Particle Reconstruction Using Roman Pot at 2nd Focus

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2024/05/13

Motivation

- Toward finalizing IR-8 vetoing power analysis with far-forward IR-8 2^{nd} focus
  - Good addition: possible physics cases
    - **Pion cloud model**
    - **Diffractive structure function**
    - Dark photon?
- In order to make physics cases on IR-8 2^{nd} focus
  - Requires to show feasibility to **reconstruct scattered proton at small-t**
- How to do
  - Requires matrices to describe particle motion through magnets
  - **For now, assumes x and y are independent** and calculates purely x- or y-dependent part of matrices respectively (**only works at certain case: DVCS ep 18 GeV$\times$275 GeV**), <u>which is fine to check out feasibility</u>. <u>In the meantime, it needs more refined approach</u>

Matrices Calculation

Matrix at Roman Pot 2nd Focus

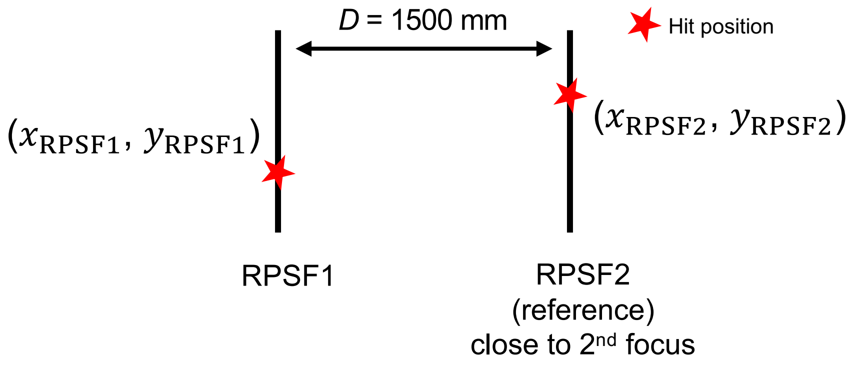
- How to define matrices at Roman Pot at Secondary Focus (RPSF)
  - Needs five trajectories in total using single particle gun simulation
    - **Protons on central track**:

      $\boldsymbol{\theta_{x,\,\mathrm{IP}} = 0}$ **mrad** and $\boldsymbol{\frac{\Delta p}{p}_{\mathrm{IP}} = 0}$
    - **Protons with small angle spread in x**:

      $\boldsymbol{\theta_{x,\,\mathrm{IP}} = 1}$ **mrad** and $\frac{\Delta p}{p}_{\mathrm{IP}} = 0$
    - **Protons with small angle spread in y**:

      $\boldsymbol{\theta_{y,\,\mathrm{IP}} = 1}$ **mrad** and $\frac{\Delta p}{p}_{\mathrm{IP}} = 0$
    - **Protons with small momentum spread in x and y**:

      $\theta_{x/y,\,\mathrm{IP}} = 1$ mrad and $\boldsymbol{\frac{\Delta p}{p}_{\mathrm{IP}} = 1\%}$



- Resulting matrices **only works on proton momentum close to 275 GeV**

Resulting Matrices

x-dependent matrix

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} \frac{\Delta p}{p} \\ \theta_x \end{pmatrix}_{\mathrm{IP}} = \begin{pmatrix} x \\ \theta_x \end{pmatrix}_{\mathrm{DET}} \quad \Rightarrow \quad \begin{pmatrix} \boldsymbol{a} & \boldsymbol{b} \\ \boldsymbol{c} & \boldsymbol{d} \end{pmatrix} = \begin{pmatrix} \mathbf{5.55} & \mathbf{0.27} \\ \mathbf{0.0189} & \mathbf{-1.261} \end{pmatrix}$$

y-dependent matrix

$$\begin{pmatrix} f & g \\ h & i \end{pmatrix} \begin{pmatrix} \frac{\Delta p}{p} \\ \theta_y \end{pmatrix}_{\mathrm{IP}} = \begin{pmatrix} y \\ \theta_y \end{pmatrix}_{\mathrm{DET}} \quad \Rightarrow \quad \begin{pmatrix} \boldsymbol{f} & \boldsymbol{g} \\ \boldsymbol{h} & \boldsymbol{i} \end{pmatrix} = \begin{pmatrix} \mathbf{0.978304} & \mathbf{0.14427612} \\ \mathbf{0.049272} & \mathbf{-0.14000692} \end{pmatrix}$$

To reconstruct protons, use inverse of x- and y-dependent matrices. Transform coordinates (position and angle) at detectors to original IP coordinates.

With Single Particle Sample
(as in a sample without beam effect)

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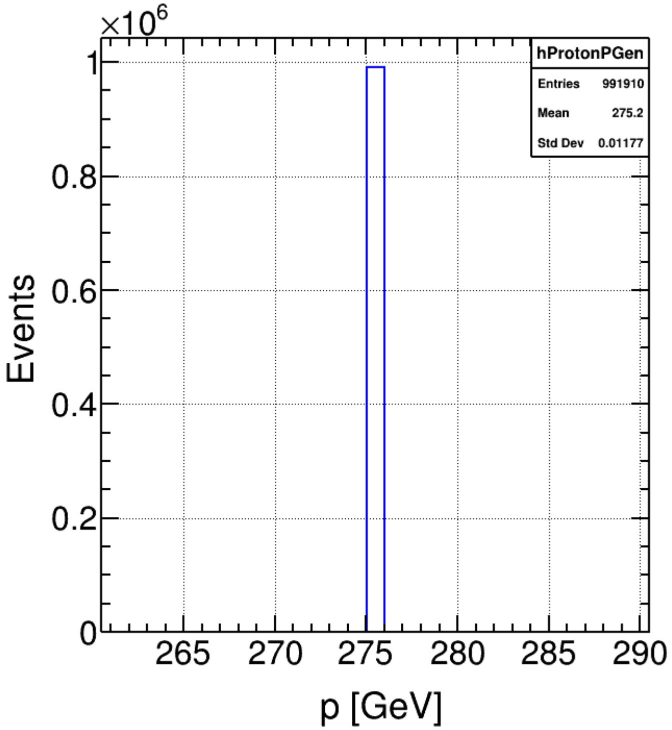
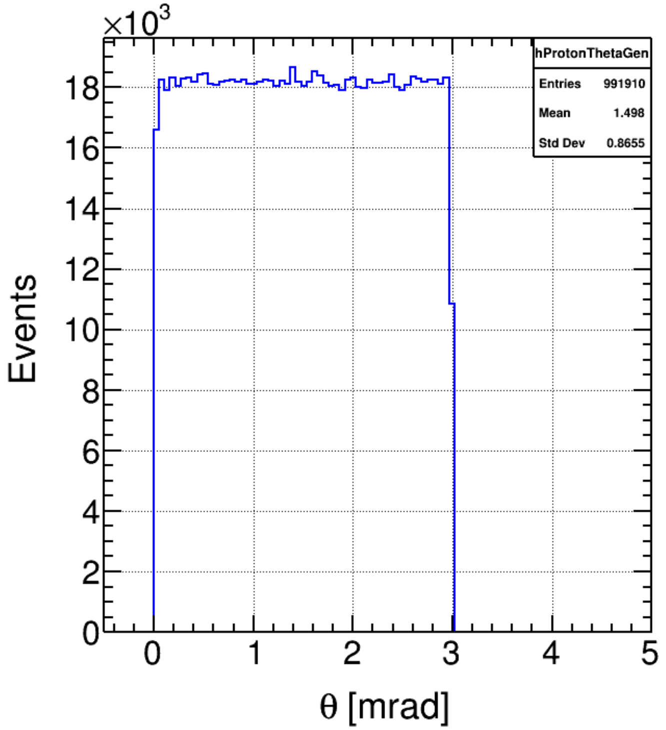
Proton with $p = 275$ GeV, $0 < \theta < 3$ mrad, and $0 < \phi < 2\pi$ rad

Thrown Proton Distribution

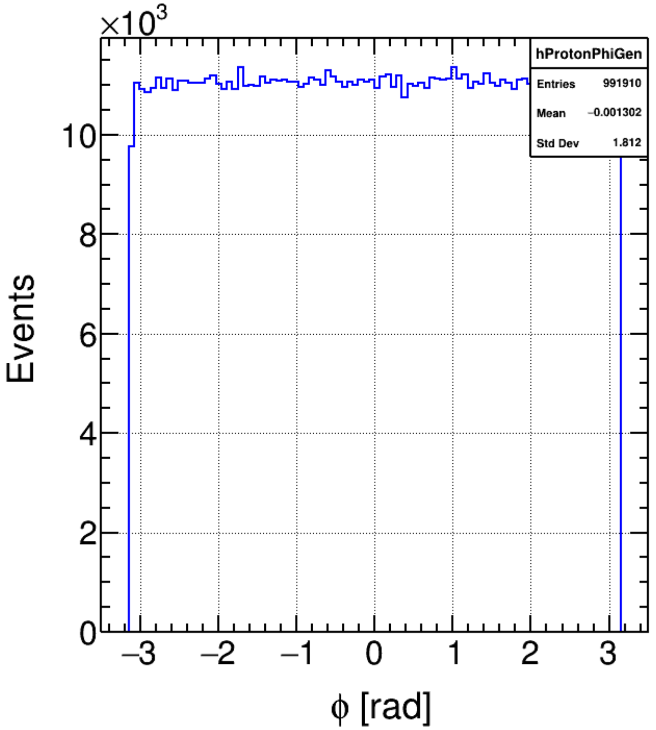
Momentum



Polar Angle



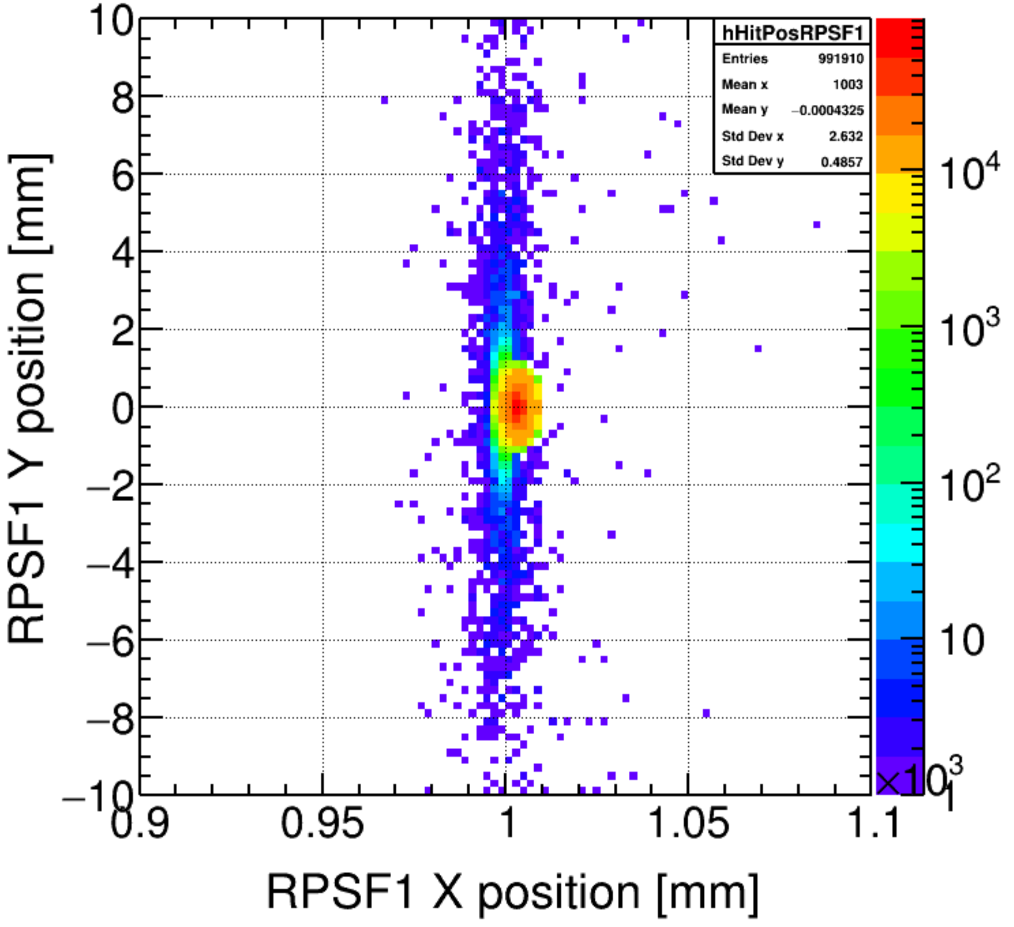
Azimuthal Angle



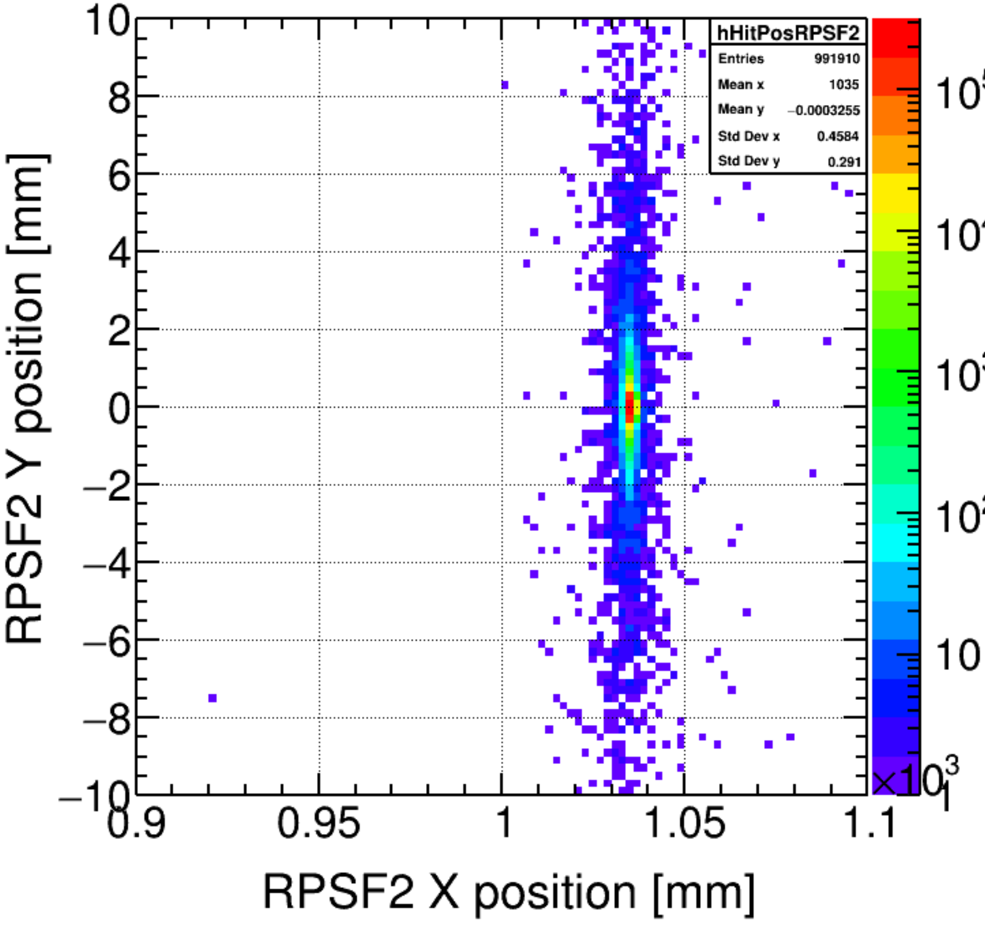
Proton with $p = 275$ GeV, $0 < \theta < 3$ mrad, and $0 < \phi < 2\pi$ rad

