Nuclear reactions studies at Basic Nuclear Physics experimental line at CNA: the case of $^{6}Li + ^{12}C$

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Outline

1. **Basic Nuclar Physics (FNB) experimental line**

2. **^{6}Li + ^{12}C reaction**
   - Motivation
   - Experimental set-up
   - Preliminary results

3. **Coclusions & outlooks**

National Accelerators Center (CNA)

CNA Centro Nacional de Aceleradores

Infraestructuras Científicas y Técnicas Singulares

Universidad de Sevilla

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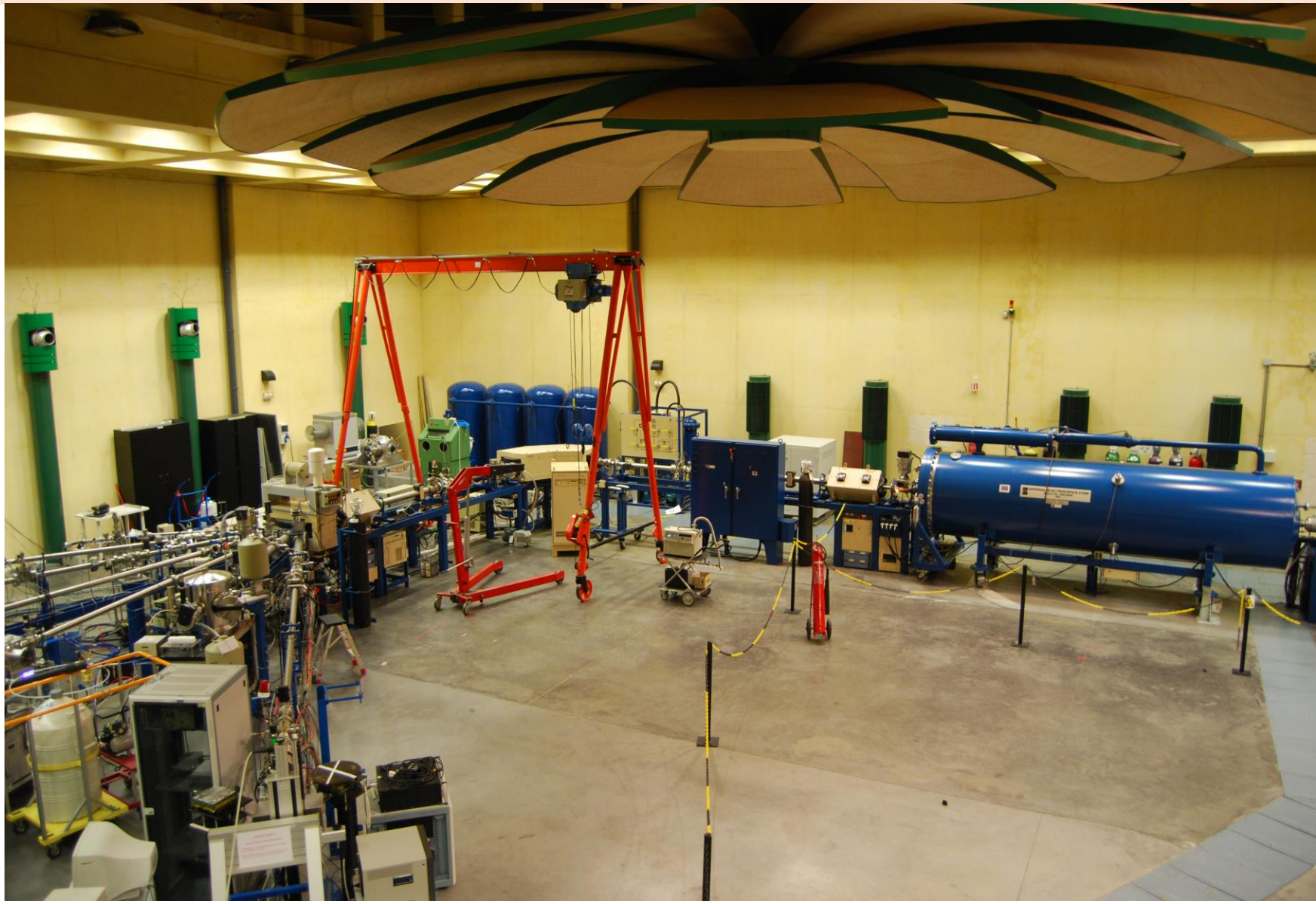
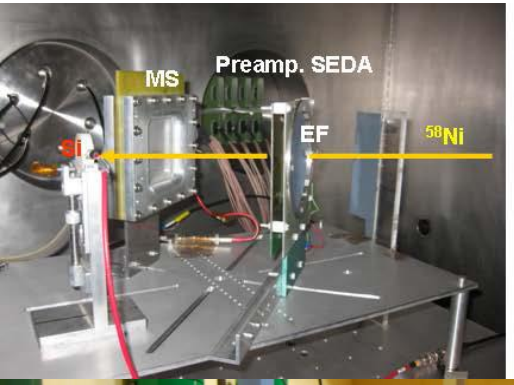
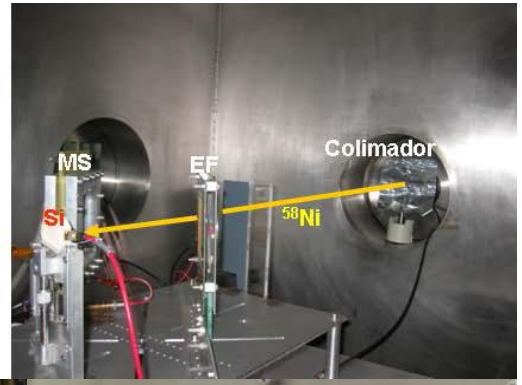
CSIC Consejo Superior de Investigaciones Científicas

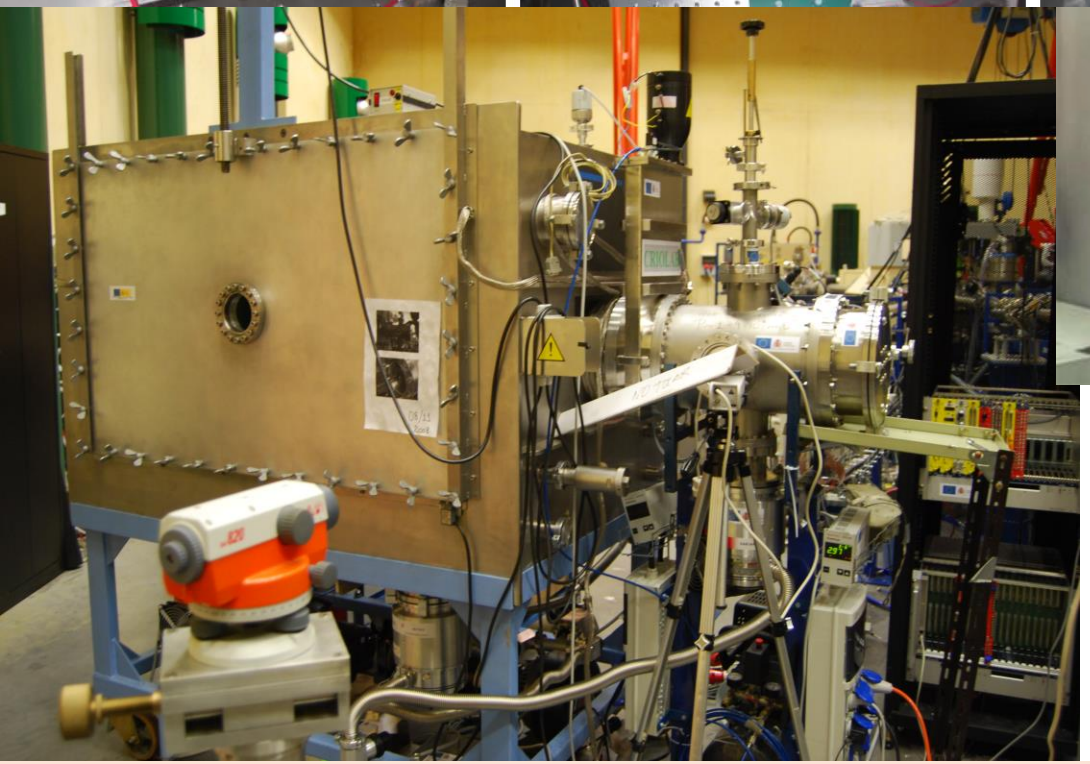
Junta de Andalucía

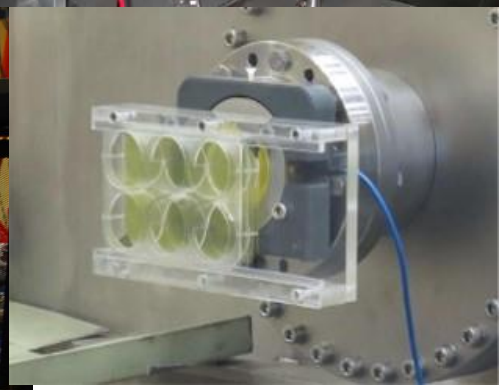


Basic Nuclar Physics (FNB) experimental line



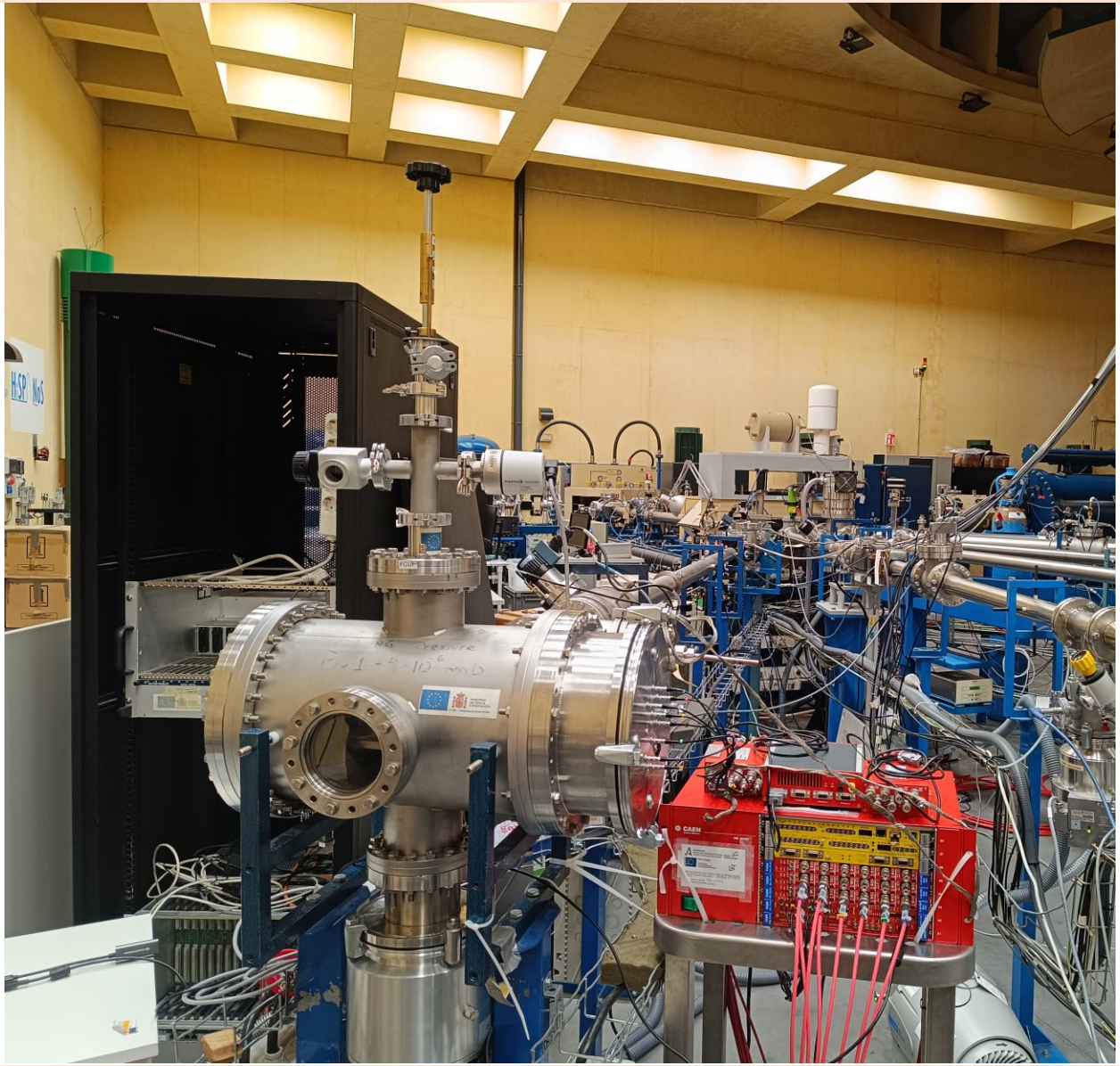






- Medical physics experiments
- Gaseous detectors development
- Test and characterization of nuclear instrumentation for experiments at other facilities

Basic Nuclar Physics (FNB) experimental line



- Medical physics experiments
- Gaseous detectors development
- Test and characterization of nuclear instrumentation for experiments at other facilities

Nuclear reaction studies with different ions (^{6}Li,^{7}Li,^{9}Be,^{10}B…) and light nuclear targets (^{12}C,^{14}N…) at FNB

Study of ^{6}Li+^{12}C reaction

$$U_N = N_r\, V_{SPP2}(r) + i\, N_i\, V_{SPP2}(r)$$

$$V_{SPP2}(r) = \iint \rho_1(\vec{r}_1)\rho_2(\vec{r}_2)\, U_0 e^{-\left(\frac{r}{a}\right)^2} e^{-\frac{4v^2}{c^2}}\, d\vec{r}_1 d\vec{r}_2$$

L. Chamon *et al.* Comput. Phys. Commun. 267, 108061 (2021)

Weakly bound projectile & medium mass target

Projectile	Targets
^{6}Li, ^{7}Li, ^{9}Be, ^{10}B	^{120}Sn
^{6}Li, ^{7}Li, ^{6}He, ^{9}Be, ^{11}Be ^{10}B	^{64}Zn

M. A. G. Alvarez, *et al.* Phys. Rev. C 100, 064602 (2019).
L. Garrido-Gómez, A. Vegas-Díaz, J.P. Fernández-García and M.A.G. Alvarez, Phys. Rev. C 109, 054608 (2024).

