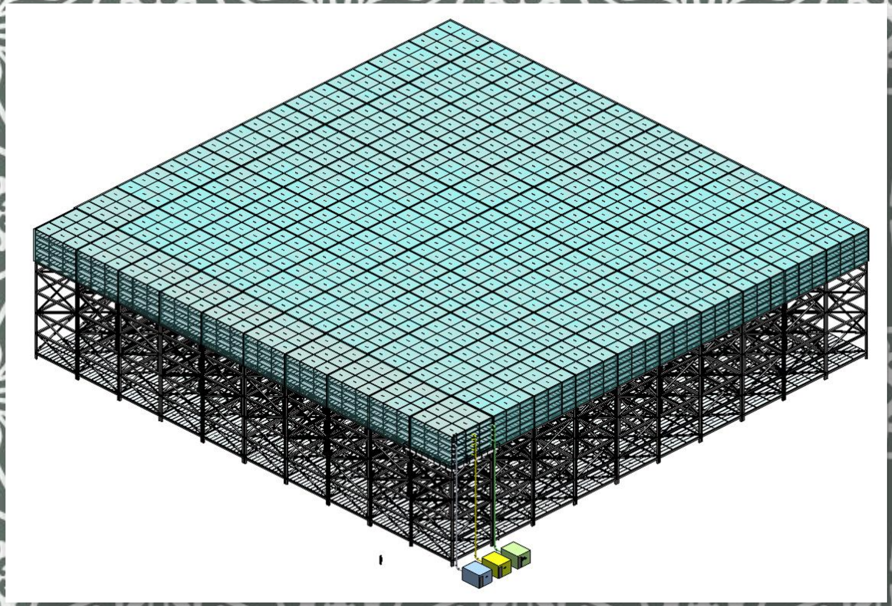
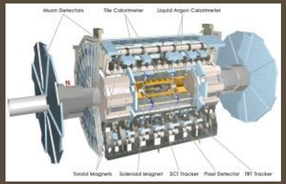
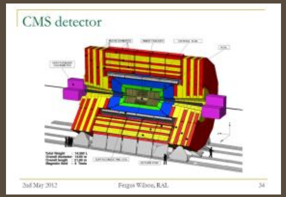


MATHUSLA BACKGROUND STUDIES

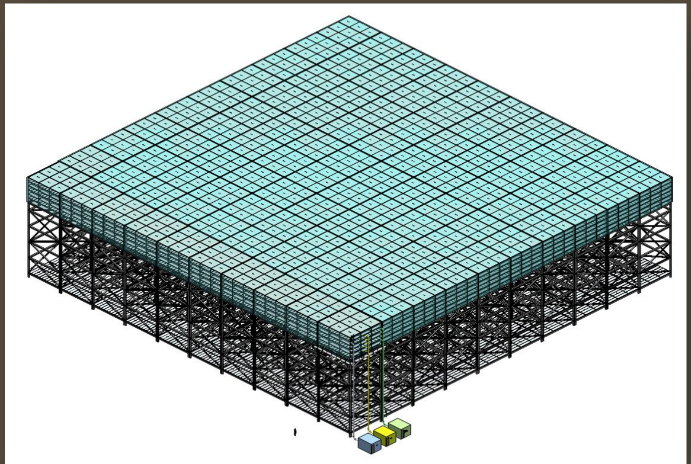
G. Watts (UW/Seattle) for
everyone working on MATHUSLA
August 27, 2018

CONTEXT



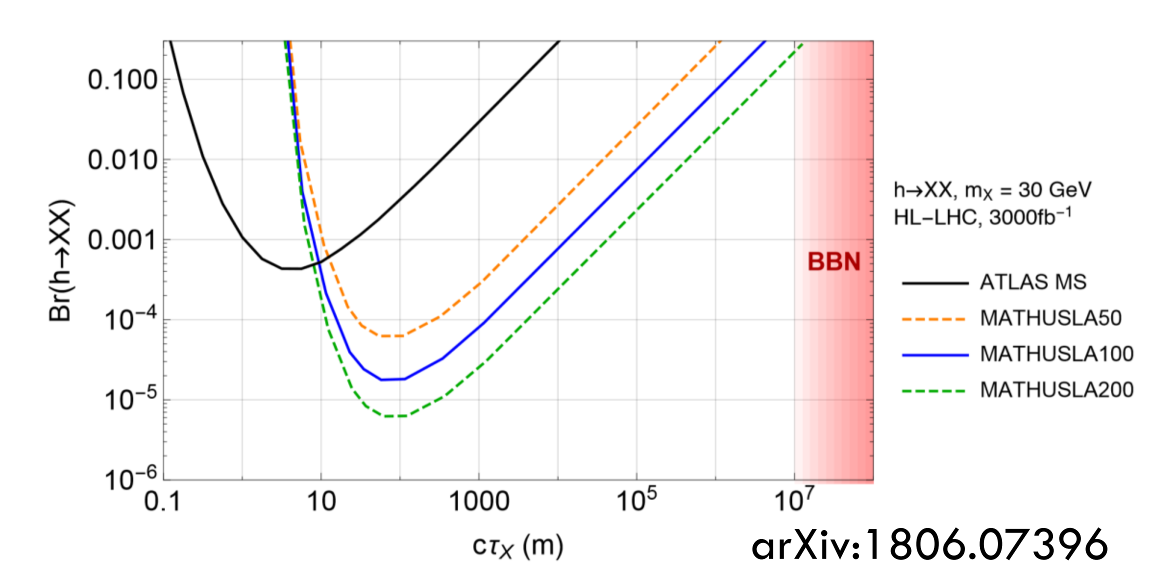


Trigger
Background



No Trigger
No Background

CONTEXT



4 decays caught by MATHUSLA
ZERO background

CONTEXT

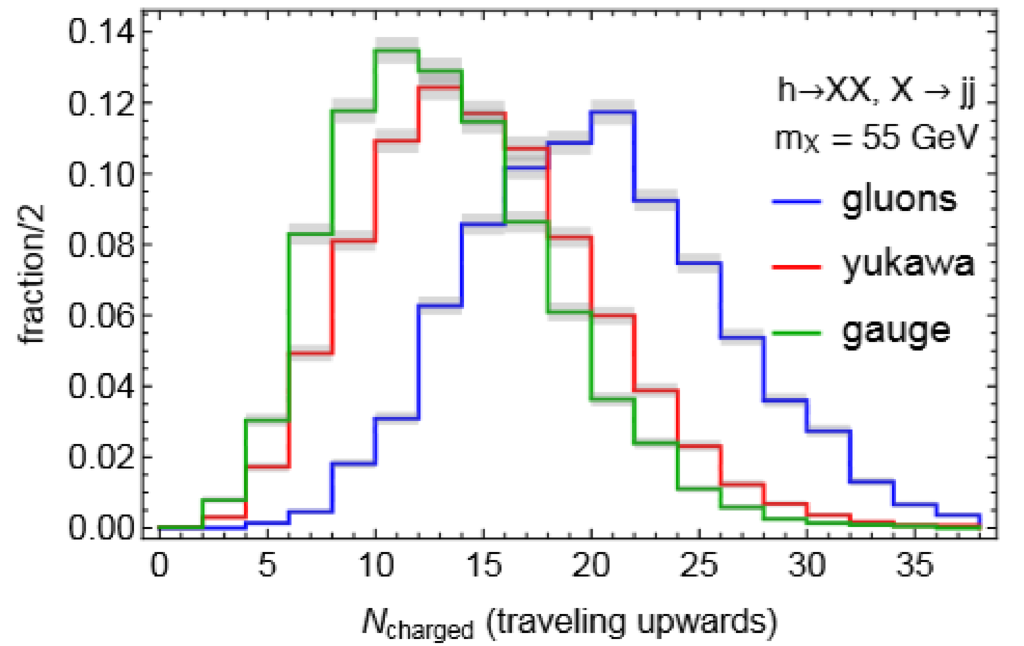
What does the signal look like?

