Muon shower study

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General Plan

We'd like to know how simulations of one or more muons compares to data. We can access this in two ways:

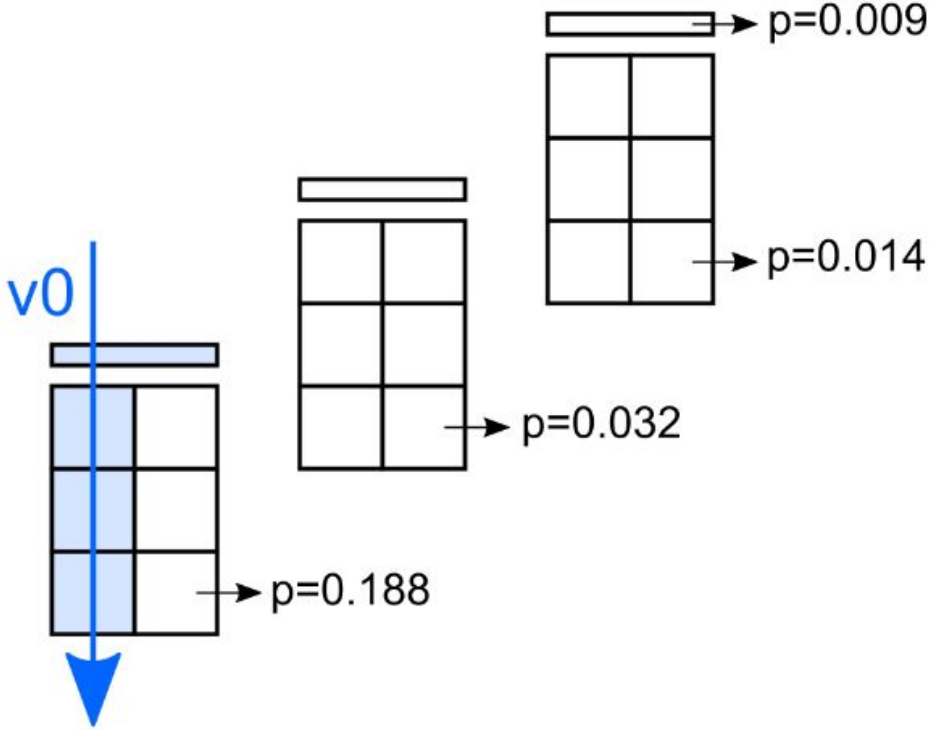
1) MCTruth. We know exactly what caused what, but it's not the best analog to experiement; we'd like to attempt to apply a similar threshold to simulation.

2) Threshold triggers. We throw away some information if we do this to our simulations, but it's a better comparison.

I'll first explore MCTruth for N>1 muon primary, then look at thresholds to see how things change.

Pulses in other layers: data vs. sim

- When a muon hits one layer, what is the rate of activity in bars in other layers?
- In data:
  - averages over all locations
  - neighboring layer: 3.1%
  - far layer: 1.4%
- In simulation:
  - lower (how much?)
- This is one of the areas where data and simulation differ significantly



MCTruth for N>1 muons: Types of hits

1) Muon-generated hits: A muon passes through a bar in another layer directly, depositing detected energy

2) Shower secondary events: Muon shower secondaries, such as electrons, interact with a bar, registering a hit

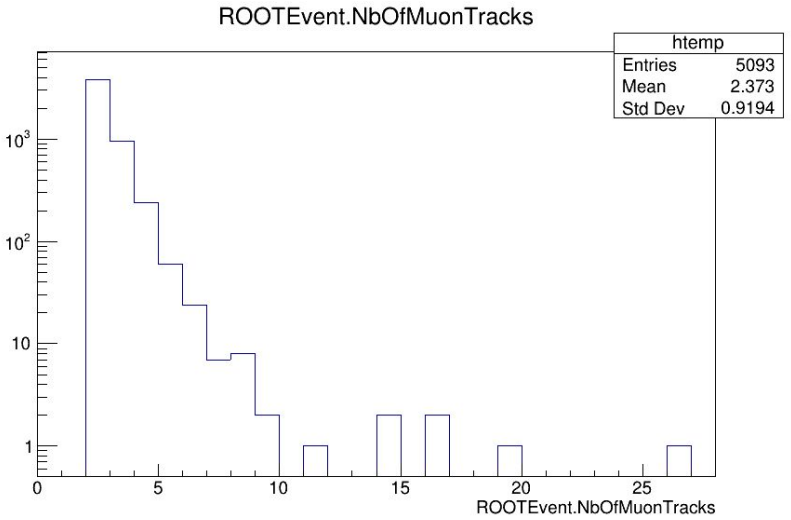
We will require a vertical cosmic hit, and seek to validate/compare to 3.2% (one-layer separation) and 1.4% (two-layer separation) for probabilities

