Arbitrary EM Fields in edep-sim

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MPD / HPTPC Simulation

The current simulation of the HPTPC uses a uniform magnetic field inside the drift volume (and everywhere).

Using a front-end for Geant4 called edep-sim to perform the simulation of particles traversing and interacting inside the TPC.

Wrote new code to allow for edep-sim to handle arbitrary EM fields. Fields are defined using a grid inside a text file.

Developed using a stand-alone copy of edep-sim and needs to be integrated into the HPTPC simulation chain.

Input GDML file

Specifying an arbitrary EM field is very similar for an uniform field. Backward compatibility is kept for uniform fields.

```
<volume name="volGArTPC">
  <materialref ref="Air"/>
  <solidref ref="GArTPC"/>
  <physvol>
    <volumeref ref="TPCChamber_vol"/>
    <positionref ref="TPCChamber_pos"/>
    <rotationref ref="identity"/>
  </physvol>
  <auxiliary auxtype="ArbBField" auxvalue="grid_z.txt"/>
</volume>
<volume name="PVBarrel_vol">
  <materialref ref="Aluminum"/>
  <solidref ref="PVBarrel"/>
  <auxiliary auxtype="BField" auxvalue="0.4 T, 0.0 T, 0.0 T"/>
</volume>
<volume name="PVEndcap_vol">
  <materialref ref="Aluminum"/>
  <solidref ref="PVEndcap"/>
  <auxiliary auxtype="BField" auxvalue="0.4 T, 0.0 T, 0.0 T"/>
</volume>
```

The ‘auxtype’ for an arbitrary field is ‘ArbBField’ or ‘ArbEField’.

Corresponding ‘auxvalue’ is the name of the grid file.

Uniform fields are specified as before, using ‘BField’ or ‘EField’ and defined using a tuple of the field components.

Input Grid File

Currently the input grid file is formatted like follows:

```
#First row is a header defining the origin offset and grid spacing
-2600.00 -4200.00 12300.00 200.00 200.00 200.00

#Next, each row contains one grid point: x,y,z,fx,fy,fz,f
-2600.00 -4200.00 12300.00 0.80 0.00 0.00 0.80
-2600.00 -4200.00 12500.00 0.80 0.00 0.00 0.80
-2600.00 -4200.00 12700.00 0.80 0.00 0.00 0.80
-2600.00 -4200.00 12900.00 0.80 0.00 0.00 0.80
-2600.00 -4200.00 13100.00 0.80 0.00 0.00 0.80
-2600.00 -4200.00 13300.00 0.80 0.00 0.00 0.80
-2600.00 -4200.00 13500.00 0.80 0.00 0.00 0.80
-2600.00 -4200.00 13700.00 0.80 0.00 0.00 0.80
-2600.00 -4200.00 13900.00 0.80 0.00 0.00 0.80
-2600.00 -4200.00 14100.00 -0.80 0.00 0.00 0.80
-2600.00 -4200.00 14300.00 -0.80 0.00 0.00 0.80
-2600.00 -4200.00 14500.00 -0.80 0.00 0.00 0.80
-2600.00 -4200.00 14700.00 -0.80 0.00 0.00 0.80
```

Units are in **mm** for position (x,y,z) and **V/cm** or **T** for electric or magnetic fields respectively (fx,fy,fz).

The global position coordinate in the Geant4 geometry is used for the grid file origin offset.

Position is calculated by z = gz * i + offset, where gz is the z-grid spacing and i is the index in the array.

Grid Interpolation

EM fields are specified using a 3D grid in xyz coordinates. Need a way to calculate the field at any arbitrary point.

The field is interpolated using a cubic convolution technique. This is more accurate than linear interpolation and faster than traditional cubic spline interpolation.

