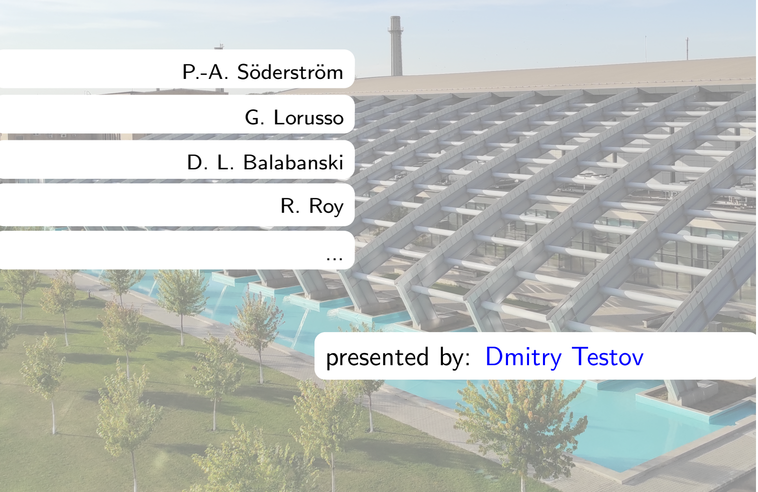
eli nuclear physics

IFIN-HH

NPL National Physical Laboratory

EURASIAN NATIONAL UNIVERSITY

Neutron production yield in alpha induced reactions on CaF_2 and ^{27}Al



P.-A. Söderström
G. Lorusso
D. L. Balabanski
R. Roy
...

presented by: Dmitry Testov

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

November 27, 2023 to December 1, 2023
Virtual
Europe/Vienna timezone

D.A. Testov[1], P.-A. Söderström[1], G. Lorusso[2], R. Roy[1,3], S. Aogaki[1], A.N. State[1], A.K. Azhibekov[4], D.L. Balabanski[1], S. Ban[1,5], R. Borcea[6], M. Brezeanu[1,7], I. Burducea[6], D. Choudhury[1,3], P. Constantin[1], M. Cuciuc[1], A. Dhal1[1], N. Djourelov[1], N. Florea[6], A. Gavrilescu[6], C. Gheorghiu[1], D. Ghita[1], L. Guardo[8], V. Iancu[1], S. Ioannidis[2], S. Ionescu[1], D. Kahl[1], K. Keunhwan[6], I. Kuncser[1], Zh. Kurmanaliyev[9], A. Kusoglu[1,10], V. Leca[1], V. Lelasseux[1], B. Mauyey[9], C. Mihai[6], R. Miron[1,7], C.V. Nedelcu[1], D. Nichita[1], S. Niculae[1], H. Pai[1], P. Parlea[1], C. Paun[1], T. Petruse[1], D. Tofan[6], A. Rotaru[1], A. Spataru[1], M. Straticiuc[6], V. Toma[1], T. Tozar[1], G. Turturica[1], V. Vasilca[1], I. Zai[1]

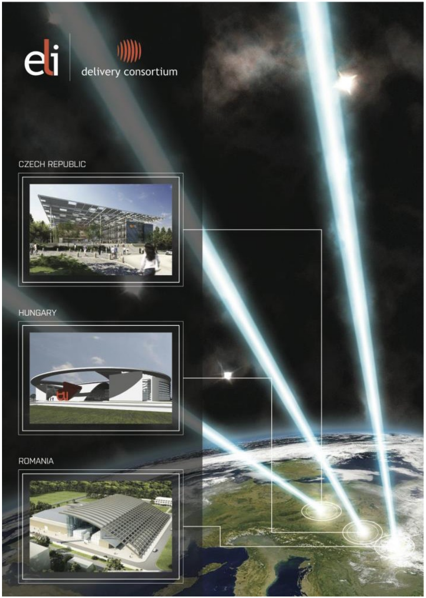
[1]Extreme Light Infrastructure-Nuclear Physics (ELI-NP), Măgurele, Romania
[2] National Physical Laboratory (NPL), UK
[3] Department of Physics, Indian Institute of Technology Ropar (IIT-RPR), Punjab, India
[4] Korkyt Ata Kyzylorda University, Kyzylorda, Kazakhstan
[5] Politehnica University of Bucharest, Bucharest, Romania
[6] Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Măgurele, Romania
[7] Faculty of Physics, University of Bucharest, Bucharest, Romania
[8] Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Catania, Italy
[9] Eurasian National University, Kazakhstan
[10] Department of Physics, Faculty of Science, Istanbul University, Istanbul, Turkey

Extreme Light Infrastructure

ELI-BEAMLINES: ***High-Energy Beam Facility*** **-** application of primary and secondary sources of high-energy radiation and particles (Prague, CZ)

ELI-ALPS: ***Attosecond Laser Science*** **-** new regimes of time resolution in broad spectral ranges (Szeged, HU)

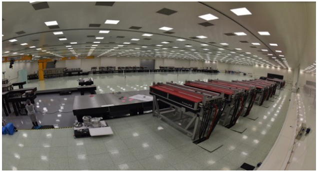
ELI-Nuclear Physics - ***Nuclear Physics Facility*****:** high-power lasers and brilliant gamma beams (up to 19 MeV) enabling novel nuclear and photonuclear studies (Magurele, RO)



