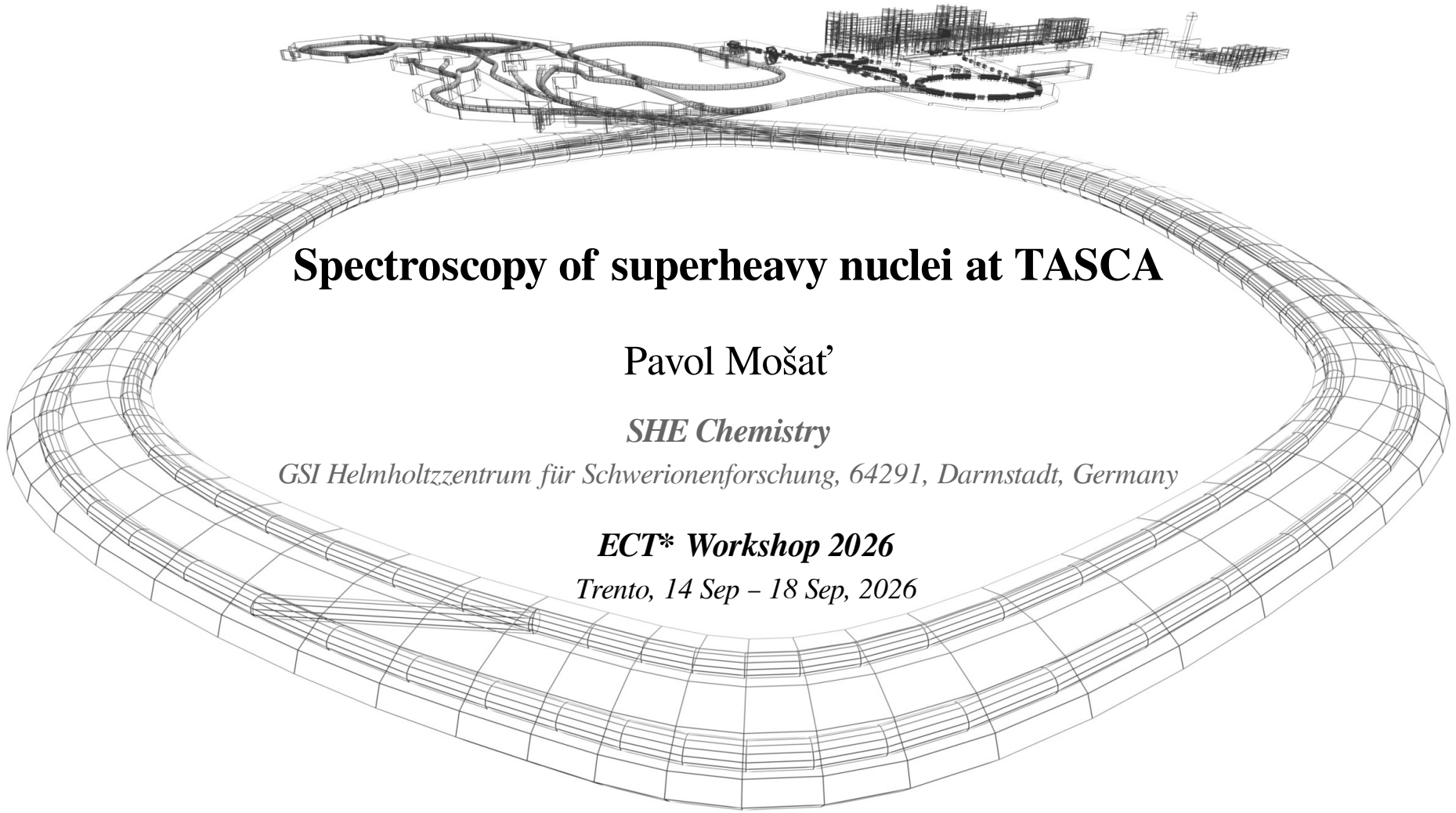


Spectroscopy of superheavy nuclei at TASCA

Pavol Mošať

SHE Chemistry

GSI Helmholtzzentrum für Schwerionenforschung, 64291, Darmstadt, Germany

ECT* Workshop 2026

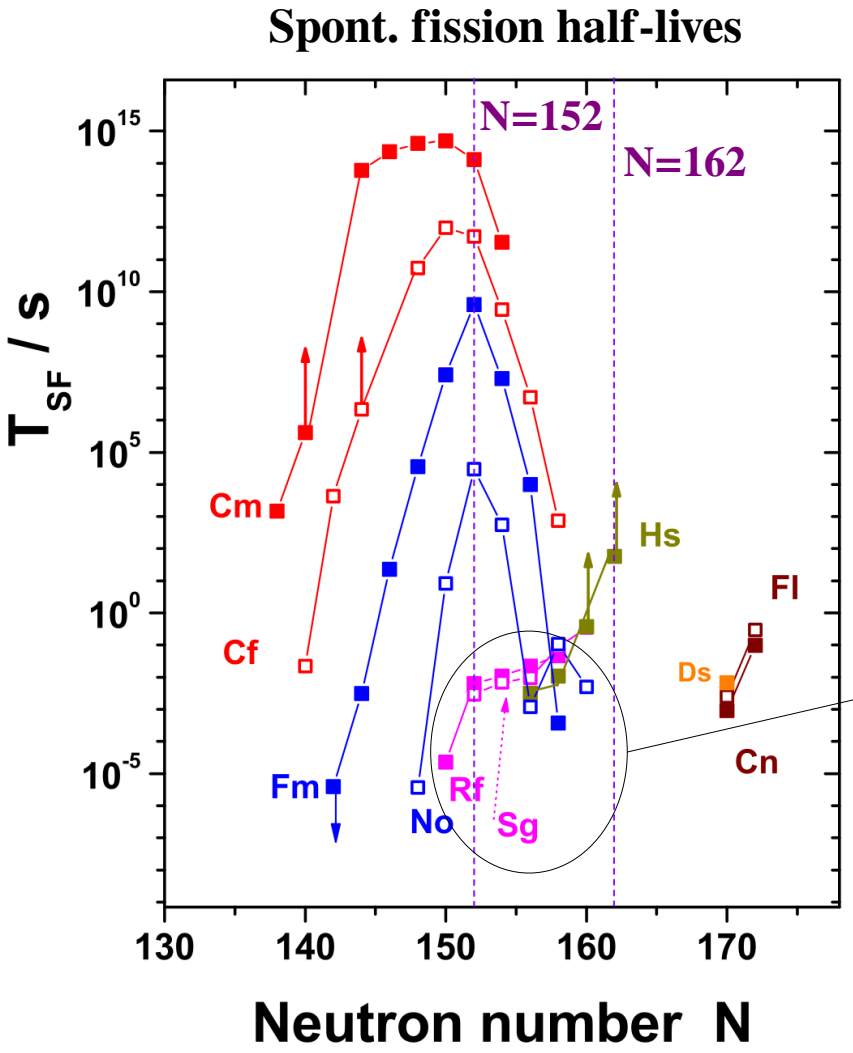
Trento, 14 Sep – 18 Sep, 2026

Content

- **Introduction and motivation**
  - Isotopic border for Rf and Sg
  - K isomerism

- **Results**
  - Discovery of ^{252}Rf
  - Discovery of ^{257}Sg
    - K isomer signature in ^{259}Sg
  - Search for K isomerism in Sg isotopes ($^{258\text{-}261}$Sg)

Spont. fission stability of Rf and Sg isotopes



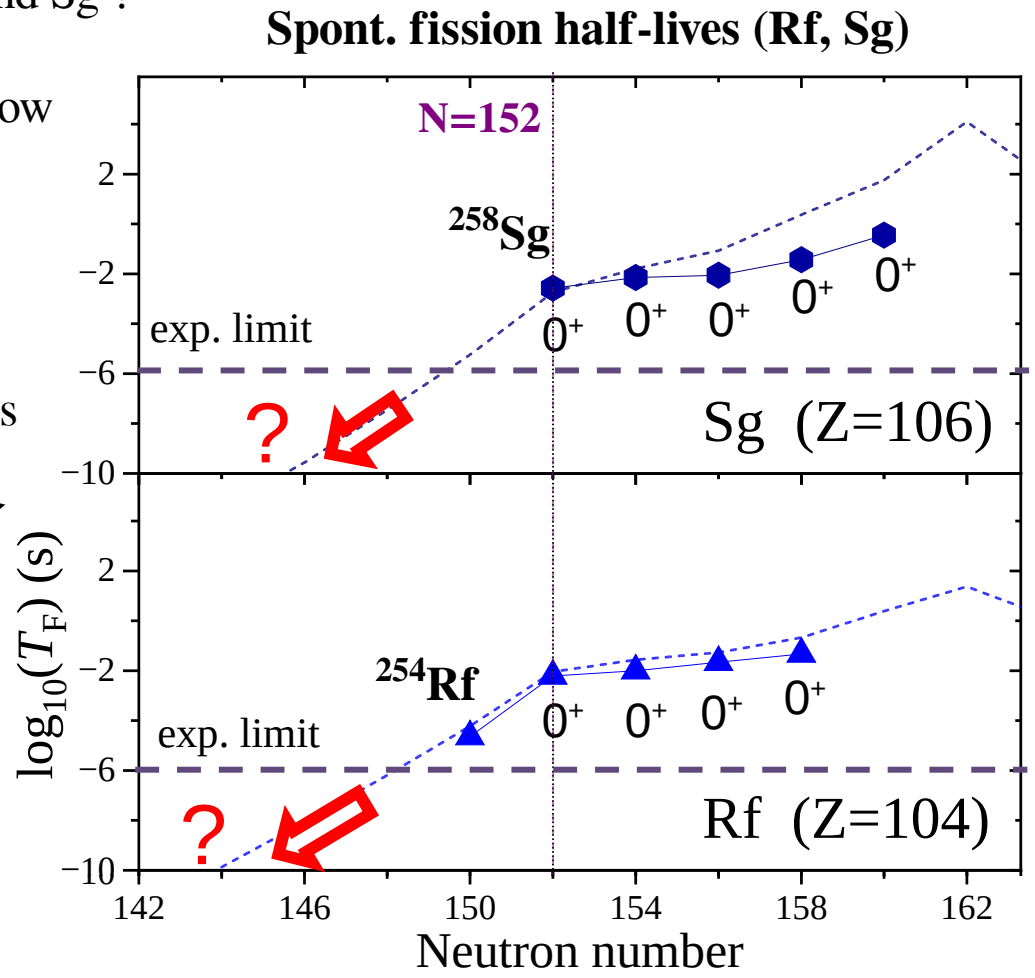
N=152 stabilization in Rf and Sg ?

Follow the T_{SF} decrease below N=152

Isotopic border ~10^{-14} s

Experimental limit ~1 μs

How to reach nuclei below the exp. limit ?

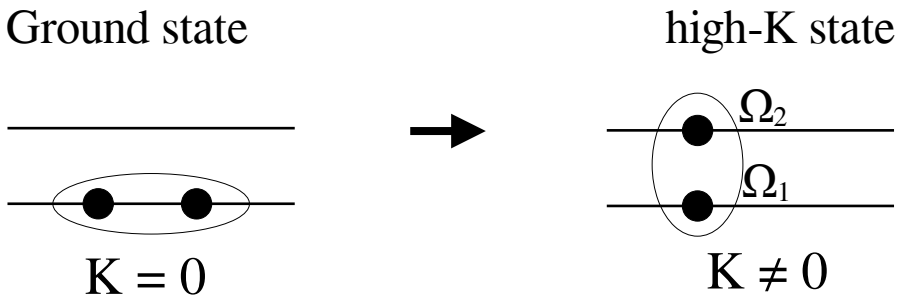


F.P. Hessberger, Eur. Phys. J. A (2017) 53: 75

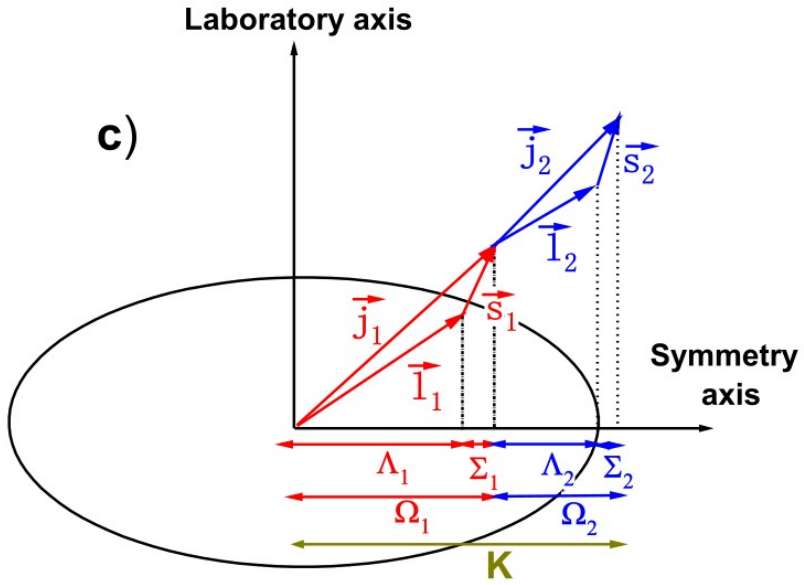
dashed lines:
R. Smolańczuk, J, Skalski and A. Sobiczewski, Phys. Rev.C **52** 1871 (1995)

K isomers

- Coupling of quasiparticles in different Nilsson orbitals
  → Multi-quasiparticle states with high-*K*



Deformed nucleus

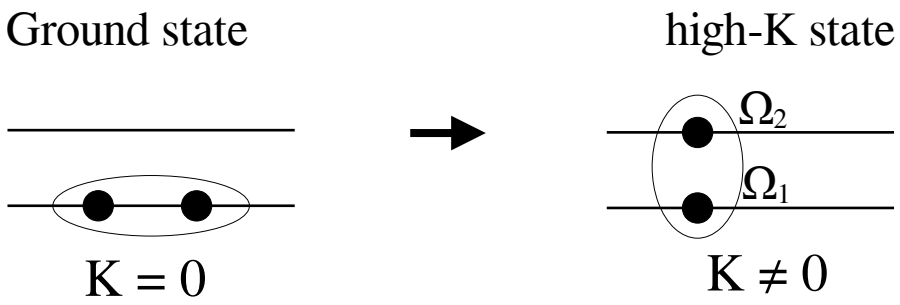


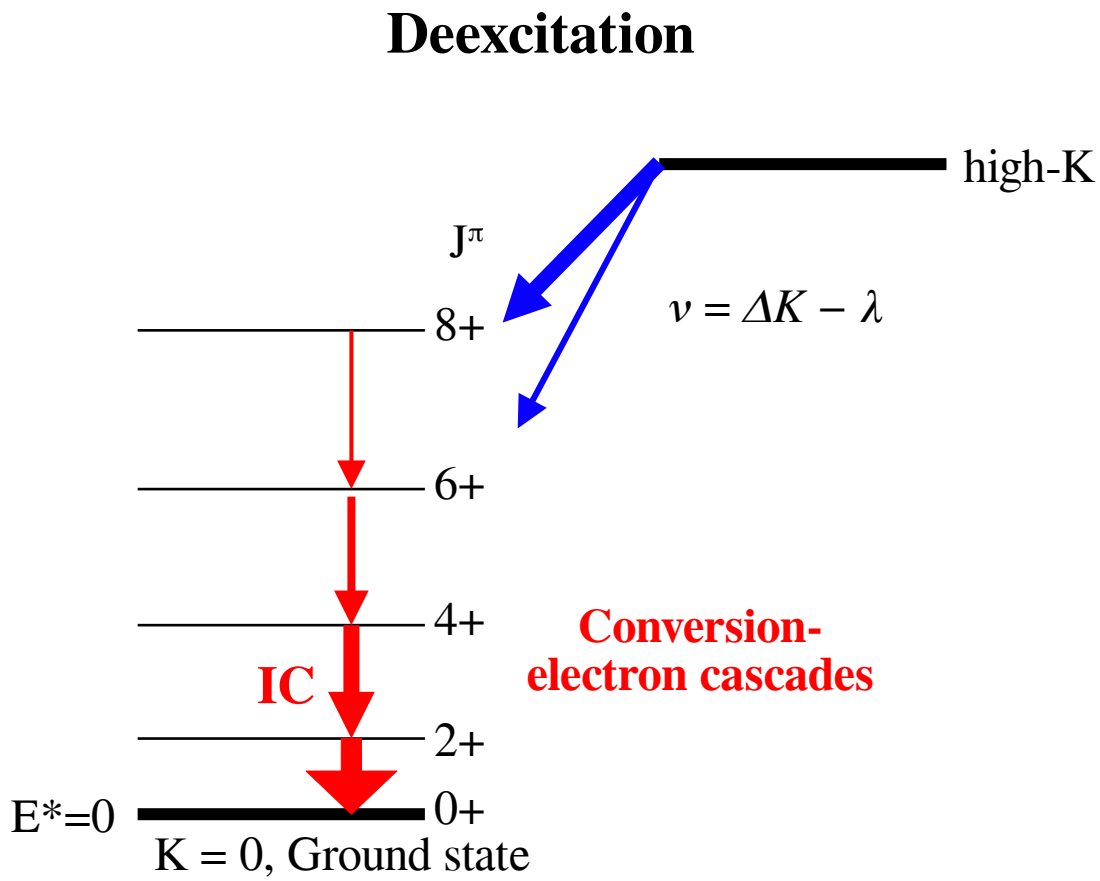
P. M. Walker and G. D. Dracoulis, Nature 399, 35 (1999)
F. G. Kondev, G. D. Dracoulis, and T. Kibédi, At. Data Nucl. Data Tables 103–104, 50 (2015)

F.P. Hessberger, arXiv:2309.10468

K isomers

- Coupling of quasiparticles in different Nilsson orbitals
  → Multi-quasiparticle states with high-K
- A large ΔK retards its deexcitation
  → K isomer (typically μs in Rf)





