

Towards the limits of stability – new decay study of the lightest mendeleviums

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Julien Piot



RÉGION
NORMANDIE

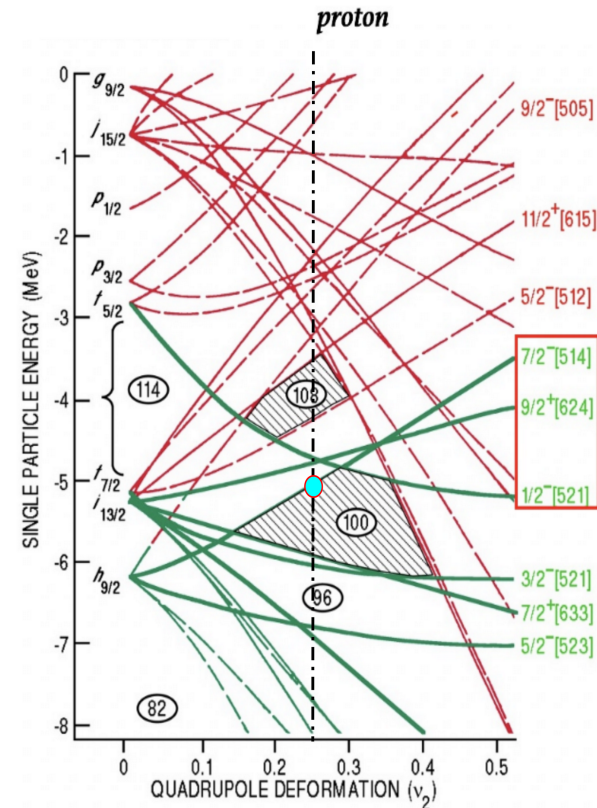
Argonne
NATIONAL LABORATORY



Outline

- Scientific motivation
- Comparison of the results from the recent experiments on $^{244,245}\text{Md}$
- The discrepancy in the results
- Results from the new experiment at FMA
- Comparison of the results
- Conclusion and Outlook

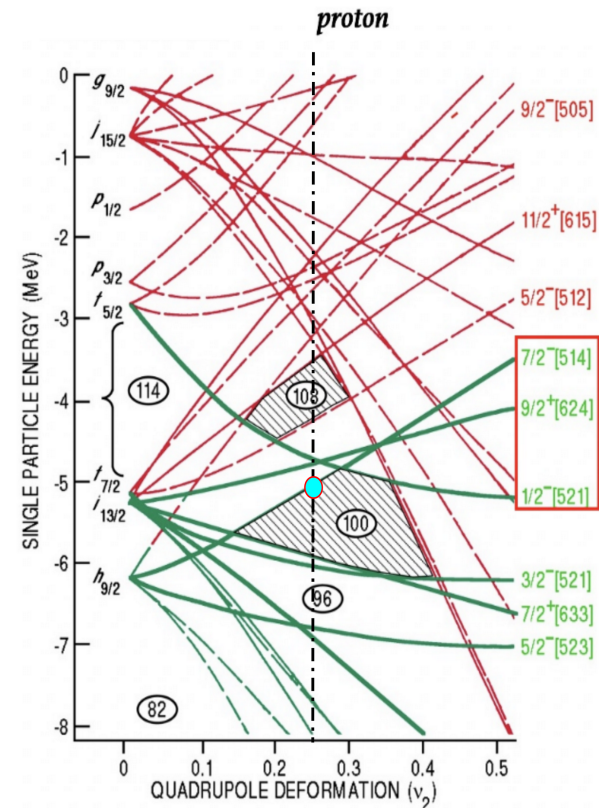
Scientific Motivation



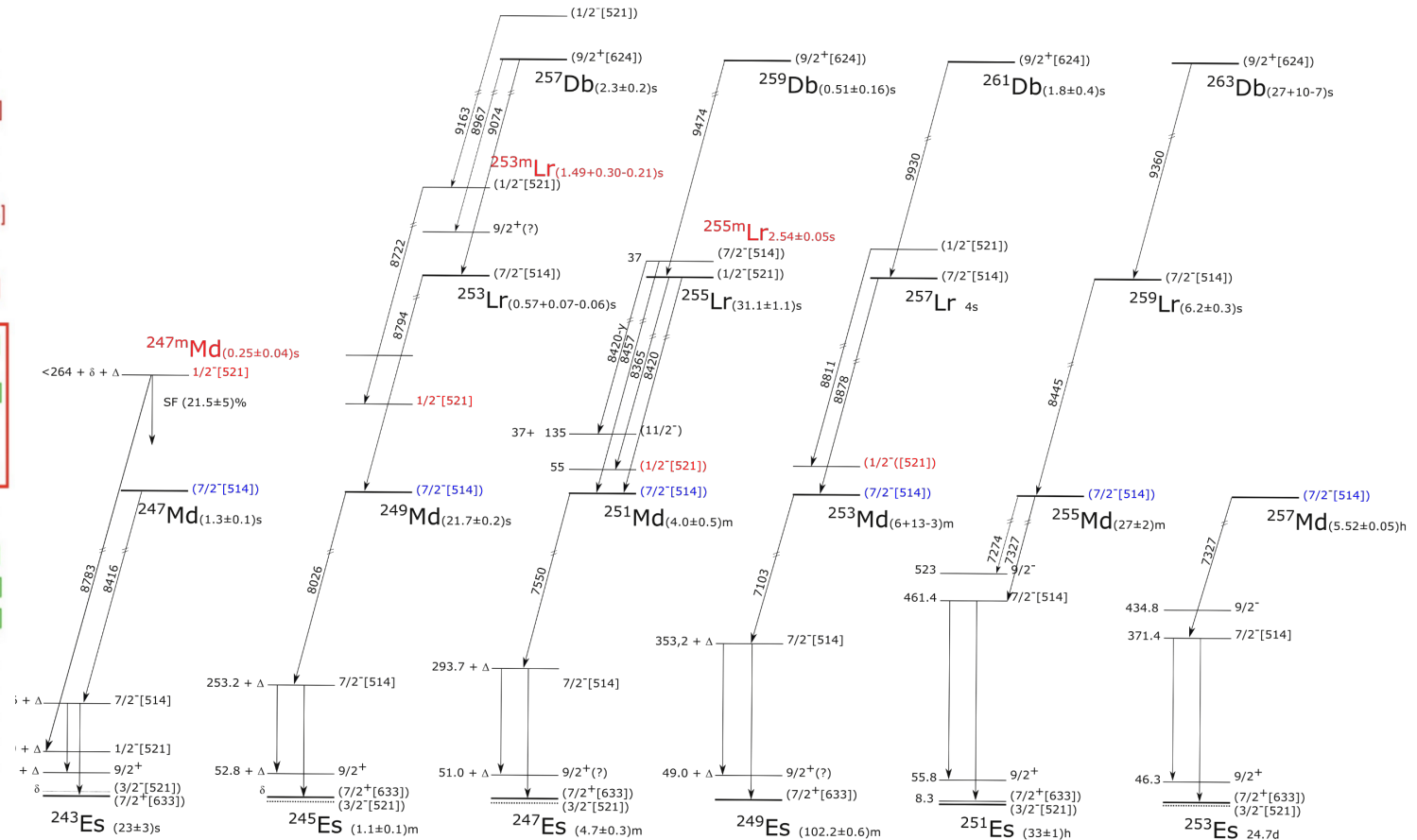
R.R. Chasman et. al. Review of
Modern Physics, 49(4):833, 1977

D. Ackermann and Ch. Theisen 2017 Phys. Scr. 92 083002

Scientific Motivation

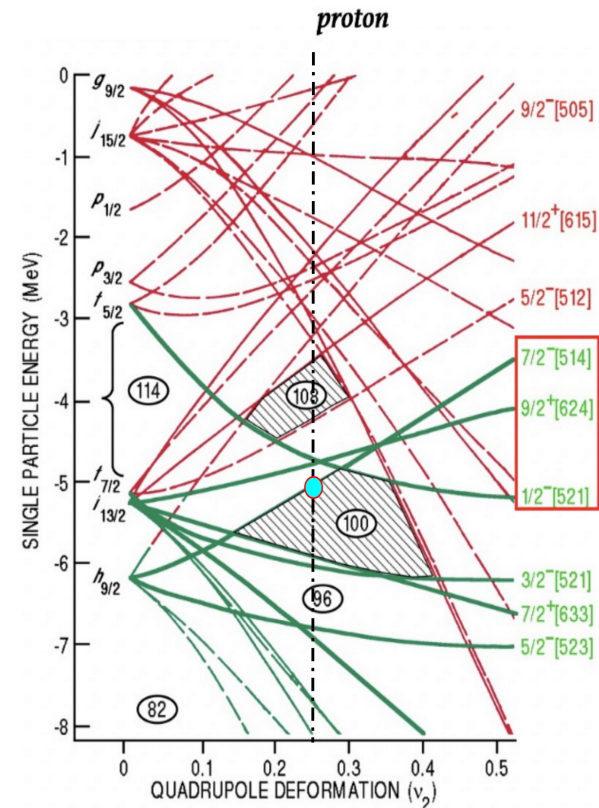


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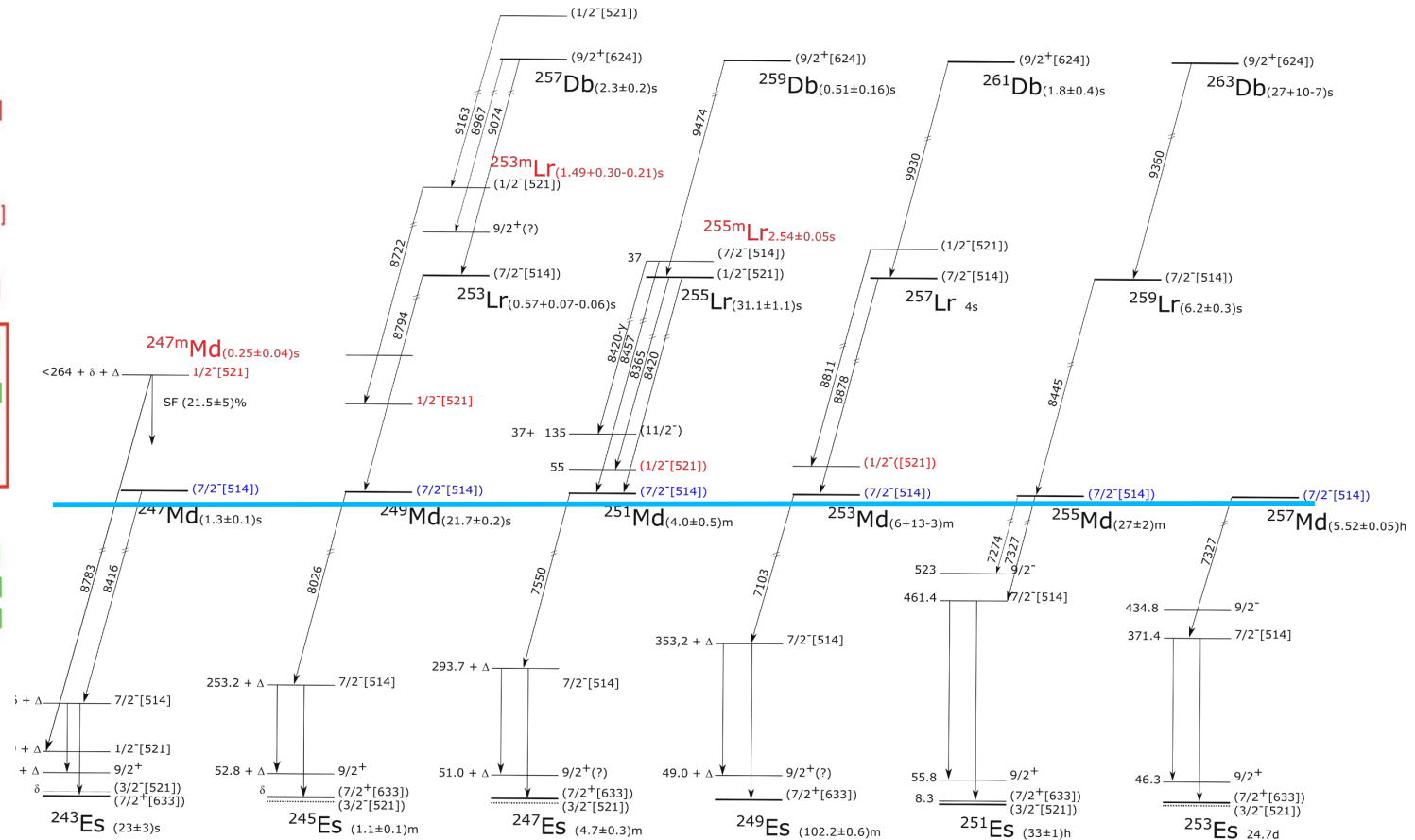


D. Ackermann and Ch. Theisen 2017 Phys. Scr. 92 083002

Scientific Motivation

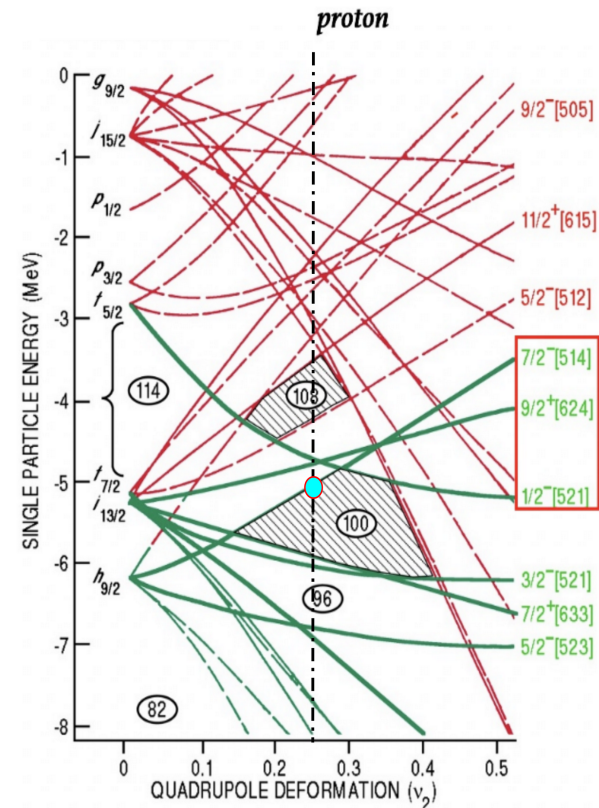


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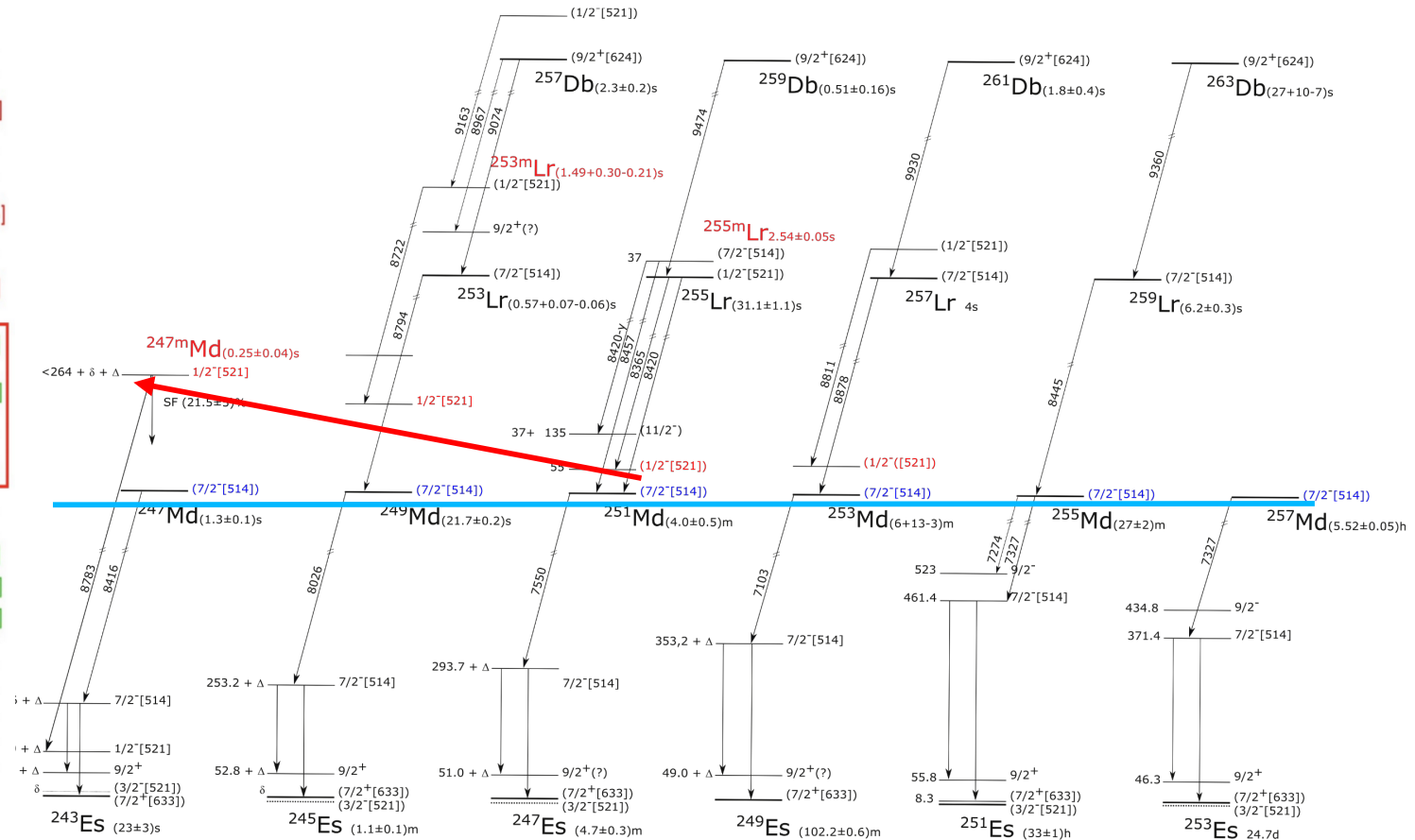