LLP

- Multiple Upward Going Tracks
- The fewer we need, the more models we are sensitive to

Cosmic Rays

- Downward going showers of charged particles
- "Muon Bundles"
- Must be separable



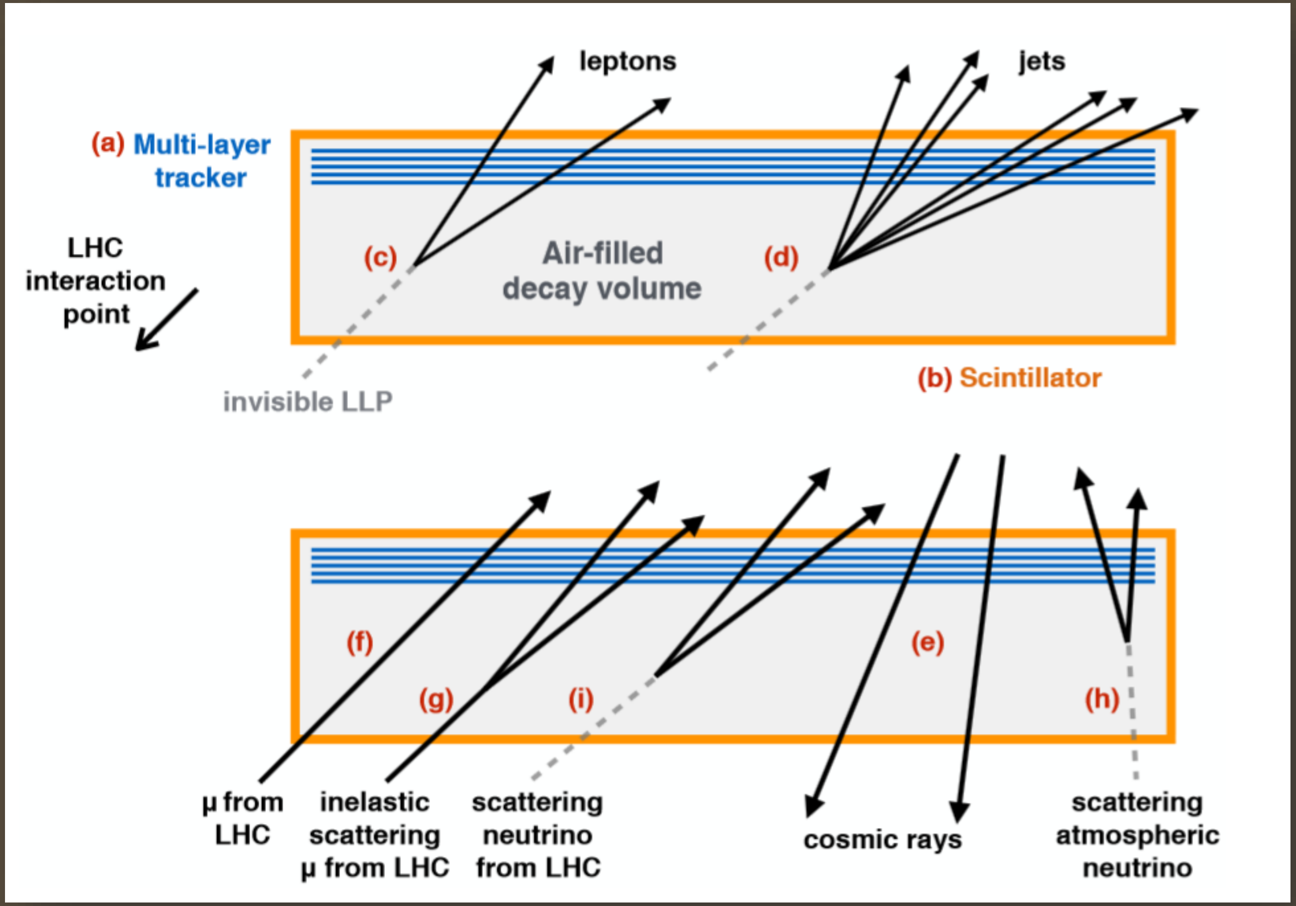
arXiv:1806.07396

BACKGROUND OVERVIEW

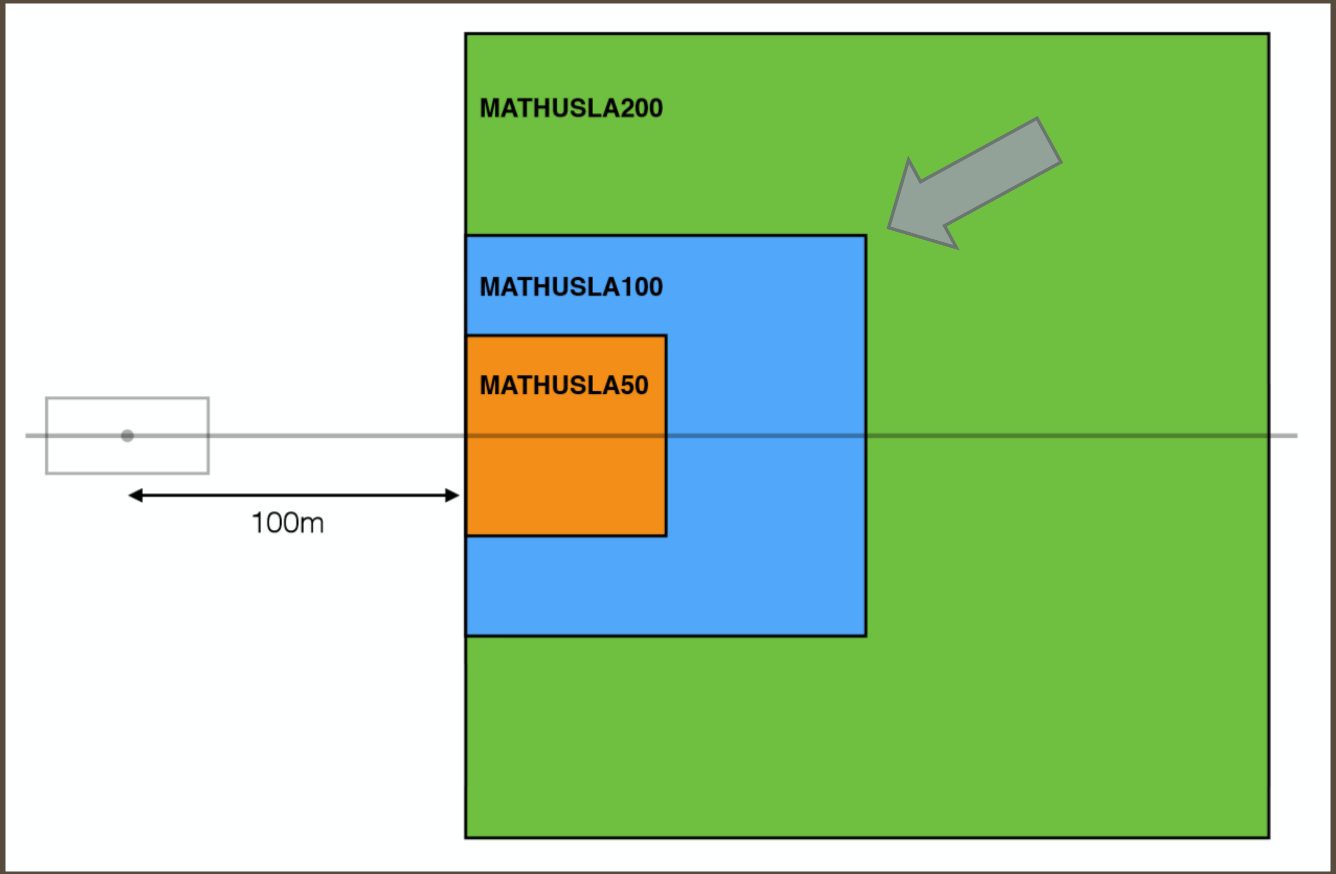
Cosmic Rays

Muons from the LHC

Neutrinos



MATHUSLA X



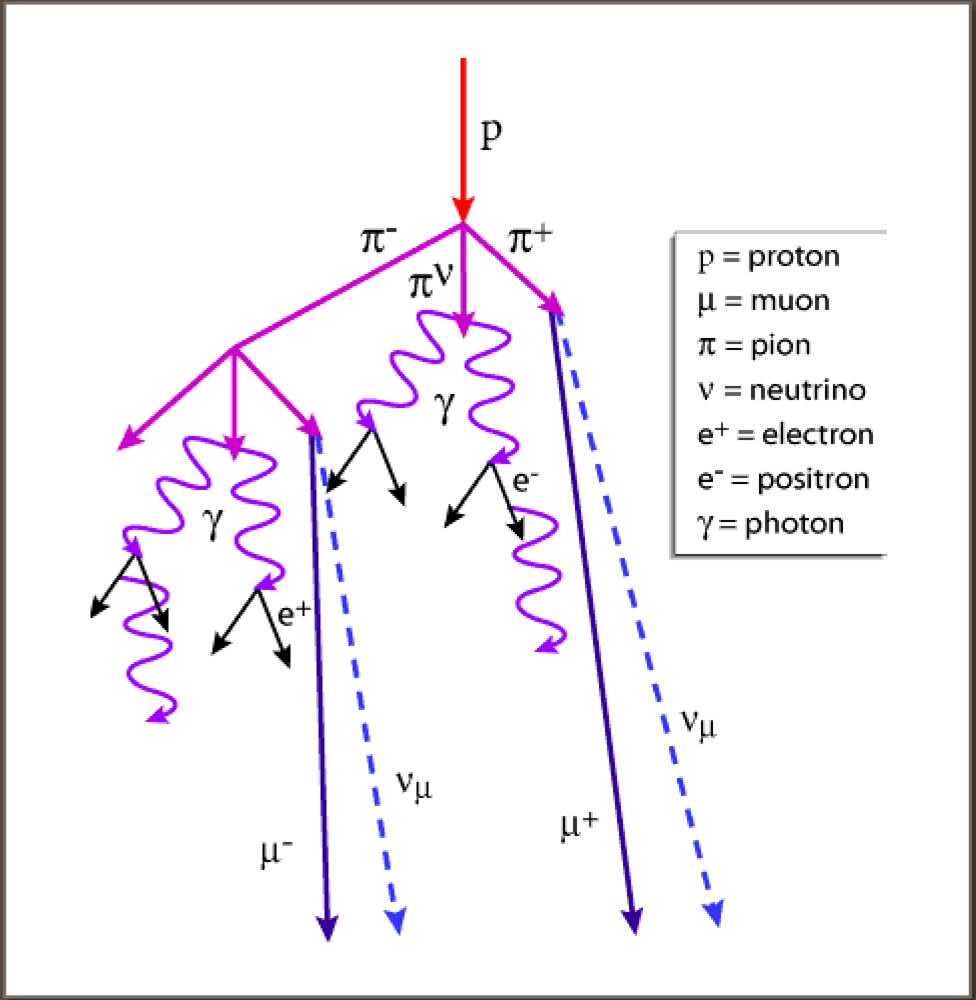
COSMIC RAYS

These are your (my) father's cosmic rays

- Muons
- Electrons
- Charged pions (not so much at ground level)

To consider:

- Total charged particle flux
- Angle of incidence of primary
- Albedo



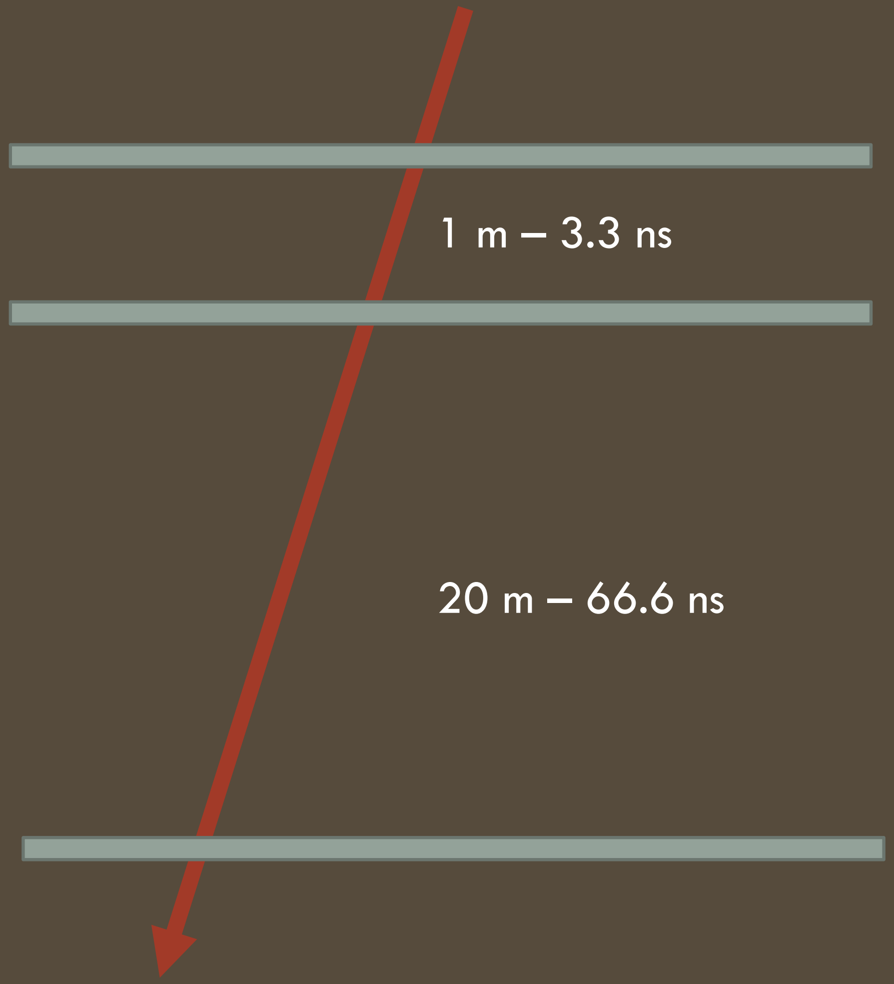
COSMIC RAY REJECTION

Timing!

- 4 1m gaps near the top
- 20 m gap at the bottom
