	1.4987997 1.8261984	**22.481996** **27.392976**	**29.975994** **36.523968**

Momentum Dispersion (D) and **Beta functions**(β_x and β_y) **at B0 position** in table are values from IP-6 beam optics file

B0 Beampipe

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

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

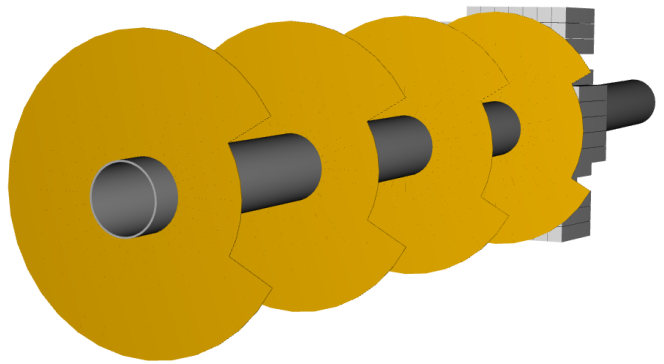
where ϵ : Emittance at z=0, $\boldsymbol{\beta}$ **: Beta function at z=B0** , D : Momentum dispersion at z=B0, $\frac{\Delta p}{p}$: Momentum spread at z=0

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**

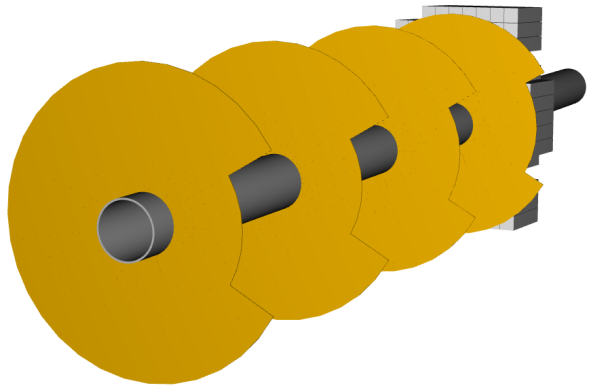
18 GeV on 110 GeV	σ_{1x} [mm] σ_{1y} [mm]	σ_{15x} [mm] σ_{15y} [mm]	σ_{20x} [mm] σ_{20y} [mm]
IP6 eAu	1.4987997 1.8261984	**22.481996** **27.392976**	**29.975994** **36.523968**

Beampipe thickness = 2 mm
Beampipe material = Beryllium (transparency for particles)
(Will try other materials ex. aluminum, stainless, copper)

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



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



Approach – pT Acceptance

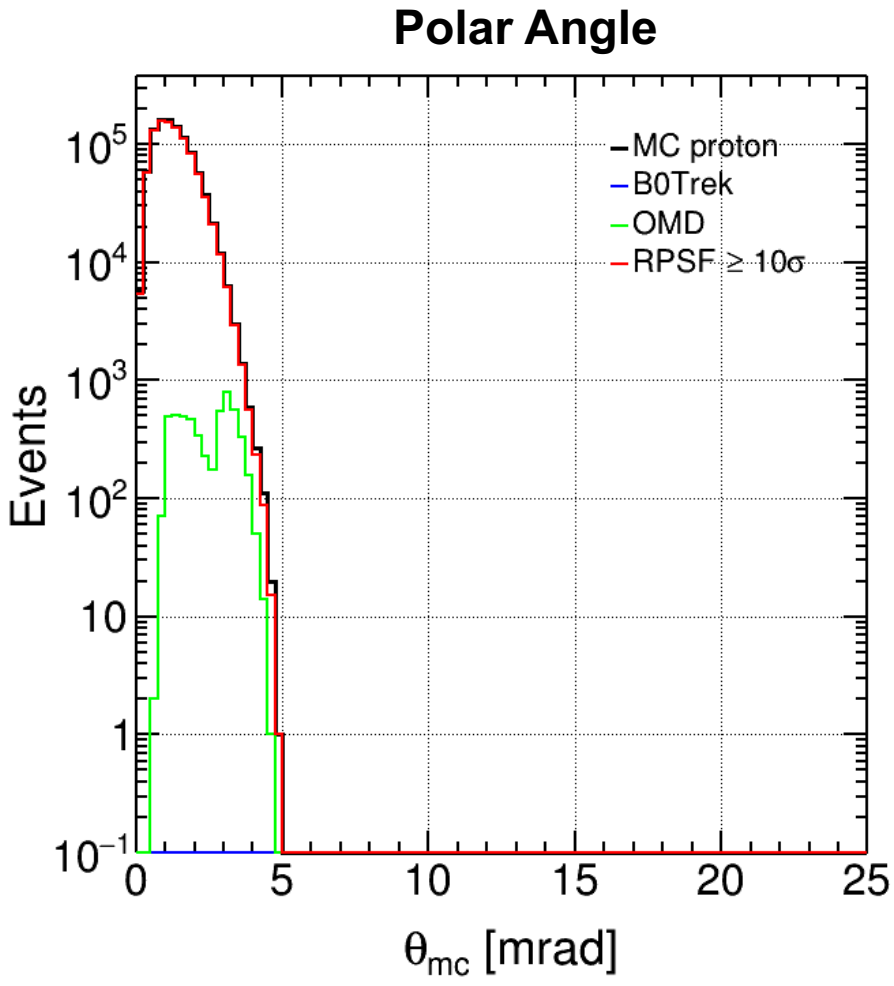
- By **tagging final-state proton**, it directly connects to **momentum transfer, t, measurement**
  - Investigate **low pT acceptance cutoffs**
- Used simulated **ep DVCS 1M** events each
  - Three beam energy combinations: ep 18×275, 10×100, and 5×41 GeV^2
    - S3/eictest/EPIC/EVGEN/EXCLUSIVE/DVCS/18x275/DVCS.3.18x275.hepmc
    - 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)***

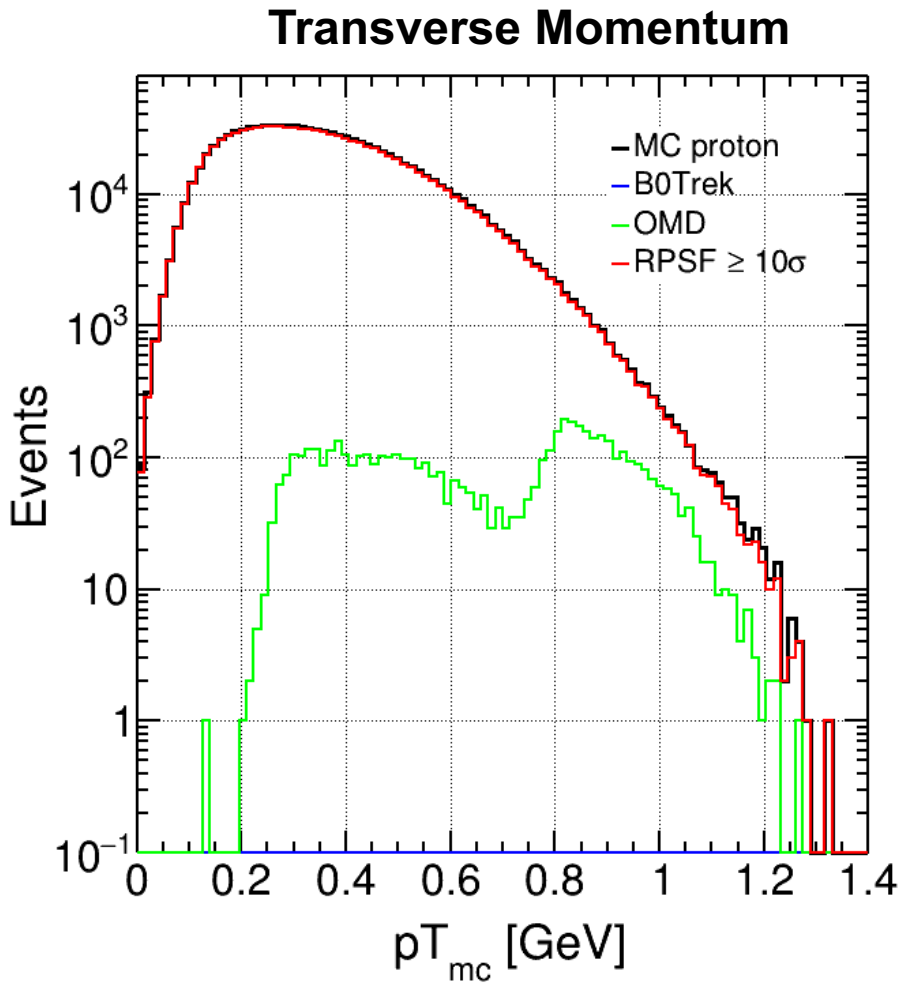
W/O Beampipe at B0

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*)**)

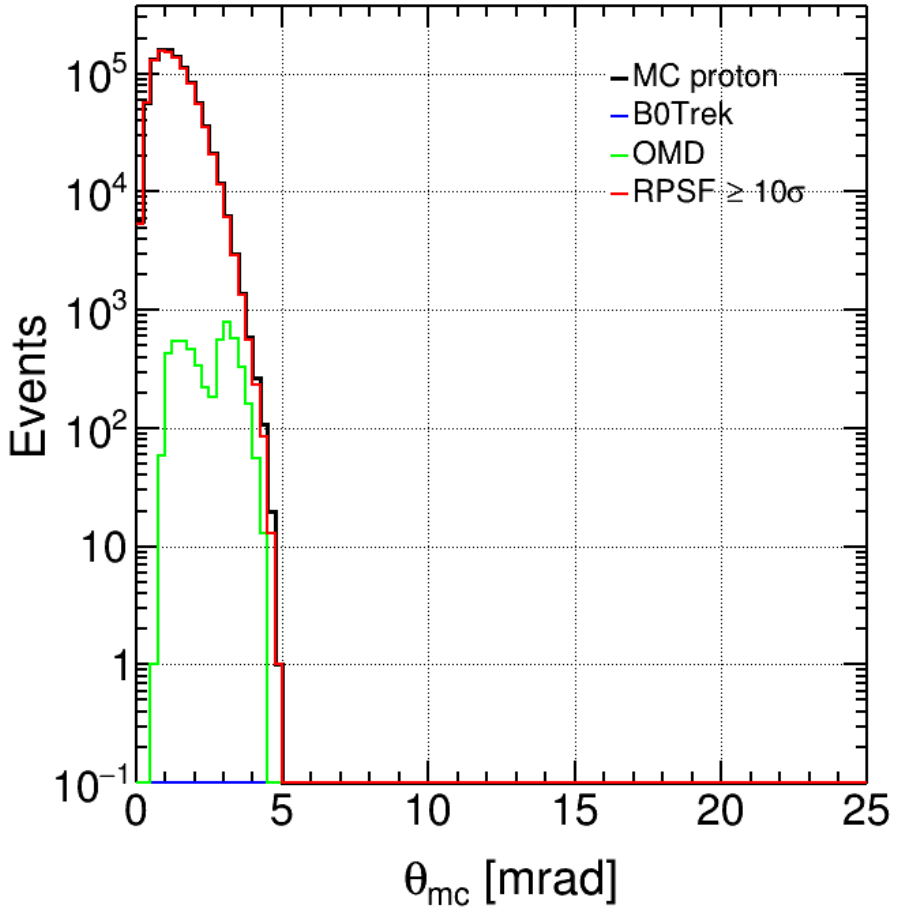
W/ Beampipe ($r_{B0\ tracker\ inner} = r_{beampipe\ outer} = 3.5$ cm) at B0

DVCS 18 GeV on 275 GeV

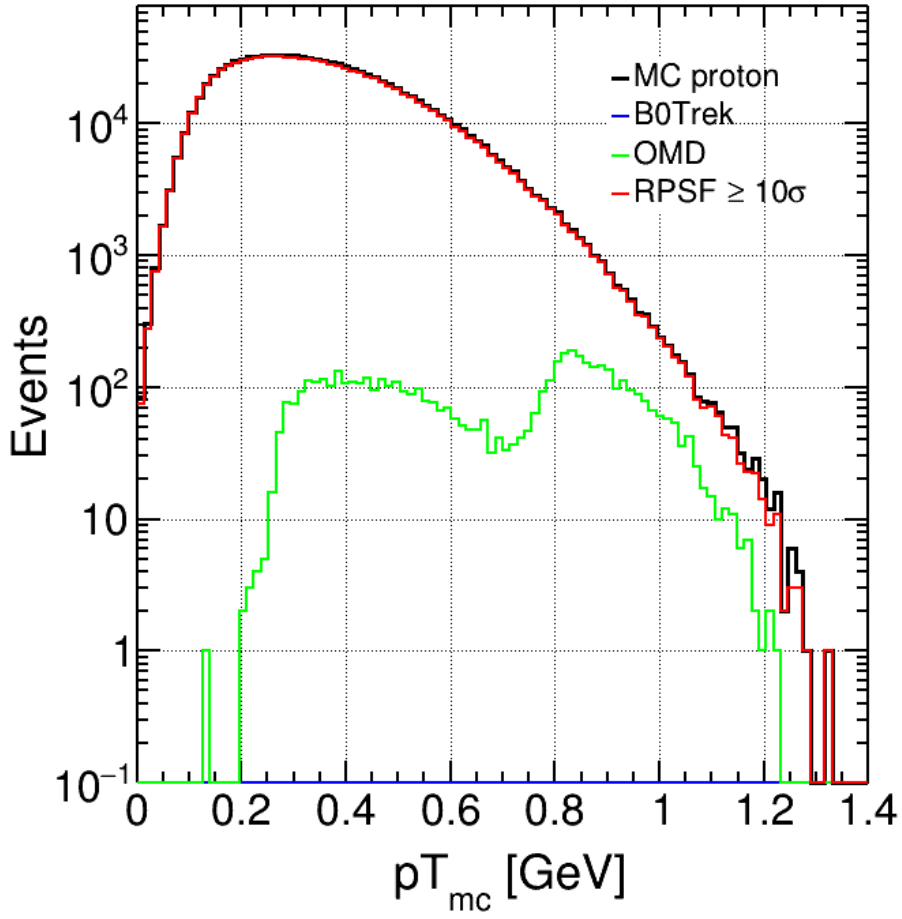
Log Scale

*Each histogram fills individually

Polar Angle



Transverse Momentum



MC
B0
OMD
RPSF

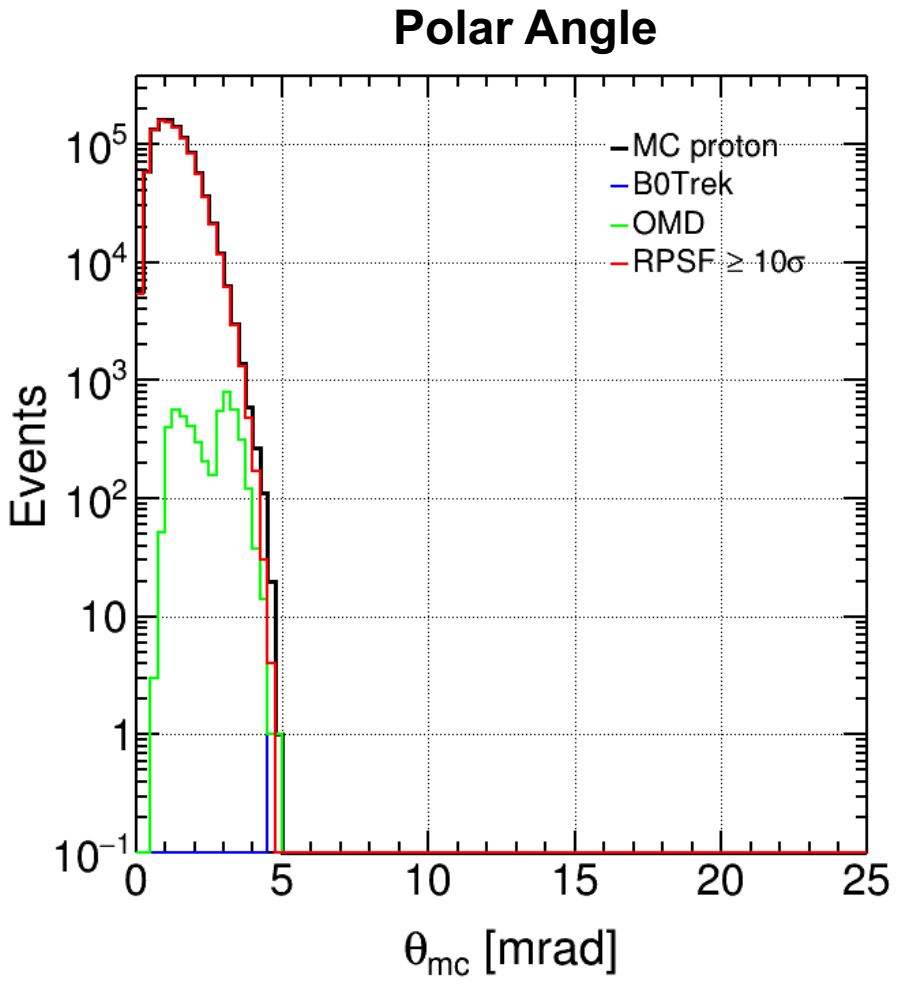
Scattered protons are very forward (< 5 mrad), measured in **Roman Pot at secondary focus** (**96.79 % events accepted** with 10σ safe distance cut based on **ep β @ IP6* (= IP8*)**)

