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UNIVERSITÄT BERN

Wir schaffen Wissen – heute für morgen

TAN 11

CHEMISTRY EXPERIMENT THEORY PHYSICS

Paul Scherrer Institute and Bern University

Andreas Türler for a TUM, GSI, JINR, Mainz, JAEA, LBNL, UCB, Oslo, Lund, IET, IMP, PSI collaboration

Nuclear and Chemical Studies with Hassium Isotopes

Nuclear and Chemical Studies with Hassium Isotopes

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Topics

Shell correction energies and static fission barriers near Z=108 and N=162

- Macroscopic-microscopic calculations

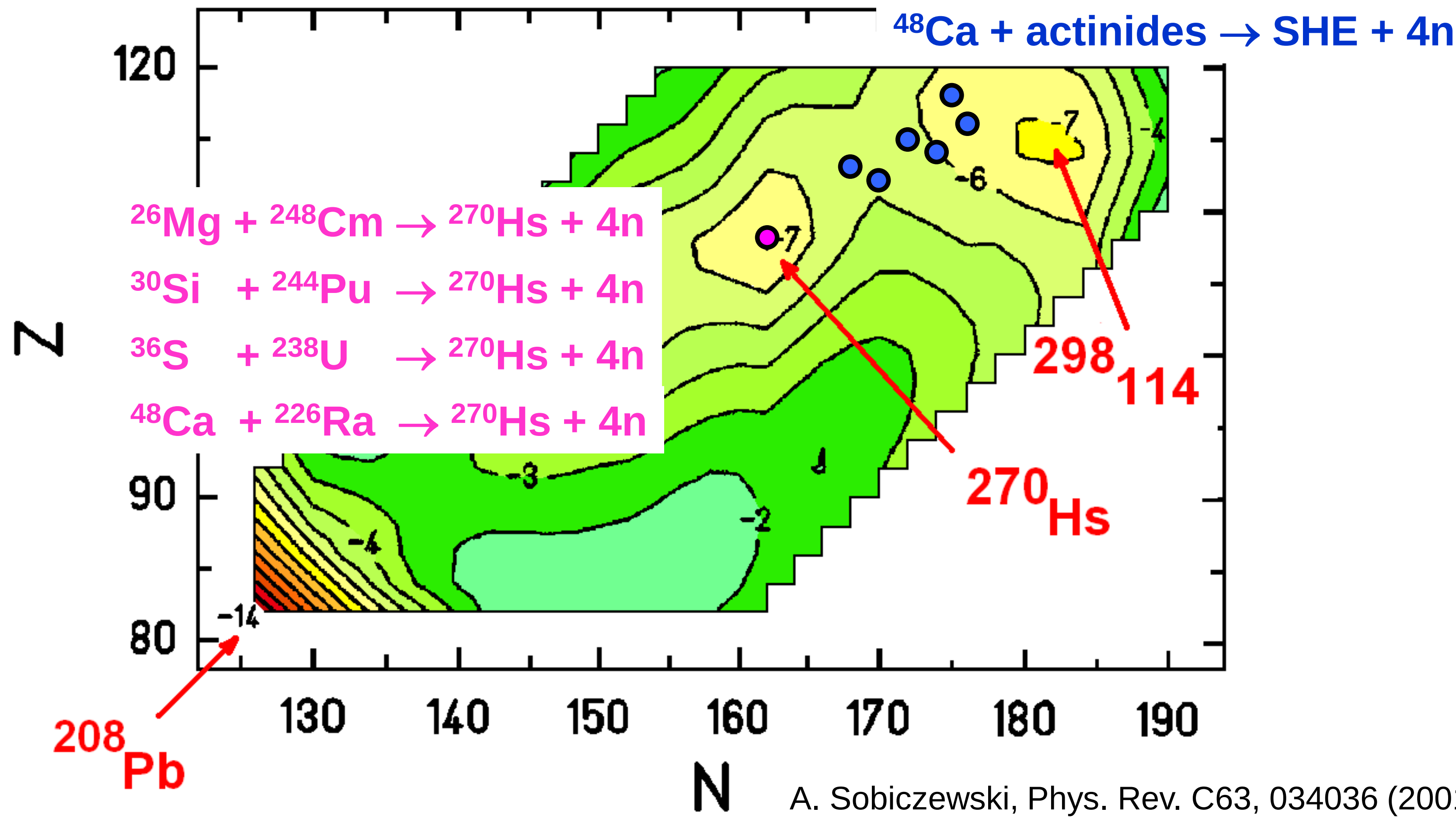
Synthesis of Hassium isotopes in reactions leading to the compound nucleus $^{274}Hs^{*}$

- Synthesis of the new nuclides ^{270}Hs and ^{271}Hs
- Evidence for isomeric states in ^{265}Sg and ^{261}Rf
- New decay properties of ^{266}Sg
- Observation of the 3n evaporation channel in the reaction $^{26}Mg+^{248}Cm$
- First results on the synthesis of ^{270}Hs in the reactions $^{36}S+^{238}U$ and $^{48}Ca+^{226}Ra$

Chemical properties of Hassium-tetroxide

Macroscopic-microscopic shell correction

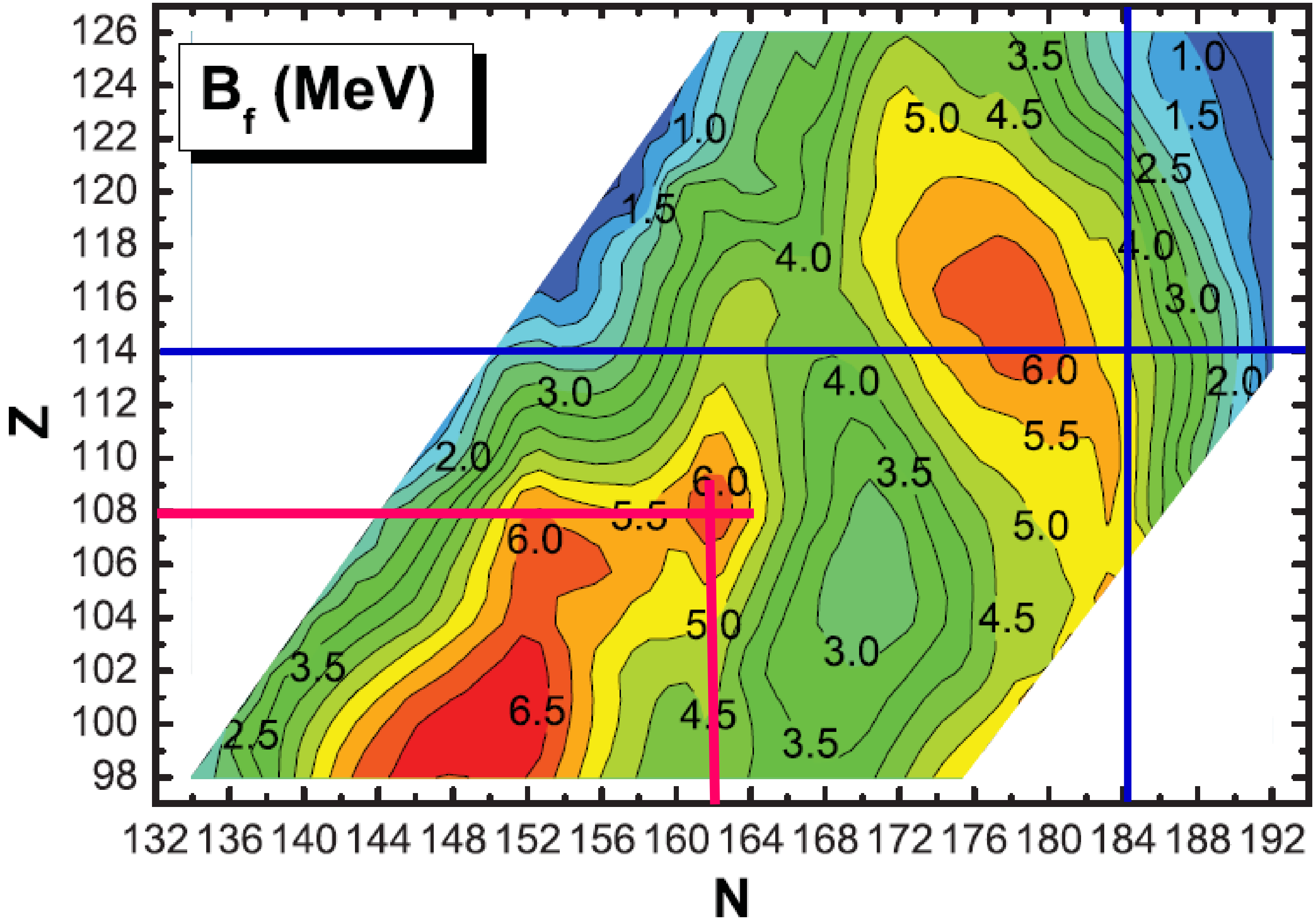
Shell correction energies for nuclides with Z≥82 and N≥126



A. Sobiczewski, Phys. Rev. C63, 034036 (2001)

Fission barriers: a similar picture!

Calculated static fission barriers heights



M. Kowal et al., Phys. Rev. C82, 014303 (2010)

Theoretical Predictions

$$\sigma_{EVR} = \sigma_{capt} \times P_{CN} \times W_{SUR}$$

Reaction	B [MeV]	Q [MeV]	(B-Q) [MeV]	$Z_1 \cdot Z_2$
$^{26}Mg + {}^{248}Cm$	126.9	-82.2	44.7	1152
$^{30}Si + {}^{244}Pu$	144.0	-98.0	46.0	1316
$^{36}S + {}^{238}U$	159.1	-116.7	42.4	1472
$^{48}Ca + {}^{226}Ra$	187.0	-153.9	33.1	1760