- Detector and readout goal: 1 ns resolution
- Chance of a single cosmic ray charged particle track being mis-identified as an upward going track (4 layers): $\sim 10^{-15}$
- Expected number of tracks from CR over the course of the HL-LHC: $\sim 10^{15}$ in MATHUSLA200

Vertexing

- Vertex reconstruction would reduce the background by several orders of magnitude
- The detector will not be searching for LLP's during large showers (deadtime)

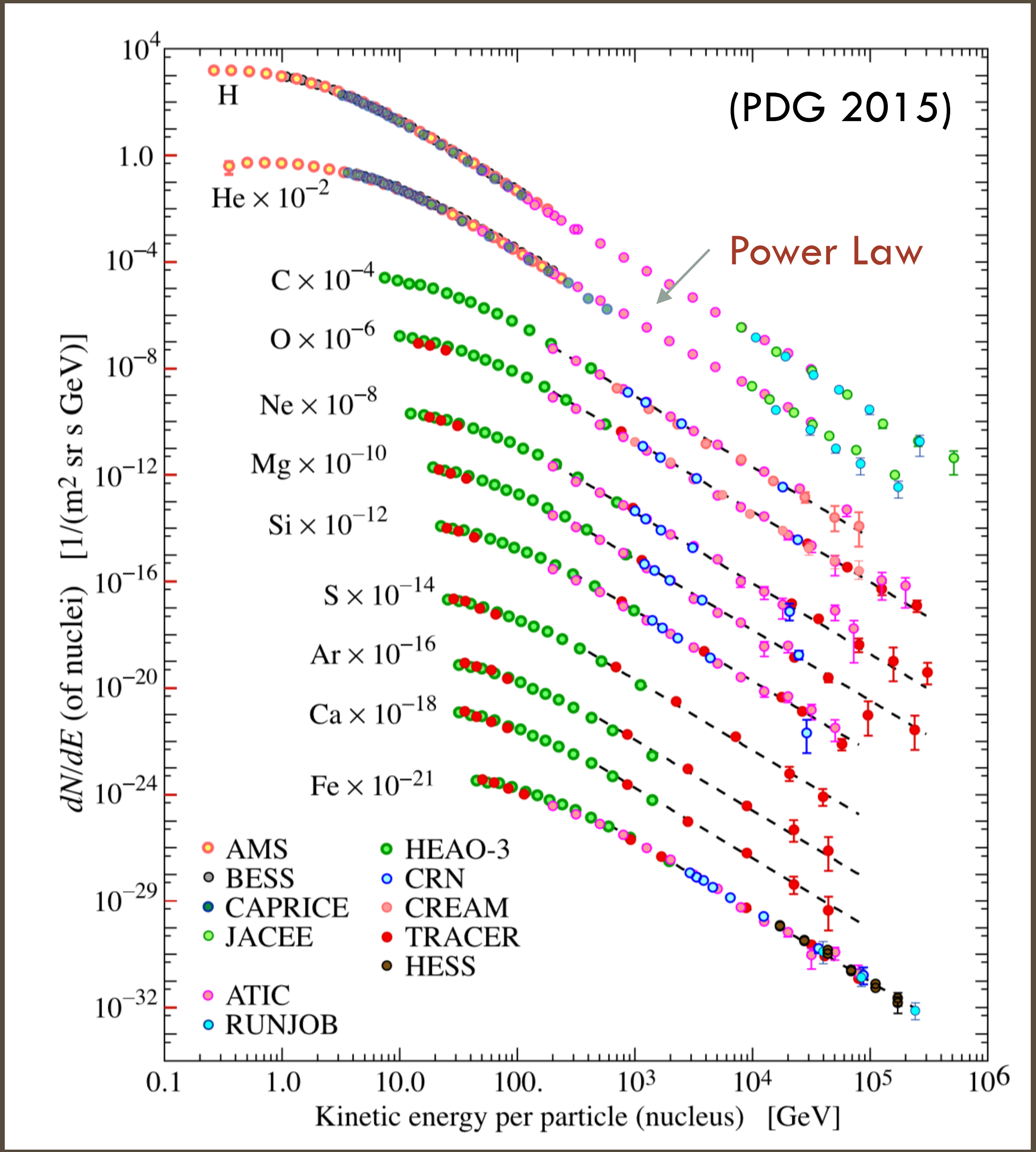


COSMIC RAYS

Classified by the primary particle incident on the atmosphere

Percent	Source
90%	Protons (H)
9%	Helium
1%	Heavier Elements

Source particle and energy both affect to affect the shower size and number of particles in the shower