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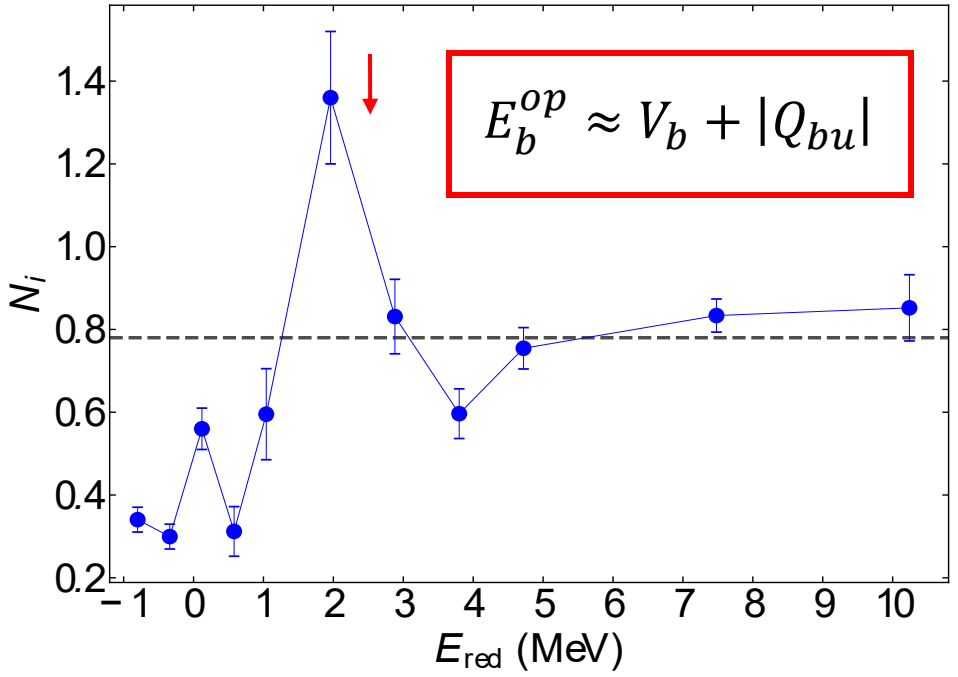
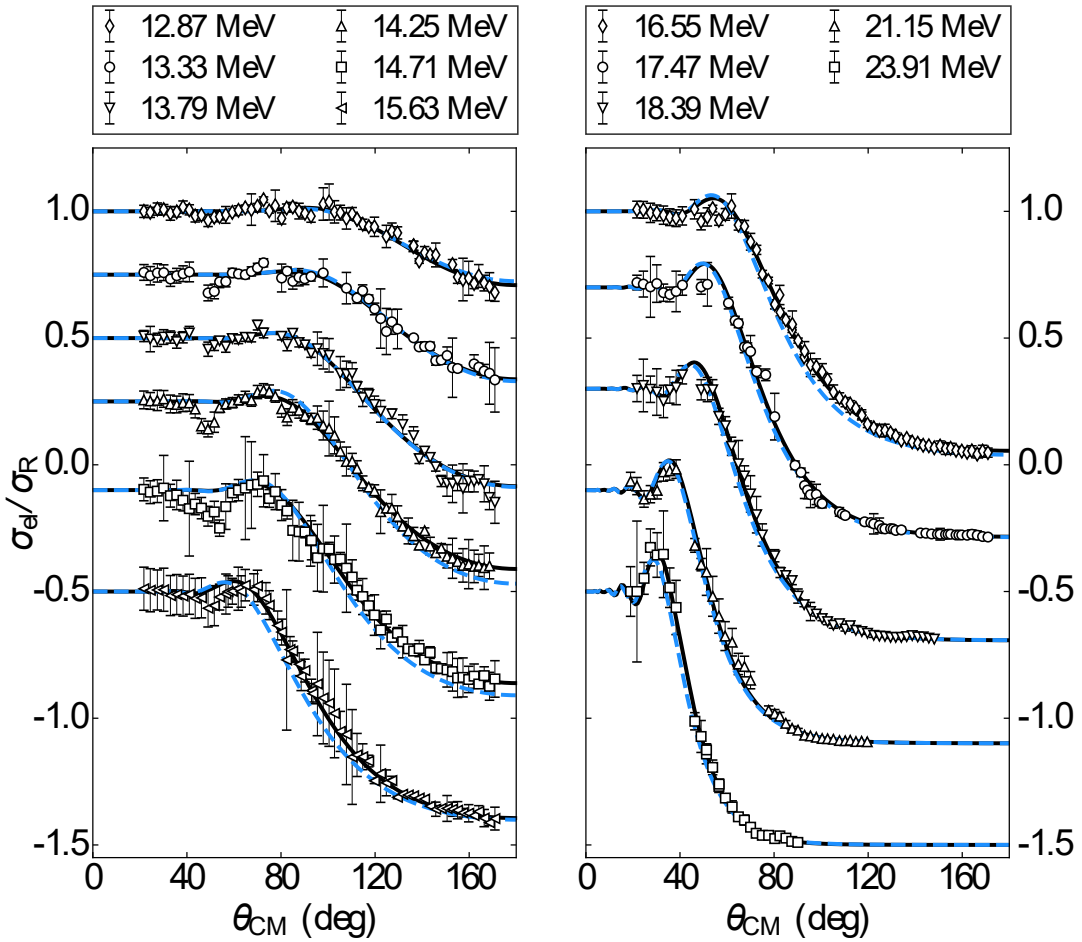


^{7}Li+^{80}Se elastic scattering cross section



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Study of $^{6}Li+^{12}C$ reaction

Weakly bound projectile & medium mass target

Projectile	Targets
^{6}Li, ^{7}Li, ^{9}Be, ^{10}B	^{120}Sn
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Study of ^{6}Li+^{12}C reaction

Weakly bound projectile & light target

Projectile	Targets
^{6}Li, ^{7}Li…	^{12}C, ^{14}N…

Weakly bound projectile & medium mass target

Projectile	Targets
^{6}Li, ^{7}Li, ^{9}Be, ^{10}B	^{120}Sn
^{6}Li, ^{7}Li, ^{6}He, ^{9}Be, ^{11}Be ^{10}B	^{64}Zn

Measured at FNB experimental line

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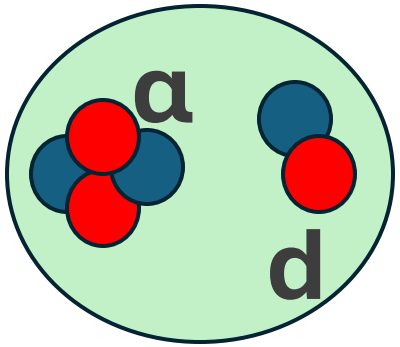
Study of ^{6}Li+^{12}C reaction

- Weakly bound nuclei
- Cluster structure (α+d)

Q_α= - 1.474 MeV

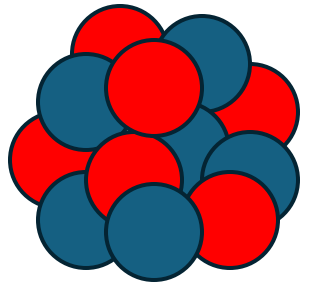


^{6}Li

+

- Tightly bound nuclei

Q_α= - 7.367 MeV



^{12}C

^{6}Li dissociation play a crucial role in the reaction dynamics

$$E_b^{op} \approx V_b + |Q_{bu}|$$

Coulomb barrier **V_b~ 4.5 MeV**

Dissociation energy **Q_α= - 1.474 MeV**

Experimental setup

Beam

- 3 MV tandem accelerator

$$E = (q + 1) \cdot V + J$$

- 10 energies from 3 MeV to 7 MeV

Coulomb barrier:
V_b~ 4.5 MeV

Dissociation energy:
Q_α= - 1.474 MeV

Target

- Thin layer of ^{12}C and ^{197}Au
- Characterized at CNA by IBA techniques

Detection & DAQ

- Surface Barrier silicon Detectors (SBD)
- Adquisition based on digitizers

Experimental setup

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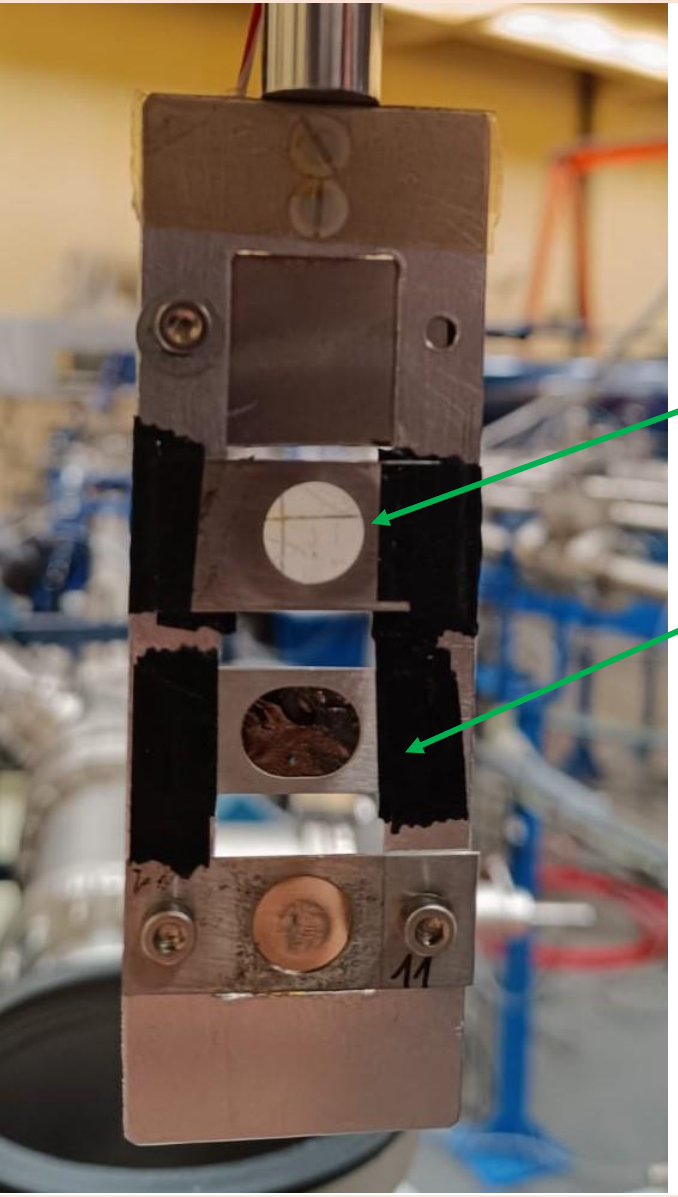


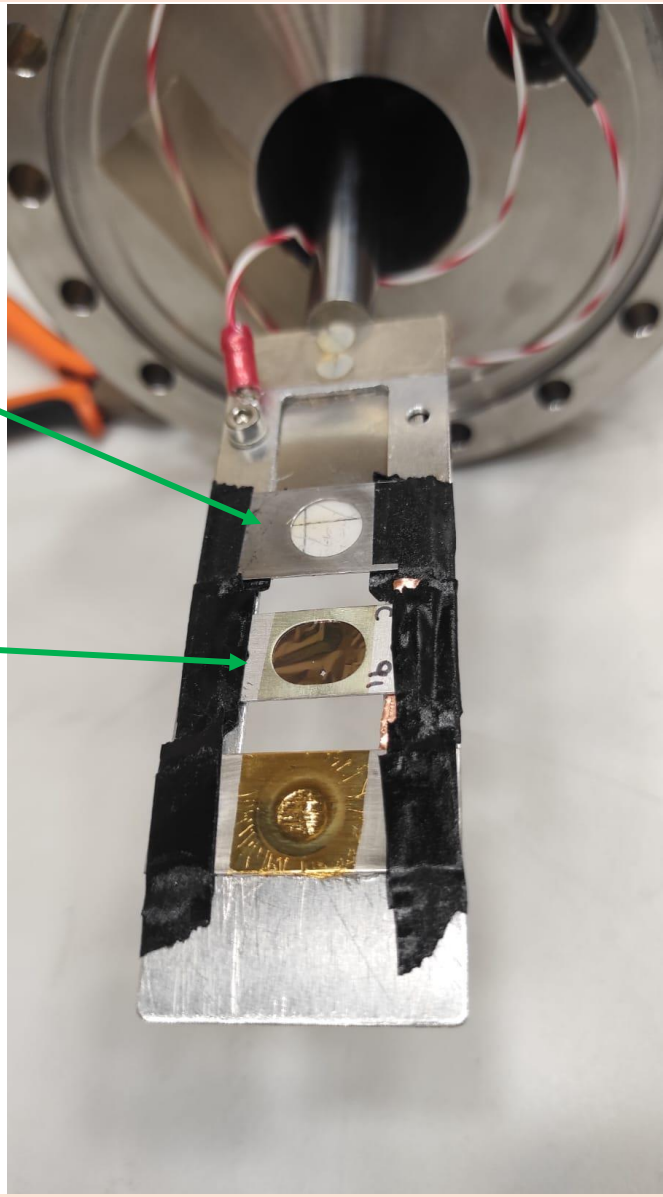
Targets

Scintillator ZnS(Ag)