D. Ackermann and Ch. Theisen 2017 Phys. Scr. 92 083002

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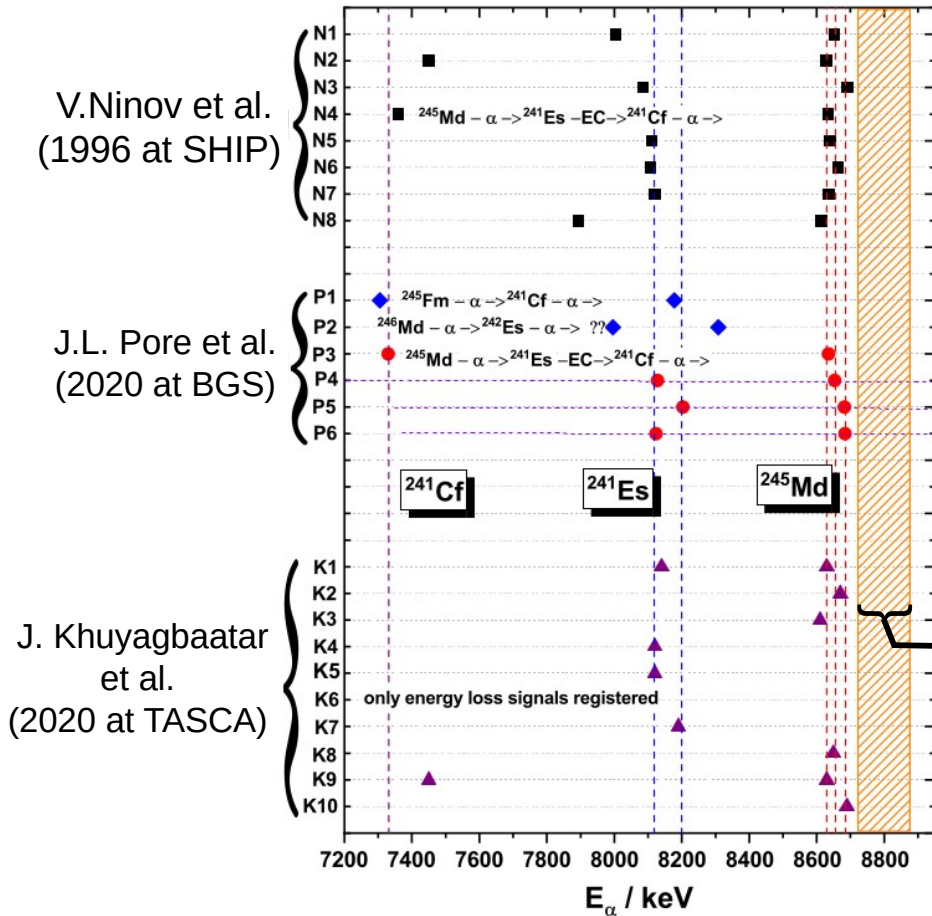


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Comparison of the reported α -decay energies

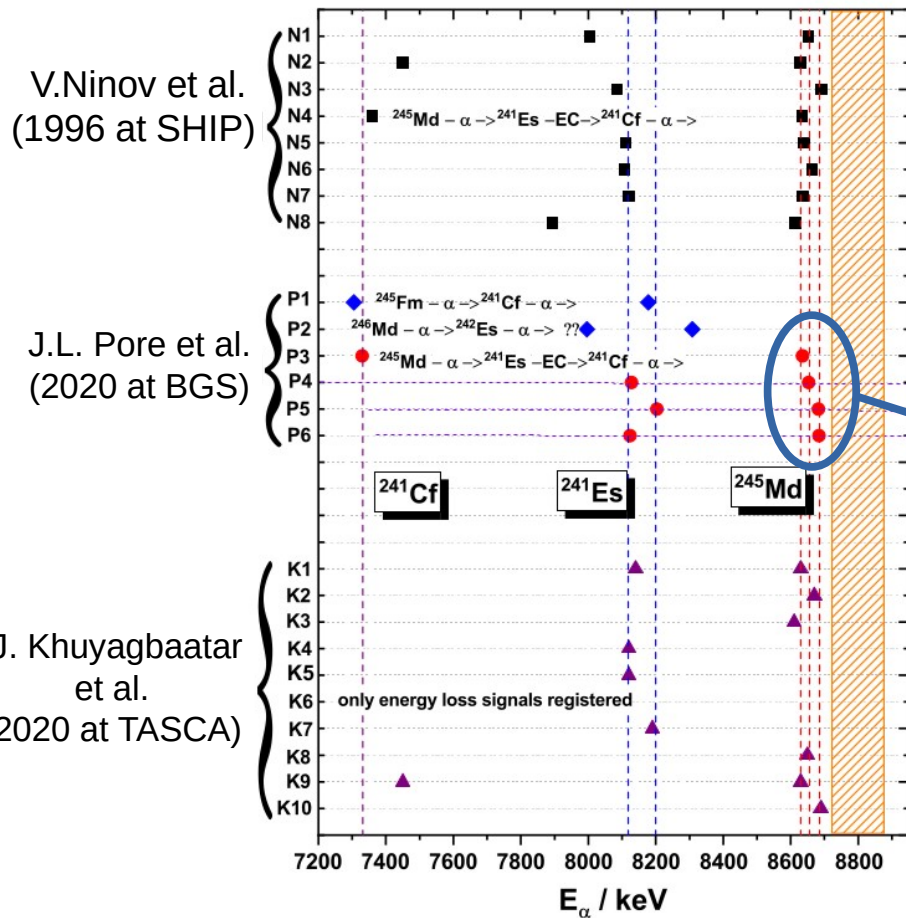


Summary of decays attributed to $^{245,244}\text{Md}$ in different experiments at GSI and Berkley.

- Each horizontal line corresponds to a single R- α - α chain

F. P. Heßberger et al., *Phys. Rev. Lett.* **126**, 182501 (2021)

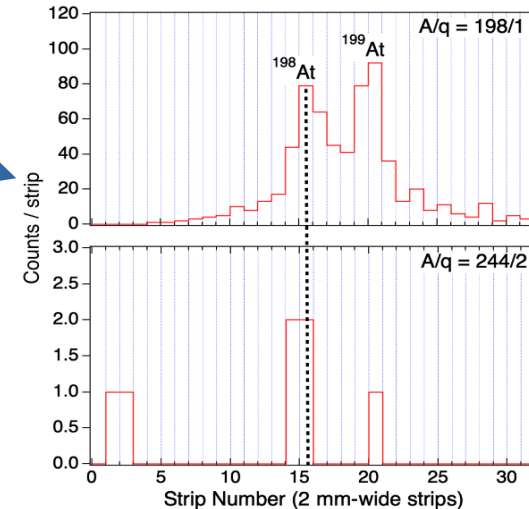
Comparison of the reported α -decay energies



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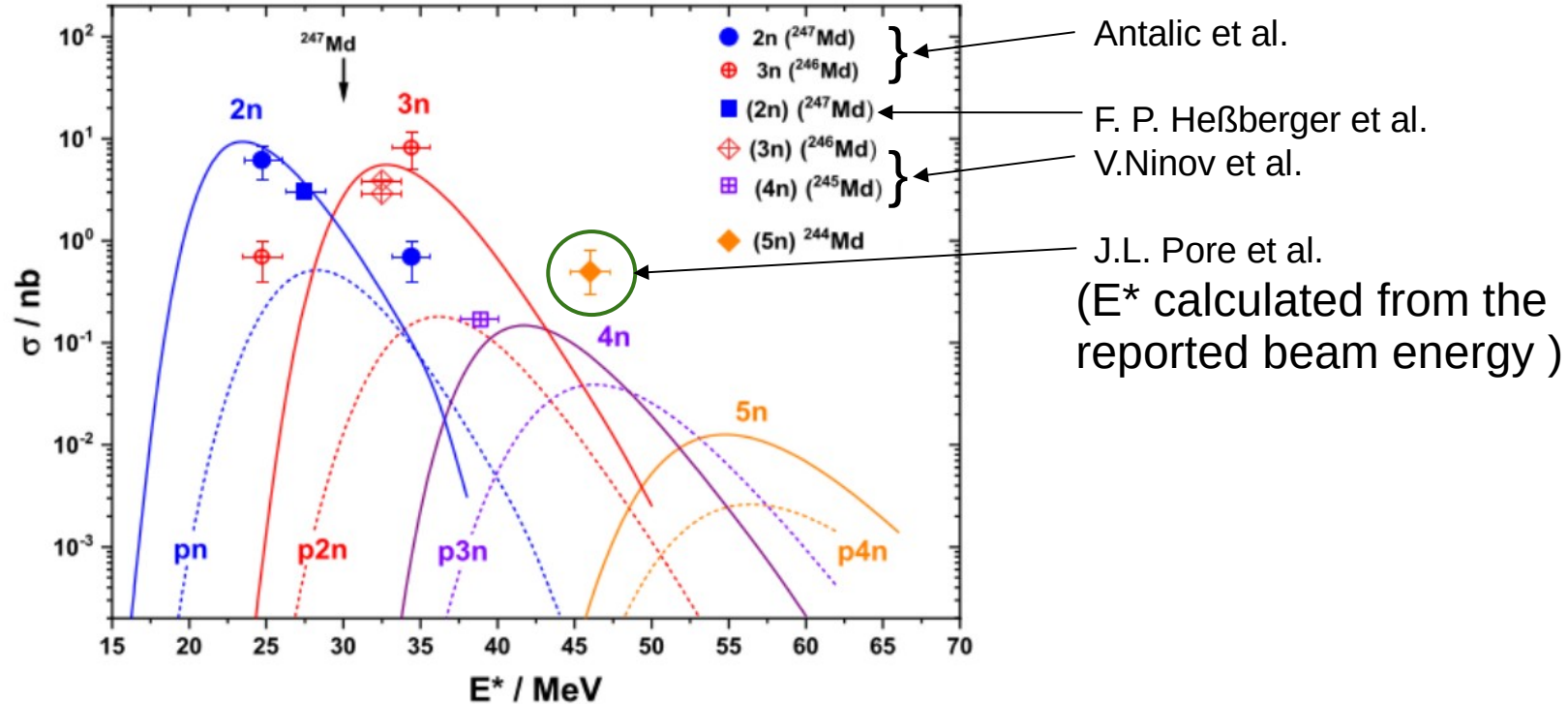
- Each horizontal line corresponds to a single R- α - α chain



Mass assignment using BGS+FIONA

J. L. Pore et al., Phys. Rev. Lett. **124**, 252502 (2020).

The discrepancy in cross-section-excitation energy



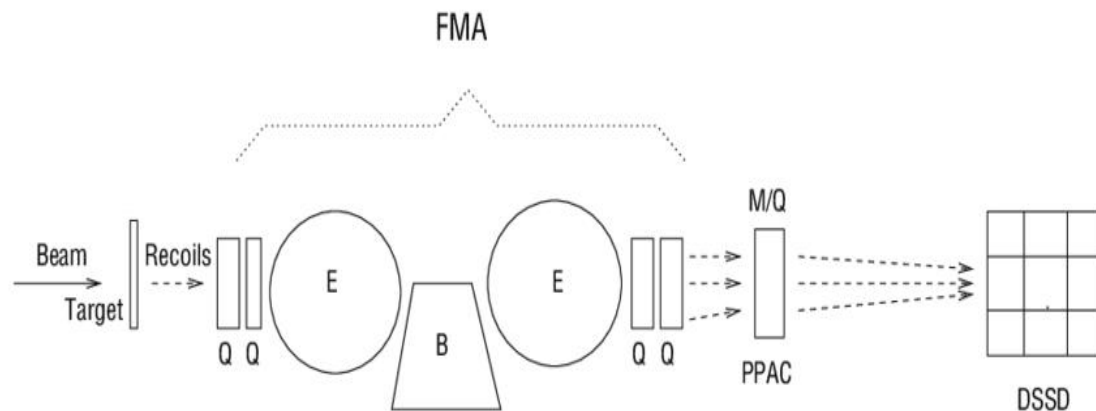
HIVAP statistical model calculations for $^{209}\text{Bi}(^{40}\text{Ar}, x\text{n})^{249-x}\text{Md}$, showing the production cross-section from different experiment as a function of compound nucleus excitation energy.