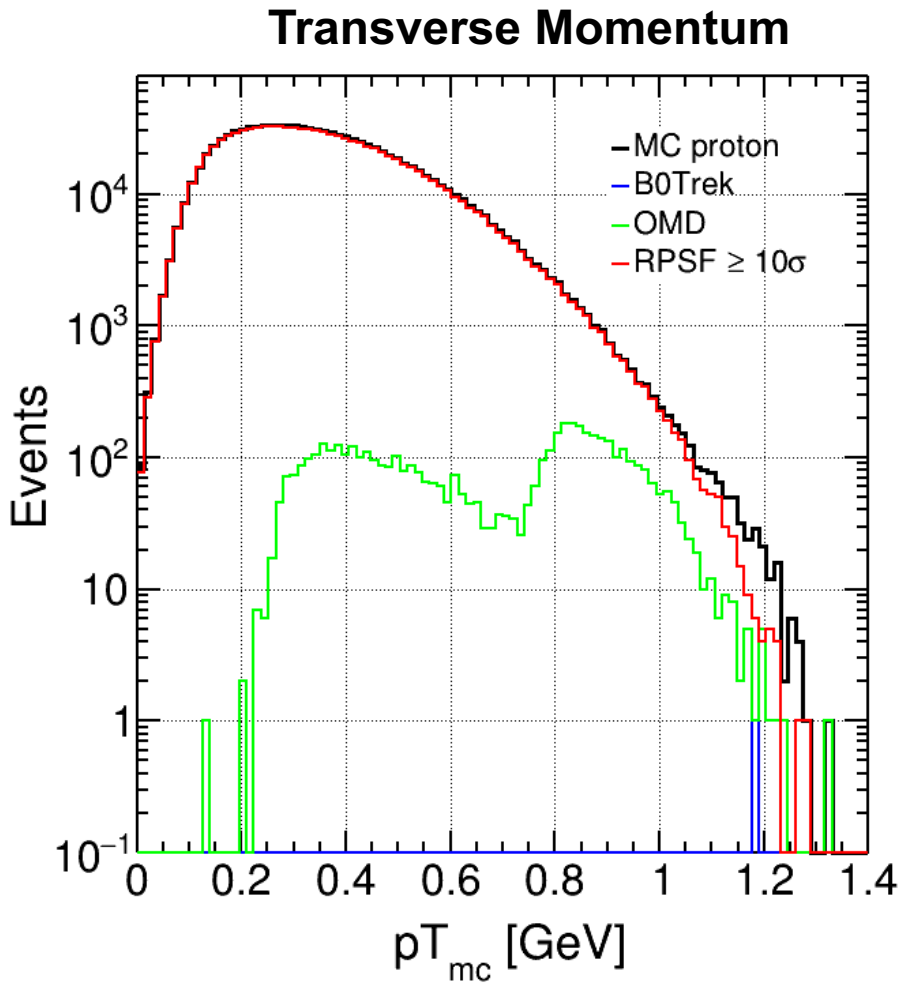
W/ Beampipe ($r_{B0\ tracker\ inner} = r_{beampipe\ outer} = 3.0$ cm) at B0

DVCS 18 GeV on 275 GeV

Log Scale

*Each histogram fills individually





MC
B0
OMD
RPSF

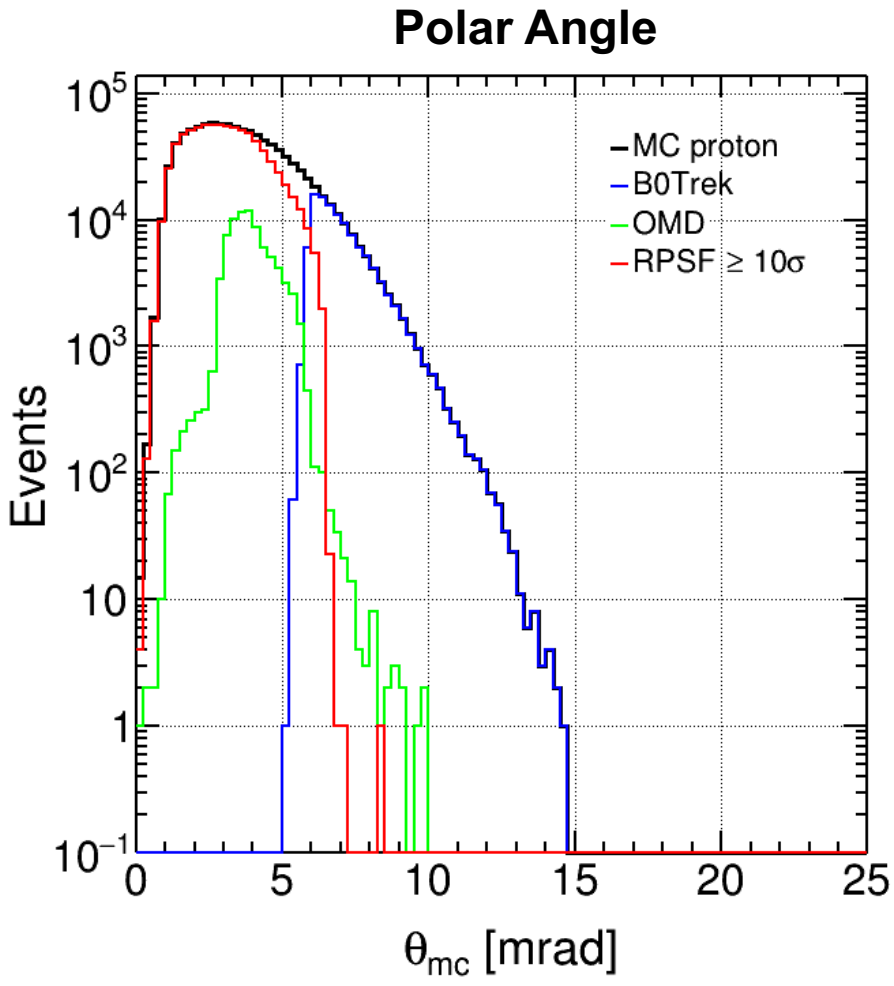
Scattered protons are very forward (< 5 mrad), measured in **Roman Pot at secondary focus** (**96.77 % events accepted** with 10σ safe distance cut based on **ep β @ IP6* (= IP8*)**)

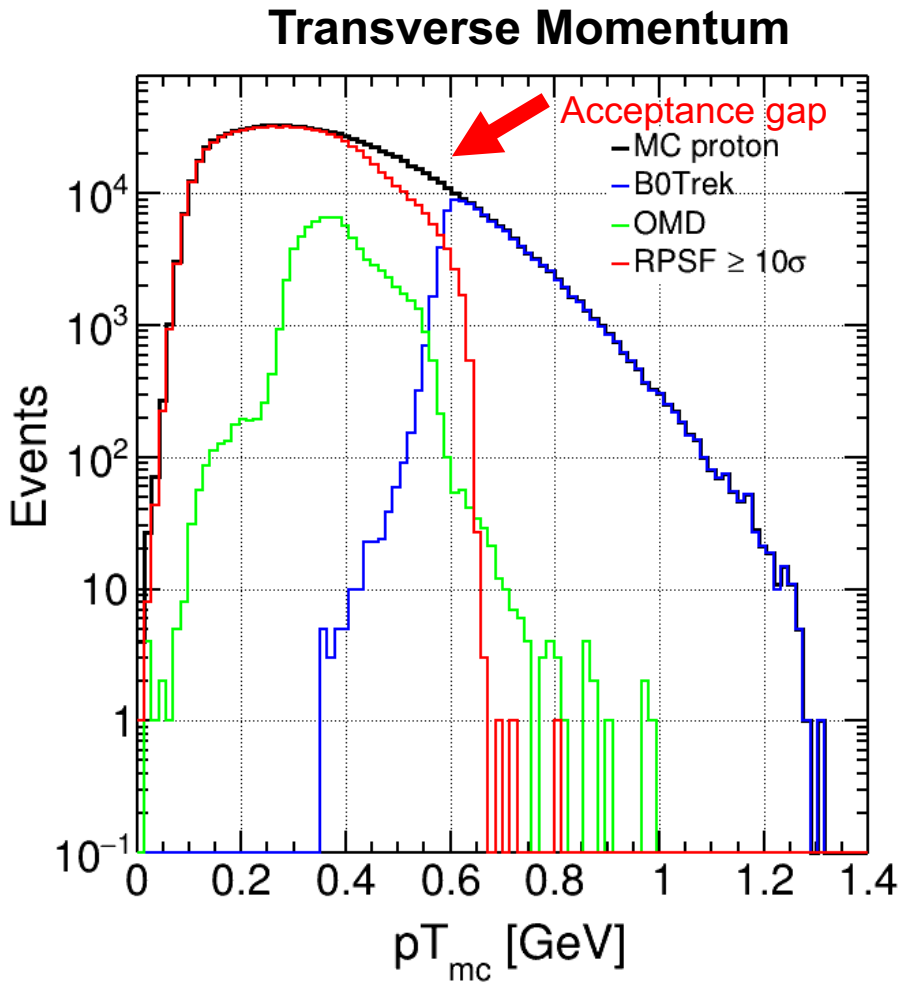
W/O Beampipe at B0

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*)**)

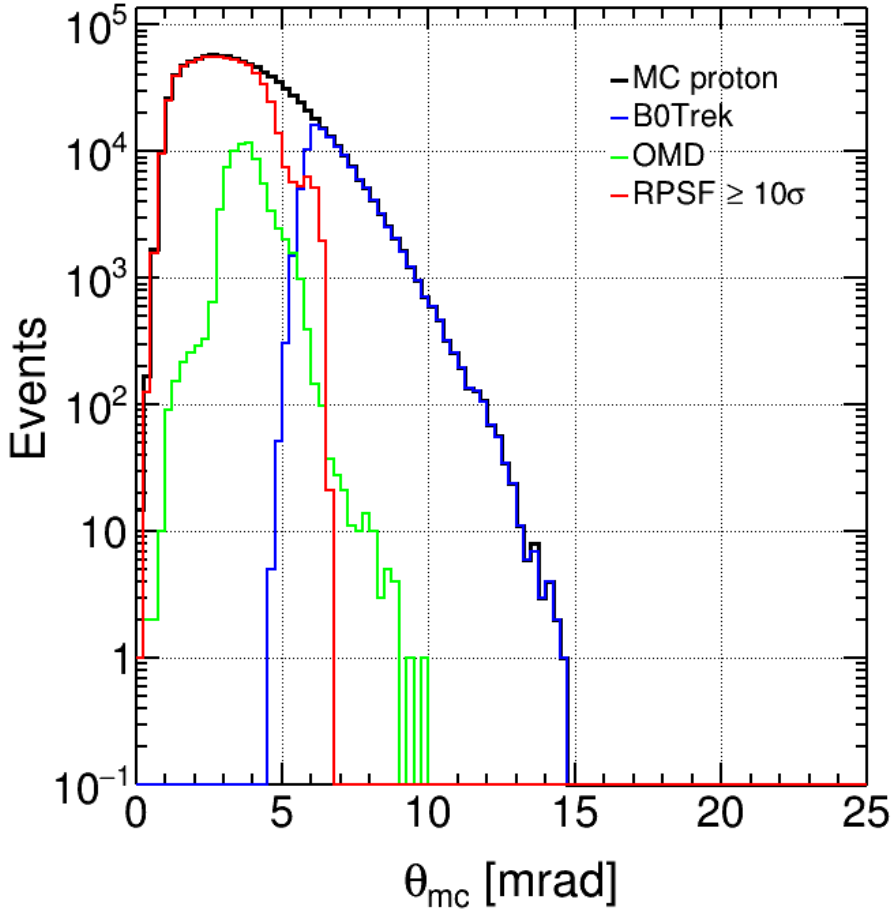
W/ Beampipe ($r_{B0\ tracker\ inner} = r_{beampipe\ outer} = 3.5$ cm) at B0