Field value

Field value at point k

Grid coordinate

$$g(x) = \sum_k c_k u\left(\frac{x - x_k}{h}\right)$$

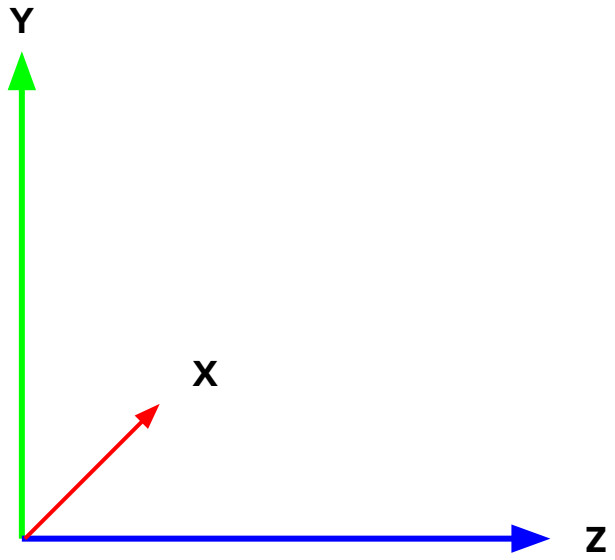
Conv kernel

Grid spacing

$$u(s) = \begin{cases} \frac{3}{2}|s|^3 - \frac{5}{2}|s|^2 + 1 & \text{for } 0 \le |s| < 1 \\ -\frac{1}{2}|s|^3 + \frac{5}{2}|s|^2 - 4|s| + 2 & \text{for } 1 < |s| < 2 \\ 0 & \text{otherwise} \end{cases}$$

R. Keys, "Cubic convolution interpolation for digital image processing," in IEEE Transactions on Acoustics, Speech, and Signal Processing, vol. 29, no. 6, pp. 1153-1160, December 1981.

Event Displays



Simulated 750 MeV negative muons starting at the edge of the TPC drift volume.

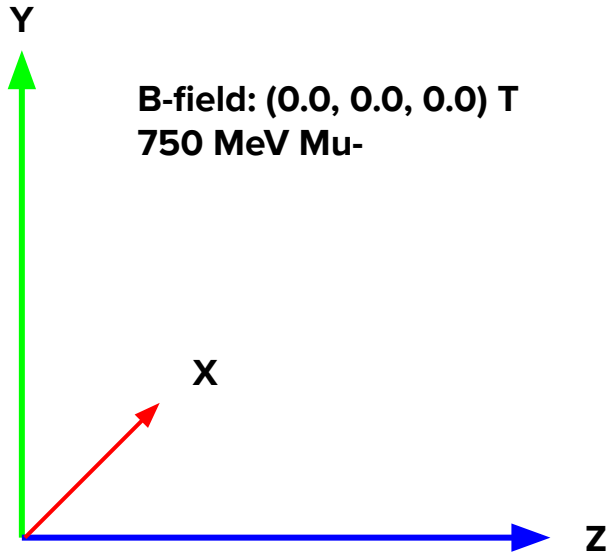
For the first few displays:

- Initial muon momentum along the positive z-axis (going left to right on the slide).
- The B-field is aligned along the positive x-axis, which is into the page/slide.

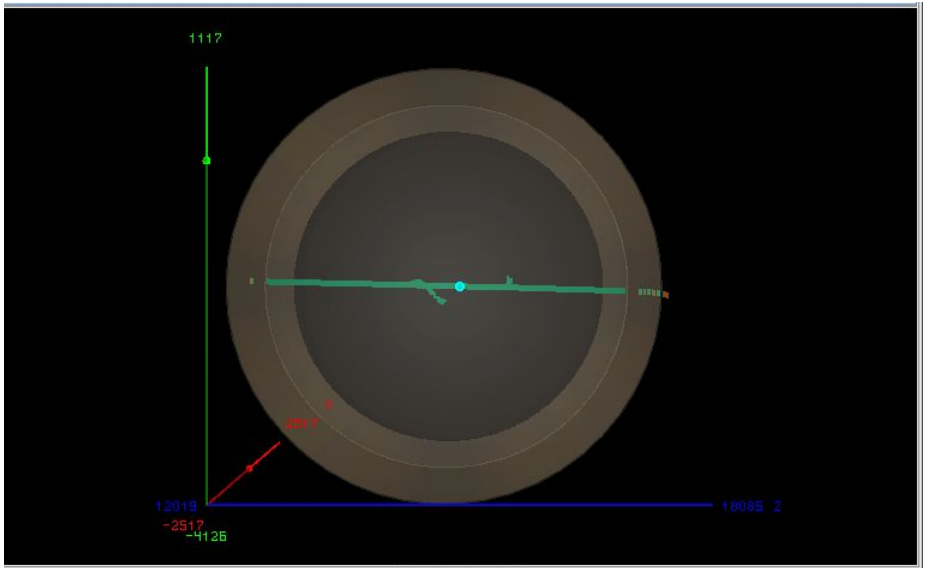
For example, given a 0.4 T field points into the page a negative muon should bend downwards.