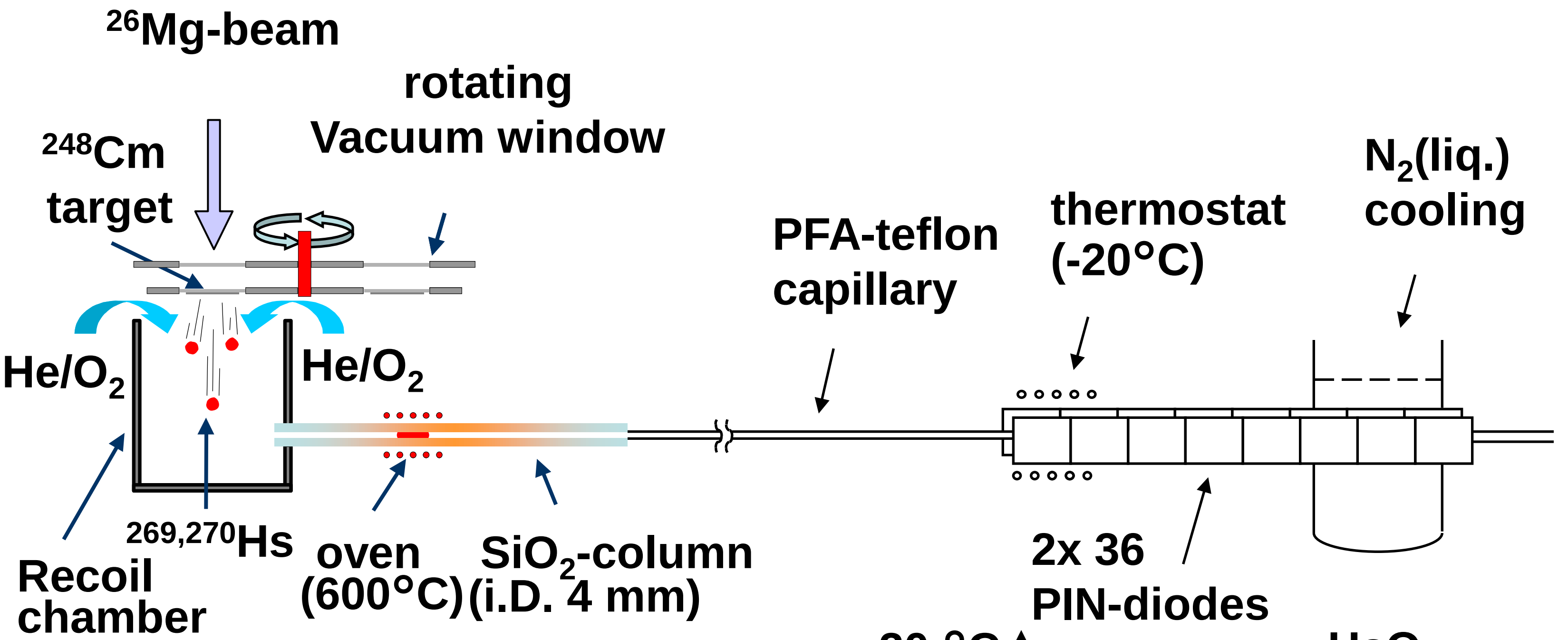
Q-value (Q)

E* (CN ^{274}Hs*)

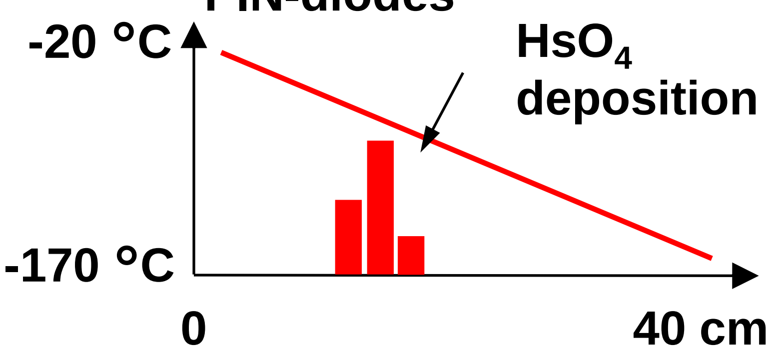
$E^* = E_{CM} - E_{Coul} + Q$

Figure: Z.H. Liu et al., PRC 74, 057602 (2006)
Animation: Ch.E. Düllmann, GSI

Chemistry: a highly efficient Hassium separator



Overall Efficiency for ^{269}Hs: 55%



Detection system COMPACT

Cryo

On-line

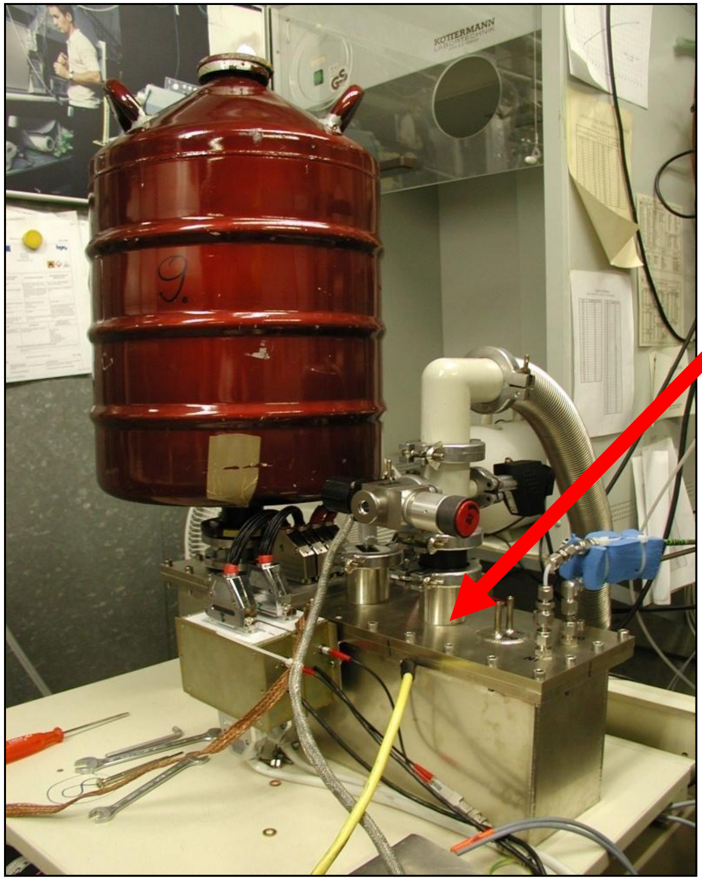
Multidetector for

Physics

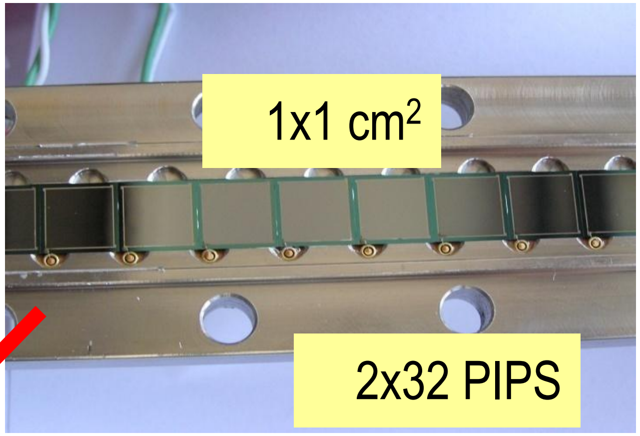
And

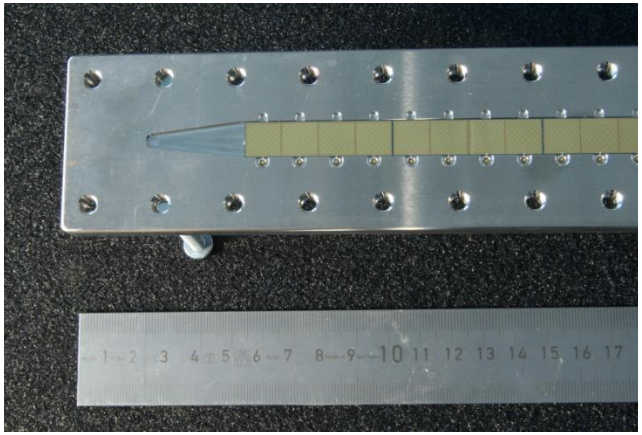
Chemistry of

Transactinides



Version 1: 78% detection eff.





Version 2: 93% detection eff.

Search for the doubly magic nucleus ^{270}Hs

$^{26}Mg + ^{248}Cm$

TABLE I. Correlated decay chains. Given are the number of the chain, the beam energy at which it was observed, energies of individual events (E_1 to E_4), the observed lifetimes of the daughter nuclei (Δt_2-Δt_4), and the assignment of the chain. The detector in which an event was observed is given in parenthesis, "T" stands for "top detector" and "B" for "bottom detector". Energies are given in MeV, fission fragment energies are not corrected for pulse height defect.

No.	E_{beam}	E_1	E_2	Δt_2	E_3	Δt_3	E_4	Δt_4	Assignment
1	145	8.93 (16T)	8.69 (16B)	32.5 s	8.29 (16T)	32.1 s	8.29 (17B)	2.50 s	^{269}Hs
2	145	9.06 (13B)	8.68 (14T)	85.6 s	93 (14T)	4.44 s			^{269}Hs
3	145	9.11 (1B)	8.68 (1B)	2.48 s	67/13 (1T/1B)	7.09 s			^{269}Hs
4	145	8.91 (15B)	8.65 (15B)	6.75 s	29 (15T)	6.69 s			^{269}Hs
5	145	9.03 (18T)	8.60 (18T)	7.70 s	111/26 (18T/19B)	6.42 s			^{269}Hs
6	145	8.92 (19B)	8.72 (19T)	6.82 s	90/101 (19T/19B)	1.29 s			^{269}Hs
7	145	8.35 (22B)	38 (22B)	116 ms					no assignment
8	145	8.85 (14T)	100/74 (14T/13B)	1.62 s					^{270}Hs
9	136	9.08 (15B)	8.71 (15T)	8.70 s	100/74 (15T/16B)	580 ms			^{269}Hs
10	136	9.10 (14T)	80/90 (14T/13B)	96.0 s					^{269}Hs[a]
11	136	8.90 (12T)	89/55 (12T/11B)	49.6 ms					^{270}Hs
12	136	8.92 (5T)	106/82 (5T/5B)	449 ms					^{270}Hs
13	136	8.88 (19T)	96/110 (19T/19B)	444 ms					^{270}Hs
14	136	9.30 (7T)	8.20 (7T)	149 s	89/95 (7T/7B)	12.0 s			^{271}Hs[a]
15	136	8.67 (9T)	117/102 (9T/9B)	306 ms					no assignment

[a]Tentative assignment.

