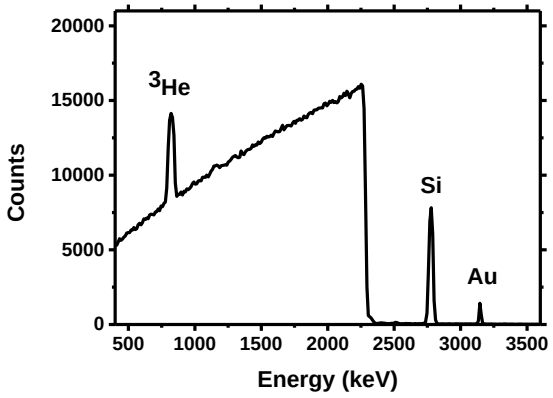
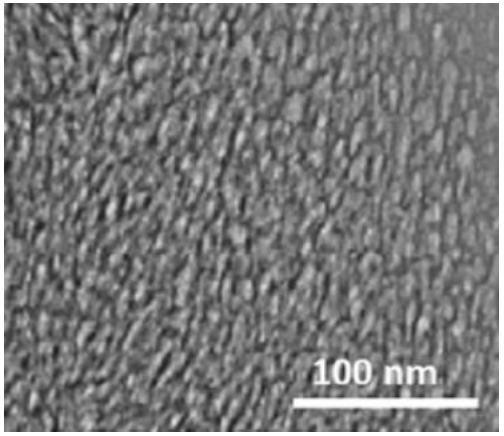
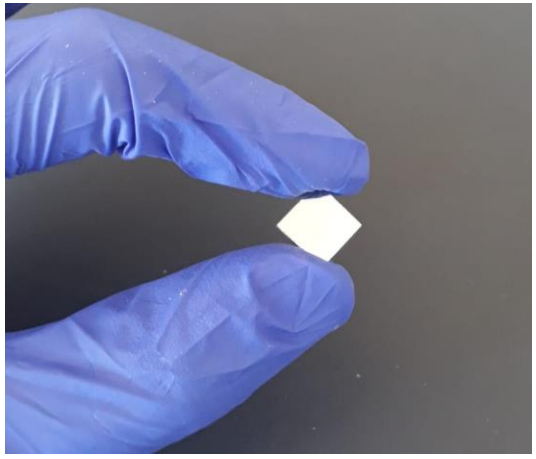
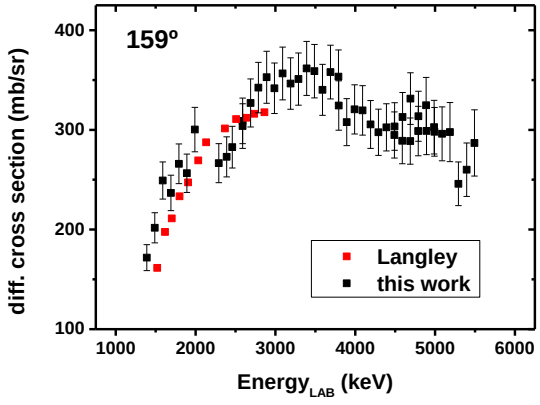
Solid ^{3}He target for nuclear reactions: differential cross-section of H+^{3}He elastic scattering from 1.0 to 5.5 MeV

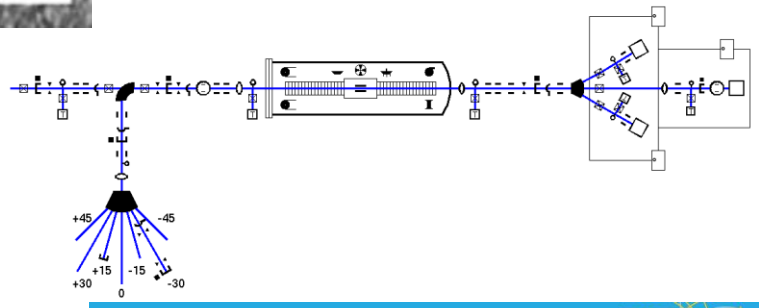
F.J. Ferrer, A. Fernández, Joao Cruz, J.P. Fernández-García, D. Hufschmidt, B. Fernández-Martínez











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Solid ^{3}He target for nuclear reactions: differential cross-section of H+^{3}He elastic scattering

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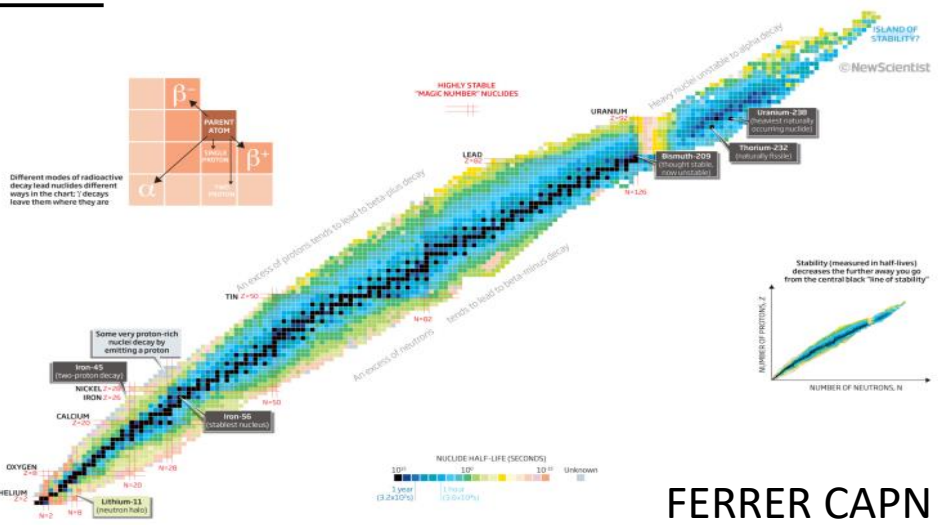
Solid ^{3}He target for nuclear reactions: differential cross-section of H+^{3}He elastic scattering

GOAL



Using nuclear reactions for investigating properties of nuclei far from the stability line ("exotic" nuclei).