ELI-NP facility

High
Power
Laser
System

Operational



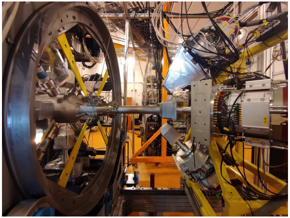
Output type	100 TW	1 PW	10 PW
Pulse energy (J)	2.7	25	242
Pulse duration (fs)	< 25	< 24	<23
Repetition rate (Hz)	10	1	1/60
Calculated Strehl ratio from measured wavefront	> 0.9	> 0.9	> 0.9
Pointing stability (μrad RMS)	< 3.4	< 1.78	< 1.27
Pulse energy stability (rms)	< 2.6 %	< 1.8 %	< 1.8 %

VEGA

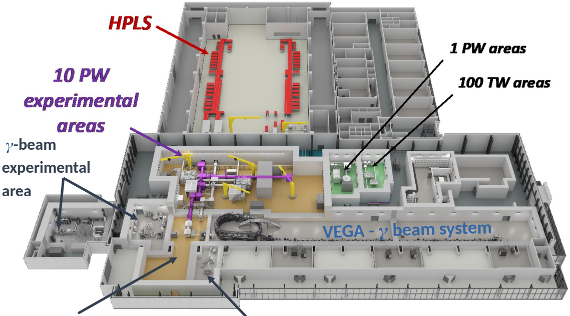
Delayed to 2026

Parameter [units]	Value
Photon energy [MeV]	1 – 19.5
Spectral density [ph/s/eV]	> 5.0 x 10^3
Bandwidth	< 0.5 %
# photons / s	>1.0x 10^{11}
# photons/sec FWHM bdw.	2.0 – 8.0·10^8
Average diametral at FWHM of beam spot [m]	<1.5 x 10^{-3}
Source rms divergence [μrad]	< 150
Radiation pulse length [ps]	0.7 – 1.5
Linear polarization	> 95 %
Repetition rate [MHz]	71.4

Extreme Light Infrastructure: gamma-beam experiments

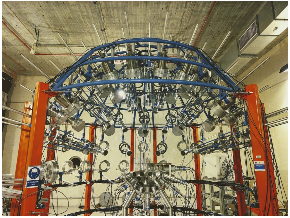


ELIADE γ-ray spectrometer (NRF)
8 clover HPGe (32 fold) detectors in CS
4 $CeBr_3$ detectors

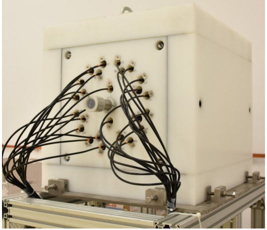


E7 10 PW + γ/e⁻
High Field QED

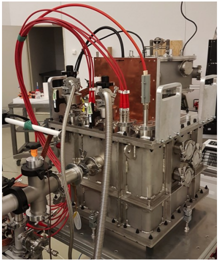
ERA positrons
Material Studies



ELIGANT γ-ray spectrometer (γ,xn)
15 LaBr3(Ce) and 19 $CeBr_3$
33 liquid and 22 Li-glass scintillator

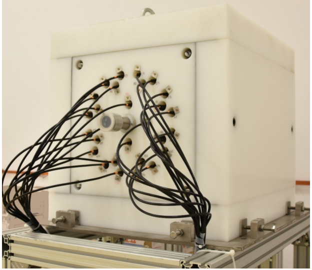


ELIGAN-TN ^{3}He long neutron counter detector



Active gas detector (TPC)

ELIGANT-TN: array of ^{3}He filled counters



High efficiency

Zero energy threshold

Zero cross-talk(multiplicity)

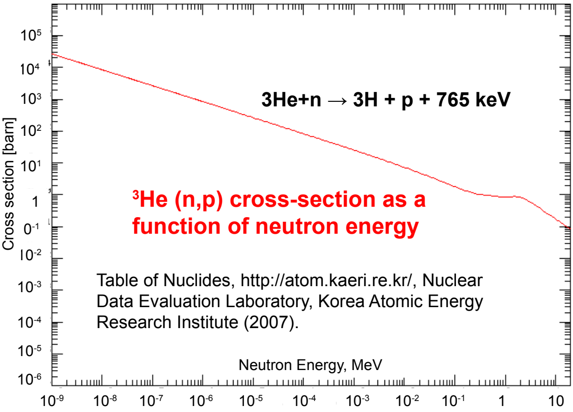
Low internal background

Perfect gamma separation

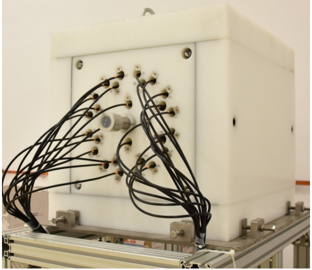
Easy in use/ geometry

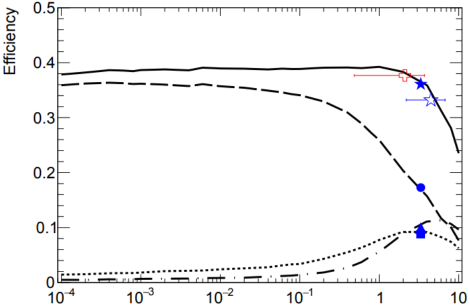
Physics cases

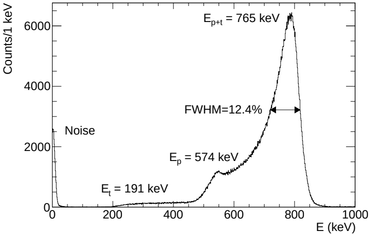
- Nucleosynthesis in the rare astrophysical proton-capture process (p-process)
- Compilation and verification of (α,n), (p,n), (γ,n) cross sections for next generation nuclear reactor applications



