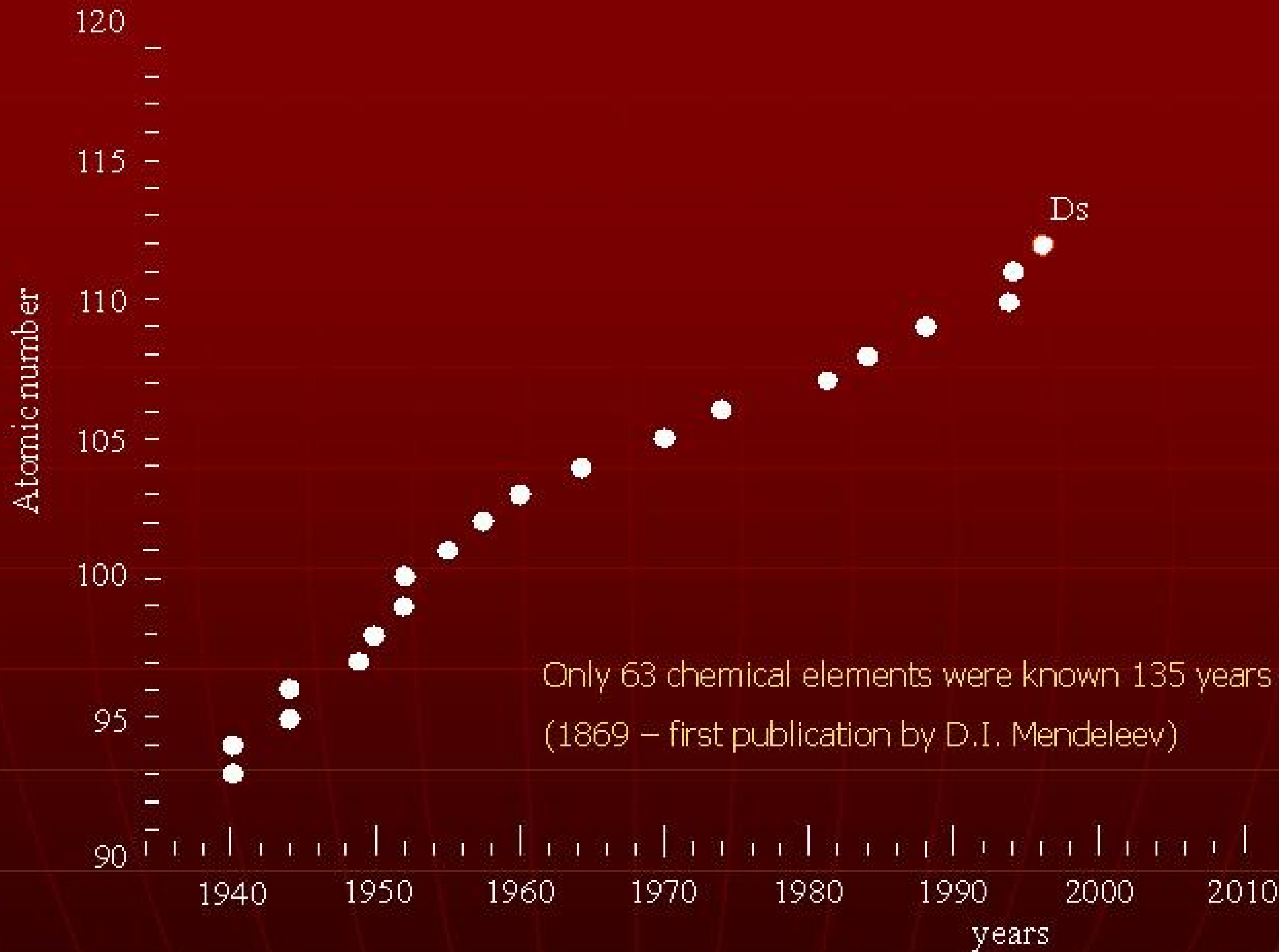
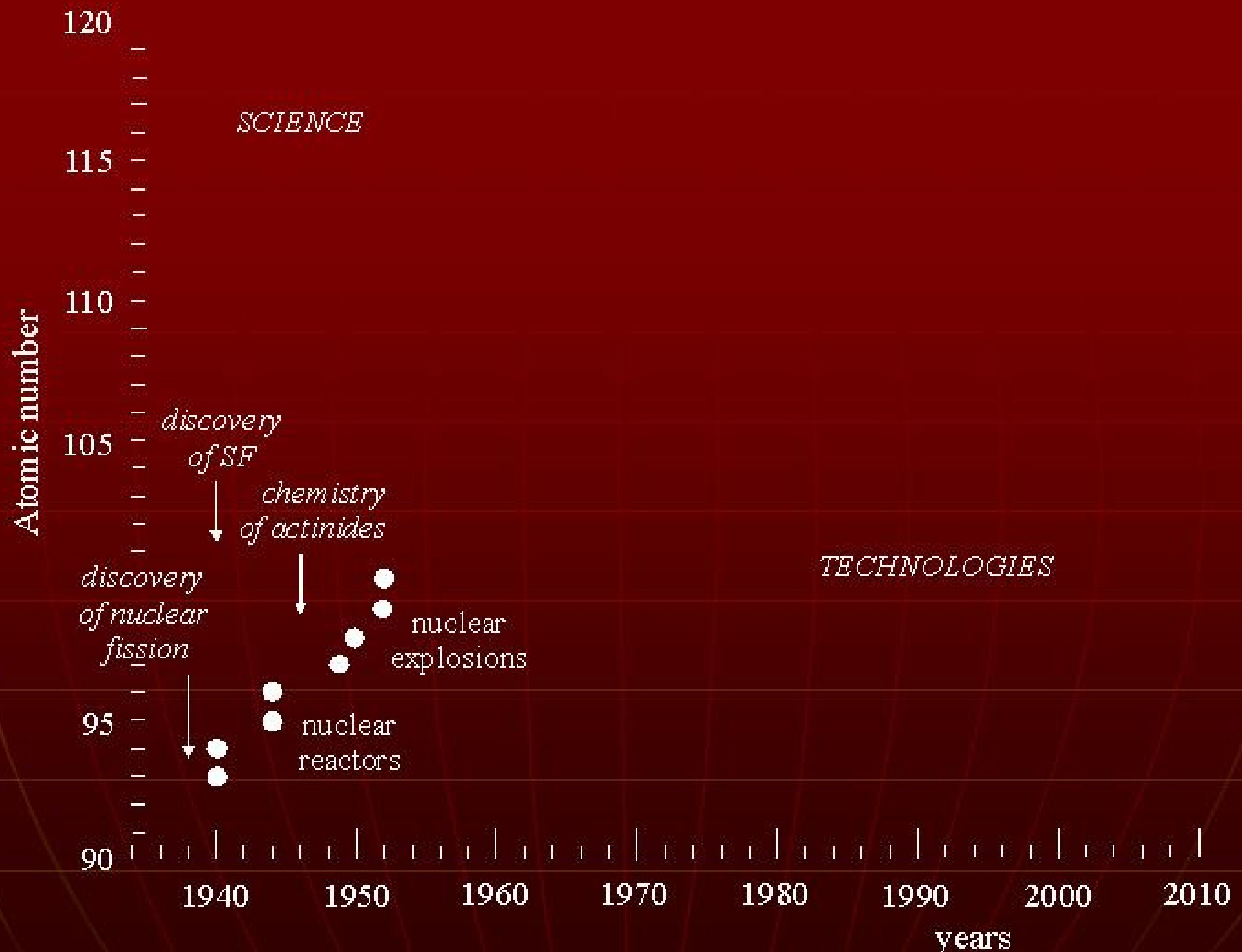
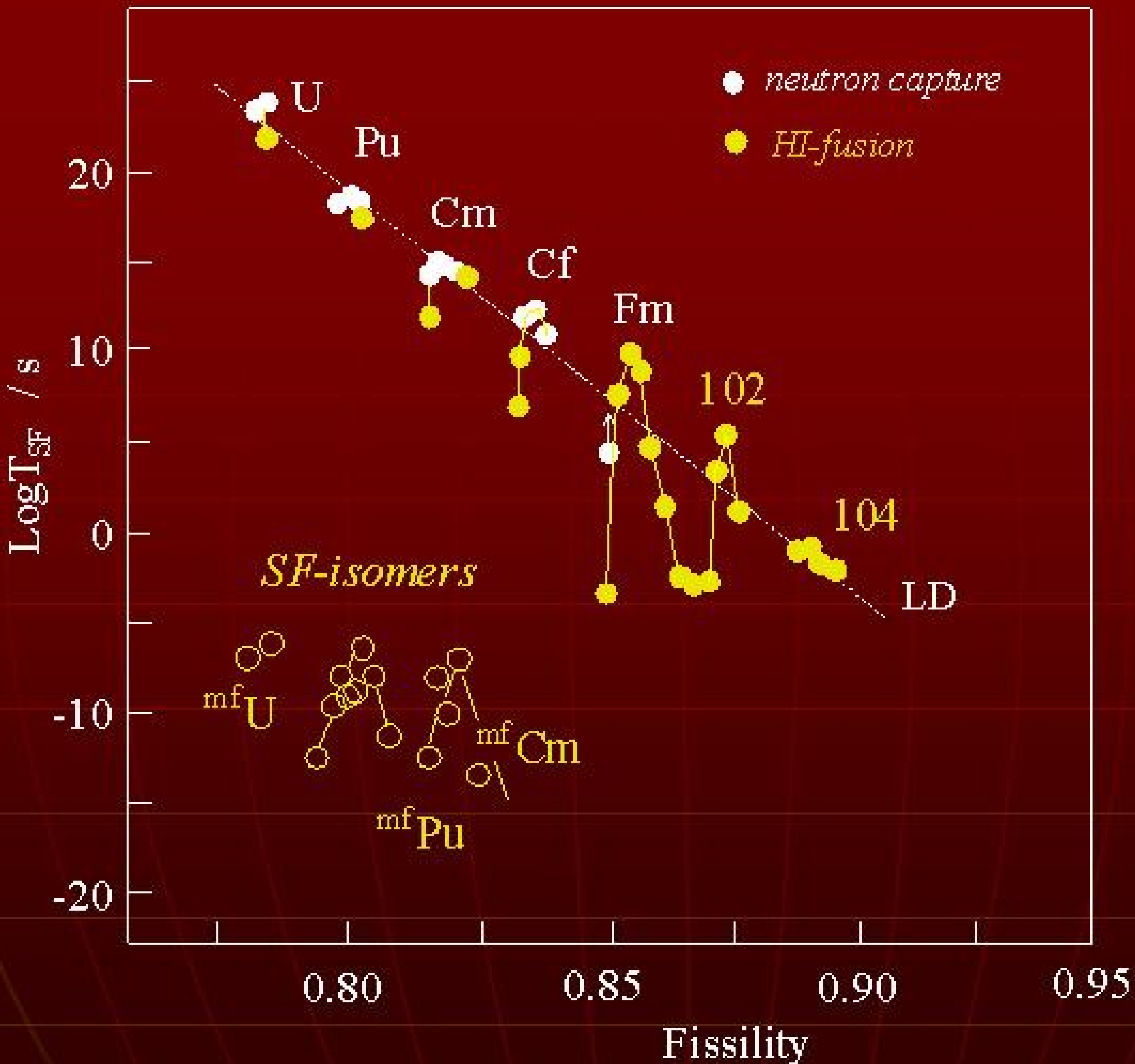

Fest Colloquium
On the occasion of
Sigurd Hofmann's 60th Birthday
Yu. Ts. Oganessian
What do we know about SHE -
Expectations and Reality
February 17, 2004 (GSI)



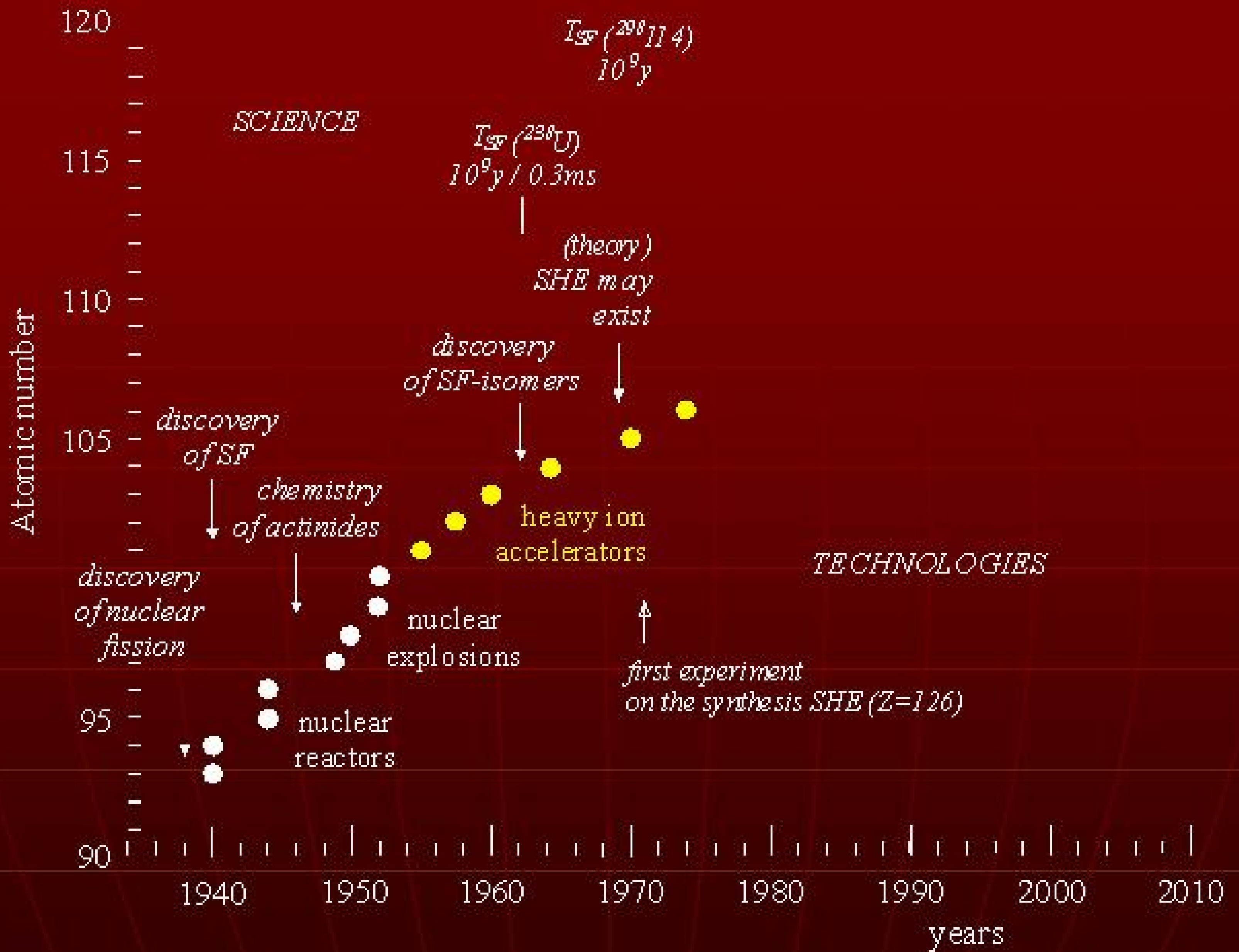
Only 63 chemical elements were known 135 years ago

