THE PRINCESS SIRINDHORN NEUTRON MONITOR

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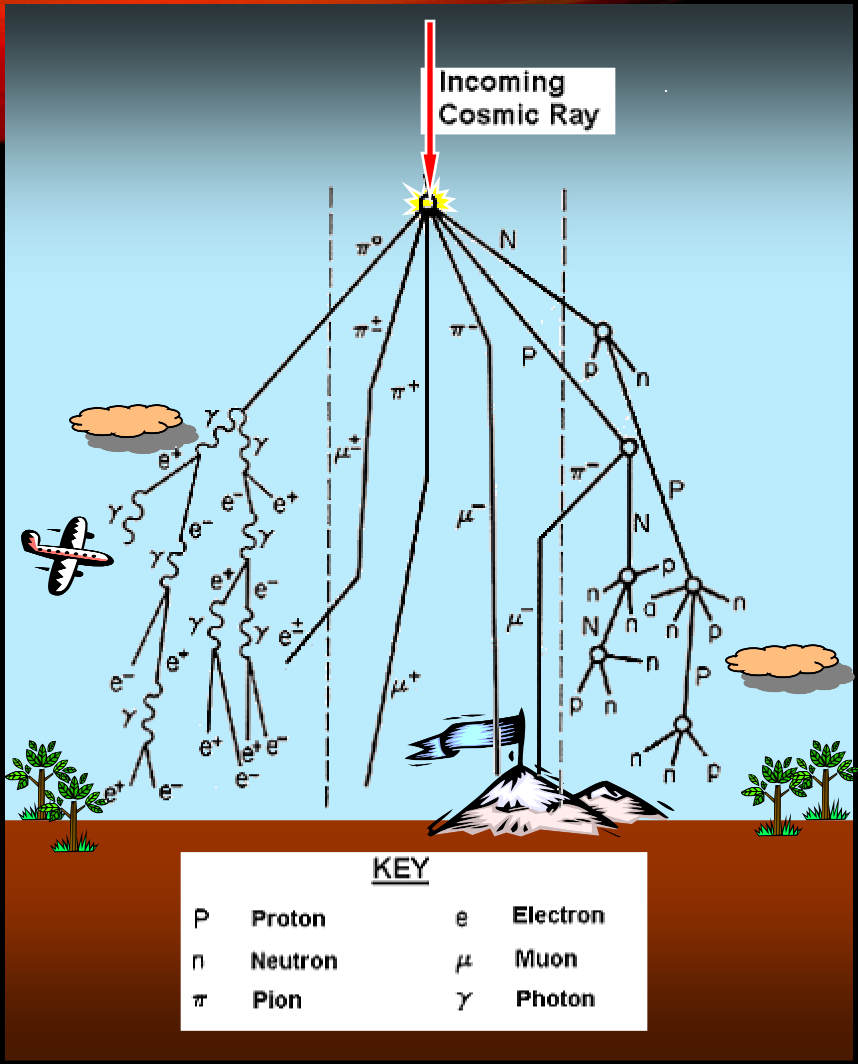
COSMIC RAYS ARE …

- Energetic particles or gamma rays from space
- Ordinary matter accelerated to high energies
- p, ^{4}He, ^{12}C, ^{16}O, … (ions) e^-, γ, μ^+, μ^-, n, …
- Main cause of biological mutations
- There are sources of Cosmic Rays (energetic particles):
  - inside the solar system (e.g., solar energetic particles)
  - outside the solar system (e.g., Galactic cosmic rays)

NEUTRON MONITORS

- Measure the number of neutrons, produced in atmospheric cascades, that reach the ground
- Indirectly measure the number of cosmic rays hitting the atmosphere
- Very sensitive to location relative to Earth's magnetic field: *cutoff rigidity*
- Originally designed by John A. Simpson (University of Chicago) in 1948



PARTICLE SHOWERS

- Cosmic rays collide with atoms in the atmosphere, producing more particles
- Electromagnetic cascades, muons, nucleons
- Secondary particles can reach ground level
- We aim to detect the neutrons

COMPONENTS OF A NM

- Reflector: Lets high-energy neutrons through and reflects low-energy neutrons
- Producer: Produces lower energy neutrons when hit by a high energy neutron
- Moderator: Reduces the energy of neutrons hitting it
- Counter: Detects the low energy neutrons
- Electronics: To process the signal

THE REFLECTOR

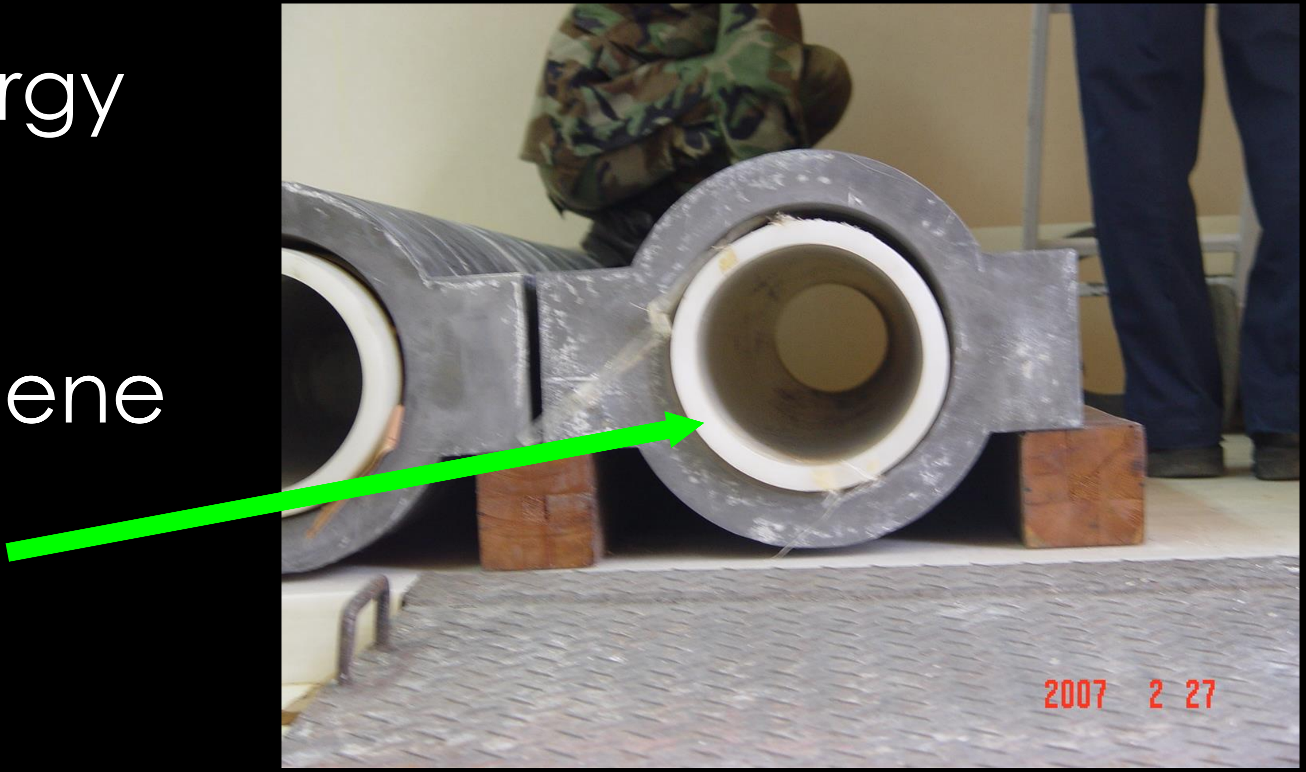
- Lets high energy neutrons through
- Keeps environmental low-energy neutrons out
- Keeps produced low-energy neutrons in
- Also acts as moderator
- Made of polyethylene

THE PRODUCER

- Produces more neutrons when hit by neutrons
- Used to amplify the signal
- Made of Pb