Using the edep-sim built-in display for these, with TPCDrift1 and TPCDrift2 highlighted.

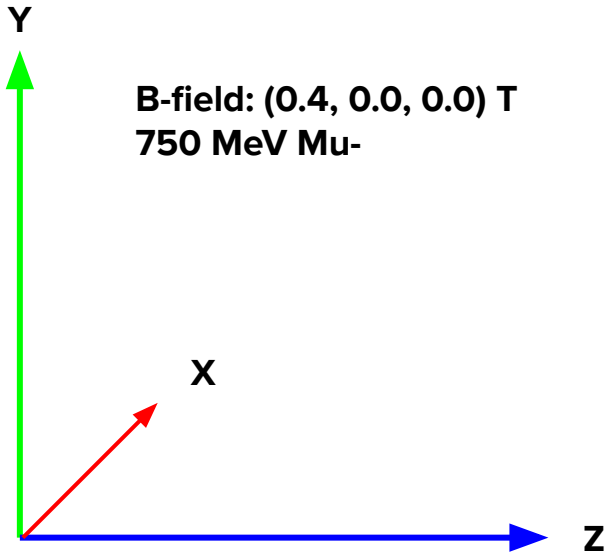
Event Displays



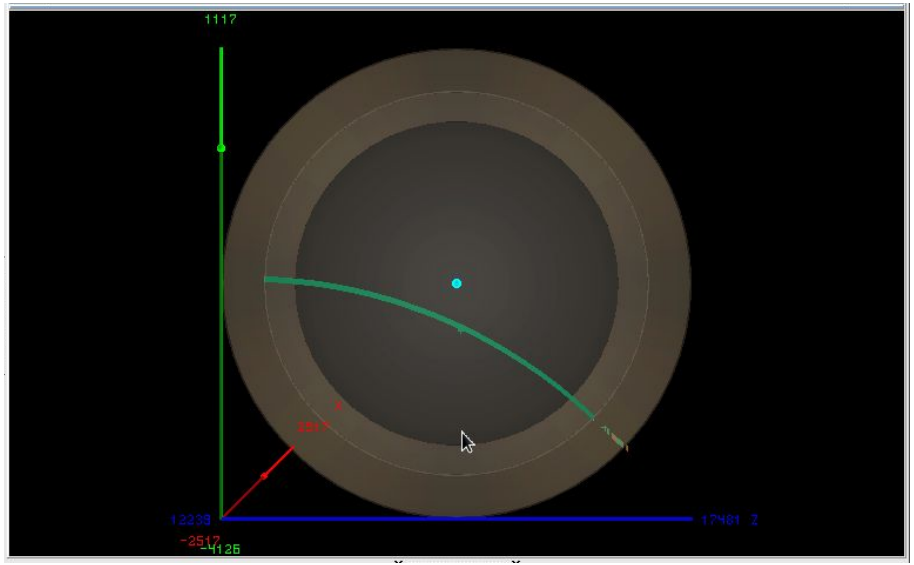
B-field: (0.0, 0.0, 0.0) T
750 MeV Mu-



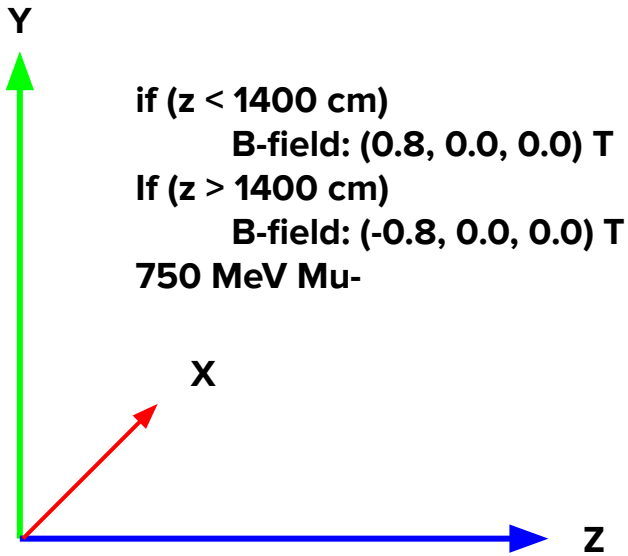