Roman Pot Hit Position

First Roman Pot Plane



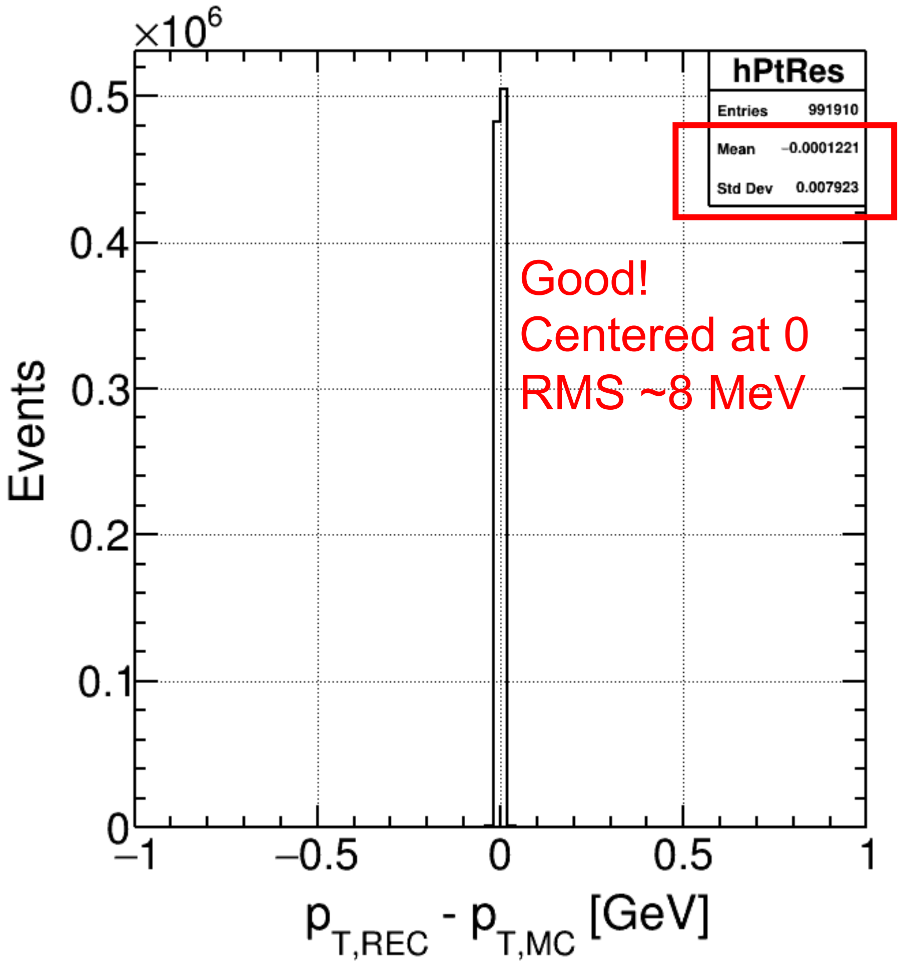
Second Roman Pot Plane



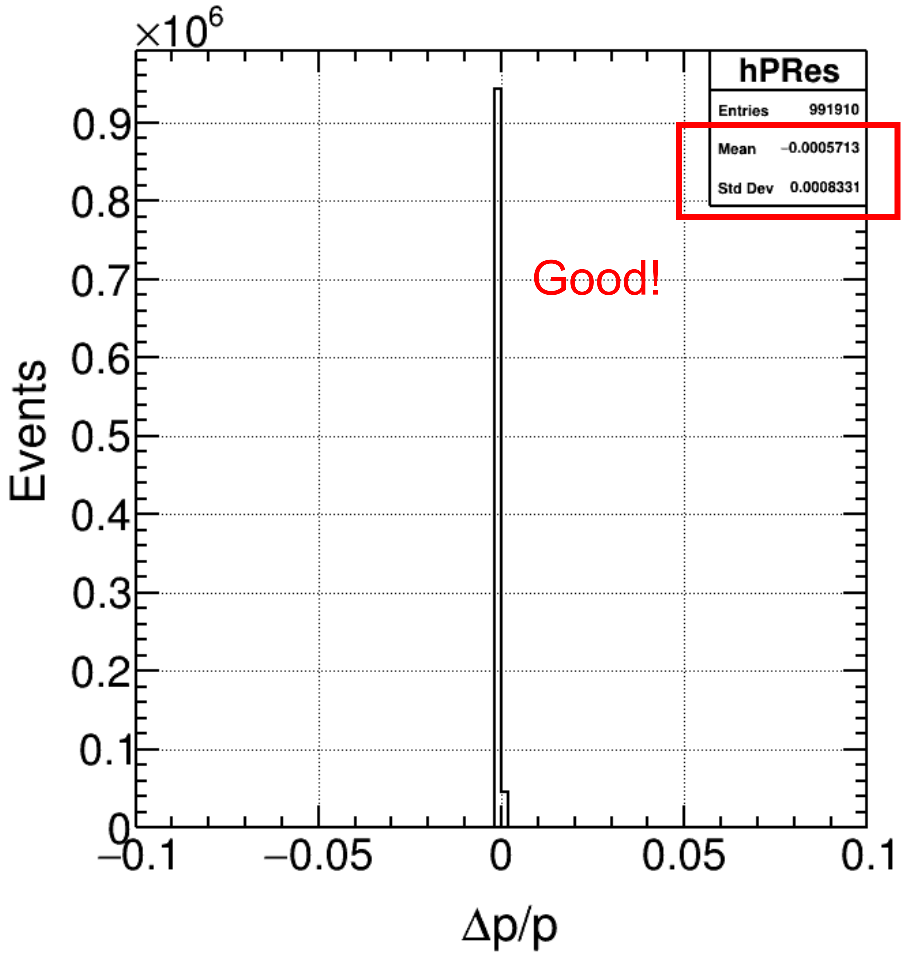
Proton with $p = 275$ GeV, $0 < \theta < 3$ mrad, and $0 < \phi < 2\pi$ rad

Reconstructed Proton Resolution

Transverse Momentum Resolution



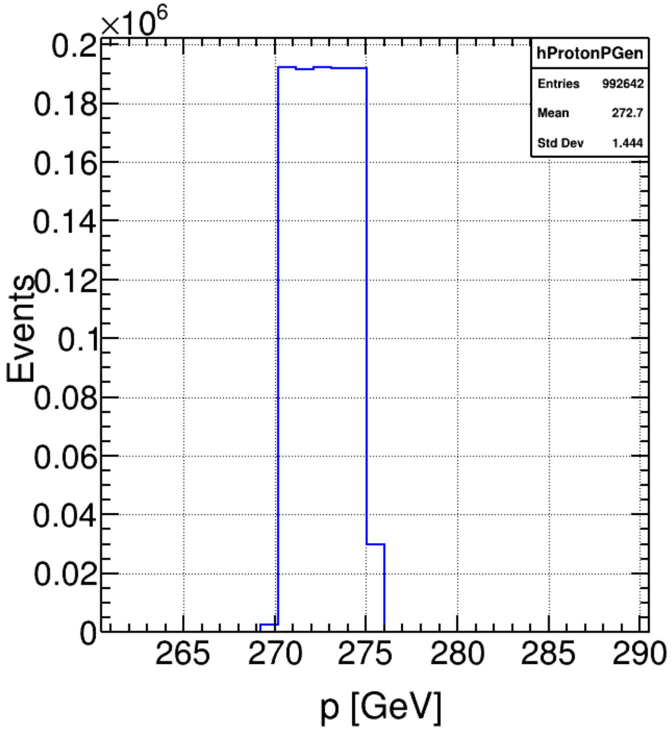
Momentum Resolution



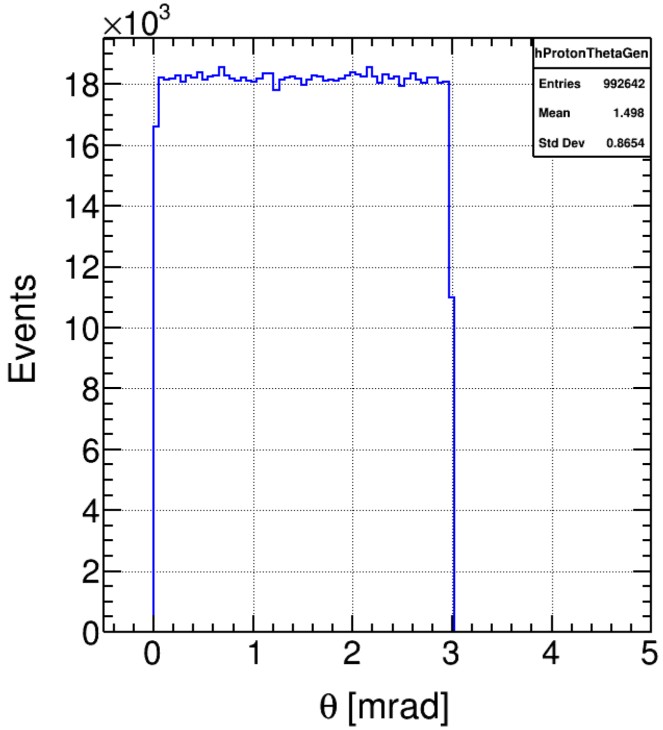
Proton with $270 < p < 275$ GeV, $0 < \theta < 3$ mrad, and $0 < \phi < 2\pi$ rad

