DEEP UNDERGROUND
NEUTRINO EXPERIMENT

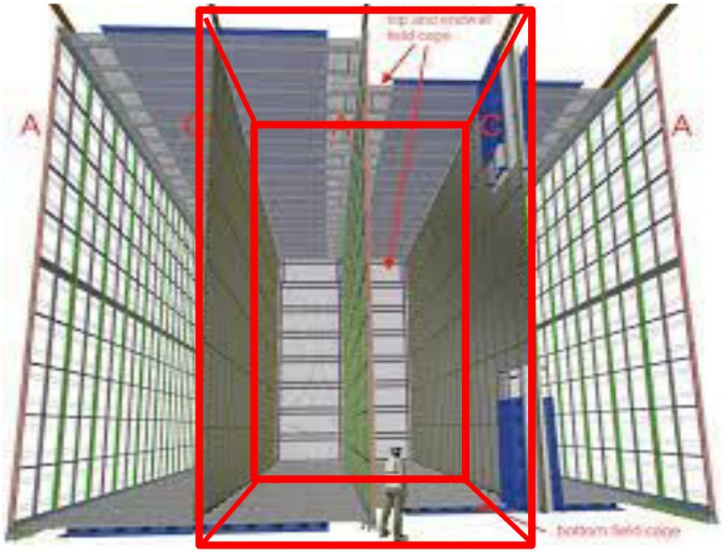
Atmospheric neutrinos containment study in DUNE FD-HD

Camille Sironneau

Sim/Reco meeting
22/04/24

Simulated sample

- Geometry : HD only, **1x2x6 APA** (1/8th of total expected volume)
- **300k events**
- Uniform distribution of vertices in fiducial volume
- Uniform distribution of neutrino direction
- Neutrino **energy flux in ~$E^{-2.5}$** → event rate in ~$E^{-1.5}$
- **All flavours**, CC/NC, normalisation of rates depending on relative cross sections
- Energy between **~100 MeV and ~ 100 GeV**



Bounds : x [-363cm; 363cm] → drift axis
y [-608cm; 608cm] → height
z [0cm; 1394cm] → beam axis

Setup of the study

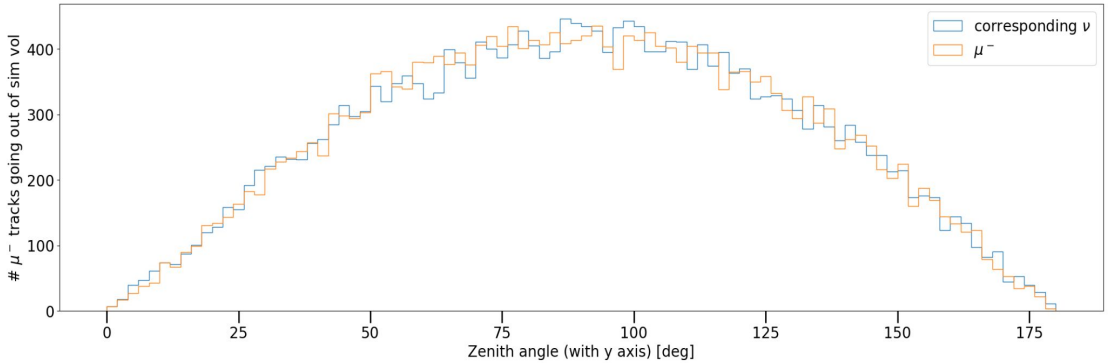
- Looked at **primary muon** tracks going out of simulated volume bounds

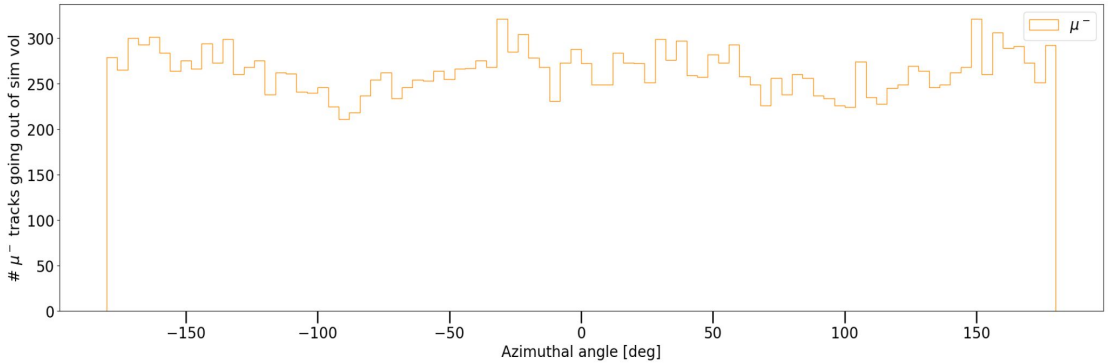
  → energy not seen by the detector and thus not accounted for in reconstruction

