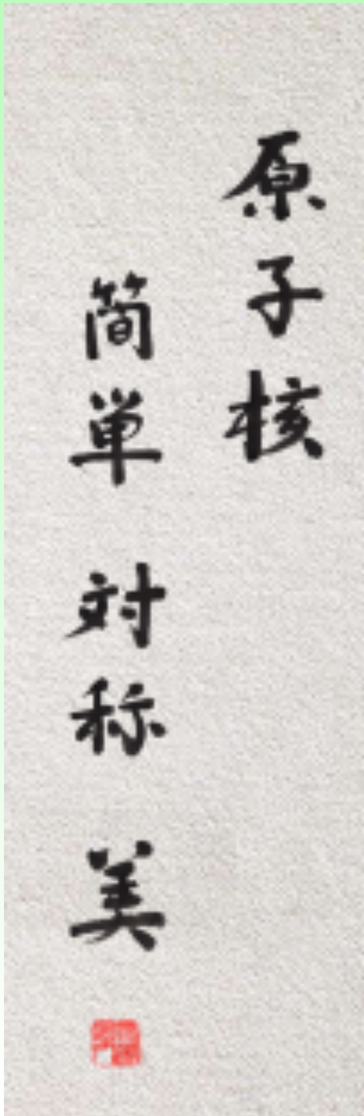
International Symposium on Simplicity, Symmetry and Beauty of Atomic Nuclei,
in honor of Professor Akito Arima’s 88 year-old birthday (米寿)
Sep. 26-28, 2018，Shanghai，China



Production cross sections for exotic nuclei with multinucleon transfer reactions

Feng-Shou Zhang

College of Nuclear Science and Technology
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1996 in IMP， Lanzhou

This work is dedicated to Prof. Akito Arima on the occasion of his 88 year-old birthday（米寿）

Front. Phys. 13(6), 132113 (2018)
https://doi.org/10.1007/s11467-018-0843-6

REVIEW ARTICLE

Production cross sections for exotic nuclei with multinucleon transfer reactions

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The main progresses in the multinucleon transfer reactions at energies close to the Coulomb barrier are reviewed. After a short presentation of the experimental progress and theoretical progress, the predicted production cross sections for unknown neutron-rich heavy nuclei and the trans-uranium nuclei are presented.

OUTLINE

1. Introduction
2. Models for calculation of production cross sections of exotic nuclei
   (1) The Improved Quantum Molecular Dynamics Model
   (2) A combination of the Grazing Model and the Dinuclear System (DNS) Model
3. RNB induced MNT
4. Summary

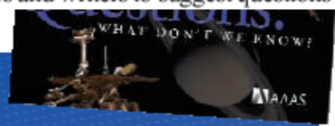
Top 125 science questions
Science 1 July 2005

Special Section

What Don't We Know?

At *Science*, we tend to get excited about new discoveries that lift the veil a little on how things work, from cells to the universe. That puts our focus firmly on what has been added to our stock of knowledge. For this anniversary issue, we decided to shift our frame of reference, to look instead at what we *don't* know: the scientific puzzles that are driving basic scientific research.

We began by asking *Science*'s Senior Editorial Board, our Board of Reviewing Editors, and our own editors and writers to suggest questions that point to critical knowledge gaps. The ground rules: Scientists
r the next 25 years, or they should at least know how to go about
hese suggestions and turn them into a survey of the big questions
s sat down to select those big questions, we quickly realized that
edge research that lies behind the responses we
ting number for *Science*'s 125th anniversary.
not a survey of the big societal challenges that
e might achieve. Think of it instead as a survey
that scientists themselves are asking. As Tom
ortunities to be exploited."
sed on several criteria: how fundamental they
will impact other scientific disciplines. Some
sition of the universe, for example. Others we
impact—whether an effective HIV vaccine is



rch 5, 2016

Contents >> NEWS

Are there stable high-atomic-number elements?
A superheavy element with 184 neutrons and 114 protons should be relatively stable, if physicists can create it.

Is superfluidity possible in a solid? If so, how?
Despite hints in solid helium, nobody is sure whether a crystalline material can flow without resistance. If new types of experiments show that such outlandish behavior is possible, theorists would have to explain how.

What is the structure of water?
Researchers continue to tussle over how many bonds each H_2O molecule makes with its nearest neighbors.


JUPITER IMAGES

What is the nature of the glassy state?
Molecules in a glass are arranged much like those in liquids but are more tightly packed. Where and why does liquid end and glass begin?

IUPAC 2016-06-08

http://iupac.org/iupac-is-naming-the-four-new-elements-nihonium-moscovium-tennessine-and-oganesson/

IUPAC is naming the four new elements **nihonium**, **moscovium**, **tennessine**, and **oganesson**

The 7th period of the periodic table of elements is complete.

10	11	12	aluminium 26.98	silicon [28.08, 28.09]	phosphorus 30.97	sulfur [32.05, 32.08]	chlorine [35.44, 35.46]	argon 39.95
28 **Ni** nickel 58.69	29 **Cu** copper 63.55	30 **Zn** zinc 65.38(2)	31 **Ga** gallium 69.72	32 **Ge** germanium 72.63	33 **As** arsenic 74.92	34 **Se** selenium 78.96(3)	35 **Br** bromine [79.90, 79.91]	36 **Kr** krypton 83.80
46 **Pd** palladium 106.4	47 **Ag** silver 107.9	48 **Cd** cadmium 112.4	49 **In** indium 114.8	50 **Sn** tin 118.7	51 **Sb** antimony 121.8	52 **Te** tellurium 127.6	53 **I** iodine 126.9	54 **Xe** xenon 131.3
78 **Pt** platinum 195.1	79 **Au** gold 197.0	80 **Hg** mercury 200.6	81 **Tl** thallium [204.3, 204.4]	82 **Pb** lead 207.2	83 **Bi** bismuth 209.0	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
110 **Ds** darmstadtium	111 **Rg** roentgenium	112 **Cn** copernicium	113 **Nh**	114 **Fl** flerovium	115 **Mc**	116 **Lv** livermorium	117 **Ts**	118 **Og**

A five-month public review is now set, expiring 8 November 2016, prior to the formal approval by the IUPAC Council.

295, ^{296}Og

$^{48}Ca + ^{249}Cf$ (51%) $+ ^{250}Cf$ (13%) $+ ^{251}Cf$ (36%) $\rightarrow ^{294,295,296}Og + xn$

Search for the heaviest atomic nuclei among the products from reactions of mixed-Cf with a ^{48}Ca beam

N. T. Brewer[1,2,3,†], V. K. Utyonkov[4], K. P. Rykaczewski[2], Yu. Ts. Oganessian[4], F. Sh. Abdullin[4], R. A. Boll[2], D. J. Dean[2], S. N. Dmitriev[4], J. G. Ezold[2], L. K. Felker[2], R. K. Grzywacz[2,3], M. G. Itkis[4], N. D. Kovrizhnykh[4], D. C. McInturff[2], K. Miernik[1,5], G. D. Owen[2], A. N. Polyakov[4], A. G. Popeko[4], J. B. Roberto[2], A. V. Sabel'nikov[4], R. N. Sagaidak[4], I. V. Shirokovsky[4], M. V. Shumeiko[4], N. J. Sims[2], E. H. Smith[2], V. G. Subbotin[4], A. M. Sukhov[4], A. I. Svirikhin[4], Yu. S. Tsyganov[4], S. M. Van Cleve[1], A. A. Voinov[4], G. K. Vostokin[4], C. S. White[2], J. H. Hamilton[6], M. A. Stoyer[7]

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(Dated: August 1, 2018)

The search for new decay chains of oganesson isotopes is presented. The experiment utilized the Dubna Gas Filled Recoil Separator and a highly segmented recoil-decay detection system. The signals from all detectors were analyzed in parallel by digital and analog data acquisition systems. For the first time, a target of mixed californium (51% ^{249}Cf, 13% ^{250}Cf and 36% ^{251}Cf) recovered from decayed ^{252}Cf sources was produced and irradiated with an intense ^{48}Ca beam. The observation of a new decay chain of ^{294}Og is reported. The prospects for reaching new isotopes ^{295,296}Og are discussed.

Radiochim. Acta **99**, 429–439 (2011) / **DOI** 10.1524/ract.2011.1860

Synthesis of the heaviest elements in ^{48}Ca-induced reactions

By Yu. Oganessian*

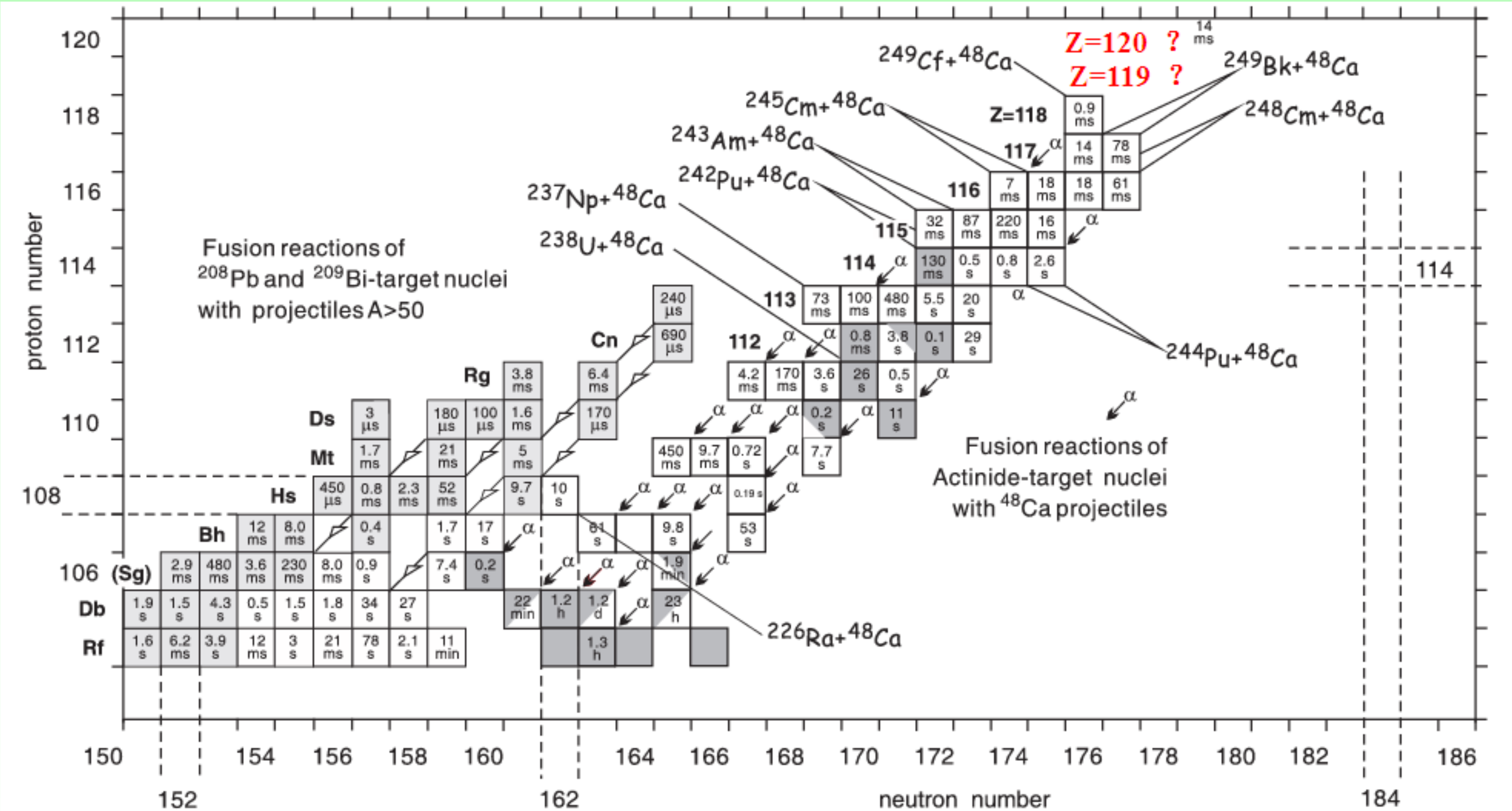


Fig. 5. Chart of the heaviest nuclides with $Z \geq 104$ and $N \geq 151$. The symbols are given in the right lower corner of the figure. To avoid making the figure too complicated, the squares contain the half-lives (without errors) only. For the nuclei synthesized in cold fusion reactions the values of $T_{1/2}$ are taken from the compilation of the published data; for the products of the reaction Act. + ^{48}Ca – the data are from Table 1.

The Discovery of Isotopes: A Complete Compilation

Michael Thoennessen, Springer, 2016

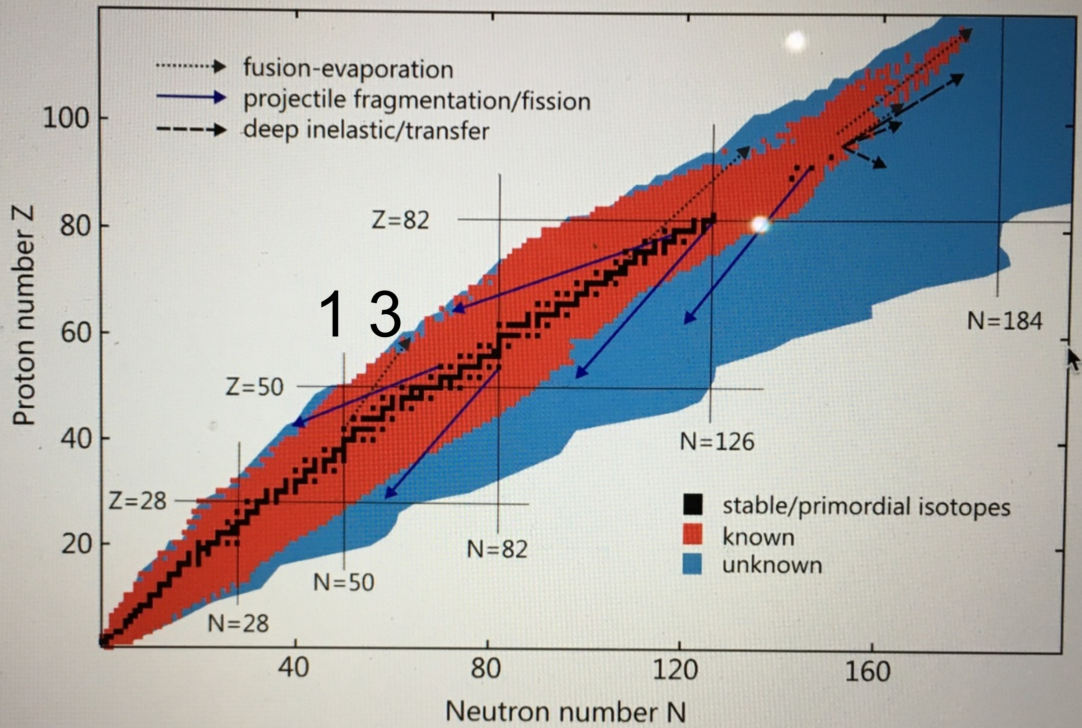


Fig. 17.3 Chart of nuclides. Stable and primordial nuclides are shown in *black*, presently known isotopes in *red* and unknown isotopes predicted to exist by Erler et al. [12] in *light blue*. Possible production mechanisms to discover new nuclides in the different regions are indicated by *arrows*.

Up to the end of 2017，3252 nuclides have been found。Natural nuclides: 288（Stable: 254, unstable: 34），the others are man made radioactive isotopes。

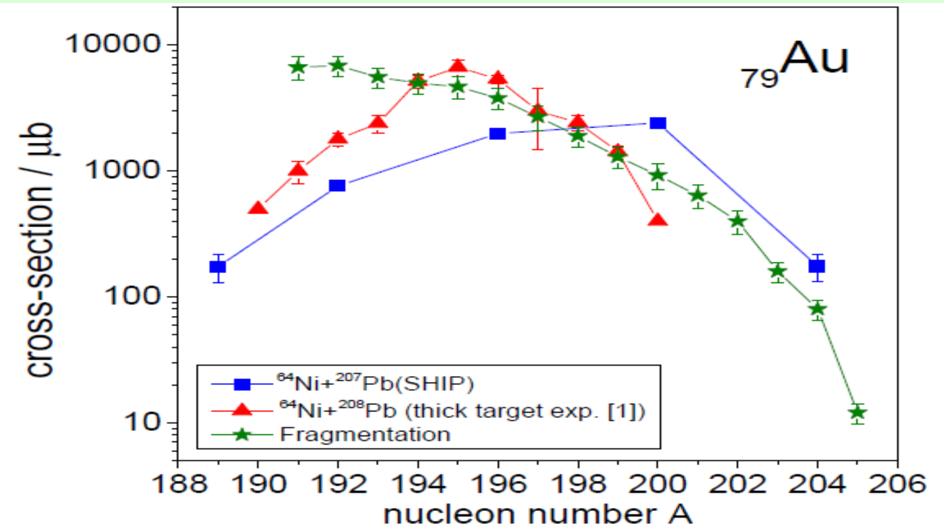
New isotopes produced in $^{238}U+^{9}Be$ at 1GeV/A J. Kurcewicz et al. PLB 717 (2012) 371 - 375

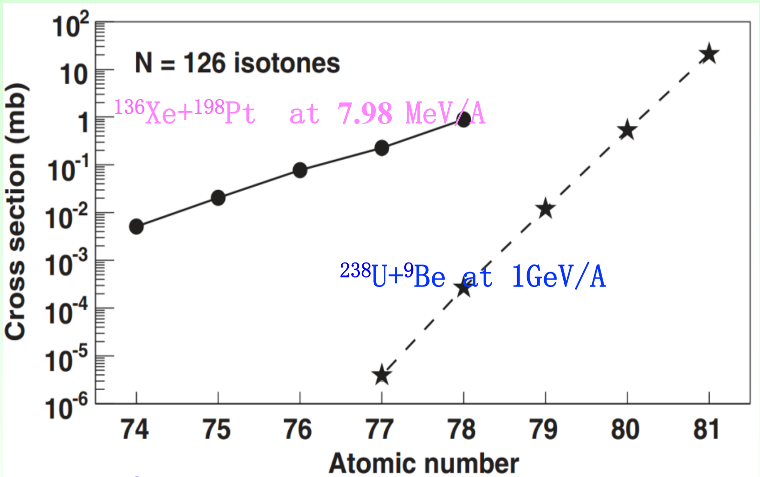
Isotope	σ (nb)	Isotope	σ (nb)	Isotope	σ (nb)	Isotope	σ (nb)
^{157}Nd*	980(40)	^{168}Gd	78(5)	^{176}Er	68(5)	^{188}Lu	0.010(3)
^{158}Nd*	201(11)	^{169}Gd	10.6(15)	^{177}Er	18(2)	^{190}Hf*	0.027(13)
^{159}Nd	39(4)	^{170}Gd	2.6(8)	^{178}Er	5.5(9)	^{193}Ta	0.017(5)
^{160}Nd	9.5(22)	^{169}Tb	751(28)	^{178}Tm*	24(3)	^{194}Ta	0.0037(19)
^{161}Nd	3.0(17)	^{170}Tb	99(6)	^{179}Tm	1.21(18)	^{195}W*	0.049(1)
^{160}Pm	518(36)	^{171}Tb	14(2)	^{180}Tm	4.5(9)	^{196}W	0.018(4)
^{161}Pm	161(9)	^{172}Tb	1.0(4)	^{181}Tm	0.6(3)	^{197}W	0.0034(17)
^{162}Pm	25(3)	^{171}Dy	441(18)	^{181}Yb*	2.3(3)	^{198}Re*	0.028(7)
^{163}Pm	4.5(15)	^{172}Dy	121(7)	^{182}Yb*	0.45(10)	^{199}Re	0.0076(27)
^{163}Sm	134(11)	^{173}Dy	18(2)	^{183}Yb	0.21(5)	^{202}Os	0.0044(20)
^{164}Sm	42(4)	^{174}Dy	1.9(6)	^{184}Yb	0.028(9)	^{203}Os	0.0025(18)
^{165}Sm	7.8(16)	^{173}Ho	341(15)	^{185}Yb	0.007(3)	^{205}Ir	0.003(2)
^{167}Eu	7.1(12)	^{174}Ho	98(6)	^{185}Lu*	0.22(7)	^{206}Pt	0.033(11)
^{168}Eu	2.0(8)	^{175}Ho	22(2)	^{186}Lu*	0.15(4)	^{207}Pt	0.008(3)
^{167}Gd	625(23)	^{176}Ho	2.2(6)	^{187}Lu	0.043(9)	^{208}Pt	0.0027(15)

fission

fragmentation

New neutron-rich isotopes of the elements between $60 \leqslant Z \leqslant 69$ are produced dominantly by fission, while fragmentation plays a dominant role in the production of the isotopes of the elements above Z = 72.



