SANDA

Supplying Accurate Nuclear Data for energy and non-energy Applications

(A Nuclear Data Euratom Project in H2020)

HORIZON2020

- BELEN-62: A beta-delayed neutron detector with spectrometric capabilities
- Measurements using BELEN

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VNIVERSITAT DE VALÈNCIA

BELEN for SANDA

GOAL

Design of a new version of the BELEN detector optimized for maximum total efficiency and spectrometric response.

COMMITMENTS

M7. Completion of the design of the new version of the BELEN detector at UPC. **UPC. M24**

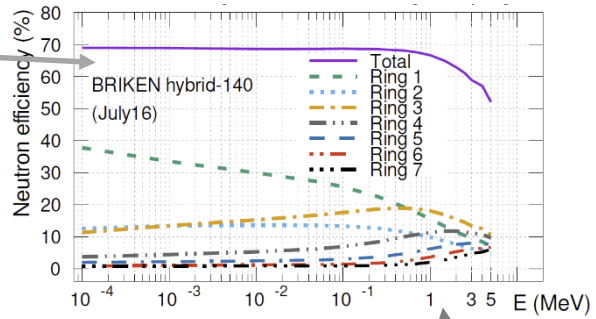
D15. Report on the development of a new technique for obtaining low resolution information on the beta delayed neutron energies with BELEN-like detectors. **UPC. M30**

The BELEN concept

BEta-de**L**ay**E**d **N**eutron detector

Set of rings made of thermal neutron detectors (He-3) embedded in a High Density Polyethylene (moderator) matrix, using a digital electronic trigger-less data acquisition system (Gasific).

GEANT4 A SIMULATION TOOLKIT



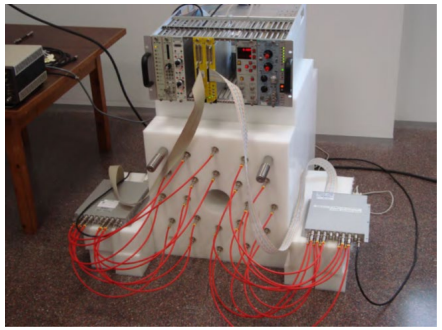
Design criteria

- Maximum efficiency
- Flat response (ε vs E_n)

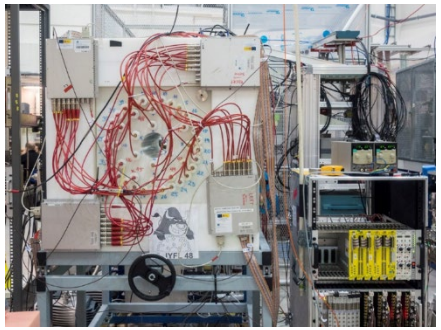
Strategy

- New HDPE matrix for each measurement campaign

BELEN 20



BELEN 48



BRIKEN 140-H

A. Tarifeño-Saldivia et. al. J. Instrum. (2017)

BRIKEN was the world largest moderated neutron counter for beta-delayed neutrons!

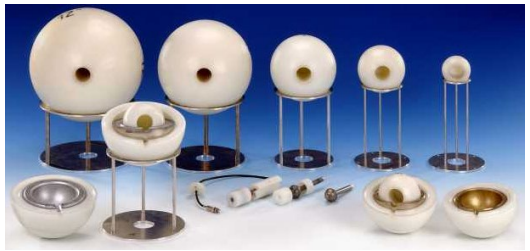
→ P_{1n}, P_{2n}, …

Bonner spheres

Very complex!

Bonner spheres (BS) spectrometers is a widespread technique for neutron spectrometry.

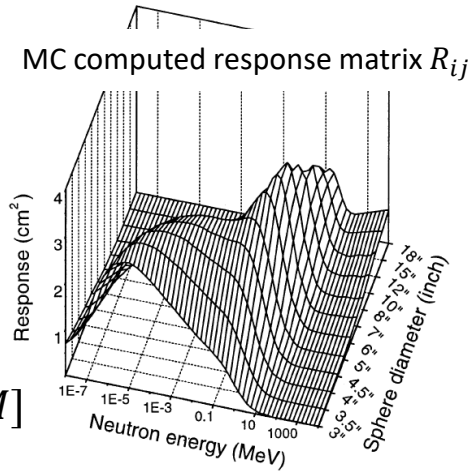
- Moderated proportional neutron counters. Useful from thermal to GeV region.
- Typically 5 up to 14 spheres
  → **Ill-posed linear inverse problem!**
- **Extensive MC simulations** and **unfolding algorithms** are required



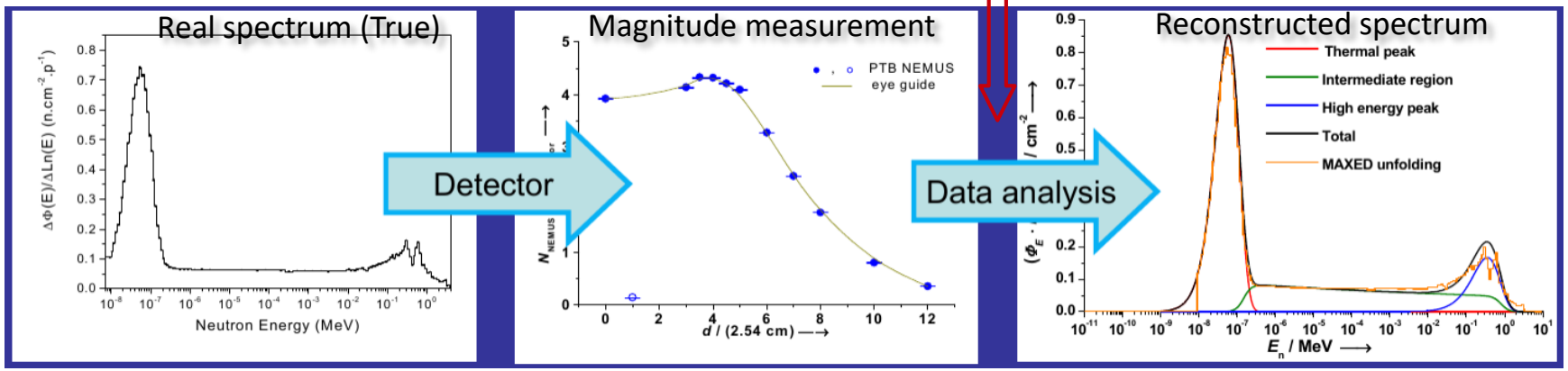
$$M_i = \int R_i(E)\phi(E)dE$$

$$M_i = \sum_j R_{ij}\phi_j \Rightarrow [\phi] = [R]^{-1}[M]$$

MC computed response matrix R_{ij}



Unfolding algorithm ← Educated guess of n-spectrum



~~**Measurement technique:**~~

real spectrum — detectors — data taking — data analysis — measured spectrum

Beta-delayed neutron spectrometry

- For nuclear structure, beta-delayed neutron spectroscopy is needed to complete the “beta strength function” when the decay populates neutron-unbound states (Madurga+2016).

