

GSI–JYFL: (super)heavy-element research — recent results

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NUSTAR week
29.10-01.11.2026, JYFL, Finland

30 September 2026

Introduction:

- (super)heavy elements research
 - *brief historical reminder about the GSI-JYFL collaboration*

Properties of (super)heavy nuclei

- Fission half-lives of even-even and odd-A nuclei / K-isomeric states
 - *Recent results from TASCA (GSI) and SHIP (GSI)*
- Fission half-lives of odd-odd nuclei / electron capture delayed fission
 - *Recent results from RITU (JYFL) and TASCA (GSI)*

Fusion and multi-nucleon transfer reactions

- *Recent results from TASCA (GSI)*

Summary and conclusion

1950's

How to synthesize these nuclei ?

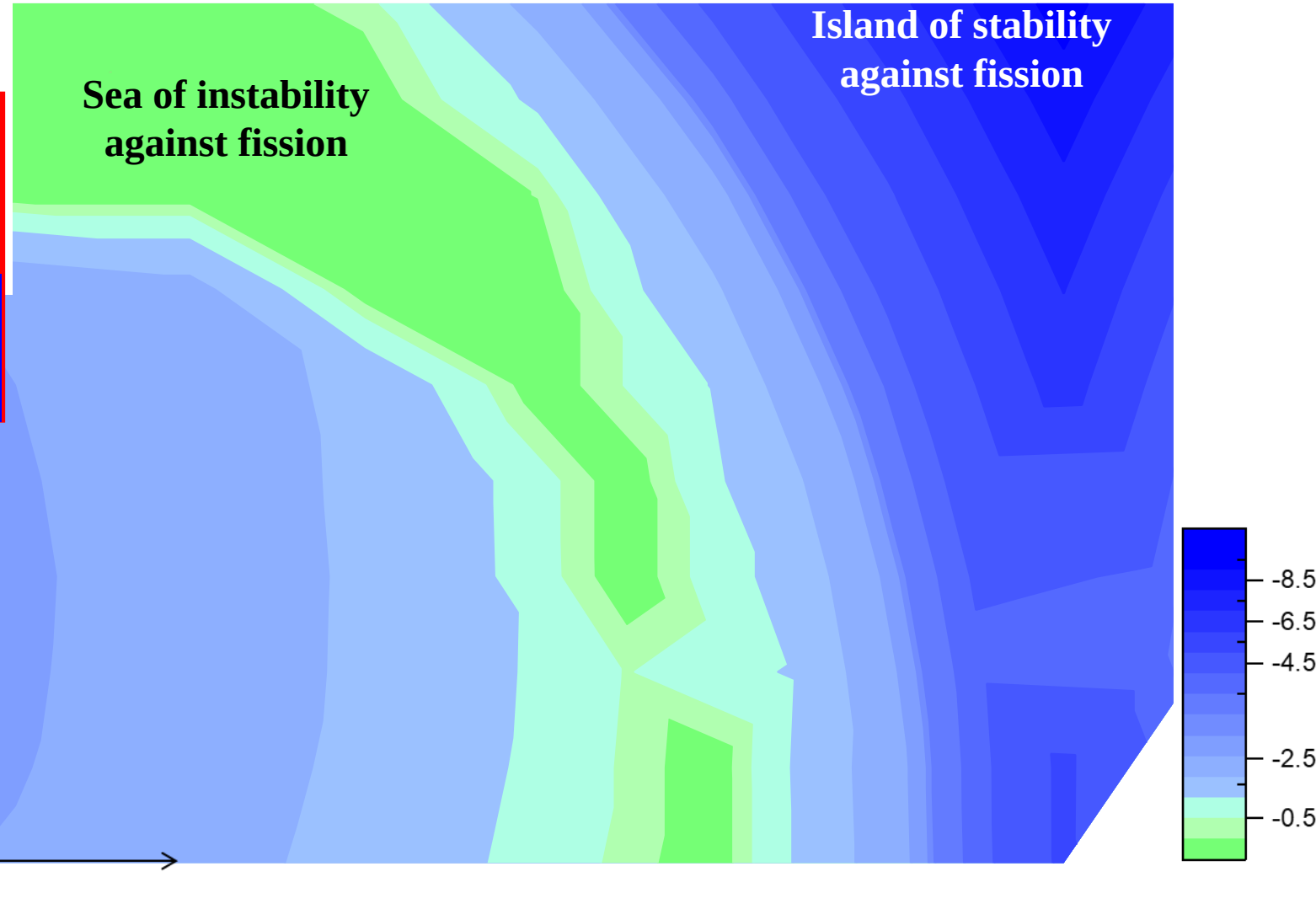
What are their physical and chemical properties ?

Can they be found in nature ?



1960-70's
Finish scientists:
M. Nurmia
P. Eskola
K. Eskola
M. Leino

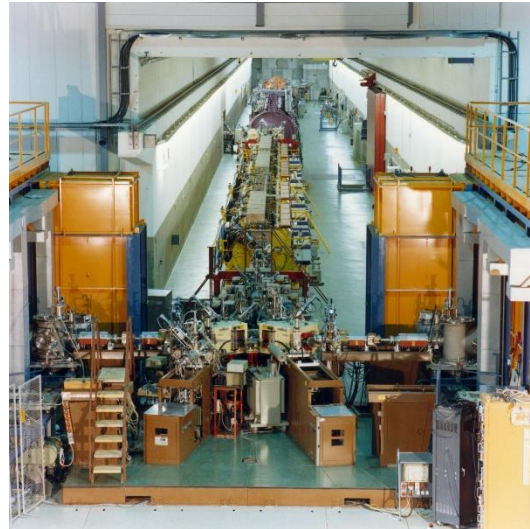
Superheavy nuclei ($Z > 103$): LDM + **Shell effect**





UNIVERSITY OF JYVÄSKYLÄ

UNILAC (Heavy-ion beam)

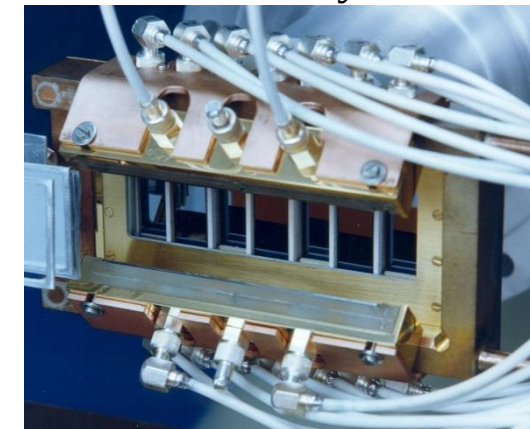


SHIP (Separator)

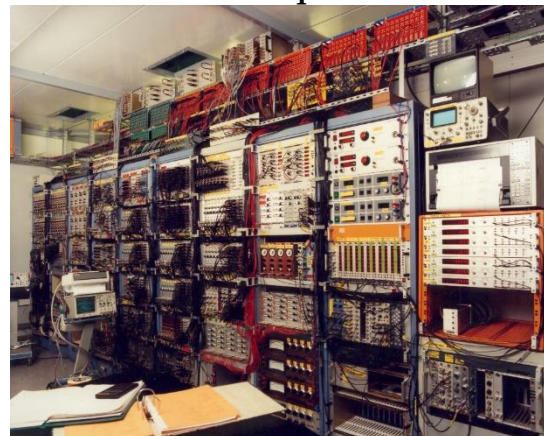


50th anniversary

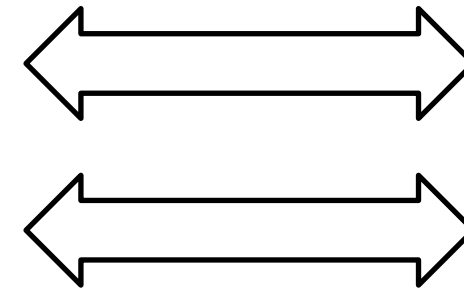
Detection system



Data acquisition



P. Armbruster
H. Ewald
G. Münzenberg
S. Hofmann
K.-H. Schmidt
W. Faust
K. Güttner,
F.P. Hessberger



K. Valli

1980's

M. Leino

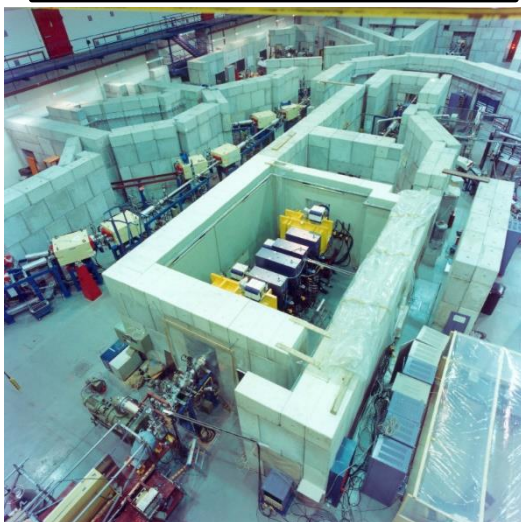
(University of Helsinki)

Discovery of element
Hassium (108)

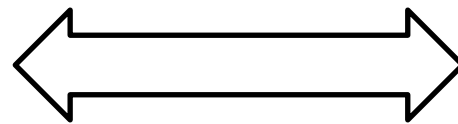
...



1970-80's: SHIP



- Synthesis of SHE
- Spectroscopy of SHN
- Nuclear reaction



Discoveries of elements
Darmstadtium (Z=110)
Roentgenium (Z=111)
Copernicium (Z=112)

Technology transfer
Discoveries of new isotopes
Nuclear spectroscopy

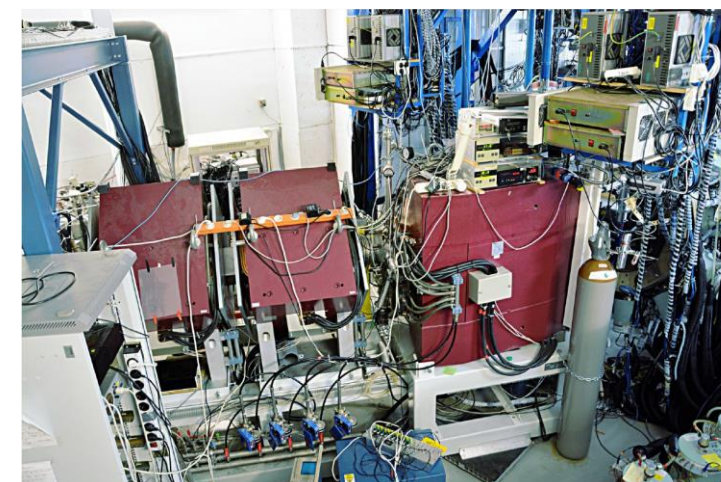


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M. Leino

1990's: RITU

J. Uusitalo ...

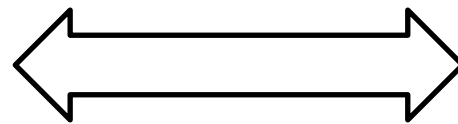


Heavy nuclei up to Db

- Synthesis
- Spectroscopy (+ in beam)



1970-80's: SHIP



Discoveries of elements
Darmstadtium (Z=110)
Roentgenium (Z=111)
Copernicium (Z=112)

Technology transfer
Discoveries of new isotopes
Nuclear spectroscopy

Confirmation of elements
Z=115 (Moscovium)
Z=117 (Tennessine)
Chemistry of Nh, Fl, and Mc

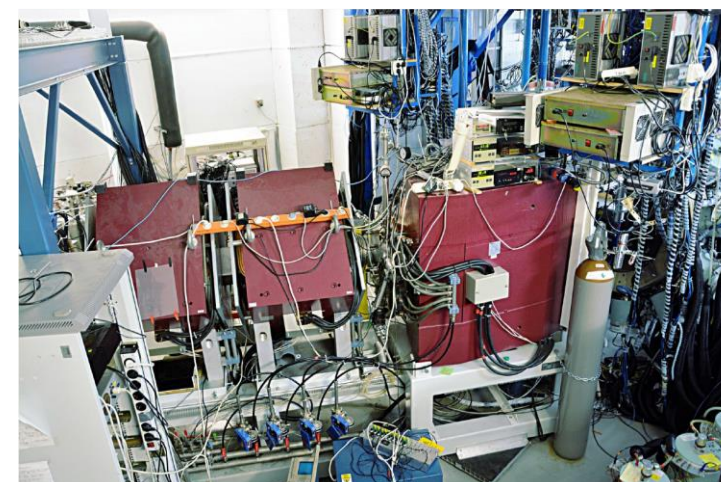


UNIVERSITY OF JYVÄSKYLÄ

M. Leino

1990's: RITU

J. Uusitalo ...



Heavy nuclei up to Db

- Synthesis
- Spectroscopy (+ in beam)

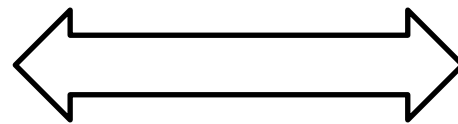
2000's: TASCA



- Chemistry of SHE
- Synthesis of SHE
- Spectroscopy of SHN



1970-80's: SHIP



Discoveries of elements
Darmstadtium (Z=110)
Roentgenium (Z=111)
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Technology transfer
Discoveries of new isotopes
Nuclear spectroscopy

Confirmation of elements
Z=115 (Moscovium)
Z=117 (Tennessine)
Chemistry of Nh, Fl, and Mc



UNIVERSITY OF JYVÄSKYLÄ

M. Leino

1990's: RITU

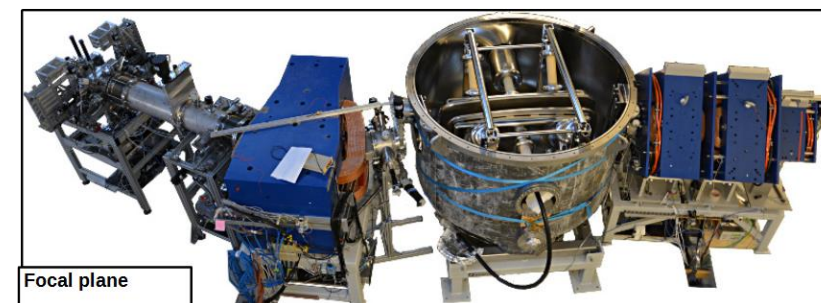
J. Uusitalo ...

