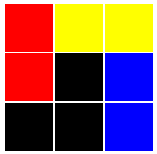
N-SI-134 and N-SI-121

Scientific Workshop on ν-Ball2

Krzysztof Miernik

UNIVERSITY
OF WARSAW



Nuclear Physics Division
University of Warsaw

July 3-5, 2024

N-SI-121

N-SI-121 experiment

- 9.05.2022 - 16.05.2022
- 10$\times$phase-I-Ge + 24$\times$Clover detectors
- 6$\times$$LaBr_3$ (ALTO) + 6$\times$$LaBr_3$ (Madrid) + 2$\times$$LaBr_3$ (Warsaw) detectors

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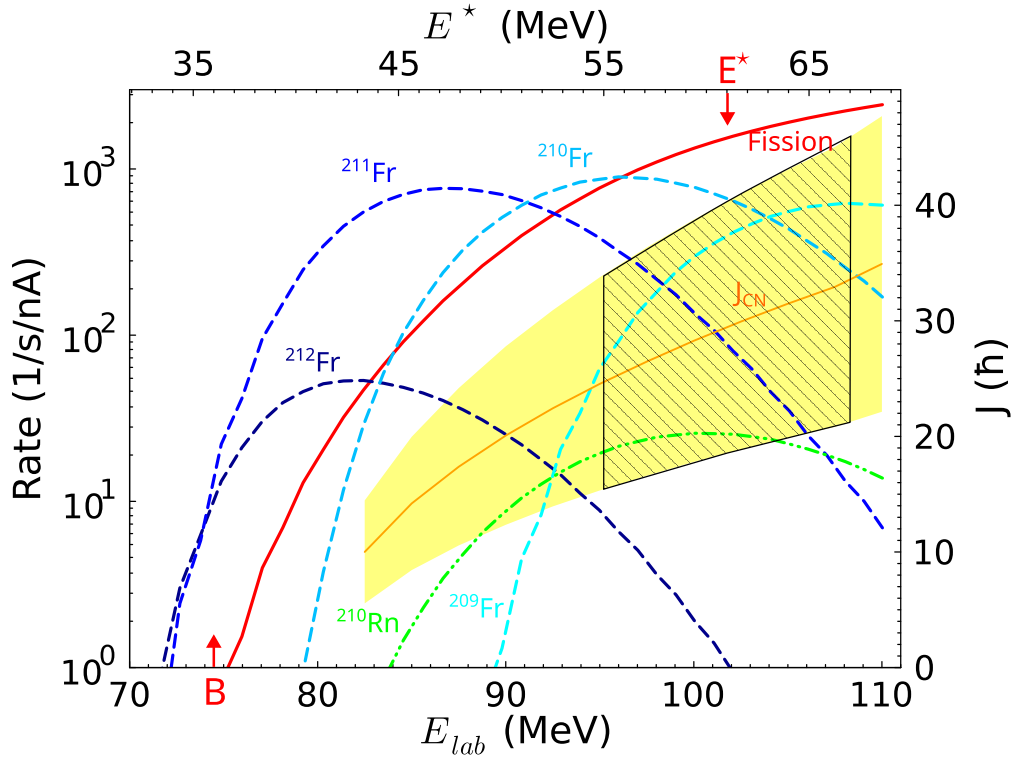

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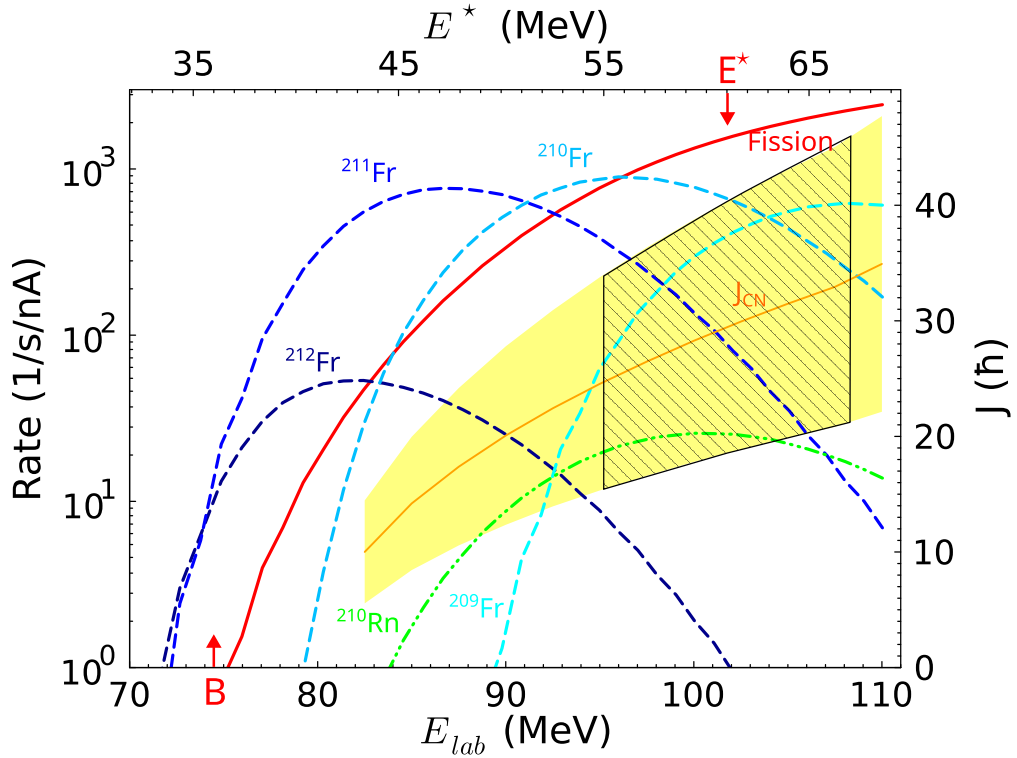

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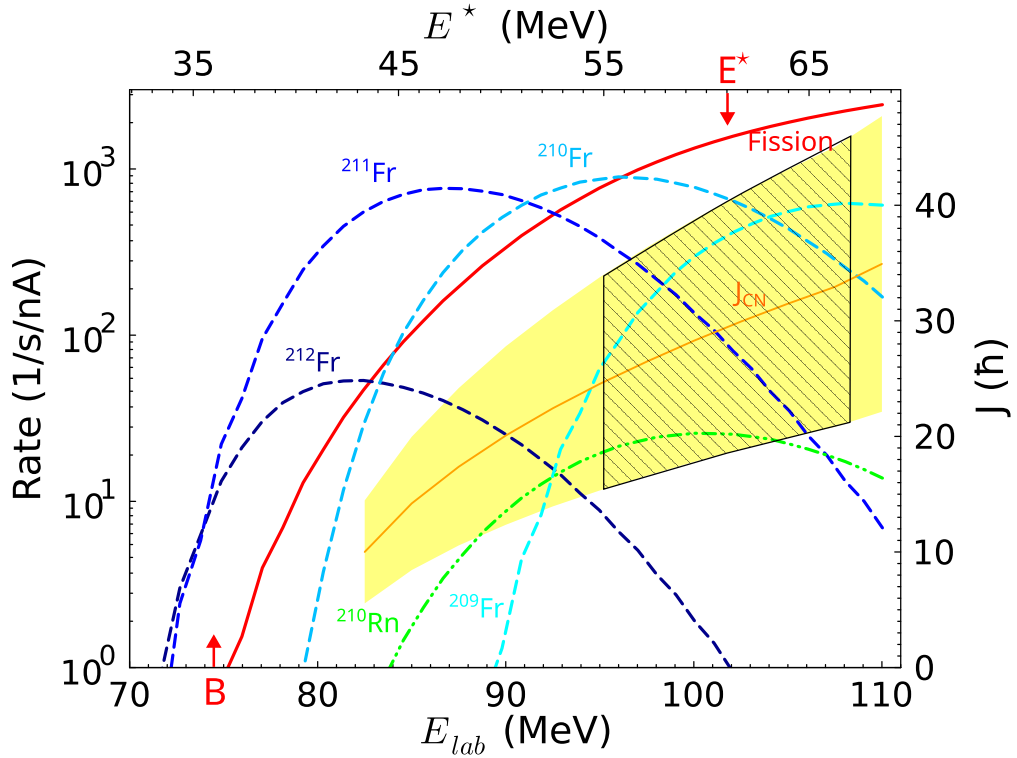

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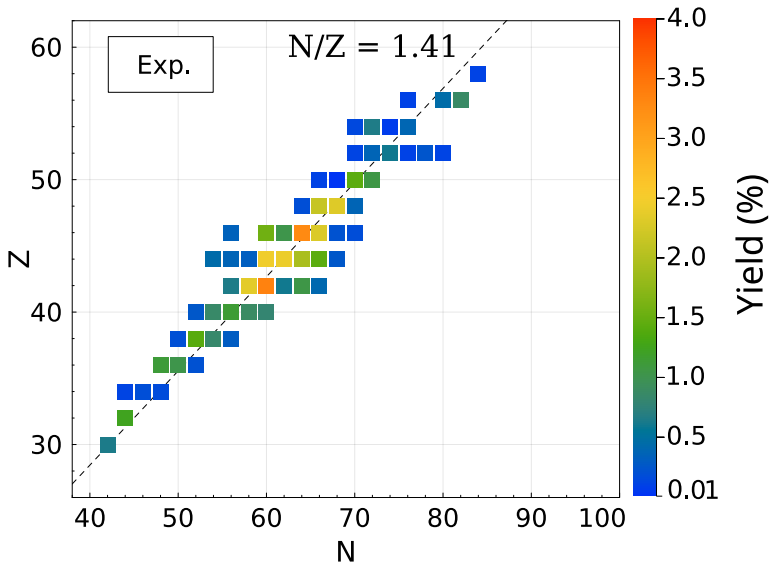
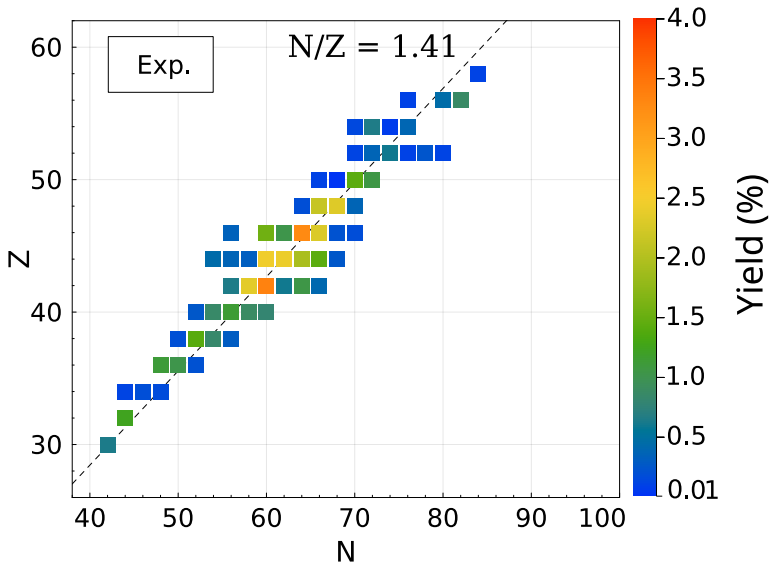
- K. M. et al., PRC 108 (2023) "Fission of ^{215}Fr studied with γ spectroscopic methods"

Results


Exp.
N/Z = 1.41
Z
N
Yield (%)
60
50
40
30
40
50
60
70
80
90
100
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.01

