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Report on QuarkNet Summer Activities

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We have been trying to predict cosmic ray counts through our detectors using the Hanlon modification to the Swordy plot (1).

We started by looking at the plot at the energy of 10^6 GeV. Hanlon's plot predicts an average cosmic ray flux of 10^-12 per square meter-steradian-GeV-second. Here is the first hurdle. Why per Gev? We concluded that this refers to the flux within an error bar of (+ or -) .5 X10^6 GeV around 10^6 GeV, divided like a histogram into "bins" of 1 GeV. The plot is not a histogram, but its logarithmic plot divides it into bins like a histogram.

Anyway, we will try to convert this flux into an actual ground count.

Now our "bin" of 10^6 Gev centered around 10^6 GeV contains 10^6 "bins" of 1 GeV. So the flux of 10^-12 per square meter-steradian-GeV-second becomes a flux of 10^-6 primary cosmic rays per square meter-steradian-second.

Kaye and Laby (2) tell us near 10^6 GeV we will get about 1 particle per 10 GeV of primary energy. This gives us about 10^5 particles at sea level. A "few percent" are muons. Let us estimate the there are 2000 muons so produced for each cosmic ray primary.

The predicted flux of rays is 10^-6 per square meter-steradian-second, so then we predict 2X10^-3 muons per square meter-steradian-second.

Kaye and Laby (2) tell us that at sea level muon flux varies as cos^2 of the zenith angle and that integrating over a hemisphere of solid angles will give us about (pi/2) of the vertical flux.

Thus our 2 X 10^-3 per square meter-steradian-GeV-second turns into 3 X 10^-3 per square meter-second.

But that is not right!

Actual muon counts are about 150/meter-second at sea level, and some 70 electrons as well, according to Kaye and Laby (2).

An alternative is to use simulation programs like CORSIKA to approximate the expected flux. The number of muons at ground level is proportional to the energy of the primary cosmic ray as *E*^(.85), according to an EEE article (4). Kaye and Laby claim that 1 charged particle results per 10 GeV at 10^16 GeV, and with a "few" percent being muons, we again see our estimate of 2000 muons. Kaye and Laby claim half of these will be within 40 meters of the core of the strike. So 1000 muons over a circle of radius 40 meters gives us an average density of .2 muons per square meter. A problem emerges with this approach. The lateral distribution function of muon density compared to distance from the core of the cosmic ray is not linear (4). The CORSIKA graph in (4) shows a 10^6 GeV strike yielding a density of 10^-3 muons per square meter as far out as 500 meters from the core, and much higher up close. Taking the graph to predict 0.1 muons per square meter at a distance of 40 meters or less from the core, we calculate 5000 square meters yielding 500 muons. We ignore the steradian spread by insisting the cosmic ray strike within 40 meters of a vertical cylinder centered on our detector. Then the flux of 10^-6 primary cosmic rays per square meter-second becomes 5X10^-3 rays per second, with a flux of 5X10^-4 muons per second for each square meter. This estimate is within an order of magnitude of our previous estimate, and is still not right!

We expect vertical muon counts to be 100 per square meter-second, according to Kaye and Laby (2).

Let us justify our focus on cosmic rays of 10^6 GeV. . The cosmic ray energy spectrum graph has slope of -2.7 at energies of 10^6 GeV, according to the HAWC website. (5) Below 10^5 GeV, few particles penetrate to sea level. What about above 10^7 GeV? Well, the flux will decrease by a factor of 10^-2.7 but the number of secondary particles produced will increase 10-fold. Thus, we will see a drop at sea level of about 10^-1.7, a factor of 50. The contribution to our counts of cosmic rays of energy bof 10^7 GeV is negligible compared to the count from 10^6 GeV. Conversely, counts from cosmic rays of energies 10^5 GeV might be higher. Our initial estimate of 3 X 10^-3 per square meter-second becomes .15 counts per square meter-second, still 2 orders of magnitude too low!

Another approach is to start with Kaye and Laby's calculations from the start (2). They state that 10^5 GeV cosmic rays produce 1 charged particle at sea level per 10 GeV, so we will have 10000 such particles. About 5 % will be within 3 meters of the core, giving some 500 charged particles of which "a few percent" will be muons. This estimate gives us about .5 muons per square meter-second.

