On Boosted Dark Matter and DarkGeant4 (DG4)

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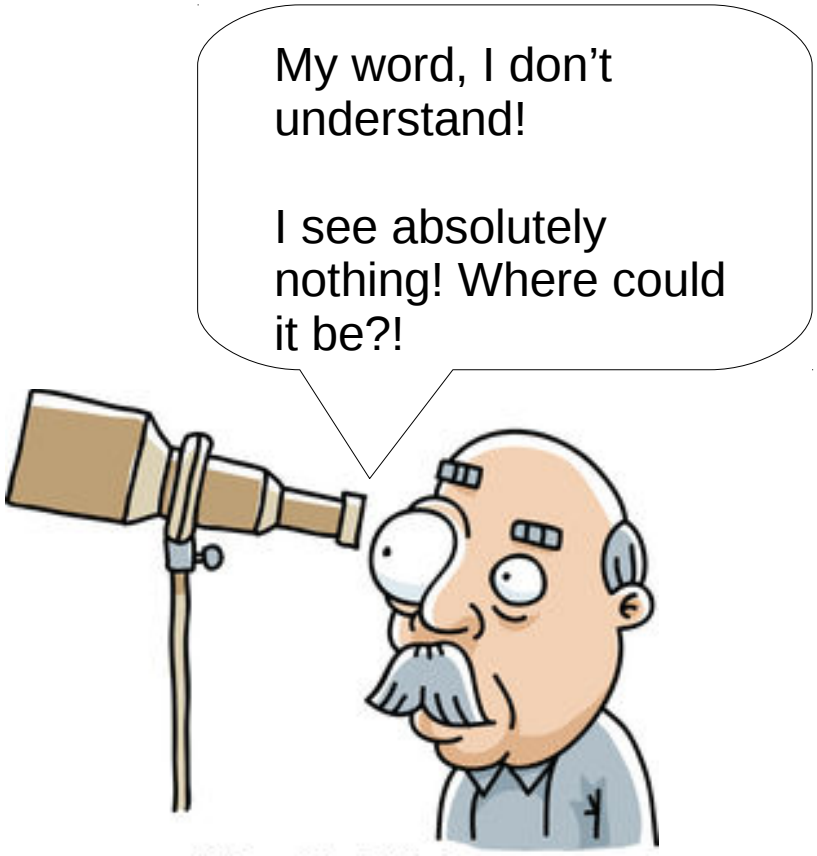
A little about myself and my work...

- I’m a first year, first semester Graduate student at the University of Texas at Arlington.
- In the past 6 months I’ve been working on a framework based on Geant4, called DarkGeant4.
- The development of this framework was initially fueled by Boosted Dark Matter (BDM) searches.

DG4

What is Dark Matter (DM)?

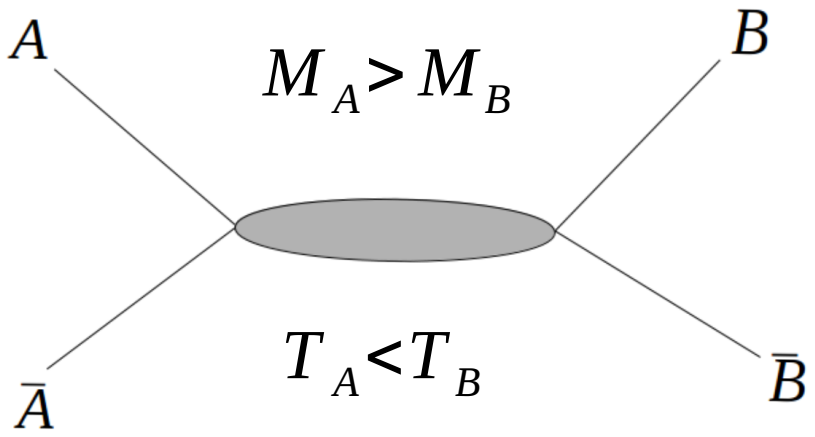
- DM was introduced to solve the missing mass problem observed throughout the universe since the early 20th century.
- Previous experiments have failed to directly detect DM.
- DM's presence is only known only through observed gravitational effects.



What is Boosted Dark Matter (BDM)?

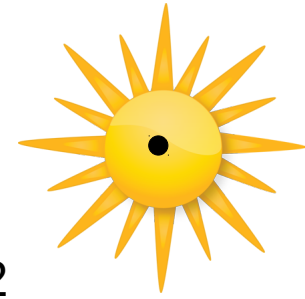
- DM model based on a extended WIMP paradigm, where DM can be one of many particles
- DM particles in this model are assumed to be similar to neutrinos, only much more massive
- Most DM is highly non-relativistic, so lorentz boosted DM provides and opportunity to observe BDM interactions if a low by reasonable energy threshold is met.

Possible annihilation channel



If M is Mass and T is Kinetic energy

DM conglomerate



- DM is believed to collect in matter-dense locations such as galactic centers, dwarf spheroidal galaxies and the inside of stars[2]
- Within these matter dense regions, DM particles have a large probability to annihilate through multi-component annihilation and semi-annihilation.