FERRER CAPN 2023FERRER CAPN 2023

unstable exotic nucleus

exotic nucleus = projectil
H or He = target

INVERSE KINEMATIC

Protons		Alphas
(^{1}H, ^{1}H)	Elastic scattering	(^{4}He,^{4}He)
(^{1}H, ^{3}H)	Two neutron transfer	(^{4}He,^{6}He)
(^{1}H, ^{5}H)	Four neutron transfer	(^{4}He,^{8}He)

Solid ^{3}He target for nuclear reactions: differential cross-section of H+^{3}He elastic scattering

He problems

Protons → **polyethylene $(CH_2)n$**

Alphas (Helium) → **GAS, no solid molecules**

Gas jet target

Image from Oak Ridge National Laboratory web page

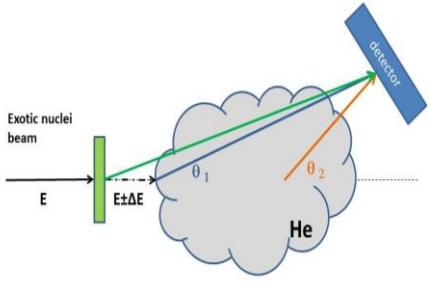
Gas cell

Image from K.E. Rehm, et al., Nucl. Instr. and Meth. Phys. Res. A, 647, (2011) 3-9.

Implanted target foils

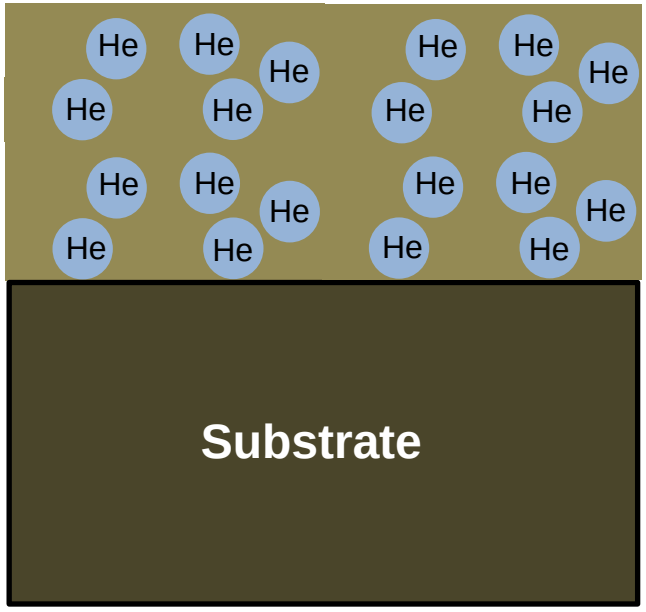
Image from Shellback Semiconductors Technology webpage

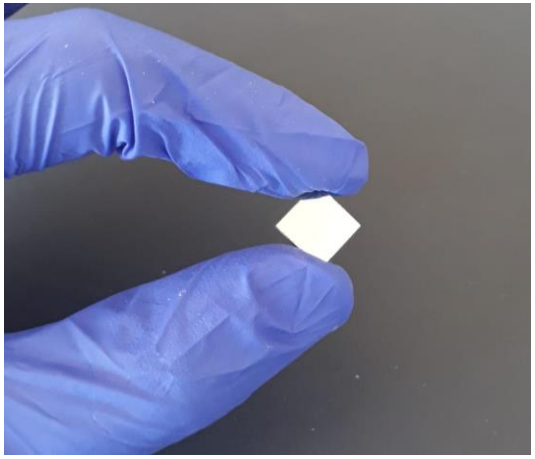
Filling the chamber



SOLID TARGETS

- **Homogeneously distributed pores structure**



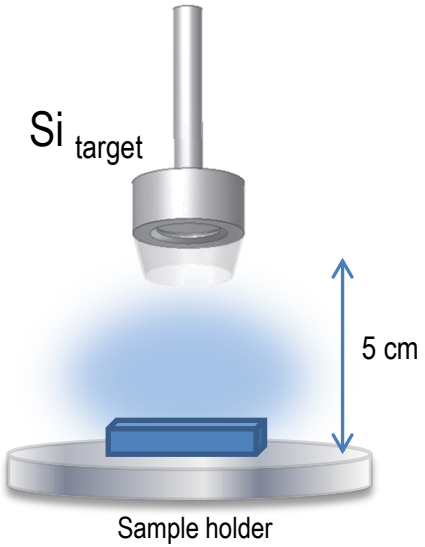


10x10x0,5 mm^3 target

Solid ^{3}He target for nuclear reactions: differential cross-section of H+^{3}He elastic scattering

Sample preparation

Magnetron Sputtering



Adjustable parameters:

- **RF/DC Power**
- **Substrate bias**
- **Gas type and Pressure**
- **Target material**

Magnetron sputtering:

- **Wide extended technique in industry**
- **Very versatile allowing to deposit on large areas**
- **Deposition on different kinds of substrates like glass or even sensible and flexible like polymers**
- **Controlling deposition parameters is possible to control the microstructure and composition**

Dynamic flux conditions
High gas consumption
⇩
very EXPENSIVE for ^{3}He (100s $/l)

Solid ^{3}He target for nuclear reactions: differential cross-section of H+^{3}He elastic scattering

A **quasistatic** procedure has been developed at the Materials Science Institute in Seville (ICMS-CSIC) [**WO/2020/099695**] to carry out the magnetron sputtering deposition procedure under the conditions of a **very low consumption of the working gas**.

