4th General Assembly – Strasbourg 27-28/05 2024

New Solid Targets for Nuclear Astrophysics Experiments

Roberta Spartà – Task 3.1 P.I.

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IFIN-HH

Task 3.1 STAR
Solid Targets for Astrophysics Research

1) Realization of ultra-pure material targets

to allow for the measurement of low reaction yields, in which signals from parasitic reactions on impurities can limit experiments;

2) Noble elements solid targets (via implantation) to measure key reactions (i.e. for s-process nucleosynthesis in evolved stars) avoiding gas targets inconvenients.

+ a service for the community:
standardized testing of the produced targets (including contaminant checks and stability tests)

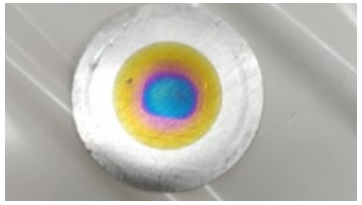
Target production

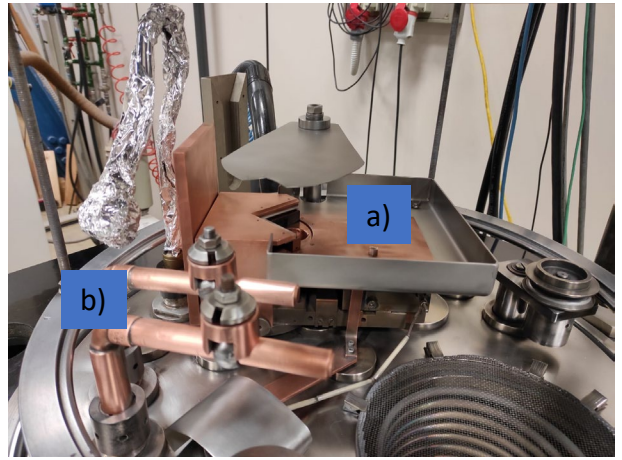
@LNS-INFN: ion implantation, PVD methods (resistive heating and electron beam-based systems), cold rolling and tablet pressing techniques

@LNL-INFN: PVD

@IFIN-HH: ion implantation, PVD methods (resistive heating and electron beam-based systems), cold rolling and tablet pressing techniques, PLD (Pulsed Laser Deposition) and methallotermic reduction

@University of Cologne: PVD, electrolysis and cold rolling





Physical Vapor deposition (PVD) @INFN-LNS:
a) Electron beam;
b) Resistive heating.

Target characterization

- in terms of thickness, uniformity, crystalline structure and chemical purity by using multiple advanced techniques
- target thickness measurement via α-scanning systems @ all the labs
- offered as a service for the community, including contaminant identification and stability tests.

Target characterization: Alpha Particle Transmission spectroscopy @INFN-LNS

Accelerator Mass Spectrometry (AMS) @ UoC

Elastic Recoil Detection Analysis (ERDA) @INFN-LNL

Electron Beam Scattering (EBS) @INFN-LNL

Rutherford Backscattering Spectrometry (RBS) @ LNS-INFN, IFIN-HH, ATOMKI and UoC

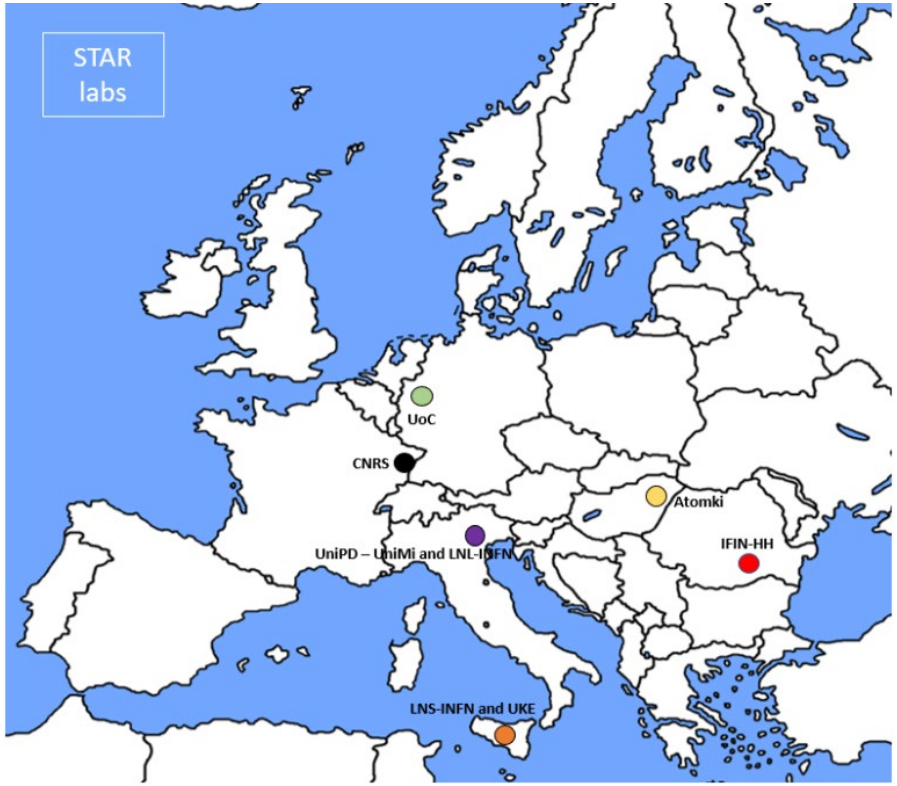
Proton Induced X-ray Emission (PIXE) @ IFIN-HH and ATOMKI

