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Production of heavy n-rich isotopes in radioactive beam induced multinucleon transfer reactions

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OUTLINE

1. Introduction
2. Experimental progress
3. Theoretical models
4. RNB induced MNT
5. Summary

Top 125 science questions, Science 1 July 2005

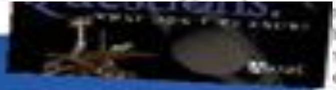
NOW?

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 … ese 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. … ot 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 … ill 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.

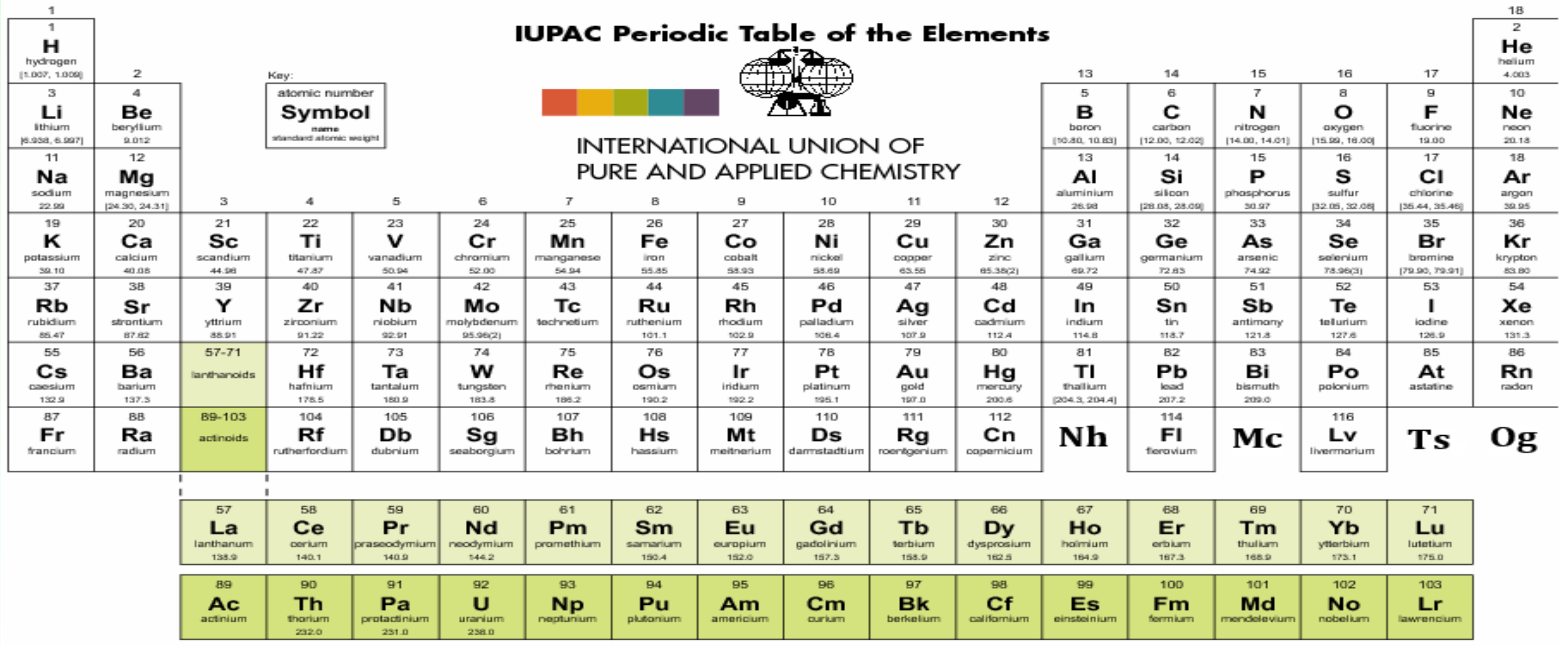
Is superfluidity possible in a solid? If so, how?
Despite hints in solid helium, nobody is sure whether a crystalline material can flow without resistance. If new types of experiments show that such outlandish behavior is possible, theorists would have to explain how.

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

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?

Published by AAAS

超重元素合成最新进展



核物理、核化学家在实验室中，通过核反应合成了Z=93-118的26个元素。

Neptunium(Np,93), Plutonium(Pu,94),…

1940, McMillan and Abelson, LBNL

$^{238}U + 1n \rightarrow {}^{239}U$ (23.5 min) , $^{-}\beta$ decay

$\rightarrow {}^{239}Np$ (2.36 d) , $^{-}\beta$ decay

$\rightarrow {}^{239}Pu$ (24390 yr)

1941, Seaborg, Wahl, Kennedy and Segre, LBNL

$^{238}U + 2d \rightarrow 2n + {}^{238}Np$ (2.1 d)

$\rightarrow {}^{238}Pu$ (88 yr)

^{239}Pu is fissionable with thermal neutrons !!!

By using **^{239}Pu**, collision with α,n, can produce

Am(Z=95), Cm(Z=96), Bk(Z=97), …

^{294}Og

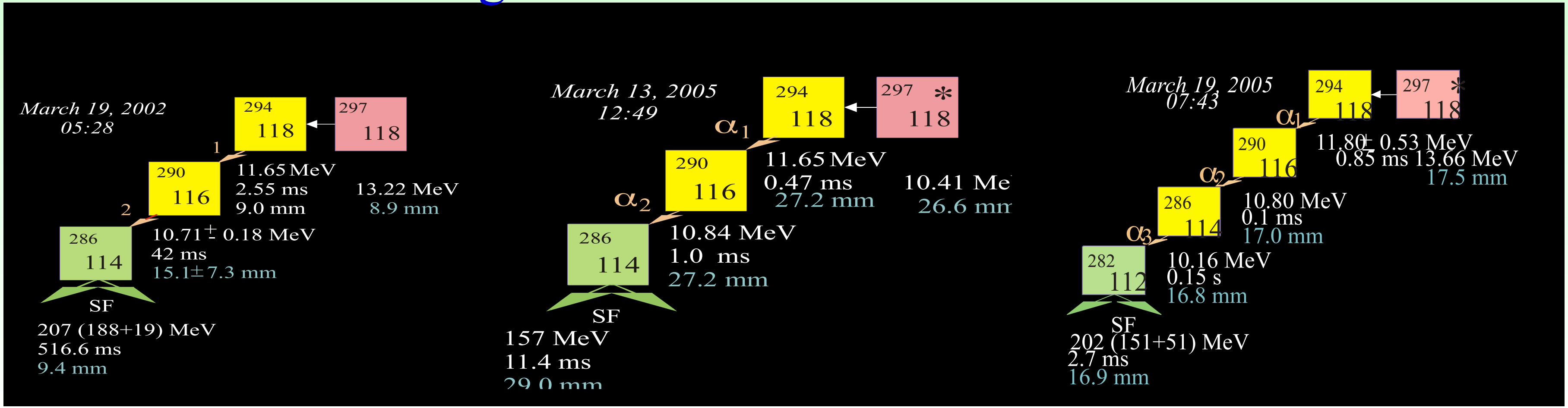
PHYSICAL REVIEW C 74, 044602 (2006)

Synthesis of the isotopes of elements 118 and 116 in the ^{249}Cf and $^{245}Cm+^{48}Ca$ fusion reactions

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, G. G. Gulbekian, S. L. Bogomolov, B. N. Gikal, A. N. Mezentsev, S. Iliev, V. G. Subbotin, A. M. Sukhov, K. Subotic, V. I. Zagrebaev, G. K. Vostokin, and M. G. Itkis
Joint Institute for Nuclear Research, 141980 Dubna, Russian Federation

K. J. Moody, J. B. Patin, D. A. Shaughnessy, M. A. Stoyer, N. J. Stoyer, P. A. Wilk, J. M. Kenneally, J. H. Landrum, J. F. Wild, and R. W. Lougheed

$$^{48}Ca+^{249}Cf\rightarrow^{294}Og+3n$$



^{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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[2] *Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*

[3] *Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA*

[4] *Joint Institute for Nuclear Research, RU-141980 Dubna, Russian Federation*

[5] *Faculty of Physics, University of Warsaw, PL-02-093 Warsaw, Poland*

[6] *Department of Physics and Astronomy, Vanderbilt University, Nashville, Tennessee 37235, USA*

[7] *Laurence Livermore National Laboratory, Livermore, California 94551, USA*

[†] *brewernt@ornl.gov*

(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.

LLNL-JRNL-754508

First Direct Measurements of Superheavy Element Mass Numbers

J. M. Gates[1,*], G. K. Pang[1], J. L. Pore[1], K. E. Gregorich[1], J. T. Kwarsick[1,2], G. Savard[3,4], N. E. Esker[1], M. Kireeff Covo[1], M. J. Mogannam[1], J. C. Batchelder[2], D. L. Bleuel[6], R. M. Clark[1], H. L. Crawford[1], P. Fallon[1], K. K. Hubbard[1,2], A. M. Hurst[1], I. T. Kolaja[2], A. O. Macchiavelli[1], C. Morse[1], R. Orford[5,7], L. Phair[1], M. A. Stoyer[6]

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PACS: 27.90.+b, 21.10.Dr, 25.70.Gh

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Abstract

An experiment was performed at Lawrence Berkeley National Laboratory's 88-Inch Cyclotron to determine the mass number of a superheavy element. The measurement resulted in the observation of two α-decay chains, produced via the ^{243}Am(^{48}Ca,xn)$^{291-x}$Mc reaction, that were separated by mass-to-charge ratio (A/q) and identified by the combined BGS+FIONA apparatus. One event occurred at A/q=284 and was assigned to ^{284}Nh (Z=113), the α-decay daughter of ^{288}Mc (Z=115), while the second occurred at A/q=288 and was assigned to ^{288}Mc. This experiment represents the first direct measurements of the mass numbers of superheavy elements, confirming previous (indirect) mass-number assignments.

