WISArD

28/05/2024 ISOL-FRANCE

Lecanuet Samuel

LP2iB
1st year PhD student

Outline

- Motivation
- 2024 experiment
- Simulations
- Results
- Conclusion

Weak interaction with β decay

Weak interaction with β decay

For a Fermi transition and an unpolarized nucleus :

$$N(\theta_{\beta\nu}, W_\beta)\mathrm{d}W_\beta \propto \left(1 + a\frac{p_\beta p_\nu}{W_\beta W_\nu}\cos(\theta_{\beta\nu}) + b\gamma\frac{m_e}{W_\beta}\right)\mathrm{d}W_\beta$$

Weak interaction with β decay

For a Fermi transition and an unpolarized nucleus :

$$N(\theta_{\beta\nu}, W_\beta)\mathrm{d}W_\beta \propto \left(1 + a\frac{p_\beta p_\nu}{W_\beta W_\nu}\cos(\theta_{\beta\nu}) + b\gamma\frac{m_e}{W_\beta}\right)\mathrm{d}W_\beta$$

angular correlation coefficient

Probe right-handed neutrino in scalar contribution

$$a = \frac{-C_S^2 + 1}{C_S^2 + 1}$$

Weak interaction with β decay

For a Fermi transition and an unpolarized nucleus :

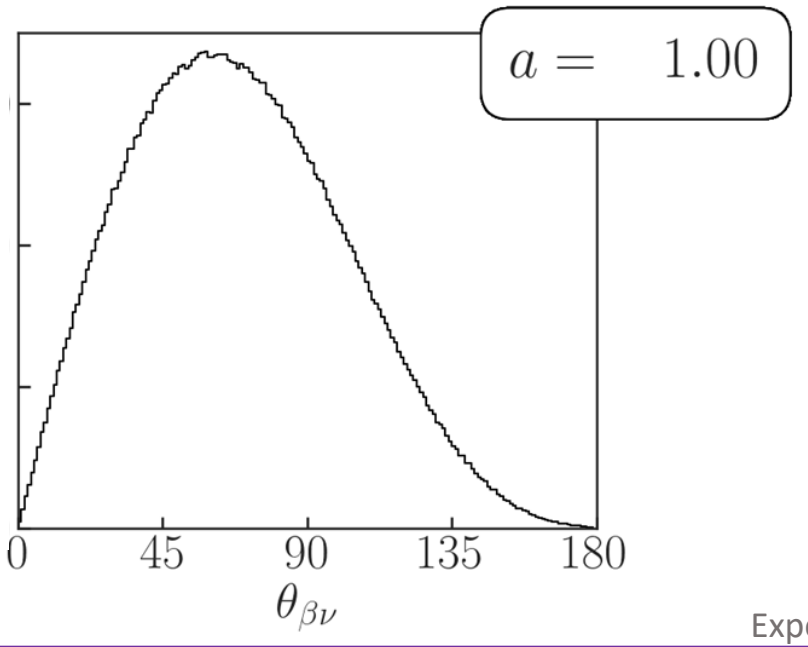
$$N(\theta_{\beta\nu}, W_\beta)\mathrm{d}W_\beta \propto \left(1 + a\frac{p_\beta p_\nu}{W_\beta W_\nu}\cos(\theta_{\beta\nu}) + b\gamma\frac{m_e}{W_\beta}\right)\mathrm{d}W_\beta$$

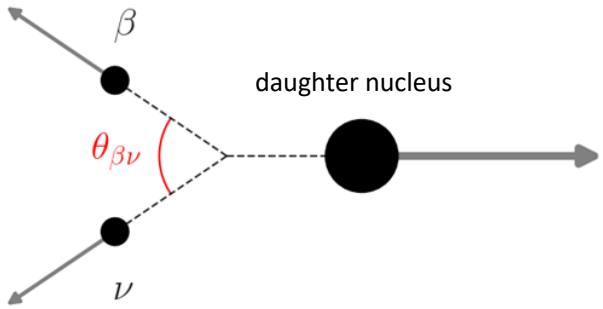
angular correlation coefficient

Probe right-handed neutrino in scalar contribution

$$a = \frac{-C_S^2 + 1}{C_S^2 + 1}$$

Standard Model (b = 0)





Experimentally â is measured (contribution of a and b)

Weak interaction with β decay

For a Fermi transition and an unpolarized nucleus :

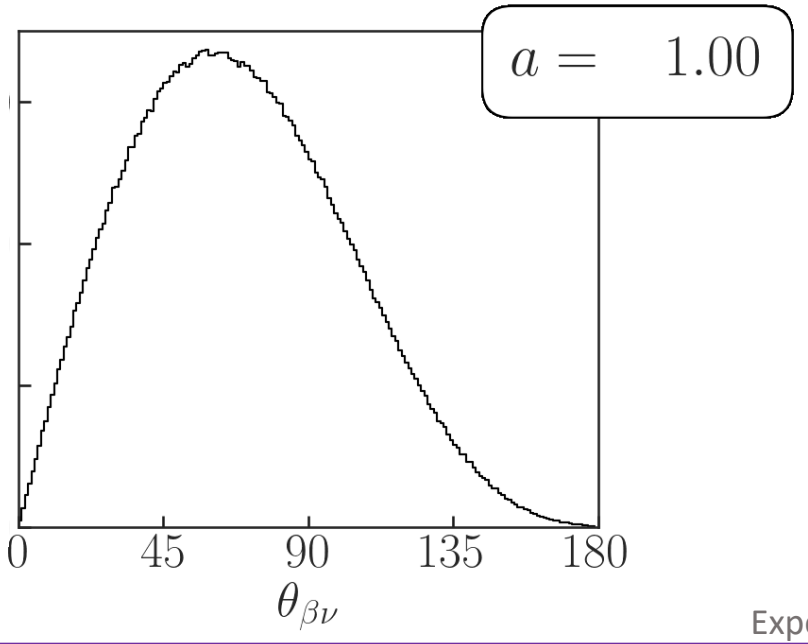
$$N(\theta_{\beta\nu}, W_\beta)\mathrm{d}W_\beta \propto \left(1 + a\frac{p_\beta p_\nu}{W_\beta W_\nu}\cos(\theta_{\beta\nu}) + b\gamma\frac{m_e}{W_\beta}\right)\mathrm{d}W_\beta$$

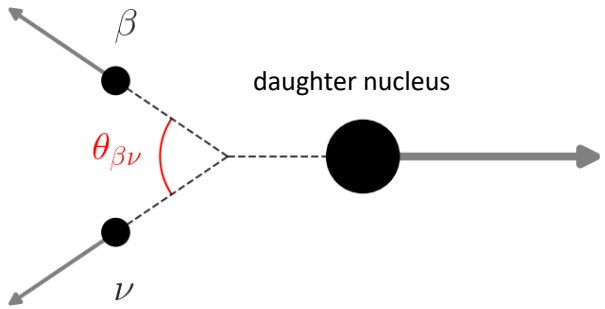
angular correlation coefficient

Probe right-handed neutrino in scalar contribution

$$a = \frac{-C_S^2 + 1}{C_S^2 + 1}$$

Beyond Standard Model (b = 0)





Beyond Standard Model

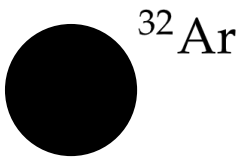
$a \neq 1$

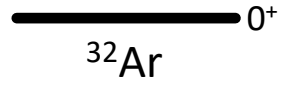
Kinematic change

Experimentally $\tilde{a}$ is measured (contribution of a and b)

Beta delayed proton emission

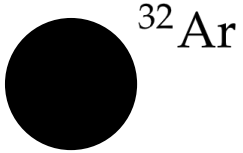
At rest :



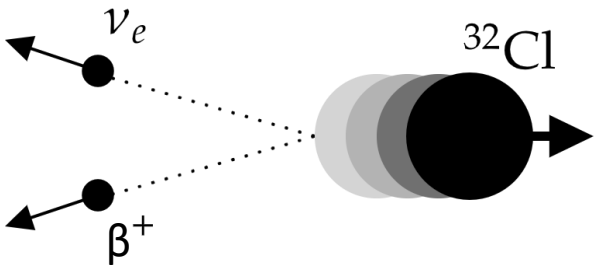


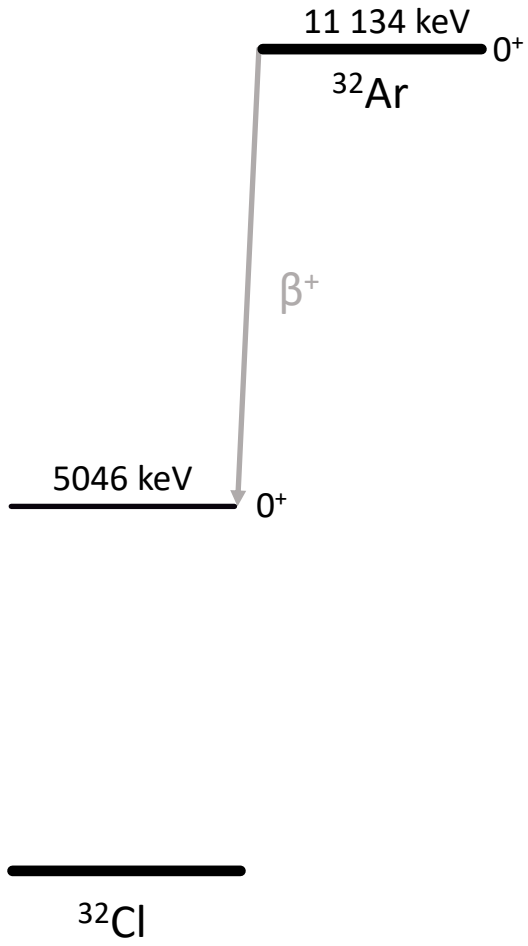
Beta delayed proton emission

At rest :



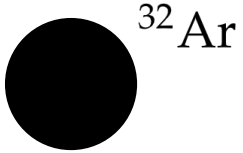
Beta decay :



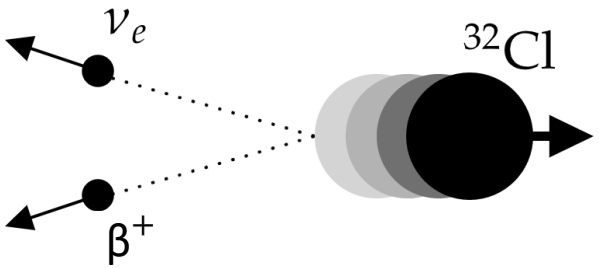


Beta delayed proton emission

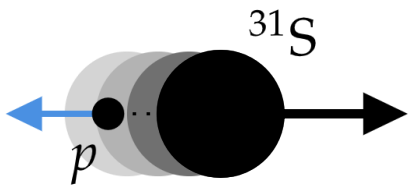
At rest :



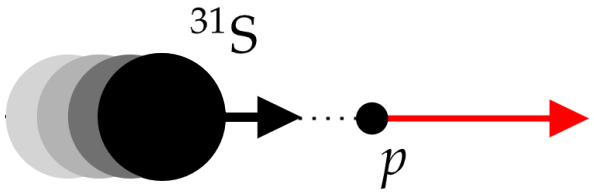
Beta decay :



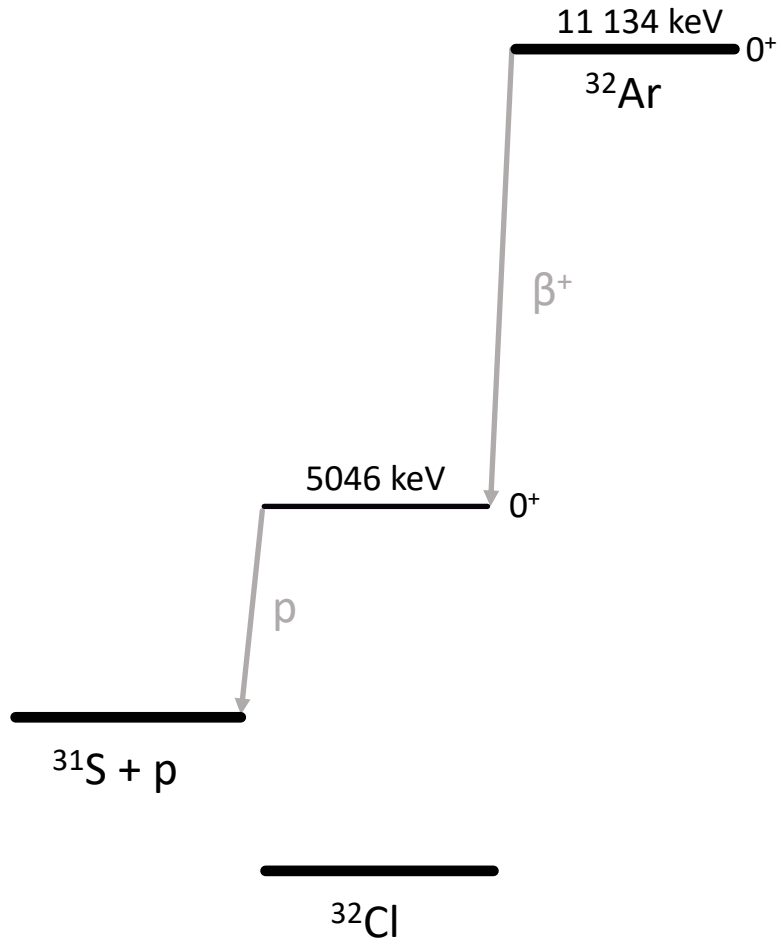
Delayed proton emission : $\overline{E}_{shift}$



