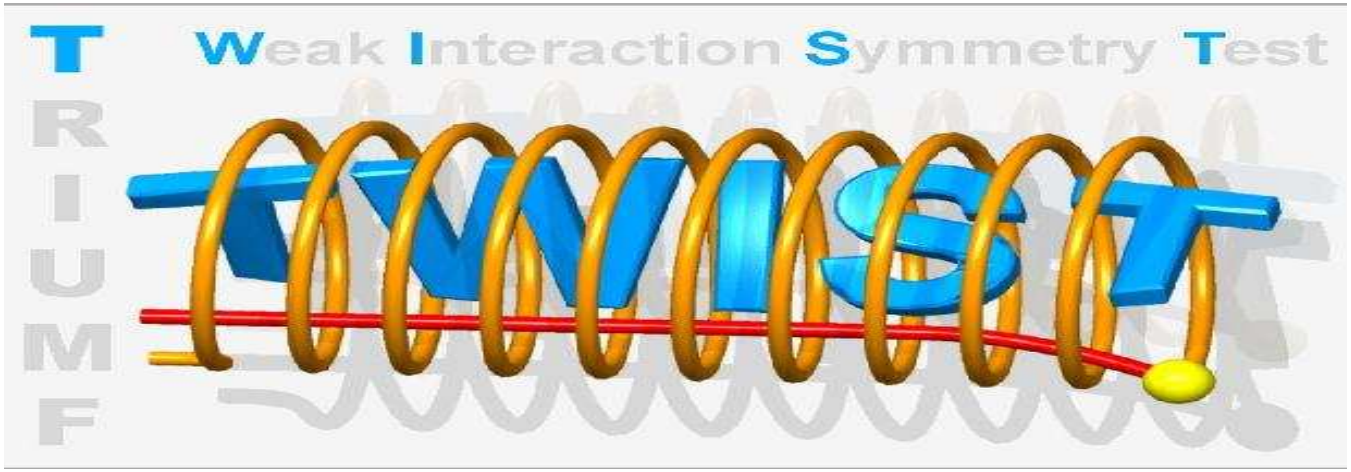
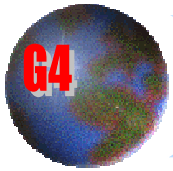


Los Alamos National Laboratory	Los Alamos, New Mexico, USA
PRC Kurchatov Institute	Moscow, Russia
Texas A&M University	College Station, Texas, USA
TRIUMF	Vancouver, BC, Canada
University of Alberta	Edmonton, AB, Canada
University of British Columbia	Vancouver, BC, Canada
University of Montreal	Quebec, Canada
University of Northern BC	Prince George, BC, Canada
University of Regina	Regina, SK, Canada
University of Saskatchewan	Saskatoon, SK, Canada
Valparaiso University	Valparaiso, IN, USA



Outline

- Physics motivation for TWIST
- The TWIST experiment
- G4 simulation – just starting
- Visualizations and GUIs
- MC comparisons and verifications
  - Preliminary G3 to G4 comparisons
  - Preliminary comparisons of GEANT to data

Physics Beyond The SM

- TWIST will perform a precise measurement of μ^+ decay

$$\mu^+ \rightarrow e^+ + \overline{\nu}_e + \nu_\mu$$

- μ^+ decay probability distribution

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

  - Electron mass neglected
  - Radiation corrections neglected

- TWIST is measuring, for the first time, the entire energy and angle distribution of e^+ from the decay of polarized μ^+.
- This will allow the determination of the Michel parameters $P_\mu\xi$, ρ, and δ with a precision of few parts in 10^4.

