Synthesis of heaviest nuclei in fusion reactions with ^{48}Ca, ^{50}Ti, ^{54}Cr & actinides

G.G.Adamian, N.V.Antonenko,

A.N.Bezbakh, J.Hong

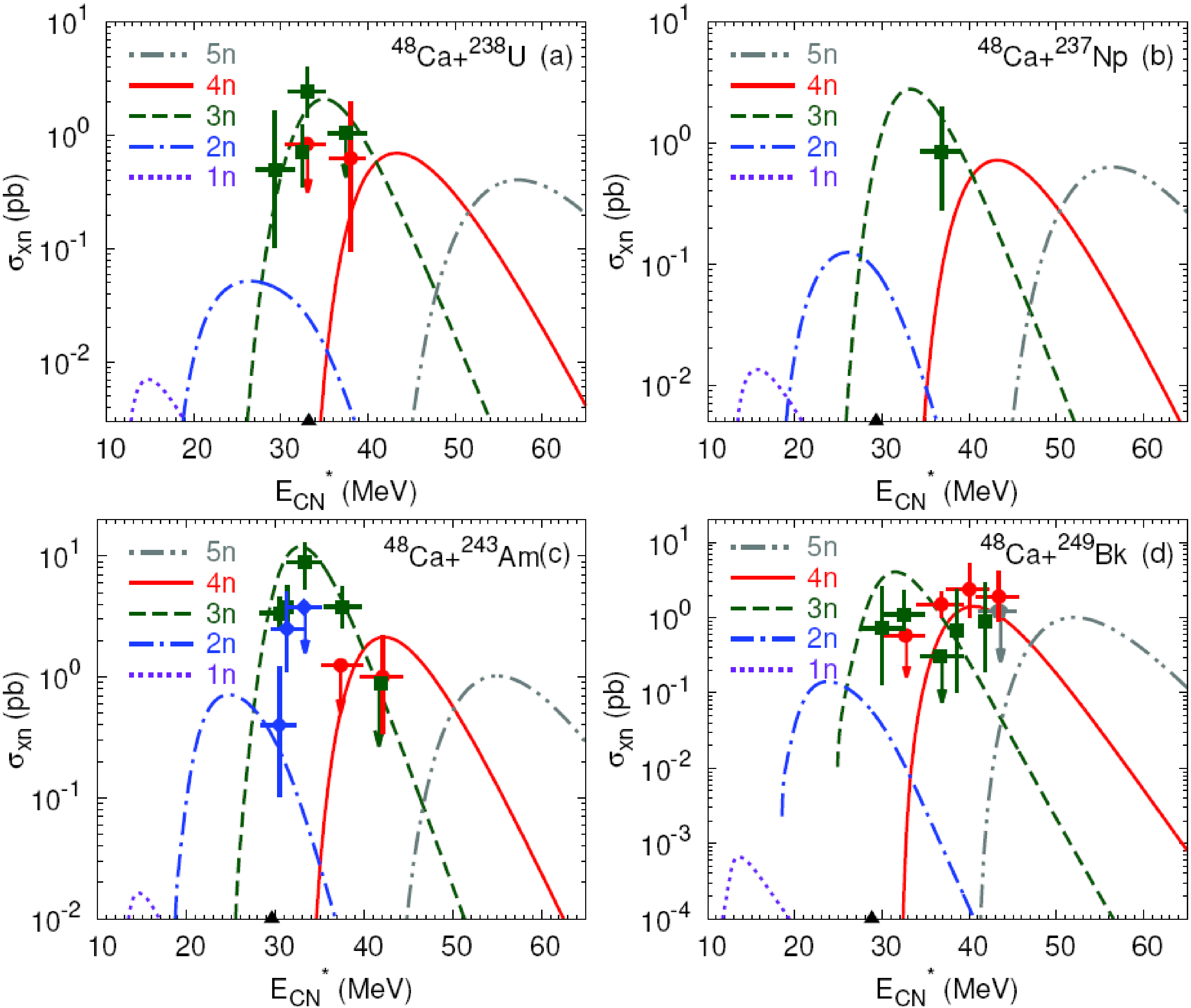
BLTP JINR, Dubna

What interesting experiments can be done with ^{48}Ca beams and actinide targets?

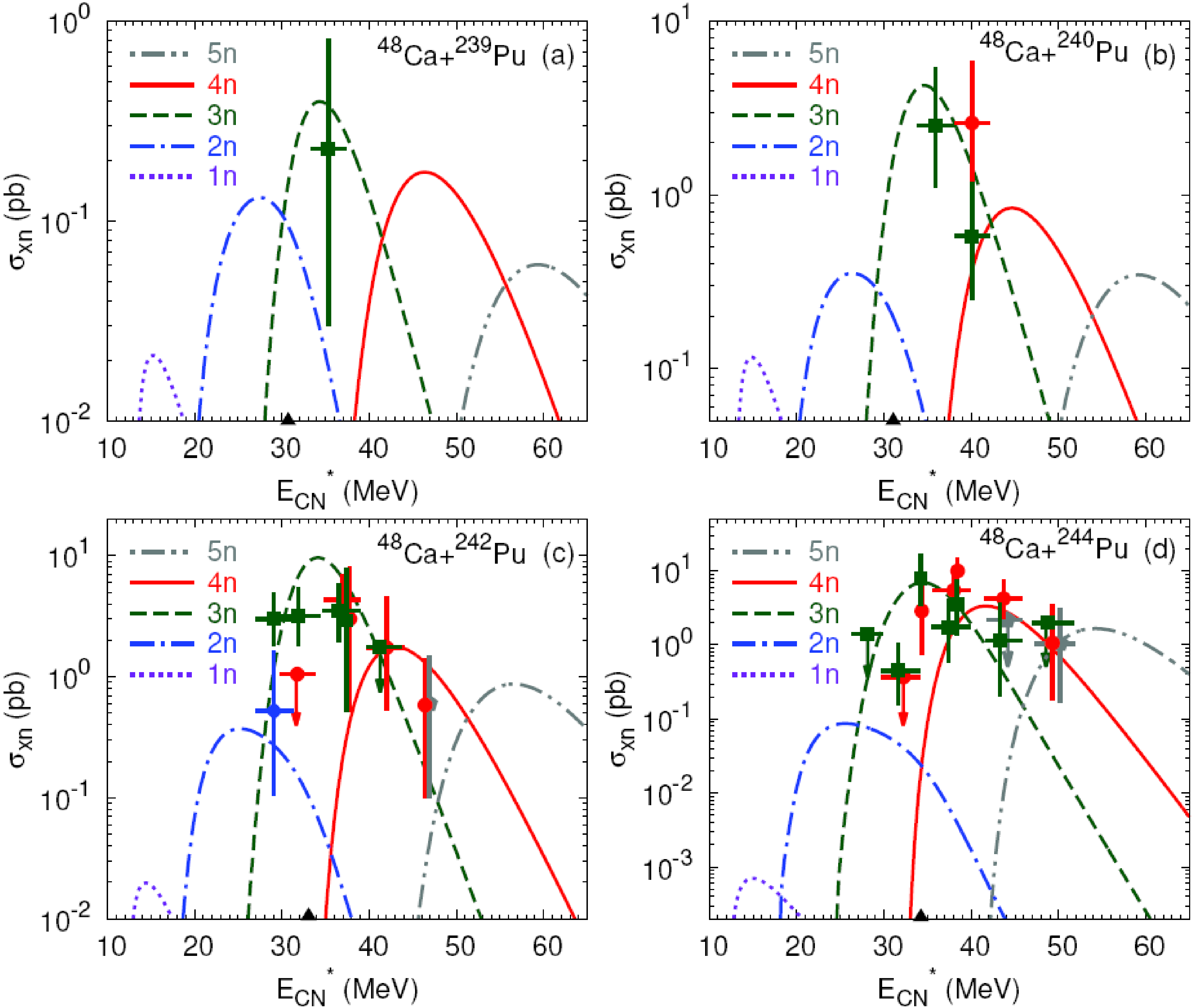
1. ***Low energies***, explore 1n and 2n evap. channels **- new isotopes of SHN**

2. ***High energies***, study of xn evaporation channels with $x > 4$

3. Production of new isotopes in the evaporation channels with emission of charged particle (α-particle, proton) **- new isotopes of SHN**



48Ca+238U (a)
48Ca+237Np (b)
48Ca+243Am(c)
48Ca+249Bk (d)
5n
4n
3n
2n
1n
σxn (pb)
ECN* (MeV)



^{48}Ca+^{239}Pu (a)
5n
4n
3n
2n
1n
σ_{xn} (pb)
E_{CN}^* (MeV)
^{48}Ca+^{240}Pu (b)
^{48}Ca+^{242}Pu (c)
^{48}Ca+^{244}Pu (d)

