First ever α-scattering with radioactive ion beams:

a novel technique to determine α-nuclear potentials away from stability

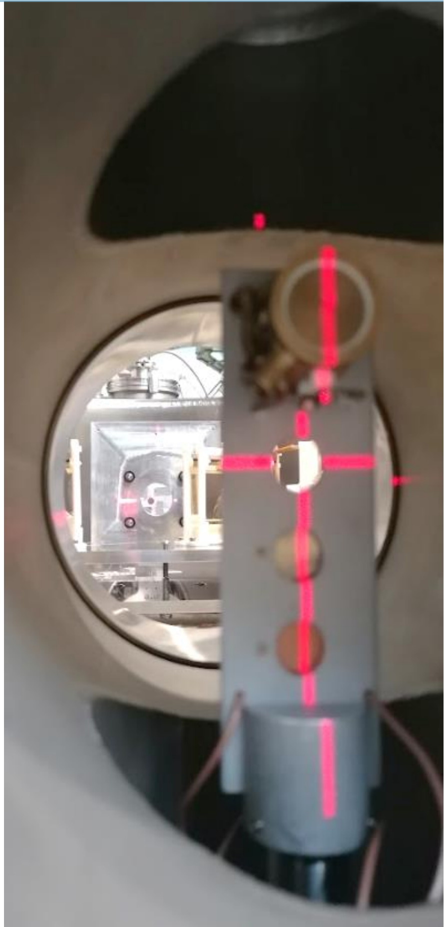
ISOLDE Workshop and Users meeting

Wednesday, 3rd December 2025

Francisco G. Barba

Outline

- Why study α-nuclear potentials?
- Challanges of the measurement
- Setup and benchmark of technique
- Status of $^{4}He(^{A}Sn,^{4}He)^{A}Sn$ analysis with exotic Sn



Motivation

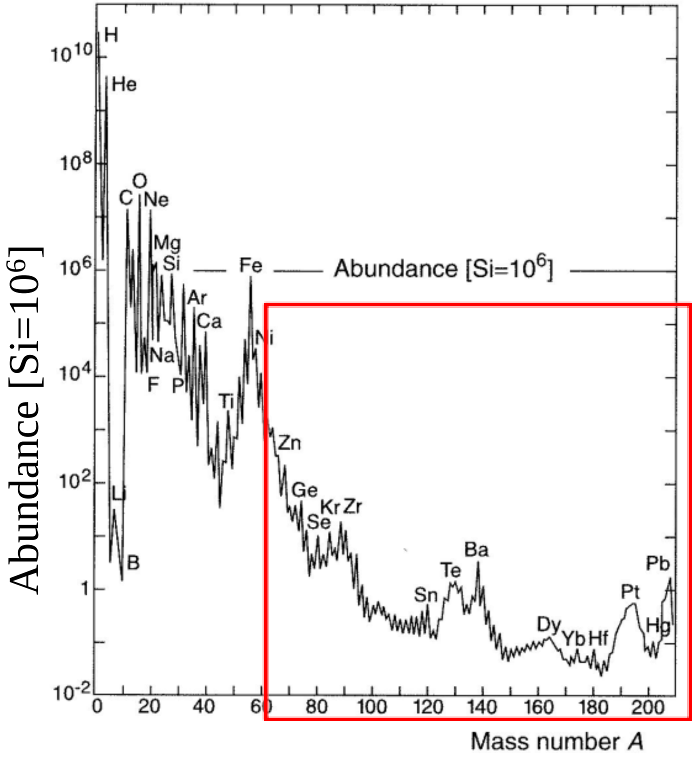
Solar Abundance Distribution (SAD)

Bulk of elements:

- BBN
- Fusion phase

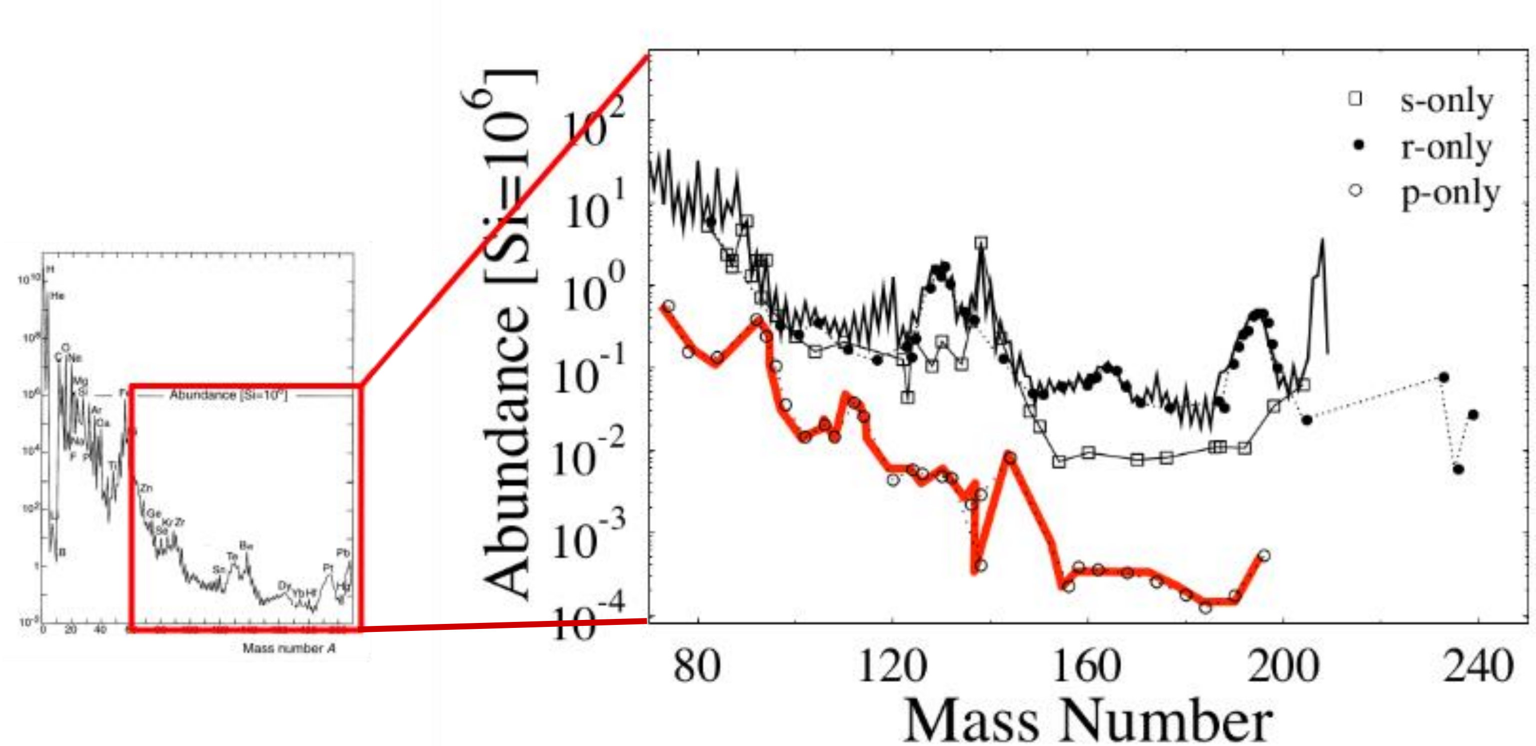
Heavy elements:

- **Neutron capture** processes



Motivation

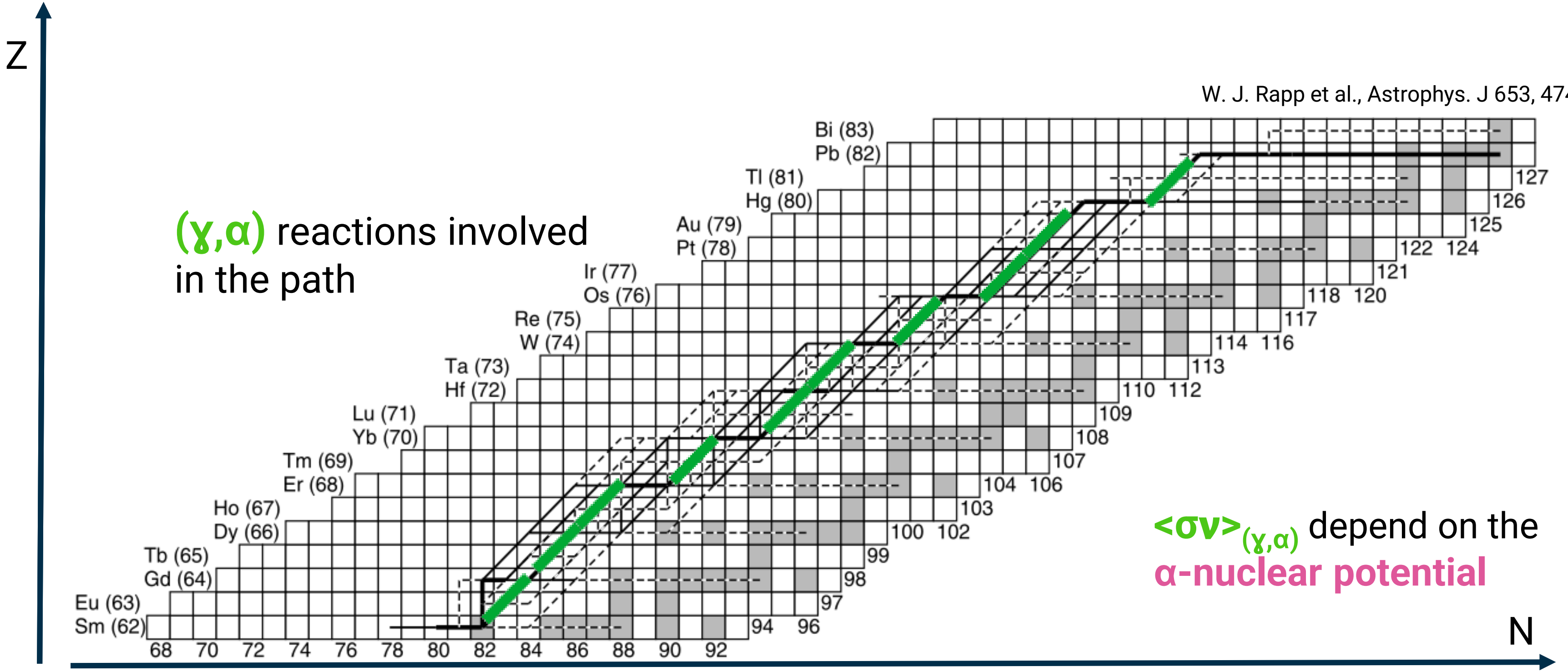
p-nuclei



Motivation

Sensitivity studies of gamma Process

W. J. Rapp et al., Astrophys. J 653, 474 (2006)

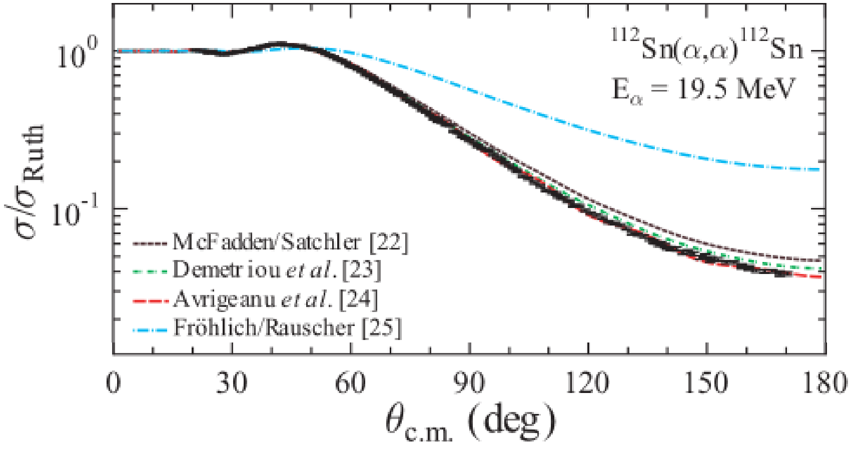


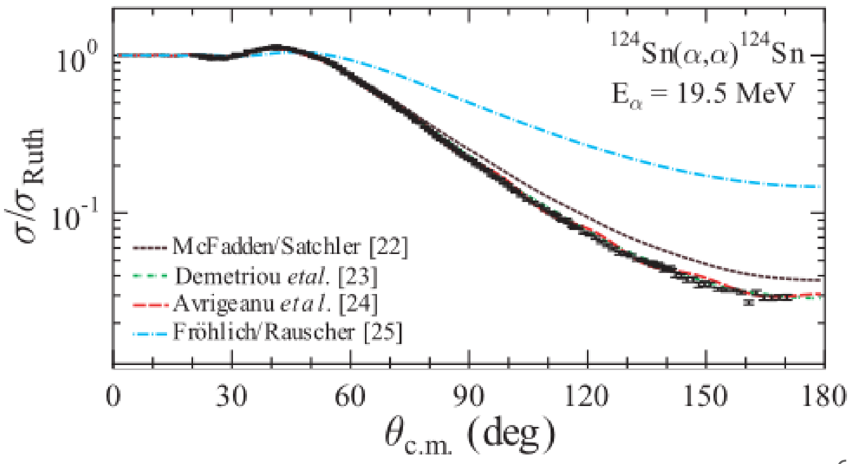
(ɣ,α) reactions involved in the path

$\langle\sigma v\rangle_{(\gamma,\alpha)}$ depend on the **α-nuclear potential**

Motivation

α-nuclear potentials: elastic scattering



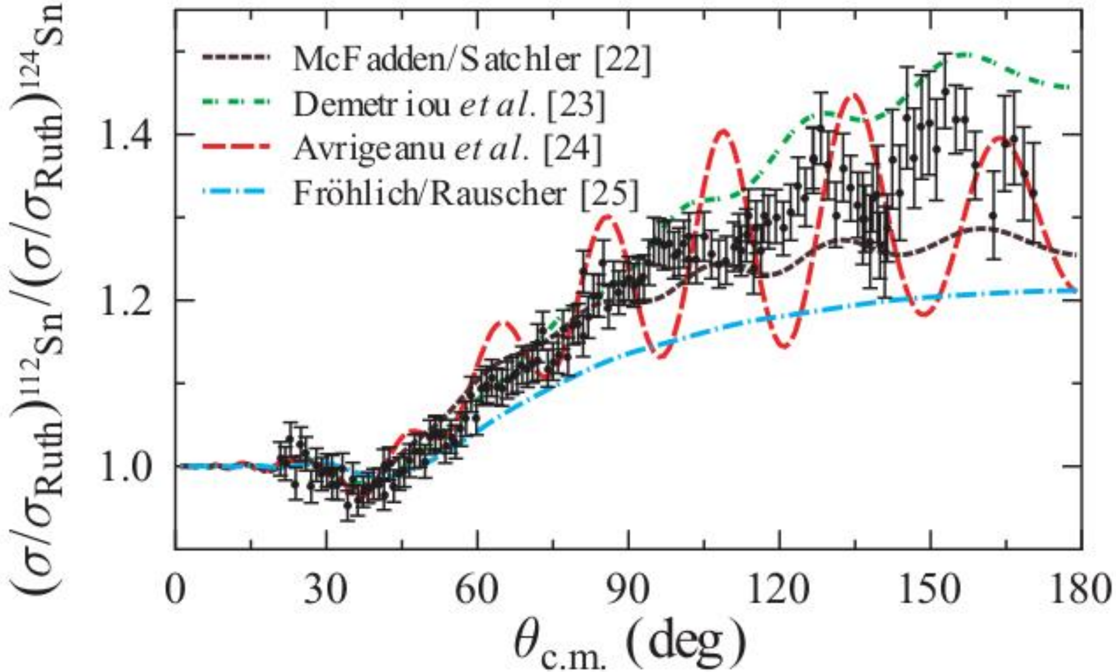


D. Galaviz, et al. Phys. Rev. C 71, 065802 (2005)

Motivation

α-nuclear potentials: elastic scattering

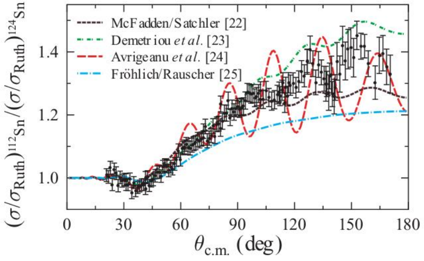
Mass dependence in stable Sn isotopes

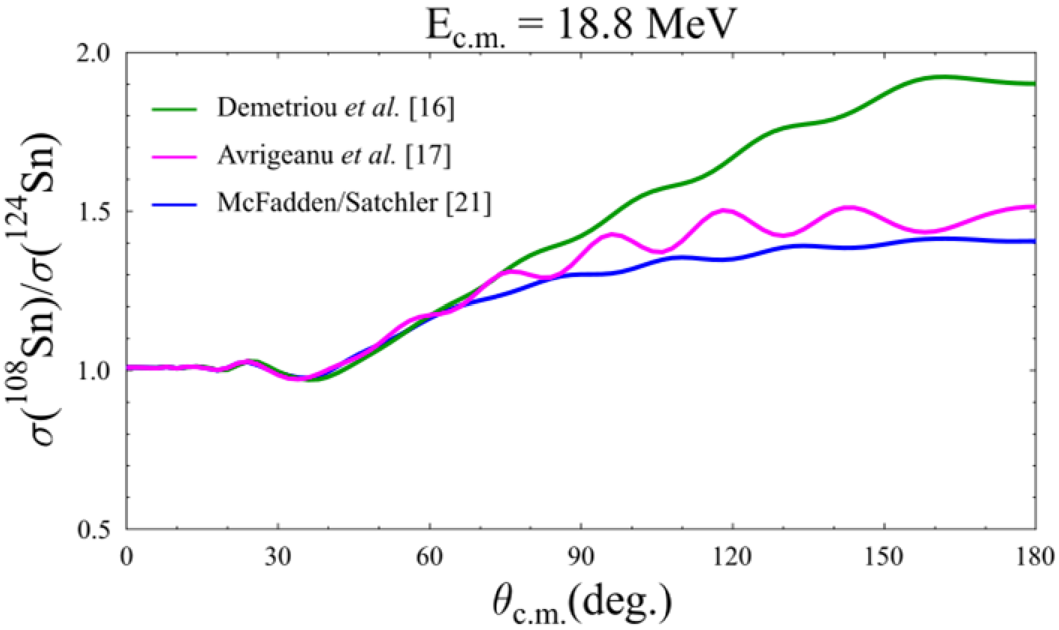


D. Galaviz et al,
PRC71, 0650802 (2005)

Motivation

α-nuclear potentials: elastic scattering

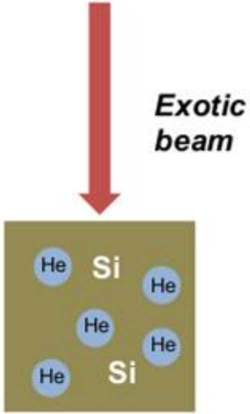


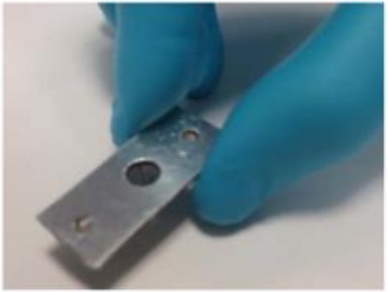


Si/He Targets

Magnetron Sputtering
Si/He thin films

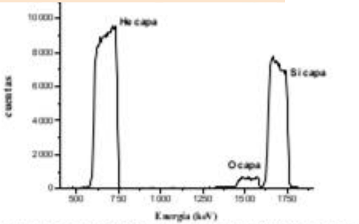
Element	Si	He	C	N	O	H
atoms/cm^2 (x10^{15})	2820	1280	100	390	380	475



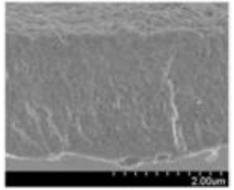


Self-supported Si:He target

V. Godinho *et al.*, ACS Omega 2016, 1 (6), 1229 (2016)



RBS spectrum of Si:He target using 2,0 MeV protons and 165° scattering angle



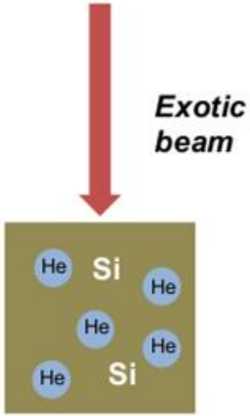
SEM corss section of the Si:He target

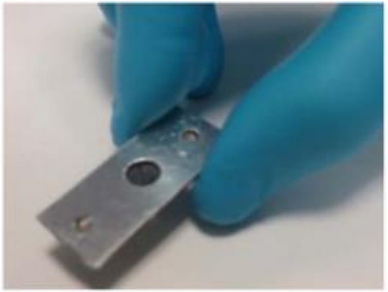
Si/He Targets

nanomatμ CNA

Magnetron Sputtering
Si/He thin films

Element	Si	He	C	N	O	H
atoms/cm^2 (x10^{15})	2820	**1280**	100	390	380	475





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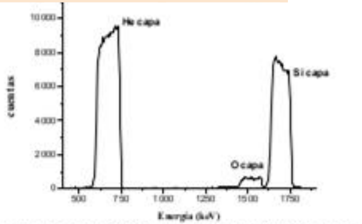
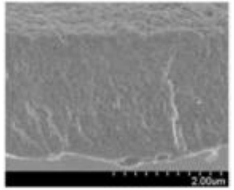


RBS spectrum of Si:He target using 2,0 MeV protons and 165° scattering angle



SEM corss section of the Si:He target

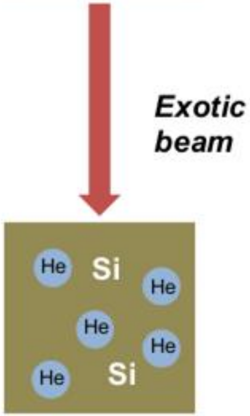
V. Godinho *et al.*, ACS Omega 2016, 1 (6), 1229 (2016)

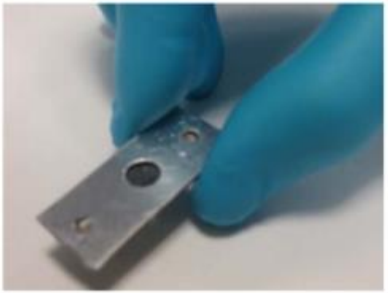
Si/He Targets

Magnetron Sputtering
Si/He thin films

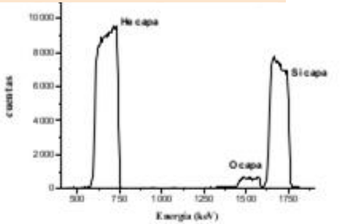
Elastic Scattering in
inverse kinematics

Element	Si	He	C	N	O	H
atoms/cm^2 ($\times 10^{15}$)	2820	**1280**	100	390	380	475

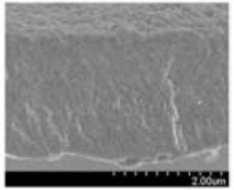




Self-supported Si:He target



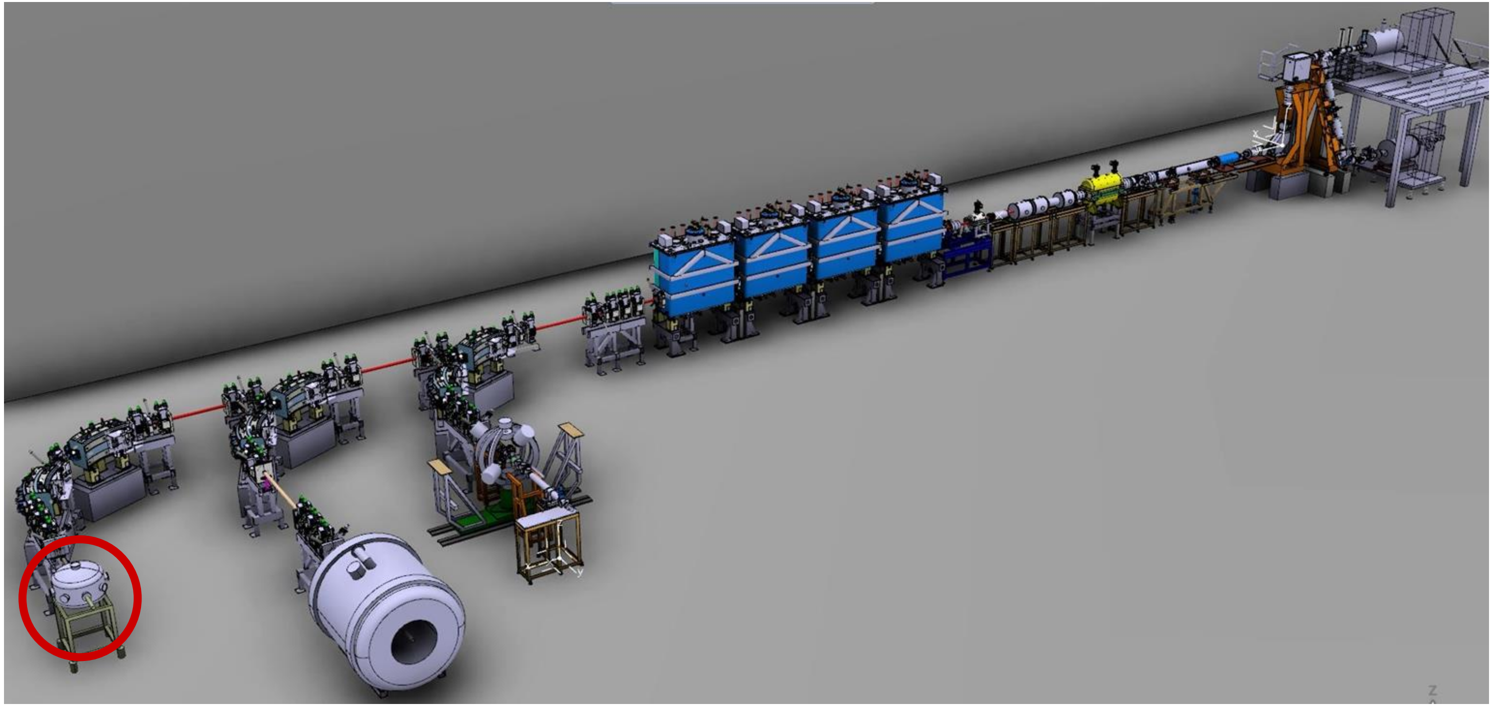
RBS spectrum of Si:He target using 2,0 MeV protons and 165° scattering angle