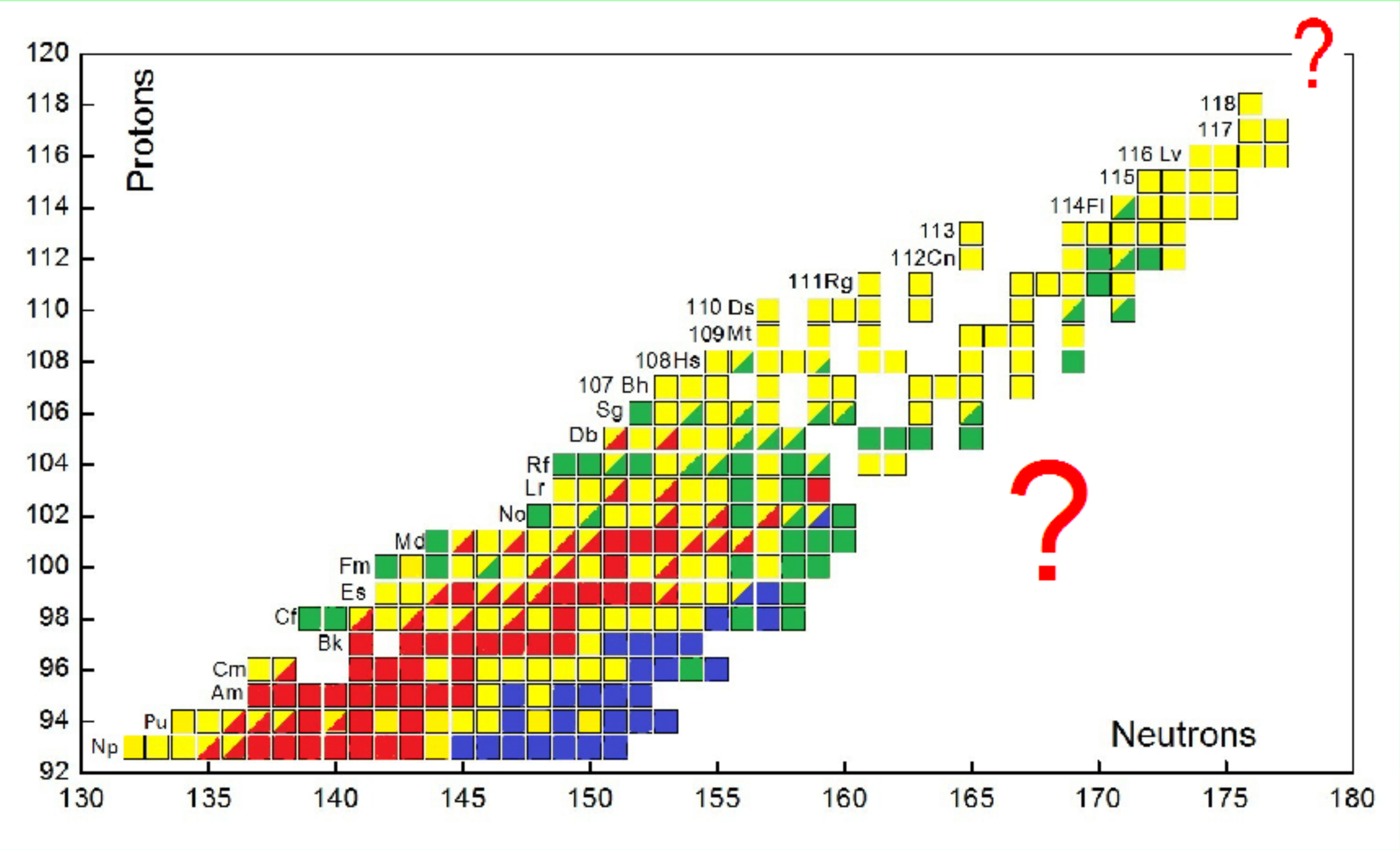


S. Heinz, O. Beliuskina, Jour. Conf. Ser. 515, 012007 (2014)

for neutron-rich nuclei:

$\sigma_{Transfer} \geq \sigma_{Fragmentation}$

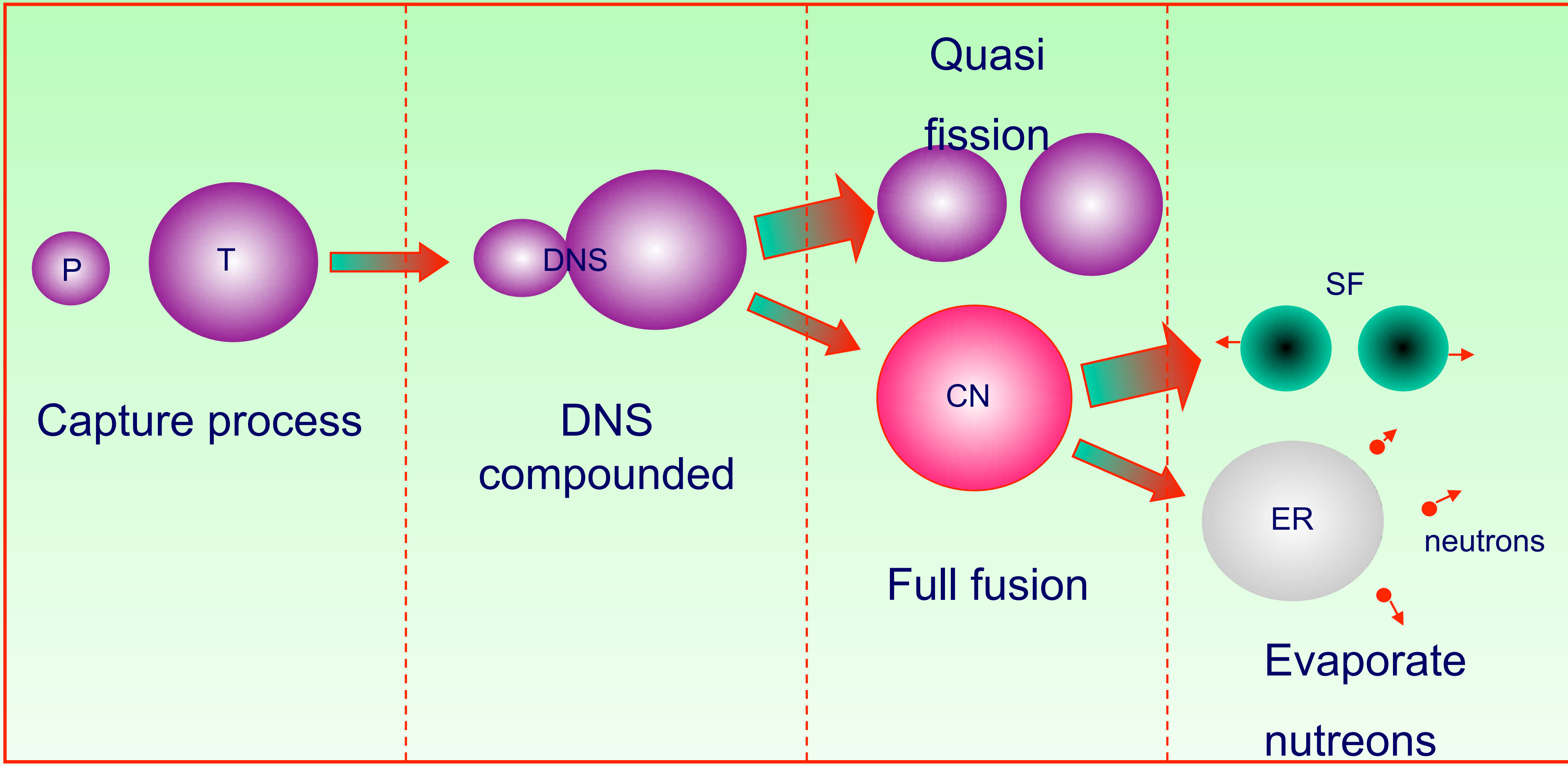
Y. X. Watanabe, et al., Phys. Rev. Lett. 115, 172503(2015)



superheavy and n-rich nuclei - transuranium

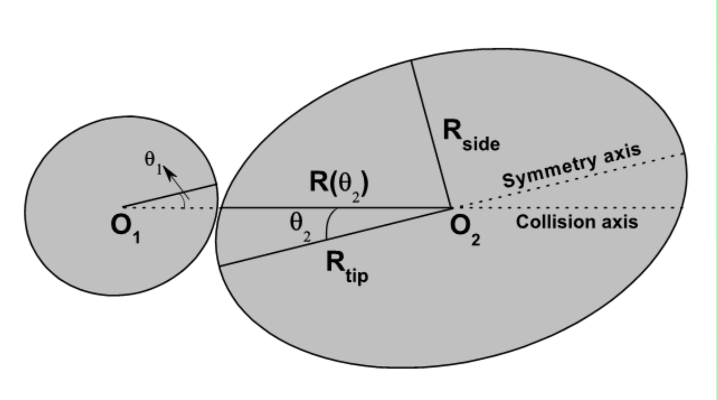
Fusion-Evaporation Reaction （DNS model）

$$\sigma_{\mathrm{ER}} = \sigma_{\mathrm{cap}} P_{\mathrm{CN}} W_{\mathrm{sur}}$$



Adamian, Antonenko, Scheid, and Volkov, NPA 627(1997)361, NPA 633(1998)409

A simple test



$$\sigma_{\rm ER} = \sigma_{\rm cap} P_{\rm CN} W_{\rm sur}$$

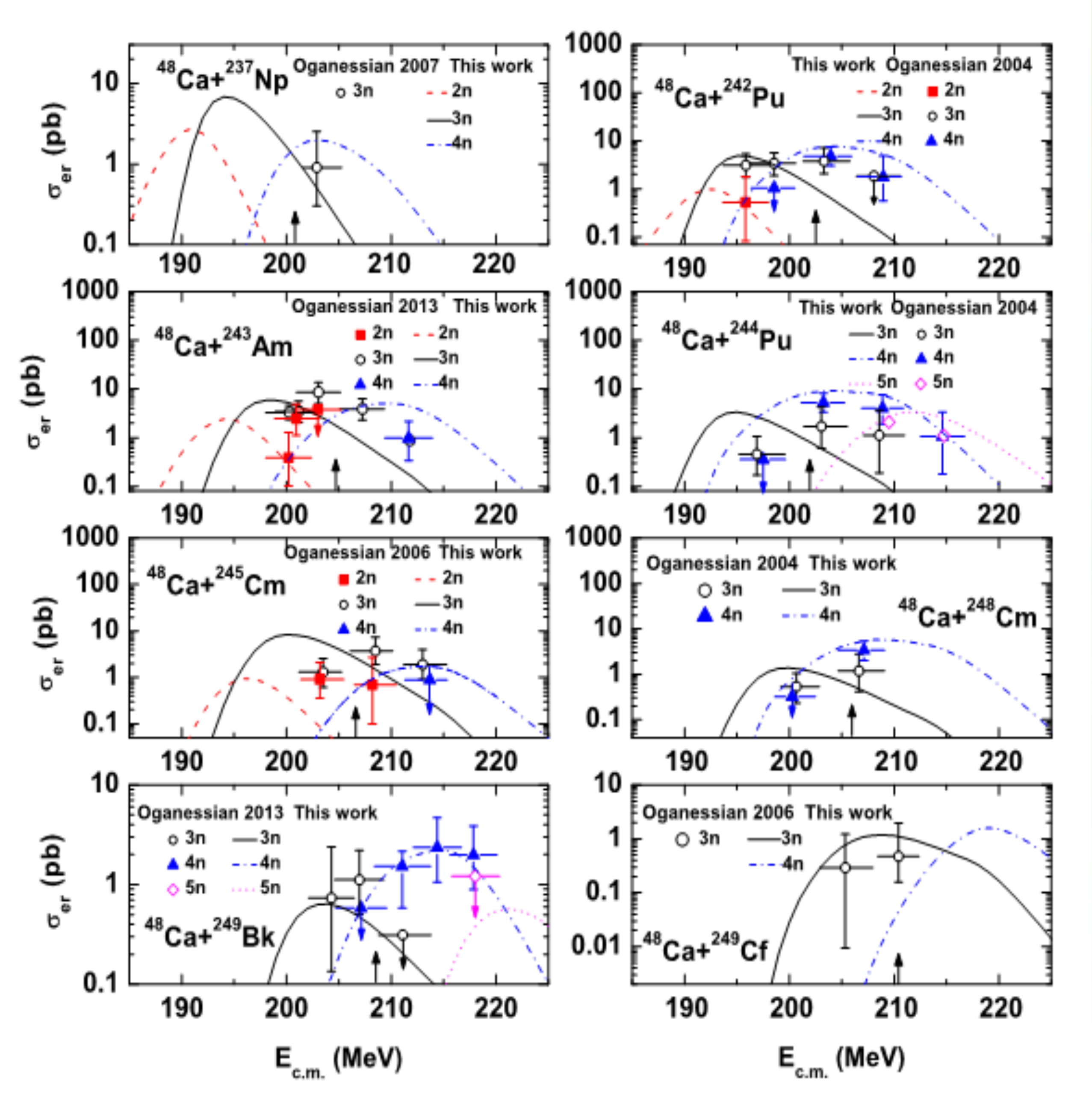
$$\sigma_{\rm cap}(E_{\rm c.m.}) = \frac{1}{4}\int_0^{\pi} \sin\theta_1\, d\theta_1 \int_0^{\pi} \sigma_{\rm cap}(E_{\rm c.m.},\theta_1,\theta_2) \sin\theta_2\, d\theta_2.$$

$$\sigma_{\rm cap}(E_{\rm c.m.},\theta_1,\theta_2) = \frac{\pi\hbar^2}{2\mu E_{\rm c.m.}} \sum_J (2J+1) T(E_{\rm c.m.},\theta_1,\theta_2,J).$$

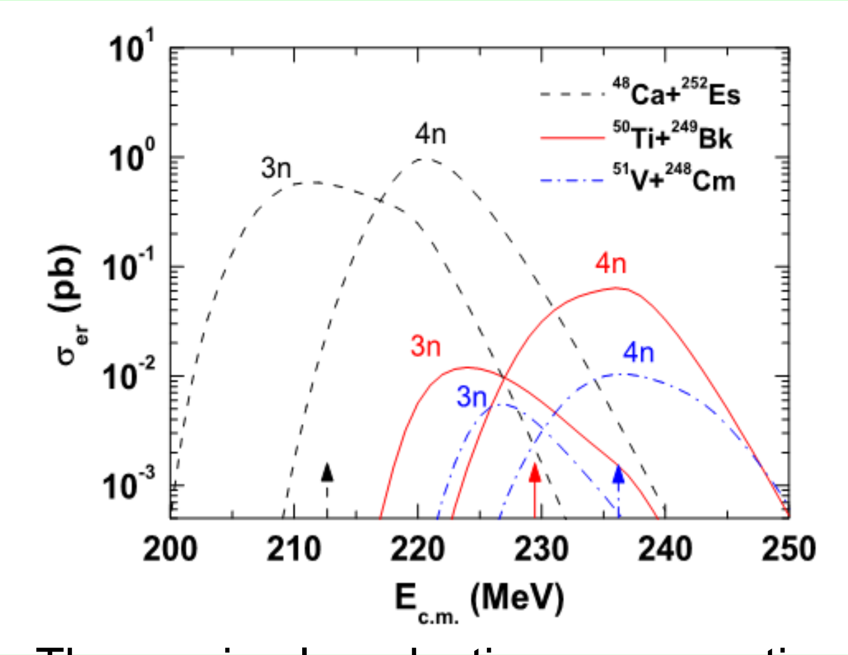
$$P_{\rm CN}(E^*,\theta_1,\theta_2) = \exp\left(\frac{C_0}{\eta}\right) \exp[C_1 \Delta R(\theta_1,\theta_2)] \times \exp\left(C_2 \frac{R(\theta_2) - R_{\rm side}}{R_{\rm tip} - R_{\rm side}}\right) \exp(C_3 E^*)$$

$W_{\rm sur}$ HIVAP code **W. Reisdorf, Z. Phys. A 300, 227 (1981)**

Comparison of the calculated ER cross sections with the experimental data for Z=113-118



Production cross sections of Z=119 and 120

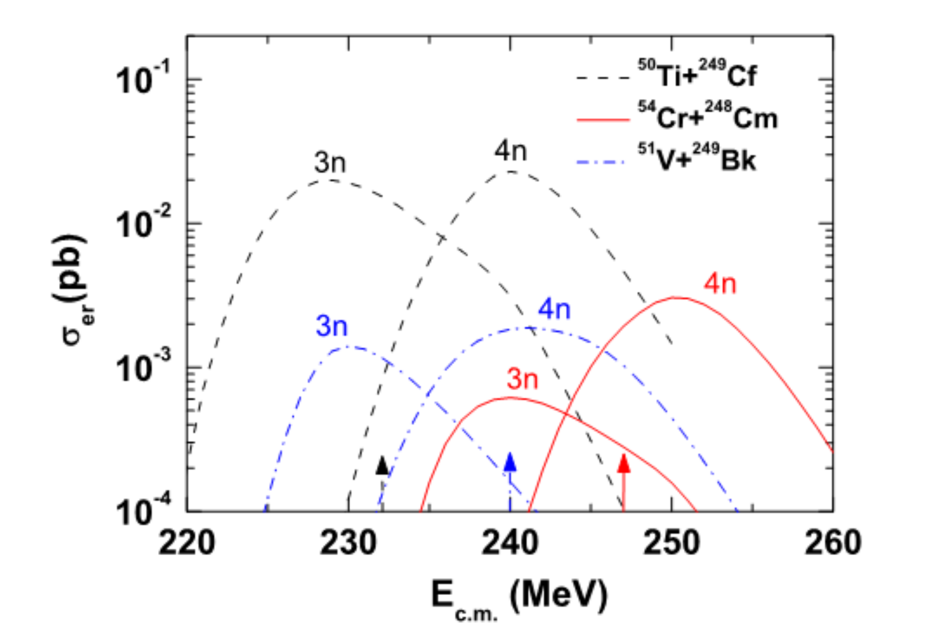


The maximal production cross sections for Z=119:

$^{48}\mathrm{Ca} + {}^{252}\mathrm{Es}$	0.96 pb
$^{50}\mathrm{Ti} + {}^{249}\mathrm{Bk}$	0.064 pb
$^{51}\mathrm{V} + {}^{248}\mathrm{Cm}$	0.01 pb

The maximal production cross sections for Z=120:

$^{50}\mathrm{Ti} + {}^{249}\mathrm{Cf}$	0.029 pb
$^{54}\mathrm{Cr} + {}^{248}\mathrm{Cm}$	0.003 pb
$^{51}\mathrm{V} + {}^{249}\mathrm{Bk}$	0.0018 pb



L Zhu, WJ Xie, FS Zhang, Physics Review C 89 (2014) 024615

PHYSICAL REVIEW C **79**, 024603 (2009)

Attempt to produce element 120 in the $^{244}Pu + ^{58}Fe$ reaction

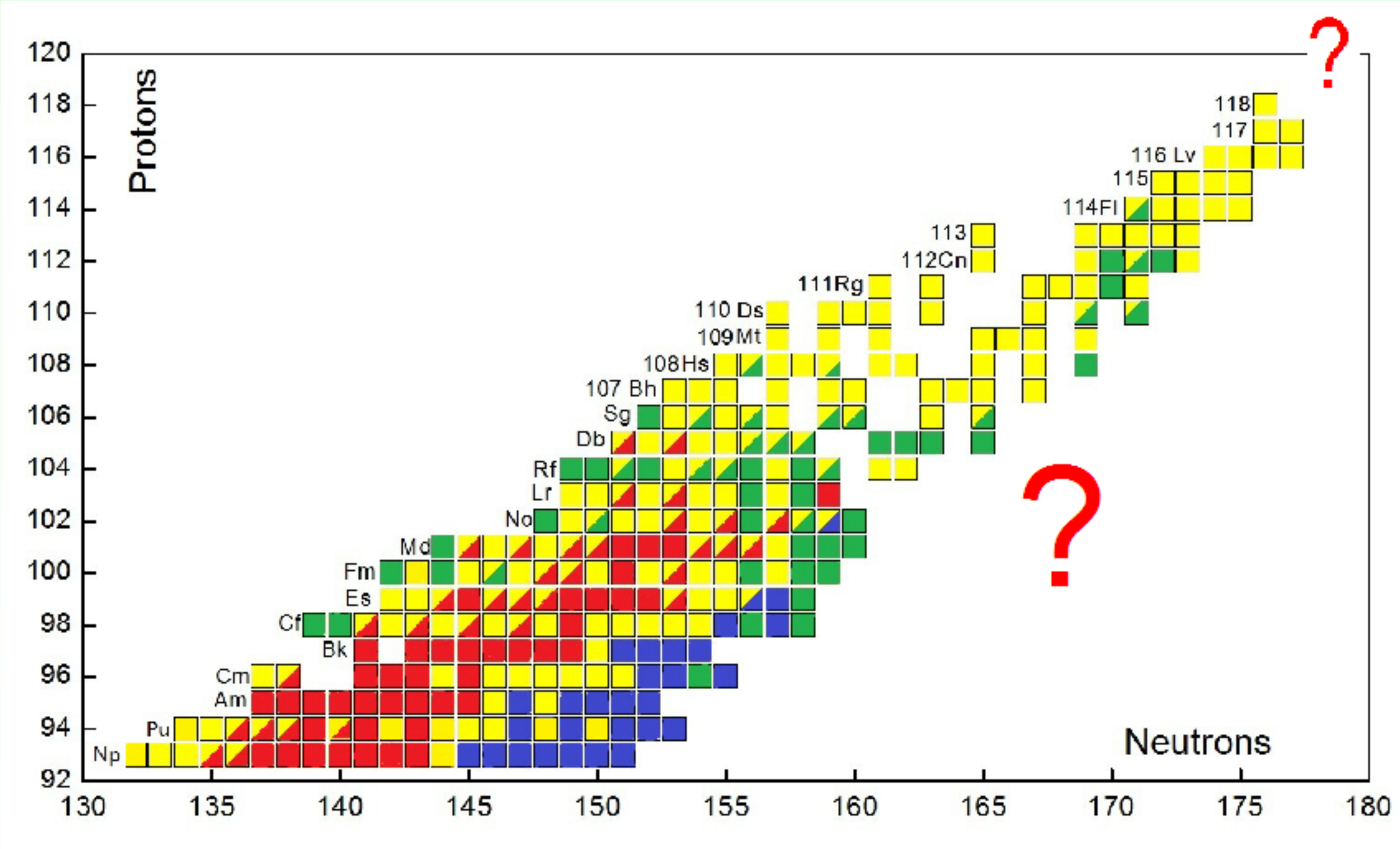
Yu. Ts. Oganessian, V. K. Utyonkov, Yu. V. Lobanov, F. Sh. Abdullin, A. N. Polyakov, R. N. Sagaidak, I. V. Shirokovsky, Yu. S. Tsyganov, A. A. Voinov, A. N. Mezentsev, V. G. Subbotin, A. M. Sukhov, K. Subotic, V. I. Zagrebaev, and S. N. Dmitriev
Joint Institute for Nuclear Research, RU-141980 Dubna, Russian Federation

R. A. Henderson, K. J. Moody, J. M. Kenneally, J. H. Landrum, D. A. Shaughnessy, M. A. Stoyer, N. J. Stoyer, and P. A. Wilk
Lawrence Livermore National Laboratory, Livermore, California 94551, USA

(Received 24 October 2008; published 5 February 2009)

An experiment aimed at the synthesis of isotopes of element 120 has been performed using the $^{244}Pu(^{58}Fe,xn)^{302-x}120$ reaction. No decay chains consistent with fusion-evaporation reaction products were observed during an irradiation with a beam dose of 7.1×10^{18} 330-MeV ^{58}Fe projectiles. The sensitivity of the experiment corresponds to a cross section of 0.4 pb for the detection of one decay.