Summary

Imploying the reactions in 1n-, 2n-channels,

one can produce the heaviest isotopes

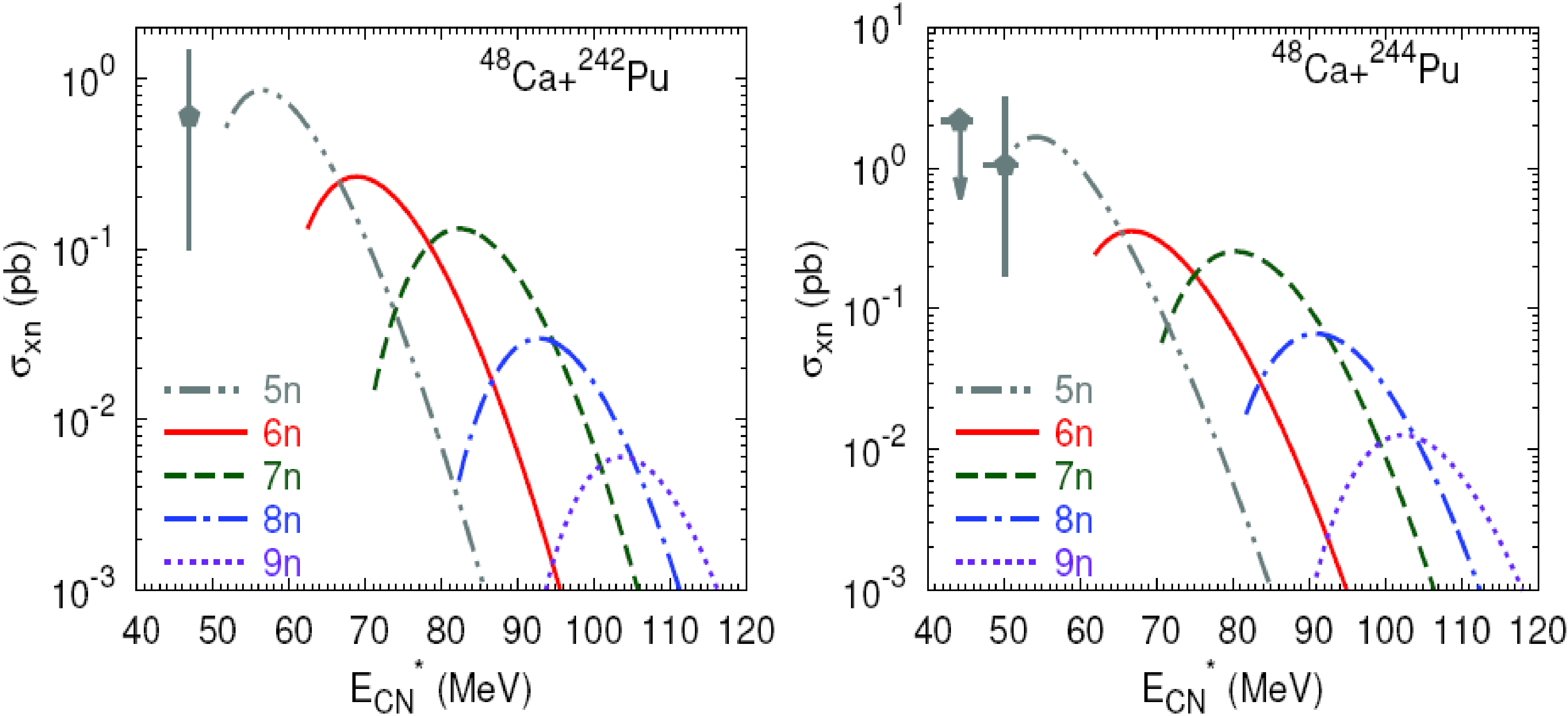
closer to the center of “island of stability” :

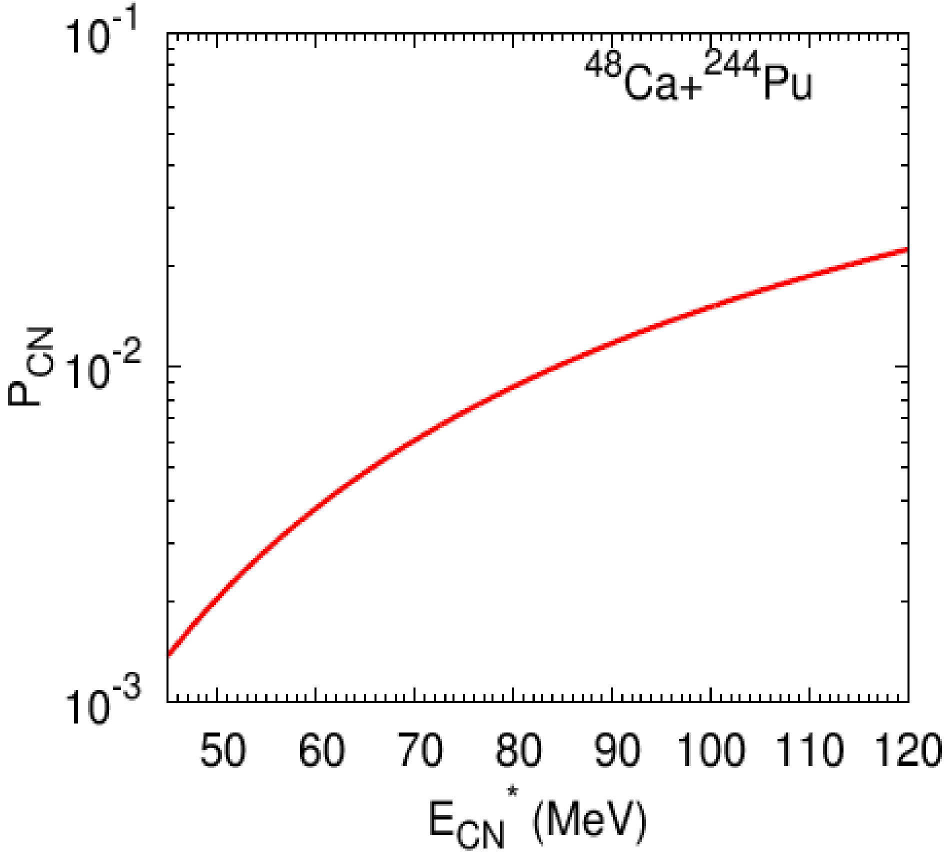
$^{284,285}Cn$, $^{283,284}Nh$, ^{294}Lv, ^{295}Ts, $^{295-297}Og$

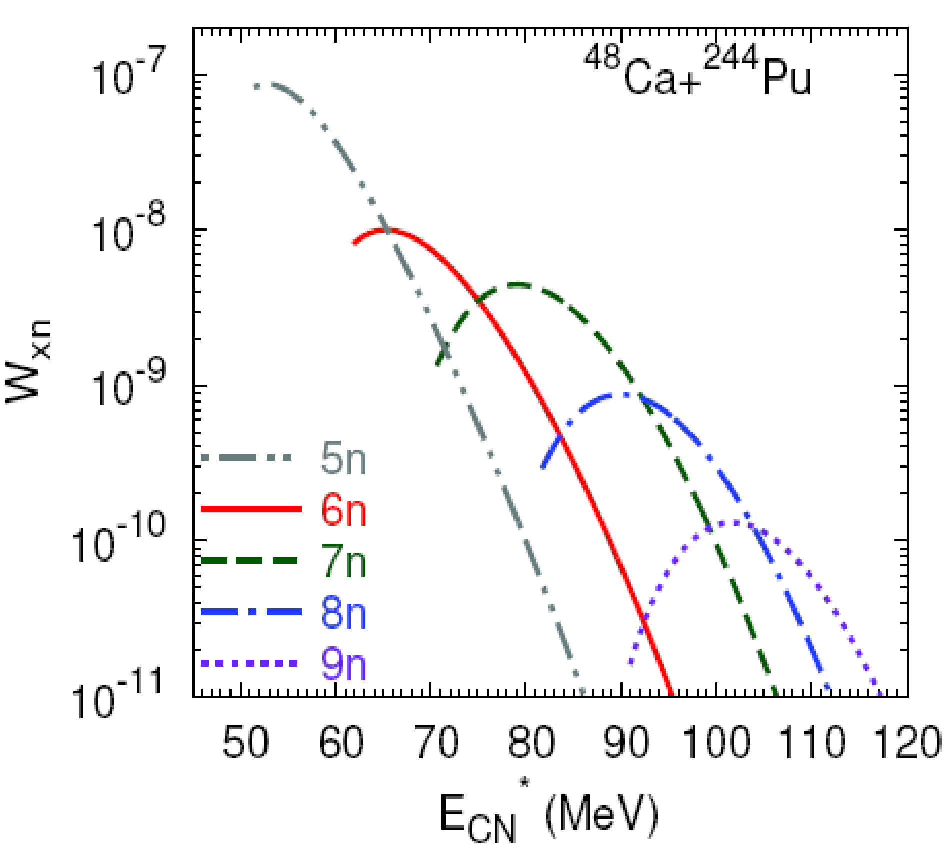
1n: 0.5 fb – 0.1 pb

2n: 30 fb – 1 pb

High energies







A weak drop of the cross section is due to

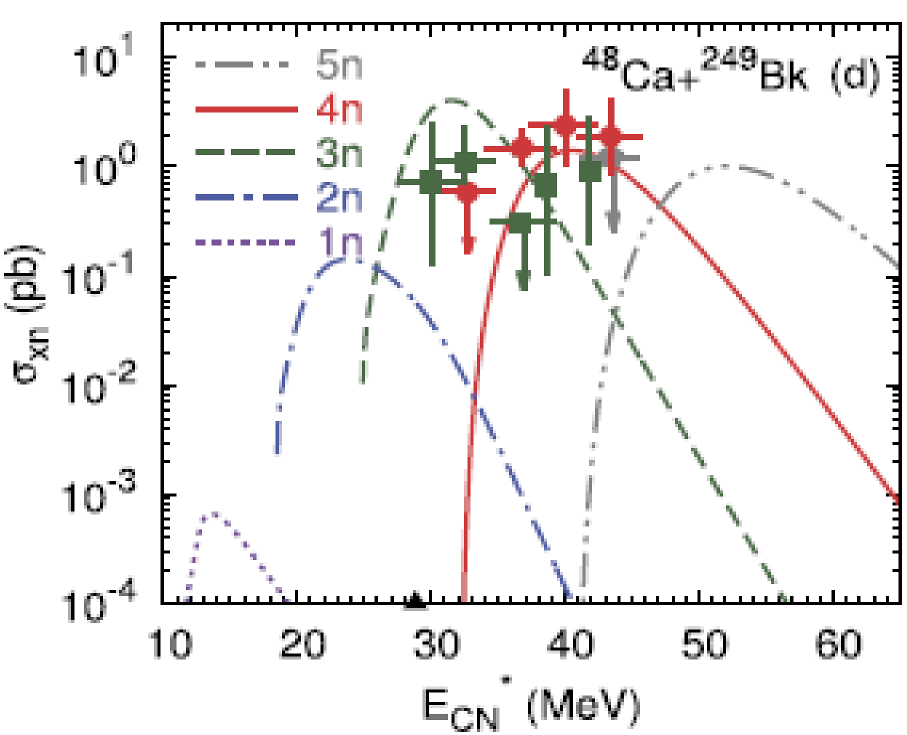
1. The interplay of fusion and survival probabilities

