First ever α-scattering with radioactive ion beams:

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

ISOLDE Workshop and Users meeting

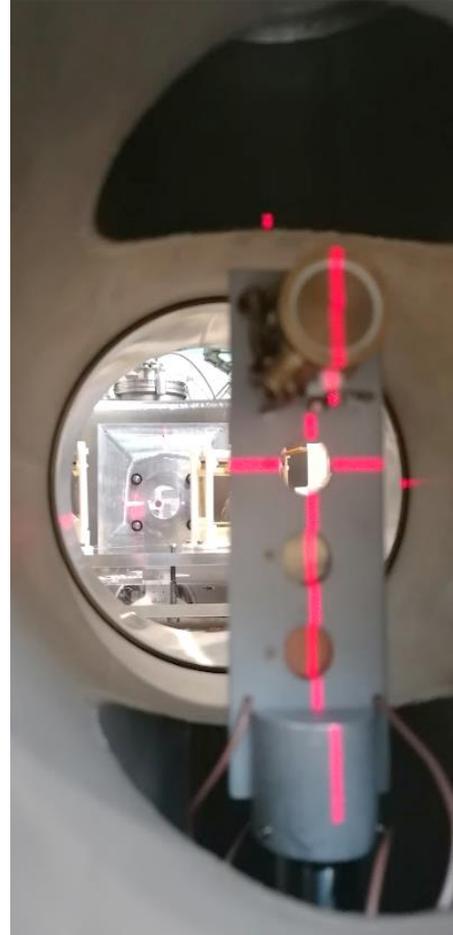Wednesday, 3rd December 2025

Francisco G. Barba

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LIP

Outline

- Why study α-nuclear potentials?

- Challanges of the measurement

- Setup and benchmark of technique

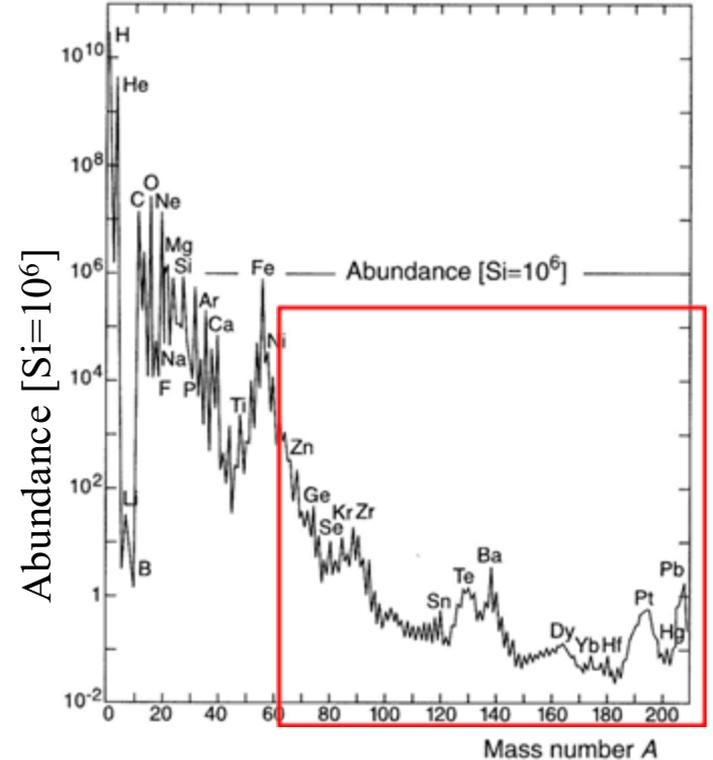- Status of $^4He(^ASn,^4He)^ASn$ analysis with exotic Sn