SM

$$\rho = \frac{3}{4}$$

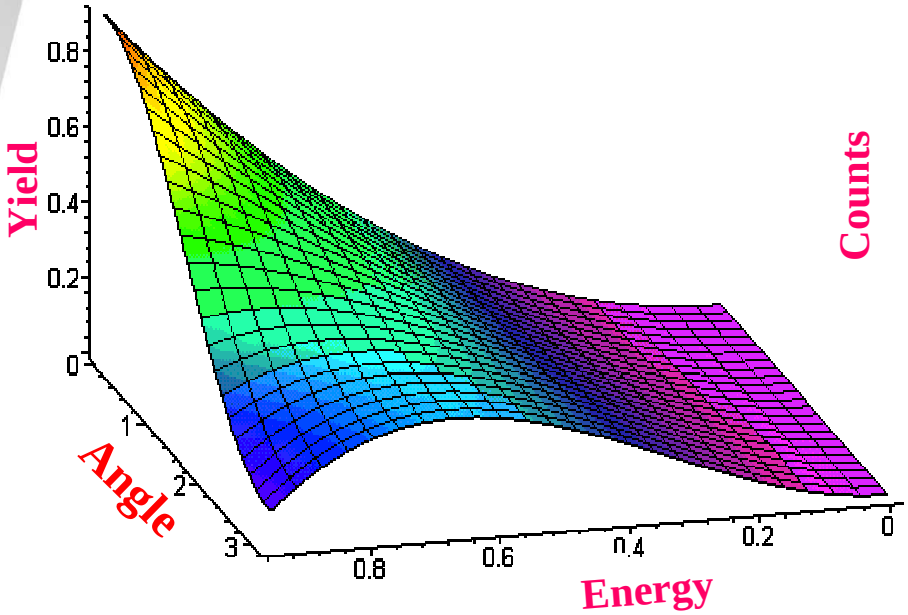
$$\delta = \frac{3}{4}$$

$$\xi = 1$$

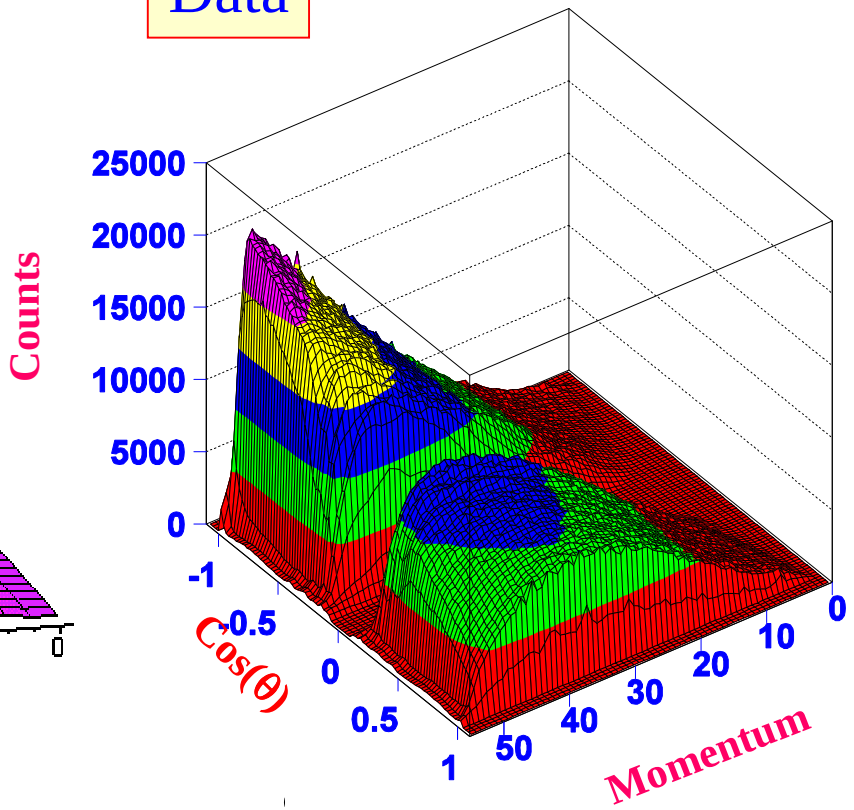
$$\eta = 0$$

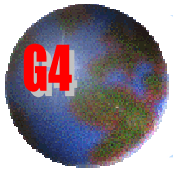
Muon Decay Distribution

SM



Data





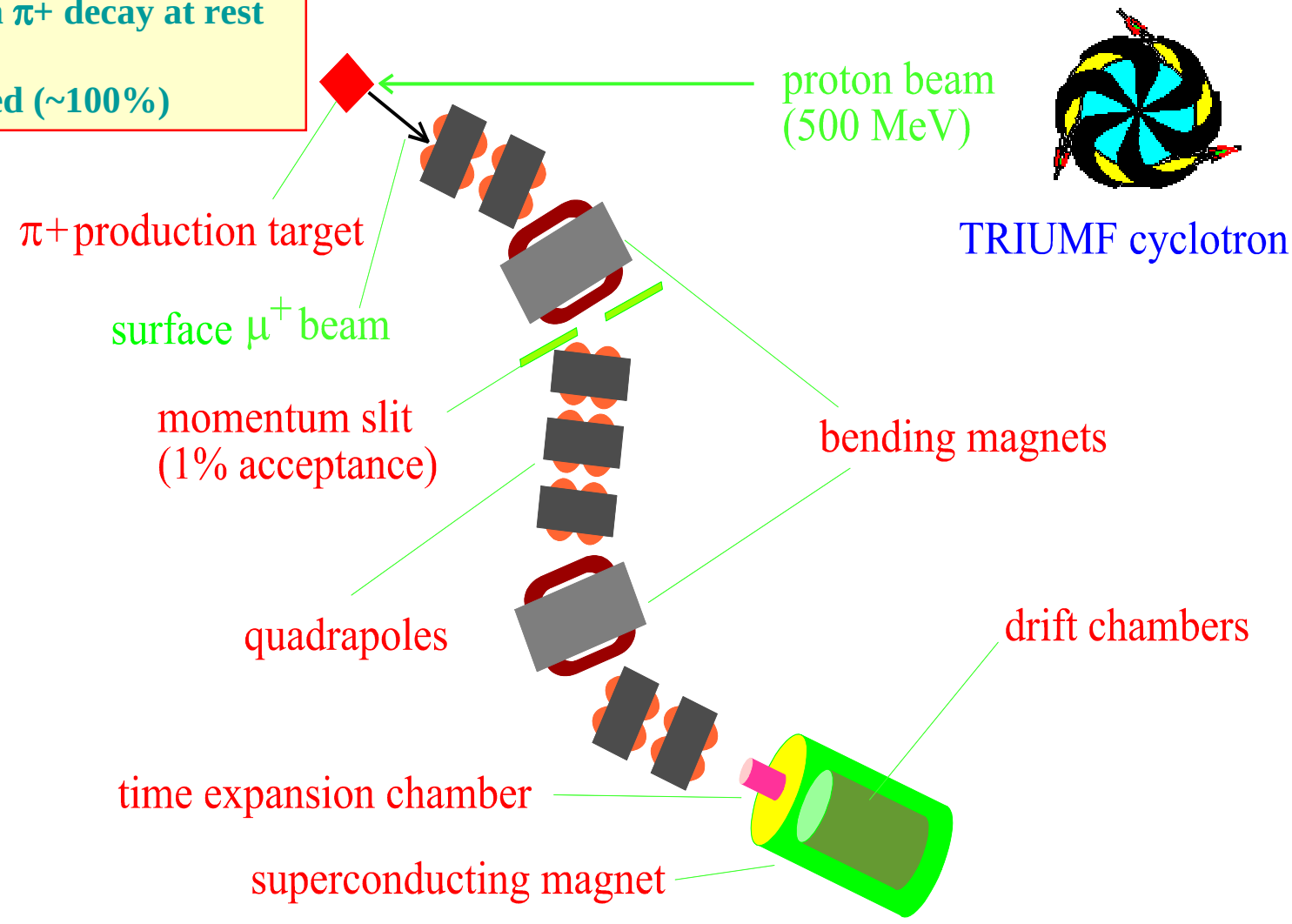
Extracting the Michel Parameters

- Fold the Standard Model distribution with a GEANT simulation of TWIST detector and compare to data
- TWIST results can be Monte Carlo dependent
- High precision requires
  - Detailed simulation of the TWIST detector using both GEANT 3 and GEANT 4.
  - Geant 3 to GEANT 4 comparisons.
  - Geant validation studies using data.
- The comparisons will include
  - Energy loss.
  - Delta ray production.
  - Multiple scattering.

The M13 Beamline

Beam

- .μ+ from π+ decay at rest
- Intense
- Polarized (~100%)



The TWIST Detector

• .μ+ is stopped in a thin planar target.
• Decay e+ is tracked through 2 T uniform field with a symmetric stack of high precision, low mass, planar drift chambers.