Thrown Proton Distribution

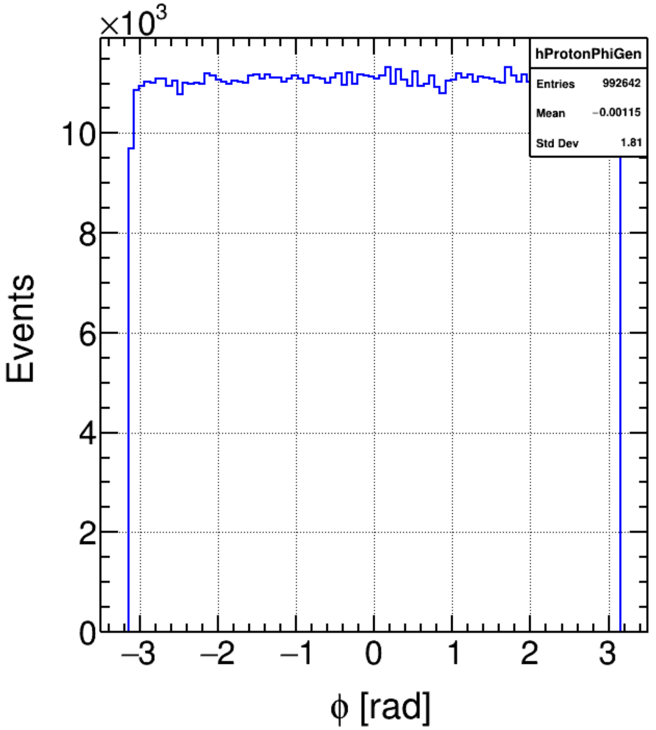
Momentum



Polar Angle



Azimuthal Angle



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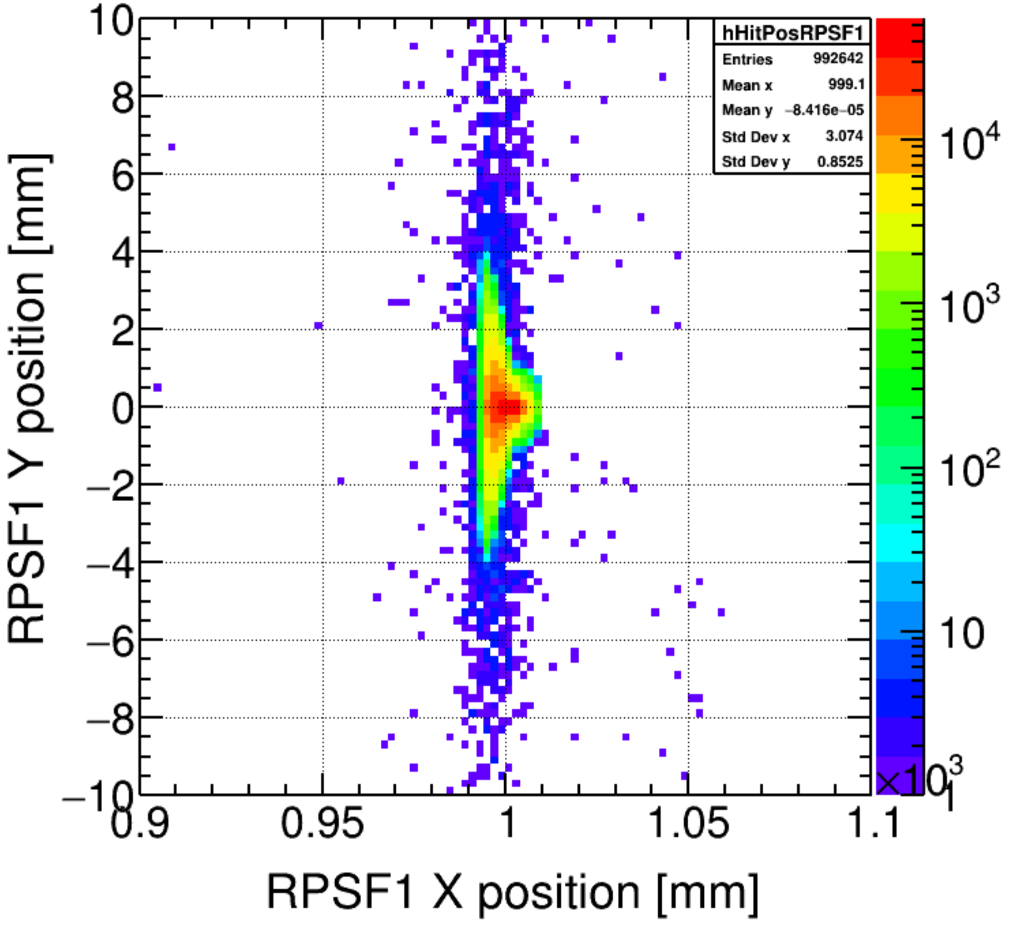
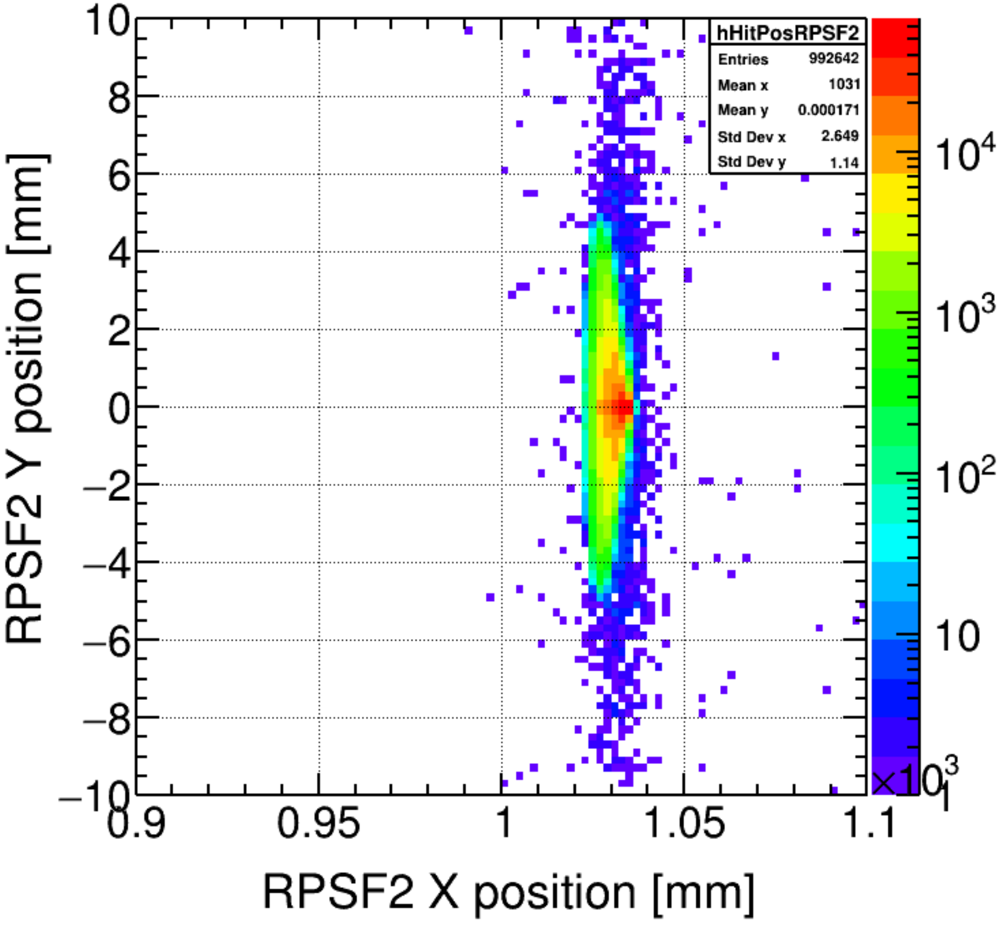
Proton with $270 < p < 275$ GeV, $0 < \theta < 3$ mrad, and $0 < \phi < 2\pi$ rad

Roman Pot Hit Position

First Roman Pot Plane



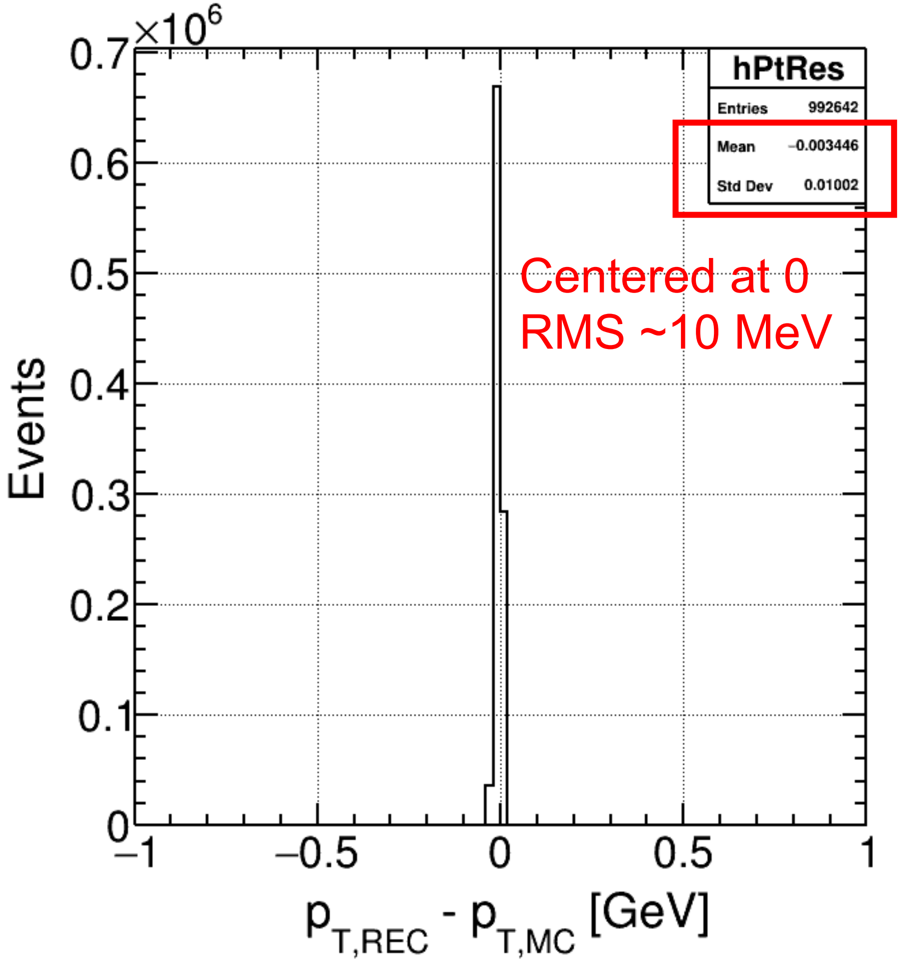
Second Roman Pot Plane



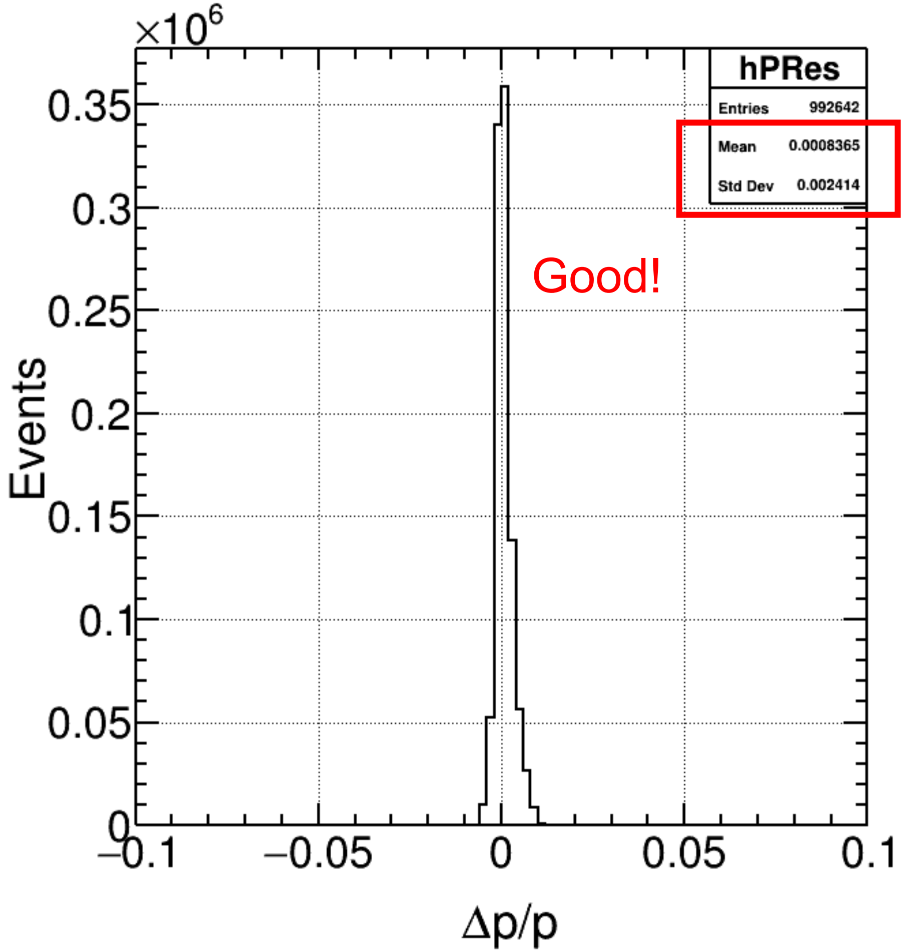
Proton with $270 < p < 275$ GeV, $0 < \theta < 3$ mrad, and $0 < \phi < 2\pi$ rad

Reconstructed Proton Resolution

Transverse Momentum Resolution

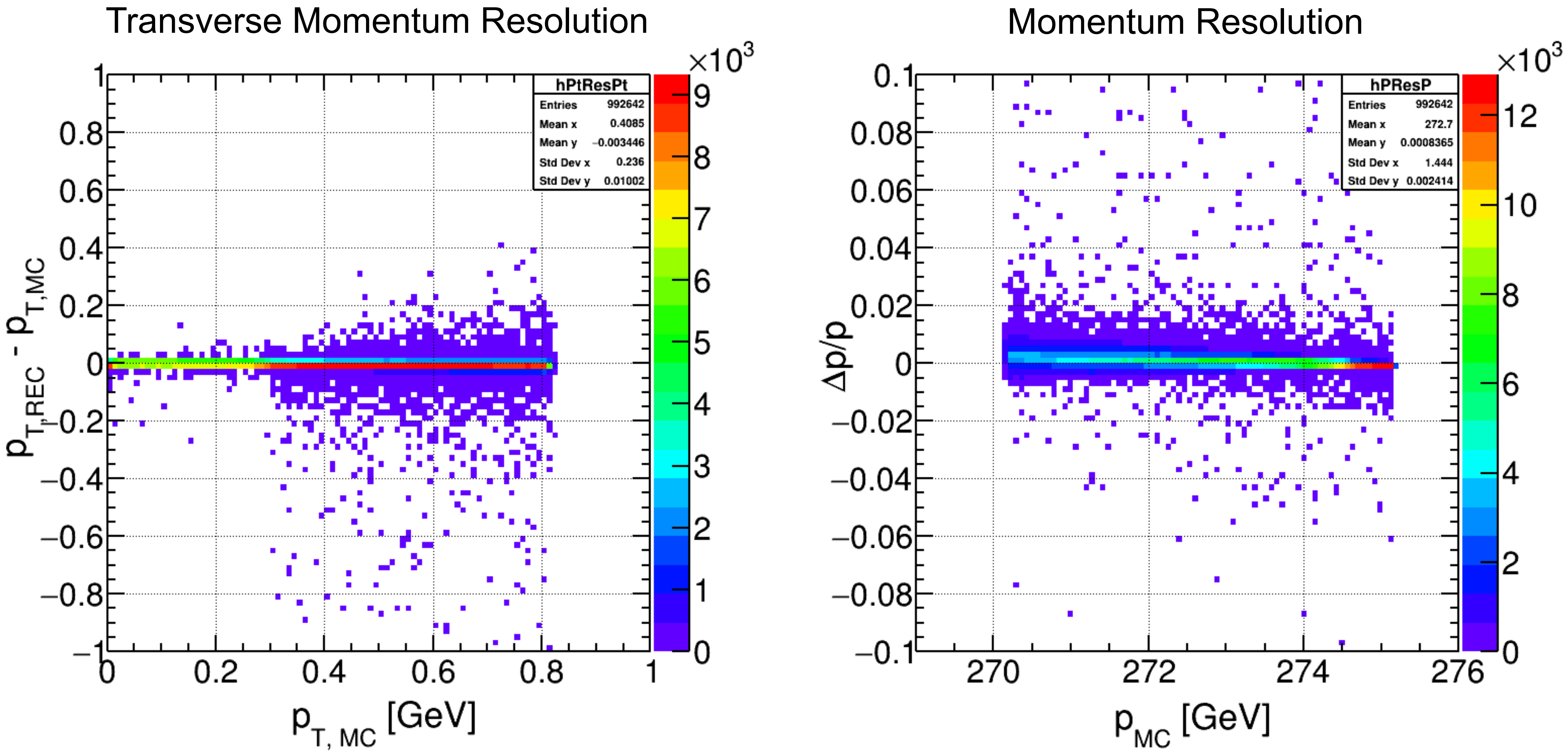


Momentum Resolution



Proton with $270 < p < 275$ GeV, $0 < \theta < 3$ mrad, and $0 < \phi < 2\pi$ rad

