The MANY project: measurement of neutron yields and spectra from (α,n) reactions in Spain

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On behalf of the
MANY collaboration

IAEA Technical Meeting on (alpha,n) nuclear data evaluation and data needs

Motivation

• **Neutron background in underground experiments due to radiogenic α-decay chains.** Nuclear astrophysics, rare-events searches.

• **Nuclear technologies.** Impact on non-proliferation. α-emitters present in fresh/irradiated nuclear fuels can create a neutron source through (α,Xn) reactions with (light) surrounding nuclei.

• **Nuclear astrophysics.** Neutron sources in collapsing stars linked to the r-process.

Nuclear data status: this workshop!
Related to MANY you can see D. Cano's talk

Measurements of Alpha Neutron Yields and spectra – MANY collaboration

MANY
A coordinated effort by Spanish research groups with the aim to carry out measurements of (α,n) reactions using available infrastructures in Spain.

Intended scope for (α,n) reactions (long term)
Measurements of cross section, neutron spectra and production yields relevant for:
- Nuclear astrophysics
- Low counting rate and underground experiments
- Nuclear technologies

Short term goal: to determine current capacities for a scientific program on (α,n) reactions based on a cost effective approach

MANY is a very recent initiative:

- Started by the end of 2019:
"(α,n) yield in low background experiments" Workshop 21-22 November 2019, CIEMAT, Madrid, Spain

- Initial activities in 2020 delayed by COVID-19 pandemic

- Commissioning of beam lines and detectors during 2021

Available infrastructures for MANY

Facilities

HISPANOS: Centro Nacional de Aceleradores – CNA, 3 MV tandem accelerator (Seville).

CMAM: Centro de MicroAnálisis de Materiales – CMAM, 5 MV tandem accelerator (Madrid).

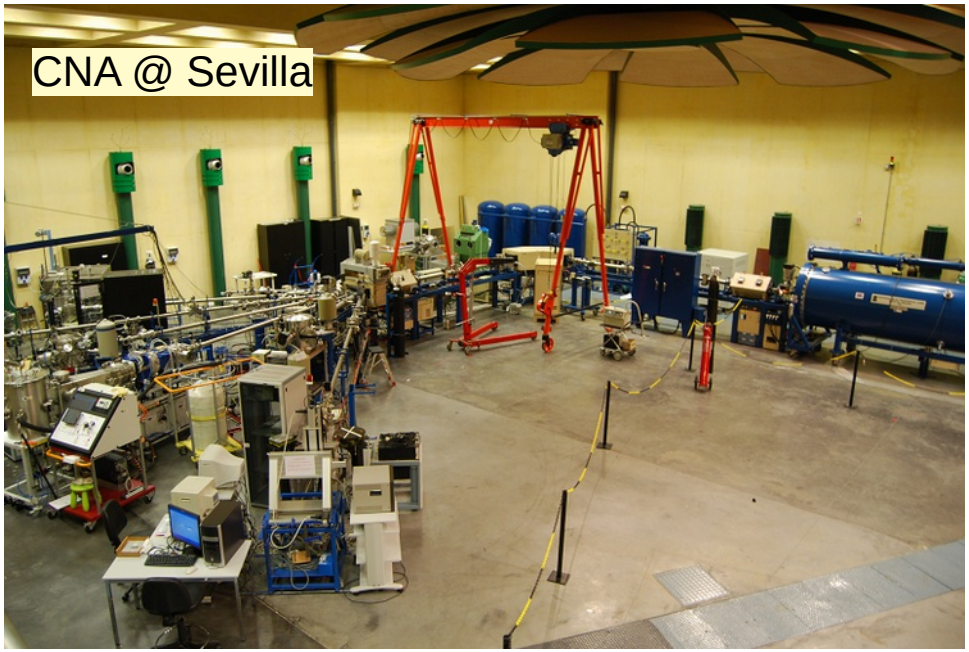
Complementary detection systems

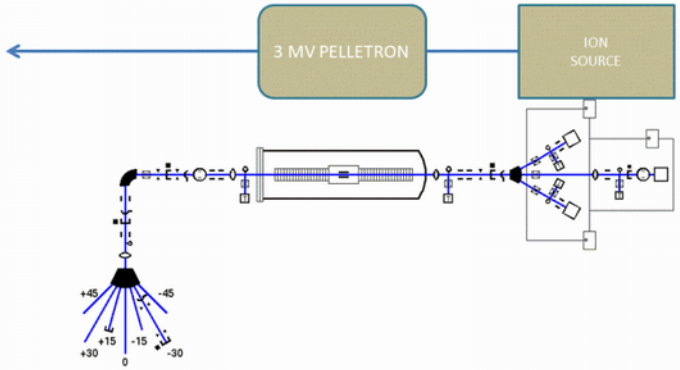
TOF spectrometer: The MOdular Neutron SpectromeTER-MONSTER

4π neutron counter: moderated 3He-filled tubes - miniBELEN

Gamma detection: array of fast scintillators - LaBr3(Ce)

Facilities: HISPANOS/CNA





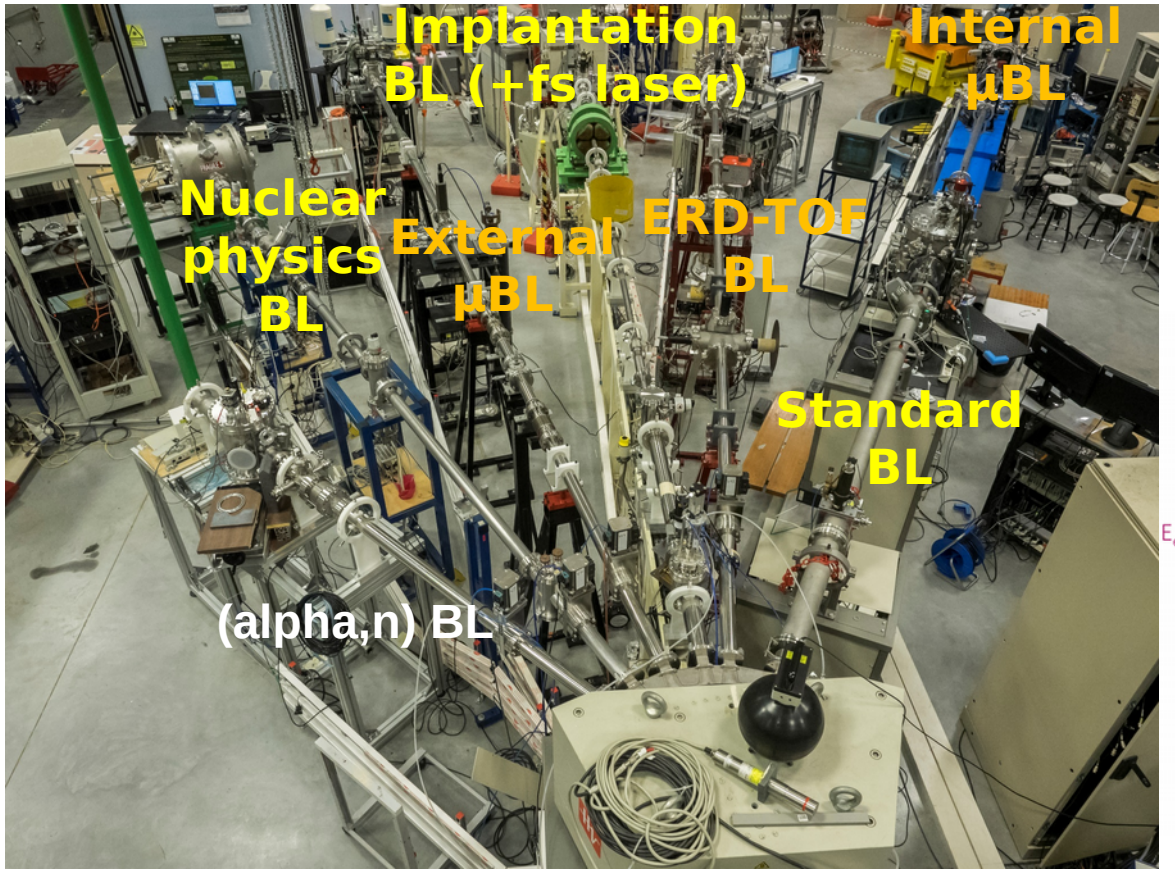
3 MV tandem accelerator
Chopper & Buncher unit installed in the LE region

CNA ^{4}He ion beam:

- Beam energy up to 9 MeV
- Continuous beam: 1 uA at the source => max. ~400 nA at the target
- Pulsed beam:
  - 2 ns FWHM
  - Up to 1 MHz frequency
  - TOF distance up to 4 m.