^{12}C target

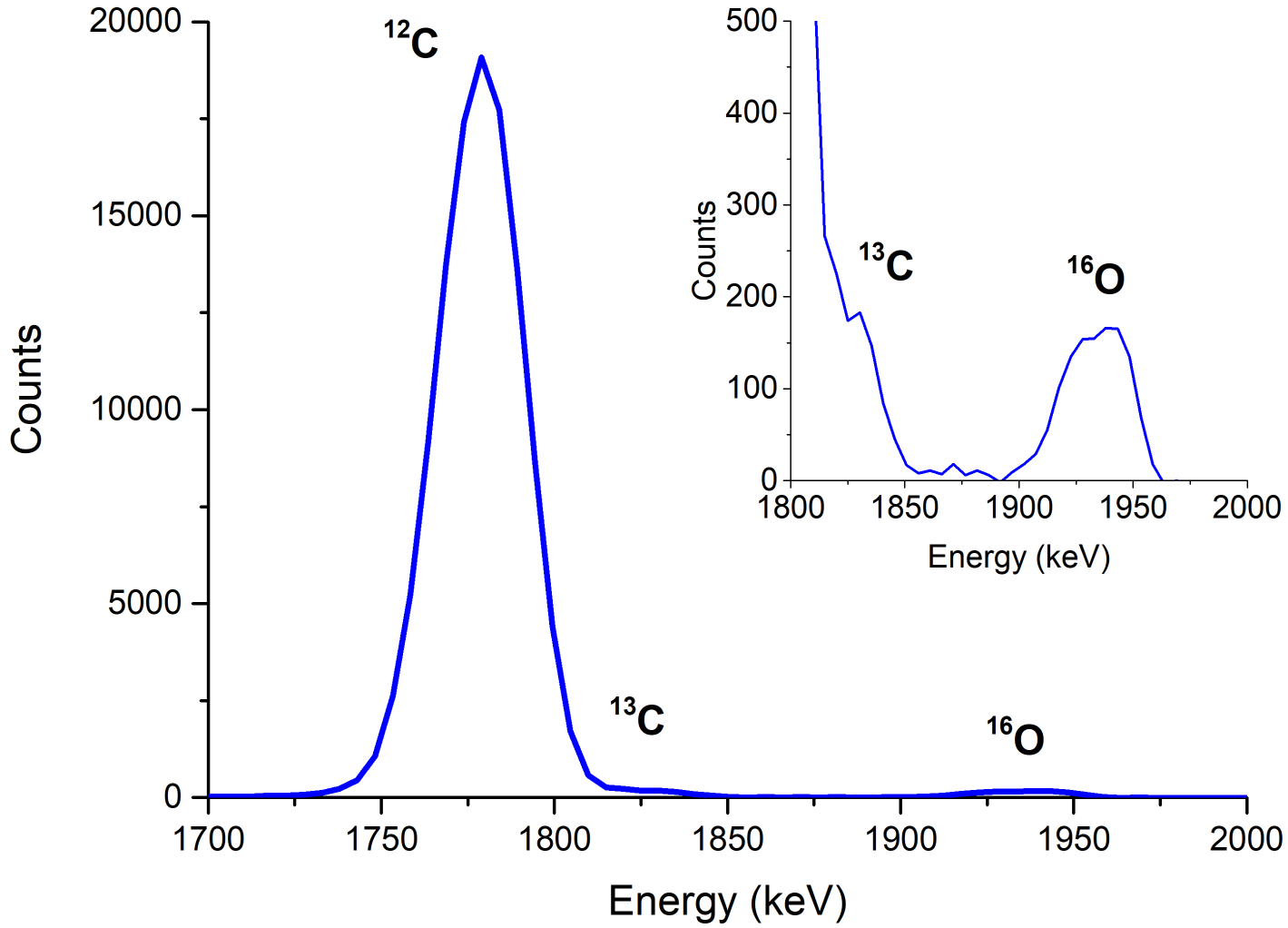
$^{12}C+^{197}Au$ target

Au for normalization



Target characterization

Characterized by p-EBS at CNA



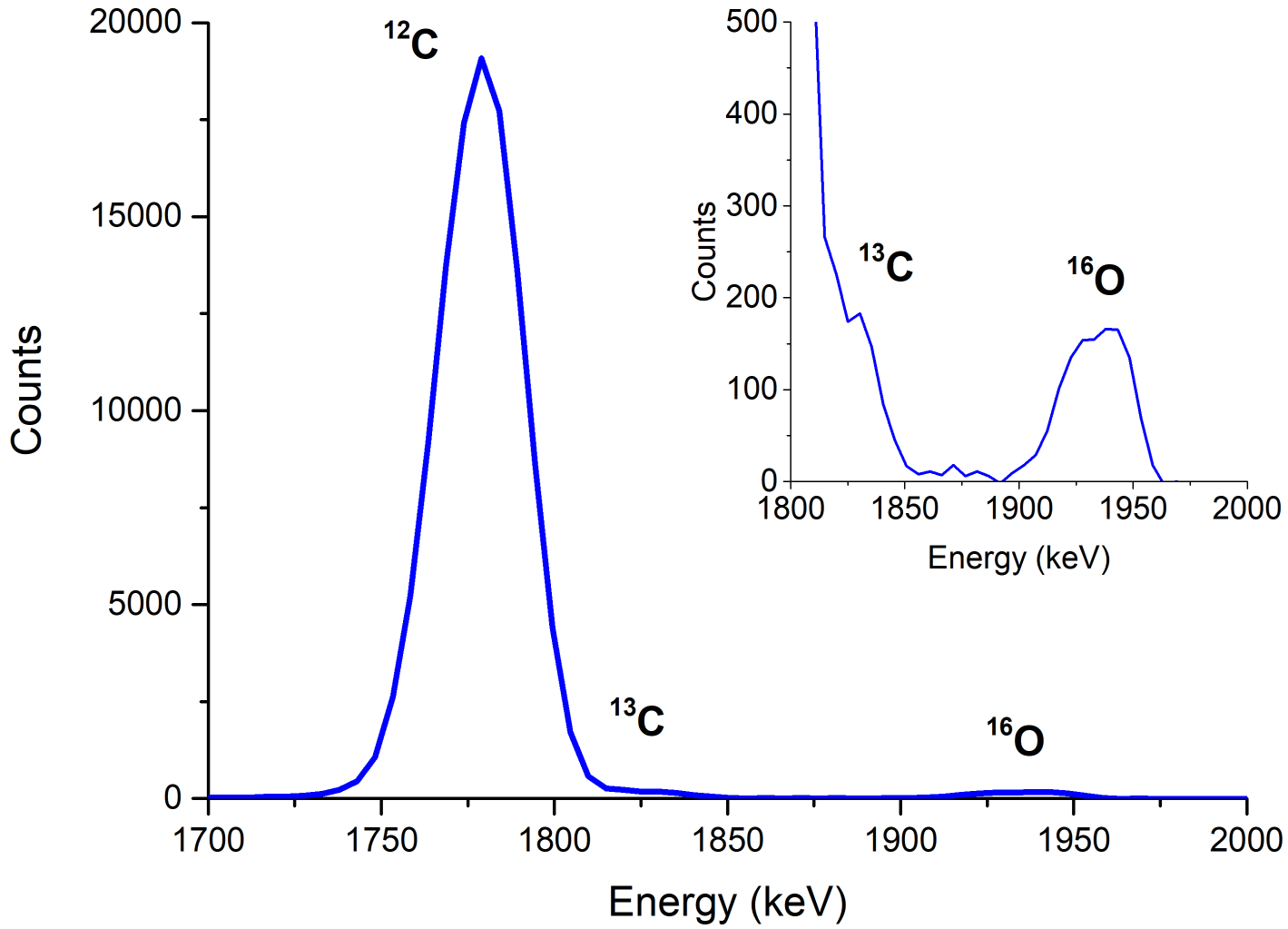
^{12}C target

Nominal thickness

91 µg/cm^2 of ^{12}C

Target characterization

Characterized by p-EBS at CNA



^{12}C target

Nominal thickness

91 µg/cm^2 of ^{12}C

Characterized thickness

115±2 µg/cm^2 of ^{12}C

1.5±0.1 µg/cm^2 of ^{16}O

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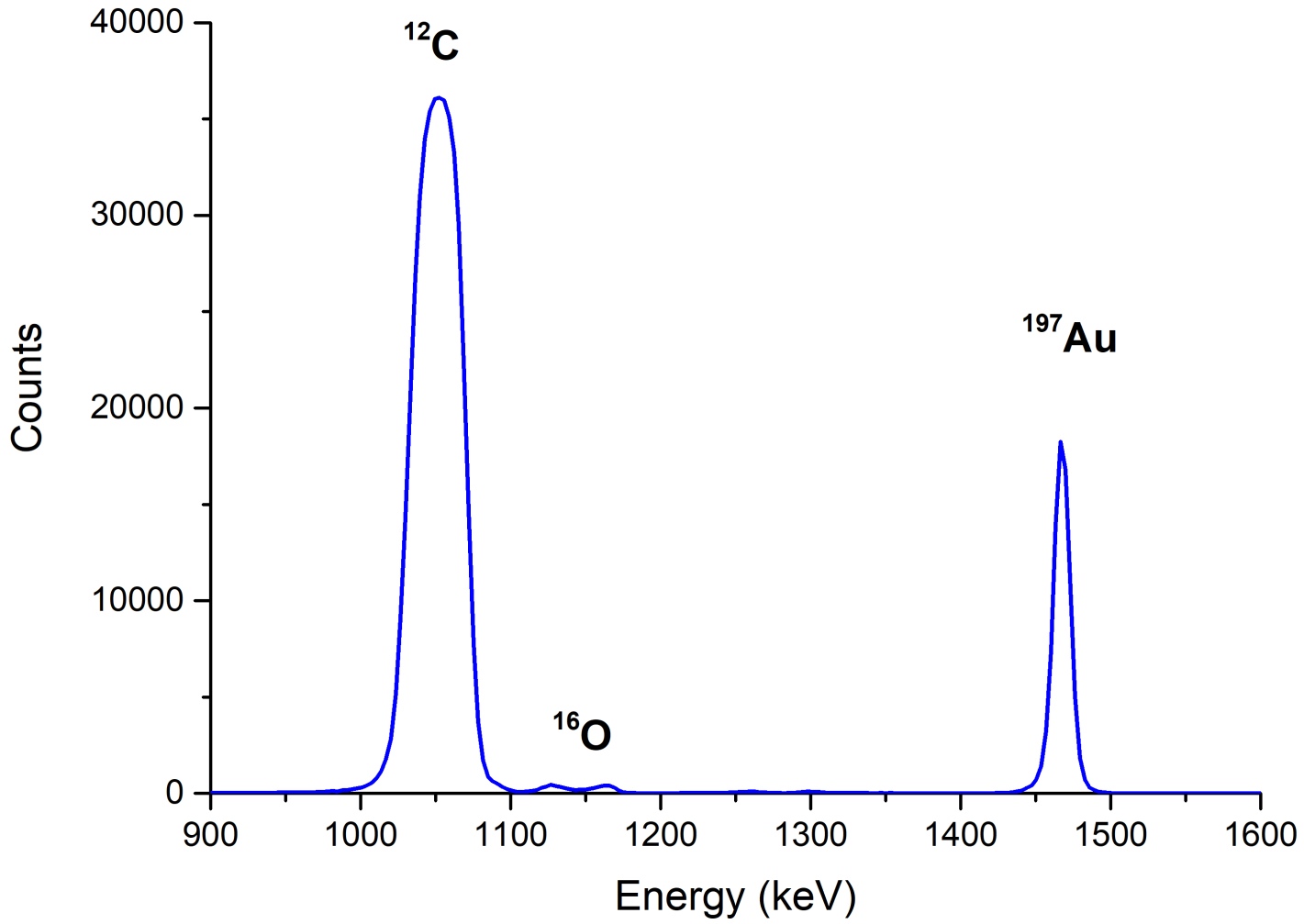

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Detection & DAQ

- Surface Barrier silicon Detectors (SBD)
- Adquisition based on digitizers

Experimental setup

Detectors

Surface Barrier silicon Detectors
- 8 SBD of 500 µm thickness
- 8 SBD of 15 µm thickness

DAQ

V1725S digitizer from CAEN
- 14 bit resolution
- Sample rate of 250 MS/s
- DPP-PHA firmware

Control interface

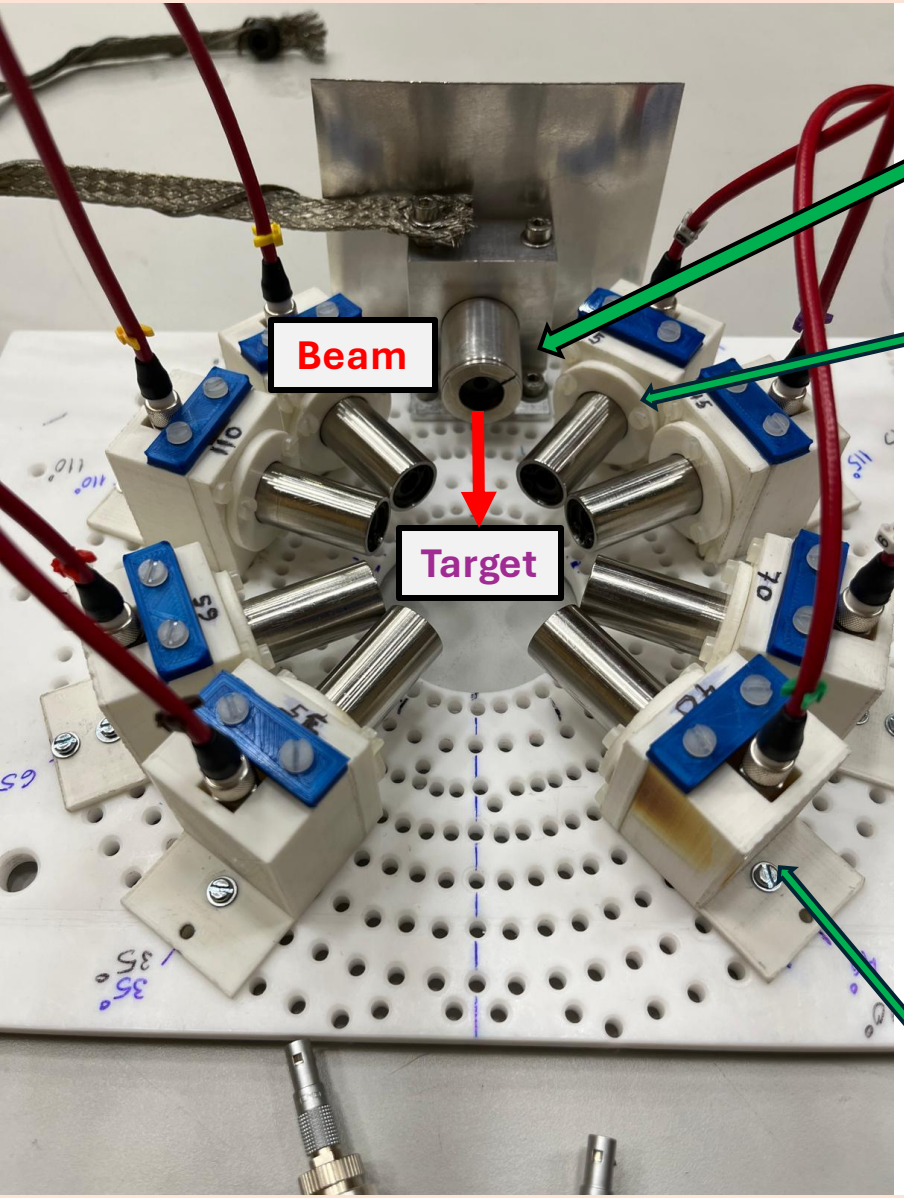
CoMPASS software from CAEN

Modular Aparatus for nuclear Reactions Spectrometry (MARS)

