Nuclear Structure and Dynamics 2019
Centro Culturale Don Orione Artigianelli
Venice
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Decay spectroscopy in the rutherfordium region (Z = 104) at SHIP

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JAEA Tokai

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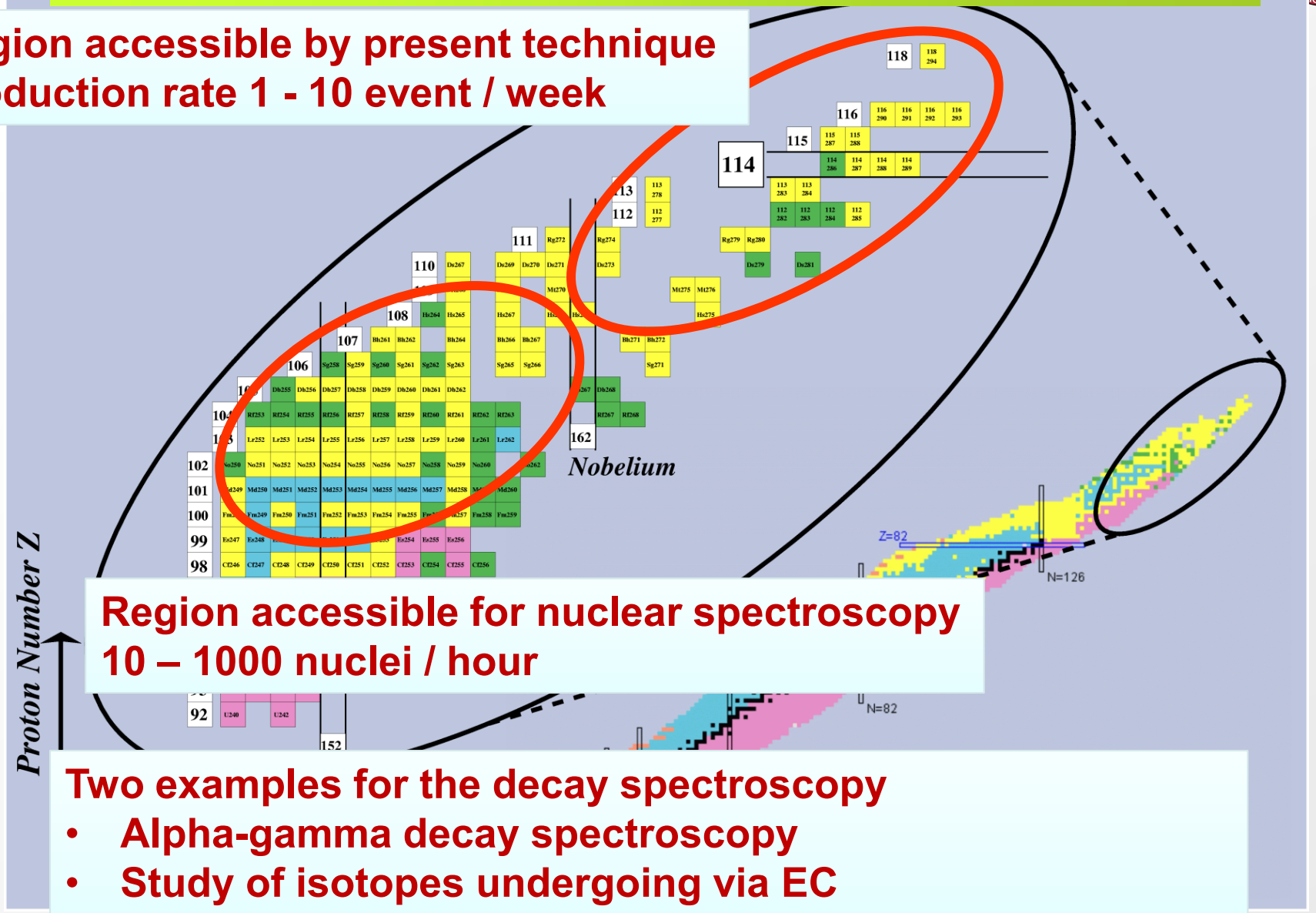
Transuranium nuclei

Region accessible by present technique
Production rate 1 - 10 event / week



Region accessible for nuclear spectroscopy
10 – 1000 nuclei / hour

Two examples for the decay spectroscopy

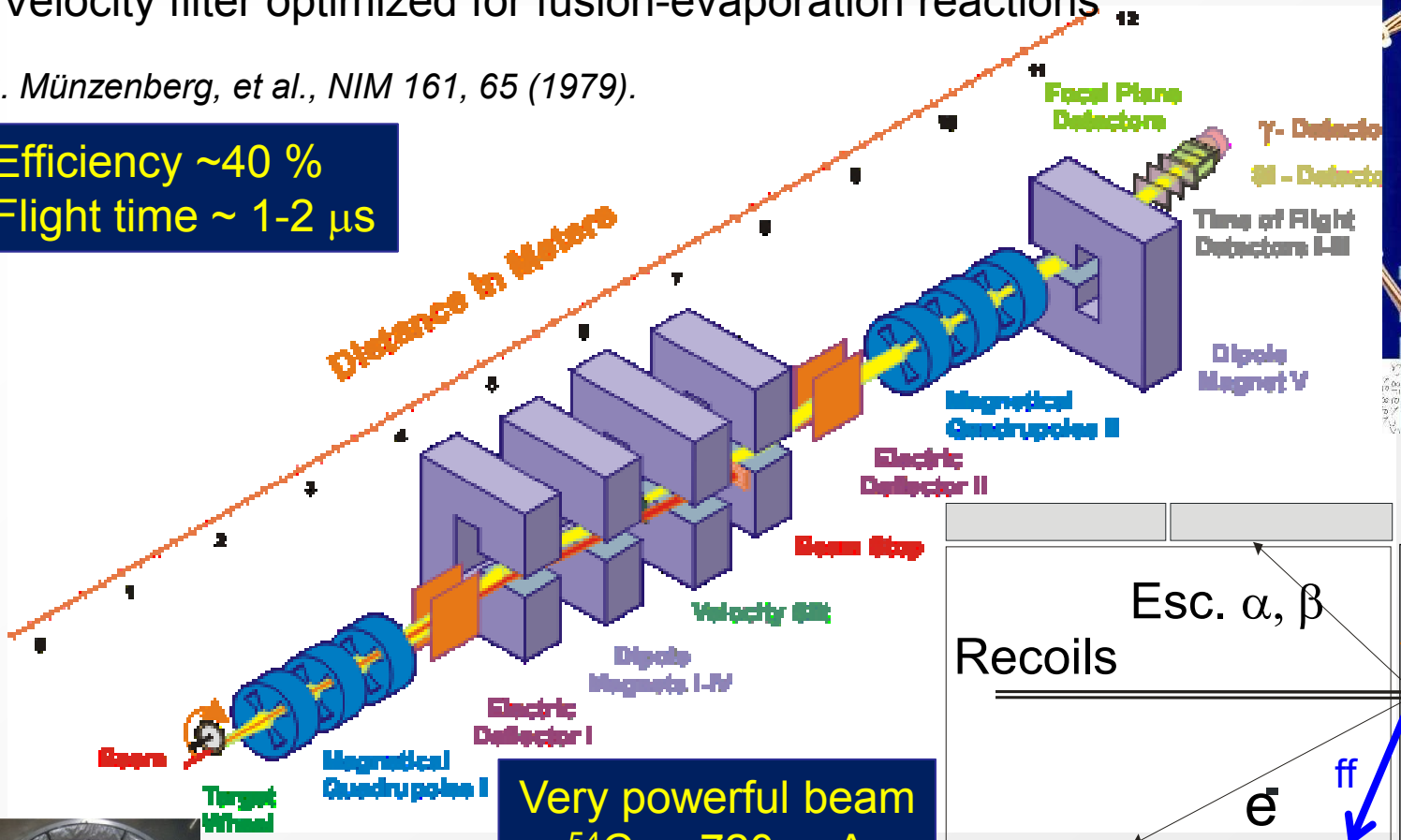
- **Alpha-gamma decay spectroscopy**
- **Study of isotopes undergoing via EC**

SHIP separator

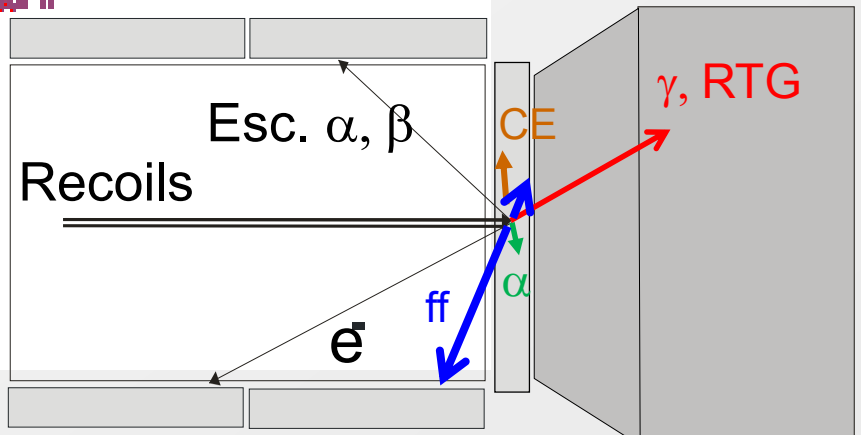
Velocity filter optimized for fusion-evaporation reactions

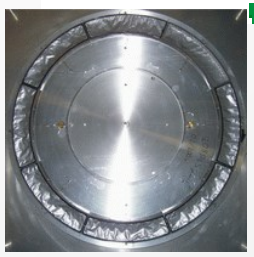
G. Münzenberg, et al., NIM 161, 65 (1979).

