# Validating the Simulation and Response Function in TWIST

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for the TWIST Collaboration

- Overview of TWIST's simulation verification needs and methods.
- Downstream Materials study.
- Energy loss validation.
- Multiple scattering validation.
- Conclusion.

# TWIST Analysis

- Muon decay parameters will be measured by comparing data to reconstructed simulation (presently GEANT3).
  - Simulation output will be reconstructed with the same software used to analyze data.
- We need to know that our simulation is not introducing biases that can affect the measurements of the muon decay parameters.
  - Need to test the simulation independently of decay parameters.

# Verification Scheme

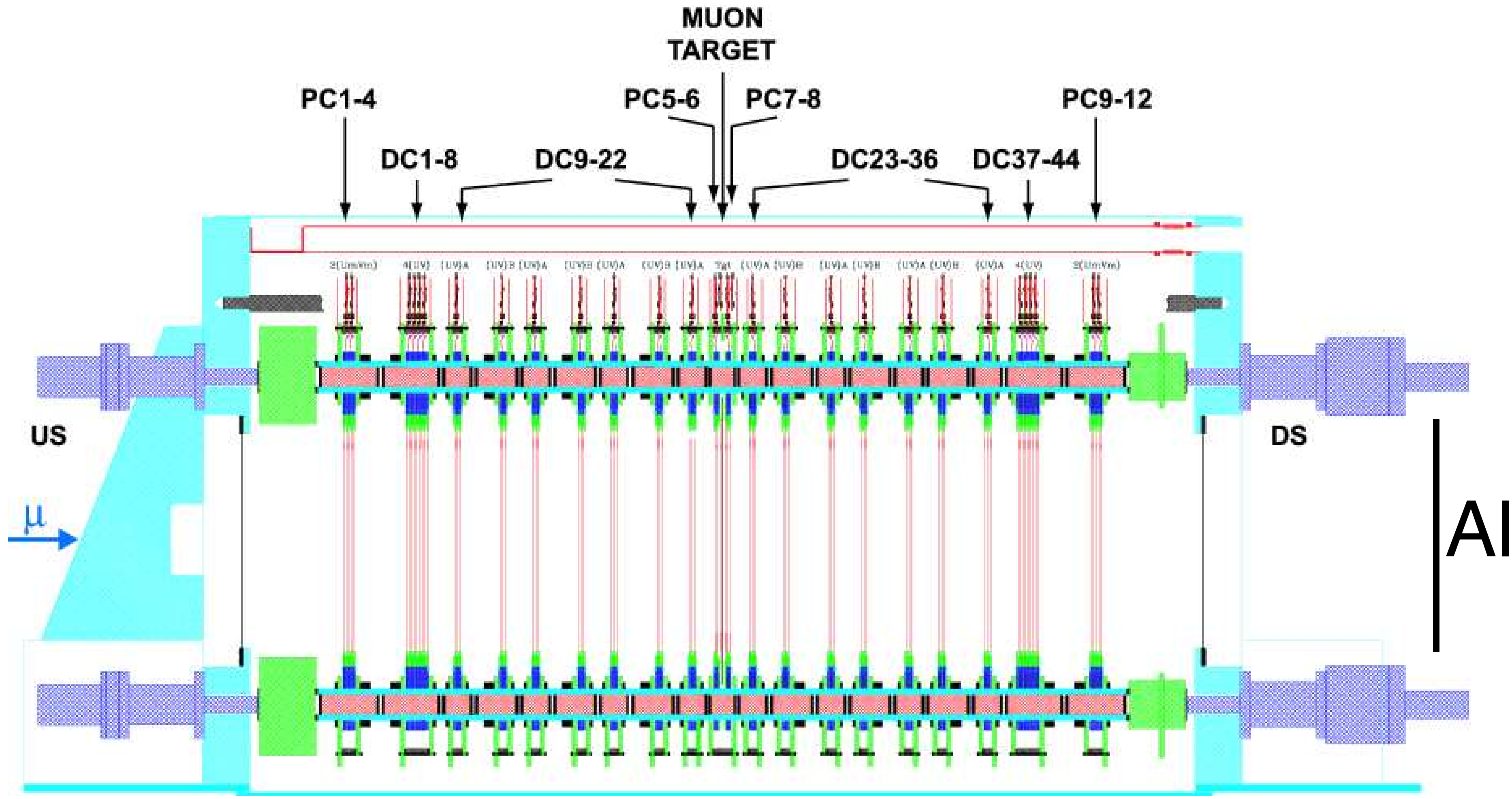
- Take data under special conditions.
- Run Monte Carlo with the same conditions.
- Analyze both with the same analysis software.
- Check that the effects of the changed conditions appear the same in data and MC.
- Determine how well we need the simulation to reproduce the data.
  - Usually by comparing relative Michel Fit results.