Results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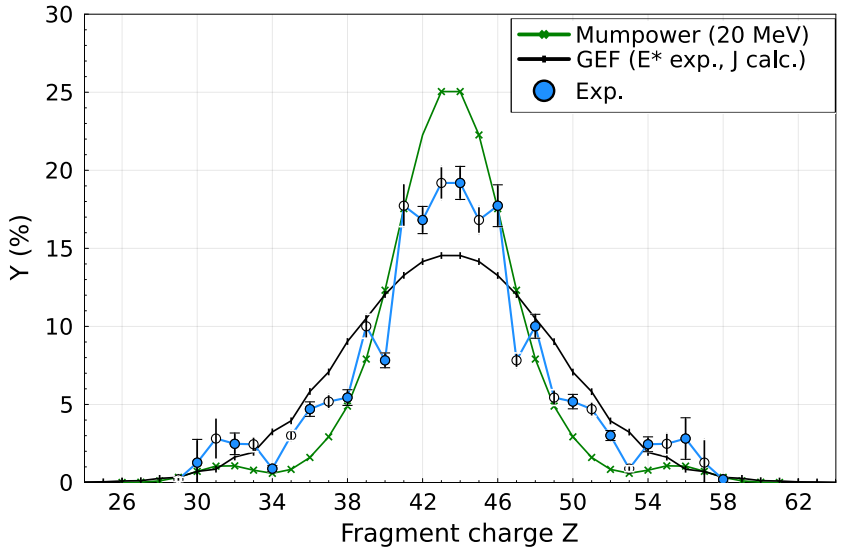
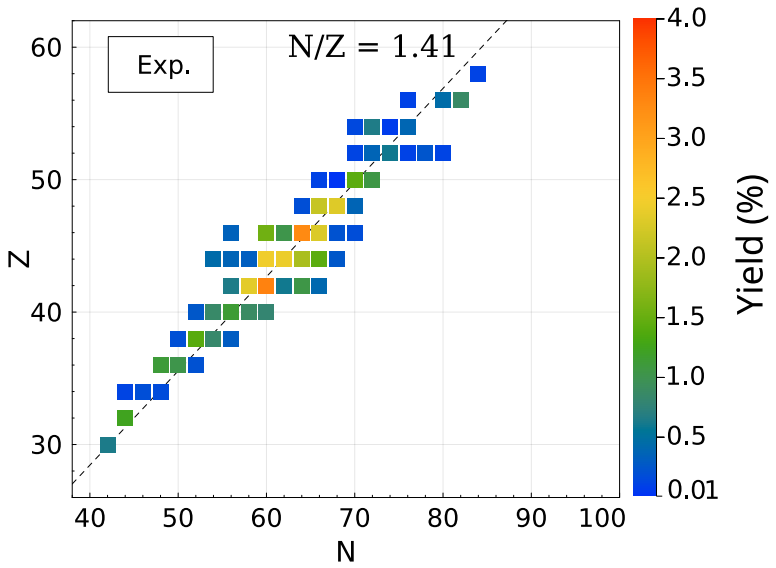
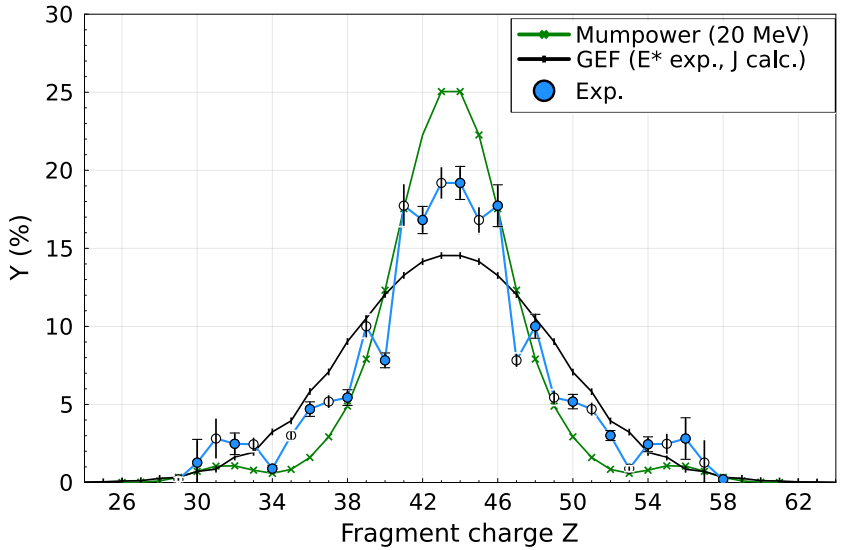

Mumpower (20 MeV)
GEF (E* exp., J calc.)
Exp.
Y (%)
Fragment charge Z
30
25
20
15
10
5
0
26
30
34
38
42
46
50
54
58
62

Results





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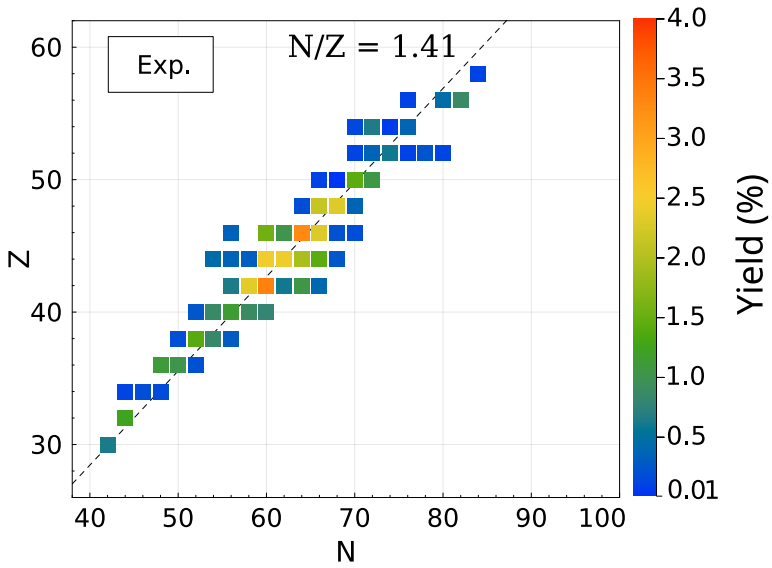

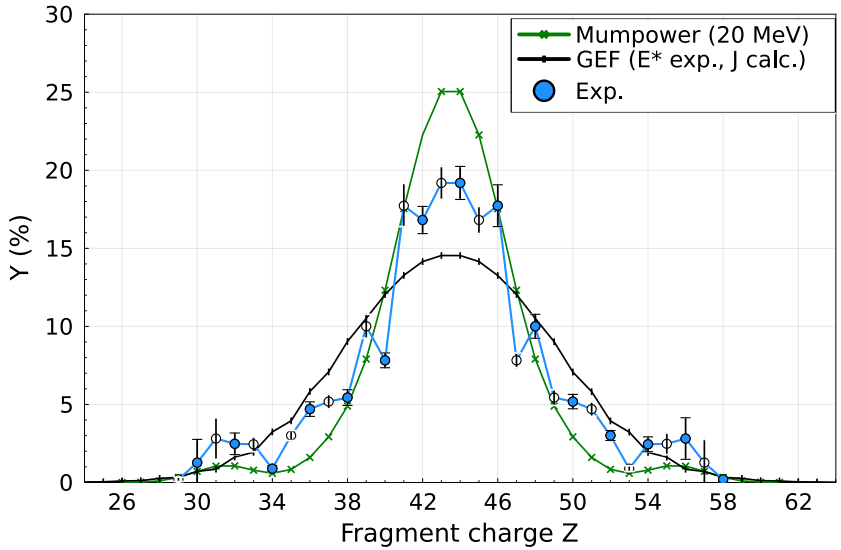

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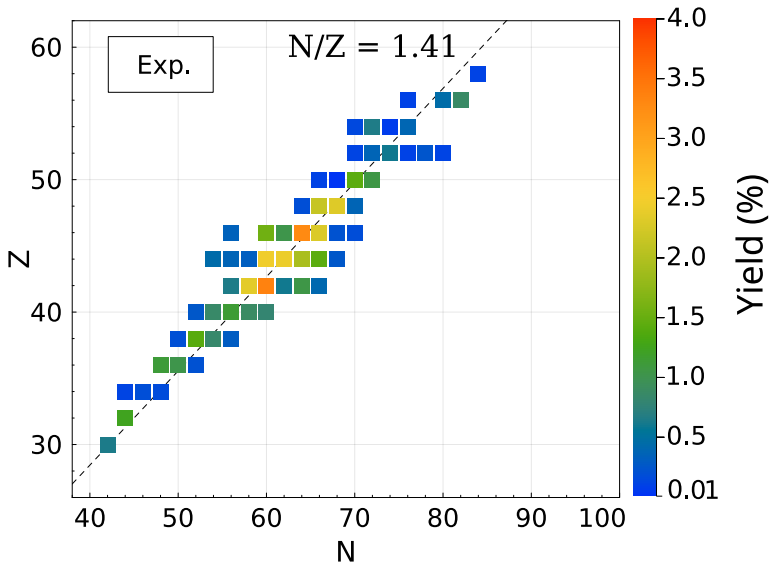

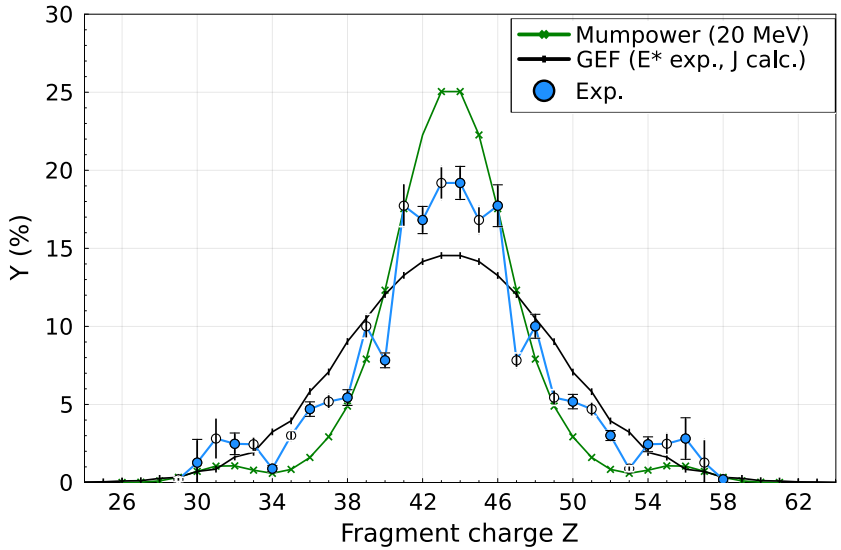

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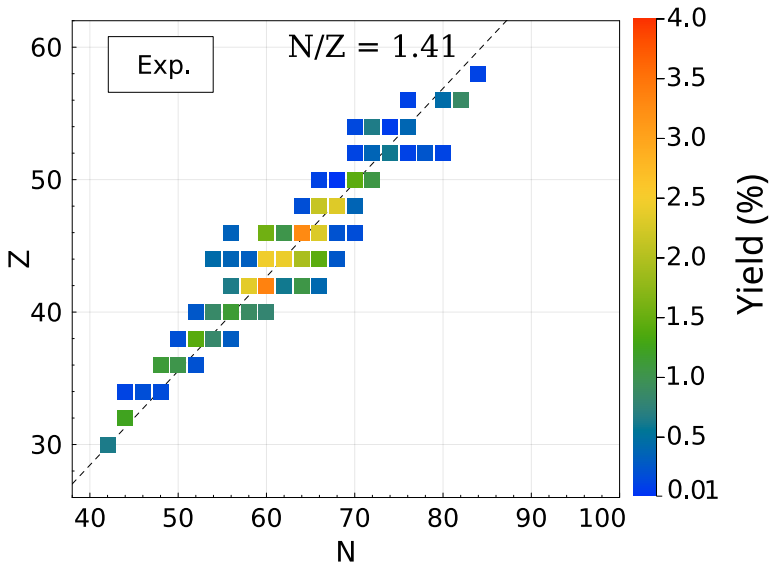

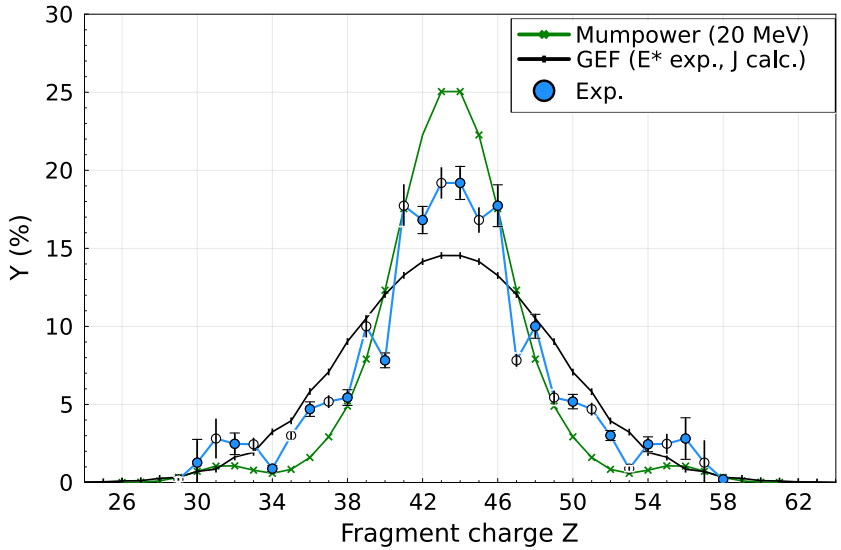

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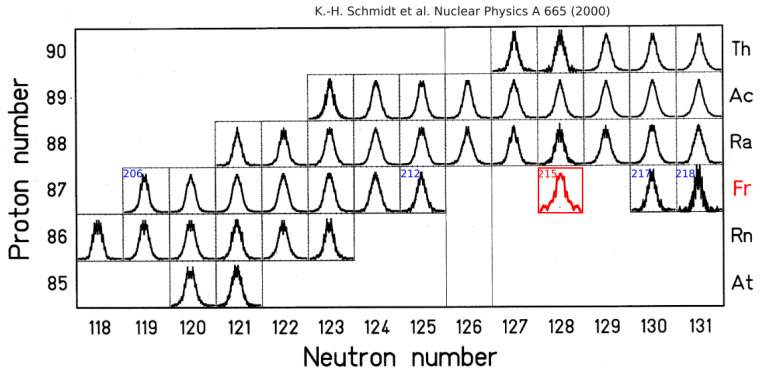