Further attempts to synthesize element 120 in this reaction would require an increased sensitivity of the experiment. To enhance the production of element 120, the choice of a more mass-asymmetric reaction like $^{248}Cm + ^{54}Cr$ (or even $^{249}Cf + ^{50}Ti$) would be preferable.



superheavy and n-rich nuclei - transuranium

More references (before)

1.Kratz, Norris and Seaborg, Mass-yield distribution in the reaction of 84Kr(605MeV) +238U, PRL33(1974)502, 156 nuclides

2. Otto, Fowlwe, Lee, and Seaborg, Mass yield distribution in the reaction of 136Xe(1150) +238U, PRL36(1976)135, 131 nuclides

3. Schadel, Kratz, Ahrens, Bruchle, Franz, Gaggeler, Warnecke, and Wirth, Isotop distributions in the reactoin of 238U(1785)+238U, PRL41(1978)469, enhancement

4.Kratz, Bruchle, Folger, Gaggeler, Schadel, Summerer, and Wirth, Search for superheavy elements in damped collisions 238U(7.3MeV/u)+238U, PRC33(1986)504, cross-section limits 10pb

5. Shen, Albinski, Gobbi, Gralla, Hildenbrand, and Herrmann, Fission and quasifission in U-induced reaction, PRC36(1987)115, mass drift

More references (recently)

1. Souliotis, Veselsky, Galanopoulos et al., Approaching neutron-rich nuclei toward the r-process path in peripheral heavy-ion collisions at 15 MeV/nucleon, PRC84 (2011)064607, 86Kr(15 MeV/u) +58,64Ni, 112,124Sn

2. Kratz, Loveland, and Moody, Syntheses of trans-U isotops with Z=<103 in multi-nucleon transfer reactions, NPA2015

3. Watanabe et al, Pathways for the production of n-rich isotopes around N=126 shell closure, 136Xe(8MeV/u) +198Pt, PRL15(2015)172503

4. Vogt et al, Light and heavy transfer products in 136Xe+238U multinucleon transfer reactions, PRC92(2015)024619, PRISMA+AGATA

5. Barrett, Loveland, et al, The 136Xe(Ecm=450MeV) + 208Pb reaction: A test of models of multi-nucleon transfer reactions, PRC91(2015)064615, 200 P+ T-like fragments

…………………………..

Recent Exp by W. Loveland

The ^{136}Xe + ^{208}Pb reaction: A test of models of multi-nucleon transfer reactions

J. S. Barrett, R. Yanez, W. Loveland

Department of Chemistry, Oregon State University, Corvallis, Oregon 97331 USA

S. Zhu, A. D. Ayangeakaa, M. P. Carpenter,
J. P. Greene, R. V. F. Janssens, T. Lauritsen

Physics Division, Argonne National Laboratory, Argonne, Illinois 60439 USA

E. A. McCutchan, A. A. Sonzogni

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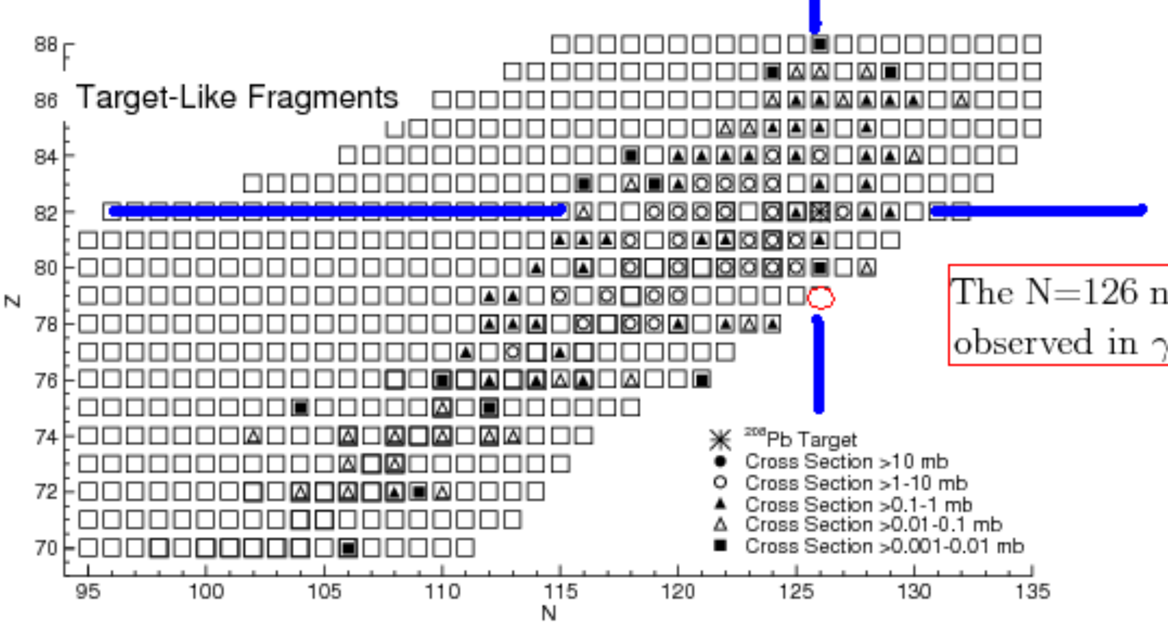
C. J. Chiara* and J. L. Harker

Physics Division, Argonne National Laboratory, Argonne, Illinois 60439 USA and Department of Chemistry and Biochemistry, University of Maryland, College Park, Maryland 20742 USA

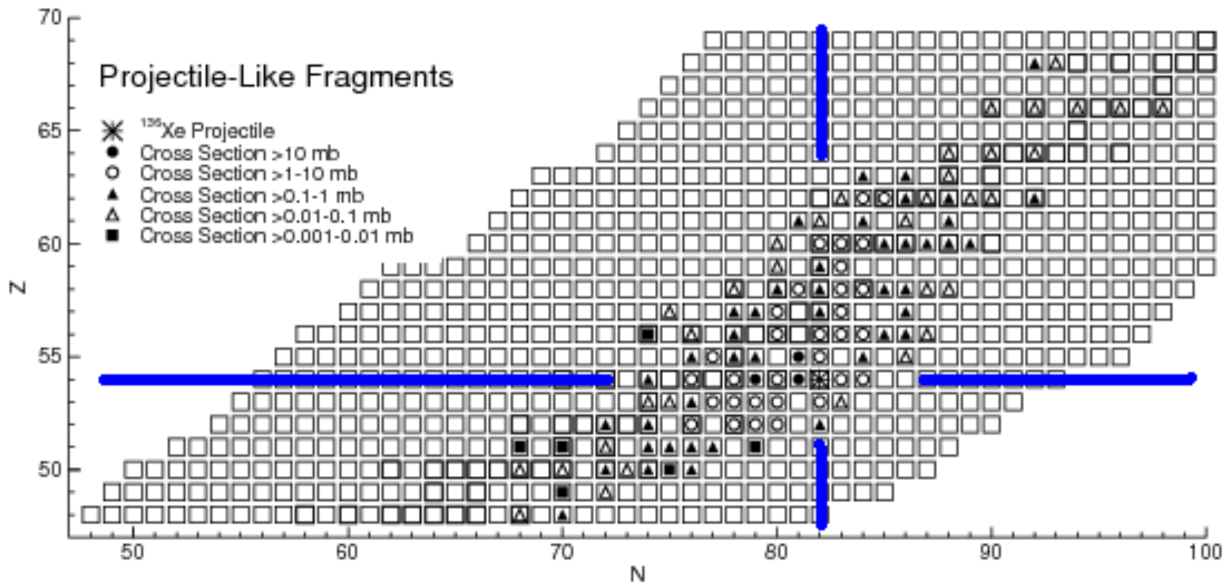
W. B. Walters

Department of Chemistry and Biochemistry, University of Maryland, College Park, Maryland 20742 USA



The N=126 nuclide ^{205}Au was observed in $\gamma\gamma$ coincidence data

Distribution of TLFs produced in the reaction of $E_{c.m.}$=450 MeV ^{136}Xe with a thick ^{208}Pb target.



Distribution of PLFs produced in the reaction of $E_{c.m.}$=450 MeV ^{136}Xe with a thick ^{208}Pb target.

IOP Publishing Journal of Physics G: Nuclear and Particle Physics

J. Phys. G: Nucl. Part. Phys. **42** (2015) 085102 (9pp) doi:10.1088/0954-3899/42/8/085102

Production of heavy neutron-rich nuclei in transfer reactions within the dinuclear system model

Long Zhu[1,2], Zhao-Qing Feng[3] and Feng-Shou Zhang[1,2,4,5]

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[2] Beijing Radiation Center, Beijing 100875, People's Republic of China
[3] Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, People's Republic of China
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E-mail: fszhang@bnu.edu.cn

Received 15 March 2015, revised 29 April 2015
Accepted for publication 7 May 2015
Published 12 June 2015

CrossMark

L. Zhu et al. JPG 42 (2015)085102

$^{136}_{54}Xe + ^{208}_{82}Pb$, 514 MeV

$^{238}_{92}U + ^{248}_{96}Cm$, 800 MeV

For target-like(Z=82) fragments,
Transfer 2, 4, and 6 protons

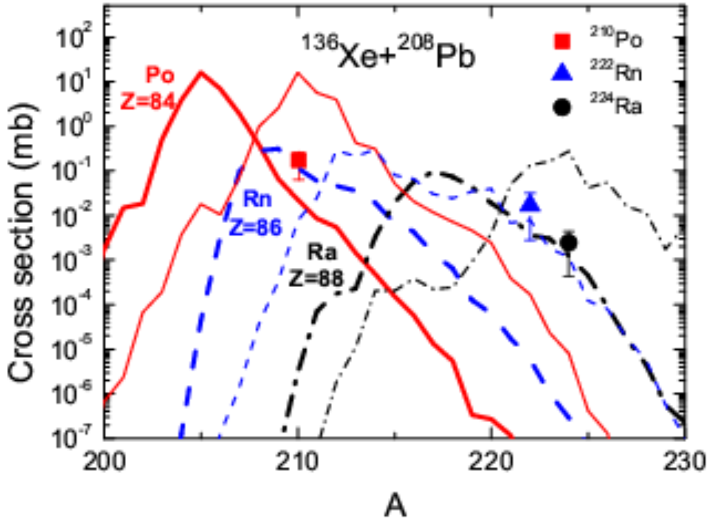

FIG. 3. The comparison of calculated production cross sections for primary (thin lines) and survived (thick lines) isotopes of Po (solid lines), Rn (dashed lines), and Ra (dash-dotted lines) with the experimental data [23] in the reaction ^{136}Xe+^{208}Pb at $E_{c.m.}$ = 514 MeV. The solid points correspond to the experimental cross sections for ^{210}Po (square), ^{222}Rn (triangle), and ^{224}Ra (circle).

Exp. Data:
Kozulin et al., PRC86 (2012)044611

For target-like(Z=96) fragments,
Transfer 3, 4, and 5 protons

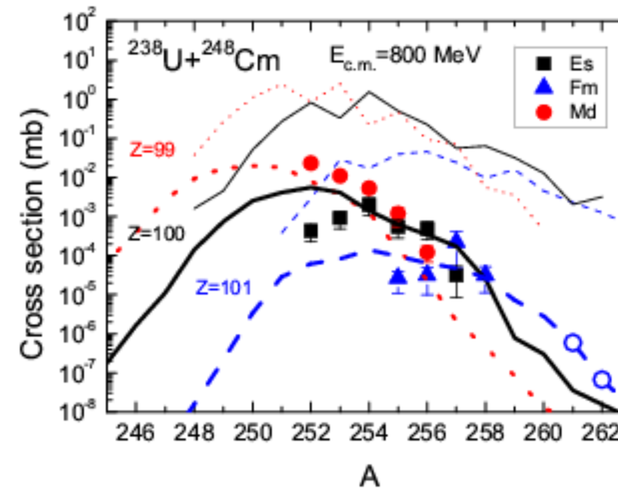

FIG. 4. Cross sections for the formation of isotopes of Einsteinium (Z = 99) (dotted lines), Fermium (Z = 100) (solid lines), Mendelevium (Z = 101) (dashed lines), and Nobelium (Z = 102) (dash-dotted line) in the reaction ^{238}U+^{248}Cm at $E_{c.m.}$ = 800 MeV. The thin and thick lines are distribution of primary and final fragments, respectively. The experimental data are taken from Ref. [24].

Exp. Data:
Schadel et al., PRL48 (1982)852

$^{176}_{70}Yb + ^{238}_{92}U$

For projectile like $_{70+z}Yb_{106+N}$

Transfer
7 protons, Eu
5 protons, Tb
3 protons, Ho
0 protons, Yb

For un know n-rich nuclei
$^{A}_{63}Eu$, A=165~168

$^{165}_{63}Eu$, N=102, ~ μb
$^{166}_{63}Eu$, N=103, ~0.5 μb
$^{167}_{63}Eu$, N=104, ~10 pb
$^{168}_{63}Eu$, N=105, ~ pb

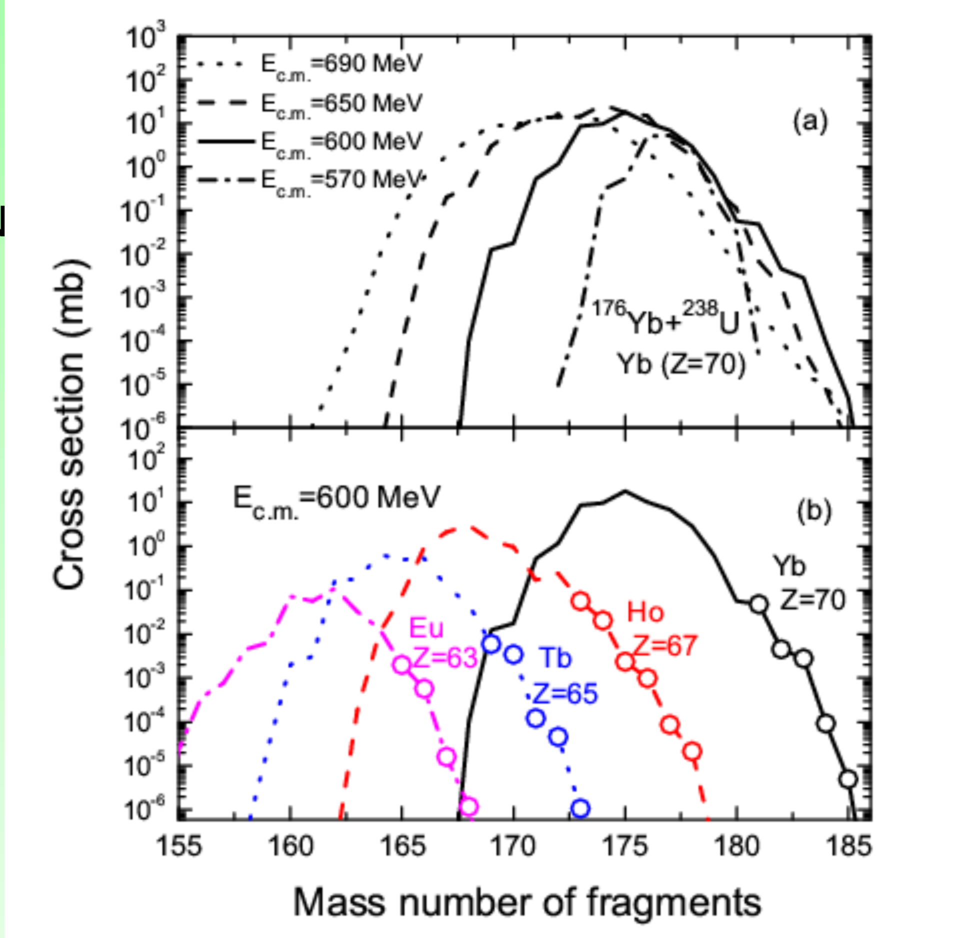

FIG. 5. (a) Production cross sections of isotopes of Yb in the transfer reaction $^{176}Yb+^{238}U$ at $E_{c.m.}$ = 570 (dash-dotted line), 600 (solid line), 650 (dashed line), and 690 MeV (dotted line). (b) Cross sections for the formation of isotopes of elements Ytterbium (solid line), Holmium (dashed line), Terbium (dotted line), and Europium (dash-dotted line) in the reaction $^{176}Yb+^{238}U$ at $E_{c.m.}$ = 600 MeV. The circles denote the unknown neutron-rich nuclei.

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2.1 The Improved Quantum Molecular Dynamics Model and MNT

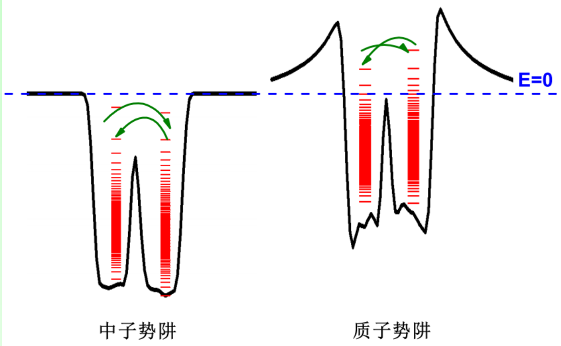
$$H = T + U_{loc} + U_{Coul},$$

$$\dot{\mathbf{r}}_i = \frac{\partial \langle H \rangle}{\partial \mathbf{p}_i}, \dot{\mathbf{p}}_i = -\frac{\partial \langle H \rangle}{\partial \mathbf{r}_i}.$$

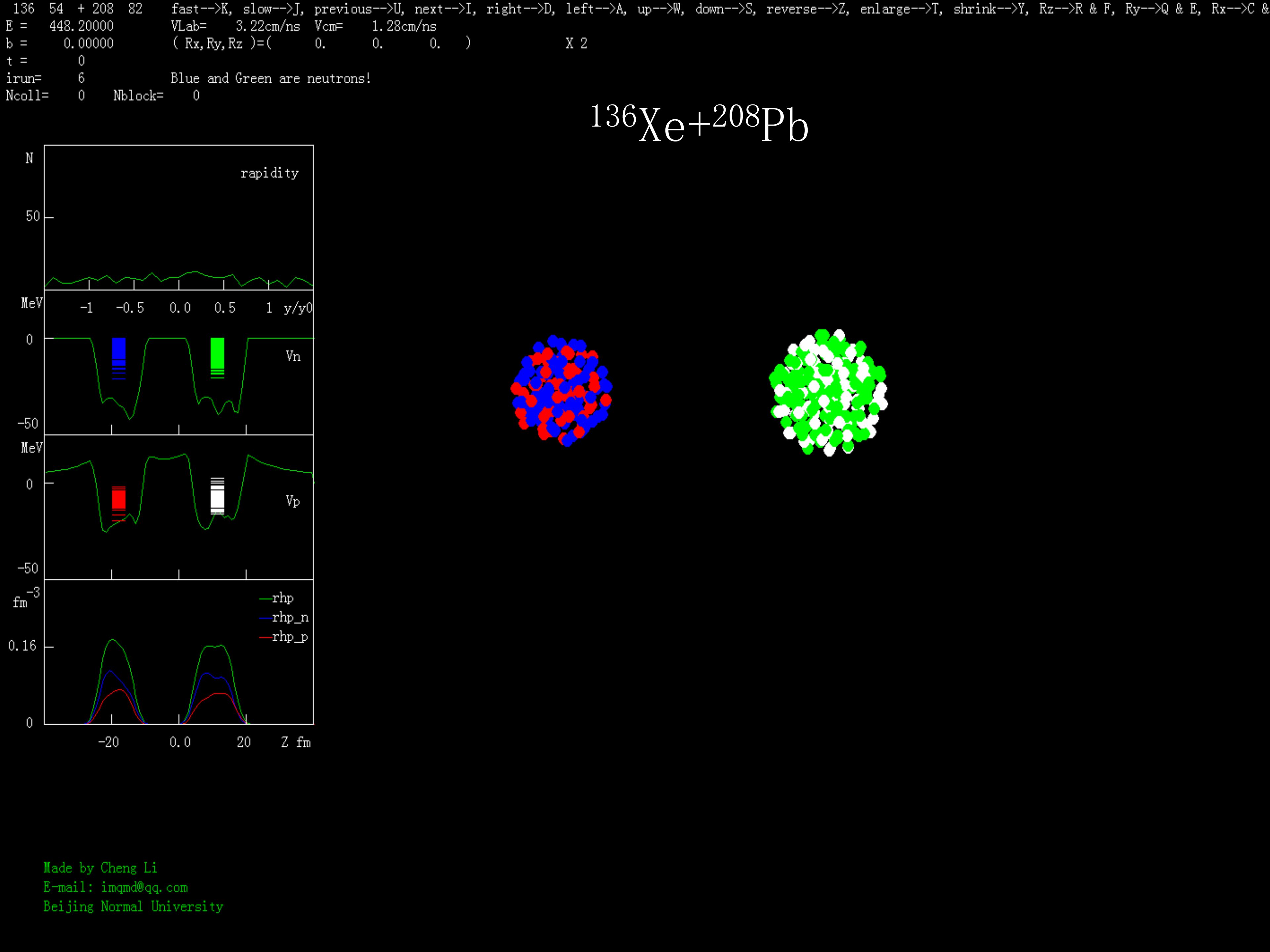
$$P_{block} = 1 - (1-\omega_i)(1-\omega_j).$$