- Used **true information** from Geant4

- For ‘reference’/sanity check, compared w/ the behaviour of **crossing tracks**
  - ie, tracks crossing the anode → going through the 2 drift volumes

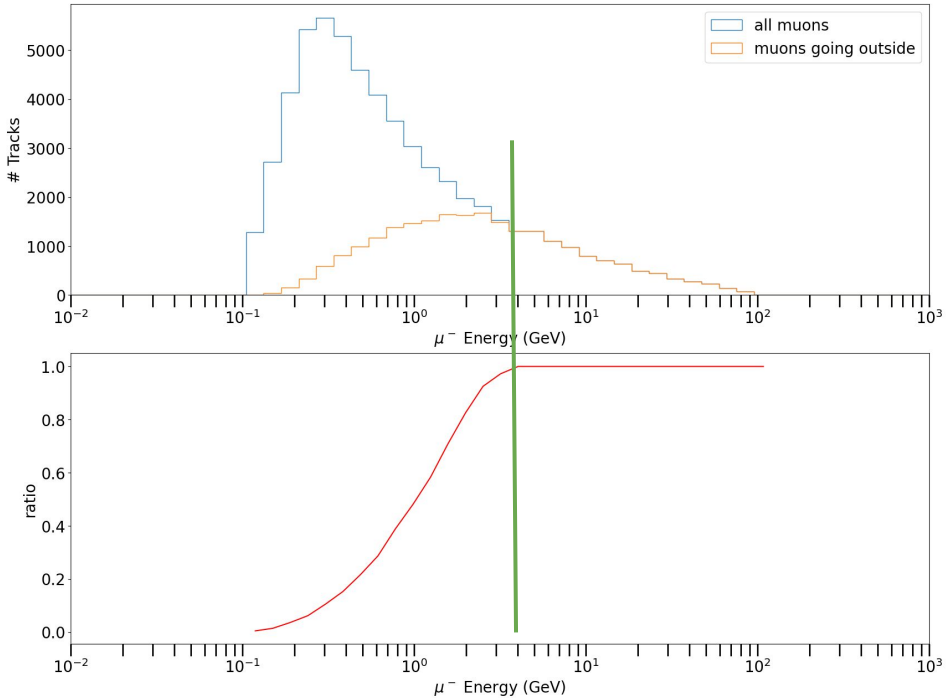
Sanity check: angular distribution of nu and mu





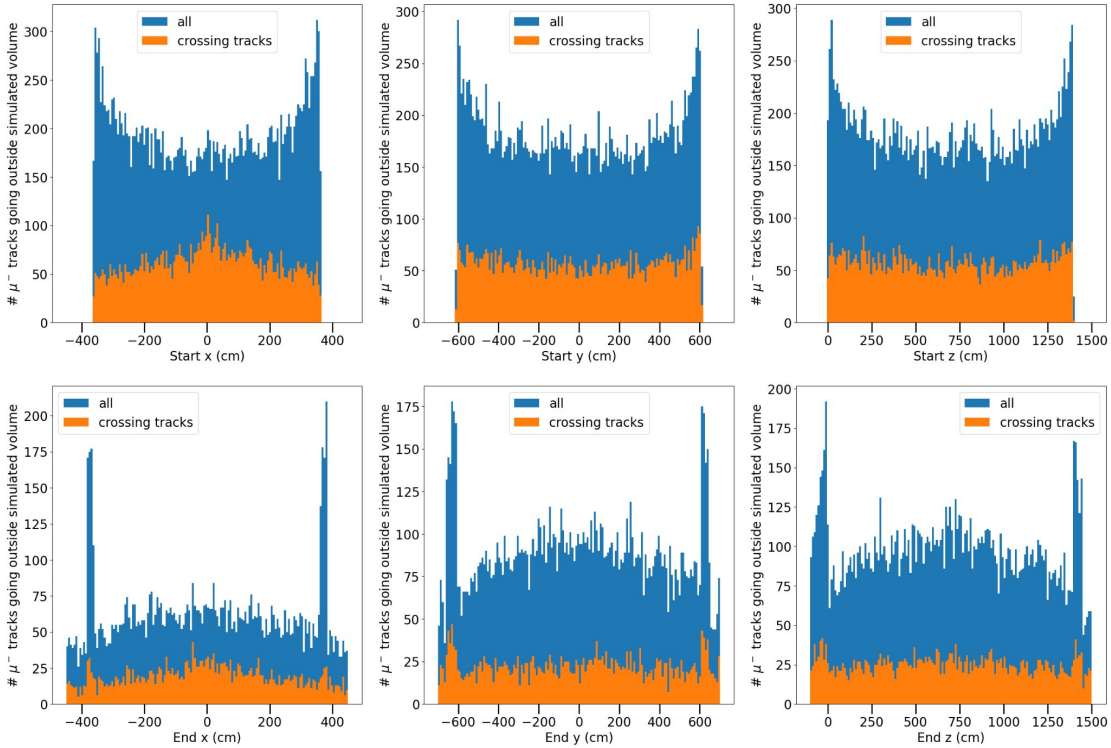
- No particular behaviour for zenith angle (vertical angle) → reassuring
- Same distribution for neutrinos and muons → as expected
- Azimuthal angle (angle with x axis in xz plane) shows dips ~-90° and 90°
  → tracks going along z axis, which is the longest side