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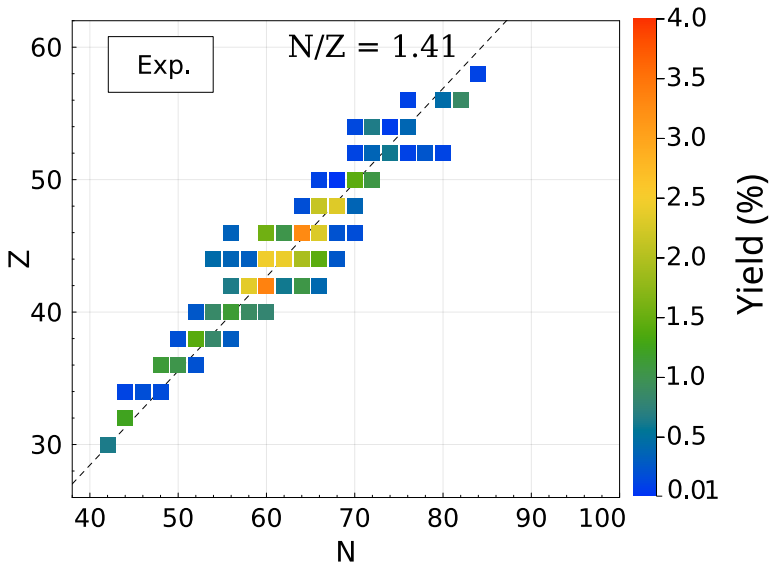

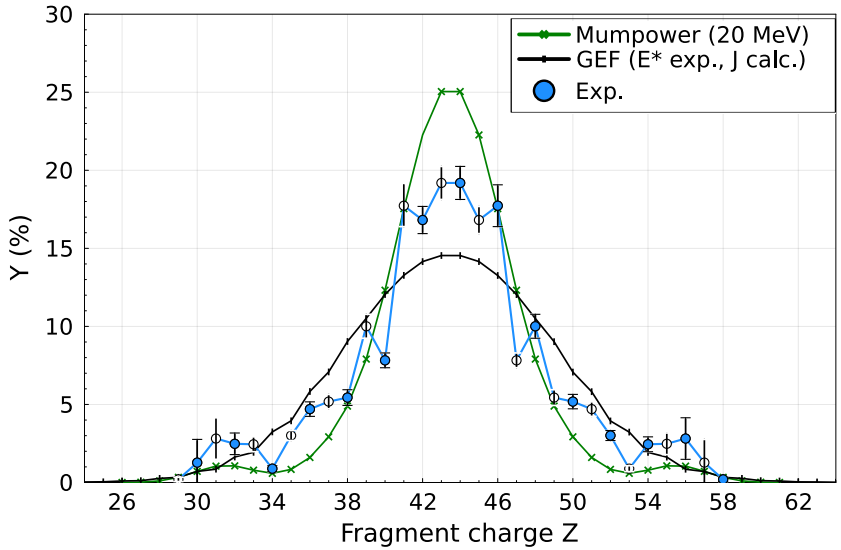

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- Asymmetric peaks in the location predicted by micro-macroscopic models
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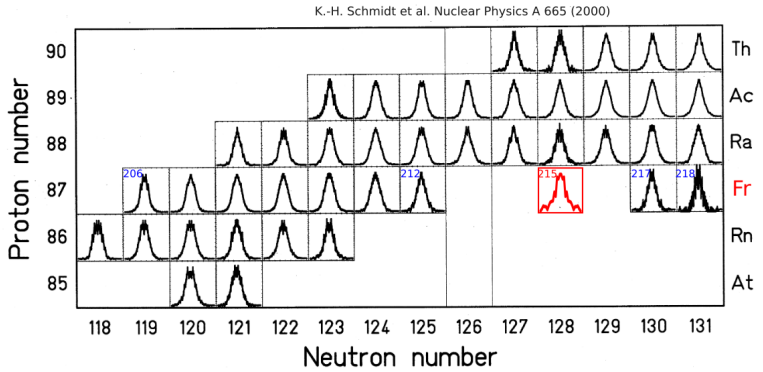
- Unknown role of multi-chance fission, angular momentum or microscopic structure influence



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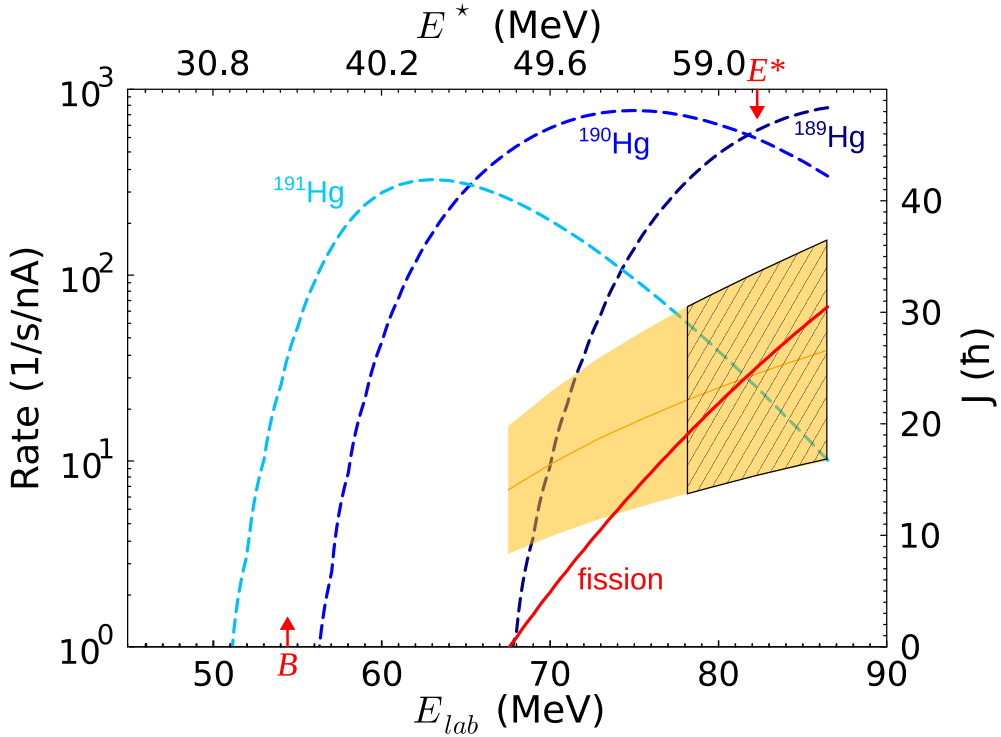

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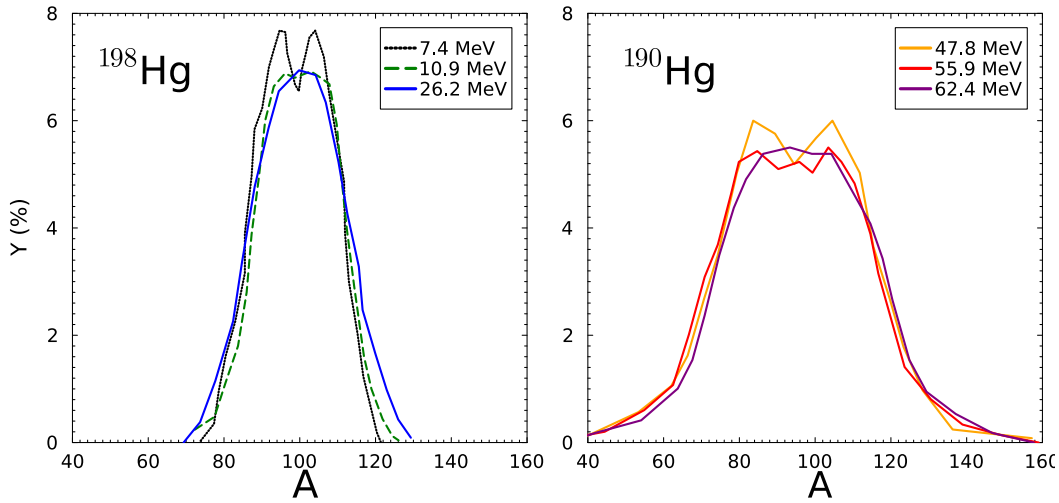

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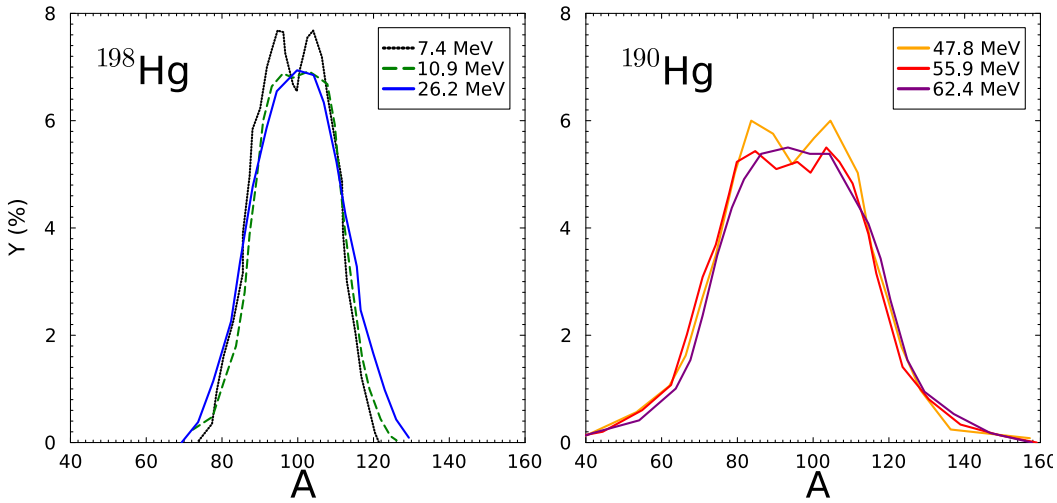

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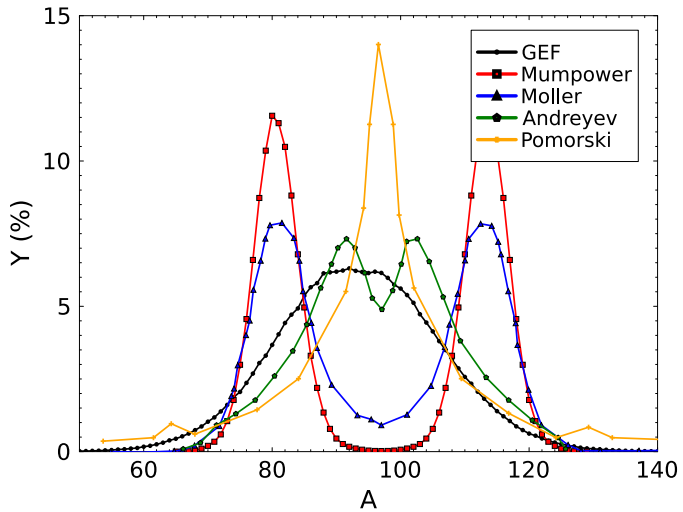
- Models do not agree in predictions for ^{194}Hg