Superconducting magnet and cryostat

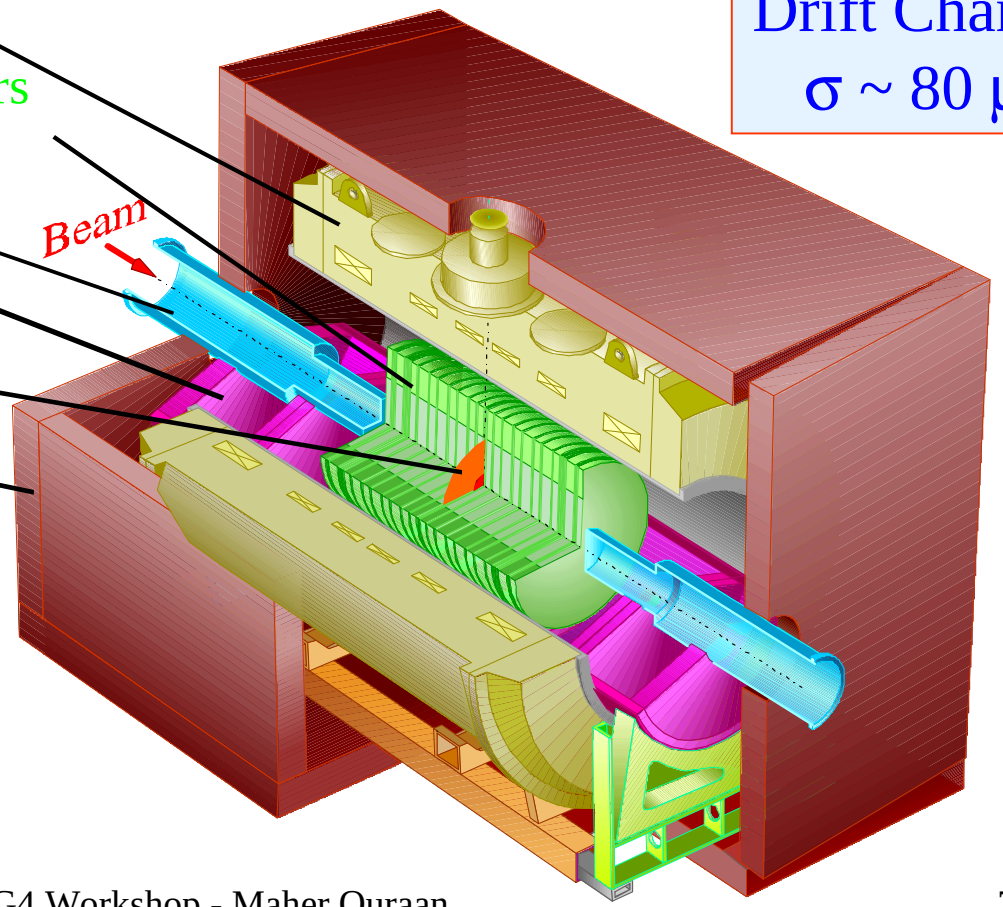
Prop. & drift chambers

Beam pipe

Support cradle

Target

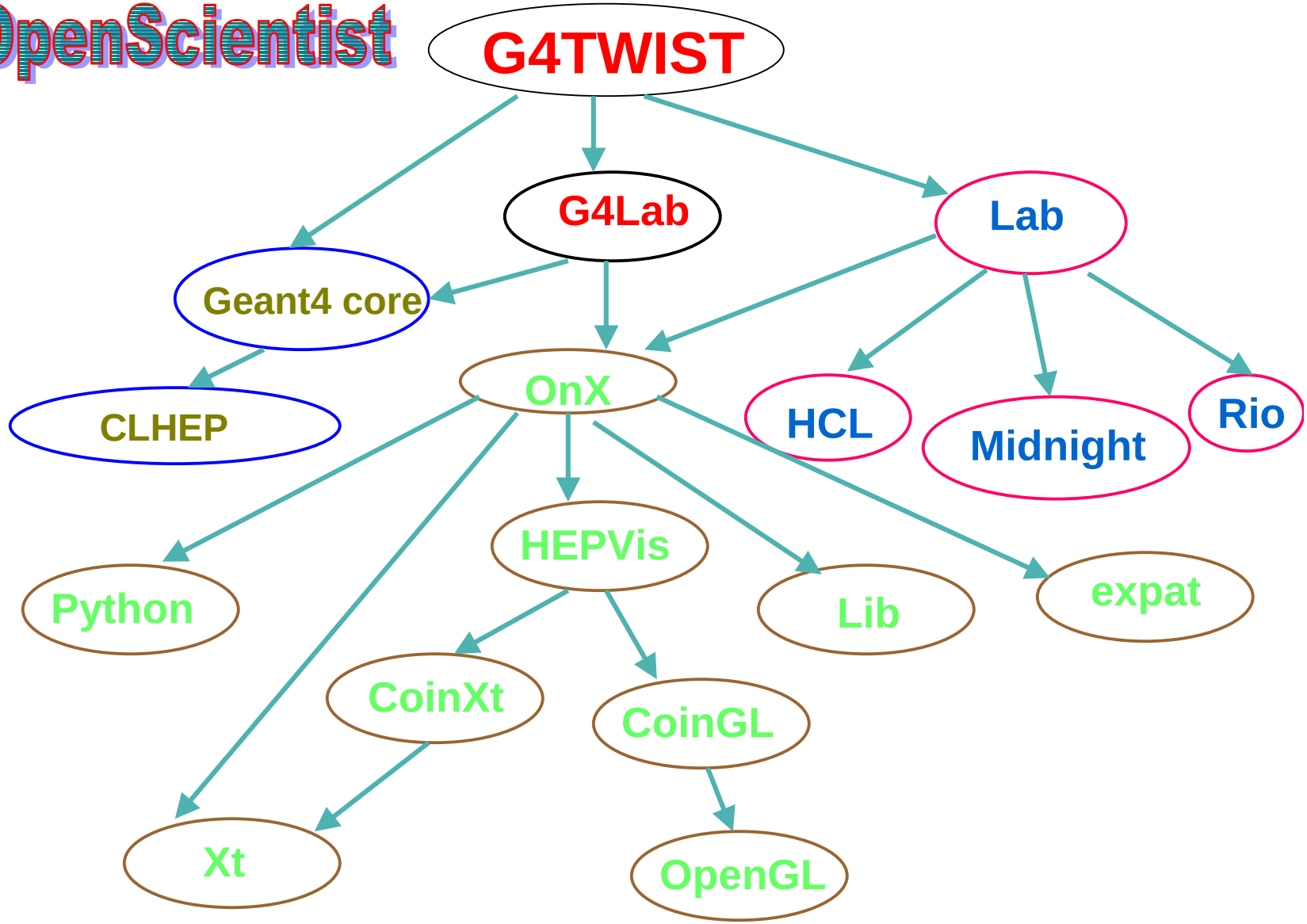
Yoke



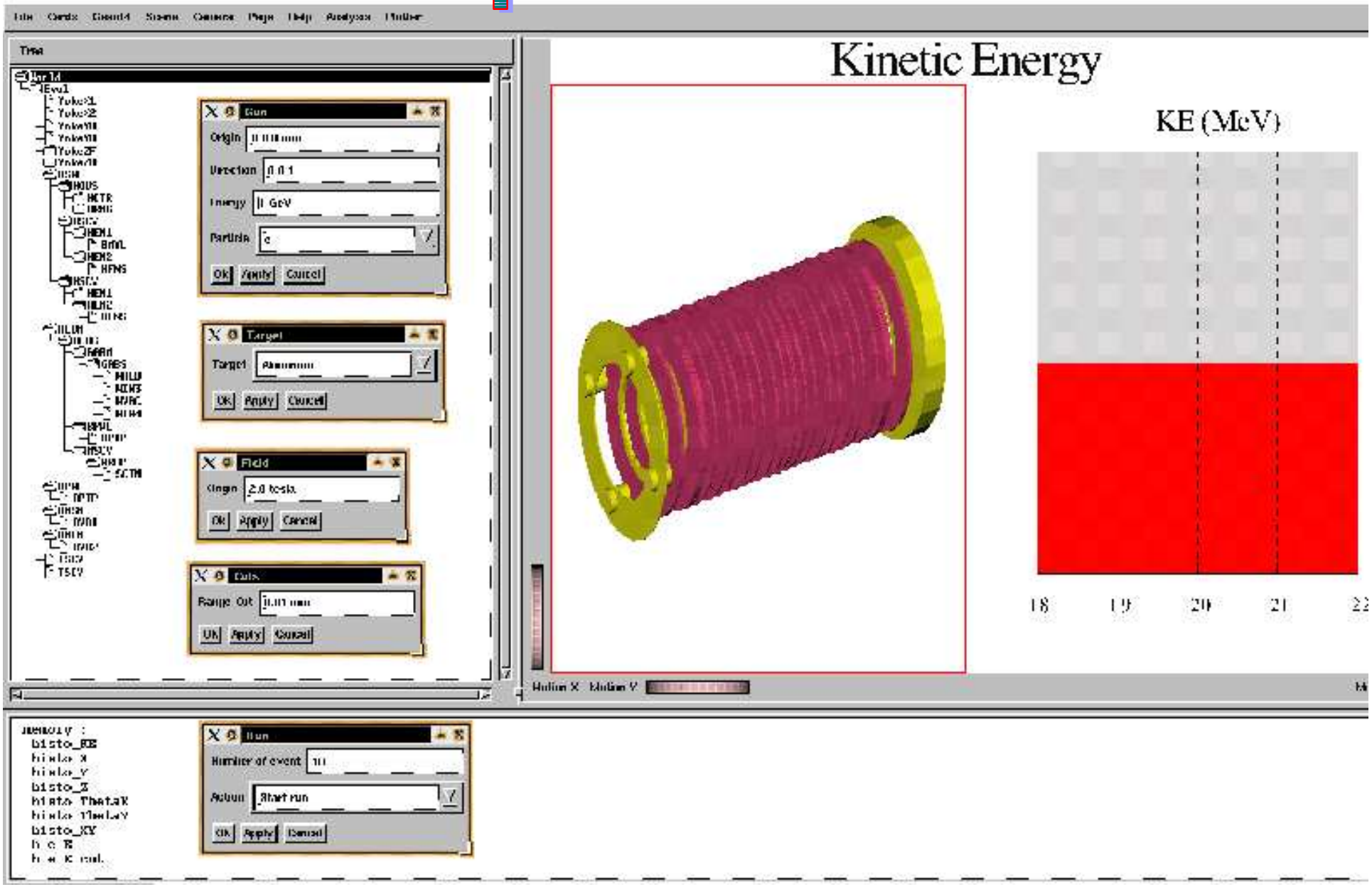
Drift Chamber
σ ~ 80 μm

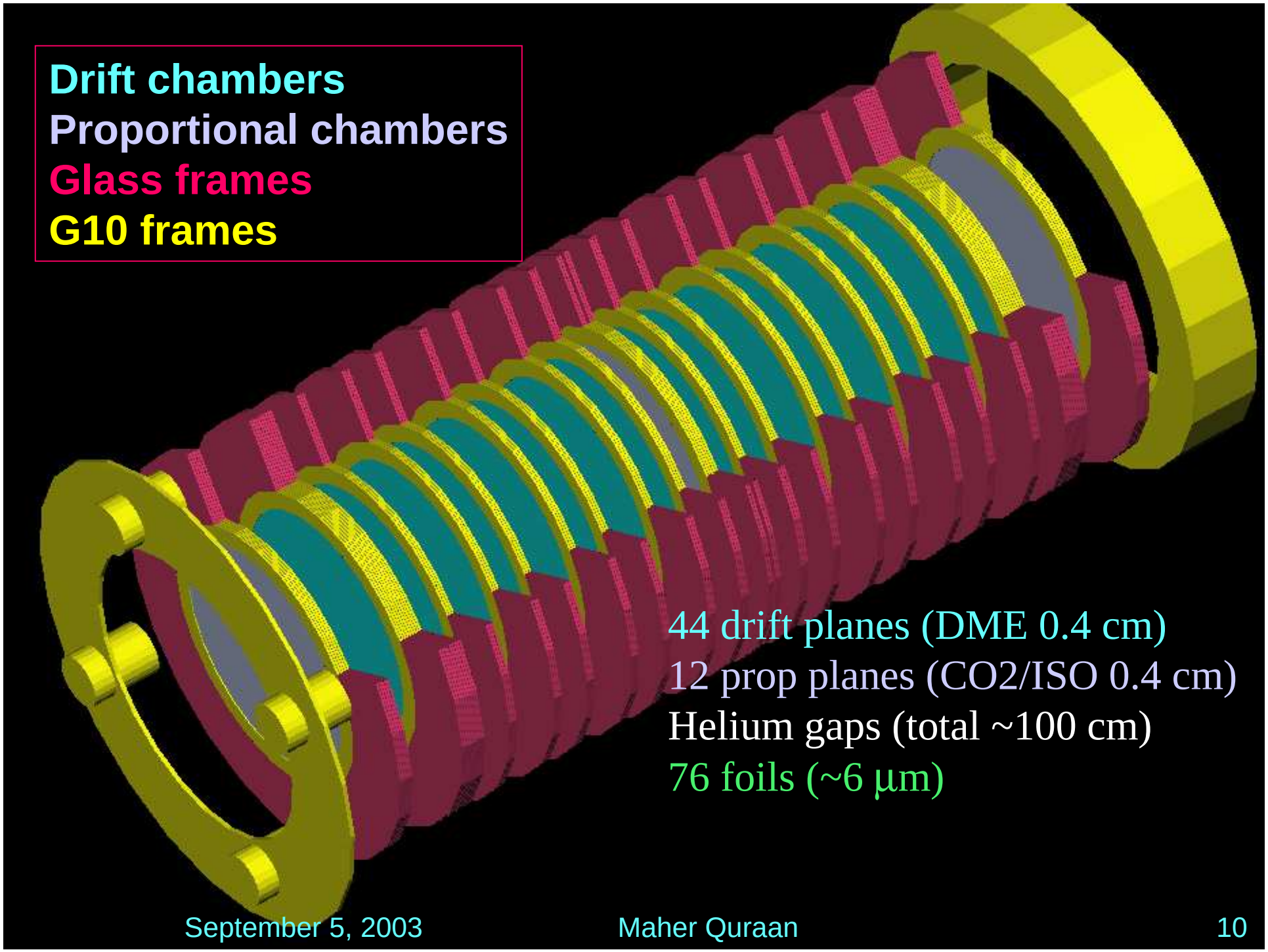
