# Outline

- Stages of the GEANT 4 program
- GEANT 4 software status
  - Geometry implementation, testing, and debugging
  - Interactive version: visualization and GUI
  - Batch version
  - Sensitive detectors and hit collection
- Example of sensitivities from GEANT 3
  - TmaxFD
- Effects of parameter settings in GEANT 4
  - Energy threshold (ranges)
  - Step size
- Direct GEANT 3 to GEANT 4 comparisons
  - Propagation in a magnetic field
  - Energy loss comparisons
  - Multiple scattering comparisons
- GEANT 4 performance tests

# Stages of the G4 program

1. Direct G3 to G4 comparisons – no digitization.
   - Can't simulate a full data set for everything
     - study how big various effects are
     - study whether effects are systematic (energy and/or angle dependent)
     - simulate a complete data sets starting with "big" effects
   - Are there any bugs in G3 or G4?
     - Geometry bugs found in G3
     - Step size bug found in G4
   - How do the various processes compare
     - energy loss
     - delta production (sensitivities to threshold)
     - multiple scattering, etc.
   - What are the sensitivities to parameter settings
     - ranges (energy cuts): can go quite low in G4
     - other parameters?
   - Many other effects can be compared!!
2. Complete digitization – if necessary
   - effects of various differences on the MPs are hard to interpret
3. Make G4 the main simulation program if we find that G3 is not adequate

# Geometry Parameters

- Reads geometry from geometry data file
  - dt_geo.00037
- Geometry variables have the same names and values in GEANT 3 for easy comparison including:
  - Parameters read in from geometry file
    - Declared in TWISTGeomRead.hh
    - Assigned in TWISTGeomRead.icc
  - Parameters declared and assigned in all geometry .inc and .par files
    - Declared in TWISTGeomParameters.hh
    - Assigned in TWISTGeomParameters.icc

# Geometry Volumes

- Geometry volume names are the same as in GEANT 3
- TWISTDetectorConstruction.hh declares the class and includes geometry variable declarations
- TWISTDetectorConstruction.cxx implements the class
  - TWISTGeomBeamLine.icc (beamline_geom.F)
  - TWISTGeomG10.icc (g10_geom.F)
  - TWISTGeomPC.icc (prop_geom.F)
  - TWISTGeomTarget.icc (targ_geom.F)
  - TWISTGeomChamber.icc (chamber_geom.F)
  - TWISTGeomHouse.icc (hous_geom.F)
  - TWISTGeomYoke.icc (yoke_geom.F)
  - TWISTGeomDC.icc (drift_geom.F)
  - TWISTGeomSC.icc (scint_geom.F)

# AIDA

**Geant 4 can be used with AIDA for histogramming**

**AIDA – Abstract Interfaces for Data Analysis**

- **Founded by an international group of computing scientists, engineers, physicists, in 1999 to help the development of software tools for academic scientific research**
- **Allows defining 1D, 2D, 3D histograms and ntuples**
- **Can use any AIDA compliant viewer w/o code modifications**
- **Analysis systems using (or planning to use AIDA) include COLT, JAS, Lizard, OpenScientist, ROOT?**

# Interactive Version - OpenScientist

- Author is Guy Barrand, LAL.
- Do not re-invent the wheel.
  - Take advantage of free and open software code that is available
    - OpenMotif, gtk+ etc for GUI
    - OpenGL, OpenInventor for graphics
    - ROOT for I/O

# OSC Packages

- Four main suites

(1) GEANT4

- CLHEP- HEP-specific utility classes such as random generators, physics vectors, geometry and linear algebra

(2) Lab – Analysis and histogramming

- AIDA – abstract interfaces for data analysis objects
- HCL – histogramming library for OpenScientist
- Midnight – fitting, based on Rene Brun C++ rewriting of MINUIT
- Rio – rewriting of ROOT I/O system

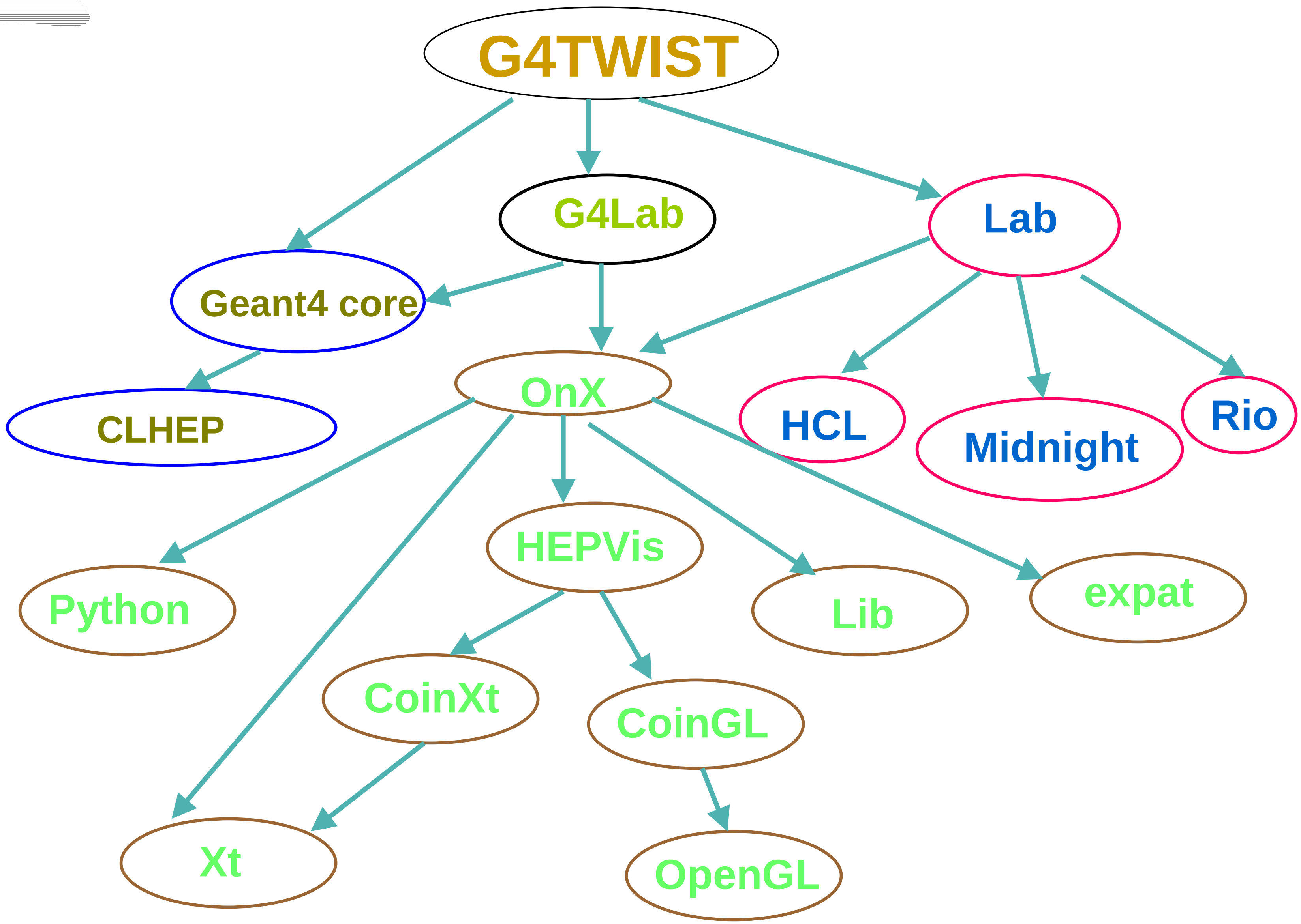
(3) OnX – Visualization and GUIs (hub for interactivity)

- Coin3D - high-level 3D graphics library with a C++ Application Programming Interface
- HEPVis - develop and maintain tools built over Open Inventor for HEP
- expat – XML reader used by OnX
- Lib – a collection of common C++ tools (parsers, etc)