(1869 – first publication by D.I. Mendeleev)


120
115
110
105
95
90
Atomic number
SCIENCE
discovery of SF
chemistry of actinides
discovery of nuclear fission
nuclear explosions
nuclear reactors
TECHNOLOGIES
1940
1950
1960
1970
1980
1990
2000
2010
years



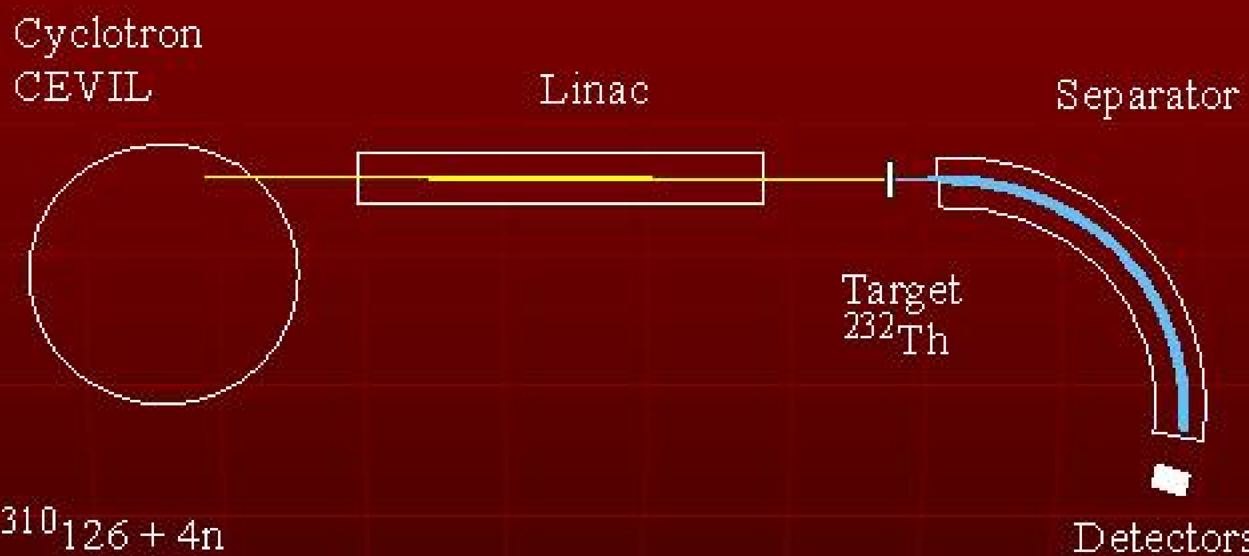
neutron capture
HI-fusion
U
Pu
Cm
Cf
Fm
102
104
LD
SF-isomers
mfU
mfPu
mfCm
LogT$_{SF}$ / s
20
10
0
-10
-20
0.80
0.85
0.90
0.95
Fissility



120
115
110
105
95
90
Atomic number
SCIENCE
T_{SF} (^{298}114)
10^9y
T_{SF} (^{238}U)
10^9y / 0.3ms
(theory)
SHE may
exist
discovery
of SF-isomers
discovery
of SF
chemistry
of actinides
heavy ion
accelerators
TECHNOLOGIES
discovery
of nuclear
fission
nuclear
explosions
first experiment
on the synthesis SHE (Z=126)
nuclear
reactors
1940
1950
1960
1970
1980
1990
2000
2010
years

First experiment on the synthesis SHE with Z=126, N=184

IPN (Orsay) 1971



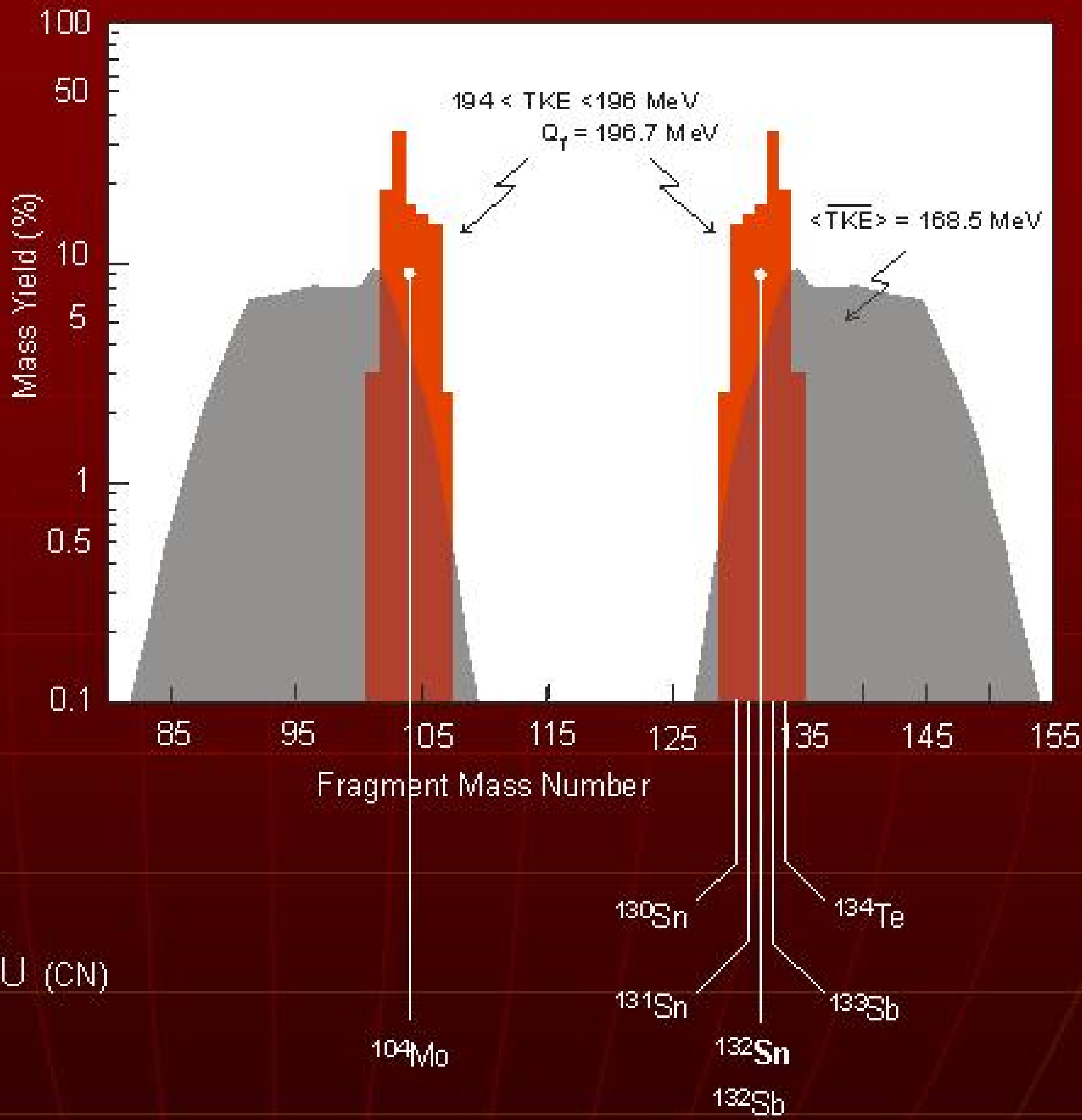
Reaction:

$^{232}Th + ^{82}Kr - ^{310}126 + 4n$

Expected cross section
was very optimistic:

σ_{4n} about 0.5 mb!

Fission fragment mass yield
at different total kinetic energies
in the $^{235}U(n_{th},f)$ reaction



$^{104}Mo + ^{132}Sn \rightarrow ^{236}U$ (CN)

Since ^{132}Sn is not available,

the next magic nucleus is ^{208}Pb

Then it is the reaction:

^{208}Pb + heavy projectile.

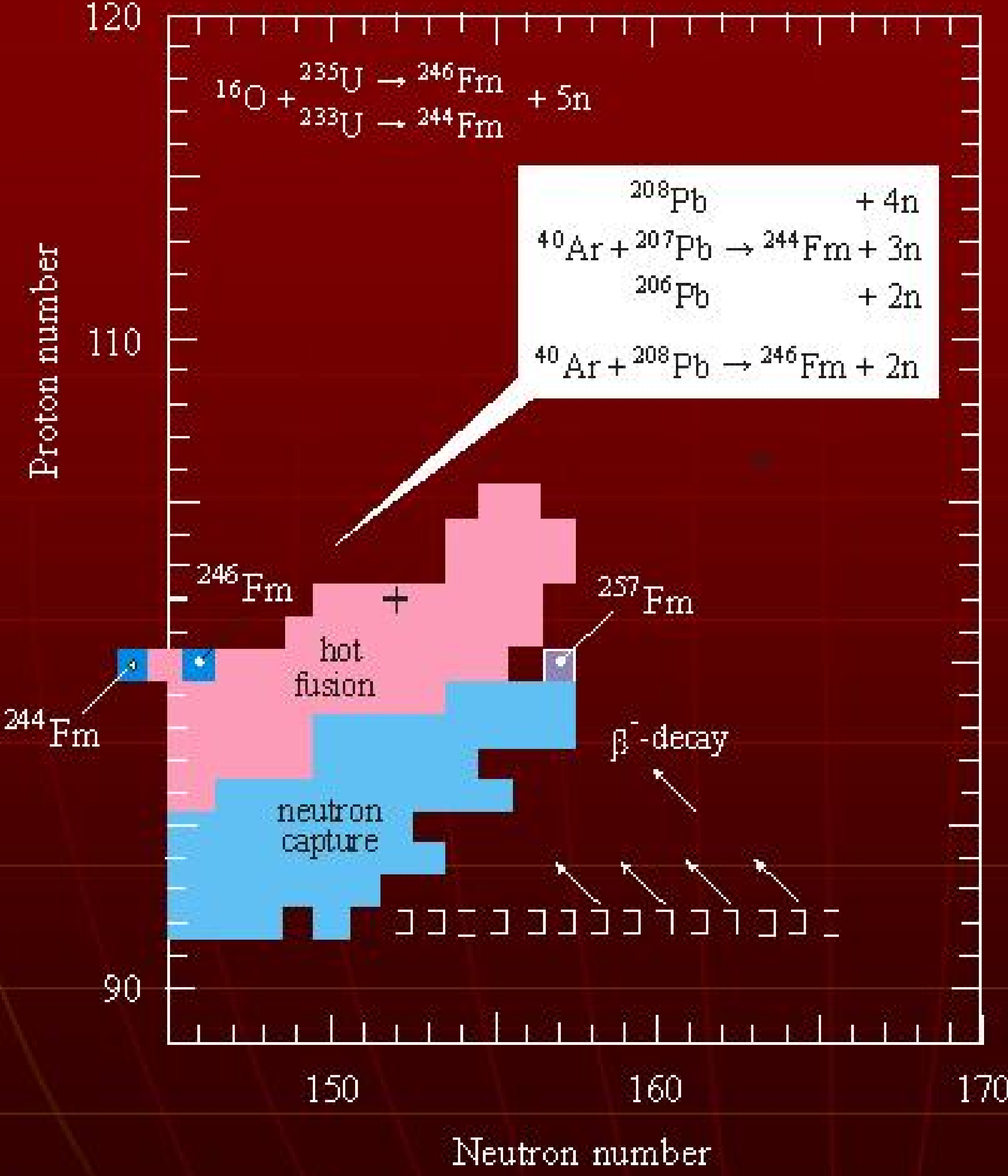
A heavy ion was ^{40}Ar

The reaction was

$$^{208}Pb + {}^{40}Ar \rightarrow {}^{258}Fm - xn$$

Dubna, 1973

Reactions of Synthesis of the Heaviest Nuclei



Sigurd Hofmann

February 15, 1944

Boehmisch-Kamnitz

1963-1968 Student of Physics (TU-Darmstadt)

1970-1974 Thesis (TU-Darmstadt)