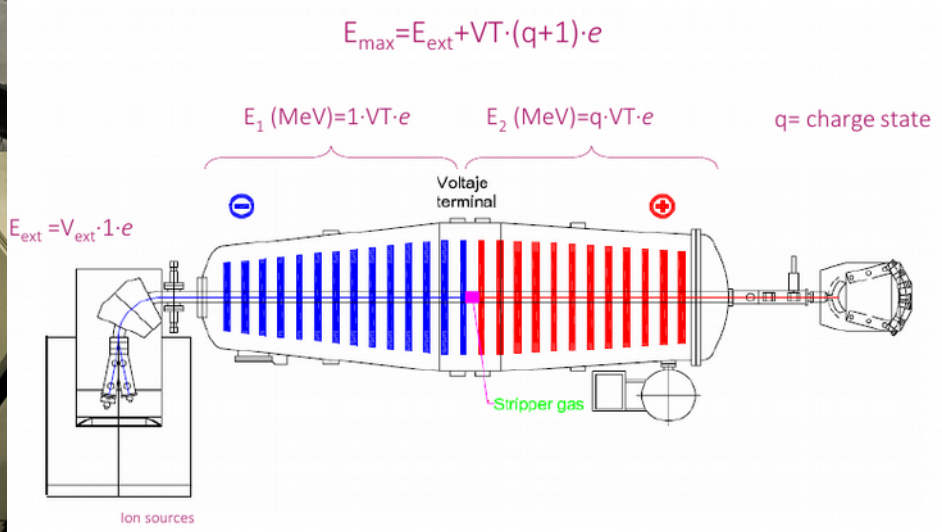
- In addition, available white and mono-energetic neutron sources useful to validate measuring techniques in (a,n) yield measurements

Facilities: CMAM



Universidad Autónoma de Madrid

CMAM



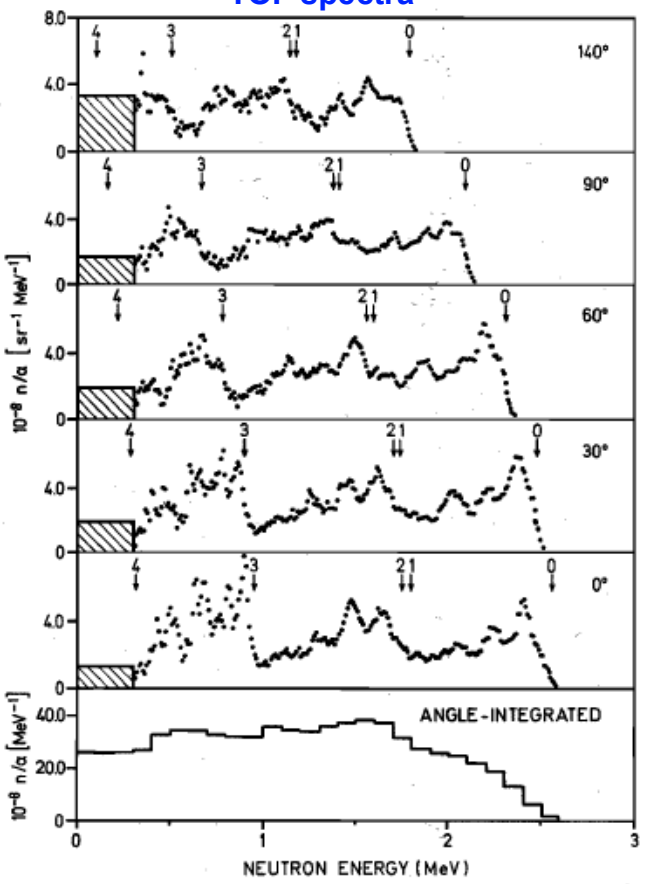
- 5 MV tandem accelerator (HVEE), in operation since 2002
- High stability, ripple below 1E-5, <50V @ 5MV
- Continuous beam, Duoplasmatron: H, He
- Upgrade just granted. H/D/He pulsed beam of 1-2 ns, repetition 4 MHz
- Nuclear physics beam line (IEM-CSIC) in operation since 2005.

Detectors: MONSTER spectrometer

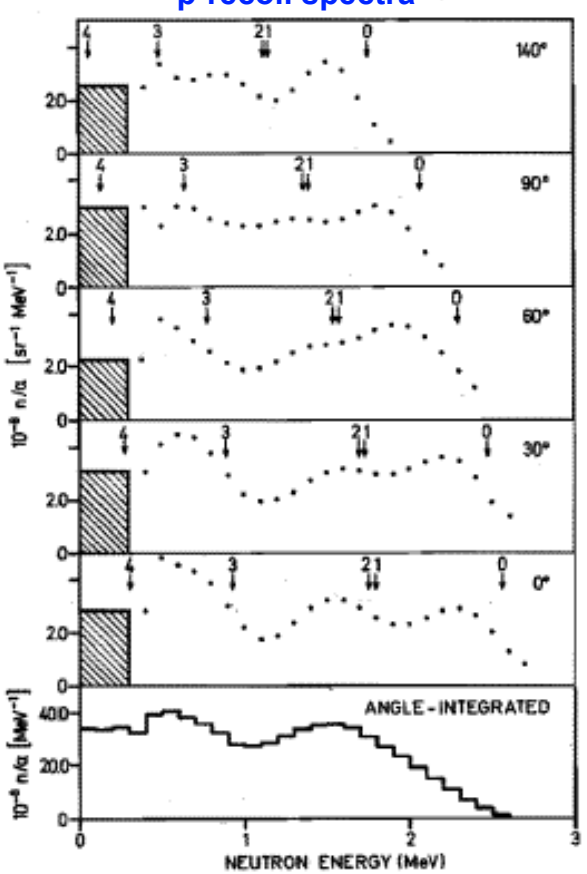
Neutron spectrum

Liquid scintillation detectors is a powerful tool for determining neutron spectra from (α,n) reaction through Time-of-Flight and deconvolution of p-recoil energy deposition analysis

TOF spectra



p-recoil spectra



- Requires a pulsed α-beam.

- n/gamma discrimination required.

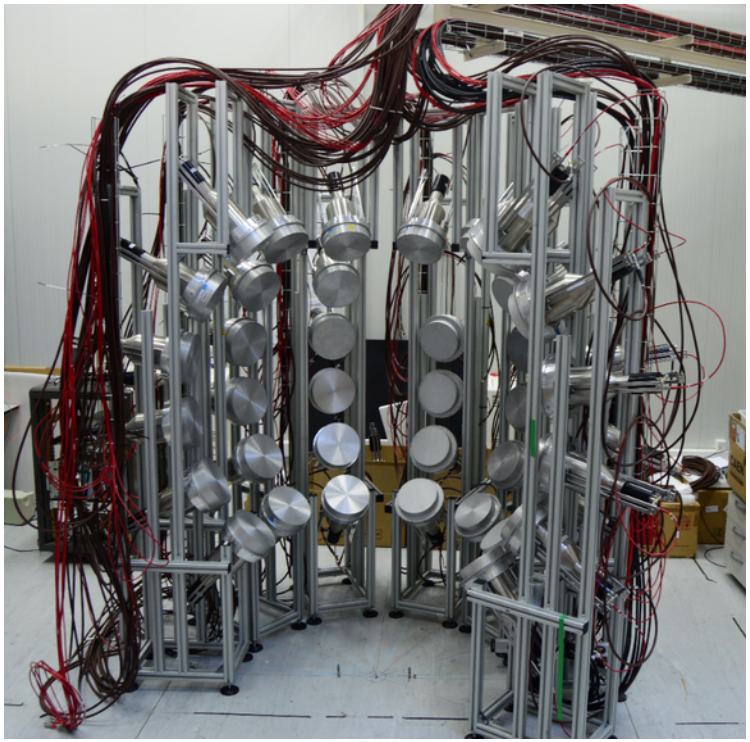
- Relative low efficiency

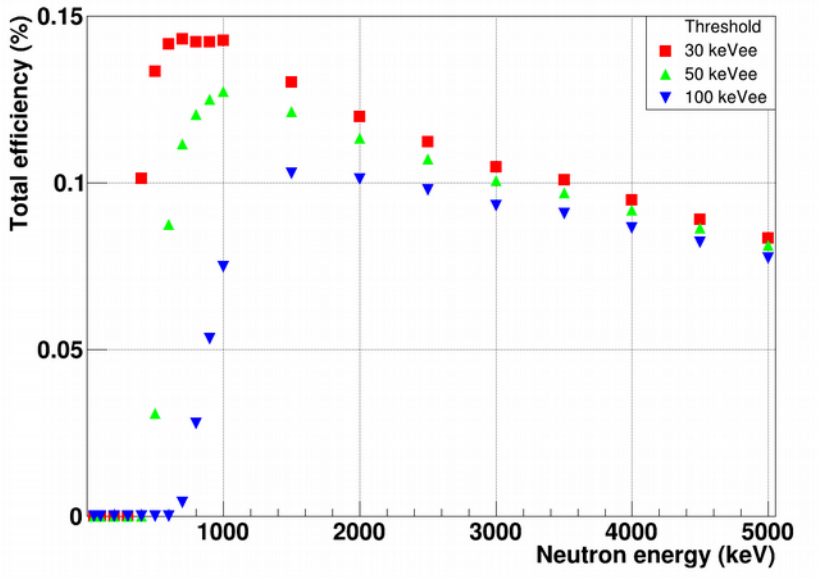
- Good energy and angular resolution.