Visualizations & GUI's:

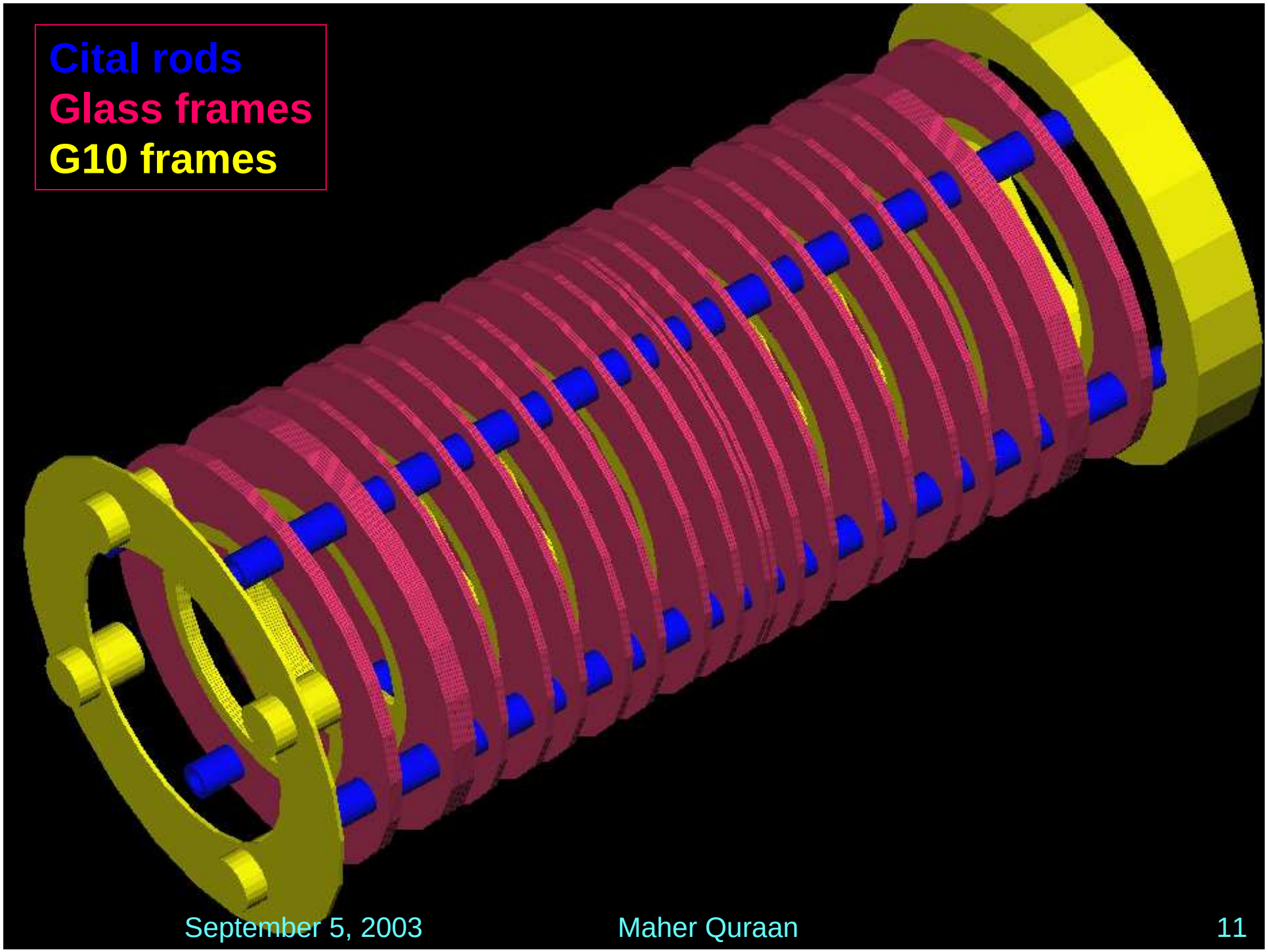
OpenScientist

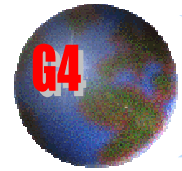


OpenScientist




Drift chambers
Proportional chambers
Glass frames
G10 frames
44 drift planes (DME 0.4 cm)
12 prop planes (CO2/ISO 0.4 cm)
Helium gaps (total ~100 cm)
76 foils (~6 μm)


