

# Status of Deconvolution for MCS

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# Status of Simulation and Analysis

- Simulations of Xe Data and LiH 200 MeV/c and 240 MeV/c Data available
- 172 MeV/c G4BL set is only recently available

## Analysis and Simulation of Xe Data

- Standard data analysis used (MAUS v2.0.0)
- Simulation conducted with an altered version of MAUS v2.1.0
  - Geometry downloaded to match run 7548
  - Download altered to ensure consistency between data and reconstruction.

## Analysis and Simulation of LiH Data

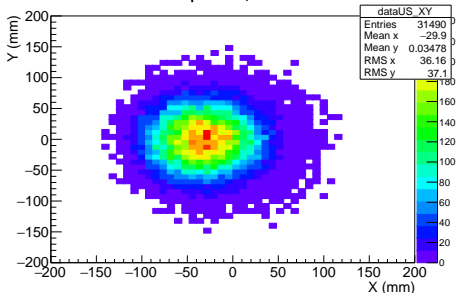
- Standard data analysis used (MAUS v2.1.0)
- Simulation conducted with an altered version of MAUS v2.1.0
  - Used geometry preprod ID 759
  - Needs to be regenerated with official geometry and MAUS release.

## Simple Event selection criteria for existing data

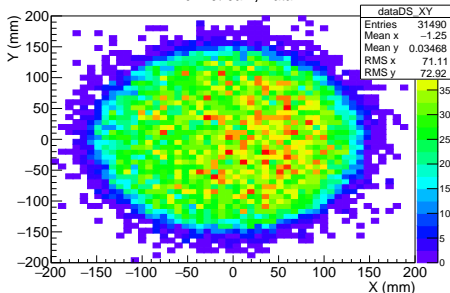
Selection	Description
TOF2 trigger	At least two raw TOF slab hits exist and at least one in each TOF plane.
TOF timing selection	Select muons from run: $TOF0 \rightarrow 1 \in \{27, 29\}$ ns for 240 MeV/c pion beams; $TOF0 \rightarrow 1 \in \{26.5, 42\}$ ns for muon beams.
Upstream, Downstream matching.	There is a track in both the upstream and downstream tracker.
Fiducial selection	For upstream tracks $\sqrt{x^2 + y^2} < 150$ mm, $\sqrt{x'^2 + y'^2} < 0.035$