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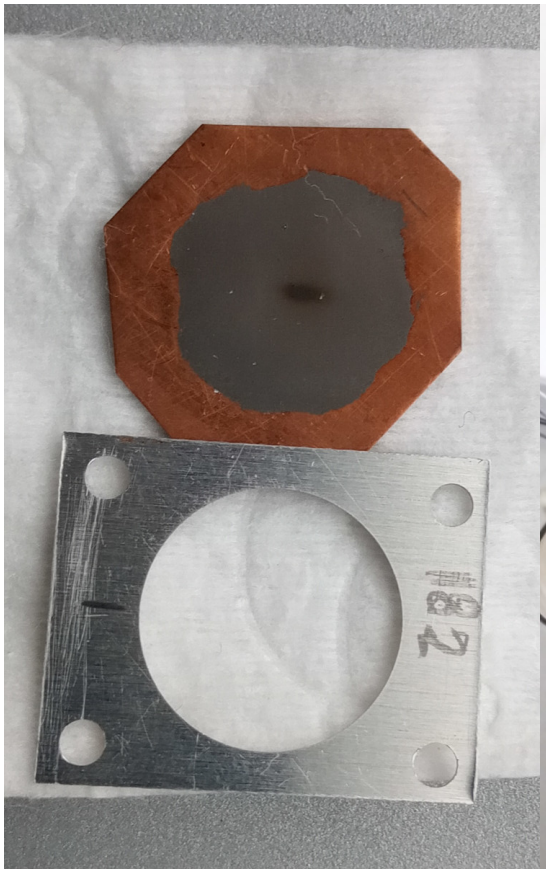
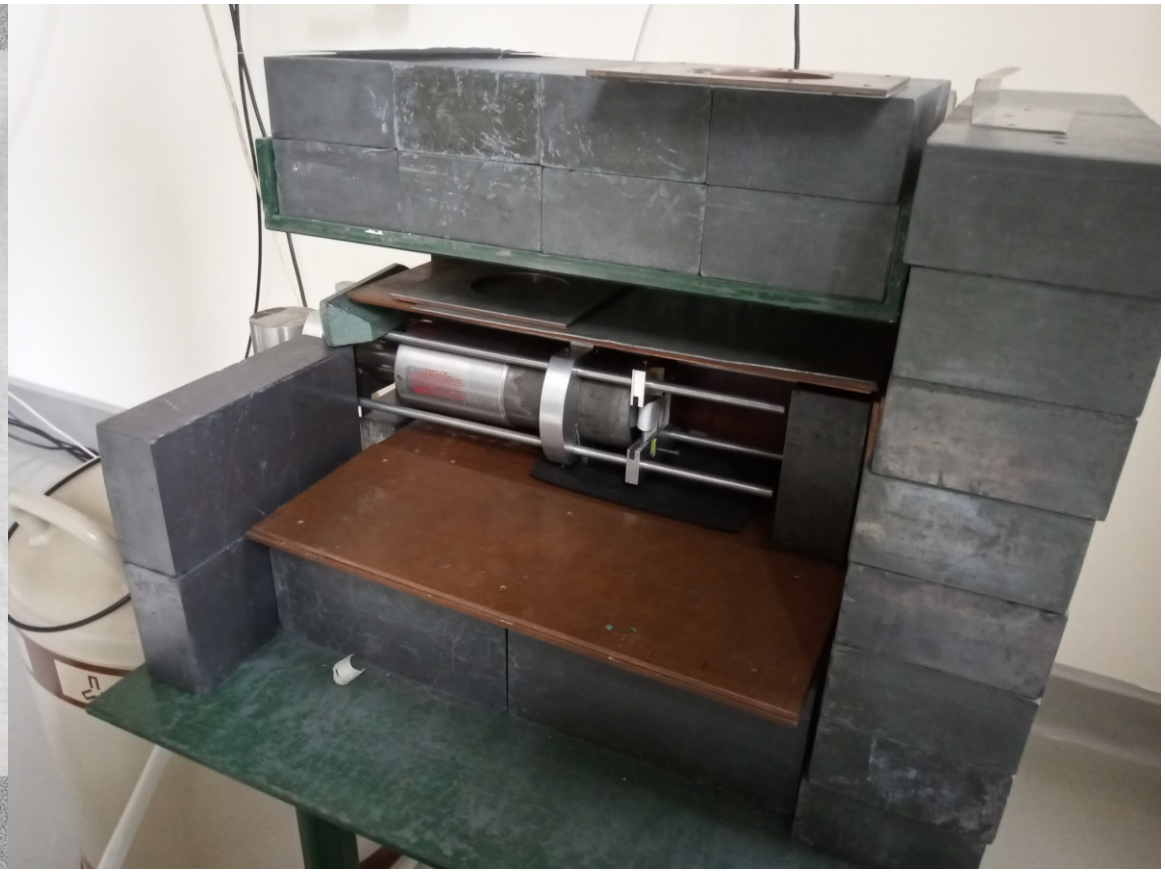
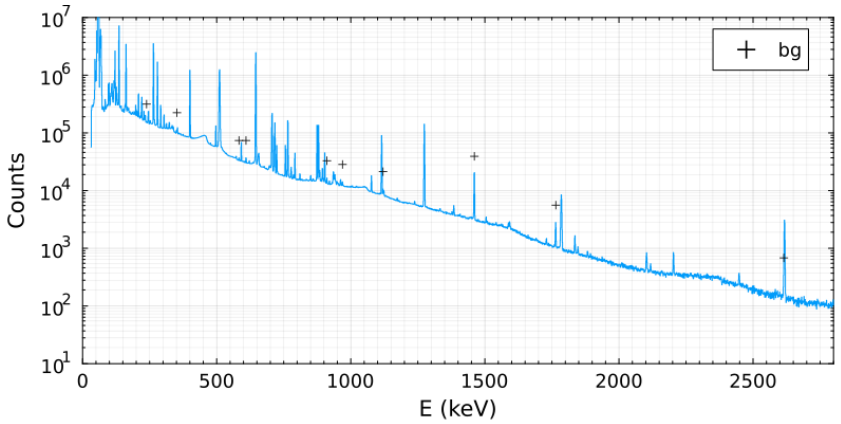
- For 146 days we have measured the radiation in a low-background shielding with an HPGe detector

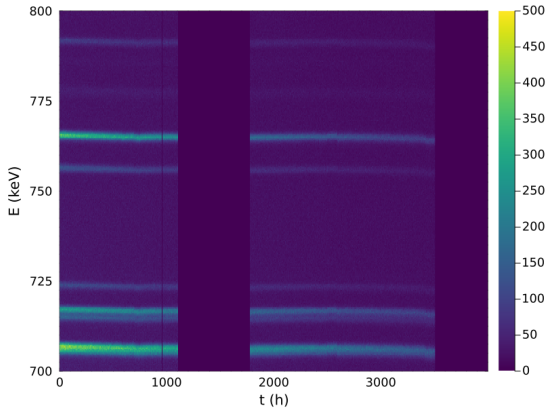


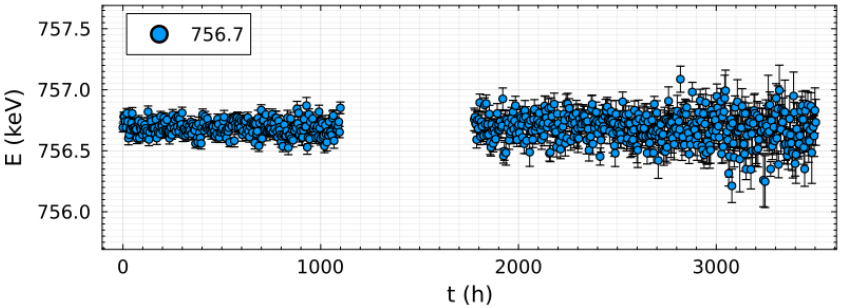


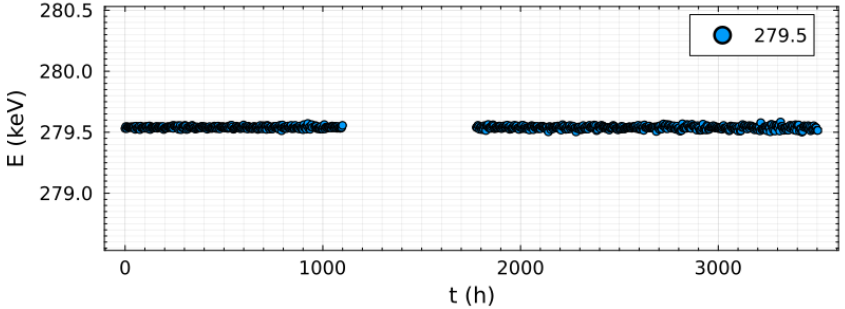
Decay data examples

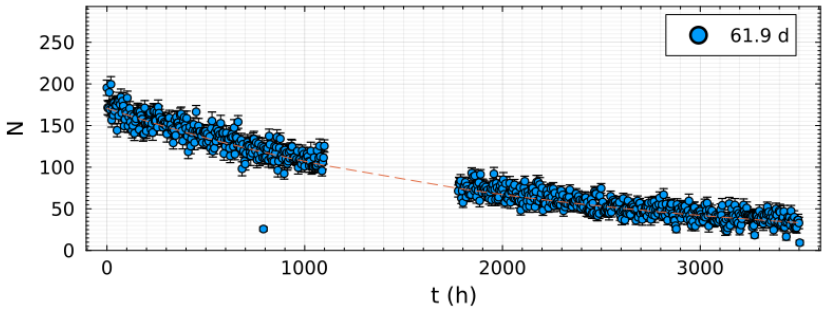
- Lead+copper shielding reduces background by 1-2 orders of magnitude (depending on energy)
- Systematical errors of calibration $\leq$0.05 keV

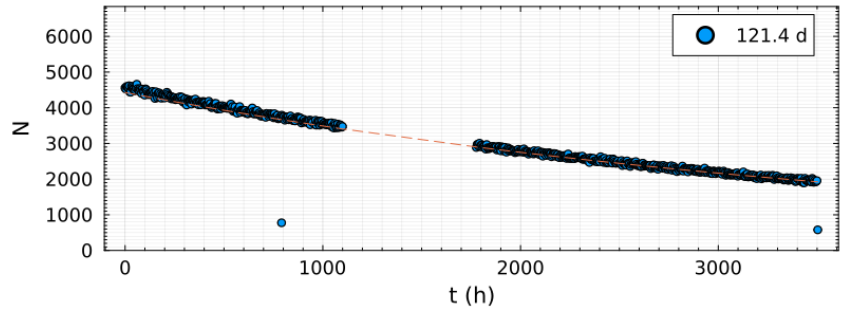












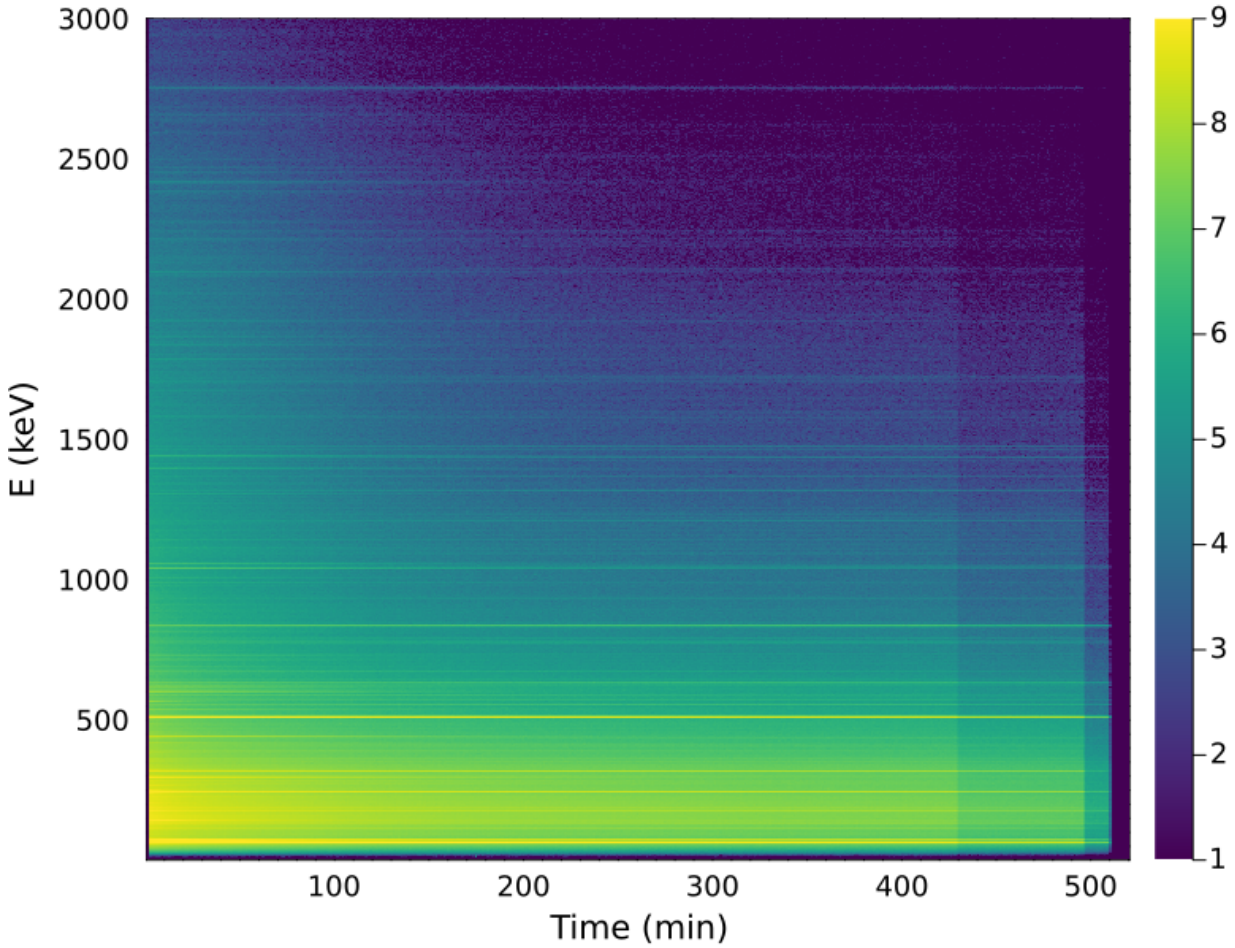
Long-lived isotopes

- By means of γ-ray energy and half-life we have identified 12 long-lived isotopes, including 7 originating from fission

