Status of and perspectives for the study of (α,n) reactions at CNA HISPANOS

(by means of activation and time-of-flight)

Carlos GUERRERO and The MANY Collaboration

Universidad de Sevilla, Seville, Spain

Centro Nacional de Aceleradores (CNA), Seville, Spain

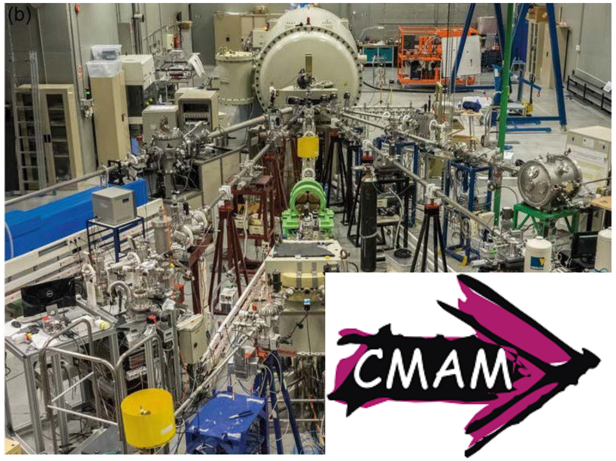
IAEA Technical Meeting on (α,n) Reaction Nuclear Data Evaluations and Data Needs

November 27th to December 1st (2023)

The MANY Collaboration (I)

Two Spanish facilities

Infraestructuras Científicas y Técnicas Singulares



UPC

Universidad de Sevilla

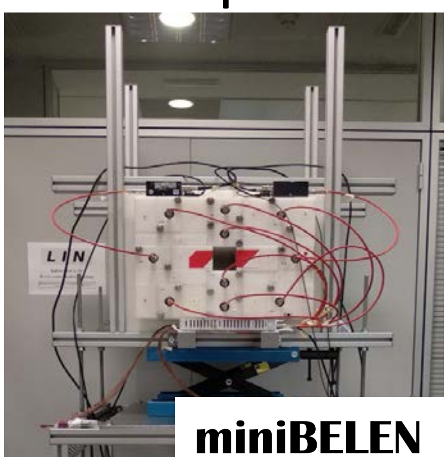
IFIC
INSTITUT DE FÍSICA CORPUSCULAR

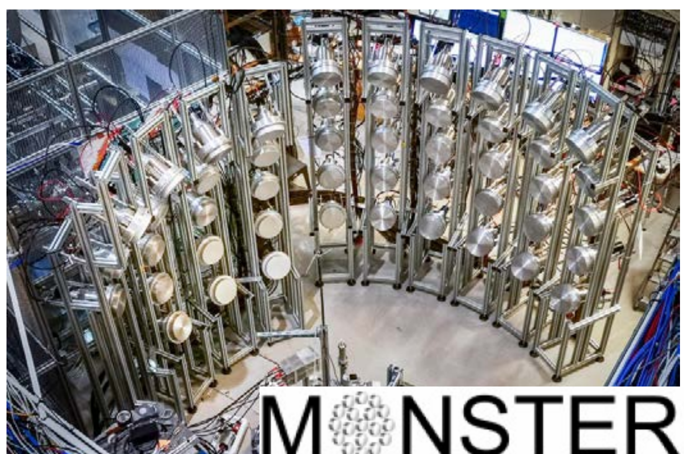
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

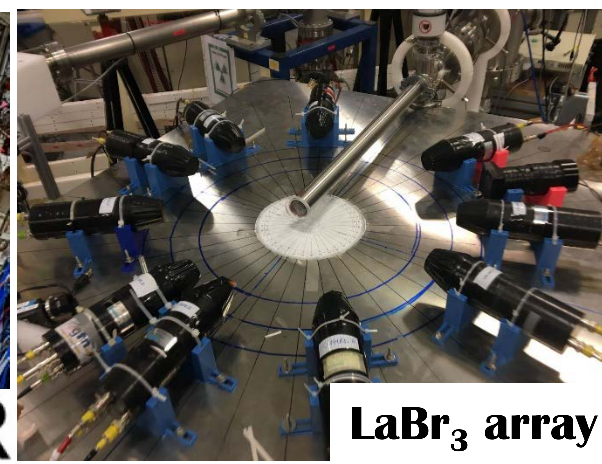
UNIVERSIDAD COMPLUTENSE MADRID

IEM
Instituto de Estructura de la Materia

Three Spanish detectors







The MANY Collaboration (II)

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The MANY Collaboration (III)

Contributions to this IAEA TM:

- C. Guerrero, *Status of and perspectives for the study of (α,n) reactions at CNA HISPANOS by means of activation and time-of-flight*
- A. de la Rada, *Innovative analysis technique of neutron time-of-flight spectra, validation, and first results in (α,n) reaction studies*
- A. Tarifeño, *Status and perspectives of thick target measurement of (α,n) reactions using the miniBELEN detector*
- N. Mont i Geli, *Preliminary results from thick target measurements of the ^{27}Al(alpha,n)^{30}P reaction cross-section using miniBELEN-10A*
- L.M. Fraile, *Measurement of Al(α,nγ)P thick-target yields and total Al(α,n) yields by activation*
- R. Santorelli, *(α,n) neutron yields for rare-event search experiments: a collaborative effort to understand the backgrounds*

MANY (α,n) at CNA HiSPANoS

HiSPANoS is a “recent” facility:

- 2013-2015: explotation of continuous neutron beams

  J. Praena et al., *“Measurement of the MACS of ^{181}Ta(n,γ) at kT=30 keV as a test of a method for Maxwellian neutron spectra generation"*, Nuc. Inst. and Met. A, 727 (2013) 1-6

- 2017-2019: commissioning of Li(p,n) epitermal neutron beams

  M. Macías et al., *“The first neutron time-of-flight line in Spain: Commissioning and new data for the definition of a neutron standard field”*, Radiation Physics and Chemistry 168 (2020) 108538

- 2019-2022: commissioning of fast (d,n) neutron beams

  M.A. Millán-Callado et al., *“Continuous and pulsed fast neutron beams at the CNA HiSPANoS facility”*, Radiation Physics and Chemistry (accepted)