# Beam Spot at Tracker for 240 MeV Pion Beam

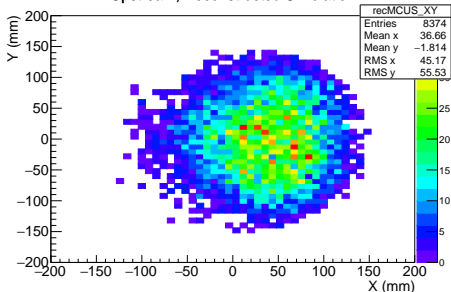
Upstream, Data



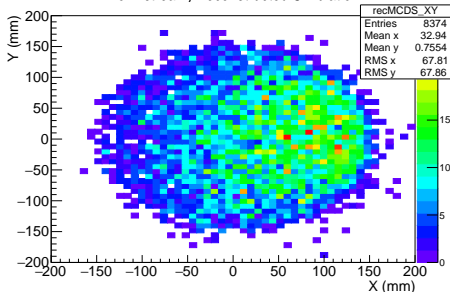
Downstream, Data



Upstream, Reconstructed Simulation

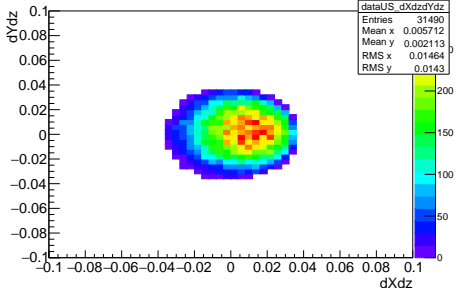


Downstream, Reconstructed Simulation

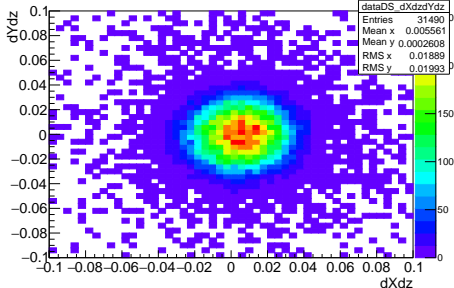


# Beam Spot at Tracker for 240 MeV Pion Beam

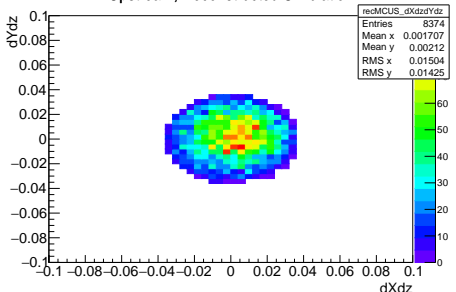
Upstream, Data



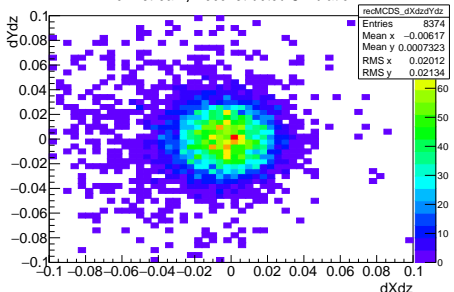
Downstream, Data



Upstream, Reconstructed Simulation

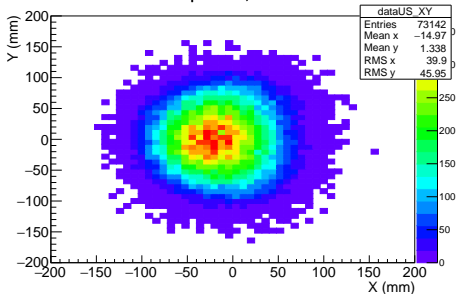


Downstream, Reconstructed Simulation

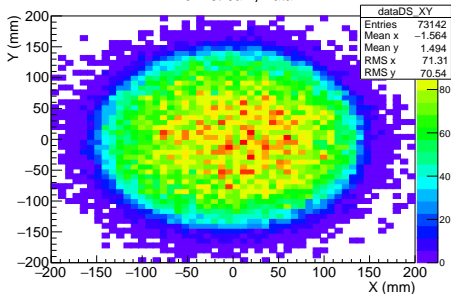


# Beam Spot at Tracker for 200 MeV Muon Beam

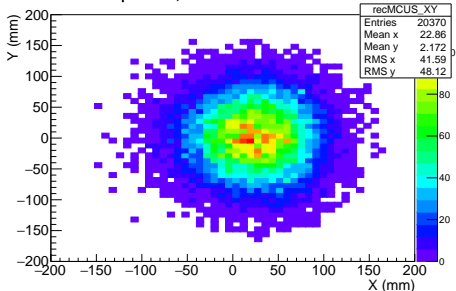
Upstream, Data



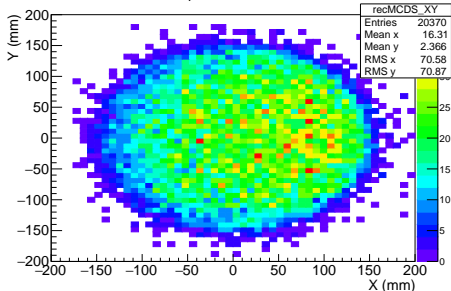
Downstream, Data



