Oleg B. Tarasov *
NCSL / MSU, USA

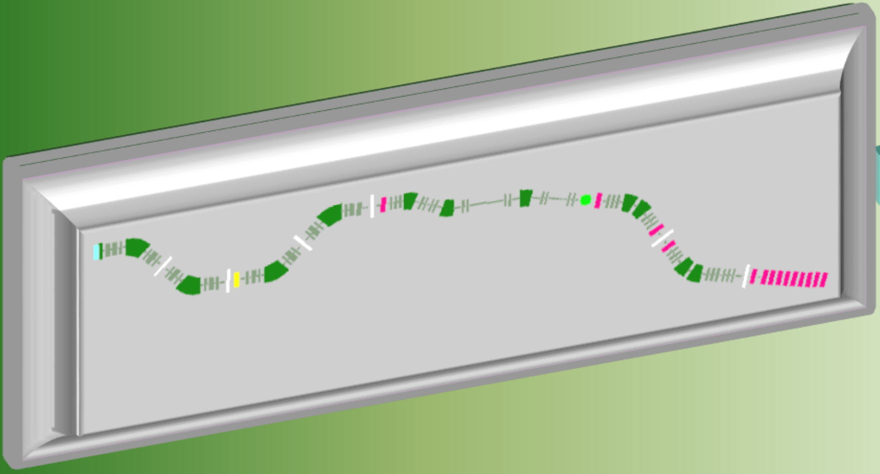
Projectile fragmentation as a tool to observe shell effects close to the neutron drip-line

EXON 2014, Kaliningrad

EXON 2014, Kaliningrad

09 / 8-13 / 2012

LISE++



LISE++

1. Introduction
    - EXON2009
    - EXON2012
2. “Calcium anomaly”
3. Abrasion-Ablation
4. More probable prefragments
5. dBE systematic
6. Summary

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* On leave from FLNR / JINR, Dubna

Introduction: Keywords of this experimental program

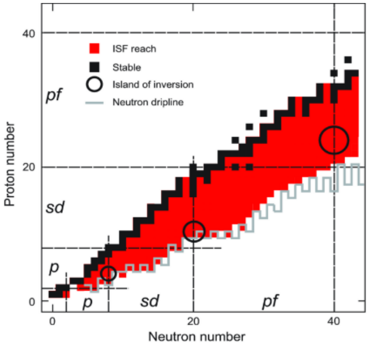
❑ Search for new isotopes

- ✓ **The limits of nuclear stability provide a key benchmark of nuclear models**
- ✓ **The context of astrophysics**
  - *Understanding the r-process abundance patterns of elements*

❑ Production mechanism

- ✓ **Production cross sections, Momentum distributions, Reaction choice**
- ✓ **Secondary beam intensities. Planning new experiments, set-ups (FRIB, RIBF, FAIR)**

❑ Nuclear structure



- ✓ **Changes in the structure of neutron-rich nuclei**
  - *Region around ^{31}Na is now known as the “island of inversion”*
  - *Deformation around neutron number N = 40 in Fe and Cr nuclei*
- ✓ **Shell closures at *N*=32 and *N*=34**
  - *Masses of exotic calcium isotopes pin down nuclear forces (^{53,54}Ca)*
    F. Wienholtz et al., Nature 498 (2013) 346
  - *Evidence for a new nuclear ‘magic number’ from the level structure of ^{54}Ca*
    D. Steppenbeck et al., Nature 502 (2013) 207

These measurements of the Ex(2^+_1) in ^{54}Ca at RIKEN found that the experimental value is 0.5 MeV smaller than the prediction of the full *pf* shell-model space with the GXPF1B effective interaction.

GXPF1B: Y. Utsuno, T. Otsuka, B. A. Brown, M. Honma, T. Mizusaki, and N. Shimizu,
PRC 86, 051301(R) (2012) ; GXPF1B5 – modified GXPF1B for 0.5 MeV shift

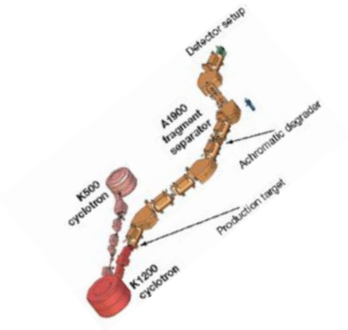
O.Tarasov@exon2014.ru

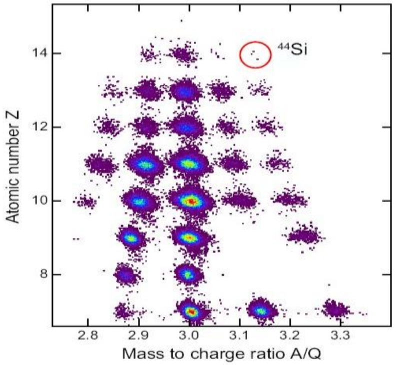
EXON 2009 :

Production of new isotopes → Two stage separation
Production cross sections → Q_g- systematics

O.T. et al., Phys.Rev. C 75, 064613 (2007)

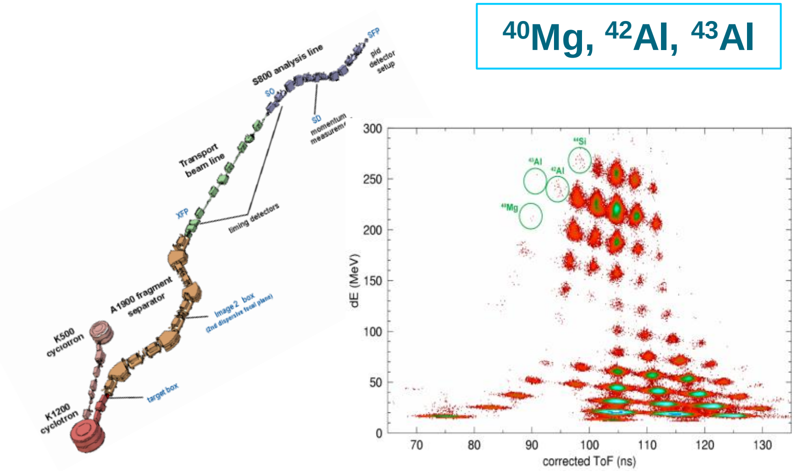
^{44}Si



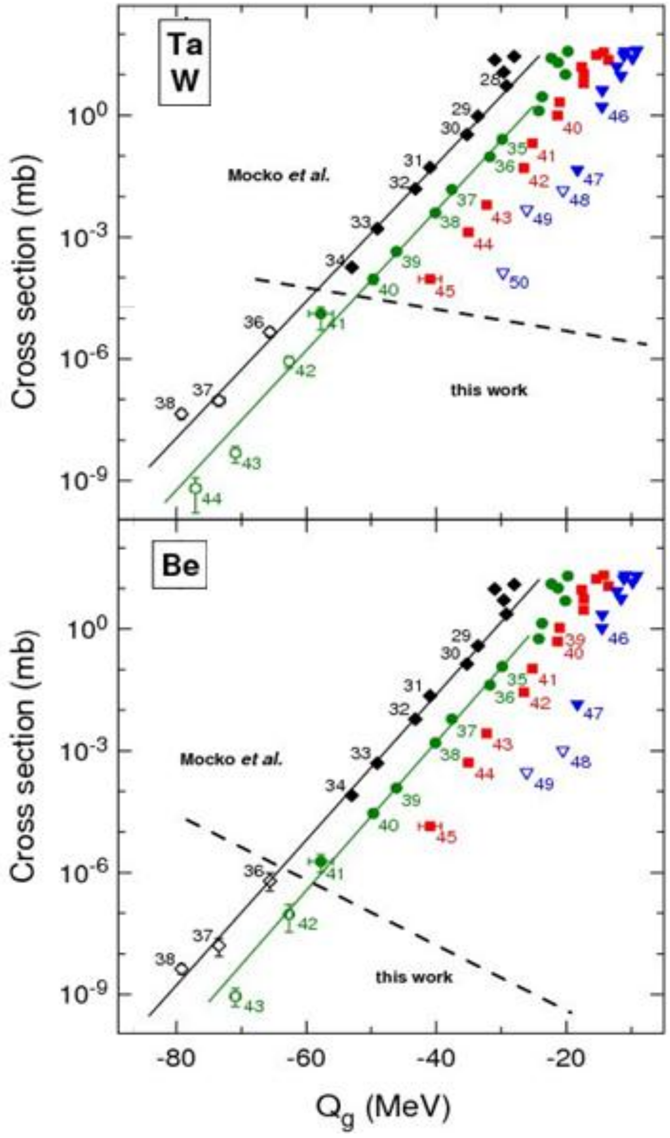


T.Baumann et al.,Nature (London) 449, 1022 (2007)

^{40}Mg, ^{42}Al, ^{43}Al



$$Q_g = ME(Z=20, A=48) - ME(Z,A)$$



^{48}Ca(140MeV/u) + W,Be

O.T. et al., Phys.Rev. C 75, 064613 (2007)

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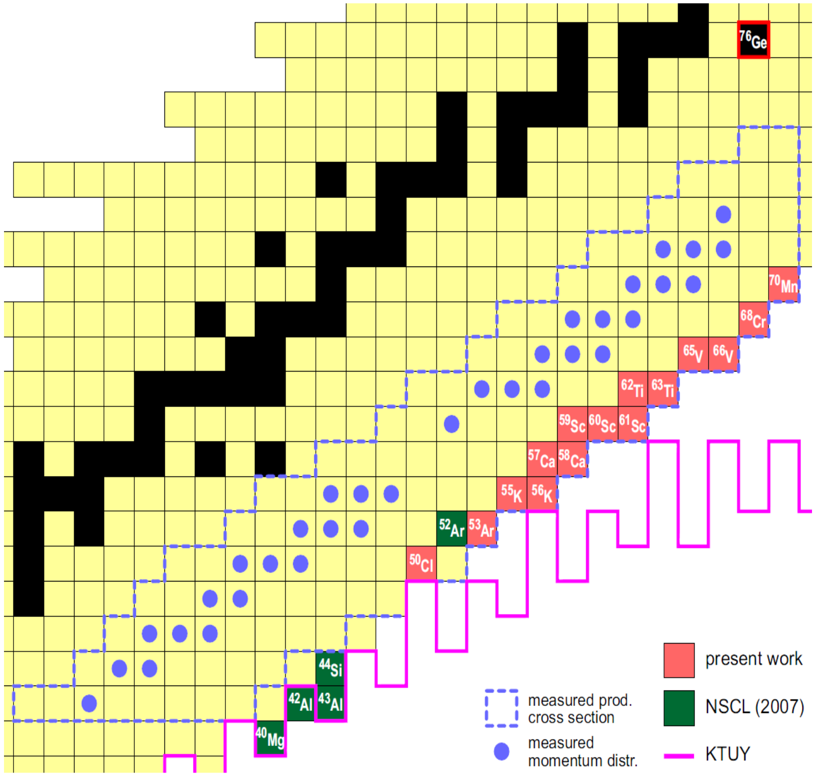
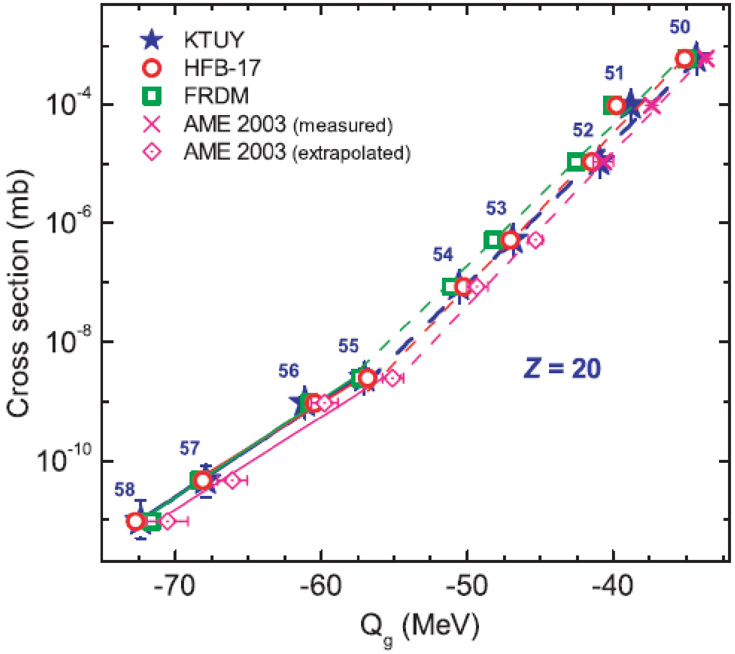
EXON 2009 :

^{76}Ge (130 MeV/u) → new isotopes, CS, momentum distributions
Q_g systematics → Possible new island of inversion ?

^{50}Cl, ^{53}Ar, ^{55,56}K, ^{57,58}Ca, ^{59,60,61}Sc,
^{62,63}Ti, ^{65,66}V, ^{68}Cr, ^{70}Mn





Enhanced cross sections might be the result of increased binding

This region (around ^{62}Ti) was previously predicted to be a new island of inversion
B. A. Brown Prog. Part. Nucl. Phys. 47 (2001) 517

Phys.Rev.Lett. 102, 142501 (2009) :	New isotopes, Evidence for a Change in the Nuclear Mass Surface
Phys.Rev.C. 80, 034609 (2009) :	Set-up, cross sections, momentum distributions
NIM A 620, 578-584 (2010) :	A new approach to measure momentum distributions

EXON 2012 : ^{82}Se (139 MeV/u) → new isotopes, CS, momentum distributions Q_g systematics → Confirmation of Calcium anomaly

So, what is “Calcium anomaly” ?
Reaction property or
Nuclear structure feature?

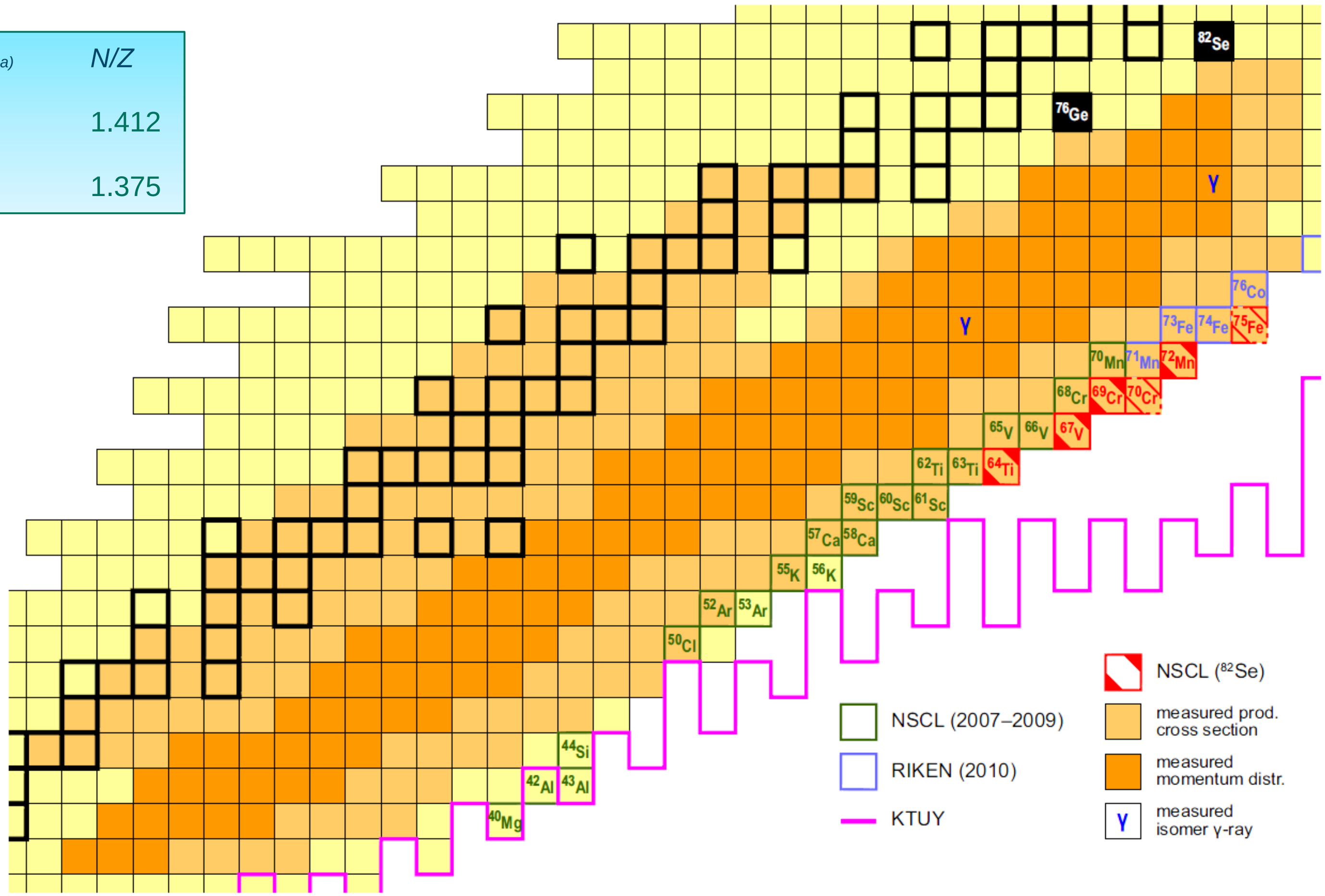
It should be checked with another beam

Beam	*E (MeV/u)*	*I (pna)*	*N/Z*
^{82}Se	139	35	1.412
^{76}Ge	130	20	1.375

$\Delta N / \Delta Z = 2$

^{64}Ti, ^{67}V, ^{69}Cr, ^{72}Mn
^{70}Cr 1event **& ^{75}Fe** 1event

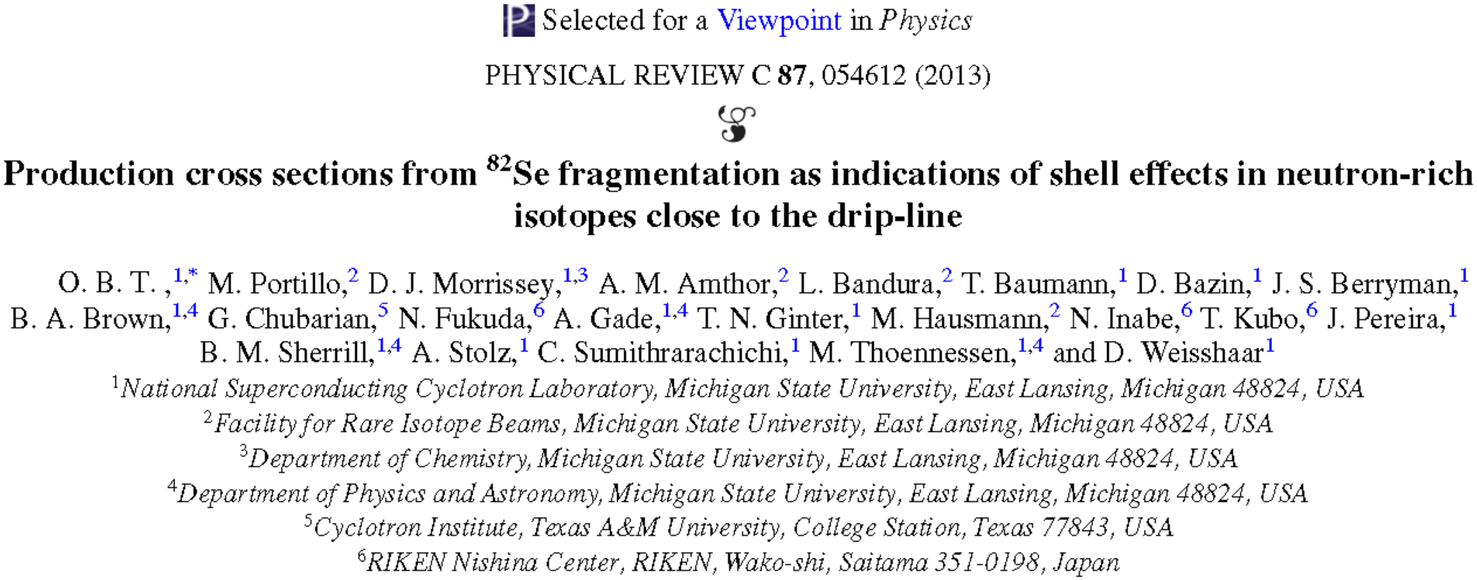
$N(\sigma_W) = 90$
$N(\sigma_{Be}) = 330$
$N(d\sigma/dp) = 126$



