

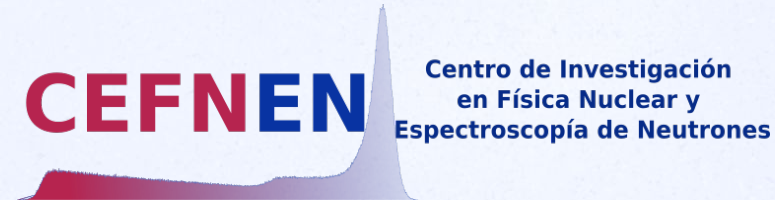


Escuela Latinoamericana
de Rayos cósmicos y sus aplicaciones



Interacción Neutrón-Materia, Espectroscopía de Neutrones Cósmicos

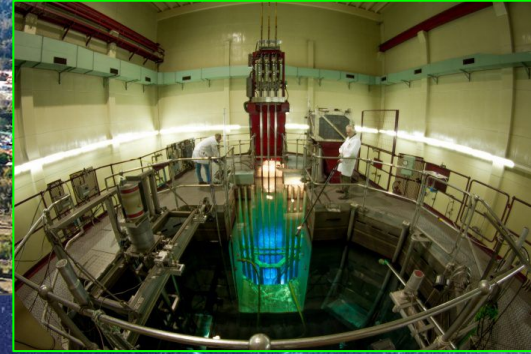
Francisco Molina,
francisco.molina@cchen.cl



Comisión Chilena de Energía Nuclear (CCHEN)

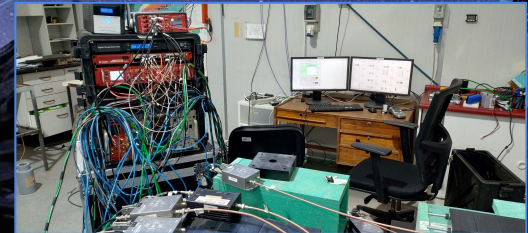


RECH-1



CEFNE

Centro de Investigación
en Física Nuclear y
Espectroscopía de Neutrones



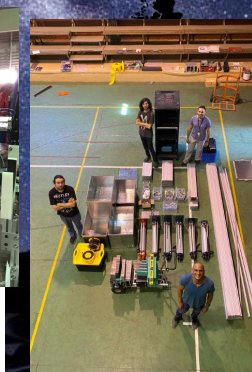
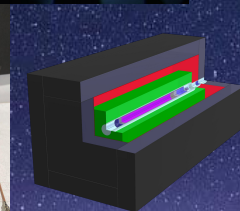
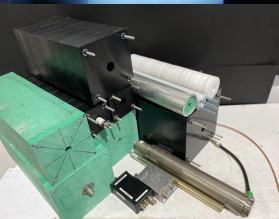
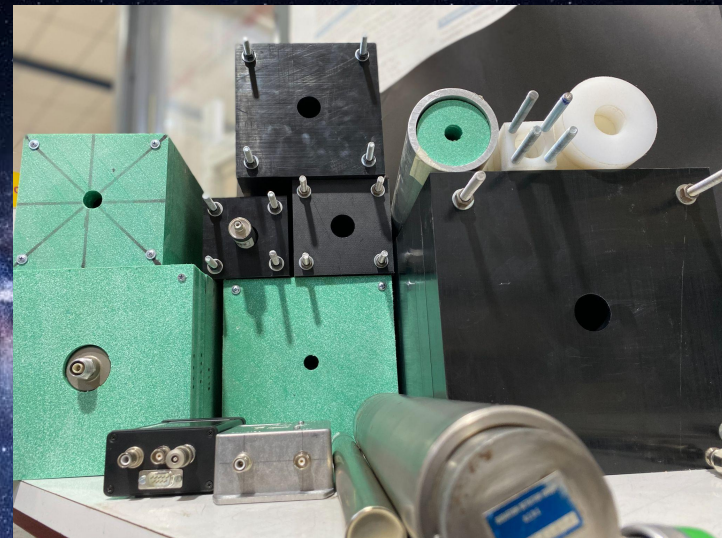
CEFREN



Scattering and Neutrino Detector

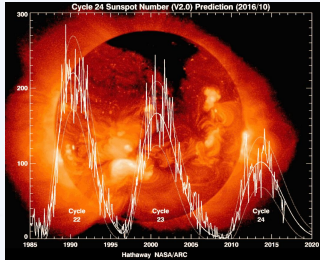
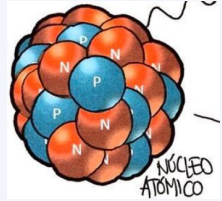


Search for Hidden Particles



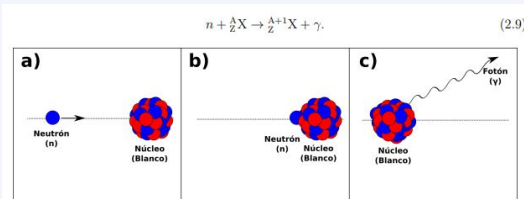
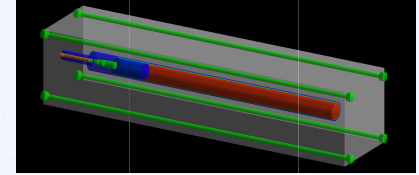
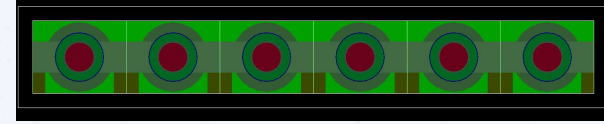
F.Molina (CCHEN-SAPHIR)

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Today's Talk Layout

- 0.- Neutrons
- 1.- Neutron detection interaction with matter
- 2.- Neutron Spectrometers
- 3.- CEFNEN-LIN Neutron Spectrometer history and different uses.
- 4.- Motivation to chase neutrons along Chile
- 5.- The Project Idea, Objectives, Plan, Results, Re-thinking, re-plan, and so on..



0.- Neutrons



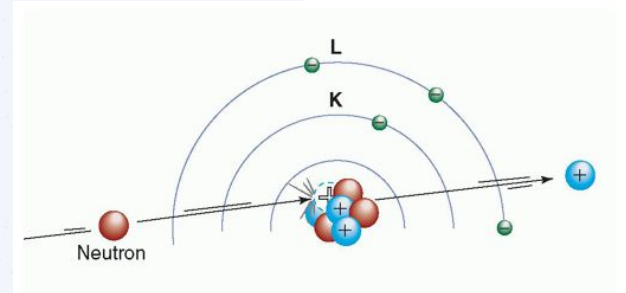
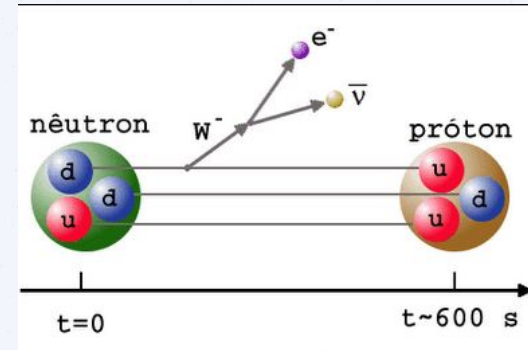
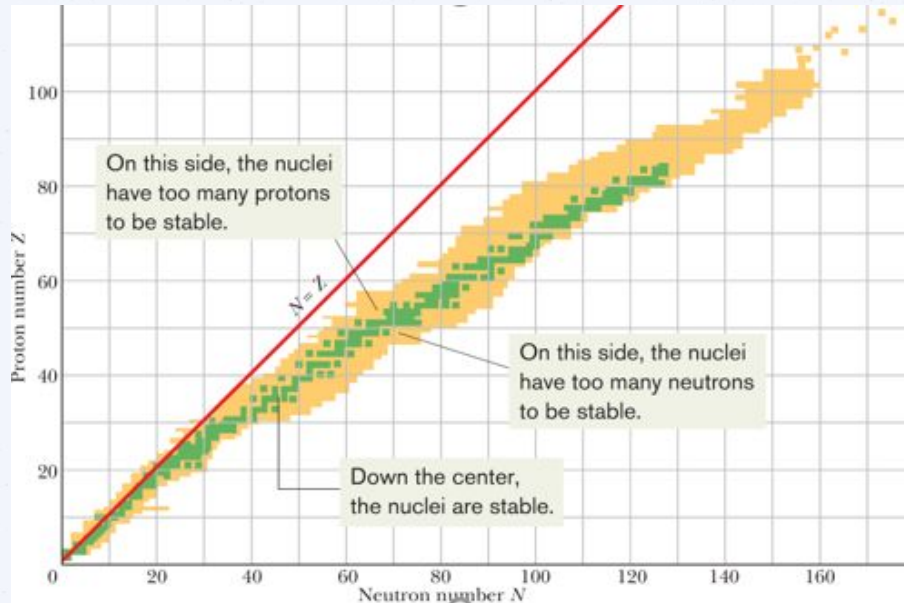
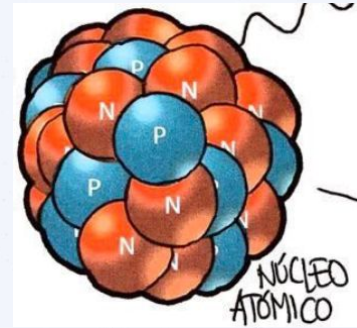
Are **one of the two** components of the atomic nucleus

Have **no electric charge**

Are the responsible of **bringing stability** to the heavier nuclei

If they are unbound **beta decay into protons** within $T_{1/2} = 10.17 \text{ min}$

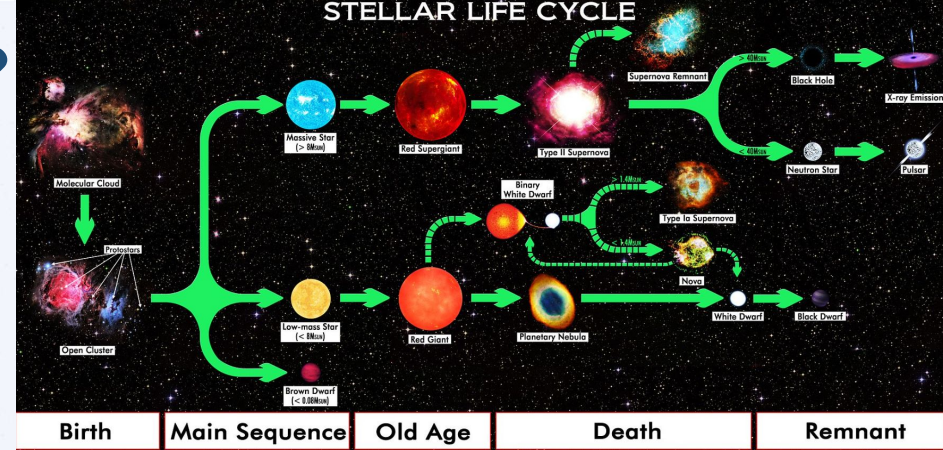
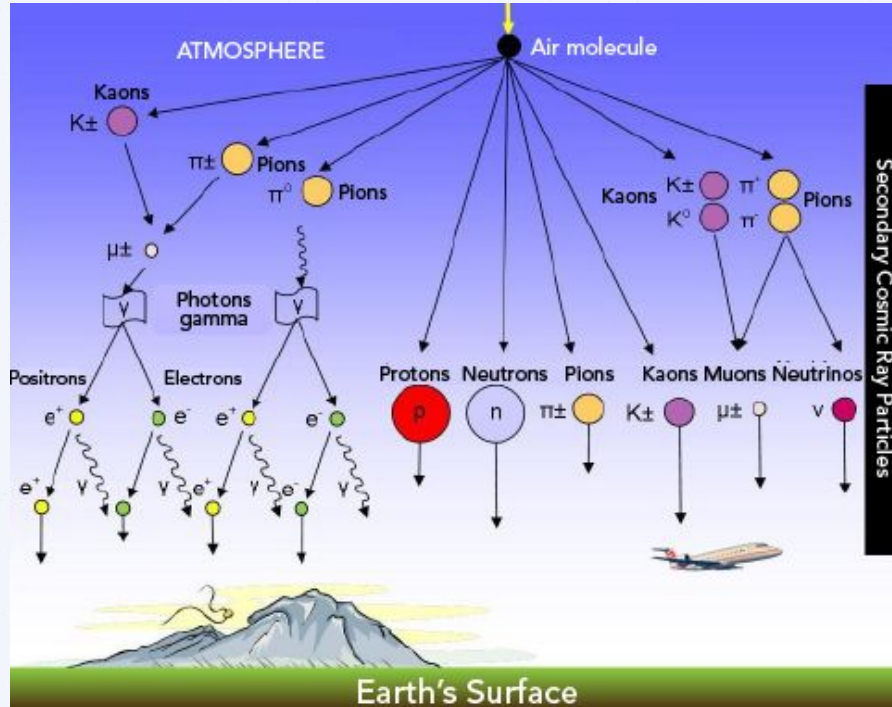
Interact with matter only through **nuclear reactions**



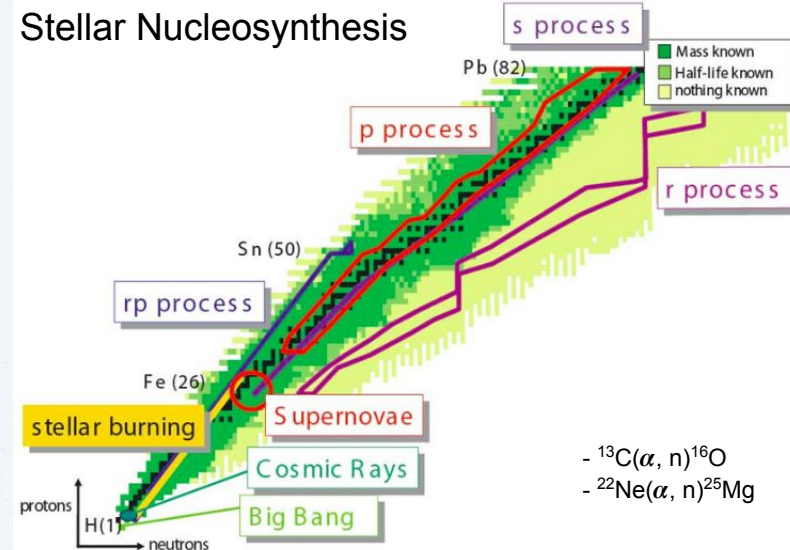
Where we can find neutrons?



In nature



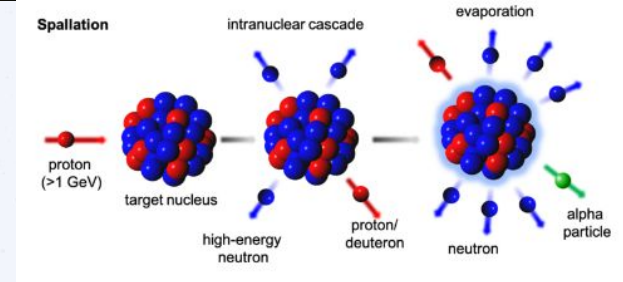
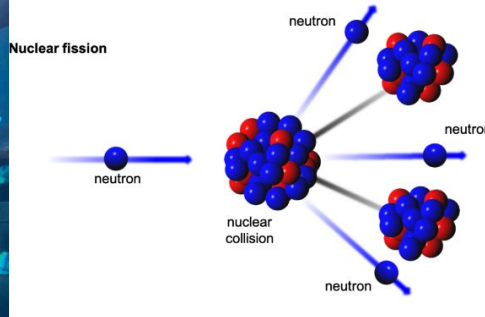
Stellar Nucleosynthesis



Where we can find neutrons?



Human-made sources





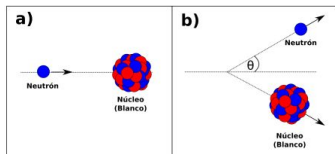
1.- Neutron Detection



Neutrons: how they interact?



Interaction with Matter



Neutron interaction with matter

Scattering

Elastic

(n,n)

Inelastic

(n,n')

Radiative Capture

(n,γ)

Charged particle emission

(n,p)
 (n,α)
 (n,d)
...

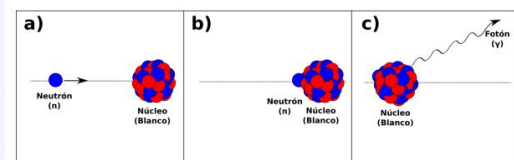
Neutron emission

$(n,2n)$
 $(n,3n)$
...

Fission

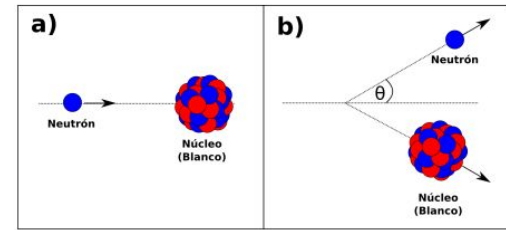
(n,f)

Absorption



Neutrons: how they interact?

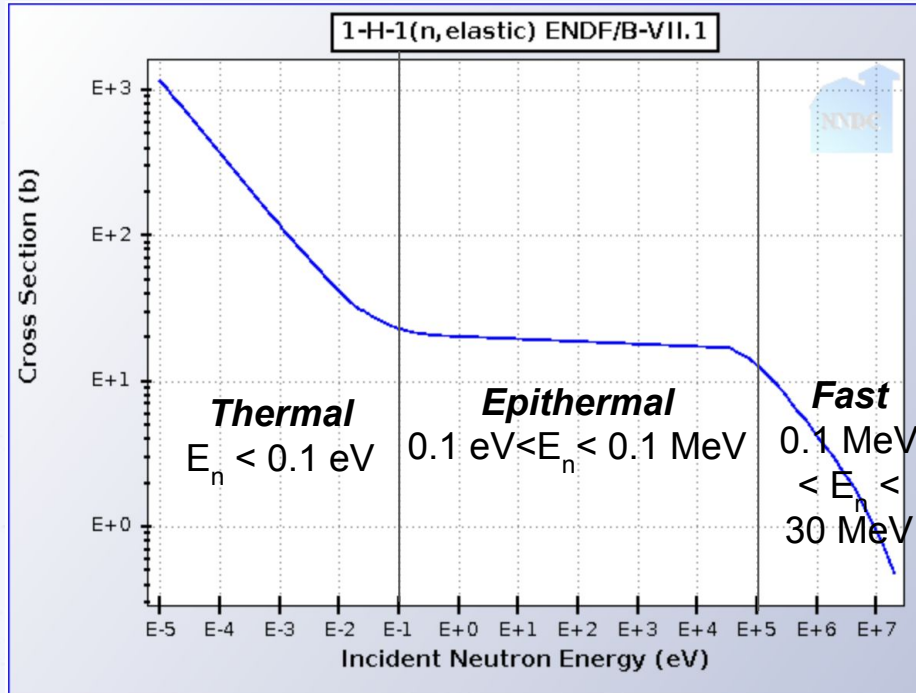

Interaction with Matter and
Cross Sections



Elastic Scattering Cross Section and Energy regions

Neutrons interact through
nuclear reactions:
Reaction Cross Section

The interaction
probability *is given by*
the cross section and
depends on the
incident neutron
energy



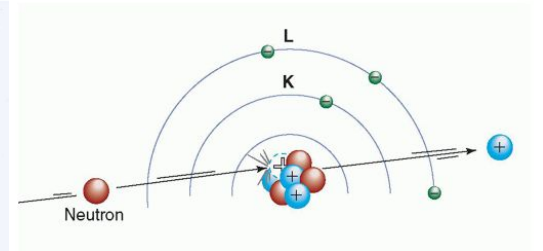
High Energy
 $E_n > 30 \text{ MeV}$



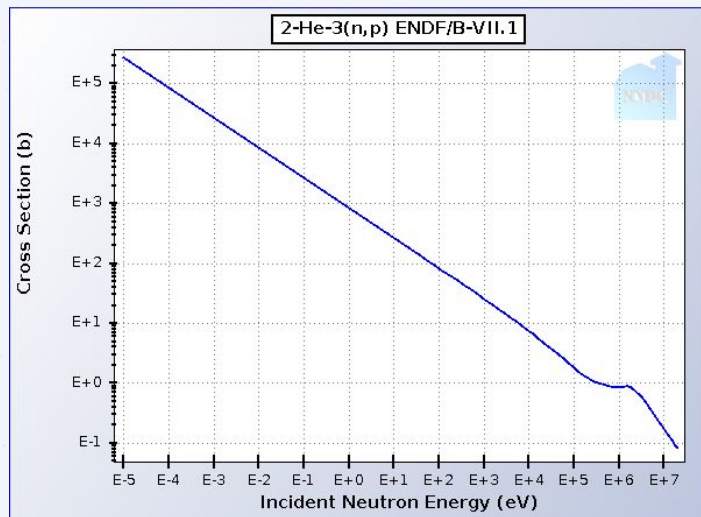
Neutrons: how they interact?


Interaction with Matter and
Cross Sections

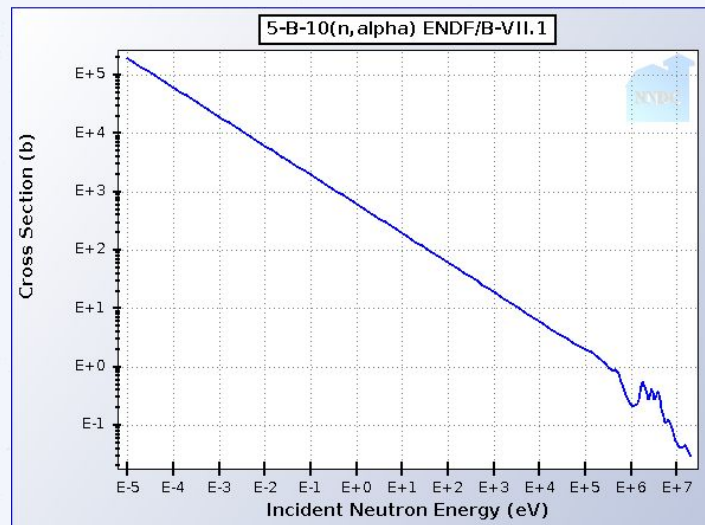
Absorption: Charged particle emission



${}^3\text{He}(n,p)t$ reaction



${}^{10}\text{B}(n,\alpha){}^7\text{Li}$ reaction



<https://www.nndc.bnl.gov/sigma/index.jsp>

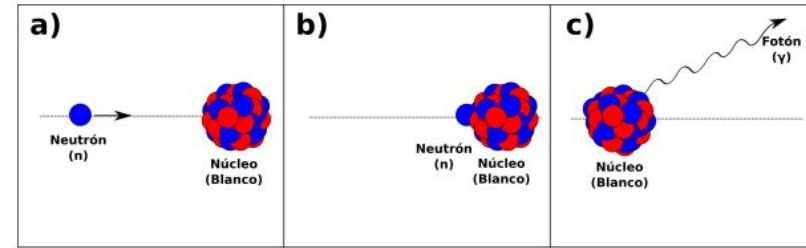


Neutrons: how they interact?

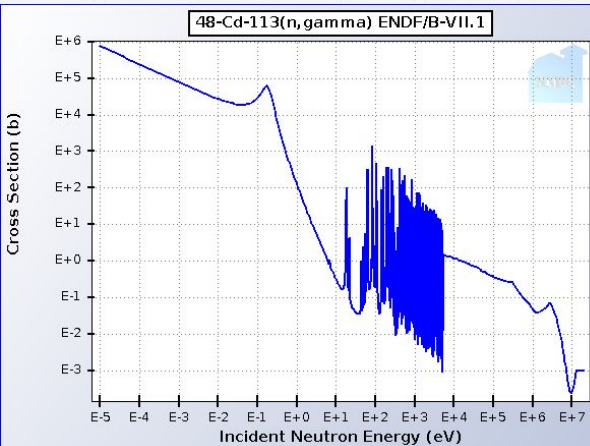
Interaction with Matter and
Cross Sections

Absorption: Radiative Capture

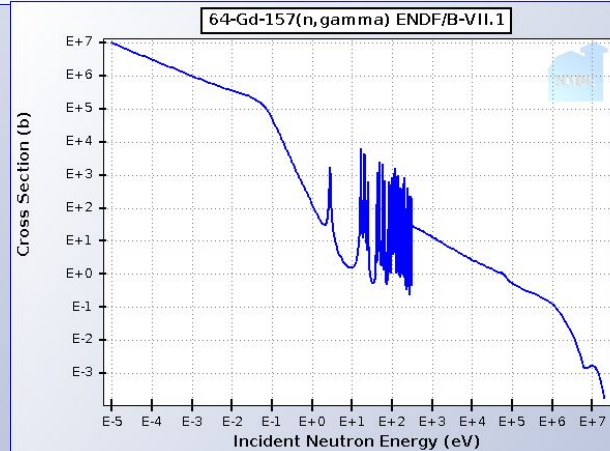
$$n + {}^A_ZX \rightarrow {}^{A+1}_ZX + \gamma. \quad (2.9)$$



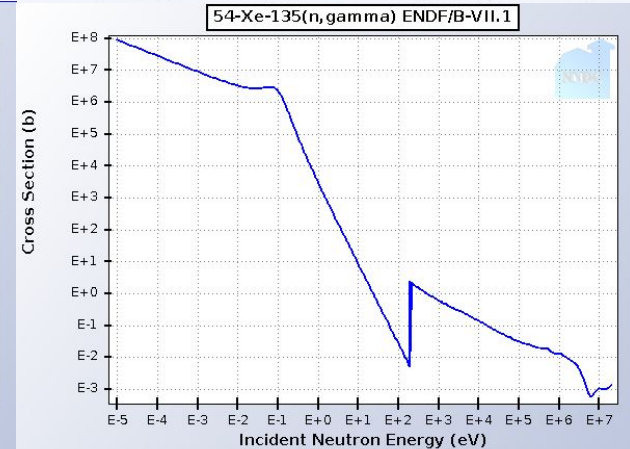
$^{113}\text{Cd}(n,\gamma)^{114}\text{Cd}$ reaction



$^{157}\text{Gd}(n,\gamma)^{158}\text{Gd}$ reaction



$^{135}\text{Xe}(n,\gamma)^{136}\text{Xe}$ reaction



Reactor control rods

Xenon poisoning

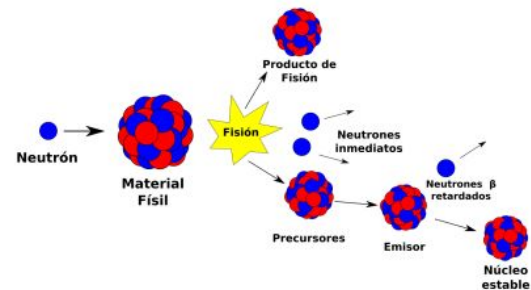
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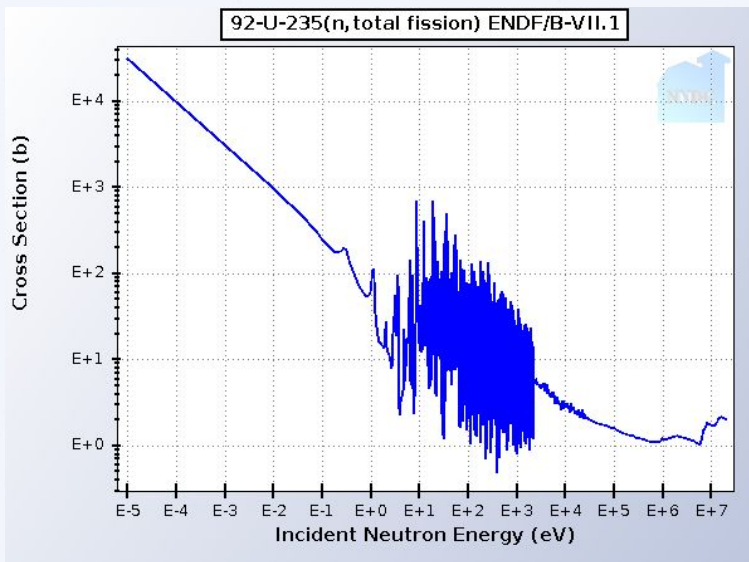
Neutrons: how they interact?