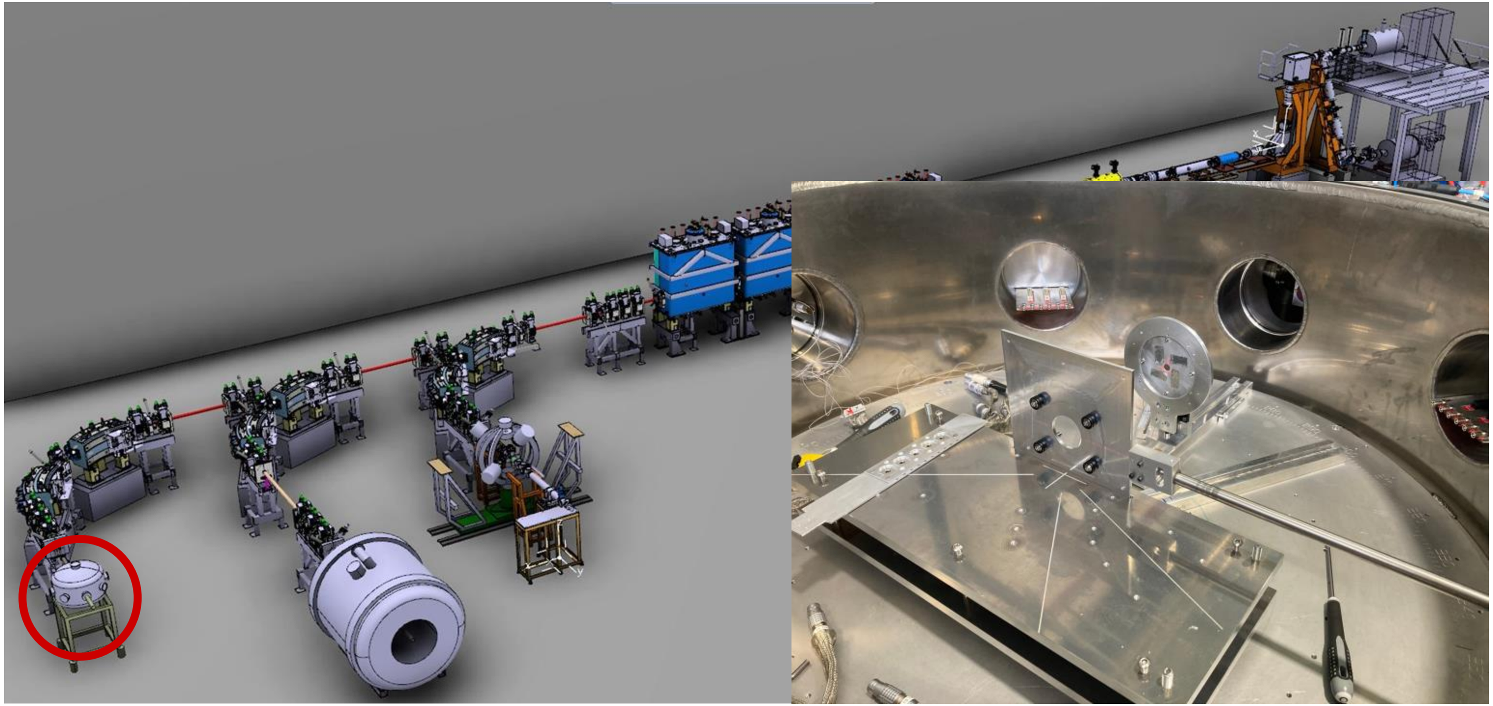
SEM corss section of the Si:He target

V. Godinho *et al.*, ACS Omega 2016, 1 (6), 1229 (2016)

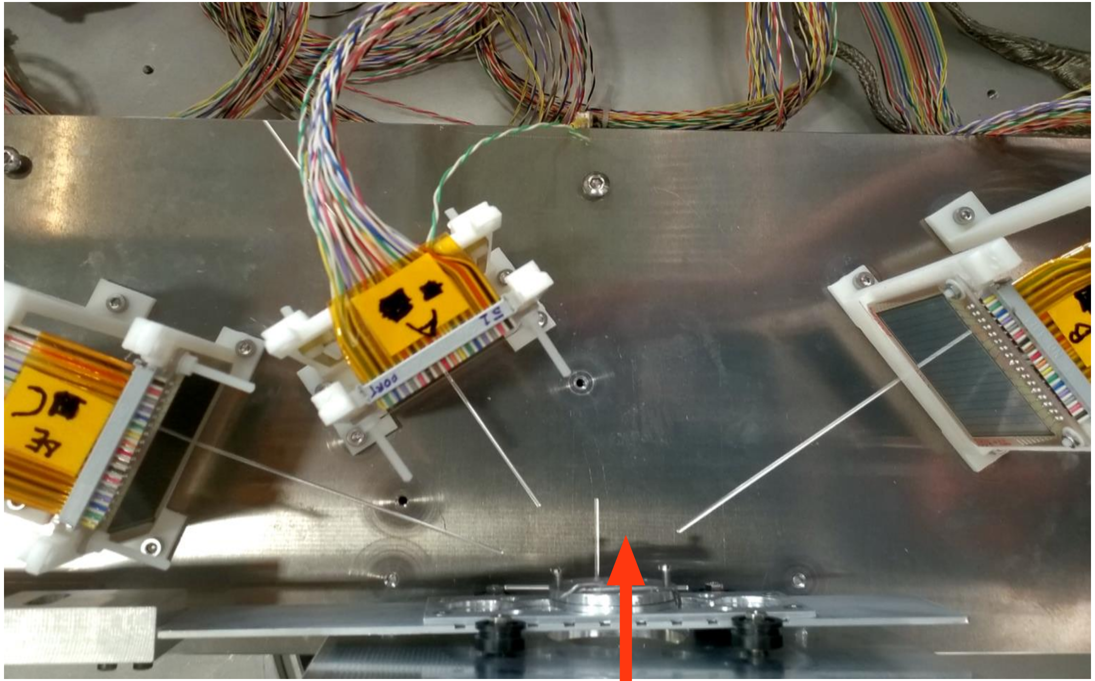
Setup



Setup



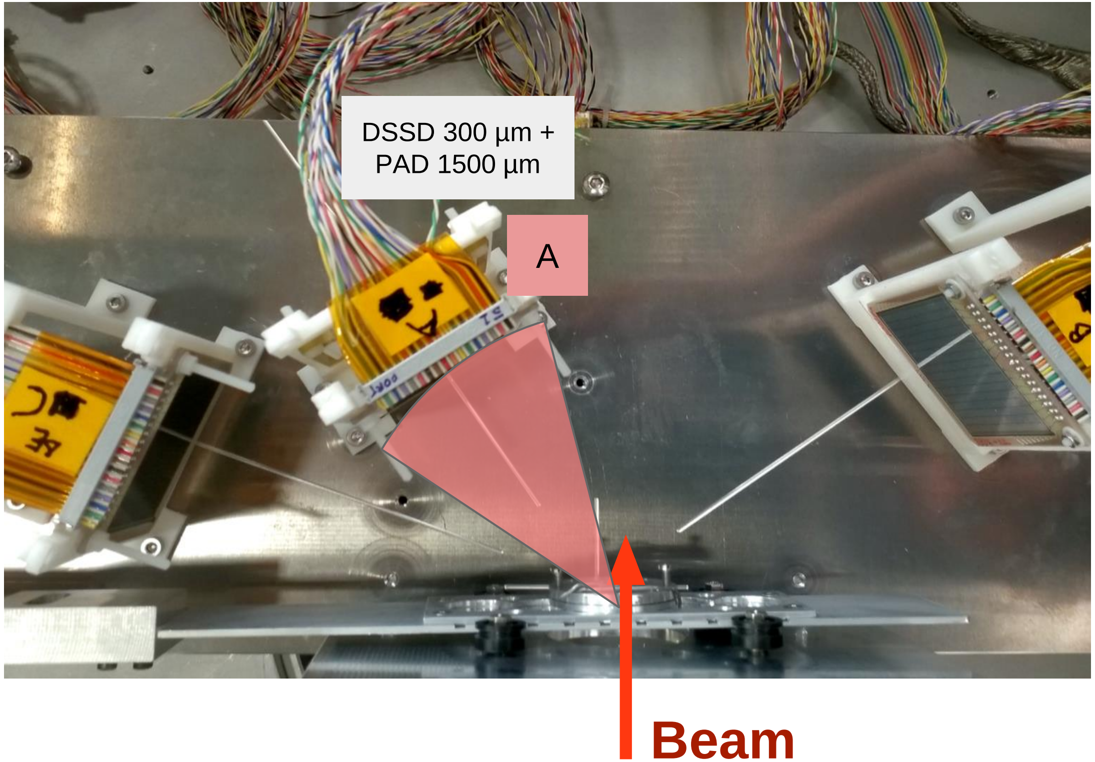
Setup



Beam

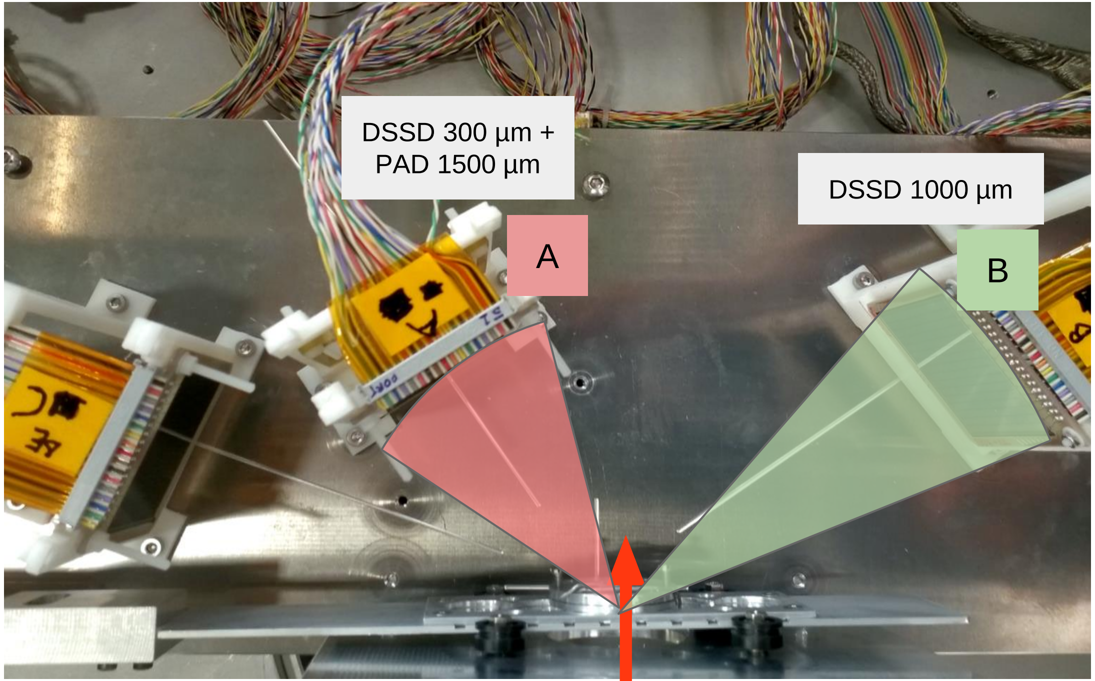
Setup

Telescope A
19º to 51º



Setup

Telescope A
19º to 51º



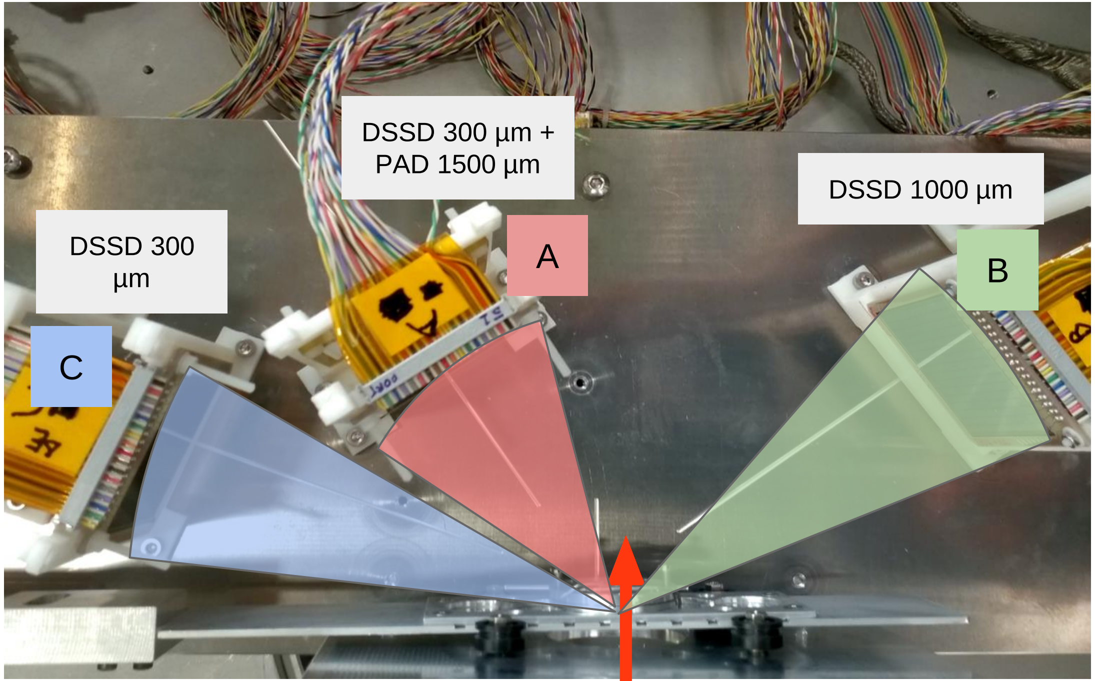
Detector B
46º to 65º

Beam

Setup

Telescope A
19º to 51º

Detector C
60º to 78º



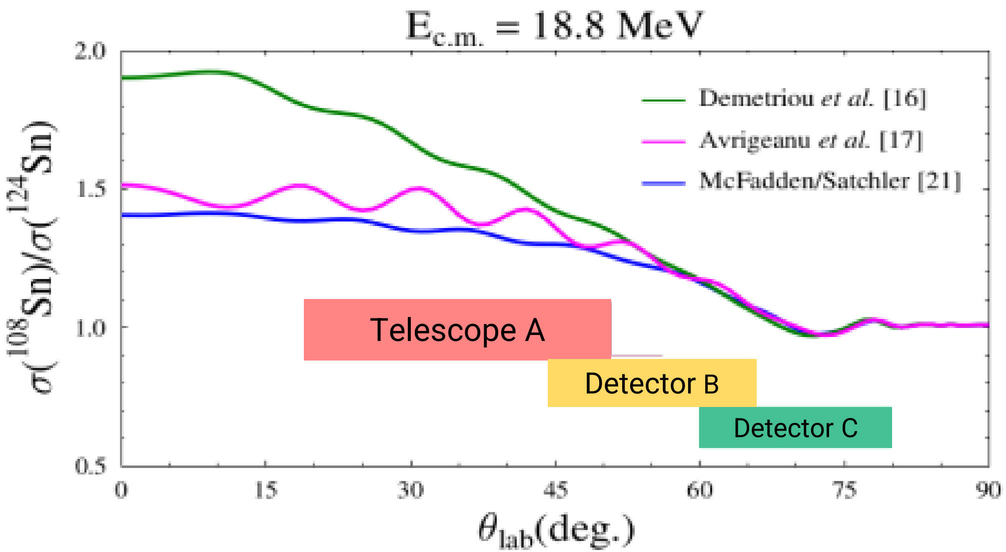
Detector B
46º to 65º

Beam

IS698 Experiment

Measurement of the $^{4}He(^{A}Sn, ^{4}He)^{A}Sn$ in inverse kinematics at the same $E_{c.m}$

mass dependance of **α-nuclear potentials** along the Sn isotopic chain



Beam and targets

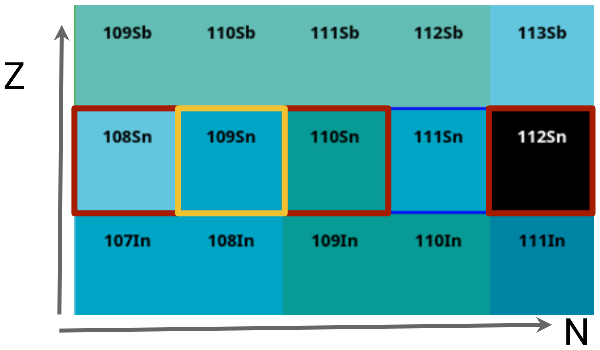
Pilot Beam E_{Beam}= 4.9 MeV/u

