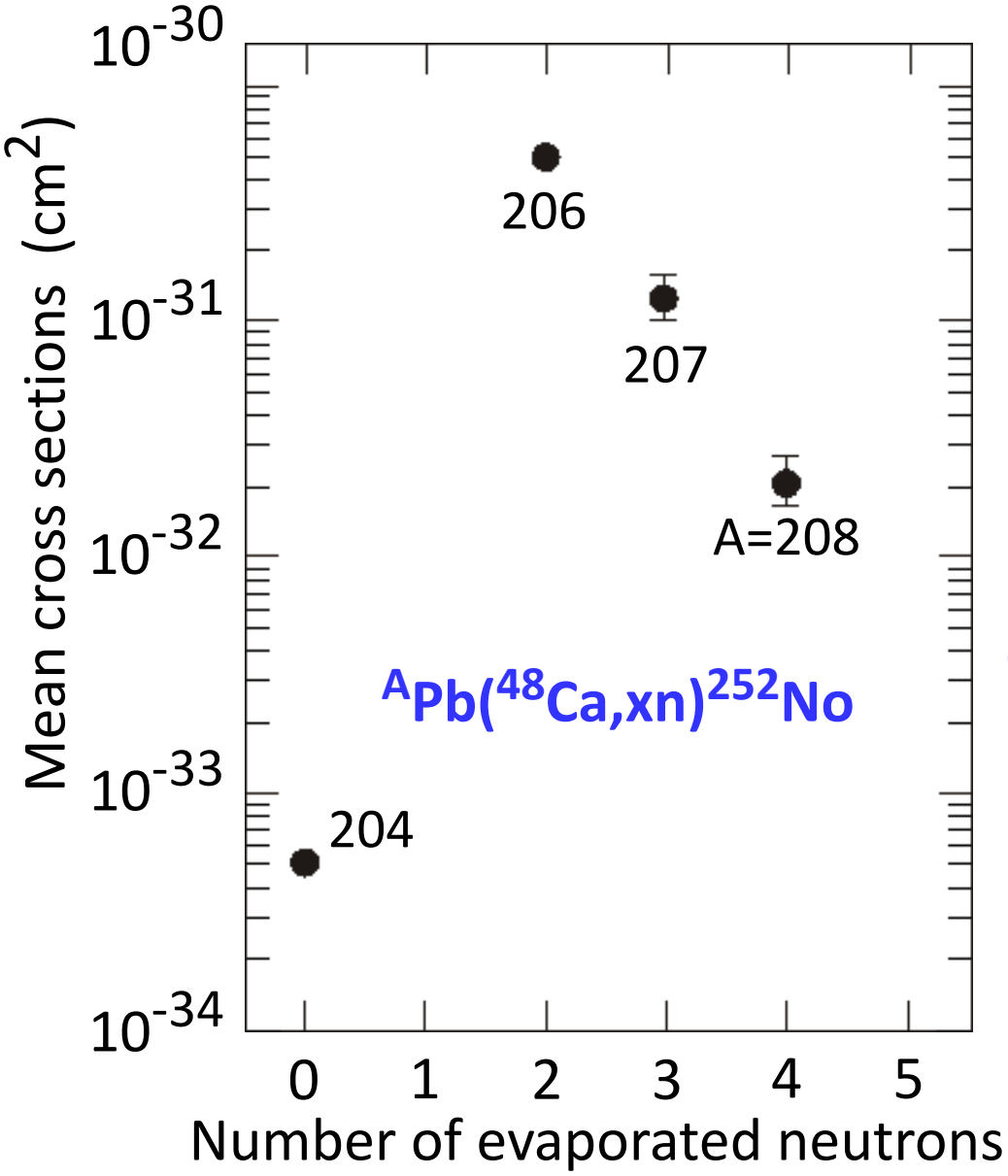
SHE in JINR

Yuri Oganessian

Flerov Laboratory of Nuclear Reactions
Joint Institute for Nuclear Research

4th International Conference on the Chemistry and Physics
of the Transactinide Elements (TAN'11)
6-10 September, 2011,Sochi, Russia.

During the studies of cold fusion reactions at Dubna, the beam of 48Ca was produced for the first time with U300 cyclotron + PIG-ion source in 1975



G.N. Flerov, Yu.Ts. Oganessian, A.A. Pleve, N.V. Pronin, Yu.P.Tretyakov

Nucl. Phys. A267 (1976) 359-364

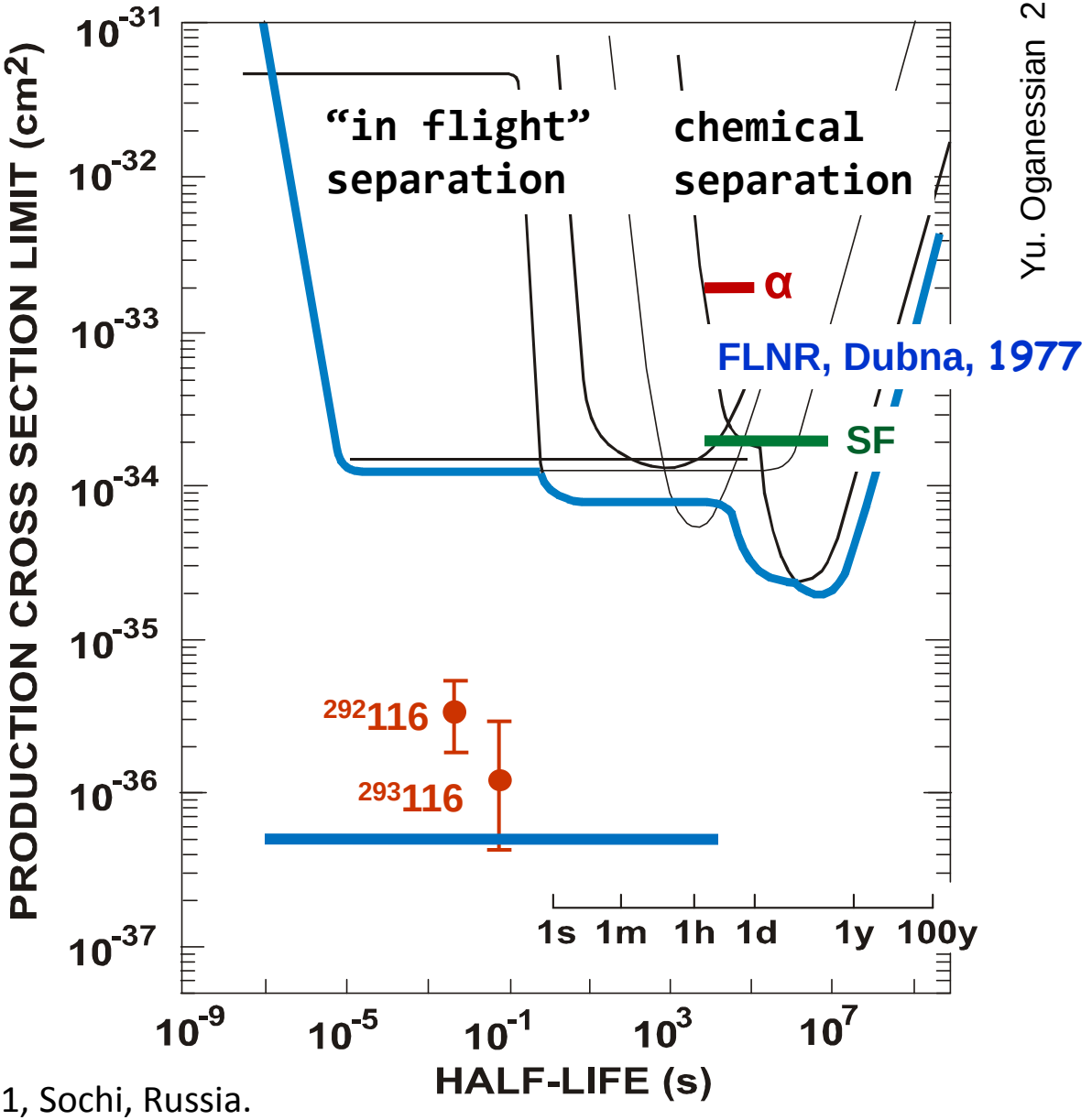
Search for Element 116 in $^{248}Cm + ^{48}Ca$ reaction

GSI, Darmstadt, Germany*
LBL, UC Berkeley, CA
Univ. of Mainz, Germany
LANL, Los Alamos, NM
EIR, Würenlingen, Switzerland

1985

FLNR, Dubna
LLNL, Livermore, CA

2000



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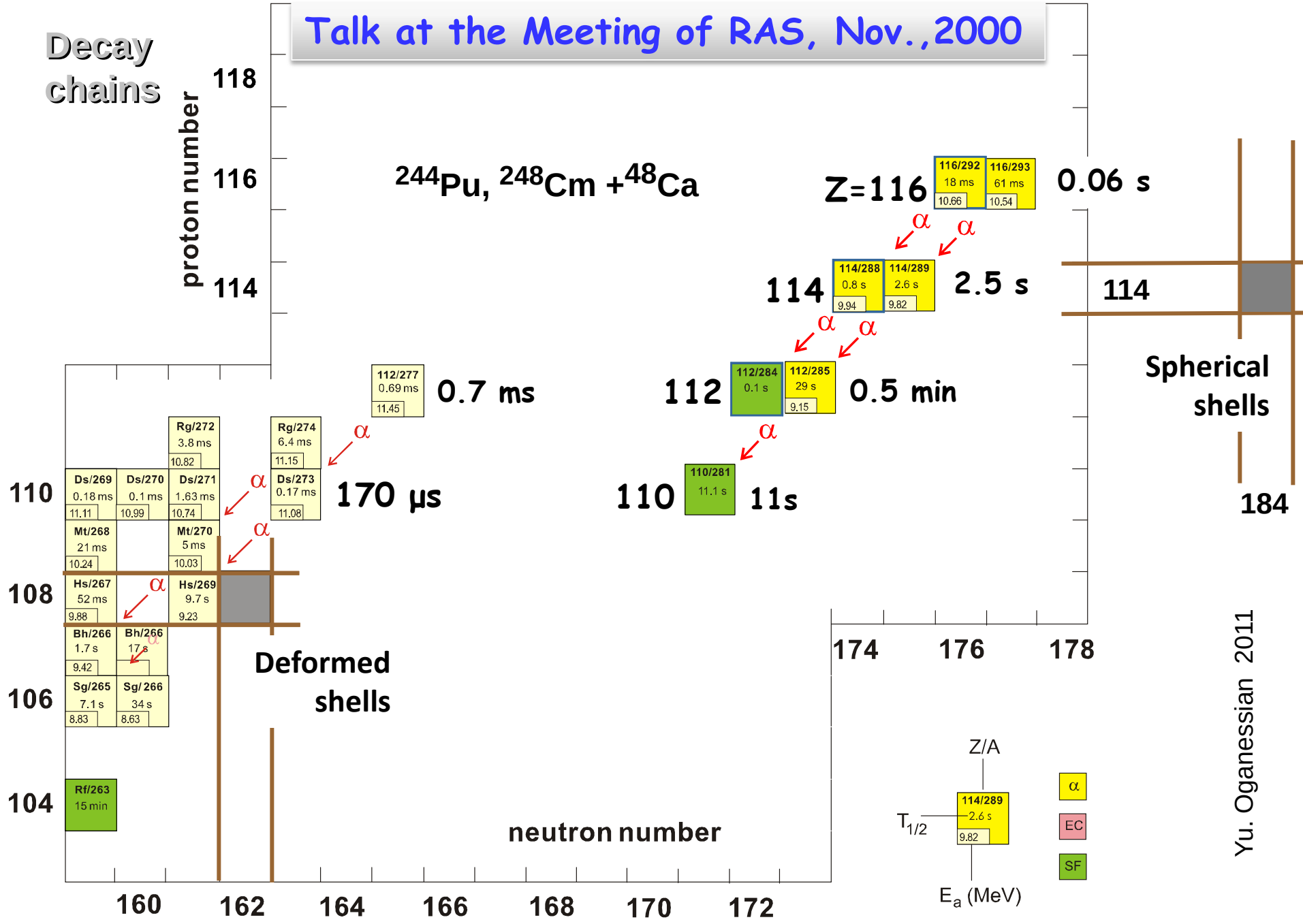
Yu. Oganessian. SHE in JINR. Sept.6, 2011, Sochi, Russia.

Talk at the Meeting of RAS, Nov.,2000

Decay chains



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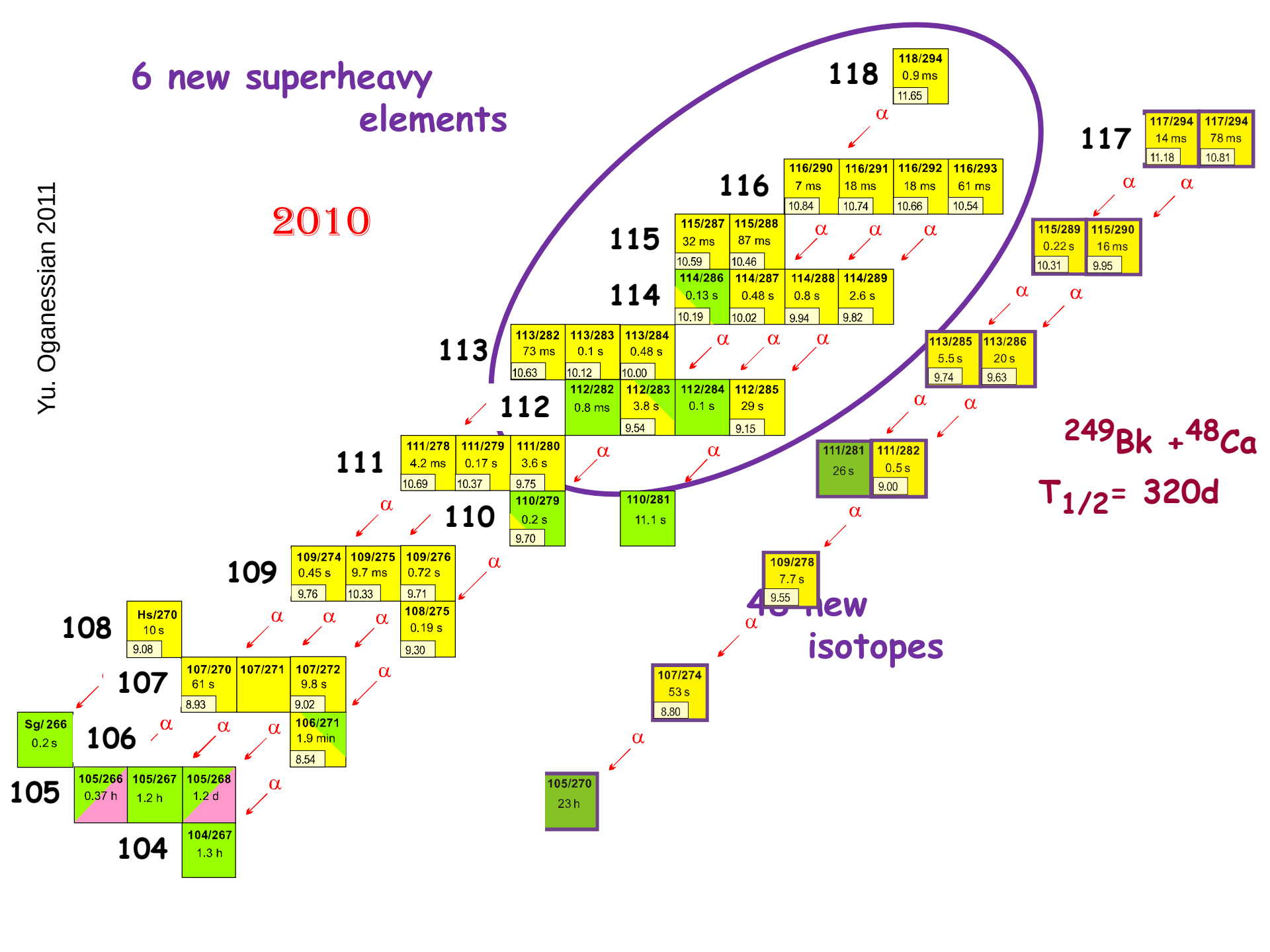
CONFIRMATIONS 2007-2010