# Verification Studies

- Studies include:
  - Material outside the detector
  - $p_{max}$ vs angle
  - $chi^2$ and confidence level distributions
  - hits per plane
  - muon stopping distribution
  - delta production cross-section
  - energy loss
  - multiple scattering
  - ...and more...

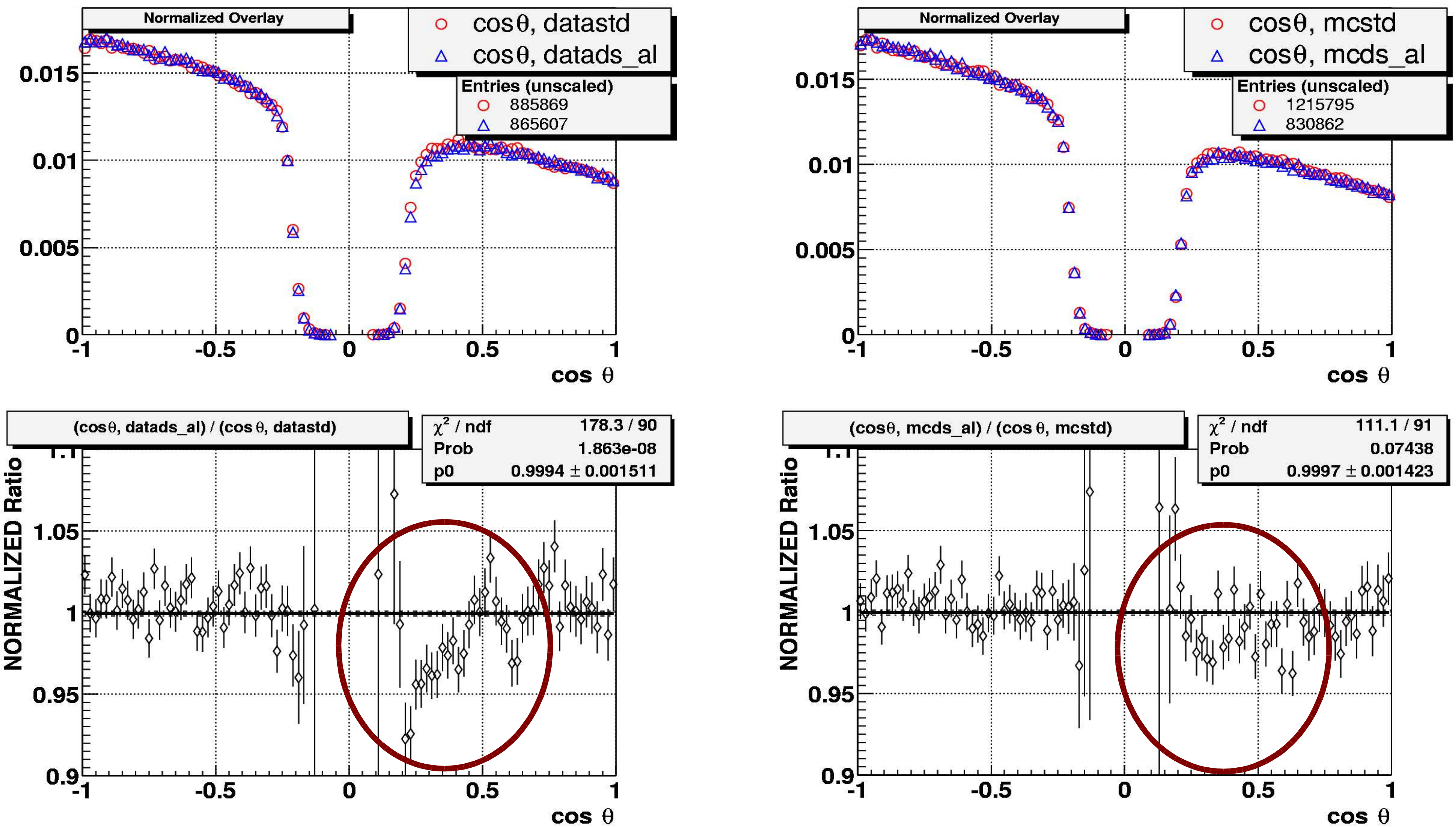
# Downstream Materials Study

- Test of response function's sensitivity to material outside the detector.
- Measure how Geant reacts to a plate of material placed downstream; compare with data.
- Use results to estimate sensitivity to other material, e.g. the upstream beam package.


MUON
TARGET
PC1-4
PC5-6
PC7-8
PC9-12
DC1-8
DC9-22
DC23-36
DC37-44
US
DS
μ
Al

# Effect of Downstream Aluminum

Data | Geant



# DS Aluminum and Michel Fits

Michel Fit Results ($\times 10^{-3}$):

| | d(rho) | d(eta) | d(xi) | d(delta) |
|---|---|---|---|---|
| MC to MC: | -2.3±2.0 | -0.15±0.11 | 3.5±2.7 | -5.0±1.4 |
| Data to Data: | -10.2±3.2 | -0.64±0.18 | -10.4±4.1 | -5.3±2.3 |
| Difference: | 8±4 | 0.5±0.2 | 14±5 | 0.3±2.7 |
| Std. Devs: | 2 | 2.3 | 2.8 | 0.1 |

- DS Aluminum plate does affect fitted Michel parameters.
- Effect is different between data and Geant.
  - Must reduce discrepancy as much as possible.
  - Estimate how this corresponds to US material discrepancy (i.e. systematic).

# DS Al and Delta Particles

- Analysis code identified more "delta" particles per event when cross-section was doubled.

- Fraction of events with identified "deltas":