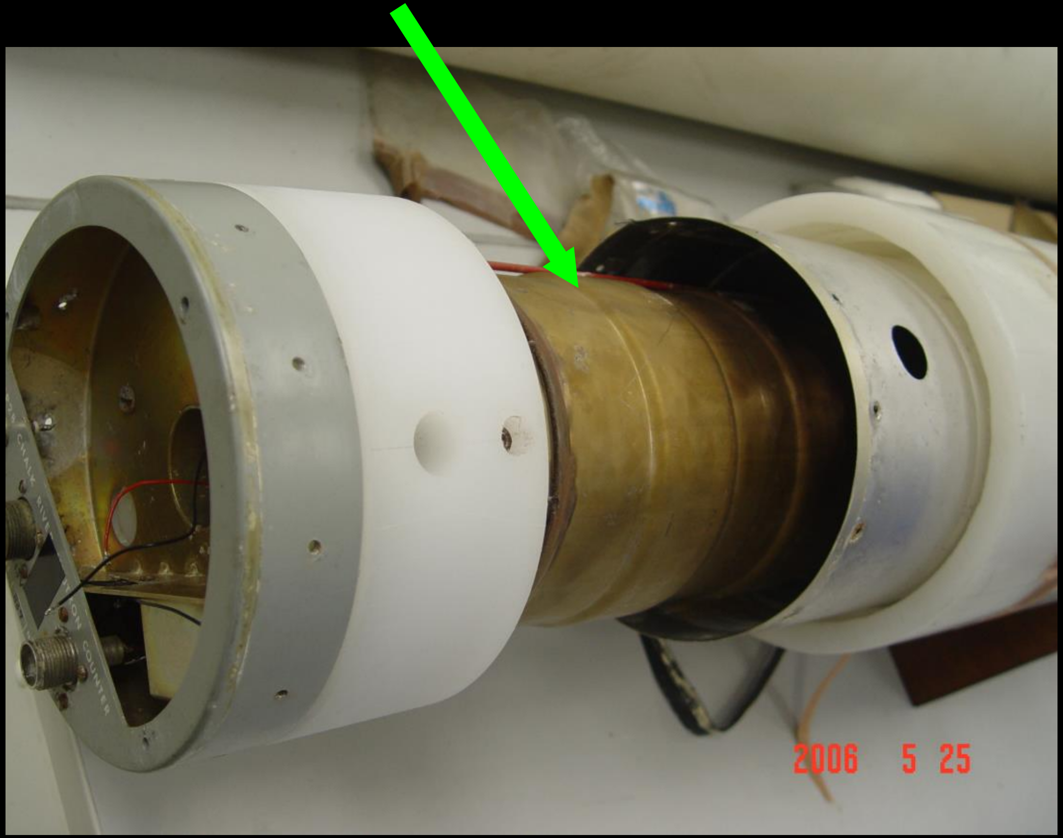
THE MODERATORS

- Decrease the energy of neutrons going through them
- Made of polyethylene

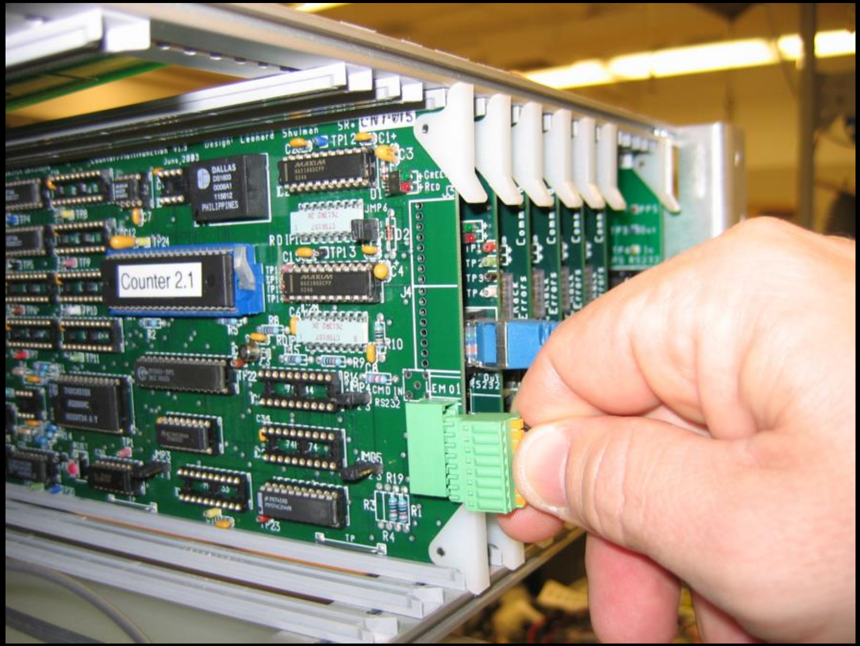


THE COUNTERS

- Filled with a BF_3 gas enriched in ^{10}B
- Produce a signal when a ^{10}B reacts with a neutron
- The cross-section of ^{10}B is highest for low-energy (thermal) neutrons
- $^{10}B + n \rightarrow {}^{7}Li + {}^{4}He$



ELECTRONICS



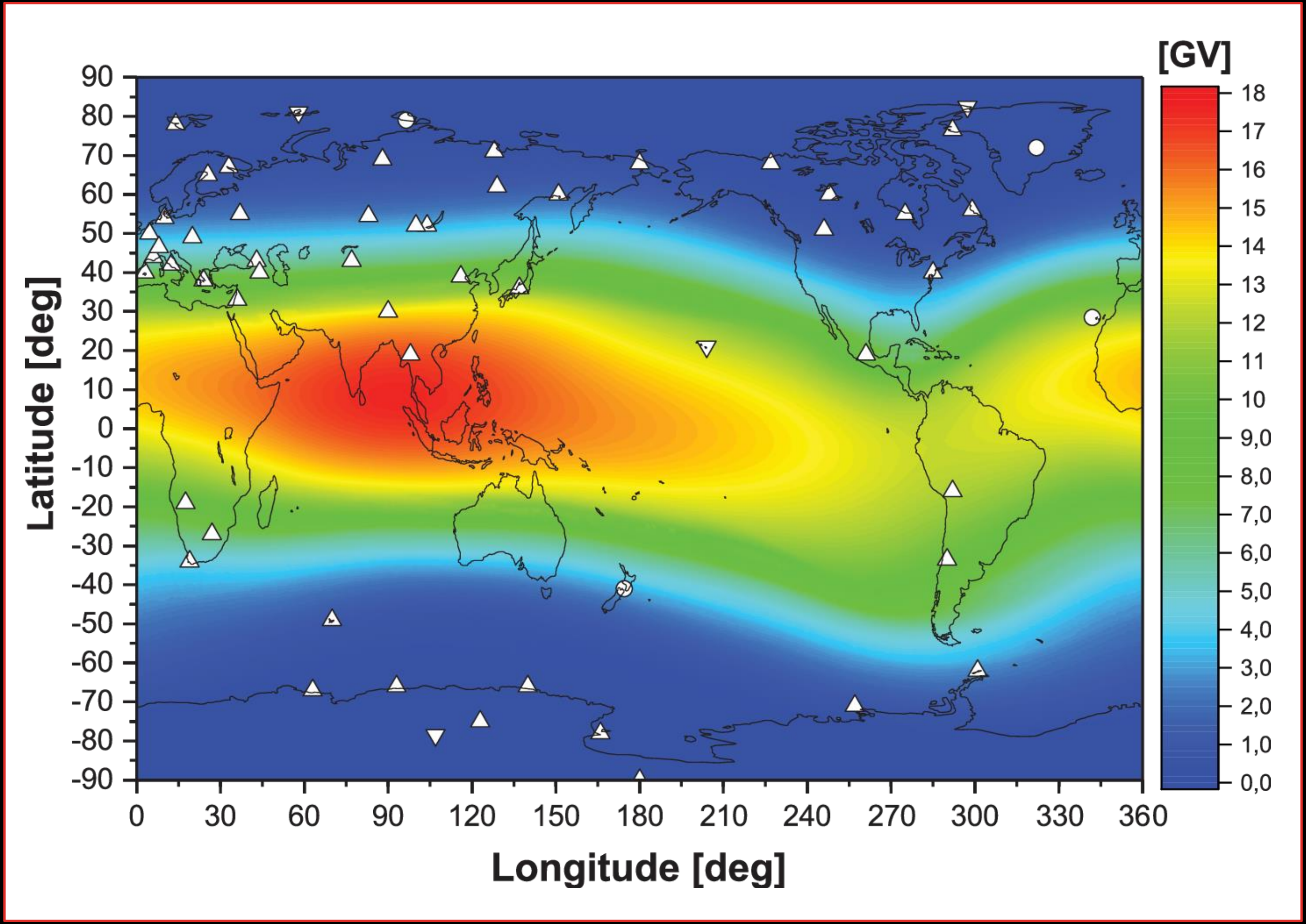
- To process the signal and interface with the computer

THE PRINCESS SIRINDHORN NEUTRON MONITOR STATION

- At Doi Inthanon
- Monitors cosmic ray intensity from minutes to decades
- Related to space weather prediction [Ruffolo 1999; Leerungnavarat et al. 2003]
- Altitude is extremely important!
- Thailand: a special location

GEOMAGNETIC CUTOFF

- Earth’s magnetic field acts as a spectrometer
- Minimum energy needed for a cosmic ray to reach a location
- Relevant property is not energy but rigidity (*pc/q*), units are GV
- PSNM has the highest cutoff rigidity of all fixed detectors (17 GV)



[Mishev & Usoskin 2020]


สถานีตรวจวัดนิวตรอนสิรินธร
Princess Sirindhorn Neutron Monitor
2007 2 26


2007 2 27


2007 2 27

Detect neutrons in $^{10}BF_3$ gas proportional counters by induced nuclear fission:

$n + {}^{10}B \rightarrow {}^{7}Li + {}^{4}He$

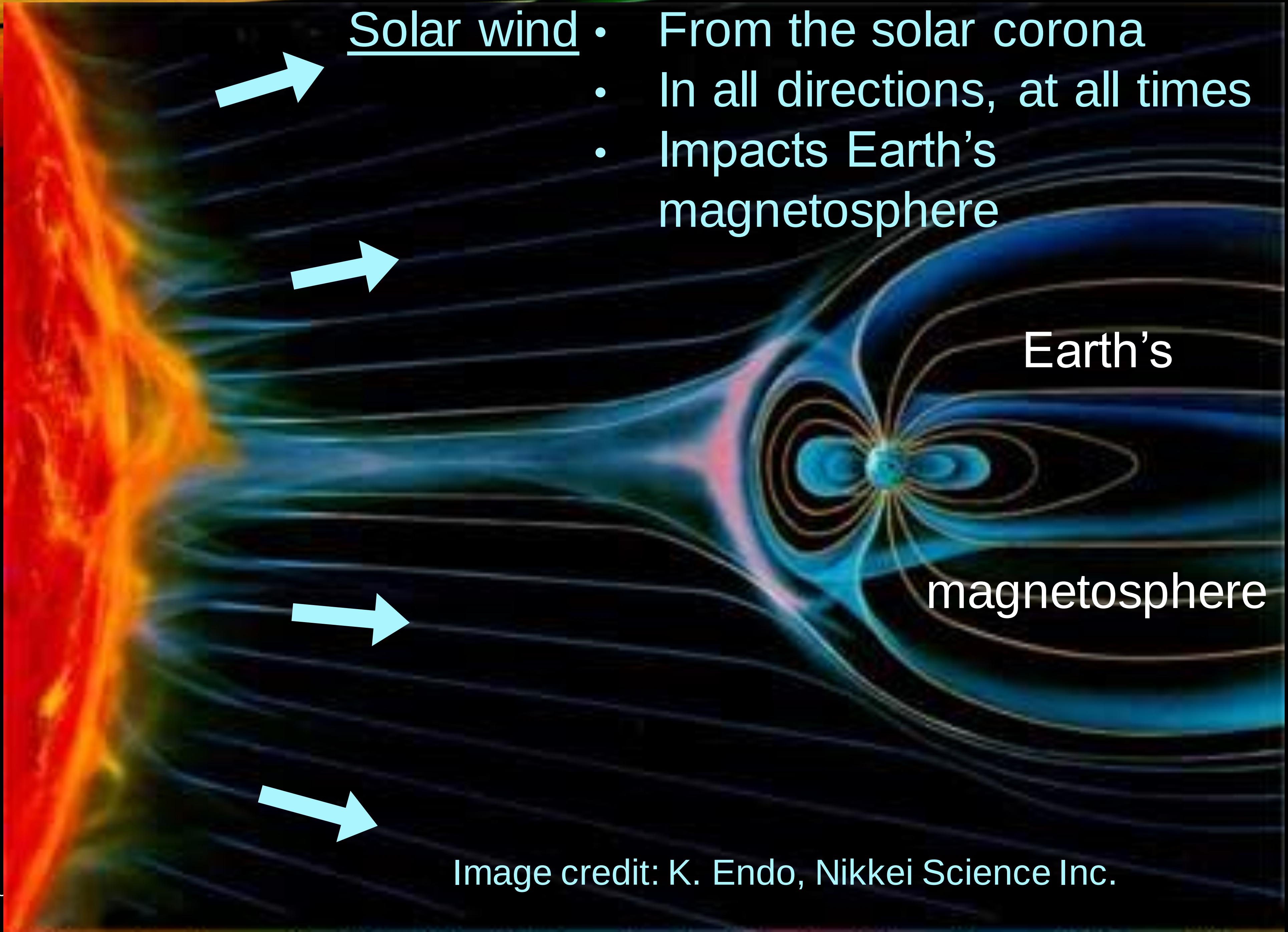
OPENING CEREMONY, JANUARY 21, 2008


Princess Sirindhorn Neutron Monitor

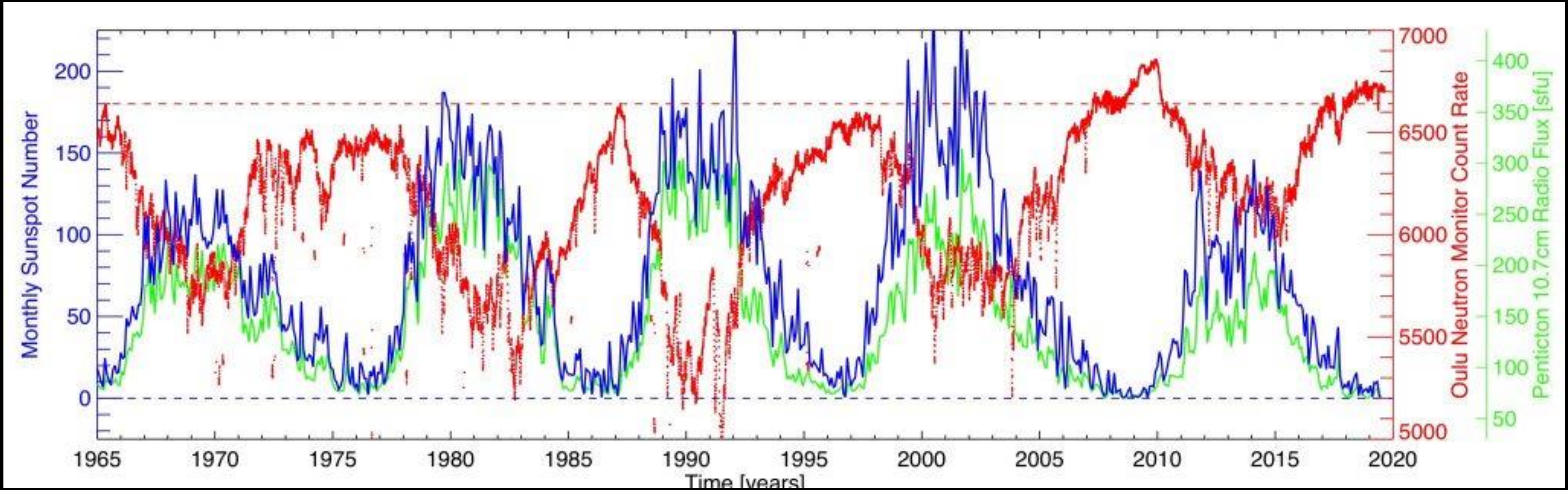
NOW, A LOW-LATITUDE NEUTRON MONITOR MEASURES GALACTIC COSMIC RAYS, BUT ...

THE MAIN PURPOSE OF A NEUTRON MONITOR IS TO MEASURE SOLAR EFFECTS ON THE GALACTIC COSMIC RAYS!

- Effects are small, so need excellent statistics
- Need a large detector of neutrons
- Mainly measure number of neutrons vs. time (we also measure neutron time delays …)


Solar wind
• From the solar corona
• In all directions, at all times
• Impacts Earth's magnetosphere
Earth's
magnetosphere
Image credit: K. Endo, Nikkei Science Inc.

11-YEAR SUNSPOT CYCLE AND 22-YEAR MAGNETIC CYCLE



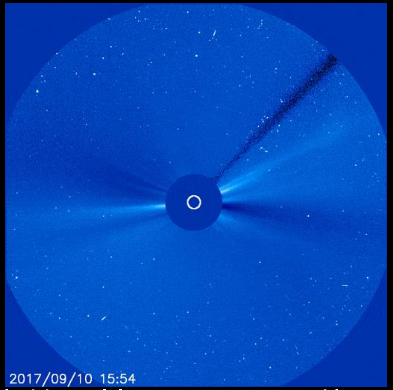
SOLAR EFFECTS ON GALACTIC COSMIC RAYS

- 11/22-year solar cycle: solar modulation (during solar maximum, Galactic cosmic rays "blown out")
- 27-day synodic variations: as Sun rotates, Earth feels fast or slow solar wind, faster wind blows out cosmic rays
- 1-day diurnal variations: as Earth rotates, we sample particles from different directions, measure anisotropy
- Solar storms: Galactic cosmic ray flux decreases as blown out by solar storm

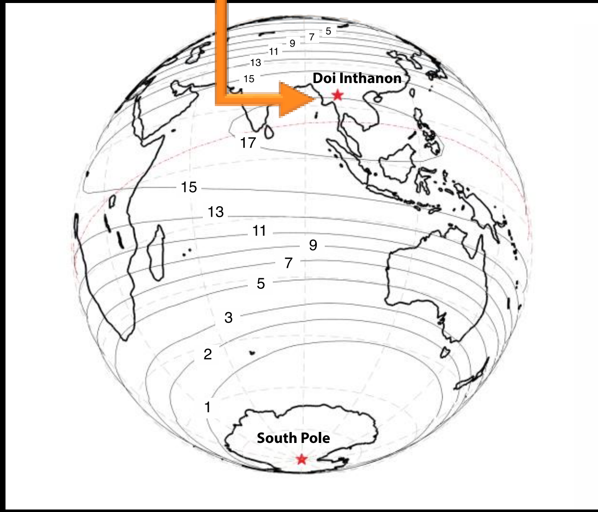
FORBUSH DECREASES OBSERVED BY NM'S

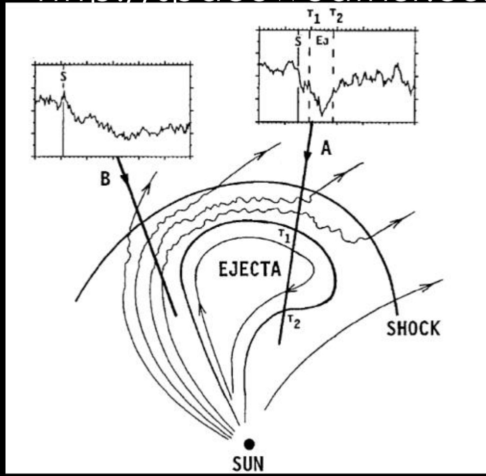
Amplitude of decrease depends on the geomagnetic cutoff rigidity: low energy were blocked more strongly by shocks.

