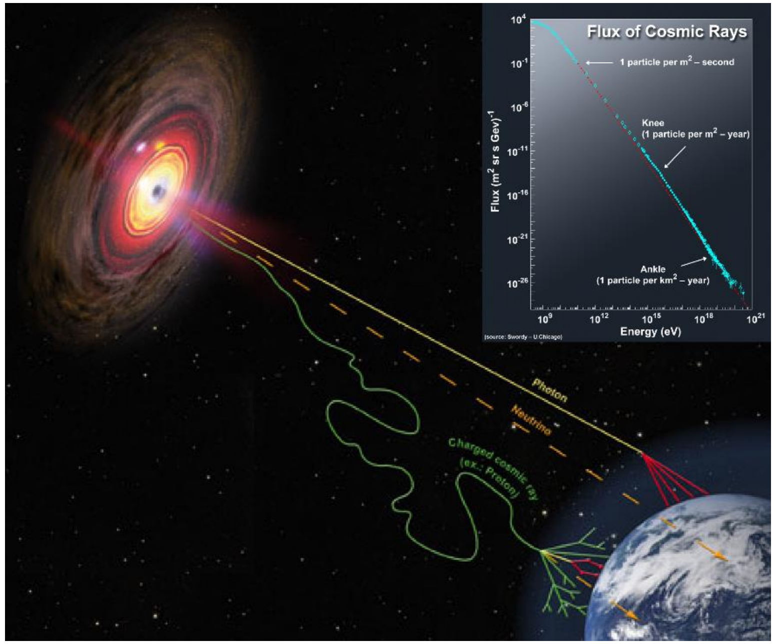
POLITECNICO MILANO 1863 | DEPARTMENT OF ENERGY

Development of a portable monitor for cosmic ray neutron observations

02.707.2025 | Andrea Cirillo

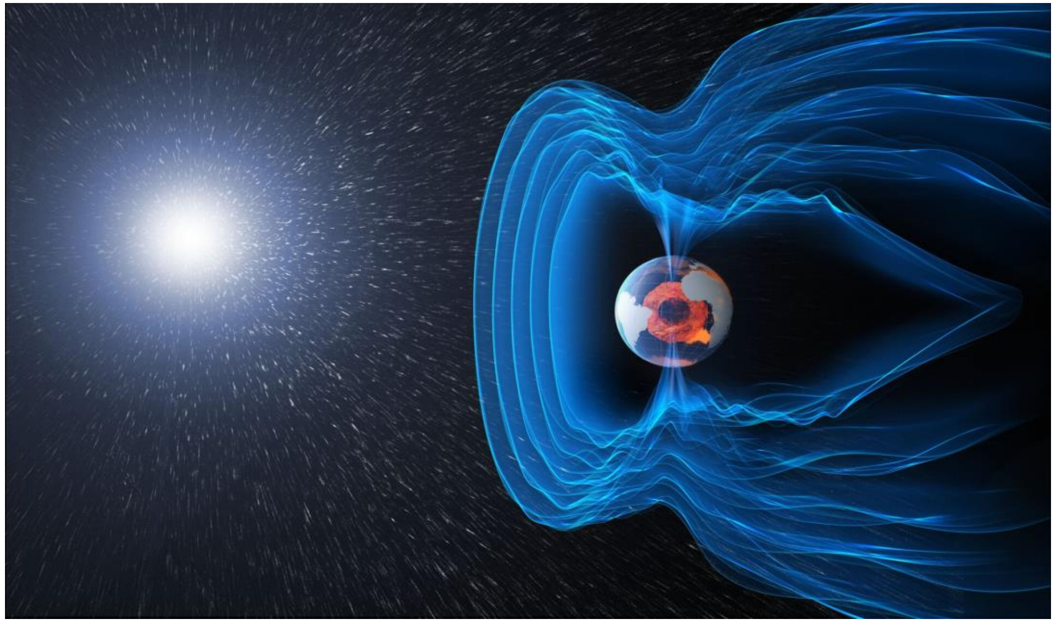
Galactic Cosmic Rays



From "Astrophysics Research," North Carolina A&T State University, https://ncat.edu/cost/departments/physics/research/astrophysics-physics.php

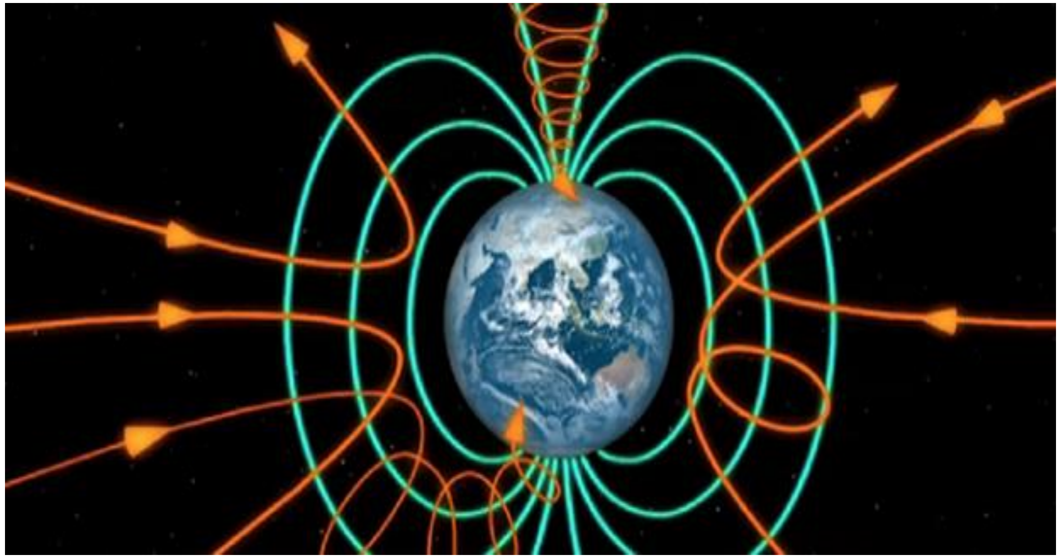
Interstellar cosmic-ray fluxes are high-energy charged particles that originate outside the solar system and travel towards the Earth atmosphere

