GEM Alignment

Hyunyong Kim* On behalf of the GEM DPG

*Texas A & M University

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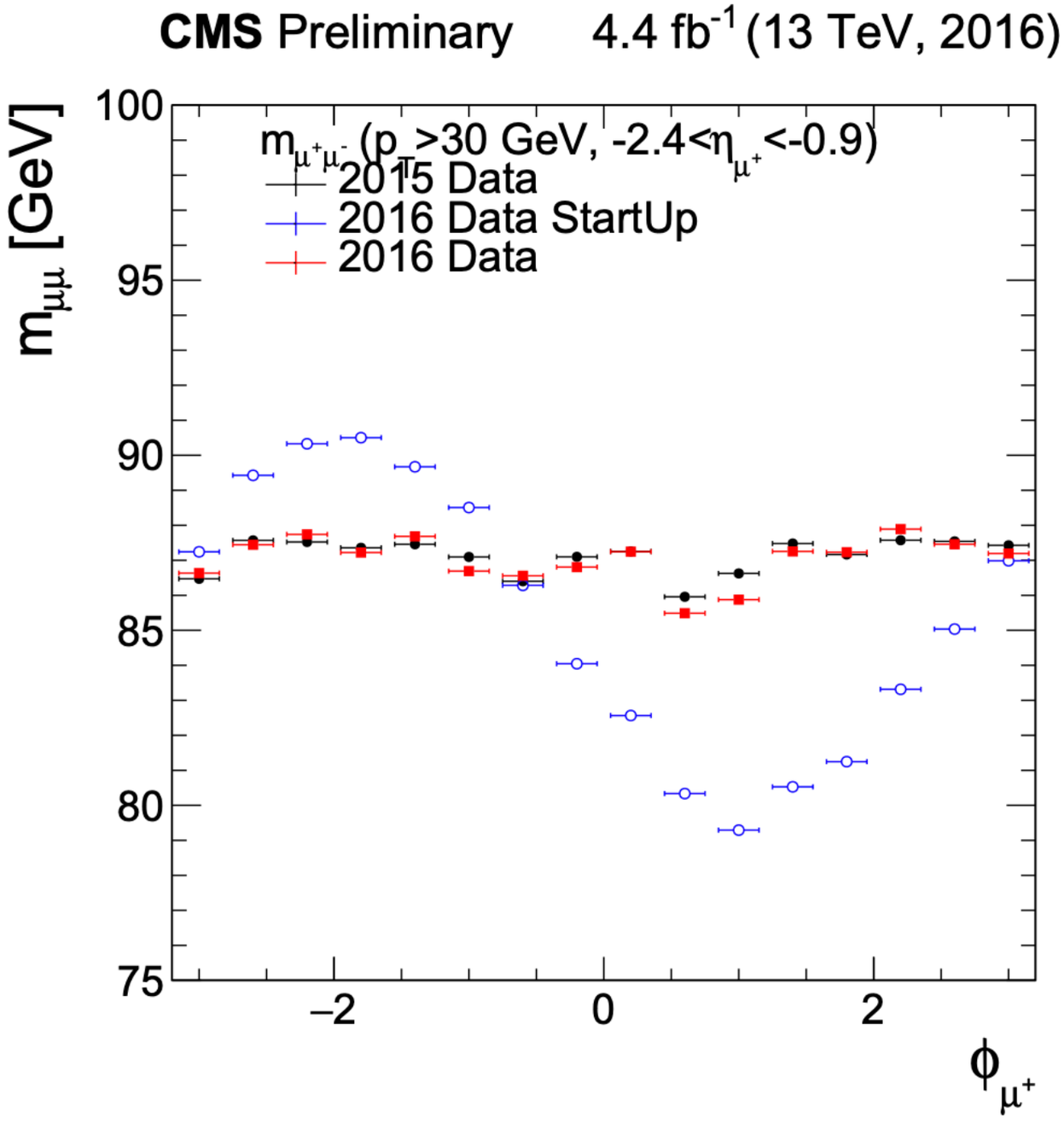
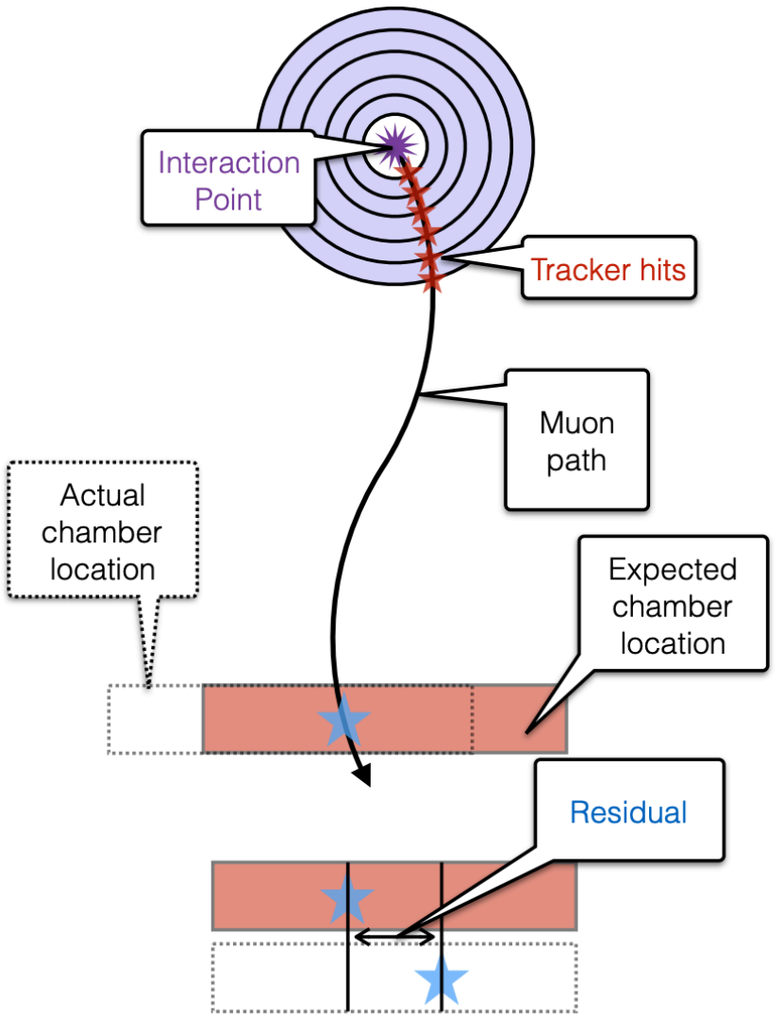
Alignment

- Misalignment causes wrong particle reconstruction
- **Why alignment is important for GEM**
  - End-cap is opened frequently: it creates misalignment
  - GEM-CSC trigger requires precise alignment



Track-based Muon Alignment

Ryan Mueller



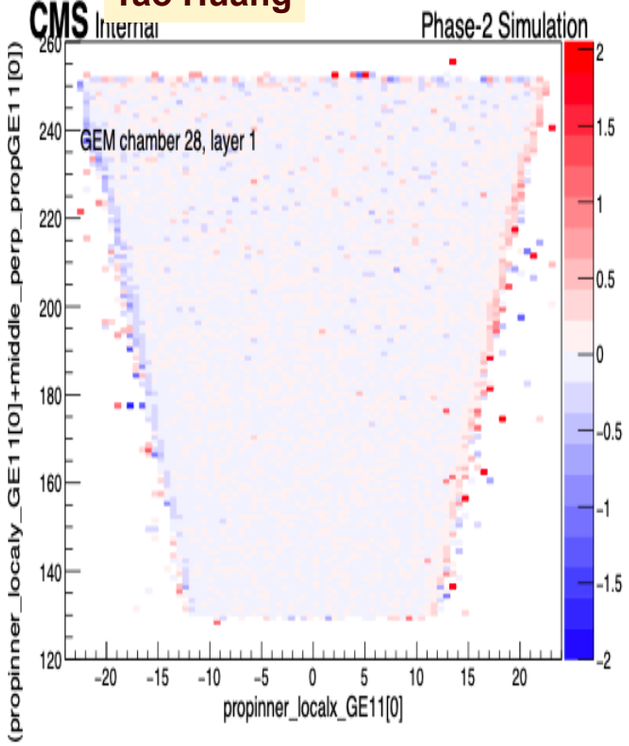
- **Track-based muon alignment (TBMuAl)**
  - propagate the tracker path of muons into muon system
  - Muon residual: difference between reconstructed position and predicted position on the muon chamber
- **The TBMuAl technique is proven to be efficient, robust, and stable in Run1 and Run2**
- The algorithm is developed and integrated into CMSSW framework
- Source of possible systematic uncertainties have been investigated and various improvements to reduce their effect are being developed
- **Muon system alignments are most important for muon reconstruction and TBMuAl has good accuracy, 100-150 μm**

TBMuAl Process

- **Pre-requisite**: updated tracker geometry and muon global position record (muon GPR)
- **TBMuAl**
  - Step1: TBMuAl running workflow → 2 days for IOV (at least 2 fb^{-1})
  - Step2: Looking at the results and 1st step validation → 3 days. If problems are found then re-running the workflow is needed
- **Physics Validation**: 1 week. Re-fit muons in Z → $\mu\mu$ and high-p_T samples with new Mu+Trk geometries
- Generating final results (DB payload with geometry) → 1 day. Useful to re-run validation for confirmation
- TBMuAl takes about 2 weeks total (after update tracker geometry and muon GPR)

GEM Alignment

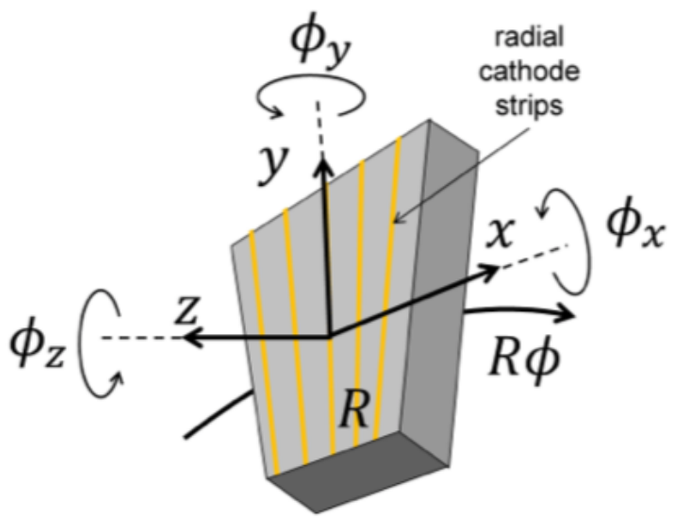
Tao Huang



GE1/1 $\Delta R\phi$ residual (in z) map in x and y (local coordinates of GE1/1). Residual for each muon is plotted in red ($\Delta R\phi > 0$) and blue ($\Delta R\phi < 0$). Ideally, one want to symmetric distribution of residual. At boundaries, the residual shows bias due to edge effect, requiring fiducial cuts.

Details on page 19

Yuriy Pakhotin



$\Delta R\phi = \cos\theta \cdot \Delta x + \sin\theta \cdot \Delta y$

θ: strip angle of recHit

Δx: $X_{prediction} - X_{recHit}$

Δy: $Y_{prediction} - Y_{recHit}$

Details on page 15

$$\begin{pmatrix} \Delta(R\phi) \\ \Delta y_o \\ \Delta\frac{d(R\phi)}{dz} \\ \Delta\frac{dy}{dz}_o \end{pmatrix} = \begin{pmatrix} 1 & \left[-\frac{x}{R}+3\left(\frac{x}{R}\right)^3\right] & -\frac{dx}{dz} & -y\frac{dx}{dz} & x\frac{dx}{dz} & -y \\ 0 & 1 & -\frac{dy}{dz} & -y\frac{dy}{dz} & x\frac{dy}{dz} & x \\ 0 & -\frac{1}{2R}\frac{dx}{dz} & 0 & \left[\frac{x}{R}-\frac{dx}{dz}\frac{dy}{dz}\right] & 1+\left(\frac{dx}{dz}\right)^2 & -\frac{dy}{dz} \\ 0 & 0 & 0 & -1-\left(\frac{dy}{dz}\right)^2 & \frac{dx}{dz}\frac{dy}{dz} & \frac{dx}{dz} \end{pmatrix} \begin{pmatrix} \delta x \\ \delta y \\ \delta z \\ \delta\phi_x \\ \delta\phi_y \\ \delta\phi_z \end{pmatrix}$$

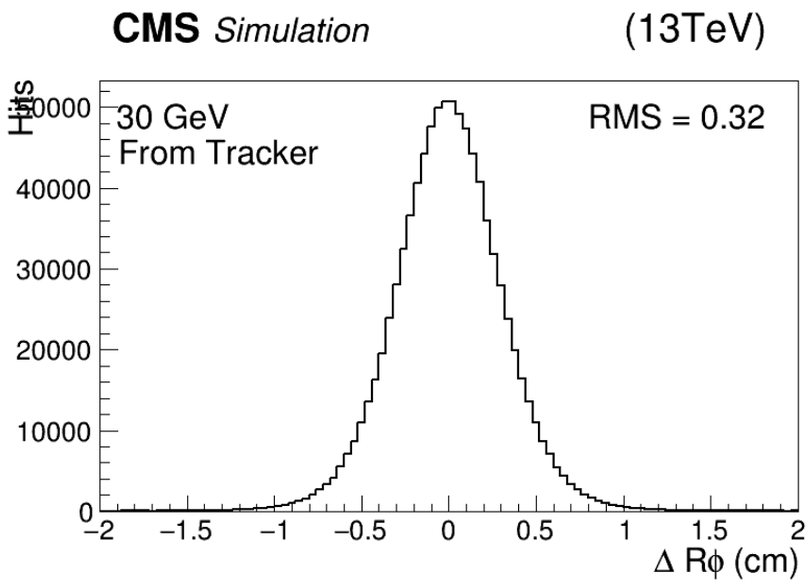
- The TBMuAl algorithm will be developed for GEM base on CSC
  - **For GEM-CSC local trigger, we also consider using the local muon alignment algorithm**
- **GEM alignment uses $\Delta R\phi$**
  - No geometrical bais
  - GEM has fine ϕ resolution
- Two degree of freedom: δx and $\delta\phi_z$

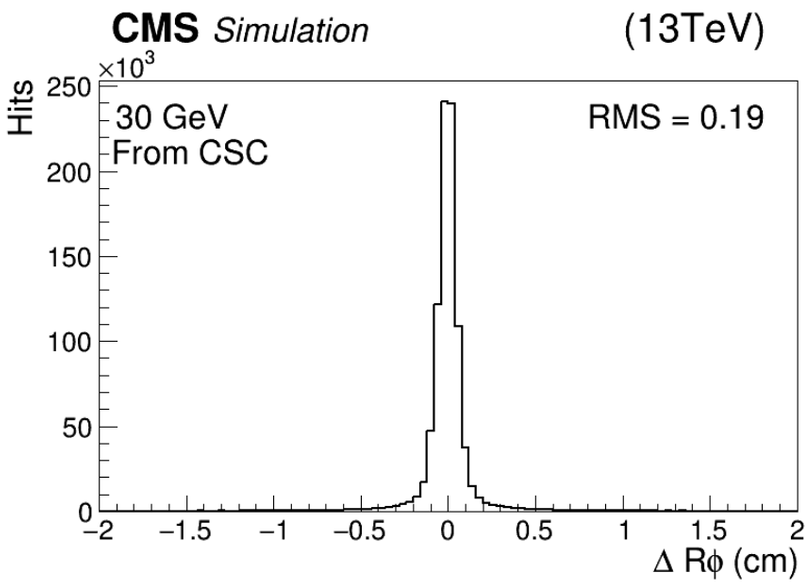
GEM Alignment Method

- **Track-based Muon Alignment**
  - Default option for GEM alignment
  - Similar to CSC
- **Propagate muon track from ME1/1**
  - Same method as TBMuAl but muon track is propagated from ME1/1
  - **It has less scattering and well correlated with ME1/1**
- **Use Millepede algorithm**
  - Muon alignment module uses Millepede for local alignment

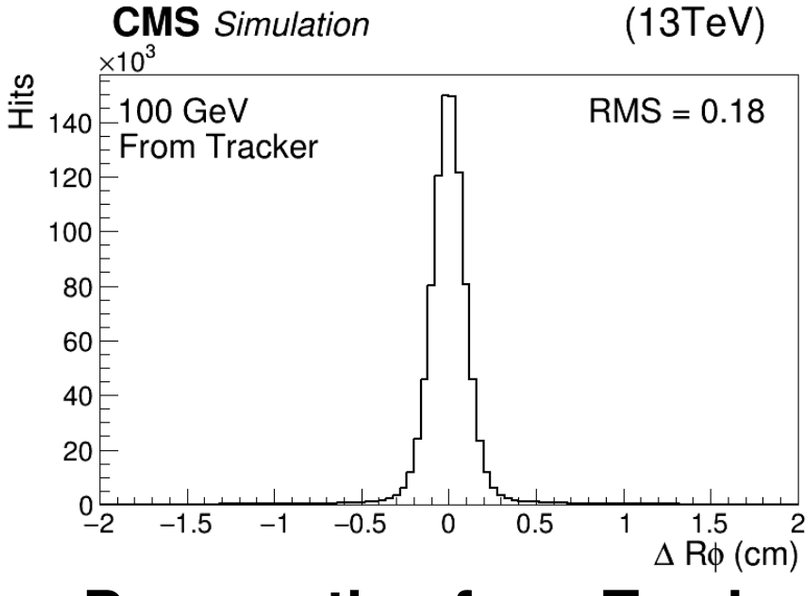
Propagation Comparison

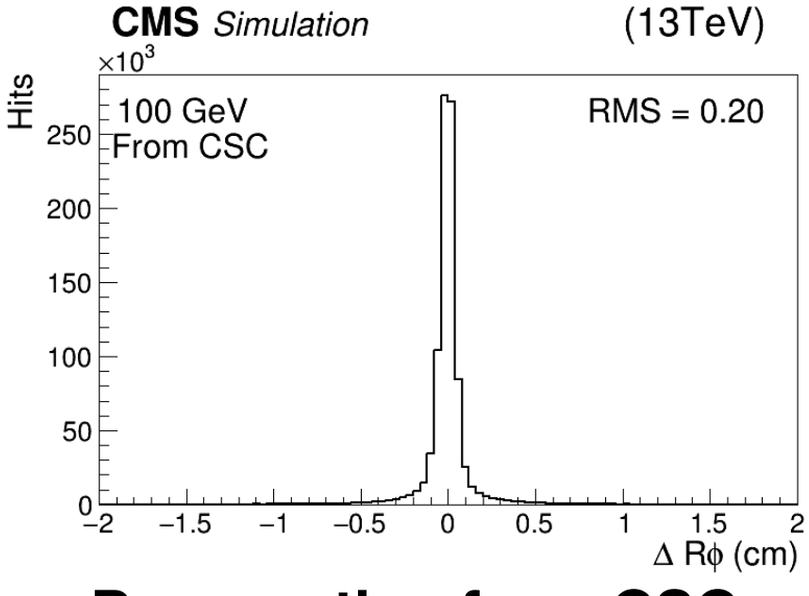
Muon p_T 30 GeV





Muon p_T 100 GeV





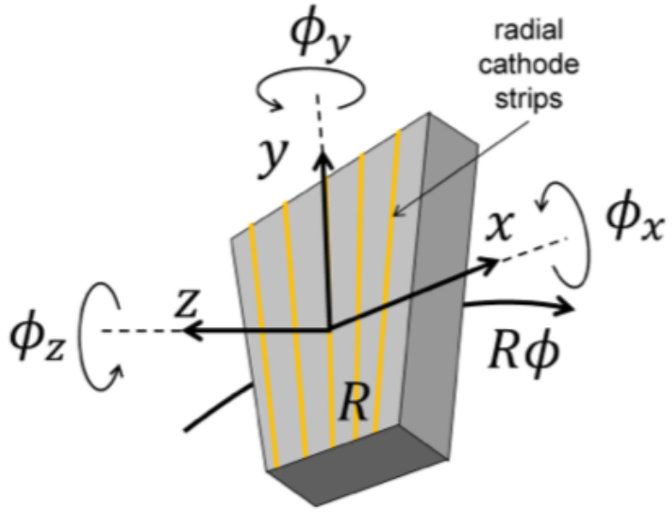
Propagation from Tracker

Propagation from CSC

- **Muon propagation from tracker has strong p_T dependency due to scattering**
- **Muon propagation from CSC has less p_T dependency then from tracker**
- **To reduce GEM-CSC alignment uncertainty (GEM and CSC alignment still need TBMuAl), using muon propagation from CSC is considered**

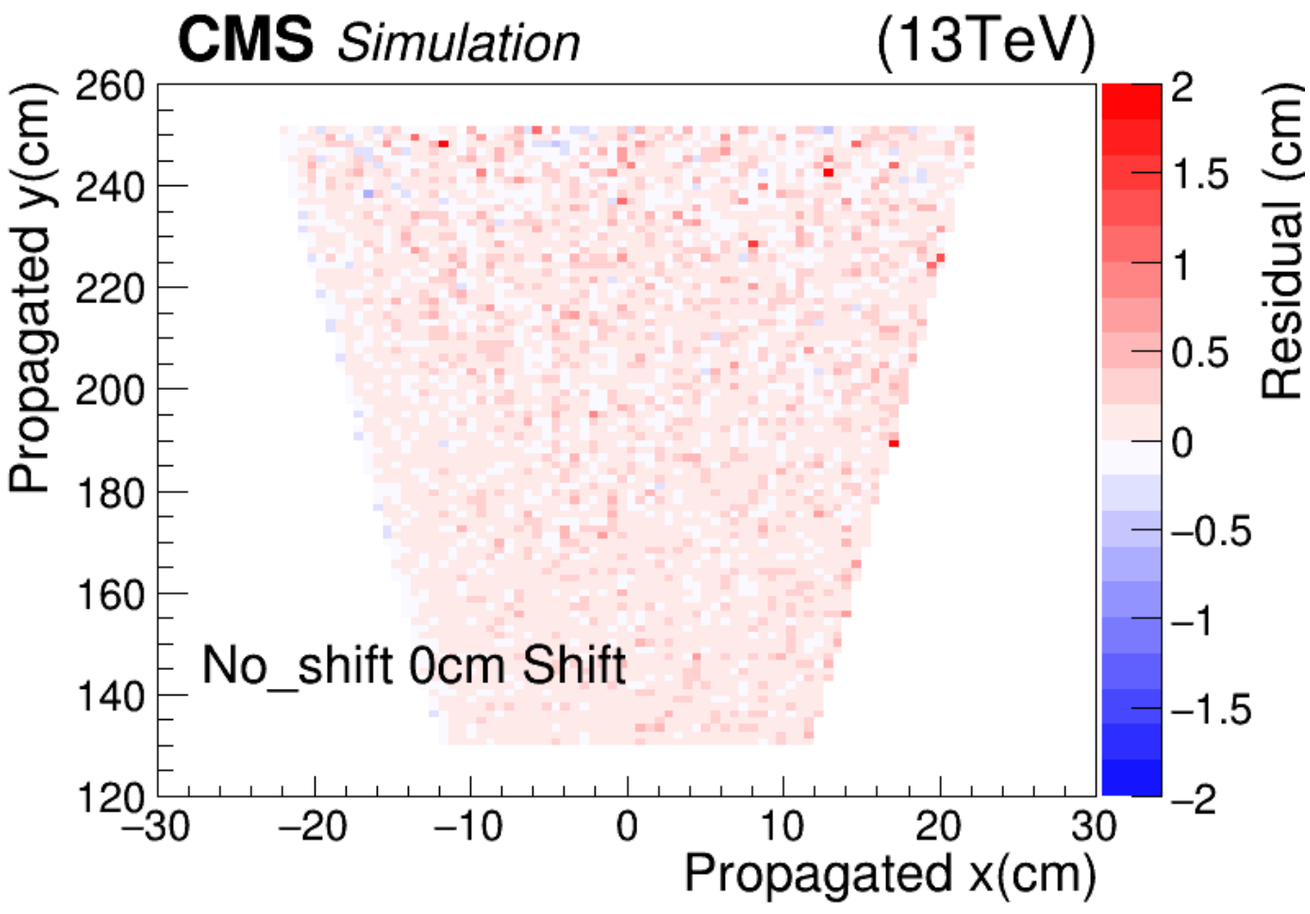
GEM Residual Study

- GEM has radial strips
  - **Δx residual has geometrical bias**
  - **CSC uses $\Delta R\phi$ residual and GEM is similar**
- Realistic single muon gun
  - Muon alignment group uses for MC study
  - **p_T range: 30 GeV < p_T < 200 GeV**
- Misaligned geometry (local coordinate)
  - x: ±0.1 cm, ±0.5 cm, ±1.0 cm
  - y: ±0.1 cm, ±0.5 cm, ±1.0 cm