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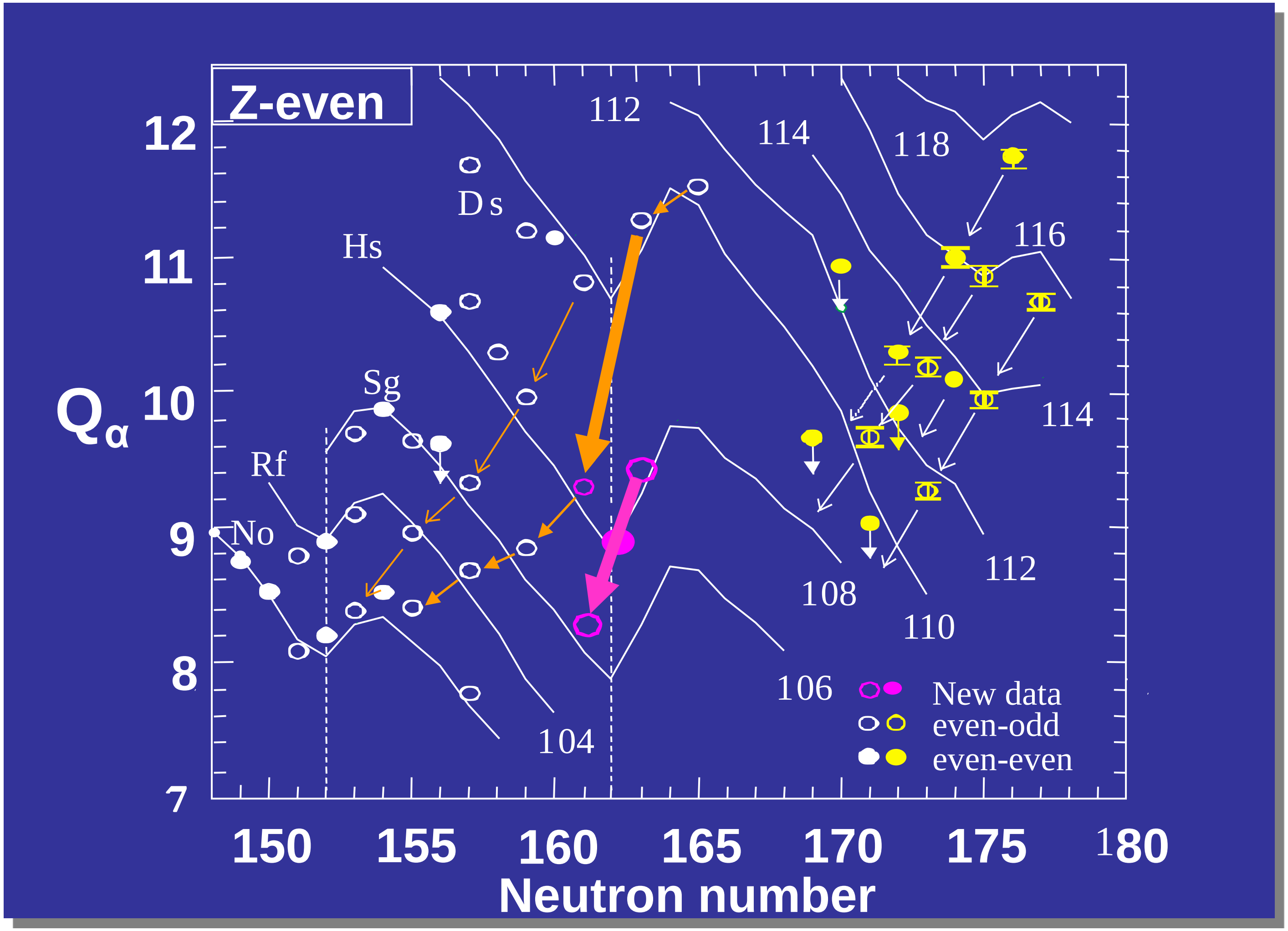
Signatures of crossing the *N*=162 neutron shell: ^{273}Ds → ^{269}Hs or ^{271}Hs → ^{267}Sg



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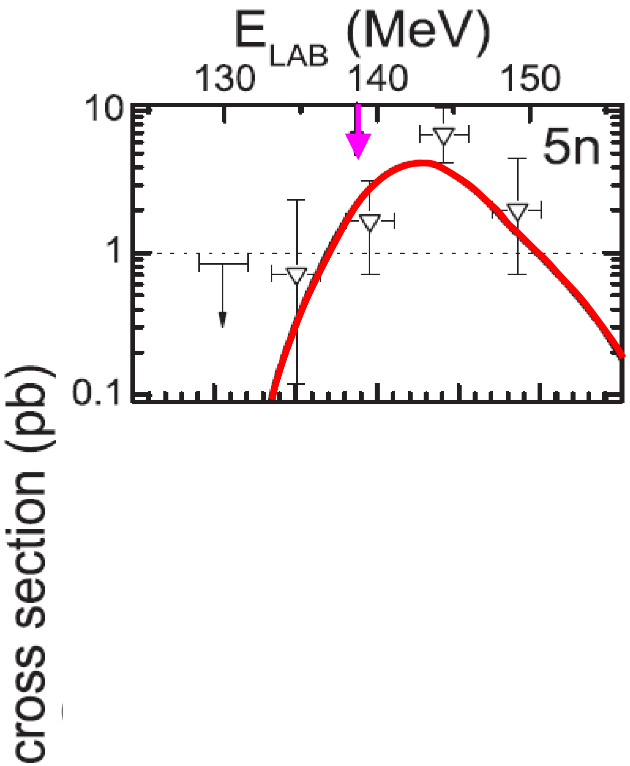
Confirmation experiment for ^{269}Hs, ^{270}Hs, and ^{271}Hs

TABLE II. Correlated decay chains observed in this work. Given are the number of the chain (continued from [5]), the beam energy at which it was observed, energies of individual events (E_1 to E_4), the observed lifetimes of the daughter nuclei (Δt_2-Δt_4), and the assignment of the chain. The detector in which an event was observed is given in parentheses. T stands for "top detector" and B for "bottom detector." Energies are given in MeV, fission fragment energies are not corrected for pulse height defects. Partial energy deposition is expected for fission fragments emitted under shallow angles.

No.	E_{beam}	E_1	E_2	Δt_2	E_3	Δt_3	E_4	Δt_4	Assignment
16	150	9.18 (14B)	8.62 (14T)	10.9 s	8.51 (14B)	4.89 s	8.24 (14T)	20.8 s	^{269}Hs
17	150	9.13 (12B)	8.68 (12T)	7.61 s	79/88 (12T/12B)	2.25 s			^{269}Hs
18	140	8.61 (10B)	83/84 (10T/10B)	3.35 s					^{265}Sg[a]
19	140	9.11 (10T)	8.63 (11B)	52.0 s	75/ − (10T)	3.04 s			^{269}Hs
20	140	[9.22 (11B)][b]	8.47 (16B)	[12.3 s][b]	84/120 (16T/16B)	128 ms			^{269}Hs[c]
21	140	8.76 (20B)	58/61 (19T/20B)	275 ms					^{270}Hs
22	140	8.81 (16B)	92/111 (16T/16B)	271 ms					^{270}Hs
23	140	9.14 (12T)	69/ − (12T)	47.9 s					^{271}Hs
24	130	9.16 (24T)	26/ − (25B)	142 s					^{271}Hs
25	130	9.02 (16B)	89/68 (15T/15B)	30.4 s					^{271}Hs
26	130	9.23 (20T)	15/83 (20T/19B)	264 s					^{271}Hs

[a]Incomplete (α)-α-SF chain from ^{269}Hs. [b]First α particle is not position correlated. [c]Tentative assignment.

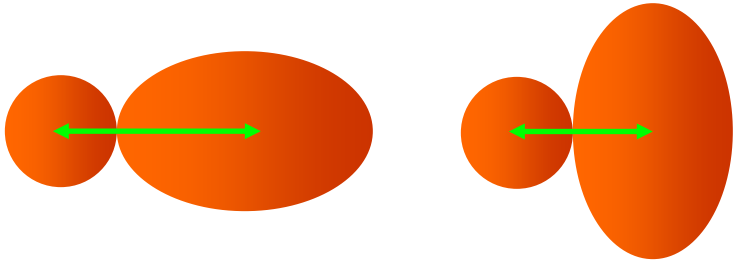
Excitation functions



^{269}Hs

location of the Bass fusion barrier

Orientation effects

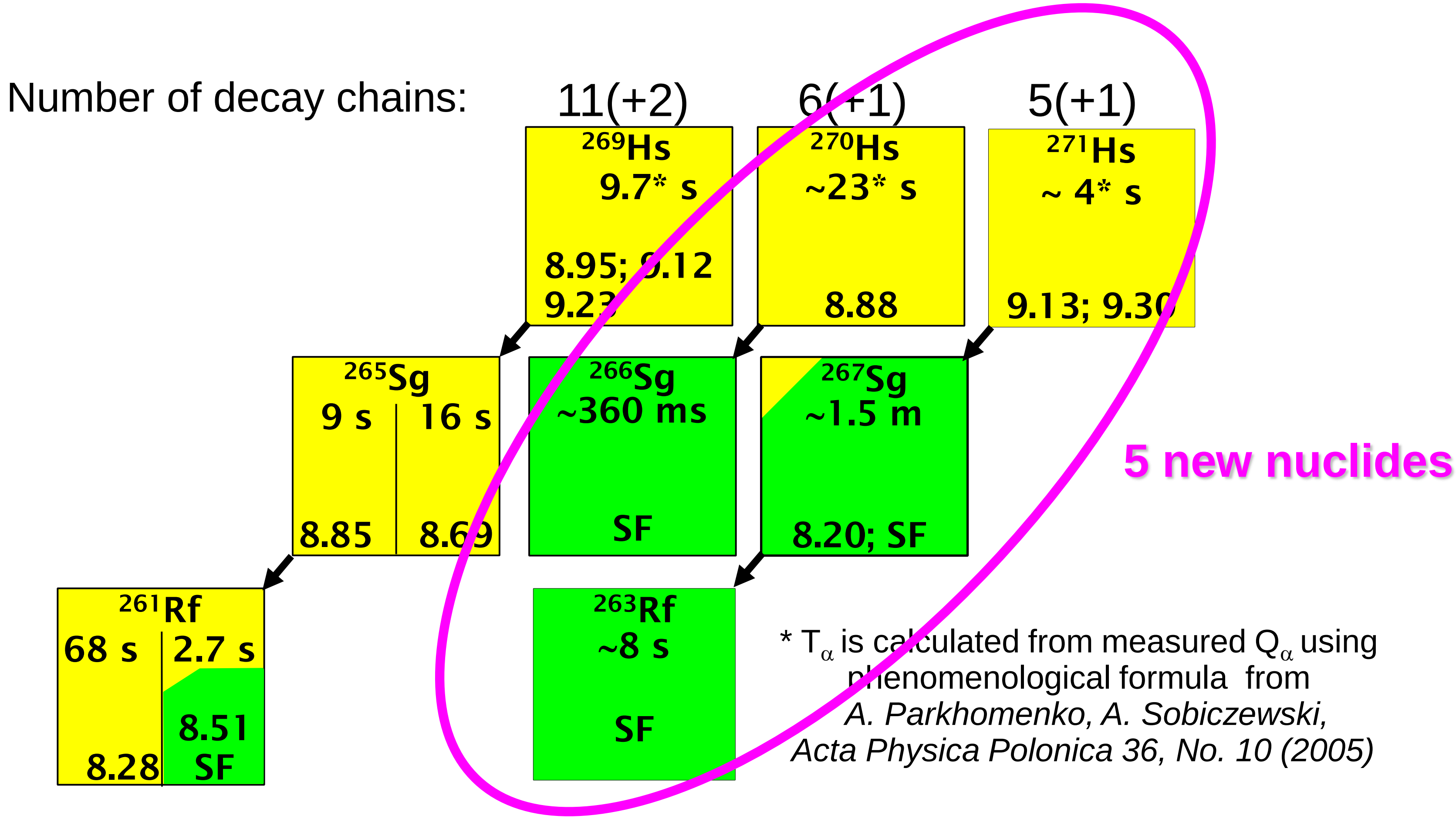


polar
low energy
(sub-barrier)

equatorial
high energy
(above barrier)

