Spectrometry of cosmic-ray neutrons with HENSA++: project status and future developments

Author: A Quero-Ballesteros

Co-authors: A Tarifeño, N Mont, J L Taín, A M Lallena and the HENSA collaboration

Junta de Andalucía

UNIVERSIDAD DE GRANADA

VNIVERSITAT DE VALÈNCIA

IFIC INSTITUT DE FÍSICA CORPUSCULAR

HENSA High Efficiency Neutron Spectrometry Array

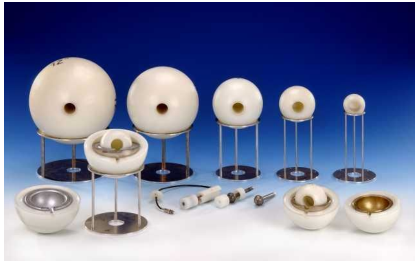
CSIC Consejo Superior de Investigaciones Científicas

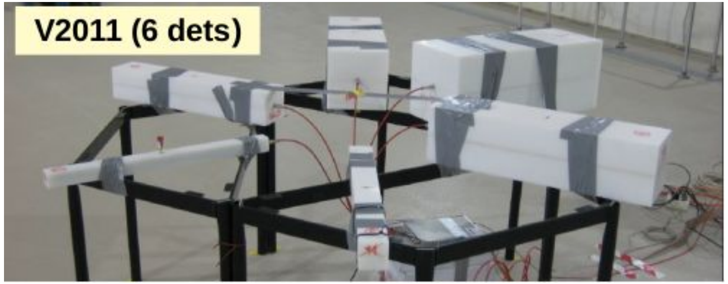
Outline

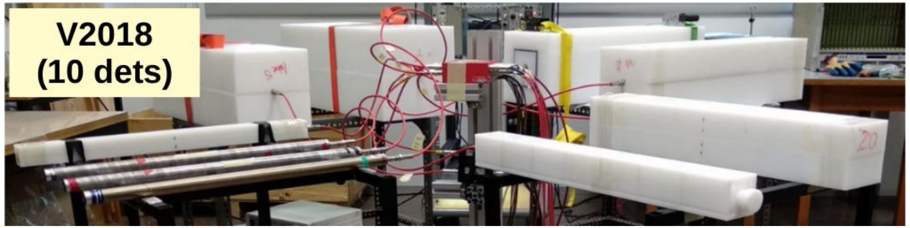
- The HENSA project
- Cosmic-ray neutrons
- HENSA measurement campaign 2020
- HENSA++ project
- Preliminary unfolding tests with HENSA++

The HENSA project: Introduction

- HENSA: "High Efficiency Neutron Spectrometry Array"
- Collaboration: 8 institutions, ~20 researchers
- Detection principle based on Bonner Sphere Spectrometers (BSS). Topology modification.
- Energy resolution from meV to GeV
- Special interest on underground facilities and cosmic-ray neutrons



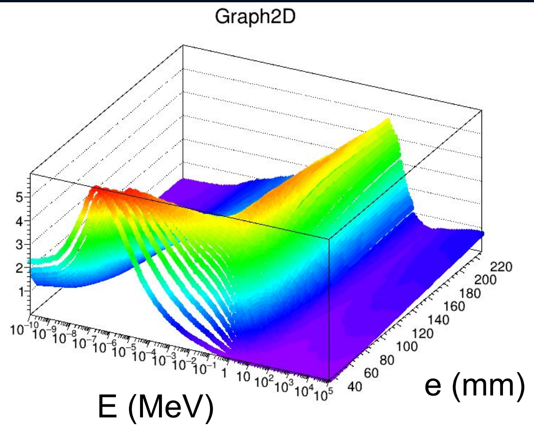




The HENSA project: Detection principle and Reconstruction

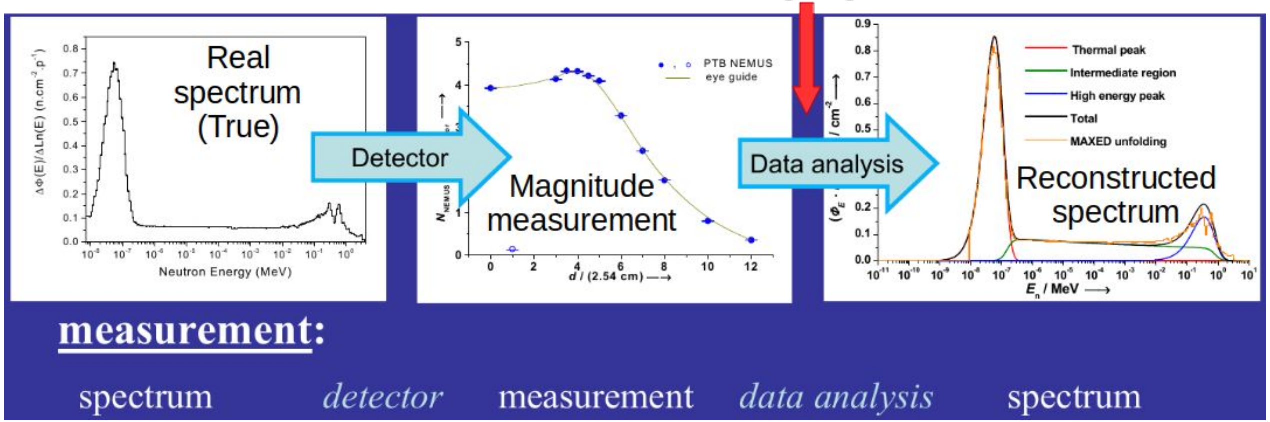
- **Detection principle** (BSS):