Reconstructed Proton Resolution



With DVCS Sample
(as in a sample with beam effect)

DVCS 18 GeV × 275 GeV Sample

- Data sample was taken from
  - 1 M exclusive events
  - S3/eictest/EPIC/EVGEN/EXCLUSIVE/DVCS/18x275/DVCS.3.18x275.hepmc
  - **No radiative component included**
- Passed through Afterburner to apply **beam effects (angular divergence & momentum spread) and crossing angle**
- **Applied only crossing angle rotation for now**
- Regarding reconstruction of scattered proton
  - Applied 10σ cut based on IR-8 ep 18 GeV × 275 GeV setting (92.5 %)

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

1σ calculation	$1\sigma_x$	$1\sigma_y$
ep β @ IR-8 RPSF (new)	0.146677	0.140271

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

- Used inverse transfer matrices from single particle gun simulation to reconstruct scattered proton momentum and t was calculated from $t = (p' - p)^2$

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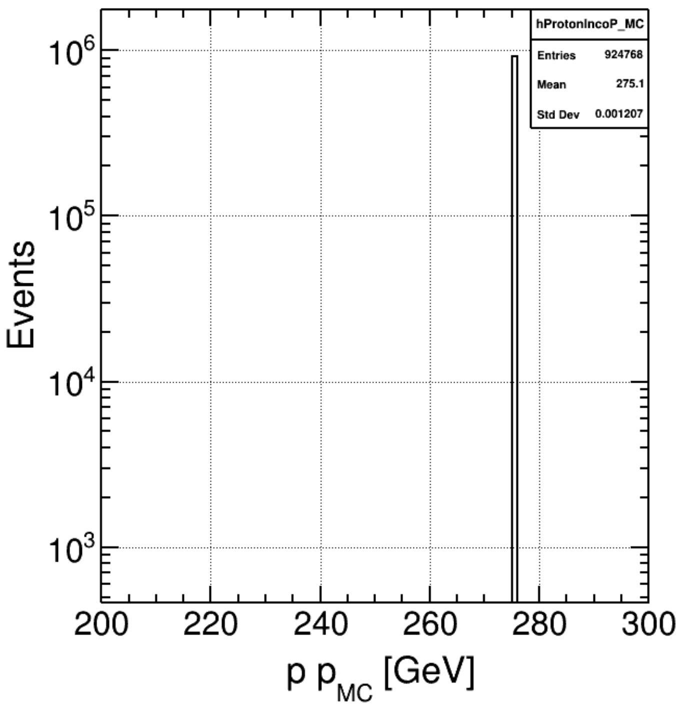
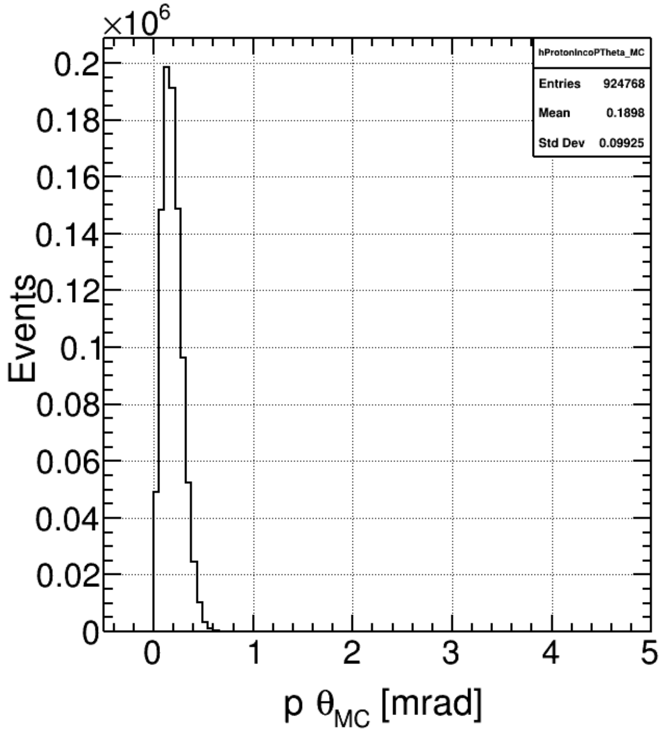
DVCS 18 GeV × 275 GeV Sample **ALL**