F. P. Heßberger et al., Phys. Rev. Lett. **126**, 182501 (2021)

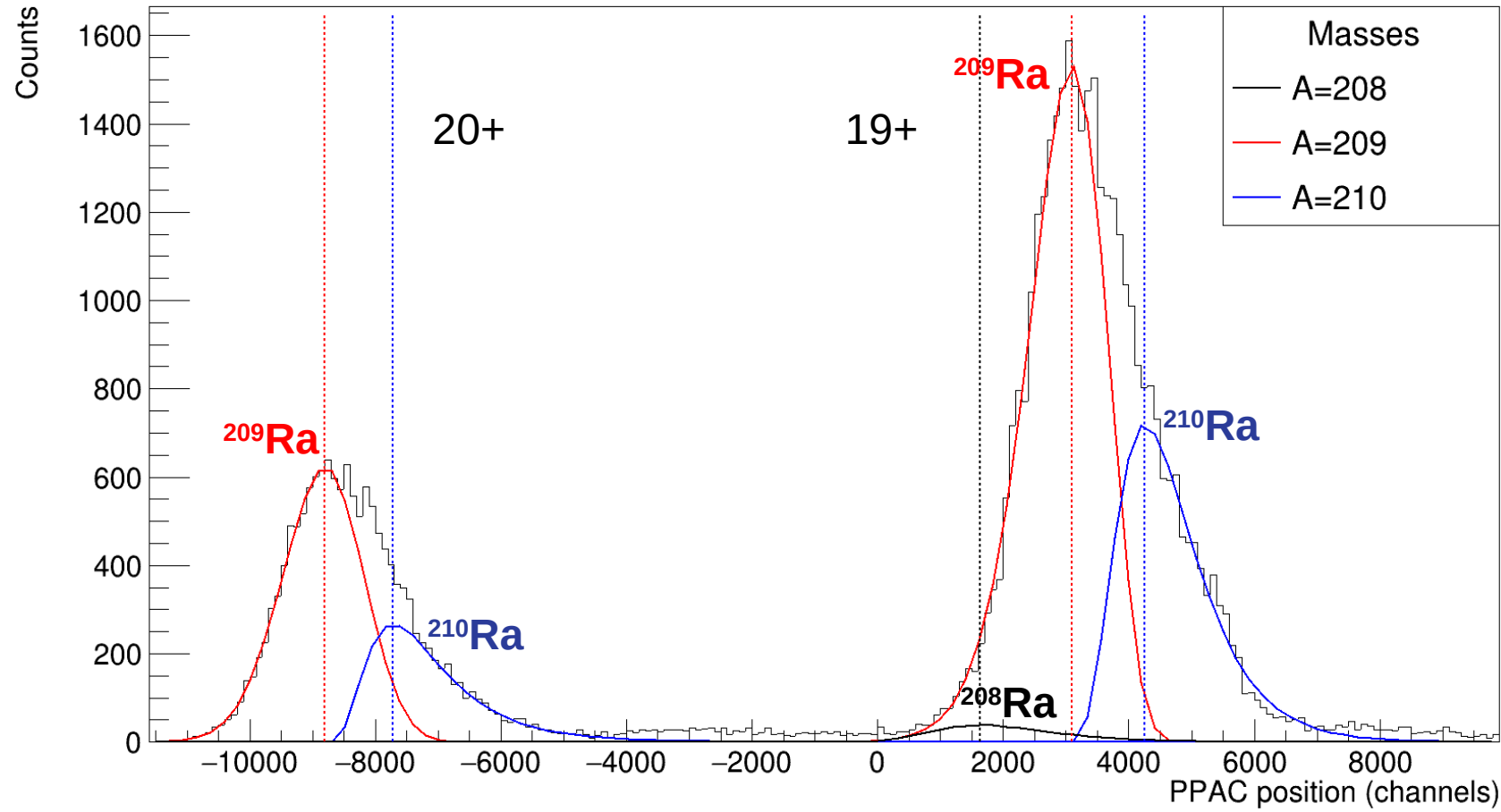
Study of neutron deficient Md at FMA

- Same reaction as Berkeley : $^{209}\text{Bi}(^{40}\text{Ar}, xn)^{249-x}\text{Md}$
- **Simultaneous A/q** as well as **alpha decay energy** measurement.

- Beam intensity: 300 pA ;
- Energy: 5.26 MeV/u ;
- Target thickness of ^{209}Bi : $\sim 450 \mu\text{g}/\text{cm}^2$;
- Cross-section of $\sim 0.5 \text{ nb}$ (reported by J.Pore et al.), expected to detect around ~ 8 ERs per day.

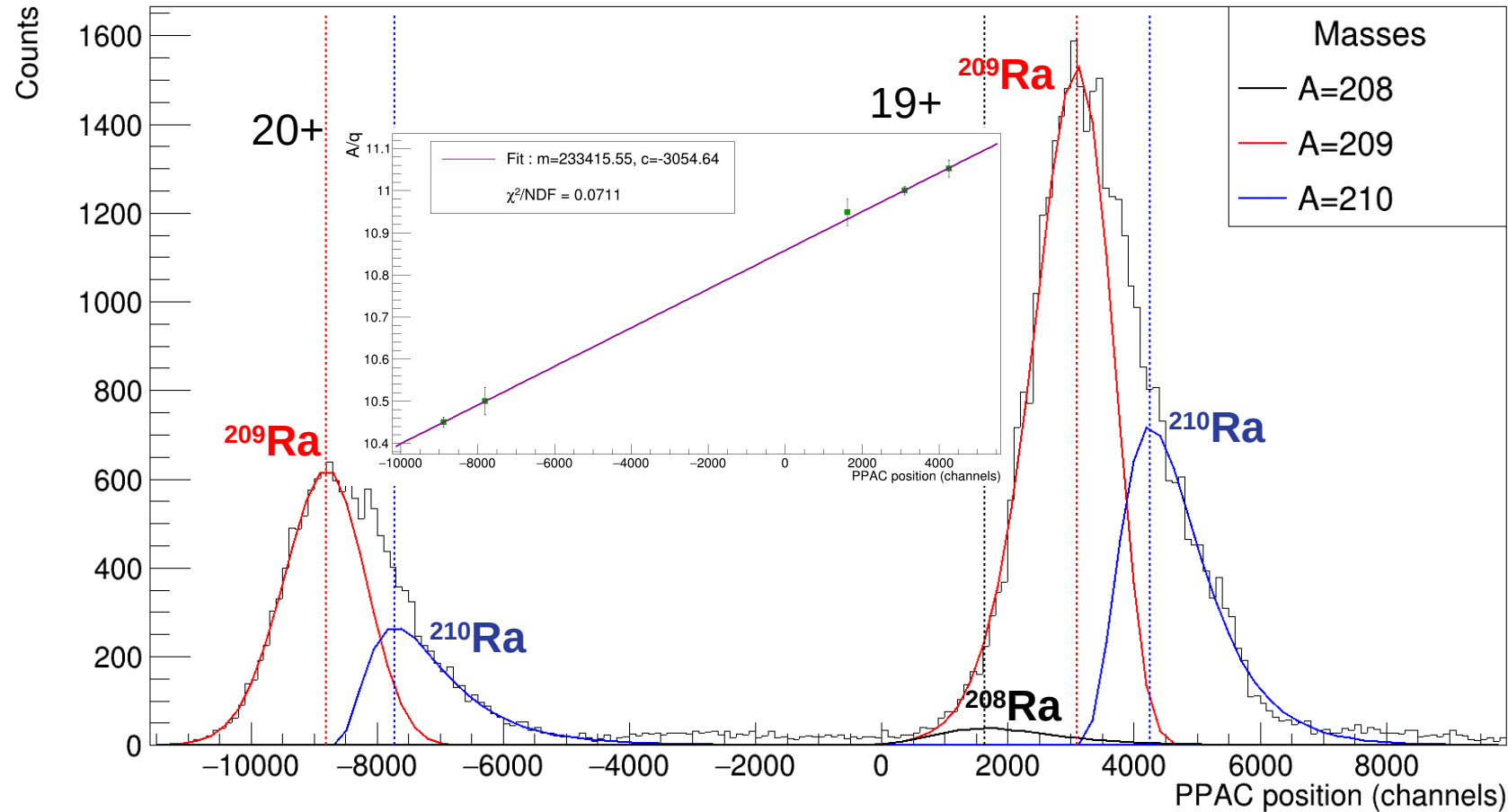


Online position calibration



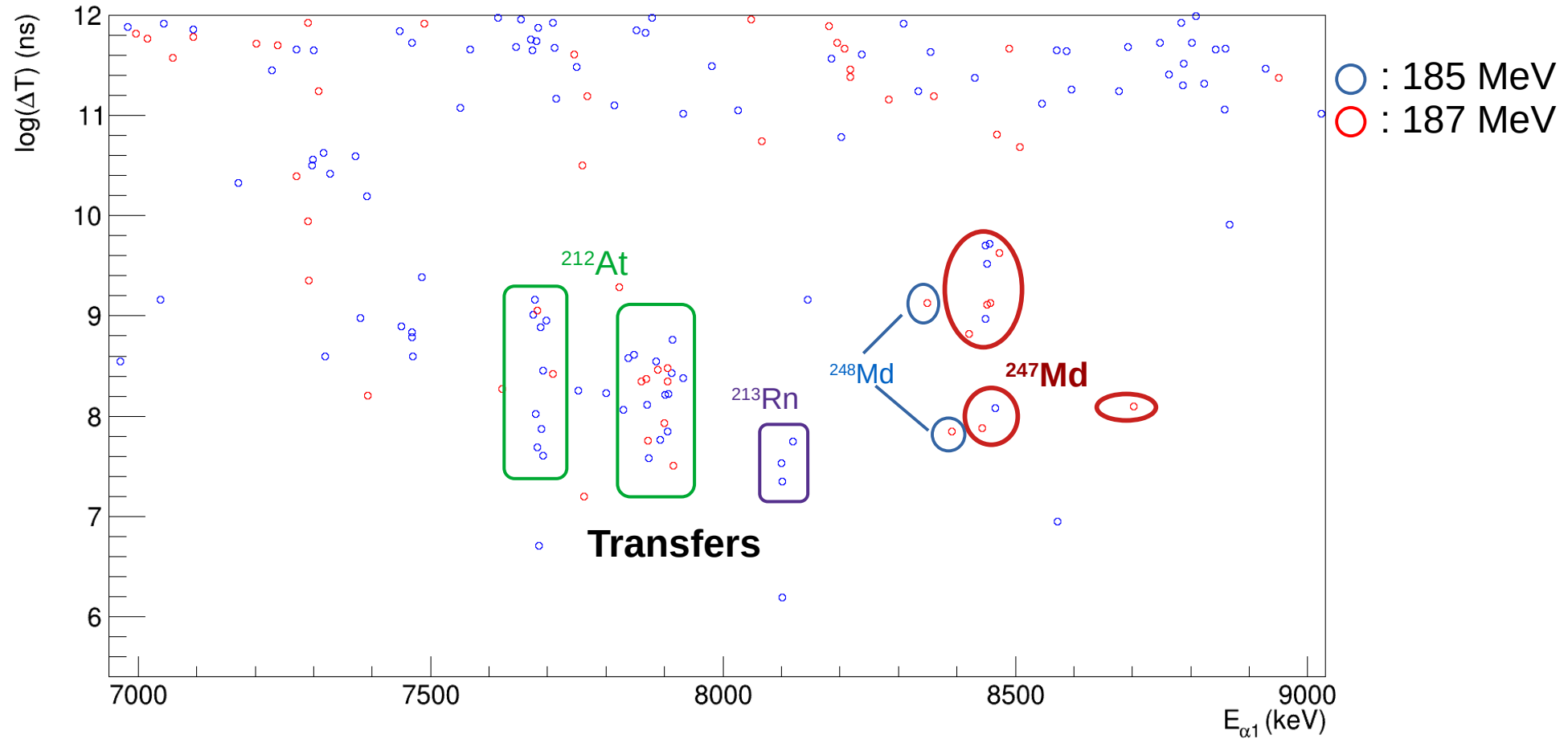
The position calibration for A/q distribution using the reaction $^{174}\text{Yb}(^{40}\text{Ar}, 4n+5n)^{209,210}\text{Ra}$.

Online position calibration



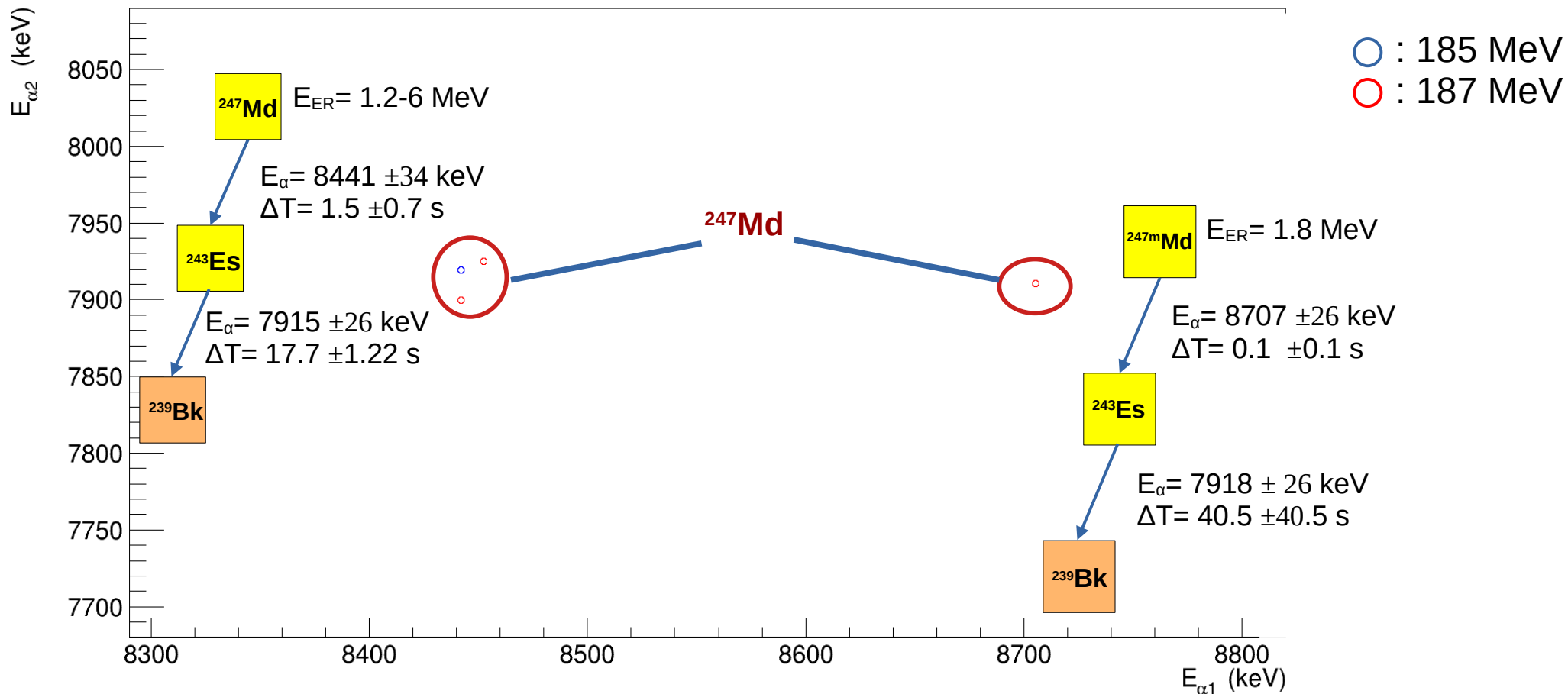
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1st gen. α - decay of ^{247}Md



