Measurement of $^{27}Al(\alpha,n\gamma)^{30}P$ thick-target yields and total $^{27}Al(\alpha,n)$ yields by activation

L.M. Fraile
Grupo de Física Nuclear & IPARCOS
Universidad Complutense, Madrid, Spain

The MANY Collaboration

Two Spanish facilities

Infraestructuras Científicas y Técnicas Singulares

UPC

Universidad de Sevilla

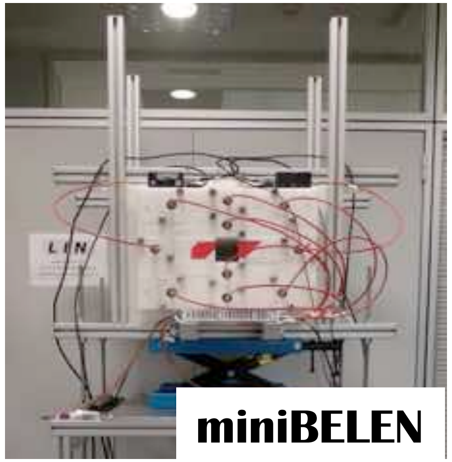
IFIC
INSTITUT DE FISICA CORPUSCULAR

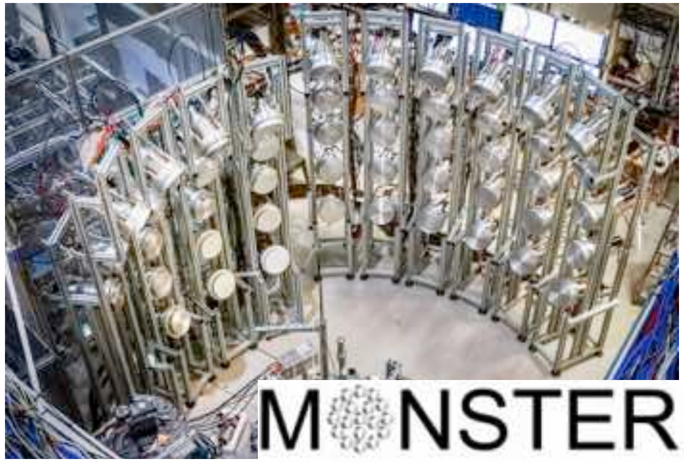
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

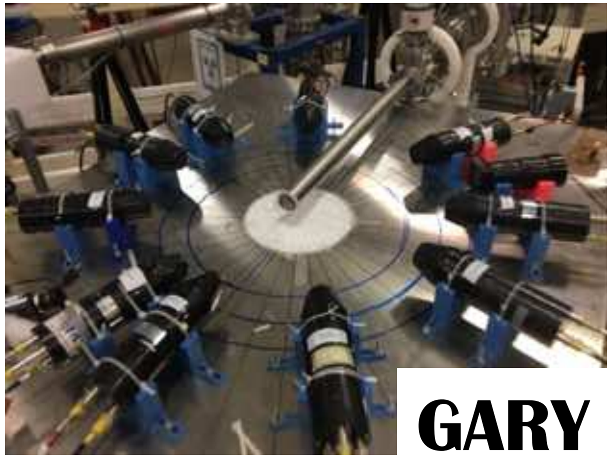
UNIVERSIDAD COMPLUTENSE MADRID

IEM
Instituto de Estructura de la Materia

Three Spanish detectors







GARY

The MANY Collaboration

O Alonso-Sañudo, L.M. Fraile, J Benito, JA Briz, A Espinosa, A Illana, M Llanos, V Martínez-Nouvilas, JR Murias, VVO Onecha, V Sánchez-Tembleque, JM Udías

N Mont-Geli, M Pallàs, F Calviño, G Cortés, A De Blas, R García

A Tarifeño-Saldivia, JL Taín, A Algora, J Balibrea-Correa, C Domingo-Pardo, J Lerendegui-Marco, E Nácher, SEA Orrigo

G García, V García Tavora, S Viñals

O Tengblad, MJG Borge, A Perea, A Nerio Aguirre

D Cano-Ott, T Martínez, E Mendoza, A Pérez de Rada, V Alcayne, EM González-Romero, V Pesudo, J Plaza, A Sánchez, R Santorelli, D Villamarín

C Guerrero, B Fernández, J Gómez-Camacho, JM Quesada

The MANY Collaboration

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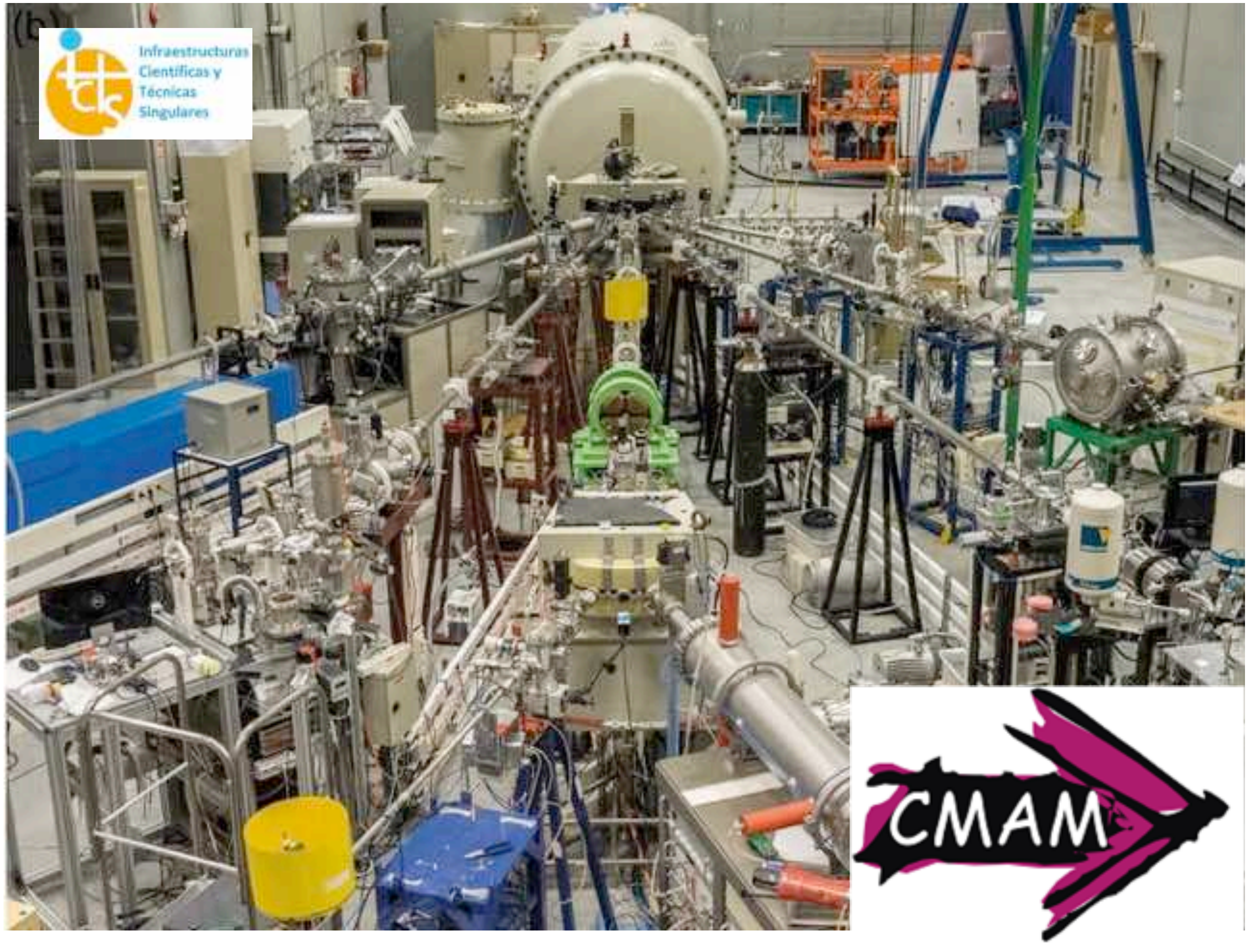
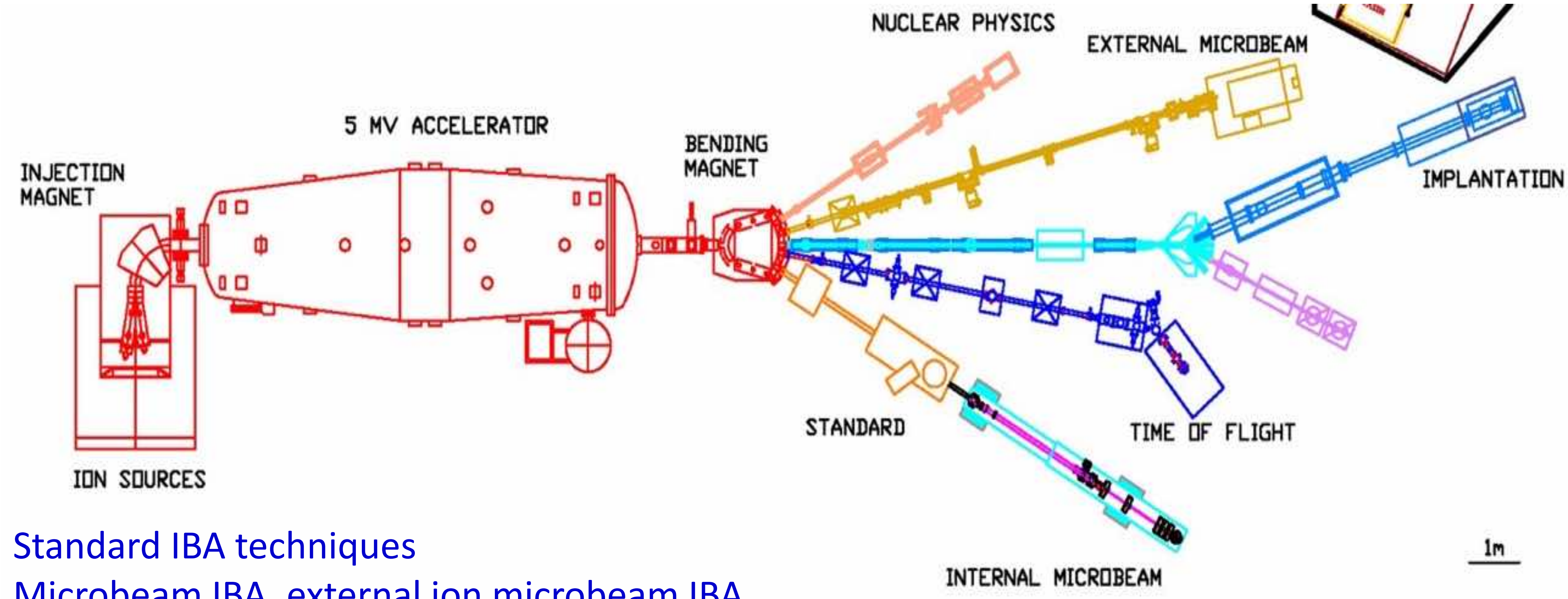


Centre for Micro Analysis of Materials (CMAM)



Standard IBA techniques
Microbeam IBA, external ion microbeam IBA
TOF depth profiling, ion implantation
fs laser/ion beam processing of materials
Nuclear Physics