PDG SAYS…

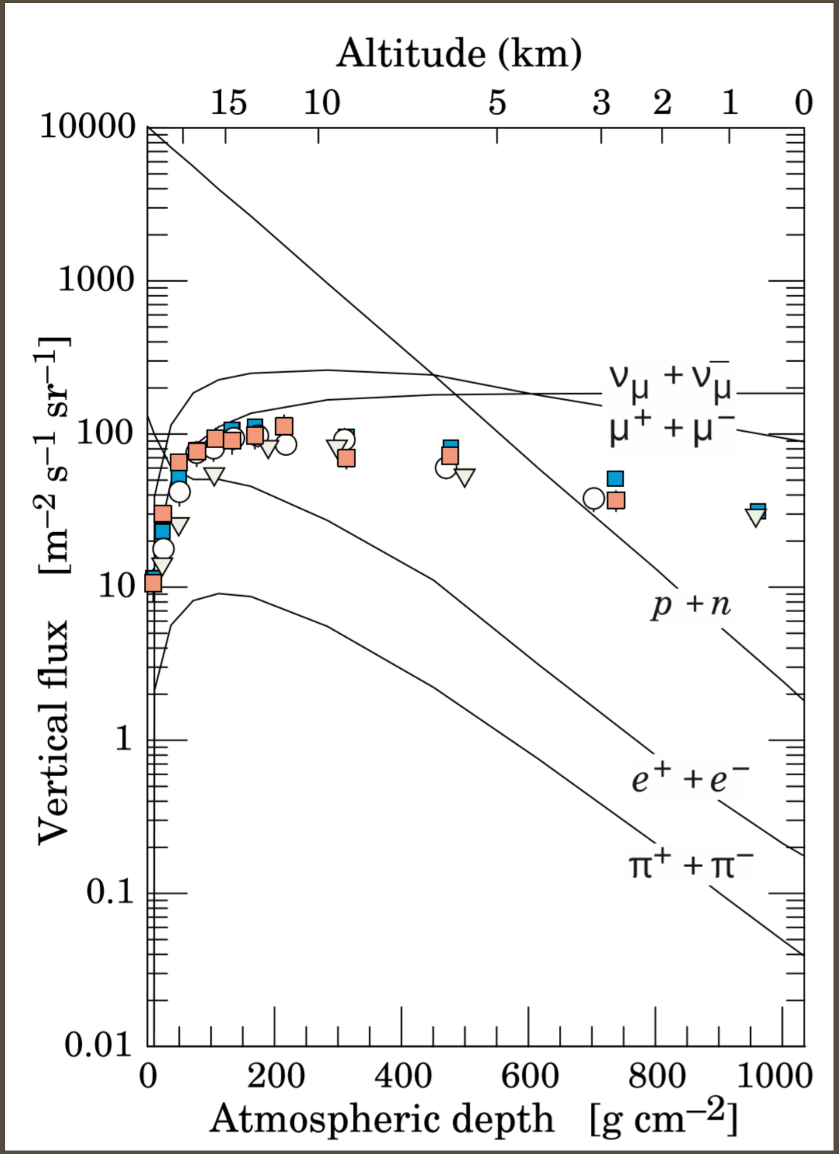
Muons

- Loose about 2 GeV of energy as they pass through atmosphere
- As a result flux is relatively flat
- Average energy of a μ at ground level is $\sim$4 GeV

Electrons

- At ground level due mostly to secondary sources
- Low energy electrons from μ decay
- High energy electrons from π decays
- Energy structure is complex
  - And not represented by this plot

This component is missing from ATLAS and CMS!



PDG SAYS...

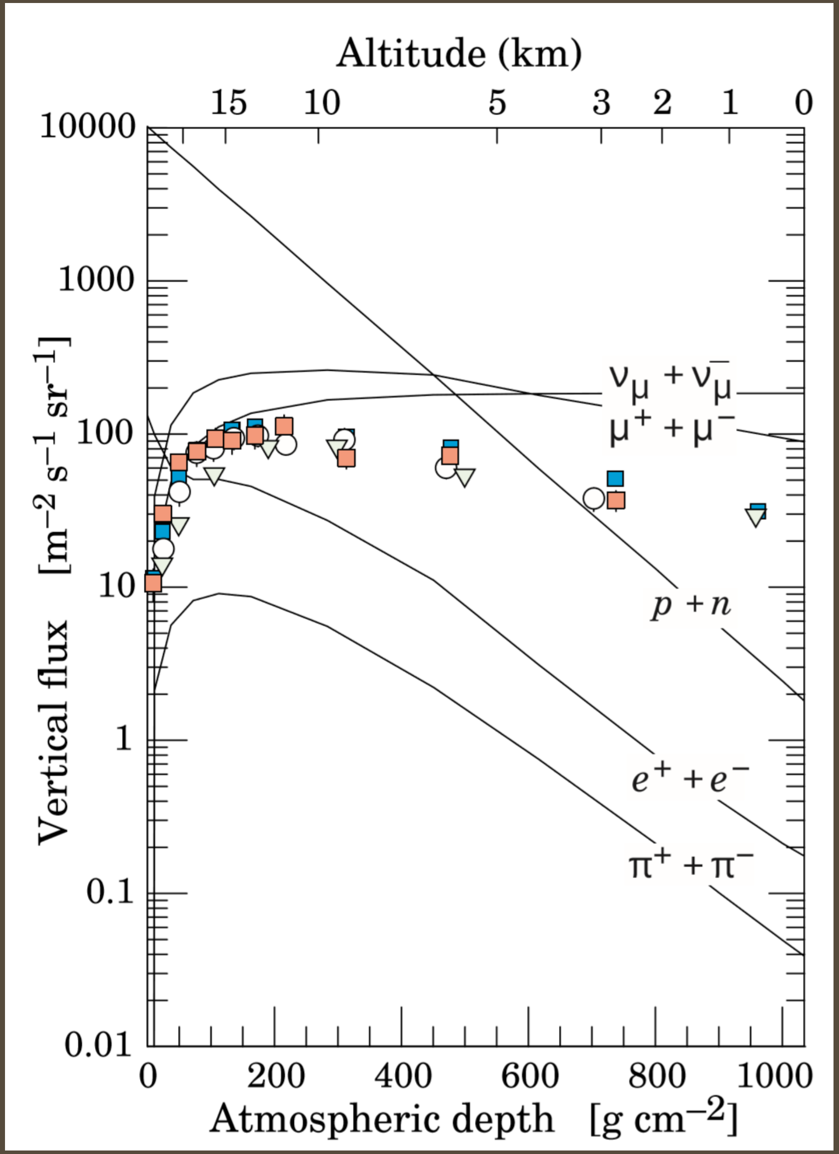
The $\sim 10^{15}$ comes from:

- 250 Hz rate per m^2
- 200×200 m detector
- 10 year lifetime
- Duty cycle ~40% for HL running

We have some problems with this simple estimate:

1. Detailed understanding of charged particle flux at the detector's elevation
2. High zenith angle cosmics rays
3. Cosmic Ray Albedo
4. Cosmic ray + other background/signal conspiracies

Need a detailed simulation to understand these effects!

