TWIST
A Precision Measurement
of
Muon Decay at TRIUMF

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TWIST Collaboration

- Physics of TWIST
- Introduction to the Experiment
- Current Status

TRIUMF WEAK INTERACTION SYMMETRY TEST

- Uses intense “Surface Muon” beam of polarised muons from pions decaying at rest on surface of production target
- Incoming muon is tracked and stopped in thin,planar target
- Decay positron is tracked through 2T uniform field with a symmetric stack of high precision, low mass, planar drift chambers

Muon Decay in a Model-Independent Form

The muon decay matrix element can be written as:

$$\frac{4G_F}{\sqrt{2}} \sum_{\substack{\gamma=S,,T \\ \varepsilon,\mu=,L}} g^{\gamma} \ \langle \bar{e}_{\varepsilon} | \Gamma^{\gamma} | \nu_e \rangle \langle \bar{\nu}_{\mu} | \Gamma_{\gamma} | \mu_{\mu} \rangle$$

with 19 real-valued parameters and one overall phase. In the Standard Model, g^{V}_{LL} = 1 and all others are zero.

The right-handed coupling of the muon can be written in terms of these parameters as:

$$Q^{\mu}_{R} = \frac{1}{4}|g^{S}_{LR}|^2 + \frac{1}{4}|g^{S}_{RR}|^2 + |g^{V}_{LR}|^2 + |g^{V}_{RR}|^2 + 3|g^{T}_{LR}|^2$$

Muon Decay and the Michel Parameters

The muon decay rate can also be written in terms of the Michel parameters. If you neglect the electron mass and radiative corrections, you obtain:

$$\frac{d^2\Gamma}{x^2\,dx\,d(\cos\theta)} \propto 3 - 3x + \frac{2}{3}\rho(4x-3) + P_\mu \xi \cos\theta \left[(1-x) + \frac{2}{3}\delta(4x-3)\right]$$

with:

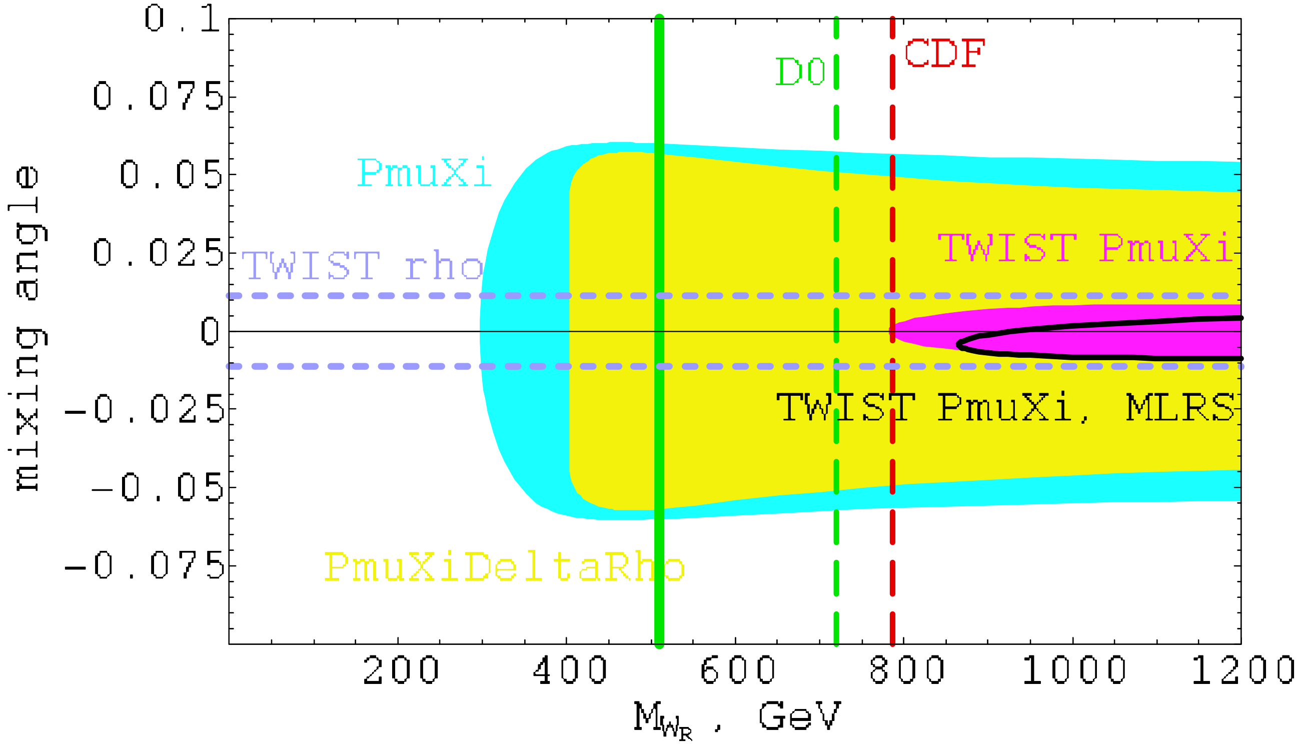
$$\begin{aligned}
\rho &= 0.7518 \pm 0.0026 \\
\eta &= -0.007 \pm 0.013 \\
\delta &= 0.7486 \pm 0.0026 \pm 0.0028 \\
P_\mu \xi &= 1.0027 \pm 0.0079 \pm 0.0030 \\
P_\mu \frac{\xi\delta}{\rho} &> 0.99682 \ (90\% \, CL)
\end{aligned}$$

Goals of TWIST

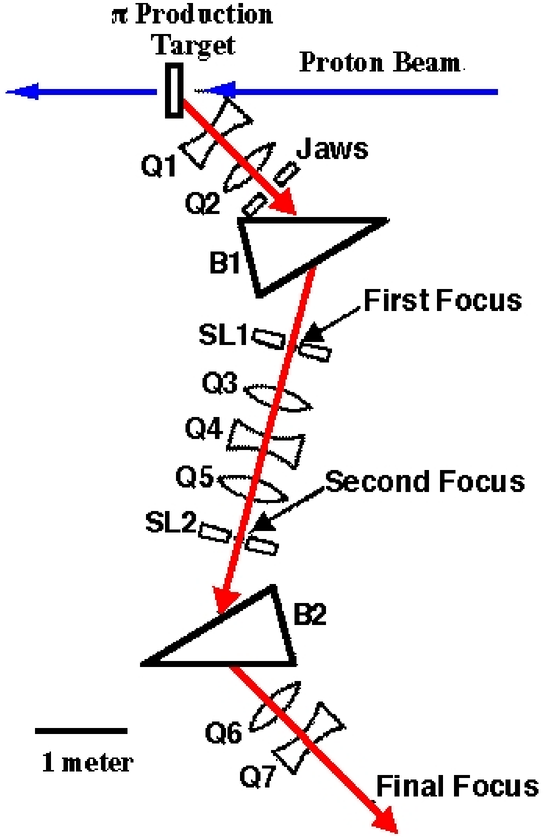
- Search for new physics through **measurements of ρ, δ, and $P_\mu\xi$ to a few parts in 10^4**.
- Model-independent limit on right-handed muon coupling:

$$Q_R^\mu = \frac{1}{2}\left[1 + \frac{1}{3}\xi - \frac{16}{9}\xi\delta\right]$$

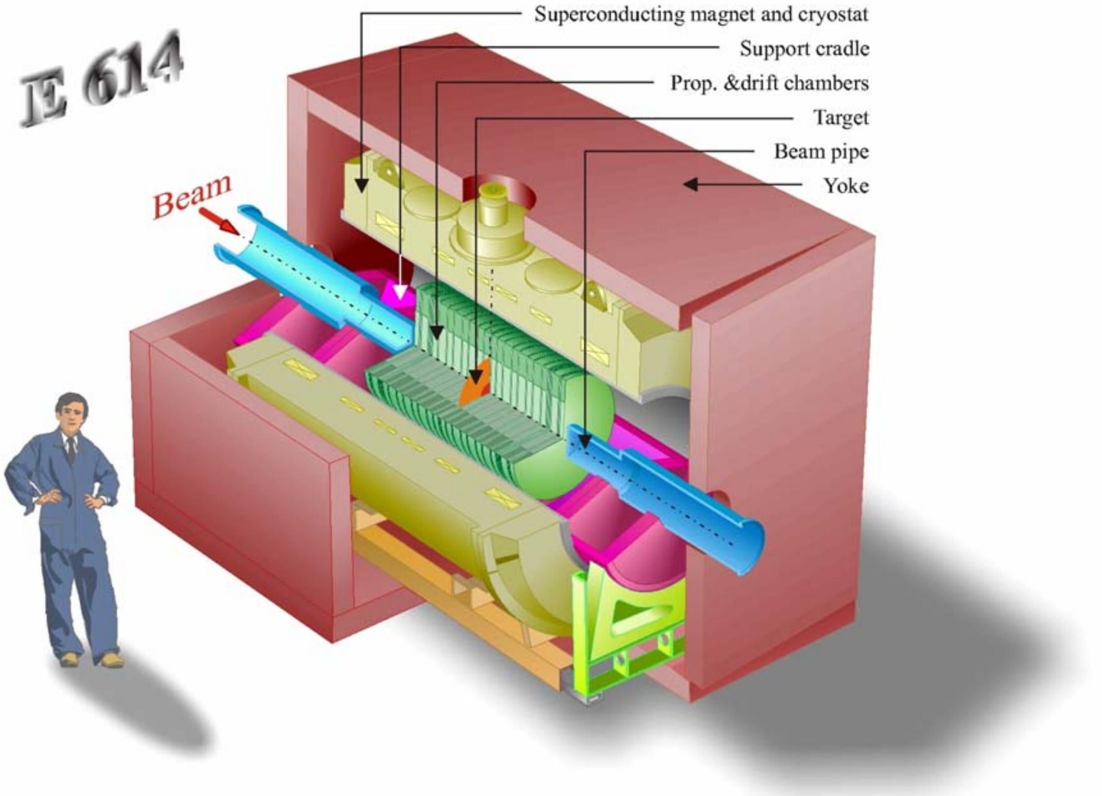
- In left-right symmetric models:

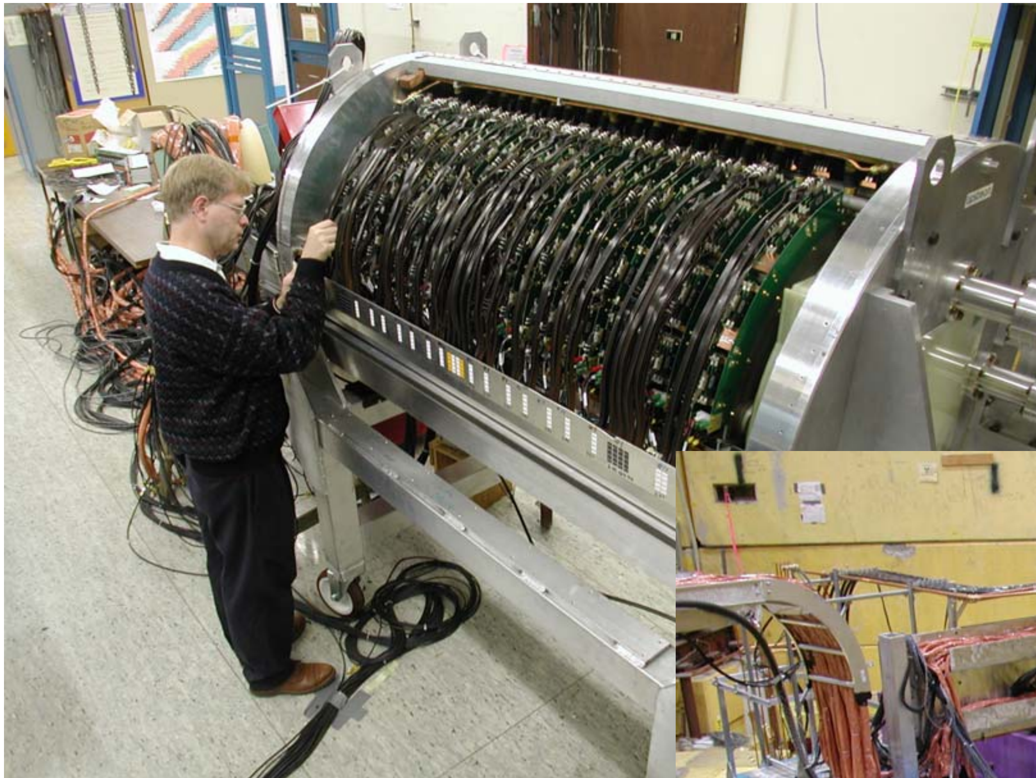


M13 Secondary Beamline at TRIUMF

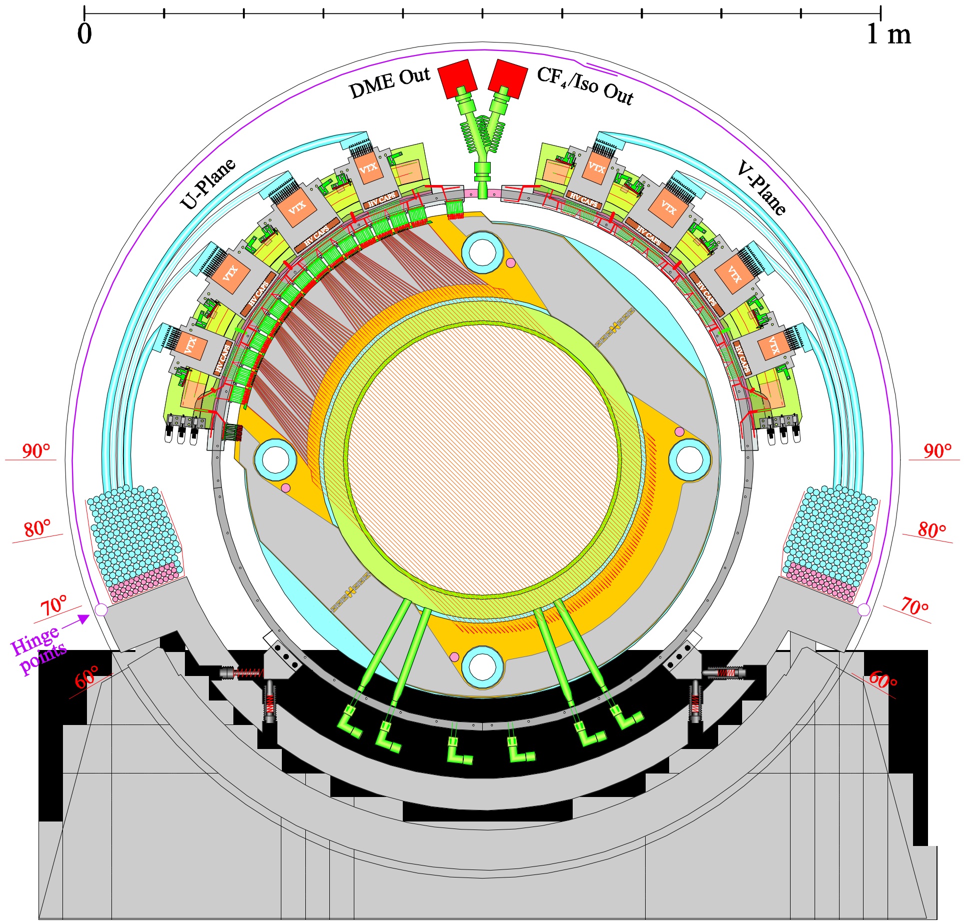


Momentum Resolution $\Delta p/p = 1\%$





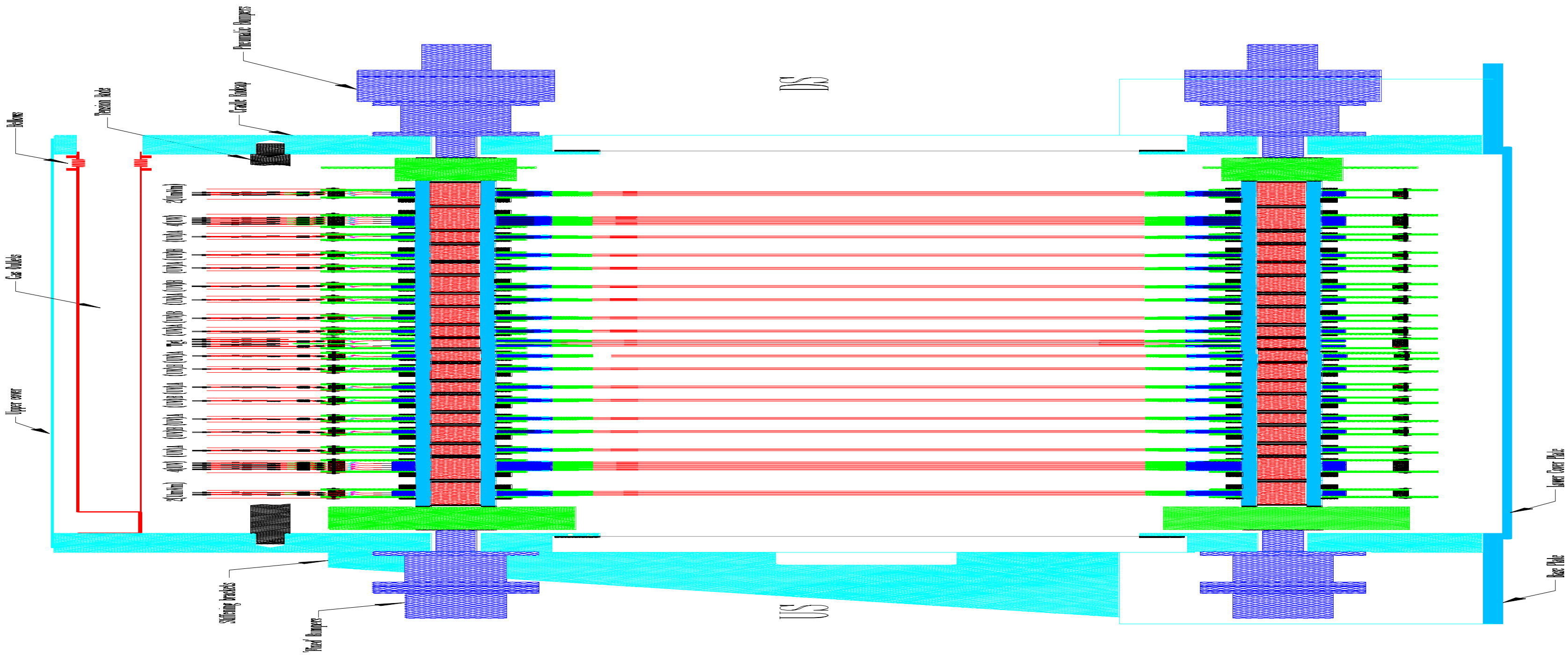
TWIST Wire Chamber Modules



- DCs:
  80 wires/plane
  DME
- MWPCs:
  160 wires/plane
  CF_4 iso-C_4H_{10}

- All wires 15 μm W(Au)
- 2, 4 or 8 planes per module

TWIST Wire Chambers



- 44 drift chambers and 12 MWPCs
- Very thin -- only ~5 x 10^{-5} X_0 per chamber
- ~ 5000 wires positioned with ~ 3 μm accuracy
- Longitudinal and transverse distances known to < 5 parts in 10^5

Analysis Strategy

If the **decay rate** is written as a function of:

$$\rho = \rho_0 + \Delta\rho$$
$$\eta = \eta_0 + \Delta\eta$$
$$P_\mu\xi = P_\mu\xi_0 + \Delta \boldsymbol{P}_\mu\xi$$
$$\delta = \delta_0 + \Delta\delta$$

It can be made **linear in** $\Delta\rho$**,** $\Delta\eta$**,** $\Delta \boldsymbol{P}_\mu\xi$**, and** $\Delta\delta$.

