Pattern Recognition for Multiple Interactions in a Neutron Monitor

P.-S. Mangeard[1], J. Clem[1], P. Evenson[1], W. Nuntiyakul[2], D. Ruffolo[3], A. Sáiz[3], A. Seripienlert[4], and S. Seunarine[5]

[1]Bartol Research Institute, University of Delaware, Newark DE, USA, [2]Chiang Mai University, Chiang Mai, Thailand, [3]Mahidol University, Bangkok, Thailand, [4]National Astronomical Research Institute of Thailand (NARIT), Chiang Mai, Thailand, [5]University of Wisconsin River Falls, River Falls WI, USA

Workshop on Machine Learning for Cosmic-Ray Air Showers

Outline

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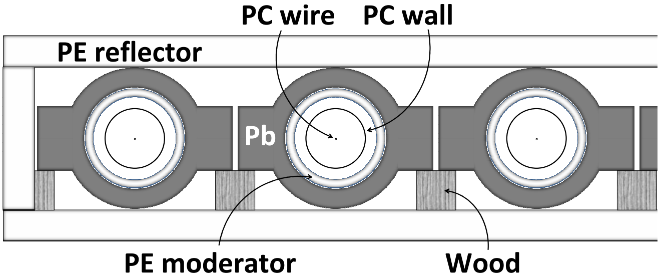
What is a Neutron Monitor?

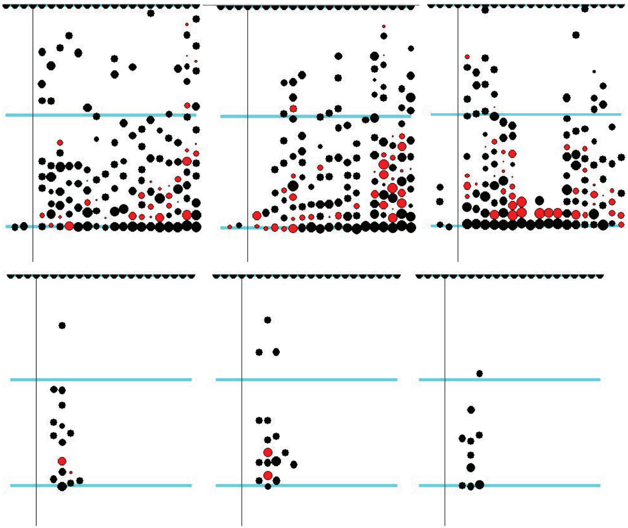
- A neutron monitor is a ground based detector that records the nucleonic component of air showers produced by cosmic rays impinging the Earth's atmosphere.
- It was invented by John Simpson in 1948



- What does a neutron monitor measure? (Example of NM64 - $\mathrm{BF_3}$)
  1. Secondary particles (SP, mostly neutrons) interact with Pb-nucleus and produce tertiary neutrons.
  2. $\mathrm{n} + {}^{10}\mathrm{B} \longrightarrow {}^{4}\mathrm{He} + {}^{7}\mathrm{Li}^{*}$
  3. Pulses are counted.
- NM are sensitive to CR above the local cutoff rigidity

Outline

Multiple interactions in a 18NM64 at Doi Inthanon (DI)



Evenson et al. [2021]

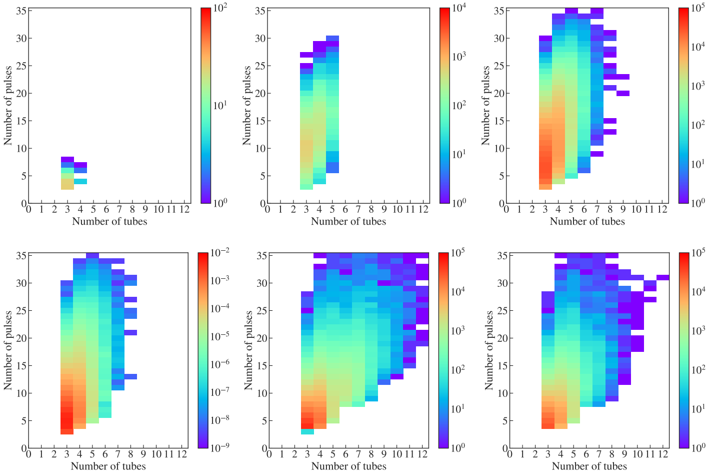
- Horizontal axis: tube position
- Vertical axis: time (upward, 1ms between blue lines)
- Each marker is a pulse
- Top: 3 **Catch** events
- What produces these large events?
  - Air shower core?
  - Coincidence between SP?
  - Very energetic SP?
- Bottom: 3 simulated 100 GeV neutrons
- Can we identify the source of an event?
- Can we use these events to assess the spectrum at rigidities above the cutoff?