They are strongly influenced by galactic magnetic fields. For example, the solar magnetic field significantly shields out planet for cosmic rays entering its atmosphere



https://www.esa.int/Science_Exploration/Space_Science/The_solar_wind

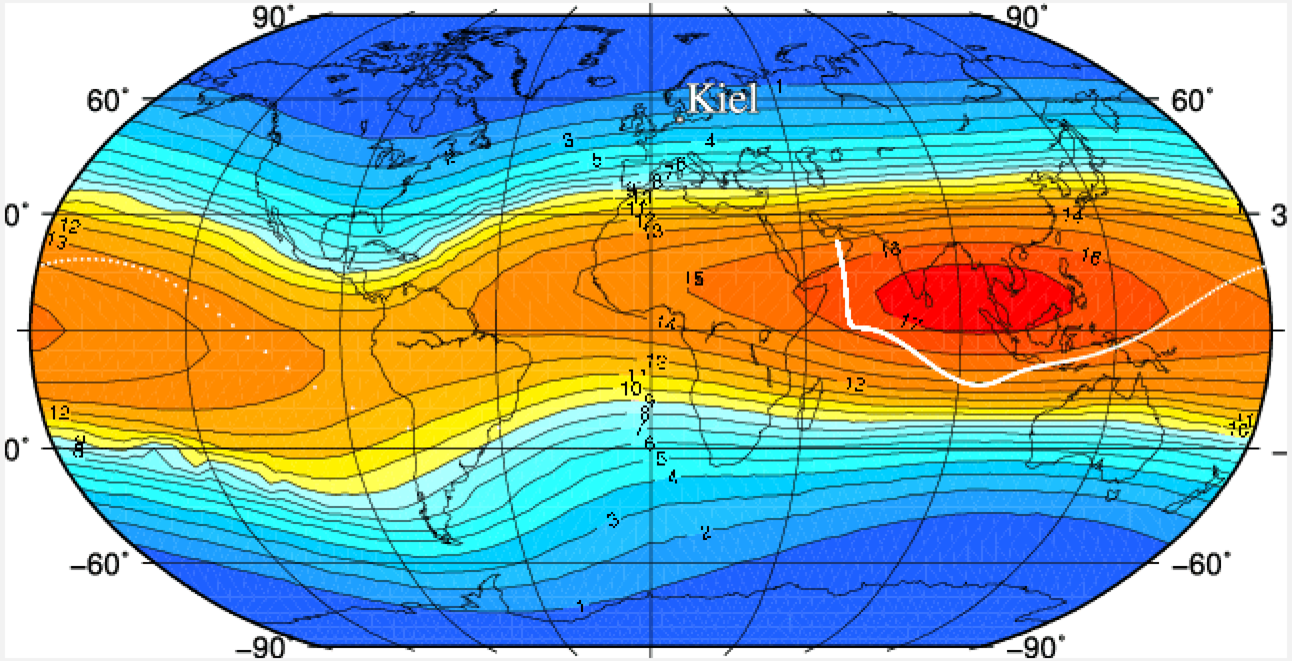
Cosmic Rays Interactions with Earth Magnetic Field



from https://swc.nict.go.jp/en/knowledge/magnetosphere.html

Once approaching the planet, cosmic rays are also affected by the earth magnetic field which bends their trajectories preventing them from reaching the surface

The **cutoff rigidity** quantifies the minimum momentum per unit charge that a charged particle must have to be reach a location on earth. It is highly anisotropic being higher for lower latitudes.

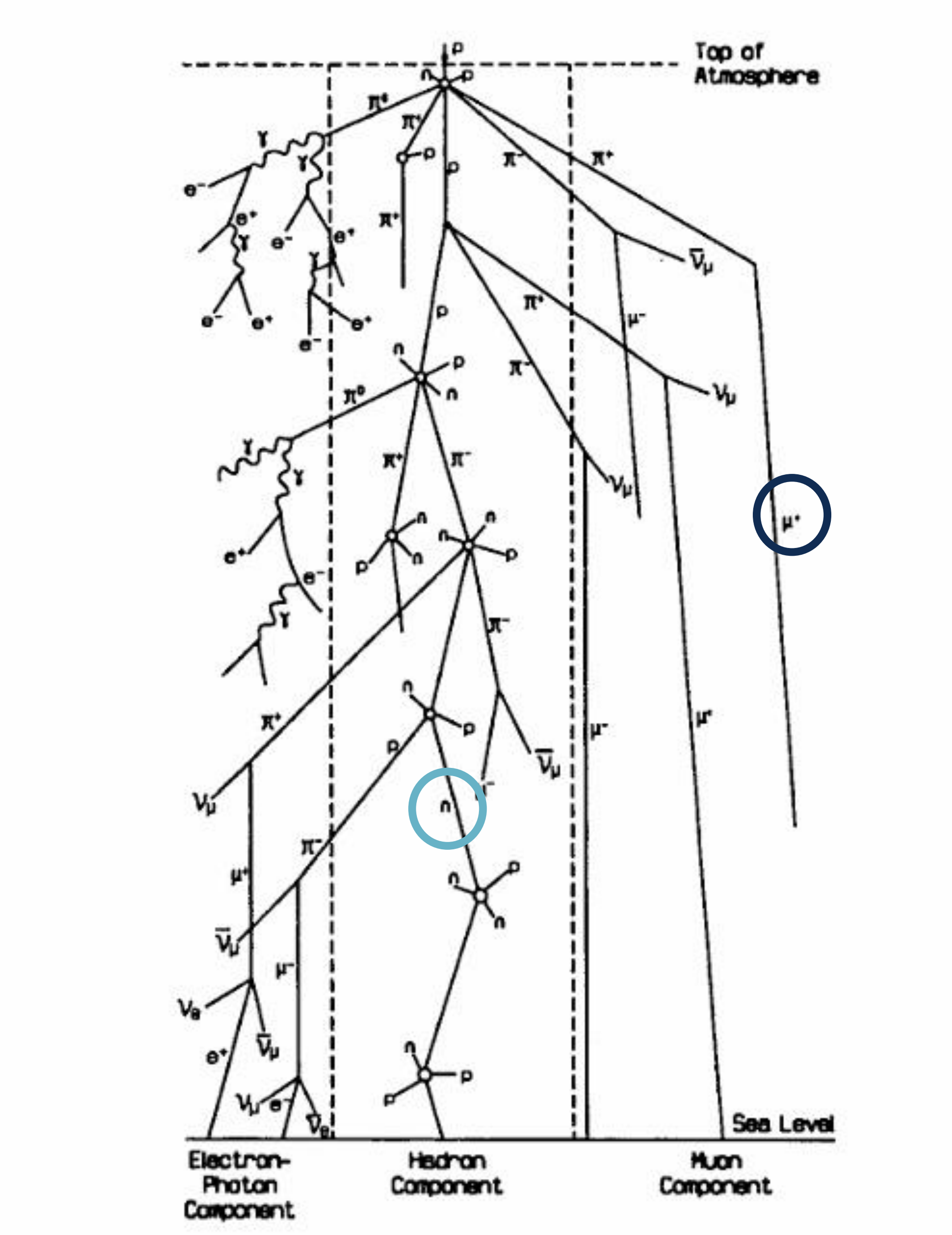


Christian T. Steiges et al., Observation of cosmic ray decreases between 1 and 5 AU.

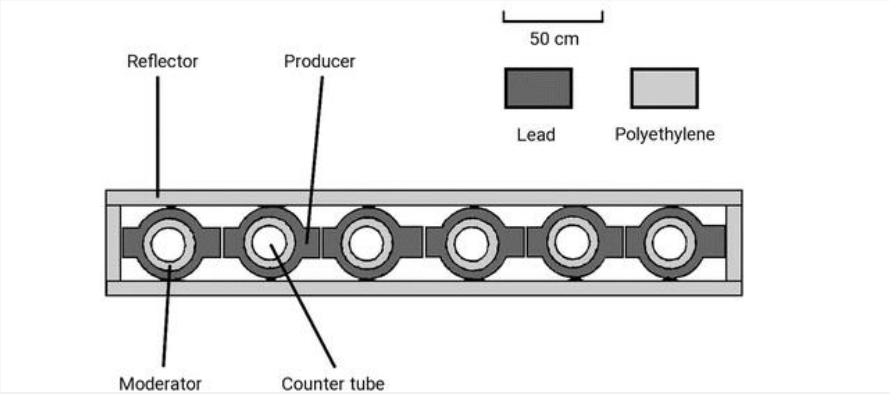
Extensive Air Showers

When entering the atmosphere, cosmic rays interact via inelastic reactions triggering **extensive air showers** and generating a secondary radiation field.

