Can we produce new isotopes of Sg→Cn with an uranium target?

Or Np one ?

Ch. Stodel et al

First Physics with the Super separator Spectrometer S^3

27-30 Mars 2017, Saclay

Isotope discovery project

Atomic Data and Nuclear Data Tables 99 (2013) 312–344

Contents lists available at SciVerse ScienceDirect

Atomic Data and Nuclear Data Tables

journal homepage: www.elsevier.com/locate/adt

ELSEVIER

Discovery of isotopes of elements with $Z \geq 100$

M. Thoennessen

National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA

	294
	293, 294
	290, 291, 292, 293
	287, 288, 289, 290
Flerovium	285, 286, 287, 288, 289
Z = 113	278, 282, 283, 284, 285, 286
Copernicium	277, 281, 282, 283, 284, 285
Roentgenium	272, 274, 278, 279, 280, 281, 282
Darmstadtium	267, 269, 270, 271, 273, 277, 279, 281
Meitnerium	266, 268, 270, 274, 275, 276, 278
Hassium	263, 264, 265, 266, 267, 268, 269, 270, 271, 273, 275, 277
Bohrium	260, 261, 262, 264, 265, 266, 267, 270, 271, 272, 274
Seaborgium	258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 269, 271
Dubnium	256, 257, 258, 259, 260, 261, 262, 263, 266, 267, 268, 270
Rutherfordium	253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 265, 267
Lawrencium	252, 253, 254, 255, 256, 257, 258, 259, 260

DE GRUYTER Pure Appl. Chem. 2016; aop

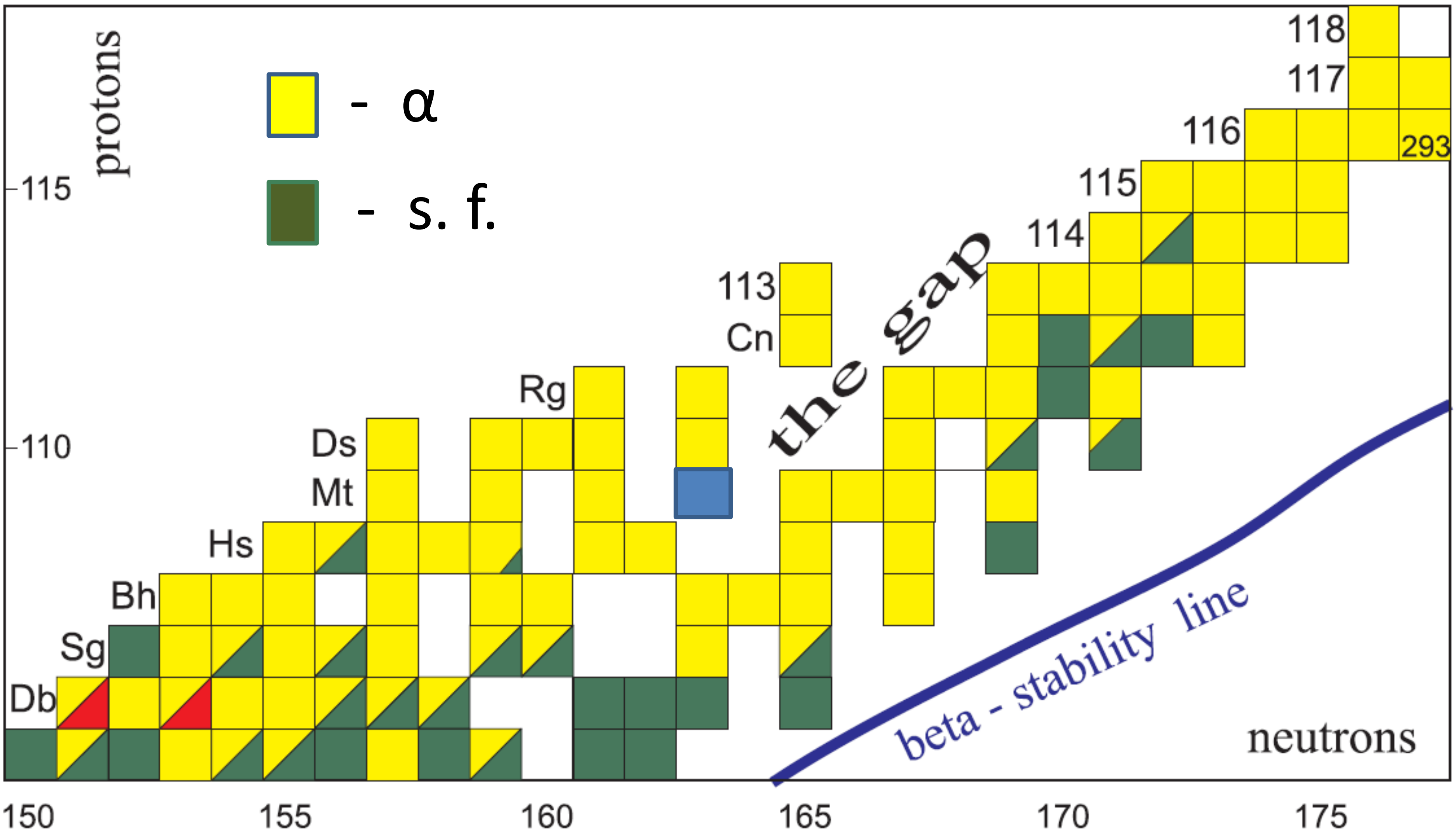
IUPAC Technical Report

Paul J. Karol[a],*, Robert C. Barber, Bradley M. Sherrill, Emanuele Vardaci and Toshimitsu Yamazaki

Discovery of the elements with atomic numbers $Z = 113$, 115 and 117 (IUPAC Technical Report)

We would like to point out that for the newest super heavy elements, cross-reaction experiments have achieved increasing importance. Cross-reactions were established as one of the Criteria for discovery in 1991 by the TWG [1] and their growing influence has been extensively deliberated within the previous and current JWPs. The key to this importance of cross-reaction lies in the fact that, even in the case of missing anchors, the *Z* of the super heavy can be reliably assigned as the sum of the *Z*s of the target and projectile if different combinations of projectile and target are found to produce the same states. Such combinations essentially circumvent possible misidentifications of *Z*.

The new elements identified in the claims considered here have distinct features from their assigned $Z = 114$ and $Z = 116$ neighbors [5]. The nature of the alpha energy spectra observed in the decays of nuclides with atomic numbers 113, 115, and 117 differ from their even-*Z* neighbors and show a wider energy spread corresponding to decay to excited states. This is further evidence that new atomic number has been produced in these studies and disfavor charged-particle emission in the evaporation process or electron capture in the decay chains. As a result a large group of super heavy nuclides are now on an island without connection to the main peninsula of known nuclei where reliable identification of *Z*, *N* becomes more and more difficult. Firmly connecting this island to the nuclear mainland should remain a priority. We encourage development of direct physical methods to determine *Z*. Particularly promising are the prospects for X-ray measurements and identification as was now attempted [22].



V. I. Zagrebaev, A. V. Karpov, and W. Greiner
PHYSICAL REVIEW C **85**, 014608 (2012).

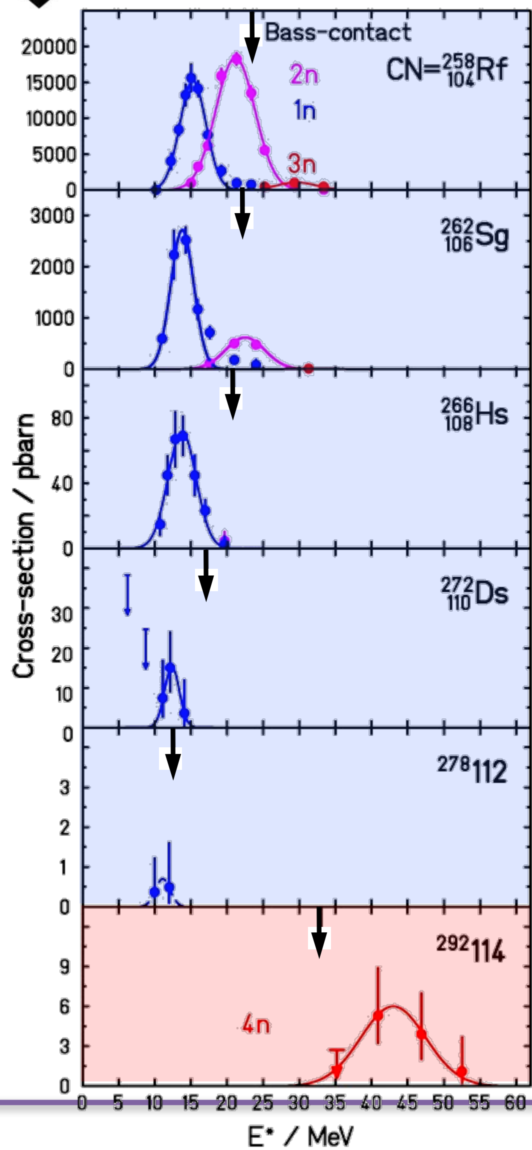
^{272} Mt: High-K states: a chance for longer half-lives.

There is a possibility, that one such high-K ground- or low-excited state may be the longest lived superheavy nucleus e.g. 272Mt~1h.