The CMAM tandetron

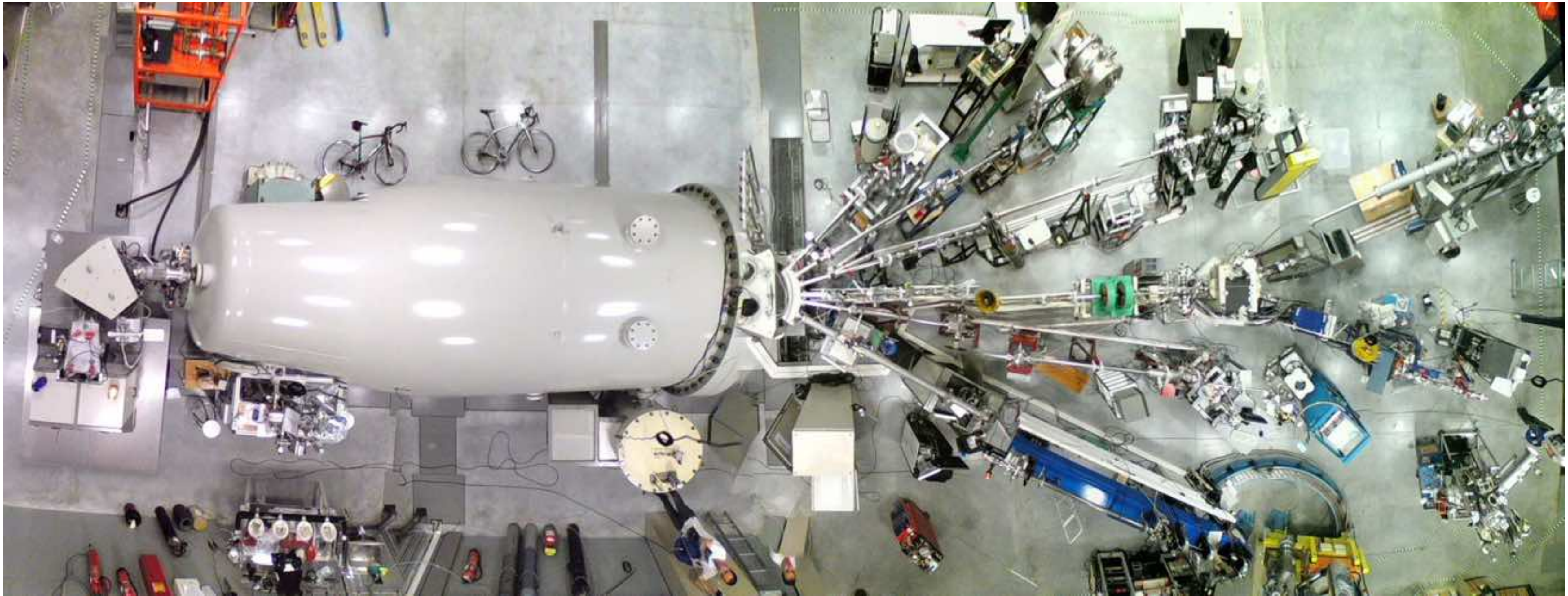
Two sources: a **plasmatron** (HVE-358) source for gaseous substances and a **negative sputtering** (HVE-860C) source for (almost) any element from solid targets.

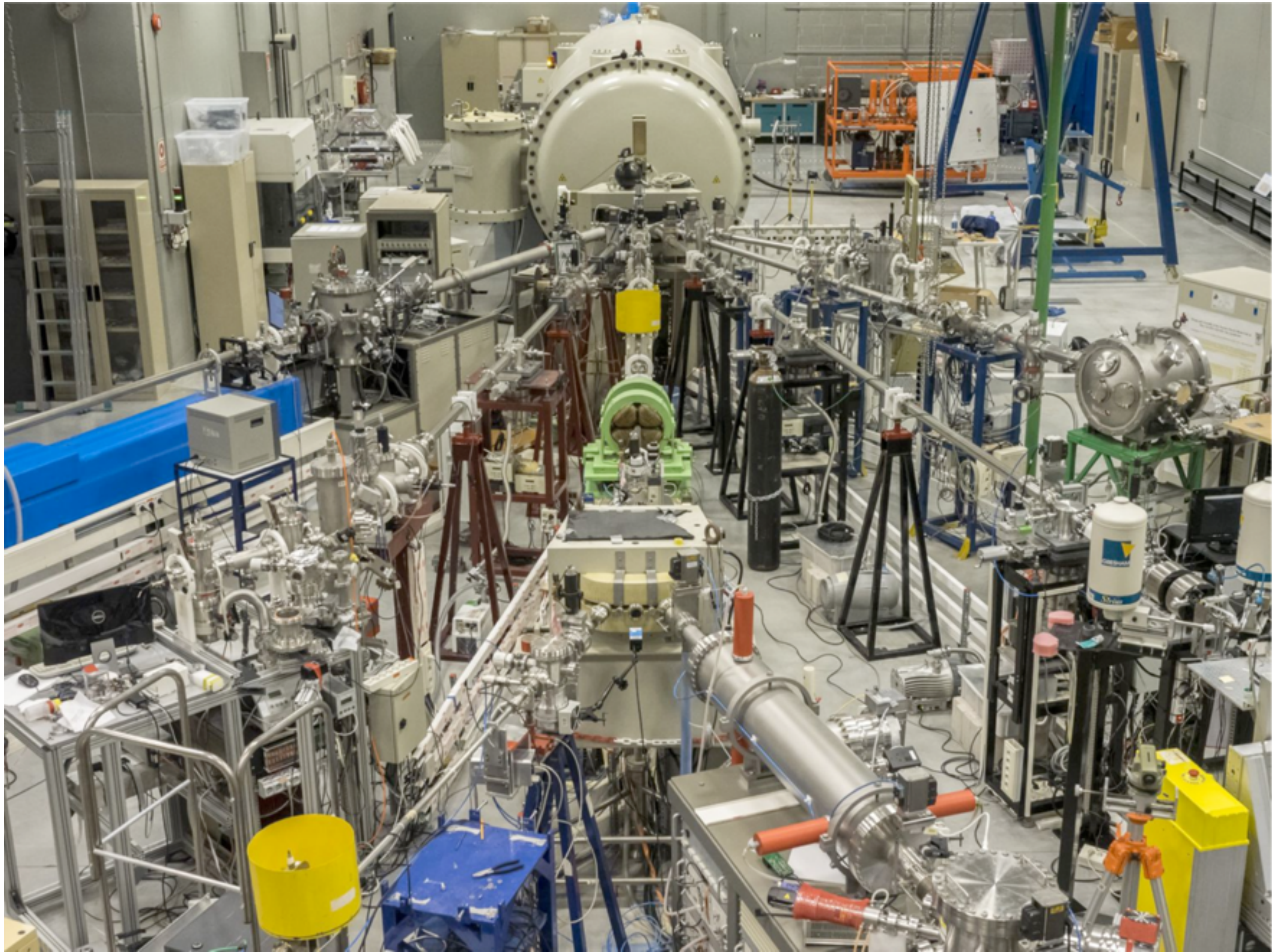
HVee tandem
5 MV maximum terminal voltaje
Cockroft-Walton acceleration

The CMAM tandetron

Maximum of (Z+1) x 5 MeV beams, minimum energy below 300 keV with decent ripple.

Terminal voltage was originally calibrated using 11 different nuclear reactions. Recalibration was required after replacement of faulty diodes (2013), about 0.3% deviation found.





Future upgrades

Beam pulsing via chopper and buncher

Pulsed beam installation and commissioning foreseen within window APR-JUN 2024

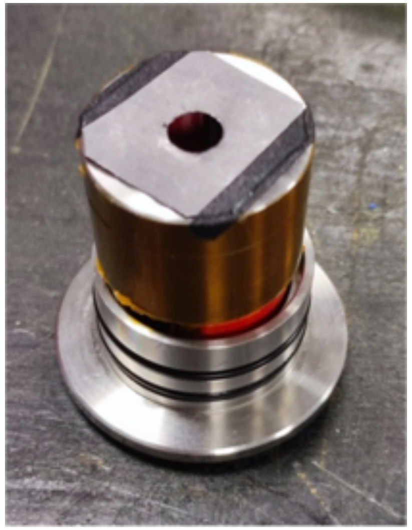
Technical meeting held between to prepare the commissioning of the pulsed beam.

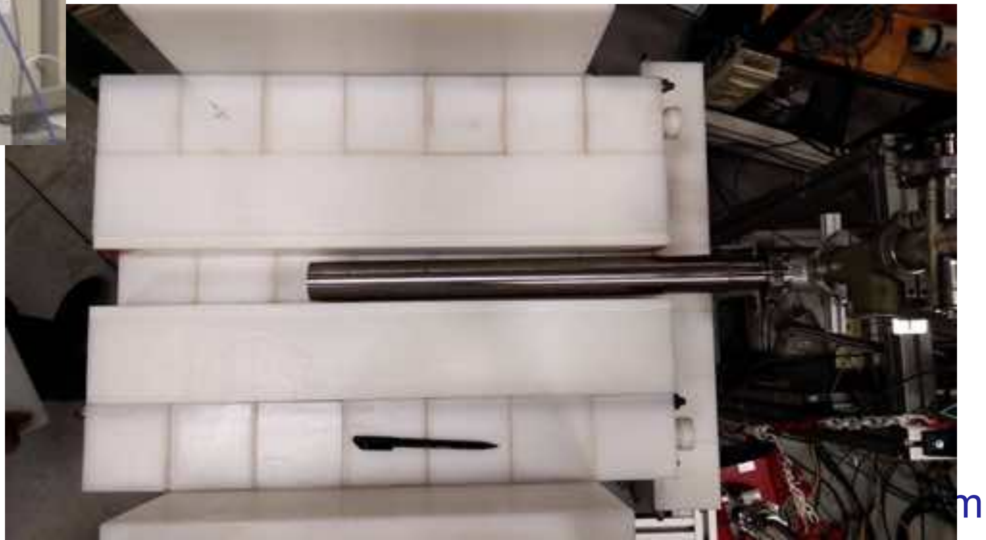
Proposal for commissioning with **alpha beams** before April 2024, for execution soon after installation

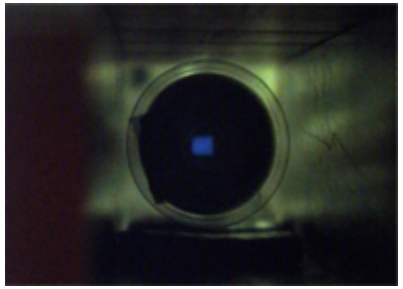
First experiments July 2024

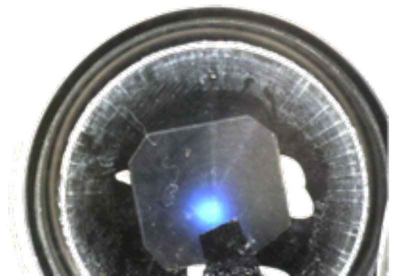
Beam line

Development of the experimental setup









(α,n) reactions

Interest of (α,n) reactions:

- nuclear technologies
- dark matter searches
- neutrino physics
- nuclear astrophysics

Experimental (α,n) cross sections exist in literature, but…

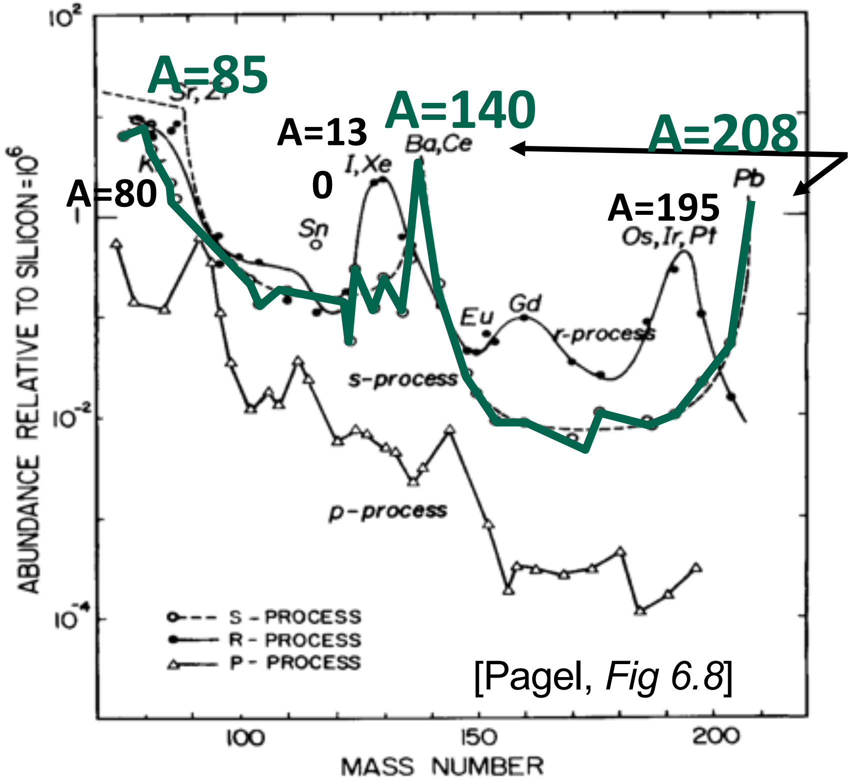
- cross section data available in the EXFOR database show large discrepancies, not compatible with the declared uncertainties.
- spectroscopic information is available only for a limited number of isotopes.
- Libraries: JENDL-AN-2005 and the TENDL series show important differences