DVCS 10 GeV on 100 GeV

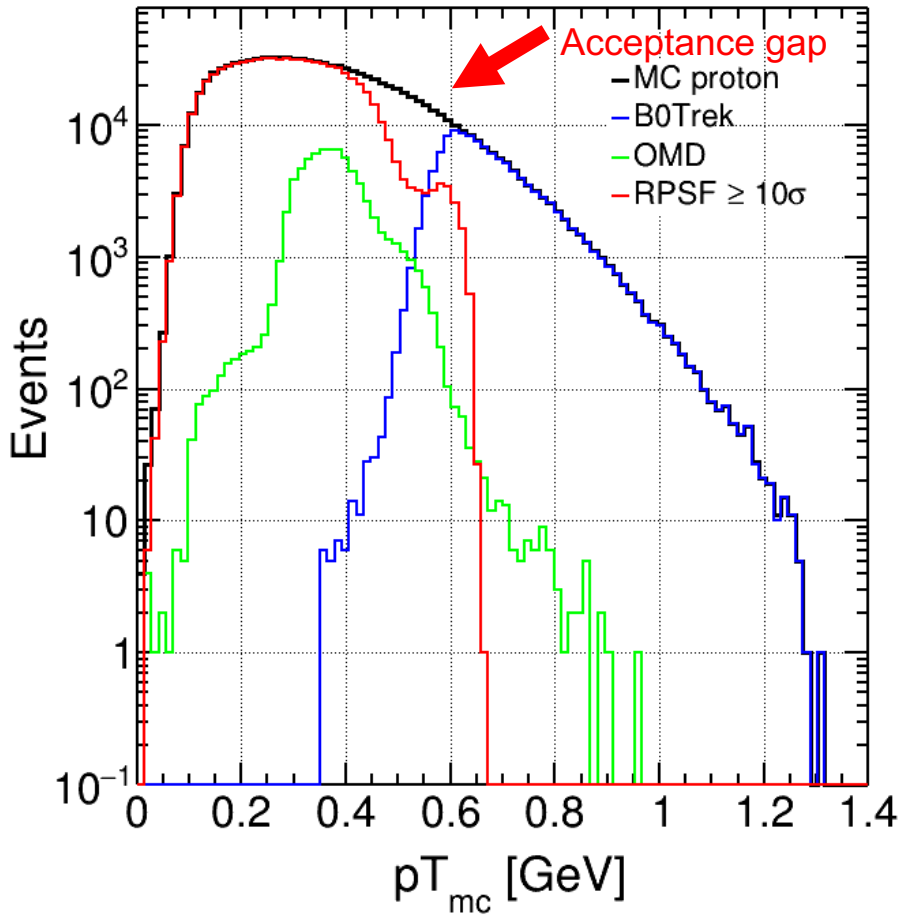
Log Scale

*Each histogram fills individually

Polar Angle



Transverse Momentum



MC
B0
OMD
RPSF

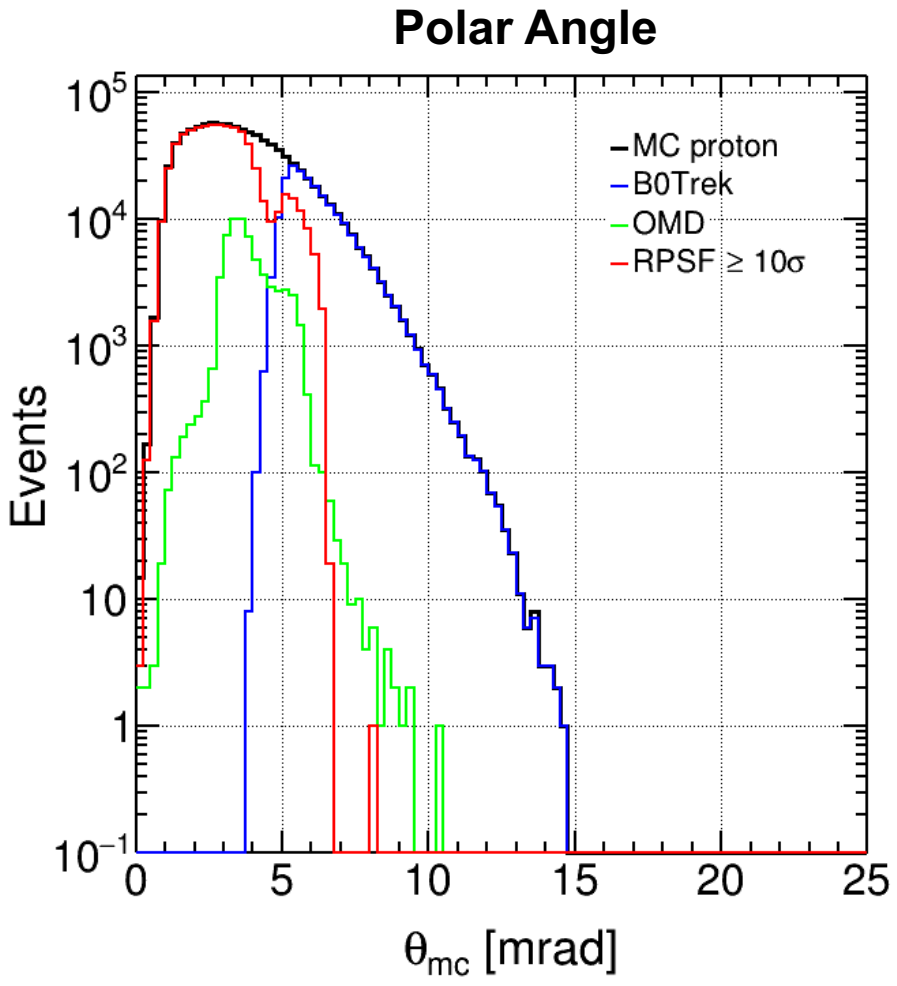
Scattered protons measured in **both B0 and *Roman Pot at secondary focus**
(**12.01 % and 75.06 % events accepted** with 10σ safe distance cut based on **ep β @ IP6* (= IP8*)**)

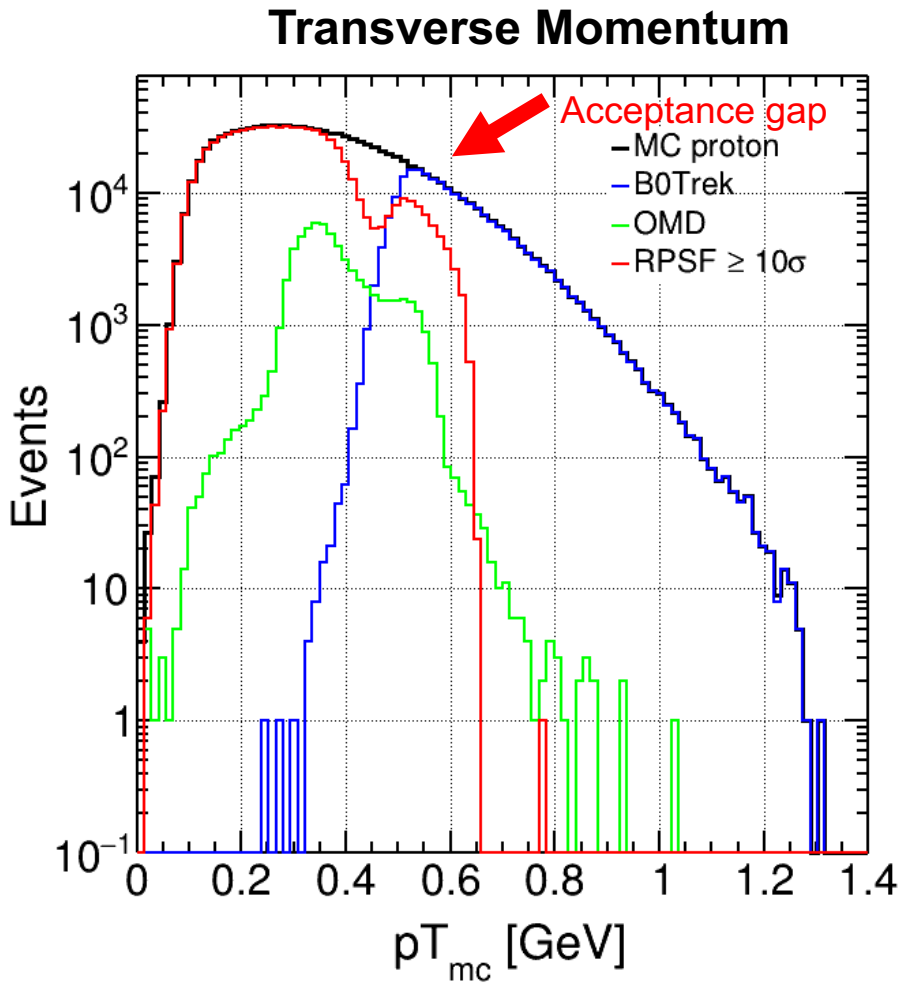
W/ Beampipe ($r_{B0\ tracker\ inner} = r_{beampipe\ outer} = 3.0$ cm) at B0

DVCS 10 GeV on 100 GeV

Log Scale

*Each histogram fills individually





MC
B0
OMD
RPSF

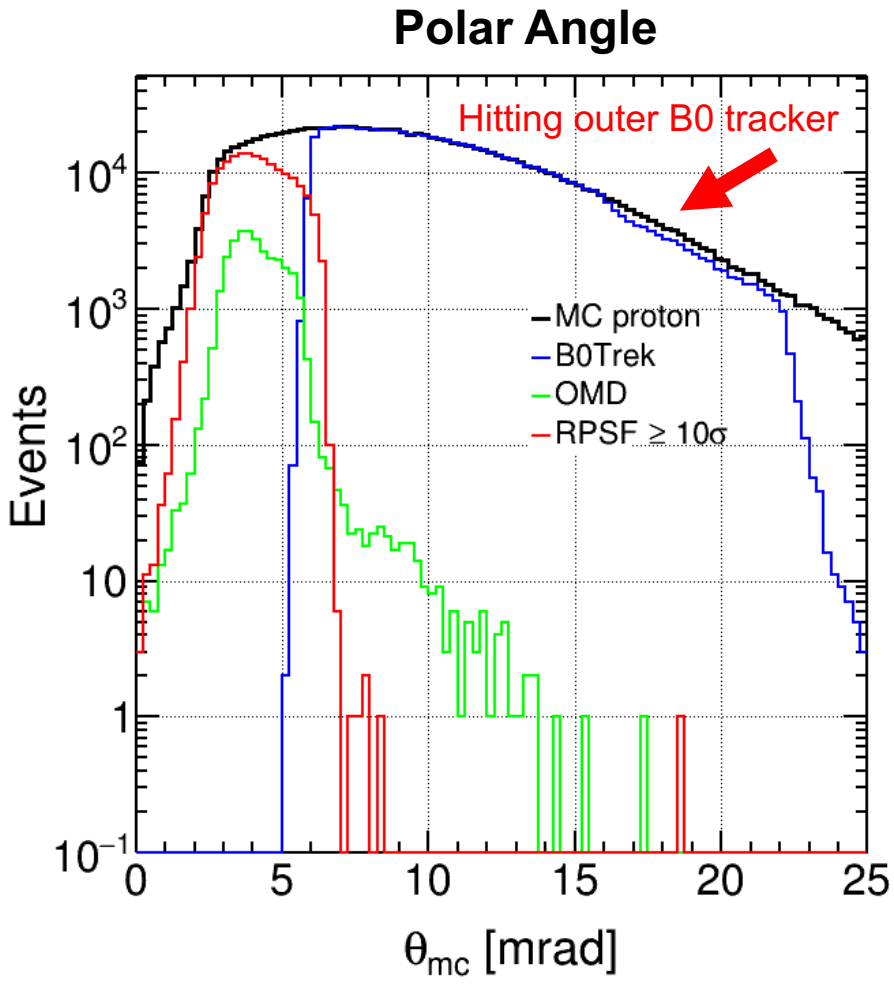
Scattered protons measured in **both B0 and *Roman Pot at secondary focus**
(**21.29 % and 71.30 % events accepted** with 10σ safe distance cut based on **ep β @ IP6* (= IP8*)**)

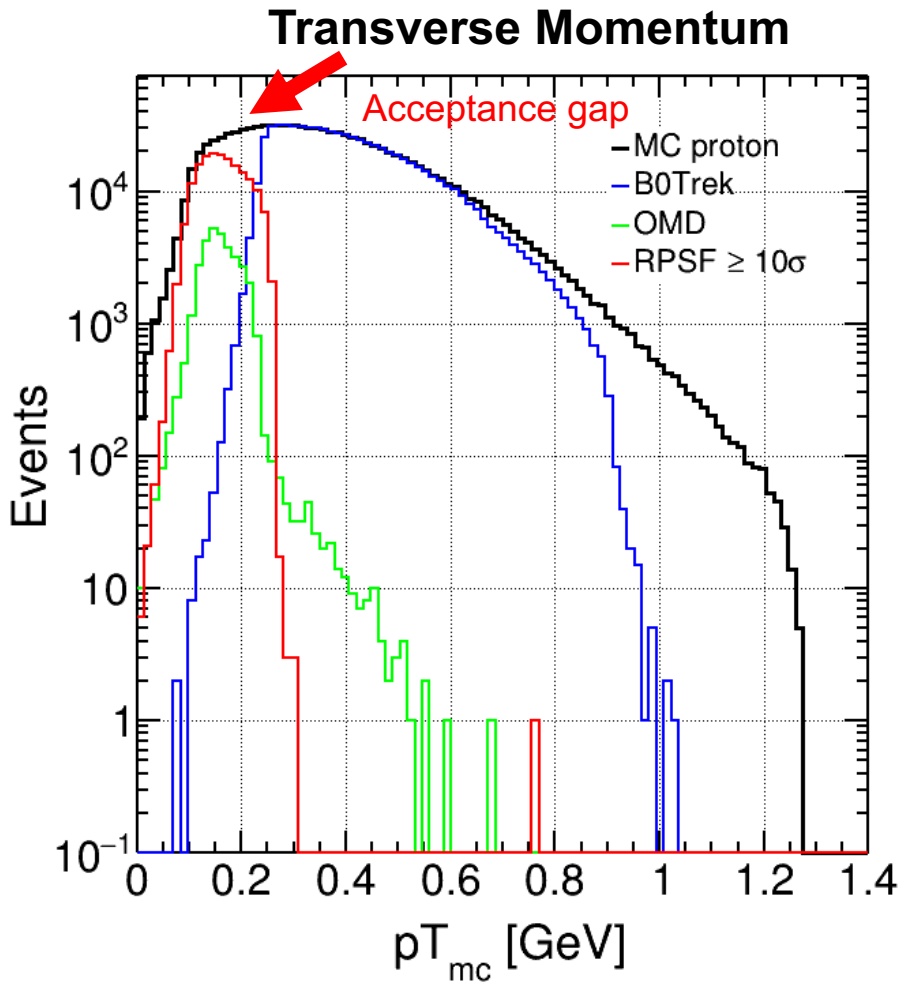
W/O Beampipe at B0

DVCS 5 GeV on 41 GeV

Log Scale

*Each histogram fills individually





MC
B0
OMD
RPSF

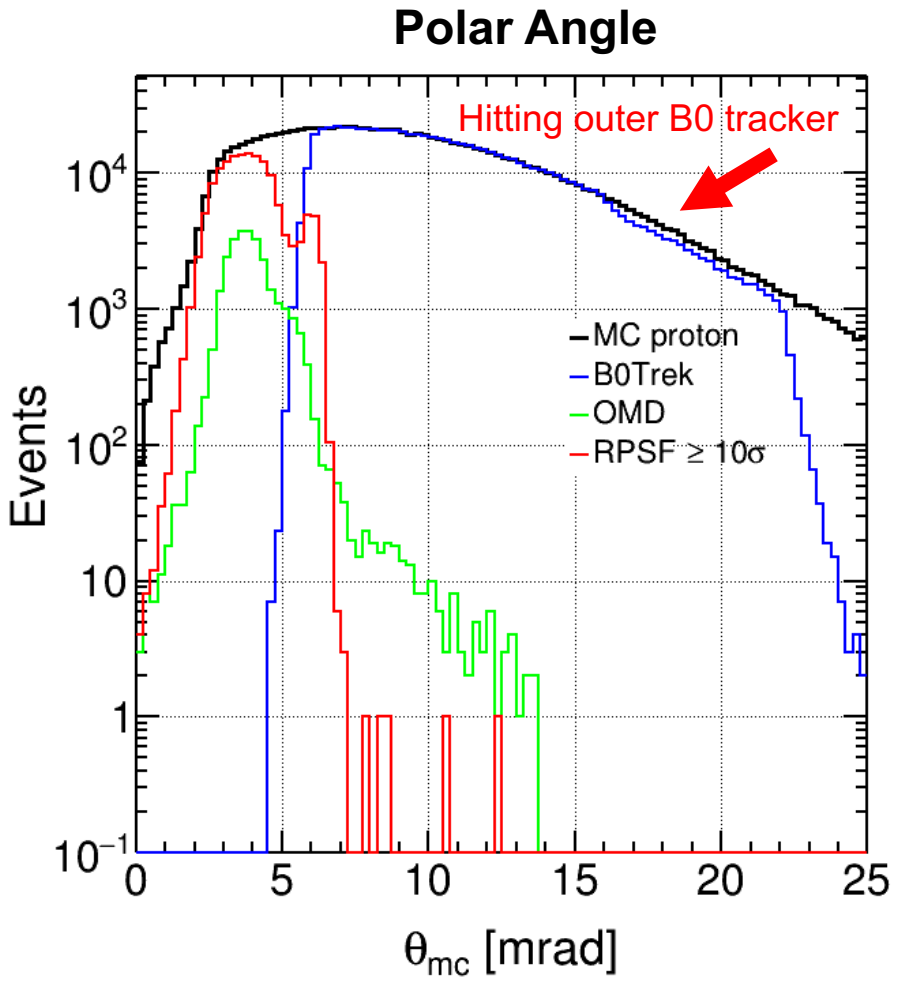
Scattered protons measured in **both *B0 and Roman Pot at secondary focus**
(**70.62 % and 17.00 % events accepted** with 10σ safe distance cut based on **ep β @ IP6* (= IP8*)**)