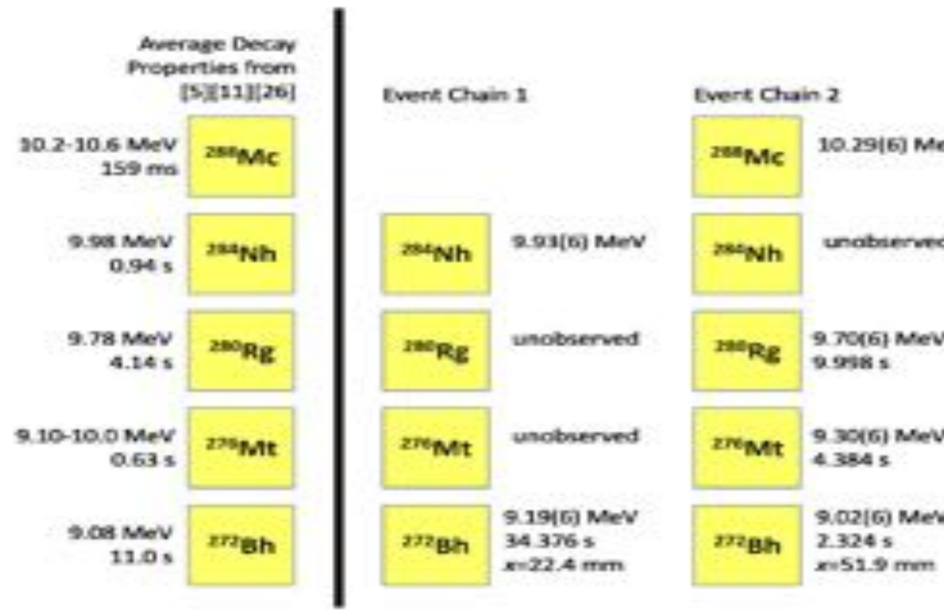
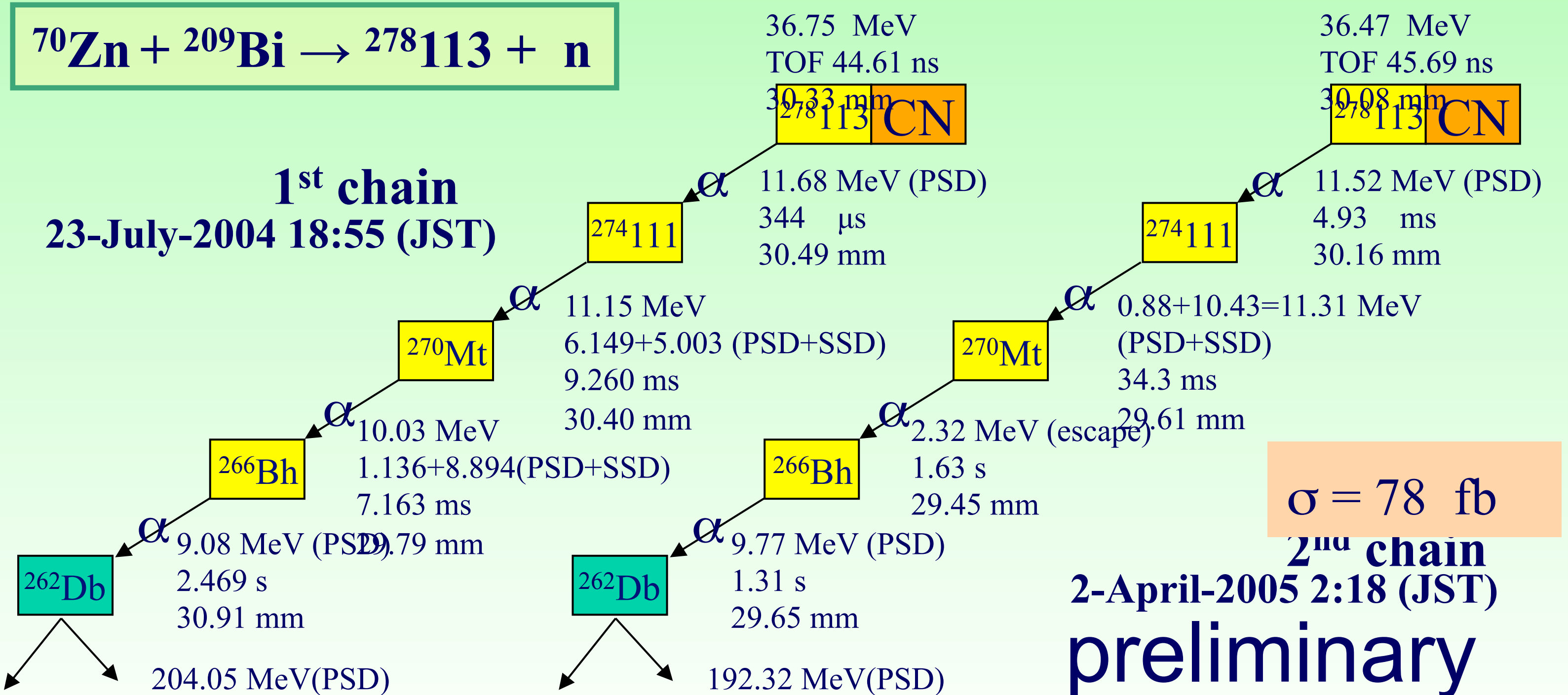


FIG. 4: (left) Average of known decay properties assigned to ^{288}Mc and its daughters [5, 11, 29]; (ri
Details of decay chains detected at the FIONA focal plane. Unobserved decays within each decay c
are indicated as "unobserved" and are assumed to have been emitted out of the open end of the dete
array. The x-position of decays observed in the focal-plane detector is also given.

^{278}Nh in RIKEN

RIKEN-Garis: Thickness of target 0.48mg/cm^2, Research period 170 days

$$^{70}\text{Zn} + {}^{209}\text{Bi} \rightarrow {}^{278}113 + n$$



J. Phys. Soc. Jpn **73**(2004)2593
From K. Morita's talk in 2005

SHE in Lanzhou

^{271}Ds

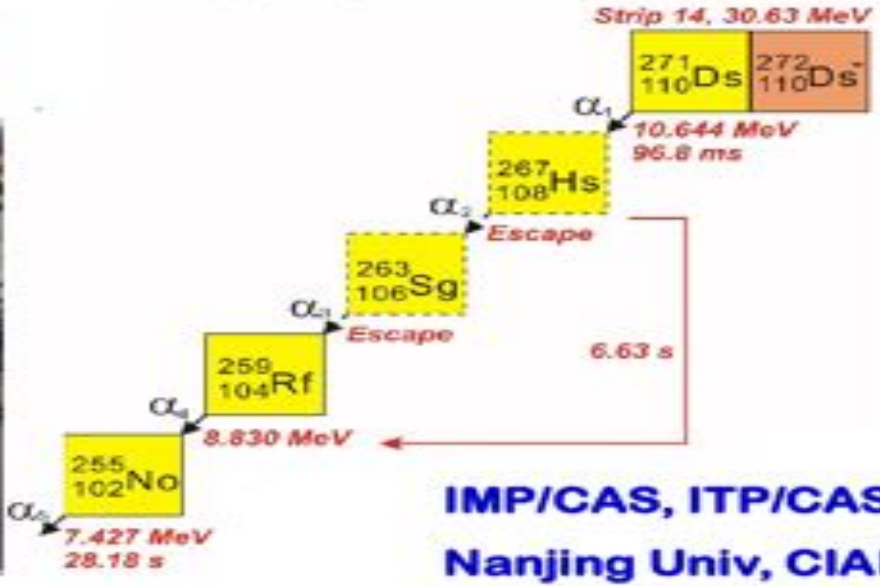
CHIN. PHYS. LETT. Vol. 29, No. 1 (2012) 012502

Observation of the Superheavy Nuclide ^{271}Ds *

ZHANG Zhi-Yuan(张志远)[1,6], GAN Zai-Guo(甘再国)[1**], MA Long(马龙)[1], HUANG Ming-Hui(黄明辉)[1], HUANG Tian-Heng(黄天衡)[1], WU Xiao-Lei(吴晓蕾)[1], JIA Guo-Bin(贾国斌)[1,6], LI Guang-Shun(李广顺)[1,6], YU Lin(郁琳)[1,6], REN Zhong-Zhou(任中洲)[2,5], ZHOU Shan-Gui(周善贵)[3,5], ZHANG Yu-Hu(张玉虎)[1], ZHOU Xiao-Hong(周小红)[1], XU Hu-Shan(徐瑚珊)[1], ZHANG Huan-Qiao(张焕乔)[4], XIAO Guo-Qing(肖国青)[1], ZHAN Wen-Long(詹文龙)[1]

2011.01.15 $^{64}Ni + ^{208}Pb \longrightarrow ^{272}Ds^*$

2011.03.15 $^{64}Ni + ^{208}Pb \longrightarrow ^{272}Ds^*$



IMP/CAS, ITP/CAS

Nanjing Univ, CIAE

Radiochim. Acta **99**, 429–439 (2011) / **DOI** 10.1524/ract.2011.1860
© by Oldenbourg Wissenschaftsverlag, München

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

By Yu. Oganessian*

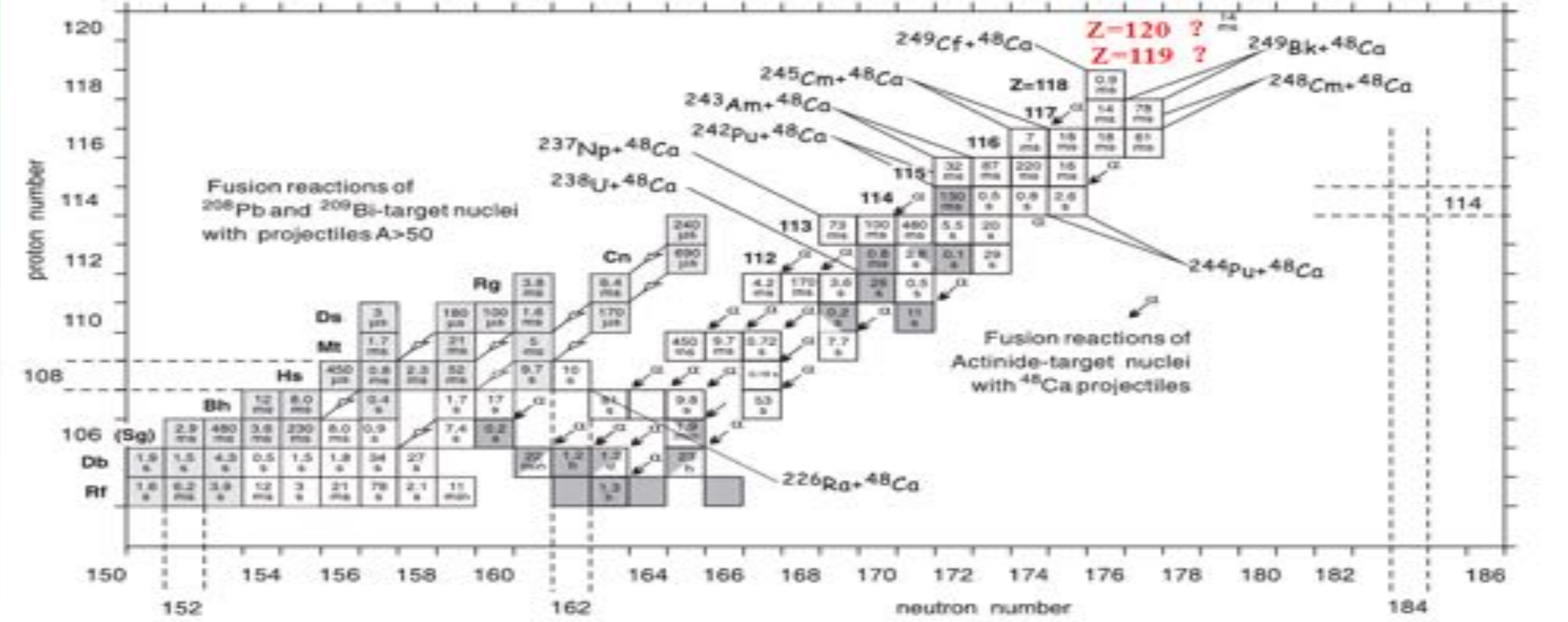
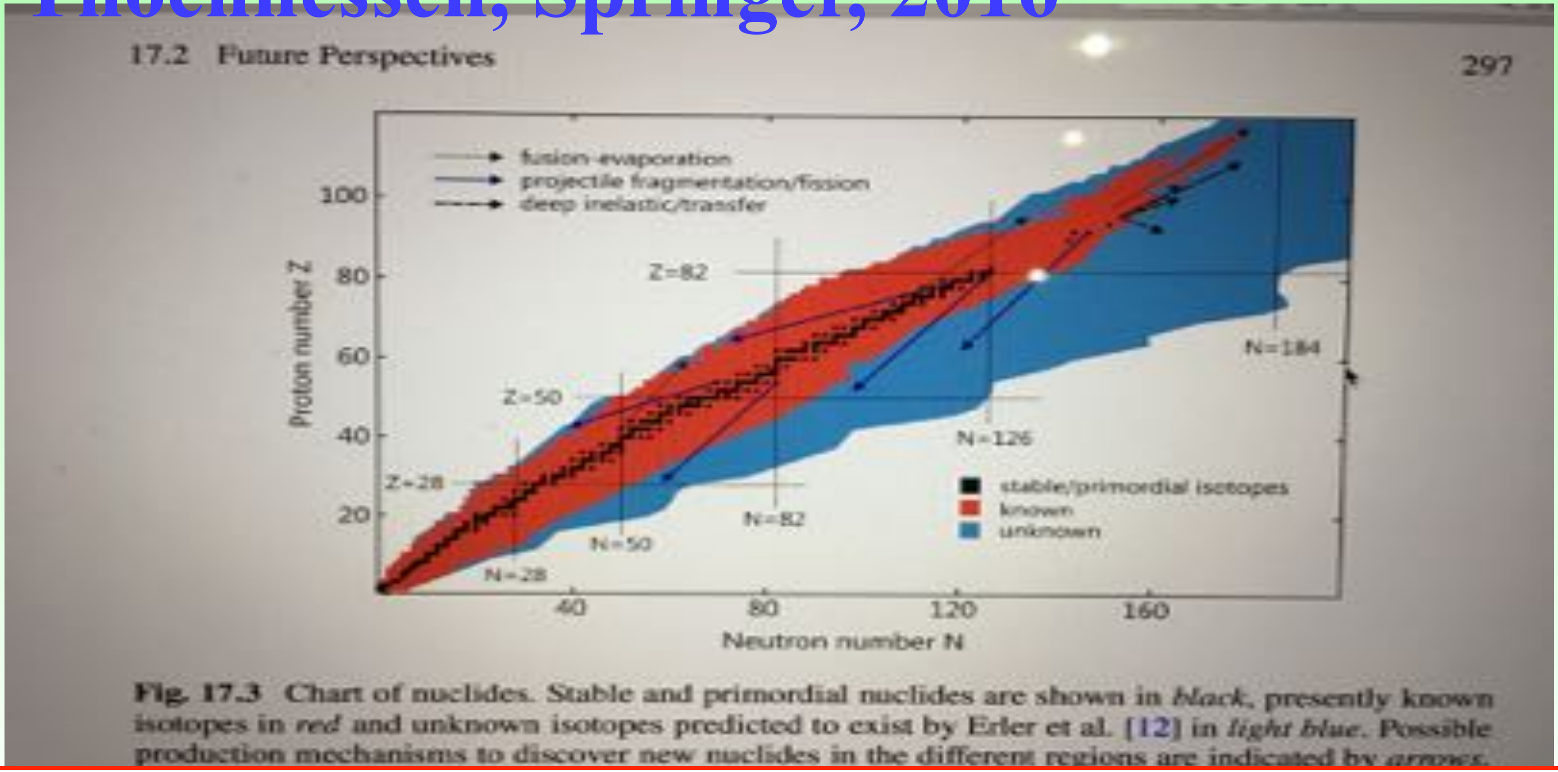