GEM $\Delta R\phi$ Residual

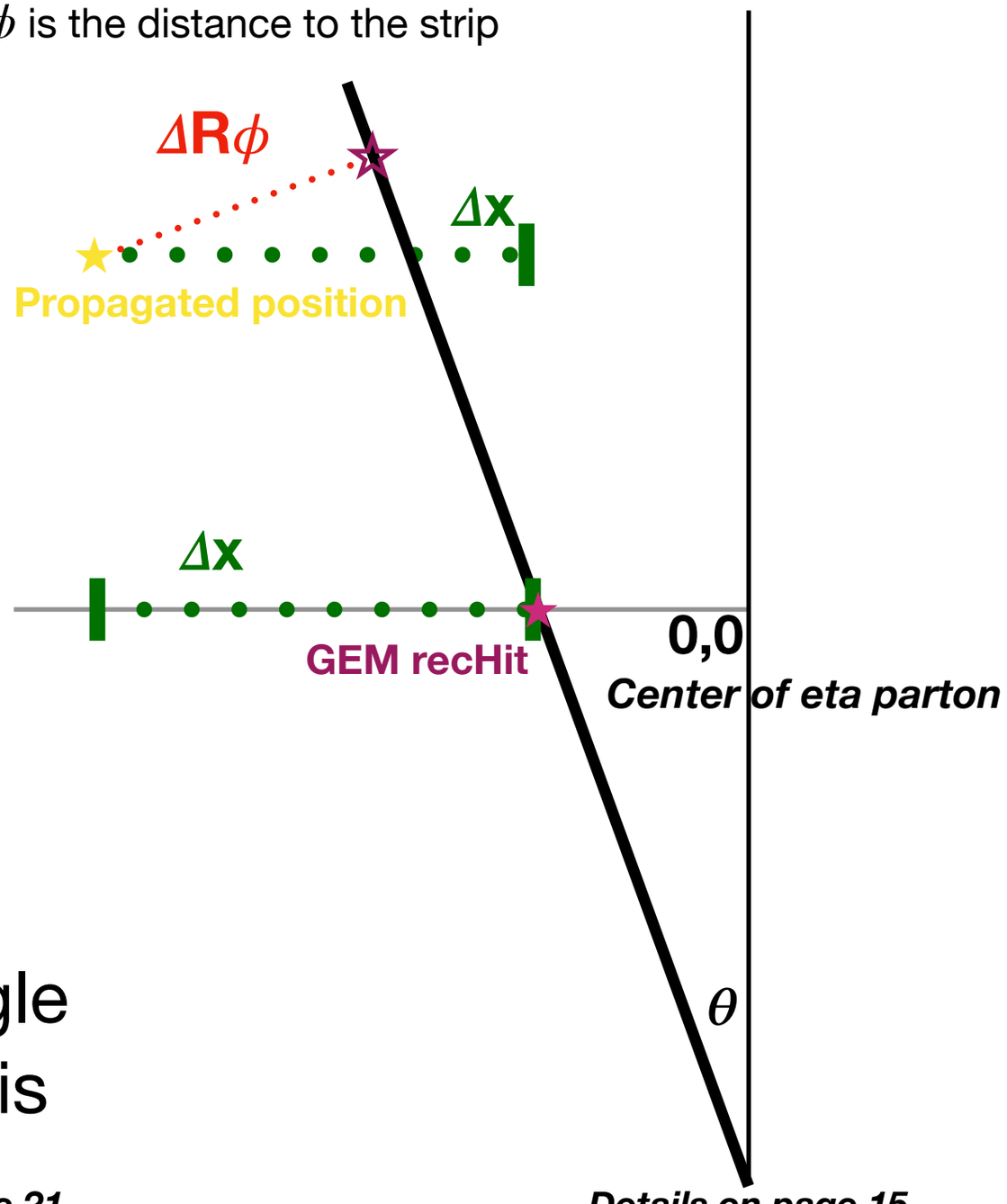
Devin Aebi



Since recHit is always at the center of the eta partition

Δx is distance to the center

$\Delta R\phi$ is the distance to the strip



Δx residual depends on the strip angle and propagated y, but $\Delta R\phi$ residual is consistence

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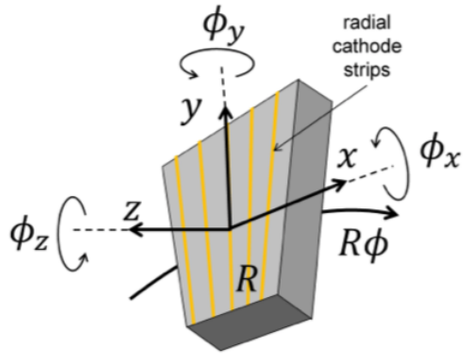
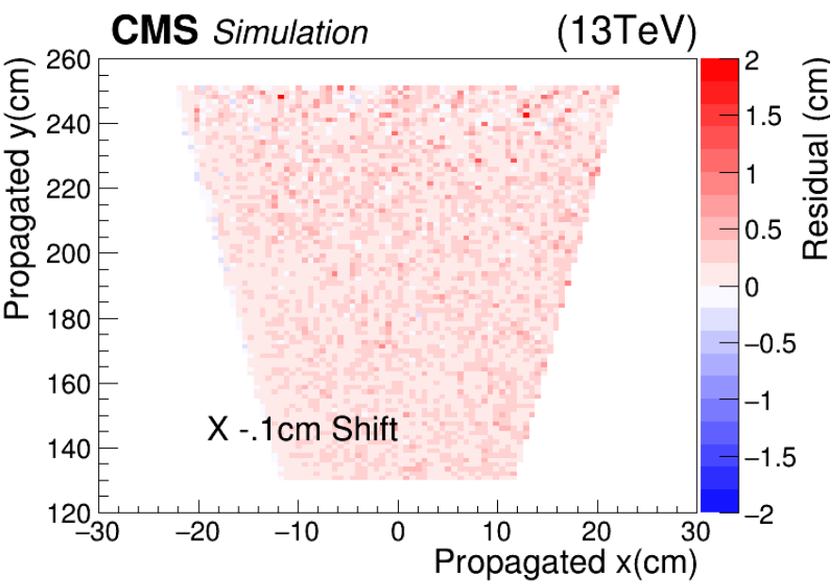
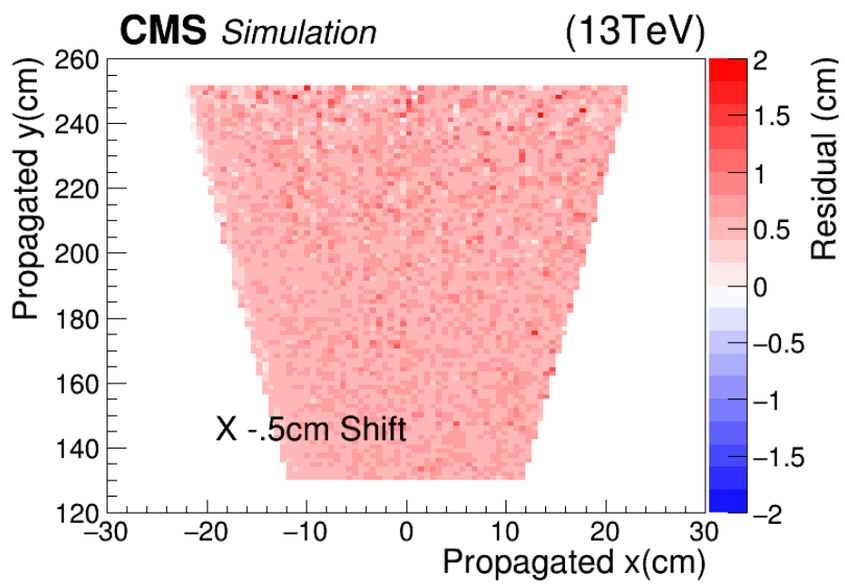
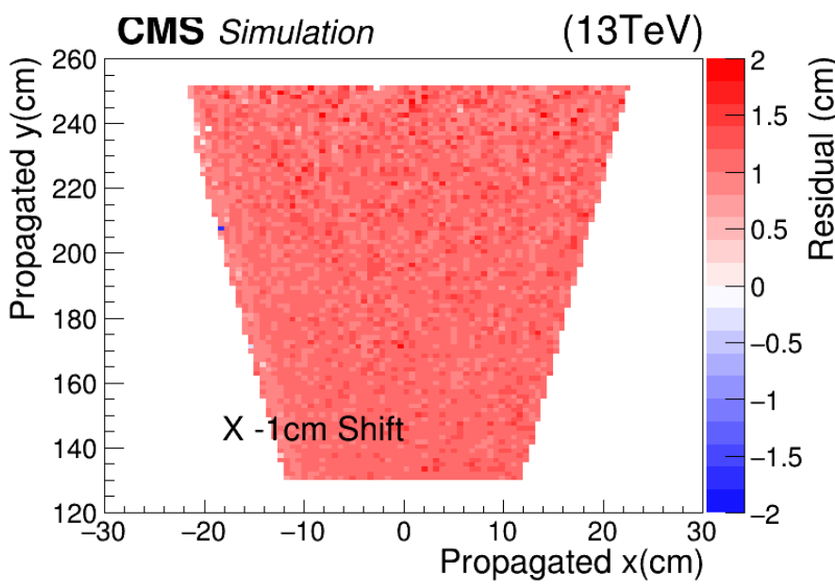
X shift