Developed at Departamento de Física Atómica Molecular y Nuclear (FAMN) Universidad de Sevilla

research proyect EQC2019-005873-P

Experimental setup



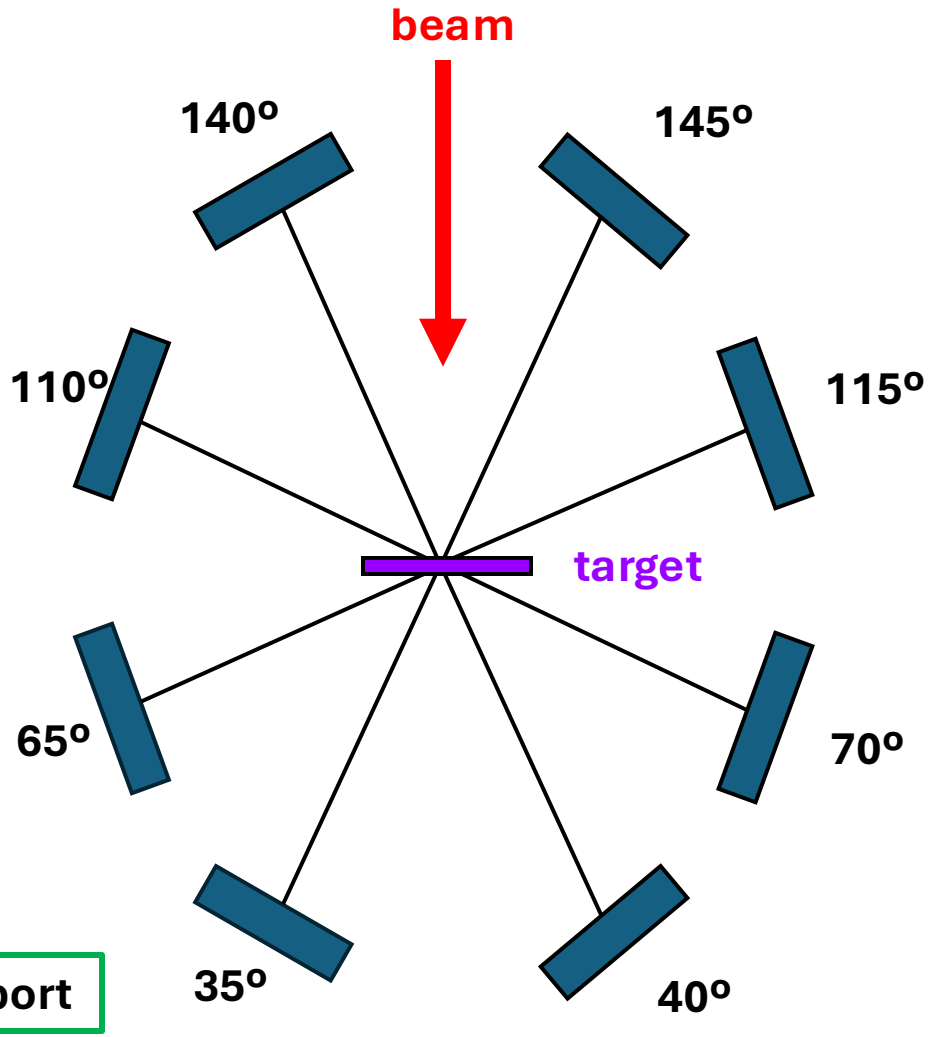
Beam collimator
Ø=2 mm

Detectors collimator
Ø=6 mm

8 Surface Barrier silicon detectors (500µm)

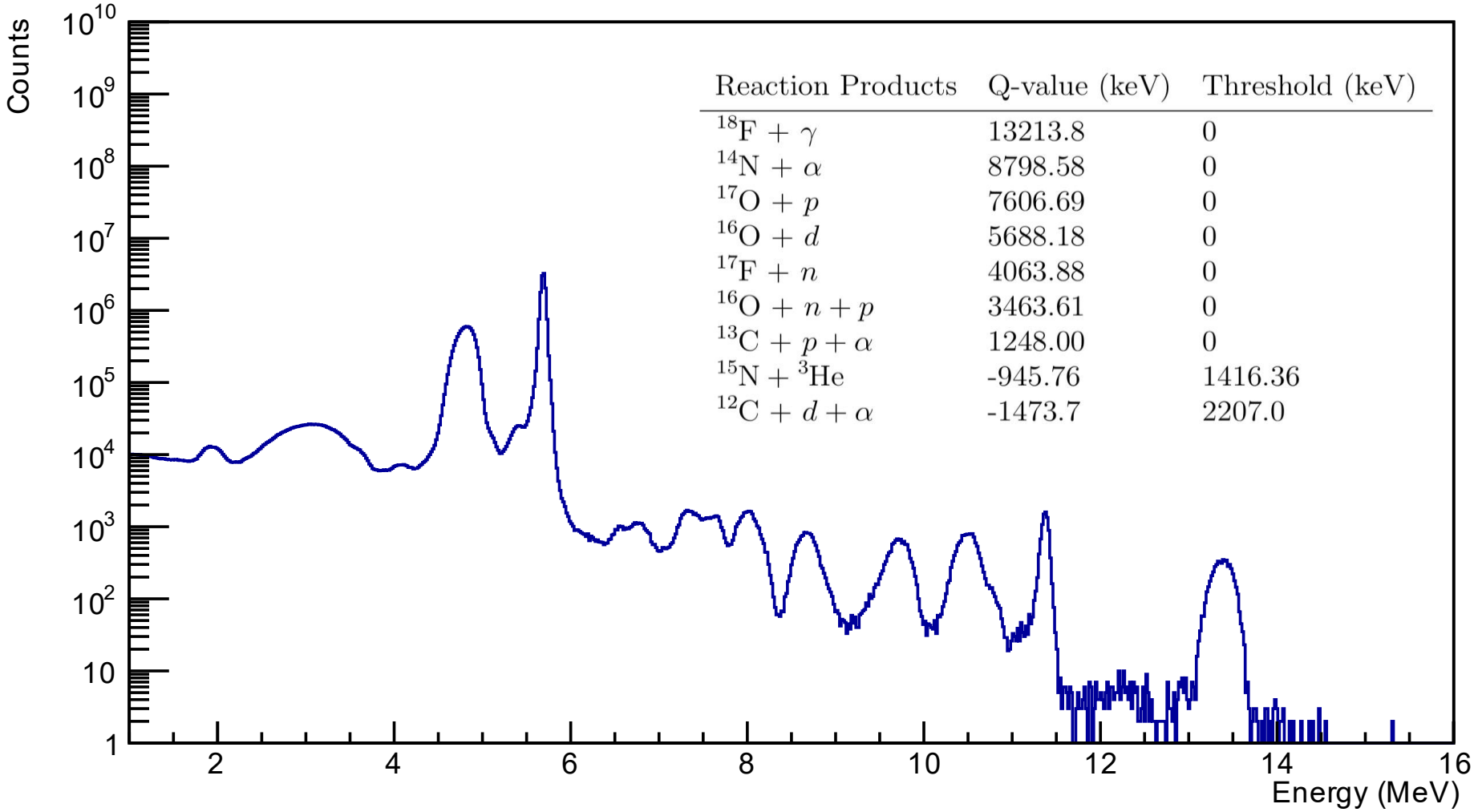
3D printed mechanical support

Detectors setup

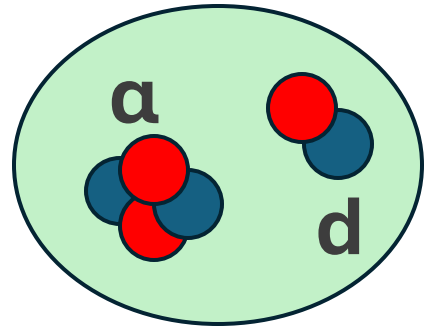


$^{6}Li+^{12}C$ reaction

$^{6}Li + ^{12}C, ^{197}Au$ at 6 MeV and 35º



Reaction Products	Q-value (keV)	Threshold (keV)
$^{18}F + \gamma$	13213.8	0
$^{14}N + \alpha$	8798.58	0
$^{17}O + p$	7606.69	0
$^{16}O + d$	5688.18	0
$^{17}F + n$	4063.88	0
$^{16}O + n + p$	3463.61	0
$^{13}C + p + \alpha$	1248.00	0
$^{15}N + ^{3}He$	-945.76	1416.36
$^{12}C + d + \alpha$	-1473.7	2207.0



^{6}Li

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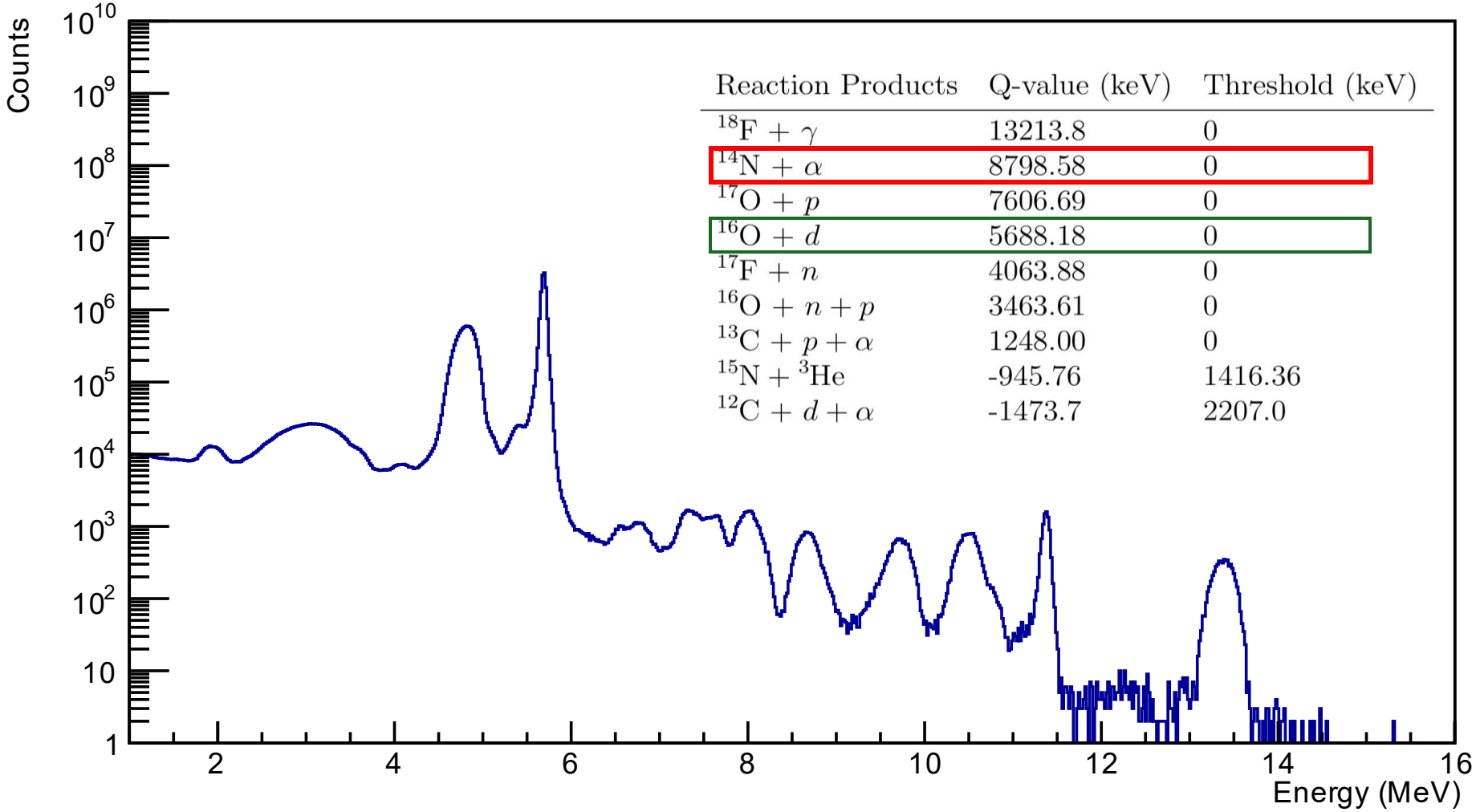

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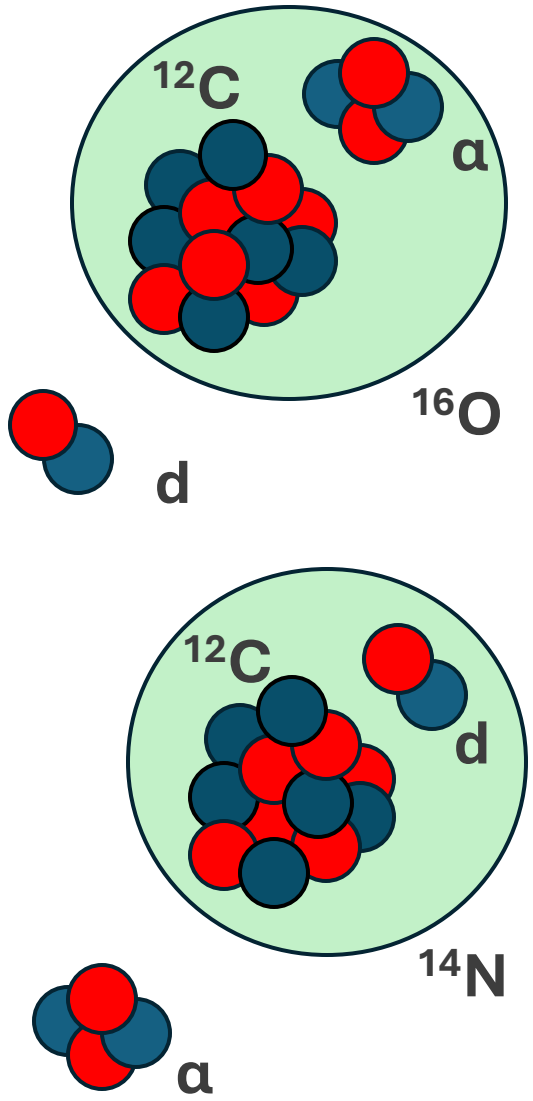