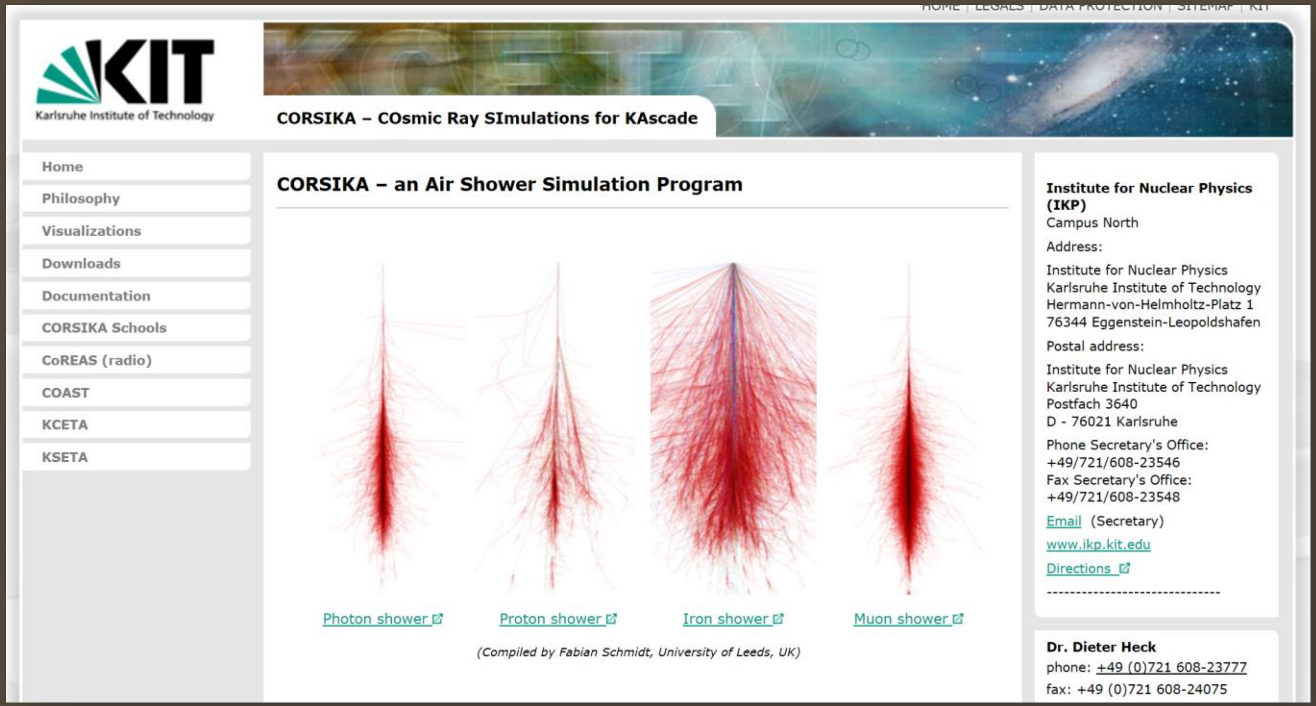


COSMIC RAY SIMULATIONS FOR KASCADE (CORSIKA)

Generate showers that can be fed to a GEANT4 simulation

- Different Primaries
- Primary Energy Spectra
- Explore angles

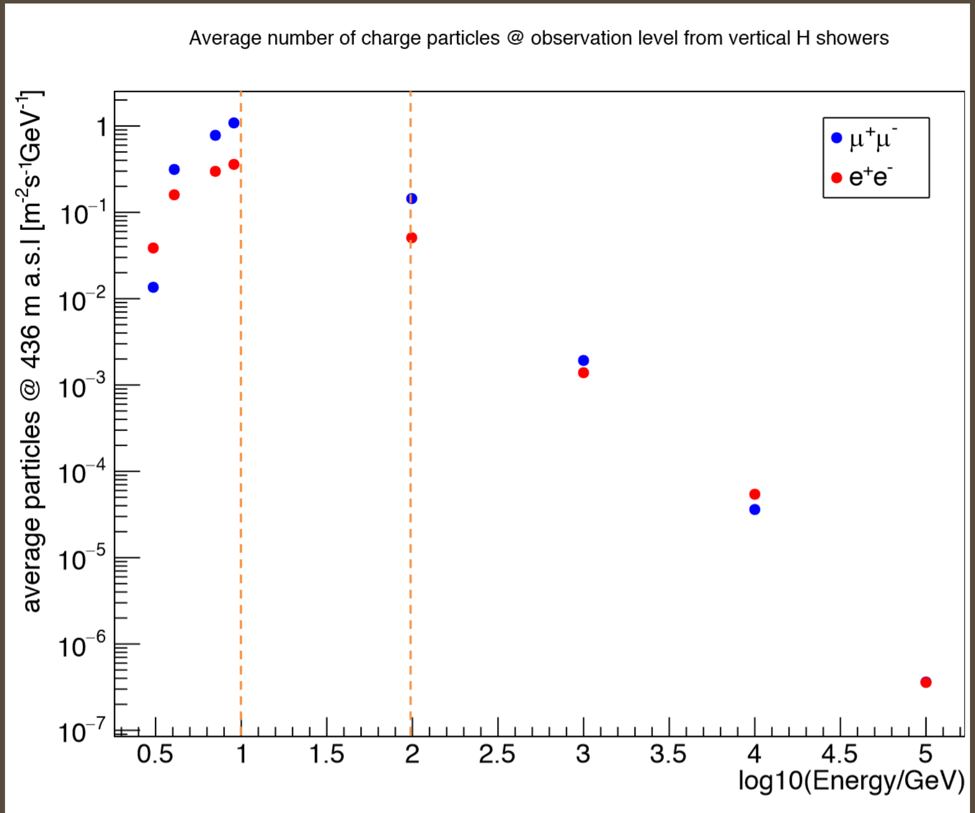
Generate showers that can be fed to a G4 simulation

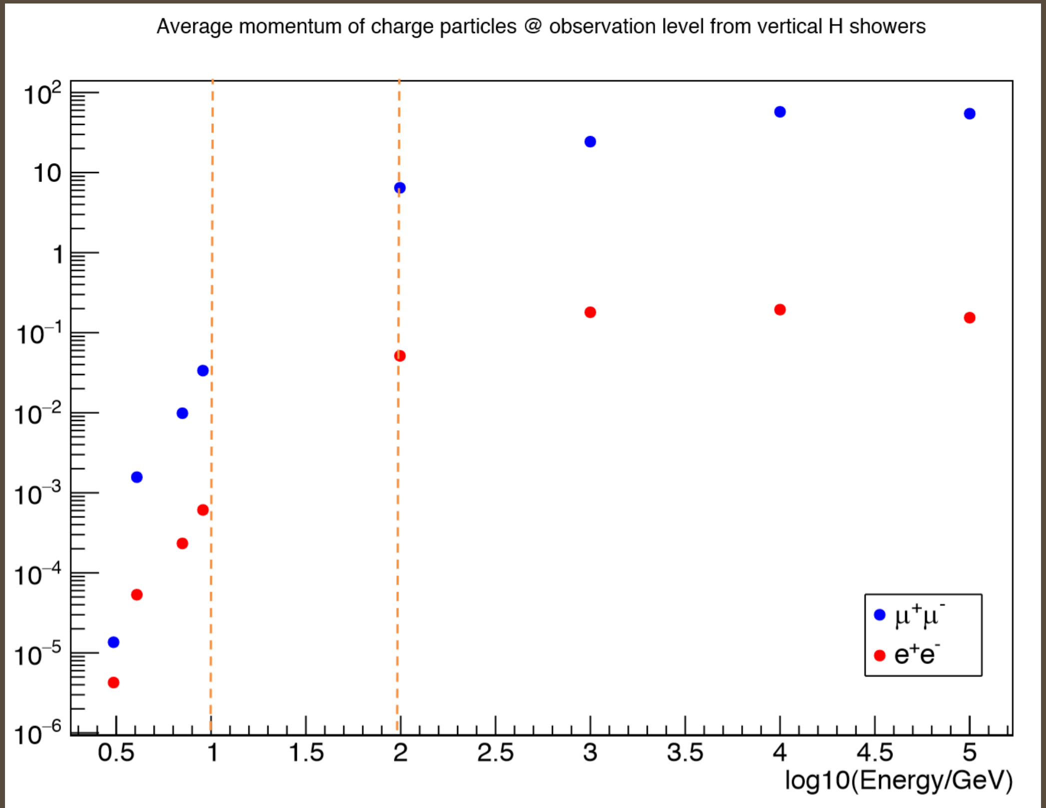


A team is busy simulating them as we speak

PROTONS FROM ABOVE (0°)