Courtesy of M. Kowal

Excitation Functions

Cold (GSI) and Hot (FLNR) Fusion



^{208}Pb + ^{50}Ti

^{54}Cr

^{58}Fe

^{64}Ni

^{70}Zn

GSI-SHIP

FLNR-DGFRS

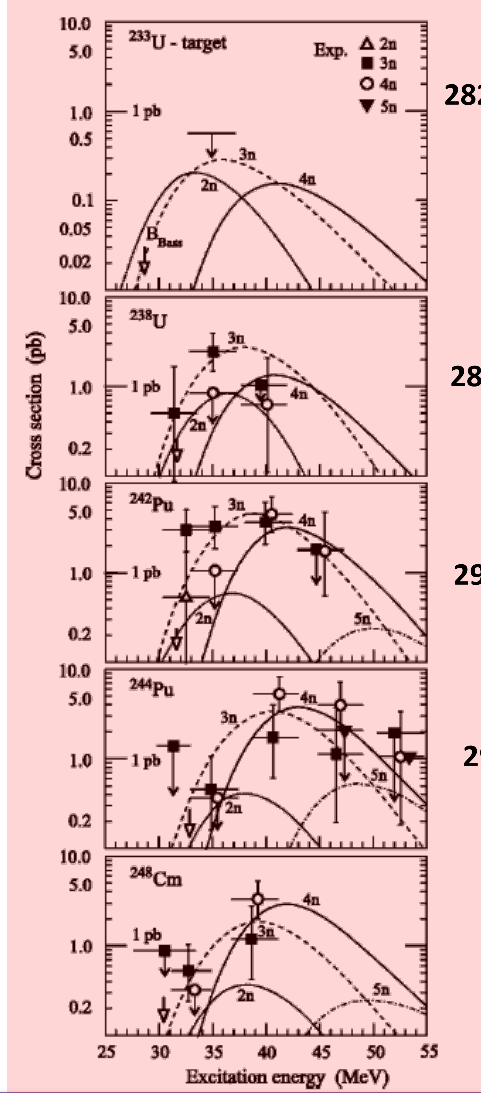
^{48}Ca + ^{233}U

^{238}U

^{242}Pu

^{244}Pu

^{245}Cm



^{282}Cn*

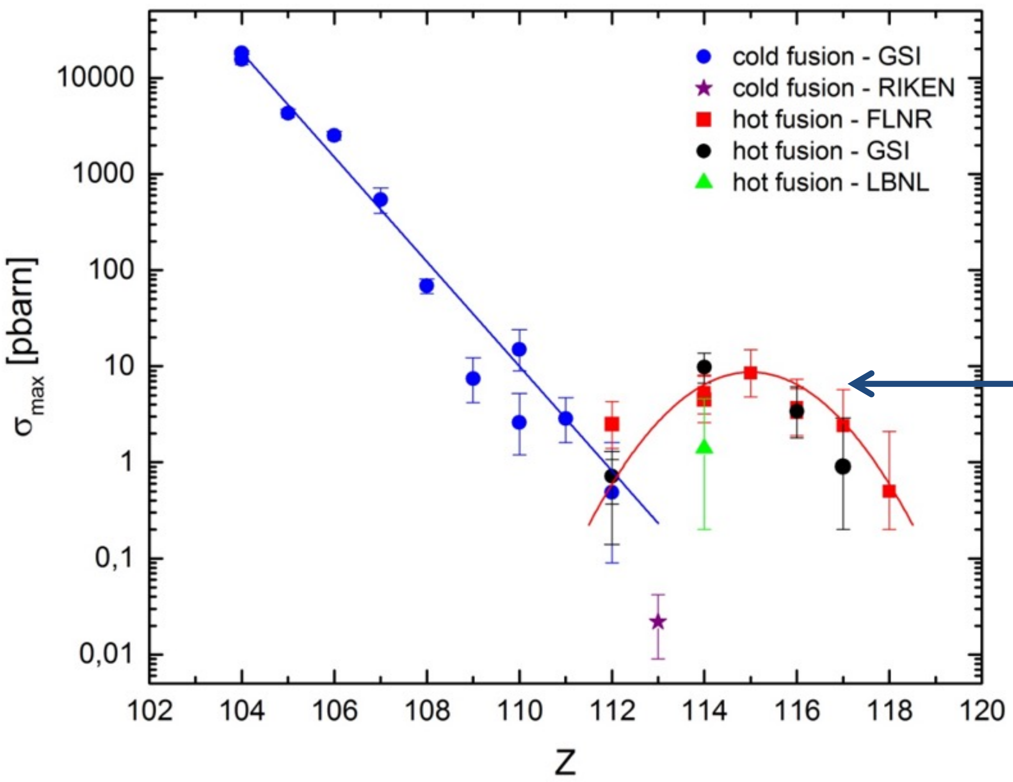
^{287}Cn*

^{290}Fl*

^{292}Fl*

^{293}Lv*

Fusion cross-sections ?

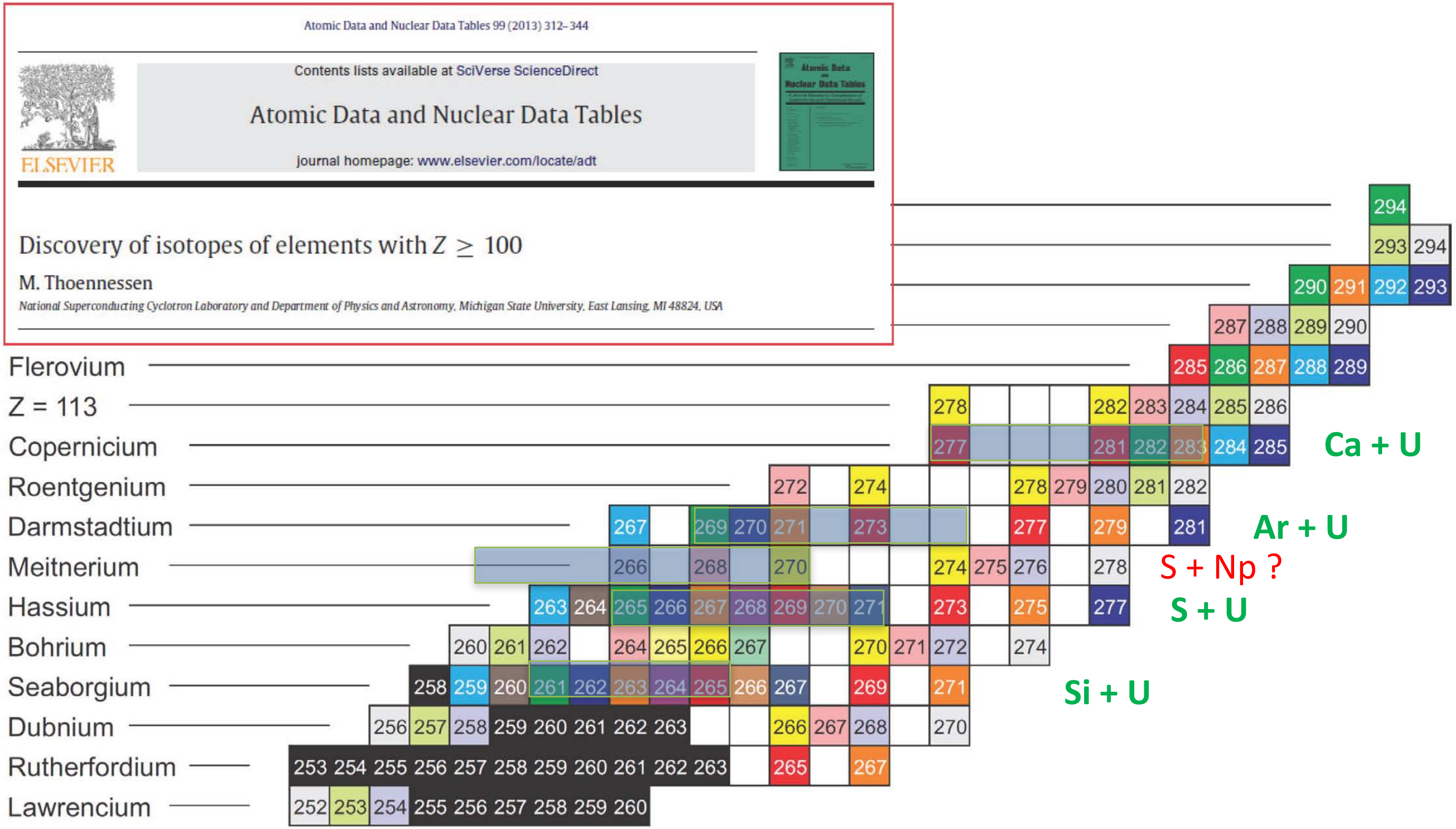


Courtesy: D. Ackermann

Fission barrier higher ?
Island ?

S^3: from « stable » to actinides ?

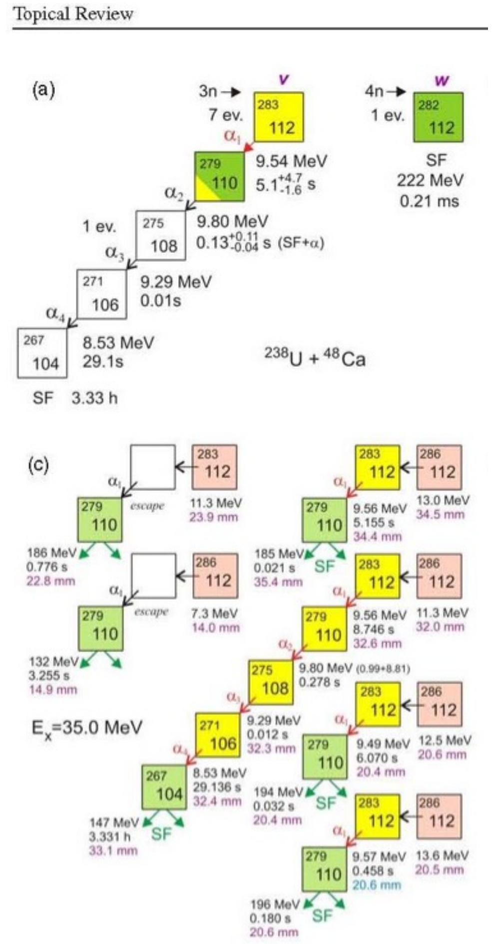
Isotope discovery project



Z=112 Cn isotopes

	277	278	279	280	281	282	283	284	285
					^{285}Fl+α	^{290}Lv+2α	^{291}Lv+2α	^{292}Lv+2α	^{293}Lv+2α
beam	^{70}Zn					^{48}Ca	^{48}Ca		
target	^{208}Pb					^{238}U	^{238}U		
channel	1n					4n	3n		
σ (pb)	1.1					0.6	2.45		
ref	*ZPA354 (1996)*					*PRC70 (2004)*	*PRC70 (2004)*		

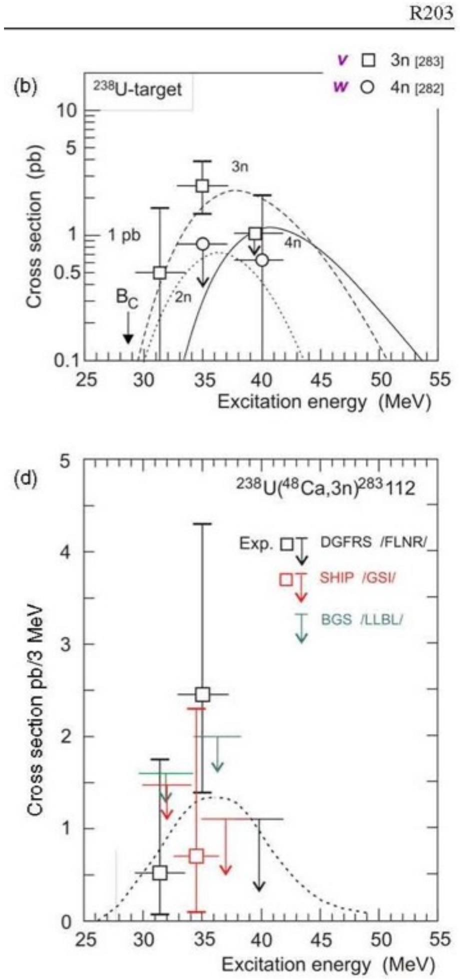
Yu. T. Oganessian, J. Phys.G. : Nucl. Part. Phys. 34(2007) R165-242