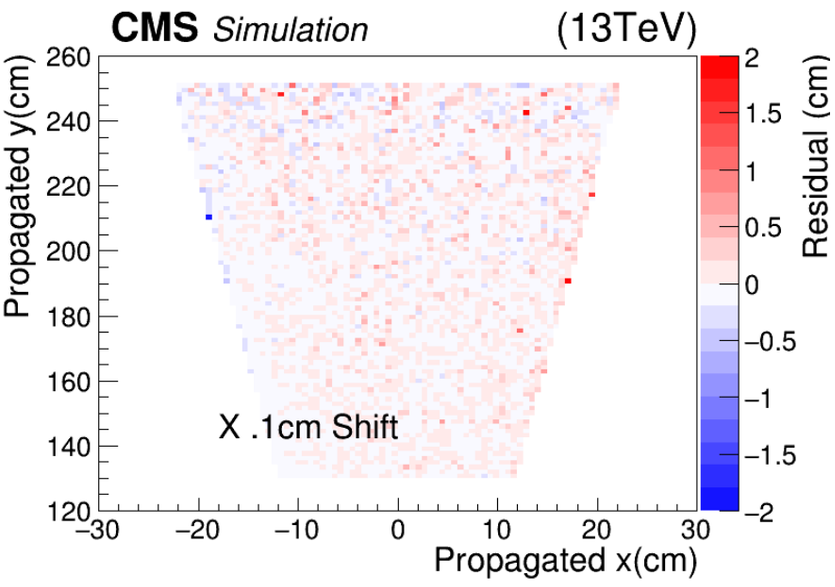
Devin Aebi

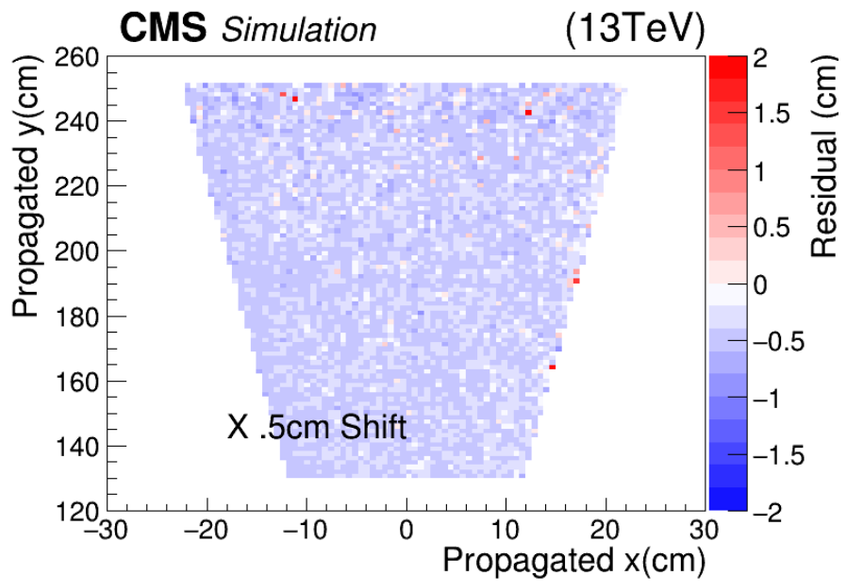


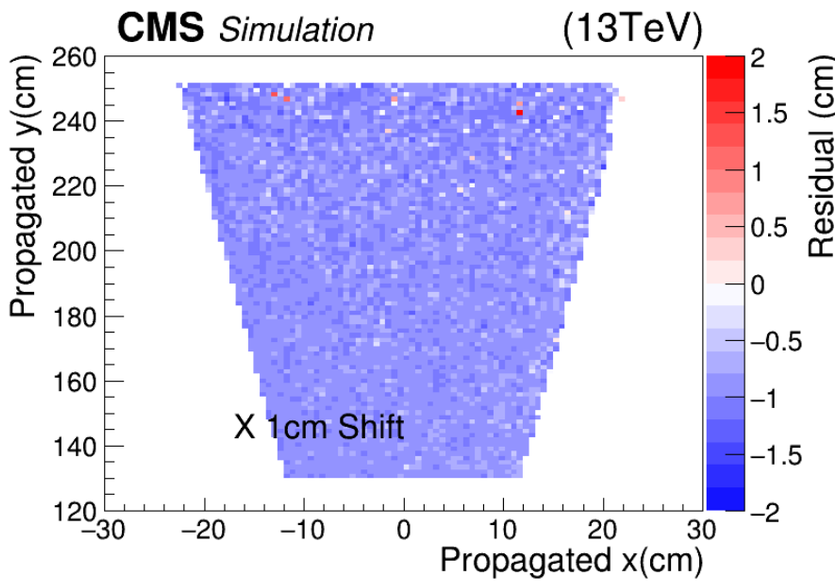




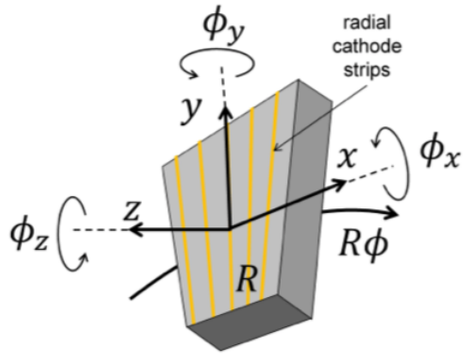




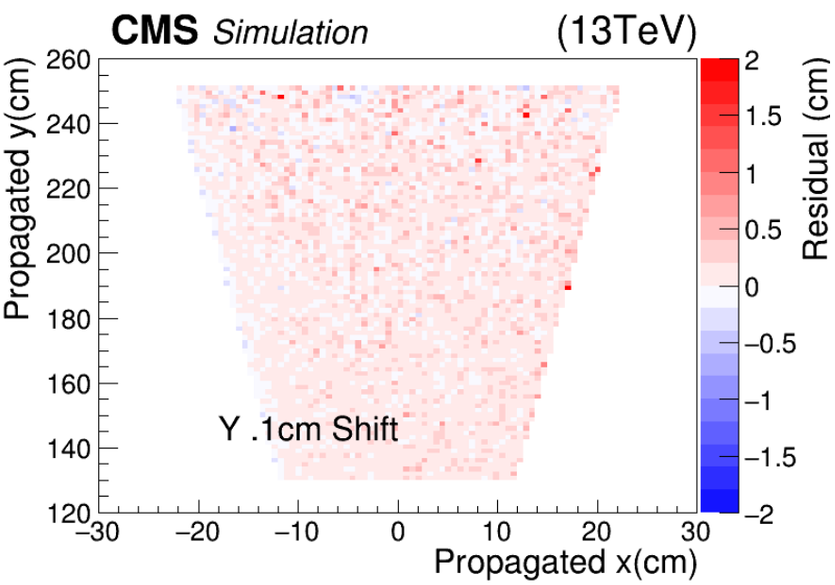


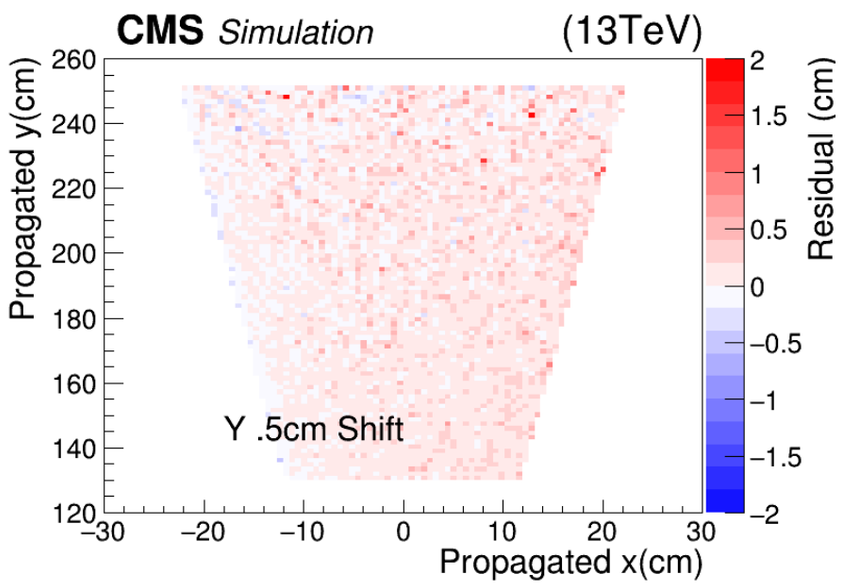


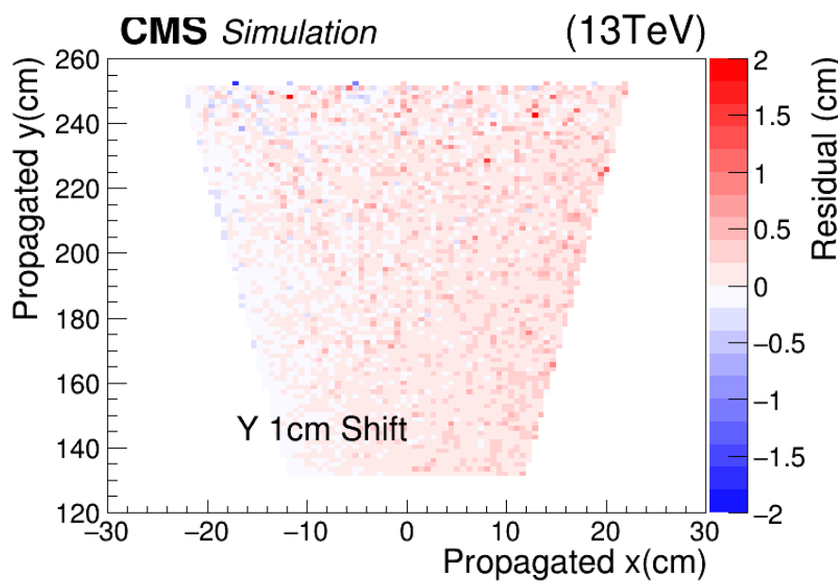
Y shift

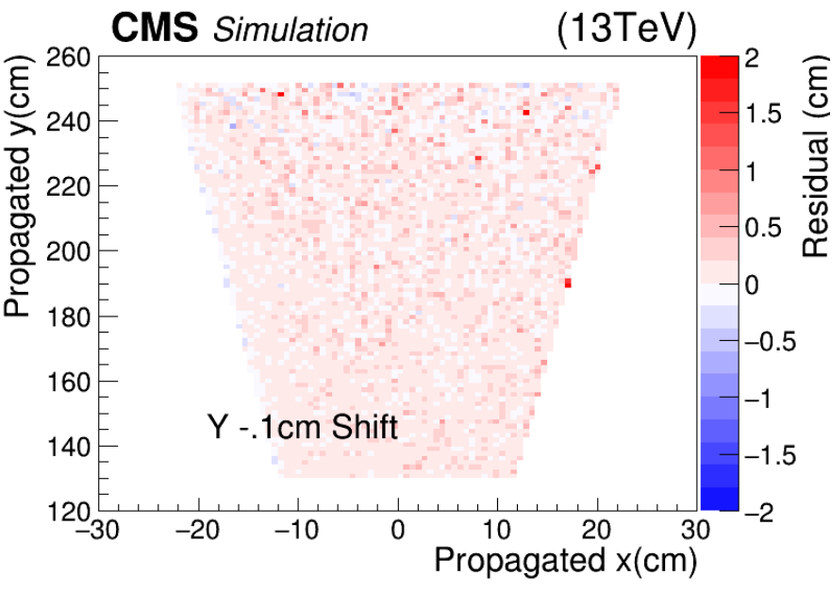


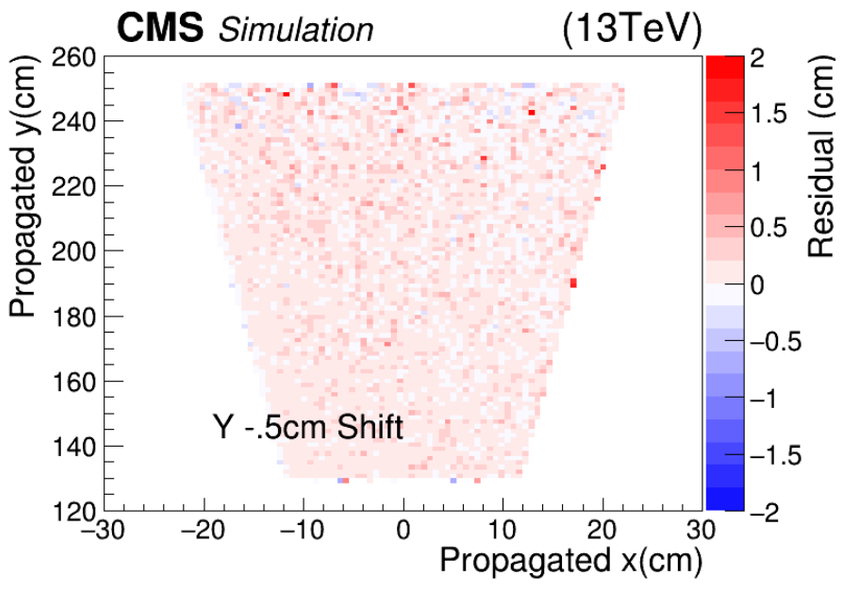
Devin Aebi

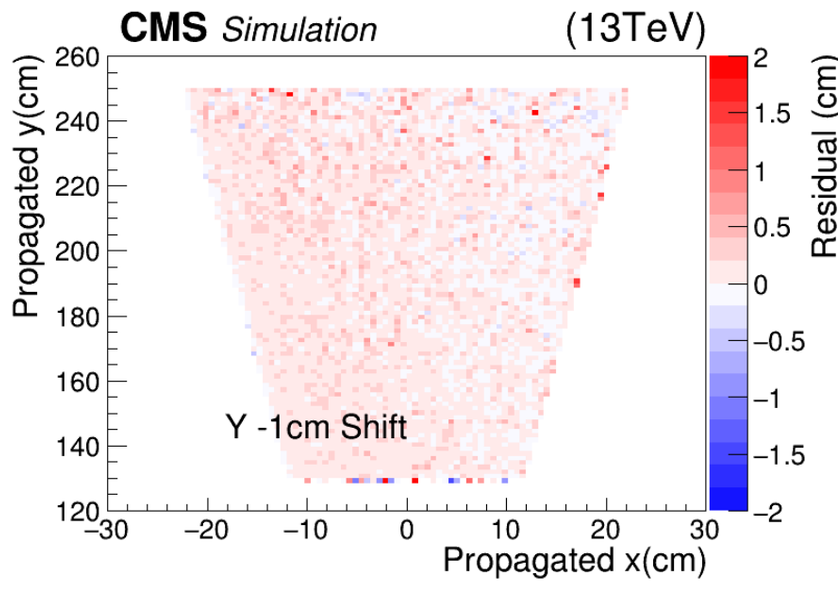












Plan

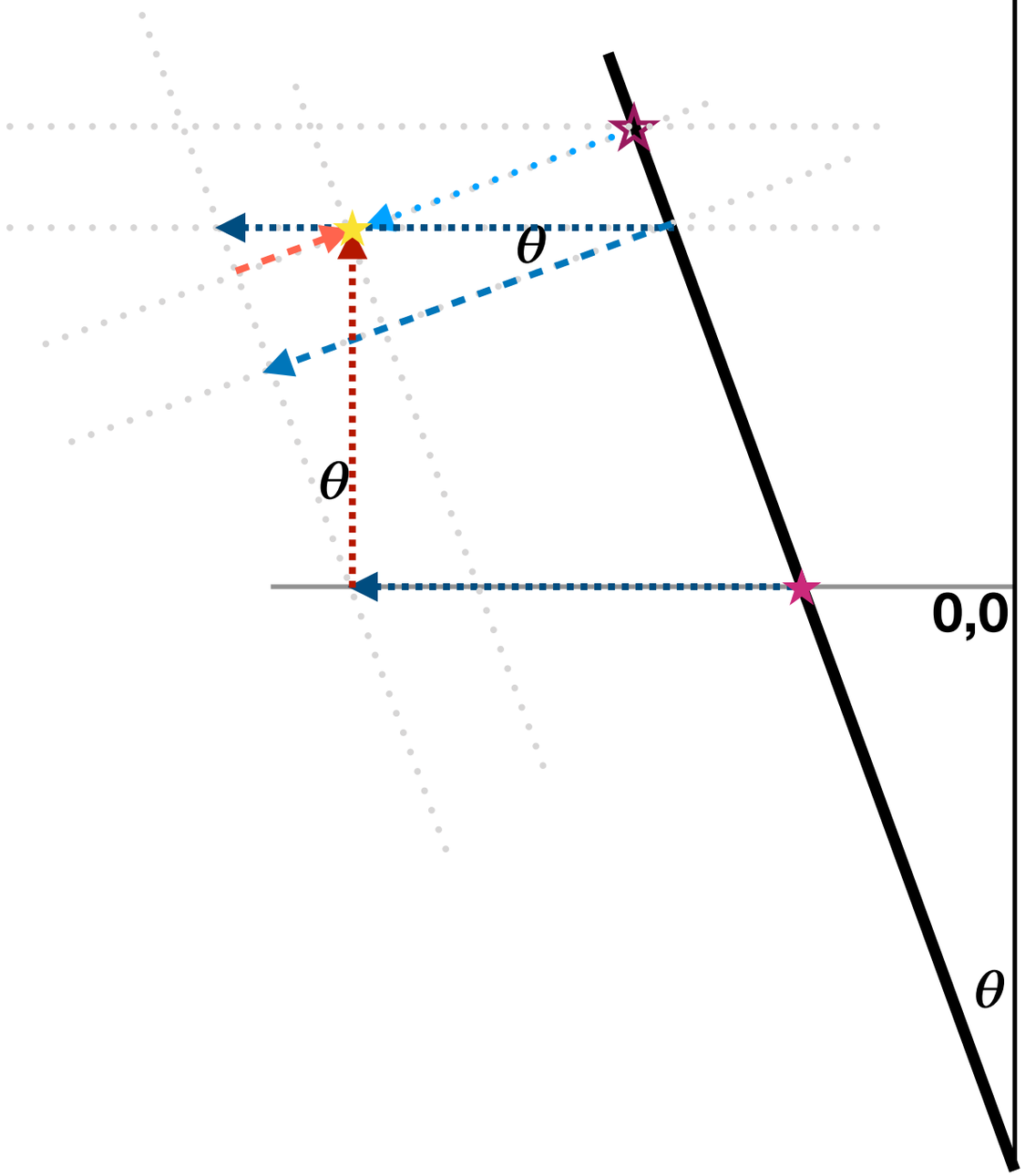
- Update GEM alignment RCD and aligner
  - Implement rotation and propagation to sub-structure
- Development TBMuAl (target 2021)
  - TBMuAl GEM code is being developed
  - Code test will use MC before collision or slice test data
- Develop local muon alignment (target June 2020)
  - Local muon alignment can use cosmic ray and collision
  - Improve GEM-CSC alignment

Summary

- Track-based GEM alignment development is ongoing
  - Consider other methods for precise GEM-CSC alignment
- GEM $\Delta R\phi$ residual study
  - **Realistic single muon samples and several misalignment geometry scenarios are tested**
  - **$\Delta R\phi$ residual shows non-geometrical bias distribution and sensitive for x and y shift**
- Local GEM alignment will be performed with cosmic ray before collision
- Track-based GEM alignment DB will be available during commissioning

Backup

Calculation $\Delta R\varphi$



$\Delta R\varphi = \cos\theta * \Delta x + \sin\theta * \Delta y$

★ **Propagation**

★ **Reconstruction**

θ **Strip angle of recHit - $\pi/2$**

~$\Delta R\varphi$

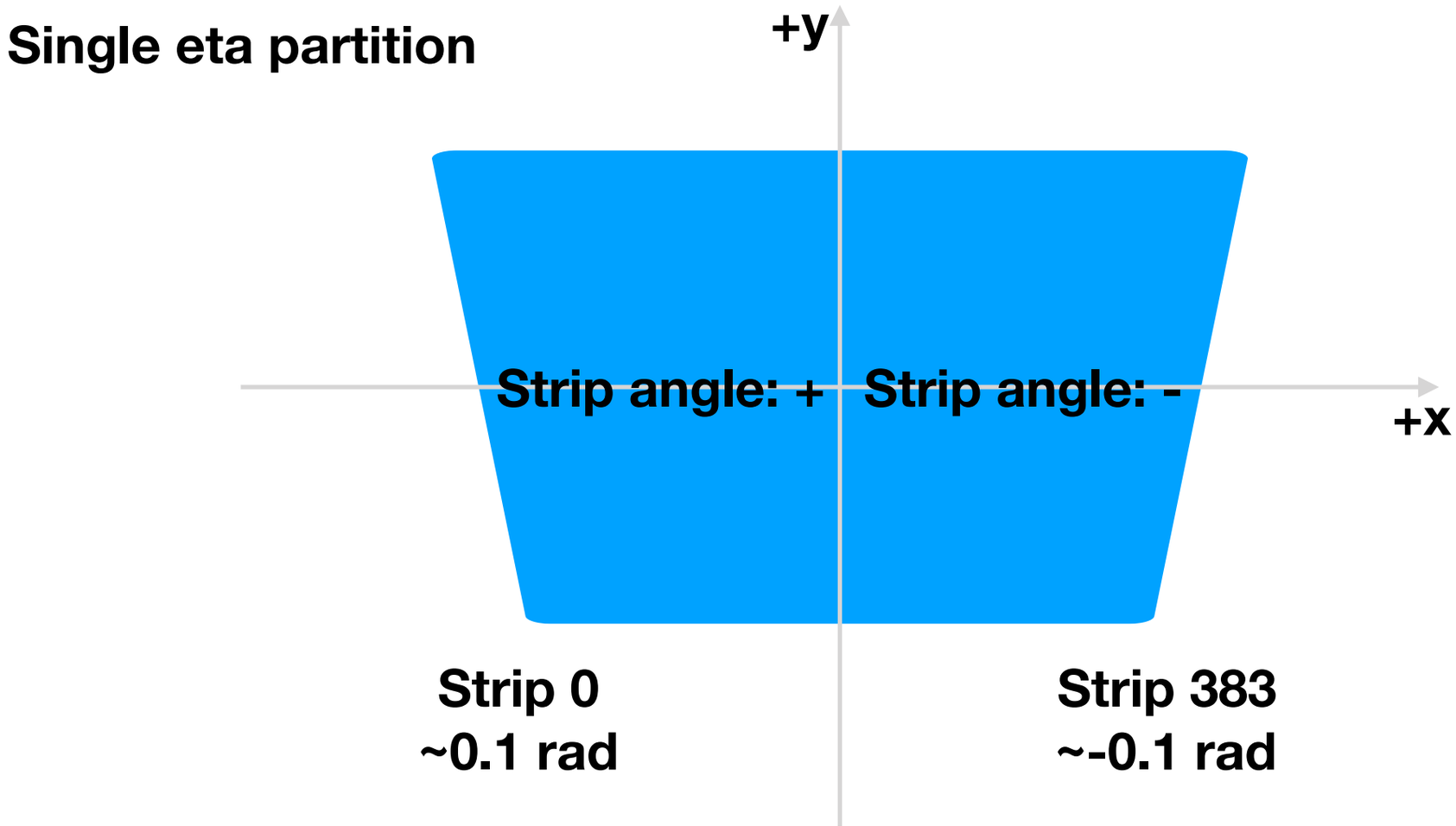
Δx

$\cos\theta * \Delta x$

Δy

$\sin\theta * \Delta y$

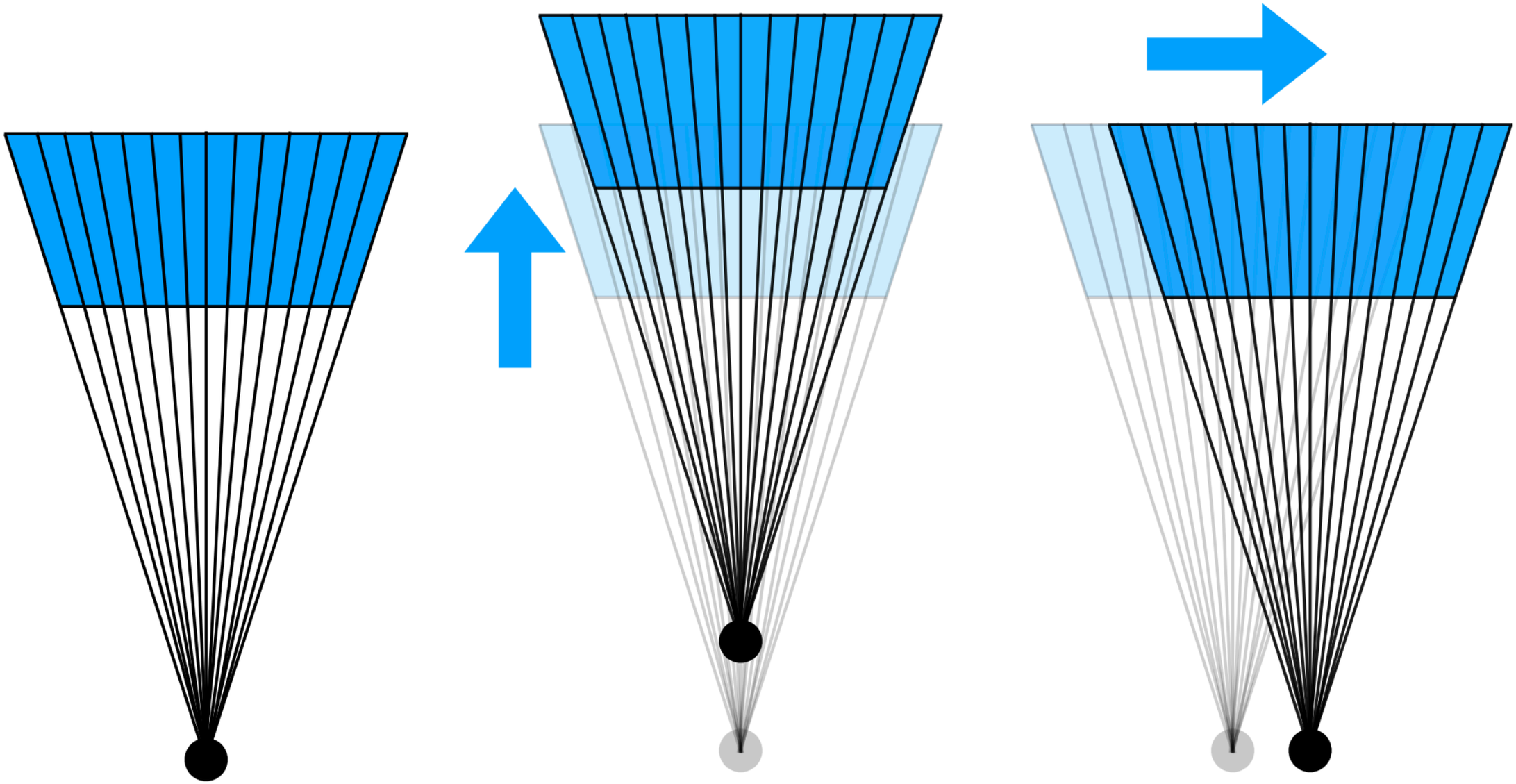
GEM Local Coordinate



$$\Delta R\varphi = \cos\theta * \Delta x + \sin\theta * \Delta y$$

Strip Angle

Devin



We calculate $\Delta R\phi$ using the strip angle, so our residuals only work if the strips are still radially point to the center

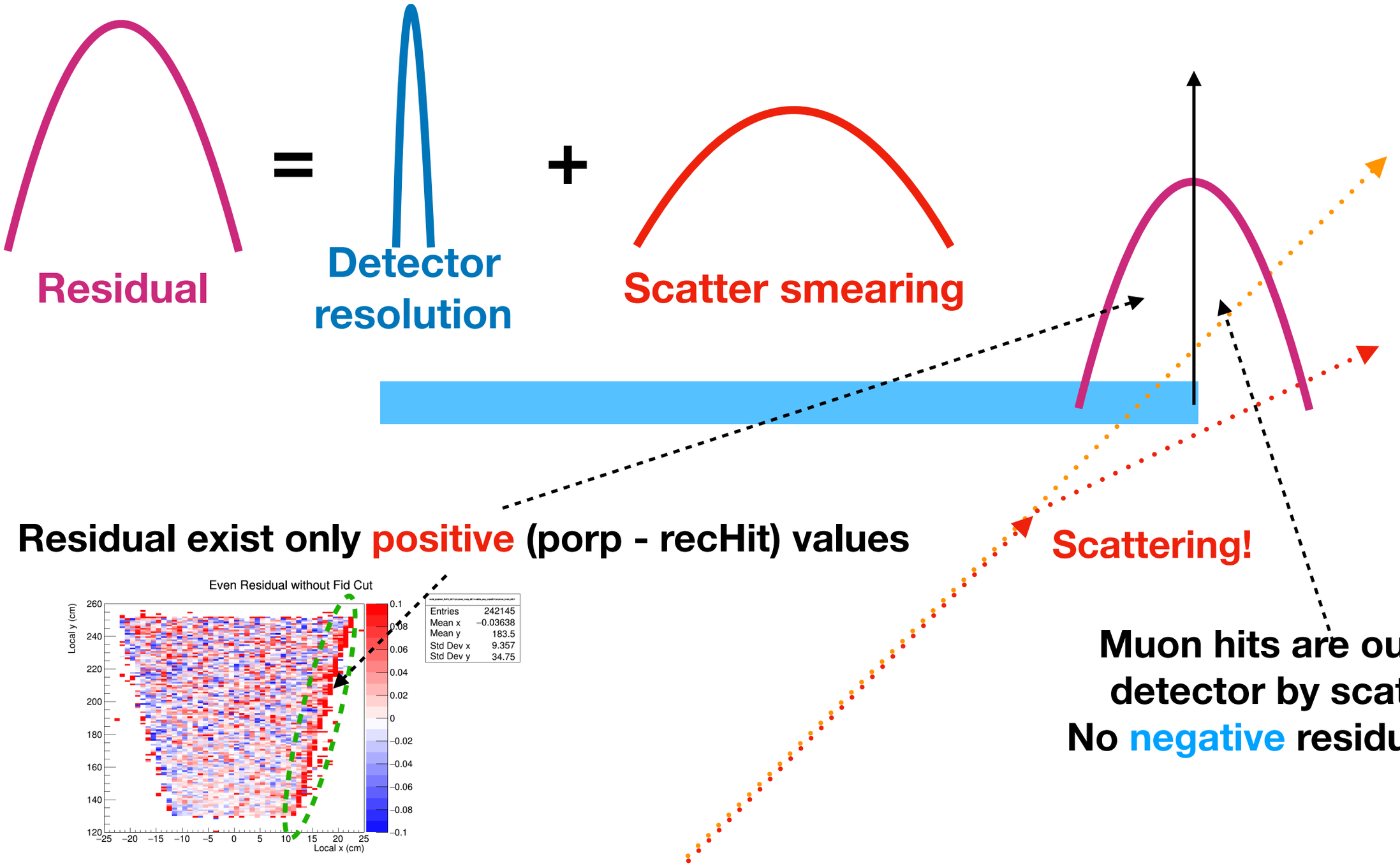
Timeline

Detectors/Trigger

- Exercise GE1/1 alignment using CR muons using local alignment (GE1/1 and CSC) with stand-alone muon (from June 2020)
- Alignment with collisions (from 2021)
- First align ME1/1 with tracker with $>$ 2 fb-1 data (30 $<$ pT (muon) $<$ 200 GeV). This is the current Track-based muon alignment (TBMuAl) processing.
  - Pre-requisite: updated Tracker geometry and Muon GPR
  - TB alignment running workflow — 2 days for 1 run through data (2 fb-1)
  - Looking at the results + 1st step validation (internal) — 3 days. If problems found then re-running of the workflow is needed - plan to run alignment frequently (with limited statistics) from Day 1 of Run3
  - 2nd step validation (physics) — 1 week. re-fit muons in $Z \to \mu\mu$ and high-pT samples with new Mu+Trk geometries
  - generating final results (DB payload with geometry) — 1 day. Useful to re-run validation for confirmation
- This TBMuAl takes about 2 weeks (after update tracker geometry and muon GPR).

From Jared

Fiducial Cut



Residual exist only positive (porp - recHit) values

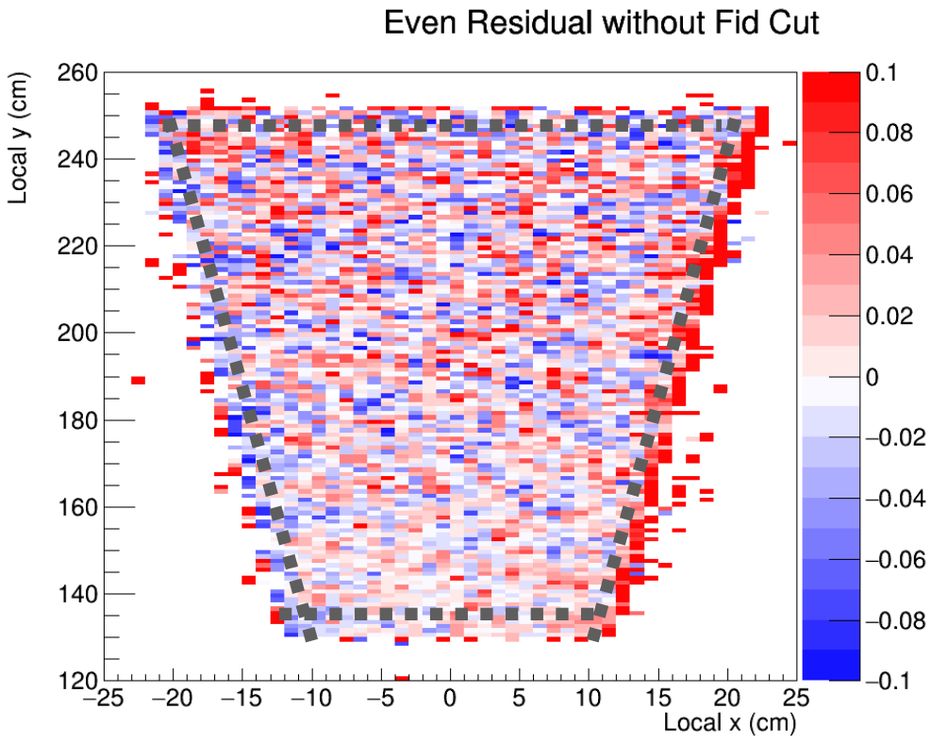
Muon hits are out of the detector by scattering;
No negative residual values

Propagation track from inner tracker **doesn't consider scattering**

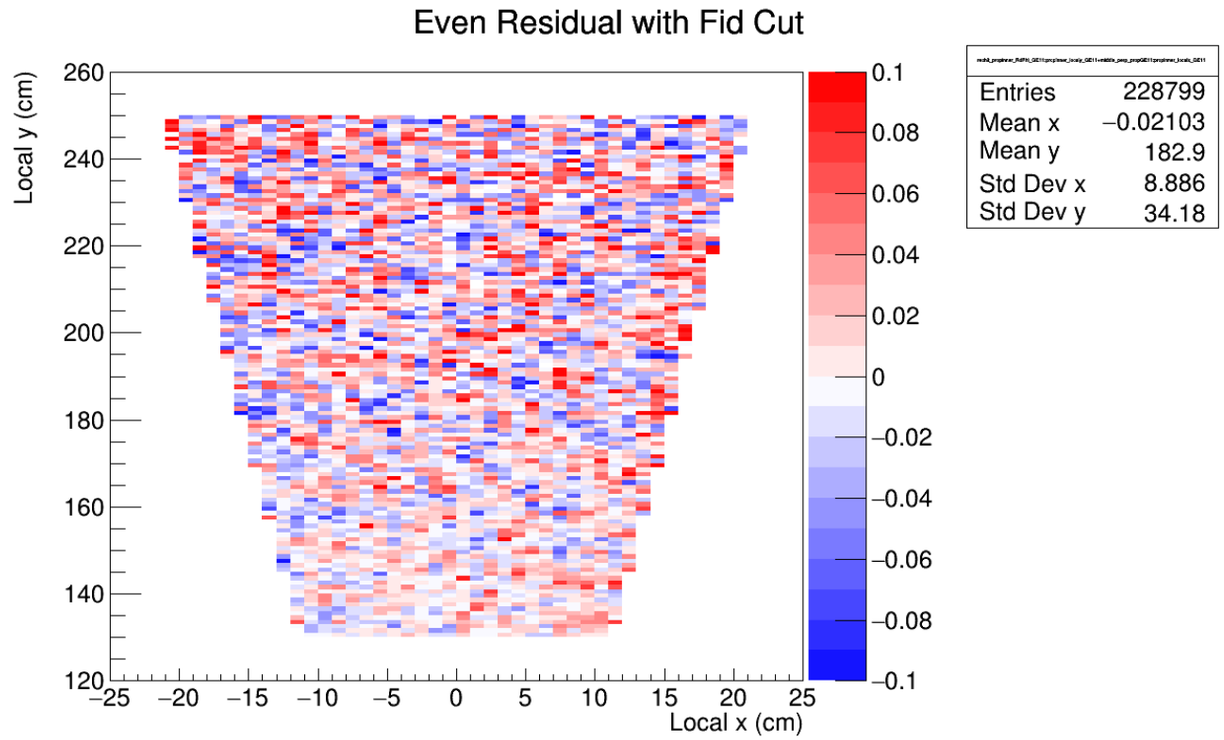
Real muon pass has scattering then smeared