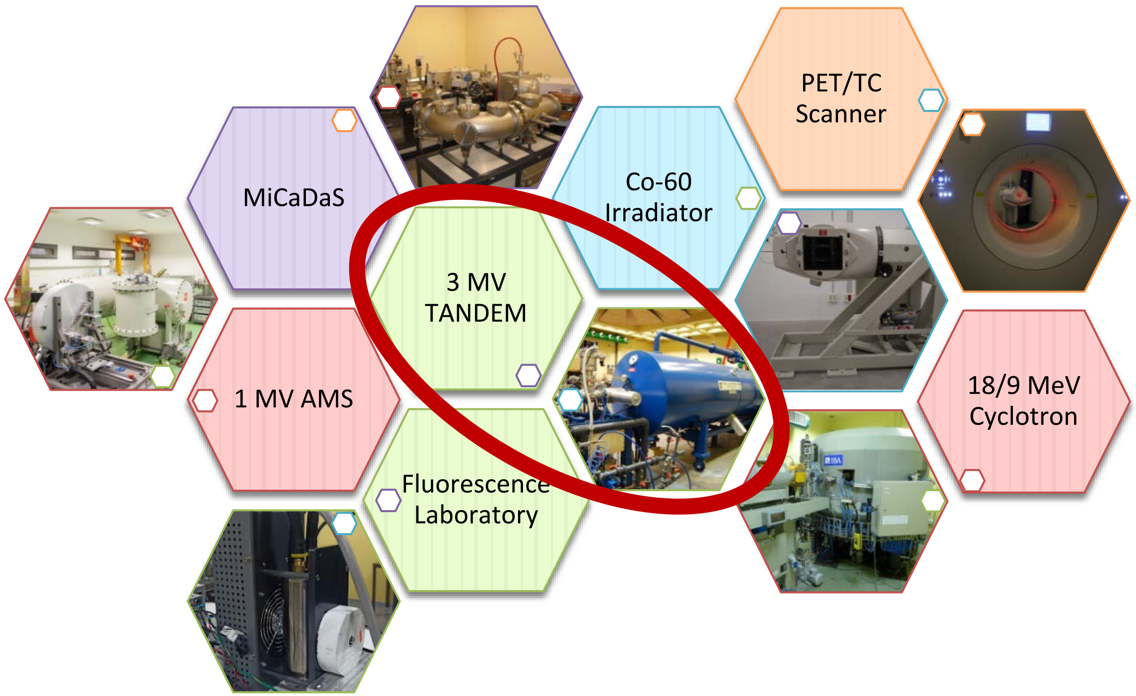
  => Today

- 2022: First tests on (α,n) neutron production

  => Today

The HISPANOS neutron facility at CNA

CNA @Universidad de Sevilla



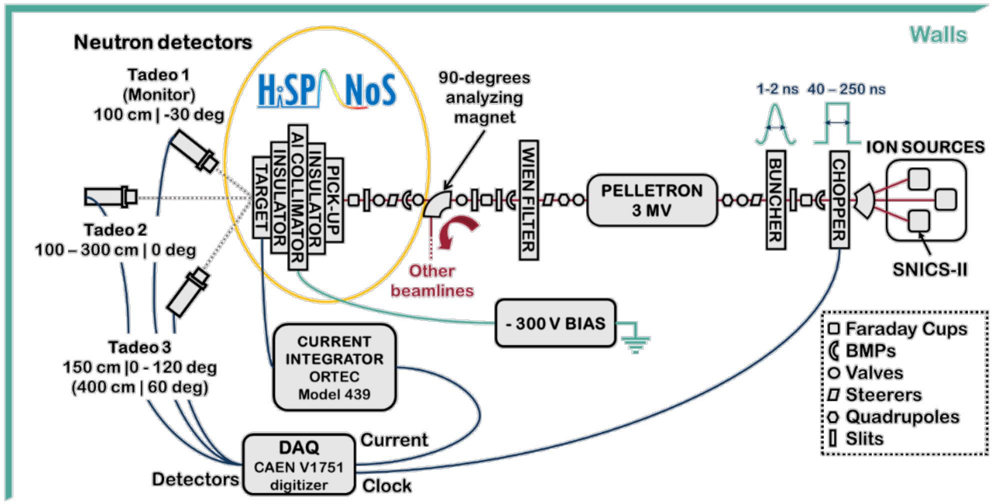
Centro Nacional de Aceleradores

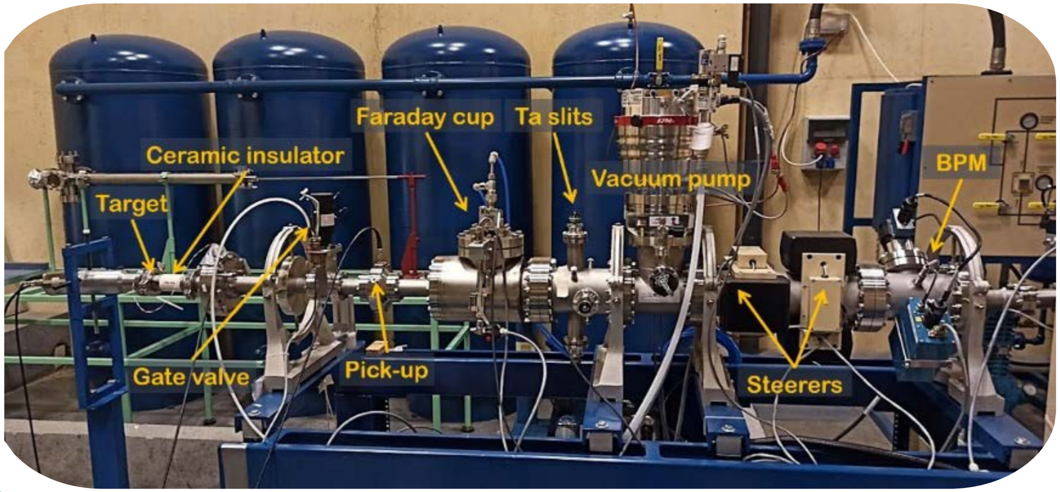
Infraestructuras Científicas y Técnicas Singulares

Multidisciplinary research center open to external users @Seville, Spain

The HiSPANoS neutron source @CNA

- HiSPANoS is **the first Accelerator-based neutron source** in Spain and it is installed at the the 3 MV Tandem Accelerator.
- Operates since:
  - **2013** in continuous mode
  - **2018** in pulsed mode



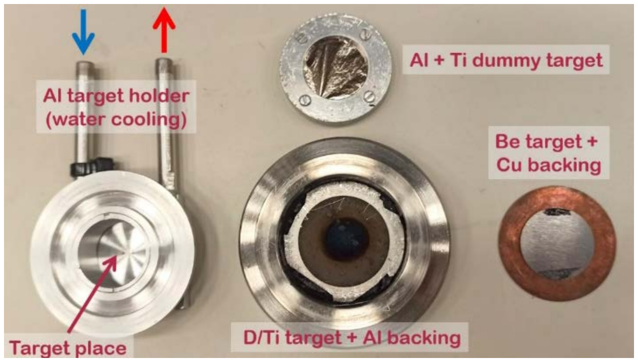


The HiSPANoS neutron source @CNA

General
- ^{1}H, ^{2}H up to 6 MeV
- ^{4}He up to 6 MeV

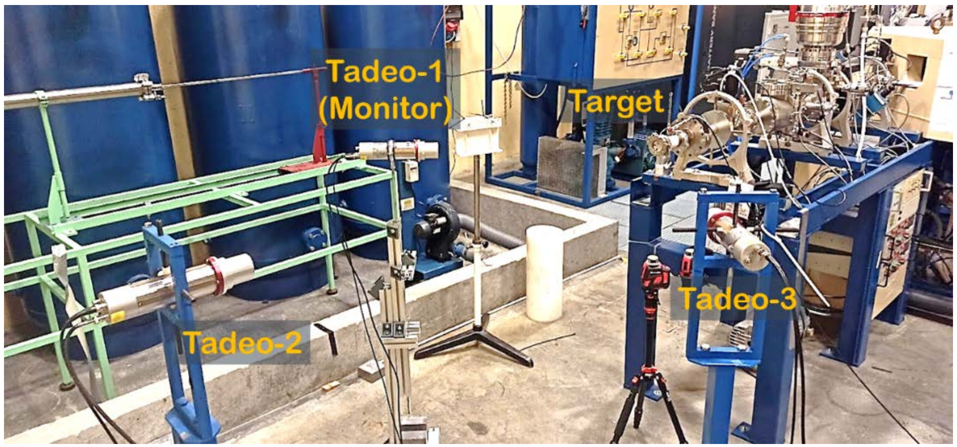
Continuous mode
- Up to 10 uA

Pulse mode
- 1-2 ns pulse width
- 32,5 kHz - 2 MHz
- 1- 4 m flight path



Reaction	Q-value (MeV)	Eth (MeV)	Target			Neutron spectra
			Material	Thickness	Diameter	
$^{2}H(d,n)^{3}He$	3,27	0,0	D/Ti	546 μg/cm^{2}	30 mm	Quasi-monoenergetic 2,2 – 6,1 MeV
$^{9}Be(p,n)^{9}B$	-1,85	2,06	Be	500 μm	25 mm	Continuum up to 4 MeV
$^{9}Be(d,n)^{10}B$	4,36	0,0				Continuum up to10 MeV
$^{7}Li(p,n)^{7}Be$	-1,64	1,88	Li	500 μm	25 mm	Continuum up to 4 MeV
$^{7}Li(d,n)^{8}Be$	15,03	0,0				Continuum up to20 MeV

HiSPANoS comissioning for FAST neutrons



Neutron Production
- Thick Be and Li targets. D/Ti thin target.
- Dummy targets

Detection
- 2”x2” EJ-301 from Scionix (n/g PSD) → Monitor
- 2”x2” EJ-309 from Scionix (n/g PSD)
  - Angle mapping (from 0 to 120 deg)
  - Distance mapping (from 100 cm to 400 cm)

Acquisition System
- CAEN V1751 4/8 Channel 10 bit 2/1 GS/s digitizer
- CoMPASS software
- ORTEC 439 digital current integrator

Background substraction
- Shadowbar: 20 cm diameter and 50 cm length PE bar + 10 cm thick lead block.

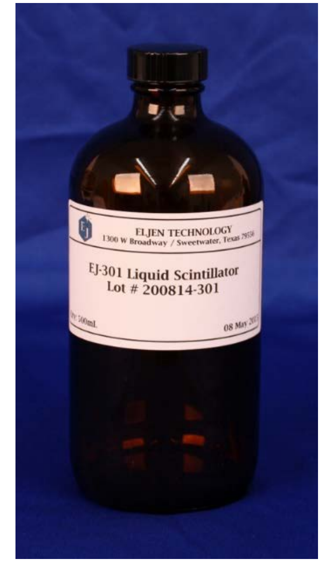
Neutron detectors

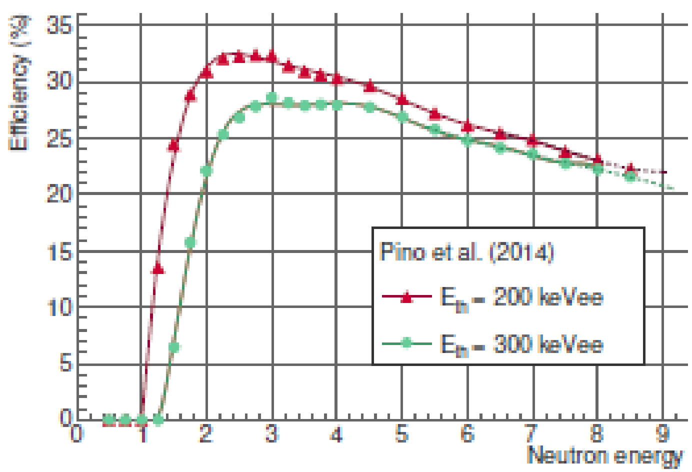
Fast neutron commissioning: TADEO detectors