Interaction with Matter and
Cross Sections

Induced Fission

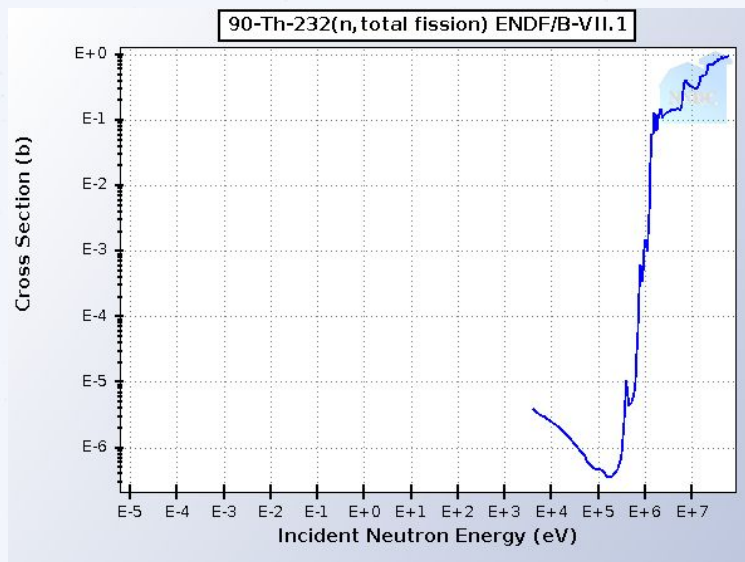


$^{235}\text{U}(n,f)$ reaction



Thermal reactor fuel

$^{232}\text{Th}(n,f)$ reaction



Fast reactor fuel

<https://www.nndc.bnl.gov/sigma/index.jsp>

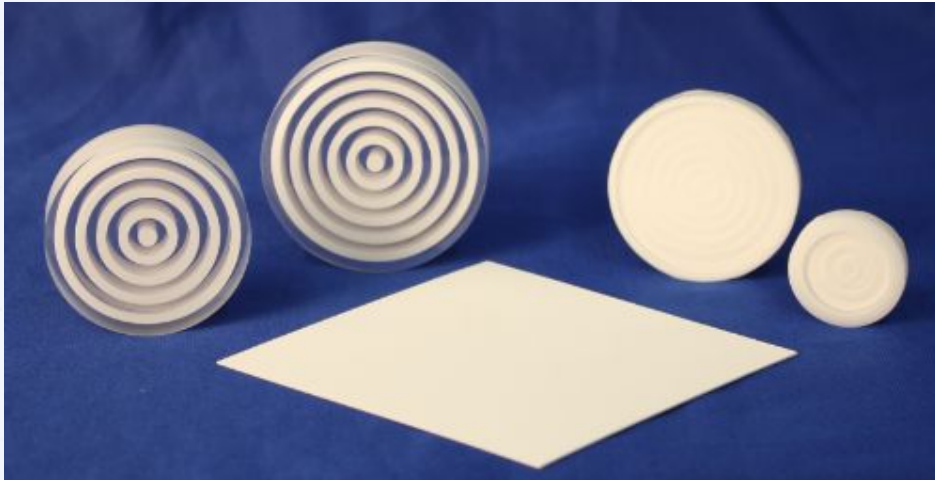
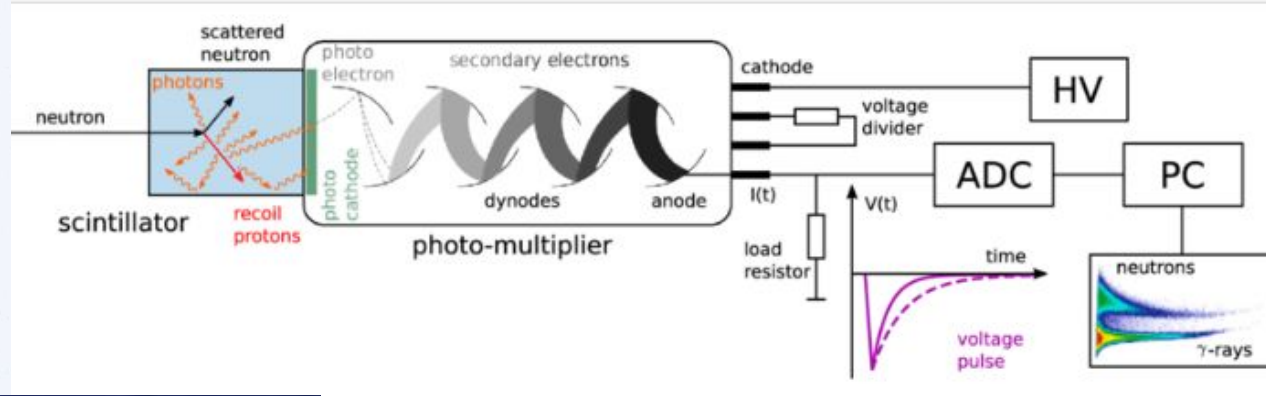


Neutrons: how to detect them?



Scintillator detector

Neutrons can transfer energy by scattering to hydrogen rich materials (protons) which can excite scintillation in molecules



Signal width $\sim$ ns
Neutron/gamma **identification**
and separation by Pulse Shape
analysis



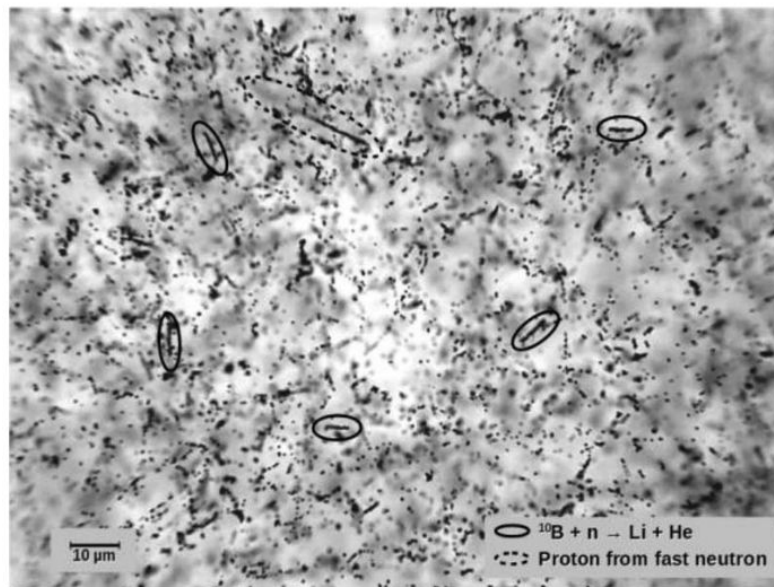
Neutrons: how to detect them?



Nuclear Emulsions

Nuclear emulsions consist mainly of gelatin and silver halide. Gelatin contains **a significant amount of hydrogen** (protons), which can be used for fast neutron detection by scattering. It is possible to add B-10 in the emulsion for thermal neutron detection.

Needs to be processed (developed) and read by microscope (time consuming) or by scanning systems + pattern recognition algorithms + GPU parallel computing. Tracks can be seen



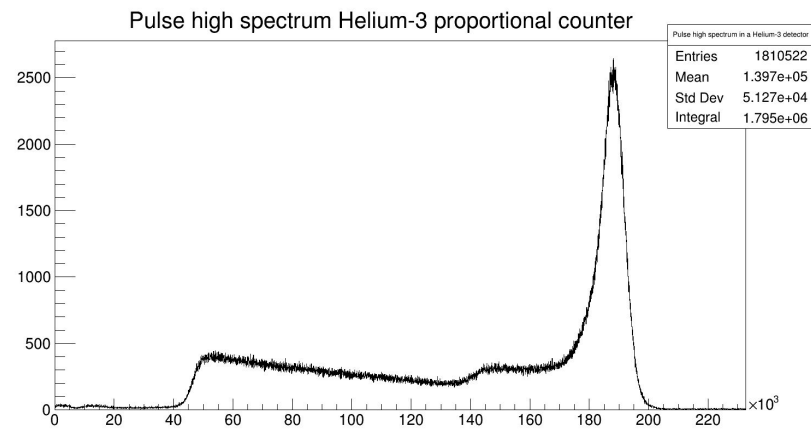
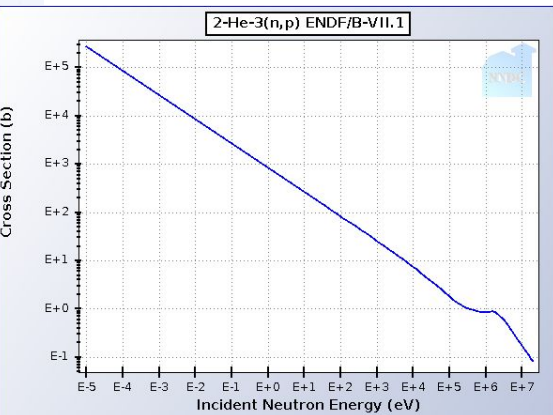
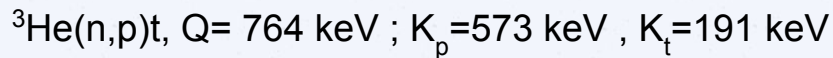
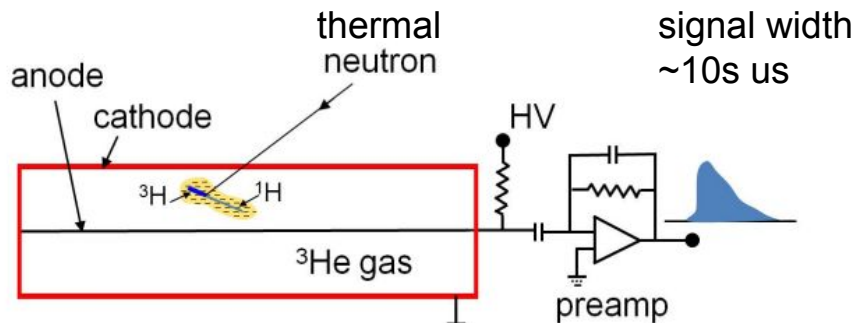
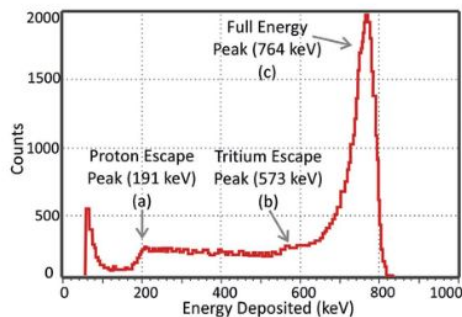
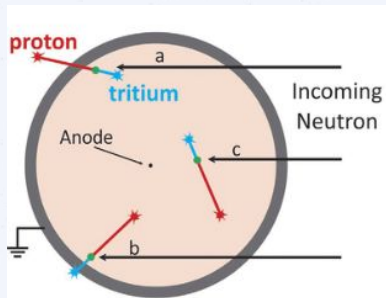
M. Lužová, et al. *Investigation of Nuclear Emulsions in Terms of Neutron Dosimetry*, Radiation Protection Dosimetry 186, 229-234 (2019)



Neutrons: how to detect them?

Proportional counters

BF_3 and Helium-3 proportional counters





2.- Neutron Spectroscopy



Obtaining Neutron Energy



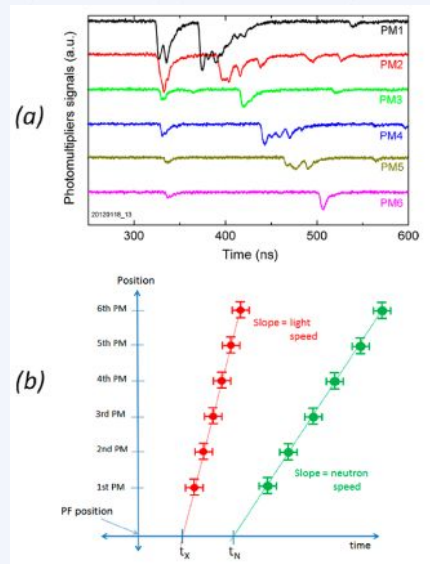
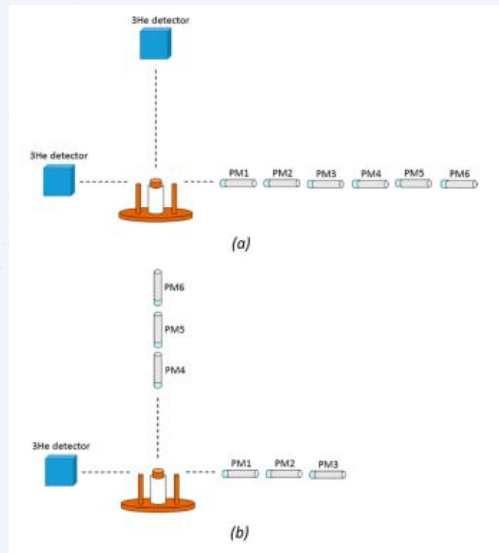
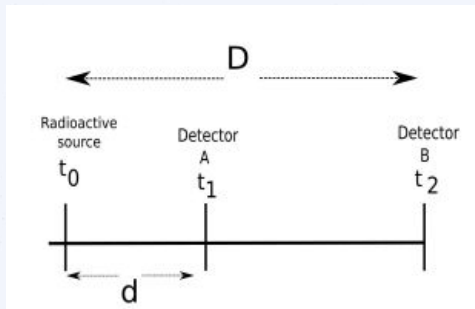
Time of Flight (ToF)

One of the most direct way to measure neutron energy is by measuring time differences between **neutron emission time** and **the neutron detection time**.

A. Simple setup and analysis (Plastic Scintillator + Oscilloscope)

D. Determination of $t=0$.

D. Energy resolution depends on the distance to source



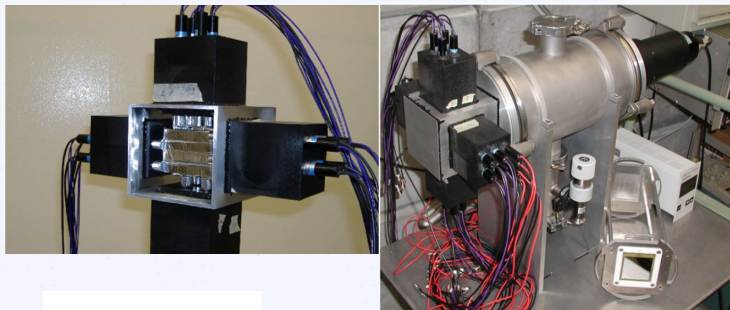
J. Moreno et al. Neutron energy distribution and temporal correlations with hard x-ray emission from a hundreds of joules plasma focus device. Plasma Phys. Control. Fusion **57** (2015) 035008



Obtaining Neutron Energy



Proton Recoil Telescope

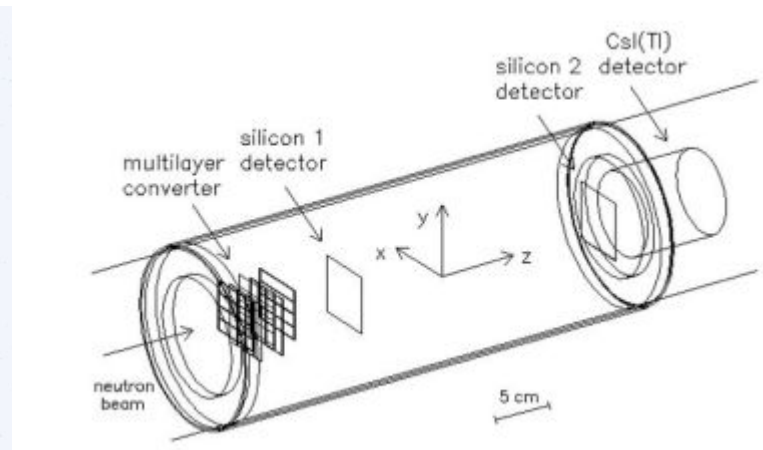
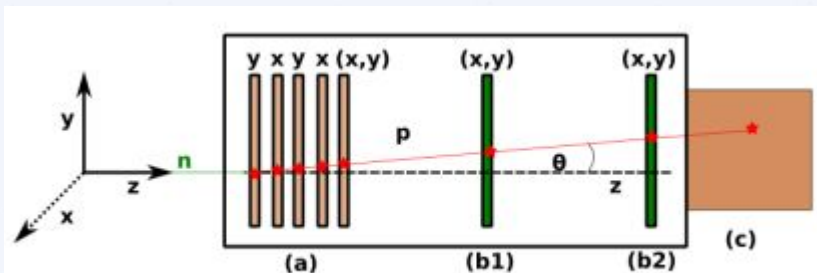
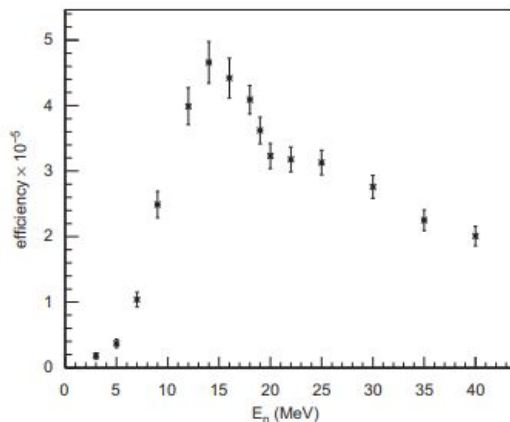


$$E_n = \frac{E_p}{\cos^2(\theta)}$$

A: Good for fast neutrons

D: Directional source

D: Not sensitive to thermal-epithermal



A. Donzella, et al. A proton recoil telescope for neutron spectroscopy. Nuclear Instruments and Methods in Physics Research A, 613:58–64, 2010

<https://doi.org/10.1016/j.nima.2009.10.135>



Obtaining Neutron Energy



Thin foil activation

Activation of several thin foils (~100 um) of pure materials (99.9%) immersed in intense neutron fields such reactor core.

A.- Point-like Flux measurements in intense fields (paper hole punch size)

D. Several non simultaneous measurements required.

D. High resolution gamma spectroscopy and unfolding algorithms

$$A_i^\infty = \int_0^\infty \sigma_i(E) \Phi(E) dE$$

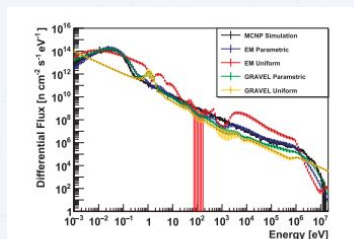
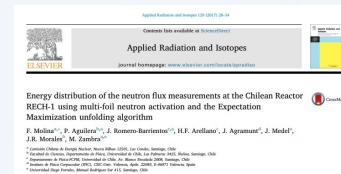
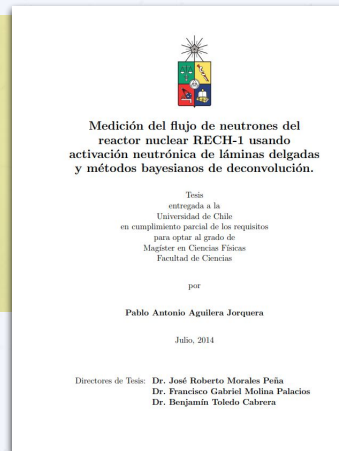
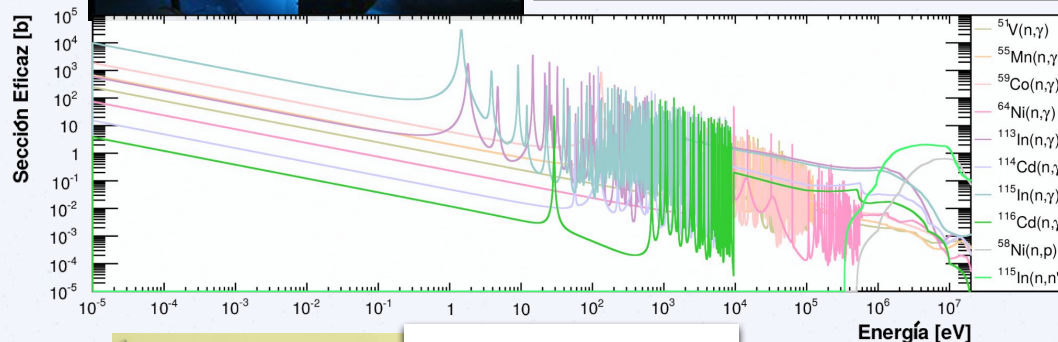
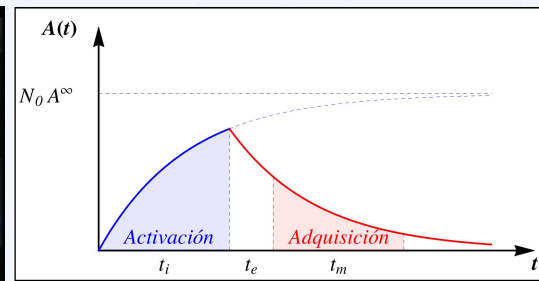


Fig. 7. Differential neutron flux as a function of the neutron energy, using the ENDF/B.VII.1 data base. Black curve is refer to MCNP simulation. Unfolding results (colored symbols) are not normalized. Uncertainty values were calculated for each energy bin group by Monte Carlo method (Cvachovec and Cvachovec). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



Obtaining Neutron Energy



Bonner Spheres

Since the 60's are the gold standard for environmental neutron flux measurements.

A. Wide range from meV - 1 GeV.
Thermal neutron detector (LiI(Eu) / ^3He) + moderator material (HDPE).

D. Needs a deconvolution algorithm to unfold the neutron flux from each sphere counting rate.

D. Needs knowledge on the neutron response function of the i-th sphere R_i

$$n_i = \int_0^\infty R_i(E) \phi(E) dE$$

CAEN SyS
Systems and Spectroscopy Solutions

NEUTRON SPECTROMETER
BONNER SPHERE

MAIN FEATURES

- Detectors: two proportional counters
- Moderators: 100 polyethylene spheres, from 8" to 12"
- Efficient connection between control box and PC
- User-friendly operational software
- Adjustable measuring parameters
- Data storage and graphical display
- Expertise in test data (JCS files)
- Energy range extension up to 5 GeV (optional)
- Special electronics for use in pulsed fields (optional)

DESCRIPTION

The Bonner sphere spectrometer consists in an array of thermal neutron detectors. The proportional counters, each housed in a spherical polyethylene moderator of different dimensions. Through the comparison between the neutron detected by each sphere, it is possible to determine the incident neutron energies. These data are processed by an unfolding code, which provides the neutron spectrum.

A special set is available upon request to extend the energy range up to 5 GeV. Each sphere is connected to a specifically designed pre-amplification and adjustment module (PREAMP-ACT) that provides a TTL pulse output completely compatible with the connected digital counting system.

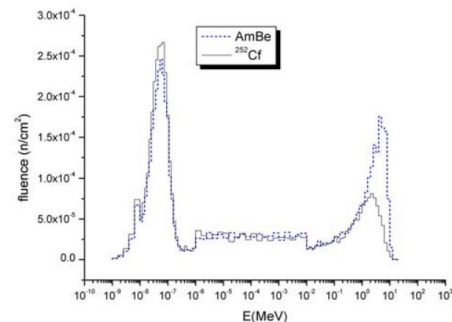
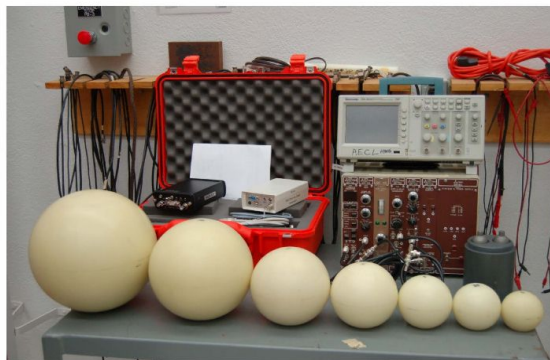
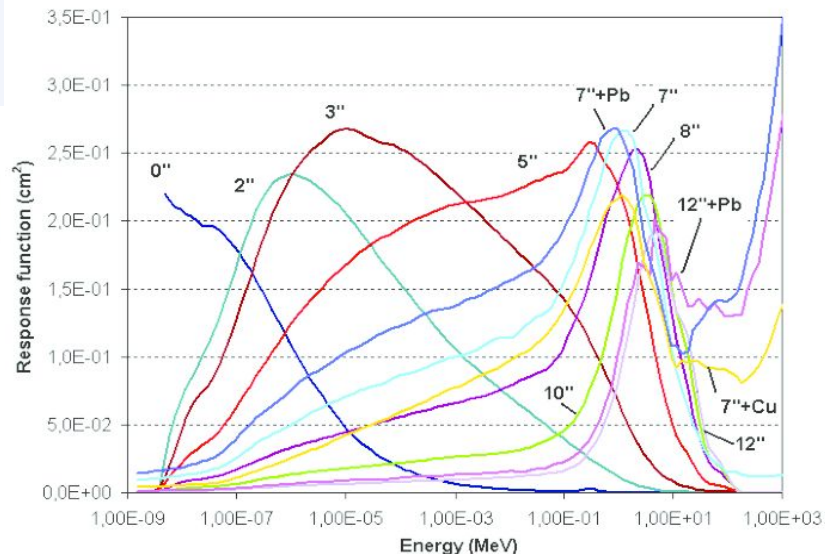
The central acquisition box is based on a 6 CH TC-16 speed DSD module, a real-time processor and a 16-bit digital field-programmable gate array. The central box is connected to a PC through an Ethernet cable, and is programmed to continuously acquire the counts coming from the detectors, also when the acquisition PC is off.



A user-friendly dedicated acquisition software is installed on the PC; it allows to start and stop the measurements as defined by the set parameters, and to store them in tabulated text files. The software allows also to modify the parameters and to visualize the read data.

The status indicator displayed in the main panel shows the following main information for each channel (legend):

- Detector name (adjustable as a parameter)
- Activation (adjustable as a parameter, i.e. green → activated)
- Counts: shows the integral counts value during the measurement, updated every second
- Average CPU: shows the average CPU during the measurement, updated every second





CEF**NEN**

Centro de Investigación
en Física Nuclear y
Espectroscopía de Neutrones

3.- CEFNEN-LIN Neutron Spectrometer



The CEFNEN-LIN Neutron Spectrometer



First steps

In 2017 with a FONDECYT project we start the design, simulation and construction of a Bonner Sphere based neutron spectrometer.

- Wide range (meV-GeV),
- able to measure continuous neutron sources (neutron beams, neutron standard sources) and pulsed neutrons



Based on IFIC spectrometer used at Canfranc Underground Laboratory. *D. Jordan et al Astroparticle Physics 42 (2013)1-6*

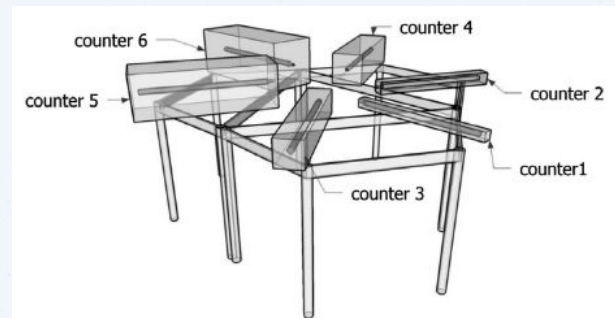
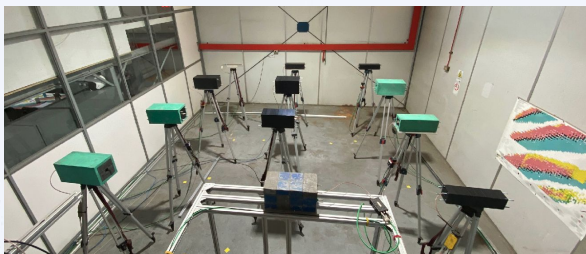


Fig. 1. View of the arrangement of the six detector modules: ^3He tube inside a polyethylene block.