(4) External packages

- OpenMotif – OnX default GUI on Linux
- Python – OnX default interpreter
- etc

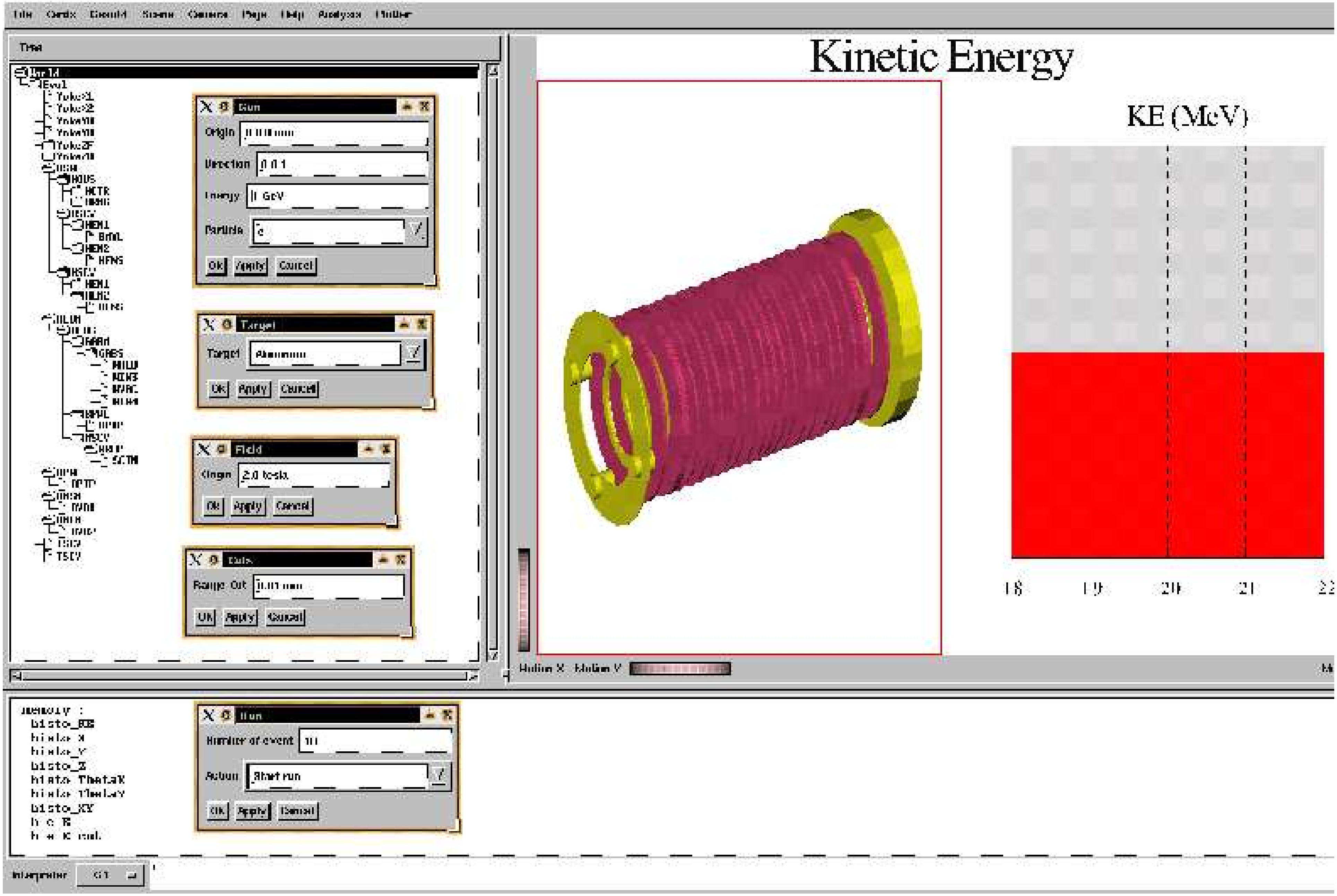
# OpenScientist hierarchy



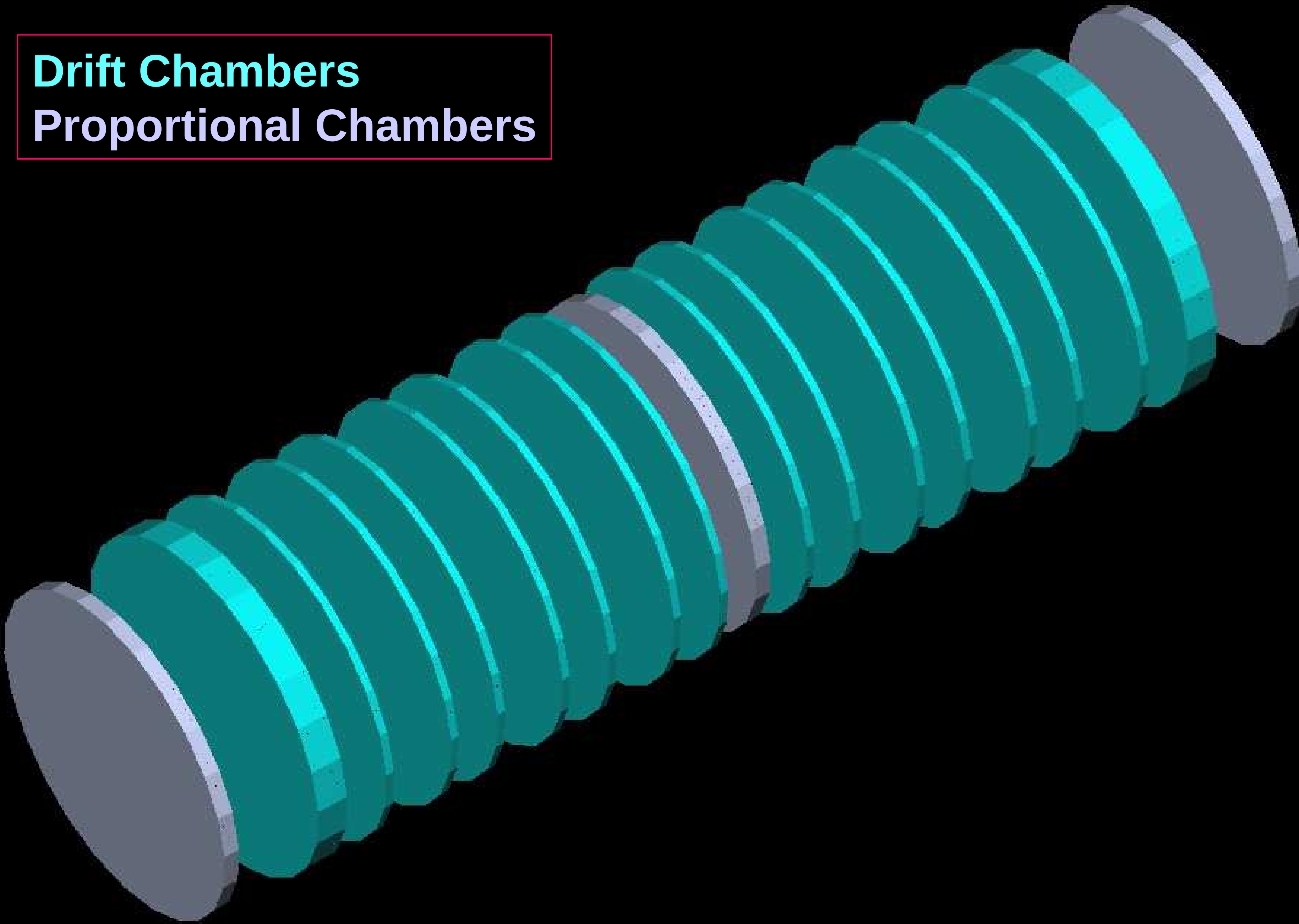
# Installed Packages

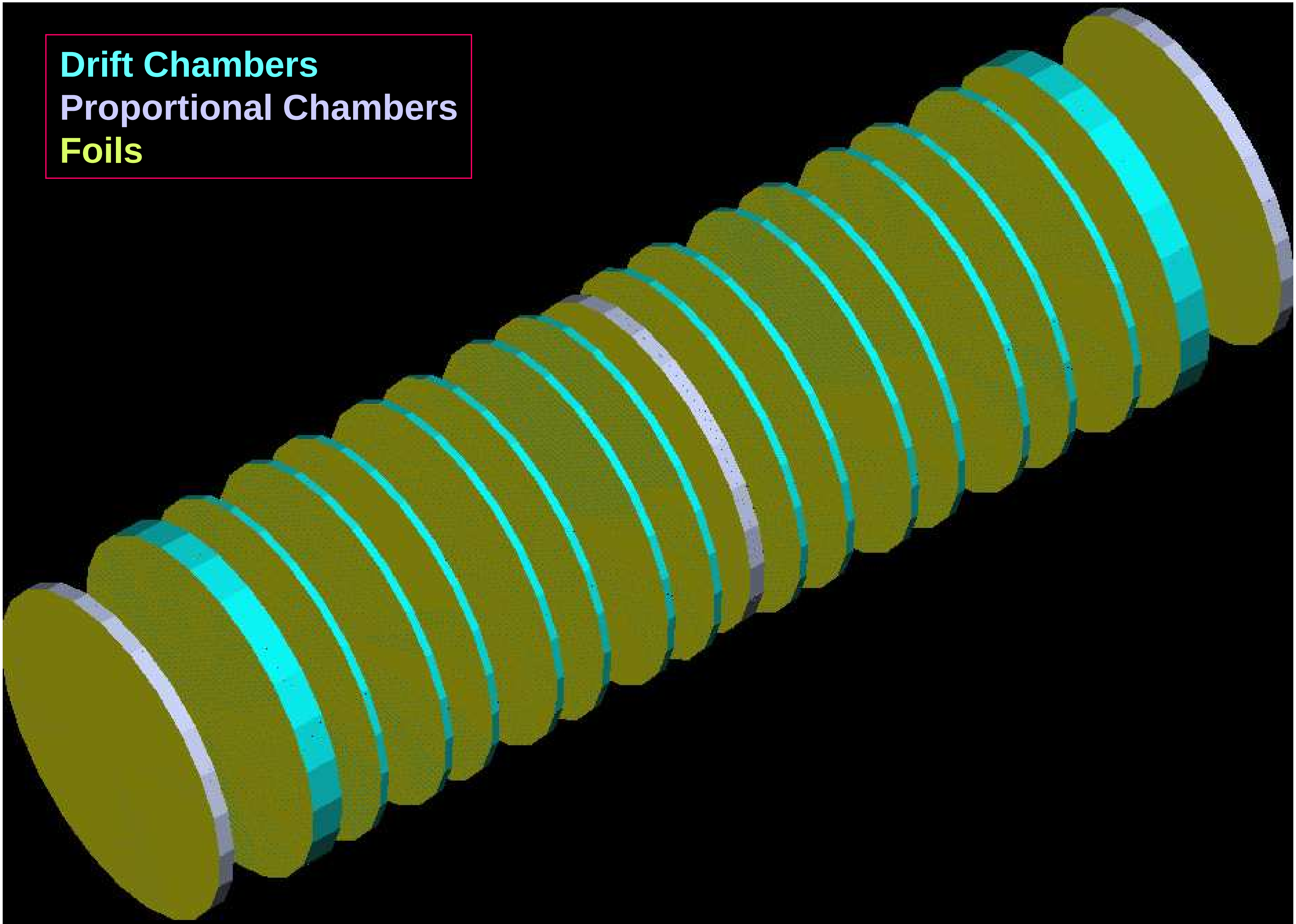
## Installed on dork

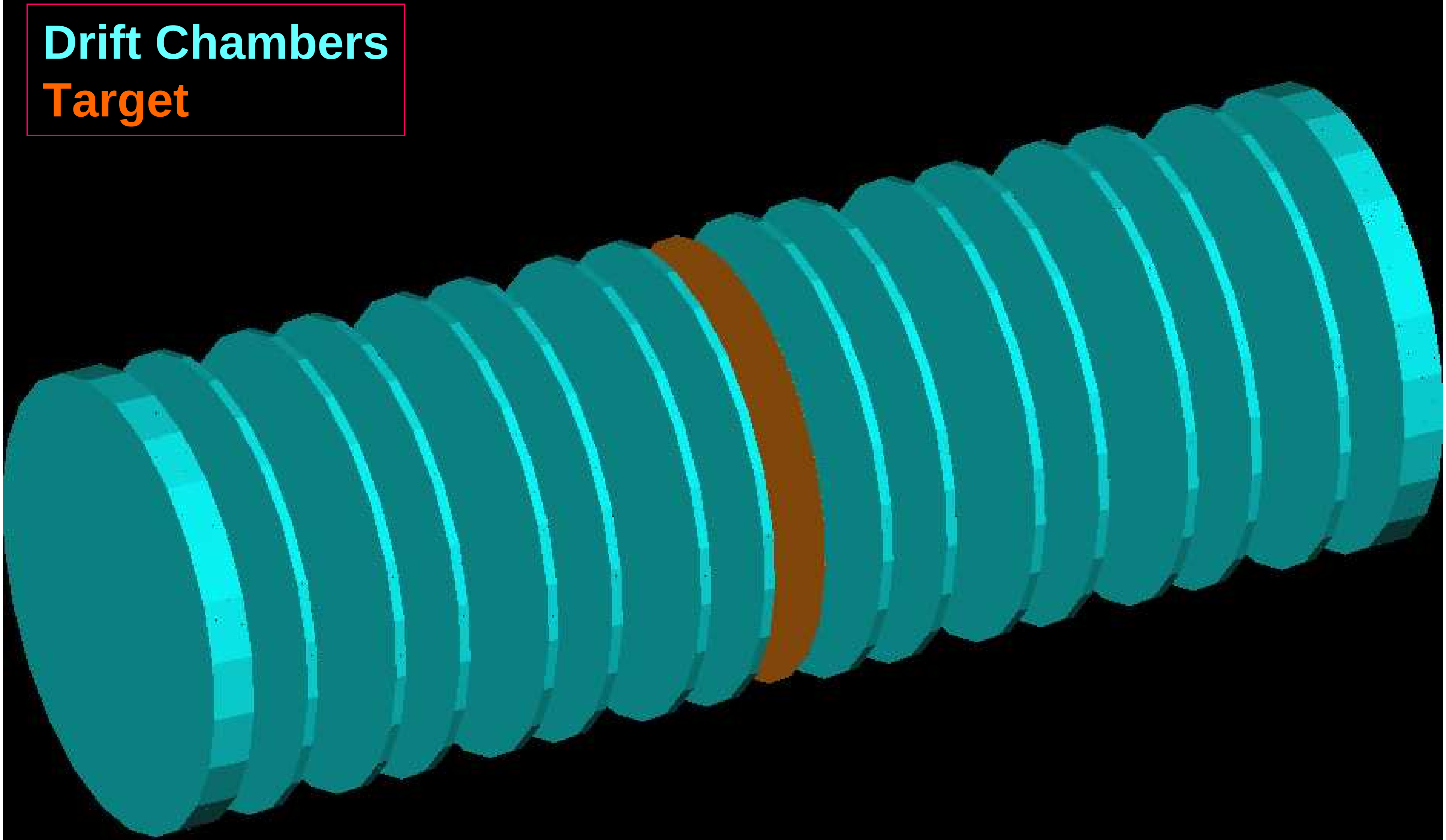
- AIDA
- CMT
- expat
- G4Lab
- G4LabSimple
- Geant4
- HEPVis
- Lib
- OnX
- Rio
- CoinGL
- CoinXt
- HCL
- Lab
- Midnight
- OpenScientist


Kinetic Energy
KE (MeV)
Gun
Origin
Direction
Energy
Particle
Ok
Apply
Cancel
Target
Field
2.0 tesla
Cuts
Range Cut
Run
Number of event
Action
Start run
histo_X
histo_Y
histo_Z
histo_ThetaX
histo_XY