$$U_{loc} = \int V_{loc} d\boldsymbol{r},$$

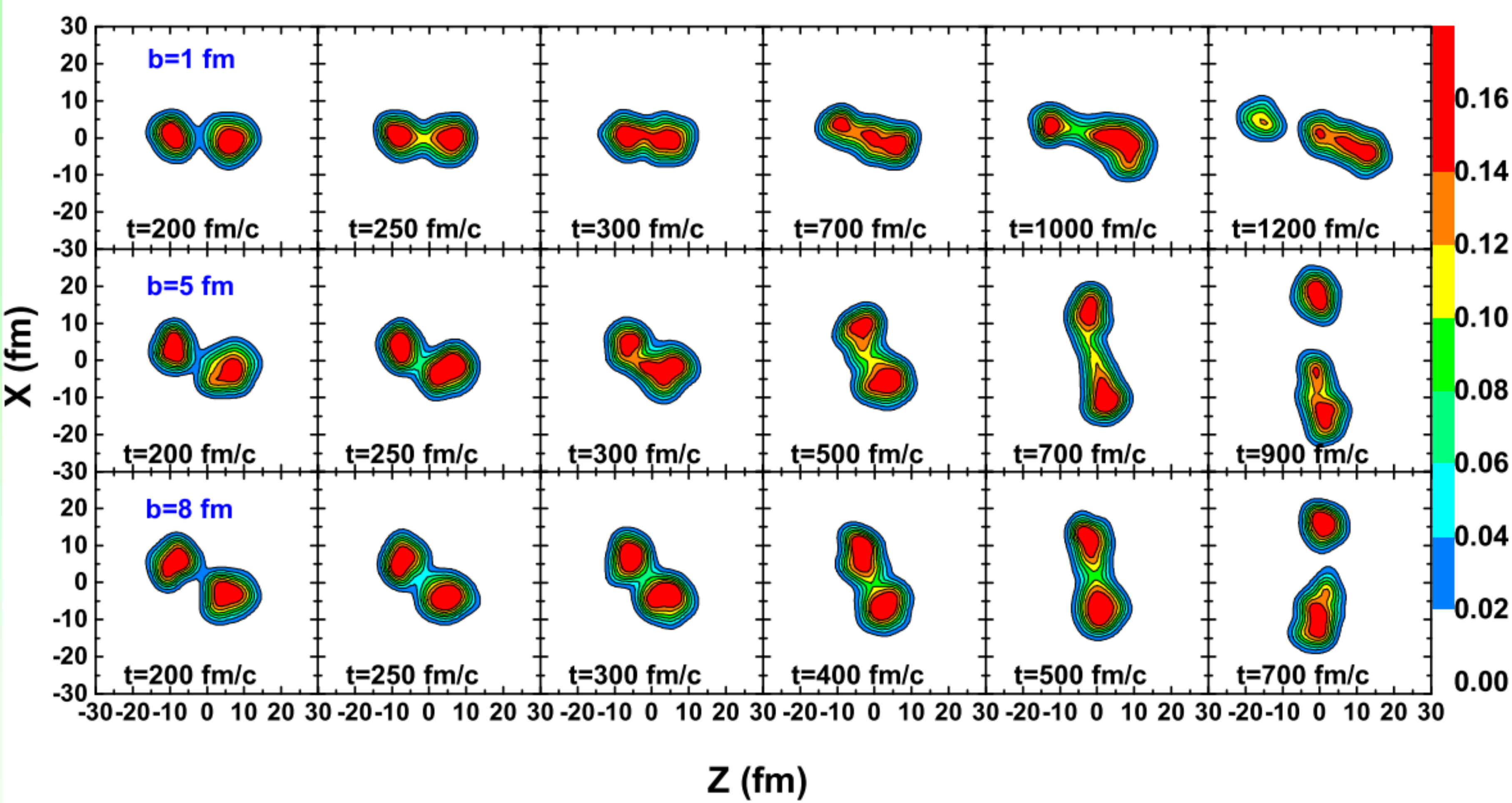
$$V_{loc} = \frac{\alpha}{2}\frac{\rho^2}{\rho_0} + \frac{\beta}{\gamma+1}\frac{\rho^{\gamma+1}}{\rho_0^{\gamma}} + \frac{g_{sur}}{2\rho_0}(\nabla\rho)^2 + \frac{C_s}{2\rho_0}(\rho^2 - \kappa_s(\nabla\rho)^2)\delta^2 + g_\tau\frac{\rho^{\eta+1}}{\rho_0^{\eta}}.$$



参数	α	β	γ	g_0	g_τ	η	C_S	κ_s	ρ_0	σ_0	σ_1
	(MeV)	(MeV)		$(MeV\,fm^2)$	(MeV)		(MeV)	(fm^2)	(fm^{-3})	(fm)	(fm)
$IQ1$	-310	258	7/6	19.8	9.5	2/3	32.0	0.08	0.165	0.49	0.16
$IQ2$	-356	303	7/6	7.0	12.5	2/3	32.0	0.08	0.165	0.88	0.09
$IQ3$	-207	138	7/6	18.0	14.0	5/3	32.0	0.08	0.165	0.94	0.018

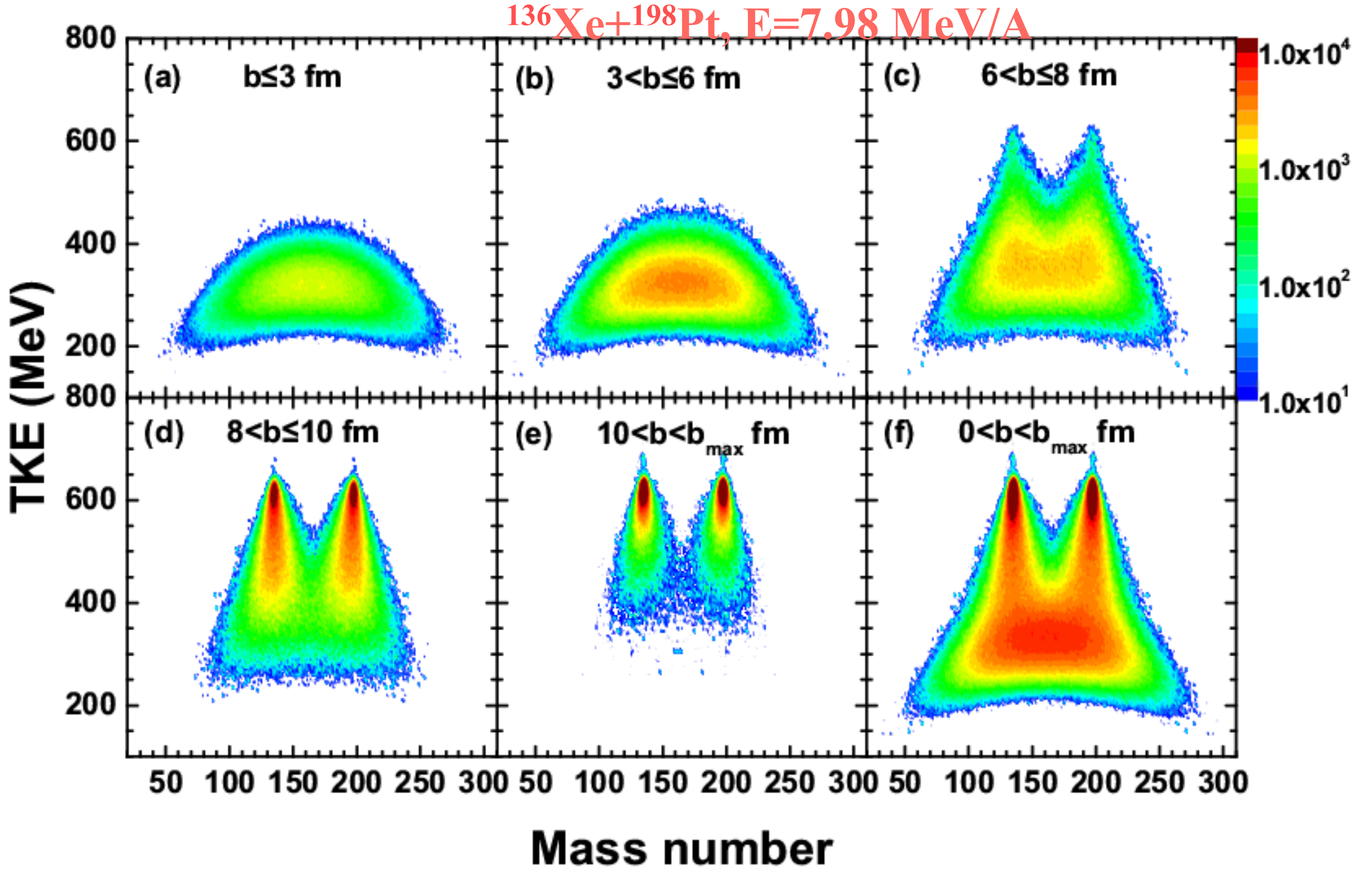

136 54 + 208 82
fast-->K, slow-->J, previous-->U, next-->I, right-->D, left-->A, up-->W, down-->S, reverse-->Z, enlarge-->T, shrink-->Y, Rz-->R & F, Ry-->Q & E, Rx-->C &
E = 448.20000
VLab= 3.22cm/ns Vcm= 1.28cm/ns
b = 0.00000
(Rx,Ry,Rz)=(0. 0. 0.)
X 2
t = 0
irun= 6
Blue and Green are neutrons!
Ncoll= 0 Nblock= 0
136Xe+208Pb
N
rapidity
50
MeV
-1 -0.5 0.0 0.5 1 y/y0
0
Vn
-50
MeV
0
Vp
-50
fm-3
rhp
rhp_n
rhp_p
0.16
0
-20 0.0 20 Z fm
Made by Cheng Li
E-mail: imqmd@qq.com
Beijing Normal University

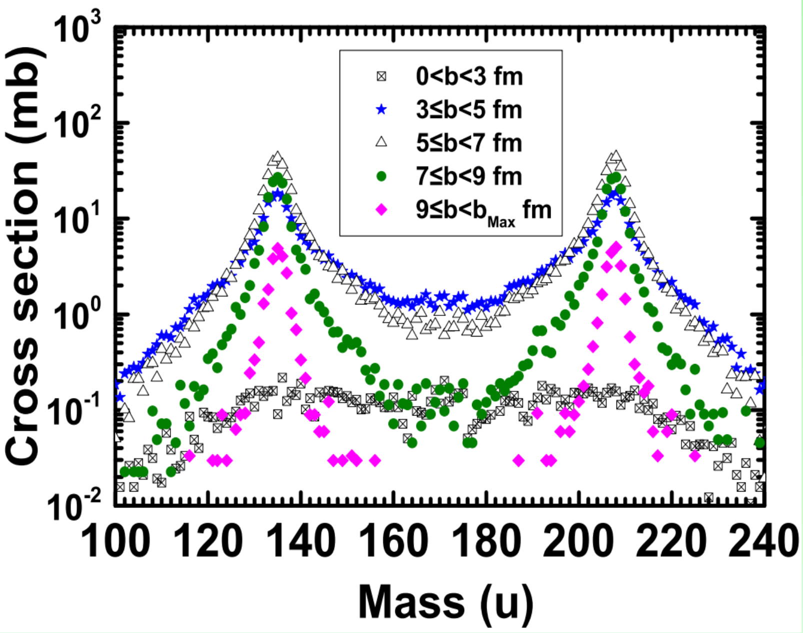
Density distribution of $^{136}Xe+^{208}Pb$ at Ec.m.=450 MeV



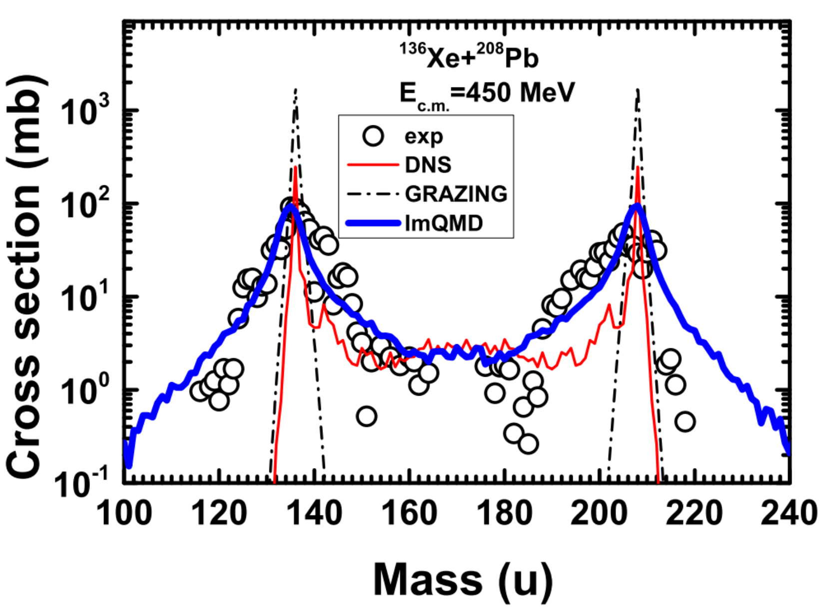
Li, Zhang, Li, Zhu, Tian, Wang, and Zhang, PRC 93, 014618 (2016)

Energy dissipation between the projectile and target





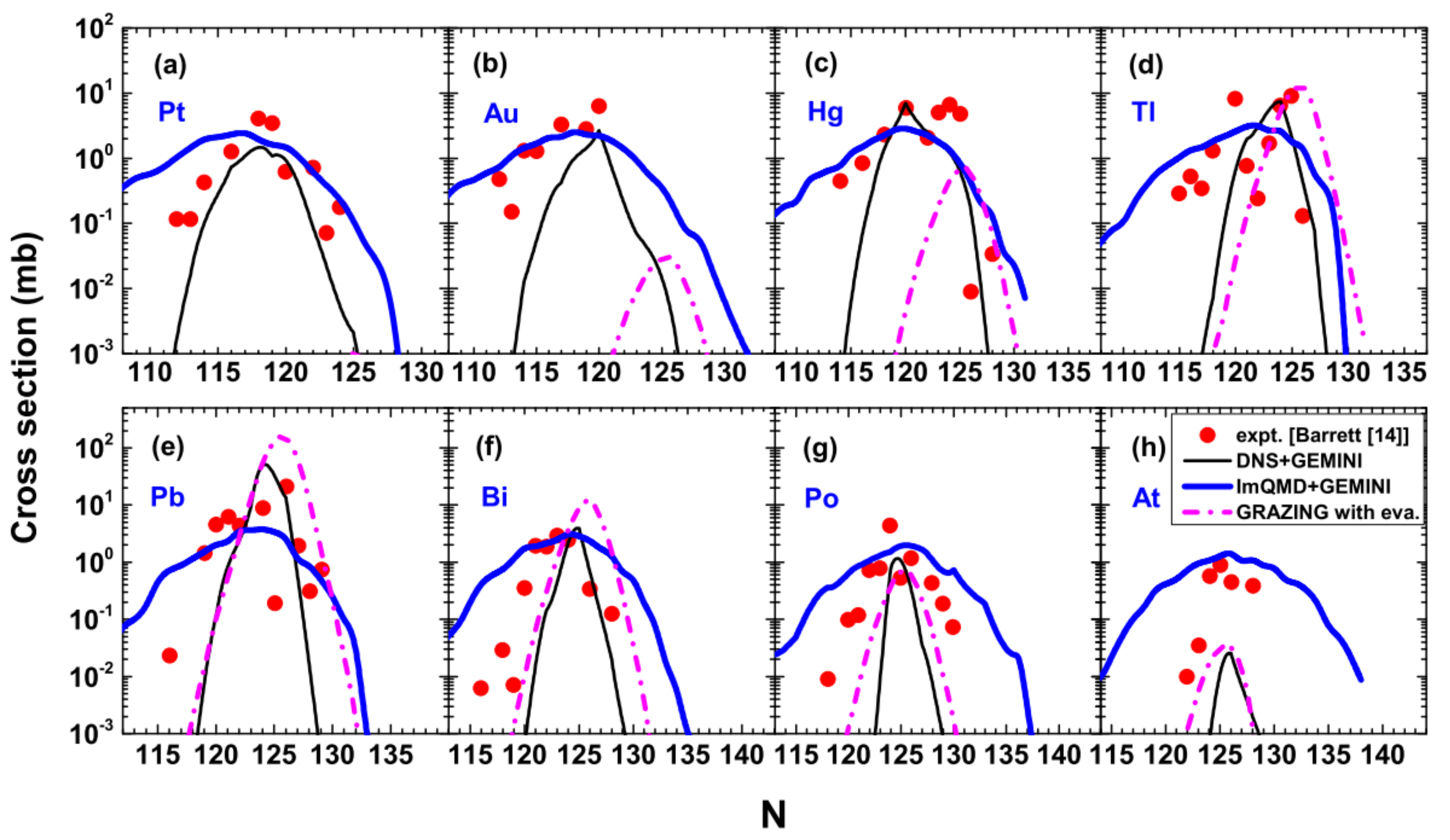
For different impact parameters



Comparison with exp. data

Li, Zhang, Li, Zhu, Tian, Wang, and Zhang, PRC 93, 014618 (2016)

Isotope distributions for $^{136}Xe+^{208}Pb$ at Ec.m. = 450 MeV



Li, Zhang, Li, Zhu, Tian, Wang, and Zhang, PRC 93, 014618 (2016)

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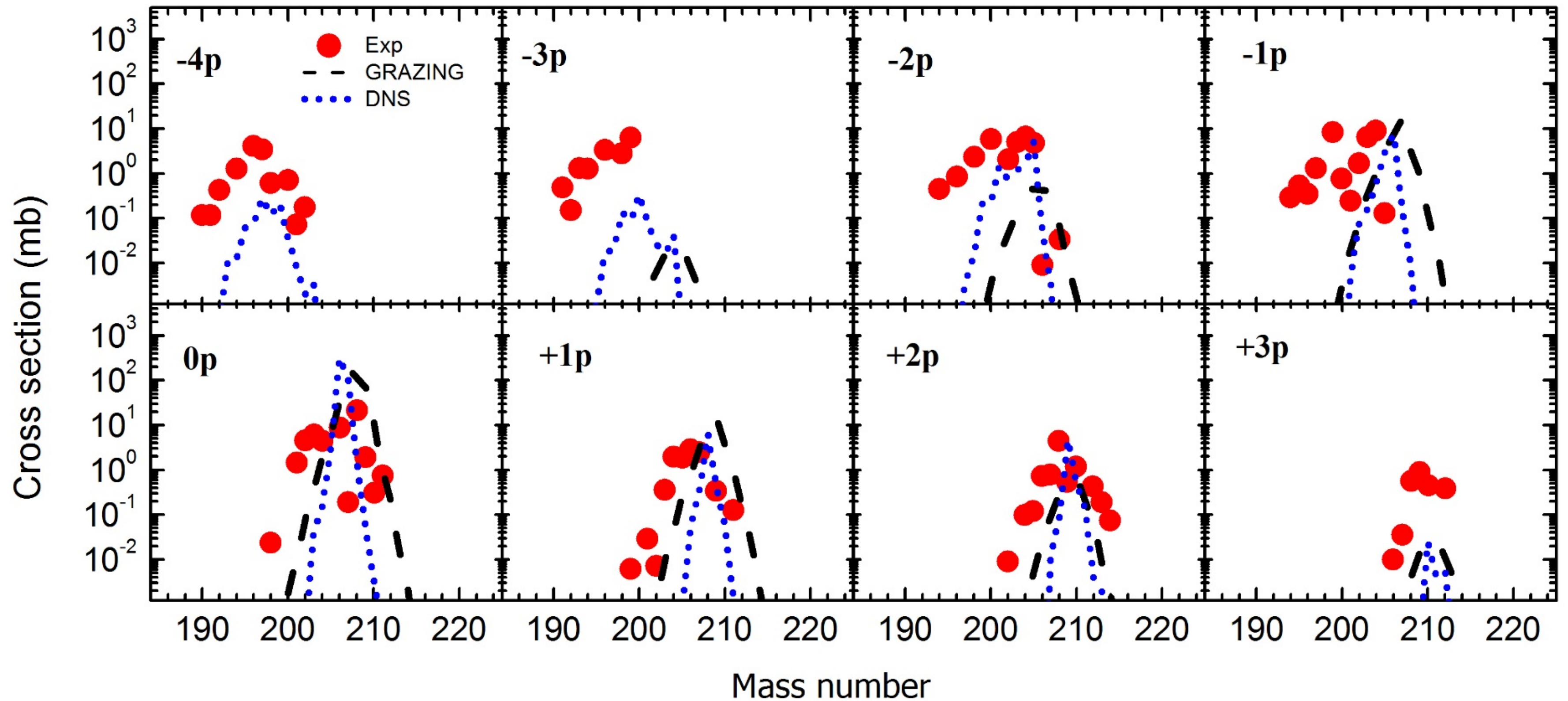
2.2 A combination of the Grazing Model and the Dinuclear System (DNS) Model

$^{136}Xe+^{208}Pb$, Ecm=450 MeV

Data: Barrett et al, PRC91(2015)06461



Results of GRAZING model is good for target-like products

Each model has Its limitations for the results.

Comparison of GRAZING and DNS: formula

GRAZING:
- deals with the nuclei scattered with probability (1-Pcap)
- quantum transition from one nuclei to another without capture

DNS:
- deals with the nuclei captured with probability Pcap
- transfer or dissipation due to transportation after capture

$$\sigma_{Grazing}^{tr}(Z,A,E) = \frac{\pi\hbar^2}{2\mu E}\sum_J (2J+1)\underline{(1-P_{cap}(E,J))}P_{trans}^{Grazing}(Z,A,E)$$

$$\sigma_{DNS}^{tr}(Z,A,E) = \frac{\pi\hbar^2}{2\mu E}\sum_J (2J+1)\underline{P_{cap}(E,J)}P_{trans}^{DNS}(Z,A,E)$$

Physical mechanisms described by these two models are mutually complementary depending on whether capture happens.