- Lack of experimental data and evaluations:
  See M Brady’s PhD thesis (1989) & last IAEA-CRP evaluation (2020)

State-of-the-art beta-delayed neutron spectrometers:

Gaseous

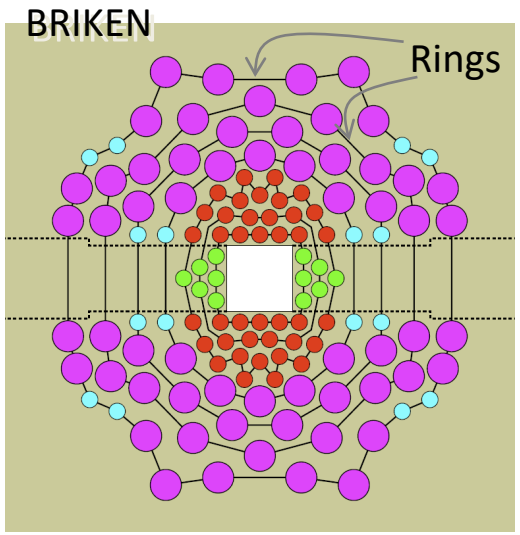
- Recoil on H (E < 200 keV)
- ^{3}He capture (E < 1.5 MeV)

TOF detectors (E_{thr} > 500 keV)

- MONSTER (Martinez+2014) or VANDLE (Peters+2016)

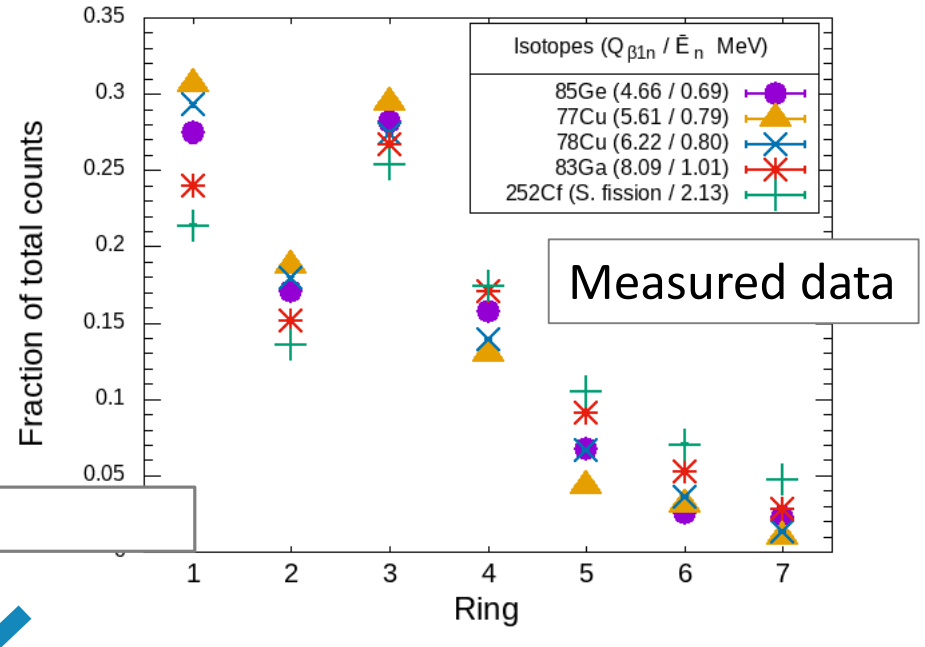
- For heavy nuclei there is a lack of experimental techniques with high sensitivity and E_{thr} < 500 keV.
- Spectrometry based on moderated proportional counters:
  - No threshold at low energies.
  - High efficiency compared to TOF detectors.
  - Suitable for very exotic nuclei.

BELEN feasibility for n-spectrometry



Each of BRIKEN's 7 rings can be, conceptually, considered as a unique Bonner sphere

Spectrometric response?



Measured data

Each ring has a, somewhat, different response depending on

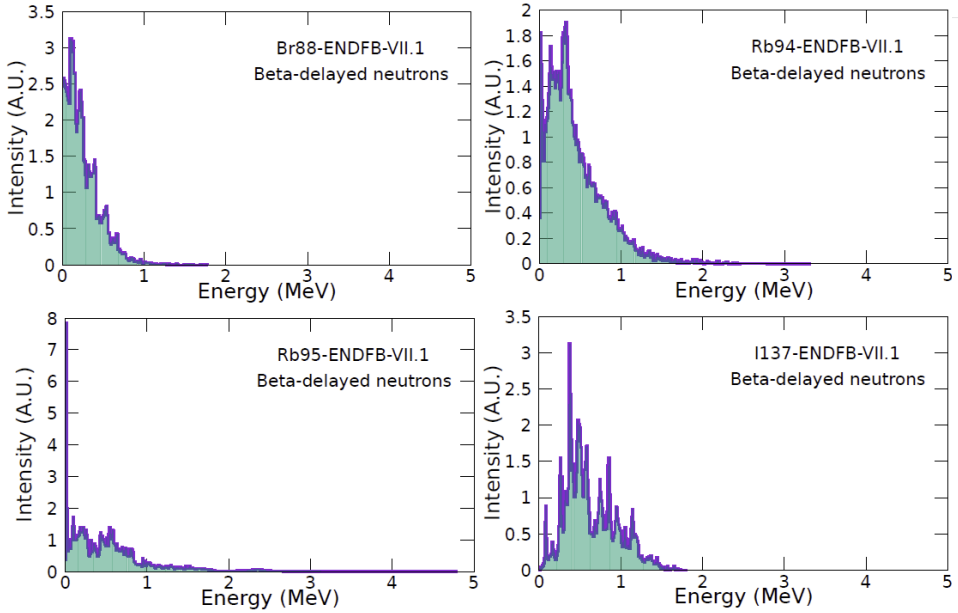
- $< E_n >$
- $Q_{\beta_{1n}}$(≈ end point E)