Confirmation of the Calcium anomaly…. Without explanation

O.Tarasov@exon2014.ru

2013 : Calcium anomaly as shell effects close to drip line


Selected for a Viewpoint in *Physics*

PHYSICAL REVIEW C **87**, 054612 (2013)

Production cross sections from ^{82}Se fragmentation as indications of shell effects in neutron-rich isotopes close to the drip-line

O. B. T. ,[1,*] M. Portillo,[2] D. J. Morrissey,[1,3] A. M. Amthor,[2] L. Bandura,[2] T. Baumann,[1] D. Bazin,[1] J. S. Berryman,[1]
B. A. Brown,[1,4] G. Chubarian,[5] N. Fukuda,[6] A. Gade,[1,4] T. N. Ginter,[1] M. Hausmann,[2] N. Inabe,[6] T. Kubo,[6] J. Pereira,[1]
B. M. Sherrill,[1,4] A. Stolz,[1] C. Sumithrarachichi,[1] M. Thoennessen,[1,4] and D. Weisshaar[1]
[1]*National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*
[2]*Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, USA*
[3]*Department of Chemistry, Michigan State University, East Lansing, Michigan 48824, USA*
[4]*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA*
[5]*Cyclotron Institute, Texas A&M University, College Station, Texas 77843, USA*
[6]*RIKEN Nishina Center, RIKEN, Wako-shi, Saitama 351-0198, Japan*

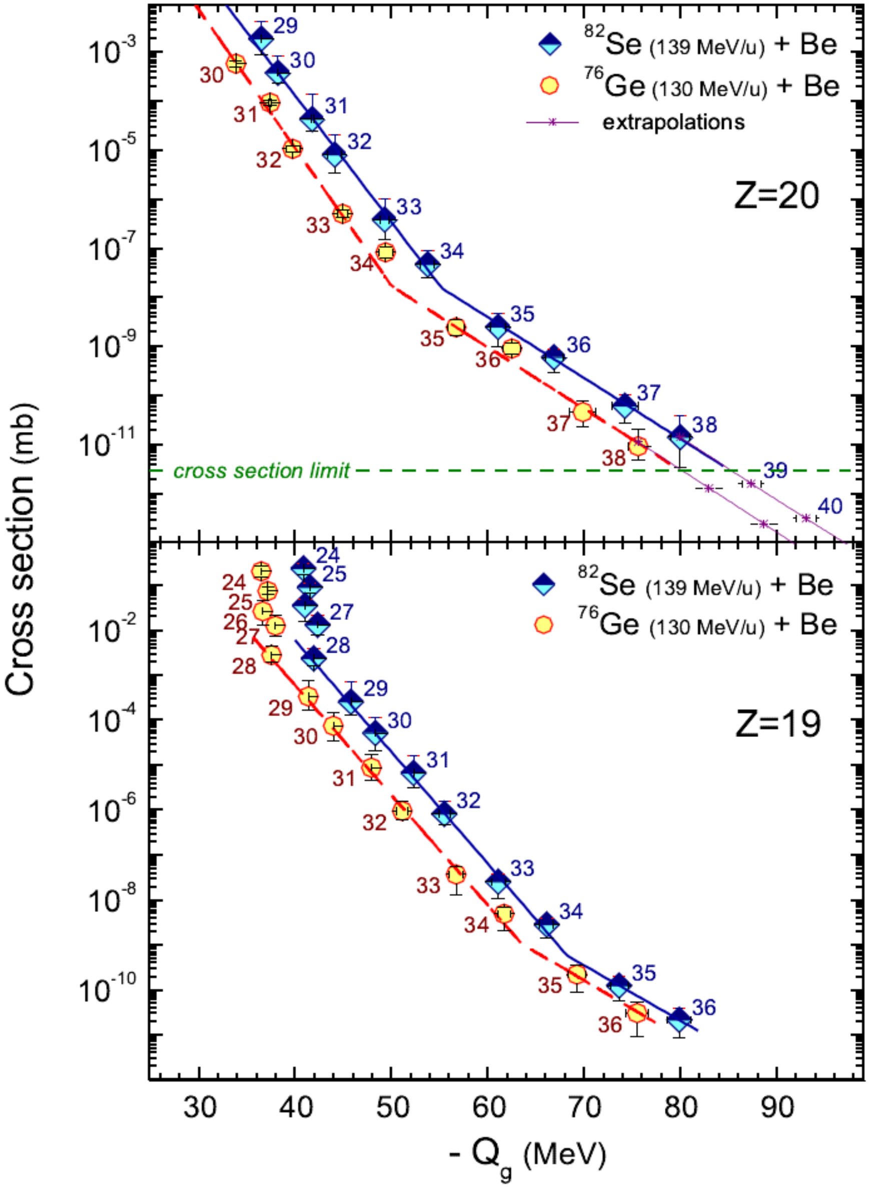
The measured cross sections were best reproduced by using masses derived from the full pf shell-model space with the GXPF1B5 [1] effective interaction modified to a recent ^{54}Ca $E_x(2^+_1)$ measurement [2].

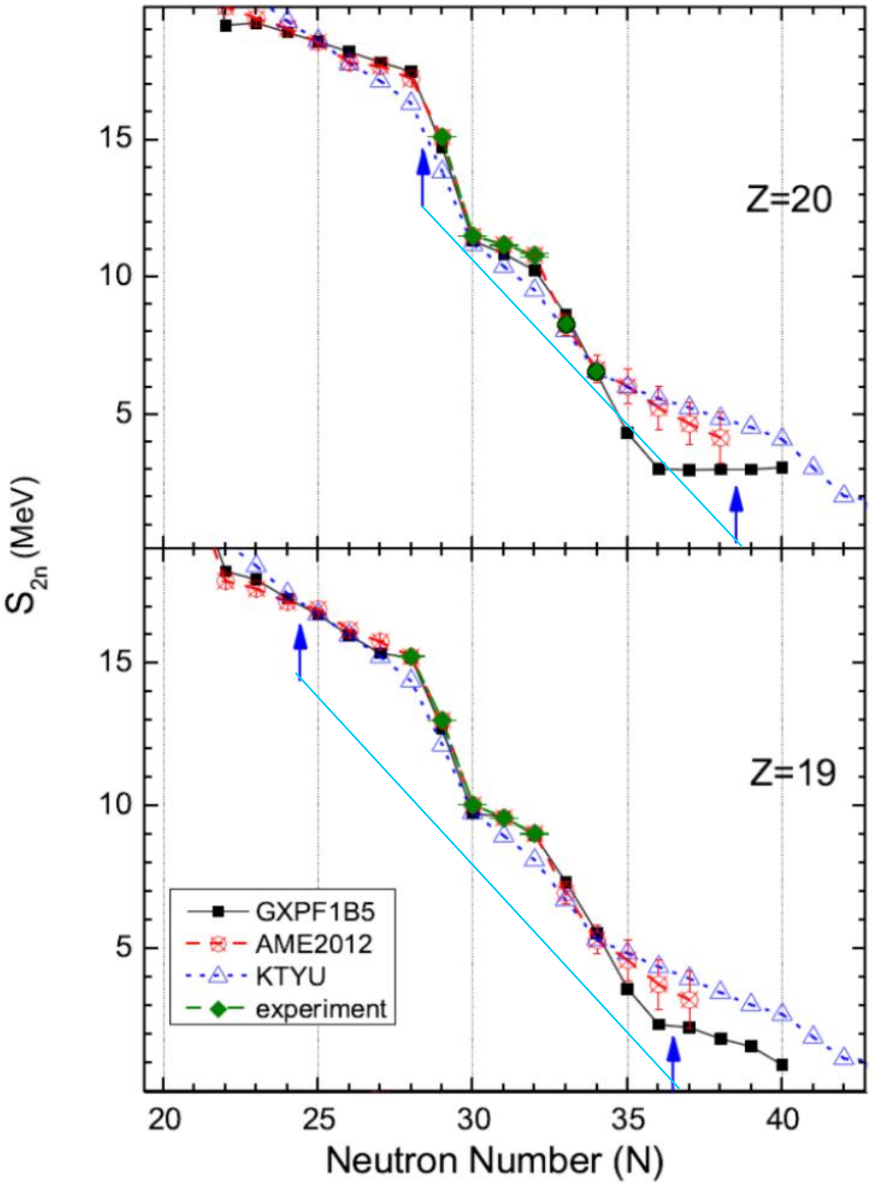
The “Calcium anomaly” can be explained with a shell model that predicts a subshell closure at $N = 34$ around $Z = 20$.

[1] M. Honma, T. Otsuka, B. A. Brown, and T. Mizusaki, Eur. Phys. J. A 25, Suppl. 1, 499 (2005)
[2] D. Steppenbeck et al., Nature 502, 207 (2013)

O.Tarasov@exon2014.ru

Q_g systematics, Two-neutron separation energy





Experimental masses:
A.T. Gallant et al., Phys. Rev. Lett. 109, 032506 (2012)
F. Wienholtz et al., Nature 498 (2013) 346

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Global trends of cross sections

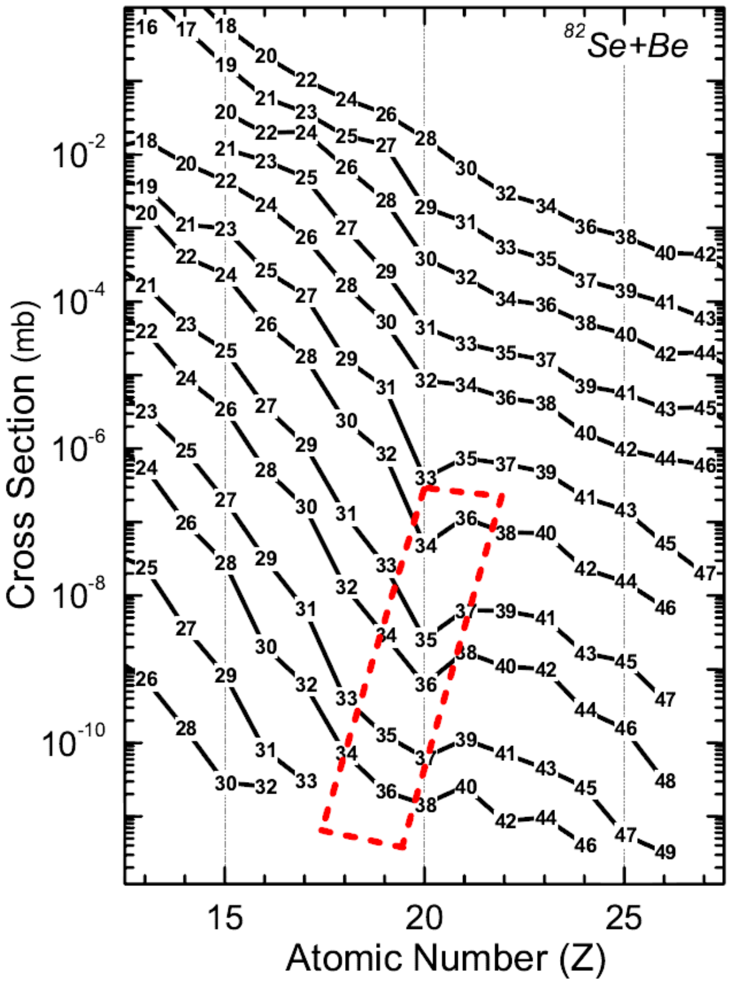


FIG. Production cross section versus atomic number (Z) for fragments from reaction of ^{82}Se with beryllium targets. **Lines are connected according to constant $N - 2Z$**, while labels represent the neutron number.

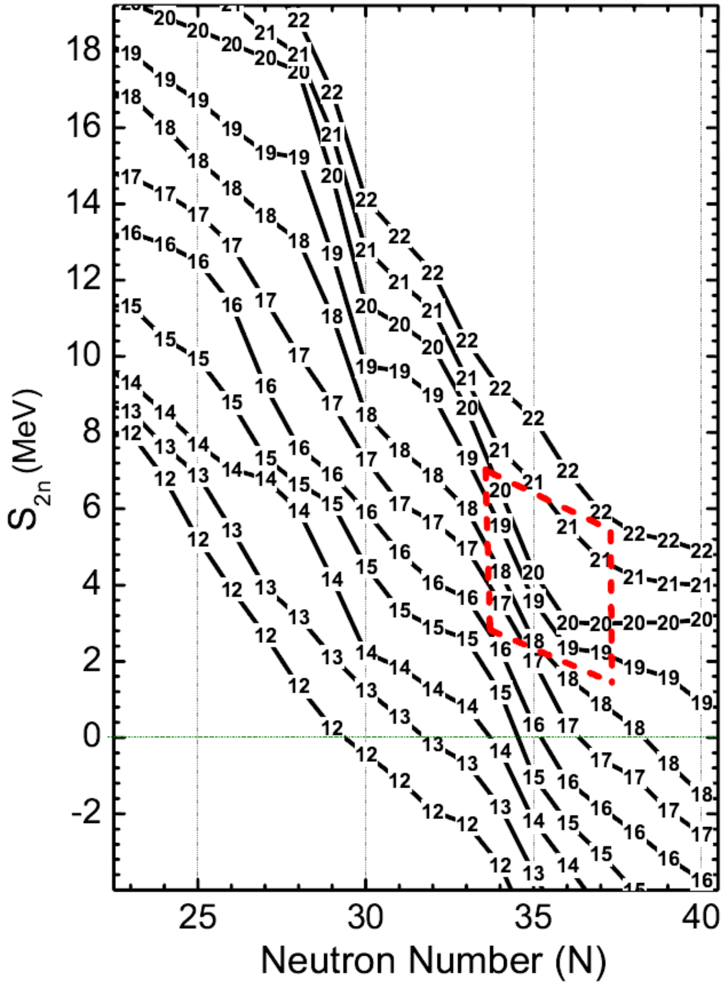
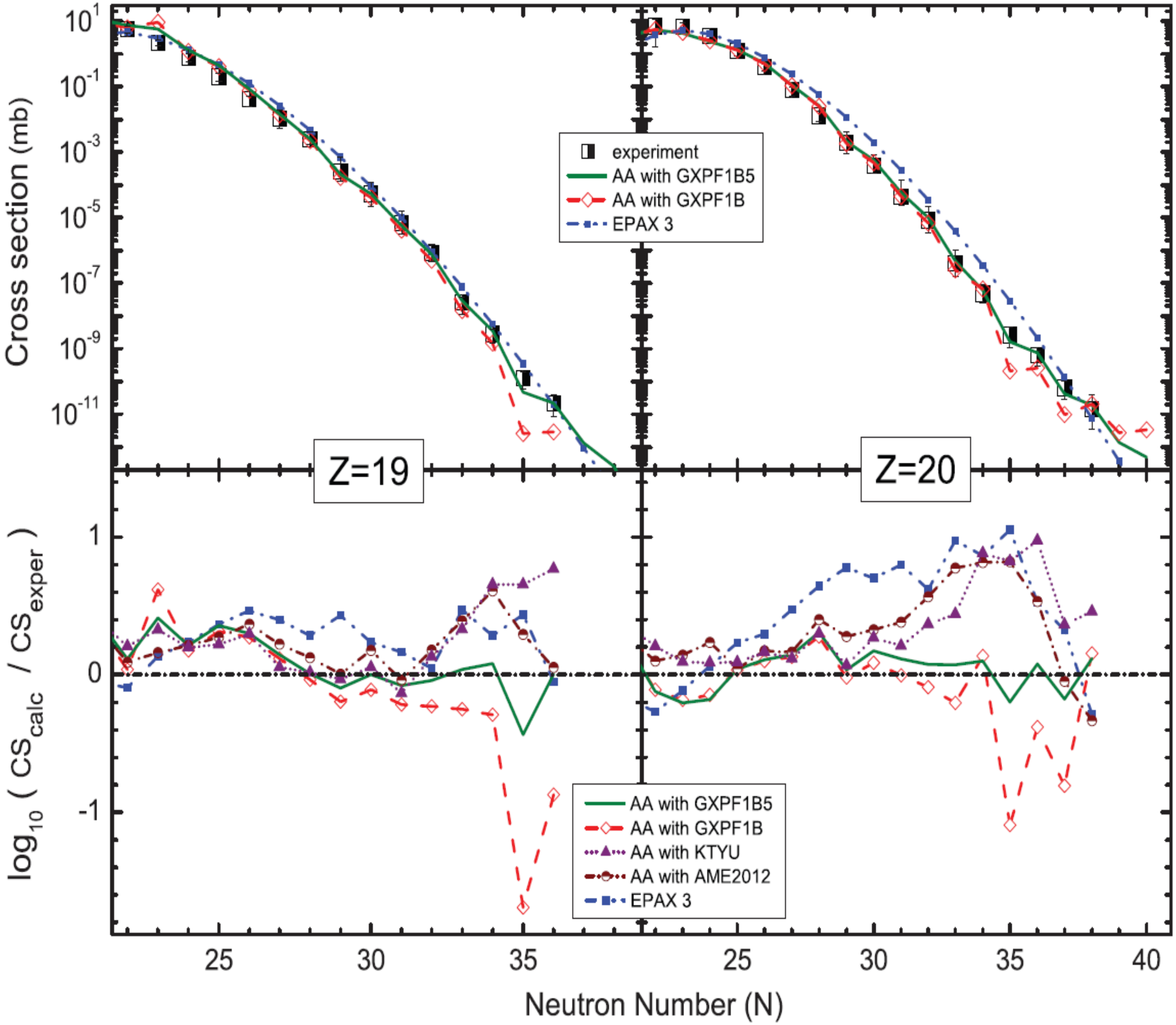


FIG. Two-neutron separation energy S_{2n} versus neutron number (N) for elements $12 \leq Z \leq 22$. Values are calculated using results from the GXPF1B5 model. Labels in the lines show atomic numbers of nuclei.