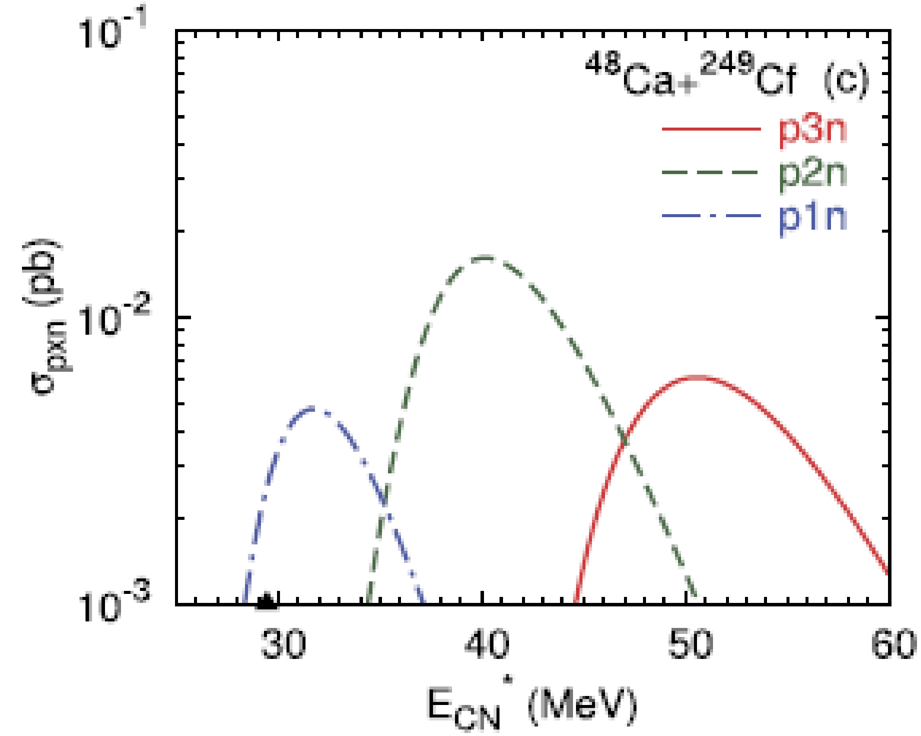
2. A weak change of the difference between the fission barrier height and neutron binding energy at 5-9 steps of n-evaporation

Summary

The decline of the cross section at the transition from 5n to 9n channel is relatively weak.

One can produce SHN with Z=114–117 in 5n-, 6n-channels

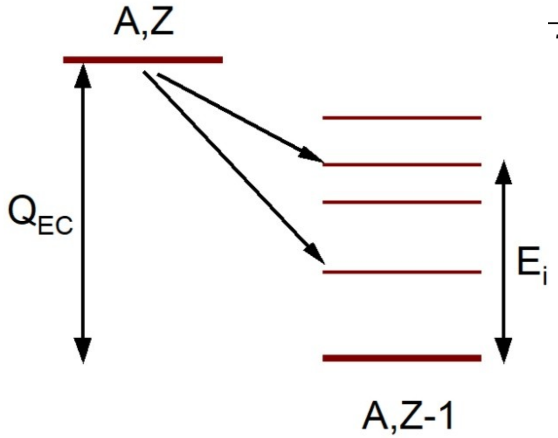




Cross sections of almost all SHN in *xn*-channels are larger than those in the charged particle evap. channels

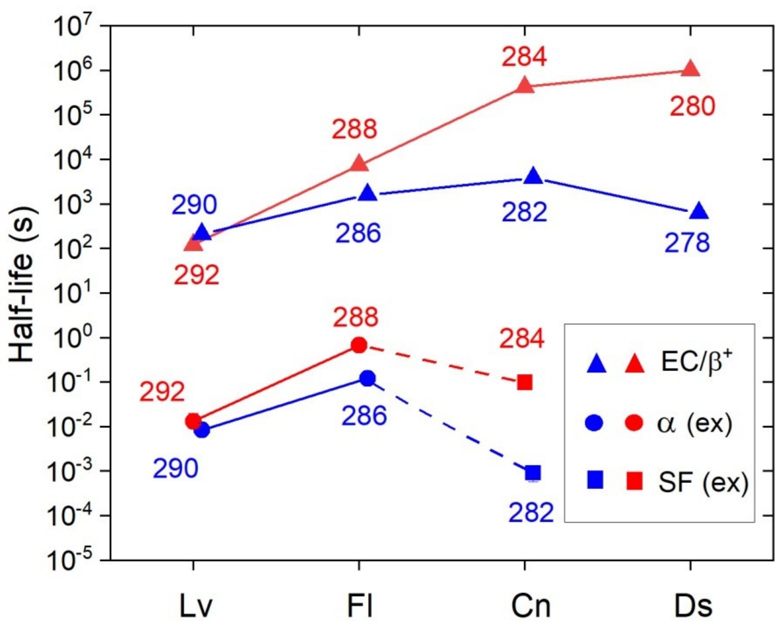
$T_{EC/\beta}$ half-lives for α-decay chains of ^{292,290}Lv

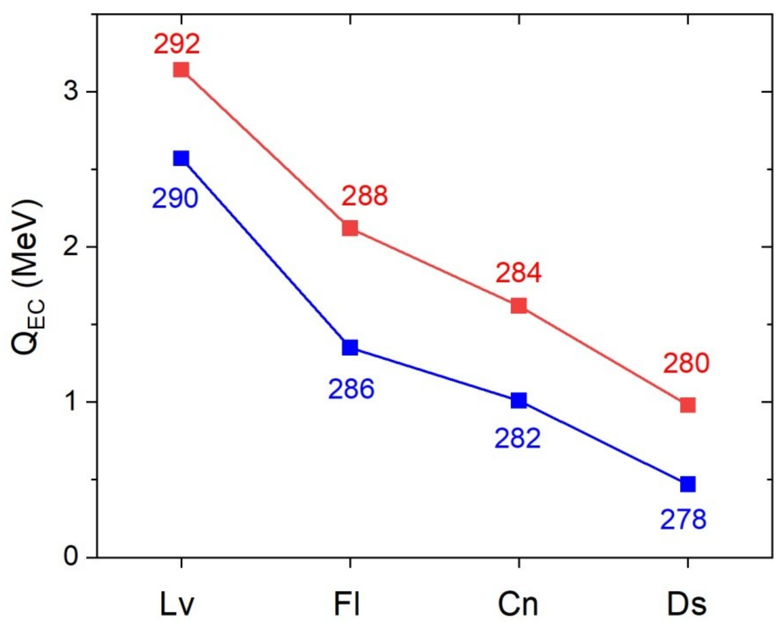
A. A. Dzhioev, BLTP, JINR



$$\frac{1}{T_{EC/\beta^+}} = \frac{1}{T_{EC}} + \frac{1}{T_{\beta^+}}\ ; \quad T_b = \frac{4131\,\mathrm{s}}{\sum\limits_{0\le E_i<Q_b} |M_{0i}|^2 f_b(Z, Q_b - E_i)}$$

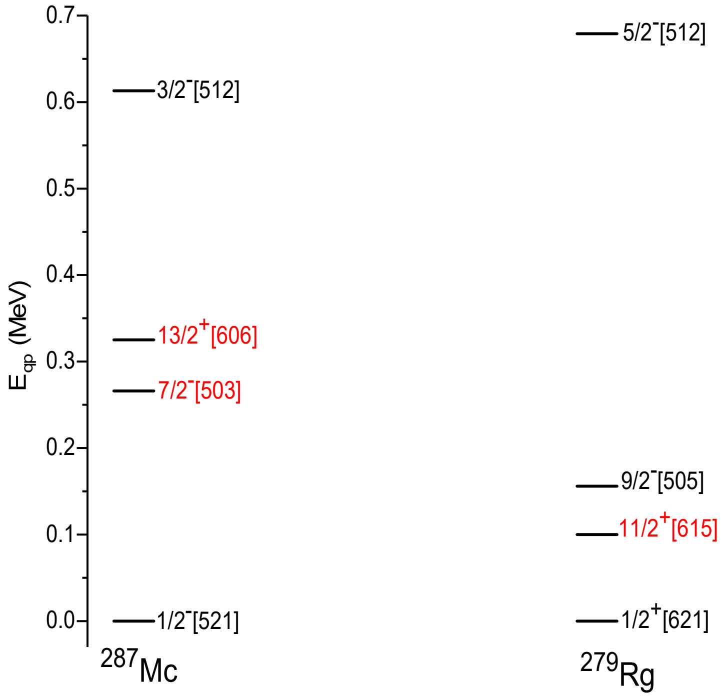
- Nuclear matrix elements $|M_{0i}|^2$ and excitation energies E_i are calculated within the QRPA with the Hamiltonian of the quasiparticle-phonon nuclear model (deformed WS , BCS pairing);
- Q_{EC} from ADNTD125(2019)1, P. Moller et al.





Low-lying spectra of nuclei in α-decay chain of ^{291}Tc

R.V.Jolos, L.A.Malov, N.Yu.Shirikova, A.B.Sushkov, E.A.Kolganova



The lowest excited states with $\Delta K \geq 3$ may be isomeric. The smaller the difference in energy, the longer the life-time.

Predicted energies of the first 2⁺ states

Nucleus	β_2	$E(2^+_1)$ (keV)
^{256}Fm	0.28	50
^{260}No	0.29	53
^{264}Rf	0.275	44 preliminary
^{280}Cn	0.18	76
^{284}Fl	0.14	198