Motivation

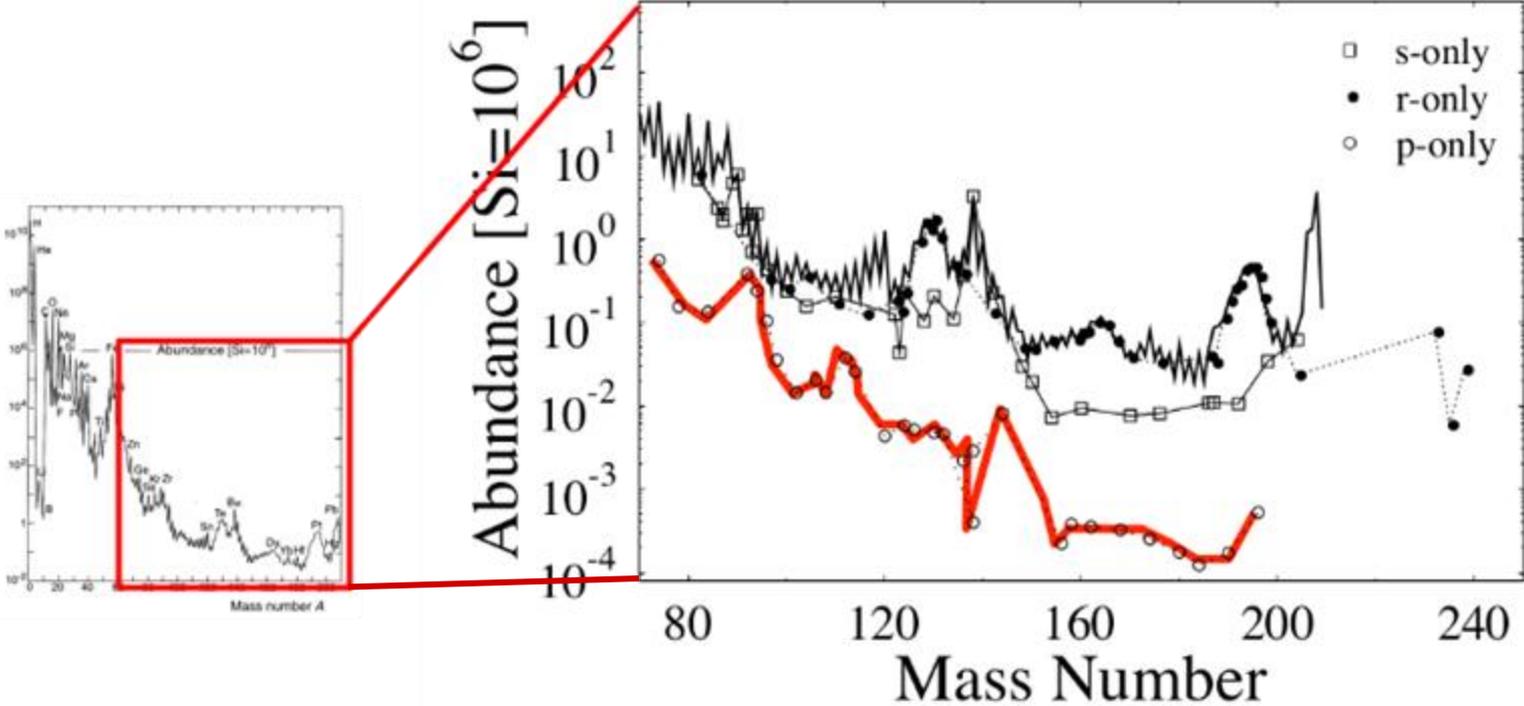**Solar Abundance Distribution (SAD)**

Bulk of elements:
- BBN
- Fusion phase
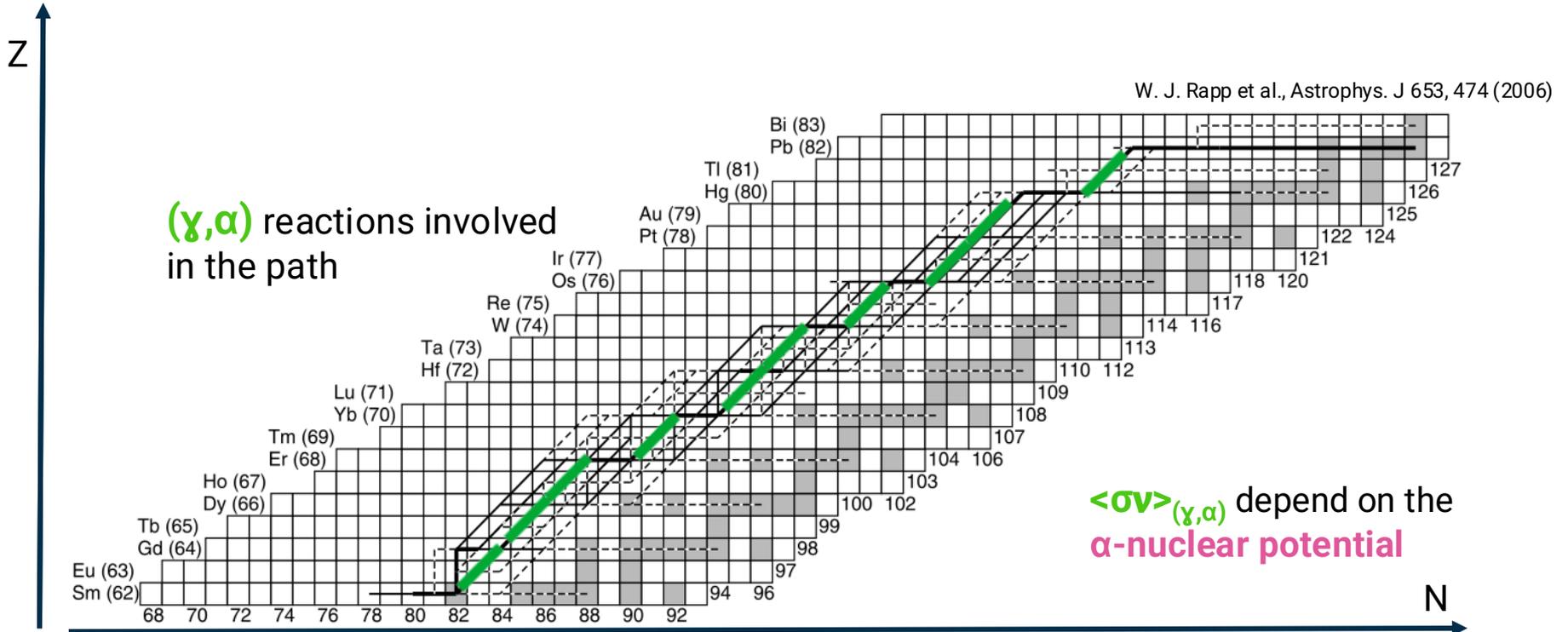
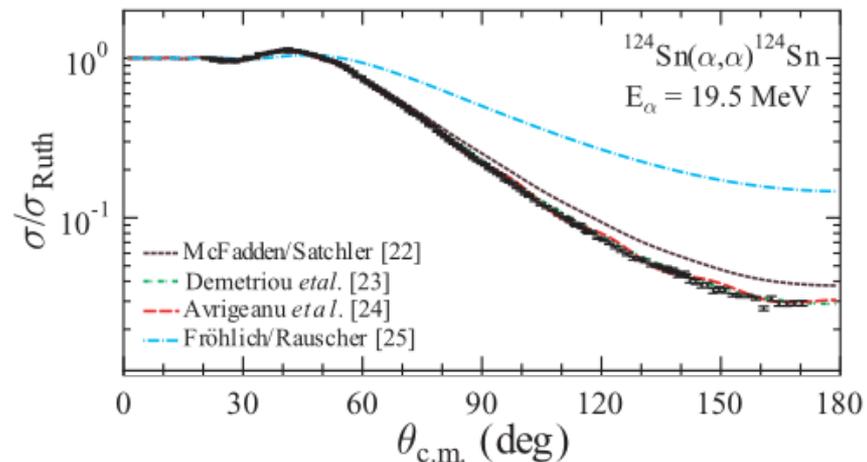Heavy elements:
- **Neutron capture** processes

p-nuclei

Sensitivity studies of gamma Process

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

(ɣ,α) reactions involved in the path

$<\sigma v>_{(ɣ,α)}$ depend on the α-nuclear potential

α-nuclear potentials: elastic scattering

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

α-nuclear potentials: elastic scattering

Mass dependence in stable Sn isotopes

McFadden/Satchler [22]
Demetriou et al. [23]
Avrigeanu et al. [24]
Fröhlich/Rauscher [25]