No such dump with other theoretical models

O.Tarasov@exon2014.ru

LISE^{++} Abrasion-Ablation model



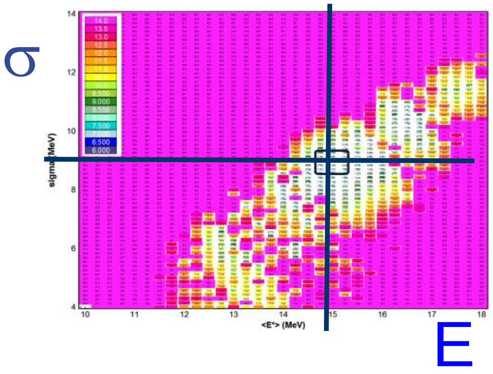
The Abrasion-Ablation model is very sensitive to the input mass values for the most exotic nuclei.

Different mass models as

- HFB9,
- HBF17,
- KTYU
- TUYY
- AME2003
- AME2012
- GXPF1B,
- GXPF1B5

were used in LISE^{++} Abrasion-Ablation excitation energy minimization procedures to compare with the experimental data

Abrasion-Ablation: Excitation energy

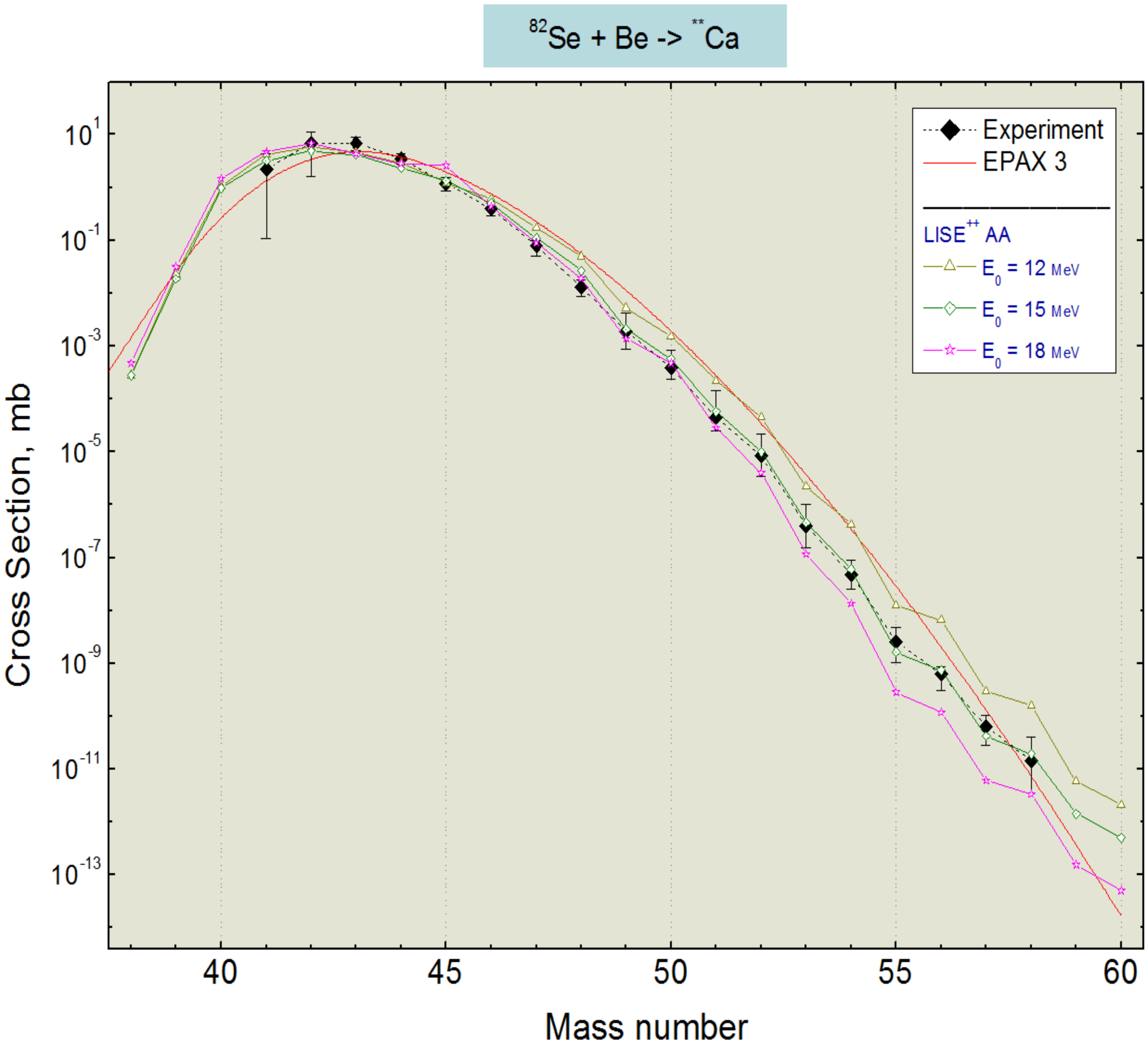


The best result to describe the experimental data of isotopes of elements 16<Z<24 has been obtained with GXPF1B5 (+ LDM0) at E*=15.0 (σ=9.15) MeV

GSI:

^{40}Ar beam:
<E>= 13.3 MeV
NPA 531 ,709 (1991)

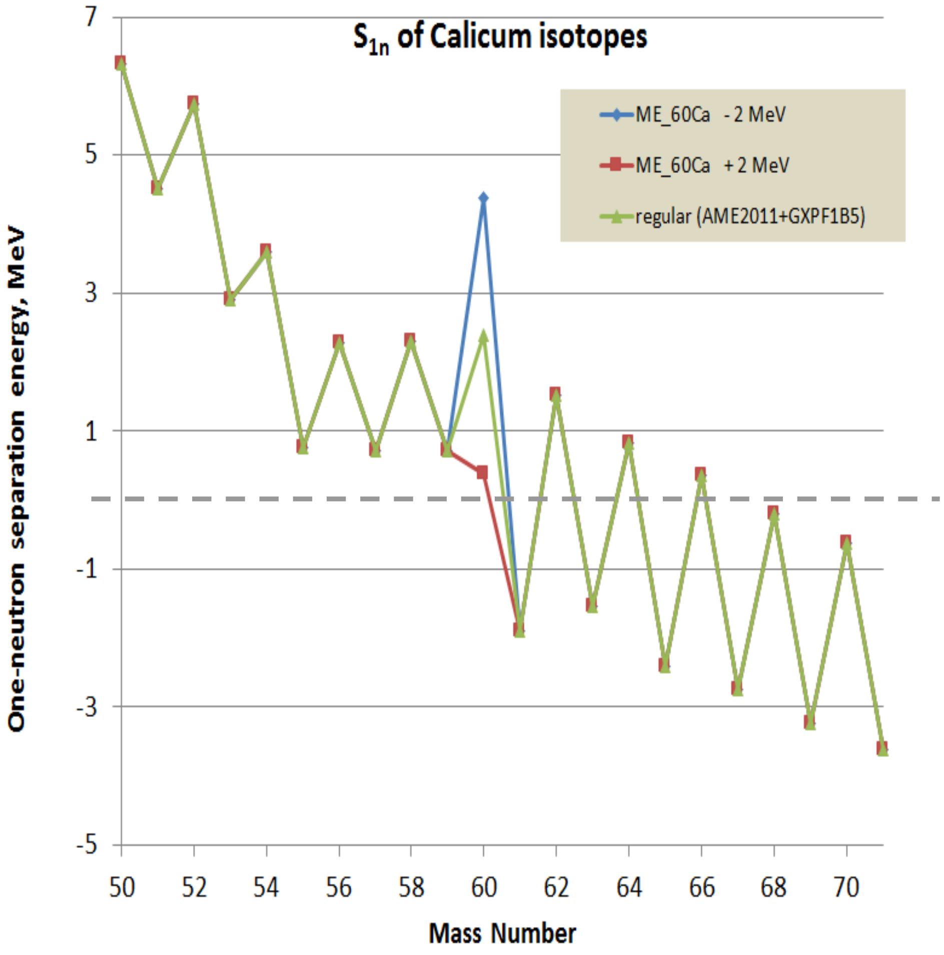
^{238}U beam:
<E>= 27 MeV (K.H.S.)

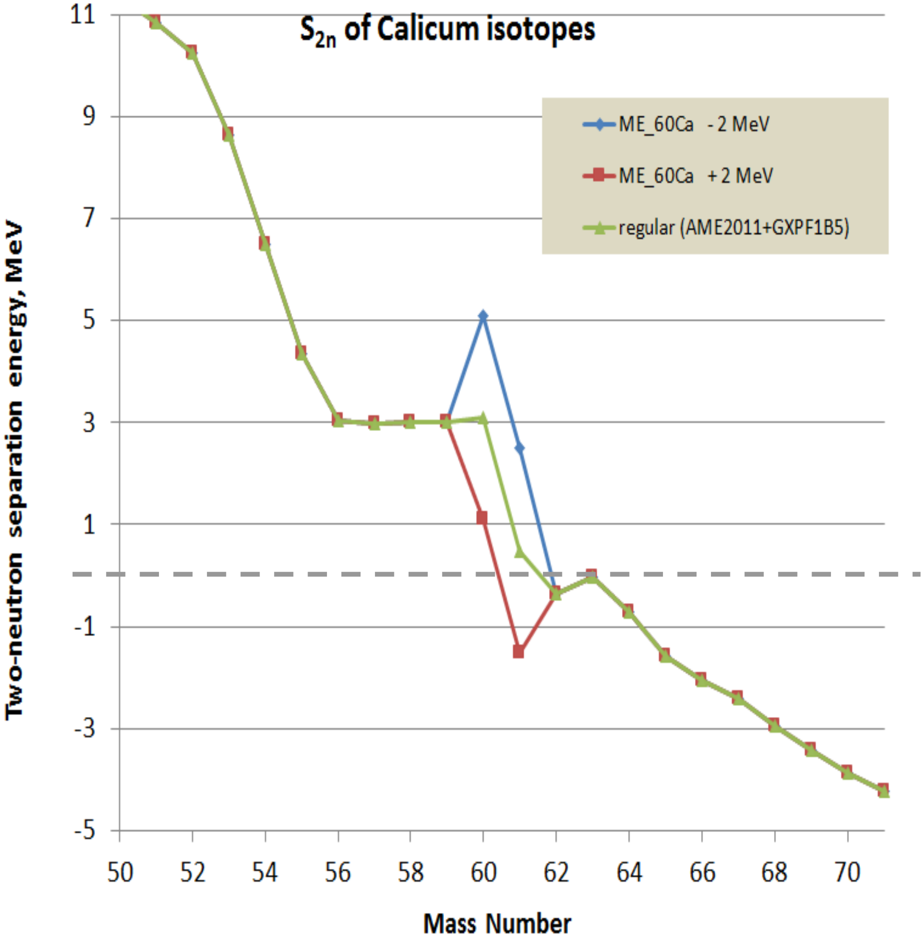


Varying masses for Abrasion-Ablation benchmarks

Let's increase (decrease) ^{60}Ca and heavier isotopes mass excesses by 2 MeV

(or decreased [increased] neutron separation energies)





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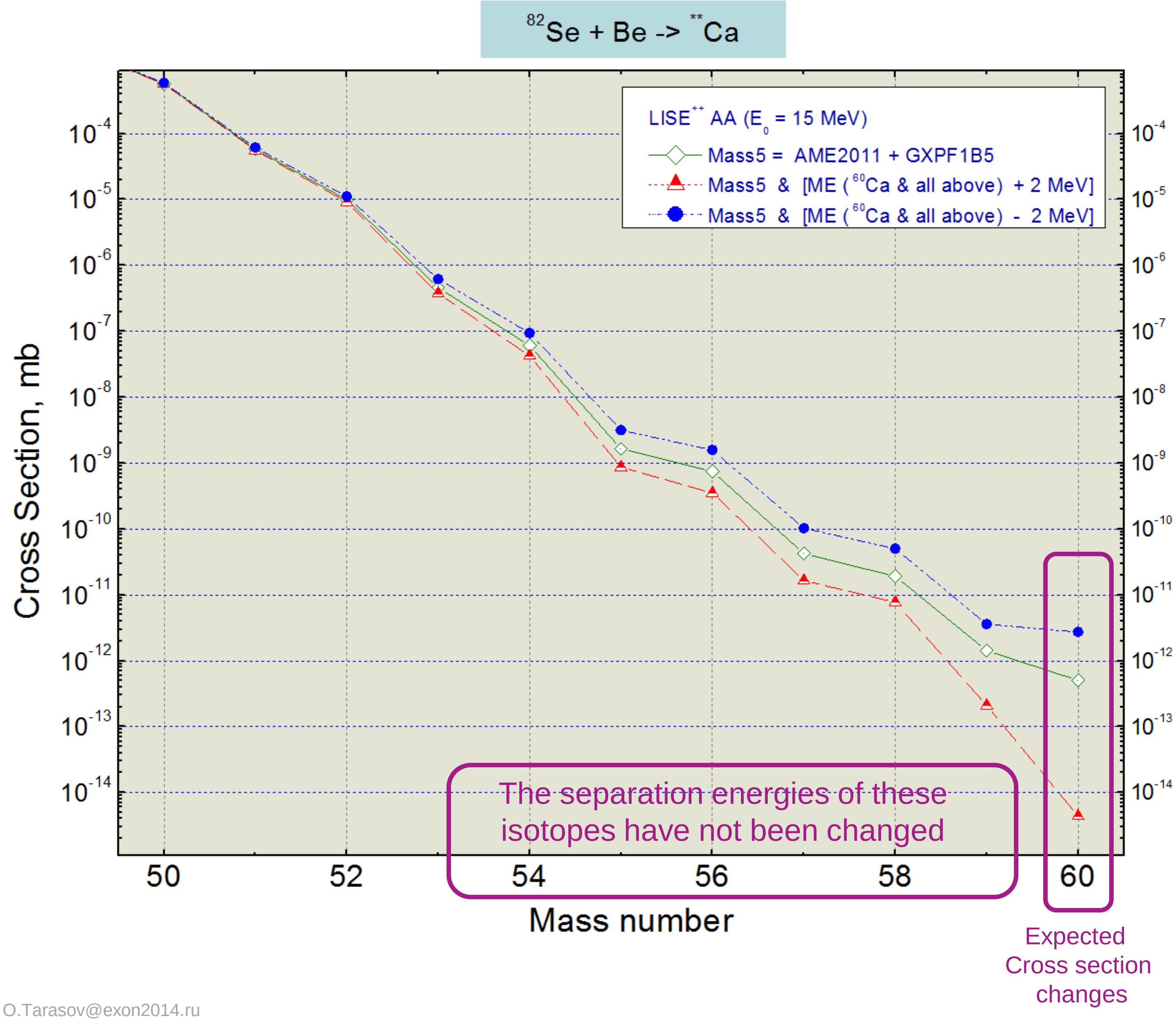
Influence of de-excitation chain precedent isotopes masses on "daughters" production cross sections



The separation energies of these isotopes have not been changed

Expected Cross section changes

1. Separation energy changes influence drastically of cross section close to the drip-line (this ^{60}Ca example)
2. **Residue cross section depends how <u>much bound are preceding isotopes</u>**
3. Deviations in cross sections are not just indicators for local low separation energies (as ^{31}Ne, ^{37}Mg), but also might provide information about shell effects close to the neutron drip-line

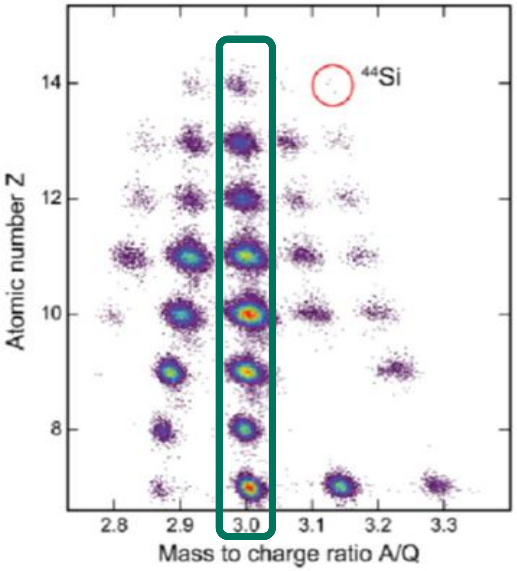
O.Tarasov@exon2014.ru

Oxygen “anomaly”

NSCL/MSU

^{48}Ca (140 MeV/u) + Ta

O.T. et al., *Phys.Rev. C 75, 064613 (2007)*

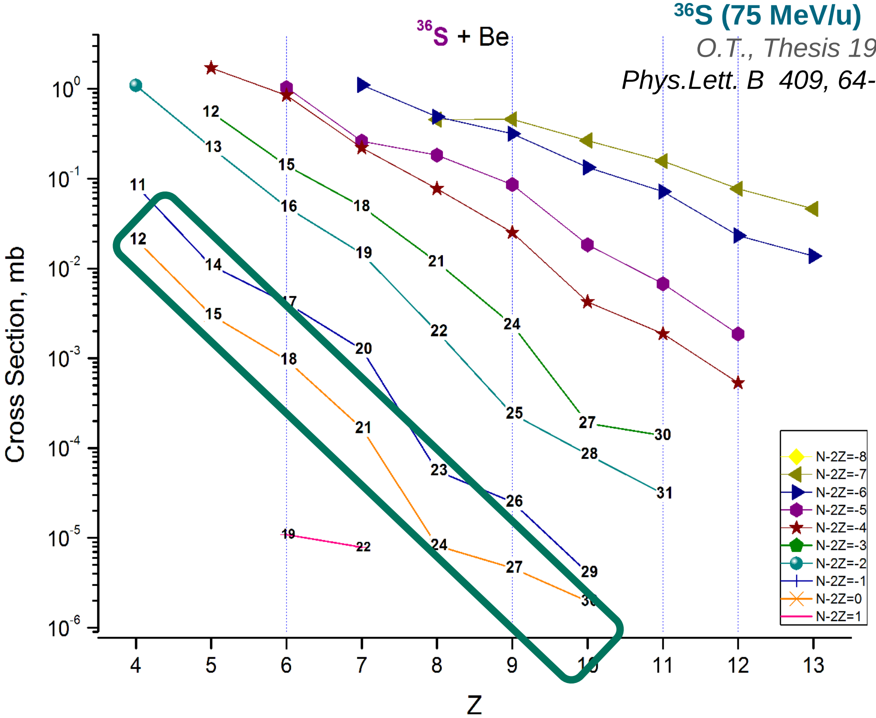


GANIL

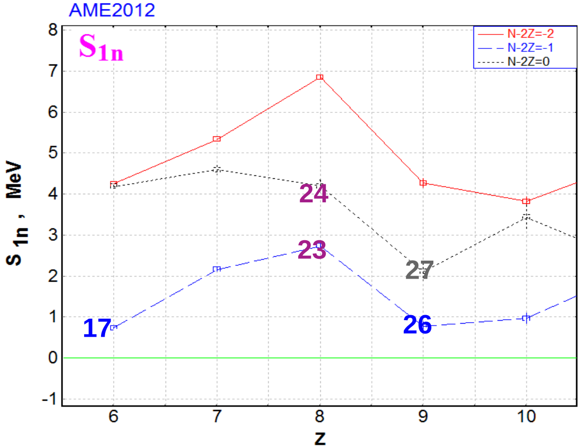
^{36}S (75 MeV/u) + Be

O.T., Thesis 1999,

Phys.Lett. B 409, 64-70 (1997)

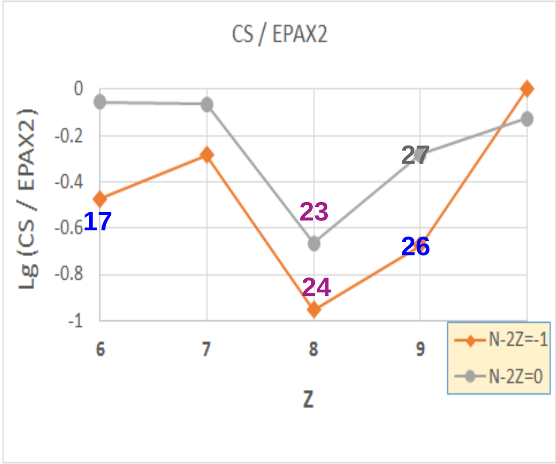


Oxygen isotopes are more particle bound



?