Fiducial Cut $\Delta\phi$

Muon gun with 50 p_T



Cut



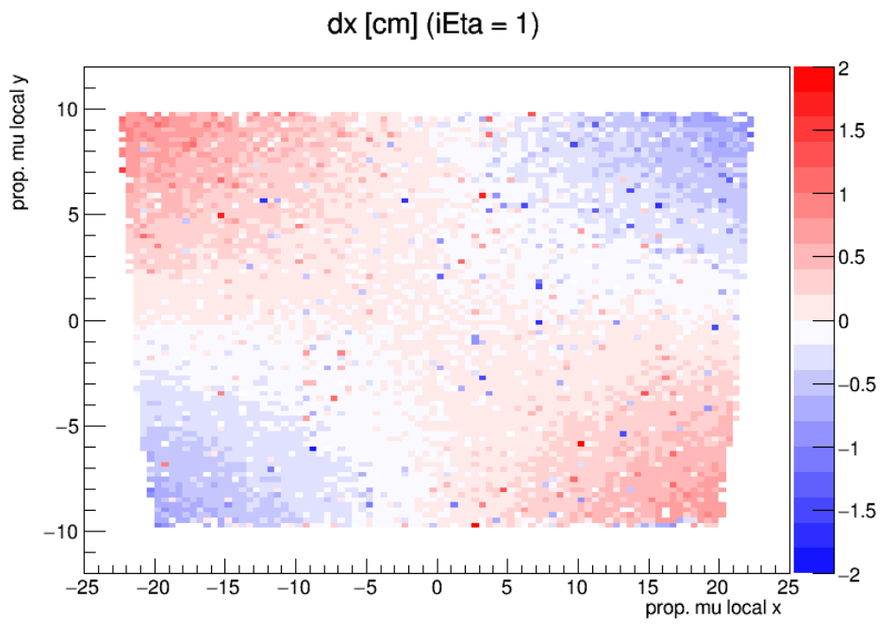
Taking 1.6 $\sigma_{\Delta\phi}$ cut from the standard deviation

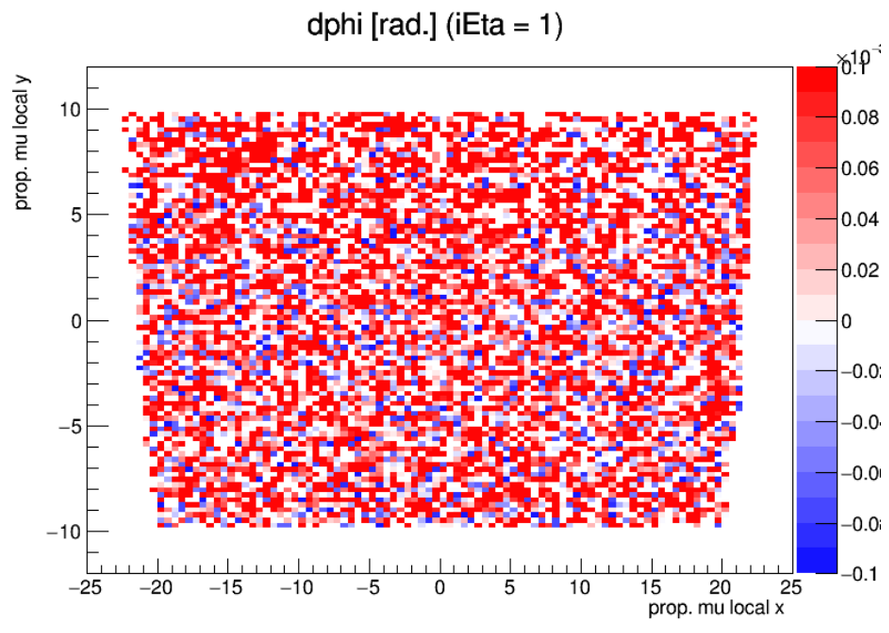
Cut ϕ : | prop. hit angle | < 0.088 - 1.6 $\sigma_{\Delta\phi}$

Cut y : 130 + 1.6 $\sigma_{\Delta x}$ < | prop. hit y | < 235 (long: 250) - 1.6 $\sigma_{\Delta x}$

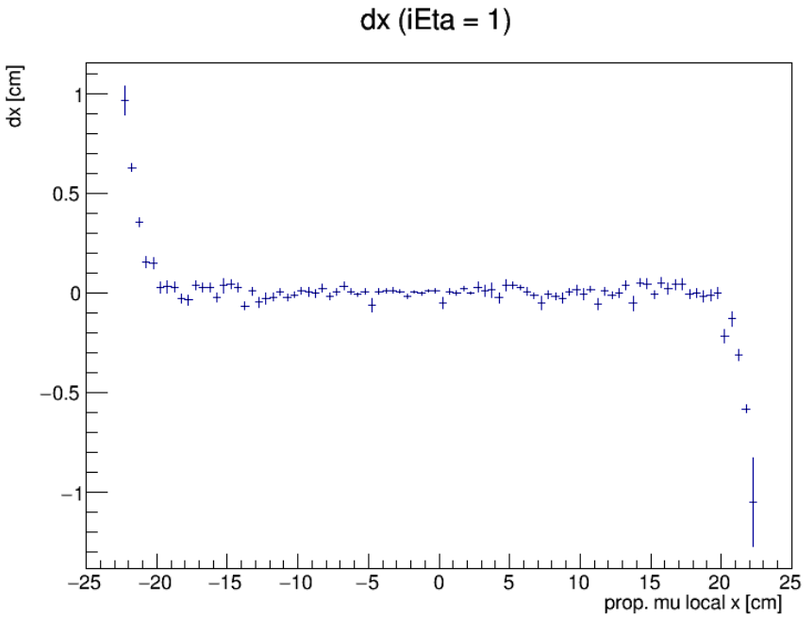
Cut study is ongoing: with **realistic muon p_T** distribution and **mis-aligned geometries**