Ann.Nucl.Energy 10, 541 (1983)

Detectors: MONSTER spectrometer

- 50 Cylindrical cells 20 x 5 cm
- Liquid scintillator BC501A / EJ301
- St. Gobain / Scientifica International SL
- 5” PMT model R4144 (R11833)



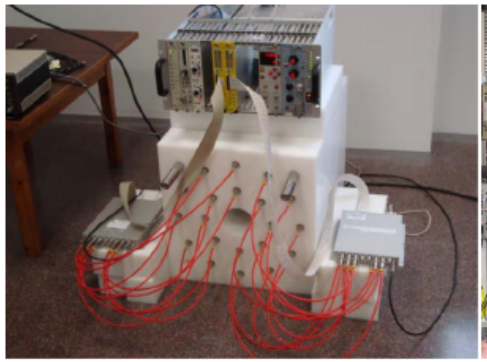


Total efficiency of 1 MONSTER module at 1m

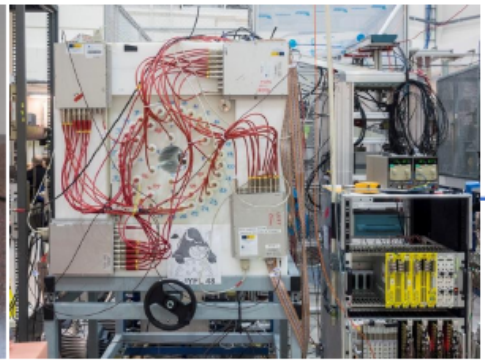
Detectors: BELEN neutron counters

A family of neutron counters based on moderated 3He-filled tubes (60cm). Extensively used for beta-delayed neutron studies with exotic beams.

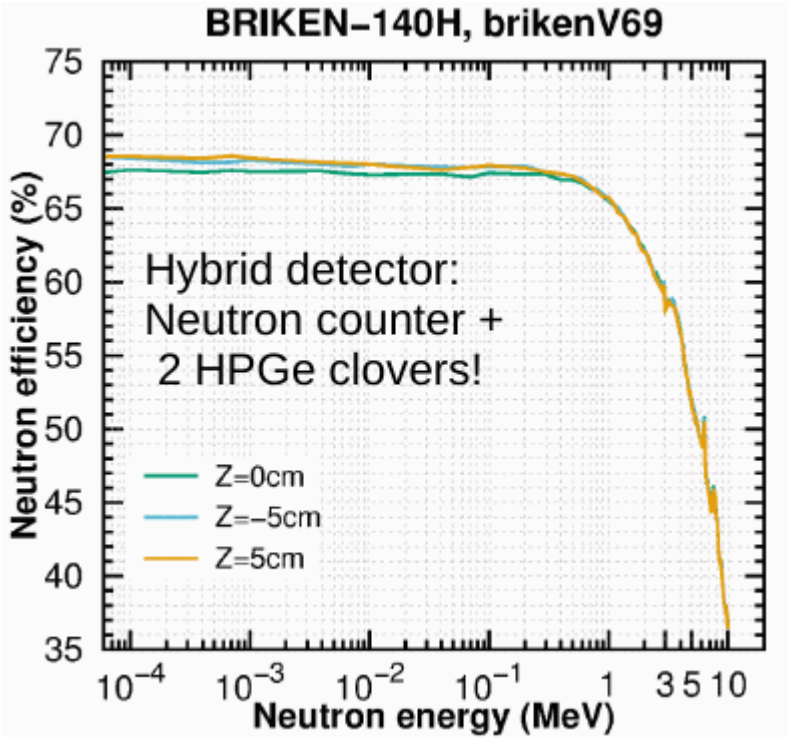
BELEN 20



BELEN 48



Nombre	Nº (p, atm)	Experimento	Efic. (<1 MeV)
BELEN-20M1	20 (20)	JYFL-2009	30%
BELEN-20M2	20 (20)	JYFL-2010	45%
BELEN-30	20 (20) + 10 (10)	GSI-2011	40%
BELEN-48M1	38 (8) + 10(10)	JYFL-2014	45%
BELEN-48M2	38(8) + 10(10)	JYFL-2014	60%



Futuro

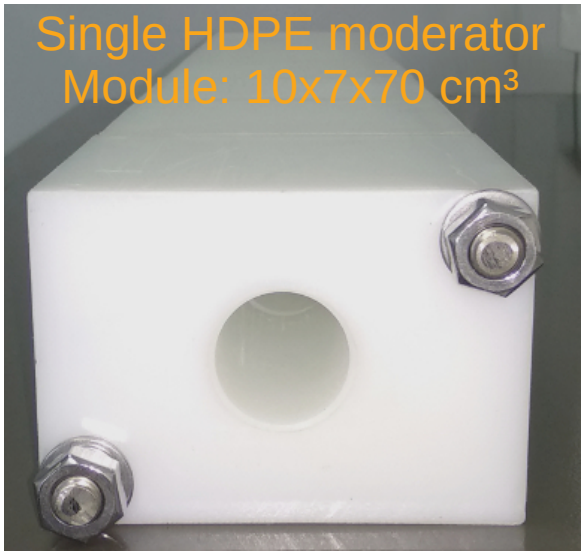
RIKEN

2021

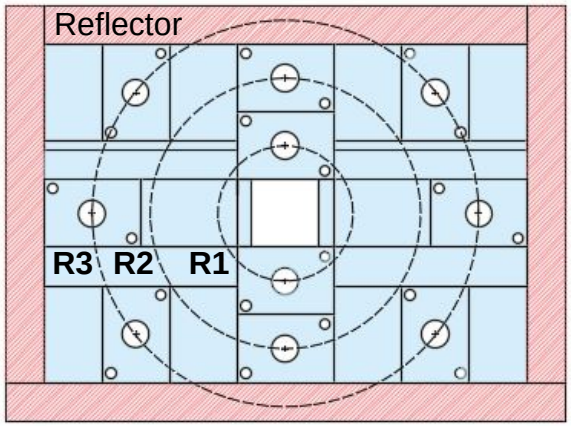
World largest beta-delayed neutron counter:
140 3He-tubes in a "swiss cheese" configuration!

Detectors: miniBELEN for (α,n) reactions

- Neutron counter based on a *modular High Density Polyethylene (HDPE) moderator*.
- High detection efficiency achieved by using ^{3}He-filled proportional counters (60 cm active length).
- Optimized design for (alpha,n) reactions up to 10MeV.
- Less than 10% relative expected variation of the nominal efficiency in the full energy range.
- Flexible system: reconfigurable for 3 optional setups

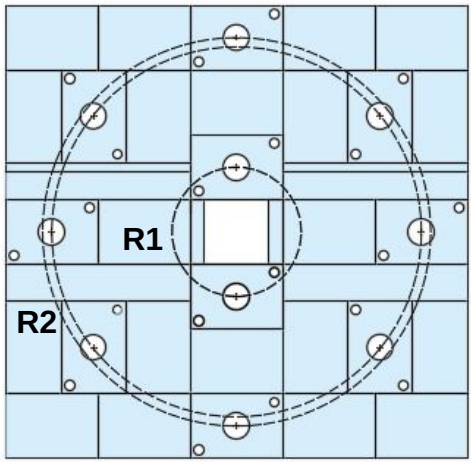


N. Mont, *"A novel modular neutron detector for (α,n) reactions: design and experimental validation"*, Master thesis, U. Sevilla, 2020.