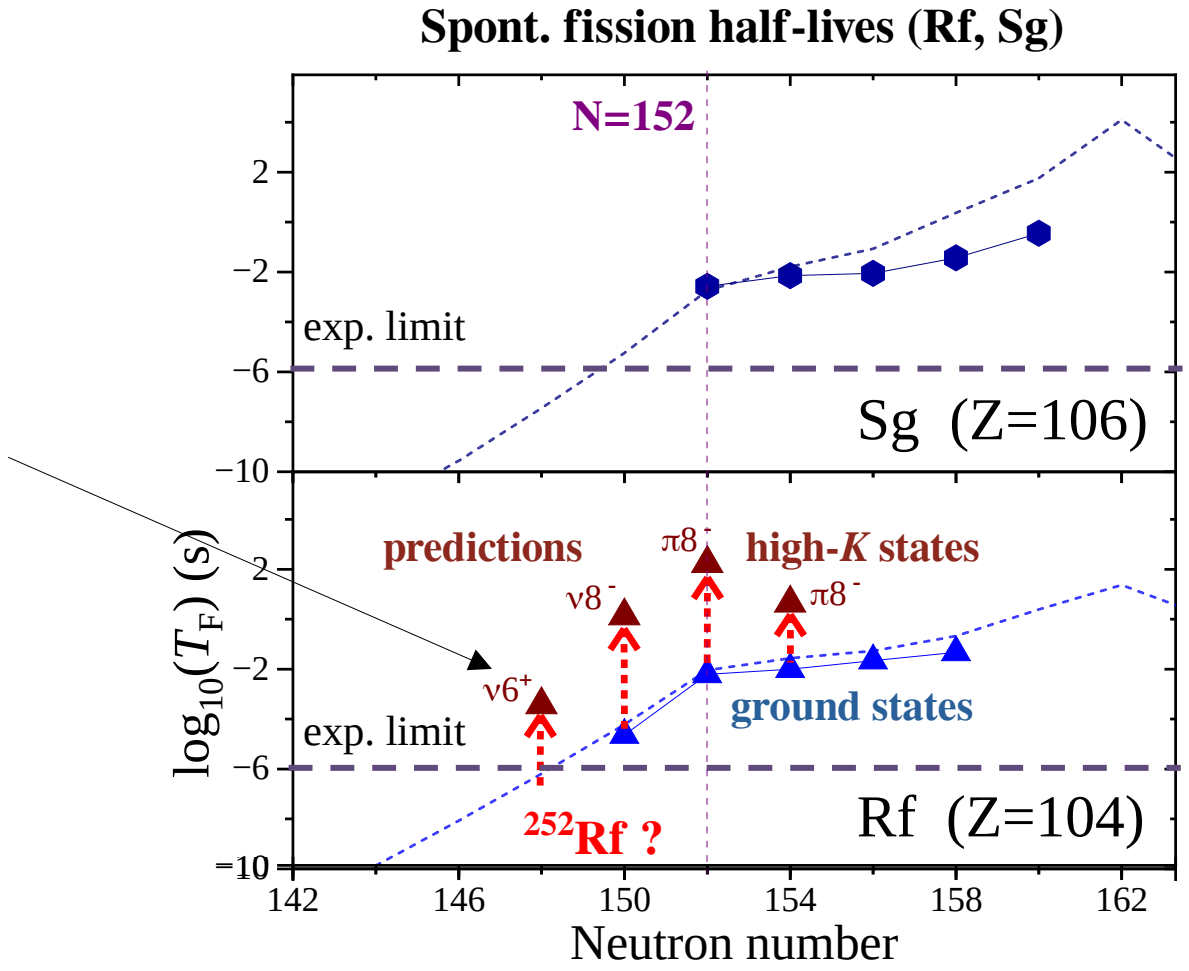
P. M. Walker and G. D. Dracoulis, Nature 399, 35 (1999)
F. G. Kondev, G. D. Dracoulis, and T. Kibédi, At. Data Nucl. Data Tables 103–104, 50 (2015)

K. E. G. Löbner, Phys. Lett. B 26, 369 (1968)

K isomers and fission hindrance

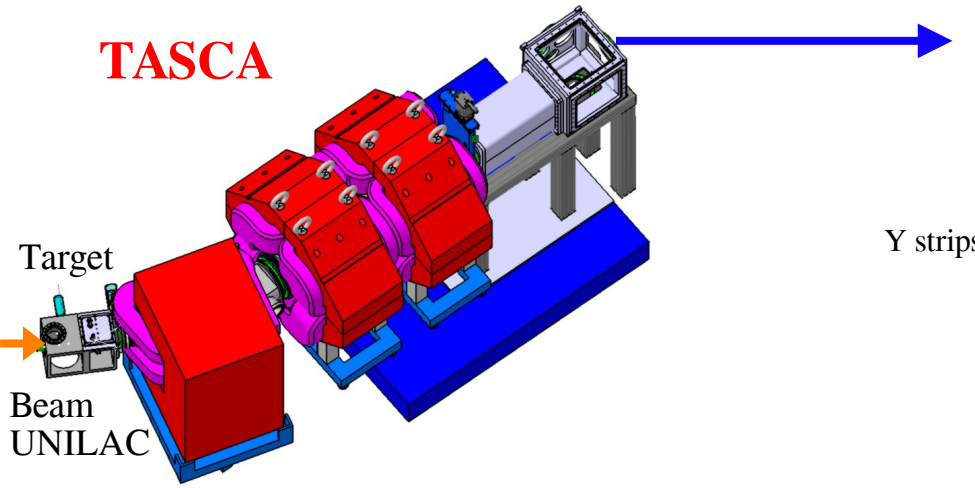
- Coupling of quasiparticles in different Nilsson orbitals
  → Multi-quasiparticle states with high-K
- A large ΔK retards its deexcitation
  → K isomer (typically μs in Rf)
- High-K multiquasiparticle states can strongly hinder fission

The ground state may not survive the separator flight – a K isomer can !

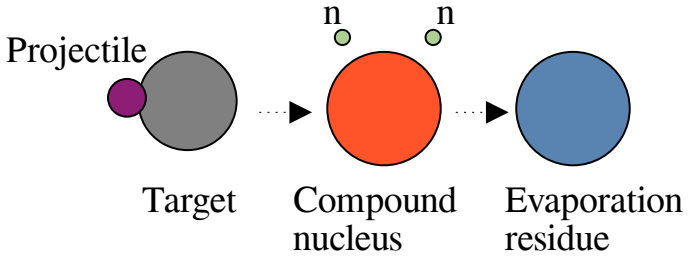


J. Khuyagbaatar, Eur. Phys. J. A 58, 243 (2022)

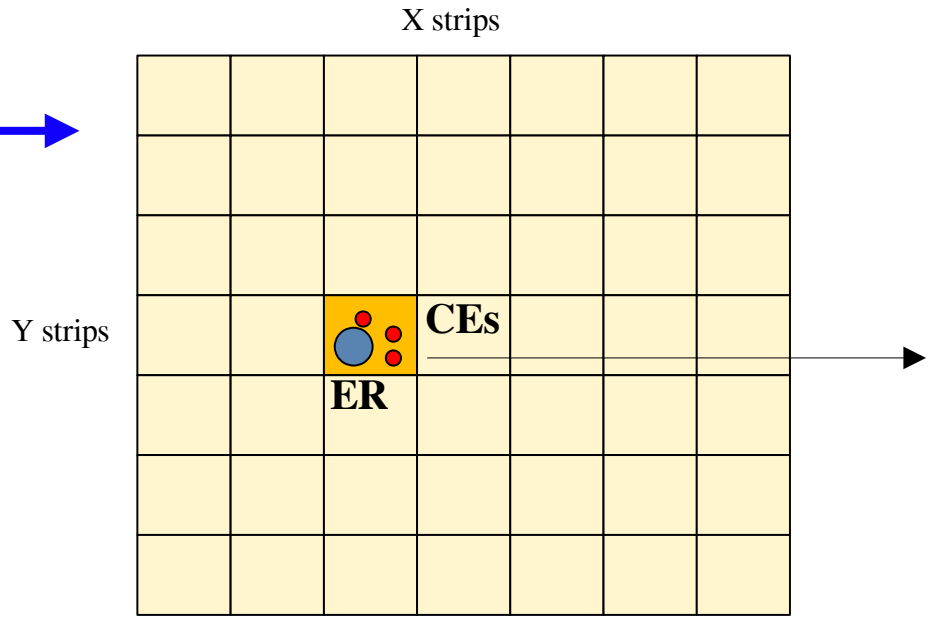
K isomeric studies at TASCA



Fusion-evaporation reactions



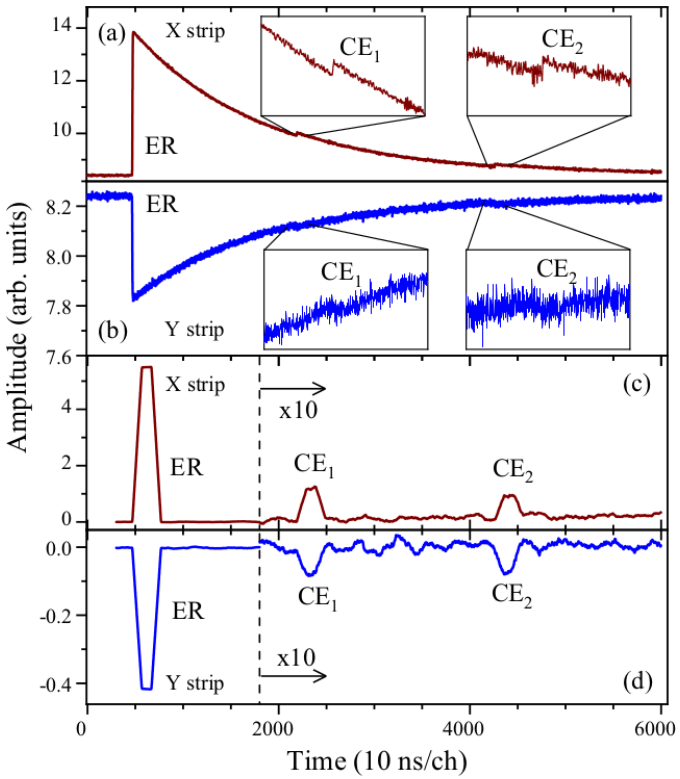
Focal plane implantation
Double sided silicon detector



- Safe identification of K isomers
  - ➔ via CE signal
- Digital electronics (traces)
- CEs in the same trace – ER triggered

Detection of K isomers

Traces



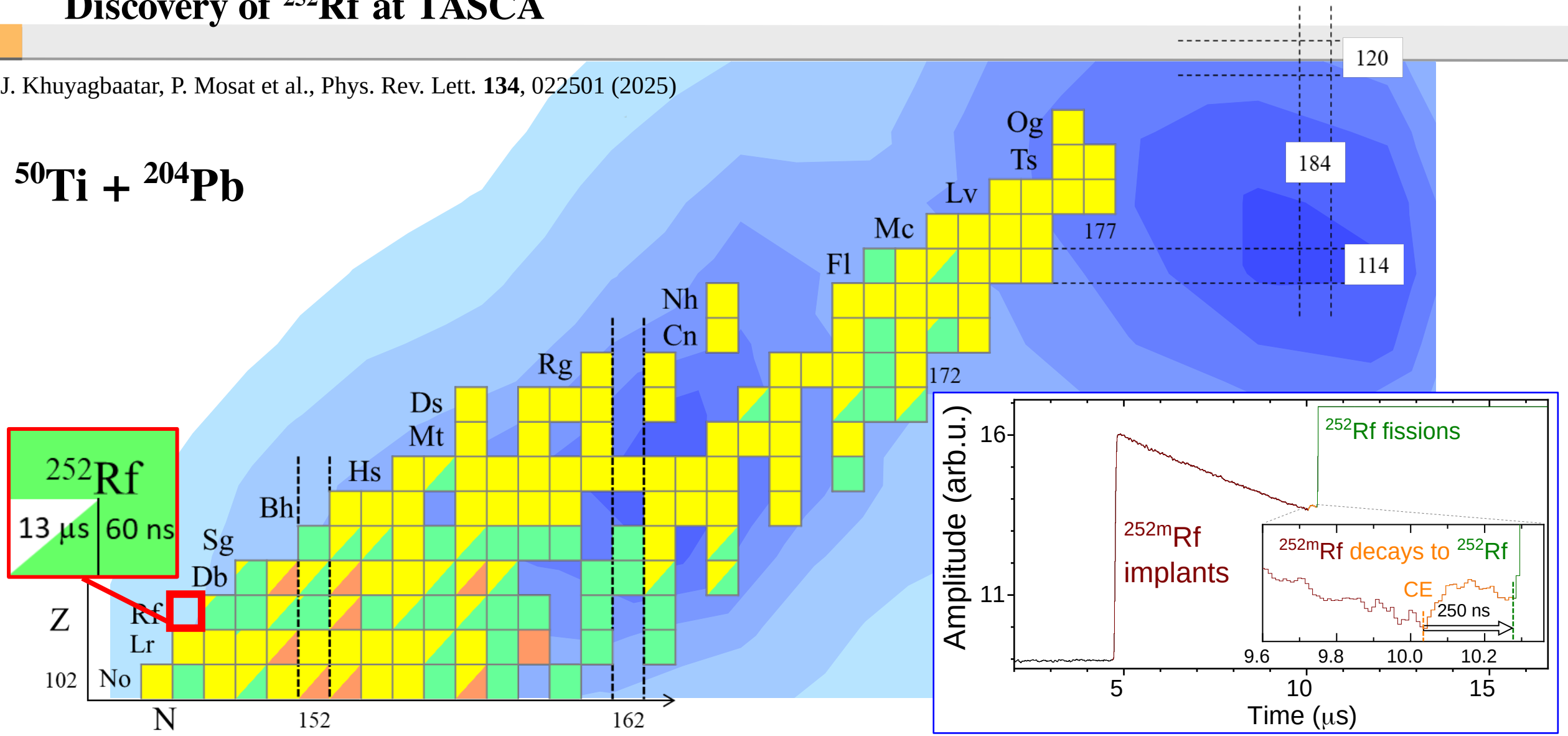
K isomers in ^{250}No, $^{254-256}$Rf via CEs

J. Khuyagbaatar et al., Nucl. Phys. A 994, 121662 (2020)
J. Khuyagbaatar *et al.*, Phys. Rev. C 103, 064303 (2021)
J. Khuyagbaatar *et al.*, Phys. Rev. C 106, 024309 (2022)

Discovery of ^{252}Rf at TASCA

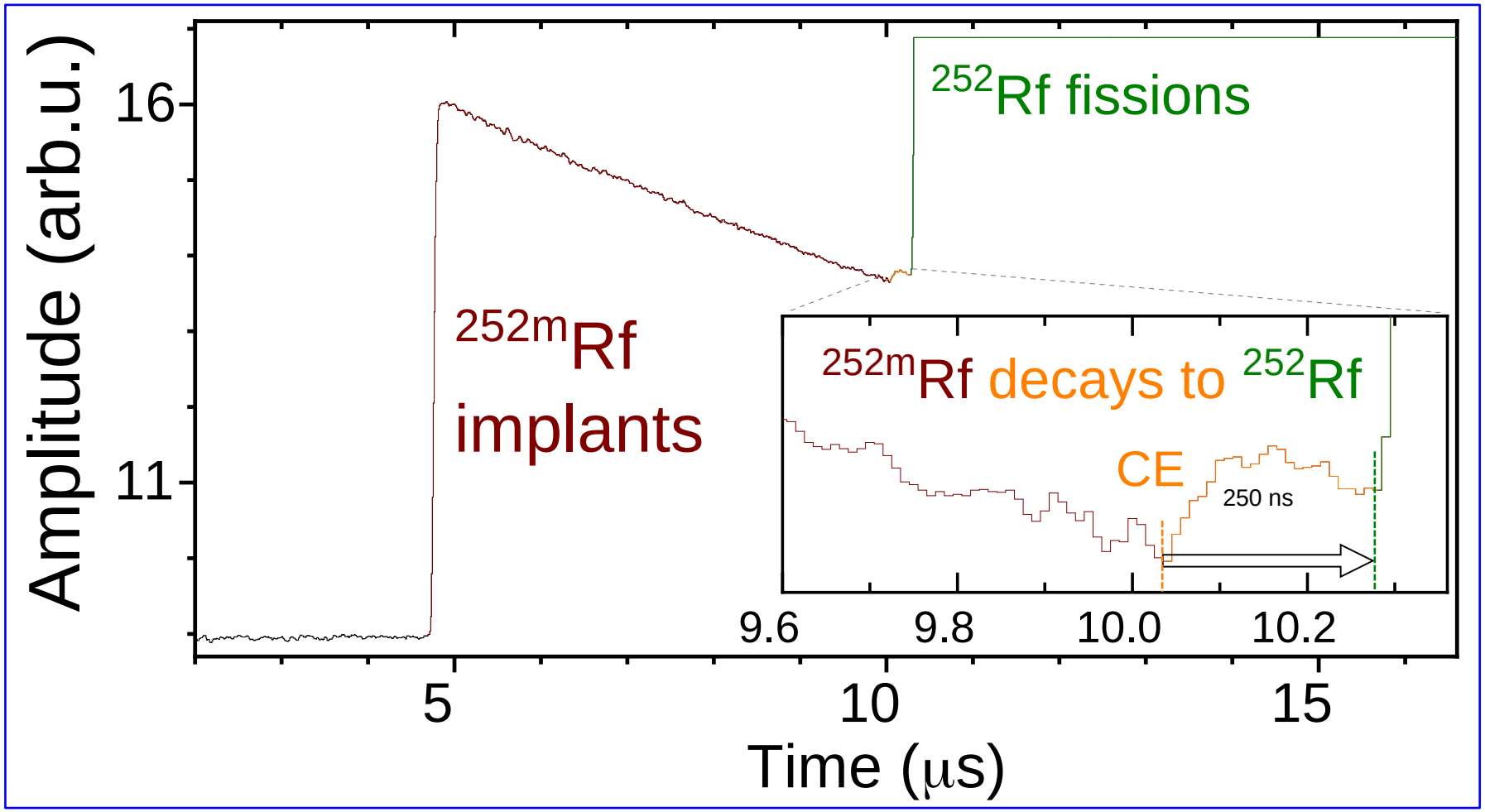
J. Khuyagbaatar, P. Mosat et al., Phys. Rev. Lett. **134**, 022501 (2025)