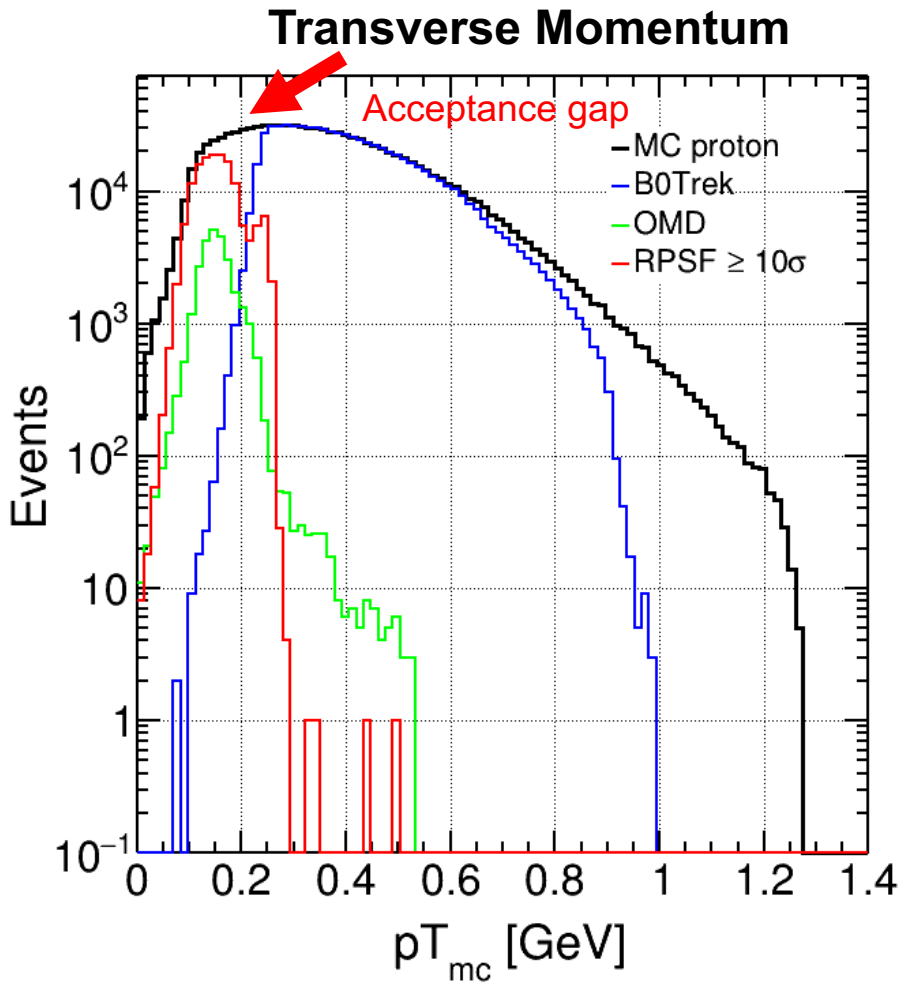
W/ Beampipe ($r_{B0\ tracker\ inner} = r_{beampipe\ outer} = 3.5$ cm) at B0

DVCS 5 GeV on 41 GeV

Log Scale

*Each histogram fills individually





MC
B0
OMD
RPSF

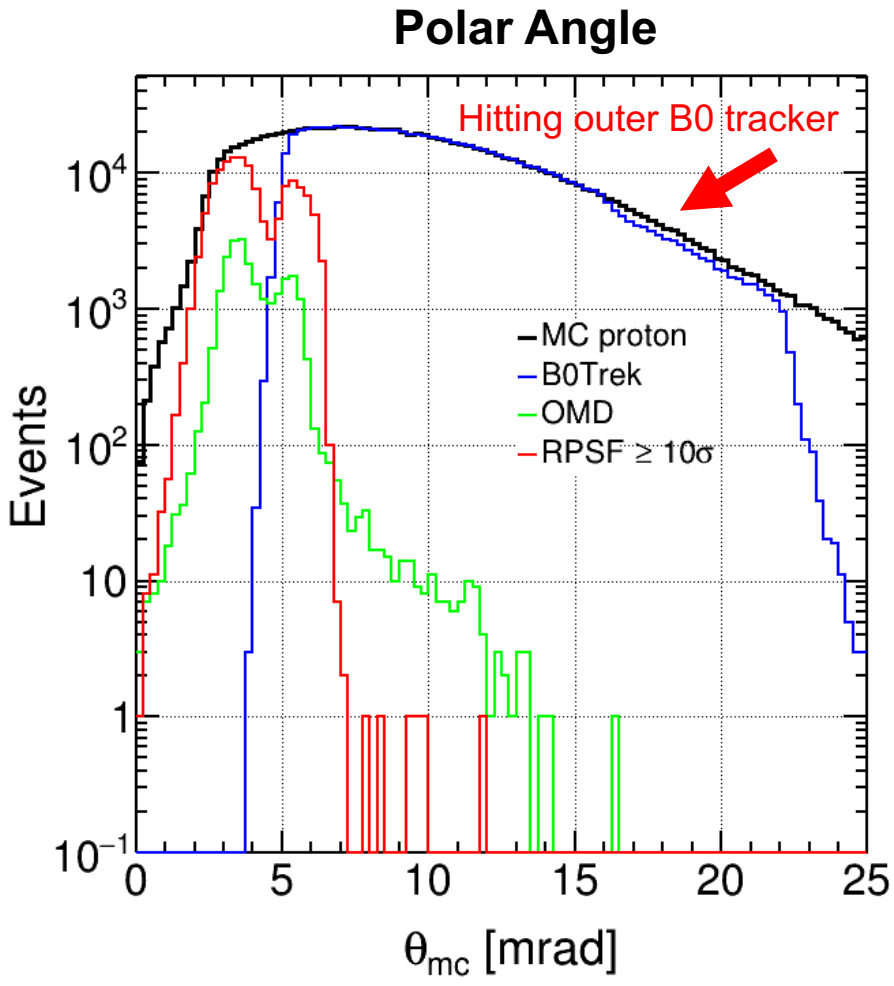
Scattered protons measured in **both *B0 and Roman Pot at secondary focus**
(**71.61 % and 14.33 % events accepted** with 10σ safe distance cut based on **ep β @ IP6* (= IP8*)**)

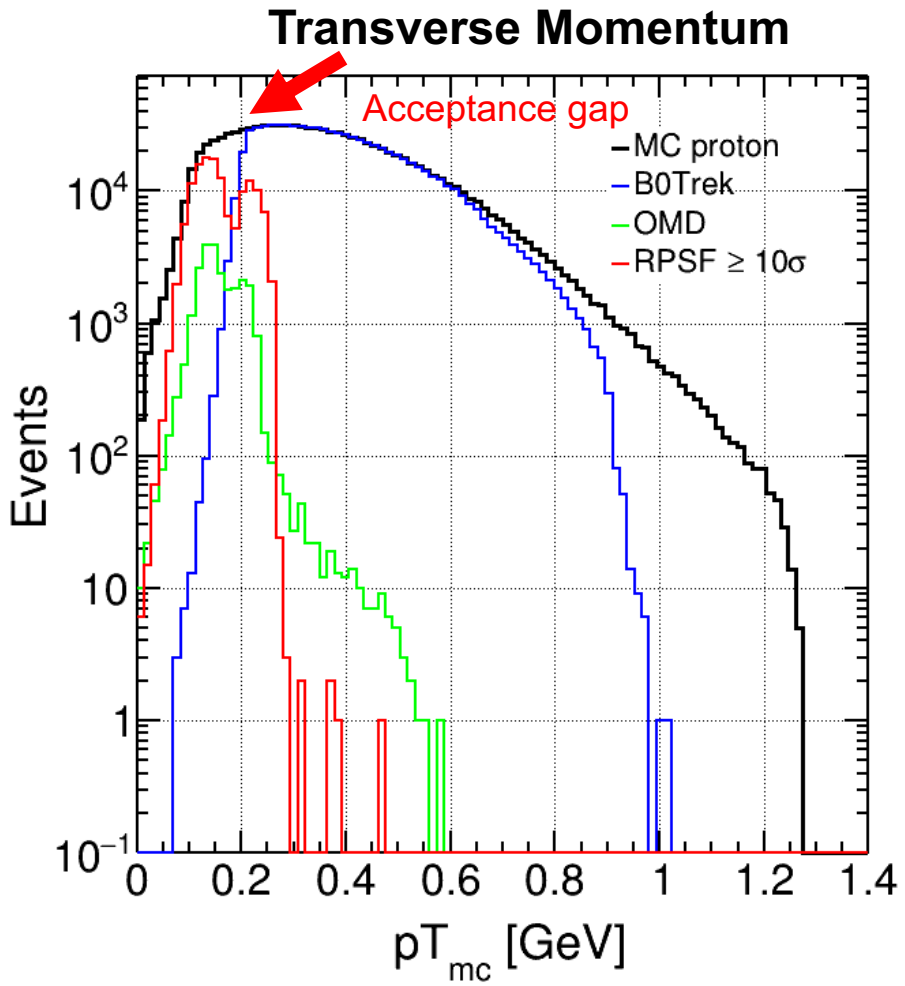
W/ Beampipe ($r_{B0\ tracker\ inner} = r_{beampipe\ outer} = 3.0$ cm) at B0

DVCS 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**
(**78.64 % and 13.63 % events accepted** with 10σ safe distance cut based on **ep β @ IP6* (= IP8*)**)

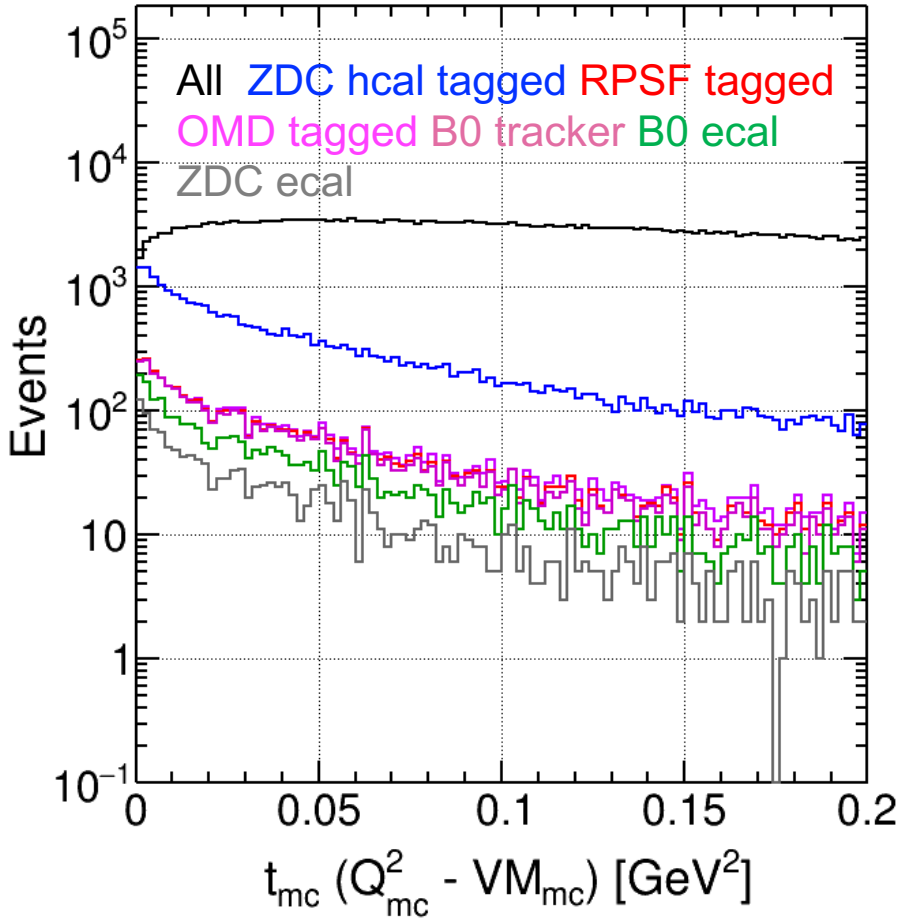
Approach – Incoherent Vetoing Efficiency

- 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 **w/ and w/o IP6 eAu beam effects** based on **EIC CDR table 3.5**
- Discarded events having **more than one electron in final state with $\eta < -1$**
- 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**