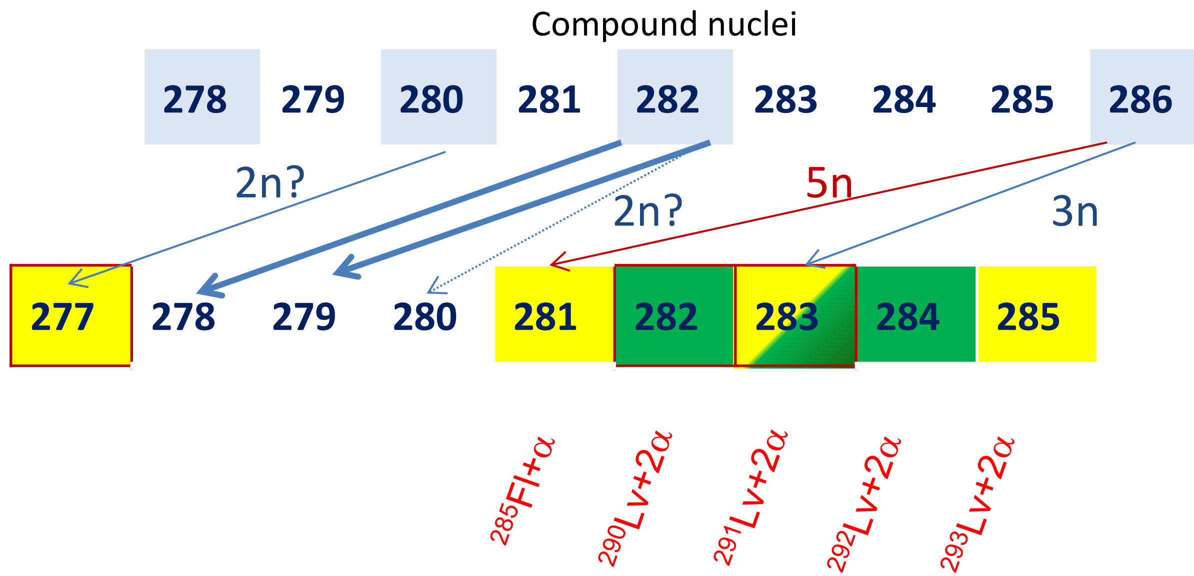


$^{40,42,43,44,46,48}Ca + ^{238}U \rightarrow ^{278,280,282,286}Cn^*$

(96.9-0.65-0.14-2.1-0.004-0.187%)

Yu. T. Oganessian, J. Phys.G. : Nucl. Part. Phys. 34(2007) R165-242





Z=110 Ds isotopes

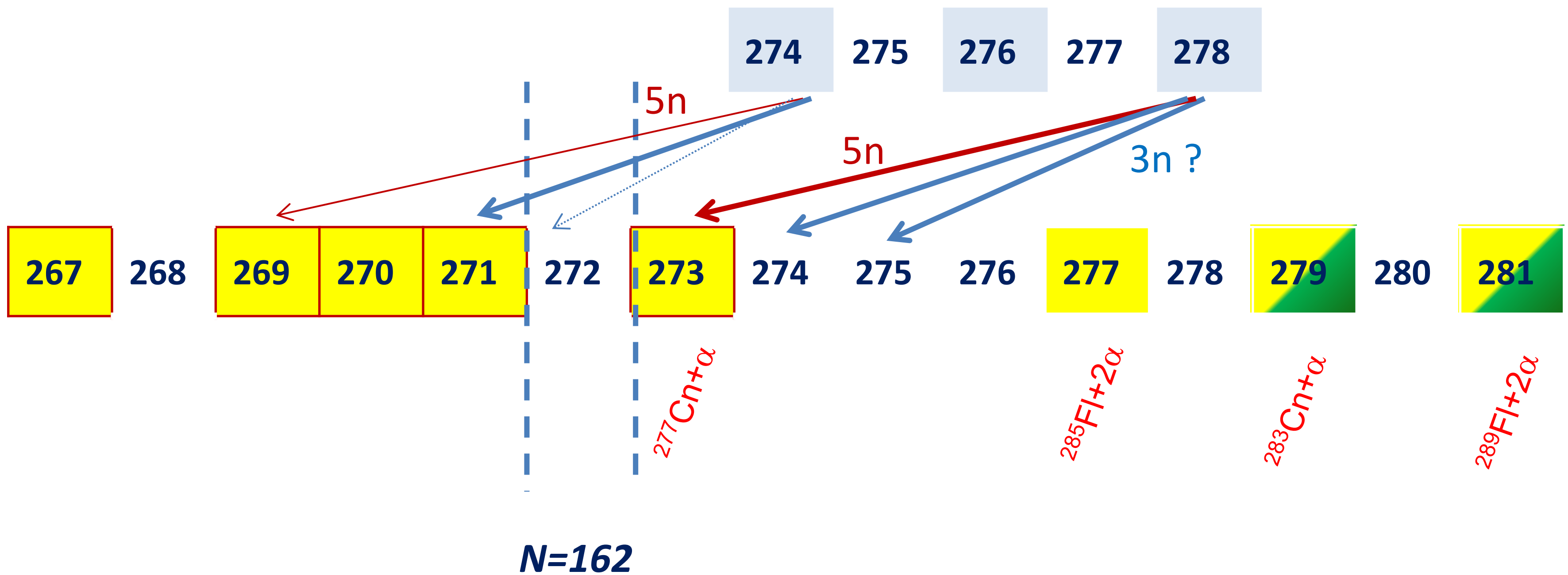
	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281
							^{277}Cn+α				^{285}Fl+2α		^{283}Cn+α		^{289}Fl+2α
beam	^{59}Co		^{62}Ni	^{64}Ni	^{64}Ni		^{34}S								
target	^{209}Bi		^{208}Pb	^{207}Pb	^{208}Pb		^{244}Pu								
channel	1n		1n	1n	1n		5n								
σ (pb)			3.3	13	15		0.4								
ref	*PRC 51 (1995)*		*ZPA350 (1995)*	*EPJA10 (2001)*	*RPP61 (1998)*		*PRC54 (1996)*								

N=162

$^{36,38,40}Ar + ^{238}U \rightarrow ^{274,276,278}Ds^*$

(0.337-0.063-99.6%)

Compound nuclei



Yu. A. Lazarev et al PRC 54, 1996

α decay of 273110: Shell closure at *N*=162

$^{244}Pu + ^{34}S = ^{273}110 + 5n$

0.4 pb

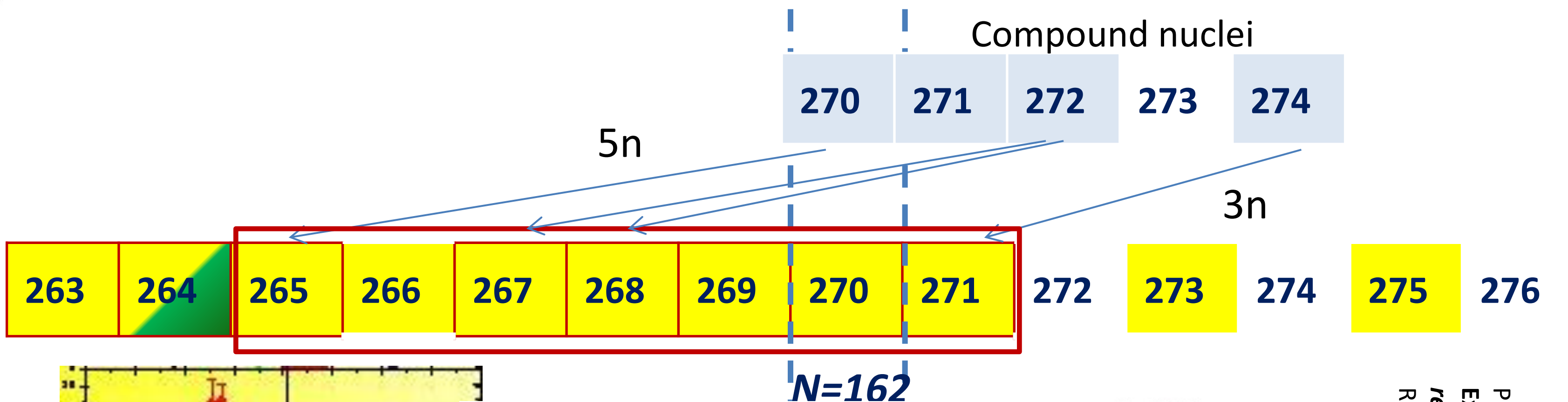
Z=108 Hs isotopes

	263	264	265	266	267	268	269	270	271	272	273	274	275	276
			$^{269}Ds+\alpha$	$^{270}Ds+\alpha$	$^{271}Ds+\alpha$		$^{277}Cn+2\alpha$	$^{269}Hs+\alpha$ $^{277}Ds+2\alpha$		???	$^{285}Fl+3\alpha$	???	$^{283}Cn+2\alpha$	???
beam	^{56}Fe	^{58}Fe	^{58}Fe		^{34}S	^{34}S ^{25}Mg	^{26}Mg	^{26}Mg	^{26}Mg					
target	^{208}Pb	^{207}Pb	^{208}Pb		^{238}U	^{238}U ^{248}Cm	^{248}Cm	^{248}Cm	^{248}Cm					
channel	1n	1n	1n		5n	4n 5n	5n	4n	3n					
σ (pb)	$21^{+13}_{-8.4}$	$2.8^{+5.1}_{-1.8}$	19^{+18}_{-11}		$1.8^{+4.2}_{-1.5}$	$0.54^{+1.3}_{-0.45}$	6	3						
ref	*PRC 79 (2009)*	*ZPA328 (1987)*	*ZPQ (1984-1997)*		*PRL 75 (1995) PRC82 (2010)*	*PRC82 (2010) PRC79(2009)*	*EPJA17 (2003) PRL97(2006)*	*PRL97 (2006)*	*PRL100 (2008)*					

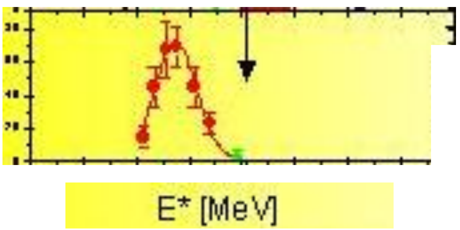
N=162

$^{32,33,34,36}S + {}^{238}U \rightarrow {}^{270,271,272,274}Hs^*$

(95 – 0,7 – 4,1 – 0,02 %)



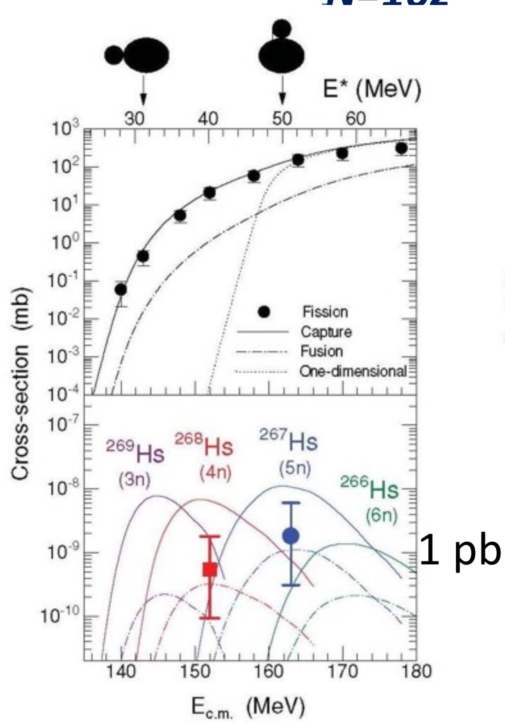
$^{208}Pb+{}^{58}Fe \rightarrow {}^{266}Hs^*$