Efficiency ~40 %
Flight time ~ 1-2 μs



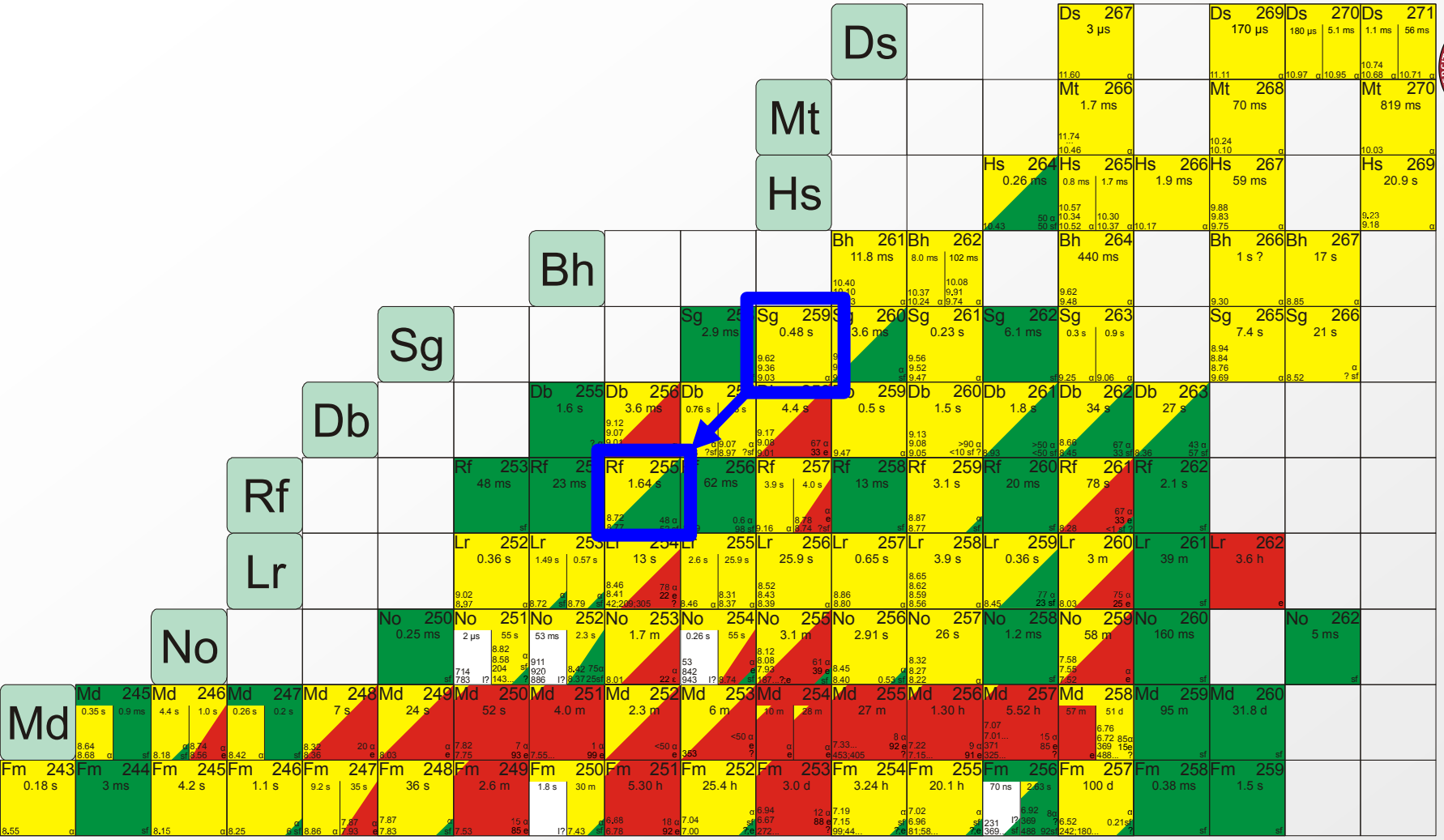
Very powerful beam
^{54}Cr ~ 720 pnA





Bi_2O_3, PbS target – 450 μg/cm²
Rotating wheel – 31 cm diameter

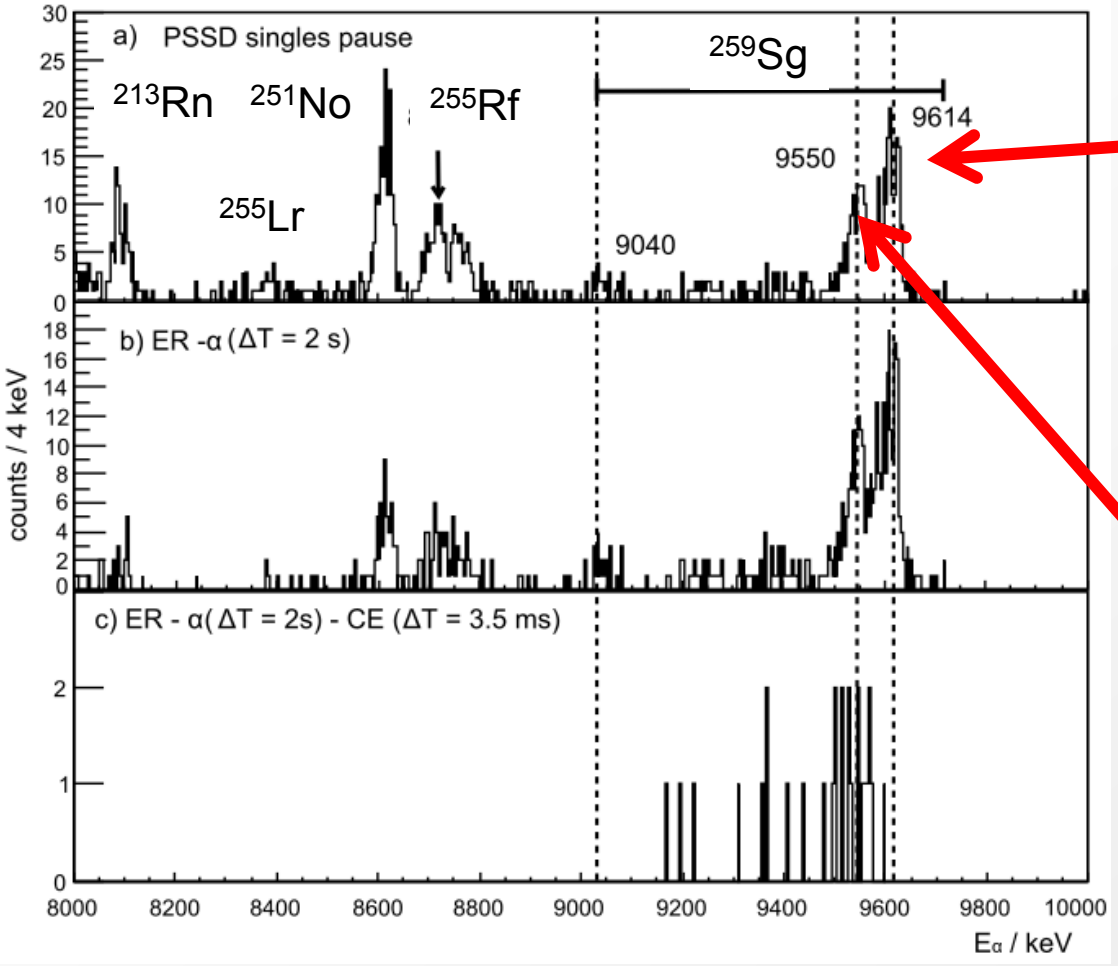
Back detector PSSD Ge-Clover

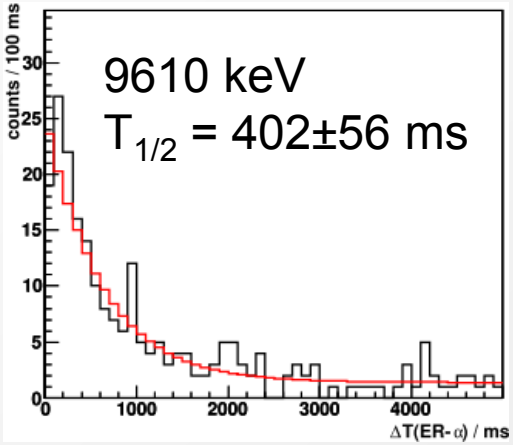


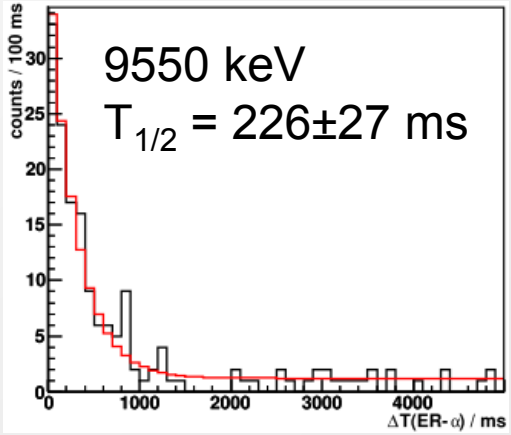
CLASSICAL TOOL: ALPHA -GAMMA DECAY

^{259}Sg AND ^{255}Rf

alpha decay of ^{259}Sg

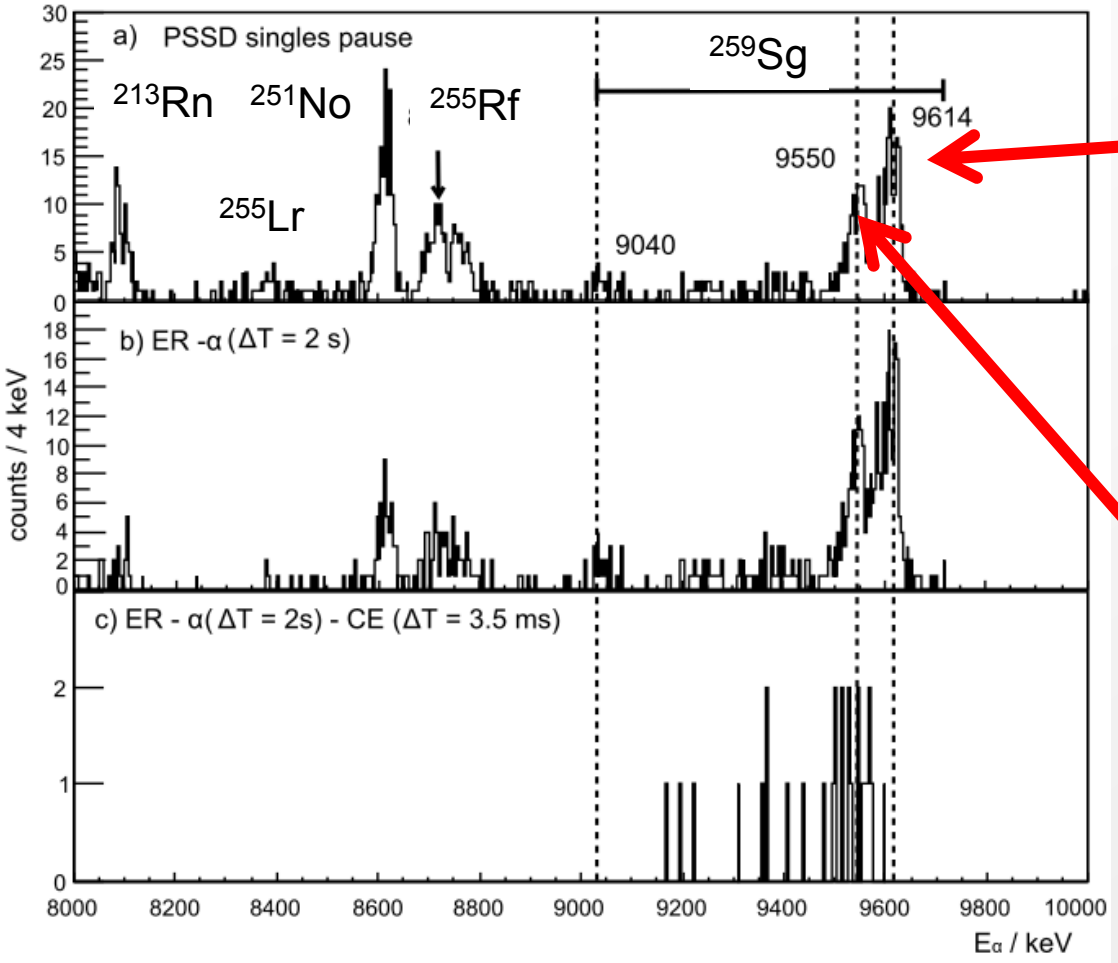


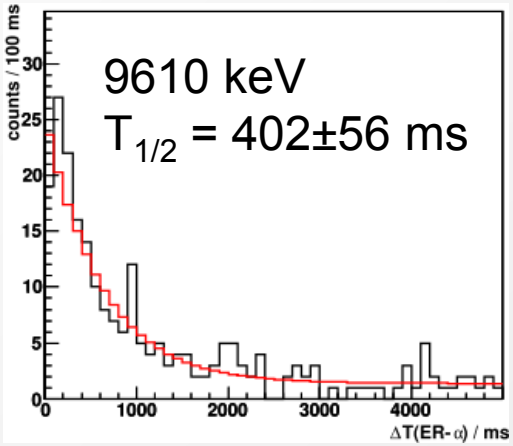