J. Saren, J. Partanen ...

2010's: MARA



- Chemistry of SHE
- Synthesis of SHE
- Spectroscopy of SHN



- Spectroscopy of medium mass nuclei
- Synthesis of exotic nuclei (proton emitters)

...



1970-80's: SHIP



UNIVERSITY OF JYVÄSKYLÄ

M. Leino

1990's: RITU

J. Uusitalo

2000's: TASCA

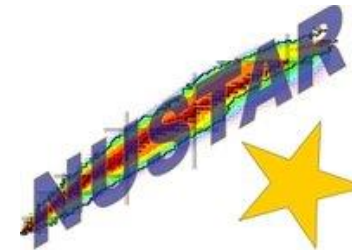
J. Saren, J. Partanen ...

2010's: MARA

2020's: ???



FAIR — Facility for Antiproton and Ion Research in Europe



■ α
■ Fission

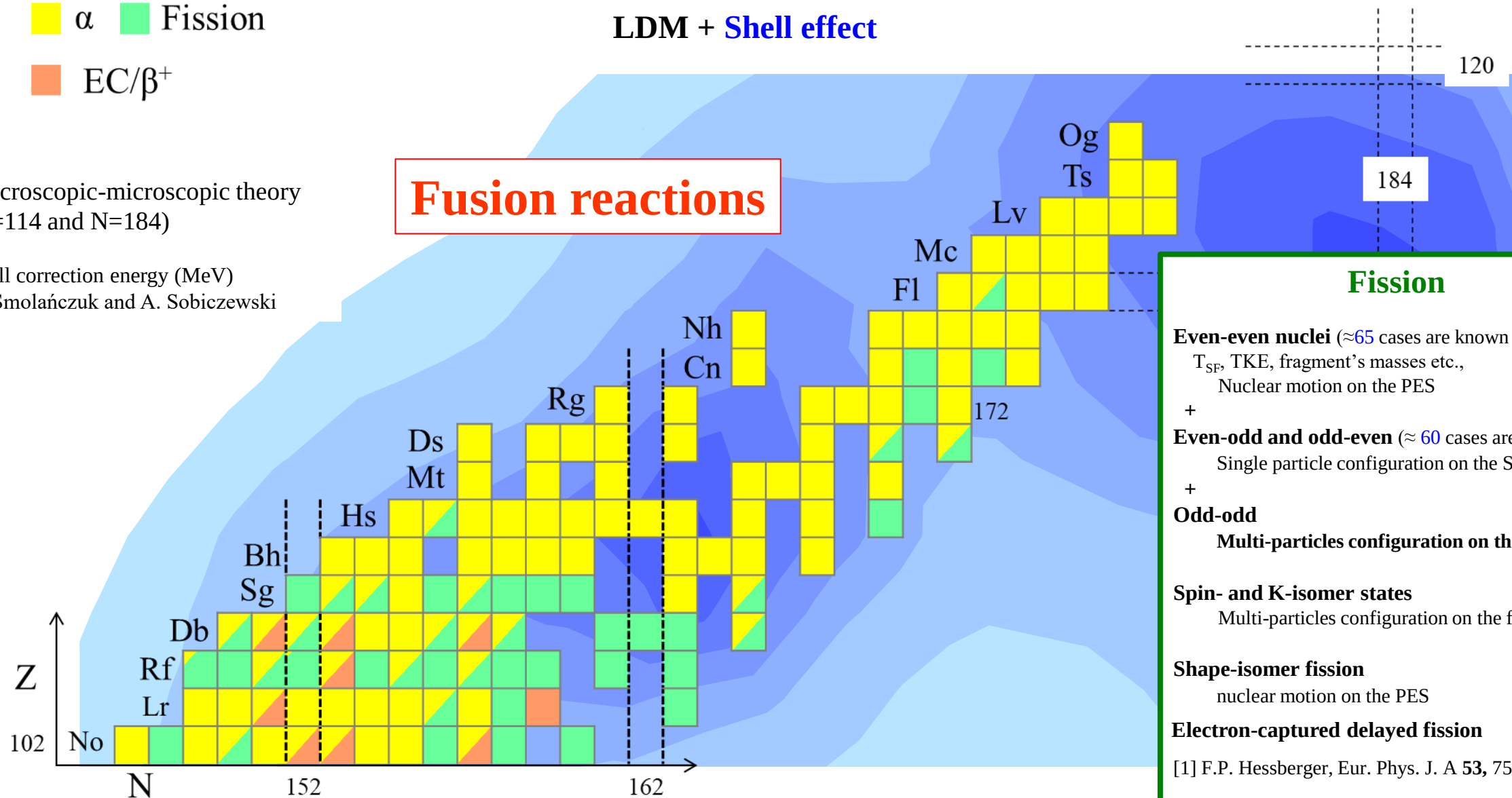
■ EC/ β^+

LDM + **Shell effect**

Macroscopic-microscopic theory
($Z=114$ and $N=184$)

Shell correction energy (MeV)
R. Smolańczuk and A. Sobiczewski

Fusion reactions



Fission

Even-even nuclei (≈ 65 cases are known [1])

T_{SF} , TKE, fragment's masses etc.,
Nuclear motion on the PES

+

Even-odd and odd-even (≈ 60 cases are known [1])

Single particle configuration on the SF

+

Odd-odd

Multi-particles configuration on the SF

Spin- and K-isomer states

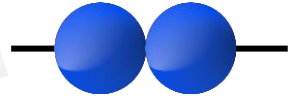
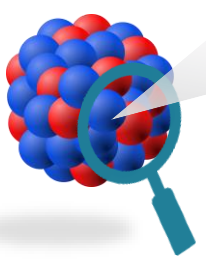
Multi-particles configuration on the fission

Shape-isomer fission

nuclear motion on the PES

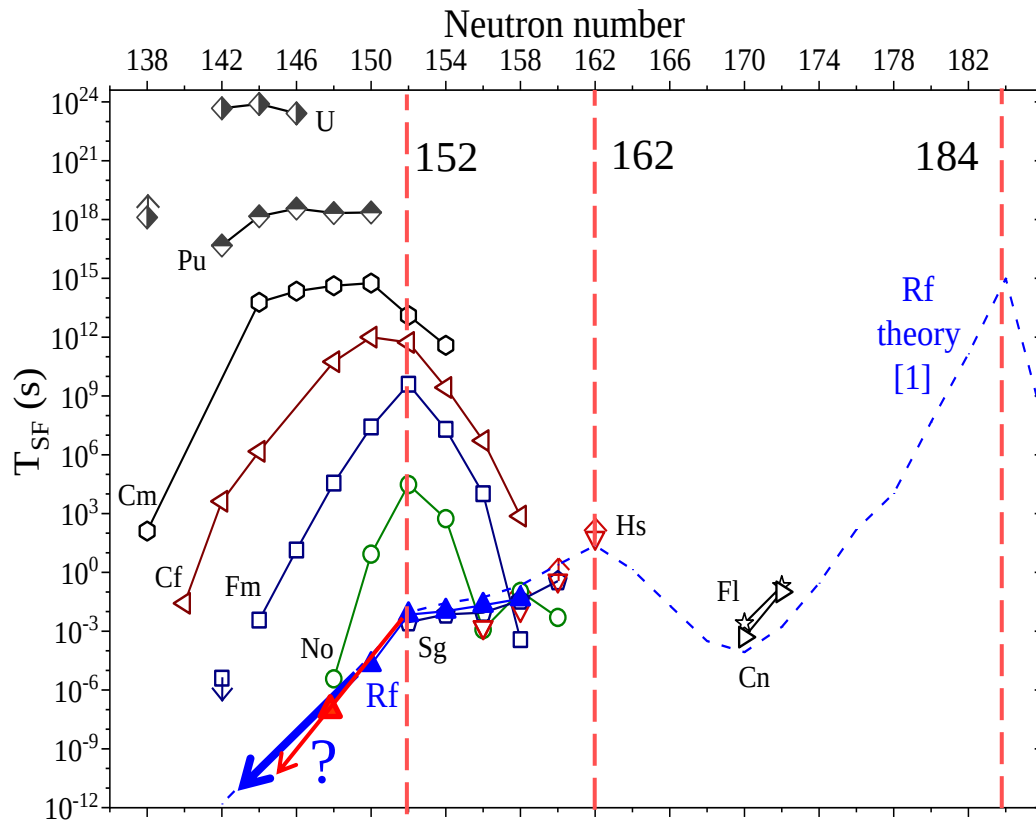
Electron-captured delayed fission

[1] F.P. Hessberger, Eur. Phys. J. A **53**, 75 (2017).



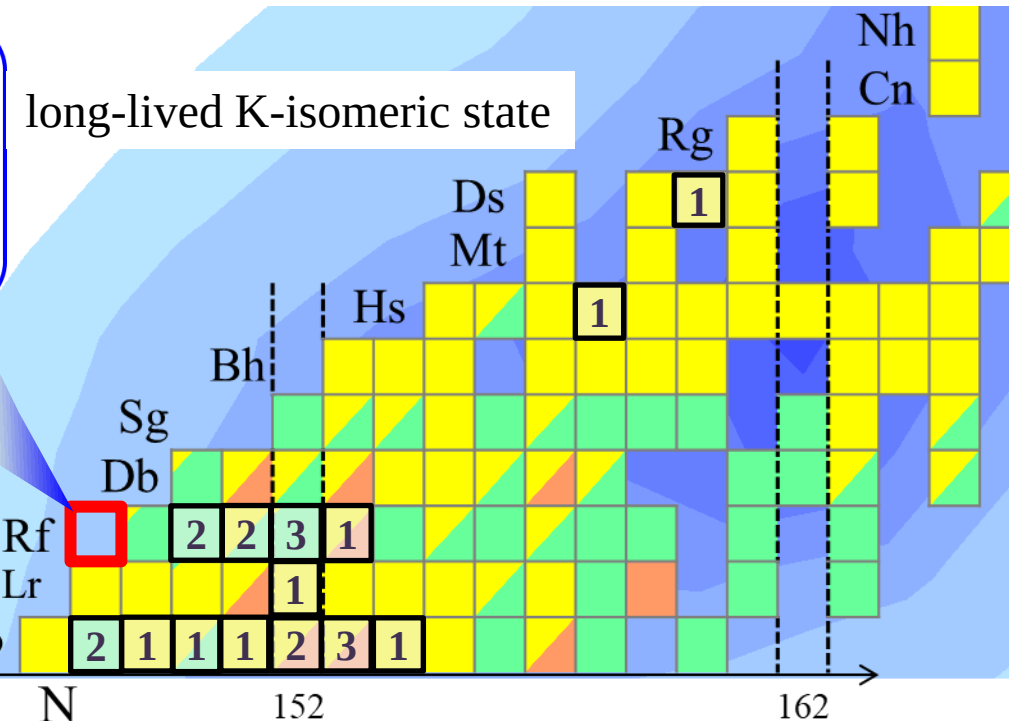
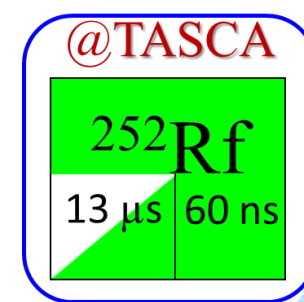
$\Omega[Nn_z\Lambda]$ Quantum numbers

$T_{SF}(\text{even-even, } J=0)$ defines the fission landscape (and location of sea of fission instability)



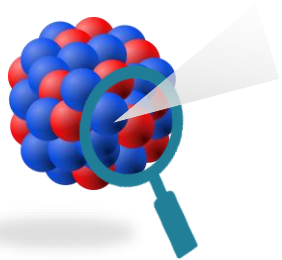
J. Khuyagbaatar et al., EPJ Web Conf. **131**, 03003 (2016).

J. Khuyagbaatar, P. Mosat et al., Phys. Rev. Lett. **134**, 022501 (2025)
Editors' Suggestion / Featured in Physics



SHN: the most stable configuration against fission is not anymore ground state !