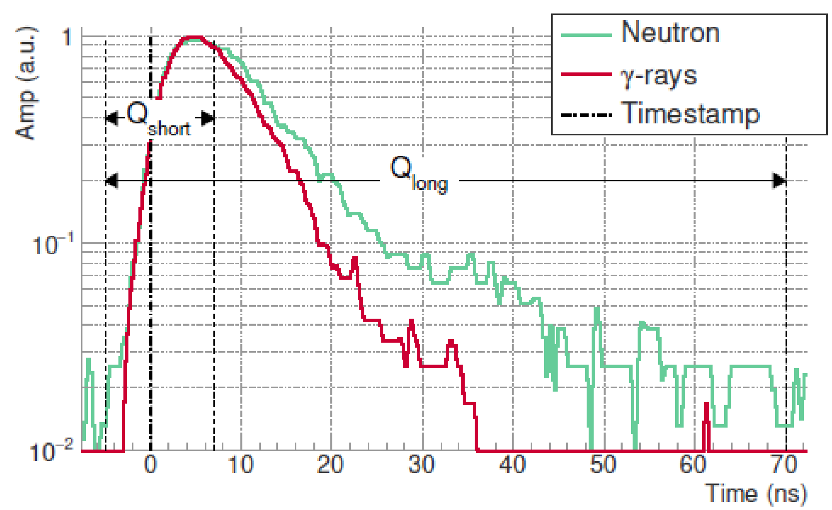
- EJ-301 from Scionix
- Pulse Shape Discrinmination (PSD) capabilities
- 2”x2” cells

(α,n) commissining: MONSTER detectors

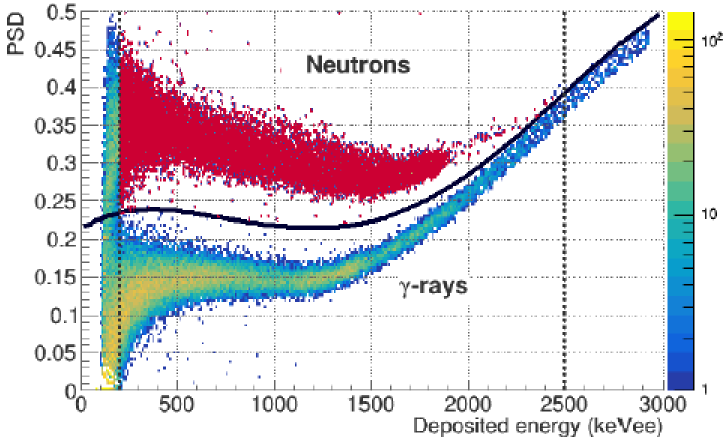
- EJ-301 from Scionix
- Pulse Shape Discrinmination (PSD) capabilities
- 5 cm x 20 cm (diam.)

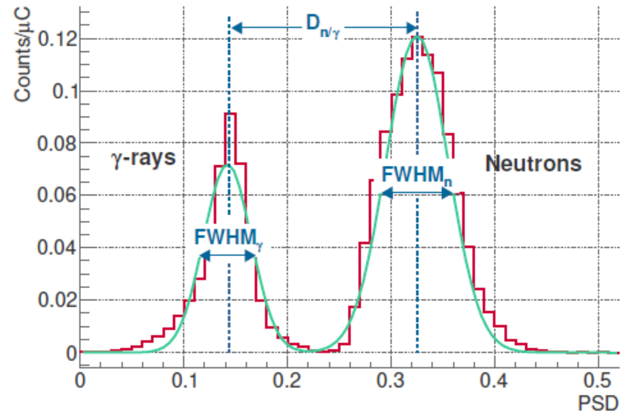


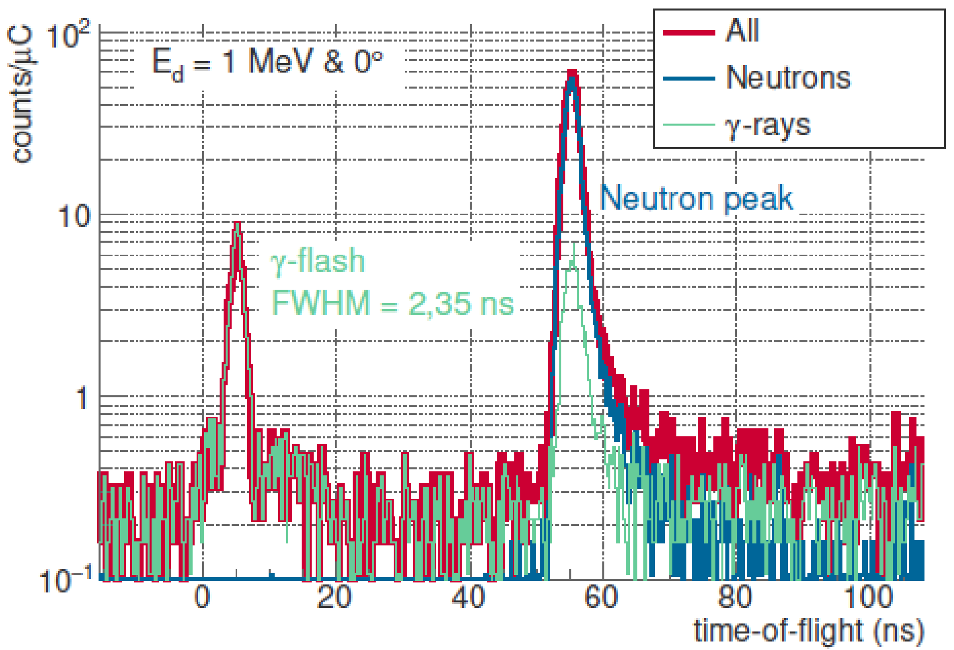




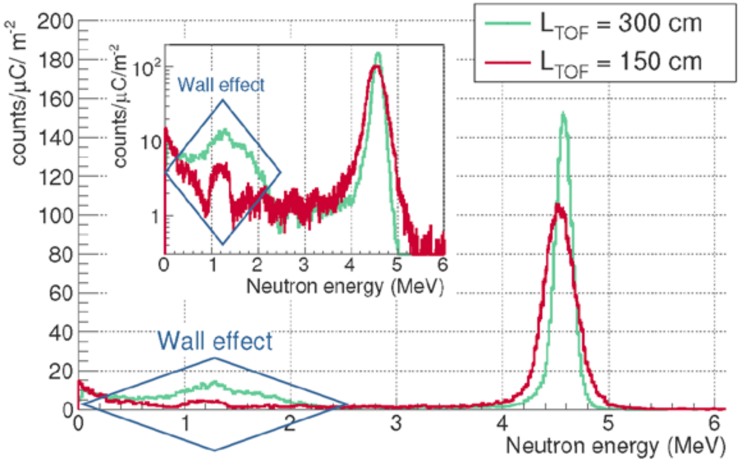
n/γ Pulse Shape Dicrimination (PSD)