Oxygen isotopes are less produced



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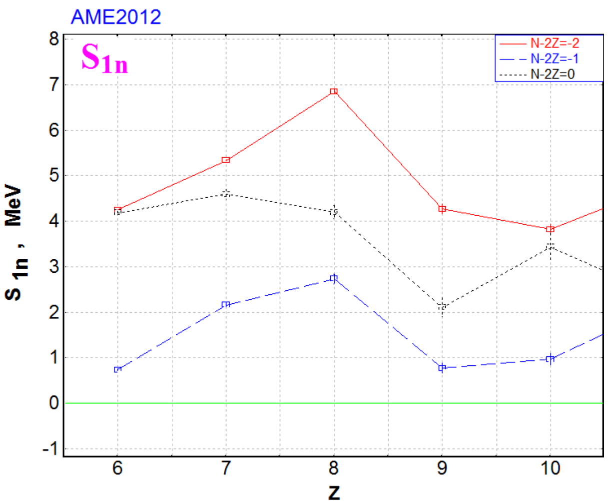
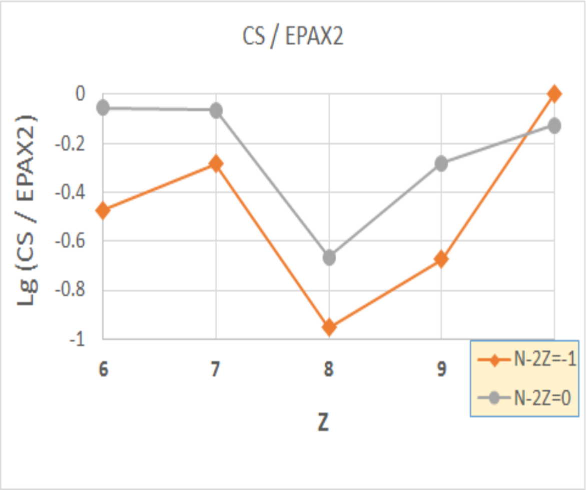
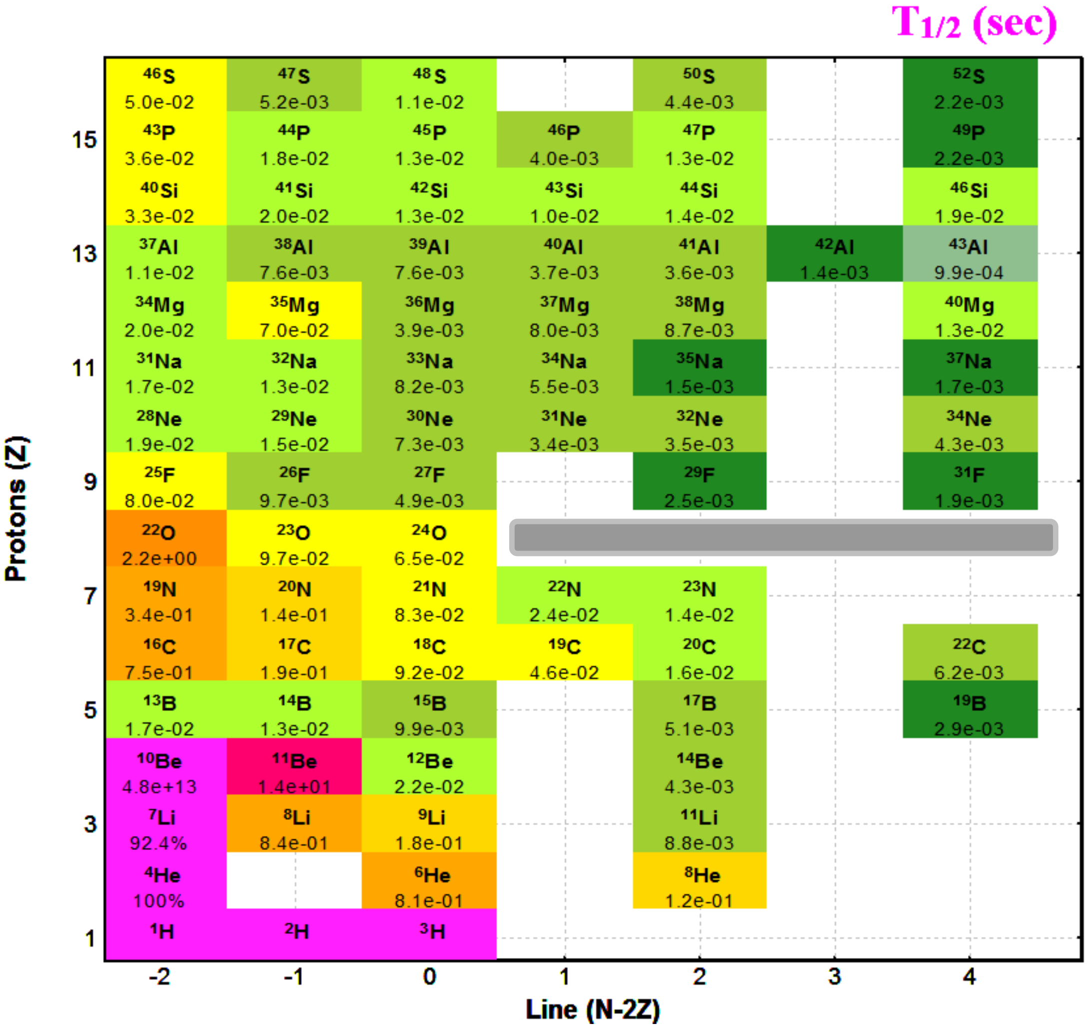
Oxygen “anomaly” : no particle-bound isotopes above ^{24}O



Oxygen isotopes are
more particle bound,
but less produced !?





T1/2 (sec)

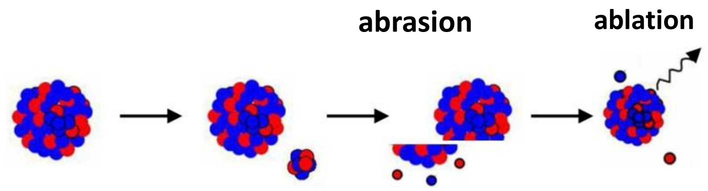
Protons (Z)	-2	-1	0	1	2	3	4
	^{46}S 5.0e-02	^{47}S 5.2e-03	^{48}S 1.1e-02		^{50}S 4.4e-03		^{52}S 2.2e-03
15	^{43}P 3.6e-02	^{44}P 1.8e-02	^{45}P 1.3e-02	^{46}P 4.0e-03	^{47}P 1.3e-02		^{49}P 2.2e-03
	^{40}Si 3.3e-02	^{41}Si 2.0e-02	^{42}Si 1.3e-02	^{43}Si 1.0e-02	^{44}Si 1.4e-02		^{46}Si 1.9e-02
13	^{37}Al 1.1e-02	^{38}Al 7.6e-03	^{39}Al 7.6e-03	^{40}Al 3.7e-03	^{41}Al 3.6e-03	^{42}Al 1.4e-03	^{43}Al 9.9e-04
	^{34}Mg 2.0e-02	^{35}Mg 7.0e-02	^{36}Mg 3.9e-03	^{37}Mg 8.0e-03	^{38}Mg 8.7e-03		^{40}Mg 1.3e-02
11	^{31}Na 1.7e-02	^{32}Na 1.3e-02	^{33}Na 8.2e-03	^{34}Na 5.5e-03	^{35}Na 1.5e-03		^{37}Na 1.7e-03
	^{28}Ne 1.9e-02	^{29}Ne 1.5e-02	^{30}Ne 7.3e-03	^{31}Ne 3.4e-03	^{32}Ne 3.5e-03		^{34}Ne 4.3e-03
9	^{25}F 8.0e-02	^{26}F 9.7e-03	^{27}F 4.9e-03		^{29}F 2.5e-03		^{31}F 1.9e-03
	^{22}O 2.2e+00	^{23}O 9.7e-02	^{24}O 6.5e-02				
7	^{19}N 3.4e-01	^{20}N 1.4e-01	^{21}N 8.3e-02	^{22}N 2.4e-02	^{23}N 1.4e-02		
	^{16}C 7.5e-01	^{17}C 1.9e-01	^{18}C 9.2e-02	^{19}C 4.6e-02	^{20}C 1.6e-02		^{22}C 6.2e-03
5	^{13}B 1.7e-02	^{14}B 1.3e-02	^{15}B 9.9e-03		^{17}B 5.1e-03		^{19}B 2.9e-03
	^{10}Be 4.8e+13	^{11}Be 1.4e+01	^{12}Be 2.2e-02		^{14}Be 4.3e-03		
3	^{7}Li 92.4%	^{8}Li 8.4e-01	^{9}Li 1.8e-01		^{11}Li 8.8e-03		
	^{4}He 100%		^{6}He 8.1e-01		^{8}He 1.2e-01		
1	^{1}H	^{2}H	^{3}H				

Line (N-2Z)

- No particle bound preceding isotopes of the same element, So “excitation energy train” cannot be slow down
- Absence of excited bound states?

O.Tarasov@exon2014.ru

Details on Abrasion-Ablation



Projectile ^{82}Se

Target ^{9}Be

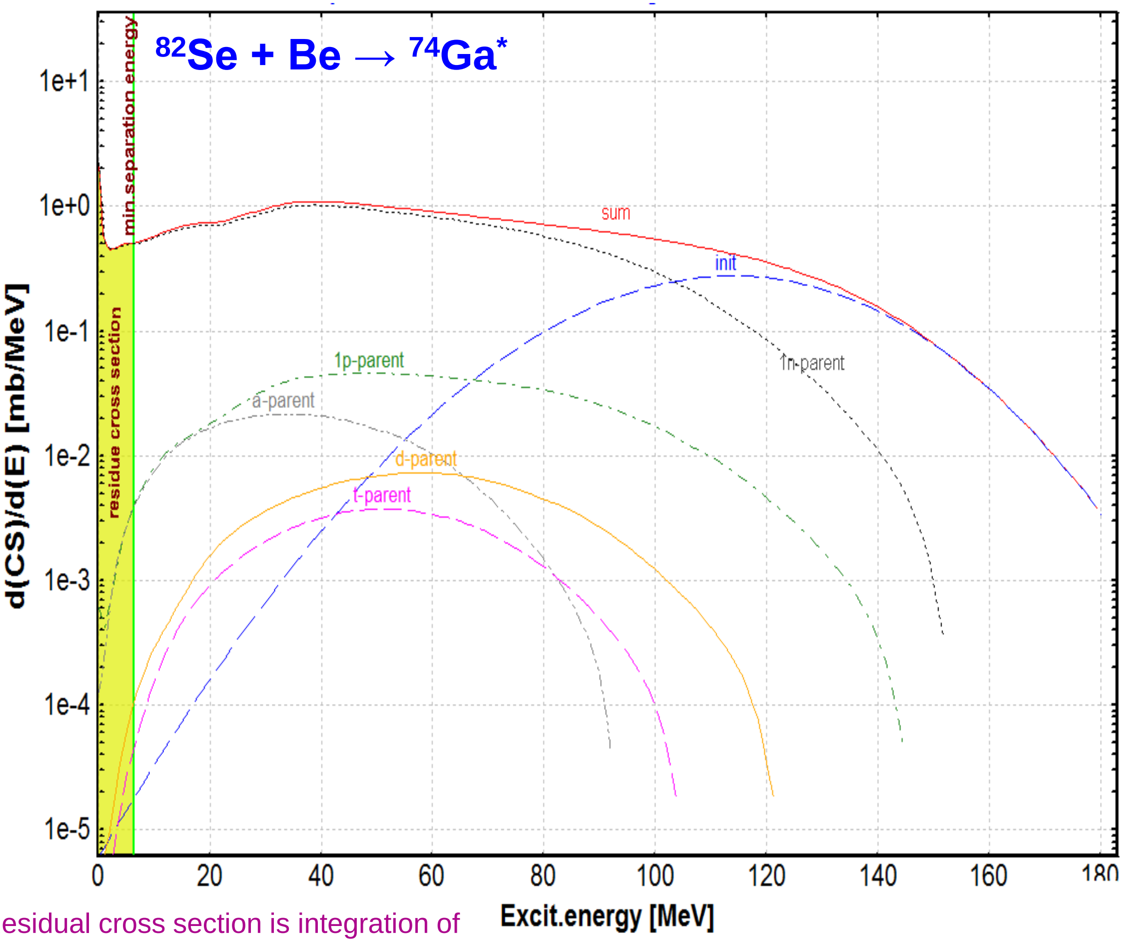
Initial prefragment ^{68}Ti*

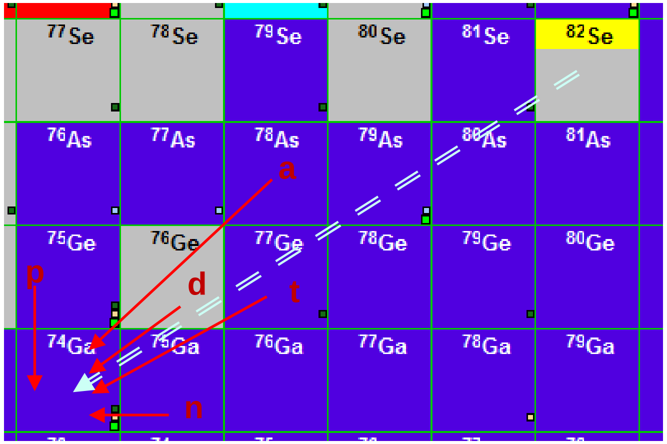
Final fragment ^{54}Ca

- The LISE^{++} AA model is initially based on the version of J.-J.Gaimard and K.H.Schmidt, NPA531 (1991) 709
- The LISE^{++} AA model is analytical, that allows to calculate low cross sections of very exotic nuclei
- The Abrasion-Ablation approach meets three principal difficulties
    a. *Determination of Excitation energy parameters (models) for each reaction*
    b. *Plenty of other parameters*
    c. *Suggesting negligible contribution of dissipation processes during abrasion (it can be true at high energies with light targets)*

- Four excitation energy models are implanted in the code
- The Ablation step (Evaporation cascade) uses a mass table to obtain separation energies

LISE^{++} Abrasion-Ablation: Input channels





Residual cross section is integration of the excitation function from 0 to the minimum of separation energy

1. Largest incoming contribution to the Total excitation function is 1n-channel
2. Largest incoming contribution to the Residue cross section is 1n-channel

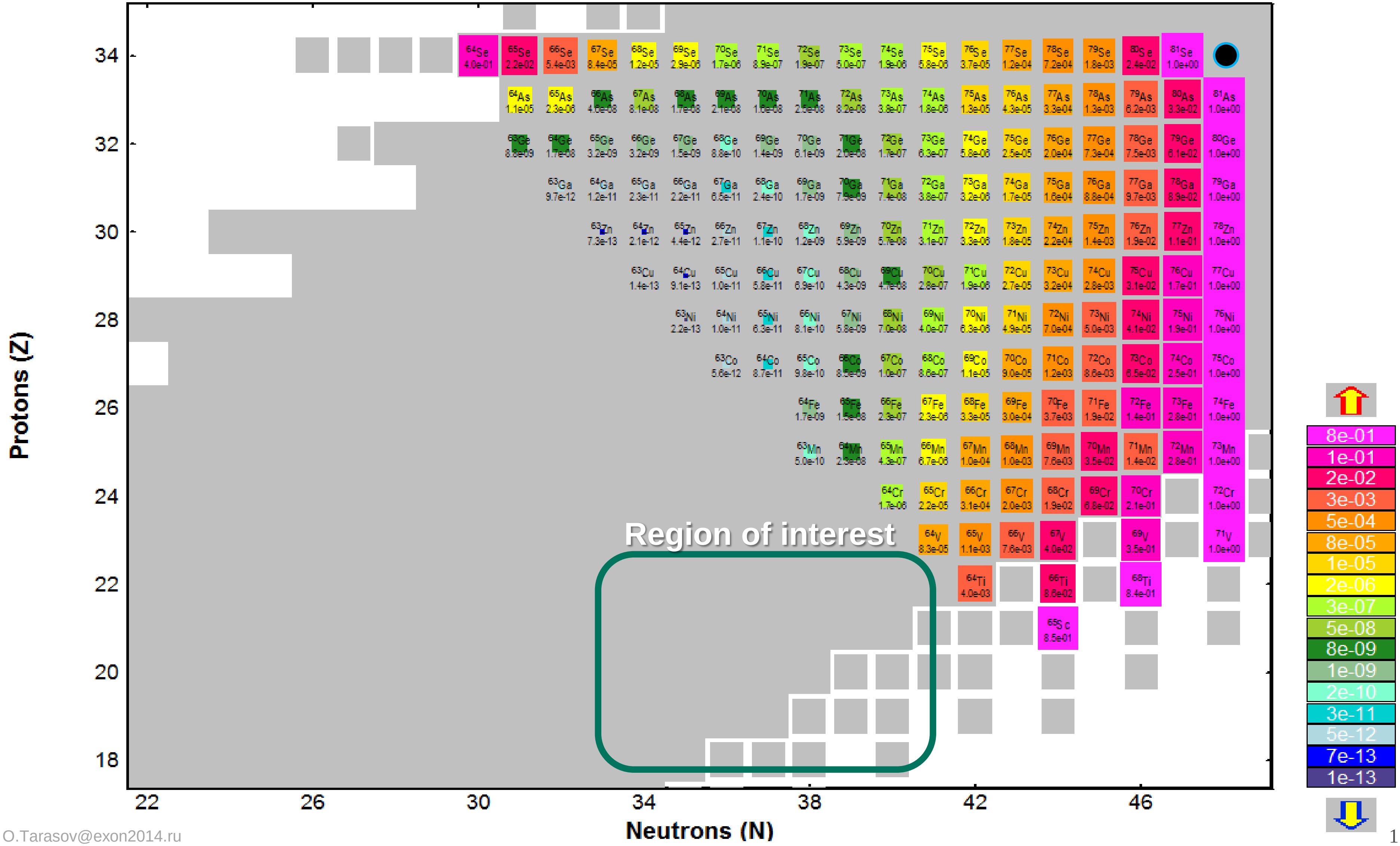
LISE^{++} Abrasion-Ablation: Decay Analysis

Current mode: Initial CS -> [S residue] / [Sr total]

ABRASION-ABLATION - ^{82}Se + Be

Excit.Energy Method:< 2 >; <E*>:15.0*dA MeV Sigma:9.15; Coef$^{\text{Thermalization}}$=5.00e-22$^{\text{MeV.s}}$ DB$_1$="GXPF1B"