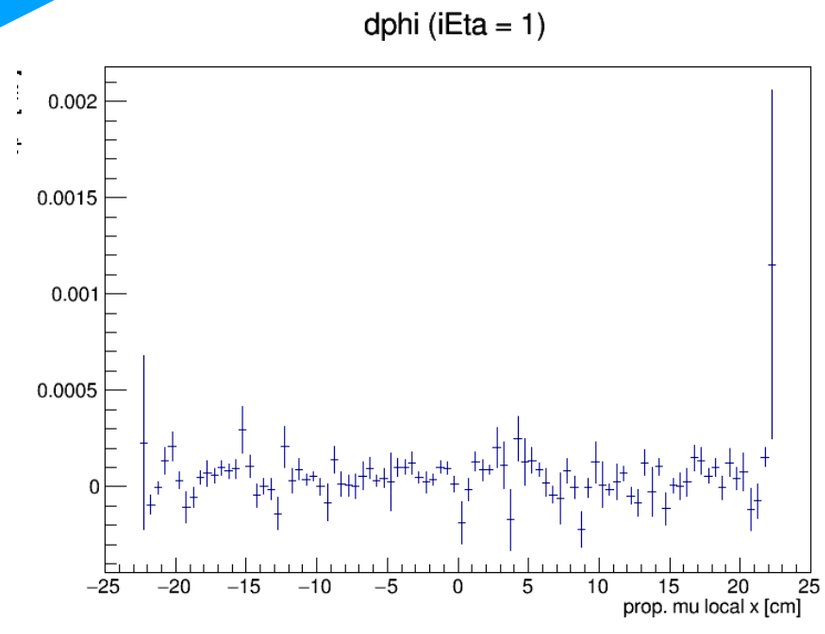
dx vs dphi



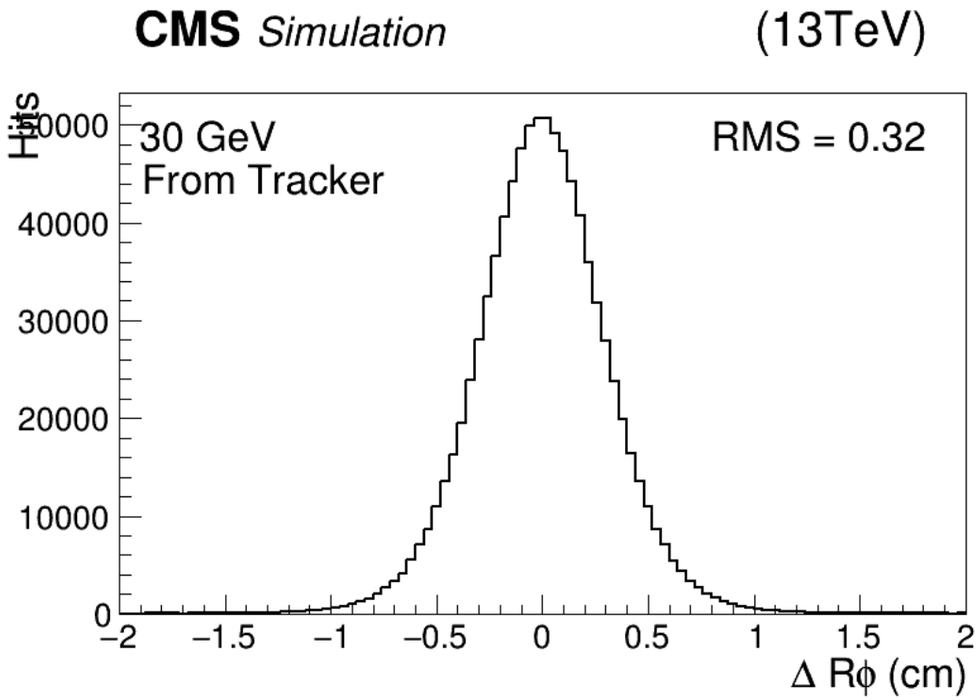


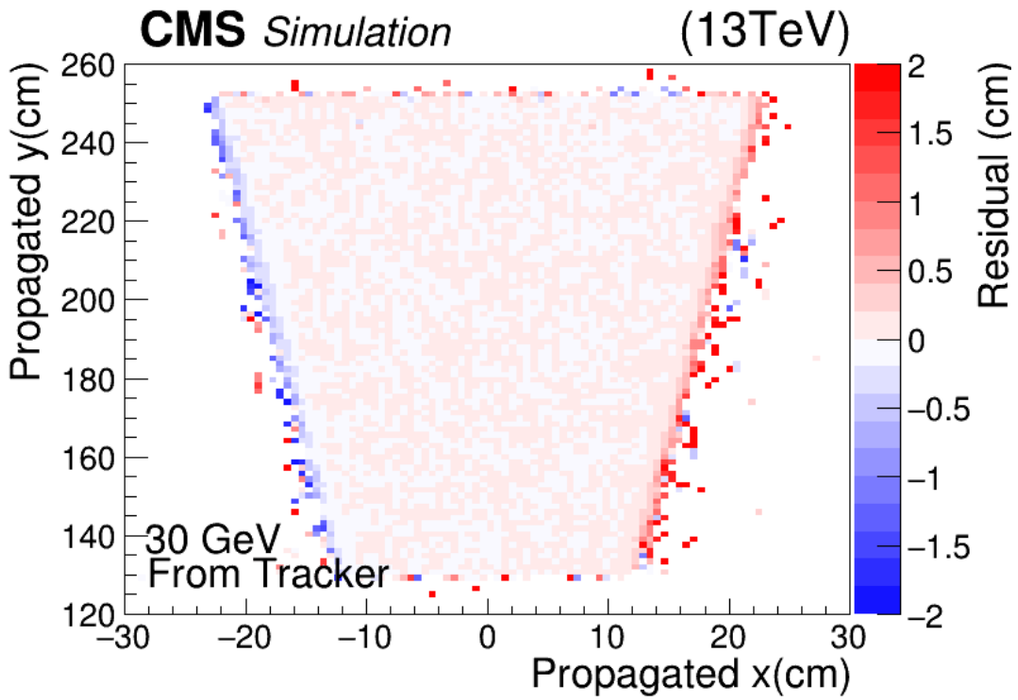
Projection

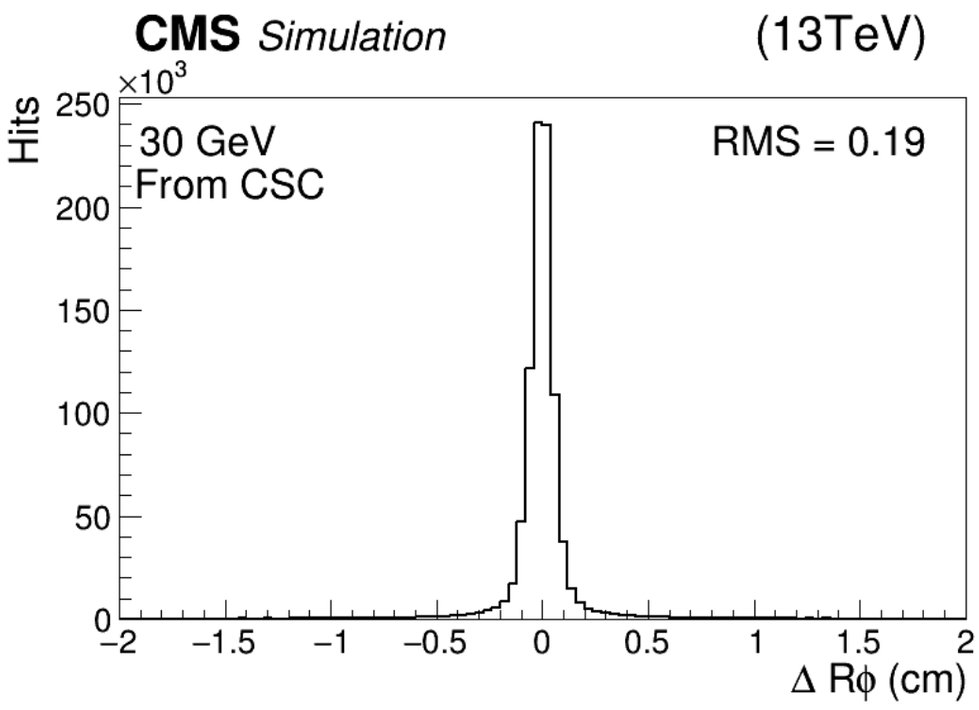


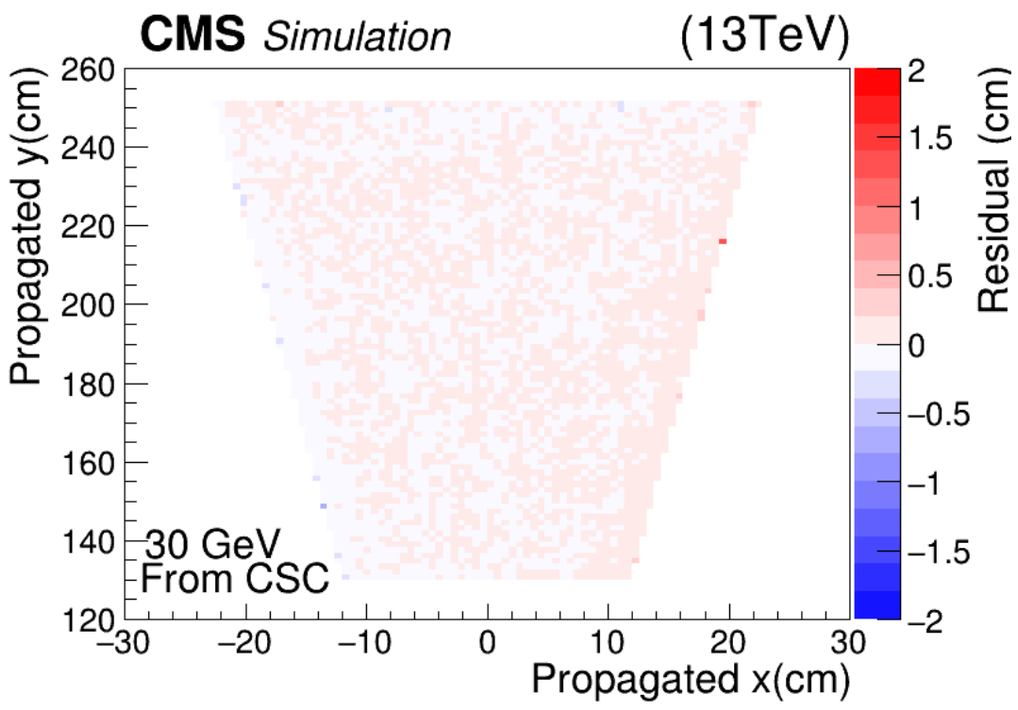


Muon p_T 30 GeV

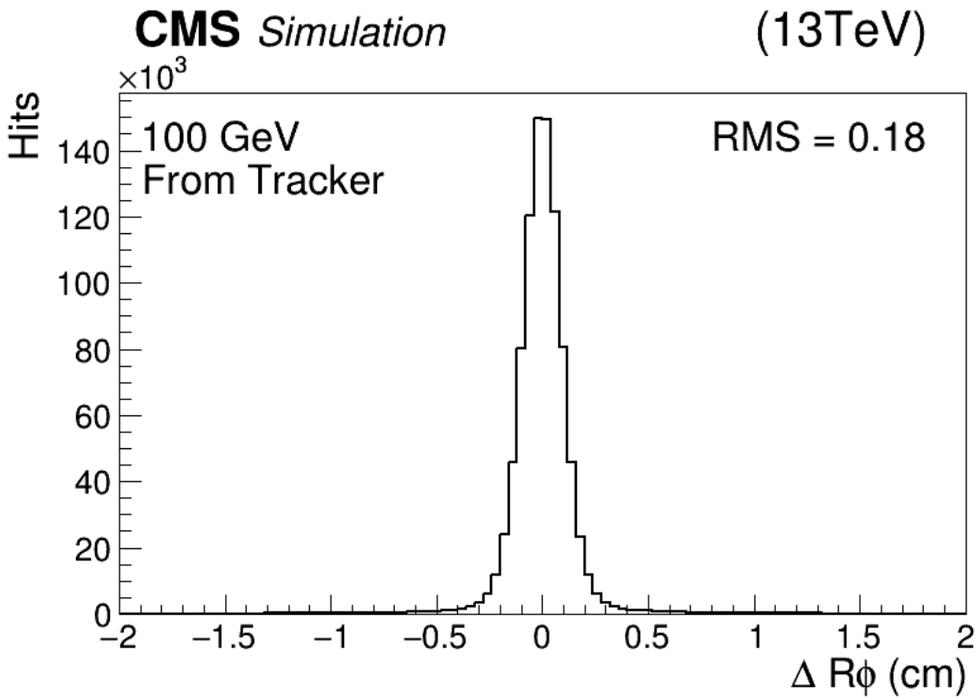


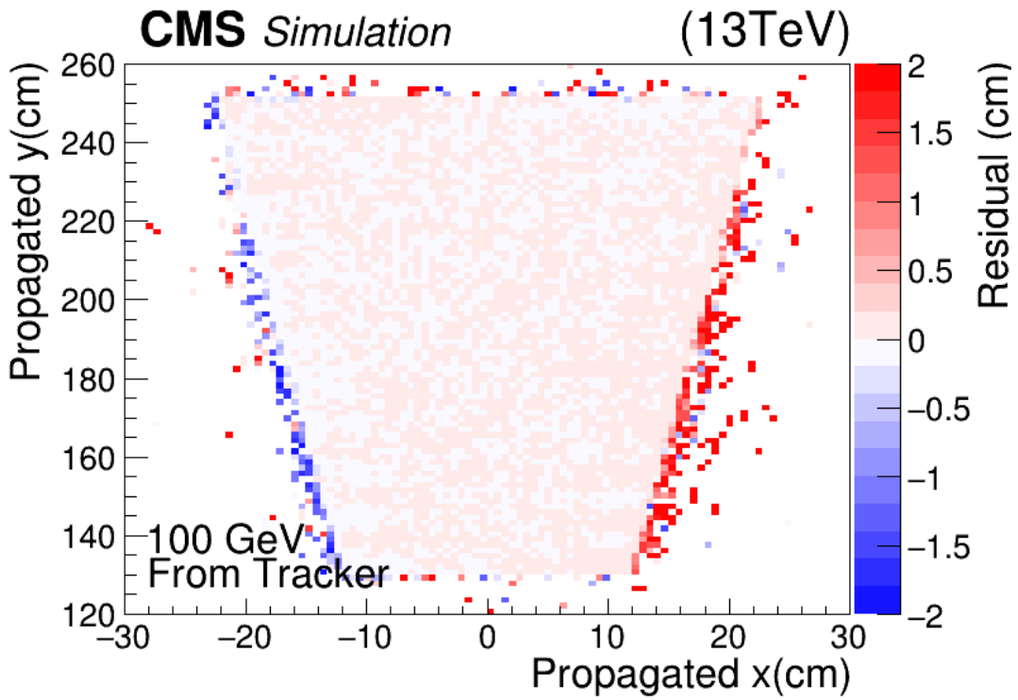


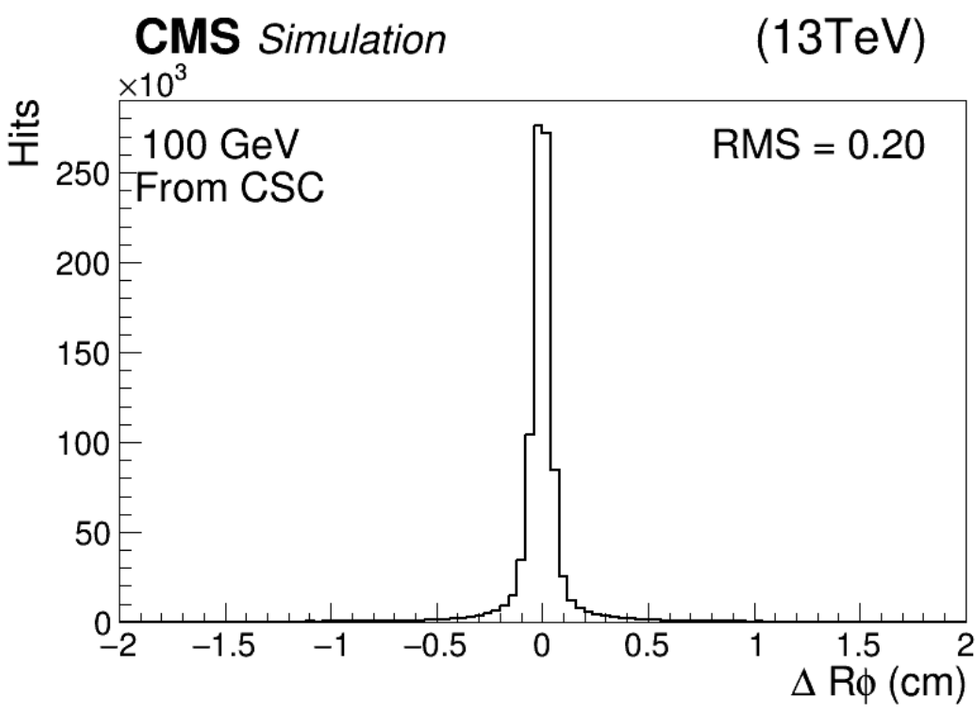


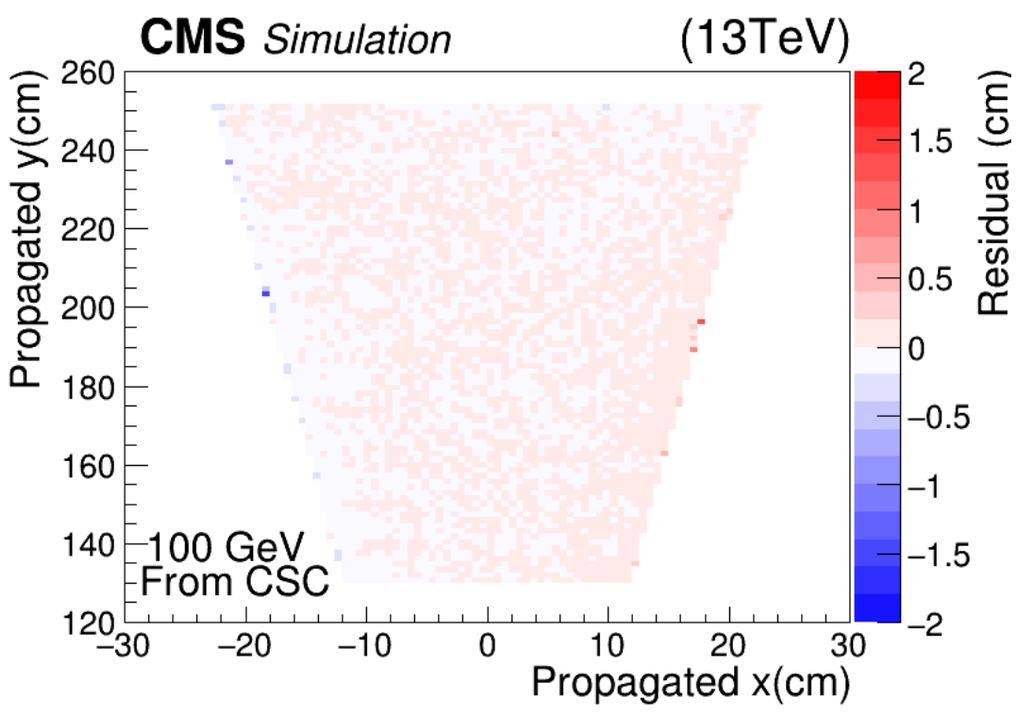


Muon p_T 100 GeV

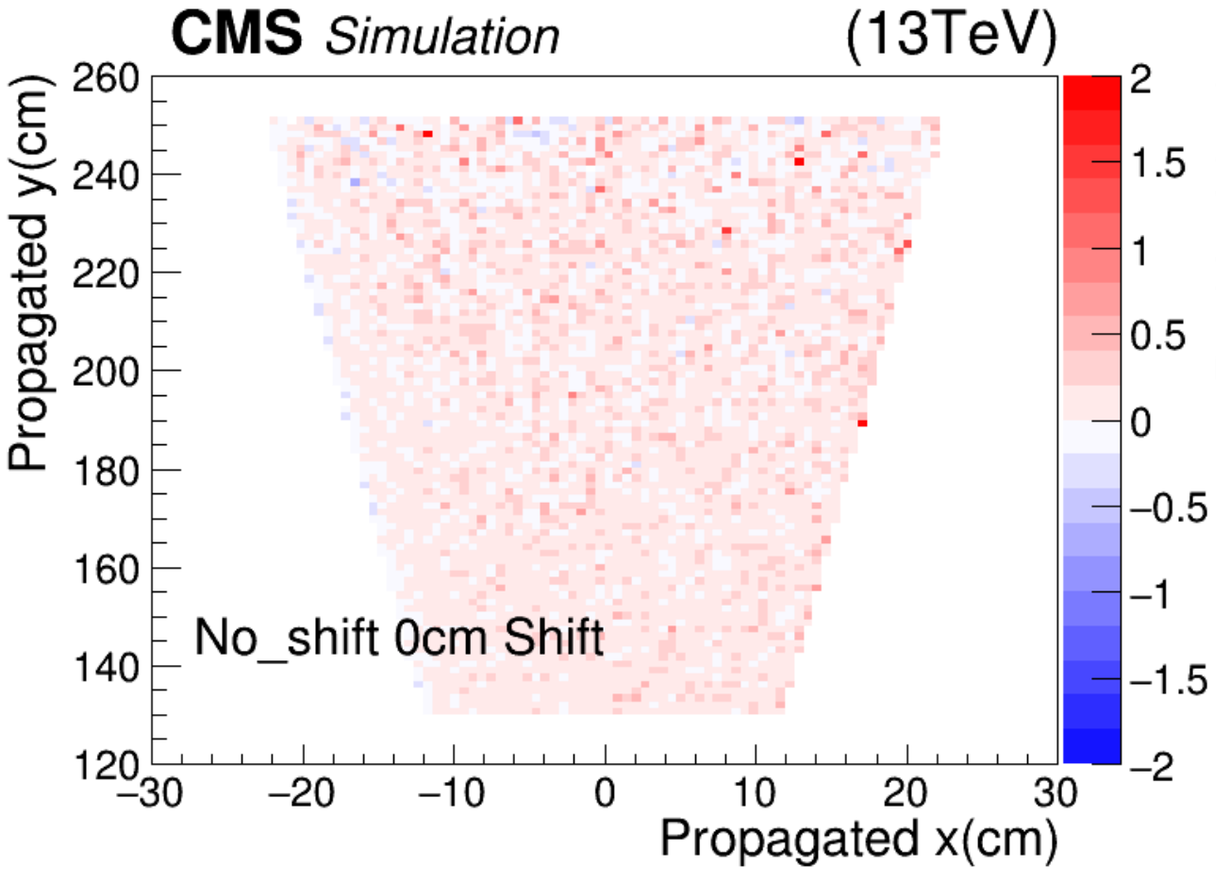


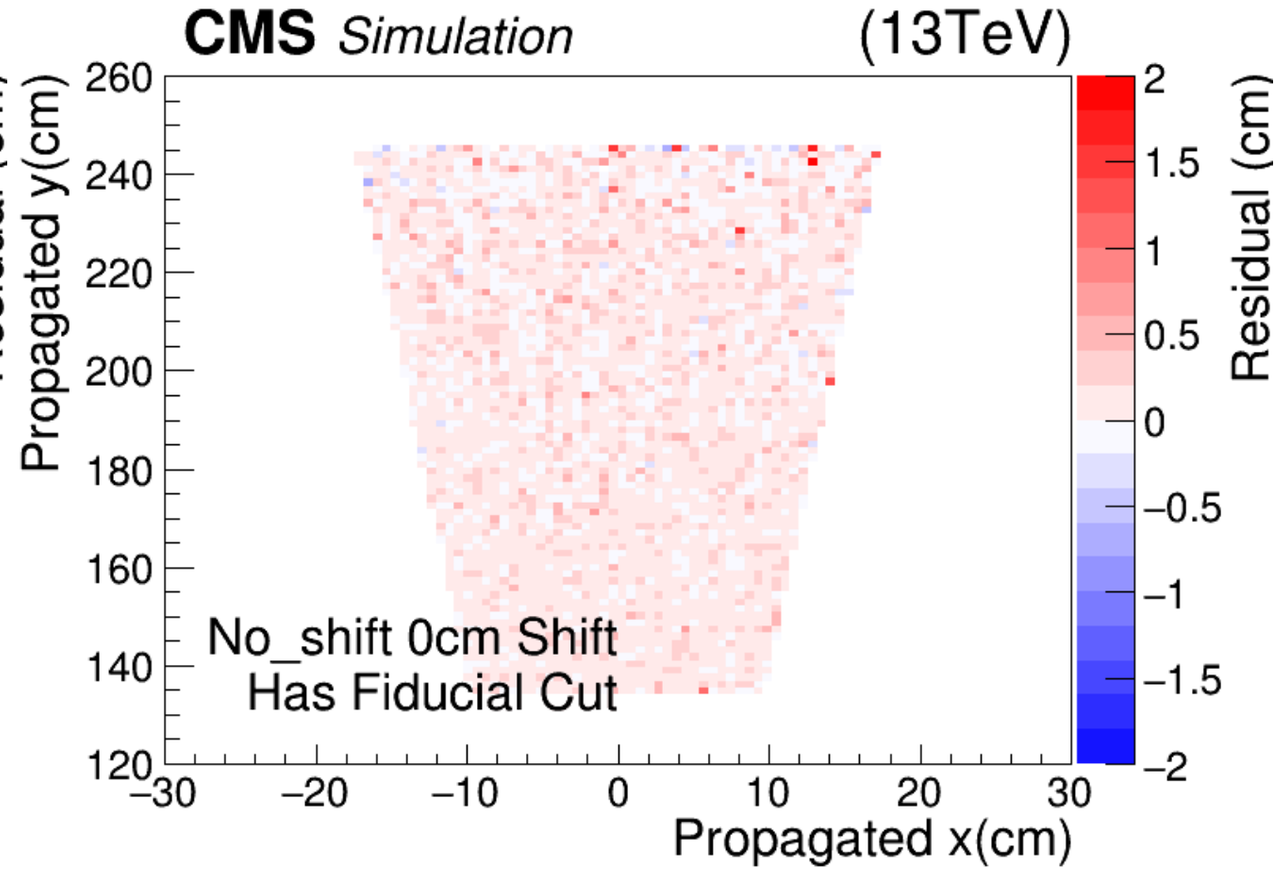




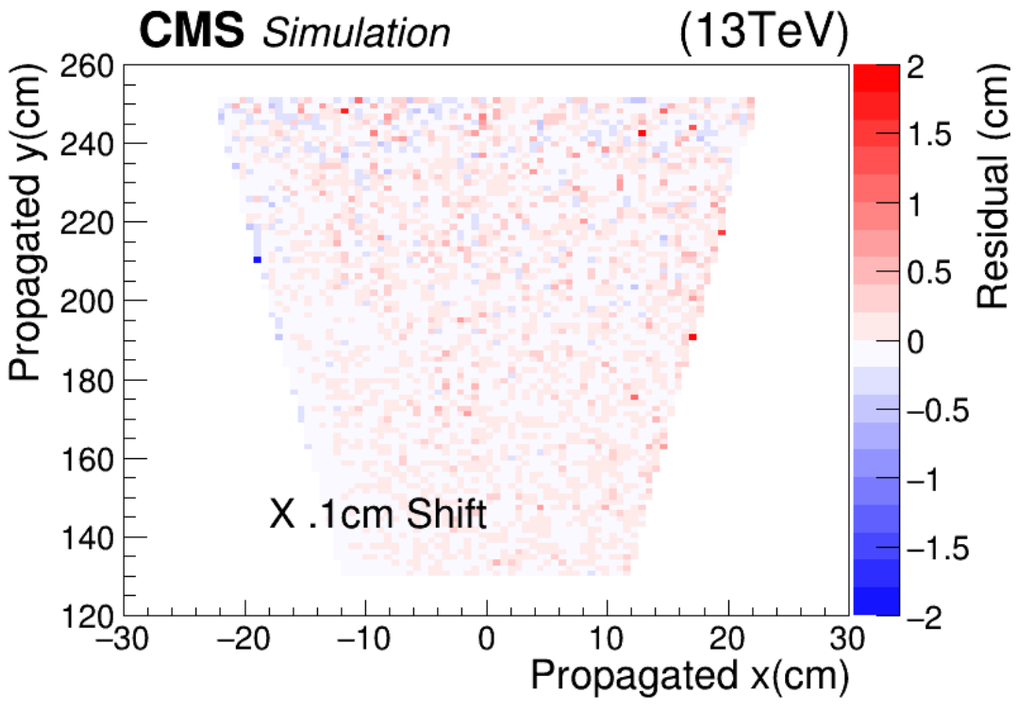


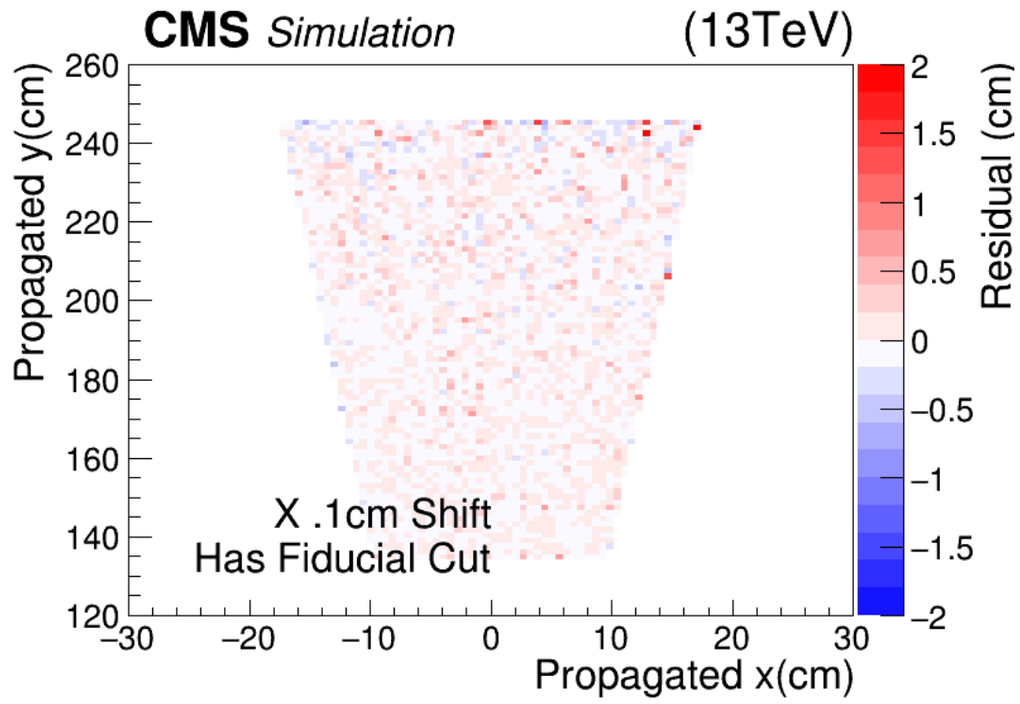
Non misaligned Geometry

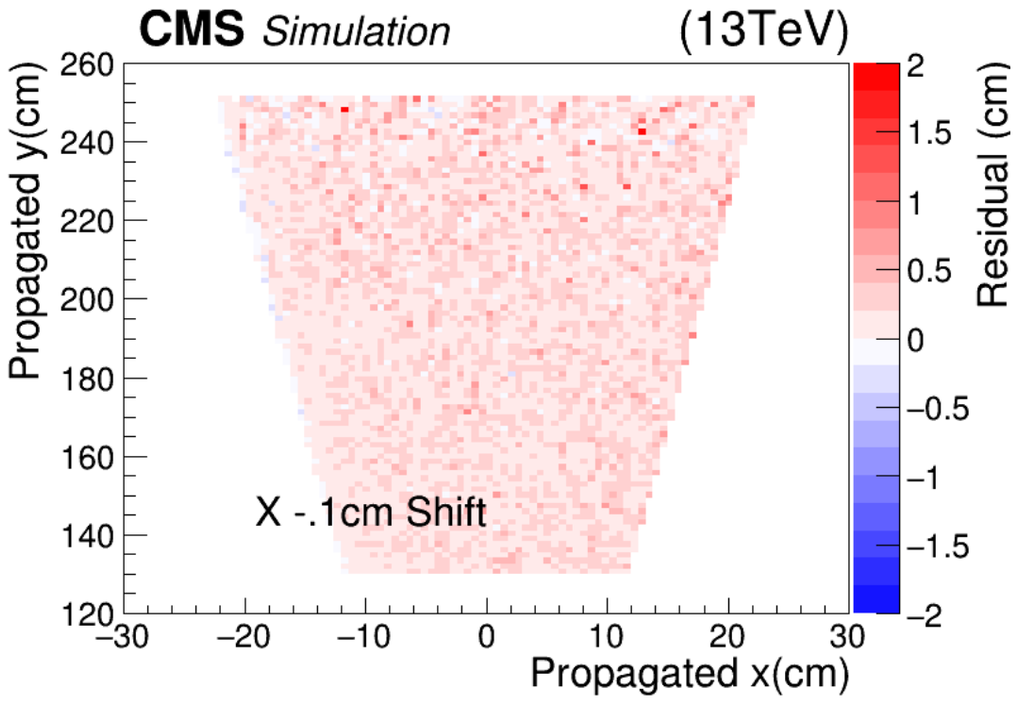


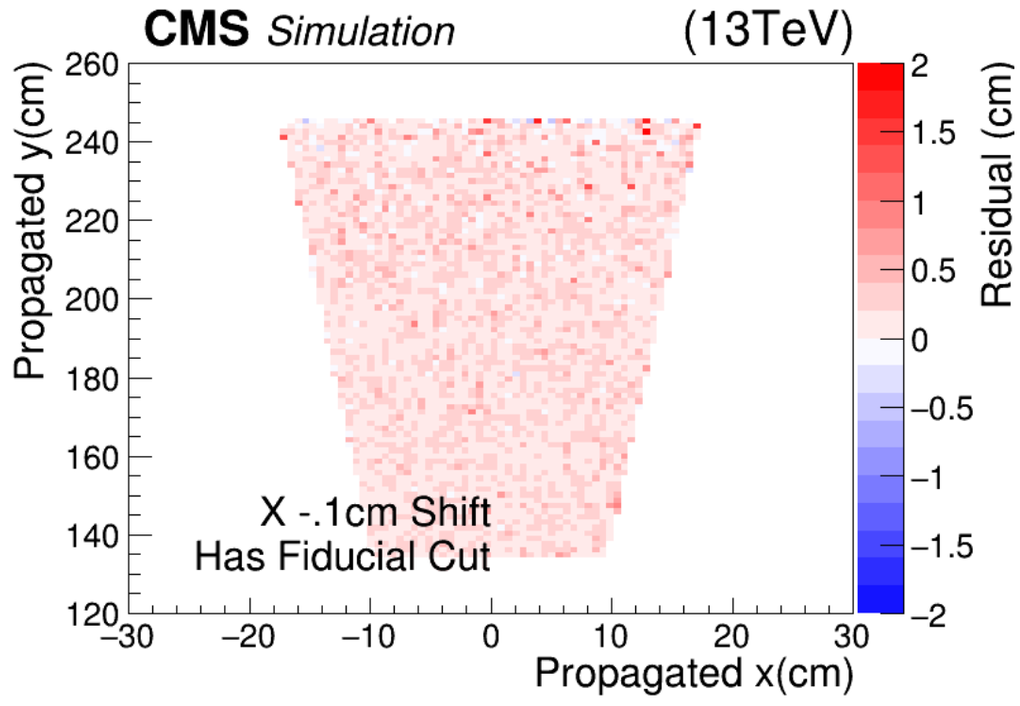


X ± 0.1 cm

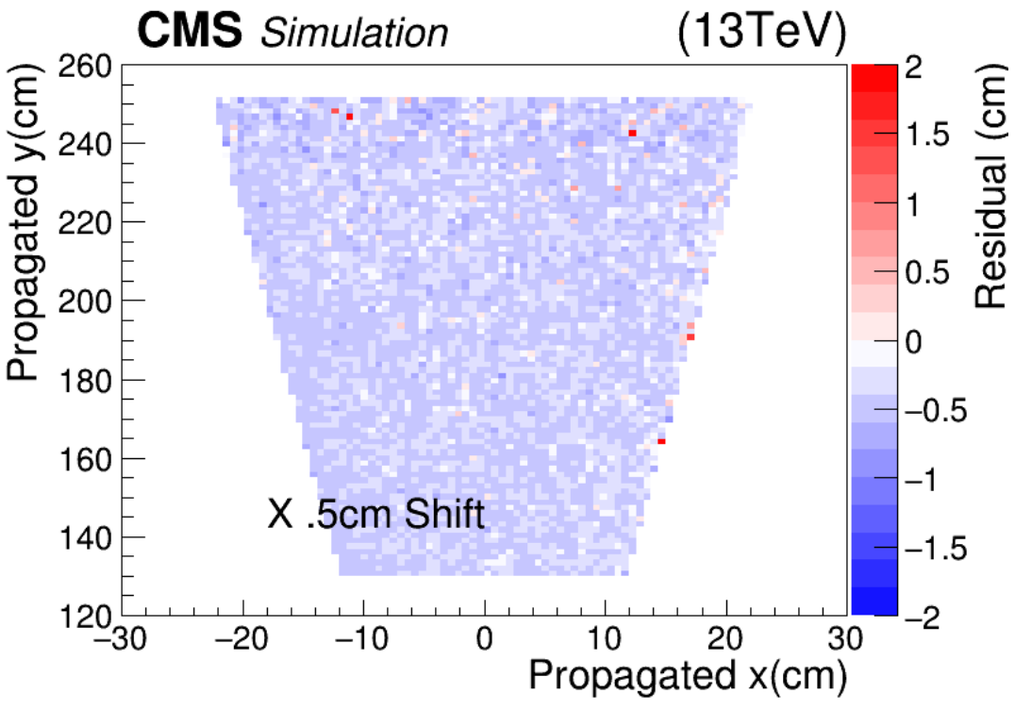

CMS Simulation
(13TeV)
X .1cm Shift
Propagated y(cm)
Propagated x(cm)
Residual (cm)

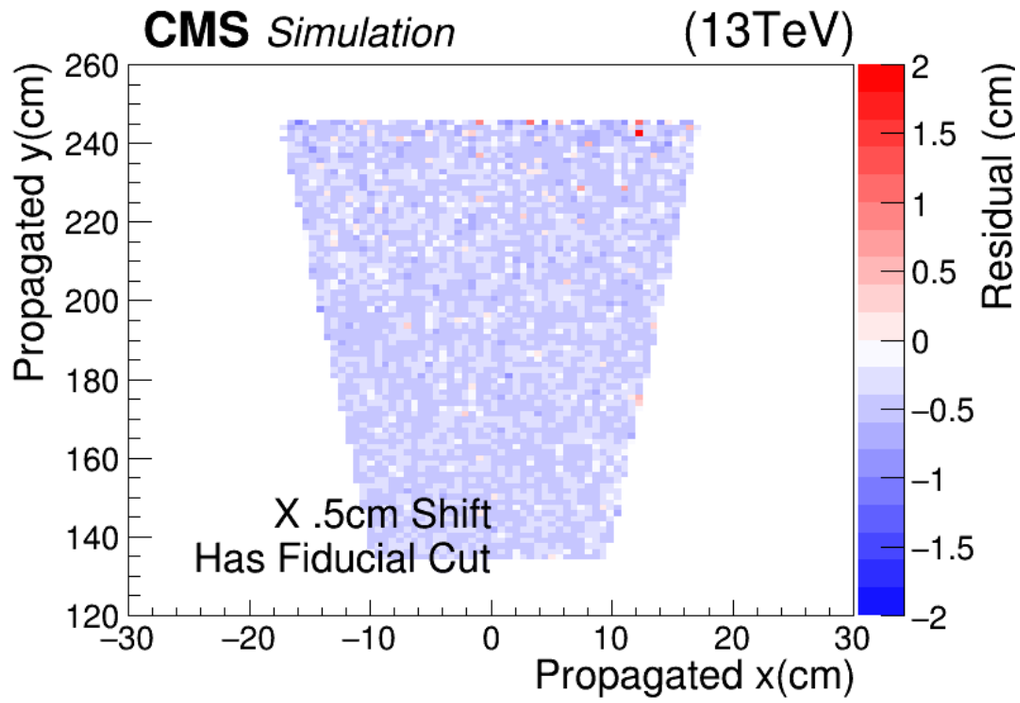

CMS Simulation
(13TeV)
X .1cm Shift
Has Fiducial Cut
Propagated y(cm)
Propagated x(cm)
Residual (cm)