A/Z	Setup	Laboratory	Publications
^{283}112	SHIP	GSI Darmstadt	Eur. Phys. A32, 251 (2007)
^{283}112	COLD	PSI-FLNR (JINR)	NATURE 447, 72 (2007)
$^{286, 287}$114	BGS	LRNL (Berkeley)	P.R. Lett. 103, 132502 (2009)
$^{288, 289}$114	TASCA	GSI – Mainz	P.R. Lett. 104, 252701 (2010)
$^{292, 293}$116	SHIP	GSI Darmstadt	Eur. Phys. (to be published)

Synthesis of SHE with ^{48}Ca-induced reactions

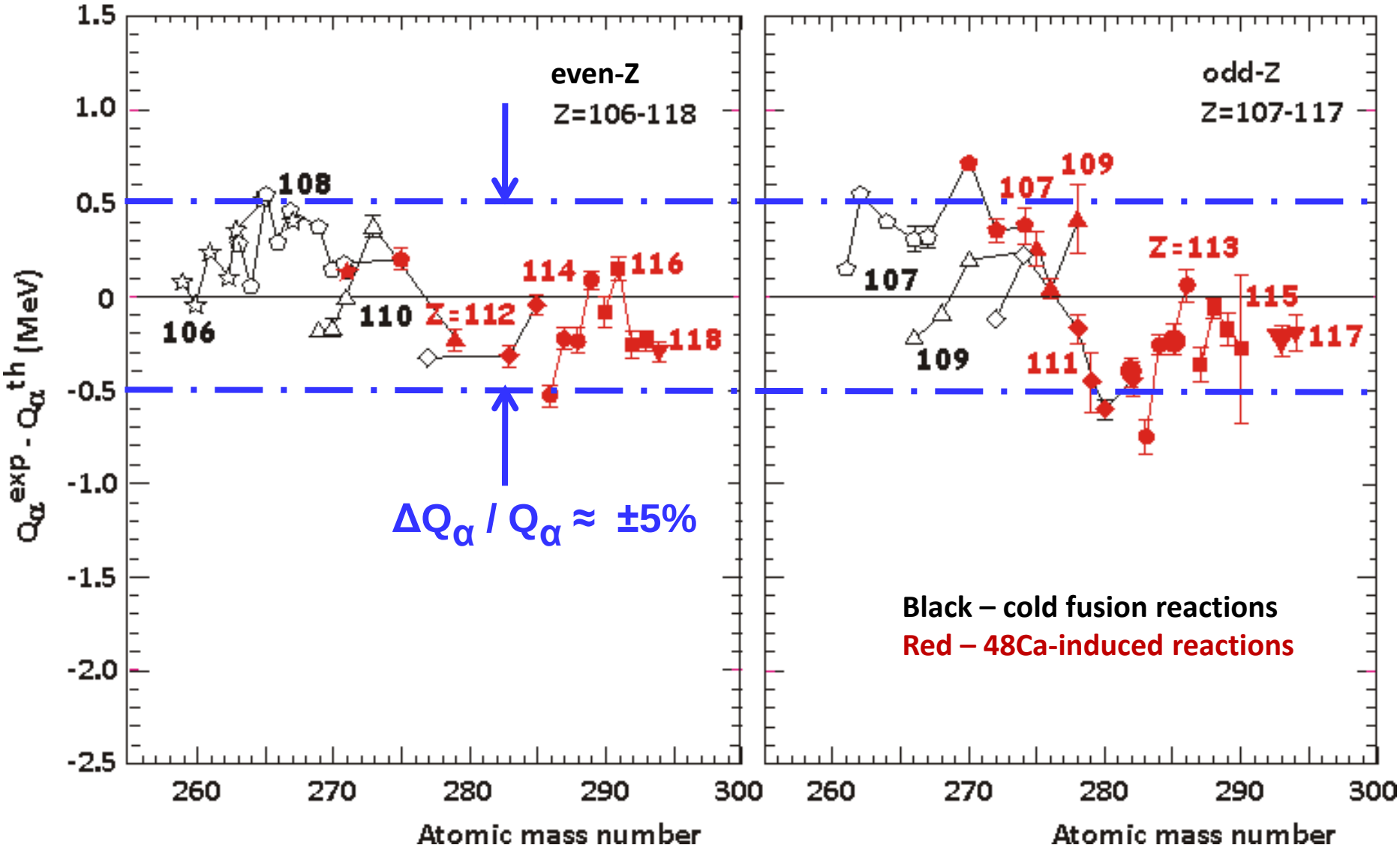
10 years

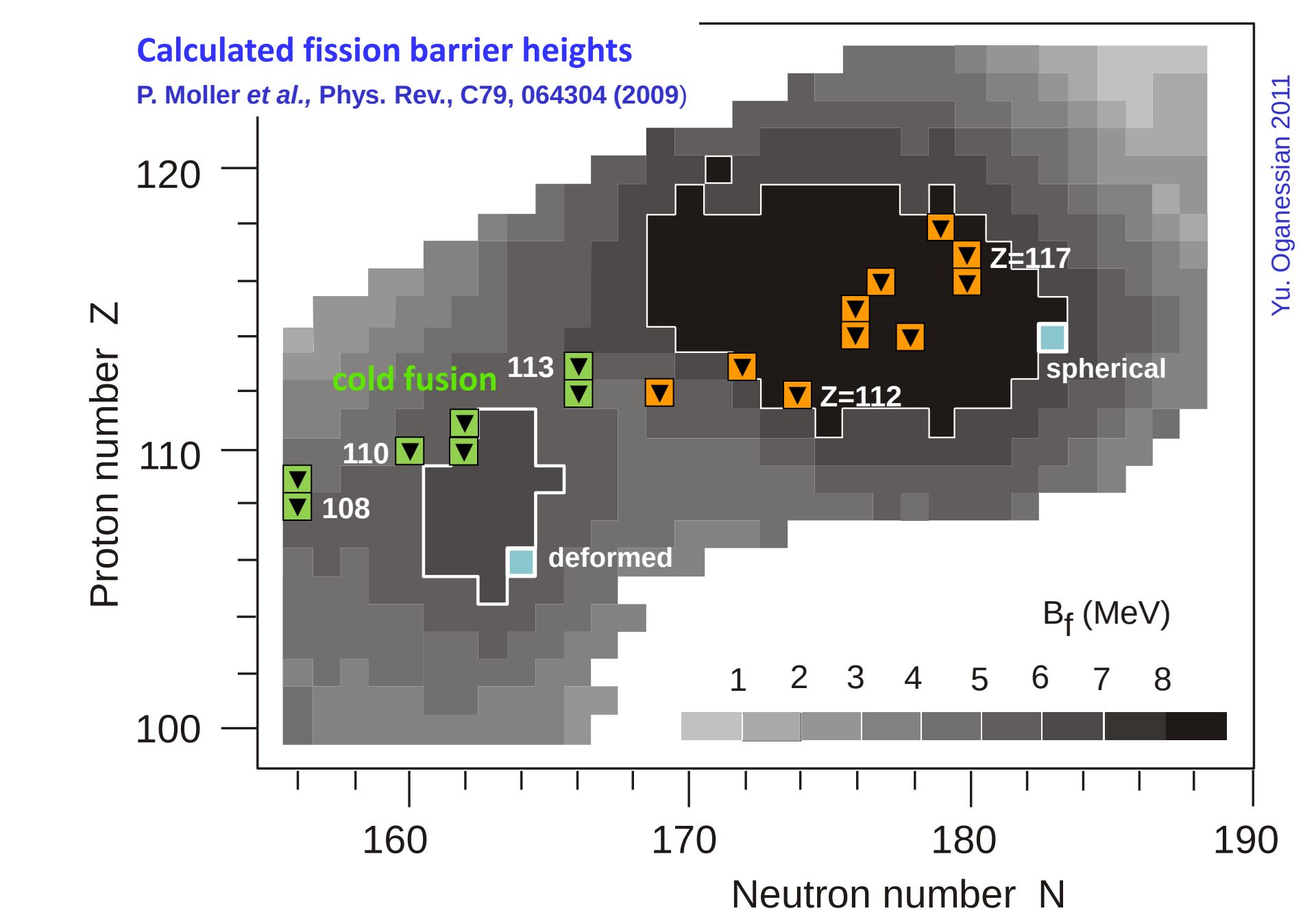

6 new superheavy elements
2010
Yu. Oganessian 2011
$^{249}Bk + ^{48}Ca$
$T_{1/2}$= 320d
48 new isotopes
118
118/294 0.9 ms 11.65
117
117/294 14 ms 11.18
117/294 78 ms 10.81
116
116/290 7 ms 10.84
116/291 18 ms 10.74
116/292 18 ms 10.66
116/293 61 ms 10.54
115
115/287 32 ms 10.59
115/288 87 ms 10.46
115/289 0.22 s 10.31
115/290 16 ms 9.95
114
114/286 0.13 s 10.19
114/287 0.48 s 10.02
114/288 0.8 s 9.94
114/289 2.6 s 9.82
113
113/282 73 ms 10.63
113/283 0.1 s 10.12
113/284 0.48 s 10.00
113/285 5.5 s 9.74
113/286 20 s 9.63
112
112/282 0.8 ms
112/283 3.8 s 9.54
112/284 0.1 s
112/285 29 s 9.15
111
111/278 4.2 ms 10.69
111/279 0.17 s 10.37
111/280 3.6 s 9.75
111/281 26 s
111/282 0.5 s 9.00
110
110/279 0.2 s 9.70
110/281 11.1 s
109
109/274 0.45 s 9.76
109/275 9.7 ms 10.33
109/276 0.72 s 9.71
109/278 7.7 s 9.55
108
Hs/270 10 s 9.08
108/275 0.19 s 9.30
107
107/270 61 s 8.93
107/271
107/272 9.8 s 9.02
107/274 53 s 8.80
106
Sg/266 0.2 s
106/271 1.9 min 8.54
105
105/266 0.37 h
105/267 1.2 h
105/268 1.2 d
105/270 23 h
104
104/267 1.3 h
α

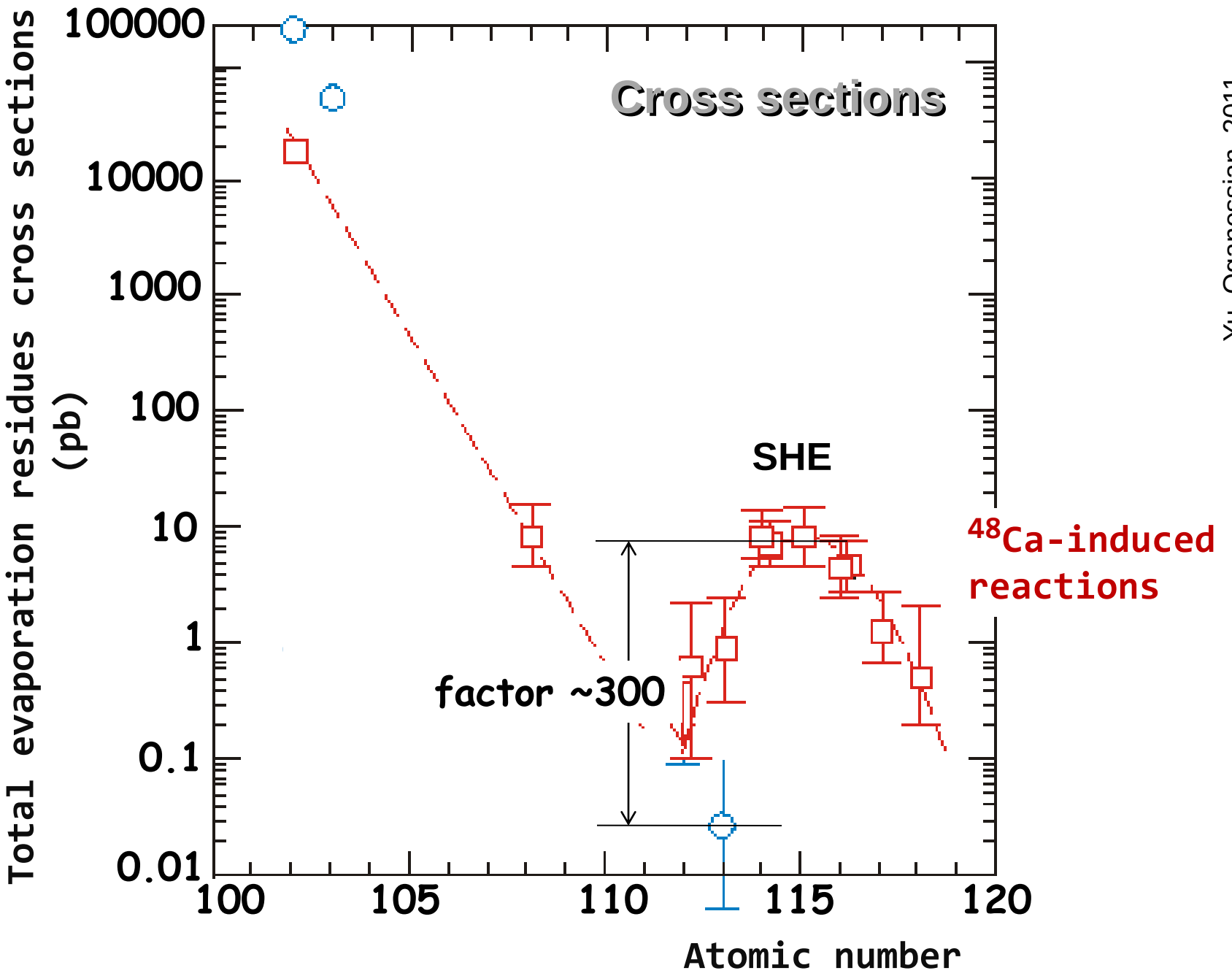
Decay properties of the superheavy nuclei