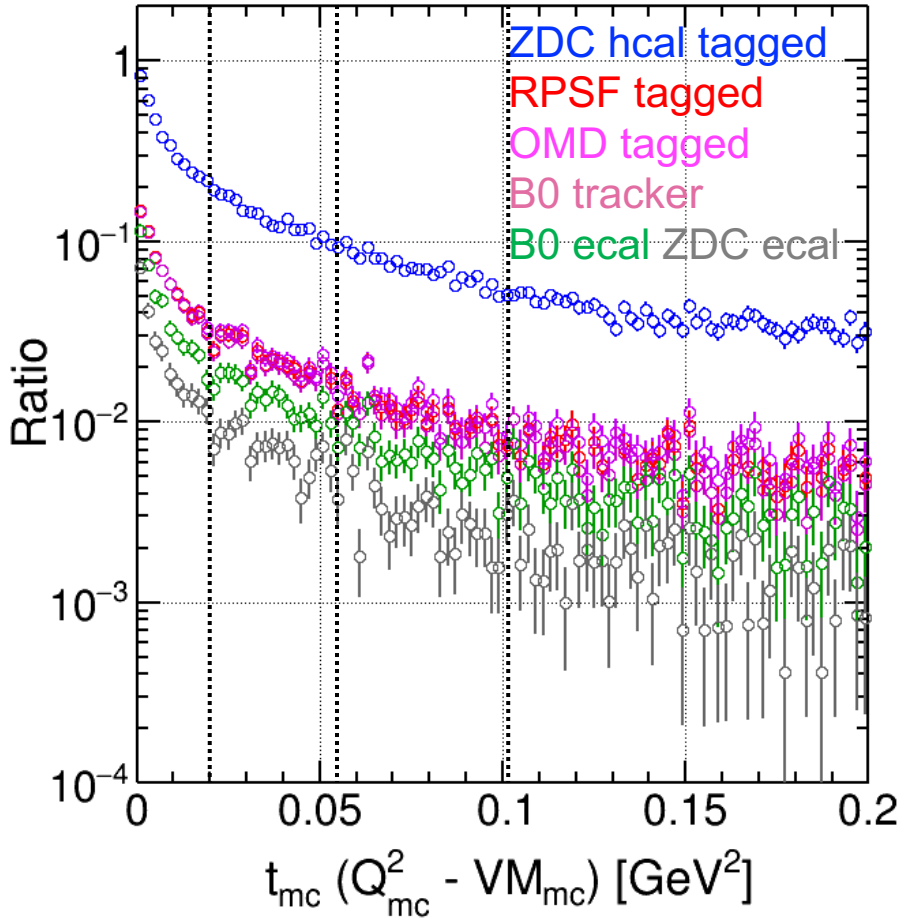
W/ Beam effects

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 ***ep β @ IP8 RPSF***

1,771 of 800,964 events were NOT vetoed

W/ Beam effects

Remaining Events

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

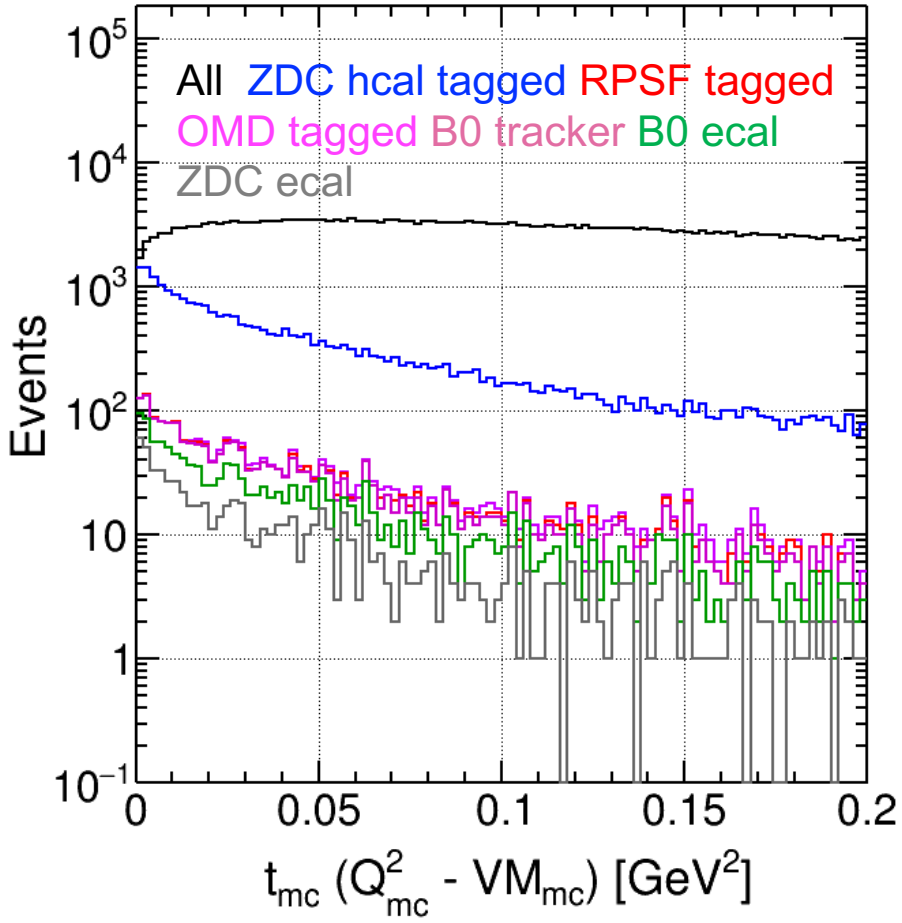
Veto Selections	Survived Events
All events	800,964
Events with one scattered electron identified	712,362 (100.0 %)
ZDC HCAL tagged	41,768 (5.86331 %)
+ RPSF tagged	7,231 (1.01507 %)
+ OMD tagged	6,781 (0.951904 %)
+ B0 tracker tagged	5,599 (0.785977 %)
+ B0 ecal tagged	3,504 (0.491885 %)
+ ZDC ECAL tagged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

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

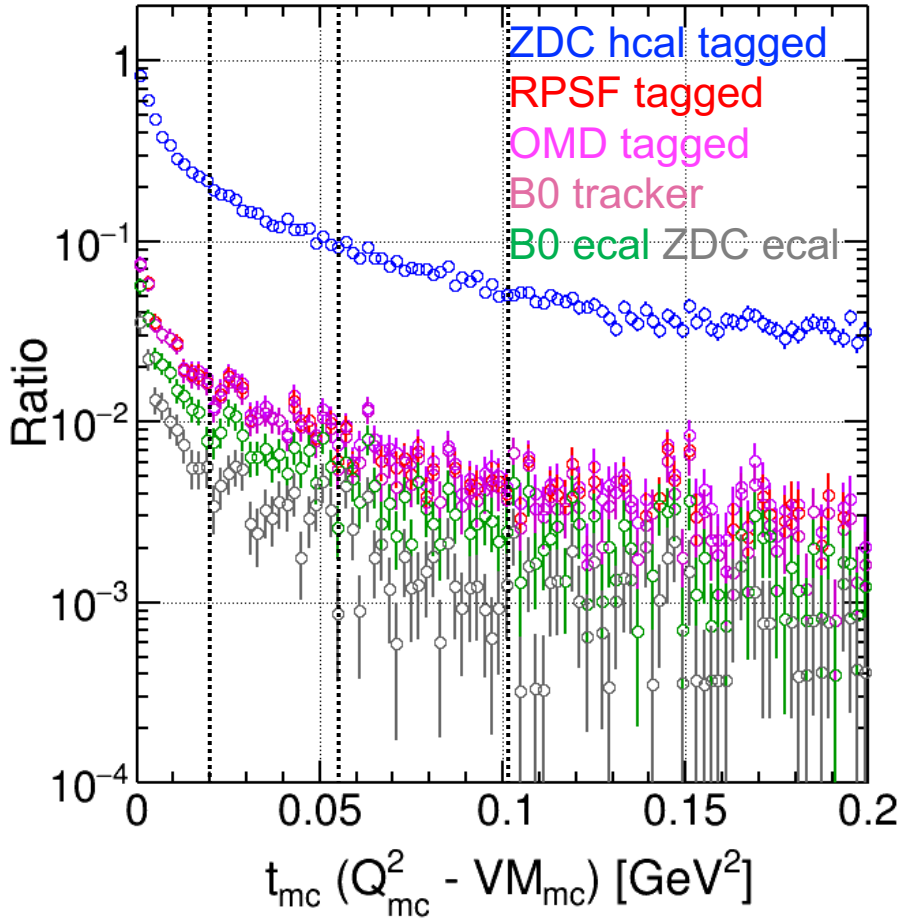
W/ Beam effects

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***

886 of 800,964 events were NOT vetoed

W/ Beam effects

Remaining Events

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

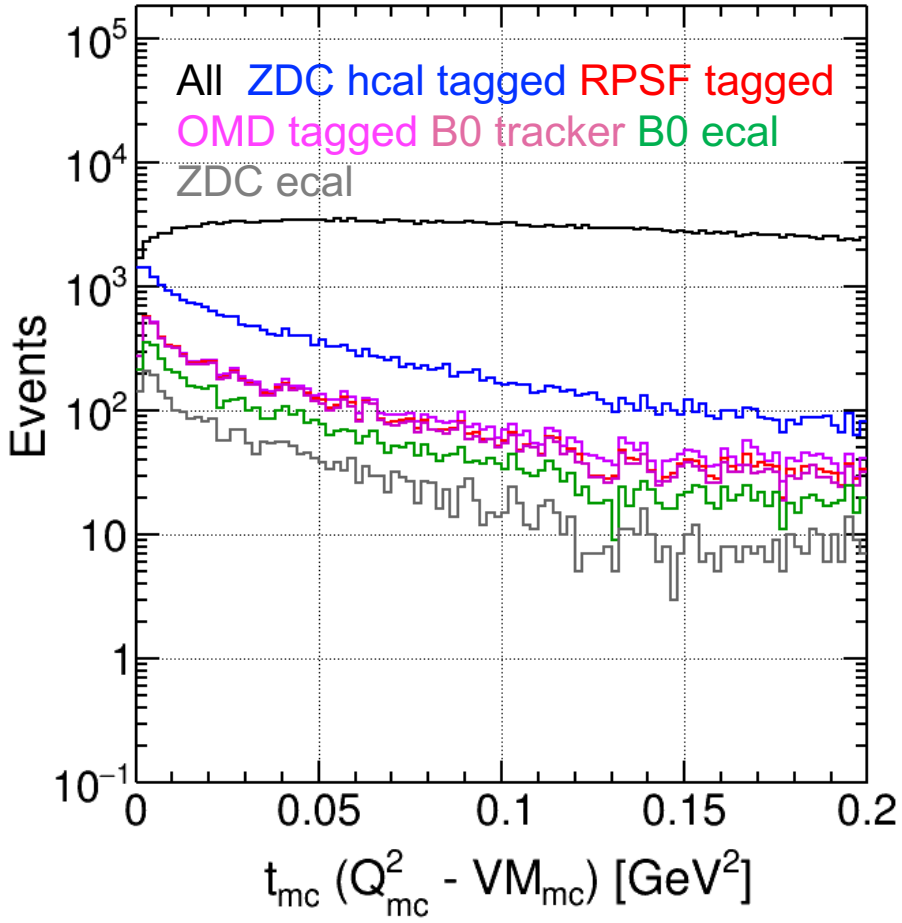
Veto Selections	Survived Events
All events	800,964
Events with one scattered electron identified	712,362 (100.0 %)
ZDC HCAL tagged	41,768 (5.86331 %)
+ RPSF tagged	3,708 (0.520522 %)
+ OMD tagged	3,472 (0.487393 %)
+ B0 tracker tagged	2,834 (0.397831 %)
+ B0 ecal tagged	1,790 (0.251277 %)
+ ZDC ECAL tagged	886 (0.124375 %)

With 10σ safe distance cut based on ***exact Wan's IP8 sigma cut***
886 of 800,964 events were NOT vetoed

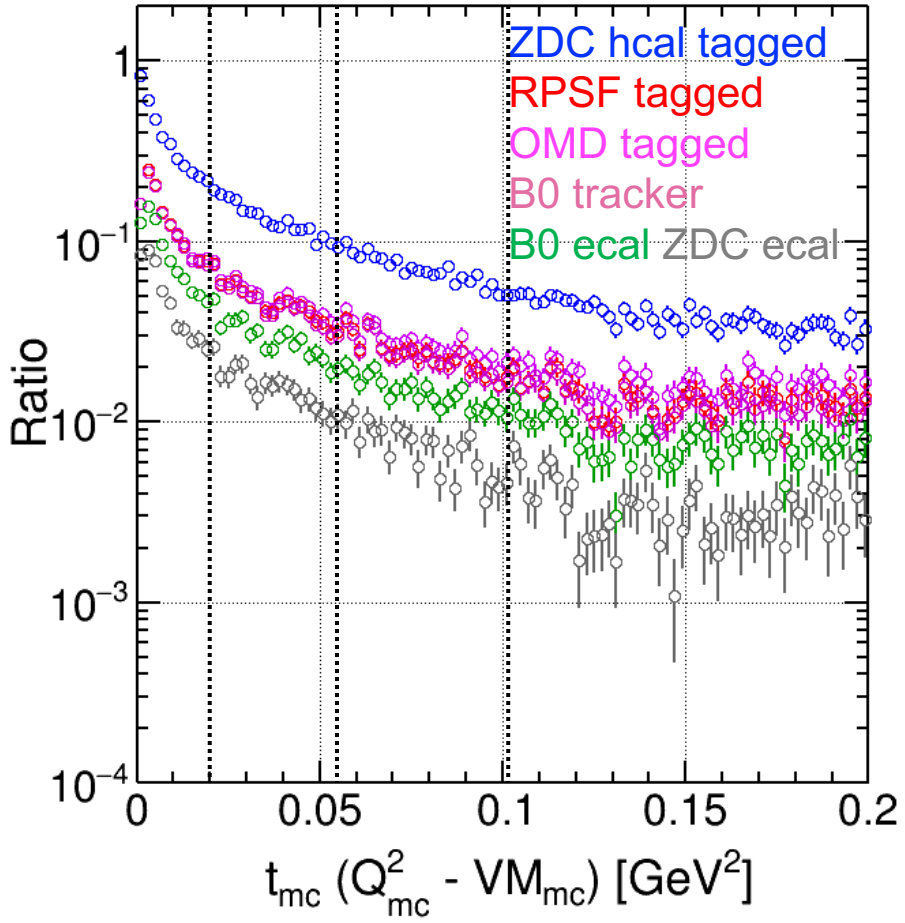
W/O Beam effects

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

W/O Beam effects

Remaining Events

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

Veto Selections	Survived Events
All events	800,978
Events with one scattered electron identified	712,384 (100.0 %)
ZDC HCAL tagged	41,752 (5.86088 %)
+ RPSF tagged	15,755 (2.21159 %)
+ OMD tagged	14,456 (2.02924 %)
+ B0 tracker tagged	11,960 (1.67887 %)
+ B0 ecal tagged	7,651 (1.074 %)
+ ZDC ECAL tagged	3,837 (0.538614 %)

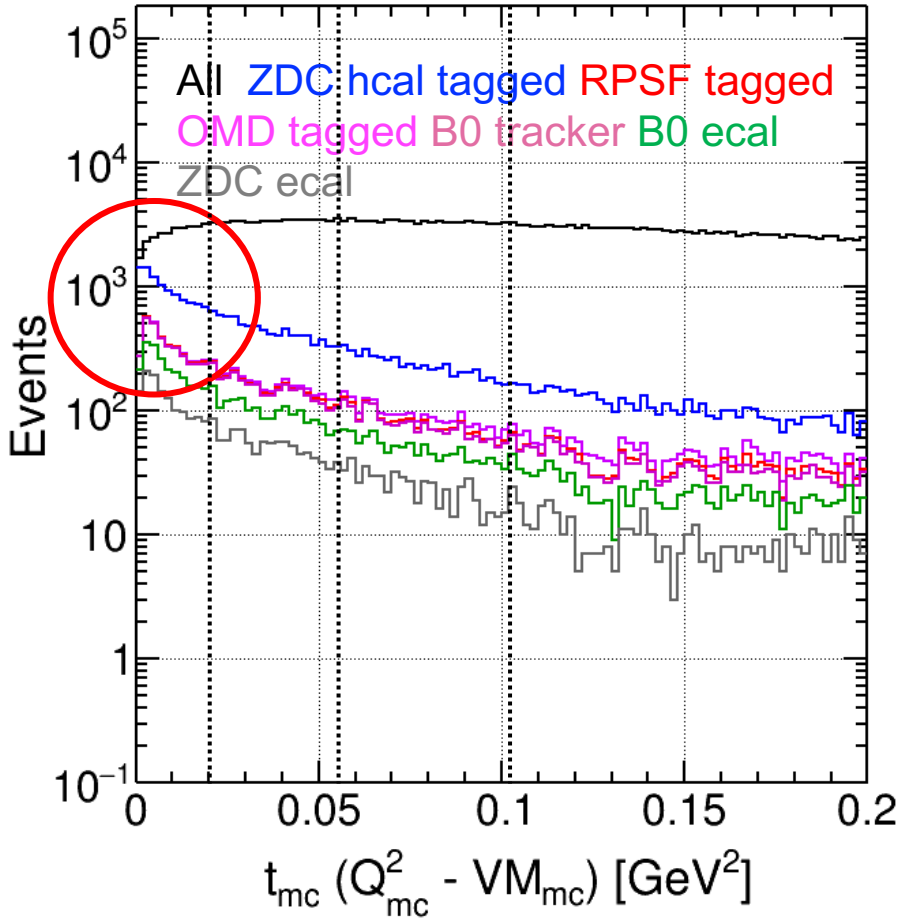
With 10σ safe distance cut based on ***exact Wan's IP8 sigma cut***
3,837 of 800,964 events were NOT vetoed