Energy decreasing



Energy increasing



High precision measurement

Some previous measurements:

Delayed gamma of ^{18}Ne (1997):	$a = 1.06(19)$	V.Egorov and al. Nucl. Phys. A, 621 (1997), 745
Delayed proton of ^{32}Ar (1999):	$\tilde{a} = 0.9989(52)_{stat}(39)_{sys}$	Adelberger and al. PRL 83 (1999) 1299
Recoil of ^{38}K^{m} (2005):	$\tilde{a} = 0.9981(30)_{stat}(37)_{sys}$	A.Gorelov and al. PRL 94 (2005) 142501
Delayed proton of ^{32}Ar (2018):	$\tilde{a} = 1.01(3)_{stat}(2)_{sys}$	V.Araujo-Escalona and al. PRC 101 (2020) 5, 055501

0.1% precision on $\tilde{a}$ → 5 eV precision on $\overline{E}_{shift}$

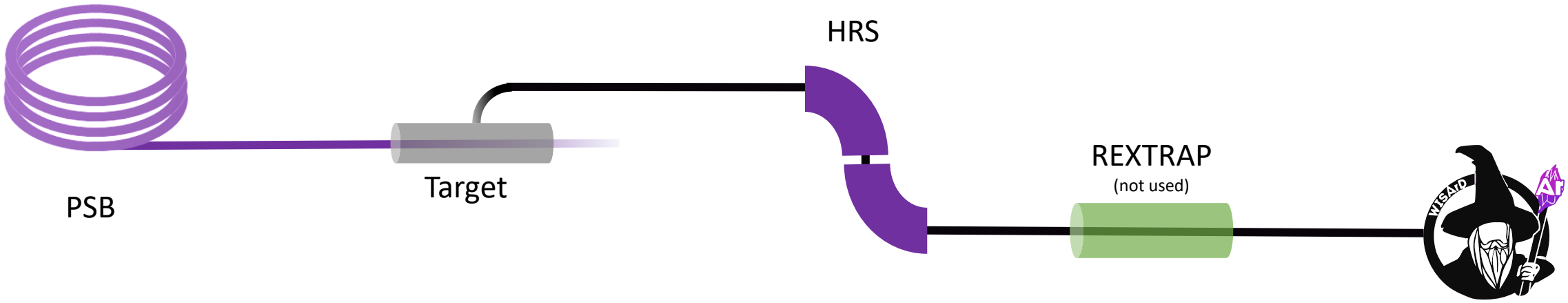
WISArD at ISOLDE

^{32}Ar production : $\mathrm{p} + \mathrm{CaO} \rightarrow \mathrm{Ar}$

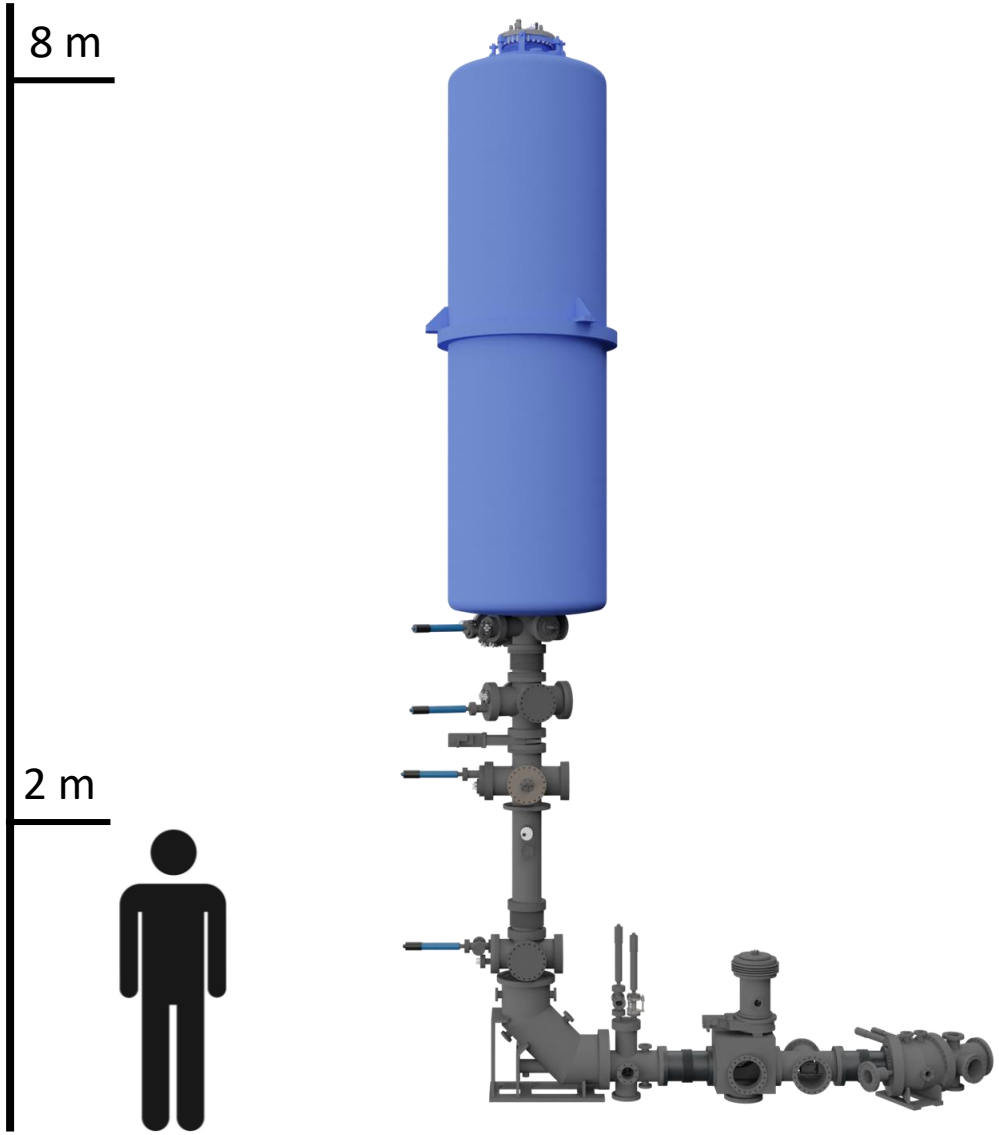
- From Proton Synchrotron Booster
- 2.5 µA at 1.4 GeV

- CaO target
- Nanostructured powder

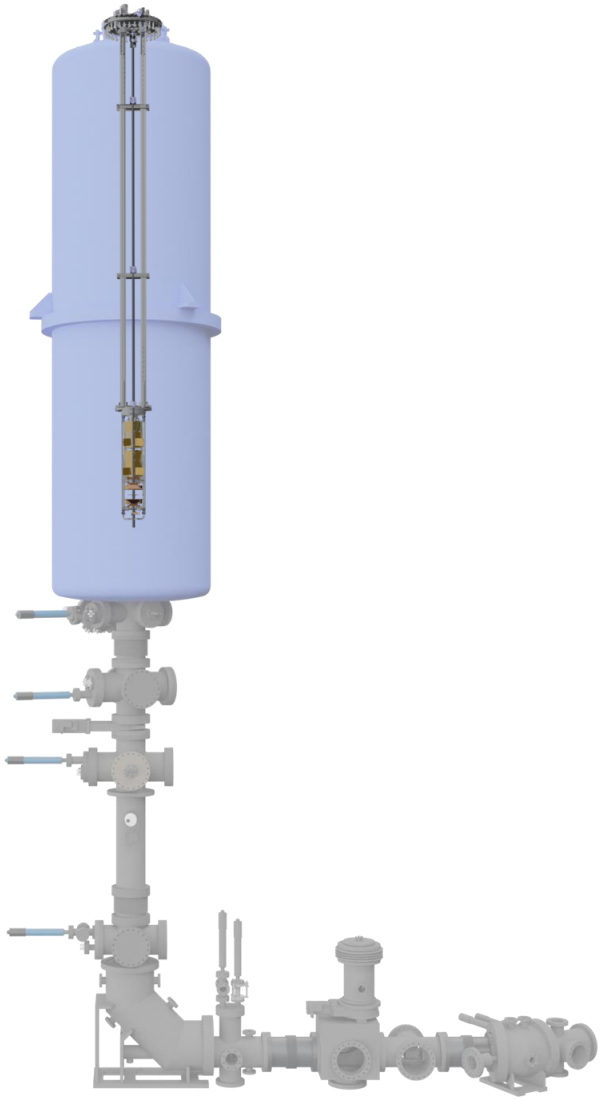
- ISOLDE HRS
- A/Q selection
- 30 keV



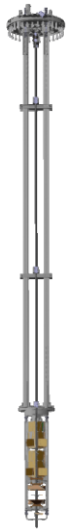
WISArD



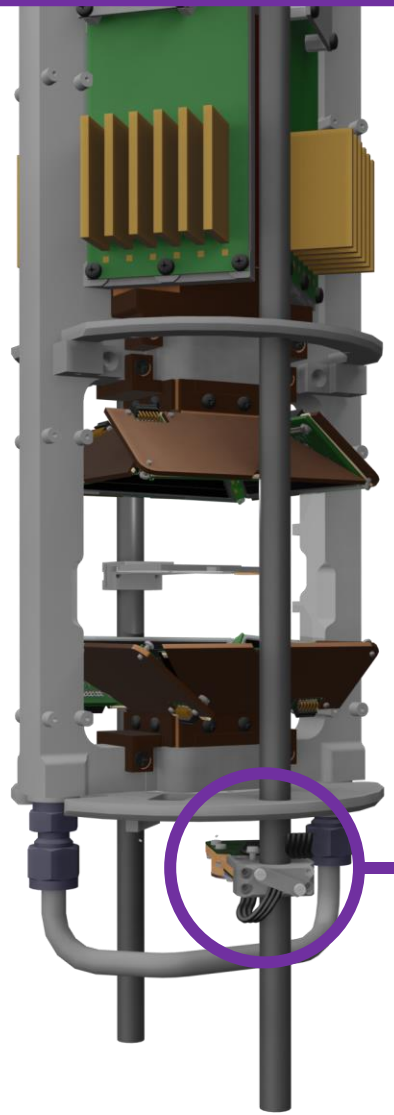
WISArD



WISArD

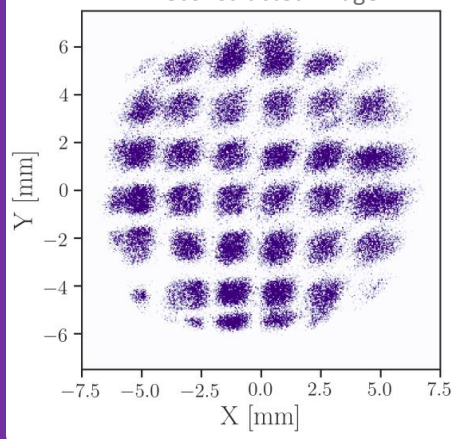


Tower: MCP

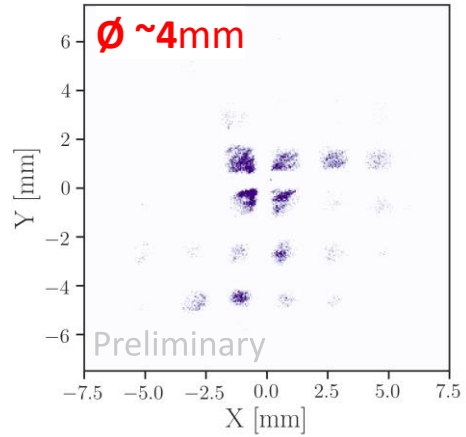


Beam scan

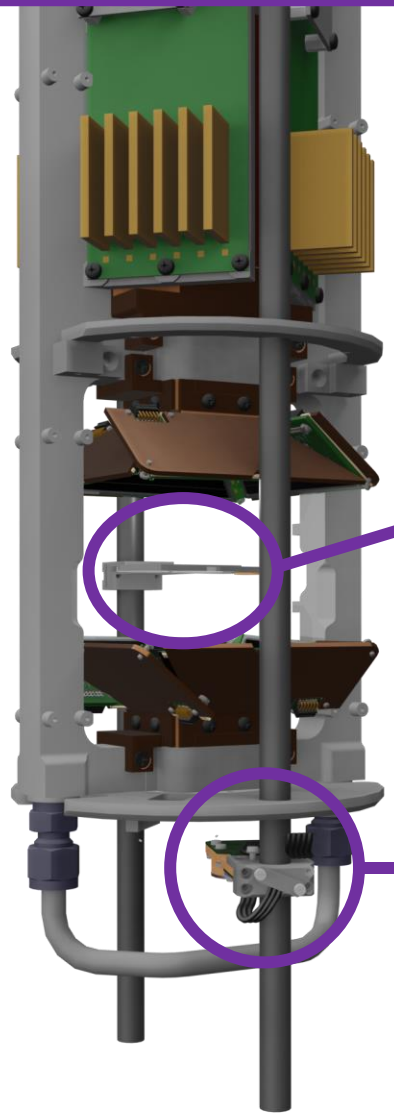
Reconstructed image



^{32}Ar Beam

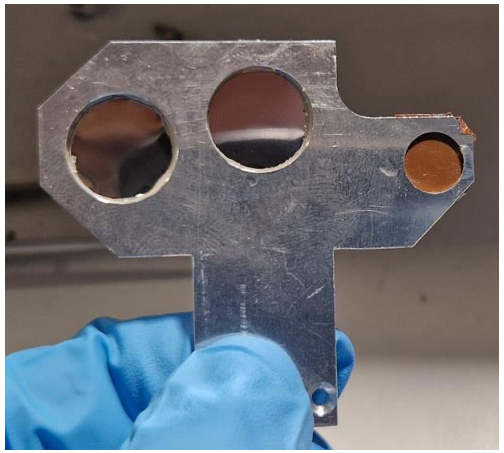


Tower: MCP



Catcher support:

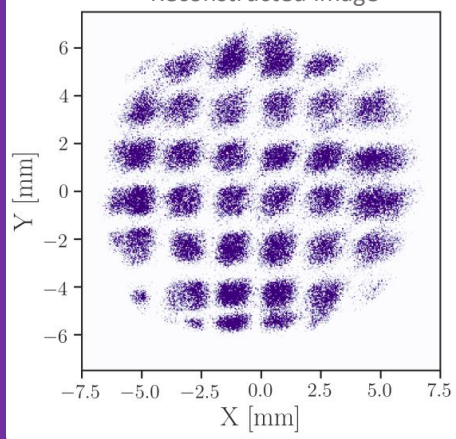
- Thin catcher 0.6 µm
- Thick catcher 6 µm
- α source (^{208}Po)



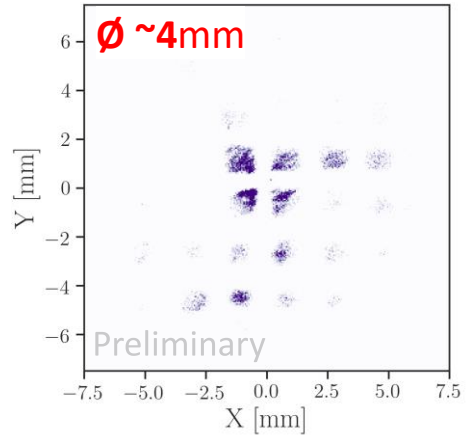
Catchers made by GANIL

Beam scan

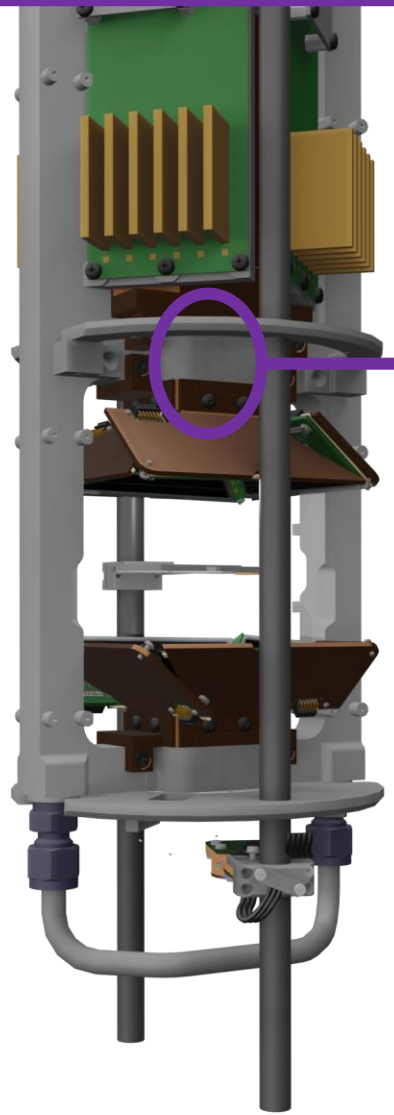
Reconstructed image



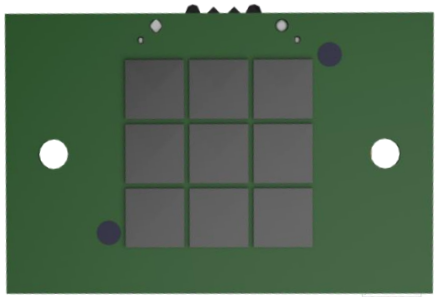
^{32}Ar Beam

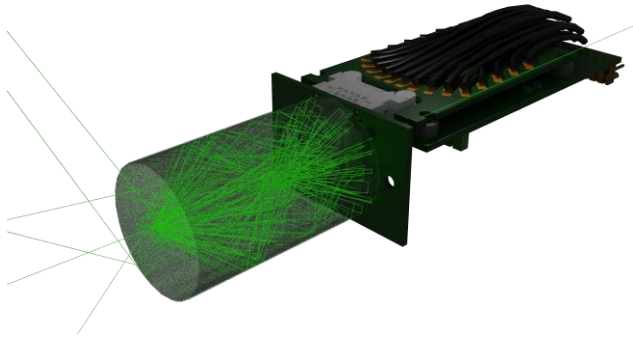


Tower: SiPMs

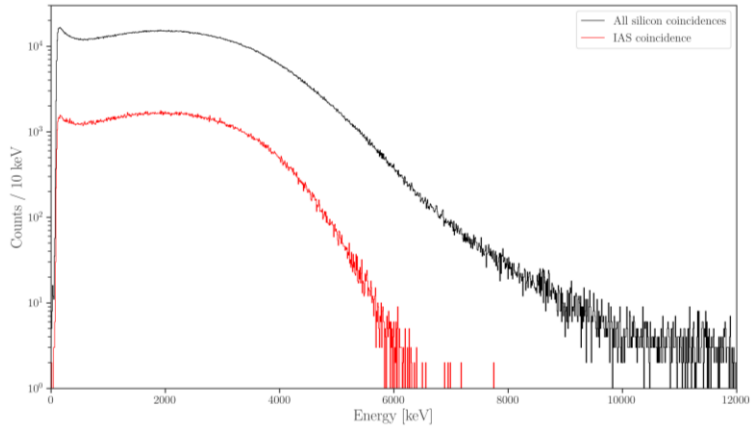


3x3 SiPMs: Onsemi MicroFJ−60035−TSV
Plastic Scintillator: EJ212





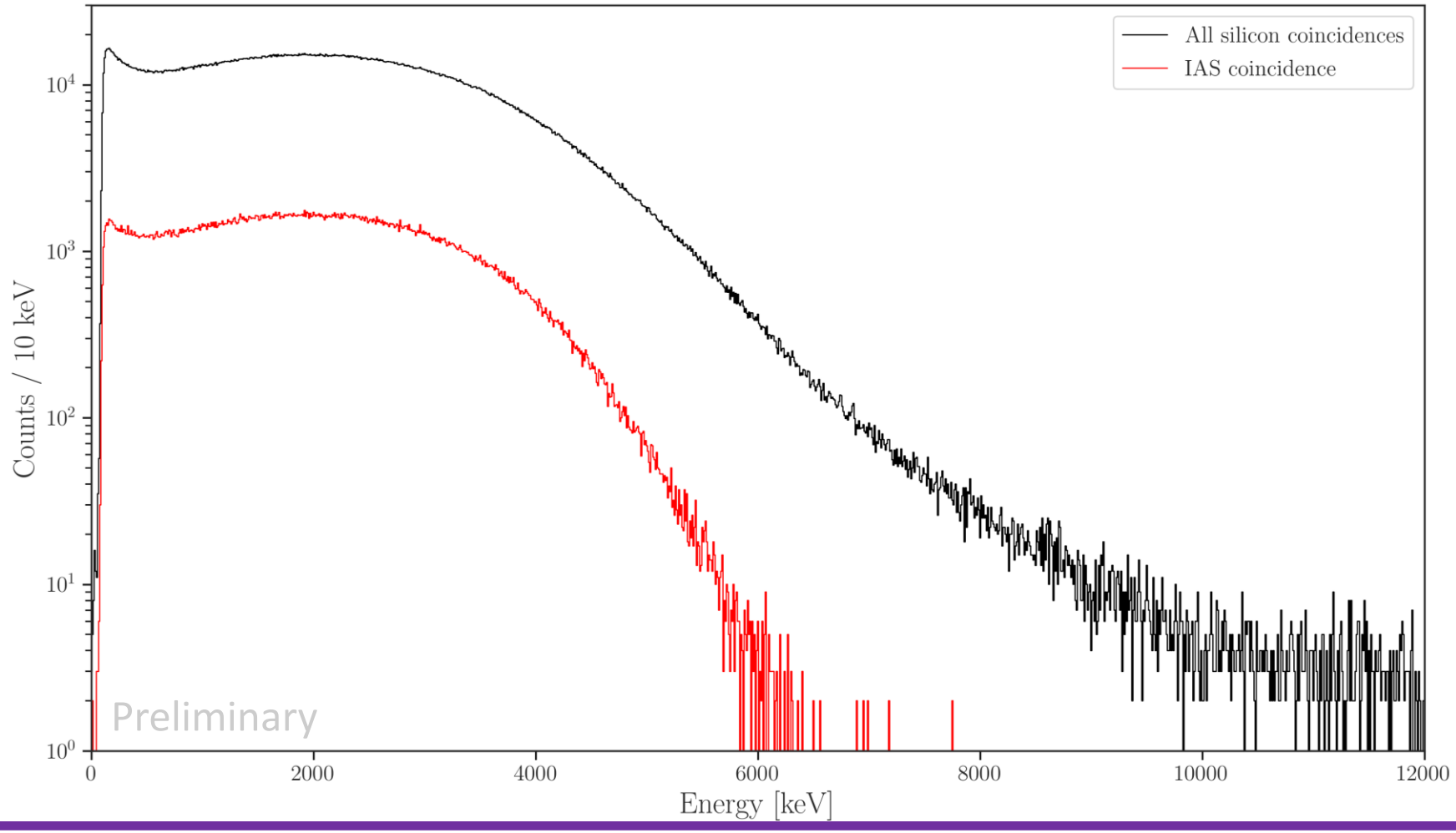
β spectrum in coincidence with silicon detectors



2024 Data taking: SiPM matrix

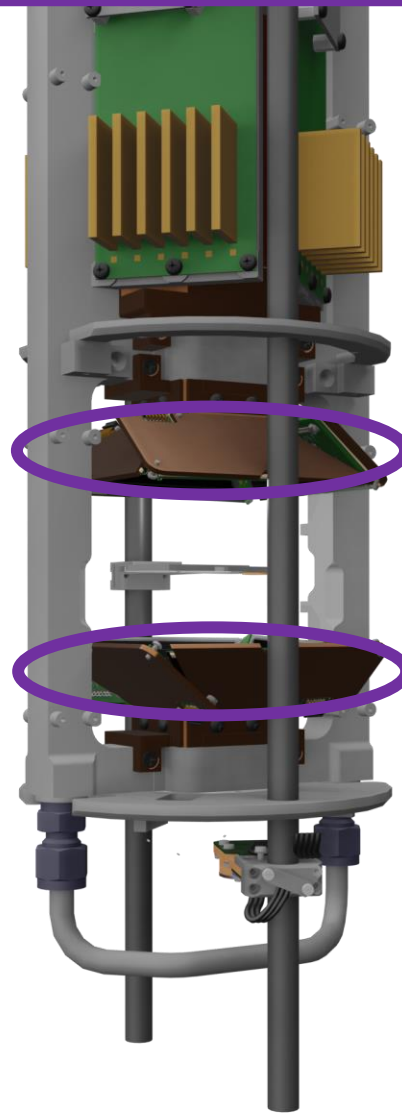
May 7 - 17

β spectrum in coincidence with silicon detectors



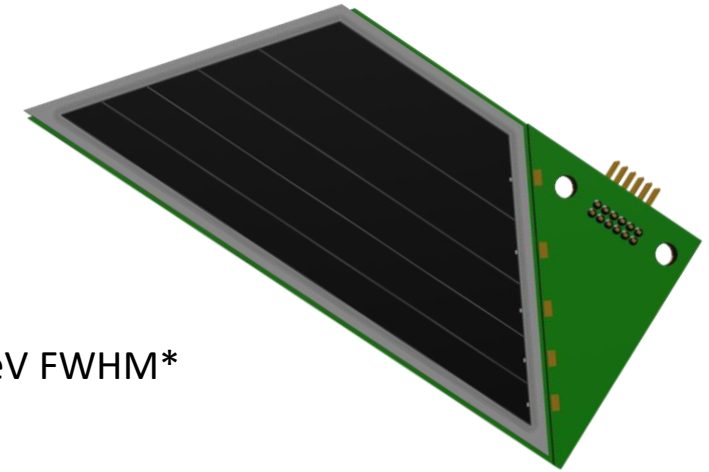
*Data from 2021

Tower: Silicon detectors



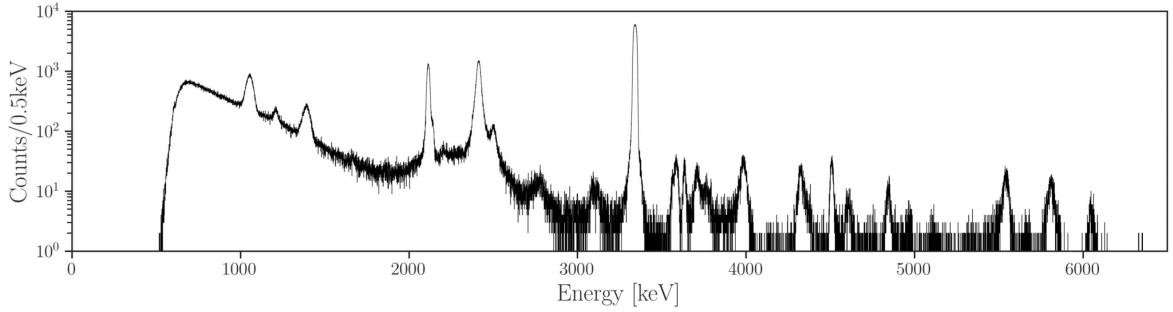
8 Silicon detectors:

- Thickness: 300 µm
- Dead-Layer: 100 nm
- Strips: 5
- Proton resolution: 10keV FWHM*
- Total solid angle: ~50%



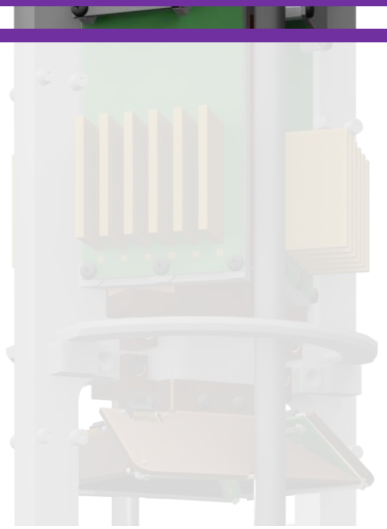
*Preliminary estimation

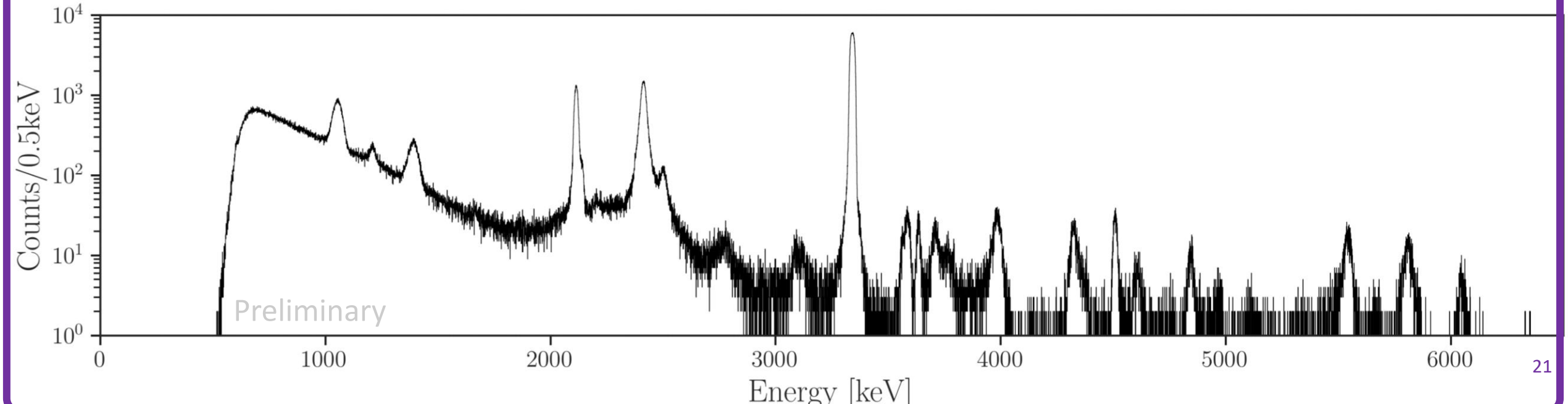
Spectra of a strip with ^{32}Ar beam



2024 Data taking: Identification

May 7 - 17



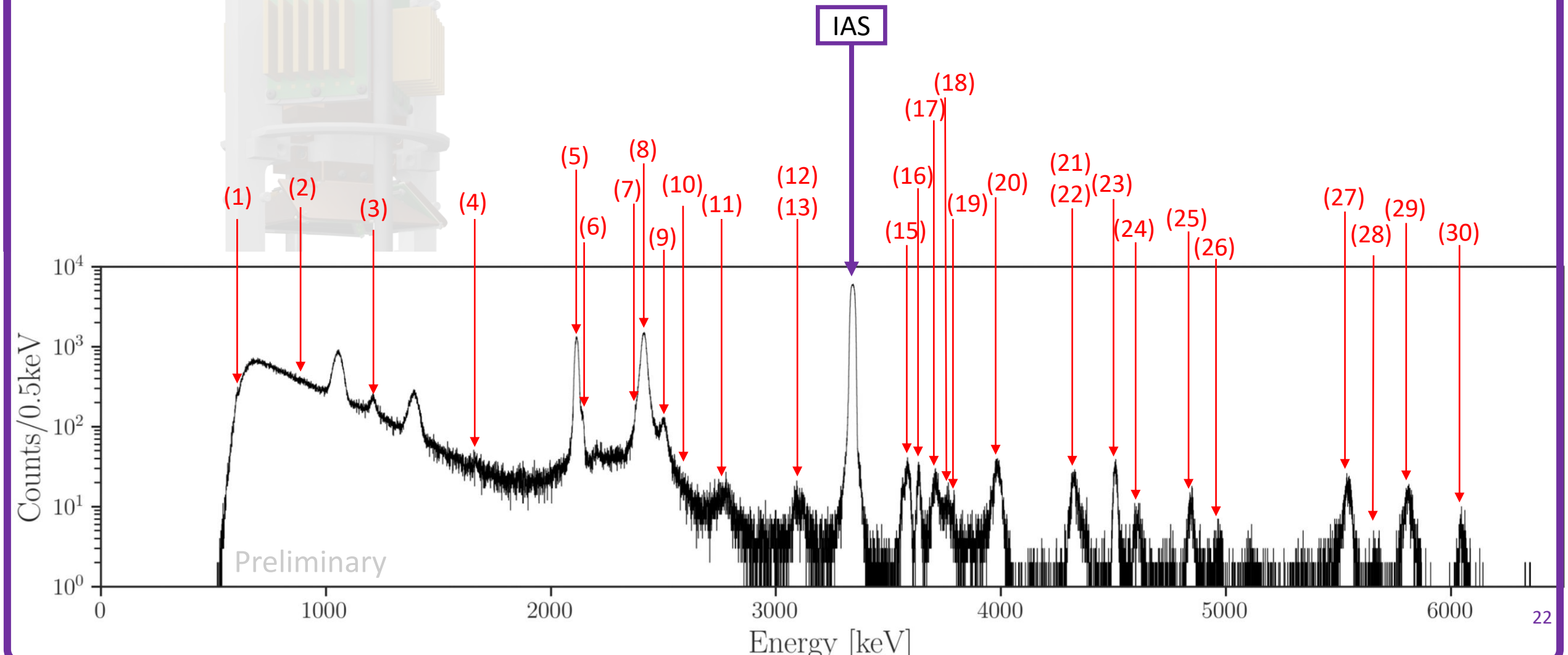


2024 Data taking: Identification

May 7 - 17

All known ^{32}Cl proton groups detected

(*) from B.Blank and al. Eur. Phys. J. A (2021) 57: 28



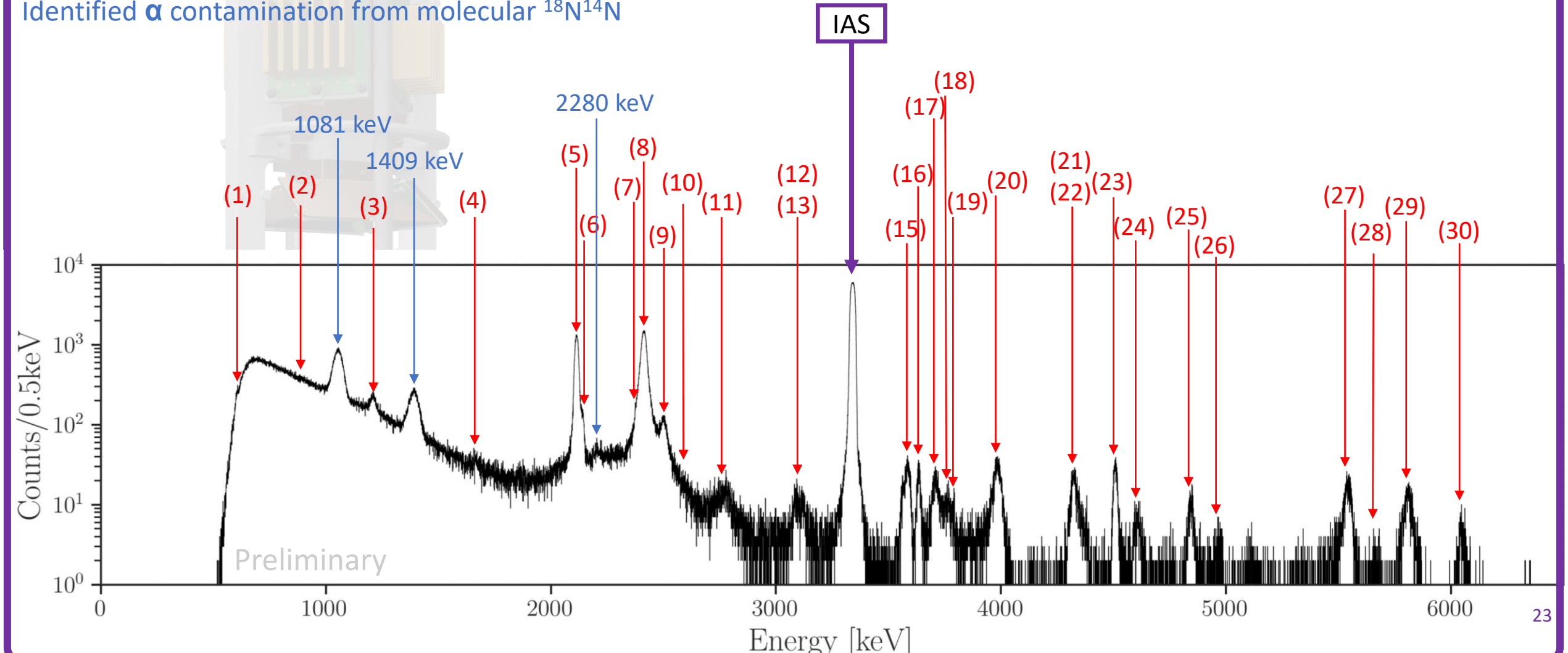
2024 Data taking: Identification

May 7 - 17

All known ^{32}Cl proton groups detected

Identified α contamination from molecular $^{18}N^{14}N$

(*) from B.Blank and al. Eur. Phys. J. A (2021) 57: 28



2024 Data taking: Identification

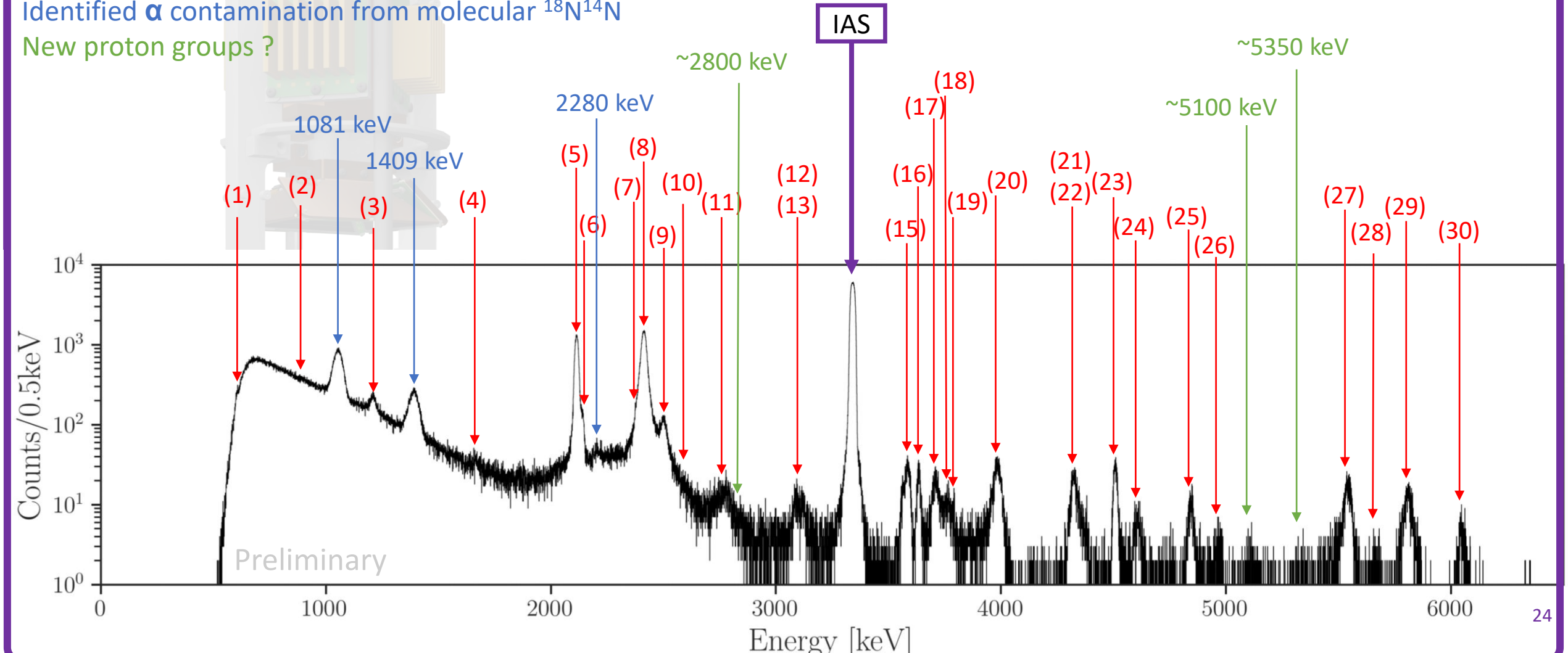
May 7 - 17

All known ^{32}Cl proton groups detected

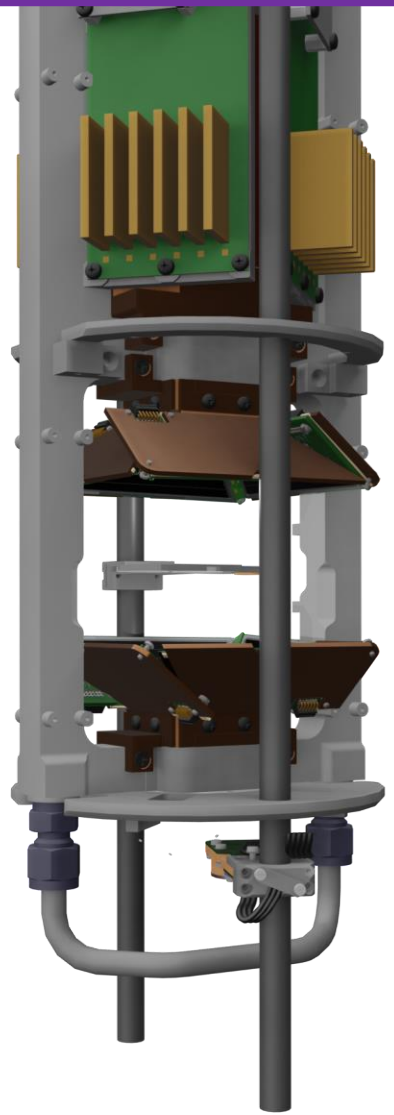
Identified α contamination from molecular $^{18}N^{14}N$

New proton groups ?