Alpha decay energy of the heaviest nuclei

Theory and experiment




Calculated fission barrier heights
P. Moller et al., Phys. Rev., C79, 064304 (2009)
Yu. Oganessian 2011
Proton number Z
120
110
100
Neutron number N
160
170
180
190
cold fusion
113
110
108
deformed
Z=112
Z=117
spherical
B_f (MeV)
1 2 3 4 5 6 7 8


Cross sections
SHE
factor ~300
48Ca-induced reactions
Total evaporation residues cross sections (pb)
100000
10000
1000
100
10
1
0.1
0.01
100
105
110
115
120
Atomic number
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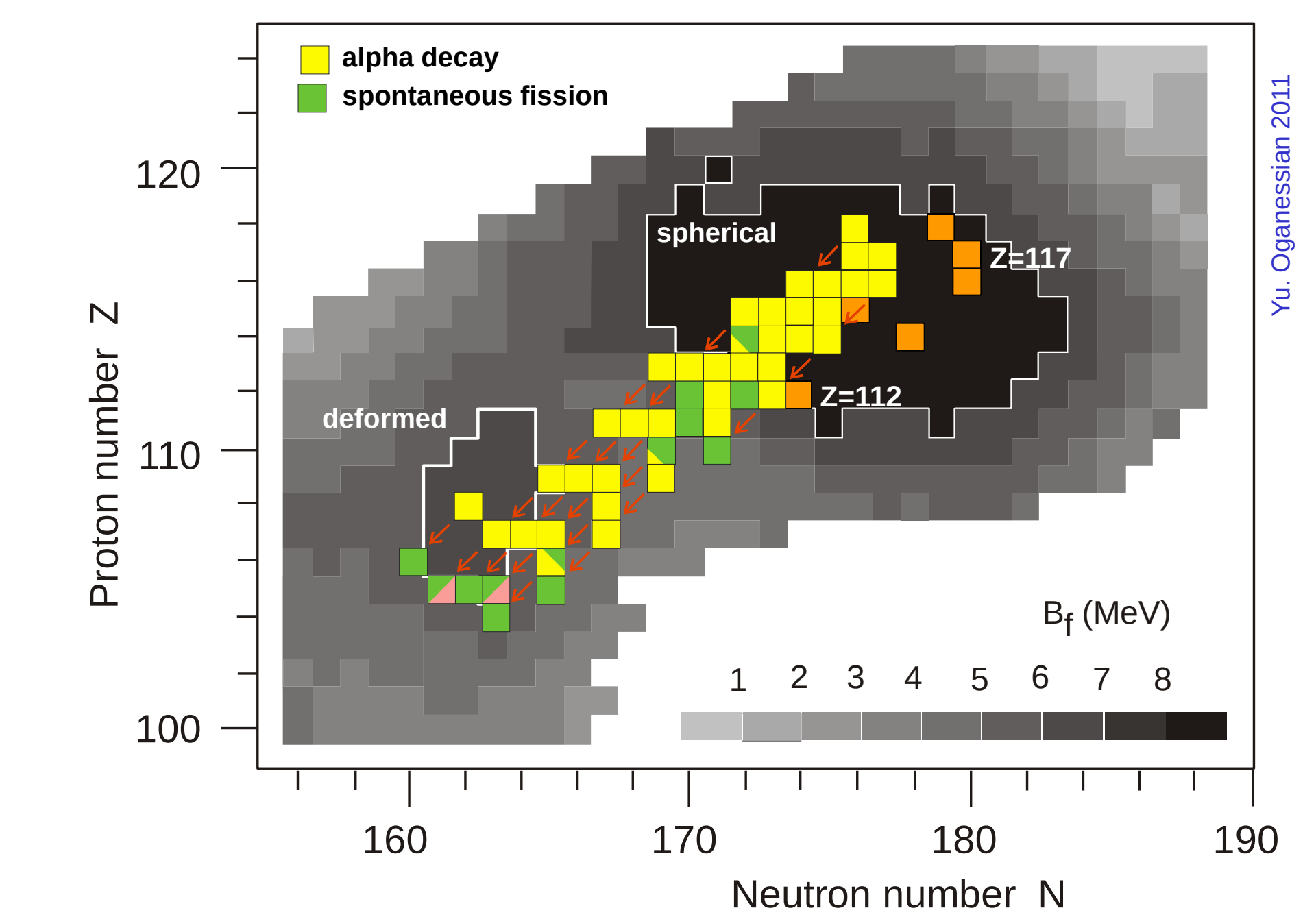
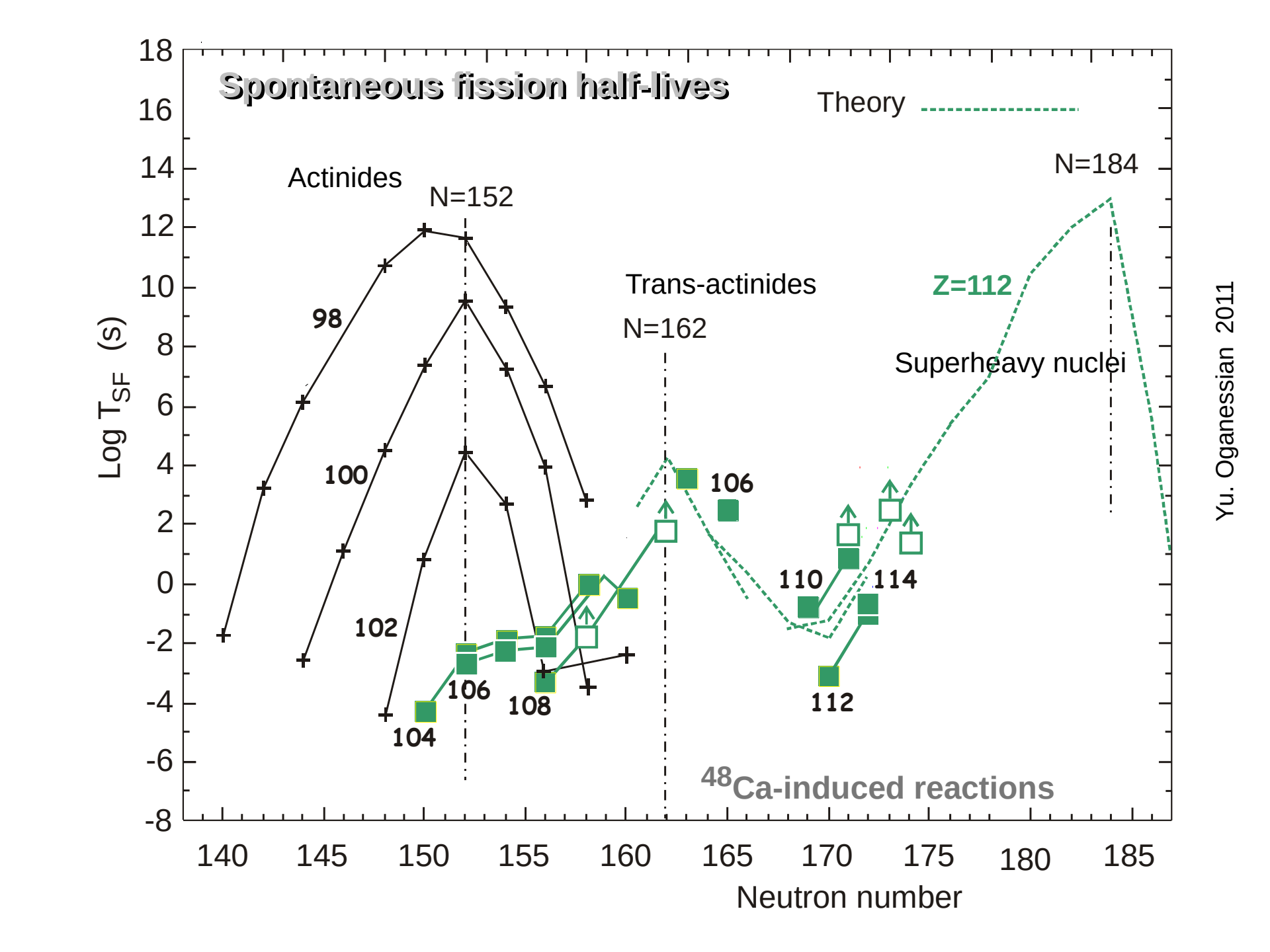


Yu. Oganessian. SHE in JINR. Sept.6, 2011, Sochi, Russia.


Spontaneous fission half-lives
Theory
Actinides
N=152
Trans-actinides
N=162
N=184
Z=112
Superheavy nuclei
98
100
102
104
106
108
106
110
112
114
48Ca-induced reactions
Log TSF (s)
Neutron number
Yu. Oganessian 2011

With Z >40% larger than that of Bi, the heaviest stable element, we see an impressive extension in nuclear survivability.

Although SHN are at the limits of Coulomb stability,

- shell stabilization lowers ground-state energy,
- creates a fission barrier,
- and thereby enables SHN to exist.

.

The fundamentals of the modern theory concerning the mass limits of nuclear matter have obtained experimental verification

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Technical achievements
&
further development

Collaborations

TARGETS

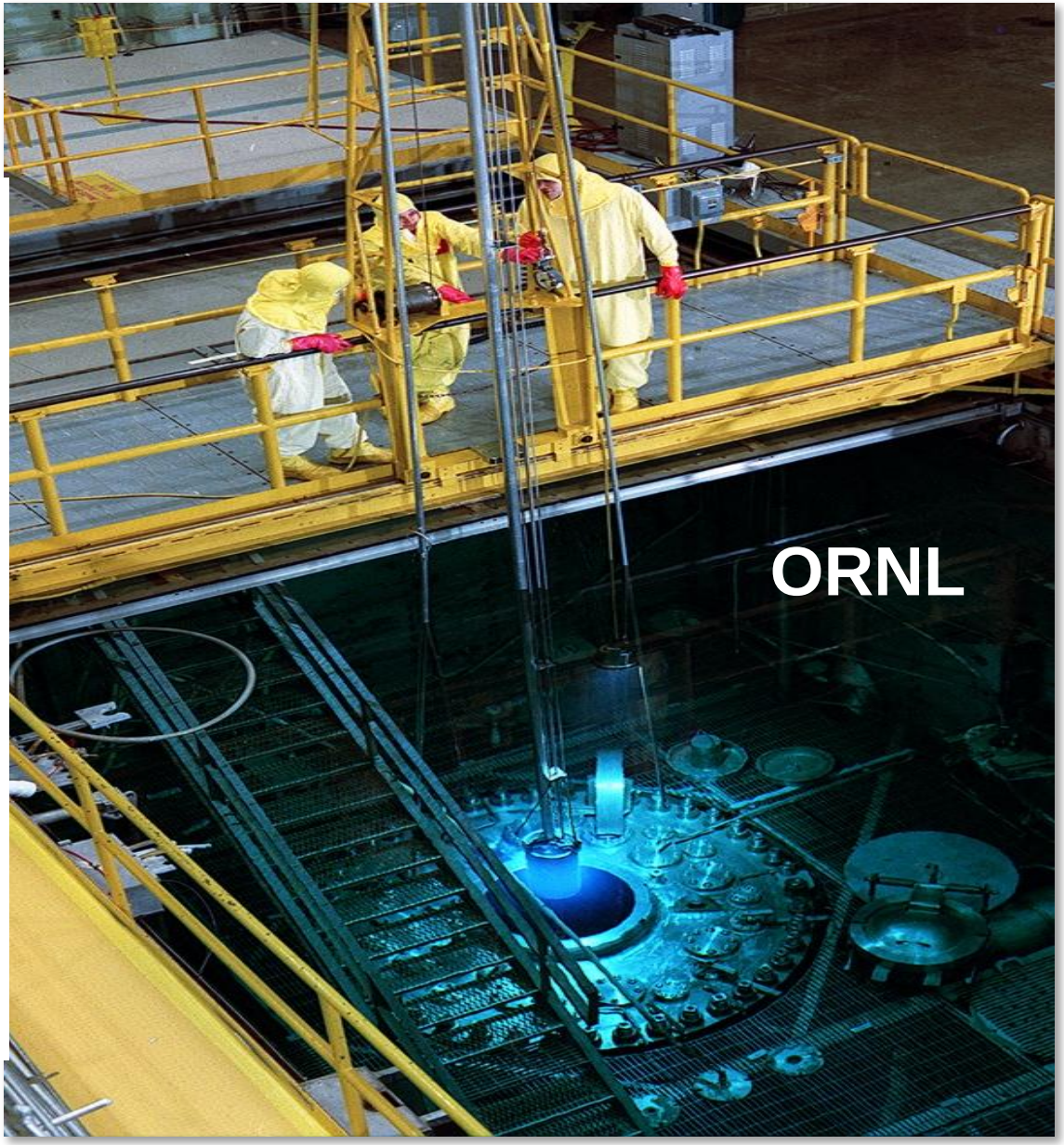
The neutron-rich isotopes of the Actinides was produced at ORNL (USA) by irradiation: of Cm and Am targets in each campaign for approximately

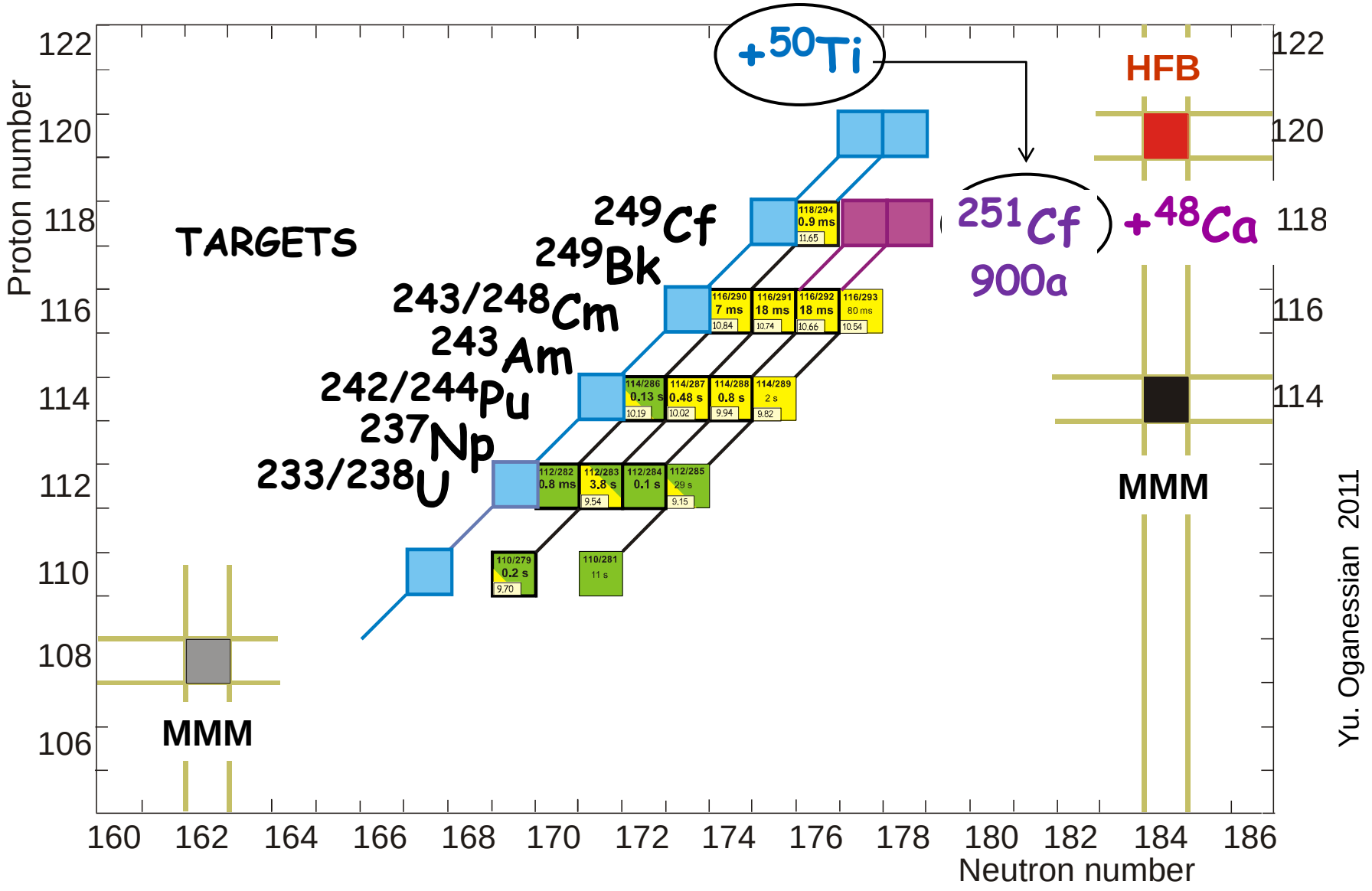
250 days

by thermal-neutron flux of

$$2.5 \times 10^{15}\ n/cm^2 \cdot s$$

in the HFIR (High Flux Isotope Reactor).