Neutrons and **Muons** generated in this way are deeply penetrating and can be detected at ground level



The NM64 Neutron Monitor



Bütikofer, Rolf. (2018). Ground-Based Measurements of Energetic Particles by Neutron Monitors.

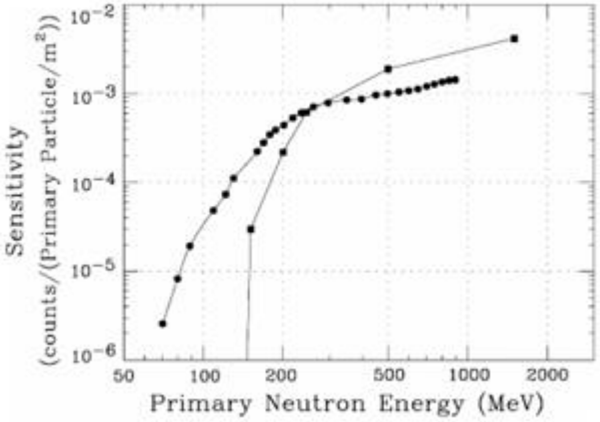
NM64 neutron monitor:

- **Lead producer:** multiplies incoming high-energy neutrons via (n,xn) reactions
- **Moderator:** thermalizes neutrons emitted after reactions in Lead to ease their detection
- **Reflector:** backscatters escaping neutrons
- **Proportional Counter:** detects thermalized neutrons

Weight of 12 tons (for a 6-tube detector)

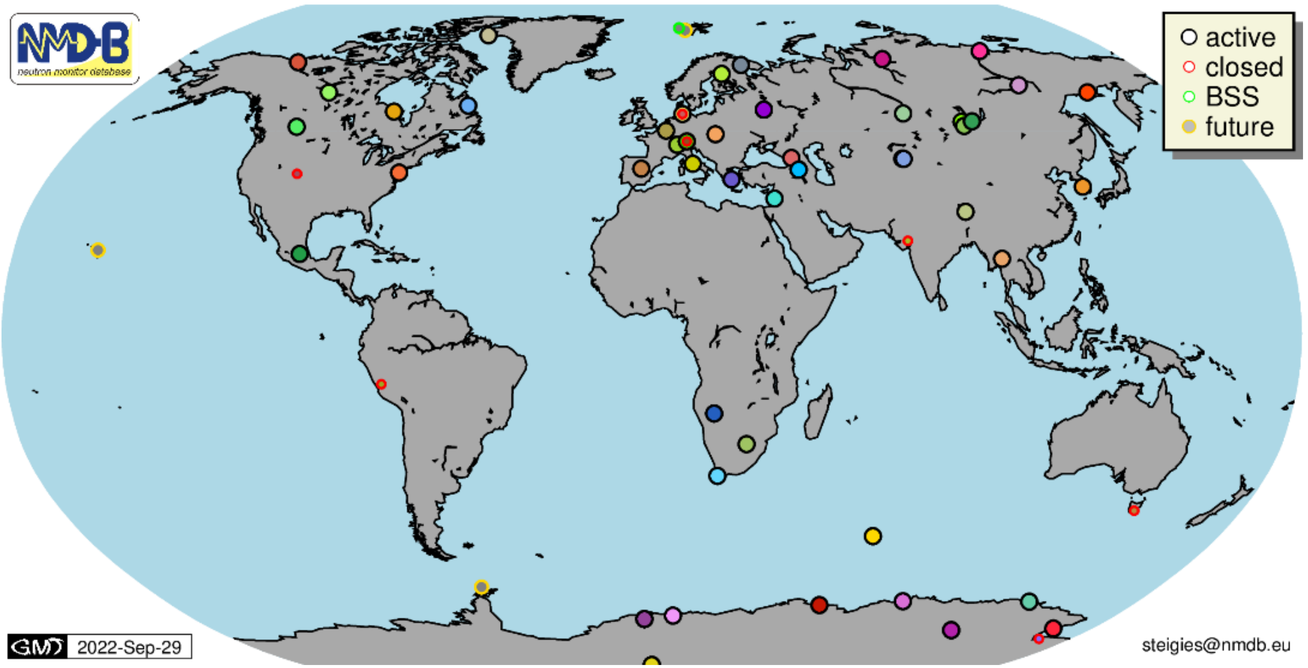
Typical Count Rate of hundred of counts per second / 10 – 20 cph/kg (Rome, June 2025)

Maximum sensitivity for high-energy neutrons



Clem, J. M. and Dorman, L. I., "Neutron Monitor Response Functions", <i>Space Science Reviews</i>, vol. 93, pp. 335–359, 2000. doi:10.1023/A:1026508915269