W/O Beam effects with NOT taking out crossing angle in t calculation

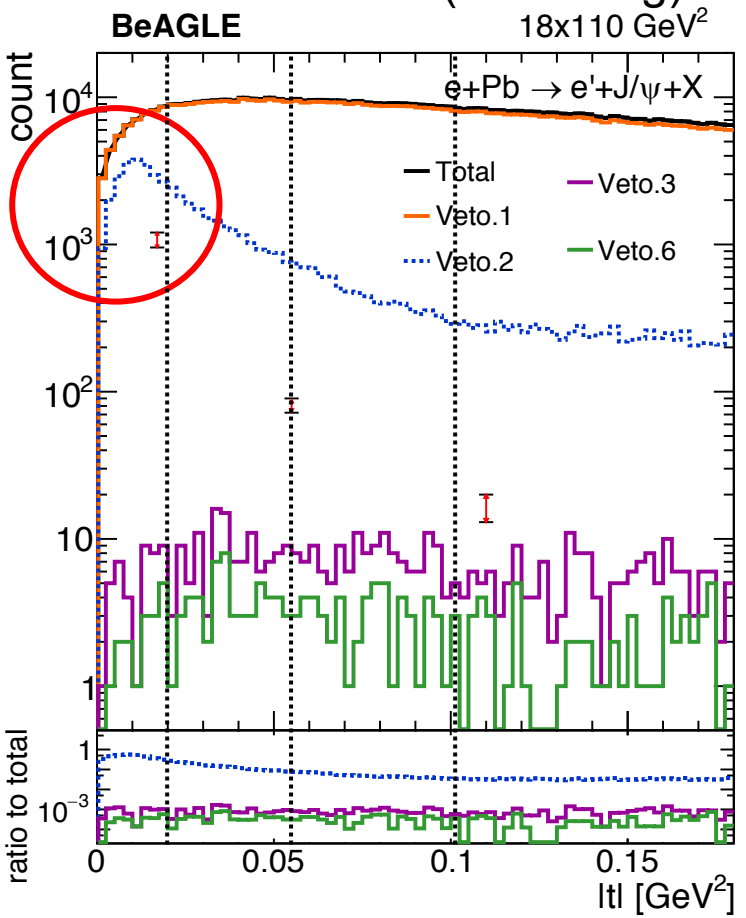
t distribution

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

IP-8 DD4hep (J. KIM)



IP-8 EicRoot (W. Chang)



Let's look at t = 0.2 (flatten)

Show similar order decreased from **total** to **ZDC HCAL veto**

Show discrepancy (factor of 10) from **ZDC HCAL veto** to **last veto**

- Slope (vetoing power 10^{-2} at first minima and not quite down to 10^{-3} at any t)
- Flat (vetoing power 10^{-3})
- More vetoed at very low t

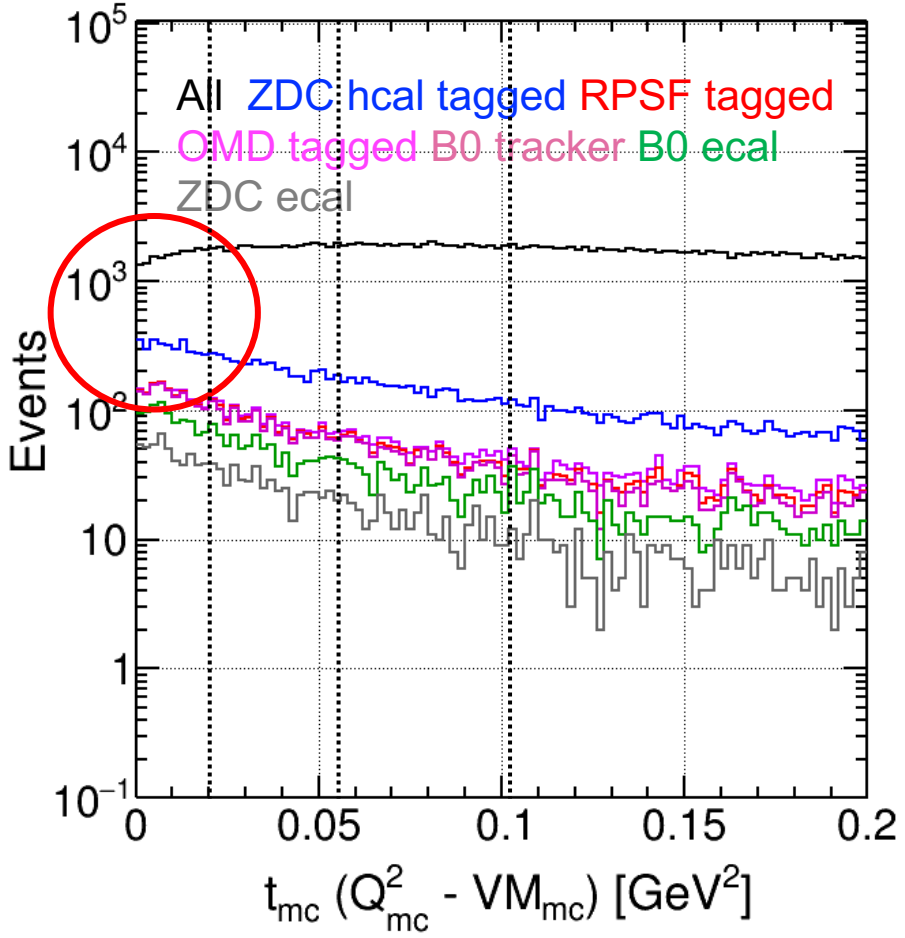
With 10σ safe distance cut based on ***exact Wan's IP8 sigma cut***

W/O Beam effects with taking out crossing angle in t calculation

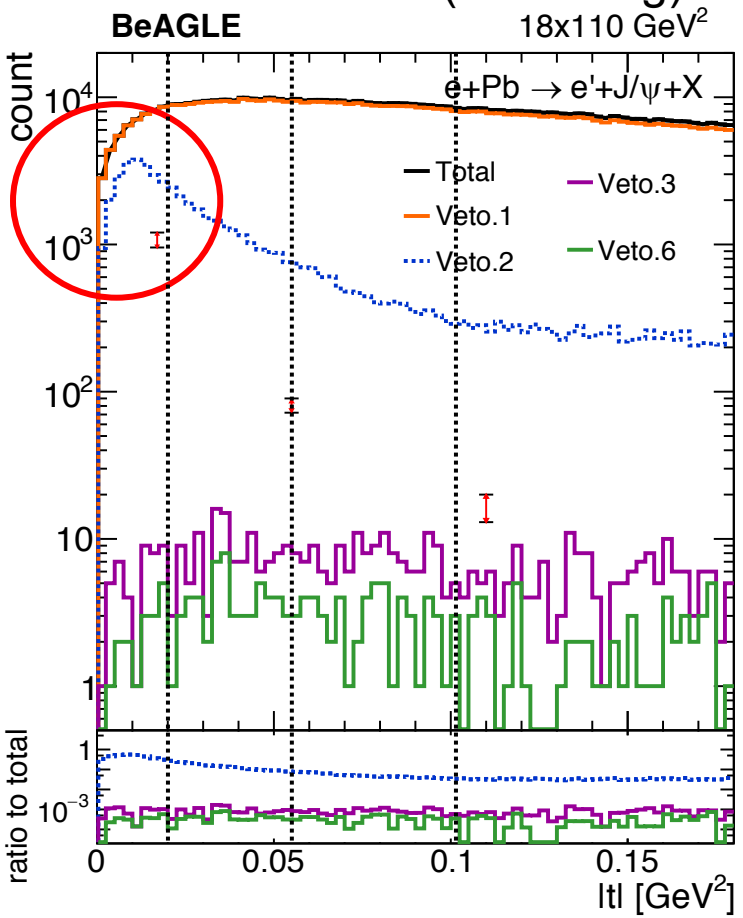
t distribution

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

IP-8 DD4hep (J. KIM)



IP-8 EicRoot (W. Chang)



Let's look at t = 0.2 (flatten)

Show similar order decreased from **total** to **ZDC HCAL veto**

Show discrepancy (factor of 10) from **ZDC HCAL veto** to **last veto**

- Slope (vetoing power 10^{-2} at first minima and not quite down to 10^{-3} at any t)
- Flat (vetoing power 10^{-3})
- More vetoed at very low t

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

Summary

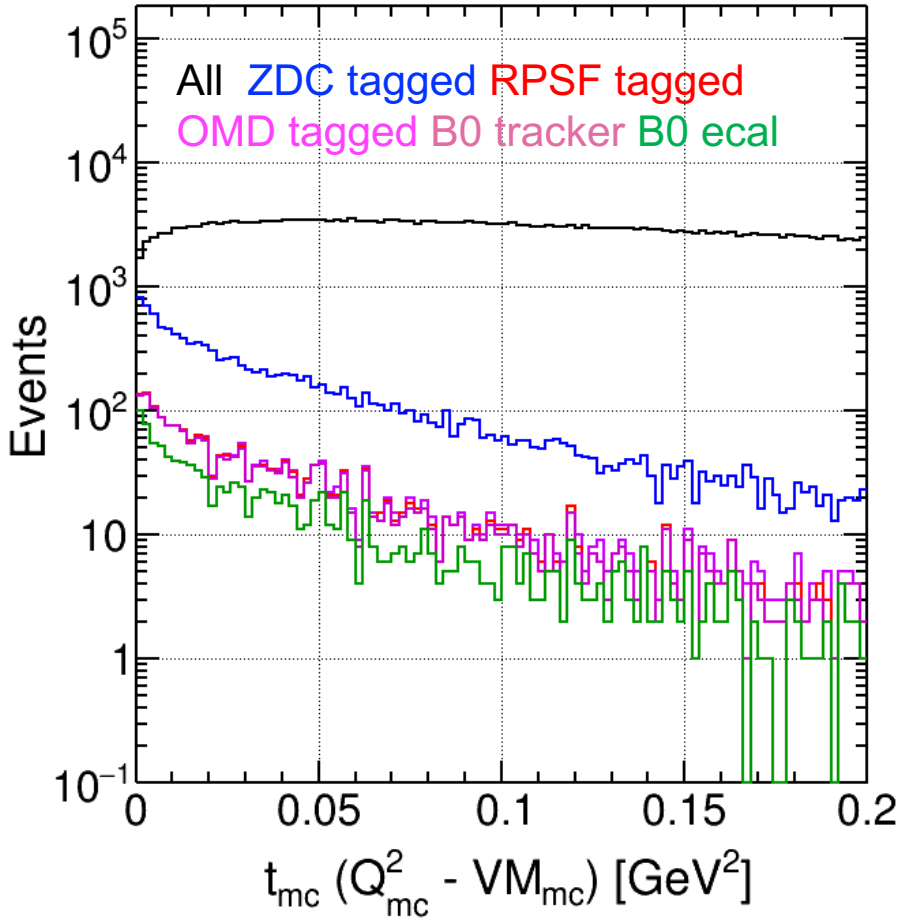
- Implemented B0 beampipe
  - Looked beampipe impact and different apertures impact
  - Used different aperture sizes based on IP6 beam parameters
- Using exclusive DVCS events, understanding acceptance gap in pT between B0 and RPSF
  - ~250 MeV for 5 GeV on 41 GeV and ~550 MeV for 10 GeV on 100 GeV
  - After adding beampipe, it has some fuzzy shape of acceptance gap since beampipe is circular shape and beam is elliptical shape
  - 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, understanding tagging 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
  - Compared Wan's IP8 study result with exact same sigma cut, but still showed discrepancy. Details needs to be confirmed and discussed. Ex) t reconstruction

Backup

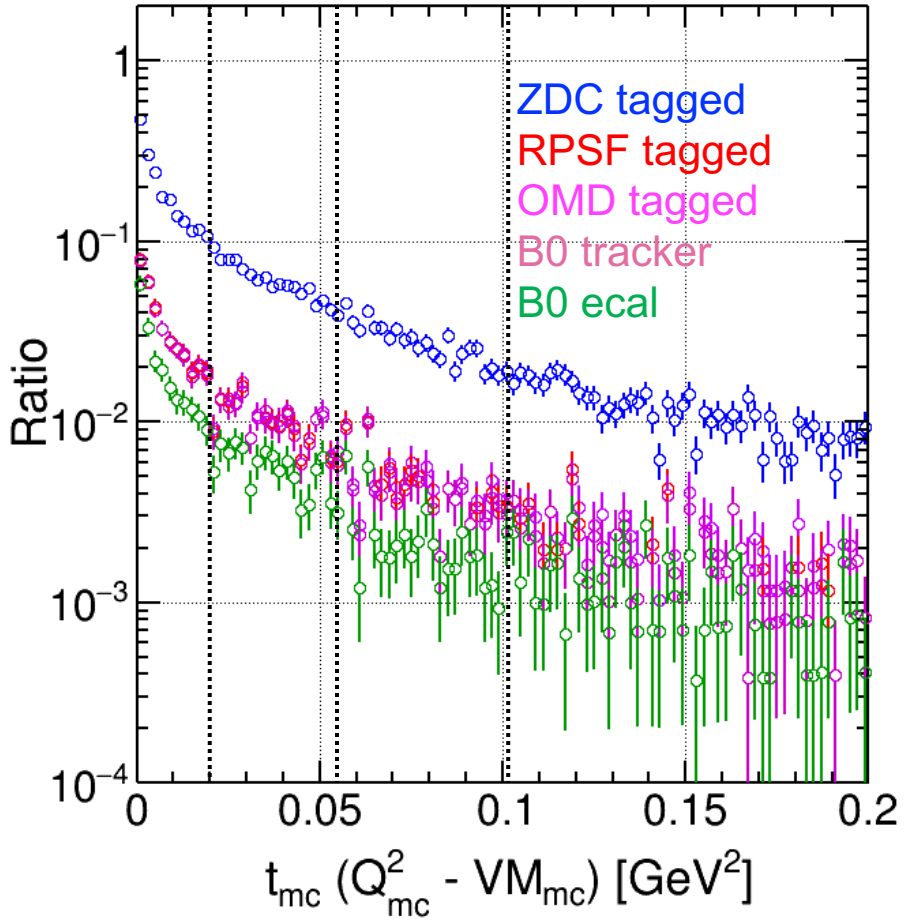
W/ Beam effects

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 ***ep β @ IP8 RPSF***

1,286 of 800,964 events were NOT vetoed

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 all components (HCAL & ECAL) tagged	15,557 (2.18386 %)
+ RPSF tagged	2,677 (0.375792 %)
+ OMD tagged	2,549 (0.357824 %)
+ B0 tracker tagged	2,250 (0.315851 %)
+ B0 ecal tagged	1,286 (0.180526 %)

With 10σ safe distance cut based on ***ep β @ IP8 RPSF***

1,286 of 800,964 events were NOT vetoed

Approach – Switch Off Beam Effects

- Current version of eic/afterburner
  - Apply **crossing angle** “and” **beam effects**

- How to switch off beam effects and only apply crossing angle
  - Create my own configuration and build my own afterburner version
    - By making all variables to be very small number (10^{-14}) except for crossing angle (when I entered all zeros, then code broken and won’t run at all)
    - Add “preset_ip8_eau_110x18_nobeameffect”

- Compare histograms between **before-burned** and **after-burned w/ or w/o beam effects**
  - Final-state protons (from eAu breakups; used incoherent events)