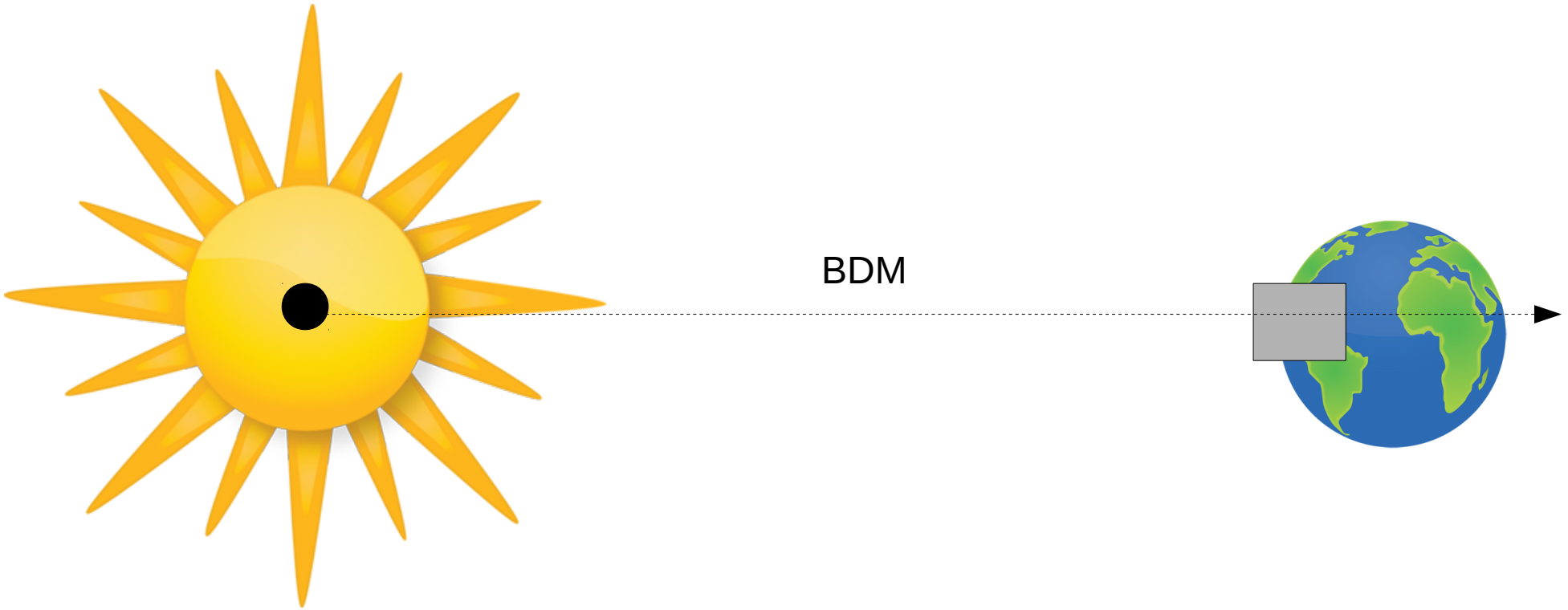
$$A\,\bar{A} \rightarrow B\,\bar{B}$$

Multiple component annihilation

$$A\,A \rightarrow \bar{A}\,\Phi$$

Semi-annihilation

BDM Point source



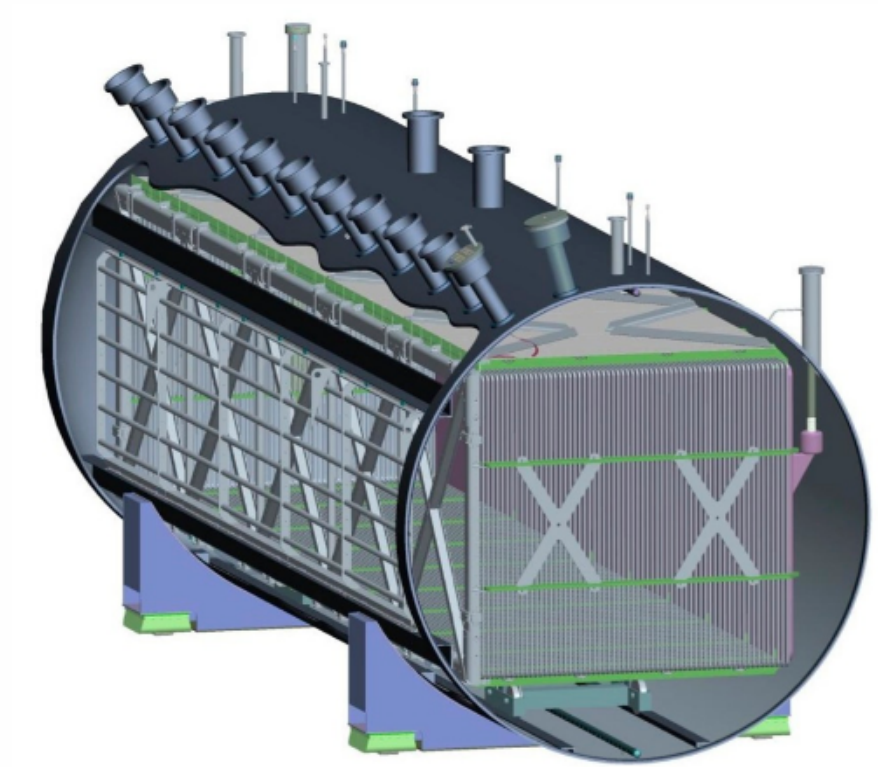
BDM being more likely to spawn from matter dense regions, affords us great ability to discriminate between signals.

BDM and neutrino signals

- The BDM may then experience a weak interaction/collision with standard model particles.
- When BDM scatters off nucleons, it may potentially generate a signal not unlike neutrino scattering events.
- Being mindful of that, it could be possible to observe these events in present and future neutrino experiments
  - Hint: MicroBooNE anyone?

MicroBooNE's place!

- The largest active LArTPC is within the MicroBooNE beamline.
- A lower energy threshold has been achieved utilizing the technology within MicroBooNE's LArTPC
- Protons scattered through BDM interactions will typically have a T < 1 GeV

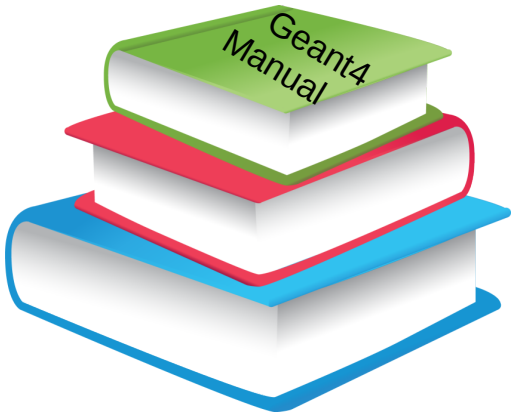


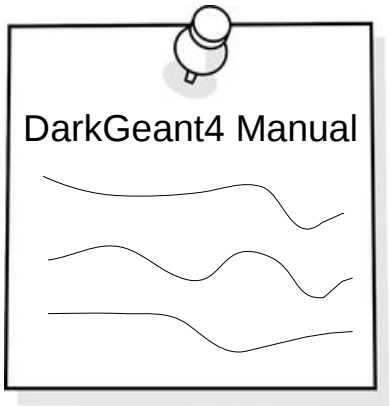
DG4

Okay, but where does DarkGeant4 come into play?

What is DarkGeant4?

- It’s an application written in C++ and Lua
- It’s built as a framework around Geant4 that allows users (you) the ability to utilize Geant4 while minimizing start up time.
- Ubuntu 16.04, Red Hat 6/7 (Derivatives) supported.