Energy (keV)	Half-life (d)	Source	Origin
84.6, 162.1, 107.9, 109.9, 245.5, 291.1	66(2)	^{183}Re (70.0 d)	^{182}W(^{12}C, ^{11}B)
792.0, 903.3	50(5)	^{184}Re (38.0 d)	^{182}W(^{12}C, ^{10}B)
117.9, 125.2, 592.2, 645.9, 717.4, 874.8, 880.3	90(2)	^{185}Re (93.6 d)	^{182}W(^{12}C, ^{9}B)
96.8, 264.5, 279.3, 303.9, 400.4	120(1)	^{75}Se (119.8 d)	^{65}Cu(^{12}C, pn)
1115.3	286(3)	^{65}Zn (244.3 d)	^{65}Cu(^{12}C, ^{12}B)
724.1, 756.8	61(2)	^{95}Zr (64.032 d)	FF
765.6	69(1)	^{95}Nb (30.0 d)	FF + ^{95}Zr decay
497.1	40(1)	^{103}Ru (39.2 d)	FF
520.4	-	^{85}Kr (86.2 d)	FF
1836.1	-	^{88}Y (106.6 d)	FF
621.9	-	^{106}Rh (30.1 s)	FF ^{106}Ru (371.8 d) $\rightarrow$
602.7	-	^{124}Sb (60.2 d)	FF

Medium lived isotopes

- After the beam was stopped the acquisition was running for about 8 hours
- Activity in the range of minutes to hours can be analyzed using that data



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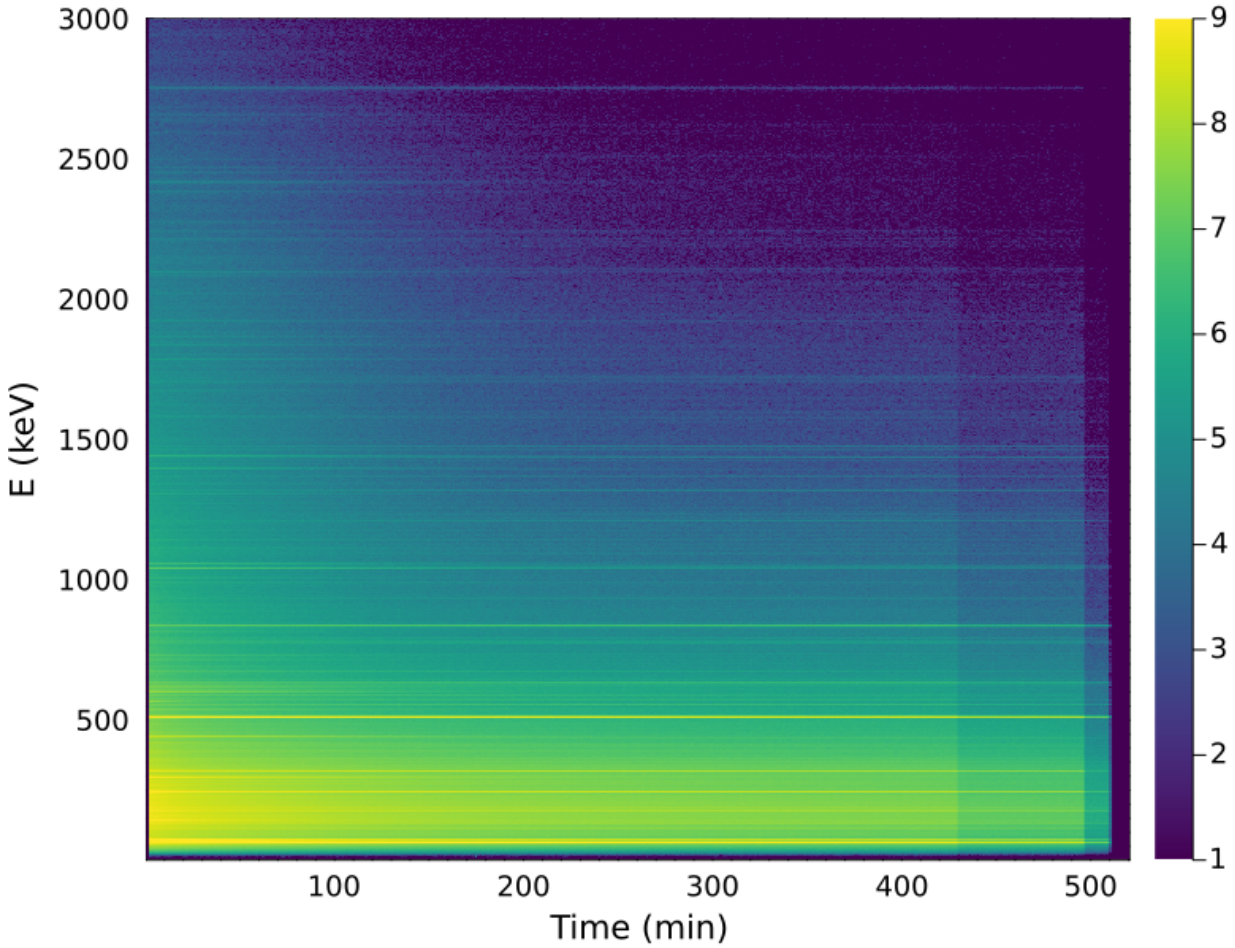
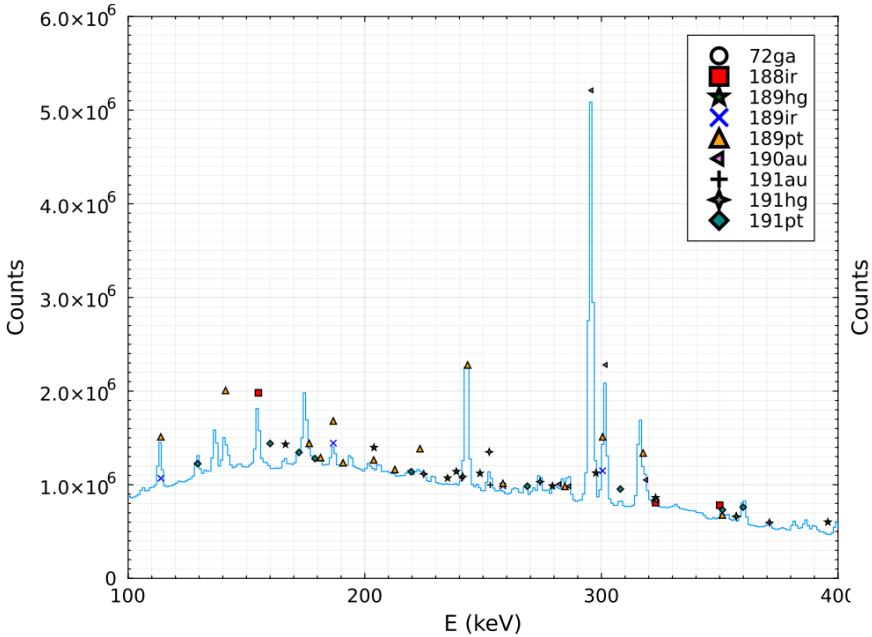
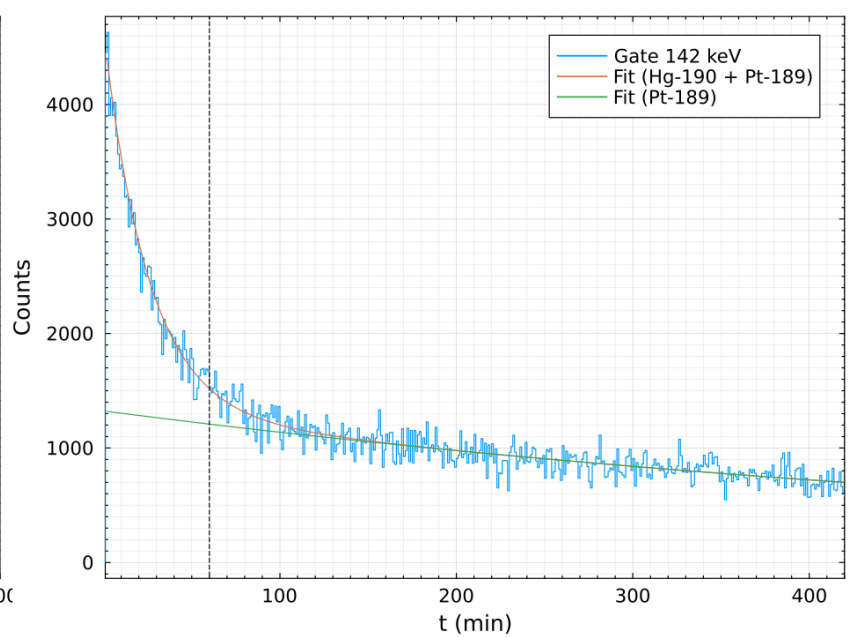


- After 7 hours the ν-ball was opened!

Medium lived isotopes

- Using half-life, gamma energies and coincidence data, isotopes can be identified





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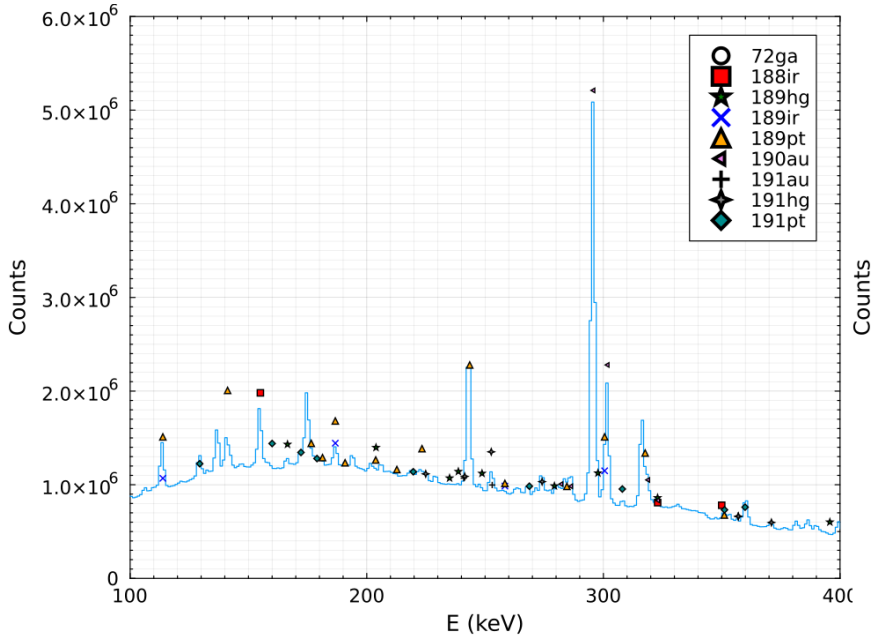

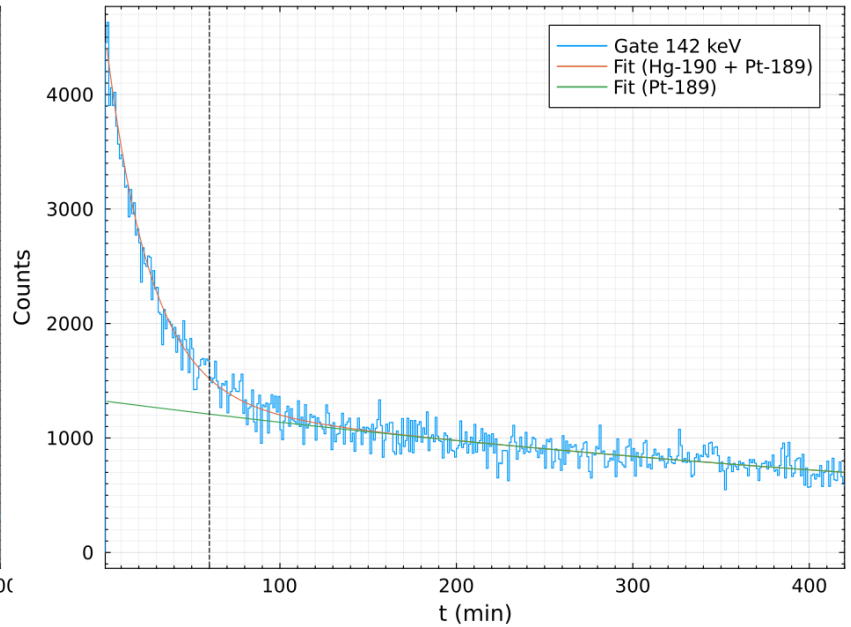

- Line 142 keV appears in the decay of ^{190}Hg (20 min) and ^{189}Pt (10.89 h).