ELIGANT neutron detector







- Moderated 28 x ^{3}He tubes (proportional mode)
- Pressure in the tubes 12 bar
- Efficiency simulated in Geant4 and MCNP
- Simulations confirmed with a PuBe neutron source (blue)
- Average of neutron spectrum can be extracted from the ring-to-ring ratio

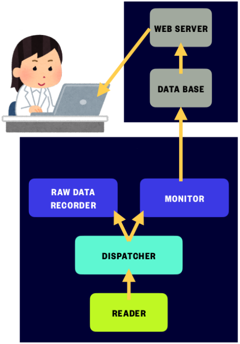
$\epsilon \sim 37\%$ (for ^{252}Cf)

Clisu et al.,EPJ Web of Conferences 284 , 01015 (2023)

DELILA data acquisition system at ELIADE

Digital Extreme Light Infrastructure Listmode Acquisition

v1725 CAEN 14 bit 250 MS/s 16 ch digitizers



DAQ-Middleware

- Developed by KEK (High Energy Accelerator Research Organization)
- Used many experiments at KEK, J-PARC
- Based on a robotics system, good real time operation and reliability
- CAEN digitizers PHA, PSD, waveform impleme
- QDC (soon)
- Using ROOT to plot and store data
- Browser-based GUI

DELILA at ELIGANT

- One event in HPGe channel:
  Channel number: 1 Byte + digitizer number: 1 Byte;
  Energy (ADC value): 2 Bytes; Time stamp: 8 Bytes
- Waveform (250 samples): 500 Bytes
- Total: 512 Bytes

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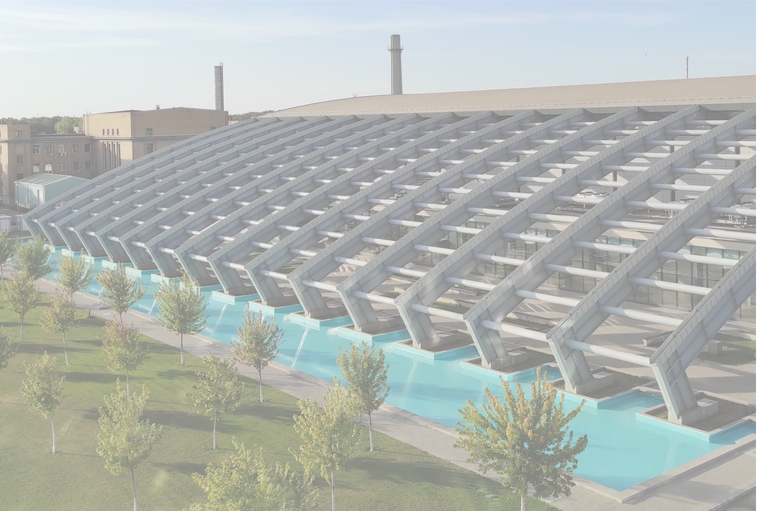
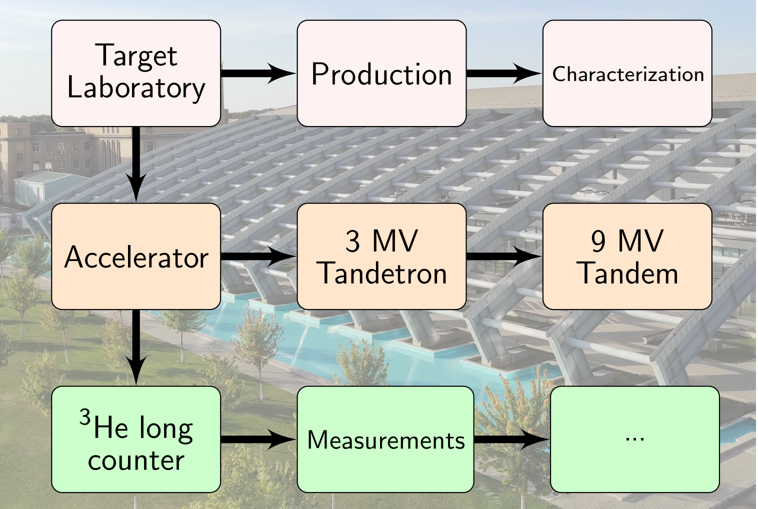
While waiting for γ-beam till 2026...