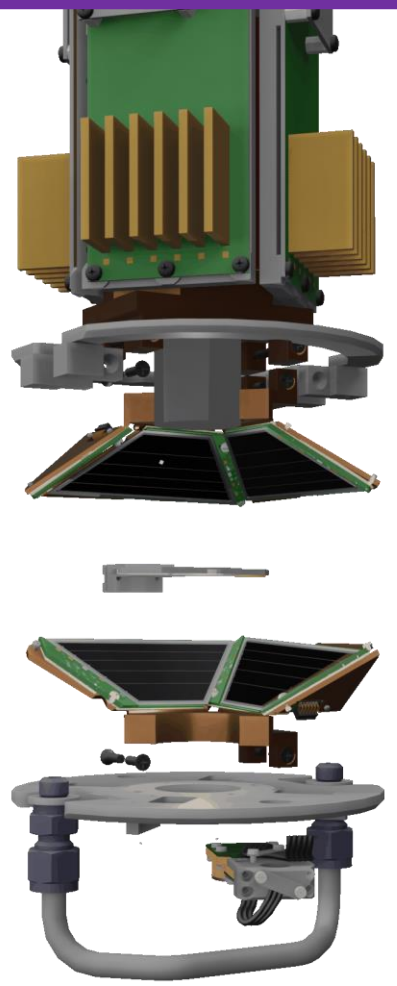
(*) from B.Blank and al. Eur. Phys. J. A (2021) 57: 28