BELEN spectrometric capability

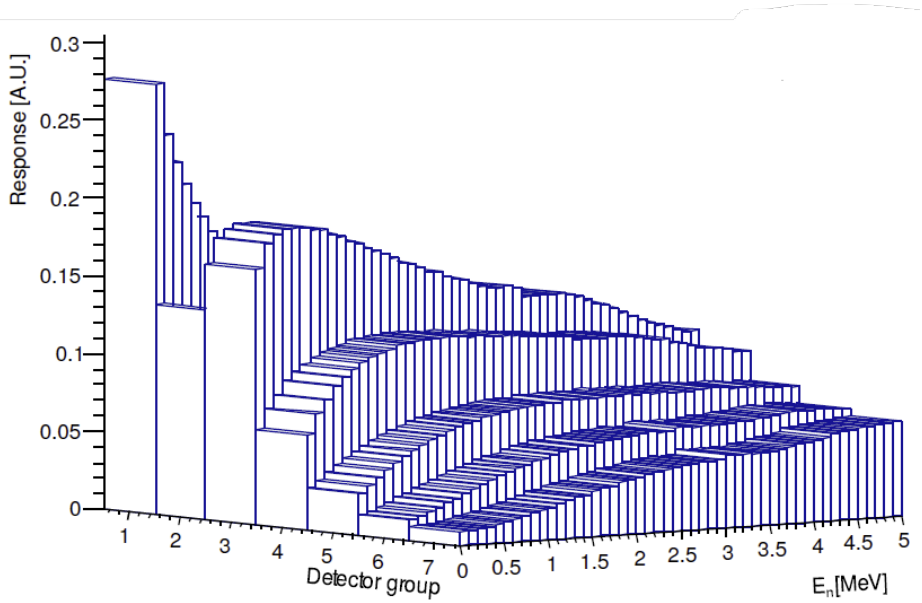
MC fake data study on BRIKEN

Study of n spectrometric capabilities of the BRIKEN 140-H for beta-delayed n's

Br-88 (<E> = 251.5 keV), Rb-94 (442.4 keV), Rb-95 (529.5 keV, and **I-137** (629.8 keV)



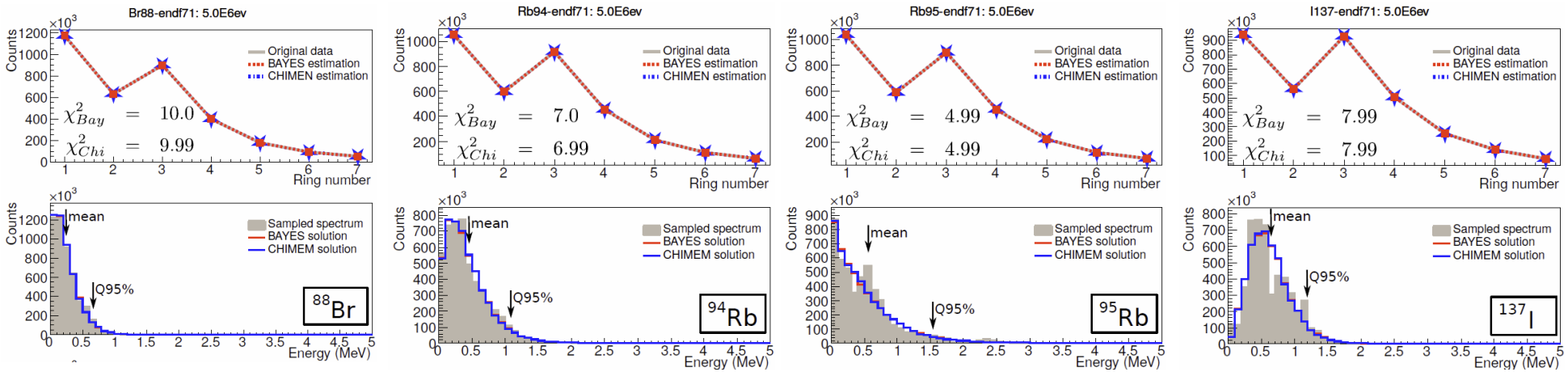
Response matrix (Geant 4 v10.0.1)



BAYES: Expectation minimization
CHIMEM: Maximum entropy

Spectrometric BELEN proof of concept

Ideal case: large statistics, no systematic errors, flat guess (no a priory knowledge)