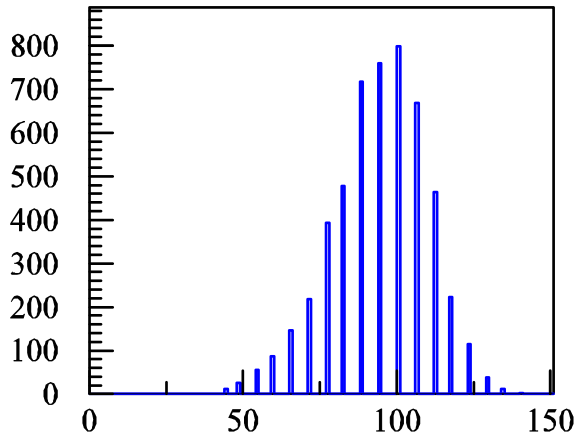
This provides the basis for our **blind analysis scheme**. We will fit our measured spectrum to a sum of a **GEANT "standard" spectrum**, produced with **unknown** ρ_0**,** η_0**,** $\boldsymbol{P}_\mu\xi_0$**, and** δ_0, together with GEANT distributions thrown according to:

$$d\Gamma/d(\Delta\rho),\ \ d\Gamma/d(\Delta\eta),\ \ d\Gamma/d(\Delta P_\mu\xi),\ \text{ and }\ d\Gamma/d(\Delta\delta).$$

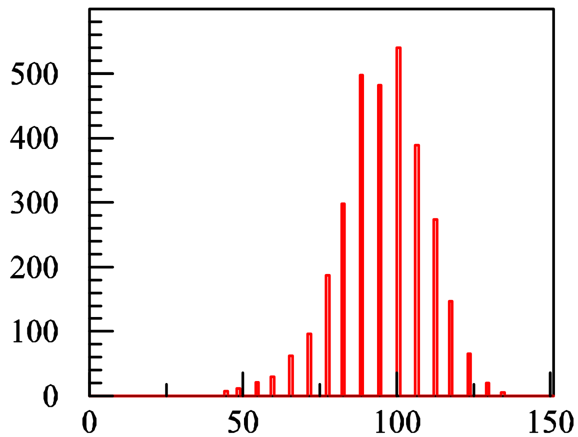
First Physics Run: Sept-Dec, '02

- **Goal: Determine** ρ **and** δ **to** $\mathbf{10^{-3}}$**.**
- Recorded ~6 x 10^9 events to tape. Note that **3 x 10^8 events suffice to measure** ρ **and** δ **with a statistical precision of ~6 x 10^{-4}**.
- Basic philosophy: If we might be sensitive to a **particular systematic effect**, can we take data in a configuration that will **make it "really big"**?
- Recorded many separate 3 x 10^8 event data sets under various experimental conditions to investigate:
  - Varying beam polarization - ("Surface" vs "cloud" muon beams)
  - Beam line and detector performance (Vary beam line,detector, time)
  - Upstream-downstream symmetry (Vary stopping point, material)
  - Momentum scale (Vary solenoid field)
  - Analysis codes (Vary trigger rate)
  - GEANT simulation quality (vary muon stop location, beam positron data)

Validating the Muon Stopping Distribution in GEANT



Muon Stops/RL vs RL (units of 10^{-5})



Muon Stops/RL vs RL (units of 10^{-5})

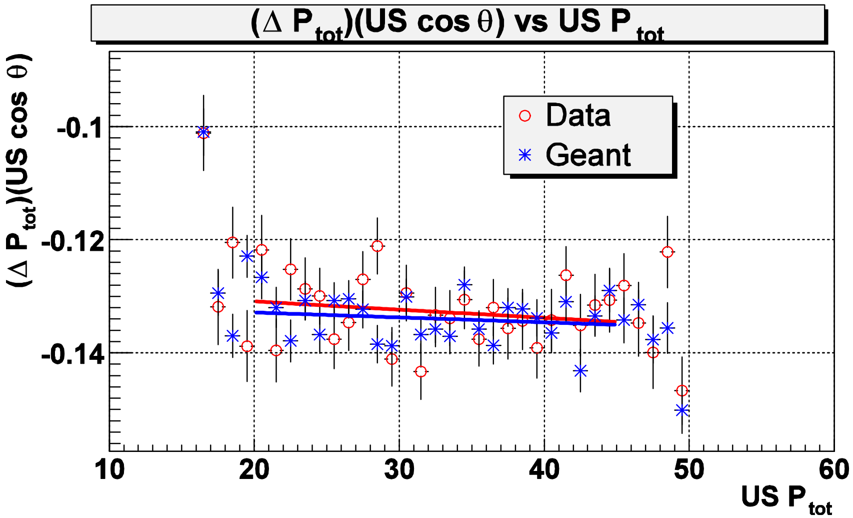
- Began with muons stopping in the center of the target in both **experiment** and **Monte Carlo**

- Inserted an upstream mylar degrader with the same known thickness in both

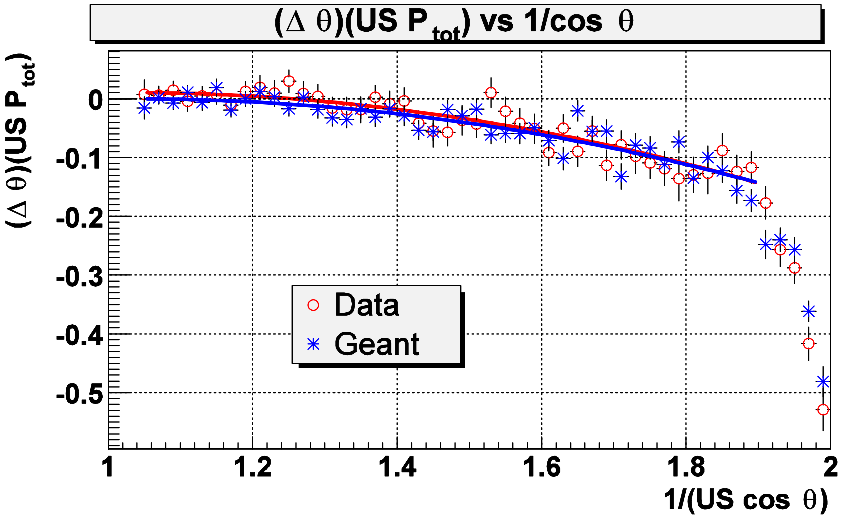
- Measured the new stopping distribution in the upstream half of the detector stack