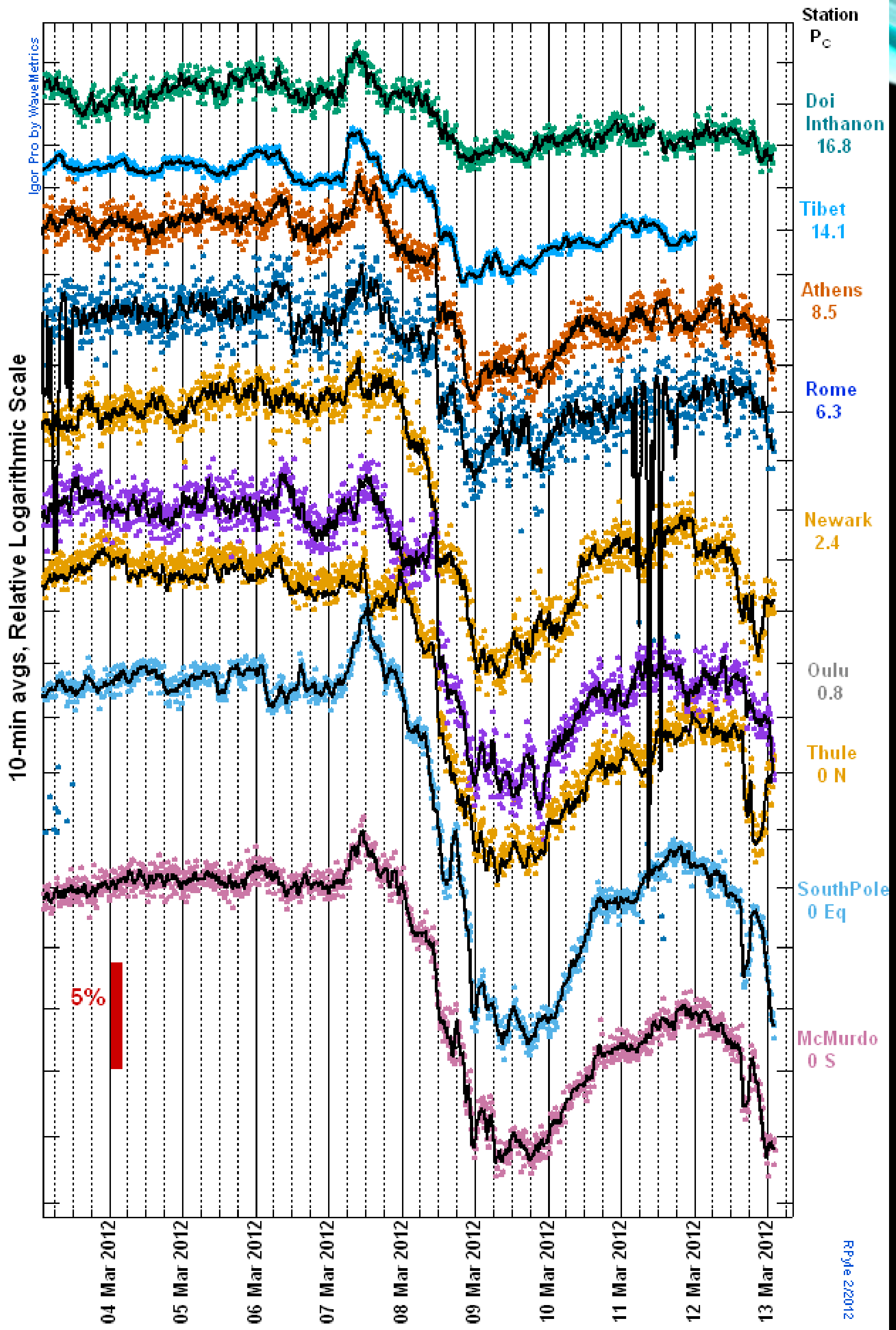

[Ruffolo et al. 2016]



http://spaceweather.com







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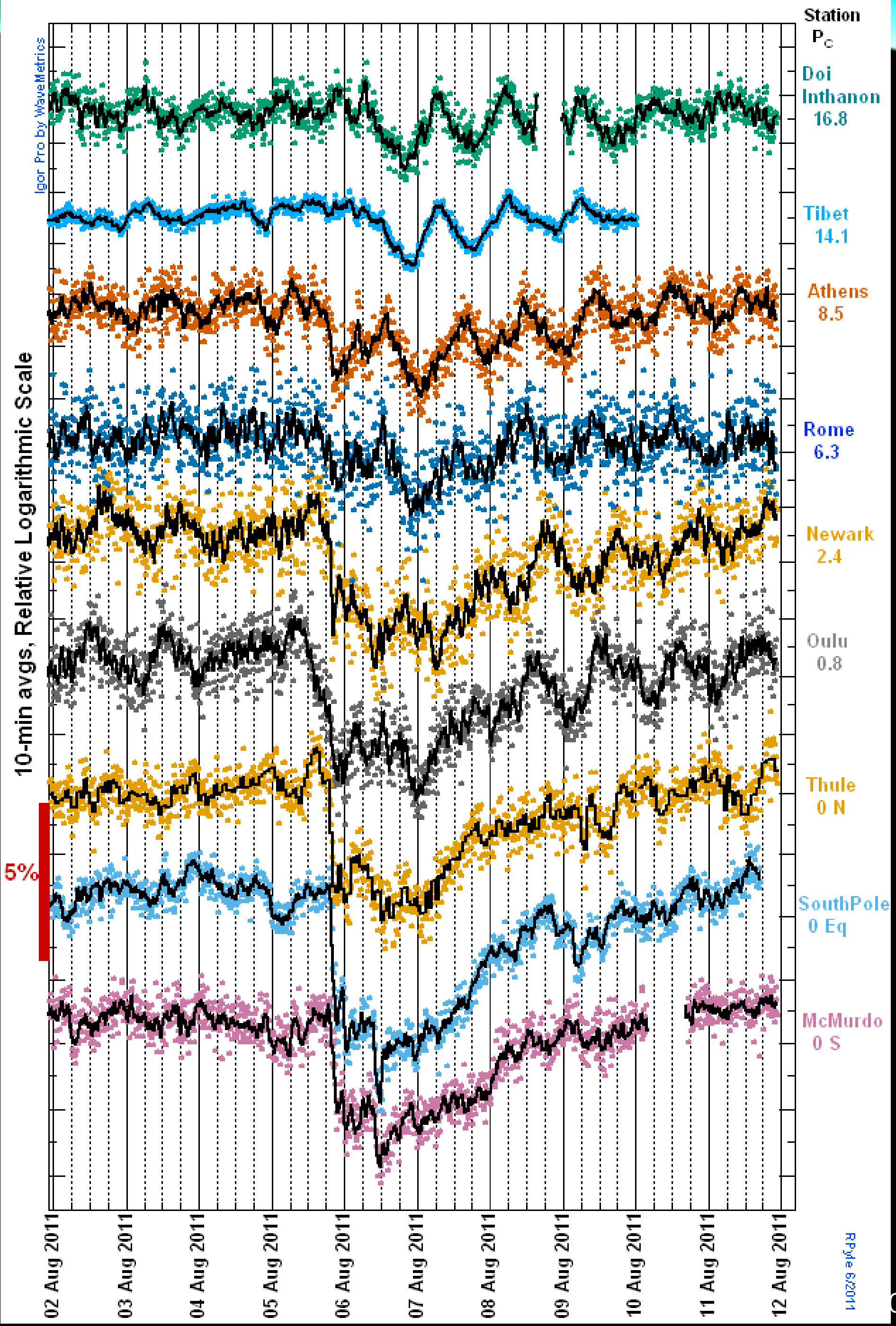
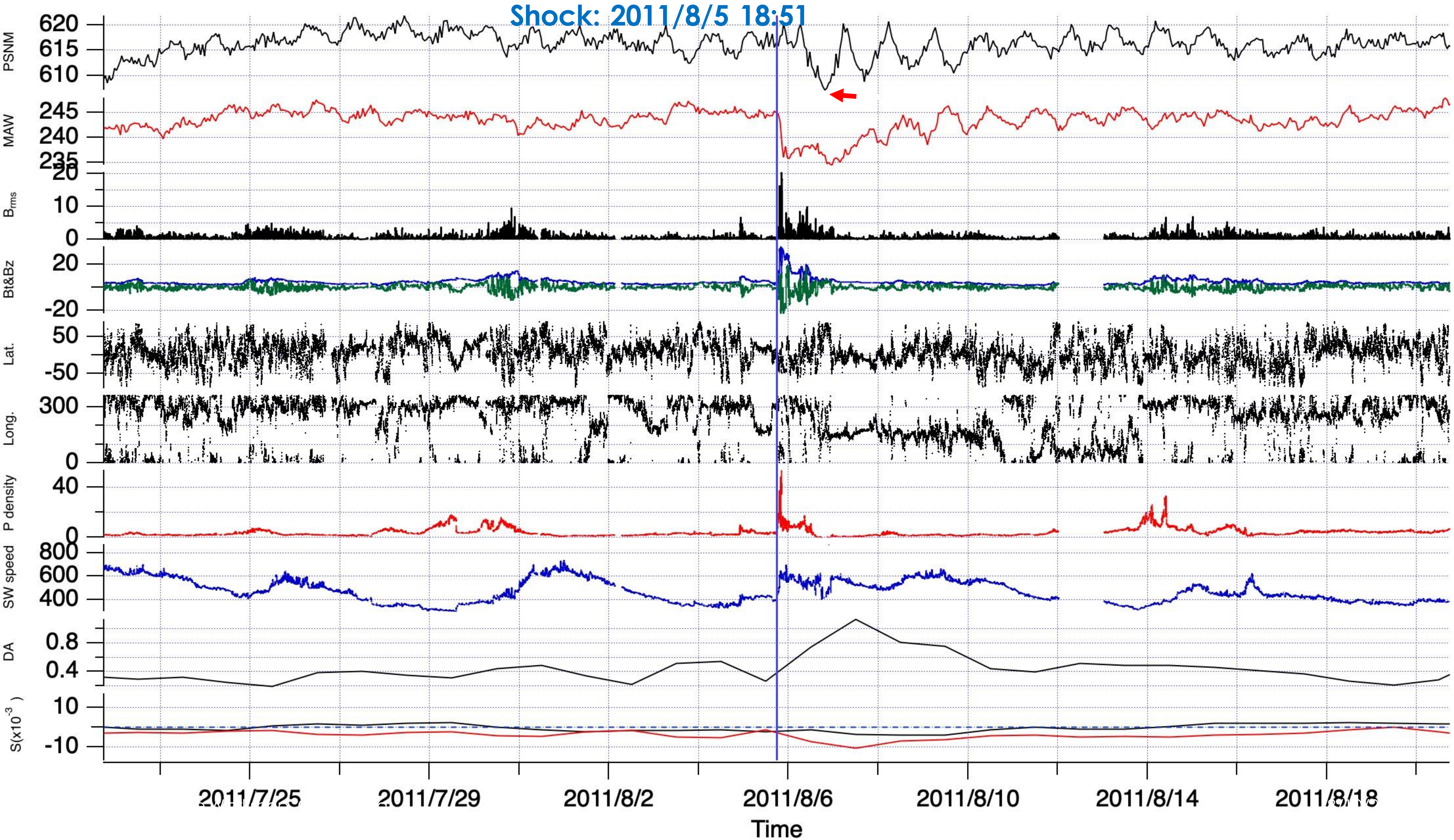
DIURNAL DIPS