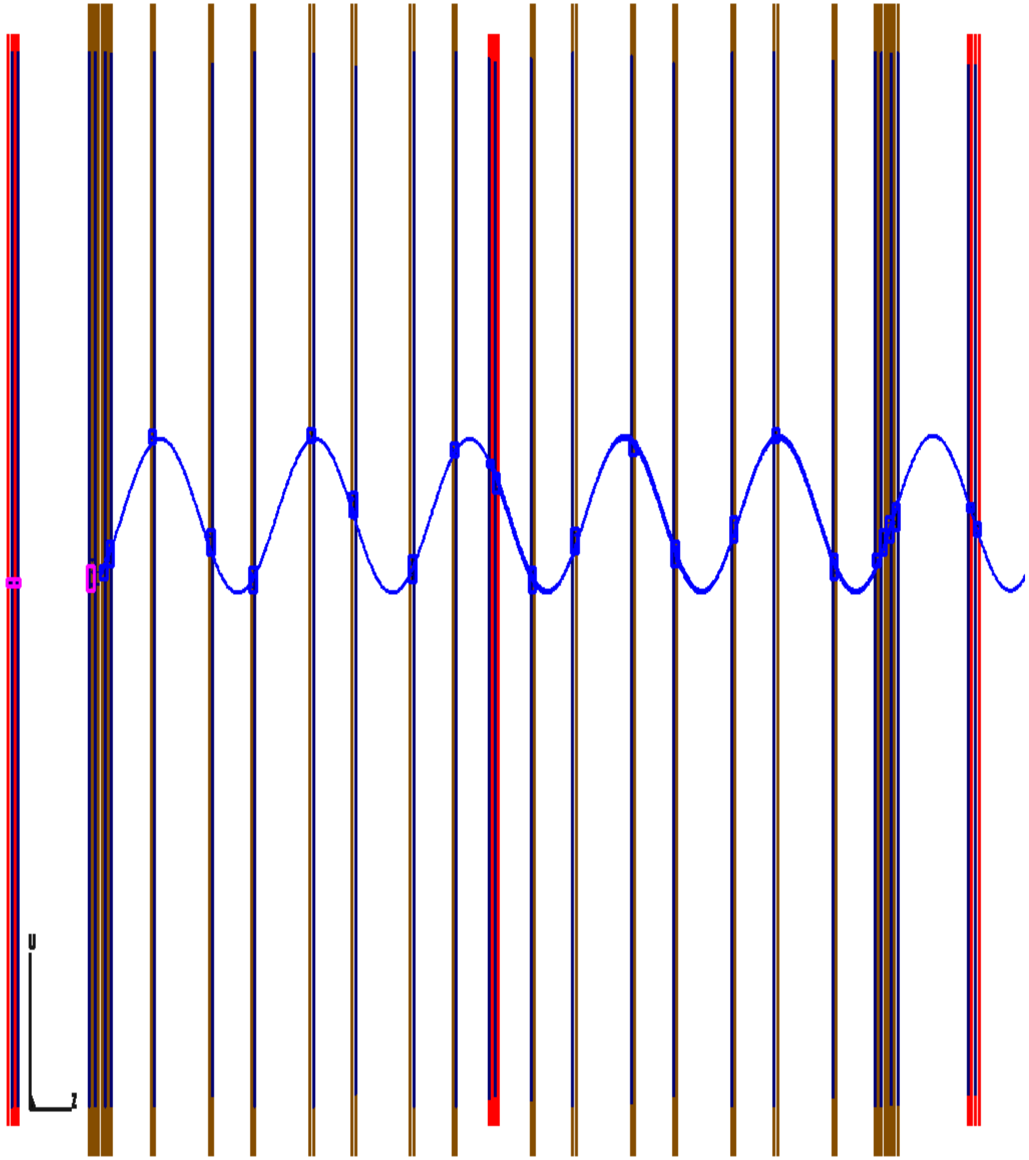
| | Std | DS Al |
|---|---|---|
| Geant, Standard: | 4.1% | 4.5% |
| Geant, 2xDeltas: | 6.8% | 7.4% |
| Data: | 3.9% | 4.3% |

- Simulation produces (roughly) the same rate of delta particles as seen in data.

- "Downstream Aluminum Discrepancy" not due to mis-simulation of delta particles.

# Detector-Spanning Positrons

- Stop muons in Dense Stack.
- Measure positron track in each detector half.
- Determine Response Function.



# Double Gaussian fits

- Fit function:

$$N_1\left[\exp\left(-\left(\frac{x-\mu}{2\sigma_1}\right)^2\right)+\left(\frac{N_2}{N_1}\right)\exp\left(-\left(\frac{x-\mu}{2\sigma_2}\right)^2\right)\right]$$