Proton Induced Gamma-ray Emission (PIGE) @ IFIN-HH

Nuclear Reaction Analysis (NRA) @ IFIN-HH, INFN-LNL and ATOMKI

Secondary Neutral-particle Mass Spectrometer (SNMS) is available @ ATOMKI

Inductively Coupled Plasma Mass Spectrometry (ICPMS) @ ATOMKI & UoC



Deliverable Number	D3.1
Deliverable Title	Report on the experimental techniques used for solid target production on the project web site
WP number	WP3
Lead beneficiary	20 – INFN
Type	Report
Dissemination Level	Public
Due Date (in months)	18

https://www.chetec-infra.eu/jra/star

Deliverable Number	D3.4
Deliverable Title	Report on testing by radioactive sources and beam bombardment of the solid targets produced
WP number	WP3
Lead beneficiary	20 – INFN
Type	Report
Dissemination Level	Public
Due Date (in months)	36

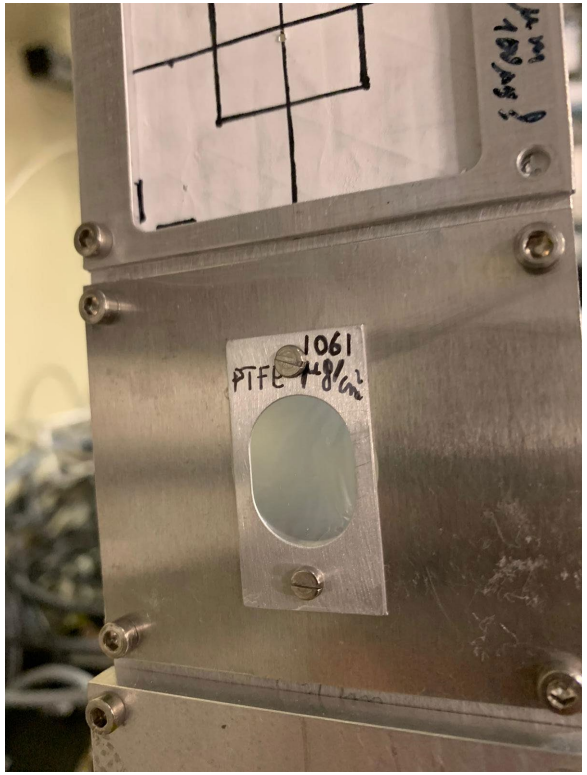
Fulfilled on time!
30/04/2024

https://www.chetec-infra.eu/jra/startest

Report: LNS results

@LNS-INFN (AsFiN group)

Reaction to study	Compound	Thickness	Beam/source used	Results
Fluorine background in New Jedi experiment (dark boson)	CaF_2 on graphite backing	150 µg/cm^2 + 30 µg/cm^2 (backing)	^{241}Am α-source	No damage reported
	PTFE $-(F_2C-CF_2)_n-$	1 mg/cm^2	^{241}Am α-source @LNS and proton beam @ UJF NPI	Resisted up to 200 nA of proton beam



Report: IFIN-HH results

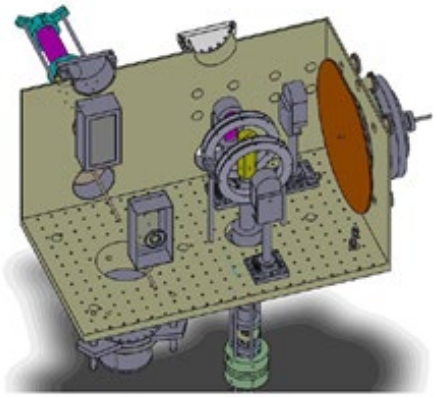
→ Alexandra Spiridon after me

Report: LNL results

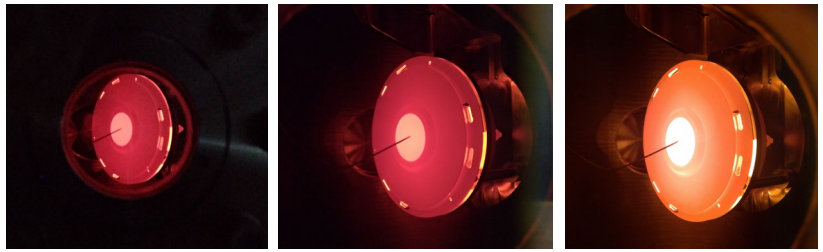
Target composition	Reaction studied
Ta_2O_5	$^{16}O(p,\gamma)^{17}F$
TiN	$^{14}N(p,\gamma)^{15}O$
TaN	$^{14}N(p,\gamma)^{15}O$
ZrN	$^{14}N(p,\gamma)^{15}O$
NaNbO	$^{23}Na(p,\alpha)^{20}Ne$
ZrD_2	p+d

Several targets produced with reactive sputtering technique (SALVIA - Setup for AnaLysis with MeV accelerators of Isotopic tArgets and their preparation)

Tested with proton beam → Excellent performances in terms of stability against irradiation with intense ion beam!