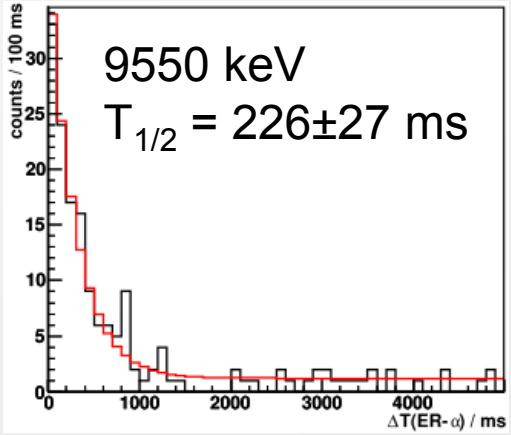


Fusion-evaporation reaction ^{54}Cr+^{206}Pb→^{259}Sg + 1n I(^{54}Cr^{8+}) = 720pnA
1 week of beamtime 750 nuclei of ^{259}Sg (assuming $b_\alpha \approx 97\%$)

alpha decay of ^{259}Sg

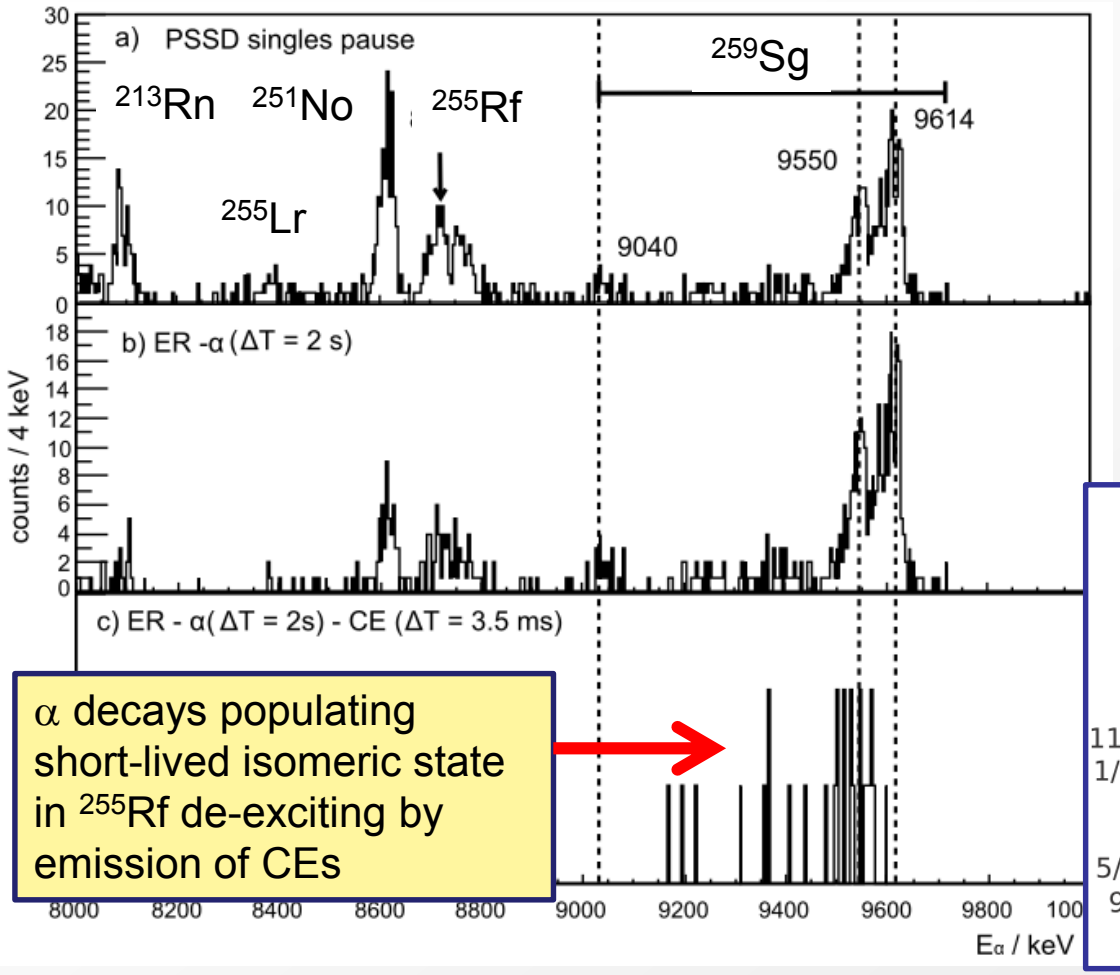




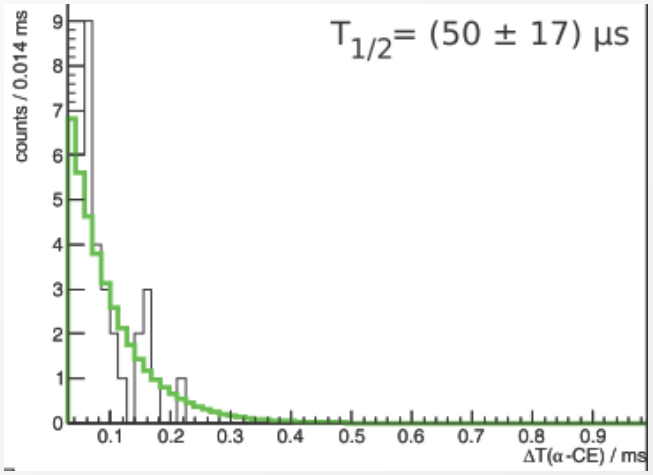


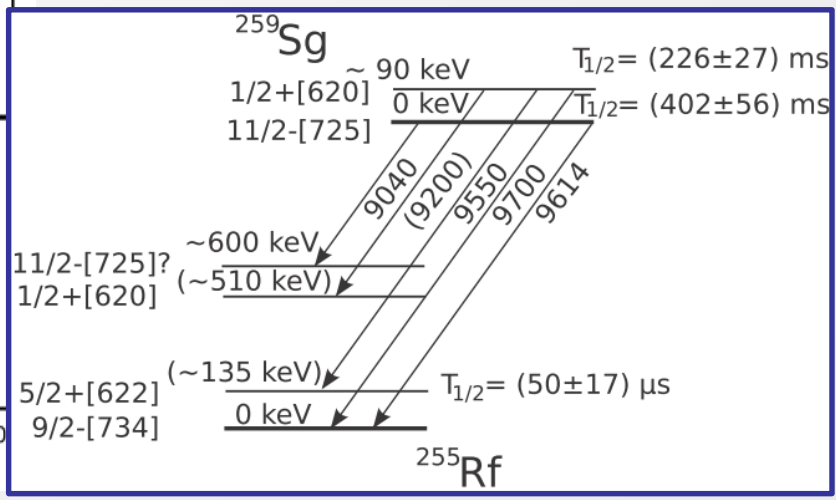
New long-lived isomeric state in ^{259}Sg exists due to the 11/2-[725] and 1/2+[620] nilsson levels known in lighter N=153 isotones.