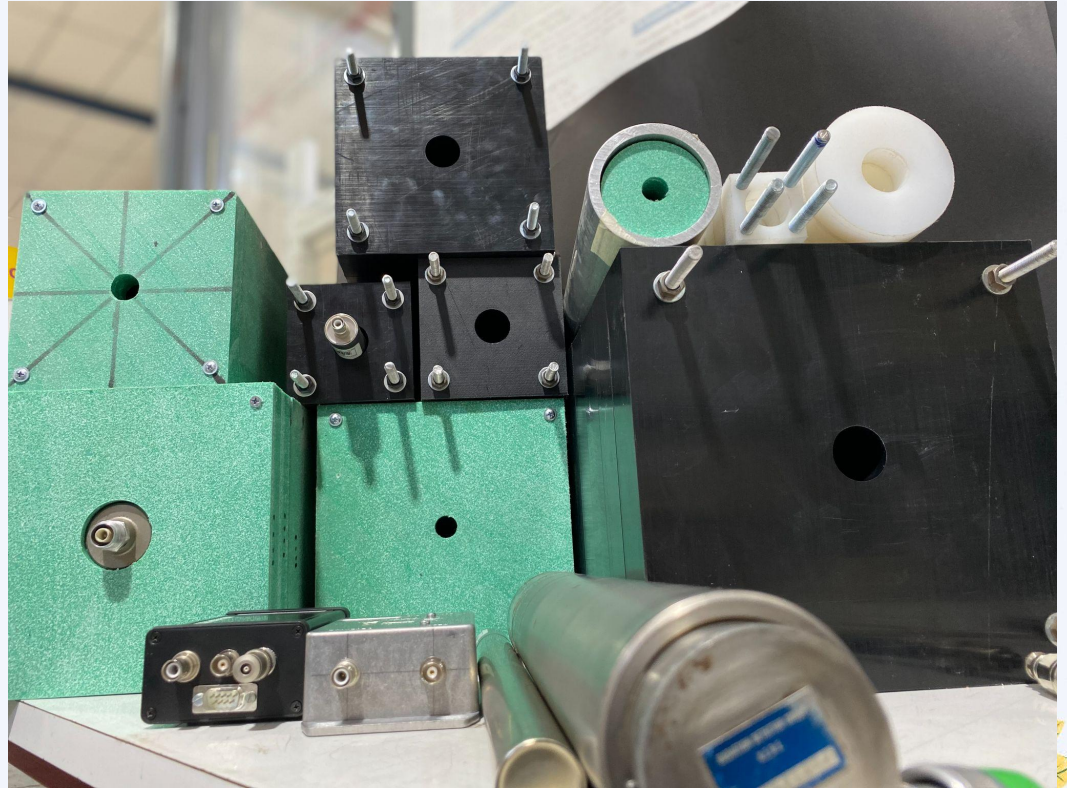
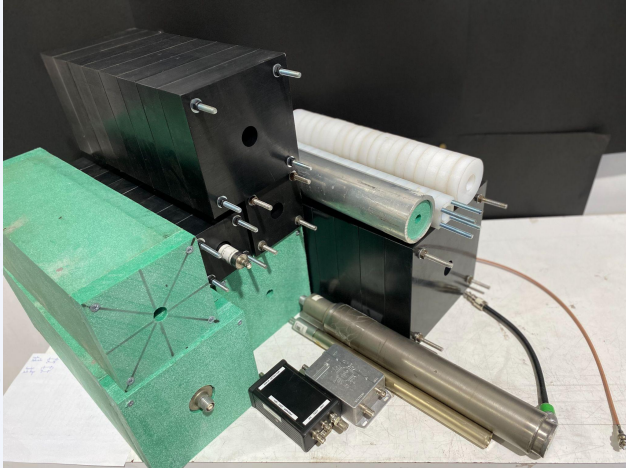


The CEFNEN-LIN Neutron Spectrometer

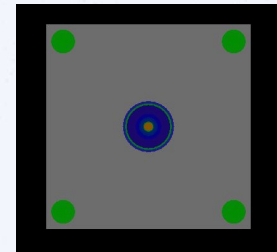
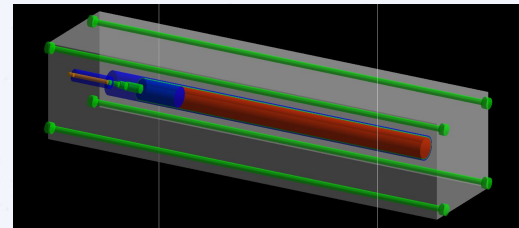
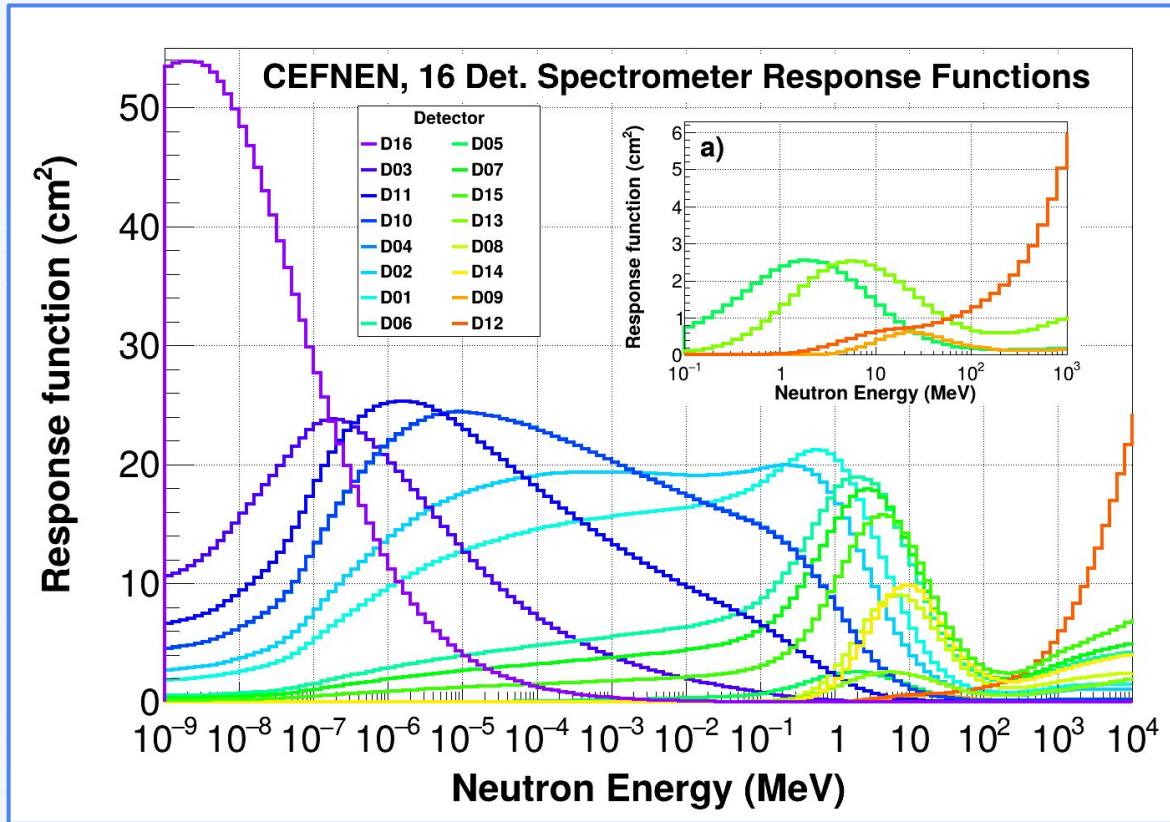


CEFNEEN Neutron Spectrometer

- Response functions $R(E)$ calculated using GEANT4 and MCNP
- Materials: HDPE, BHDPE (5%), Aluminum, Cadmium, Lead, Graphite
- Proportional counters ^3He #12 1" (4 atm), #4 2.5" (20 atm).



The CEFNEN-LIN Neutron Spectrometer



The CEFNEN-LIN Neutron Spectrometer



CEFNEEN Neutron Spectrometer

n_i : Experimental

$R_i(\mathbf{E})$: MC Simulations

$\phi(\mathbf{E})$: Unfolding Algorithms

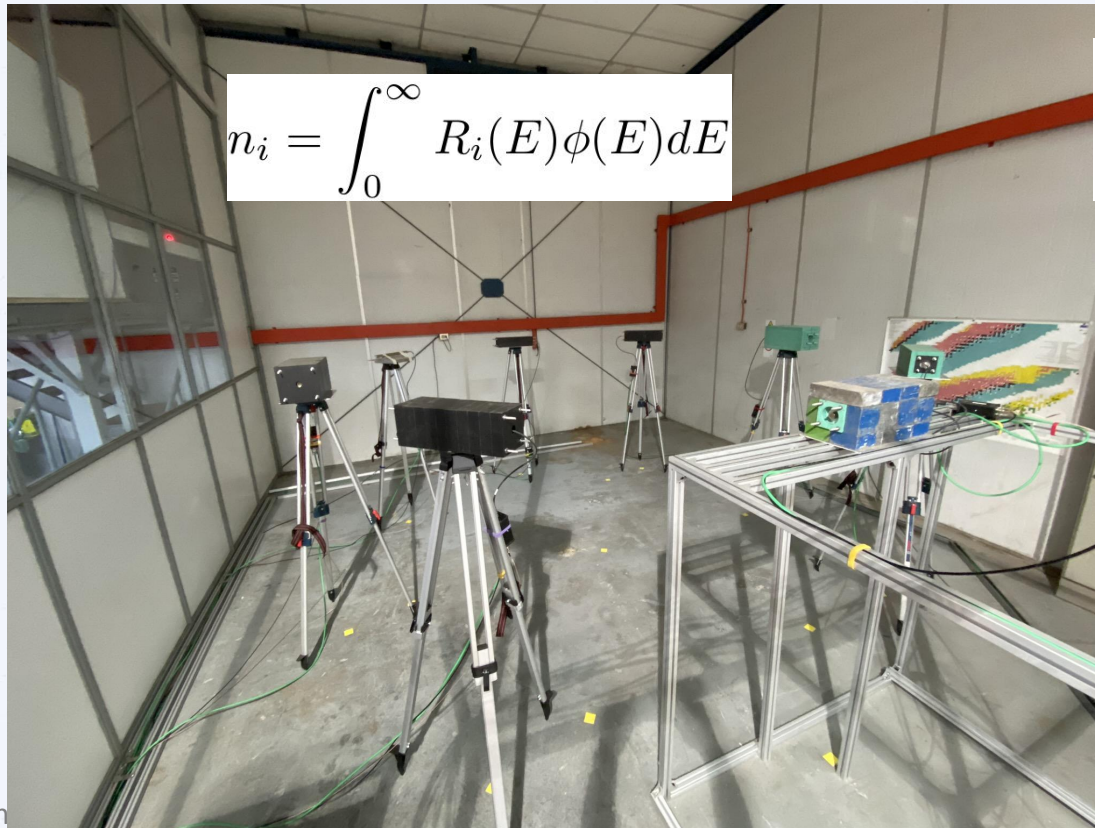
$$n_i = \int_0^{\infty} R_i(E) \phi(E) dE$$

$$n_i = \sum_j^N R_{ij} \phi_j \Delta E_j$$

$$\vec{n} = \mathbb{R} \vec{\Phi}$$

$$\vec{\Phi} = \mathbb{R}^{-1} \vec{n}$$

used for different
neutron fields



Algunos usos del espectrómetro CEFREN



Caso 1: Espectro de neutrones en haz de reactor RECH-1

Caracterización del espectro de un haz de neutrones

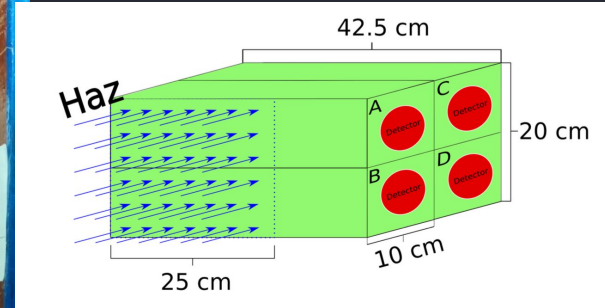
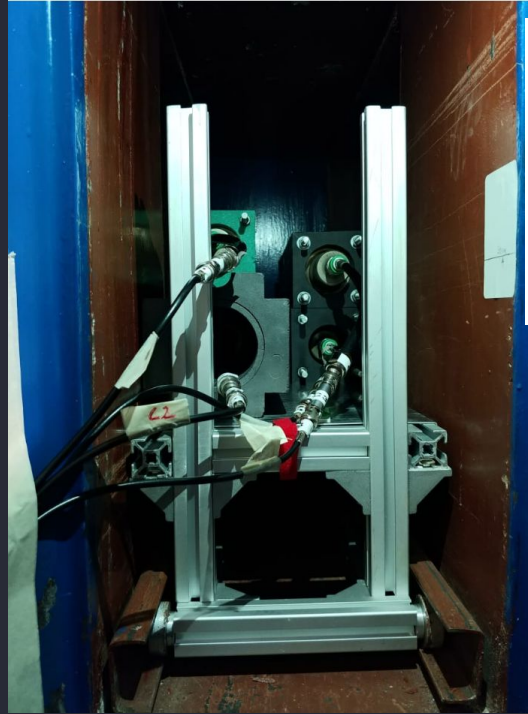
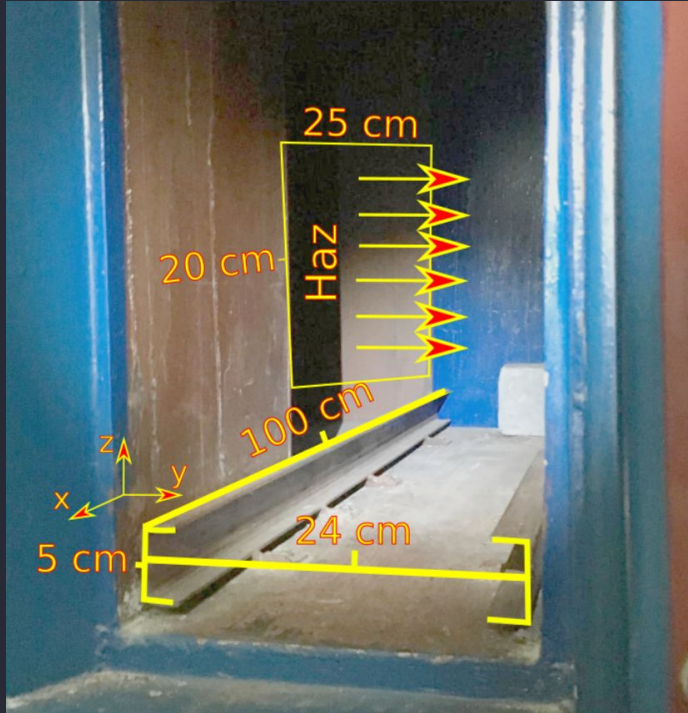
Problema: caracterización de haz de neutrones mediante espectroscopía de neutrones $\Phi(E)$.

Observable: tasas de conteo.

$$N_i = \sum_j \varepsilon_{ij}(E) \Phi_j$$

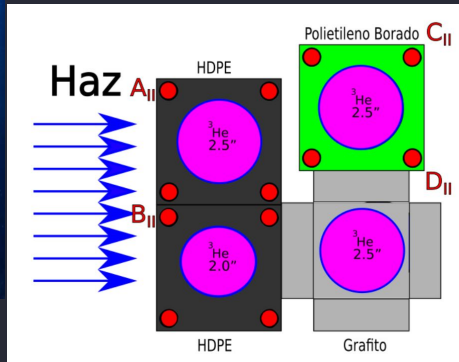
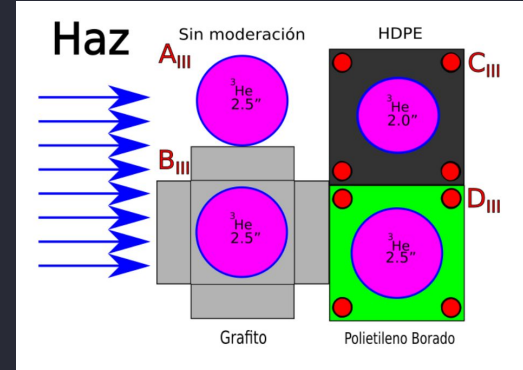
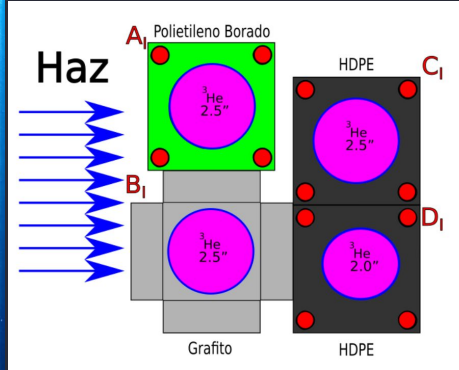
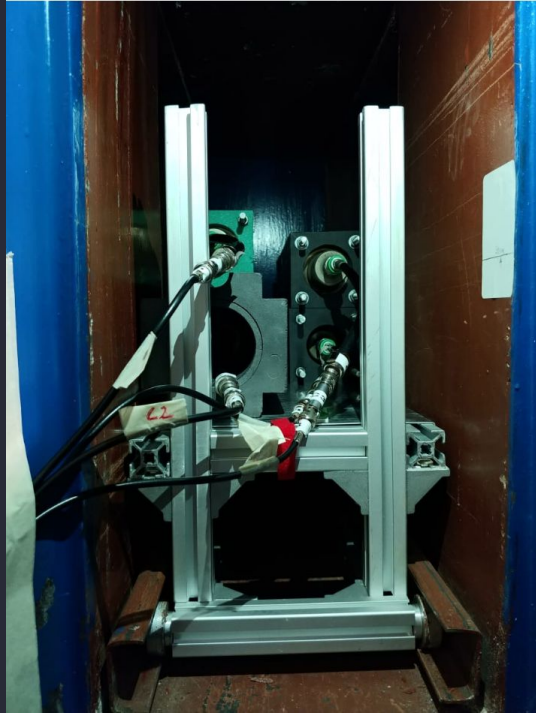


Setup experimental



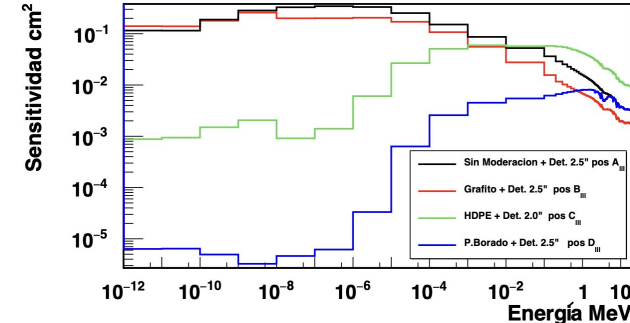
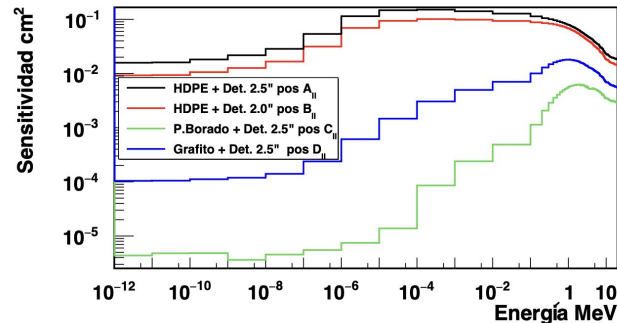
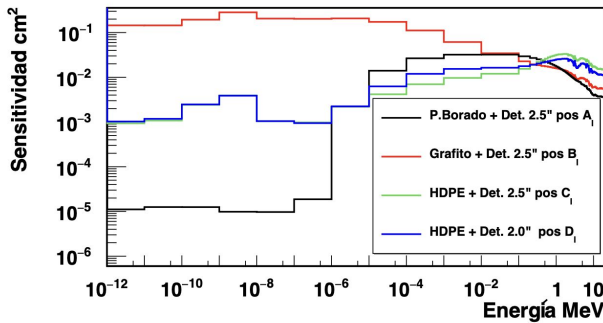
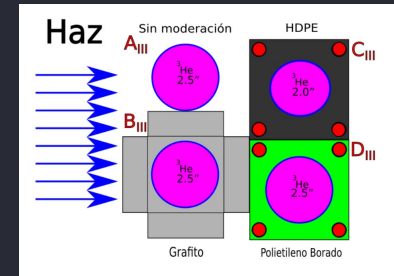
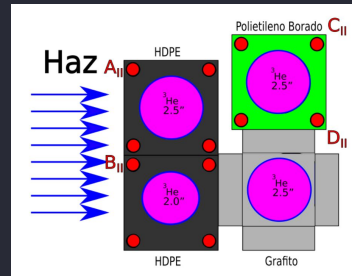
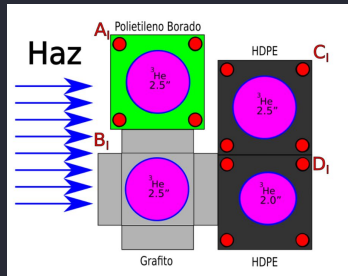
Clave: Eficiencia de haz calculada debe incluir a detectores vecinos.

Setup experimental

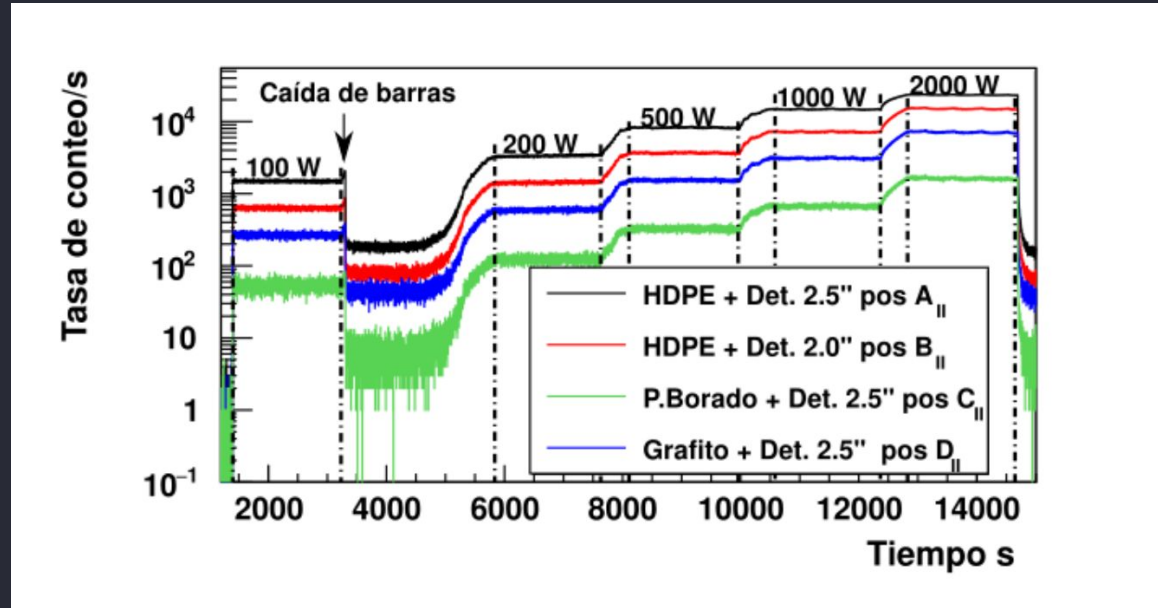


3 configuraciones, 12
sistemas de detección
distintos

Respuesta a haz de neutrones

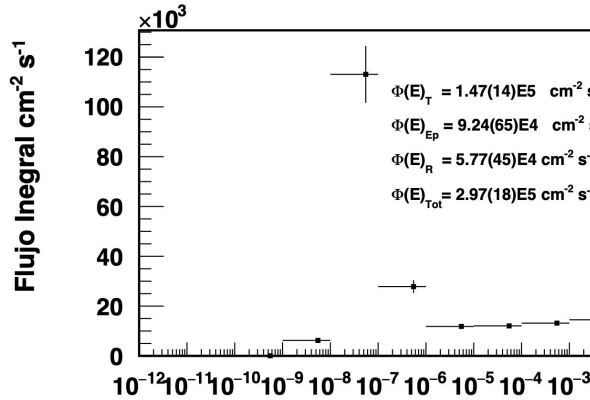


Tasa de conteo por potencia de operación.



Tasa de conteo vs tiempo, Haz N°1, cuatro configuraciones BSS , potencia 100 W → 2000 W.
Andrés Riuz Tesis Magister Ciencias Físicas, U. Chile (2023).

Flujo de neutrones por potencia de operación.



Detección de flujo continuo de neutrones a energías en el rango de micro a mega electronvoltio

Tesis
entregada a la
Universidad de Chile
en cumplimiento parcial de los requisitos
para optar al grado de
Magíster en Ciencias con mención en Física
Facultad de Ciencias

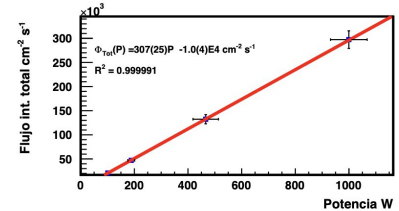
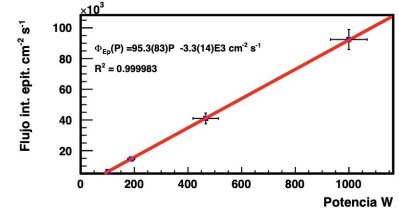
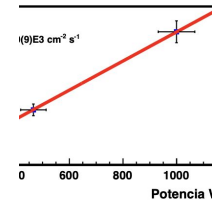
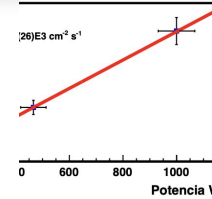
por

Andrés Emilio Ruiz Flores

Octubre, 2021

Director de Tesis: Prof. Hugo Francisco Arellano Sepúlveda

Co-Director de Tesis: Dr. Francisco Gabriel Molina Palacios



Consecuencia: Medidas de flujo en rango de operación lineal extrapoladas a potencia de operación 5 MW.

	Flujo Integral térmico [m ⁻² s ⁻¹]	Flujo Integral rápido [cm ⁻² s ⁻¹]	Flujo Integral total [cm ⁻² s ⁻¹]
999(68)	1.5(1) × 10 ⁵	9.2(7) × 10 ⁴	3.0(2) × 10 ⁵
5E6	7.6(23) × 10 ⁸	4.8(14) × 10 ⁸	1.5(4) × 10 ⁹



Caso 2: Neutrones pulsados en dispositivos plasma foco (2017-2020)

FONDECYT Regular 1171467 (2017-2020); Tesis Magister Selene Parra, U. Chile.

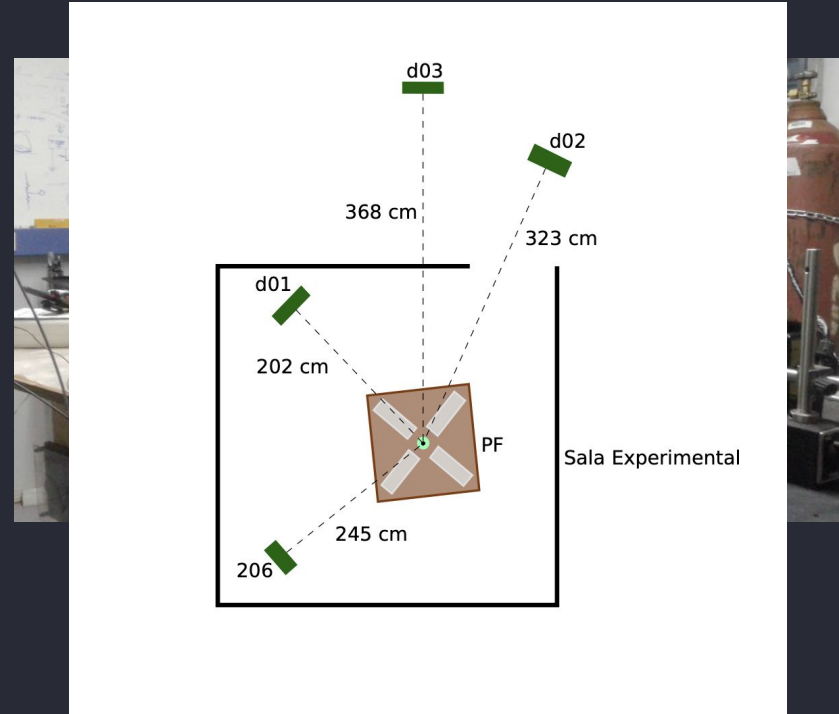
Caracterización la emisión de neutrones pulso por pulso

El Problema: estudiar emisión de neutrones pulsados en reacciones de fusión $D+D \rightarrow {}^3\text{He} + n$ (2.45 MeV) en plasma focus. $\Delta t \sim 10\text{'s} - 100\text{'s ns}$.