Cital rods
Glass frames
G10 frames



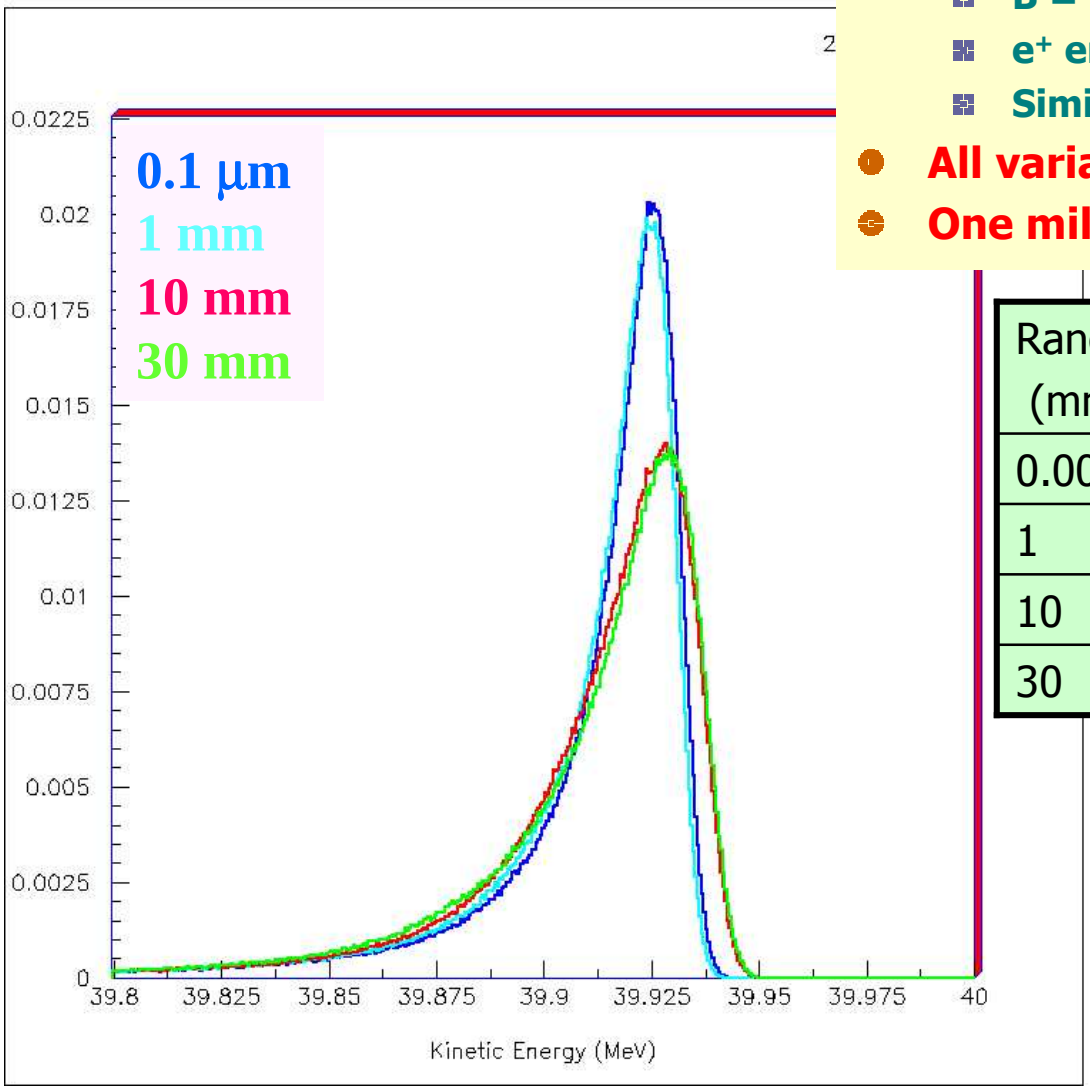
Stages of G3 to G4 Comparisons

- Direct comparisons of G3 and G4
  - Find bugs!!
  - Set step-sizes, and range/energy cuts.
  - e+ and μ+ ELOSS, MSC, δ-ray production.
- Comparisons of the reconstructed Spectra
  - Requires further development of G4.
  - Digitization.
- Comparisons of Michel spectra
  - Quantify various effects on the values of the Michel parameters.
  - Requires generating a large number of events.

1 billion events/set
Requires a lot of CPU time!

G4 Range Cut

- **Beam**
  - e+ Starting position: (0,0,2) cm
  - KE = 40 MeV
  - $\theta = 30^0, \phi = 0^0$
  - B = 2 T
  - e^+ energy threshold= 1 keV in G4
  - Similar step sizes in G3 and G4
- **All variables plotted at z=51 cm**
- **One million events simulated**



Range (mm)	DME	He-N	Mylar
0.0001	1 keV	1 keV	1 keV
1	1	1	418
10	33.5	1	2750
30	62.7	2.6	8320

ELOSS in TWIST Detector

G3 vs G4

Start beam: (0,0,0)cm

Beam KE: 40 MeV

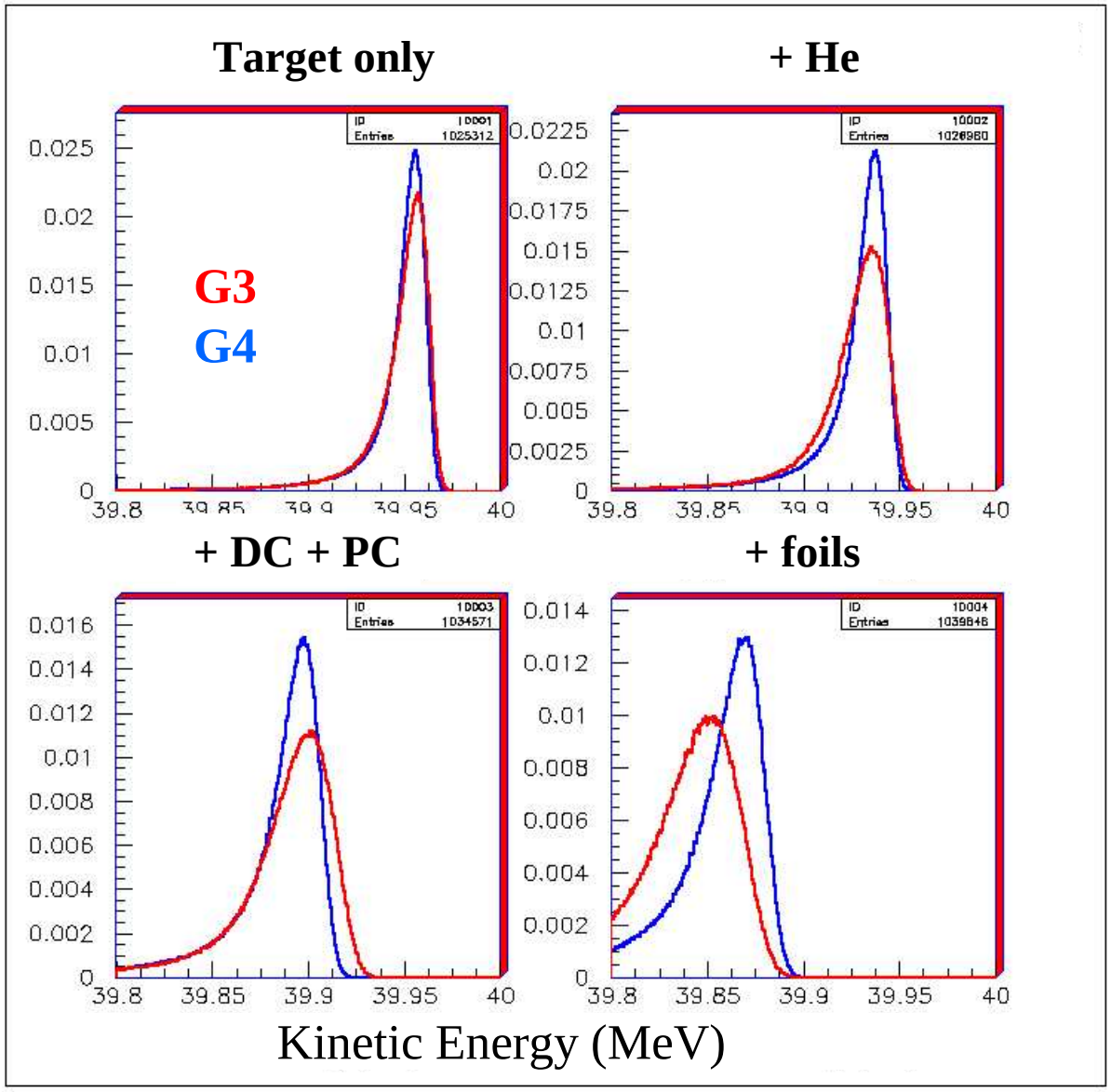
Beam angle: 30º

Range Cut = 1 μm

Step size

- **Target:10 μm**
- **He : 450 μm**
- **DC : 450 μm**
- **PC : 450 μm**
- **Foils: 1 μm**