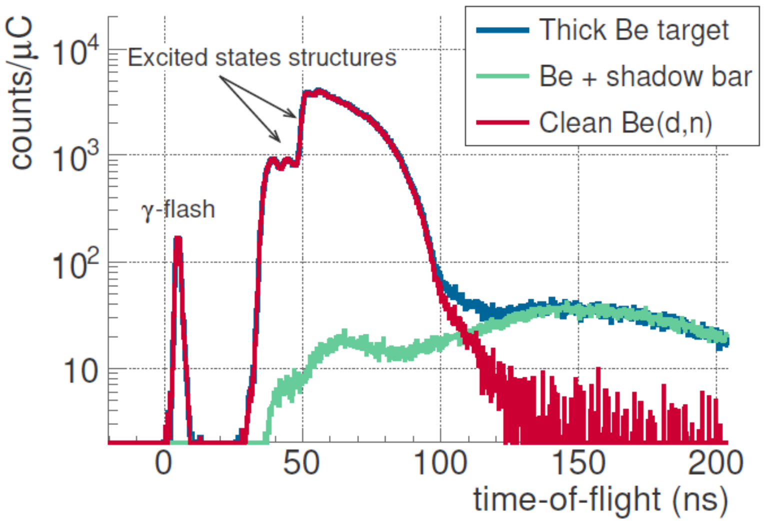


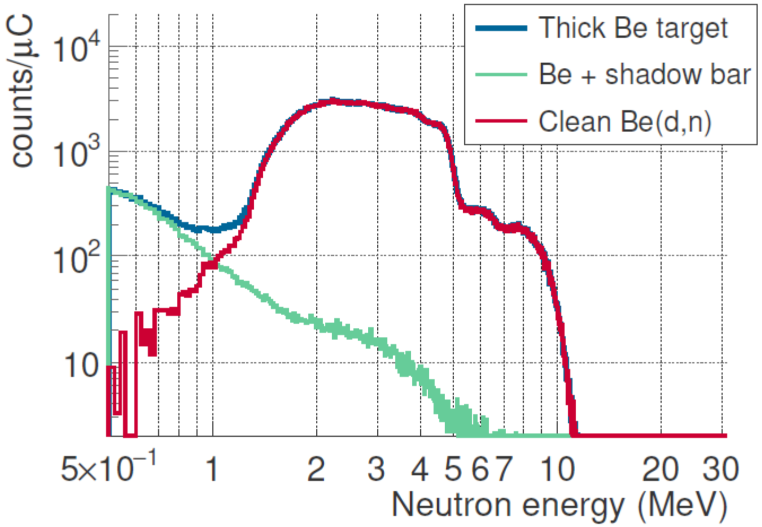




Background: neutron scattering



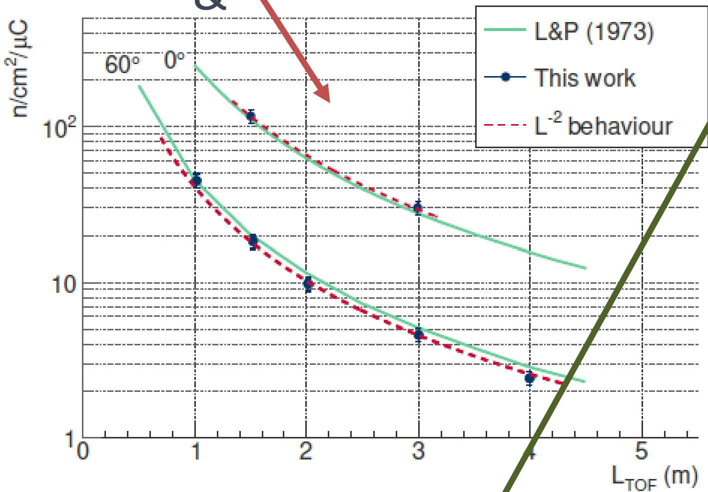


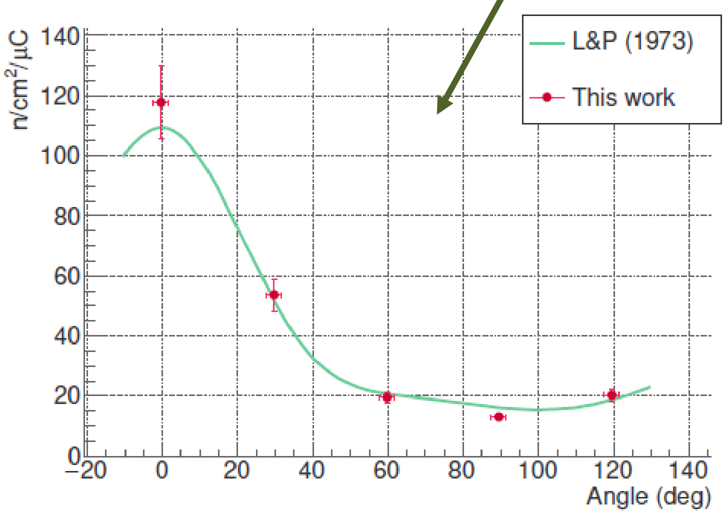


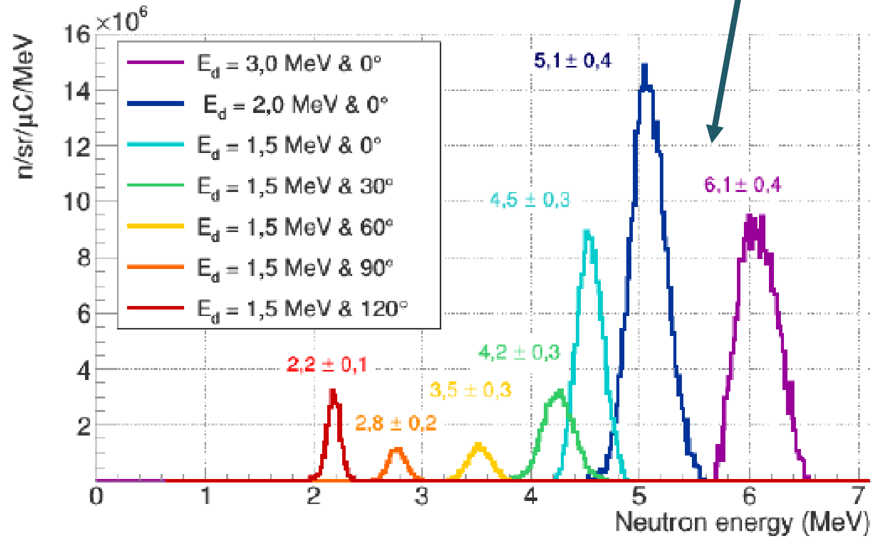
Validation of monoenergetic neutron beams

Monoenergetic beams from $^{2}H(d,n)$ reactions:

neutron flux & angular distribution & neutron energy
&



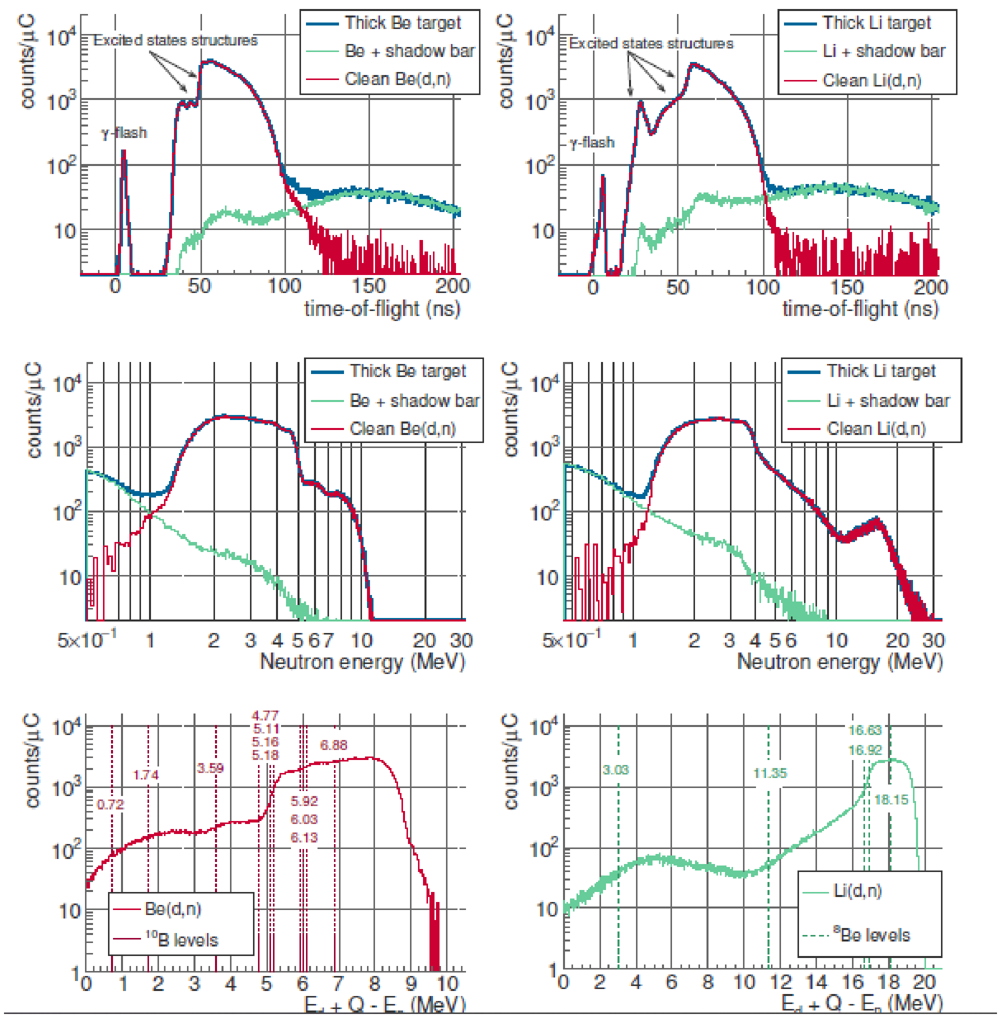


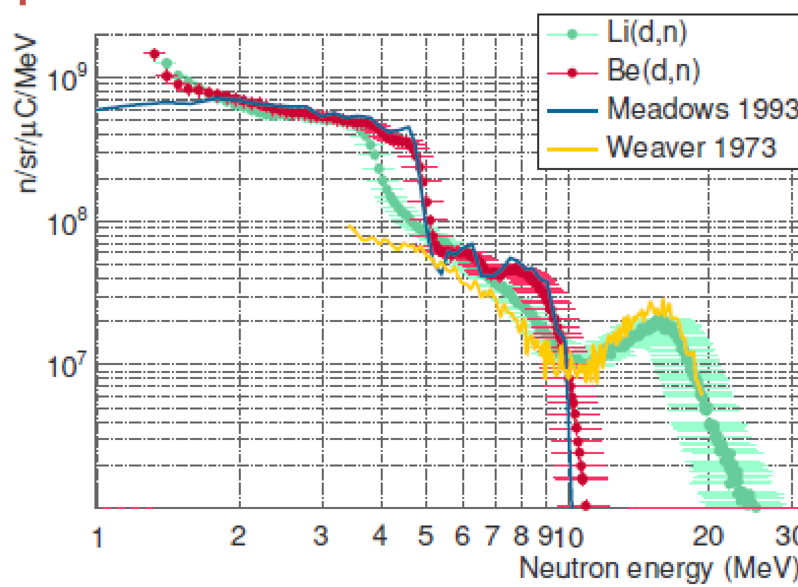


E_d (MeV)	θ (deg)	E_n (MeV)	ΔE/E	Φ_n ($n/sr/\mu C$)	Φ_n ($n/cm^2/s$) *Continuous*	*Pulsed*
1,5	120	2,2	5%	$4{,}5(0{,}4)\cdot 10^5$	100(10)	4,0(0,4)
1,5	90	2,8	7%	$2{,}7(0{,}3)\cdot 10^5$	60(6)	2,4(0,2)
1,5	60	3,5	8%	$4{,}1(0{,}4)\cdot 10^5$	90(9)	3,6(0,4)
1,5	30	4,2	7%	$1{,}2(0{,}1)\cdot 10^6$	270(30)	11(1)
1,5	0	4,5	7%	$2{,}6(0{,}2)\cdot 10^6$	590(20)	23(2)
2,0	0	5,1	8%	$3{,}1(0{,}3)\cdot 10^6$	680(30)	27(3)
3,0	0	6,1	7%	$3{,}7(0{,}4)\cdot 10^6$	830(30)	33(3)