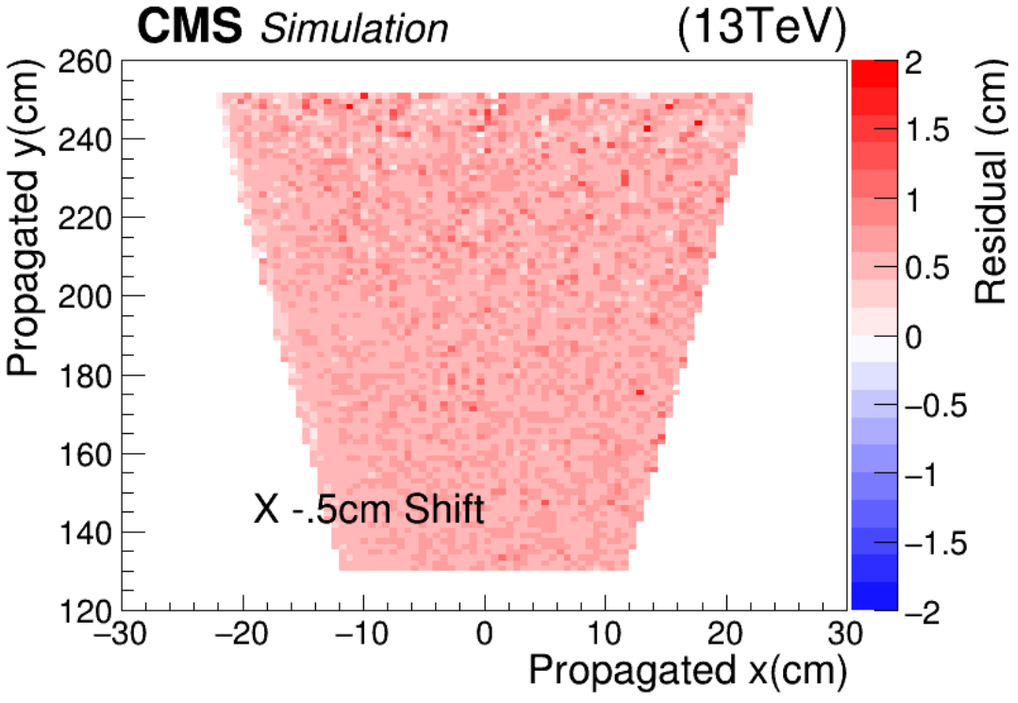

CMS Simulation
(13TeV)
X -.1cm Shift
Propagated y(cm)
Propagated x(cm)
Residual (cm)

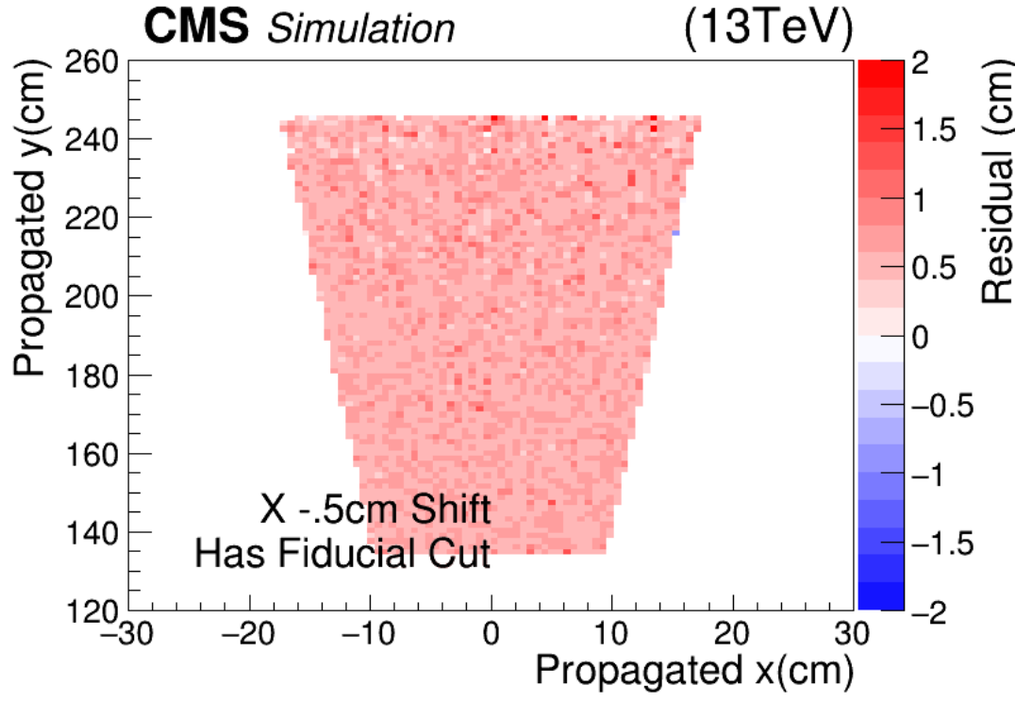

CMS Simulation
(13TeV)
X -.1cm Shift
Has Fiducial Cut
Propagated y(cm)
Propagated x(cm)
Residual (cm)

X ± 0.5 cm

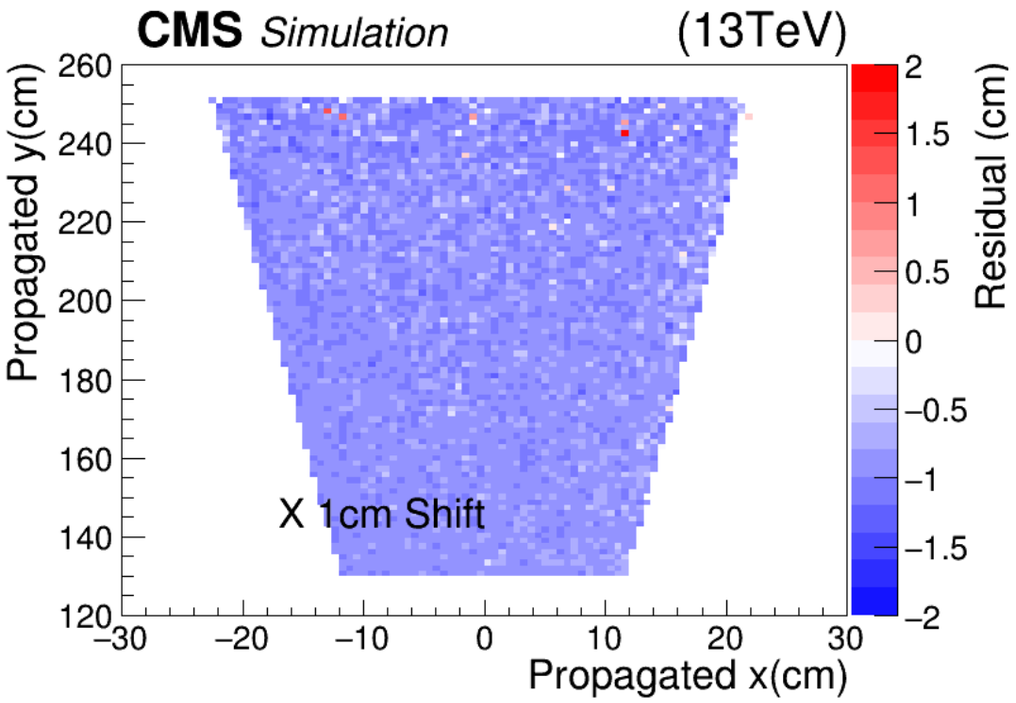

CMS Simulation
(13TeV)
X .5cm Shift
Propagated y(cm)
Propagated x(cm)
Residual (cm)

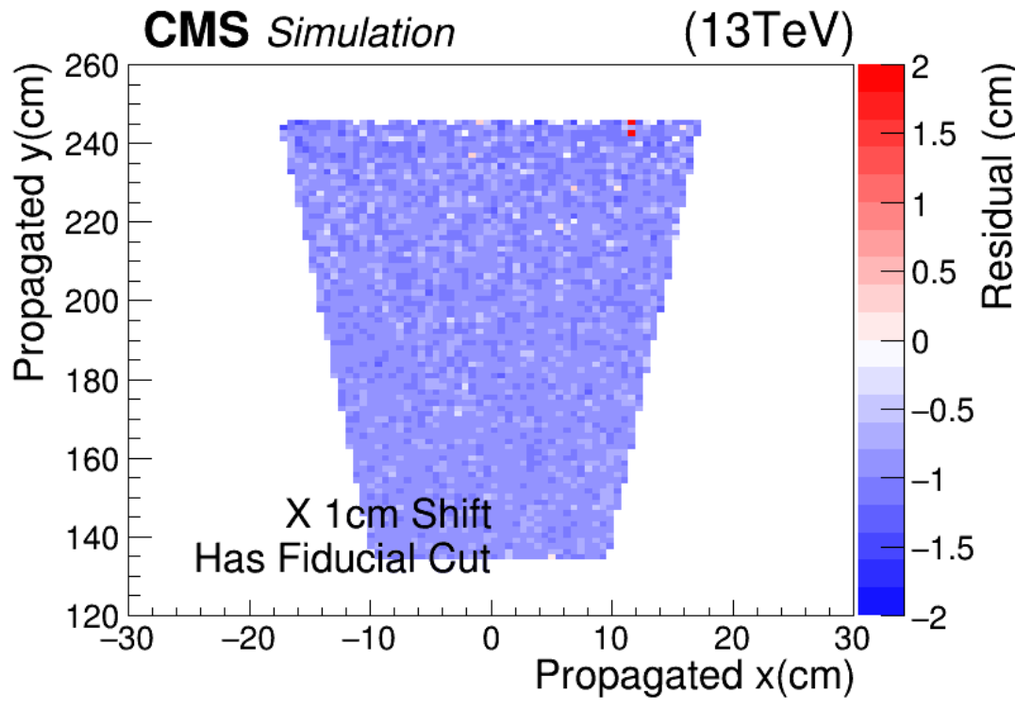

CMS Simulation
(13TeV)
X .5cm Shift
Has Fiducial Cut
Propagated y(cm)
Propagated x(cm)
Residual (cm)

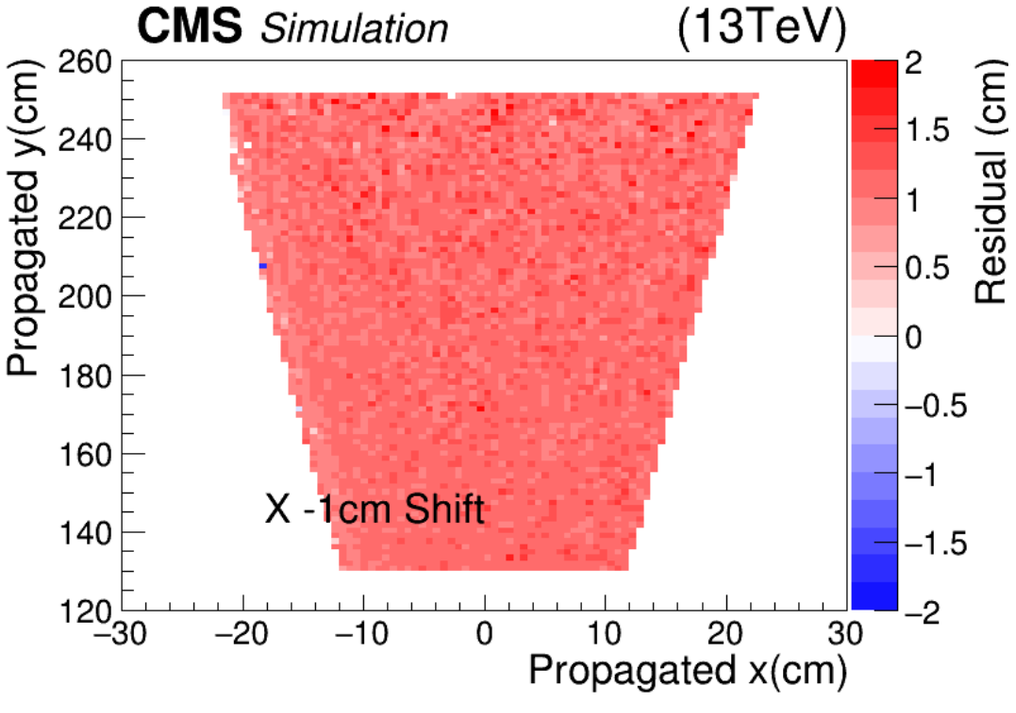

CMS Simulation
(13TeV)
X -.5cm Shift
Propagated y(cm)
Propagated x(cm)
Residual (cm)

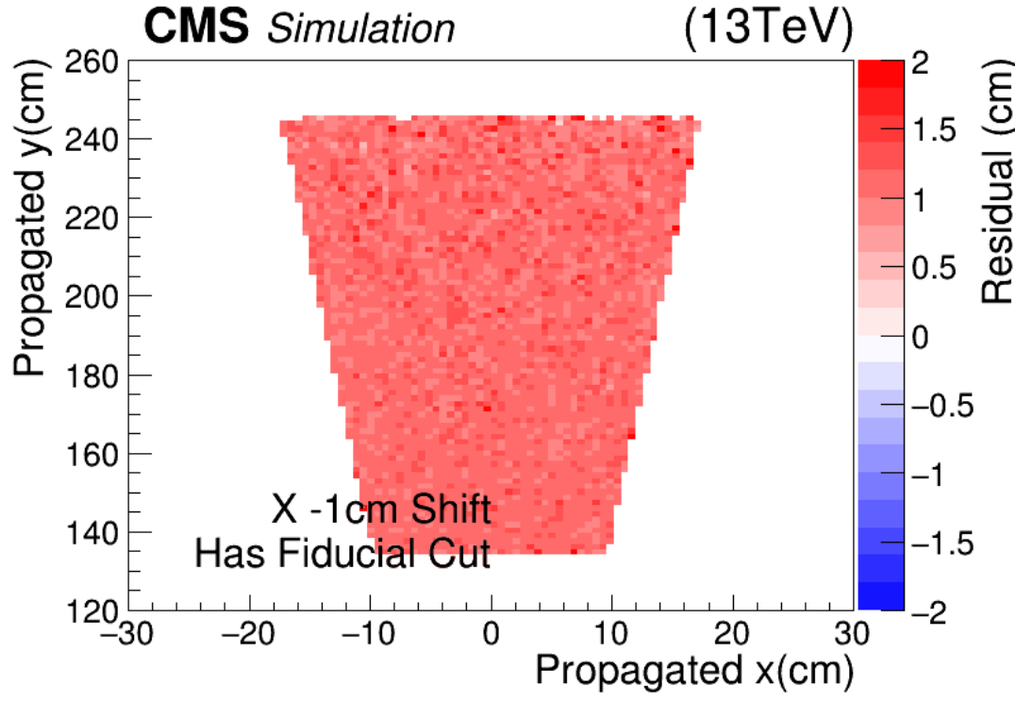

CMS Simulation
(13TeV)
X -.5cm Shift
Has Fiducial Cut
Propagated y(cm)
Propagated x(cm)
Residual (cm)

X ± 1.0 cm

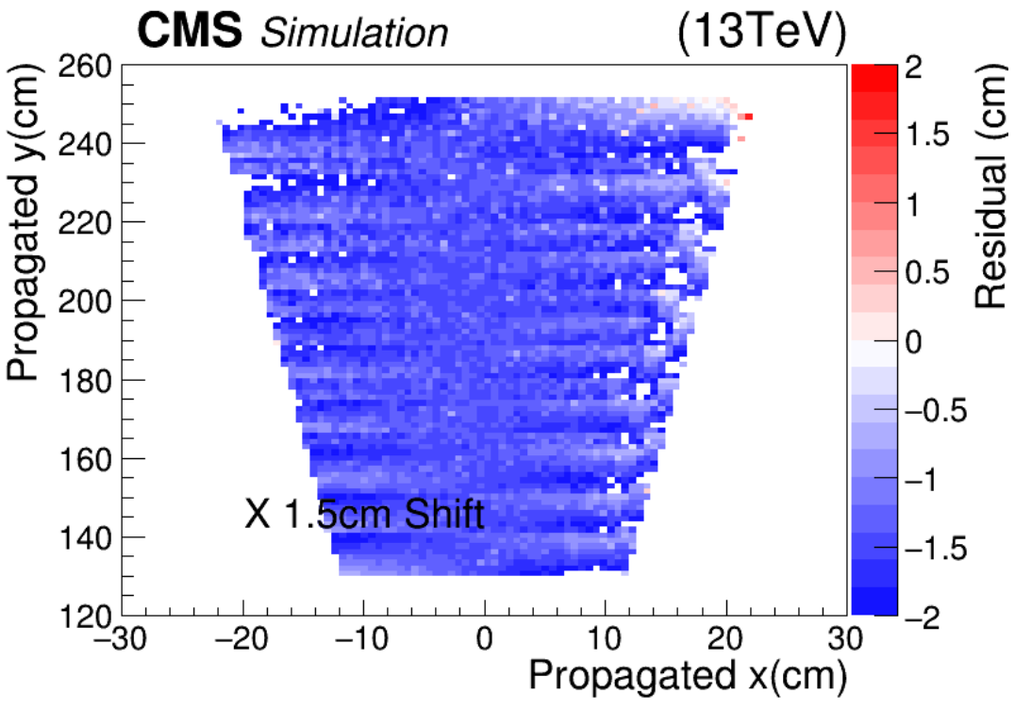

CMS Simulation
(13TeV)
X 1cm Shift
Propagated y(cm)
Propagated x(cm)
Residual (cm)

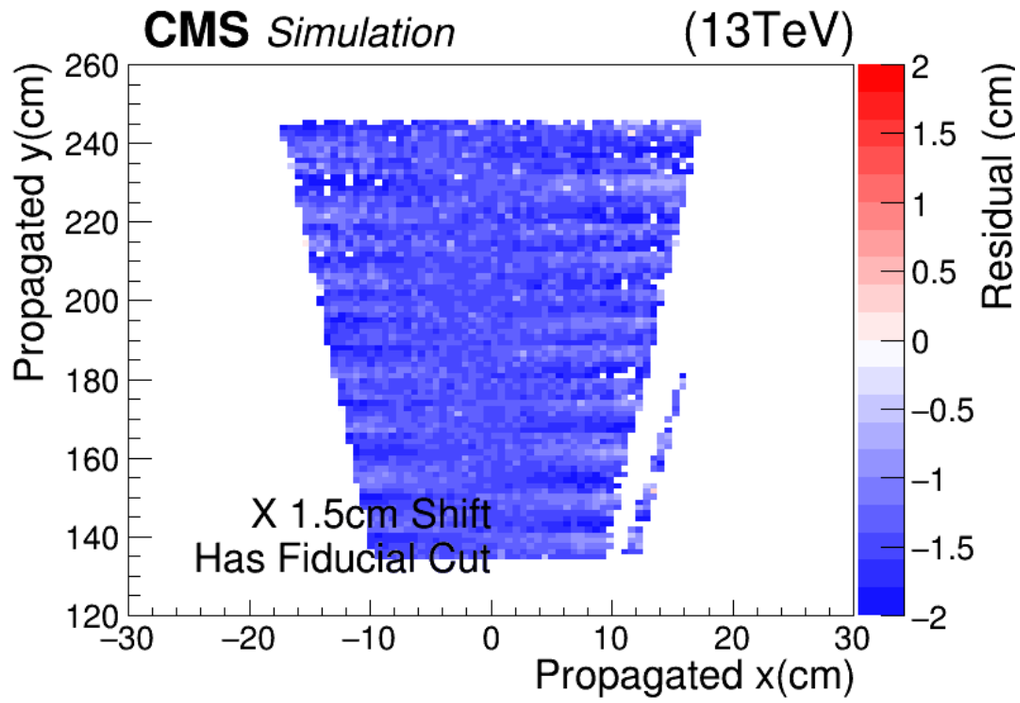

CMS Simulation
(13TeV)
X 1cm Shift
Has Fiducial Cut
Propagated y(cm)
Propagated x(cm)
Residual (cm)

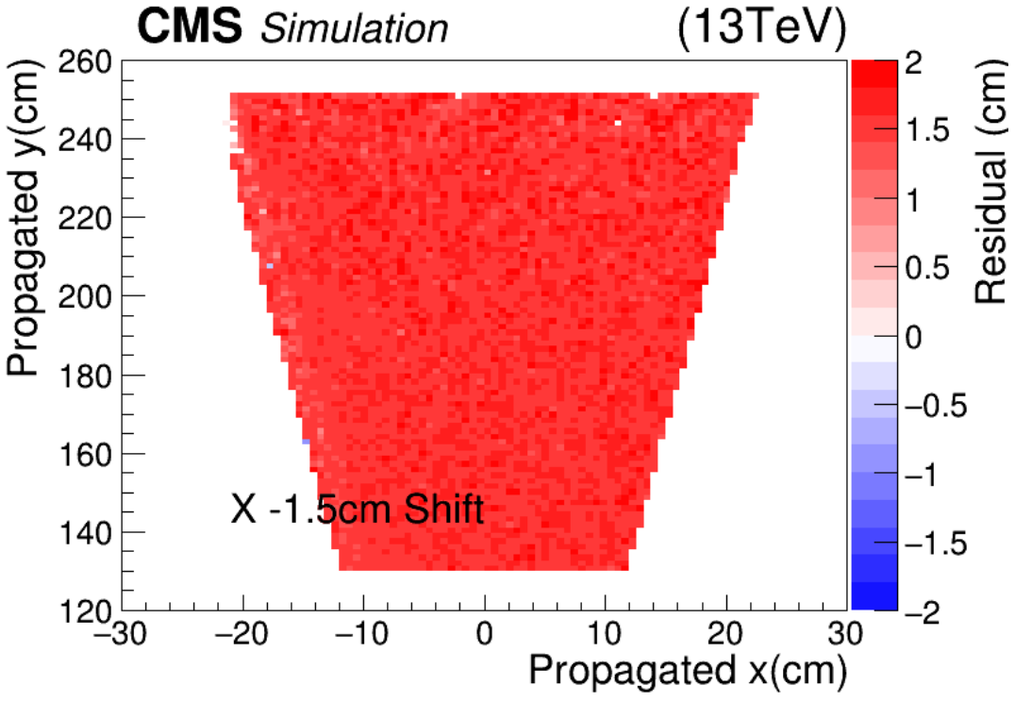

CMS Simulation
(13TeV)
X -1cm Shift
Propagated y(cm)
Propagated x(cm)
Residual (cm)