NP=64; SE:"DB1+Cal0" Density:"auto" GeomCor:"On" TunIg:"auto" $^{\text{Fis}}$Bar=#1 Bar$^{\text{Fac}}$=1.00 Modes=$^{1010\ 1010\ 010}$



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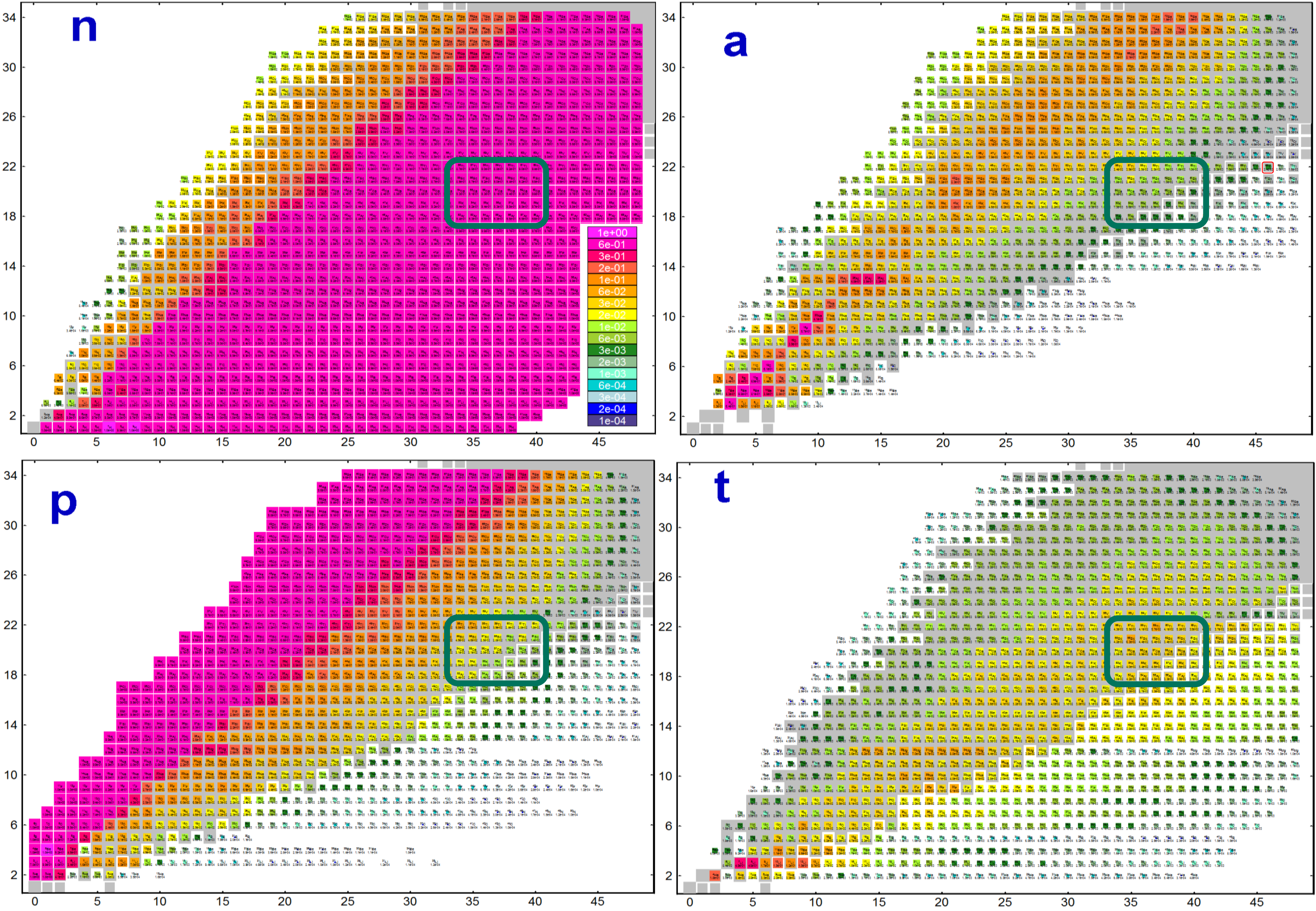
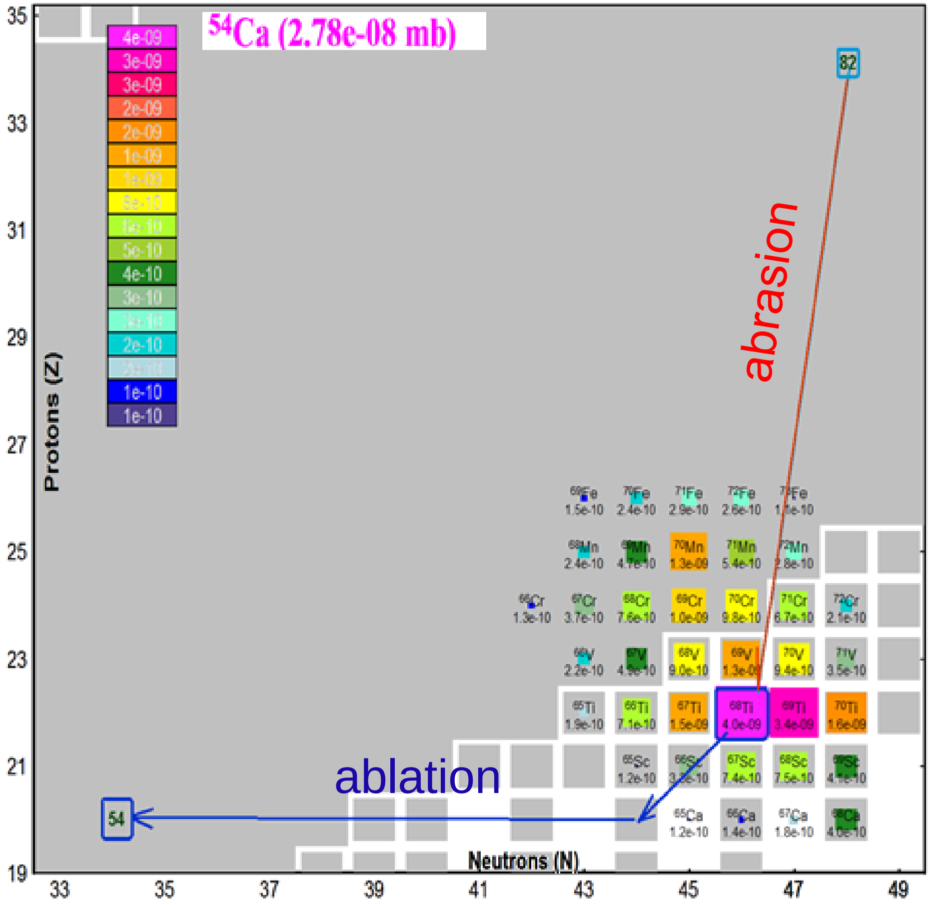
Output one evaporation channel / total (sum of all channels)

(one scale for all plots)

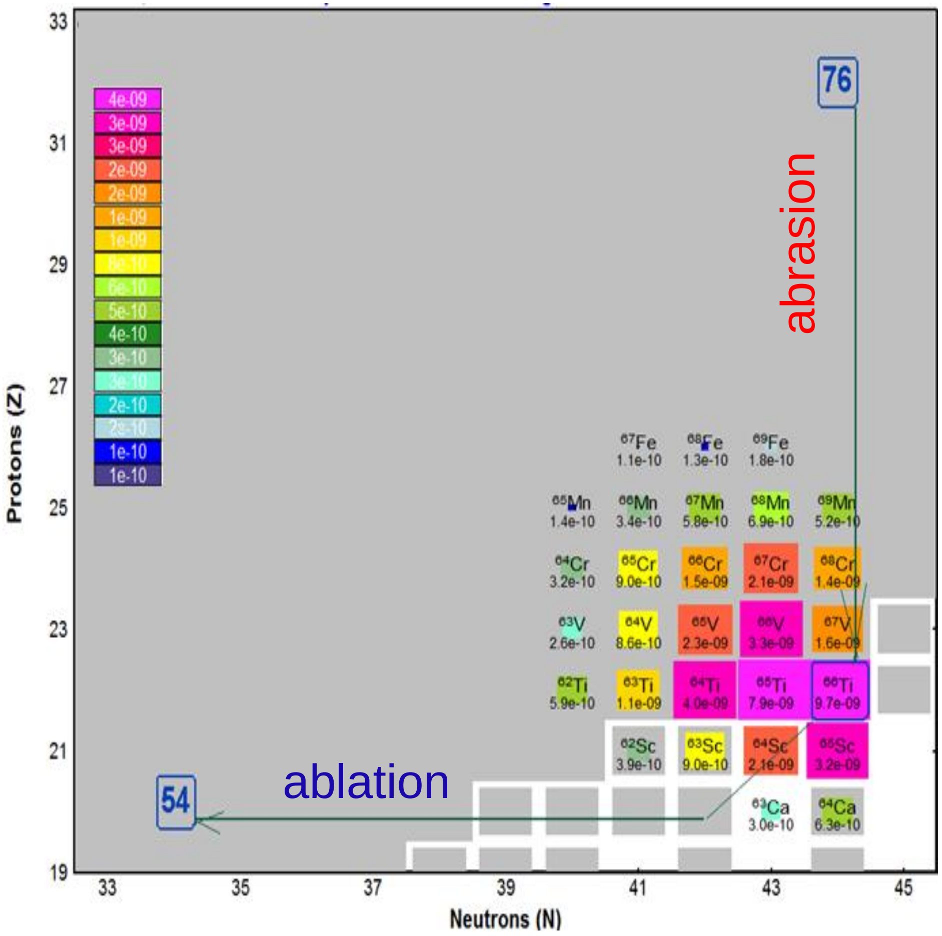


LISE^{++} AA: Initial prefragments plot for final residue ^{54}Ca

^{82}Se + Be



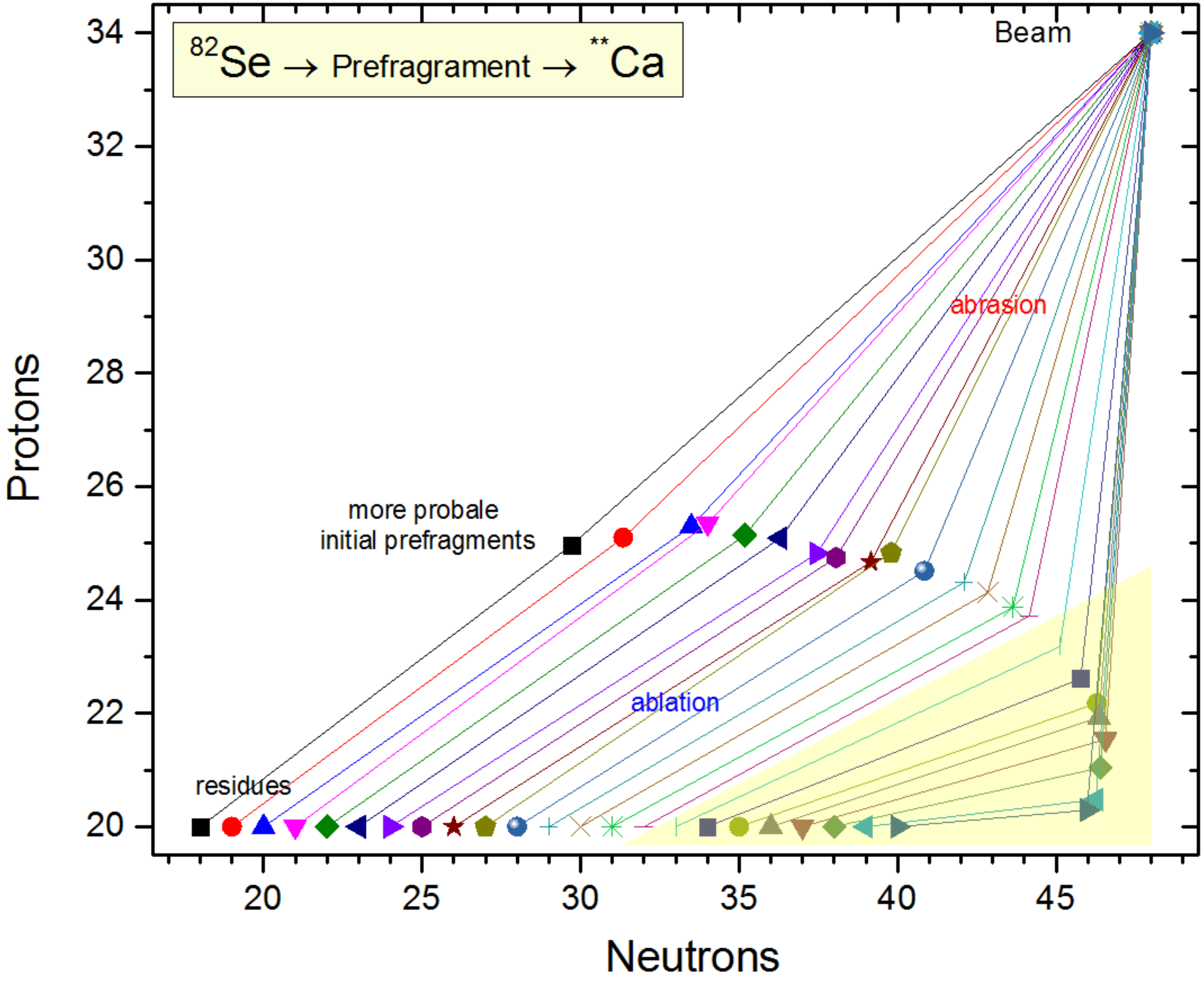
^{76}Ge + Be



More probable prefragments are Ti-isotopes (dZ=2)

O.Tarasov@exon2014.ru

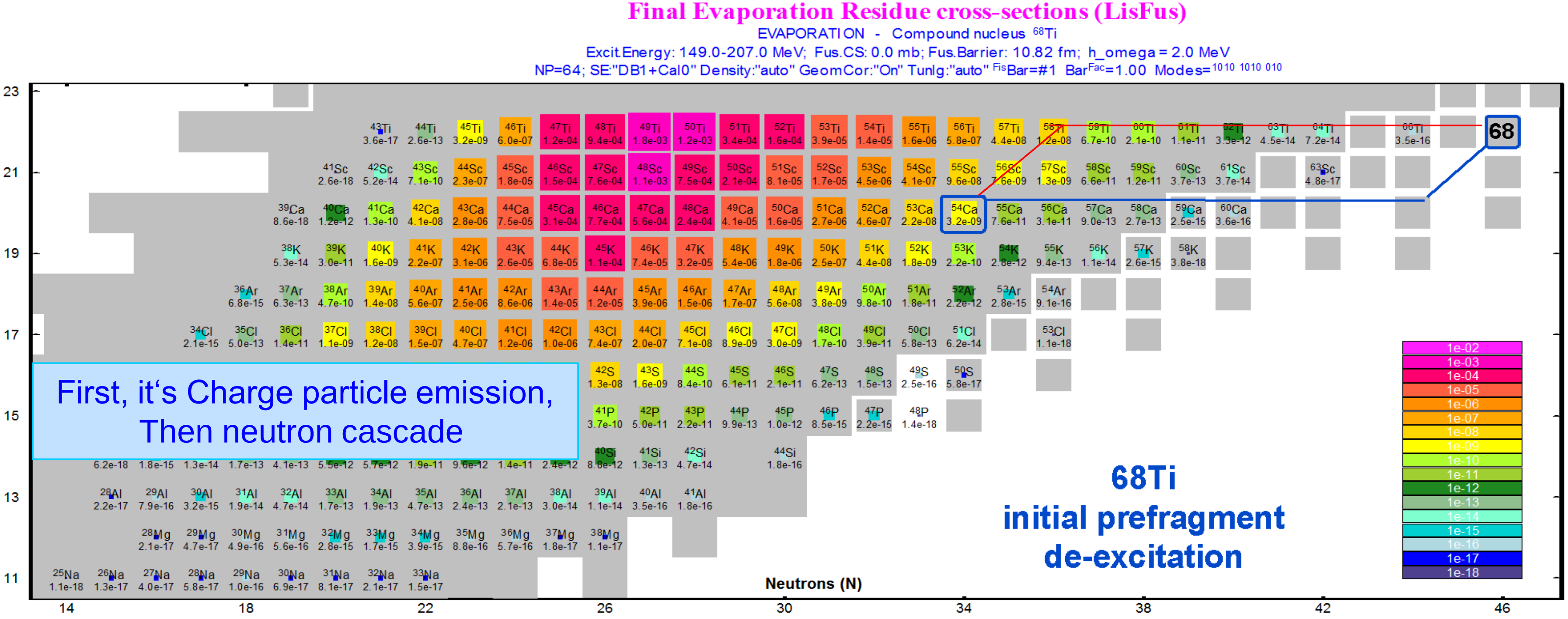
Initial prefragments to produce Calcium isotopes



Region of interest
“Calcium anomaly”

O.Tarasov@exon2014.ru

^{68}Ti* → ^{54}Ca



Final Evaporation Residue cross-sections (LisFus)

EVAPORATION - Compound nucleus ^{68}Ti

Excit.Energy: 149.0-207.0 MeV; Fus.CS: 0.0 mb; Fus.Barrier: 10.82 fm; h_omega = 2.0 MeV

NP=64; SE:"DB1+Cal0" Density:"auto" GeomCor:"On" Tunlg:"auto" ^{Fis}Bar=#1 Bar^{Fac}=1.00 Modes=$^{1010\ 1010\ 010}$

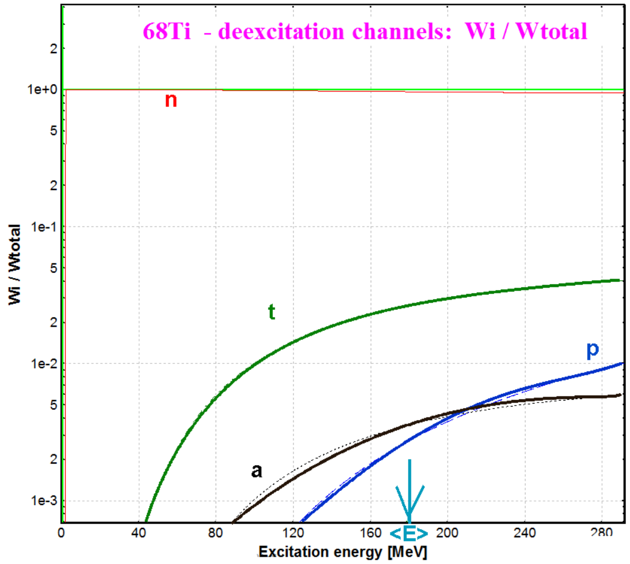
First, it‘s Charge particle emission,
Then neutron cascade