The Neutron Monitor Database

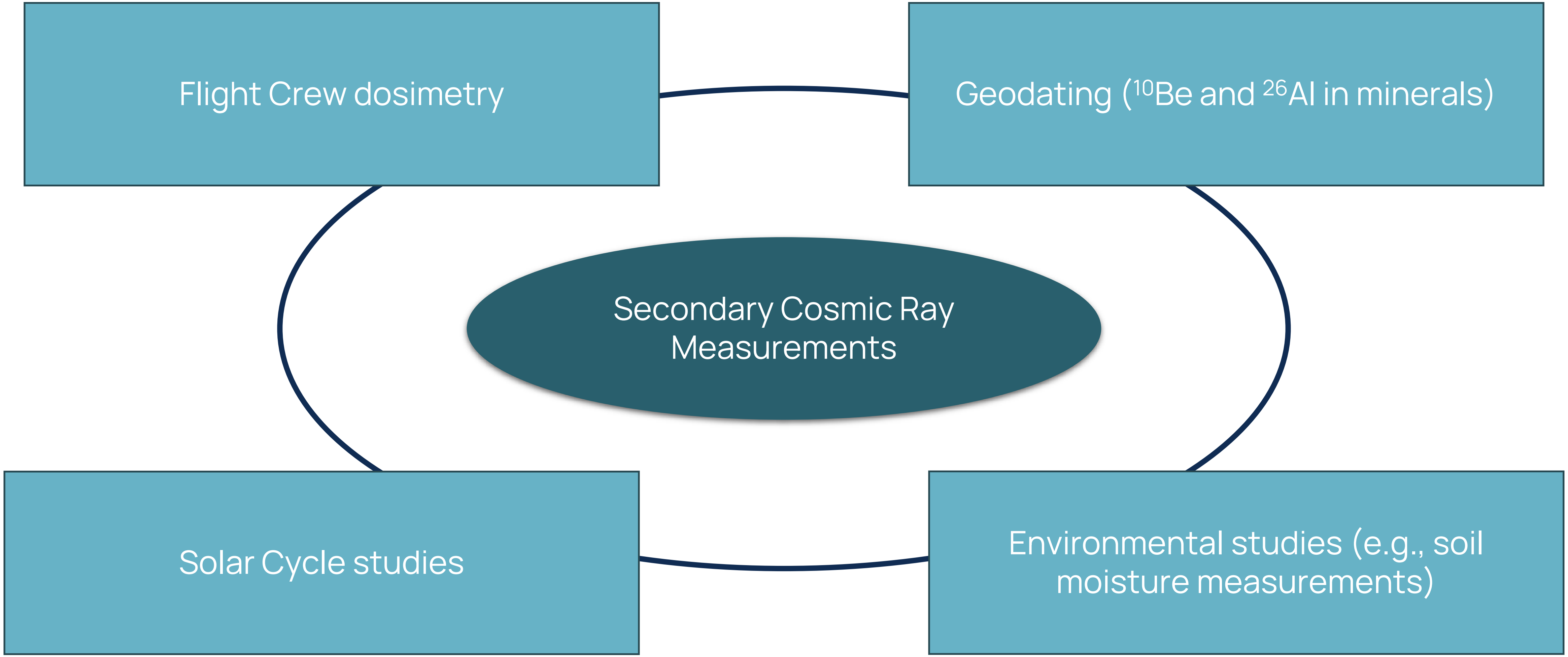


Neutron Monitor Database (NMDB), Station overview map. https://www.nmdb.eu/station/

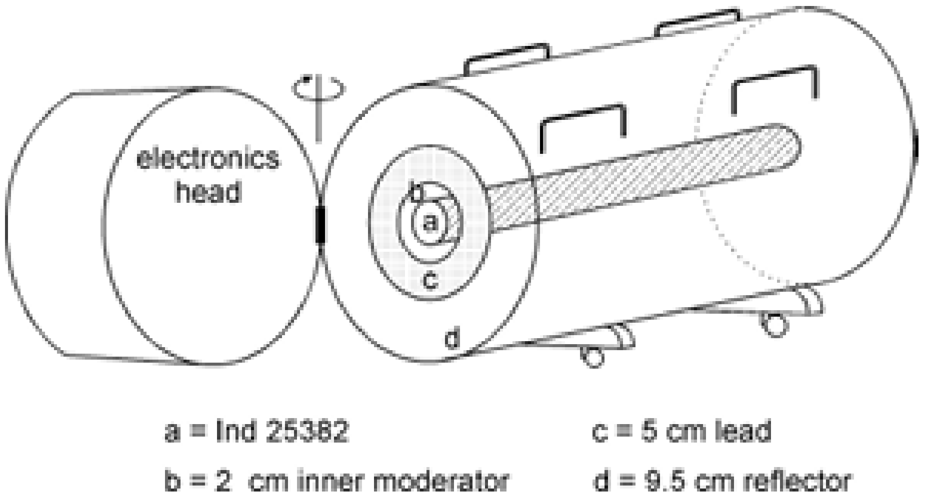
Global Neutron Monitor Station:

- Around 50 detectors in several locations (cutoff rigidities from 0 to 17GV)
- Mainly Distributed in the northern hemisphere
- Hard to install in remote locations

Applications



The Mini Neutron Monitor



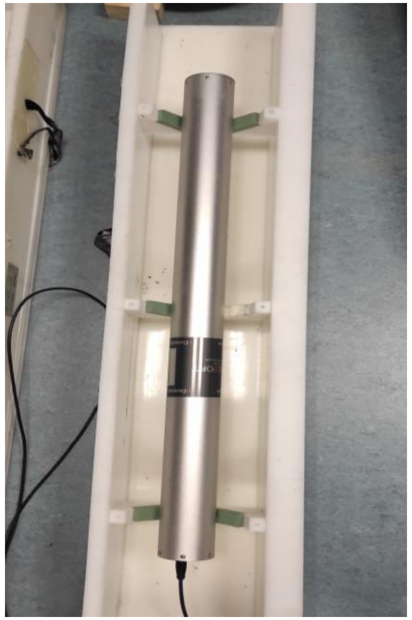
Weight ~ 220 kg

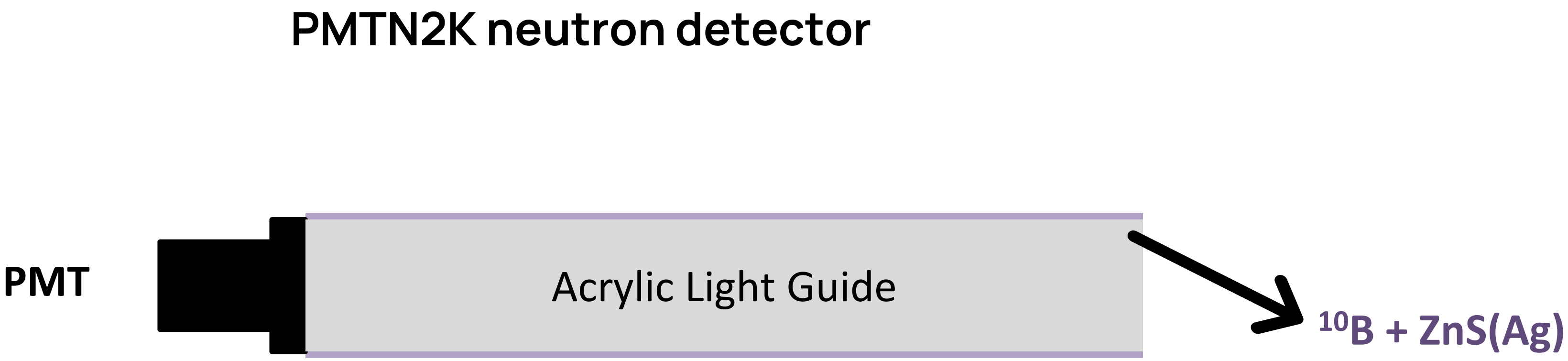
Reference: Moraal, H., "A mobile neutron monitor to intercalibrate the worldwide network", in International Cosmic Ray Conference, 2001, vol. 10, p. 4083.

Pros	Cons
• Valid option to improve the global neutron monitor network especially in remote locations • Possibility of Airborne measurements	• Worse absolute counting efficiency than NM64 (but comparable in terms of cps/kg) • Sensitivity to lower energy neutrons (and to environmental effects)

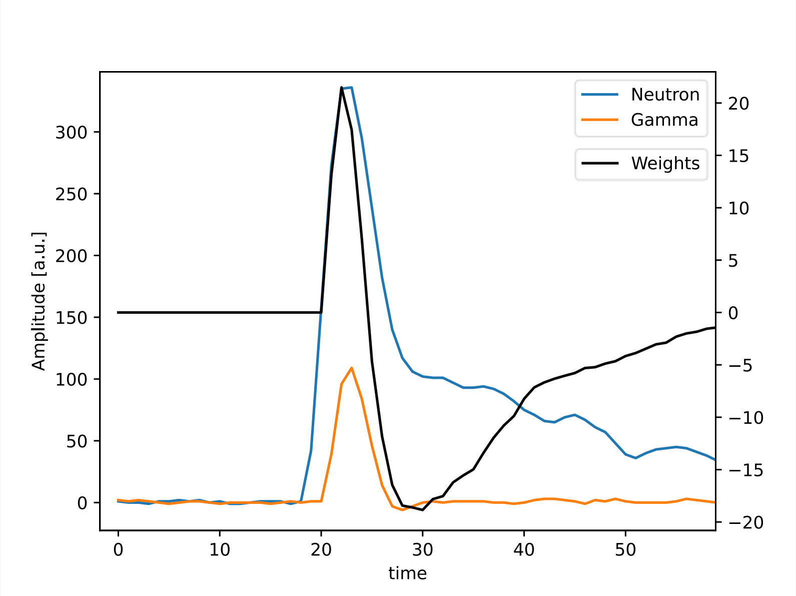
Innovative neutron detectors: BPI PMTN2K