Fig. 5. Chart of the heaviest nuclides with $Z \geq 104$ and $N \geq 151$. The symbols are given in the right lower corner of the figure. To avoid making the figure too complicated, the squares contain the half-lives (without errors) only. For the nuclei synthesized in cold fusion reactions the values 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

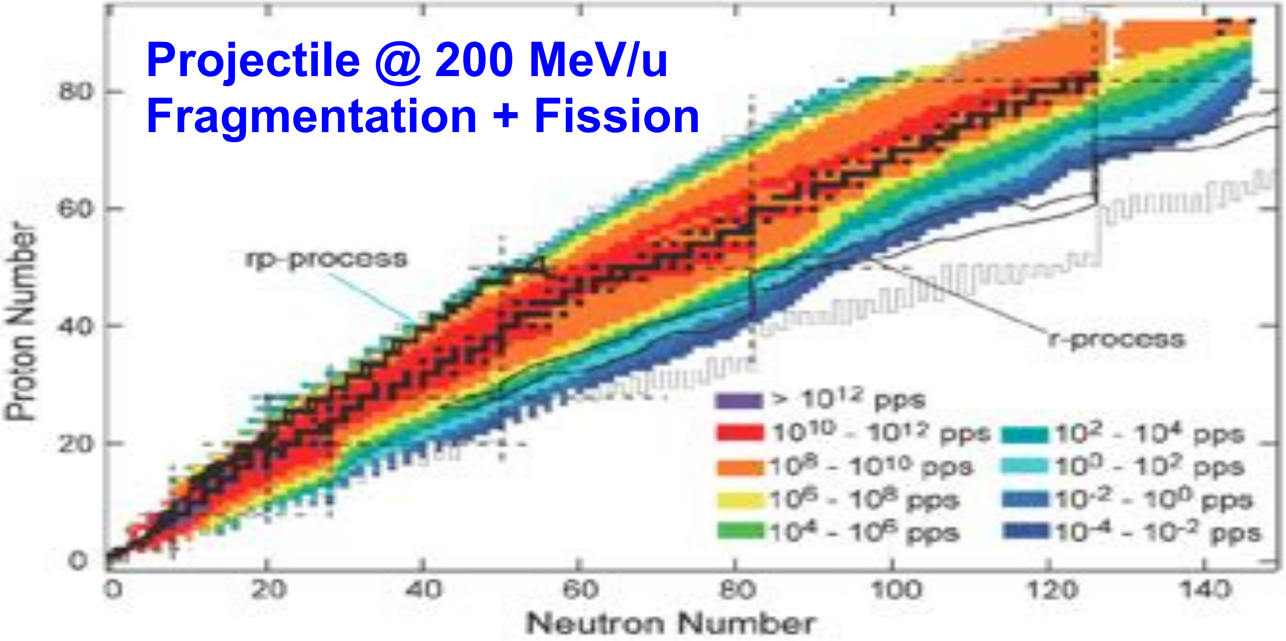
Michael Thoennessen, Springer, 2016



Up to the end of 2018， 3386 nuclides have been found。 Natural nuclides: 288（Stable: 254, unstable: 34）， the others are man-made radioactive isotopes

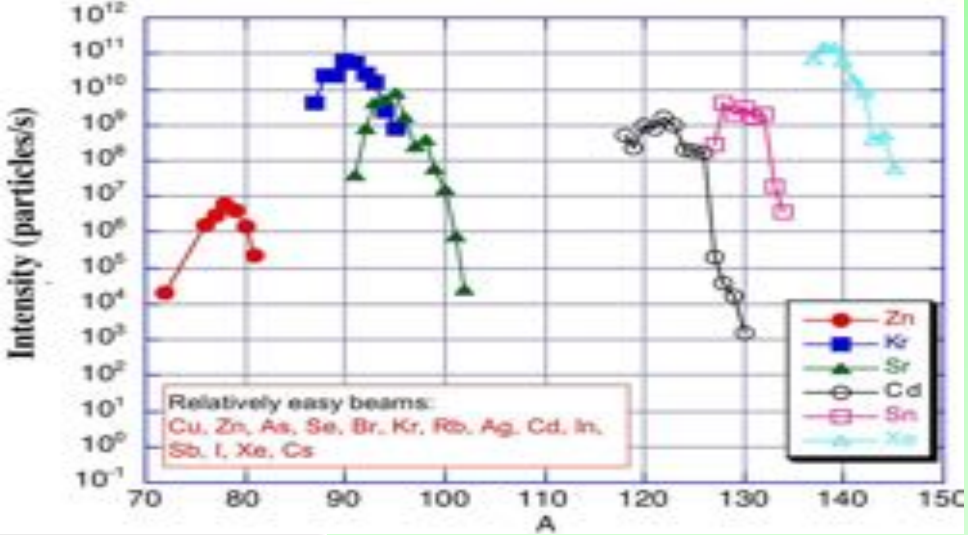
What Nuclides Will FRIB Produce?

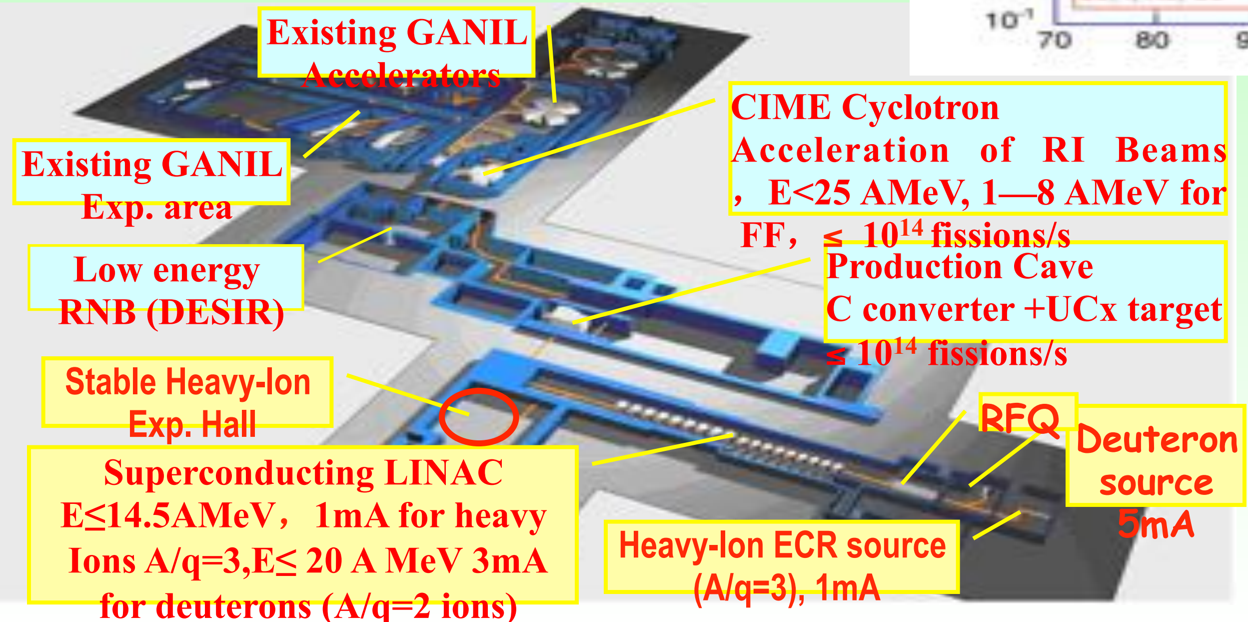
- FRIB will produce more than 1000 NEW isotopes at useful rates (4500 available for study)
- Theory is key to making the right measurements
- Exciting prospects for study of nuclei along the drip line to mass 120 (compared to 24)
- Production of most of the key nuclei for astrophysical modeling
- Harvesting of unusual isotopes for a wide range of applications



Rates are available at http://groups.nscl.msu.edu/frib/rates/

SPIRAL II (GANIL)



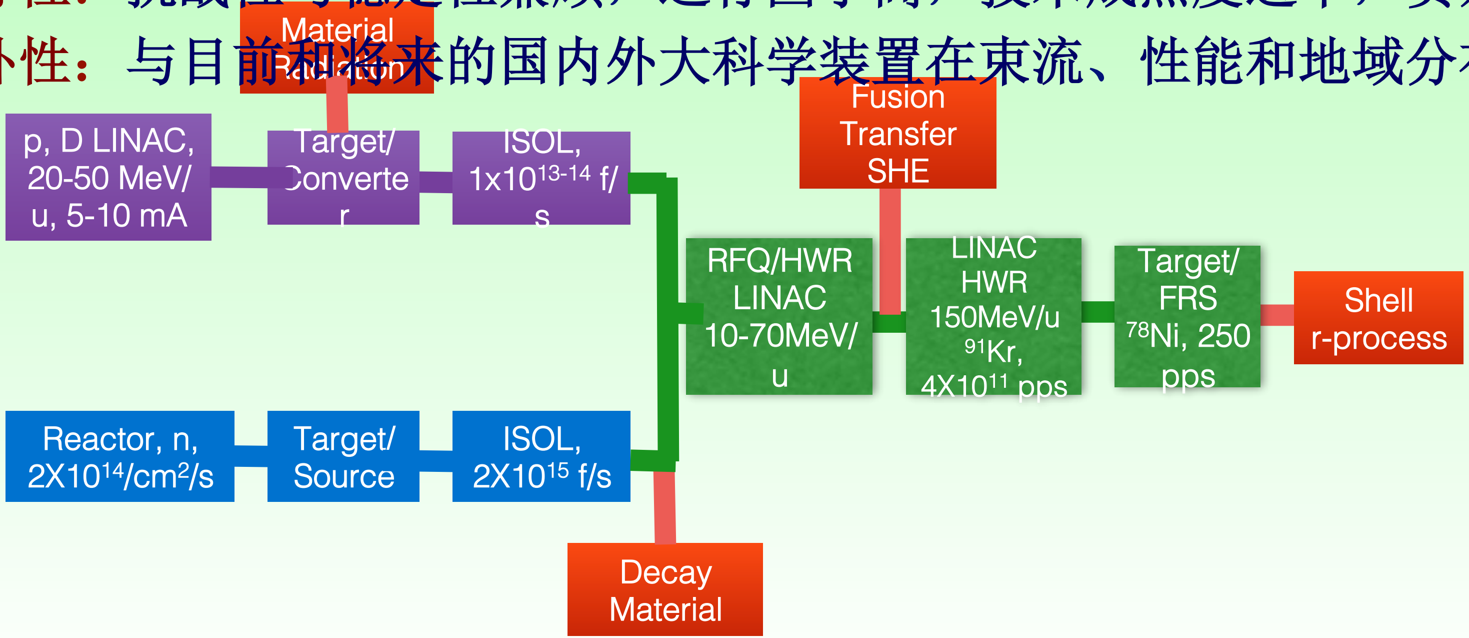


HIAF 布局

	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	~1.0×10^{11} ppp

北京丰中子束流装置（BISOL）介绍

- 先进性：ISOL+PF结合，堆器耦合，可提供国际一流的束流强度和研究平台
- 多用性：通过多束流、多能量和多平台，满足从基础到应用的各种需求
- 可行性：挑战性与稳定性兼顾，运行因子高，技术成熟度适中，费效比高
- 互补性：与目前和将来的国内外大科学装置在束流、性能和地域分布合理