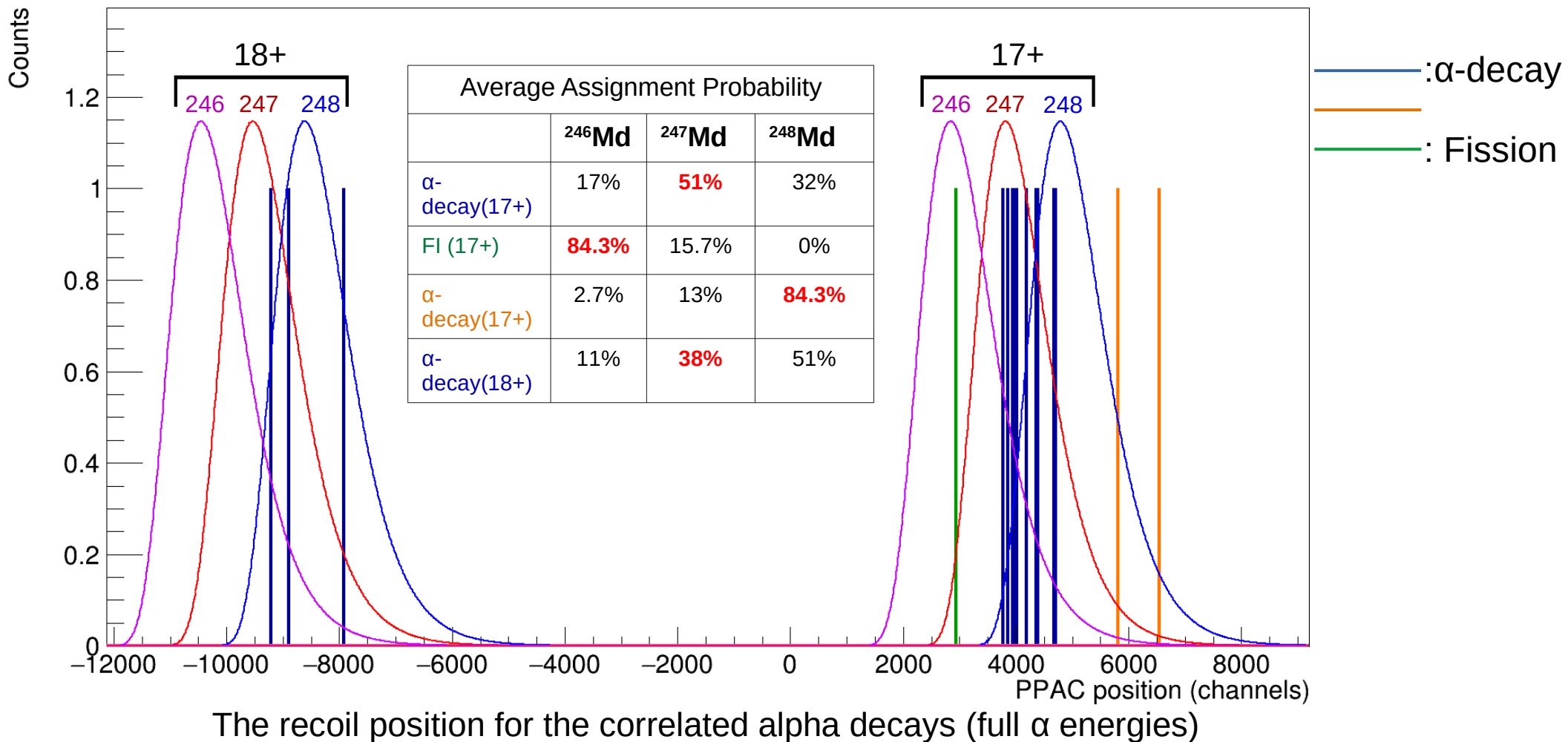
11 position and time correlated 1st gen. alpha decays (full α energies) : ^{247}Md

2nd gen. α decay energy vs 1st gen. α decay energy

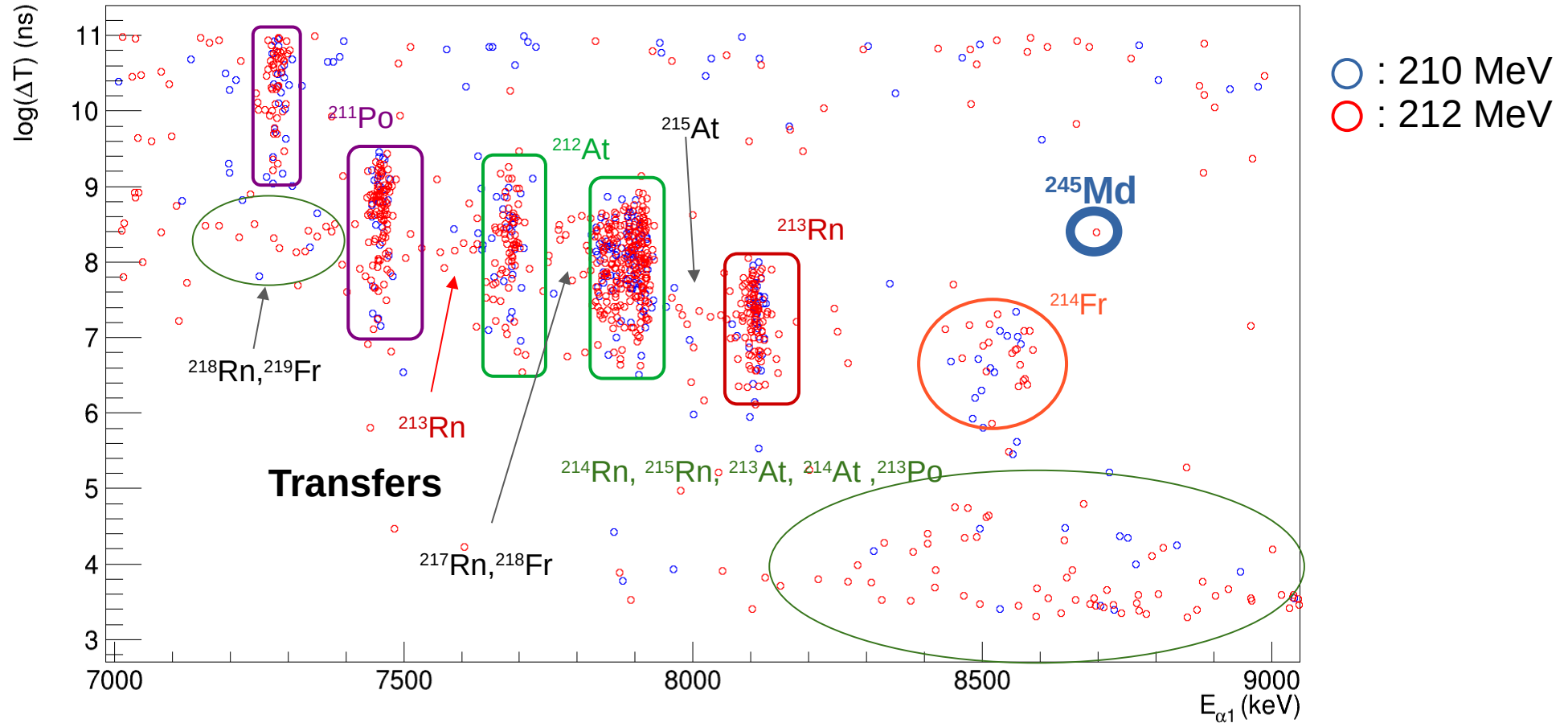


4 position and time correlated 1st gen. & 2nd gen. alpha decays (full α energies) : ^{247}Md

Mass number identification of Md recoils

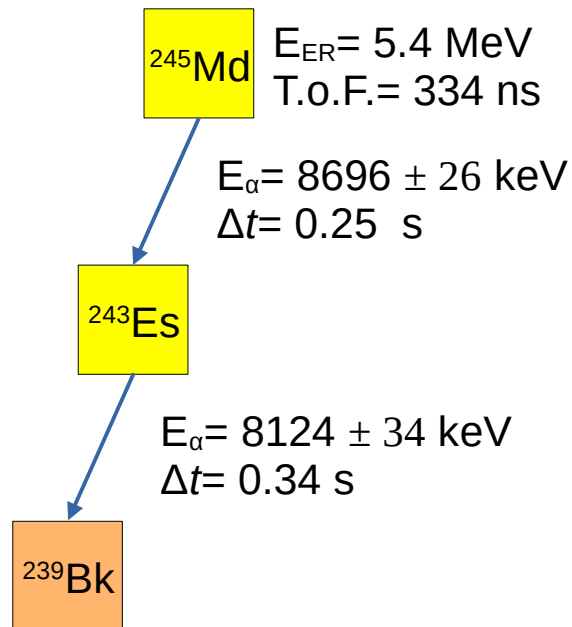


1st gen. α - decay of ^{245}Md

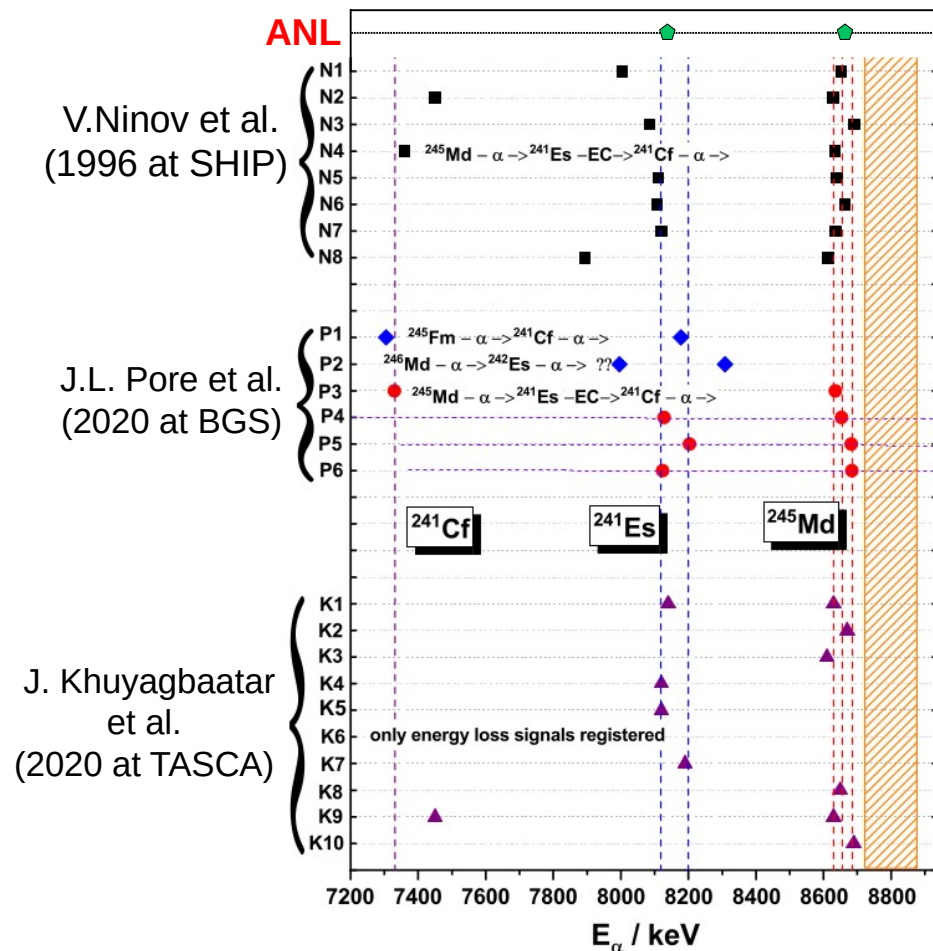


1 position and time correlated 1st generation alpha decay : ^{245}Md

Comparison of the α -decay with previous results



α -decay energies consistent with previous results.



F. P. Heßberger et al., Phys. Rev. Lett. **126**, 182501 (2021)

Fission events



$E_{ER} = 5.7 \text{ MeV}$

$E_{FI} = 28 \text{ MeV}$

$\Delta t = 51 \mu\text{s}$

+ Si-box event of 18 MeV



$E_{ER} = 1.6 \text{ MeV}$

$E_{FI} = 36 \text{ MeV}$

$\Delta t = 31 \mu\text{s}$

+ Si-box event of 16 MeV



$E_{ER} = 5.2 \text{ MeV}$

$E_{FI} = 117 \text{ MeV}$

$\Delta t = 71 \mu\text{s}$

- The implant DSSD and Si-box detectors were not calibrated for Fission.
- Any single decay event $> 100 \text{ MeV}$ or binary events $> 10 \text{ MeV}$ is considered as Fission.

Fission events



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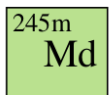


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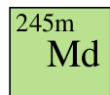
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$E_{ER} = 9.5$