Cocktail of ^{12}C, ^{16}O, ^{20}Ne and ^{32}S

Sn Beam E_{Beam}= 4.9 MeV/u

^{112}Sn (I ≈ 30 pA) ^{108}Sn (I ≈ 50 pA)

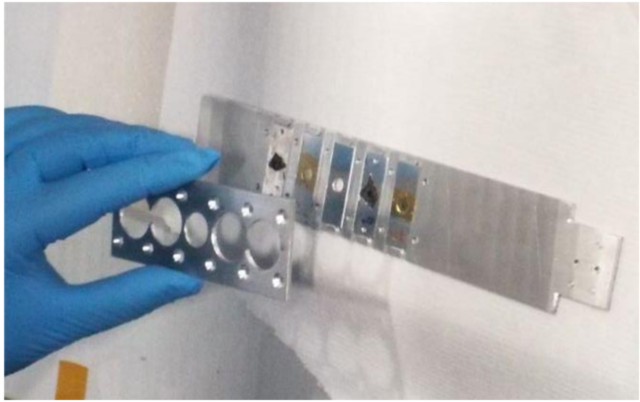
^{110}Sn (I ≈ 80 pA) ^{109}Sn (I ≈ 90 pA)



Targets

^{197}Au ≈ 300 µg/cm²

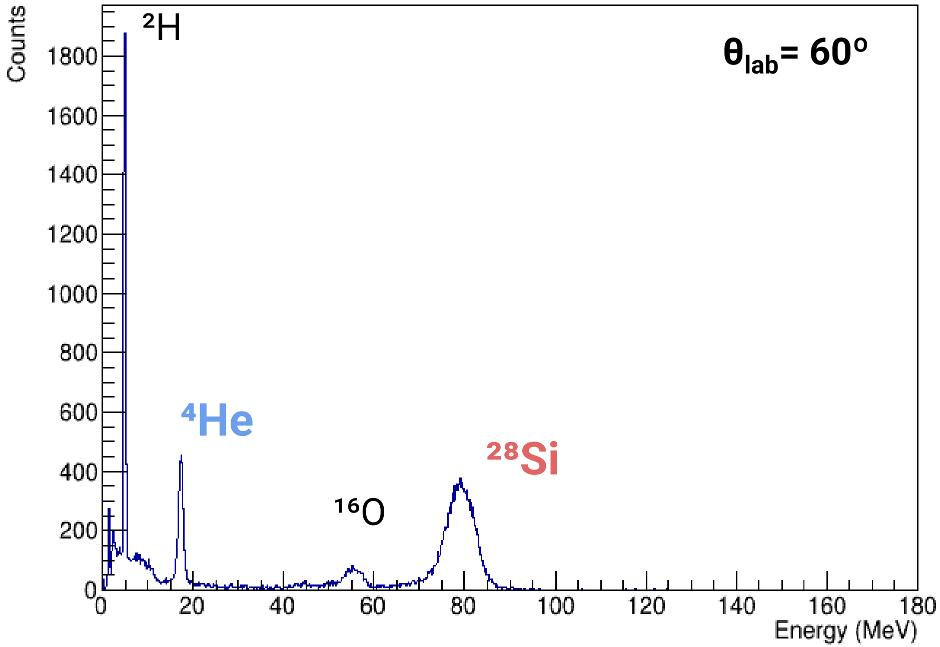
^{4}He ≈ 2 x 10^{18} atoms/cm²



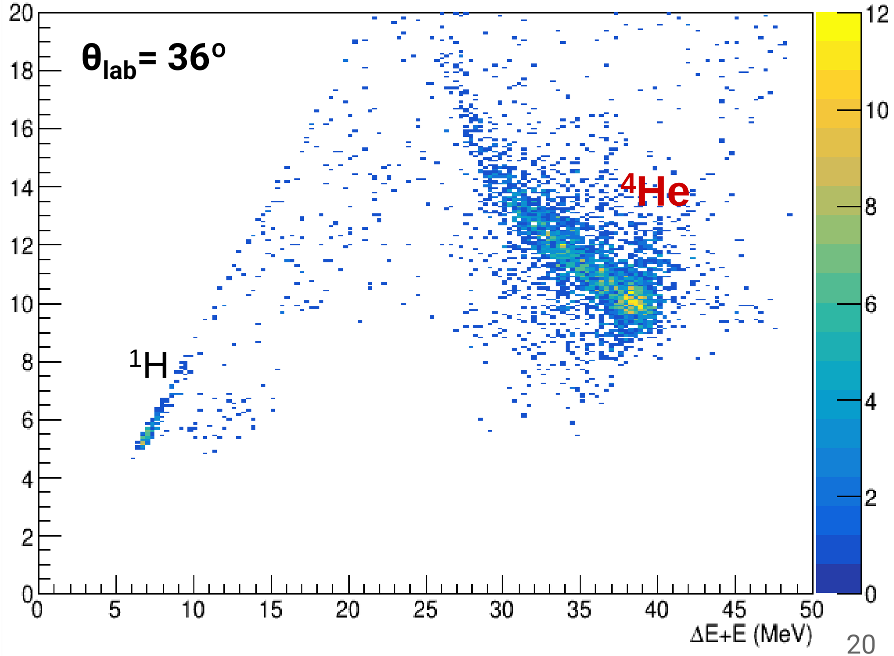
Experimental Data

$^{4}\mathrm{He}(^{A}\mathrm{Sn},^{4}\mathrm{He})^{A}\mathrm{Sn}$ @ 4.9 MeV/u

^{112}Sn beam scattering on **Si/He-target**



^{108}Sn beam scattering on **Si/He-target**



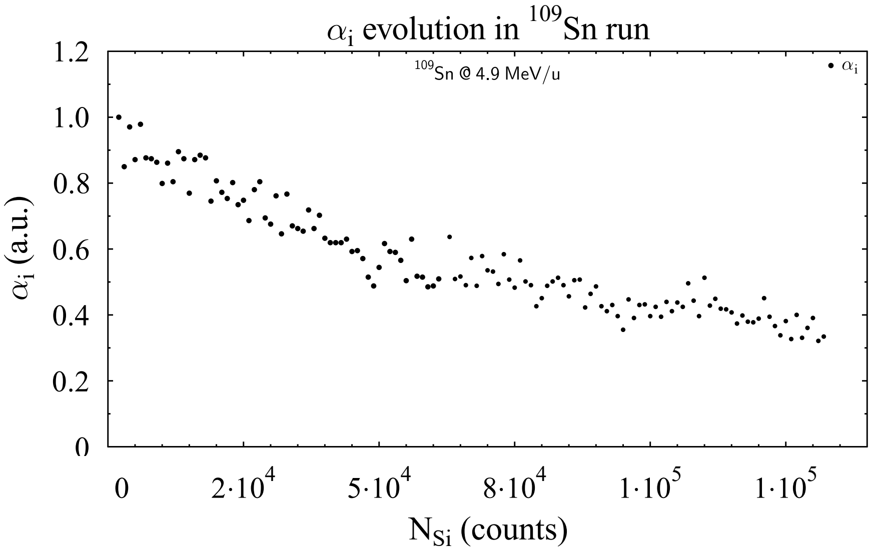
Before counting...!

Amount of ^{4}He over time

^{4}He amount decreases

Need to account the different amount of ^{4}He on each run

★ **Normalize the integral of ^{4}He to the ratio He/Si at 60º**



Before counting...!