Incoming Proton Distribution - MC

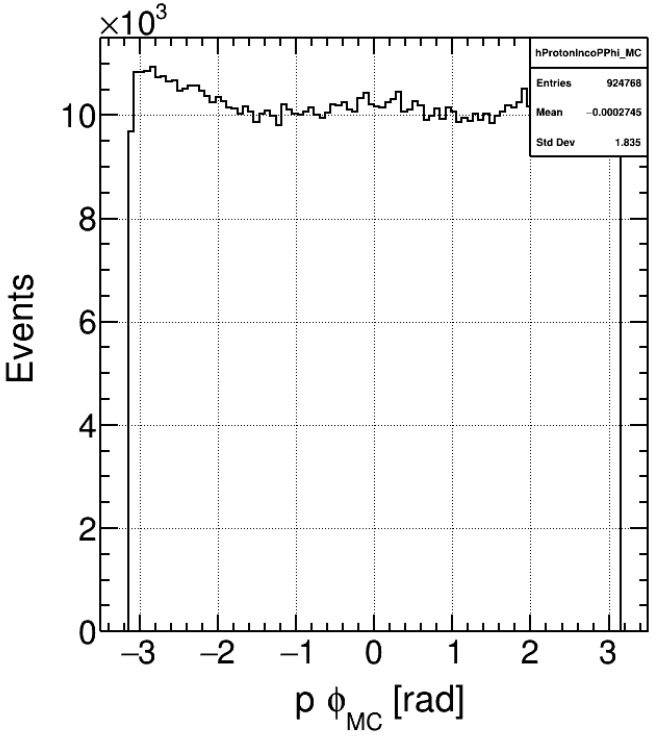
Momentum



Polar Angle

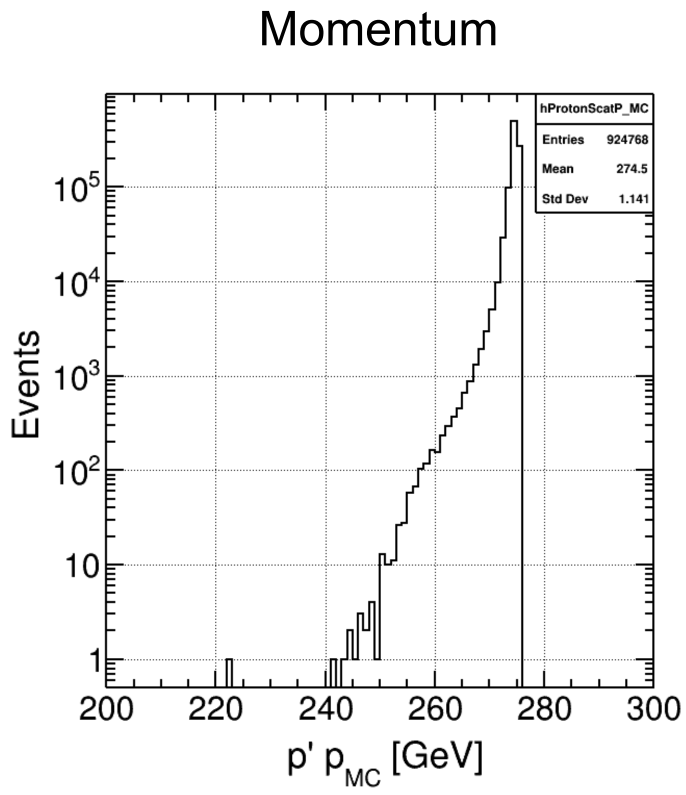


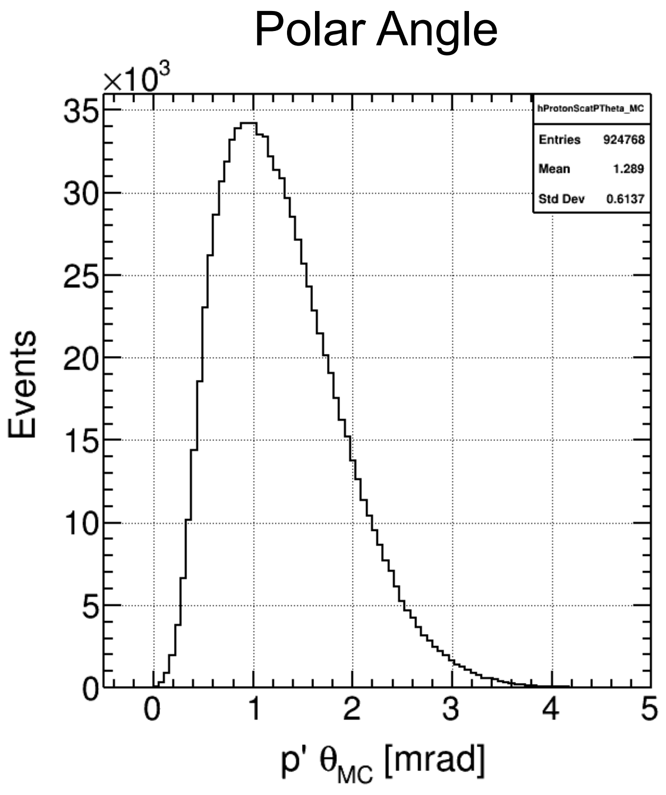
Azimuthal Angle

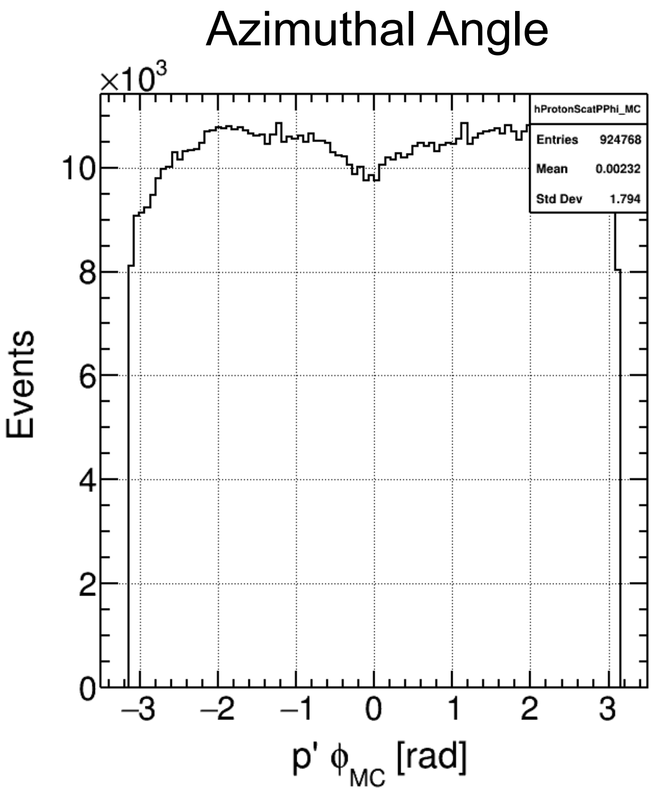


DVCS 18 GeV × 275 GeV Sample **ALL**

Scattered Proton Distribution - MC



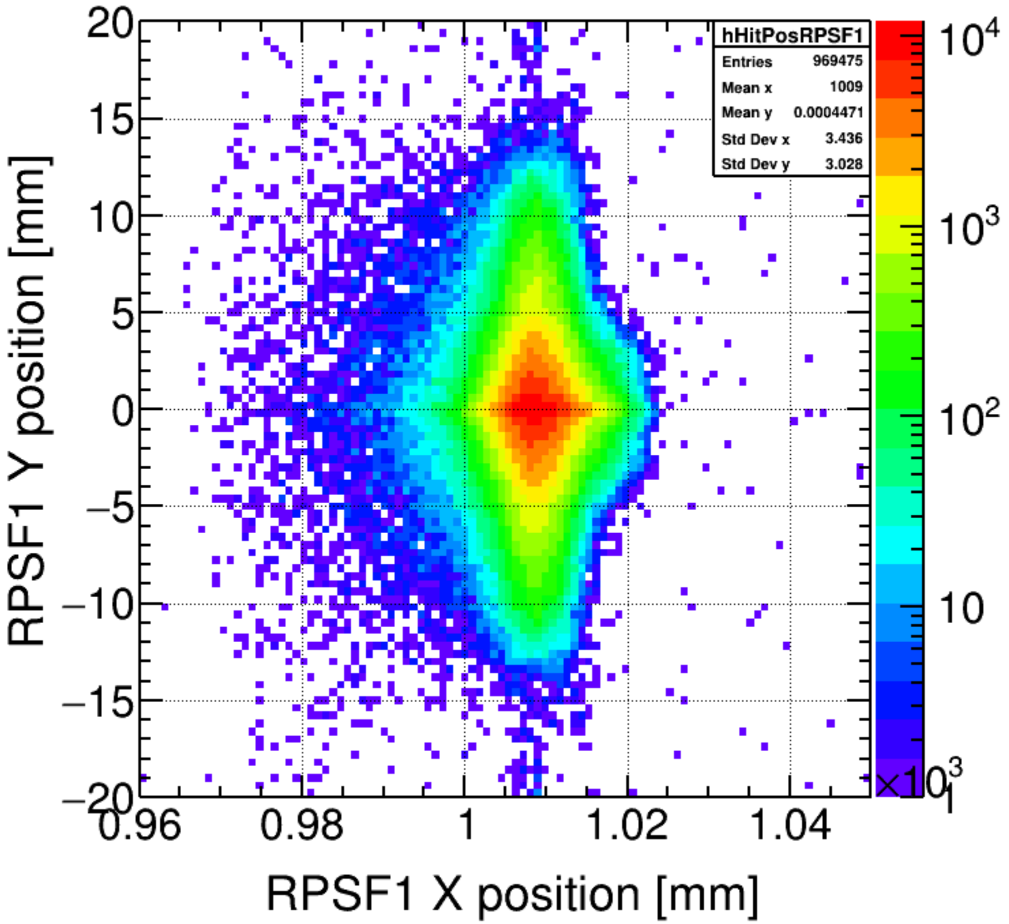




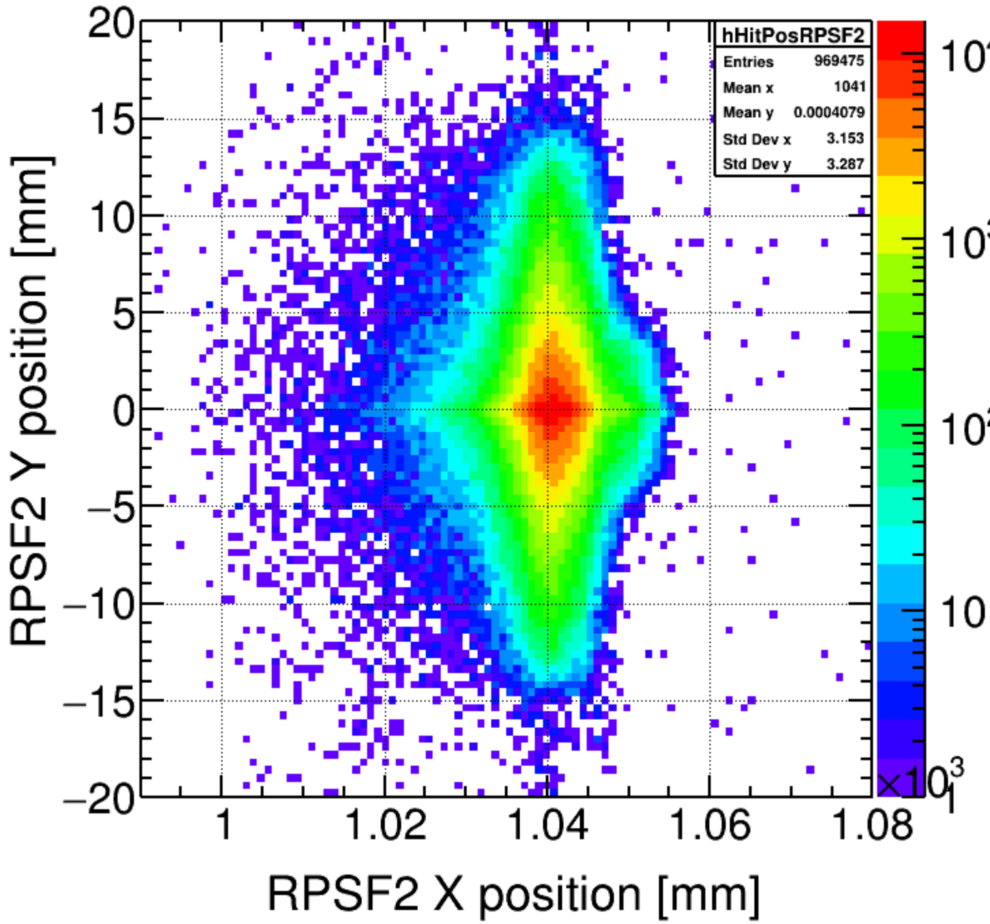
DVCS 18 GeV × 275 GeV Sample **ALL**

Raw Hit Level Information – Detector

First Roman Pot Plane



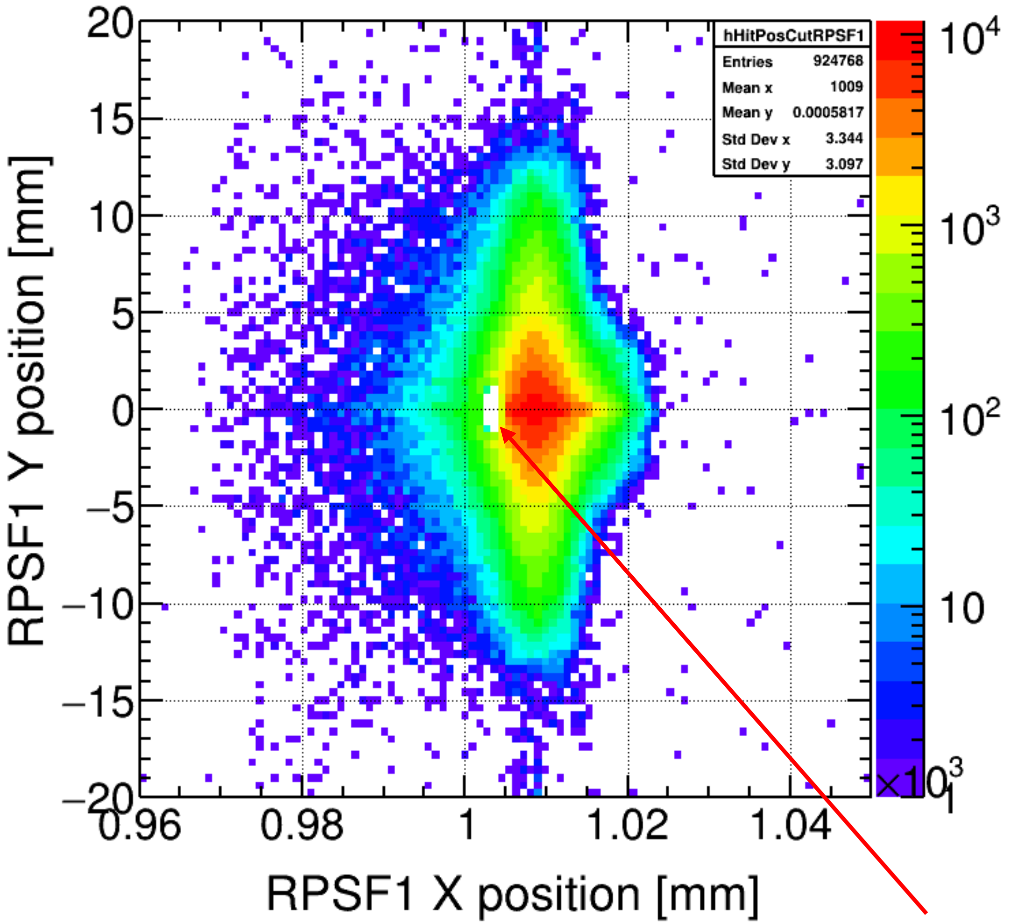
Second Roman Pot Plane



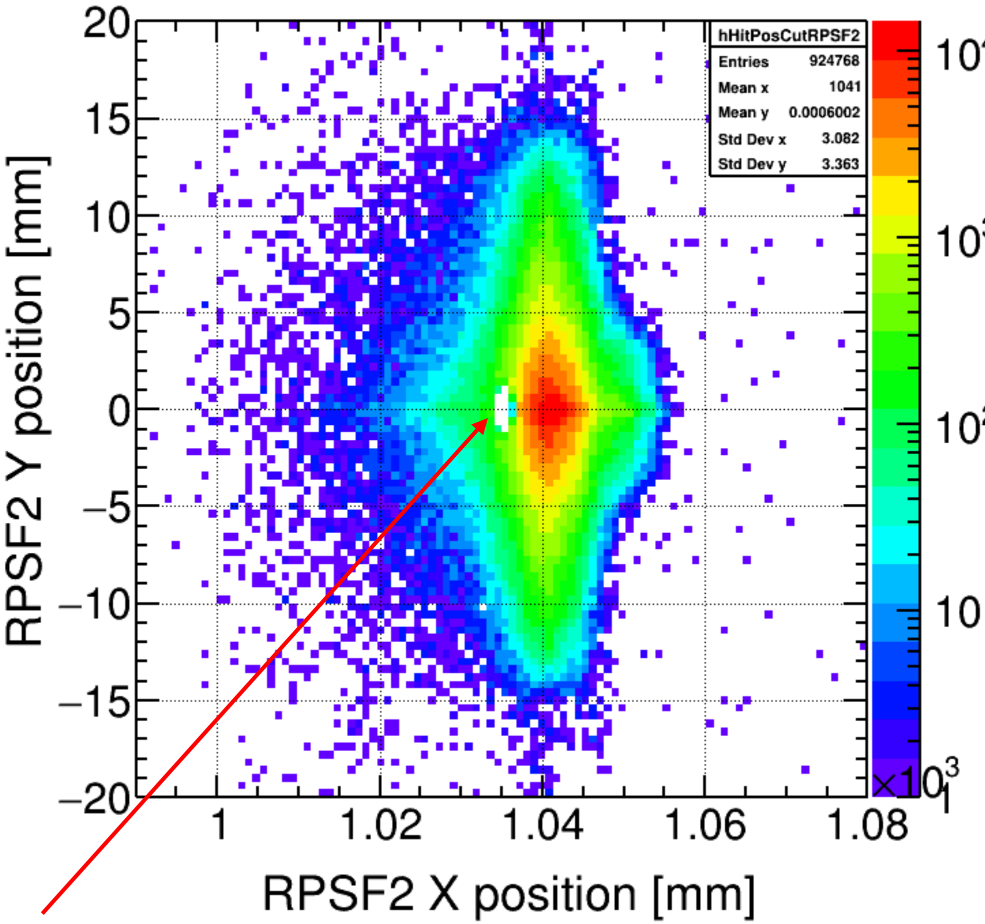
DVCS 18 GeV × 275 GeV Sample **ALL**

Raw Hit Level Information – Detector

First Roman Pot Plane