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



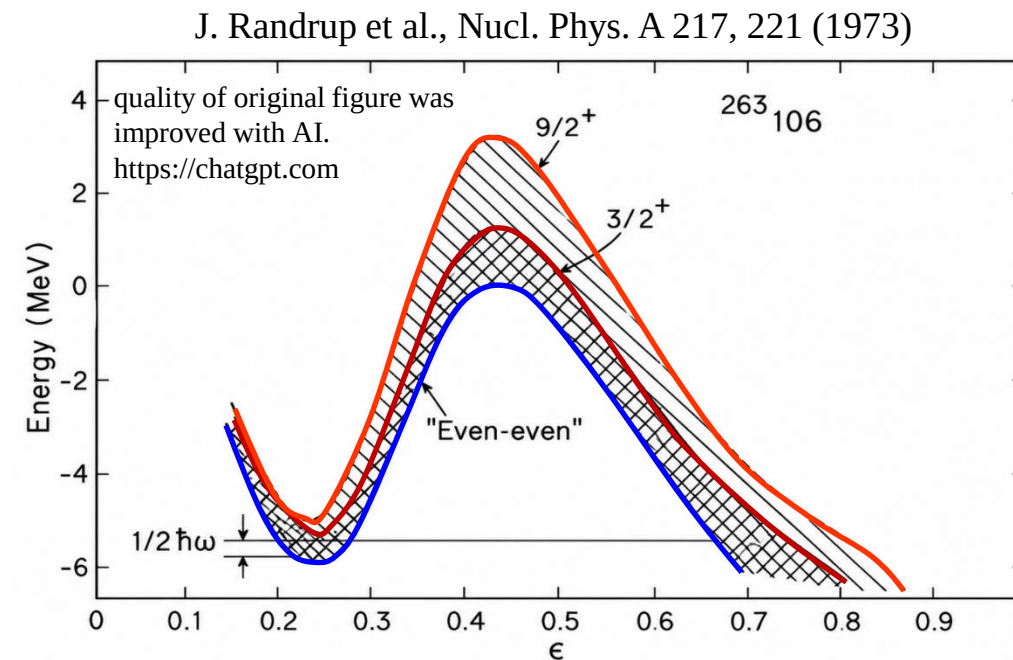
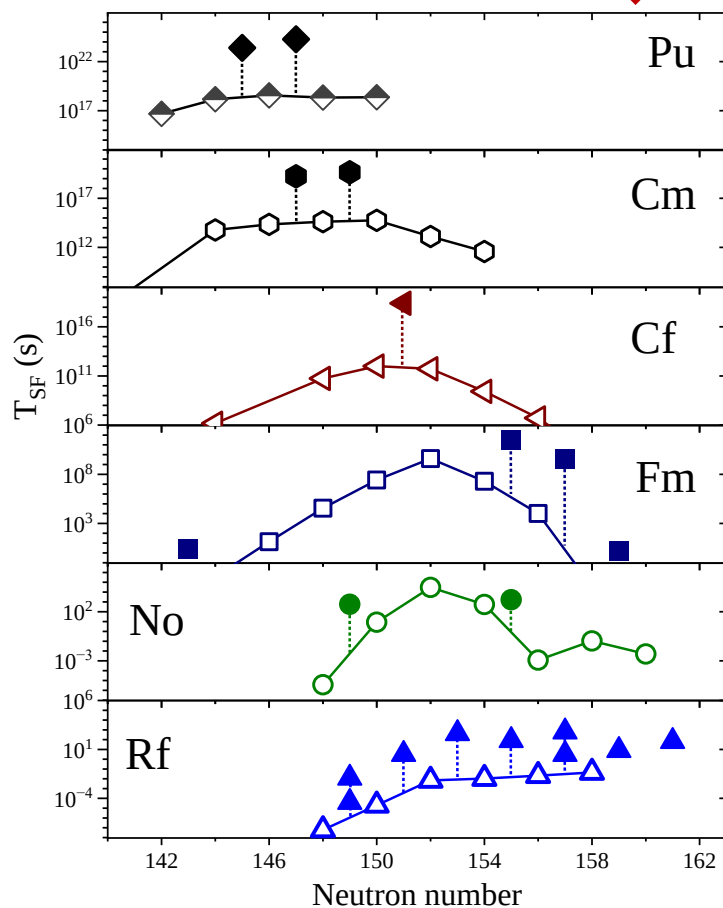
$\Omega[Nn_z\Lambda] \rightarrow$ Fission hindrance

$$T_{SF}(\text{odd-A}, J>0) > T_{SF}[\text{odd-A}, J=0]$$

Experiment



Theory



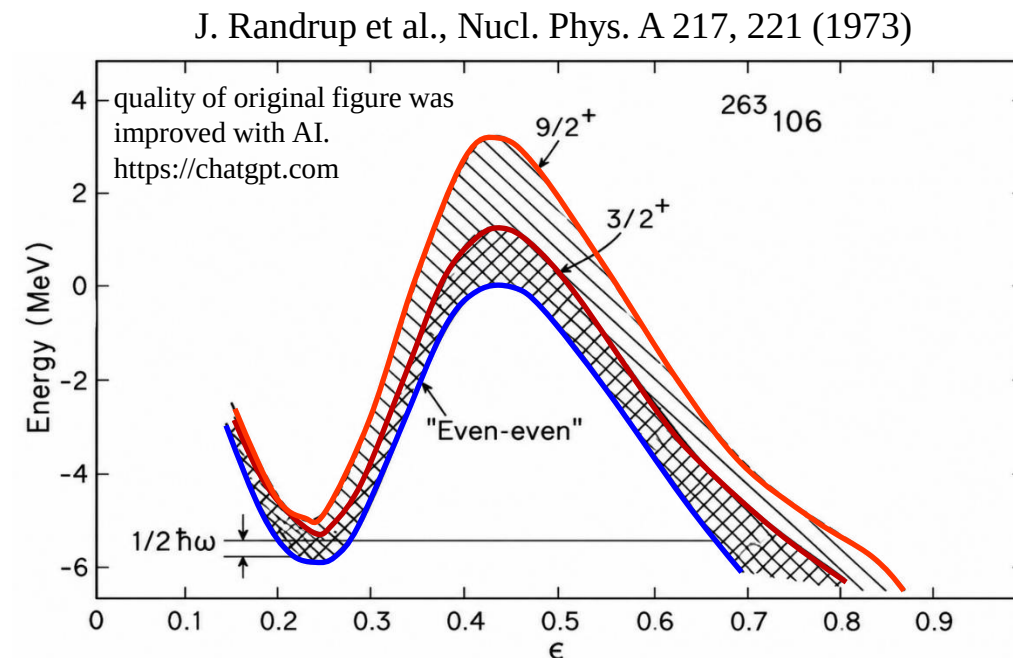
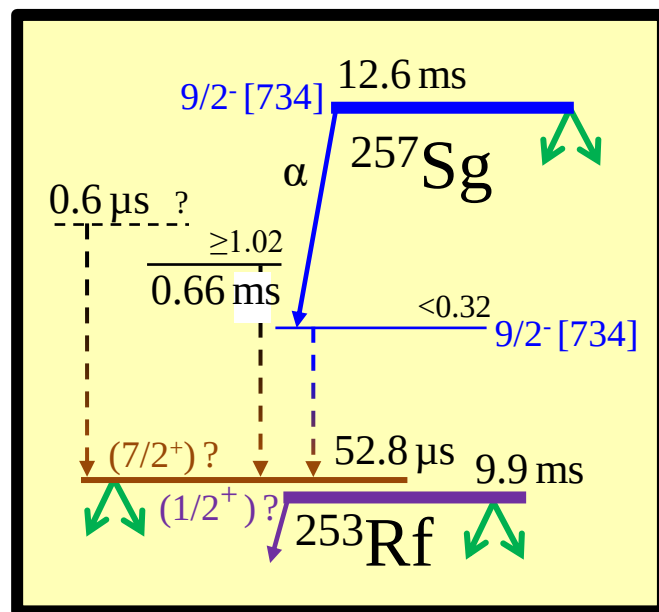
Theory predicts that in the same nucleus

$$T_{SF}(\text{odd-A}, J_1>0) < T_{SF}(\text{odd-A}, J_2>J_1)$$

It was never confirmed
No experimental fission data!

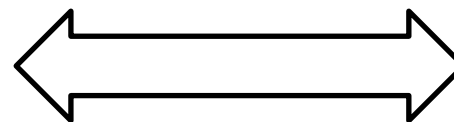
P. Mosat, J. Khuyagbaatar, et al., Phys. Rev. Lett. **134**, 232501 (2025)

Editors' Suggestion / PRL collection 2025



???

$$T_{\text{SF}}(^{253}\text{Rf}, 1/2^+) > T_{\text{SF}}(^{253}\text{Rf}, 7/2^+)$$



Theory predicts that in the same nucleus

$$T_{\text{SF}}(\text{odd-A}, J_1 > 0) < T_{\text{SF}}(\text{odd-A}, J_2 > J_1)$$

It was never confirmed
No experimental fission data!

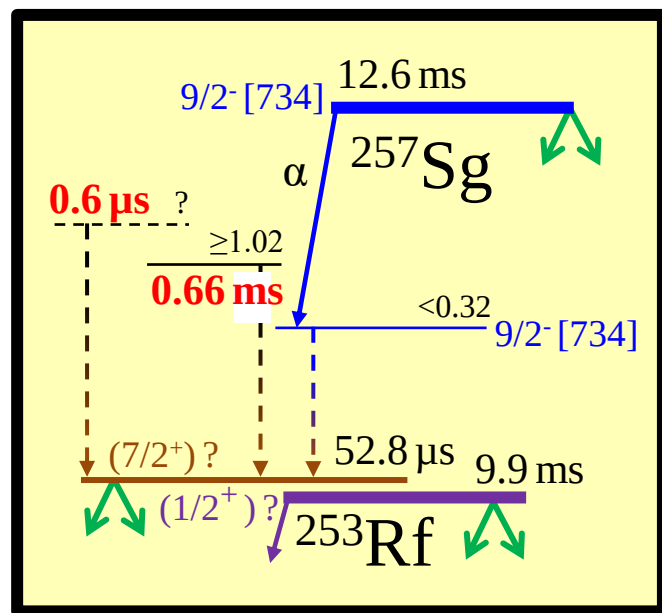
Data on ^{253}Rf are from

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

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

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

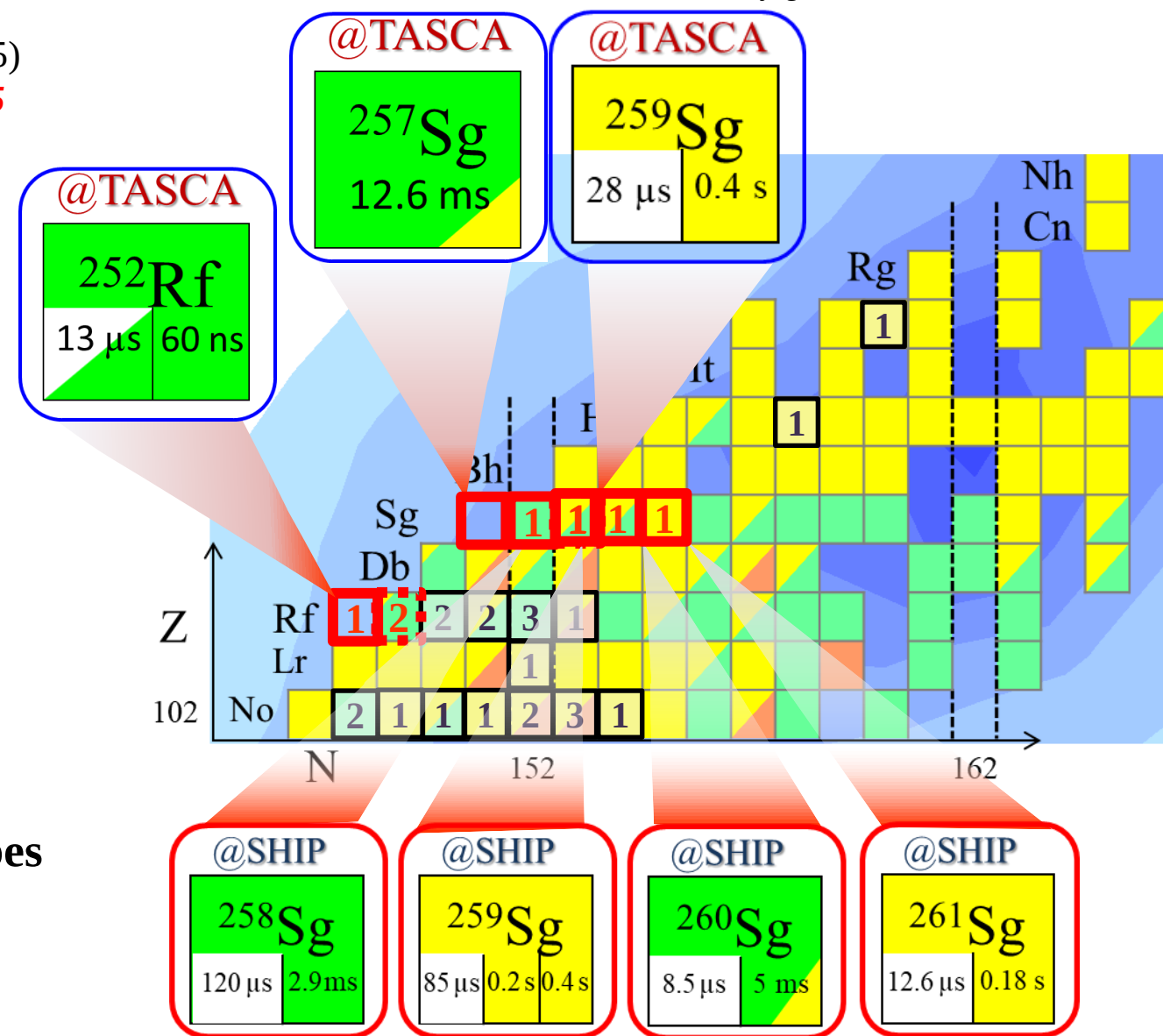
Editors' Suggestion / PRL collection 2025