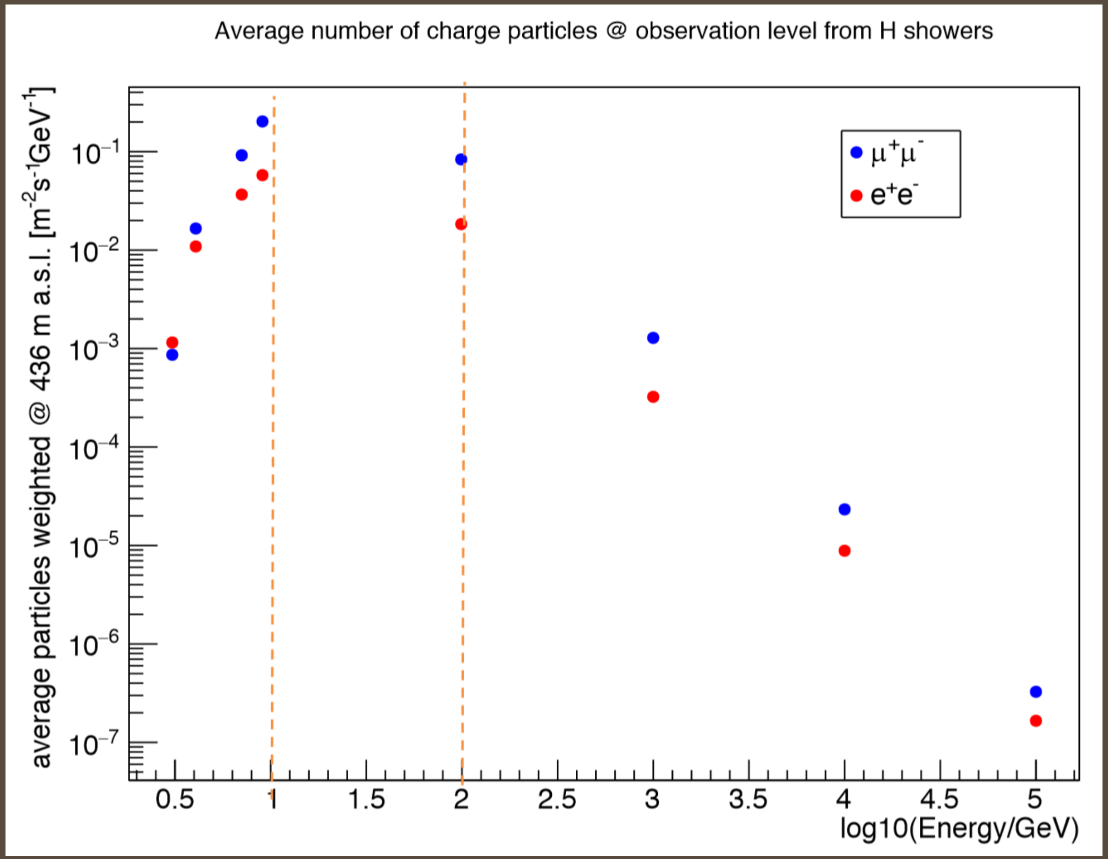
5M Showers

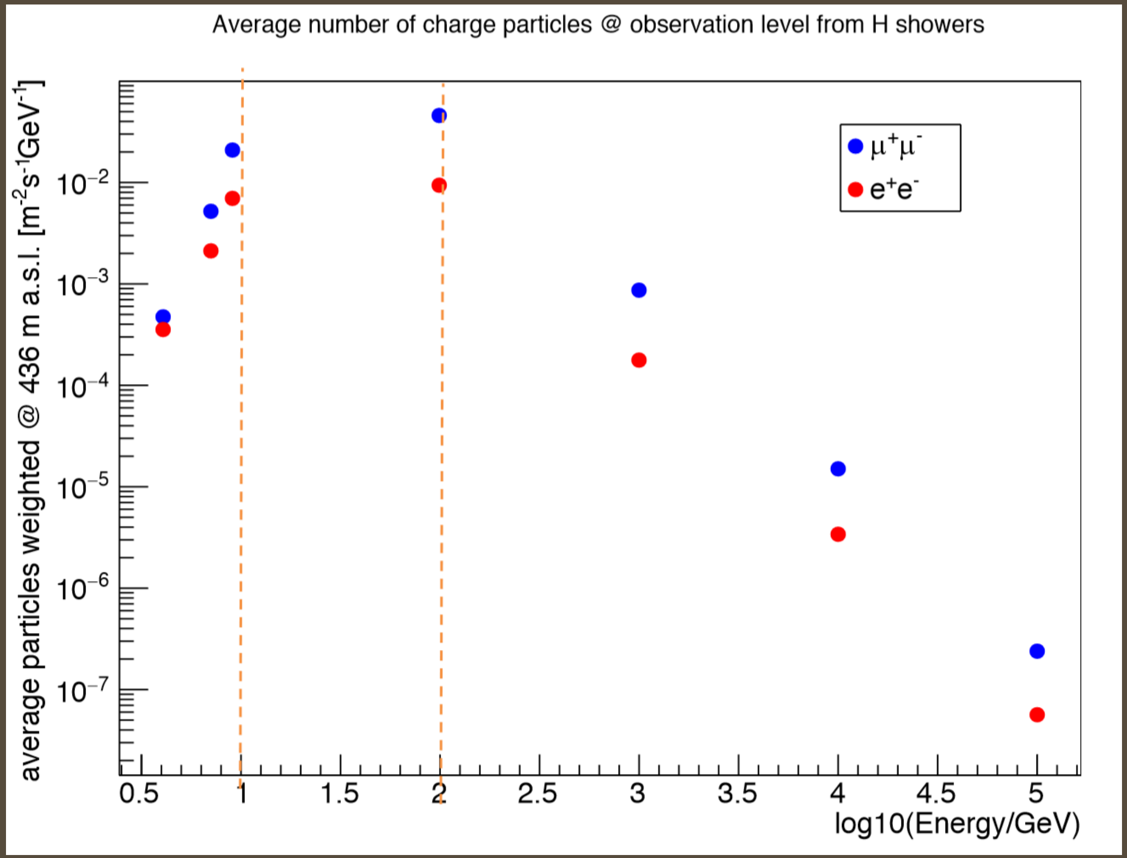




AT 45° AND 60°

5M Showers Each





SOME QUICK THOUGHTS

Extra atmosphere quickly cuts down flux at high angles

- But these are much more likely to fool our rejection algorithm
- Could require the addition of side-pannel veto chambers

Simulations progressing

- Raw files soon available for everyone to look at
- Need to learn how to feed them into G4.

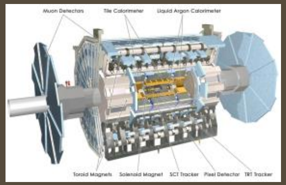
Build a Library

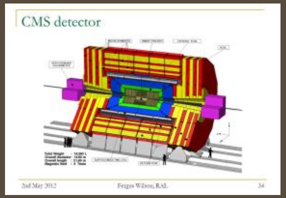
- The pile-up of MATHUSLA
- Overlay on other events, slew in time, etc.