Combination

To be consistent with GRAZING model and DNS model:

- The same heavy-ion potential with none free parameters

$$U_{aA} = -16\pi\gamma a \frac{R_a R_A}{R_a + R_A} \frac{1}{1 + \exp[(r - R_a - R_A)/a]} \quad (4)$$

where

$$\frac{1}{a} = 1.17[1 + 0.53(A_a^{-1/3} + A_A^{-1/3})] \quad (5)$$

$$R_i = 1.2A_i^{1/3} - 0.09 \quad (6)$$

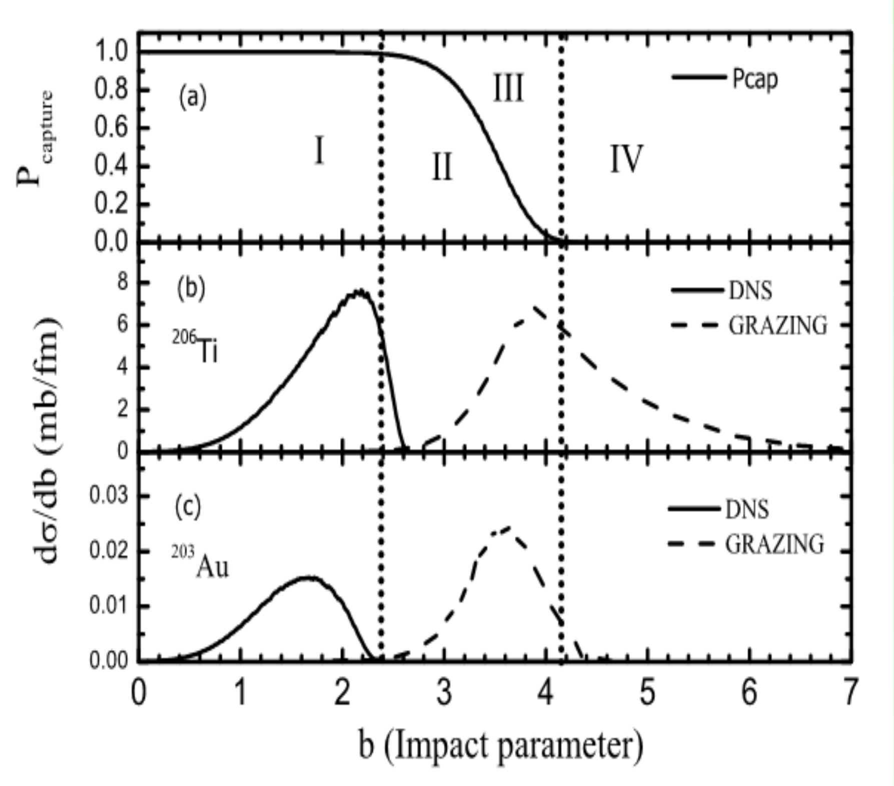
$$\gamma = 0.95(1 - 1.8\frac{(N_a - Z_a)(N_A - Z_A)}{A_a A_A}). \quad (7)$$

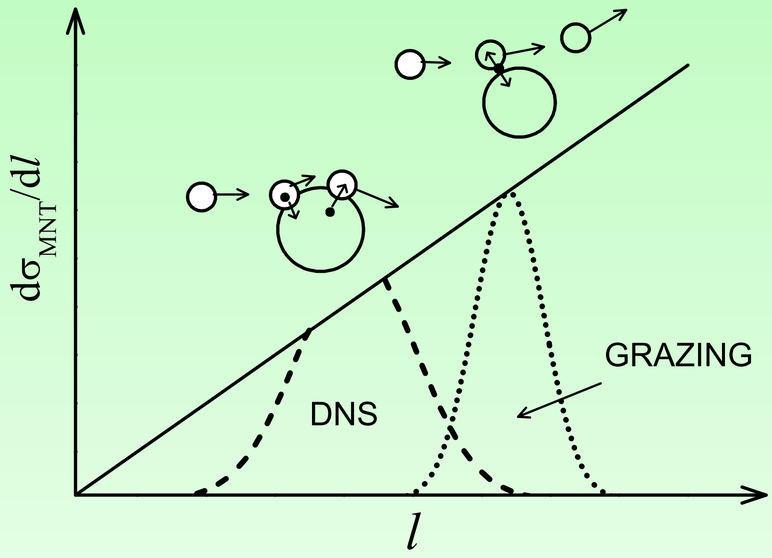
- Extract capture probability from GRAZING model into DNS model

$$P_c(E,l) = \int P(E_r)T_l(E - Er)dE_r.$$

- Extract grazing angular momentum from GRAZING model into DNS model to predict interaction time

Based on *Pcap* and *b: transfer reactions can be clearly clarified into four areas by these two models.*



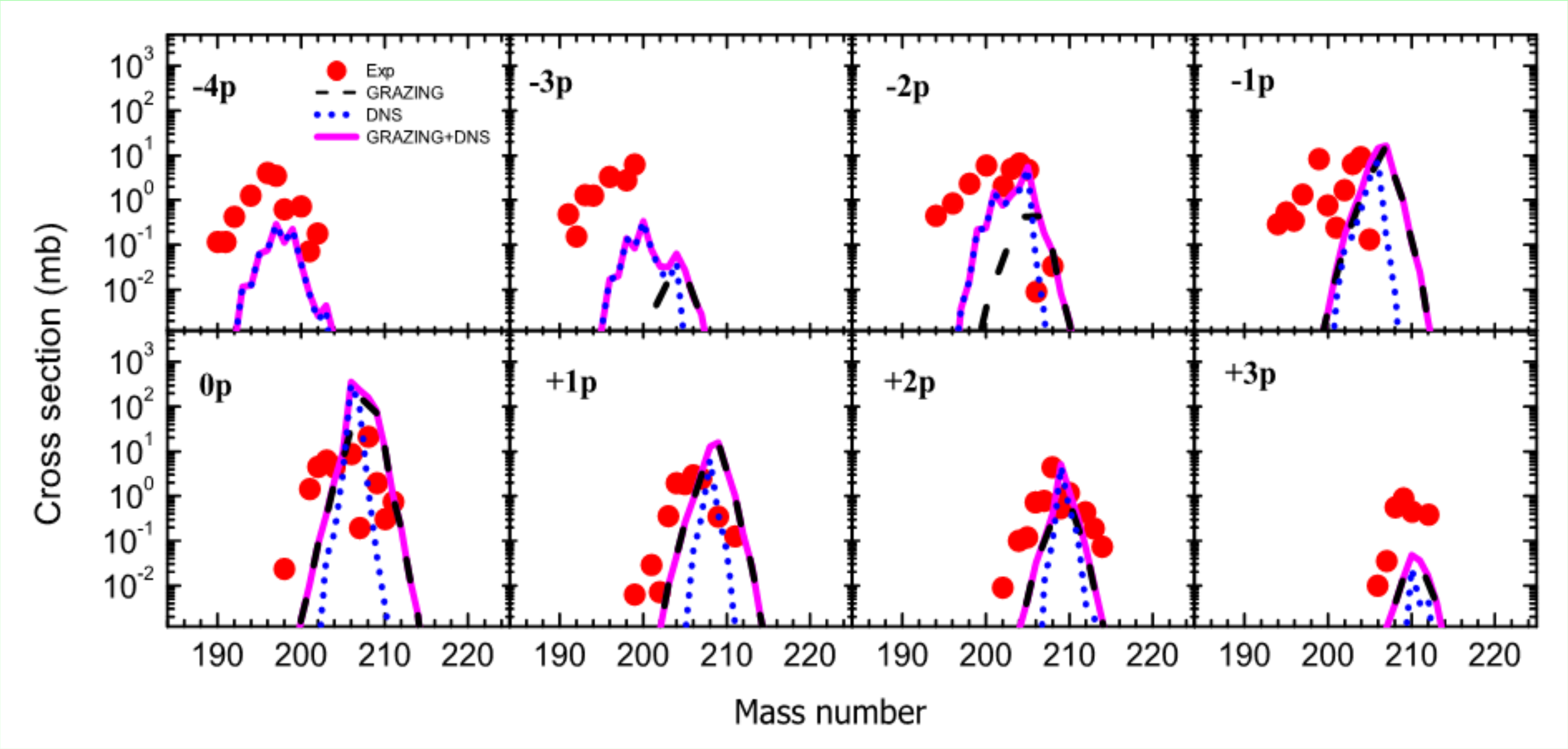


$^{136}Xe+^{208}Pb$ Ecm=450 MeV

Fröbrich98, et al, Phys. Rep. 292, 131 (1998)

Wen, Li, Zhu, Lin, and Zhang JPG 44(2017)115101

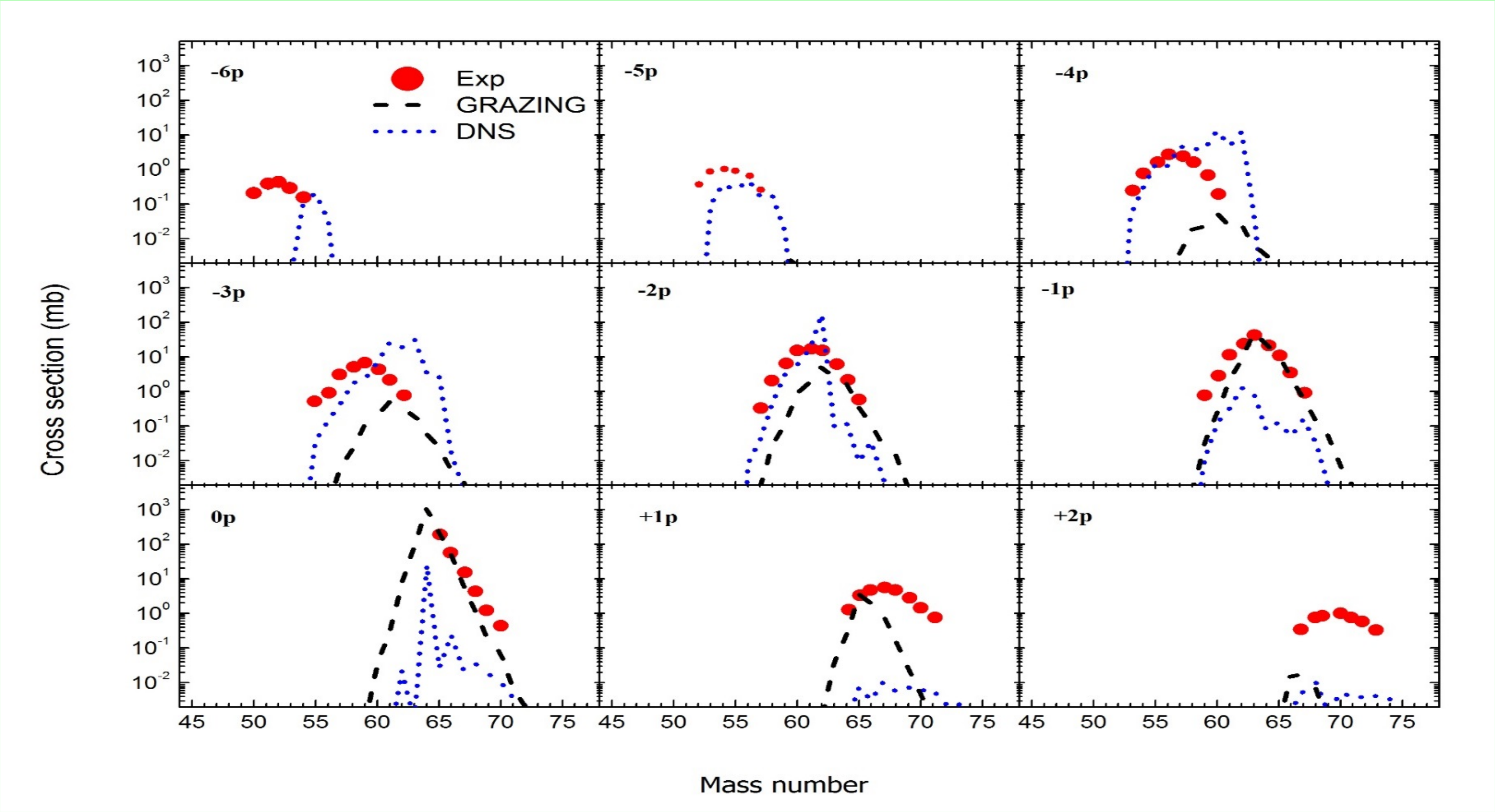
^{136}Xe+^{208}Pb, Ecm=450 MeV



Combination of results by GRAZING+DNS is better

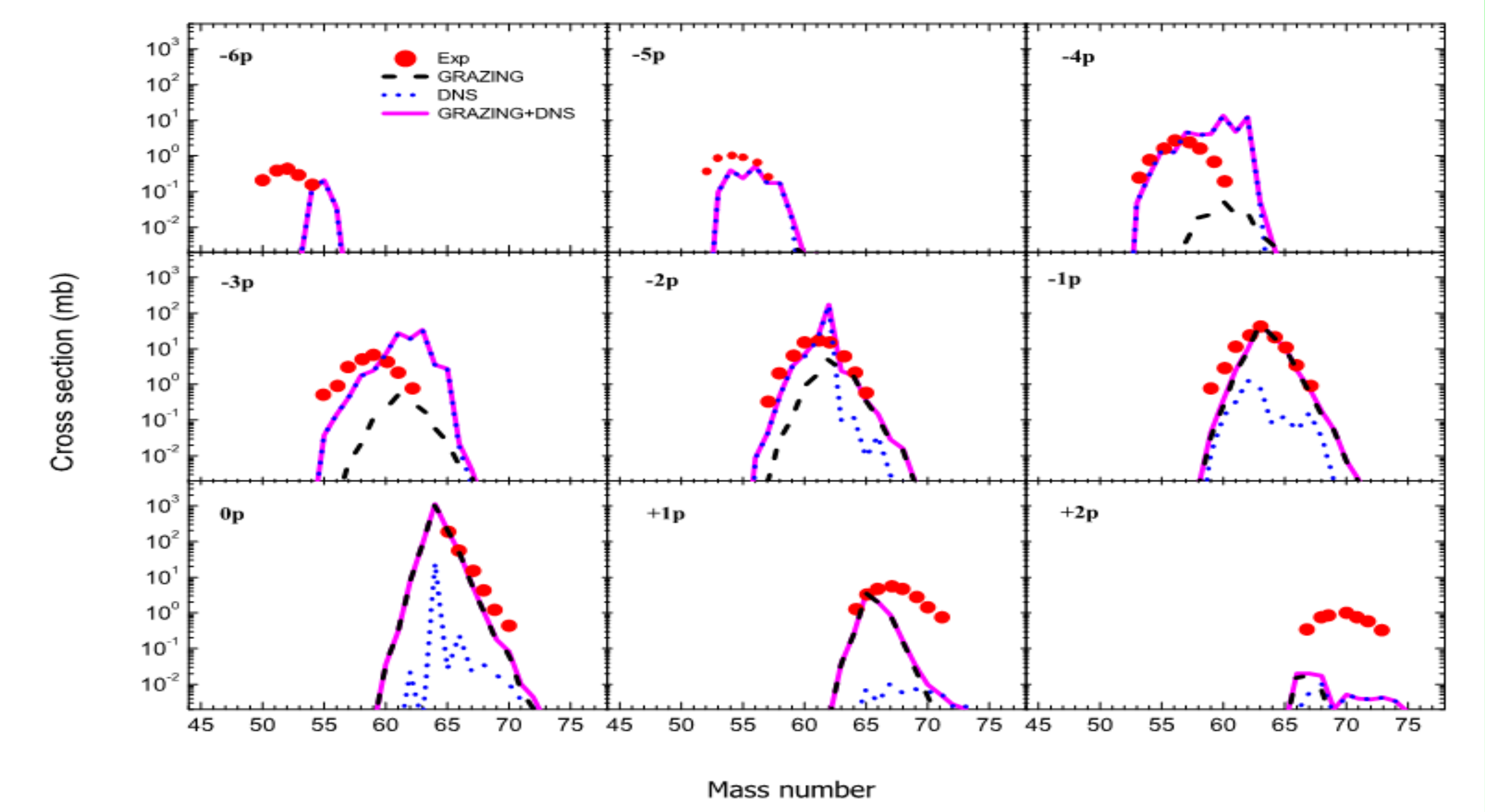
Wen, Li, Zhu, Lin, and Zhang JPG 44(2017)115101

$^{64}Ni+^{238}U$, Ecm=307 MeV



Contrast of results by these two models is more obvious

$^{64}Ni+^{238}U$, Ecm=307 MeV



Results are also significantly improved by GRAZING+DNS

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J. Phys. G: Nucl. Part. Phys. **44** (2017) 115101 (12pp) https://doi.org/10.1088/1361-6471/aa8b07

Mechanism of multinucleon transfer reaction based on the GRAZING model and DNS model

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Wen, Li, Zhu, Lin, and Zhang, JPG 44(2017)115101

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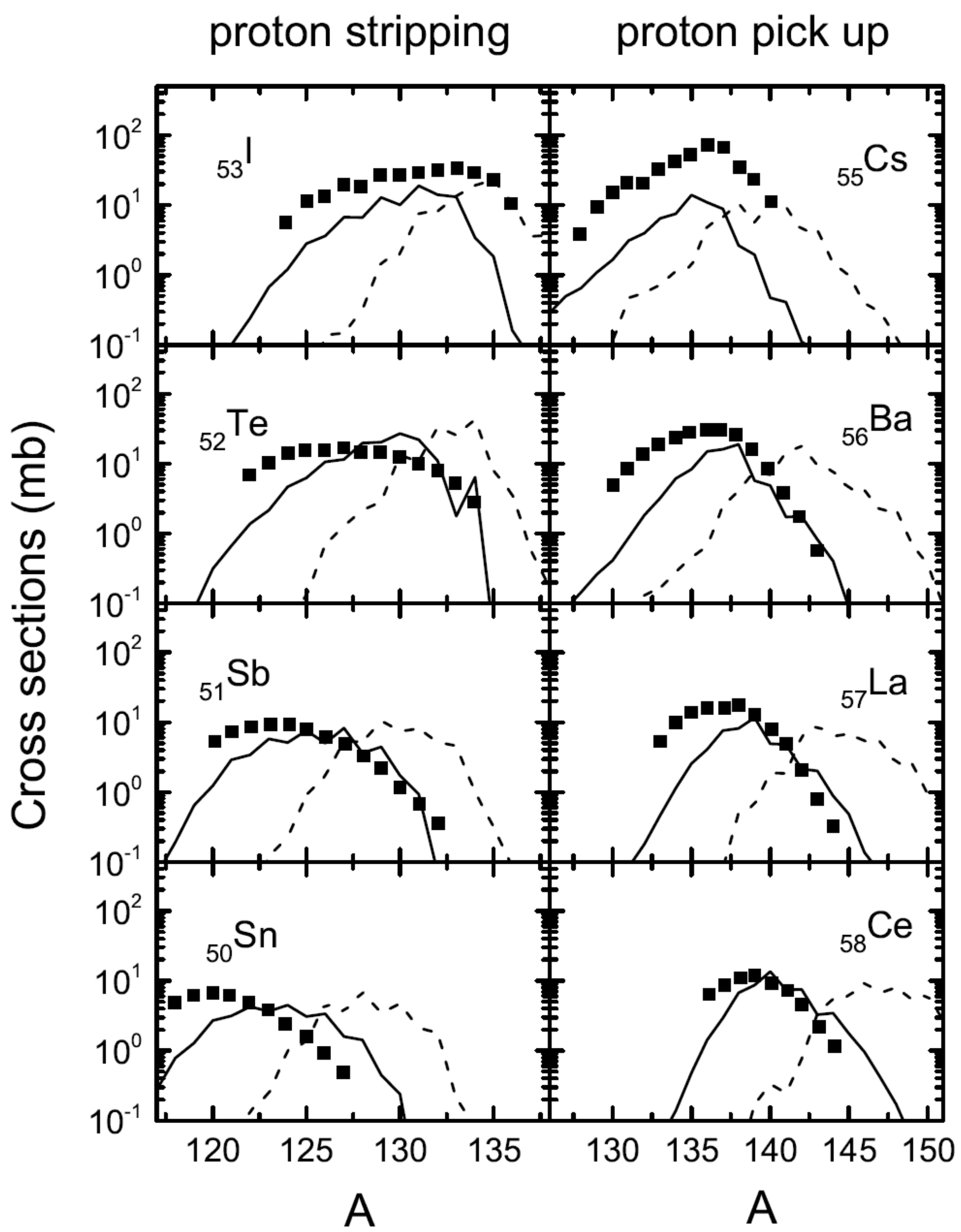
3. Transfer Reaction induced by RNB

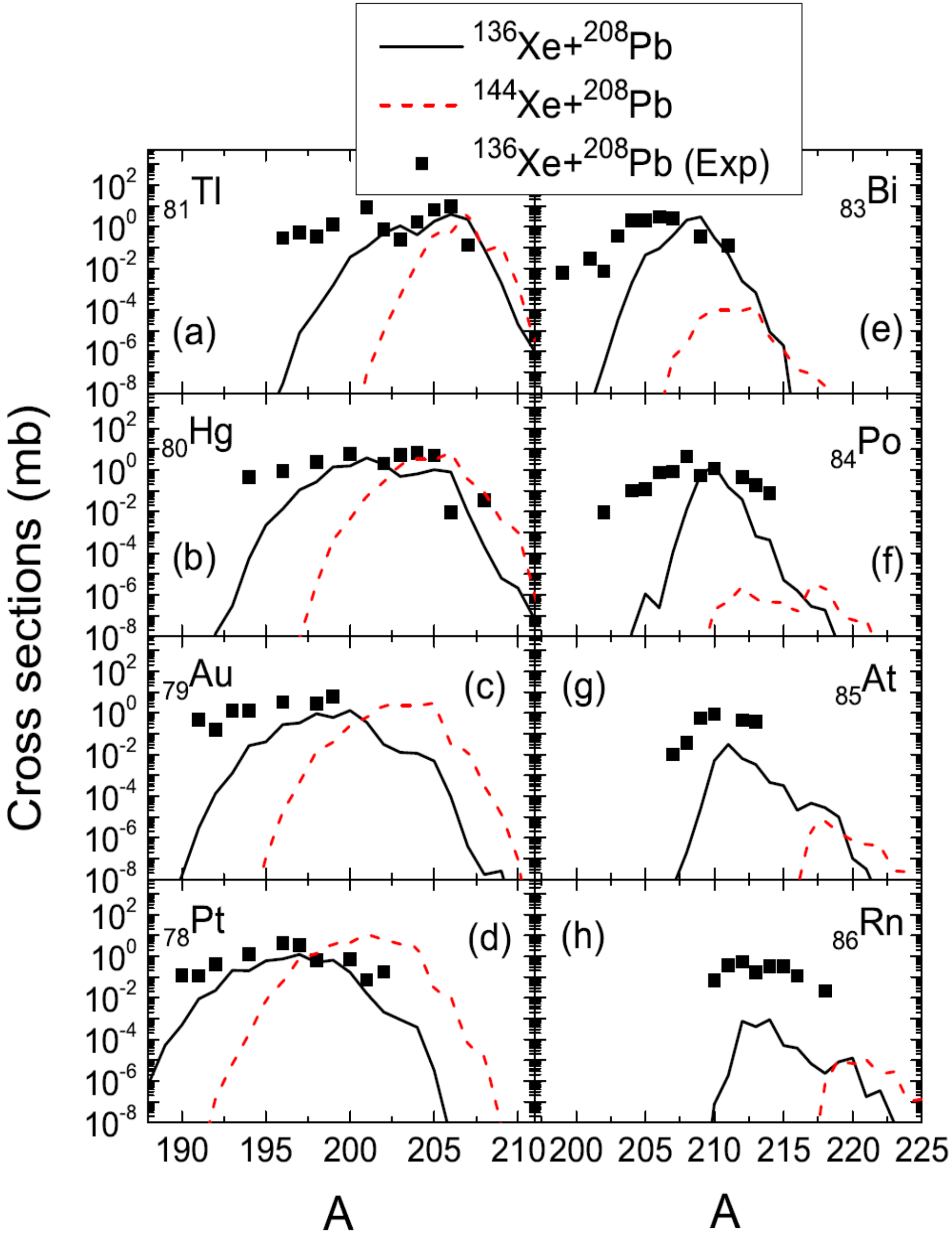


$^{136}Xe+^{198}Pt$

$E_{c.m} = 643$ MeV

Date: Y. X. Watanabe et al. PRL 115, 172503 (2015).