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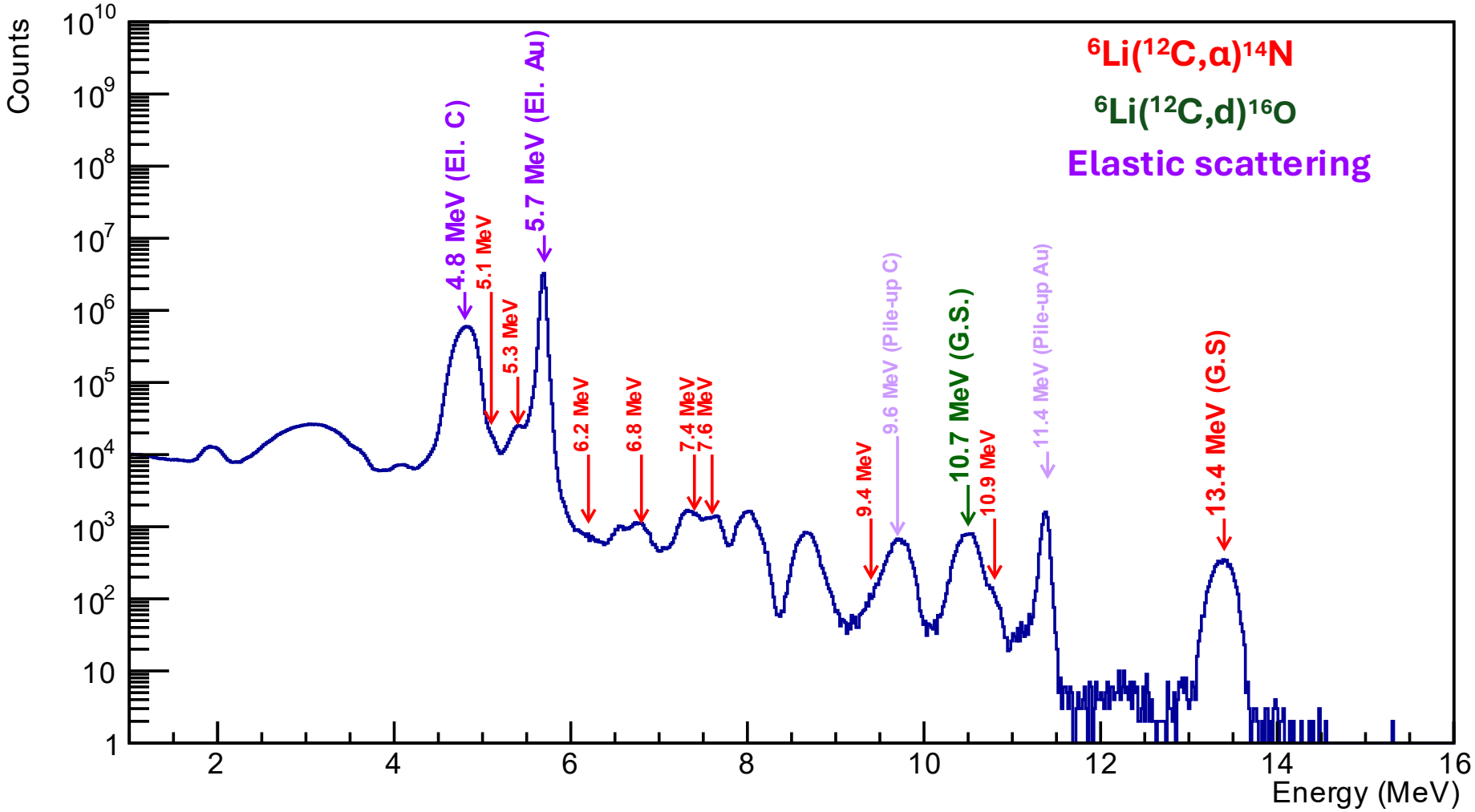
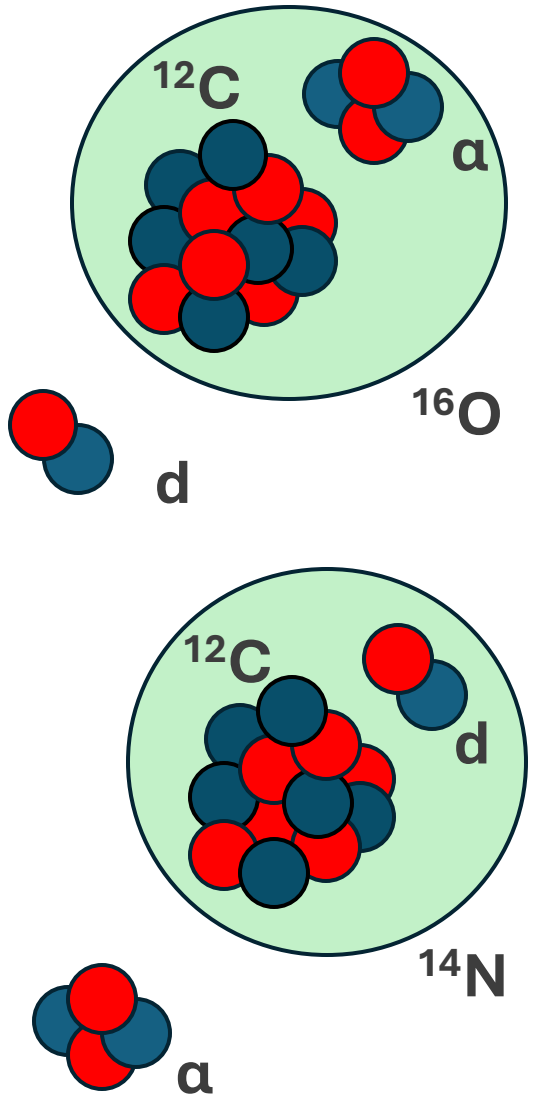
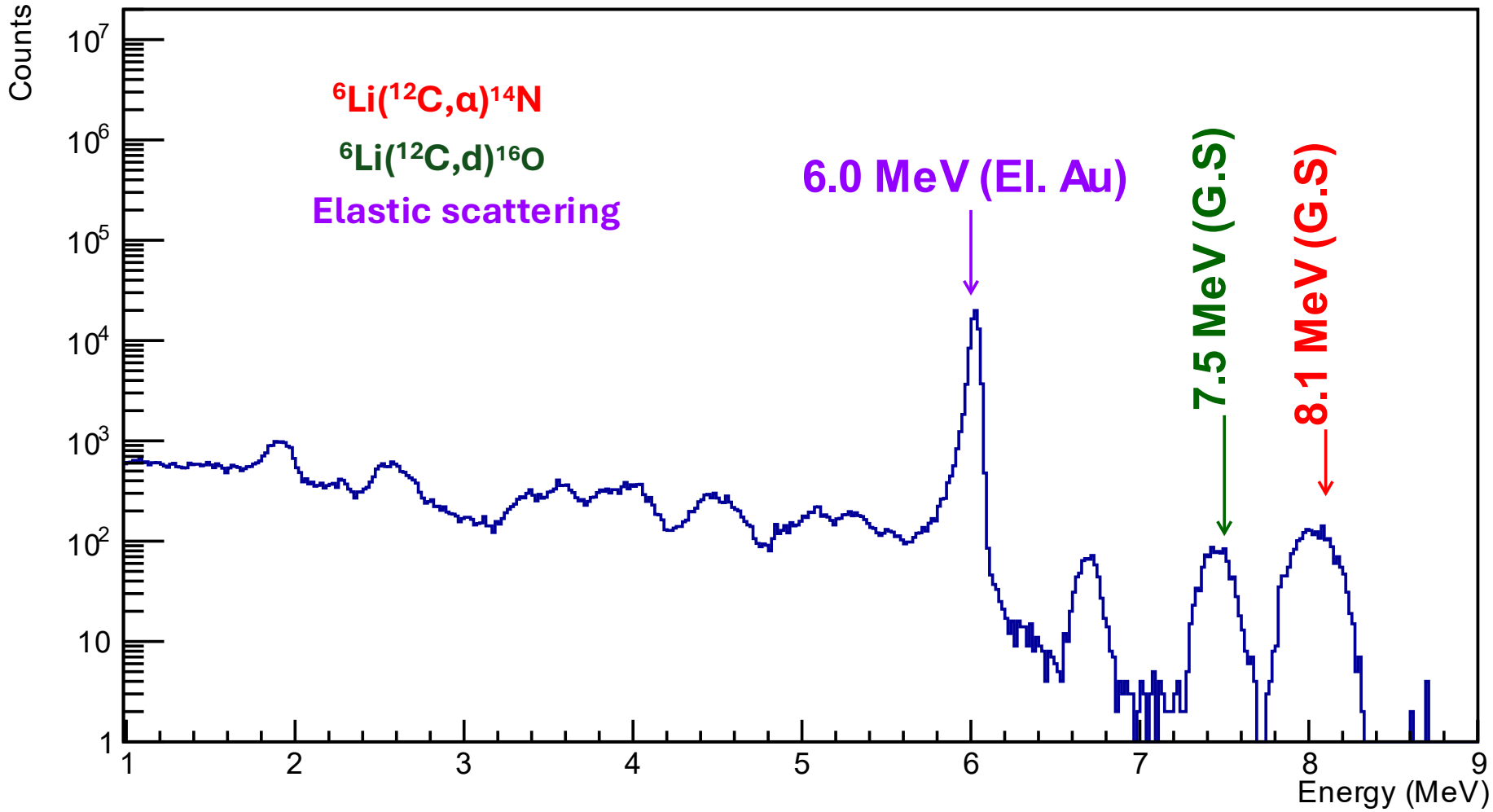
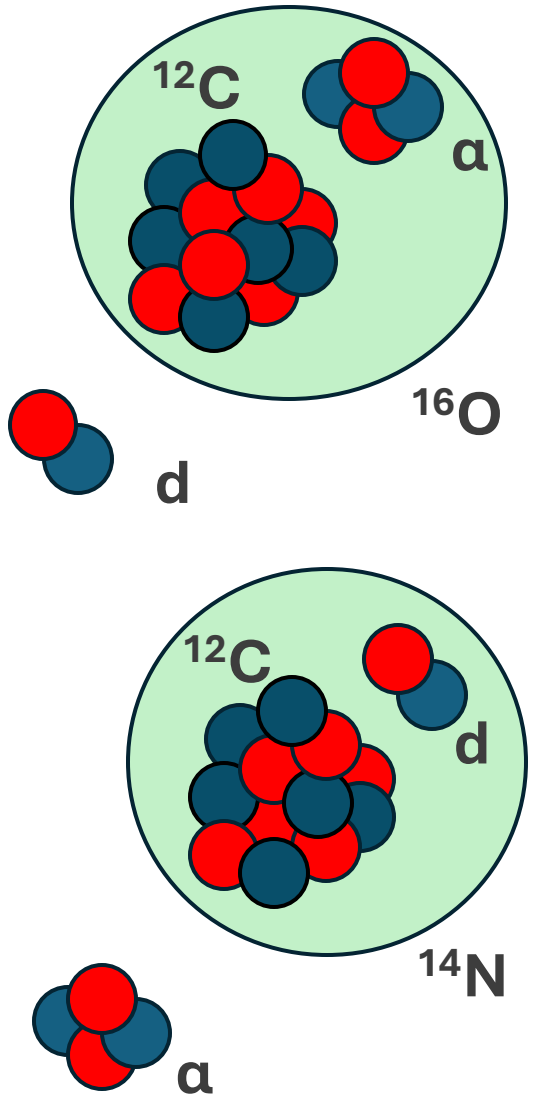




$^{6}Li+^{12}C$ reaction

$^{6}Li + ^{12}C, ^{197}Au$ at 6.5 MeV and 110º





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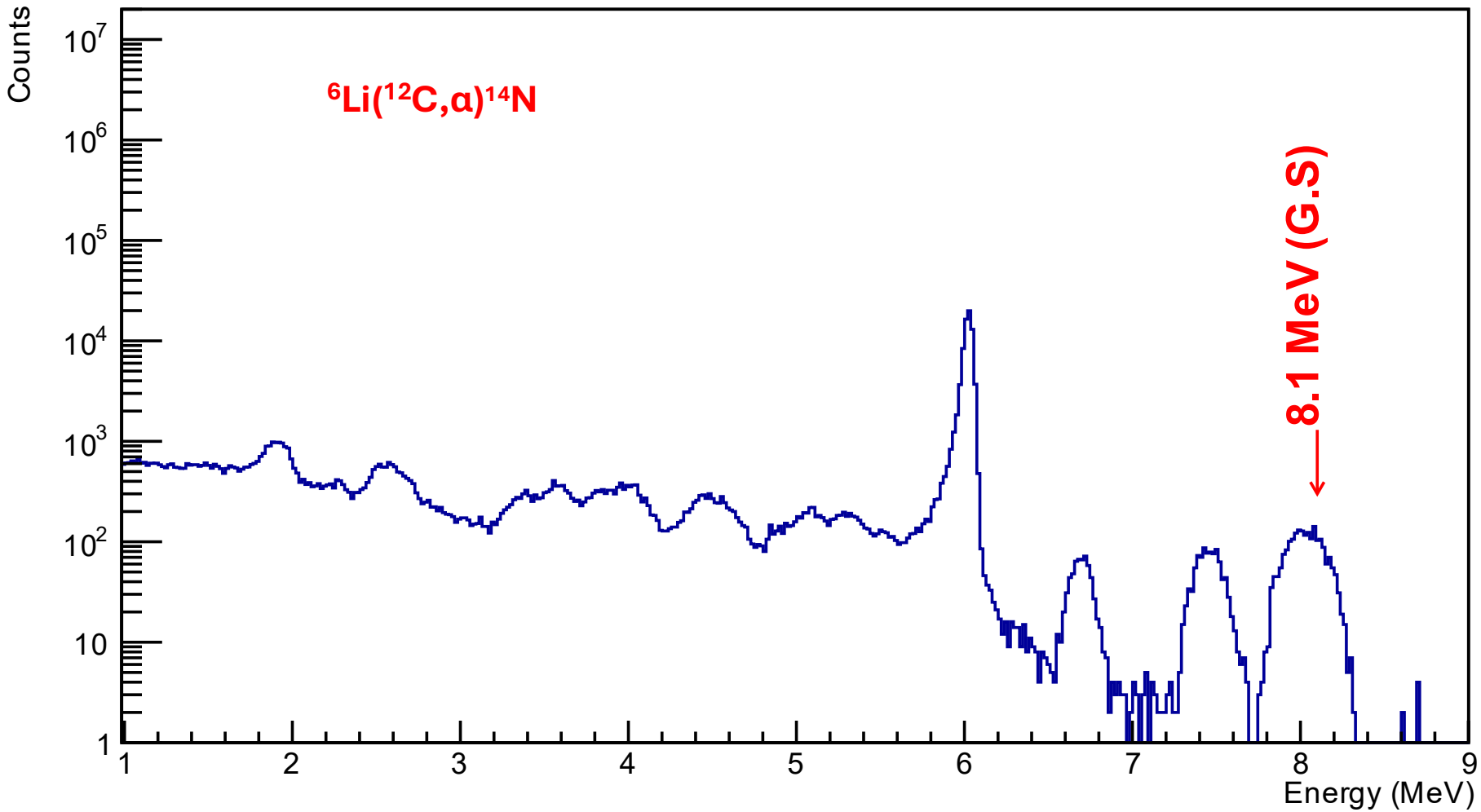
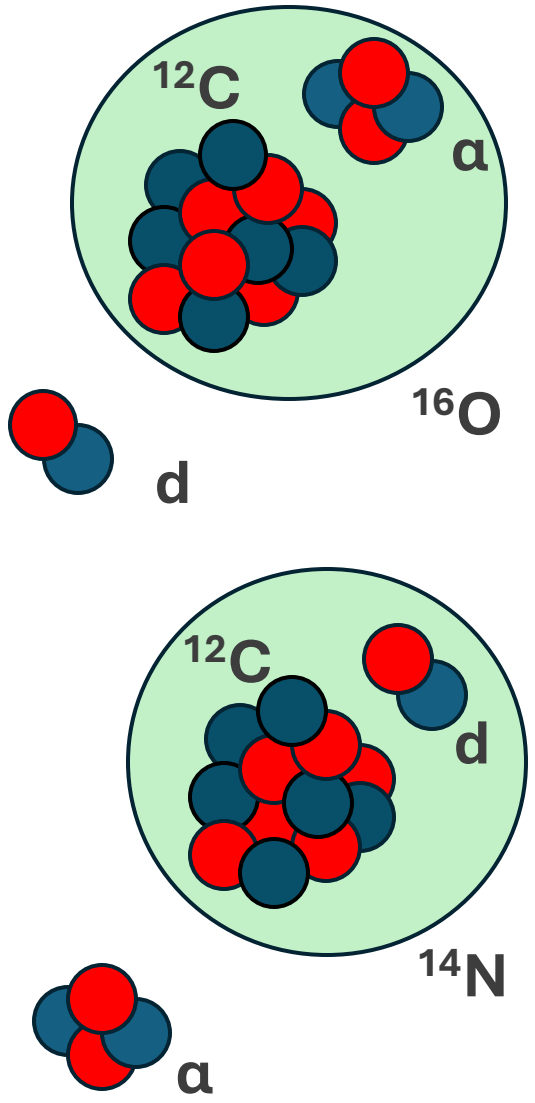
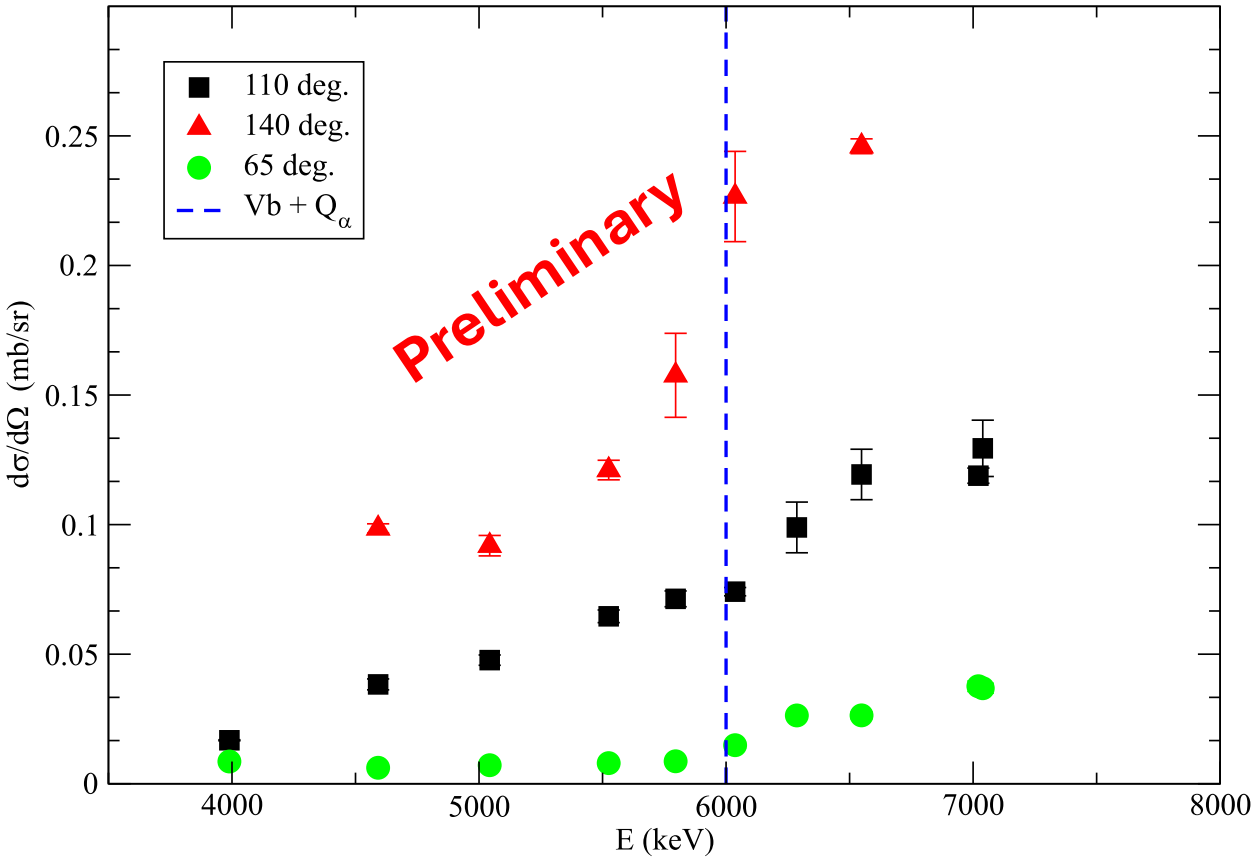