DRASTIC REDUCTION

(>99.5%)

OF THE GAS CONSUMPTION

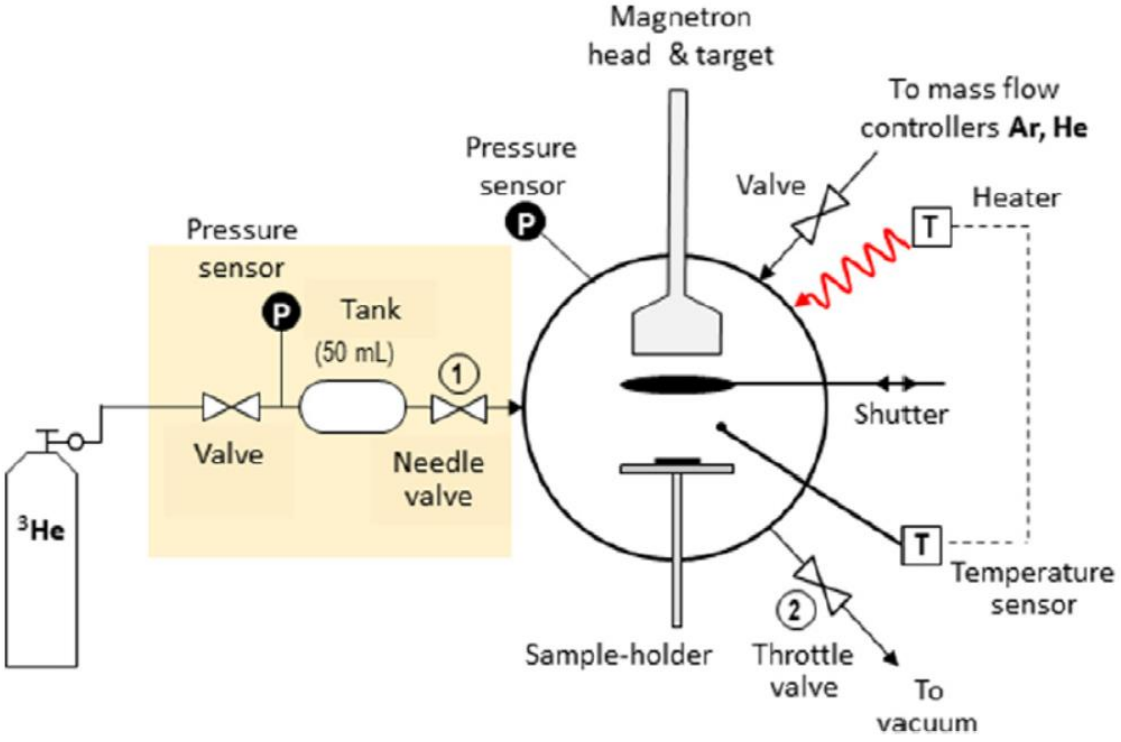
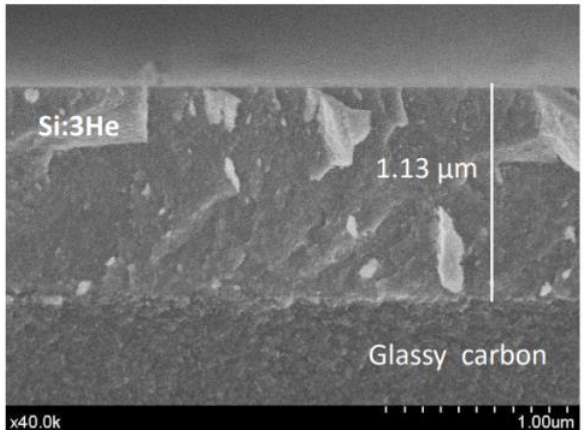


Figure from A. Fernández et al. Mater. Des., 186 (2020), p. 108337

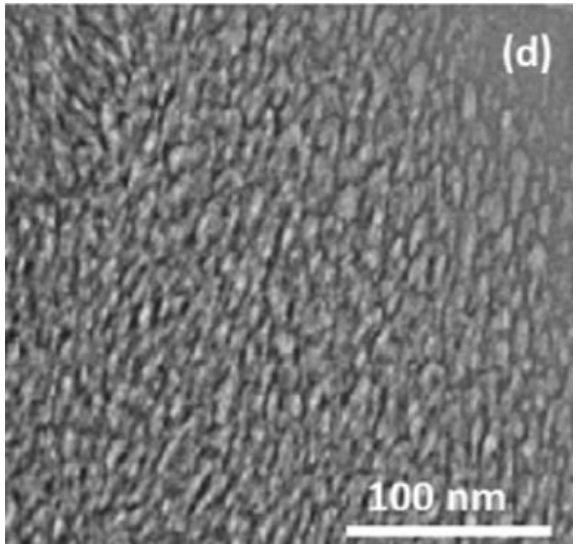
Solid ^{3}He target for nuclear reactions: differential cross-section of H+^{3}He elastic scattering