Main finding



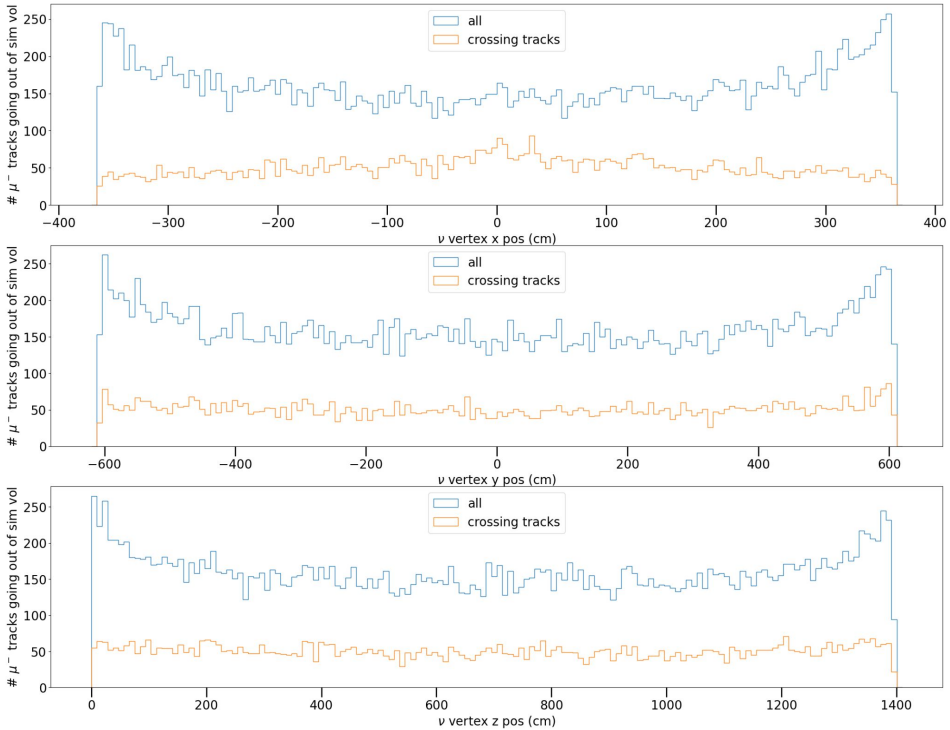
All muons with energy > ~4 GeV seem to escape the detector volume