Preliminary results

$^{12}C(^{6}Li,\alpha_0)^{14}N$ cross section energy distribution



$$E_b^{op} \approx V_b + |Q_{bu}| \quad \Rightarrow \quad E_b^{op} \approx 6000\ keV$$

Preliminary results

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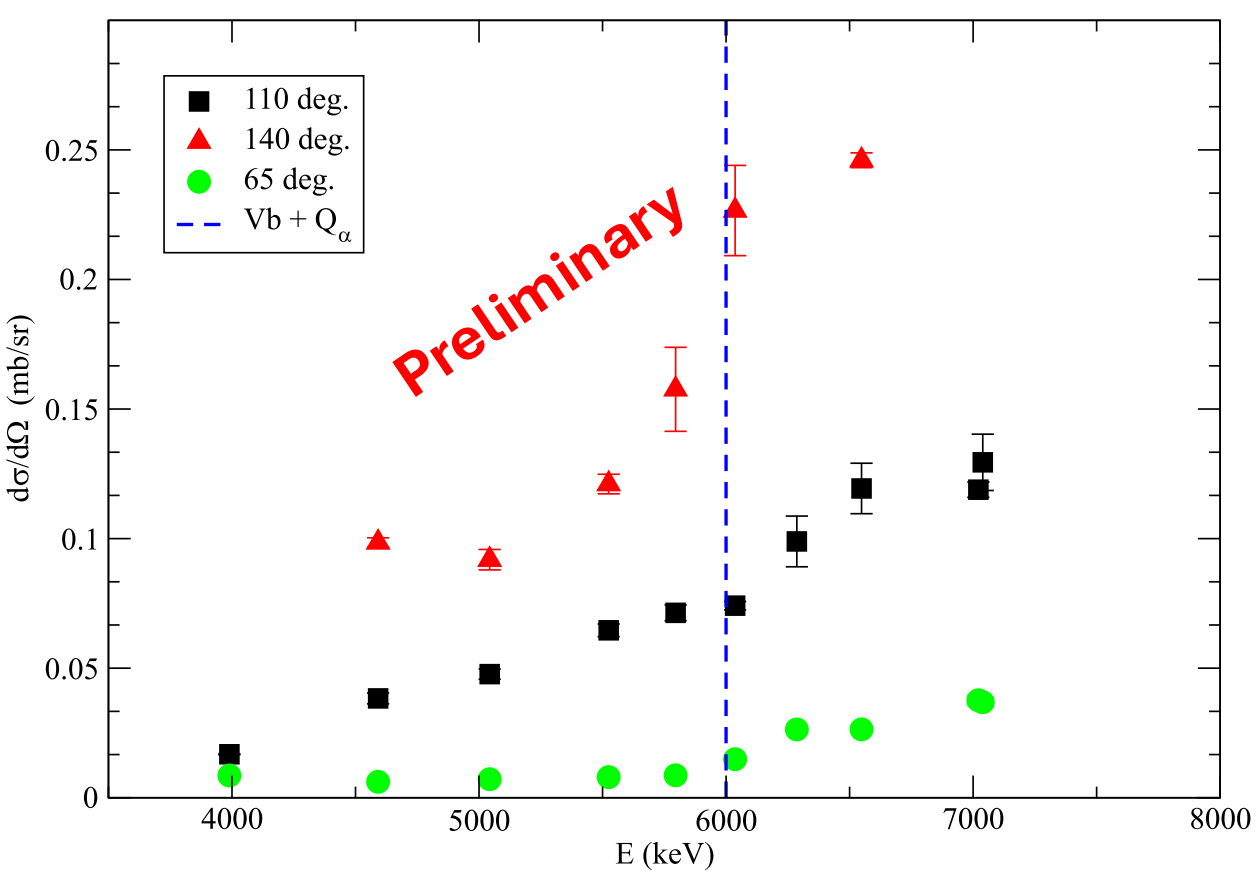

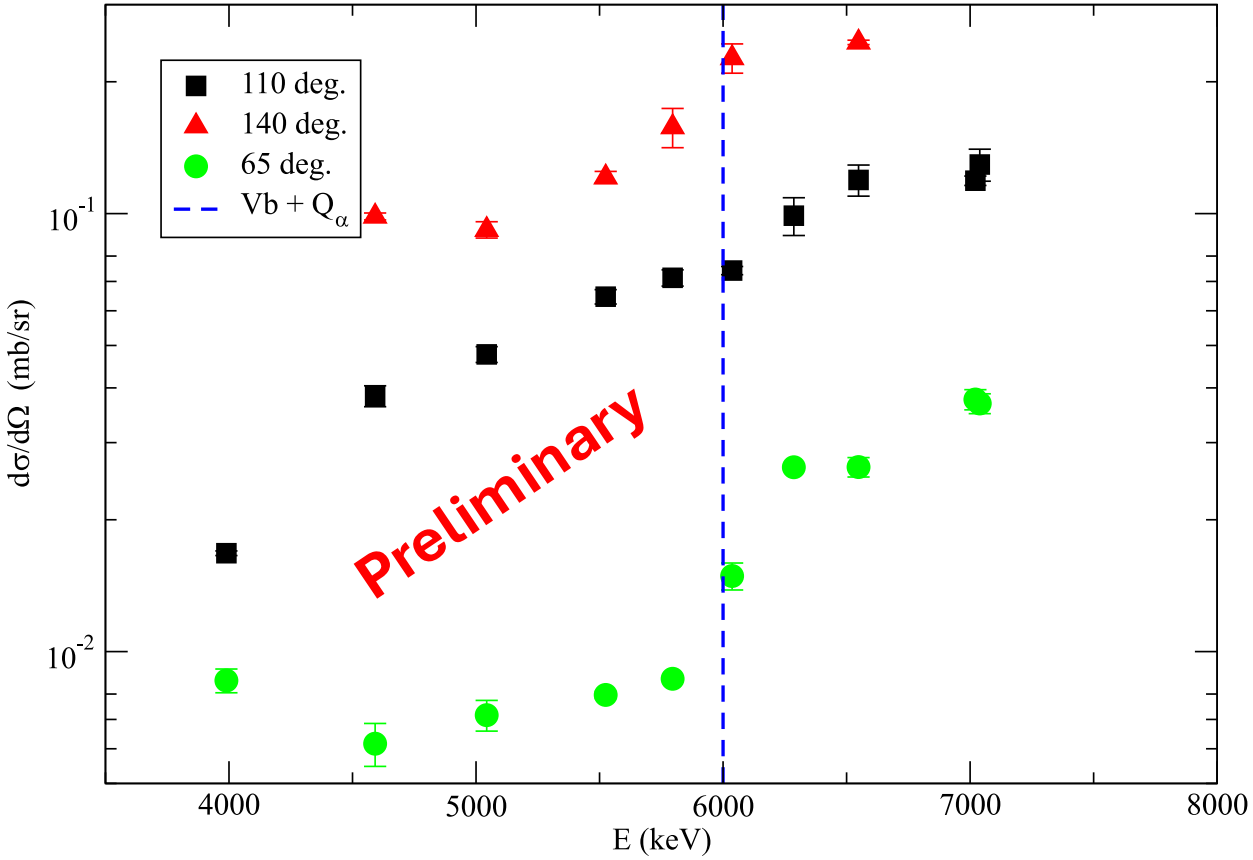

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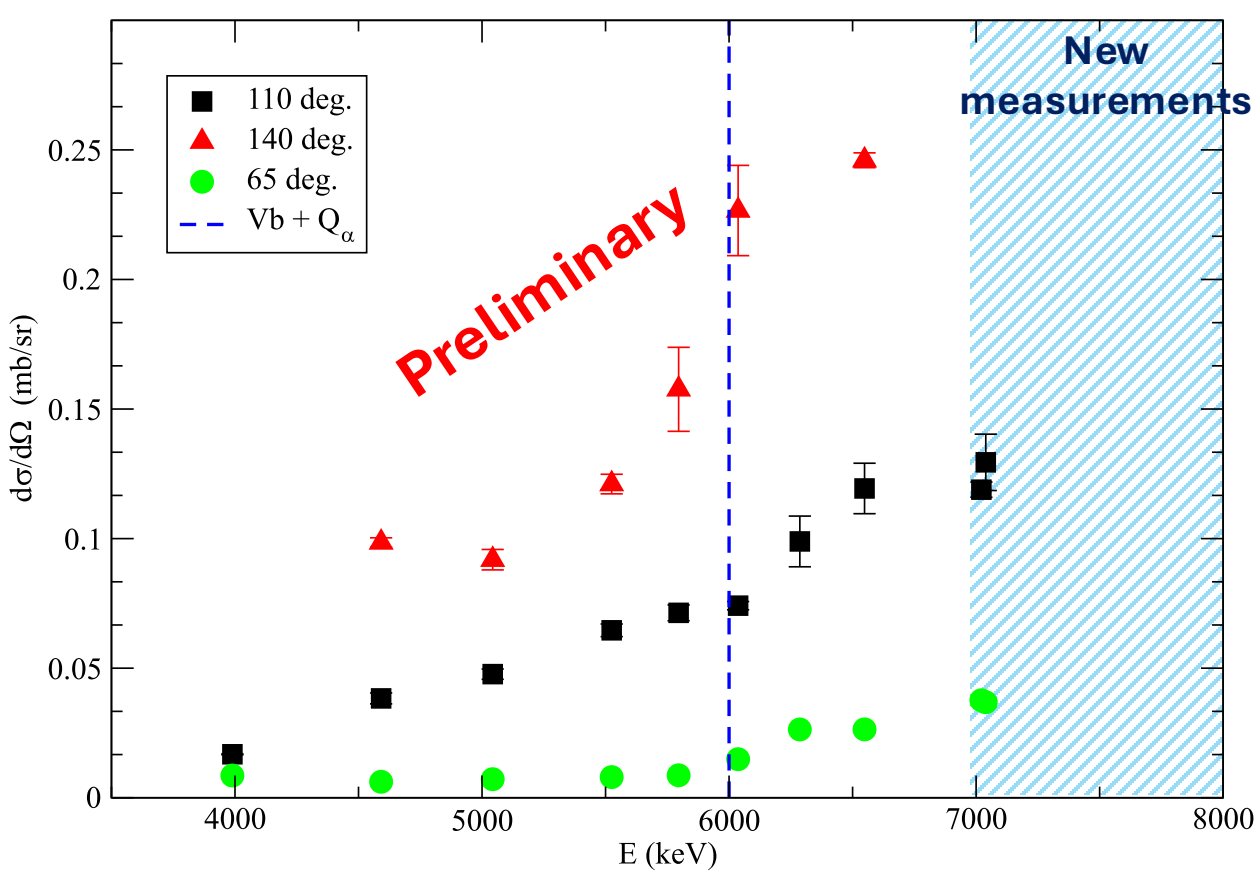