Drift Chambers
Proportional Chambers

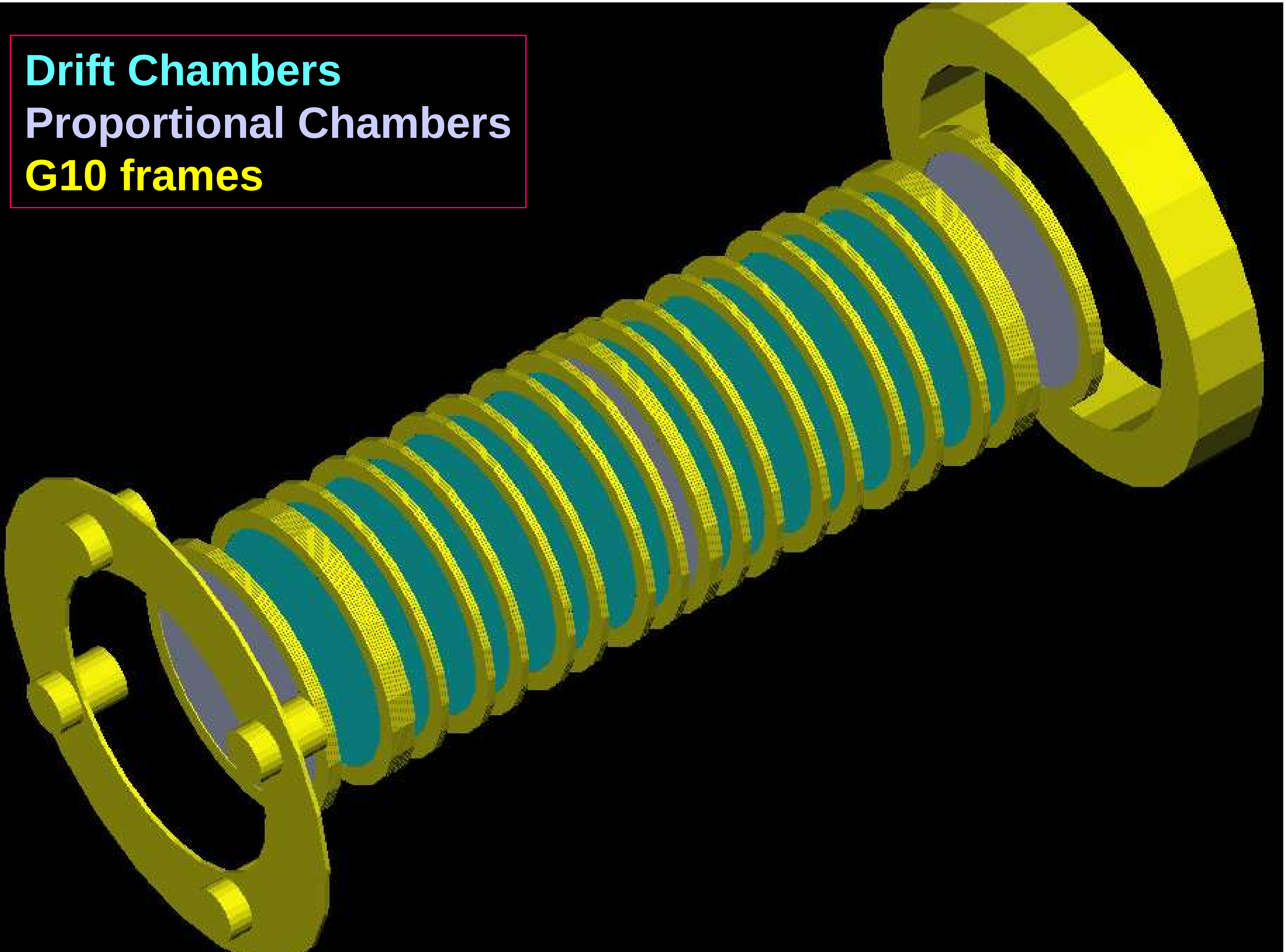


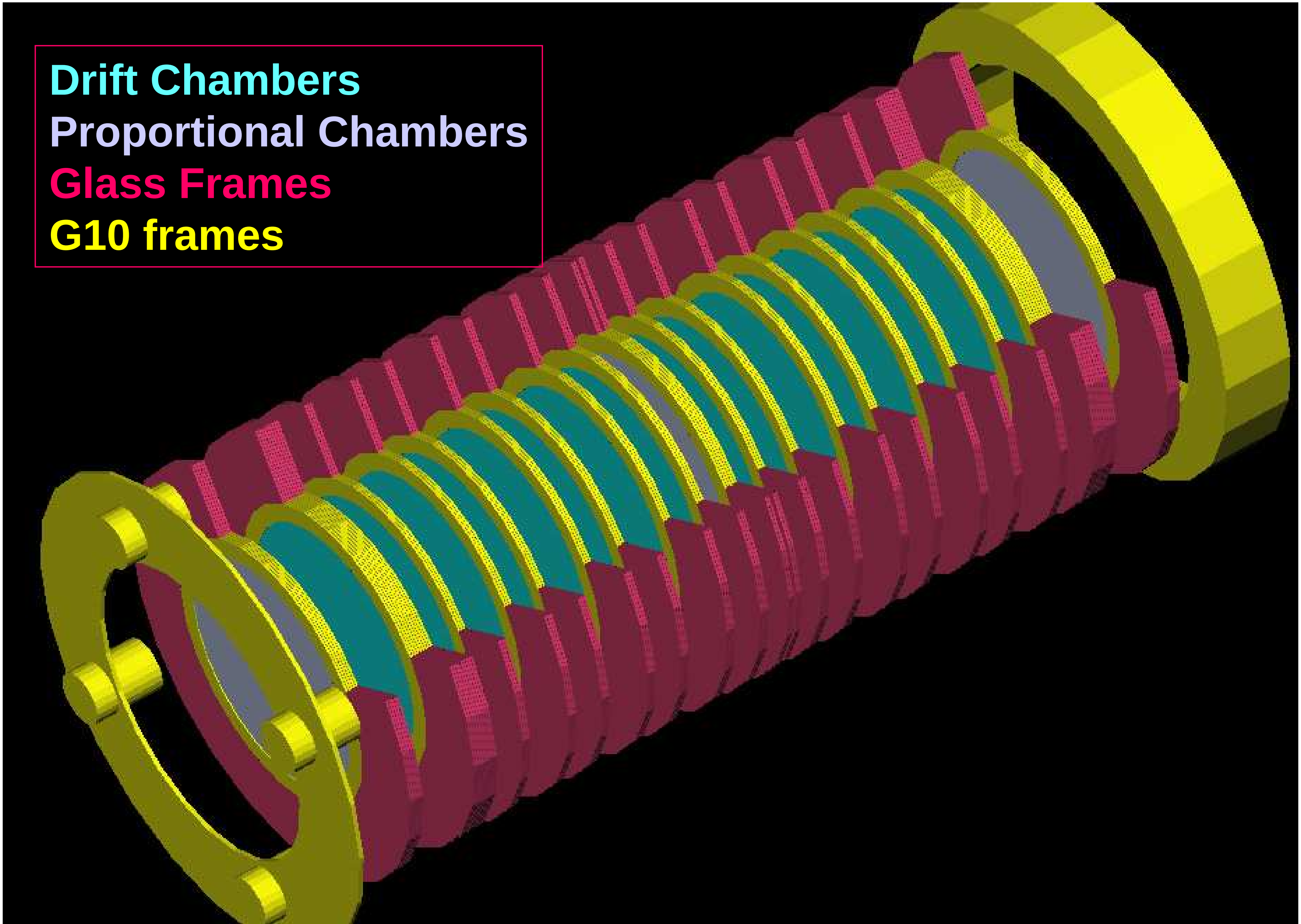

Drift Chambers
Proportional Chambers
Foils

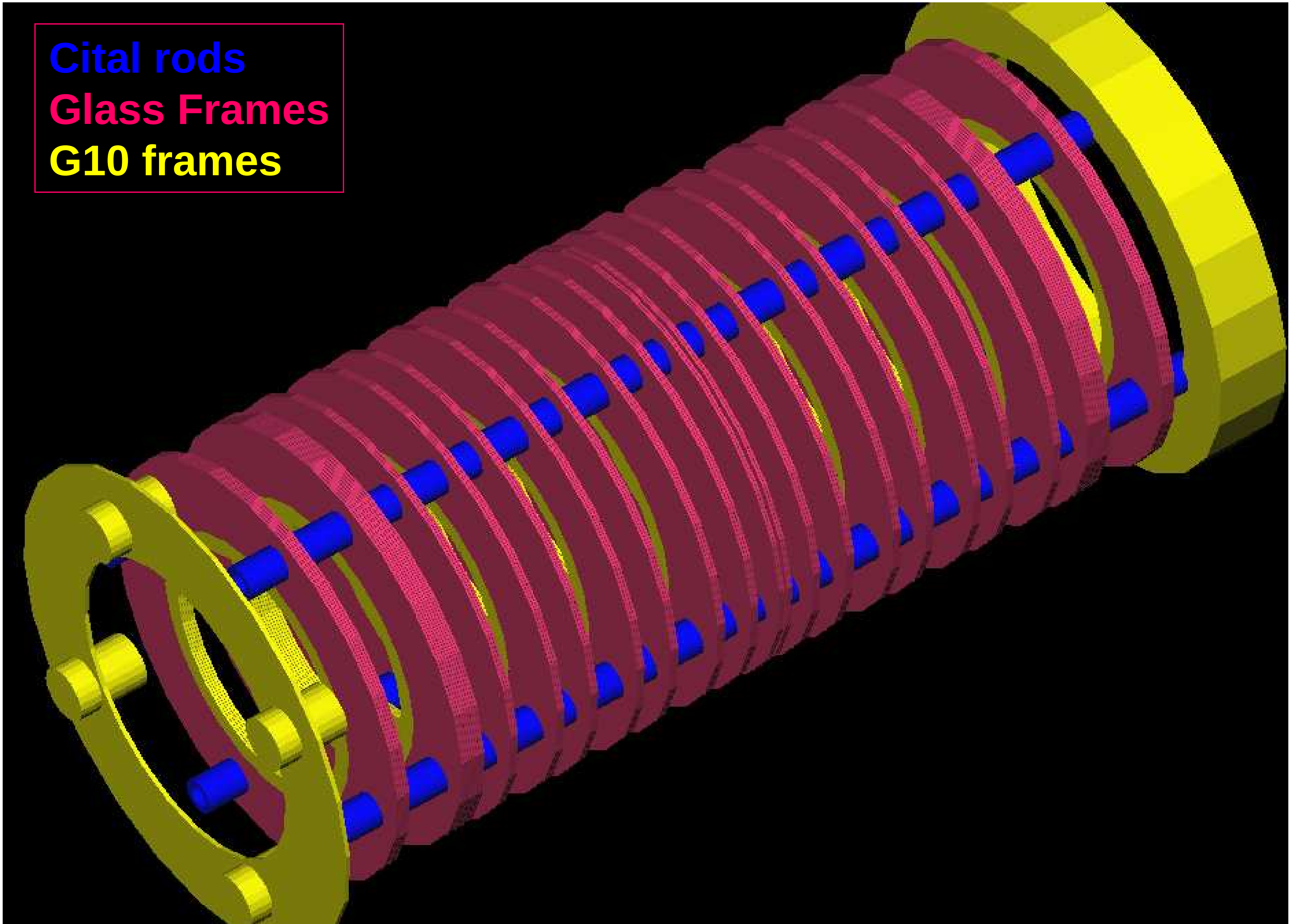


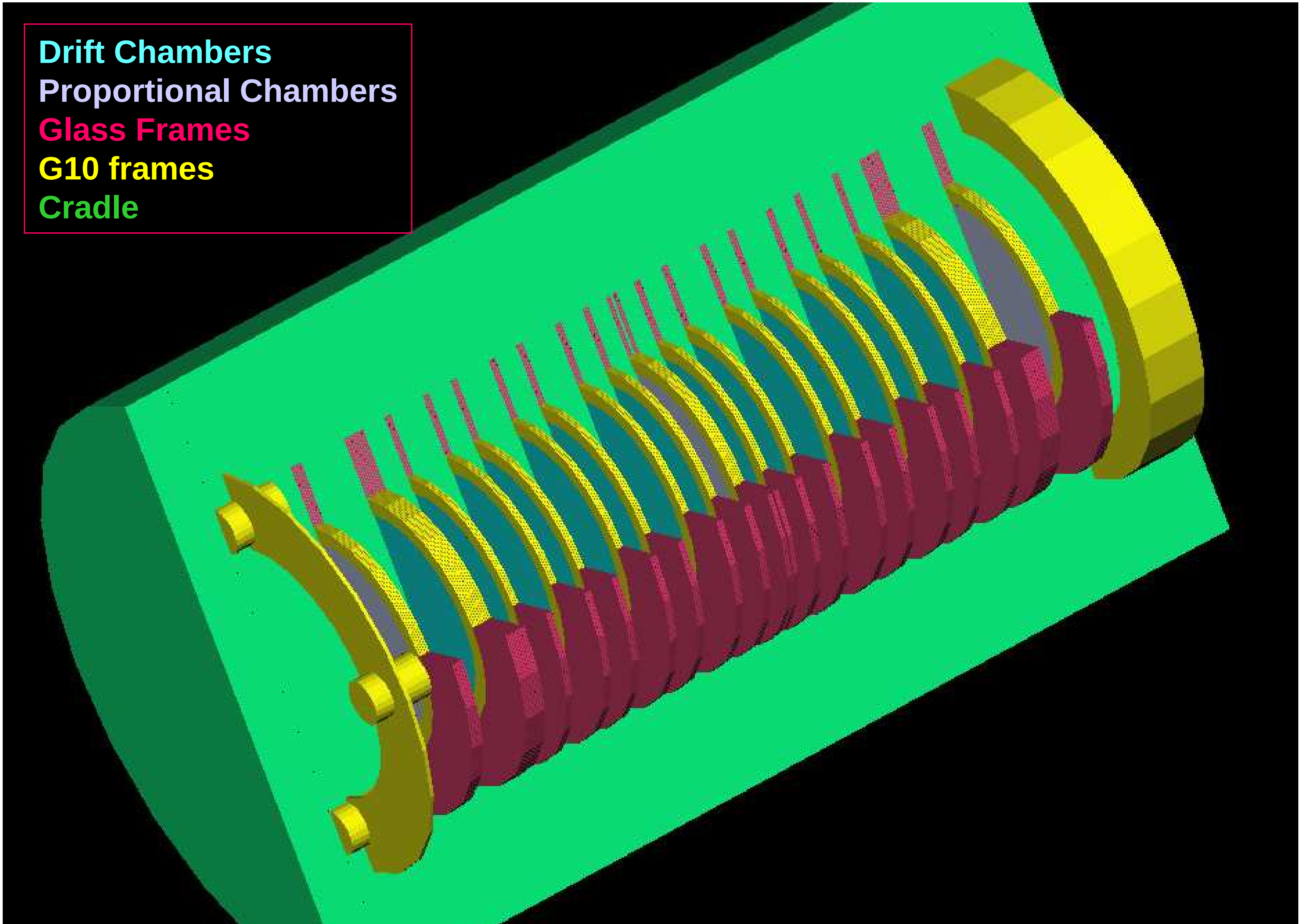
Drift Chambers
Target

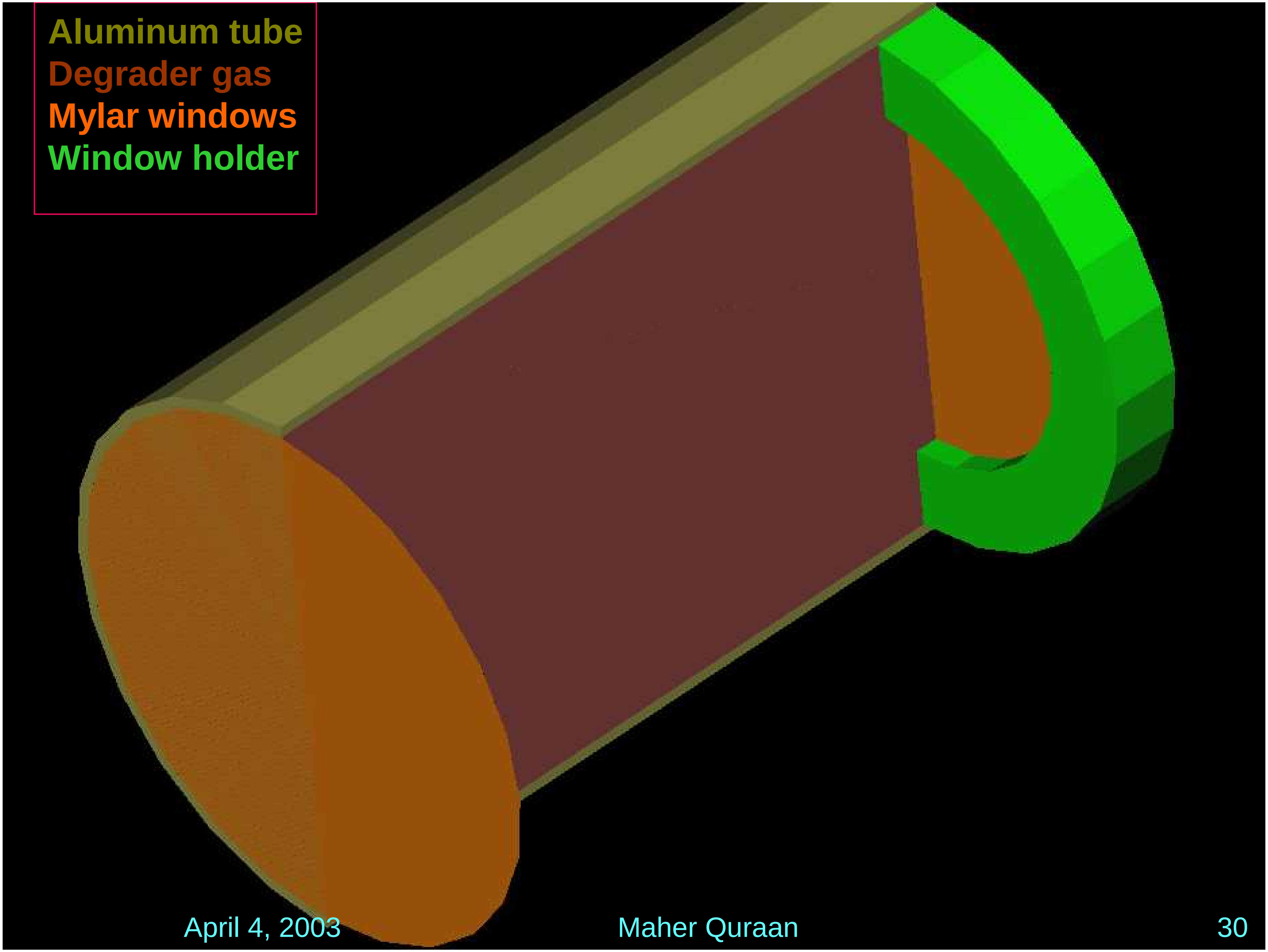
**Drift Chambers**
**Proportional Chambers**
**G10 frames**

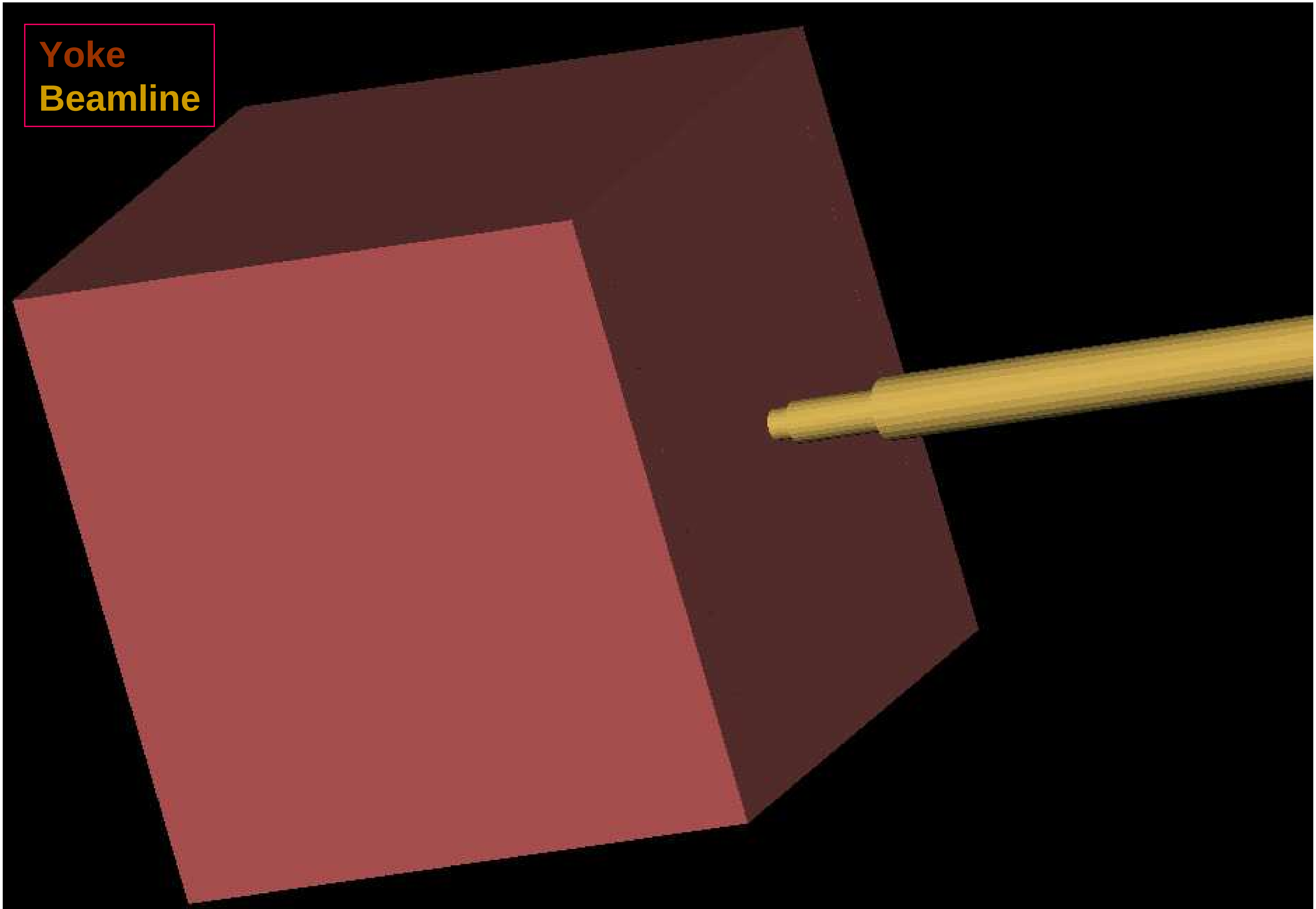



Drift Chambers
Proportional Chambers
Glass Frames
G10 frames


Cital rods
Glass Frames
G10 frames


Drift Chambers
Proportional Chambers
Glass Frames
G10 frames
Cradle


Aluminum tube
Degrader gas
Mylar windows
Window holder


Yoke
Beamline

# Batch Version - twist.mac

```
# Set verboses
# ==========
/control/verbose 0
/run/verbose 1
/tracking/verbose 0
/event/verbose 0
/process/verbose 0

# Set Particle gun properties
# ======================
# Particle: implemented options: e+, e-, mu+, mu-, gamma
/gun/particle e+

# Kinetic energy. Allowed units: eV, keV, MeV, GeV
/gun/energy 40 MeV

# Beam origin x y z. Allowed units: m, cm, mm, ...
/gun/position 0 0 2 cm

# momemtum direction unit vector px py pz
# theta = 30, phi = 0
/gun/direction 0.5 0.0 0.8660
# theta = 70, phi = 0
# /gun/direction 0.93969 0.0 0.34202

# Set detector features
# ===============
# Target material
/TWISTdetector/setTargetMat Aluminum

# Magnetic field value (uniform field along z)
/TWISTdetector/setField 2 tesla