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

α-nuclear potentials: elastic scattering

Si/He Targets

Magnetron Sputtering
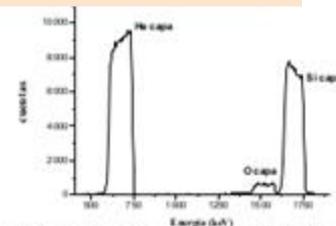Si/He thin films

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

Exotic beam

Self-supported Si:He target

RBS spectrum of SiHe target using 2.0 MeV protons and 165° scattering angle

SEM corss section of the SiHe target

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

Si/He Targets

Magnetron Sputtering
Si/He thin films

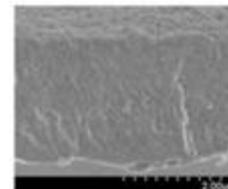| Element	Si	He	C	N	O	H
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Exotic beam

Self-supported Si:He target

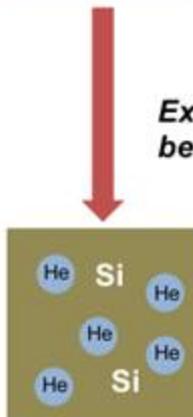RBS spectrum of SiHe target using 2.0 MeV protons and 165° scattering angle
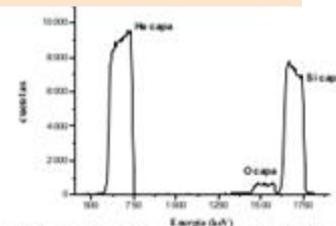
SEM cross section of the Si:He target

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 (x10^{15})	2820	**1280**	100	390	380	475

Exotic beam

RBS spectrum of Si:He target using 2.0 MeV protons and 165° scattering angle

Self-supported Si:He target

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

DSSD 300 µm +
PAD 1500 µm

A

Beam

Setup

Telescope A
19º to 51º

Detector B
46º to 65º

DSSD 300 μm +
PAD 1500 μm

DSSD 1000 μm

A

B

Beam

Setup

Telescope A
19º to 51º

Detector C
60º to 78º

DSSD 300 μm

DSSD 300 μm +
PAD 1500 μm

DSSD 1000 μm

Detector B
46º to 65º

C

A

B

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

$$^4He(^ASn,^4He)^ASn \text{ @ } 4.9 \text{ MeV/u}$$

^{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 <u>decreases</u>

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

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

α_i evolution in ^{109}Sn run

^{109}Sn @ 4.9 MeV/u

α_i (a.u.)

N_{Si} (counts)

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**

$$\alpha_i = \frac{N_{He}^i(60°)}{N_{Si}^i(60°)} \frac{N_{Si}^0(60°)}{N_{He}^0(60°)}$$