$E_{FI} = 125$

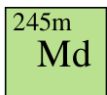
$\Delta t = 0.00321 \text{ s}$



$E_{ER} = 10.0$

$E_{FI} = 122$

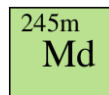
$\Delta t = 0.00106 \text{ s}$



$E_{ER} = 9.8$

$E_{FI} = 48$

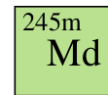
$\Delta t = 0.000802 \text{ s}$



$E_{ER} = 14.1$

$E_{FI} = 74$

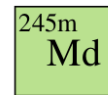
$\Delta t = 0.000520 \text{ s}$



$E_{ER} = 10.4$

$E_{FI} = 58$

$\Delta t = 0.000653 \text{ s}$



$E_{ER} = 12.4$

$E_{FI} = 135$

$\Delta t = 0.00112 \text{ s}$



$E_{ER} = 13.2$

$E_{FI} = 122$

$\Delta t = 0.0027 \text{ s}$



$E_{ER} = 14.1$

$E_{FI} = 103$

$\Delta t = 0.00395 \text{ s}$



$E_{ER} = 10.6$

$E_{FI} = 90$

$\Delta t = 0.00437 \text{ s}$



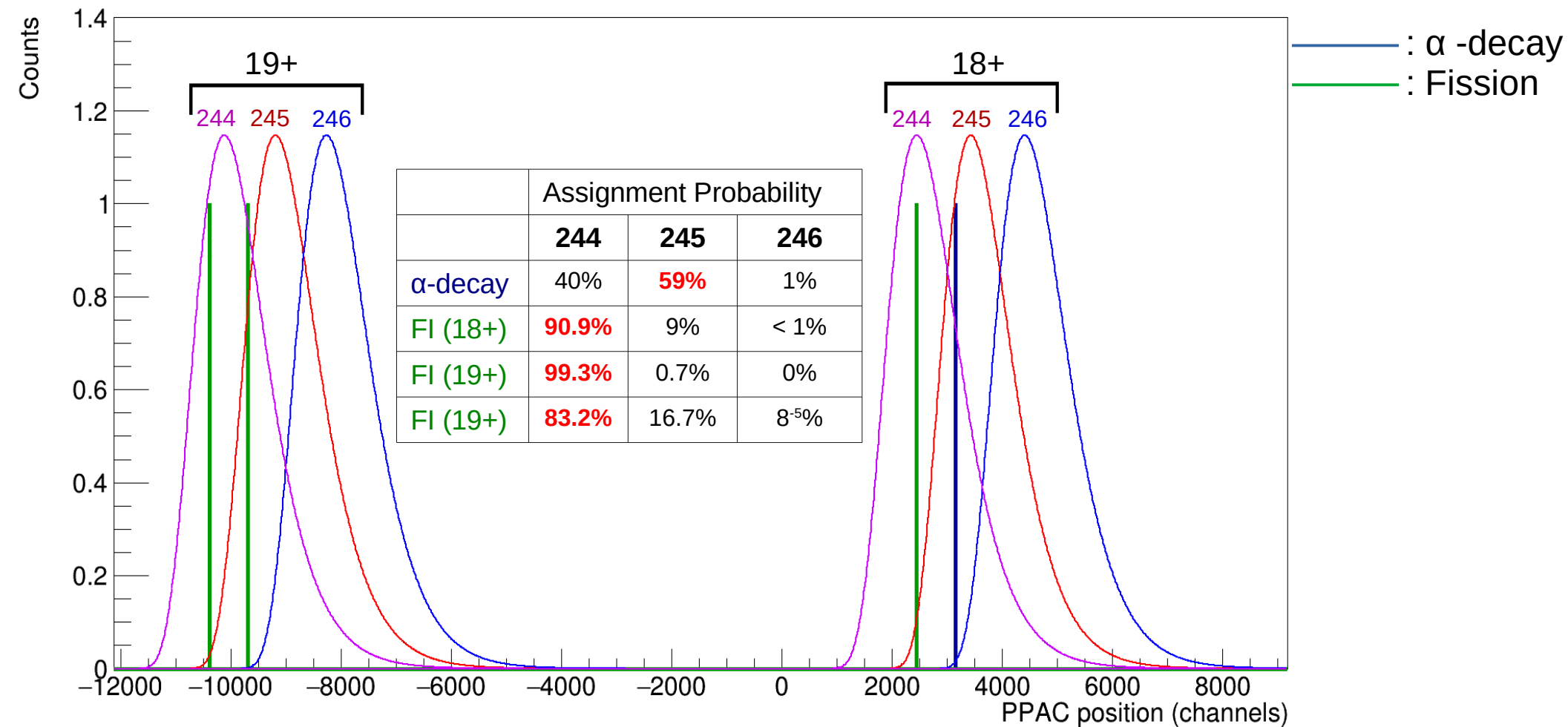
$E_{ER} = 13.9$

$E_{FI} = 125$

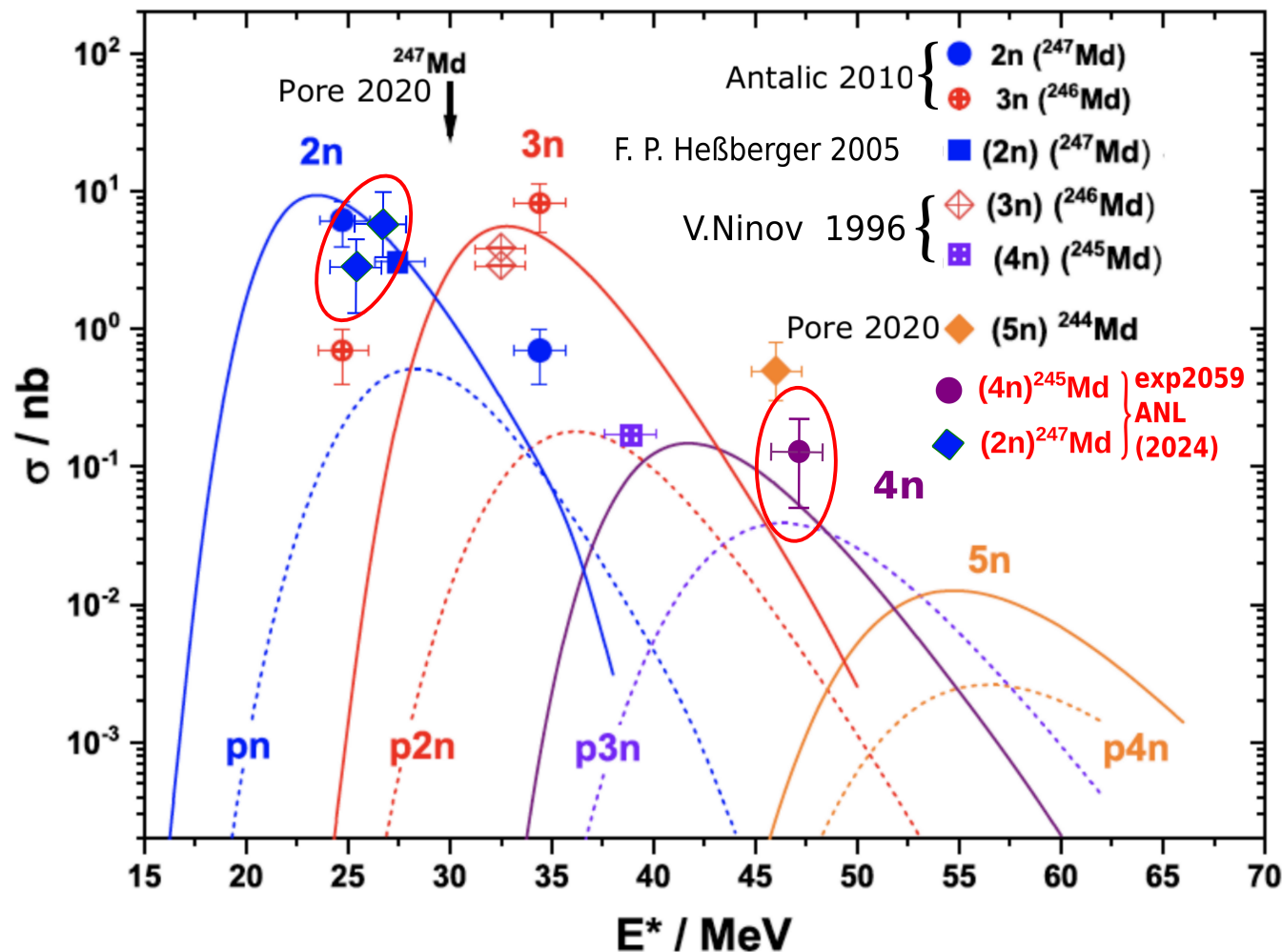
$\Delta t = 0.00703 \text{ s}$

J. Khuyagbaatar et al., Phys. Rev. Lett. 125, 142504 (2020)

Mass-assignment for Md recoils



Cross-section for FMA events



$$E_{\text{beam}} \sim 187 \text{ MeV}$$

$$\sigma(247) \sim 6.9^{+4.6}_{-2.9} \text{ nbarn}$$

$$E_{\text{beam}} \sim 185 \text{ MeV}$$

$$\sigma(247) \sim 2.6^{+1.3}_{-1.9} \text{ nbarn}$$

$$E_{\text{beam}} \sim 212 \text{ MeV}$$

$$\sigma(245) \sim 101.04^{+90.94}_{-75.52} \text{ pbarn}$$

Conclusion and Outlook

- **1** recoil- α - α decay chain observed for ^{245}Md , with decay energy consistent with GSI and Berkeley .
- **3** spontaneous fission events observed with tentative mass-assignment to $A=244$.
- We do not confirm the **mass-assignment** from the experiment at Berkeley.
- **11** recoil- α decay chains have been observed for ^{247}Md consistent with previous studies .
- Due to the low statistics and low resolution only probabilistic mass identification was possible .
- The experiment is planned to be repeated at **S³** for better statistics, **GANIL** in the future .

Acknowledgement

S. Kumar^{1,2}, D. Ackermann¹, J. Piot¹, D. Sewerniak³, V. Karayonchev³, S. Antalic⁴, Ch. Stodel¹, B. Andel⁴, A. Bahini¹, K. Bhatt³, C. Burns⁵, M. Carpenter³, R. Chakma³, A. Ertoprak³, K. Hauschild⁶, F.G. Kondev³, A. Korichi^{3,6}, T. Lauritsen³, A. Lopez-Martens⁶, A. McFarlane⁷, J. Mist⁴, C. Mueller Gattermann³, D. Potterveld³, S. Raeder⁸, W. Reviol³, H. Savajols¹, N. Sensharma³, R.S. Sidhu^{8,9}, M. Siliciano³, and B. Sulignano¹⁰

¹*Grand Accélérateur National d'Ions Lourds(GANIL), Caen, France*

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³*Argonne National Laboratory, Lemont, Illinois, USA*

⁴*Comenius University, Bratislava, Slovakia*

⁵*University of Massachusetts Lowell, Lowell, Massachusetts, USA*

⁶*IJC Lab, Orsay, France*

⁷*University of York, York, England*

⁸*GSI, Darmstadt, Germany*

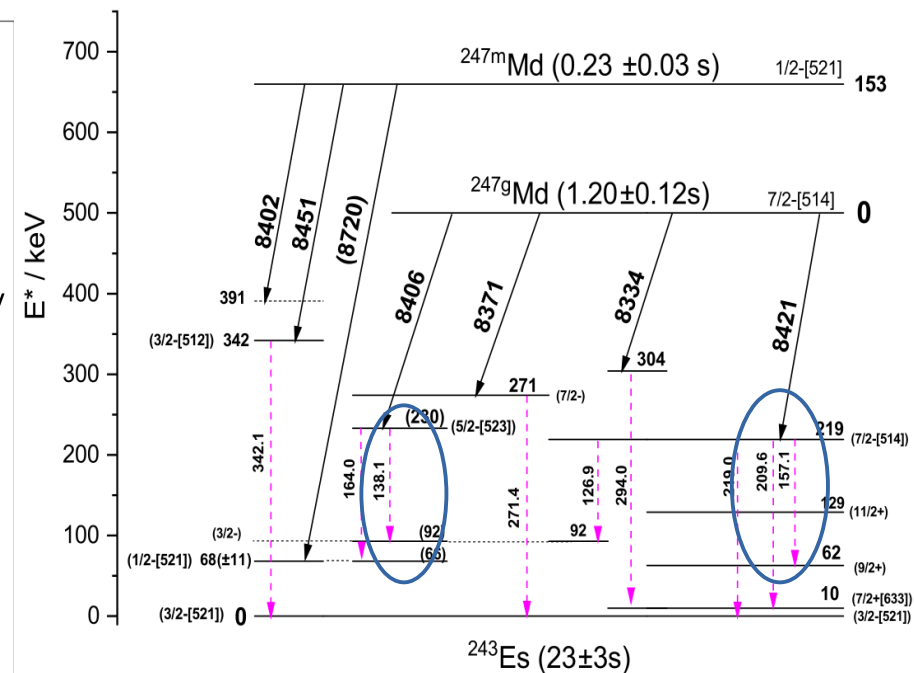
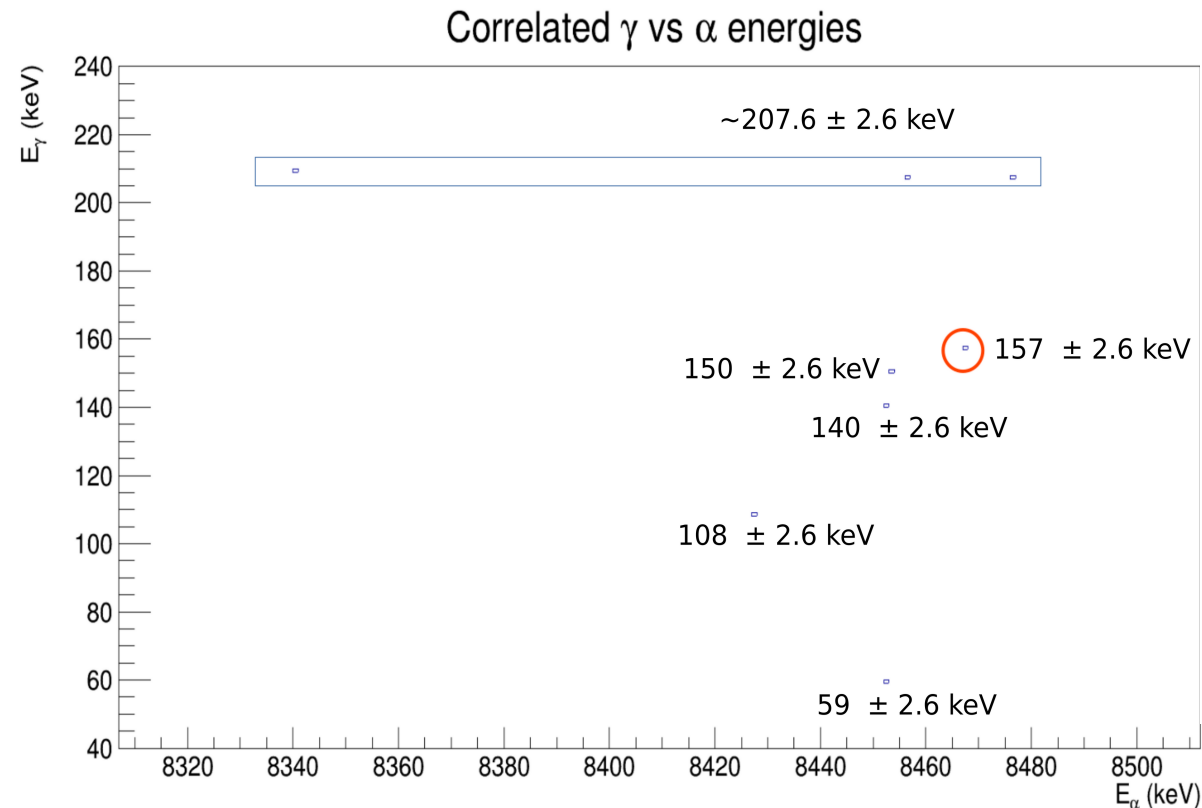
⁹*University of Edinburgh, Edinburgh, Scotland and*

¹⁰*IRFU/DPhN CEA Scalay, France*

Thank you for your Attention

Backup Slides

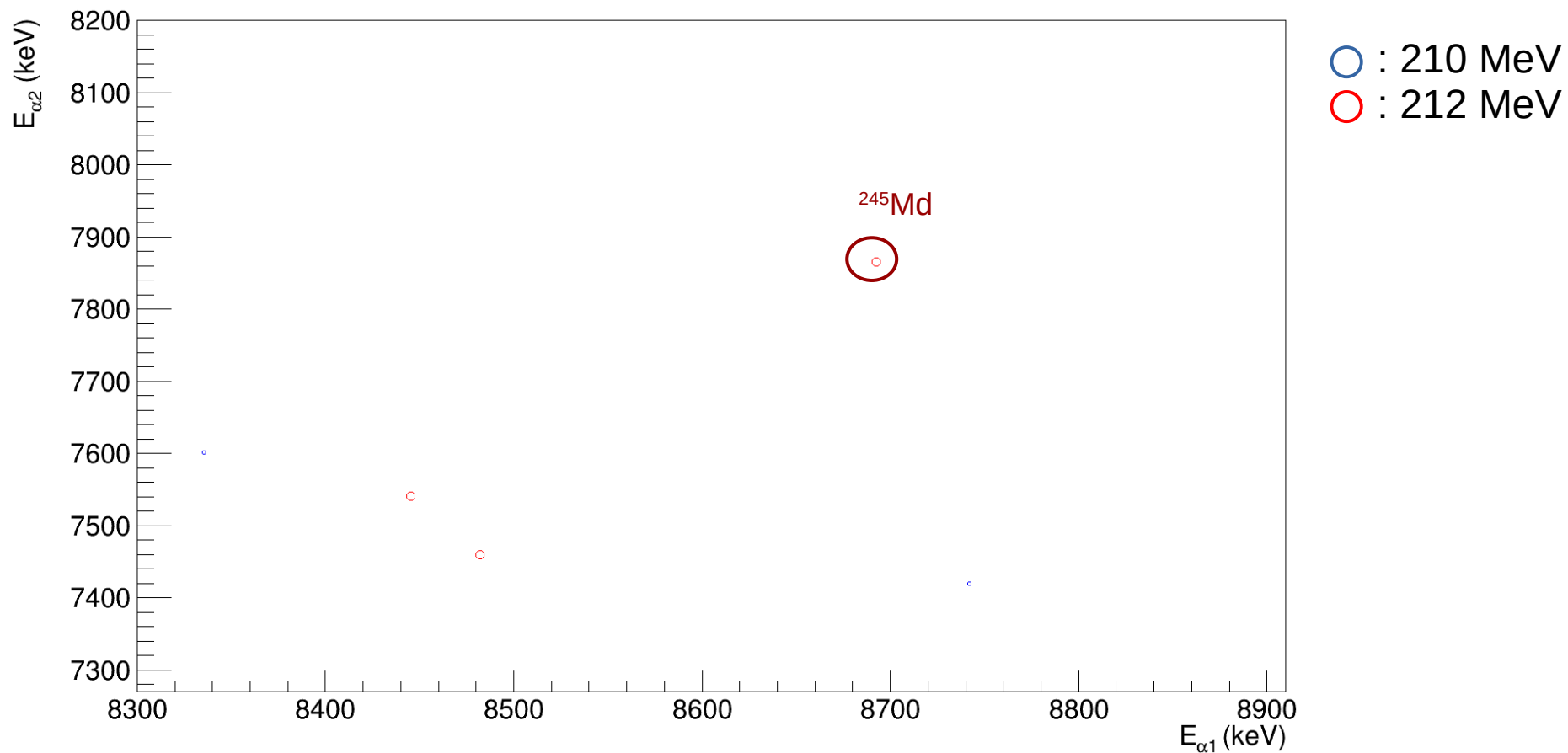
Comparison of the decays with published results