I'll look at 2+ muons for this study, so we can see the effects of adding nontrivial muon multiplicity to the dataset

Choice of multiplicity

Using the ALICE muon multiplicity distribution measurements and attempting to draw out an approximation for small N. Results in the distribution shown in the top right

This is solely based on the exponential parameter between the first 2 points in the ALICE plot, extracted via WebPlotDigitizer



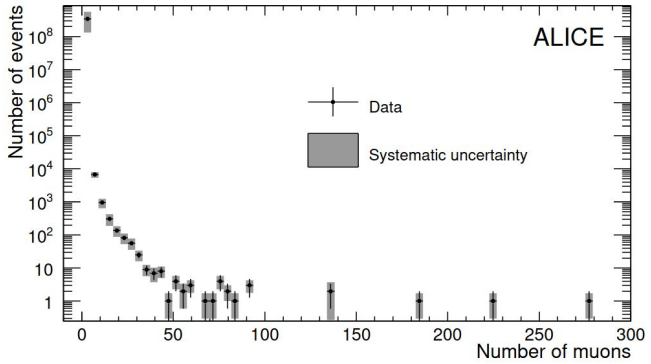


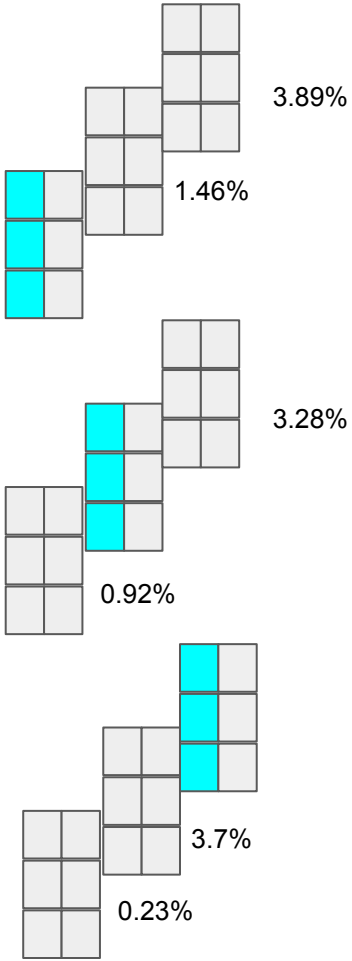
Figure 5. Muon multiplicity distribution of the whole sample of data (2010-2013) corresponding to 30.8 days of data taking.

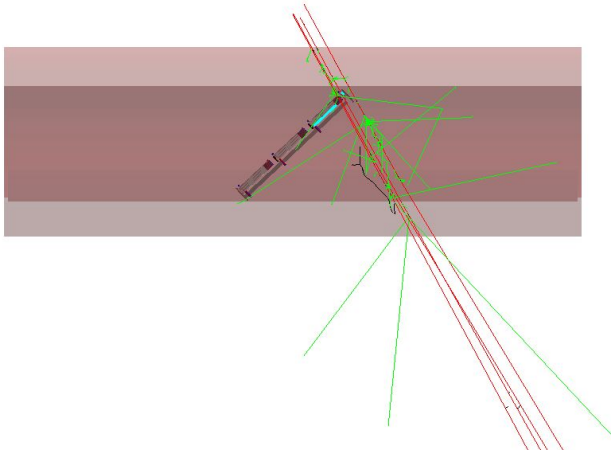
Simulation results

FOR VERTICAL MUONS THAT HIT LAYER 1:
Hits in layer 2: 24/617 = 3.89%
17 direct muons
Hits in layer 3: 9/617 = 1.46%
4 direct muons

FOR VERT. MUONS THAT HIT LAYER 2:
Hits in Layer 1: 7/763 = 0.92%
1 direct muon
Hits in layer 3: 25/763 = 3.28%
19 direct muons

FOR VERT. MUONS THAT HIT LAYER 3:
Hits in layer 1: 2/882 = 0.23%
0 direct muons
Hits in layer 2: 33/882 = 3.7%
14 direct muons