HIVAP calculations with parameters of
Reisdorf and Schädel, Z. Phys. A **343, 47 (1992)**

Observed Nuclides



* T_α is calculated from measured Q_α using phenomenological formula from *A. Parkhomenko, A. Sobiczewski, Acta Physica Polonica 36, No. 10 (2005)*

^{270}Hs: Jan Dvorak *et al.*, Physical Review Letters **97**, 242501 (2006)
^{271}Hs: Jan Dvorak *et al.*, Physical Review Letters **100**, 132503 (2008)

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Analysis of the decay of ^{265}Sg

Ch. E. Düllmann, A. Türler, Phys. Rev. C064320 (2008)

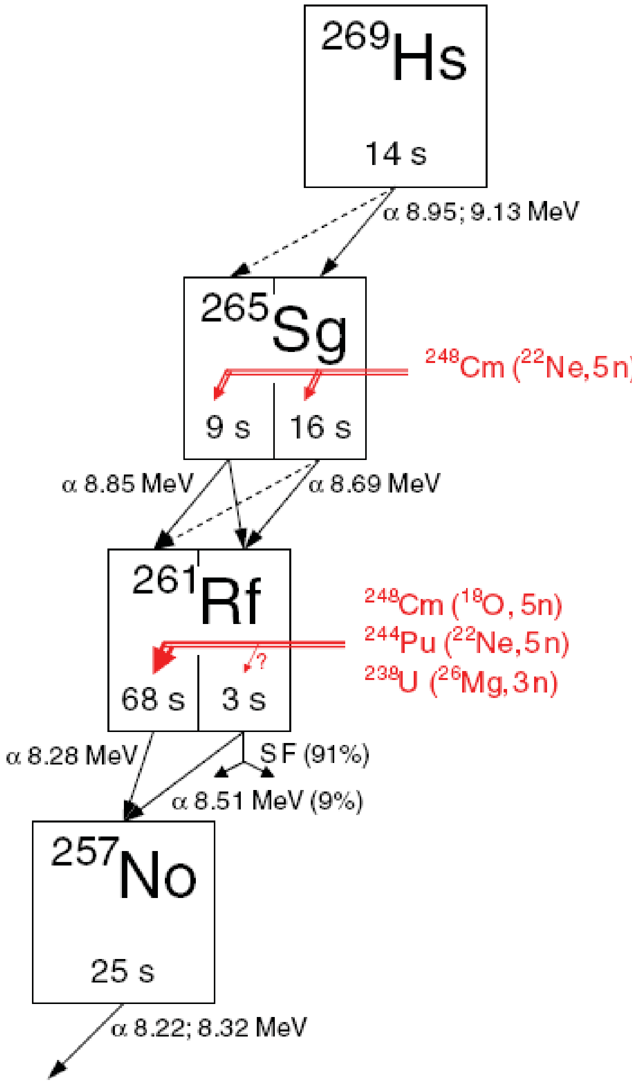
From the literature 60 decays of ^{265}Sg have been reported, in 58 cases the alpha decay energy was measured.

In 36 cases ^{265}Sg was produced directly as EVR

In 22 cases ^{265}Sg was produced as daughter of ^{269}Hs

In 24 cases ^{265}Sg decayed by alpha-particle emission to ^{261a}Rf

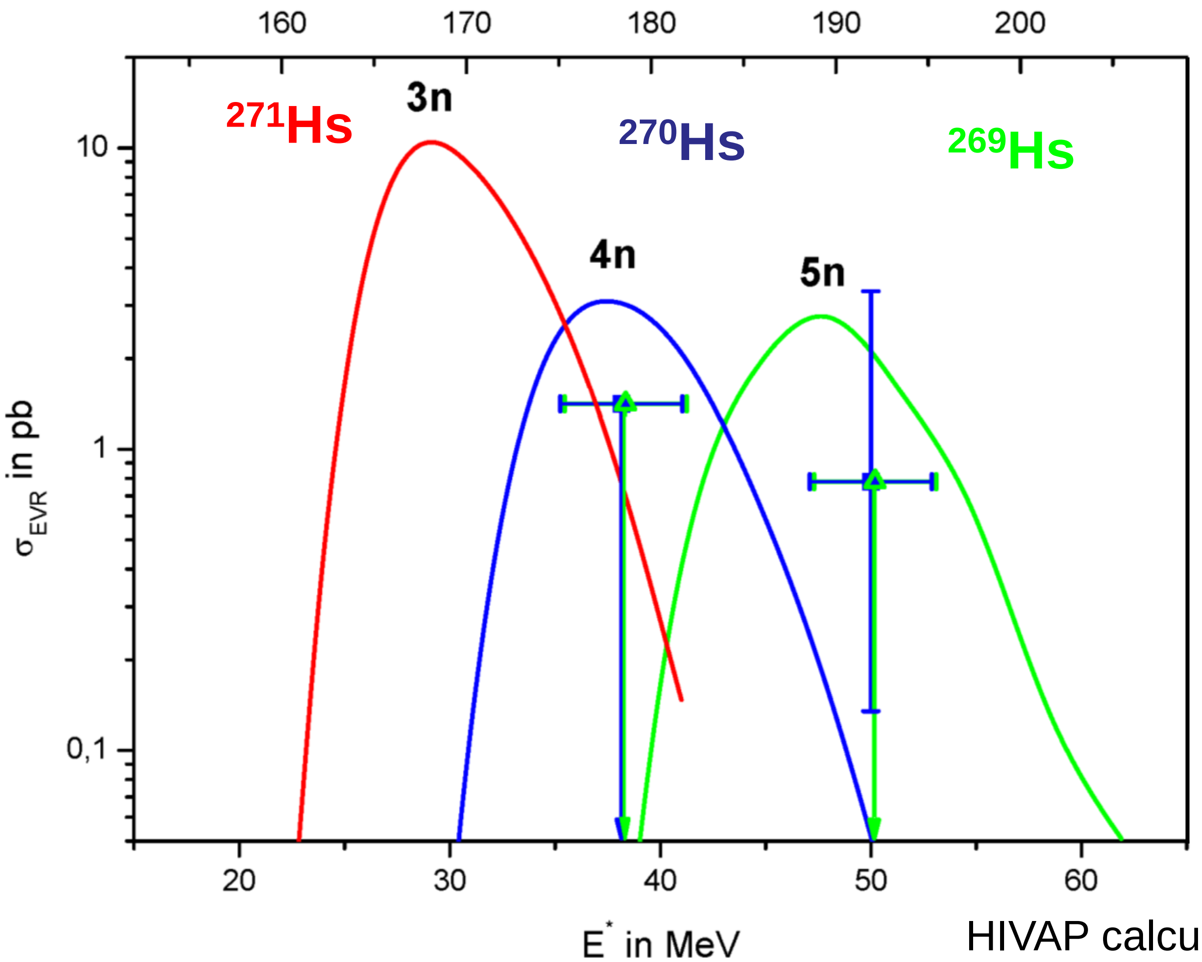
In 34 cases ^{265}Sg decayed by alpha-particle emission to ^{261b}Rf



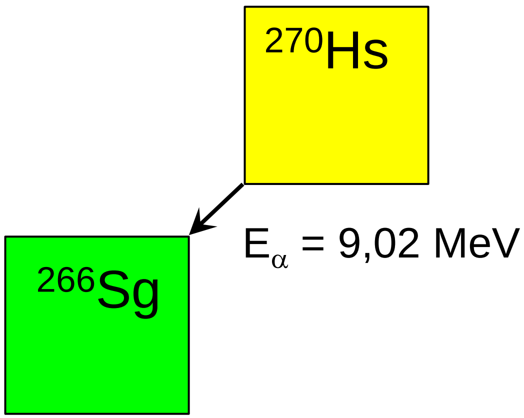
Recently fully confirmed in experiments by Haba et al.!

An alternative reaction: $^{238}U(^{36}S, xn)^{274-x}Hs$

R. Graeger et al., Phys. Rev. C81, 061601R (2010)



Only 1 event at E*=50 MeV

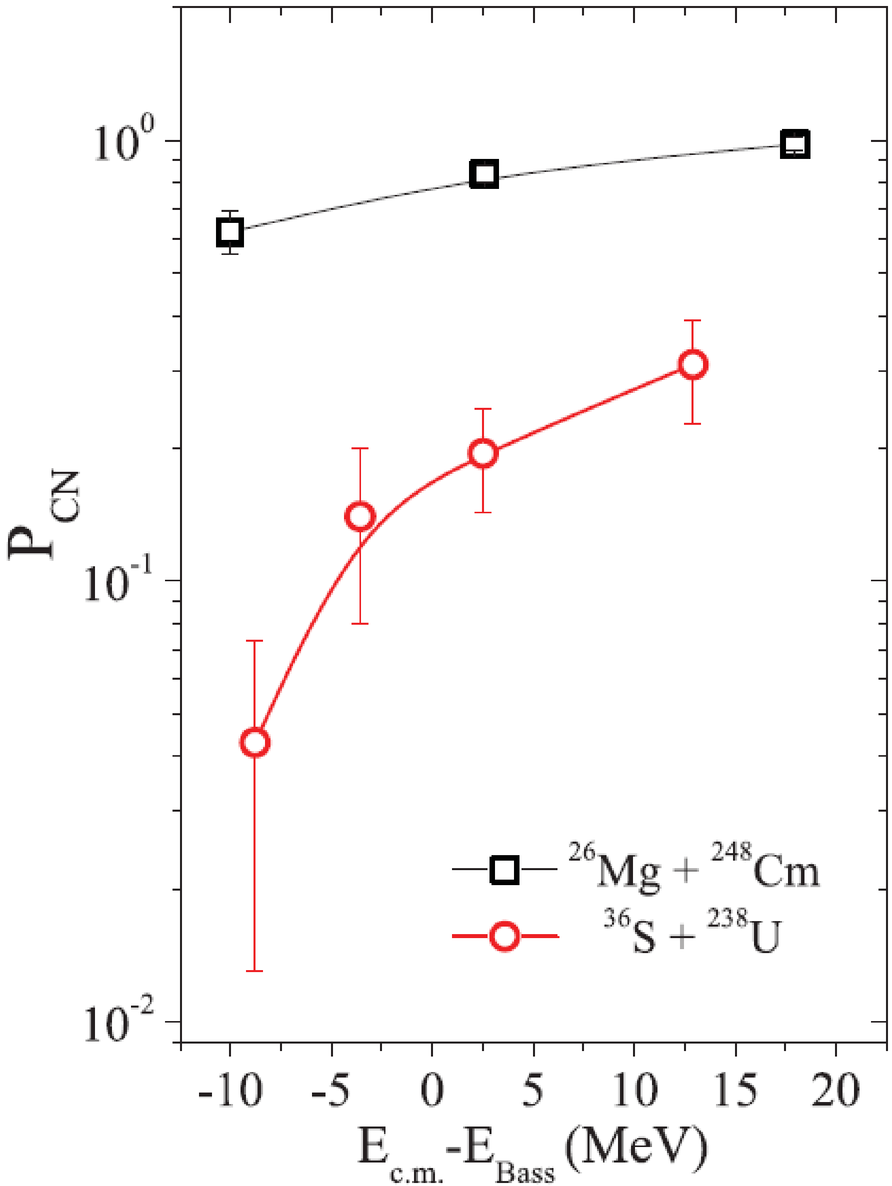


sf 41 + ? MeV

Δt = 23,492 ms

HIVAP calculations with parameters of Reisdorf and Schädel, Z. Phys. A **343, 47 (1992)**