Validation of "broad" neutron beams

Broad neutron beams from Li(d,n) and Be(d,n) reactions: flux & energy





Reaction	E_d (MeV)	Max. E_n (MeV)	Φ_n ($n/sr/\mu C$)	Φ_n (n/cm^2/s) *Continuous*	*Pulsed*
Li(d,n)	5,75	$\sim$ 20	2,2(0,2)·10^{10}	5,0(0,5)·10^{6}	2,0(0,2)·10^{5}
Be(d,n)	5,75	$\sim$ 10	2,5(0,3)·10^{10}	5,4(0,5)·10^{6}	2,2(0,2)·10^{5}

Test experiment on ^{27}Al(α,n)

Facility
Experimental set-up
(detectors + DAQ)
Measuring strategy
Analysis strategy

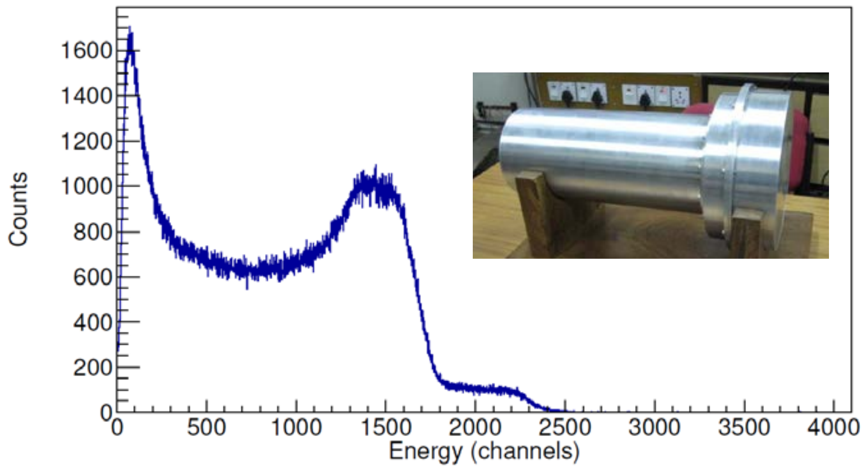
Validated for ^{2}H induced reactions
=> let's see for (α,n)

Experimental set-up

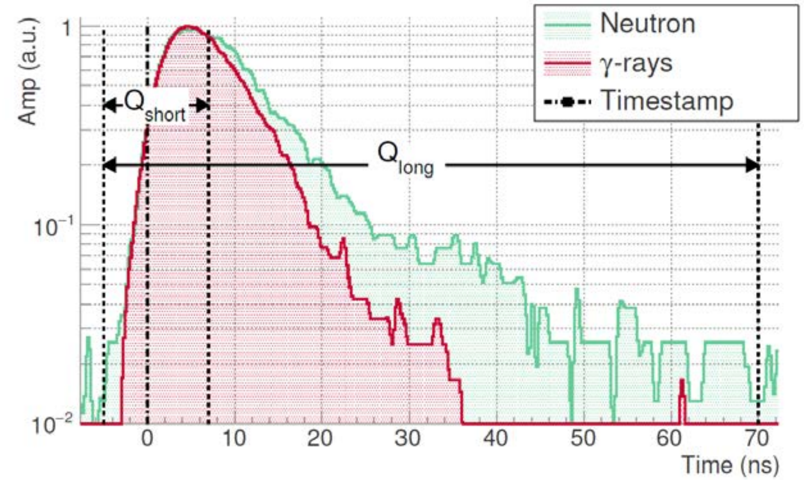
MONSTER module

ToF measurement: MONSTER

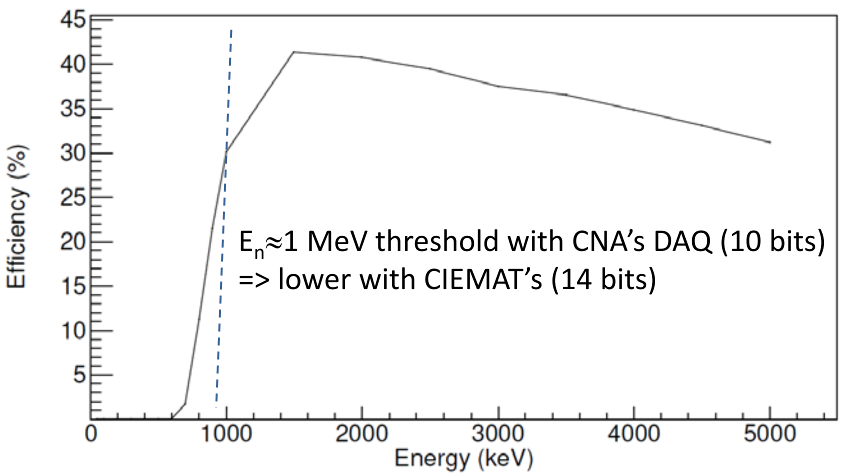
Response to a ^{60}Co source



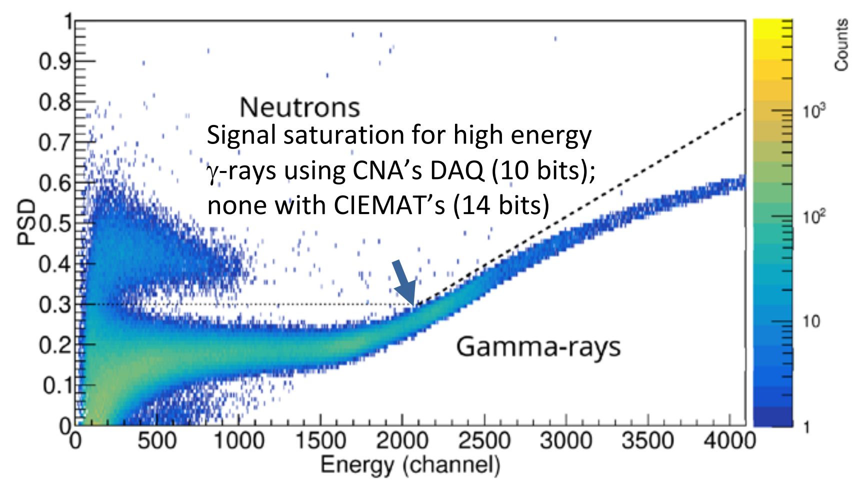
Signals shape



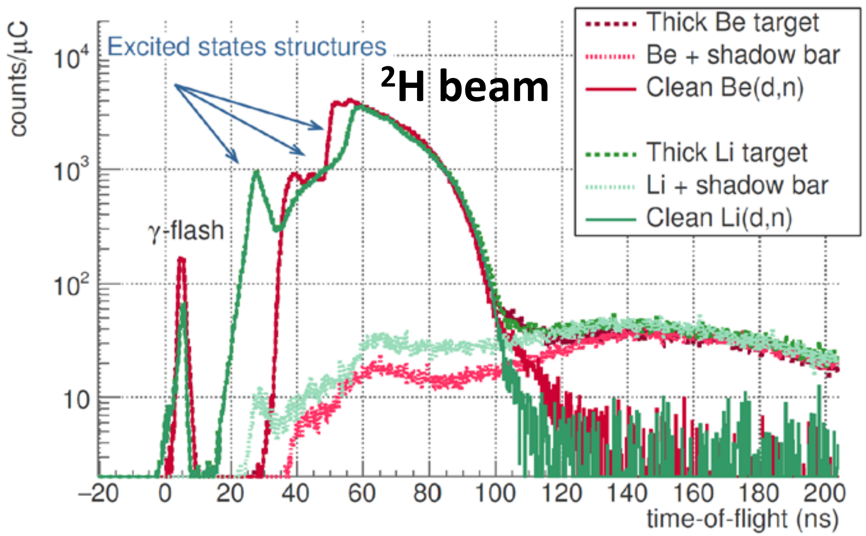
Efficiency from Geant4 simulations by CIEMAT



Pulse Shape Discrimination (PSD)