New isomer in ^{255}Rf



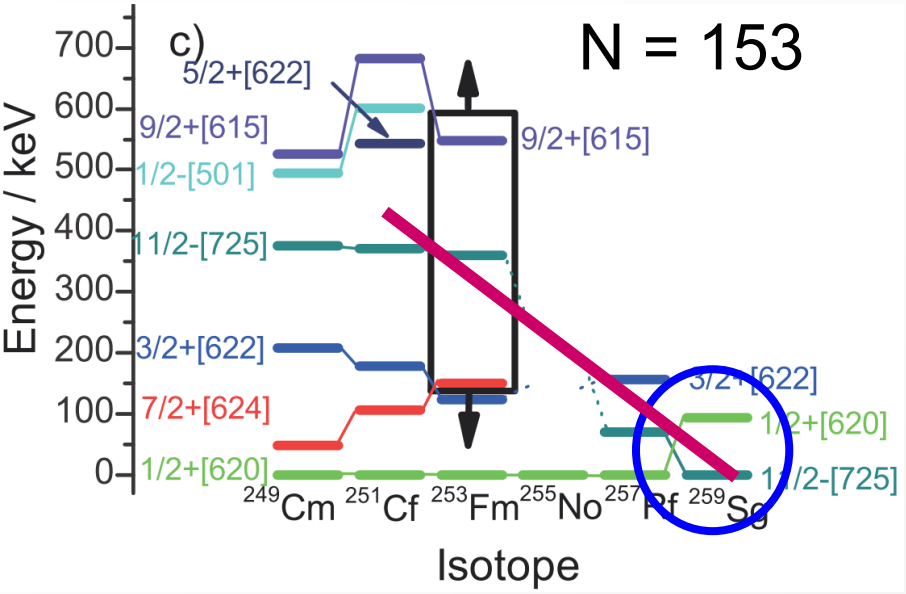
α decays populating short-lived isomeric state in ^{255}Rf de-exciting by emission of CEs

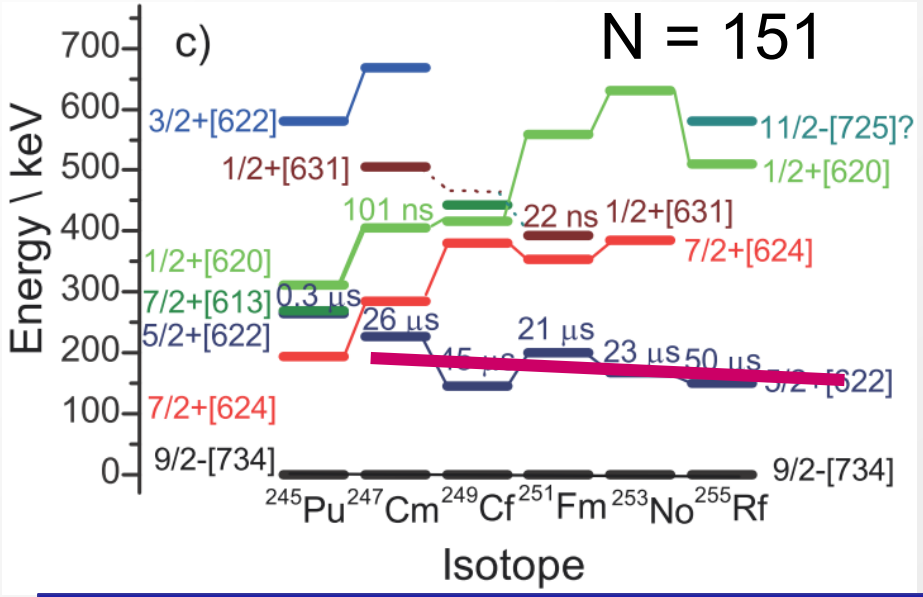




New short-lived (50 ± 17) μs isomeric state in ^{255}Rf at ≈ 135 keV assigned as 5/2+[622] state similarly to lighter N=151 isotones.

N=153 and 151 isotones systematics





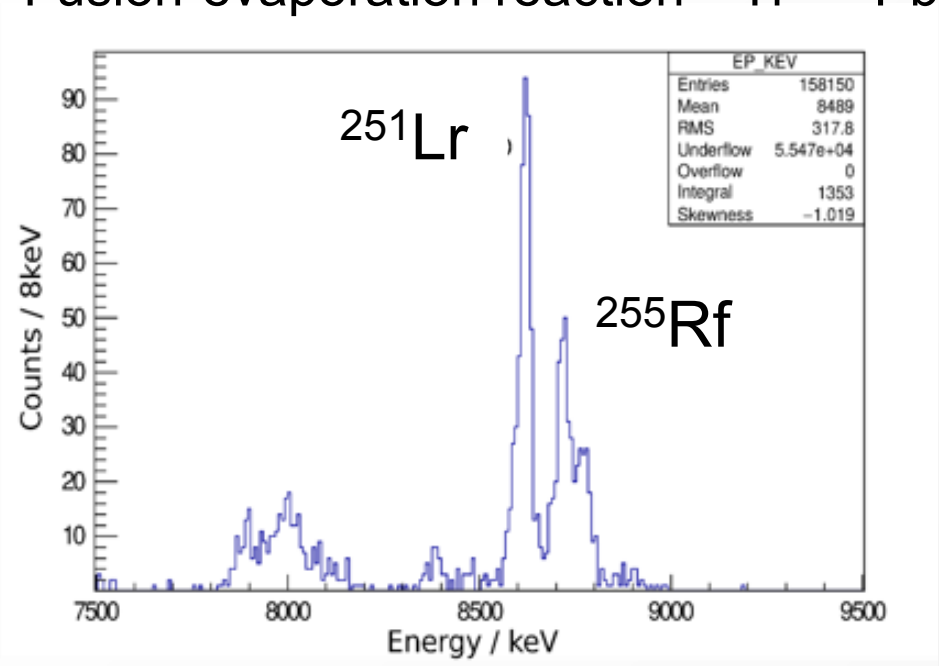
Significant change of the g.s. configuration for N=153 isotones from 1/2+[620] to 11/2-[725] .

Short lived isomers few 10 µs at 140 – 250 keV, not predicted by most of the theoretical models, known up to the ^{255}Rf.

Possible explanation by phonon-particle interaction suggested already for ^{249}Cf in 1975 - possible mixing with $\{9/2\text{-}[734] \oplus 2^-\}_{5/2^+}$ [S.W. Yates et al. Phys. Rev. C 12, 442 (1975)].

… another new isomer in ^{255}Rf

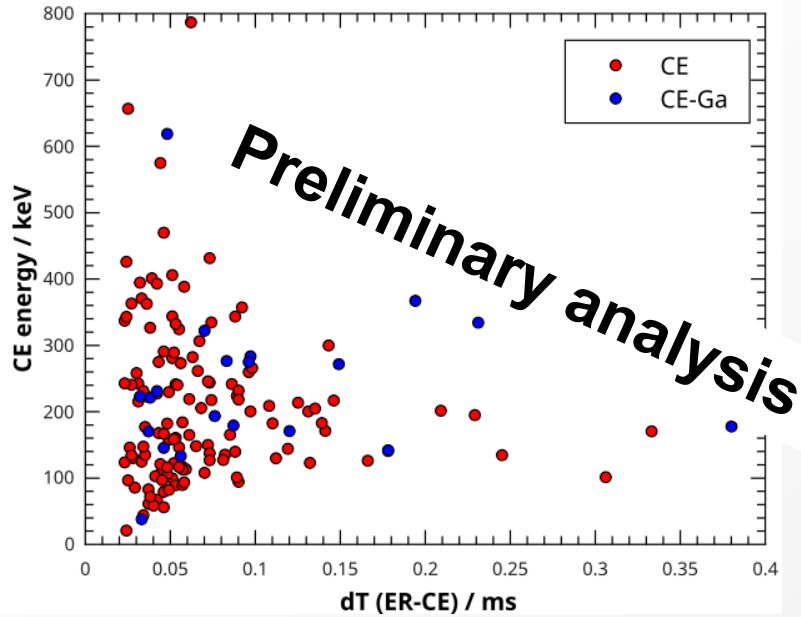
Fusion-evaporation reaction ^{50}Ti+^{207}Pb → ^{255}Rf + 2n ~1300 events