Morphological Characterization

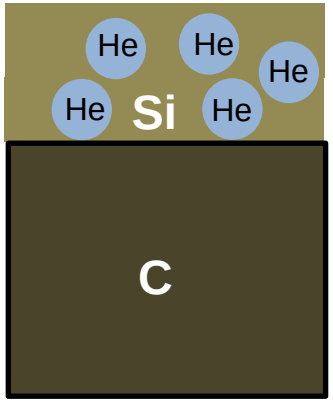
SEM and TEM



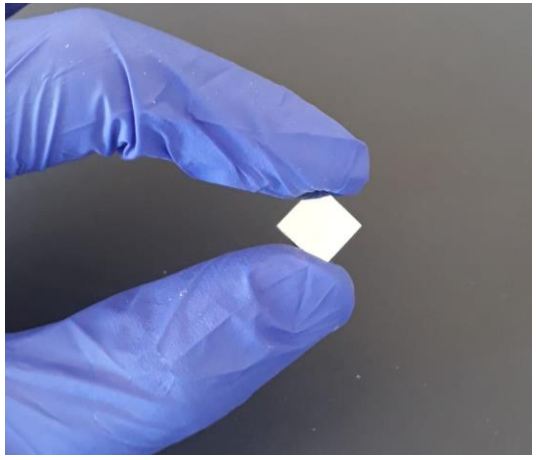
SEM cross-sectional view



TEM cross-sectional view



Homogeneously distributed pores structure

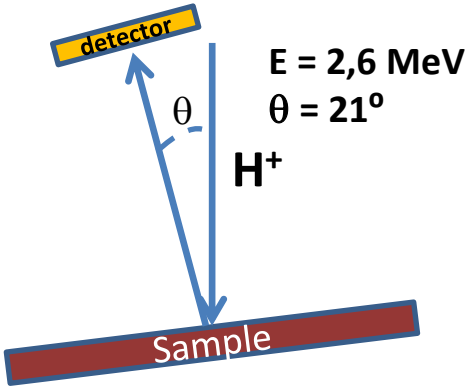


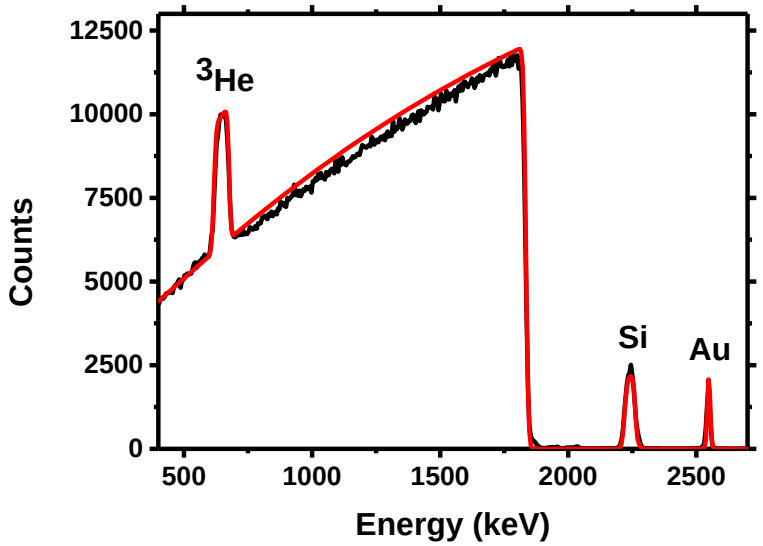
10x10x0,5 mm^3 target

Solid ^{3}He target for nuclear reactions: differential cross-section of H+^{3}He elastic scattering

Elemental Characterization

Proton Elastic Backscattering Spectroscopy





SIMNRA software and Langley cross section

High amount of He!!! ^{3}He/Si = 0,20

Sample	thickness (10^{15}at/cm^2)	Au (%at)	Si (%at)	^{3}He (%at)	Au (μg/cm^2)	Si (μg/cm^2)	^{3}He (μg/cm^2)
1st layer	30,0 ± 1,5	100	--	--	8,92 ± 0,45	--	--
2nd layer	5300 ± 250	--	82,6 ± 1,1	17,3 ± 0,8	--	204,5 ± 10,2	4,48 ± 0,25

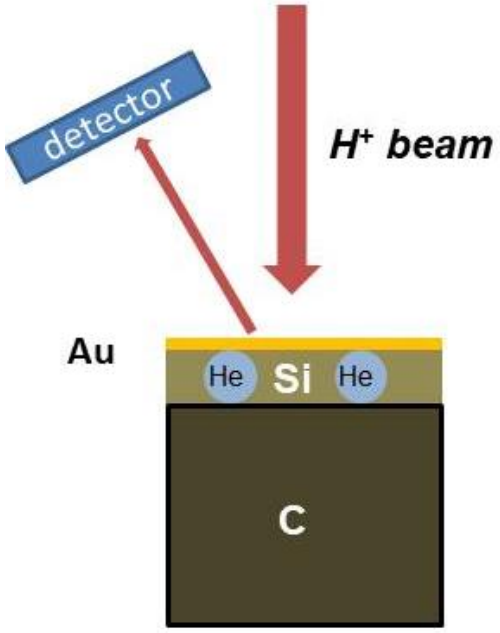
Solid ^{3}He target for nuclear reactions: differential cross-section of H+^{3}He elastic scattering