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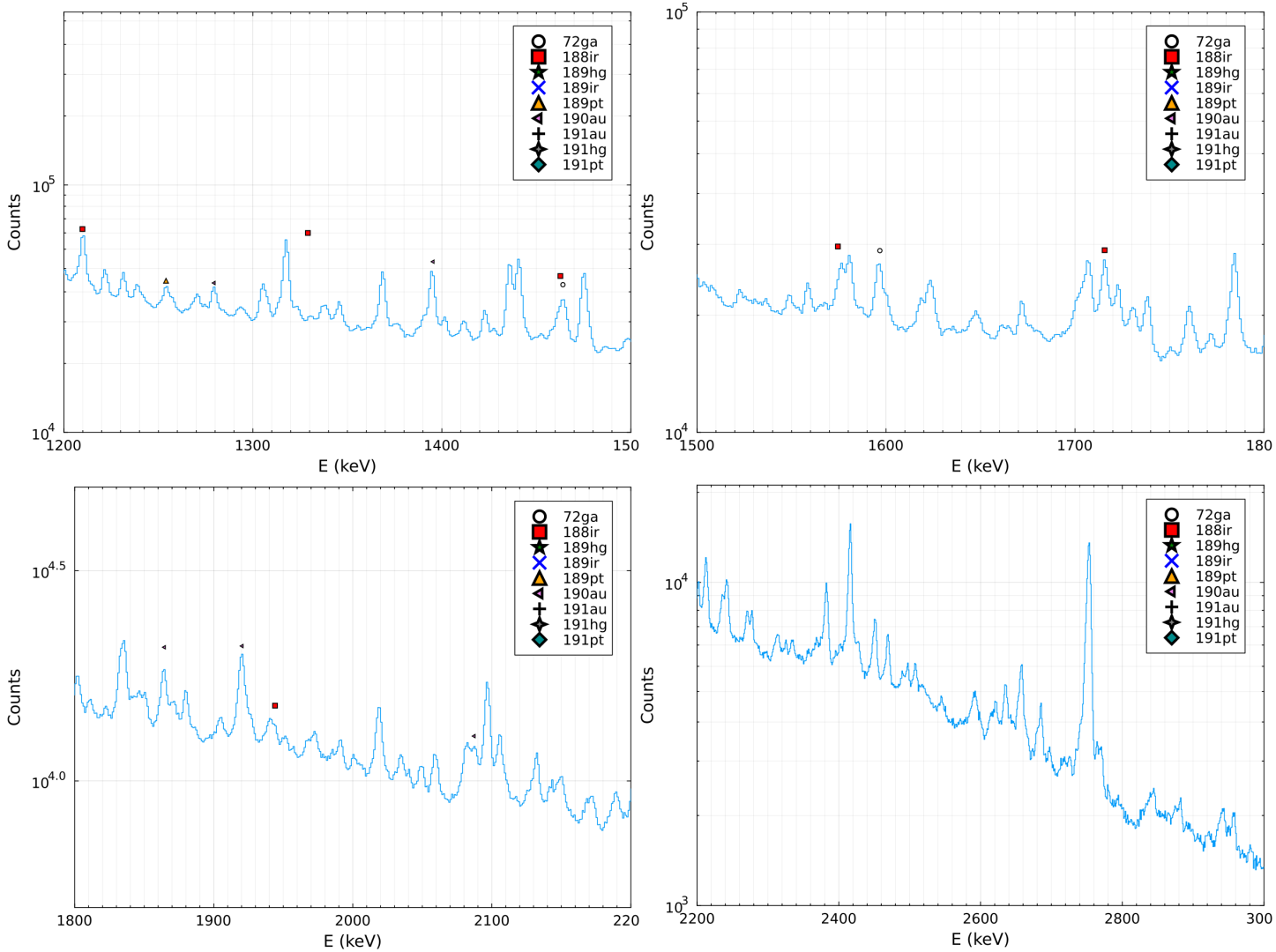
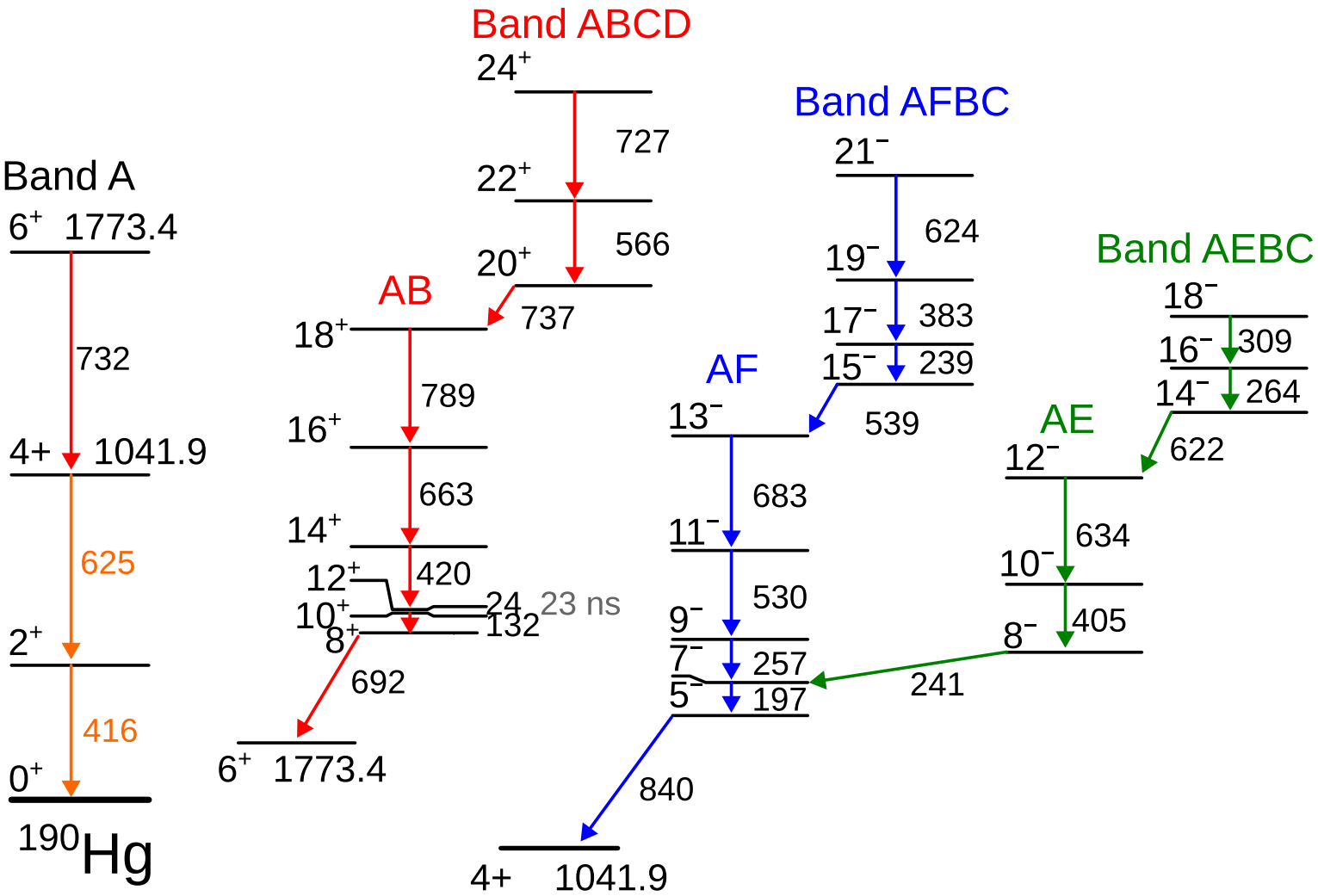


After identification, the on-line data can be combined to access detailed decay information (delayed coincidences).

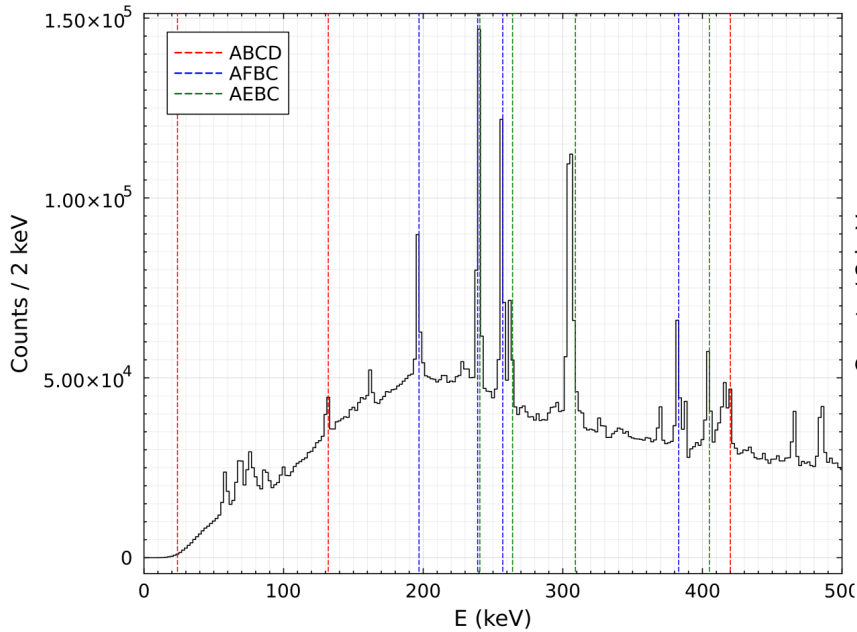
Bands in ^{190}Hg

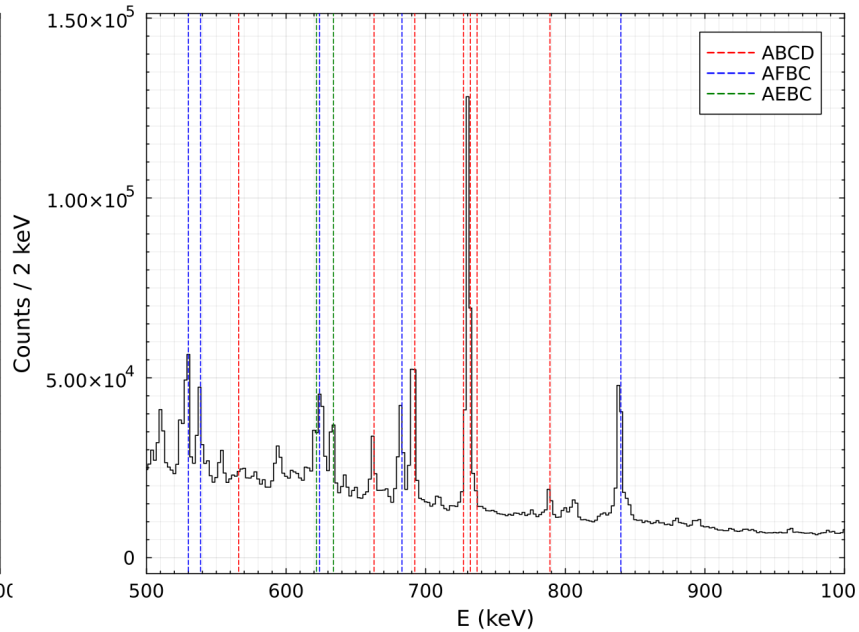
- One of the main reaction channels $^{182}\mathrm{W}\left(^{12}\mathrm{C}, 4n\gamma\right)$,
- High-spin structure of this nucleus was studied before in similar reactions $^{160}\mathrm{Gd}\left(^{34}\mathrm{S}, 4n\gamma\right)$, $^{170}\mathrm{Er}\left(^{24}\mathrm{Mg}, 4n\gamma\right)$, $^{181}\mathrm{Ta}\left(^{14}\mathrm{N}, 5n\gamma\right)$



$\gamma - \gamma - \gamma$ tests with ^{190}Hg

- $\gamma - \gamma$ gate on 416-625 keV transitions in ^{190}Hg





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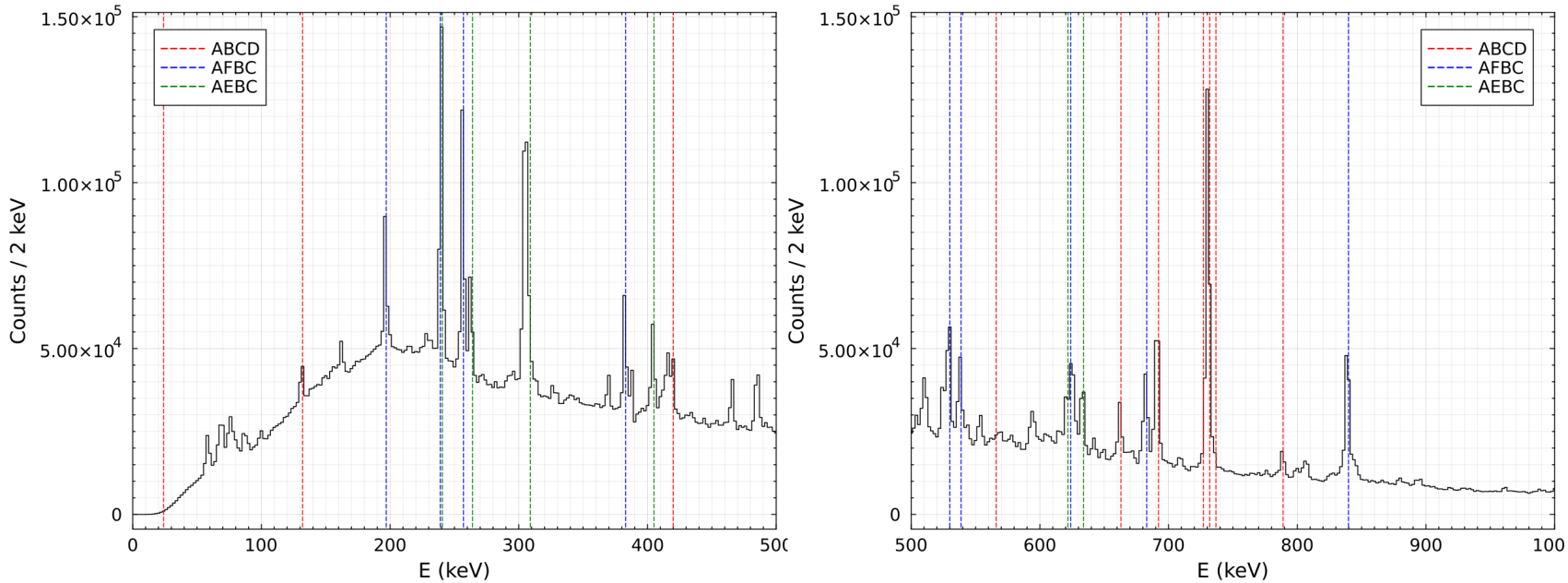


- Prompt gate (± 15 ns) and coincidence window (20 ns) was too restrictive!