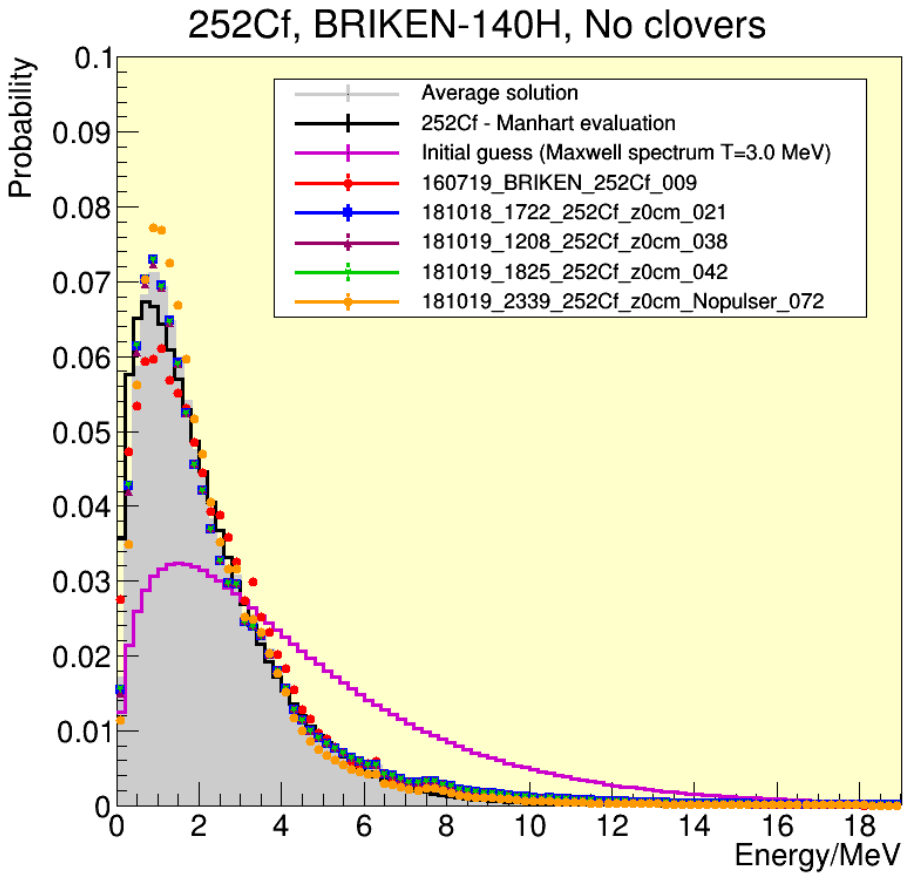
	Ratio <E>		Ratio Q5%		Ratio Q95%	
	Chimem	Bayes	Chimem	Bayes	Chimem	Bayes
Br-88	0.9825	0.9830	0.9795	0.9785	1.0009	0.9956
Rb-94	1.0079	1.0040	1.0675	1.0560	1.0128	1.0085

	Ratio <E>		Ratio Q5%		Ratio Q95%	
	Chimem	Bayes	Chimem	Bayes	Chimem	Bayes
Rb-95	1.0141	1.0122	1.0126	1.0239	1.0021	1.0071
I-137	1.0069	1.0061	0.9722	0.9587	1.0200	1.0184

- Good agreement between the true and the unfolded solutions from both codes
- For spectra with local peaks, the unfolded solution is a smooth function following the general trend of the original
- Need experimental validation

Spectrometric BELEN: experimentally possible?

- Real data for ^{252}Cf from the BRIKEN project (UPC+IFIC).
- Proof-of-concept for spectrometry using “ring” structure in BRIKEN-140H.
- Spectrum reconstructed with Bayesian algorithm from 5 different measurements.
- Interesting potential application for development of a **new generation beta-delayed neutron counters** with spectrometric capabilities.



Good agreement with Manhart evaluation!

New BELEN design

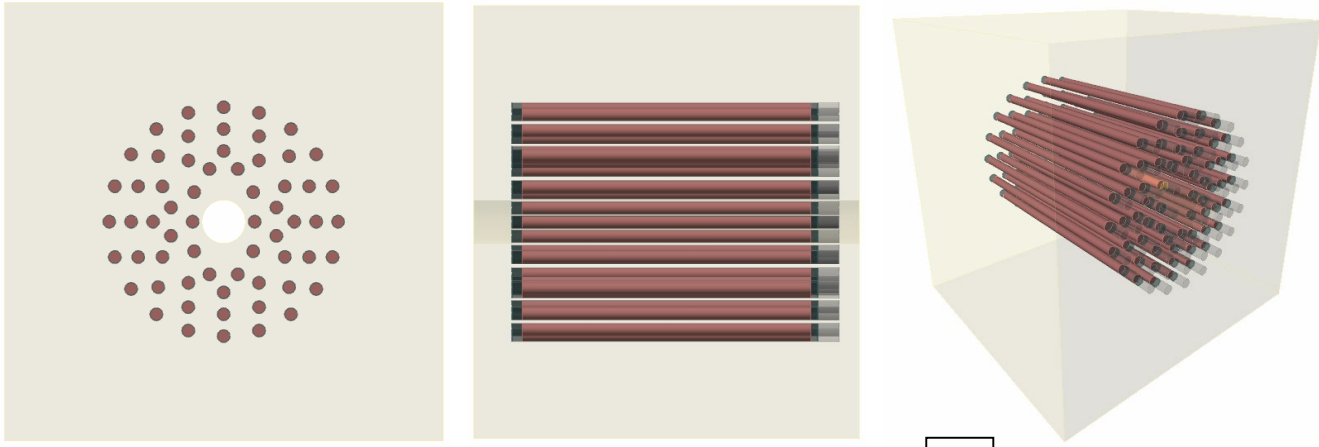
Design criteria

- Optimization of the detector design by MC calculations
- Maximum efficiency achievable
- Focus on spectrometric response up to 10 MeV
- ↓Flat response (ε vs E_n)

Strategy

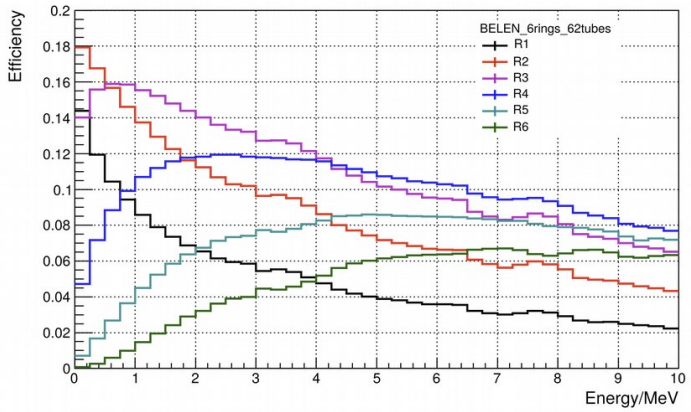
- Exploratory study for UPC 3He tubes (LND, 1” diam, 8 atm, 60 cm active length)
- Geometry similar to BELEN-48: Moderator (90x90 cm^2), with circular hole 4.5 cm radius
- ≈60 tubes (L=60 cm, D=1”, p=8 atm)
  - Constrained by ^{3}He price
  - Total UPC + IFIC budget: ≈50 tubes (currently)
  - Possible budget in the midterm: up to 65 tubes including lower pressure units

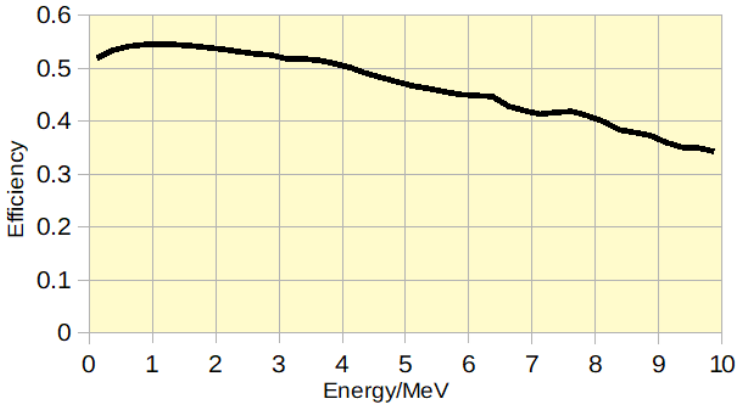
New BELEN design: BELEN-62



Best candidate!