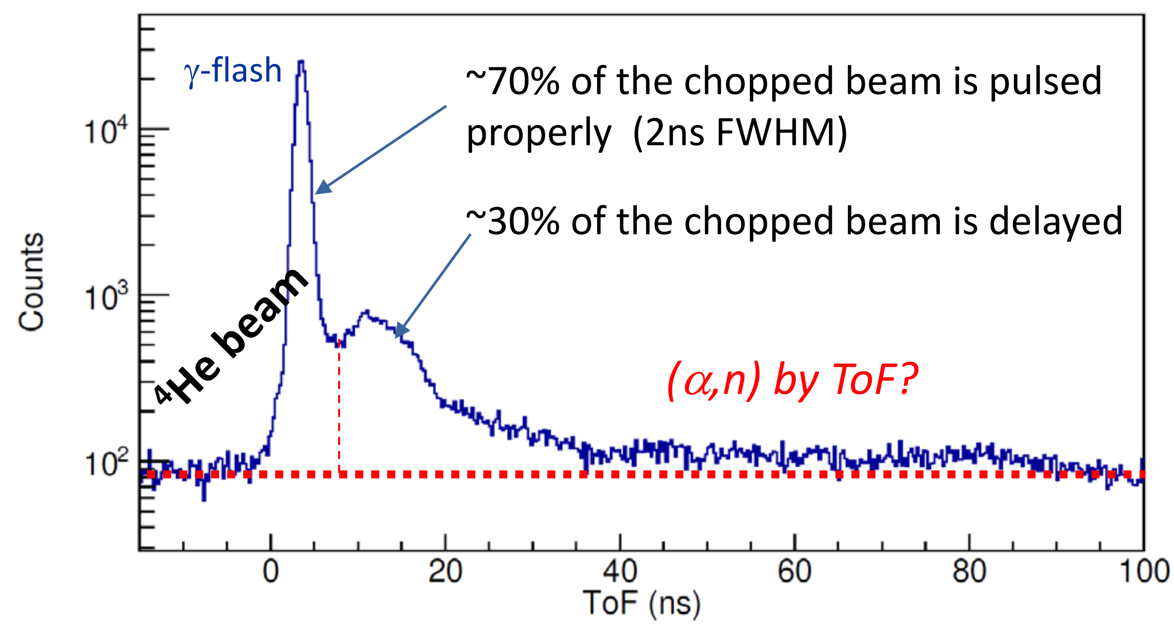
ToF measurement: the pulsed α beam



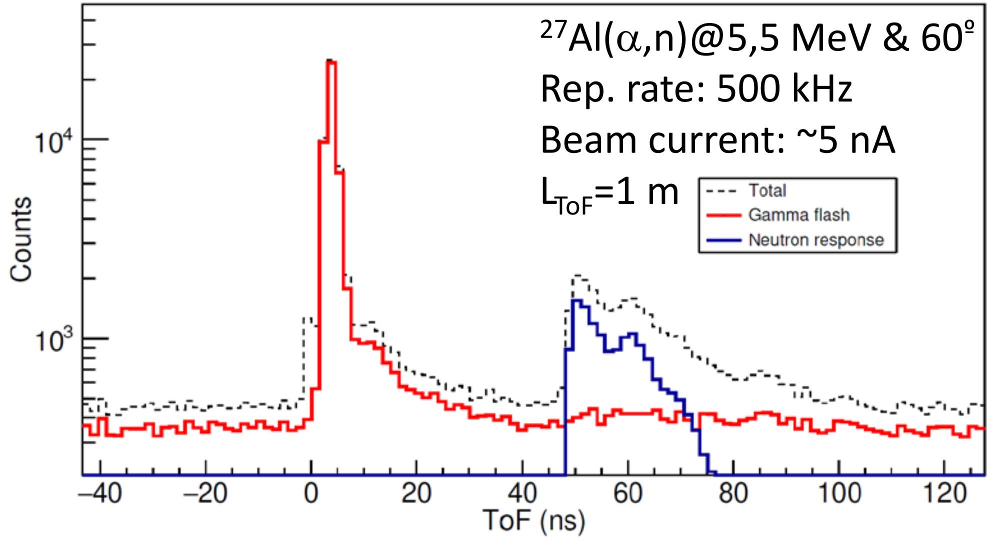
The buncher is designed only for “H”

Bunching ^{4}He (α) requires a modification by the manufaturer (NEC): ongoing.

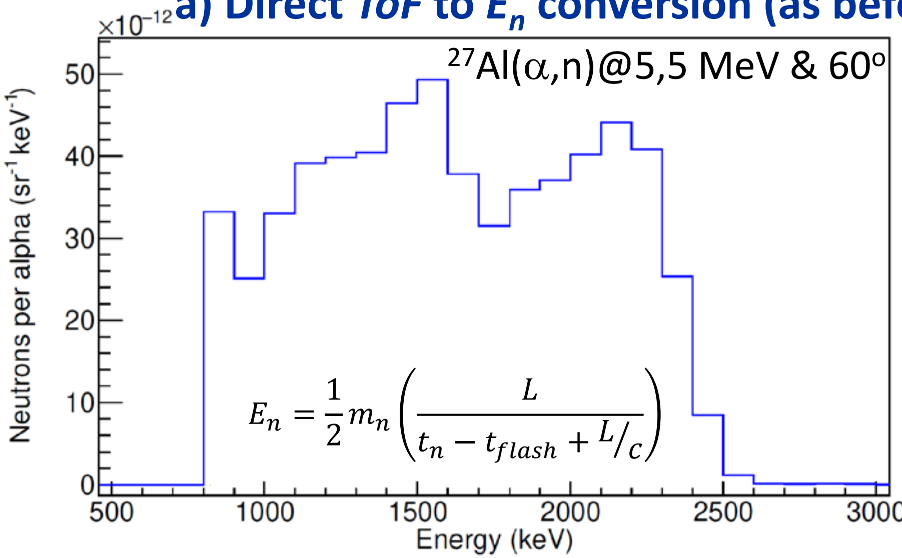
What can we do as of now so far?



ToF measurement: data analysis (I)

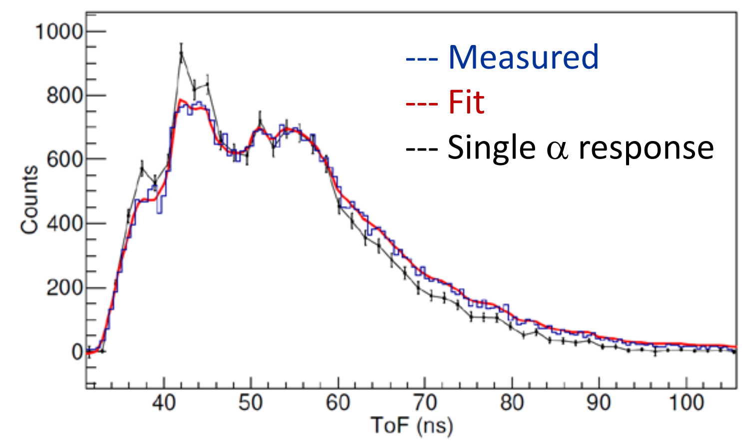


a) Direct *ToF* to *E_n* conversión (as before)

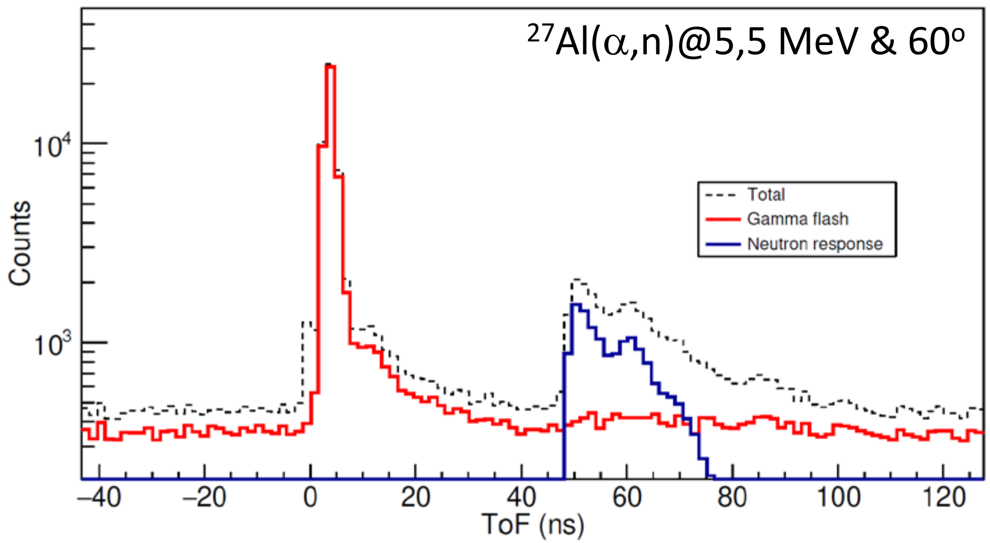


b) Inverse problem / deconvolution

- 50 parameter ToF distribution for a single "α" particle
- Runs over γ-flash and "fits" the measured ToF distribution



ToF measurement: data analysis (II)