TOTAL:
Adjacent layer hits: 74/2262 = 3.27% (+/- 0.4%)
Far layer hits: 11/1499=0.73% (+/- 0.22%)

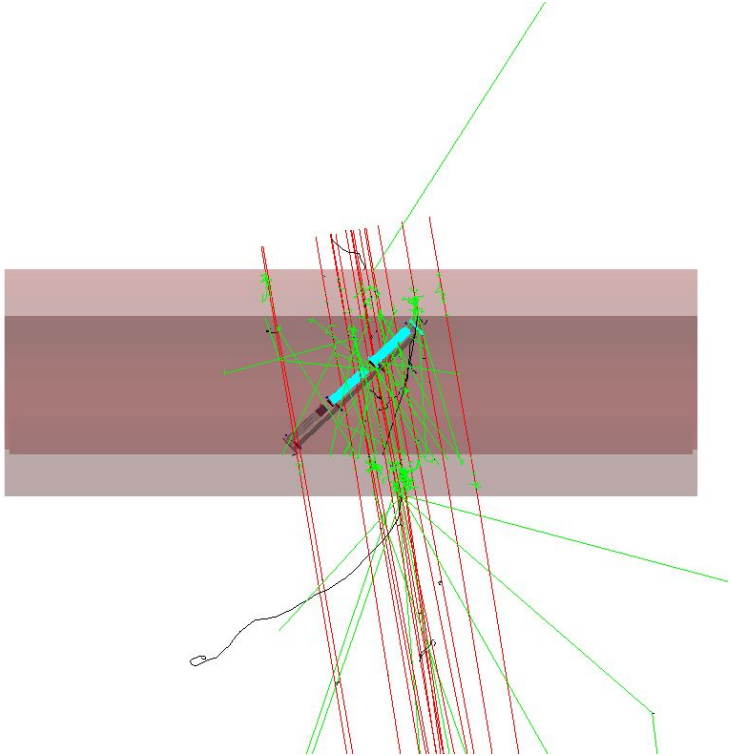
Events with multiple vertical muons: (2262 vertical cosmics)
1 + 2 shower events: 5
2 + 3 shower events: 3
1 + 3 shower events: 0

Conclusions

- Certain backgrounds are more likely based on geometry (vertical in layer 3 means the solid angle the gammas need to hit is lower for layer 1)

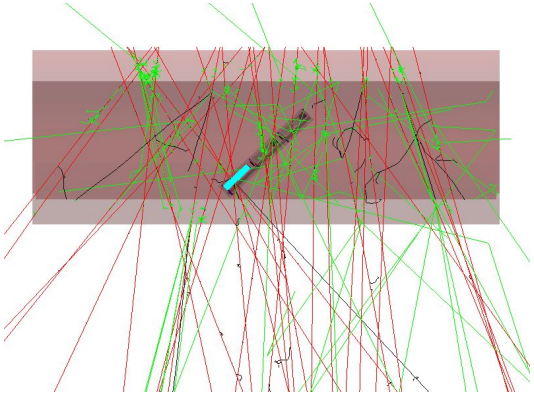
- Rates seem closer to experiment. But it's not a perfect analog; "muon triggers" here use MCTruth, so there's no threshold comparison to experiment

  Let's see how a threshold changes our comparisons



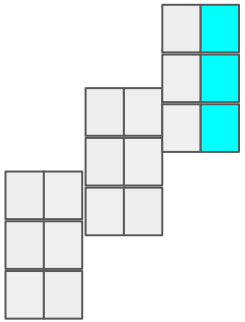
From September: Cosmic muon coincidence prob

Probability for shower products to hit the muon and the muon itself to miss the detector: 0.327



For events with a 3-stack muon trigger:

- Probability to see hits in non-trigger bars: 0.116
- Probability to see hits in bars in other layer: 0.020
  - Breaks down to ~1.8% adjacent, ~0.2% far



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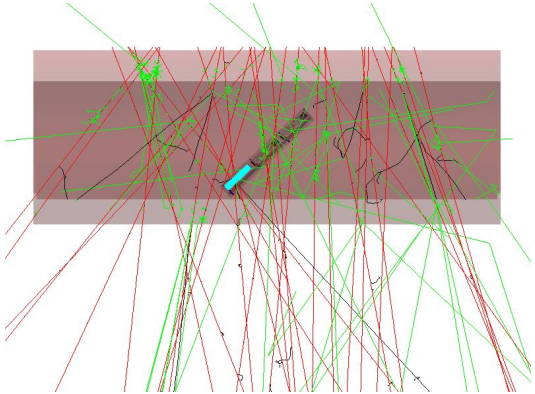