α_i evolution in ^{109}Sn run

Before counting...!
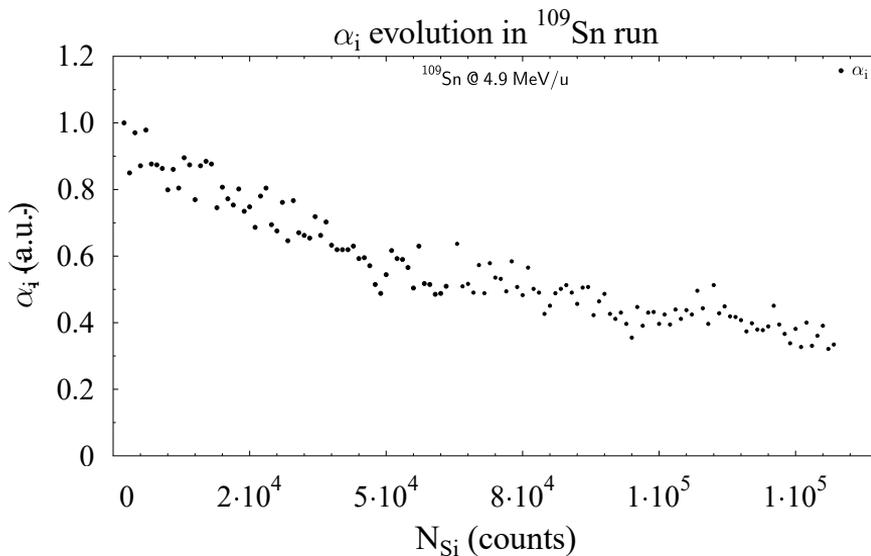
Amount of ⁴He over time

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

α_i evolution in ^{109}Sn run

$$\alpha_i = \frac{N_{He}^i(60°)}{N_{Si}^i(60°)} \frac{N_{Si}^0(60°)}{N_{He}^0(60°)}$$

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Preliminary results

⁴He(¹¹²Sn,¹¹²Sn)⁴He @ 18.9 MeV (CM)

$$\frac{d\sigma_{He}}{d\Omega}(\theta) = \sum_i \left(\frac{N_{He}^i(\theta)/\alpha_i}{N_{Si}^i(60°)} \right) \left(\frac{d\sigma_{Si}}{d\Omega}(60°) \right)_{\text{Ruth}}$$

Preliminary results

⁴He(¹¹²Sn,¹¹²Sn)⁴He @ 18.9 MeV (CM)

$$\frac{d\sigma_{He}}{d\Omega}(\theta) = \sum_i \left(\frac{N^i_{He}(\theta)/\alpha_i}{N^i_{Si}(60°)} \right) \left(\frac{d\sigma_{Si}}{d\Omega}(60°) \right)_{Ruth}$$

Rutherford normalised differential cross-section

Preliminary results

Rutherford normalised differential cross-section

$^{108}Sn(\alpha,\alpha)^{108}Sn$

PRELIMINARY

Rutherford normalised differential cross-section

$^{110}Sn(\alpha,\alpha)^{110}Sn$

PRELIMINARY

Rutherford normalised differential cross-section

$^{109}Sn(\alpha,\alpha)^{109}Sn$

PRELIMINARY

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

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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

Detector A

- Select regions for elastically scattered alpha-particles

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

20Ne + 197Au elastic scattering Elab=98 MeV

Elastic scattering angular distribution

σ/σ_r

θc.m. (deg)

Reaction4Exp.us.es

Detector A – inelastic channels

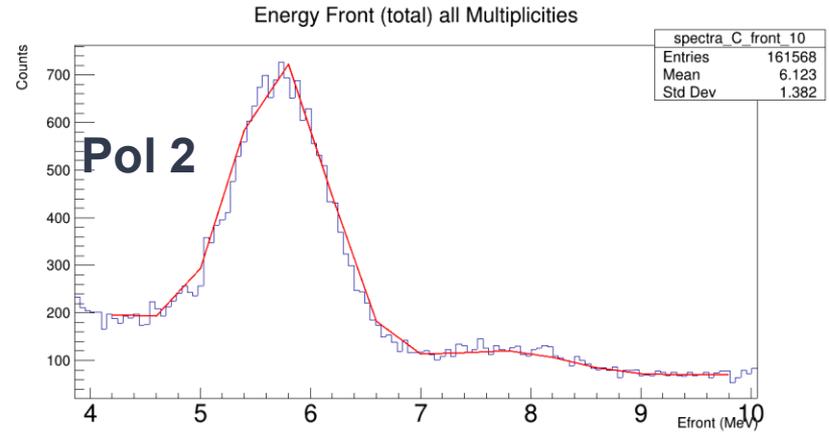| E(level) (keV)	XREF	Jπ(level)
0.0	ABCDEFGHIJKLMNOPQ	0+
1256.69 4	BCDEFGHIJKLMN PQ	2+
2150.87 5	BC E LMN	2+
2190.81 6	C E H LMNO Q	0+
2247.39 6	BC EF HIJKLMN P	4+
2354.21 6	BC EF H LMN PQ	3-
2476.16 11	BC E H MN Q	2+
2520.70 7	BC EFGHI MN P	4+
2549.22 14	EF HIJK MN	6+
2556.6 3	B	(2+)
2617.62 18	E MN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