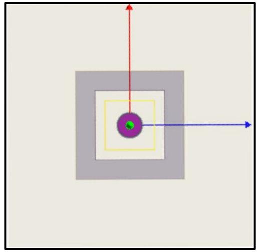
Counter with high sensitivity to thermal neutrons + Materials with a good moderation-capture ratio and metal converters → Sensitivity from thermal to GeV neutrons



- **Spectrum reconstruction**:

Unfolding algorithm

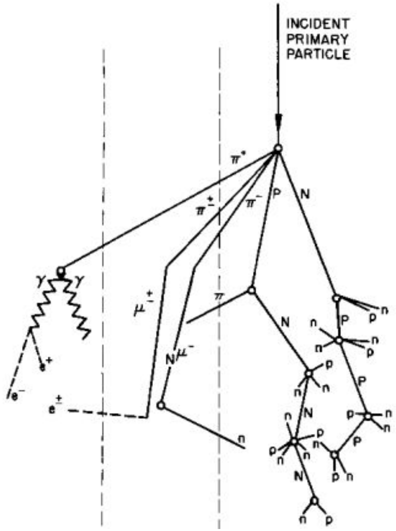


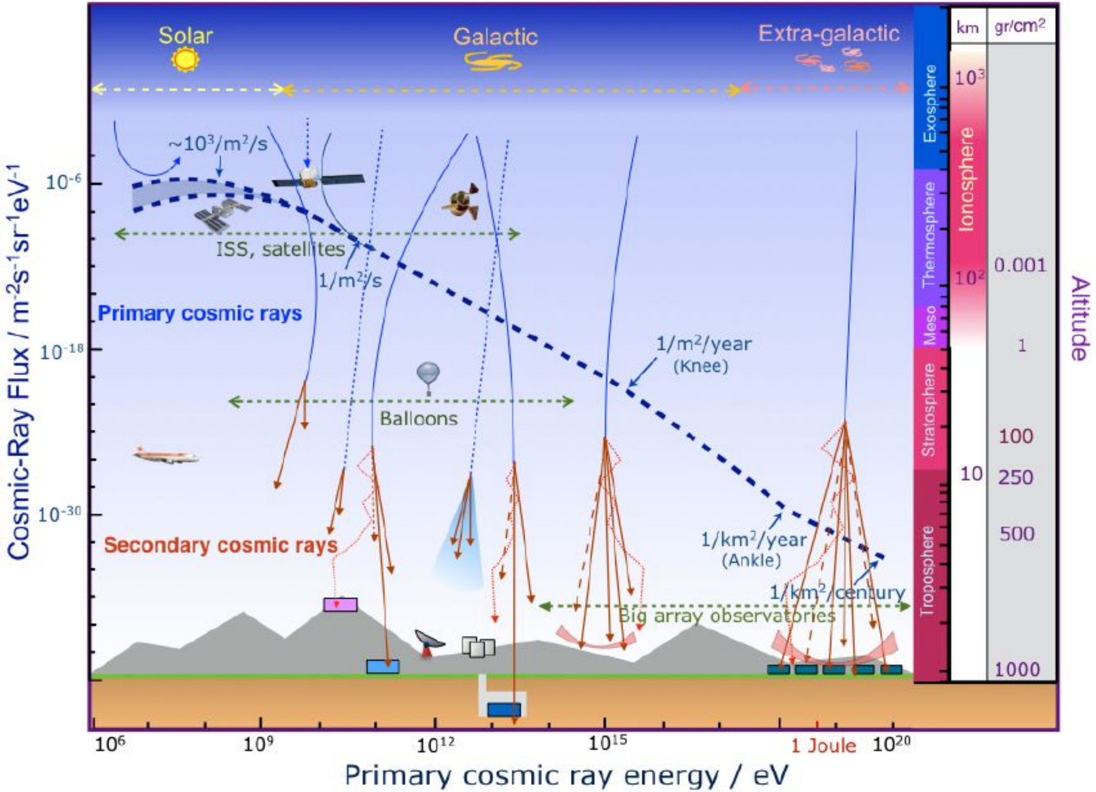


Cosmic-ray neutrons: Origin

- Primary cosmic-rays: protons, He nucleus

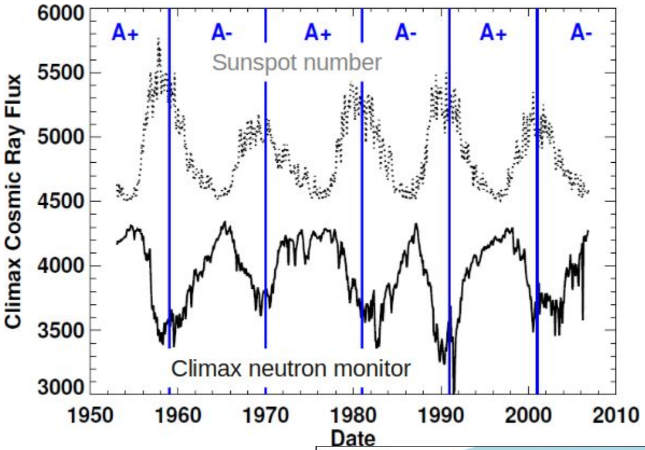
- Neutrons are produced as secondaries

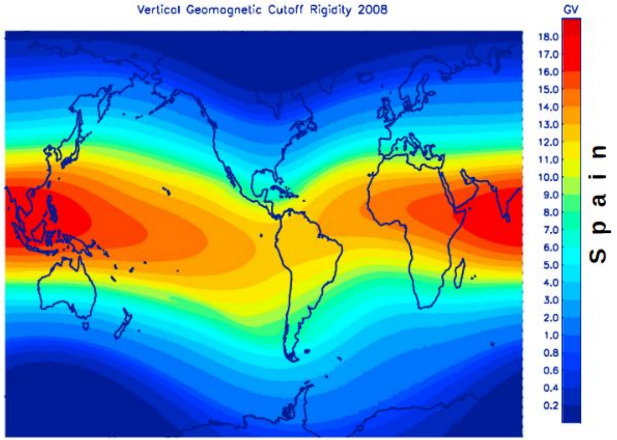


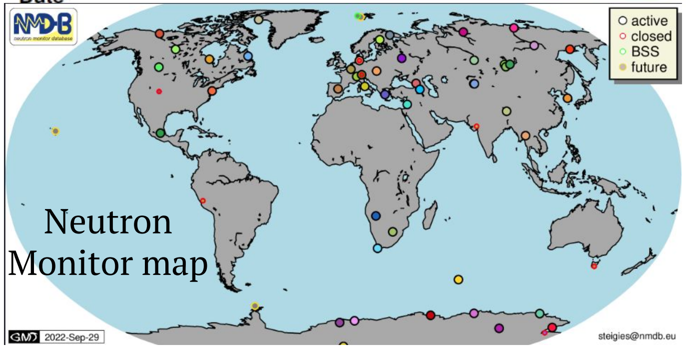


Cosmic-ray neutrons: Interest

- Monitor solar activity
- Detect Forbush Decreases and Ground Level Enhancements
- Complement Neutron Monitors information
- Spanish territory covers a wide range of Rc (5-12 GV) in comparison with USA (1.5-4.5 GV)