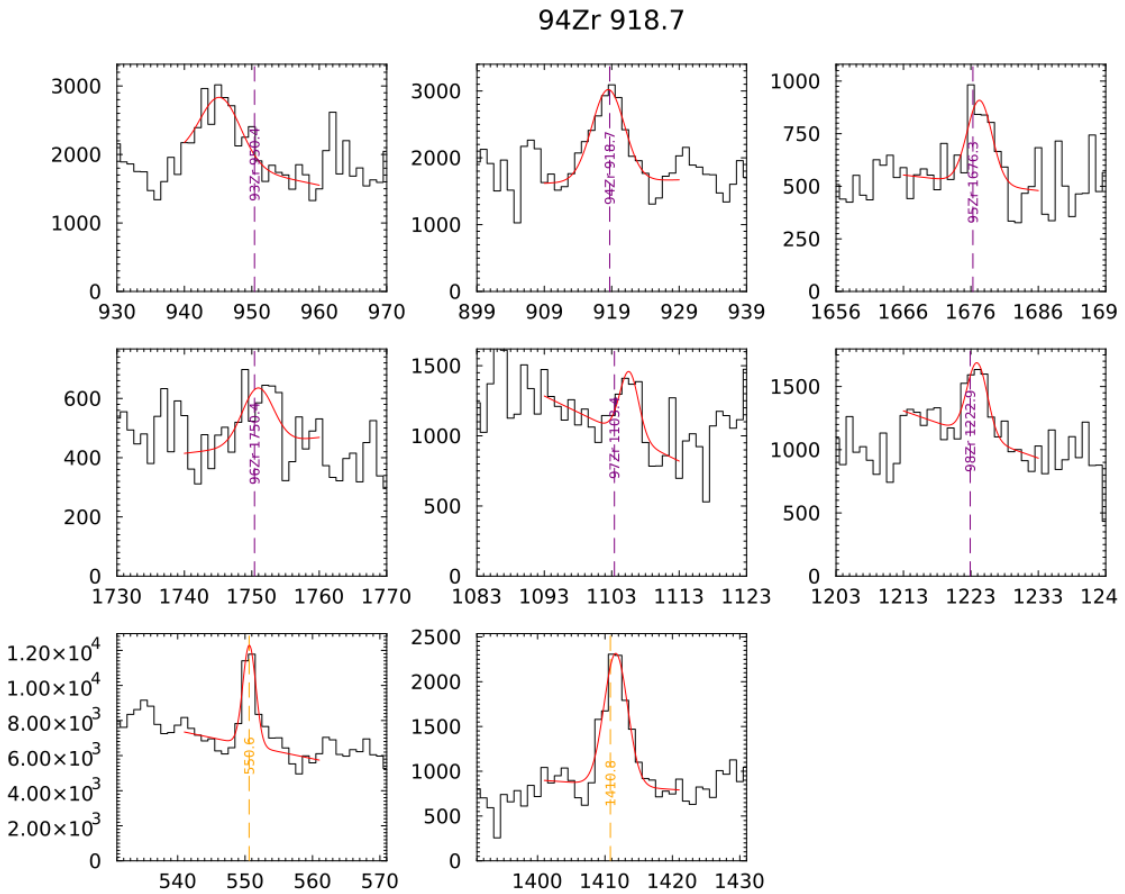
$$\frac{N_{\gamma\gamma\gamma}}{N_{\gamma\gamma}} = 0.6$$

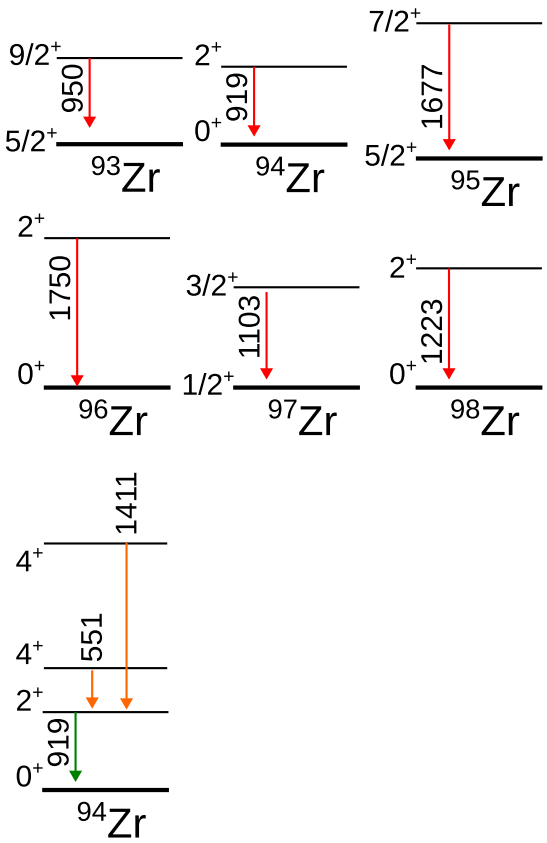
- With prompt gate (± 20 ns) and coincidence window (40 ns)

$$\frac{N_{\gamma\gamma\gamma}}{N_{\gamma\gamma}} = 1.0$$

- A new scan of the whole dataset is ongoing!

$\gamma - \gamma$ analysis

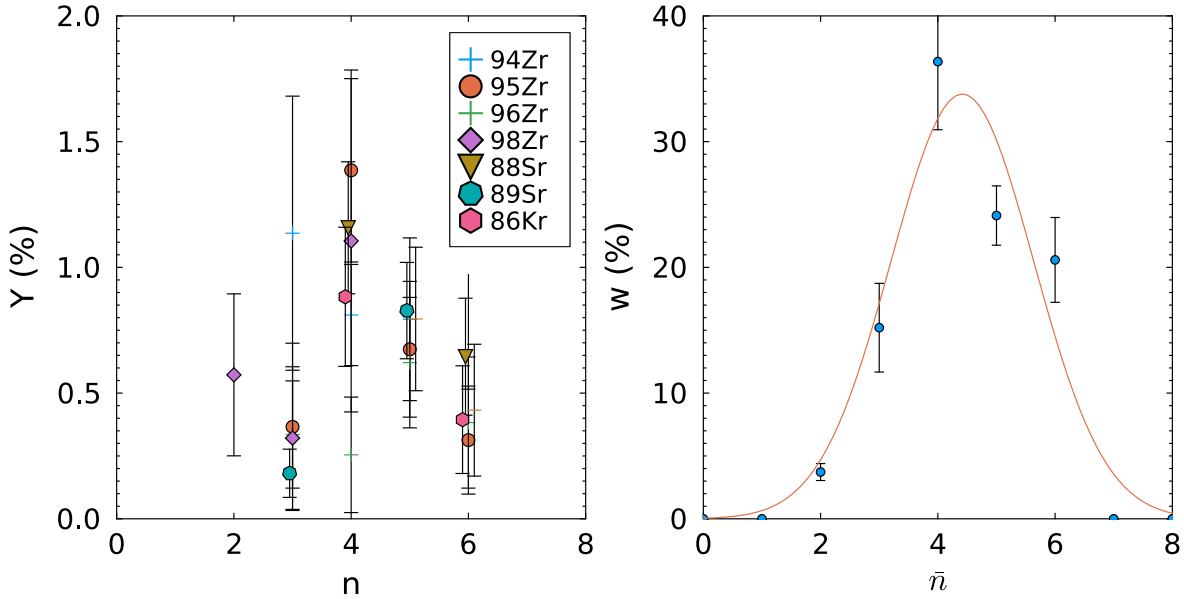




Isotope yields can be determined by finding all possible cascades leading to the ground state or by coincidence of the lowest transitions between the fission partners.

Prompt neutrons

- Experimental number of emitted neutrons based on partners detection ($\bar{n} = 4.3(4)$)



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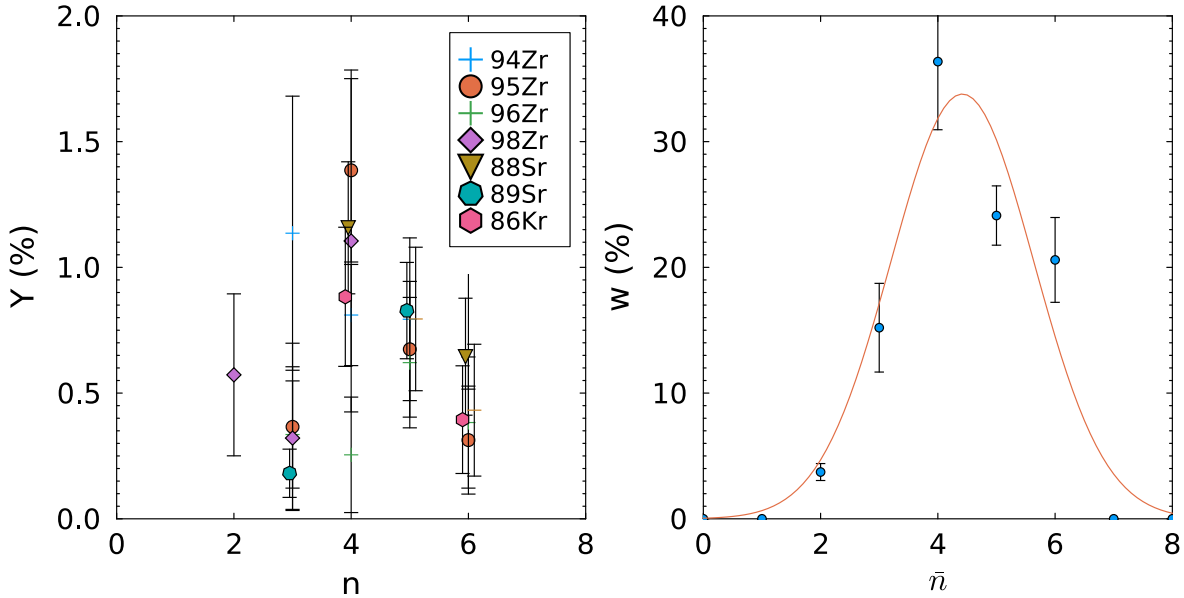
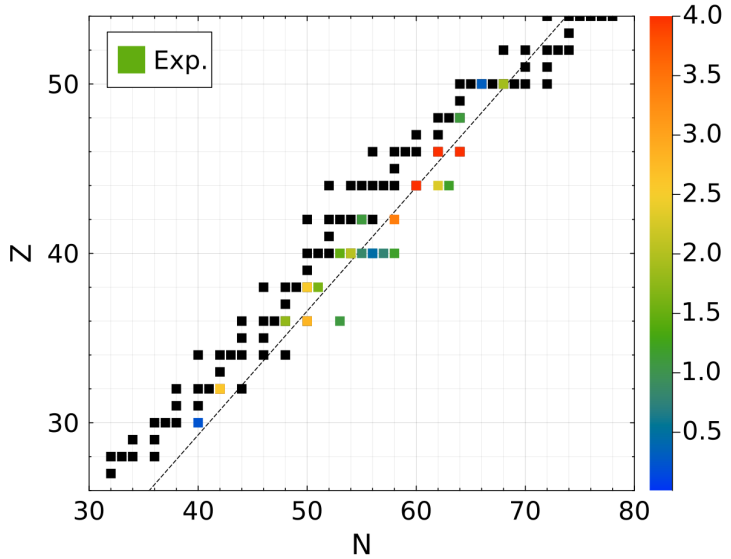
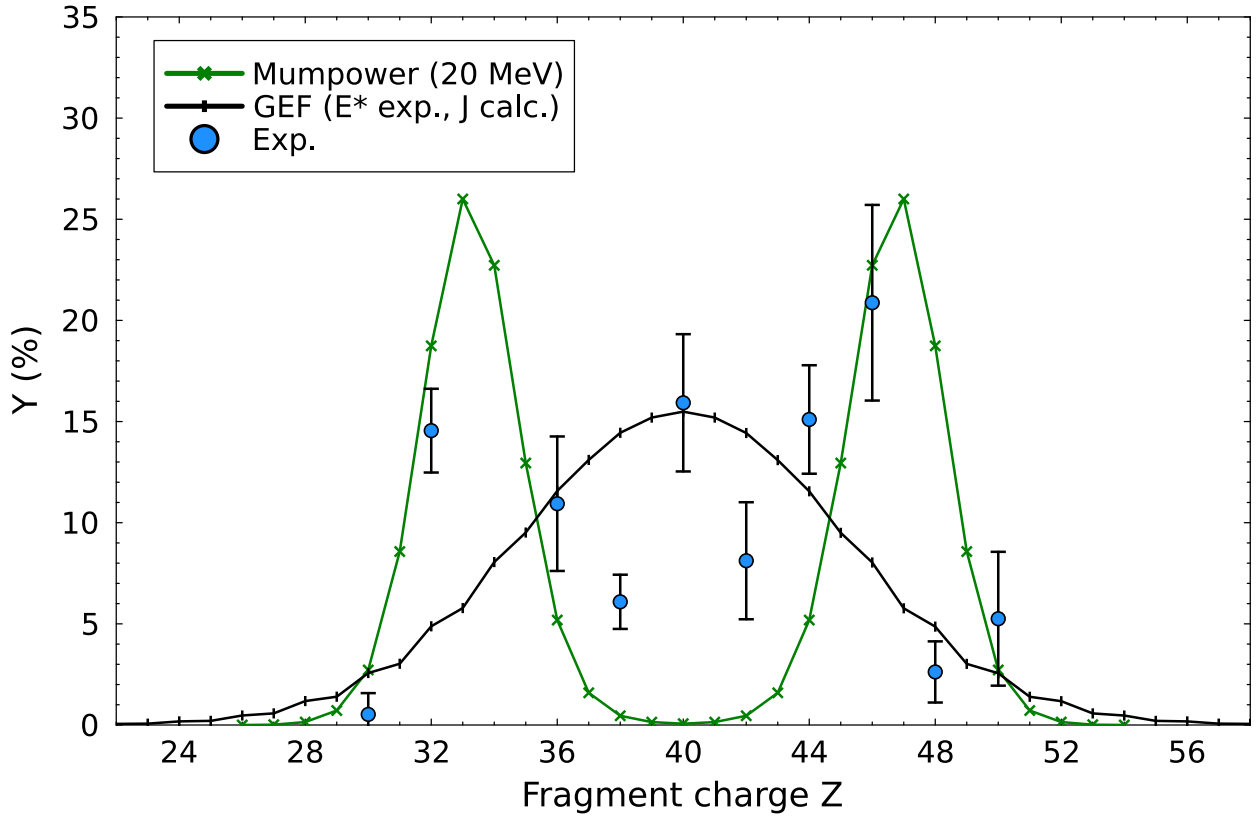