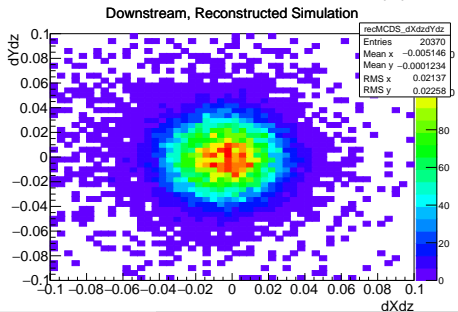
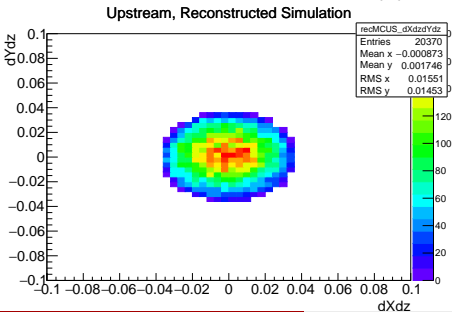
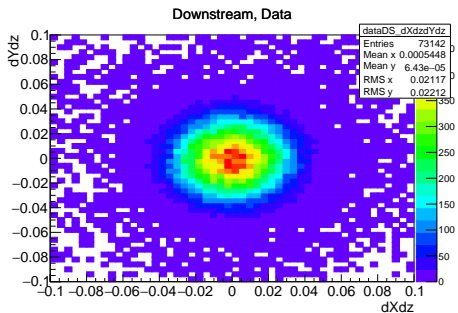
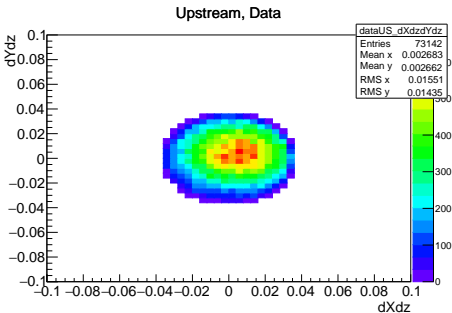
Upstream, Reconstructed Simulation



Downstream, Reconstructed Simulation

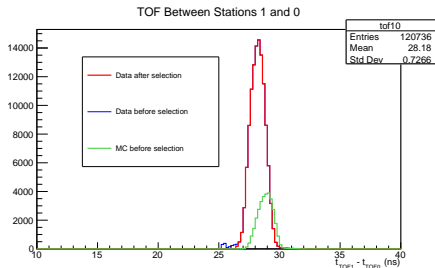


# Beam Spot at Tracker for 200 MeV Muon Beam

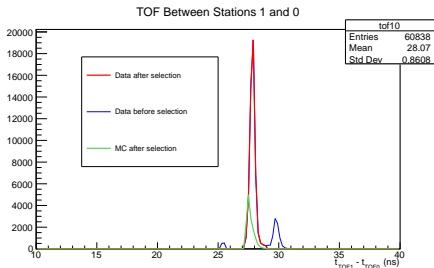


# Momentum Difference Between Data and Simulation

## 200 MeV/c Muon Beam



## 240 MeV/c Pion Beam

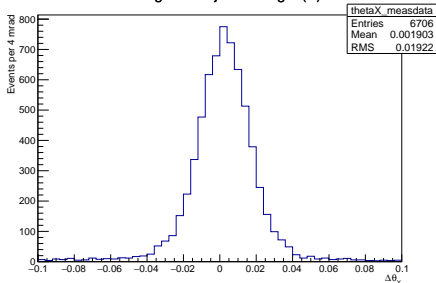


- Momenta of simulated G4Beamline files do not match muon beam data
  - ▶ Known issue that is being corrected.

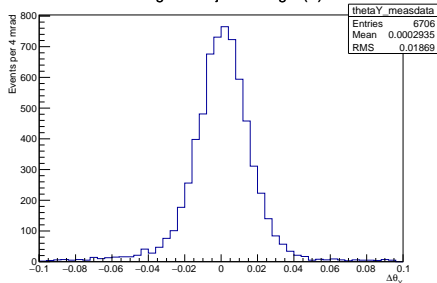


# Raw Scattering Distributions: He Filled Absorber

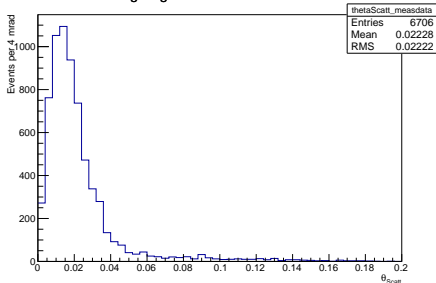
### Change in Projected Angle (X)