Cal: Zhu, Su, Xie, and Zhang PLB 707, 423 (2017).

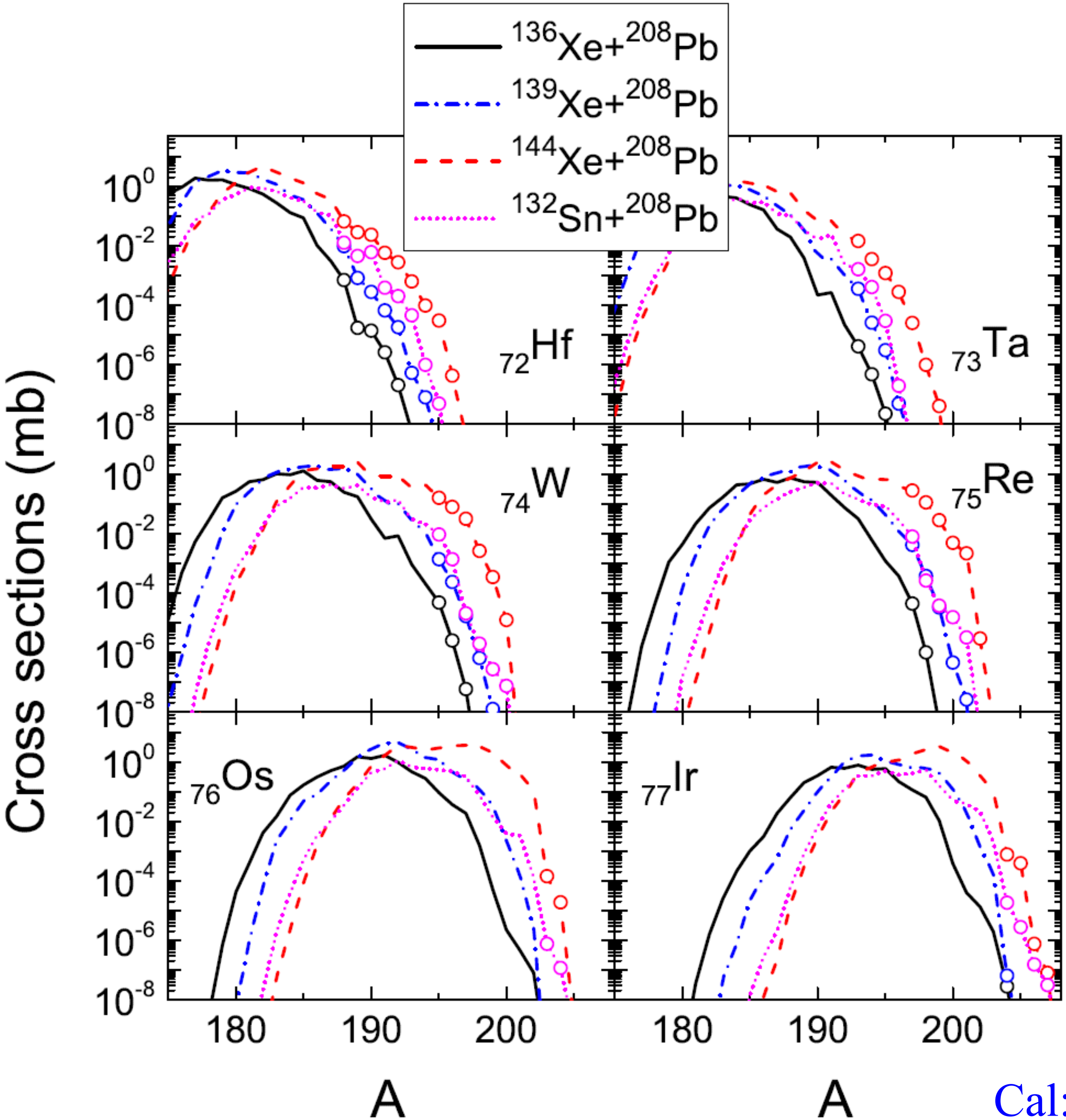


Cal: Zhu, Su, Xie, and Zhang PLB 707, 423 (2017).

It is favorable to produce n-rich nuclei with charge number less than targets.

$E_{c.m}$=450 MeV

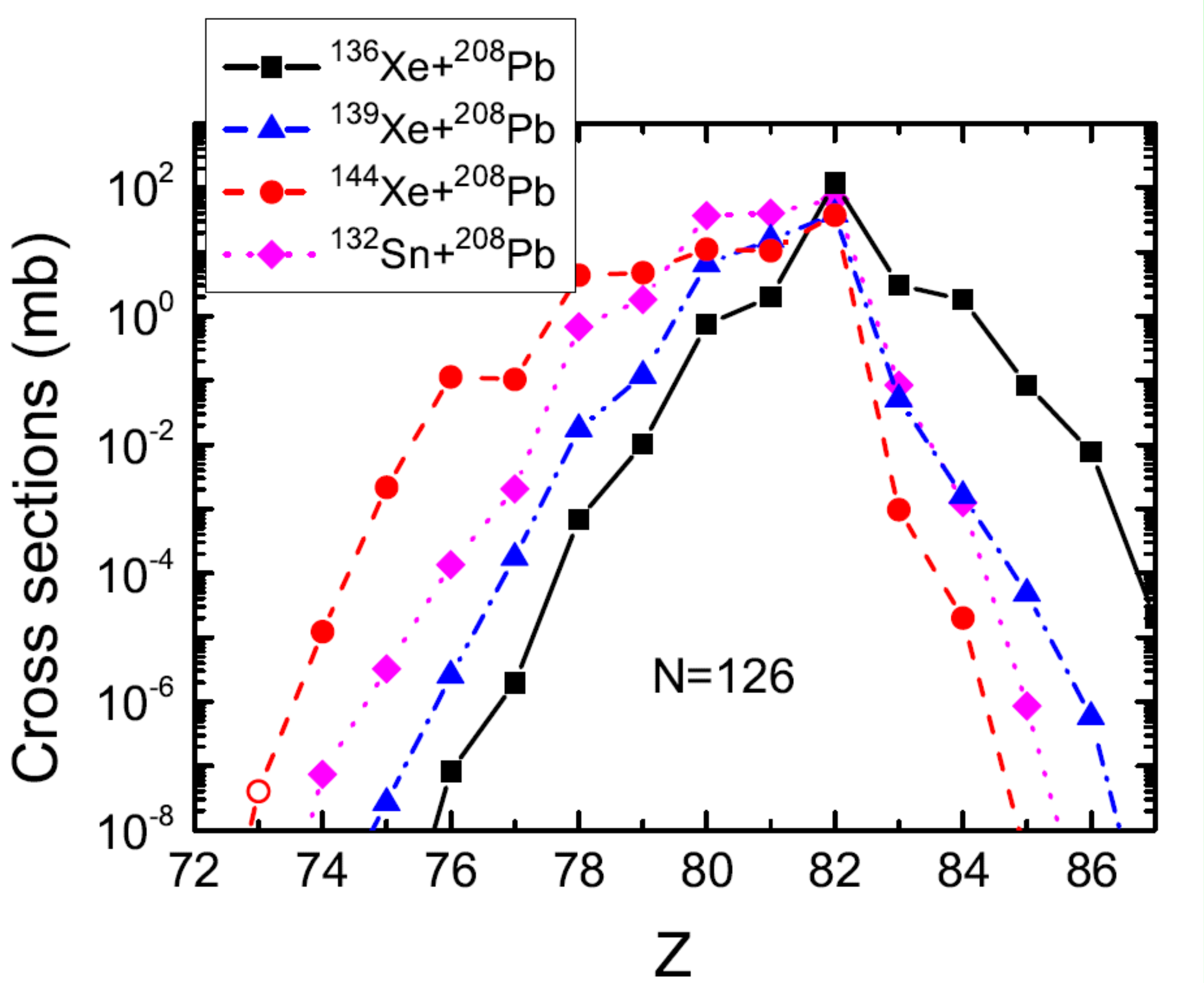
Data: J. S. Barrett et al., PRC 91, 064615 (2015).



The circles denote the unknown n-rich isotopes.

$E_{c.m.}=1.1V_{int}$

Cal: Zhu, Su, Xie, and Zhang PLB 707, 423 (2017).



Cross sections of nuclei with neutron closed shell N = 126 for reactions ^{136}Xe, ^{139}Xe, ^{144}Xe, and ^{132}Sn with ^{208}Pb， Ec.m. = 1.1V_{CN}.

Open symbols denote unknown isotopes (^{198}Ta).

Zhu, Su, Xie, and Zhang, PLB 707, 423 (2017)

Physics Letters B 767 (2017) 437–442

Contents lists available at ScienceDirect

Physics Letters B

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Theoretical study on production of heavy neutron-rich isotopes around the $N = 126$ shell closure in radioactive beam induced transfer reactions

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[e] Beijing Radiation Center, Beijing 100875, China
[f] Center of Theoretical Nuclear Physics, National Laboratory of Heavy Ion Accelerator of Lanzhou, Lanzhou 730000, China

Zhu, Su, Xie, and Zhang, PLB767(2017)417-442

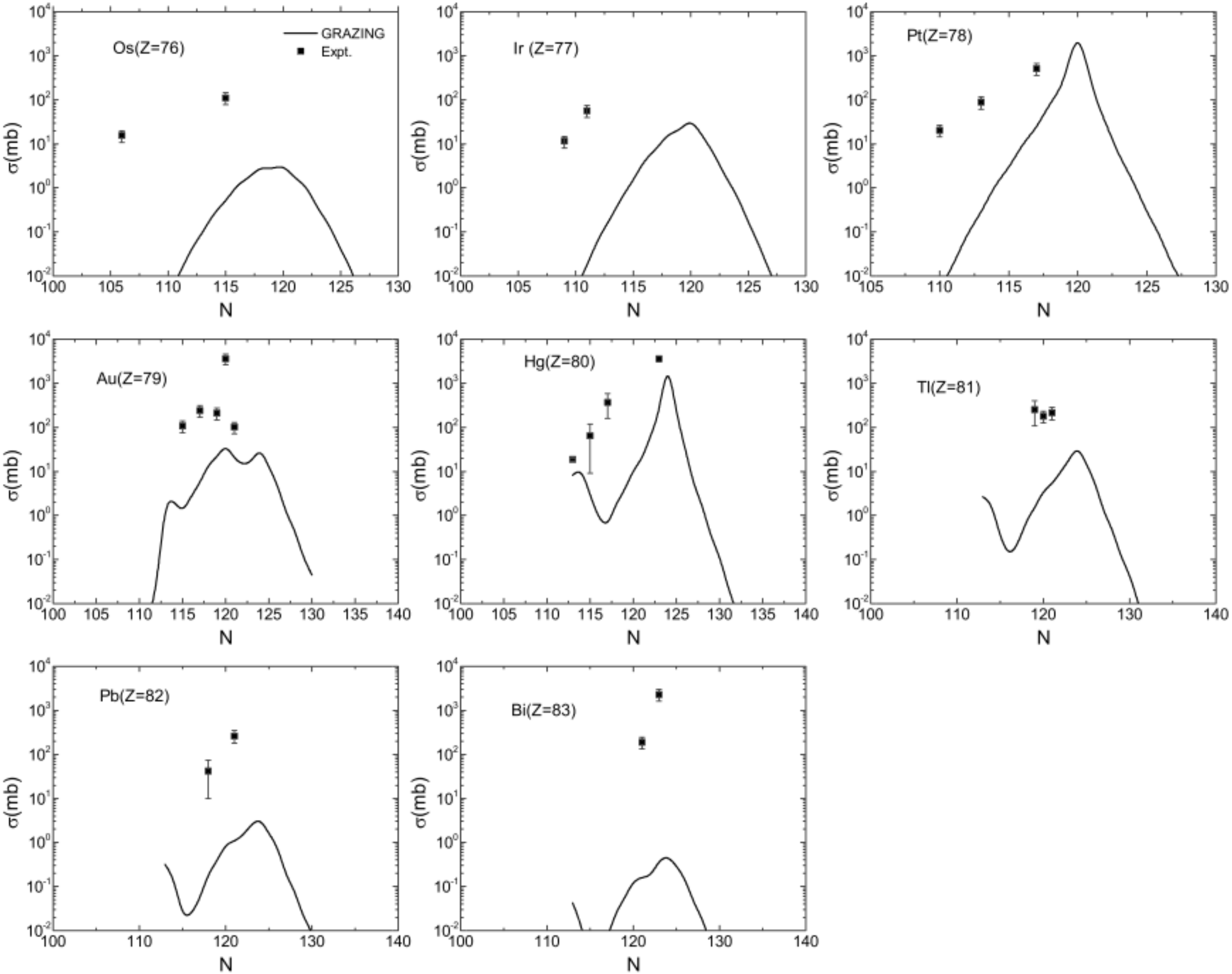

Fig. 1. The observed fragment yields for the $E_{c.m.} = 619$ MeV $^{204}Hg + ^{198}Pt$ reaction compared to the predictions of the GRAZING model.

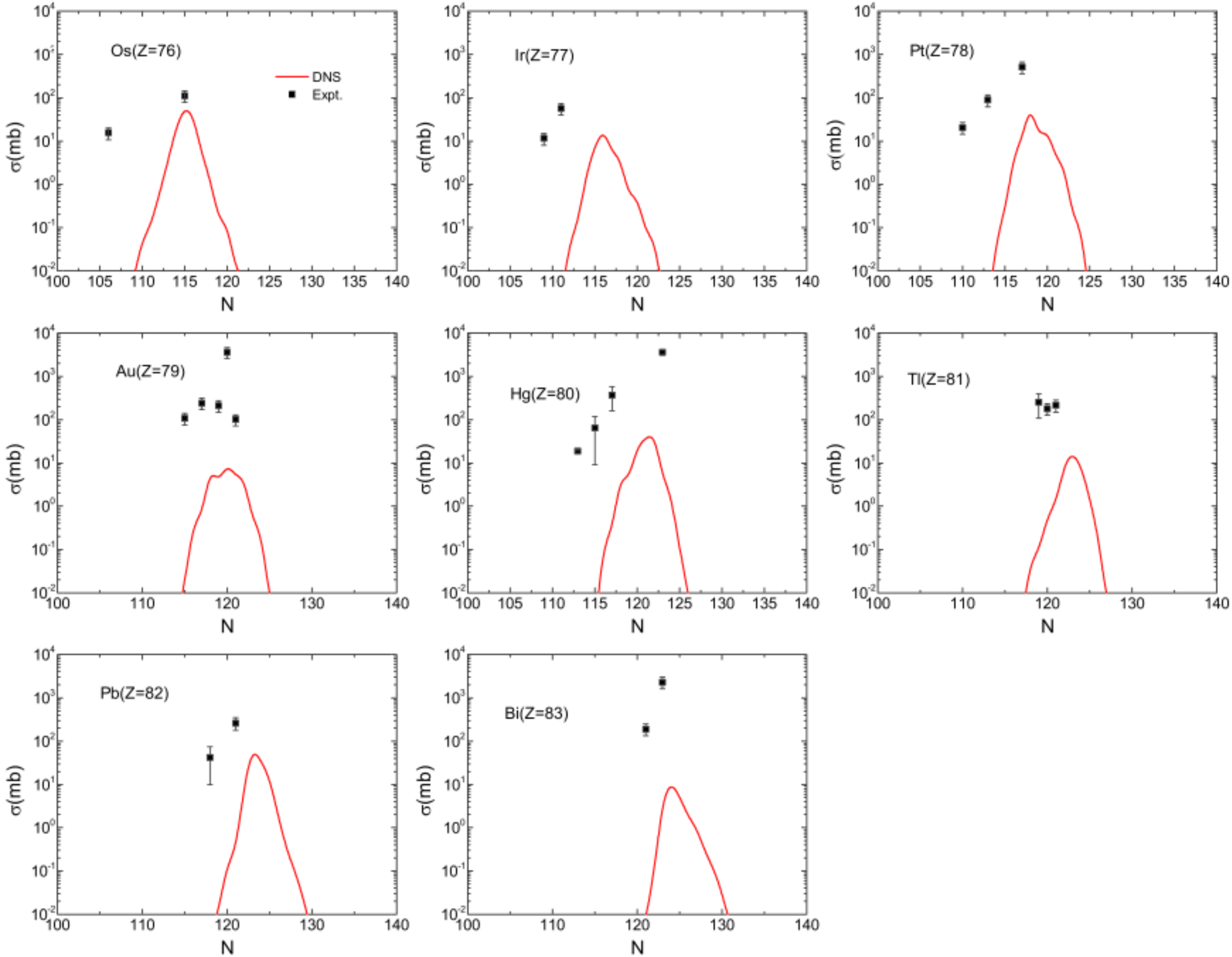

Fig. 2. The observed fragment yields for the $E_{c.m.} = 619$ MeV $^{204}Hg + ^{198}Pt$ reaction compared to the predictions of the DNS model.

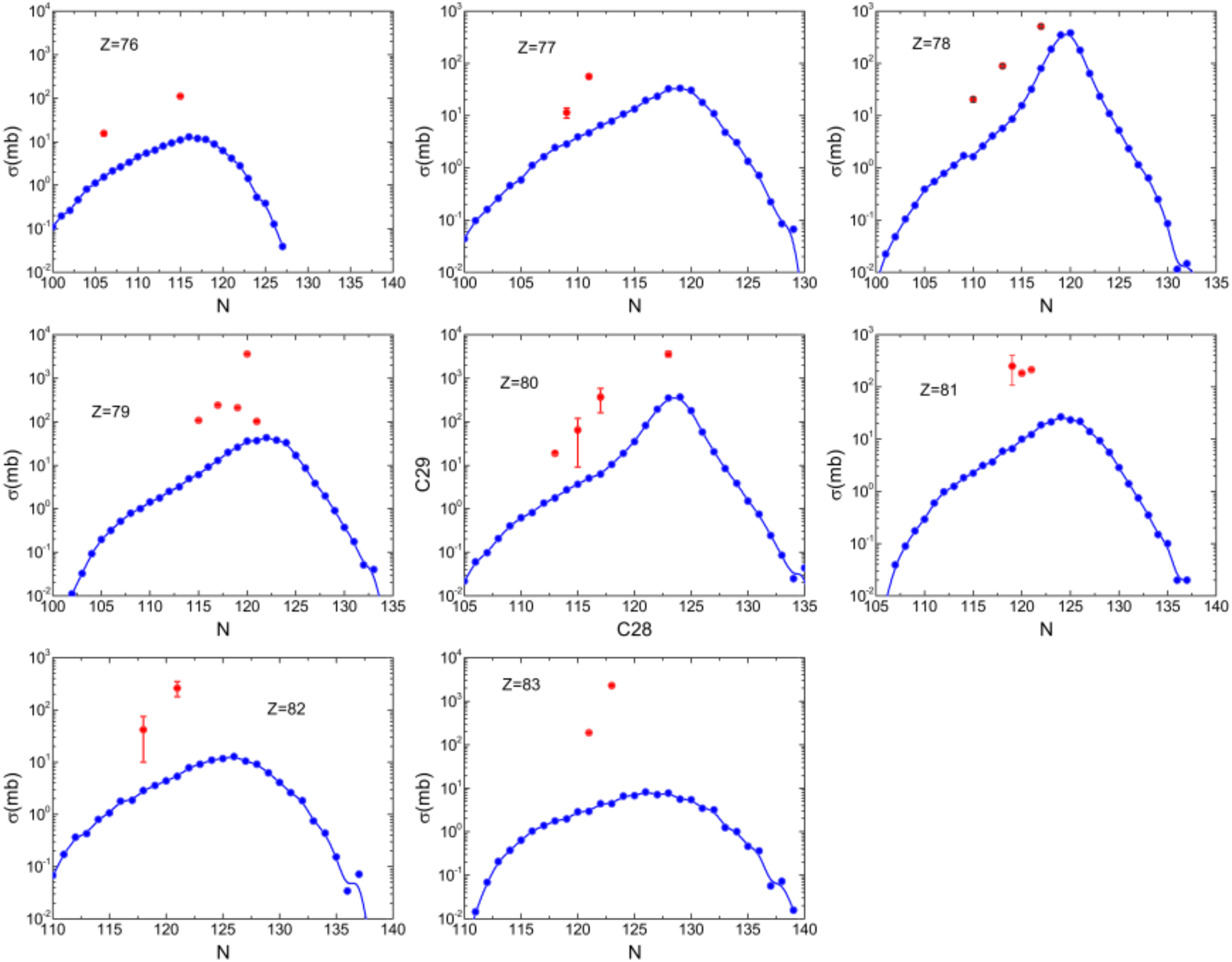

Fig. 5. The observed fragment yields (red circles) for the $E_{c.m.} = 619$ MeV ^{204}Hg + ^{198}Pt reaction compared to the predictions (blue circles and line) of the ImQMD model. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

Comparision with experimental work in ANL

Physics Letters B 771 (2017) 119–124

Contents lists available at ScienceDirect

Physics Letters B

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Modeling multi-nucleon transfer in symmetric collisions of massive nuclei

T. Welsh [a], W. Loveland [a,*], R. Yanez [a], J.S. Barrett [a], E.A. McCutchan [b], A.A. Sonzogni [b], T. Johnson [b], S. Zhu [c], J.P. Greene [c], A.D. Ayangeakaa [c], M.P. Carpenter [c], T. Lauritsen [c], J.L. Harker [d], W.B. Walters [d], B.M.S. Amro [e], P. Copp [e]