Other updates from our labs:

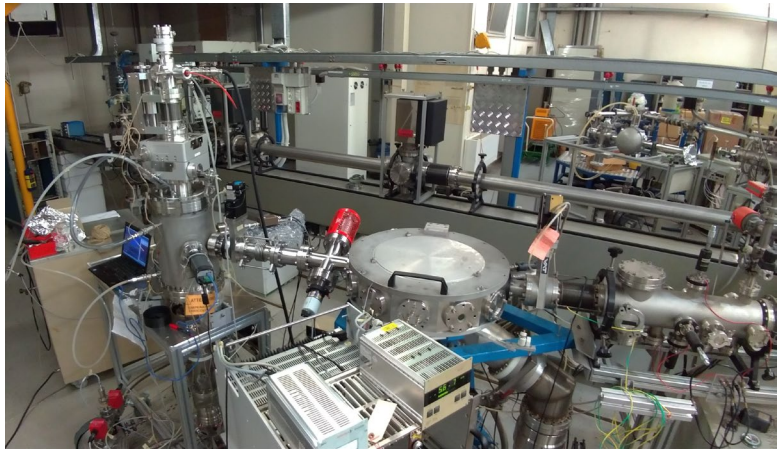


- UniPD, UniMI & INFN LNL:

HEAT (study of hydrogen desorption from carbon targets)

- **GOAL OF THE PROJECT:** understand the desorption of hydrogen contamination in carbon targets to be used for $^{12}C+^{12}C$ experiments.
- **METHODOLOGY:** Targets are heated up to ~1000°C, and ERDA and NRA are used to assess H content before/after heating

Data taking concluded in Oct. 2023, data analysis ongoing. Setup no longer on beamline, but available upon request



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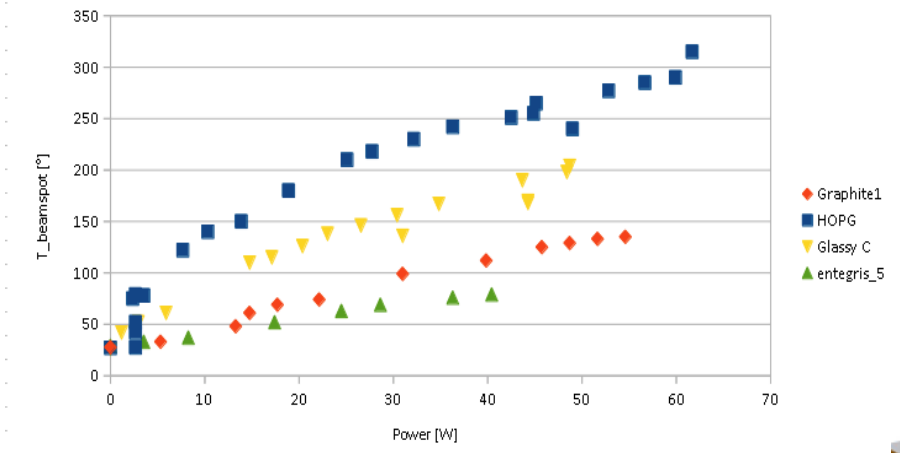
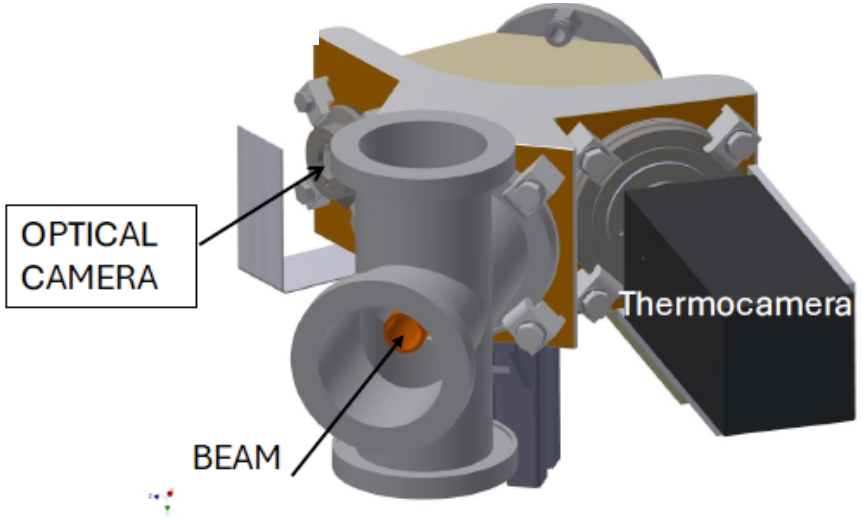
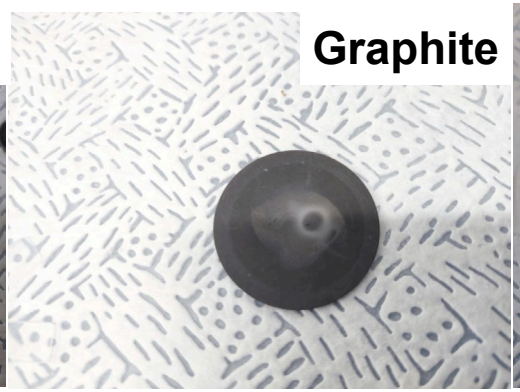
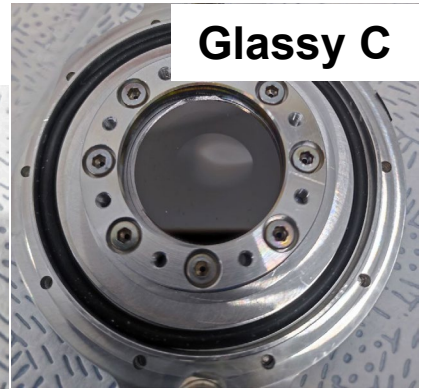
Tests on carbon targets for $^{12}C+^{12}C$ measurement at Felsenkeller