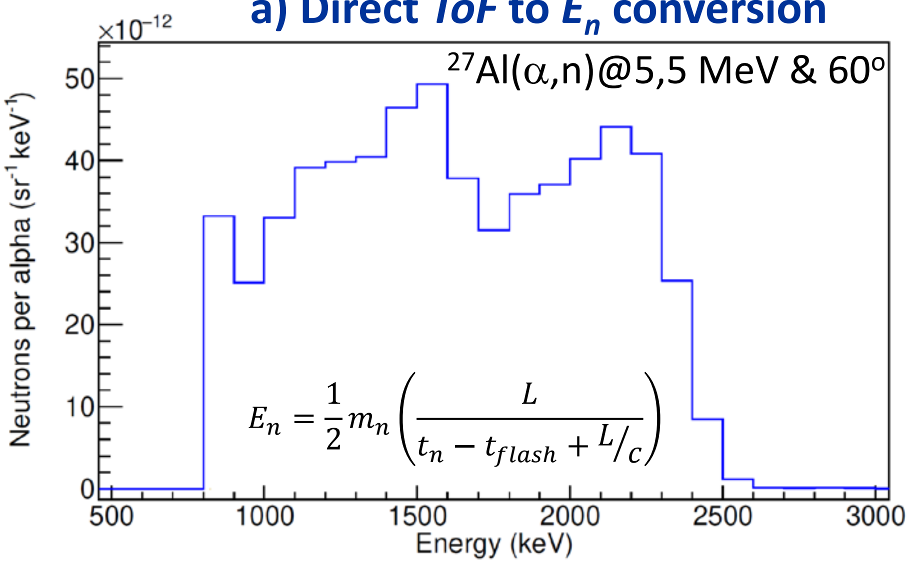


Strategy:

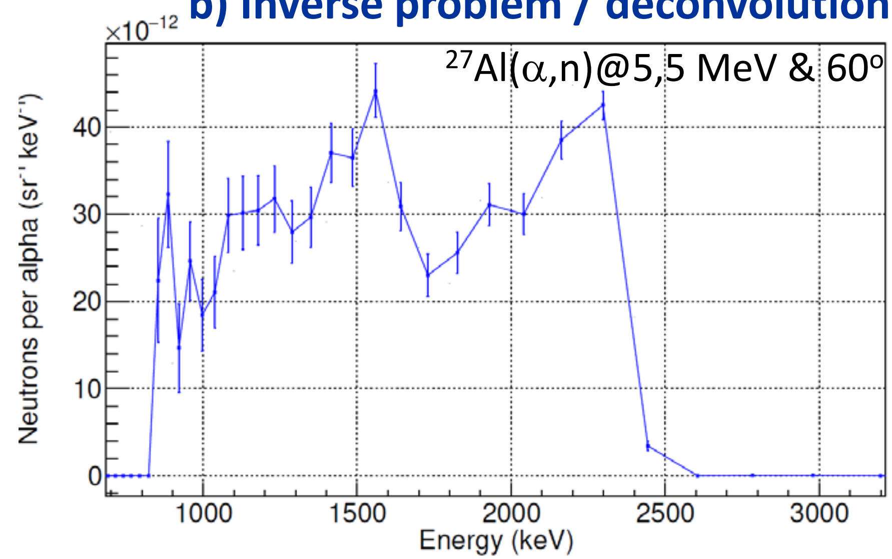
- ToF measured simultaneously with CNA's & CIEMAT'S DAQs.
- Analysis and spectrum deconvolution made independently by CNA and CIEMAT for internal cross check and comparison.

=> Results presented herein correspond to CNA's análisis.