What information do we have for each event?

- Position of each pulse
- Time of each pulse with respect to the trigger time
- Amplitude of each pulse
- 18 Tubes
- Dead time of about 90×10^{-6} sec between pulses.

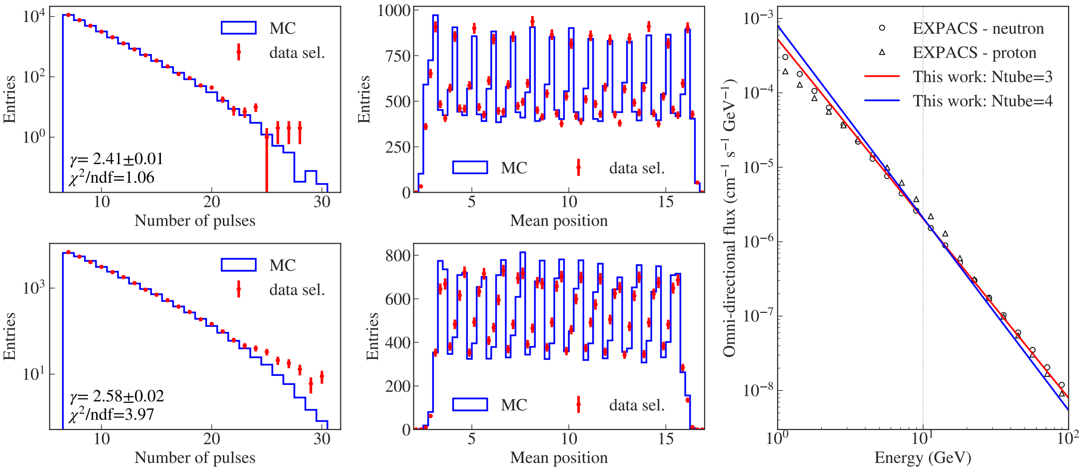
Outline

Number of pulses vs. Number of tubes



Top left two panels: Simulated 1 and 100 GeV, pencil beam, normal incidence. Top right: Simulated 1 to 100 GeV E^{-1} spectrum, uniform illumination at variable zenith angles. Bottom left: The 1 to 100 GeV spectrum re-weighted to $E^{-2.5}$. Bottom center: Approximately two days of data. Bottom right: Subset of actual data. Evenson et al. [2021]

Simple selection and power law fit



This is promising. We can determine a reasonable spectrum of the secondary nucleons above the detector, Evenson et al. [2021].

Outline

The Neutron Monitors

Extension of the NM measurements

Classical Approach

Toward Machine Learning

Toward Machine Learning

- Separate three classes of events:
  1. Energetic secondary particles
  2. Coincidence of secondary particles
  3. Large events (origin to be determined)
- By eye, 1 and 2 overlap a lot
- By eye, 2 and 3 overlap a lot
- Extract energy information from 1
- It seems to be a problem where a machine learning algorithm could perform well
- Where to start?

First naive attempt (1)

- Simulated single neutrons 0.5-500 GeV injected above the detector
- Selection: No pulses in the edge tubes
- Input: Some variables that makes sense
  - Number of pulses (1 var.)
  - Number of tubes (1 var.)
  - Sum of the pulse amplitudes (1 var.)
  - Number of pulses for each tube (16 var.)
  - Averaged position of the pulses (1 var.)
  - Standard deviation of the pulse positions (1 var.)
  - Number of cluster (1 var.)
- Output
  - Injection position (in unit tube number)
  - Energy of the neutron
- Tools
  - python3, sklearn, RandomForestRegressor
  - Default parameters, validation size at 0.3

Conclusion

- We aim to extend the measurements provided by the neutron monitors
- Recent developments allow us to record detailed information about timing and spatial for large events in a neutron monitor
- We think some kind machine algorithm should help us understand/classify the different sources of these events
- We are really at the start of the project with little experience using ML so this workshop will help us better target the tools we need.

References

Paul Evenson, John Clem, Pierre-Simon Mangeard, Waraporn Nuntiyakul, David Ruffolo, Alejandro Sáiz, Achara Seripienlert, and Surujhdeo Seunarine. Multiple particle detection in a neutron monitor. *PoS*, ICRC2021:1240, 2021. doi: 10.22323/1.395.1240.