Provided by Prof. Weiping Liu

Accelerator	Driver Linac		Post Acc.	Cyclotron
Particle	proton	U^{+79}	RI beam	proton
Beam energy	600 MeV	200 MeV/u	18.5 MeV/u	70 MeV
Beam current	660 μA	8.3 pμA	-	1 mA
Power on target	400 kW	400 kW	-	70 kW

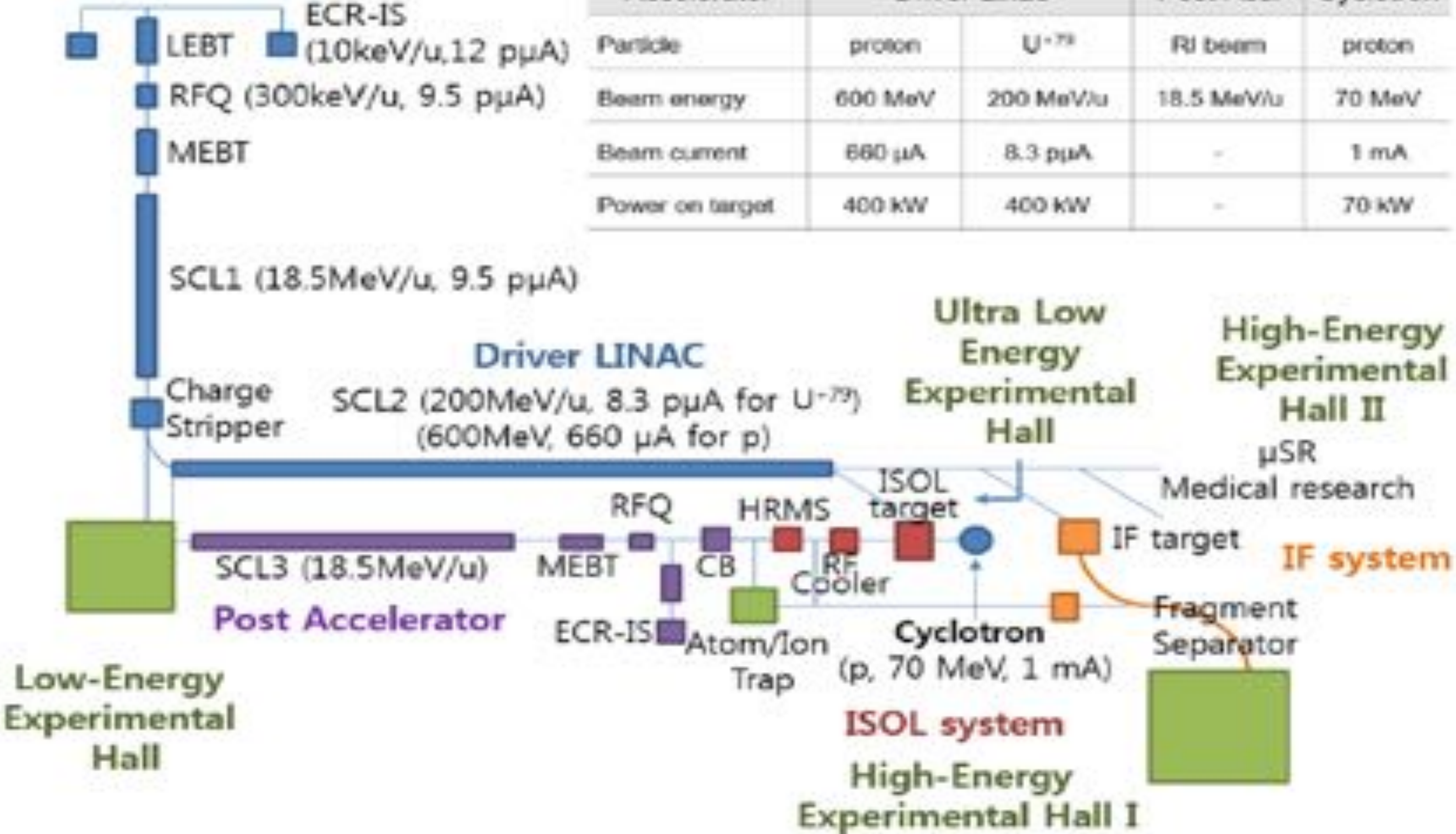
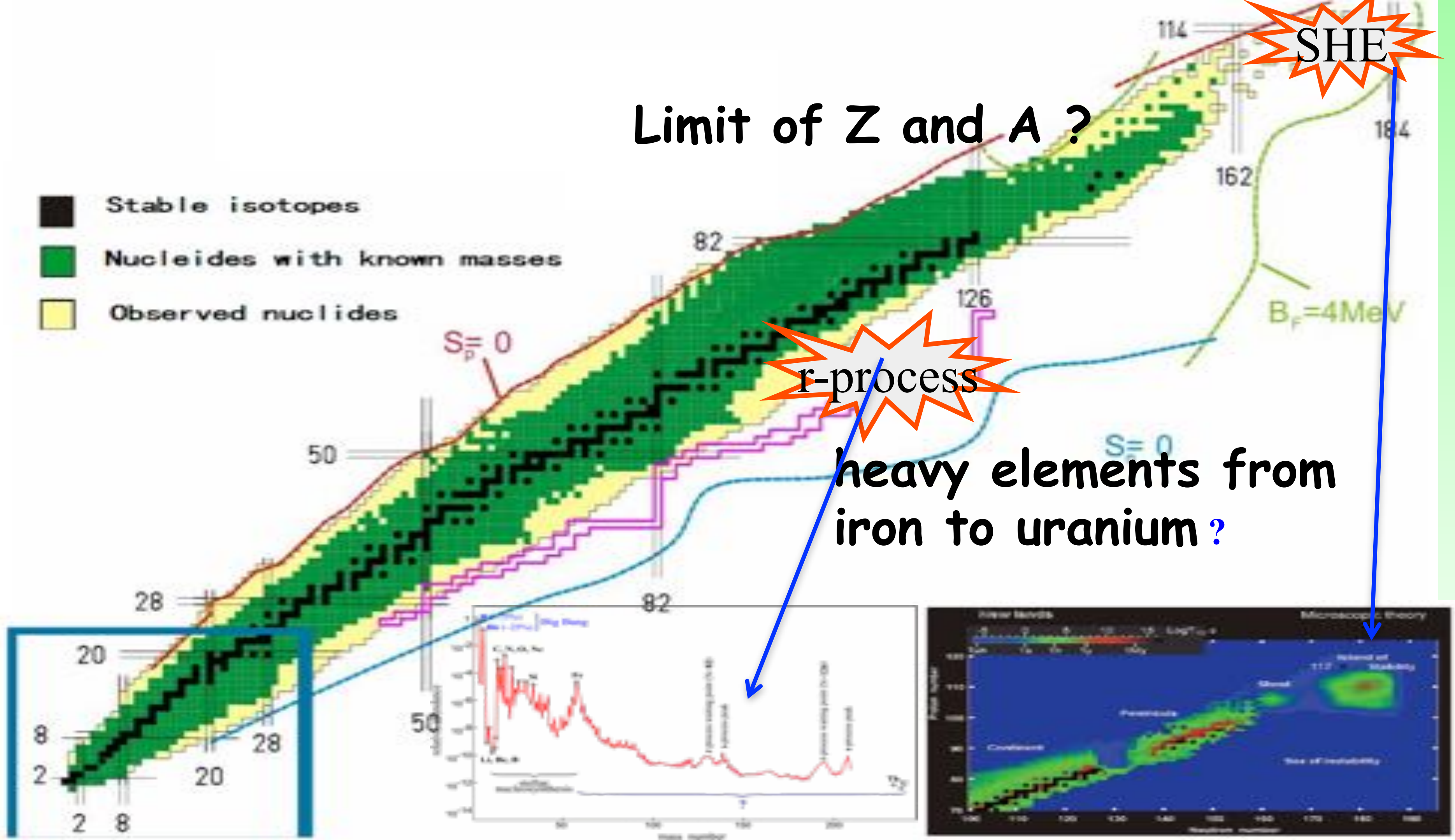


TABLE 1. Expected energy ranges and intensities at the experimental target for some selected radioactive ion beams at RAON.

Beam nuclide	Energy (MeV/u)	Intensity (pps)
^{106}Sn	10–250	$\sim 10^9$
^{132}Sn	5–250	$\sim 10^7$
^{140}Xe	10–250	$\sim 10^8$
^{142}Xe	10–250	$\sim 10^7$


Limit of Z and A ?
heavy elements from
iron to uranium ?
SHE
r-process
Stable isotopes
Nucleides with known masses
Observed nuclides
S_p= 0
S_n= 0
B_f=4MeV
114
184
162
82
126
50
28
20
8
2

Article

Identification of strontium in the merger of two neutron stars

https://doi.org/10.1038/s41586-019-1676-3

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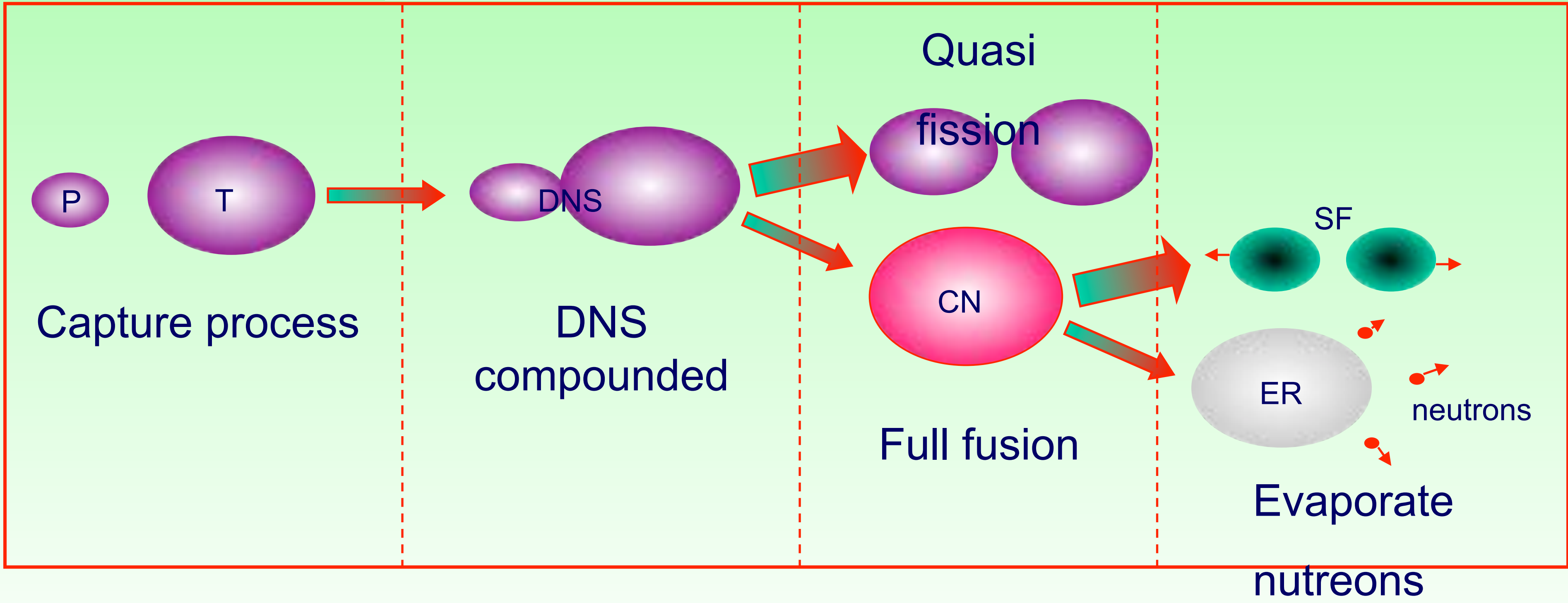
Published online: 23 October 2019