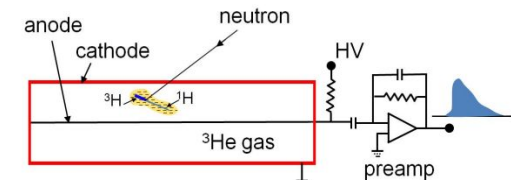
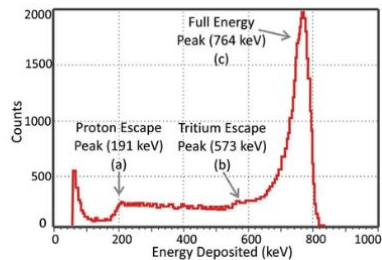
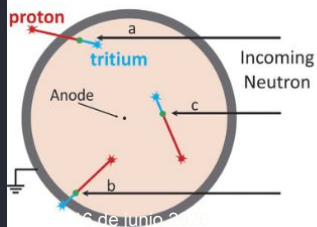
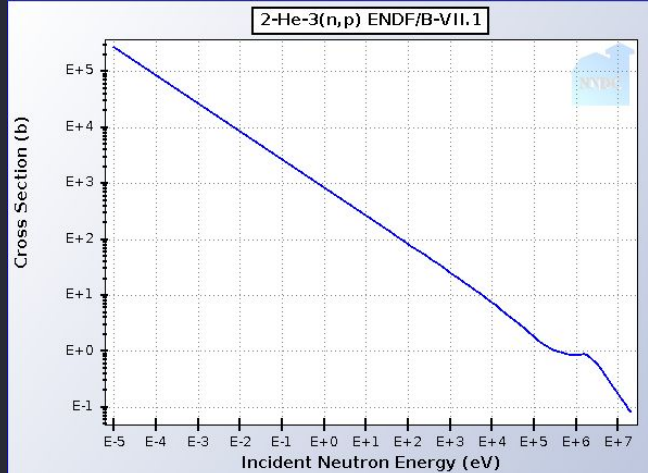
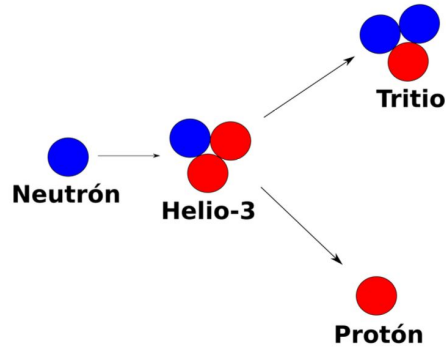
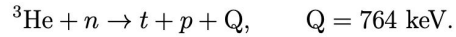
El observable: Señal apilada de neutrones detectados por pulso.

$$N_i = \sum_j R_{ij} Y_j, \quad R_{ij} = \varepsilon_{ij}(E, \Omega)$$

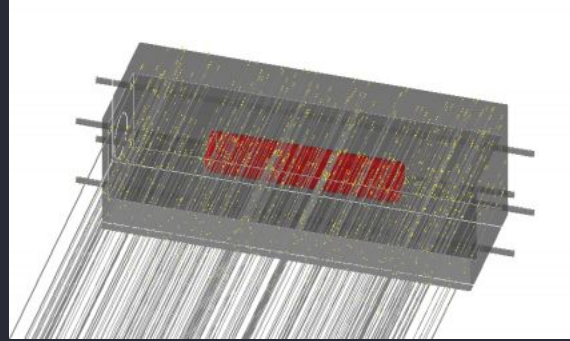
La Respuesta: Eficiencia absoluta de neutrones directos



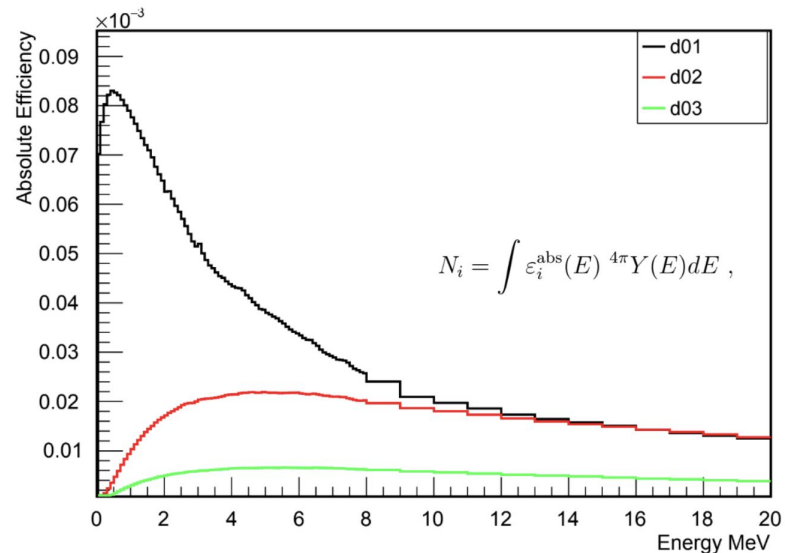
Detección de neutrones con contadores proporcionales de ^3He



Eficiencia absoluta



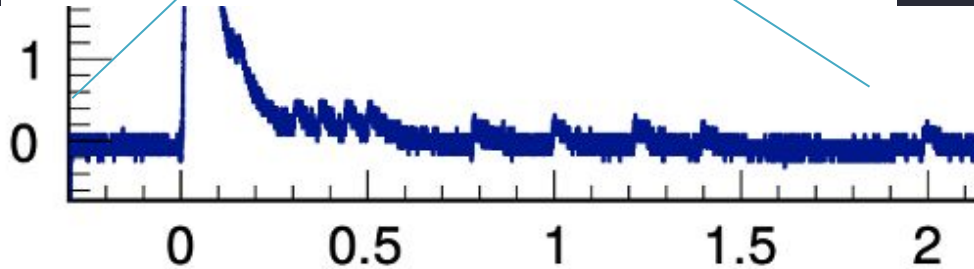
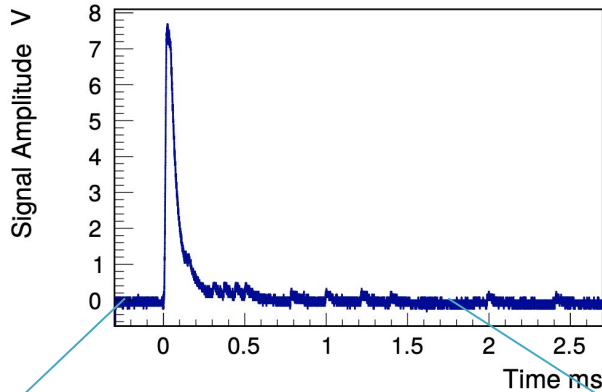
Detector	Moderador	Prop.
d01	12 cm HDPE	2" 3He, 20 atm
d02	10 cm HDPE + 5 cm 5%B HDPE	2" 3He, 20 atm
d03	10 cm 5%B HDPE	2.5" 3He, 20 atm



Respuesta: Simulaciones Monte Carlo con GEANT 4

- 10^6 neutrones por región de energía
- $0 < E_n < 8$ MeV binning 100 keV
- $8 < E_n < 20$ MeV binning 1 MeV

Neutrones detectados por pulso

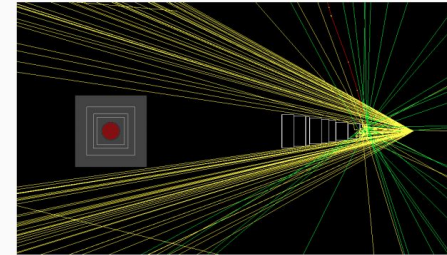


El detector no solo cuenta neutrones directos, sino que también neutrones de scattering con los materiales de la sala.

La clave: uso de conos de sombra, para detección de neutrones indirectos

$$d_i = d_{\text{directos}} + \underbrace{d_{\text{scattering}} + d_{\text{background}}}_{\text{indirectos}}$$

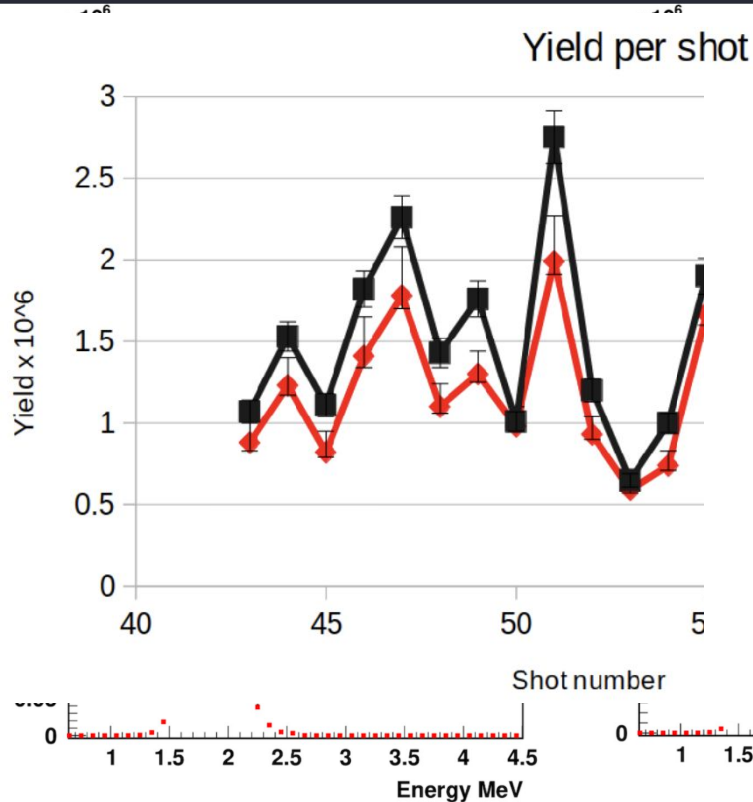
Método del Cono de Sombra



Detector	Scattering %
d01	63(3)
d02	57(3)
d03	94(4)
206	58(2)

Yield por pulso

Obtener yield por cada pulso



Función Respuesta de detección y medida
de flujo neutrónico pulsado en
dispositivos plasma foco

Tesis
entregada a la
Universidad de Chile
en cumplimiento parcial de los requisitos
para optar al grado de
Magister en Ciencias Físicas
Facultad de Ciencias

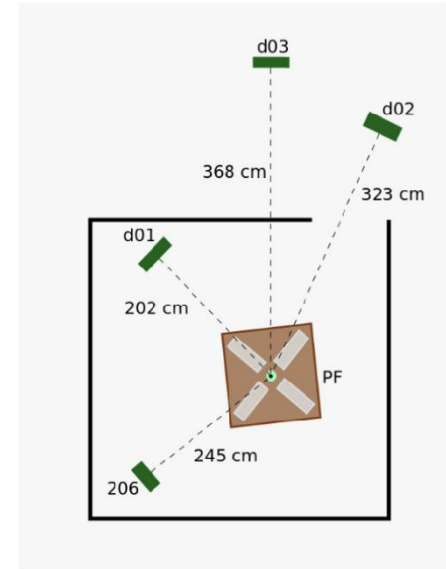
por

Byron Parra

Directores de Tesis: Dr. Hugo Arellano Sepúlveda
Dr. Francisco Molina Palacios

Tesis no depositada aún

206
LIN



31	$1.55(9) \cdot 10^6$	$1.16(5) \cdot 10^6$
62	$1.53(9) \cdot 10^6$	$1.06(4) \cdot 10^6$

The CEFNEN-LIN Neutron Spectrometer



Pulsed Neutrons from Plasma focus
device Part II. Jan-Mar 2020

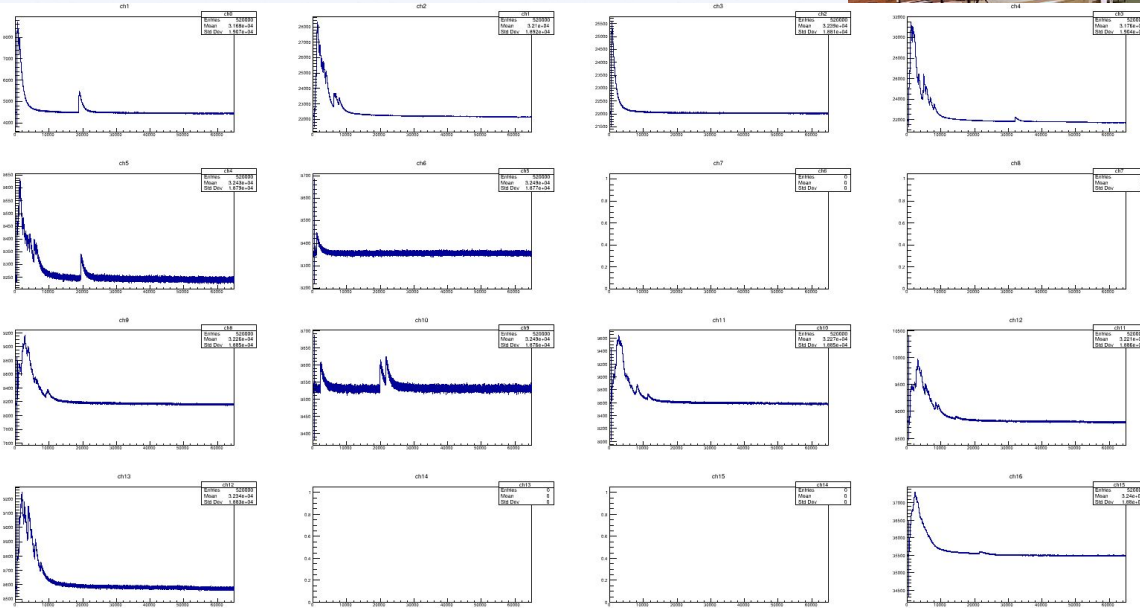
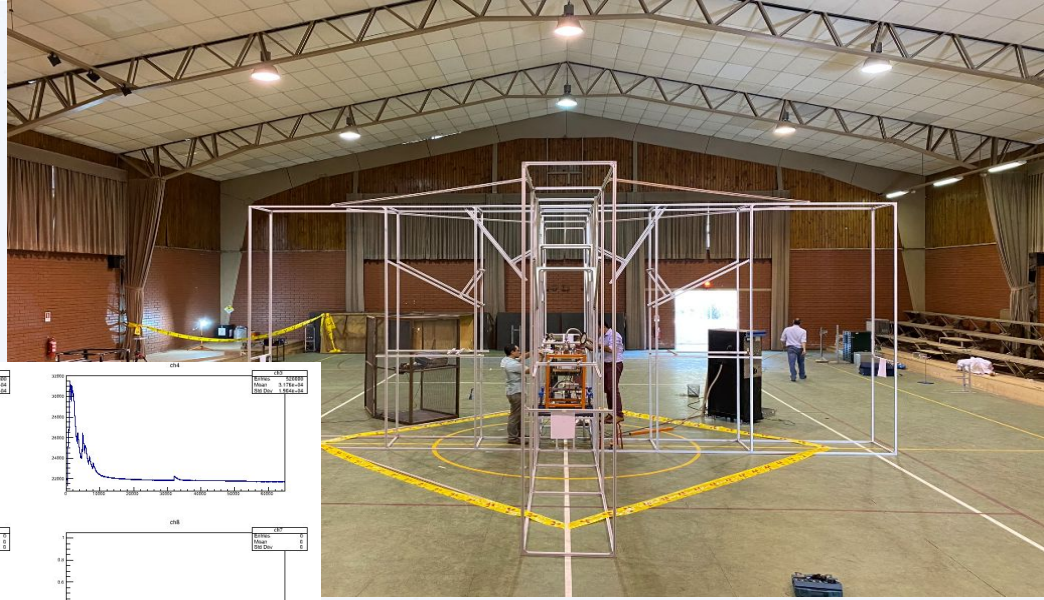
Low room scattering conditions



The CEFNEN-LIN Neutron Spectrometer



Pulsed Neutrons from Plasma
focus device Part II. Jan-Mar 2020



- Acquisition system based on digitizer STRUCK 3316 250 MSPS (16ch)
- Triggered by a current plasma signal





Caso 3: Chile como laboratorio natural: Estudio de neutrones cósmicos.

FONDECYT Regular 1221364 (2022-2026); Tesis Doctoral Franco López, UNAB,
Tesis Ing.Física Luis Gonzalez, UNAB; Tesis Ing. Física, Vicente Millar, UNAB.

The CEFNEN-LIN Enviromental Neutron Flux



COVID-19 Lockdown Mar-Nov 2020

Different configurations, pulse shape analysis and long term measurements.



The CEFNEN-LIN Enviromental Neutron Flux



COVID-19 Lockdown Mar-Nov 2020

Pulse shape analysis - Struck 3316 digitizer

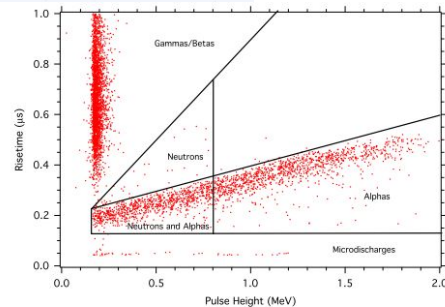
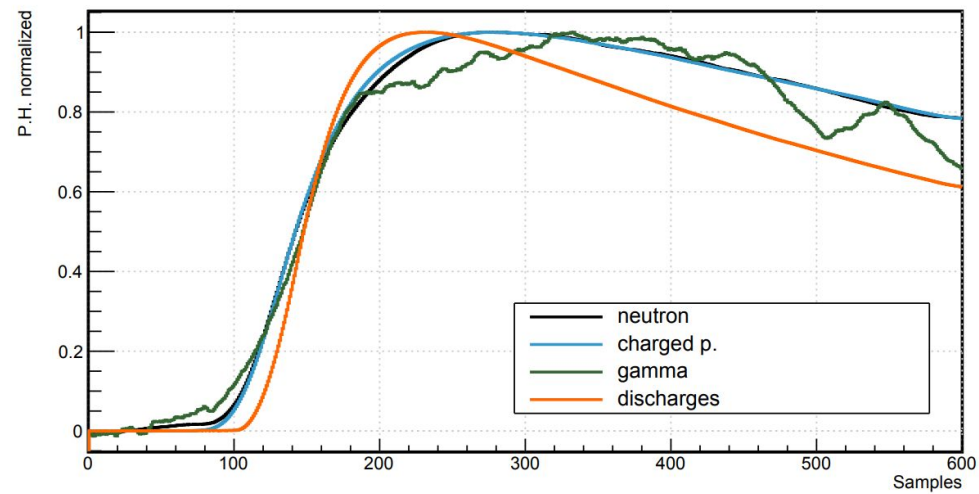
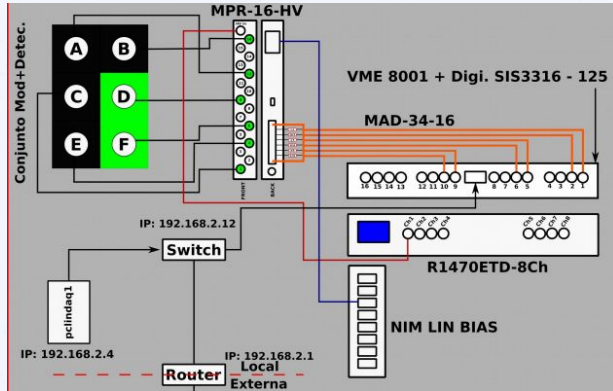
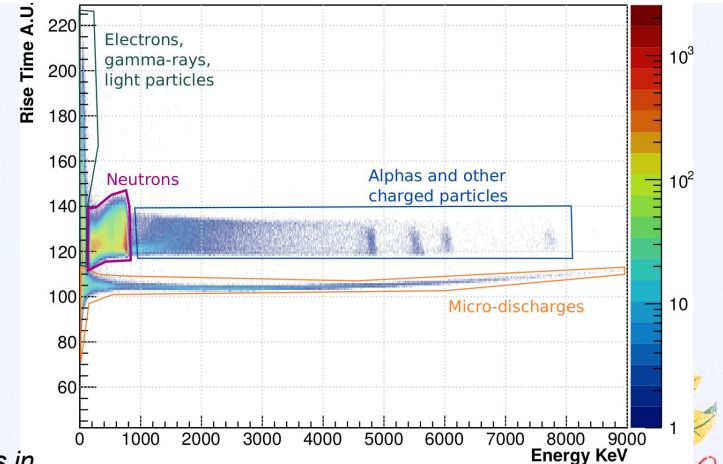


Fig. 6. Rise time versus pulse height data from a ^3He proportional counter placed in a low background underground lab at the Kimballton Underground Research Facility. The black lines and labels serve to indicate the predominate type of event in the region. The low neutron flux facilitates the study of the internal alpha-particle contamination of the counters. This counter has a broad alpha spectrum and a low microdischarge rate, as shown in the labeled regions.



T.J. Langford et al. *Nuclear Instruments and Methods in Physics Research A* 717 (2013) 51–57



CEFNE

Centro de Investigación
en Física Nuclear y
Espectroscopía de Neutrones



Motivation for chasing neutrons throughout Chile

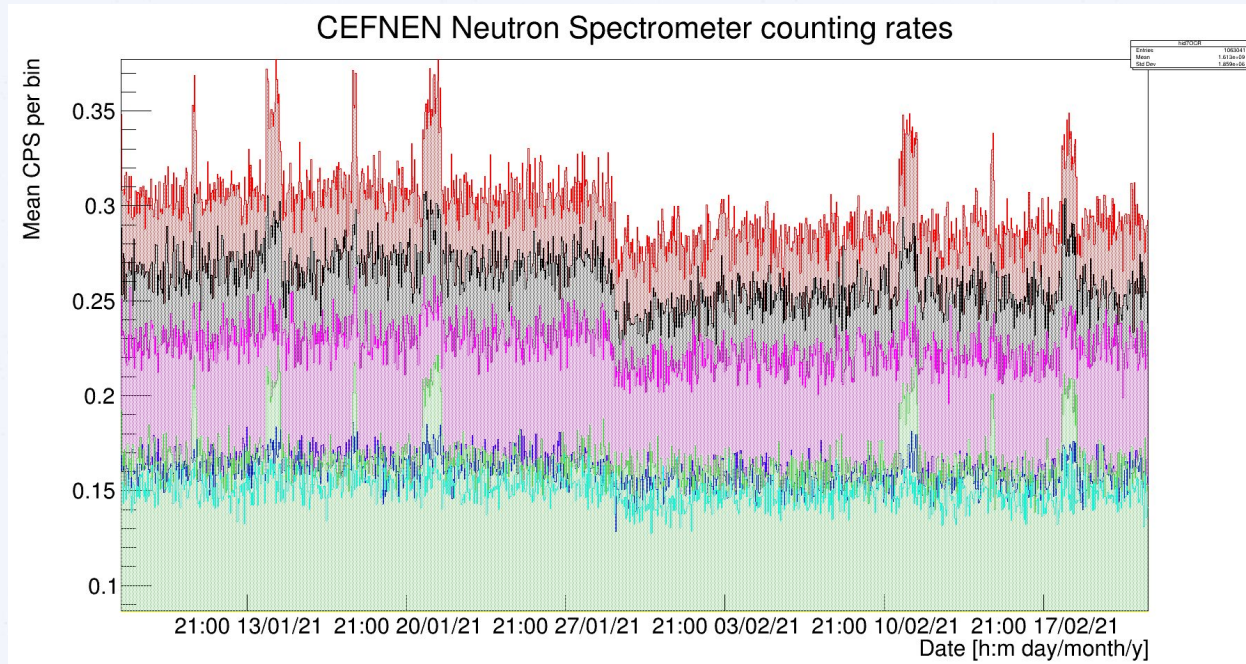


The CEFNEN-LIN Neutron Spectrometer



Dic 2020- Mar 2021

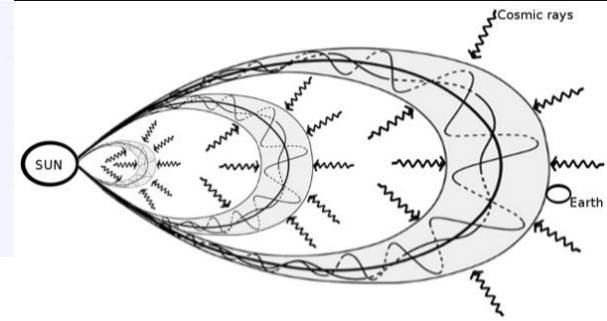
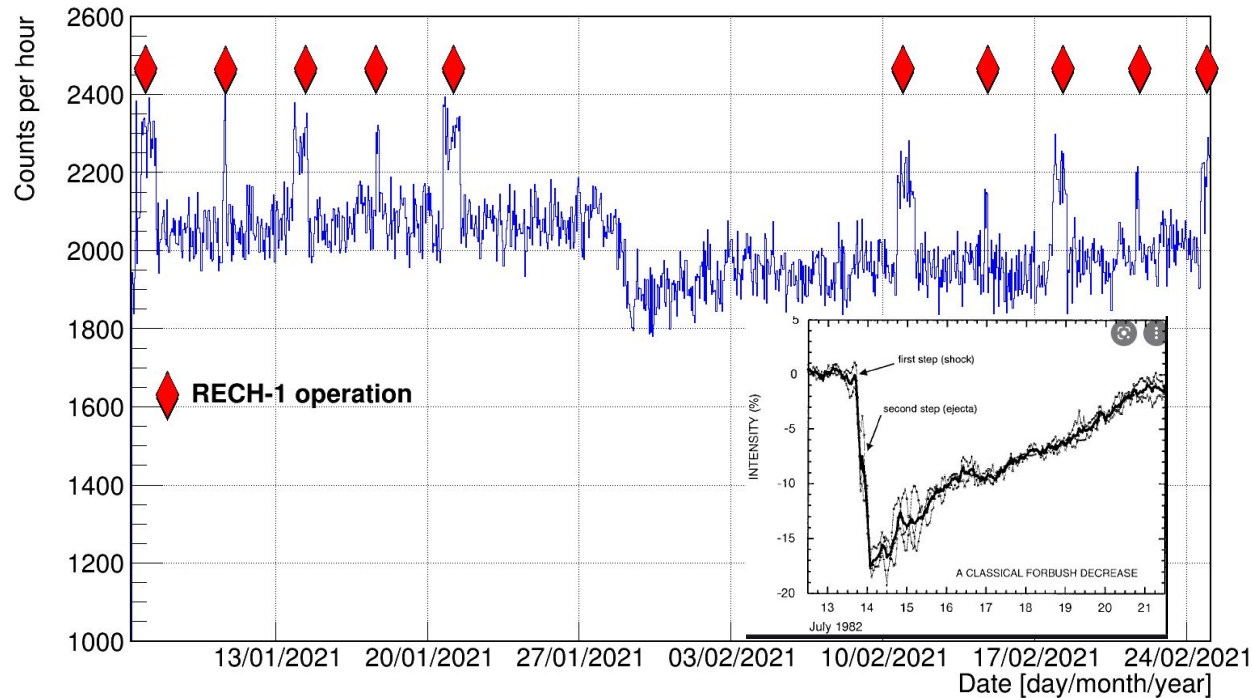
At the end of 2020 we were able to particle identification of signals by pulse shape analysis. We leave our spectrometer measuring background neutrons for long periods of time.



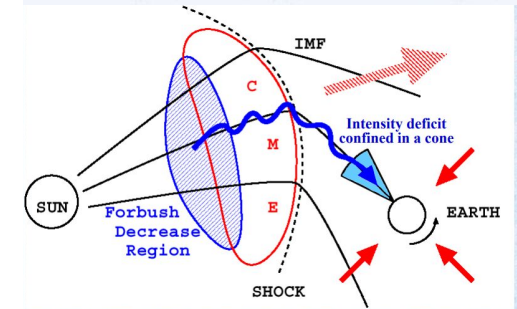
The CEFNEN-LIN Neutron Spectrometer



The ghost of a Furbush decrease



Forbush decrease due to a coronal mass ejection CME (once each 10-15 years)



were we the only ones that saw this Forbush decrease?