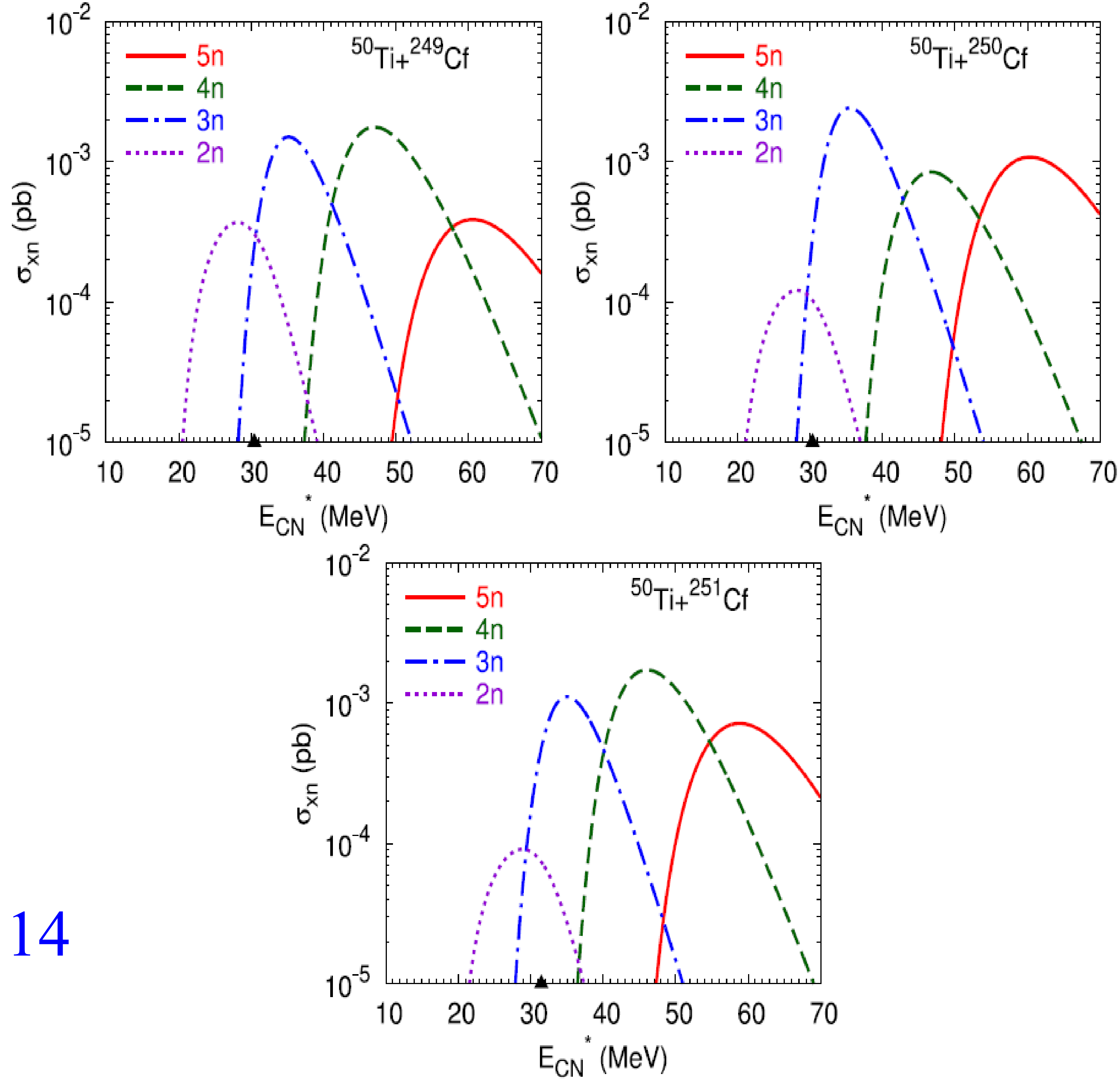
Fusion reactions with ^{50}Ti and ^{54}Cr

Within the dinuclear system model we analysed the dependence of the production cross section of SHN on the predicted shell structure and magic number of SHN

Different predictions of the properties of heaviest nuclei were used:

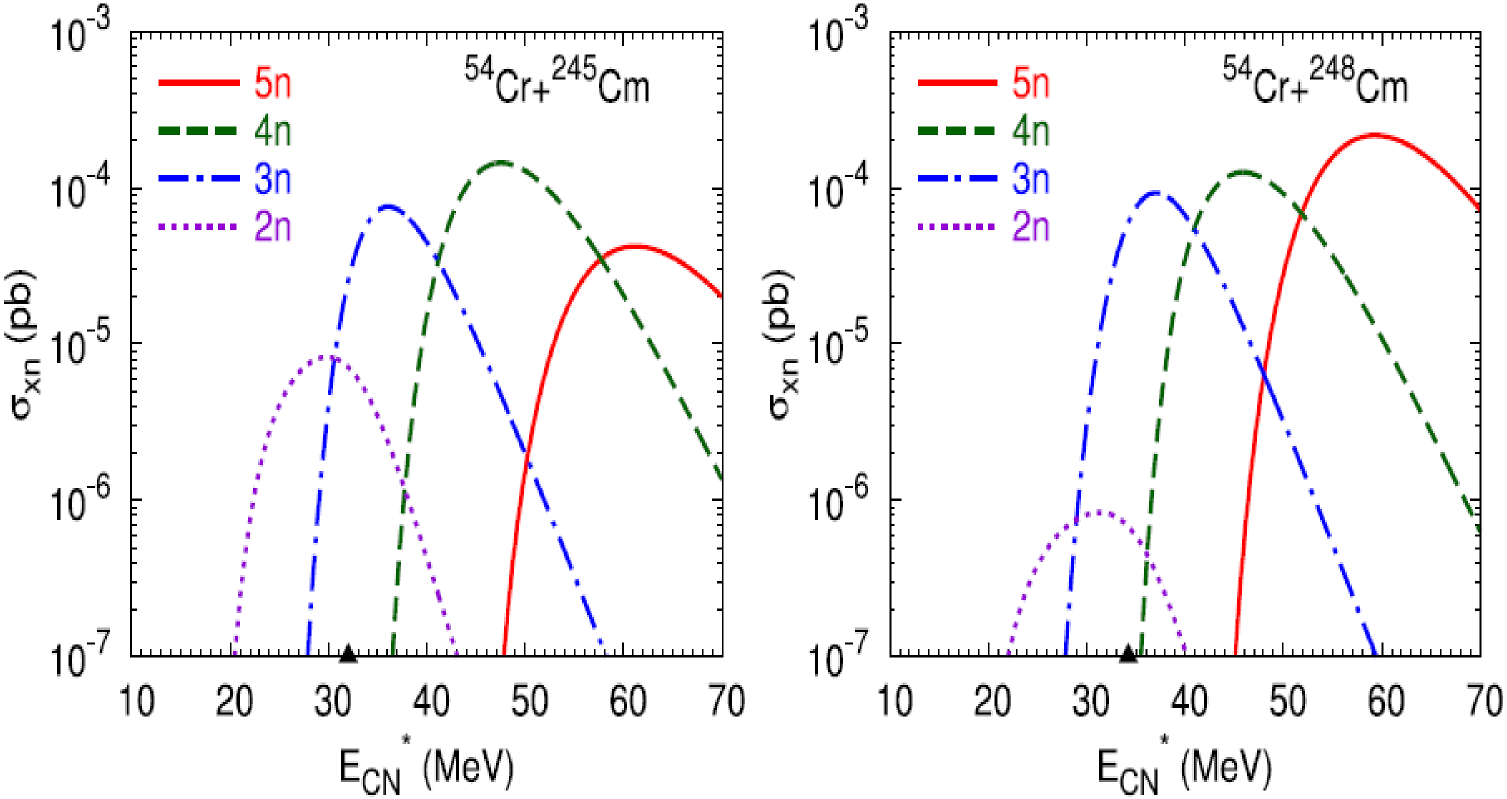
1) mass table from Mac-Mic (2012), Z=120-126

2) mass table from Mac-Mic (2021), Z=114



$^{50}Ti+^{249}Cf$
$^{50}Ti+^{250}Cf$
$^{50}Ti+^{251}Cf$
5n
4n
3n
2n
σ_{xn} (pb)
E_{CN}^{*} (MeV)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10
20
30
40
50
60
70