^{50}Ti + ^{204}Pb



Discovery of ^{252}Rf at TASCA

J. Khuyagbaatar, P. Mosat et al., Phys. Rev. Lett. **134**, 022501 (2025)

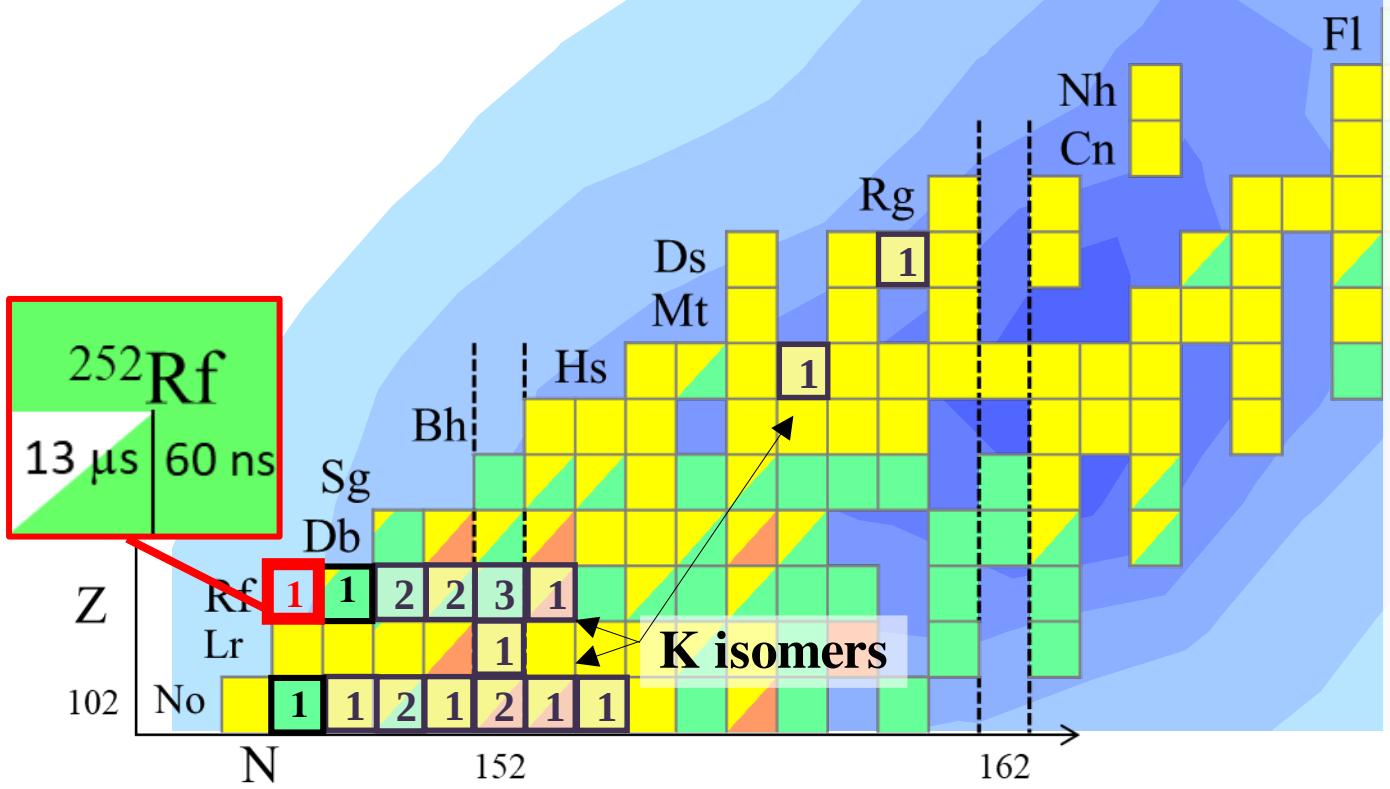


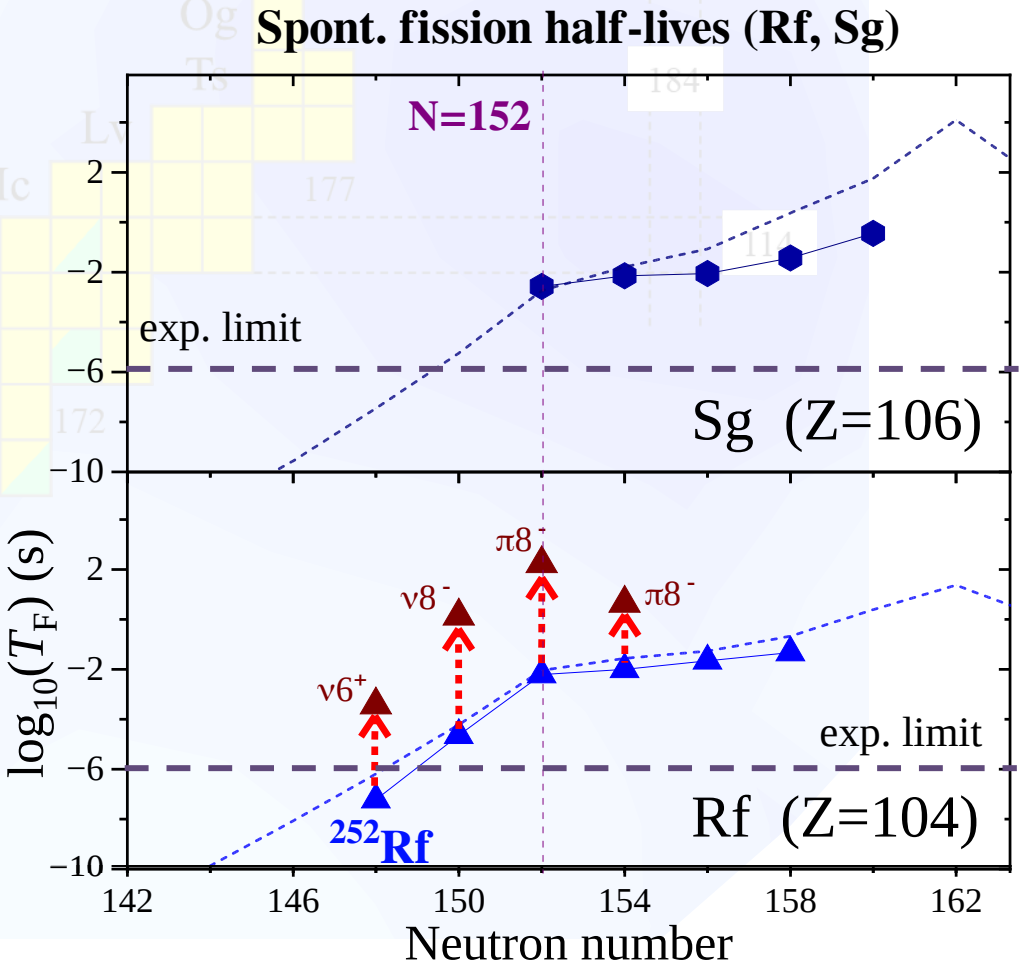
Discovery of ^{252}Rf at TASCA

A 13-µs *K* isomer enabled access to the 60-ns fission

J. Khuyagbaatar, P. Mosat et al., Phys. Rev. Lett. **134**, 022501 (2025)

Editors' Suggestion / Featured in Physics

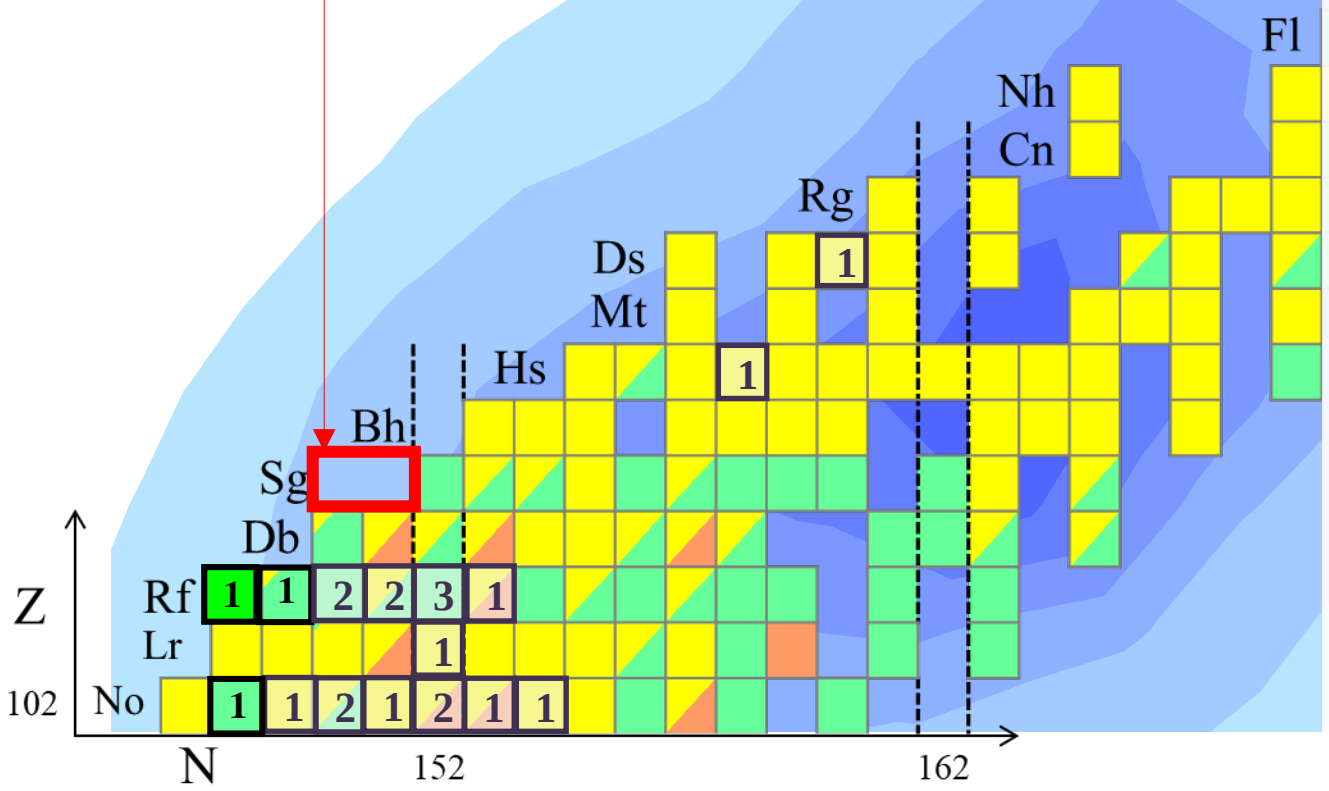


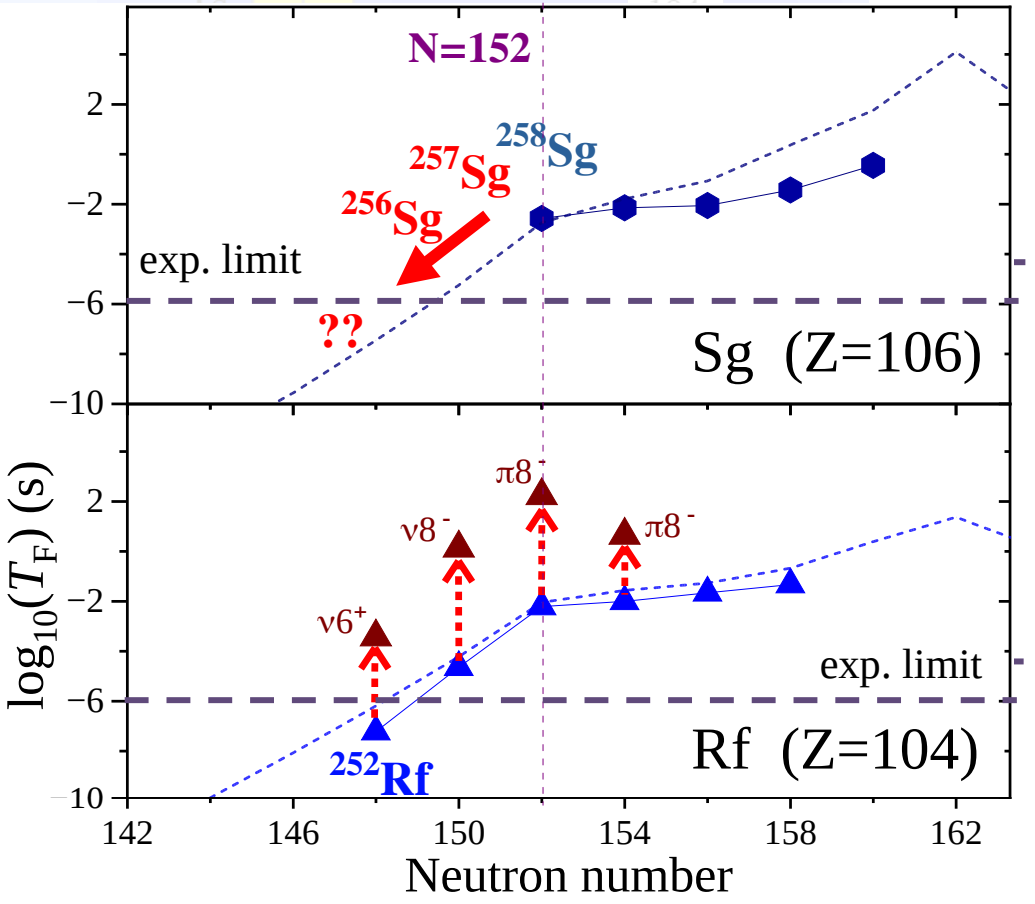


D. Ackermann, S. Antalic and F. P. Heßberger, Eur. Phys. J. Spec. Top. 233, 1017 (2024)

Towards the isotopic border of Sg

What about the next Sg isotopes?