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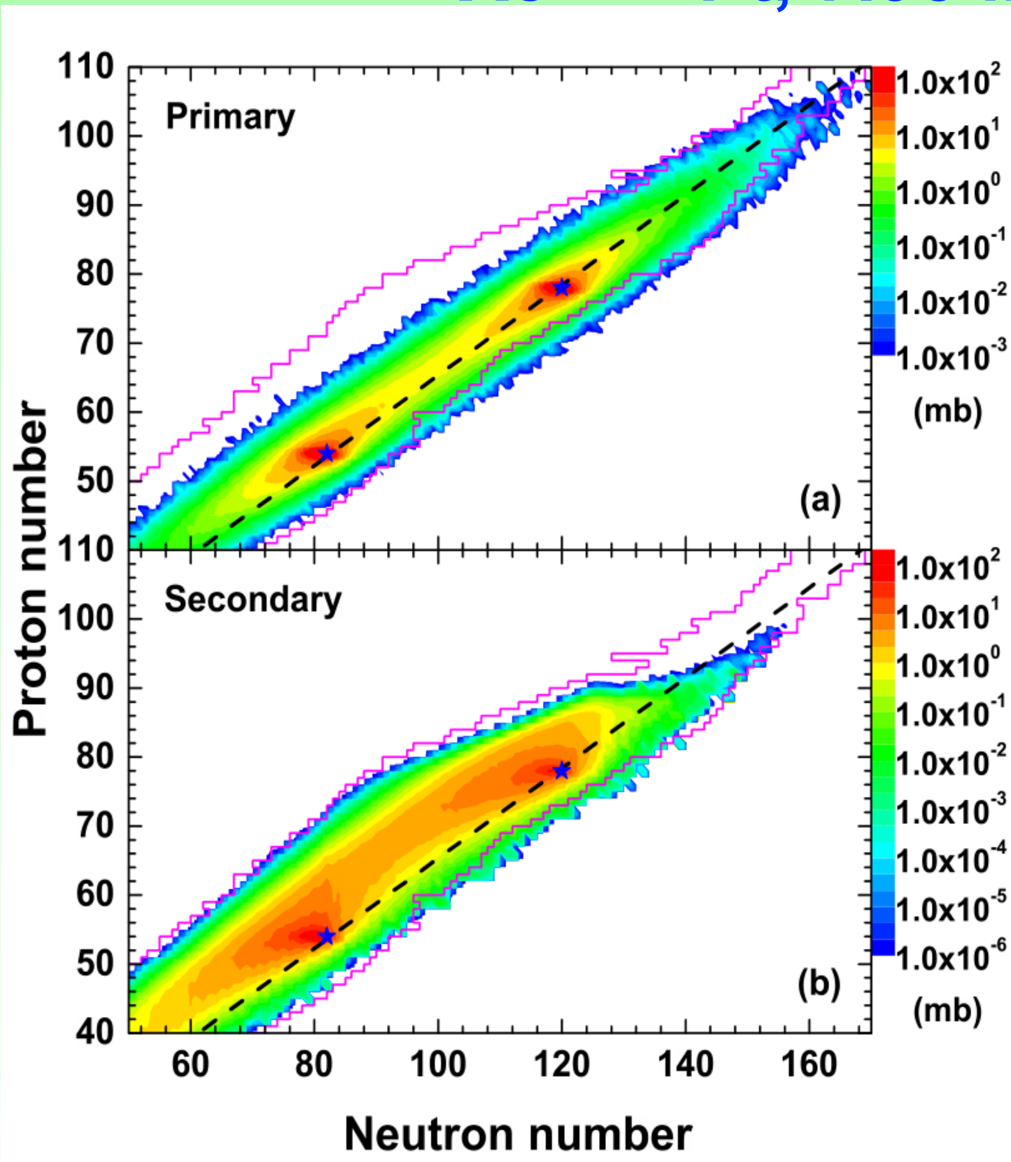
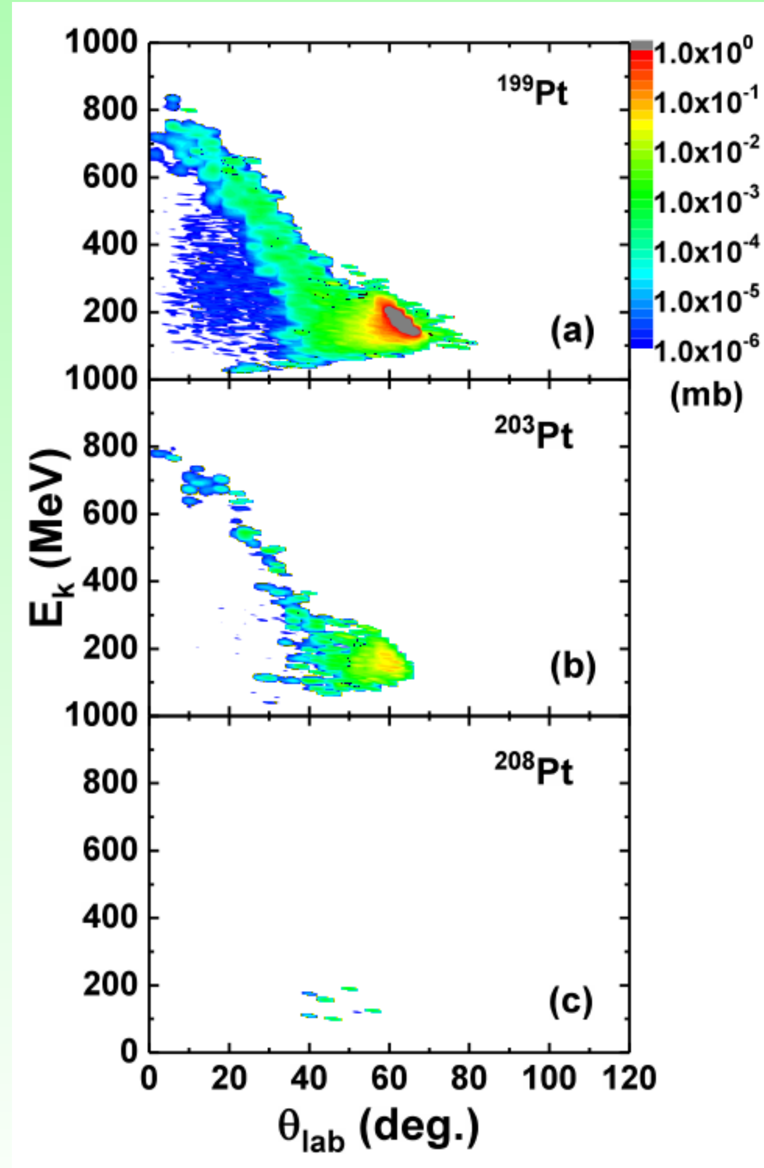
Isotope production cross sections for ^{199}Pt, ^{203}Pt, and ^{208}Pt

^{136}Xe + ^{198}Pt, 7.98 MeV/u





Li, Zhu, Wen, Zhang, Phys. Lett. B 776 (2018) 278.

Physics Letters B 776 (2018) 278–283

Contents lists available at ScienceDirect

Physics Letters B

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Production mechanism of new neutron-rich heavy nuclei in the $^{136}Xe + ^{198}Pt$ reaction

Cheng Li [a,b], Peiwei Wen [a,b], Jingjing Li [a,b], Gen Zhang [a,b], Bing Li [a,b], Xinxin Xu [a,b], Zhong Liu [c], Shaofei Zhu [d], Feng-Shou Zhang [a,b,e,*]

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ABSTRACT

The multinucleon transfer reaction of $^{136}Xe + ^{198}Pt$ at $E_{lab} = 7.98$ MeV/nucleon is investigated by using the improved quantum molecular dynamics model. The quasielastic, deep-inelastic, and quasifission collision mechanisms are studied via analyzing the angular distributions of fragments and the energy dissipation processes during the collisions. The measured isotope production cross sections of projectile-like fragments are reasonably well reproduced by the calculation of the ImQMD model together with the GEMINI code. The isotope production cross sections for the target-like fragments and double differential cross sections of ^{199}Pt, ^{203}Pt, and ^{208}Pt are calculated. It is shown that about 50 new neutron-rich heavy nuclei can be produced via deep-inelastic collision mechanism, where the production cross sections are from 10^{-3} to 10^{-6} mb. The corresponding emission angle and the kinetic energy for these new neutron-rich nuclei locate at 40°–60° and 100–200 MeV, respectively.

Production of n-rich $^{209\text{-}212}$Pt isotopes

PHYSICAL REVIEW C **98**, 014613 (2018)

Production of neutron-rich $^{209–212}$Pt isotopes based on a dinuclear system model

Gen Zhang,[1,2] Cheng Li,[2] Pei-Wei Wen,[3] Jing-Jing Li,[1,2] Xin-Xin Xu,[1,2] Bing Li,[1,2] Zhong Liu,[4] and Feng-Shou Zhang[1,2,5,*]
[1]*The Key Laboratory of Beam Technology and Material Modification of Ministry of Education, College of Nuclear Science and Technology, Beijing Normal University, Beijing 100875, China*
[2]*Beijing Radiation Center, Beijing 100875, China*
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(Received 8 May 2018; published 23 July 2018)

The production cross sections of new neutron-rich nuclei $^{209–212}$Pt are investigated with multinucleon transfer reactions by the dinuclear system model. It is found that the ^{133}Sn + ^{204}Hg and ^{145}Xe + ^{208}Pb systems are advantageous to produce the neutron-rich nuclei, in which the production cross sections are much higher than those produced in projectile fragmentation reactions. The optimal incident energies for these two systems are about 1.18 and 1.40 times the Coulomb barrier, respectively. The highest cross sections of unknown isotopes $^{209–212}$Pt in the ^{145}Xe + ^{208}Pb reaction are 2.7 nb, 0.4 nb, 8.2 pb, and 2.7 pb, respectively, and those for the ^{133}Sn + ^{204}Hg reaction are 1.7 nb, 0.4 nb, 23.3 pb, and 4.8 pb, respectively.

DOI: 10.1103/PhysRevC.98.014613

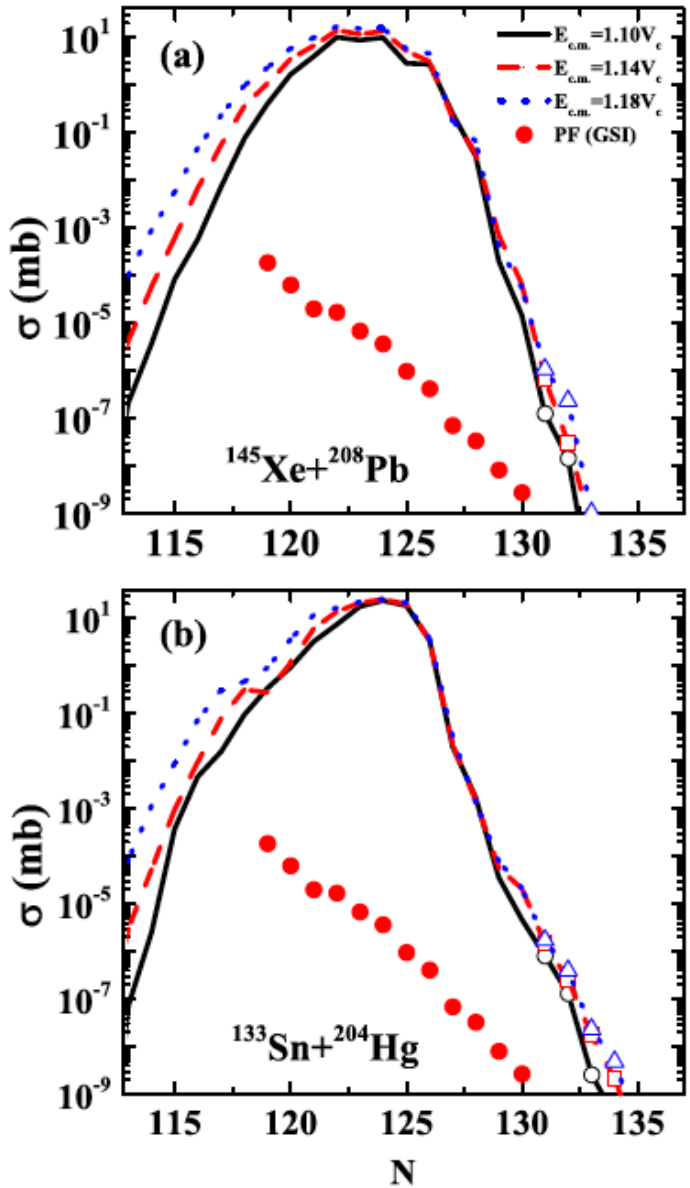

FIG. 4. Final isotopic production cross sections of Pt in $^{145}\mathrm{Xe} + {}^{208}\mathrm{Pb}$ (a) and $^{133}\mathrm{Sn} + {}^{204}\mathrm{Hg}$ (b) at $E_{\mathrm{c.m.}} = 1.10V_{\mathrm{C}}$, $1.14V_{\mathrm{C}}$, and $1.18V_{\mathrm{C}}$. The solid circles are experimental data of 1 GeV/A $^{238}\mathrm{U} + {}^{9}\mathrm{Be}$ from Ref. [6]. The blank circle, square, and triangle symbols denote the unknown neutron-rich isotopes produced at $E_{\mathrm{c.m.}} = 1.10V_{\mathrm{C}}$, $1.14V_{\mathrm{C}}$, $1.18V_{\mathrm{C}}$, respectively. The production cross sections of the

TABLE I. A brief summary of the neutron-rich Pt isotopes.

Reaction	E_{lab}	Method	Isotope	Ref.
$^{196}\mathrm{Pt}(^{2}\mathrm{H}, {}^{1}\mathrm{H})^{197}\mathrm{Pt}$	5 MeV	LP	$^{197}\mathrm{Pt}$	[7]
$^{198}\mathrm{Pt}(n, \gamma)^{199}\mathrm{Pt}$	0–1 keV	NC	$^{199}\mathrm{Pt}$	[8]
$^{199}\mathrm{Pt}(n, \gamma)^{200}\mathrm{Pt}$	–	NC	$^{200}\mathrm{Pt}$	[9]
$^{204}\mathrm{Hg}(n, \alpha)^{201}\mathrm{Pt}$	1 MeV	LP	$^{201}\mathrm{Pt}$	[10]
$^{204}\mathrm{Hg}(n, 2pn)^{202}\mathrm{Pt}$	21 MeV	LP	$^{202}\mathrm{Pt}$	[11]
$^{208}\mathrm{Pb} + {}^{9}\mathrm{Be}$	1 GeV/nucleon	PF	$^{203\text{–}204}\mathrm{Pt}$	[12]
$^{238}\mathrm{U} + {}^{9}\mathrm{Be}$	1 GeV/nucleon	PF	$^{205}\mathrm{Pt}$	[4]
$^{238}\mathrm{U} + {}^{9}\mathrm{Be}$	1 GeV/nucleon	PF	$^{206\text{–}208}\mathrm{Pt}$	[6]

TABLE II. The production cross sections of $^{209-212}$Pt isotopes. $\Delta U^{\mathrm{Xe+Pb}}$ and $\Delta U^{\mathrm{Sn+Hg}}$ are the ΔU values of $^{145}\mathrm{Xe} + {}^{208}\mathrm{Pb}$ and $^{133}\mathrm{Sn} + {}^{204}\mathrm{Hg}$ reactions, respectively. $\sigma^{\mathrm{Xe+Pb}}$ and $\sigma^{\mathrm{Sn+Hg}}$ are the production cross sections of these two systems, respectively.

Isotope	$\Delta U^{\mathrm{Xe+Pb}}$	$\Delta U^{\mathrm{Sn+Hg}}$	$E_{\mathrm{c.m.}}/V_{\mathrm{C}}$	$\sigma^{\mathrm{Xe+Pb}}$ (pb)	$\sigma^{\mathrm{Sn+Hg}}$ (pb)
^{209}Pt	7.62 MeV	16.42 MeV	1.10	123.1	813.4
			1.14	657.1	1471
			1.18	1066.0	1690
			1.30	2684.8	779.9
			1.40	2641.7	501.8
			1.50	965.8	165.1
^{210}Pt	10.73 MeV	17.37 MeV	1.10	14.2	131.4
			1.14	31.1	254.7
			1.18	227.6	389.5
			1.30	113.3	176.5
			1.40	418.2	97.2
			1.50	52.0	77.9
^{211}Pt	21.20 MeV	20.14 MeV	1.10		2.6
			1.14		17.7
			1.18	1.0	23.3
			1.30	5.1	14.3
			1.40	7.6	7.7
			1.50	8.2	4.9
^{212}Pt	21.47 MeV	23.85 MeV	1.10		
			1.14		2.1
			1.18		4.8
			1.30	2.2	3.4
			1.40	2.7	2.1
			1.50	1.9	

Production of n-rich $^{280-283,290-292}$Fl isotopes

PHYSICAL REVIEW C **98**, 014626 (2018)

Theoretical study on production of unknown neutron-deficient $^{280–283}$Fl and neutron-rich $^{290–292}$Fl isotopes by fusion reactions

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We attempt to calculate the production cross sections of unknown $^{280–283}$Fl and $^{290–292}$Fl isotopes by using hot fusion reaction mechanism within the dinuclear system model. The production of unknown neutron-deficient Fl isotopes ($^{280–283}$Fl) is studied in the reactions ^{44}Ca + ^{242}Pu and ^{36}S + ^{249}Cf with the maximum evaporation residue cross sections values 0.91 pb, 6.17 pb, 36.16 pb, and 2.02 pb, respectively. The use of neutron-rich radioactive beams ^{44}Ar and ^{46}Ar may help us produce new neutron-rich Fl isotopes via fusion reaction mechanism only if an extremely high beam intensity were to be achieved in the future. The maximum production cross sections of unknown neutron-rich isotopes ($^{290–292}$Fl) in the reactions ^{46}Ar + ^{248}Cm and ^{46}Ar + ^{250}Cm are predicted to be 4.06 pb, 8.55 pb, and 3.35 pb, respectively. At present, reaction with radioactive ion beams is not a promising method to produce neutron-rich superheavy nuclei and other reaction mechanisms such as transfer reaction need to be developed.

DOI: 10.1103/PhysRevC.98.014626

Production of n-rich $^{280\text{-}283,290\text{-}292}$Fl isotopes

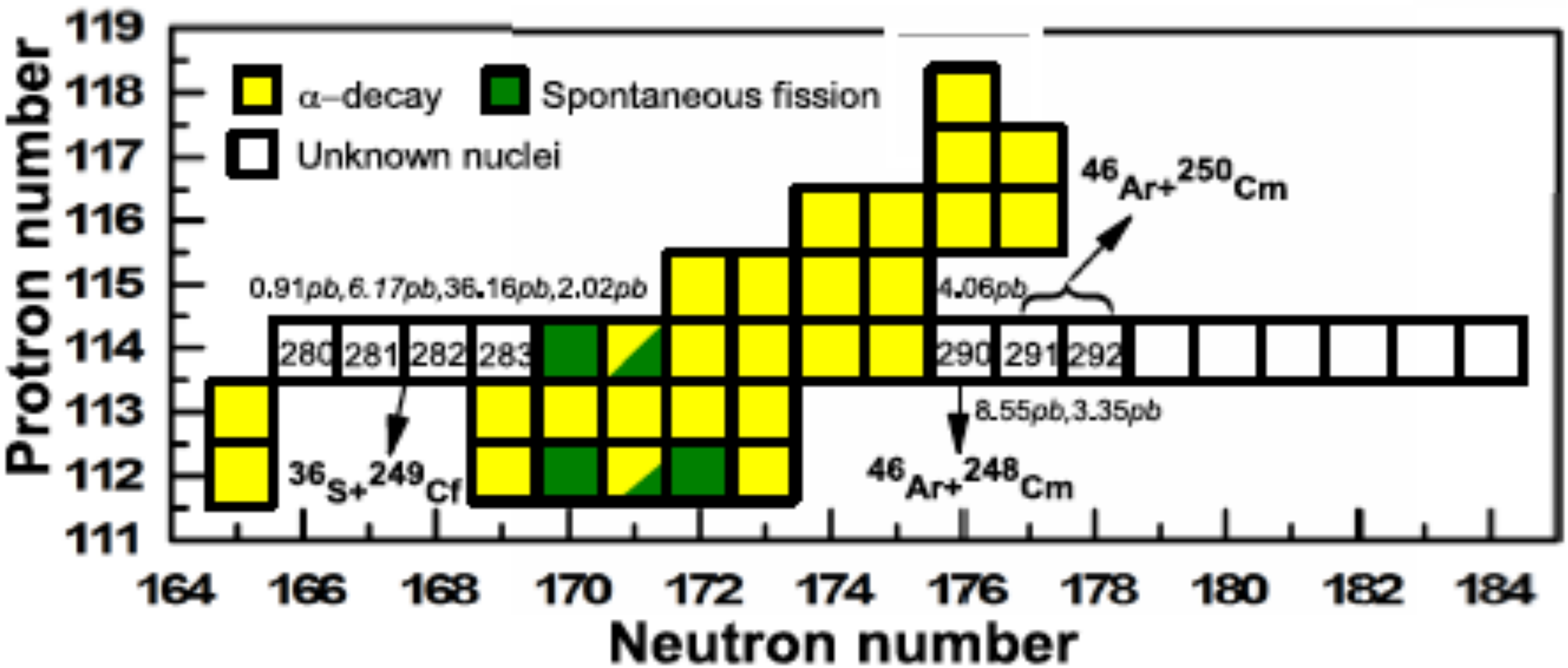

FIG. 5. Superheavy nuclei ($Z > 112$) region at the top-right part of the nuclear map. The filled squares and open squares denote the known nuclei and the predicted ones, respectively. Yellow and olive indicate the α decay and SF, respectively. The optimal reaction systems and the corresponding production cross sections are signed in the graph.