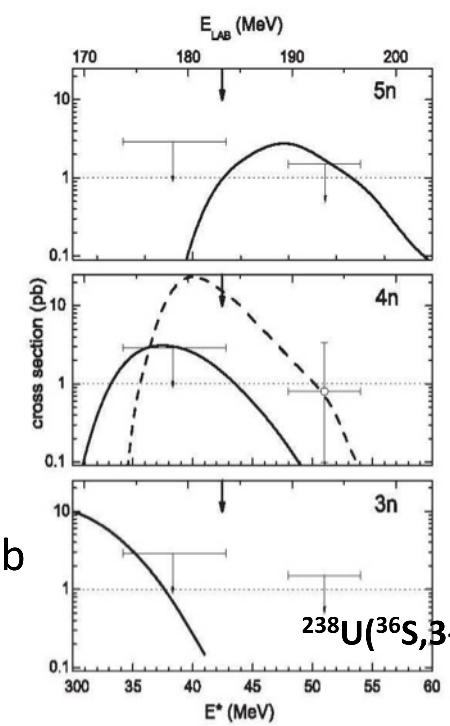


K. Nishio, PRC82(2010) 024611

$\sigma_{ER\_calc}(3n) \approx \sigma_{ER\_calc}(4n)$
Below Bass barrier and deformed actinide targets==« considerable yield » of n-rich nuclei: access to new Ds isotopes (S+Pu)

$^{238}U(^{34}S,4–5n)^{267–268}Hs$



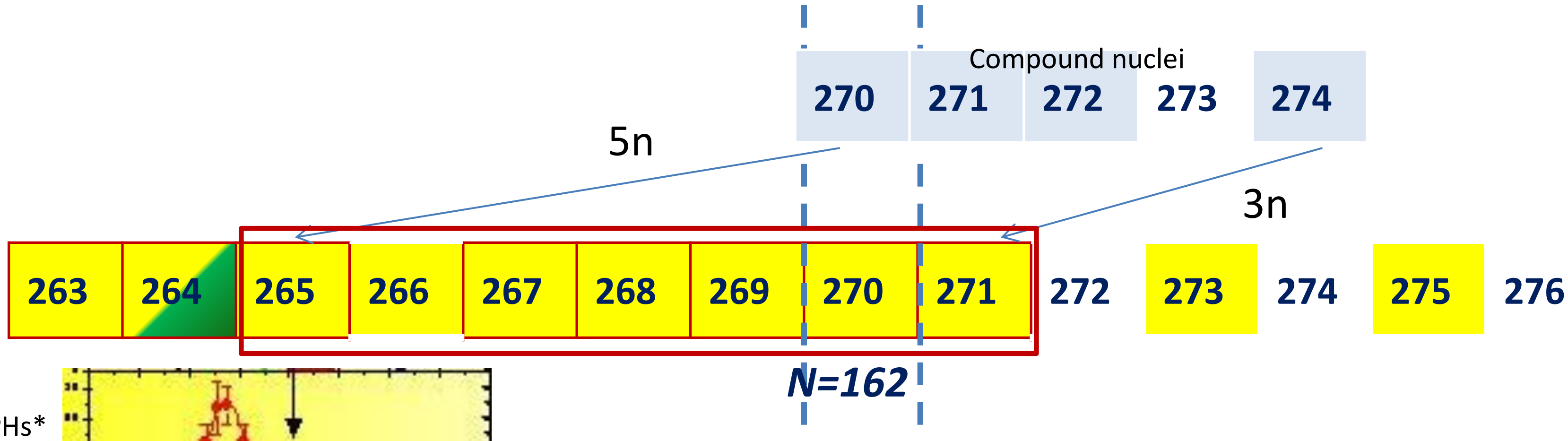


$^{238}U(^{36}S,3-5n)^{269–271}Hs$

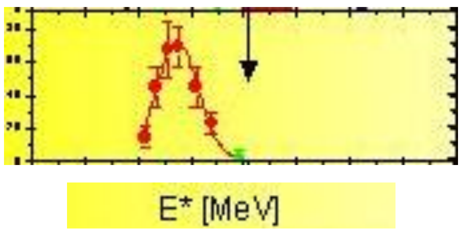
PHYSICAL REVIEW C **81**, 061601(R) (2010)
Experimental study of the $^{238}U(^{36}S,3–5n)^{269–271}Hs$ reaction leading to the observation of 270Hs
R. Graeger, D. Ackermann, ...

$^{32,33,34,36}S + ^{238}U \rightarrow ^{270,271,272,274}Hs^*$

(95 – 0,7 – 4,1 – 0,02 %)



$^{208}Pb + ^{58}Fe \rightarrow ^{266}Hs^*$



I= 2 → 10 pμA

σ= 10 pb; ε= 10%

5 atoms/day

<u>S³:</u>

Excitation functions ?

Checking σ(3n) ≈ σ(4n)

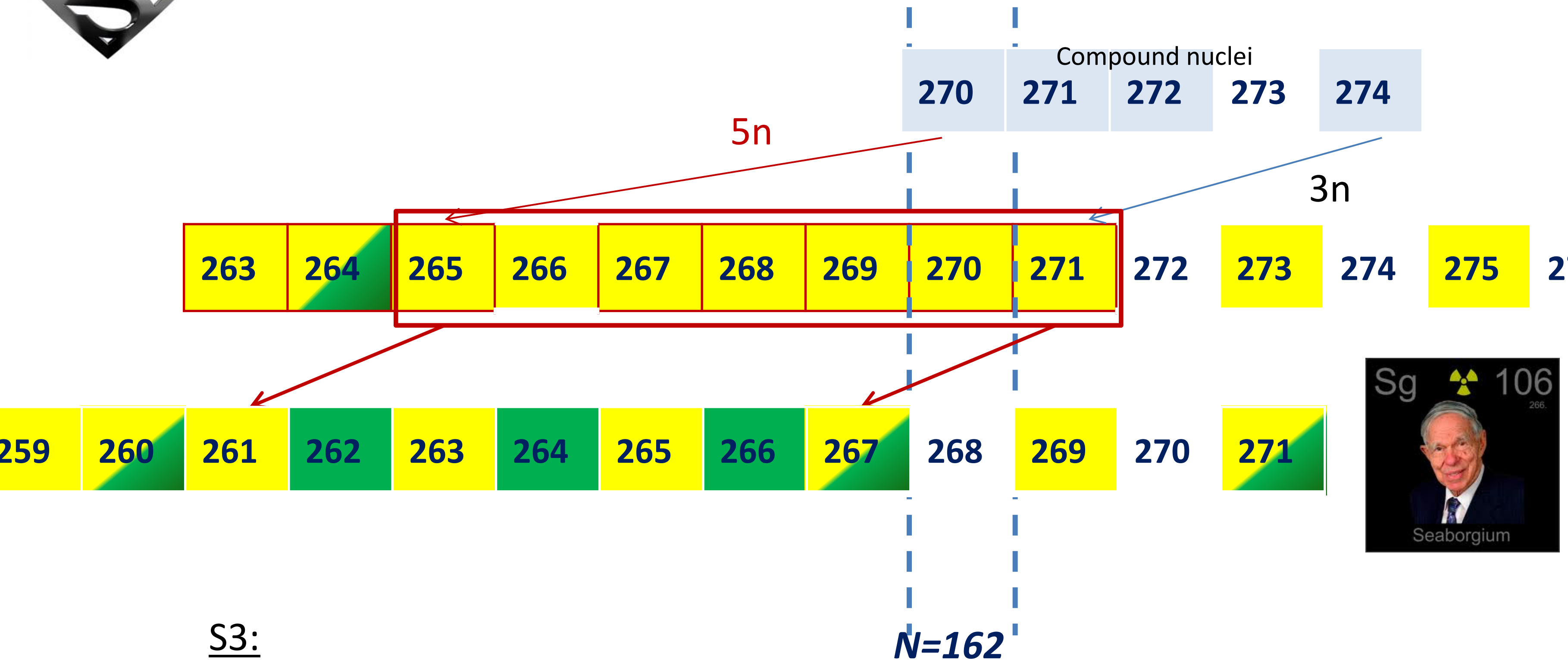
Observation of $^{269..271}Hs$

Scarce data on ^{268}Hs

Influence of neutrons in beams

$^{32,33,34,36}S + {}^{238}U \rightarrow {}^{270,271,272,274}Hs^*$

(95 – 0,7 – 4,1 – 0,02 %)

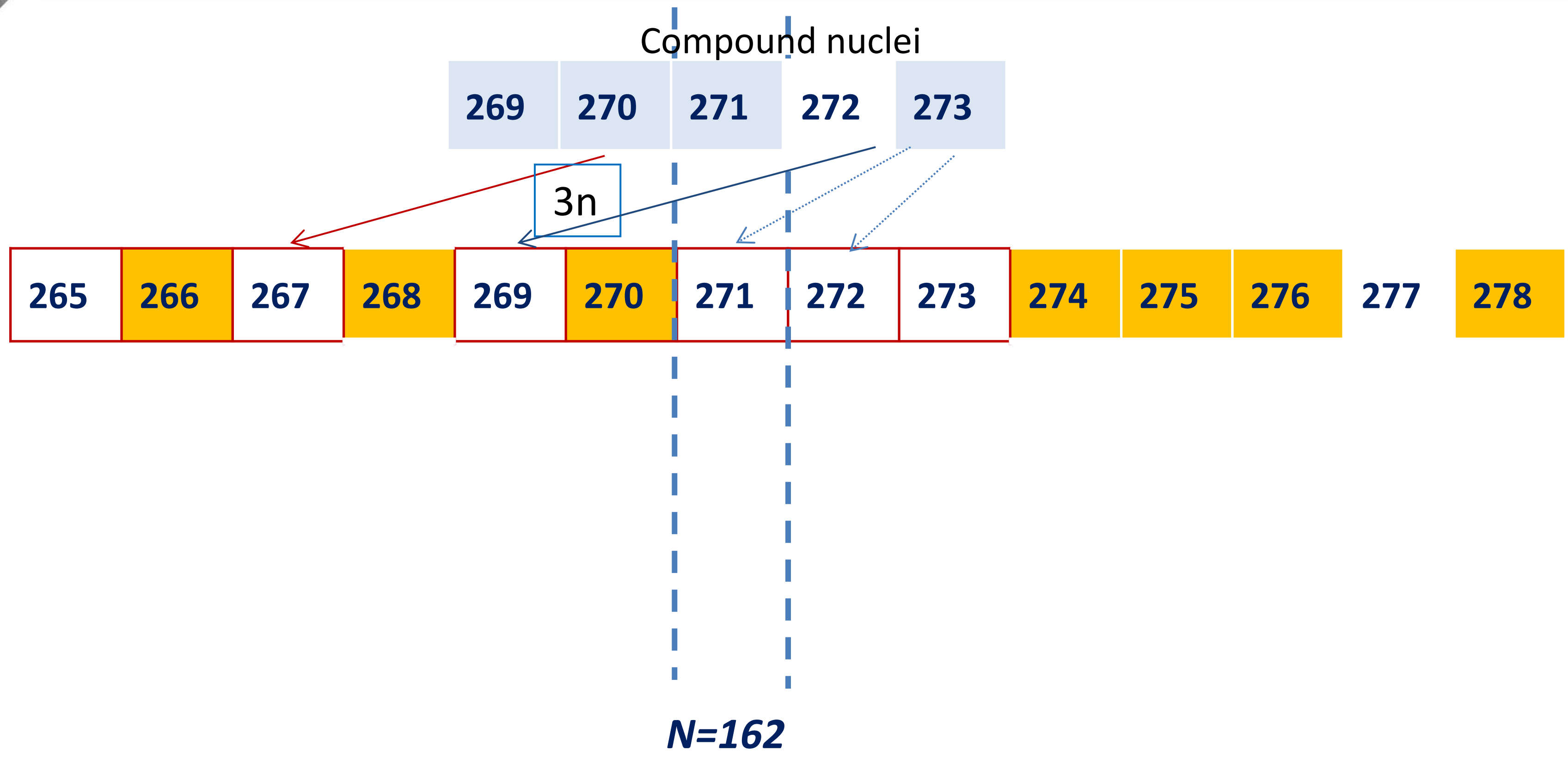


S3:

Decays to known Sg isotopes

$^{32,33,34,36}S + ^{237}Np \rightarrow ^{269,270,271,273}Mt^*$

(95 – 0,7 – 4,1 – 0,02 %)



Référence cross-sections ?