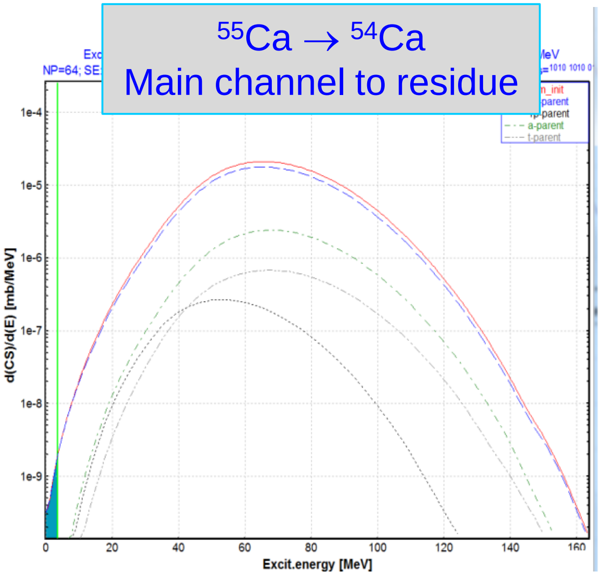
**68Ti
initial prefragment
de-excitation**

Probability for ^{68}Ti*(Ex=180MeV)
t = 2.6e-2
a = 3.6e-3
p =9.3e-3

Probability (dZ=2)
t^2 = 6.8e-4
a = 3.6e-3
p^2 =8.7e-5

It is necessary to create the MC version to gate for ^{54}Ca residual in order to answer where (**Ti → **-4Ca) de-excitation by charge particles is more probable





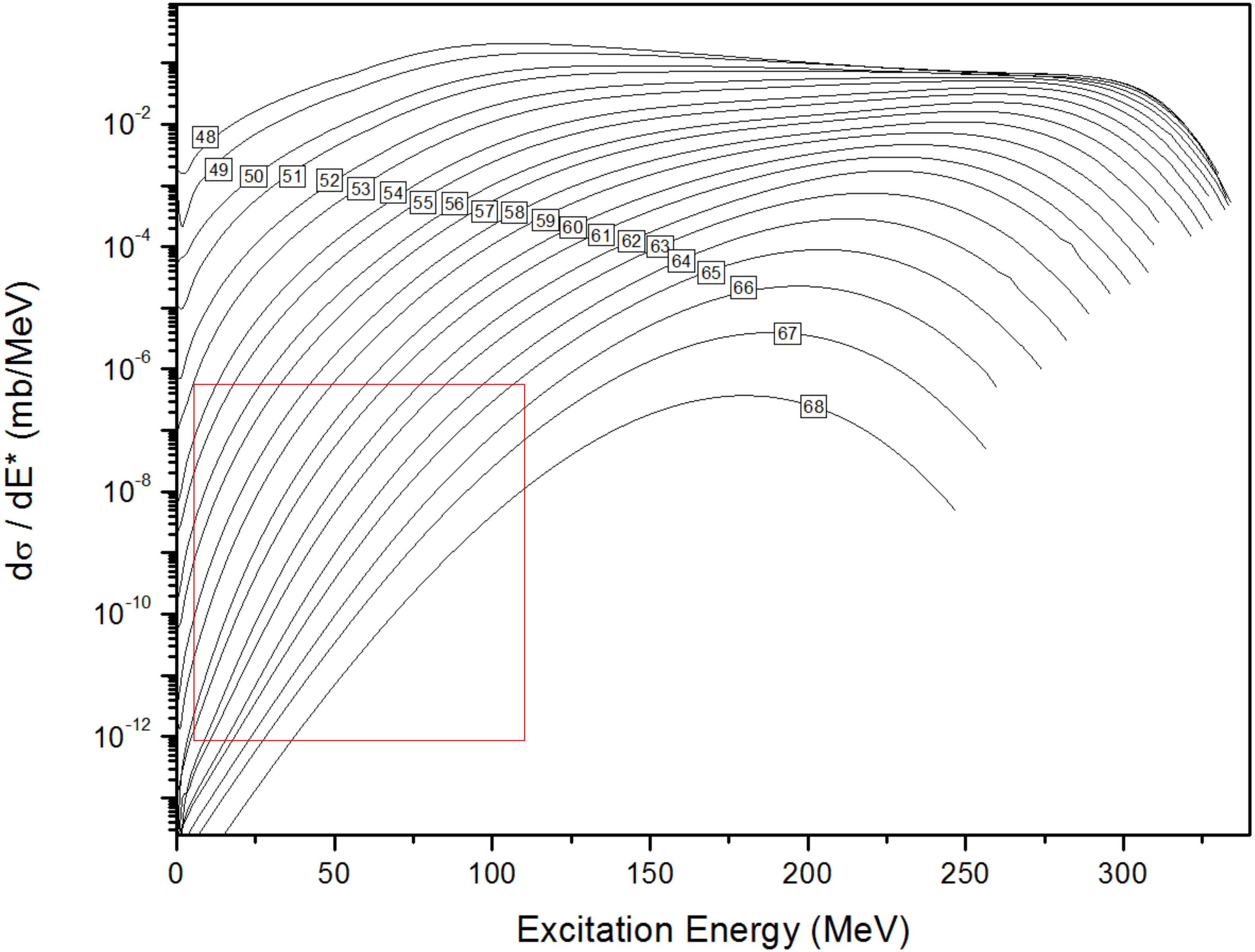
^{55}Ca → ^{54}Ca
Main channel to residue

O.Tarasov@exon2014.ru

Excitation functions A=48-68 (E^*_0 = 15 MeV)

LISE++ AA

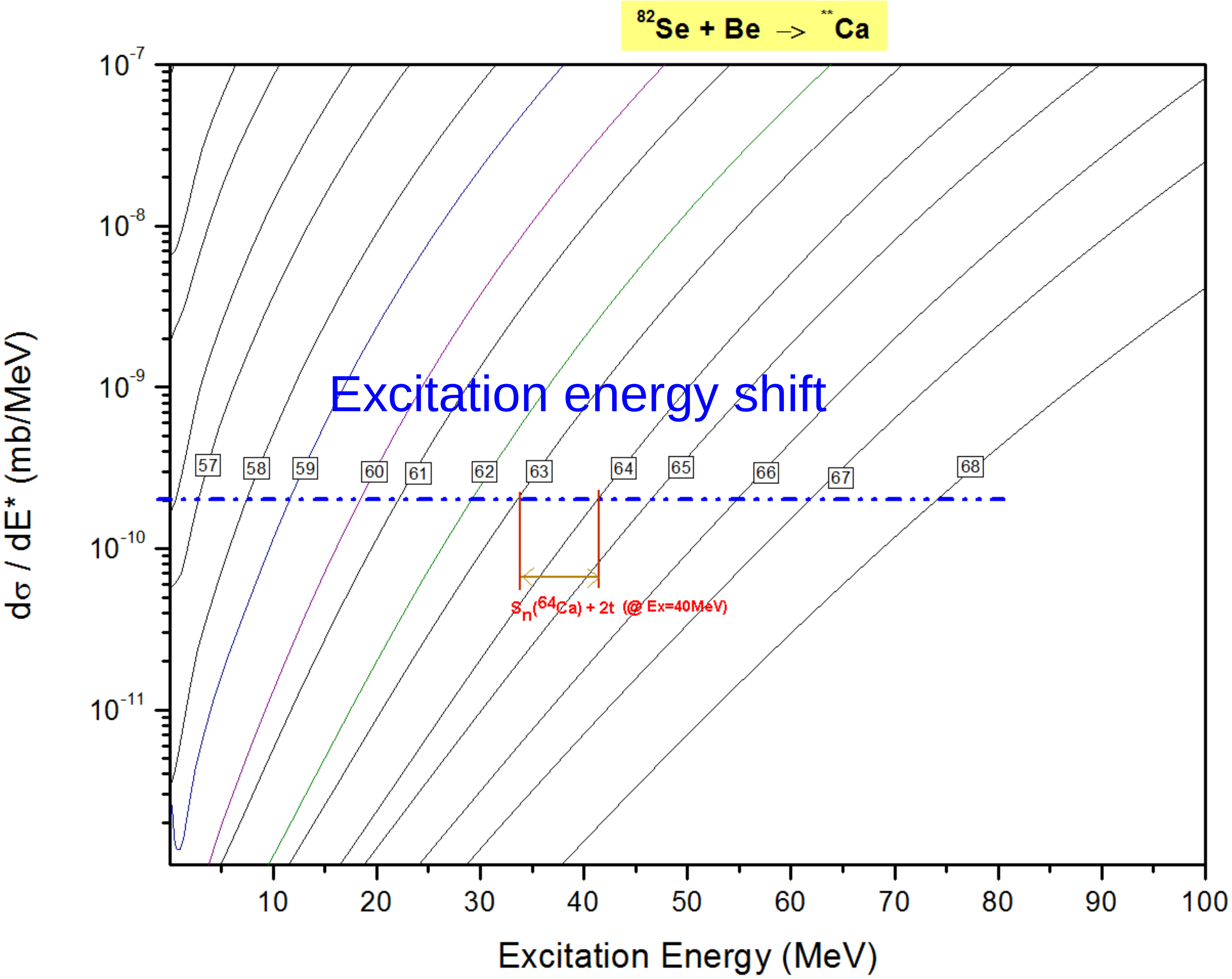
^{82}Se + Be –> **Ca



O.Tarasov@exon2014.ru

Excitation functions A=48-68 (E^*_0 = 15 MeV)

Zoom



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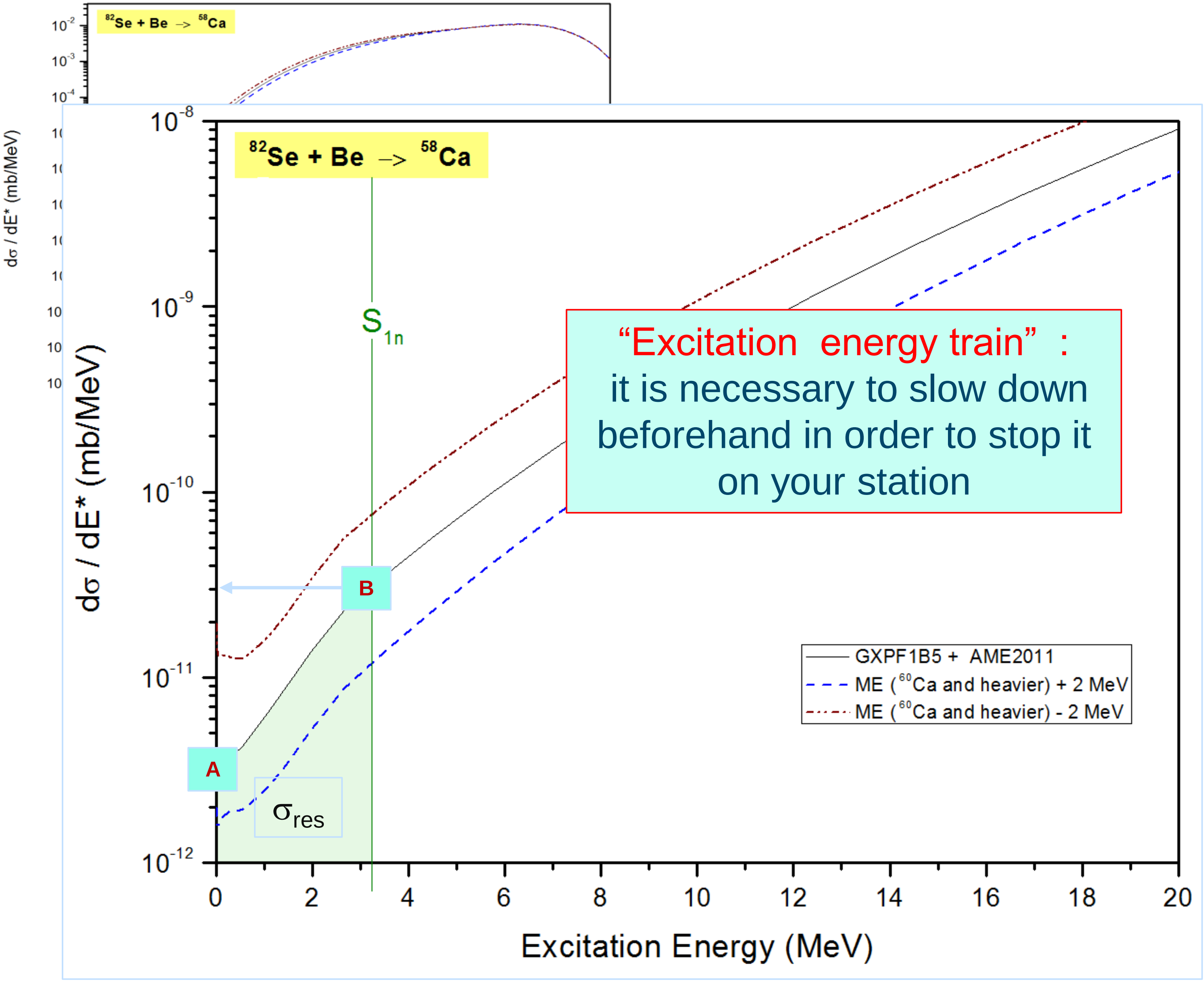
De-excitation process & excitation energy of daughter nucleus:

Excitation energy shift



"Excitation energy train" : it is necessary to slow down beforehand in order to stop it on your station

^{58}Ca $\sigma(0)$ = A

^{58}Ca $\sigma(3.2)$ = B

1. $S_{1n}(^{58}Ca)$=3.2 MeV : $\sigma(S_{1n})$=B is moving to E^*=0 for ^{57}Ca excitation function
   ^{57}Ca $\sigma(0)$ = B

2. Let's assume $S_{1n}(^{58}Ca)$=0 MeV, then in the first rough approach :

   $\sigma(0)$=A is the same value @ E^*=0 for ^{57}Ca

   ^{57}Ca $\sigma(0)$ ~ A

   ^{57}Ca $\sigma(\underline{2.6})$ ~ B

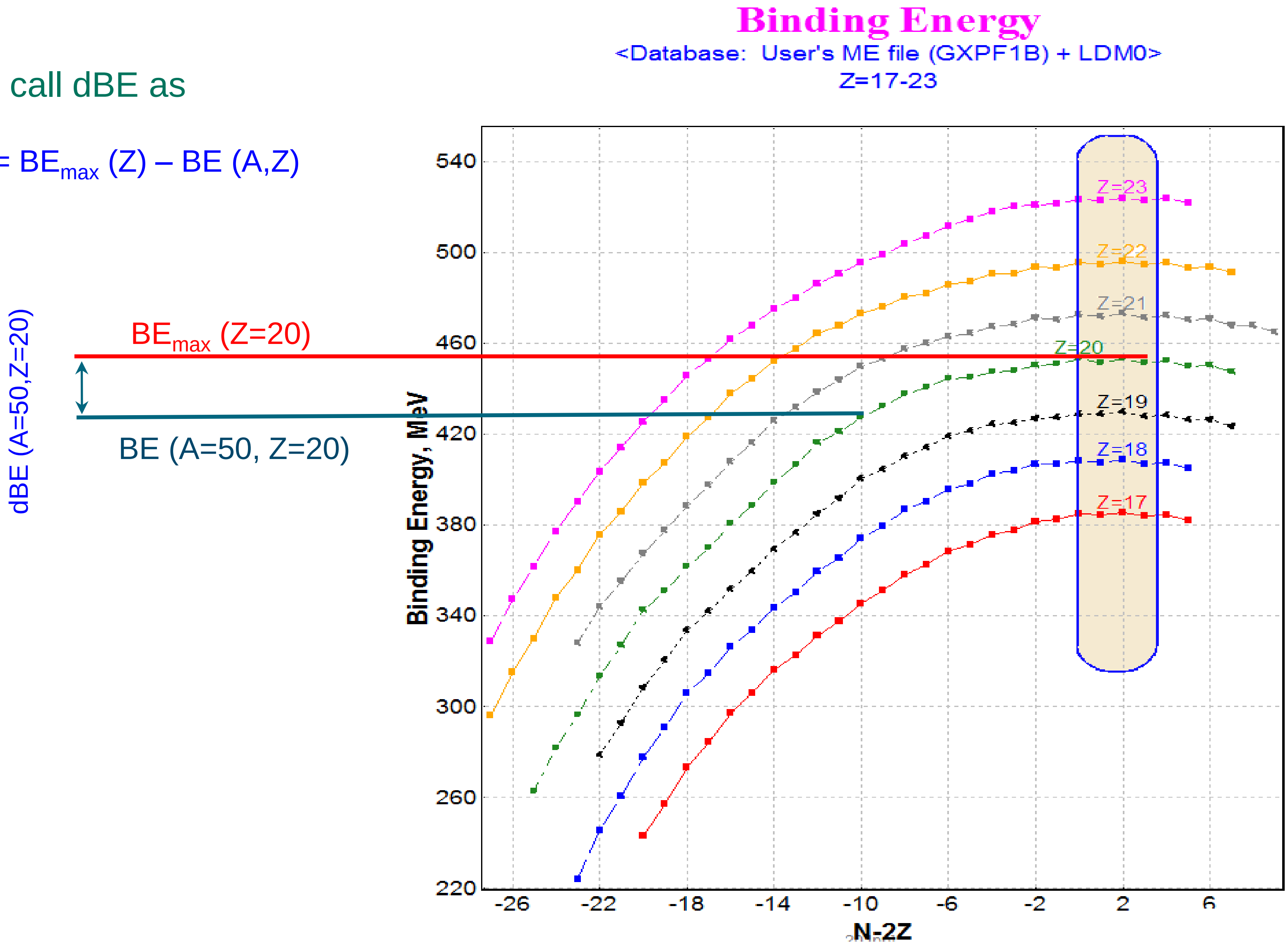
O.Tarasov@exon2014.ru

Excitation energy k shifts

$$\Sigma S_n(A,Z) = BE_{max}(Z) - BE(A,Z)$$

Lets call dBE as

$$dBE(A,Z) = BE_{max}(Z) - BE(A,Z)$$



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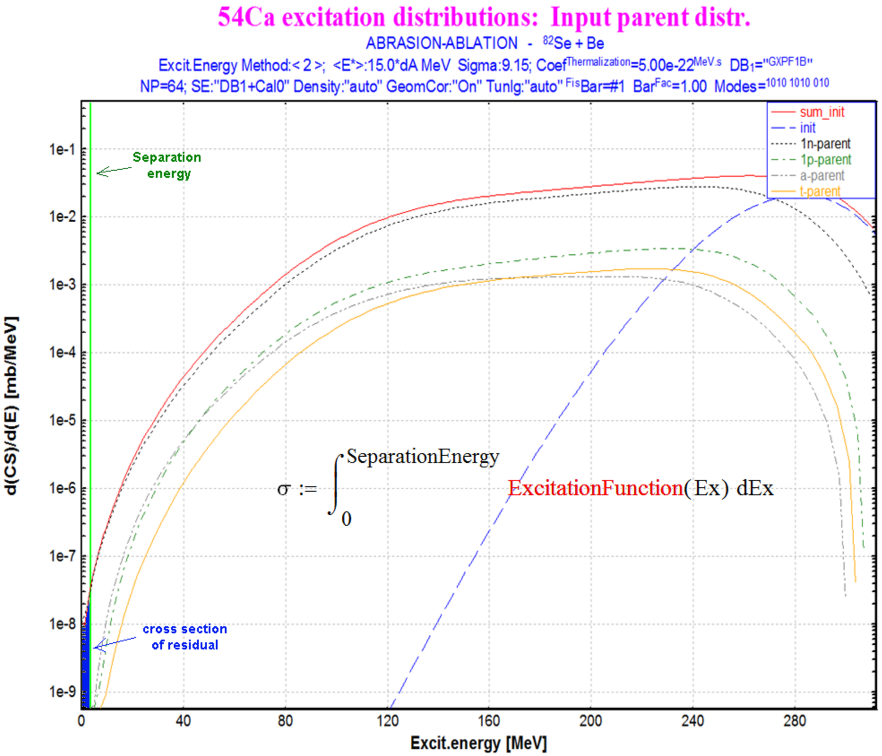
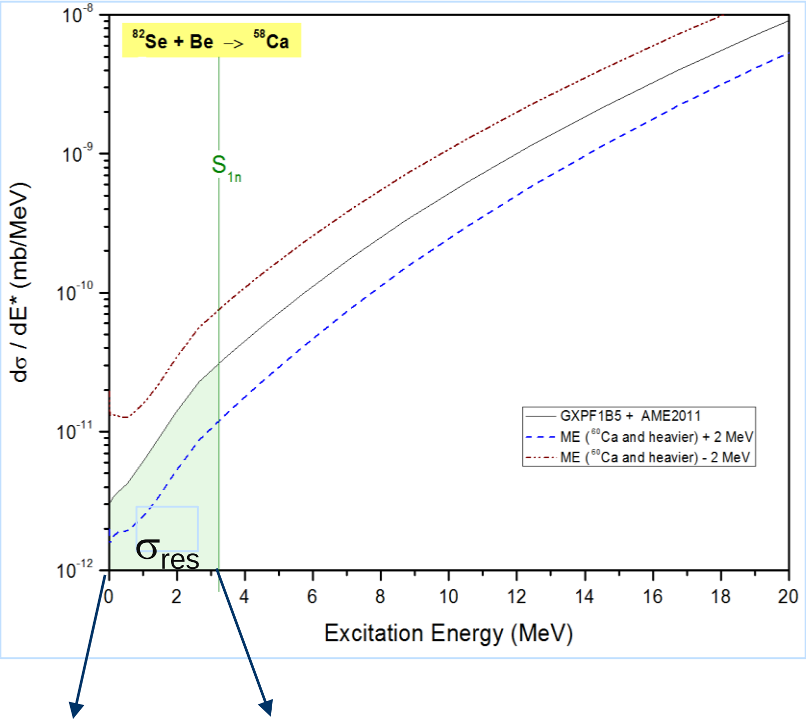
Residue Cross Section of neutron-rich isotopes





dBE(Z,N) dBE(Z,N+1)

$$\sigma\,(Z,N) = f\,[\,dBE(Z,N),\, S_n(Z,N)]$$

$S_n(Z,N)$	minimum separation energy
$dBE(Z,N)$	difference between the maximum biding energy for isotopes (Z) and binding energy of the nucleus (Z,N)