Start - End points of all muon tracks going out



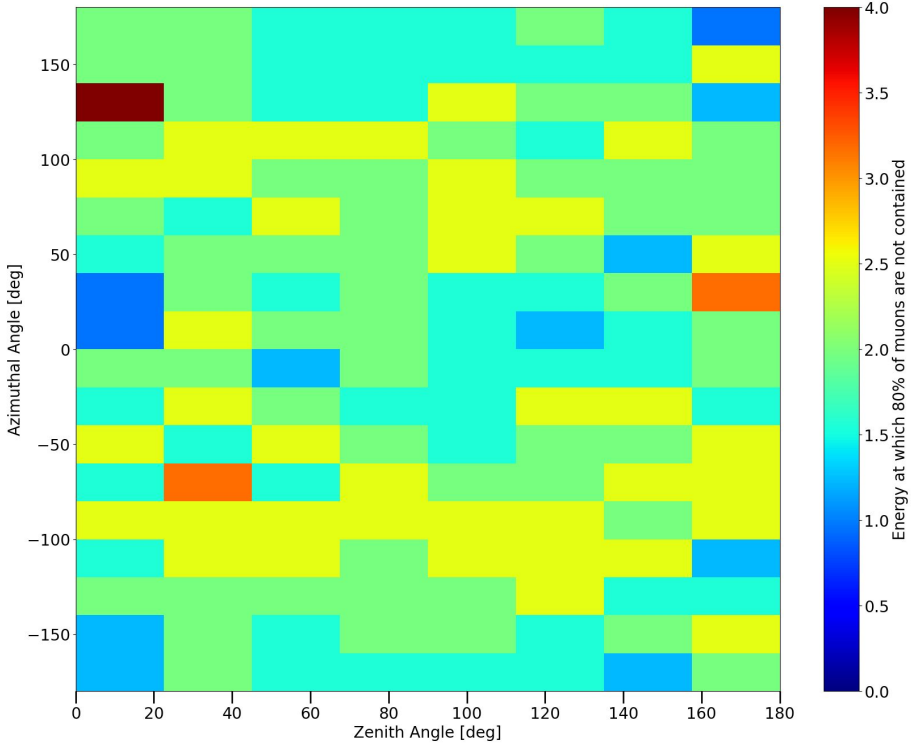
- Plot number of tracks going out of the simulated volume
- More tracks escape near the edges of the volume → logical
- small peak for tracks starting around and crossing the anode → also logical

Primary vertex position for tracks not contained



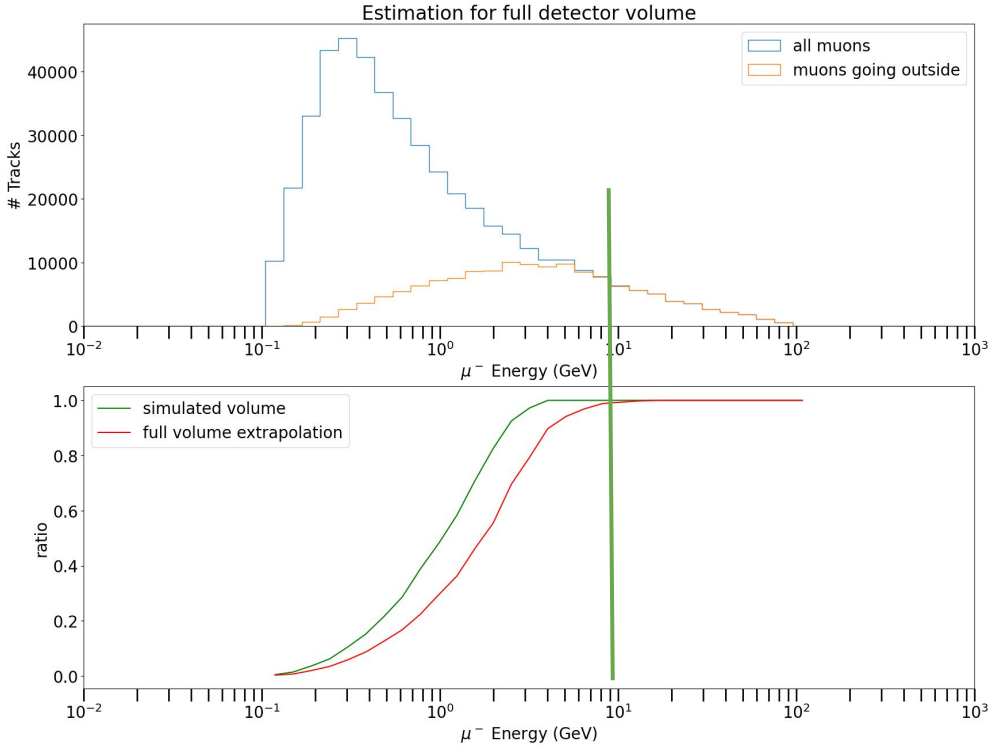
- Doesn't seem a big dependance on vtx position except for vertices near the edges → makes sense
- Uniform behaviour for crossing tracks

E-threshold where 80% of muons are not contained



- **Mostly around a few GeV** as expected but sometimes even lower than 1 GeV
- Threshold seems to be lower when tracks follow the x axis (azimuthal angle ~0° or 180°) → logical, smallest dimension
- Threshold seems lower for vertical tracks → logical as well