KE plotted @ 51cm

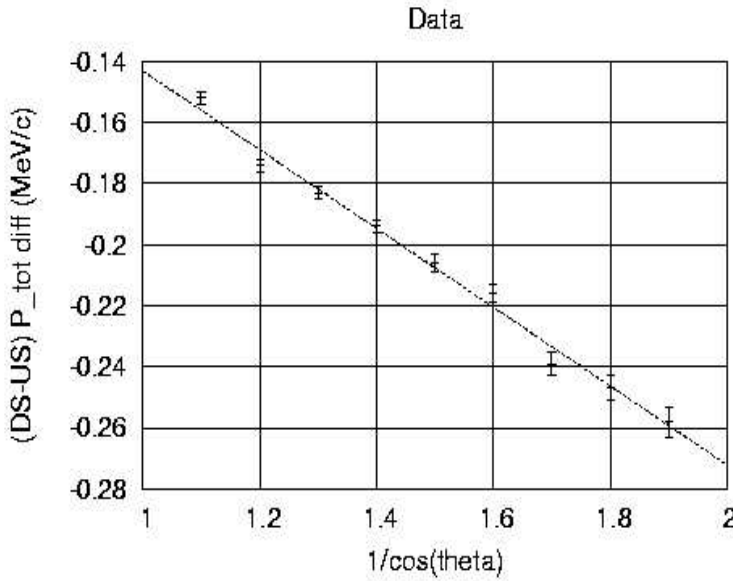


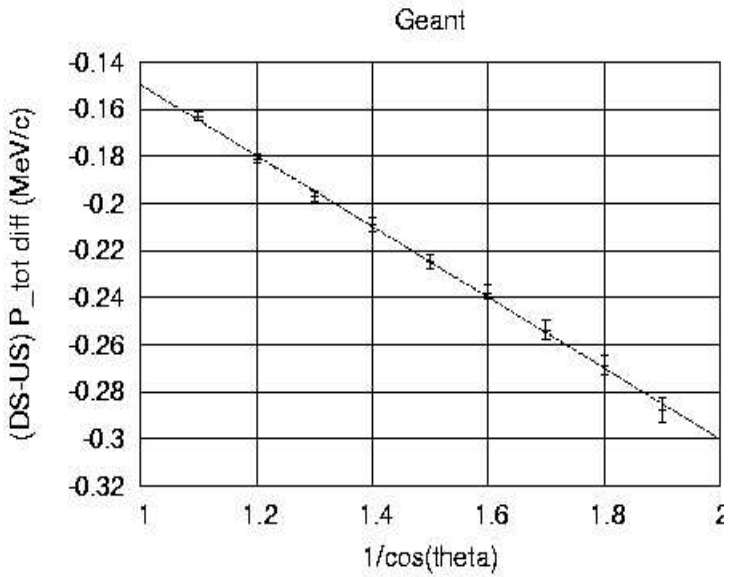
Energy Scale

- Foils see 40% less ELOSS in G4 than G3.
- However, TWIST has some handle on ELOSS.
  - Planar geometry arranged perpendicular to B field results in energy loss given by

$$E(z) = E_o - \frac{\alpha}{\cos(\vartheta)}$$

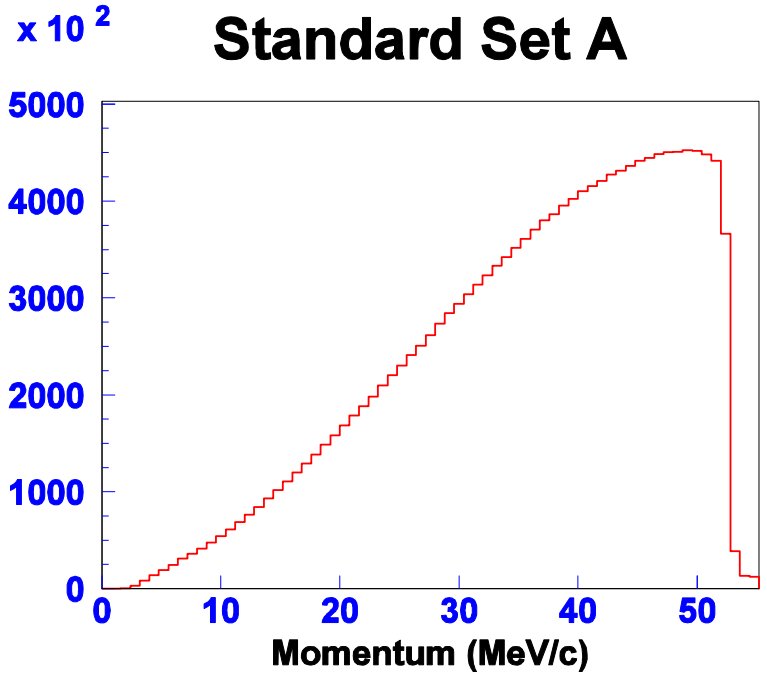
  - Comparisons of data to Monte Carlo allow adjusting the energy scale.





GEANT to Data Comparisons

- Energy Calibrations
  - Decay e+ edge (from μ+ decay).
  - e+ positron beam.
  - .π+ to e+ decay (mono-energetic).
- Mucn stopping distributions
  - ADCs on proportional chambers surrounding the target allow accurate determination of muon stopping distribution within target.