(α,n) reactions in astrophysics

The origin of heavy elements in the solar system

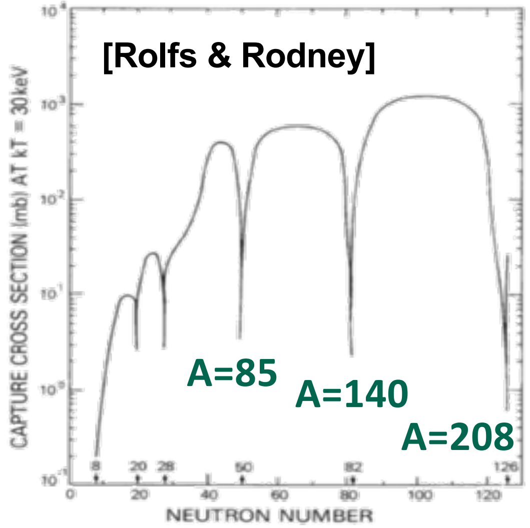
Nuclear astrophysics

· sources of neutrons for the slow neutron-capture process
· radionuclide production by energetic solar particles
· nucleosynthesis of light r-process nuclei in n-driven winds
· optical potentials



Abundance peaks: n capture along valley of stability → s-process

- slow neutron captures
- 50% of the isotopes above Fe



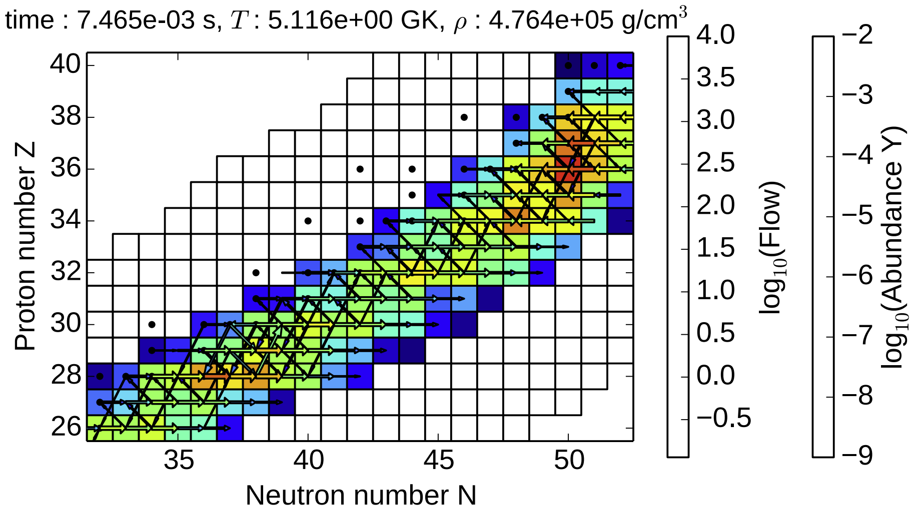
Weak r-process

· light neutron-rich nuclei

Impact of (α, n) reactions on weak r-process in neutrino-driven winds

J Bliss[1], **A Arcones**[1,2,4,5], **F Montes**[3,6] **and J Pereira**[3,6]

[1] Institut für Kernphysik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany
[2] GSI Helmholtzzentrum für Schwerionenforschung, Planckstr. 1, D-64291 Darmstadt, Germany
[3] National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI 48824, United States of America



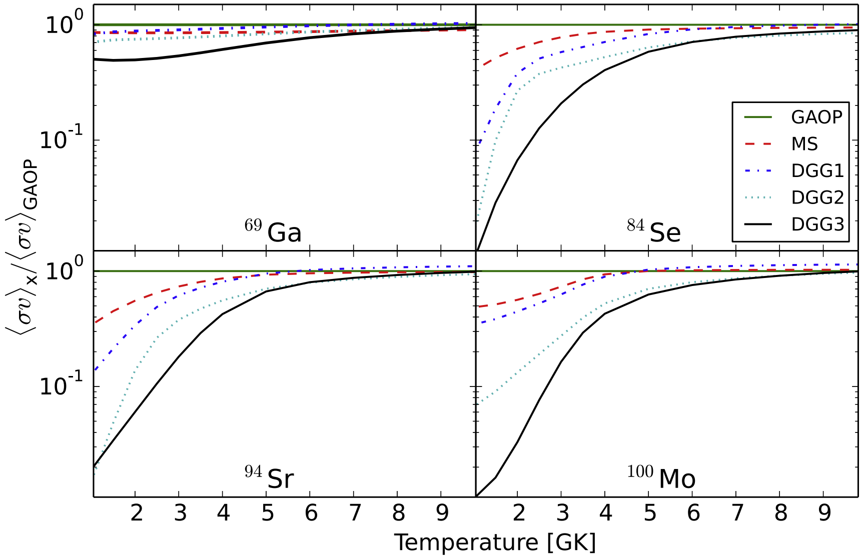


Figure 4. Theoretical ^{69}Ga(α, n) ^{72}As, ^{84}Se(α, n) ^{87}Kr, ^{94}Sr(α, n) ^{97}Zr, and ^{100}Mo(α, n) ^{103}Ru reaction rates using the alpha optical potentials: global alpha optical potential (GAOP) [36, 53], phenomenological fit of McFadden and Sachtler (MS) [54], three different versions of the model of Demetriou-Grama-Goriely (DGG1-3) [36, 55] (the other nuclear inputs are determined from the default set of sources given in [33], with the exception of masses, which were taken from [56] if available, or from the FRDM mass model [57] otherwise). The reaction rates are normalized to the ones calculated with the GAOP model.

Theoretical x-sections
Optical potentials

Impact of (α,n) reaction rate uncertainties on the abundances

Measurements by activation

Activation cross section measurement of the ^{100}Mo(α,n)^{103}Ru reaction for optical potential studies

T.N. Szegedi[1,2], G.G. Kiss[1], Gy. Gyürky[1] and P. Mohr[1,3]
[1]Institute for Nuclear Research, Bem square 18/c, H-4026 Debrecen, HU
[2]University of Debrecen, Egyetem ter 1, H-4032 Debrecen, HU
[3]Diakonie-Klinikum, D-74523 Schwäbisch Hall, Germany

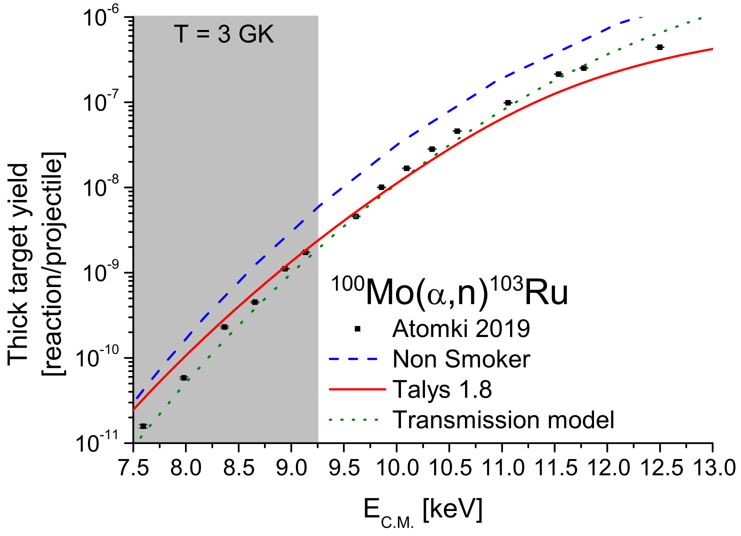


Figure 3. Preliminary ^{100}Mo(α,n)^{103}Ru thick target yield results compared to theoretical predictions calculated using the Talys 1.8 code (red line), Non Smoker code (blue dashed line) and a simple transmission model calculation (green dotted line).

Cross sections of α-induced reactions for targets with masses A $\approx$ 20–50 at low energies

Peter Mohr[1,2,a]

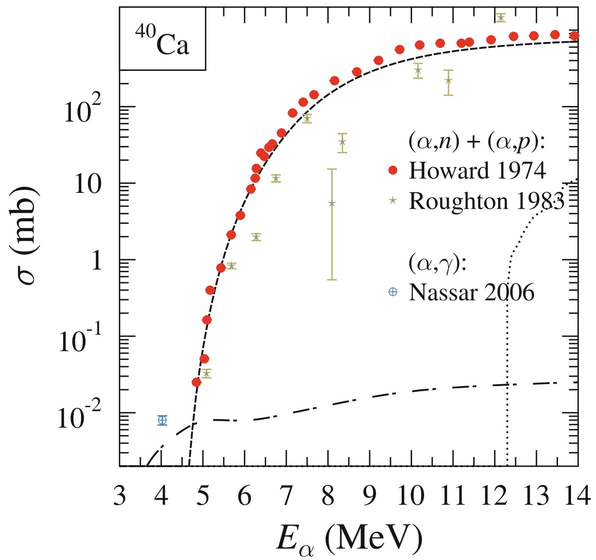


Fig. 20. Cross sections of the ^{40}Ca$(\alpha,n)^{43}$Ti, ^{40}Ca$(\alpha,p)^{43}$Sc, and ^{40}Ca$(\alpha,\gamma)^{44}$Ti reactions. The experimental data have been taken from [70,82,50]. The additional dash-dotted line shows the StM calculation for the (α,γ) reaction. Further discussion see text.

Countrate estimates at low E (go underground!)

$^{22}Ne(\alpha,n)^{25}Mg$

E_x = 10.9 – 11.5 MeV

S_α=10.6 MeV

E^R_{CM} = 537 keV

2 counts/hour

$^{13}C(\alpha,n)^{16}O$

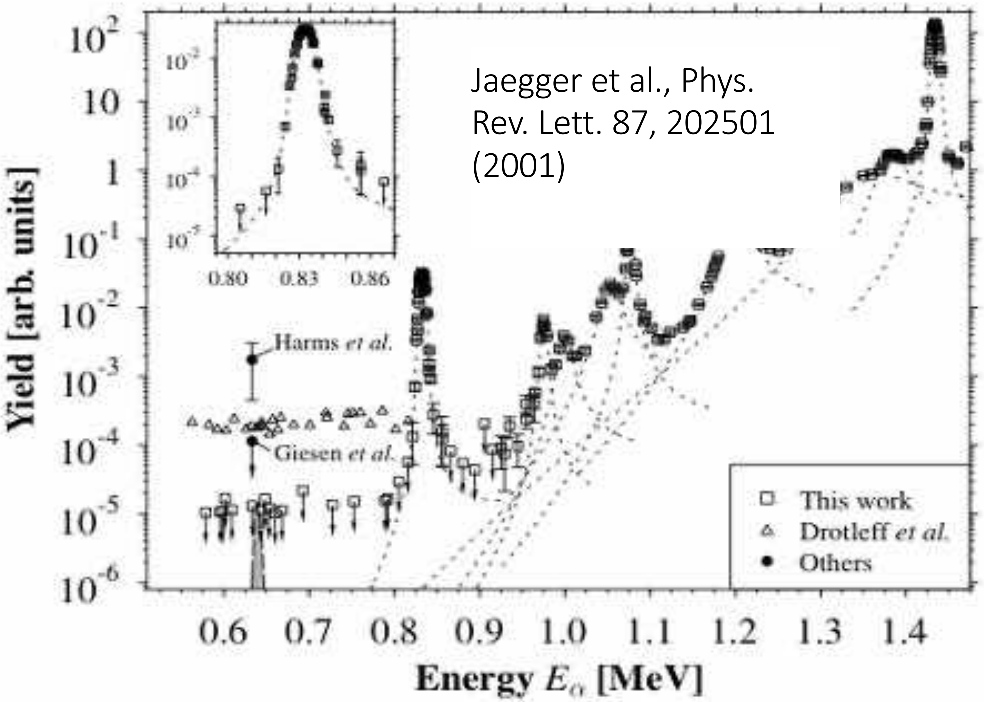
E_r^{CM} = 150 keV to E_r^{CM} = 230 keV

$\sigma \approx 10^{-13}$ b

0.5 counts/hour

I (^{4}He) ≈ 100 μA and
n detection eff of η ≈ 50%

Jaegger et al., Phys. Rev. Lett. 87, 202501 (2001)



Heil et al., Phys. Rev. C 78, 025803 (2008)