A possible explanation

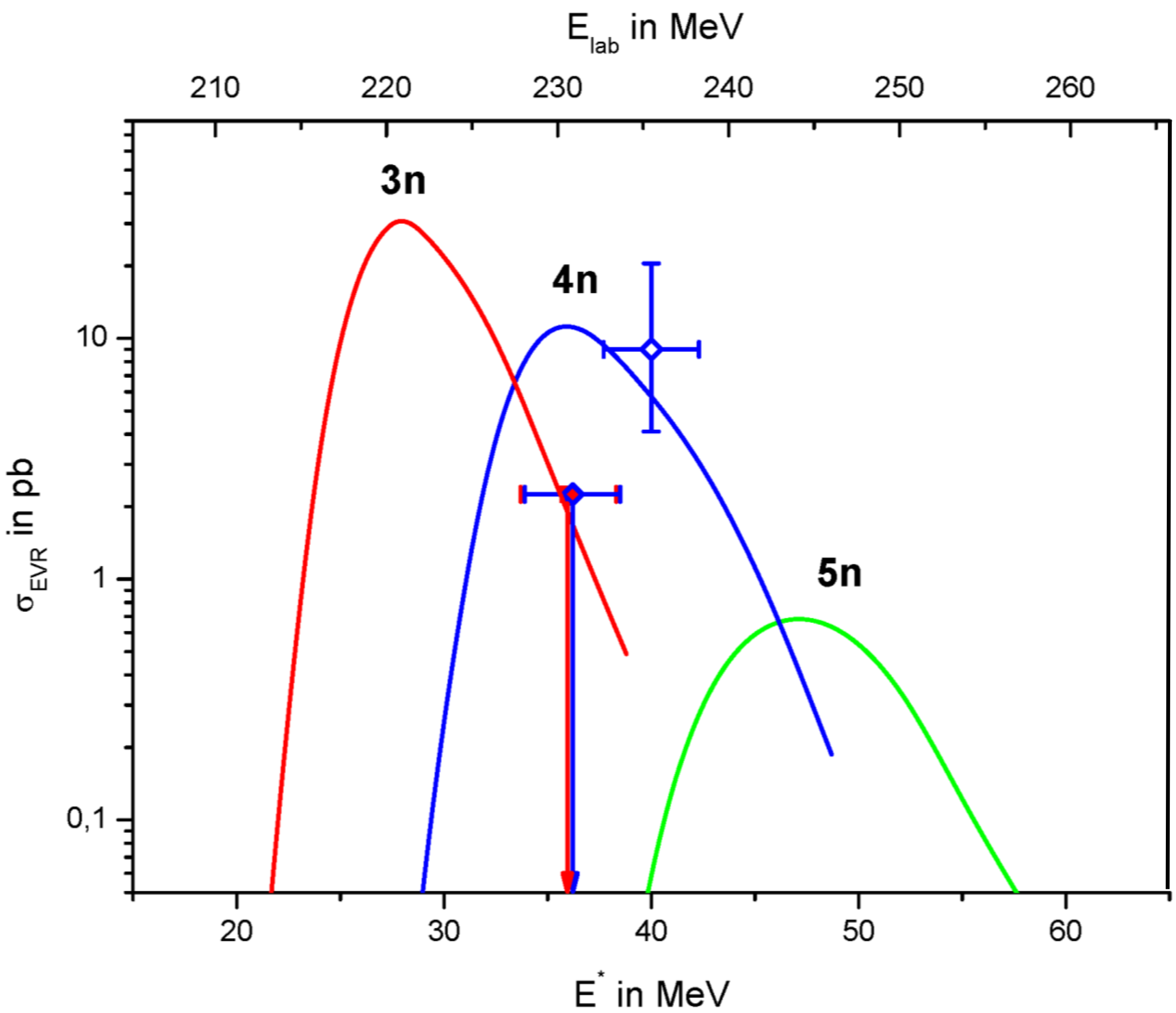


Δ(B-Q) = 2.3 MeV (only!)
but
ΔP_{CN} = Factor 5 – 10!

Reaction	B [MeV]	Q [MeV]	(B-Q) [MeV]	$Z_1 \cdot Z_2$
$^{26}Mg + ^{248}Cm$	126.9	-82.2	44.7	1152
$^{30}Si + ^{244}Pu$	144.0	-98.0	46.0	1316
$^{36}S + ^{238}U$	159.1	-116.7	42.4	1472
$^{48}Ca + ^{226}Ra$	187.0	-153.9	33.1	1760

I.M. Itkis et al., PRC 83, 064613 (2011)

Preliminary results: $^{226}Ra(^{48}Ca, xn)^{274-x}Hs$



Very recent experiment by V. Utyonkov et al., at DGFRS / FLNR

6 events ^{270}Hs observed at E* = 40 MeV

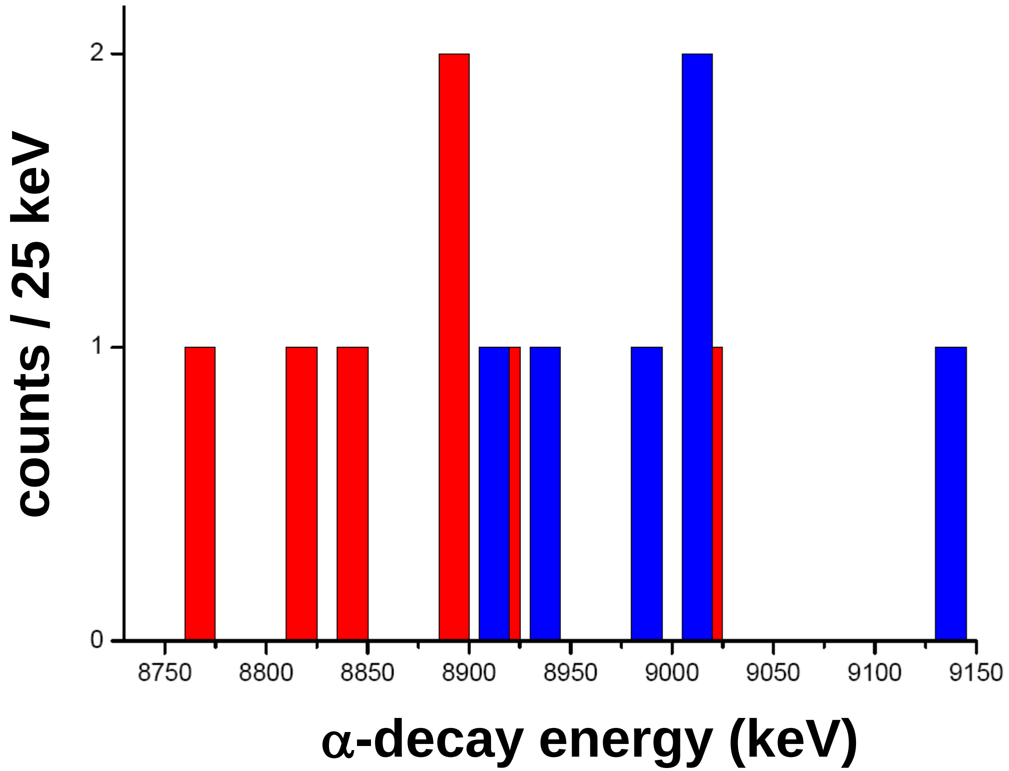
HIVAP calculations with HIVAPSI (R. Dresser et al.)

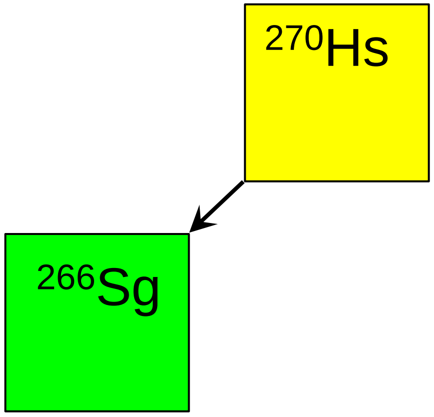
^{270}Hs from chemistry exp. ↔ ^{270}Hs from physics exp.