Validating the Positron Interactions in GEANT

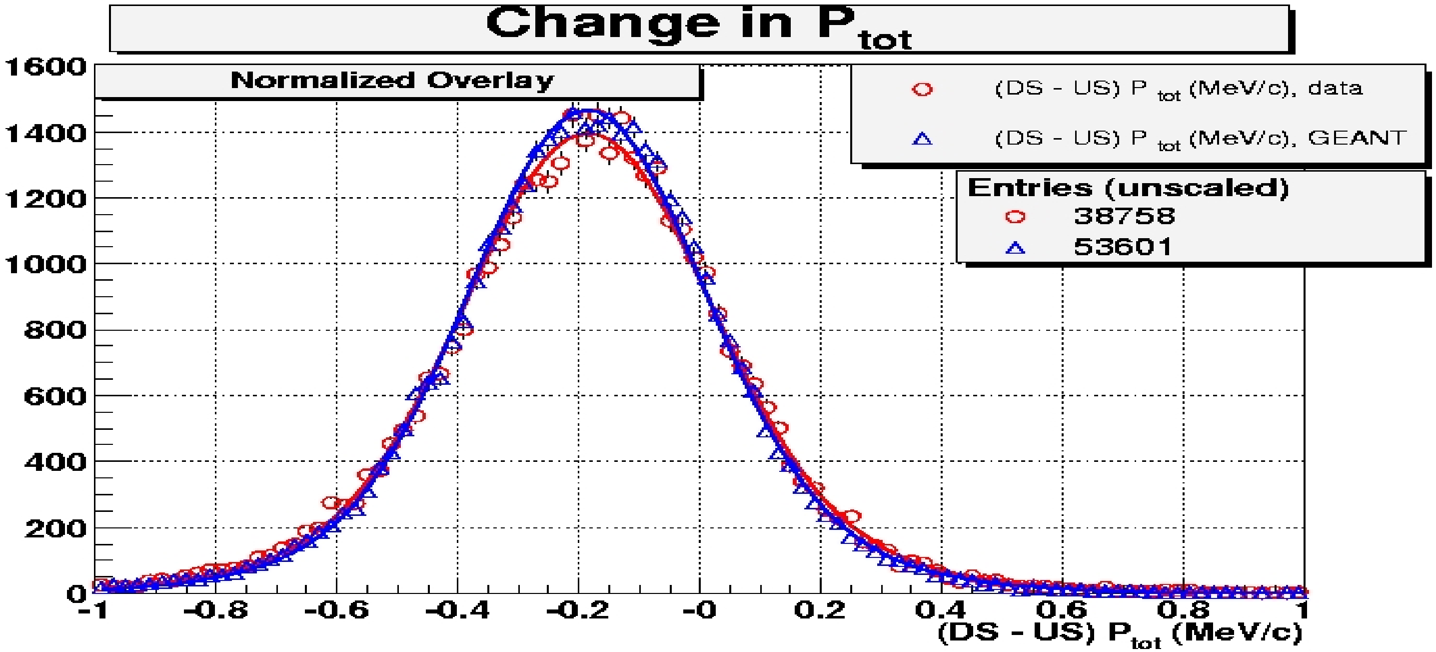
Energy loss

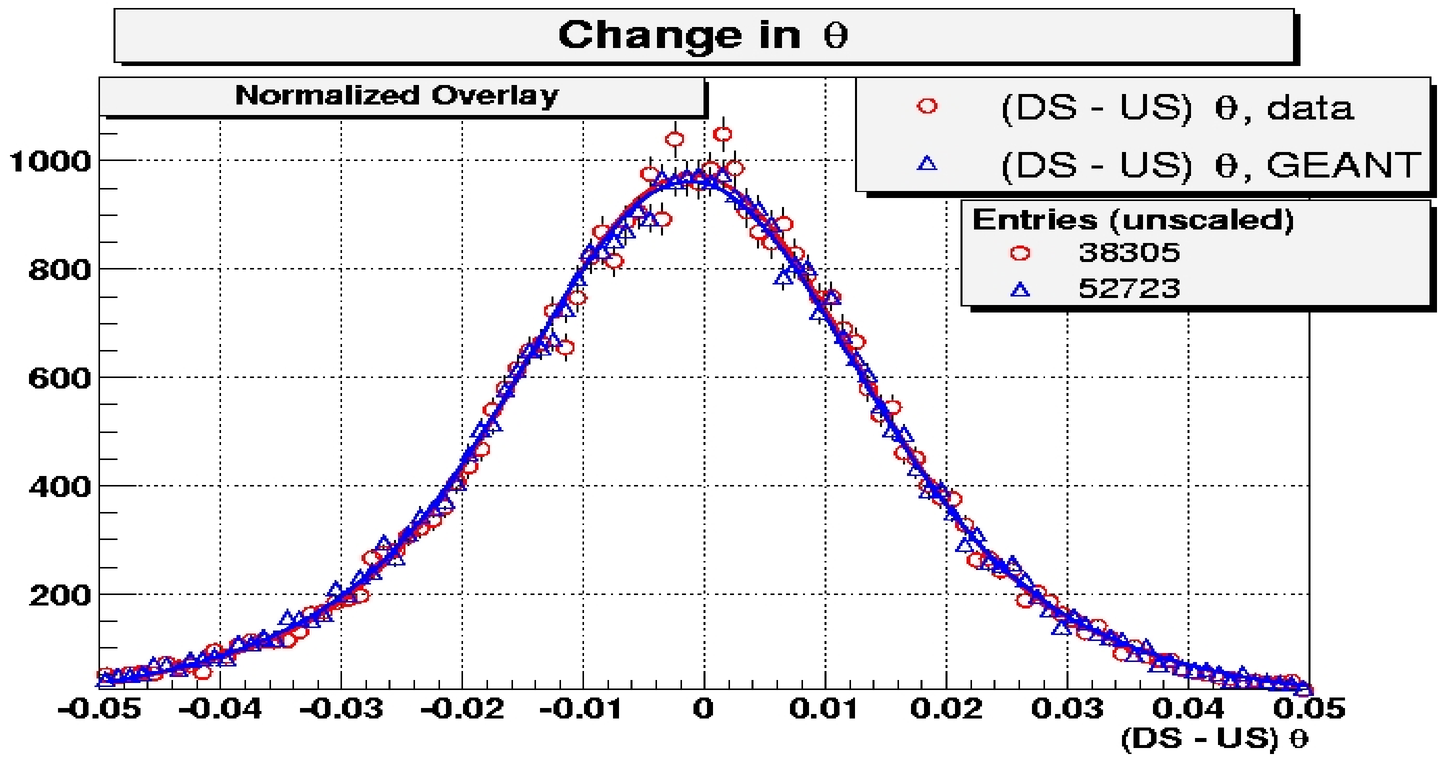


Multiple scattering

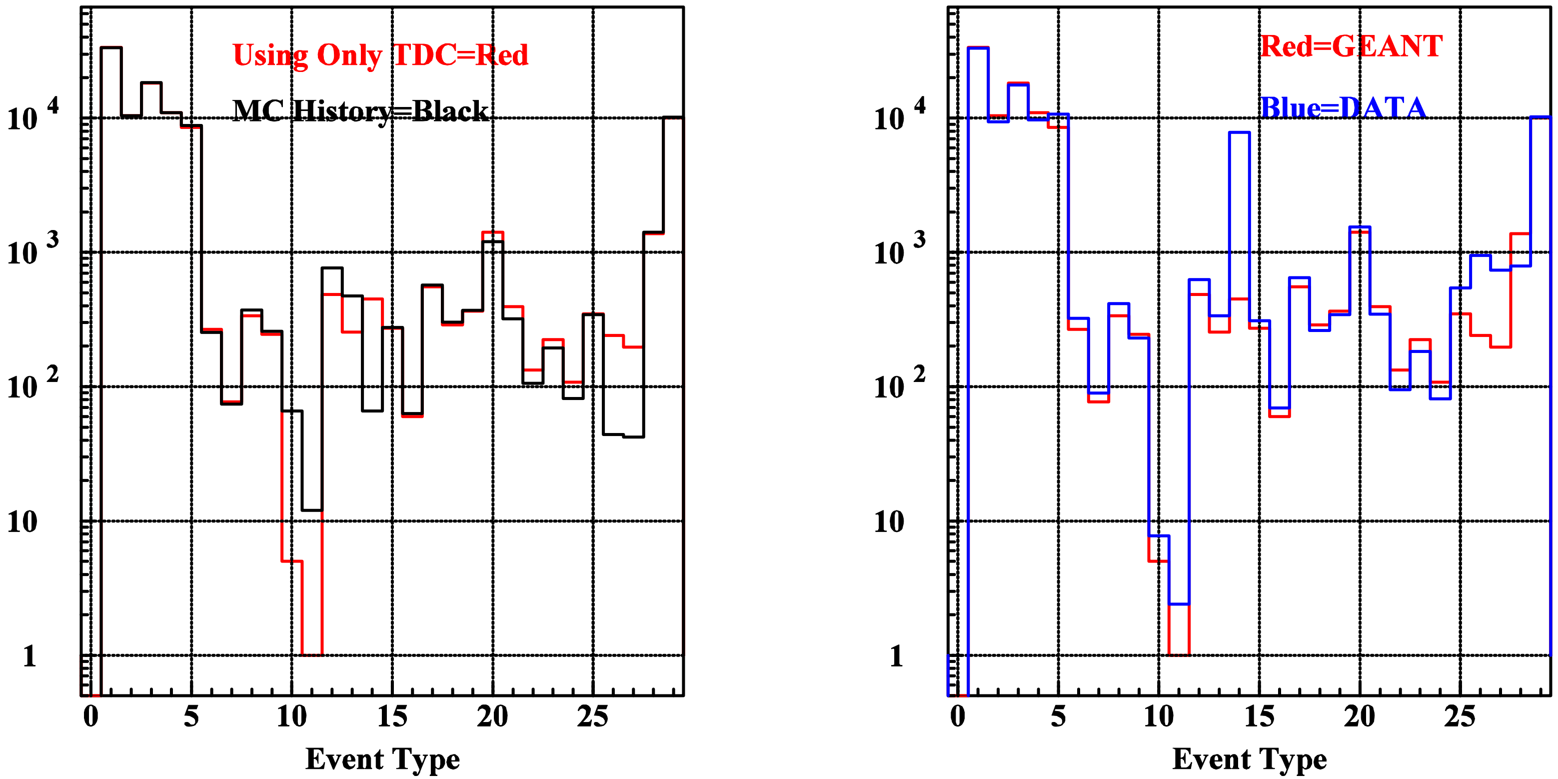


- Stop muons near the upstream end of the system
- **Track** decay positrons **independently** before and after the target
- Compare the two reconstructions
- Measures energy loss and multiple scattering in **data** and **GEANT**


Change in P_{tot}
Normalized Overlay
(DS - US) P_{tot} (MeV/c), data
(DS - US) P_{tot} (MeV/c), GEANT
Entries (unscaled)
38758
53601
(DS - US) P_{tot} (MeV/c)


Change in θ
Normalized Overlay
(DS - US) θ, data
(DS - US) θ, GEANT
Entries (unscaled)
38305
52723
(DS - US) θ