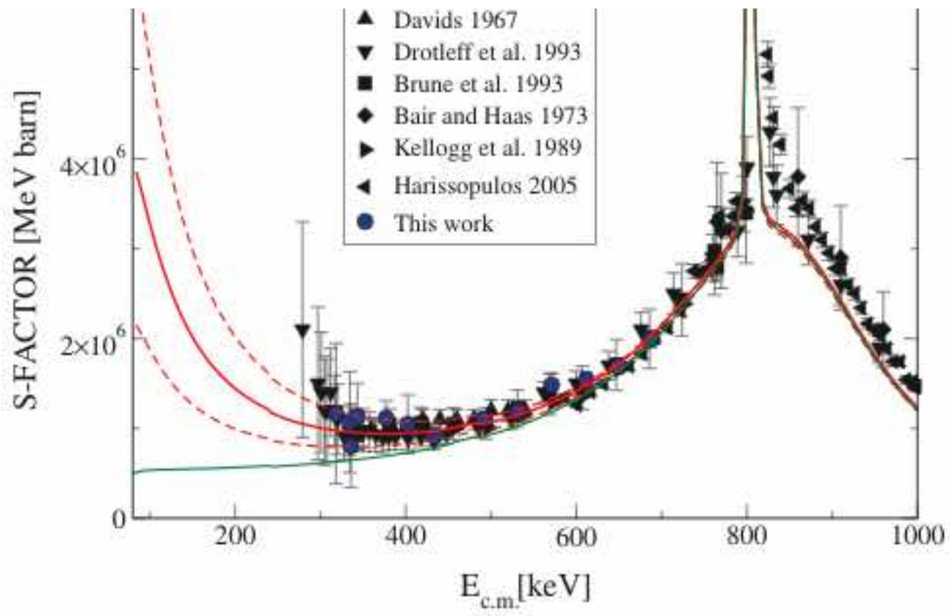


TABLE I. Isotopes for each (α, n) cross sections are catalogued in the EXFOR and JENDL databases

Isotope	EXFOR	JENDL	Isotope	EXFOR	JENDL	Isotope	EXFOR	JENDL
^{6}Li	Yes	Yes	^{7}Li	Yes	Yes	^{8}Li	Yes	No
^{9}Be	Yes	Yes	^{10}B	Yes	Yes	^{11}B	Yes	Yes
^{12}C	No	Yes	^{13}C	Yes	Yes	^{14}N	Yes	Yes
^{15}N	Yes	Yes	^{16}O	Yes	No	^{17}O	Yes	Yes
^{18}O	Yes	Yes	^{19}F	Yes	Yes	^{20}Ne	Yes	No
^{21}Ne	Yes	No	^{22}Ne	Yes	No	^{23}Na	Yes	Yes
^{24}Mg	Yes	No	^{25}Mg	Yes	No	^{26}Mg	Yes	No
^{27}Al	Yes	Yes	^{28}Si	Yes	Yes	^{29}Si	Yes	Yes
^{30}Si	Yes	Yes	^{31}P	Yes	No	^{34}S	Yes	No
^{35}Cl	Yes	No	^{41}K	Yes	No	^{40}Ca	Yes	No
^{48}Ca	Yes	No	^{45}Sc	Yes	No	^{46}Ti	Yes	No
^{48}Ti	Yes	No	^{51}V	Yes	No	^{50}Cr	Yes	No
^{55}Mn	Yes	No	^{54}Fe	Yes	No	^{59}Co	Yes	No
^{58}Ni	Yes	No	^{60}Ni	Yes	No	^{62}Ni	Yes	No
^{64}Ni	Yes	No	^{63}Cu	Yes	No	^{65}Cu	Yes	No
^{64}Zn	Yes	No	^{66}Zn	Yes	No	^{68}Zn	Yes	No
^{70}Zn	Yes	No	^{69}Ga	Yes	No	^{71}Ga	Yes	No
^{70}Ge	Yes	No	^{72}Ge	Yes	No	^{74}Ge	Yes	No
^{76}Ge	Yes	No	^{75}As	Yes	No	^{76}Se	Yes	No
^{86}Sr	Yes	No	^{89}Y	Yes	No	^{93}Nb	Yes	No
^{92}Mo	Yes	No	^{94}Mo	Yes	No	^{100}Mo	Yes	No
^{98}Ru	Yes	No	^{107}Ag	Yes	No	^{109}Ag	Yes	No
^{115}In	Yes	No	^{121}Sb	Yes	No	^{123}Sb	Yes	No
^{130}Te	Yes	No	^{127}I	Yes	No	^{131}Ta	Yes	No

evaluations/nuclear data and simulate yields (https://tendl.web.psi.ch/tendl_2019/talys.html)

TALYS (TENDL) vs. evaluated data (JENDL-AN-2005) show differences

Yields are relevant but the energy distribution of neutrons depends on cross-section details

Angular correlation effects are (generally() assumed to be negligible.

(α,n) and α-induced reactions in fusion

Fusion Engineering and Design 86 (2011) 1298–1301

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Fusion alpha loss diagnostic for ITER using activation technique

G. Bonheure[a,*], M. Hult[b], R. González de Orduña[b], P. Vermaercke[c], A. Murari[d], S. Popovic

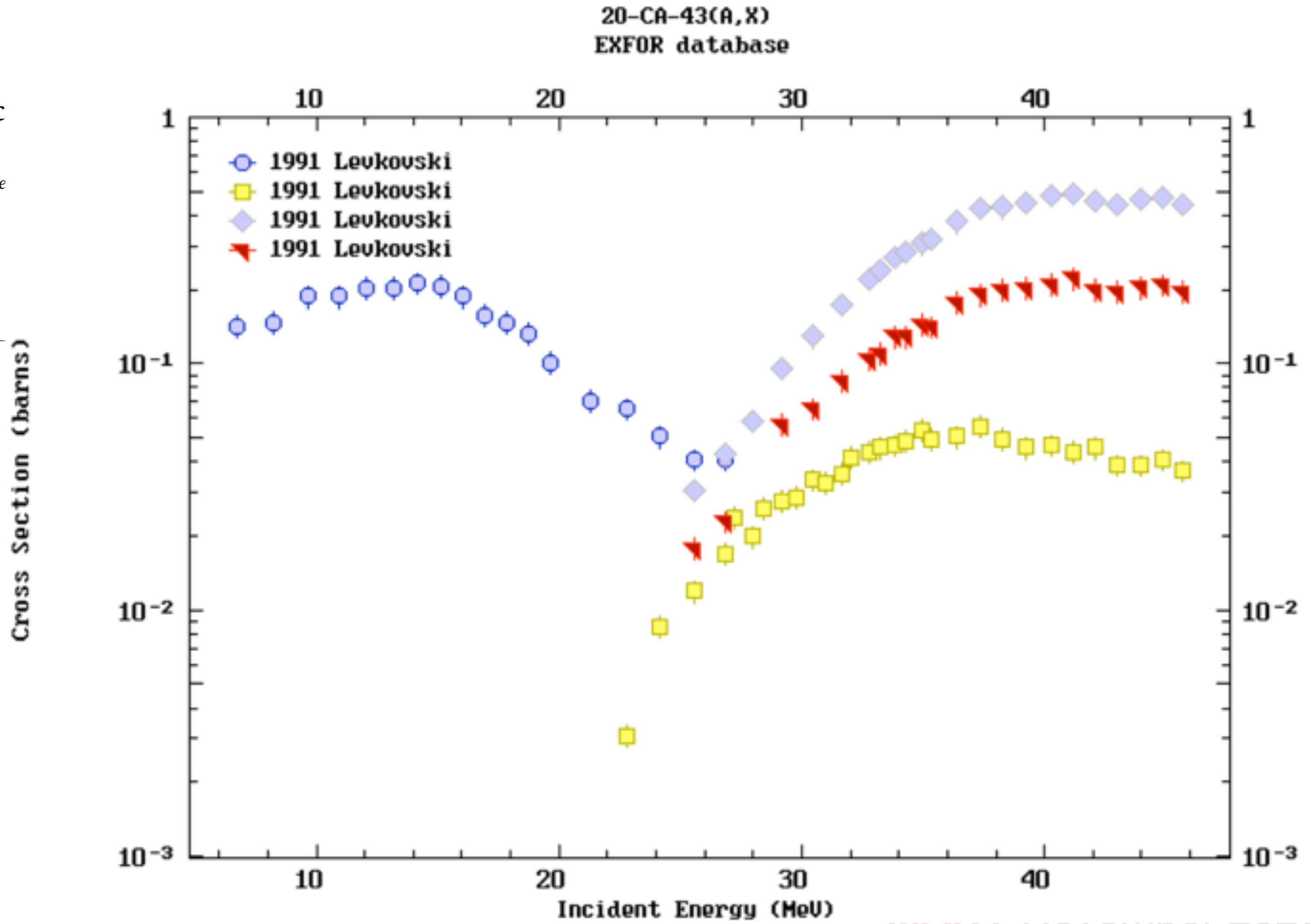
[a] Laboratory for Plasma Physics, TEC Partner Association "Euratom-Belgian State", Royal Military Academy, Avenue de la Renaissance, 30, Kunstherle Belgium
[b] Institute for Reference Materials and Measurements (IRMM), Retieseweg 111, B-2440 Geel, Belgium
[c] SCK CEN, Boeretang, B-2400 Mol, Belgium
[d] Association EURATOM/ENEA, Consorzio RFX, 4-35127 Padova, Italy
[e] EURATOM/CCFE Association, Culham Science Centre, Abingdon, OX14 3DB, UK
[f] Association Euratom-IPP.CR, Institute of Plasma Physics AS CR, v.v.i., Za Slovankou 3, CZ-182 00 Praha 8, Czech Republic

INSTITUTE OF PHYSICS PUBLISHING — PLASMA PHYSICS AND CONTROLLED FUSION

Plasma Phys. Control. Fusion **46** (2004) S107–S118 — PII: S0741-3335(04)74980-5

Overview of neutron and confined/escaping alpha diagnostics planned for ITER

M Sasao[1], A V Krasilnikov[2], T Nishitani[3], P Batistoni[4], V Zaveryaev[5], Yu A Kaschuck[2], S Popovichev[6], T Iguchi[7], O N Jarvis[6], J Kallne[8], C L Fiore[9], L Roquemore[10], W W Heidbrink[11], A J H Donne[12], A E Costley[13] and C Walker[14]



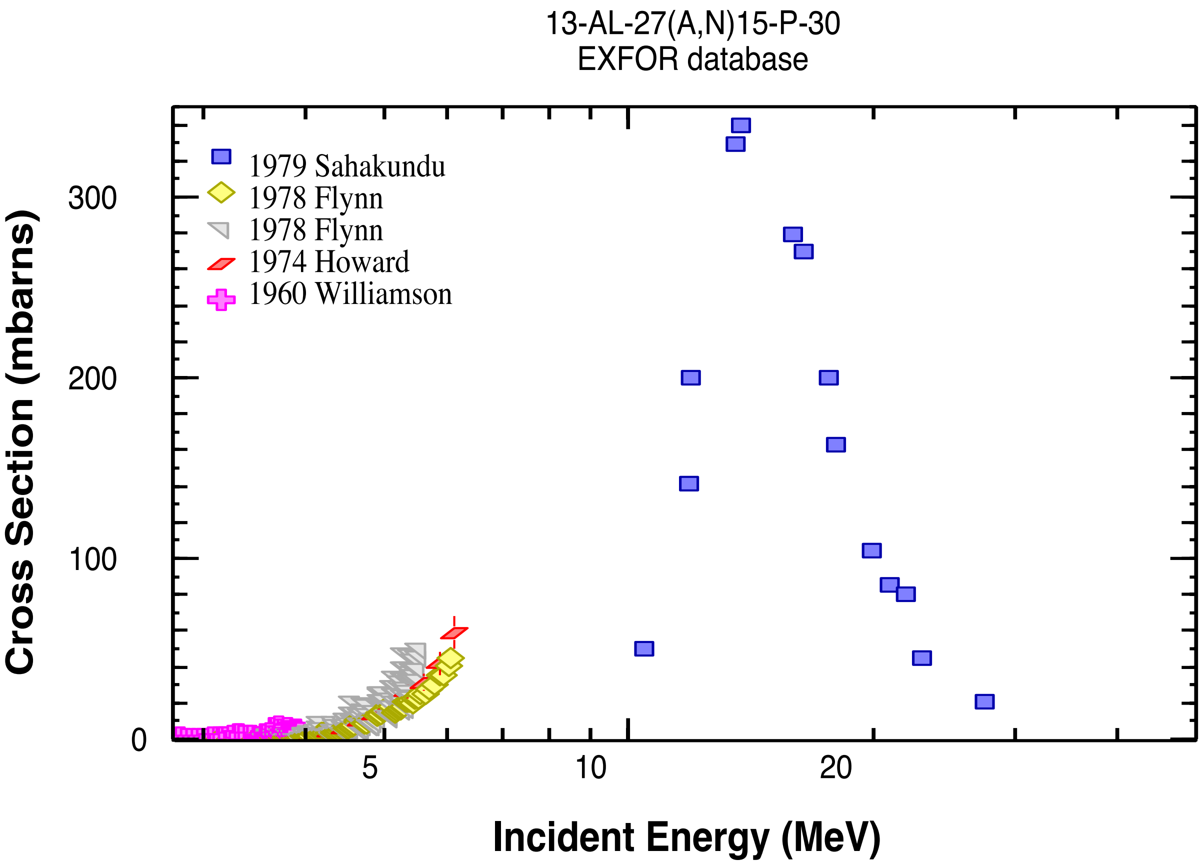
Measurement of $^{27}Al(\alpha,n\gamma)^{30}P$ reaction yields