Parenthesis Neutron monitors (NMs)

Measure high energy neutrons induced by cosmic rays

*1953: “Pile” type monitor - IGY (1957)
J. A. Simpson

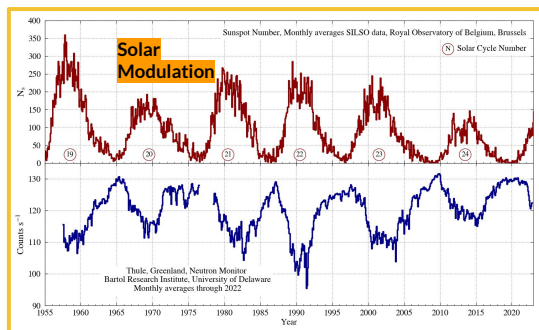
Need for improved
detection efficiency for CR
studies on short time scales

✦1964: Monitor NM-64
H. Carmichael



Top:
WDC-SILSO
Royal
Observatory of
Belgium,
Brussels

Bottom: NM in
Thule,
Greenland -
Research
Institute,
University of
Delaware, USA

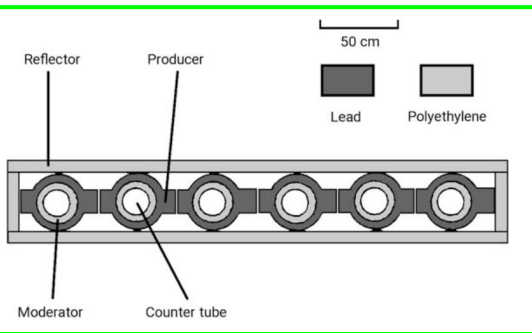


Neutron capture reaction

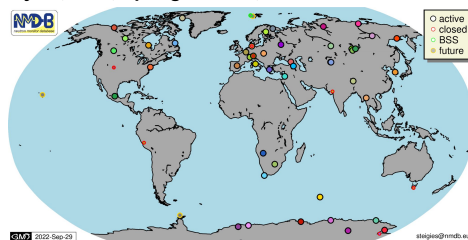
$^3\text{He}(n, p)t$ reaction

$^{10}\text{B}(n, \alpha)^7\text{Li}$ reaction

*J.A Simpson et al., *Cosmic Radiation Intensity-Time Variations and Their Origin. I. Neutron Intensity Variation Method and Meteorological Factors*, Phys. Rev., 1953



R. Bütikofer, *Solar Particle Radiation Storms Forecasting and Analysis*, Ch.6, Springer Cham, 2018.



NMDB: Real-time neutron counting rate



Increase ~3 times the
efficiency

✦C J. Hatton and H. Carmichael, *Experimental investigation of the NM-64 neutron monitor*, Can. J. Phys., 1964

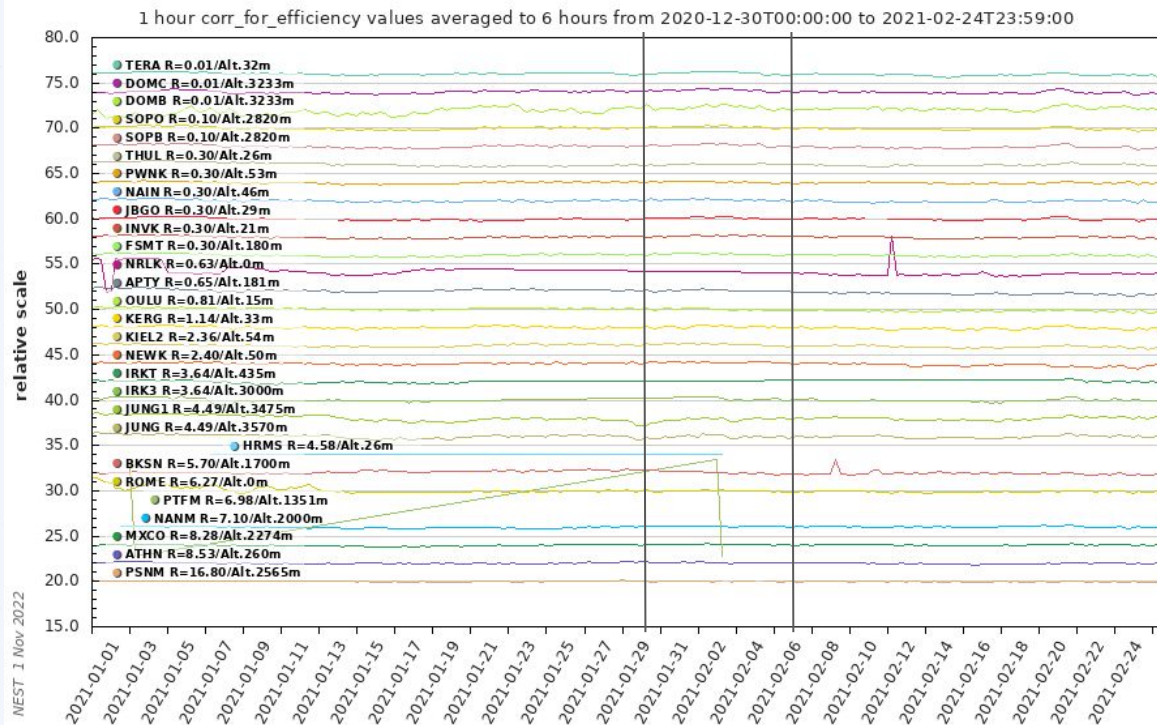
The CEFNEN-LIN Neutron Spectrometer



The ghost of a Forbush decrease

NMDB: the Neutron Monitor Database

Real-Time Database for high-resolution Neutron Monitor measurements



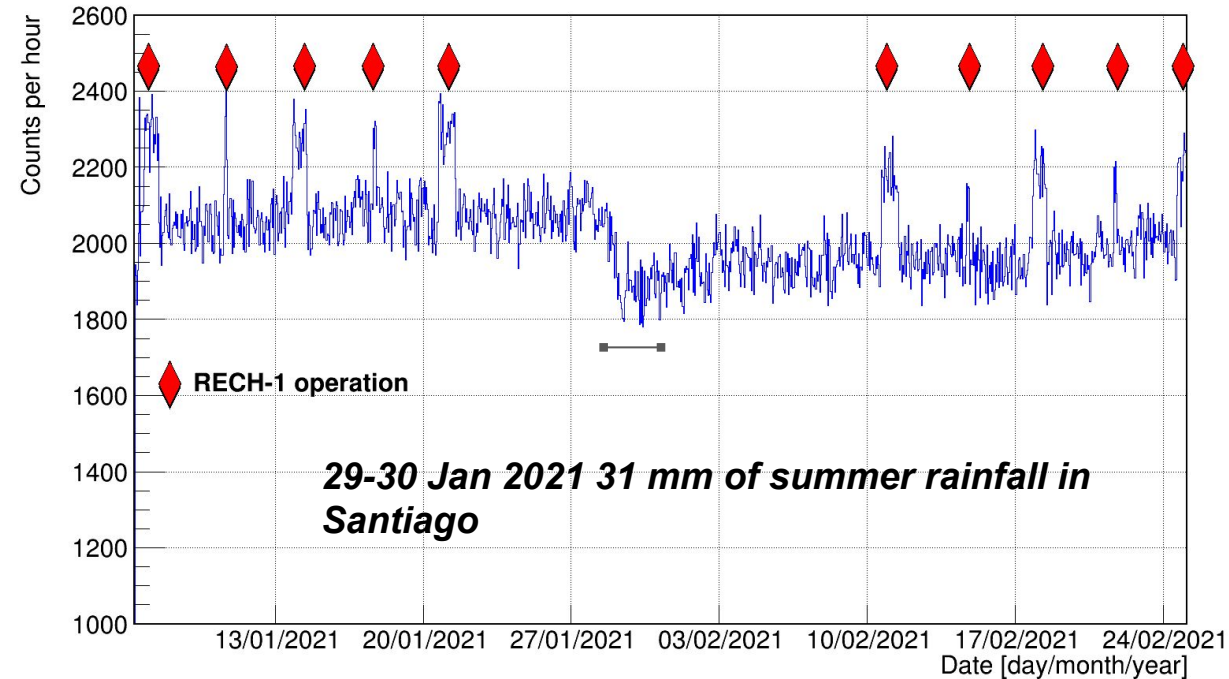
None of the 50 NM saw *our* Forbush decrease. Must be something else



The CEFNEN-LIN Neutron Spectrometer



The ghost of a ~~Furbush decrease~~ Local Variables interfering with our detectors





Questions to be solved

- 1.- How does the local variables affect neutron counting rates and neutron flux spectrum?
- 2.- Are Neutron Monitors (NM-64 / IGY-57) counting rates suffering from local variables?
- 3.- It is possible to correct it?





Questions to be solved

- 1.- **How does the local variables affect neutron counting rates and neutron flux spectrum?**
- 2.- Are Neutron Monitors counting rates suffering from local variables?
- 3.- It is possible to correct it?

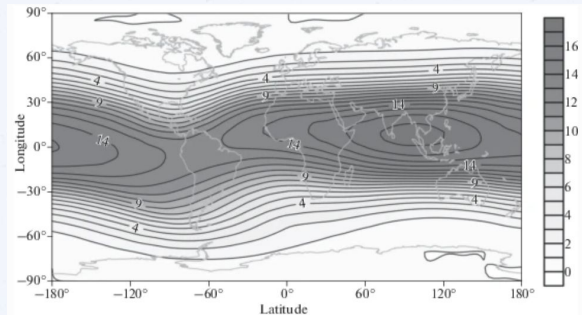
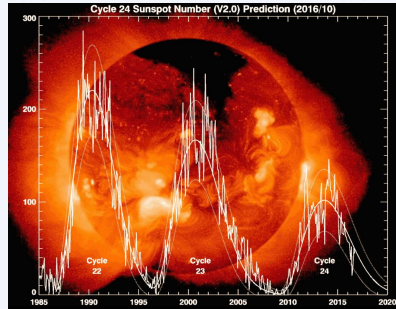


Shape of neutron fluxes on ground measurements



Analytical Functions for Cosmic-ray neutron spectra

The neutron spectra in ground measurements depends on: **s** (solar activity- solar modulation), **r_c** (geomagnetic cut-off rigidity), **d** (atmospheric depth), **E** (neutron energy) and **w** (soil humidity). Sato & Niita, Radiation Research 166, 544-555 (2006)



2006

RADIATION RESEARCH 166, 544-555 (2006)
0033-7587/06 \$15.00
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Analytical Functions to Predict Cosmic-Ray Neutron Spectra in the Atmosphere

Tatsuhiko Sato^{a,*} and Koji Niita^a

^a Japan Atomic Energy Agency (JAEA) and ^b Research Organization for Information Science and Technology (RIST), Ibaraki, Japan

$$\Phi_G(s, r_c, d, E, w)$$

$$= \Phi_L(s, r_c, d)[\phi_B(s, r_c, d, E)f_G(E, w) + \phi_T(E, w)],$$

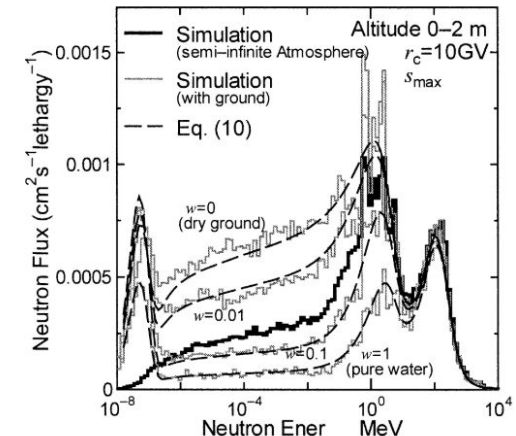


FIG. 9. Calculated neutron spectra at the ground level in comparison with the corresponding spectrum in the semi-infinite atmosphere.

Shape of neutron fluxes on ground measurements



Analytical Functions for Cosmic-ray neutron spectra

The neutron spectra in ground measurements depends on: **s** (solar activity), **r_c** (geomagnetic cut-off rigidity), **d** (atmospheric depth), **E** (neutron energy) and **w** (soil humidity). T. Sato, PLoS ONE 10(12): e0144679. doi:10.1371/journal.pone.0144679

2015



RESEARCH ARTICLE

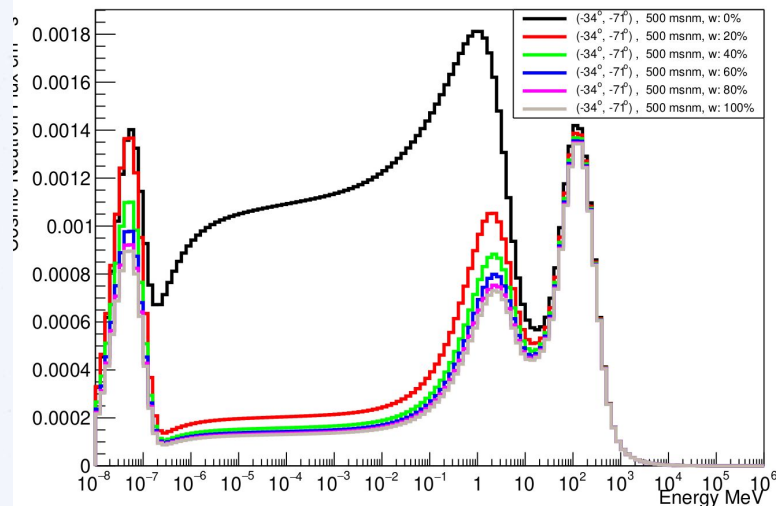
Analytical Model for Estimating Terrestrial Cosmic Ray Fluxes Nearly Anytime and Anywhere in the World: Extension of PARMA/EXPACS

Tatsuhiko Sato*

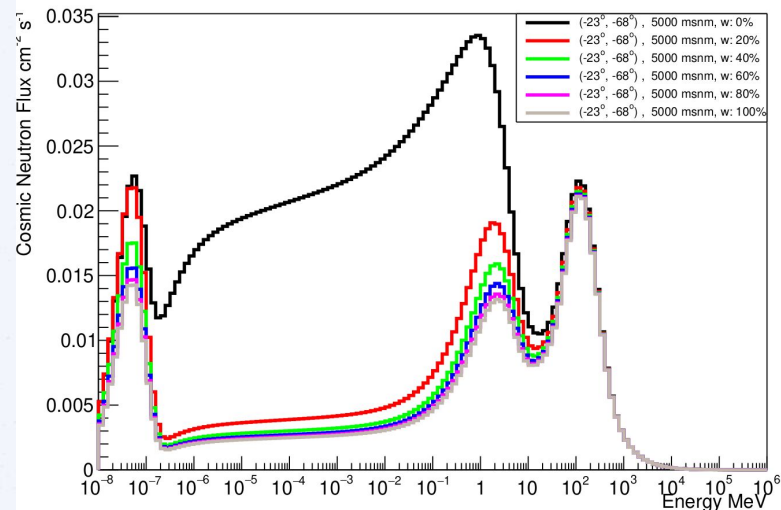
Research Group for Radiation Transport Analysis, Japan Atomic Energy Agency (JAEA), Shirakata 2-4, Tokai, Ibaraki 319-1195, Japan

* sato.tatsuhiko@jaea.go.jp

Santiago EXPACS Cosmic-ray ground neutron spectra



ALMA EXPACS Cosmic-ray ground neutron spectra



Seasonal Neutron fluxes measurements



Radiation Protection Dosimetry (2009), Vol. 136, No. 4, pp. 256–261
Advance Access publication 3 September 2009

doi:10.1093/rpd/ncp161

CONTINUOUS MEASUREMENT OF SECONDARY NEUTRONS FROM COSMIC RADIATION AT MOUNTAIN ALTITUDES AND CLOSE TO THE NORTH POLE—A DISCUSSION IN TERMS OF $H^*(10)$

W. Rühm*, V. Mares, C. Pioch, G. Simmer and E. Weitzenegger
Helmholtz Zentrum München, German Research Center for Environmental Health (GmbH), Institute of Radiation Protection, Ingolstädter Landstr. 1, 85764 Neuherberg, Germany

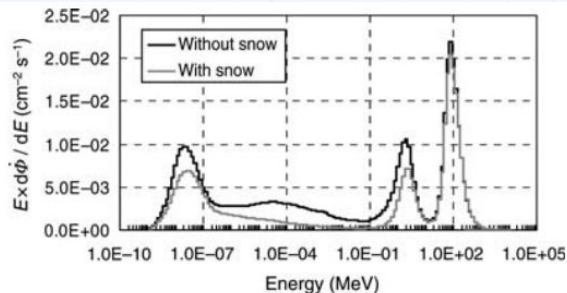


Figure 5. Six-hours neutron spectra obtained on 17 August (sunny and dry weather) and 7 September 2007 (heavy snow fall), on the UFS⁽¹²⁾; the corresponding weather conditions can be seen in Figure 6.

2009

$$N_i = \int_0^{\infty} R_i(E) \phi(E) dE = \int_0^{\infty} A_i \varepsilon_i(E) \phi(E) dE$$

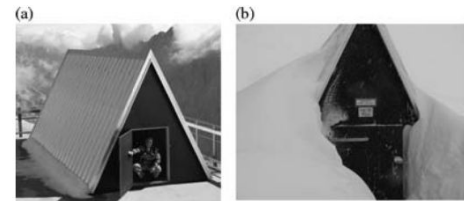


Figure 6. (a) Situation on 17 August 2007; (b) situation on 7 September 2007.

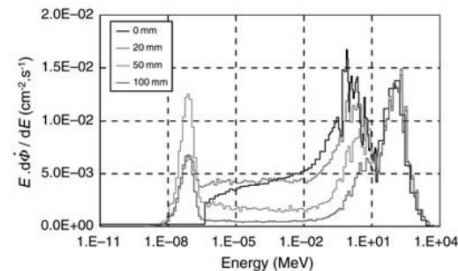


Figure 7. Variation of the neutron fluence energy distribution calculated free-in-air at an altitude of 2609 m (black line⁽⁵⁾; FLUKA) after penetration through a water layer of various thicknesses (various grey lines; MCNPX).





Questions to be solved

1.- How does the local variables affect neutron counting rates and neutron flux spectrum?

Soil moisture (w) affects the thermal and epithermal-fast neutron region but not to the High energy region. Even though could be other local variables that can affect the spectrum.





Questions to be solved

- 1.- How does the local variables affect neutron counting rates and neutron flux spectrum?
- 2.- Are Neutron Monitors counting rates suffering from local variables?**
- 3.- It is possible to correct it?



How does the local variables affect the NM64?



NM-64, Carmichael standard is sensitive to epithermal neutron fluxes

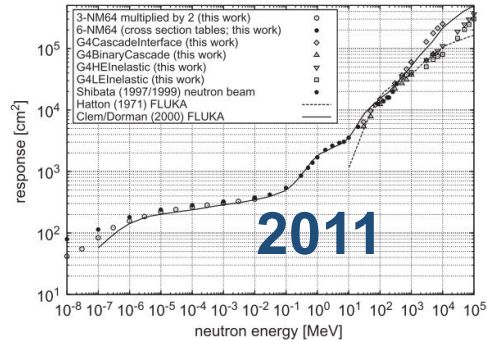
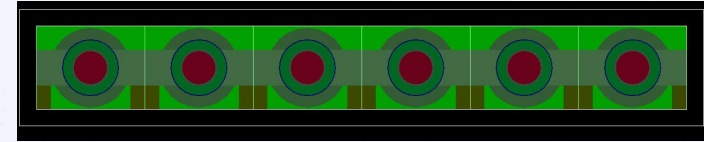
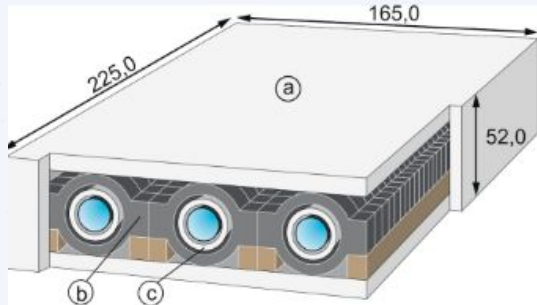
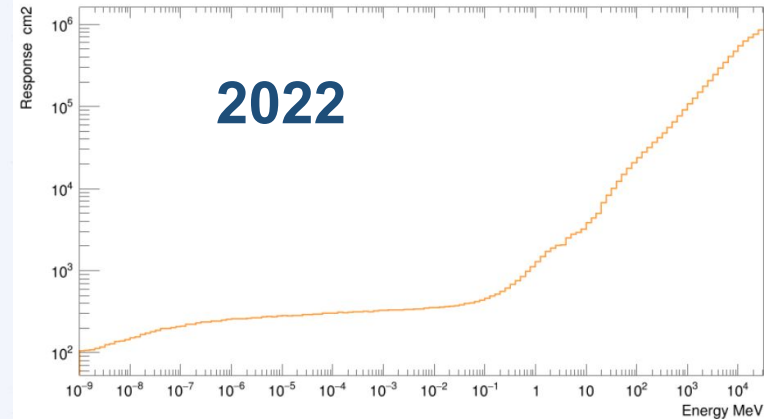


Fig. 3. Neutron response function for one 6-NM64 section of the NM in Barentsburg. Below 20 MeV, the GEANT4 calculations are based on experimental cross-sections; above 20 MeV, different physics models were used. The response of a 3-NM64 sub-unit (scaled by two) is additionally shown for energies below 100 keV (open circles). For comparison, the FLUKA results [22,23] and experimental data by Shibata et al. [24,25] are also shown.



6-NM64 Simulated Response Function



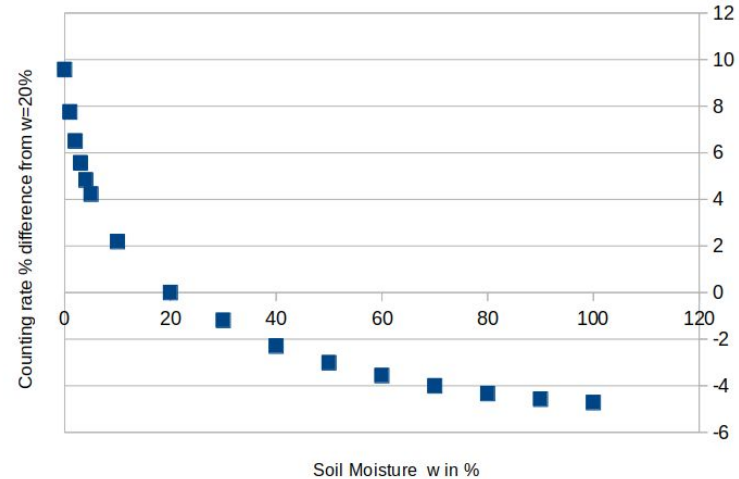
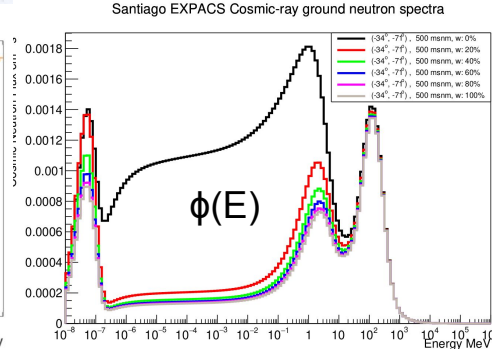
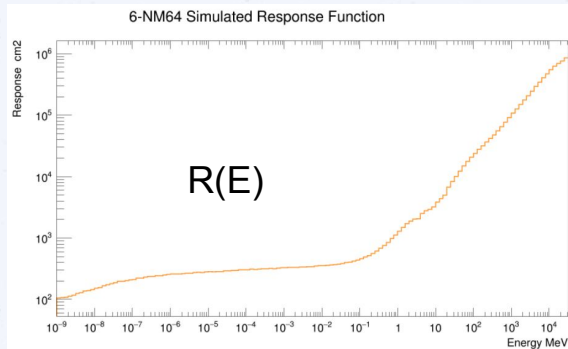
C. Pioch et al. / Nuclear Instruments and Methods in Physics Research A 626–627 (2011) 51–57



How does the local variables could affect the NM64?



$$N_i = \int_0^{\infty} R_i(E) \phi(E) dE = \int_0^{\infty} A_i \varepsilon_i(E) \phi(E) dE$$



w is just soil moisture, What about neutron absorbers (or scattering) isotopes in soil such B, N, C etc. ?



Internal Communication with V. Yanke (2022)



Cosmic ray studies with neutron detectors | Volume 1 (2021)

183

KIEL-UP • DOI: 10.38072/2748-3150/p23

Snow Effect on the neutron monitor network for 2018-2019

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https://conf2020.nmdb.eu/pdf/kiel-up_2748-3150_v1_210521.pdf



Monitoring of the thickness of the snow cover based on the neutron component data of cosmic rays

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¹Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation of the Russian Academy of Sciences (IZMIRAN), Troitsk, Moscow, Russia

²Israel Cosmic Ray and Space Weather Center with Emilio Segre Observatory on Mt. Hermon, affiliated to Tel Aviv University, Ariel University, Shamir Research Institute, and Israel Space Agency, Israel

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Pos (ICRC21)

<https://pos.sissa.it/395/282/pdf>

Dr. Viktor Yanke, Head of Cosmic Ray Department of the Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation of the Russian Academy of Science.





Questions to be solved

2.- Are Neutron Monitors (NM-64 / IGY-57) counting rates suffering from local variables?

Yes, but currently darts point to snow accumulation





Questions to be solved

- 1.- How does the local variables affect neutron counting rates and neutron flux spectrum?
- 2.- Are Neutron Monitors (NM-64 / IGY-57) counting rates suffering from local variables?
- 3.- **It is possible to correct it?**



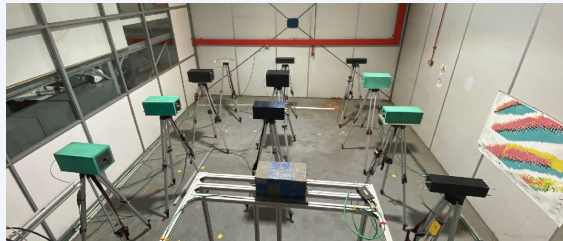


Questions to be solved

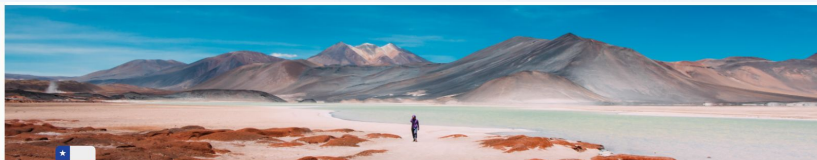
3.- It is possible to correct it?

We think it is possible but neutron flux and local variable data is needed to be analyzed under different conditions.





Chasing neutrons throughout Chile

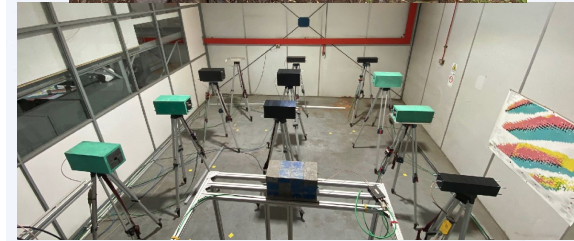
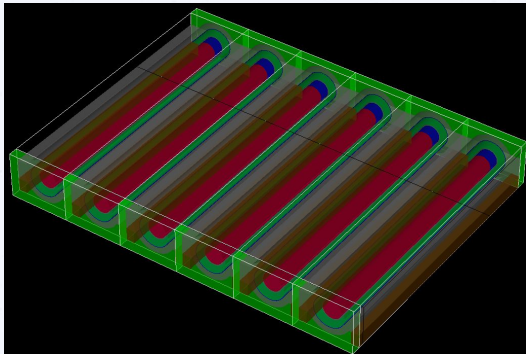


Cosmic Ray Neutron Spectroscopy and Local Variables simultaneous measurement studies throughout Chile

Area: Física Nuclear Fundamental, Física Nuclear Aplicada, Espectroscopia de Neutrones, Instrumentación Nuclear, Dosimetría de Neutrones, Simulaciones Monte Carlo
CEFEN Project: Fondo de neutrones cósmicos, Simulaciones Monte Carlo



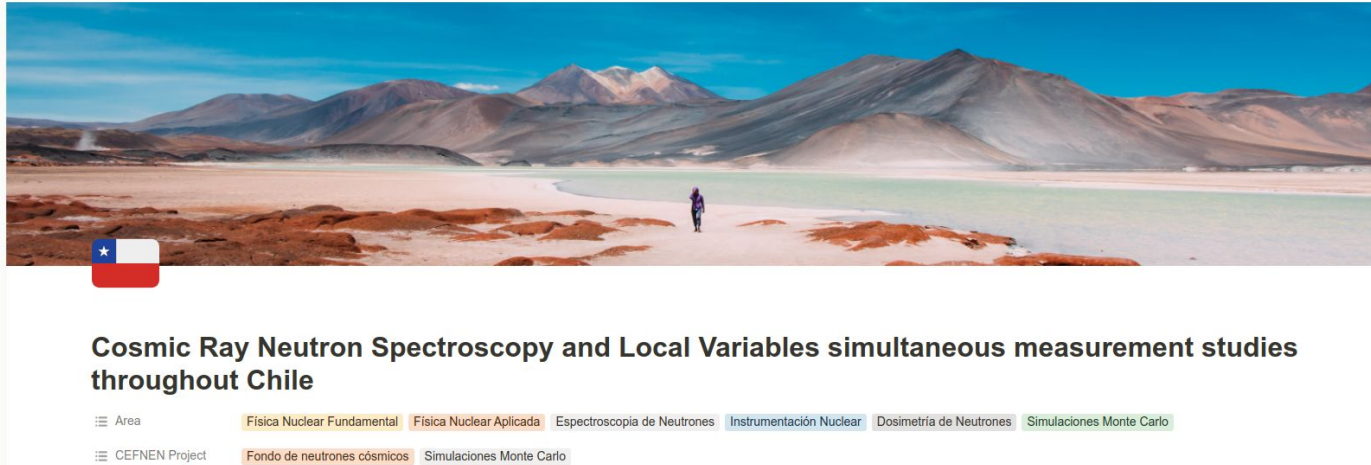
2.- Design, construct and test a small spectrometer to correct the NM-64 neutron counting rates due to local variables conditions



Project Objective



The objective of this project is to systematically study local variables such as atmospheric pressure, soil moisture, relative humidity, temperature and soil composition and their relation with the neutron flux at ground level in the range 1 meV - ~ 10 GeV throughout Chile's different climates and soil types, using the CEFNEN neutron spectrometer in a broad multidisciplinary scientific collaboration. **(Fondecyt Regular 1221364, 04/2022-03/2026)**



Why Chile?