NMs have observed diurnal variations of the GCR flux due to the Earth's rotation.

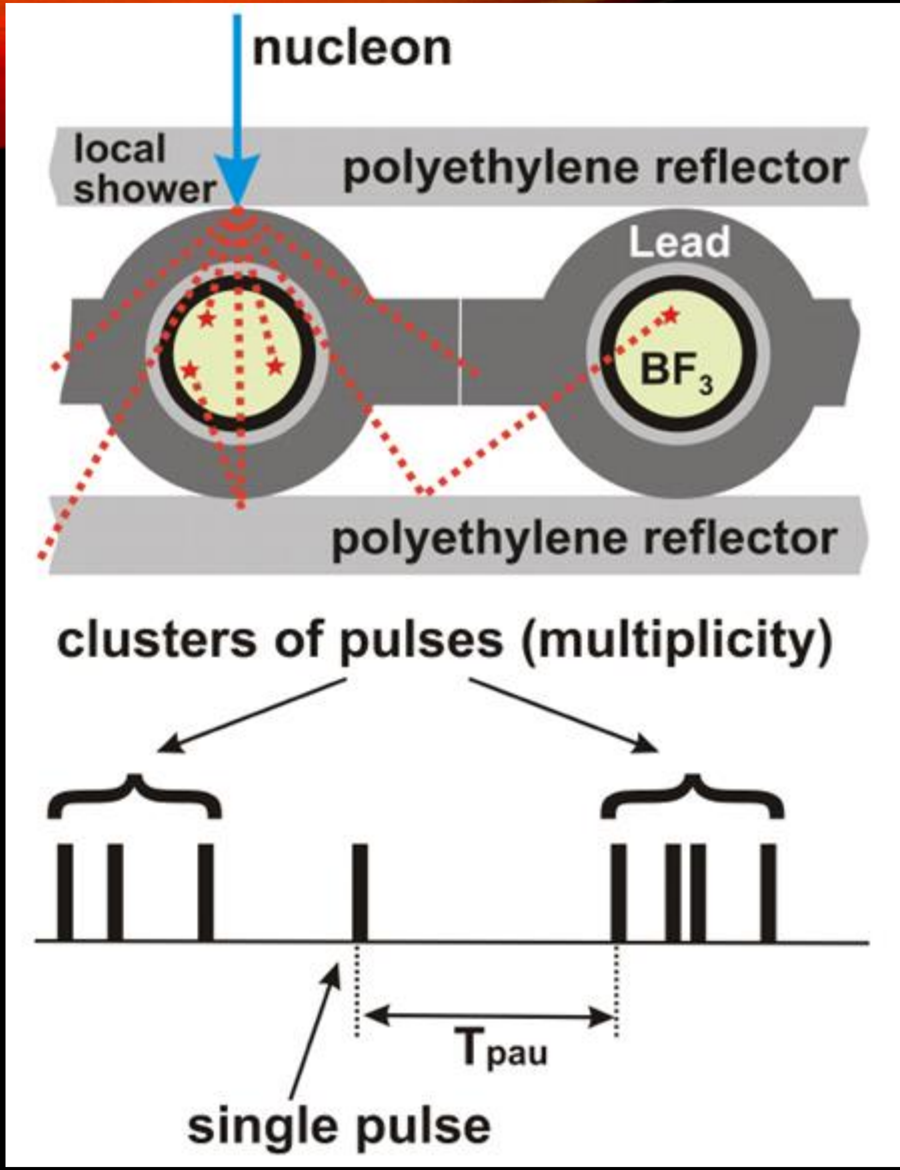
The viewing direction of PSNM sweeps across the sky when Earth rotates.

Sometime, PSNM observed FD at only some direction. We call that "diurnal dip"





Shock: 2011/8/5 18:51
PSNM
620
615
610
MAW
245
240
235
B_rms
20
10
0
Bt&Bz
20
-20
Lat.
50
-50
Long.
300
0
P density
40
0
SW speed
800
600
400
DA
0.8
0.4
S(x10^-3)
10
-10
2011/7/25
2011/7/29
2011/8/2
2011/8/6
2011/8/10
2011/8/14
2011/8/18
Time