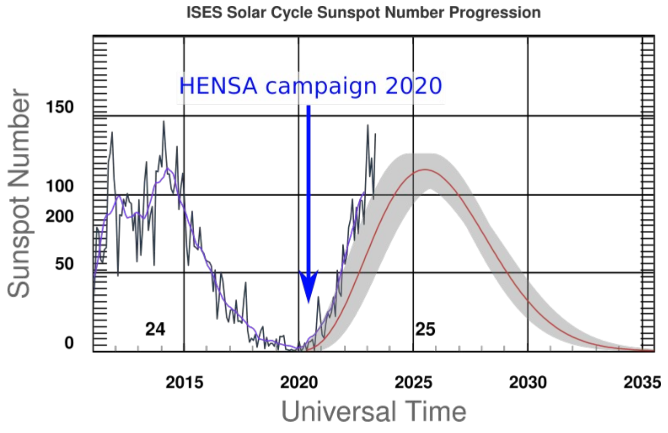


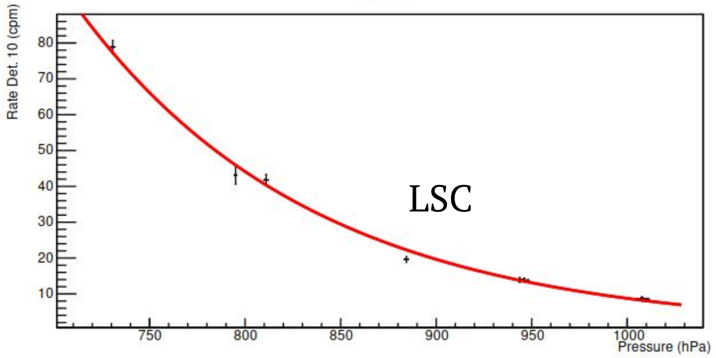




Neutron Monitor map

HENSA measurement campaign 2020





HENSA campaign along the **Spanish territory** close to the minimum of solar activity (2020, solar cycle #25)

Cosmic ray induced neutron background
+ Cosmic ray physics and space weather
+ Environmental radiation dosimetry
+ Single-event upsets in microelectronics

HENSA
High Efficiency Neutron Spectrometry Array

www.hensaproject.org

N. Mont (PhD)

IFIC INSTITUT DE FÍSICA CORPUSCULAR
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
VNIVERSITAT DE VALÈNCIA

HENSA++ project

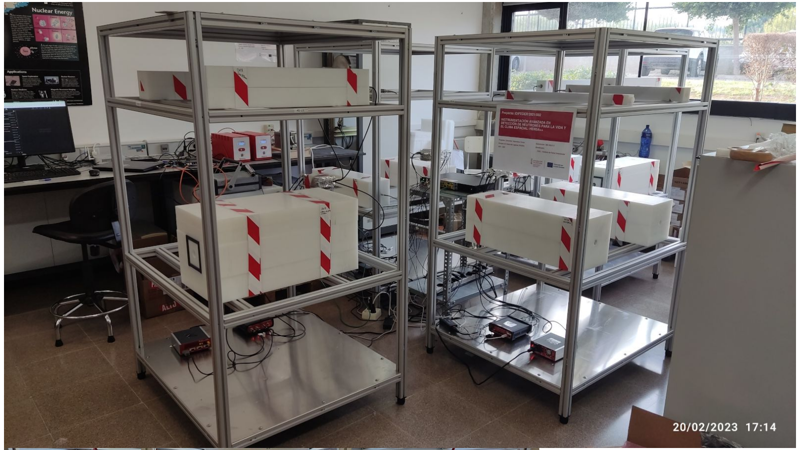
- Intended to improve "poor" resolution in HENSA-V2019 (10 dets → 15 dets).
- Setup designed to measure cosmic-ray neutrons in a high altitude facility
- Precision data on neutron flux variations ~1h