Lugar	Altura msnm	Latitud	Longitud	Cutoff Rig. GV
Arica	2	-18.47	-70.30	11.68
Putre	3500	-18.20	-69.56	11.68
Visviri	4083	-17.60	-69.48	11.74
ALMA	5000	-23.02	-67.75	10.88
San Pedro de Atacama	2408	-22.91	-68.20	10.90
Calama	2400	-22.46	-68.92	11.12
Antofagasta	40	-23.62	-70.39	10.94
P. Agua Neg.	4780	-30.19	-69.83	9.87
Vallenar	380	-28.58	-70.76	10.15
La Serena	28	-29.91	-71.25	9.99
Farellones	2400	-33.32	-70.23	9.44
Santiago 1	760	-33.45	-70.53	9.45
Santiago 2	500	-33.45	-70.93	9.45
Santiago 3	600+300	-33.45	-70.70	9.44
Valparaíso	10	-33.03	-71.59	9.57
Sewell	2200	-34.08	-70.74	9.34
Rancagua	572	-34.17	-70.74	9.33
San Fernando	329	-34.58	-70.89	9.26
Curicó	228	-34.98	-71.24	9.23
Talca	102	-35.40	-71.64	9.20
Linares	165	-35.84	-71.57	9.10
Chillán	124	-36.60	-72.08	8.99
Concepción	12	-36.82	-73.02	9.00
Temuco	115	-38.74	-72.62	8.67
Valdivia	5	-39.80	-73.25	8.53
Puerto Montt	14	-41.47	-72.94	7.99
Coyahique	302	-45.57	-72.08	7.40
Puerto Natales	3	-51.73	-72.49	5.44
Punta Arenas	34	-53.14	-70.88	4.84
Isla Rey Jorge	605	-62.21	-58.93	2.74
Rapa Nui	157	-27.15	-109.43	11.82
Juan Fernandez	0	-33.64	-78.83	9.78

almost all type of climates



Different soil types



Longitudinal country



MILLENNIUM INSTITUTE FOR SUBATOMIC PHYSICS AT HIGH-ENERGY FRONTIER SAPHIR



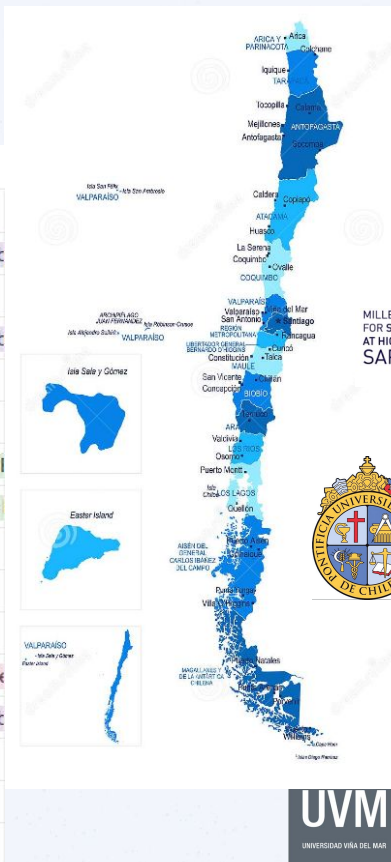
UNIVERSIDAD DE ATACAMA



Part 1: Plan Measurements throughout Chile in Collaboration



Aa Name	📍 Ciudad	≡ Universidad/Instituto	≡ Especialidad
Francisca Garay	Santiago	Pontificia Universidad Católica	Física de Altas Energías
Alfredo Vega	Valparaíso	Universidad de Valparaíso	Física de Altas Energías
Samuel Ortega	Talca	Universidad de Talca	Ciencias Agronómicas
Juan Carlos Helo	La Serena	Universidad de La Serena	Física de Altas Energías
Fernando Guzman	Antofagasta	Universidad Católica del Norte	Ciencia de Materiales
Boris Barja	Punta Arenas	Unviersidad de Magallanes	Meteorología
Orlando Soto	La Serena	Universidad de La Serena	Electrónica Física de Altas
Francisco Correa	Valdivia	Universidad Austral	Gravitación Física de Altas
Roberto Lineros	Antofagasta	Universidad Católica del Norte	Física de Altas Energías
José Barea	Concepción	Universidad de Concepción	Física Nuclear Teórica
Rodolfo Figueroa	Temuco	Universidad de La Frontera	Física Médica
Maximiliano Rivera	Santiago	Universidad Técnica Federico	Física de Altas Energías
Pablo Ulloa	La Serena	Universidad de La Serena	Física de Altas Energías
Judit Lisoni	Valdivia	Universidad Austral	Ciencia de Materiales
Francisco Gonzalez	Viña del Mar	Universidad de Viña del Mar	Biología molecular
Sergio Flores	Copiapó	Universidad de Atacama	Astronomía



MILLENNIUM INSTITUTE
FOR SUBATOMIC PHYSICS
AT HIGH-ENERGY FRONTIER
SAPHIR



UNIVERSIDAD
DE ATACAMA

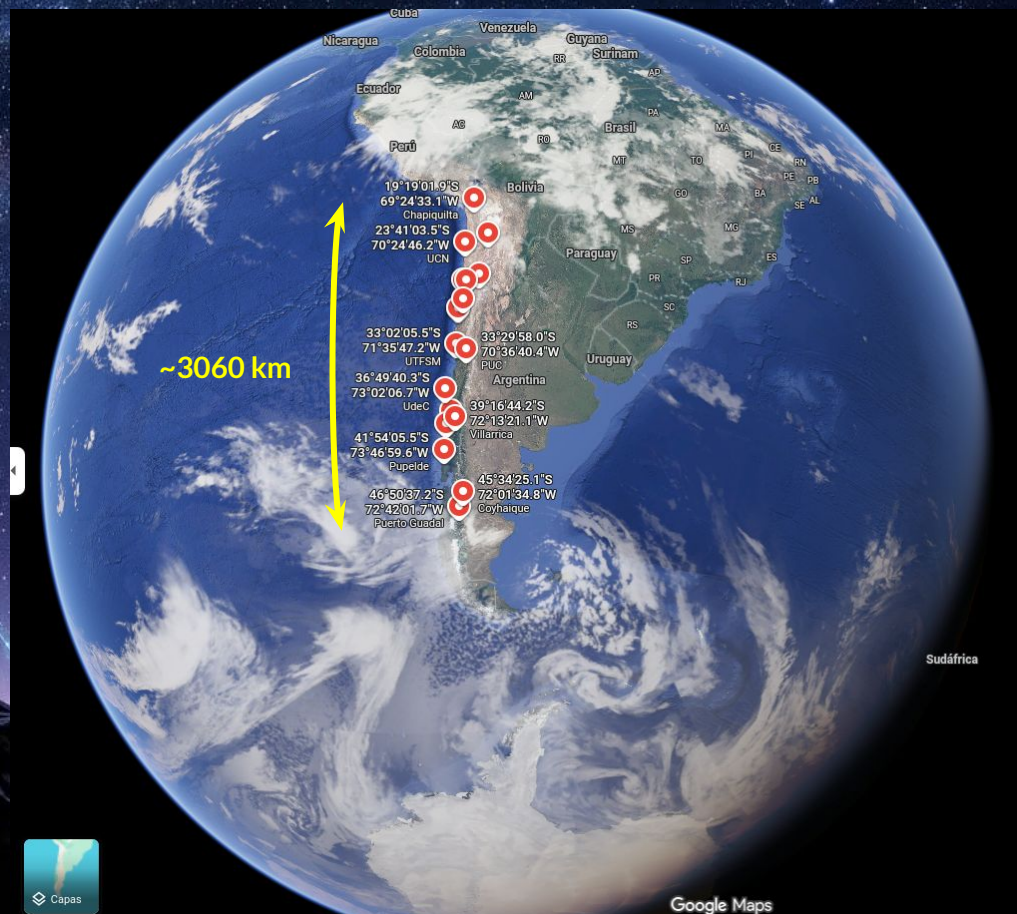


Campañas Experimentales

- 6 Camp. Exp (2022-2025):
- 18 locaciones: gran altura, nivel del mar, desiertos, salares, bosques, orilla de lagos, zonas urbanas, quebradas
- Distancia recorrida: > 3,000 km



CHILE



Campañas Experimentales

High altitude



@LCO, Atacama Region



@Salar de Maricunga, Atacama Region



@Desierto de Atacama



@Chapiquilta

Desert

Sea Level



@UFRO, Temuco



@UdC, Concepción



@Puerto Guadal

CHILE



Sea Level & Forest



@Pupelde, Chiloé



@Coyhaique



@San Pedro de Atacama

Google Maps

Campañas Experimentales Preparación y desarrollo



Campañas Experimentales: Término



Retomando el problema físico

Neutron Spectrum Measurements: BS method, Unfolding

CEFLEN Spectrometer



How can we measure the neutron spectrum?

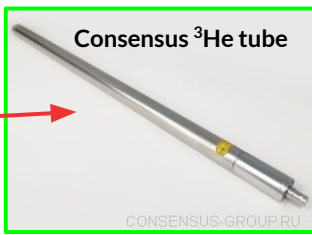
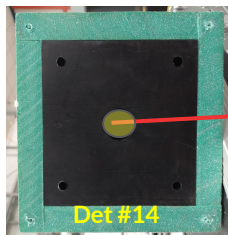
Neutron counting rate

$$n_i = \int_0^{\infty} R_i(E) \phi(E) dE$$

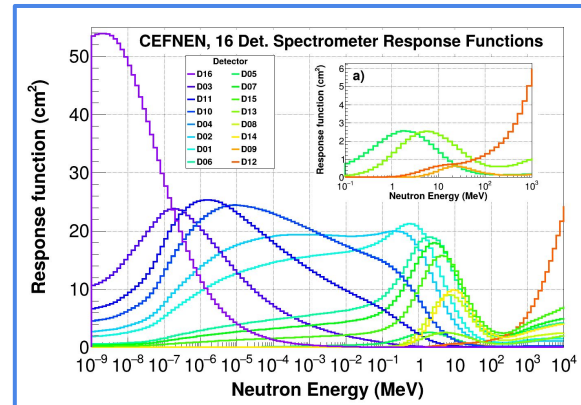
- 16 moderator-detectors nested configurations.
- Boxes & cylindrical geometries.
- Mod mat: HDPE, 5%B-HDPE, Graphite, Cd and Pb.
- ³He proportional counter, 4 atm, 33 cm long effective, 1" diameter
- Sensitivity: meV to GeV.

DAQ

- 16 charge-sensitive preamps
- SIS3316-125 STRUCK Digitizer
- DAQ Software: GASIFIC



Sensitivity: meV → GeV



Inverse Problem

Effects (CR) → Cause (Neutron flux)

Expectation-Maximization (EM) unfolding algorithm

Input

Initial Seed

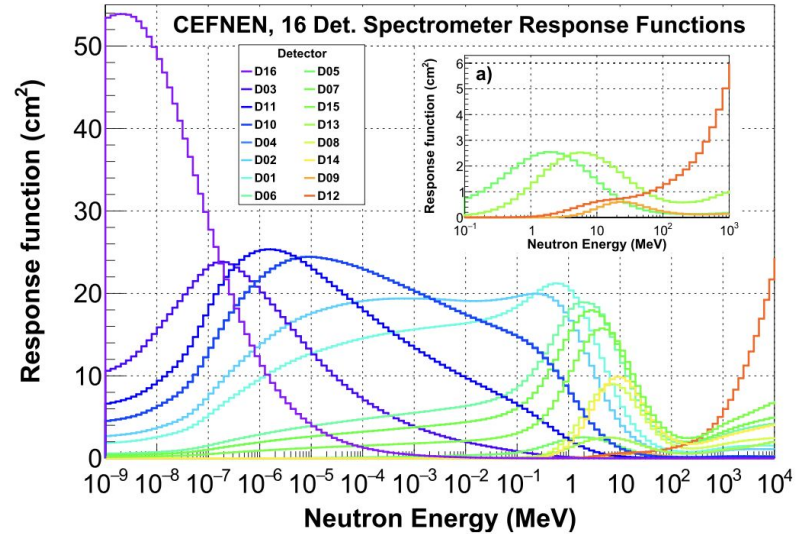
$$\phi_j^{(s+1)} = \frac{1}{\sum_{i=1}^N R_{ij}} \sum_{i=1}^N \frac{R_{ij} \phi_j^{(s)} n_i}{\sum_{k=1}^M R_{ik} \phi_k^{(s)} \Delta E_k} \quad \Phi_j^{(s=0)}$$

Espectrómetro de neutrones CEFNEN

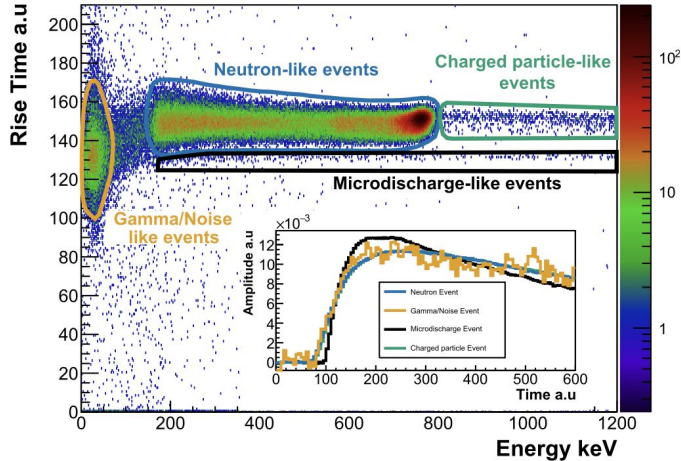
Setup en terreno



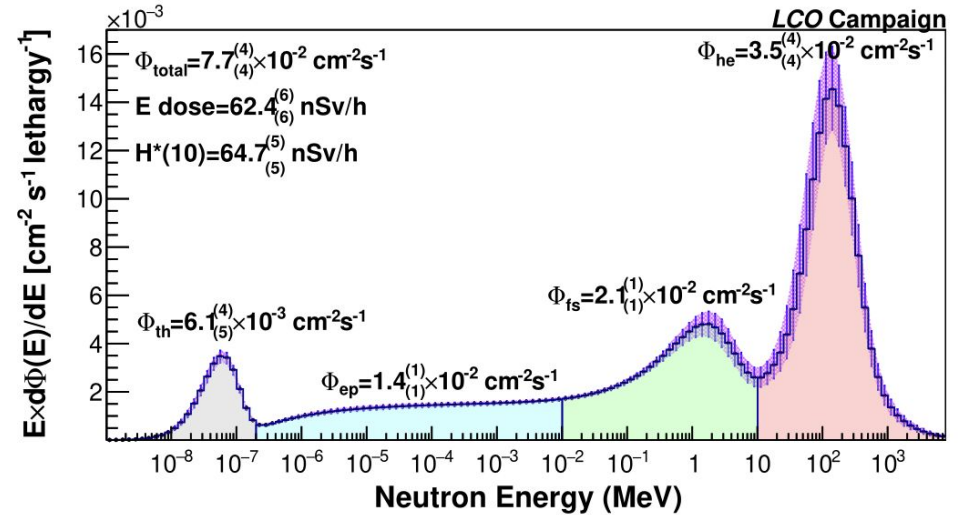
Respuesta isotrópica



Observable, ¿señal es neutrón detectado?



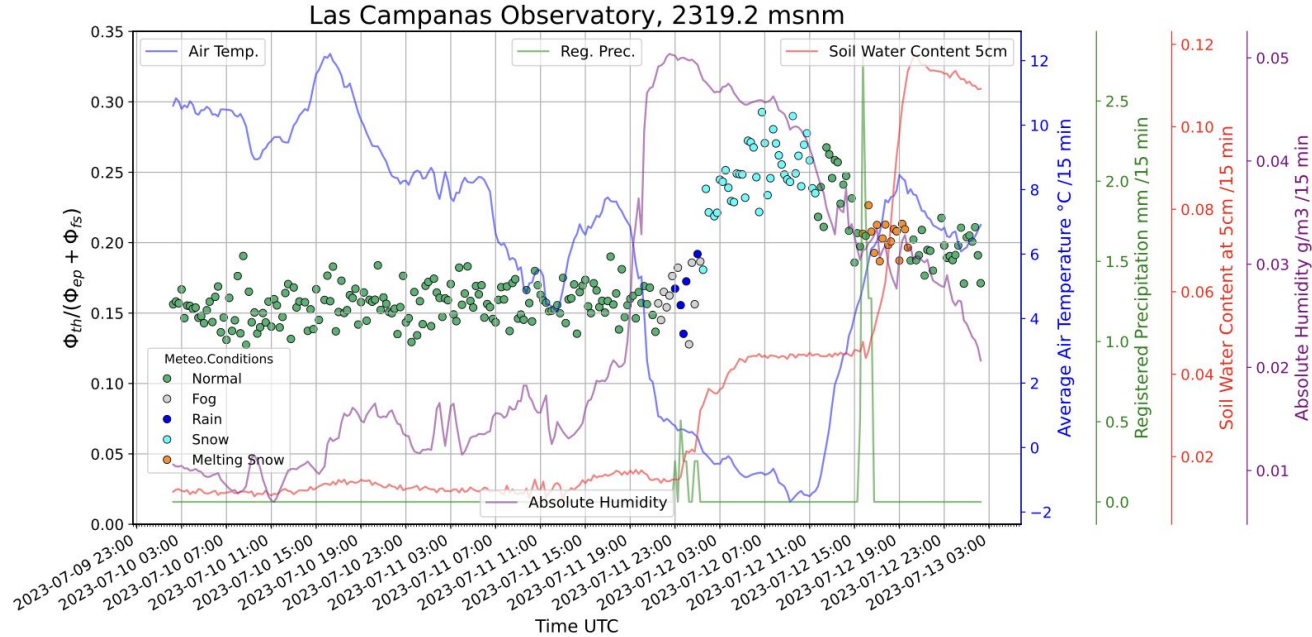
Flujo de neutrones en intervalos de 15 min



F.López-Usquiano, F.Molina, et al. Astroparticle Physics 179 (2026) 103238

Observable: tasa de conteo cada 15 min a partir de señales en detectores de ^3He . Se deben discriminar señales tipo neutron por PSA.

Razón espectral: **magnitud** que relaciona variable local “precipitación” con flujo de neutrones



Rain: $P_{dt} > 0$, $\bar{T}_{air} > 0^\circ\text{C}$, wetting soil ($\Delta\theta_{5\text{ cm}} > 0$), and near saturation ($\delta_{dew} < 2^\circ\text{C}$).

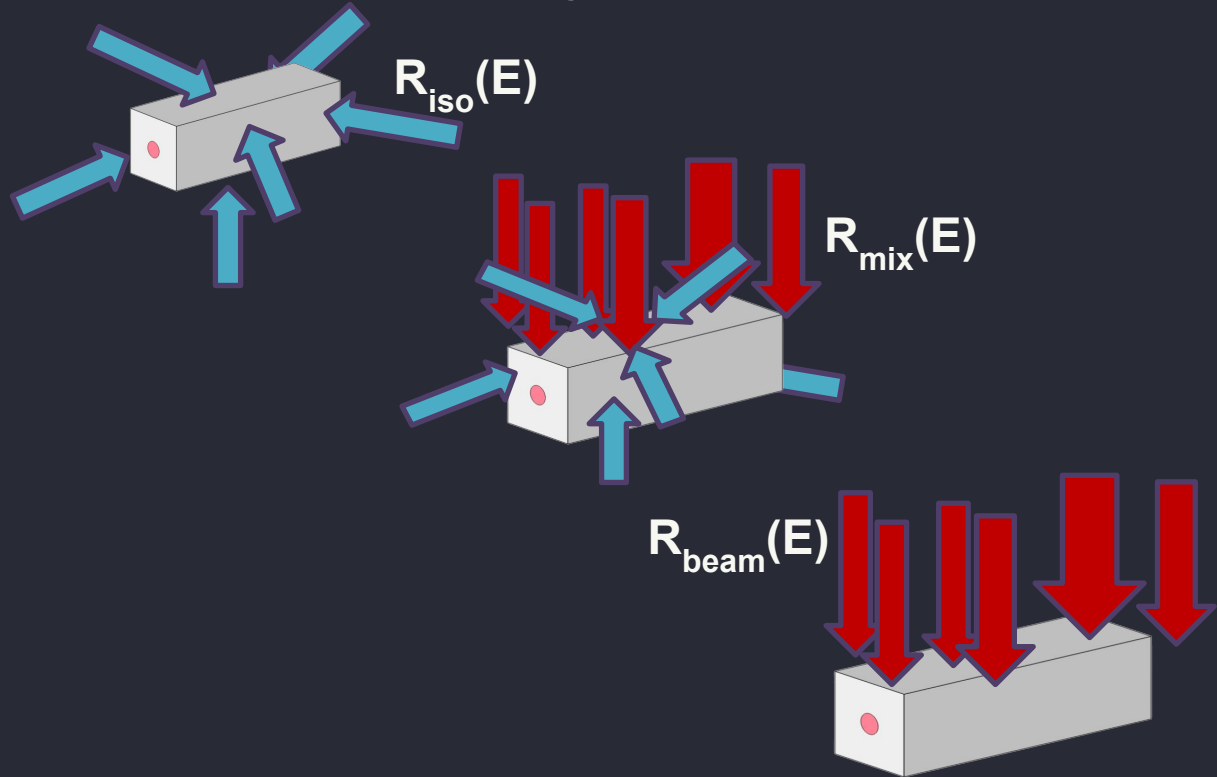
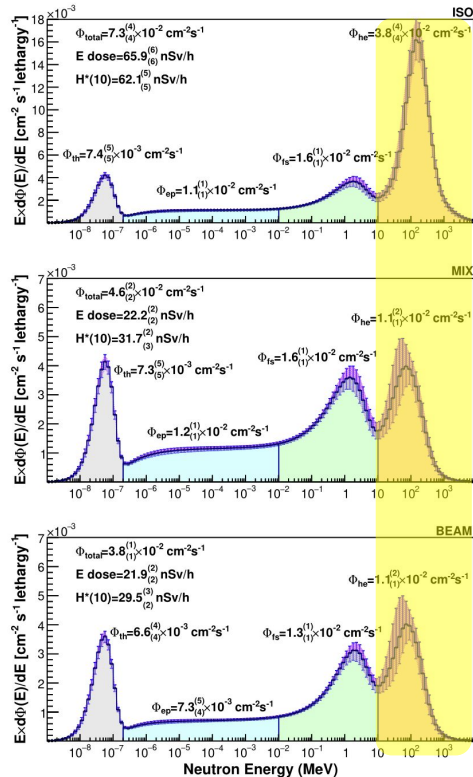
Snow: $P_{dt} = 0$ (tipping bucket may not trigger immediately with solid precipitation), $\bar{T}_{air} \leq 0^\circ\text{C}$, and high humidity ($\delta_{dew} < 2^\circ\text{C}$).

Melting snow: Periods following a snow event (<24h) with $\bar{T}_{air} > 0^\circ\text{C}$ and a strong increase in soil moisture ($\Delta\theta_{5\text{ cm}} > 0.05 (\theta_{5\text{ cm}}/24\text{h})$), indicating rapid infiltration of meltwater.

Fog: Near-saturation conditions ($\delta_{dew} < 2^\circ\text{C}$ or $\text{RH} \geq 95\%$) without precipitation or significant soil wetting ($|\Delta\theta_{5\text{ cm}}| < 0.2\%$).

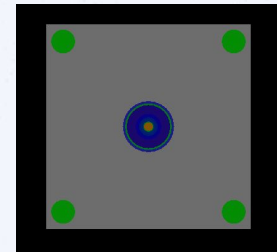
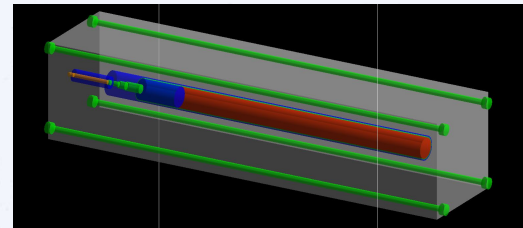
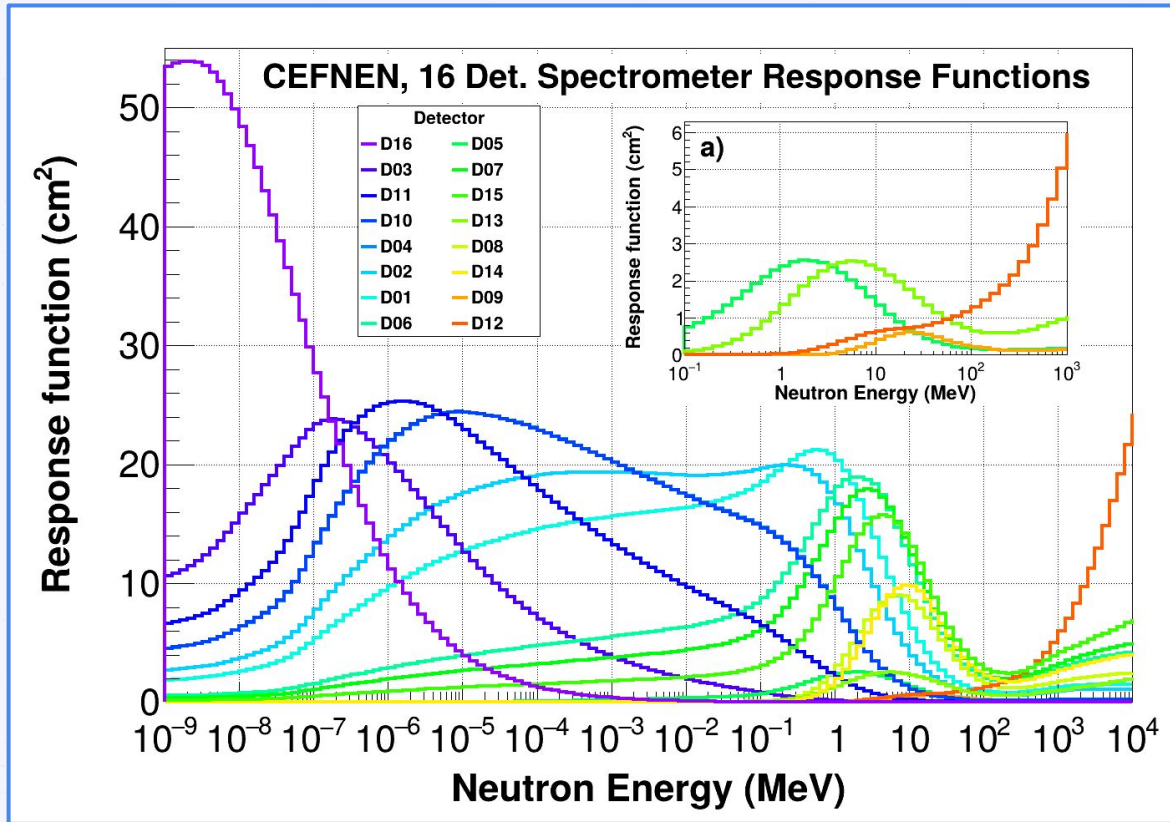
Normal: Reference conditions not meeting any of the above criteria.