1. $\sigma\,(Z,N) \sim [dBE(Z,N)+a_1)]^{a2} * S_n(Z,N)$

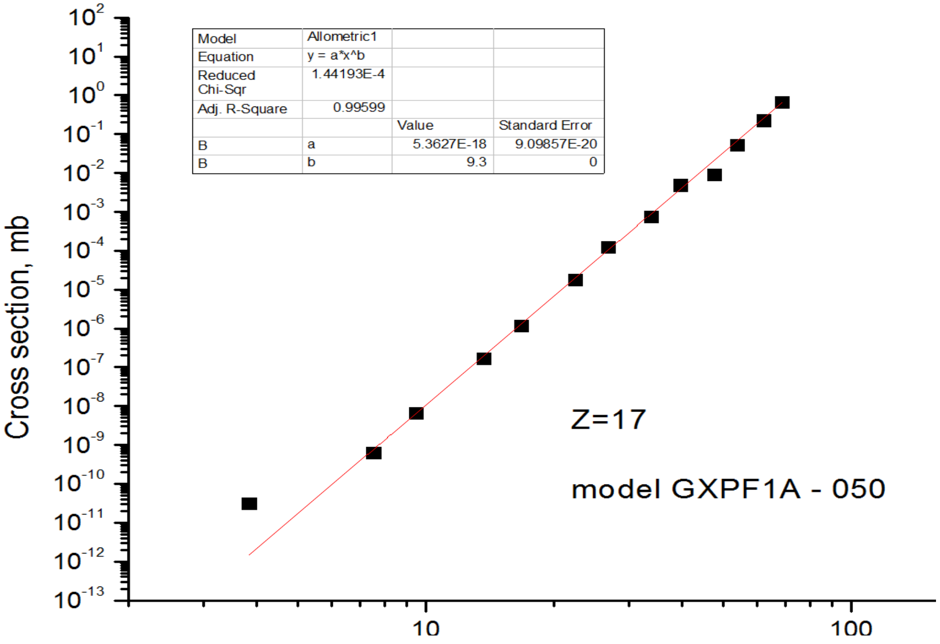
If $S_n(Z,N) \le 0$, Then $\sigma\,(Z,N) = 0$,
whereas Q_g or BE/A systematics show unbound nuclei

Or Using $dBE(Z,N\text{-}1) = dBE(Z,N) + S_n(Z,N)$,

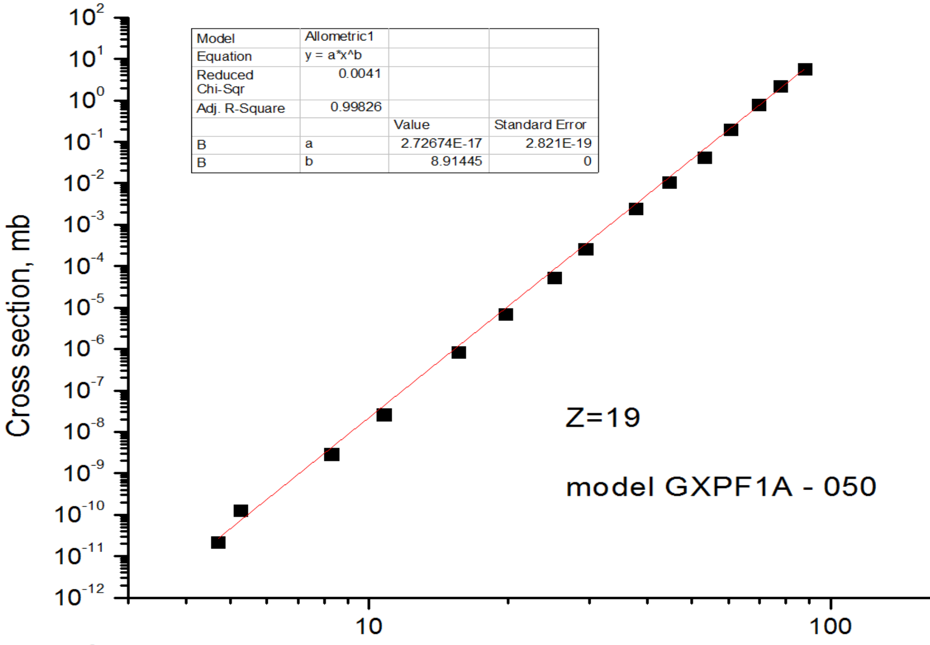
2. $\sigma\,(Z,N) \sim dBE(Z,N+1)$

O.Tarasov@exon2014.ru

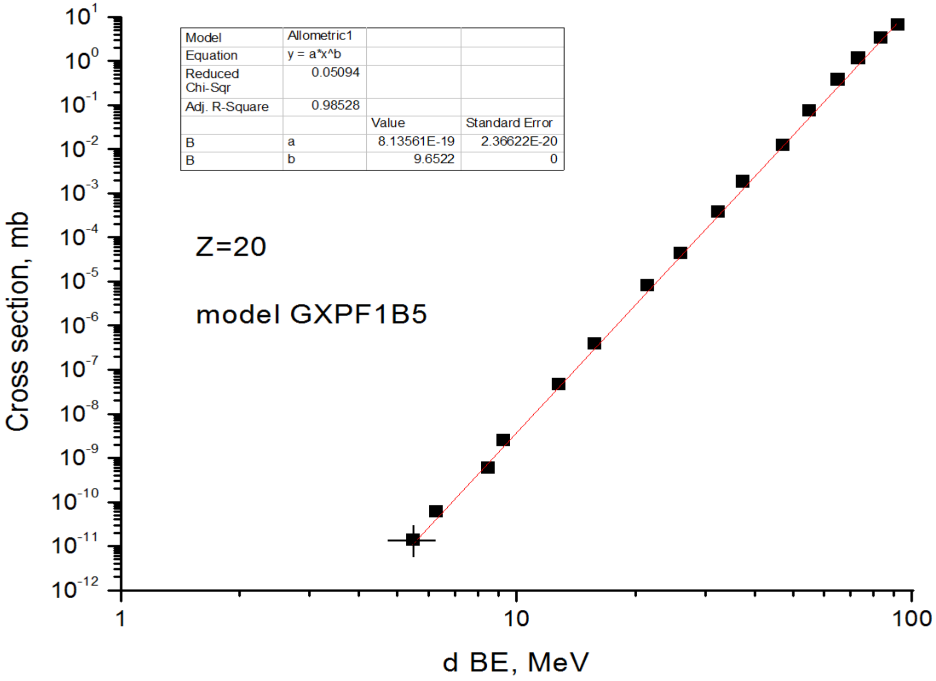
dBE Cross Section Systematic vs. Experiment



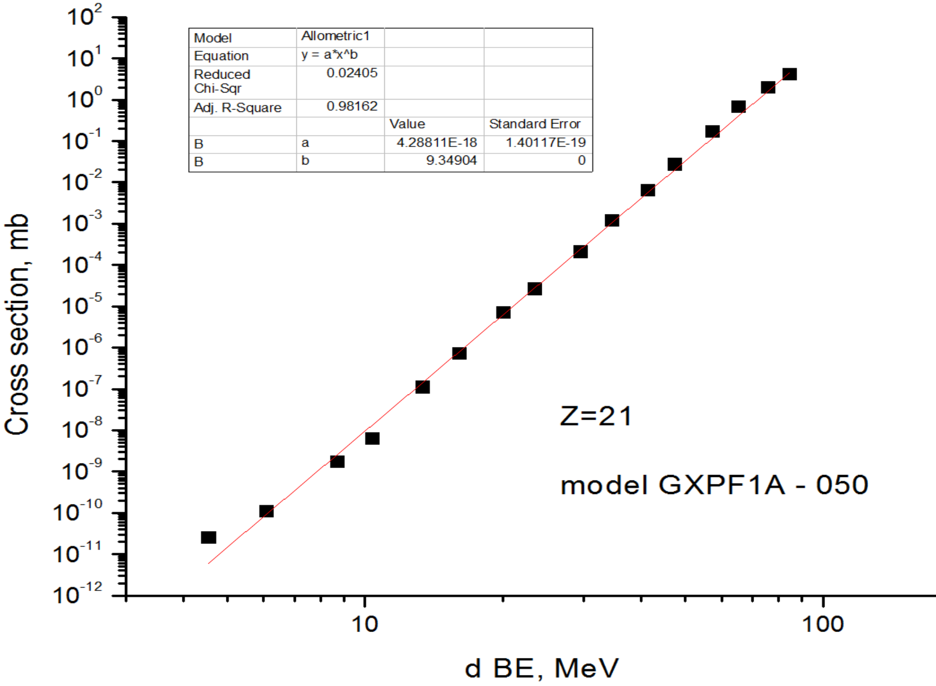
Model	Allometric1		
Equation	y = a*x^b		
Reduced Chi-Sqr	1.44193E-4		
Adj. R-Square	0.99599		
		Value	Standard Error
B	a	5.3627E-18	9.09857E-20
B	b	9.3	0



Model	Allometric1		
Equation	y = a*x^b		
Reduced Chi-Sqr	0.0041		
Adj. R-Square	0.99826		
		Value	Standard Error
B	a	2.72674E-17	2.821E-19
B	b	8.91445	0

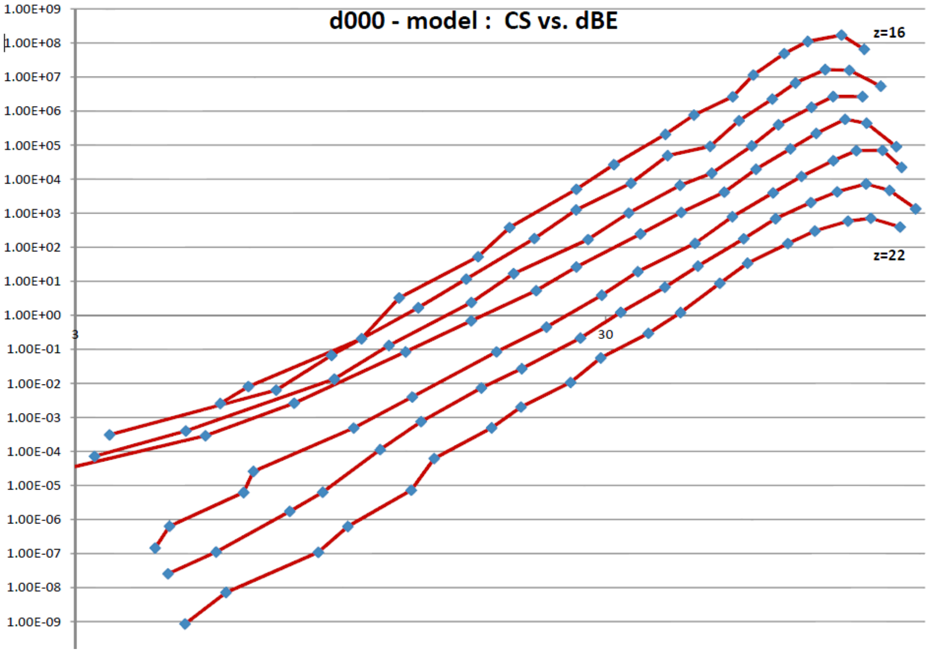


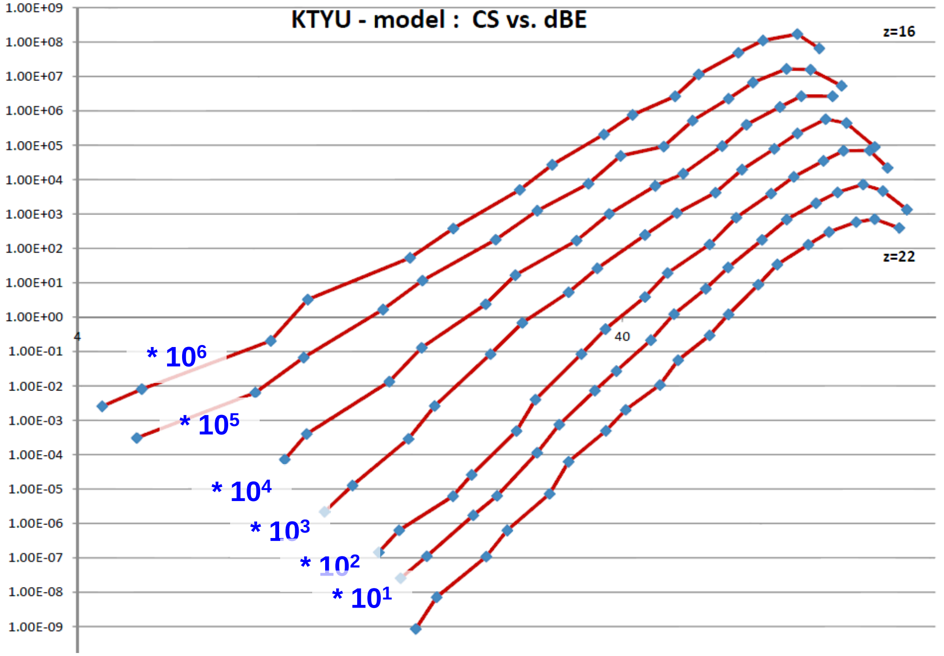
Model	Allometric1		
Equation	y = a*x^b		
Reduced Chi-Sqr	0.05094		
Adj. R-Square	0.98528		
		Value	Standard Error
B	a	8.13561E-19	2.36622E-20
B	b	9.6522	0

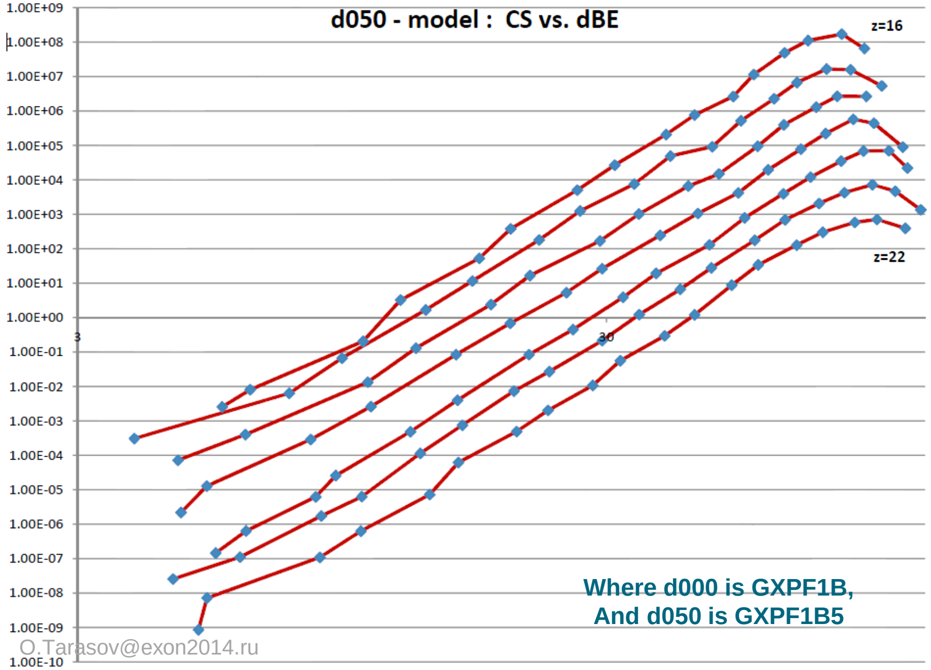


Model	Allometric1		
Equation	y = a*x^b		
Reduced Chi-Sqr	0.02405		
Adj. R-Square	0.98162		
		Value	Standard Error
B	a	4.28811E-18	1.40117E-19
B	b	9.34904	0