+50Ti
HFB
TARGETS
249Cf
249Bk
243/248Cm
243Am
242/244Pu
237Np
233/238U
251Cf
900a
+48Ca
MMM
MMM
118/294
0.9 ms
11.65
116/290
7 ms
10.84
116/291
18 ms
10.74
116/292
18 ms
10.66
116/293
80 ms
10.54
114/286
0.13 s
10.19
114/287
0.48 s
10.02
114/288
0.8 s
9.94
114/289
2 s
9.82
112/282
0.8 ms
112/283
3.8 s
9.54
112/284
0.1 s
112/285
29 s
9.15
110/279
0.2 s
9.70
110/281
11 s
Proton number
Neutron number
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Rotating Targets from Actinide at DGFRS

Target quality	Target preparation	Accepted Max. beam intensity	Accepted Max. beam dose
best	electrolysis	2.1 pμA	$2.5 \cdot 10^{19}$
worse	painting	1.3 pμA	$0.5\text{-}2.5 \cdot 10^{19}$

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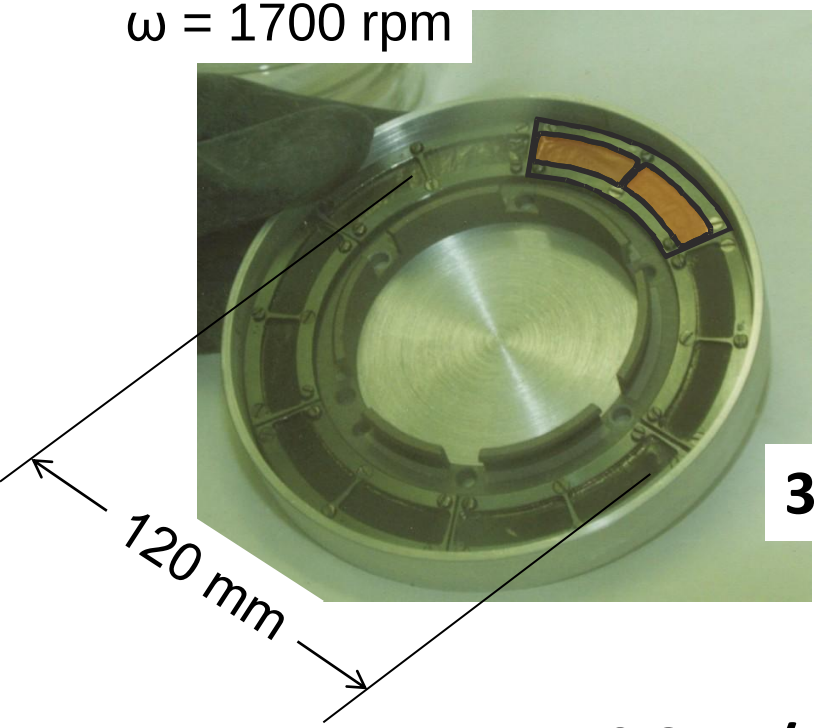
Target

ω = 1700 rpm



1.0 mg/cm²

100 cm²

36 cm²

0.3mg/cm²
on 1.5 μm-Ti foil

For rotating target of D=360 mm the intensity of the beam could be increased up to **10-12 pμA**

Total amount of target material Is about **100 mg**

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BEAMS

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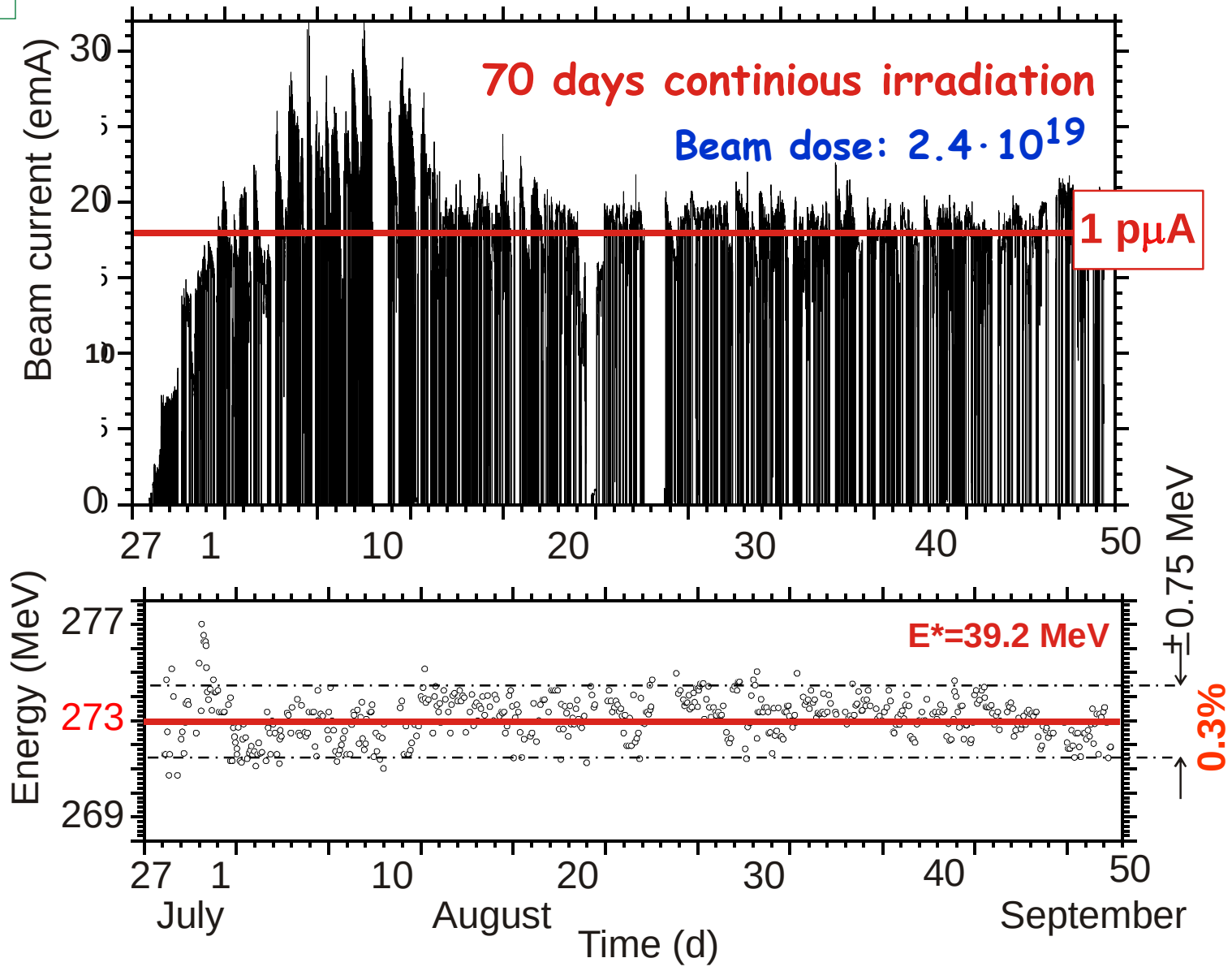

Increase of the beam intensity and beam dose

There are two options:

Options	Beam intensity /pμA/	Beam dose /per year/
Upgrade the U-400 cyclotron for acceleration $^{48}Ca^{+8}$ ions with the new ECR-source	2.5	$0.5 \cdot 10^{20}$
Create a new accelerator specially for production and studies of SHE	10-20	$\approx 4 \cdot 10^{20}$

At the target position for cross section 10 pb the expected production rate could be about 30/day

DETECTORS

From the characteristics of the DGFRS, it follows that with a ^{48}Ca-beam dose of

$3 \cdot 10^{17}$ realized in 1 day

the observation of

one decay event

corresponds to the production cross section of

about 10 pb.

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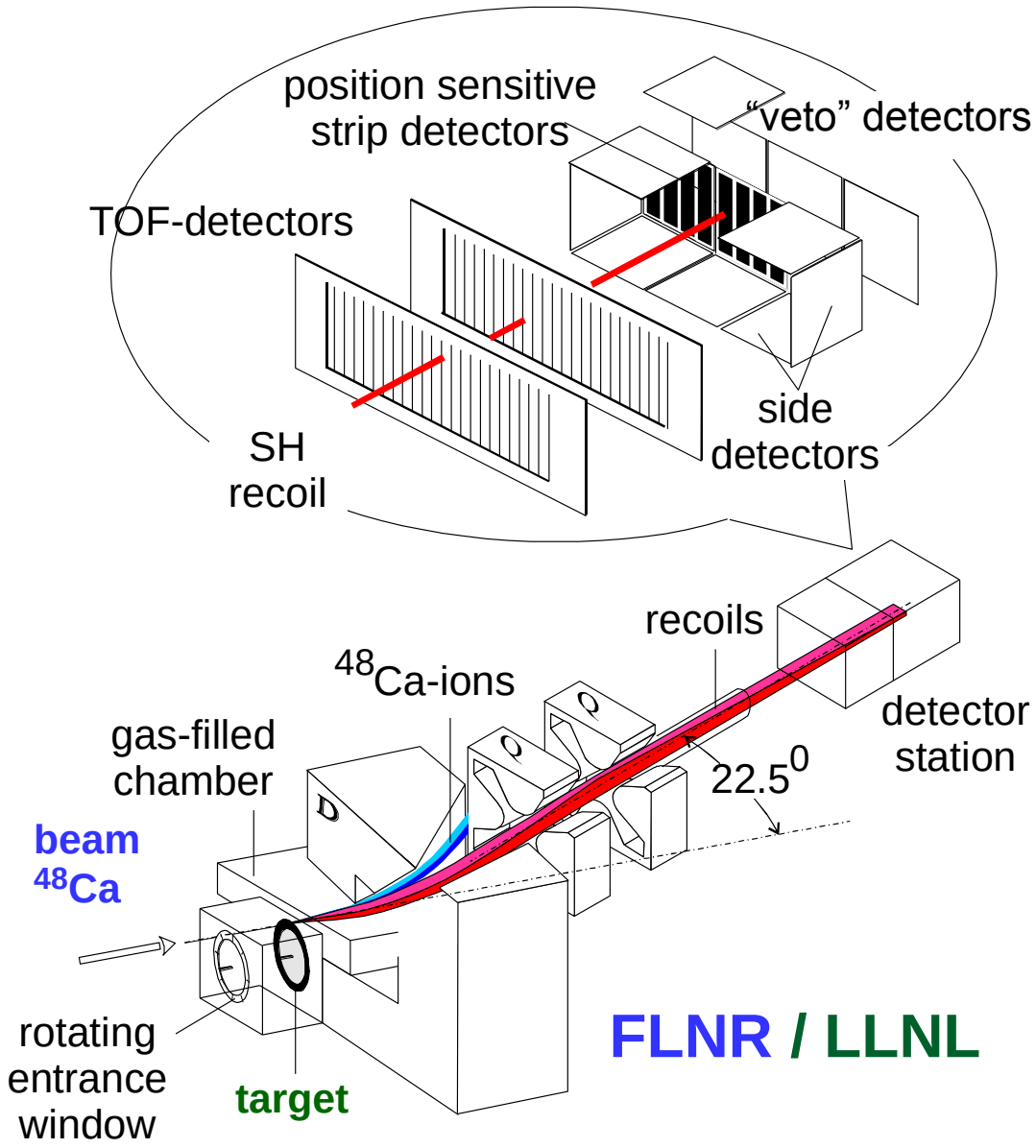
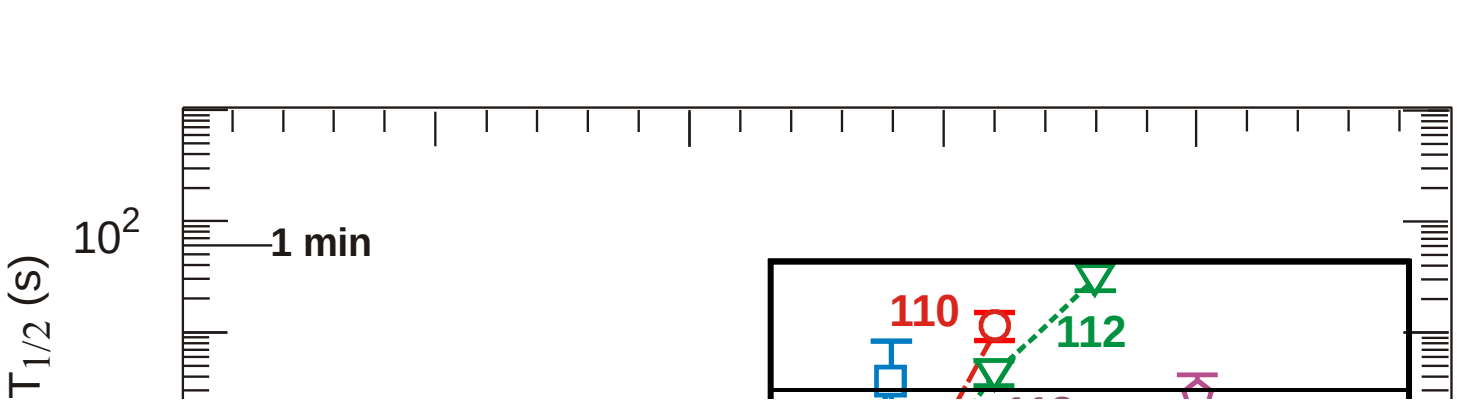