Pregunta Incómoda: cómo afecta la direccionalidad del campo neutrónico al flujo obtenido

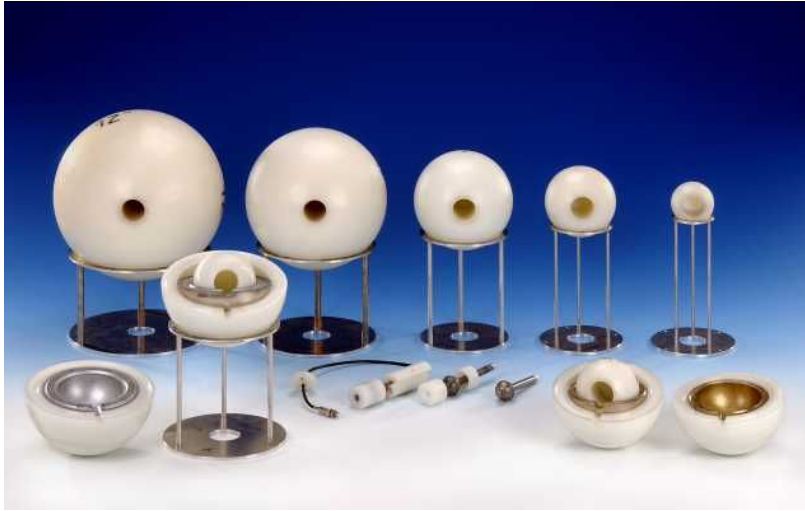


Importancia de la función respuesta de detección

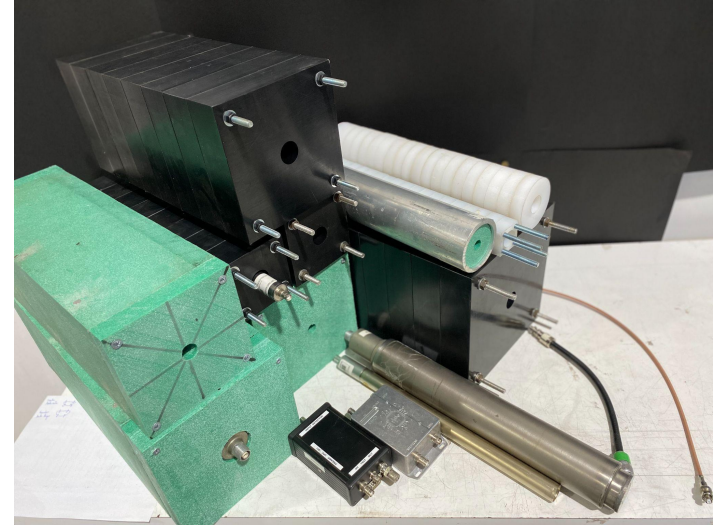
The CEFNEN-LIN Neutron Spectrometer



Change of geometry: CEFNEN Spectrometer



NEMUS Spectrometer (PTB, Germany)

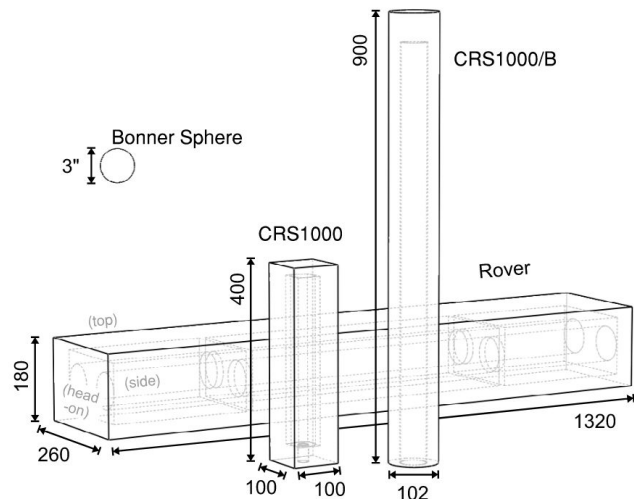


CEFNEN Spectrometer (CHILE)

We are sensitive to the field direction -> We need to address this in the RF calculation

Change of geometry: CEFNEN Spectrometer

Same geometry of CRNS detectors



Doi: <https://doi.org/10.1016/j.nima.2018.06.052>,
Hydroinnova Dessilet et al. (EEUU)

Simulation -> Using an Isotropic neutron field

CEFNEN Spectrometer

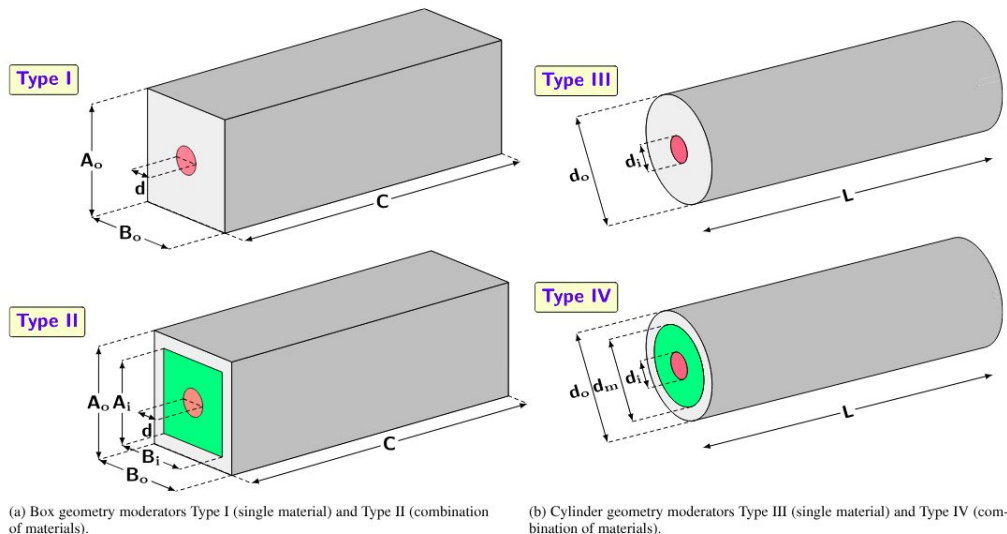


Figure 1: Different types of moderators geometries used at CEFNEN neutron spectrometer.

Why angular response matters for ground-level cosmic-ray neutrons?

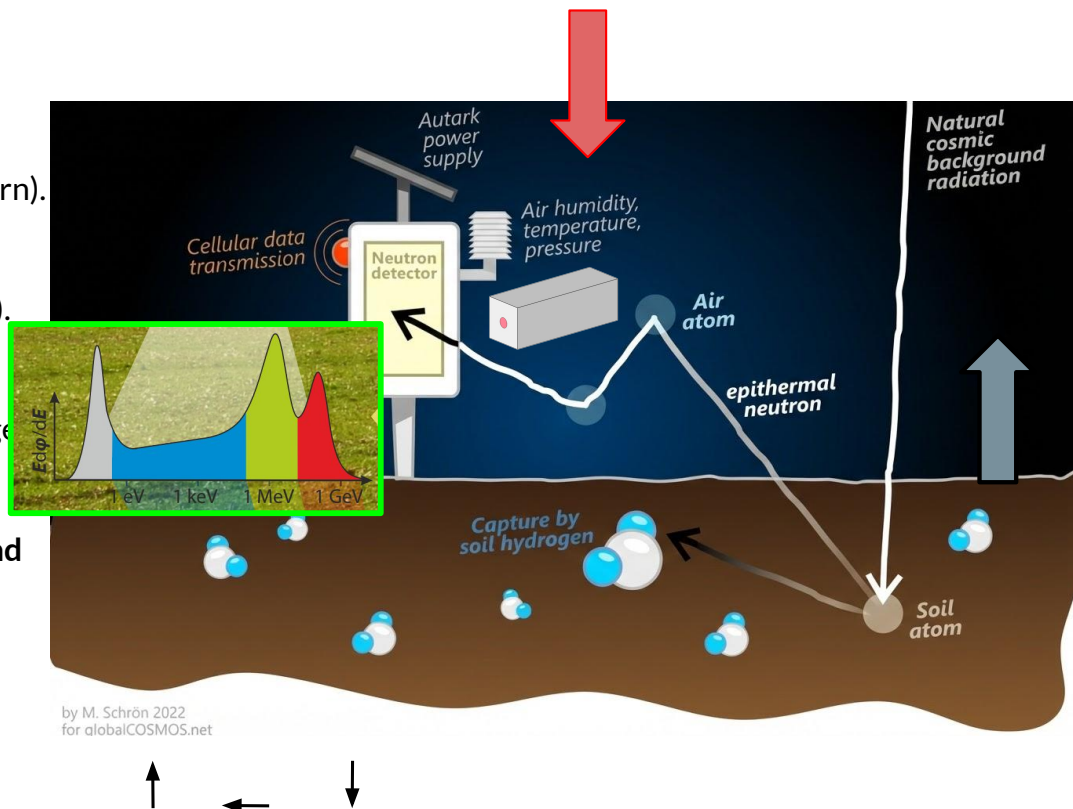
The near-ground neutron field is a **mixture of downward cascade + upward albedo** (ground return).

The **zenith-angle distribution depends on energy** (directionality is not constant across the spectrum).

Non-spherical moderators can show **orientation-dependent efficiency** → counts change with angle even for the same $\Phi(E)$.

If angular effects are ignored, unfolding can **misread direction as a spectral change** (systematic bias).

Directional effects can propagate into **biased unfolded spectra** unless $R(E, \alpha)$ is characterized



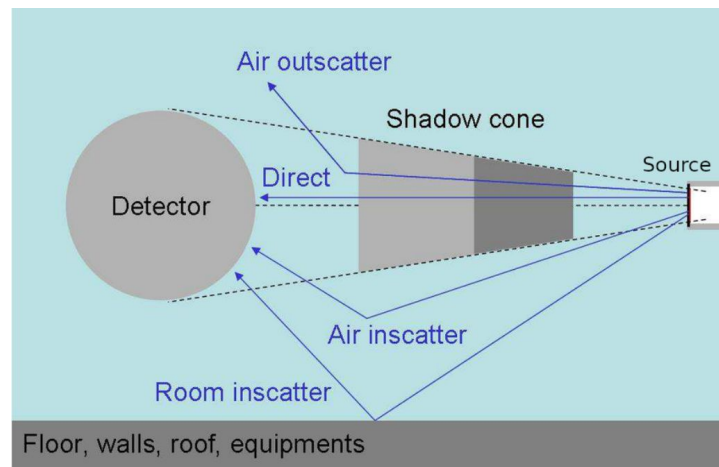
Response Function Characterization

Low neutron scattering facility @CCHEN



Room dimensions: 5.90mx6.50mx10m
Structure dimensions: 1.56mx6mx3m
(minimum scatter from ground and roof)

Materials: Extruded aluminum profiles to
minimize scattering radiation



Response Function Characterization

Low neutron scattering facility @CCHEN



The base is mounted on a linear rail system



Response Function Characterization

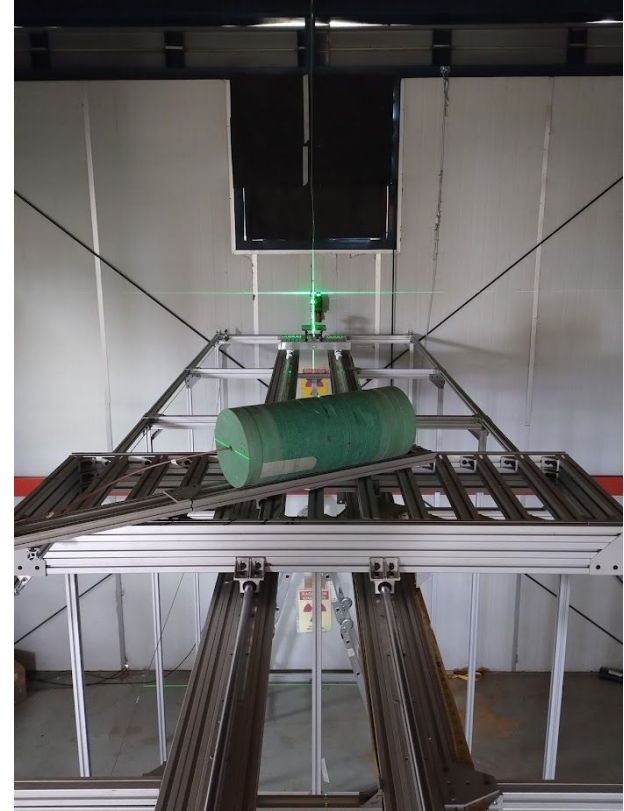
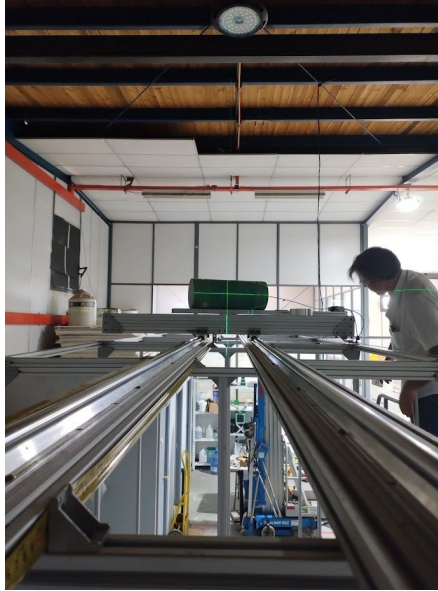
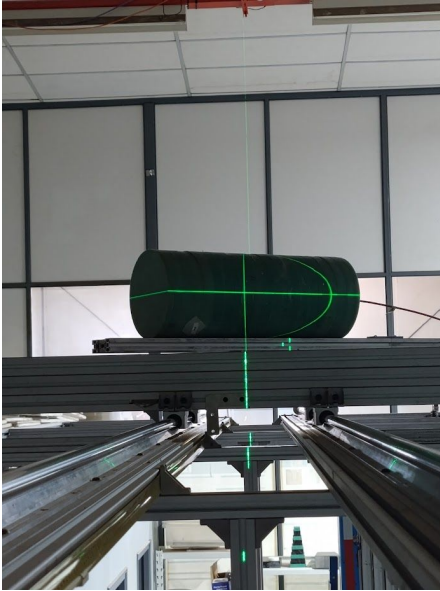
Low neutron scattering facility @CCHEN



The base is mounted on a linear rail system
Measurement distances from the source range from 0.5 m to 4.25 m.

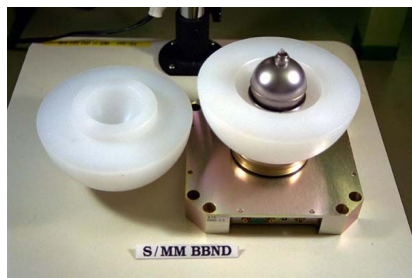
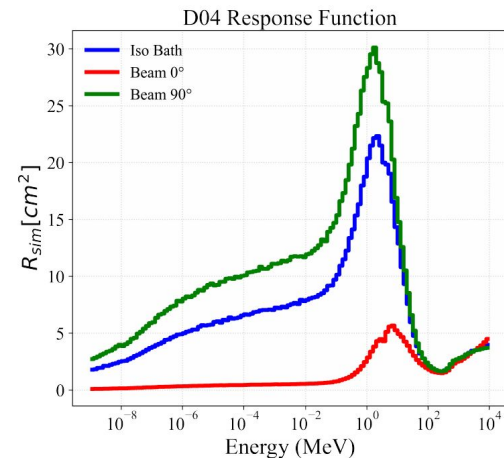
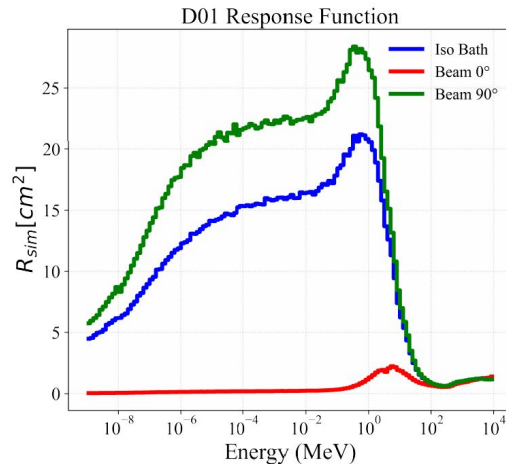
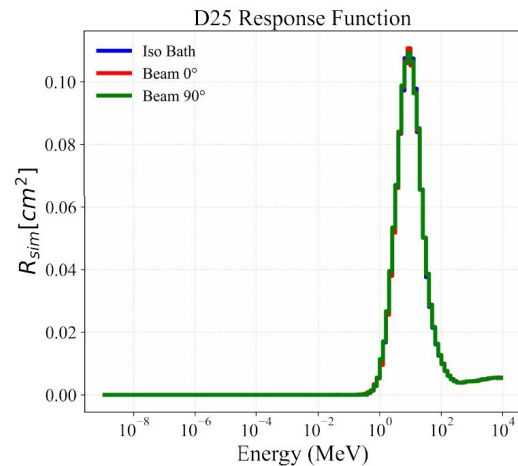
Response Function Characterization

Low neutron scattering facility @CCHEN

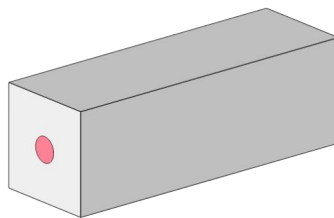


The detector is mounted on a rotating base.
Laser system: we can align the detector center to the source center.

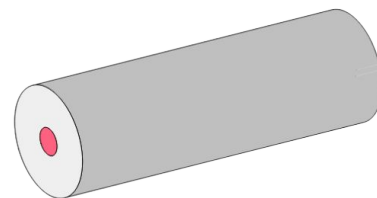
Anisotropía geométrica de detectores no esféricos



**Detector esférico
moderado**



**Detector caja
moderado**

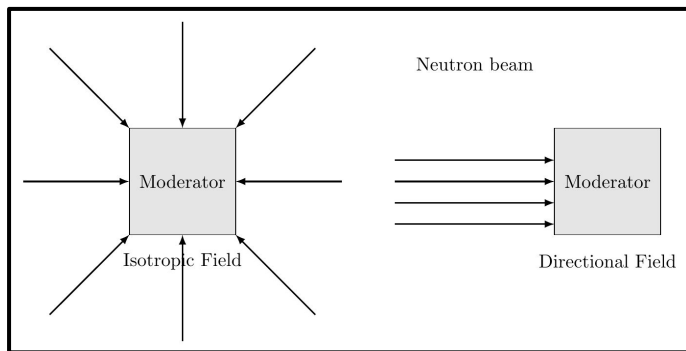


**Detector cilindrico
moderado**

Anisotropía geométrica de detectores no esféricos

Cuantificación:
Razón de anisotropía
geométrica

$$\mathcal{K} = \frac{R_{\text{BEAM}}}{R_{\text{ISO}}}$$



R_{ISO}

R_{BEAM}

Campo de neutrones
isotrópico

Campo de neutrones con
incidencia vertical sobre la
cara larga (haz de neutrones)

ID	Geometry & Description	$\mathcal{K}$
<i>CEFEN array (Non-Spherical)</i>		
D01	Box, HDPE (12 × 12 cm)	1.38
D02	Box, HDPE (10 × 10 cm)	1.37
D03	Box, HDPE (4 × 4 cm)	1.28
D04	Cyl, HDPE ($\phi = 7.5$ cm)	1.42
D05	Cyl, Al + BHDPE	1.37
D06	Box, HDPE (18 × 18 cm)	1.37
D07	Box, HDPE (20 × 20 cm)	1.36
D08	Box, BHDPE (Outer) + HDPE (Inner)	2.33
D09	Box, BHDPE (20 × 20 cm)	1.29
D10	Cyl, HDPE ($\phi = 8$ cm)	1.43
D11	Cyl, HDPE ($\phi = 6$ cm)	1.41
D12	Box, High Energy (Pb+Cd+BHDPE)	5.00
D13	Box, Graphite Core	1.80
D14	Box, HDPE Core	1.96
D15	Box, HDPE (24 × 24 cm)	1.30
D16	Cyl, Bare Counter	1.15
<i>Reference Bonner spheres (Spherical)</i>		
D20	Sphere, HDPE ($R = 3.5''$)	1.04
D21	Sphere, HDPE ($R = 4.5''$)	1.05
D22	Sphere, HDPE ($R = 6.25''$)	1.06
D23	Sphere, HDPE ($R = 12.0''$)	1.08
D24	Sphere, BHDPE ($R = 12.0''$)	1.00
D25	Sphere, BHDPE ($R = 6.25''$)	1.00
D26	Sphere, BHDPE ($R = 4.5''$)	1.00
D27	Sphere, BHDPE ($R = 3.5''$)	1.01
D28	Sphere, Vacuum (Bare)	1.00

Retomando el análisis: Unfolding

Neutron Spectra Unfolding

Neutron Counting Rate

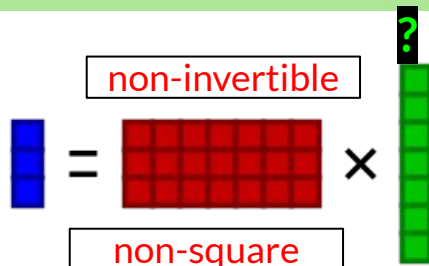
discretize

$$n_i = \int_0^{\infty} R_i(E) \phi(E) dE$$

$$n_i = \sum_{j=1}^M R_{ij} \Phi_j$$

$$\begin{pmatrix} n_1 \\ \vdots \\ n_{16} \end{pmatrix}_{16 \times 1} = \begin{pmatrix} R_1(E_1) & \cdots & R_1(E_{150}) \\ \vdots & \ddots & \vdots \\ R_{16}(E_1) & \cdots & R_{16}(E_{150}) \end{pmatrix}_{16 \times 150} \times \begin{pmatrix} \Phi(E_1) \\ \vdots \\ \Phi(E_{150}) \end{pmatrix}_{150 \times 1}$$

An underdetermined system: more unknowns than equations



Inverse Problem

Effects (CR) → Cause (Neutron flux)

We have: Counting rates & response functions

- Ideally, we want a solution that fits the data while remaining physically plausible.

Maximum Likelihood Expectation Maximization (MLEM)

Iterative algorithm for finding maximum likelihood solutions in problems that contain incomplete observations

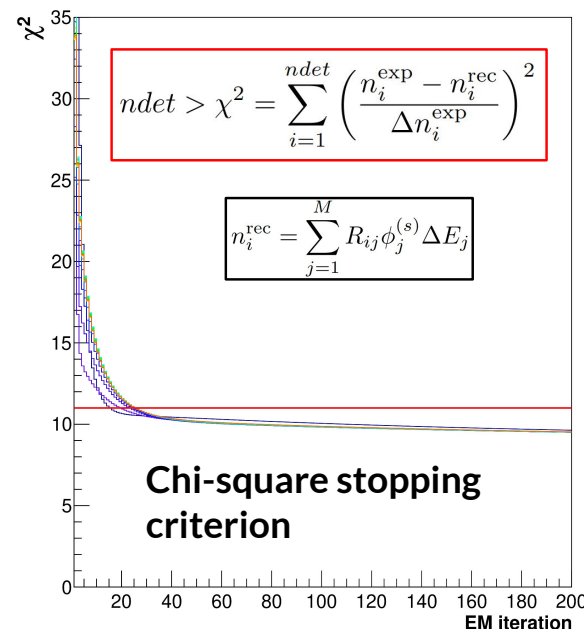
Any histogram that maximizes the log-likelihood of the unfolding problem is called a maximum likelihood estimator $\hat{\phi}_{ML}$ f ϕ

The ML estimate can always be found computationally by using the expectation-maximization (EM) algorithm (Dempster et al. (1977))

$$\phi_j^{(s+1)} = \frac{\phi_j^{(s)}}{\sum_{i=1}^N R_{ij}} \sum_{i=1}^N \frac{R_{ij} n_i}{\sum_{k=1}^M R_{ik} \phi_k^{(s)} \Delta E_k}$$

To avoid overfitting, we applied **regularization** techniques

Early stopping: stop when the output no longer improves



Maximum Likelihood Expectation Maximization (MLEM)

$$\phi_j^{(s+1)} = \frac{\phi_j^{(s)}}{\sum_{i=1}^N R_{ij}} \sum_{i=1}^N \frac{R_{ij} n_i}{\sum_{k=1}^M R_{ik} \phi_k^{(s)} \Delta E_k}$$

1) Chi-square
stopping criterion

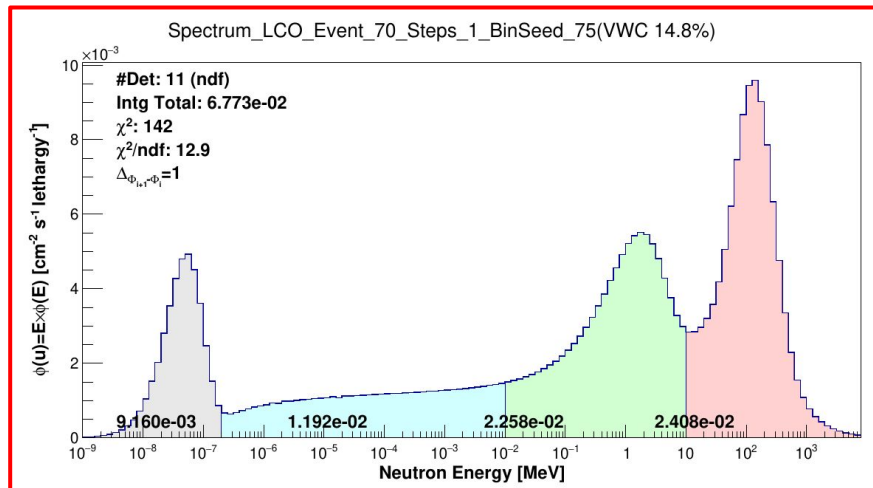
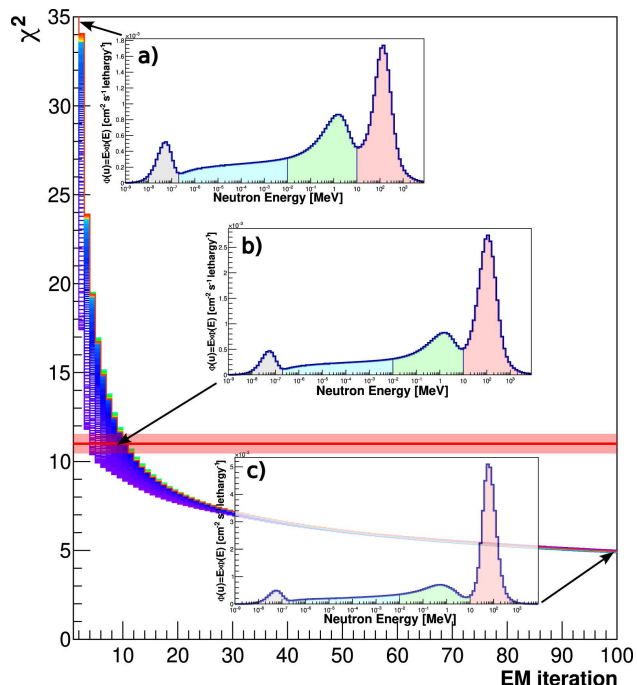
$$ndet > \chi^2 = \sum_{i=1}^{ndet} \left(\frac{n_i^{\text{exp}} - n_i^{\text{rec}}}{\Delta n_i^{\text{exp}}} \right)^2$$

$$n_i^{\text{rec}} = \sum_{j=1}^M R_{ij} \phi_j^{(s)} \Delta E_j$$

2) Diff stopping
criterion

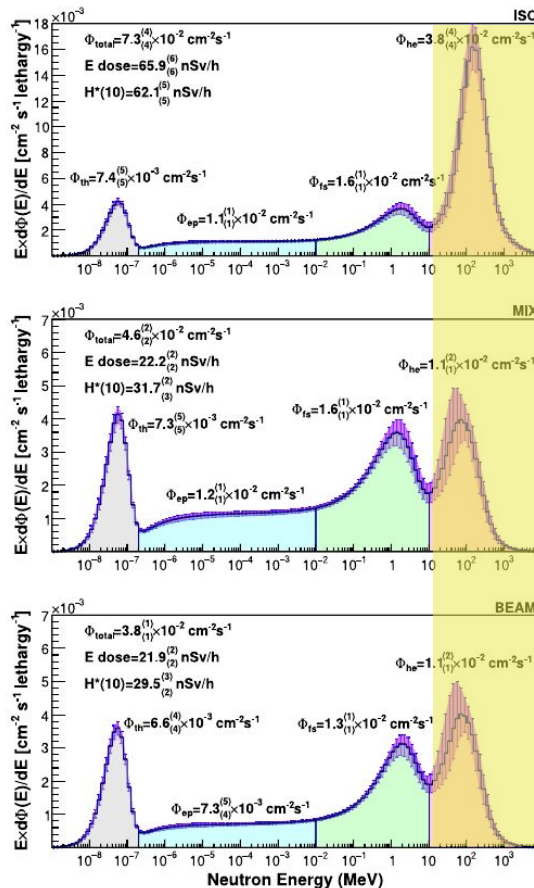
$$\Delta\Phi = \frac{\sum_{j=1}^{M=129} |\Phi_j^{(s+1)} - \Phi_j^{(s)}|}{\sum_{j=1}^{M=129} \Phi_j^{(s)}} < 0.02$$

3) #iterations (MLEM) < 20



Retomando el análisis: Resultados

Robustez de la razón espectral y rol de la anisotropía



Funciones respuesta, uso de 3 hipótesis

-Caso isotrópico (ISO): $k=1$

-Caso haz (BEAM): $k = \text{valores tabla}$,

-Caso mezcla (MIX) :

peak RF > 10 MeV -> k tabla (BEAM)

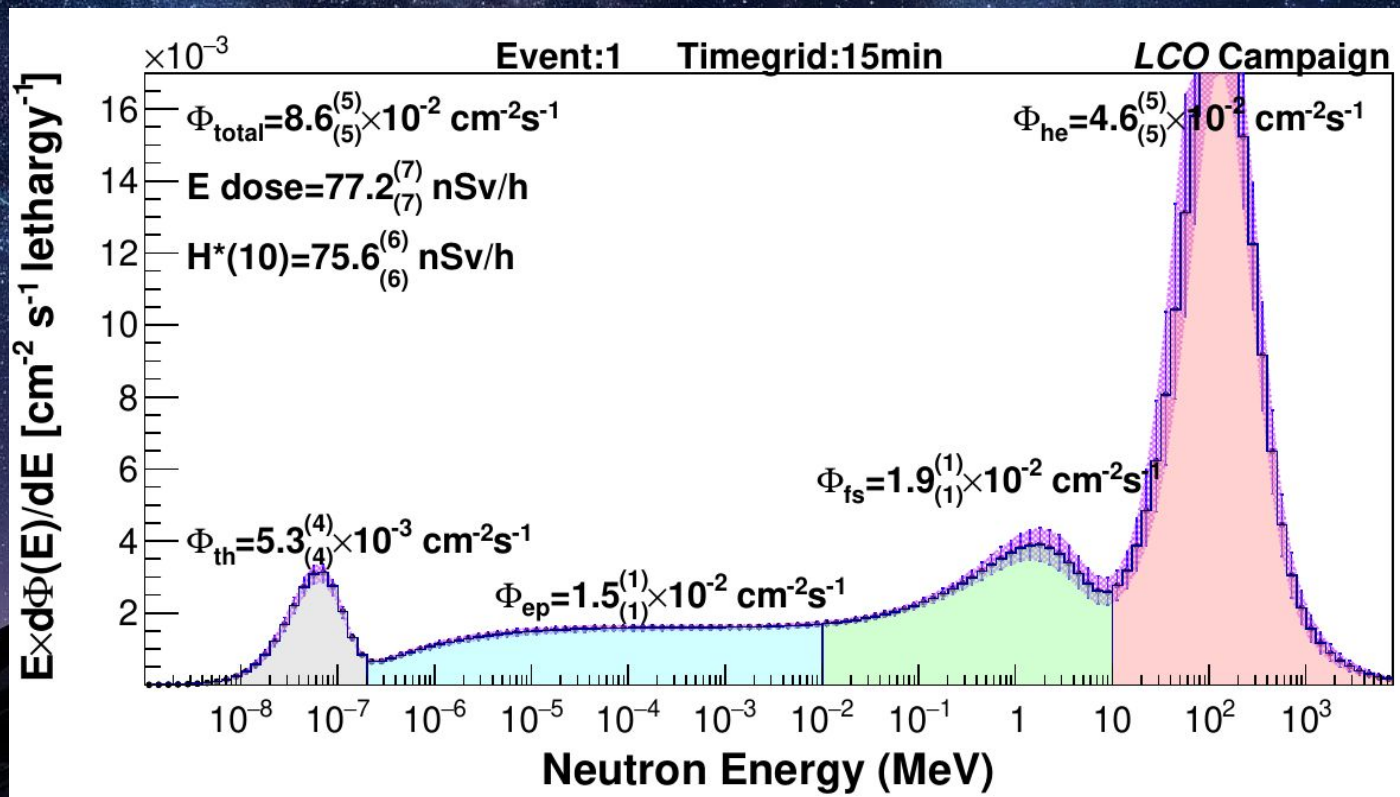
peak RF < 10 MeV -> $k = 1$ (ISO)

Región de alta energía (> 10 MeV) sensible a anisotropía: Hipótesis angular del campo y geometría del detector: factor ~3-5 veces ISO c/r BEAM/MIX

La razón espectral R se mantiene robusta: +34% a +43% (aumento después de lluvia y nieve)

$$\mathcal{R}(t) \equiv \frac{\Phi_{\text{th}}}{\Phi_{\text{ep}} + \Phi_{\text{fs}}}$$

Espectro de neutrones en LCO cada 15 minutos



¿Qué le pasa al espectro cuando cambia el ambiente local?