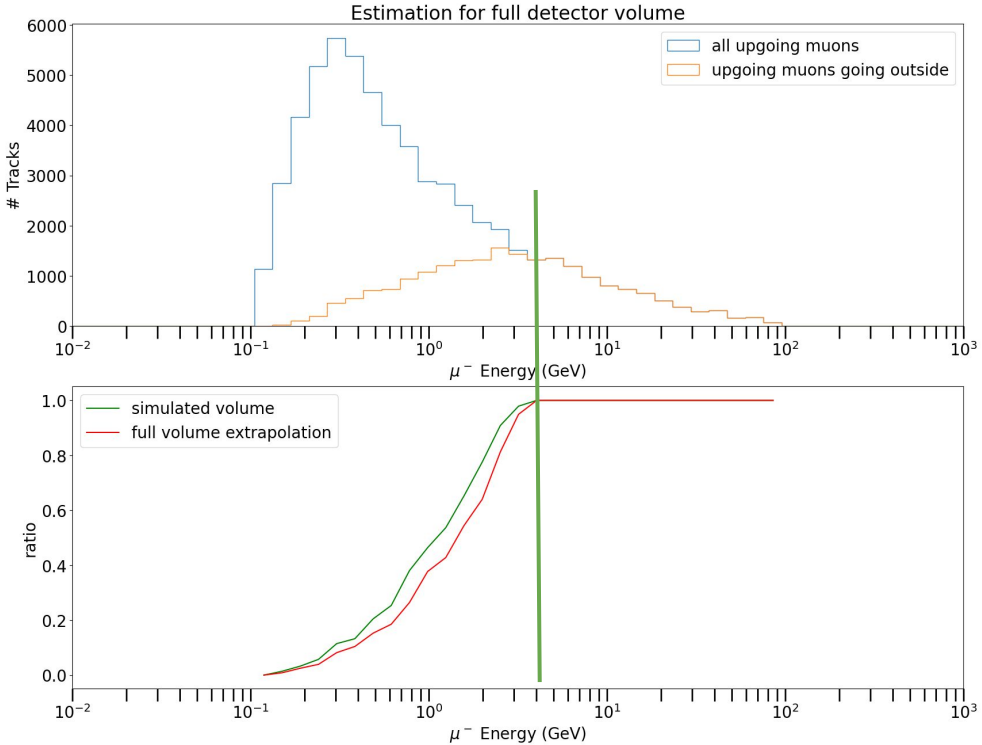
Extrapolation to full det volume



- Used Geant momentum to estimate muon range
- Compared computed end-point to full detector limits for each of the 8 “simulated” volumes

  → sort of duplicate the simulation
- Get new estimation of containment
- **Threshold for fully not contained ~9GeV** so twice better than before

Upgoing atmospherics



- Select muons with **zenith angle cos between -1 and -0.75** to study behavior of upgoing neutrinos only
- Curves present roughly the same behavior → height doesn't change between sim and full volume
- **All muon tracks go out when E > 4GeV**

Summary and conclusions

- Containment study with 1x2x6 geometry simulation shows that **primary muons** produced in atmospheric neutrino interactions **completely escape the detector when have energy >4 GeV**

  → need to work on **Multiple Coulomb Scattering** to get best energy reco possible

- When **extrapolate to full detector volume**, see ~ the same E-escape threshold for upgoing neutrinos, which are the ones we are most interested in

  → might need more statistics (notably for angle studies) but simulation or not of full volume doesn't seem to impact physics studies

Thanks a lot for your attention !

MCS Energy estimation

Energy reconstruction - Current state

- Currently, energy reconstruction done using three different methods:

Method 1 (ν_μ):
Energy of longest track
+ Hadronic energy

Method 2 (ν_e):
Energy of shower with the most charge deposited
+ Hadronic energy

Method 3:
In case everything else fails, add all deposited charges

(Method 1 and 2 are always computed, the decision is given later with CVN score)

slides from one of Henrique Souza's presentations

NOTE:

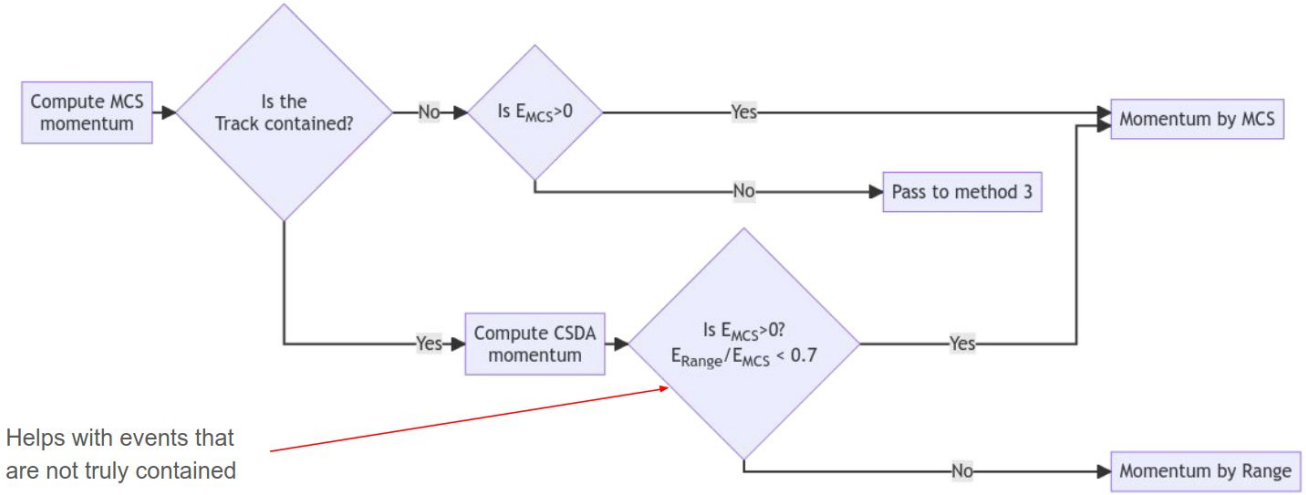
- Hadronic energy is computed by adding the total deposited charge (corrected by lifetime), but removing the hits associated with the lepton (longest track or most charged shower)
- Method 2 and Method 3 are equivalent, with the difference of adding the electron mass.

MCS Energy estimation

Energy reconstruction - Method 1

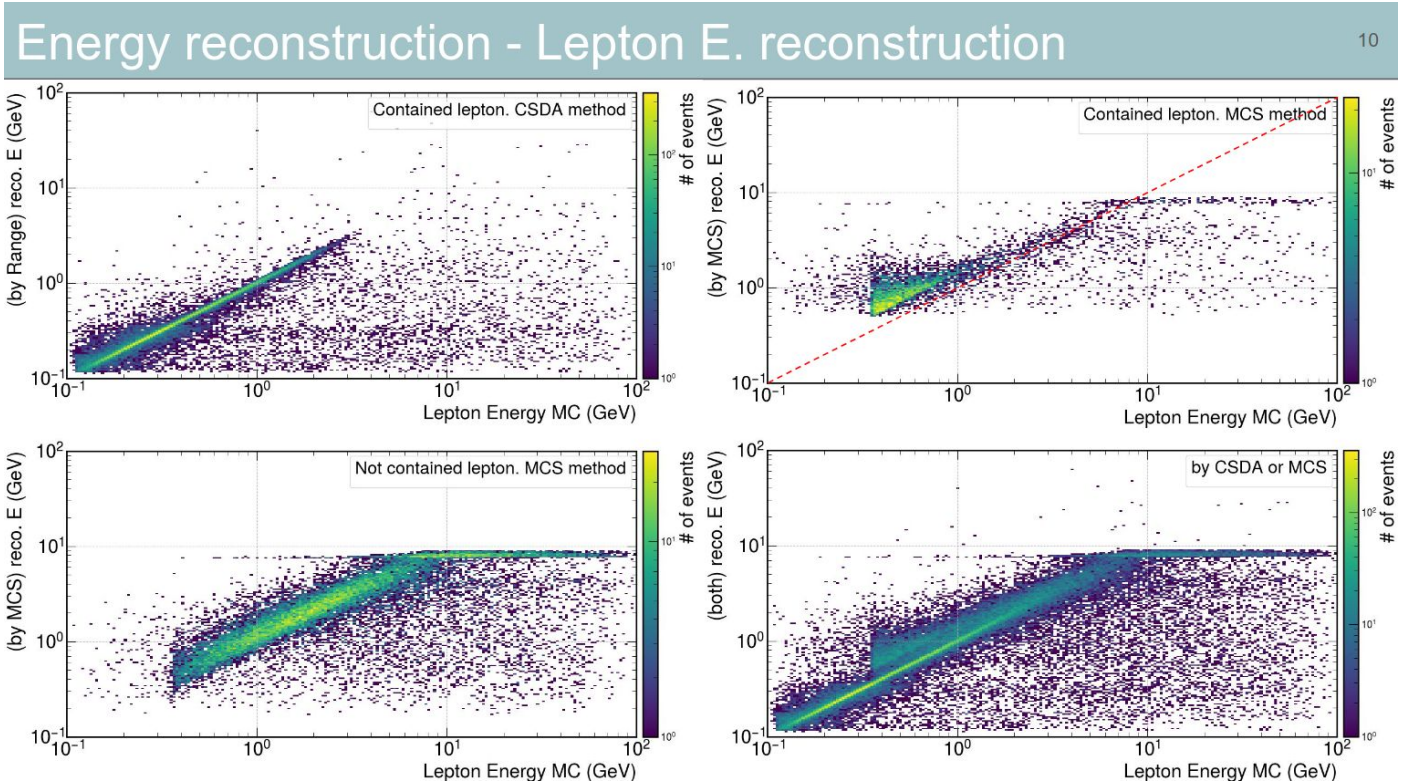
Method 1 (ν_μ):
Energy of longest track
+ Hadronic energy