E_α = 8.88±0.05 MeV

E_α = 9.00±0.08 MeV

$T_{1/2} = 7.6^{+5.2}_{-2.3}$ s





$T_{1/2}(^{266}Sg) = 310^{+188}_{-85}$ ms

$T_{1/2}(^{266}Sg) = 284^{+195}_{-82}$ ms

SF half-lives of Seaborgium Nuclides

K.E. Gregorich et al., Phys. Rev. C74, 044611 (2006)

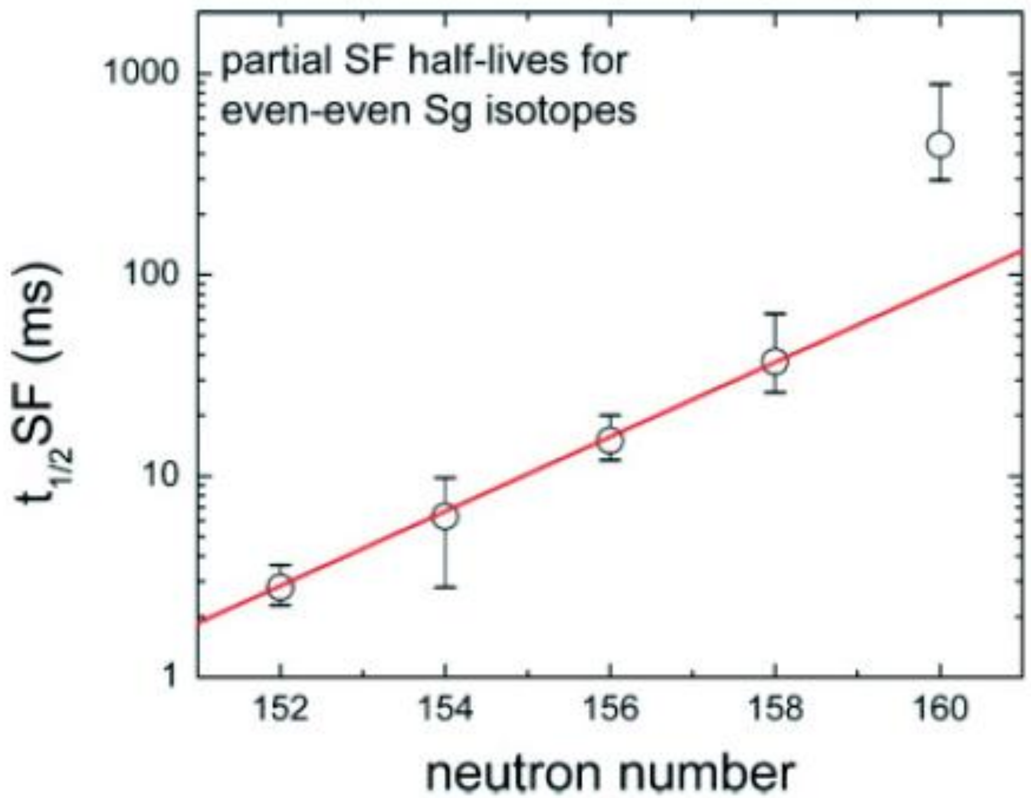
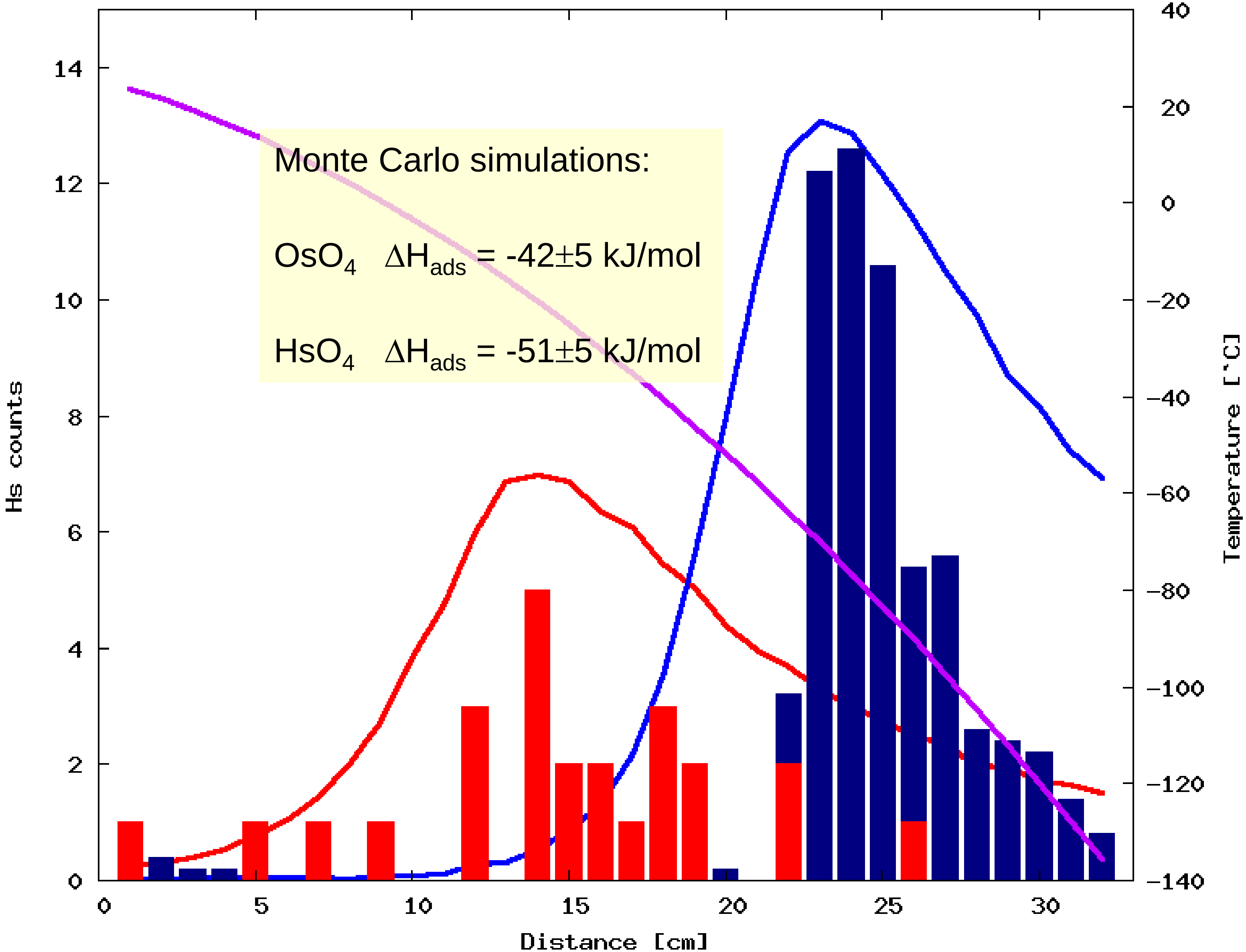


FIG. 3. (Color online) Partial spontaneous fission half-lives for even-even Sg isotopes. The line is drawn to guide the eye.

Thermochromatography of HsO_4



Conclusions

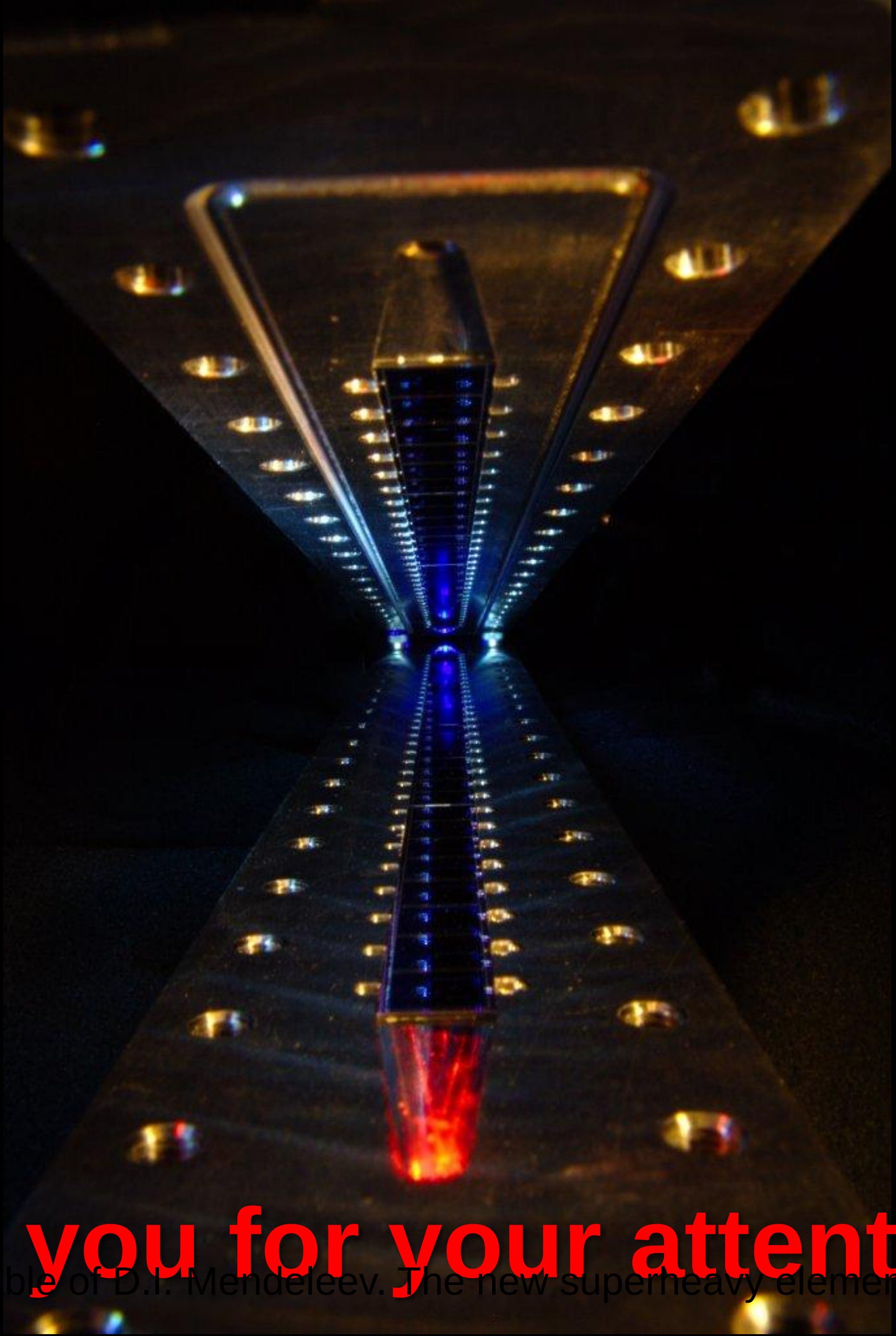
- The contribution of chemistry to SHE research is vital due to the high decontamination factors achieved (especially in combination with a recoil separator)
- Evidence for isomeric states in ^{265}Sg and ^{261}Rf observed in the decay chains of ^{269}Hs
- Discovery of the new “doubly magic” nucleus ^{270}Hs, new decay properties of ^{266}Sg
- Indications for the new nucleus ^{271}Hs and its decay products ^{267}Sg and ^{263}Rf
- Contrary to predictions the reaction ^{36}S + ^{238}U has a small cross section for the 4n and 5n reaction channel
- The decay properties of ^{270}Hs were confirmed using the reaction ^{226}Ra(^{48}Ca, 4n) with high cross section ($\approx$ 10 pb) for the 4n reaction channel.

Acknowledgements

This work was supported by the German Bundesministerium für Bildung und Forschung (BMBF) under contract No. 06MT247I

I thank GSI Darmstadt and the staff of the UNILAC for providing intense and stable beams of the exotic projectile ^{36}S.