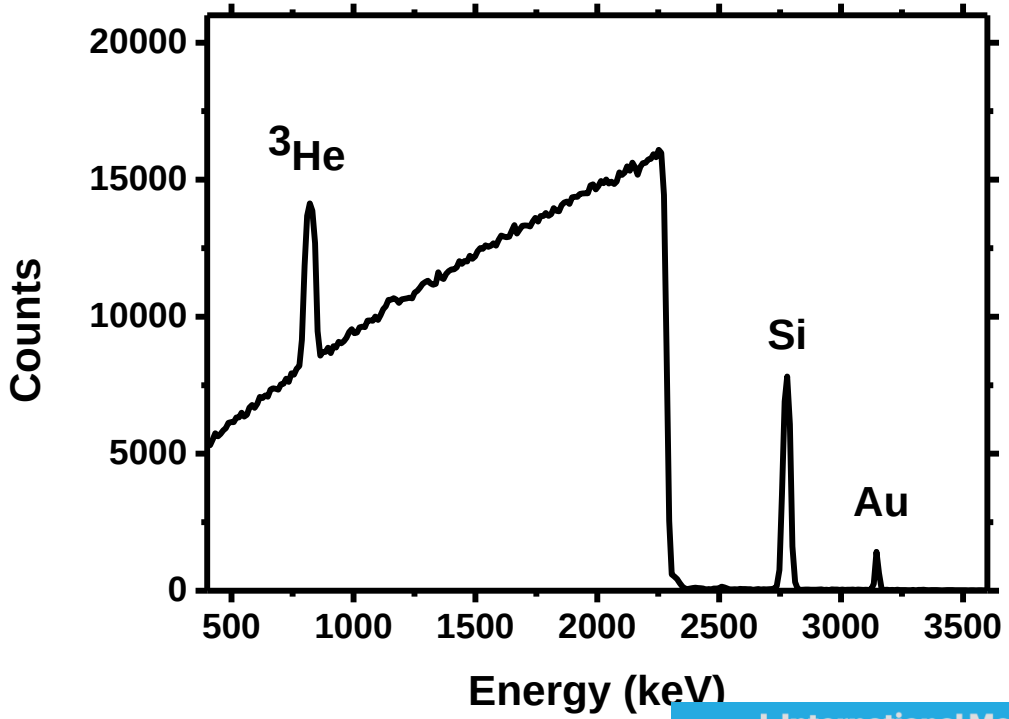
^{3}He(^{1}H,^{1}H) ^{3}He Elastic scattering

Backscattering ($\theta > 90°$)

Nt_{Au} = 30 x10^{15} at/cm^2
Nt_{He} = 900 x10^{15} at/cm^2

$$\frac{d\sigma}{dE_{He}}(E,\theta) = \frac{d\sigma}{dE_{Au,Ruth}}(E_0,\theta) \cdot \left(\frac{A_{He}}{A_{Au}}\right) \cdot \left(\frac{Nt_{Au}}{Nt_{He}}\right)$$





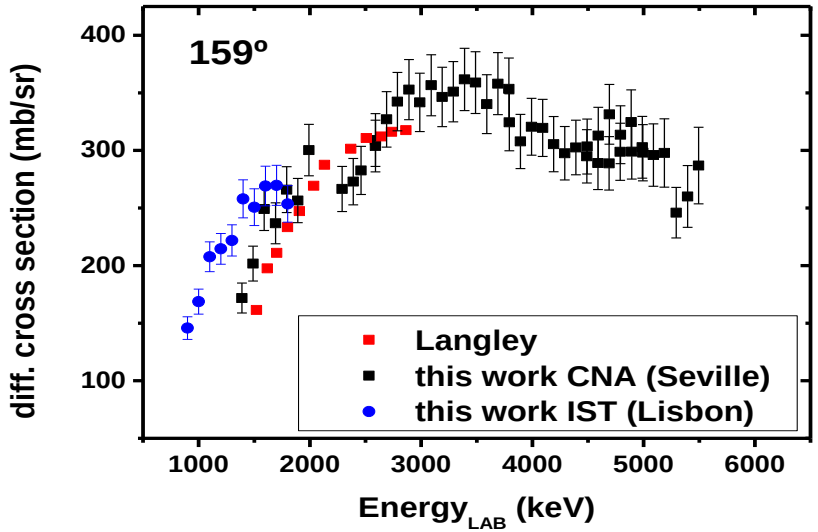
E_p = 3200 keV
θ = 165°

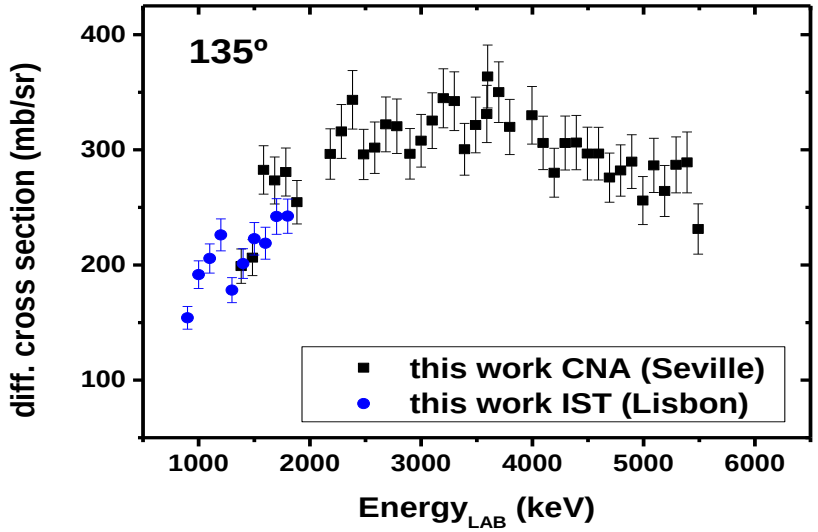
Solid ^{3}He target for nuclear reactions: differential cross-section of H+^{3}He elastic scattering