Event Displays



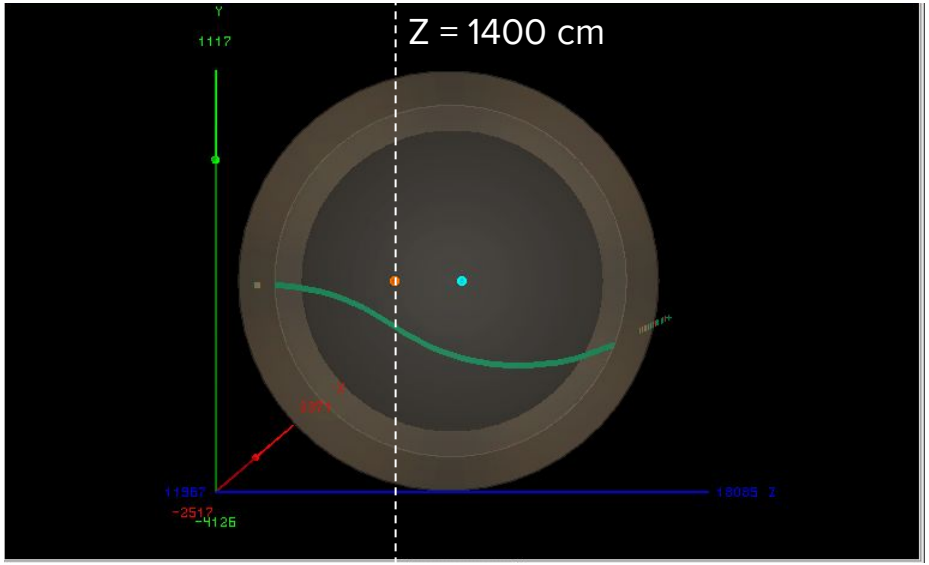
B-field: (0.4, 0.0, 0.0) T
750 MeV Mu-



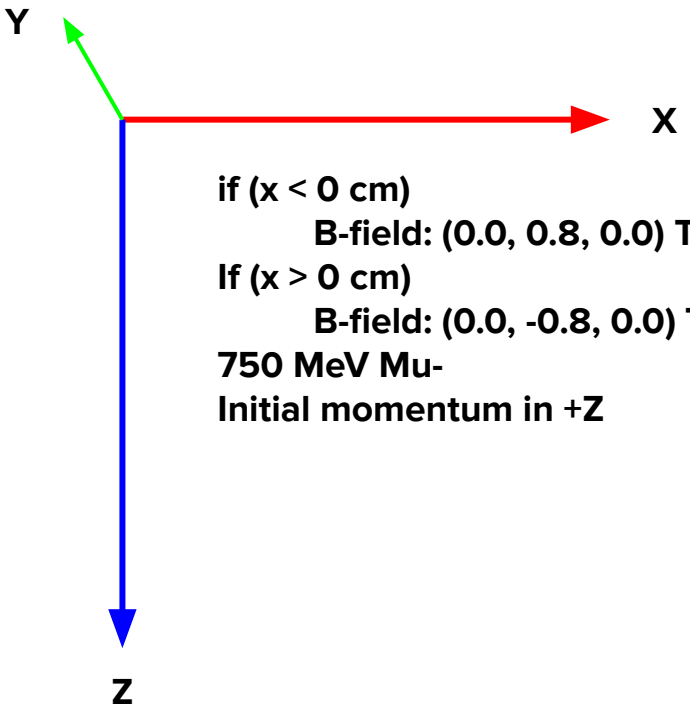
Event Displays



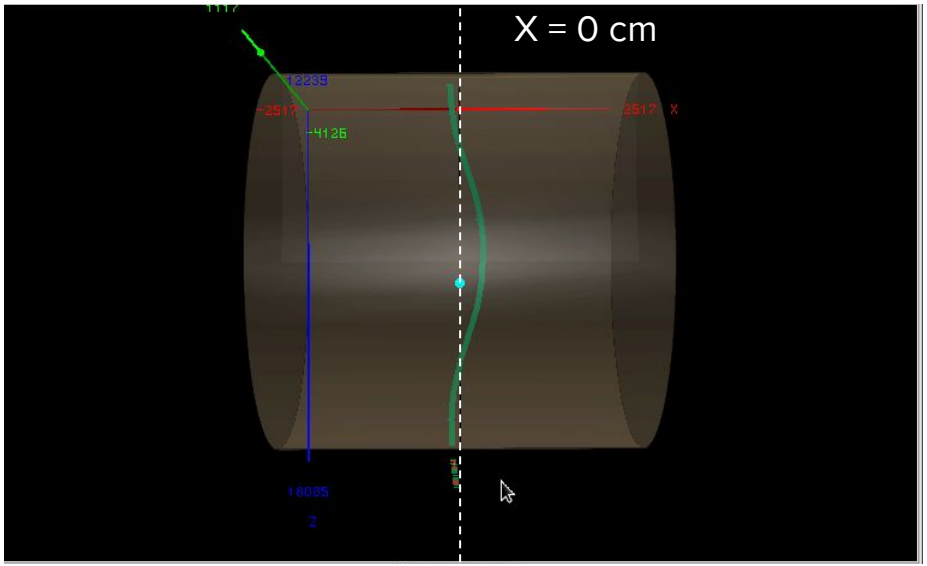
if (z < 1400 cm)
B-field: (0.8, 0.0, 0.0) T
If (z > 1400 cm)