Ring	Tubes	R, cm
1	2	6.38
2	4	8.58
3	8	11.20
4	12	14.50
5	16	19.00
6	20	23.50





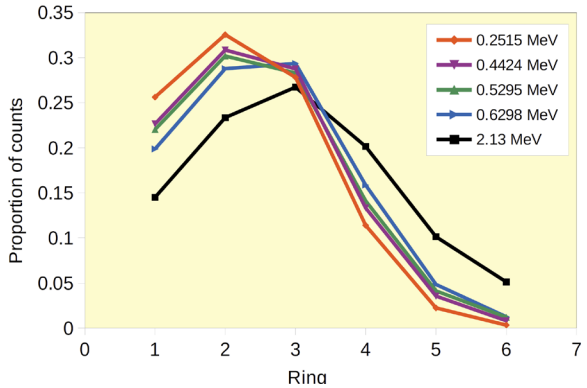
Efficiency > 50% un to 4 MeV
Nearly flat response up to 4 MeV!

New BELEN, expected performance

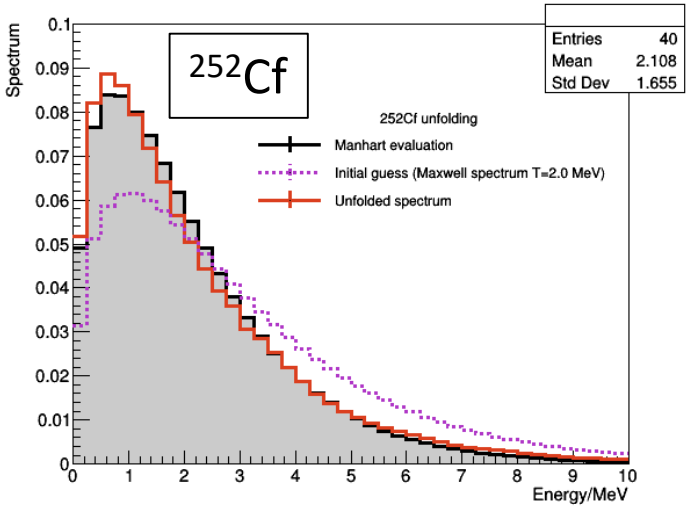
MC fake data study on BELEN-62

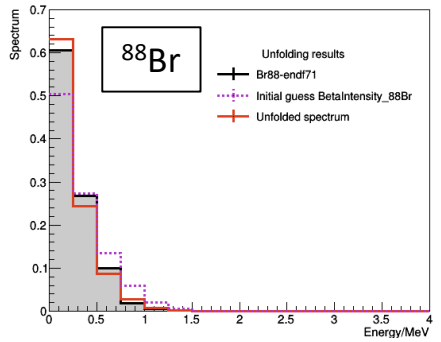
GEANT4 A SIMULATION TOOLKIT

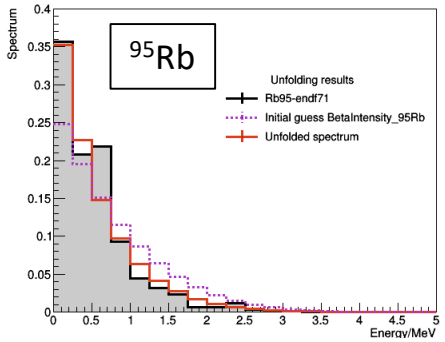
Nuclide	$Q_{\beta n}$, MeV	<E>, MeV
Cf-252	---	2.13
Br-88	1.922	0.2515
Rb-94	3.452	0.4424
Rb-95	4.883	0.5295
I-137	2.001	0.6298

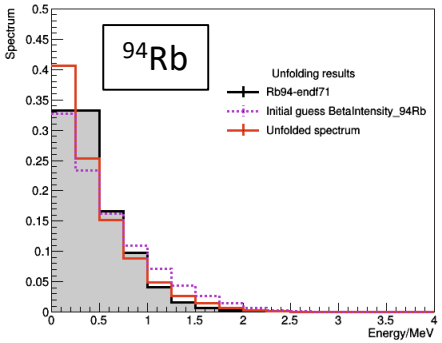


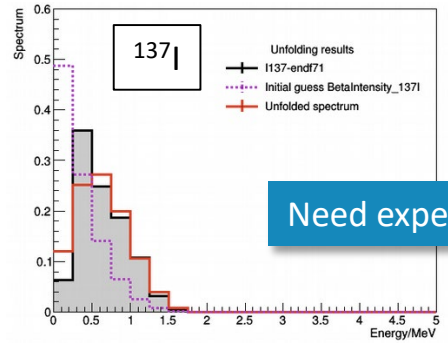
Educated guesses,
- Fission: Maxwellian
- Beta: Constant beta strength











Nuclide	Ratio <E>
Cf-252	1.019
Br-88	1.033
Rb-94	1.032
Rb-95	1.091
I-137	1.023

Need experimental validation

BELEN in SANDA

Final remarks

- Preliminary proof of concept for spectrometric capabilities in a BELEN-like detector achieved with BRIKEN-140H.
- BELEN-62, a new beta-delayed neutron detector design has been accomplished with low resolution spectrometric capabilities in the energy range up to 10 MeV.
- The new design is expected to provide low resolution spectrometry (≈ 100 – 250 keV) with high detection efficiency (≈ 53%).
- BELEN-62 provides improved performance in terms of detection efficiency/flatness with respect to BELEN-48 and BRIKEN.