Other updates from our labs:

- Strasbourg (CNRS):

^{12}C target for the STELLA experiment @Target Thickness Measurement Station :

x-y scanning with α source (on/off beam irradiation track)

temperature drift compensation

Acta Phys. Pol. B Proc. Suppl. 17, 3-A33 (2024)

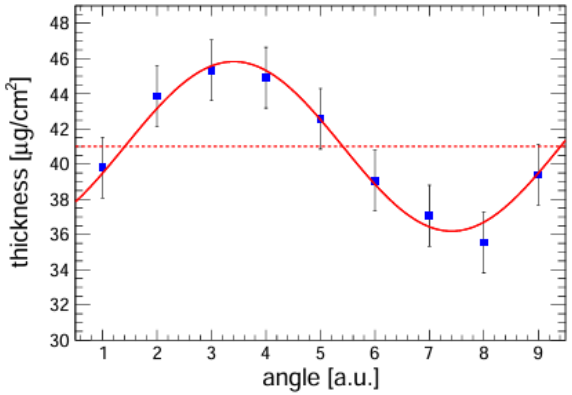


Fig. 2. (Colour on-line) Target thickness scan as a function of the position, where position 1 and 9 are identical measurements and repeated. The red solid curve represents a fit, the red dashed curve is the average thickness from the fit.

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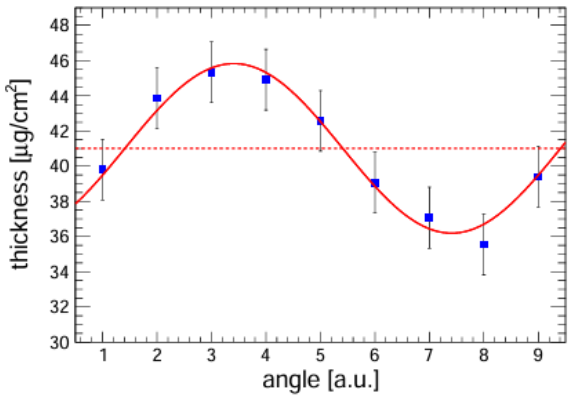
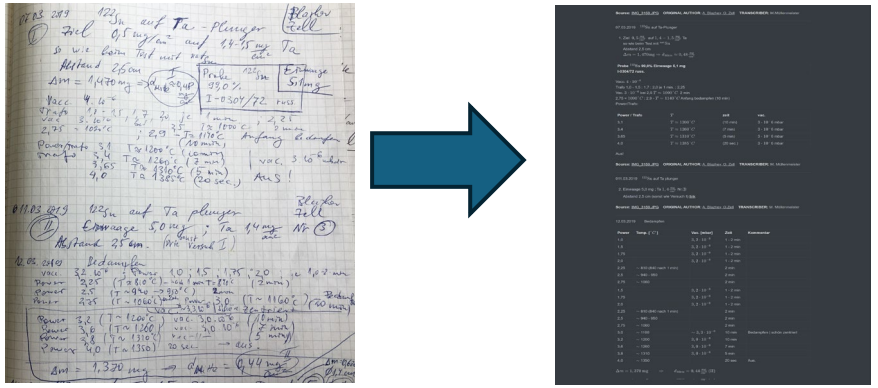