B-field: (-0.8, 0.0, 0.0) T
750 MeV Mu-



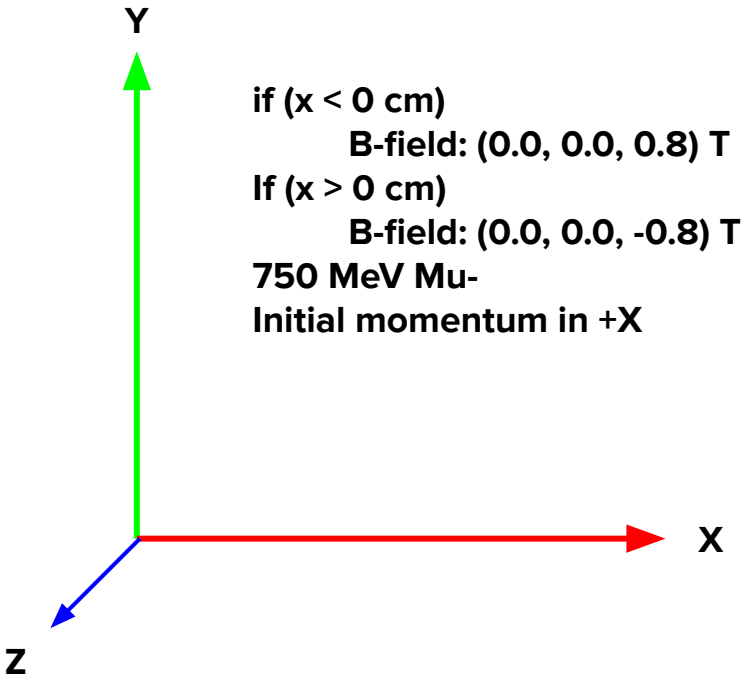
Event Displays



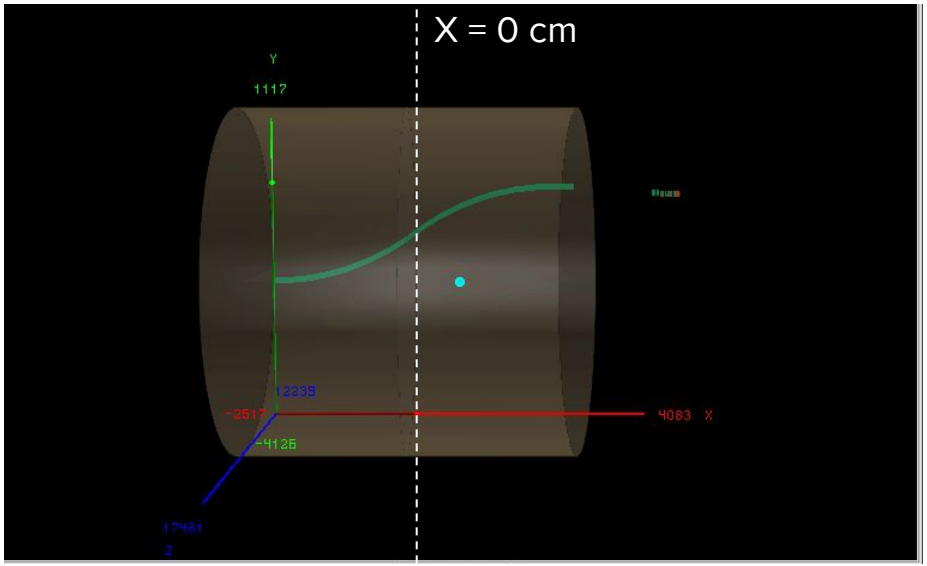
if (x < 0 cm)
B-field: (0.0, 0.8, 0.0) T
If (x > 0 cm)
B-field: (0.0, -0.8, 0.0) T
750 MeV Mu-
Initial momentum in +Z