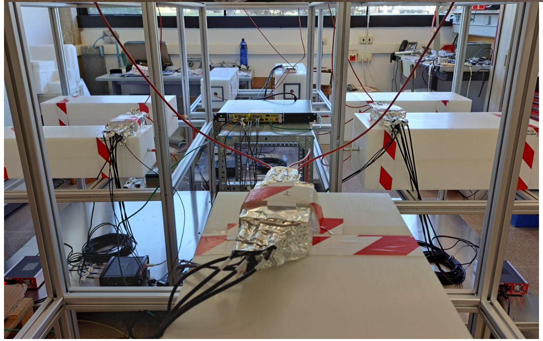
Proyecto: IDIFEDER/2021/002

INSTRUMENTACIÓN AVANZADA EN DETECCIÓN DE NEUTRONES PARA LA VIDA Y EL CLIMA ESPACIAL: HENSA++

Programa Comunitat Valenciana Fondo Europeo de Desarrollo regional (FEDER)
2021 - 2027

Subvención: 260.199,21 €
Beneficiario:
CSIC – Instituto de Física Corpuscular

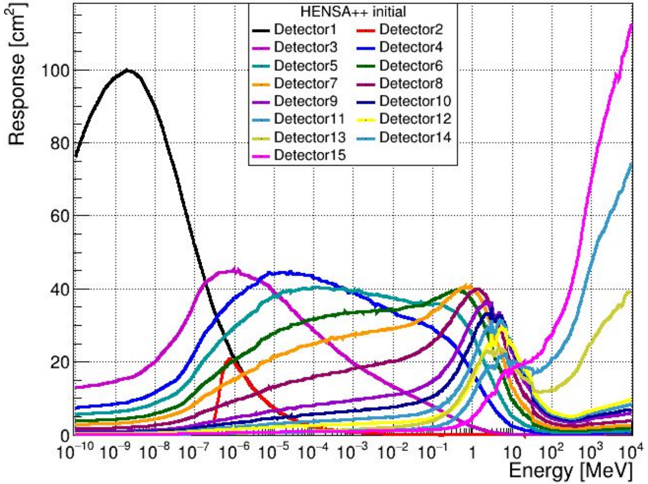




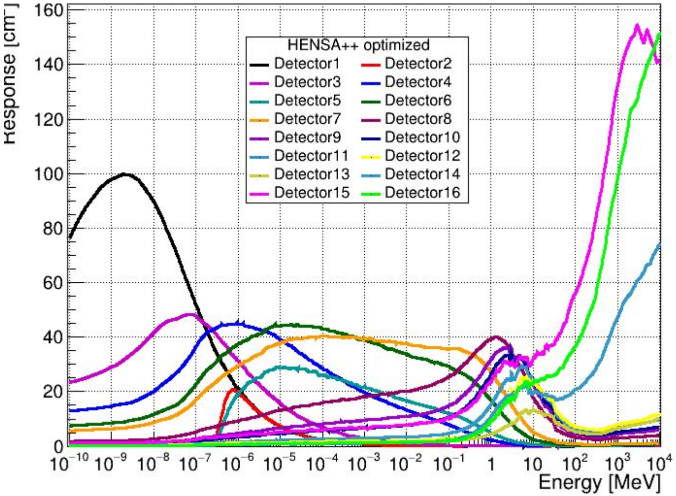
HENSA++ setup (IFIC Gamma & Neutron Lab)

HENSA++ project: Response matrix

HENSA++ proposal design



HENSA++ optimized version

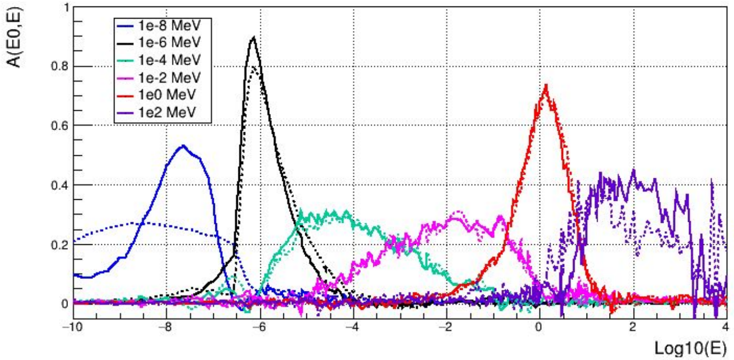


- Explored hundreds of configurations via Monte Carlo calculations
- Optimization based on improving the resolving power of the array & tradeoff with technical viability (construction & weight)

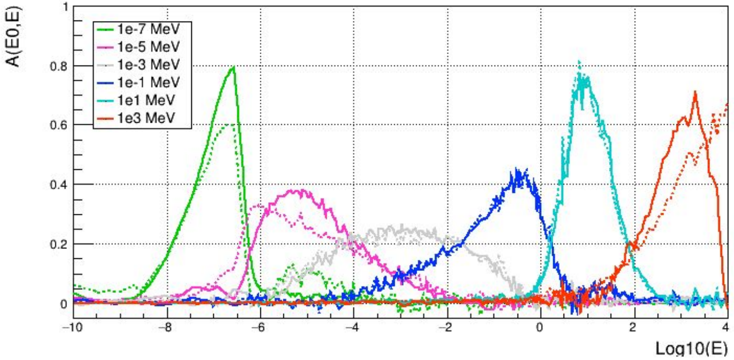
MC simulations performed with the Geant4 application ***ParticleCounter***