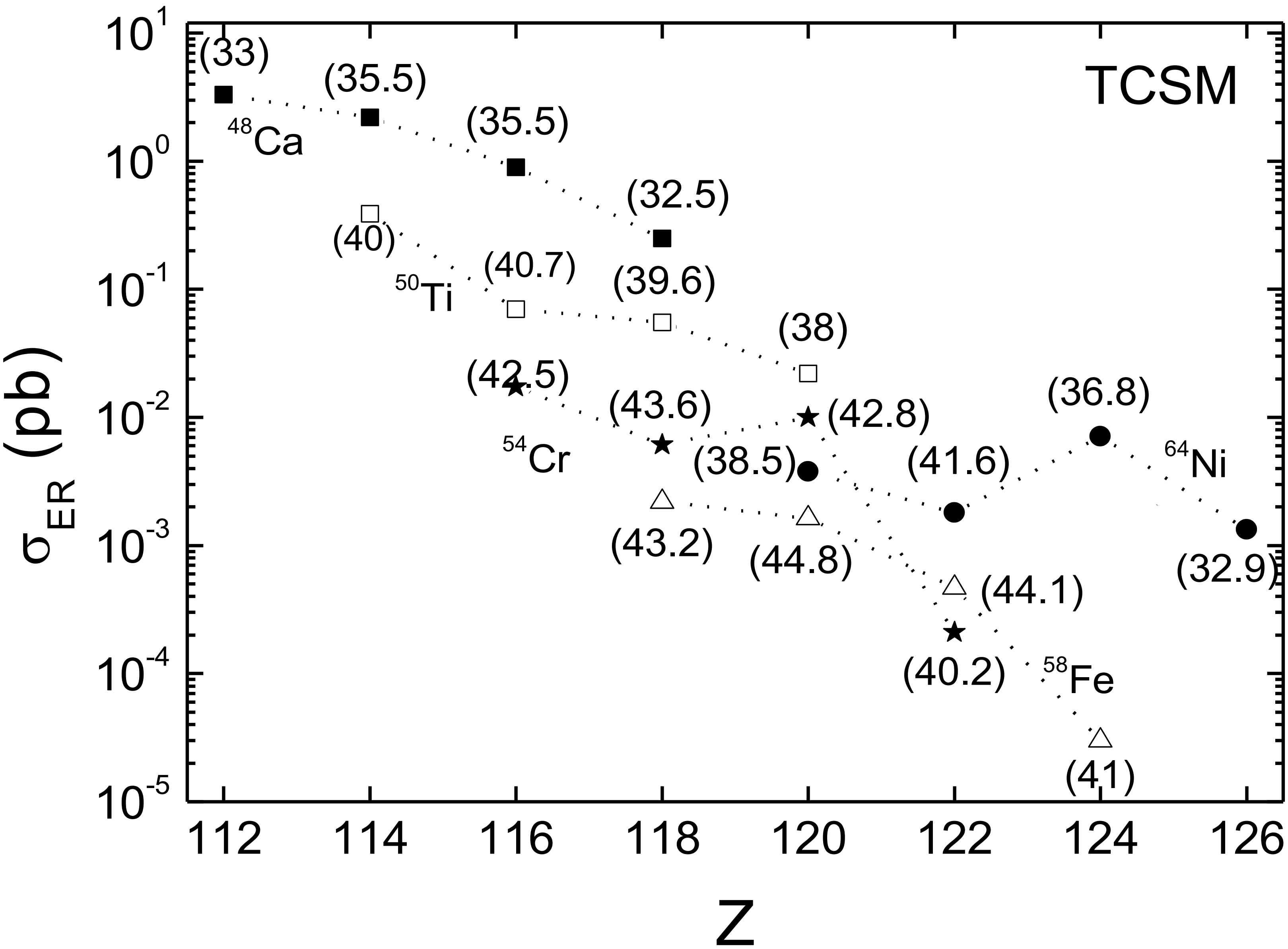
Z=114

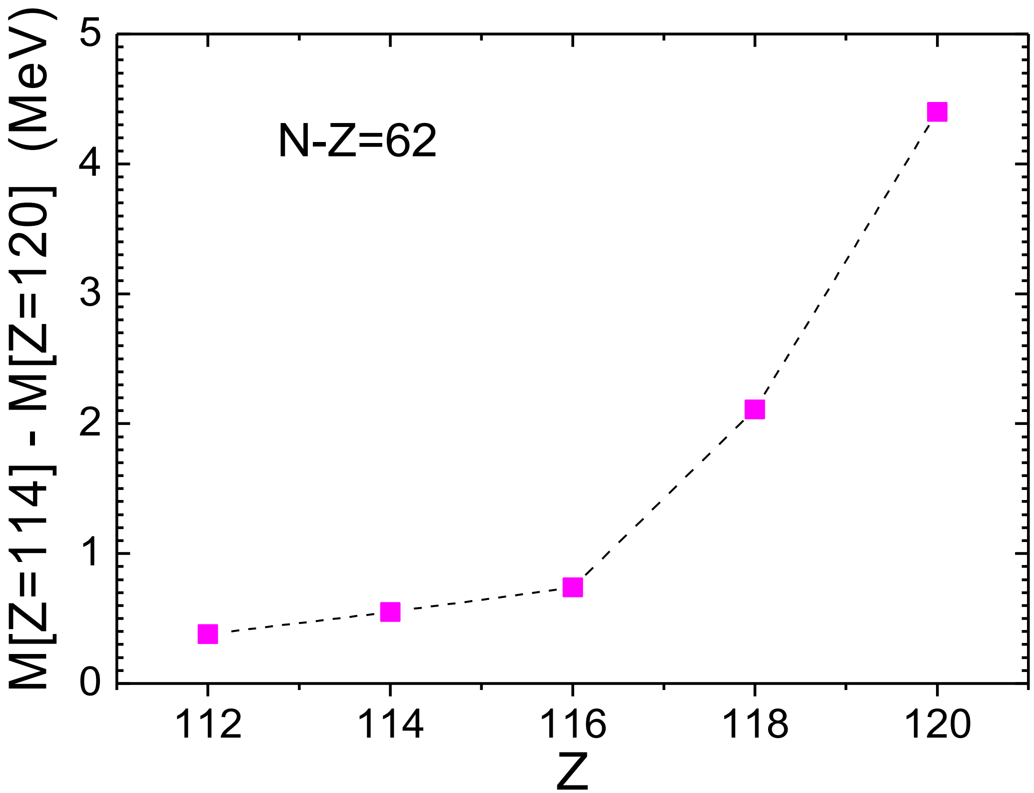


10-3
10-4
10-5
10-6
10-7
σxn (pb)
5n
4n
3n
2n
54Cr+245Cm
10 20 30 40 50 60 70
ECN* (MeV)
54Cr+248Cm
ECN* (MeV)

Z=114

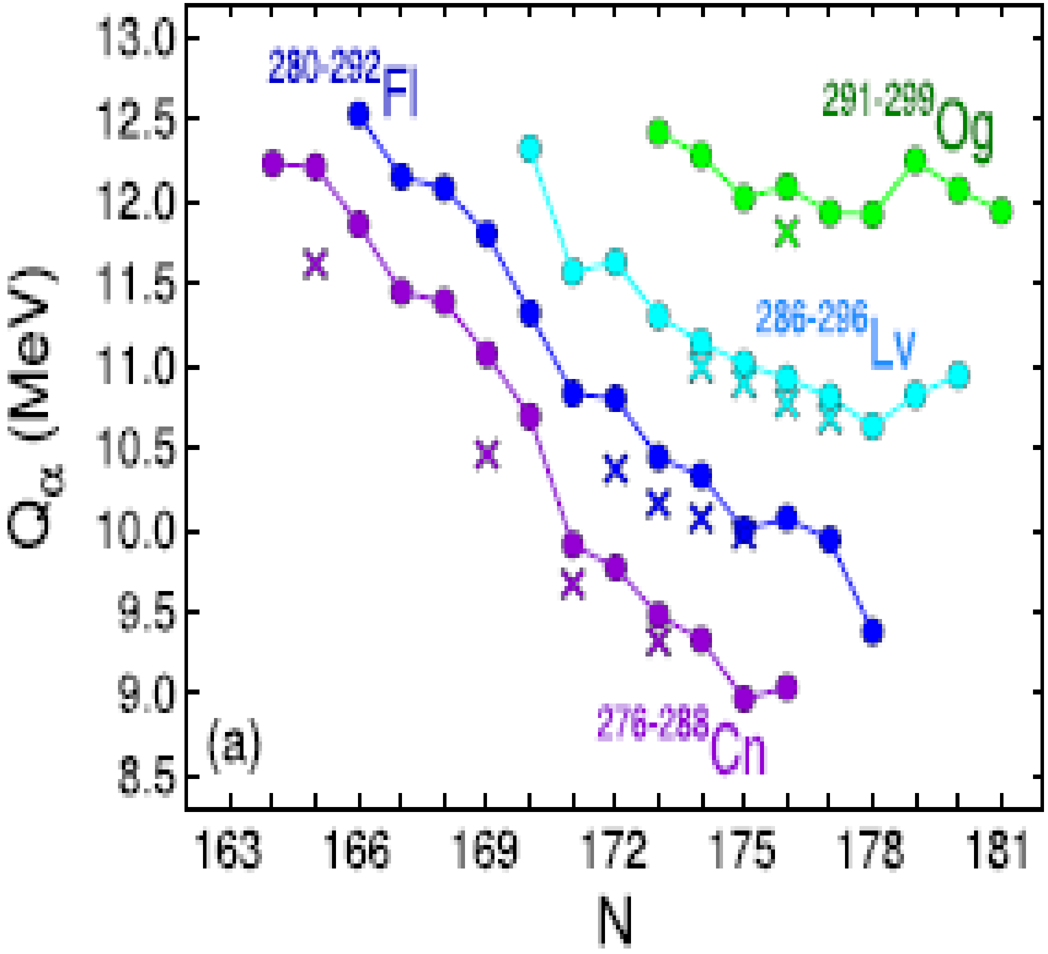
Z=120-126


TCSM
σ_{ER} (pb)
Z
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
112
114
116
118
120
122
124
126
^{48}Ca
^{50}Ti
^{54}Cr
^{58}Fe
^{64}Ni
(33)
(35.5)
(35.5)
(32.5)
(40)
(40.7)
(39.6)
(38)
(42.5)
(43.6)
(42.8)
(38.5)
(41.6)
(36.8)
(43.2)
(44.8)
(44.1)
(40.2)
(32.9)
(41)