Lots of work left to do

MUONS FROM THE LHC

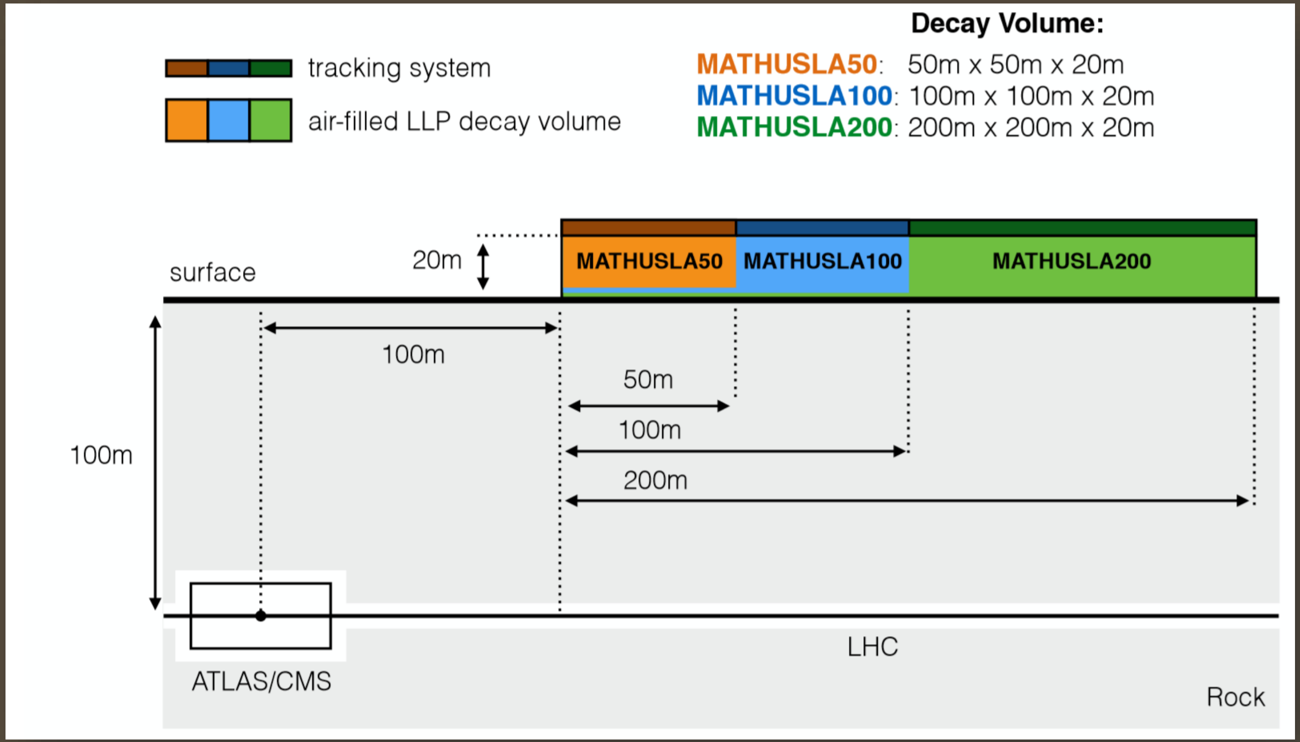
IP μ spectra





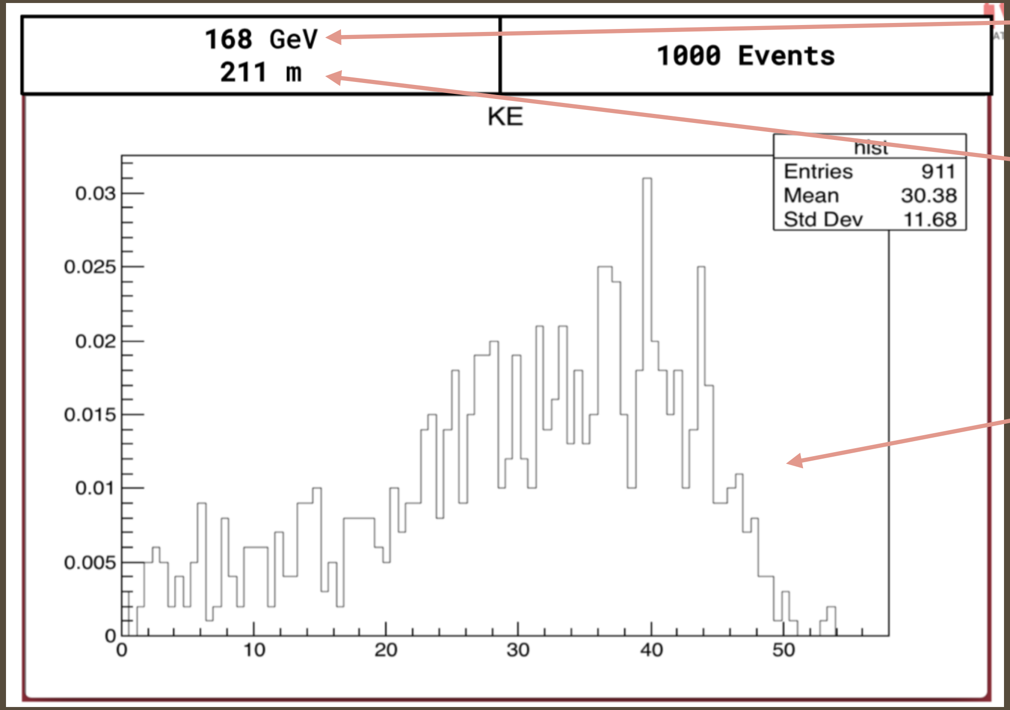
MadGraph5

GEANT4 Rock Propagation → Decay Estimation



We have not yet used a complete G4 chain

G4 ROCK PROPAGATION



Source Muon Energy

Scan up to 190 GeV, extrapolate from there

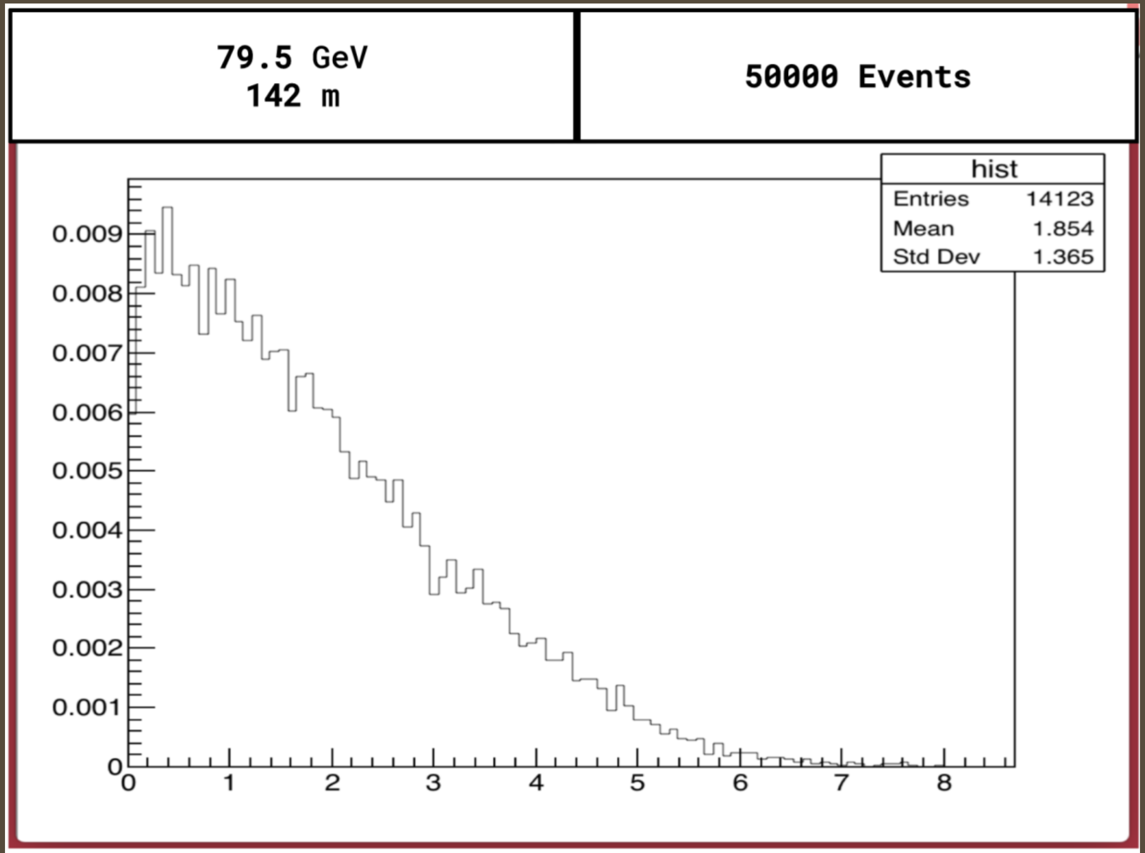
Rock Thickness

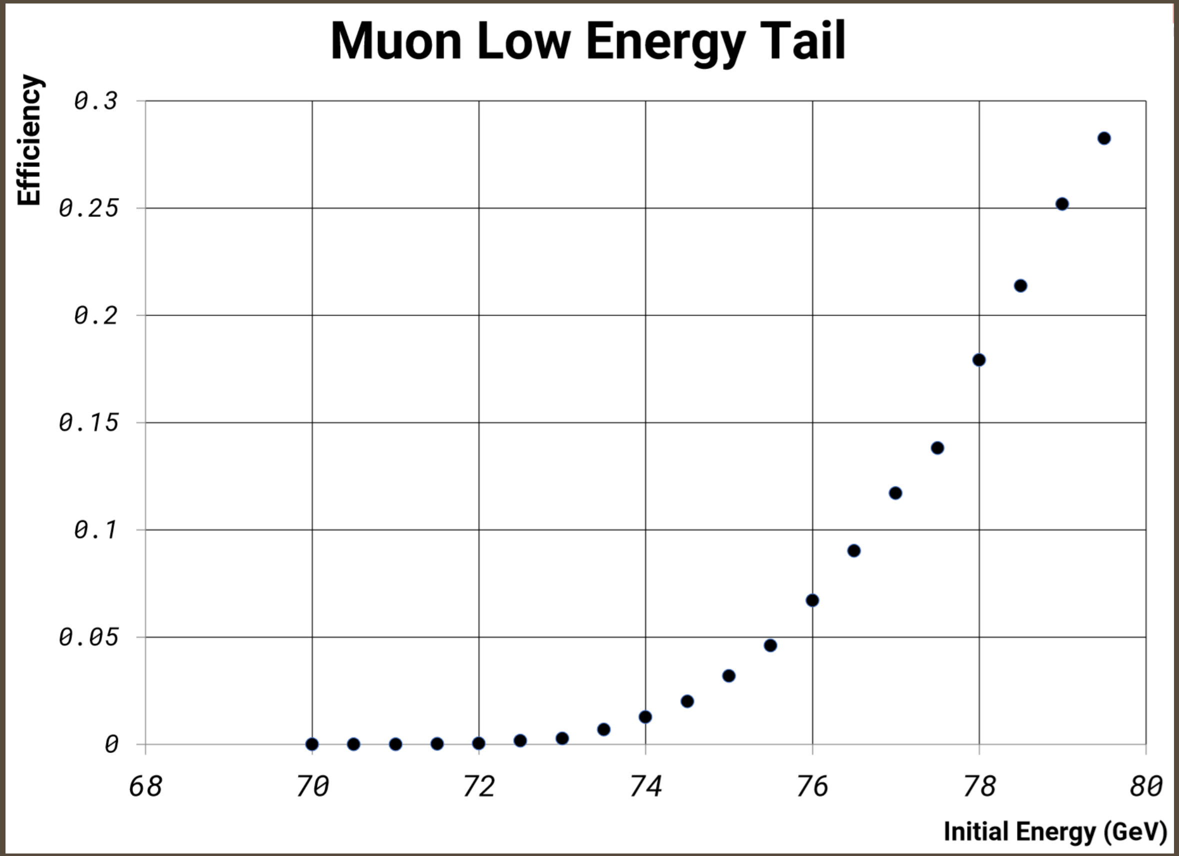
Scan between 142 and 334 m

Rock Thickness

Resulting energy of muon after making it through rock
89 didn't make it

LOW ENERGY MUONS





Hermetic Veto not included!