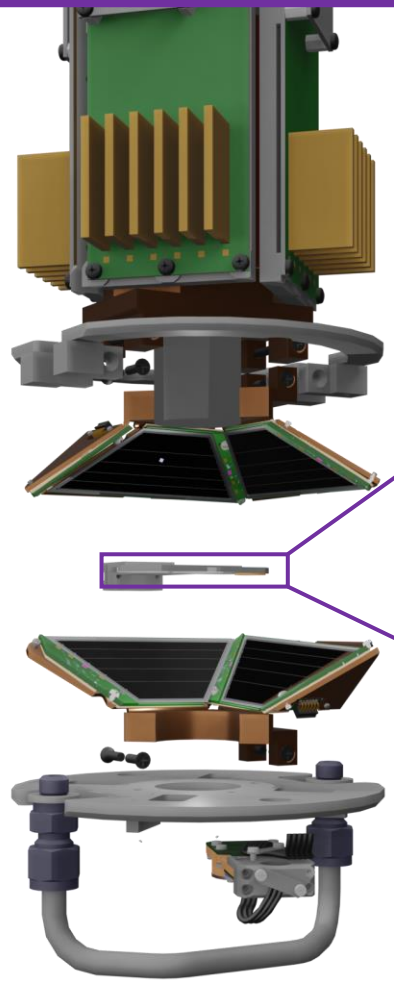
Extraction of a

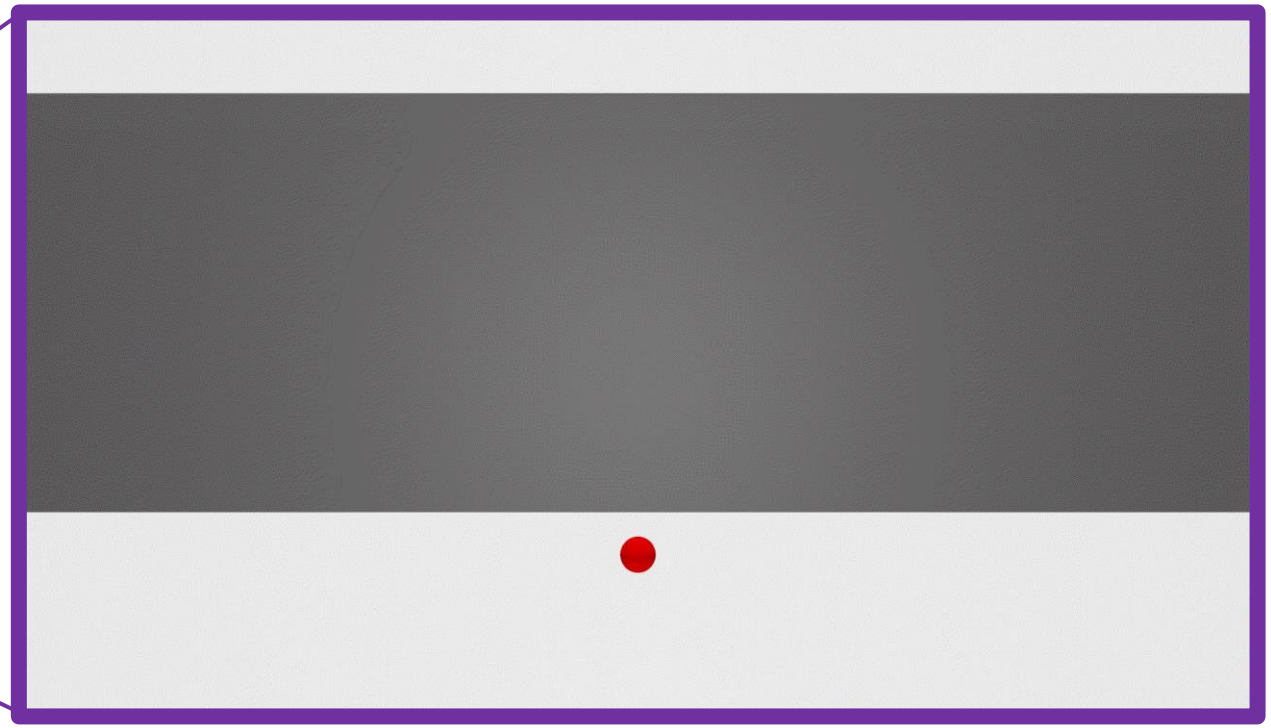


Extraction of a

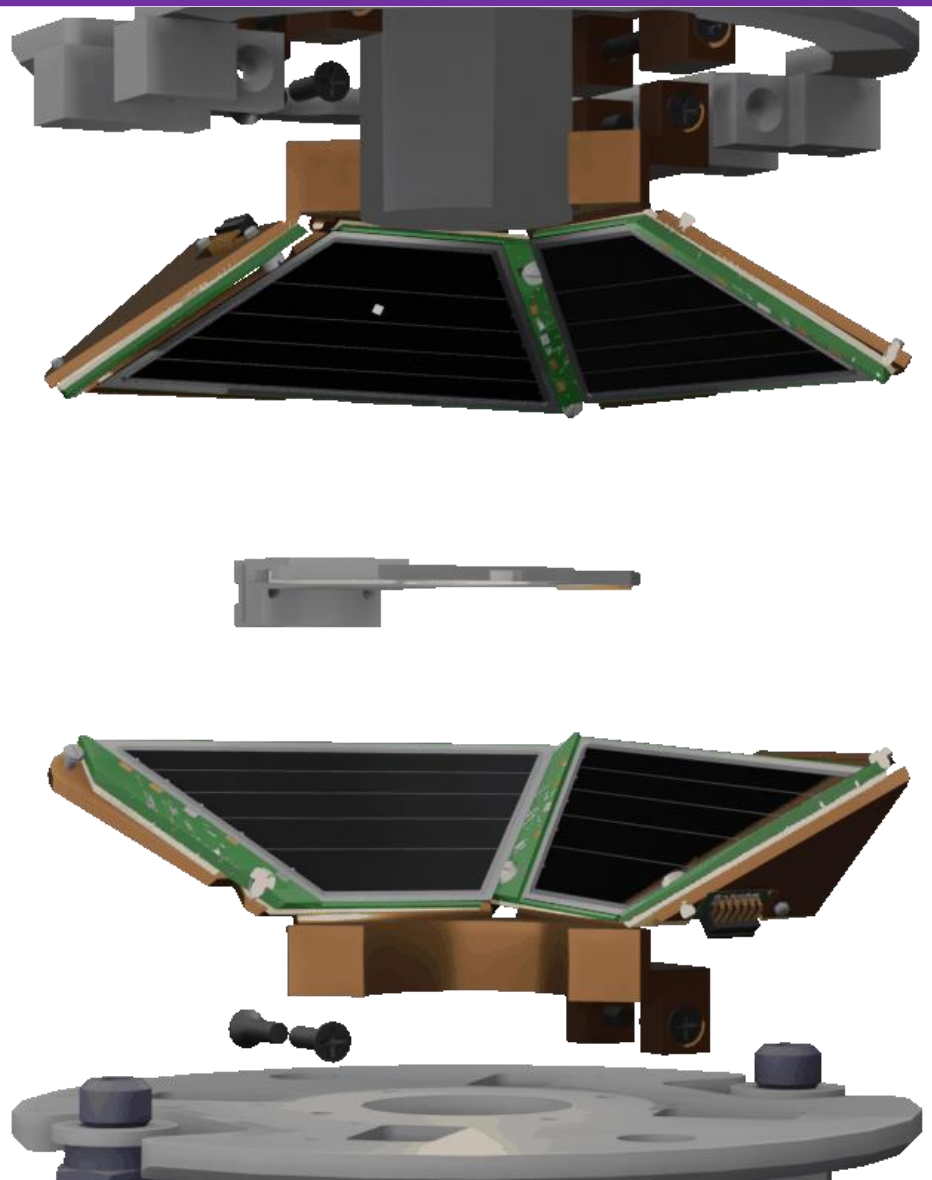


Extraction of a

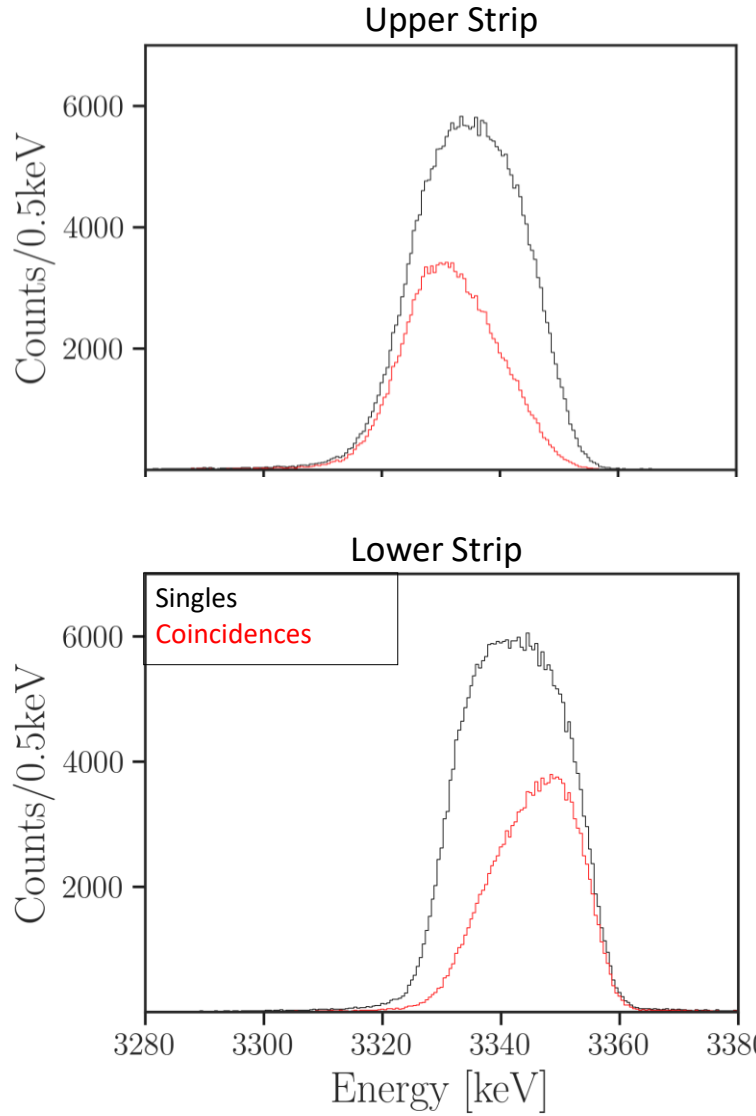




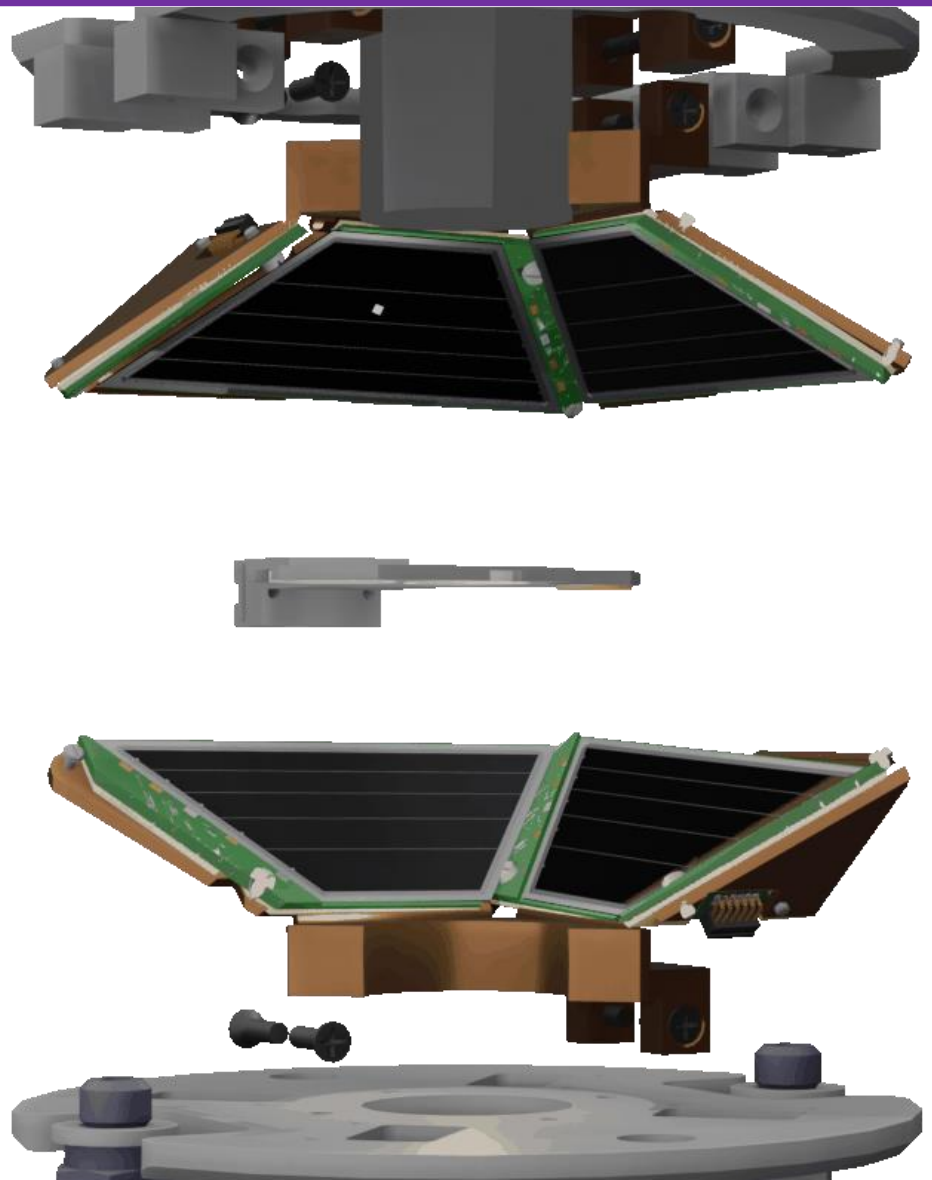
Extraction of a



$$\overline{E}_{shift} = \left|\overline{E}_{singles} - \overline{E}_{coinc}\right|$$



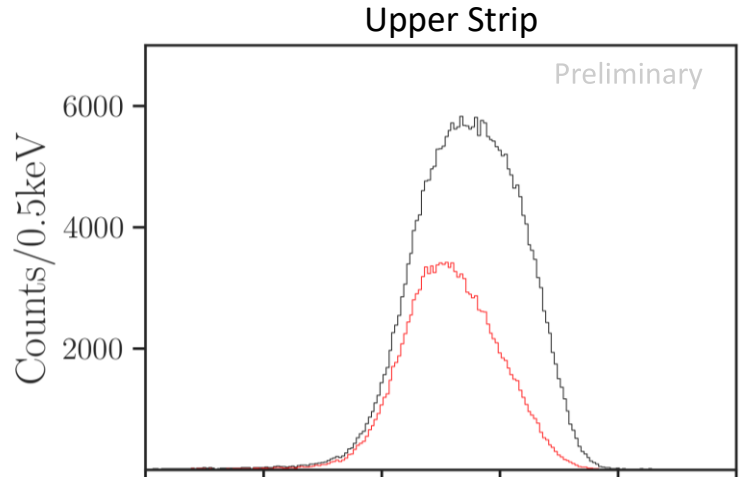
Extraction of a

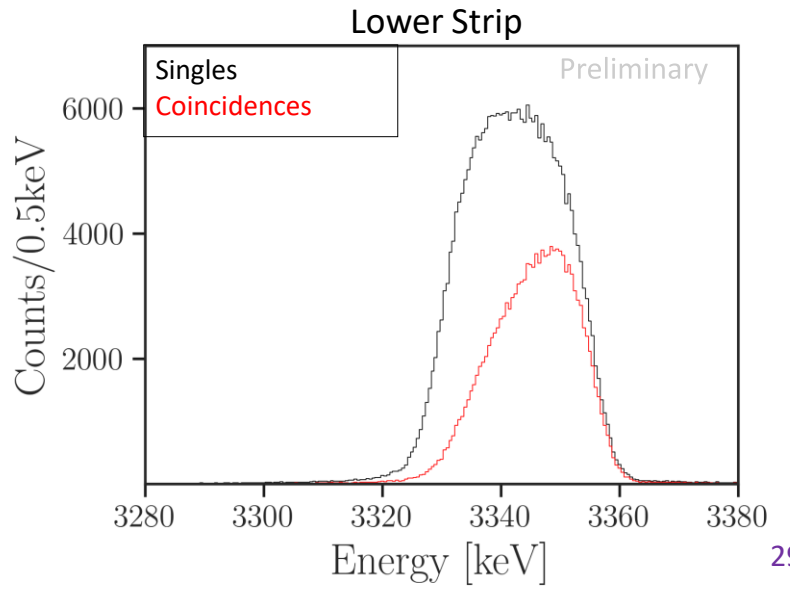


$$\overline{E}_{shift} = \left|\overline{E}_{singles} - \overline{E}_{coinc}\right|$$

Simulations

$$\tilde{a}$$





CRADLE++

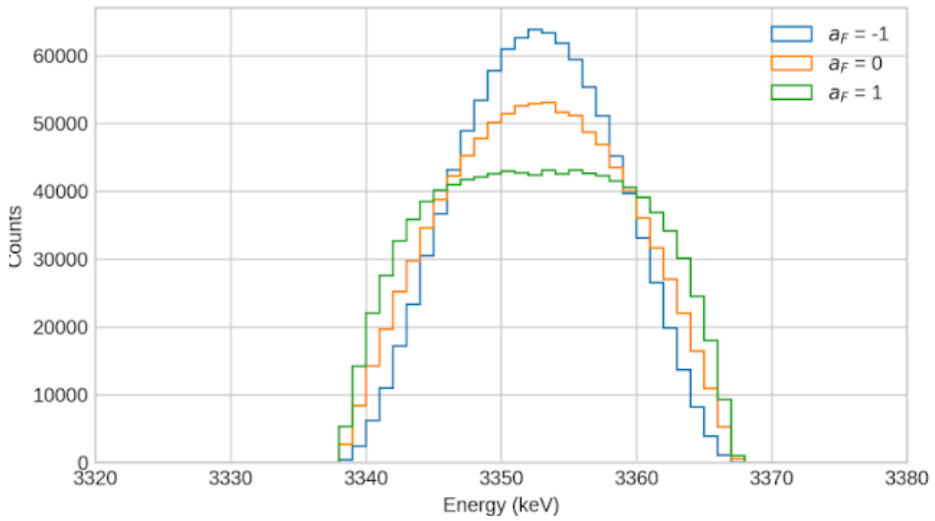
Geant4

Event generator:

GitHub

- β, α, γ and proton decay implemented
- Precise β spectrum (corrections up to 10^{-4})
- Generate a decay chain with kinematics
- Able to generate in Beyond Standard Model cases

proton IAS peak of ^{32}Ar for different *a*



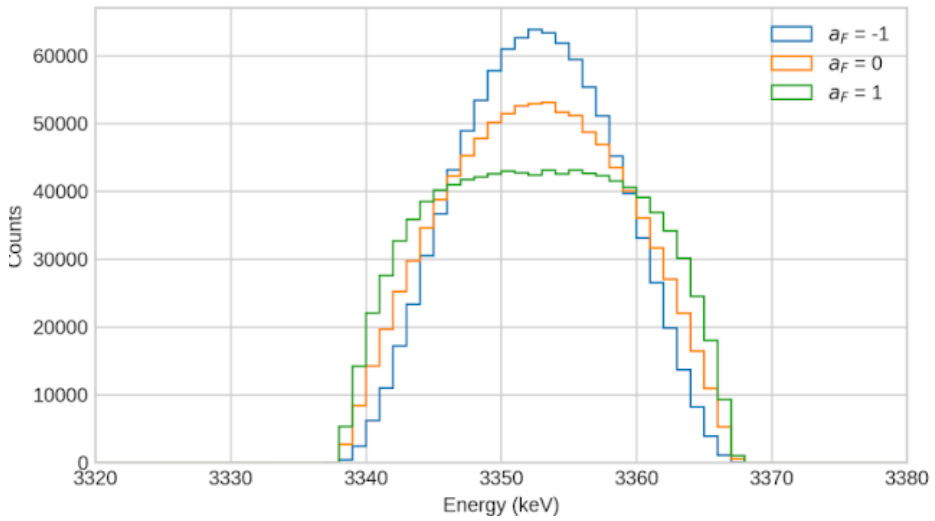
L.Hayen and al. : arXiv 2009.11364

CRADLE++

Event generator:

- β, α, γ and proton decay implemented
- Precise β spectrum (corrections up to 10^{-4})
- Generate a decay chain with kinematics
- Able to generate in Beyond Standard Model cases

proton IAS peak of ^{32}Ar for different *a*



L.Hayen and al. : arXiv 2009.11364

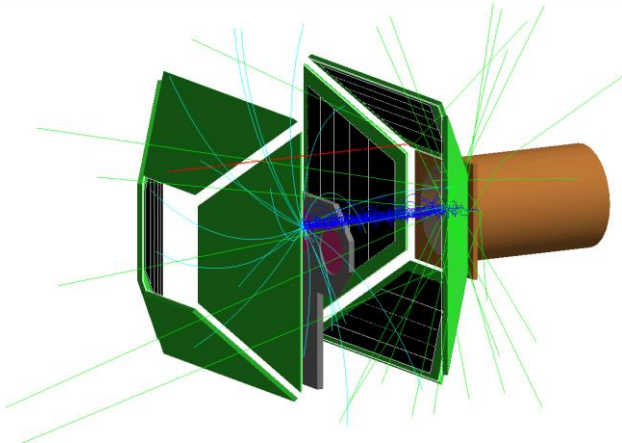
Geant4

Generator:

- Efficient output CRADLE file reader
- Implantation point from SRIM

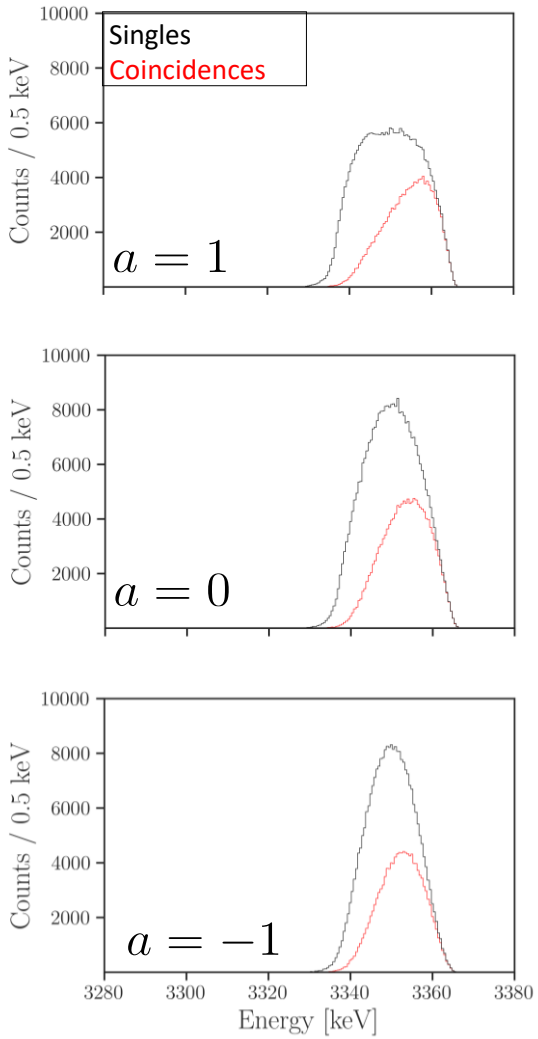
Geometry:

- Homogeneous magnetic field
- 48 silicon detectors implemented
- Energy deposit in plastic scintillator (no optical simulation)



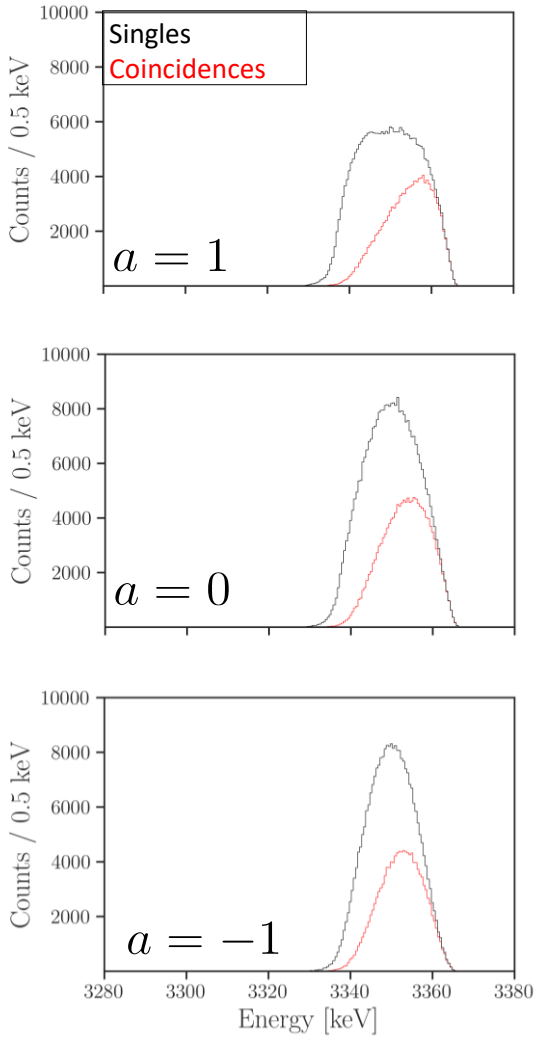
Extraction of a

Simulations

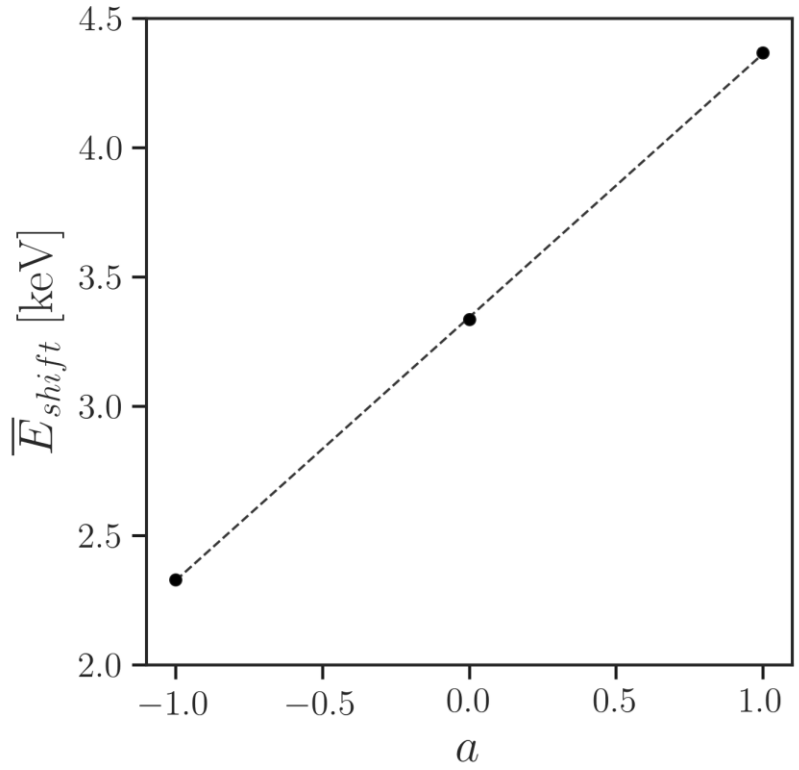


Extraction of a

Simulations

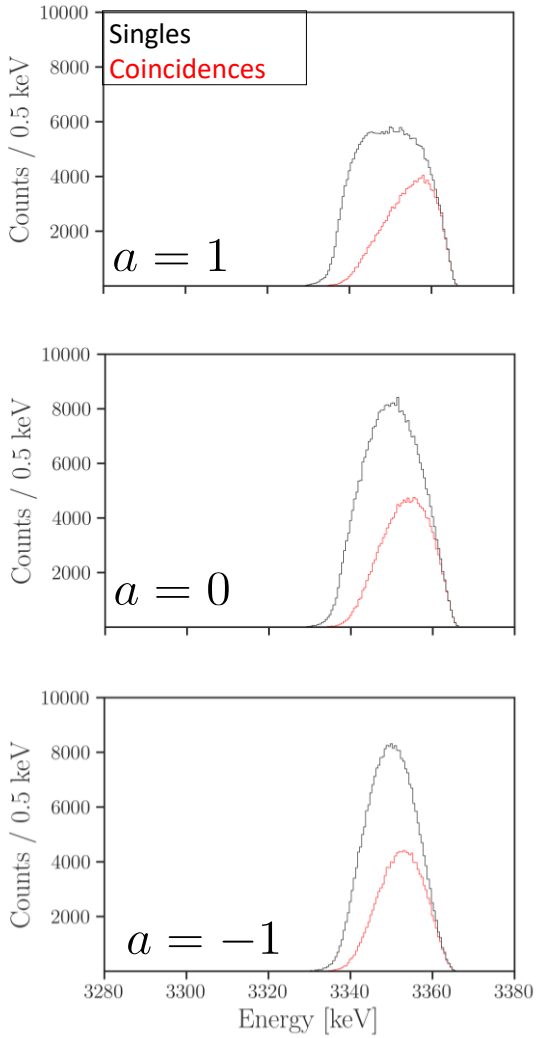


Linear dependency between $\overline{E}_{shift}$ and a

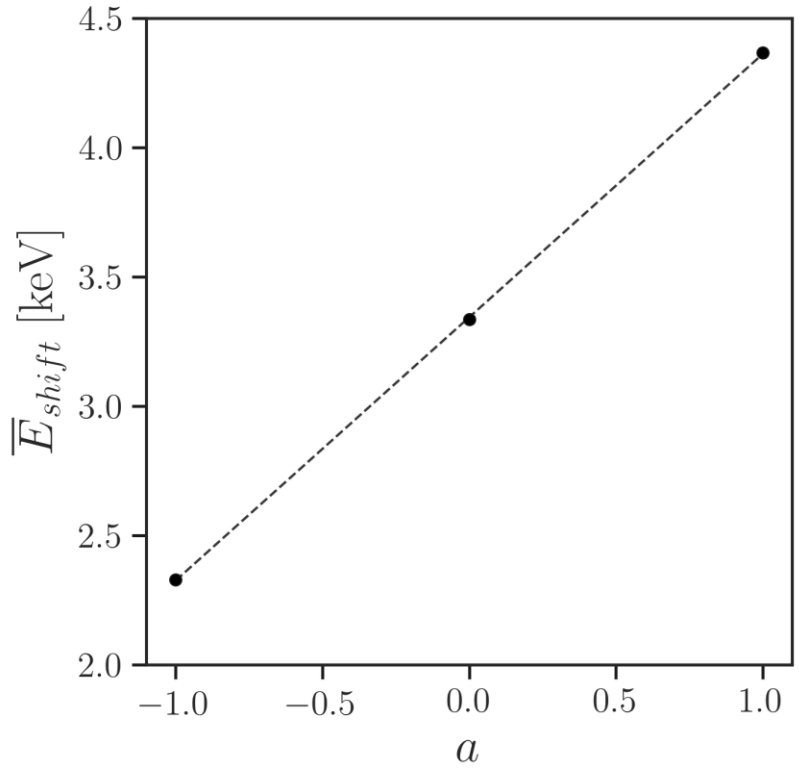


Extraction of a

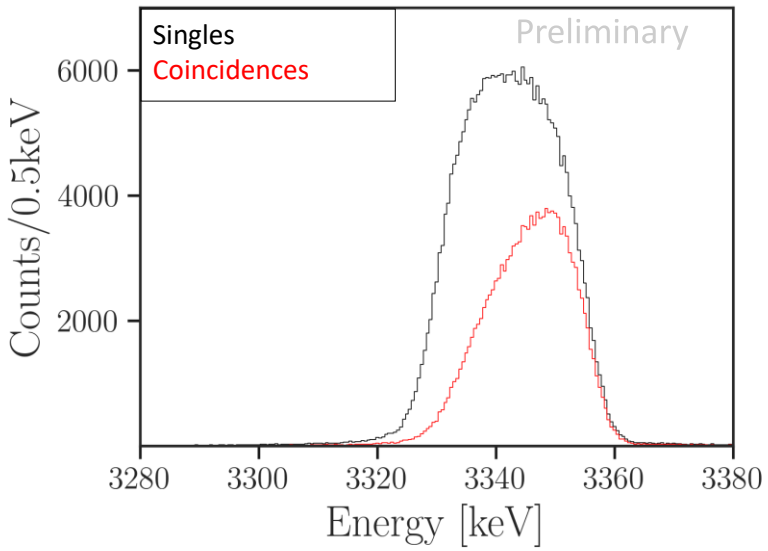
Simulations



Linear dependency between $\overline{E}_{shift}$ and a



Experimental data from last week



Extraction of a

Statistical error

2018*	200 000 events	$\Delta\tilde{a} = 0.027$
2021	700 000 events	$\Delta\tilde{a} = 0.017$
2024	12 000 000 events	$\Delta\tilde{a} = 0.002$ (estimated)

Systematic error

Main sources	Uncertainty				Improvement
	2018*	$\Delta\tilde{a}$	(estimated) 2024	$\Delta\tilde{a}$	
β-backscattering	~15%	17	~ 10%	< 10	Lower threshold
Dead layer thickness	430 ± 300 nm	12	100 ± 5 nm	0.3	New detectors
Catcher thickness	6.70 ± 0.15 µm	5	0.60 ± 0.02 µm	0.3	RBS measurement
Source radius/position	± 3 mm	1	± 0.5 mm	0.2	MCP beam profile
Detector position	± 1 mm	0.3	± 0.5 mm	0.2	Laser alignment
Calibration	~ 5 keV	10	~ 1 keV	2	^{33}Ar runs, new detectors
		$\times 10^{-3}$		$\times 10^{-3}$	

*V. Araujo-Escalona PhysRevC.101.055501

Extraction of a

Final result

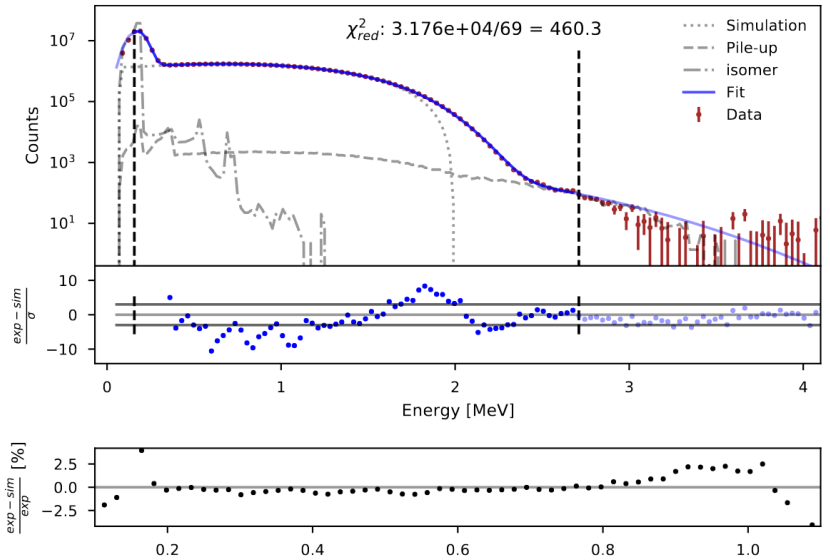
2018 : $\tilde{a} = 1.007(32)_{stat}(25)_{sys}$

2021 : $\tilde{a} = 1.002(17)_{stat}$ On going systematic analysis

2024 : $\tilde{a} = ?$ On going analysis

Other experiment @ WISArD: INESS

- Beta-Spectrum shape measurement of ^{144}In
- Effect of weak magnetism



Thanks to the whole WISArD team

P. Alfaurt, P. Ascher, D. Atanasov, B. Blank, F. Cresto, L. Daudin, X. Fléchard, G.Frémont, M. Gerbaux, J. Giovinazzo, S. Grévy, J. Ha, C. Knapen, R.Lica, M. Pomorski, M.Roche, N. Severijns, S. Vanlangendonck, M. Versteegen, D. Zakoucky