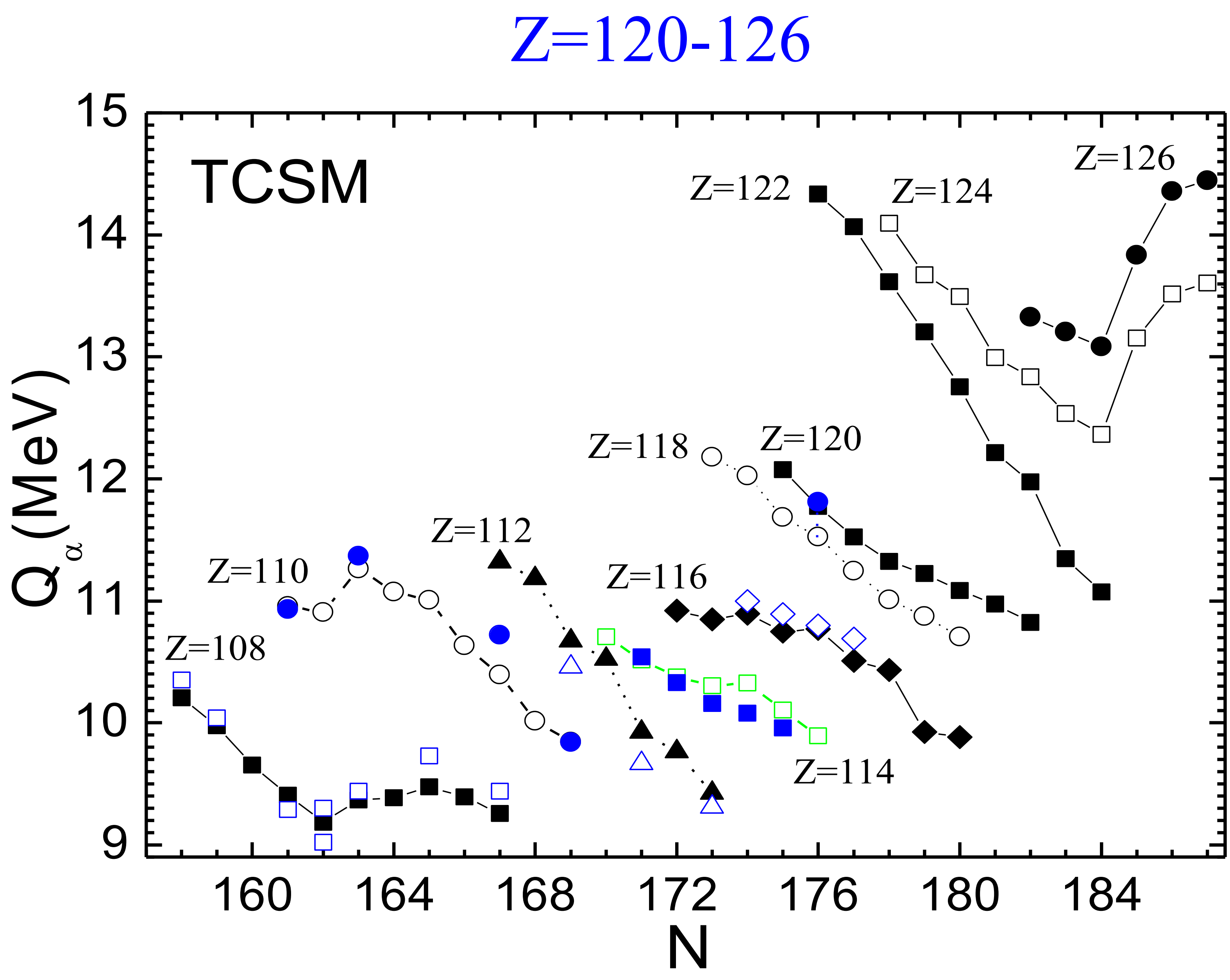


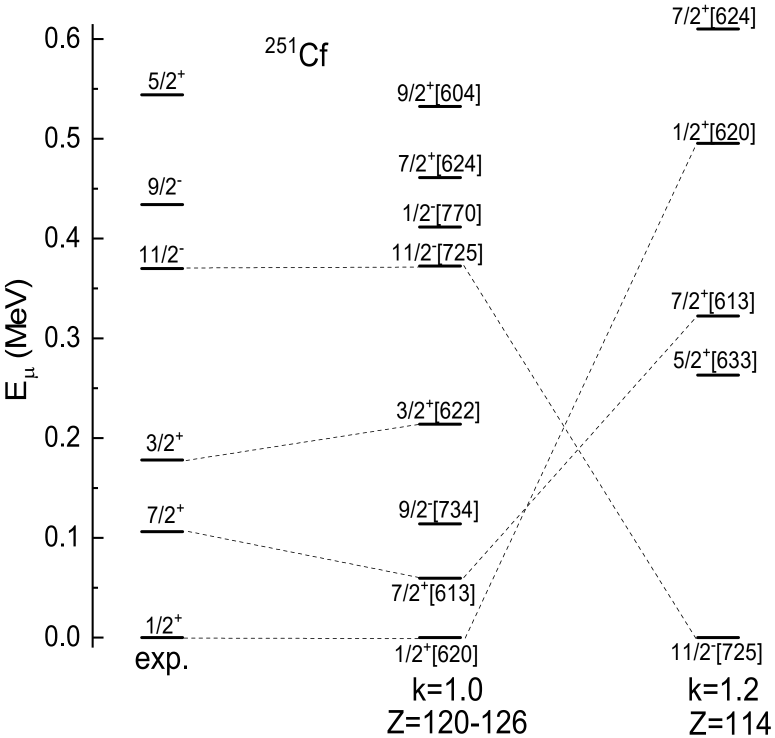
M[Z=114] - M[Z=120] (MeV)
N-Z=62
0
1
2
3
4
5
112
114
116
118
120
Z

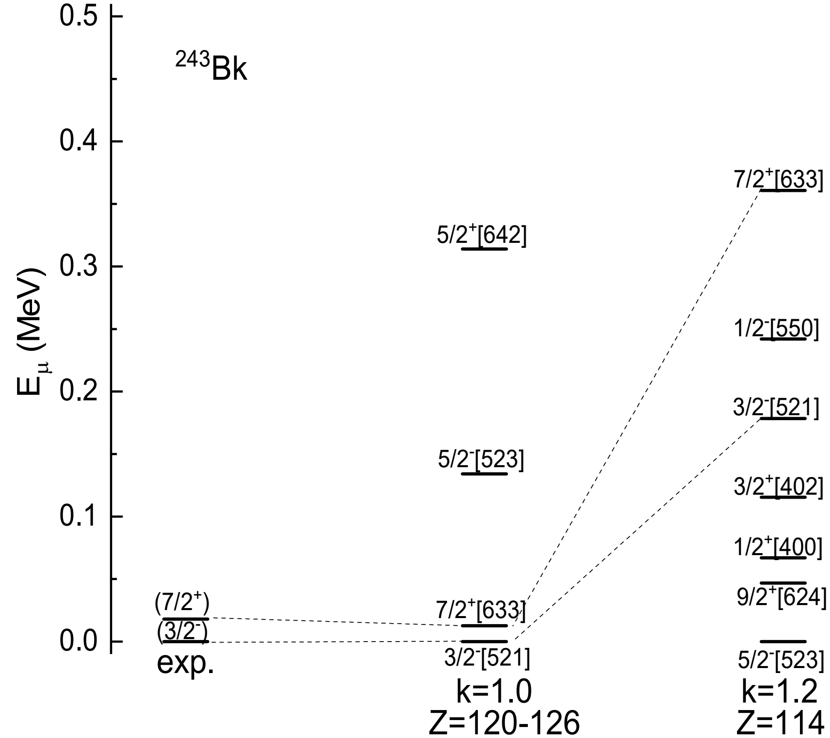
Z=114

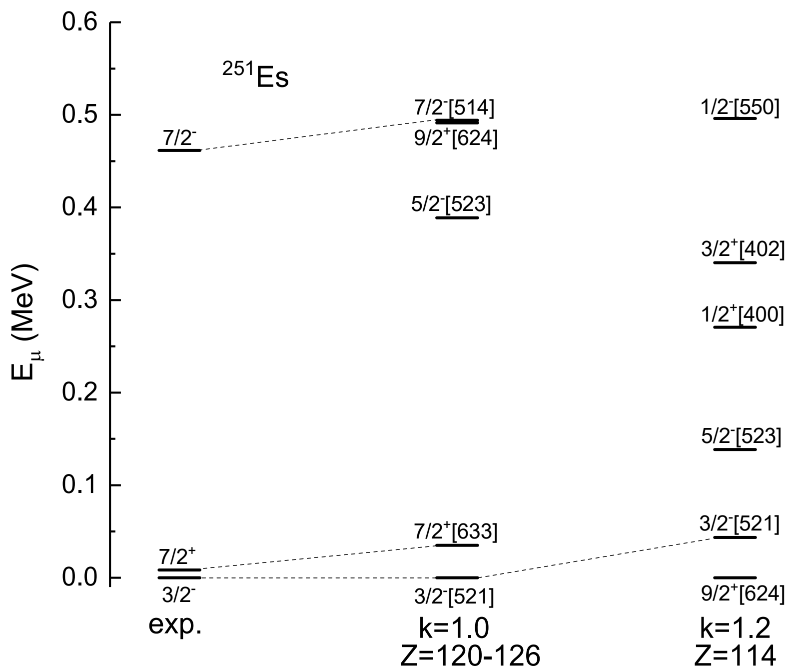


P.Jachimowicz, M.Kowal, J.Skalski,
At. Data Nucl. Data Tables 138 (2021) 101393


Z=120-126
TCSM
Z=108
Z=110
Z=112
Z=114
Z=116
Z=118
Z=120
Z=122
Z=124
Z=126
Q_α (MeV)
N
15
14
13
12
11
10
9
160
164
168
172
176
180
184

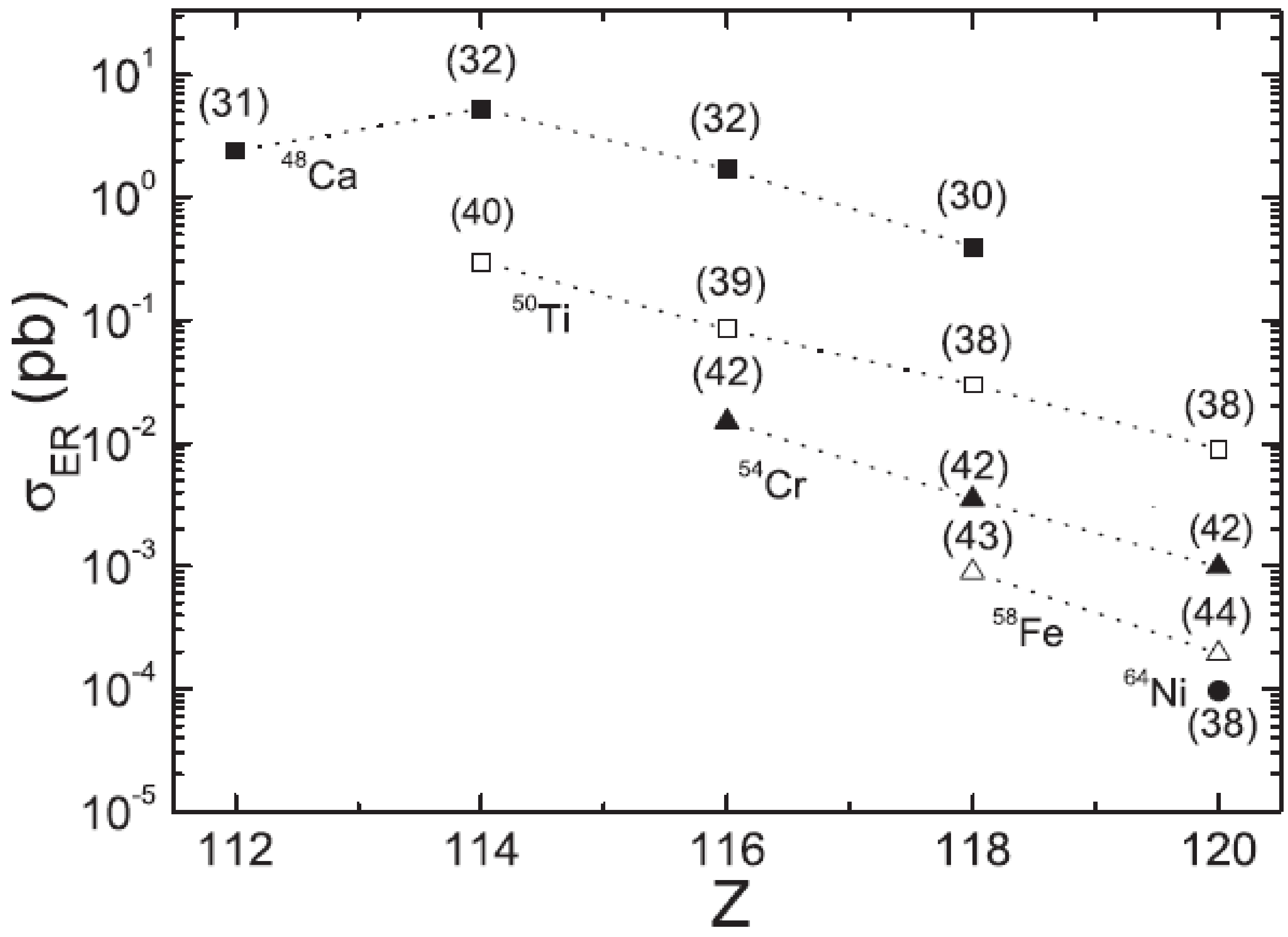






Importance of spectroscopy!