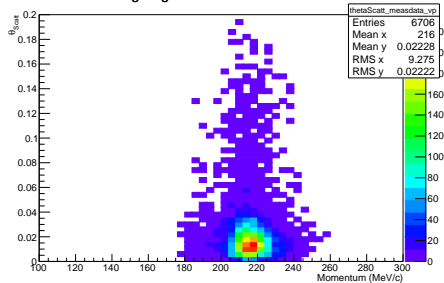
### Change in Projected Angle (Y)



### Scattering Angle between Momentum Vectors

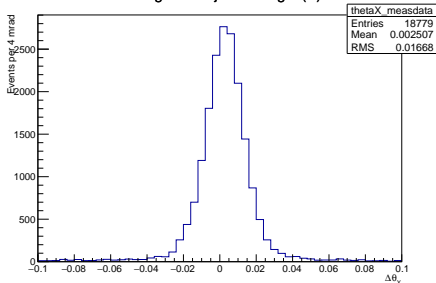


### Scattering Angle between Momentum Vectors

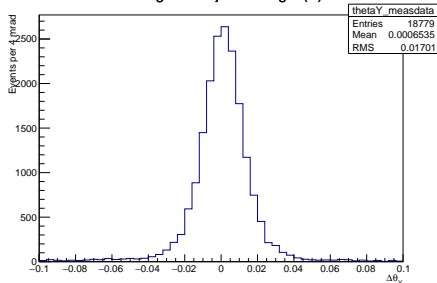


# Raw Scattering Distributions: Empty 200 MeV/c $\mu^+$ Beam

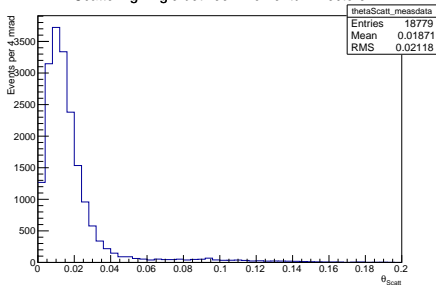
### Change in Projected Angle (X)



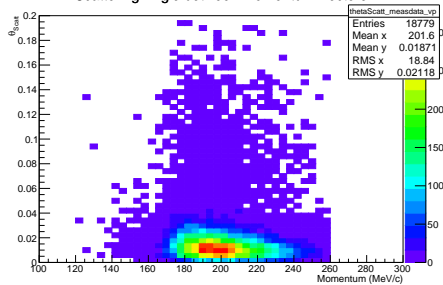
### Change in Projected Angle (Y)



### Scattering Angle between Momentum Vectors

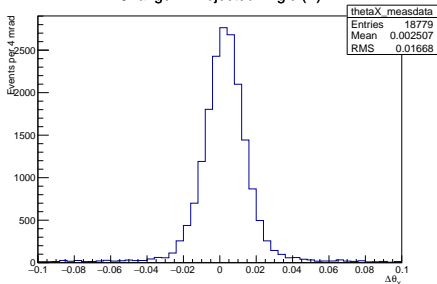


### Scattering Angle between Momentum Vectors

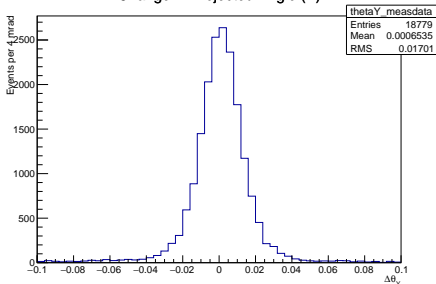


# Raw Scattering Distributions: LiH 172 MeV/c $\mu^+$ Beam

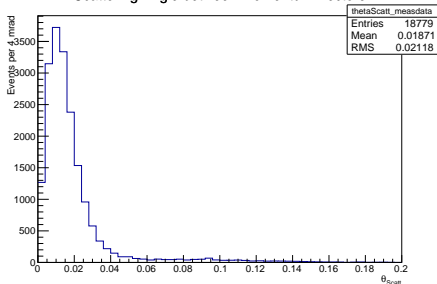
### Change in Projected Angle (X)