Darach Watson[1,2*], Camilla J. Hansen[1,2,20], Jonatan Selsing[1,2,20], Andreas Koch[4], Daniele B. Malesani[1,2,5], Anja C. Andersen[1], Johan P. U. Fynbo[1,2], Almudena Arcones[6,7], Andreas Bauswein[7,8], Stefano Covino[9], Aniello Grado[10], Kasper E. Heintz[1,2,11], Leslie Hunt[12], Chryssa Kouveliotou[13,14], Giorgos Leloudas[1,5], Andrew J. Levan[15,16], Paolo Mazzali[17,18] & Elena Pian[19]

Half of all of the elements in the Universe that are heavier than iron were created by rapid neutron capture. The theory underlying this astrophysical r-process was worked out six decades ago, and requires an enormous neutron flux to make the bulk of the elements[1]. Where this happens is still debated[2]. A key piece of evidence would be the discovery of freshly synthesized r-process elements in an astrophysical site. Existing models[3–5] and circumstantial evidence[6] point to neutron-star mergers as a probable r-process site; the optical/infrared transient known as a 'kilonova' that emerges in the days after a merger is a likely place to detect the spectral signatures of newly created neutron-capture elements[7–9]. The kilonova AT 2017gfo—which was found following the discovery of the neutron-star merger GW170817 by gravitational-wave detectors[10]—was the first kilonova for which detailed spectra were recorded. When these spectra were first reported[11,12], it was argued that they were broadly consistent with an outflow of radioactive heavy elements; however, there was no robust identification of any one element. Here we report the identification of the neutron-capture element strontium in a reanalysis of these spectra. The detection of a neutron-capture element associated with the collision of two extreme-density stars establishes the origin of r-process elements in neutron-star mergers, and shows that neutron stars are made of neutron-rich matter[13].

Fusion-Evaporation Reaction （DNS model）

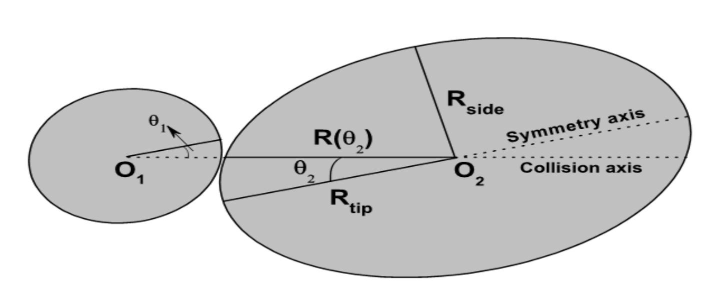
$$\sigma_{ER} = \sigma_{cap} P_{CN} W_{sur}$$



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

A simple test

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



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

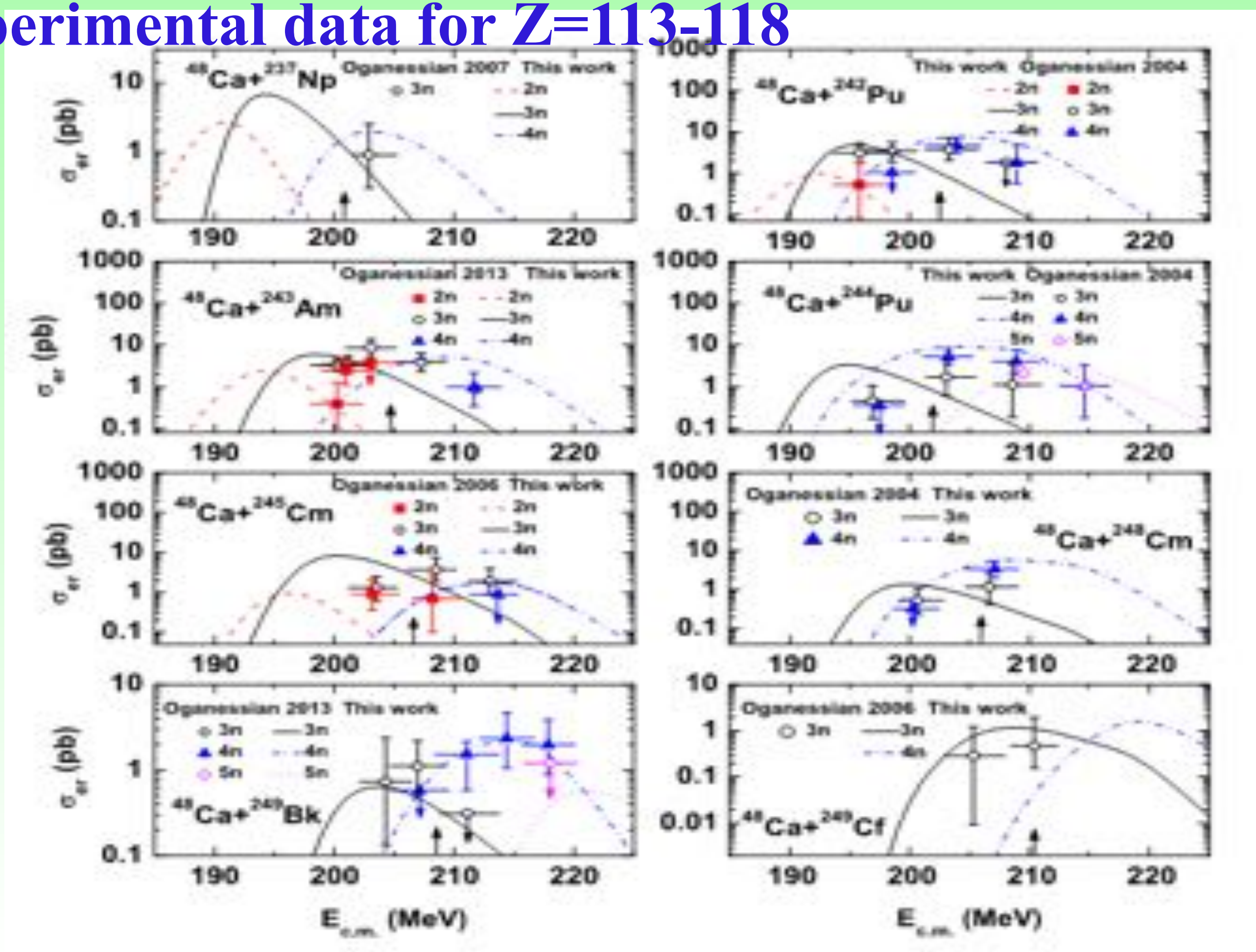
$$\sigma_{cap}(E_{c.m.},\theta_1,\theta_2) = \frac{\pi\hbar^2}{2\mu E_{c.m.}} \sum_J (2J+1)T(E_{c.m.},\theta_1,\theta_2,J).$$

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

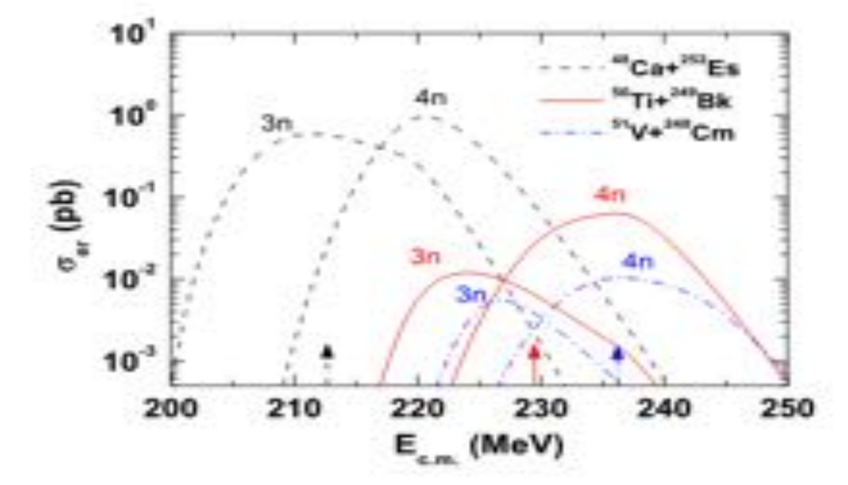
W_{sur} HIVAP code

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

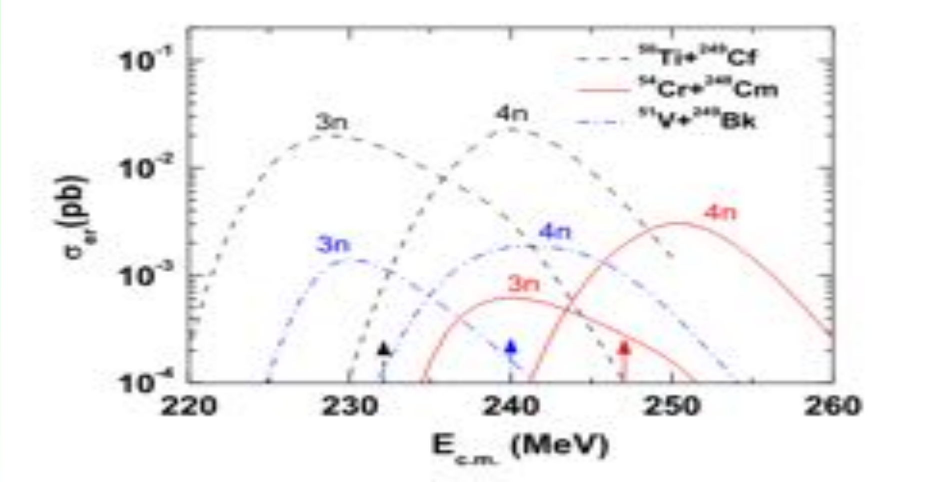


The maximal production cross sections for Z=119:

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

The maximal production cross sections for Z=120:

$^{50}Ti + ^{249}Cf$	0.029 pb
$^{54}Cr + ^{248}Cm$	0.003 pb
$^{51}V + ^{249}Bk$	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
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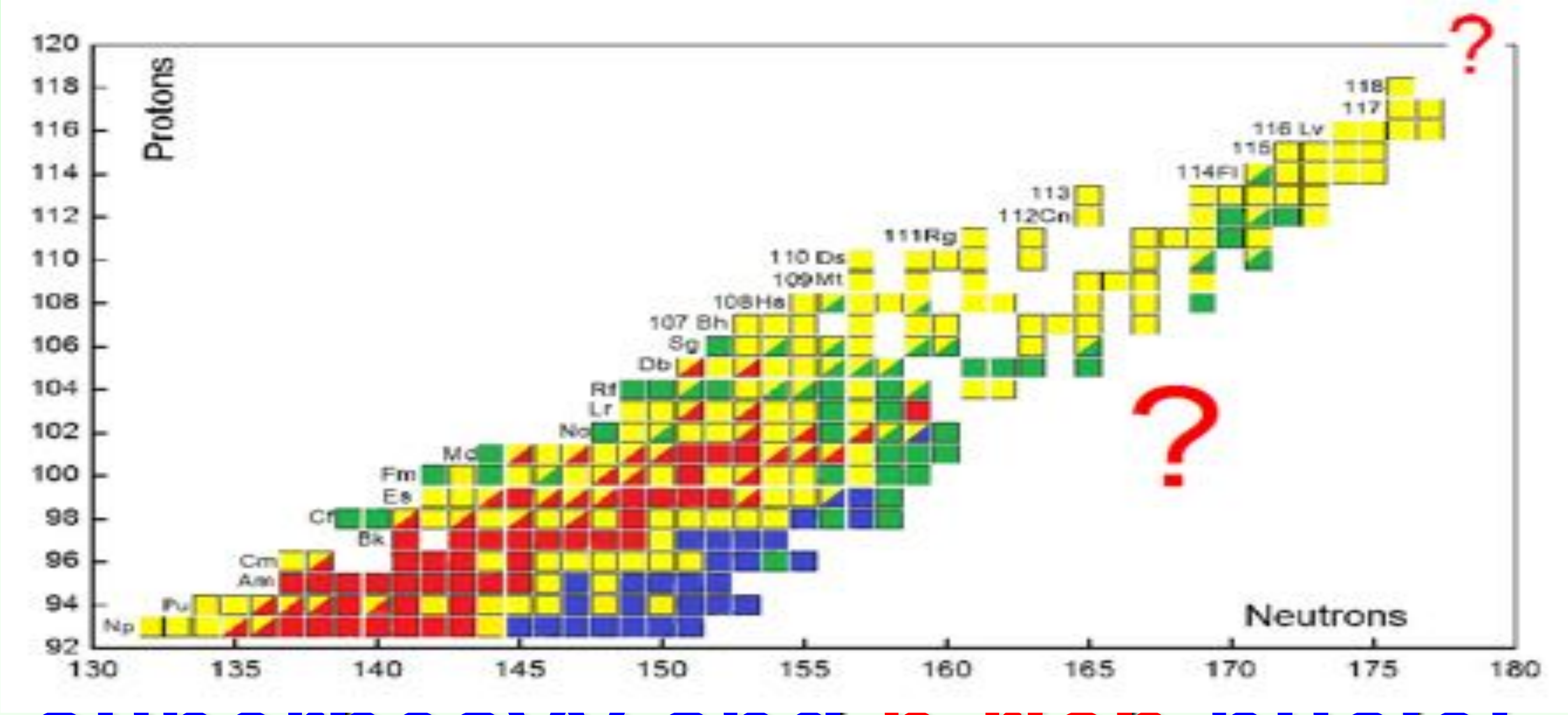
R. A. Henderson, K. J. Moody, J. M. Kenneally, J. H. Landrum, D. A. Shaughnessy, M. A. Stoyer, N. J. Stoyer, and P. A. Wilk
Lawrence Livermore National Laboratory, Livermore, California 94551, USA

(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.



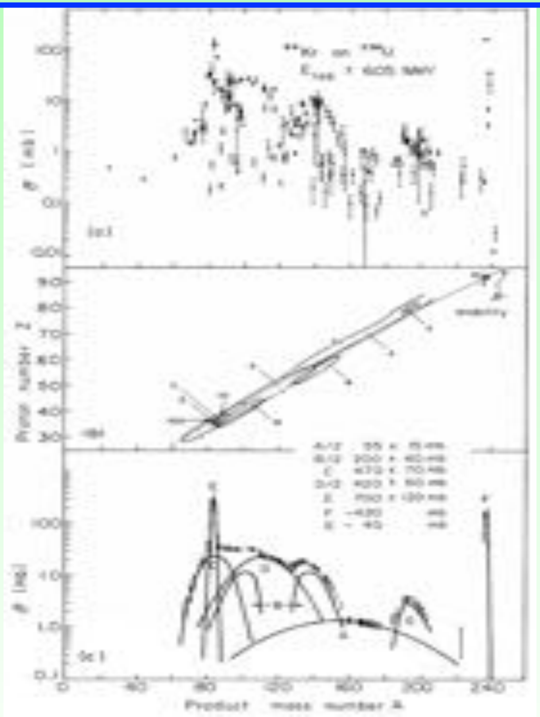
superheavy and n-rich nuclei - transuranium

OUTLINE

1. Introduction
2. Experimental progress
3. Theoretical models
4. RNB induced MNT
5. Summary

Experimental progress

Many research about transfer reactions has been done during the last 70s-80s.
Such as ^{40}Ar, ^{56}Fe, ^{84}Kr, ^{136}Xe, ^{238}U with ^{238}U; ^{40}Ar, $^{40,48}Ca$, ^{238}U with ^{248}Cm; ^{84}Kr with ^{209}Bi *et al.*

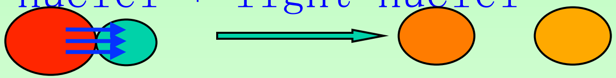


156 nuclides were produced

J. V. Kratz, et al., Phys. Rev. Lett. 33, 502(1974)

a) Produce neutron-rich nuclides

heavy nuclei + light nuclei



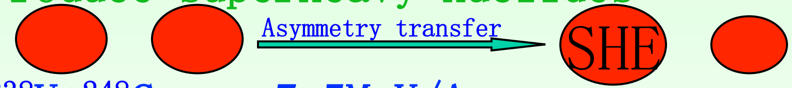
1, $^{40}Ar+^{238}U$ 340MeV

7 new isotopes: 54Ti, ^{56}V, $^{58,59}Cr$, ^{61}Mn, $^{63,64}Fe$

2, $^{56}Fe+^{238}U$ 465MeV

2 new isotopes: ^{57}V and ^{58}V

b) Produce superheavy nuclides



3, $^{238}U+^{248}Cm$ 7.5MeV/A

Up to FM and Md have been produced (No SHE)

1, D. Guerrau, et al., Z. Phys. A 295, 105(1980)
2, H. Breuer, et al., Phys. Rev. C 22, 2454(1980)
3, M. Schäde, et al., Phys. Rev. Lett. 48, 852 (19

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

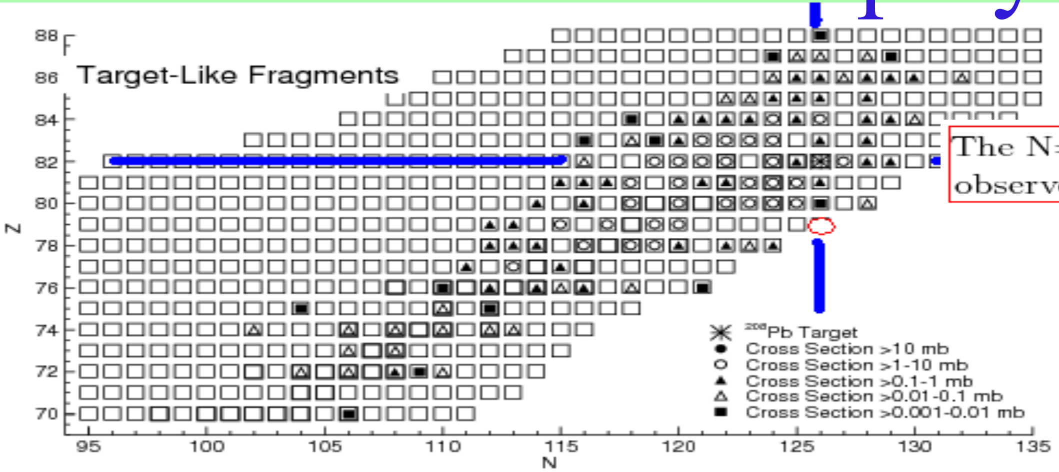
2. Kratz, Loveland, and Moody, Syntheses of trans-U isotops with Z=<103 in multi-nucleon transfer reactions, NPA2015

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

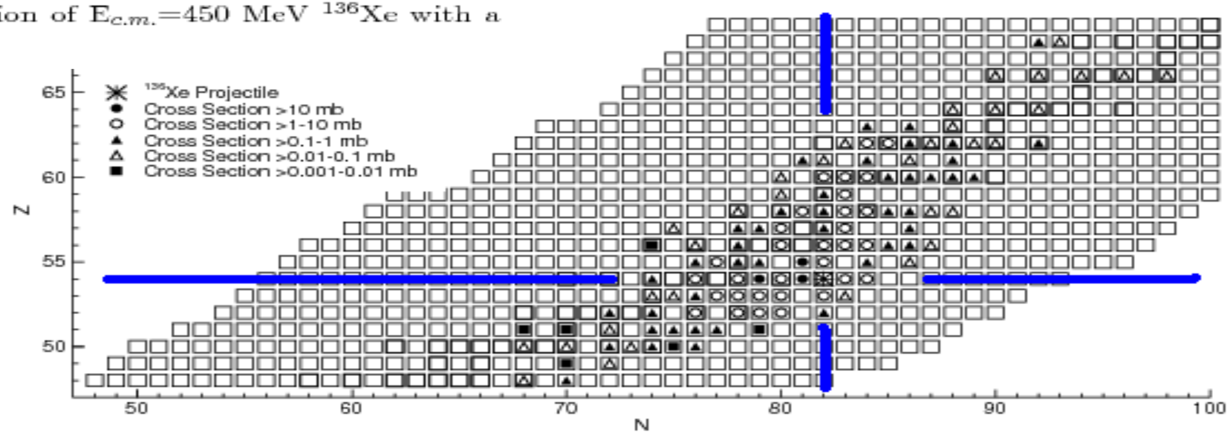
5. Barrett, Loveland, et al, The 136Xe(Ecm=450MeV) + 208Pb reaction: A test of models of multi-nucleon transfer reactions, PRC91(2015)064615, 200 P+ T-like fragments

Recent Exp by W. Loveland



The 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

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[2] Beijing Radiation Center, Beijing 100875, 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

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

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

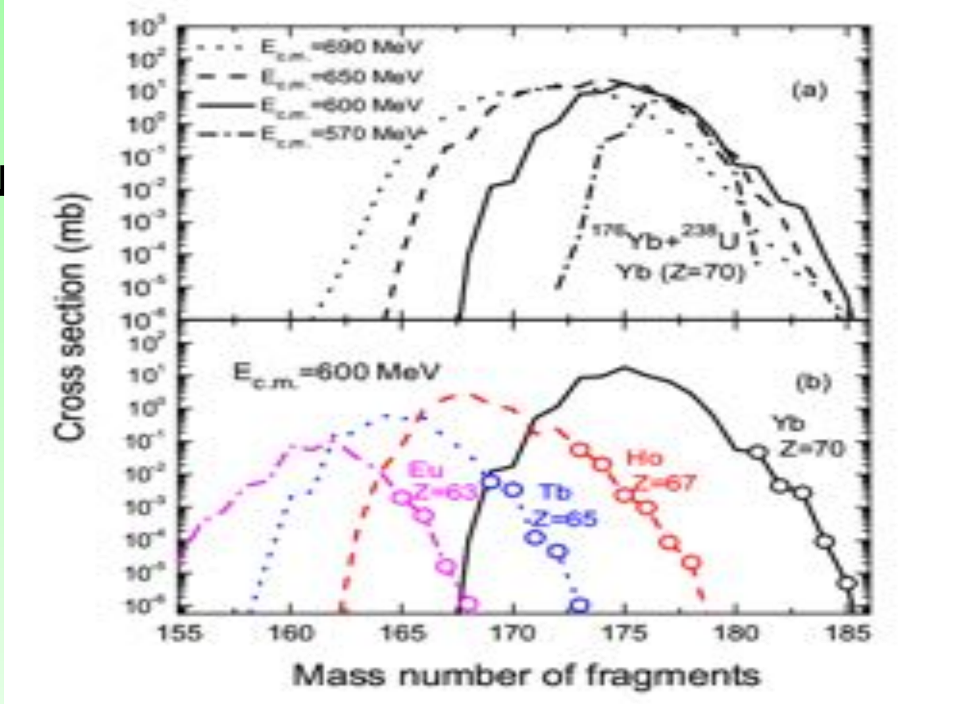

FIG. 5. (a) Production cross sections of isotopes of Yb in the transfer reaction $^{176}Yb+^{238}U$ at $E_{c.m.}$ = 570 (dash-dotted line), 600 (solid line), 650 (dashed line), and 690 MeV (dotted line). (b) Cross sections for the formation of isotopes of elements Ytterbium (solid line), Holmium (dashed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