MSC in 1 Module

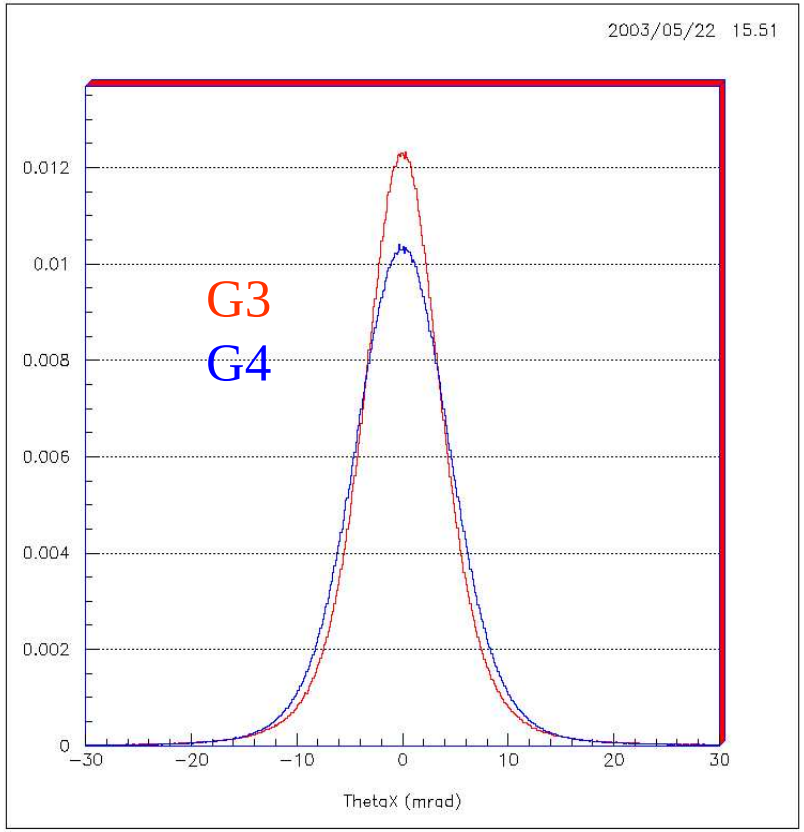
20 MeV e+ beam

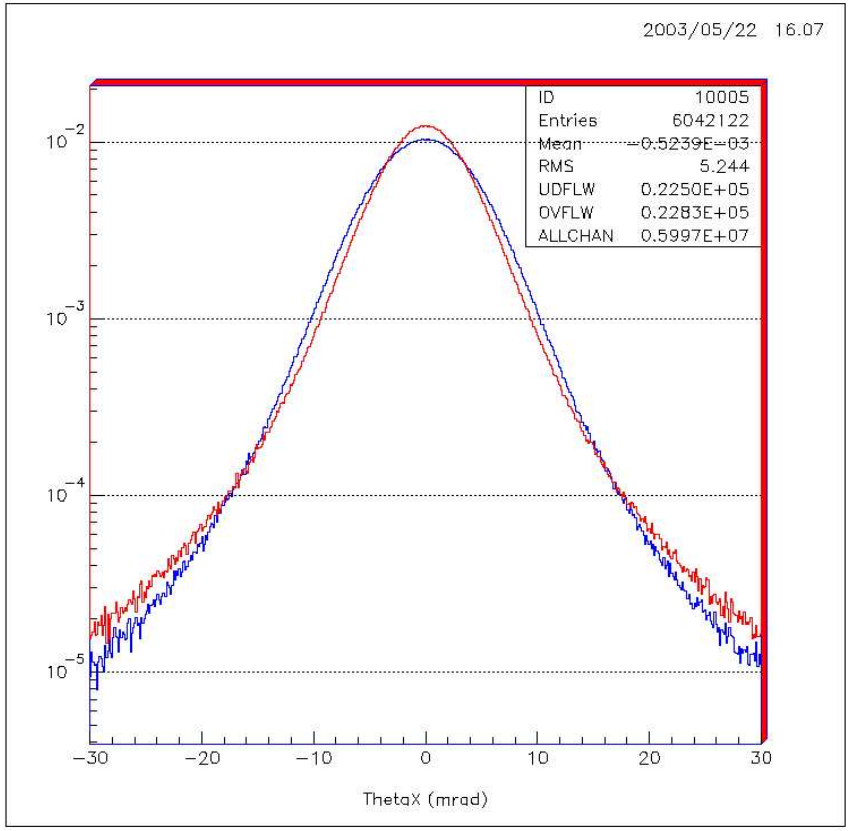
$\theta = 30^0, \phi = 0^0$

1 Module + 4 cm of helium

no field

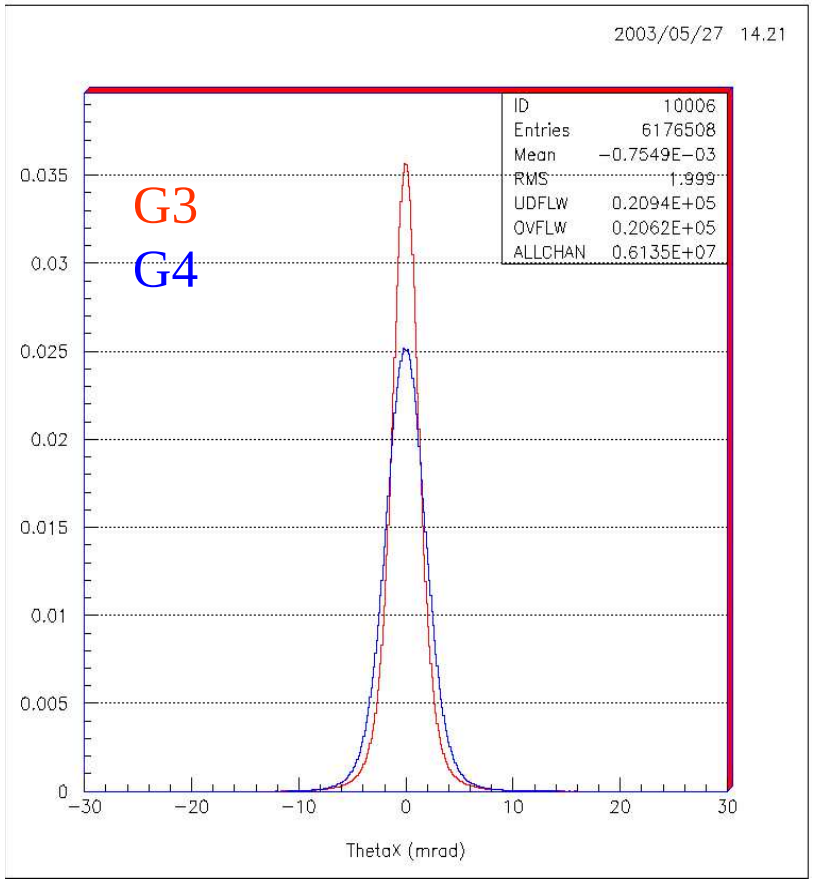
- e^+ energy threshold= 1 keV in G4
- Similar step sizes in G3 and G4
- One million events simulated