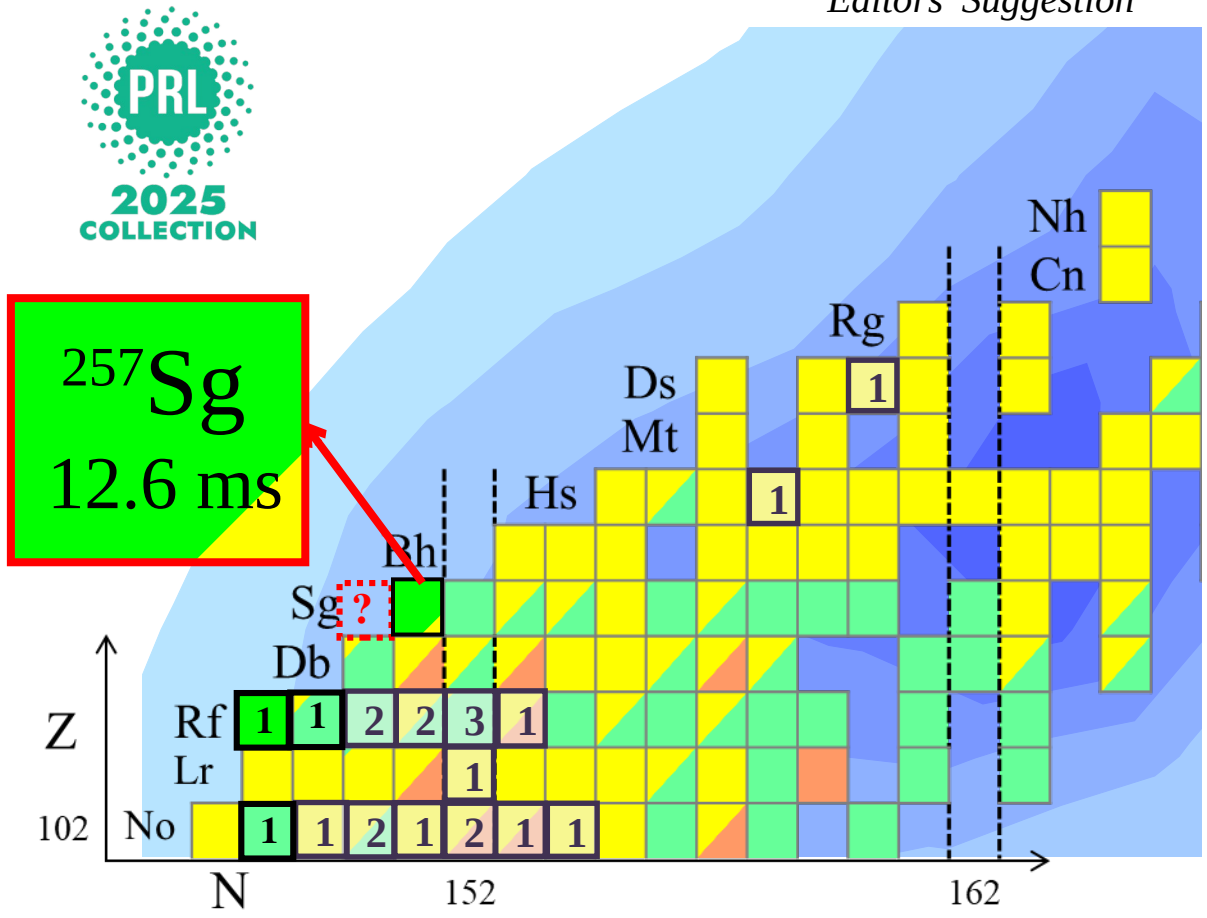


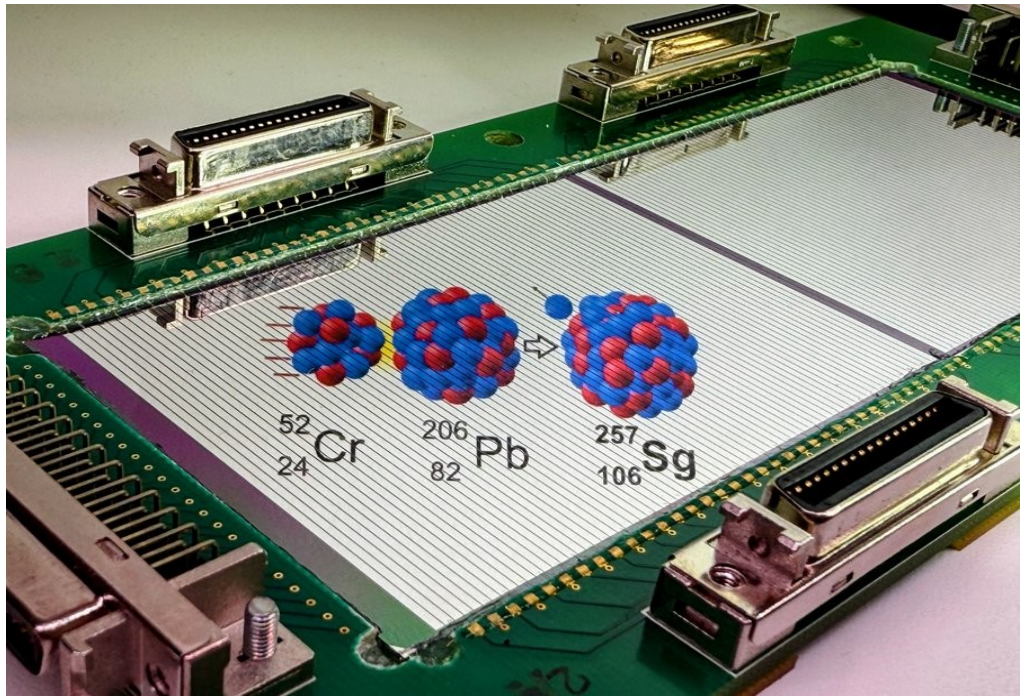
New isotope ^{257}Sg

Discovery of the new isotope ^{257}Sg @TASCA

P. Mosat, J. Khuyagbaatar et al., Phys. Rev. Lett. 134, 232501 (2025)

Editors' Suggestion



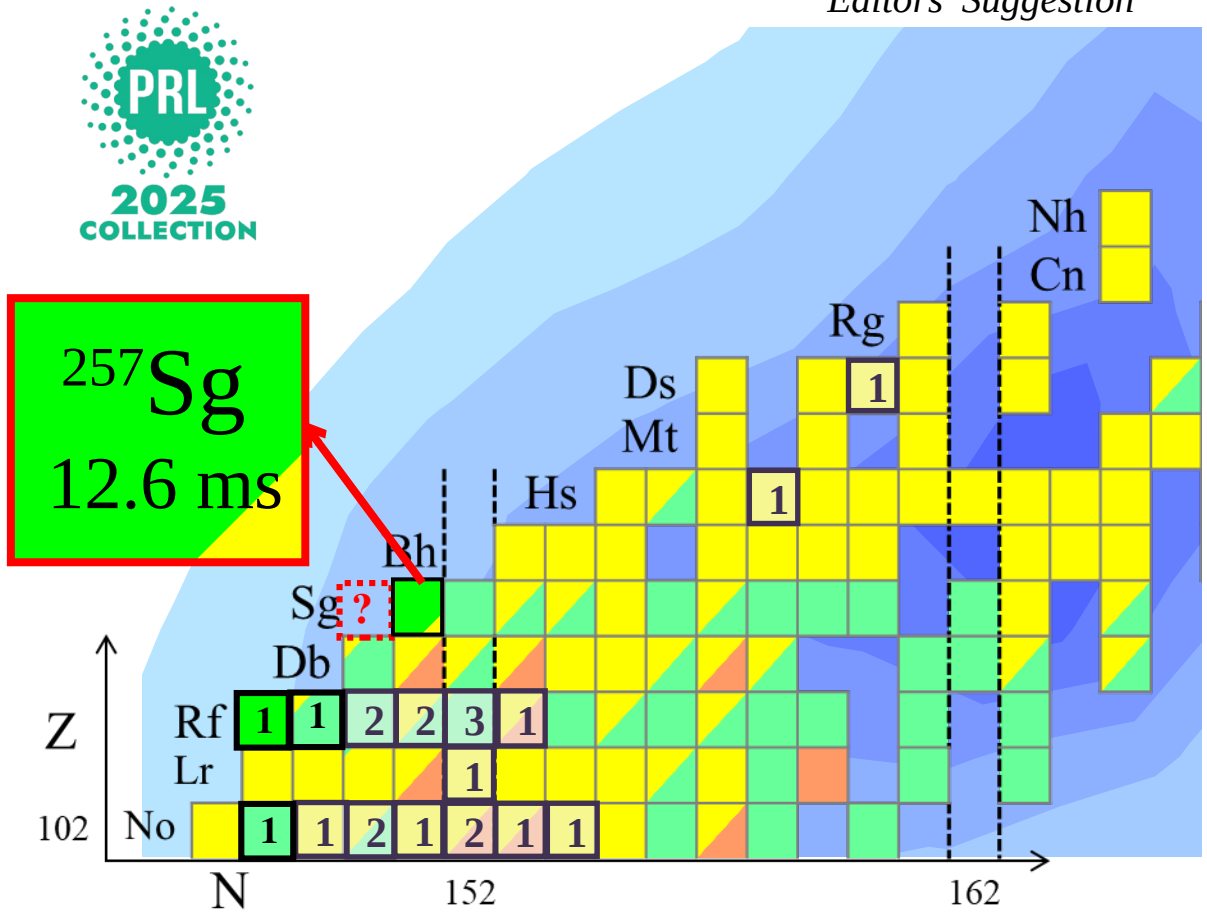


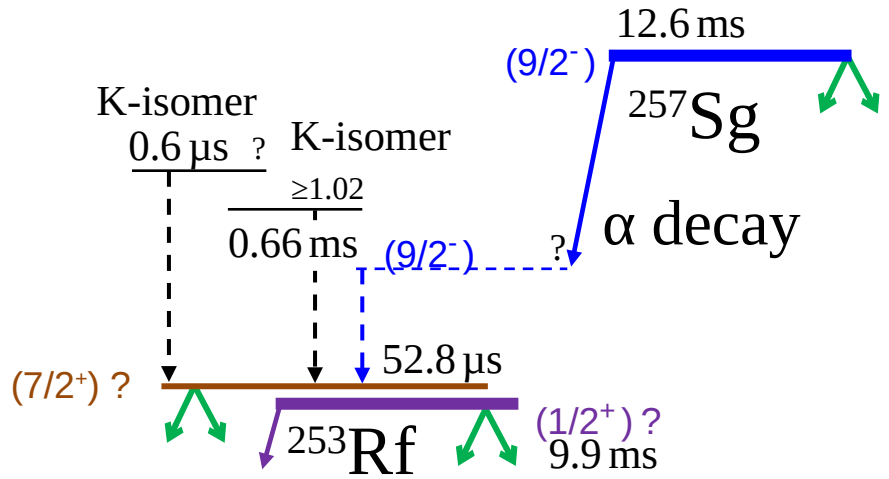
New isotope ^{257}Sg – alpha decay

Discovery of the new isotope ^{257}Sg @TASCA

P. Mosat, J. Khuyagbaatar et al., Phys. Rev. Lett. 134, 232501 (2025)

Editors' Suggestion





Larger K => Smaller hindrance

Experimentally unknown
Theoretically was not predicted

A. Lopez-Martens et al., Phys. Rev. C. **105**, L021306 (2022).

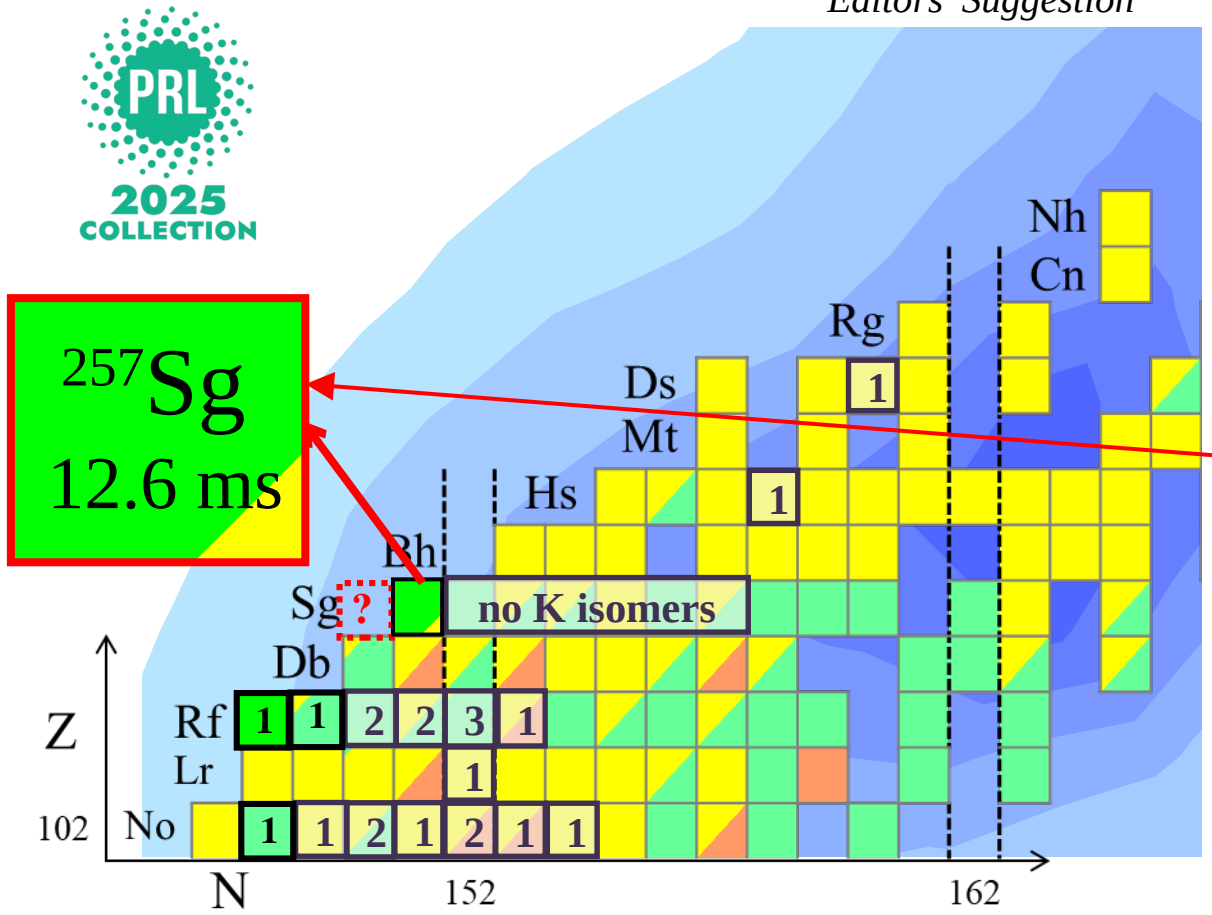
J. Khuyagbaatar et al., Phys. Rev. C. **104**, L031303 (2021).

Search for ^{256}Sg ?

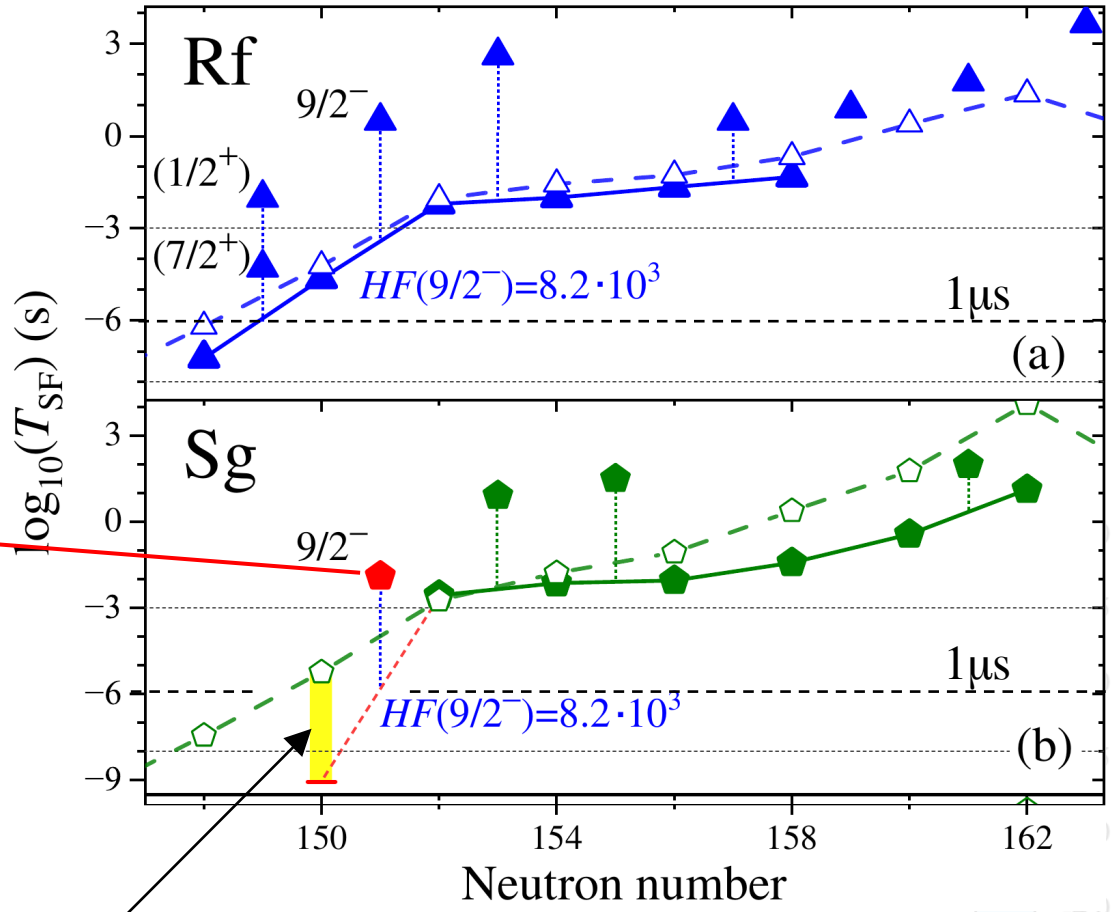
Discovery of the new isotope ^{257}Sg @TASCA

P. Mosat, J. Khuyagbaatar et al., Phys. Rev. Lett. 134, 232501 (2025)

Editors' Suggestion

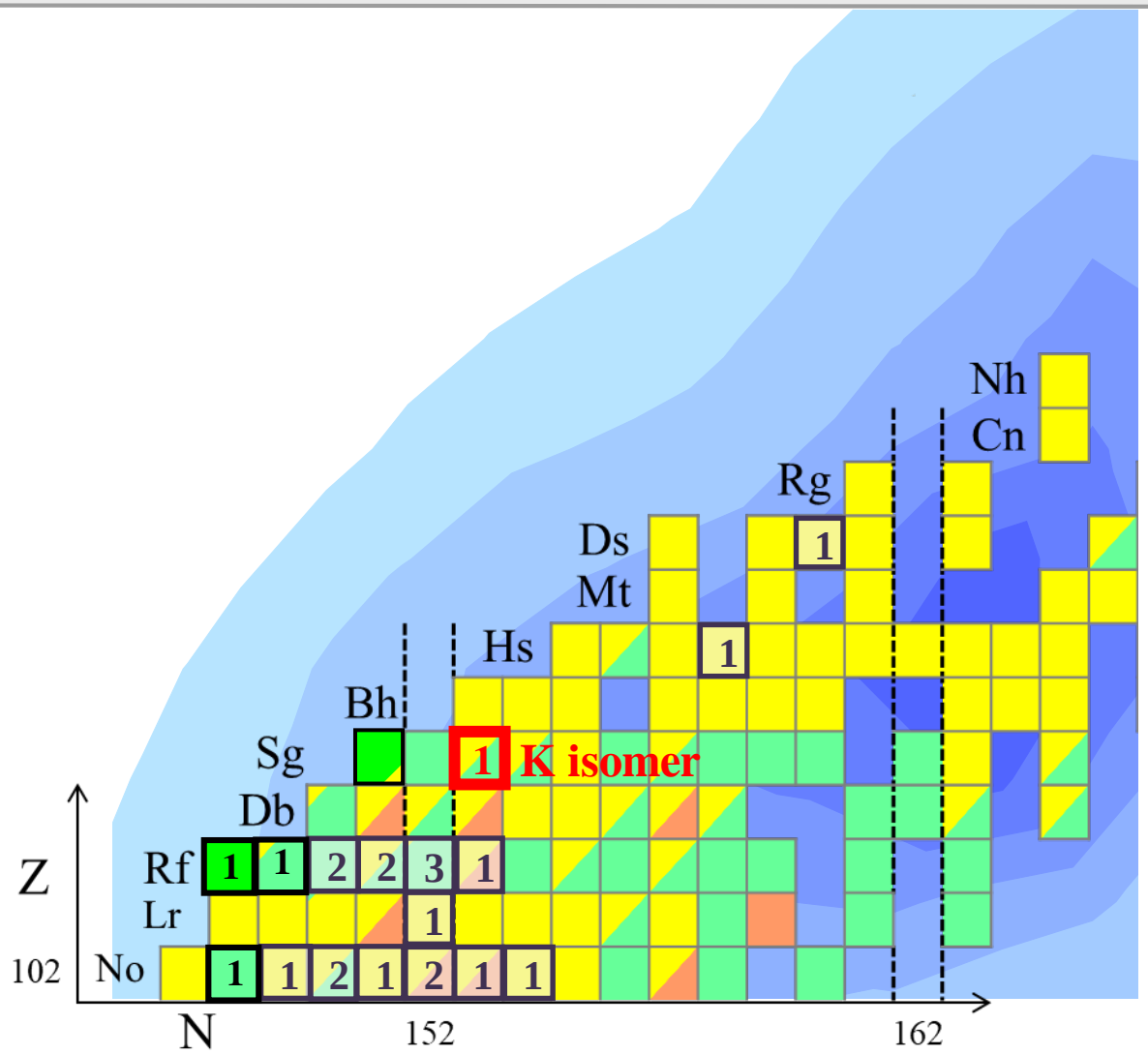


Spont. fission half-lives (Rf, Sg)



Steep drop of T_{SF} not excluded for ^{256}Sg
– *K* isomers may provide access!