Particle Counter

HENSA++ project: Resolving power optimization



Dotted: Initial | Continuous: Optimized



LogE	Mean(vInit)	Mean(vOpt)	SD(vOpt)/SD(vInit)-1
-8	-7.72	-7.69	-44.20%
-7	-6.76	-6.86	-51.11%
-6	-5.76	-5.89	-20.37%
-5	-4.93	-4.86	-24.11%
-4	-3.93	-3.98	-4.65%
-3	-3.00	-2.98	-8.27%
-2	-2.07	-2.08	-2.13%
-1	-1.12	-1.09	2.56%
0	-0.08	-0.09	-1.71%
1	0.91	0.94	-2.15%
2	1.43	1.72	-38.90%
3	2.71	2.73	-39.72%

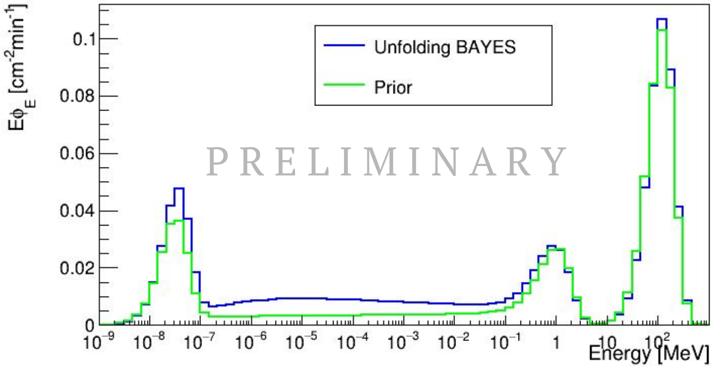
ELSEVIER
Nuclear Instruments and Methods in Physics Research A 480 (2002) 690–695
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

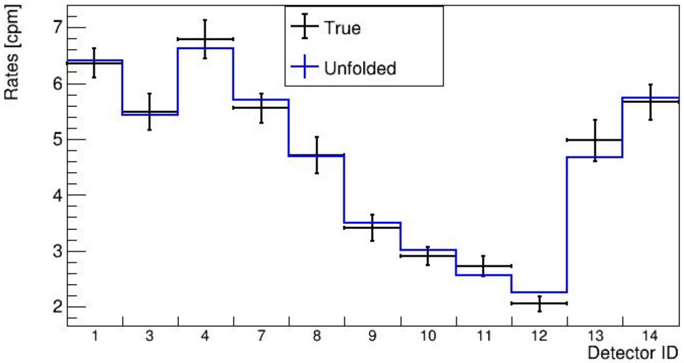
Resolving power of a multisphere neutron spectrometer

Marcel Reginatto*

$$< \phi >_{E_0} = \int A(E_0, E)\phi(E)dE$$

Preliminary unfolding test with HENSA++





-) Unfolding IFIC Lab Data 22May-03Jun

-) Deconvolution via BAYES algorithm (Expectation Maximization)

-) HENSA++ initial setup

-) Removed detectors 5, 6, 15

-) High energy peak dominates (concrete surrounding the laboratory)

D'Agostini, G (1995). Nuclear Instruments and Methods in Physics Research Section A 362(2-3), 487-498.

Taín, J. L., & Cano-Ott, D. (2007). Nuclear Instruments and Methods in Physics Research Section A. 571(3), 728-738.

Acknowledgements

- Ayudas predoctorales de la Junta de Andalucía. Convocatoria 2021. PREDOC _00231

Junta de Andalucía

- Proyecto IDIFEDER/2021/002: “INSTRUMENTACIÓN AVANZADA EN DETECCIÓN DE NEUTRONES PARA LA VIDA Y EL CLIMA ESPACIAL: HENSA++”. Generalitat Valenciana. IFIC, CSIC-UV.

GENERALITAT VALENCIANA

UNIÓN EUROPEA
Fondo Europeo de Desarrollo Regional (FEDER)
Una manera de hacer Europa

Thanks for your attention

Back up

HENSA setup

"Passive" part

Detector name	Material of the coat	Dimensions
Det1	Bare	-
Det2	HDPE	… 0 cm³
Det3	HDPE	7x7x70 cm³
Det4	HDPE	12x12x70 cm³
Det5	HDPE	18x18x70 cm³
Det6	HDPE	22.5x22.5x70 cm³
Det7	HDPE	27x27x70 cm³
Det8	HDPE + Pb	… mm Pb thickness
Det9	Cd	0.5mm thickness
Det10	HDPE + Pb + Cd	25x25x70 cm³ + 0.75mm Cd +10mm Pb

Moderator

Metal shell

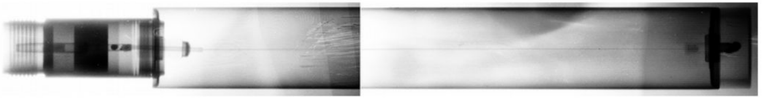
"Active" part

- He-3 cylindrical detector tube model: LND-252248 (10 atm)
- Nuclear reaction:

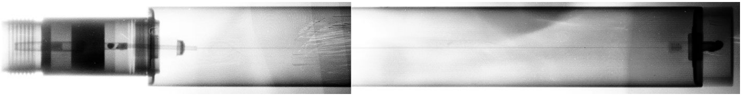
$$^3He + n \rightarrow ^3H + p \quad (Q = 0.764\ MeV)$$

- Thermal neutrons cross section:

$$\sigma_{thermal} = 5330\ barns$$



HENSA setup: “active part”



Detection reaction:

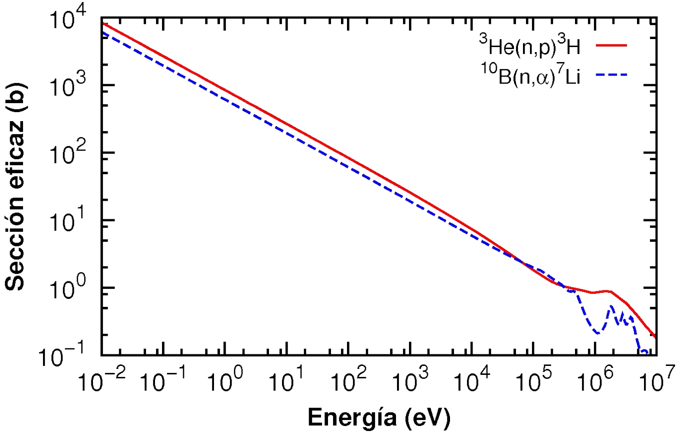
$$^{3}He + n \rightarrow {}^{3}H + p \qquad Q = 0.764\ MeV$$

High Thermal cross section!!: 5330b

Table 13-1. Neutron and gamma-ray interaction probabilities in typical gas proportional counters and scintillators

Thermal Detectors	Interaction Probability: Thermal Neutron	Interaction Probability: 1-MeV Gamma Ray
^{3}He (2.5 cm diam, 4 atm)	0.77	0.0001
Ar (2.5 cm diam, 2 atm)	0.0	0.0005
BF_3 (5.0 cm diam, 0.66 atm)	0.29	0.0006
Al tube wall (0.8 mm)	0.0	0.014
Fast Detectors	**Interaction Probability: 1-MeV Neutron**	**Interaction Probability: 1-MeV Gamma Ray**
^{4}He (5.0 cm diam, 18 atm)	0.01	0.001
Al tube wall (0.8 mm)	0.0	0.014
Scintillator (5.0 cm thick)	0.78	0.26

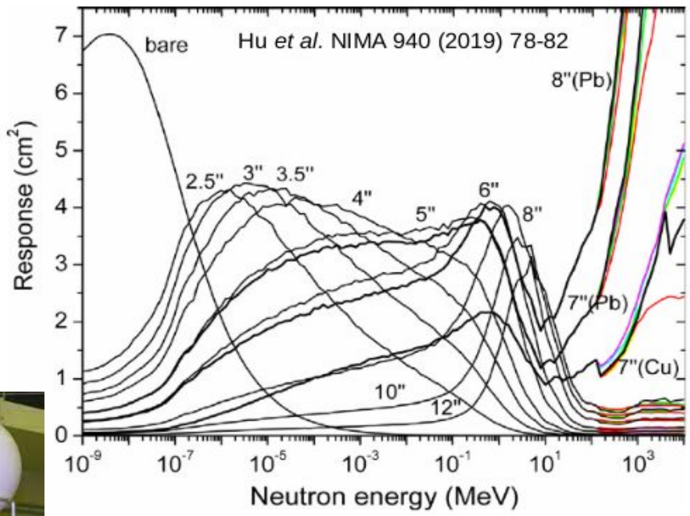
*Extracted from Neutron Detectors, T. W. Crane and M. P. Baker



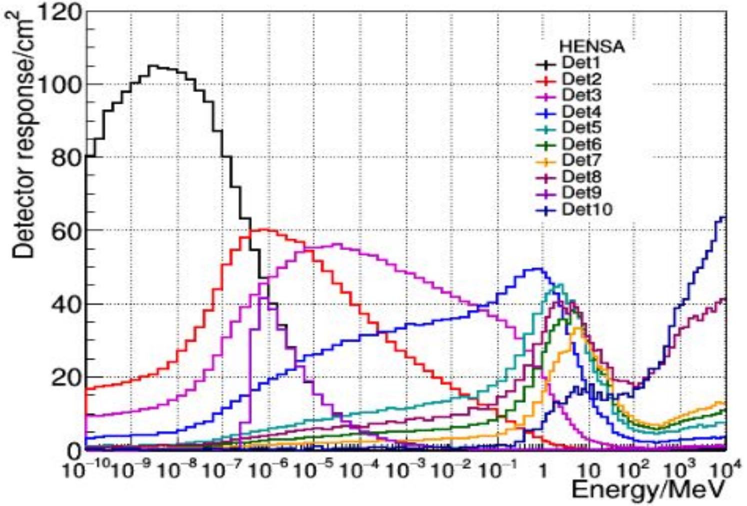
- These neutron counters are gaseous ionization detectors that use 3He as converting gas.
- Due to the high thermal capture cross section, 3He filled counters have a high neutron sensitivity.
- For non-thermal neutrons, the high efficiency can be exploited by using moderators.
- In addition, the low gamma-ray sensitivity makes these detectors very attractive for neutron spectroscopy (Bonner spheres).