13.02.1974 Examination, Dr.rer.nat.

1974 Permanent Position (GSI-Darmstadt)

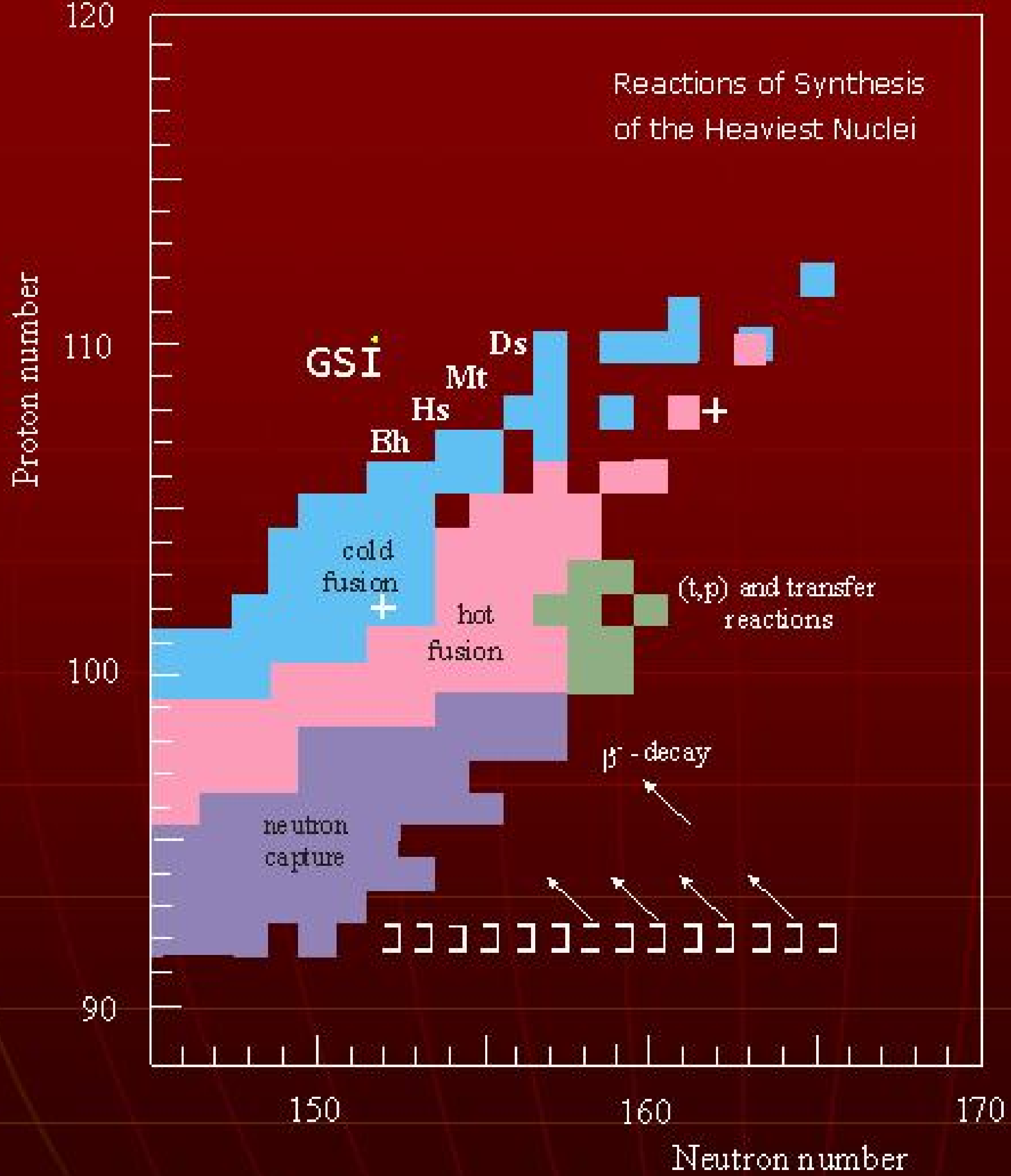
1989 Responsible for experiments at SHIP

Z=107-109
α-radioactivity
p-radioactivity
Nuclear reactions

1994 Discovery of Element 110 (Ds)

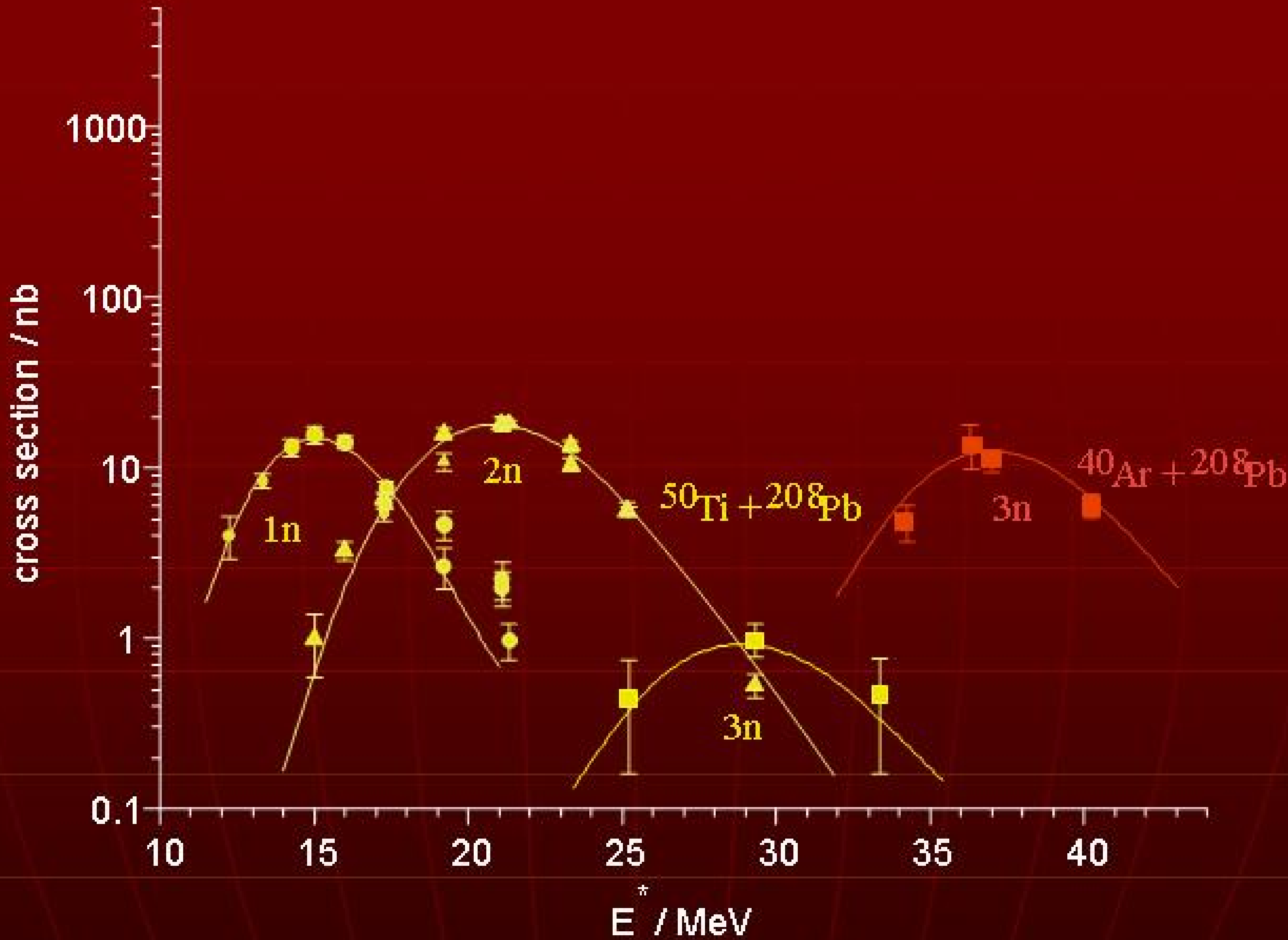
Z=111-112

2004.....

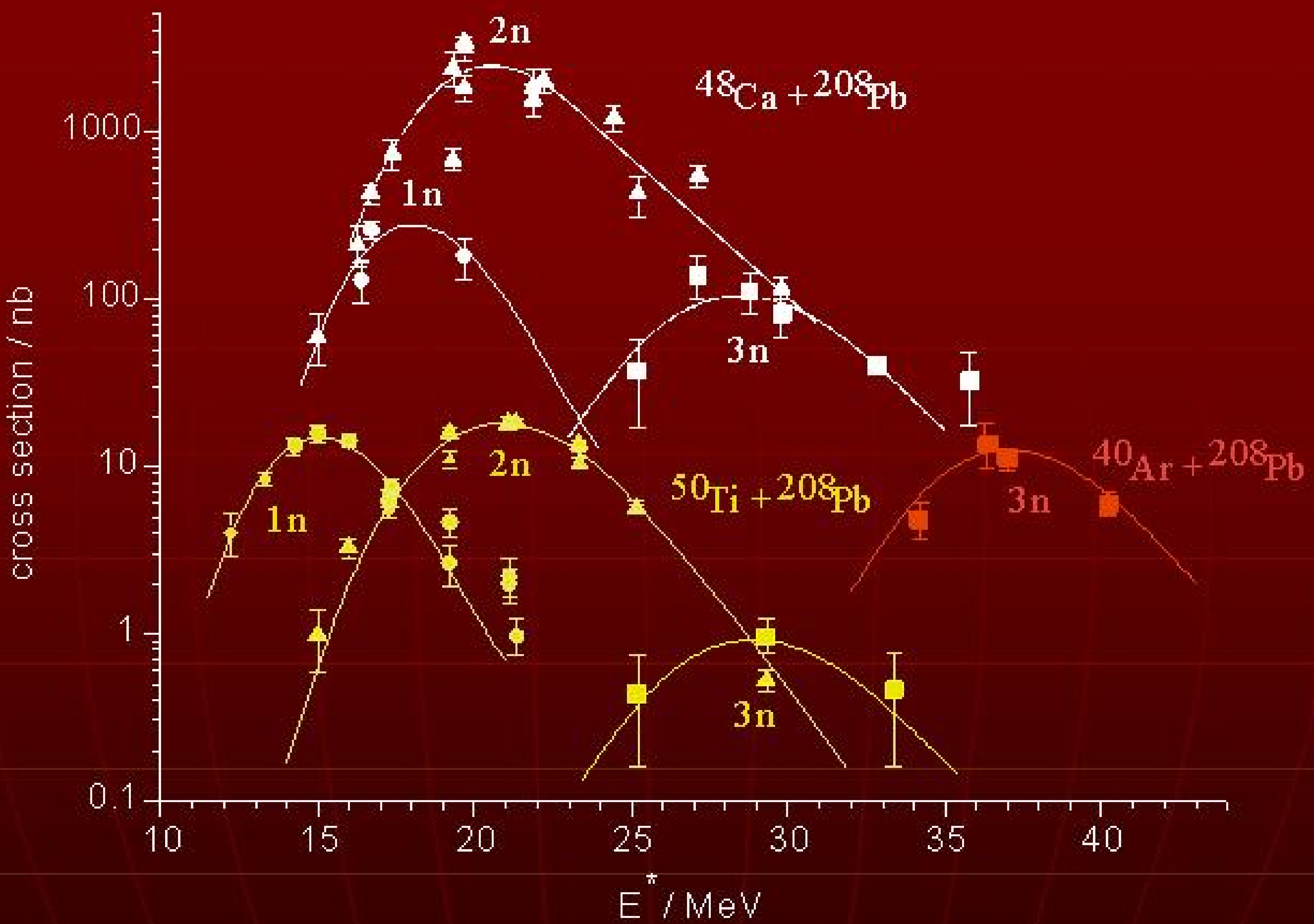

Reactions of Synthesis
of the Heaviest Nuclei
Proton number
Neutron number
120
110
100
90
150
160
170
GSI
Ds
Mt
Hs
Bh
cold
fusion
hot
fusion
(t,p) and transfer
reactions
β⁻ - decay
neutron
capture

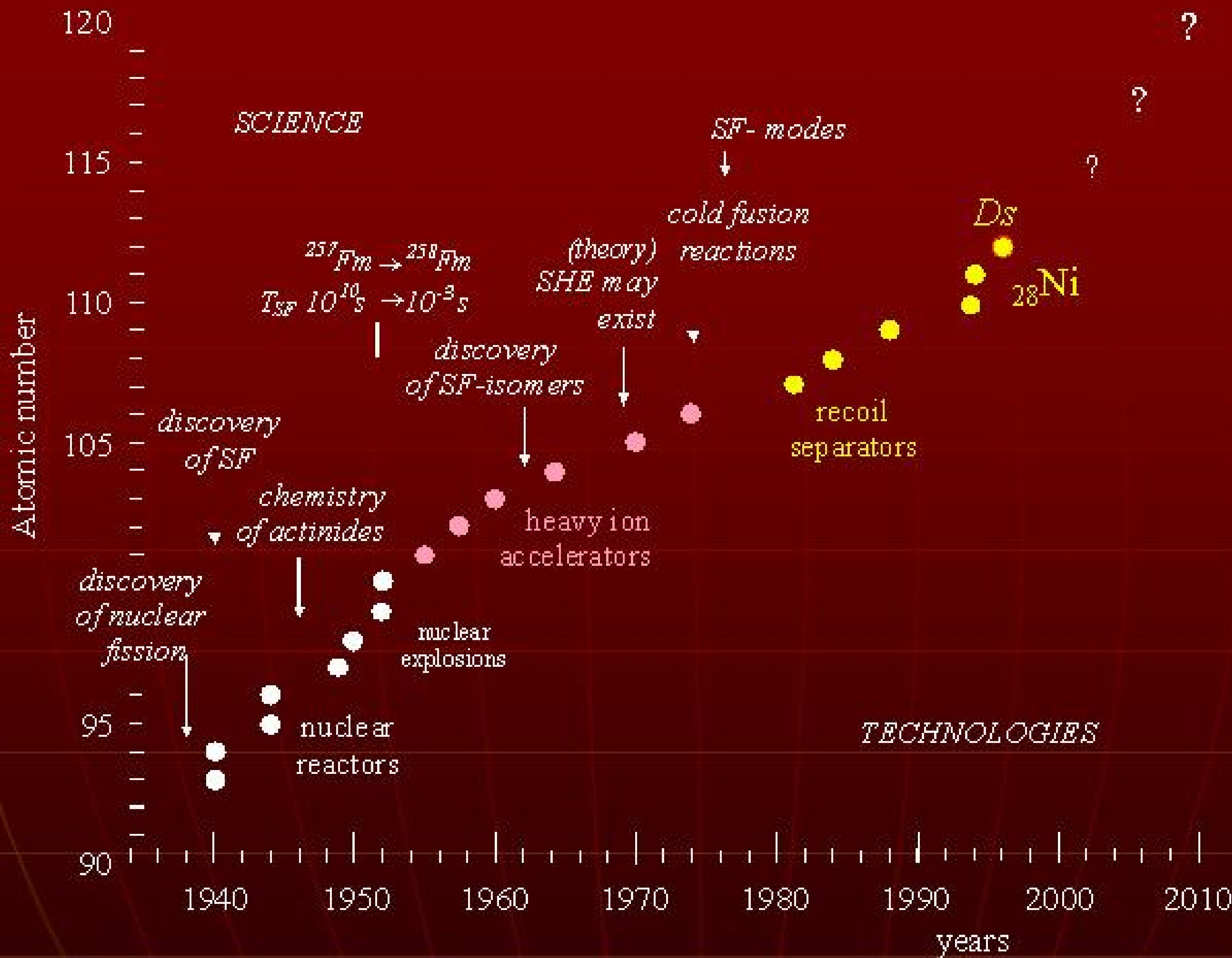

Ds


1000
100
10
1
0.1
cross section / nb
10
15
20
25
30
35
40
E* / MeV
40Ar + 208Pb
3n



cross section / nb
1000
100
10
1
0.1
10
15
20
25
30
35
40
E* / MeV
1n
2n
3n
50Ti + 208Pb
40Ar + 208Pb
3n


2n
$^{48}Ca + ^{208}Pb$
1000
1n
100
3n
cross section / nb
10
2n
$^{50}Ti + ^{208}Pb$
$^{40}Ar + ^{208}Pb$
3n
1n
1
3n
0.1
10
15
20
25
30
35
40
E^* / MeV


Atomic number
120
115
110
105
95
90
1940
1950
1960
1970
1980
1990
2000
2010
years
SCIENCE
TECHNOLOGIES
discovery of nuclear fission
discovery of SF
chemistry of actinides
$^{257}Fm \rightarrow {}^{258}Fm$
$T_{SF}\ 10^{10}s \rightarrow 10^{-3}s$
discovery of SF-isomers
(theory) SHE may exist
cold fusion reactions
SF- modes
nuclear reactors
nuclear explosions
heavy ion accelerators
recoil separators
Ds
$_{28}$Ni
?
?
?