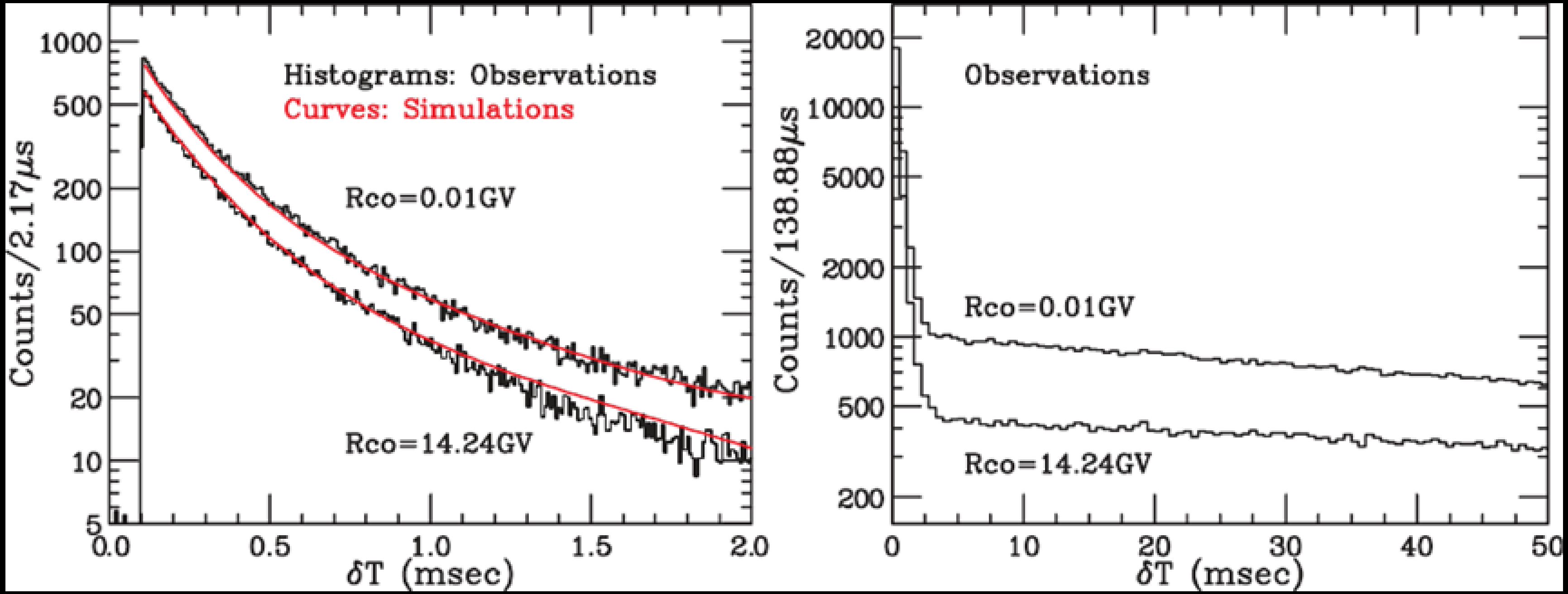
MULTIPLICITY AND COSMIC RAY ENERGY

- NMs were originally designed to give a count rate as a proxy of cosmic ray flux through Earth's magnetic field at a location
- No energy information
- The producer (Pb) is used to amplify the signal: multiple counts per event
- Multiplicity increases with energy

[Balabin et al, 2011]

TIME-DELAY DISTRIBUTIONS

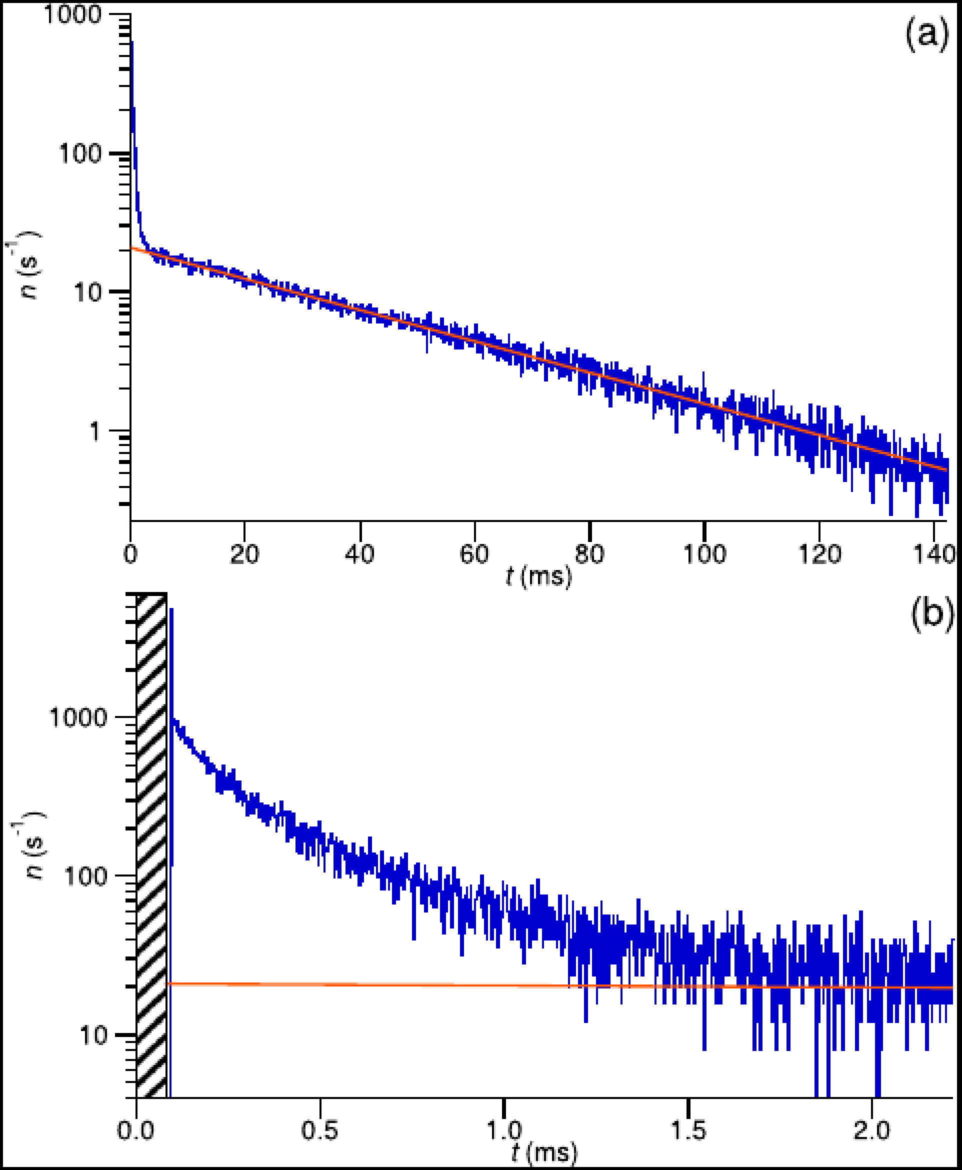
- Distribution of times between consecutive detections shows an exponential tail of uncorrelated counts
- Bieber et al. (2004) used Monte Carlo simulations to reproduce observed histograms for a given CR spectrum, but discrepancies were significant



[Bieber et al, 2004]

TIME-DELAY DISTRIBUTIONS

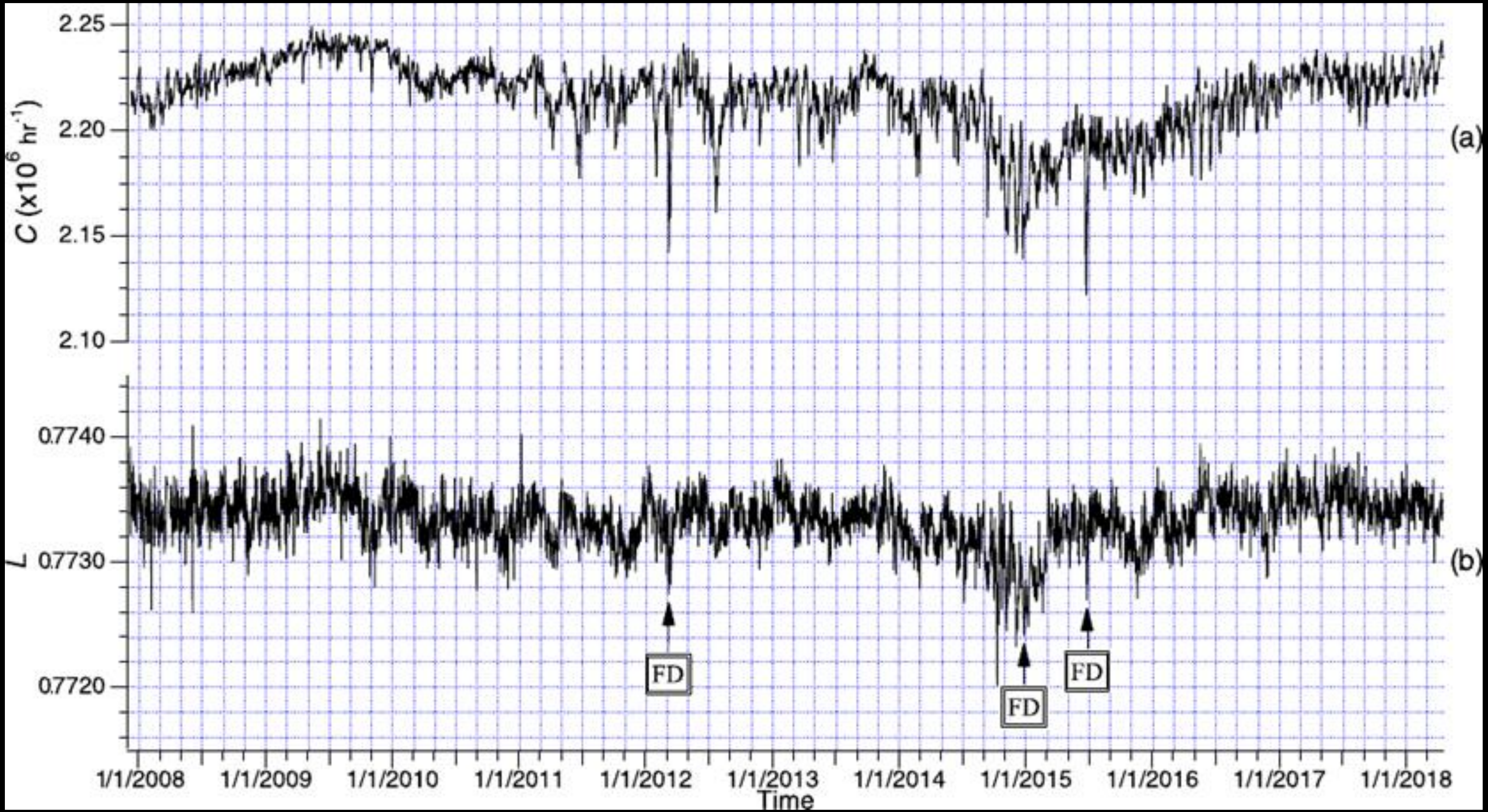
- Ruffolo et al (2016) used an exponential fit to estimate the rate of clusters (or "leaders")
- Chance coincidences do not affect the result
- The ratio of leader pulses to total pulses, or "leader fraction", can be interpreted as inverse multiplicity