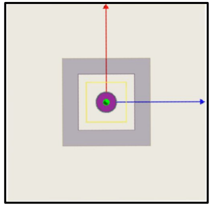
HENSA comparison with BSS

Standard extended Bonner Spheres



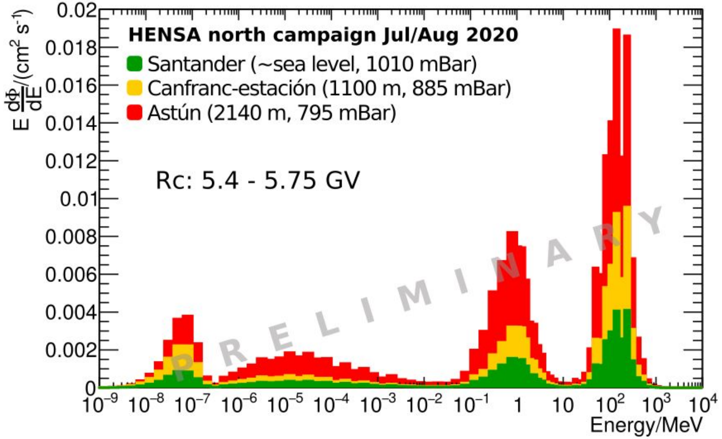
HENSA 2019 version

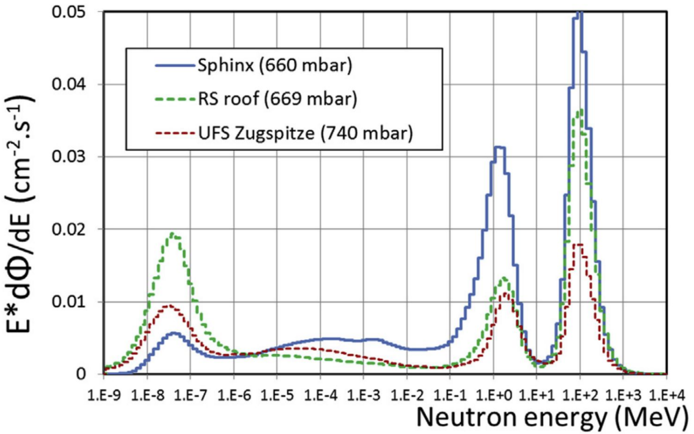


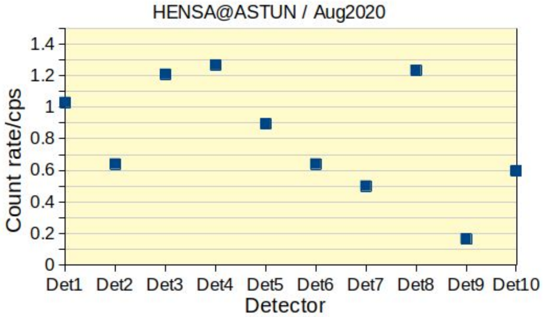


- HENSA neutron response is **5-15** times greater than standard BSS thanks to the increase in the detector active length
- The change in the topology is not a problem in isotropic fields

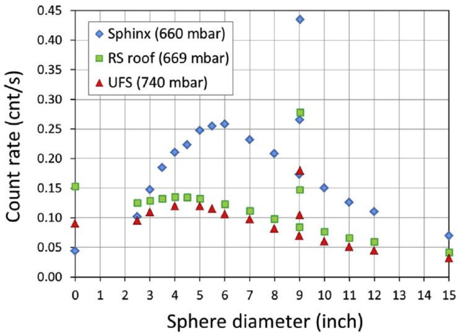
HENSA first deconvolutions







N. Mont (PhD)



- Confirmed structure and flux magnitude with HENSA
- Confirmed effect of higher sensitivity of HENSA with respect to conventional BSS.
- Over 2000 m altitude, relative uncertainty in count rates at 1h time window is ~2% or less.

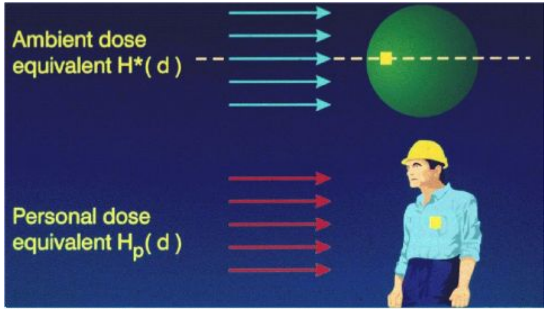
Neutron dosimetry

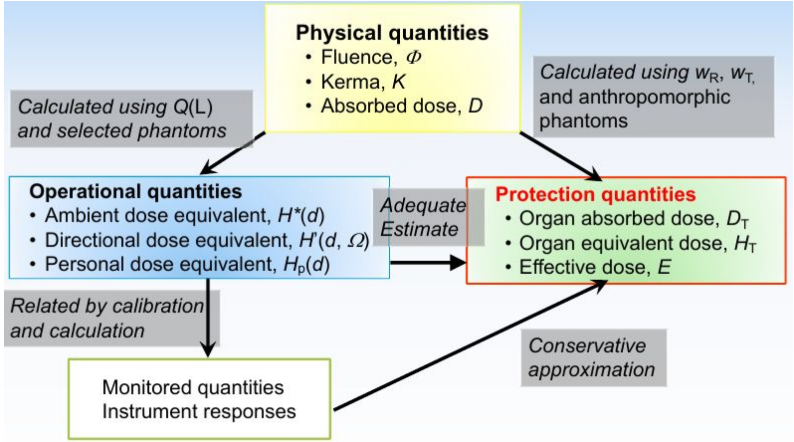
- For area monitoring, the operational quantity to link the external radiation to the effective dose is the ambient dose equivalent H*(d).

- Ambient dose equivalent at a point in a radiation field is the dose equivalent that would be produced by the corresponding expanded and aligned field in the ICRU sphere, made of tissue equivalent material, at a depth d, on the radius opposing the direction of the aligned field.

- The recommended value of d for effective dose is d=10mm.