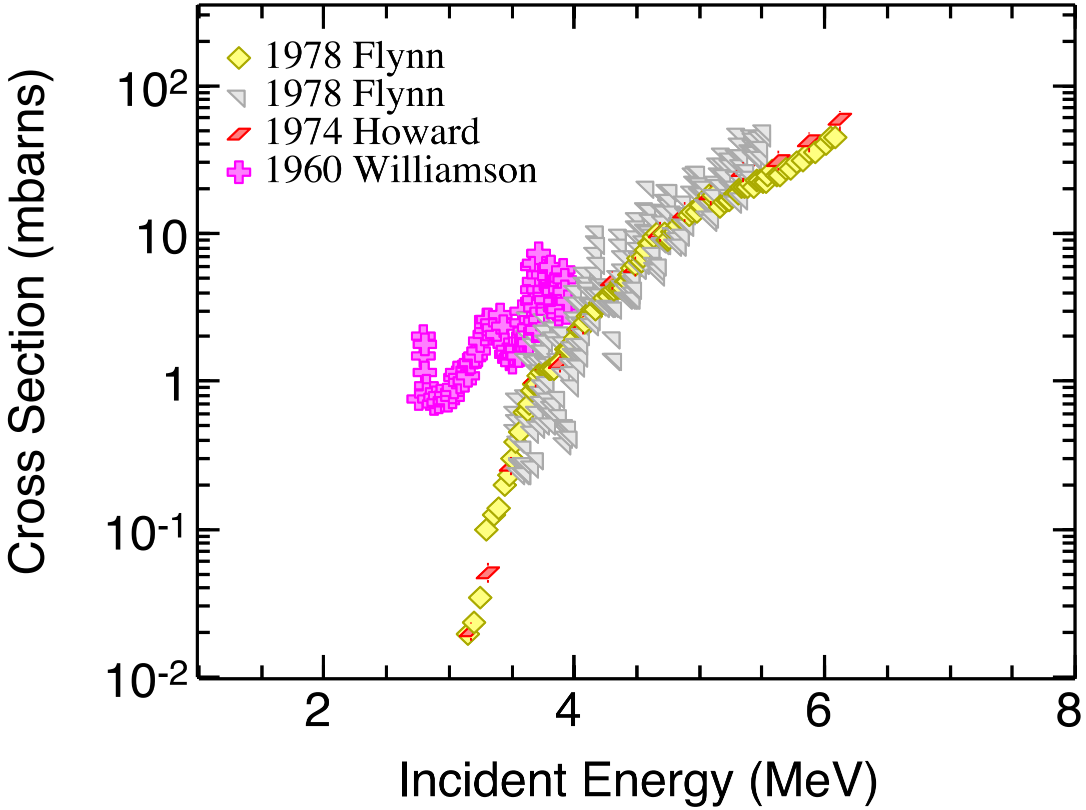
MOTIVATIONS

- Reference reaction: benchmarking
- Test new beamline at CMAM
- Develop and optimize new setup
- Crosscheck measurements:
  direct neutrons*, gamma rays and activation

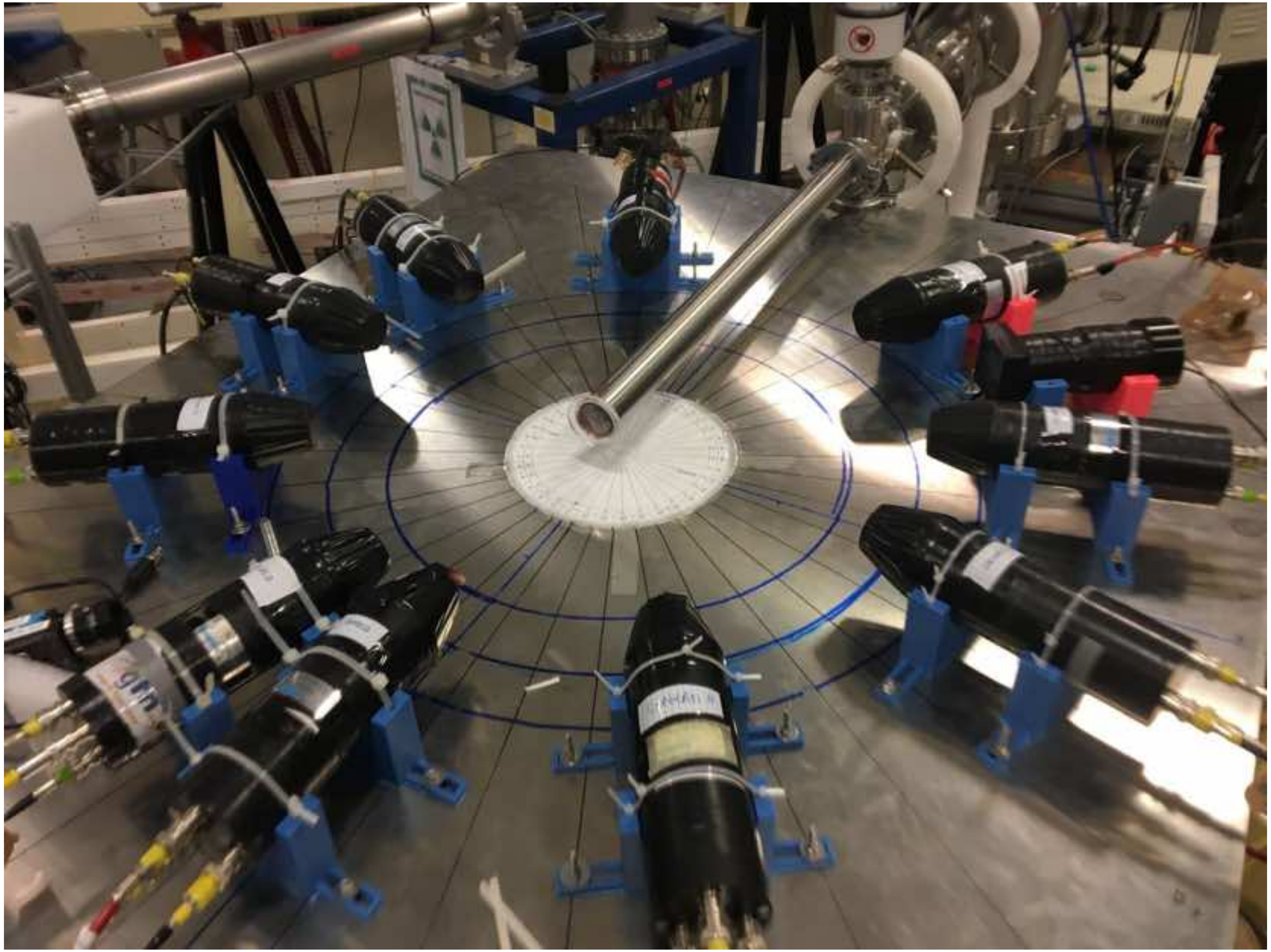
* Neutron measurements with MINBELEN at CMAM described by Nil Mont et al. yesterday

$^{27}Al(\alpha,n)^{30}P$ available data





GARY detection setup



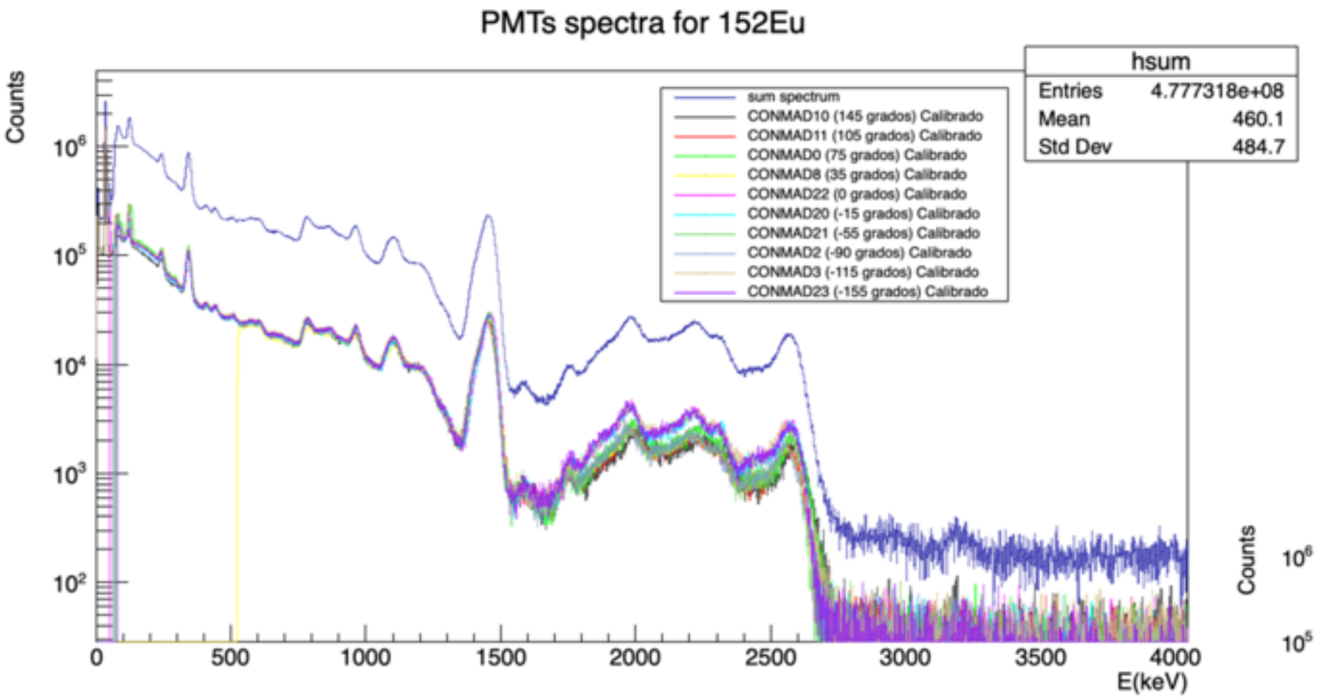
Gamma-detector array for Alpha-induced Reaction Yield measurements