We acknowledge the support of the ISOLDE technical team

Weak interaction

Example of the β^+ decay : $u \longrightarrow d + e^+ + \nu_e$ $\quad {}^{A}_{Z}\mathrm{X} \longrightarrow {}^{A}_{Z-1}\mathrm{X}' + e^+ + \nu_e$

$$\mathcal{L}_{Lee-Yang} = + \overline{p}\gamma^{\mu} n \overline{e} \gamma_{\mu}(C_V + C'_V\gamma_5)\nu$$
$$- \overline{p}\gamma^{\mu}\gamma_5 n \overline{e} \gamma_{\mu}(C_A\gamma_5 + C'_A)\nu$$
$$+ \overline{p} n \overline{e}(C_S + C'_S\gamma_5)\nu$$
$$+ \frac{1}{2}\overline{p}\sigma^{\mu\nu} n \overline{e} \sigma_{\mu\nu}(C_T + C'_T\gamma_5)\nu$$
$$- \overline{p}\gamma_5 n \overline{e}(C_P\gamma_5 + C'_P)\nu$$
$$+ h.c$$

→ Vector

→ Axial-Vector

→ Scalar

→ Tensor

→ Pseudo-Scalar (HEP)

Beyond Standard Model : $C_V = C'_V = 1 \quad C_A = C'_A \simeq 1.27 \qquad C_S = ? \quad C_T = ?$

Weak interaction

$$a\xi = |M_F|^2(-C_S^2 - C_S'^2 + C_V^2 + C_V'^2) - \frac{|M_{GT}|^2}{3}(-C_T^2 - C_T'^2 + C_A^2 + C_A'^2)$$

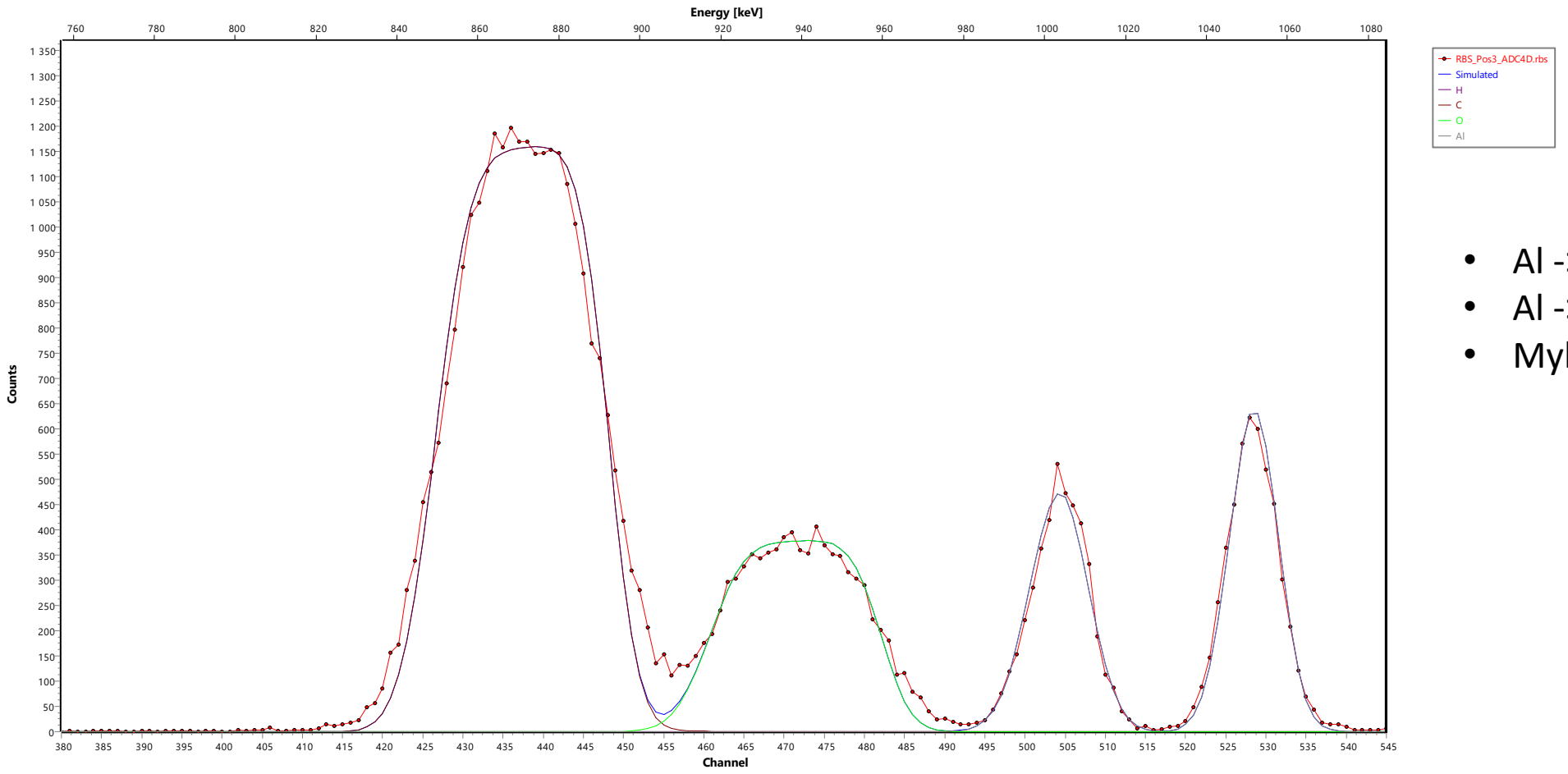
$$b\xi = 2|M_F|^2(C_S C_V + C_S' C_V') + 2|M_{GT}|^2(C_T C_A + C_T' C_A')$$

$$\xi = |M_F|^2(C_S^2 + C_S'^2 + C_V^2 + C_V'^2) + |M_{GT}|^2(C_T^2 + C_T'^2 + C_A^2 + C_A'^2)$$

$$\tilde{a} = \frac{a}{1 + b\left\langle \frac{m_e}{E_0} \right\rangle}$$

RBS measurement

Proton beam at 1.2 MeV
Angle of detection 135°



- Al -> 70 ± 5 nm
- Al -> 52 ± 5 nm
- Mylar -> 665 ± 25 nm

Analysis from Stéphanie Sorieul

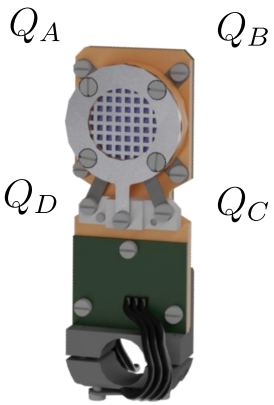
Annex: MCP reconstruction

Usual formula

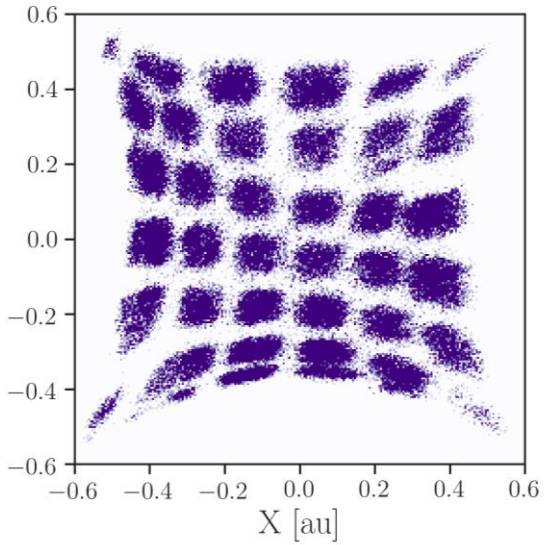
Q: charge collected by one corner

$$x = \frac{Q_B + Q_C - Q_A - Q_D}{Q_A + Q_B + Q_C + Q_D}$$

$$y = \frac{Q_B - Q_C + Q_A - Q_D}{Q_A + Q_B + Q_C + Q_D}$$



Deformed image



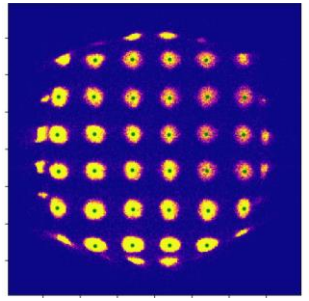
New empirical formula

$$x = -\frac{log\left(\frac{Q_B Q_C}{Q_A Q_D}\right)}{log\left(\frac{Q_A Q_B Q_C Q_D}{(Q_A+Q_B+Q_C+Q_D)^4}\right)}$$

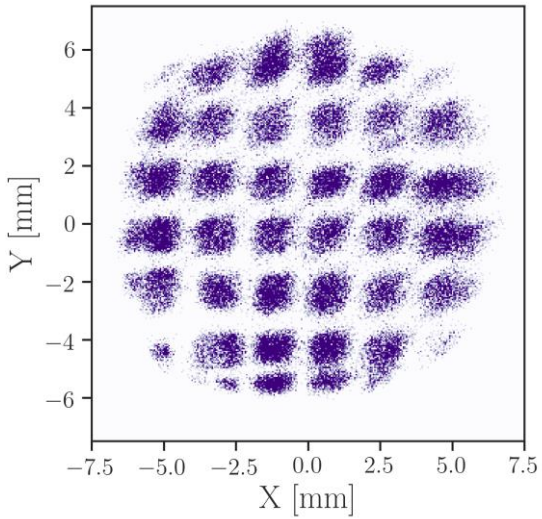
$$y = -\frac{log\left(\frac{Q_B Q_D}{Q_A Q_C}\right)}{log\left(\frac{Q_A Q_B Q_C Q_D}{(Q_A+Q_B+Q_C+Q_D)^4}\right)}$$

Corners gain match

Quick algorithm to fit the image with the mask



Final image

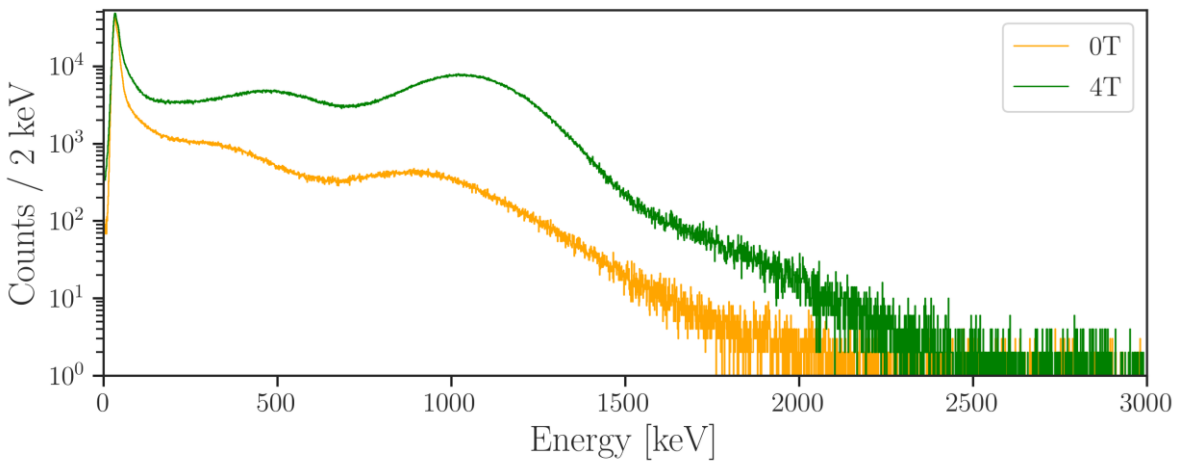


2024 Data taking: Source measurement

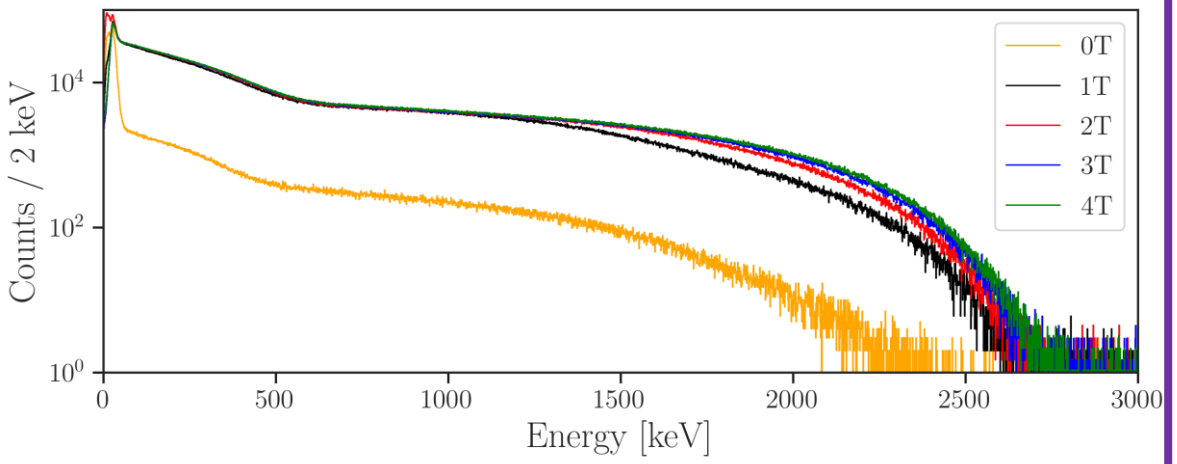
May 7 - 17

β sources: Threshold determination, calibration, detection efficiency as a function of B

^{207}Bi



^{90}Sr



α sources: detection efficiency as a function of B

- ^{148}Gd
- ^{239}Pu
- ^{241}Am
- ^{244}Cm