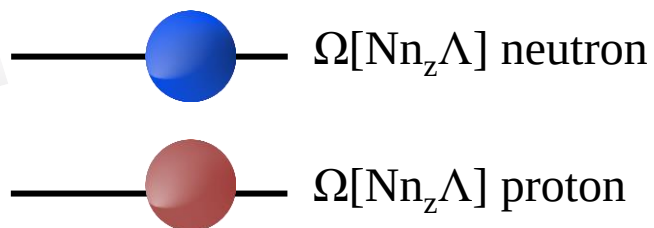
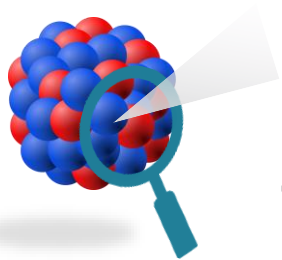


Two K-isomeric states in ^{253}Rf

Discovery of K-isomeric states in seaborgium isotopes

P. Mosat, B. Andel, J. Khuyagbaatar, et al.,
Phys. Rev. C. **144**, 034321 (2026)



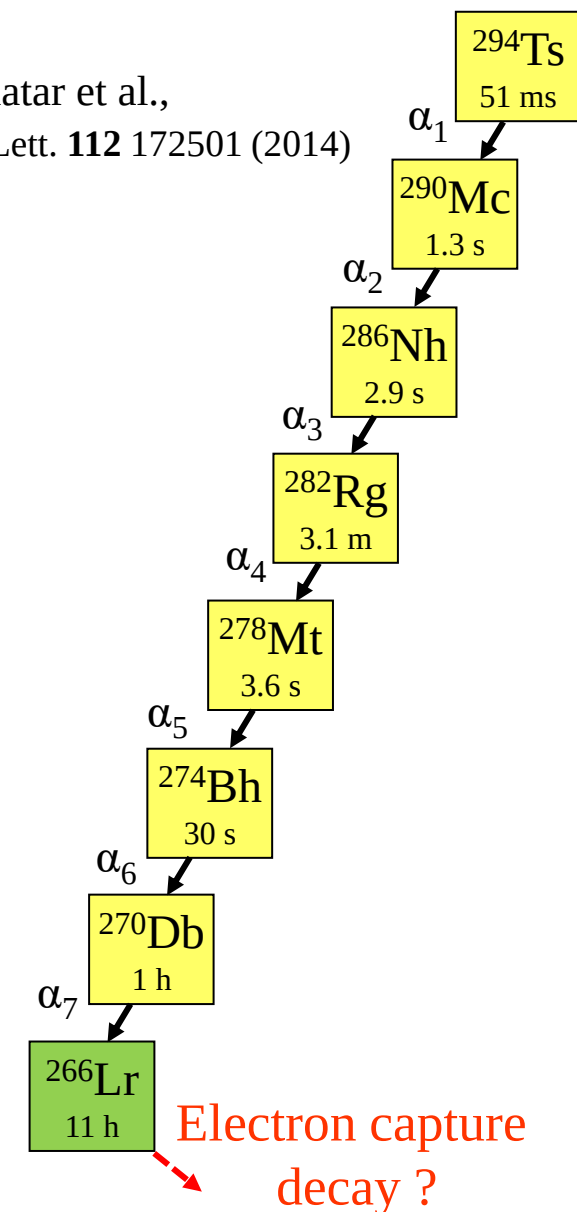


$$T_{SF}(\text{odd-odd}) \gg T_{SF}[\text{even-even}]$$

Experiment

In odd-odd nuclei “no” fission was identified but observed.

J. Khuyagbaatar et al.,
Phys. Rev. Lett. **112** 172501 (2014)



Discovered in 1966: V.I. Kuznetsov, N.K. Skobelev, and G.N. Flerov

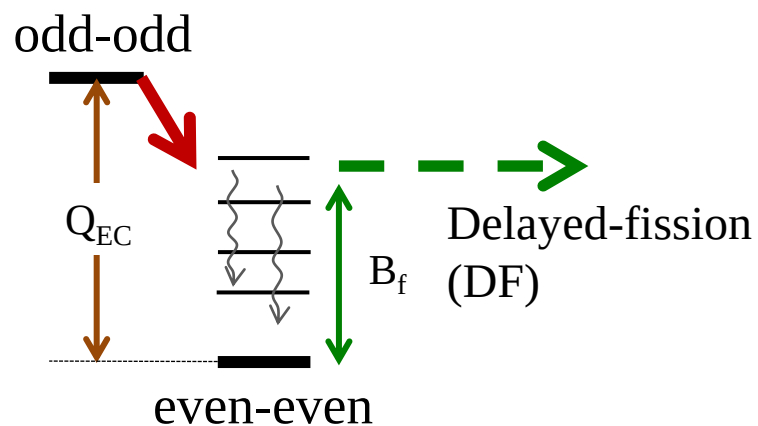
Sov. J. Nucl. Phys. **4**, 70 (1967).

Sov. J. Nucl. Phys. **4**, 202 (1967).

Sov. J. Nucl. Phys. **5**, 191 (1967).

Explained in 1969: E.Y. Berlovich, and Y.N. Novikov,

Phys. Lett. B **29**, 155 (1969).

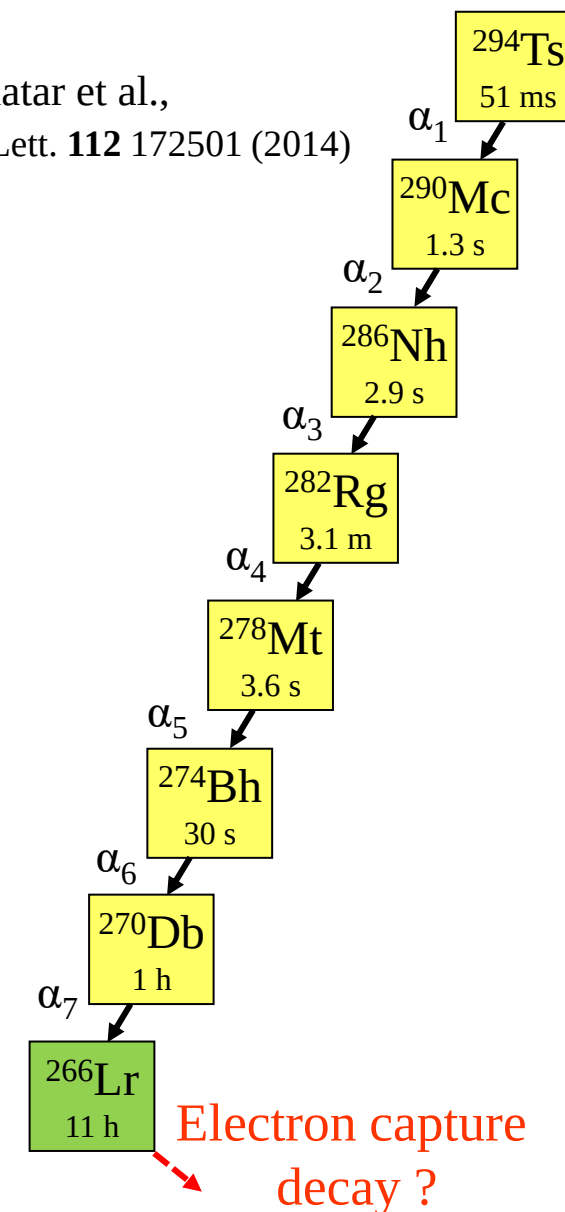


Experimental ECDF probability:

$$P_{ECDF} = N_{DF} / N_{EC}$$

J. Khuyagbaatar et al.,

Phys. Rev. Lett. **112** 172501 (2014)



Discovered in 1966: V.I. Kuznetsov, N.K. Skobelev, and G.N. Flerov

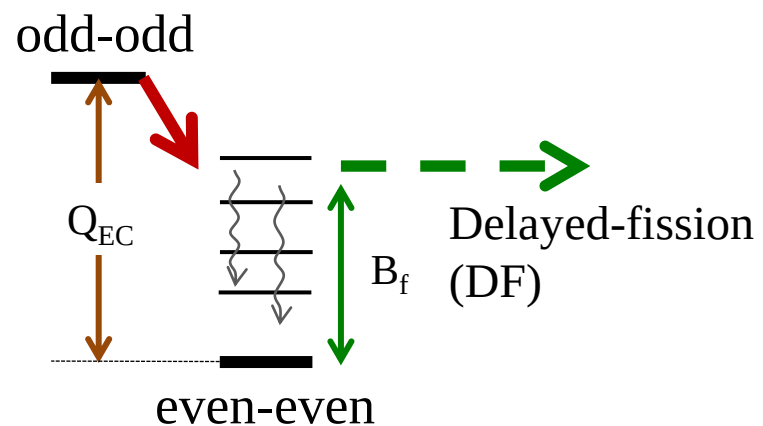
Sov. J. Nucl. Phys. **4**, 70 (1967).

Sov. J. Nucl. Phys. **4**, 202 (1967).

Sov. J. Nucl. Phys. **5**, 191 (1967).

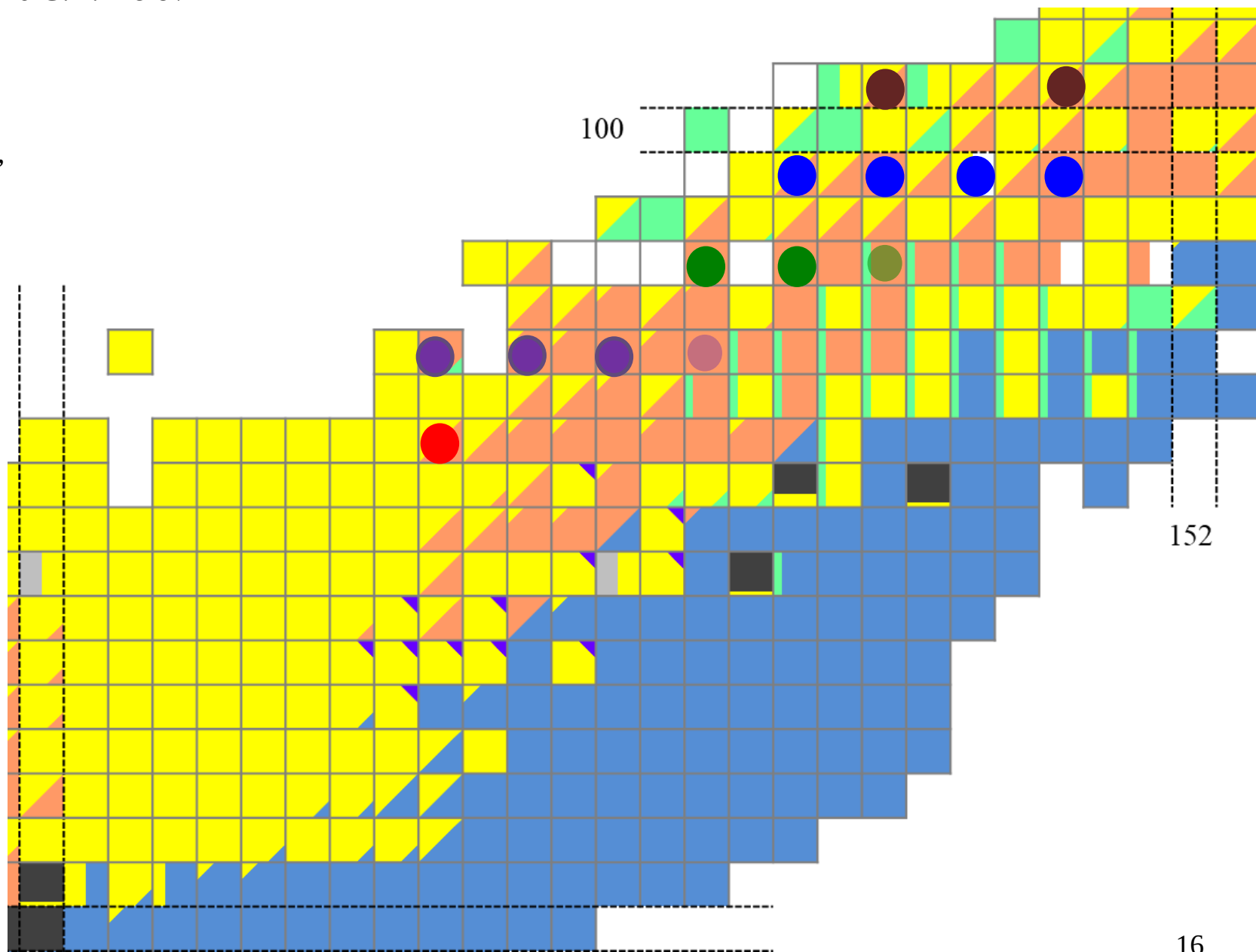
Explained in 1969: E.Y. Berlovich, and Y.N. Novikov,

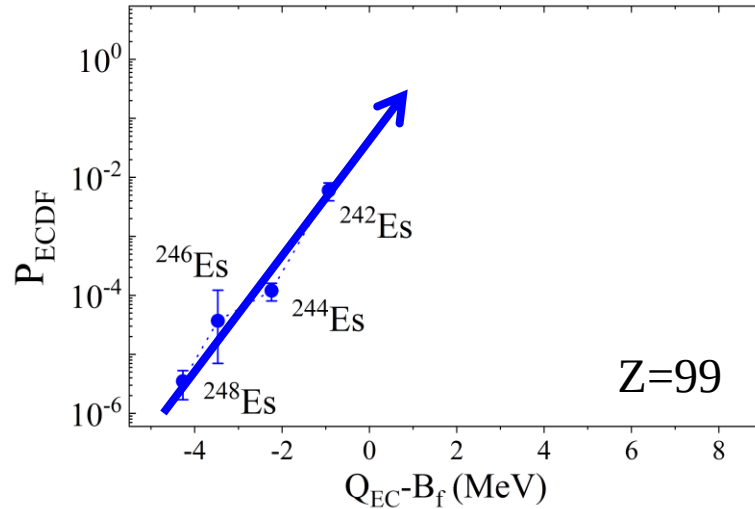
Phys. Lett. B **29**, 155 (1969).