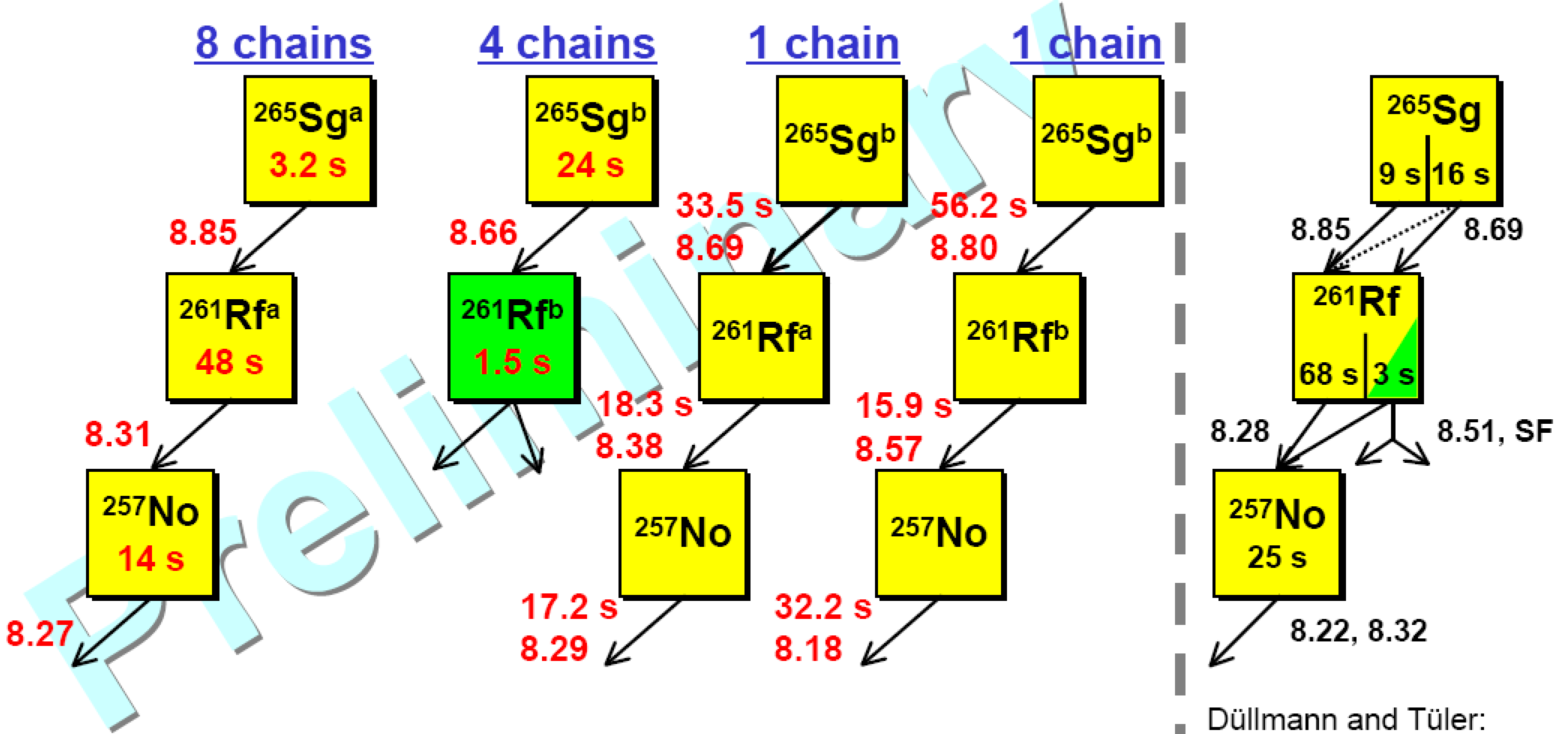
I thank V. Utyonkov and his staff of the DGFRS, Flerov Laboratory of Nuclear Reactions, Dubna for providing preliminary results of the reaction $^{48}Ca + ^{226}Ra$



Thank you for your attention!

able of D.I. Mendeleev. The new superheavy element

Preliminary data for the reaction $^{248}Cm(^{22}Ne, 5n)^{265}Sg$ measured at GARIS (RIKEN) by H. Haba (TASCA 2008)



Düllmann and Tüler: PRC **77**, 064320 (2008).

14 correlations (35 α/fission events) on ^{265}Sg, ^{261}Rf, and ^{257}No

***Bρ* = 2.07±0.01 Tm, Δ*Bρ*/*Bρ* = 8.4±1.1%**

Preliminary results: $^{226}Ra(^{48}Ca, xn)^{274-x}Hs$ (communicated by V. Utyonkov, FLNR)

tsy108
14.07.08
“01:58”, str 11
01:58

ER: 15.993 MeV
16.33 mm

Hs 270
8.940 [2.278+6.662] MeV
6.4194 s #8 150 keV
13.75 mm

Sg 266
193.9 [170.6+23.3] MeV
0.1629 s #7
16.70 mm

tsy119
16.07.08
“05:51”, str 7
05:11

ER: 13.812 MeV
14.45 mm

Hs 270
9.009 MeV 85 keV
8.1642 s
13.84 mm

Sg 266
168.6 MeV
0.2450 s
14.32 mm

tsy124
18.07.08
“11:18”, str 7
10:39

ER: 11.461 MeV
23.53 mm

Hs 270
9.024 [1.132+7.892] MeV
9.7087 s #6 134 keV

Sg 266
>187.9 [166.3+>21.6] MeV
0.0708 s #8
24.10 mm

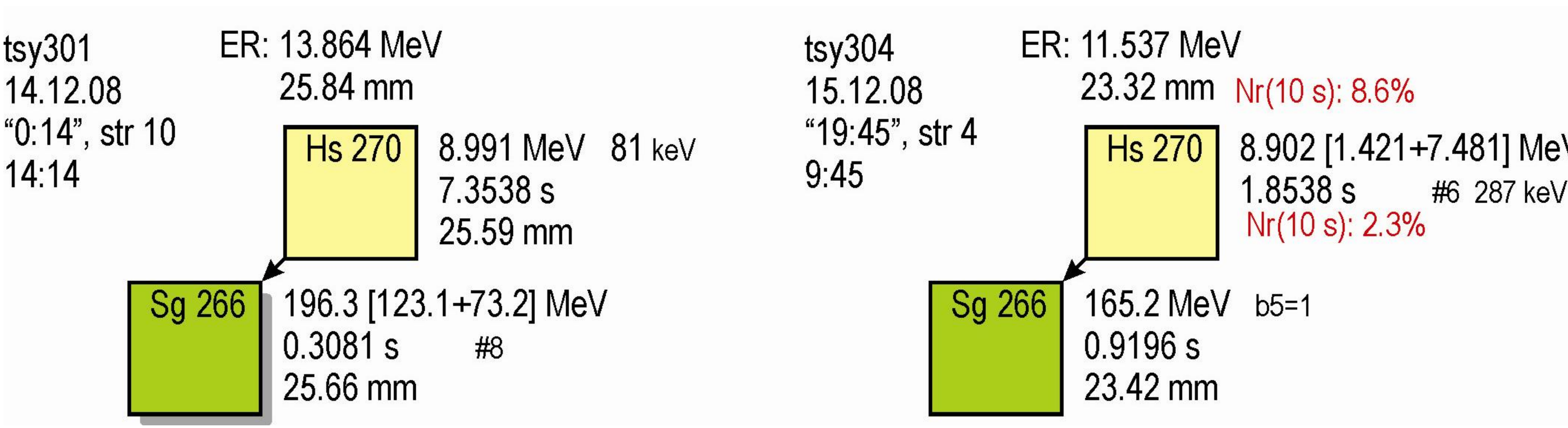
tsy129
19.07.08
“12:28”, str 8
11:49

ER: 11.356 MeV
31.40 mm

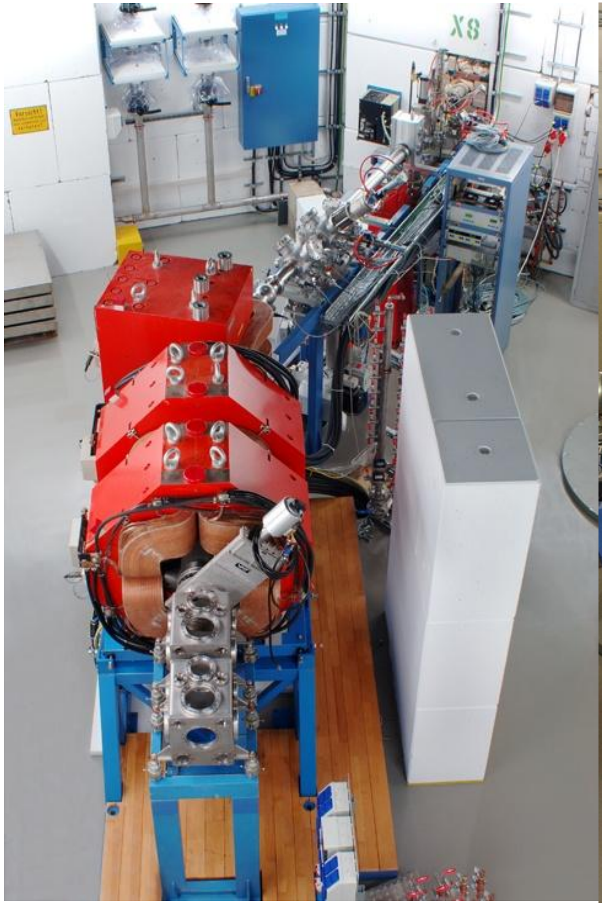
Hs 270
9.133 MeV 109 keV
31.9395 s
30.24 mm