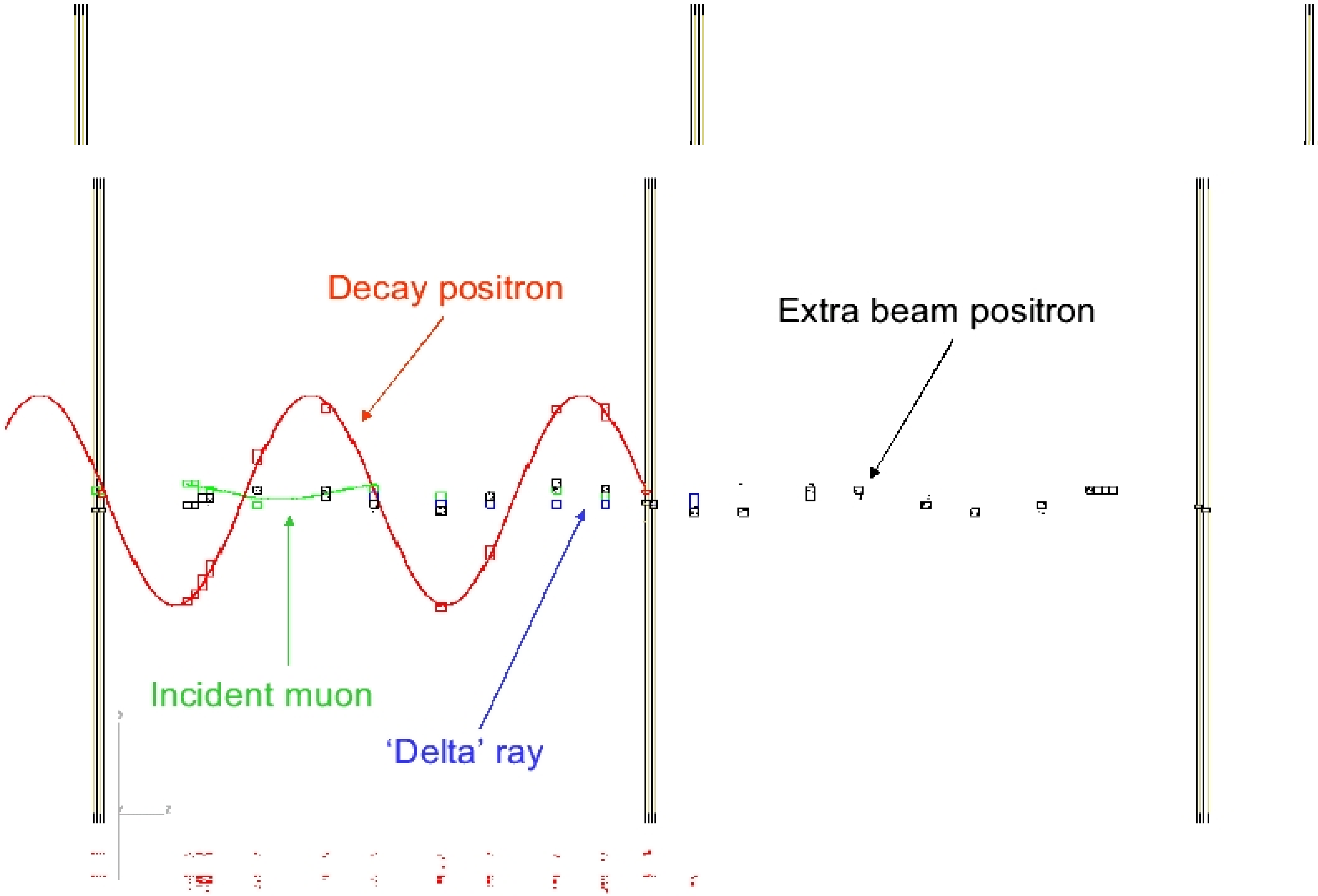
Classifying Events: What Really Happened?



Do **MC analysis** and **history** match?

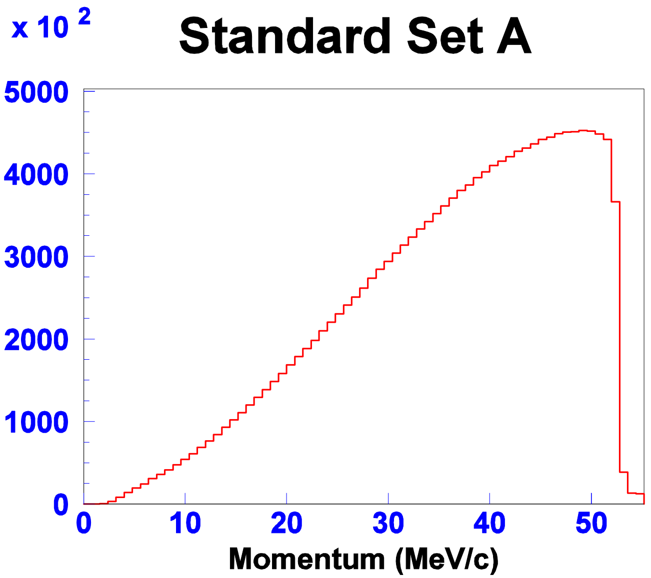
Do **MC** and **data** match?