4He(112Sn,4He)112Sn Energy deposited by scattered alphas for different thicknesses   no change

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

4He(112Sn,4He)112Sn Energy deposited by scattered alphas for different thicknesses   fact=1.27; dtheta$_A$=-0.6

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

4He(112Sn,4He)112Sn Energy deposited by scattered alphas for different thicknesses   fact=1.27; dtheta_A=-0.6

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

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

- Adjusted deltaE thickness to 315 um and removed angular shift

4He(112Sn,4He)112Sn Energy deposited by scattered alphas in 1050 um Si   fact= 1.26; dtheta$_A$= 0
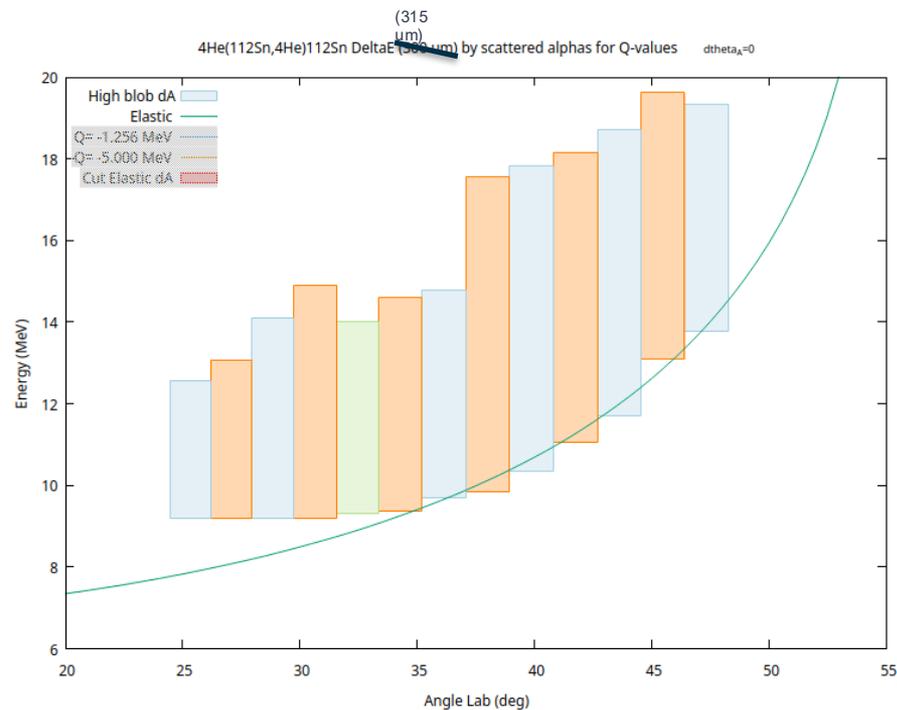
4He(112Sn,4He)112Sn DeltaE (3?? um) by scattered alphas for Q-values   dtheta$_A$=0

(315 um)

315 um

735 um

High blob A
Elastic
Q= -1.256 MeV
Q= -3.000 MeV
Q= -5.000 MeV
Q= -10.00 MeV
Cuts Elastic A

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

Pilot Beam on ^{197}Au target

^{20}Ne

$\theta_{lab} = 60°$

^{12}C ^{16}O ^{32}S

Run 13: Counts normalized to $\Delta\Omega$ and σ_{Ruth}

- Detector A
- Detector B
- Detector C

$N_i/\Delta\Omega_{cm}/\sigma_{Ruth}$

θ_{CM} (deg)