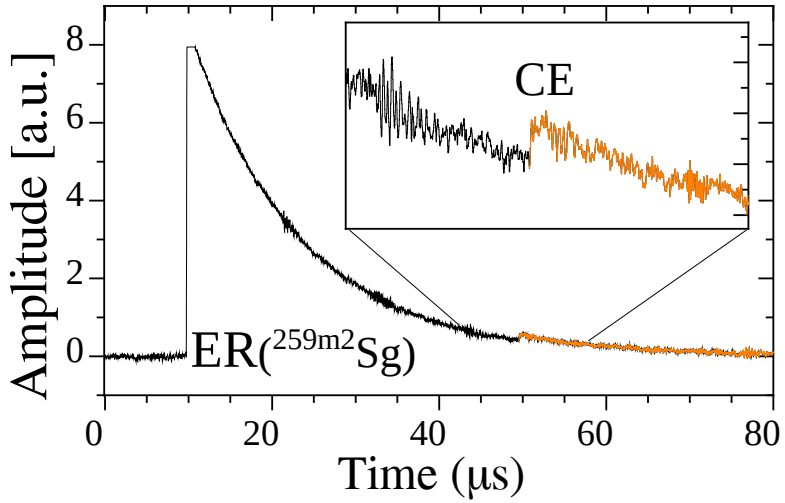
K isomer signature in ^{259}Sg



D. Ackermann, S. Antalic and F. P. Heßberger, Eur. Phys. J. Spec. Top. 233, 1017 (2024)

P. Mosat, J. Khuyagbaatar et al., Phys. Rev. Lett. 134, 232501 (2025)

First indication of a *K* isomer in ^{259}Sg



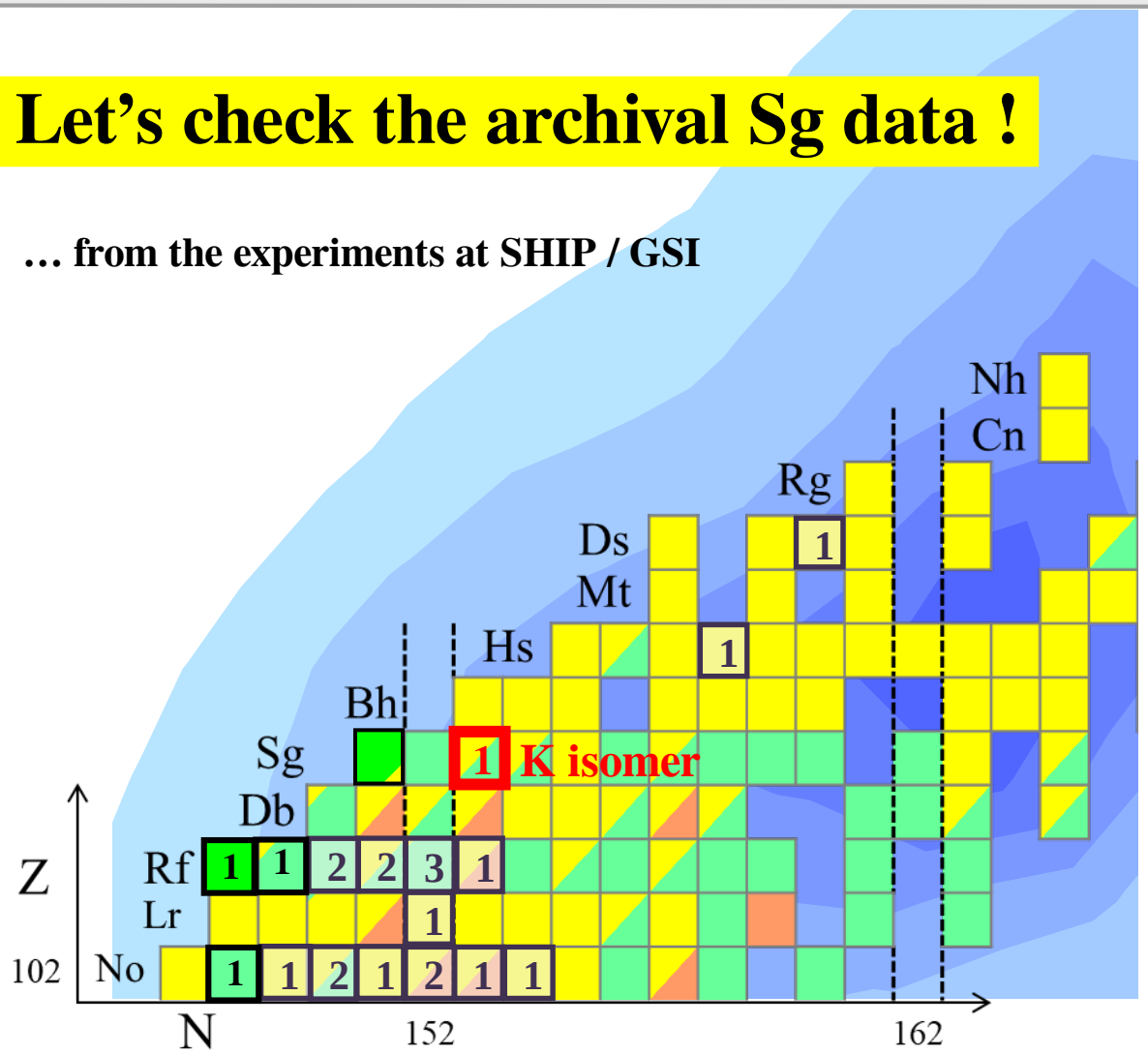
$T_{1/2}$ = **28 μs** (+126 / -15)

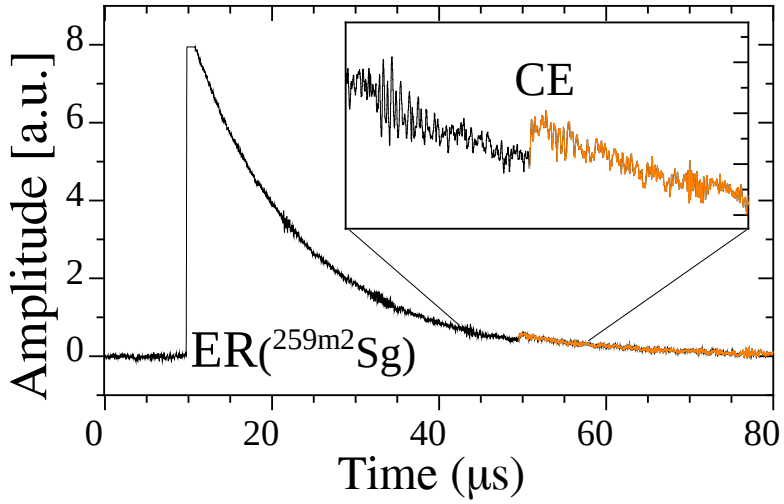
K isomerism in Sg

P. Mosat, J. Khuyagbaatar et al., Phys. Rev. Lett. 134, 232501 (2025)

Let's check the archival Sg data !

… from the experiments at SHIP / GSI





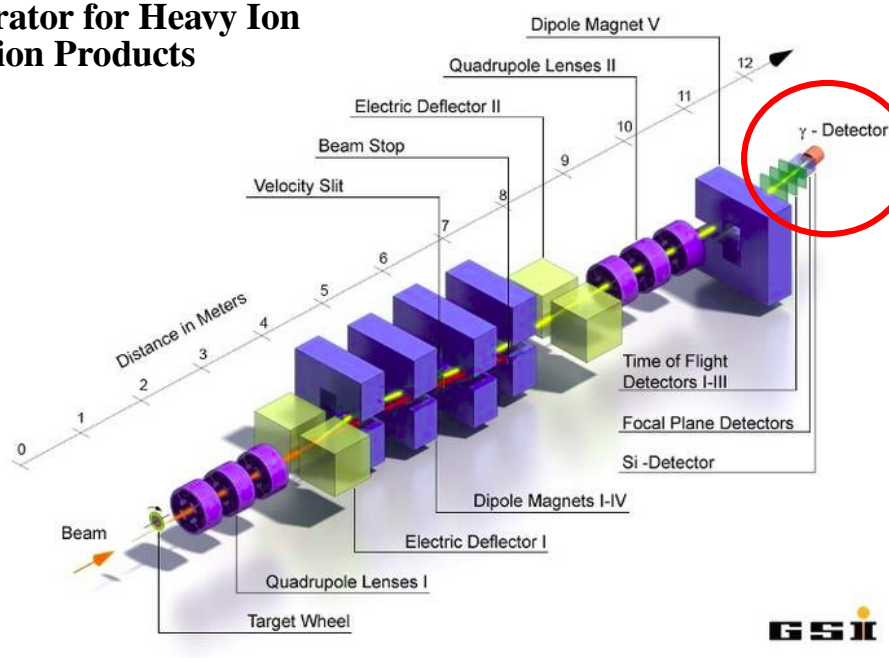
High-*K* states predicted in ^{258,259,260,261}Sg

F. Xu, E. Zhao, R. Wyss, and P. Walker, Phys. Rev. Lett. 92, 252501 (2004)
G. G. Adamian, N. V. Antonenko, and W. Scheid, Phys. Rev. C 81, 024320 (2010)
H. L. Liu, P. M. Walker, and F. R. Xu, Phys. Rev. C 89,044304 (2014)
P. Jachimowicz, M. Kowal, and J. Skalski, Phys. Rev. C 92, 044306 (2015)
P. Jachimowicz, M. Kowal, and J. Skalski, Phys. Rev. C 112, 064317 (2025)

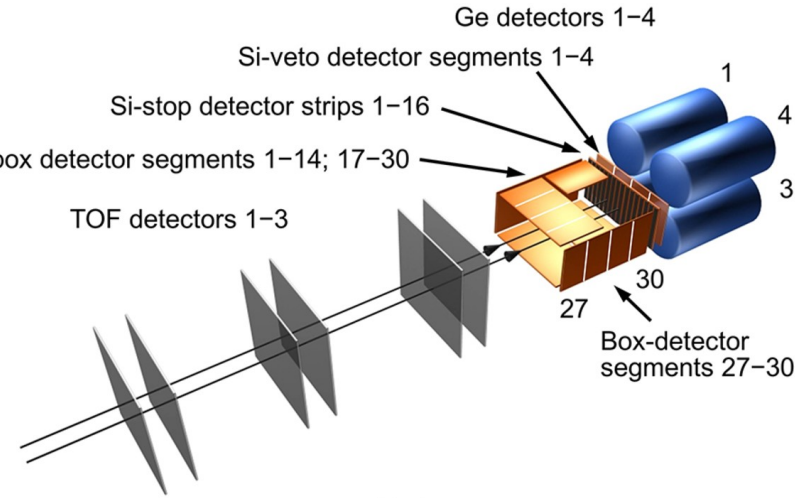
D. Ackermann, S. Antalic and F. P. Heßberger, Eur. Phys. J. Spec. Top. 233, 1017 (2024)

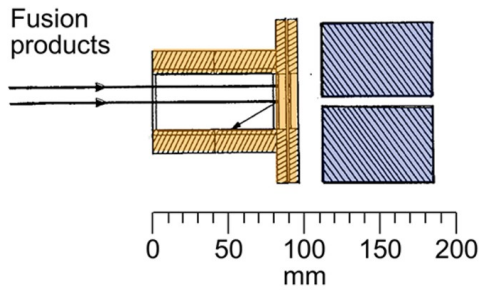
Sg decay spectroscopy campaign at SHIP (2003-2009)

Separator for Heavy Ion reaction Products

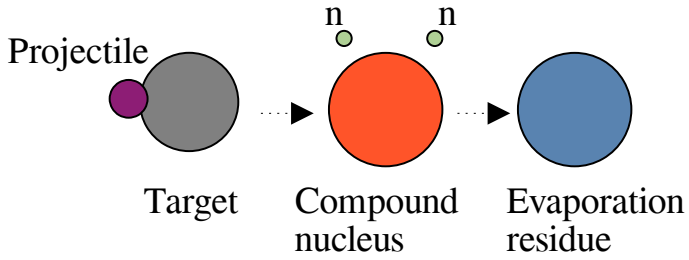


Focal plane detector system





Fusion-evaporation reactions



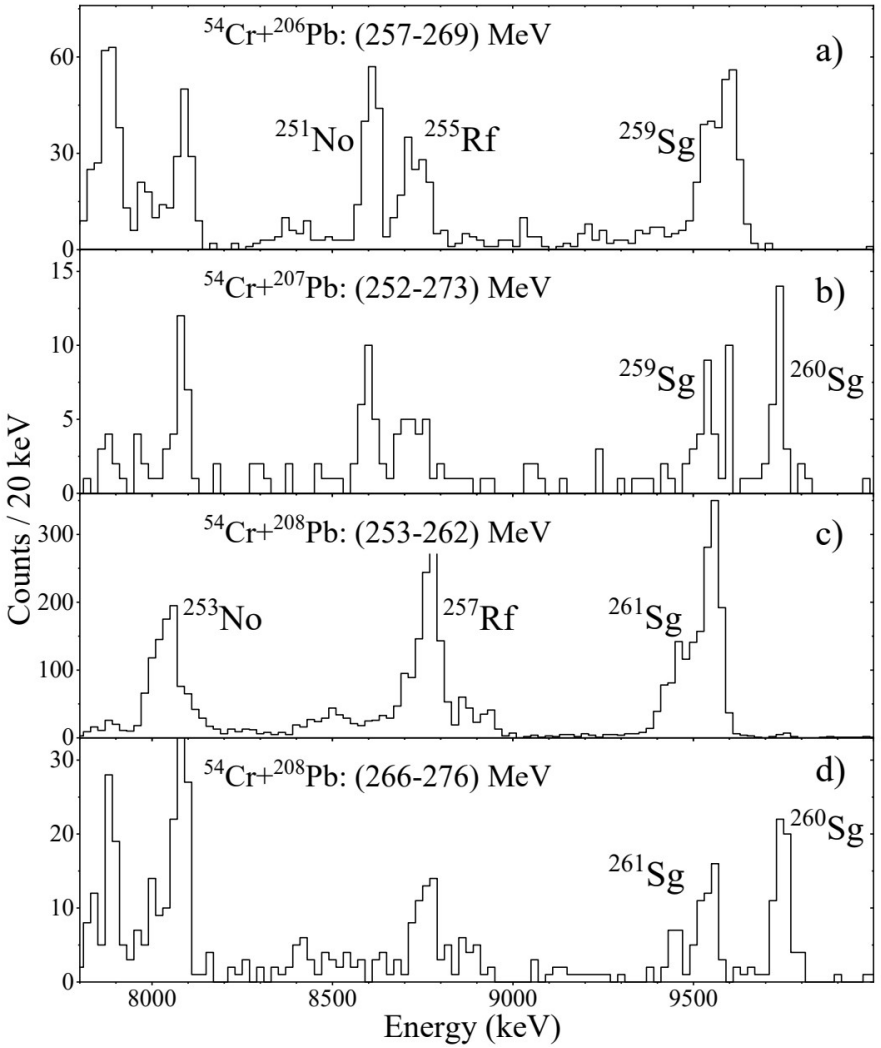
$^{54}Cr + ^{206, 207, 208}Pb$

www.gsi.de

S. Hofmann, et al., Eur. Phys. J. A 52, 180 (2016)

K isomer search in Sg data (SHIP, 2003-2009)

Beam-off energy spectra



Analysis of Sg data:

- Search for delayed CEs in the same strips

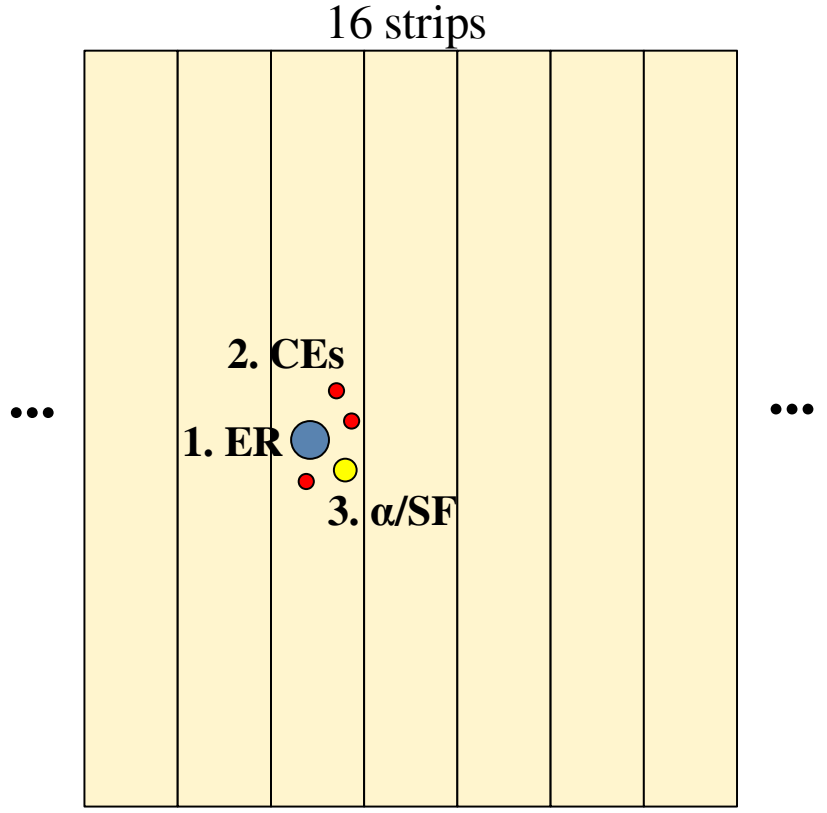
261Sg
B. Streicher, et al.,
Eur. Phys. J. A 45, 275 (2010)

259Sg
S. Antalic, et al.,
Eur. Phys. J. A 51, 41 (2015)

260Sg
B. Sulignano, Ph.D. thesis,
JGU Mainz, Germany (2007)
F.P. Heßberger, et al.,
Eur. Phys. J. A 41, 145 (2009)

258Sg
J. Mišt, Master thesis,
Comenius University
in Bratislava (2021)

Position-sensitive silicon strip detector

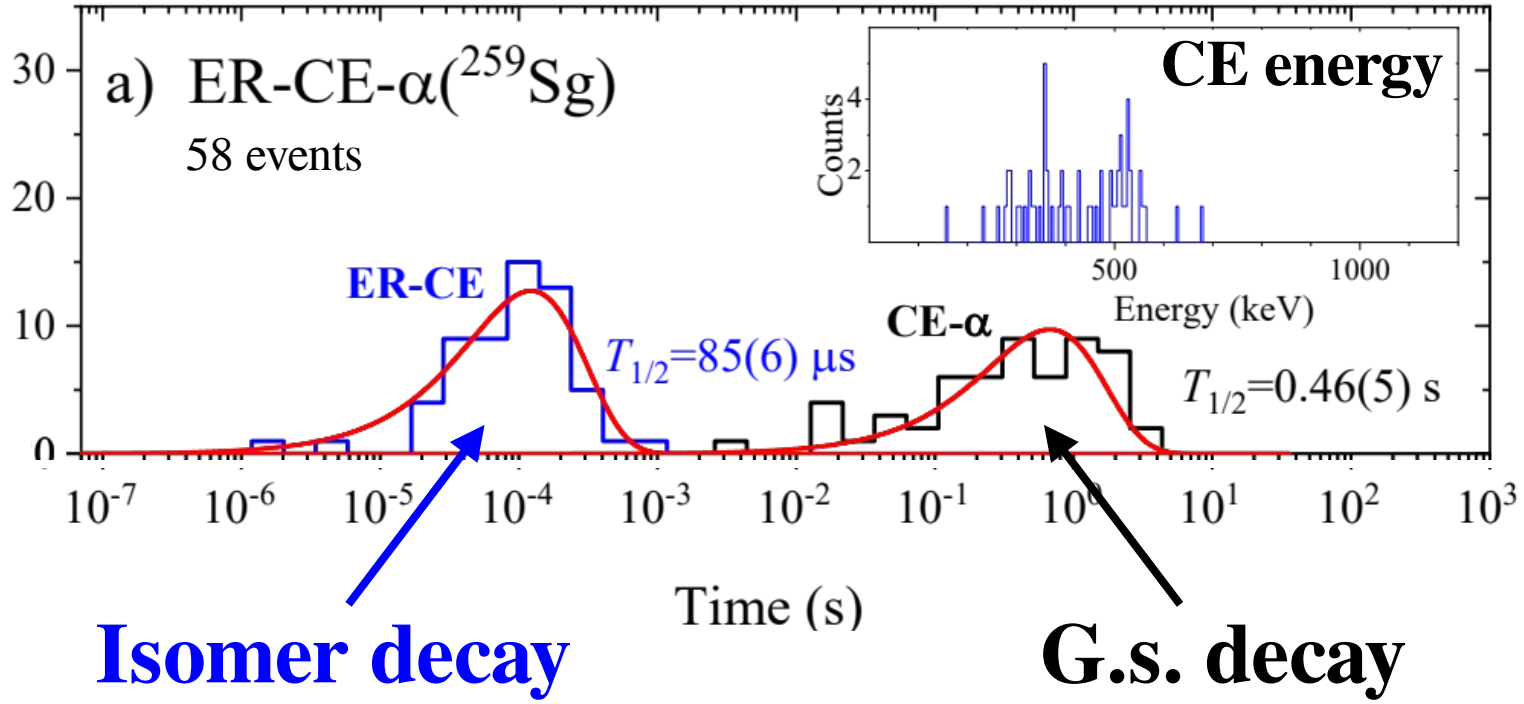


Correlations: ER – CE – α / SF

Same position

Isomer in ^{259}Sg

Δt distributions



Isomer decay

G.s. decay

$T_{1/2}$ = 85 μs (6)