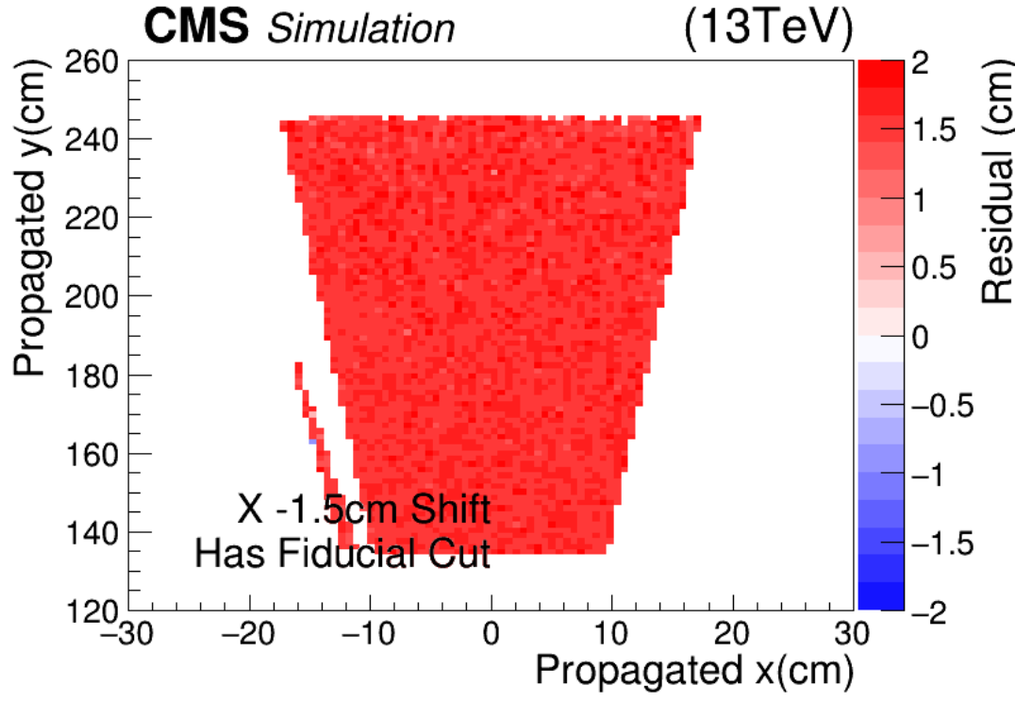

CMS Simulation
(13TeV)
X -1cm Shift
Has Fiducial Cut
Propagated y(cm)
Propagated x(cm)
Residual (cm)

X ± 1.5 cm

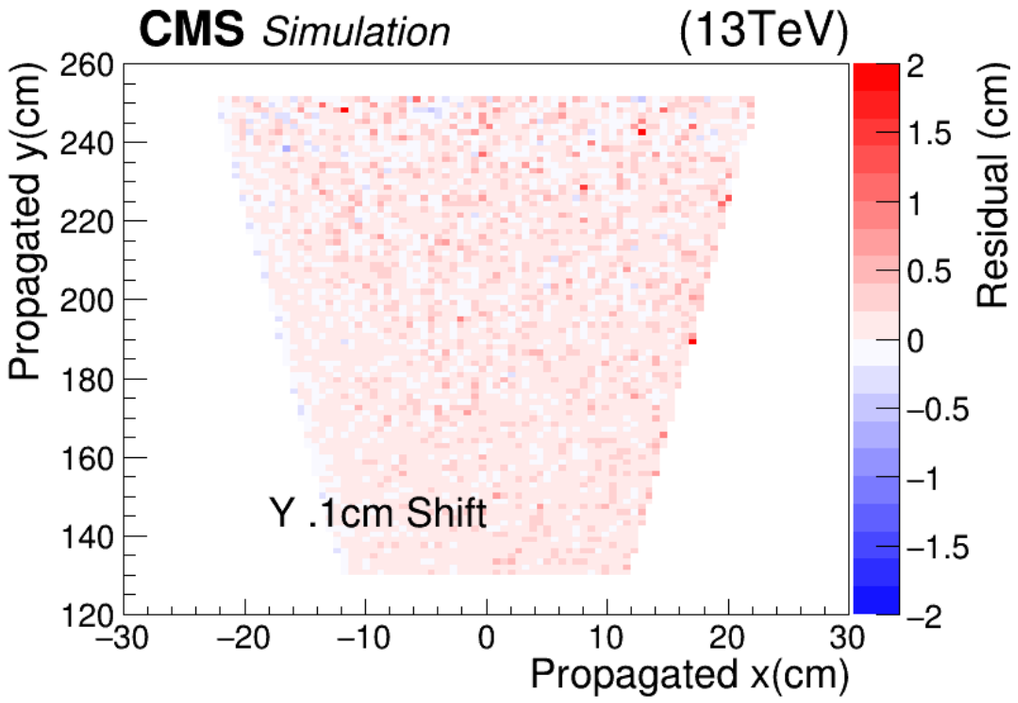

CMS Simulation
(13TeV)
X 1.5cm Shift
Propagated y(cm)
Propagated x(cm)
Residual (cm)

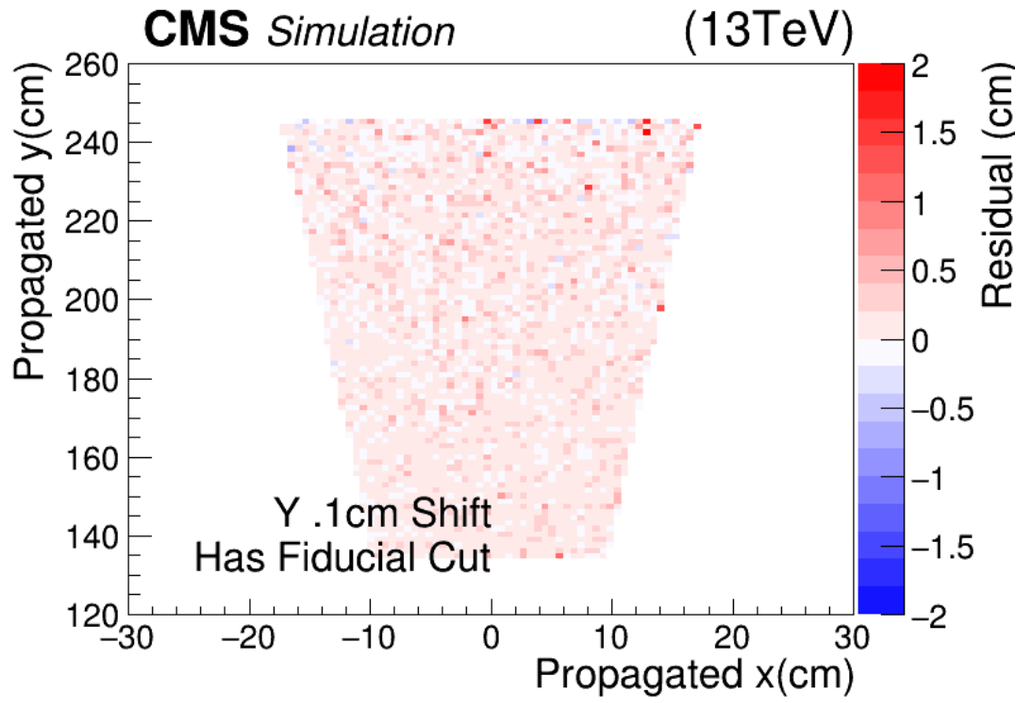

CMS Simulation
(13TeV)
X 1.5cm Shift
Has Fiducial Cut
Propagated y(cm)
Propagated x(cm)
Residual (cm)

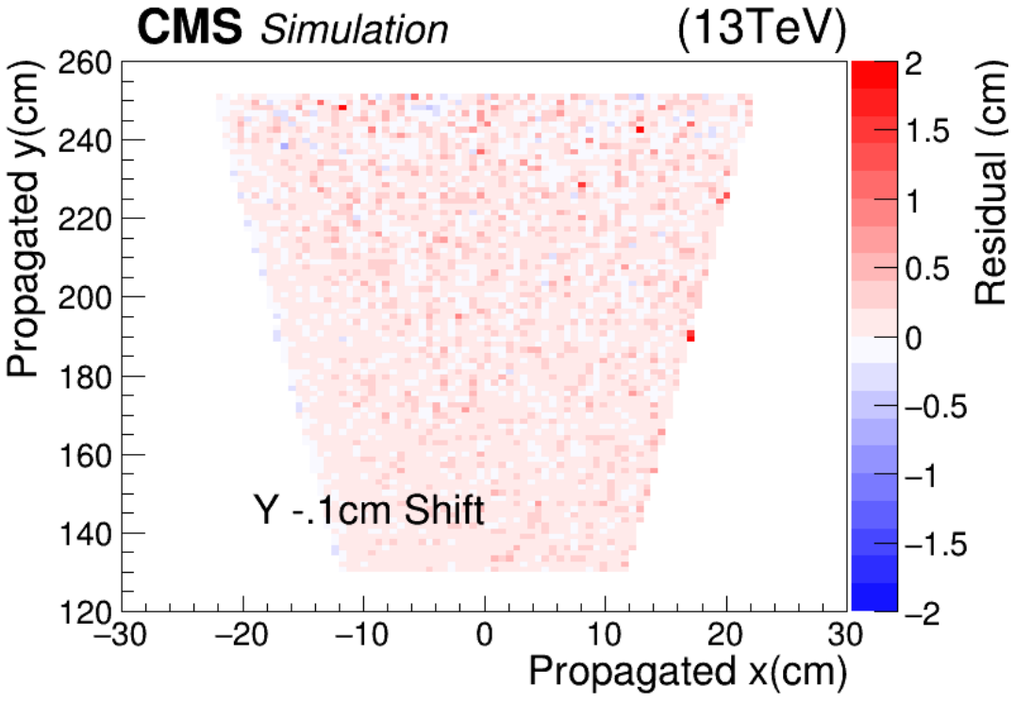

CMS Simulation
(13TeV)
X -1.5cm Shift
Propagated y(cm)
Propagated x(cm)
Residual (cm)

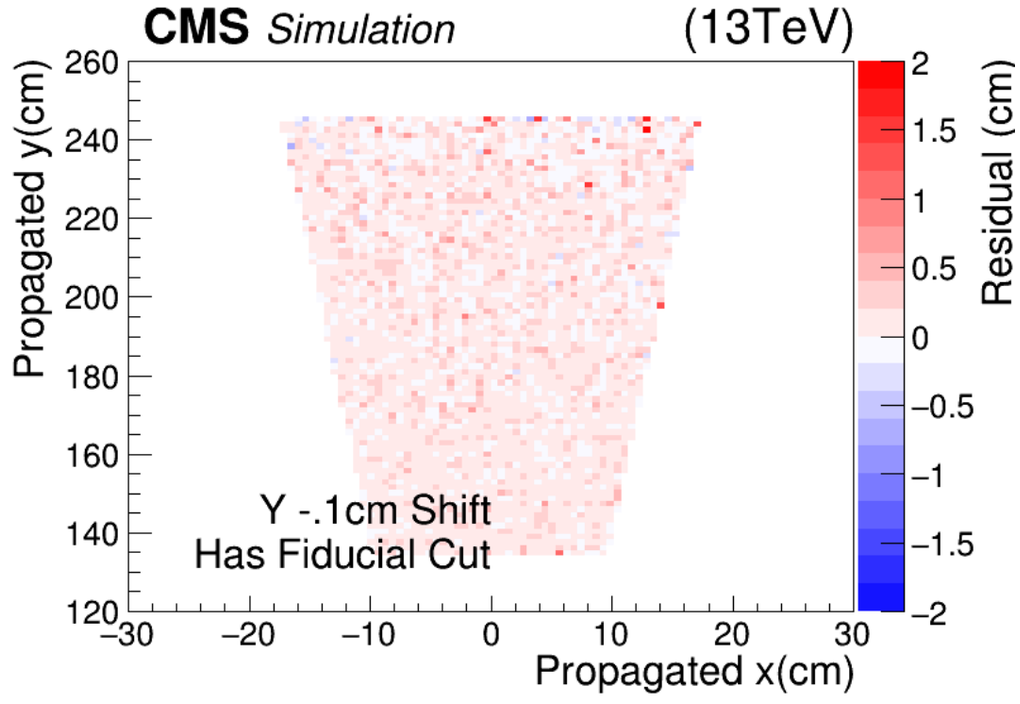

CMS Simulation
(13TeV)
X -1.5cm Shift
Has Fiducial Cut
Propagated y(cm)
Propagated x(cm)
Residual (cm)

Y ± 0.1 cm

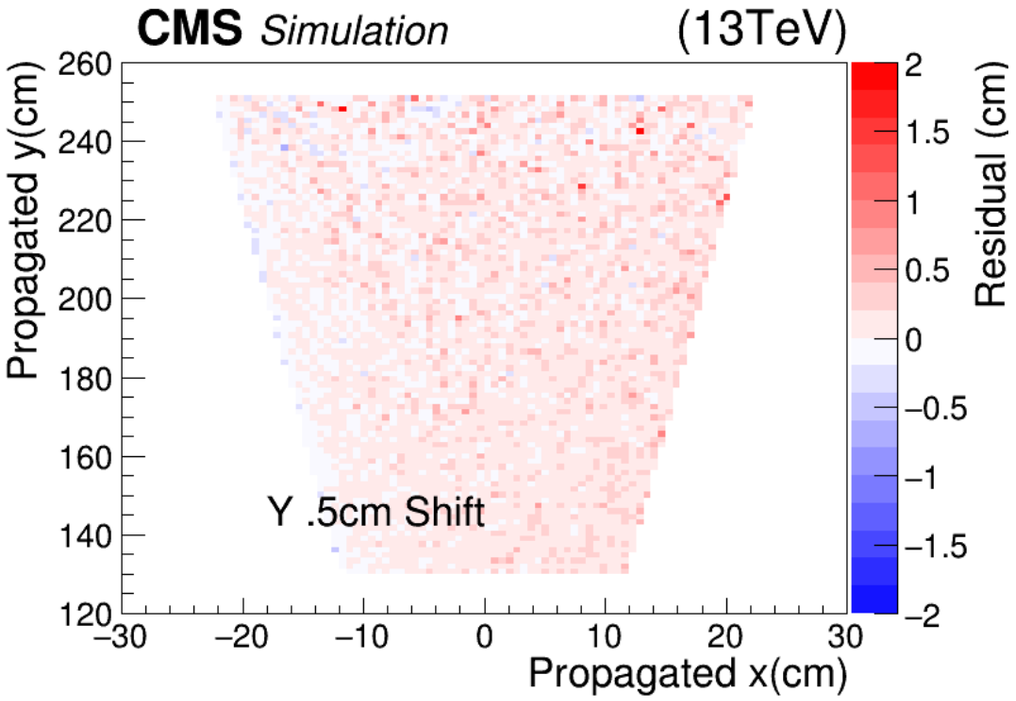

CMS Simulation
(13TeV)
Propagated y(cm)
Propagated x(cm)
Residual (cm)
Y .1cm Shift

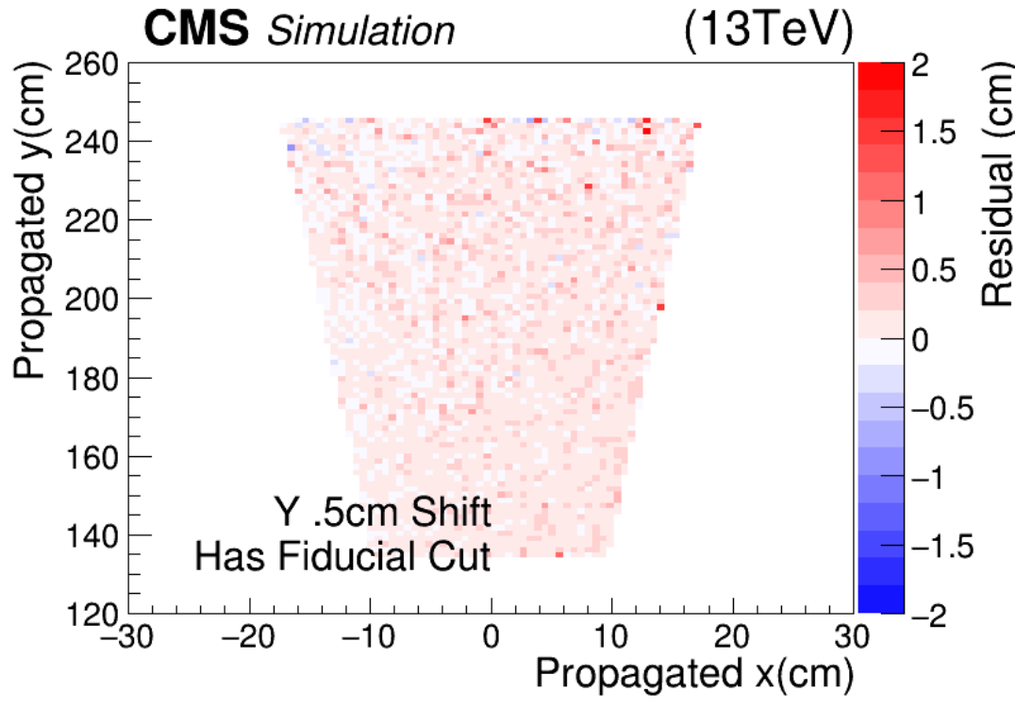

CMS Simulation
(13TeV)
Propagated y(cm)
Propagated x(cm)
Residual (cm)
Y .1cm Shift
Has Fiducial Cut

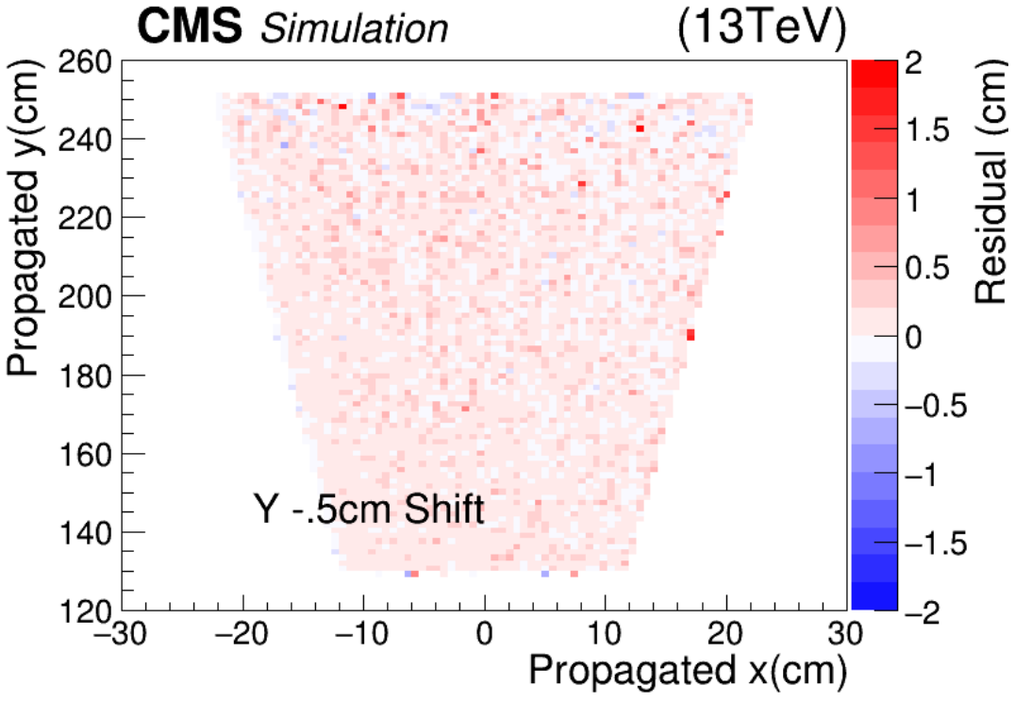

CMS Simulation
(13TeV)
Propagated y(cm)
Propagated x(cm)
Residual (cm)
Y -.1cm Shift

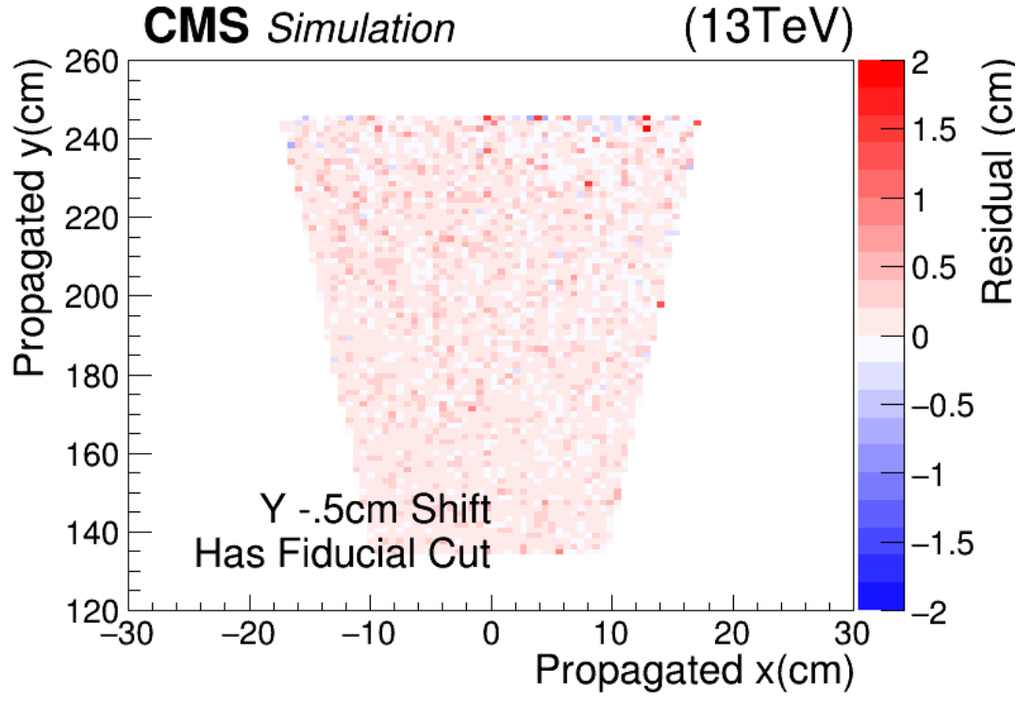

CMS Simulation
(13TeV)
Propagated y(cm)
Propagated x(cm)
Residual (cm)
Y -.1cm Shift
Has Fiducial Cut

Y ± 0.5 cm

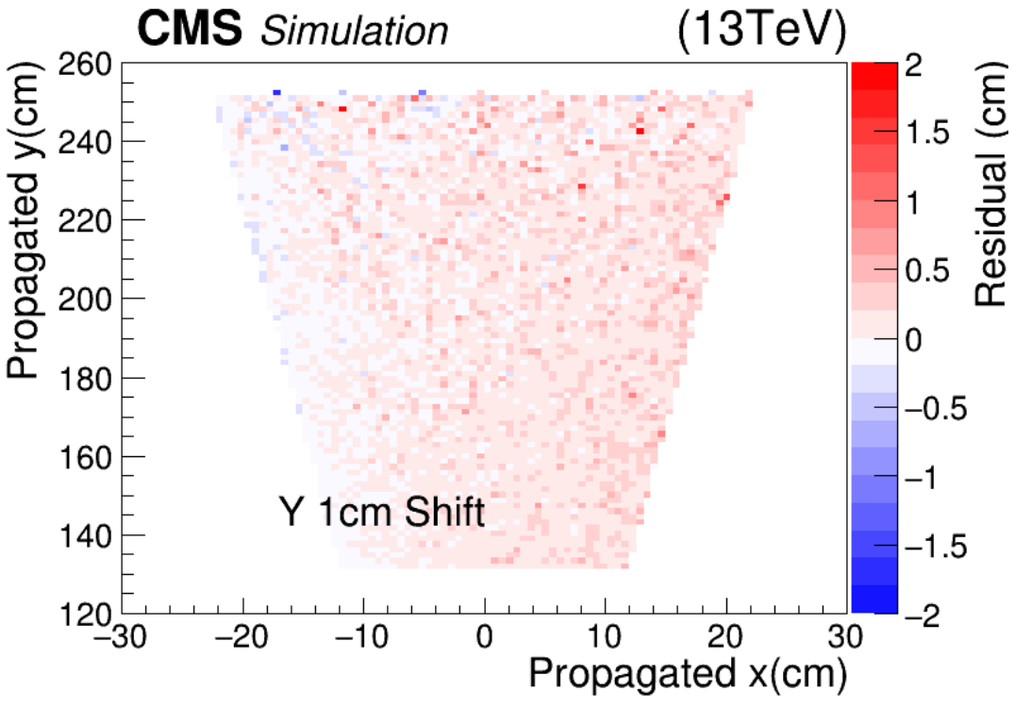

CMS Simulation
(13TeV)
Propagated y(cm)
Propagated x(cm)
Residual (cm)
Y .5cm Shift