And that is still wrong!

We have also been working on getting widely separated detectors to "point" to the spot and time the primary cosmic ray struck the atmosphere and created a shower. Such an indication would let us flag large showers detected over a wide region.

In principle, 5 detectors could "point" to a source. The 5 detectors yield 4 differences between their detection times and places, and those 4 differences would highlight the original primary cosmic ray strike time and place.

In particular, if the primary cosmic ray strikes at (x_0, y_0, z_0, t_0), and each detector i = 1, 2, 3, 4, 5 detects a resulting muon at (x_i, y_i, z_i, t_i), then we can calculate that

Note that all quantities are empirically known, and so we have 4 linear equations in 4 unknowns - easily solved with matrices.

The practical problem lies in the error bars of such a solution. At least 1 detector must be at a different height z than the others to ensure linear independence. But even if a detector is atop a building, its z is paltry compared to that of the original strike, which is likely to be 15 kilometres high, or even more. A small error in measuring yields a large error in computing the original strike's z. A similar problem obtains for timing errors.

We are still working on a practical solution, perhaps in tandem with using CORSIKA to simulate the rays.

(1) William Hanlon's reworking of the cosmic ray energy spectrum, correcting Swordy's original plot.

online at https://www.physics.utah.edu/~whanlon/spectrum1.png

(2) Kaye and Laby cosmic ray characteristics and physical constants online at

http://www.kayelaby.npl.co.uk/general_physics/2_7/2_7_7.html

(3) B.Skuse, The riddle of ultra-high energy cosmic rays Physics world August 2018

Online at

https://physicsworld.com/a/the-riddle-of-ultrahigh-energy-cosmic-rays/

(4) M. Abbrescia et al Cosmic rays Monte Carlo simulations for the Extreme Energy Events Project *European Physical Journal Plus* 2014

(5) High Altitude Water Cherenkov Gamma-ray Observatory

“Cosmic rays/ cosmic ray energy spectrum” online at

https://www.hawc-observatory.org/science/cosmicrays.php#sec:crSpec

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Cosmic ray spectra and muon characteristics at sea level and underground.

R.A. Mewaldt, Cosmic Rays online at http://www.srl.caltech.edu/personnel/dick/cos_encyc.htm

Cosmic ray energies, spectra, characteristics.

Murat Boratov, Probing theories with cosmic rays online at

http://physik.uibk.ac.at/hephy/lectures/seminar/2002ws/article2/

Theoretical implications of cosmic rays and how to distinguish theories.

William Hanlon’s reworking of the cosmic ray energy spectrum, correcting Swordy’s original plot.

online at https://www.physics.utah.edu/~whanlon/spectrum1.png

Swordy’s original plot online at

https://www.semanticscholar.org/paper/The-Cosmic-Ray-Energetics-and-Mass-(-CREAM-)-Timing-Beatty-Ahn/5bc6d7c8787e4458a0537a2365bac47805d04ff5/figure/0

High altitude Water Cherenkov Gamma ray observatory website online at

https://www.hawc-observatory.org/details/gcr.php

Gamma ray cosmic rays (bursts)

Ice Cube master class online at

https://masterclass.icecube.wisc.edu/en/icetop/measuring-cosmic-rays

Cosmic rays from the knee to the highest energies Johannes Blümer a , Ralph Engel a , Jörg R. Hörandel online at

http://particle.astro.ru.nl/pub/JPPNP63-293.pdf

Detailed discussion of measuring muons from cosmic rays, spectra and significance of spectra graphs.

High-energy cosmic-ray acceleration

M. Bustamante et al., online at

https://cds.cern.ch/record/1249755/files/p533.pdf

Detailed discussion of how cosmic ray particles might be accelerated.

Cosmic-ray energy spectrum and composition up to the ankle − the case for a second Galactic component

S. Thoudam et al., online at

https://arxiv.org/pdf/1605.03111.pdf

Discussion of how cosmic ray energy spectra shape have theoretical implications.