Experimental ECDF probability:

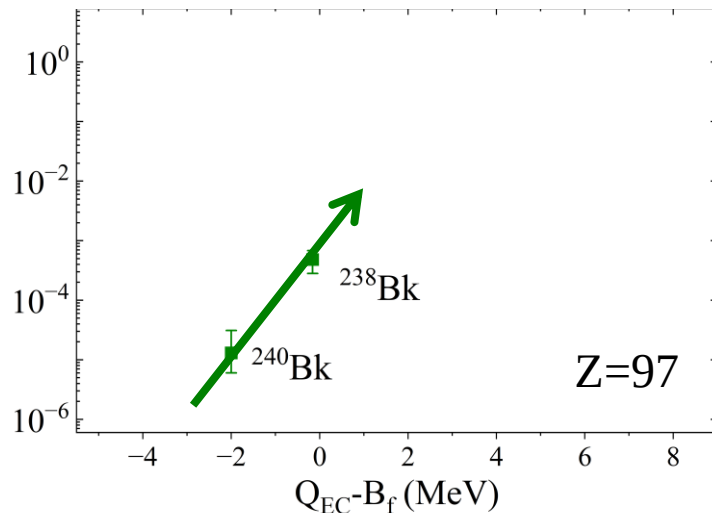
$$P_{ECDF} = N_{DF} / N_{EC}$$





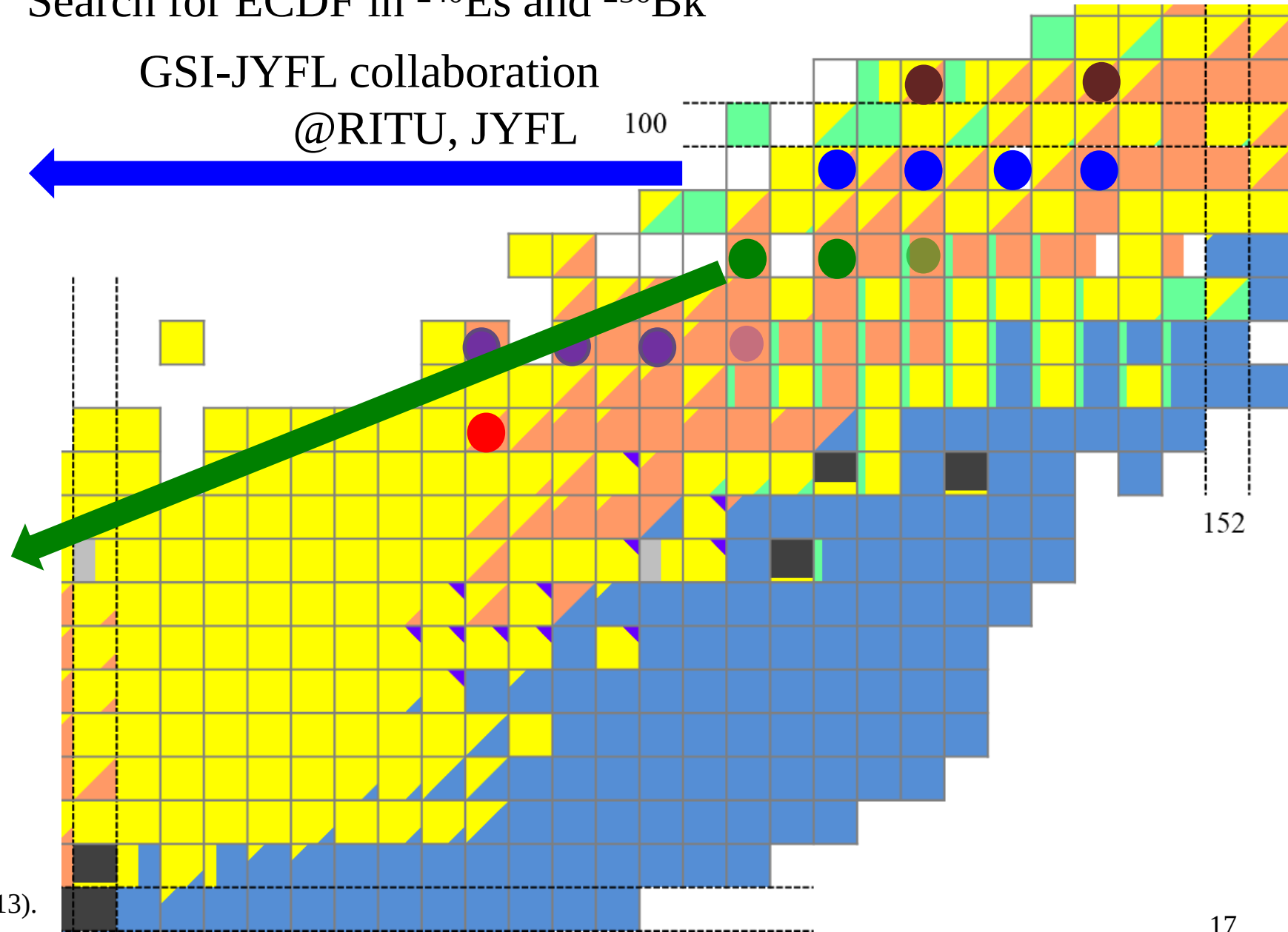
Search for ECDF in ^{240}Es and ^{236}Bk

GSI-JYFL collaboration
@RITU, JYFL



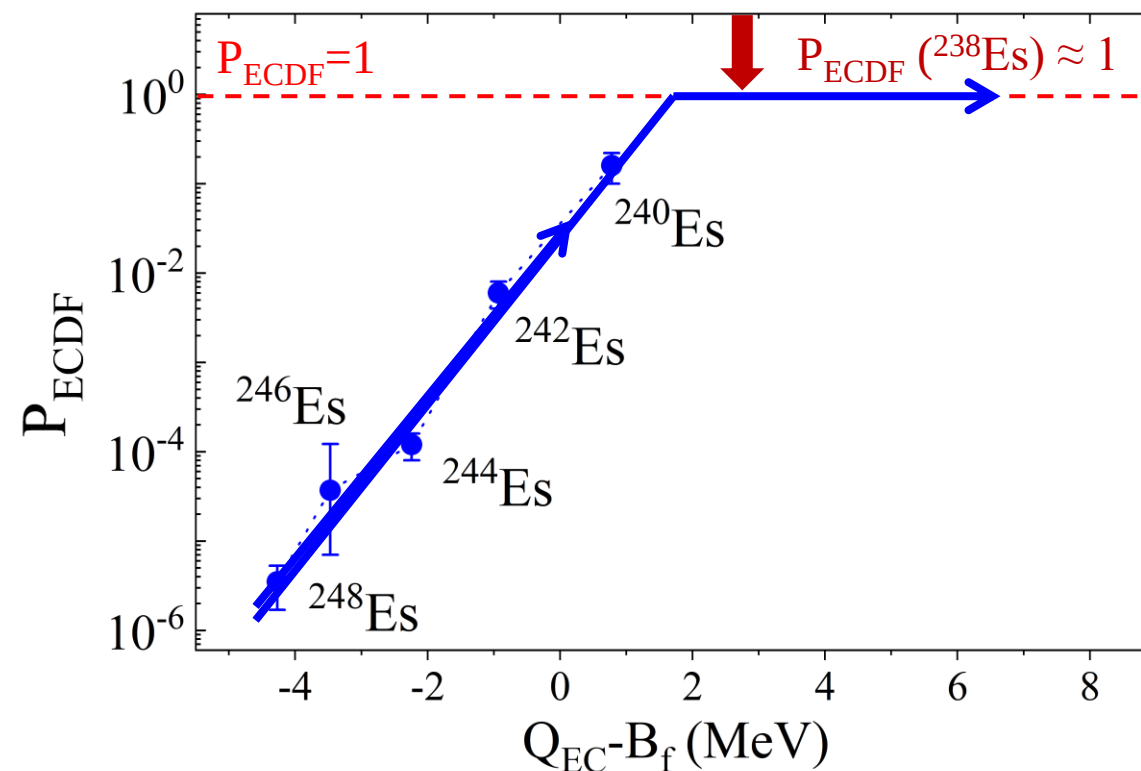
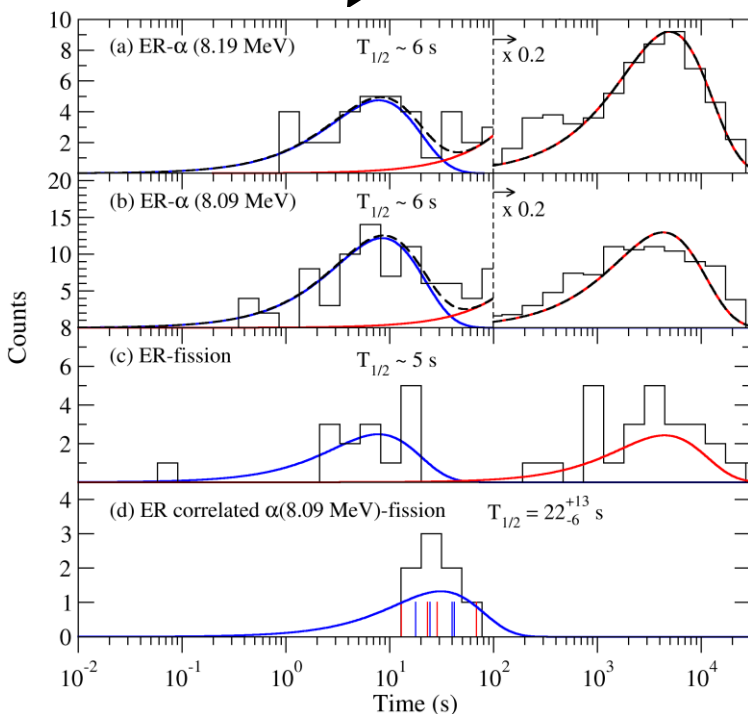
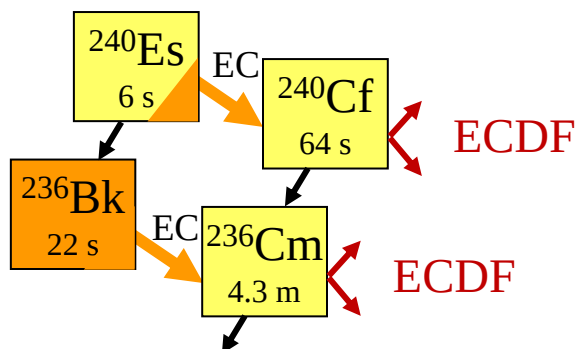
Experimental ECDF probability:

$$P_{\text{ECDF}} = N_{\text{DF}} / N_{\text{EC}}$$



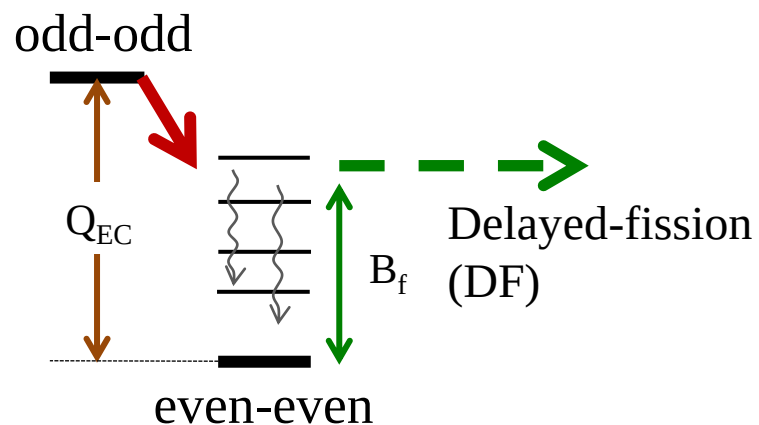
Towards saturation of the electron-capture delayed fission probability: The new isotopes ^{240}Es and ^{236}Bk