Aim: Developing neutron monitor based on innovative detectors





Characterization of the PMTN2K detector



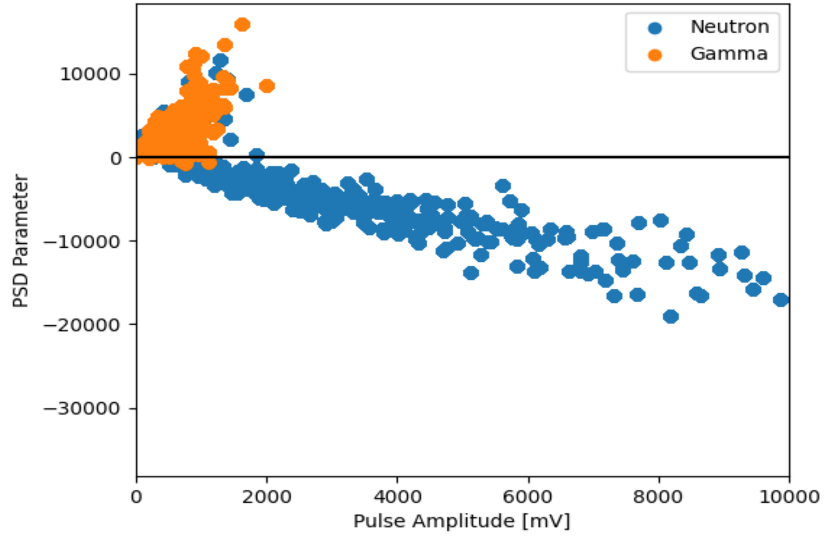
$$P = \sum_k w_k y_k$$

Weighting function

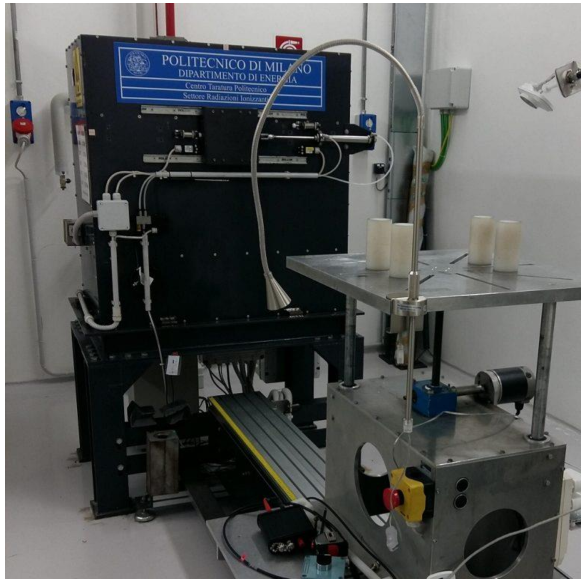
Pulse Amplitude

Particle types are separated for $P>0$ and $P<0$

Setting **proper thresholds** on pulse amplitude and P the neutron events can be isolated



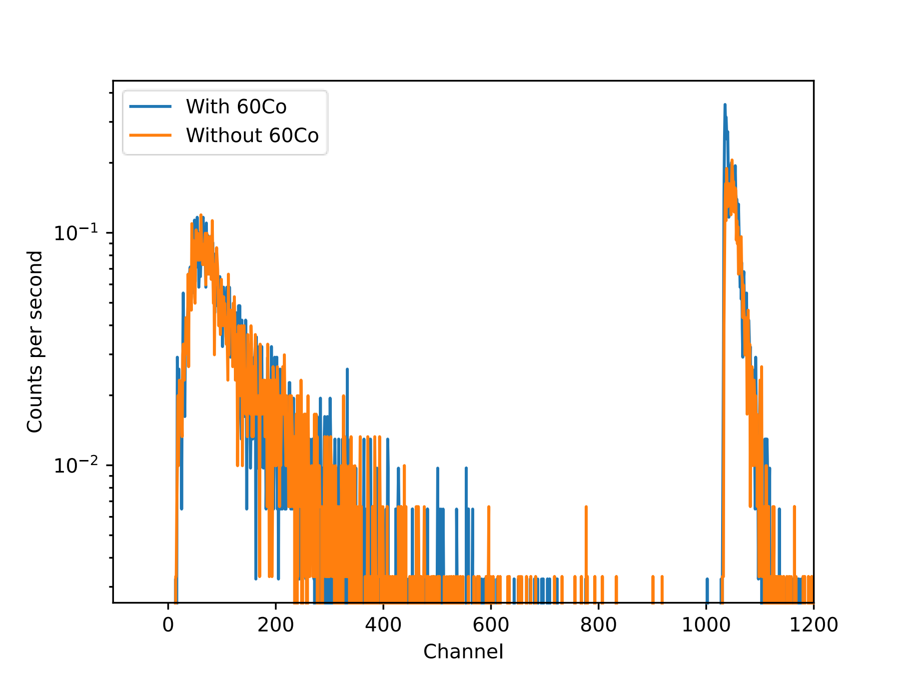
Neutron/Photon Discrimination



LAT n° 104
Calibration Center

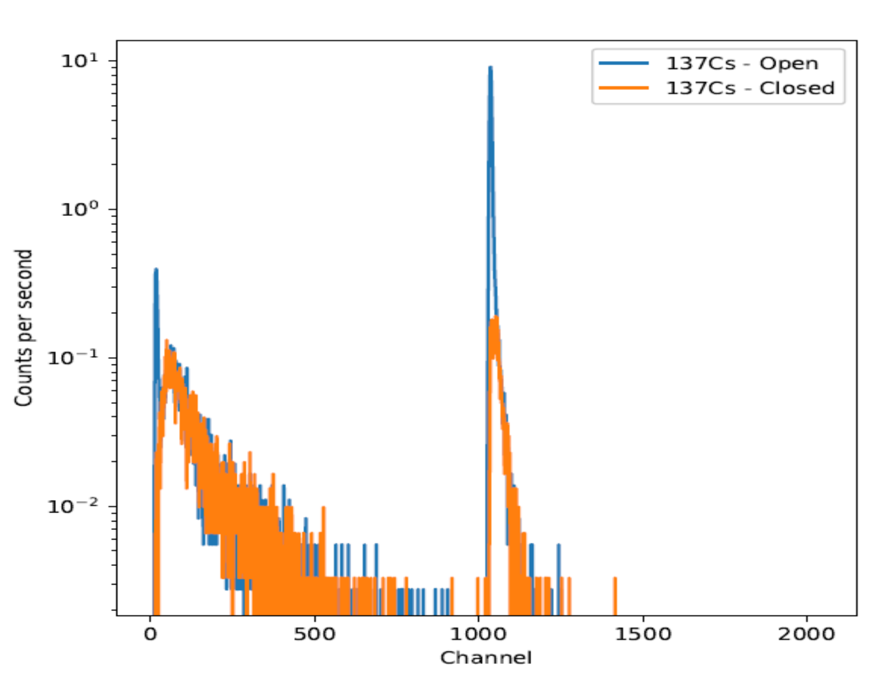
^{60}Co (0.03mSv/h)