There remains a question –
what a ^{132}Sn beam can give us?

We can now write a lot of reactions:

$^{132}Sn + {}^{170}Er \rightarrow Z=118$
$^{132}Sn + {}^{176}Yb \rightarrow Z=120$ etc

But how can we check if these nuclei can fuse?

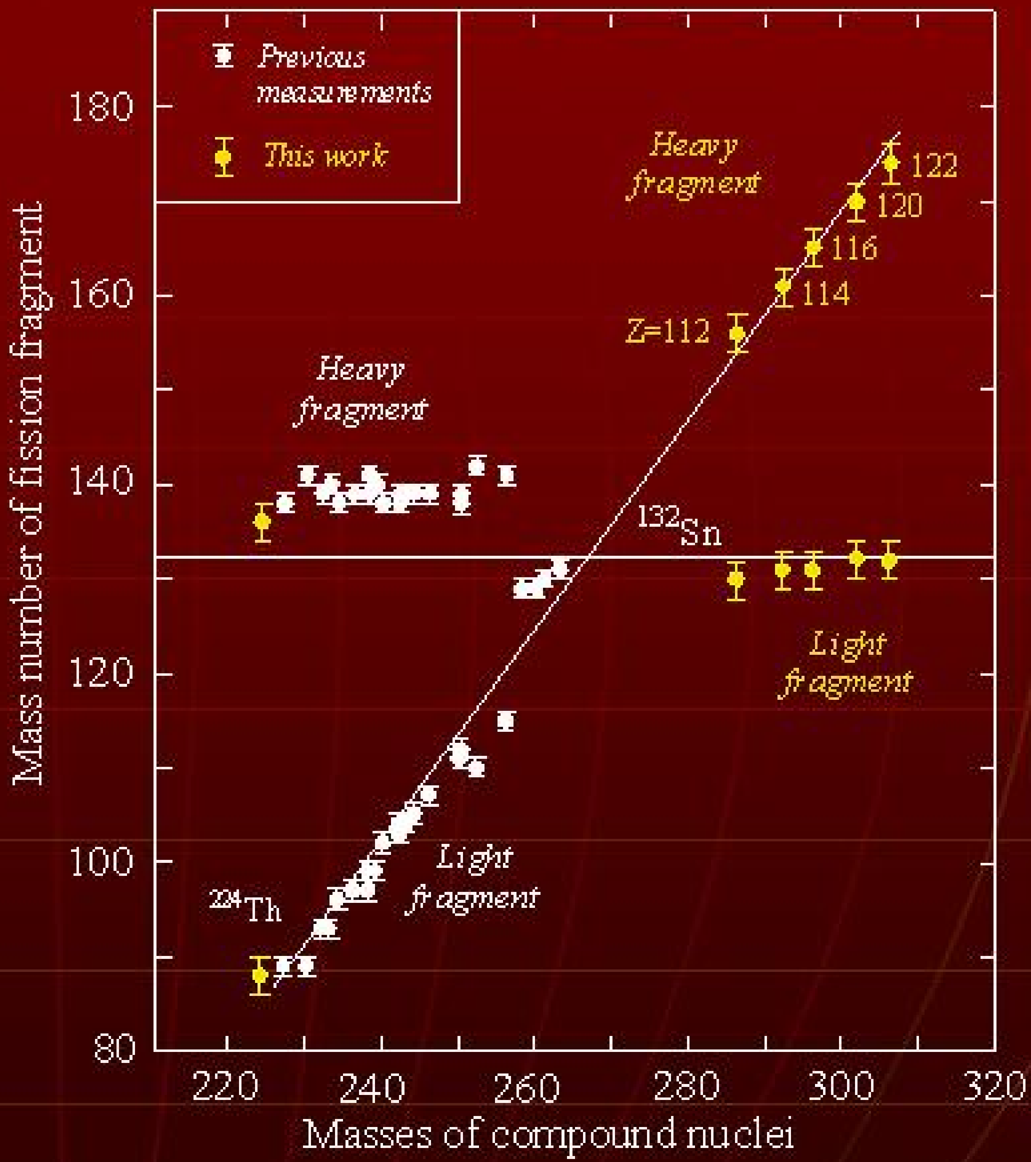
To what degree test experiments of the type:

^{124}Sn (N=74) + $^{136}Xe \rightarrow {}^{260}Rf^{*}$
instead of N=82

are the answer to the question?

Now let us get back to ^{48}Ca.....

Mass Asymmetry in Low Energy Binary Fission

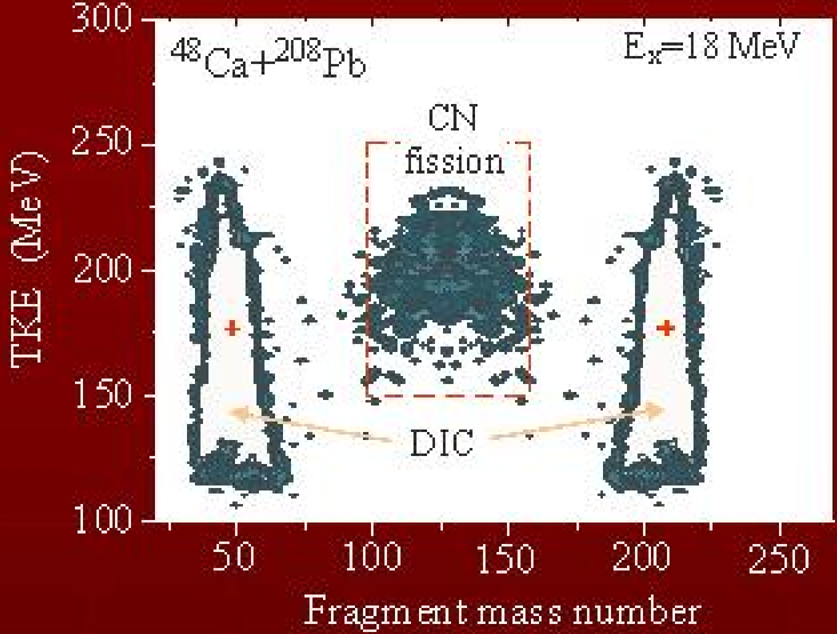


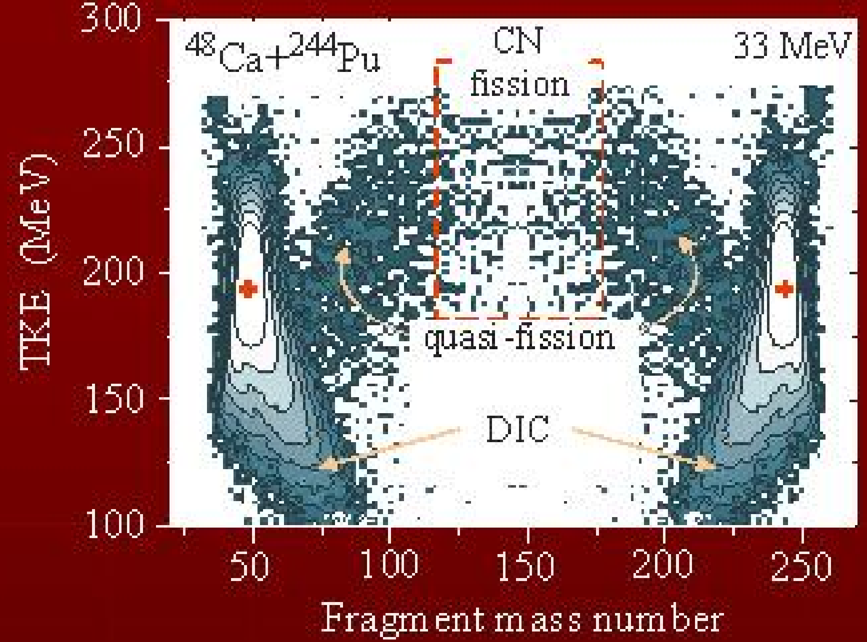
Here there are two questions:

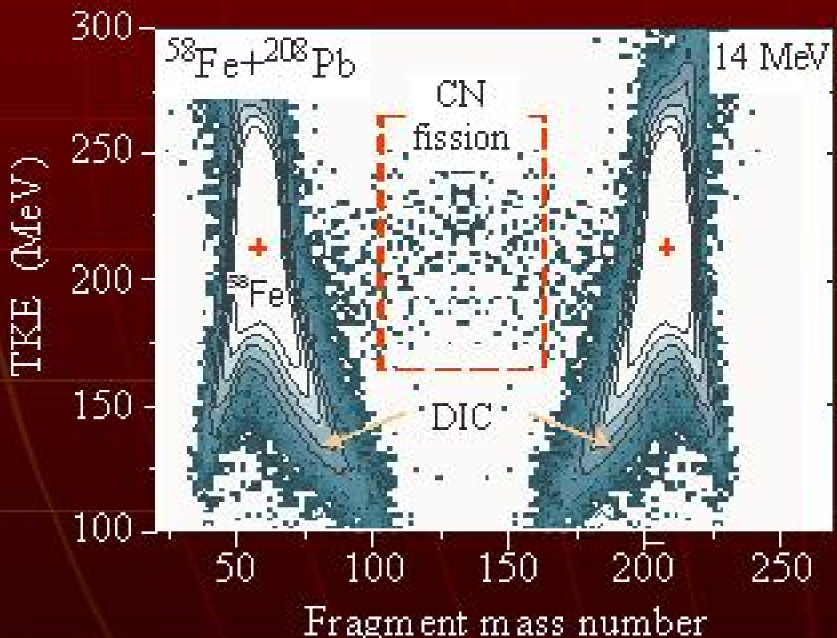
What is the fusion probability for ^{48}Ca and actinide nuclei?

What is the survival probability of the compound nucleus with

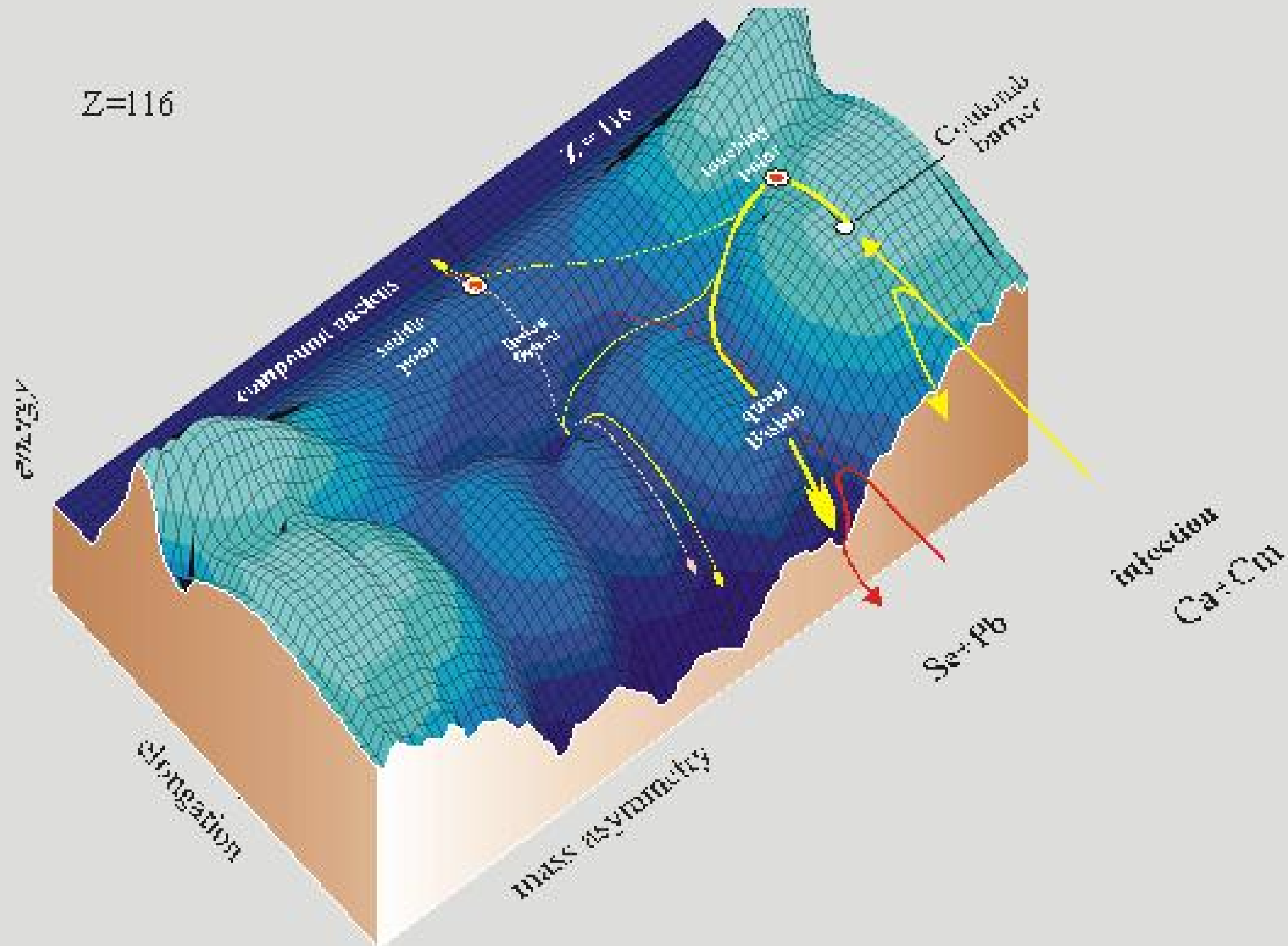
$Z=114$-118 at the excitation energy $E^{*} \geq 30$ MeV?