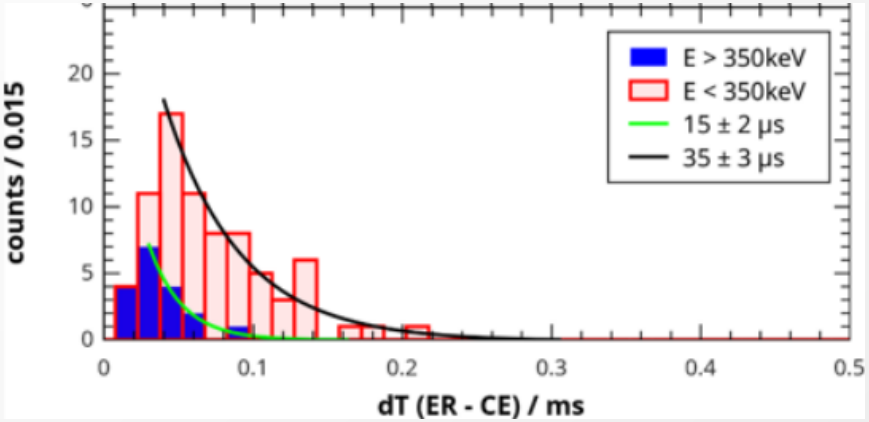


Besides its fission properties (see the poster by Pavol Mošať) we aimed at **delayed coincidences of ER-CE-SF/α**

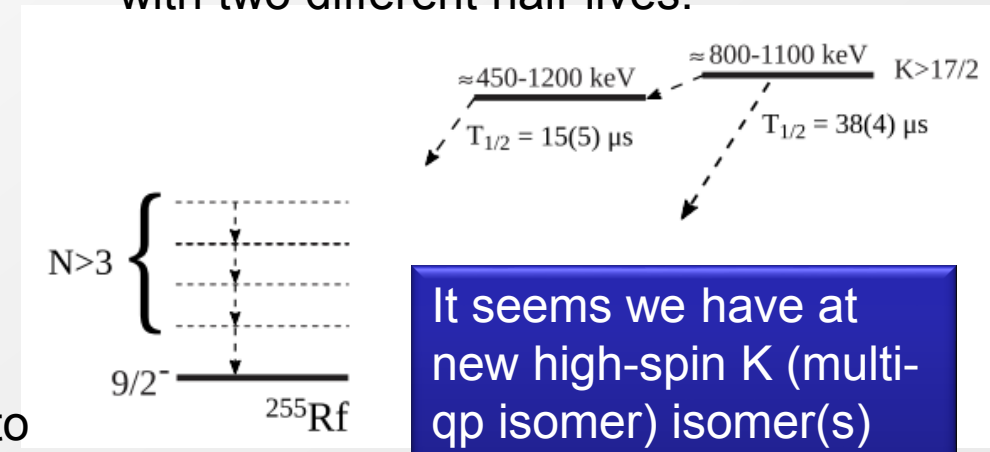
And another new isomer in ^{255}Rf

Fusion-evaporation reaction ^{50}Ti+^{207}Pb → ^{255}Rf + 2n ~1300 events





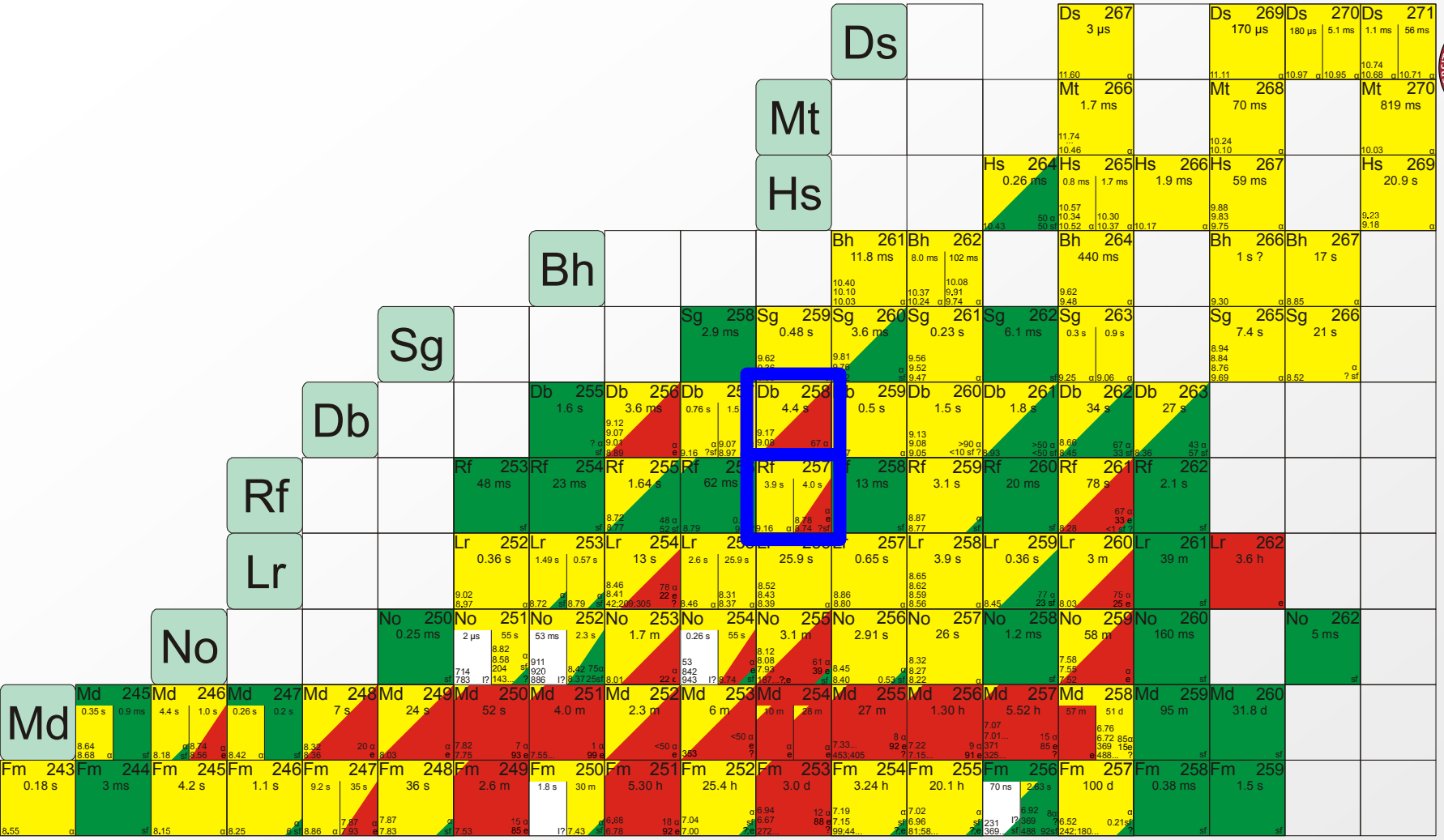
Indication of different CE energies with two different half-lives.



Besides its fission properties (see the poster by Pavol Mošať) we aimed at **delayed coincidences of ER-CE-SF/α**

Several ten events of CE with energy up to the 900 keV; some in coincidence with γ up to the 600 keV

It seems we have at new high-spin K (multi-qp isomer) isomer(s) at ~ 1 MeV exc. energy.