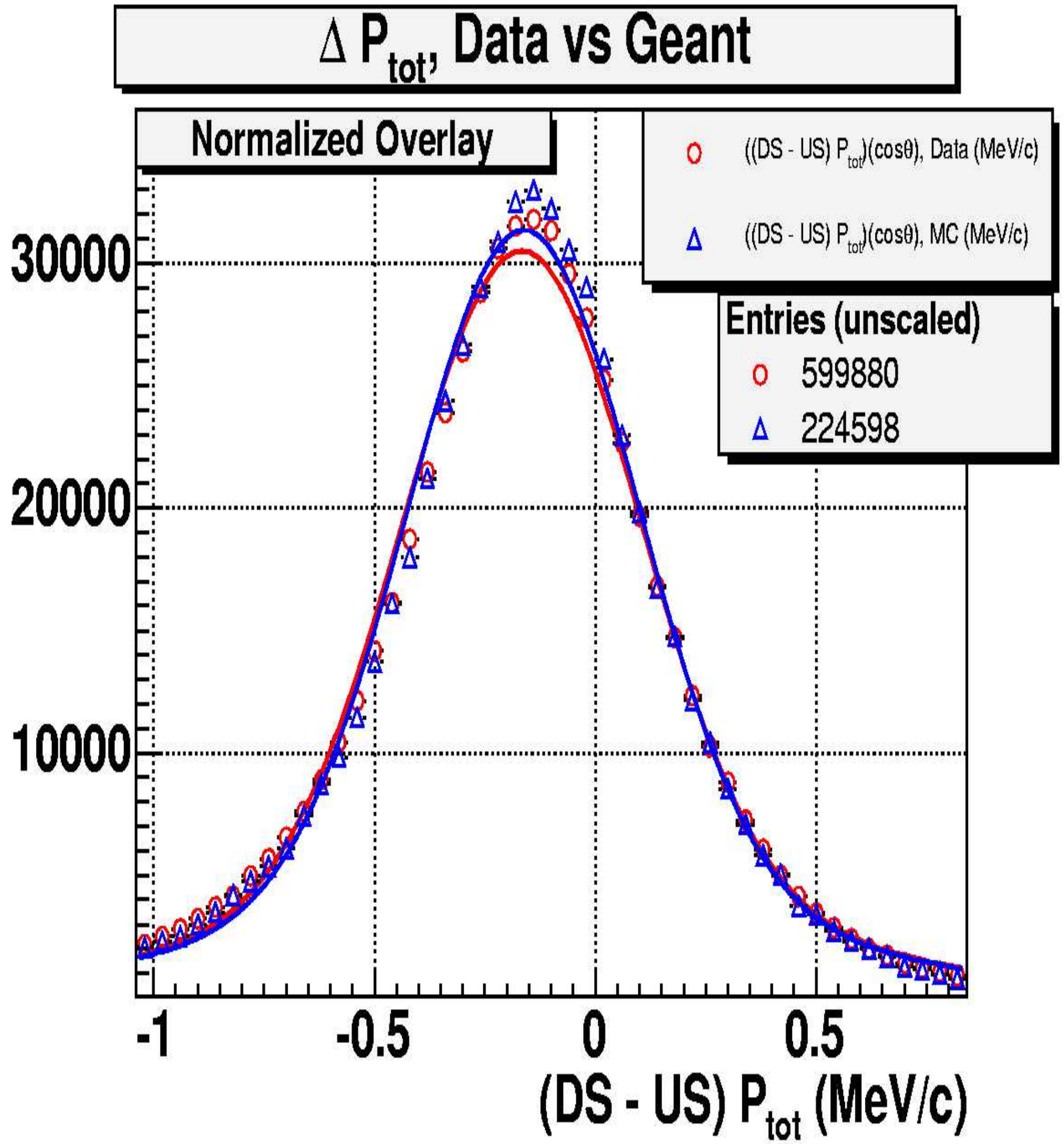
Fit Parameters:

$$N_{1,}\ \left(\frac{N_2}{N_1}\right),\ \sigma_{1,}\ \sigma_{2,}\ \mu$$

Weighted Width:

$$\frac{N_1\sigma_1+N_2\sigma_2}{N_1+N_2}$$

# Energy Loss

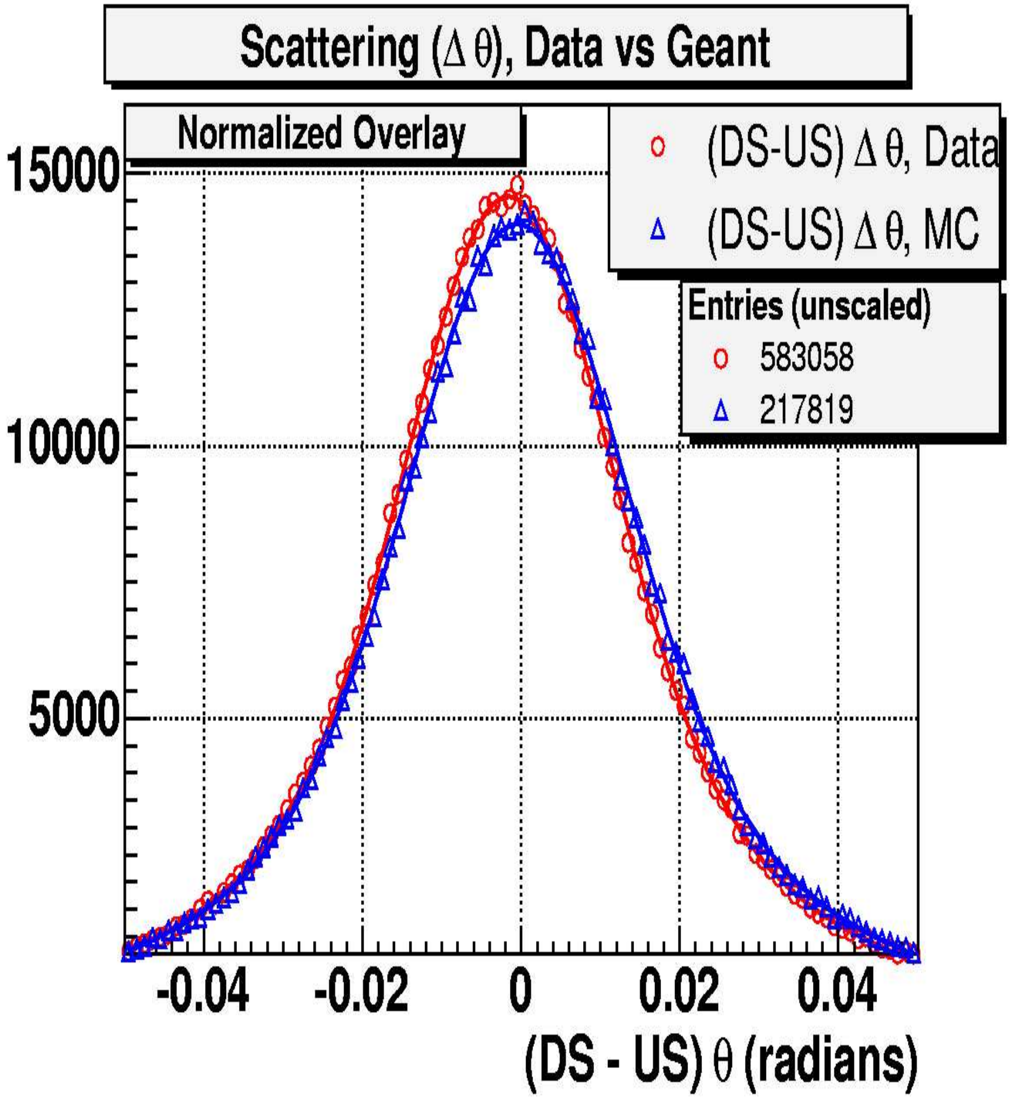



- Mean:
  Geant: -161.9±0.7 keV
  Data: -161.4±0.5 keV
  Diff: 0.5±0.9 keV
- Weighted Width:
  Geant: 306±2 keV
  Data: 314±2 keV
  Diff: 8±3 keV

# Energy Loss Requirements

- Need error/bias in energy loss to be small compared to energy reconstruction requirements.
- Example: Energy loss for 35MeV/c e+ is about 130keV. (0.130)/(35)=0.004.
  - So for 1e-3 measurement, energy loss accuracy of a few percent (i.e. a few keV) should be sufficient (assuming uncertainties in decay parameters are linear in momentum uncertainty).

# Multiple Scattering




- Mean:
  Geant: -0.47±0.04 mr
  Data: -1.61±0.03 mr
  Diff: 1.14±0.05 mr
- Weighted Width:
  Geant: 16.9±0.6 mr
  Data: 16.3±0.5 mr
  Diff: 0.6±0.8 mr

# Multiple Scattering Requirements

- Need error/bias in multiple scattering to be small compared to angle reconstruction requirements.
- Example: Say typical scattering is 50 mrad (~2xHWHM) for track at about 0.8 rad (pi/4). (0.05/0.80)=0.07.
  - So for a 1e-3 measurement, multiple scattering accuracy of a few percent (i.e. around a milliradian) should be sufficient (assuming uncertainties in decay parameters are linear in angle uncertainty).

# Conclusions

- Verifying that response function is correctly simulated is vital to TWIST.
- High-precision studies of GEANT3 are underway.
  - Studies must be independent of muon decay parameters.
- Simulation agrees strongly with real data.
  - Once discrepancies are understood, this knowledge will be incorporated into our simulation.