E_{CE} up to 700 keV

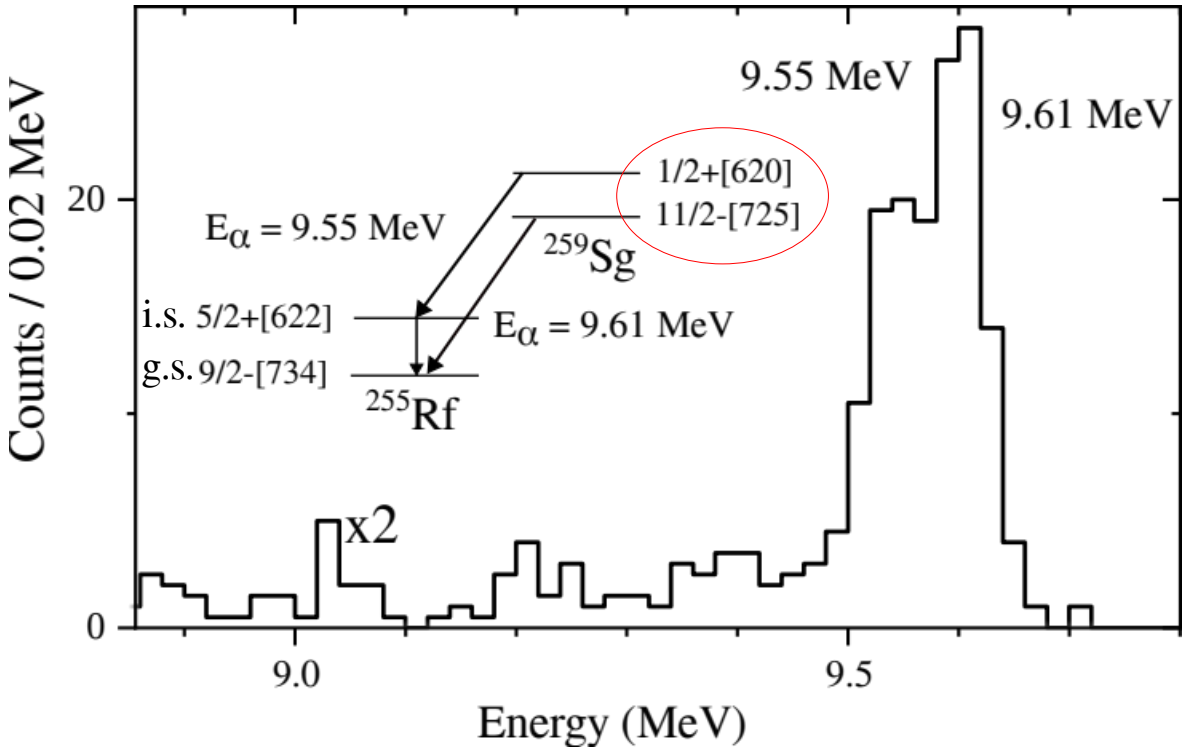
P. Mosat, et al., accepted in Phys. Rev. C

Origin of the isomer in ^{259}Sg

Which of the two states is fed by the new isomer?

...let's check the alpha energies!

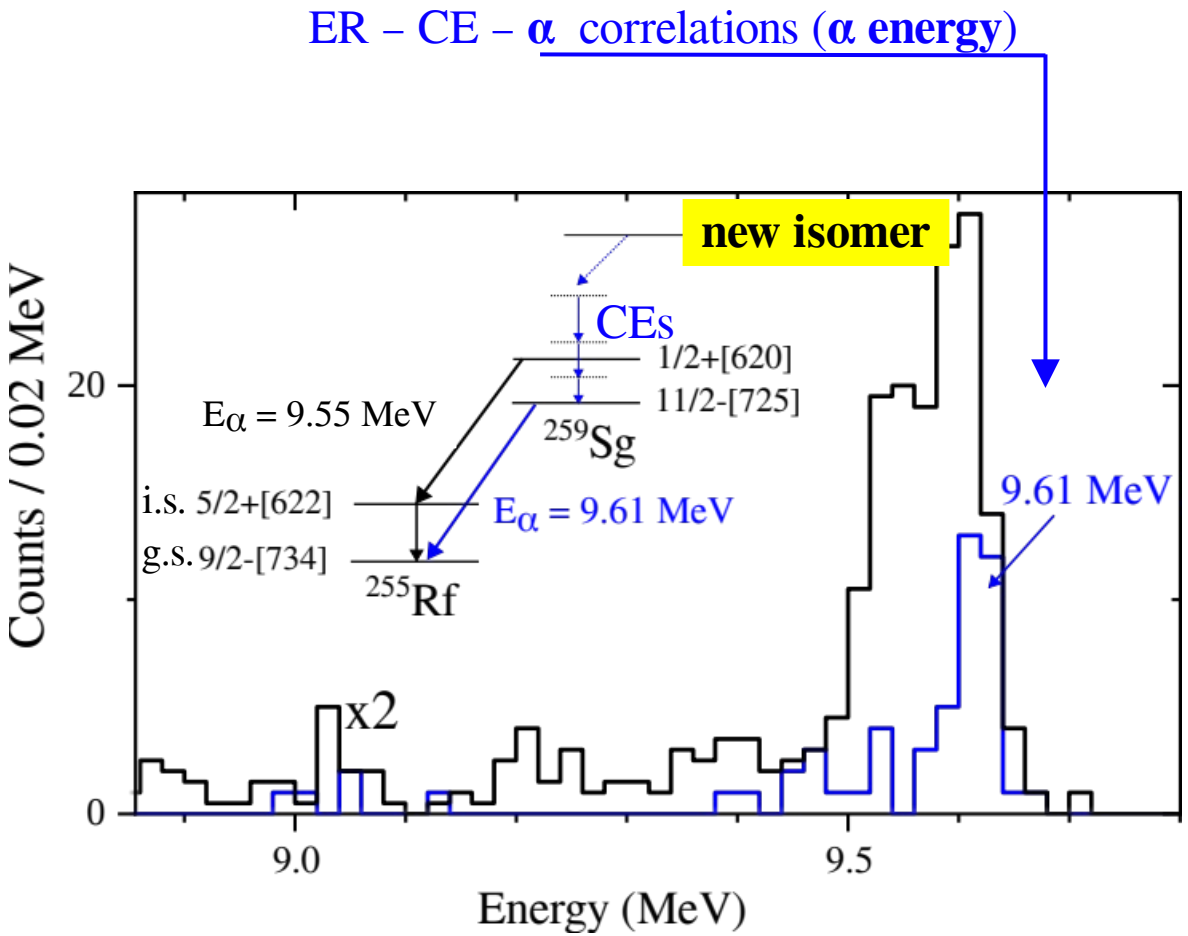
Beam-off spectrum of implantation Si detector



S. Antalic, et al., Eur. Phys. J. A 51, 41 (2015)

Origin of the isomer in ^{259}Sg

9.61 MeV (11/2$^-$) follows the new isomer deexcitation in ^{259}Sg

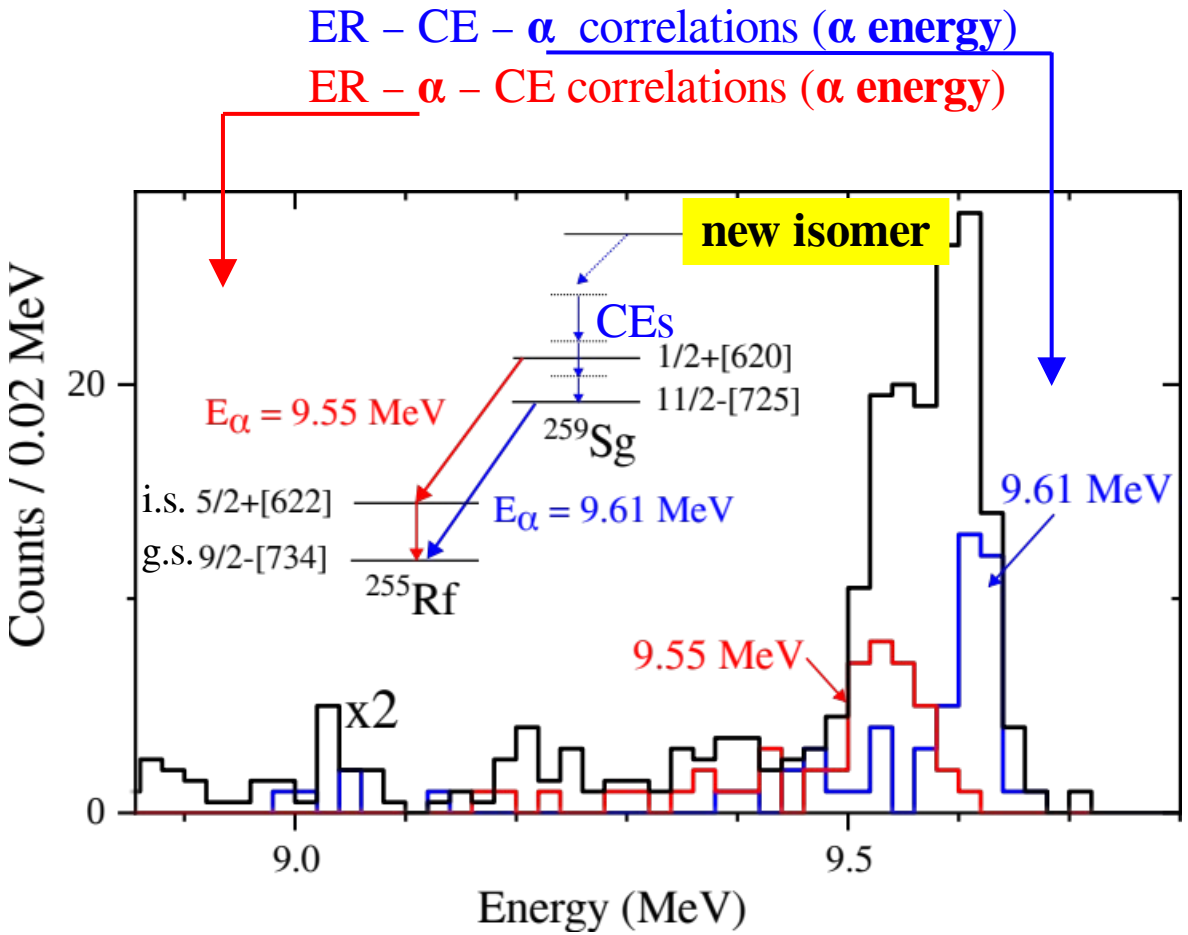


P. Mosat, et al., accepted in Phys. Rev. C

Origin of the isomer in ^{259}Sg

9.61 MeV (11/2$^-$) follows the new isomer deexcitation in ^{259}Sg

9.55 MeV (1/2$^+$) precedes the 5/2$^+$ isomer deexcitation in ^{255}Rf



P. Mosat, et al., accepted in Phys. Rev. C

K isomer in ^{259}Sg

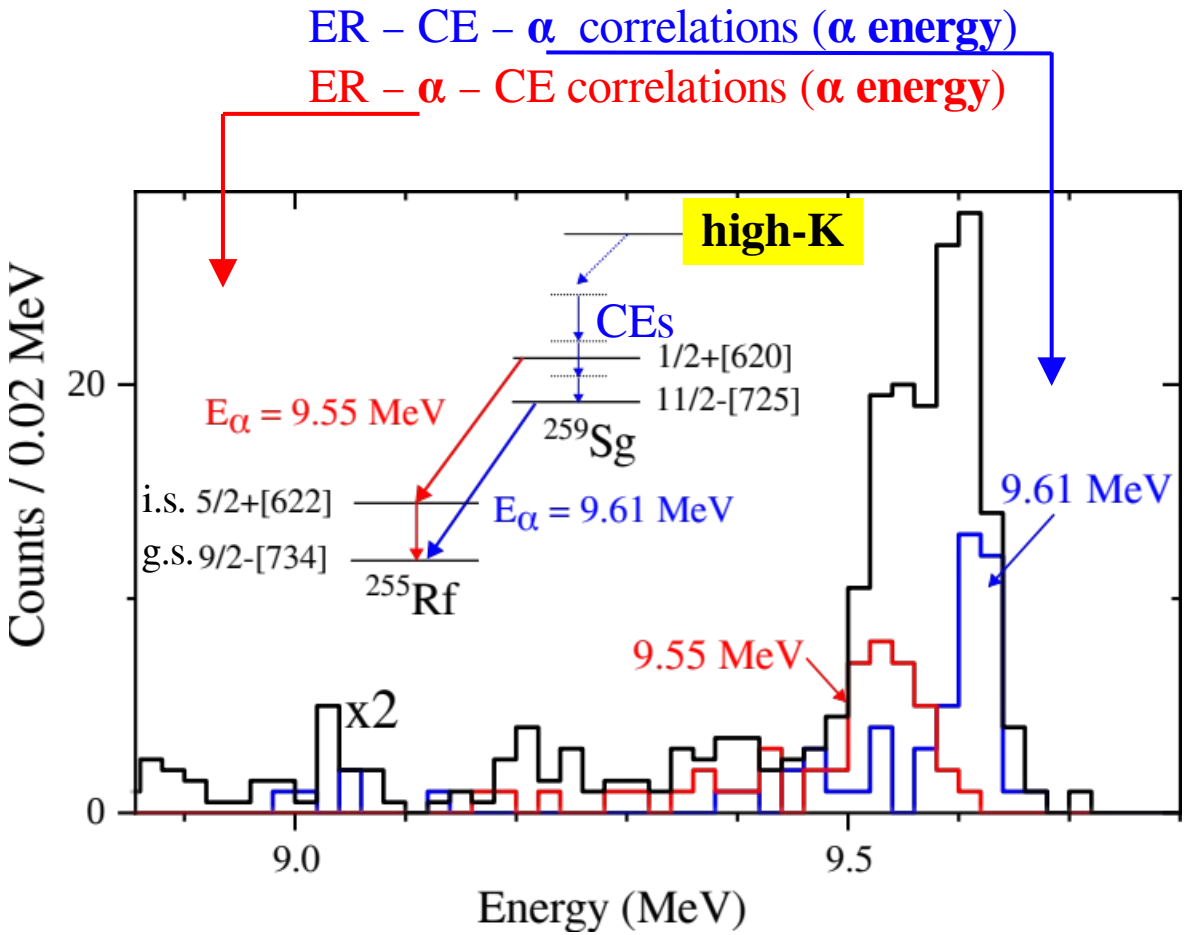
9.61 MeV ($11/2^-$) follows the new isomer deexcitation in ^{259}Sg

9.55 MeV ($1/2^+$) precedes the $5/2^+$ isomer deexcitation in ^{255}Rf

Origin of the new isomer in ^{259}Sg:

- **feeding the $11/2^-$ ground state (higher-K)**
- **E_{exc} > 700 keV** **$T_{1/2}$ = 85 μs (6)**