Self-consistent nonrel. Mean-Field predictions (**Z=120**)



H. Lenske, L.A. Malov

Summary

Mac-Mic (Z=120-126) :

$^{50}Ti+^{249}Cf$ - 23 fb & $^{54}Cr+^{248}Cm$ - 10 fb

Nonrel. MFM (Z=120) :

$^{50}Ti+^{249}Cf$ - 8 fb & $^{54}Cr+^{248}Cm$ - 1 fb

Z=120 nuclei with **N=175-179** are expected to

have $\mathbf{Q_a}$ about **12.1 - 11.2 MeV**

and lifetimes **1.7 ms - 0.16 s**

These $\mathbf{Q_a}$ are about **2 MeV** smaller than those

from P. Möller, A. Sobiczewski, M. Kowal (**Z=114)**

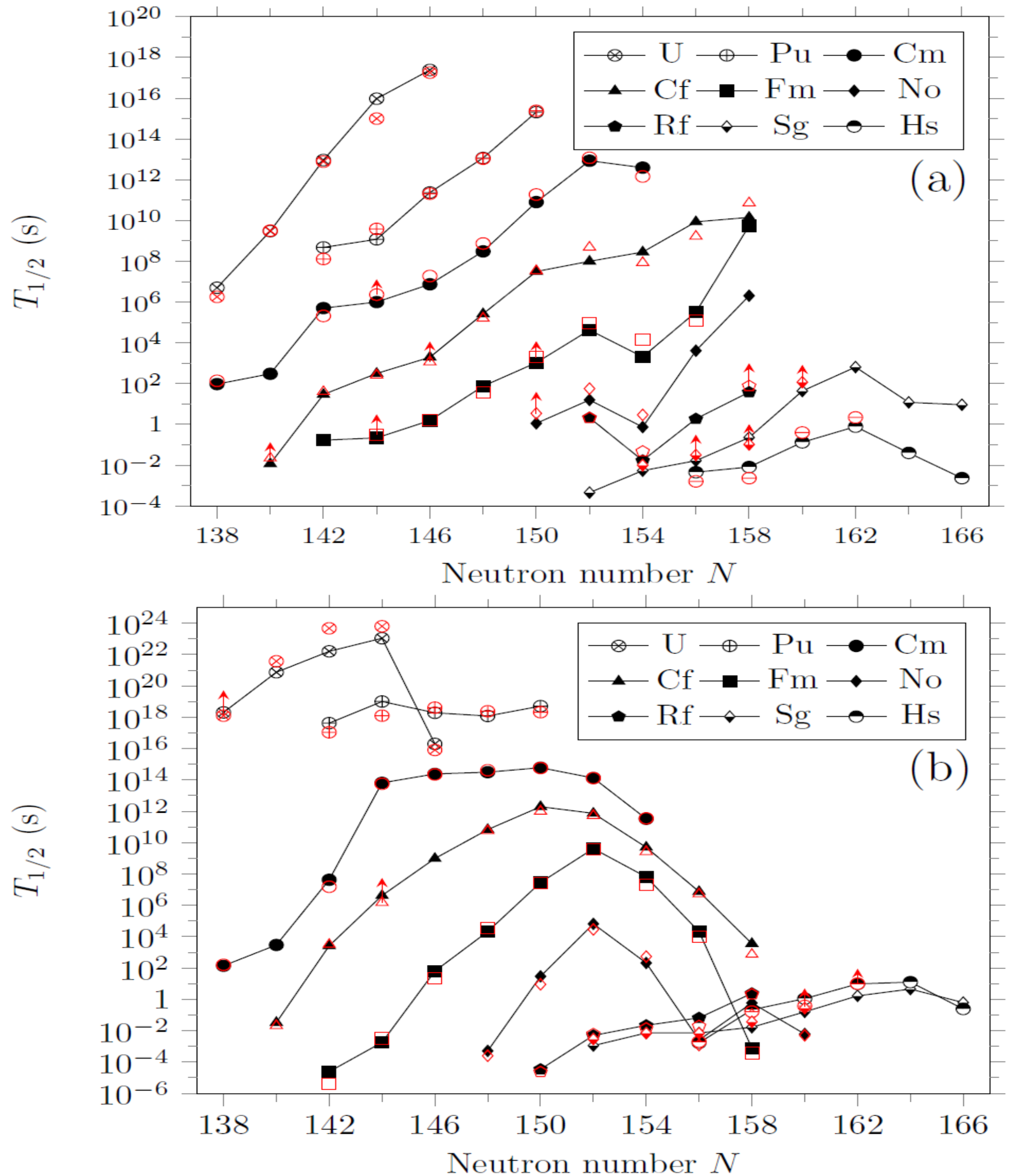
Experimental measurement of $\mathbf{Q_a}$ for at least one isotope of **Z=120** nucleus would help us to set proper shell model for the **SHE** with **Z>118** !