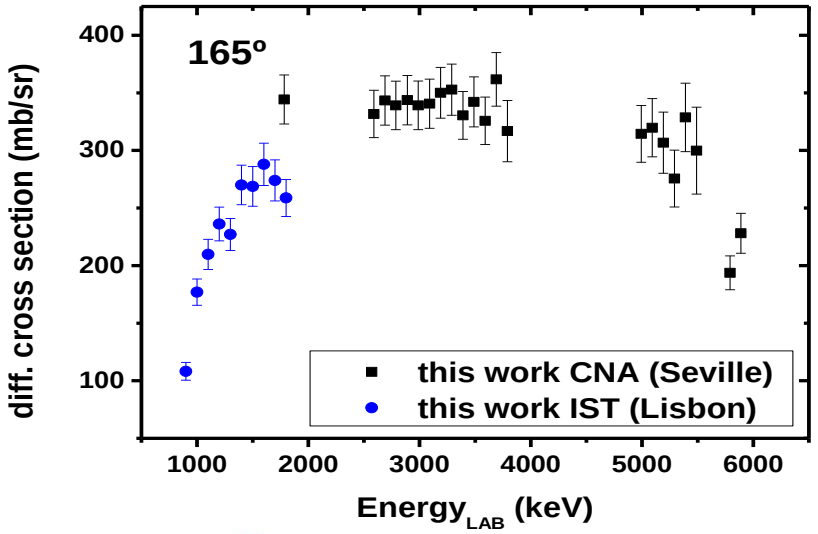
^{3}He(^{1}H,^{1}H) ^{3}He Elastic scattering

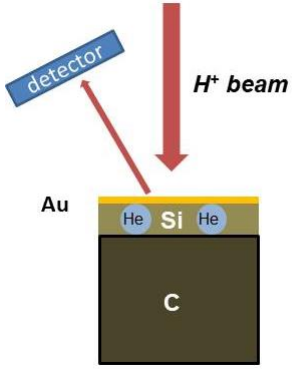
Backscattering ($\theta > 90°$)

PRELIMINARY RESULTS





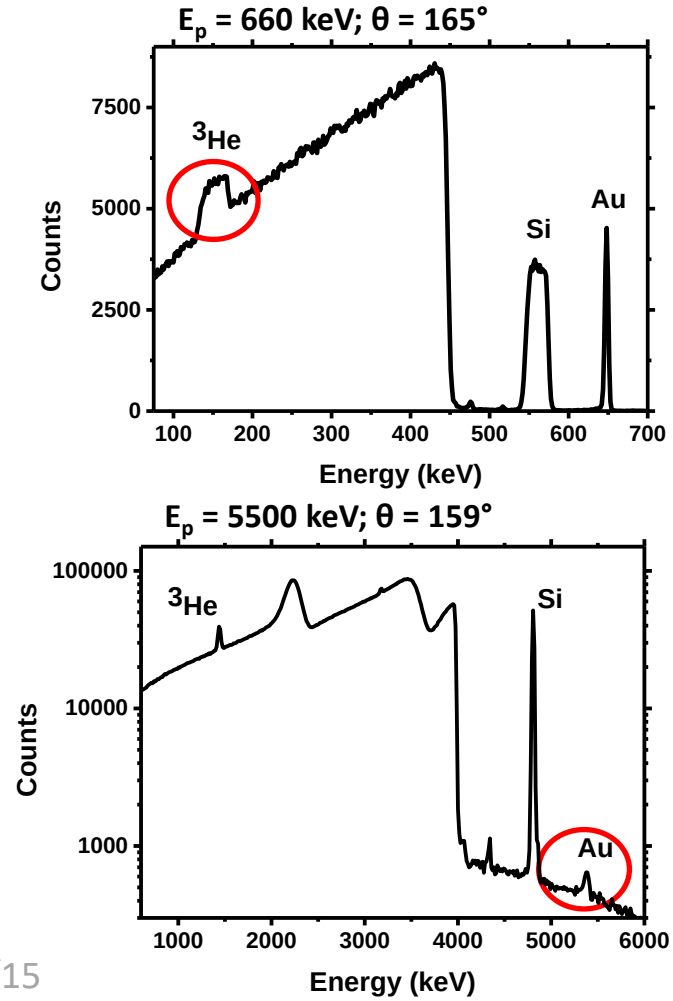




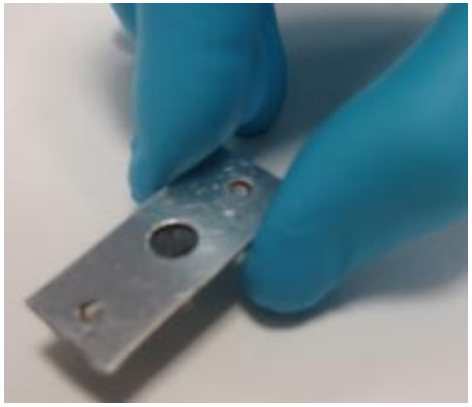
Si: 4400 x10^{15} at/cm^2
^{3}He: 900 x10^{15} at/cm^2