Experimentalist

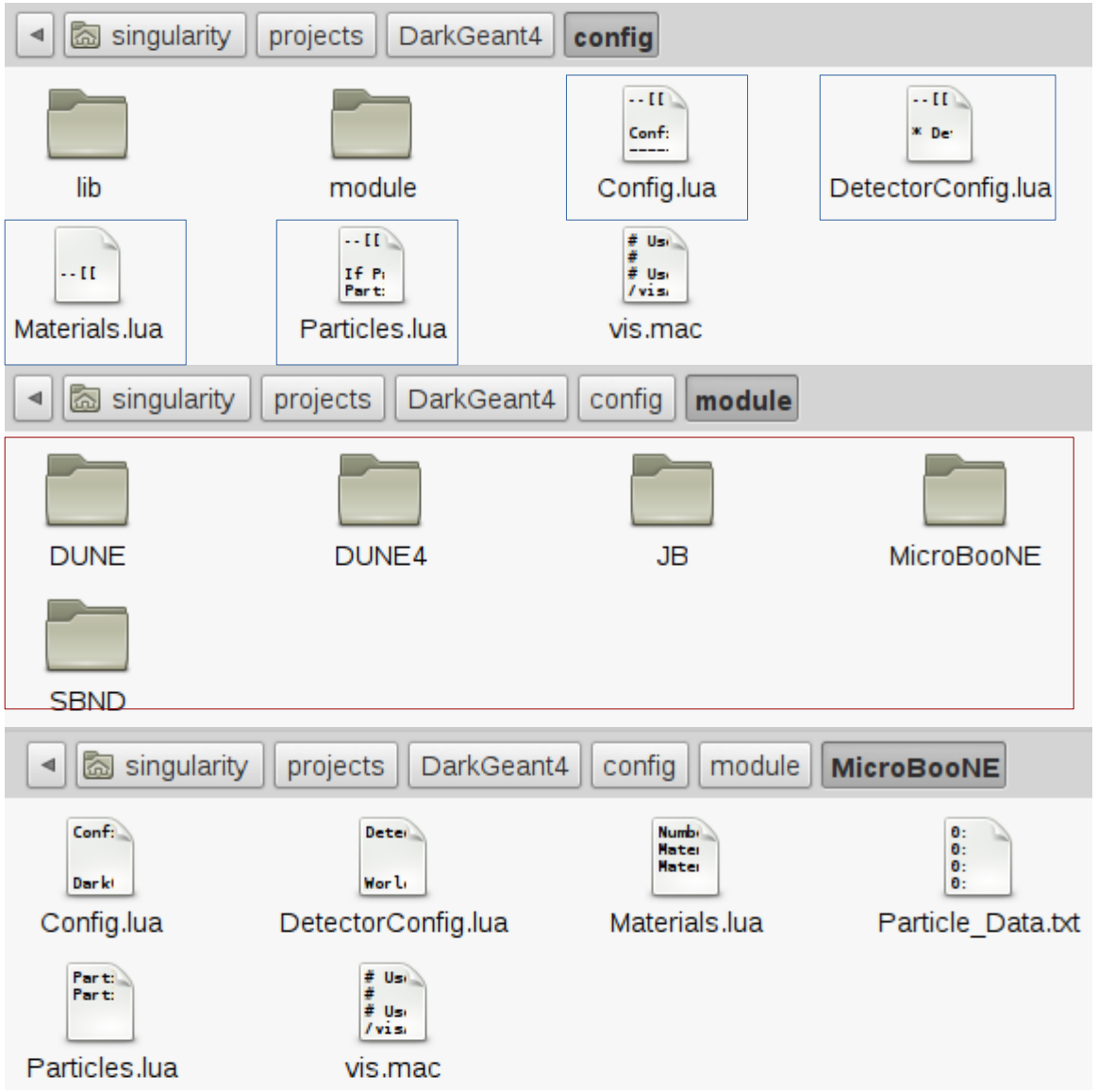
Theorist

DarkGeant4: Bridging the gap between experimentalist and theorist collaboration.

Today's feature highlight

- Lua Configuration Engine
  - Utilization of modules for separate and concurrent configs.
  - Defining Detector Geometry using Lua Scripts.
  - Human readable by design.
- Simulating with pre-generated events or with on the fly event generation
- Corsika-to-DarkGeant4 converter.

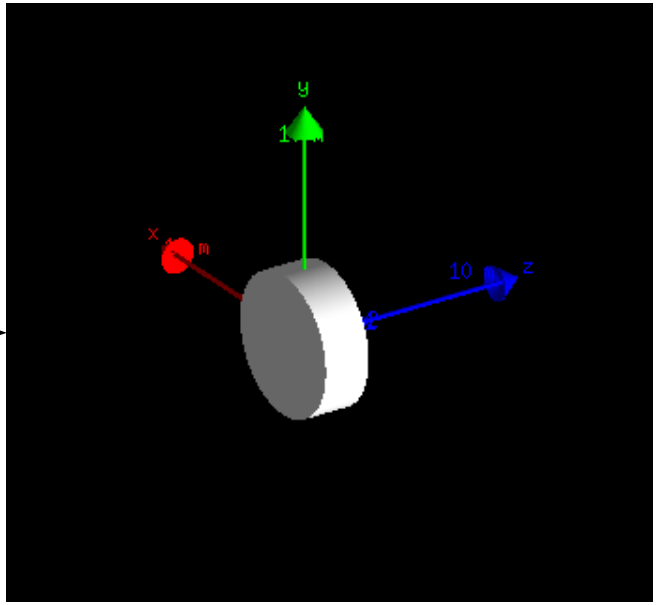
Lua Modules



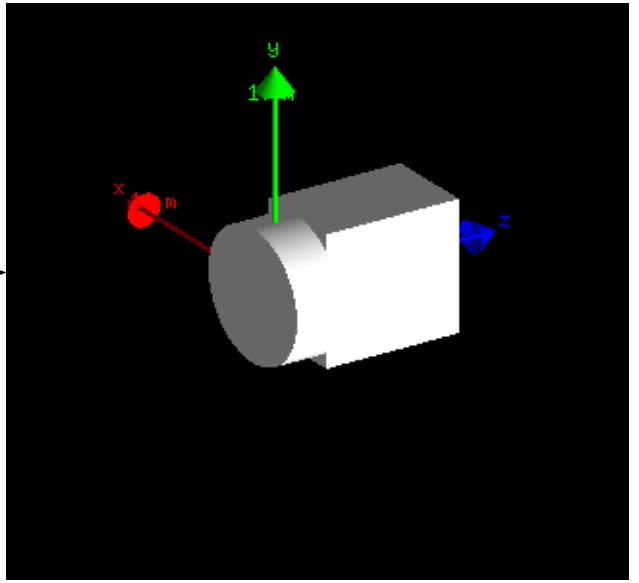
- Four main .lua files, with defaults located in /config
- Modules store different set of config files which are self contained and separate from other configurations
- Gives you the opportunity to test out different models, different geometry etc, concurrently.

Lua detector interface

```
World = { Material = "G4_AIR",
          Volume_Type = "Box",
          half_X = 20.0,
          half_Y = 20.0,
          half_Z = 20.0,
          Inside = "None",
          Position = {0, 0, 0} }

DetectorComponent_1 = { Material = "Liquid Argon",
                        Volume_Type = "Cylinder",
                        Inner_Radius = 0.0,
                        Outer_Radius = 3.0,
                        Half_Length = 1,
                        Position = { 0, 0, 0 },
                        Inside = "World" }
```




```
World = { Material = "G4_AIR",
          Volume_Type = "Box",
          half_X = 20.0,
          half_Y = 20.0,
          half_Z = 20.0,
          Inside = "None",
          Position = {0, 0, 0} }

DetectorComponent_1 = { Material = "Liquid Argon",
                        Volume_Type = "Cylinder",
                        Inner_Radius = 0.0,
                        Outer_Radius = 3.0,
                        Half_Length = 1,
                        Position = { 0, 0, 0 },
                        Inside = "World" }

DetectorComponent_2 = { Material = "Liquid Argon",
                        Volume_Type = "Box",
                        half_X = 2.0,
                        half_Y = 3.0,
                        half_Z = 3.0,
                        Position = {0, 0, 4},
                        Inside = "World"}
```



Additional Component

DarkGeant4 event generation

Events by file input

Event#	label	E/c (GeV/c)	P_x (GeV/c)	P_y (GeV/c)	P_z (GeV/c)	X (m)	Y (m)	Z (m)
0:	gamma	0.000982449	5.475e-05	-0.000531411	-0.000824507	313.381	-660.368	225.765
0:	gamma	0.00232344	0.000198817	0.00130336	-0.00191314	314.844	-566.843	225.765
0:	gamma	0.000174224	-3.04338e-05	-6.82685e-05	-0.000157376	300.895	-599.852	225.765

```
Particle_File = "Particle_Data.txt"
Particle_File_Type = "Four Vector, with position, with name"
```