Z= 106 Sg isotopes*

	258	259	260	261	262	263	264	265	266	267	268	269	270	271
decay			^{264}Hs+α	^{265}Hs+α	^{270}Ds+2α	^{271}Ds+2α		^{269}Hs+α ^{277}Ds+2α	^{270}Hs+α	^{271}Hs+α		^{285}Fl+4α		^{283}Cn+3α
beam	^{51}V	^{54}Cr	^{54}Cr	^{54}Cr	^{30}Si	^{18}O ^{30}Si	^{30}Si	^{22}Ne ^{30}Si	^{22}Ne					
target	^{209}Bi	^{207}Pb	^{207}Pb ^{208}Pb	^{208}Pb	^{238}U	^{249}Cf ^{238}U	^{238}U	^{248}Cm ^{238}U	^{248}Cm					
channel	2n	2n	1n 2n	1n	6n	4n 5n	4n	5n 3n	4n					
σ (pb)	38	320	22 280	500	22^{+51}_{-18}	≈300 67^{+67}_{-37}	10^{+10}_{-6}	260 $3.5^{+8.1}_{-2.9}$	80					
ref	*ZPA359 (1997)*	*ZPA322 (1985)*			*EPJA29 (2006)*	*PRL33 (1974) EPJA29 (2006)*	*EPJA29 (2006)*	*PRC57 (1998) EPJA29 (2006)*	*PRC57 (1998)*					

PRC74, 2006

N=152 ***N=162***

Eur. Phys. J. A 29, 281-287 (2006)

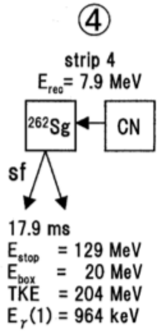
Measurement of evaporation residue cross-sections of the reaction $^{30}Si + {}^{238}U$ at subbarrier energies

K. Nishio et al

$E_{c.m.}$ = 144.0 MeV

^{262}Sg

22^{+51}_{-18}pb



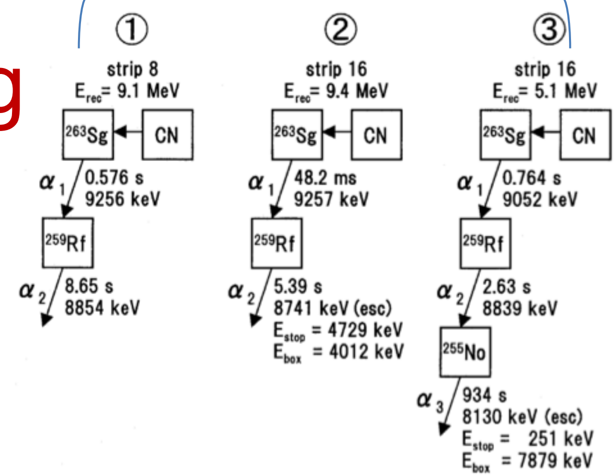
SF TKE = 204 MeV

$T_{1/2} = 12.4^{+56}_{-6}$ ms

+γ ray@964 keV of ^{262}Sg

^{263}Sg

67^{+67}_{-37}pb



EPJA10 (2001) S. Hofmann:

$^{207}Pb(^{64}Ni,n)^{270}Ds$ (15pb)

$T_{1/2} = 6.9^{+3.8}_{-1.8}$ ms

TKE = 222±10 MeV

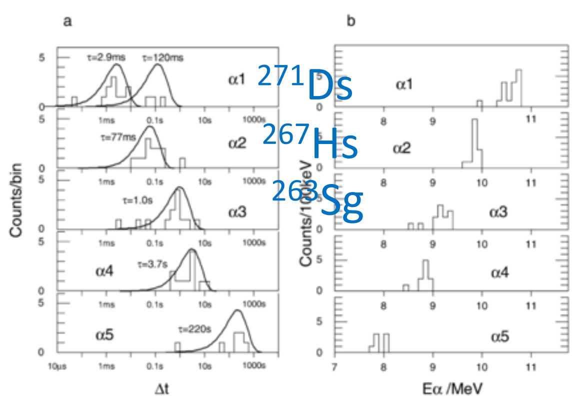
Viola = 210 MeV

9.06 and 9.25 MeV :2 different levels

PRL33 (1974) A. Ghiorso:

$^{249}Cf(^{18}O,4n)^{263}Sg$ (≈300 pb)

- 73±3 events @9.06MeV
- 14 events @9.25 MeV
- T1/2 = 0.9±0.2 sec



EPJA21 (2004) K. Morita:

$^{208}Pb(^{64}Ni,n)^{271}Ds$ (15pb)

Isomeric states ?

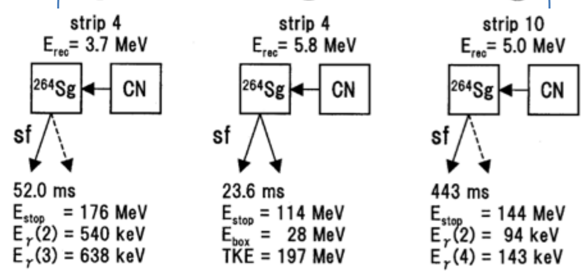
Eur. Phys. J. A 29, 281-287 (2006)

Measurement of evaporation residue cross-sections of the reaction $^{30}Si + ^{238}U$ at subbarrier energies

K. Nishio et al

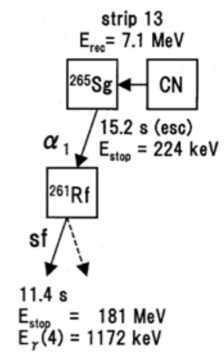
10^{+10}_{-6} pb

^{264}Sg



$E_{c.m.}$ = 133.0 MeV

^{265}Sg



SF $T_{1/2} = 120^{+126}_{-44}$ ms

TKE (Viola) = 210 MeV

No reference !!!

$T_{1/2\text{-calc}}$=2.3 sec (PRC52 (1995) R. Smolanczuk)
= 20* T_{exp}

	Tcalc/Texp
^{258}Sg	2
^{260}Sg	2
^{262}Sg	10
^{264}Sg	20

EPJA17 (2003) 505 A. Türler:

$^{248}Cm(^{26}Mg,5n)^{269}Hs$

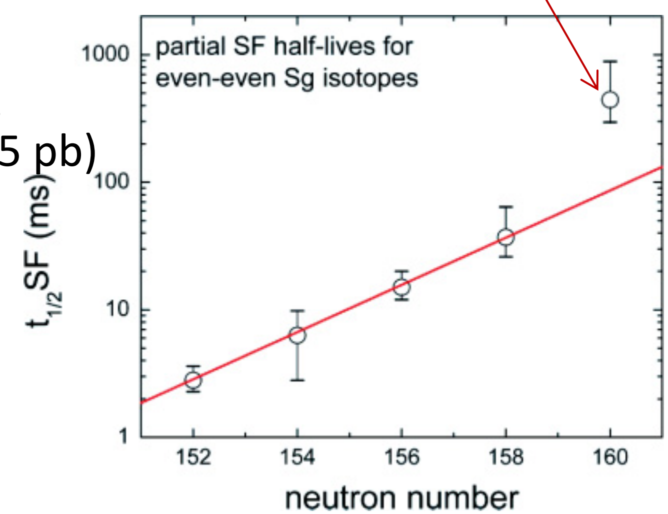
EPJA14 (2002) S. Hofmann:

$^{208}Pb(^{70}Zn,n)^{277}Cn$ (0.5 pb)

$T_{1/2} = 7.9^{+6.4}_{-2.4}$ s

K.E. Gregorich, PRC74(2006) :

^{266}Sg



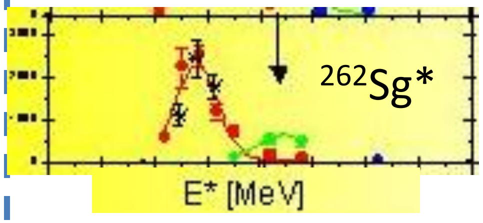
$^{28,29,30}Si + ^{238}U \rightarrow ^{266,267,268}Sg^*$

(92,2 – 4,6 – 3,1 %)

Compound nuclei
266 267 268

5n
3n
N=162

258 259 260 261 262 263 264 265 266 267 268 269 270 271

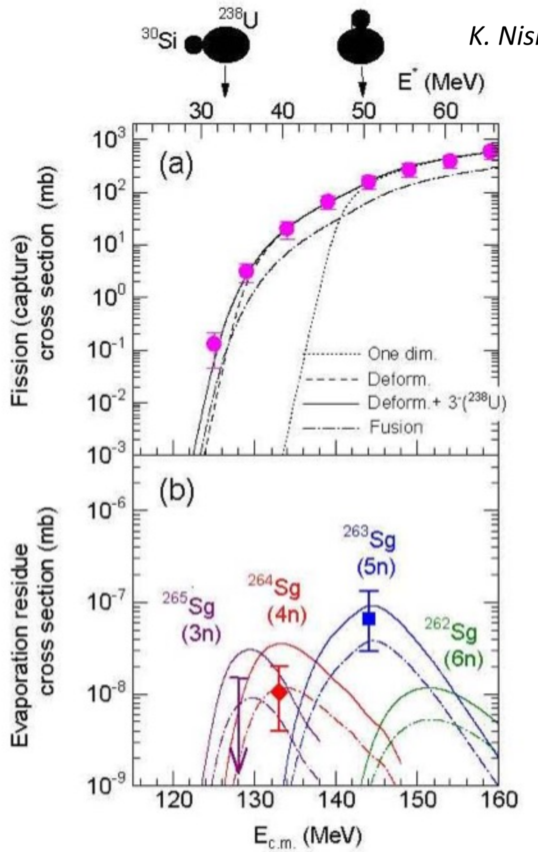


N=152

I= 1 → 10 pμA
σ= 10 pb; ε= 10%
5 atoms/day

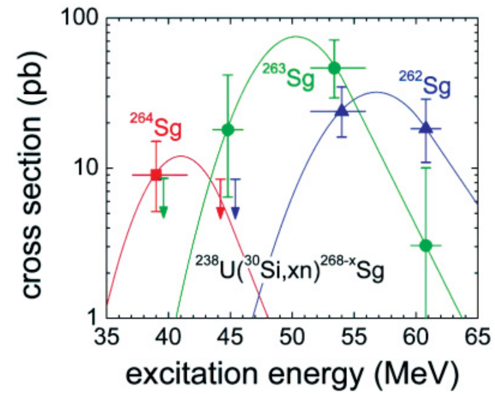
S3:
Excitation functions ?
Influence of neutrons in beams