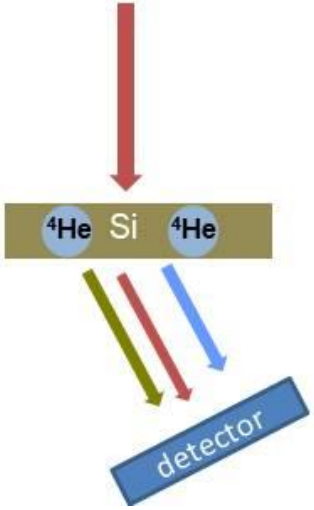
Perspectives: Next future

- ***Tailoring of the targets depending on the used proton energy.***



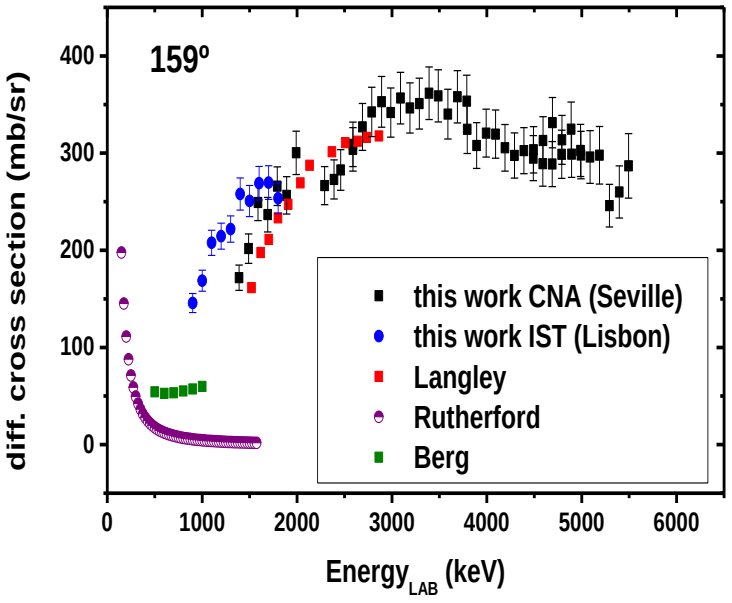
- ***Testing self-supported targets (as ^{4}He targets); forward scattering***



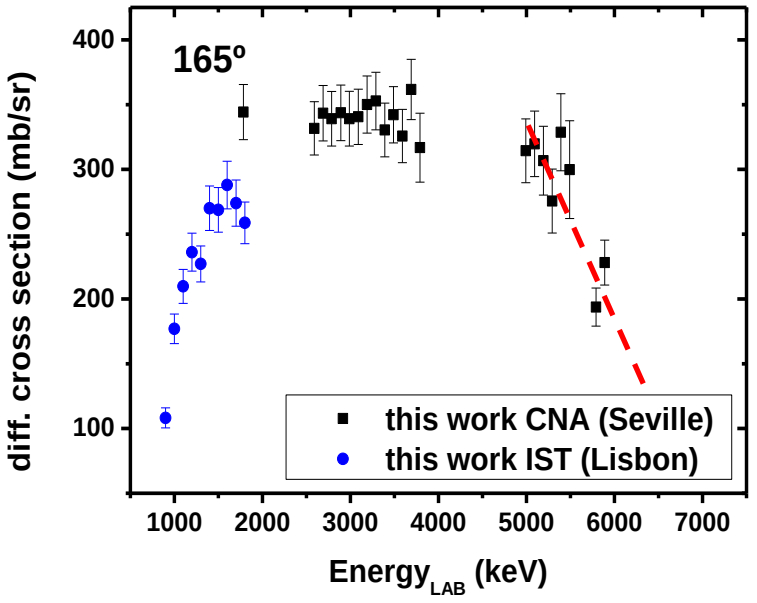


Perspectives: Next future

- ***Lower Energy (E < 500 keV) Rutherford contribution Cross Section***

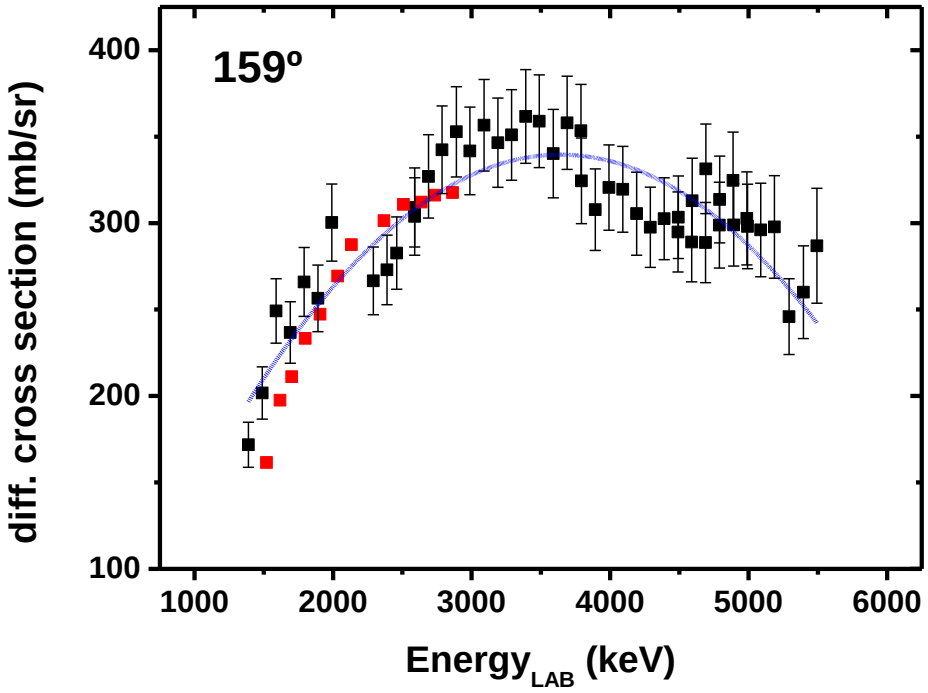


- ***Higher Energy (E > 6000 keV) Possible decrease of the Cross Section***



Perspectives: Next future

R-matrix calculation to study the resonant states of ^{4}Li (checking capability of the targets)



CONCLUSIONS

- ***The H+^{3}He reaction at energies between 1,5 and 5,5 MeV at different angles using a ^{3}He solid target was measured for the first time at CNA.***
- ***The measured differential cross sections are in good agreement with the only results of found in literature (Langley).***
- ***The specially prepared Si-^{3}He thin solid film has demonstrated its capability as a suitable target for experimental studies on nuclear reactions involving ^{3}He targets.***