The Cosmic-ray energy spectrum observed with the surface detector of the Telescope Array Experiment, T. Abu-Zayyad et al. online at

http://iopscience.iop.org/article/10.1088/2041-8205/768/1/L1/meta#apjl468239s3

Simulating cosmic rays with CORSIKA.

http://www.kayelaby.npl.co.uk/general_physics/2_7/2_7_7.html

Kaye and Laby cosmic rays characteristics and physical constants.

Lateral Distribution Functions of Extensive Air Showers A. Geranios et al. online at https://indico.nucleares.unam.mx/event/4/session/8/contribution/837/material/paper/0.pdf

Discussion of how number of observed muons at ground level falls off with distance from core of strike.

Special relativity in the school laboratory: a simple apparatus for cosmic-ray muon detection

P Singh and H Hedgeland, online at

http://iopscience.iop.org/article/10.1088/0031-9120/50/3/317/meta#ped510721app1

The Extreme Energy Events experiment: an overview of the telescopes performance

M.Abbrescia et al.

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Italian high school network of cosmic ray muon detectors

B.Skuse, The riddle of ultra-high energy cosmic rays Physics world August 2018

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https://physicsworld.com/a/the-riddle-of-ultrahigh-energy-cosmic-rays/

M. Abbrescia et al Cosmic rays Monte Carlo simulations for the Extreme Energy Events Project *European Physical Journal Plus* 2014