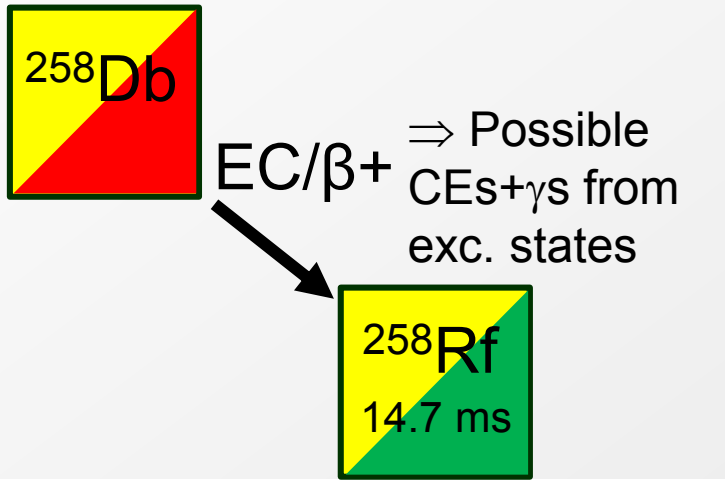


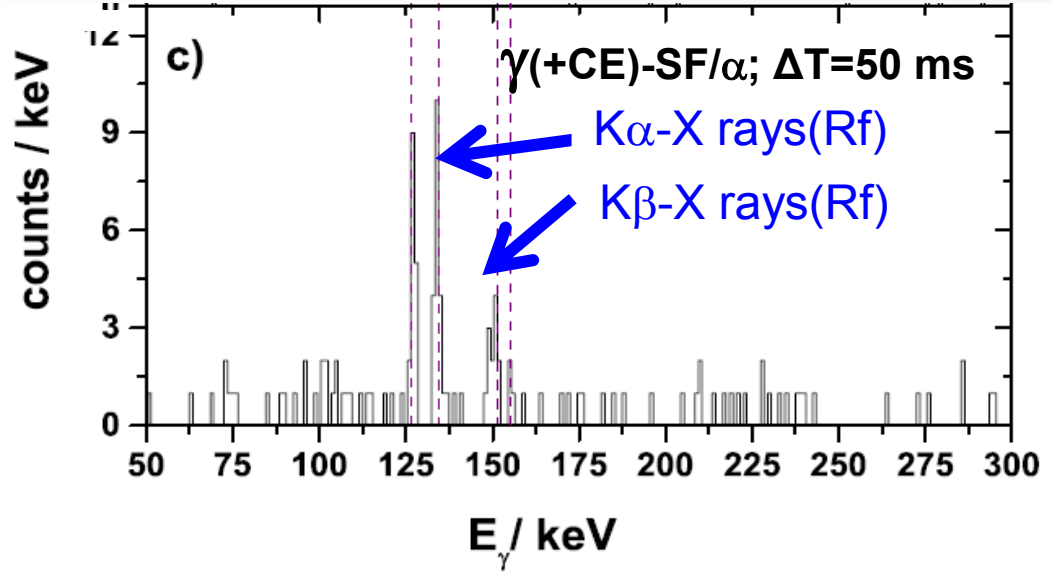
EC IN HEAVIEST NUCLEI

^{258}Db AND ^{257}Rf

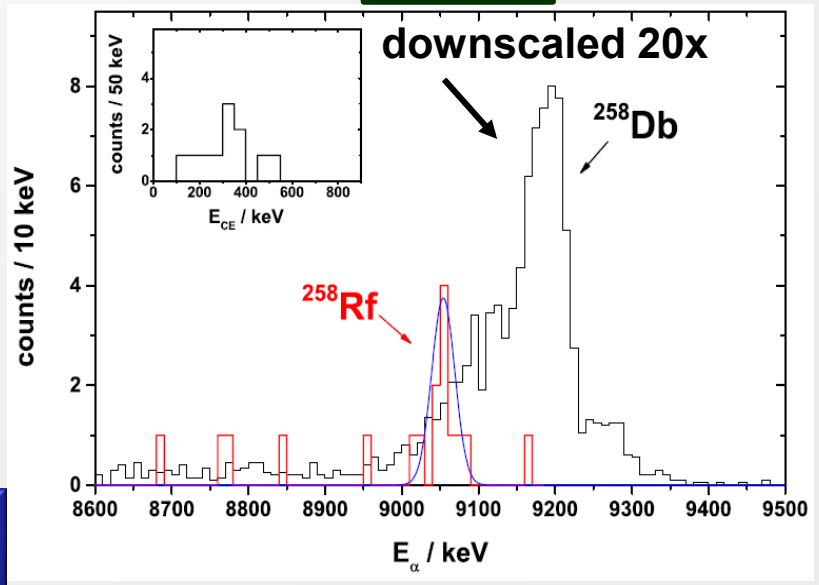
EC identified via CE-X-ray coincidences

- Production in $^{50}Ti+^{209}Bi \rightarrow ^{258}Db + 1n$
- 8.5 days of beamtime, ≈ 3000 nuclei of ^{258}Db
- Delayed CE-α/SF coincidences (ΔT<50 ms) resembled Rf X-rays.





F.P. Hessberger et al. Eur. Phys. J A, 52, 328 (2016)



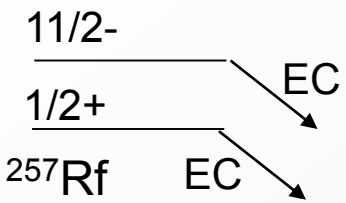
First confirmation of EC decay for ^{258}Db;
Direct Z identification of fissions via X rays.
Precise Q_α value for ^{258}Rf.

Gate at Fm X rays allowed very sensitive selection; almost pure ^{258}Rf

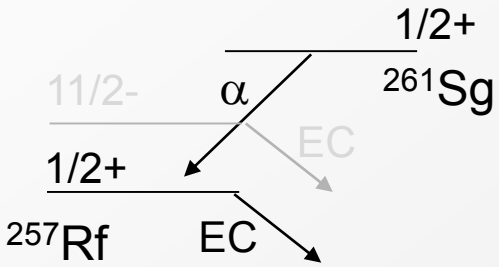
Beta-decay studies ^{257}Rf

Search for an EC decay in ^{257}Rf by looking at delayed CE(+X-ray) - α correlations.

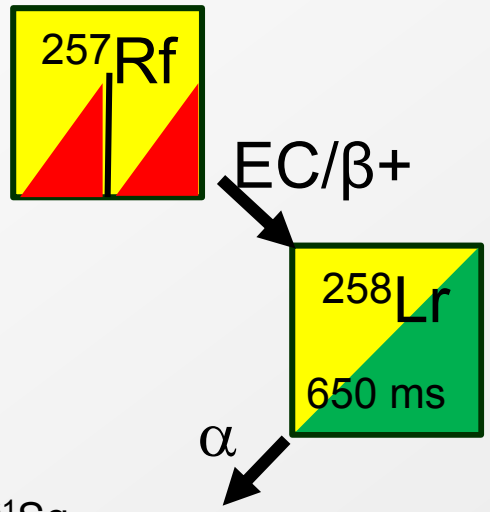
CE(+X-ray) from de-excitation cascade in ^{257}Lr

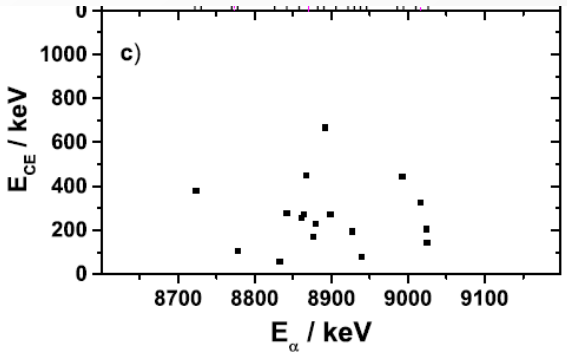


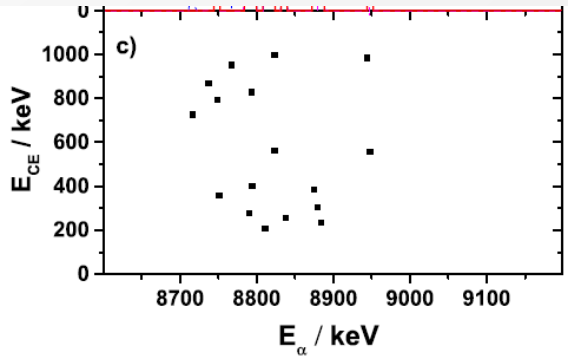
Direct production ^{257}Rf (populated low and high-spin state)

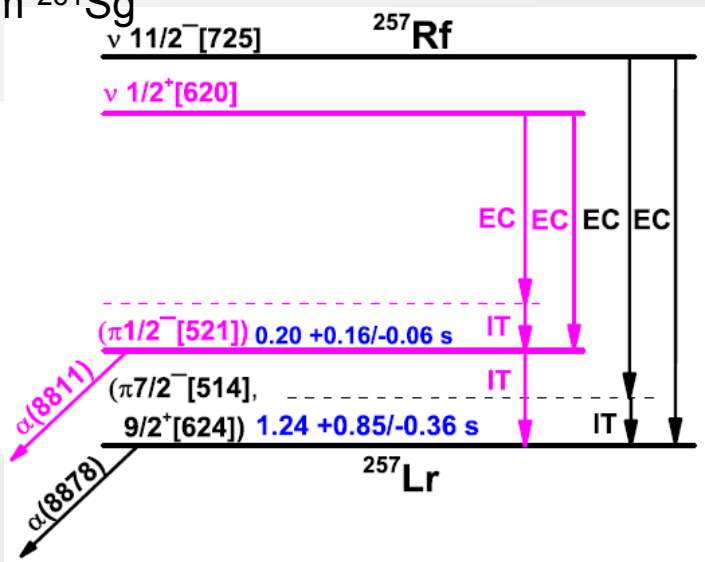


Indirect production ^{257}Rf from ^{261}Sg (populated low spin state)







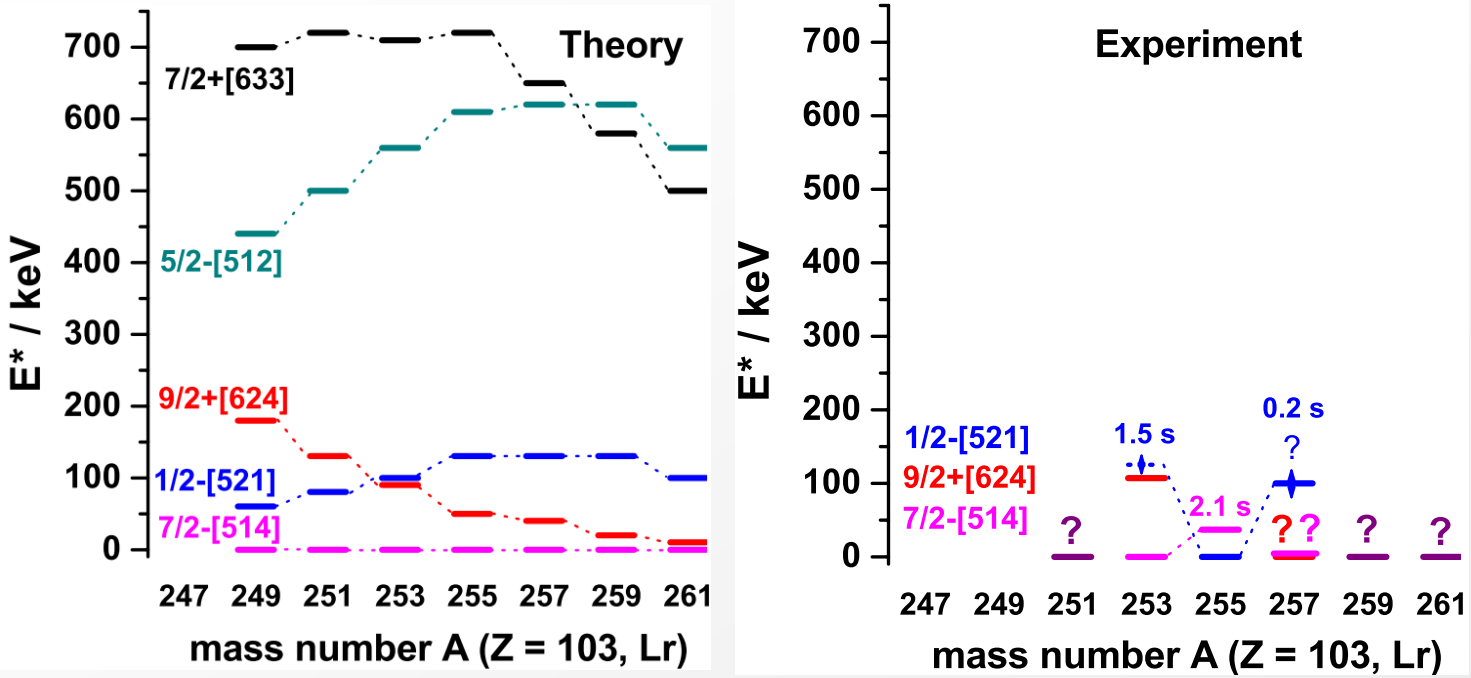


F.P. Heßberger, EPJ Web of Conferences 131, 02005 (2016)