Associated Lua code to load that file

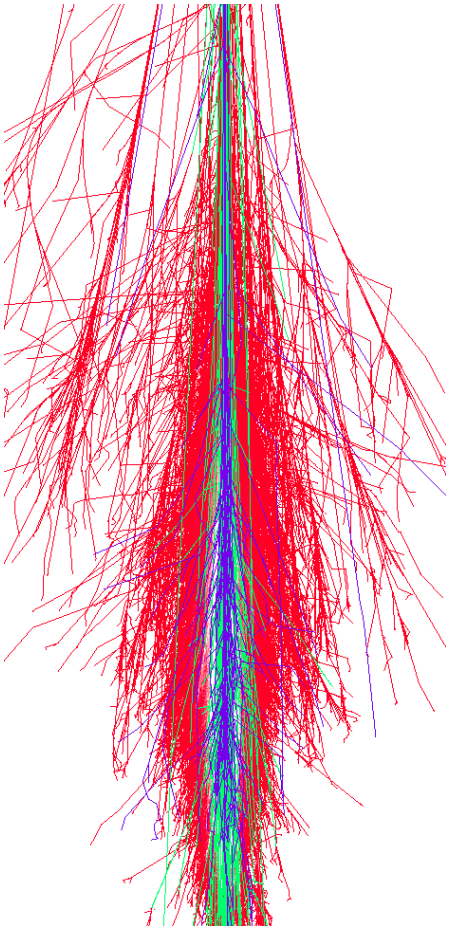
On the fly event generation

```
Particle_Table = { Particle_Name = "mu+",
                   -- Positions specified by a user defined lua function
                   Particles_Position = Particle_Position_Function,
                   -- Along the Z-axis
                   Momentum_Direction = {0.0, 0.0, 1.0},
                   -- Energy in GeV
                   Energy = 3.0,
                   Number_Of_Events = 20
                   Primaries_Per_Event = 1 }
```

Particle_Name, Particles_Position, Momentum Direction and Energy can be defined as a Lua function, providing substantial flexibility.

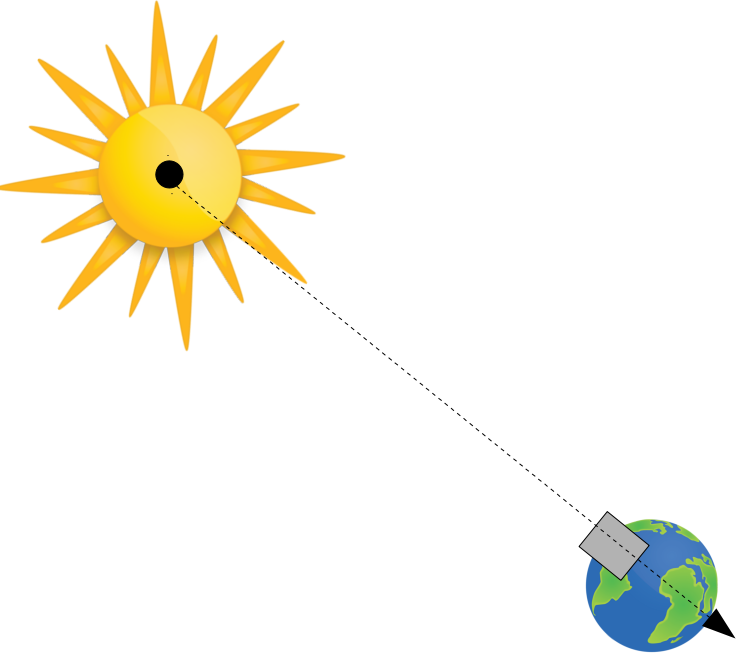
Corsika-To-DarkGeant4 Converter

- Corsika is a program that simulations cosmic-ray showers.
- Corsika's output can be readily used in DG4 through the use of the included converter, written primarily by Hunter Sullivan (Grad UT Alrington)



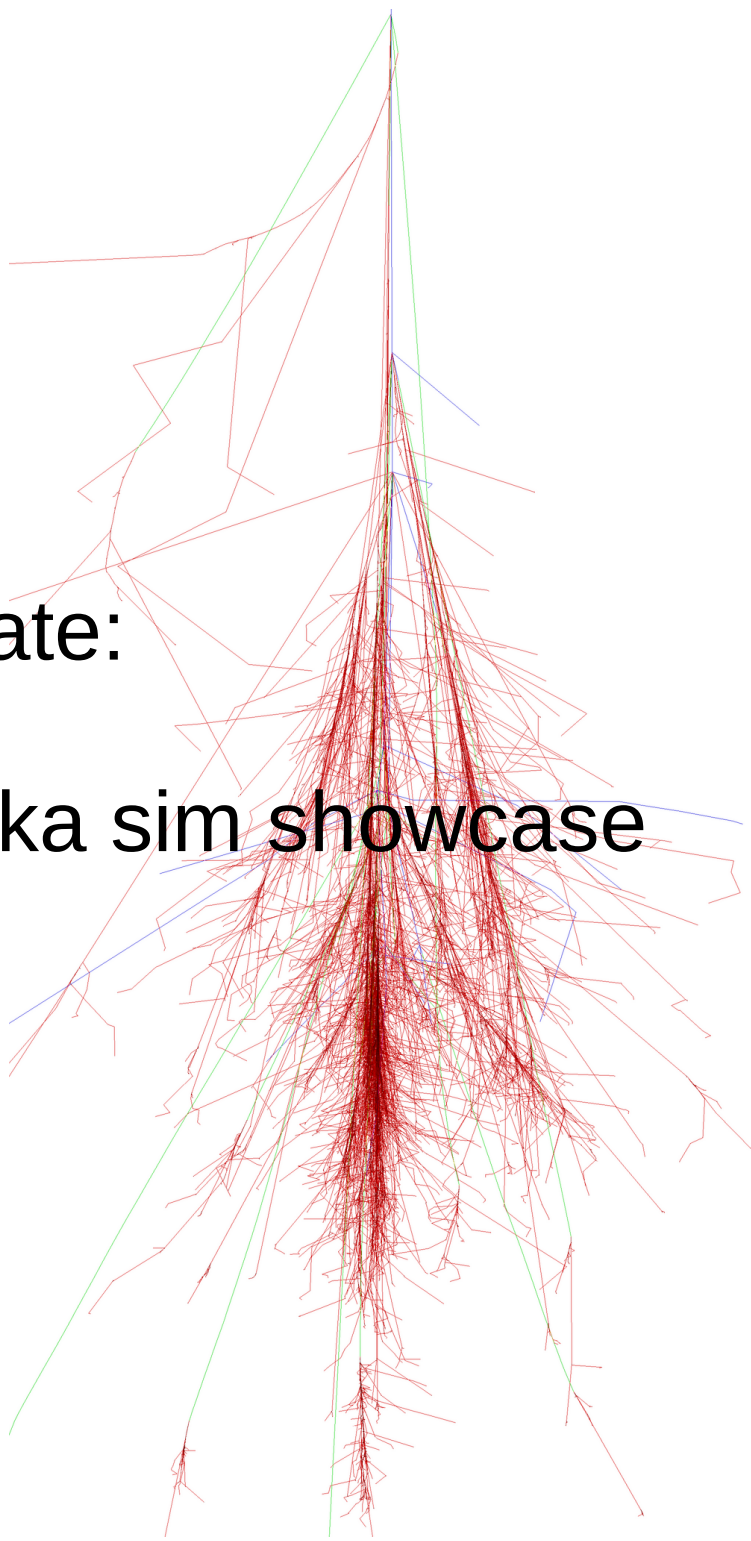
Proton induced cosmic-ray shower

DG4



To Simulate:

Simple BDM and Corsika sim showcase

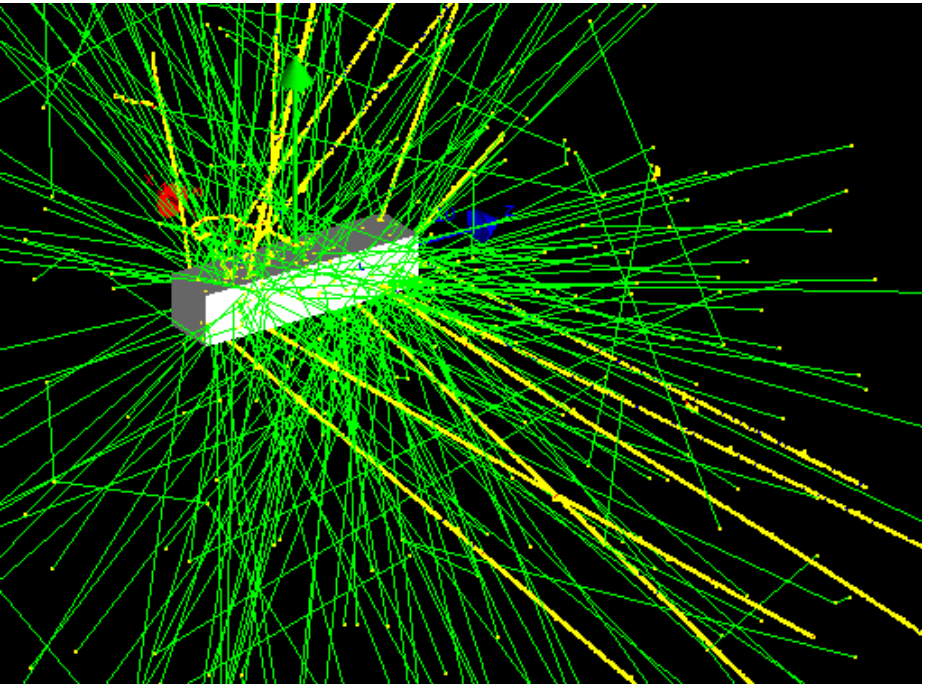


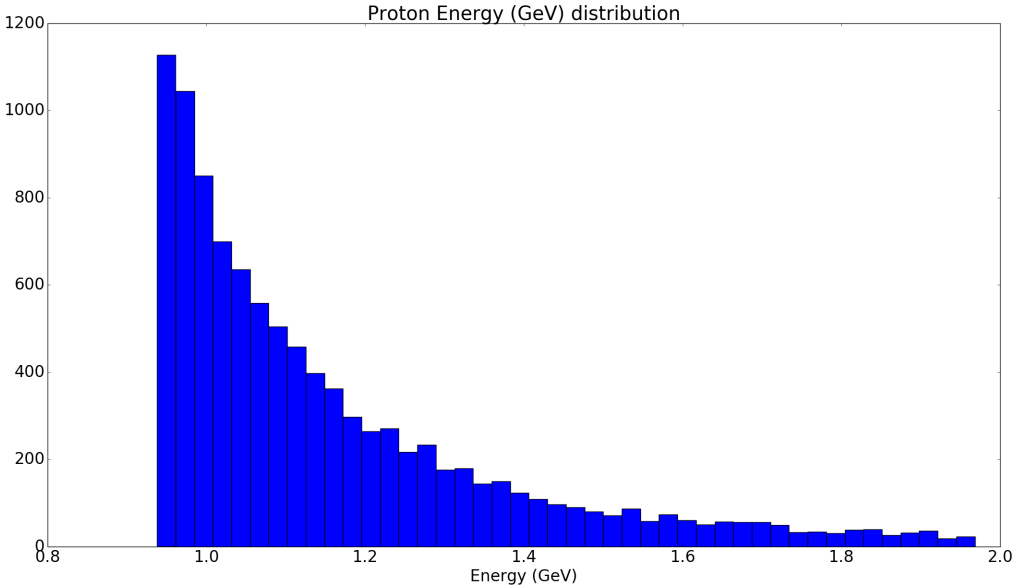
Theorist's simple BDM model

Point source BDM beam along the Z axis scatters off a Liquid Argon nucleus, causing a proton to be ejected