[Ruffolo et al, 2016]

LEADER FRACTION

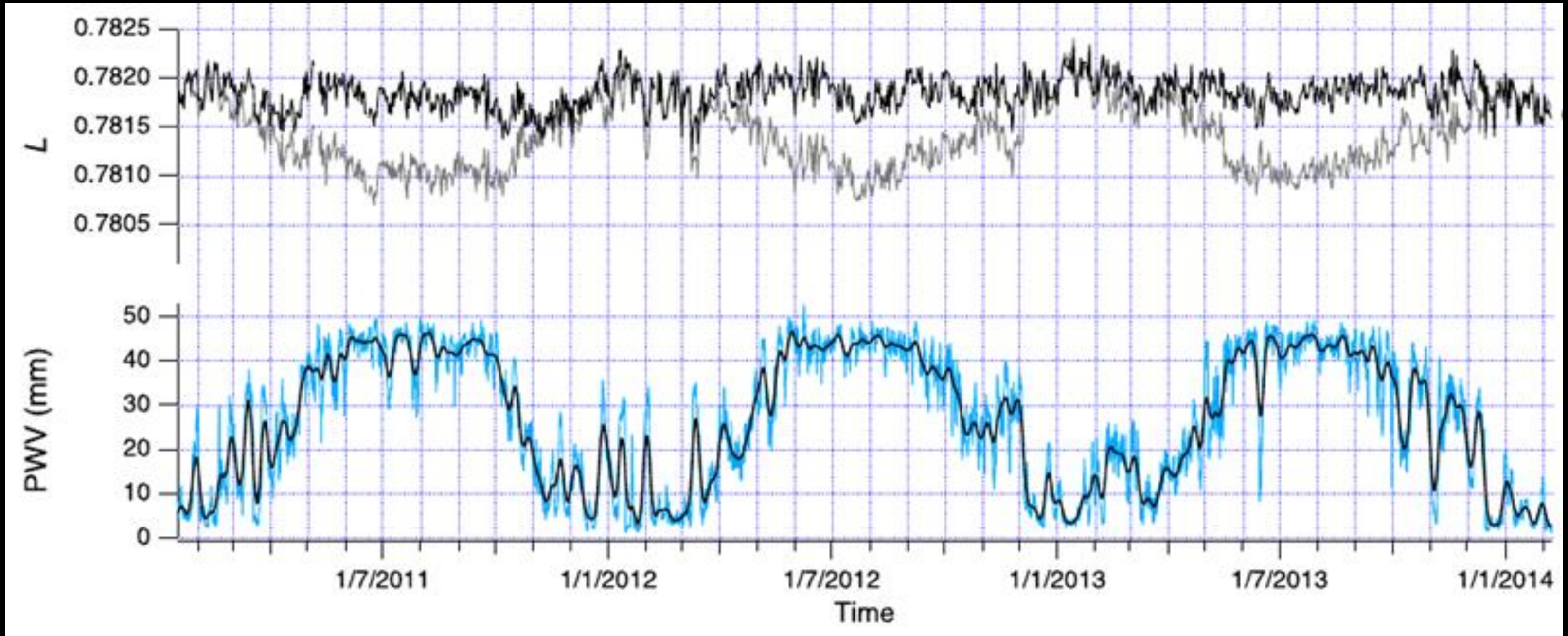
- Banglieng et al (2020) presented a 10-year long time series of leader fraction L at the Princess Sirindhorn Neutron Monitor at high rigidity cutoff, showing variations of interest



[Banglieng et al, 2020]

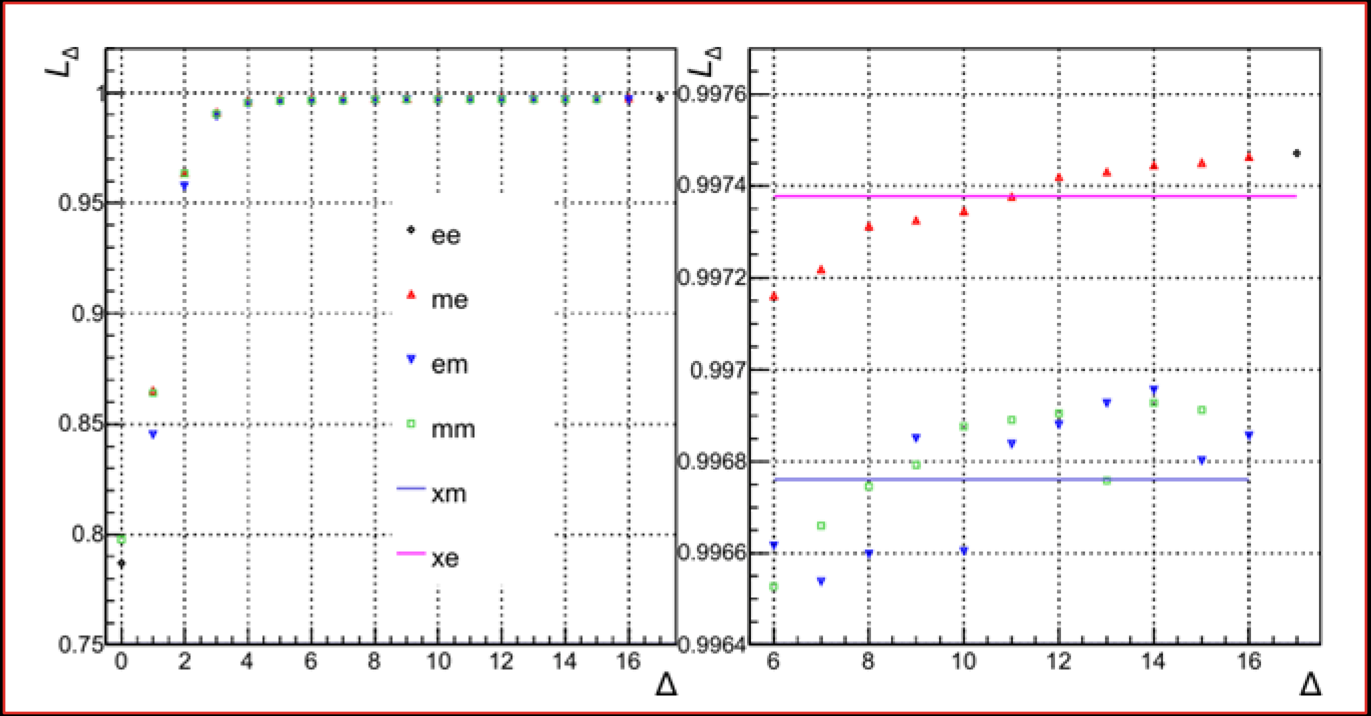
LEADER FRACTION

- The measured value of *L* is affected by high atmospheric humidity
- Analysis requires accumulating histograms: hourly data at best
- The value depends on the exact value of the dead time: not trivial to compare between stations



CROSS-COUNTER LEADER FRACTION

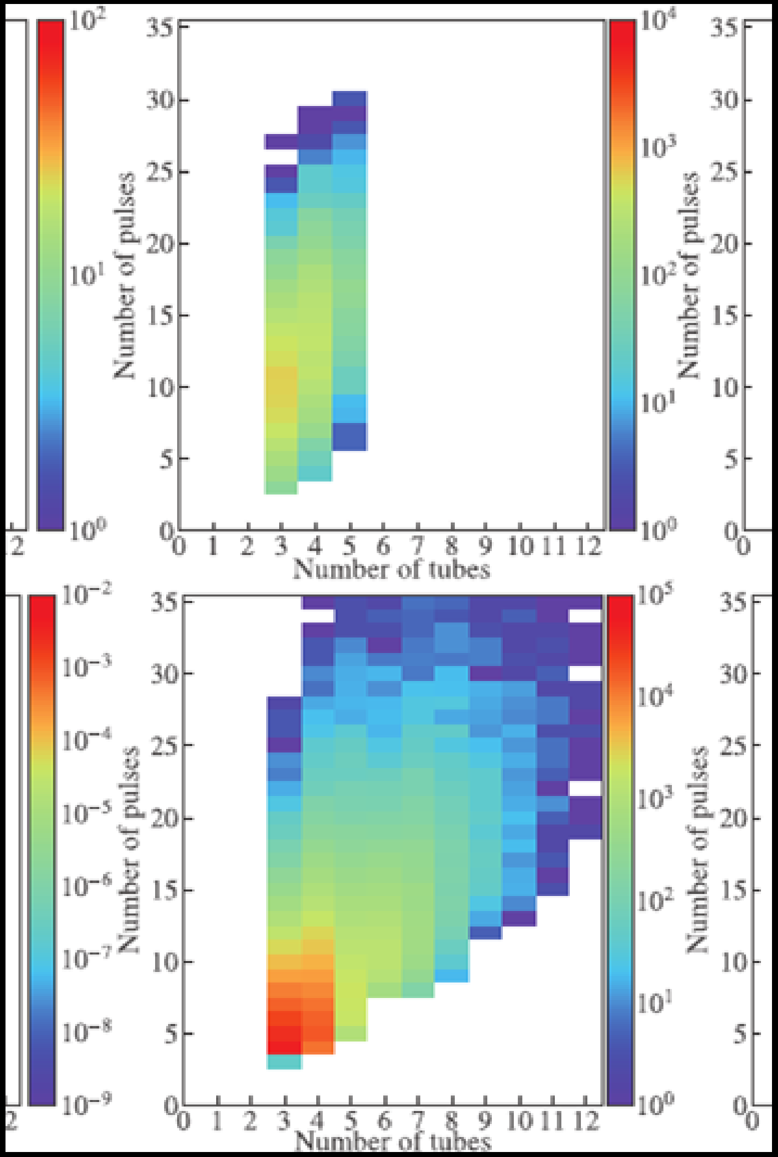
- Synchronization of counter timer clocks allows to study correlations across the monitor
- Cross-L related to atmospheric cascades