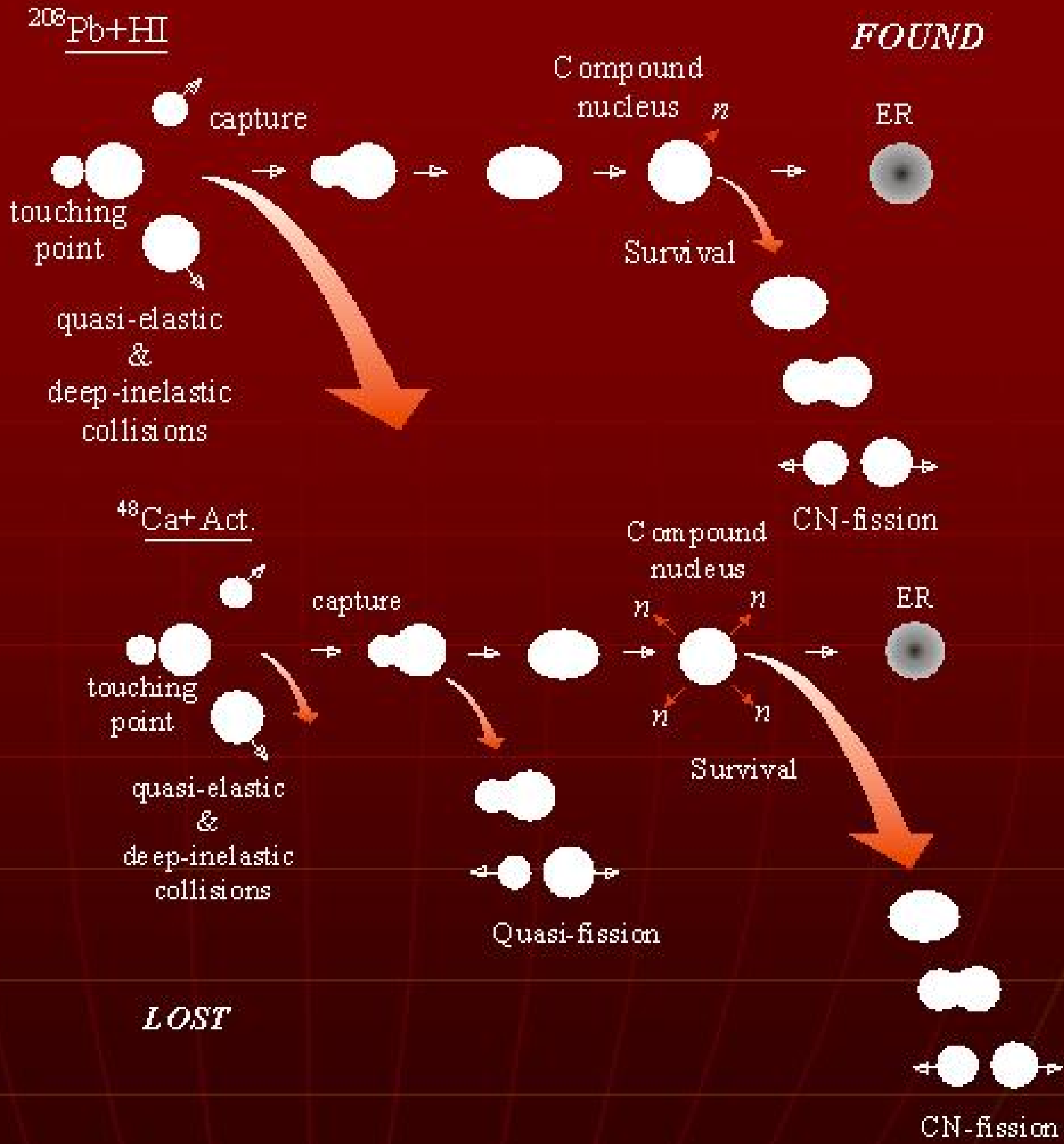


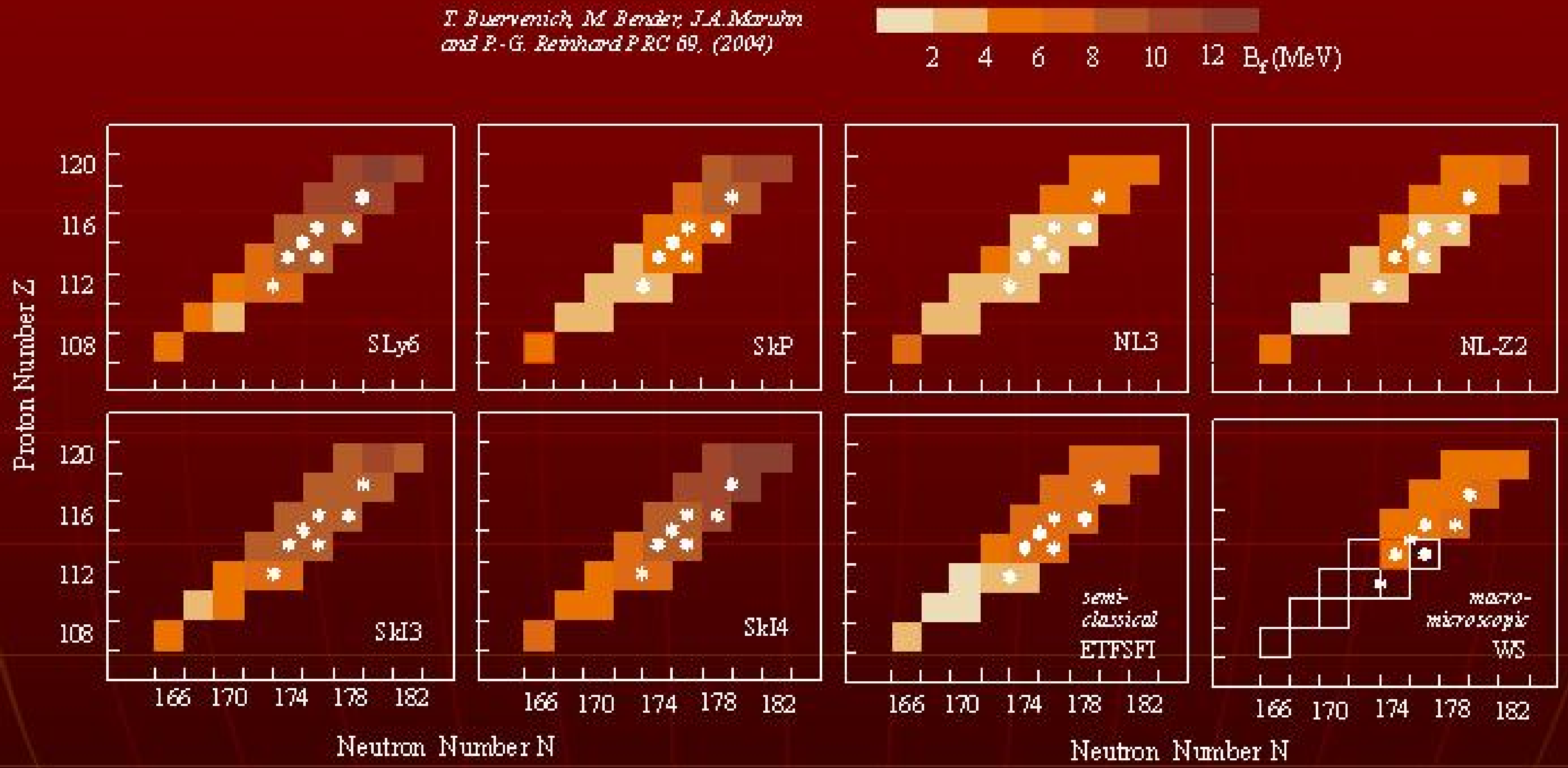


M. Itkis et al., (2002)
Fragment Energy and Mass Distributions
in Cold and Hot Fusion Reactions

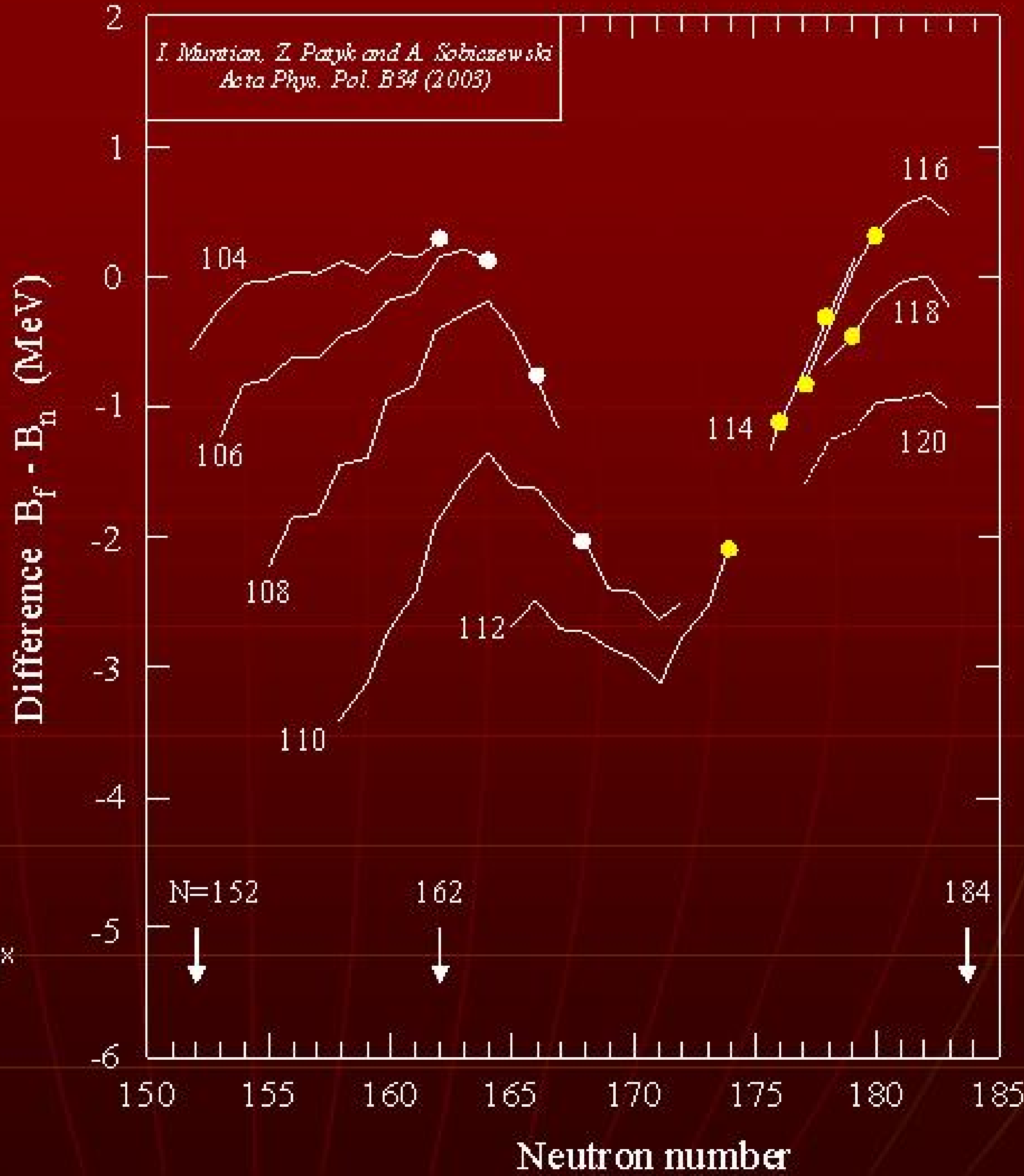

Z=116
Z = 116
compound nucleus
touching point
Coulomb barrier
quasi fission
injection
Ca+Cm
Sn+Pb
mass asymmetry
elongation
energy

Lost & Found in Fusion - Fission Reactions





T. Buervenich, M. Bender, J.A.Maruhn
and P.-G. Reinhard PRC 69, (2004)
2 4 6 8 10 12 B_f (MeV)
Proton Number Z
120
116
112
108
SLy6
SkP
NL3
NL-Z2
SkI3
SkI4
semi-
classical
ETFSI
macro-
microscopic
WS
166 170 174 178 182
Neutron Number N



$$P_{surv.} \sim [\exp(B_f - B_n) / T]^x$$

Production rate (ε=40%) at the cross section 1pb:

now - 10 SH atoms / y

Consumption of the ^{48}Ca (68%) - 0.5 mg/h

beam intensity - $5 \cdot 10^{12}$/s

beam time - 2000 h/y

Isotopes:

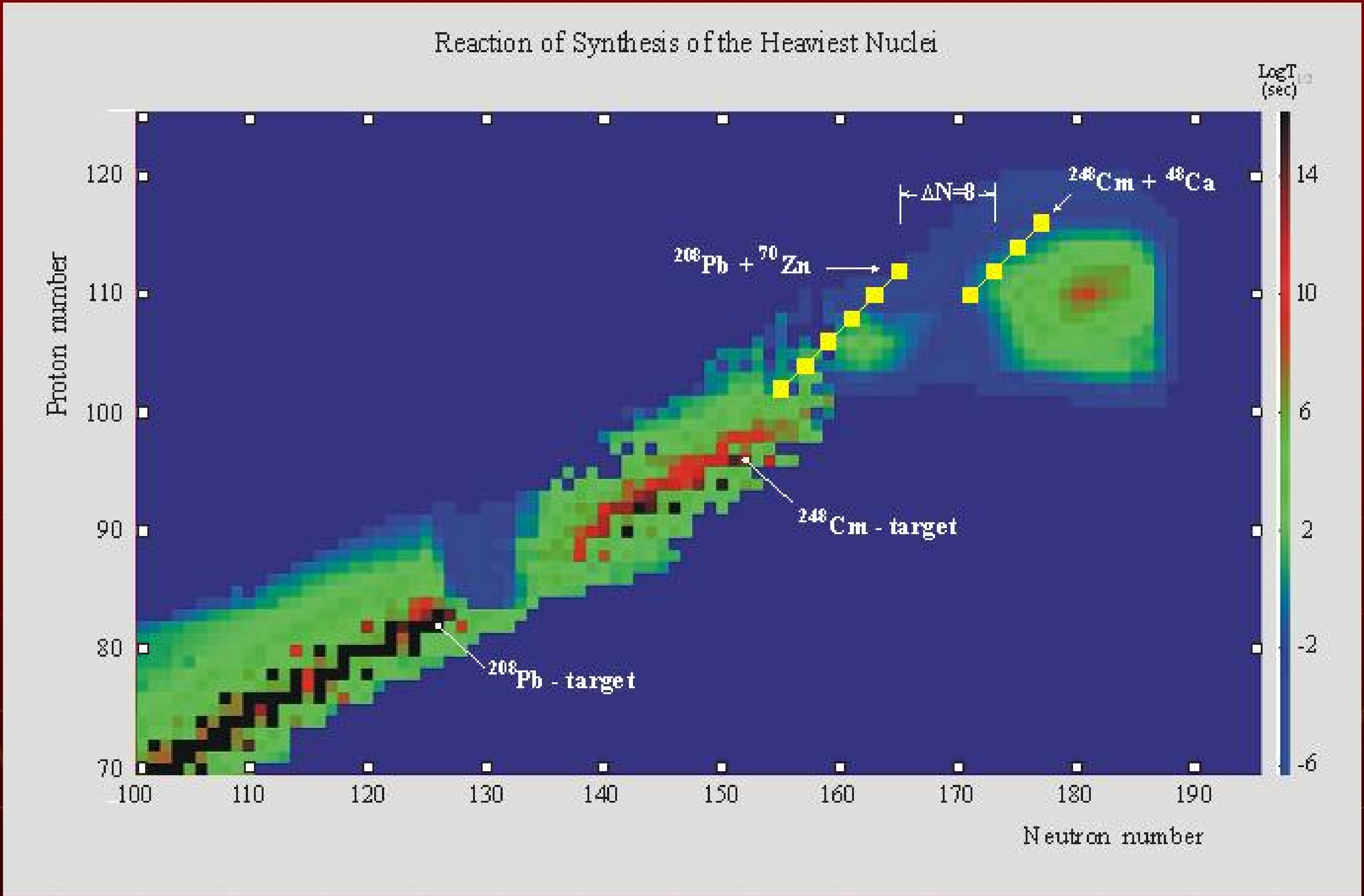
U[238], **Pu**[242, 244], **Am[243]**, **Cm**[245, 247], Cf[249] **+ ^{48}Ca → Z = 112 - 118**

technology of the target preparation - 0.3 mg/cm^2

isotope enrichment - 98-99%
S2-separator
(Sarov)

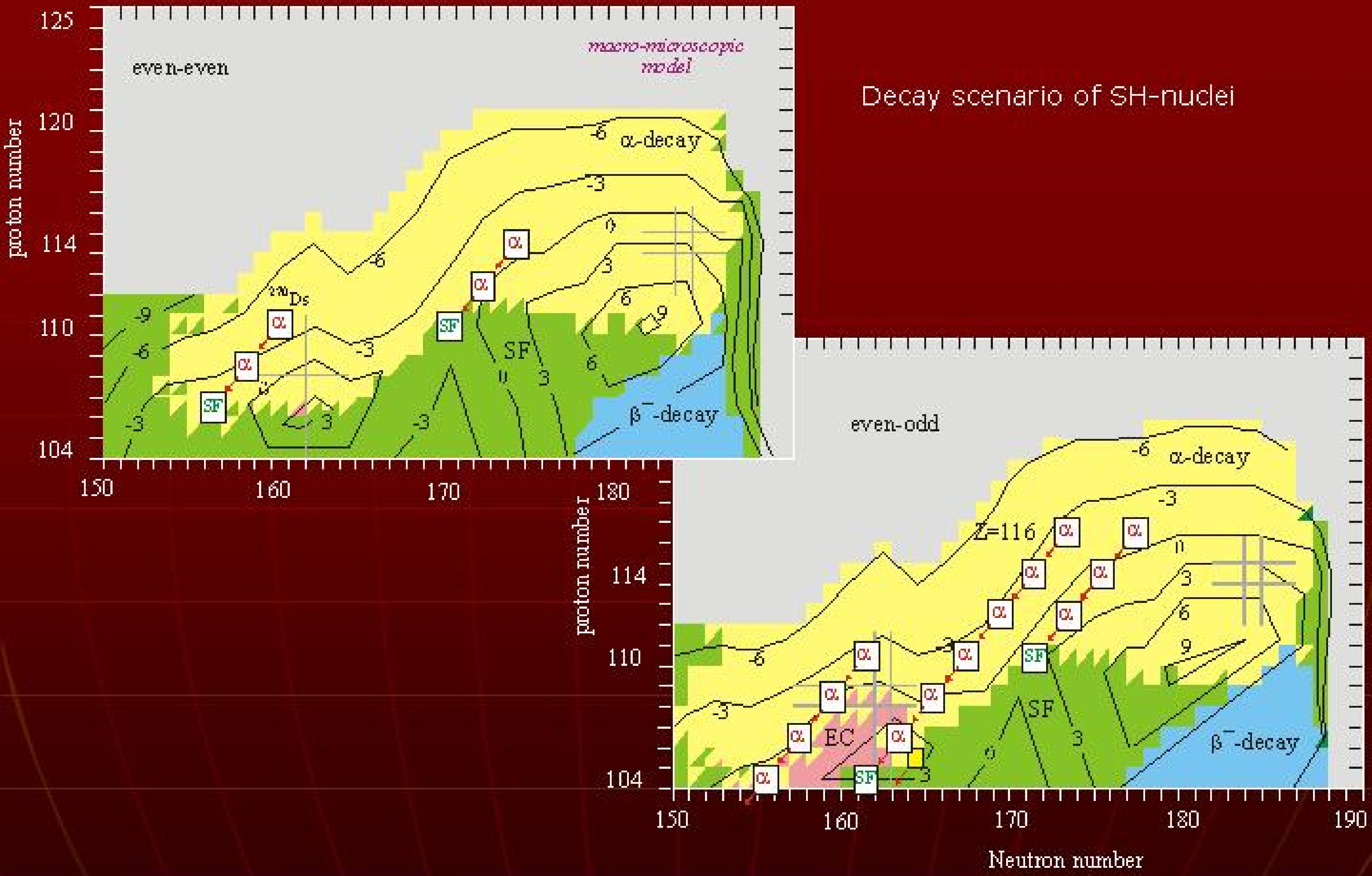
Separation of super heavy nuclei and detection their radioactive decay

now: DGFRS

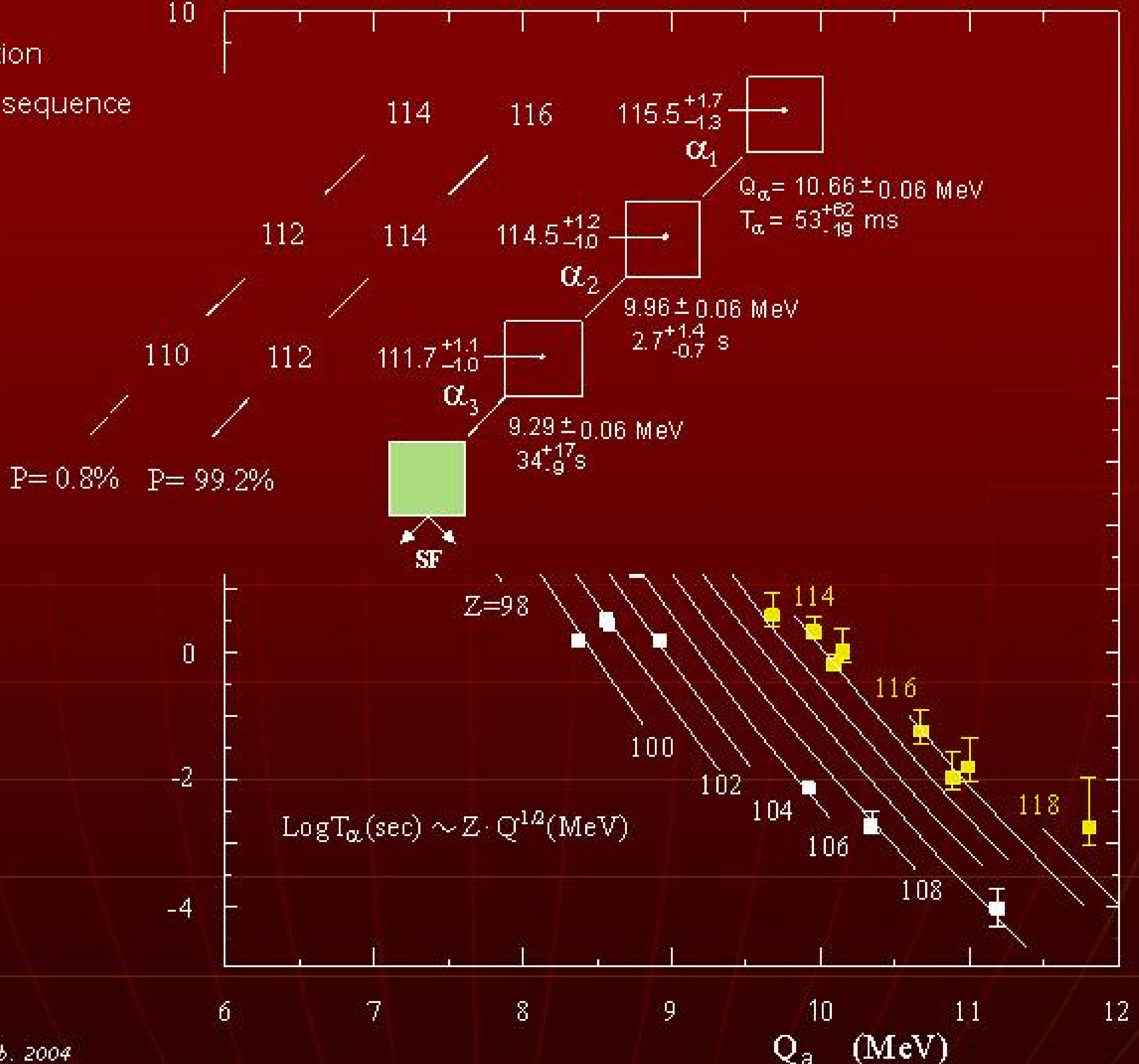


Reaction of Synthesis of the Heaviest Nuclei
LogT1/2
(sec)
Proton number
Neutron number
70
80
90
100
110
120
100
110
120
130
140
150
160
170
180
190
14
10
6
2
-2
-6
ΔN=8
248Cm + 48Ca
208Pb + 70Zn
248Cm - target
208Pb - target