Configurations

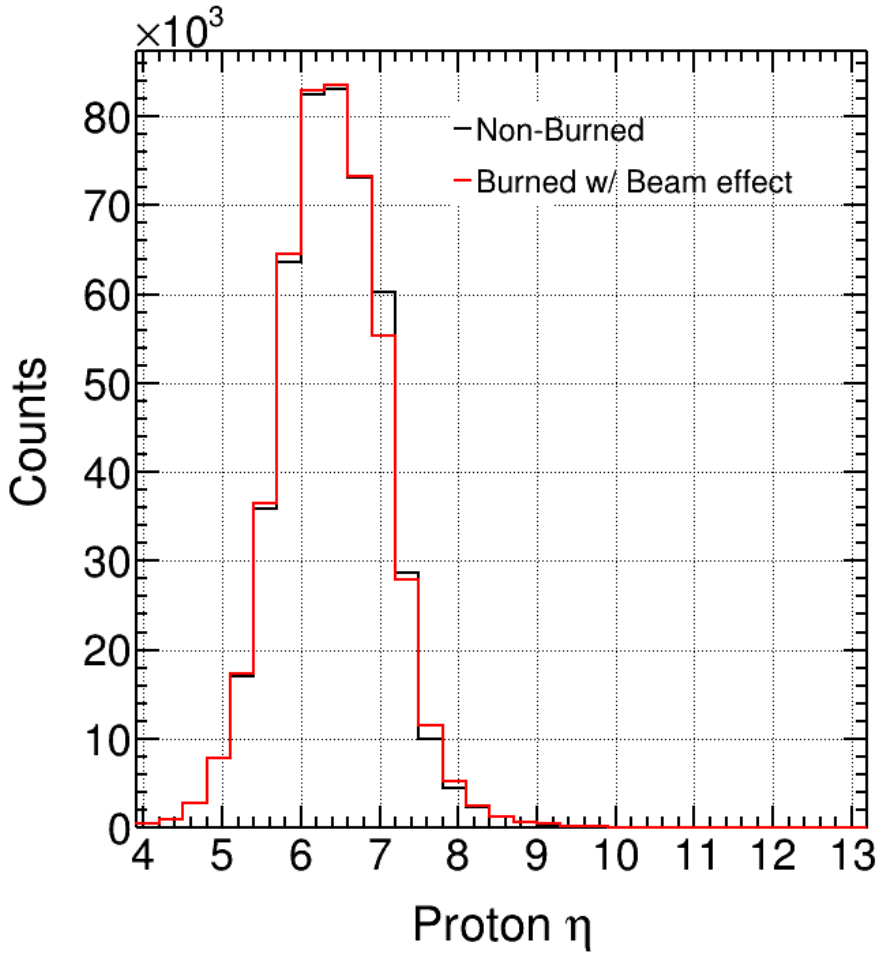
w/ beam effects

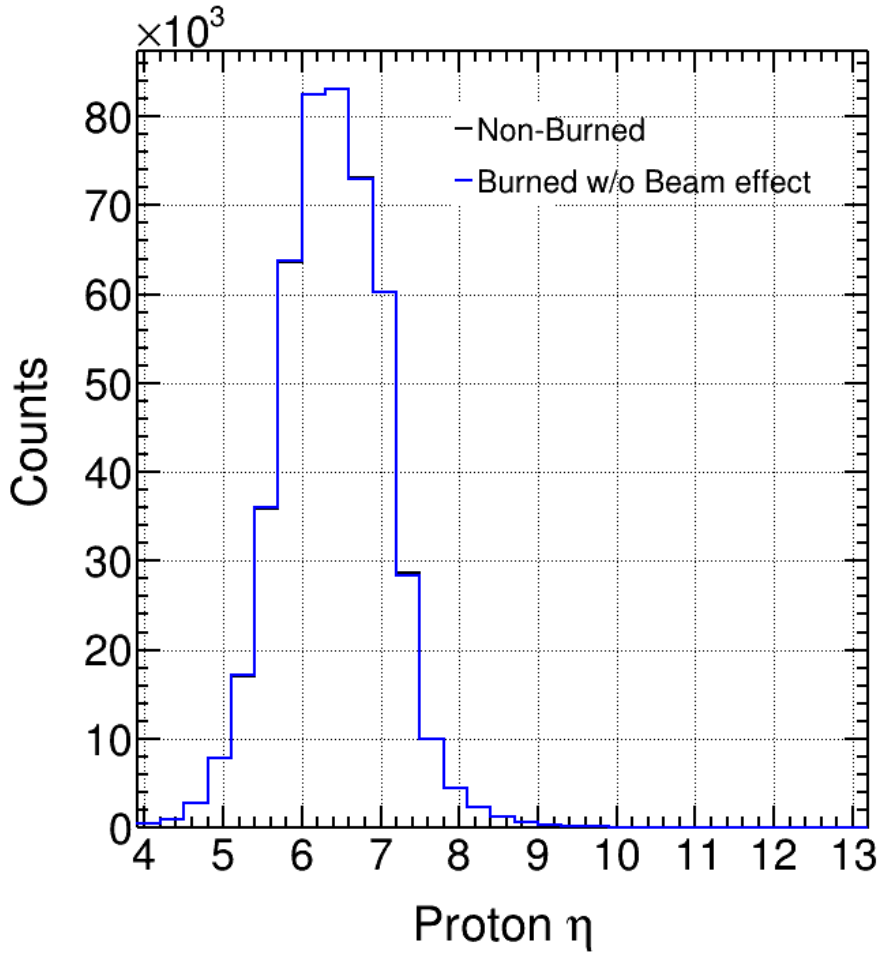
```
// ------------------------------------------------------------------
// ======================== IP 8 ====================================
// ------------------------------------------------------------------

ab::AfterburnerConfig ab::EicConfigurator::preset_ip8_eau_110x18() {
    ab::AfterburnerConfig cfg;

    cfg.crossing_angle_hor = -35e-3;            // Crossing angle in horizontal plane [rad]
    cfg.crossing_angle_ver = 0;              // Crossing angle in vertical plane [rad]

    cfg.hadron_beam.beta_crab_hor = 500000.0;
    cfg.lepton_beam.beta_crab_hor = 150000.0;

    // Beam divergence
    cfg.hadron_beam.divergence_hor = 218e-6;
    cfg.hadron_beam.divergence_ver = 379e-6;
    cfg.lepton_beam.divergence_hor = 101e-6;
    cfg.lepton_beam.divergence_ver = 37e-6;

    // Beam beta star [mm]
    cfg.hadron_beam.beta_star_hor = 910;
    cfg.hadron_beam.beta_star_ver = 40;
    cfg.lepton_beam.beta_star_hor = 1960;
    cfg.lepton_beam.beta_star_ver = 410;

    // RMS emittance
    cfg.hadron_beam.rms_emittance_hor = 43.2 * nm;
    cfg.hadron_beam.rms_emittance_ver = 5.8 * nm;
    cfg.lepton_beam.rms_emittance_hor = 20 * nm;
    cfg.lepton_beam.rms_emittance_ver = 0.6 * nm;

    // RMS bunch length
    cfg.hadron_beam.rms_bunch_length = 7 * cm;
    cfg.lepton_beam.rms_bunch_length = 0.9 * cm;

    return cfg;
}
```

w/o beam effects

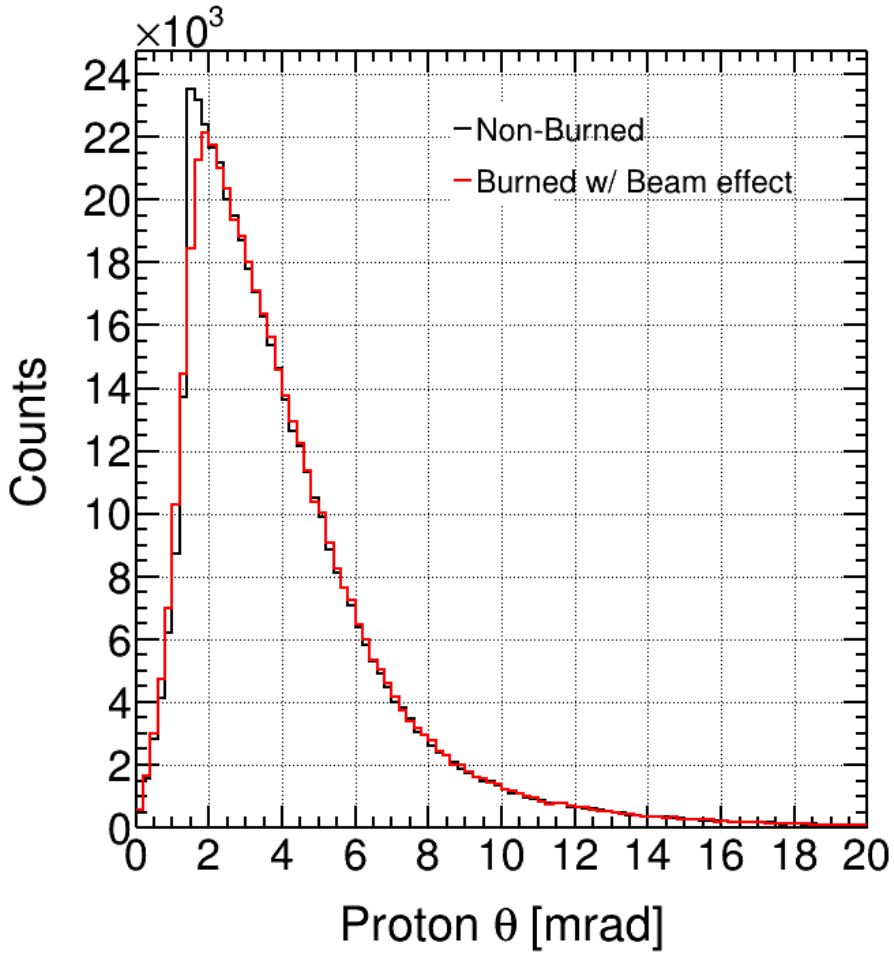
```
////////////////////////////////////////////////////////////////////////////////
// Setting with no beam effects
////////////////////////////////////////////////////////////////////////////////
ab::AfterburnerConfig ab::EicConfigurator::preset_ip8_eau_110x18_nobeameffect() {
    ab::AfterburnerConfig cfg;

    cfg.crossing_angle_hor = -35e-3; // Crossing angle in horizontal plane [rad]
    cfg.crossing_angle_ver = 1e-14;      // Crossing angle in vertical plane [rad]

    cfg.hadron_beam.beta_crab_hor = 1e-14;
    cfg.lepton_beam.beta_crab_hor = 1e-14;

    // Beam divergence
    cfg.hadron_beam.divergence_hor = 1e-14;
    cfg.hadron_beam.divergence_ver = 1e-14;
    cfg.lepton_beam.divergence_hor = 1e-14;
    cfg.lepton_beam.divergence_ver = 1e-14;

    // Beam beta star [mm]
    cfg.hadron_beam.beta_star_hor = 1e-14;
    cfg.hadron_beam.beta_star_ver = 1e-14;
    cfg.lepton_beam.beta_star_hor = 1e-14;
    cfg.lepton_beam.beta_star_ver = 1e-14;

    // RMS emittance
    cfg.hadron_beam.rms_emittance_hor = 1e-14 * nm;
    cfg.hadron_beam.rms_emittance_ver = 1e-14 * nm;
    cfg.lepton_beam.rms_emittance_hor = 1e-14 * nm;
    cfg.lepton_beam.rms_emittance_ver = 1e-14 * nm;

    // RMS bunch length
    cfg.hadron_beam.rms_bunch_length = 1e-14 * cm;
    cfg.lepton_beam.rms_bunch_length = 1e-14 * cm;

    return cfg;
}
////////////////////////////////////////////////////////////////////////////////
```