High-*K* multi-quasiparticle isomer



P. Mosat, et al., accepted in Phys. Rev. C

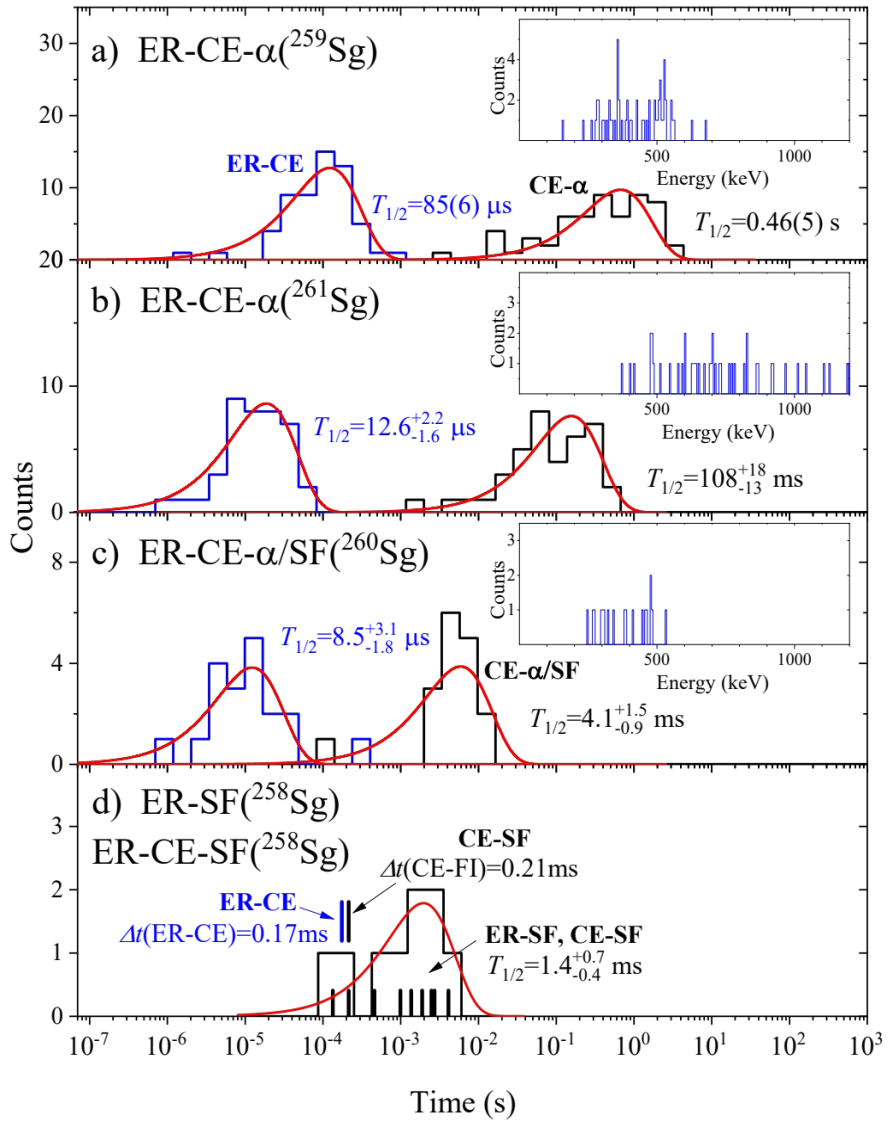
K isomers in $^{258\text{-}261}$Sg

^{259}Sg

^{261}Sg

^{260}Sg

^{258}Sg

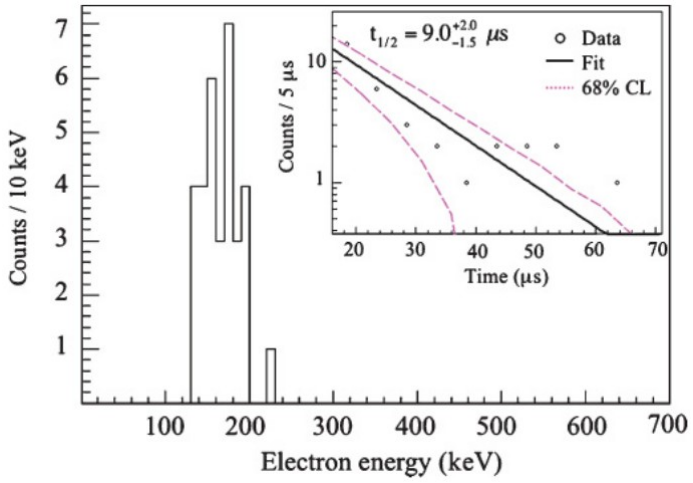


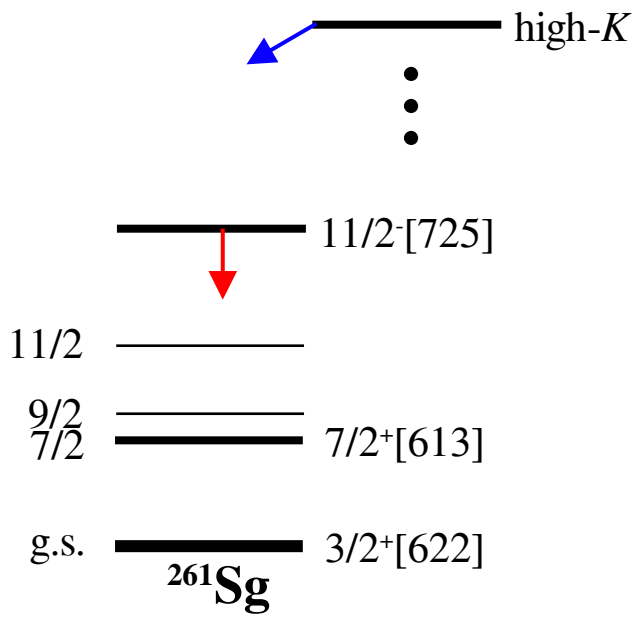
Isotope	N	$T_{1/2}$, [μs]	E^*, [MeV]	Origin
^{258m}Sg	1	120^{+578}_{-55}	> 0.25	m-qp
^{259m2}Sg	58	85 ± 6	> 0.7	m-qp
^{260m}Sg	19	$8.5^{+3.1}_{-1.8}$	> 0.5	m-qp
^{261m}Sg	44	$12.6^{+2.2}_{-1.6}$	> 1.2	m-qp/sp

P. Mosat, et al., accepted in Phys. Rev. C

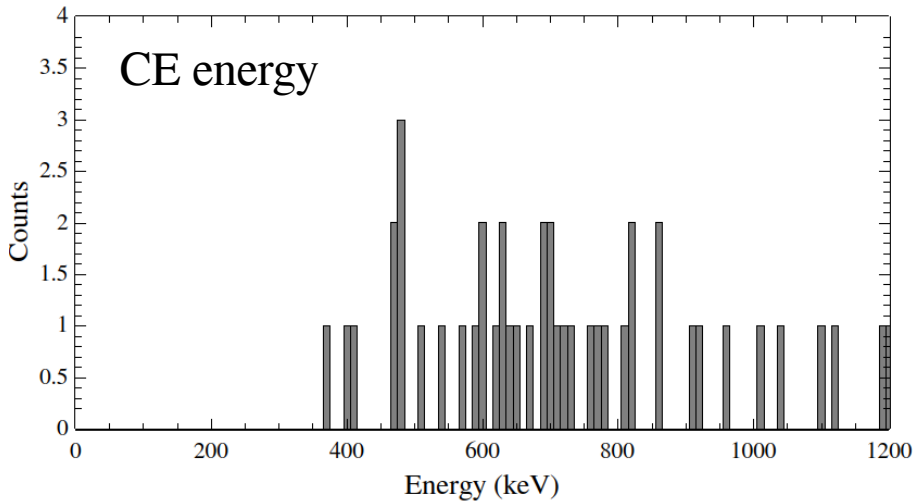
Isomer in ^{261}Sg

ER – **CE** – α





ER – **CE** – α



$E_{exc} \simeq 200$ keV

11/2⁻[725] isomer (single-particle)

$E_{exc} > 1200$ keV

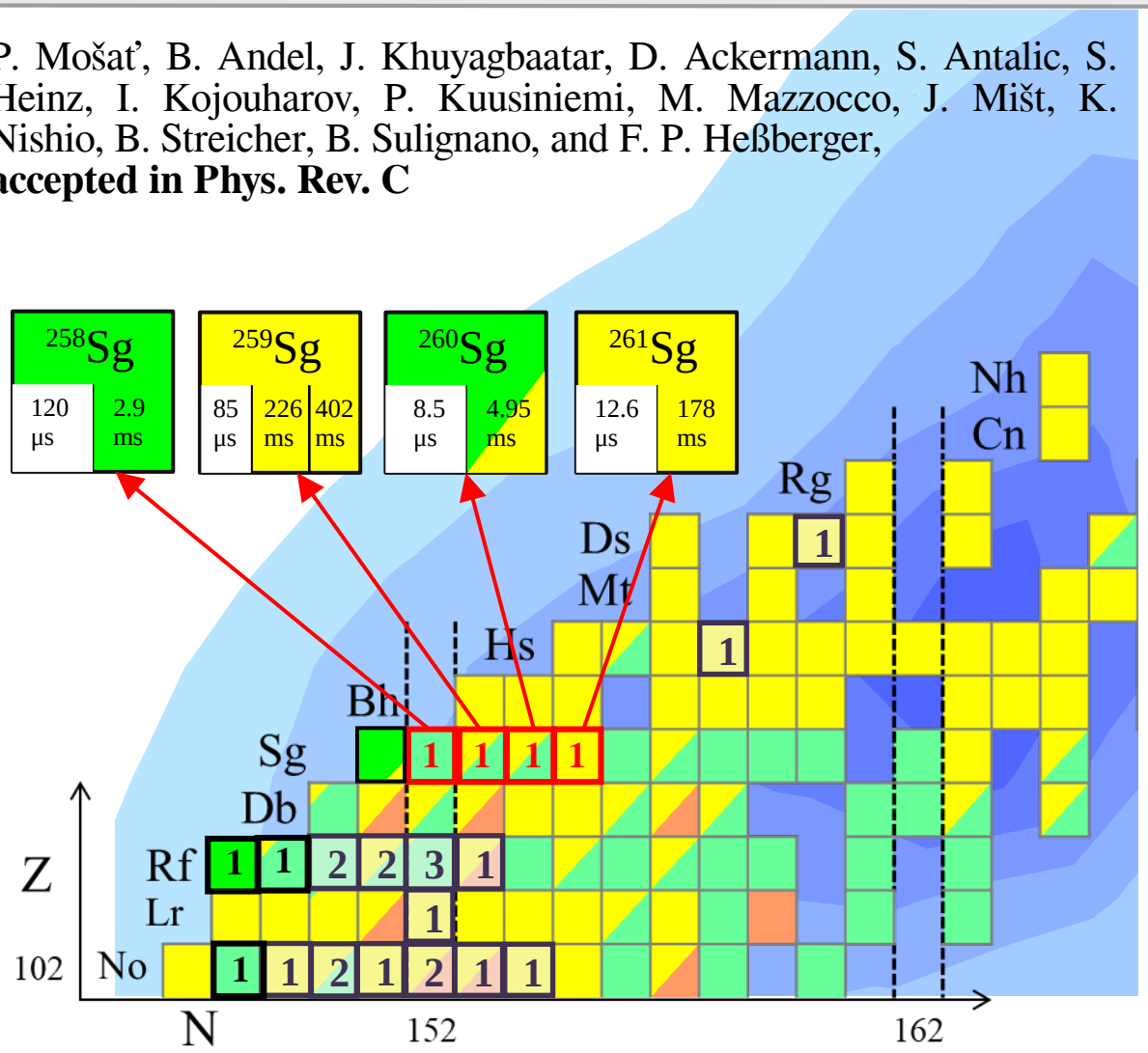
→ **K isomer** (multi-quasiparticle)

J.S. Berryman, et al., Phys Rev. C 81, 064325 (2010)

P. Mosat, et al., accepted in Phys. Rev. C

Discovery of K isomers in Sg isotopes

P. Mošať, B. Andel, J. Khuyagbaatar, D. Ackermann, S. Antalic, S. Heinz, I. Kojouharov, P. Kuusiniemi, M. Mazzocco, J. Mišt, K. Nishio, B. Streicher, B. Sulignano, and F. P. Heßberger,
accepted in Phys. Rev. C



Isotope	N	$T_{1/2}$, [μs]	E^*, [MeV]	Origin
^{258m}Sg	1	120^{+578}_{-55}	> 0.25	m-qp
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^{261m}Sg	44	$12.6^{+2.2}_{-1.6}$	> 1.2	m-qp/sp

- Microsecond isomeric activities observed in ^{258}Sg – ^{261}Sg isotopes
- K isomerism established in Sg isotopes (high-*K* m-qp)
- Further spectroscopy is needed to determine the exact *K* values and configurations
- **_K_ isomer(s) may enable the identification and study of ^{256}Sg**

ECT* EUROPEAN CENTRE FOR THEORETICAL STUDIES IN NUCLEAR PHYSICS AND RELATED AREAS
FONDAZIONE BRUNO KESSLER

The Physics and Chemistry of the Heaviest Elements

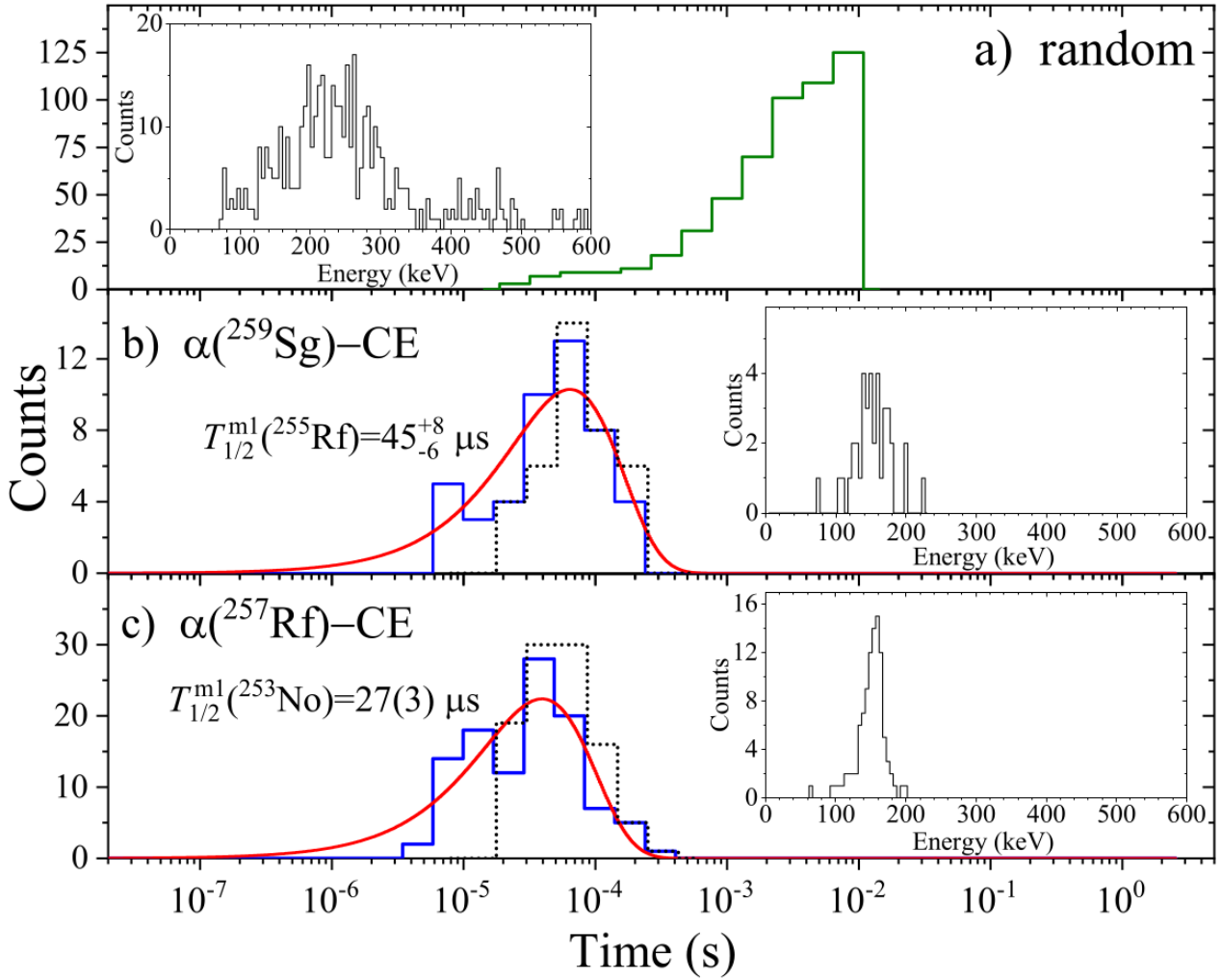
Thank you

Summary

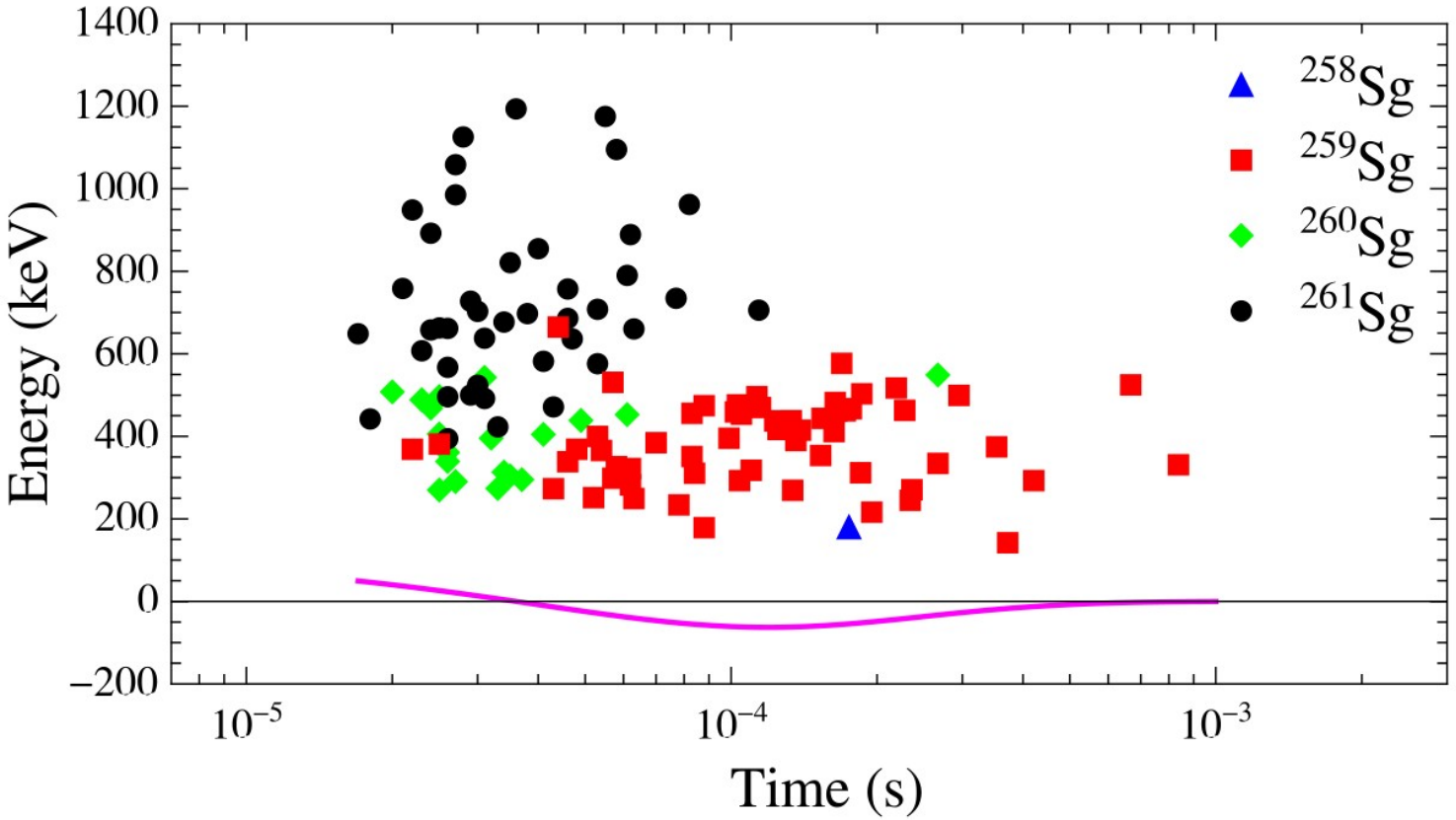
- **Discovery of ^{252}Rf**
  - A 13-μs K isomer enabled access to the 60-ns fission
- **Discovery of ^{257}Sg**
  - Steep drop of T_{SF} not excluded for ^{256}Sg
  - K isomer signature in ^{259}Sg
- **K isomerism established in Sg isotopes ($^{258\text{-}261}$Sg)**