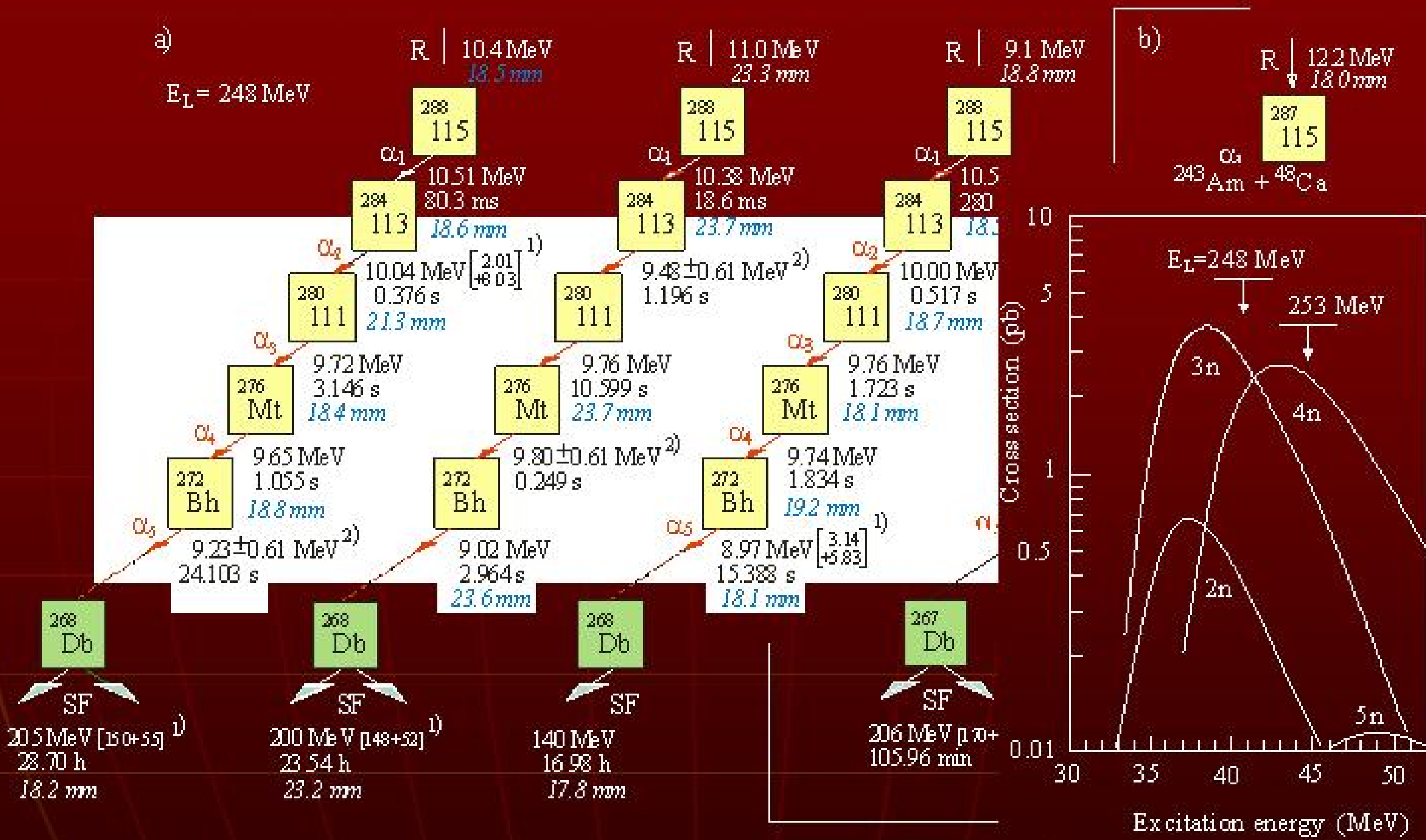
Decay scenario of SH-nuclei

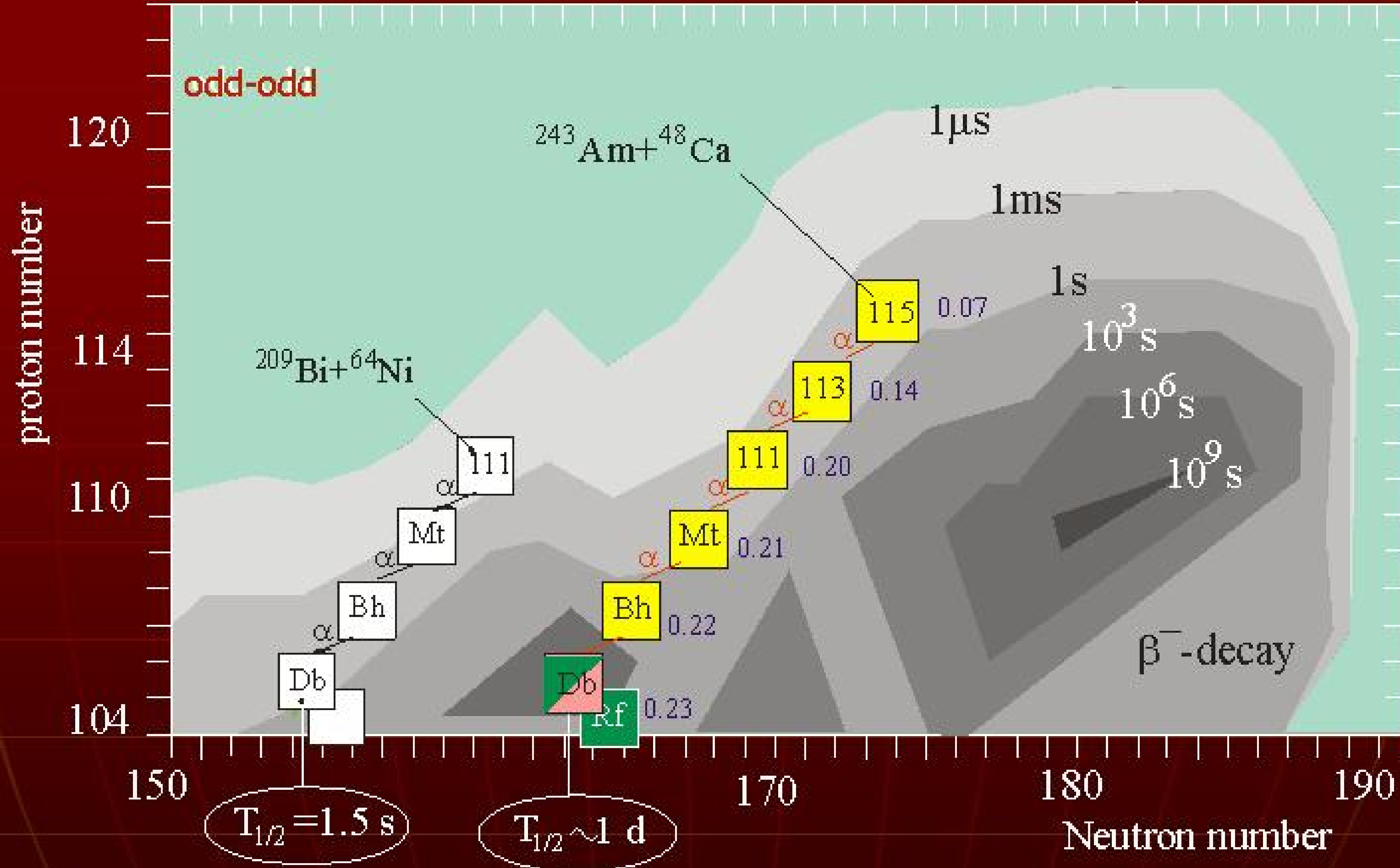


Z – identification of the decay sequence

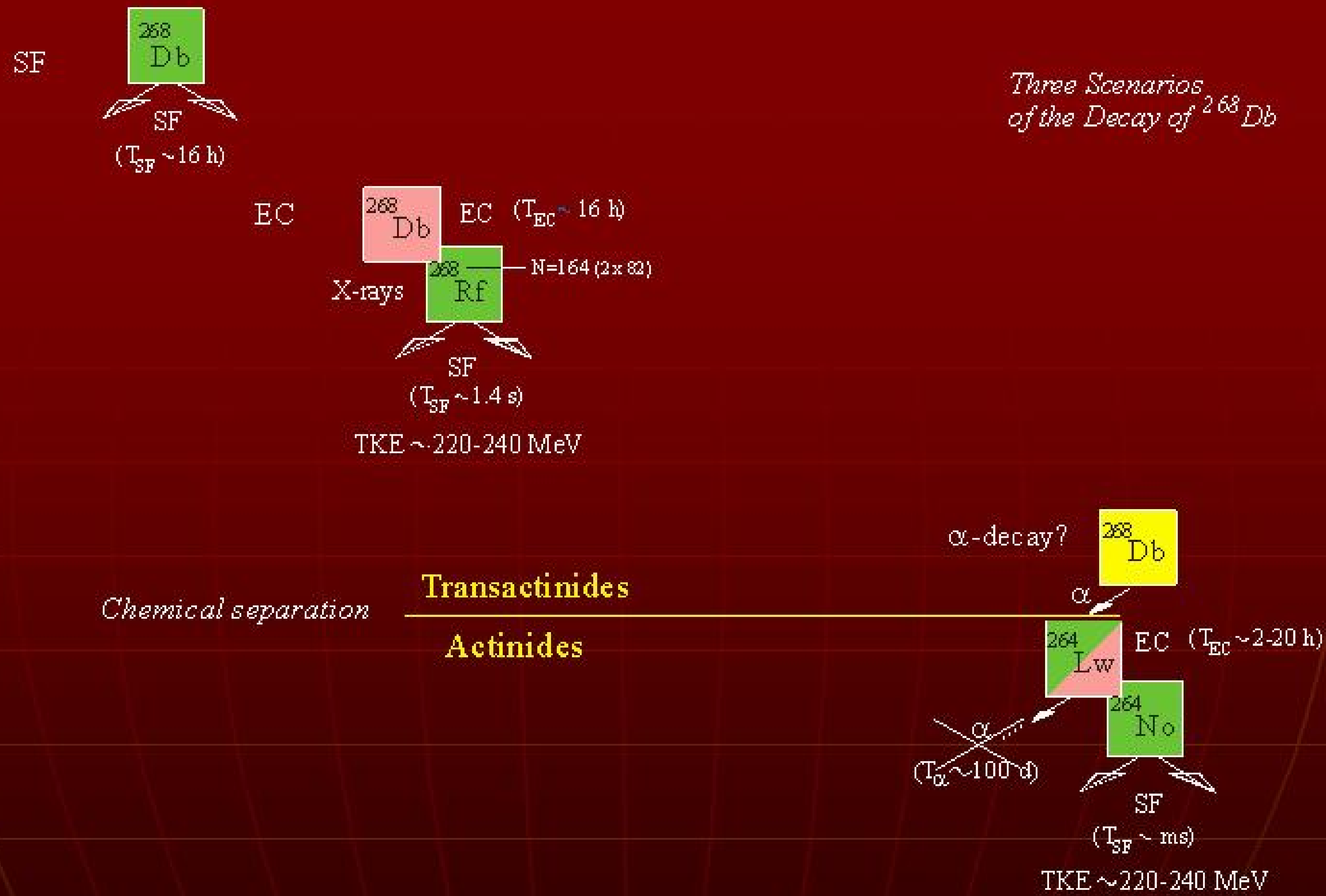


Decay Chains Observed in 243Am + 48Ca Reaction

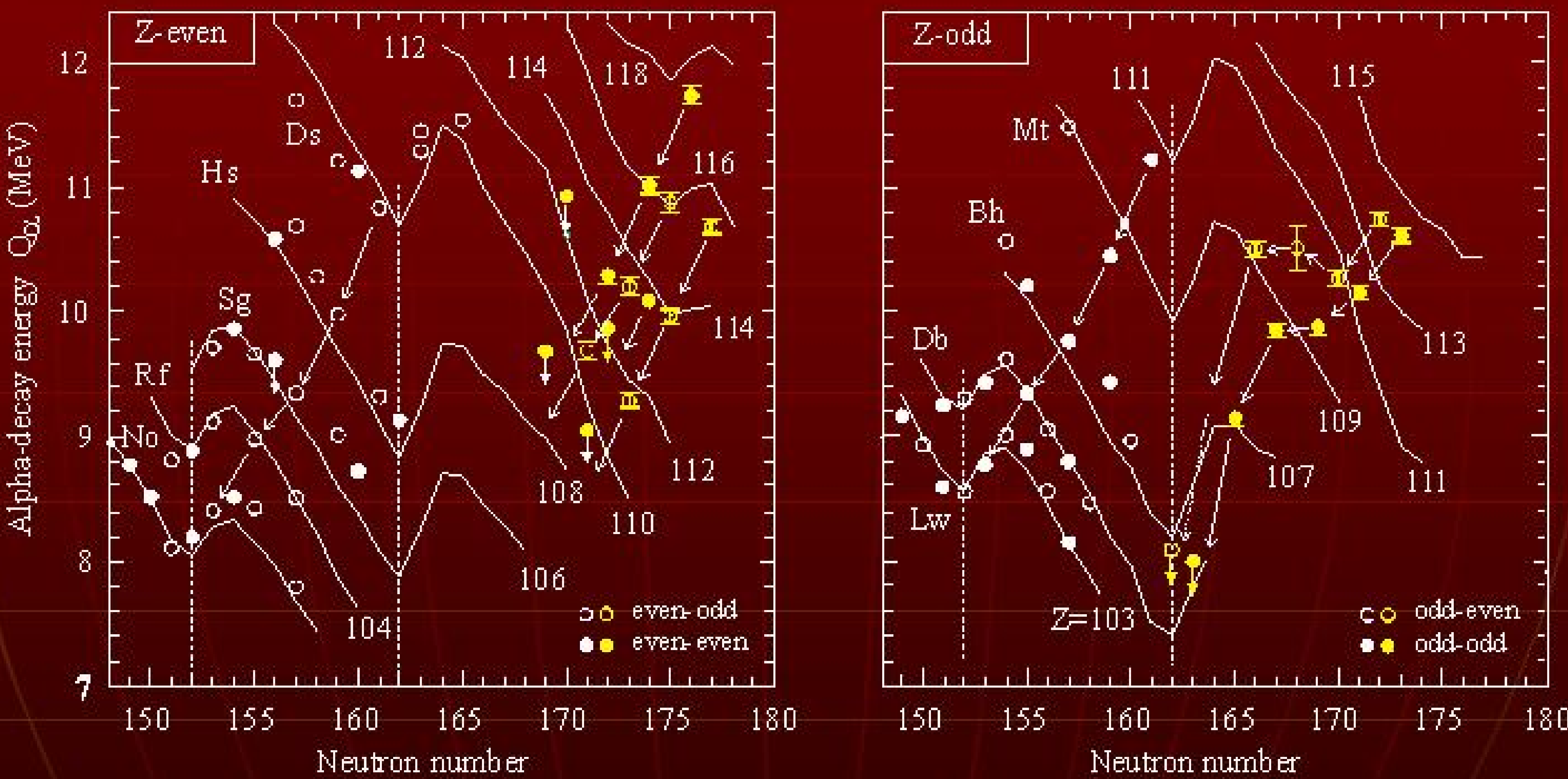




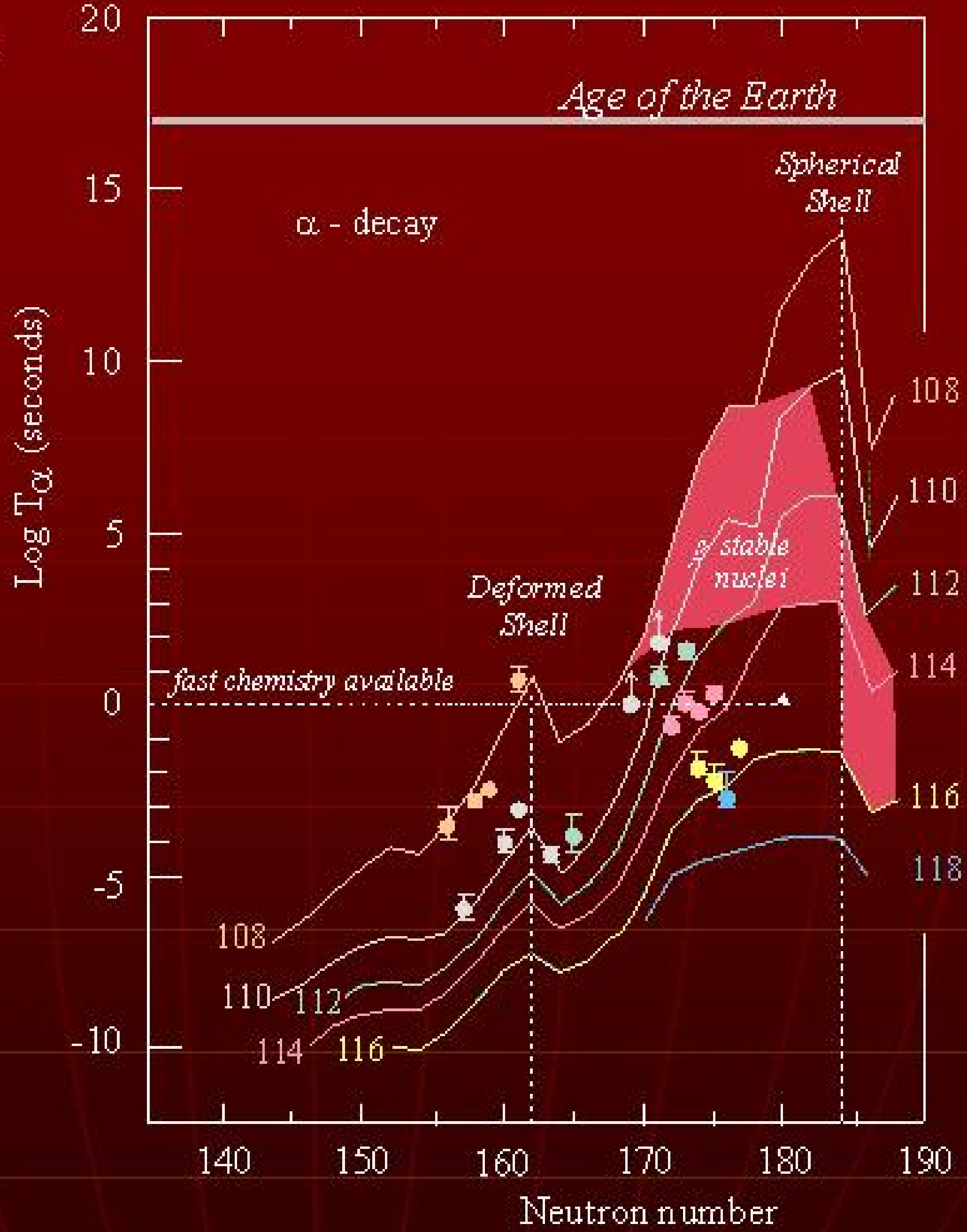
odd-odd
proton number
120
114
110
104
150
170
180
190
Neutron number
1μs
1ms
1s
10^3 s
10^6 s
10^9 s
β⁻-decay
243Am+48Ca
209Bi+64Ni
115
0.07
113
0.14
111
0.20
Mt
0.21
Bh
0.22
Db
Rf
0.23
α
111
Mt
Bh
Db
T1/2 =1.5 s
T1/2 ~1 d