$(\alpha$, n) program at ELI-NP / IFIN-HH

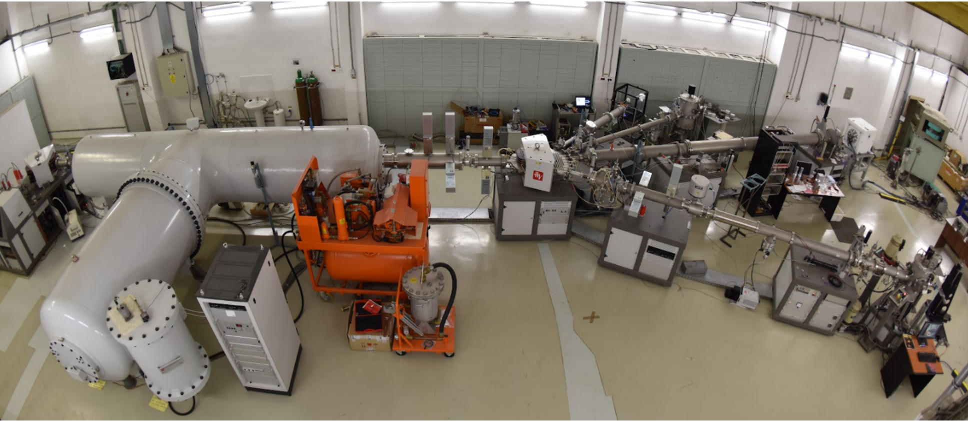


(α, n) program at ELI-NP / IFIN-HH

Fuel Management	Low background application	Fusion α monitors	Astrophysics	Pre-equilibrium
^{19}F(α,n)^{22}Na (performed)	^{13}C(α,n)^{16}O (performed)	^{76}Ge(α,n)^{79}Se (proposal)	^{10}B(α,n)^{13}N (proposal)	^{19}F(α,n)^{22}Na (performed)
	^{27}Al(α,n)^{30}P (performed)	^{10}B(α,n)^{13}N (proposal)		
	^{30}Si(α,n)^{33}S (idea)	^{76}Ge(α,γ) (idea)		

performed   proposal   idea

3 MV Tandetron

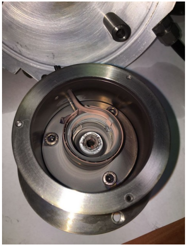


I. Burducea et al., NIM B, Volume 359, 15:12-19, 2015
G. Velișa et al., Europ. Phys. J. Plus 136(11):1171, 2021
M. Straticiuc et al., NIM B, Volume 528: 45-53, 2022

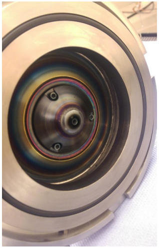
3 MV Tandetron

Courtesy of M. Stratuciuc

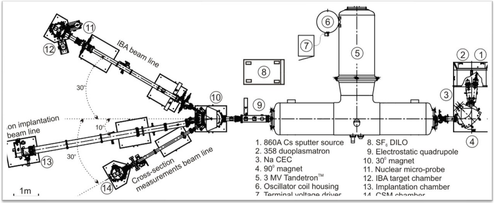
Ions for Applications
3 MV Tandetron™



860 Cs Sputtering Ion source



358 Duoplasmatron



358 "Duoplasmatron" Source

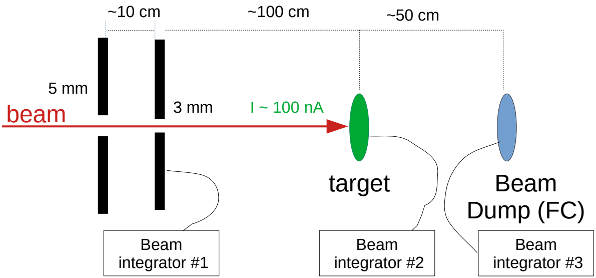
$^{1}H^{-}$	> 40 μA
$^{4}He^{-}/^{3}He^{-}$	> 3 μA

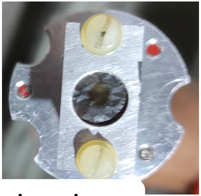
860A Sputter Source

$^{11}B^{-}$	>40 μA
$^{12}C^{-}$	>80 μA
$^{16}O^{-}$	>80 μA
$^{28}Si^{-}$	>80 μA
$^{31}P^{-}$	>40 μA
$^{58}Ni^{-}$	>70 μA
$^{63}Cu^{-}$	>70 μA
$^{75}As^{-}$	>10 μA
$^{197}Au^{-}$	>80 μA