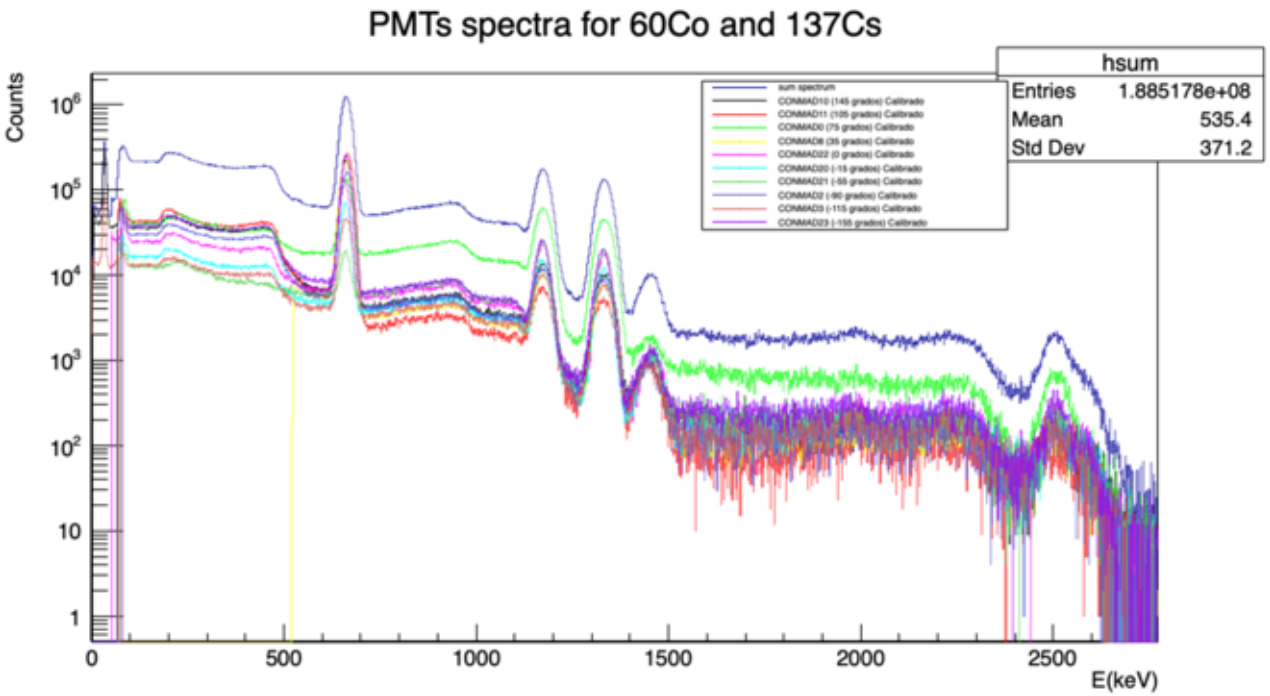
$LaBr_3(Ce)$ based array

HPGe detectors

Monitoring neutron detectors

Example calibration $LaBr_3(Ce)$ spectra

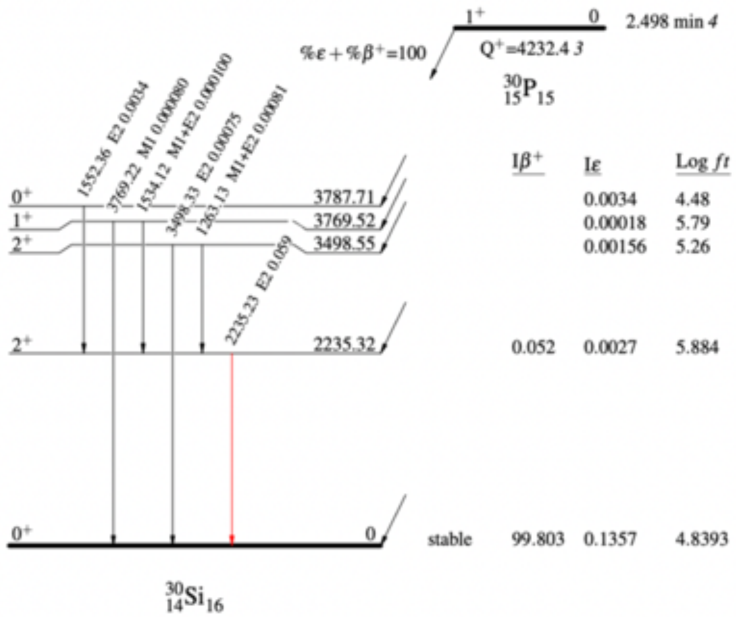


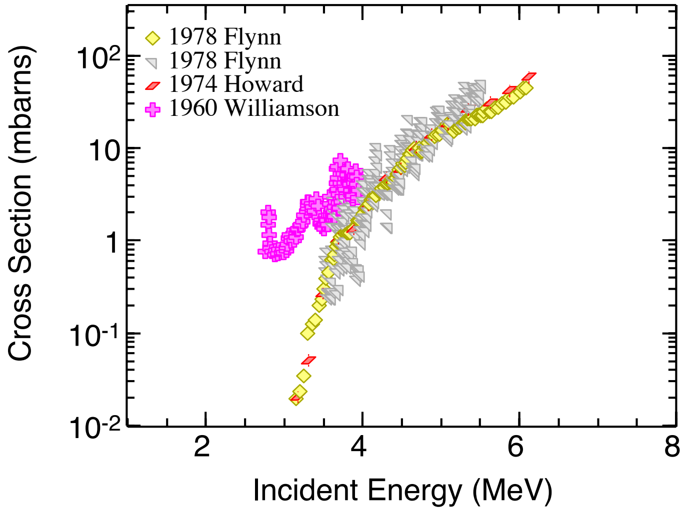


Measurements

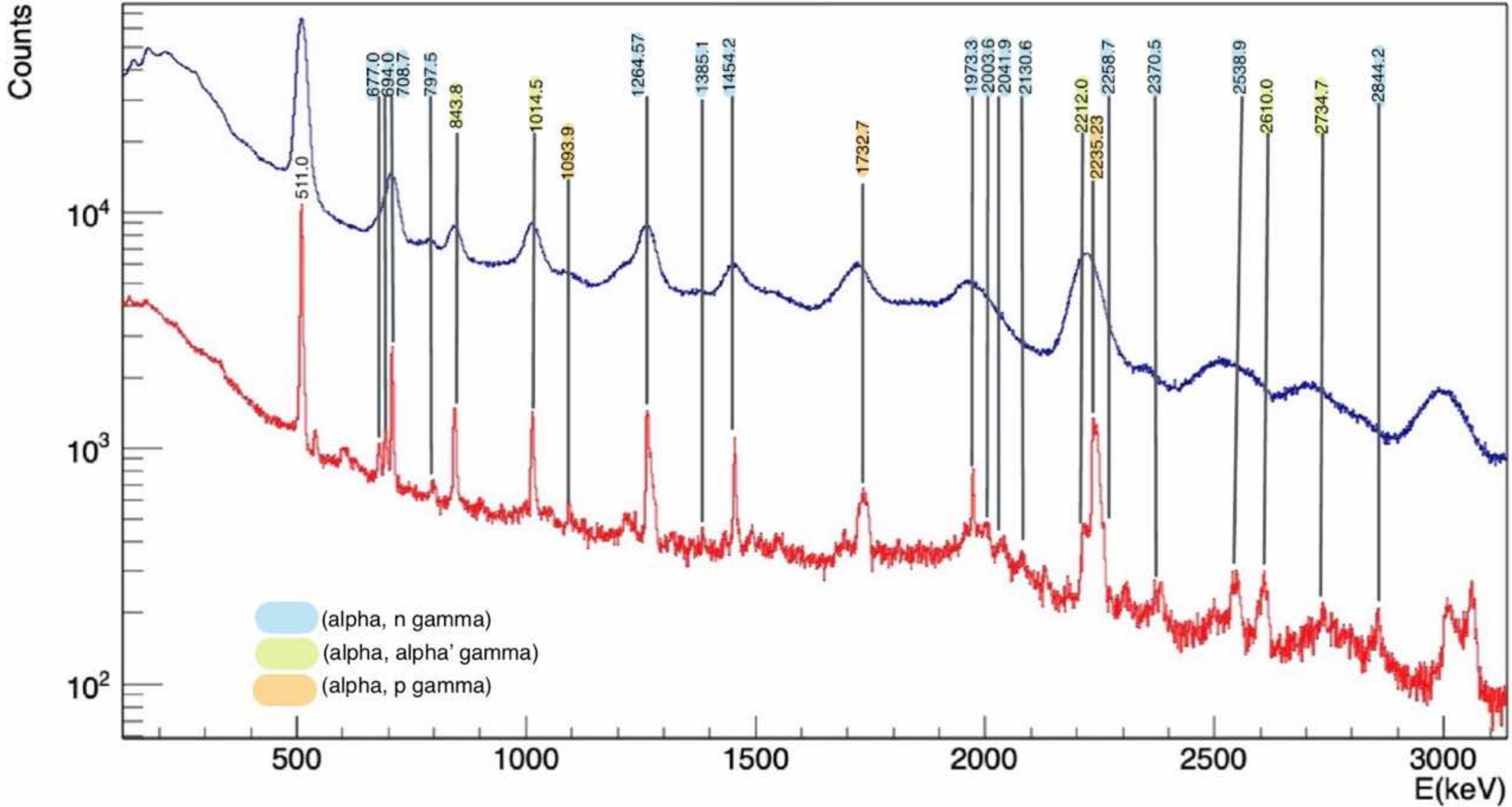
Productos de la reacción	Q-value (keV)	Threshold (keV)
$^{31}P+\gamma$	9668.60	0
$^{30}Si+\gamma$	2372.04	0
$^{27}Al+\alpha$	0	0
^{30}P+ n	-2642.41	3034.40
^{29}Si+ d	-6012.59	6904.52

Energy range from ~3-15 MeV.
Online measurements and activation
Decay measurement when possible