Second Roman Pot Plane

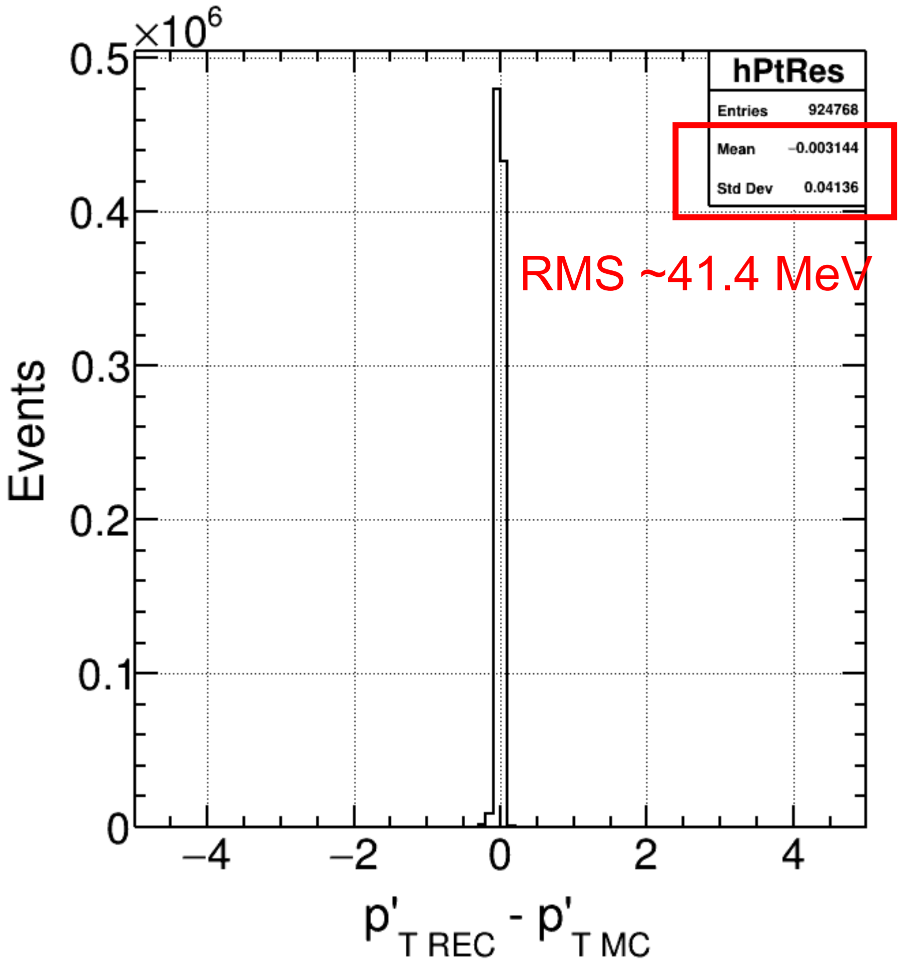


10σ cut

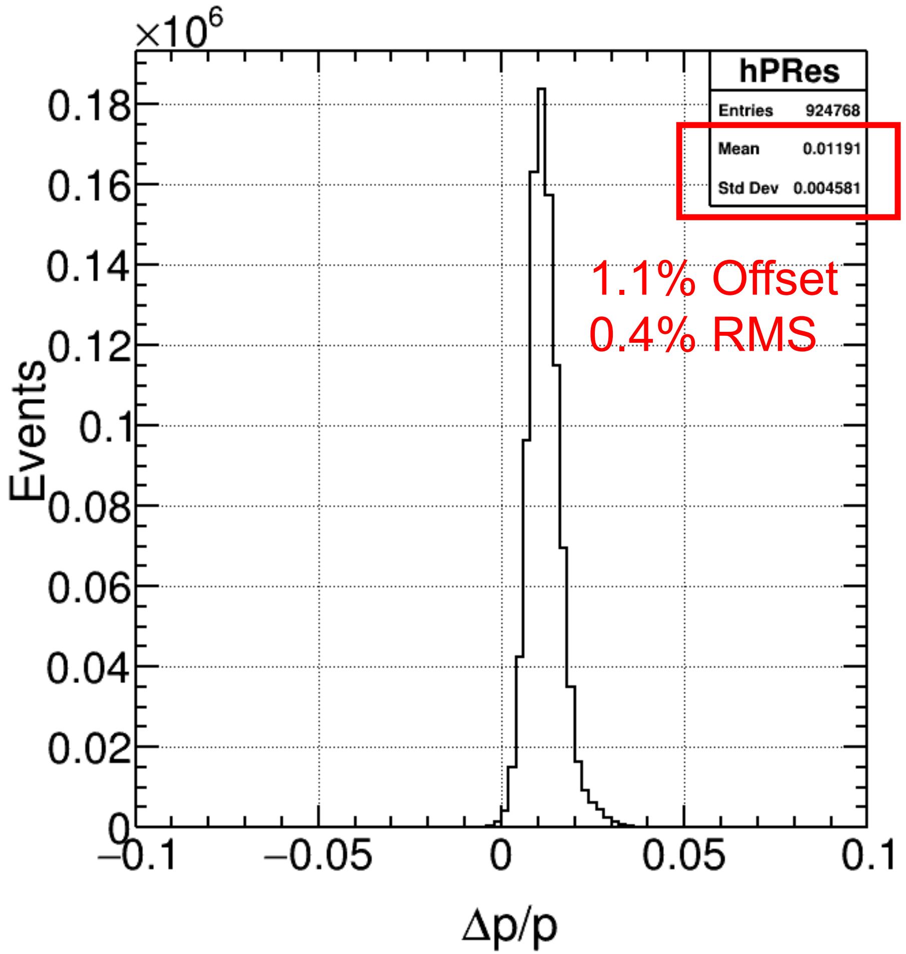
DVCS 18 GeV × 275 GeV Sample **ALL**

Reconstructed Proton Resolution

Transverse Momentum Resolution



Momentum Resolution

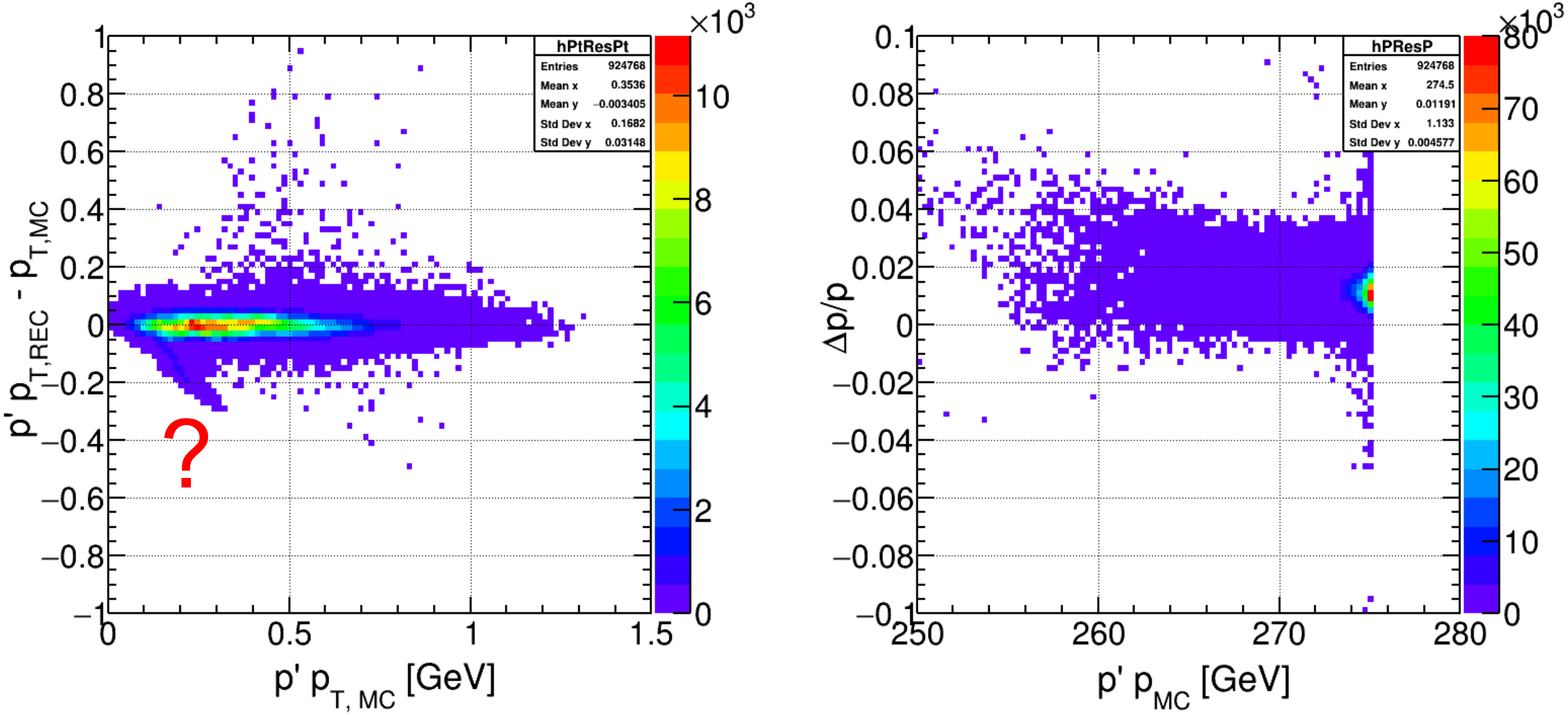


DVCS 18 GeV × 275 GeV Sample **ALL**

Reconstructed Proton Resolution

Transverse Momentum Resolution

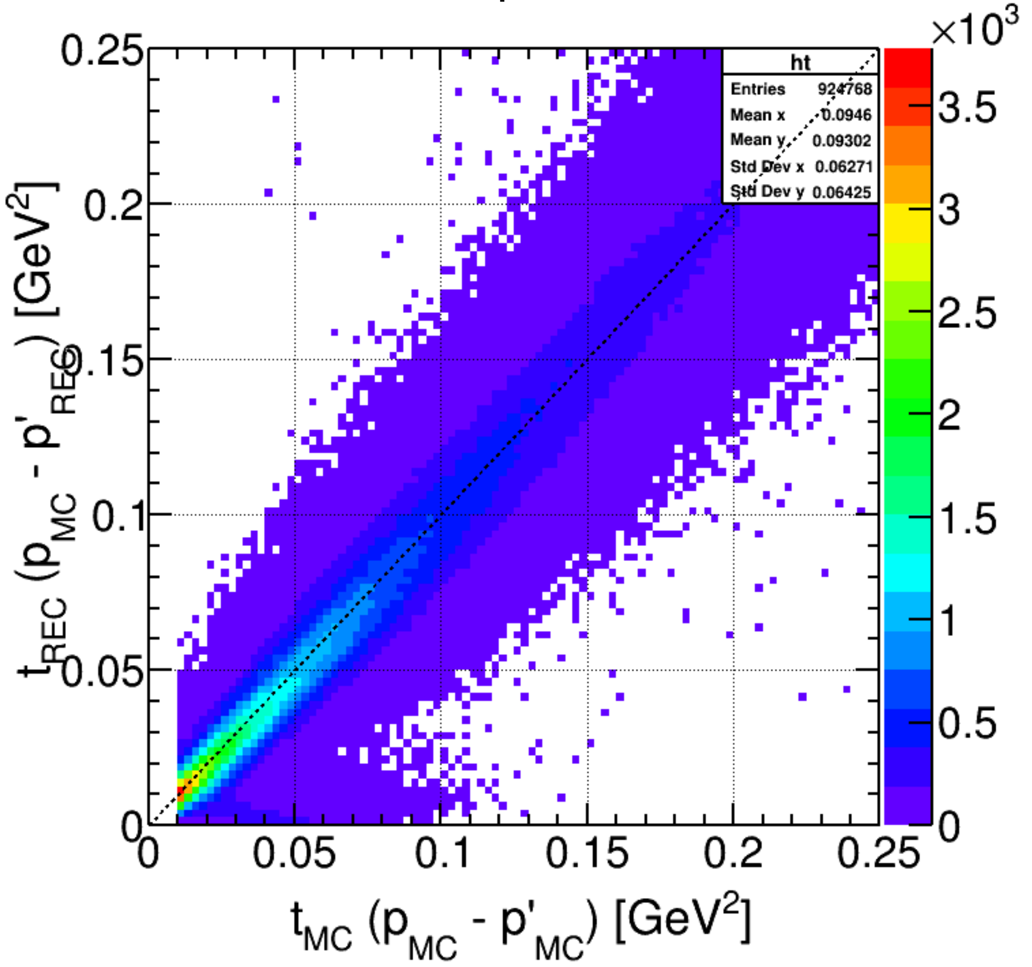
Momentum Resolution



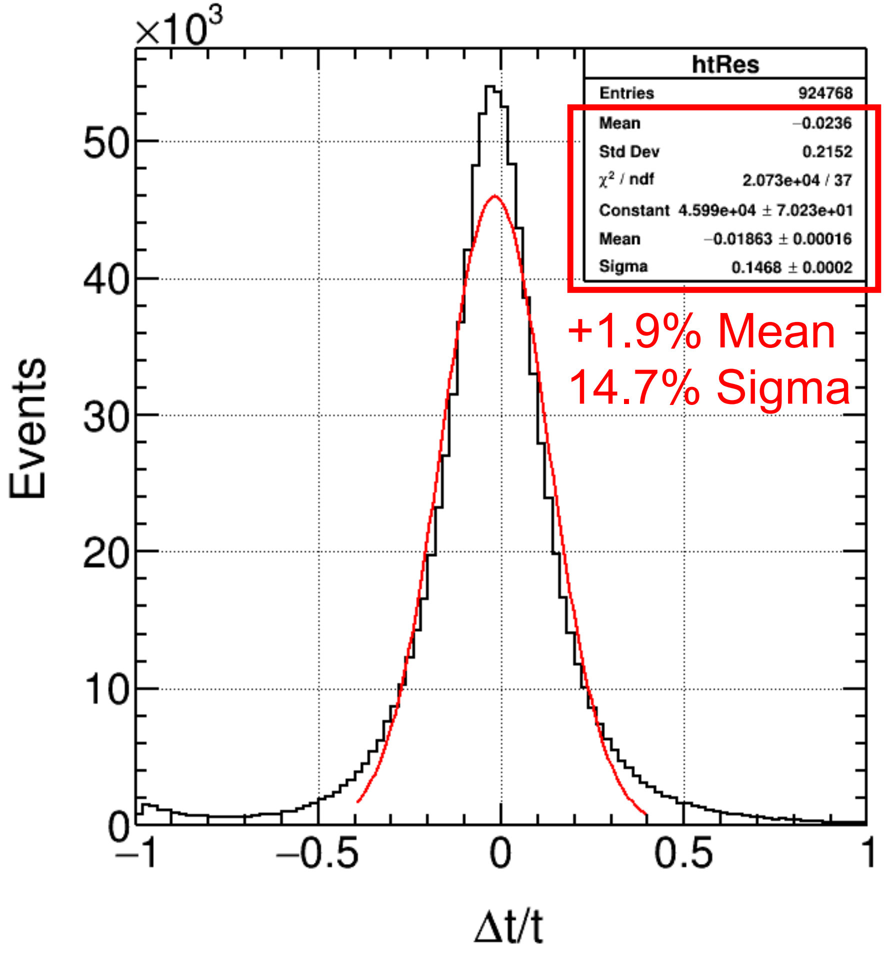
DVCS 18 GeV × 275 GeV Sample **ALL**

t Calculation Using Proton (p, p')

t Comparison



t Resolution



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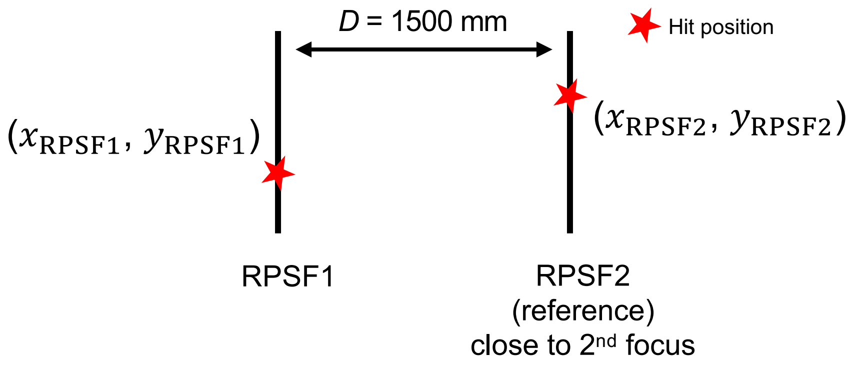
Summary