I. Burducea et al., NIM B, vol. 359, 15: 12–19, (2015)

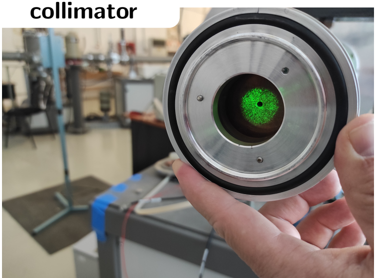
ELIGANT-TN @ 3 MV IFIN Tandetron

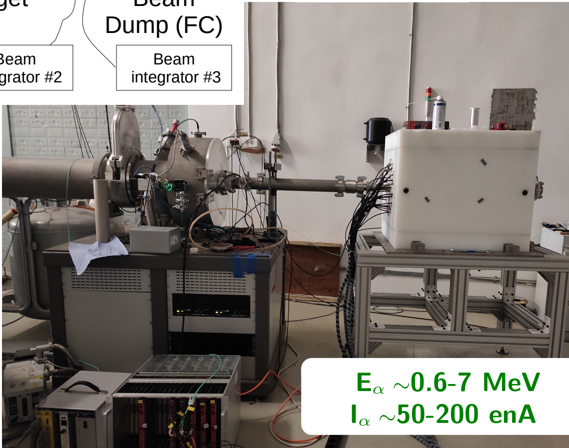




target

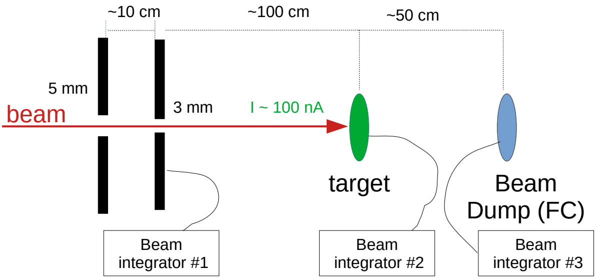
collimator

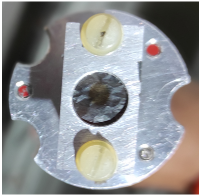




E_α ~0.6-7 MeV
I_α ~50-200 enA

ELIGANT-TN @ 3 MV IFIN Tandetron

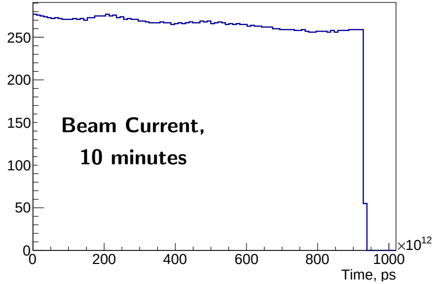




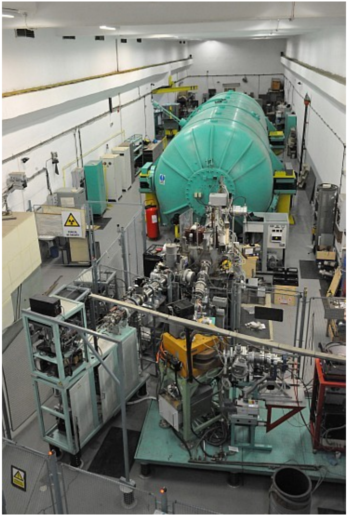
On-line monitoring:

InfluxBD, Grafana

ORTEC 439



The 9 MV Tandem accelerator



Built by High Voltage Engineering Corporation (HVEC) in 1973, upgraded from the original terminal voltage of 7.5 MV (FN machine) to 9 MV. Major upgrades during the last years.

Ion sources:

- SNICSII sputter negative ion source source for negative helium ions
- MC-SNICSII sputter negative ion source dedicated for AMS

HV generator: pelletron system; Voltage: 9 MV

Available beams: p (2 – 18 MeV), α (3 – 27 MeV)
a broad range of heavy ions

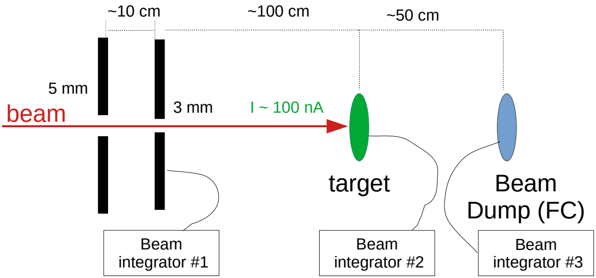
Pulsing systems:

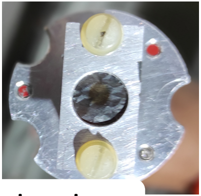
- milliseconds: chopper
- nanoseconds: chopper + buncher

- 2 experimental halls
- 7 beam lines

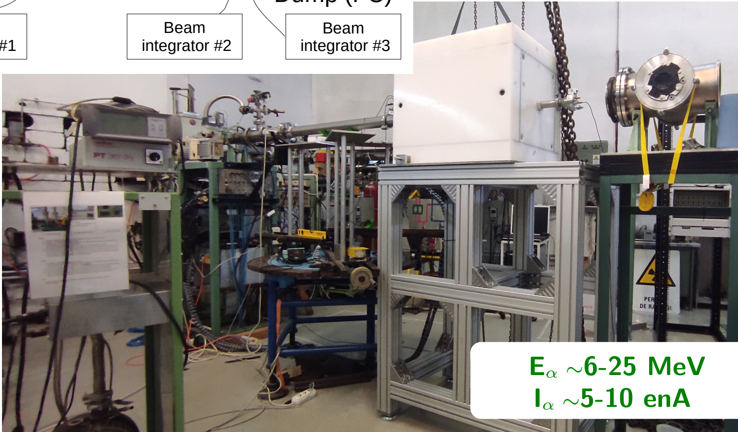
PAC for 3 MV / 9 MV, each November distributes time [March-February]