# CO2 fraction in CO2/He gas absorber
#/TWISTdetector/setCO2frac 0.1
```

```
# Set range cuts
# ============

# At 0.1 micron a minimum energy of 1 KeV is used for
      all materials

/run/particle/setCut 0.1 mm
/run/initialize
/run/particle/dumpCutValues


# Activate/inactivate processes
# ======================

# Activate/inactivate all processes
# /process/inactivate

# Inactivate selected processes
# Comment out the process that you wish to inactivate
#/process/inactivate eIoni
#/process/inactivate eBrem
#/process/inactivate annihil
#/process/inactivate compt
#/process/inactivate phot
#/process/inactivate conv
/process/inactivate MuIoni
/process/inactivate MuBrems
/process/inactivate MuPairProd
/process/inactivate Decay
/process/inactivate Scintillation
/process/inactivate OpBoundary
/process/inactivate OpAbsorption
/process/inactivate msc

# Run
# ====
/run/beamOn 1000000
```

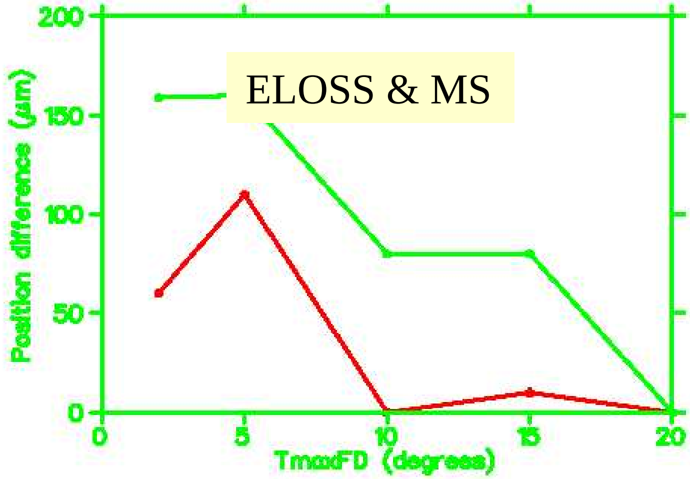
## Sensitive Detectors

- Define a class for each type of sensitive detector which inherits the Geant class G4VSensitiveDetector
  - TWISTDriftChamberSD.hh
  - TWISTPropChamberSD.hh
  - TWISTPropThinChamberSD.hh
  - TWISTTimeScintSD.hh
  - TWISTScintSD.hh
- Implement the sensitive detector classes
  - TWISTDriftChamberSD.cc
  - TWISTPropChamberSD.cc
  - TWISTPropThinChamberSD.cc
  - TWISTTimeScintSD.cc
  - TWISTScintSD.cc