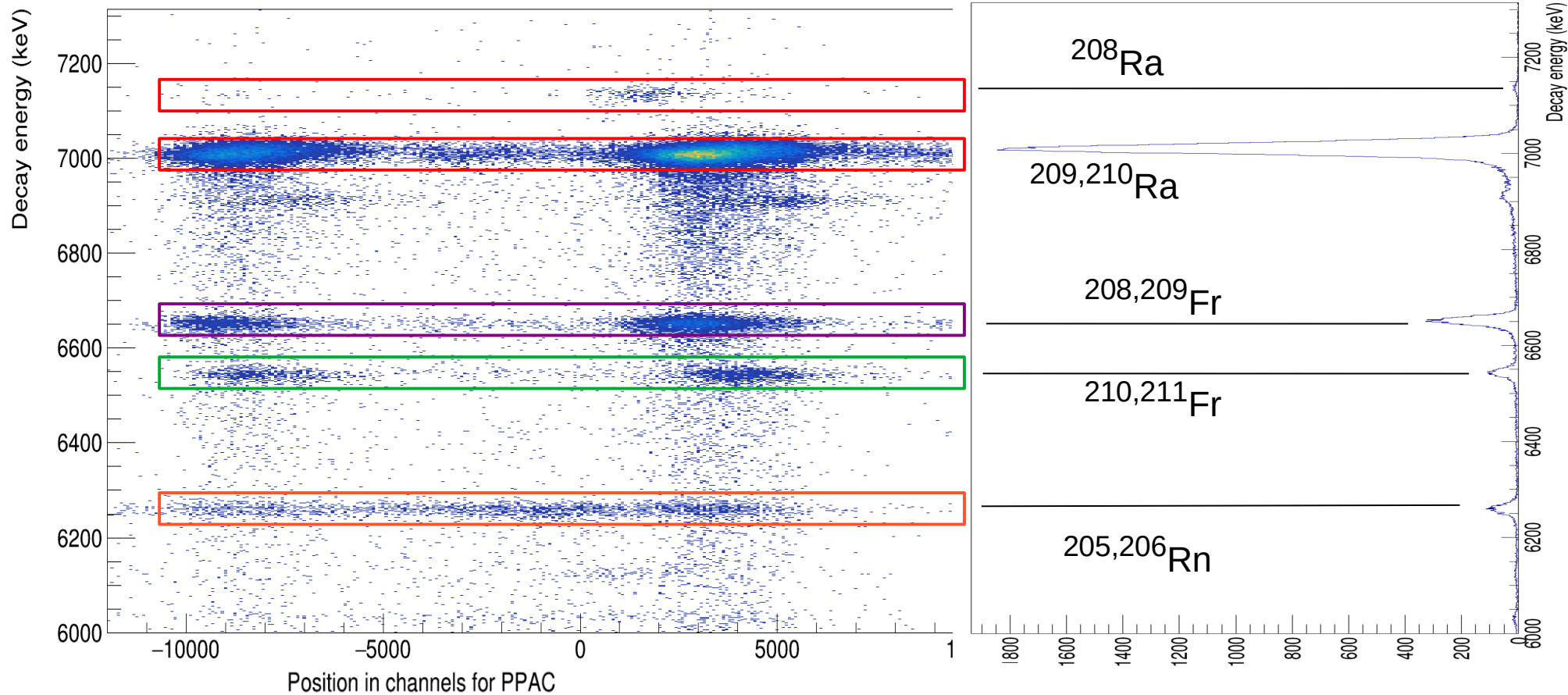
F. P. Heßberger et al., Eur. Phys. J. A (2022) 58:11

The position and time correlated 1st generation alpha decays (full α energies)

2^{nd} gen. α decay energy vs 1^{st} gen. α decay energy

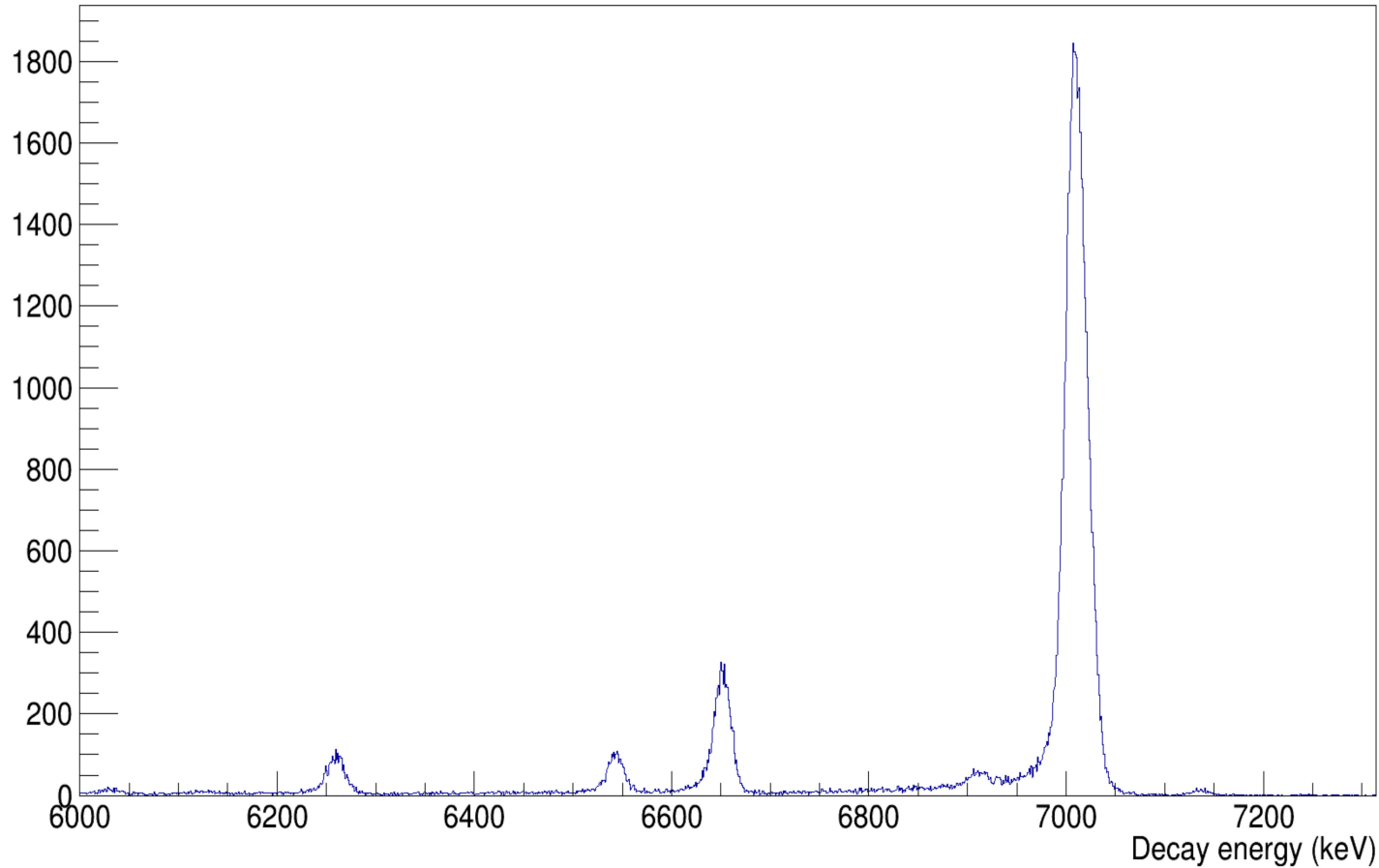


Online position calibration



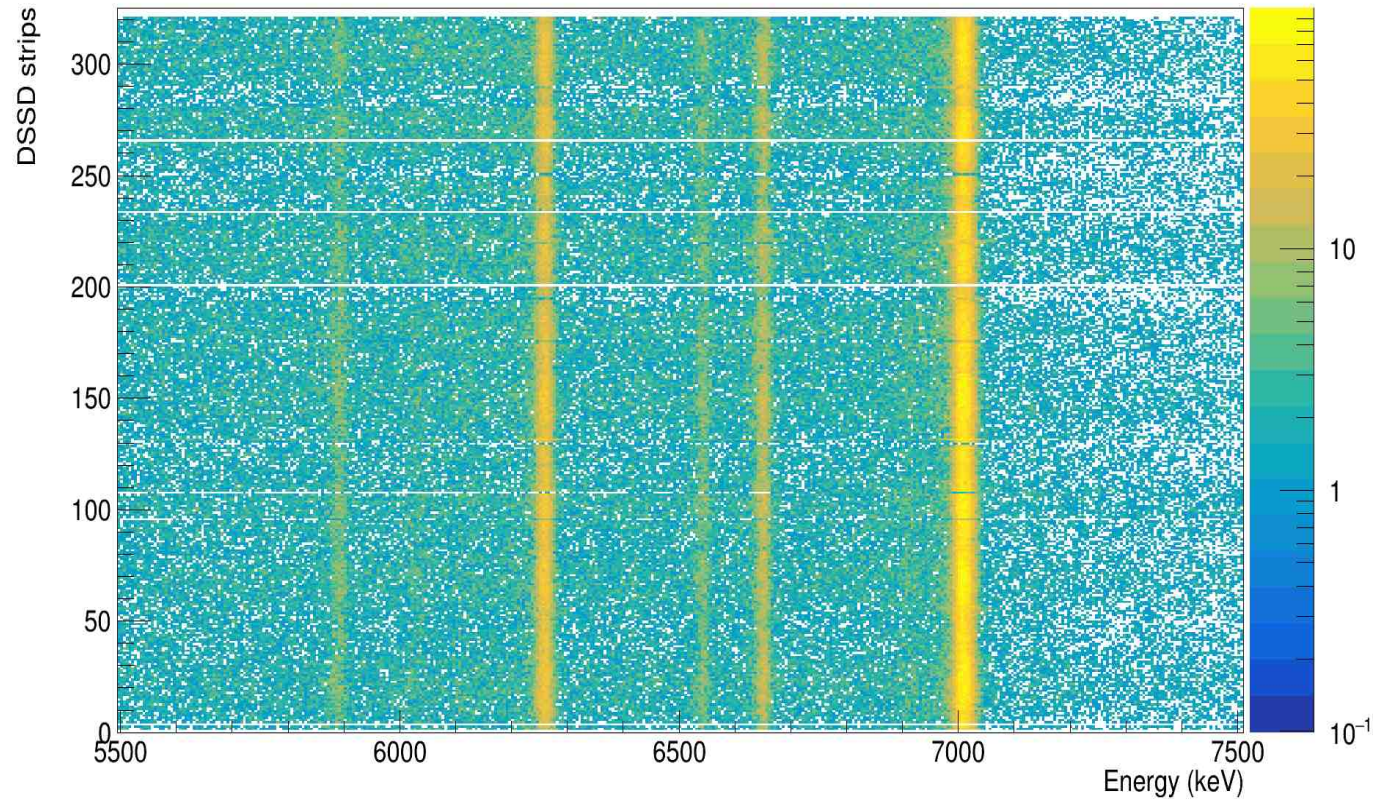
The position and DSSD calibration for A/q distribution and energy using the $^{174}\text{Yb}(^{40}\text{Ar}, 4n+5n)^{209,210}\text{Ra}$ reaction.

Online energy calibration



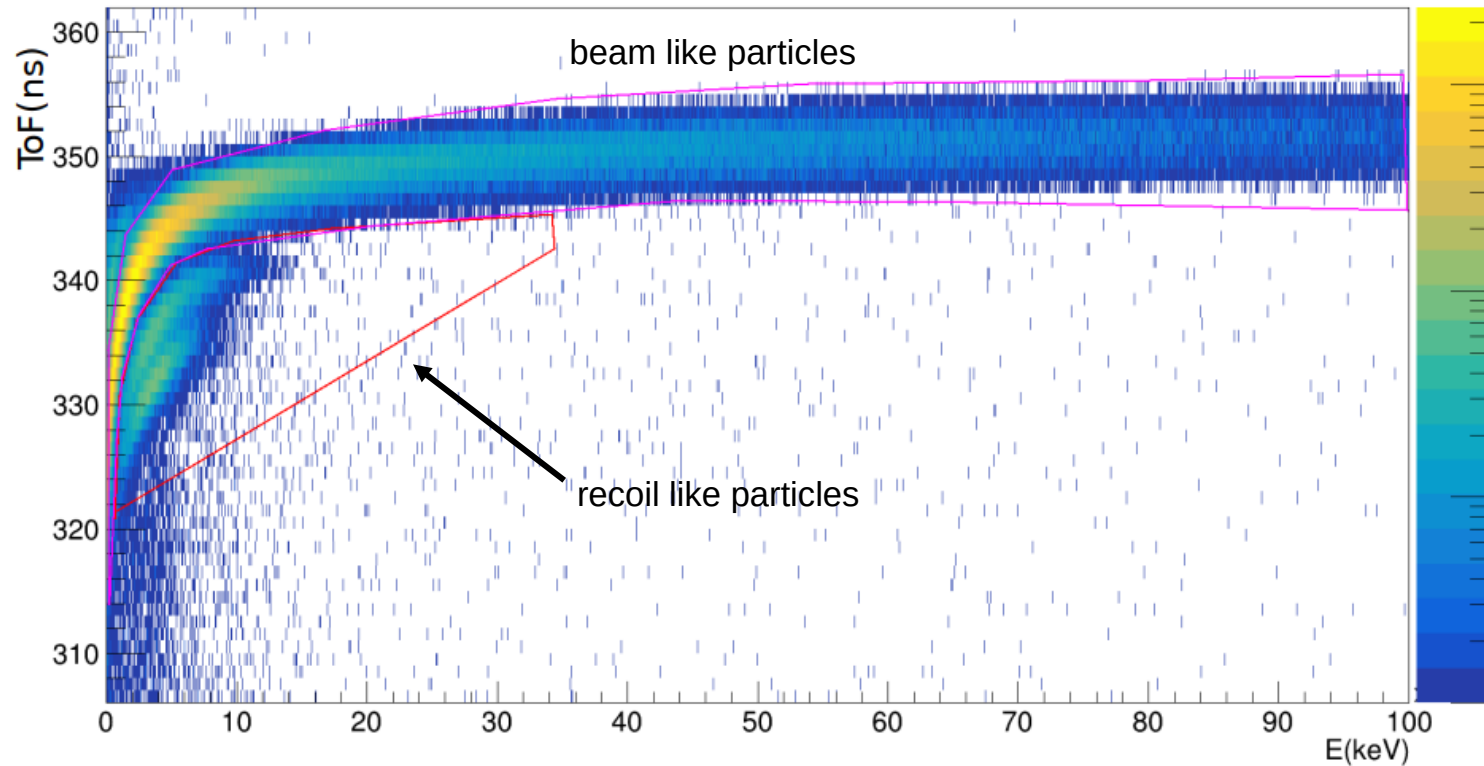
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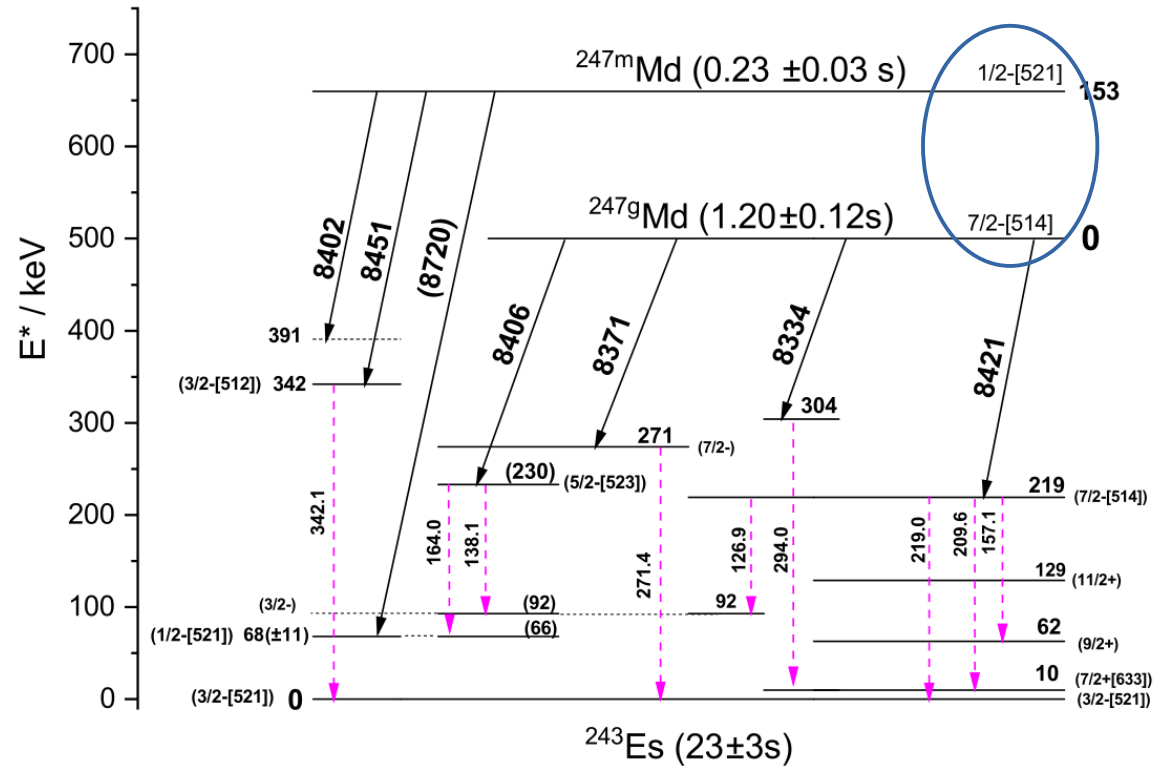
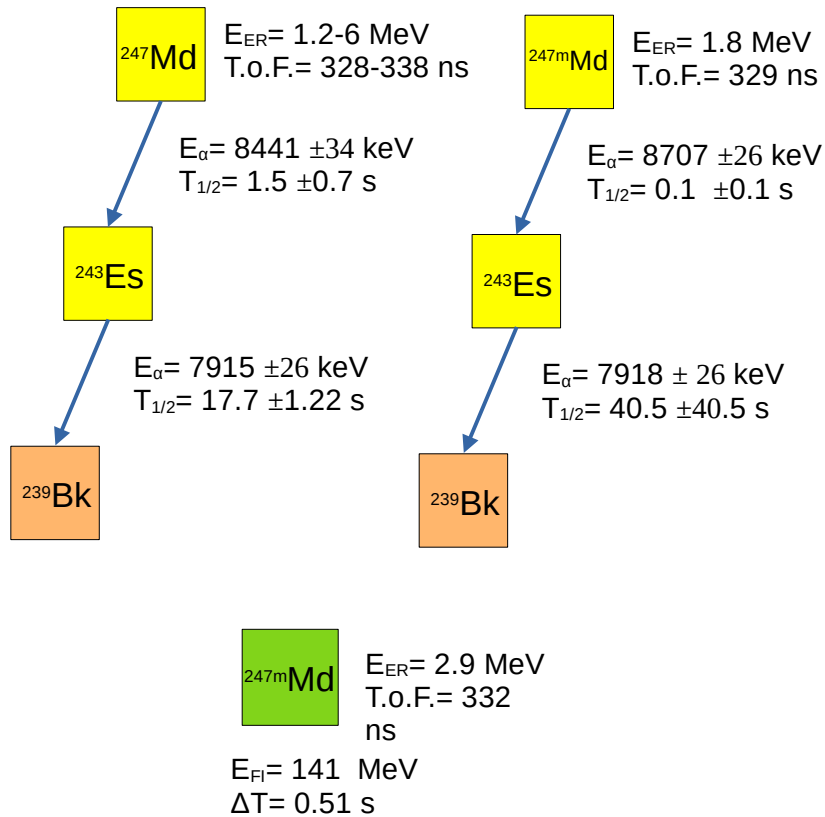
The position and DSSD calibration for A/q distribution and energy using the $^{174}\text{Yb}(^{40}\text{Ar}, 4n+5n)^{209,210}\text{Ra}$ reaction.