ELIGANT-TN @ 9 MV IFIN Tandem





target



E_α ~6-25 MeV
I_α ~5-10 enA

Target Preparation laboratory

http://tandem.nipne.ro/target_lab.php

Research services: Preparation and characterization of targets for nuclear structure experiments for IFIN-HH 9 MV Tandem Accelerator and international research facilities collaborators

Fully equipped target laboratory:

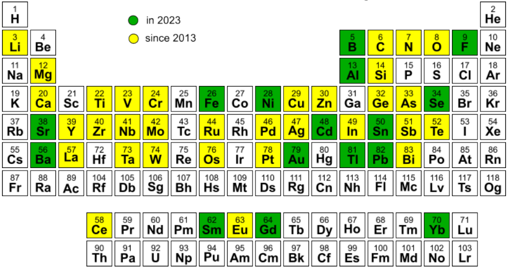
Methods:

- PVD - Physical Vapor Deposition
  - resistive heating
  - electron beam-based systems
- Cold rolling
- Tablet pressing

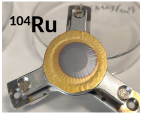
Characteristics of targets:

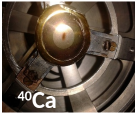
- material (natural/isotopically enriched)
- self-supported or backed
- thickness in units of μg/cm² - mg/cm²
- backing characteristics

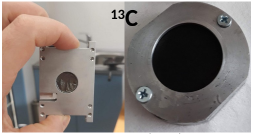
Elements featured in the nuclear targets



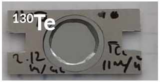
Examples of targets:

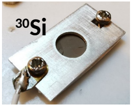






Physics Letters B 834 (2022) 137398





Journal of Radioanalytical Nuclear (2015) 305, 707
Journal of Radioanalytical Nuclear (2018), 316, 725
Vacuum (2019), 161, 162

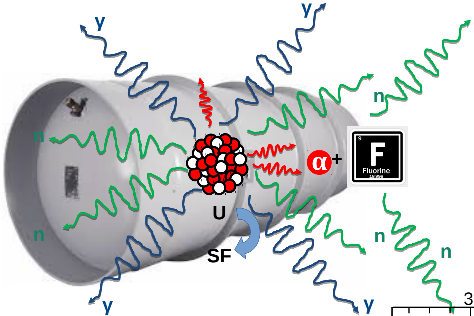
EPJ Web of Conferences (2020) 229, 03001
Vacuum (2023) 215, 112250
INTDS Newsletter (2023) submitted

The experiments

Reaction	Energy	Accelerator	status
^{19}F(α,n)^{22}Na	$\sim$3-7 MeV	3 MV	analysis
	$\sim$6-17 MeV	9 MV	analysis
^{13}C(α,n)^{16}O	$\sim$5-7 MeV	3 MV	analysis
	$\sim$7-17 MeV	9 MV	analysis
^{27}Al(α,n)^{30}P	$\sim$3-7 MeV	3 MV	analysis
^{10}B(α,n)^{13}N	$\sim$0.6-3 MeV	3 MV	2024*
^{76}Ge(α,n)^{79}Se	$<$7 MeV	3 MV	2024*

* Spokeperson G. Lorusso

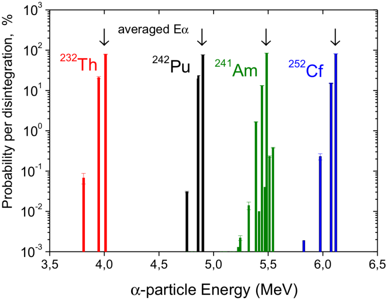
First motivation: ^{19}F

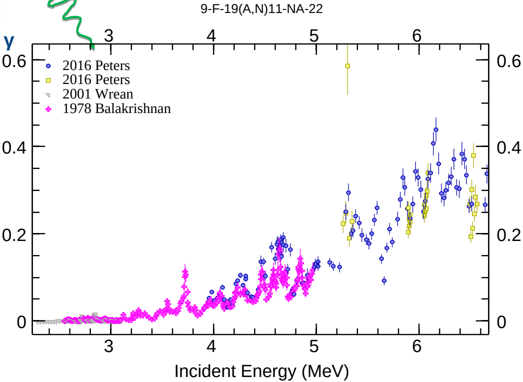


Nuclear fuel management

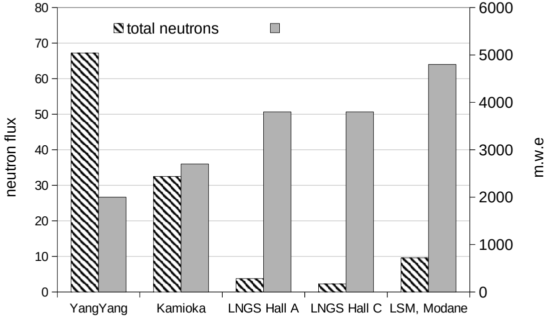
$^{13}_{6}$C	$^{17}_{8}$O	$^{18}_{8}$O	$^{19}_{9}$F

- Cross-sections
- $\langle E_n \rangle$
- Angular correlations





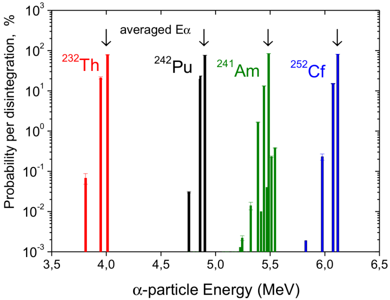
Neutron background in different underground laboratories