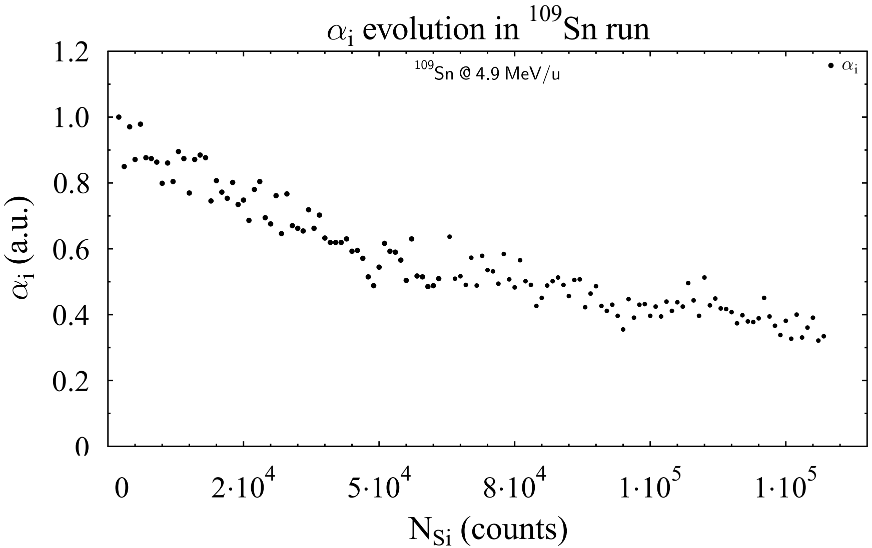
Amount of ^{4}He over time

^{4}He amount <u>decreases</u>

Need to account the different amount of ^{4}He on each run

★ **Normalize the integral of ^{4}He to the ratio He/Si at 60º**

$$\alpha_i = \frac{N^i_{He}(60^\circ)}{N^i_{Si}(60^\circ)} \frac{N^0_{Si}(60^\circ)}{N^0_{He}(60^\circ)}$$



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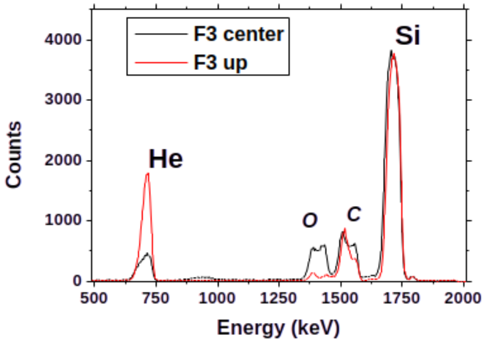
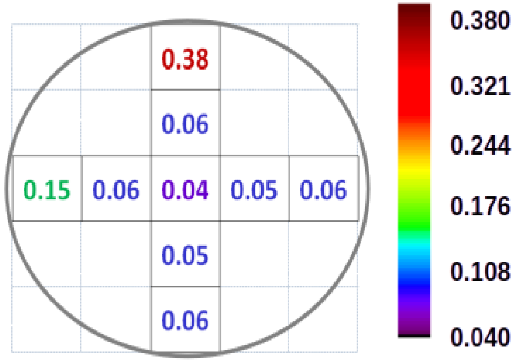
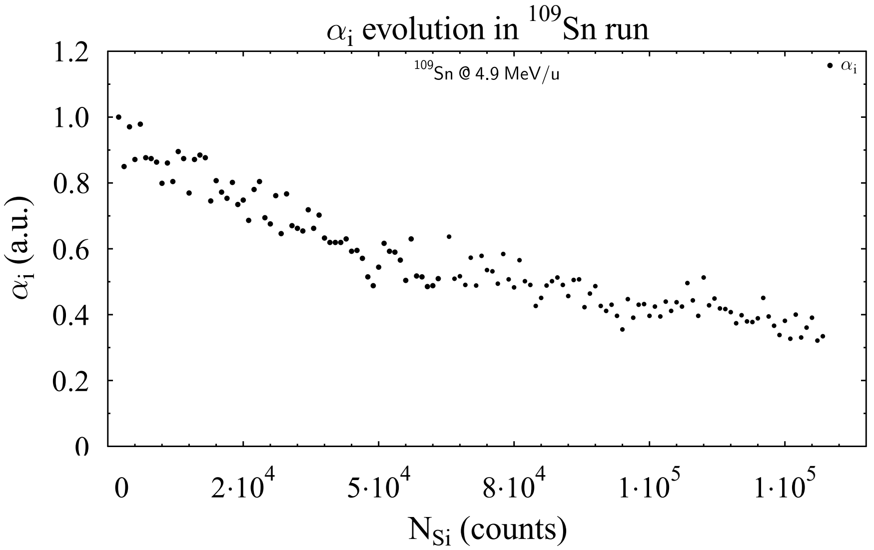


p-RBS spectrum of the F3 Si:He in different target points after IS698



He/Si ratio obained from p-EBS analysis of the F3 Si:He after IS698



$$\alpha_i = \frac{N^i_{He}(60°)}{N^i_{Si}(60°)}\,\frac{N^0_{Si}(60°)}{N^0_{He}(60°)}$$

Preliminary results

$^{4}He(^{112}Sn,^{112}Sn)^{4}He$ @ 18.9 MeV (CM)

$$\frac{d\sigma_{He}}{d\Omega}(\theta) = \sum_{i} \left(\frac{N^{i}_{He}(\theta)\,/\alpha_i}{N^{i}_{Si}(60^\circ)} \right) \left(\frac{d\sigma_{Si}}{d\Omega}(60^\circ) \right)_{\text{Ruth}}$$

Preliminary results

$^4He(^{112}Sn,^{112}Sn)^4He$ @ 18.9 MeV (CM)

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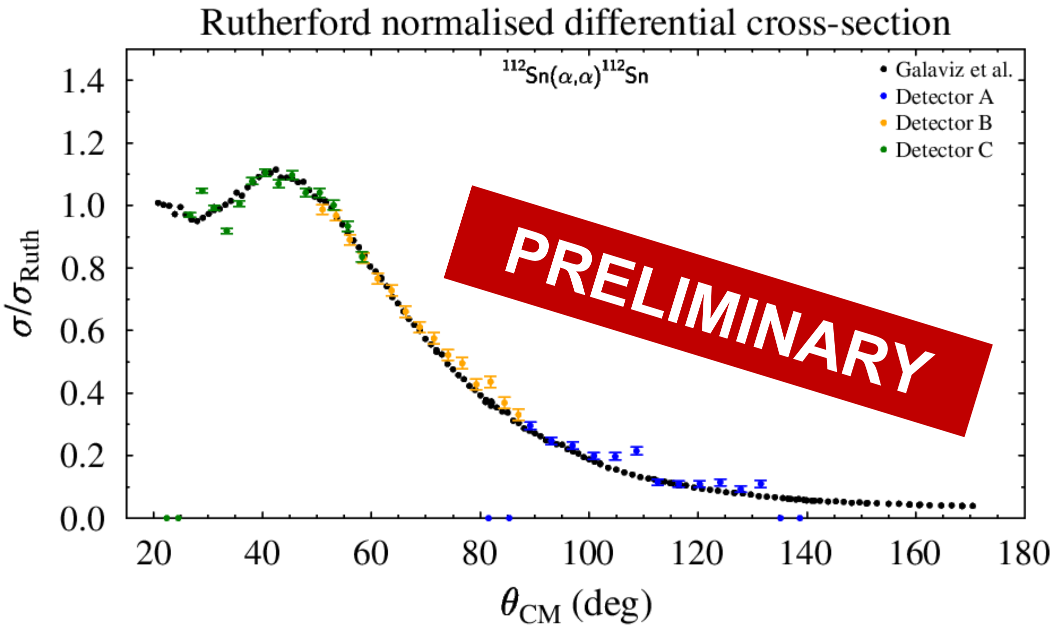

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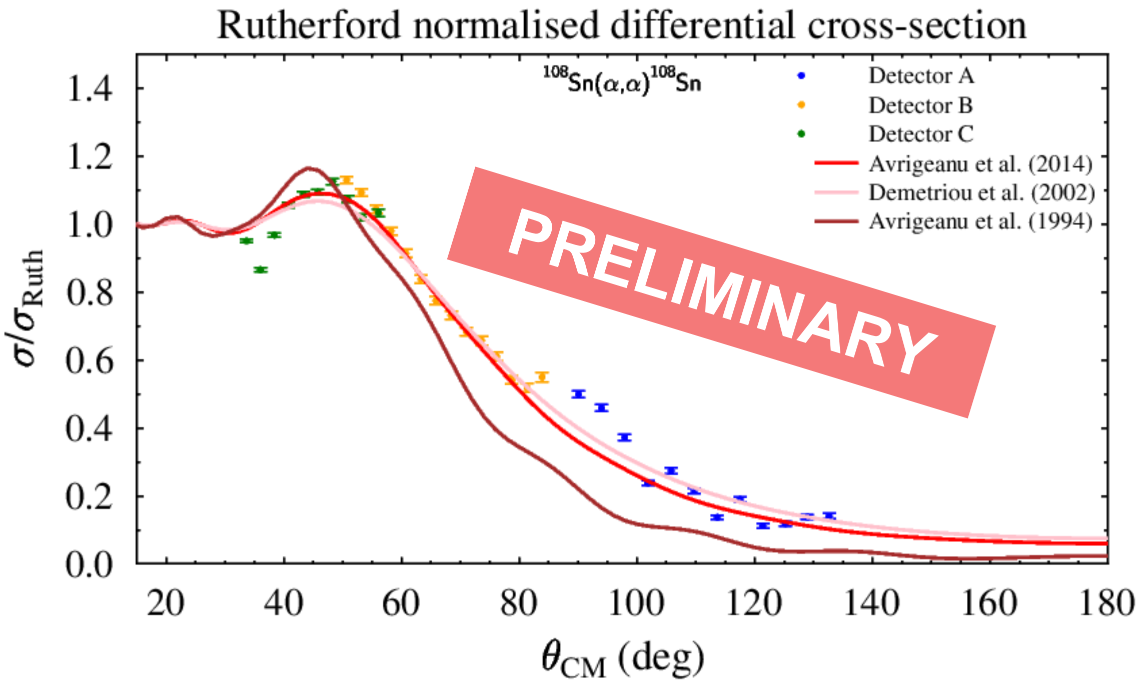
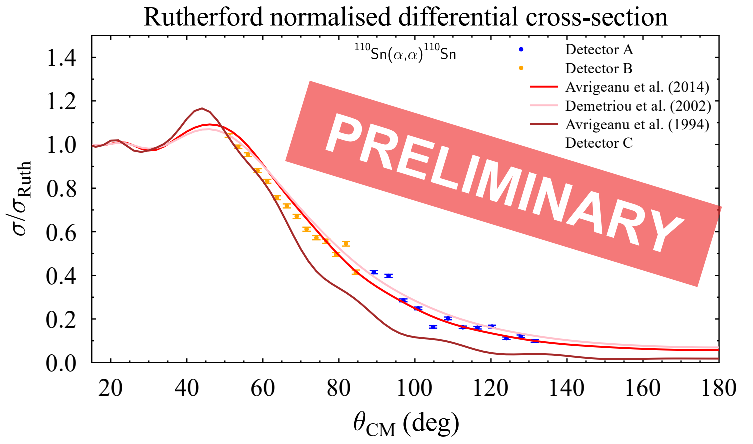
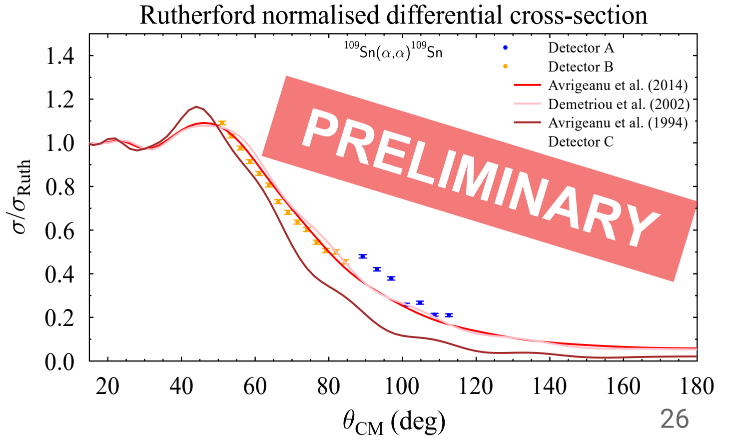






Conclusions

- **Four angular distributions** measured covering a large angular range.
- **Good performance** of high concentration ^{4}He targets
- **Analysis defined** for all the angular regions.
- **Technique benchamarked** with previously measured data in direct kinematics
- **Preliminary data on radioactive** nuclei showing consistency of the method

Acknowledgments

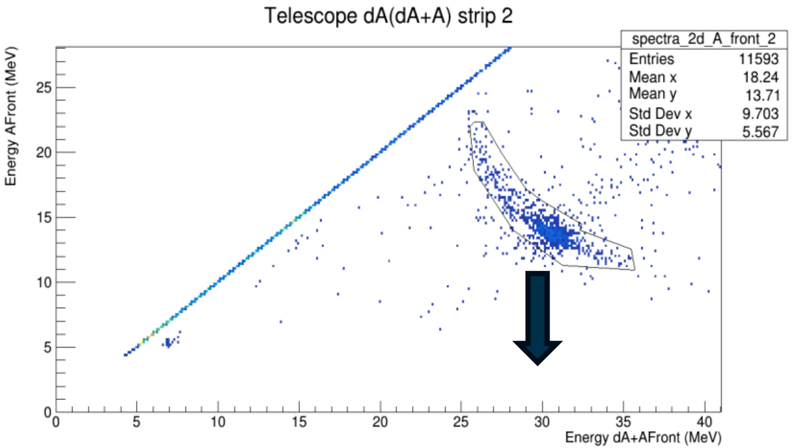
D. Galaviz, J. Ferrer, A. M. Sánchez-Benítez, L. Acosta, B. Amorim, F. G. Barba, M. L. Benito, M. J. Borge, J. Cederkall, M. M. R. Chisti, M. La Cognata, J. G. Correia, Y. Demane, A. Di Pietro, C. Ducoin, E. Fadakis, A. Fernández, B. Fernandez, J. P. Fernández, P. Figuera, L. M. Fonseca, L. M. Fraile, S. Freeman, V. García, V. Godinho, J. Gómez Camacho, D. Hufschmidt, K. Johnston,U. Koester, L. Lamia, B. Olaizola, A. Perea, R. Pires, A. Rodriguez, S. Rothe, E. Siesling, O. Tengblad, P. Teubig, A. Tumino, M. Xarepe