Dubna Gas-Filled Recoil Separator



"on line"

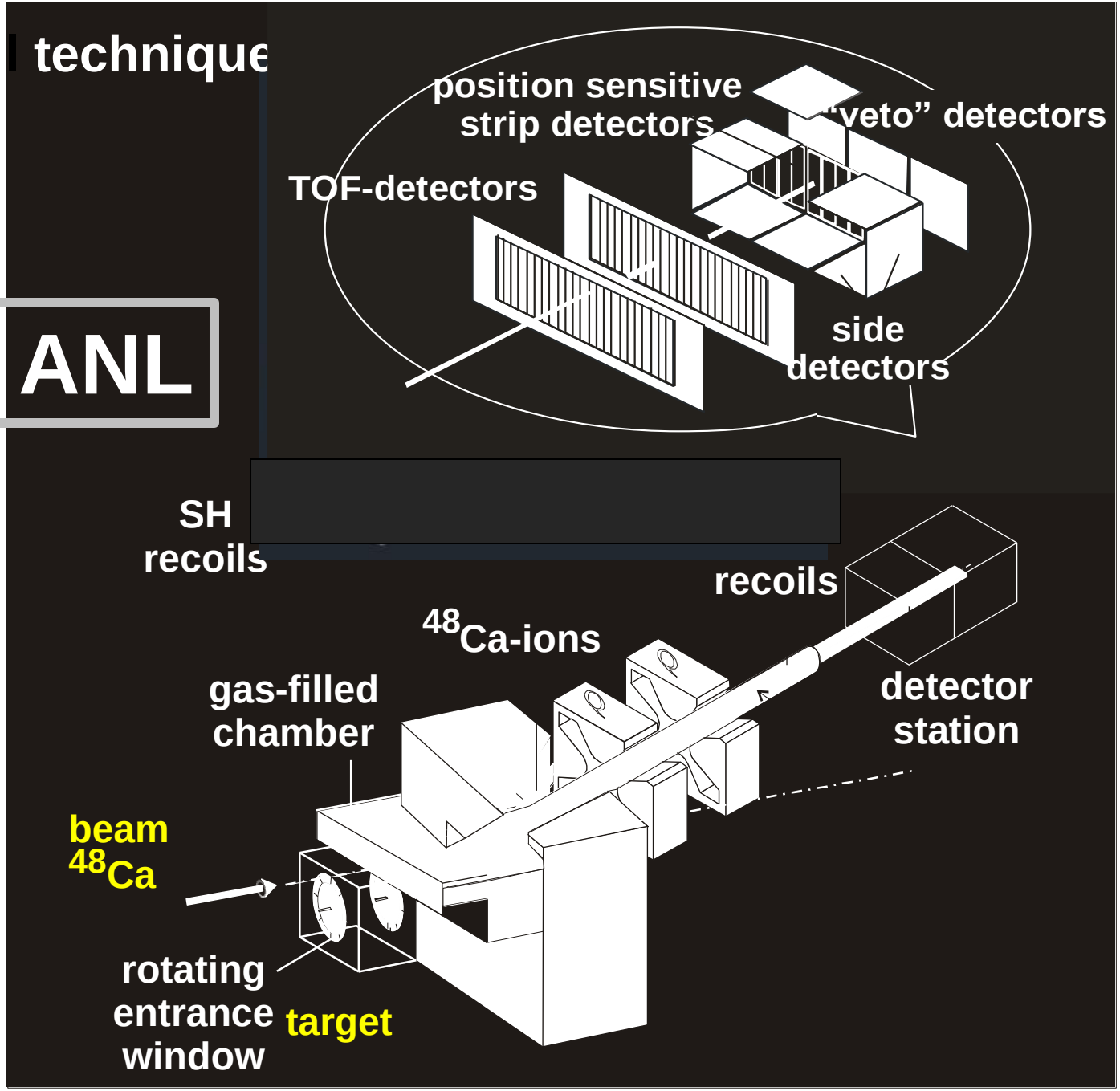
"gas catcher"

Mass Analyzer of Super Heavy Atoms (MASHA)

A. Rodin
Saturday, after coffee break

Experimental I technique

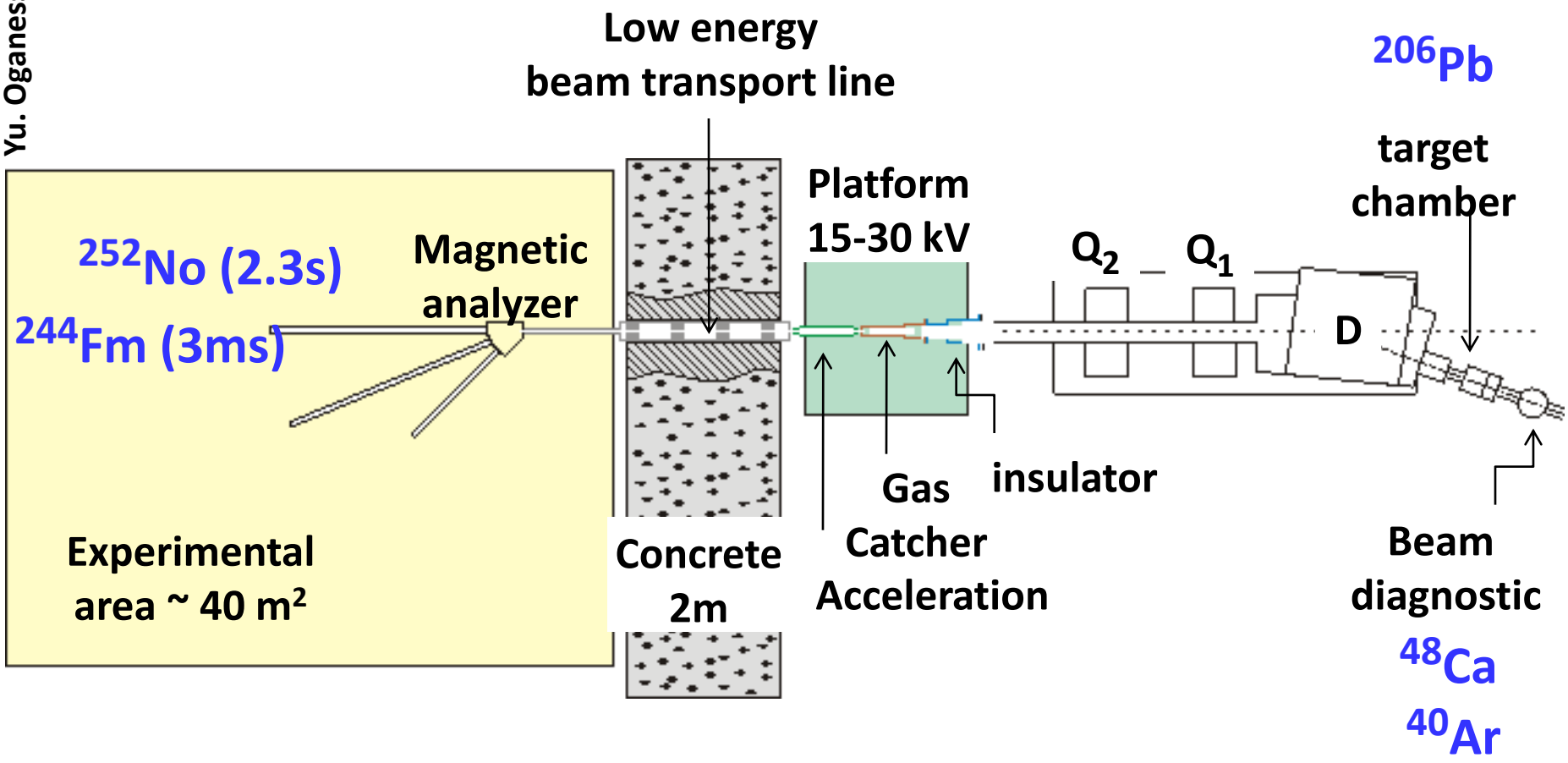
FLNR / ANL



Yu. Oganessian 2011

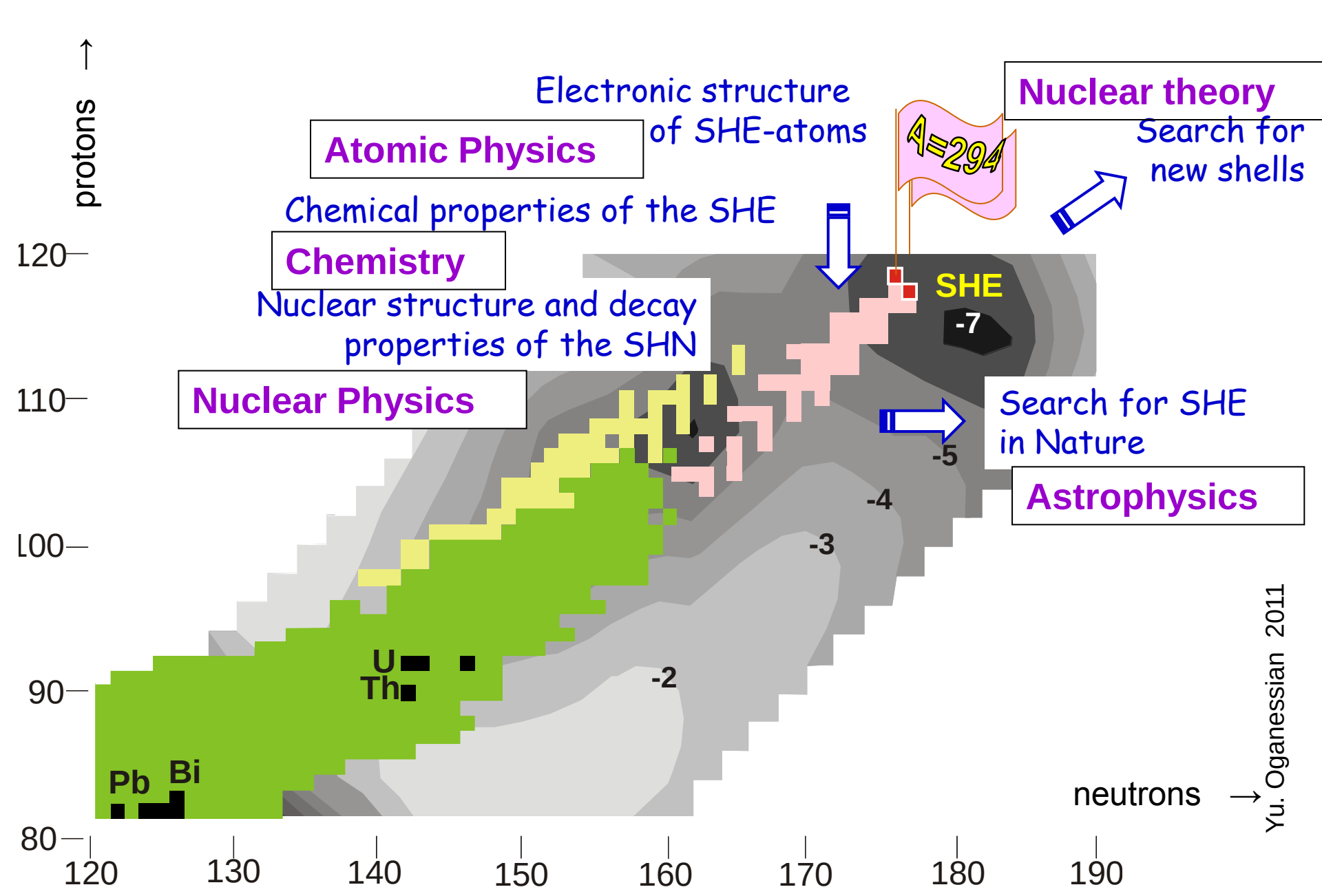
On-line Studies of SH-nuclei with Gas Catcher

Yu. Oganessian 2011



Consequences

Related sciences



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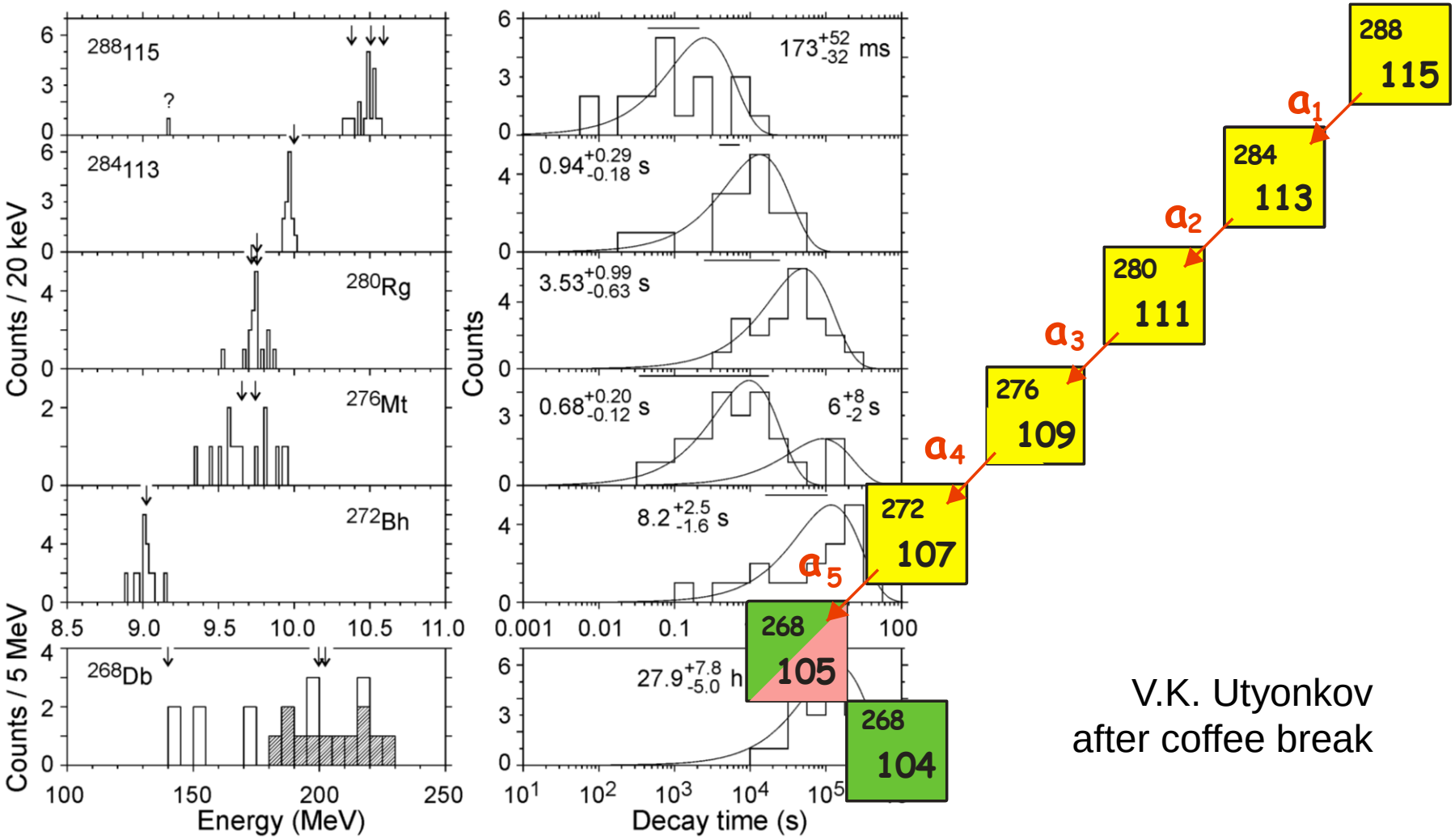
Reaction: $^{243}Am + ^{48}Ca \rightarrow 3n +$