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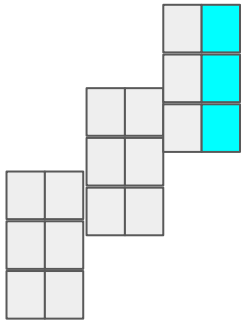


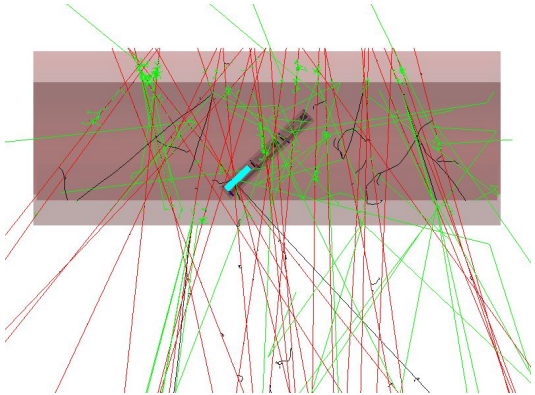
This was done before updates to the cavern diameter, the energy distribution, and the angular distribution. Each of the updates was *relatively* minor, but there could be a net effect.

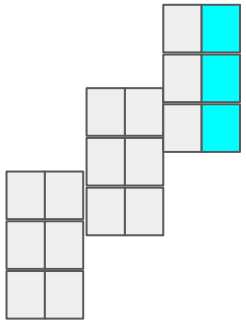
Current Cosmic activity probability (N=1 muons)

Using a 625 PE threshold for the 3-stack muon trigger (pre-calibration, so a bit rough):

- Probability to see hits in non-trigger bars in the same layer: 18.4% (compare: 18.8%)

- Probability to see hits in bars in other layer: 7.5%
  - 6.1% adjacent layer (compare: 3.1%)
  - 1.37% far layer (compare: 1.4%)





Seems the difference is basically gone, and in fact the sim overestimates for the adjacent layer. PE efficiency is 2x, and most adjacent-layer detections are small; could be turning lots of zeros into detections.

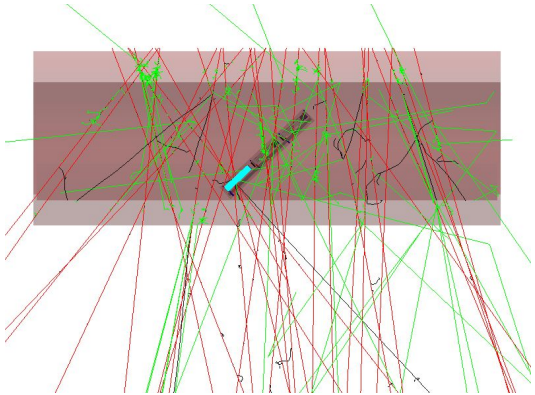
Current Cosmic activity probability (N>1 muons)

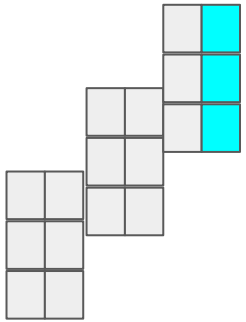
Using a 625 PE threshold for the 3-stack muon trigger (pre-calibration, so a bit rough):

- Probability to see hits in non-trigger bars in the same layer: 22.3% (compare: 18.8%)

- Probability to see hits in bars in other layer: 13.5%
  - 10.9% adjacent layer (compare: 3.1%)
  - 2.6% far layer (compare: 1.4%)

So, under the “threshold” method, rather than going straight from MC truth, we see basically a 2x factor for the other-layer hit probabilities





Final Conclusions

- Adding in multiple muons adds a component that hits the other parts of the detector at ~2x the rate of single muon events after integrating over the multiplicity distribution

- After redoing some of the studies, the comparison isn’t so bad. Depends on the thresholds and calibrations chosen, but changes to the sim seem to have improved the agreement over time

- Final note: Using the argument in the ALICE paper and extrapolating to N=1, I’d guess that 84% of events have N=1 at least, could be more. Multiplicity effects could be minor compared to the normal showers in light of this estimate, at least for the demonstrator