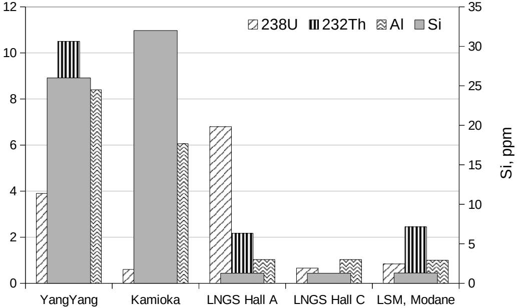


$^{13}_{6}$C $^{17}_{8}$O $^{18}_{8}$O

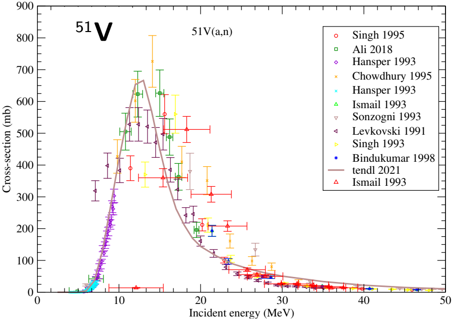
$^{27}_{13}$Al $^{29}_{14}$Si $^{30}_{14}$Si

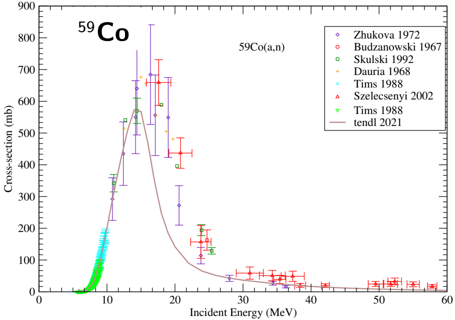
...

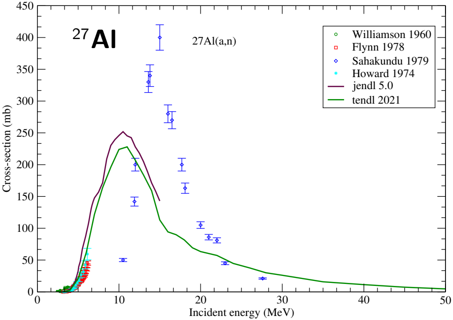


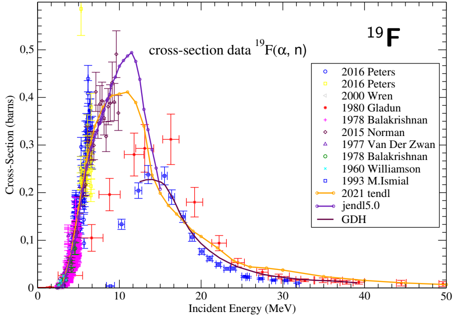


Cross-sections (α,n) reaction on ^{51}V, ^{59}Co, ^{27}Al and ^{19}F

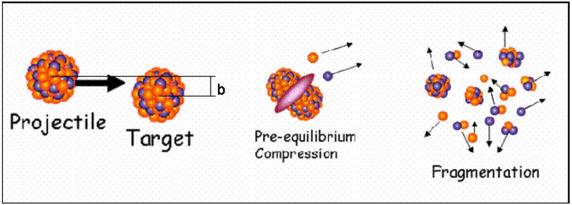








Pre-equilibrium processes in a nuclear reaction



Direct process ($\sim 10^{-22}$ s)

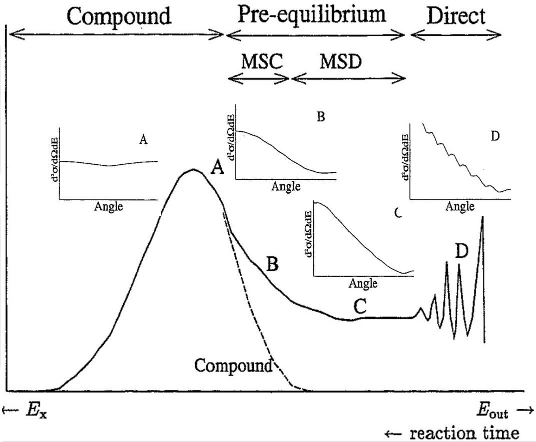
- particles emitted in the direction (forward) of projectiles at similar energy
- elastic (optical model)/ inelastic scattering (DWBA, Distorted Wave Born Approximation)

Compound process ($\sim 10^{-16}$ s)

- particles emitted isotropically , maxwellian energy distribution
- Hauser-Feshbach theory for particle emission probabilities

Pre-compound process

- Intarnuclear cascade models (ICS)
- hybrid and exciton models
- Geometry Dependent Hybrid Models (GDH)



Nuclear reaction codes specific for α-induced reactions

Since (α, n) reactions are in paramount of importance for fundamental science and numerous applications in the applied science there are at least 3 nuclear reaction codes available for users to describe/predict neutron production yield up to several tens of incident energy.