I.S.Rogov, H.Paska

Alpha decay

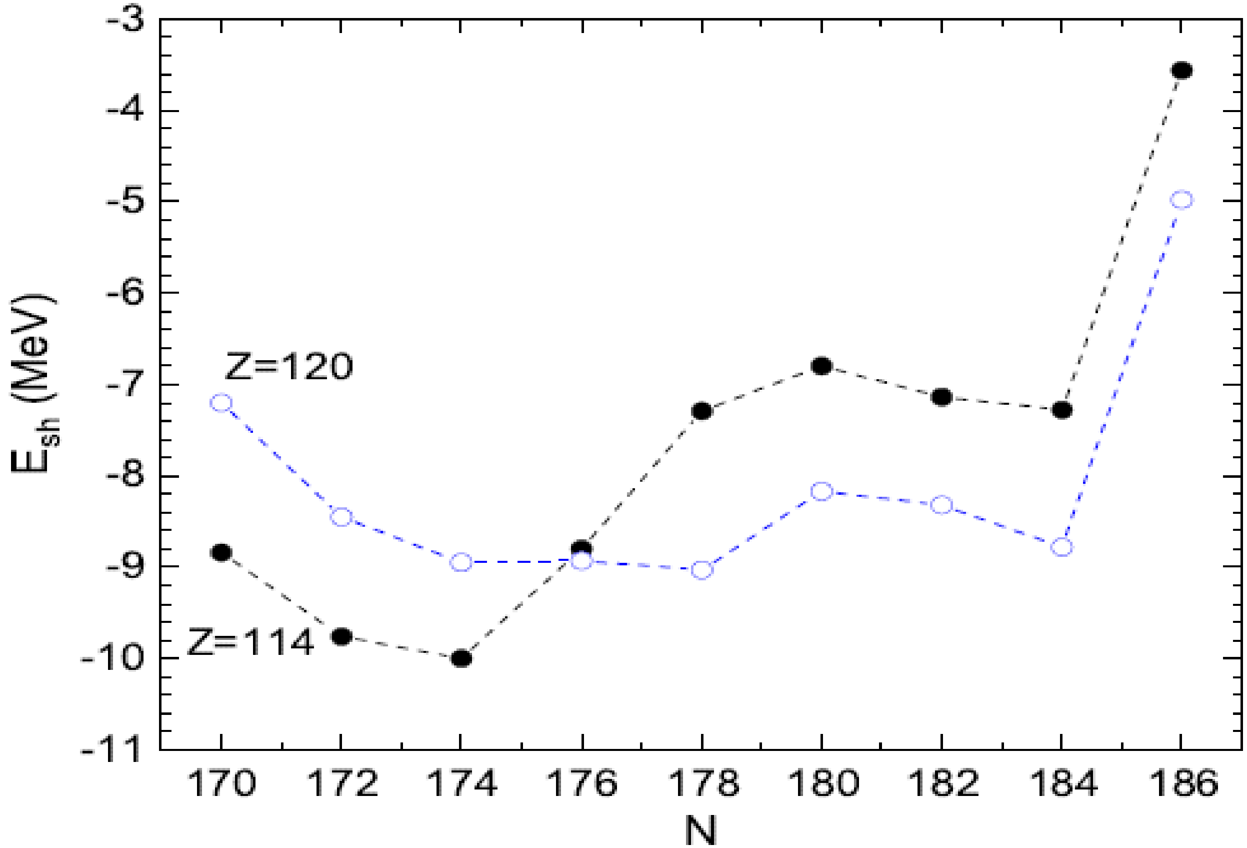
Spontaneous fission

Fission is inverse to Fusion

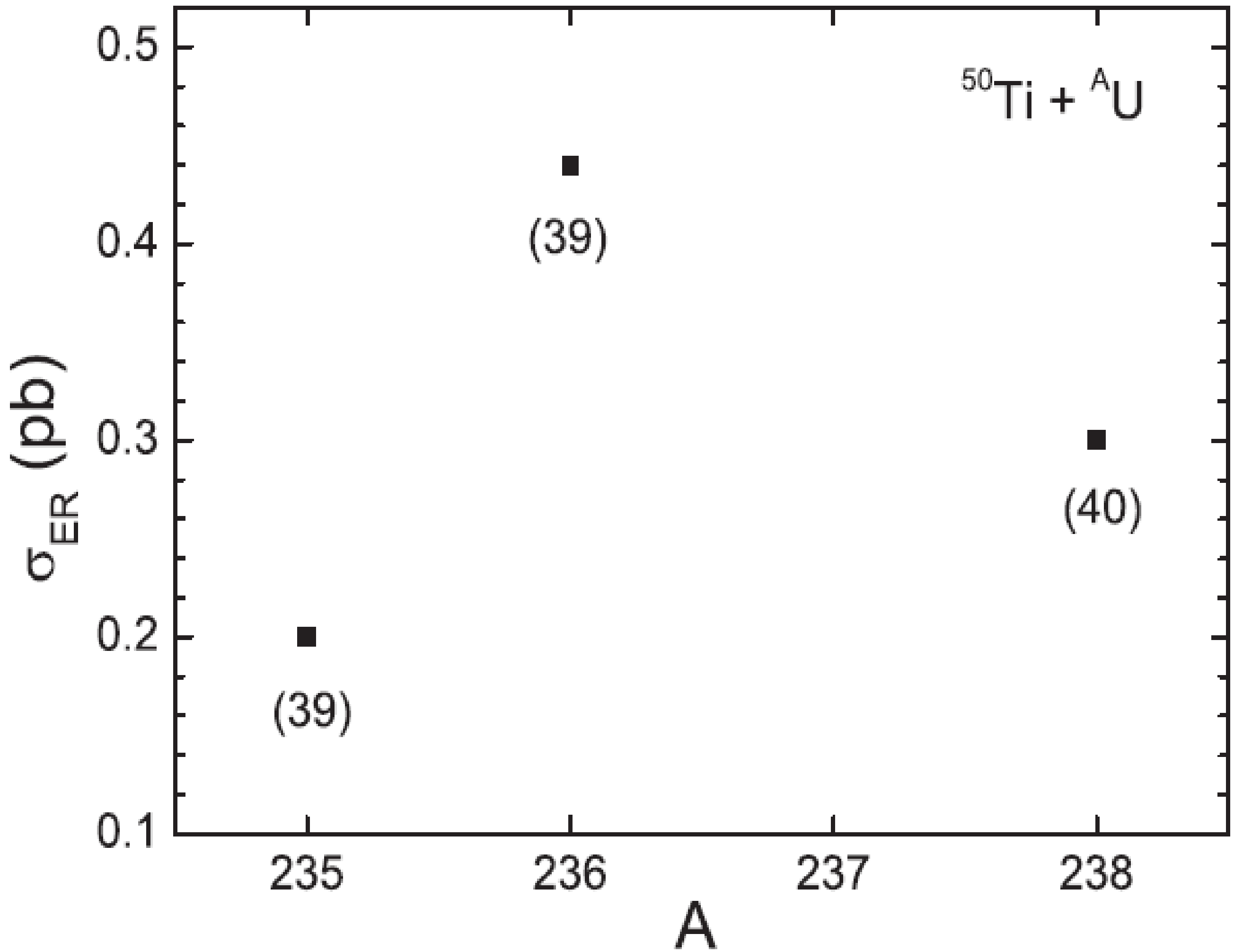


Thank you!

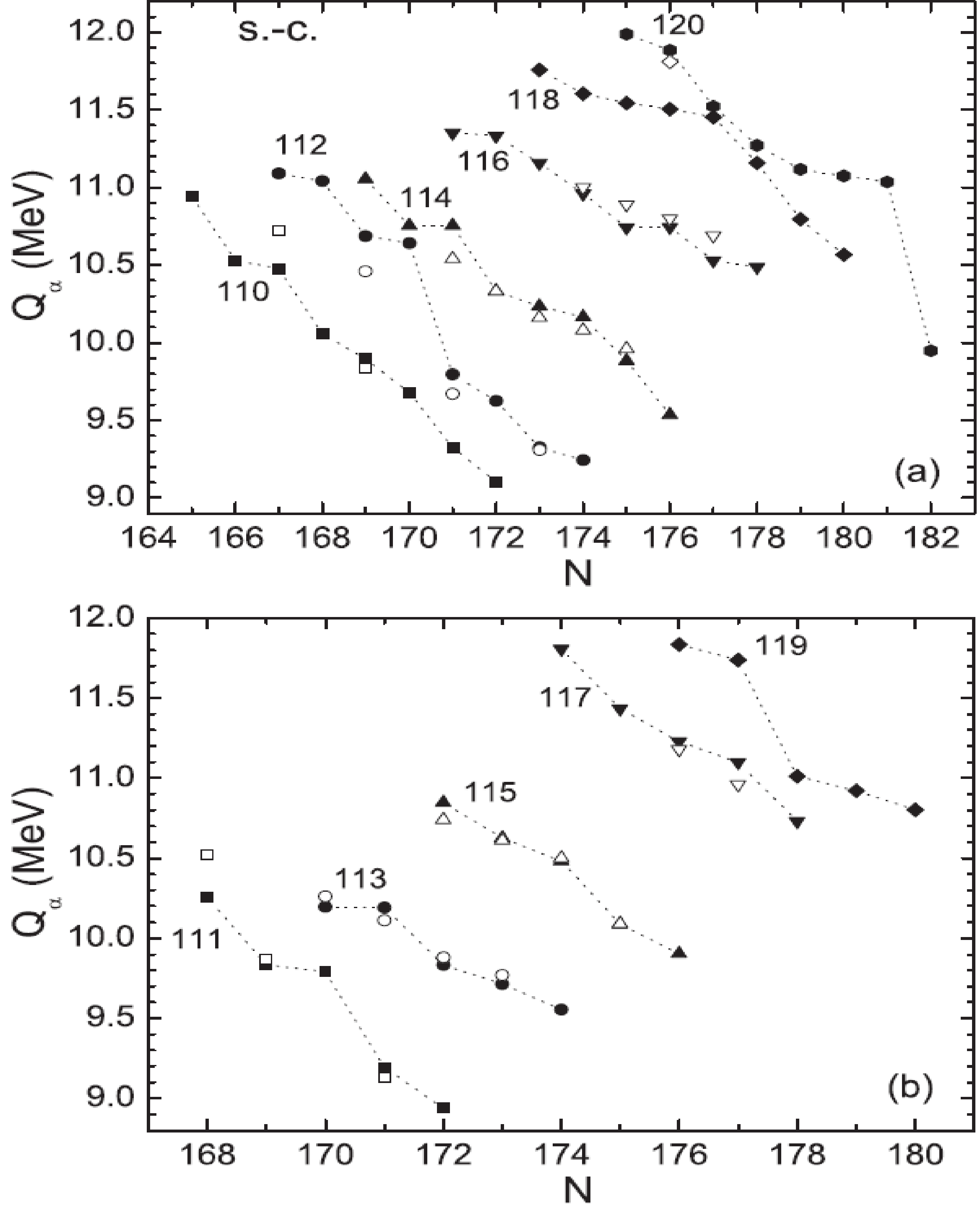
Self-Consistent Mean-Field Treatment

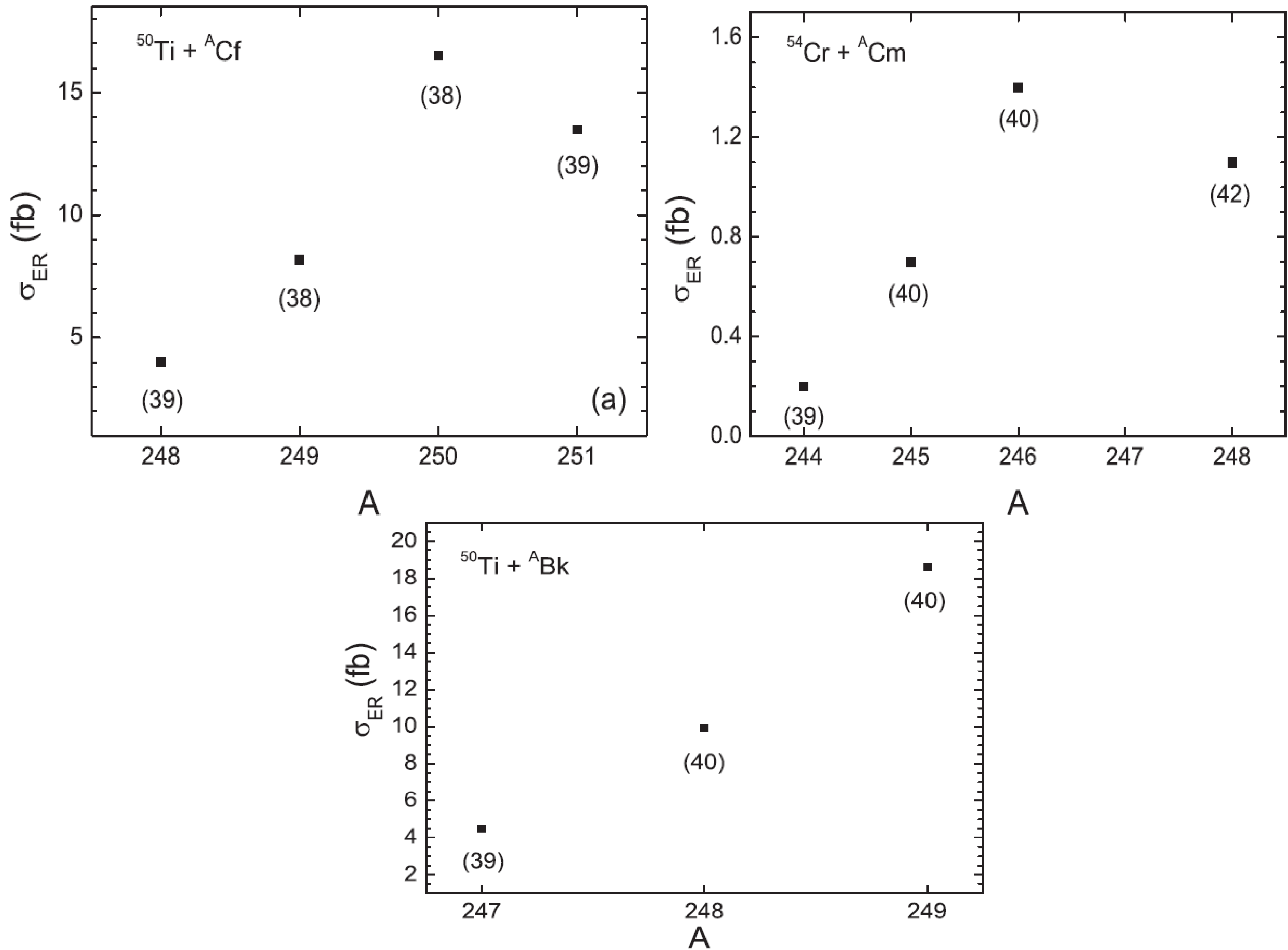


L.A. Malov et al.



0.5
0.4
0.3
0.2
0.1
σ_ER (pb)
50Ti + AU
(39)
(39)
(40)
235
236
237
238
A


s.-c.
120
118
116
114
112
110
Q_α (MeV)
N
(a)
119
117
115
113
111
(b)



^{50}Ti + ^{A}Cf
(a)
σ_ER (fb)
A
248
249
250
251
5
10
15
(39)
(38)
(38)
(39)
^{54}Cr + ^{A}Cm
0.0
0.4
0.8
1.2
1.6
244
245
246
247
248
(39)
(40)
(40)
(42)
^{50}Ti + ^{A}Bk
2
4
6
8
10
12
14
16
18
20
247
248
249
(39)
(40)
(40)