- Originally computed with the Q-L relationship of ICRP 26; now with ICRP Publication 60 revised Q-L (ICRU Report 57/ICRP Publication 74, 1996)





Single-events upset in microelectronics

Electronic devices contain semiconductor materials (Si)

↓

Most of then are doped with boron (neutron absorber)

↓

In the absorption, Li7 and alpha particles are generated and they can ionize the atoms of the device

↓

This can change bits


INDEPENDENT

Support us | Contribute | Subscribe | LOGIN

NEWS | CORONAVIRUS ADVICE | UK POLITICS | US POLITICS | 2020 ELECTION | VOICES | SPORT | CULTURE | INDY/LIFE | INDYBEST | INDY100 | LONG READS | VOUCHERS

Cosmic particles can change elections and cause planes to fall through the sky, scientists warn

Tiny invisible particles can cause bits of information held by computers to 'flip' with potentially serious ramifications

Ian Johnston Science Correspondent in Boston | @montaukian | Friday 17 February 2017 16:40

Data on cosmic rays neutrons helps to improved knowledge on performance and lifetime of strategic infrastructure: power grids, communications, avionics, defense, etc.

Resolving power

- Average flux at a certain energy

$$< \phi >_{E_0} = \int A(E_0, E)\phi(E)dE$$

- The kernel function A is a pdf on the flux

$$\int A(E_0, E)dE = 1$$

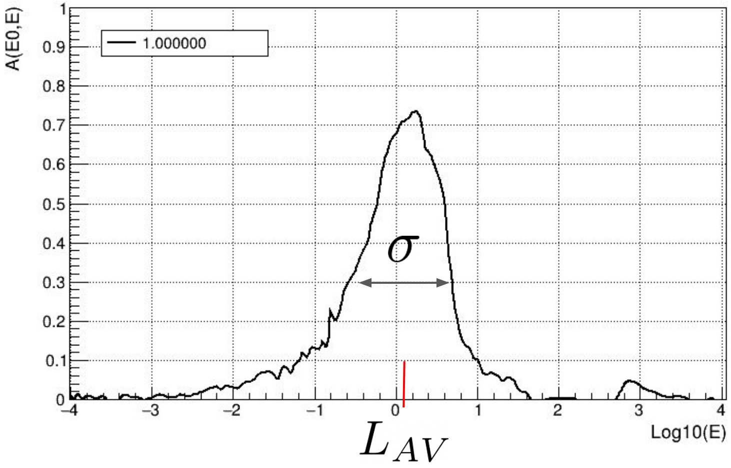
$$A(E_0, E) = \sum_{i=1}^{n} a_i(E_0)R_i(E)$$

M. Reginatto, Nuclear Instruments and Methods in Physics Research A 480 (2002) 690–695

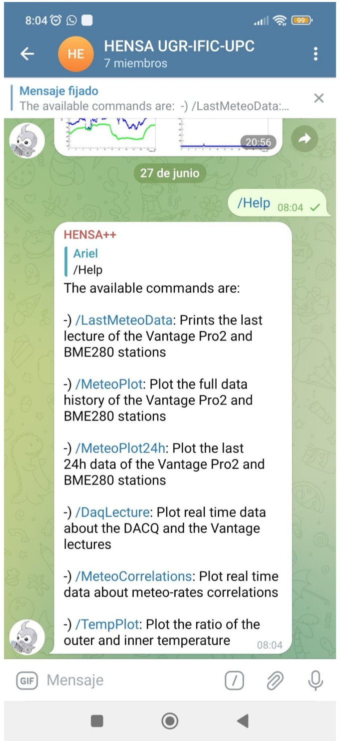
- We search for the {a_i} that minimizes:

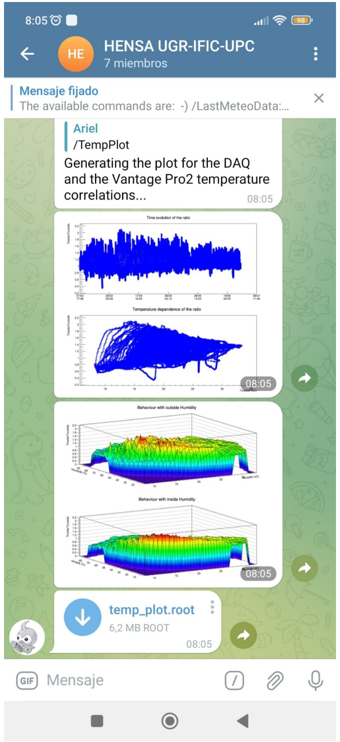
$$Min : \int J(E_0, E)\left[A(E_0, E)^2\right] dE$$

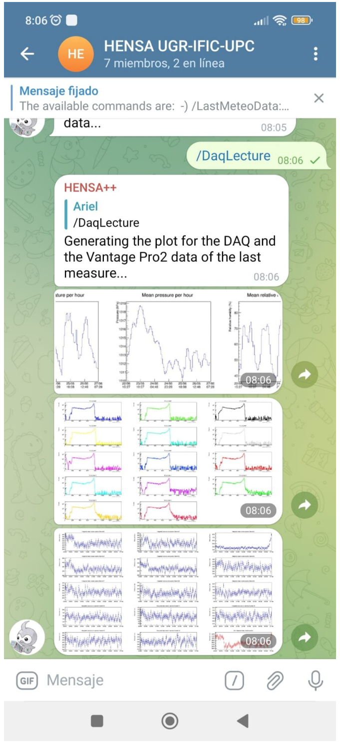
$$J(E_0, E) = (E - E_0)^2$$



HENSA++ Telegram bot







HENSA++ bot: remote "shift" available everywhere with just a mobile phone!

HENSA++ permanent site: OAJ

Optimization