Background Suppression using Time-of-flight- Energy cut



Time-of-Flight(ToF) vs Energy of recoil plot between PPAC and DSSD.

Comparison of the decays with published results

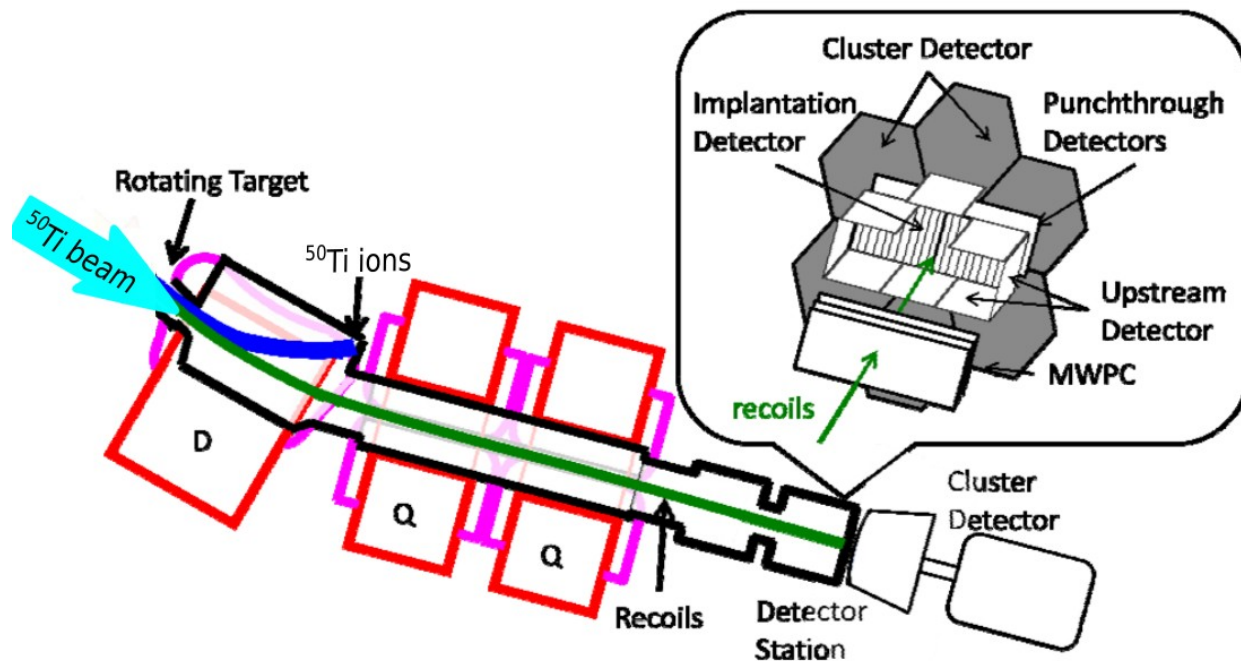


F. P. Heßberger et al., Eur. Phys. J. A (2022) 58:11

The position and time correlated 1st generation alpha decays (full α energies)

Experiment at GSI: TASCA

J. Khuyagbaatar et al., Phys. Rev. Lett. 125, 142504 (2020)

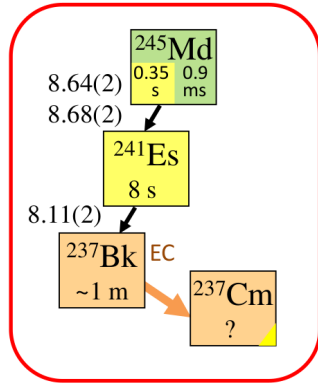


Gas filled recoil separator

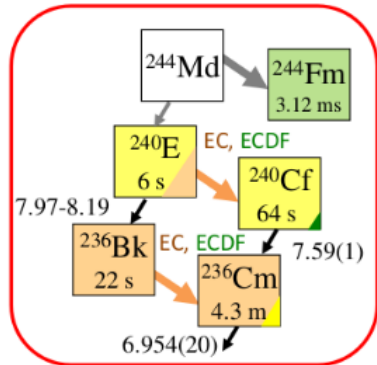
- Reaction: $^{197}\text{Au}(^{50}\text{Ti}, xn)^{247-x}\text{Md}$
- Centre-of-Target beam energies: 231.5 and 239.8 MeV

17 possible decay chains observed for isotopes $^{244,245}\text{Md}$ at $E^*=26.2$ and 32.7 MeV

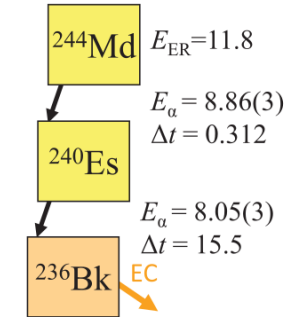
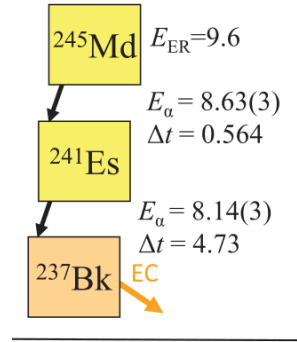
Experiment at GSI: TASCA



V. Ninov et al., Zeit. Phys. A 356, 11 (1996)

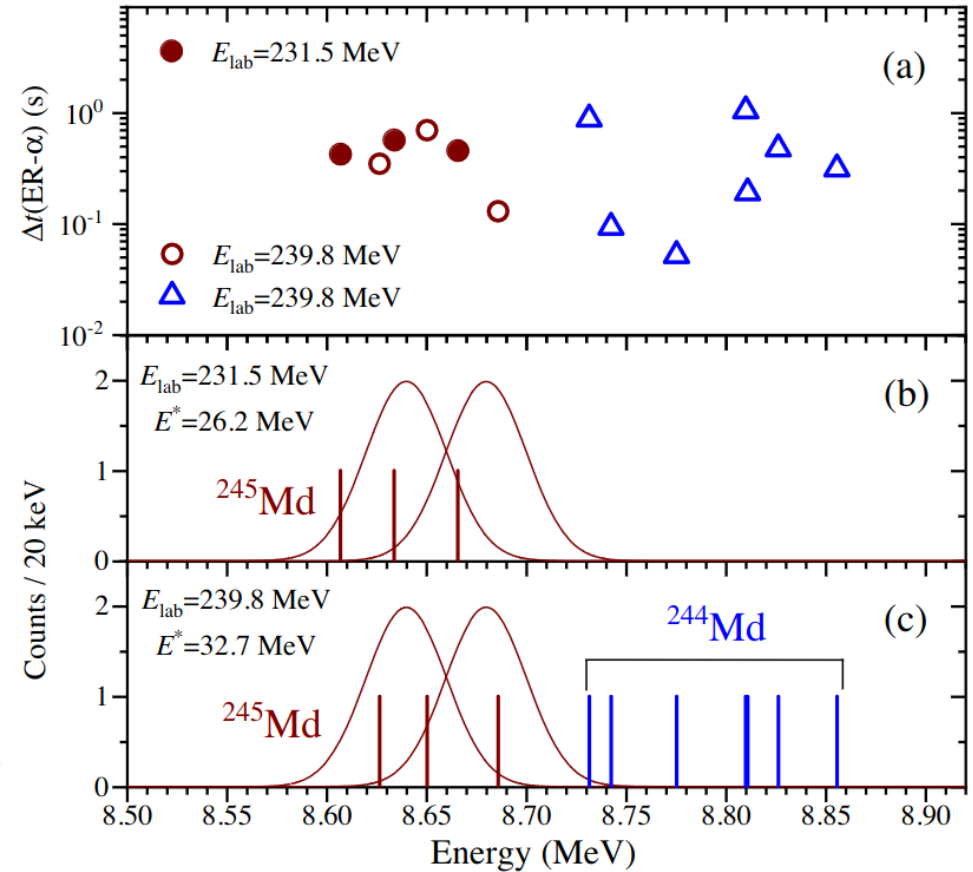


J. Konki, J. Khuyagbaatar, J. Uusitalo, et al., Phys. Lett. B 764, 265 (2017)



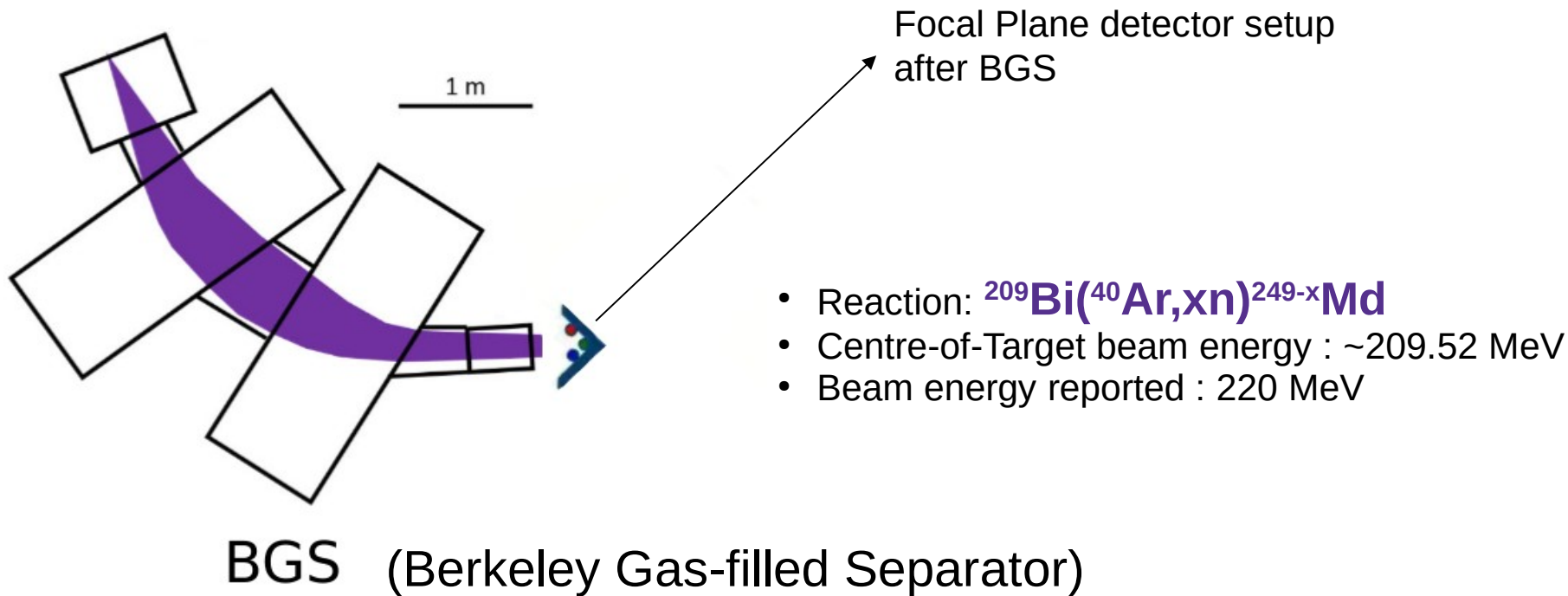
$$T_{1/2}(^{245}\text{Md}) = 0.33^{+0.15}_{-0.08} \text{ s}$$

$$T_{1/2}(^{244}\text{Md}) = 0.30^{+0.19}_{-0.09} \text{ s}$$



Experiment at Berkley : BGS

Base image derived from J. L. Pore et al., Phys. Rev. Lett. 124, 252502 (2020)

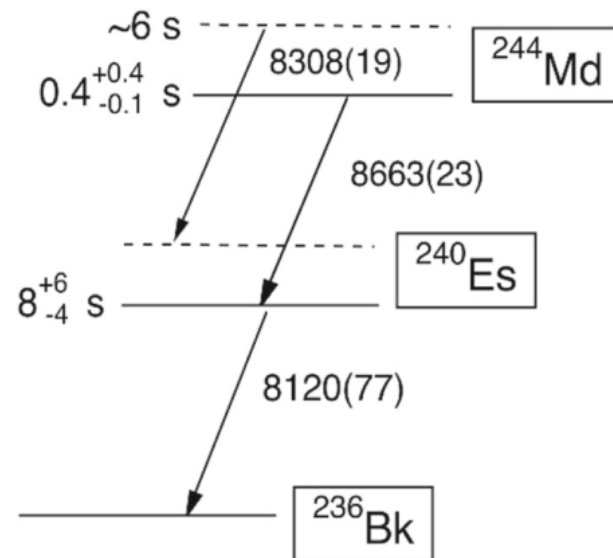


6 decay chains were observed.