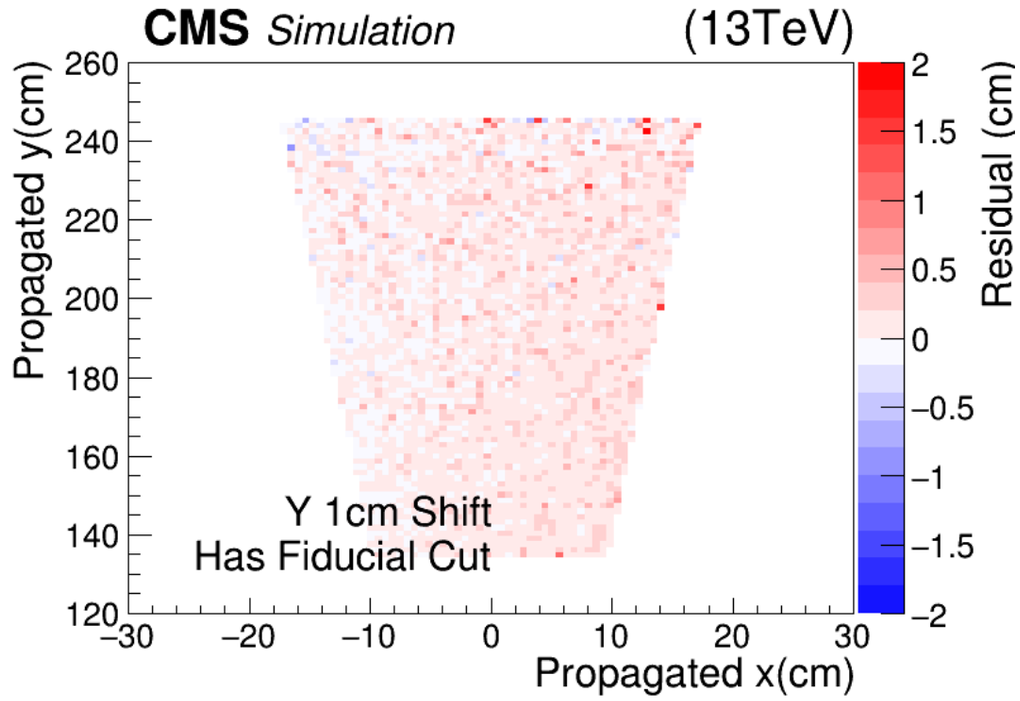

CMS Simulation
(13TeV)
Propagated y(cm)
Propagated x(cm)
Residual (cm)
Y .5cm Shift
Has Fiducial Cut

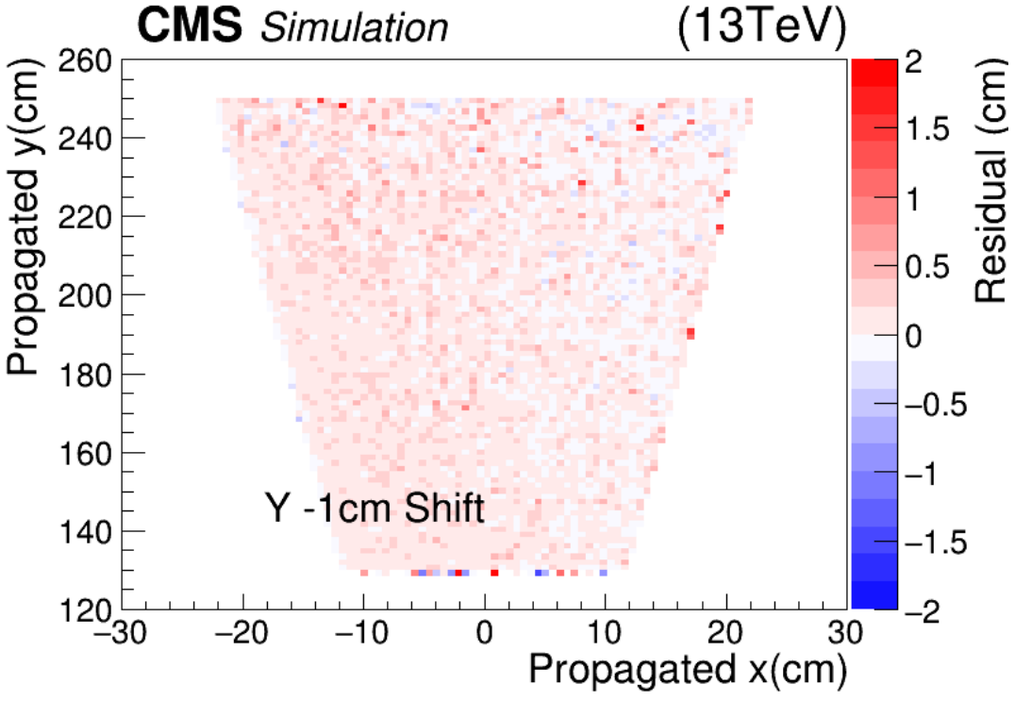

CMS Simulation
(13TeV)
Propagated y(cm)
Propagated x(cm)
Residual (cm)
Y -.5cm Shift

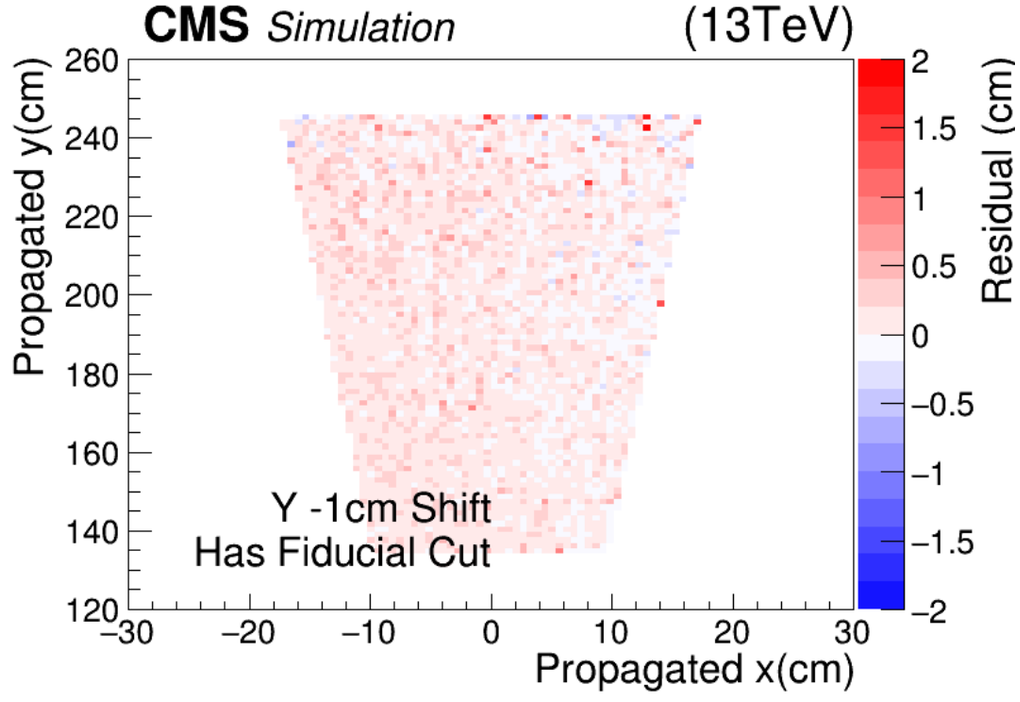

CMS Simulation
(13TeV)
Propagated y(cm)
Propagated x(cm)
Residual (cm)
Y -.5cm Shift
Has Fiducial Cut

Y ± 1.0 cm

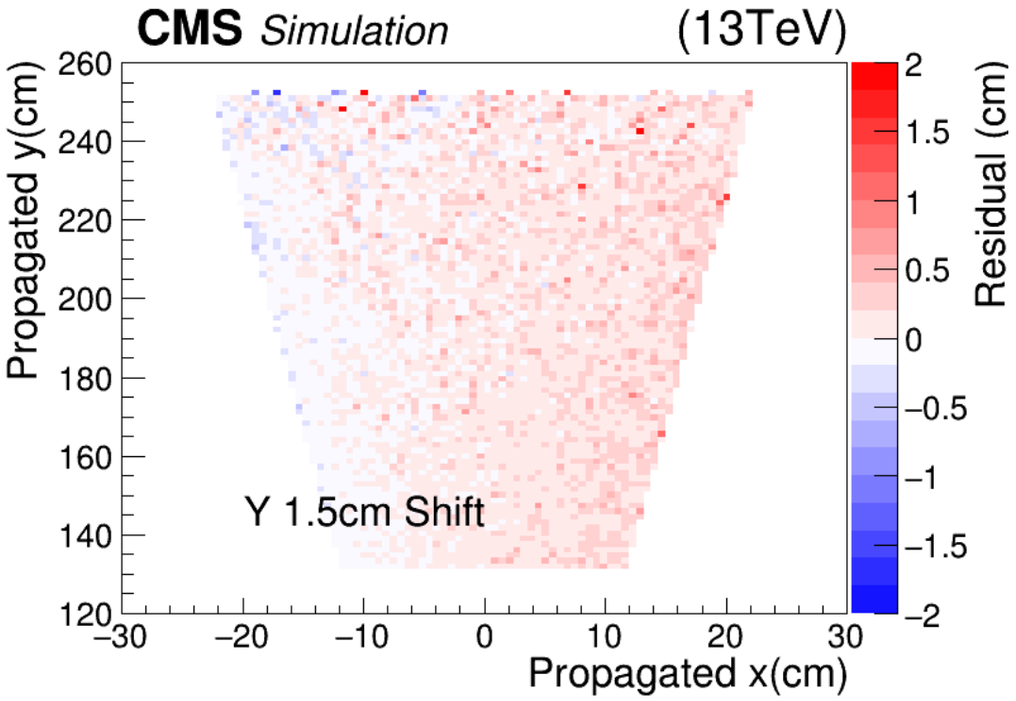

CMS Simulation
(13TeV)
Y 1cm Shift
Propagated y(cm)
Propagated x(cm)
Residual (cm)

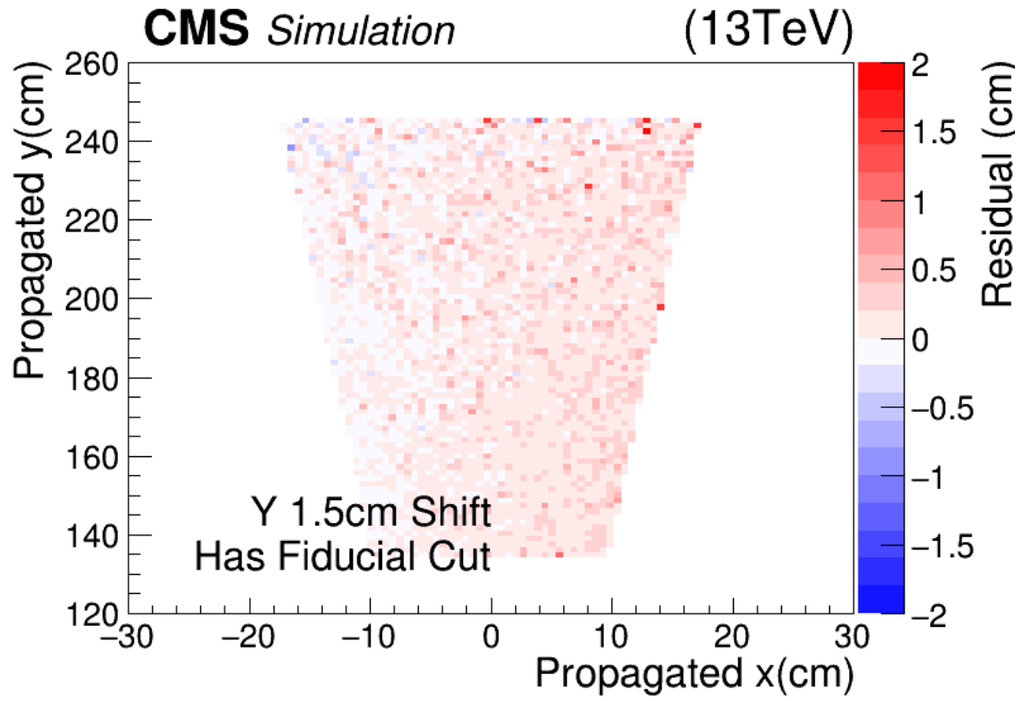

CMS Simulation
(13TeV)
Y 1cm Shift
Has Fiducial Cut
Propagated y(cm)
Propagated x(cm)
Residual (cm)

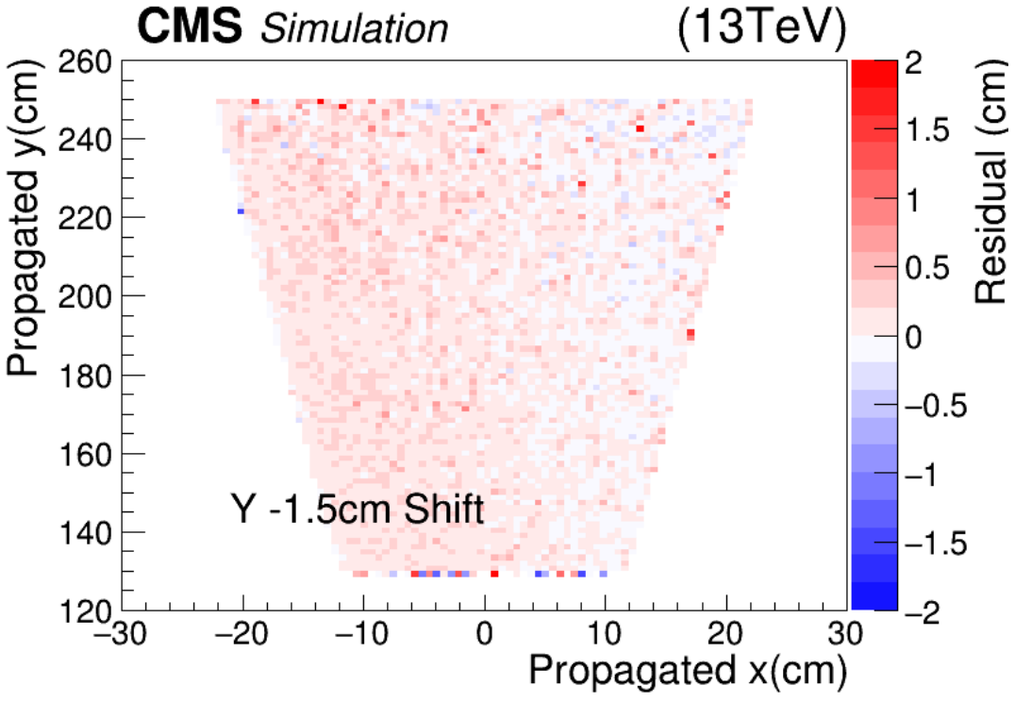

CMS Simulation
(13TeV)
Y -1cm Shift
Propagated y(cm)
Propagated x(cm)
Residual (cm)

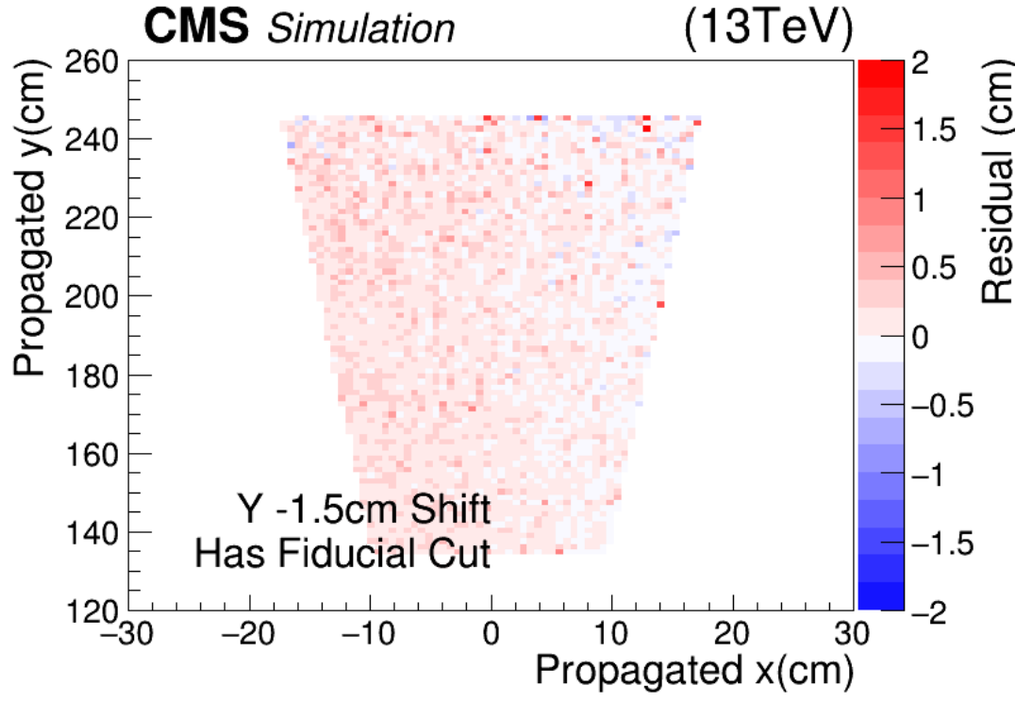

CMS Simulation
(13TeV)
Y -1cm Shift
Has Fiducial Cut
Propagated y(cm)
Propagated x(cm)
Residual (cm)

Y ± 1.5 cm

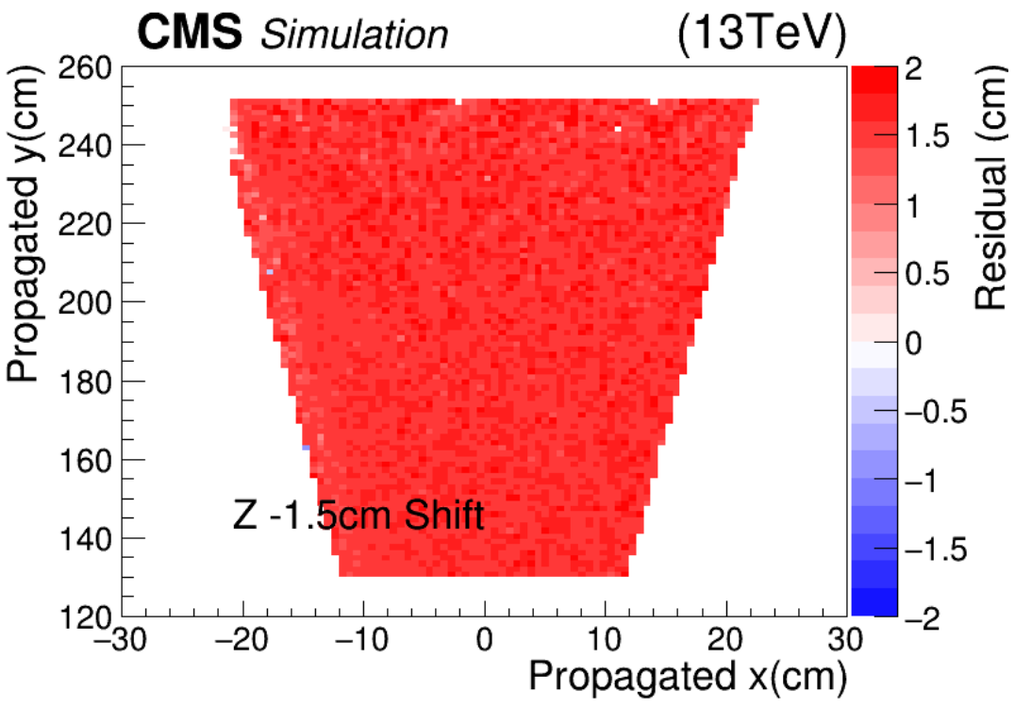

CMS Simulation
(13TeV)
Y 1.5cm Shift
Propagated y(cm)
Propagated x(cm)
Residual (cm)

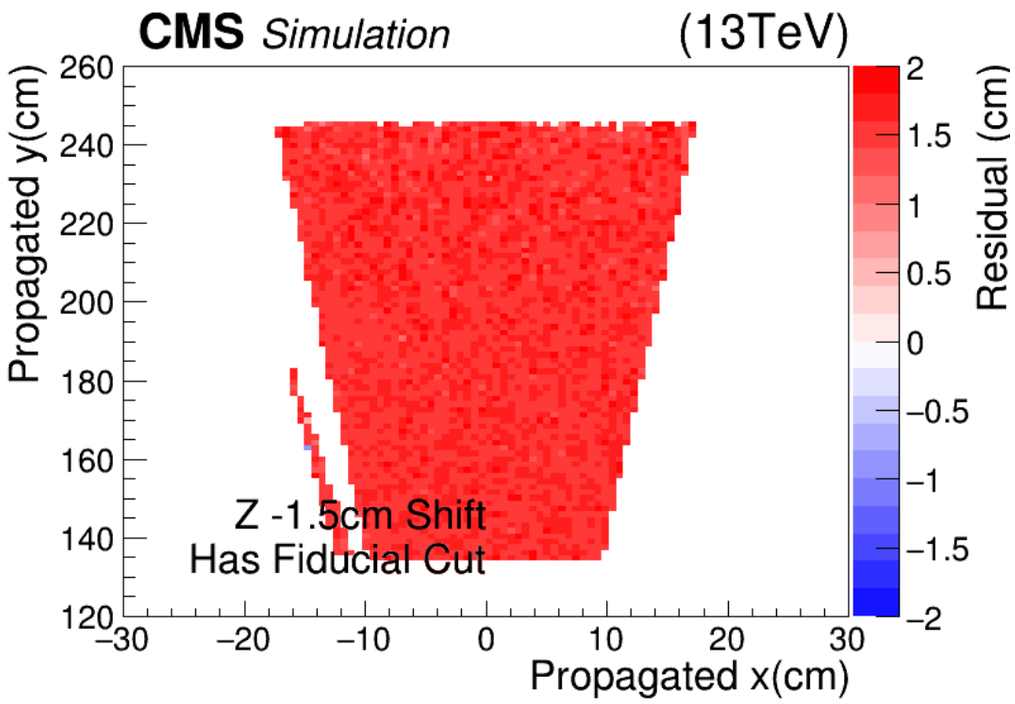

CMS Simulation
(13TeV)
Y 1.5cm Shift
Has Fiducial Cut
Propagated y(cm)
Propagated x(cm)
Residual (cm)


CMS Simulation
(13TeV)
Y -1.5cm Shift
Propagated y(cm)
Propagated x(cm)
Residual (cm)


CMS Simulation
(13TeV)
Y -1.5cm Shift
Has Fiducial Cut
Propagated y(cm)
Propagated x(cm)
Residual (cm)

Z - 1.5 cm


CMS Simulation
(13TeV)
Propagated y(cm)
Propagated x(cm)
Residual (cm)
Z -1.5cm Shift


CMS Simulation
(13TeV)
Propagated y(cm)
Propagated x(cm)
Residual (cm)
Z -1.5cm Shift
Has Fiducial Cut