- Using yield of identified isotopes (internal cascades only, 26 isotopes): $N/Z = 1.366 \Rightarrow 4.7$ n



Charge yield (preliminary)

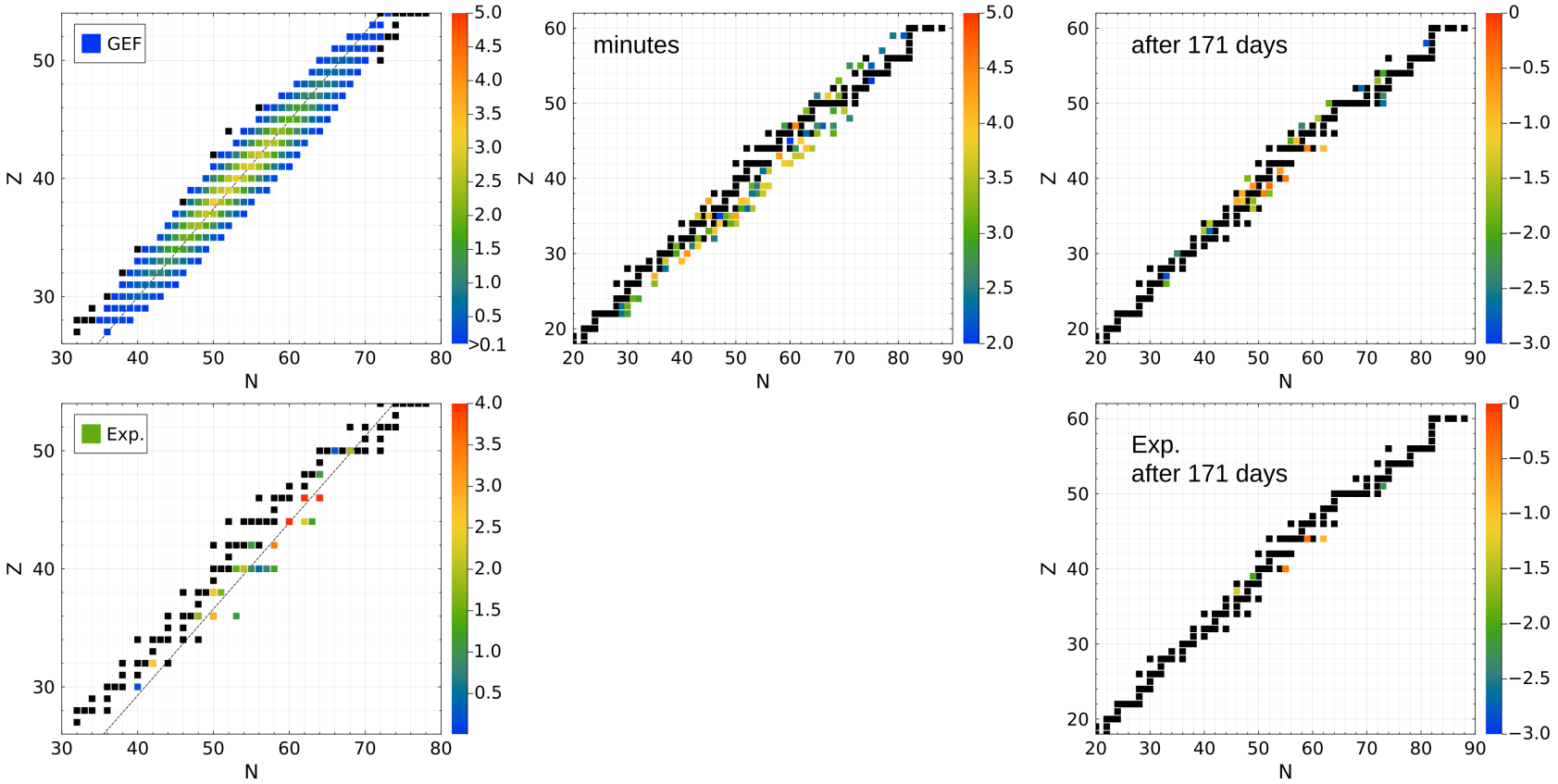
- Charge yield distribution shows asymmetric component (flat-top?)



- GEF model combined with fission E^* distribution (HIVAP) and J distribution (PACE4):
  - Symmetric fission
  - Prompt neutron emission $N/Z = 1.336 \Rightarrow 7$ n
  - Multi-chance fission (35%-20%-19%-8%)

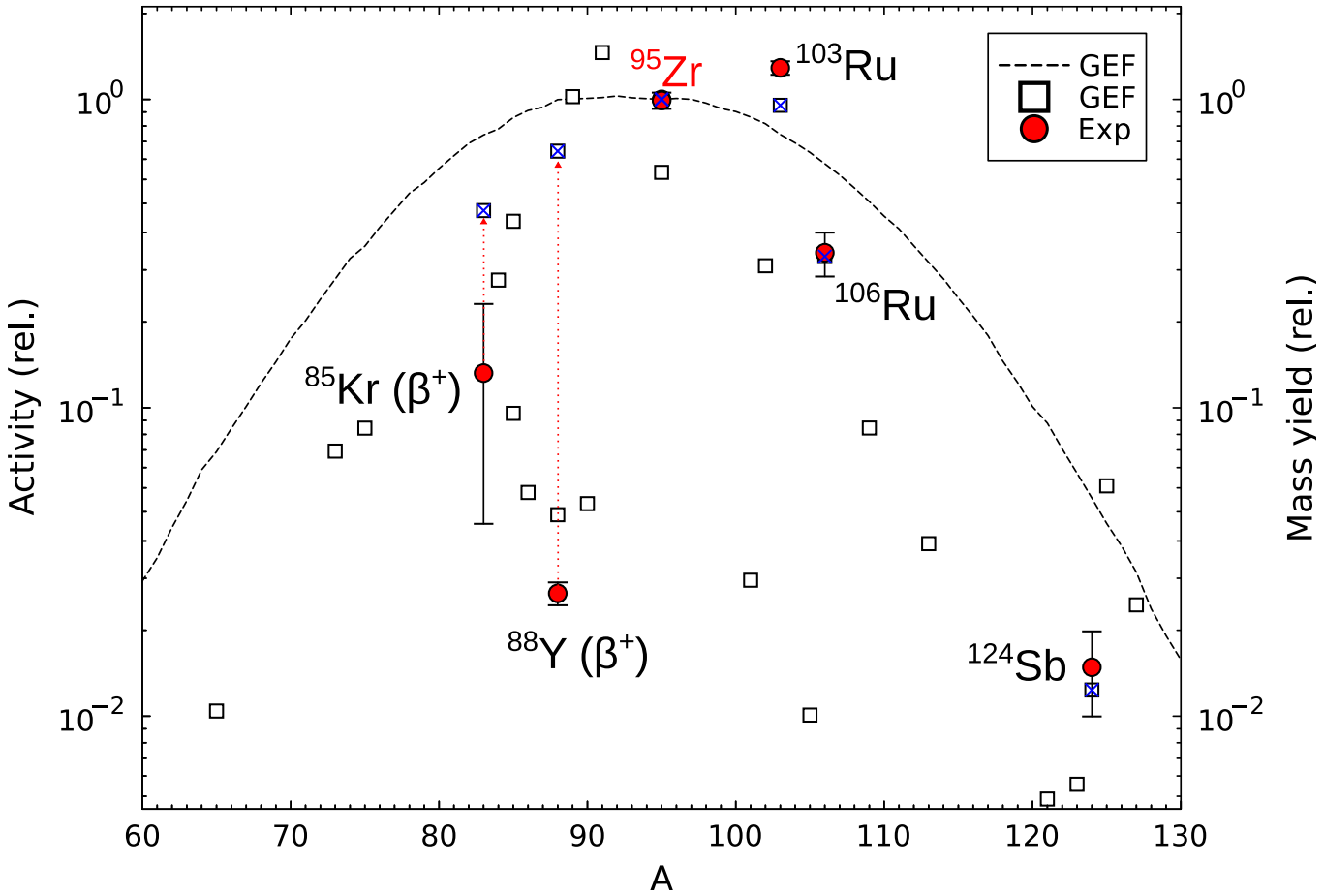
Decay calculations

- Time evolution of fission fragment distribution was calculated (including β-decays and β-delayed neutron emission).
- Results can be compared with the experimental medium- and long-lived activity measurements.
- This method can give independent confirmation of the method based on the prompt γ radiation (is immune to the issue of the g.s. feeding).



Decay data

- Activity of fragments after 171 days, starting from the GEF model results, can be compared with the experimental data (both normalized to the activity of ^{95}Zr)



- GEF underpredicts asymmetric fragment ($^{103}_{44}$Ru) compared to the symmetric ($^{95}_{40}$Zr)
- β^- isotopes are generally in agreement, but overpredicted number of prompt neutrons results in disagreement for β^+-decaying isotopes.

N-SI-134 - Summary

- Both experiments were focused on fission studies with γ-spectroscopy methods
- $\gamma - \gamma - (\gamma)$ coincidences were tested with high statistics fusion-evaporation data.
- Too restrictive timing conditions reduced significantly coincidence data (new scan is ongoing).
- First results from gamma spectroscopy of fission fragment analysis indicate an important influence of asymmetric fission components.
- Results do not agree with the GEF model (higher number of prompt neutrons, only symmetric mode)
- The role of multi-chance fission, angular momentum or microscopic structure influence is again unclear
- Complementary long-lived isotopes measurement confirms results from the prompt γ studies
- Analysis is not finished but shows promising results!
- Another experiment was performed at Warsaw Cyclotron in March 2024 ($^{32}\mathrm{S} + {}^{112}\mathrm{Sn} \rightarrow {}^{144}\mathrm{Dy}$)

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Participants of N-SI-121 and N-SI-134

A. Algora, J.A. Briz, G. Charles, S. Czajkowski, P. Czyż, N. Dzysiuk, A. Fijałkowska, L.M. Fraile, P. Garczyński, K. Hauschild, C. Hiver, A. Korgul, T. Kurtukian-Nieto, M. Lebois, M. Llanos, A. Lopez-Martens, K.M. Deby Treasa, J. Ljungvall, I. Matea, L. Mathiew, J. Mielczarek, J.R. Murias, G. Pasqualato, W. Poklepa, H.A. Rösch-Kabadayi, A. Skruch, K. Solak, K. Szlezak, K. Stoyachev, I. Tsekhanovich, J.N. Wilson, S. Zajda