a) Direct *ToF* to E_n conversion



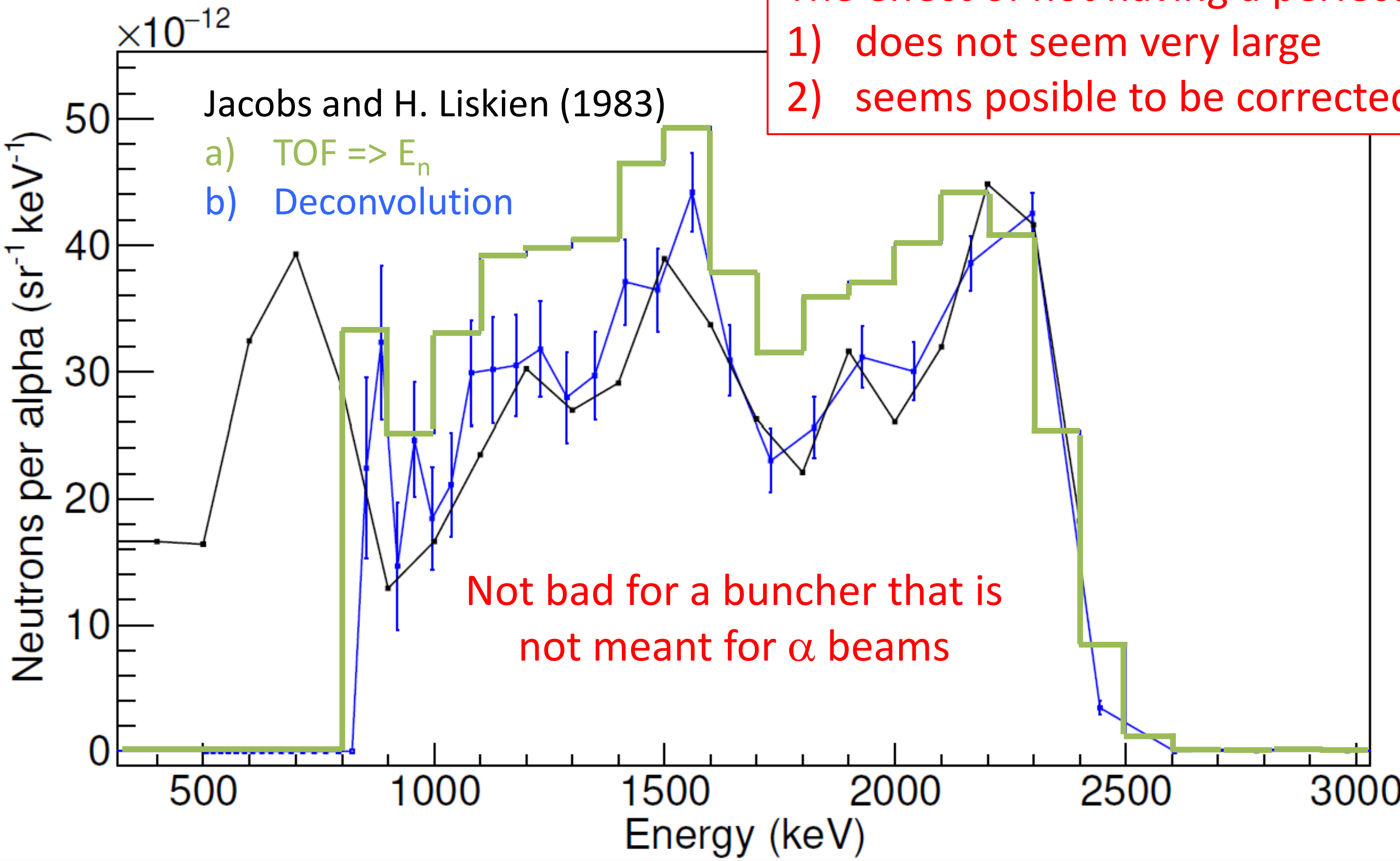
b) Inverse problem / deconvolution



ToF measurement: results @ 5,5 MeV

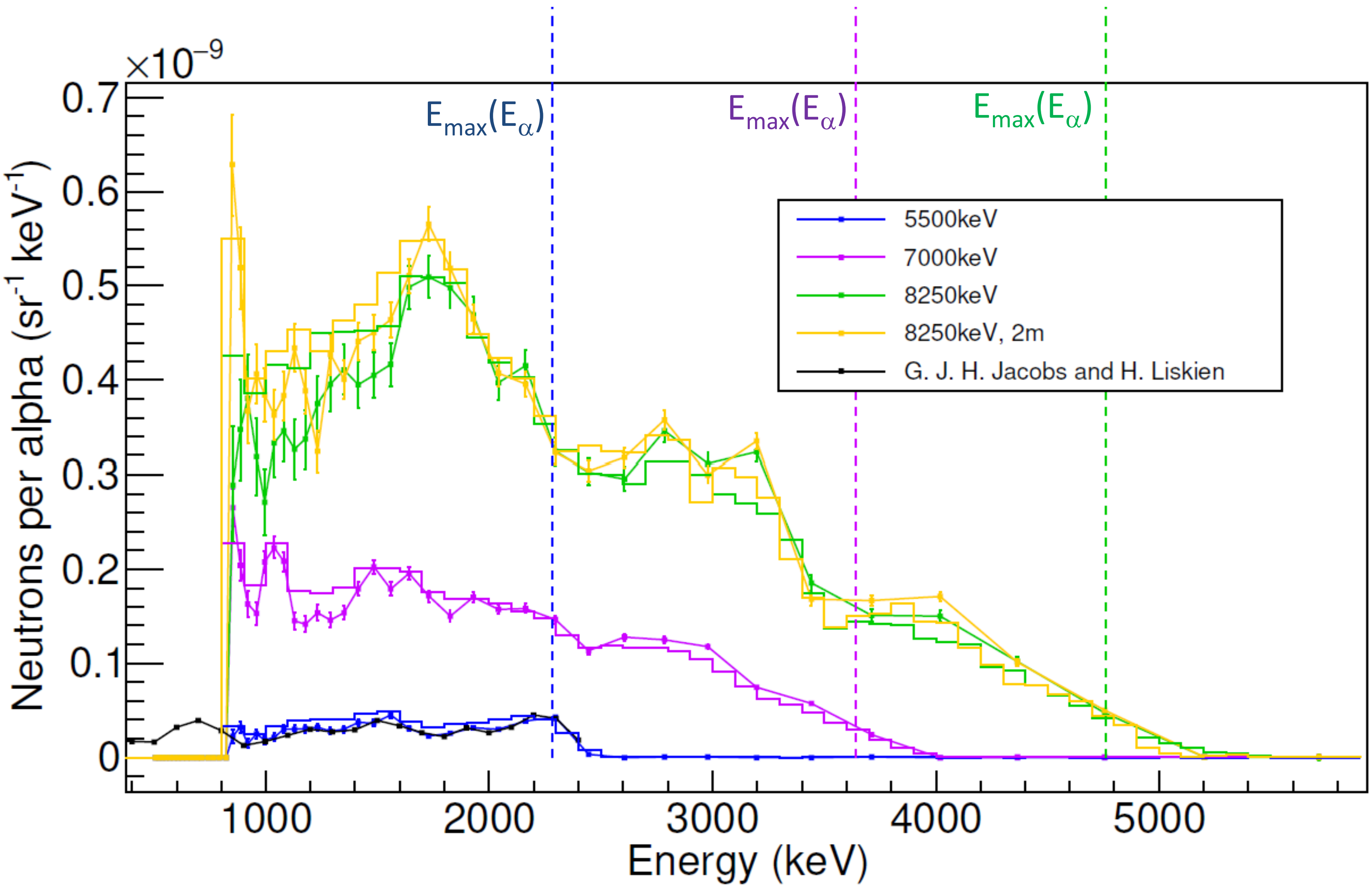
Very good agreement in both absolute value and neutron energy with the only experiment available in the literature.

The effect of not having a perfect bunching:
1) does not seem very large
2) seems posible to be corrected for



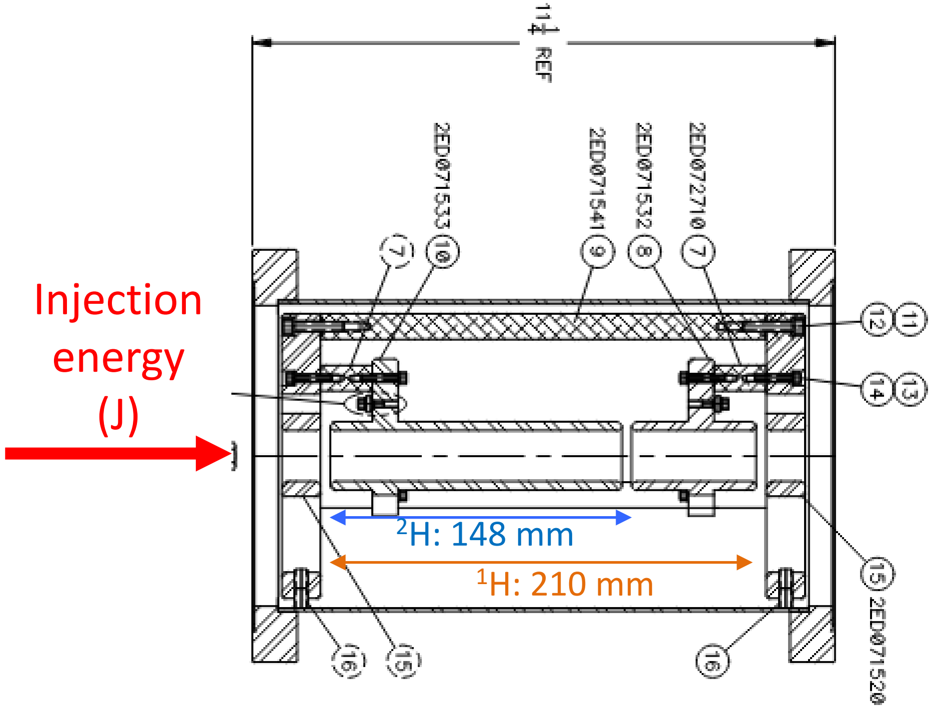
Not bad for a buncher that is not meant for α beams

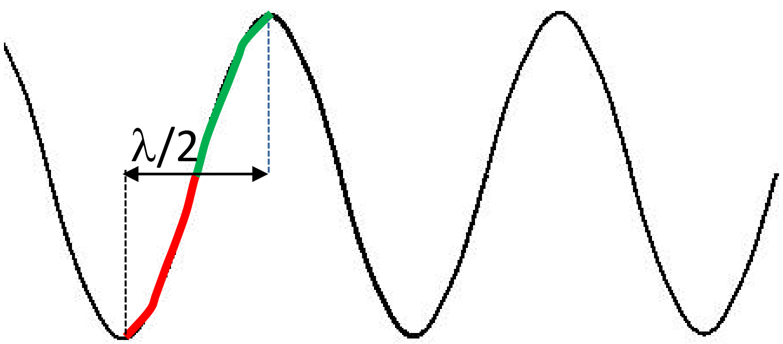
ToF measurement: results @ 5,5 to 8,5 MeV



Foreseen upgrades

New buncher (2024)





Beam	J=59 keV	J=72 keV
^{1}H	**210 mm**	
^{2}H	**148 mm**	
^{4}He	**105 mm**	116 mm

3 elements buncher ordered to NEC:

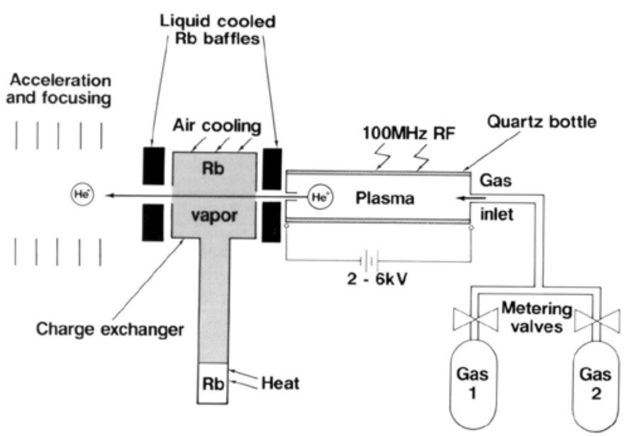
- Optimized for ^{1}H, ^{2}H and ^{4}He at 72 keV
- Expected end 2024

New ion source (2025)

Current: ALPHATROSS

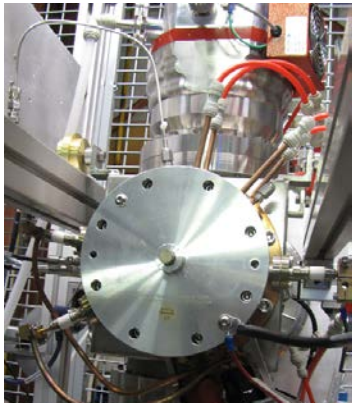
- RF-charge exchange ion source
- He current ~2-3 μA

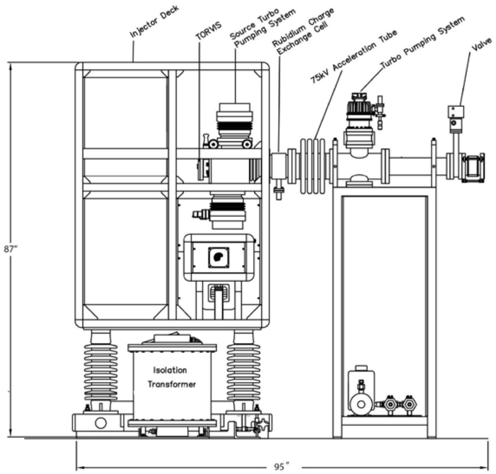
The Alphatross source is a compact, reliable source of light negative ions. A positive RF source injects immediately into a compact rubidium charge exchange cell.



Soon: TORVIS

- Toroidal Volume Ion Source
- He current ~20 μA





Summary, Conclusions & Outlook

Summary, conclusions and outlook

- At the **CNA HiSPANoS** facility both **Thick Target Yield (TTY)** and double differential energy and angle **cross sections** measurements are feasible through **activation** and **time-of-flight**.

- The current buncher produces α pulses with up to ~30% unbunched...
  => "Deconvolution" algorithm allows accurate E_n reconstruction

- First ^{27}Al(α,n) measurement with $LaBr_3$ & a CIEMAT's **MONSTER** module
- Results from CNA's analysis:
  - **TTY:** Good E_α dependence but a factor of 1.9 overestimation (to be studed).
  - **$\sigma(E_\alpha,\theta)$**: Good agreement with data at 5,5 MeV, nice data at higher energies

- **(α,n) ToF measurements feasible already**
- **Room for improvement**
  => new buncher by **end of 2024**
  => Higher intensity (**x10**) ion source **in 2025**

EC-Horizon-APRENDE

$\sigma(E_\alpha,E_n,\theta)$ of Al and Be (α,n) reaction up to 9 MeV