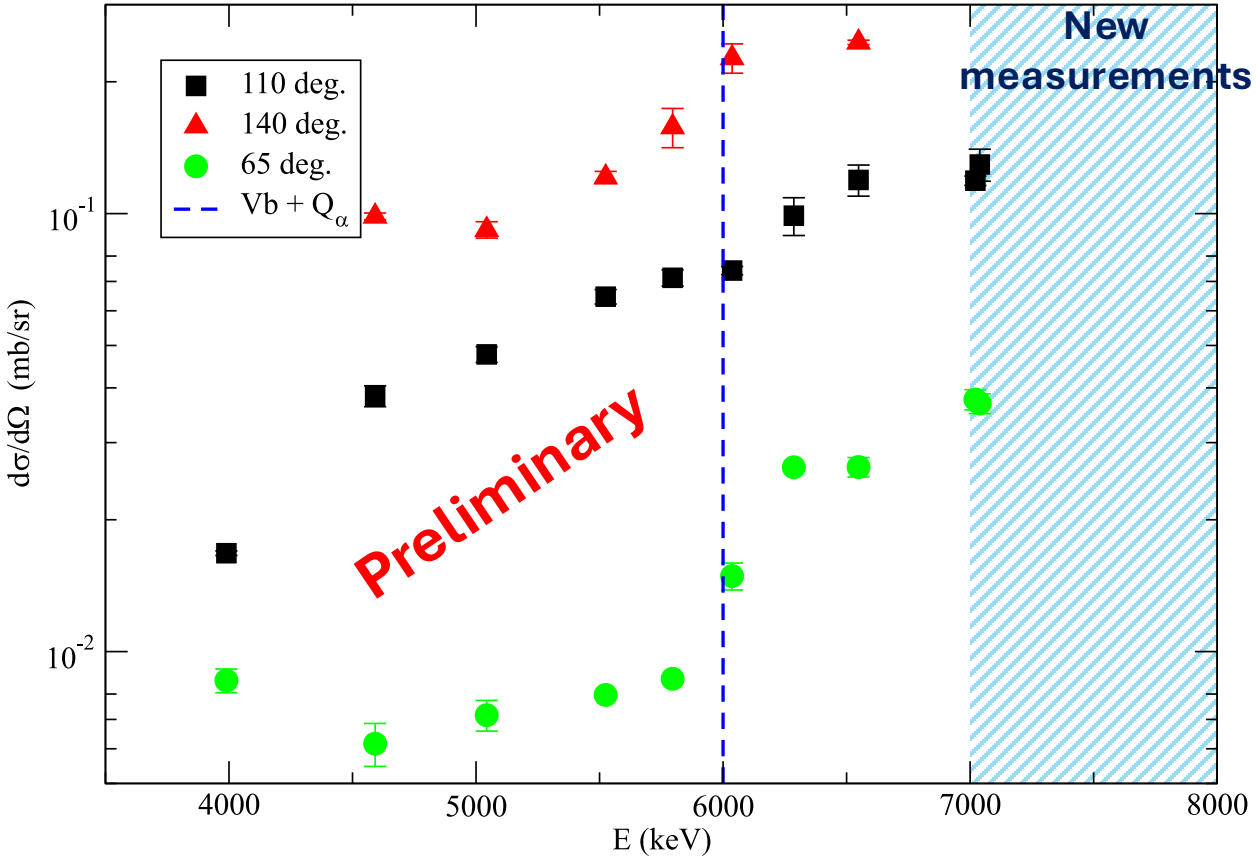

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Conclusions

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- We have studied the **^{6}Li+^{12}C nuclear reaction** at energies around the Coulomb barrier at the **FNB** experimental line using **MARS**.

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- We have obtained preliminary **cross section energy distribution** for the **^{6}Li(^{12}C,α)^{14}N reaction** at different angles.

- The preliminary results point to a **increase of the ^{6}Li(^{12}C,α)^{14}N channel cross section** around the $V_b + |Q_{bu}|$ energy. Deeper analysis is required.

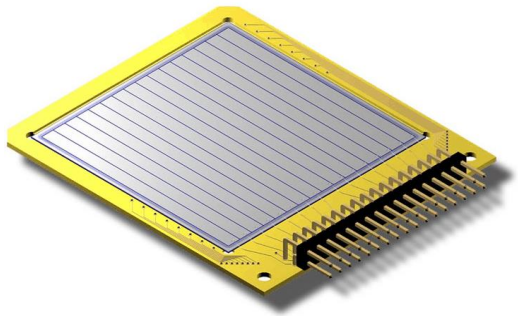
Outlooks

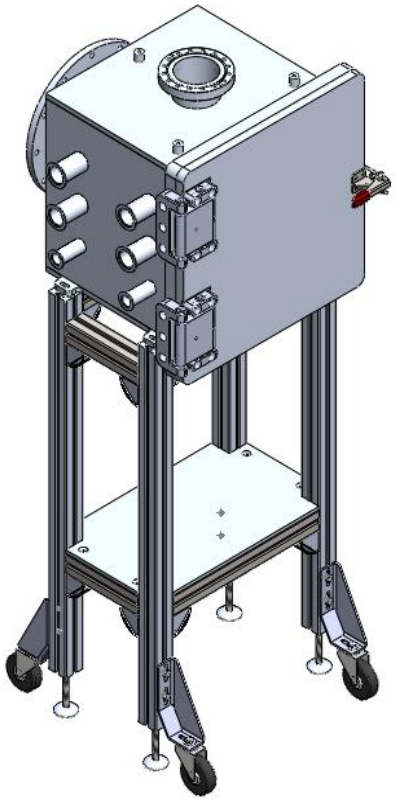
Analysis

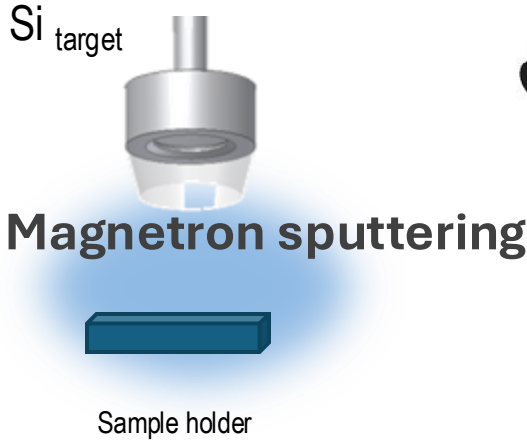
- $^{6}Li(^{12}C,d)^{16}O$ and $^{6}Li(^{12}C,\alpha)^{14}N^{*}$ analysis
- Analysis of the measurements at higher energies

Setup improvement

- New (bigger) chamber
- S/DSSSD detectors
- New target holder controller
- Magnetron sputtering for target development







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- Plan Estatal I+D+I research proyect PID2021-123879OB-C21
- Plan Estatal I+D+I research proyect PGC2018-096994
- Plan Andaluz de Investigación, Desarrollo e Innovación research proyect P20-01247
- IReNA (National Science Fundation, Grant No. OISE-1927130)
- Plan Estatal I+D+I research proyect EQC2019-005873-P

Extra

Cross section

$$\frac{\sigma_{el.}}{d\Omega}(\theta_{c.m.}) = F(\theta) \cdot K \cdot \frac{N_C^{el.}}{N_{Au}^{el.}}$$

$$K = \left(\frac{Z_{Au}A_C}{Z_C A_{Au}}\right)^2 \frac{N_A^{Au}}{N_A^C}$$

$$F(\theta) = \frac{sin^4\left(\frac{\theta_{c.m.}^C}{2}\right)}{sin^4\left(\frac{\theta_{c.m.}^{Au}}{2}\right)} \frac{J_C^{lab\to c.m.}}{J_{Au}^{lab\to c.m.}}$$

$$\frac{\sigma_{reac.}}{d\Omega}(\theta_{c.m.}) = \frac{N_C^{reac.}}{N_C^{el}} \cdot \frac{J_{reac.}^{lab\to c.m.}}{J_{el.}^{lab\to c.m.}} \cdot \frac{\sigma_{el.}}{d\Omega}(\theta_{c.m.})$$

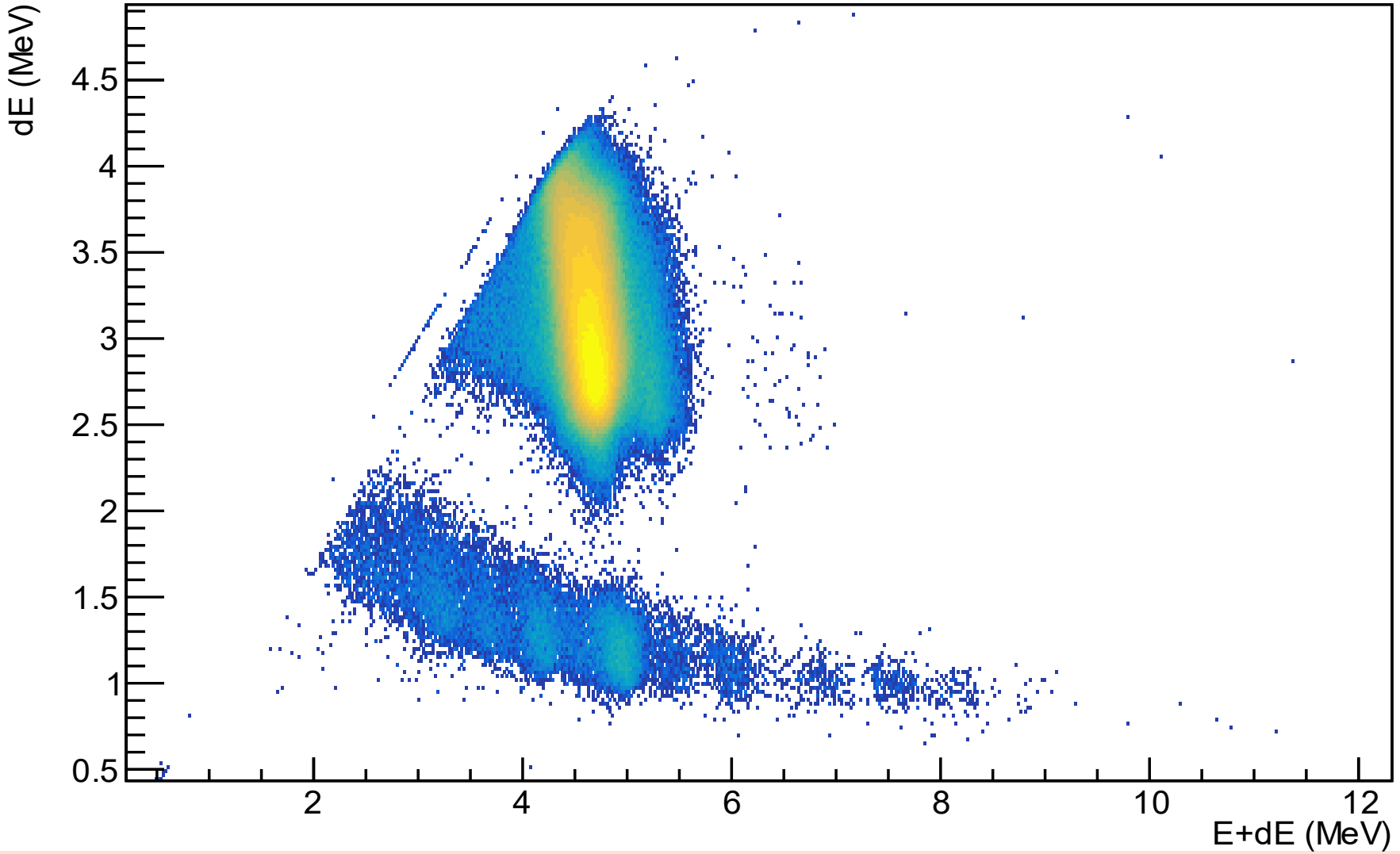
$$\frac{\sigma_{reac.}}{d\Omega}(\theta_{c.m.}) = \frac{N_C^{reac.}}{N_{Au}^{el.}} \cdot \frac{J_{reac.}^{lab\to c.m.}}{J_{el.}^{lab\to c.m.}} \cdot F(\theta) \cdot K$$