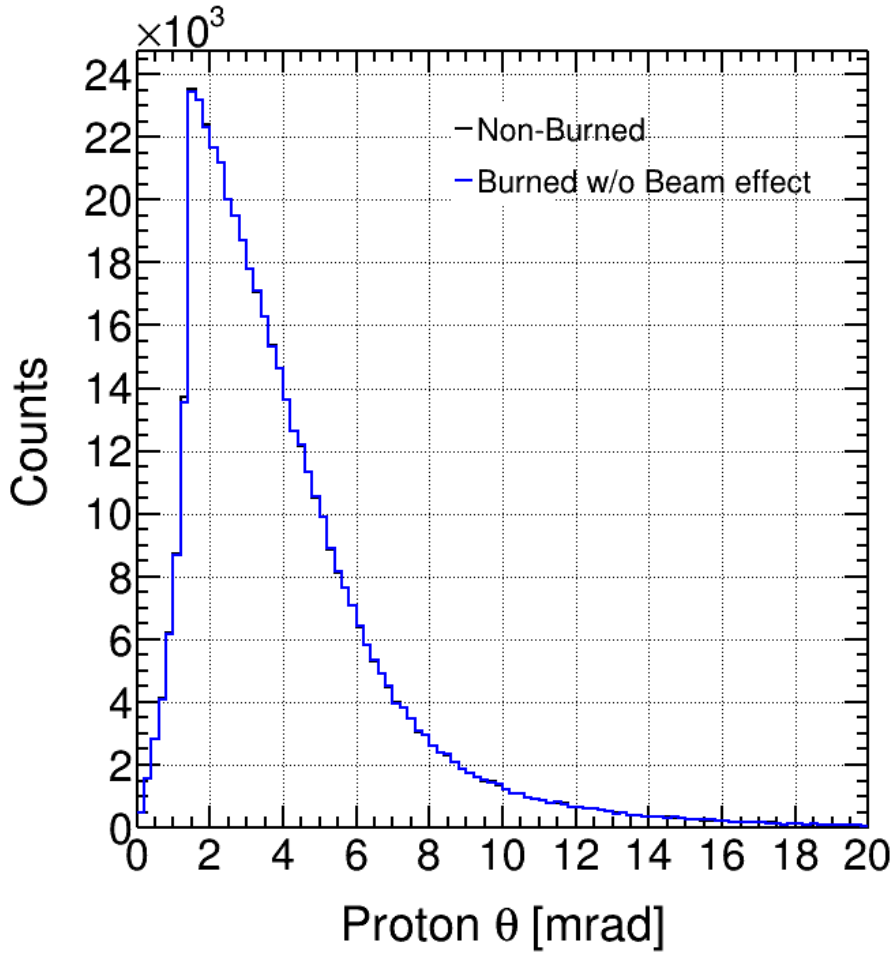
Pseudo-Rapidity



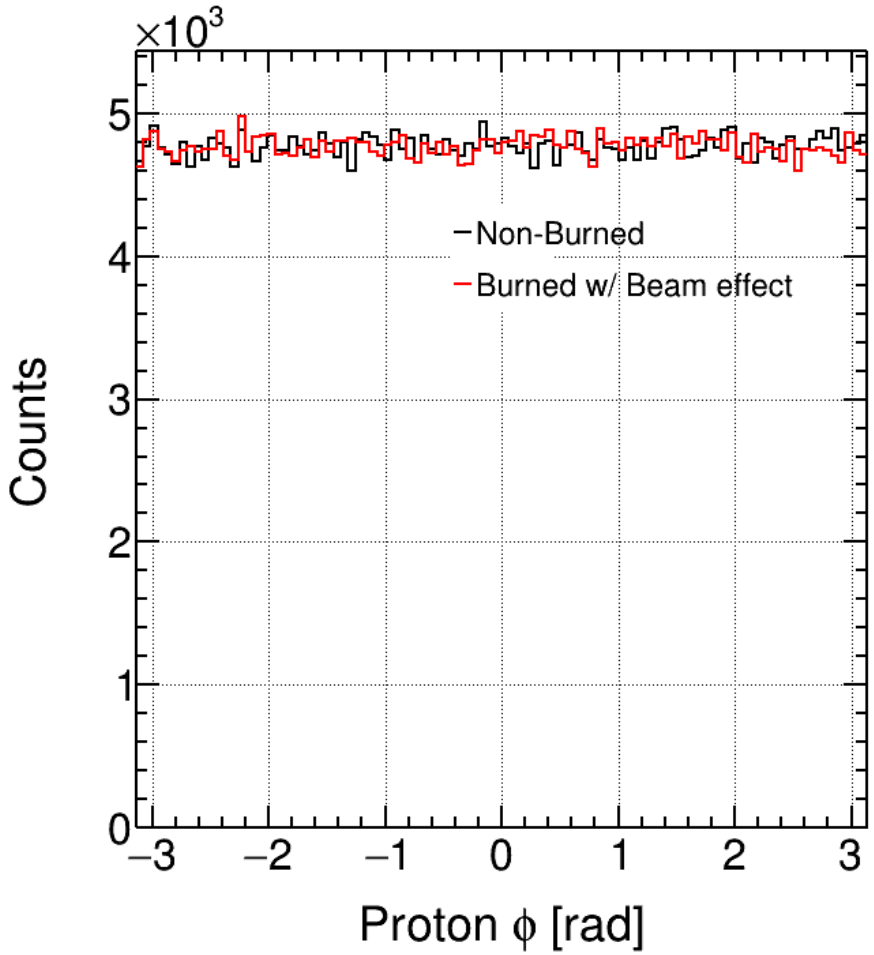


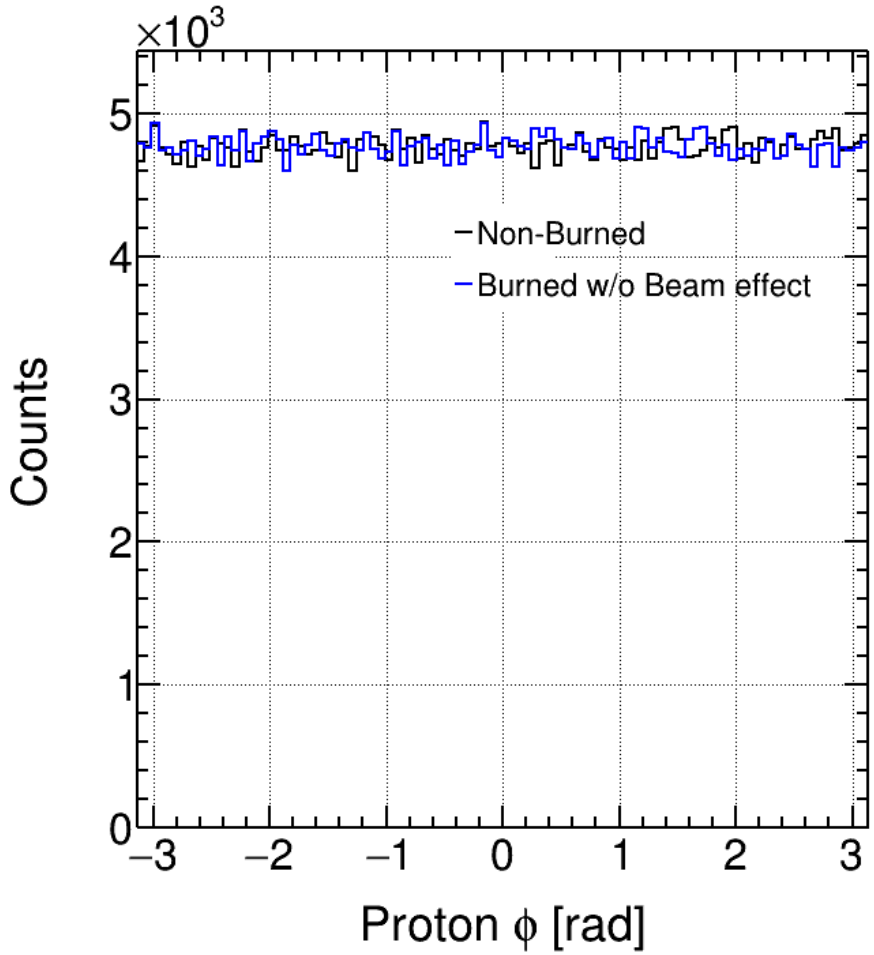
Scattering Angle



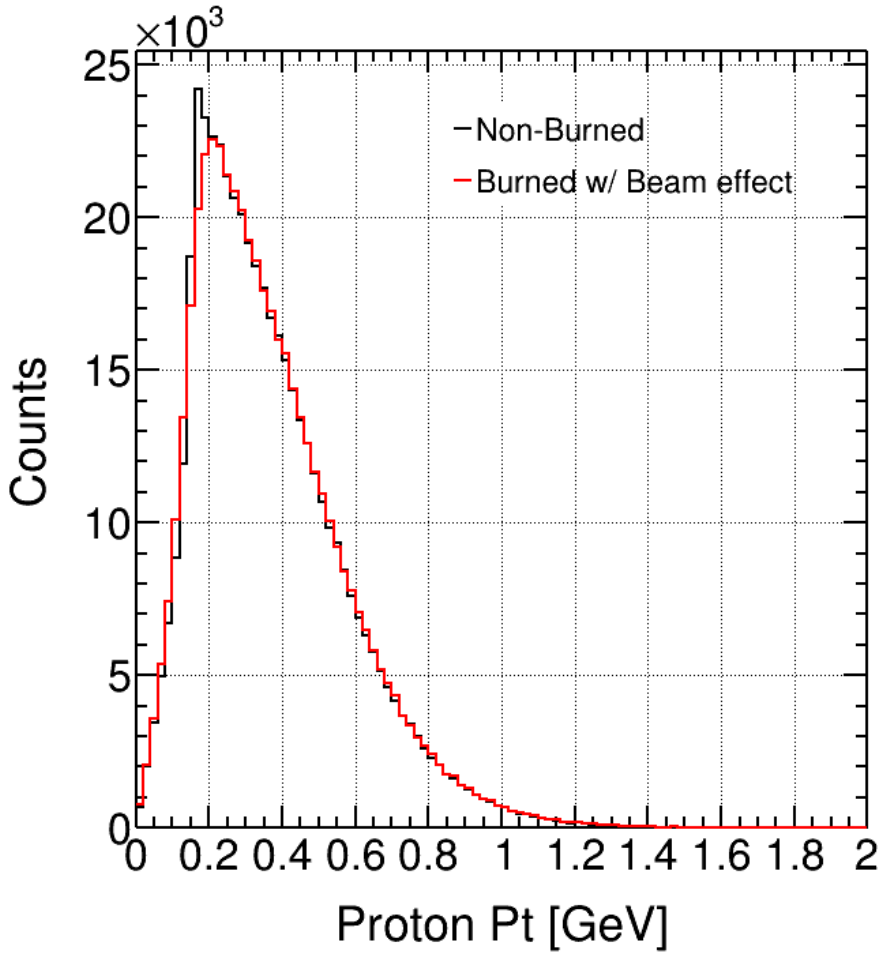


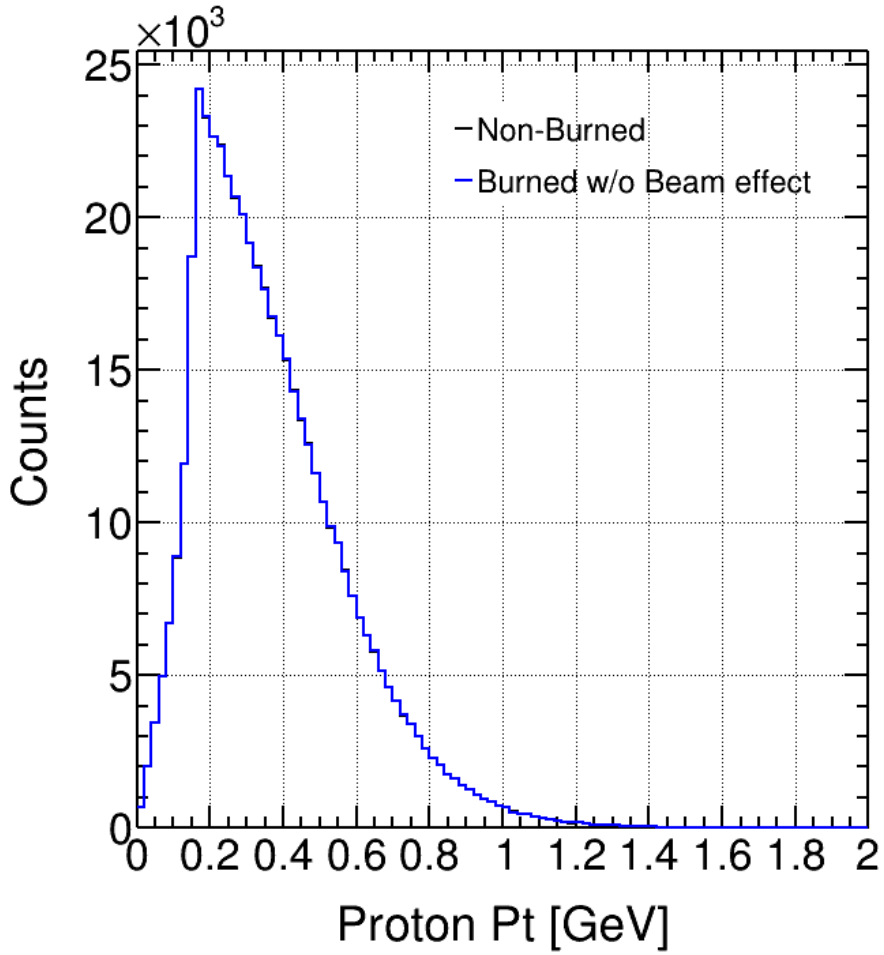
Azimuthal Angle



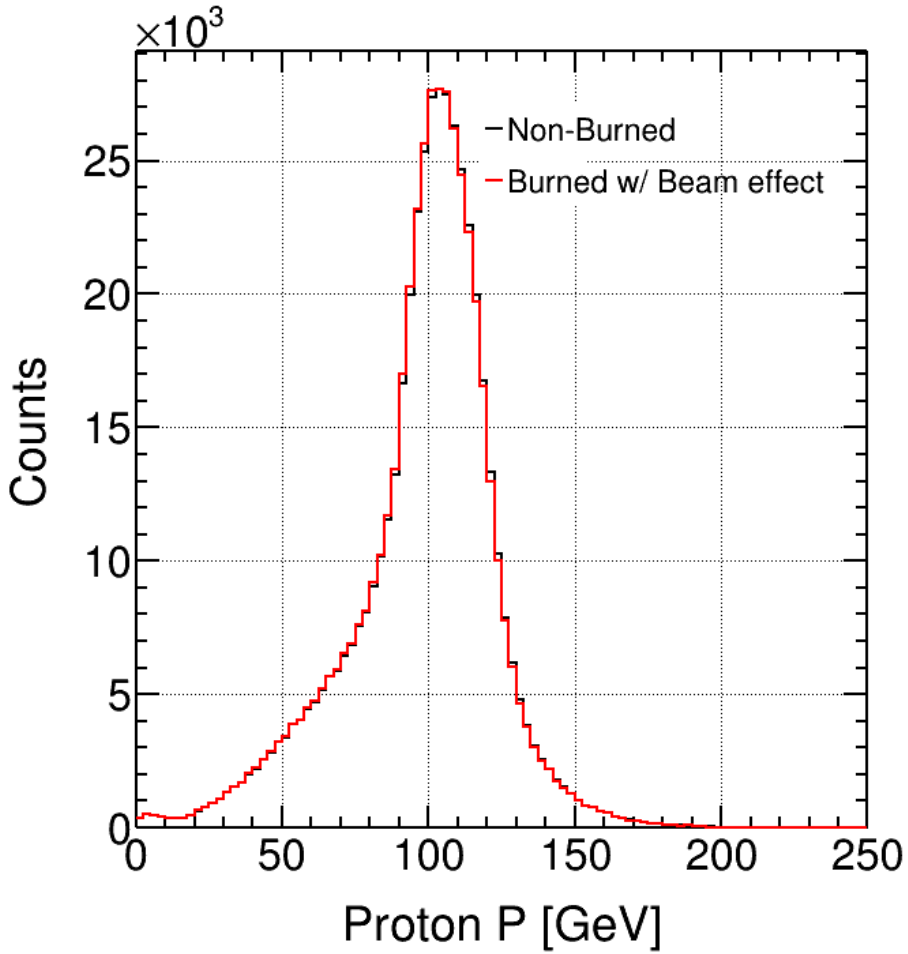


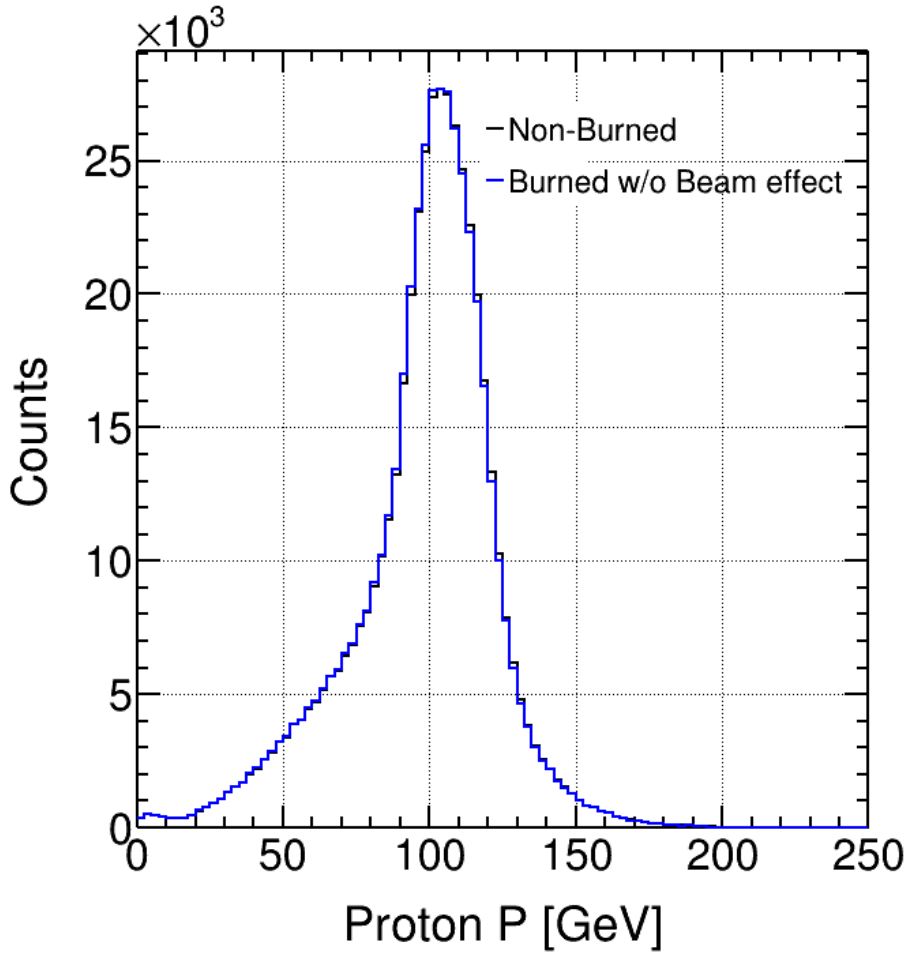
Transverse Momentum





Momentum


×10^3
Non-Burned
Burned w/ Beam effect
Counts
Proton P [GeV]
0
5
10
15
20
25
0
50
100
150
200
250


×10^3
Non-Burned
Burned w/o Beam effect
Counts
Proton P [GeV]
0
5
10
15
20
25
0
50
100
150
200
250