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Some bibliography

- ***"Novel solid 4He targets for experimental studies on nuclear reactions: 6Li+4He differential cross-section measurement at incident energy of 5.5 MeV",*** *F.J. Ferrer, B. Fernández, J.P. Fernández-García, F.G. Barba, A. Fernández, D. Galaviz, V. Godinho, J. Gómez-Camacho, A.M. Sánchez-Benítez, Eur. Phys. J. Plus 135 (2020) 465 (1-8).*

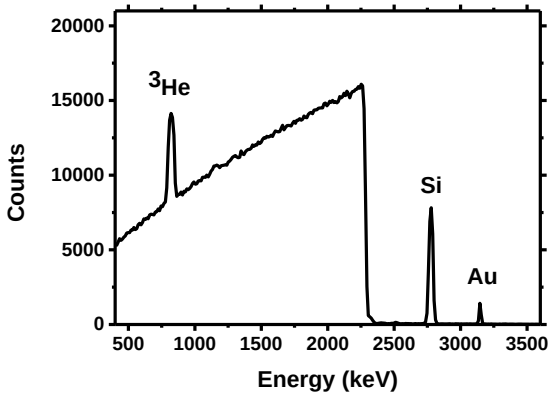
- ***"Characterization and validation of a-Si magnetron sputtered thin films as solid He target with high stability for nuclear reactions",*** *V Godinho, F. Ferrer, B. Fernández, J. Caballero-Hernandez, J. Gómez-Camacho, A. Fernández, ACS Omega, 1 (2016) 1229−1238.*

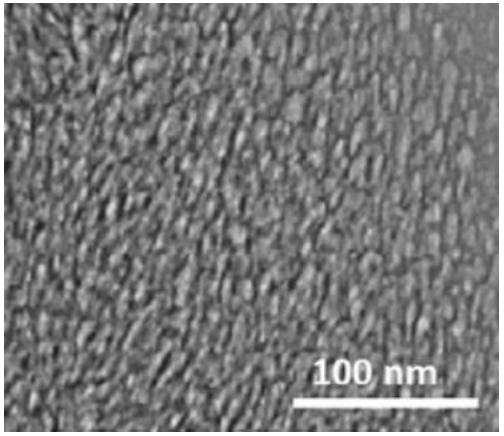
- ***"Low gas consumption fabrication of 3He solid targets for nuclear reactions",*** *A. Fernández, D. Hufschmidt, J.L. Colaux, J.J. Valiente-Dobón, V. Godinho, M.C. Jiménez de Haro, D. Feria, A. Gadea, S. Lucas, Mater. Des., 186 (2020) 108337*

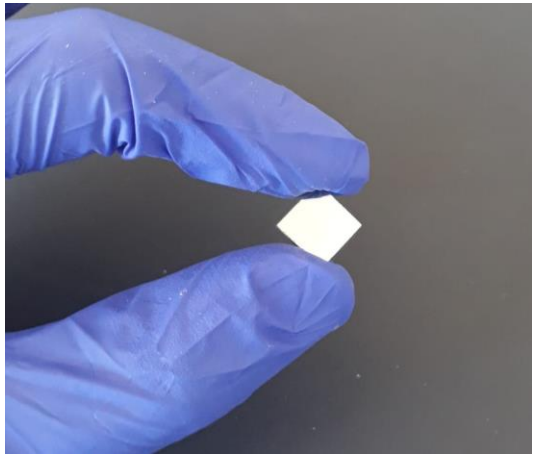
- ***"Method for obtaining a solid material with gaseous aggregates by means of magnetron cathode sputtering in static or quasistatic conditions to reduce the use of gas",*** *A. Fernández, D. Hufschmidt, V. Godinho, M.C. Jiménez de Haro, ,2020, Patent WO2020099695A1*

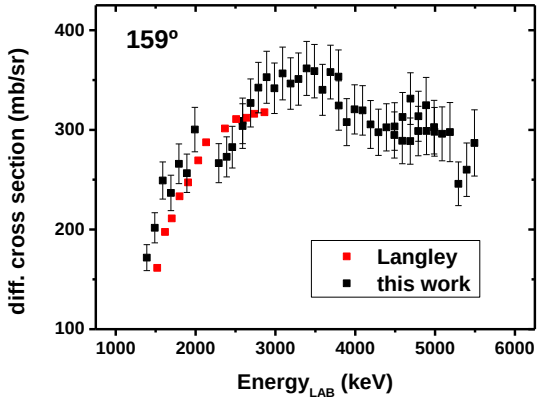
- ***"Solid target of noble gases for nuclear reactions",*** *V. Godinho, J. Caballero, A. Fernández, F.J. Ferrer, J.Gómez-Camacho, B. Fernández-Martínez, 2017, Patent WO2017207848A1*

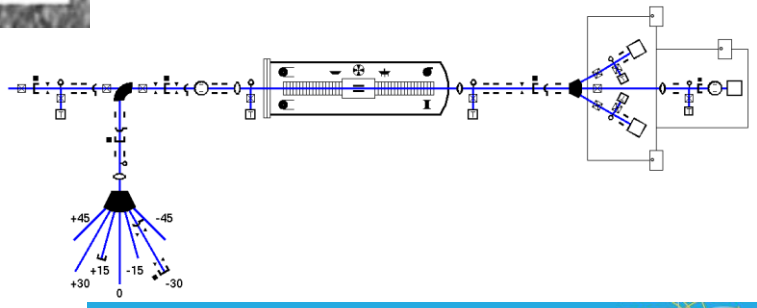
Thank you for your attention











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