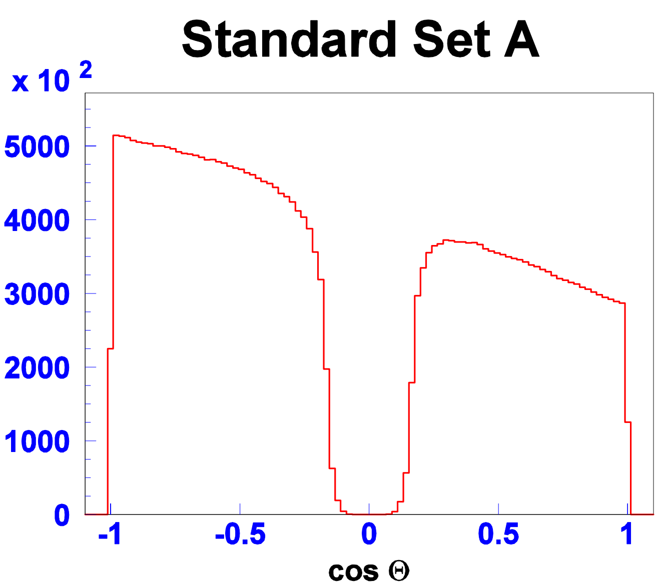
Same Monte Carlo analysis

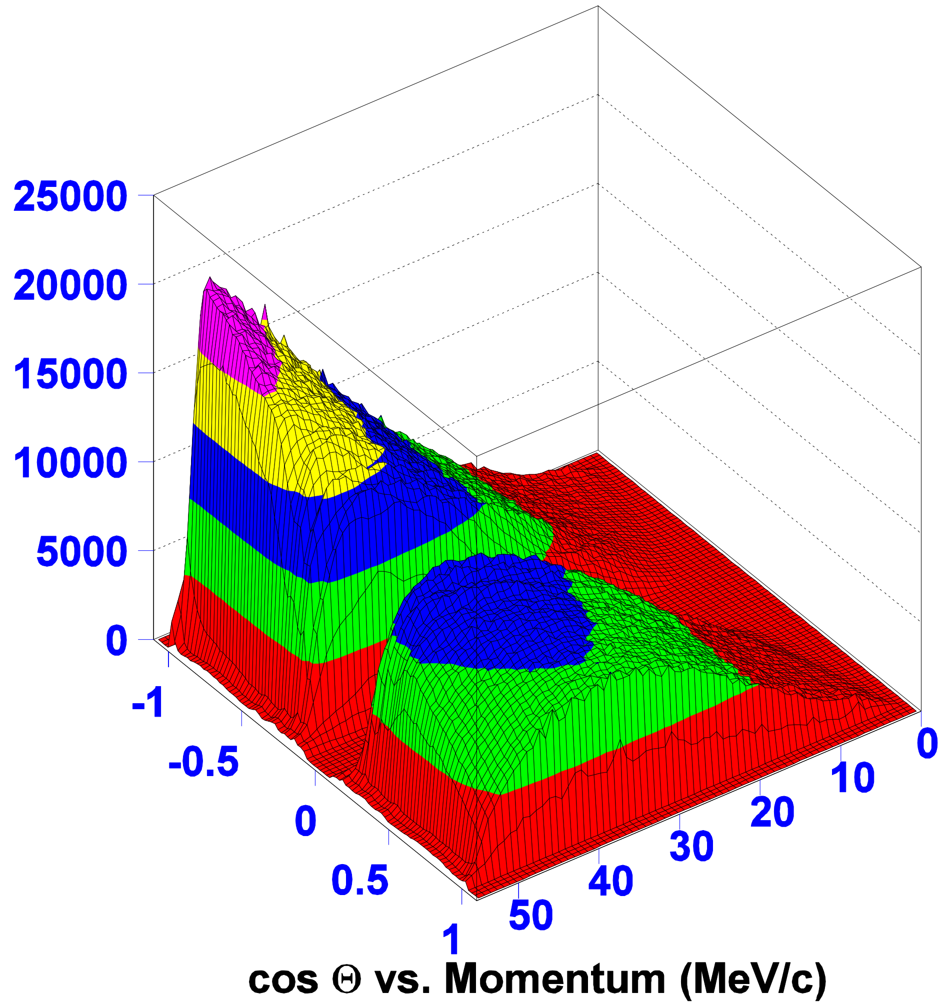


Decay positron
Extra beam positron
Incident muon
'Delta' ray

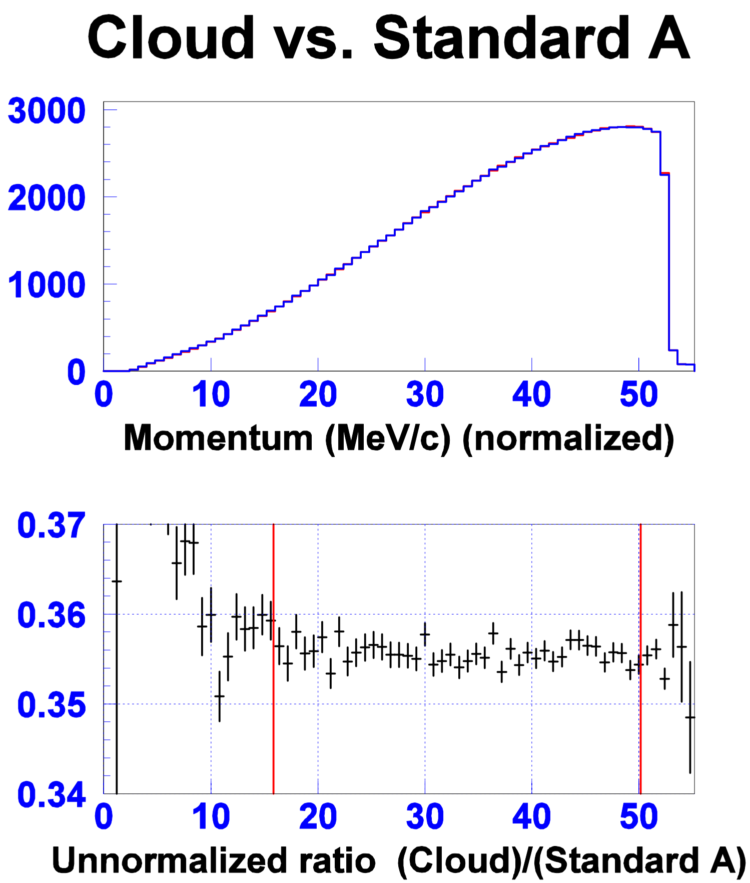
Surface Muon Data Set taken under "Standard" Conditions