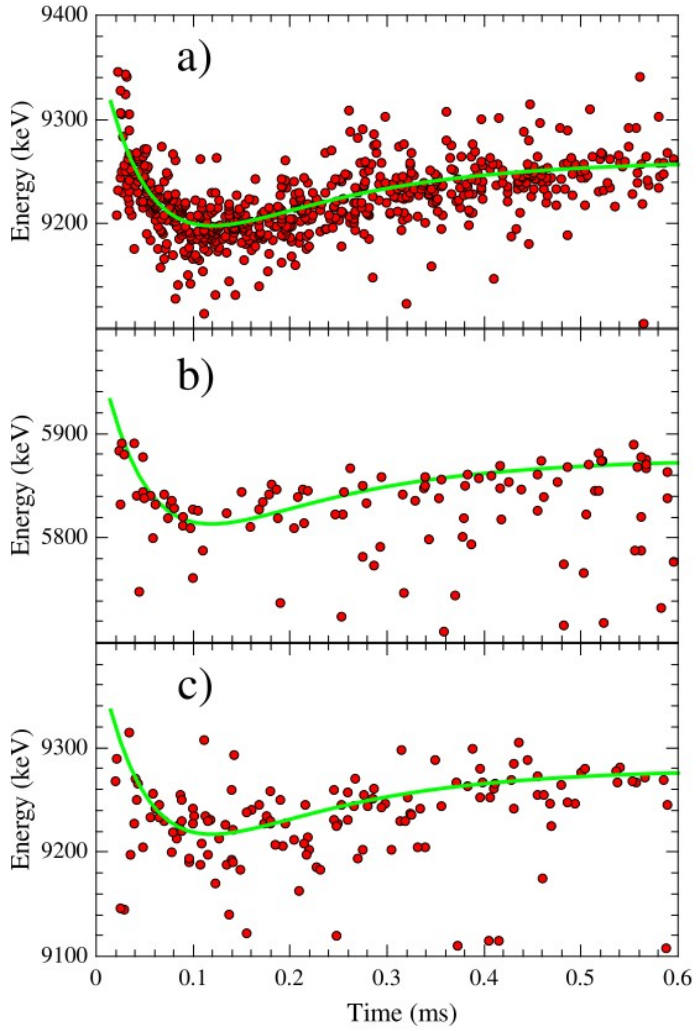
FAIR Phase 0 Research Program

Singleparticle isomers 5/2+[622]

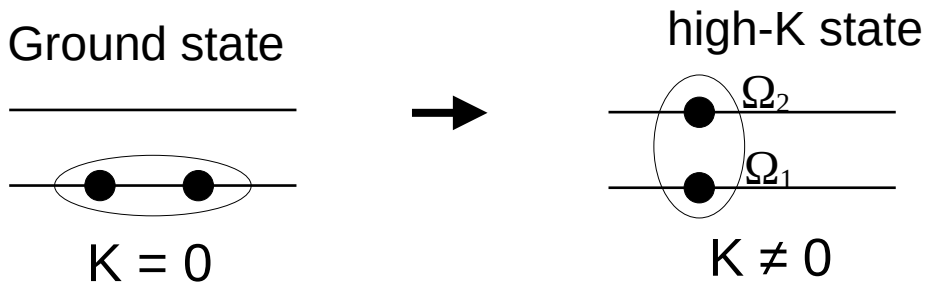


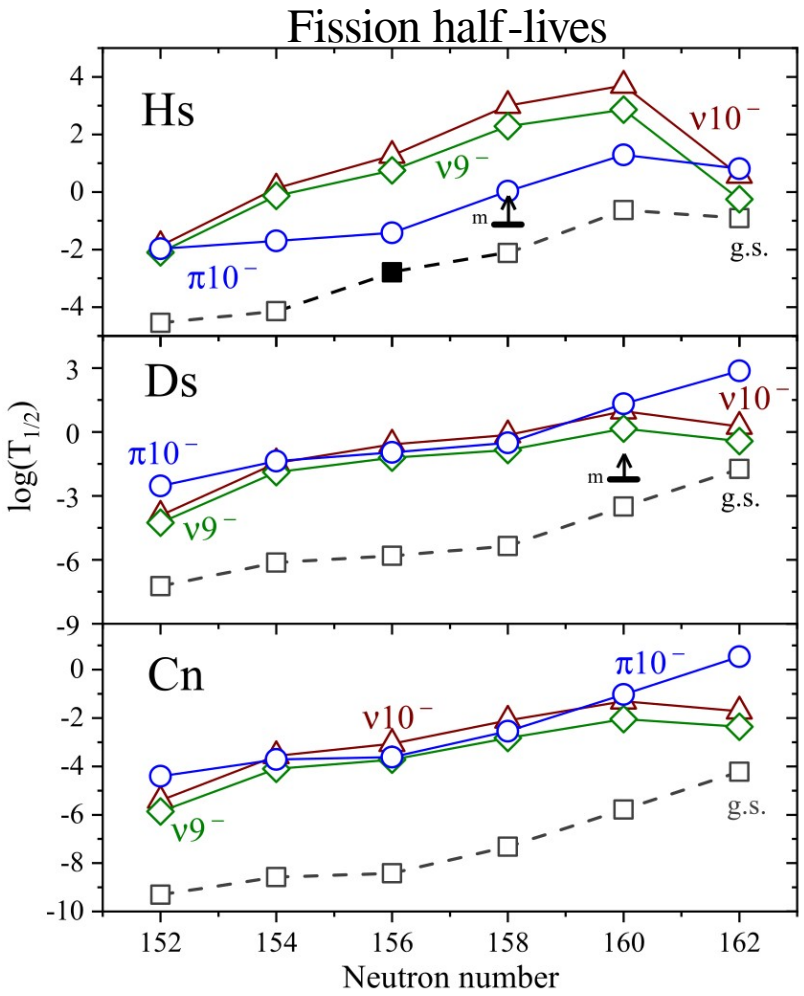
CE energy correction





- Coupling of nucleons on different orbitals
- Multi-quasiparticle states
- high-K → K-isomers
- Alpha decaying K isomers
- Strong fission hindrance
  - → more stable against fission than ground state
  - → „clouds of stability“ in SHN



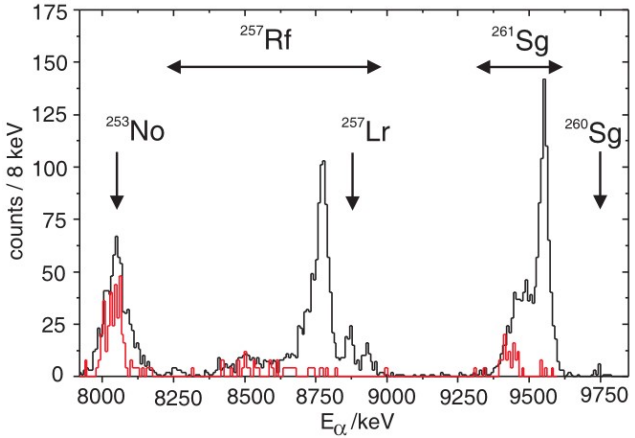


J. Khuyagbaatar, Eur. Phys. J. A 58, 243 (2022)

S. Hofmann, et al., Eur. Phys. J. A 10, 5–10 (2001)

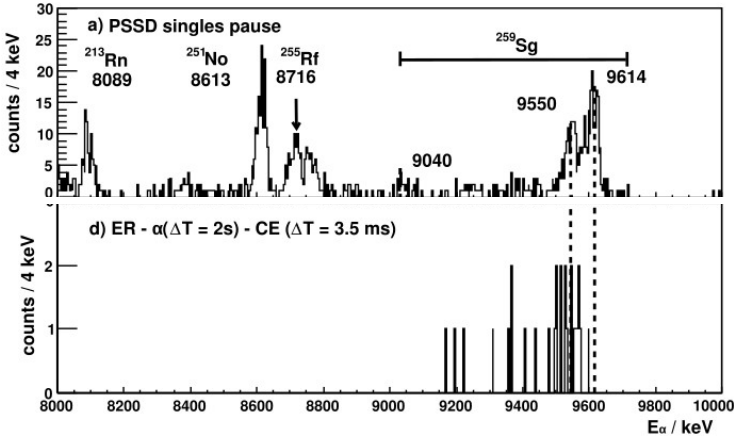
D. Ackermann, Prog. of Theor. Phys. Suppl. 196, 255 (2012)

Sg decay spectroscopy campaign at SHIP (2003-2009)



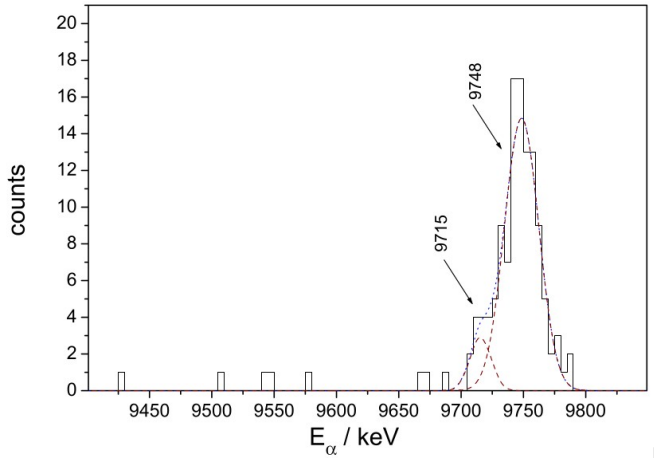
^{261}Sg

B. Streicher, et al.,
Eur. Phys. J. A 45, 275 (2010)



^{259}Sg

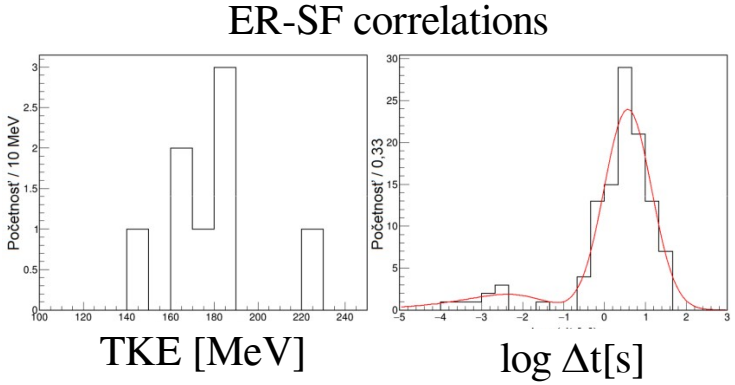
S. Antalic, et al.,
Eur. Phys. J. A 51, 41 (2015)



^{260}Sg

B. Sulignano, Ph.D. thesis,
JGU Mainz, Germany (2007)

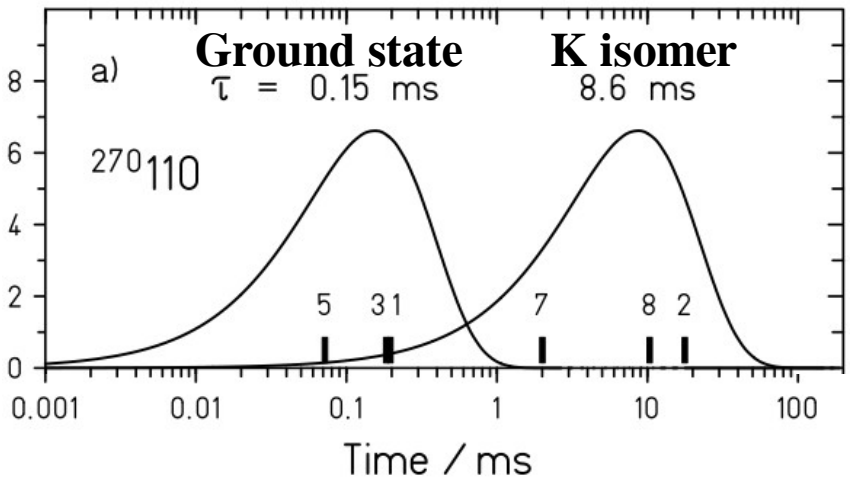
F.P. Heßberger, et al.,
Eur. Phys. J. A 41, 145 (2009)



^{258}Sg

J. Mišt, Master thesis,
Comenius University
in Bratislava (2021)

K isomer studies at SHIP



Alpha decaying K isomers in ^{270}Ds and ^{266}Hs

S. Hofmann, et. al, Eur. Phys. J. A 10, 5–10 (2001)

D. Ackermann, Prog. of Theor. Phys. Suppl. 196, 255 (2012)

K isomers identified via delayed γ (– CE):

- High statistics needed

^{252}No
B. Sulignano, et al., Eur. Phys. J. A 33, 327 (2007)

^{255}Lr
S. Antalic, et al., Eur. Phys. J. A 38, 219 (2008)

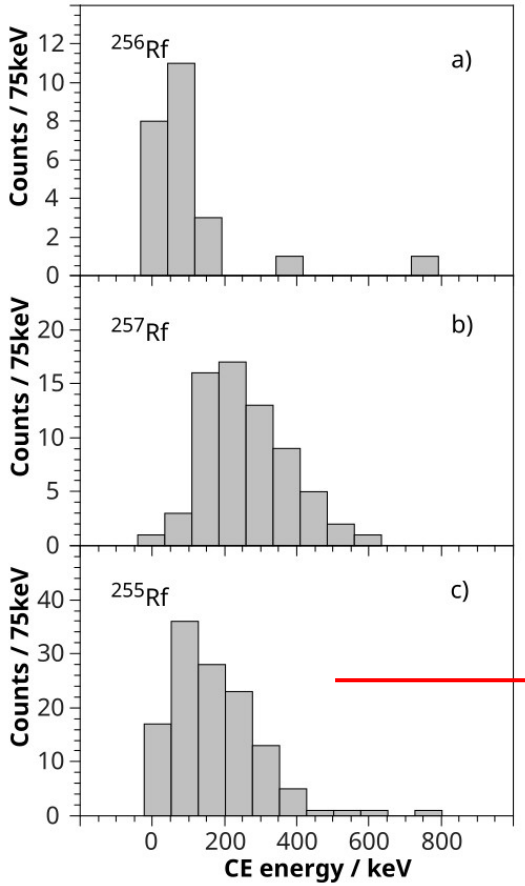
^{254}No
F.P. Heßberger, et al., Eur. Phys. J. A 43, 55 (2010)

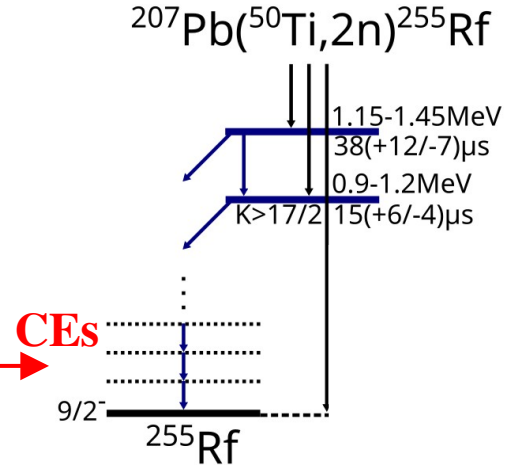
^{253}No
S. Antalic, et al., Eur. Phys. J. A 47, 62 (2011)

K isomer search at SHIP via CE signals

Rf

ER – **CE** – SF/α correlations



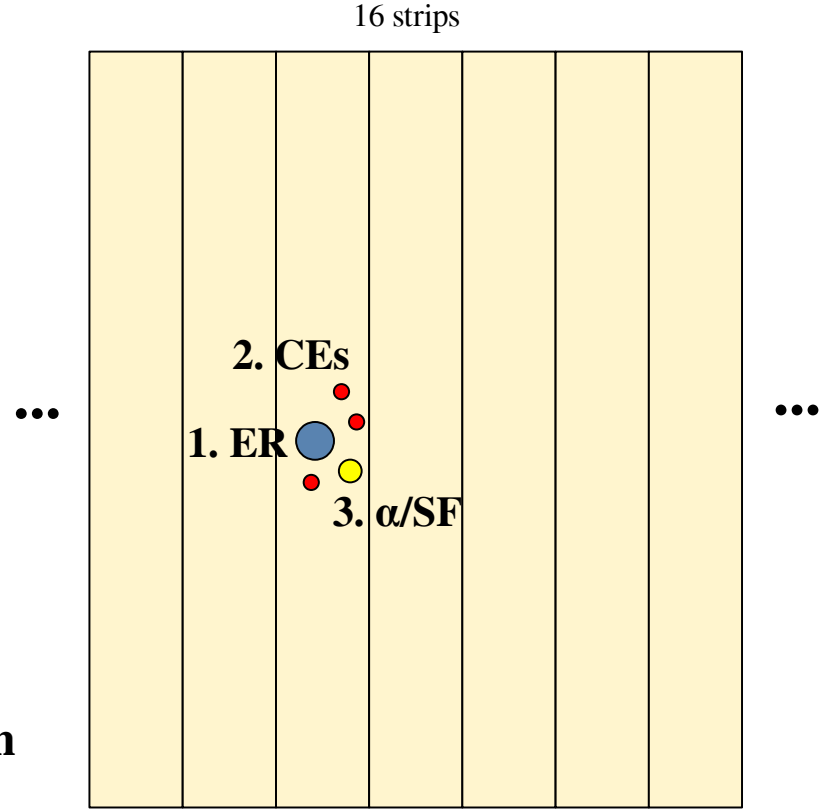


P. Mosat, et al., Phys. Rev. C 101, 034310 (2020)
R. Chakma et al., Phys. Rev. C 107, 014326 (2023)

Tresholds low enough for CE detection

- CE signals often without position
- Safe identification of K isomers

Position-sensitive silicon strip detector



Implantation Deexcitation Decay

Correlations: ER – CE – α / SF

Same position

P. Mosat, et al., Acta Physica Polonica B 51, 849 (2020)