- No change in the neutron spectrum
- Contribution in the γ spectrum



^{137}Cs (2mSv/h)

- Pile up effects in the neutron spectrum can be discarded with a threshold



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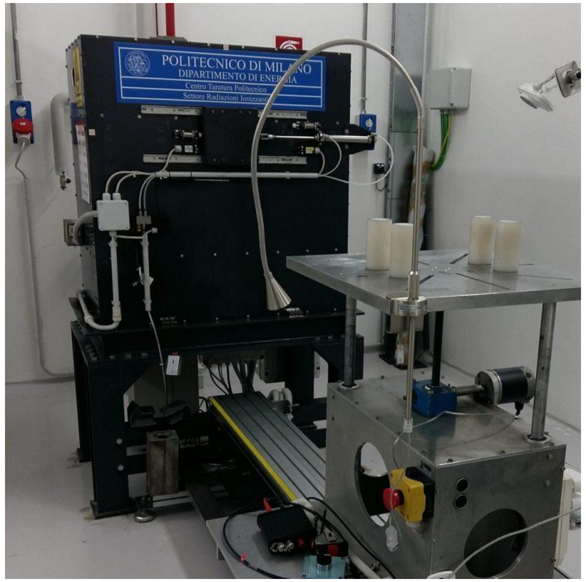

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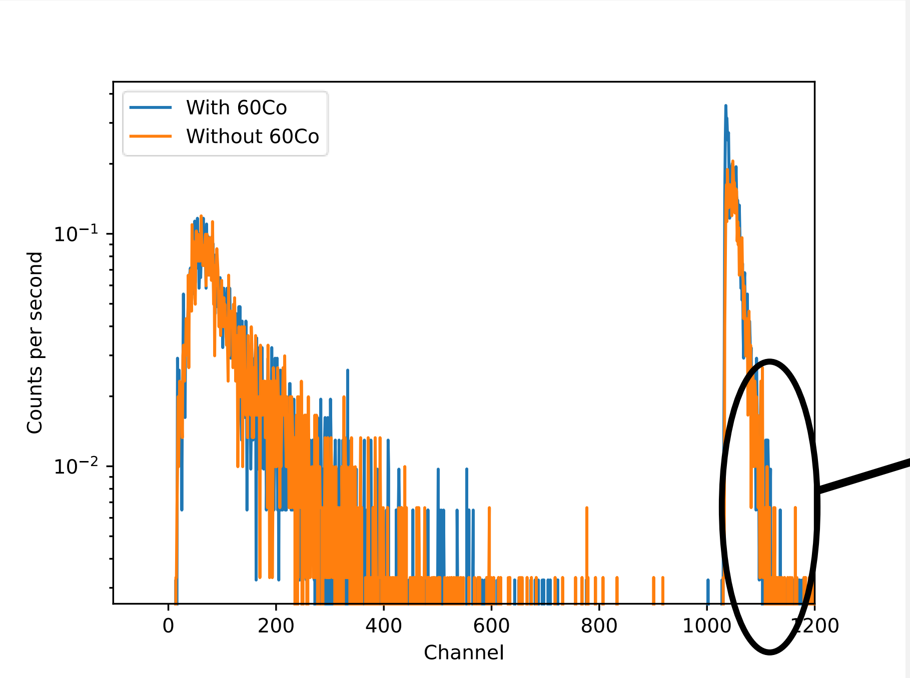

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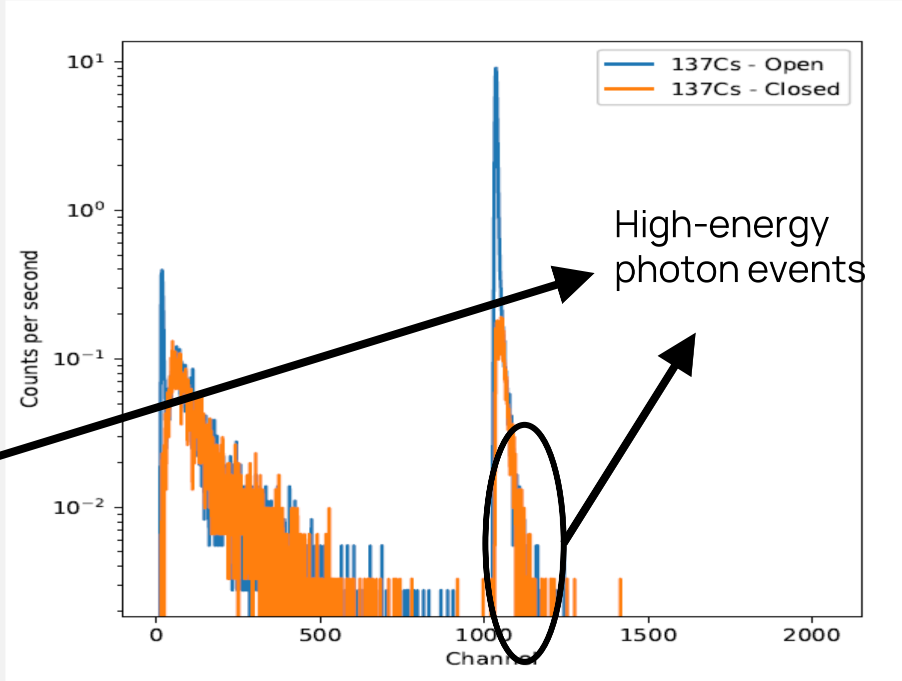
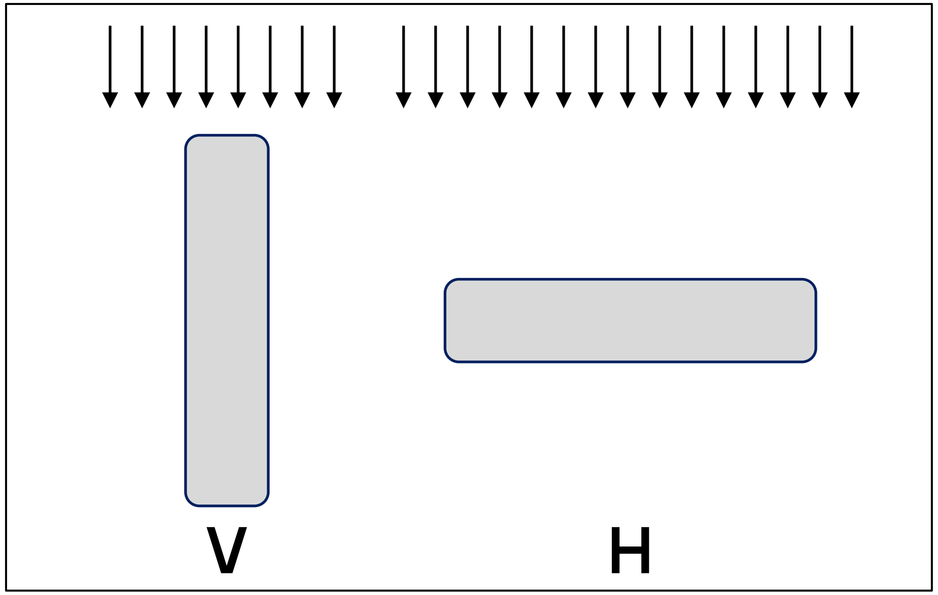
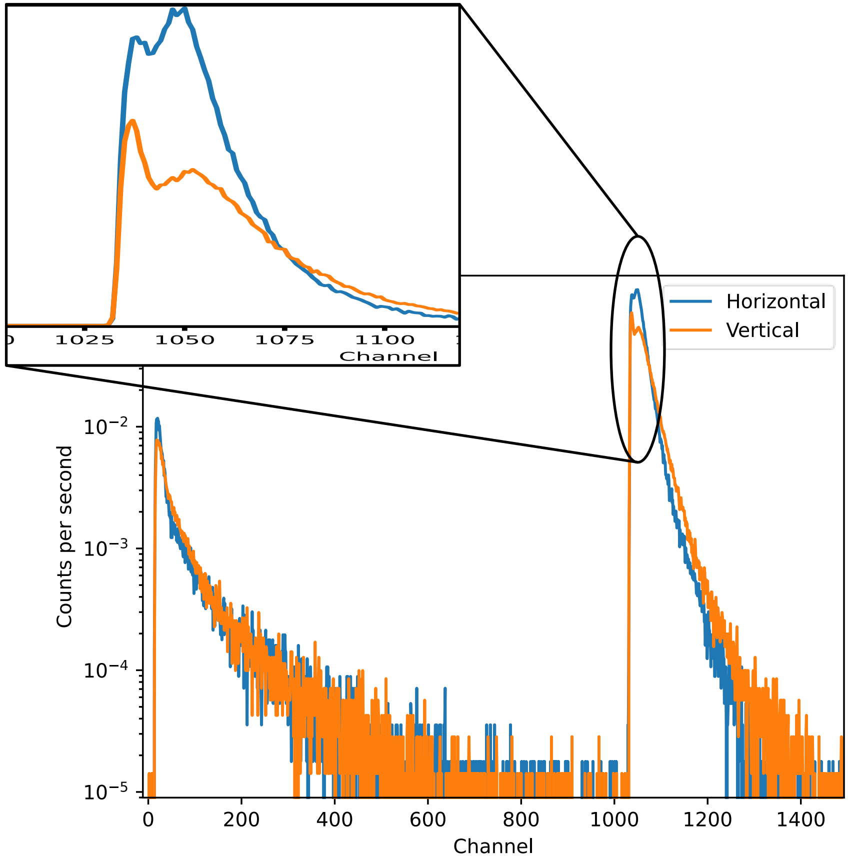