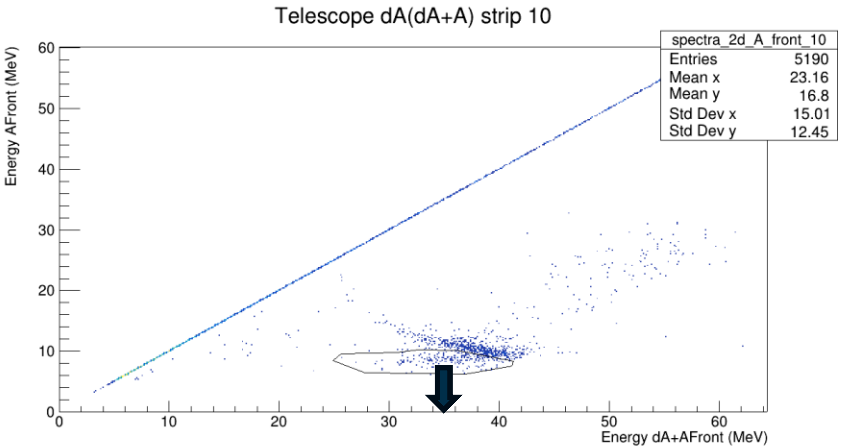
RENASCER Project: CERN/FIS-PAR/0009/2021
SCORE Project: EXPL/FIS-NUC/0364/2021
FCT PhD Fellowship: UI/BD/154300/2022
Spanish Project: PID2023-147569NB-C22

BACKUP SLIDES

Detector A

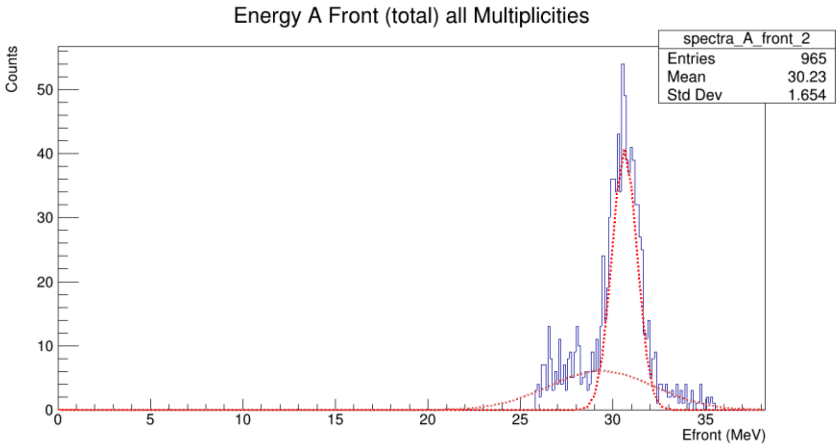
- Separate what is punchthough (consider Elastic Peak higher energy)
- Projection on Total Energy Axis

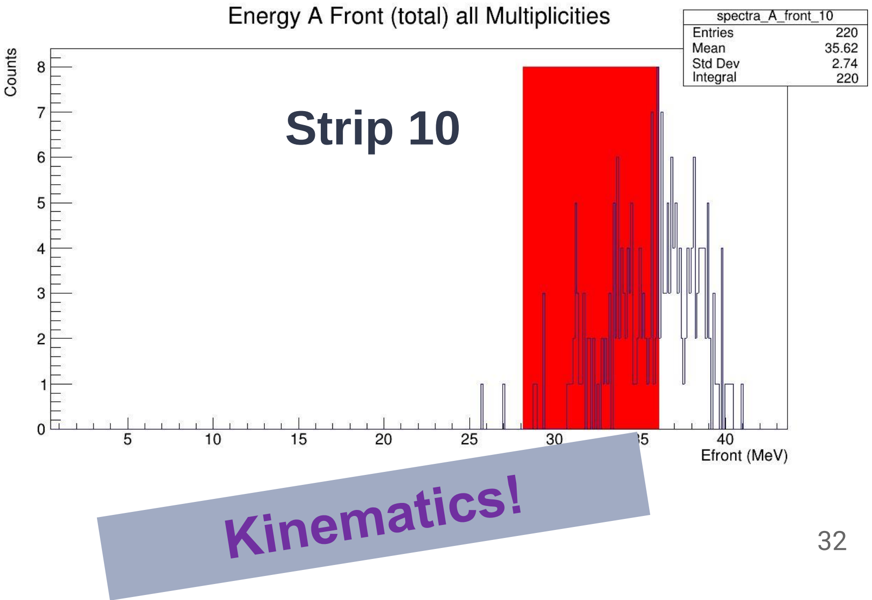




Detector A

- Select regions for elastically scattered alpha-particles





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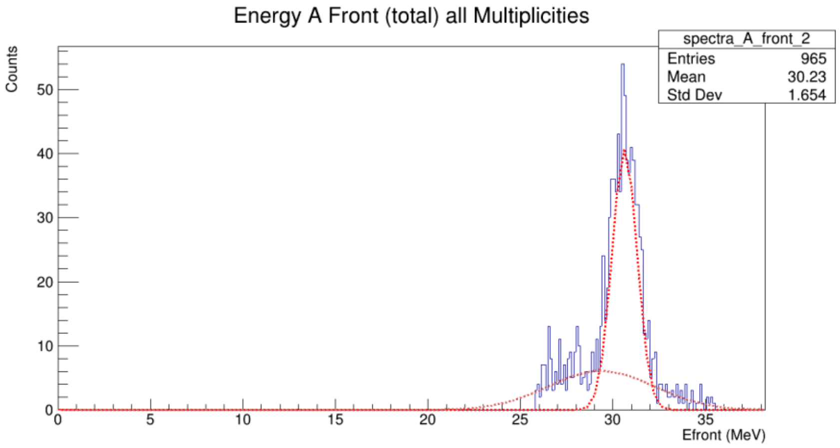
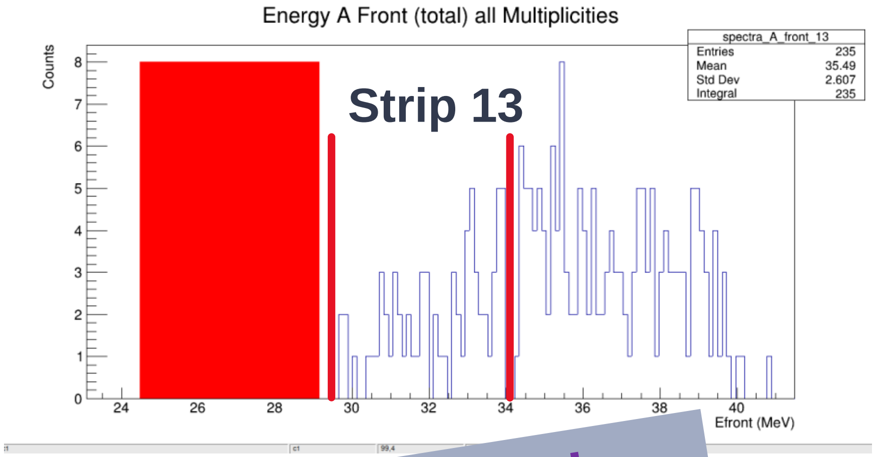




Kinematics!

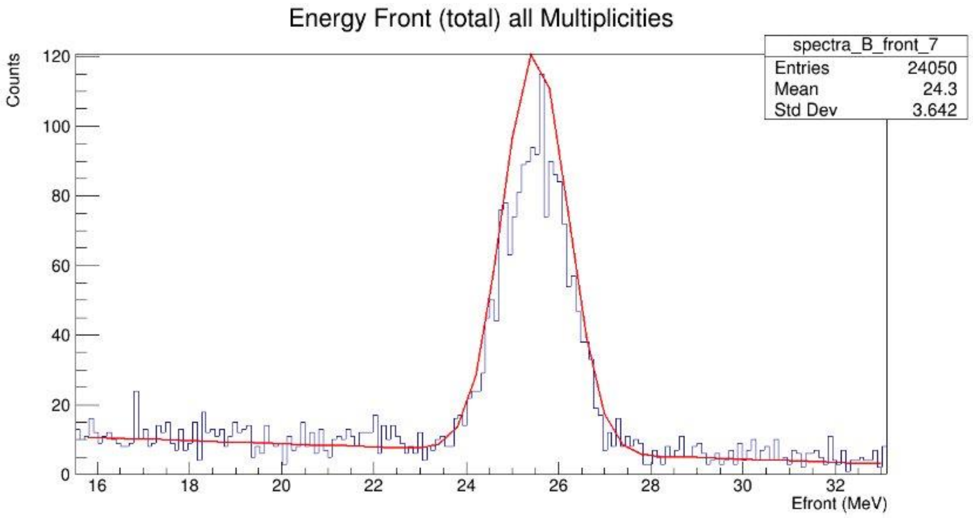
Detector B

I wish they all could be detectors B….!

Fit Gaus + pol1

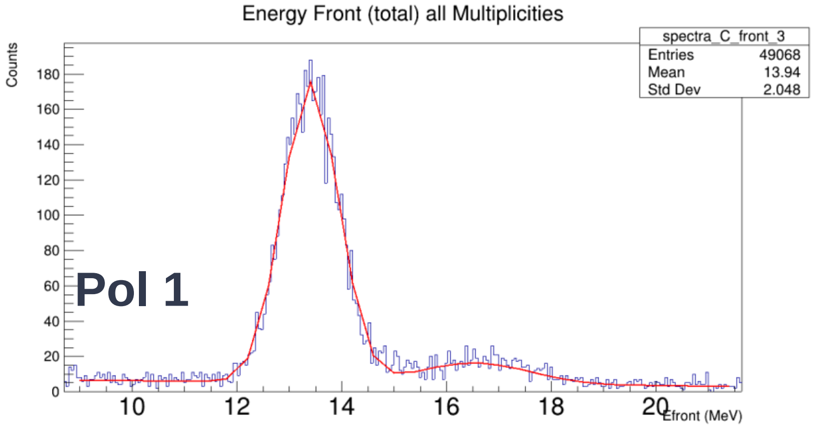
Integrate in centroid +/- sigma

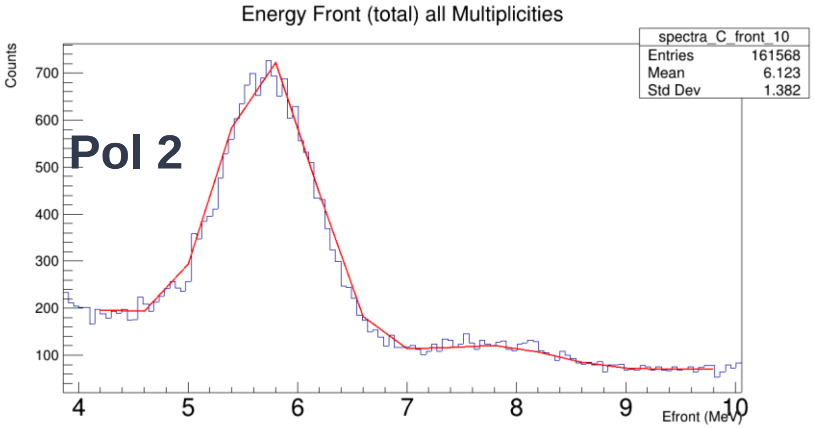
Apply counter-bg/counter factor to integral in **each pixel**



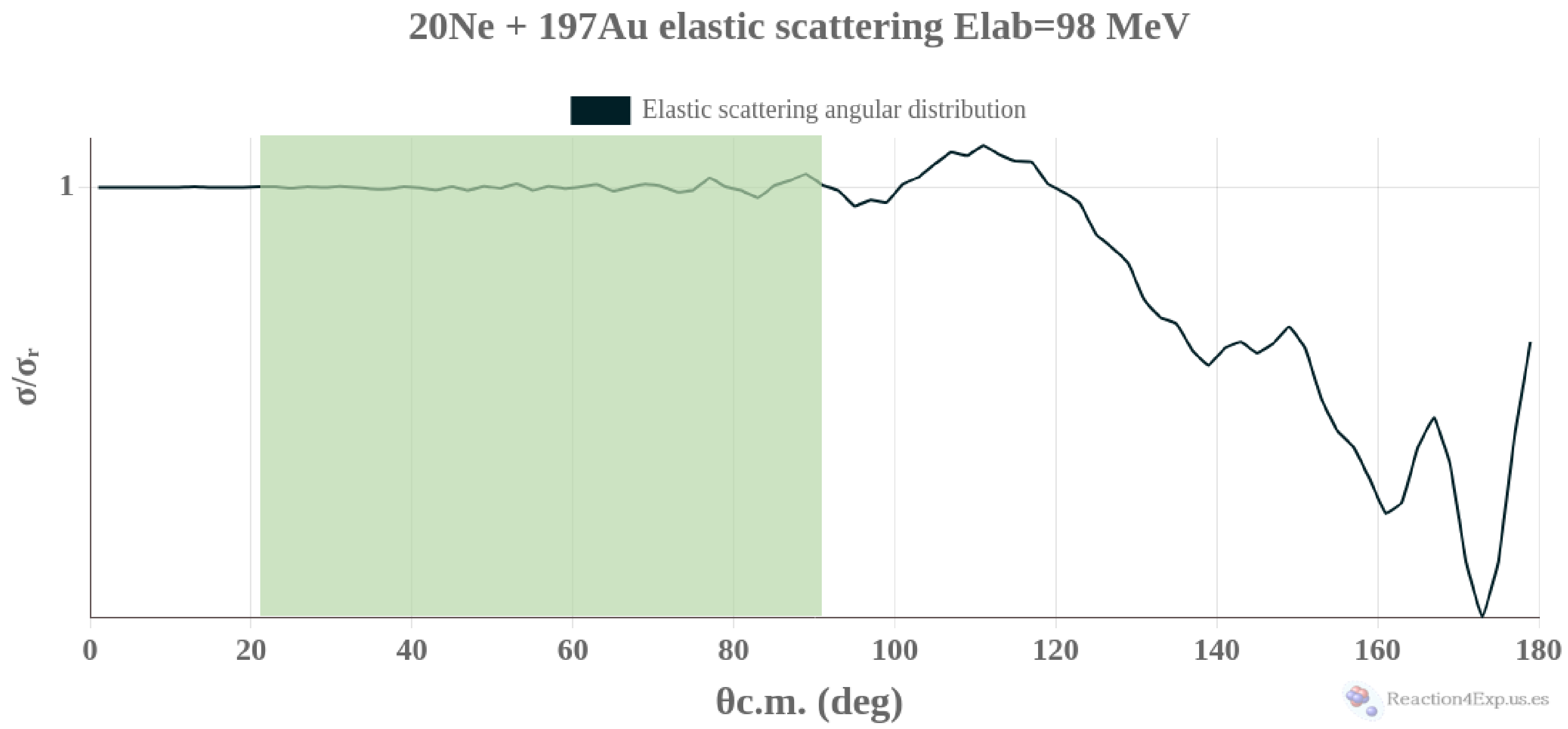
Detector C

Separete Linear bg from quadratic bg
Fit gaus+gaus+pol
Integrate in centroid1-sigma1 and centroid2+sigma2
Apply counter-bg/counter to the amounts in **each pixel**