[Sáiz et al, 2019]

STUDY OF INDIVIDUAL CLUSTERS OF COUNTS

- Individual events can be sampled and analyzed in detail
- We try to reconstruct the total energy of incoming cosmic ray
- "Calorimeter" approach



[Evenson et al, 2021]

MONTE CARLO SIMULATION

- What is a Monte Carlo (MC) method?
  - A type of computer algorithm that evaluates an average (integral) or other statistical properties by selecting a random sample from the population space.
- When to use MC?
  - Many "dimensions" of integration.
  - The problem is not easily expressed as an integral, e.g., there are many random choices.
  - Sometimes MC is much easier to program.

FLUKA: A MONTE CARLO PROGRAM

- What is FLUKA?
  - FLUktuierende KAskade
  - Performs Monte Carlo simulations of particle transport and interactions in matter, especially good for low-energy neutrons
- Applications of FLUKA:
  - Design of particle detectors for high energy physics, cosmic ray studies, and gamma ray astronomy
  - Study of shielding and radiation damage to materials
  - Dosimetry, medical physics and radiobiology

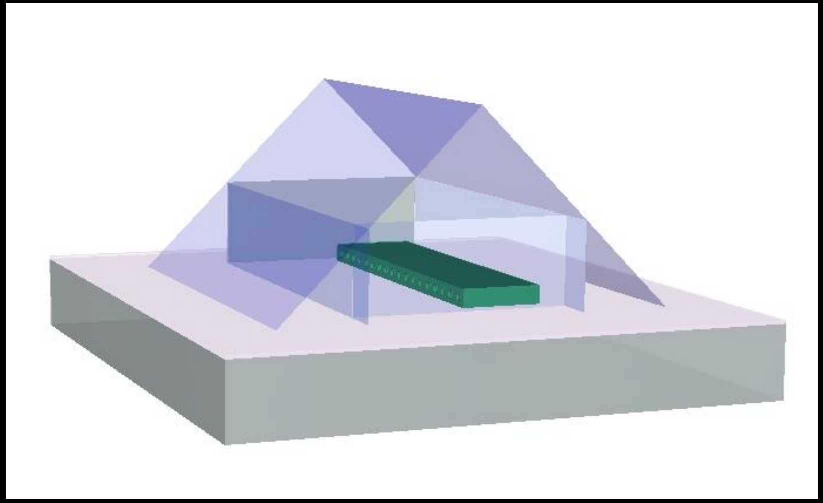
SIMULATION STEPS

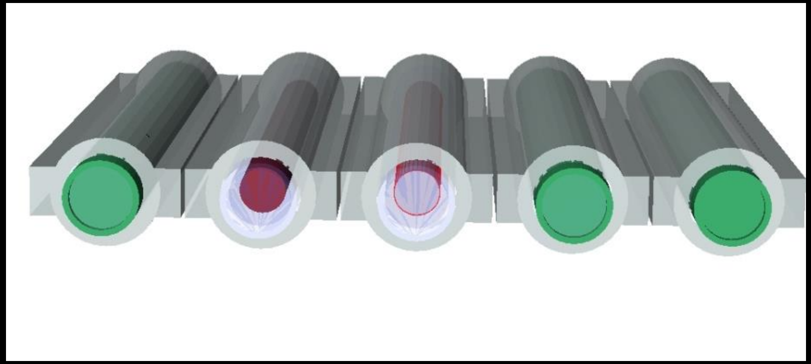
Model Geometry and specify type of materials for PSNM

Specify type of particle beams

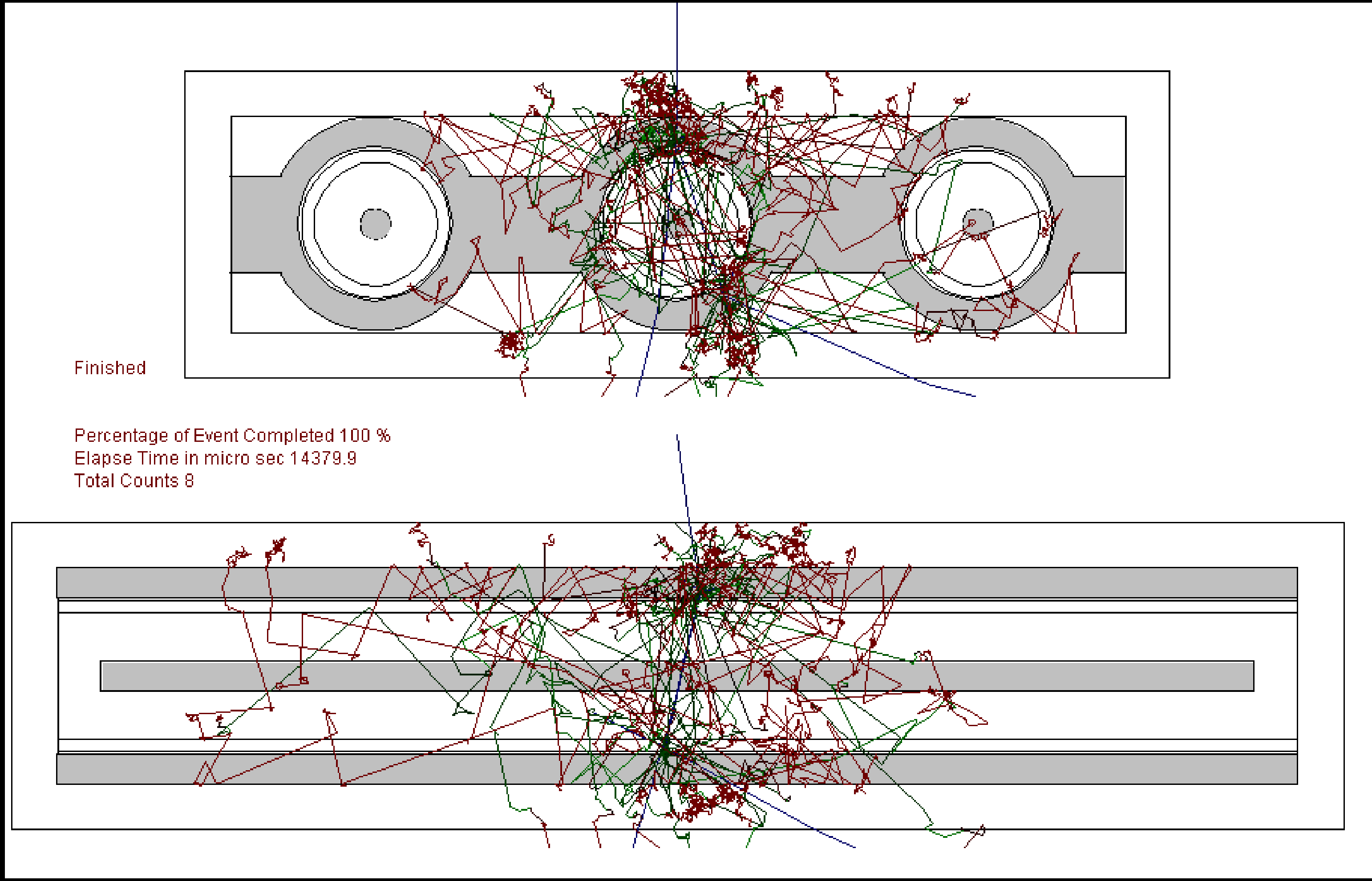
Specify energy of particle beams

Operate FLUKA simulation





SIMULATED INTERACTION IN A NEUTRON MONITOR



http://www.bartol.udel.edu/~clem/nm/display/intro.html

CONCLUSIONS

- Princess Sirindhorn neutron monitor operating already for 16 years
- Highest cutoff rigidity for a fixed cosmic ray detector
- Right here at Doi Inthanon!
- Several solar effects studied

- Thank you!