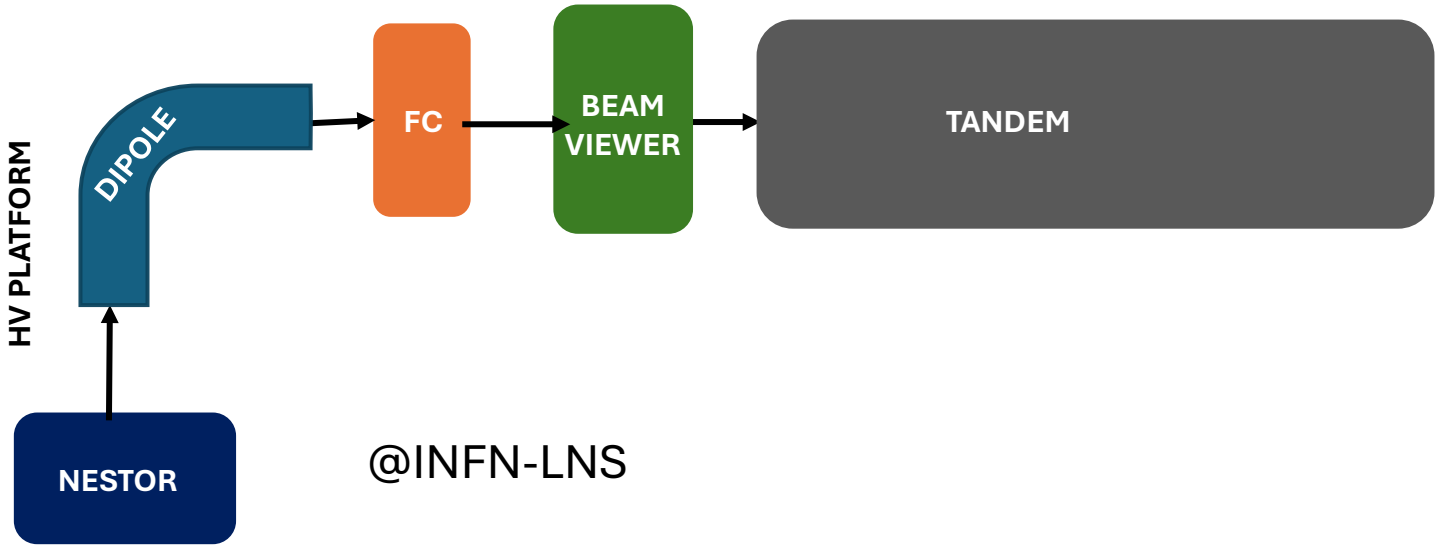
Fig. 2. (Colour on-line) Target thickness scan as a function of the position, where position 1 and 9 are identical measurements and repeated. The red solid curve represents a fit, the red dashed curve is the average thickness from the fit.

- University of Cologne

Ongoing digitization of target makers handbook (contains procedures for hard to handle materials)



Goal 2 status



@INFN-LNS

POT-LNS work in progress

2nd option @DFA of UniCT with the Singletron

RBS analysis?

Next steps

Production of NEST in Catania & Next deliverable D3.7: Publication of production protocols, characterization procedures, and results (month 48)

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Conclusions

Service of target characterization: chetec-infra@hzdr.de

These results testify how STAR has gathered European target laboratories in a context where they can learn from mutual experiences and cooperate for the first time.

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Conclusions

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STAR people:

R. Spartà, G.L. Guardo, M. La Cognata, G. Lanzalone, A. Massara, A. Tumino,
T. Szücs,
S. Courtin, M. Heine, M. Moukaddam, , J. Nippert
N. Florea,, A. Spiridon, L. Trache
A. Caciolli, R. Depalo, D. Mengoni, D. Piatti, J. Skowronski
F. Heim, M. Mullenmeister, A. Zilges
…

Thanks for your attention!
Now Dr. Spiridon about IFIN-HH results

IFIN-HH results

- Primarily targets were produced for an ongoing study on ion-ion fusion reactions at sub-Coulomb barrier energies
  - using **activation method** (preferrably thick targets, but thin were tested too)

short-lived nuclei (< 1-2 hrs)

longer-lived nuclei (> 1-2 hrs)