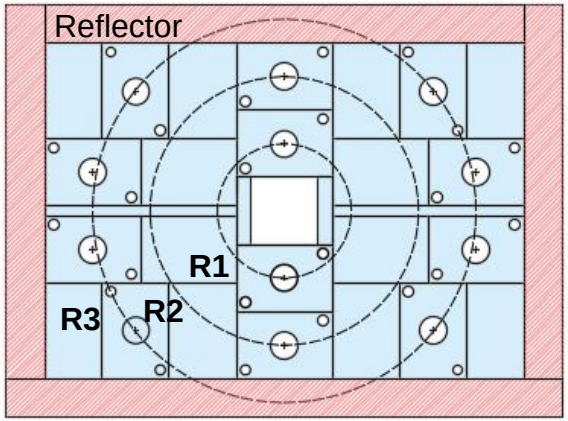
MiniBELEN-10A:
- 10 ^{3}He-tubes, 3 rings
- Moderator: 58x43x70cm³
- Reflector 4cm thickness
- Nominal efficiency up to 10 MeV:

$\varepsilon_{nominal} = 6.8 \pm 0.5$ %



MiniBELEN-10B:
- 10 ^{3}He-tubes, 2 rings
- Moderator: 50x49x70cm³
- Nominal efficiency up to 10 MeV:

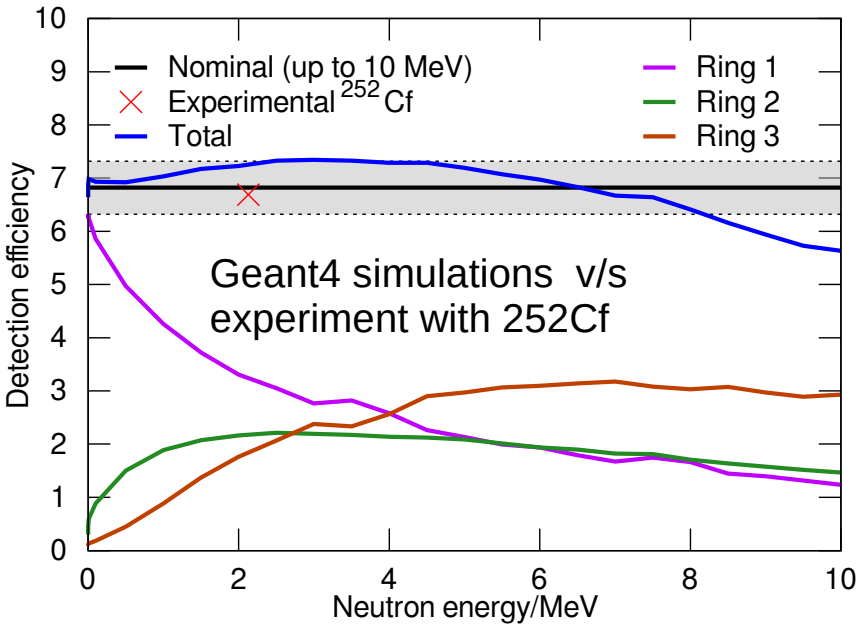
$\varepsilon_{nominal} = 5.3 \pm 0.3$ %

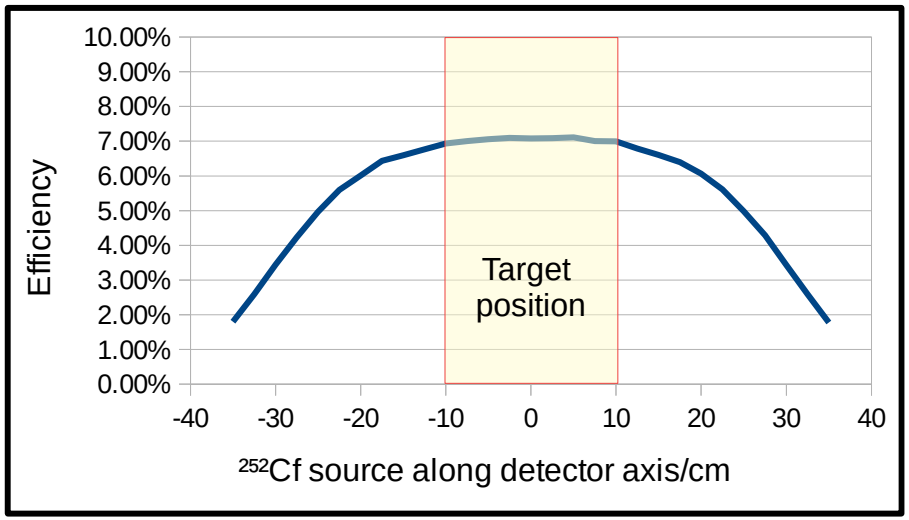


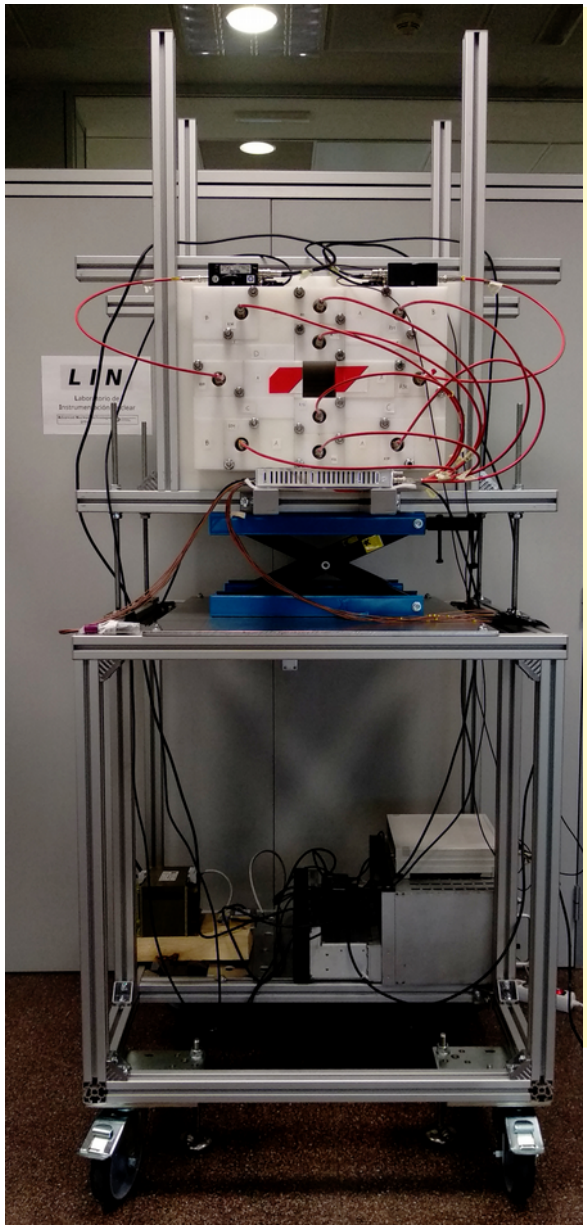
MiniBELEN-12:
- 12 ^{3}He-tubes, 3 rings
- Moderator: 50x35x70cm³
- Reflector 4cm thickness
- Nominal efficiency up to 10 MeV:

$\varepsilon_{nominal} = 8.2 \pm 0.6$ %

Detectors: miniBELEN-10A



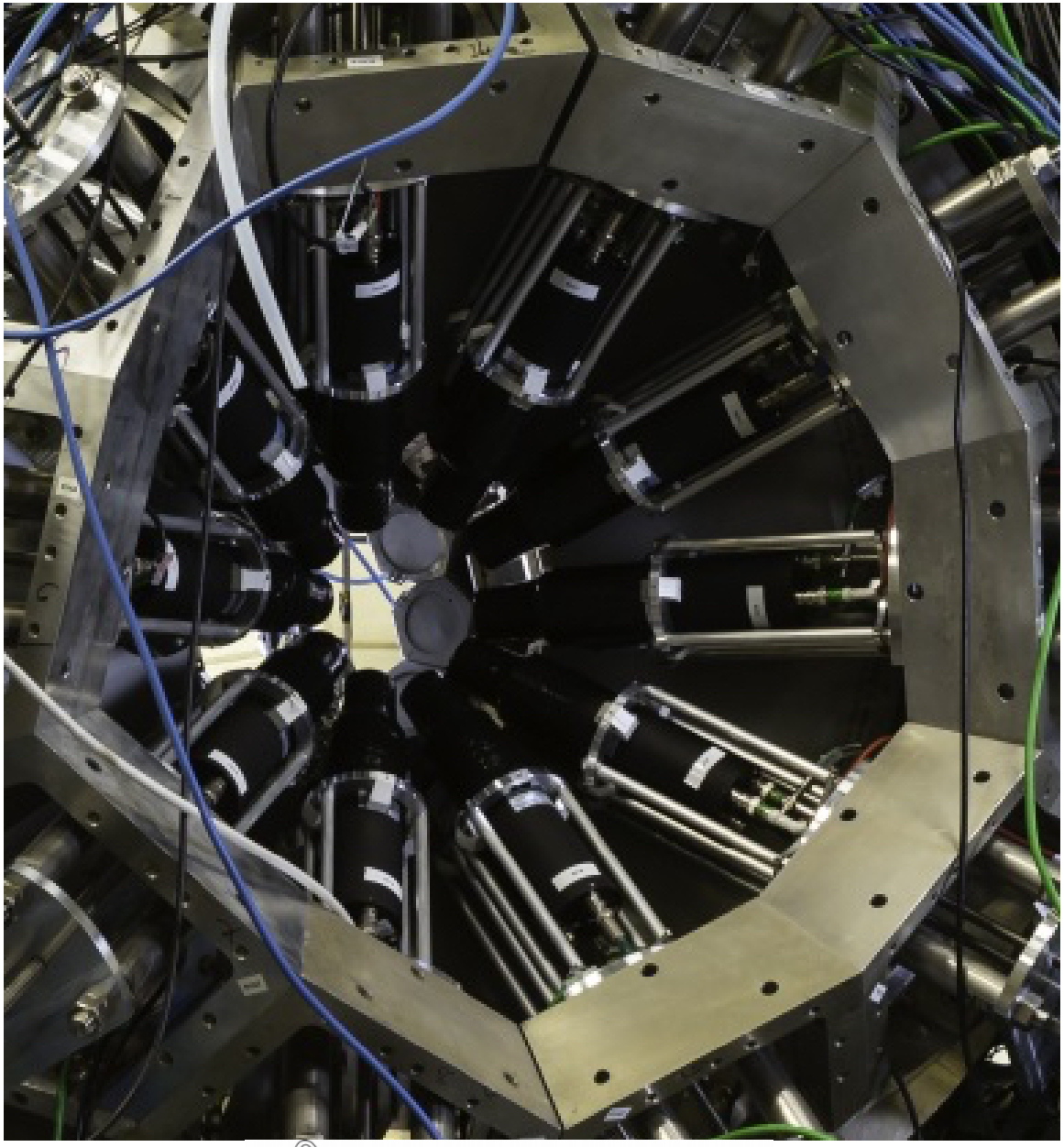




- Detector assembled and operative since Jan 2021.
- Data acquisition based on fully digital electronics.
- Experimental characterization for ^{252}Cf source. Good agreement with G4 simulations.
- Commissioning for ^{27}Al(α,n) production yield measurements in progress at CMAM.

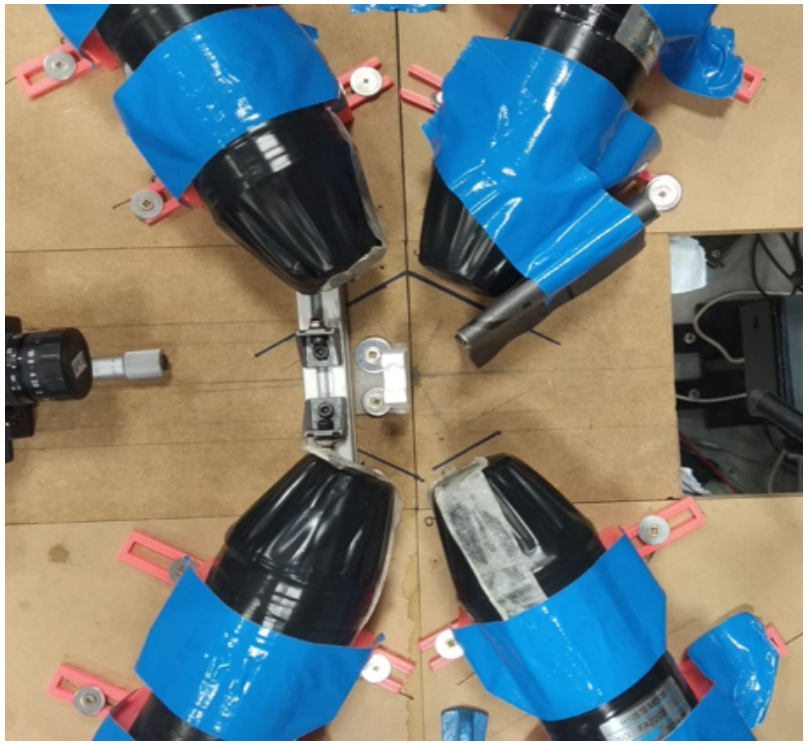
N. Mont, PhD thesis (UPC)

Detectors: gamma detection array



Fast scintillator detectors based on FATIMA design:

- $LaBr_3(Ce)$ crystals
- Fast PMTs
- Digital electronics with high-rate capability



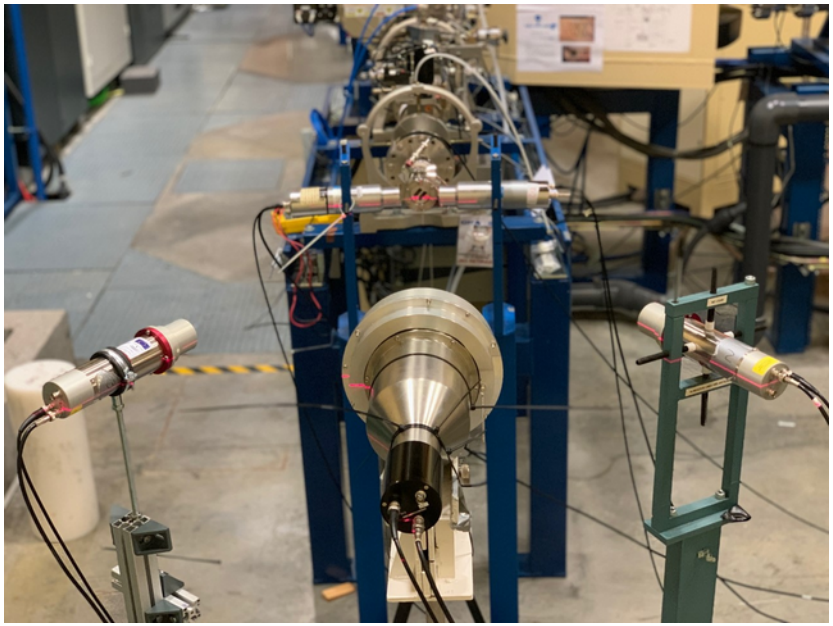
UNIVERSIDAD COMPLUTENSE MADRID

FATIMA8 at selected angles

Commissioning: status and progress

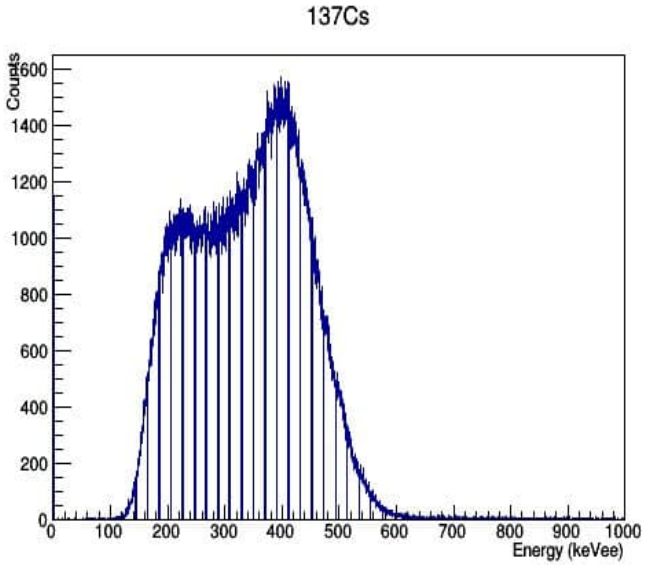
MONSTER module test @ CNA:

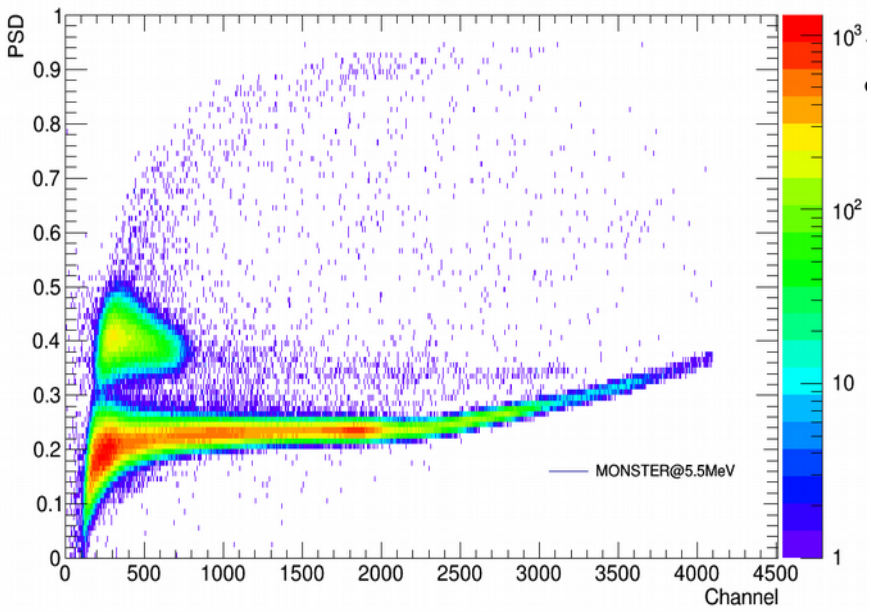
- Neutron detectors: MONSTER @75cm/0º + 2xTADEO @75cm/30º
- Gamma detectors (t_0-correlation): 2x LaBr3 (1,5”x1,5” @90º)
- Continuous alpha beam at 5, 5.5 y 5.75 MeV @ ~200 nA
- 27Al target without suppression
- Current monitor on target + CI ORTEC 439
- DAQ: CAEN V1751 (1 GS/s @ 10 bits, with PSD)

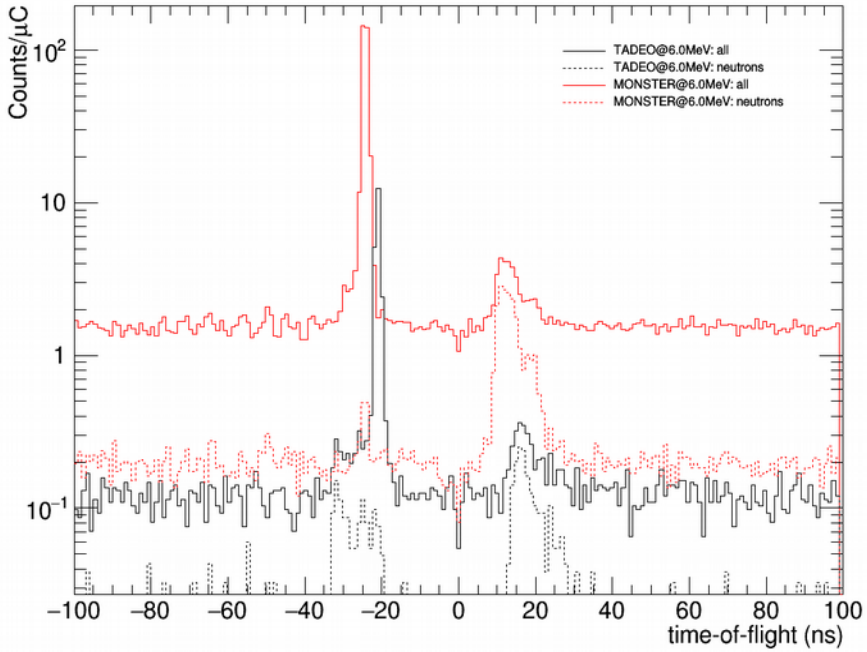


Commissioning: status and progress

- Required high threshold in order to avoid large counting rates (noise). To be solved by using dedicated MONSTER DAQ.
- Pulse shape discrimination and correlation with LaBr3 capabilities.
- **Commissioning with MONSTER array and pulsed beam planned for 2022.**

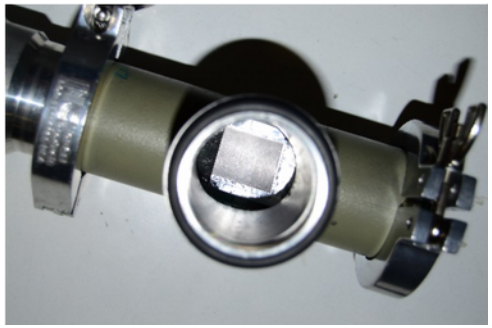






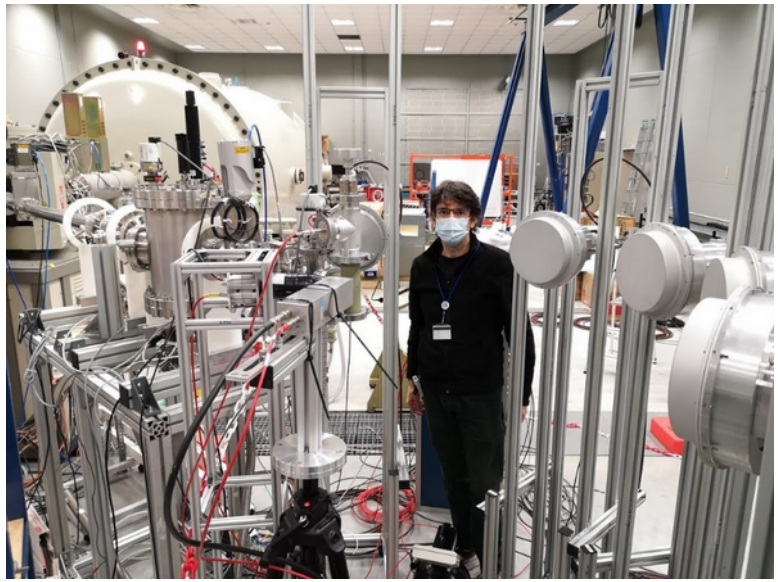
Commissioning: status and progress

MONSTER commissioning test @ CMAM:



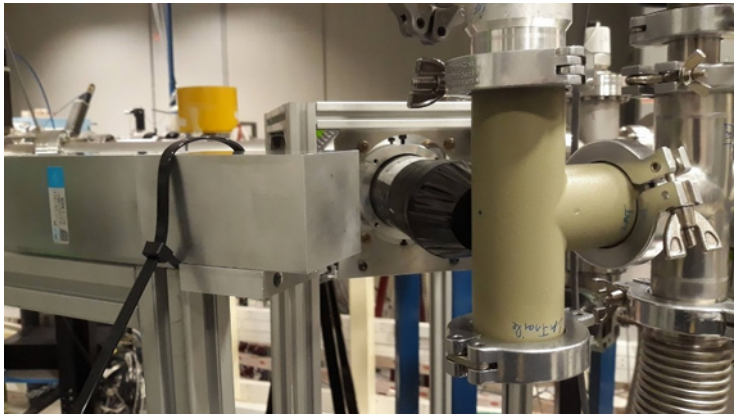
Done:

- First commissioning test at CMAM facility with ^{27}Al(α,n) and continuous α beam at 5.0, 5.5 and 8.0 MeV has been performed
- 5 Monster detectors at 0, 30, 60, 90, 140º
- LaBr3 detectors for gamma-rays
- Data still under analysis



Next:

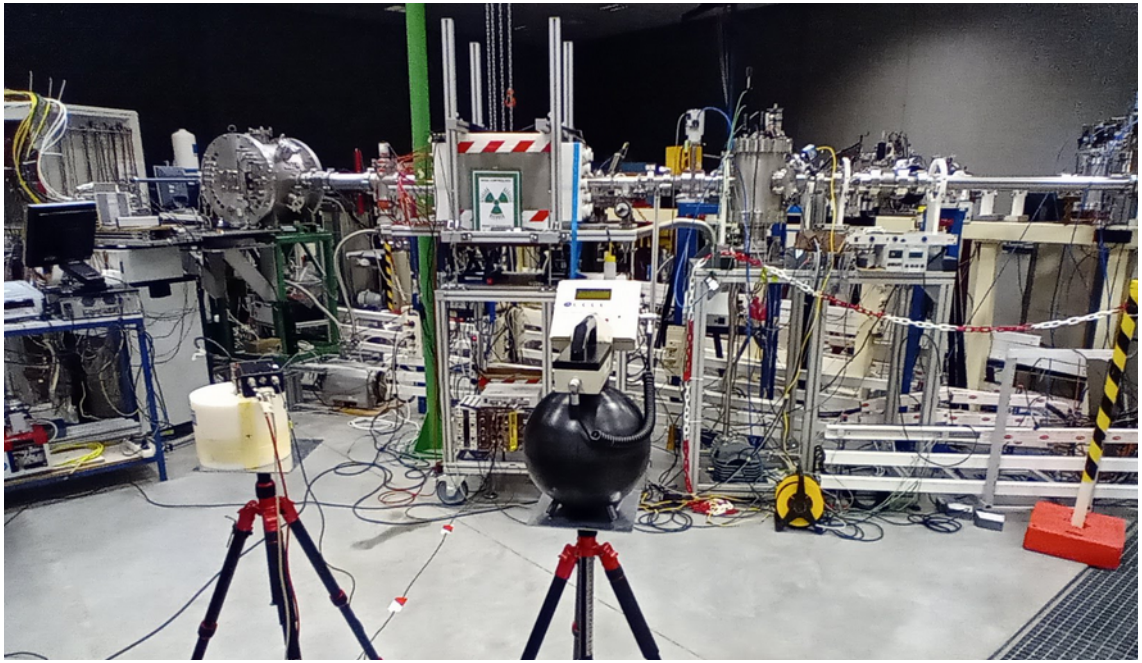
- Commisioning test at CNA facility to be performed next 2022
- Pulsed α beam at 5.0, 5.5, 6.0, 7.0 and 8.0 MeV
- Target of ^{27}Al