- Extracted matrices at Roman Pot at secondary focus
  - Decoupling x and y components for now
  - Demonstrated with single particle gun sample which has **no beam effect** (p_T RMS ~ 8-10 MeV)
- Checked with **DVCS** data sample (**beam effect + crossing angle**) if reconstruction is done properly
  - Expected worse than single particle gun sample because of beam effect
  - Momentum reconstruction has 1.1 % bias and 0.4 % rms
  - Transverse momentum reconstruction has no bias and 41.4 MeV rms
  - Checked reconstruction for only $p_{MC} > 270$ GeV, but not much different from all
- **TODO**
  - Check reconstruction with/without beam effect (using afterburner reverse method)
  - Investigate weird arm in p_T distribution
  - Check desired t resolution to access information in impact parameter or diffractive structure function

Backup Slides

Offset for Matrices

- Used **centered protons**
  - Set to ($\theta = 0$ ($\boldsymbol{\theta_x = 0}$, $\boldsymbol{\theta_y = 0}$), $\boldsymbol{\phi = 0}$, $\boldsymbol{p = 275}$ **GeV**)
  - Obtained below in **global coordinate**
    - $x_{\mathrm{RPSF}}{}' = x_{\mathrm{RPSF2}} = 1035.34$ mm
    - $y_{\mathrm{RPSF}}{}' = y_{\mathrm{RPSF2}} = 2.88049\mathrm{e}^{-6}$ mm
    - $\theta_{x,\,\mathrm{RPSF}}{}' = \frac{(x_{\mathrm{RPSF2}} - x_{\mathrm{RPSF1}})}{D} = 21.3023$ mrad
    - $\theta_{y,\,\mathrm{RPSF}}{}' = \frac{(y_{\mathrm{RPSF2}} - y_{\mathrm{RPSF1}})}{D} = 1.92057\mathrm{e}^{-6}$ mrad



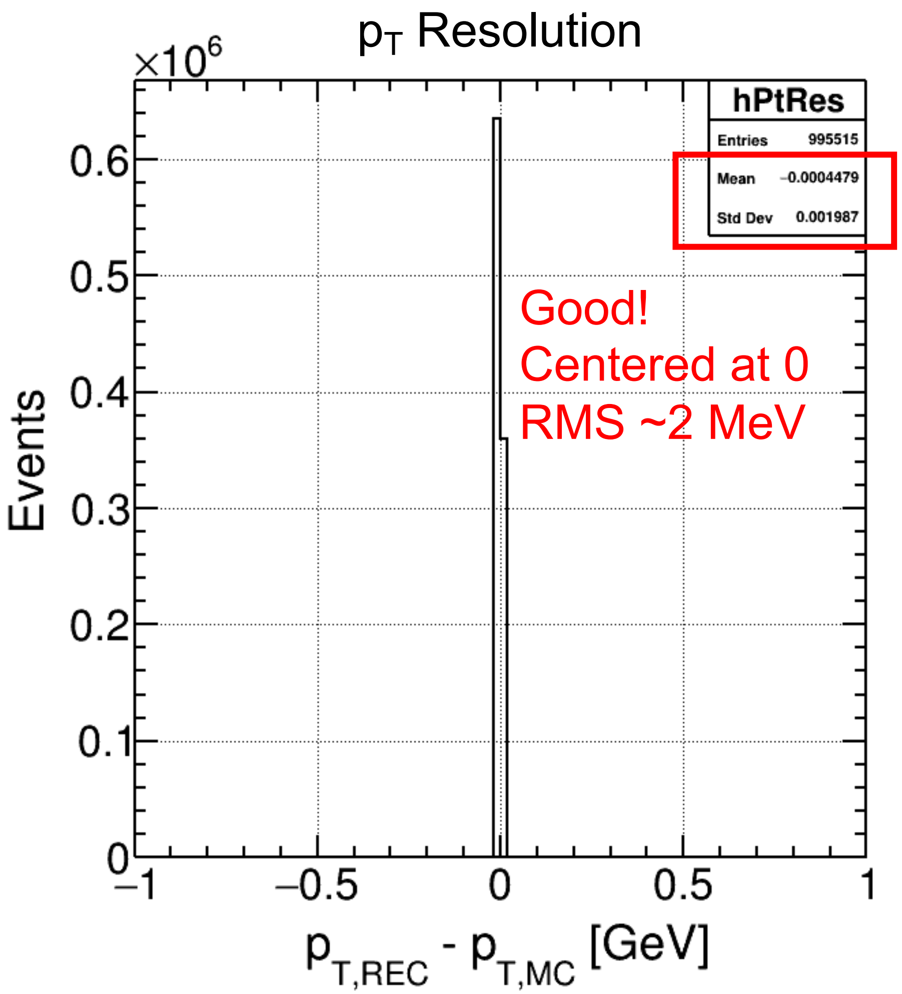
Angular Spread for Matrices

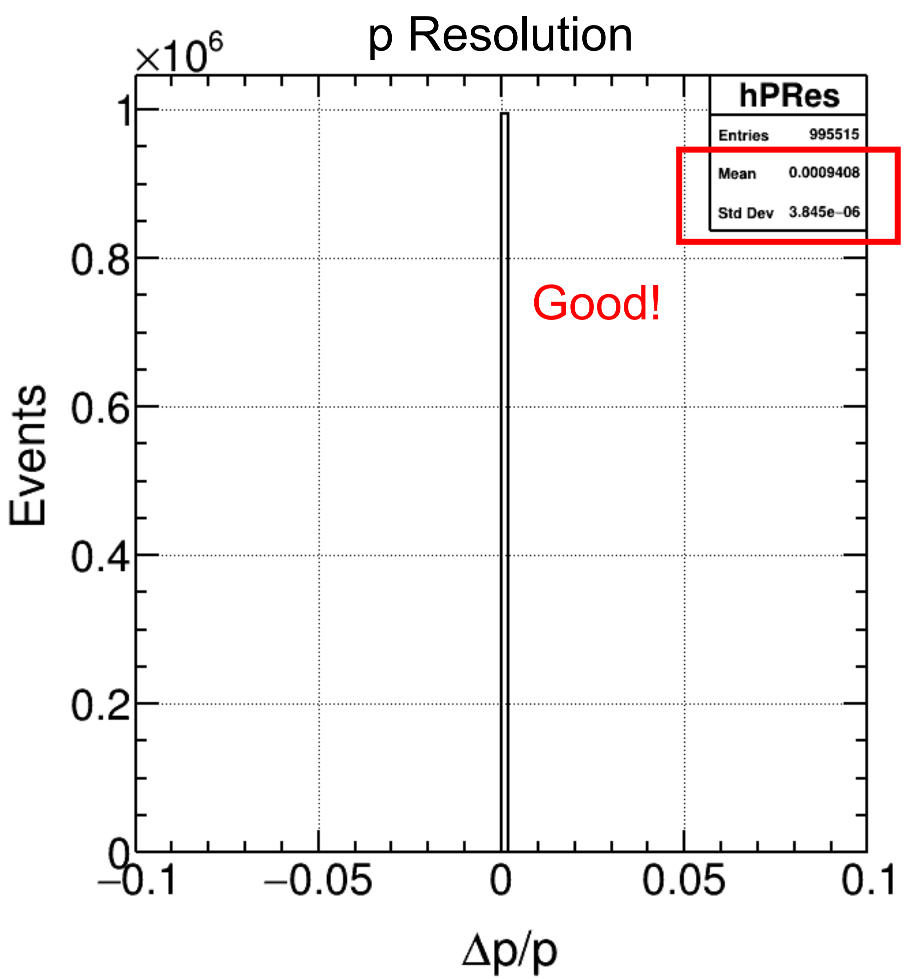
- Used **protons with $\boldsymbol{\theta_{x,\,\mathrm{IP}}} = \mathbf{1}$ mrad** and $\frac{\Delta p}{p}_{\mathrm{IP}} = 0$
  - Set to ($\theta = 1$ mrad ($\boldsymbol{\theta_x} = \mathbf{1}$ **mrad**, $\theta_y = 0$), $\boldsymbol{\phi} = \mathbf{0}$, $\boldsymbol{p} = \mathbf{275}$ **GeV**)
  - Obtained below in **global coordinate**
    - $x_{\mathrm{RPSF}} = x_{\mathrm{RPSF2}} = 1035.61$ mm
    - $y_{\mathrm{RPSF}} = y_{\mathrm{RPSF2}} = -1.10669\mathrm{e}^{-6}$ mm
    - $\theta_{x,\,\mathrm{RPSF}} = \frac{(x_{\mathrm{RPSF2}} - x_{\mathrm{RPSF1}})}{D} = 20.0413$ mrad
    - $\theta_{y,\,\mathrm{RPSF}} = \frac{(y_{\mathrm{RPSF2}} - y_{\mathrm{RPSF1}})}{D} = -7.37861\mathrm{e}^{-7}$ mrad
- Used **protons with $\boldsymbol{\theta_{y,\,\mathrm{IP}}} = \mathbf{1}$ mrad** and $\frac{\Delta p}{p}_{\mathrm{IP}} = 0$
  - Set to ($\theta = 1$ mrad ($\theta_x = 0$, $\boldsymbol{\theta_y} = \mathbf{1}$ **mrad**), $\boldsymbol{\phi} = \boldsymbol{\pi/2}$, $\boldsymbol{p} = \mathbf{275}$ **GeV**)
  - Obtained below in global coordinate
    - $x_{\mathrm{RPSF}} = x_{\mathrm{RPSF2}} = 1035.34$ mm
    - $y_{\mathrm{RPSF}} = y_{\mathrm{RPSF2}} = 0.144279$mm
    - $\theta_{x,\,\mathrm{RPSF}} = \frac{(x_{\mathrm{RPSF2}} - x_{\mathrm{RPSF1}})}{D} = 21.3023$ mrad
    - $\theta_{y,\,\mathrm{RPSF}} = \frac{(y_{\mathrm{RPSF2}} - y_{\mathrm{RPSF1}})}{D} = -0.140005$ mrad

Momentum Spread for Matrices

- Used **protons with** $\frac{\Delta \boldsymbol{p}}{\boldsymbol{p}}_{\textbf{IP}} = \boldsymbol{-0.01}$ and $\theta_{x,/y \text{ IP}} = 1$ mrad
  - Set to ($\theta = 1$ mrad ($\boldsymbol{\theta_x} = \mathbf{1}$ **mrad**, $\theta_y = 0$), $\boldsymbol{\phi} = \mathbf{0}$, $\boldsymbol{p} = \mathbf{272.25}$ **GeV** ($\frac{\Delta \boldsymbol{p}}{\boldsymbol{p}} = \boldsymbol{-0.01}$))
  - Obtained below in **global coordinate**
    - $x_{\text{RPSF}} = x_{\text{RPSF2}} = 1030.06\ \text{mm}$
    - $y_{\text{RPSF}} = y_{\text{RPSF2}} = 1.86678\text{e}^{-7}\ \text{mm}$
    - $\theta_{x,\text{ RPSF}} = \frac{(x_{\text{RPSF2}} - x_{\text{RPSF1}})}{D} = 20.0224$ mrad
    - $\theta_{y,\text{ RPSF}} = \frac{(y_{\text{RPSF2}} - y_{\text{RPSF1}})}{D} = 1.24466\text{e}^{-7}$ mrad
- Used **protons with** $\frac{\Delta \boldsymbol{p}}{\boldsymbol{p}}_{\textbf{IP}} = \boldsymbol{-0.01}$ and $\theta_{x,/y \text{ IP}} = 1$ mrad
  - Set to ($\theta = 1$ mrad ($\theta_x = 0$, $\boldsymbol{\theta_y} = \mathbf{1}$ **mrad**), $\boldsymbol{\phi} = \boldsymbol{\pi/2}$, $\boldsymbol{p} = \mathbf{272.25}$ **GeV** ($\frac{\Delta \boldsymbol{p}}{\boldsymbol{p}} = \boldsymbol{-0.01}$))
  - Obtained below in **global coordinate**
    - $x_{\text{RPSF}} = x_{\text{RPSF2}} = 1030.64\ \text{mm}$
    - $y_{\text{RPSF}} = y_{\text{RPSF2}} = -0.834025\ \text{mm}$
    - $\theta_{x,\text{ RPSF}} = \frac{(x_{\text{RPSF2}} - x_{\text{RPSF1}})}{D} = 21.3032$ mrad
    - $\theta_{y,\text{ RPSF}} = \frac{(y_{\text{RPSF2}} - y_{\text{RPSF1}})}{D} = -0.189277$ mrad