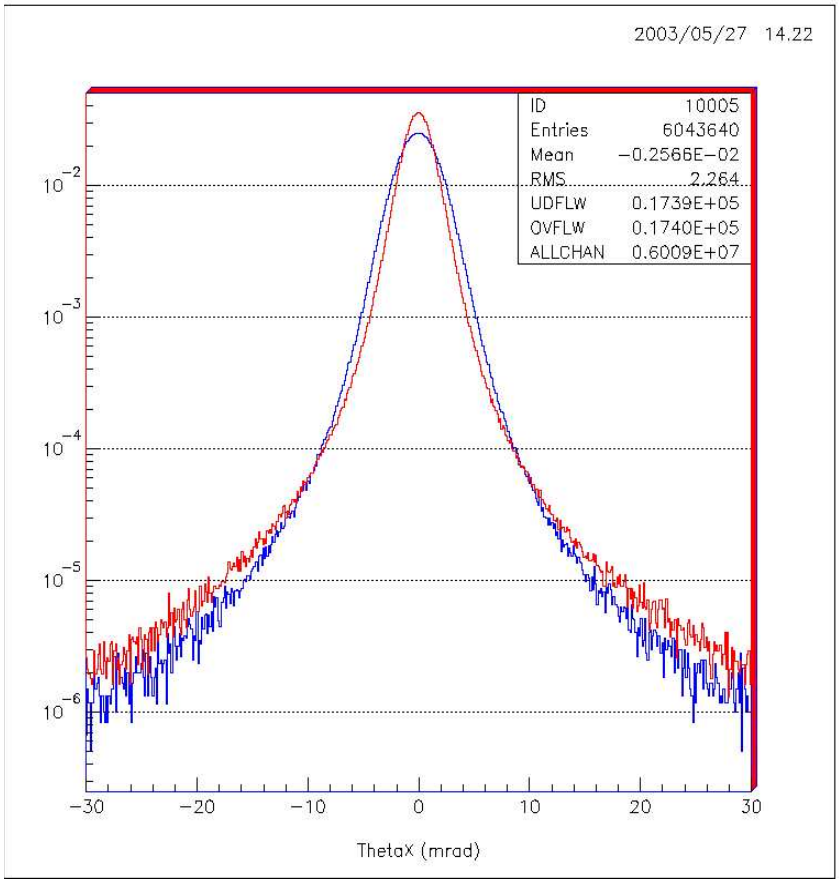




MSC in 1 Module

60 MeV e+ beam



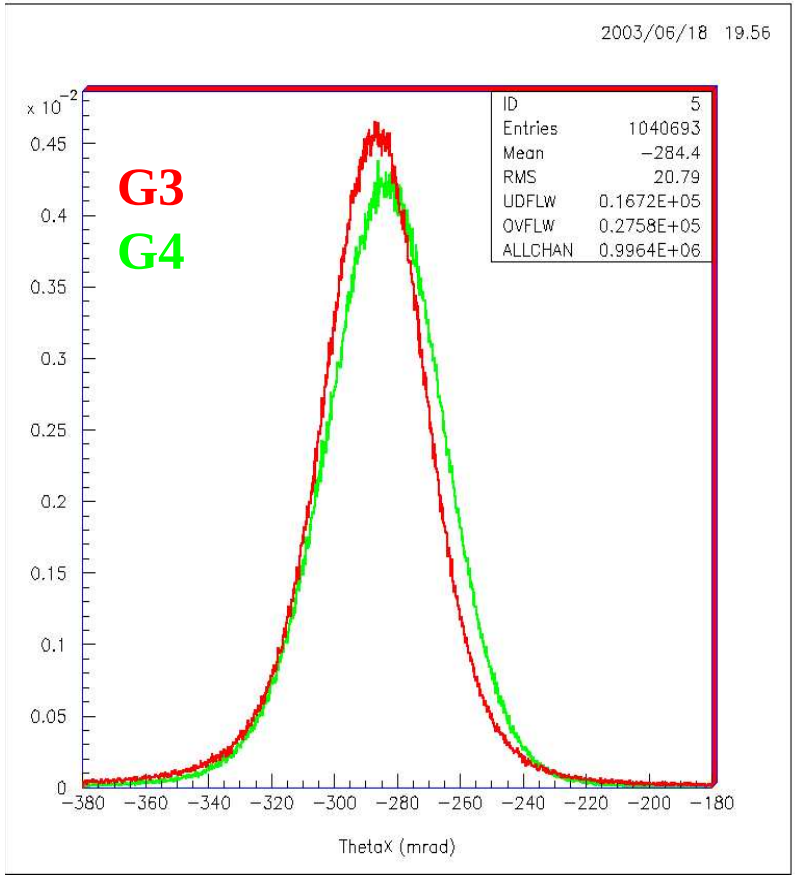


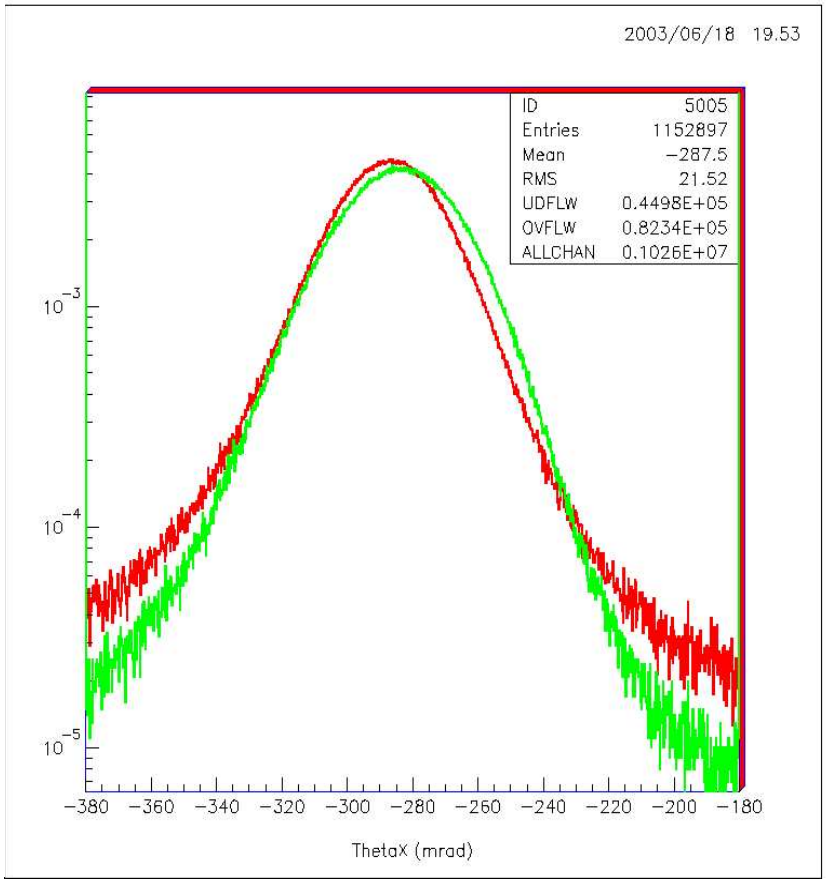
Accumulation of MSC in B Field

40 MeV e+ beam

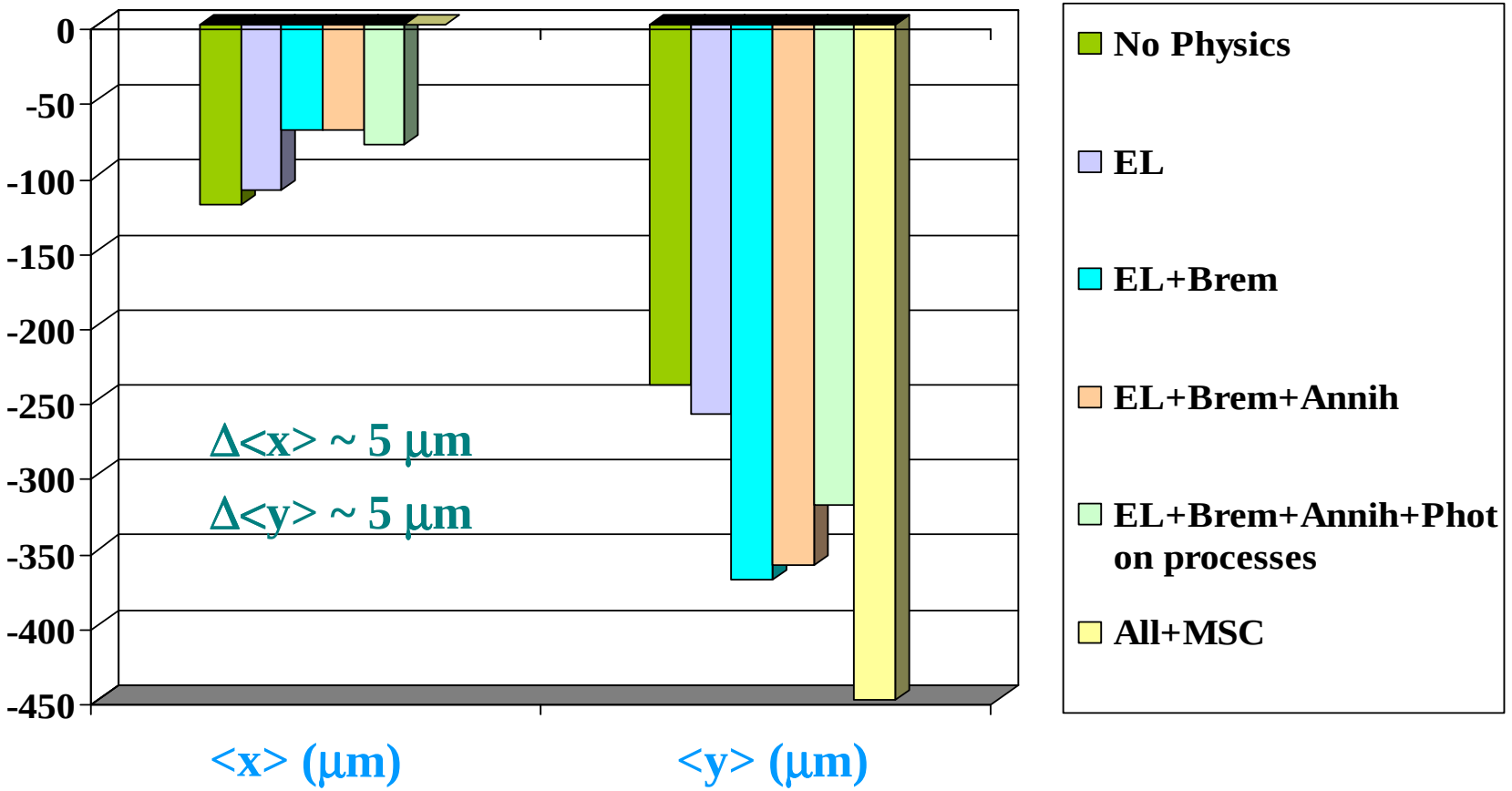
Half stack (no target)

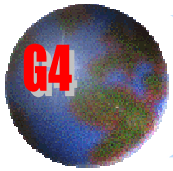
B = 2 T





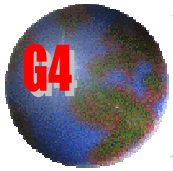
Comparison of Physics Processes





G4 Performance Tests

Range Cut (mm)	0.0001	0.01	1	10	50
CPU (ms/event)	30.4	20.2	12.8	11.5	10.9
% slower than G3	322%	180%	78%	60%	50%



Conclusions

- TWIST will make several G3 to G4 comparisons of EM processes.
- Various data sets will be used for high precision GEANT verifications including energy loss and multiple scattering.
- The TWIST detector will allow testing GEANT's performance in a series of planar low mass and thin media geometries.
- We currently see differences between G3 and G4, and are in the process of understanding the origin of these differences, and quantifying their effects on the Michel parameters.
- Advanced visualizations and GUIs (OpenScientist) are very valuable tools for simulation development.