F.P. Heßberger et al, Eur. Phys. J. A52, 192 (2016)

Despite of limited statistics indication new isomer in ^{257}Lr assigned as 1/2-[521]

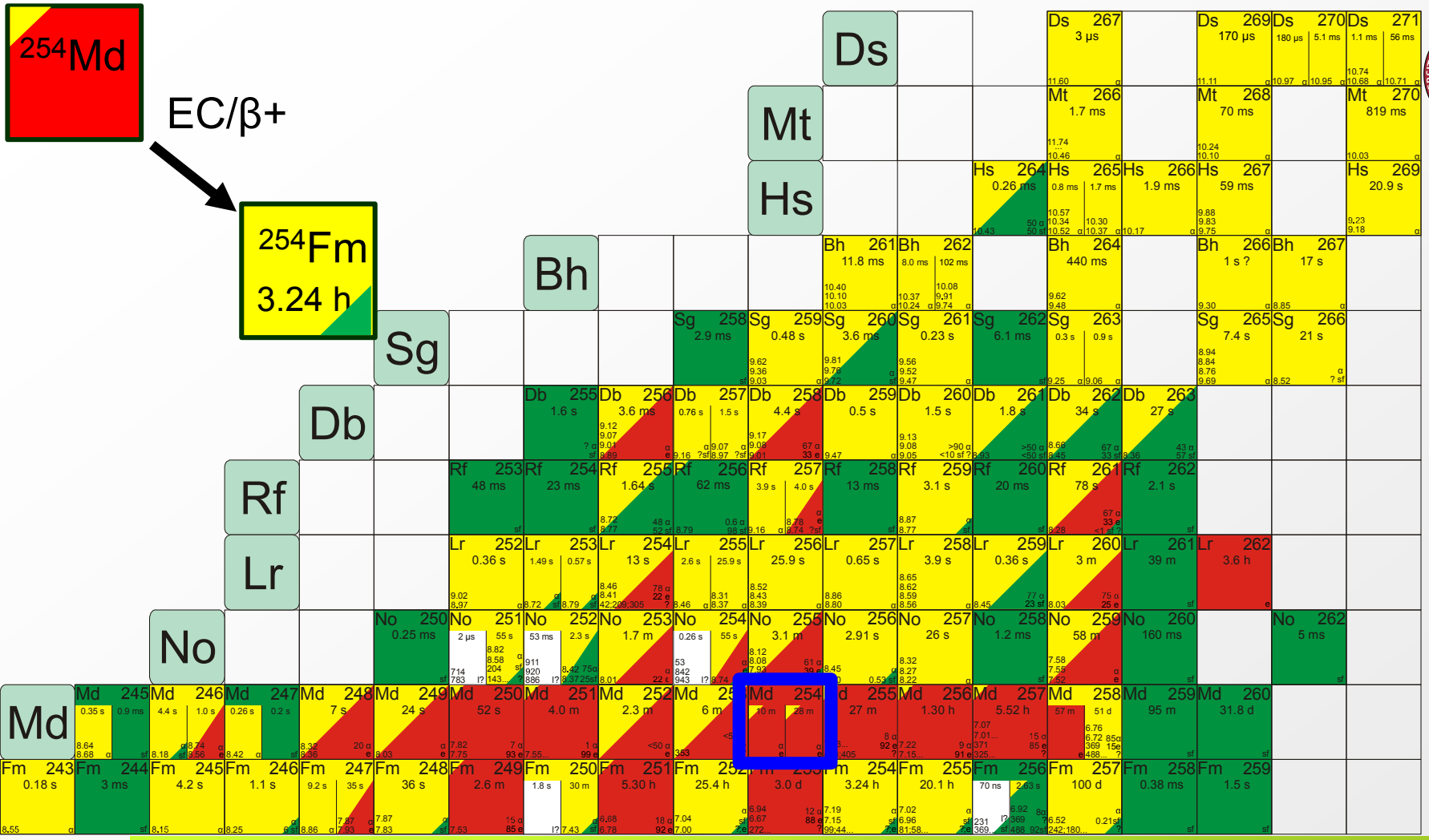
Level systematics for Lr isotopes



A. Parkhomenko and A. Sobiczewski, APPB 35, 2447 (2004)

1/2-[521] and 7/2-[514] states stem from $2f_{5/2}$ and $2f_{7/2}$ defining possible the shell gap at Z=114. Both responsible for isomers in Lr isotopes.

Uncertain g.s. configuration for most of the Lr isotopes and completely missing data on excited levels.
There are not almost any new data available in last 10 years



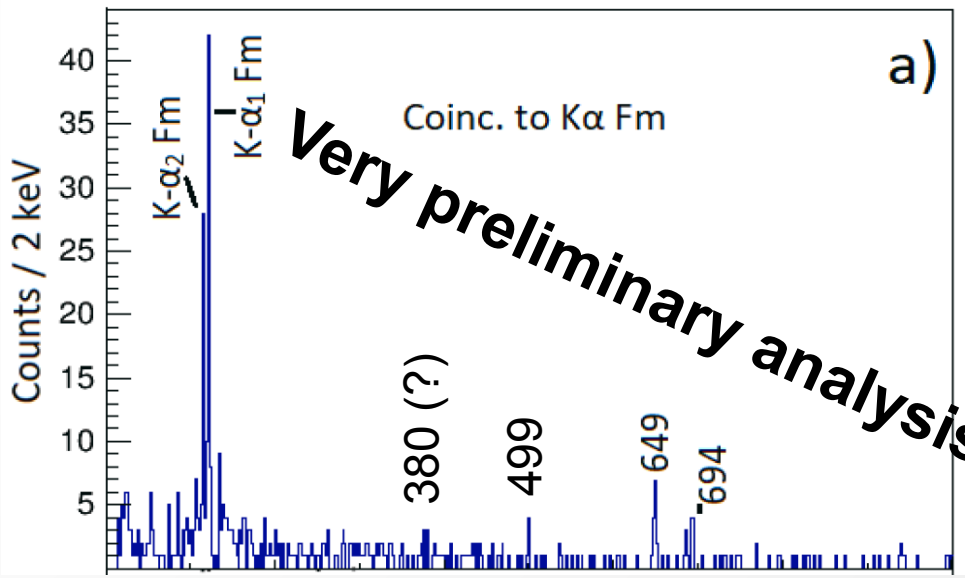
ANOTHER EC DECAY STUDY… ^{254}Md

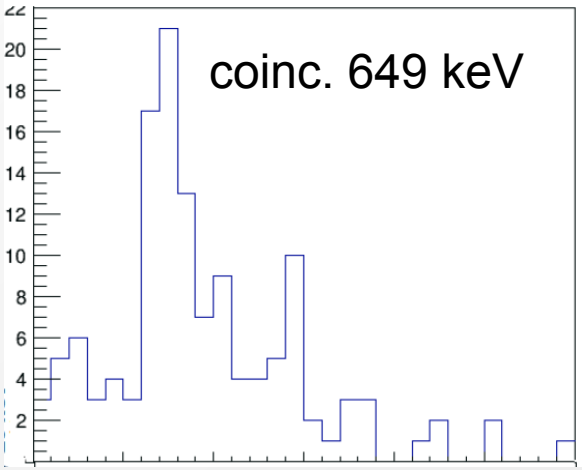
EC of ^{254}Md to ^{254}Fm

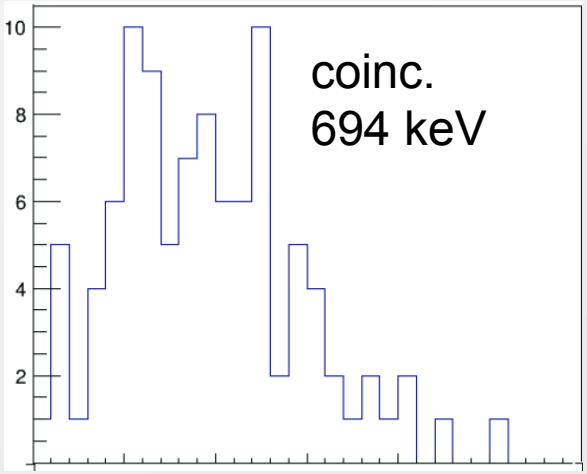
^{254}Md (produced via EC of ^{254}No in ^{48}Ca+^{208}Pb) decays to ^{254}Fm