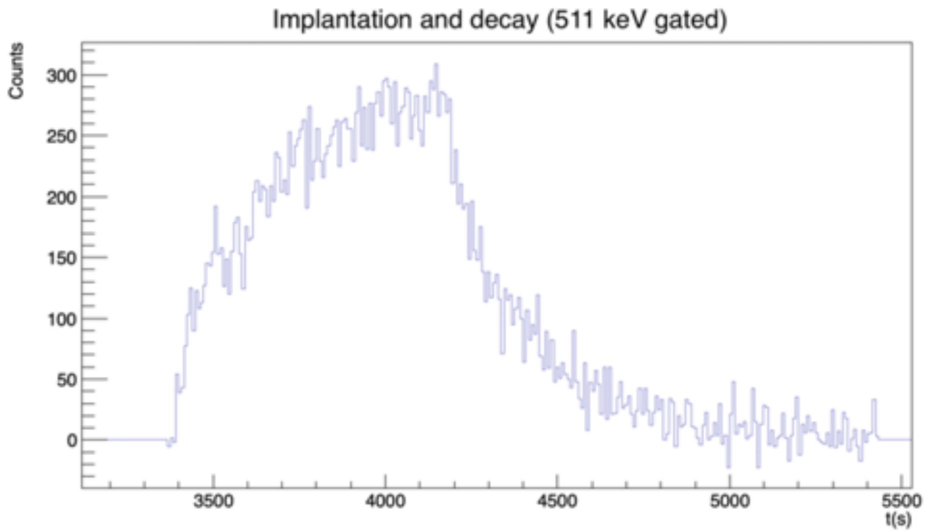


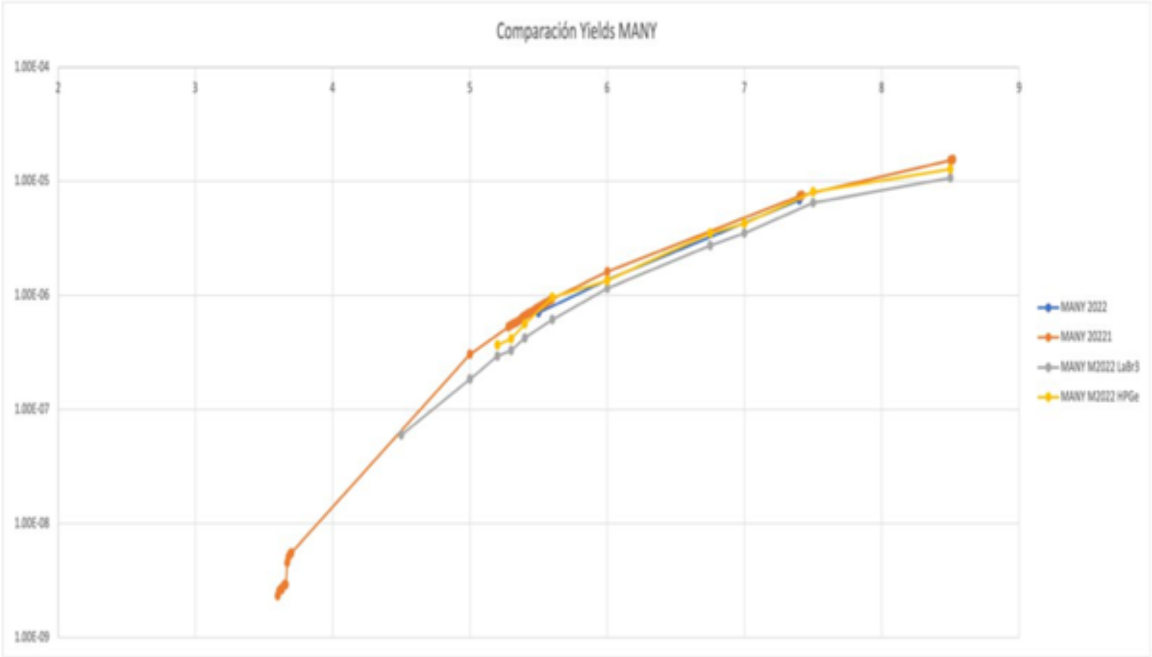
Gamma-ray identification at 15 MeV



Activation measurements

Activation measurements





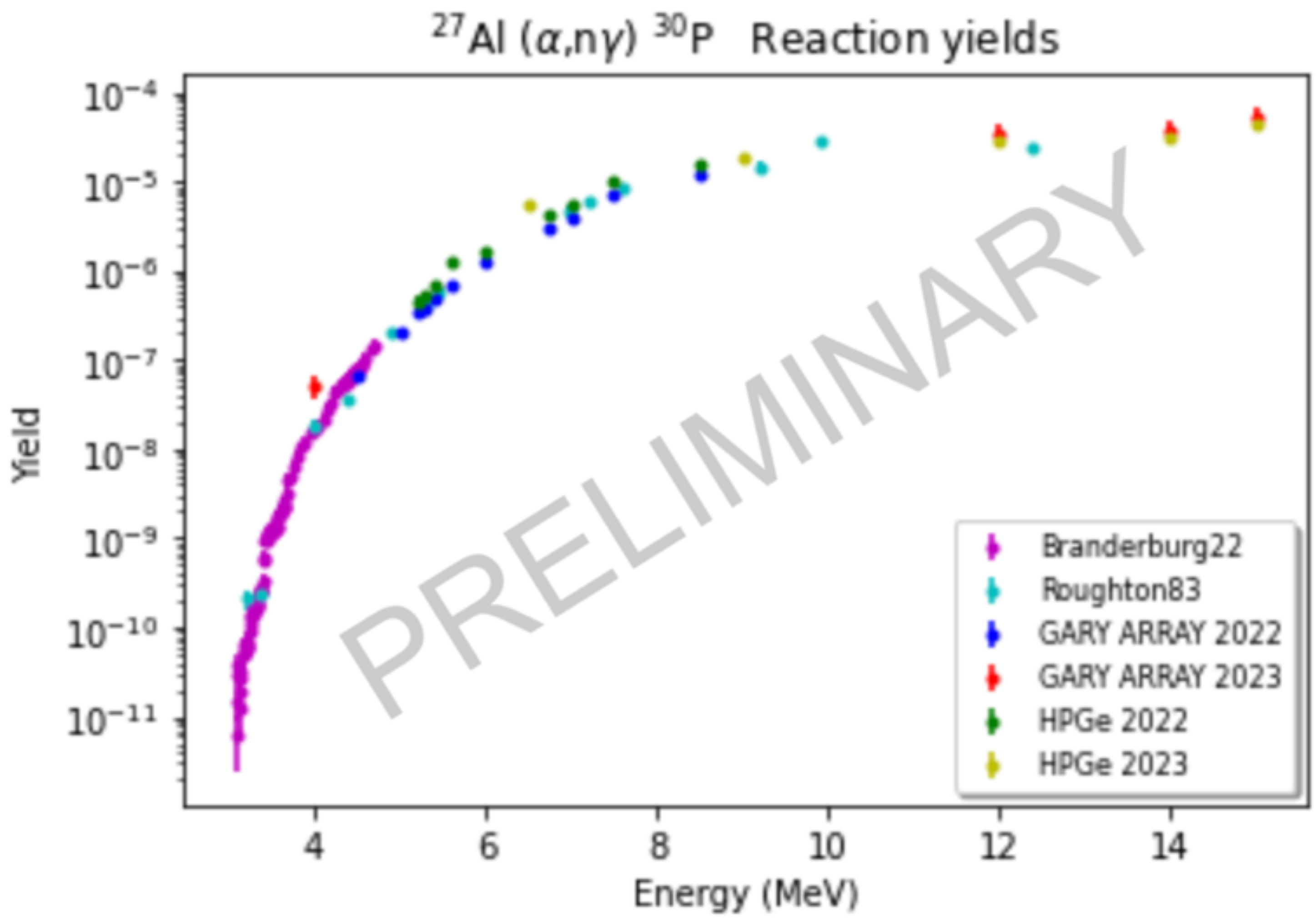
Measurements available up to 14 MeV

- Using decay of 511 keV when possible
- Using total rate (activation + decay)
- Using activation time

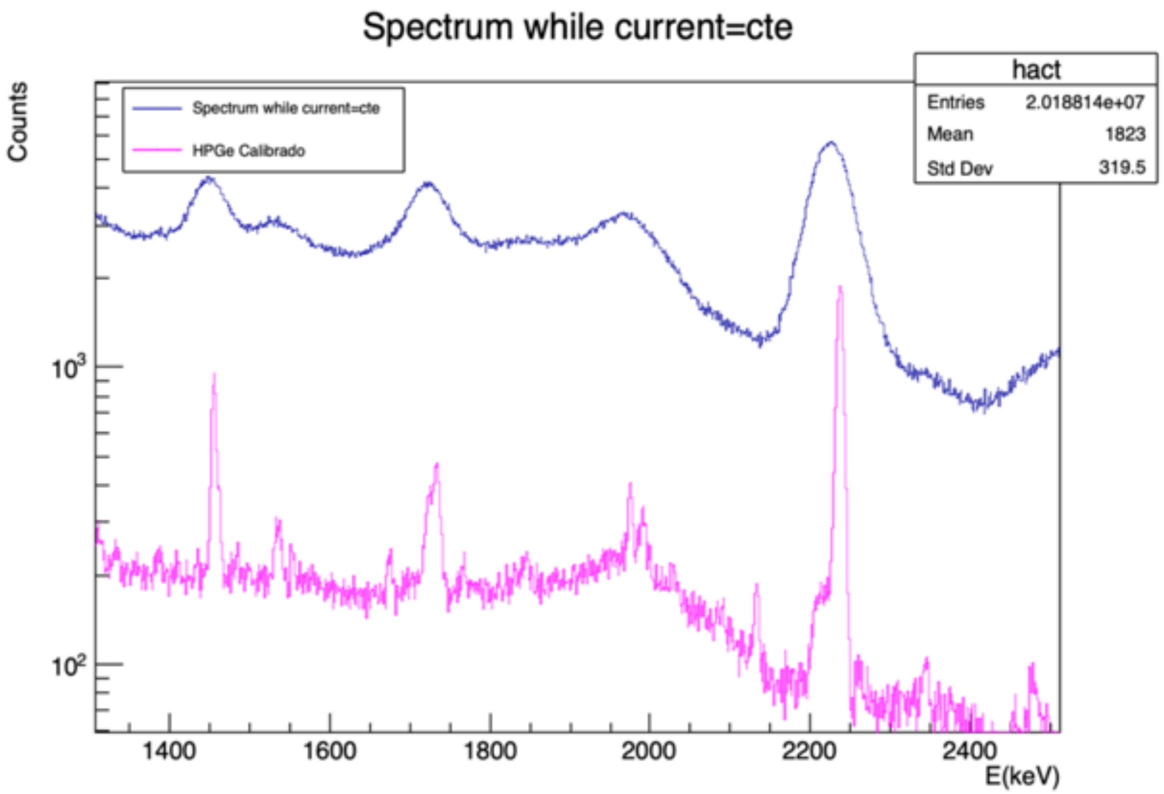
HPGe seems to work fine

$LaBr_3$(Ce) array

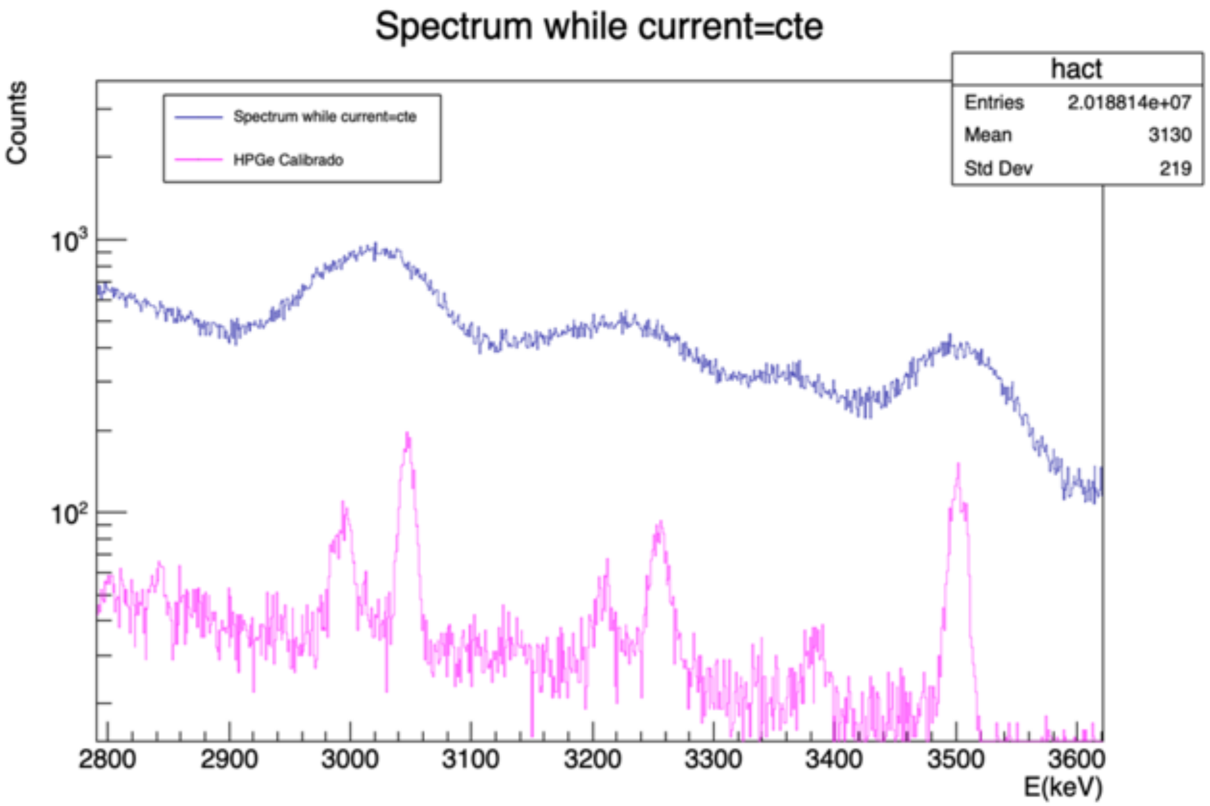
Preliminary total $^{27}Al(\alpha,n)$ yields from activation