K. Nishio, EPJA 29 (2006)

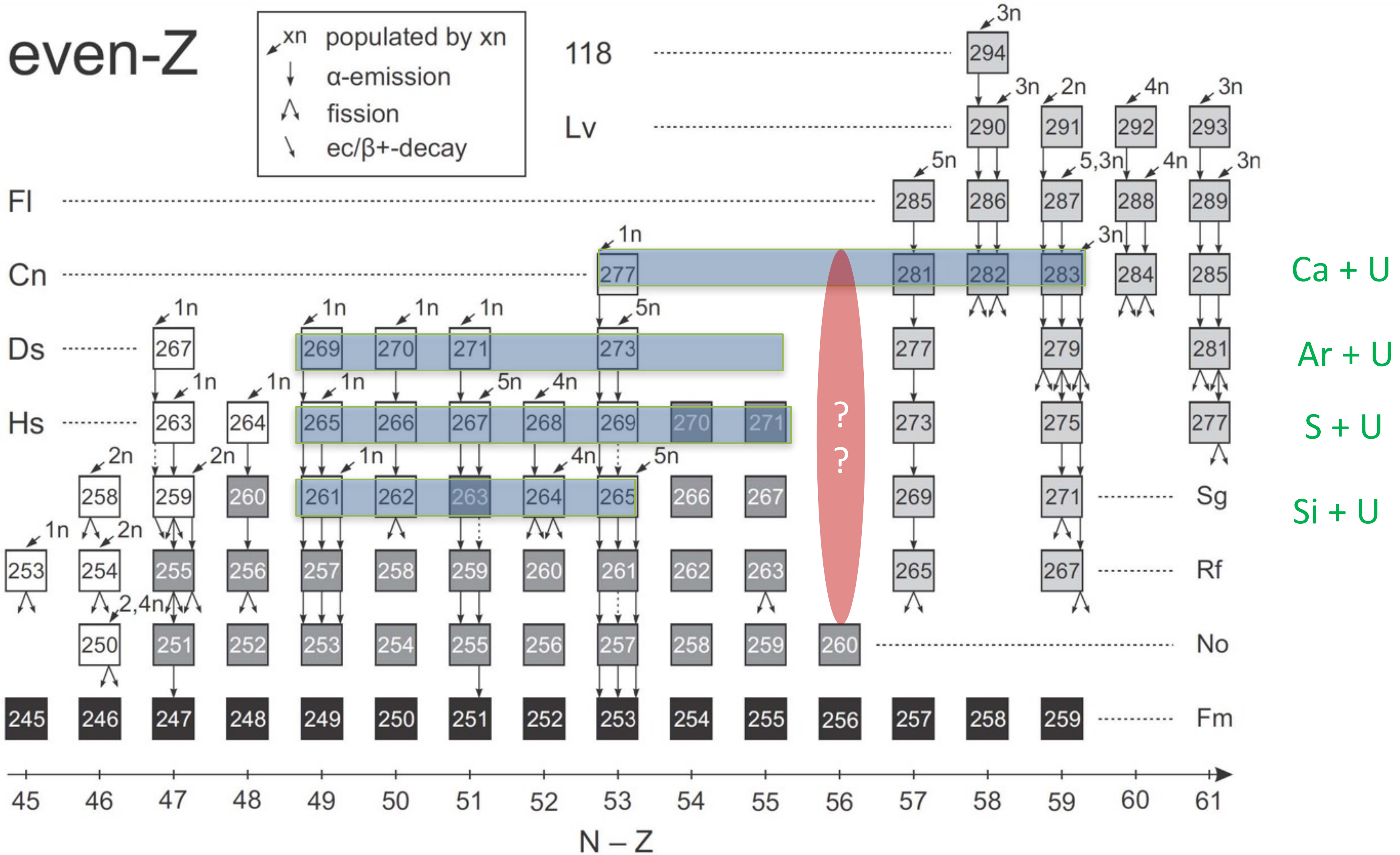


3 and 4n: ($^{30}Si + ^{238}U$)
σ_{ER_exp}*5 or 4 = σ_{ER_calc}
Quasifission contribution

K. E. Gregorich, PRC 74 (2006)



Z versus N–Z


even-Z
xn populated by xn
α-emission
fission
ec/β+-decay
118
Lv
Fl
Cn
Ds
Hs
Sg
Rf
No
Fm
?
?
Ca + U
Ar + U
S + U
Si + U
N – Z

✓some isotopes have scarce data (1970's and 80's experiments) and still some questions about their structure; it looks worth to reproduce these data with higher statistics.

✓Production via 2 channels?

✓ Study for Z even with U target to be done with ^{237}Np target:

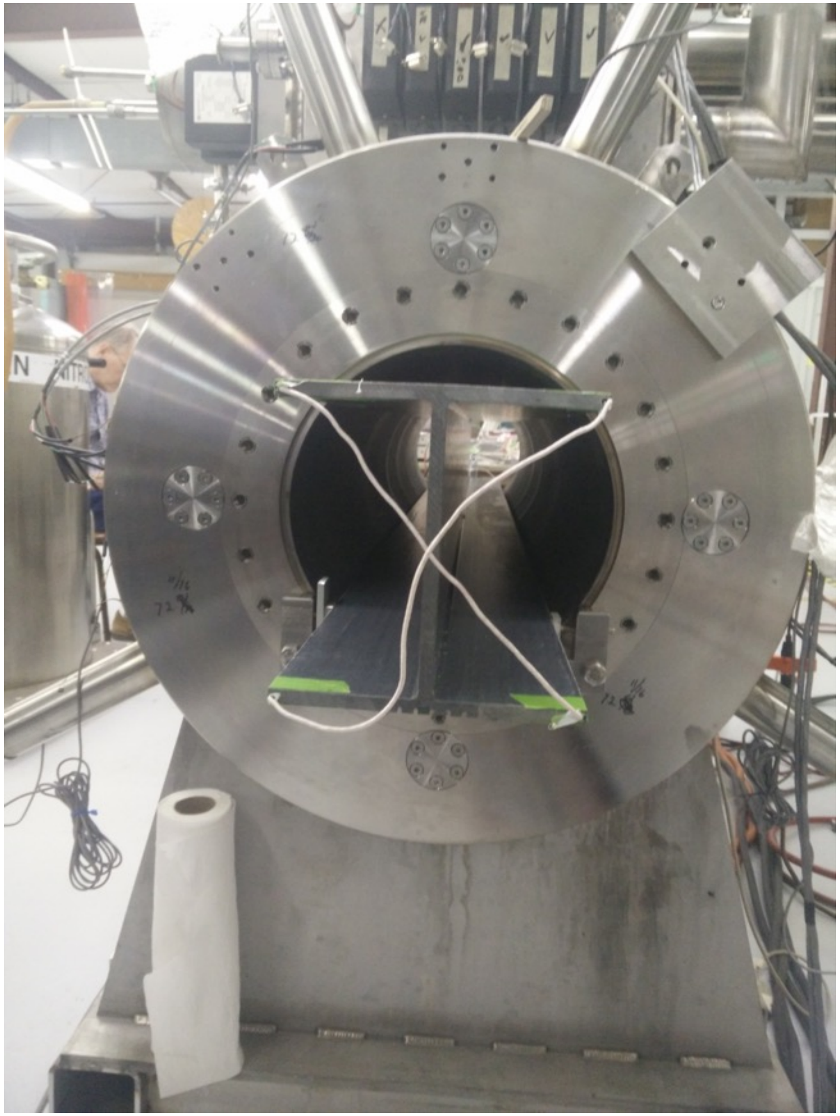
^{237}Np + ^{36}S → ^{273}Mt or other odd Z isotopes ?

✓What about reaction mechanism ?

- no full experimental excitation functions on SHE
- latest data on Z=90-92 and for SHE only with one system projectile/target
- Which experiments could help theory ?
- What are experimental and theoretical "precisions" ? (to estimate the cross-section)

....