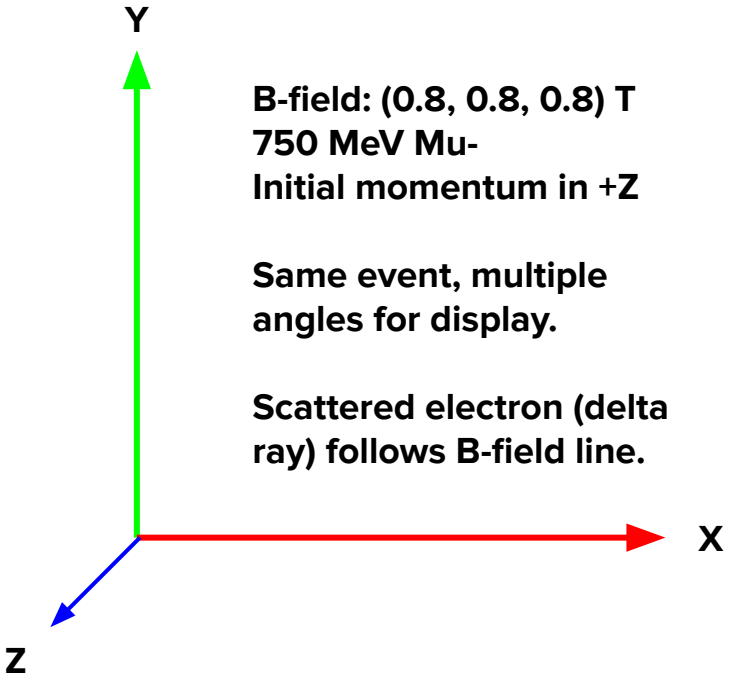
Event Displays



if (x < 0 cm)
B-field: (0.0, 0.0, 0.8) T
If (x > 0 cm)
B-field: (0.0, 0.0, -0.8) T
750 MeV Mu-
Initial momentum in +X