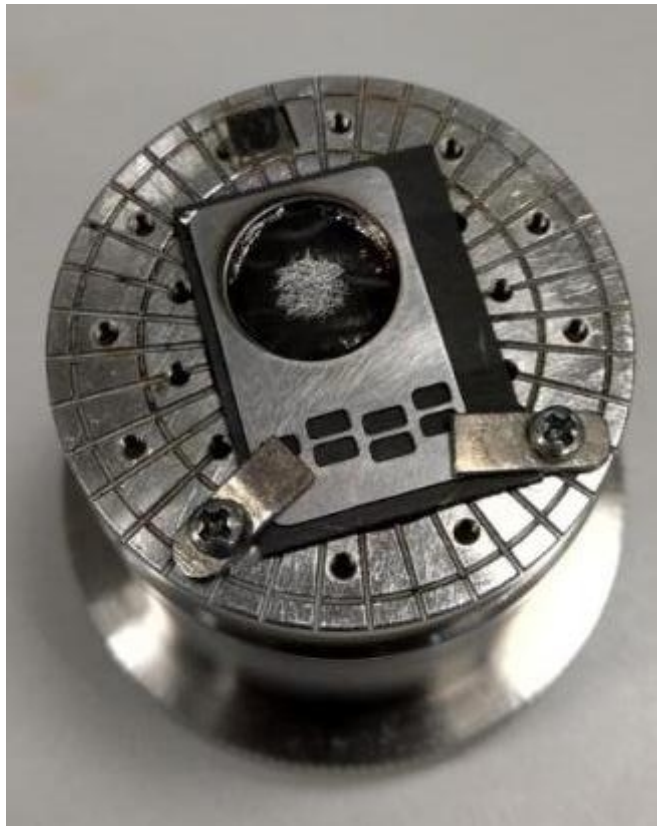
IFIN-HH results

- Primarily targets were produced for an ongoing study on ion-ion fusion reactions at sub-Coulomb barrier energies
  - using **activation method** (preferrably thick targets, but thin were tested too)
- Goals: first and foremost, durable under beam currents > 1-5 pμA and irradiations longer than 1 hr and handling (transportation over large distances)

Reaction to study	Method	Target material	Thickness	Production method	Tested with	Result
$^{13}C + ^{16}O$	^{16}O beam on ^{13}C targets	^{13}C powder (on Ta backing 3mg/cm^2)	~130-150 nm* (~30μg/cm^2)	PVD	^{16}O beam [various intensities], RBS, SEM	Did not hold for irradiations with I > 1 pμA Complete deterioration in beam spot area

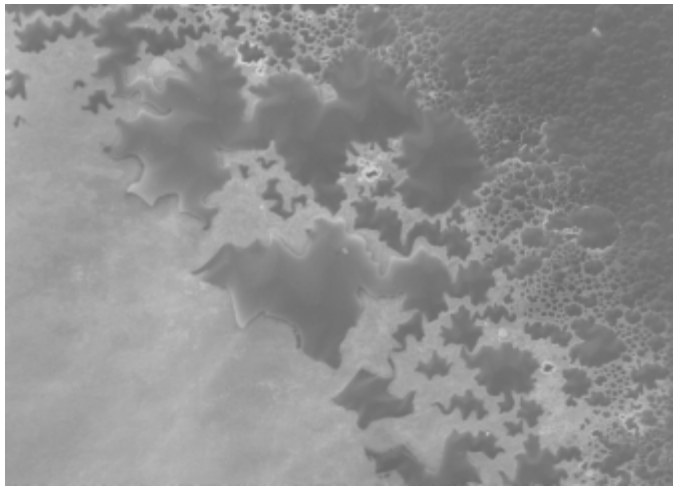
* max that could be obtained due to time constraints and exfoliation issues

IFIN-HH results



Target pre-irradiation

Target post-irradiation with I ~ 5 μA



Picture taken with SEM at 100x

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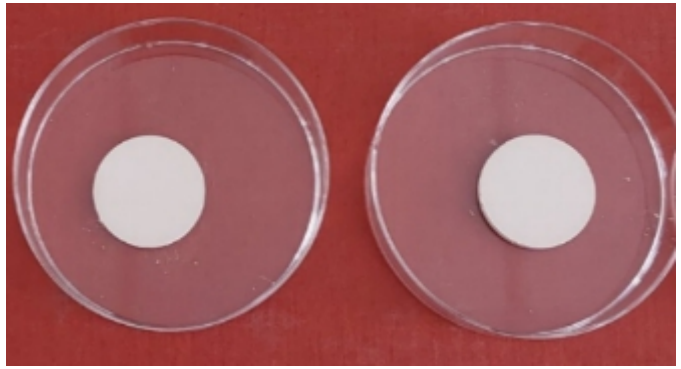
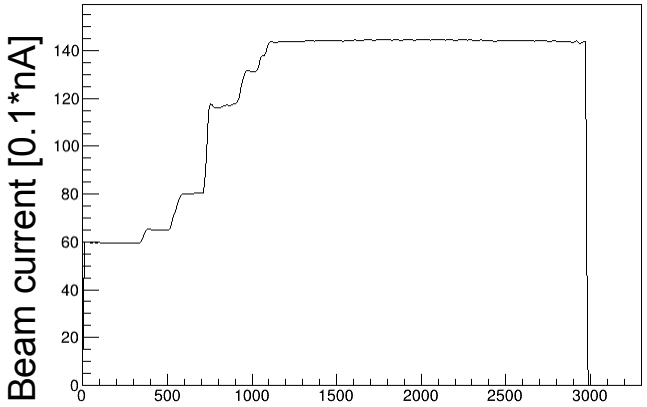
Reaction to study	Method	Target material	Thickness	Production method	Tested with	Result
$^{13}C + ^{16}O$	^{13}C beam on ^{16}O targets	CeO2 powder	1 mm (0.8-1 g/cm^2)	Tablet pressing*	^{13}C beam, SEM	Can hold for max 1 hr irradiations and I < 7 μA Crack under temperature changes even with target cooling