CONVOLVE WITH μ DECAYS

Process	Rate in MATHUSLA100	Rate in MATHUSLA200
Upwards-traversing μ in decay volume	$(2.0 - 2.5) \times 10^6$	$(3.1 - 4.0) \times 10^6$
$\mu \to e\nu\nu$	$(3.0 - 3.2) \times 10^3$	$(5.5 - 6.8) \times 10^3$

Single upward going track
Vertexing selection will fail

"Kinked" track or single upward going track.

These backgrounds are high rate enough to be interesting when convolved with a Cosmic Ray shower

These backgrounds will likely be a calibration tool for our simulation

Hermetic Veto not included!

CONVOLVE WITH μ DECAYS

Process	Rate in MATHUSLA100	Rate in MATHUSLA200
$\mu \to ee e\nu\nu$	0.10 - 0.11	0.19 - 0.23
Inelastic Scattering (air in decay volume)	0.3 – 0.6	0.8 - 1.1
Inelastic Scattering (support structure)	$(200-350)\times\left[\frac{\xi_{\text{iron}}}{10\%}\right]$	$(490-680)\times\left[\frac{\xi_{\text{iron}}}{10\%}\right]$
Delta Rays (μ liberating atomic e with $E_e > 1$ GeV in decay volume)	120 - 160	210 - 310

Low rate, also hermetic veto should further reduce rate by 95%-99%

Veto vertex reconstruction near material

Opening Angle Cut

MUONS FROM THE LHC

Need detailed G4 simulation to better understand this background

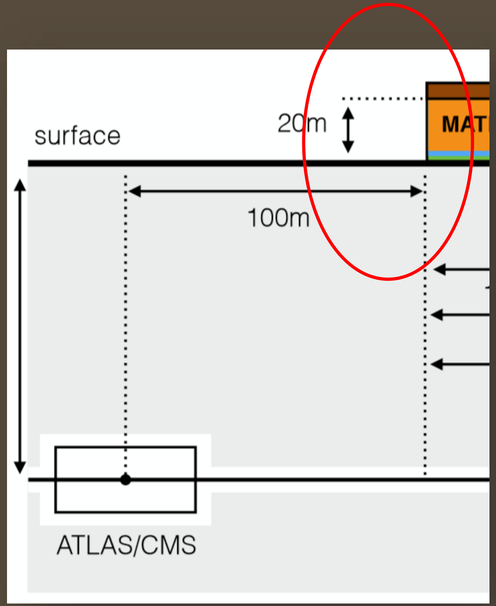
- Vertices produced in detector support structure
- Vertices produced in foundation
- Vertices produced in service buildings
- Fill out edge cases in our simulation

This background will likely always be calculated with a muon gun convolved with a muon $d\sigma/dE$.

- Too inefficient to calculate anything else

One of the main motivations for the bottom layer veto

- Vertices reconstructed near near-wall might have to be vetoed as well as no coverage by bottom plane in current proposed design.
- Wall on the LHC side would eliminate that (or extended flat apron)



NEUTRINOS FROM COSMIC RAYS

Potentially avoids hermetic veto!

From Cosmic Rays:

We split ν final states can be split into three classes

1. Final states with protons and at least one other charged particle
2. Final states with more than 2 charged particles
3. Final state with 1 or less charged particles

$$\sum_{\text{PFS}} N_i \approx \begin{cases} 60 \text{ at MATHUSLA200} \\ 15 \text{ at MATHUSLA100} \end{cases}$$

$$\sum_{\text{not PFS}} N_i \approx \begin{cases} 10 \text{ at MATHUSLA200} \\ 2.5 \text{ at MATHUSLA100} \end{cases}$$

Ignore

Several techniques to reject the final states with protons:

1. The vertex direction will be omni-directional – apply a directionality cut
2. Decay products mean that the vertex products will be a rather narrow cone
3. Low energy neutrinos will have a wide code, but their products will be slow moving enough we should be able to reject them

Adds a potential time-of-flight rejection cut that will impact low mass, unboosted signal (not very much)

NEUTRINOS FROM THE LHC

Sources of LHC neutrinos:

- Direct production ($W \to \mu\nu$)
- Decays from π, etc.

1. Start with MadGraph5 to get spectra
2. Use ν Cosmic Ray Analysis procedure
   - Can't use the point-back-to-IP rejection
3. Total estimated to be less than 0.1 events over the HL-LHC

1. Start with MadGraph5 to get spectra
2. Propagate through detector (CMS)
3. Use ν Cosmic Ray Analysis procedure
4. Total estimated to be less than 1 events over the HL-LHC

NEUTRINOS

We need a better understanding of ν decays

- GENIE is the default simulation package used by the ν community for nucleon interactions
- We've had it running and are now bringing it up in our infrastructure
- This will give us a much better understanding of ν background vertex topologies

GENIE is limited w.r.t. what we are used to in a generator

- Given a ν momentum, and a nucleon
- Calculates cross section and gives decay products
- We will have to convolve this with ν production cross sections, initial momentum spectra and direction, etc.

OTHER SOURCES OF BACKGROUND

Cosmic Ray Albedo

- Back scatter from a muon hitting the ground or some part of the support structure
- Potentially Contains both downward going muons and upward going vertex

Muons from other accelerator sources

- The collision points are the only sources of beam-material interactions
- We will have to carefully think through any other sources, especially those that can enter MATHUSLA through its side walls

STATUS OF THE G4 SIMULATION

To test many of the tricky backgrounds we need a G4 simulation

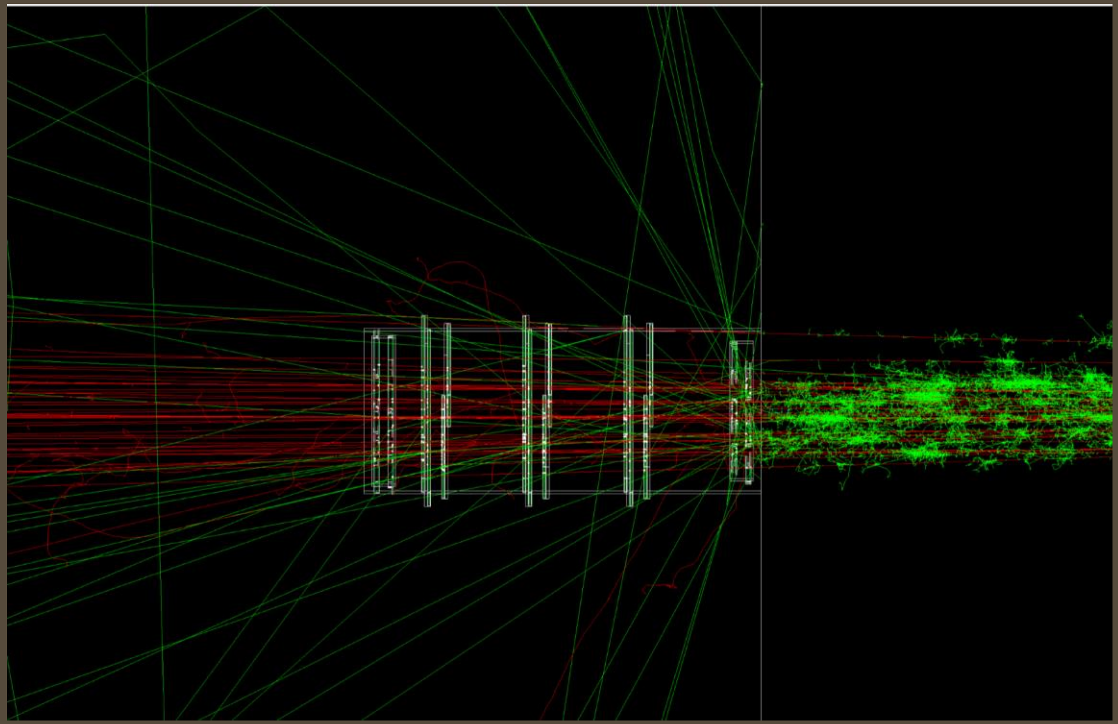
- First versions are appearing

But we need infrastructure around it too

- Converting CORSIKA output to input into G4
- Tracking Algorithms
- Vertex Algorithms

Most of this now exists in pieces

- We are slowly getting everything put together
- More systematic queries:
  - How many layers needed
  - Are the side walls needed for veto
  - Other possible design decisions



CONCLUSIONS

The Background Estimates look solid

- Many are overestimates on purpose
- There are some holes we need to fill in!
- The low background limit looks feasible.
- Many estimates are not using the full power of MATHUSLA
  - Vertexing, for example

The collaboration is updating its background estimates

- First estimates backed with GEANT4 simulation have appeared
- We will continue to update our understanding

Most urgently needed backgrounds need full simulation

- Slowly building infrastructure for this