Contribution of cosmic-ray muons

Contribution of **cosmic ray muons**: measurements in horizontal and vertical configuration





H
- Higher Flux
- Lower Energy

V
- Lower Flux
- Higher Energy

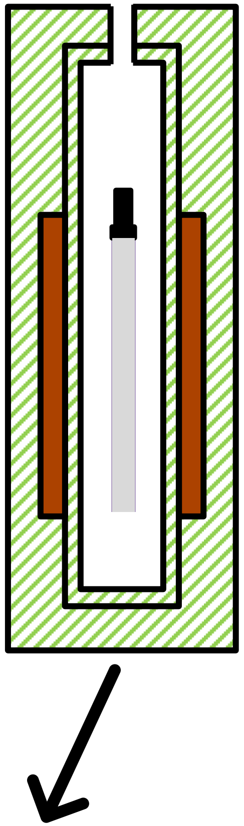
Moderator Design and Optimization

Purpose

Increase the detector sensitivity to high-energy neutrons

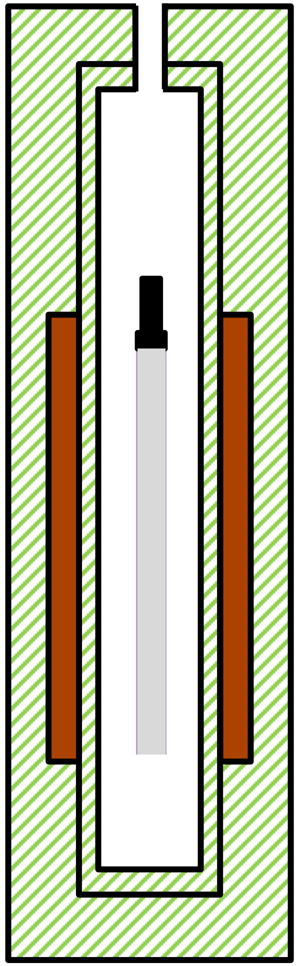
Optimization

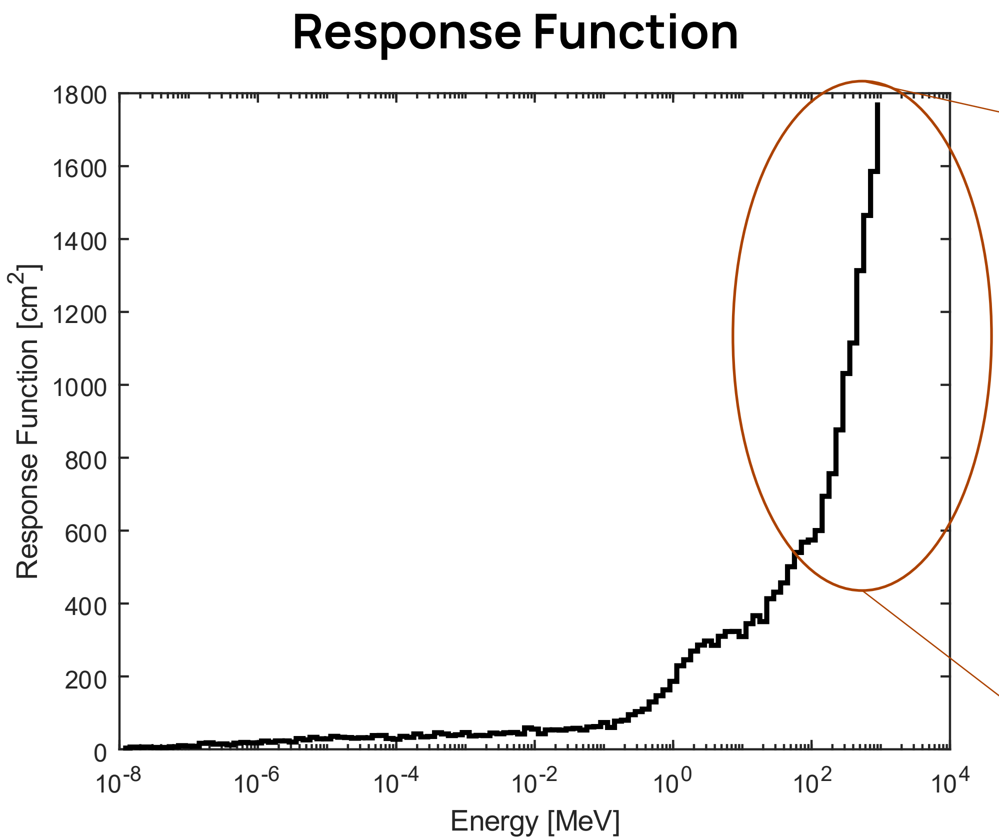
Sensitivity	Absolute value of cps
SNR	Relevance of neutrons above 10 MeV
Weight	Manufacturing possibility