Transverse Momentum and Momentum

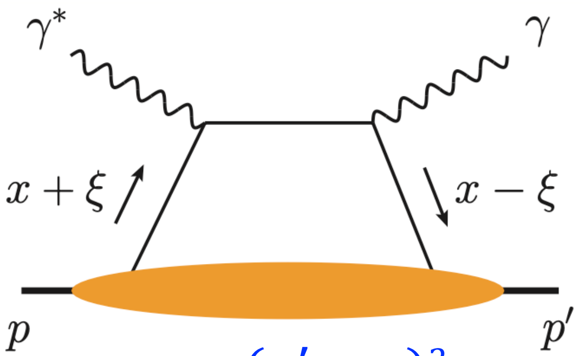




Spatial Imaging of Nucleon – Approach

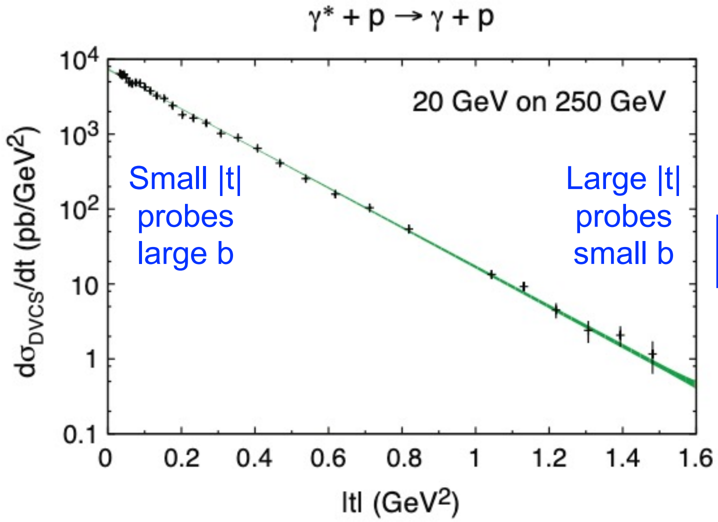
Fourier transform in t provides **spatial distribution of quarks/gluons**

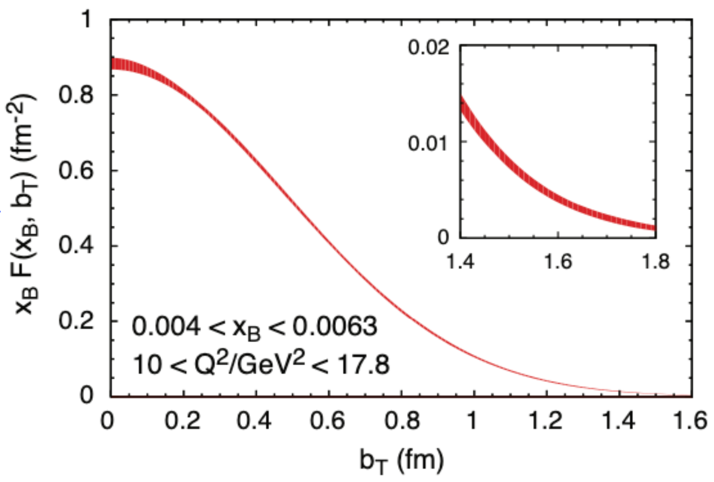
Imaging of nucleon with **quarks**



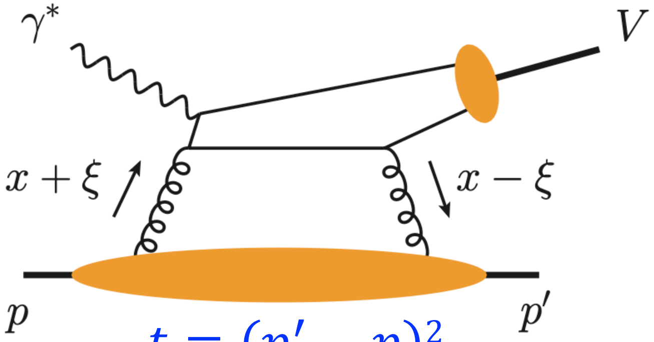
$t = (p' - p)^2$

From EIC White Paper

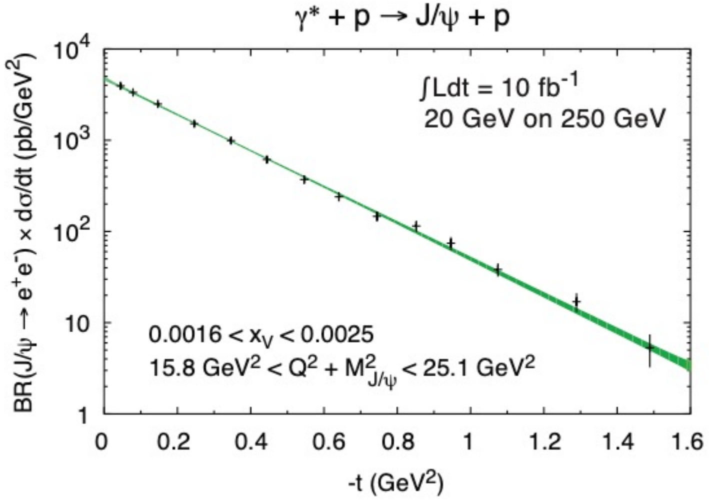


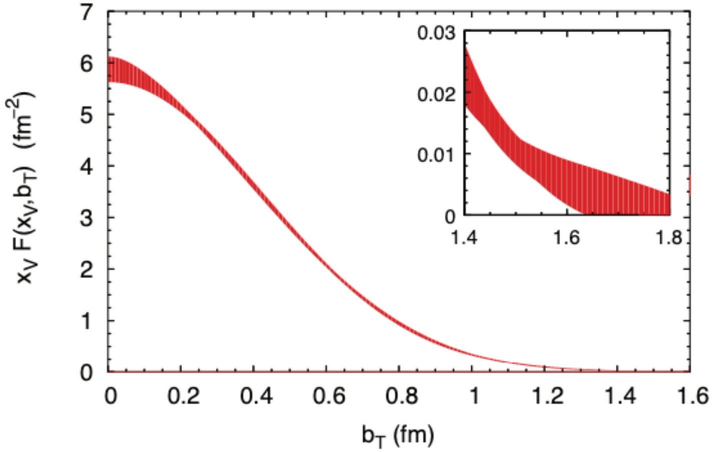


Imaging of nucleon with **gluons**

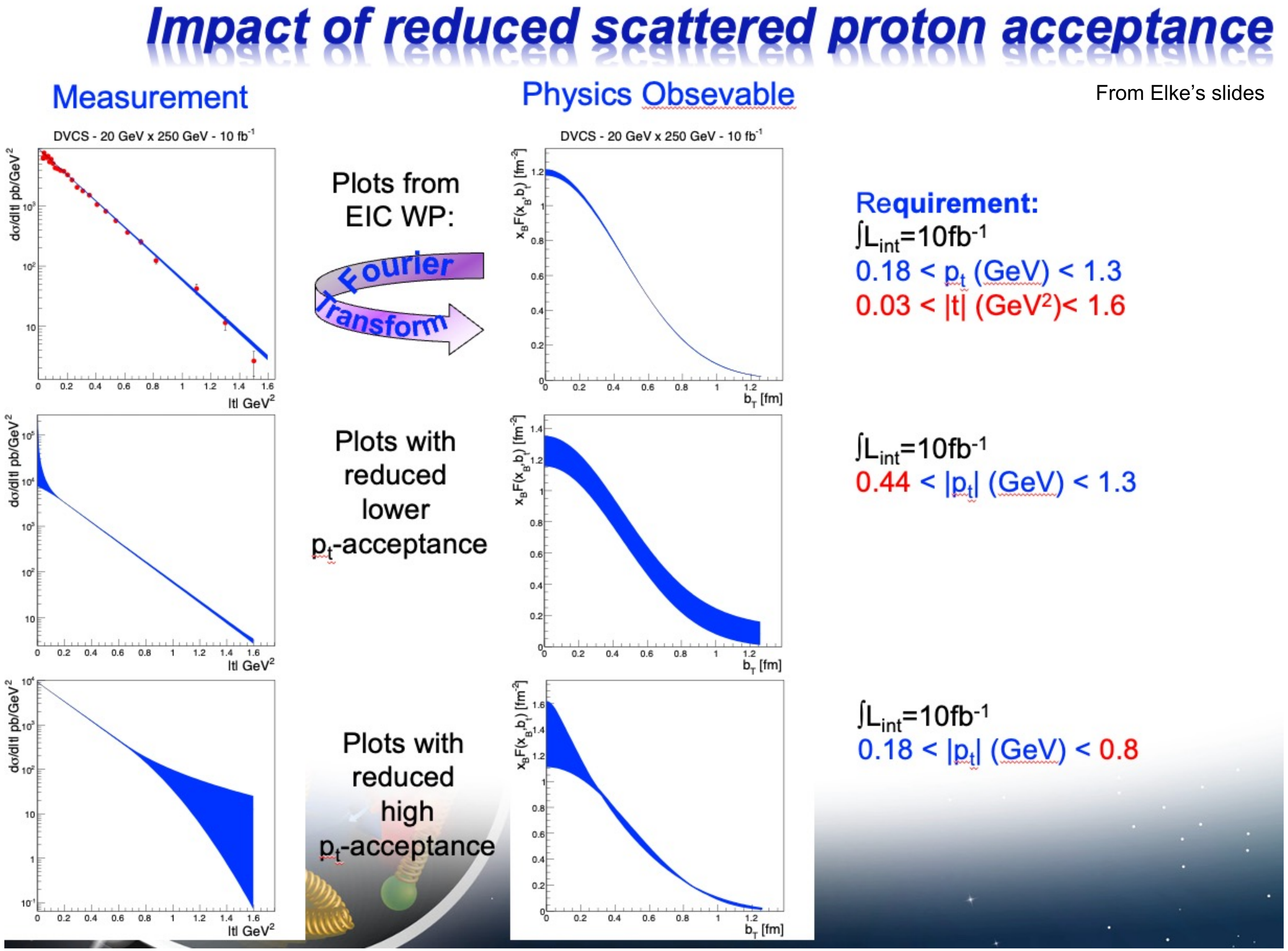


$t = (p' - p)^2$





Spatial Imaging of Nucleon – Approach



IR-8 2nd focus greatly improves **forward acceptance**

- **Excellent low-p$_T$ acceptance** for protons and light nuclei from exclusive reactions at very small t
- **Detection of target fragments**

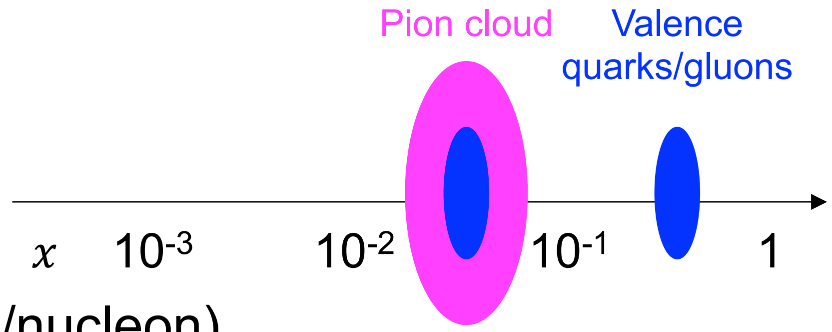
Opportunity to **probe large b** (outside nucleon's primary volume: not related to internal nucleon structure)

Pion Cloud Model

One of possible scenarios describing what proton looks like with increasing energy

Parton core

+ Surrounded by a meson cloud (pions/kaons)



Pions/kaons in **outer rim** of nucleus/nucleon

(different from Sullivan process: pions/kaons **inside** nucleus/nucleon)

→ Large impact on gluon and sea-quark observables

Of particular interest at large b is change of transverse spatial distribution of gluons/quarks with x

→ Help us to better understand mechanism of confinement

Approach:

t reconstruction using DVCS events and evaluate impact of scattered proton acceptance at low t

Diffractive Structure Function

Possibility for constraining F_L^D Diffractive longitudinal structure function: sensitive to gluon content

Large Rapidity Gap (LRG) method

PHYSICAL REVIEW D **105,** 074006 (2022)

Diffractive longitudinal structure function at the Electron Ion Collider

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(Received 14 December 2021; accepted 18 March 2022; published 14 April 2022)

Possibilities for the measurement of the longitudinal structure function in diffraction $F_{\mathrm{L}}^{\mathrm{D}}$ at the future U.S. Electron Ion Collider are investigated. The sensitivity to $F_{\mathrm{L}}^{\mathrm{D}}$ arises from the variation of the reduced diffractive cross section with center-of-mass energy. Simulations are performed with various sets of beam energy combinations and for different assumptions on the precision of the diffractive cross section measurements. Scenarios compatible with current EIC performance expectations lead to an unprecedented precision on $F_{\mathrm{L}}^{\mathrm{D}}$ at the 5–10% level in the best measured regions. While scenarios with data at a larger number of center-of-mass energies allow the extraction of $F_{\mathrm{L}}^{\mathrm{D}}$ in the widest kinematic domain and with the smallest uncertainties, even the more conservative assumptions lead to precise measurements. The ratio R^{D} of photoabsorption cross sections for longitudinally to transversely polarized photons can also be obtained with high precision using a separate extraction method.

DOI: 10.1103/PhysRevD.105.074006

Eur. Phys. J. C (2011) 71:1836
DOI 10.1140/epjc/s10052-011-1836-6

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Measurement of the diffractive longitudinal structure function F_L^D at HERA

H1 Collaboration

Abstract First measurements are presented of the diffractive cross section $\sigma_{ep\to eXY}$ at centre-of-mass energies $\sqrt{s}$ of 225 and 252 GeV, together with a precise new measurement at $\sqrt{s}$ of 319 GeV, using data taken with the H1 detector in the years 2006 and 2007. Together with previous H1 data at $\sqrt{s}$ of 301 GeV, the measurements are used to extract the diffractive longitudinal structure function F_L^D in the range of photon virtualities $4.0 \le Q^2 \le 44.0$ GeV^2 and fractional proton longitudinal momentum loss $5 \times 10^{-4} \le x_{\mathbb{P}} \le 3 \times 10^{-3}$. The measured F_L^D is compared with leading twist predictions based on diffractive parton densities extracted in NLO QCD fits to previous measurements of diffractive Deep-Inelastic Scattering and with a model which additionally includes a higher twist contribution derived from a colour dipole approach. The ratio of the diffractive cross section induced by longitudinally polarised photons to that for transversely polarised photons is extracted and compared with the analogous quantity for inclusive Deep-Inelastic Scattering.