COMMITMENTS

M7.	Completion of the design of the new version of the BELEN detector at UPC. **UPC. M24**
D15.	Report on the development of a new technique for obtaining low resolution information on the beta delayed neutron energies with BELEN-like detectors. **UPC. M30**

Next steps:

- Funding request for 15 new tubes (4 - 8 atm depending on price, spares tubes included).
- Final iteration of design based on available hardware, and type of experiment.
- Experimental validation of the spectrometric concept.

Measurements with BELEN

GOAL

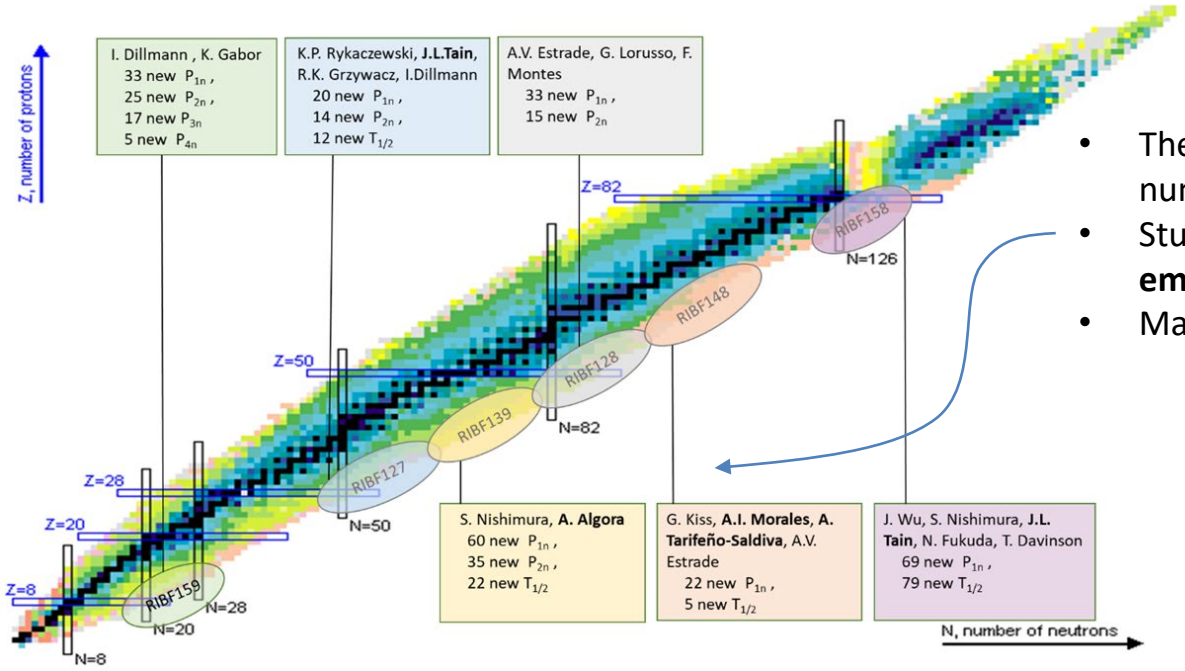
Perform new measurements with the BELEN detector and the GASIFIC data acquisition.

COMMITMENTS

D2.6 Report of the decay data measurements performed with DTAS and BELEN. **IFIC. M42**

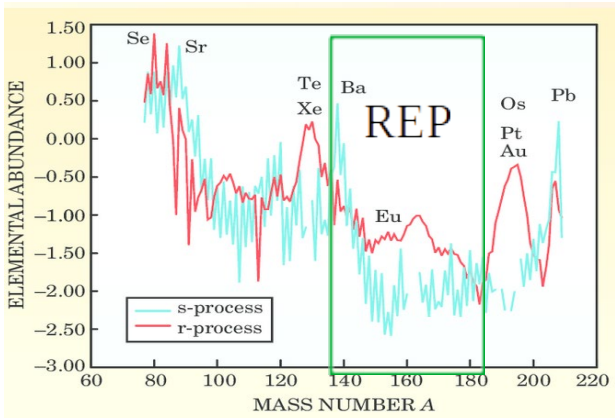
REP BRIKEN experiments

The **BRIKEN collaboration** ran an extensive measurement program of β-decay using BRIKEN 140-H and AIDA at the Riken Nishima Center (Japan). >50 participants from 18 international institutions.



BRIKEN experiments in the r-process zone

- The REP BRIKEN experiment focused on **Rare-Earth Peak** at mass number A~160 to describe the **r-process** abundances in the region.
- Studied very rich neutron isotope **half-lives ($T_{1/2}$)** and **neutron emission probabilities (P_{xn})**.
- Max Pallàs Solís PhD thesis.



Adapted from Cowan, John J. et. al. Physics Today (2004)

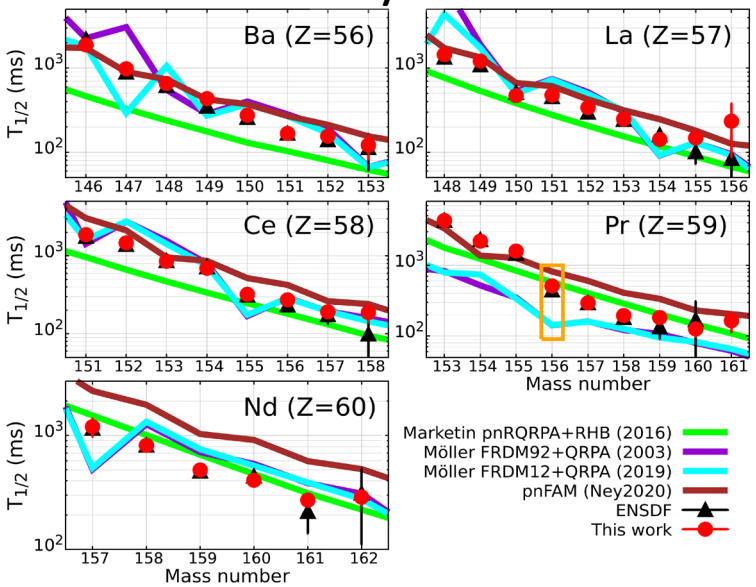
BRIKEN REP Results

- **39 $T_{1/2}$ remeasured** with improved precision.
- **2 P_{1n} remeasured** with improved precision.
- **1 new $T_{1/2}$.**
- **20 new P_{1n} .**