- Multi Coulomb Scattering (MCS):
  Computes momentum by angle of scattering
- Constant slow down approximation (CSDA):
  Uses particle range to estimate momentum



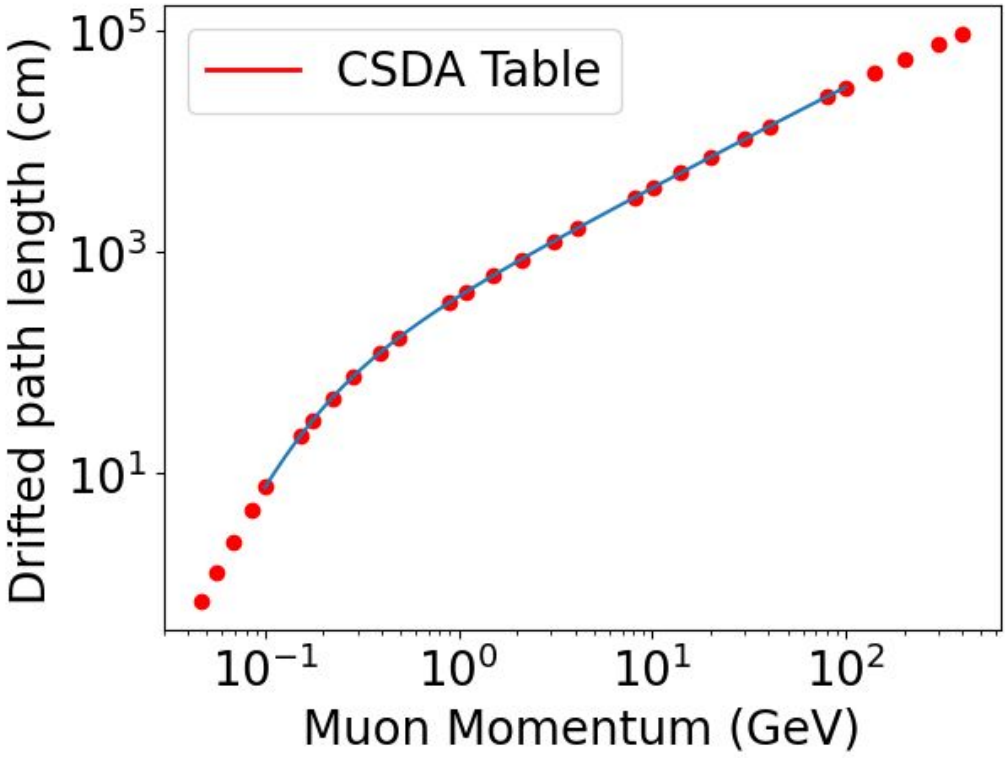
slides from one of Henrique Souza's presentations