Production of n-rich $^{261-263}$No isotopes

PHYSICAL REVIEW C **95**, 054612 (2017)

Production cross sections of neutron-rich $^{261-263}$No isotopes

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The fusion excitation functions of $^{249-263}$No are studied by using various reaction systems based on the dinuclear system model. The neutron-rich radioactive beam ^{22}O is used to produce neutron-rich nobelium isotopes, and the new neutron-rich isotopes $^{261-263}$No are synthesized by ^{242}Pu(^{22}O,3n)^{261}No, ^{244}Pu(^{22}O,4n)^{262}No, and ^{244}Pu(^{22}O,3n)^{263}No reactions, respectively. The corresponding maximum evaporation residue cross sections are 0.628, 4.649, and 1.638 μb, respectively. The effects of the three processes (capture, fusion, and survival) in the complete fusion reaction are also analyzed. From investigation, a neutron-rich radioactive beam as the projectile and neutron-rich actinide as the target could be a new selection of the projectile-target combination to produce a neutron-rich heavy nuclide.

DOI: 10.1103/PhysRevC.95.054612

TABLE I. A brief summary of the No isotopes.

Reaction	E_{lab}(MeV)	Method	Channel	Isotope	References
^{48}Ca + ^{206}Pb	213.5–242.5	FE	$4n$	^{250}No	[11]
^{48}Ca + ^{204}Pb	213.5–242.5	FE	$2n$	^{250}No	[11]
^{12}C + ^{244}Cm	78 − 90	FE	$5n$	^{251}No	[12]
^{18}O + ^{239}Pu	96	FE	$5n$	^{252}No	[13]
^{16}O + ^{242}Pu	102	FE	$5n$	^{253}No	[13]
^{22}Ne + ^{238}U	—	FE	$6n$	^{254}No	[9]
^{15}N + ^{243}Am	82–84	FE	$4n$	^{254}No	[9,10]
^{22}Ne + ^{238}U	177	FE	$5n$	^{255}No	[14]
^{22}Ne + ^{238}U	110–120	FE	$4n$	^{256}No	[15]
^{13}C + ^{248}Cm	63–68	FE	$4n$	^{257}No	[12]
^{13}C + ^{248}Cm	67.6	FE	$3n$	^{258}No	[16]
^{18}O + ^{248}Cm	88–106	FE	$\alpha 3n$	^{259}No	[17]
^{18}O + ^{254}Es	99	MNT	–	^{260}No	[18]

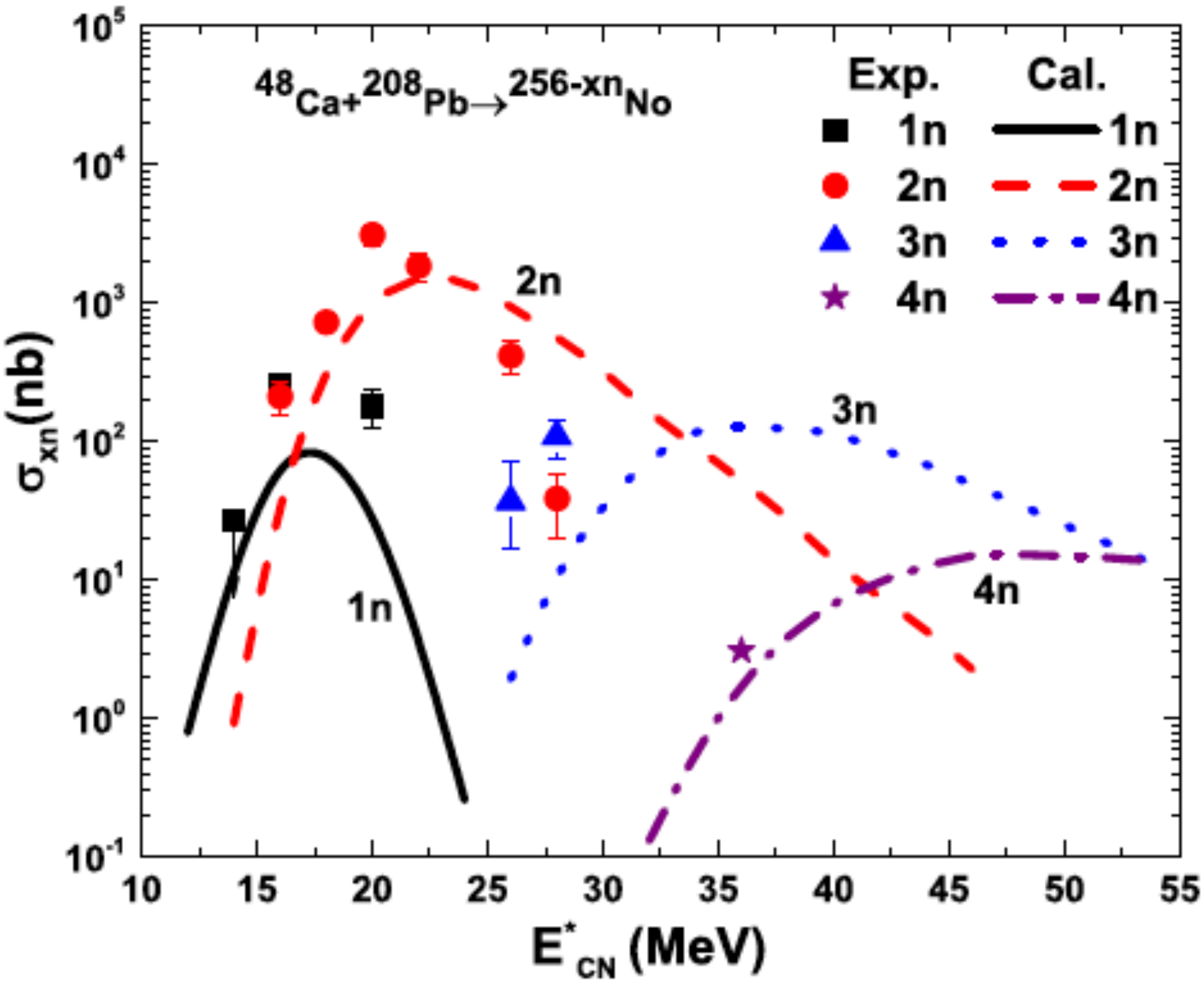
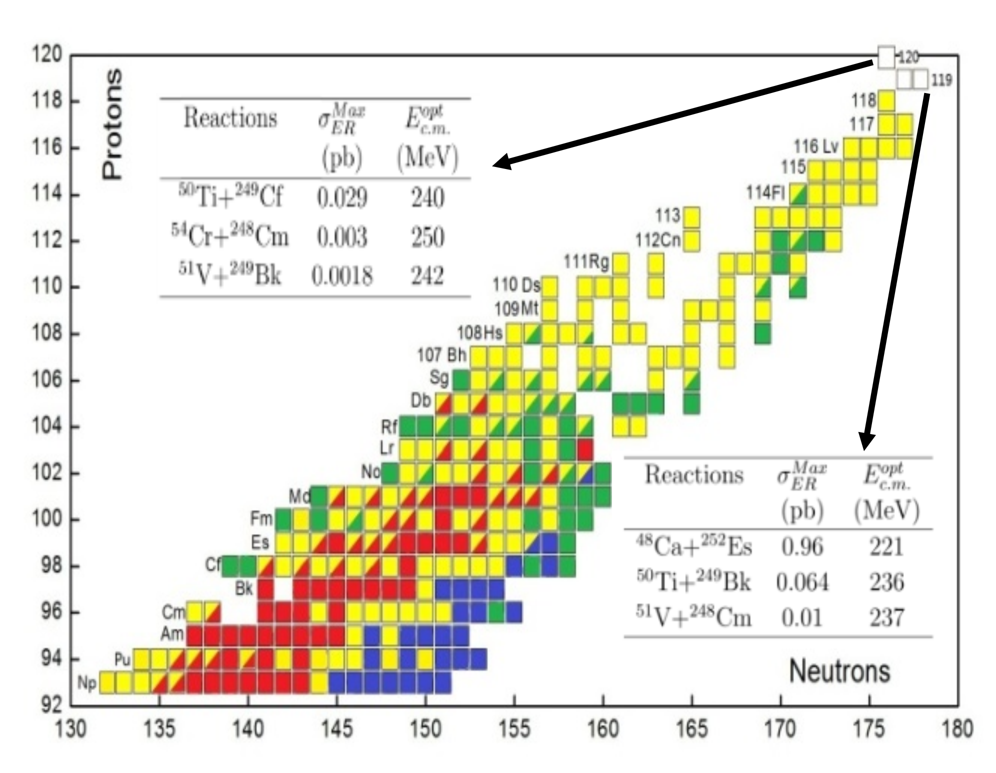


FIG. 5. The excitation functions in the xn-evaporation channels ($x = 1$–4) for the ^{48}Ca + ^{208}Pb reaction. The solid, dashed, dotted, and dash-dotted lines indicate calculated results of the 1n, 2n, 3n, and 4n channels, respectively. The circles, squares, triangles, and pentagon represent the available experimental data [11] for the 1n, 2n, 3n, and 4n channels, respectively.

TABLE II. The production cross sections of $^{249-263}$No isotopes in FE reactions. The mass number and half-lives of these isotopes are tabulated in columns 1 and 2. The corresponding reactions, the incident energy in the laboratory frame E_{lab}, and the excitation energy E^* are listed in columns 3–5. The experimental values of the evaporation residue cross sections σ_{exp} in column 6 are taken from Refs. [11,51]. The calculated results are shown in the last column. For the reactions without experimental data, the calculated cross sections are the value.

Mass number	Half-life	Reaction	E_{lab} (MeV)	E^* (MeV)	σ_{exp} (nb)	σ_{cal} (nb)
249	—	^{228}Th(^{26}Mg,5n)	164.9	74.0	—	1.2
250	4.2^{+12}_{-9} μs	^{204}Pb(^{48}Ca,2n)	216.7	23.2	$13.2^{+10.1}_{-6.7}$	17.2
		^{206}Pb(^{48}Ca,4n)	242.4	43.9	$0.26^{+0.19}_{-0.13}$	2.0
		^{228}Th(^{26}Mg,4n)	140.4	52.0	—	23.9
251	0.8 ± 1 s	^{206}Pb(^{48}Ca,3n)	226.2	30.7	30^{+9}_{-7}	44.2
		^{244}Cm(^{12}C,5n)	83.0	49.7	90	8.3
252	2.47 ± 2 s	^{206}Pb(^{48}Ca,2n)	217.1	23.3	515^{+80}_{-47}	168.4
		^{230}Th(^{26}Mg,4n)	135.8	48.8	—	169.6
		^{244}Cm(^{12}C,4n)	73.3	40.6	250	490.7
253	1.62 ± 15 min	^{206}Pb(^{48}Ca,1n)	217.4	23.6	58^{+16}_{-17}	32.9
		^{207}Pb(^{48}Ca,2n)	216.7	22.4	1310^{+430}_{-410}	2343.7
		^{230}Th(^{26}Mg,3n)	133.6	47.0	—	172.4
		^{244}Cm(^{13}C,4n)	72.8	40.5	300	219.6
		^{246}Cm(^{12}C,5n)	83.0	50.3	240	49.6
254	51 ± 10 s	^{208}Pb(^{48}Ca,2n)	216.7	22.3	2050^{+460}_{-340}	1604.7
		^{244}Cm(^{13}C,3n)	69.8	37.7	120	445.7
		^{246}Cm(^{12}C,4n)	72.0	39.9	1000	3510.2
		^{246}Cm(^{13}C,5n)	78.5	46.6	560	169.0
255	3.52 ± 21 min	^{242}Pu(^{18}O,5n)	106.8	58.0	—	88.3
		^{246}Cm(^{13}C,4n)	69.5	38.0	620	444.6
		^{248}Cm(^{12}C,5n)	77.8	46.3	580	27.2
256	2.91 ± 5 s	^{242}Pu(^{18}O,4n)	93.9	46.0	—	1212.0
		^{246}Cm(^{13}C,3n)	67.5	36.1	70	62.3
		^{248}Cm(^{12}C,4n)	71.2	39.9	1000	1686.5
		^{248}Cm(^{13}C,5n)	74.8	43.5	660	67.2
257	25 ± 3 s	^{242}Pu(^{18}O,3n)	91.8	44.0	—	586.2
		^{244}Pu(^{18}O,5n)	105.8	58.0	—	100.0
		^{248}Cm(^{12}C,3n)	69.2	38.0	160	1884.8
		^{248}Cm(^{13}C,4n)	70.5	39.4	1100	613.0
258	1.2 ± 2 s	^{244}Pu(^{18}O,4n)	95.0	48.0	—	706.6
		^{248}Cm(^{13}C,3n)	71.1	40.0	—	3526.1
259	58 ± 5 ms	^{242}Pu(^{22}O,5n)	106.9	58.0	—	105.7
		^{244}Pu(^{18}O,3n)	90.7	44.0	—	487.1
260	106 ± 8 ms	^{242}Pu(^{22}O,4n)	93.8	46.0	—	1277.6
261	—	^{242}Pu(^{22}O,3n)	91.6	44.0	—	628.1
		^{244}Pu(^{22}O,5n)	100.8	52.0	—	346.9



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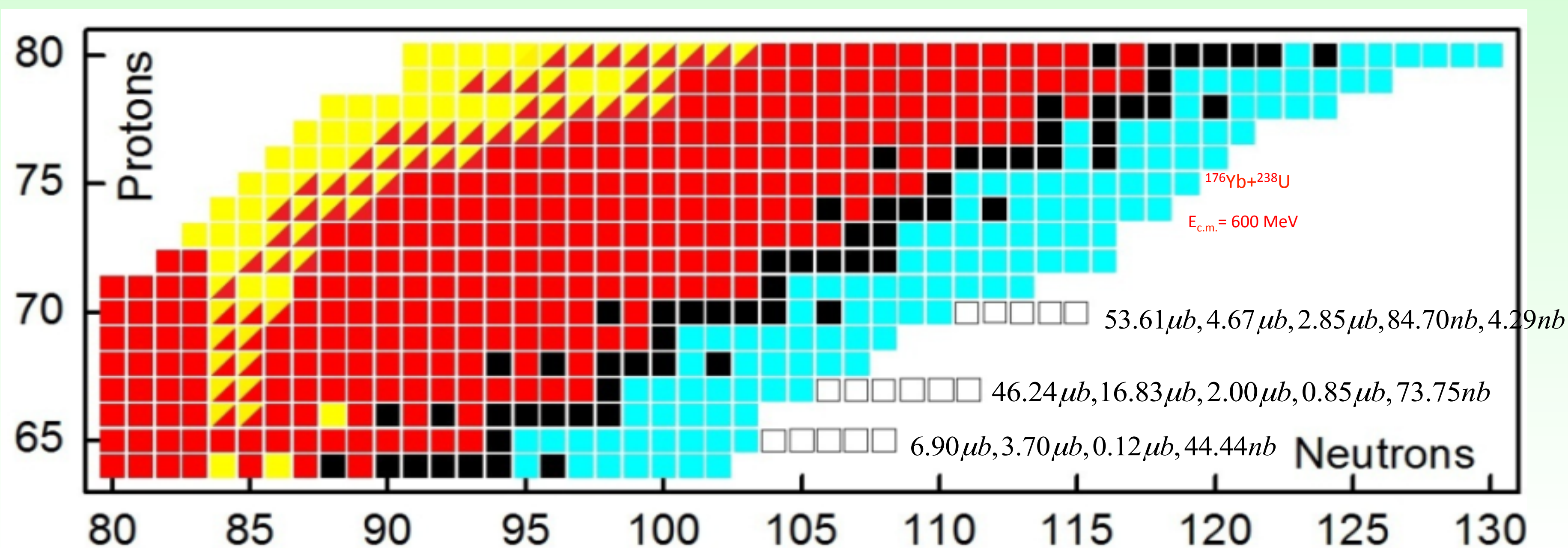

Effects of the shell corrections on the alpha-decay of the $^{280\text{-}305}$Fl isotopes

PHYSICAL REVIEW C **98**, 034312 (2018)

Effect of shell corrections on the α-decay properties of $^{280–305}$Fl isotopes

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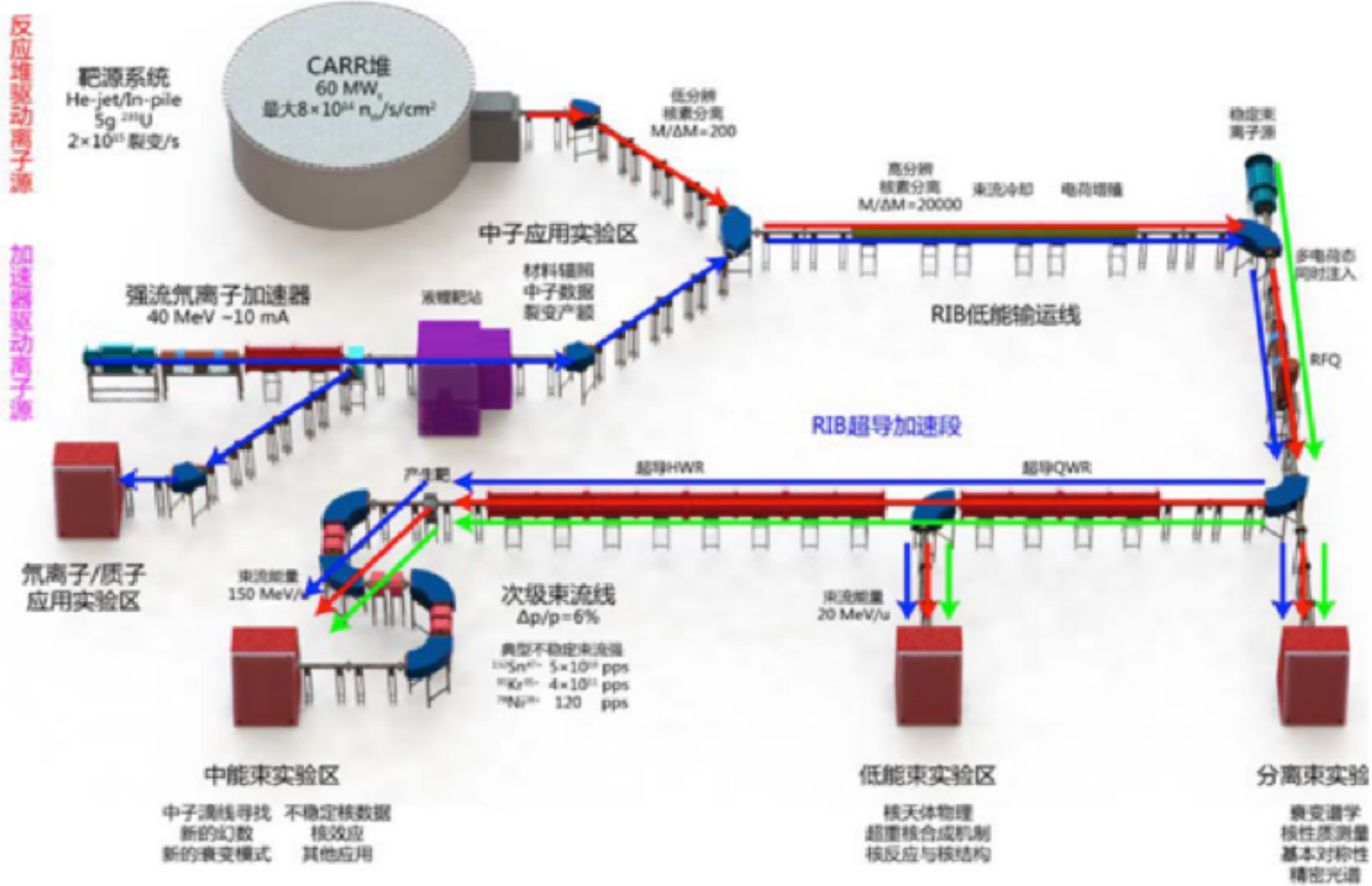
The α-decay half-lives of $^{285–289}$Fl isotopes and their decay chains are investigated by employing the generalized liquid-drop model (GLDM), the unified fission model, the Royer's analytical formula, and the universal decay law. For the GLDM, we take into account the shell correction. The agreement between the experimental data and the calculations indicates that all the methods we used are successful to reproduce α-decay half-lives of $^{285–289}$Fl. For the unknown nuclei, the α-decay half-lives have been predicted by inputting α-decay energies (Q_α) extracted from the finite-range droplet model and the updated Weizsäcker-Skyrme-4 (WS4) model. It is found that the shell correction would enlarge the calculated α-decay half-lives in the region from ^{292}Fl to ^{298}Fl, where the shell effects are evident. We confirm that $N = 184$ is the neutron magic number and $N = 178$ is the submagic number by analyzing the α-decay half-lives and the shell correction energies. The competition between α-decay and spontaneous fission is discussed in detail and the decay modes of $^{280–283}$Fl and $^{290–305}$Fl have been predicted. Our calculations are in good agreement with the experiments for the decay properties of $^{284–289}$Fl. We also predict ^{284,286}Fl with both α-decay and spontaneous fission. The $^{280–283,290–295,297}$Fl isotopes are α decay, $^{300–305}$Fl undergo spontaneous fission, and ^{296,298,299}Fl would have both α-decay and spontaneous fission. We also predict the decay chains of $^{280–283,290,291}$Fl.

OUTLINE

1. Introduction
2. Models for calculation of production cross sections of exotic nuclei
   (1) The Improved Quantum Molecular Dynamics Model
   (2) A combination of the Grazing Model and the Dinuclear System (DNS) Model
3. RNB induced MNT
4. Summary

北京ISOL沙盘模型

北京在线同位素分离丰中子束流装置



HIAF 布局

	Ions	Energy	Intensity
SECR	U^{34+}	14 keV/u	0.05 pmA
iLinac	U^{34+}	17 MeV/u	0.028 pmA
BRing	U^{34+}	0.8 GeV/u	$\sim 1.0 \times 10^{11}$ ppp

1. GRAZING model is suitable for estimating the isotope production cross sections only for Z = −1 to +2, (ANL data, talk by W. Loveland, Shaofei Zhu).

2. The ImQMD calculations give reasonable predictions of the isotope production cross sections for Z = −3 to 0.

3. With a combination of GRAZING and DNS model, Nuclear reactions can be clearly clarified, and Description of transfer reaction cross sections can be clearly understood. MNT=Grazing + DIC.

4. The beam ^{144}Xe shows great advantages for producing unknown neutron-rich nuclei around the N = 126 shell closure.

5. HIAF and Beijing ISOL provide good opportunities.

Thank you for your attention !

Happy Birthday！Professor Arima

Peach flowers