Approximately 40 cm × 1 m

Calculated Response Function



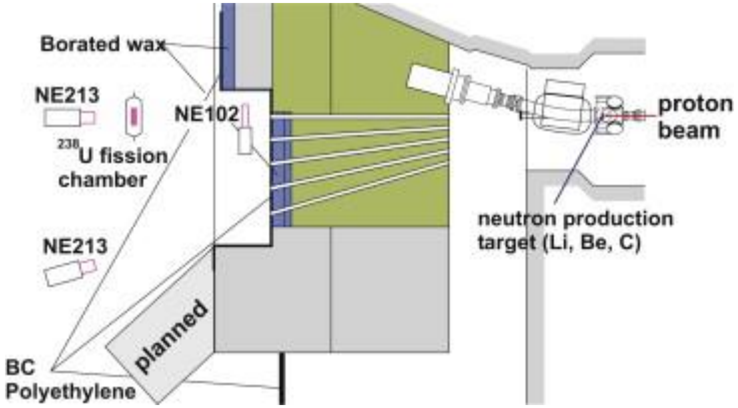


Need: calibration in an adequate energy range

Challenges:

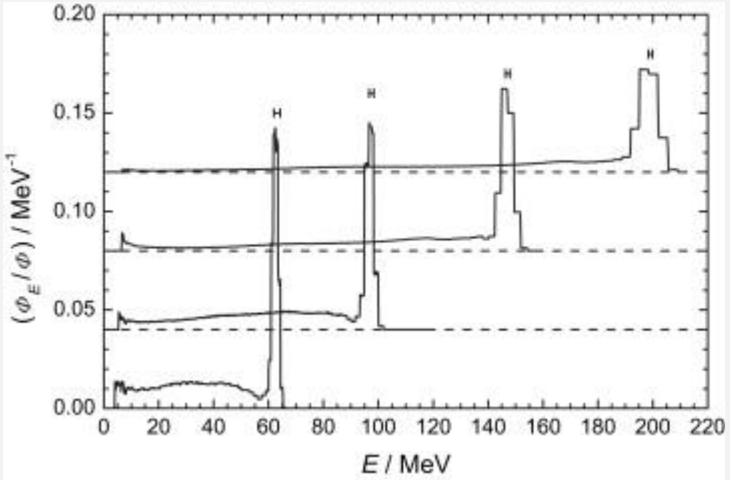
- Dependence on high energy physics models and Monte Carlo code
- Difficulty of finding adequate facilities

iThemba quasi Monoenergetic Neutron Fields

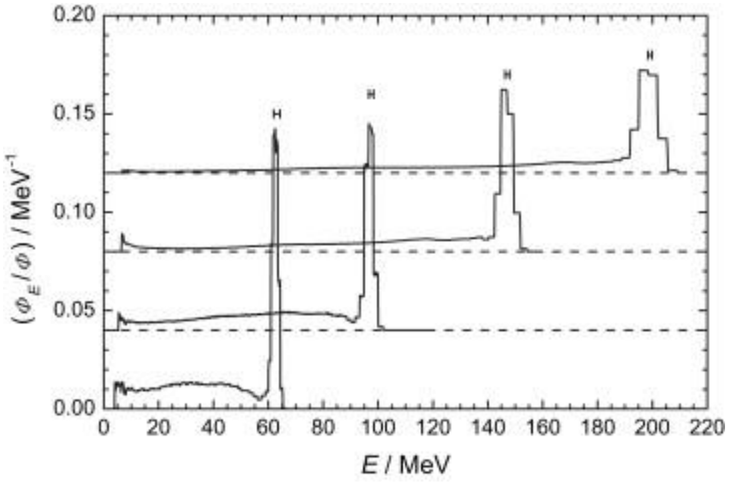


Quasi – monoenergetic neutron fields can be obtained above 20 MeV with $^7Li(p,n)^7Be$ reaction

The generated neutron spectrum is **angular dependent** and shows a **continuous tail of low energy neutrons**



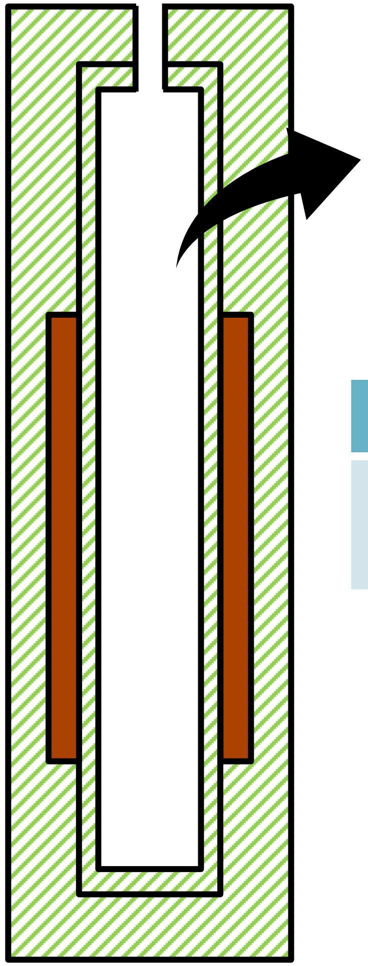
Measurement in quasi Monoergetic Neutron Fields



Low Energy Neutrons Continuum → Measurements at **different angles**

Scattered Component → **Shadow Cone** Technique ?

Simulated Count Rates



The inner volume can host up to 4 detectors

	1 Detector	2 Detectors	3 Detectors	NM64
Cph/kg (approx)	33	61	103	20

Data referred to a simulated spectrum for 5GV cutoff rigidity at sea level

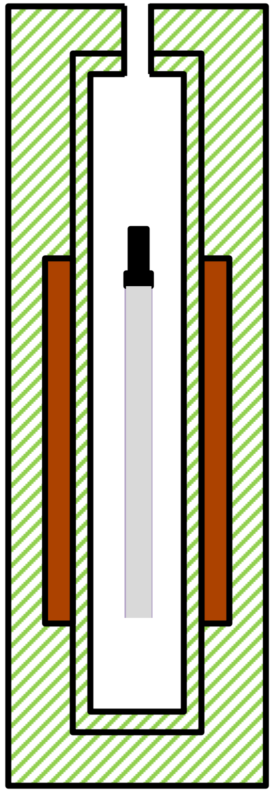
Conclusions

An innovative, high-sensitivity thermal neutron detector can be employed for developing new monitors for secondary cosmic rays

A moderator was designed to enhance sensitivity to high energy neutrons was designed and manufactured

The detector sensitivity to cosmic ray muons and the pulse shape discrimination histogram allows simultaneous detection of different secondary cosmic particles

The validation of the calculated response needs reference fields and calibration procedures for high-energy neutrons



Thank You For Your Attention

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