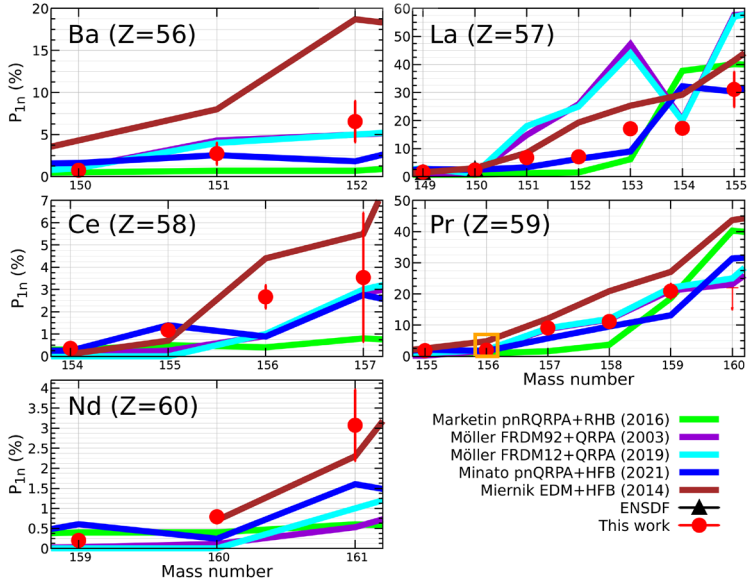
Astrophysical impact currently under development in collaboration with GSI Theoretical Nuclear Astrophysics Group

M. Pallas PhD

$T_{1/2}$

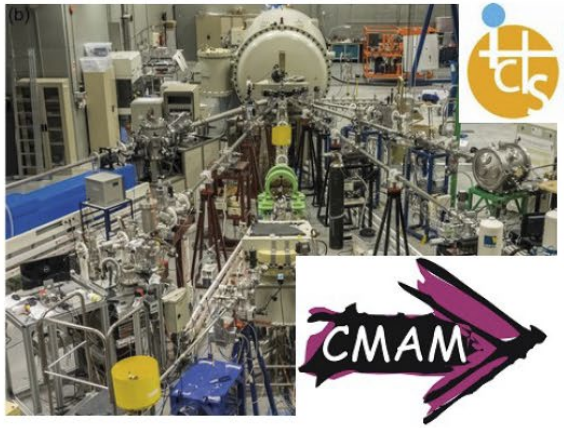


P_{1n}



Study of decay properties of Ba to Nd nuclei (A~160) relevant to the formation of the r-process rare-earth peak, M. Pallas et al. [EPJ Web of Conf. Volume 284, 2023]