Prompt gamma-ray measurements



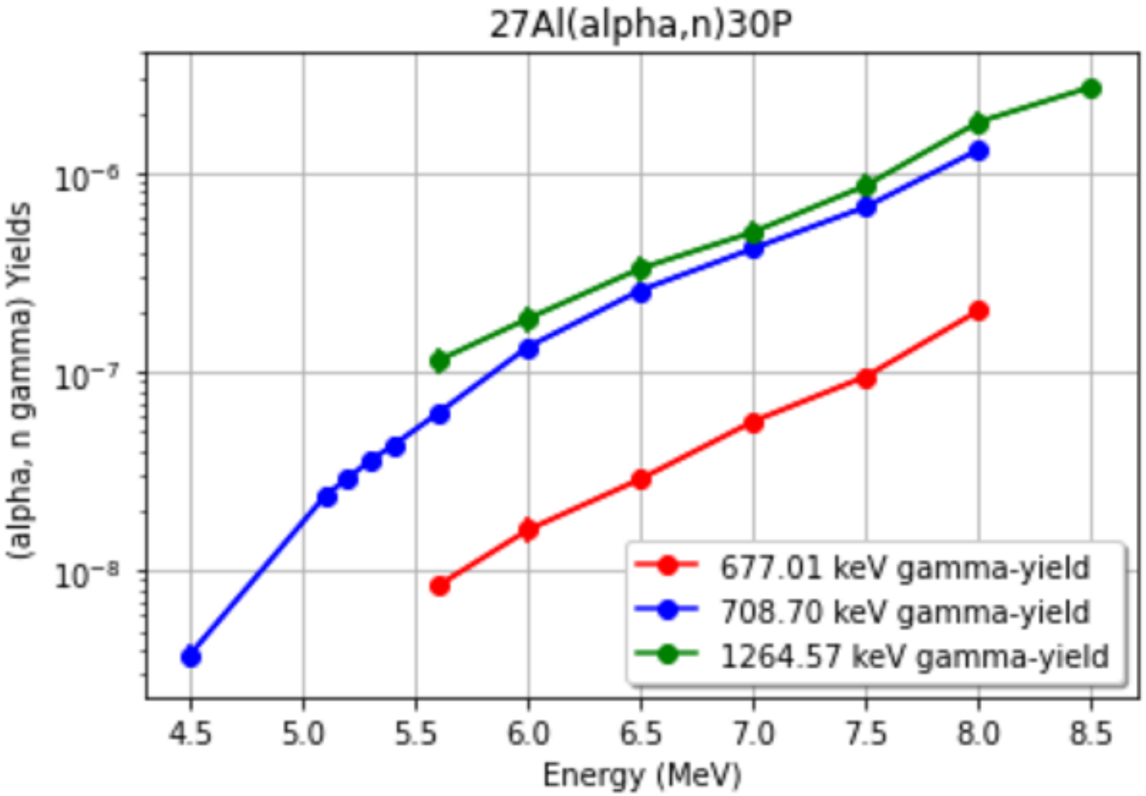
1973 keV

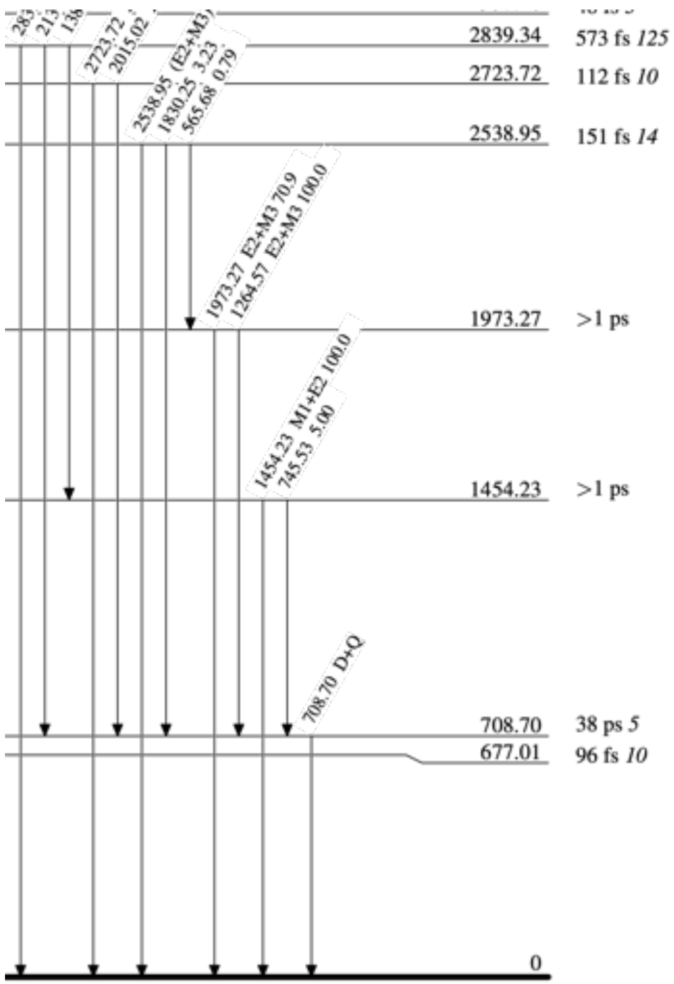


2997 & 3047 keV

Preliminary $^{27}Al(\alpha,n\gamma)^{30}P$ thick-target yields

Gamma yields





Angular distributions

Eur. Phys. J. A (2015) **51**: 56
DOI 10.1140/epja/i2015-15056-5

THE EUROPEAN PHYSICAL JOURNAL A

Review

Cross sections of α-induced reactions for targets with masses A $\approx$ 20–50 at low energies

Peter Mohr[1,2,a]

[1] Diakonie-Klinikum, D-74523 Schwäbisch Hall, Germany
[2] Institute for Nuclear Research ATOMKI, H-4001 Debrecen, Hungary

Analysis of Angular Distributions in the $C^{13}(\alpha,n)O^{16}$ Reaction*

J. P. Schiffer,† Alfred A. Kraus, Jr.,‡ and J. R. Risser
The Rice Institute, Houston, Texas

(Received September 4, 1956)

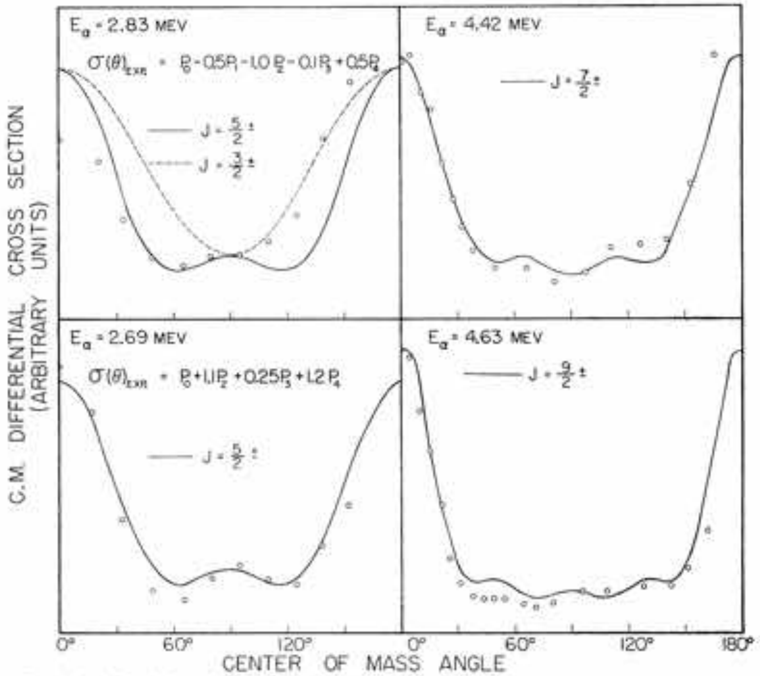
From the study of the angular distributions in the $C^{13}(\alpha,n)O^{16}$ reaction, angular momentum assignments have been obtained for thirteen states of the compound nucleus, O^{17}. Some relative parity assignments were made on the basis of interference effects.

$$\sigma(\theta) \sim \sum_\nu Z(lJlJ,1/2\nu)^2 P_\nu(\cos\theta).$$

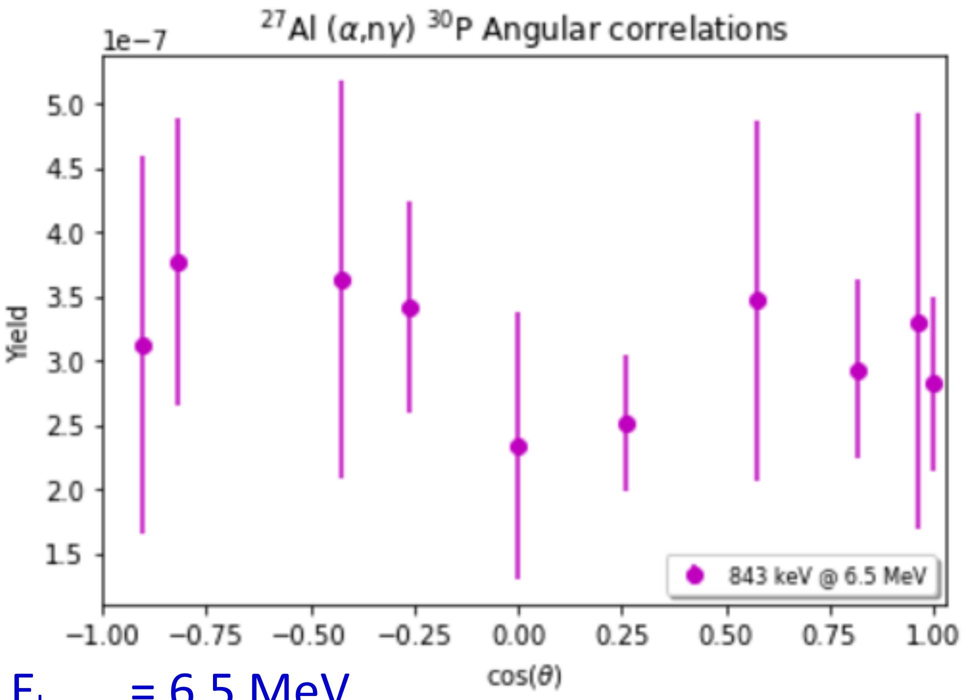
Specific case for 0^+ g.s.

TABLE I. Angular distributions for the $C^{13}(\alpha,n)$ reaction.

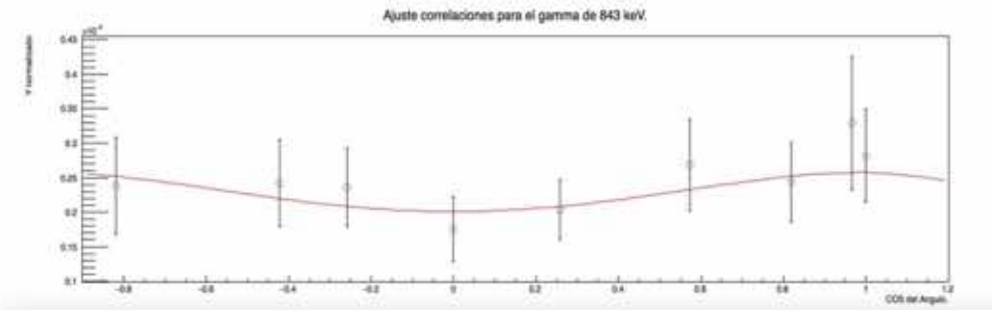
Compound state angular momentum	P_0	P_2	Coefficient of P_4	P_6	P_8
$1/2^\pm$	2				
$3/2^\pm$	4	4			
$5/2^\pm$	6	48/7	36/7		
$7/2^\pm$	8	200/21	648/77	200/33	
$9/2^\pm$	10	400/33	1620/143	320/33	980/143
Interference terms between states of same parity					
1/2–3/2		−4			
1/2–5/2		6			
1/2–7/2			−8		
3/2–5/2		−12/7	−72/7		
3/2–7/2		72/7	40/7		



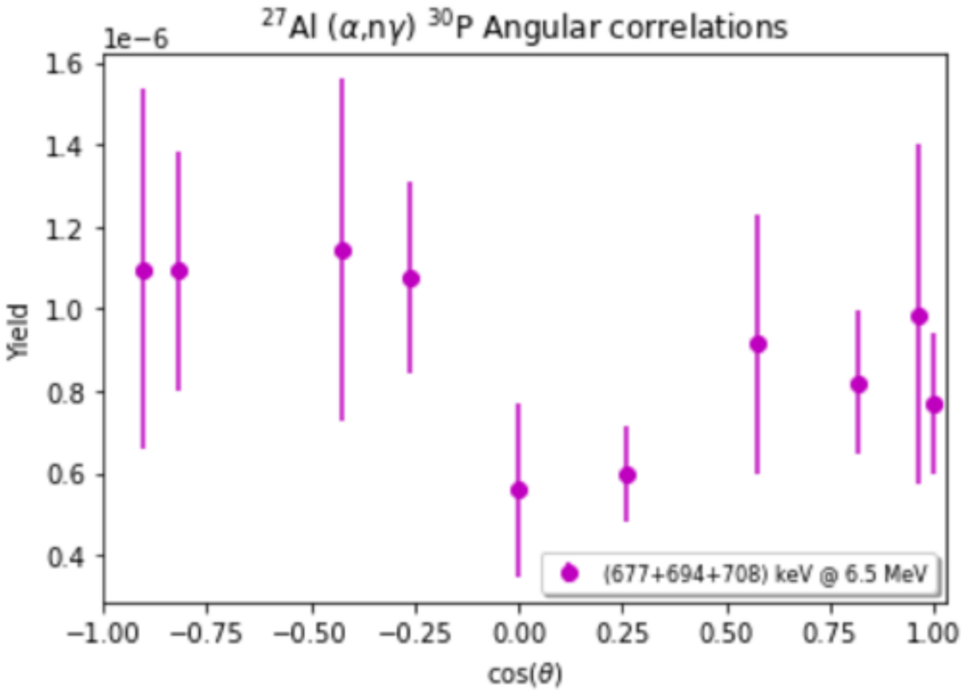
Preliminary angular information



E_{beam} = 6.5 MeV



^{27}Al(α,α'γ)^{27}Al



^{27}Al(α,nγ)^{30}P

Sizeable differences as a function of angle
Work ongoing…

Summary and perspectives

Commissioning of CMAM beamline and gamma detection setup
We face issues with reproducibility of beam focussing, positioning, stability
New target system with movable faces
Current monitoring seems to be fine
Bunching coming soon

Re-measurement of $^{27}Al(\alpha,n)^{30}P$ reaction by activation
- measurement during activation and decay consistent (online + decay)

(alpha,n gamma) measurement
- gamma yields (thick target)

Dead time effect might be relevant at high energies

Analysis almost ready (Odette Alonso-Sañudo)
Paper being drafted
Instrumentation and methods should be described in a technical paper