Φ_{total}

Total

Φ_{th}

Thermal

Φ_{ep}

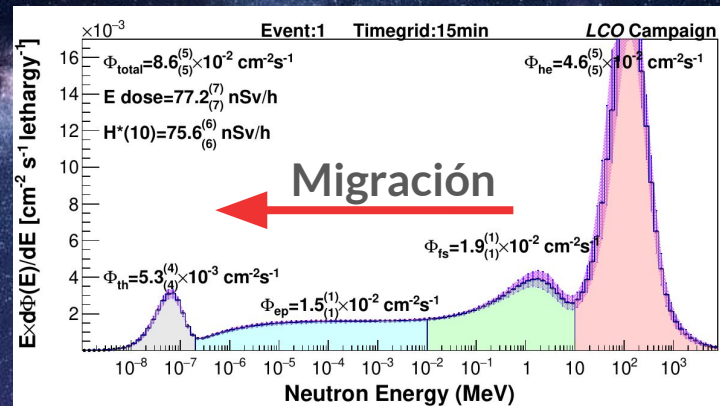
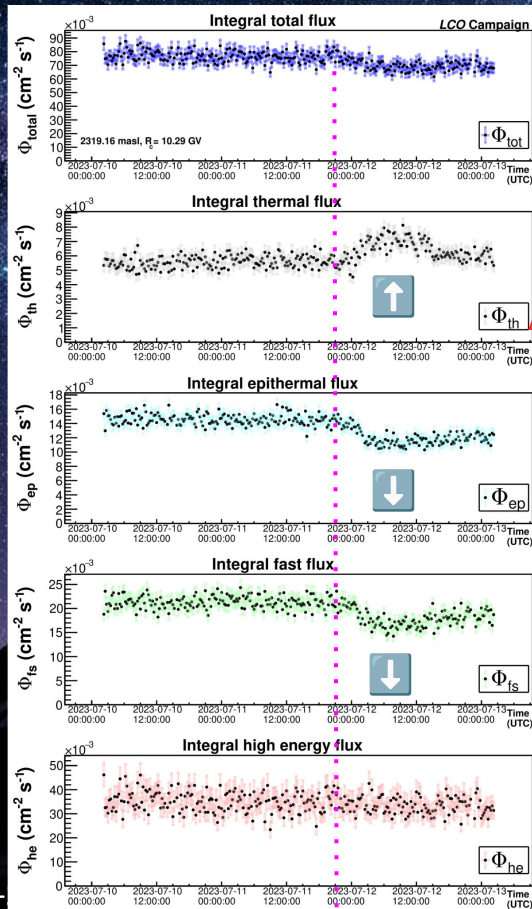
Epithermal

Φ_{fs}

Fast

Φ_{he}

High
energy



Flujo neutrones térmicos



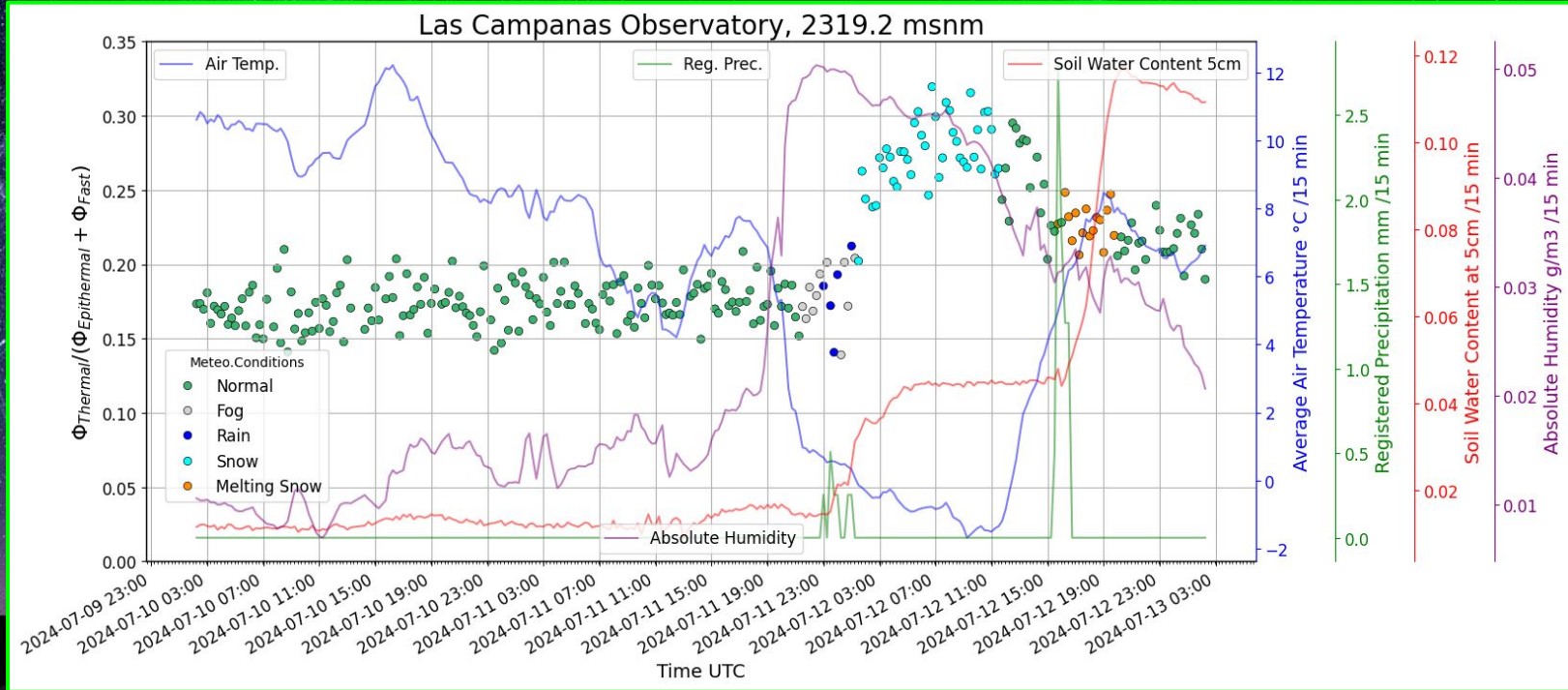
Flujo de neutrones epitermicos
y rápidos

Inicio: Lluvia
& nevazón

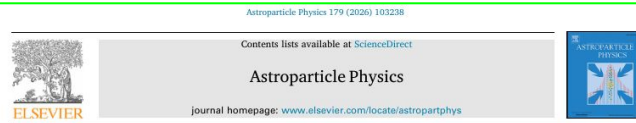
francisco.molina@cchen.cl

propusimos un observable

$$\mathcal{R}(t) \equiv \frac{\Phi_{\text{th}}}{\Phi_{\text{ep}} + \Phi_{\text{fs}}}$$



Publicación 2026



Field neutron spectroscopy of cosmic-ray neutrons in Chile using the CEFNEN portable spectrometer: Instrumentation and test at Las Campanas Observatory (2320 m.a.s.l.)

F. López-Usquiano ^{a,b,c}, F. Molina ^{a,b,c}, J. Romero-Barrientos ^{a,b}, M. Zambra ^{a,d},
J. Ruiz-Pineda ^{a,e}, P. Aguilar ^a, L.A. González-Saavedra ^{c,b,a}, V. Millar-Bravo ^{c,b,a},
F. Aguilar-Carvaial ^{a,b,d}, G. Prieto ^g

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² Las Campanas Observatory, Carnegie Institution of Washington, Raúl Bitrán 1200, La Serena, Chile

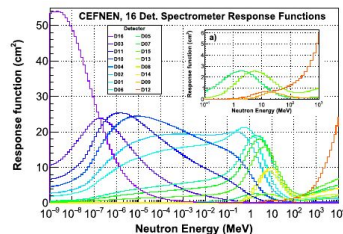
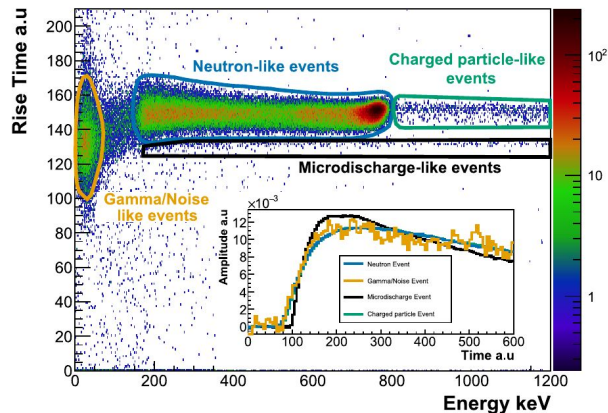
DOI: <https://doi.org/10.1016/j.astropartphys.2026.103238>

Fig. 1. Detection response functions calculated by Geant4

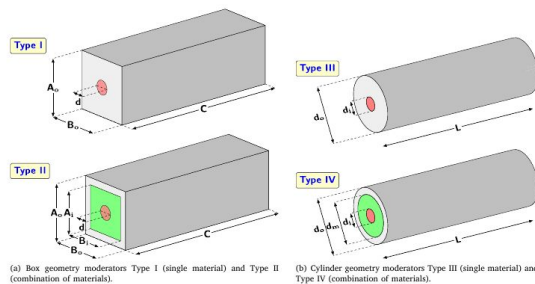


Fig. 2. Different types of moderators geometries used at CEFNEN neutron spectrometer

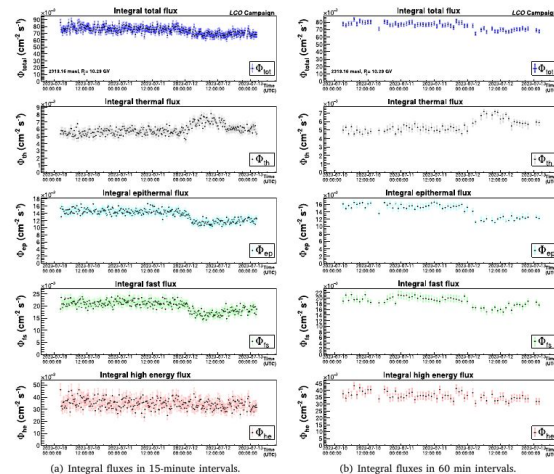


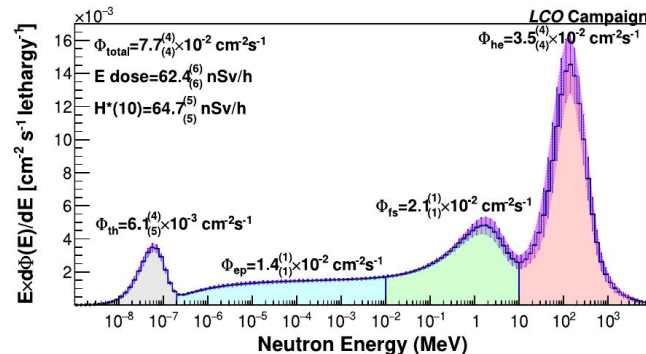
Fig. 11. Time series of integral neutron fluxes at LCO by energy region, accumulated over 15 and 60 min.

$$\mathcal{R}(t) \equiv \frac{\Phi_{\text{th}}}{\Phi_{\text{ep}} + \Phi_{\text{fs}}}$$

Razón espectral

$$\mathcal{K} = \frac{R_{\text{BEAM}}}{R_{\text{ISO}}}$$

Razón de anisotropía geométrica



Futuro

- (Presente) Análisis 6/18 campañas
- (Presente) Colaboraciones internacionales. Simulaciones MC (Luigui M./Christian S.) + detectores complementarios (WCD). Nuevas ideas y aplicaciones.



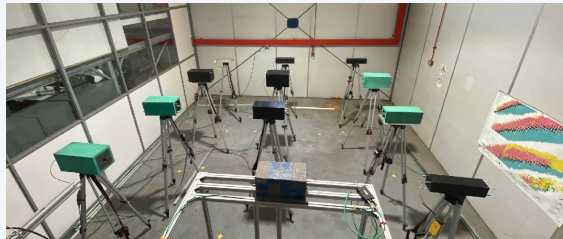
Escuela Latinoamericana
de Rayos cósmicos y sus aplicaciones



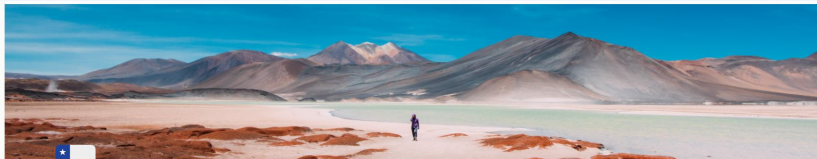


Muchas Gracias





Thank you very much



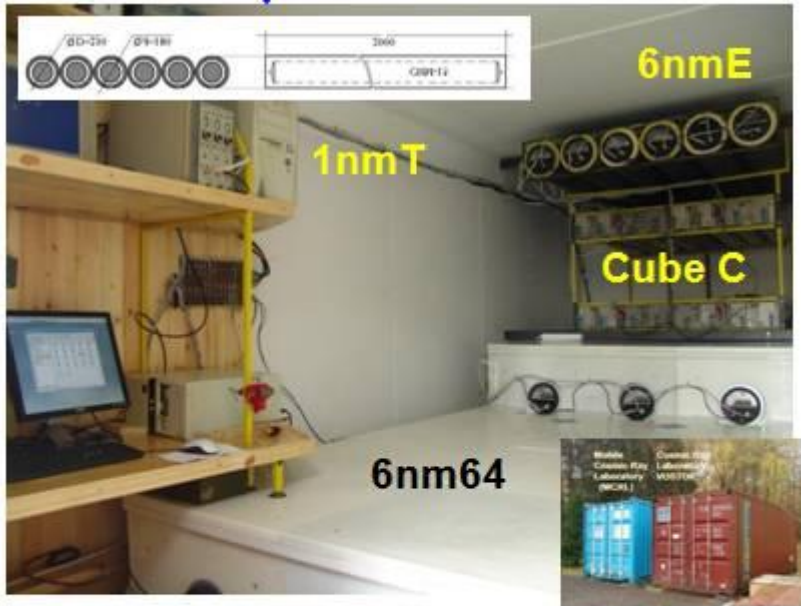
Cosmic Ray Neutron Spectroscopy and Local Variables simultaneous measurement studies throughout Chile

Area: Física Nuclear Fundamental, Física Nuclear Aplicada, Espectroscopia de Neutrones, Instrumentación Nuclear, Dosimetría de Neutrones, Simulaciones Monte Carlo
CEFEN Project: Fondo de neutrones cósmicos, Simulaciones Monte Carlo

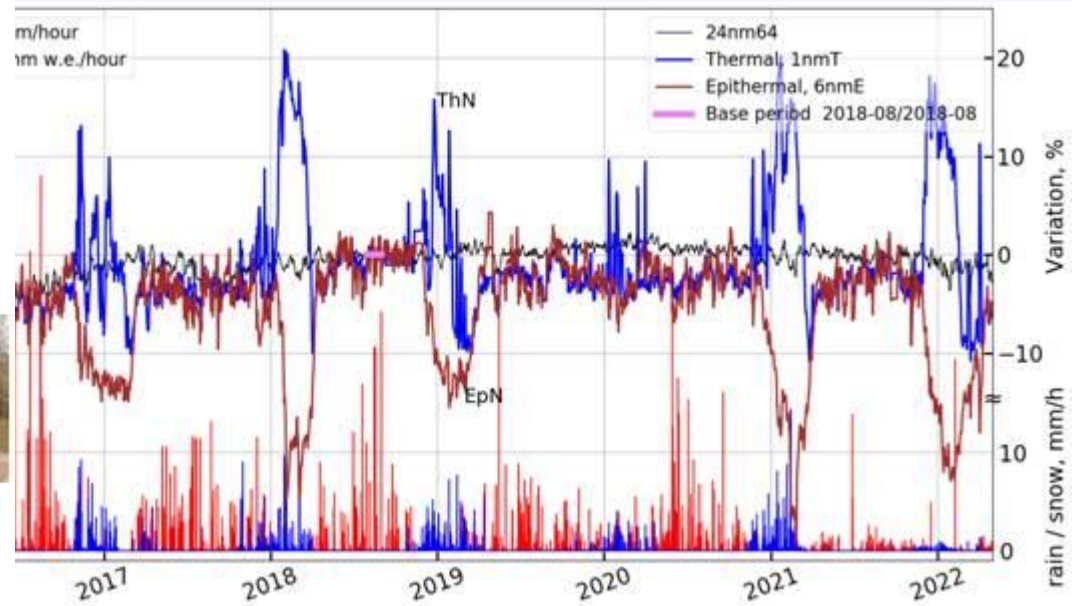




Internal Communication with V. Yanke



Epithermal neutron fluxes



Motivation: Ground Cosmic Rays Neutron Flux PARMA



The neutron spectra in ground measurements depends on:

s (solar activity), r_c (geomagnetic rigidity), d (atmospheric depth), E (neutron energy) and w (soil humidity).

Simulation of Extensive Air Showers (EAS) using PHITS

- Atmosphere 28 concentric spherical shells. Max altitude 86 km. Each shell density according to US Standard Atmosphere 1976
- Earth is a sphere with $r=6378.14$ km, 60% SiO_2 , 20% Al_2O_3 , 20% H_2O (w)
- Primary Cosmic Rays: from H to Ni ($Z=1-28$) with energies up to 1 TeV.

2015

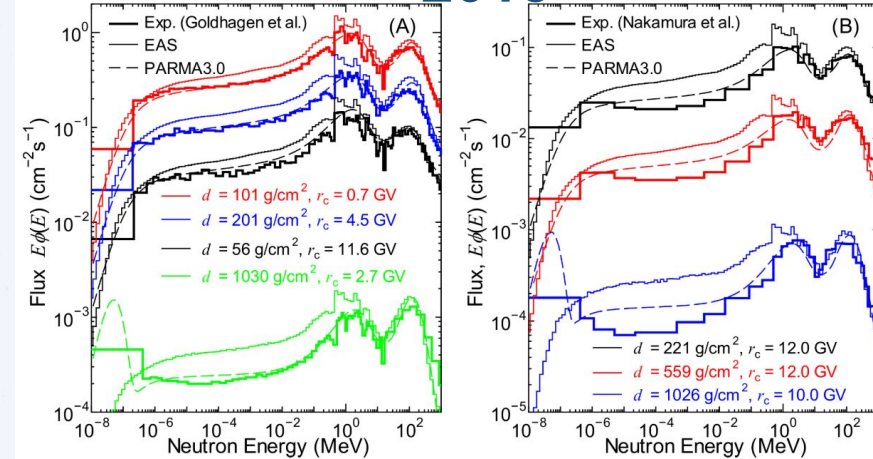


Fig 2. Neutron fluxes measured in aircraft as well as on ground [42,43] in comparison with corresponding calculated data obtained from EAS simulation and PARMA3.0.

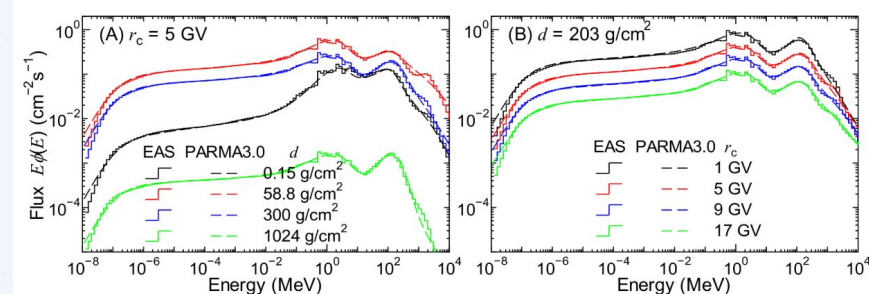
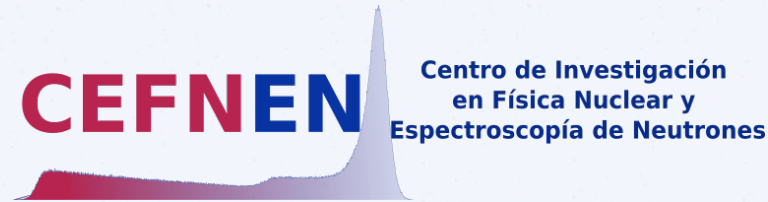


Fig 11. Neutron fluxes obtained by EAS simulation and those calculated using PARMA3.0. The left and right panels show the atmospheric depth and the vertical cut-off rigidity dependences of the fluxes, respectively.

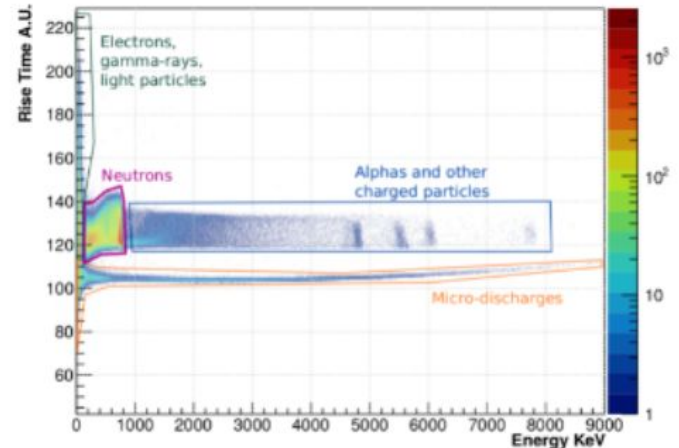
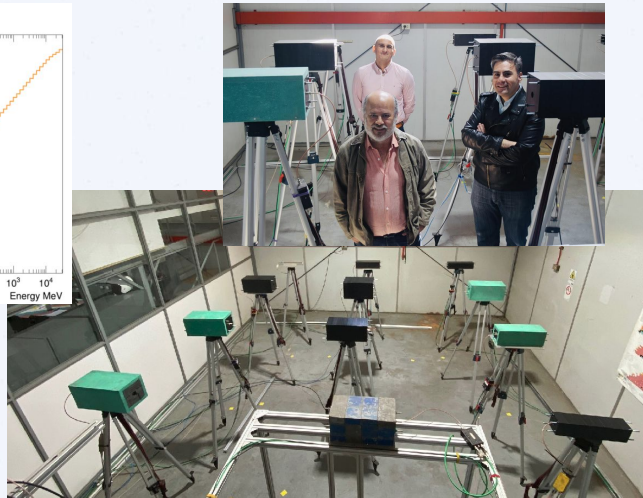
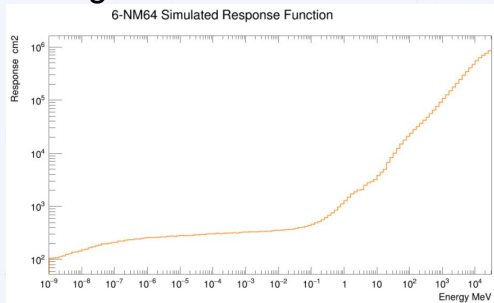
doi:10.1371/journal.pone.0144679.g011

Chasing neutron throughout Chile

Francisco Molina, Marcelo Zambra and Jaime Romero



Abstract: In this webinar we invite you to a journey that starts at CCHEN, implementing and developing a neutron spectrometer based on Bonner' sphere method to characterize reactor neutron beams and pulsed neutrons fusion sources. During COVID-19 lockdown this equipment was set to measure environmental neutrons produced by cosmic rays when a misinterpreted phenomena motivates the idea and objectives of a new project that implies to haul approximately a ton of gear across the diverse geography of our country. The expected results will probably do not led into a new physics but will help to count neutrons properly and disentangle the neutron flux dependence on the local variables such soil type, soil humidity, temperature, among others.



Webinar Chasing neutrons throughout Chile

0.- What is a neutron

1. Neutrons where to find them?,

1. In Nature: In Stars, Supernovae, Cosmic Rays
2. In Manmade controlled Nuclear Reactions: Fission (Nuclear Reactors), Fusion (Fusion Reactors), Alpha (Standard neutron sources), Spallation sources,

2. Neutrons how to detect them?

1. Interaction with Matter
2. Scintillator detectors, Proportional counters, Recoil, Passive detectors

3. Neutrons what you can do with them? (Hacer para PUC, quizás ocultar para el WEBINAR)

1. Non destructive analysis: Diffraction, Activation, radiography/tomography
2. Cancer treatment. BNST
3. Radiomedicines
4. Referencia al ILL

4. How to measure a neutron energy?

1. Neutron energy regions (también en 2.1 junto con Sección eficaz)
2. TOF
3. Recoil Emulsions
4. Bonner Spheres Spectrometer

5. The CCHEN Nuclear Research Lab Neutron Spectrometer

1. Geometry and Materials used
2. Uses: Characterization of RECH-1 beam line and Pulsed Neutron Spectroscopy of Plasma Focus device
3. Ambiental neutrons after March 2020. Motivation for the Cosmic Neutron Project

6. Chasing Neutrons Throughout Chile

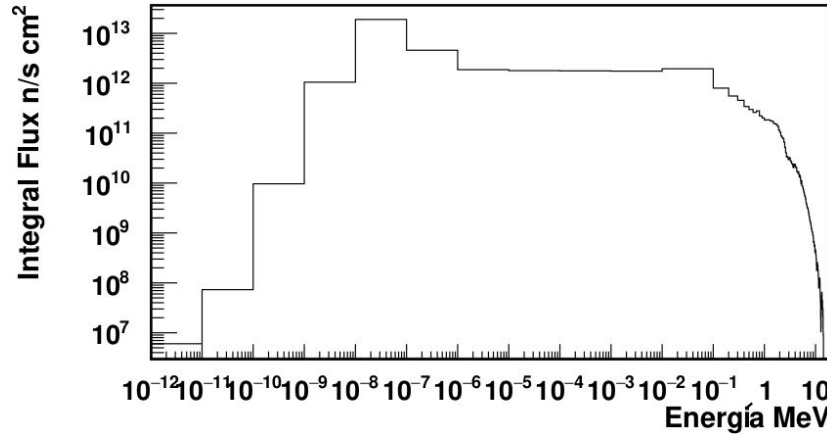
1. The Idea and objective

1. why in Chile? (Latitude Longitude and Geomagnetic rigidity) -> Cosmic neutron fluxes dependencies> (s,d,rc,E,w)
2. Neutrons, the soil and environmental variables
3. Neutron Monitors NMDB and reported stations

Extrapolación a 5 MW

5.4 Obtención del flujo integral de neutrones

- Se utiliza el método de máxima expectación.
- Se utilizaron las tasas de conteo de neutrones corregidas, las sensibilidades de detección y el flujo semilla obtenido desde MCNP6.



$$n_{\lambda_i}^* = \sum_j^N S_{ij} \phi_j \Delta E_j$$