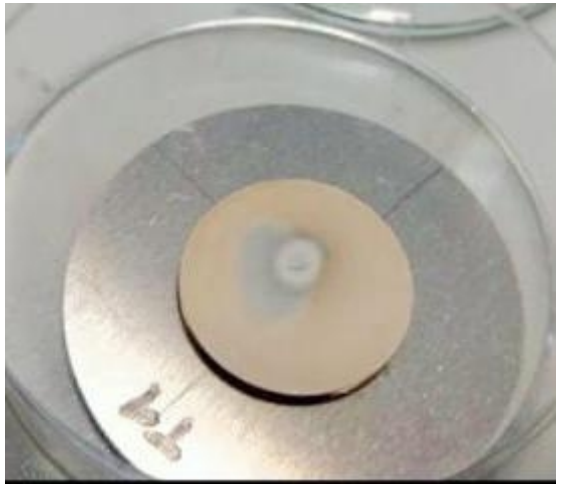
* fragile when handled

IFIN-HH results

Photo of freshly pressed targets







Target after irradiation

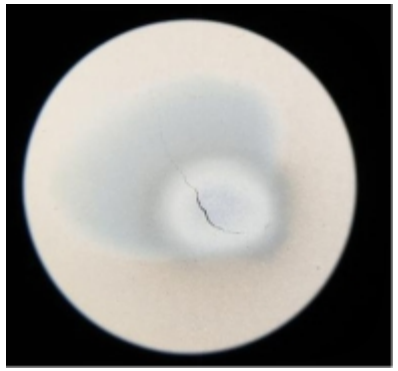


Photo with 8x magnification

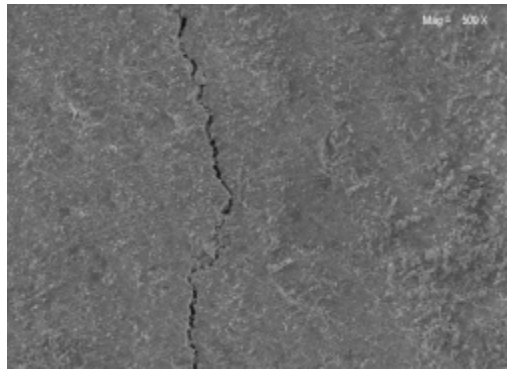
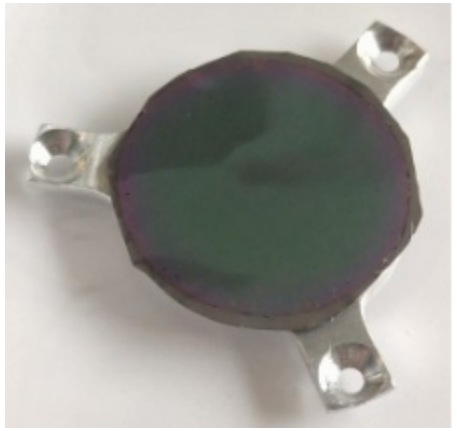


Photo with SEM at 500x

IFIN-HH results

- Primarily targets were produced for an ongoing study on ion-ion fusion reactions at sub-Coulomb barrier energies
  - using **activation method** (preferrably thick targets, but thin were tested too)
- Goals: first and foremost, durable under beam currents > 1-5 pμA and irradiations longer than 1 hr and handling (transportation over large distances)

Reaction to study	Method	Target material	Thickness	Production method	Tested with	Result
$^{13}C + {}^{16}O$	^{13}C beam on ^{16}O targets	Ta_2O_5	Several (< 0.5 mg/cm^2)	Anodization of Ta foil in water	^{13}C beam, RBS	Good uniformity, large number of O atoms, easy handling Did not hold for irradiations with I > 1 pμA



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- Goals: first and foremost, durable under beam currents > 1-5 pμA and irradiations longer than 1 hr and handling (transportation over large distances)

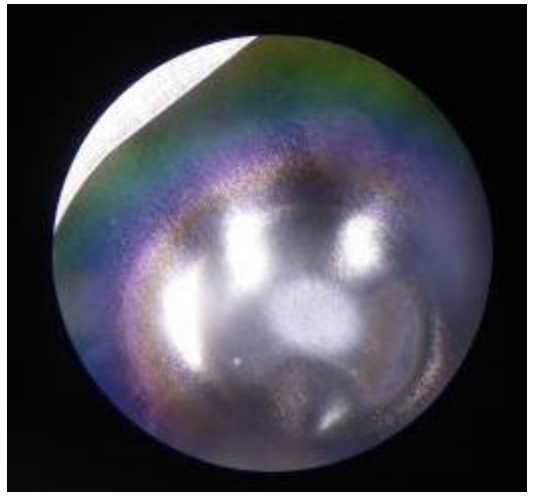
Reaction to study	Method	Target material	Thickness	Production method	Tested with	Result
$^{13}C + {}^{16}O$	^{13}C beam on ^{16}O targets	WO_3 (on Ta backing)*	~ 240 nm (~200 μg/cm^2)	PVD	^{13}C beam, RBS	Good uniformity, large number of O atoms, easy handling Did not hold for irradiations with I > 1 pμA