$$B + Ar \rightarrow B + Cl^{-1} + p$$

The ejected proton carries a large forward momenta along the Z axis

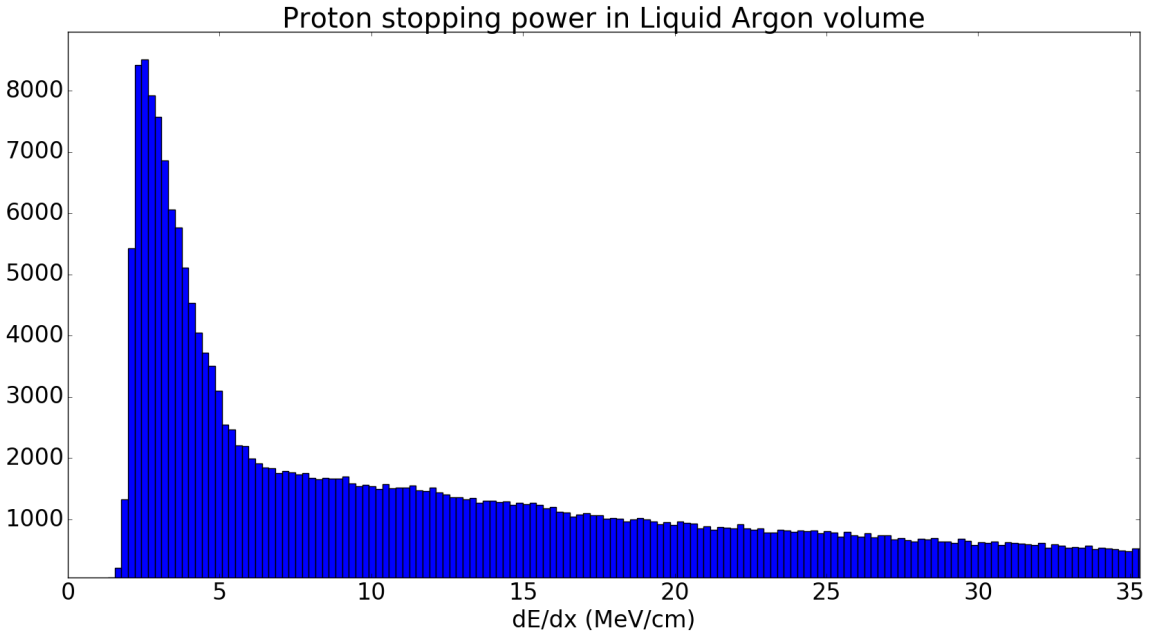


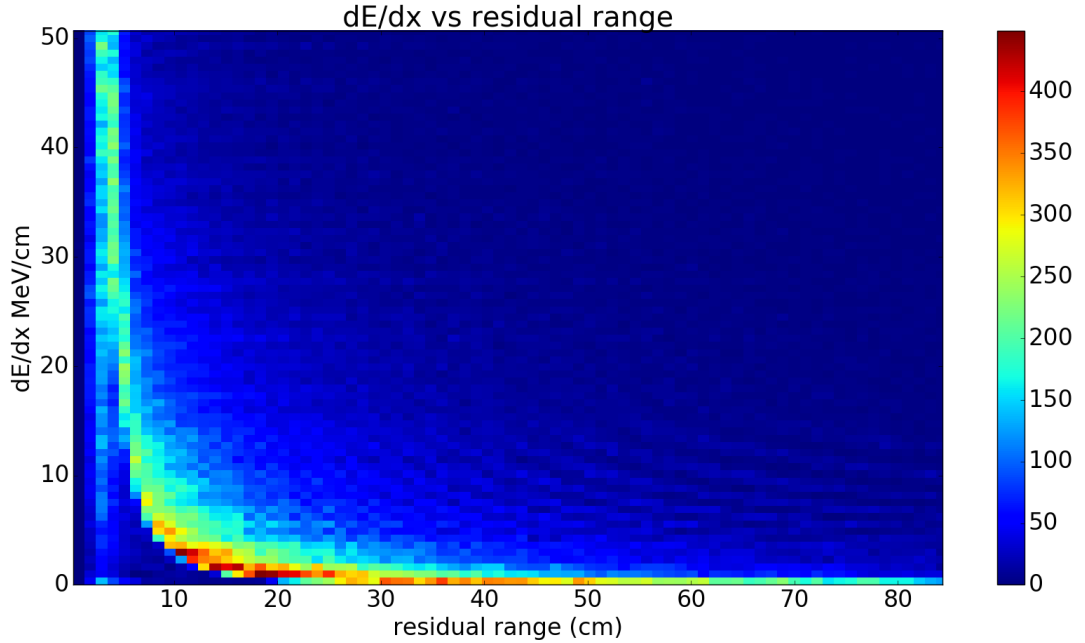


We generated 10k events and uniformly distributed the starting positions of the ejected protons across within a MicroBooNE LArTPC like geometry

Model was provided by theorists from The University of Wisconsin-Madison

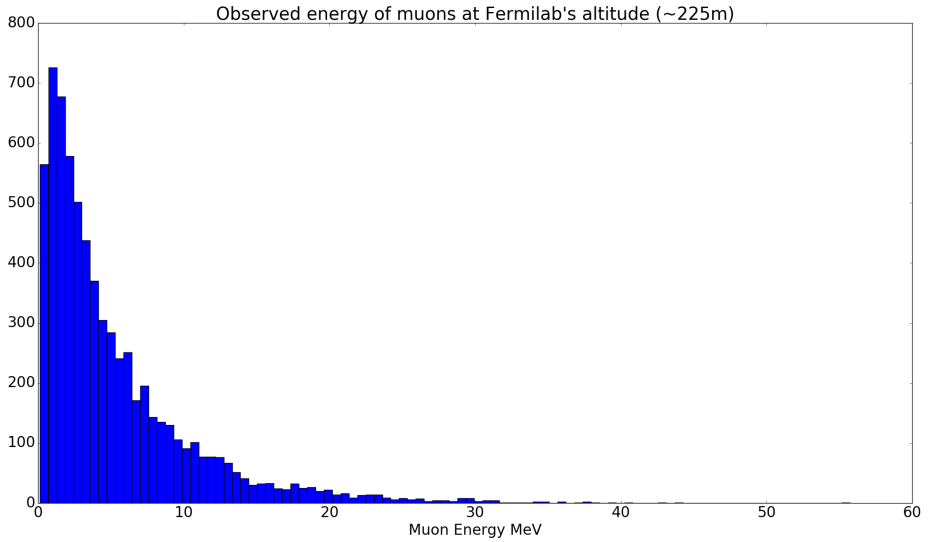
Information from DarkGeant4



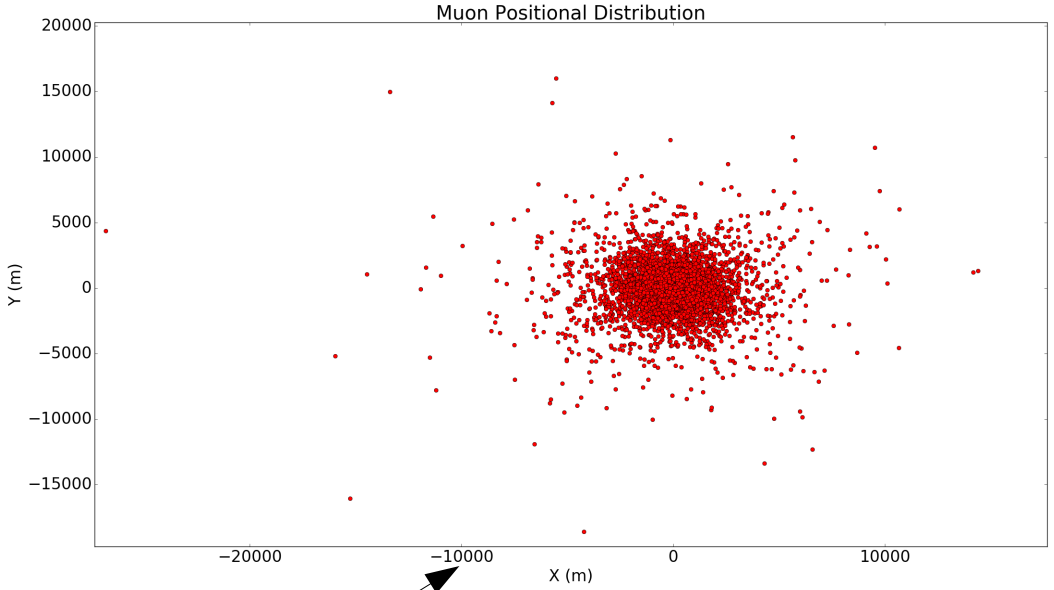


Corsika Simulation

- Simulated 10000 proton induced cosmic-ray showers
- E range 1-100 GeV
- Observational level set to 225m (~Altitude at Fermilab)
- Recreated a very simple MicroBooNE installation