Old case – observed in 1970 by Fields et al
Only very basic data are available

Suggested 1- and 3- long-lived states





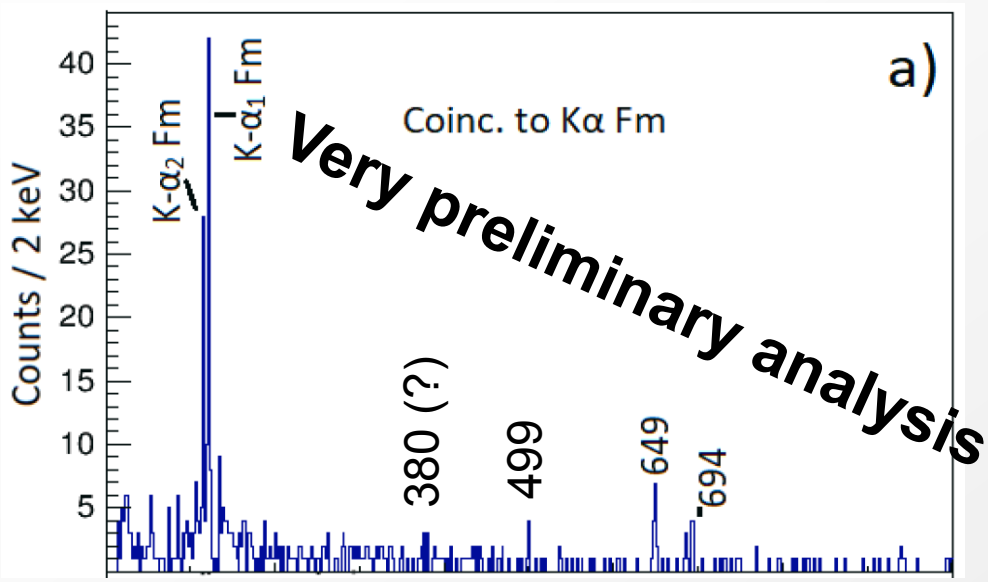


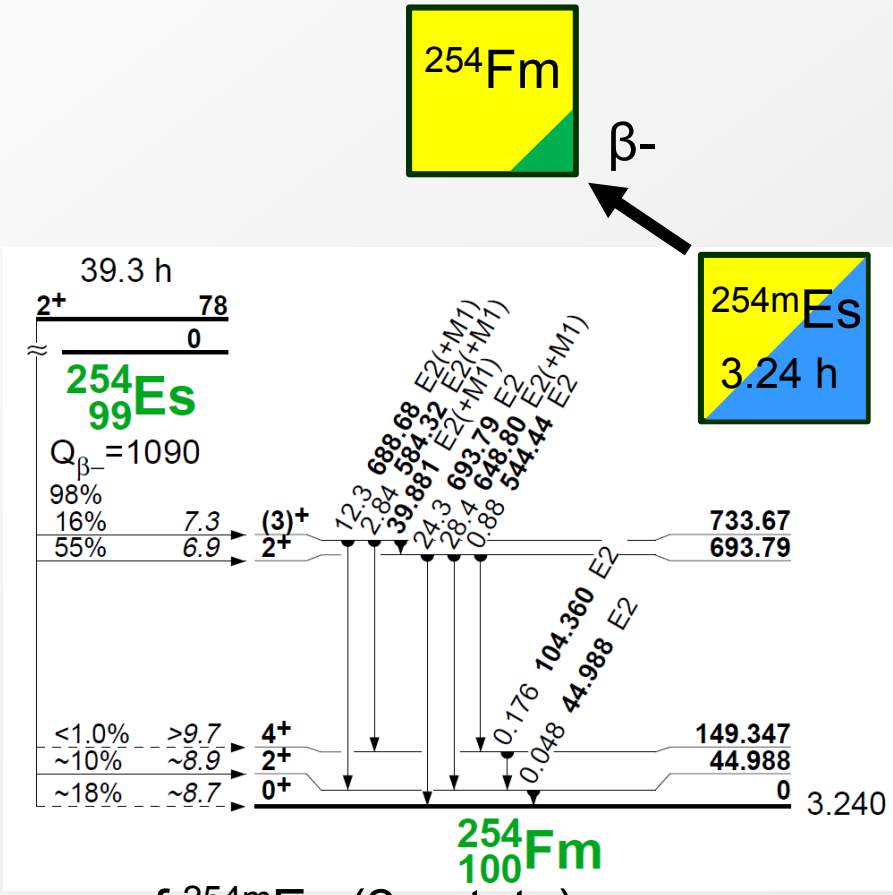
γs in coinc. with CE up to 600 keV and Fm X-rays

A. Broniš, Project of PhD Thesis

CE with high energy γ transitions up to 700 keV and Fm X rays
Populated state at 1200 – 1400 keV (considering bind. energy)

EC of ^{254}Md to ^{254}Fm





649 and 694 keV γ lines known from β- decay of ^{254m}Es (2+ state)

The β- decay of ^{254m}Es involves a transitions between low-spin states. Do we expect something similar for EC of ^{254}Md is higher?

EC of ^{254}Md to ^{254}Fm

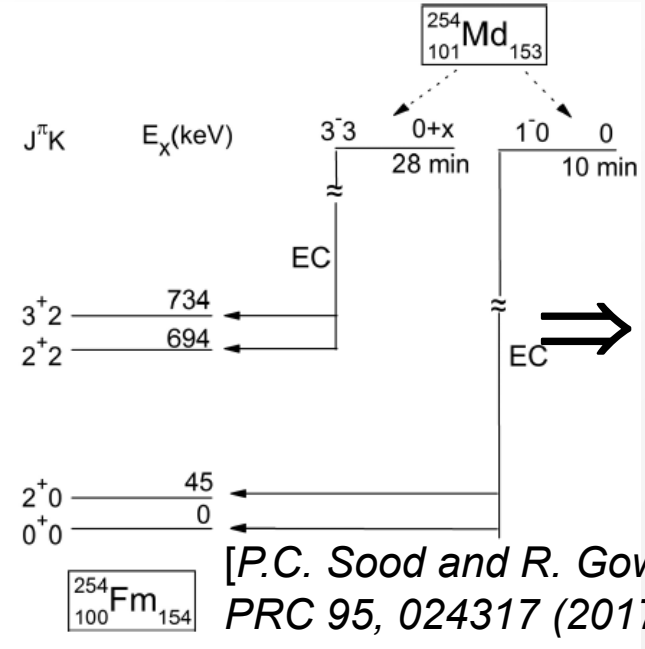
We should expect low spin states in ^{254}Md

π7/2-[514] $\oplus$ ν1/2+[620] …… 3-

π1/2-[521] $\oplus$ ν1/2+[620] …… 1-

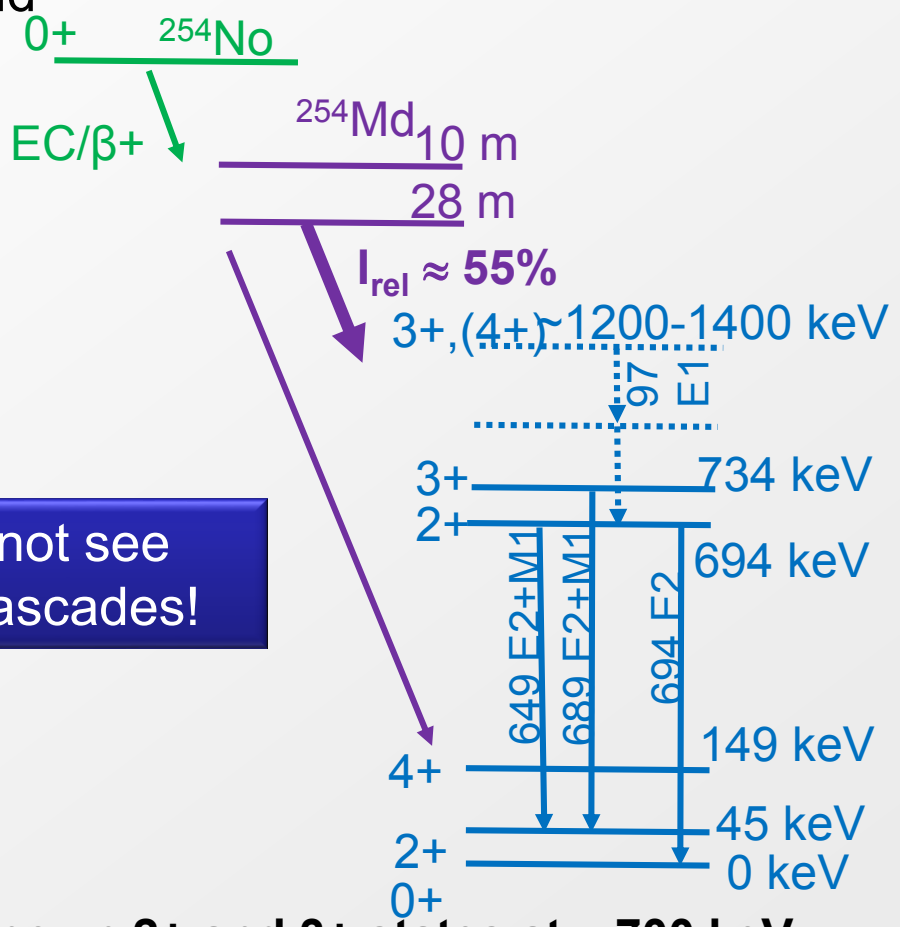
π7/2-[514] $\oplus$ ν3/2+[622] …… 2-

π1/2-[521] $\oplus$ ν3/2+[622] …… 2-



[*P.C. Sood and R. Gowrishankar, PRC 95, 024317 (2017)*]

We should not see any CE-γ cascades!



55% of al EC transitions goes well *above* known 2+ and 3+ states at ≈ 700 keV

$\Rightarrow$ There are higher spin states populated than expected and thus also initial in ^{254}Md

It seems, the ambiguity for available single particle levels is critical issue again

Conclusion

- Besides α-decay studies the EC might provide interesting data (using delayed coincidences with CE+X-ray coincidences); see e.g. ^{258}Db, ^{257}Rf, ^{253,254}Md…

  It's tricky, but possible.
- Level systematics above fermium remains very uncertain especially for isotopic chains $\Rightarrow$ it's really difficult to predict and explain decay characteristics of heaviest isotopes.
- There is still lot of work for both – theory and experiment - in the region of heaviest nuclei.

Thank you