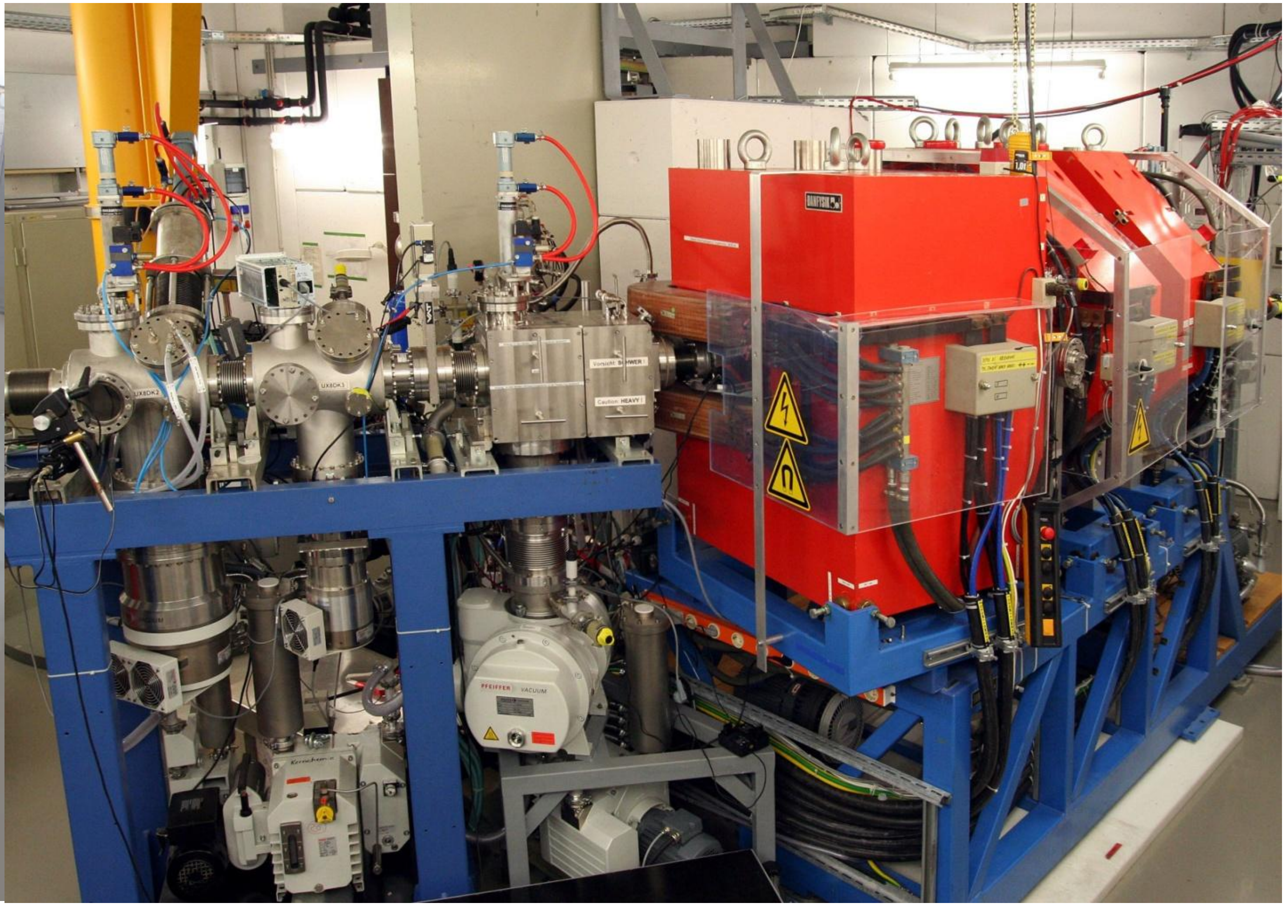
Sg 266
148.7 MeV
0.7517 s
29.98 mm

Preliminary results: ^{226}Ra(^{48}Ca, xn)$^{274\text{-}x}$Hs (communicated by V. Utyonkov, FLNR)



TASCA - Trans Actinide Separator and Chemistry Apparatus

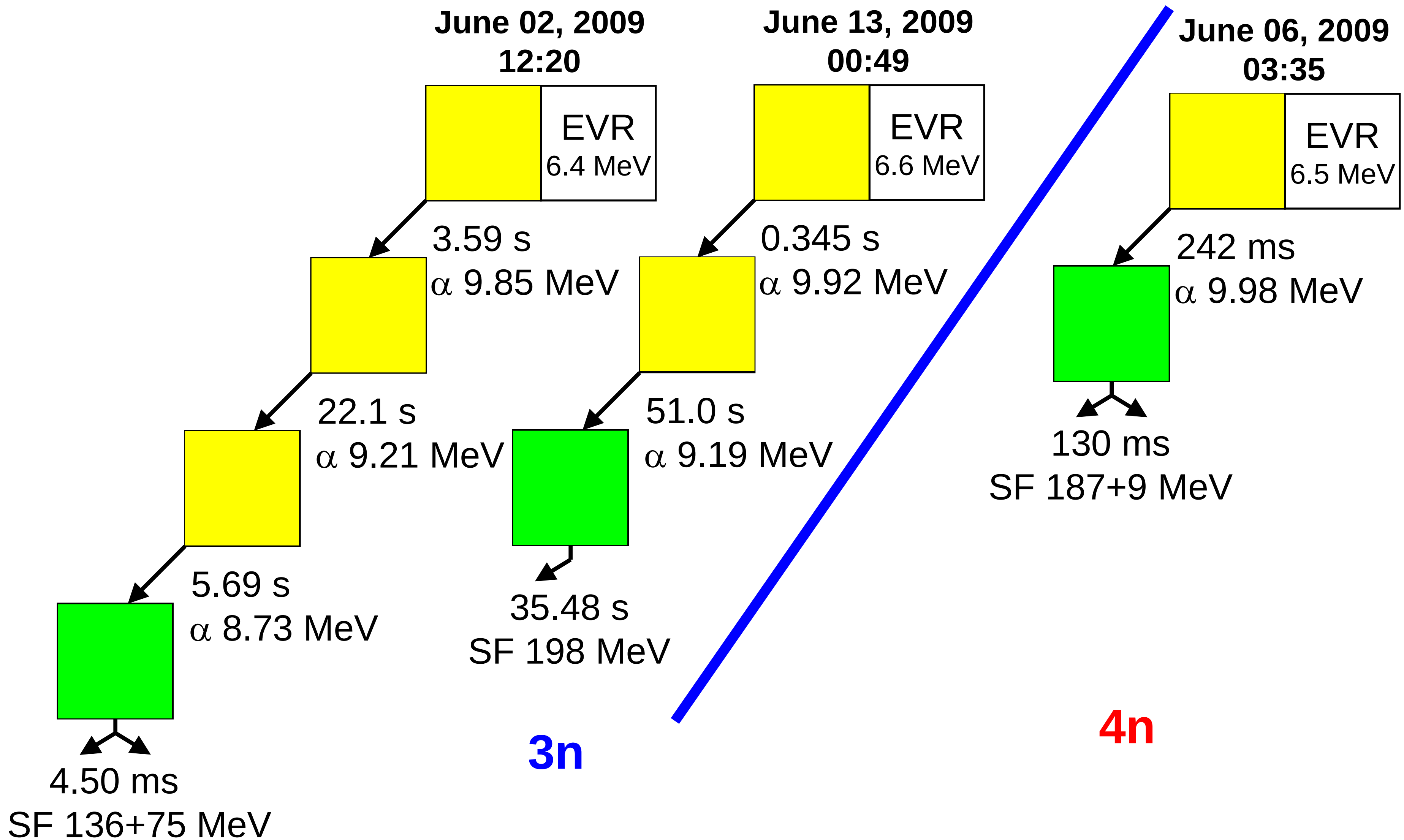




TASCA home page: http://www-w2k.gsi.de/tasca/

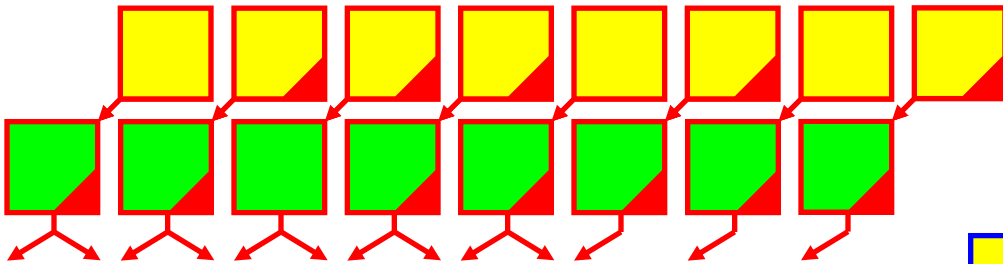
Observation of three types of decay chains

$^{244}\mathrm{Pu} + {}^{48}\mathrm{Ca} \rightarrow {}^{292}114^*$

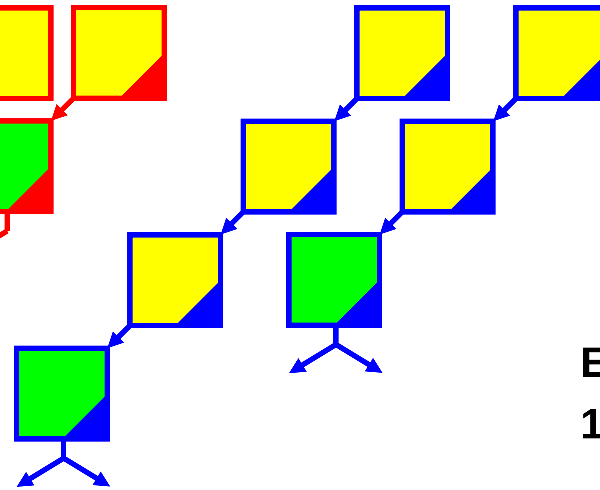


Observed Decay Chains (HTM)

8 chains from $^{288}114$ (4n)

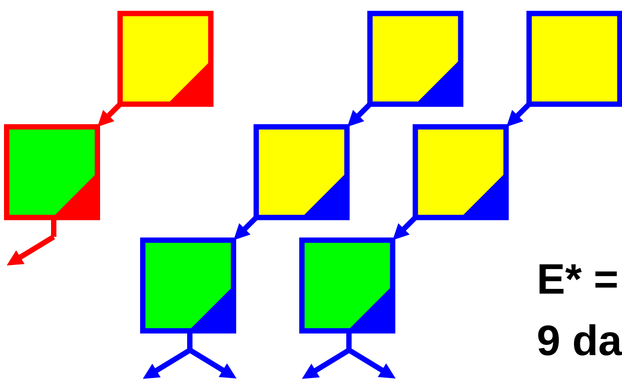


2 chains from $^{289}114$ (3n)



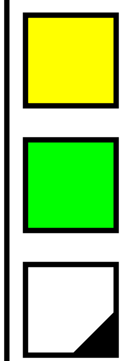
E* = 42 MeV (HTM)
14 days of beamtime

1 chains from $^{288}114$ (4n)
2 chains from $^{289}114$ (3n)



E* = 38 MeV (HTM)
9 days of beamtime

Summary:
10x $^{288}114$
3x $^{289}114$



α decay

SF

outside of beam pulse

Comparison of decay data (DGFRS ↔ TASCA)

$$^{48}\mathrm{Ca}+{}^{244}\mathrm{Pu} \rightarrow {}^{292}114^{*} \rightarrow {}^{289}114+3n$$

Published FLNR

- **$^{289}114$**: $2.6^{+1.2}_{-0.7}$ s; α 9.82±0.05
- **^{285}Cn**: 29^{+13}_{-7} s; α 9.15±0.05
- **^{281}Ds**: $11.1^{+5.0}_{-2.7}$ s; SF

Yu.Ts. Oganessian
J. Phys. G 34 (2007) R165

Average *TASCA HTM*

4 chains

- **$^{289}114$**: $0.97^{+0.97}_{-0.32}$ s; α 9.87±0.03
- **^{285}Cn**: 30^{+30}_{-10} s; α 9.21±0.03
- **^{281}Ds**: 20^{+20}_{-7} s; SF
- **^{277}Hs**: 3^{+15}_{-1} ms; SF

Ch.E.D. *et al.*
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