HELIUM
REFRIGERATED
LIQUID
UN-1963



Vidéo 1
Vidéo 2

Production of SHE with Z=106-108-110-112

$^{40-48}Ca + ^{238}U \rightarrow ^{278-286}112^*$

$^{36-40}Ar + ^{238}U \rightarrow ^{274-278}Ds^*$

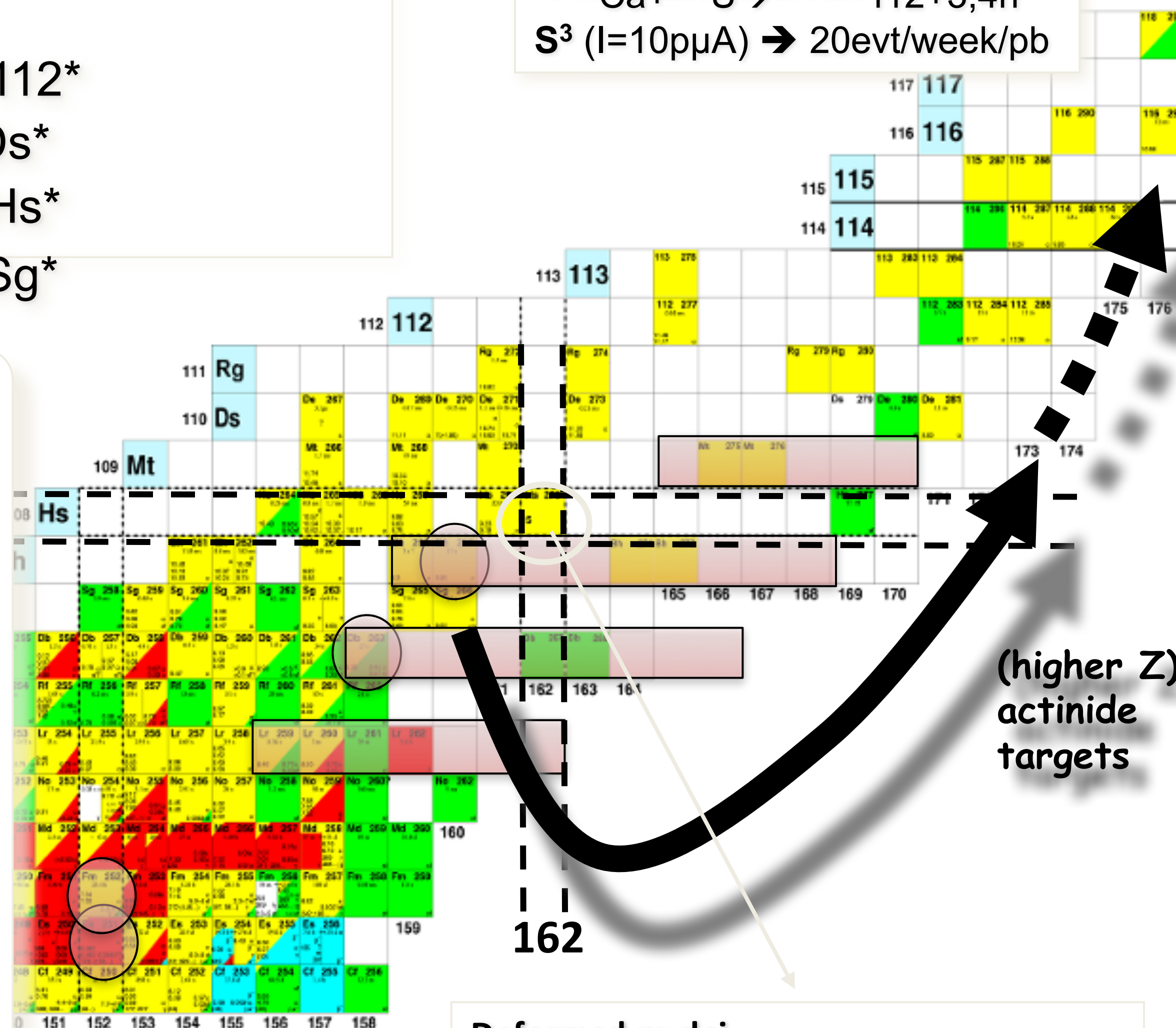
$^{32-36}S + ^{238}U \rightarrow ^{270-274}Hs^*$

$^{28-30}Si + ^{238}U \rightarrow ^{266-268}Sg^*$

Isotopic exploration

$^{40-48}Ca + ^{238}U \rightarrow ^{275-283}112 + 3,4n$

S^3 (I=10pμA) ➔ 20evt/week/pb



Deformed nuclei

$^{40}Ar + ^{238}U \rightarrow ^{274}Ds\ (+4n) \rightarrow ^{270}Hs + \alpha$

S^3 (I=50pμA) ➔190evt/week@σ_{th}=2pb

At the crossing road for

Reaction of synthesis :

- Link hot to cold fusion
- Isospin dependent reaction mechanism studies
- X-section systematics

Decay properties :

- K-isomers
- SF decay (T_{SF} half-lives)
- Alpha decays ($Q\alpha$ & half-lives)

Trans-actinide chemistry

GS properties

- Mass measurements …

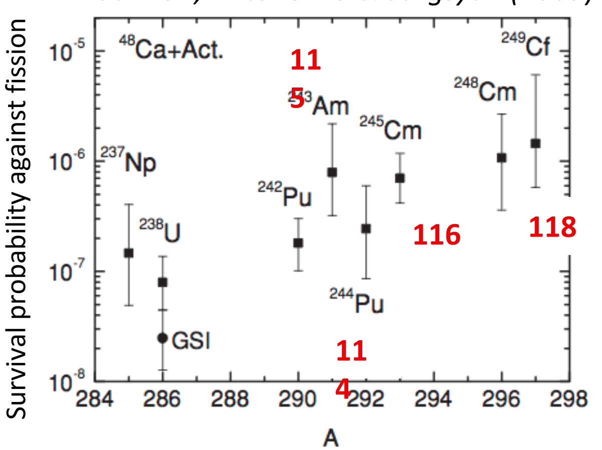
Toward the Heaviest elements

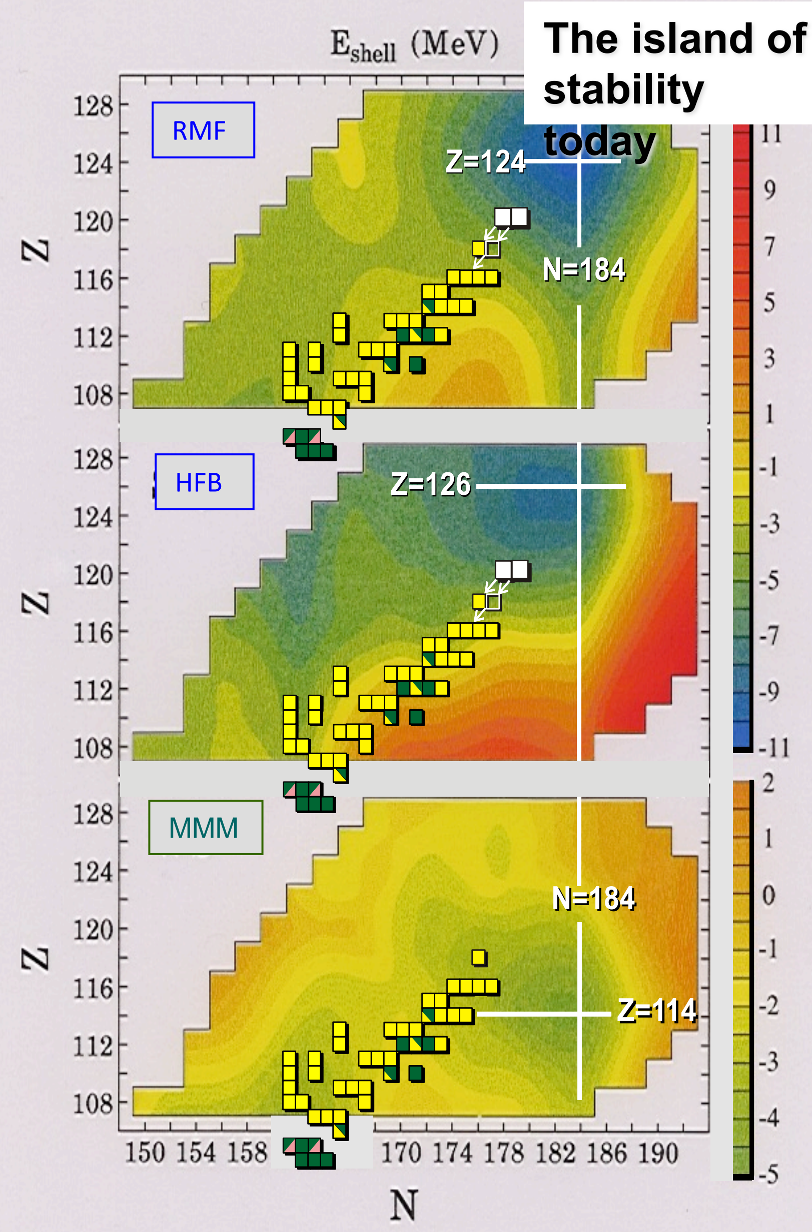
An evaluation of Opportunities & Difficulties

A very prospective evaluation: NOT a first year experiment
In the framework of a full SHE study program

The island of stability today
N=184 : common to all models, strong effect observed
Z=114, 120, 126 ?
shell stabilization lowers:
the ground-state energy,
creates a fission barrier,
and thereby enables the SHN to exist.

Adamian, Antonenko & Sargsyan (2009)