Argonne 探测装置： FMA + Gammasphere

PHYSICAL REVIEW C 91, 064615 (2015)

$^{136}Xe + ^{208}Pb$ reaction: A test of models of multinucleon transfer reactions

J. S. Barrett, W. Loveland, and R. Yanez
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, and T. Lauritsen
Physics Division, Argonne National Laboratory, Argonne, Illinois 60439 USA

Physics Letters B 773 (2017) 119–124

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Physics Letters B

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$^{204}Hg+^{198}Pt$反应

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],

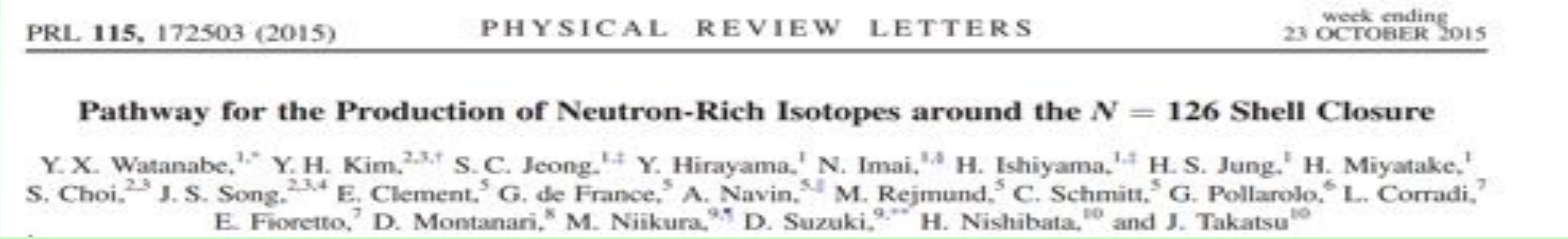
PHYSICAL REVIEW C 99, 044604 (2019)

The $^{136}Xe + ^{198}Pt$ reaction: A test of models of multi-nucleon transfer reactions

V. V. Desai, W. Loveland, K. McCaleb, and R. Yanez
Department of Chemistry, Oregon State University, Corvallis, Oregon 97331, USA

G. Lane, S. S. Hota, M. W. Reed, and H. Watanabe
Department of Nuclear Physics, Research School of Physics and Engineering, The Australian National University, Canberra, Australian Capitol Territory 2601, Australia

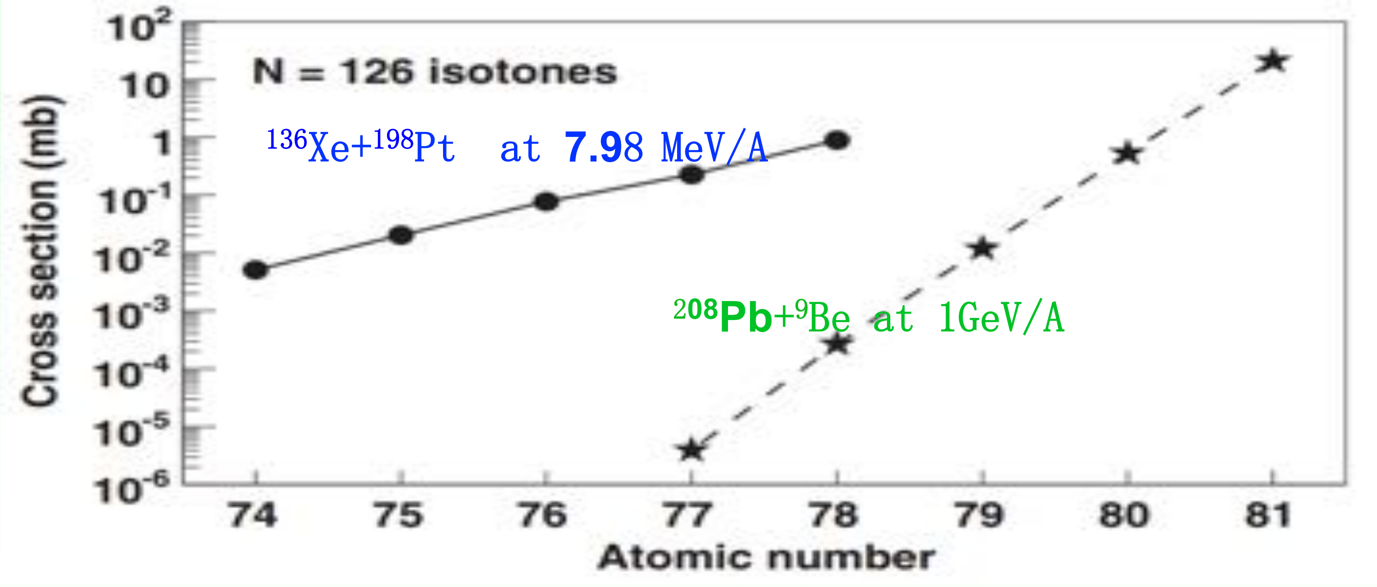
GANIL 探测装置：VAMOS++ 同位素探测能力：10^{-2} mb



PRL 115, 172503 (2015) PHYSICAL REVIEW LETTERS week ending 23 OCTOBER 2015

Pathway for the Production of Neutron-Rich Isotopes around the N = 126 Shell Closure

Y. X. Watanabe,[1,*] Y. H. Kim,[2,3,†] S. C. Jeong,[1,‡] Y. Hirayama,[1] N. Imai,[1,§] H. Ishiyama,[1,‡] H. S. Jung,[1] H. Miyatake,[1] S. Choi,[2,3] J. S. Song,[2,3,4] E. Clement,[5] G. de France,[5] A. Navin,[5,‖] M. Rejmund,[5] C. Schmitt,[5] G. Pollarolo,[6] L. Corradi,[7] E. Fioretto,[7] D. Montanari,[8] M. Niikura,[9,¶] D. Suzuki,[9,**] H. Nishibata,[10] and J. Takatsu[10]



证据：
多核子转移反应产生丰中子核的截面远大于碎裂反应，高约4个量级

Dubna 探测装置： CORSET (TOF)

PHYSICAL REVIEW C 86, 044611 (2012)

Mass distributions of the system $^{136}Xe + ^{208}Pb$ at laboratory energies around the Coulomb barrier: A candidate reaction for the production of neutron-rich nuclei at $N = 126$

E. M. Kozulin,[1] E. Vardaci,[2] G. N. Knyazheva,[1] A. A. Bogachev,[1] S. N. Dmitriev,[1] I. M. Itkis,[1] M. G. Itkis,[1] A. G. Knyazev,[1] T. A. Loktev,[1] K. V. Novikov,[1] E. A. Razinkov,[1] O. V. Rudakov,[1] S. V. Smirnov,[1] W. Trzaska,[3] and V. I. Zagrebaev[1]
[1]*Flerov Laboratory of Nuclear Reaction, Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia*
[2]*Dipartimento di Scienze Fisiche dell'Universitá degli Studi di Napoli "Federico II" and Istituto Nazionale di Fisica Nucleare,*

PHYSICAL REVIEW C 89, 014614 (2014)

Shell effects in damped collisions of ^{88}Sr with ^{176}Yb at the Coulomb barrier energy

E. M. Kozulin, G. N. Knyazheva, S. N. Dmitriev, I. M. Itkis, M. G. Itkis, T. A. Loktev, K. V. Novikov, and A. N. Baranov
Flerov Laboratory of Nuclear Reaction, Joint Institute for Nuclear Research, 141980 Dubna, Moscow Region, Russia

W. H. Trzaska
Department of Physics, University of Jyväskylä, Jyväskylä, Finland

PHYSICAL REVIEW C 96, 064621 (2017)

Inverse quasifission in the reactions $^{156,160}Gd + ^{186}W$

E. M. Kozulin,[1] V. I. Zagrebaev,[1,*] G. N. Knyazheva,[1] I. M. Itkis,[1] K. V. Novikov,[1] M. G. Itkis,[1] S. N. Dmitriev,[1] I. M. Harca,[1,2,3] A. E. Bondarchenko,[1] A. V. Karpov,[1] V. V. Saiko,[1] and E. Vardaci[4]
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[2]*Faculty of Physics, University of Bucharest, Romania*

中科院近物所

Nuclear Inst. and Methods in Physics Research, B xxx (2019) xxx-xxx

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, B

journal homepage: www.elsevier.com

Monte-Carlo simulation of ion distributions in a gas cell for multinucleon transfer reaction products at LENSHIAF spectrometer

Yong-Sheng Wang[a,b,c], Wen-Xue Huang[a,*], Yu-Lin Tian[a,b], Jun-Ying Wang[a], Cheng Li[d,e], Feng-Shou Zhang[d,e], Kai Zhao[f], Xiao-Hong Zhou[a], Hu-Shan Xu[a]

[a] CAS Key Laboratory of High Precision Nuclear Spectroscopy, Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China
[b] School of Nuclear Science and Technology, University of Chinese Academy of Sciences, Beijing 100049, China
[c] School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China

Fig. 3. A simple model for the simulation including a target, a titanium foil and a cylindrical gas cell.

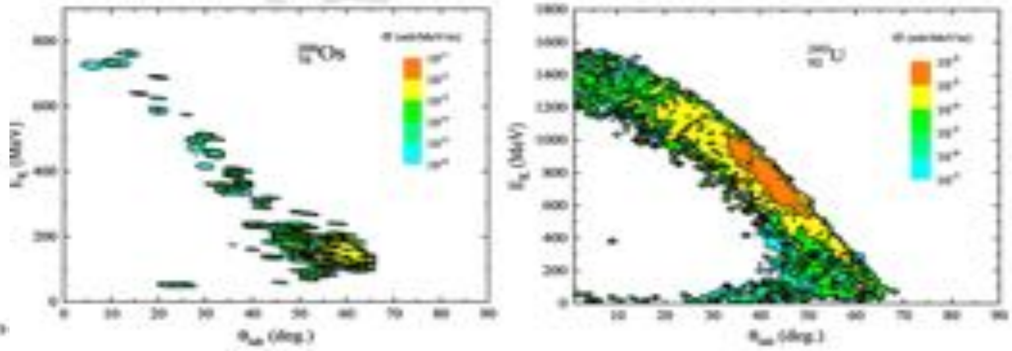


Fig. 2. Double differential cross sections of Os in the ... (left) and U in ... (right).