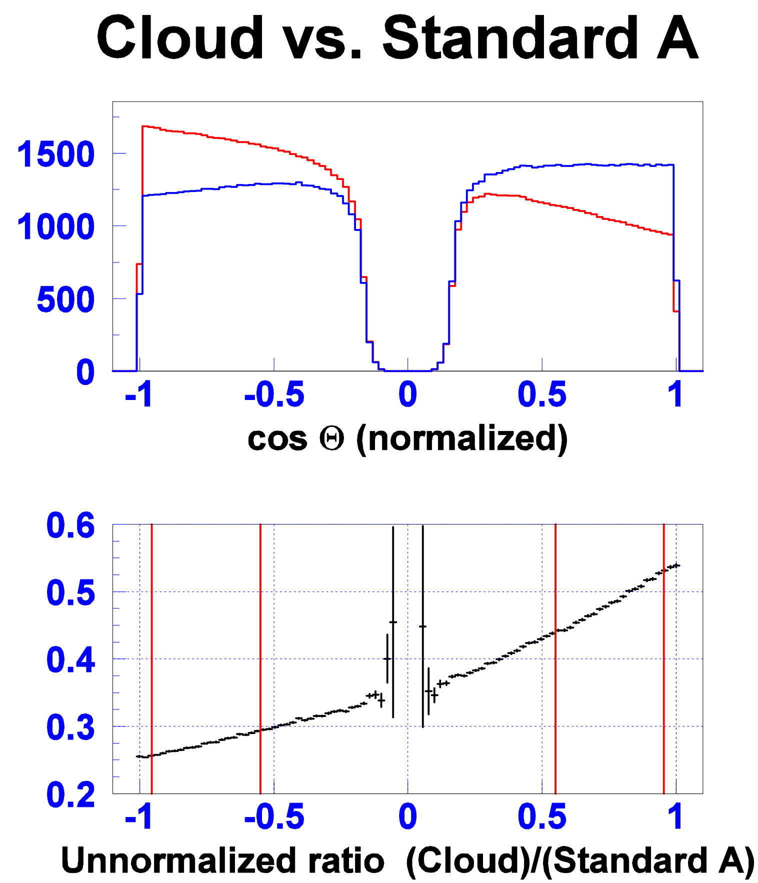


Comparing Cloud Muons to Surface Muons



Events in Standard A data set 16112307

Events in Cloud data set 5730232

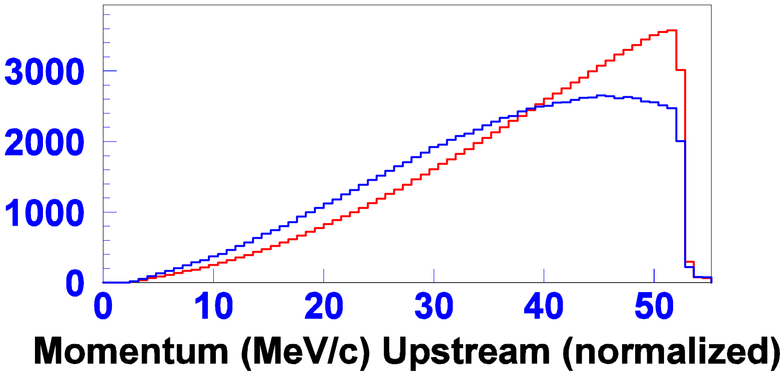


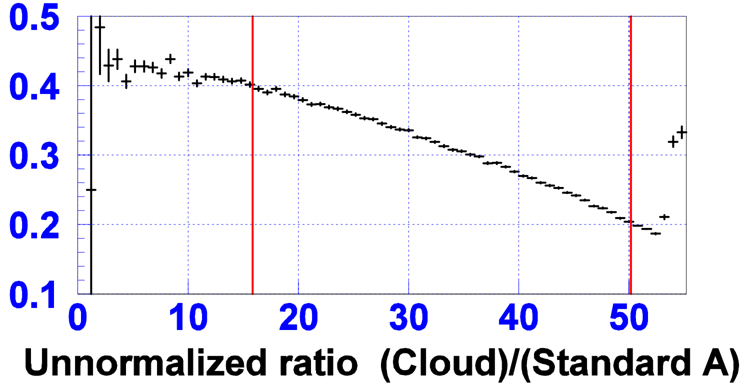
Events in Standard A data set 30534801

Events in Cloud data set 10832352

More Cloud Muons vs. Surface Muons

Cloud vs. Standard A

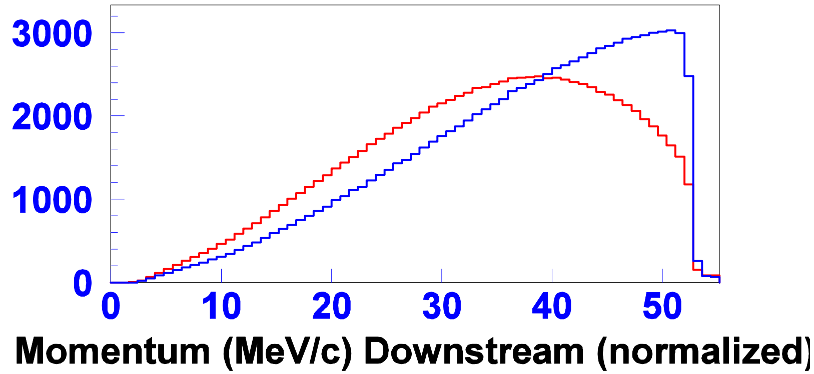


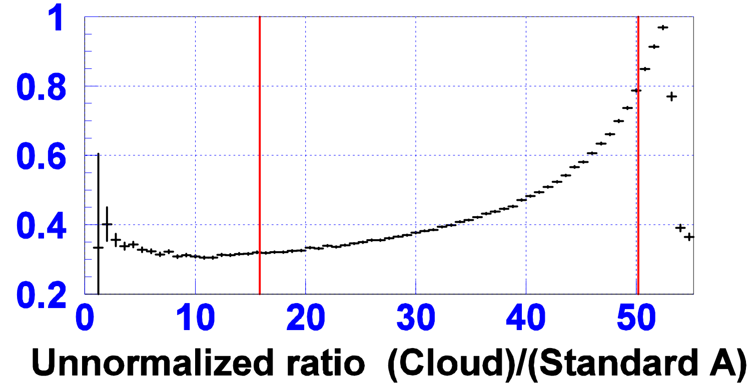


Events in Standard A data set 9579373

Events in Cloud data set 2686038

Cloud vs. Standard A



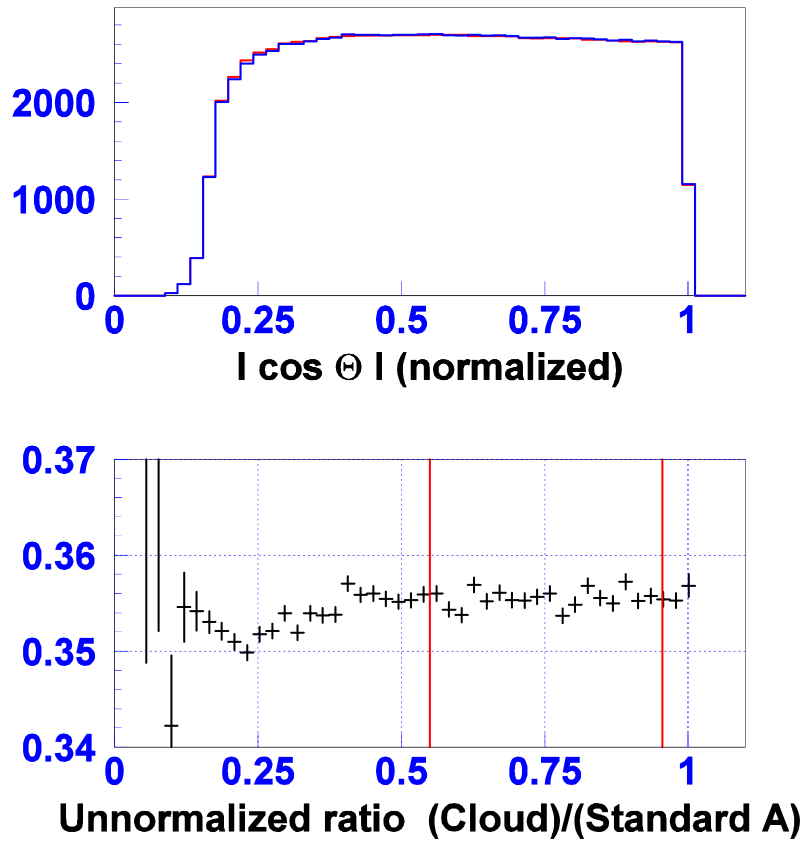


Events in Standard A data set 6214309

Events in Cloud data set 2865119

More Cloud Muons vs. Surface Muons

Cloud vs. Standard A

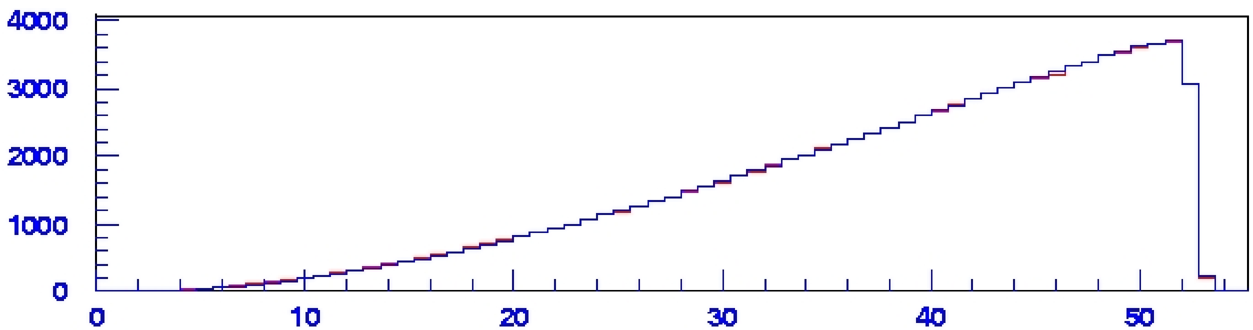


Events in Standard A data set 30534801

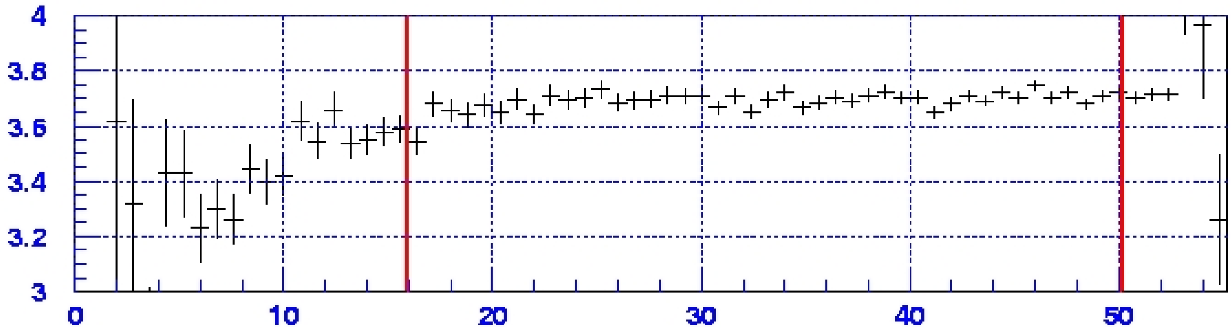
Events in Cloud data set 10832352

2003/05/12 19.12

DCHV 1850V vs. Standard A



Normalized overlay of Momentum (MeV/c), Upstream



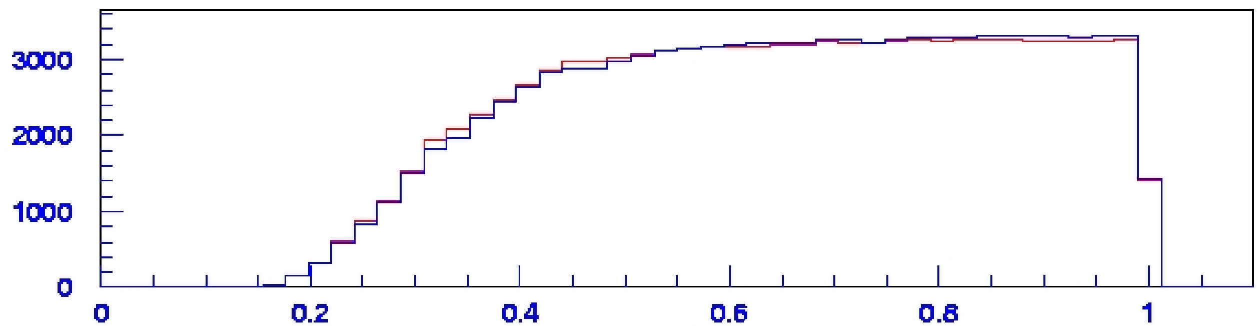
Unnormalized ratio of histograms, (DCHV 1850V)/(Standard A)

Events in Standard A data set 1481827

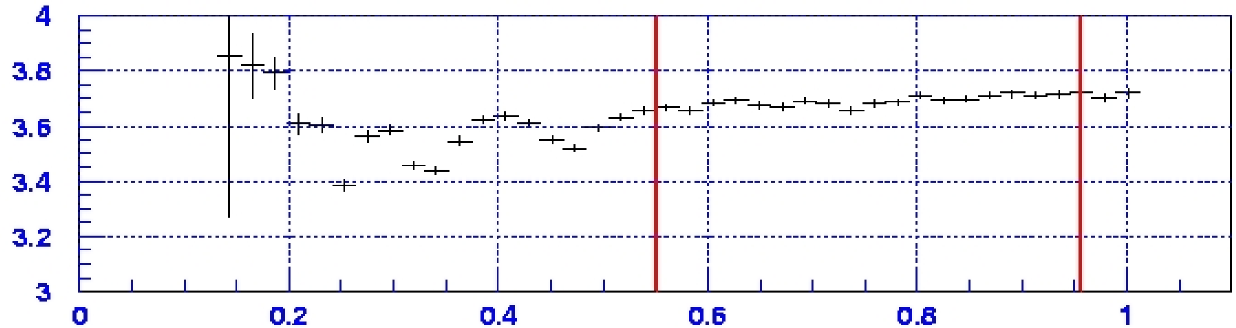
Events in DCHV 1850V data set 5472748

2003/05/12 19.12

DCHV 1850V vs. Standard A



Normalized overlay of ABS(cos(theta))



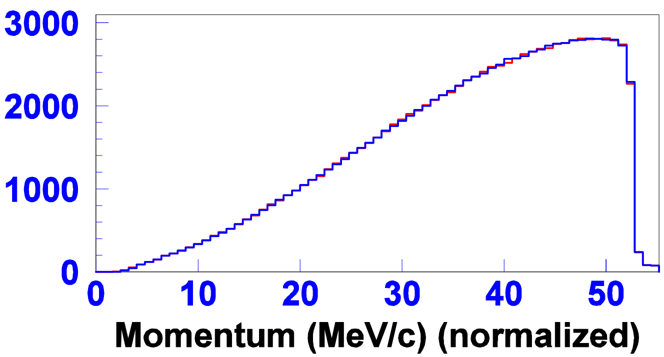
Unnormalized ratio of histograms, (DCHV 1850V)/(Standard A)