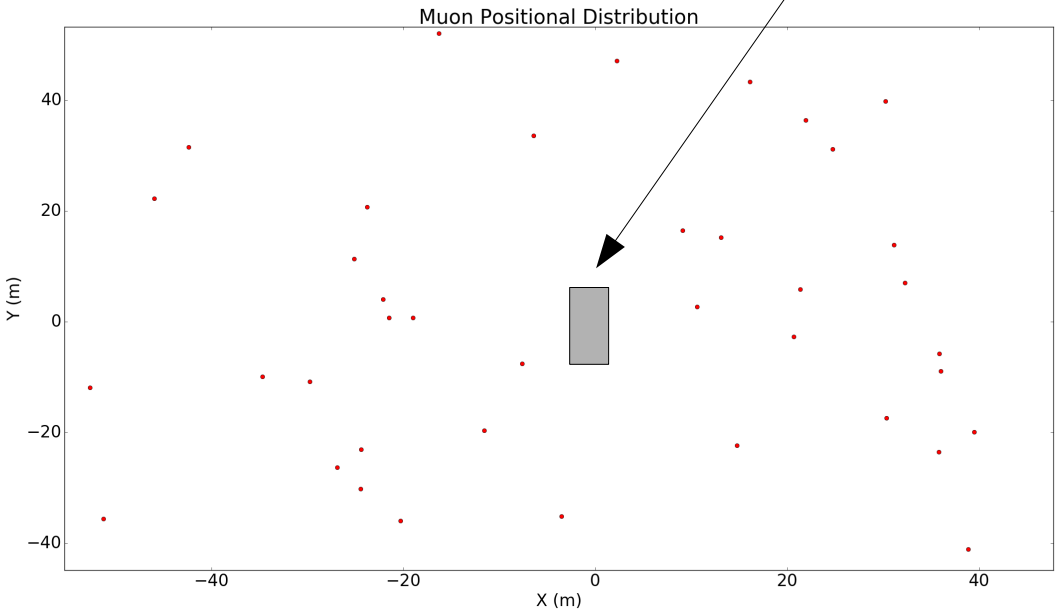


Sim information (Corsika)



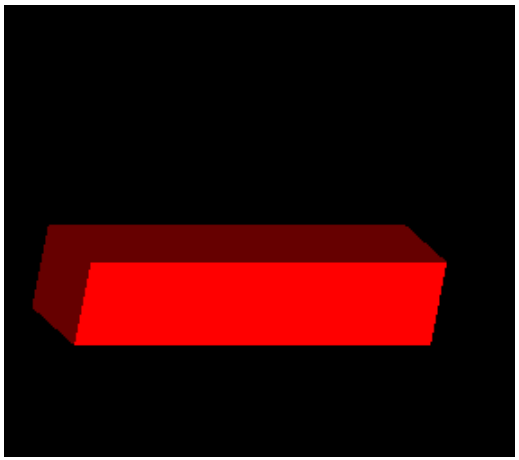
That's 10km away from the detector!

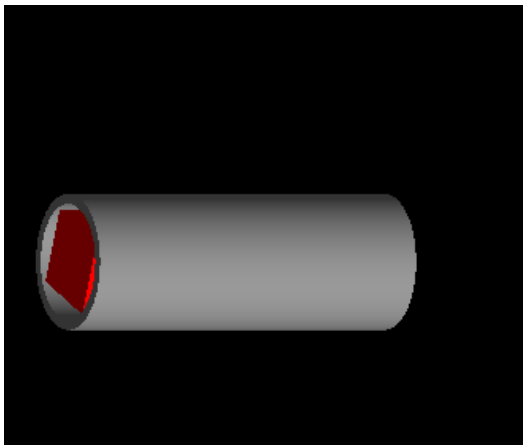
Depiction of LArTPC Location



Building the simulation

- Start with a block of LAr with the same dimensions as the active LArTPC at MicroBooNe.
- Then I enclosed the LAr volume with an exterior cylindrical volume made of steel.

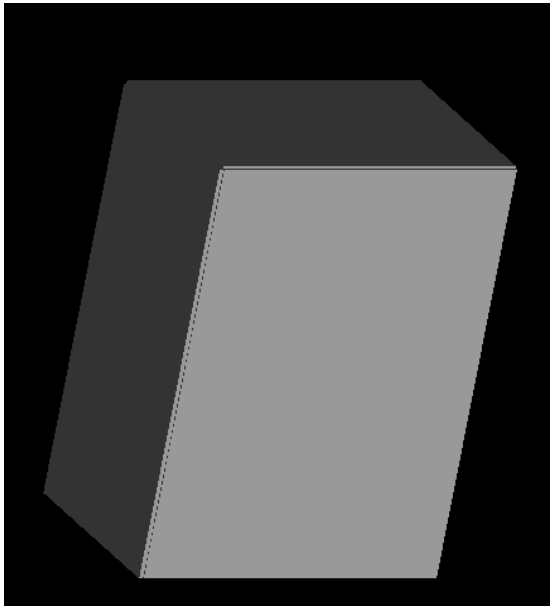


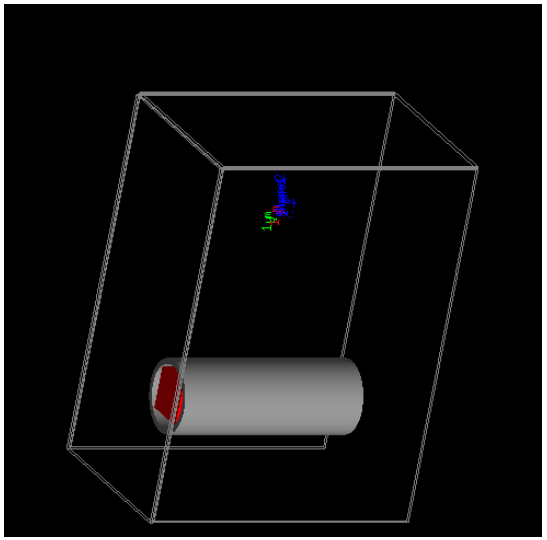


These are not to specifications, I'm merely just showing it can be done.

Building the simulation

- The volumes are then enclosed in a set of steel walls, <u>again not to specifications</u>
- 70 total lines of Lua script as of now.





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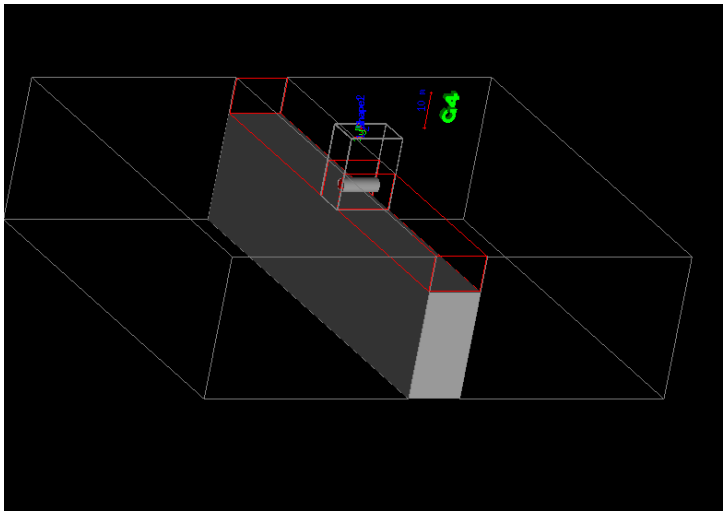
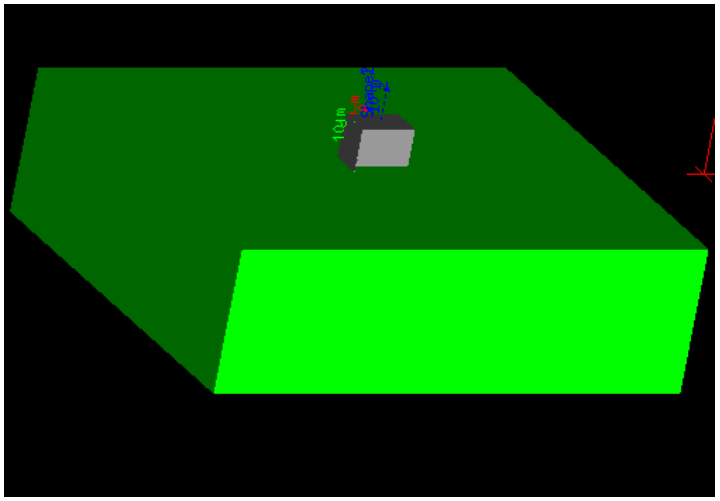
Building the simulation