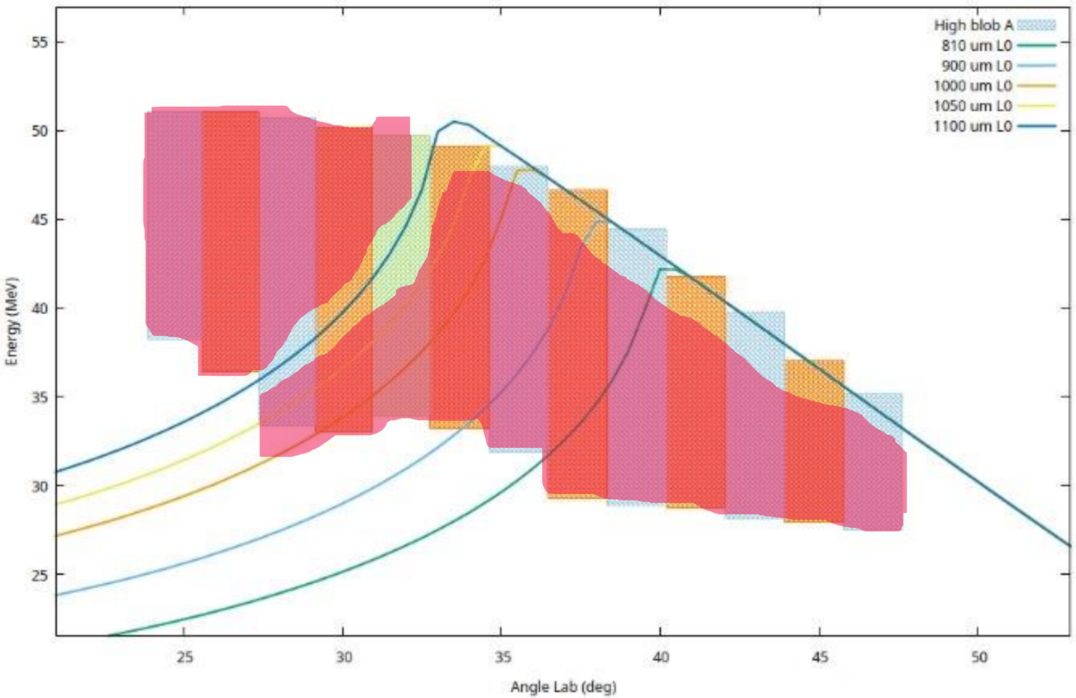
Backup: Pilot Beam calculated xs



Detector A – inelastic channels

E(level) (keV)	XREF	Jπ(level)
0.0	ABCDEFGHIJKLMNOPQ	0+
1256.69 4	BCDEFGHIJKLMN PQ	2+
2150.87 5	BC E LMN	2+
2190.81 6	C E H LMNO Q	0+
2247.39 6	BC EF HIJKLMN P	4+
2354.21 6	BC EF H LMN PQ	3-
2476.16 11	BC E H MN Q	2+
2520.70 7	BC EFGHI MN P	4+
2549.22 14	EF HIJK MN	6+
2556.6 3	B	(2+)
2617.62 18	E MN	0+
2721.06 14	B E MN	2+
2756.02 9	B E M	3+

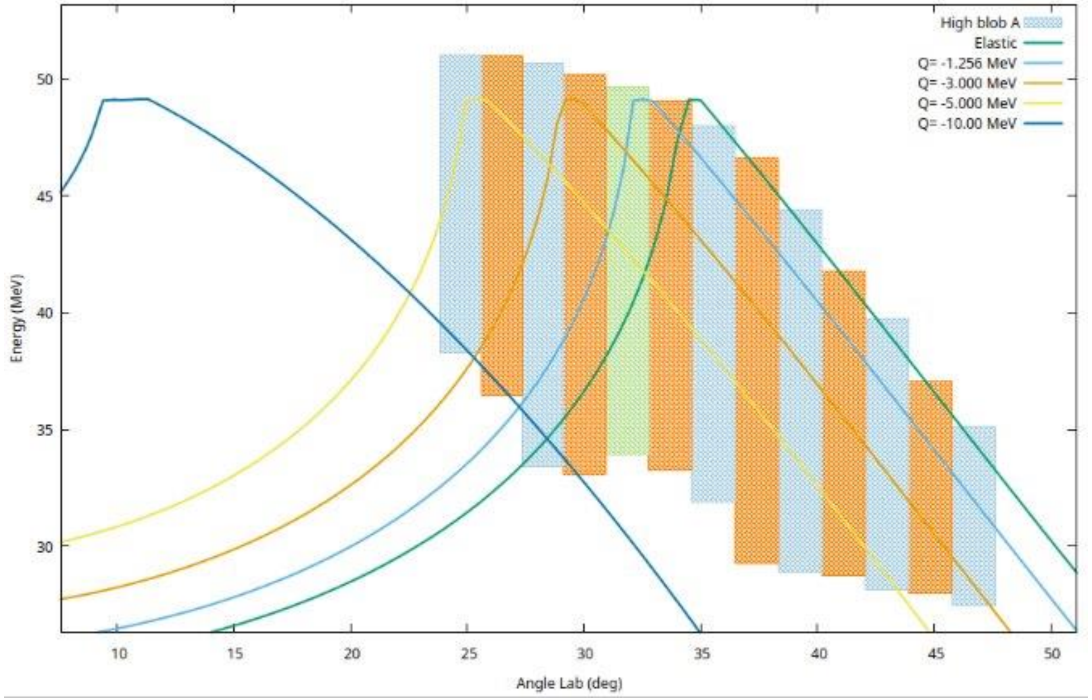
Energy deposited by elastic scattered ^{4}He in different Si thicknesses



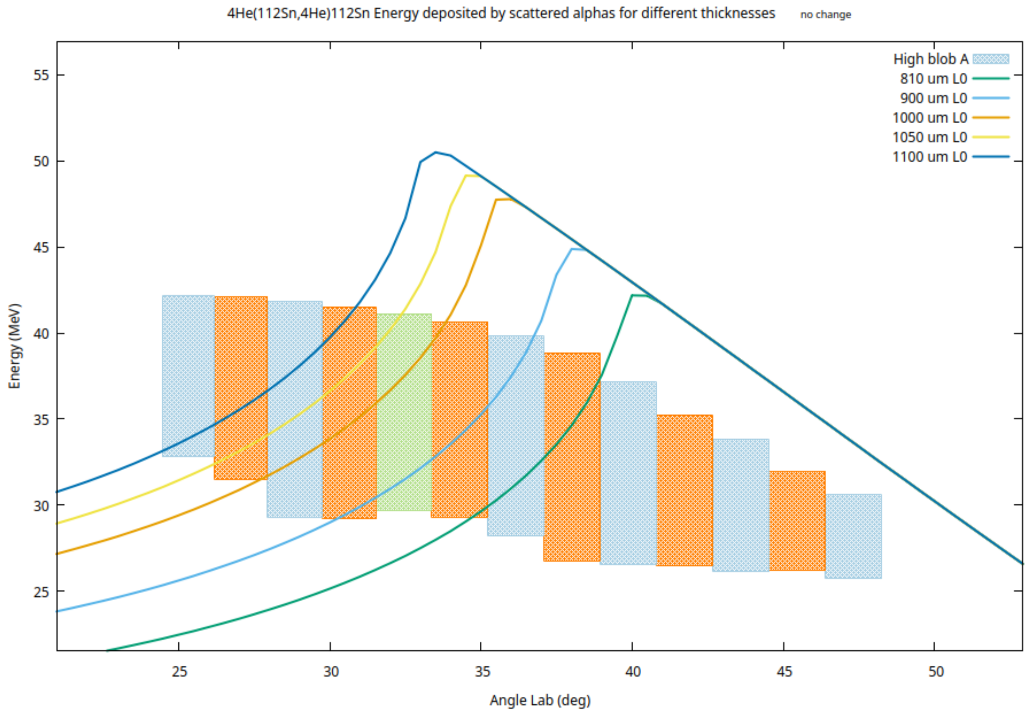
Detector A

E(level) (keV)	XREF	J^{π}(level)
0.0	ABCDEFGHIJKLMNOPQ	0+
1256.69 *4*	BCDEFGHIJKLMN PQ	2+
2150.87 *5*	BC E LMN	2+
2190.81 *6*	C E H LMNO Q	0+
2247.39 *6*	BC EF HIJKLMN P	4+
2354.21 *6*	BC EF H LMN PQ	3-
2476.16 *11*	BC E H MN Q	2+
2520.70 *7*	BC EFGHI MN P	4+
2549.22 *14*	EF HIJK MN	6+
2556.6 *3*	B	(2+)
2617.62 *18*	E MN	0+
2721.06 *14*	B E MN	2+
2756.02 *9*	B E M	3+

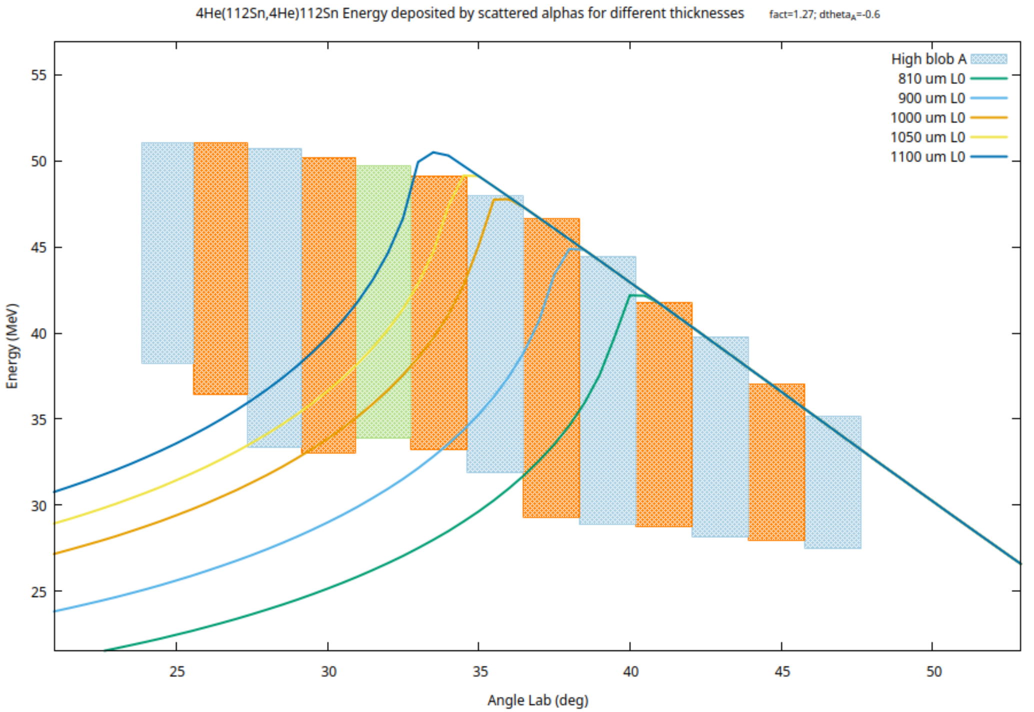
Energy deposited by scattered ^{4}He in 1050 um Si for different Sn excited states