$^{6}Li+^{12}C$ reaction

Two-dimensional spectrum

$^{6}Li + ^{12}C$
@ 6 MeV

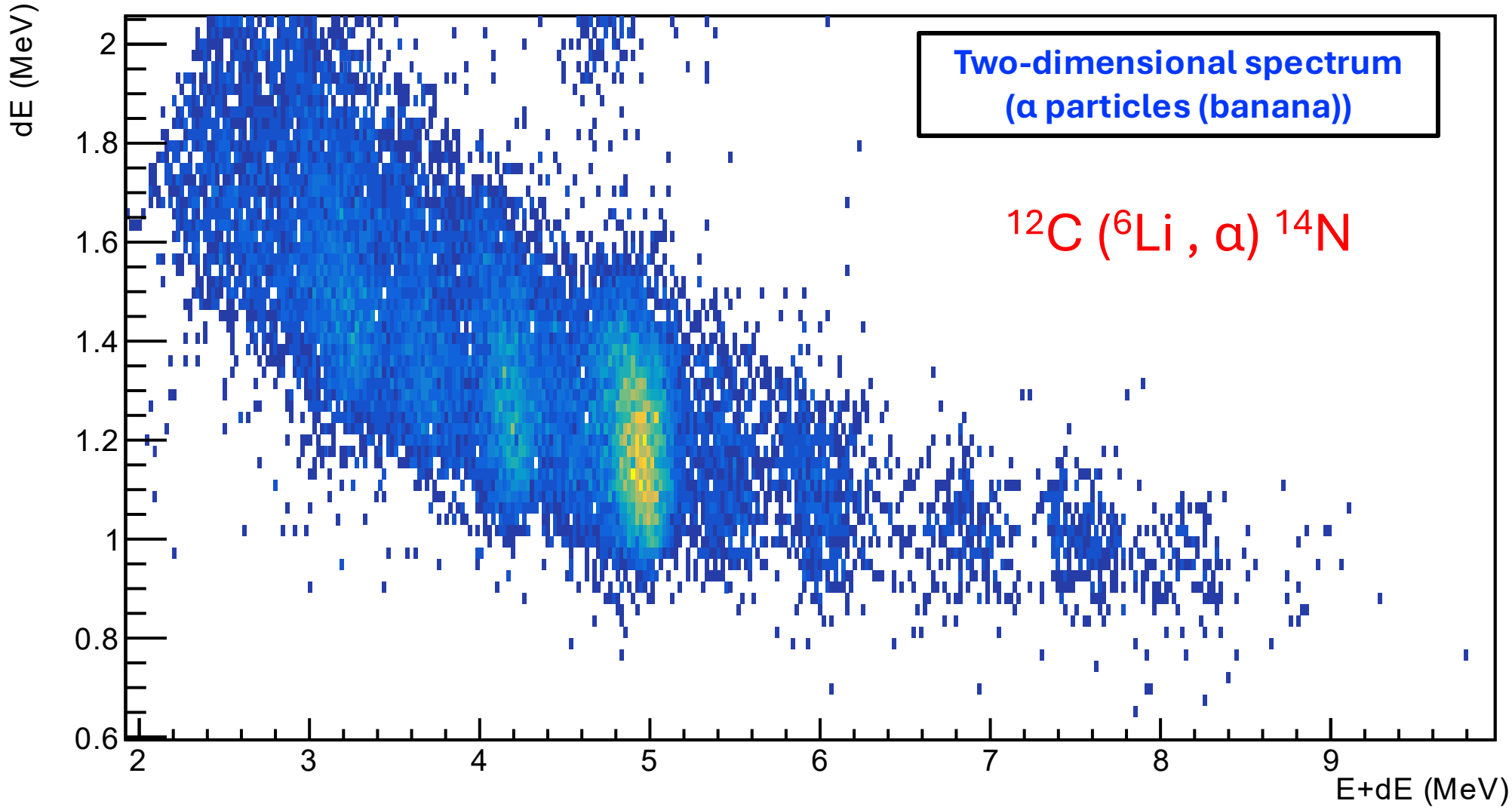
Detector @ 35º



$^{6}Li+^{12}C$ reaction

$^{6}Li + ^{12}C$
@ 6 MeV

Detector @ 35º

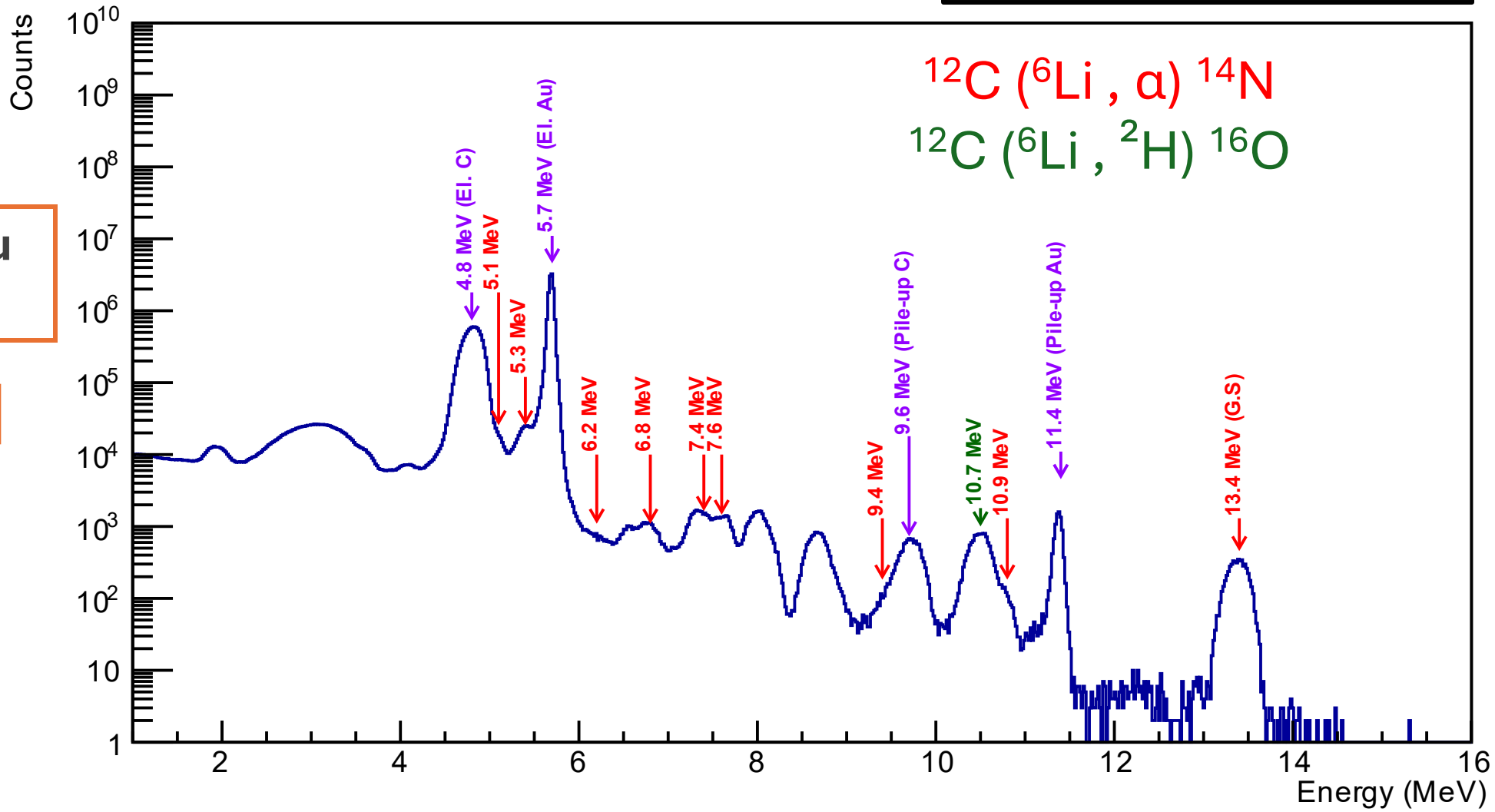


$^{6}Li+^{12}C$ reaction

One-dimensional spectrum

$^{6}Li + ^{12}C, ^{197}Au$ @ 6 MeV

Detector @ 35º

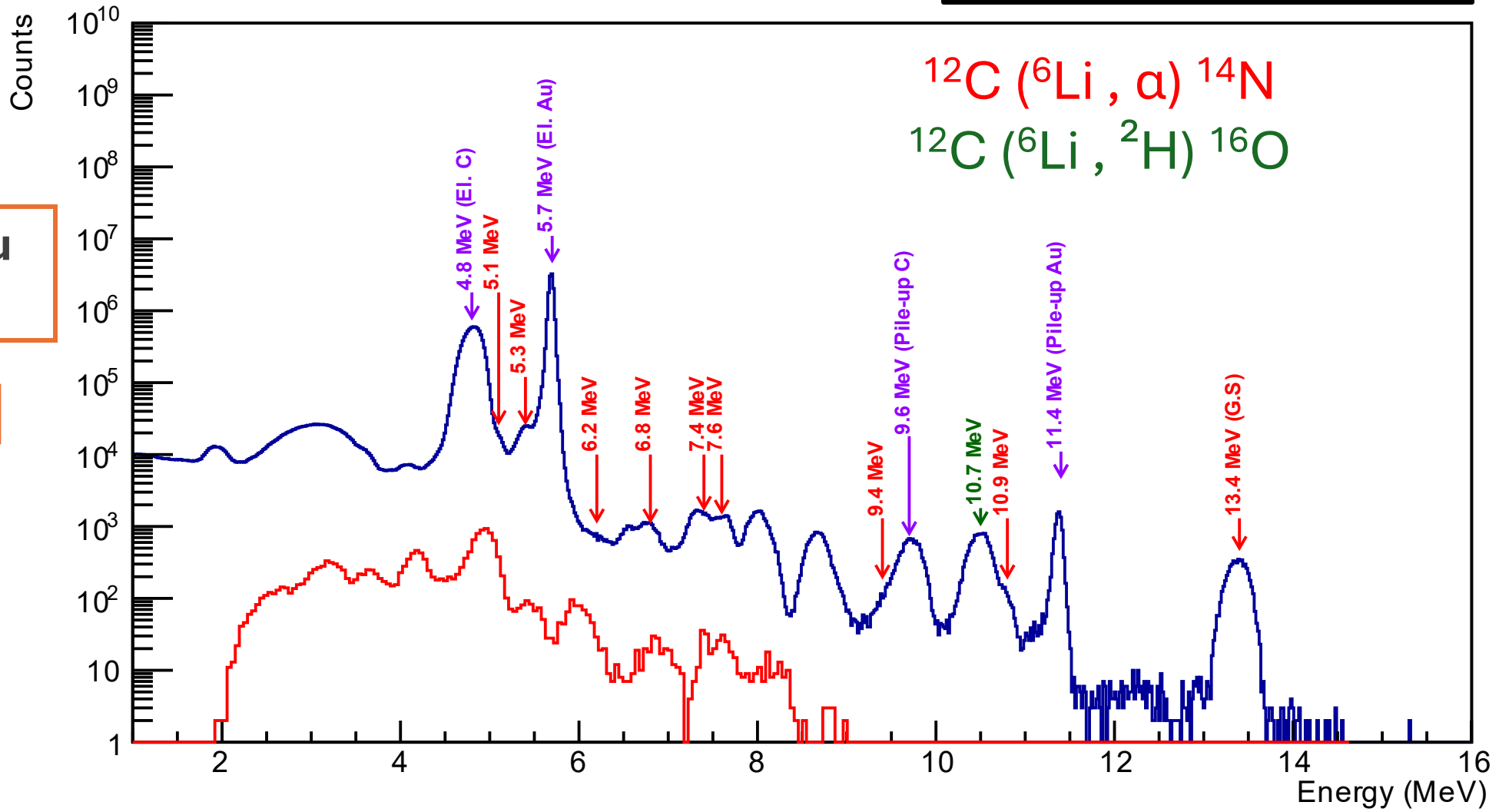


$^{6}Li+^{12}C$ reaction

One-dimensional spectrum

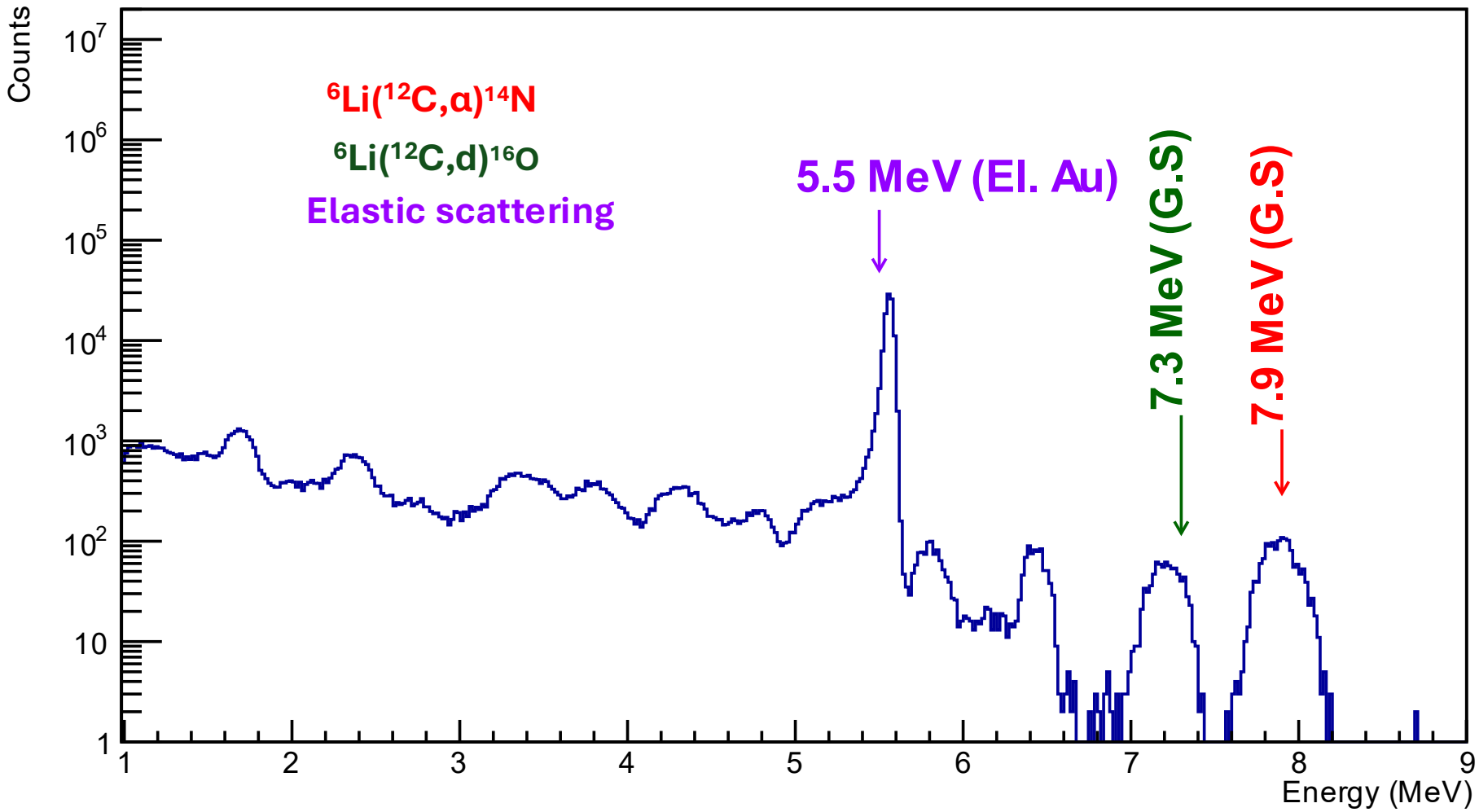
$^{6}Li + ^{12}C, ^{197}Au$ @ 6 MeV

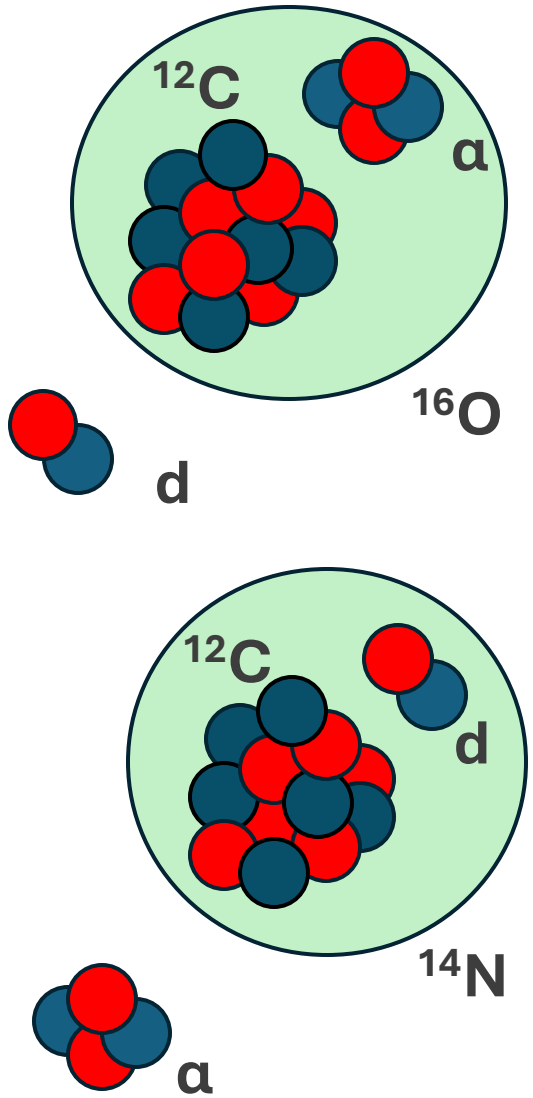
Detector @ 35º



$^{6}Li+^{12}C$ reaction

$^{6}Li + ^{12}C, ^{197}Au$ at 6.5 MeV and 110º





MARS


A1422 preamps
DT5423 power distributor
V6519P HV
power supplies
V1725S digitizer
V1718 bridge
VENTUS
CAEN
DT5423
VME 8008B