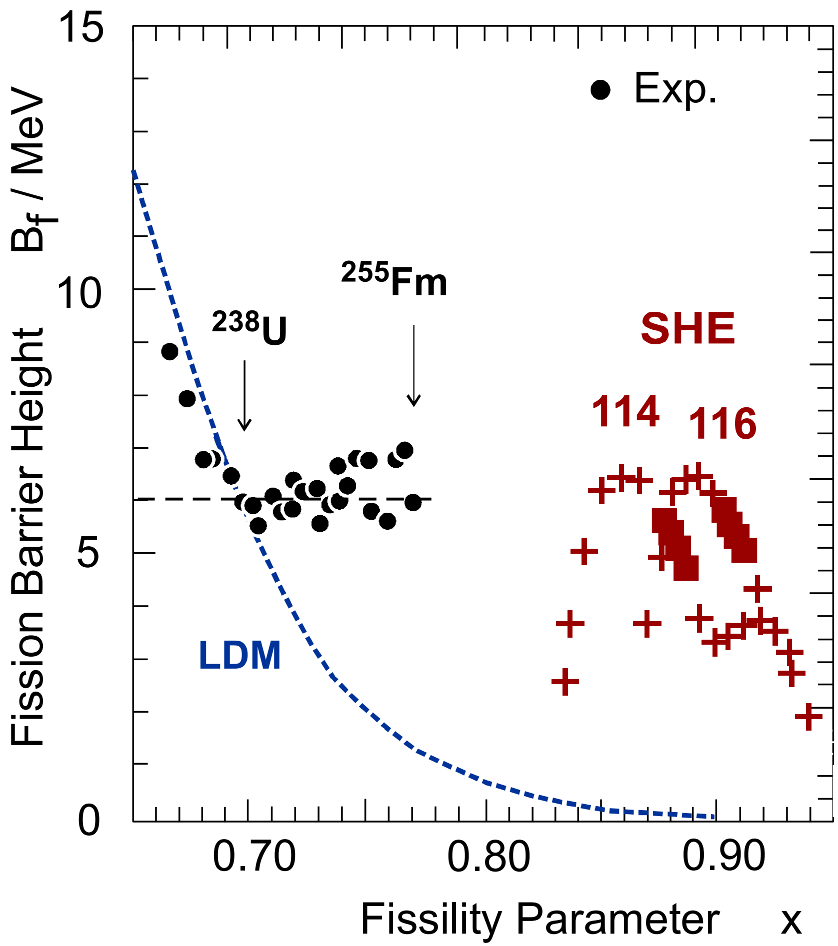




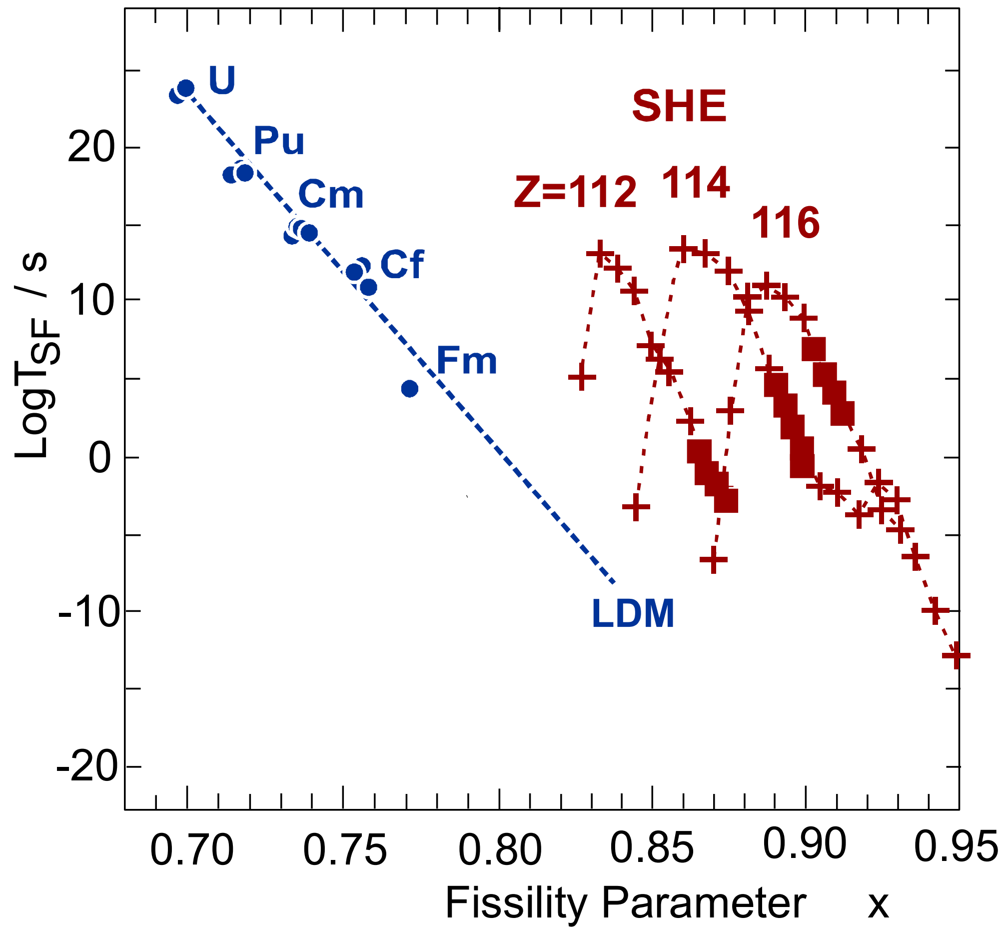
Production cross sections
➔ Seem to indicate a shell closure Z ≥ 120

Predictions of the microscopic theory

Fission Barriers



...and Half - Lives



R. Smolańczuk, Phys. Rev. C 56 (1997) 812

Yuri Oganessian. “ Heaviest Nuclei”. Seminar at GANIL, March 18, 2010, Caen, France

Cross sections

Yu. Oganessian *et al.* PR C69, 054607 (2004)

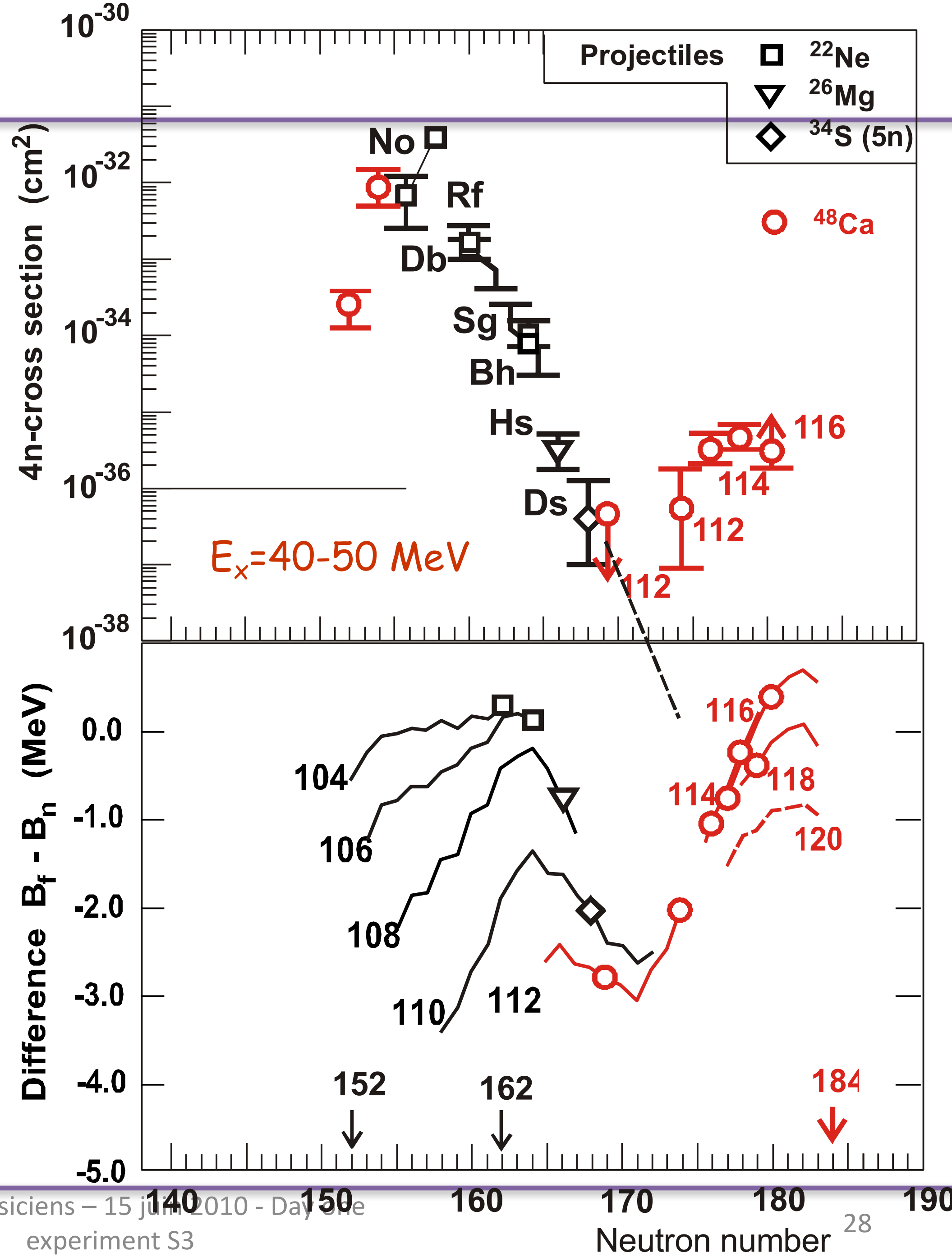
$$\sigma_{xn} \sim (\Gamma_n / \Gamma_f)^x;$$

x — number of evaporated neutrons

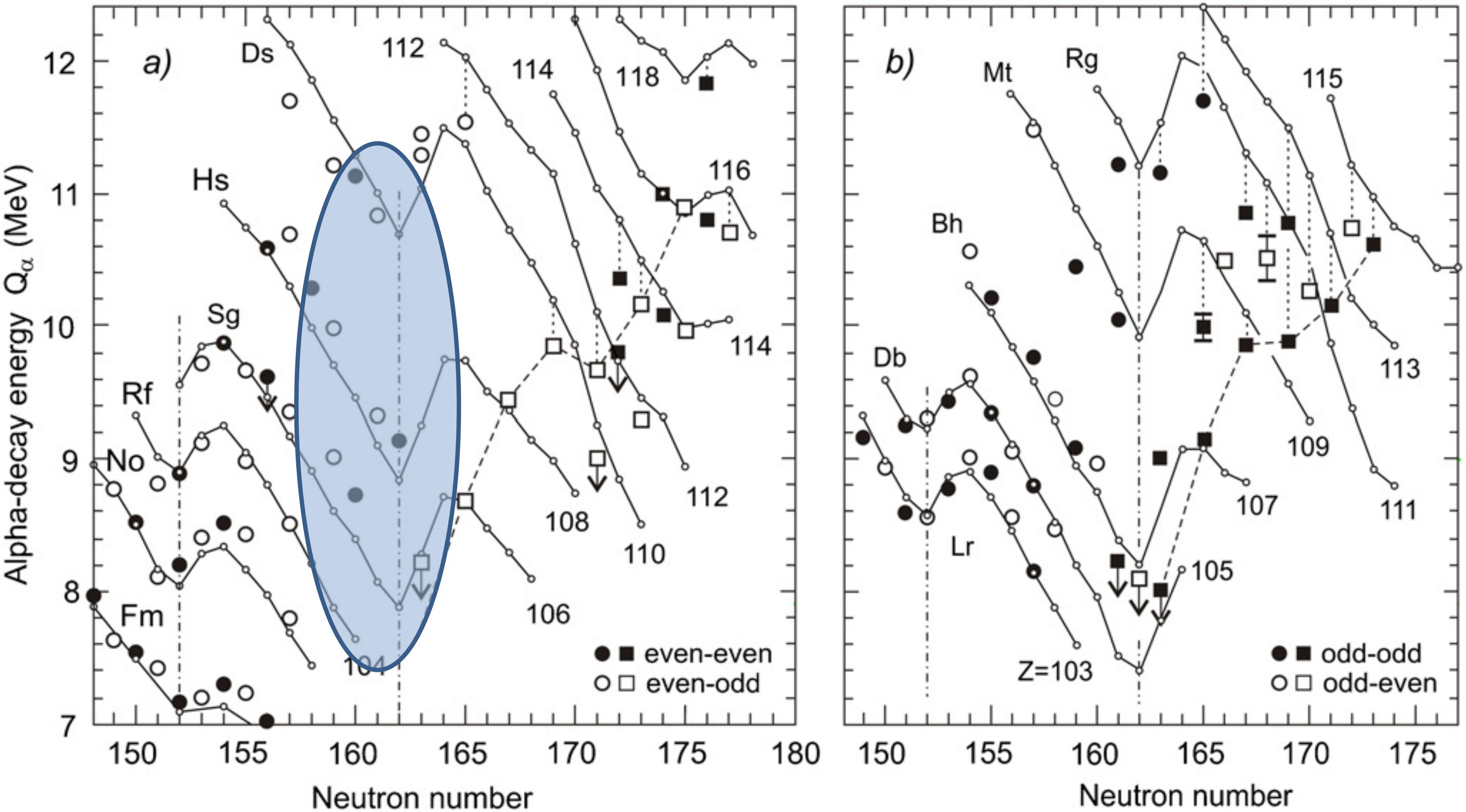
$$(\Gamma_n / \Gamma_f) \sim \exp\,[(B_f - B_n)]$$

$$B_f = B_f^{LD} + \Delta E^{Shell}$$

0



Alpha-decay energy



JPG 34, 2007 – Y. Oganessian

Figure 27. Alpha-decay energy versus neutron number of trans-fermium nuclei. (a) Isotopes of even-*Z elements with Z 100. (b) Isotopes of odd-Z elements with Z 103. Circles denote* nuclei synthesized in hot fusion reactions with light ions (22Ne, 26Mg, 36S) and in cold fusion with massive projectiles; squares correspond to the nuclei, produced in 48Ca-induced reactions. Dashed lines represent long sequences of correlated decays of the nuclei 288115 and 291116, observed in the reactions 243Am + 48Ca and 245Cm + 48Ca (see panel (a)), respectively. The solid lines are drawn through the values of *Qα (small open circles), calculated in the MM-model [39, 144]. The* closed neutron shells *N = 152 and N = 162 are shown by the vertical dashed-dotted lines.*