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

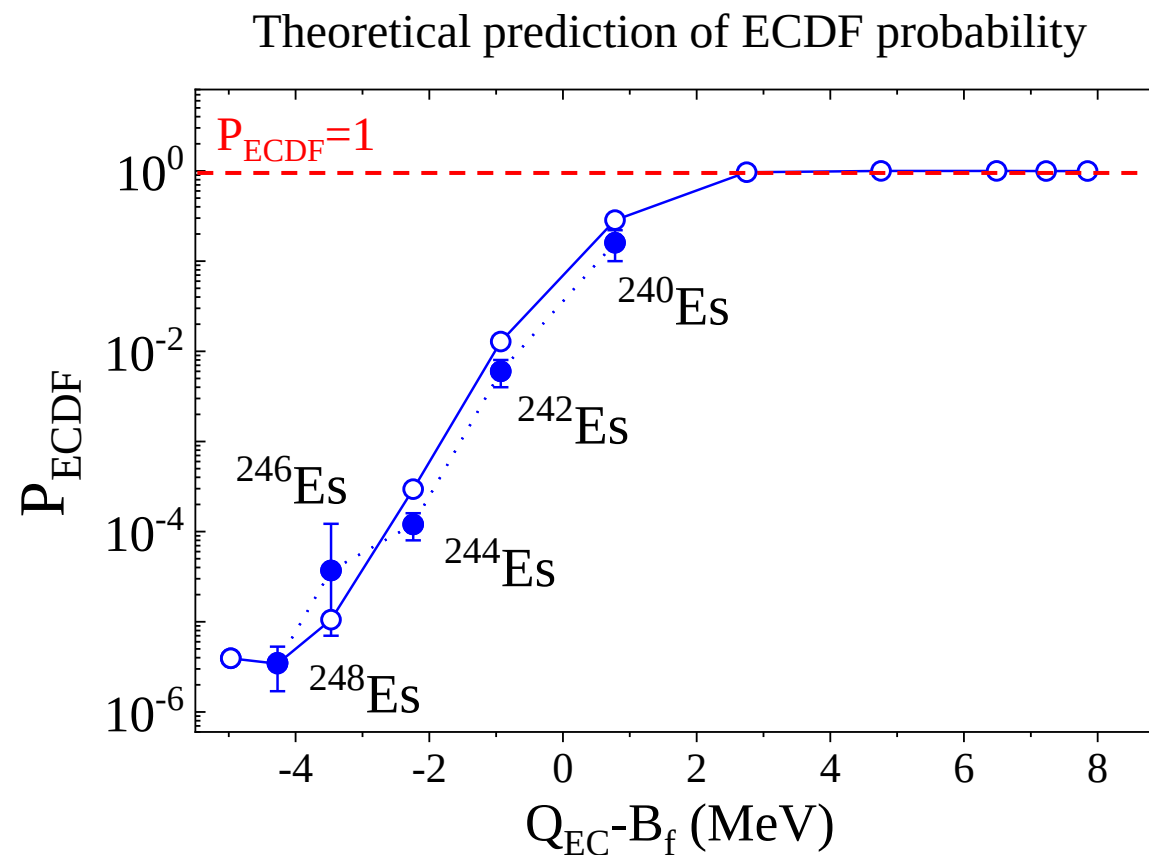
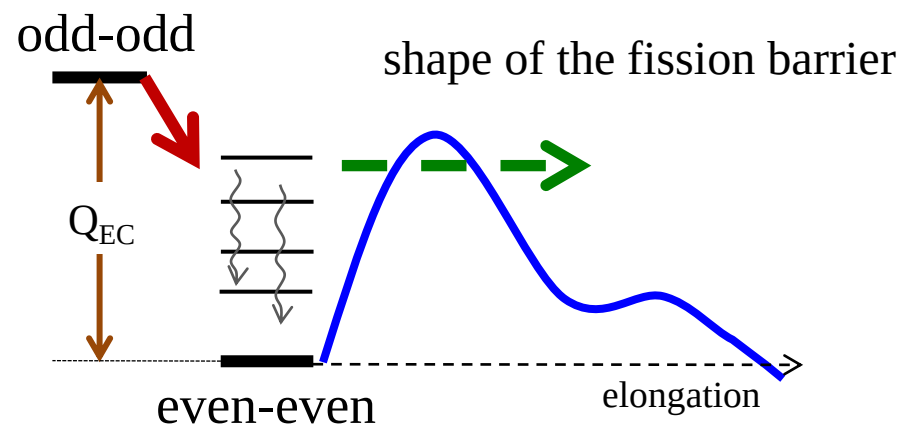


Q_{EC} : P. Moller et al., At. Data and Nuc. Data Tables 59, 185 (1995).

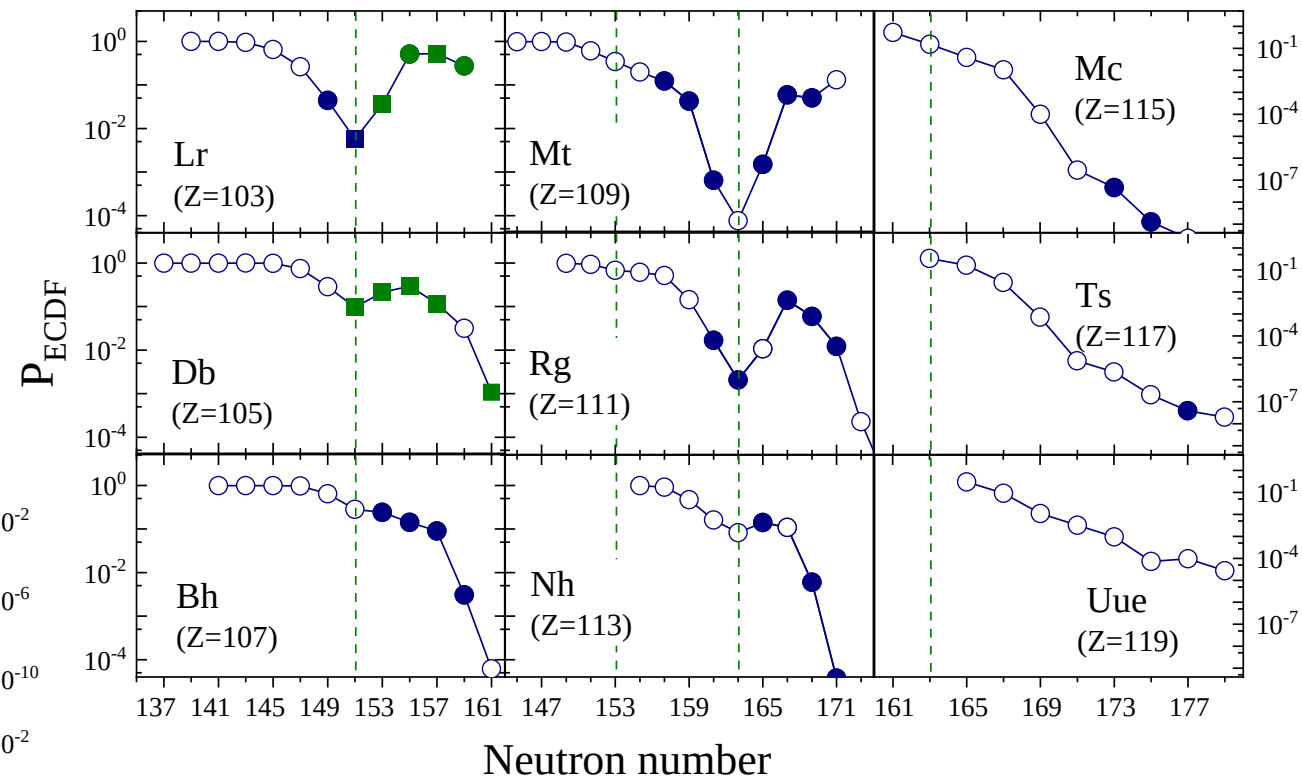
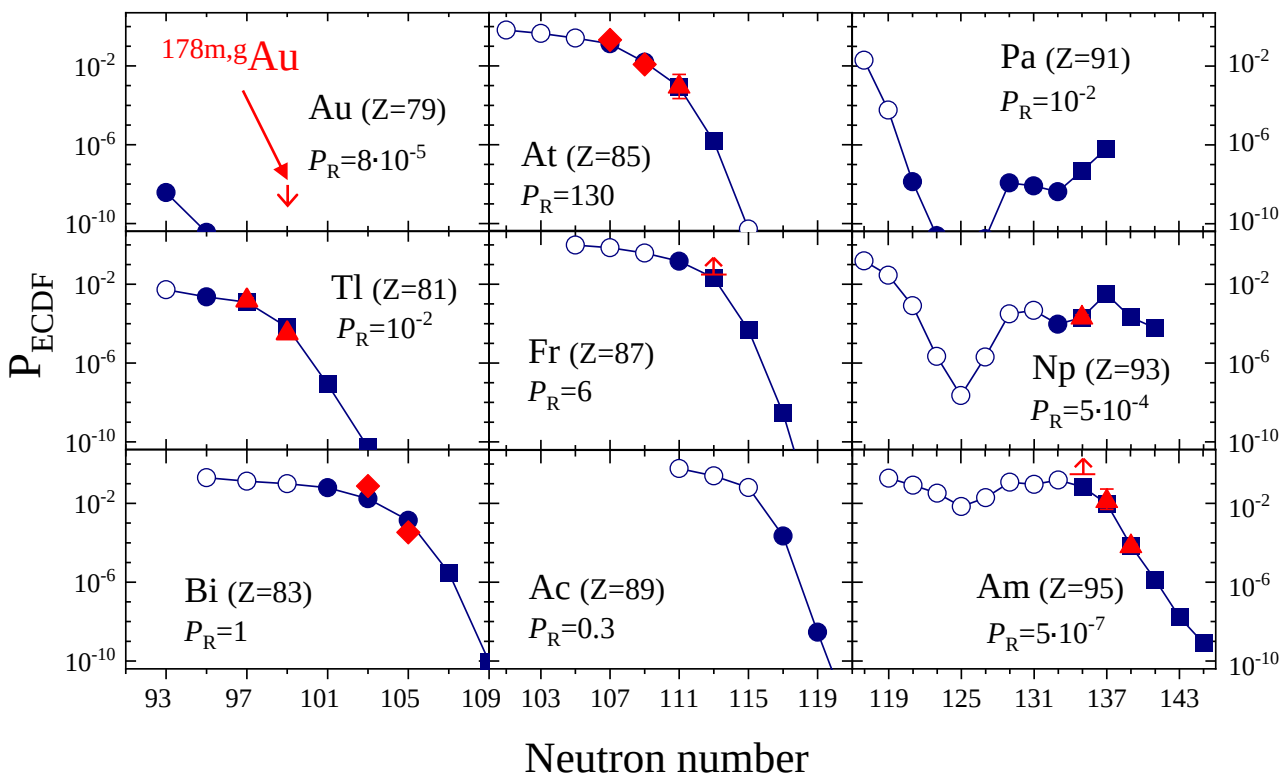
B_f : P. Moller, et al., Phys. Rev. C 79 064304 (2009).



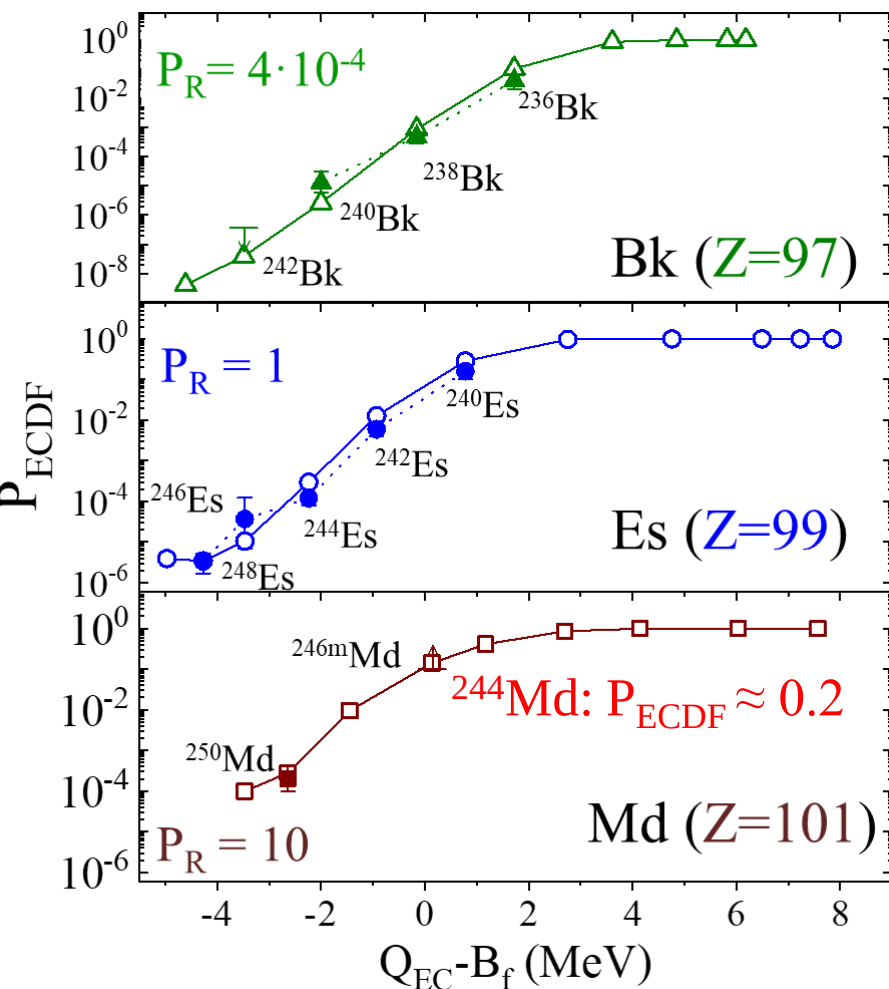
J. Khuyagbaatar, Eur. Phys. J. A 55, 134 (2019).