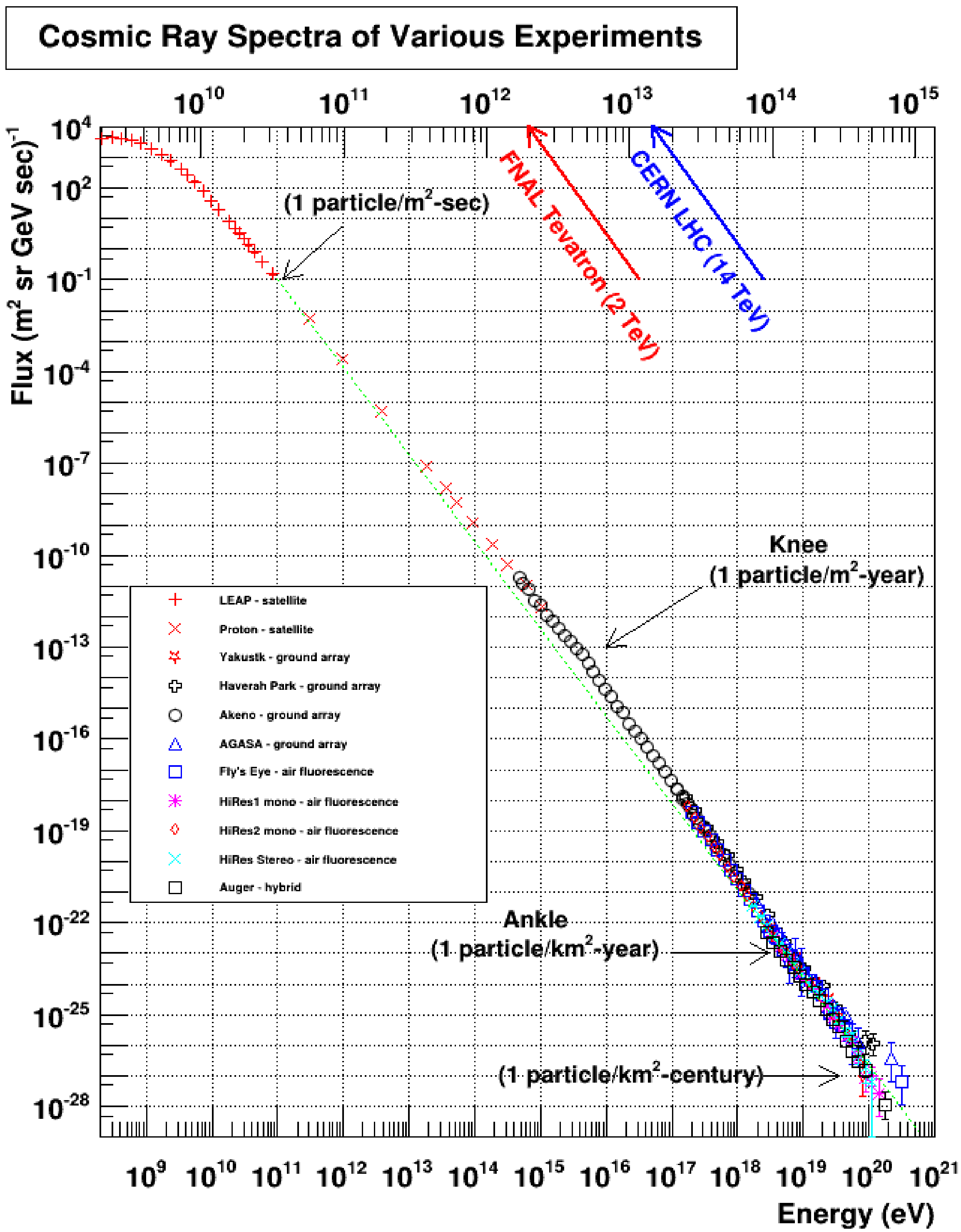

Figure 1: Hanlon Modification to original Swordy plot. Reproduced by permission of William Hanlon, University of Utah

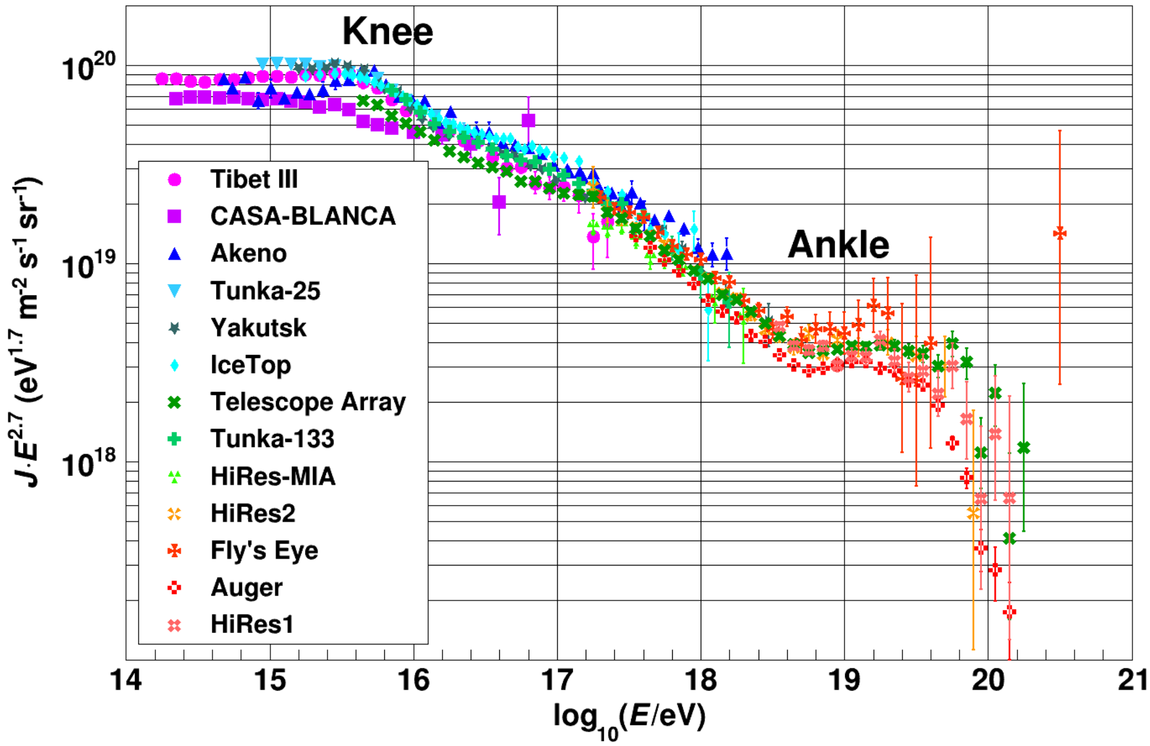

Figure 2: Most recent high-energy cosmic ray spectrum data. Reproduced by permission of William Hanlon, University of Utah