## Hit Collection

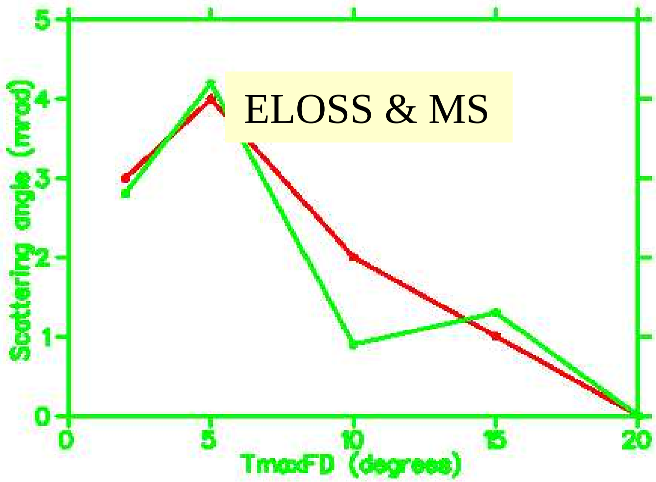
- Define a hit collection class for each type of sensitive detector which inherits the Geant class G4VHit
  - TWISTDriftChamberHit.hh
  - TWISTPropChamberHit.hh
  - TWISTPropThinChamberHit.hh
  - TWISTTimeScintHit.hh
  - TWISTScintHit.hh
- Implement the sensitive detector classes
  - TWISTDriftChamberHit.cc
  - TWISTPropChamberHit.cc
  - TWISTPropThinChamberHit.cc
  - TWISTTimeScintHit.cc
  - TWISTScintHit.cc

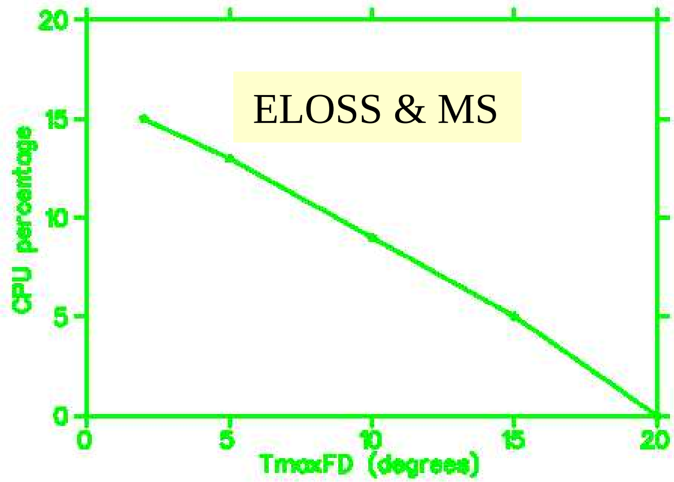
# GEANT 3 TmaxFD




NO ELOSS or MS

| TmaxFD | <x> (cm) | <y> (cm) |
|---|---|---|
| $0^0$ | 2.782 | -2.529 |
| $20^0$ | 2.782 | -2.529 |



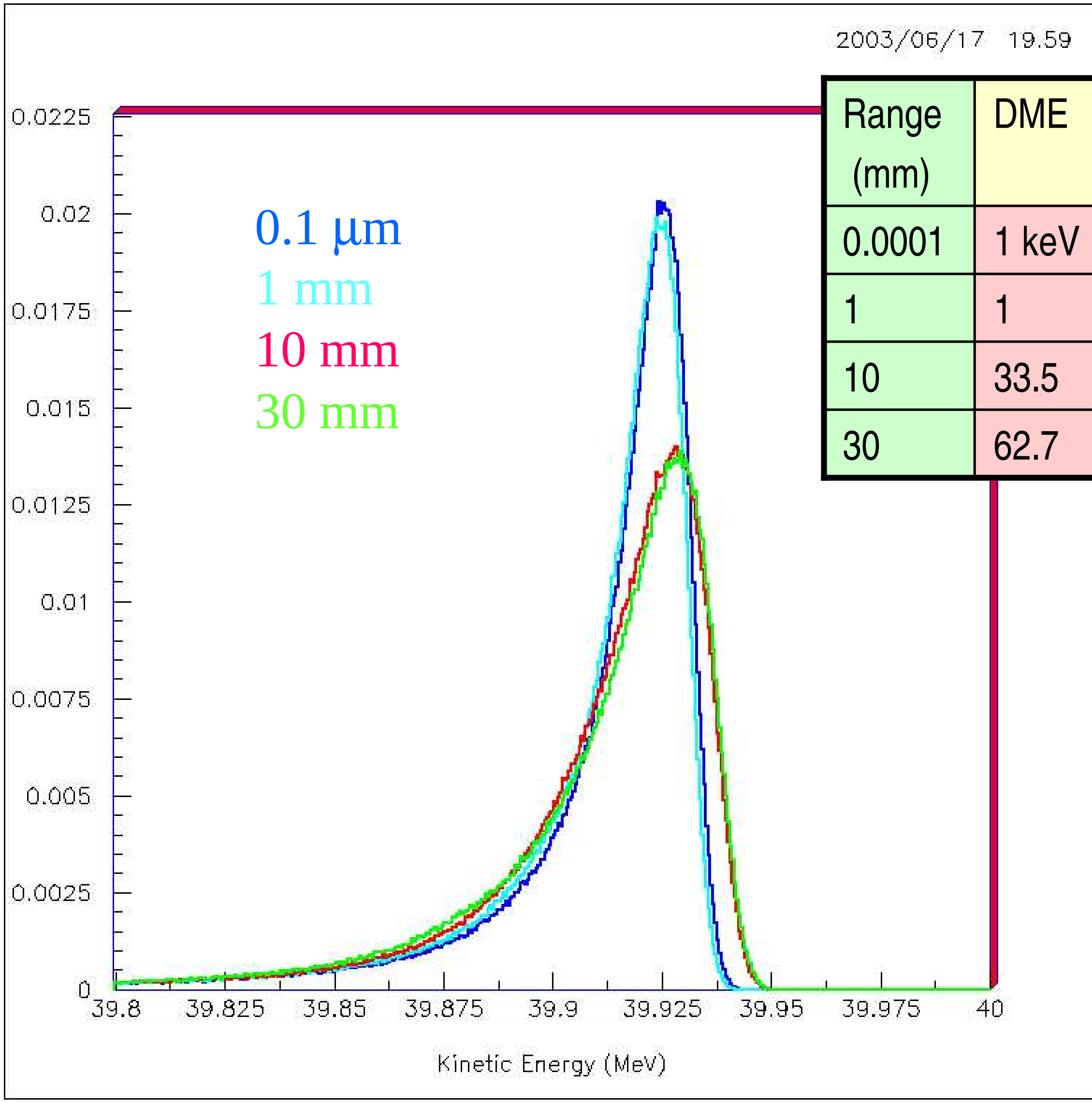
# Electromagnetic Physics Processes

- Energy Loss
  - Explicit production of delta rays above an energy threshold
    - Bhabha scattering for positrons
  - Continuous energy loss below
    - Berger-Seltzer formula
- Bremmstrahlung
  - Using cross sections compiled by Berger and Seltzer (G3 & G4)
    - 1keV-10GeV
    - Dielectric suppression of bremsstrahlung used in both G3 and G4
    - Landau-Pomeranchuk-Migdal in G4 only
      - Suppression of bremsstrahlung photon production due to multiple scattering
- Multiple scattering
  - Moliere theory in G3
    - Computes only angular distribution after each step
  - Lewis theory in G4
    - Computes both angular and spatial distributions after each step

# Energy Cut for Various Ranges

| Range Cut (mm) | 0.0001 | 0.01 | 1 | 10 | 50 |
|---|---|---|---|---|---|
| Vacuum | 1 keV | 1 keV | 1 keV | 1 keV | 1 keV |
| DME | 1 | 1 | 1 | 1 | 84.3 |
| He/Ni | 1 | 1 | 1 | 1 | 5.24 |
| He/CO2 | 1 | 1 | 1 | 1 | 11.7 |
| Air | 1 | 1 | 1 | 1 | 60 |
| CF4/ISO | 1 | 1 | 1.23 | 1 | 104 |
| Mylar | 1 | 9.35 | 418 | 2750 | 13000 |
| Aluminum | 1 | 33.9 | 597 | 4550 | 25800 |
| Tungsten | 1 | 81.4 | 2310 | 29200 | 310000 |

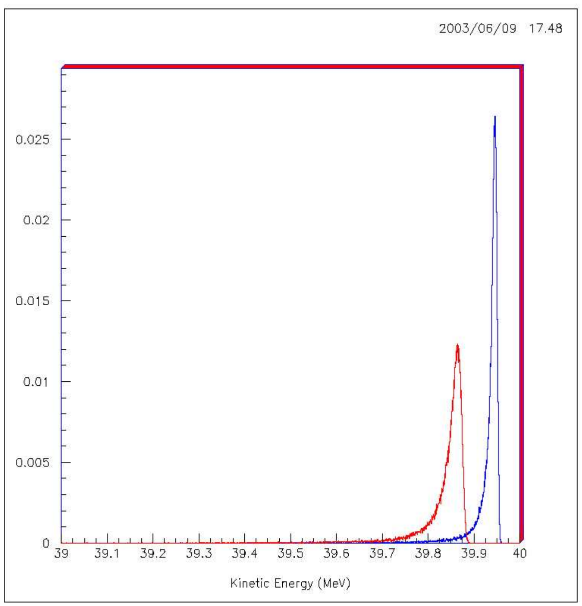
# Parameter Settings in G4 - Ranges

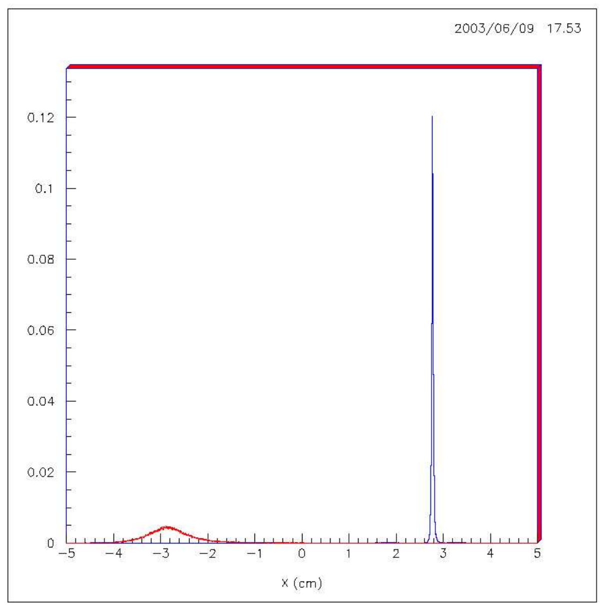


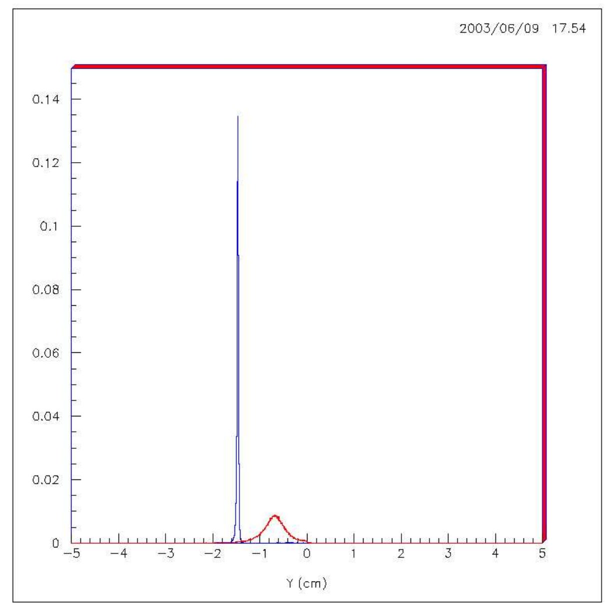

| Range (mm) | DME | He-N | Mylar |
|---|---|---|---|
| 0.0001 | 1 keV | 1 keV | 1 keV |
| 1 | 1 | 1 | 418 |
| 10 | 33.5 | 1 | 2750 |
| 30 | 62.7 | 2.6 | 8320 |

# Parameter Settings in G4 - maxStep

| maxStep (mm) | <x> (cm) | <y> (cm) | <KE> (cm) |
|---|---|---|---|
| 200 | -2.603 | -0.7684 | 39.83 |
| 400 | -2.603 | -0.7684 | 39.83 |
| 430 | 2.736 | -1.471 | 39.93 |
| 450 | 2.736 | -1.470 | 39.93 |
| 500 | 2.736 | -1.471 | 39.93 |



# GEANT 3 vs GEANT 4

- Comparisons of energy loss and multiple scattering
  1. Ionization energy loss only
  2. + bremsstrahlung
  3. + annihilation
  4. + photo-electric + compton scattering + photon conversion
  5. + multiple scattering