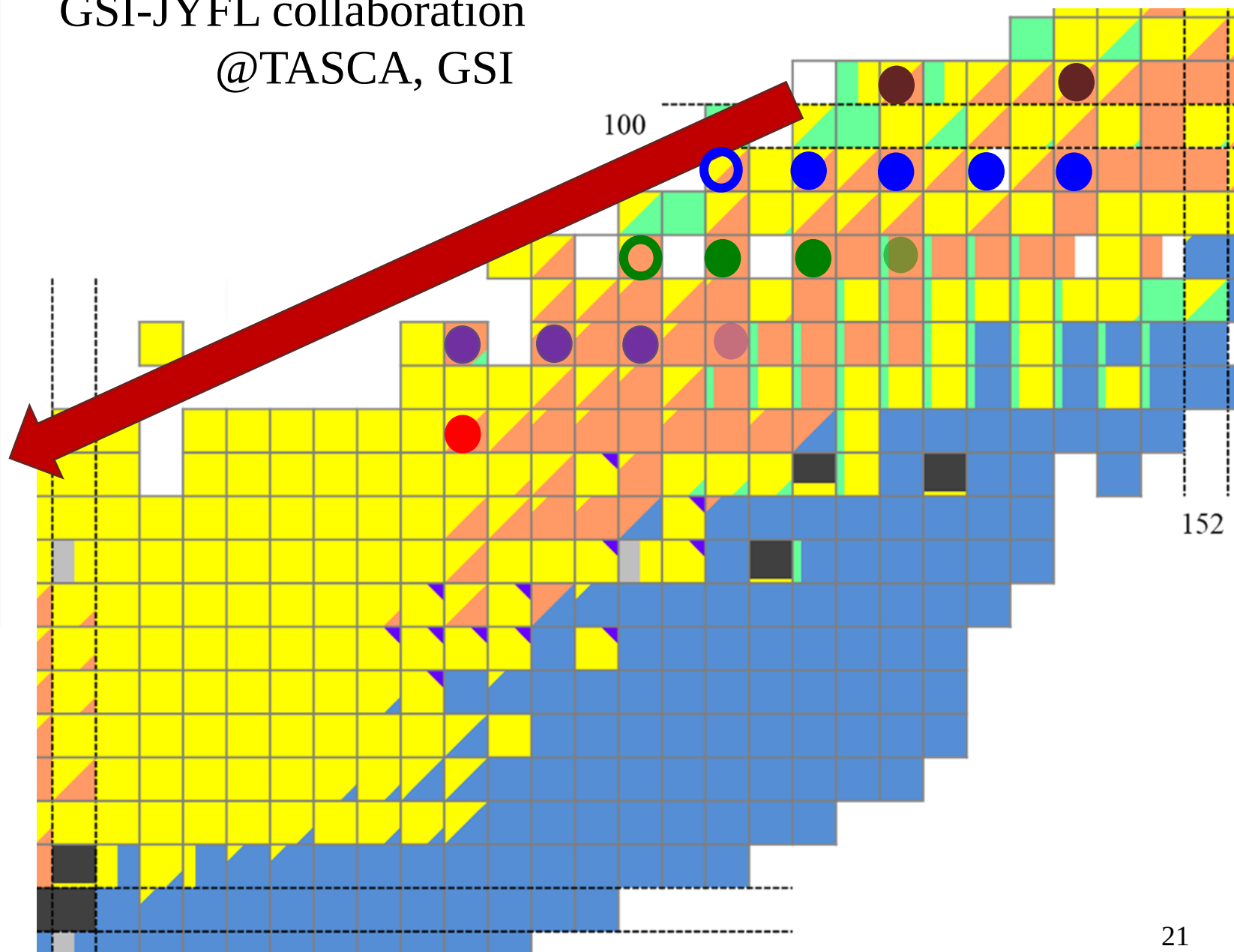
Very recent data on P_{ECDF} for $^{178\text{m}}\text{Au}$ and $^{178\text{g}}\text{Au}$
B. Andel et al., Phys. Rev. C 113, 014325 (2026)



ECDF is one of the main decay mode of neutron-deficient (neutron-rich) superheavy nuclei, if EC (β^-) takes place.

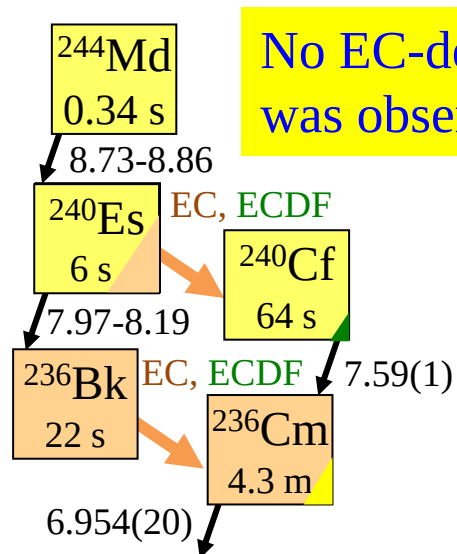
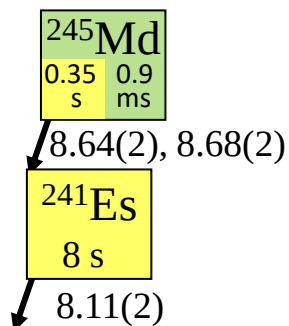


GSI-JYFL collaboration
@TASCA, GSI

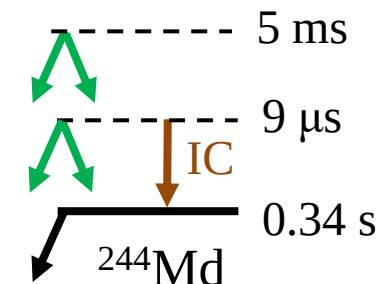


J. Khuyagbaatar et al.,
Phys. Rev. Lett. **125** 142504 (2020)

J. Khuyagbaatar @NUSTAR week 2026



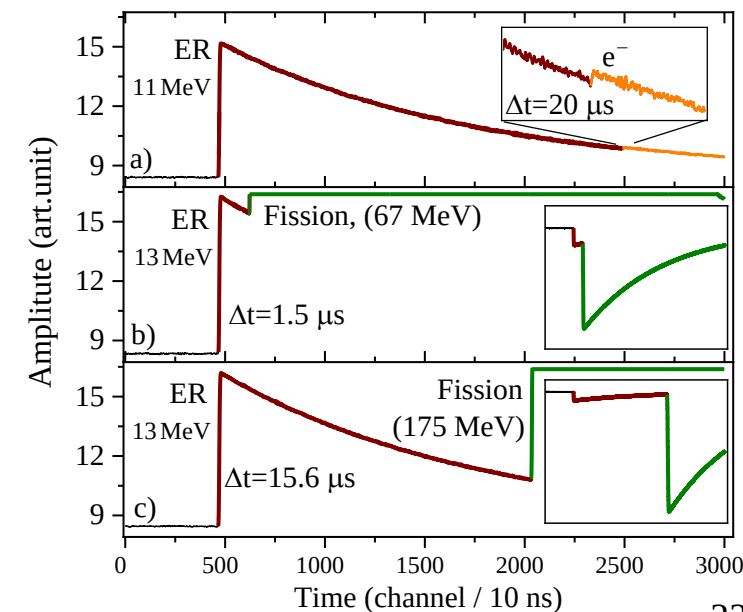
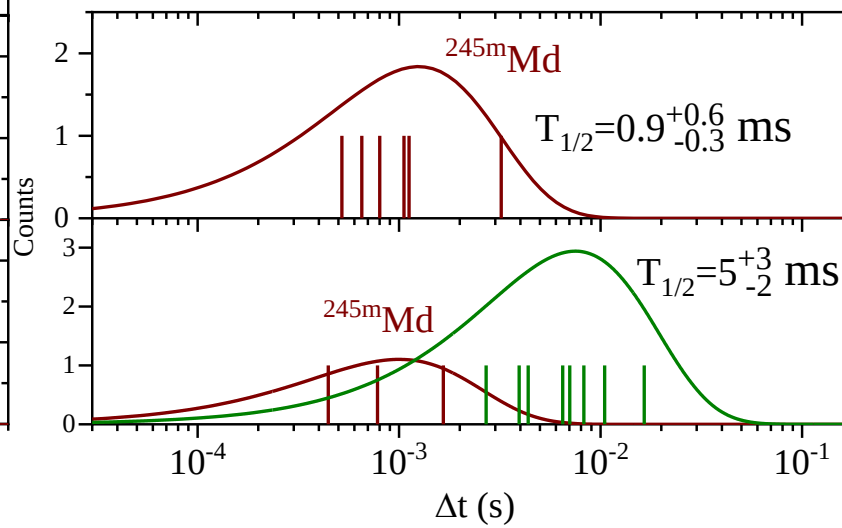
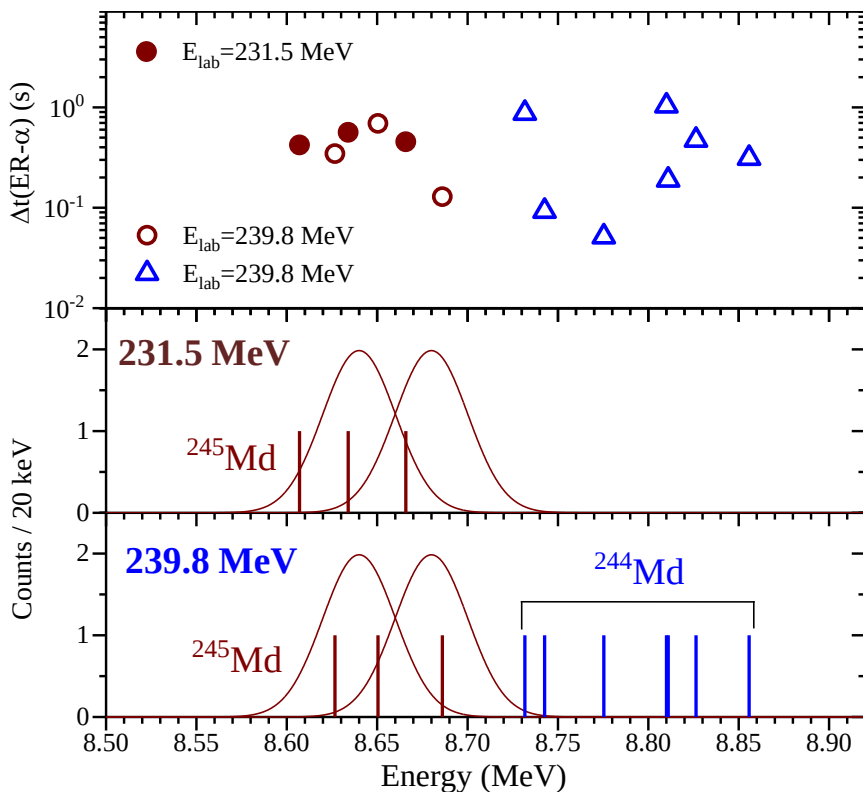
No EC-decay branch
was observed

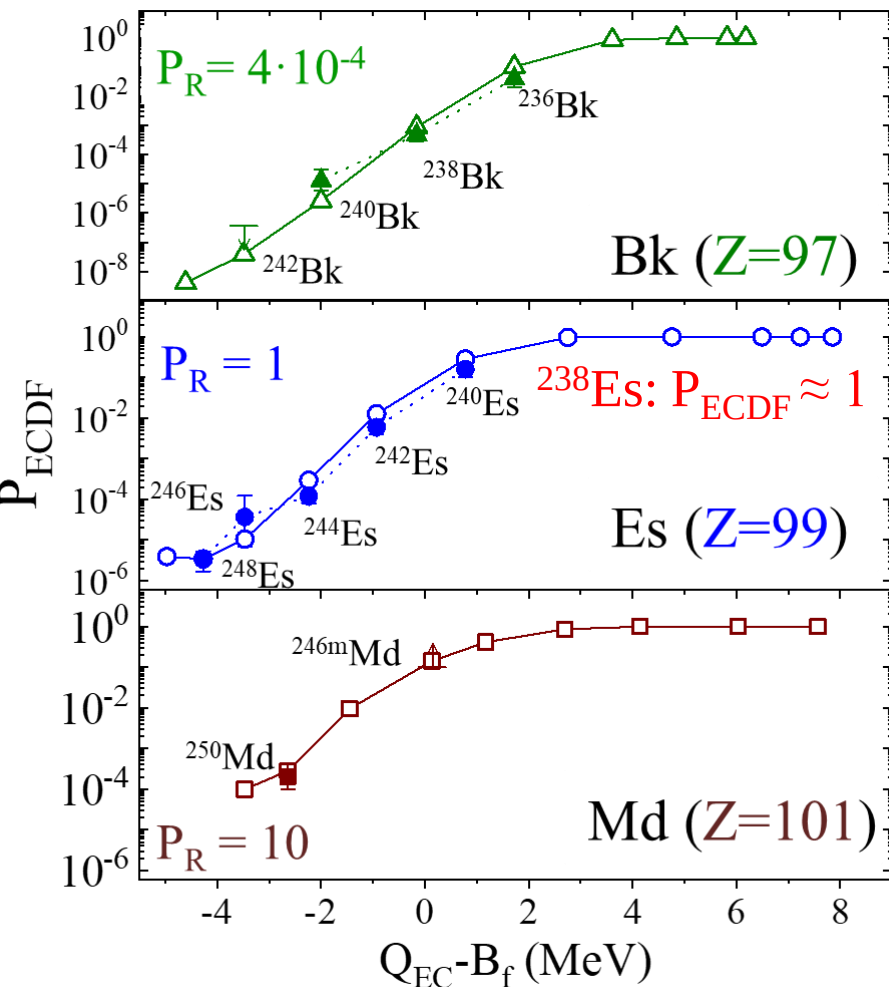


Never seen before!