V.K. Utyonkov
after coffee break

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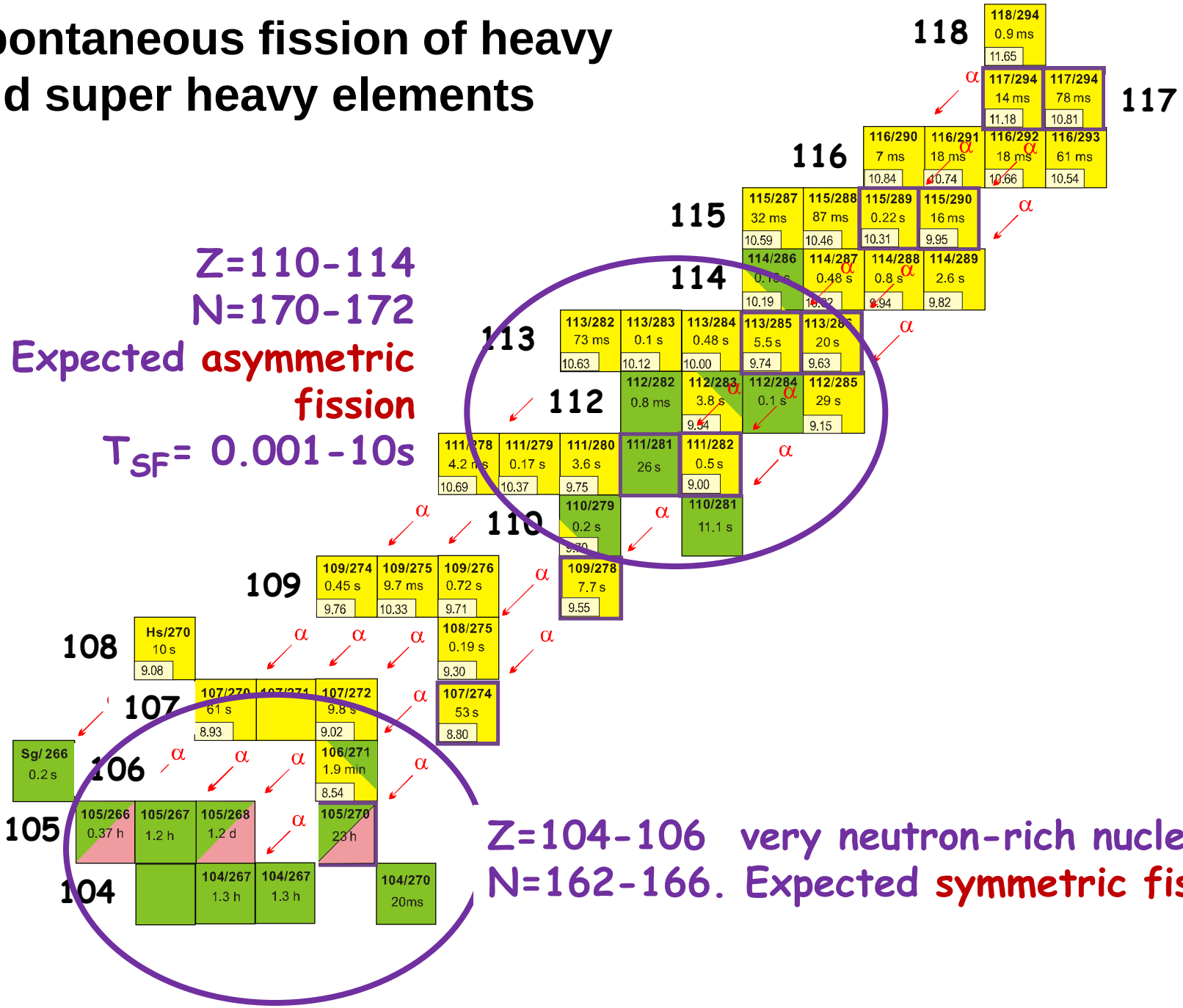
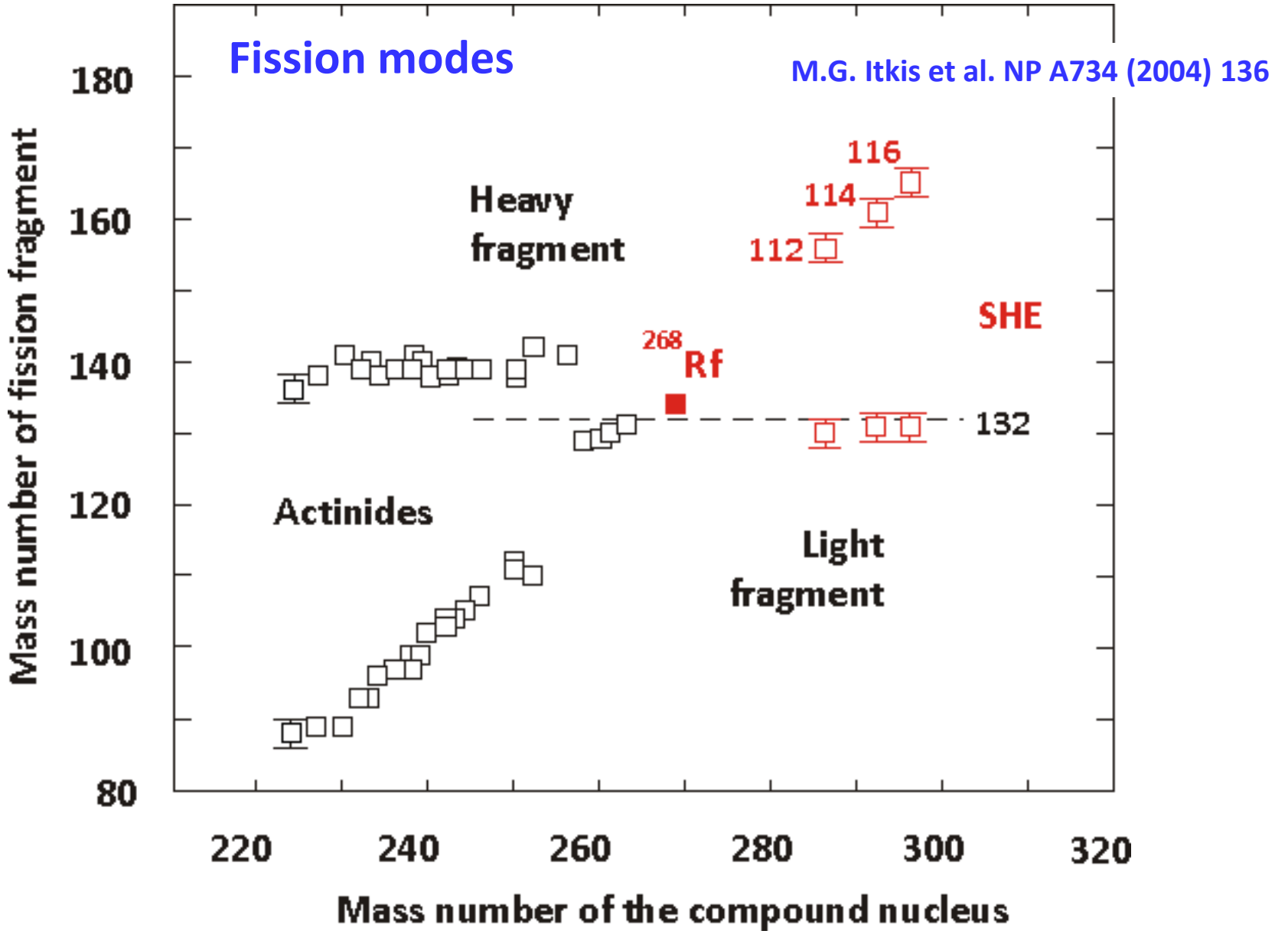
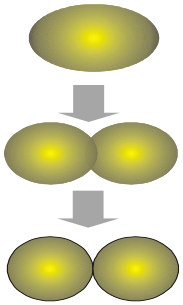
Nuclear fission

Spontaneous fission of heavy and super heavy elements



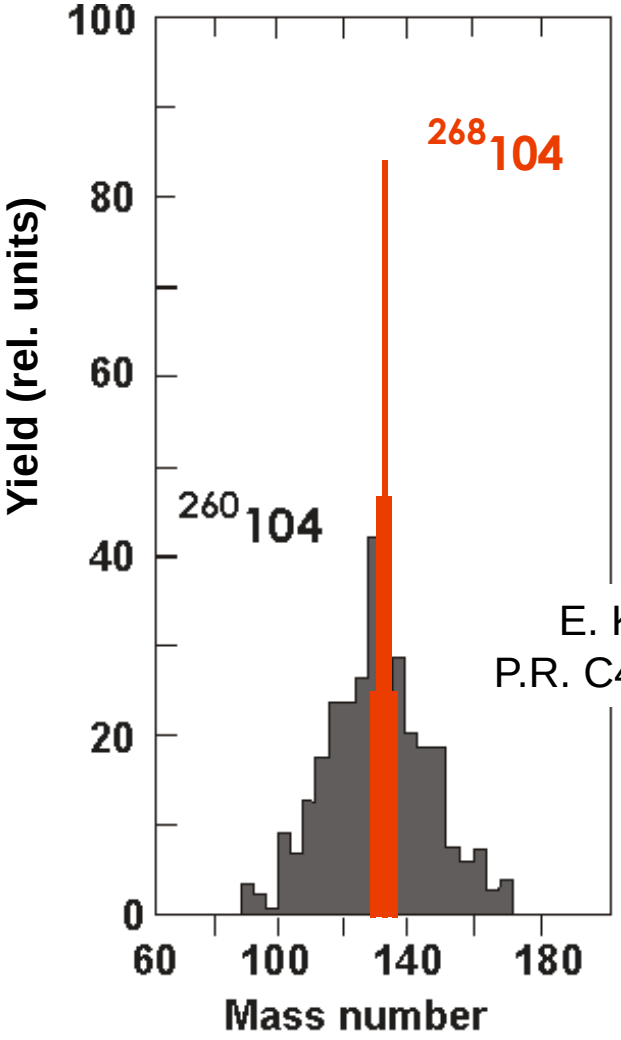

Fission modes
M.G. Itkis et al. NP A734 (2004) 136
Heavy fragment
Actinides
Light fragment
116
114
112
SHE
268 Rf
132
Mass number of fission fragment
Mass number of the compound nucleus
180
160
140
120
100
80
220
240
260
280
300
320



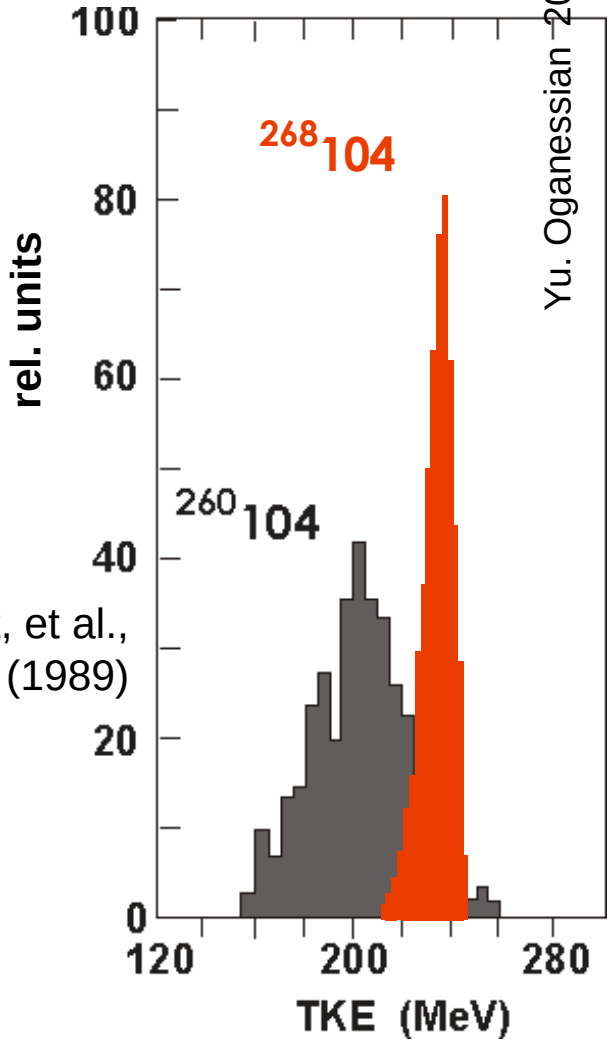
$Z_1 \approx Z_2 = \mathbf{50}\text{-}54$

$N_1 = N_2 = \mathbf{82}$

$Q_F = 268$ MeV



E. K. Hulet, et al.,
P.R. C40, 770 (1989)



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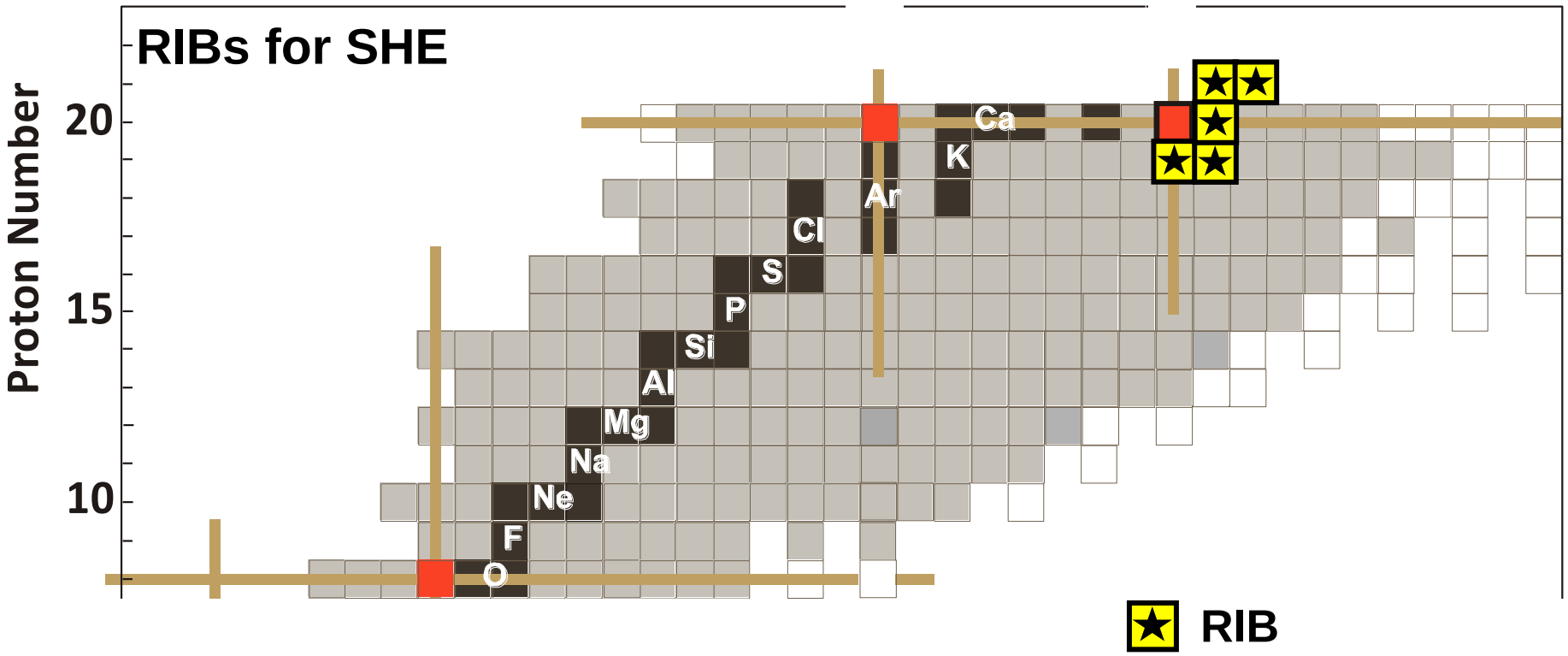
Towards closed shell N=184

Synthesis SHE with RIB



Realistic RIB intensities for the synthesis of SHE could be obtained for the isotopes close to 48Cf produced in simplest reaction like stripping, nucleon transfer, knock-out, charge exchange etc.