March 2021

Commissioning: status and progress

miniBELEN-10A commissioning test @ CMAM:



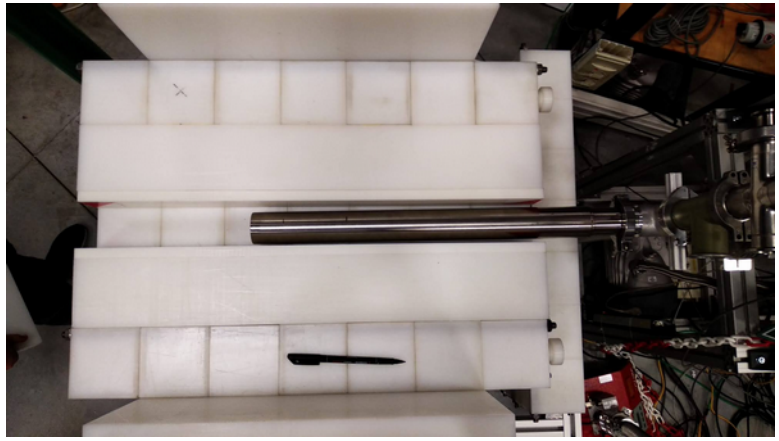
MiniBELEN-10A (neutron counter):
- HDPE moderator.
- ^{3}He-filled proportional counters (20, 10, 8 and 4 atm).
- Cadmium and boron shieldings.
- Shielding in beam (removable).

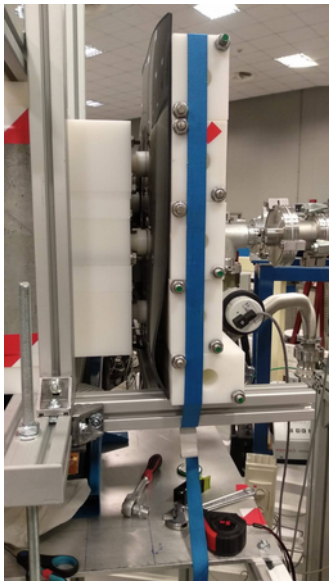
LINrem2 (neutron dosimeter):
- HDPE moderator.
- ^{3}He-filled proportional counter.
- **Current integrator:** Ortec 439.
- **LaBr3 detector (gamma detector).**
- **Al and Ta thick targets. Ta for bkgn assessment**

Collimator:
- 7 mm diameter Ta collimator.
- It could be used as current supressor (200 V).

CMAM accelerator (α particles, q = +2).

March 2021

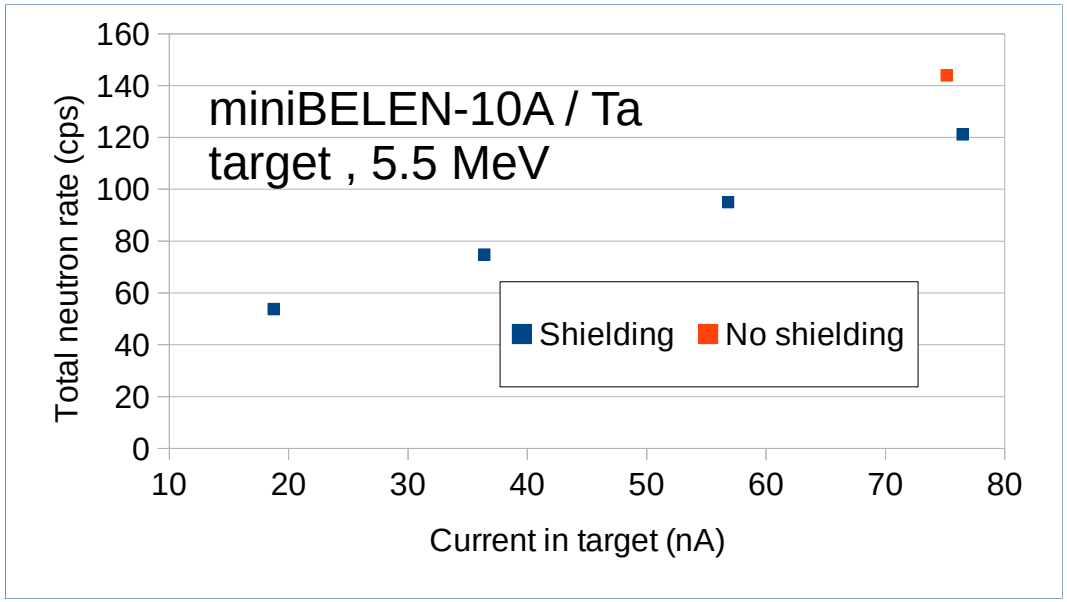


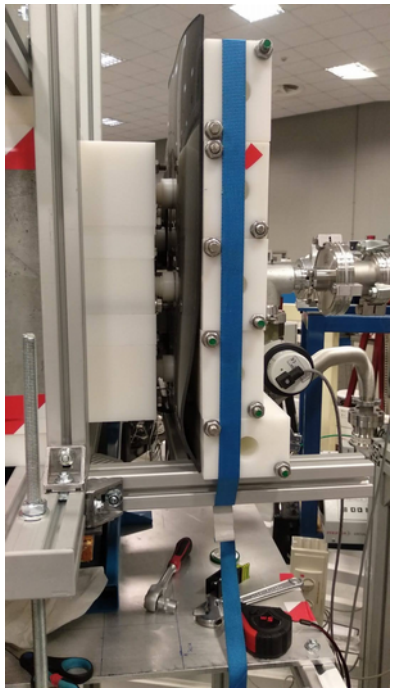


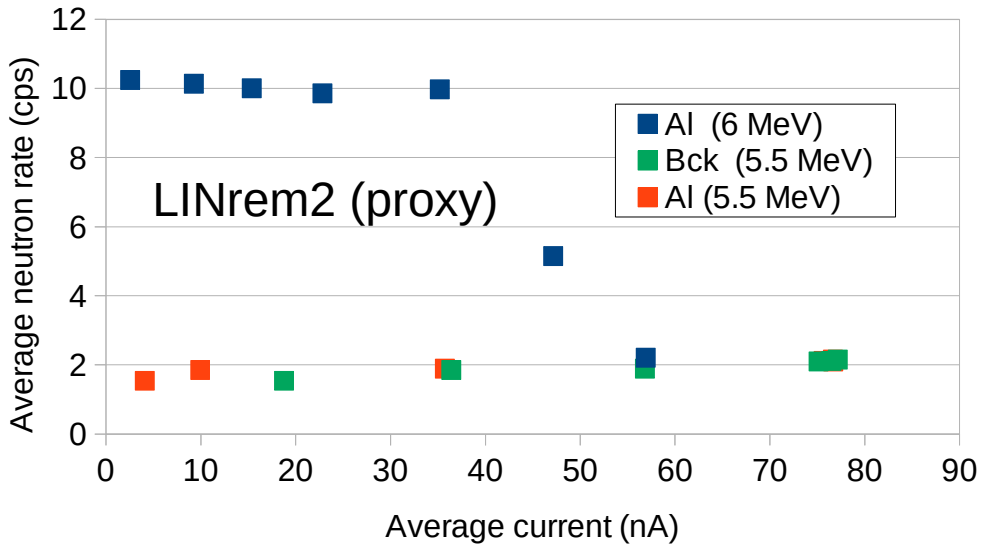
Suppression failed during the test!