- The steel enclosure was then placed into a soil like substance, with minor clipping between certain volumes.
- 115 lines of Lua script in total to build this recreation.

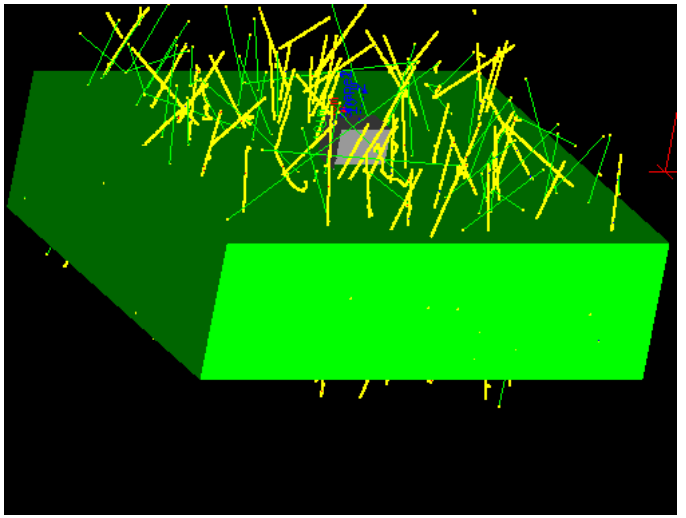


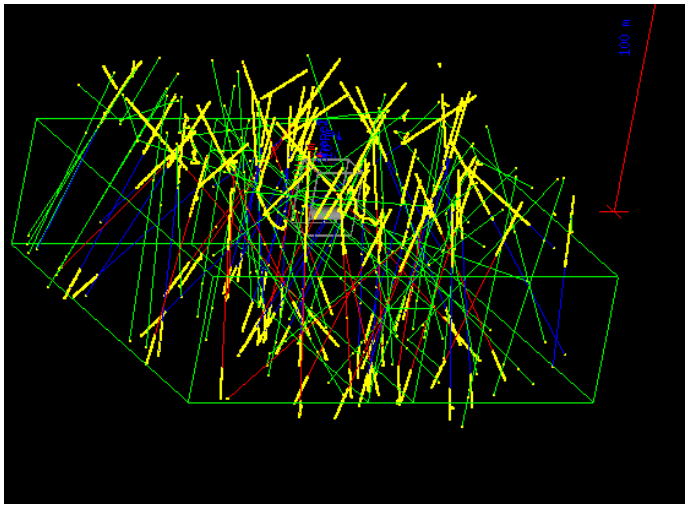


DG4

Cosmic-Ray Shower

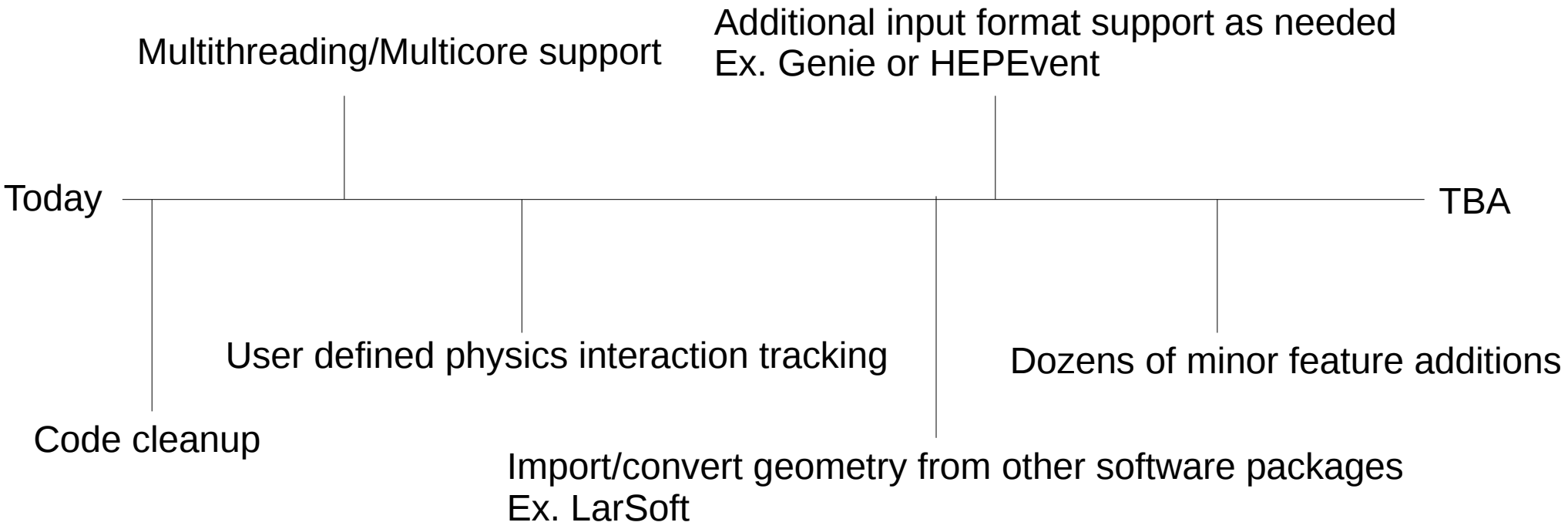
- Finally a corsika cosmic-ray shower which was converted to a DG4 format was simulated.
- Building this fairly simple recreation of the LArTF took a mere 20 minutes with DG4.





DG4

Future DarkGeant4 development



Additional collaborators welcome!

DG4

Access and Demo

- Code is hosted on a private github repository that will eventually be made public!
- If you want access to this code, please contact Dr. Asaadi at jonathan.asaadi@uta.edu
- If you want to see DarkGeant4 in action, feel free to find me and I'll be happy to give you a demo!

Special thank you to...

- Dr. Jonathan Asaadi (PI UT Arlington)
- Hunter Sullivan (Grad UT Arlington)
- Ilker Parmaksiz (Undergrad UT Arlington)
- Other Grad/undergrad in my group

And….

DG4

You, the audience! Thank you so much for attending my talk!