MCS Energy estimation

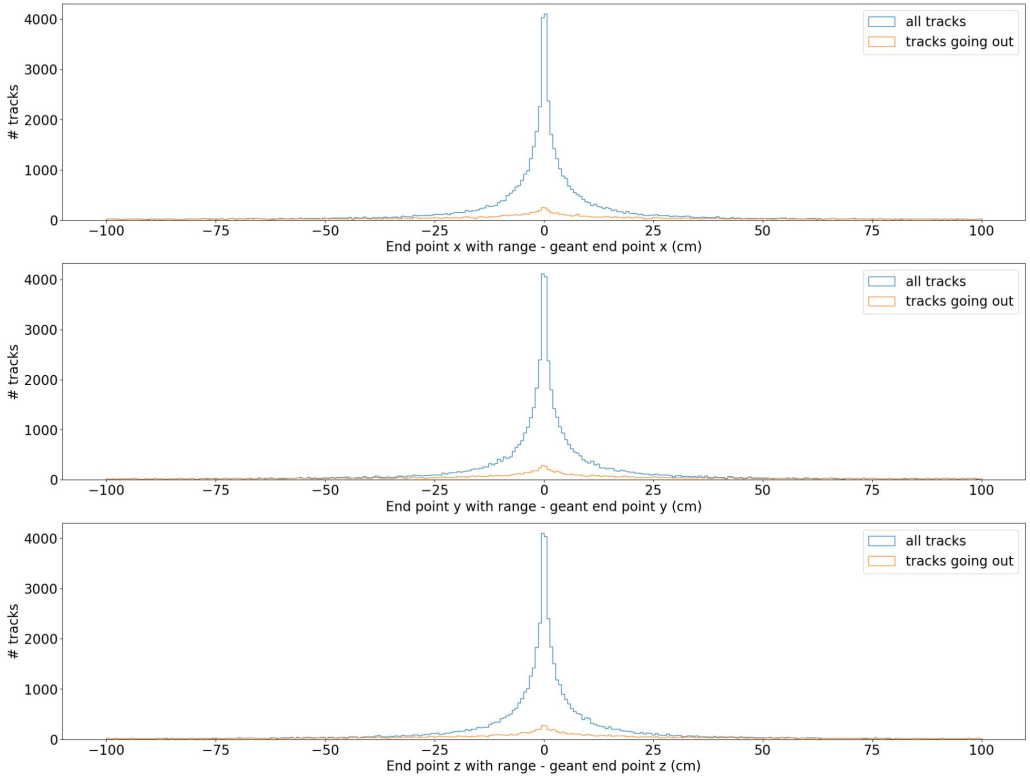


slides from one of Henrique Souza's presentations

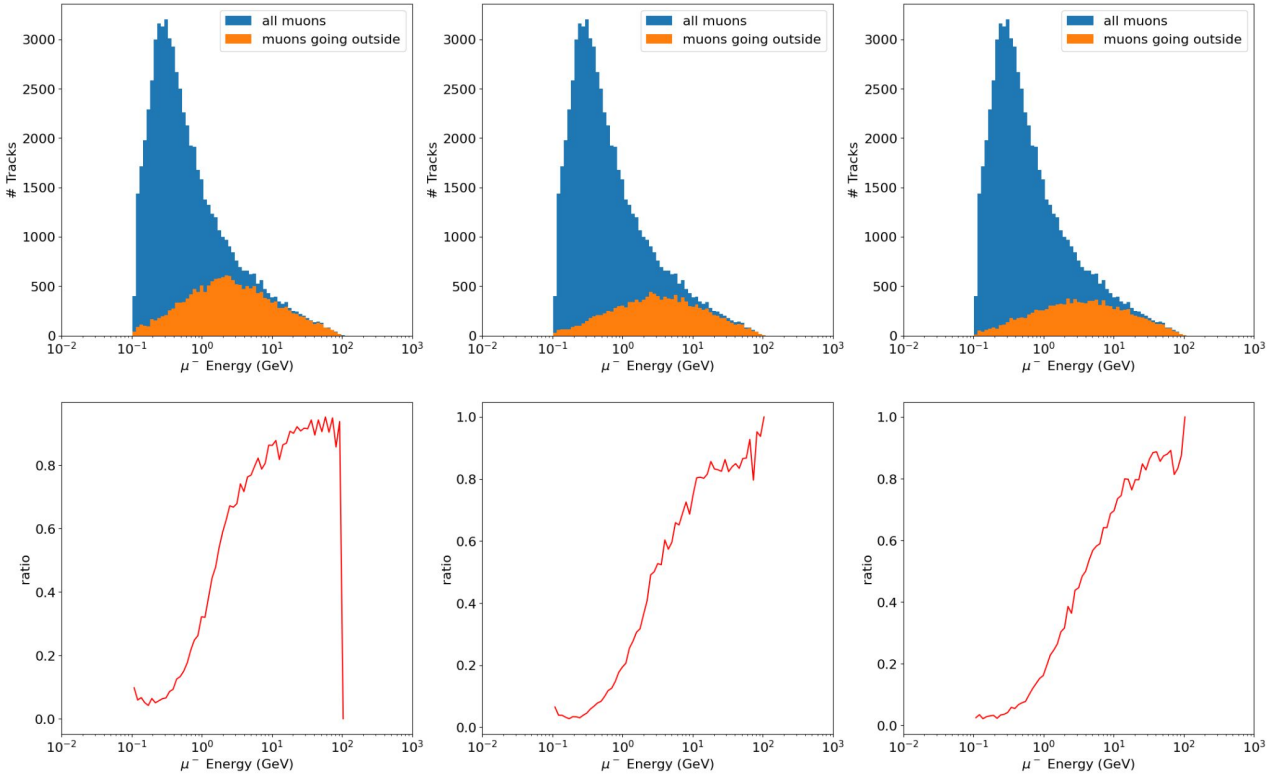
Muon range computation



Muon range computation



Containment study



x axis *y axis* *z axis*