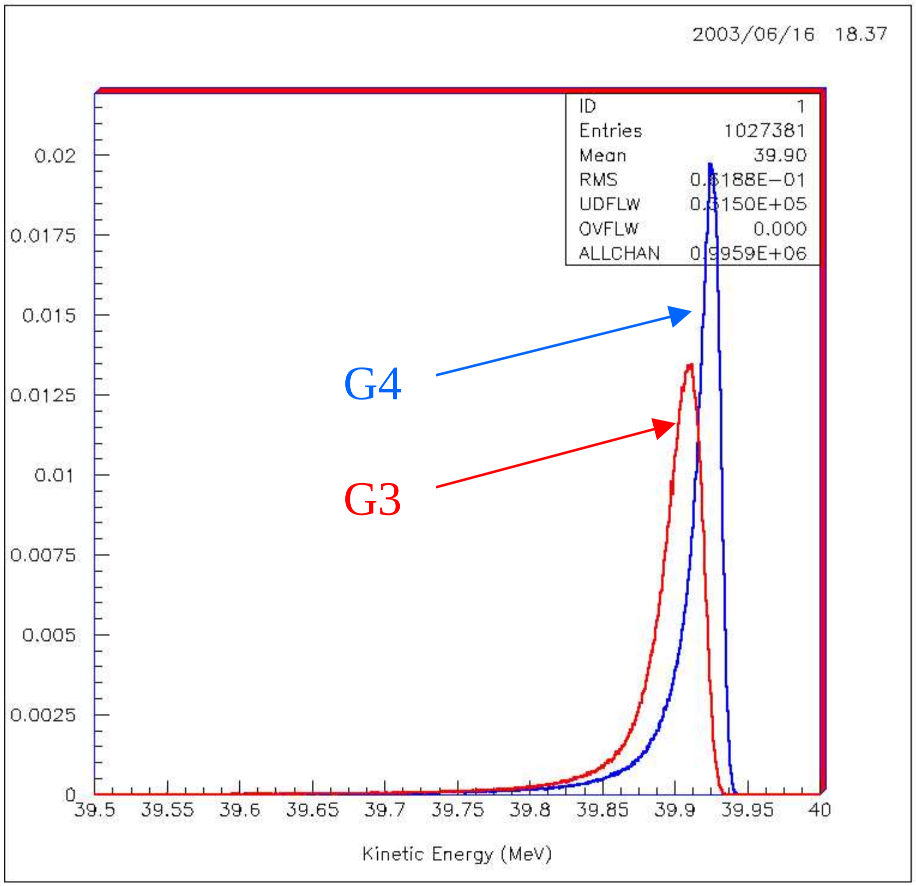
- Compare various quantities as the particle crosses a plane perpendicular to z
  1. Kinetic energy
  2. X and Y position
  3. Crossing angles in XZ and YZ planes

# Beam and Settings

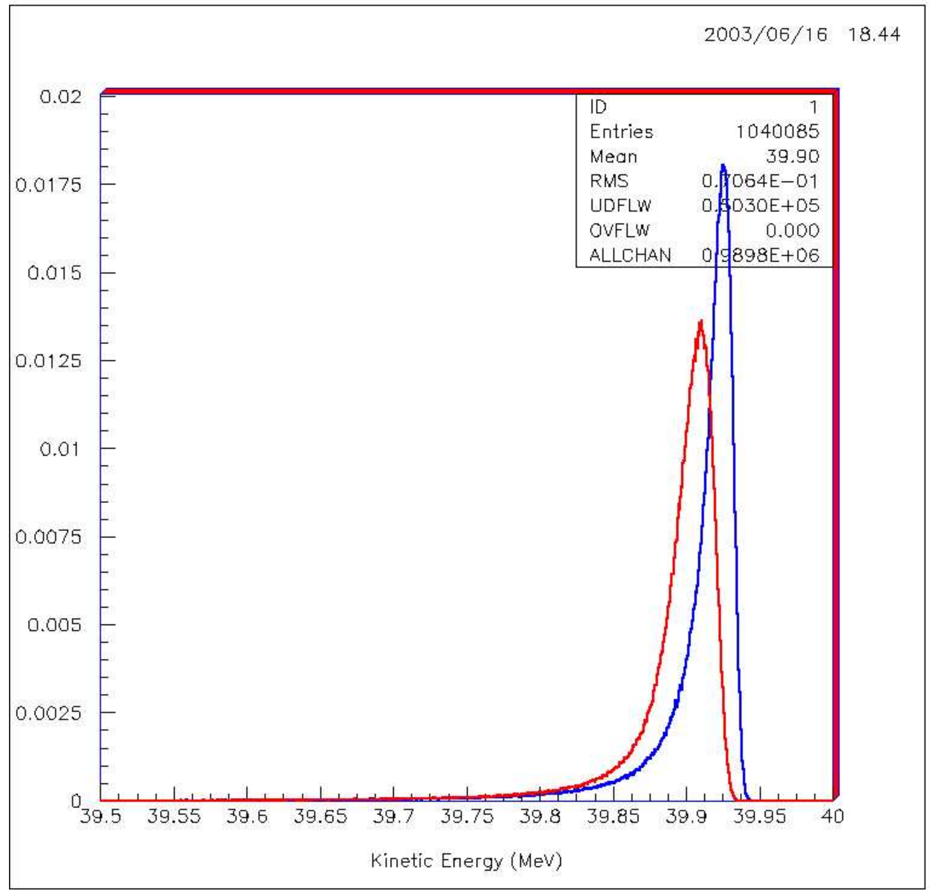
- Beam
  - e+ Starting position: (0,0,2) cm
  - Kinetic energy: 40 MeV
  - Theta = $30^0$
  - Phi = $0^0$
- Steps and settings
  - Field: 2 tesla
  - Range: 1 keV in G4
  - Step: 430 $\mu$m in DC cells (both G3 and G4)
  - TmaxFD: $5^0$ in G3
- All variables plotted at (0,0,51) cm
- One million events simulated