Three Scenarios
of the Decay of 268 Db
SF
268
Db
SF
(TSF ~16 h)
EC
268
Db
EC (TEC ~ 16 h)
X-rays
268
Rf
N=164 (2x 82)
SF
(TSF ~1.4 s)
TKE ~ 220-240 MeV
α-decay?
268
Db
α
Chemical separation
Transactinides
Actinides
264
Lw
EC (TEC ~2-20 h)
264
No
α
(Tα ~100 d)
SF
(TSF ~ ms)
TKE ~220-240 MeV

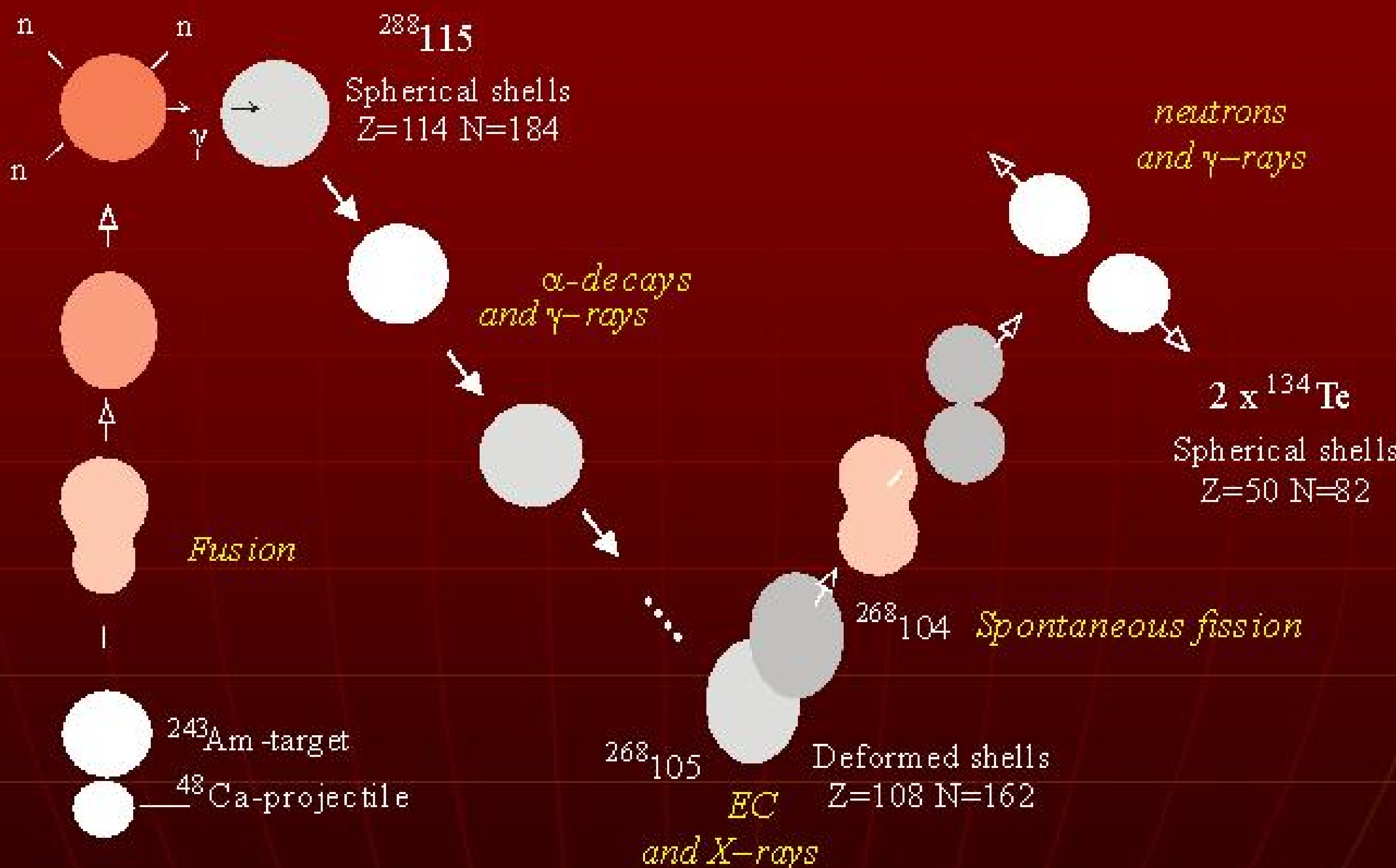
Alpha-decay energy vs. neutron number for isotopes of elements Z > 102



Theory and Experiment

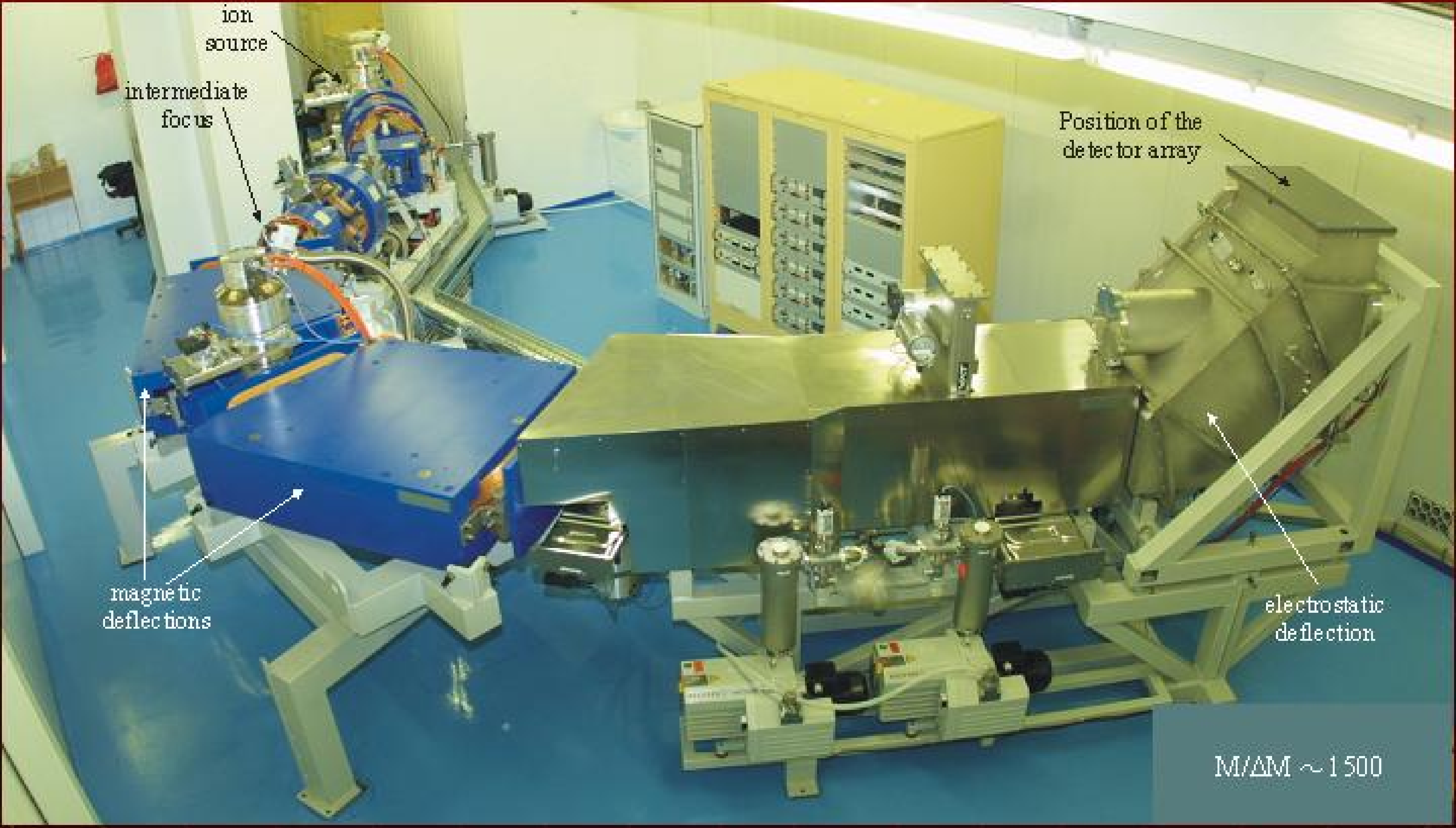


Nuclear transformations



Mass Analyzer of Super Heavy Atoms

(MASHA)



Consumption
of ^{48}Ca (68%) - 0.5 mg/ [0.25mg/h]

beam
intensity - $5 \cdot 10^{12}$/s [$5 \cdot 10^{13}$/s]

beam time - 2000 h/y [6000h/y]

Isotopes:

U[238], Np[237], Pu[244], Cm[247] + ^{48}Ca[...^{64}Ni] → Z = 114 - 122

technology of the
target preparation - 0.3 mg/cm^2 [1.0 mg/cm^2]

isotope enrichment - 98-99% [99.9%]

Separation of super heavy nuclei and
detection of their radioactive decay

now: SHIP, DGFRS, SAASY, GARIS,....

new facilities.....
such as MASHA but more fast!

+ neutron and γ-arrays: DEMON, EUROBALL,
AGATA,....

Production rate (ε=40%)
at the cross section 1pb:

now - 10 / y
could be - **1.000 / y**

at the cross section 5 pb (Z=114)
counting rate (α,SF) - **$3 \cdot 10^{-4}$/s**

Consumption — ***new ECR-source*** (Berkeley)

Beam intensity — ***new accelerator*** cyclotron (Dubna) or linac(Frankfurt)

Beam time — ***continuous operation***

new target area

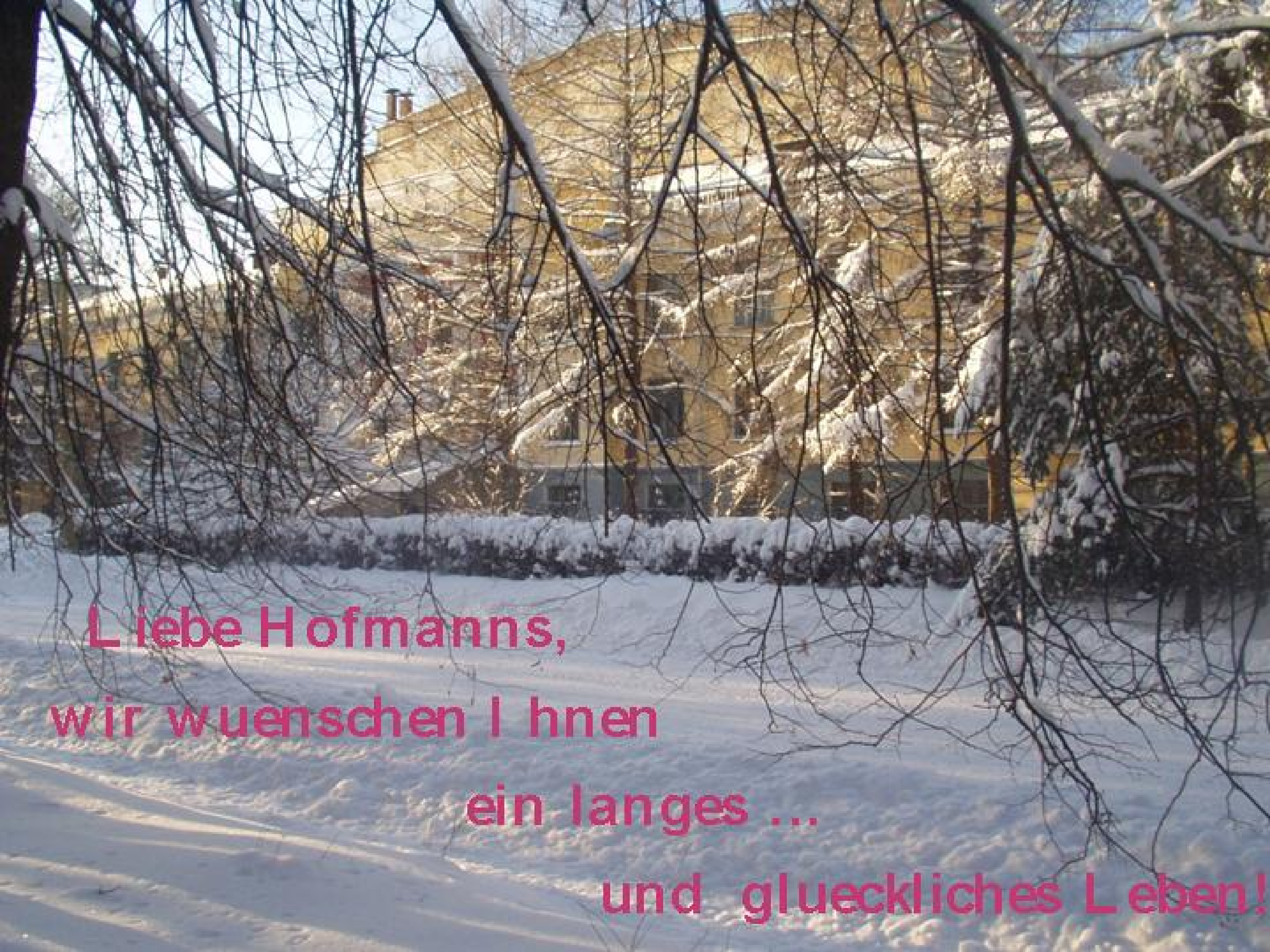
Targets

Z = 114 - 122

Separation and detection

new facilities.....
and new detectors


90
1940
1950
1960
1970
1980
1990
2000
2010
years


Liebe Hofmanns,
wir wuenschen Ihnen
ein langes ...
und glueckliches Leben!