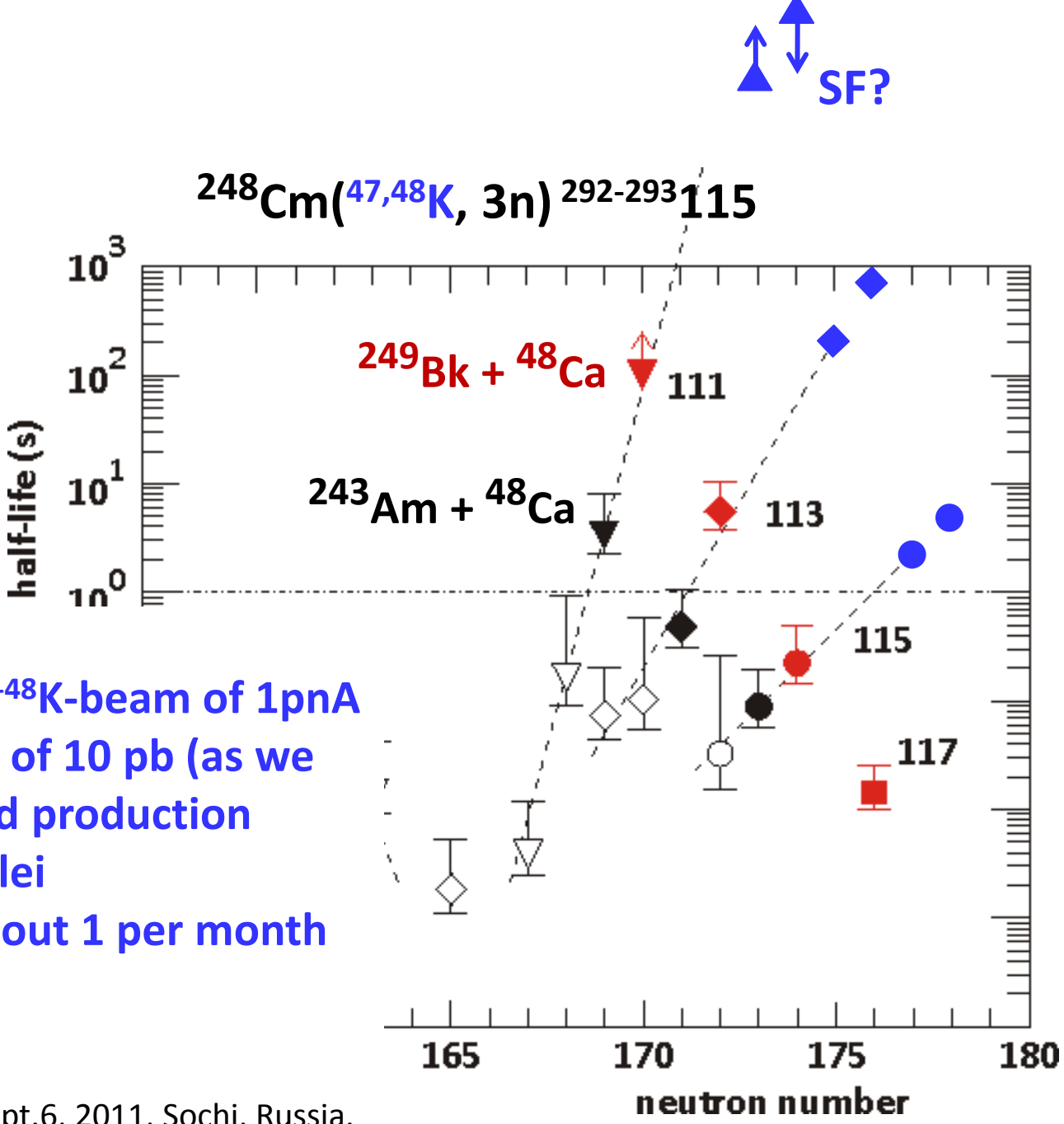
Neutron Number

an example:

One proton stripping reaction:
$^{48}Ca \rightarrow {}^{47}K$ (17,5s)

or

Charge exchange reaction:
$^{48}Ca \rightarrow {}^{48}K$ (6,8s)



At the intensity of $^{47\text{-}48}K$-beam of 1pnA and 3n-cross section of 10 pb (as we have today) expected production rate of $^{292\text{-}293}115$ nuclei is about 1 per month

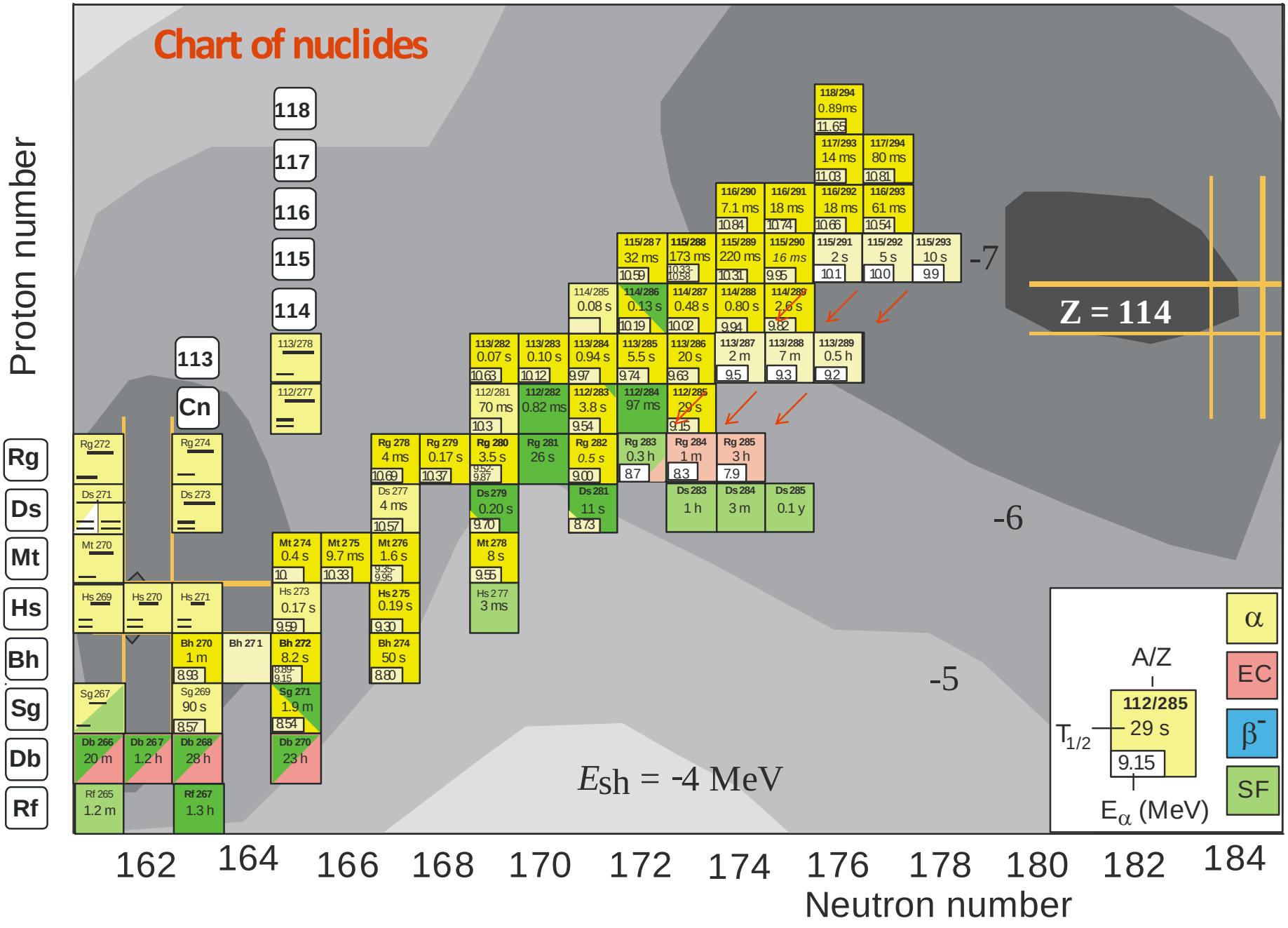
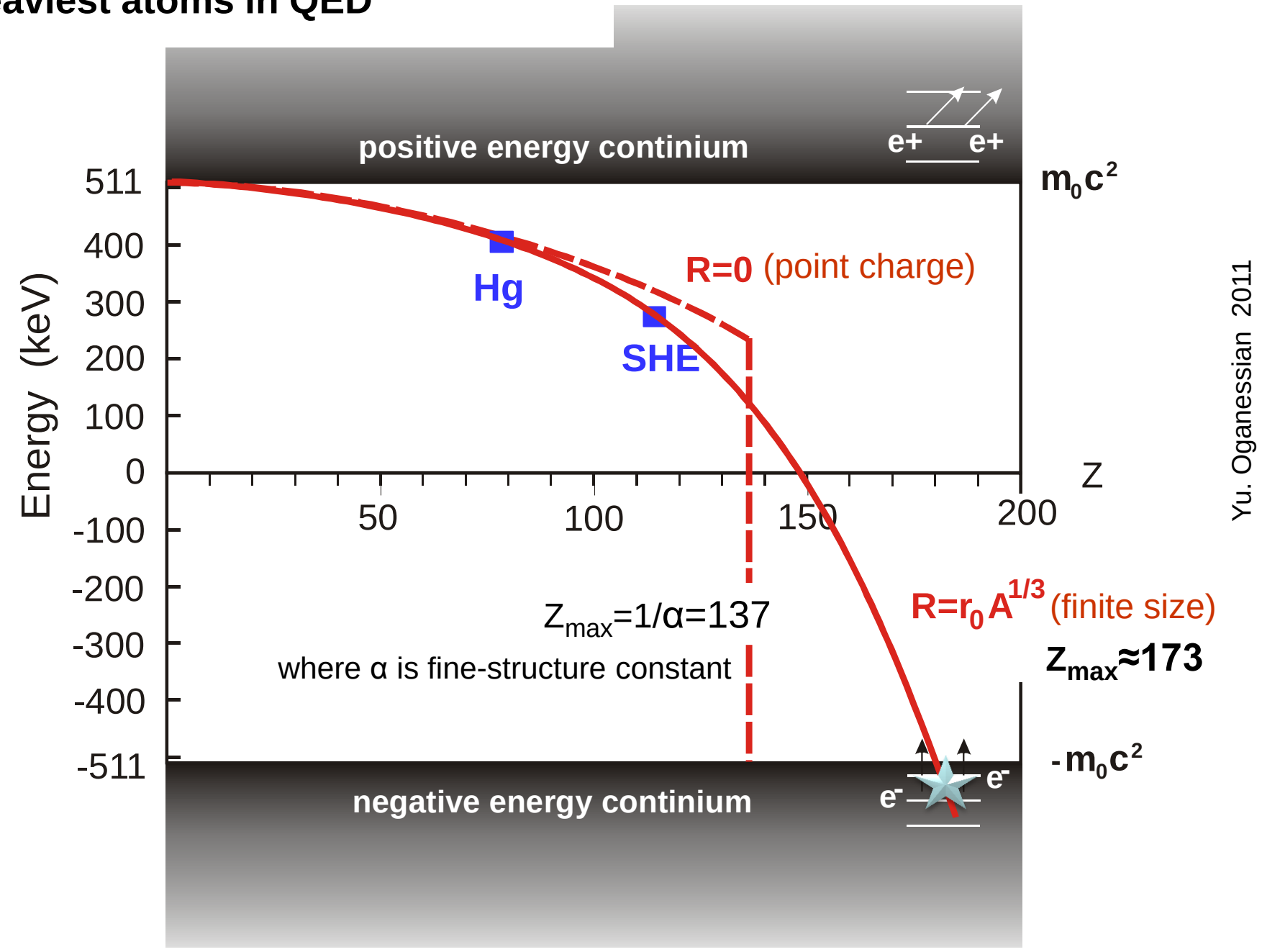