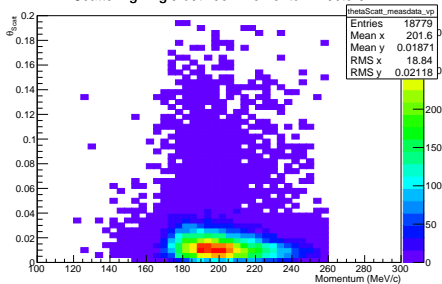
### Change in Projected Angle (Y)



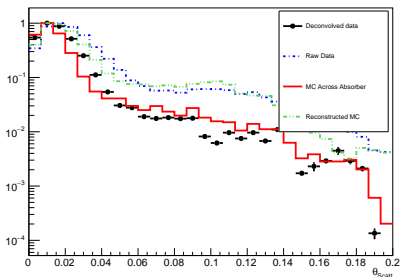
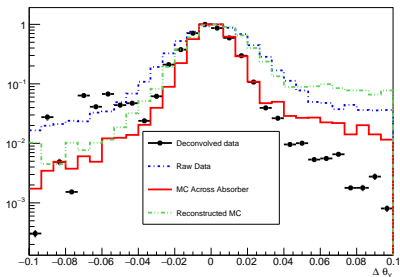
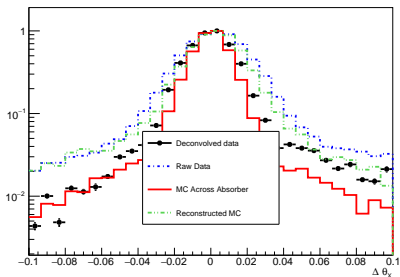
### Scattering Angle between Momentum Vectors



### Scattering Angle between Momentum Vectors

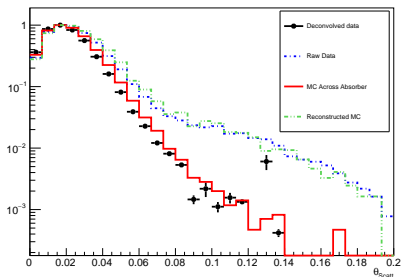
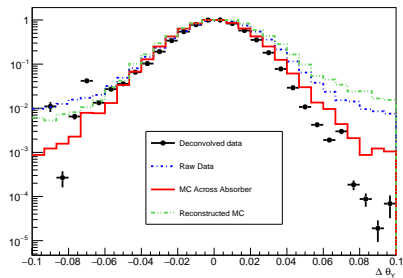
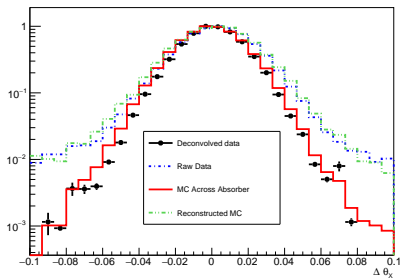


# Deconvolution Applied to Xenon Data



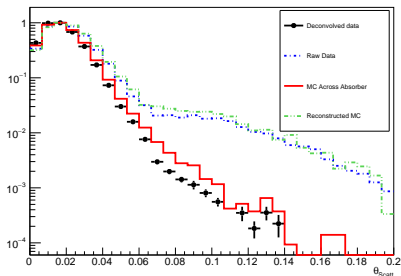
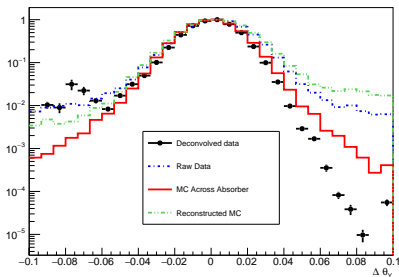
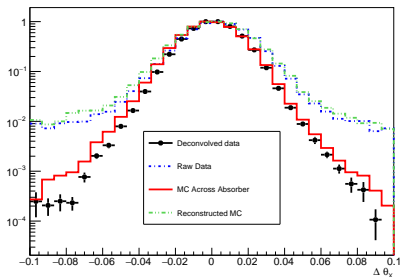
- Expect data and simulation to produce similar widths
- There is a clear problem in  $\theta_Y$ 
  - ▶ Suspected to be due to geometry related issues
  - ▶ Quad positions and tracker rotations.
- $\theta_X$  appears better behaved.