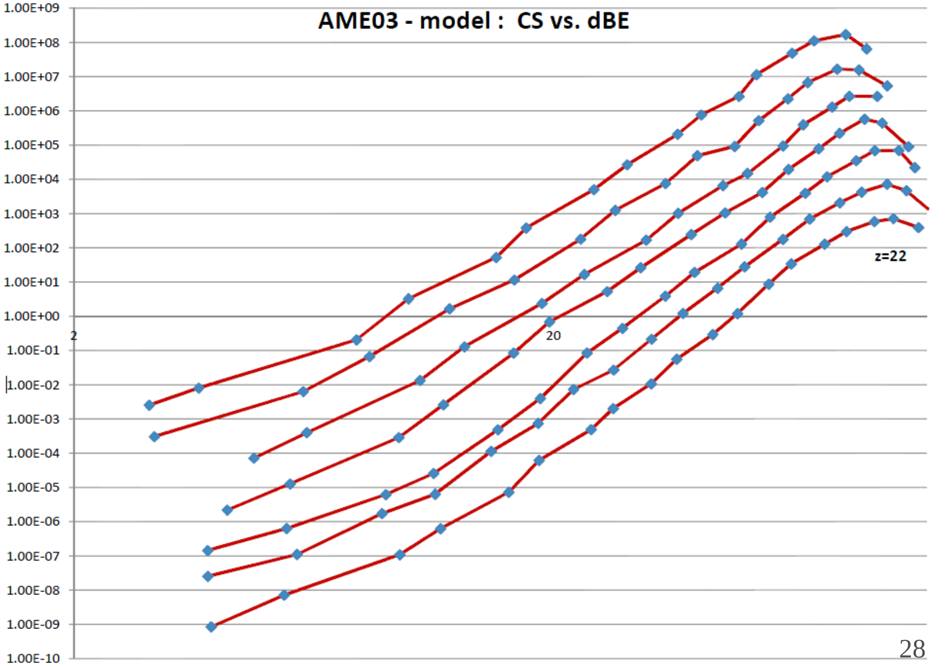
dBE Cross Section Systematic with different Mass Models vs. ^{82}Se Experimental Data


d000 - model : CS vs. dBE


KTYU - model : CS vs. dBE


d050 - model : CS vs. dBE

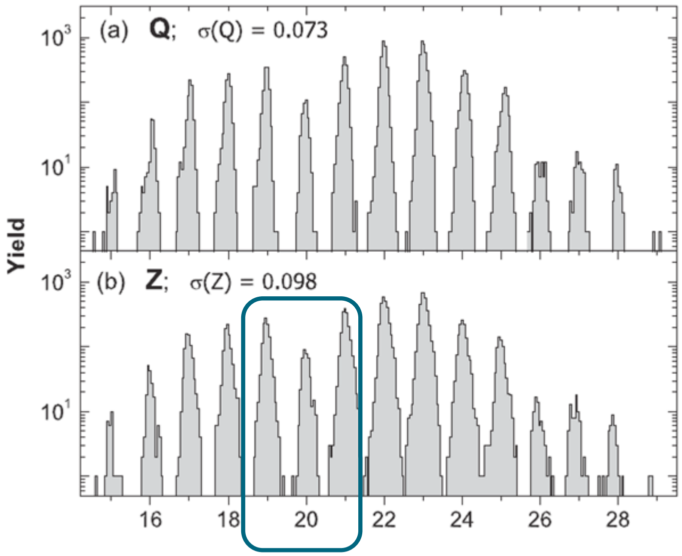
**Where d000 is GXPF1B,
And d050 is GXPF1B5**

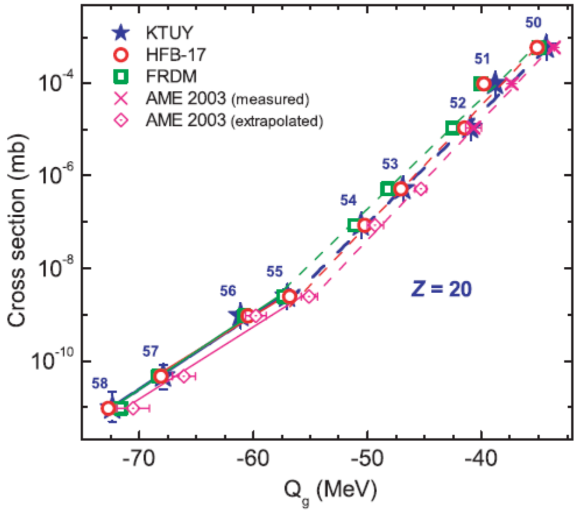

AME03 - model : CS vs. dBE

O.Tarasov@exon2014.ru

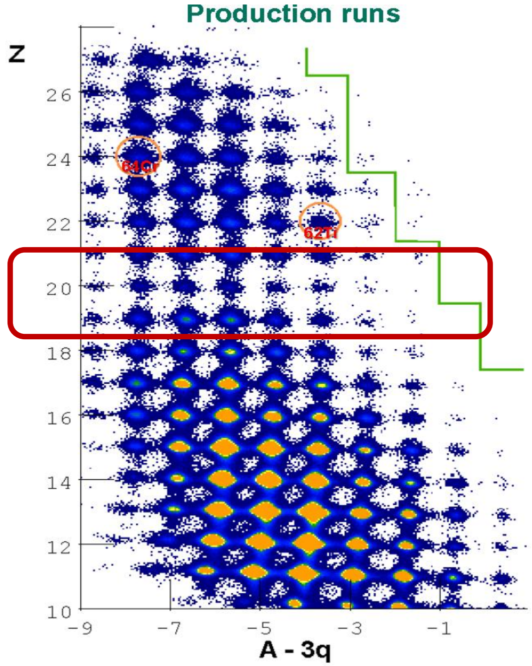
“Calcium anomaly” observation

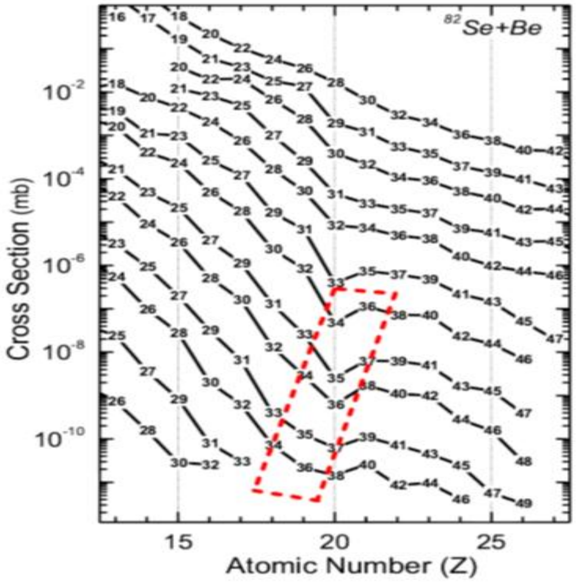
^{76}Ge





^{82}Se





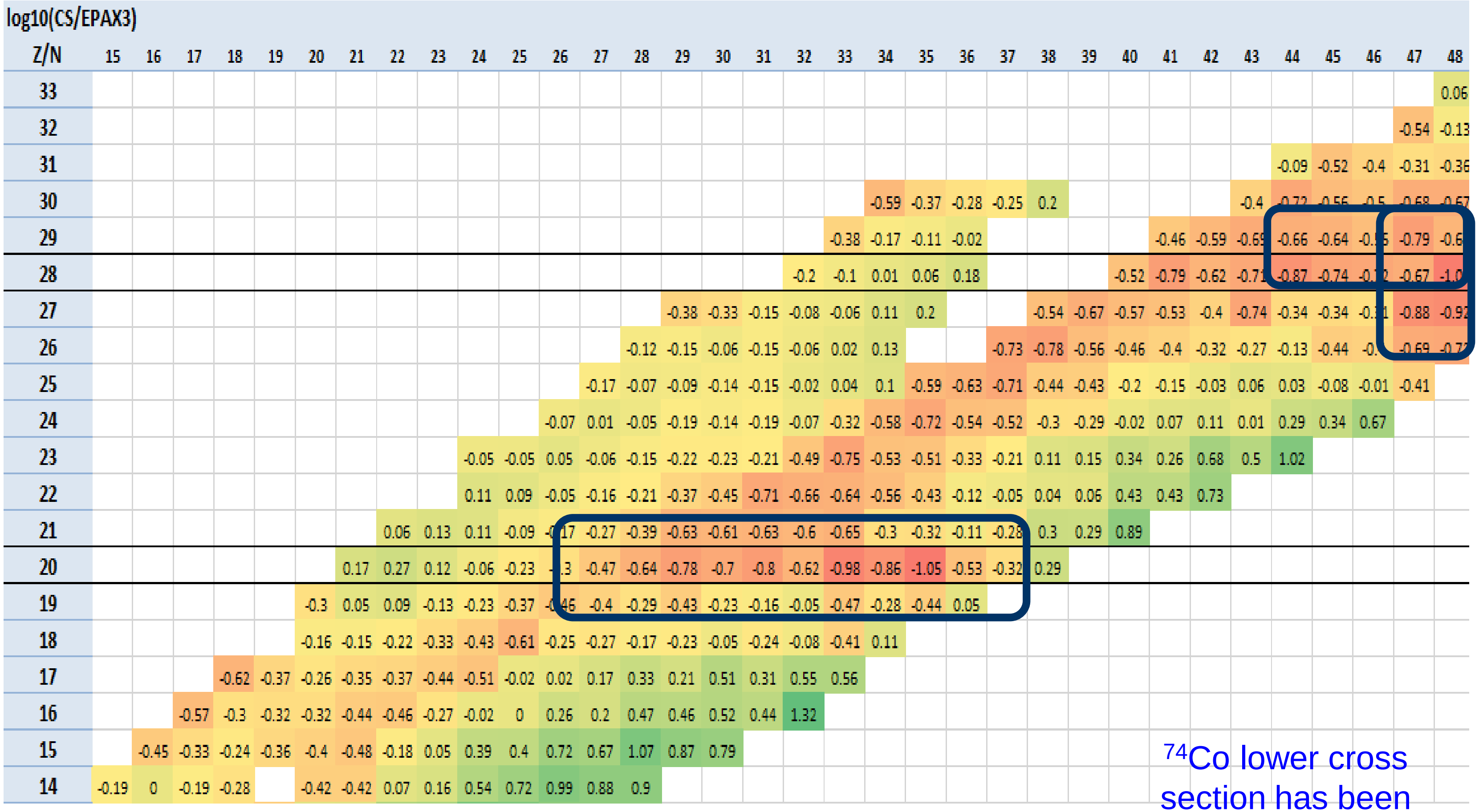
O.Tarasov@exon2014.ru

Another representation of Anomalies

^{82}Se (139 MeV/u) + Be

Phys. Rev. C **87**, 054612 (2013)

Log10 (Experimental Cross Sections / EPAX 3.15)



log10(CS/EPAX3)

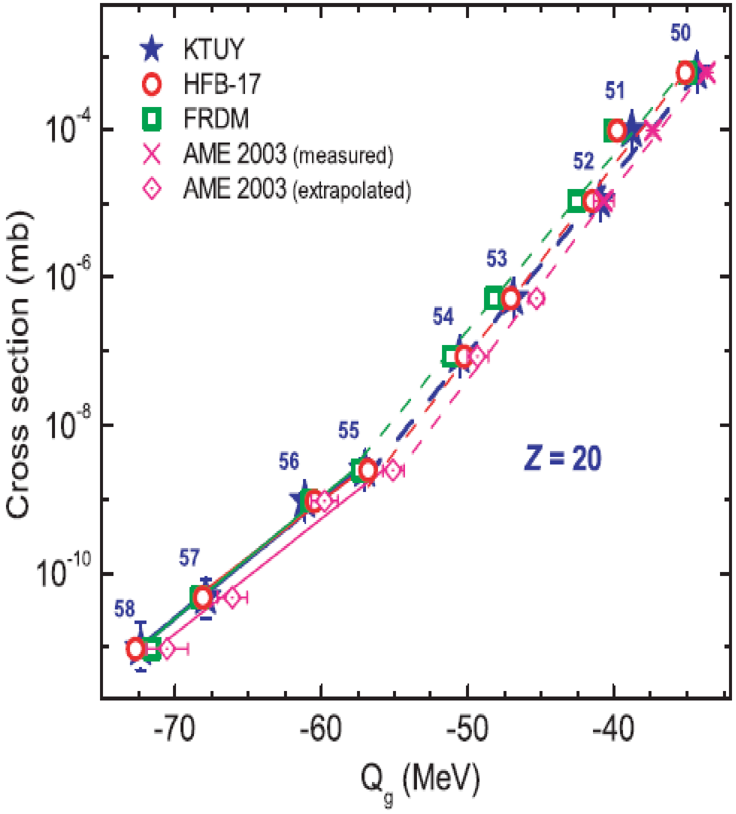
Z/N	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
33																																		0.06
32																																	-0.54	-0.13
31																														-0.09	-0.52	-0.4	-0.31	-0.36
30																				-0.59	-0.37	-0.28	-0.25	0.2					-0.4	-0.72	-0.56	-0.5	-0.68	-0.67
29																			-0.38	-0.17	-0.11	-0.02					-0.46	-0.59	-0.69	-0.66	-0.64	[illegible]	-0.79	[illegible]
28																		-0.2	-0.1	0.01	0.06	0.18				-0.52	-0.79	-0.62	-0.71	-0.87	-0.74	[illegible]	-0.67	[illegible]
27															-0.38	-0.33	-0.15	-0.08	-0.06	0.11	0.2			-0.54	-0.67	-0.57	-0.53	-0.4	-0.74	-0.34	-0.34	[illegible]	-0.88	-0.92
26														-0.12	-0.15	-0.06	-0.15	-0.06	0.02	0.13			-0.73	-0.78	-0.56	-0.46	-0.4	-0.32	-0.27	-0.13	-0.44	[illegible]	-0.69	[illegible]
25													-0.17	-0.07	-0.09	-0.14	-0.15	-0.02	0.04	0.1	-0.59	-0.63	-0.71	-0.44	-0.43	-0.2	-0.15	-0.03	0.06	0.03	-0.08	-0.01	-0.41	
24												-0.07	0.01	-0.05	-0.19	-0.14	-0.19	-0.07	-0.32	-0.58	-0.72	-0.54	-0.52	-0.3	-0.29	-0.02	0.07	0.11	0.01	0.29	0.34	0.67		
23										-0.05	-0.05	0.05	-0.06	-0.15	-0.22	-0.23	-0.21	-0.49	-0.75	-0.53	-0.51	-0.33	-0.21	0.11	0.15	0.34	0.26	0.68	0.5	1.02				
22										0.11	0.09	-0.05	-0.16	-0.21	-0.37	-0.45	-0.71	-0.66	-0.64	-0.56	-0.43	-0.12	-0.05	0.04	0.06	0.43	0.43	0.73						
21								0.06	0.13	0.11	-0.09	-0.17	-0.27	-0.39	-0.63	-0.61	-0.63	-0.6	-0.65	-0.3	-0.32	-0.11	-0.28	0.3	0.29	0.89								
20							0.17	0.27	0.12	-0.06	-0.23	[illegible]	-0.47	-0.64	-0.78	-0.7	-0.8	-0.62	-0.98	-0.86	-1.05	-0.53	-0.32	0.29										
19						-0.3	0.05	0.09	-0.13	-0.23	-0.37	-0.46	-0.4	-0.29	-0.43	-0.23	-0.16	-0.05	-0.47	-0.28	-0.44	0.05												
18						-0.16	-0.15	-0.22	-0.33	-0.43	-0.61	-0.25	-0.27	-0.17	-0.23	-0.05	-0.24	-0.08	-0.41	0.11														
17				-0.62	-0.37	-0.26	-0.35	-0.37	-0.44	-0.51	-0.02	0.02	0.17	0.33	0.21	0.51	0.31	0.55	0.56															
16			-0.57	-0.3	-0.32	-0.32	-0.44	-0.46	-0.27	-0.02	0	0.26	0.2	0.47	0.46	0.52	0.44	1.32																
15		-0.45	-0.33	-0.24	-0.36	-0.4	-0.48	-0.18	0.05	0.39	0.4	0.72	0.67	1.07	0.87	0.79																		
14	-0.19	0	-0.19	-0.28		-0.42	-0.42	0.07	0.16	0.54	0.72	0.99	0.88	0.9																				

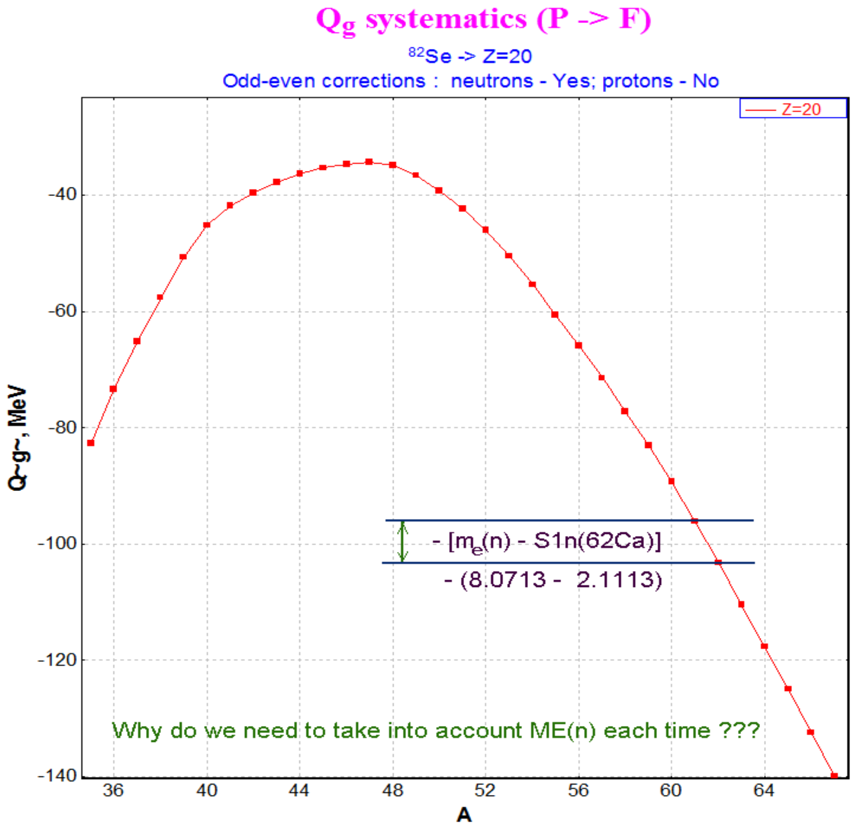
?

^{74}Co lower cross section has been observed in other experiments with a ^{82}Se beam

What is Qg systematics? Just tendency indicator

^{82}Se




Qg systematics (P -> F)

^{82}Se -> Z=20

Odd-even corrections : neutrons - Yes; protons - No

- [m_e(n) - S1n(62Ca)]

- (8.0713 - 2.1113)

Why do we need to take into account ME(n) each time ???

In Q_{gg} systematics “this” neutron is compensated by conjugated products

O.Tarasov@exon2014.ru

Production cross sections as a nucleus structure study tool

1. Even one registered event (non-zero production cross section) provides information for nucleus structure : particle bound or not

2. There are very low statistics, and spectroscopy experiments are difficult (or impossible) to perform, Systematic production cross sections can provide some indications about structure of observed isotopes, and even provide hints about structures of preceding non-observed isotopes

3. Even it is difficult to evaluate masses from AA analysis (one particular cross section kink, or depression for several isotopes), though production cross section analysis is powerful test of theoretical mass models

4. dBE-systematics advantages:

   a. deduced, not assumed
   b. start energy point
   c. unbound nuclei are out of the systematics
   d. can be used for other reaction mechanisms,
   where neutron rich nuclei are produced after emission large number of neutrons
   e. no parameters, the same slope?
   f. no any odd-even corrections and so on.

O.Tarasov@exon2014.ru

Open questions

1. What is proper expression (parameterization) for dBE-systematics?
2. Why slopes are similar for all elements?
3. Why is turnover point is always in the dBE-place (stability line?)?
4. What is contribution of dissipation at low energies or with heavy targets
5. Can Monte Carlo study of prefragment distribution and channels preceding to final residue explain the data?
   New experiments will be useful as well.

Discussions with Prof. D.J.Morrissey
are very appreciated.

O.Tarasov@exon2014.ru