Commissioning: status and progress

Assessment of the background conditions







- LINrem2 can be used as a proxy for external background monitoring.
- Beam setup not optimized for the target position (6 MeV problems)
- miniBELEN background rates were greater in the inner rings. Background produced around the target.

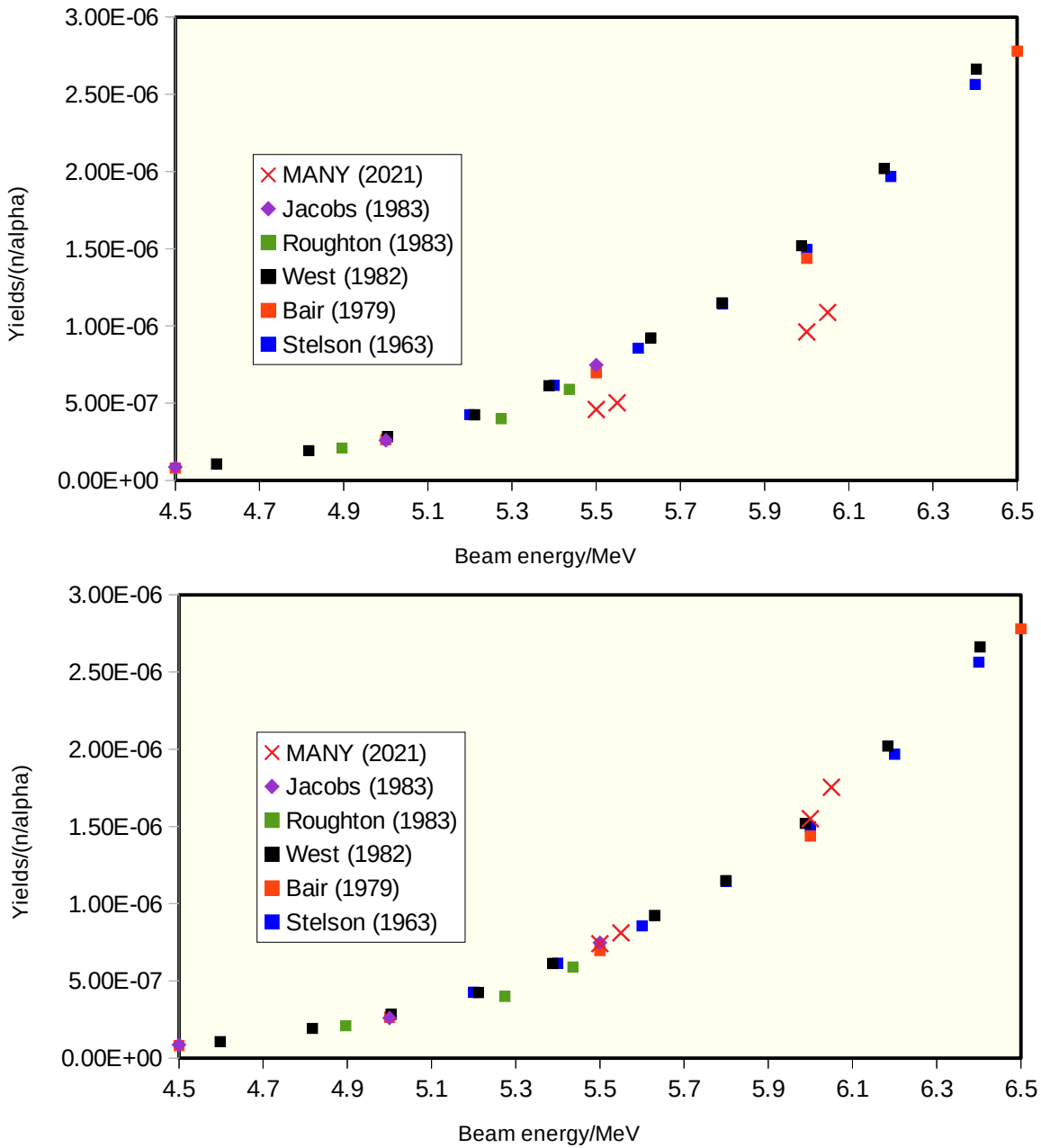
Required improvements on target holder and beam line setting.

Production yields for 27Al

- Our absolute yields from the commissioning test measurements are not consistent with reported experimental values.
- The underestimation of the neutron yield does not depend on the beam energy so it is compatible with and overestimation of the beam current.
- A correction factor estimated from the 5.5 MeV results in good agreement with the other data points.

$$\text{Factor} = \frac{Y_{MANY}}{Y_{av}} = 0.63 \pm 0.02$$

Improvements on reliable estimation of the beam current on target are priority!

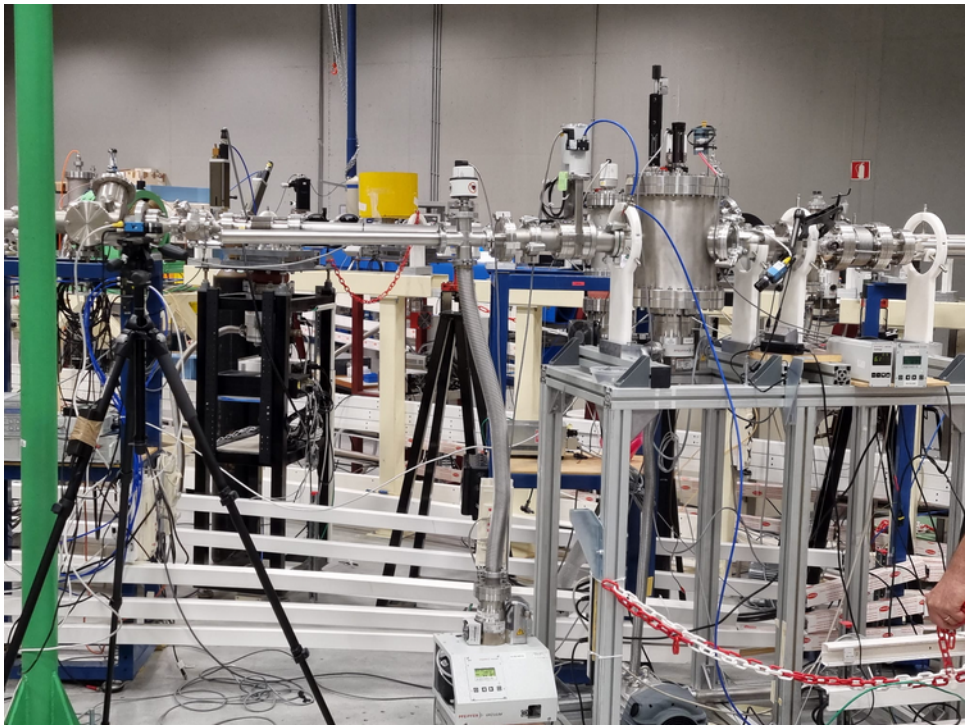


Commissioning: status and progress

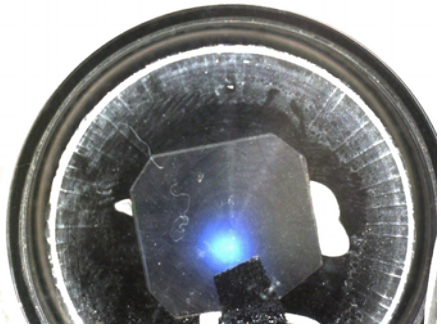
Beamline commissioning at CMAM (Sep-Oct/21)

- Optimized setting for stable focal point at the target position for miniBELEN-10A (without extra beam optics)

- New target holder including collimator and suppression constructed. Ready for testing.



Optimized focal point



Verification of absolute beam current measurements to be done by the end of November.

Summary and remarks

- Up to now, we have been focused on the technical aspects (challenges and corrective actions).

- Around 1.5 days spent on detector tests and commissioning (CNA/CMAM & MONSTER/miniBELEN-10A). Lot of lessons!

- Also a good opportunity for young people: 1 Phd + 2 master fully students involved.

- **CMAM:**

Commissioning with continuous beam in progress. New run for miniBELEN-10A and gamma array expected for Dec/21. Implementation of pulsed beam will take longer.

- **CNA:**

Commissioning with pulsed beam + MONSTER planned for 2022. Commissioning with miniBELEN-10A expected after summer.

- MANY will provide new opportunities for physics with (α,n) reactions once positive commissioning results are demonstrated.

Open question about short term strategy: focus on cross sections or production yield measurements? Depends on the target community?

MANY collaboration

The MANY project: measurement of neutron yields and spectra from (α,n) reactions in Spain

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Thanks