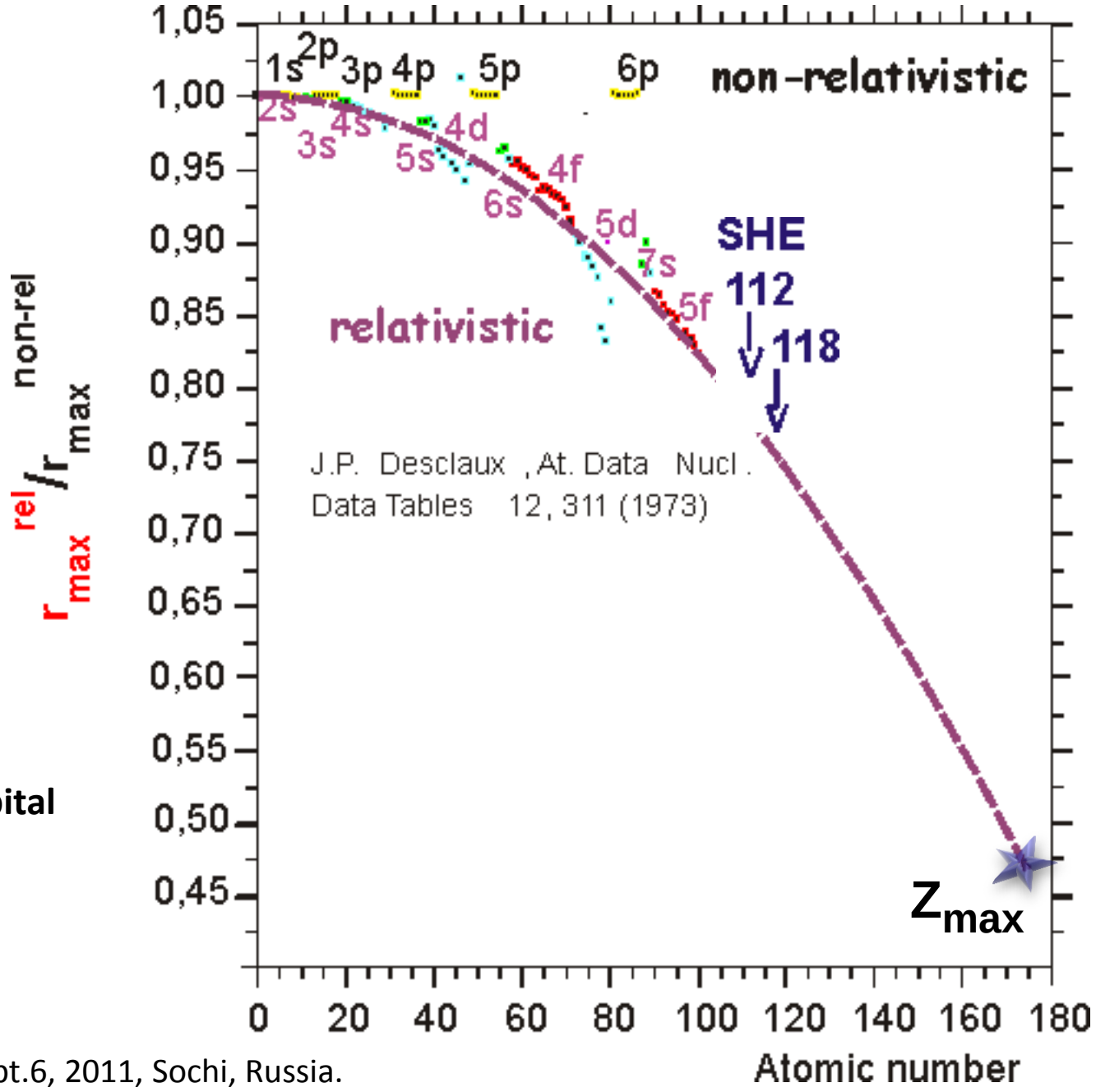
Chart of nuclides
Proton number
Neutron number
Z = 114
-7
-6
-5
E_{sh} = -4 MeV
A/Z
112/285
29 s
9.15
$T_{1/2}$
E_α (MeV)
α
EC
β⁻
SF
Rg
Ds
Mt
Hs
Bh
Sg
Db
Rf
Cn
113
118
117
116
115
114
162
164
166
168
170
172
174
176
178
180
182
184

Heaviest Atoms

Heaviest atoms in QED



Relativistic Contraction



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r_{max} - **principal maximum of the wave function of the outermost orbital**

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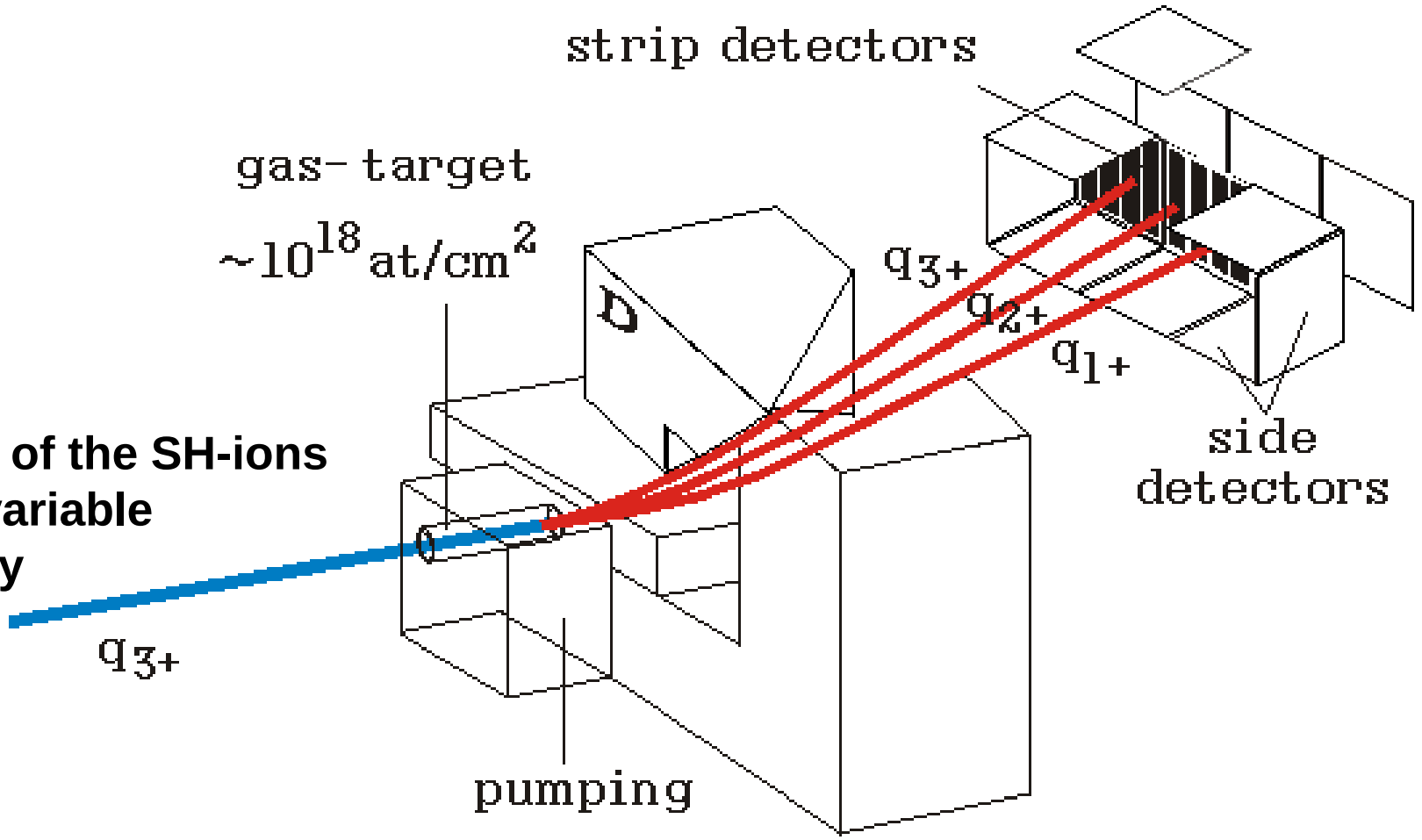
SH- ion charge exchange reactions with various gas-targets



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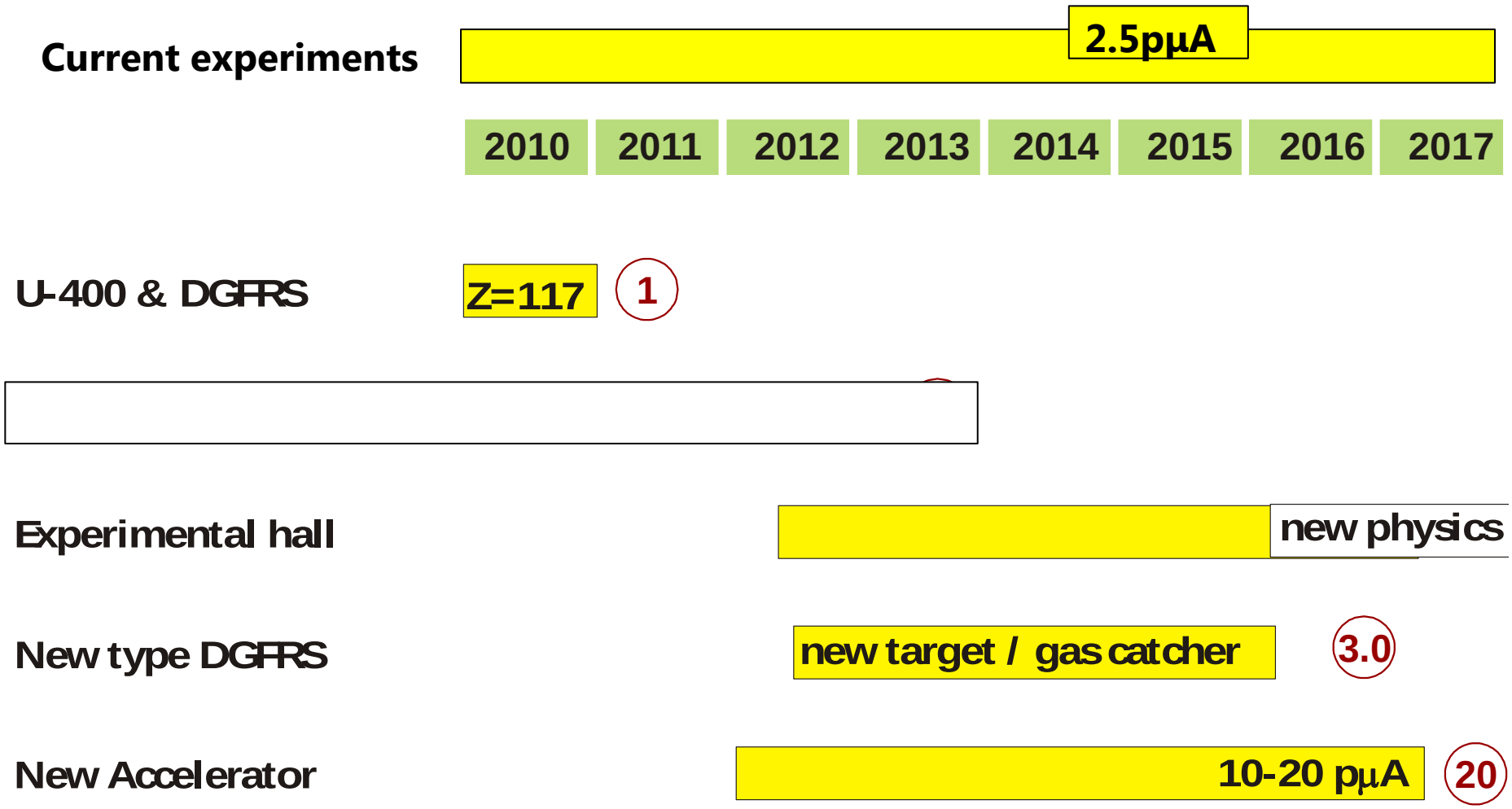
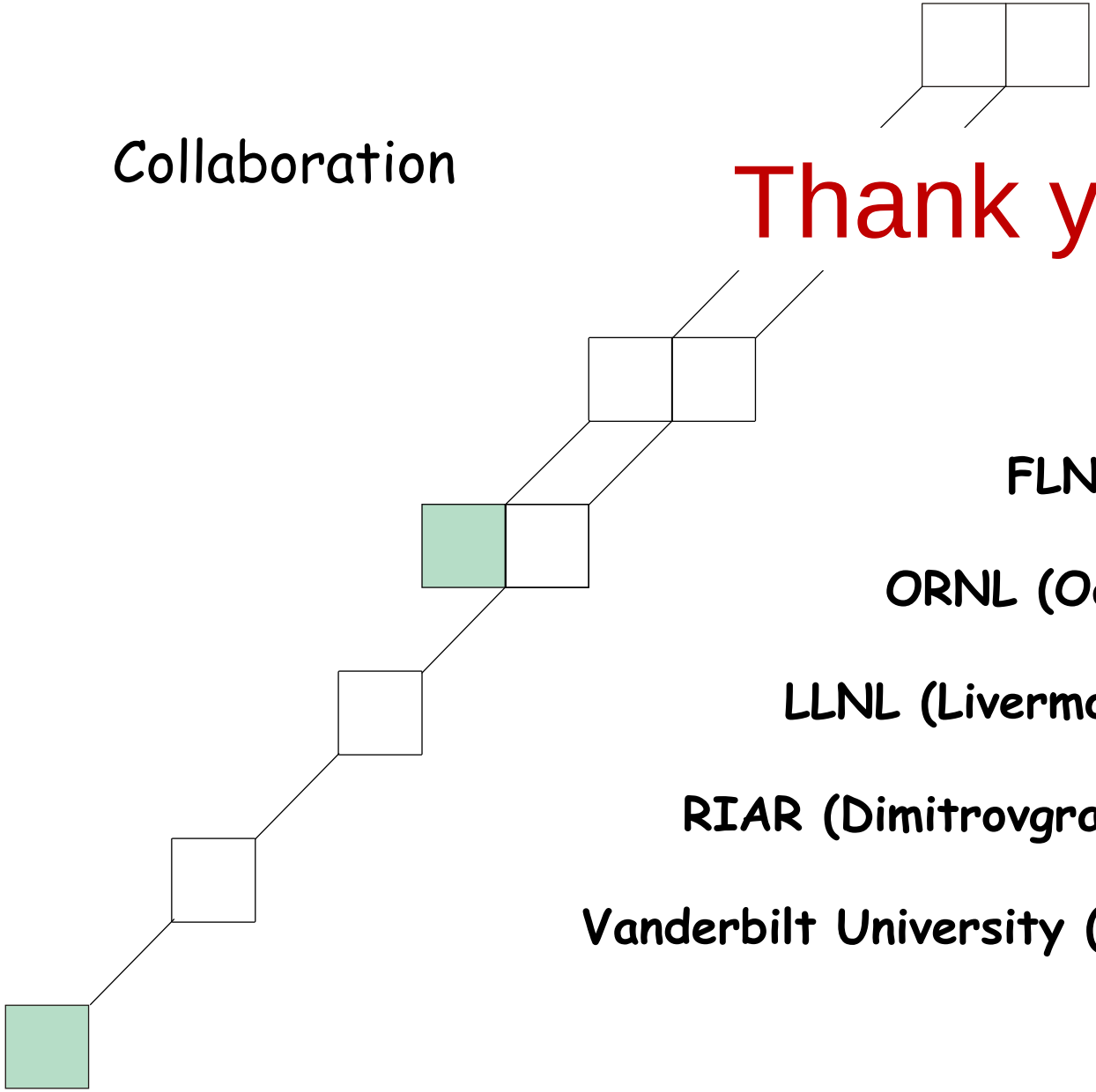
Gain factors for production of Super-heavy nuclei



Yu. Oganessian SHE in JINR, Sept.6, 2011,Sochi, Russia.

Collaboration

Thank you



FLNR, JINR (Dubna)

ORNL (Oak-Ridge, USA)

LLNL (Livermore, USA)

RIAR (Dimitrovgrad, Russia)

Vanderbilt University (Nashville, USA)