* targets tested as part of TNA experiment (proposal 23203309-ST for Dec 2023)

IFIN-HH results

Target after RBS measurements

Target after irradiation



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Reaction to study	Method	Target material	Thickness	Production method	Tested with	Result
$^{13}C + ^{19}F$	^{13}C beam on ^{19}F targets	LiF powder	1 mm	Tablet pressing*	^{13}C beam	Overwhelming contamination in prompt spectra from reactions on Li (that also produced dangerous rates in the detector) Did not hold for irradiations with I > 1 μA and longer than 1 hr

* fragile when handled

IFIN-HH results

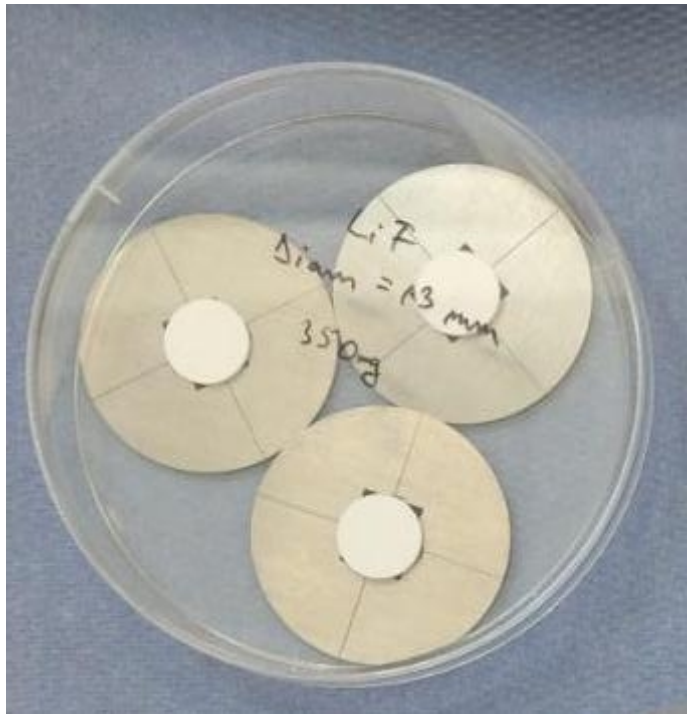
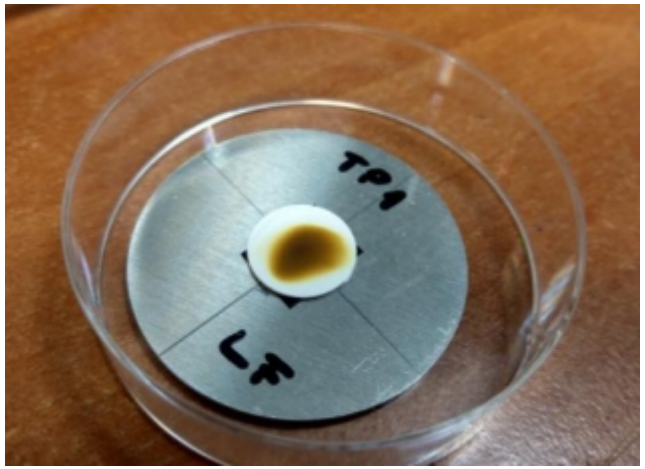
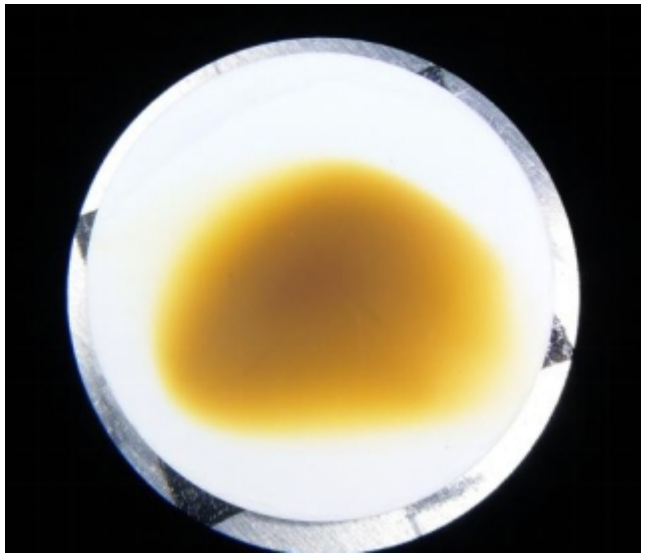


Photo of freshly pressed targets



Target after irradiation



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$^{13}C + ^{19}F$	^{13}C beam on ^{19}F targets	BaF_2 powder	1 mm	Tablet pressing*	^{13}C beam	Did not hold for irradiations with I > 1 μA and longer than 1 hr

* very fragile when handled

Solid Targets for Astrophysics Research

Task 3.1