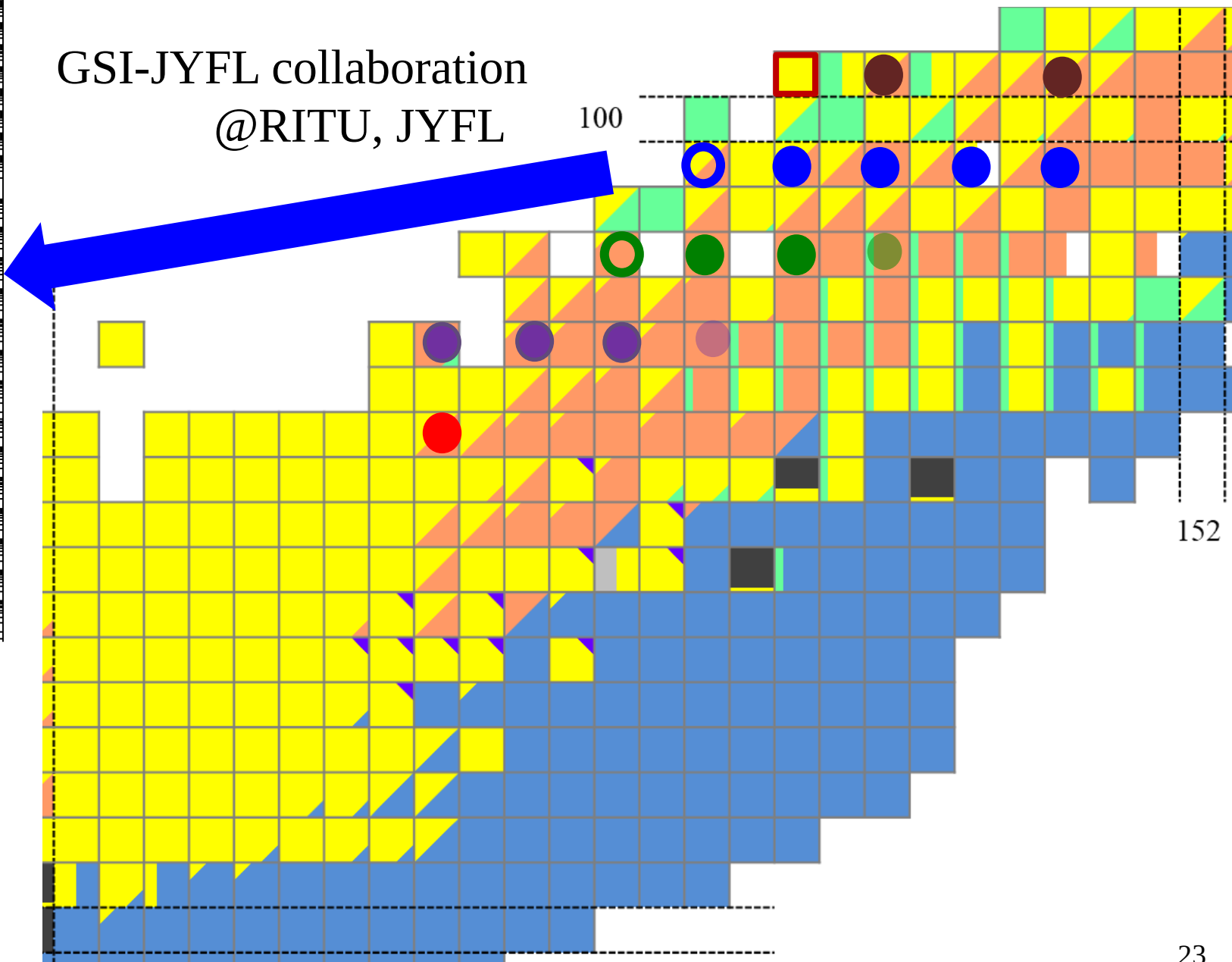
$T_{\text{SF}}(\text{odd-odd}) \gg T_{\text{SF}}[\text{even-even}]$

??





GSI-JYFL collaboration
@RITU, JYFL



Search for ECDF

J. Khuyagbaatar, Eur. Phys. J. A **55**, 134 (2019)

Search for sea of instability

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

Examining the robustness of N=126 shell

J. Khuyagbaatar et al., Phys. Rev. Lett. **115**, 242502 (2015)

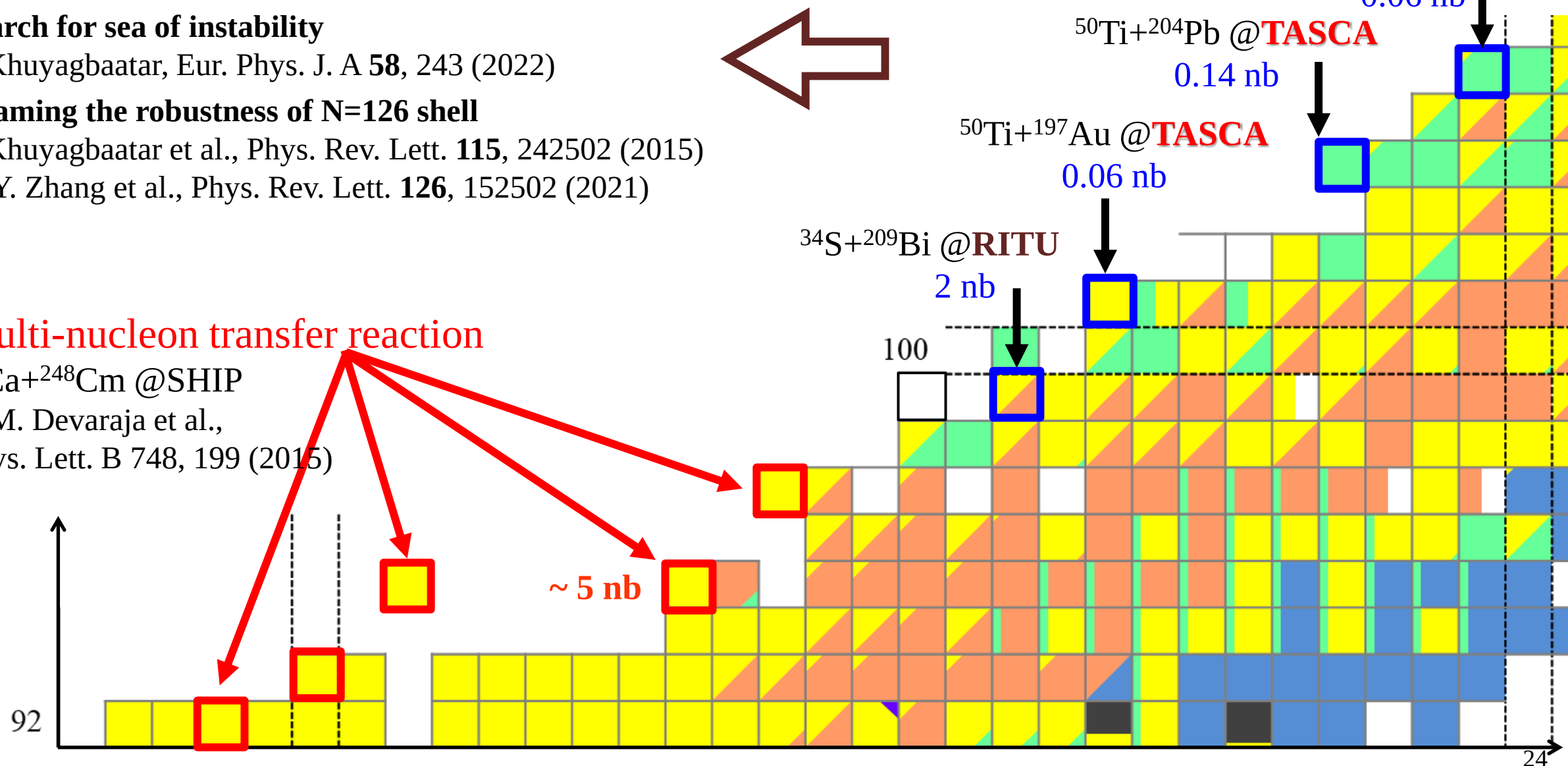
Z. Y. Zhang et al., Phys. Rev. Lett. **126**, 152502 (2021)

...

Multi-nucleon transfer reaction

$^{48}\text{Ca} + ^{248}\text{Cm}$ @SHIP

H.M. Devaraja et al.,
Phys. Lett. B **748**, 199 (2015)



$^{48}\text{Ca} + ^{\text{nat}}\text{Re}$ @TASCA

J. Khuyagbaatar, P. Mosat et al., Phys. Rev. C. **114**, L011302 (2026)

$^{48}\text{Ca} + ^{185}\text{Re}$: **< 0.02 nb**

No event for ^{229}Am

$^{48}\text{Ca} + ^{187}\text{Re}$: **0.1 nb**

The new isotope ^{231}Am

The new isotopes ^{231}Am and ^{235}Bk

@**SHANS-2**, IMP, Lanzhou, China

J. Wang et al., Phys. Lett. B 875, 140365 (2026)

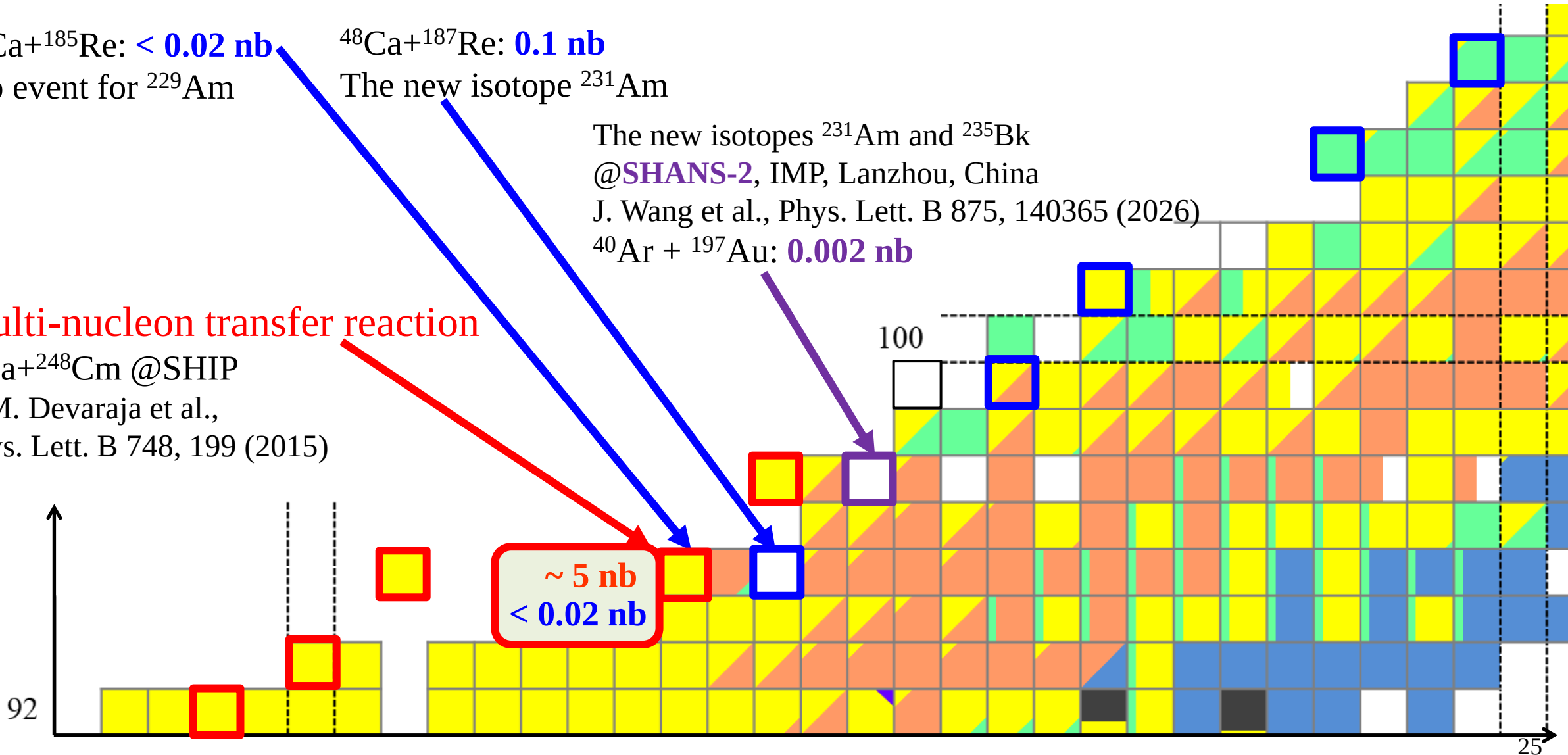
$^{40}\text{Ar} + ^{197}\text{Au}$: **0.002 nb**

Multi-nucleon transfer reaction

$^{48}\text{Ca} + ^{248}\text{Cm}$ @SHIP

H.M. Devaraja et al.,

Phys. Lett. B 748, 199 (2015)





J. Khuyagbaatar, B. Kindler,
A. Yakushev, N. Kurz,
Ch.E. Düllmann, M. Block,
P. Mosat H. Brand,
E. Jäger, F.P. Heßberger,
J. Krier, A. Hübner,
B. Schausten, B. Lommel,
L. Lens V.Yakusheva
H.M. Albers A.Mistry
R.A. Cantemir S. Heinz
Y. Wei I.Kojouharov
S. Löchner P. Kuusiniemi
P. Wiczorek M. Mazzocco
J. Ballof S. Streicher



A.Di Nitto,
J.V. Kratz
L. Lens
M. Götz
S. Götz
D. Dietzel
K. Hermainski



M. Leino
J. Uusitalo
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GSI-JYFL are shaping the (super)heavy element research over five decades

An interest on the fission properties of (super)heavy nuclei is renewed

- Discoveries of ^{252}Rf , ^{257}Sg @TASCA
- Discoveries K-isomeric states ^{252}Rf , ^{259}Sg @TASCA, $^{258-261}\text{Sg}$ @SHIP
- Discoveries of ^{240}Es , ^{236}Bk @RITU
- Discovery of ^{244}Md @TASCA

Fission hindrance due to the single(multi) particle configuration is not yet understood

ECDF is yet to be explored in superheavy nuclei

Need more comprehensive experimental data

- Fusion and multinucleon transfer reactions

Thank you
for your kind attention