# Energy Loss

Ionization energy loss only
δ threshold = 1 keV in G4

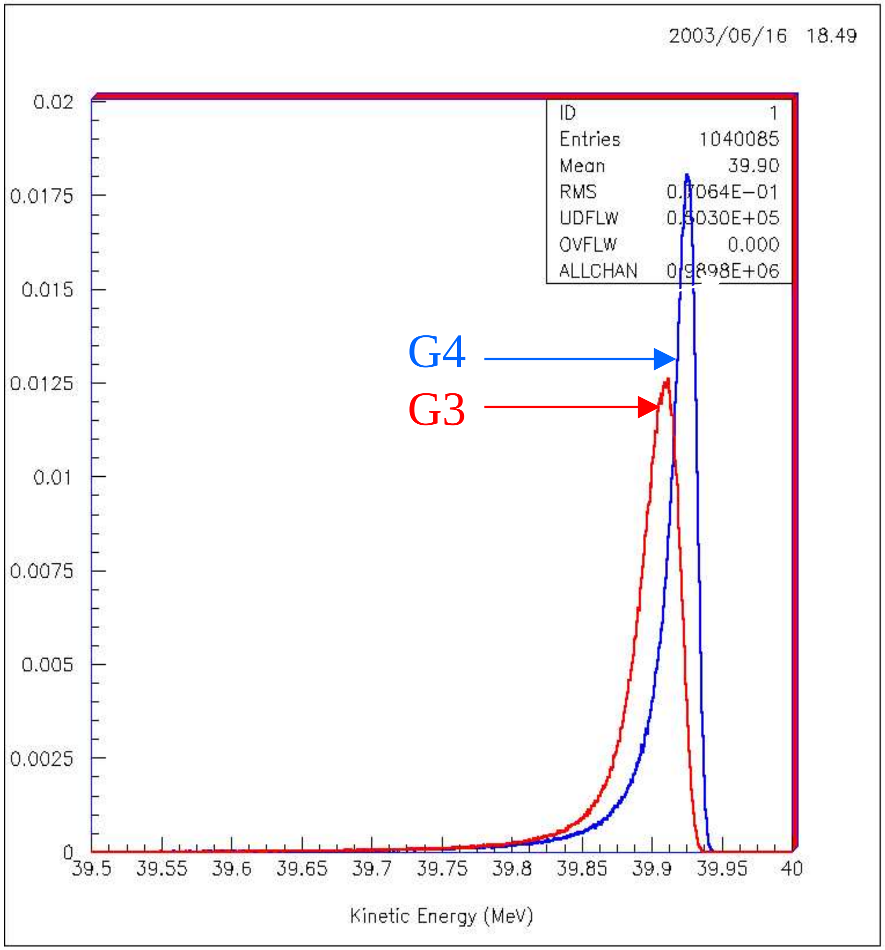



+ bremsstrahlung
δ threshold = 1 keV in G4

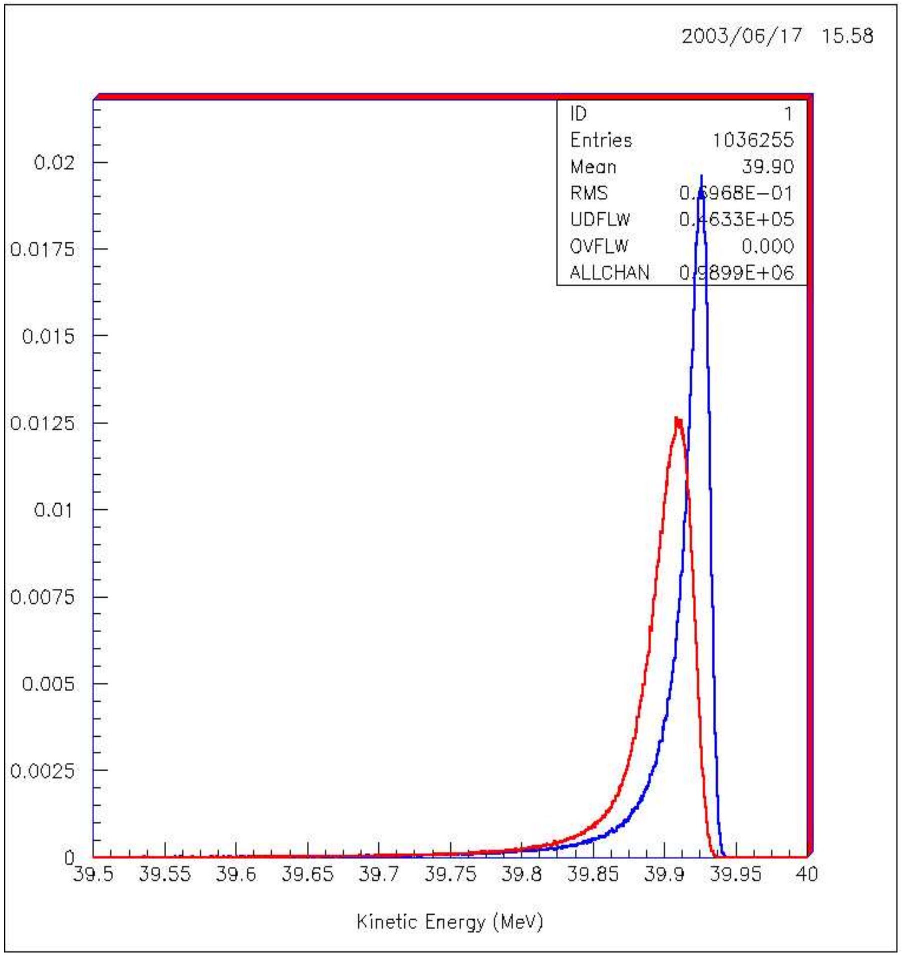


# Energy Loss

+ annihilation

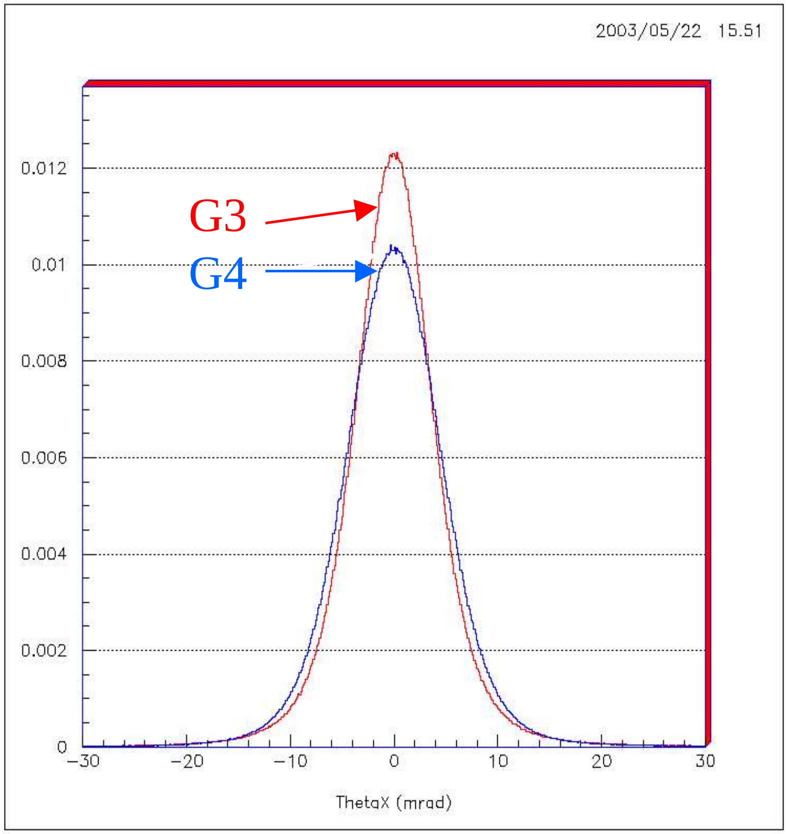


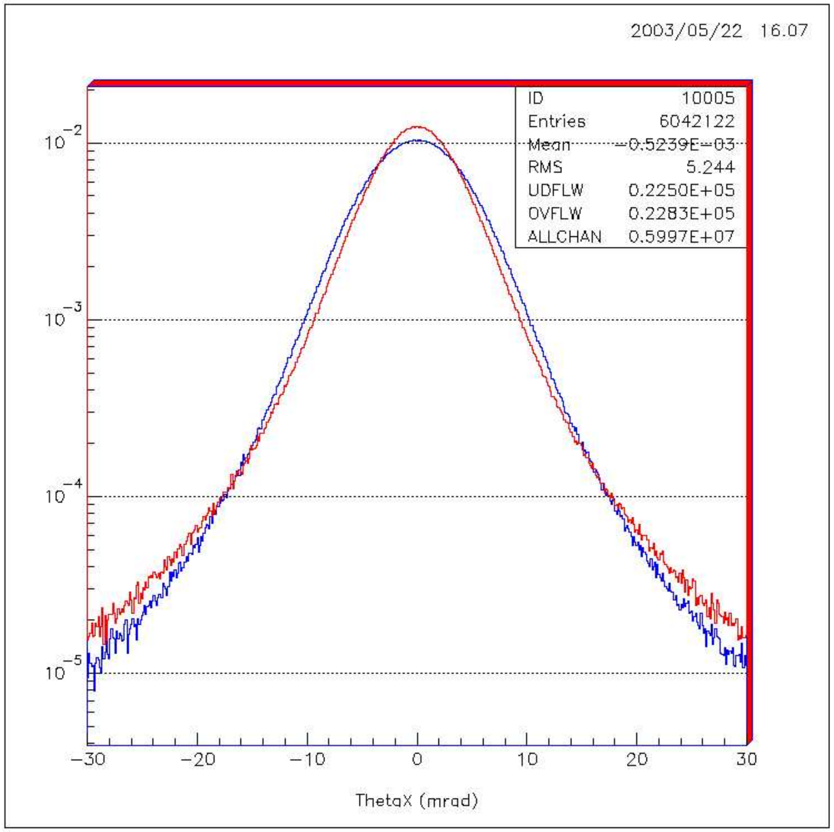

+ photon processes



# Multiple Scattering in One Module @ 20 MeV/c

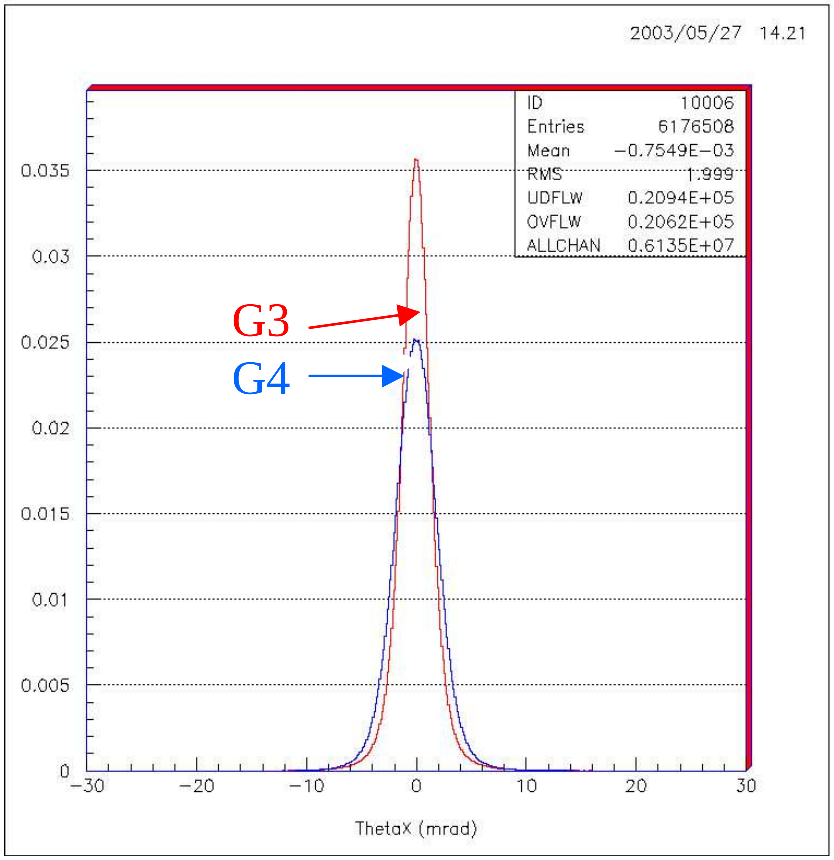
1 Module + 4 cm of helium
20 MeV e+ beam
no field

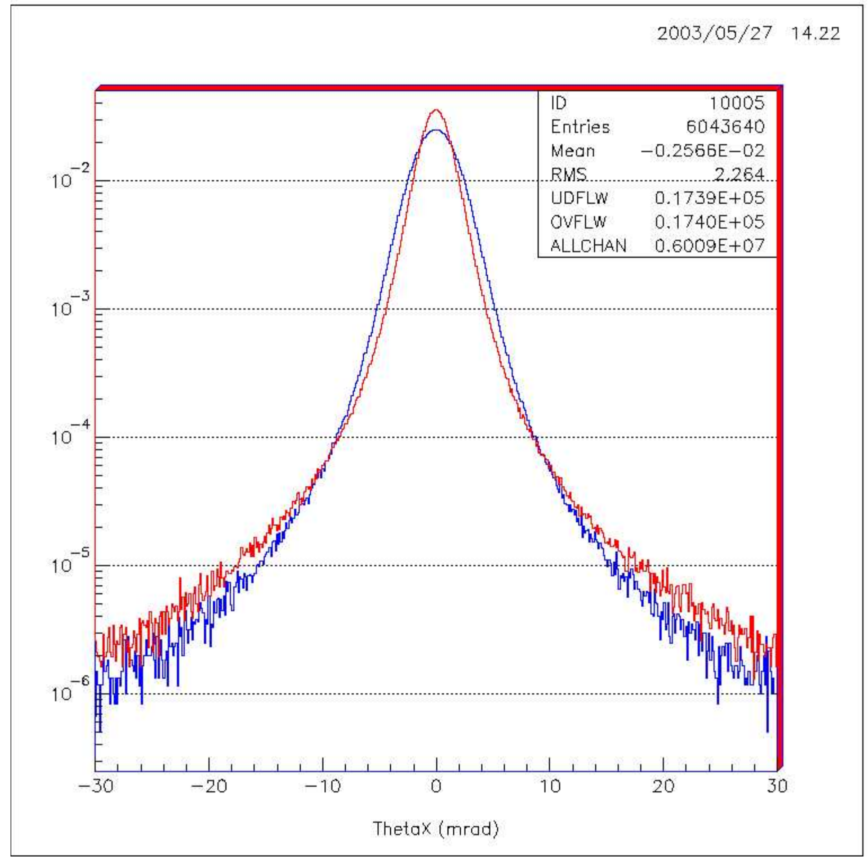


# Multiple Scattering in One Module @ 60 MeV

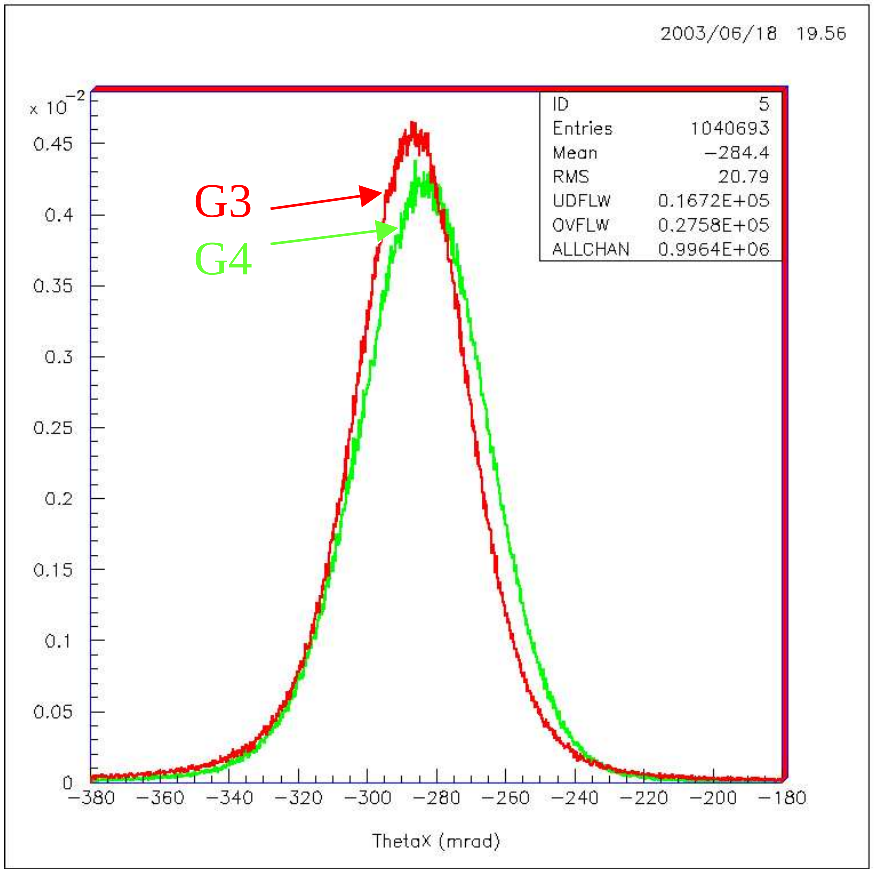
1 Module + 4 cm of helium
60 MeV e+ beam
no field