Experiment at Berkley : BGS

Evt. no.	E_{α_1} (keV)	EVR- α_1 Δt (s)	E_{α_2} (keV)	α_1 - α_2 Δt (s)	E_{α_3} (keV)	α_2 - α_3 Δt (s)
1	8178(23)	0.60	7305(23)	27.34	...	...
2	8308(19)	9.18	7996(19)	14.37	...	...
3	8635(18)	0.88	7330(18)	18.95	...	...
4	8653(25)	0.13	8128(25)	1.20	7086(25)	75.97
5	8682(20)	0.31	8203(20)	10.00	...	...
6	8684(20)	1.16	8124(20)	7.65	...	...

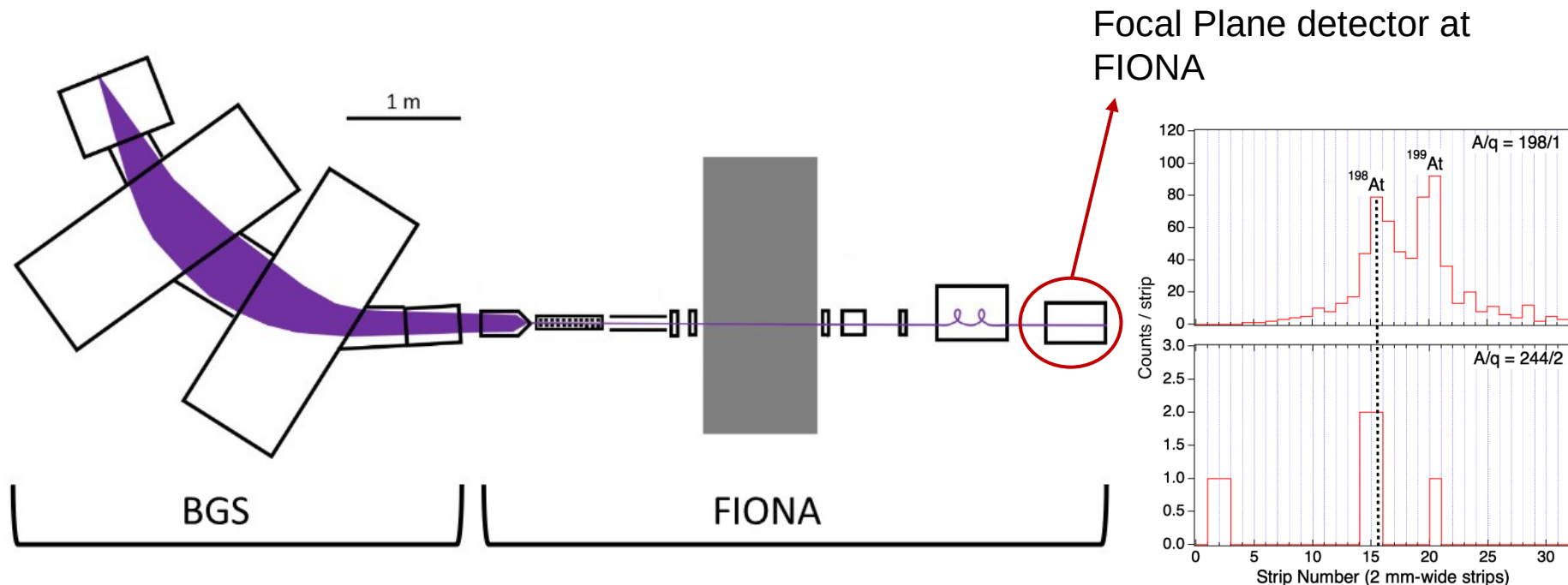
J. L. Pore et al., Phys. Rev. Lett. 124, 252502 (2020)



- A total of 6 Evaporation Recoil(implant)- α - α events (including one Recoil- α - α - α) detected at the BGS focal plane.
- First probable assignment of α decay energy for ^{236}Bk .

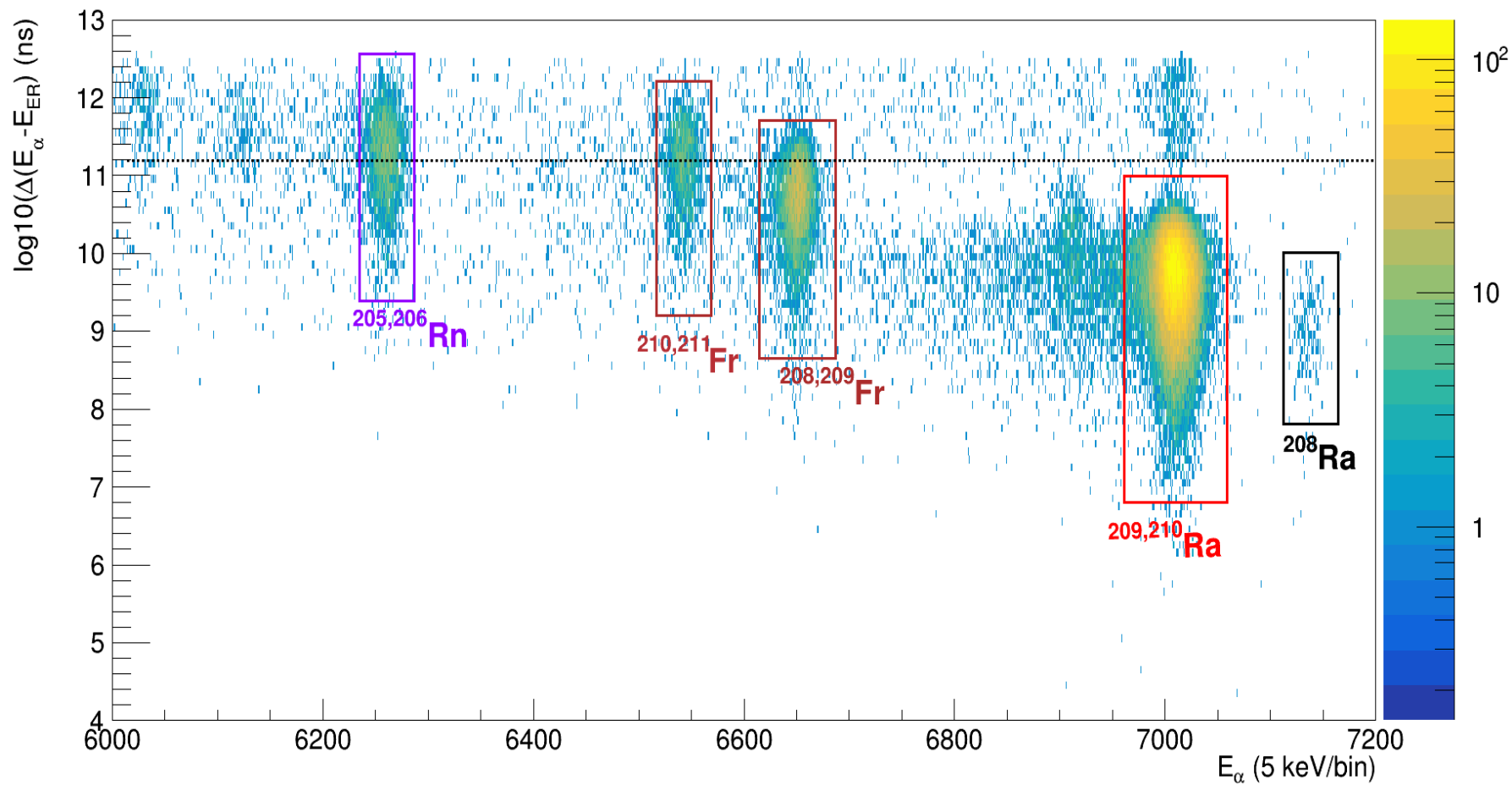
Experiment at Berkley : BGS + FIONA

J.L. Pore et al., Phys. Rev. Lett. 124, 252502 (2020)

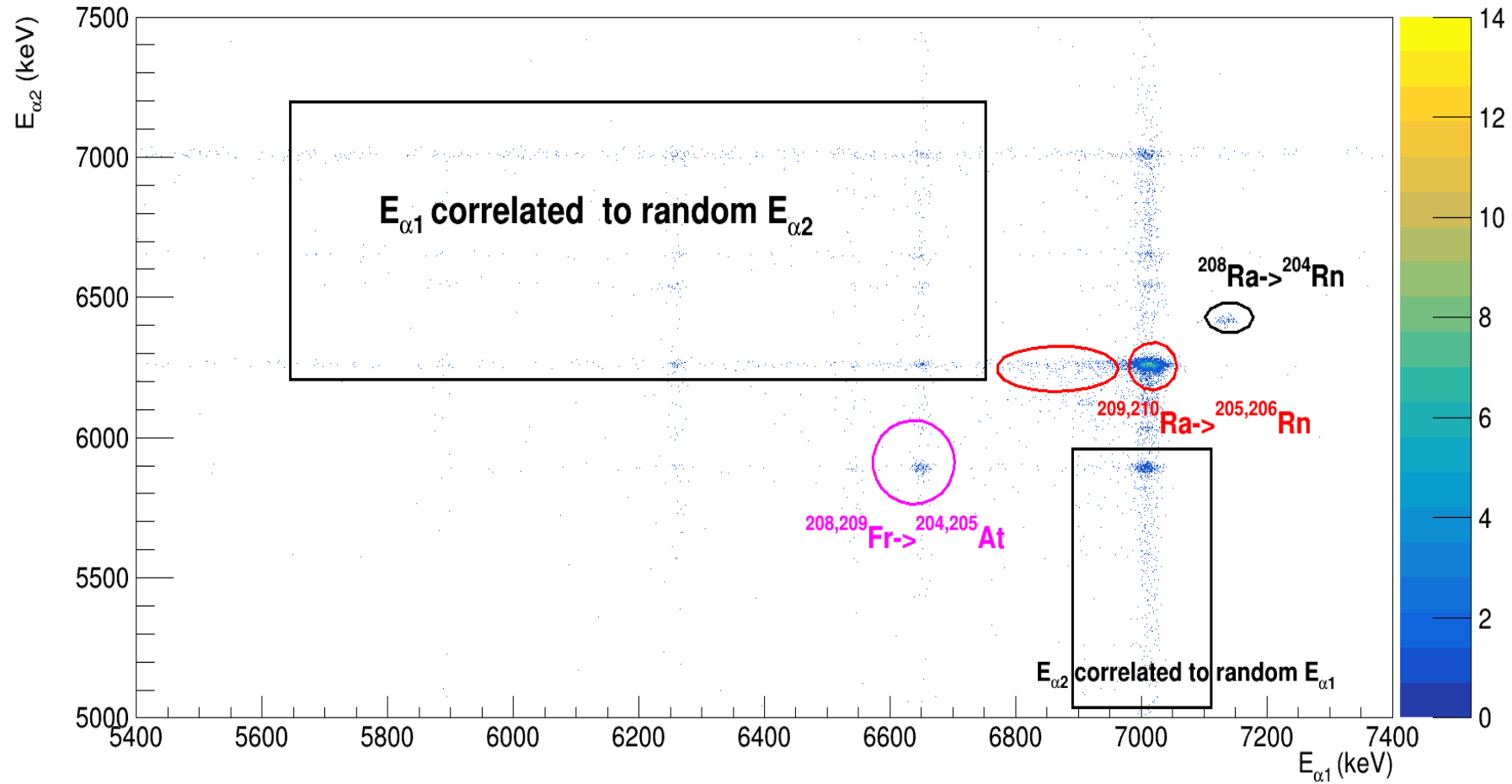


- Ions from BGS are slowed (1), bunched (2), re-accelerated (3) and directed to focal plane detector of FIONA through a trochoidal spectrometer (4).
- Mass-assignment through position alignment with the calibration ions.

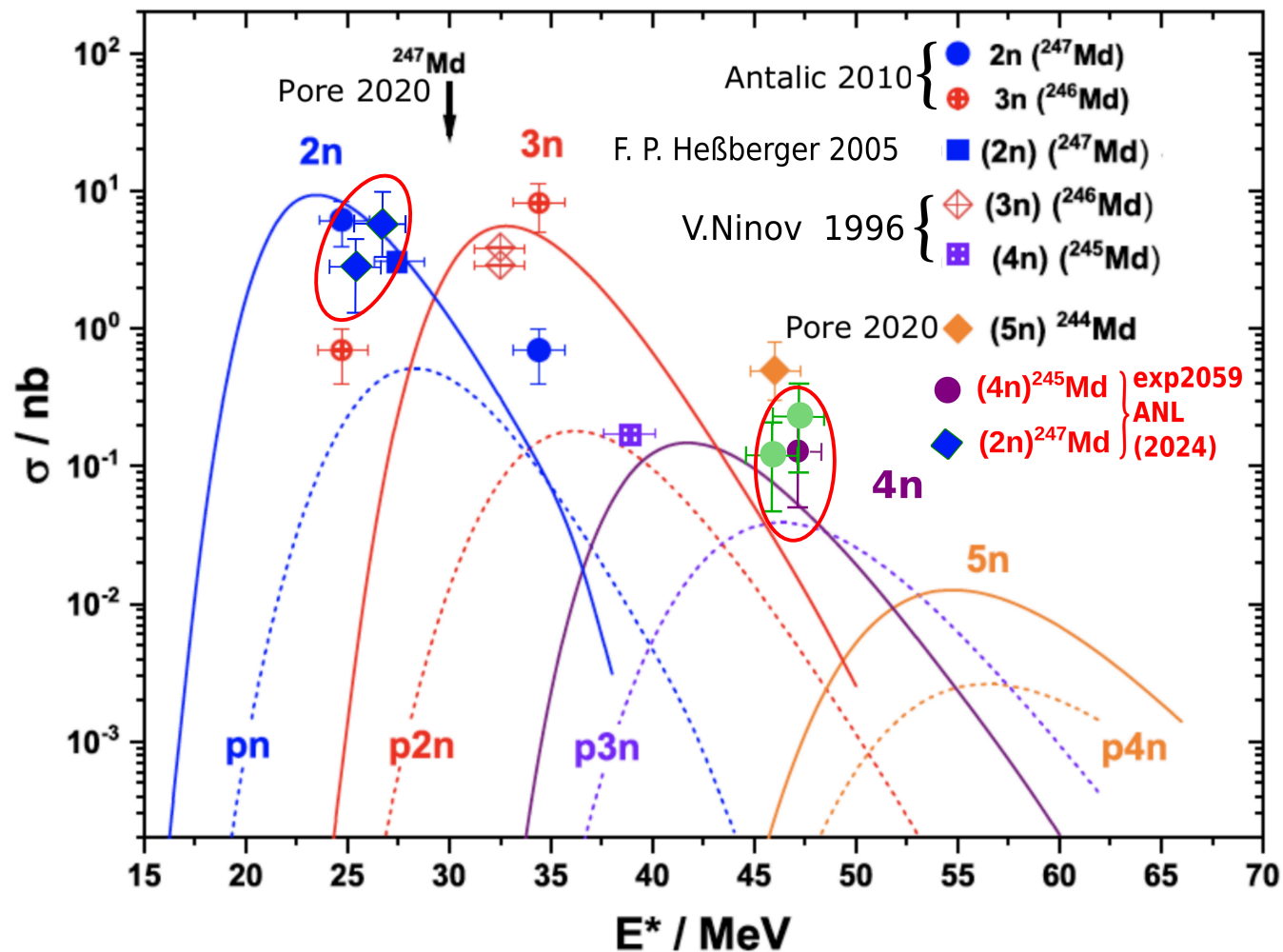
Yb runs $\log_{10}(T1)$ vs $E1$



Yb runs E1E2



Cross-section for FMA events



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$$\sigma(247) \sim 6.9^{+4.6}_{-2.9} \text{ nbarn}$$

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