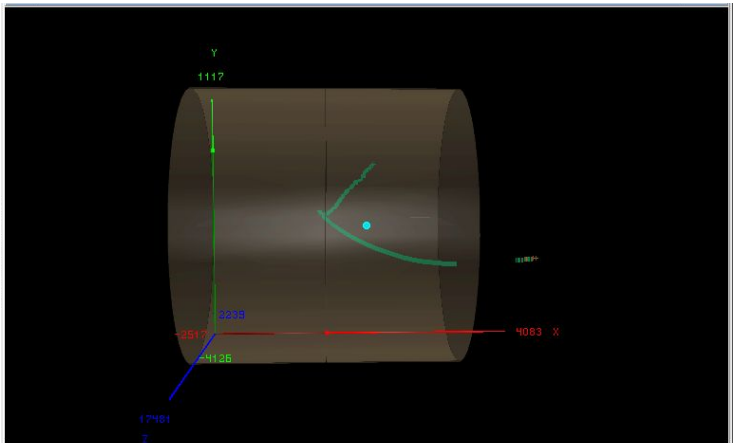
Event Displays

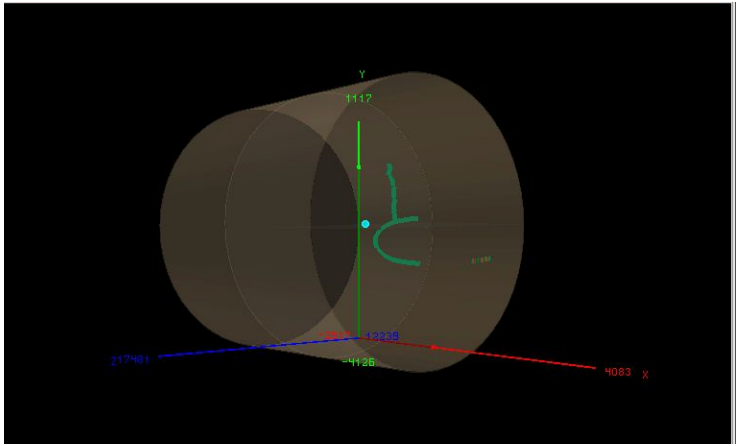


B-field: (0.8, 0.8, 0.8) T
750 MeV Mu-
Initial momentum in +Z

Same event, multiple angles for display.

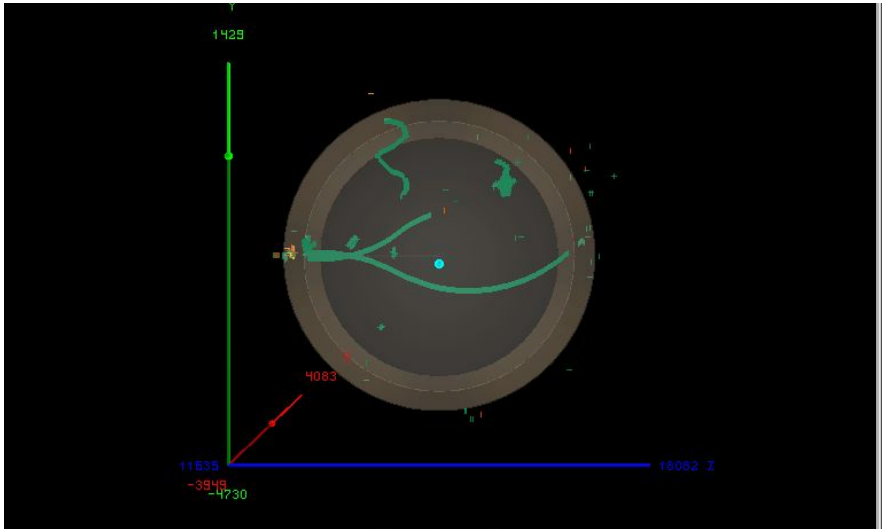
Scattered electron (delta ray) follows B-field line.

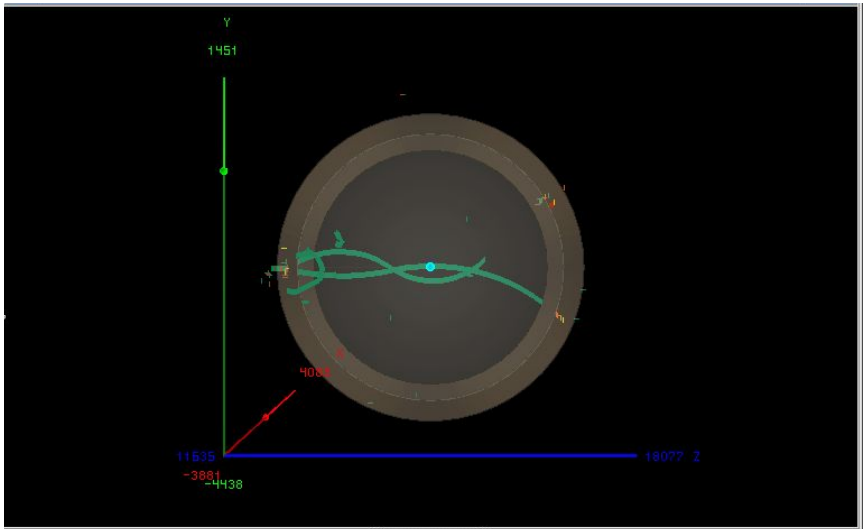




Bonus Event Displays

Same split magnetic field in X, but using 5 GeV pi- (in +Z direction) as the initial particle.





Summary

Working system for arbitrary EM fields built into edep-sim, and planning to integrate code in the official EDepSim repository.

Several implementation details should be discussed, e.g. format of input grid files.

And as always, needs more testing. Ask me about accidentally simulating the TPC with a 4000 T field sometime.

Further extensions?

- Implement tri-linear grid interpolation as an alternative method for faster processing.
- Implement defining EM fields as polynomials for even faster processing and less memory usage.