TENDL JENDL EMPIRE

Optical Model:

- Shape elastic angular distribution
- Cross section
- Inelastic process using either coupled channels (deformed nuclei) or DWBA (spherical nuclei)
- Transmission coefficients for compound and pre-compound processes

Compound:

- Hauser-Feshbach approach

Pre-Compound:

- Two-component exciton models
- exciton model with angular momentum conservation and γ-ray emission (EMPIRE)

Nuclear data for plasma diagnostics (α detection)

D + *T* → ^{4}He (3.52 MeV) + *n* (14.1 MeV)

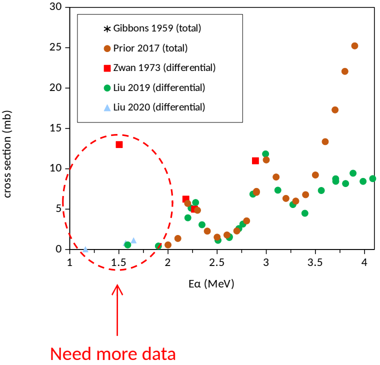
- ❑ The ITER design relies on a particles delivering their energy into the plasma to achieve ignition
- ❑ α loss causes radiation damage in plasma facing components
- ❑ <u>α loss needs to be well understood (in the range 1 – 3.5 MeV)</u>
- ❑ Foils activation measurements:
  - Needs γ-signal above neutron activation background
  - Mechanical constraint
  - Half-life of activation products needs to be right
  - Reaction threshold < 3.5 MeV
  - Accurate cross section data are key to identify the right materials

Packer et al. Nucl Fusion **58** (2018) 096013

Courtesy of Giuseppe Lorusso

$^{10}B(a,n)^{13}N$ cross section for plasma diagnostics

NPL National Physical Laboratory



Courtesy of Giuseppe Lorusso

Key features of $^{10}B(a,n)^{13}N$ reaction

- Boron carbide B_4C is an extremely hard and high temperature ceramic material
- commercially available with high purity
- its activation product ^{13}N has a convenient half-life (9.9 min)
- g-rays from ^{13}N decay are not expected to suffer significant interference from products of neutron activation.
- reaction has recently been used at the National Ignition Facility (NIF) for al monitoring
- One of the very few reactions with no threshold, sensitive to ~1 MeV alphas

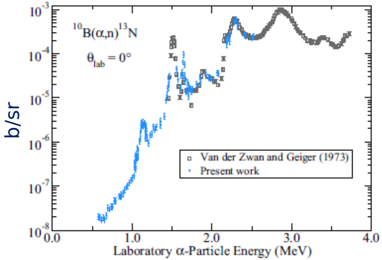
$^{10}B(a,n)^{13}N$ astrophysics motivation

NPL National Physical Laboratory

$^{2}H(\alpha,\gamma)^{6}Li(\alpha,\gamma)^{10}B$ → $^{10}B(\alpha, d)^{12}C$ / $^{10}B(\alpha,n)^{13}N$

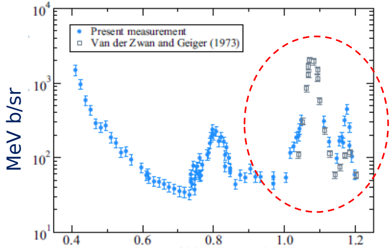
Contribution to C and N element in primordial stars, additional to the main 3 α

Laboratory differential cross section



Courtesy of Giuseppe Lorusso

Differential S factor (MeV b/ sr)

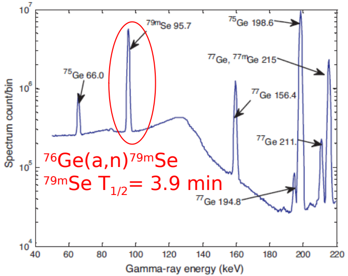


Goals of the proposed measurement

- Validation of Q. Liu 2020
- Address the discrepancy with Vand der Zwan 1973

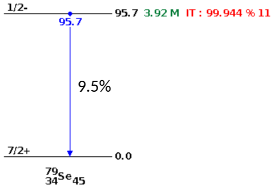
$^{76}Ge(a,n)^{79m}Se$ for plasma diagnostics

Simulated γ-spectrum from ITER-exposed Ge



G. Bonheure et al., Fusion Engineering and design 80 (2013) 513

^{79m}Se



- Plasma simulation shows that this reaction can provided a good signal-to-noise ratio
- No cross-section data exists!!
- We are only sensitive to ($^{79m}Se+^{79}Se$) yields

Courtesy of Giuseppe Lorusso

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

November 27, 2023 to December 1, 2023
Virtual
Europe/Vienna timezone

Neutron production yield in alpha induced reactions on CaF_2 and ^{27}Al

ELIGANT characterization

Analysis

Proposals

EUROPA project

non-resonant reactions

^{13}C(α,n)^{16}O

^{76}Ge(α,n)^{79}Se

nEUtROn resPonse of mAterials for nuclear and fusion reactors

resonant reactions

^{27}Al(α,n)^{30}P

^{10}B(α,n)^{13}N

^{19}F(α,n)^{22}Na

γ-n coincidence

<E>

target, contaminants

target switcher

You are welcome to join!