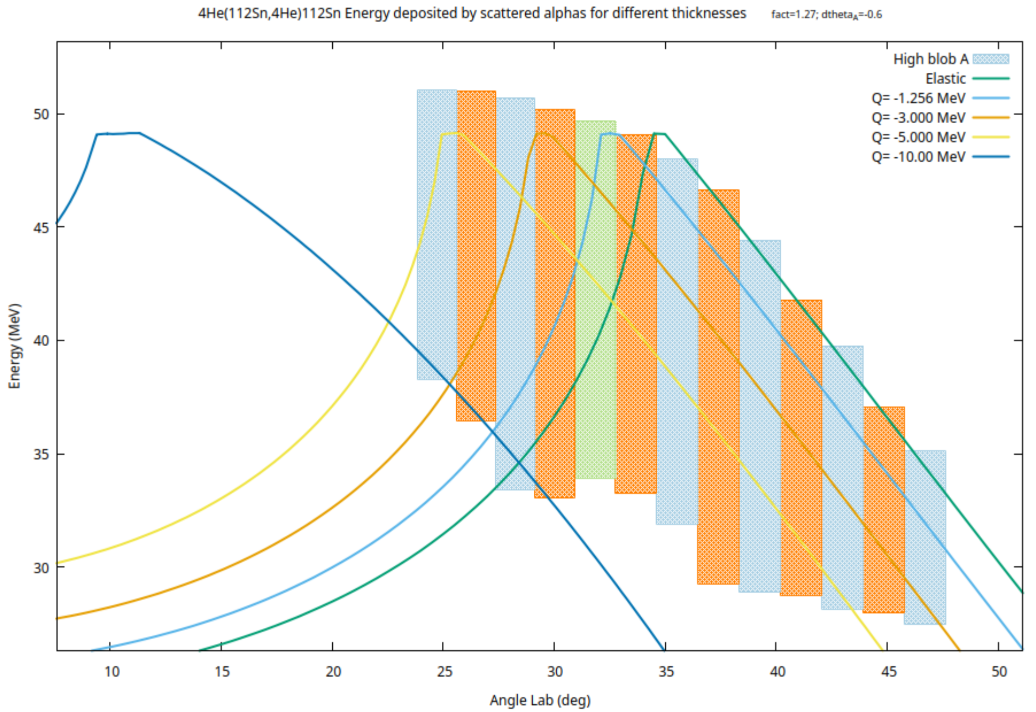
- Energy deposited by alphas from elastic scattering at different thicknesses



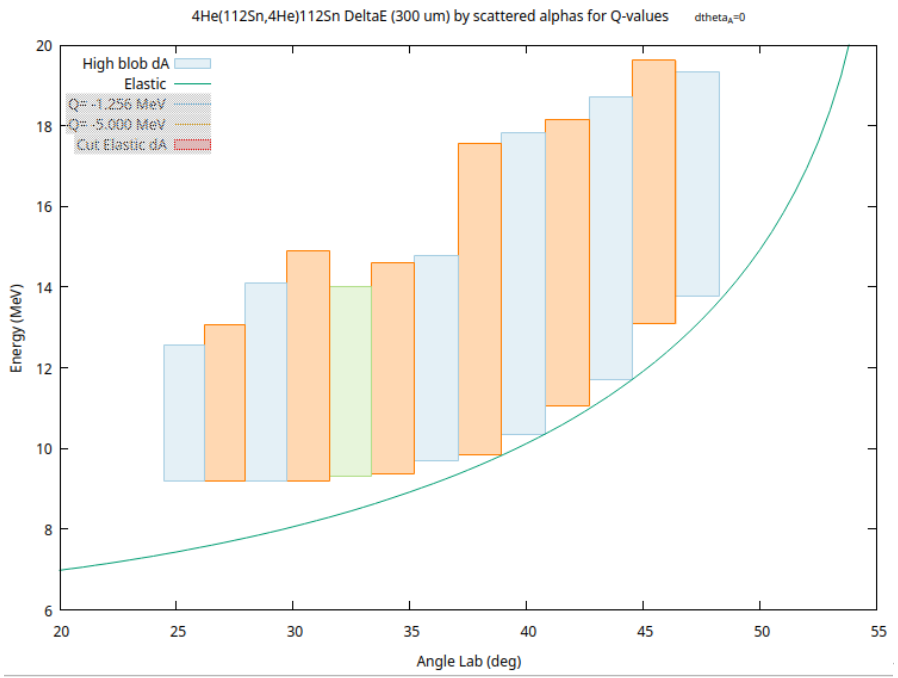
- Adjusted gain **in pad** and angular shifted to meet the kinematic curves



- Assuming thickness of **1050 um** in the telescope

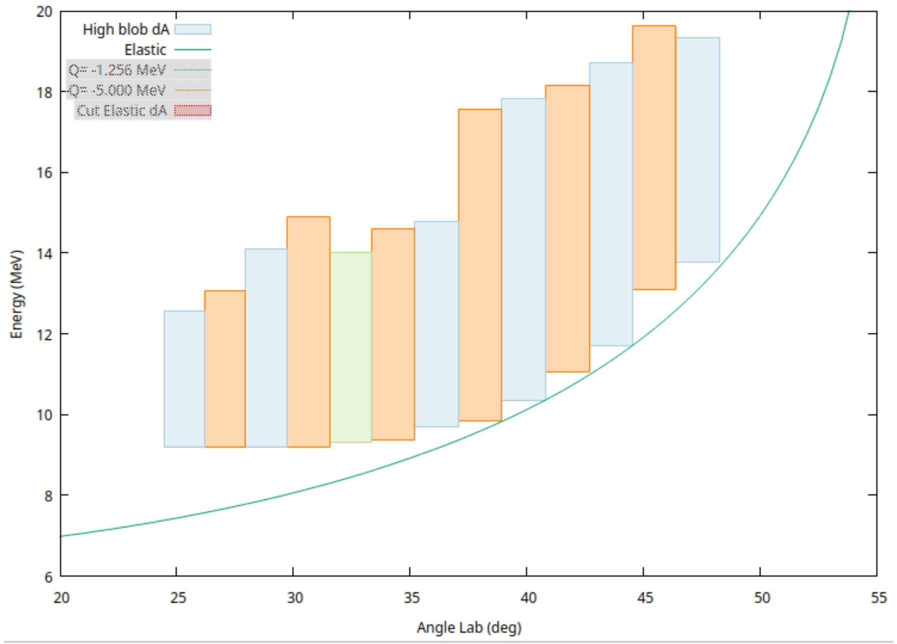


- Energy deposited by elastic alphas in deltaE detector (300 um)

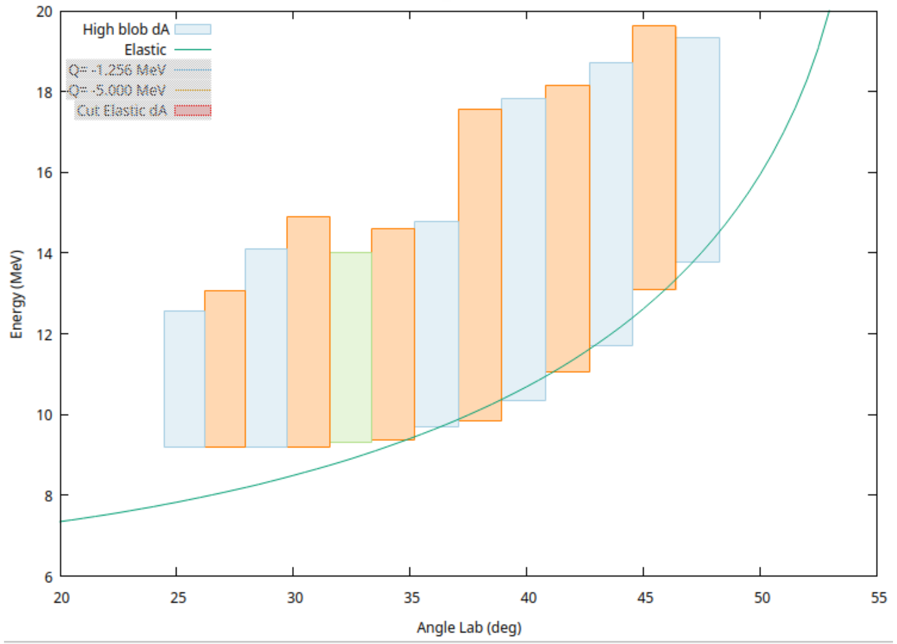


- Adjusted deltaE thickness to 315 um and removed angular shift

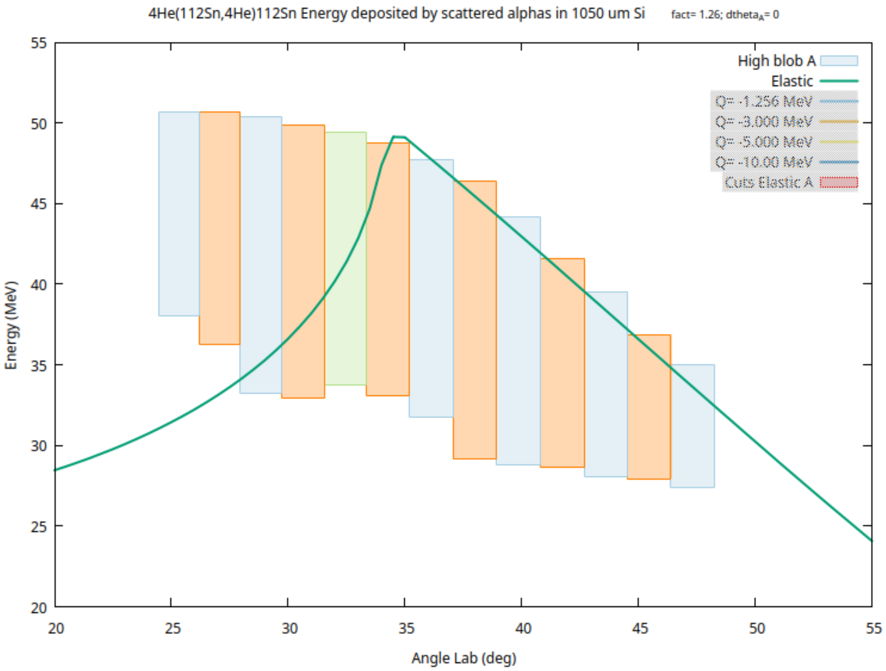
4He(112Sn,4He)112Sn DeltaE (300 um) by scattered alphas for Q-values dtheta$_A$=0



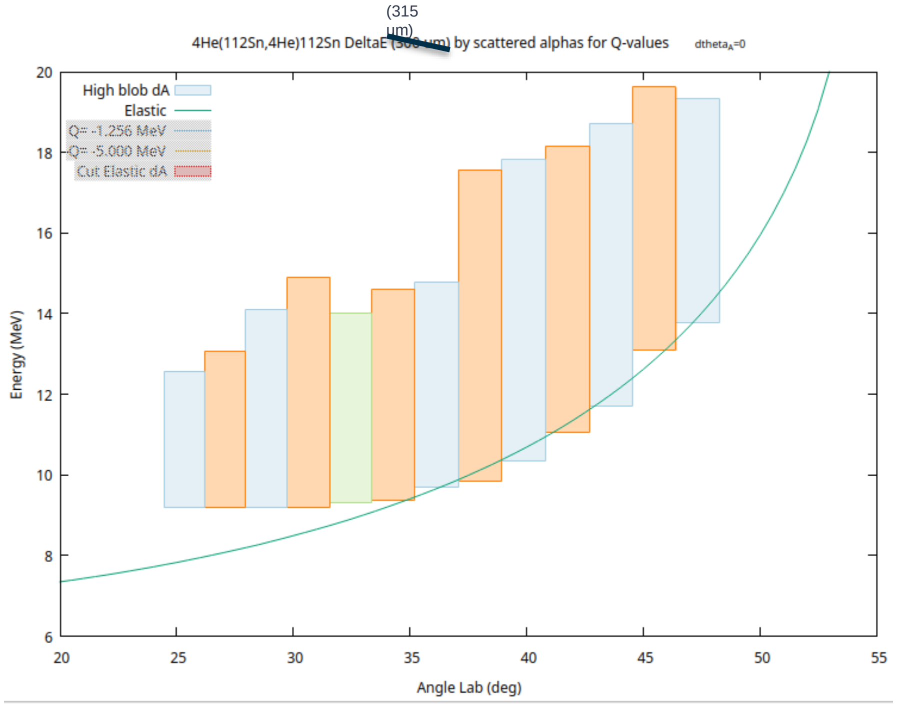
(315 um)
4He(112Sn,4He)112Sn DeltaE ~~(300 um)~~ by scattered alphas for Q-values dtheta$_A$=0



315
um
735 um



4He(112Sn,4He)112Sn Energy deposited by scattered alphas in 1050 um Si
fact= 1.26; dthetaA= 0
High blob A
Elastic
Q= -1.256 MeV
Q= -3.000 MeV
Q= -5.000 MeV
Q= -10.00 MeV
Cuts Elastic A
Energy (MeV)
Angle Lab (deg)



(315
um)
4He(112Sn,4He)112Sn DeltaE
by scattered alphas for Q-values
dthetaA=0
High blob dA
Elastic
Q= -1.256 MeV
Q= -5.000 MeV
Cut Elastic dA
Energy (MeV)
Angle Lab (deg)

Angular Calibration

$^{197}Au(^{20}Ne,^{20}Ne)^{197}Au$ @ 4.9 MeV/u

Pilot Beam Spectra