miniBELEN. The MANY collaboration



Infraestructuras Científicas y Técnicas Singulares

HiSPANoS

CNA Centro Nacional de Aceleradores

Six research groups

UPC

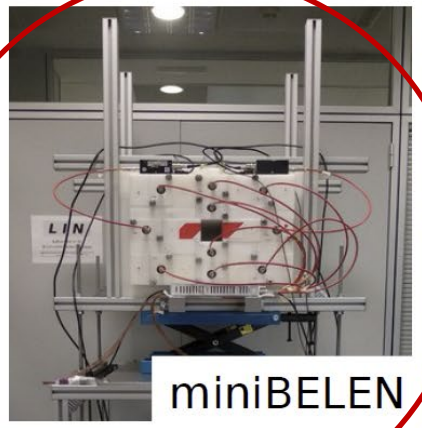
Universidad de Sevilla

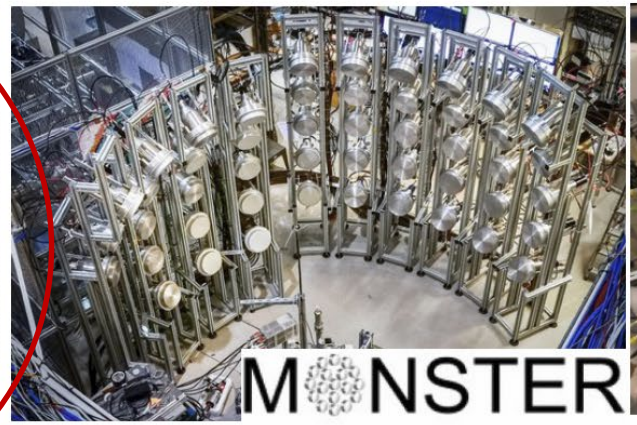
IFIC Institut de Física Corpuscular

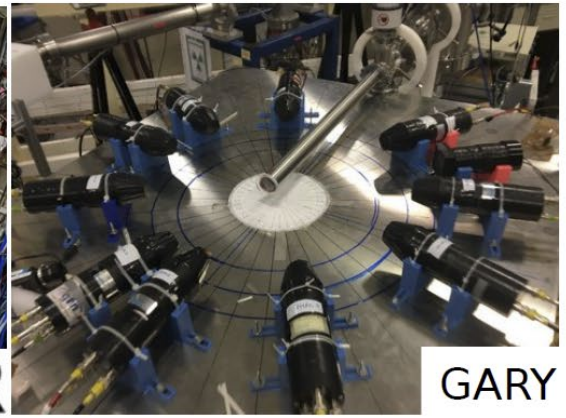
Universidad Complutense Madrid

IEM

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas







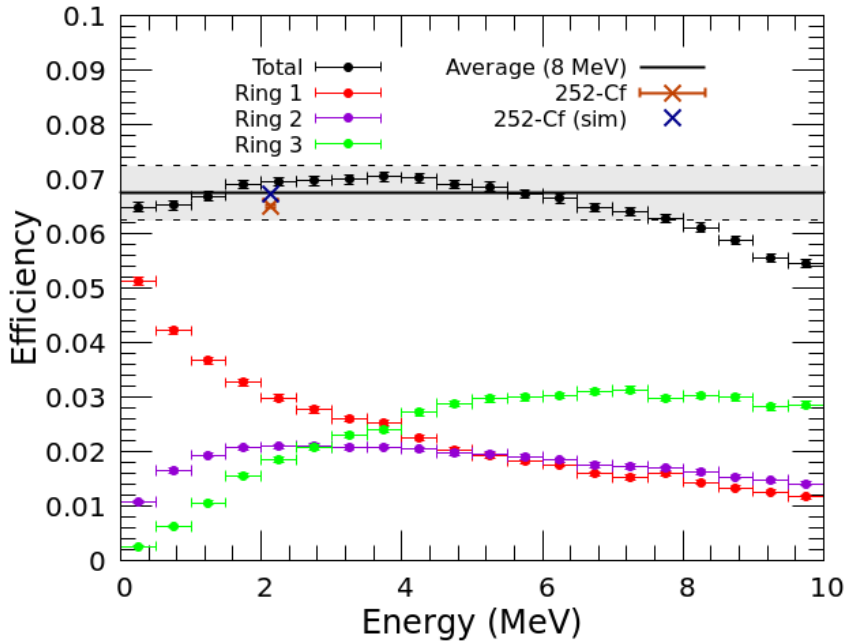
Three Spanish detectors

MANY
Project presentation

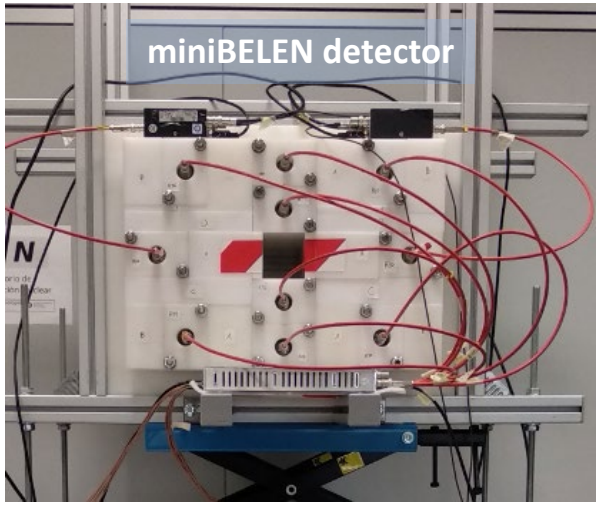
MANY: Measurement of Alpha Neutron Yields

Design and commissioning of a new modular neutron moderated counter (miniBELEN) with a flat efficiency up to 8 MeV using the GASIFIC data acquisition system.

N. Mont PhD



$\epsilon = 6.743(0.500)\ \%$

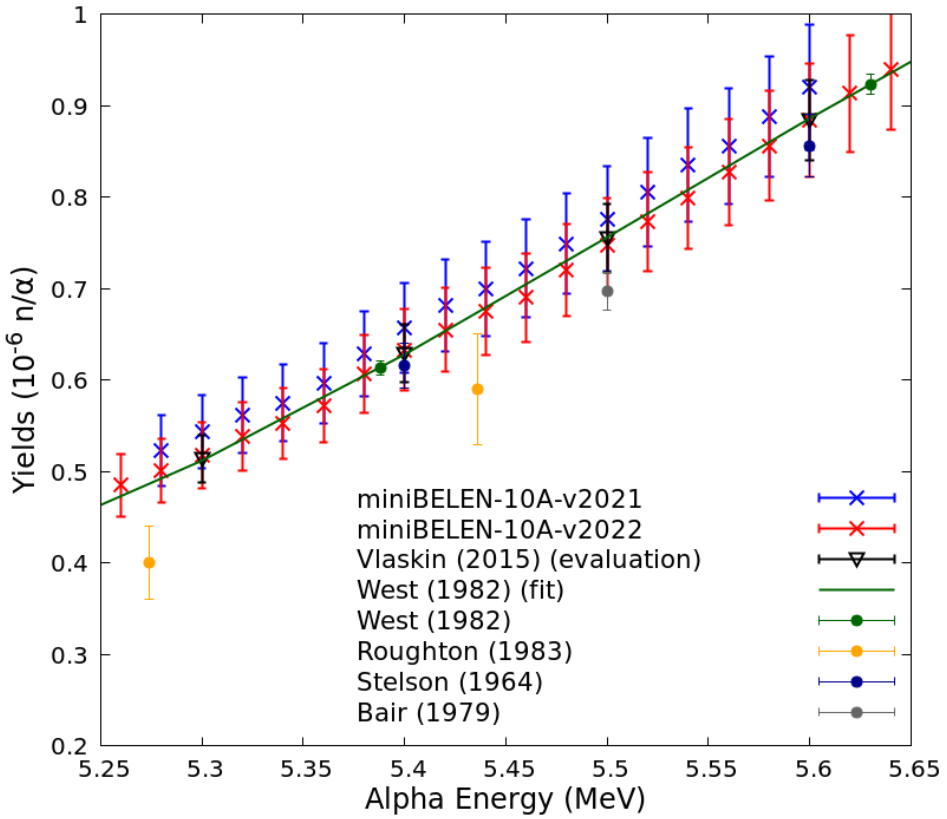


^{3}He-filled detectors + Cd filters, embedded in HDPE (moderated neutron counter)

miniBELEN: A modular neutron counter for (α, n) reactions. N. Mont et al. EPJ Web of Conf. Volume 284, 2023

Commissioning of miniBELEN at CMAM

Measurement of the thick-target yields from $^{27}Al(\alpha,n)^{30}P$ from 4 to 8 MeV (20 keV energy steps).



Two versions of the detector: 2021 and 2022 (differences in the ^{3}He gas pressure)

Commissioning of miniBELEN-10A, a moderated neutron counter with a flat efficiency for thick-target neutron yields measurements. N. Mont et al. EPJ Web of Conf. Volume 290, 2023

We are now working on the determination of the reaction cross-sections from differential measurements of the thick-target yields.

Final remarks

- Large campaign of β delayed neutron emitters at RIKEN
- Preliminary results for the REP peak
- miniBELEN designed and commissioned.
- Opening of (α,n) reactions cross-section measurements in Spain.

COMMITMENTS

D2.6	Report of the decay data measurements performed with DTAS and BELEN. IFIC. M42

Next steps:

- REP-Peak: Astrophysical impact in collaboration with GSI
- MANY: New campaign in CNA.
- 2 PhD thesis.