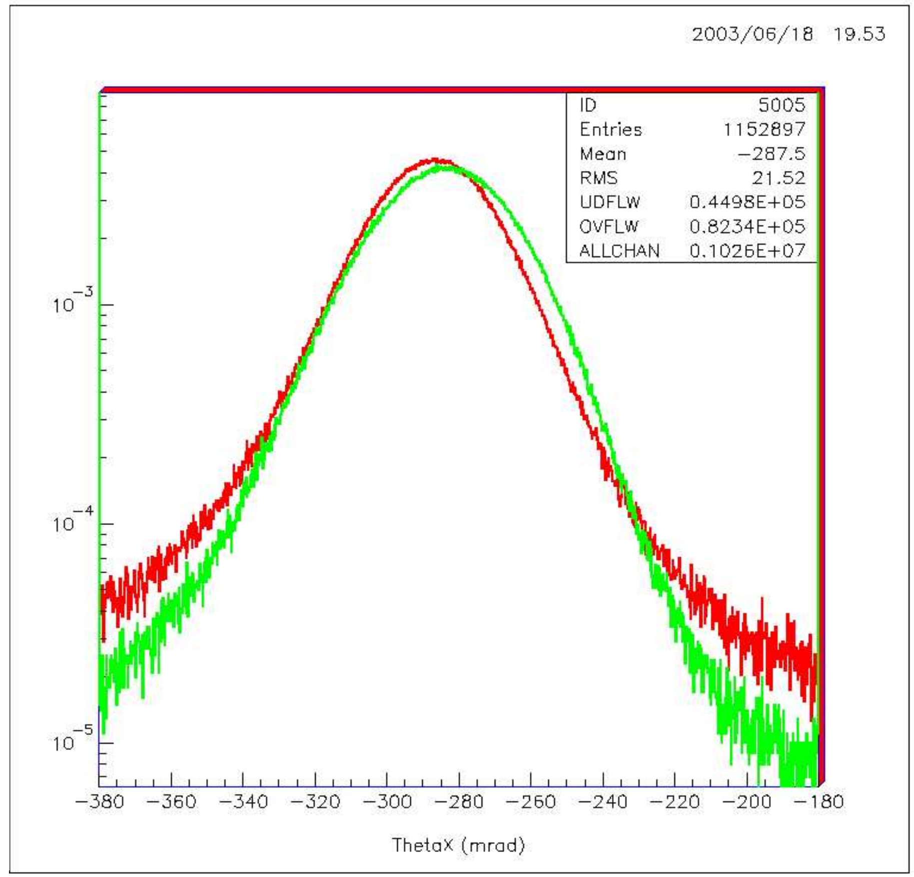


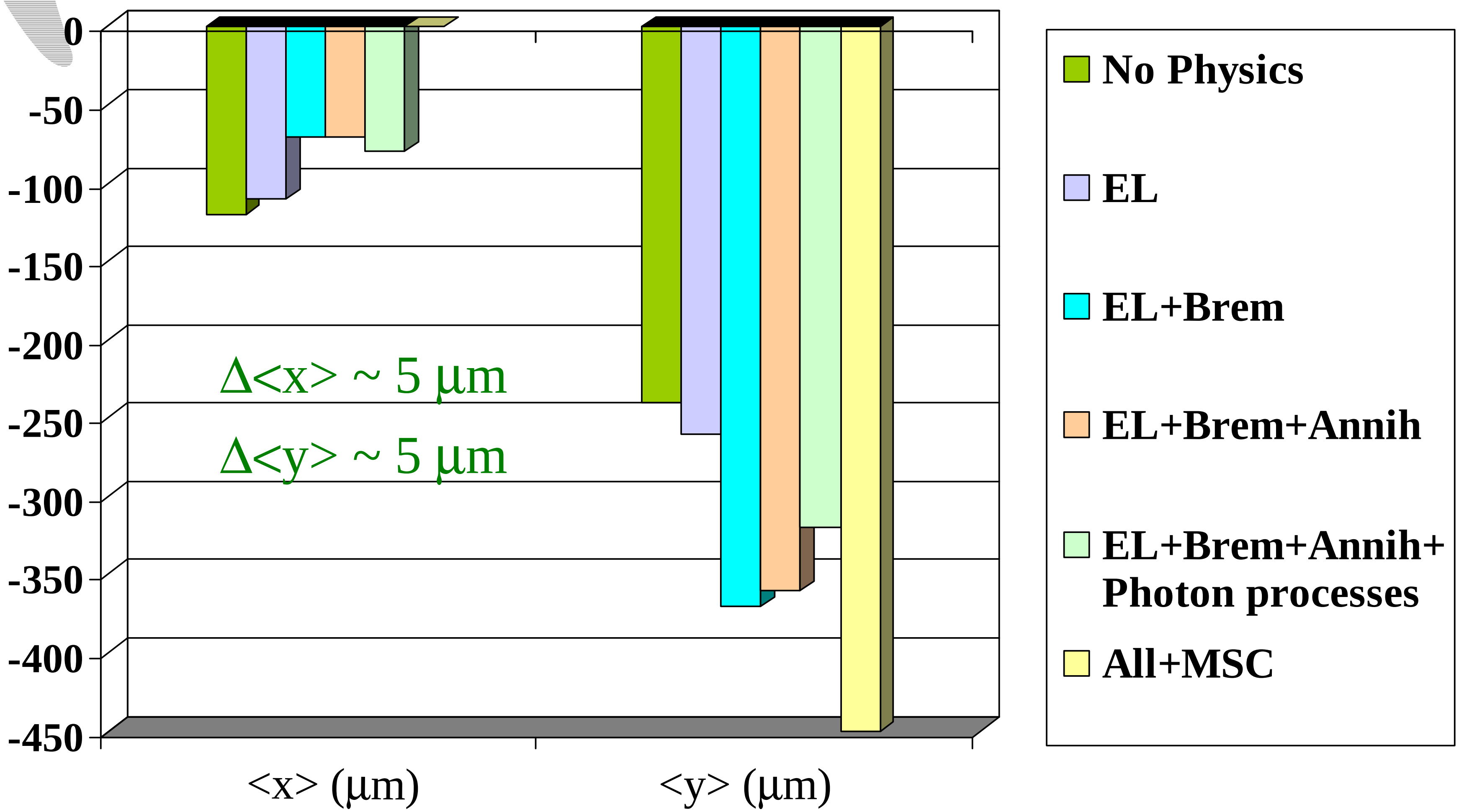
# Acculmulation of Multiple Scattering in a Magnetic Field

Entire half stack (excluding target)
40 MeV e+ beam
2 tesla field

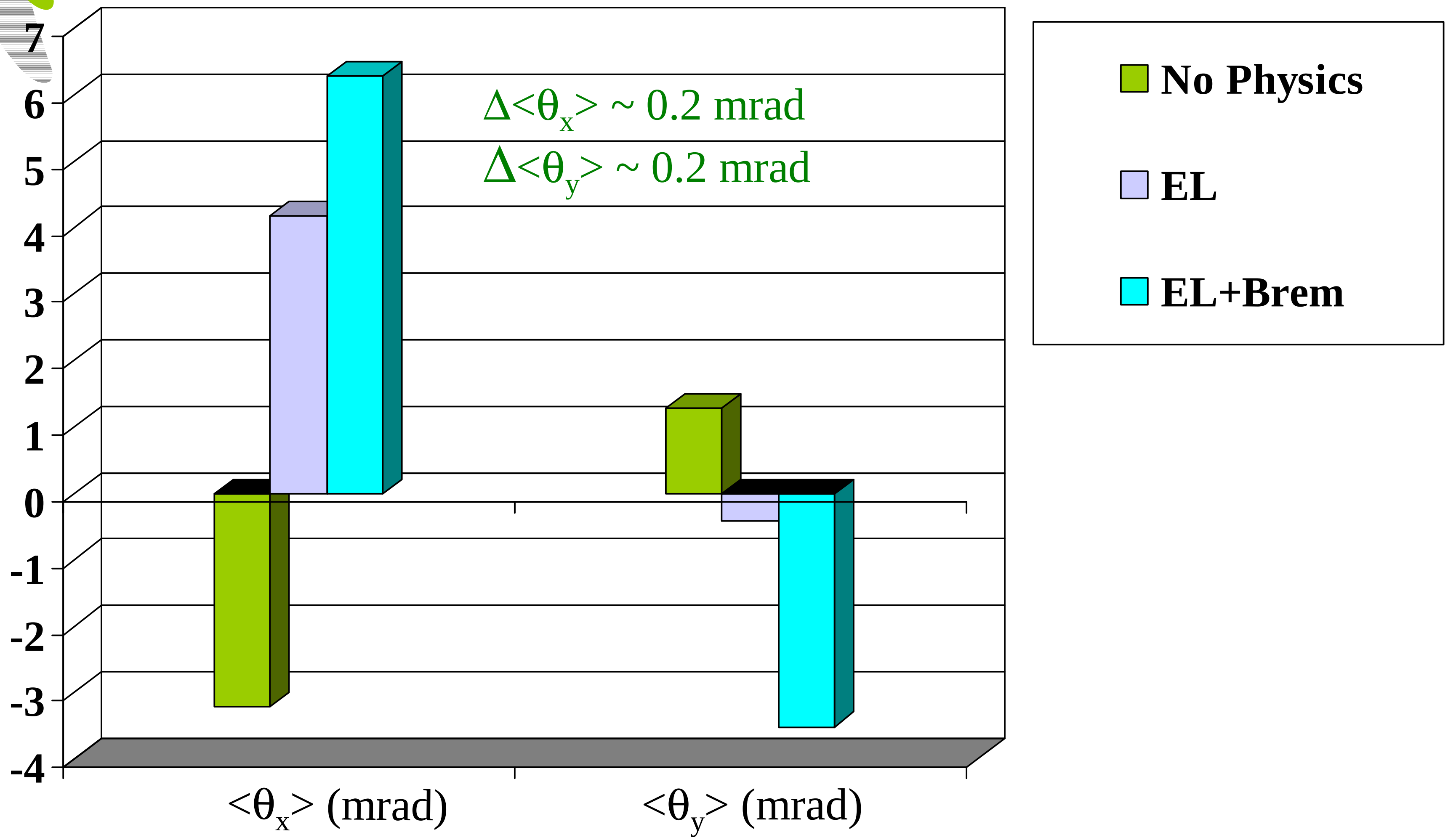


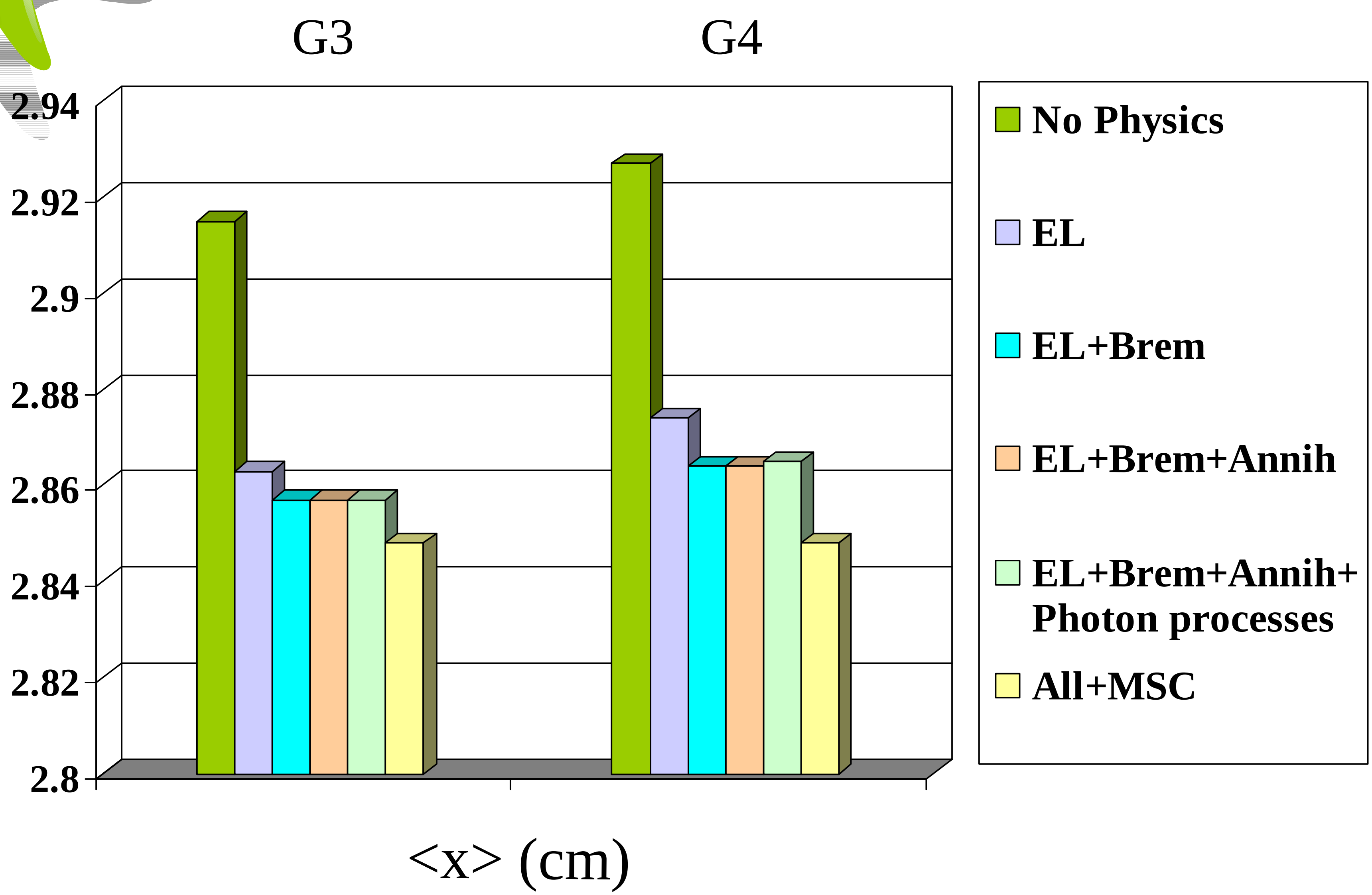
# Beam Mean Position



# Beam Crossing Angle



# Beam Crossing Angle



# GEANT 4 Performance

- More than 100 Million events generated under different conditions
  - No crashes!
  - Got stuck in an infinite loop once
    - Need to install cuts on overall track length, time, etc.
  - Found a bug for small step sizes
- CPU study – results on next page!!
  - Slower than GEANT 3 right now
  - Comparison to GEANT 3 not fair!
    - Physics and sampling processes have been improved in GEANT 4 and likely contain more calculations
    - Energy thresholds (ranges) are implemented differently
    - Etc
  - Many factors effecting CPU has not been investigated
    - Geometry optimizations
    - Compiling optimizations
    - Parameter optimizations
    - Other factors?
  - At this stage CPU optimizations are not a priority!

# G4 Performance - CPU Tests

| Range Cut (mm) | 0.0001 | 0.01 | 1 | 10 | 50 |
|---|---|---|---|---|---|
| CPU (ms/event) | 30.4 | 20.2 | 12.8 | 11.5 | 10.9 |
| Relative to G3 | 322% | 180% | 78% | 60% | 50% |
| **Vacuum** | 1 keV | 1 keV | 1 keV | 1 keV | 1 keV |
| **DME** | 1 | 1 | 1 | 1 | 84.3 |
| **He/Ni** | 1 | 1 | 1 | 1 | 5.24 |
| **He/CO2** | 1 | 1 | 1 | 1 | 11.7 |
| **Air** | 1 | 1 | 1 | 1 | 60 |
| **CF4/ISO** | 1 | 1 | 1.23 | 1 | 104 |
| **Mylar** | 1 | 9.35 | 418 | 2750 | 13000 |
| **Aluminum** | 1 | 33.9 | 597 | 4550 | 25800 |
| **Tungsten** | 1 | 81.4 | 2310 | 29200 | 310000 |

# THE END