# Deconvolution Applied to LiH 200 MeV/c Data



● Definite bias in negative tails.

# Deconvolution Applied to LiH 240 MeV/c Data



- Definite bias in negative tails.
- $\theta_X$  looks reasonable;  $\theta_Y$  does not.
  - ▶ could be a bias in the beam position.
  - ▶ could be a problem with the tracker angle  $\theta_Y$ .
  - ▶ Both problems exist in this simulation.

## Summary of Widths (So Far)

Assuming that the biases do not affect the widths ...

Parameter	240 MeV/c Xe (mrad)	200 MeV/c LiH (mrad)	240 MeV/c LiH (mrad)
$\theta_X^{RMS}$ Deconvolved	$21.84 \pm 0.09$	$17.71 \pm 0.05$	$14.91 \pm 0.04$
$\theta_X^{RMS}$ MC Truth	$19.2 \pm 0.2$	$18.8 \pm 0.1$	$15.89 \pm 0.06$
$\theta_X^{RMS}$ Raw Data	$26.5 \pm 0.1$	$22.92 \pm 0.08$	$20.51 \pm 0.09$
$\theta_X^{RMS}$ Recon. MC	$25.35 \pm 0.24$	$23.68 \pm 0.17$	$21.39 \pm 0.01$
$\theta_Y^{RMS}$ Deconvolved	$20.21 \pm 0.09$	$18.99 \pm 0.05$	$17.53 \pm 0.05$
$\theta_Y^{RMS}$ MC Truth	$19.38 \pm 0.16$	$19.02 \pm 0.10$	$15.93 \pm 0.05$
$\theta_Y^{RMS}$ Raw Data	$26.43 \pm 0.13$	$22.92 \pm 0.08$	$20.40 \pm 0.09$
$\theta_Y^{RMS}$ Recon. MC	$27.36 \pm 0.26$	$23.82 \pm 0.17$	$21.50 \pm 0.10$

- This is only a subset of the available statistics.
- Not certain how to treat the deconvolved uncertainties
  - ▶ Used  $RMS/\sqrt{N}$  for uncertainty.
  - ▶ Not sure that this is the correct factor after deconvolution.

# Systematic Calculations

## PDG Scattering and uncertainties at 200 MeV

Material	$z/X_0$	$\theta_0$ (mrad)	$\frac{d\theta_0}{dp} \sigma_p$ (mrad)	$\frac{d\theta_0}{dX_0} \sigma_{X_0}$ (mrad)	$\frac{d\theta_0}{dz} \sigma_z$ (mrad)
LiH	0.064	19.3	0.021	0.021	0.193
Tracker He	0.00015	0.91	$9.9 \times 10^{-4}$	$1.3 \times 10^{-7}$	0.009
Al Window	0.00179	22.0	0.003	0.039	0.032
Scint. Fibres	0.0175	10.0	0.011	0.026	0.101

- Material specifications taken from geometry and supporting materials (when available)
- $\theta_0$  calculated using full formula (with log term)
- Errors assume analytic derivative of formula and guesses of the source uncertainties
  - ▶ 5 MeV/c uncertainty in the momentum from the TOFs based on presentation by Mark Rayner
  - ▶ Arbitrary 11% uncertainty in  $X_0$  from the PDG
  - ▶ Equally arbitrary 1% in the material thicknesses.
- Really should evaluate these systematics in simulation.



# Sum of Systematic Uncertainties at 3 Momenta

## Fractional Uncertainties

Source Effect	172 MeV/c	200 MeV/c	240 MeV/c
p smearing (5 MeV/c)	0.0073	0.0050	0.0031
$X_0$ (0.11 mm)	0.0015	0.0015	0.0015
Z (1%)	0.0034	0.0034	0.0034
$\pi$ Contamination (3%)	$2.4 \times 10^{-6}$	$1.96 \times 10^{-6}$	$1.46 \times 10^{-6}$
Quadratic Sum	0.0082	0.0062	0.0049
$1/(\sum \sigma_j)^2$	14921	25712	42384

- Presents the limit beyond which we receive diminishing returns
  - ▶ Would like the statistical uncertainty to be 30% of above numbers (factor of 9 increase).