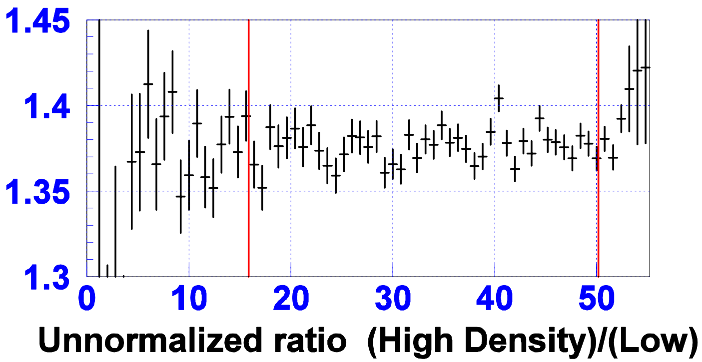
Events in Standard A data set 3957969

Events in DCHV 1850V data set 14454754

Atmospheric Pressure and Muon Stopping Location

High Density vs. Low

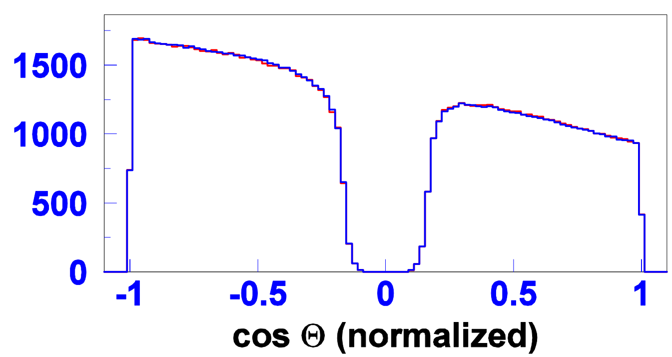


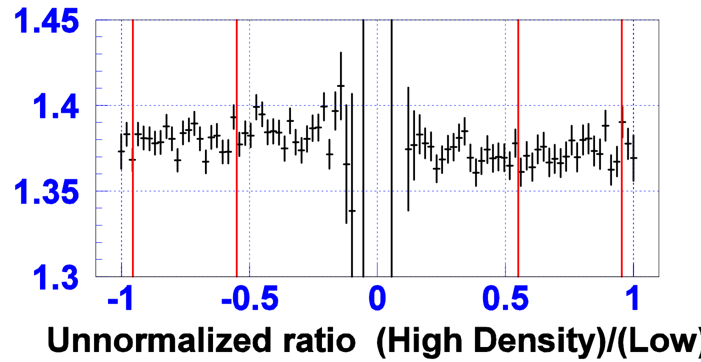


Events in Low data set 2324119

Events in High Density data set 3200343

High Density vs. Low



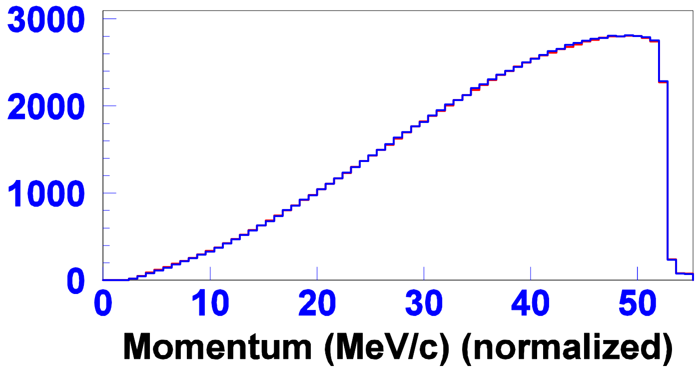


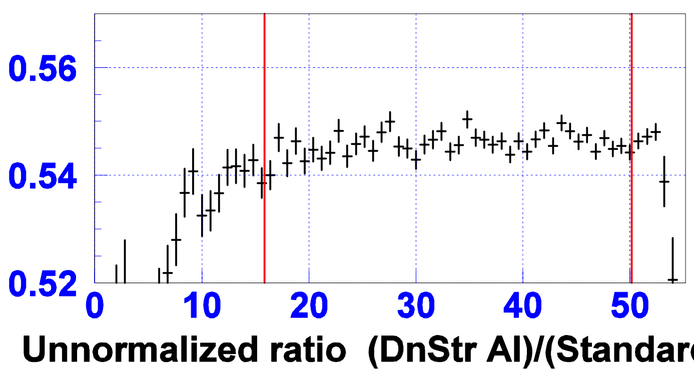
Events in Low data set 4401366

Events in High Density data set 6064934

Additional Material Downstream of the Detector

DnStr Al vs. Standard A

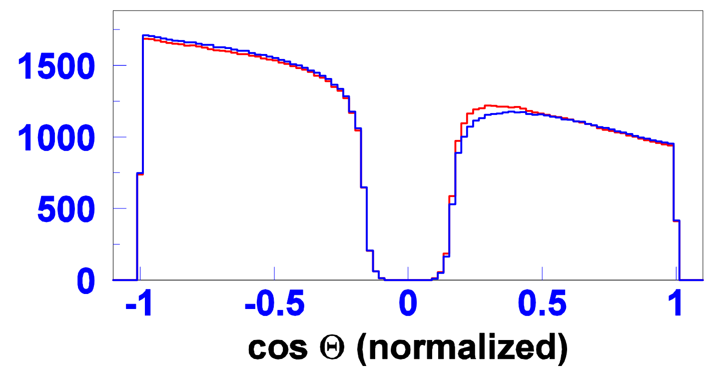


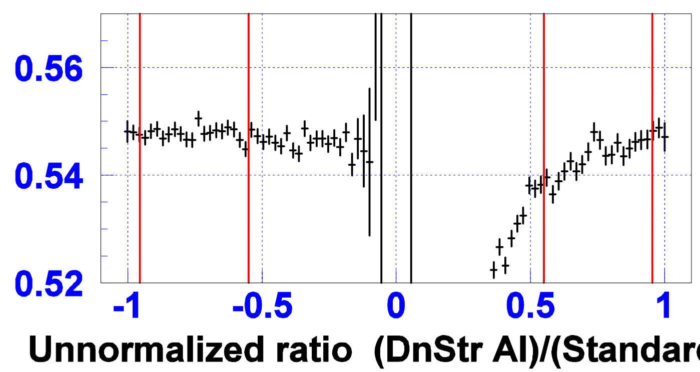


Events in Standard A data set 16112307

Events in DnStr Al data set 8779997

DnStr Al vs. Standard A

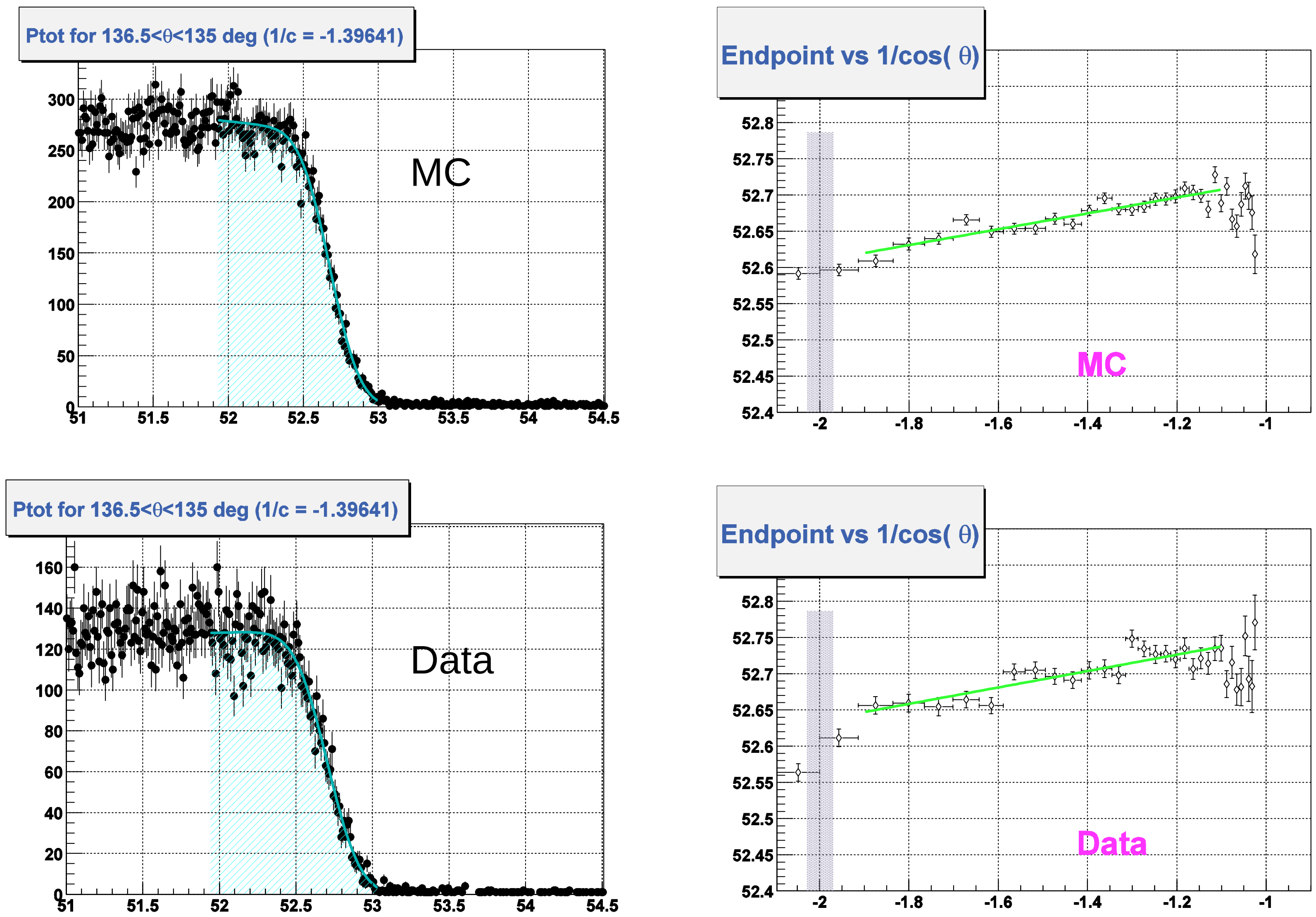




Events in Standard A data set 30534801

Events in DnStr Al data set 16499435

Endpoint Fits for Momentum Calibration Check



Conclusions

- TWIST is the first experiment ever to measure the full muon decay energy-angle spectrum simultaneously.

- The ultimate goal of TWIST is to improve our knowledge of ρ, δ, and $P_\mu\xi$ by over an order of magnitude in each case. We may also improve our knowledge of η. This will give us model-independent sensitivity to right-handed vector bosons with masses up to 800 GeV in left-right symmetric theories, plus sensitivity to right-handed muon coupling through scalar or tensor interactions.

- The data in hand should provide measurements of ρ **and** δ **to ~10^{-3}**.

- We hope to have the existing data analyzed by the **end of this year**.