OUTLINE

1. Introduction
2. Experimental progress
3. Theoretical models
4. RNB induced MNT
5. Summary

多核子转移反应理论进展

一、唯象模型：

1. Dinuclear system (DNS)

2. GRAZING

3. Complex WKB (CWKB)

4. Langevin equations

5. Deep-inelastic transfer (DIT)

…

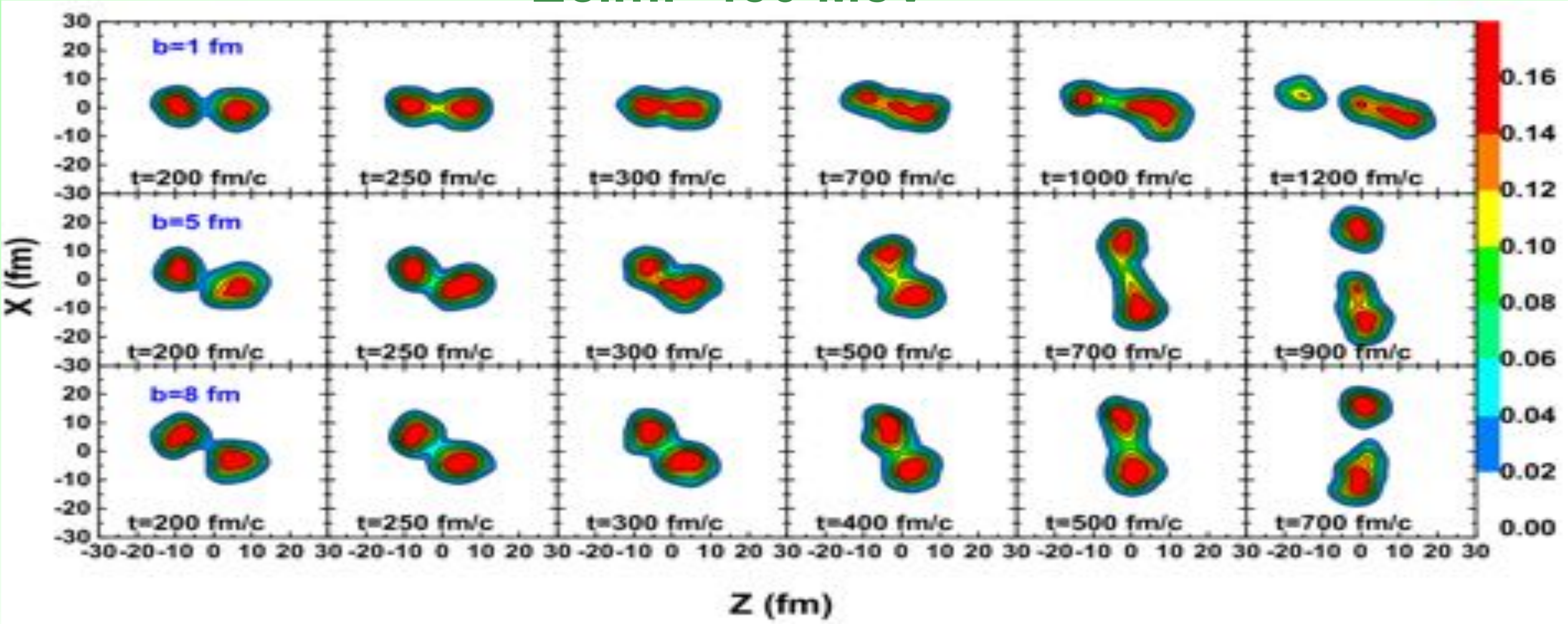
二、微观模型：

1.Time-dependent Hartree-Fock(TDHF)

2.Quantum molecular dynamics (QMD)

…

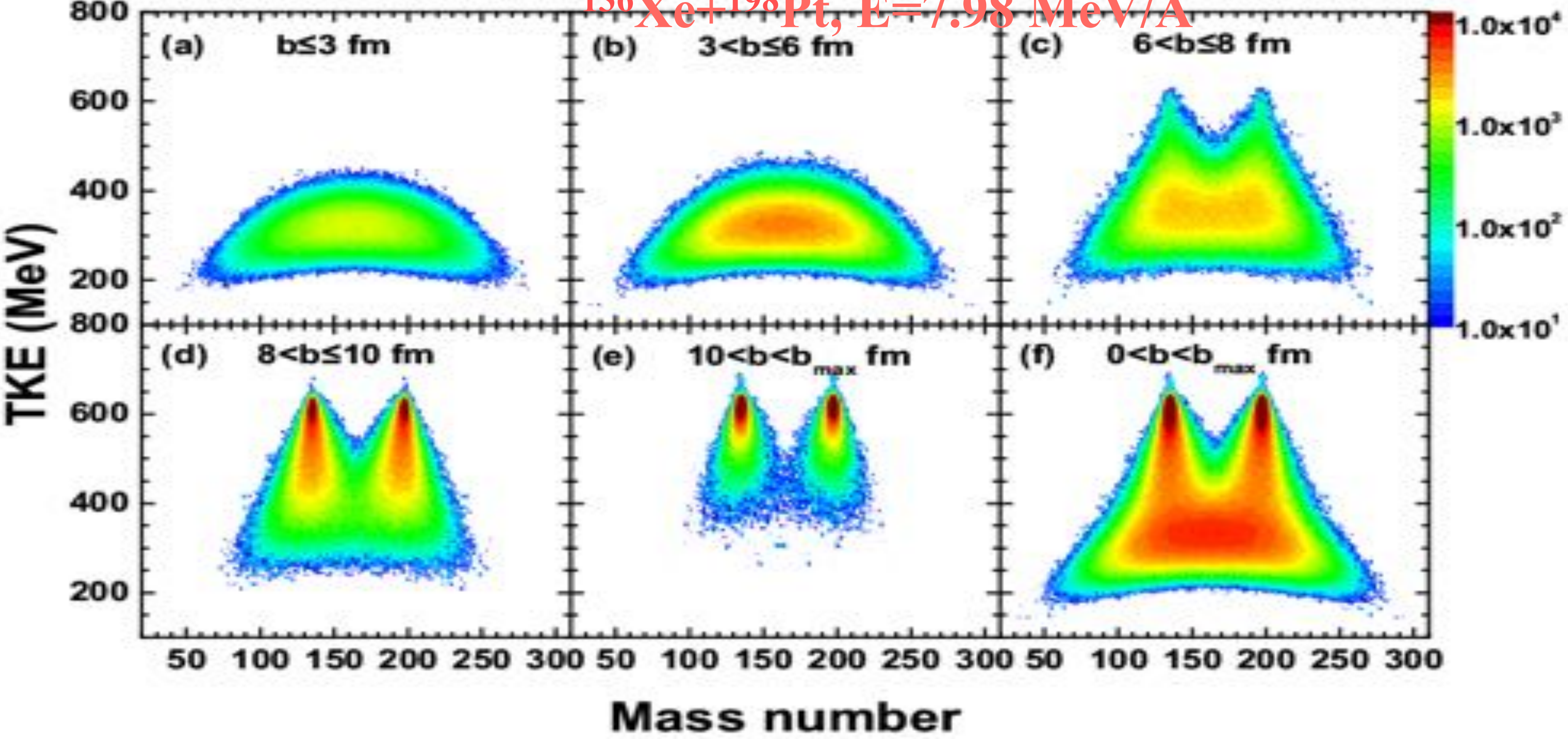
Density distribution of $^{136}Xe+^{208}Pb$ at Ec.m.=450 MeV

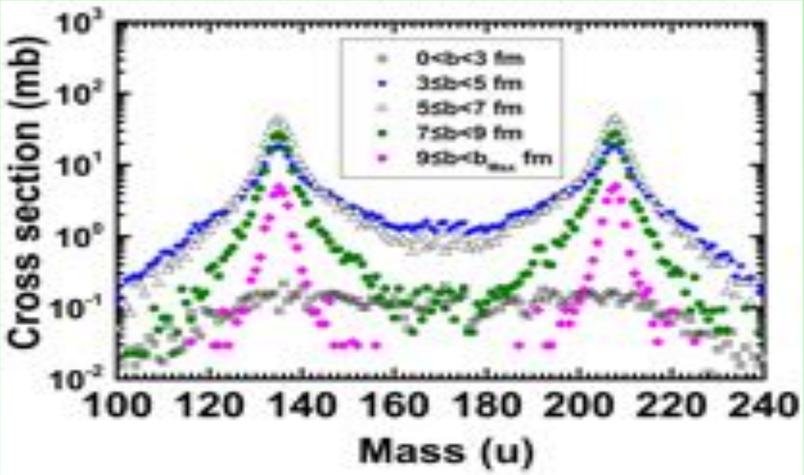


Li, Zhang, Li, Zhu, Tian, Wang, and Zhang, PRC 93, 014618 (2016)

Energy dissipation between the projectile and target

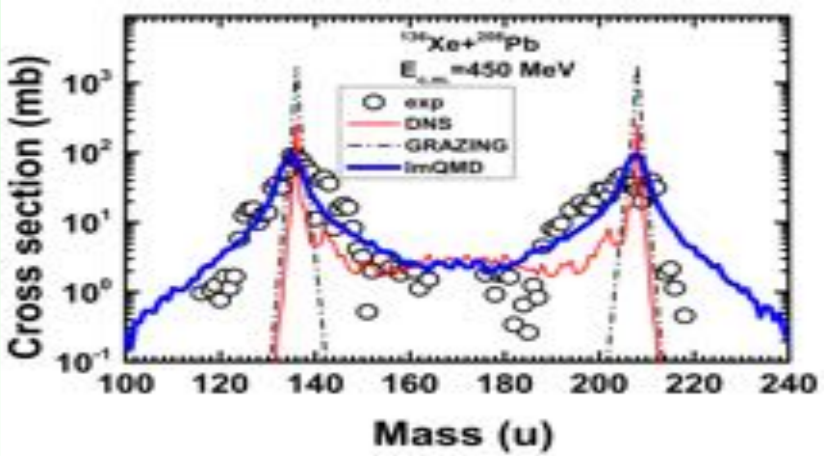
$^{136}Xe+^{198}Pt$, E=7.98 MeV/A





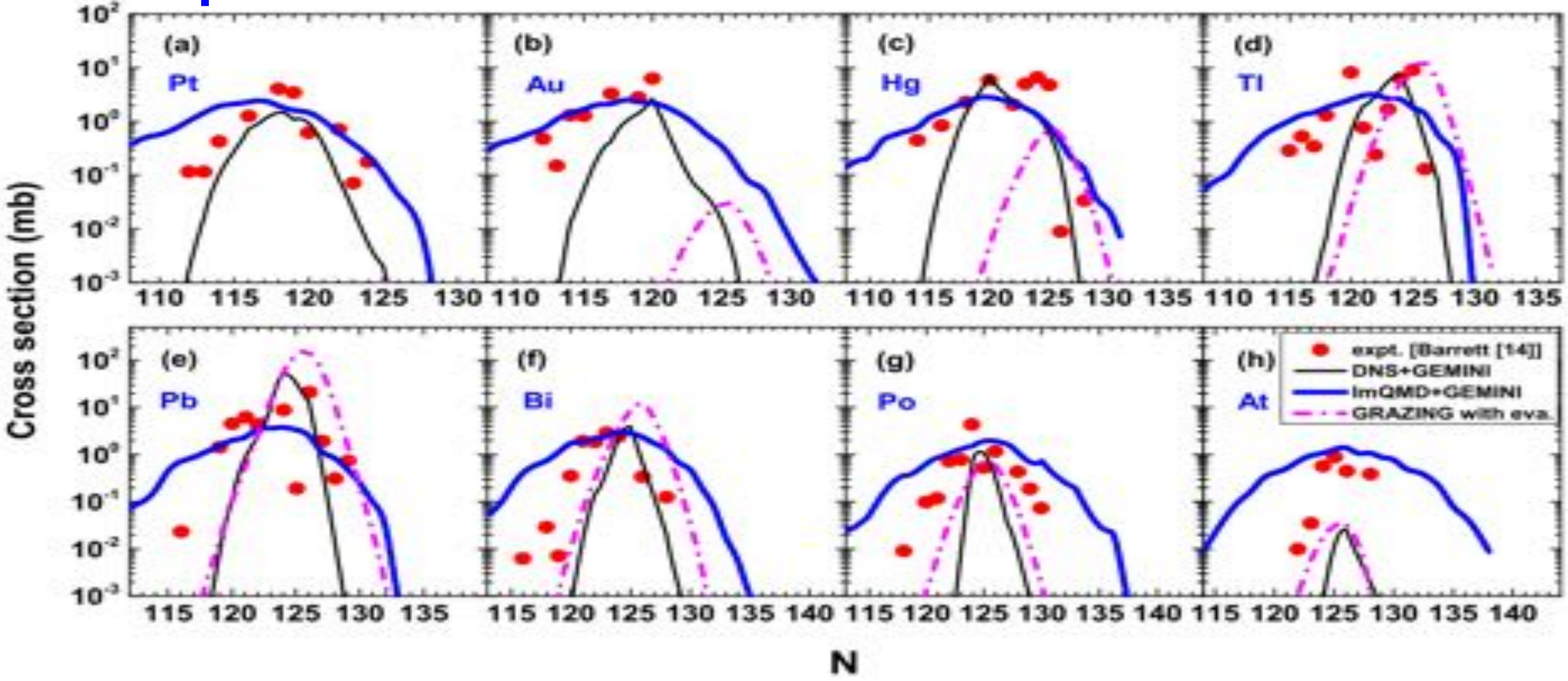
For different impact parameters

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)

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:

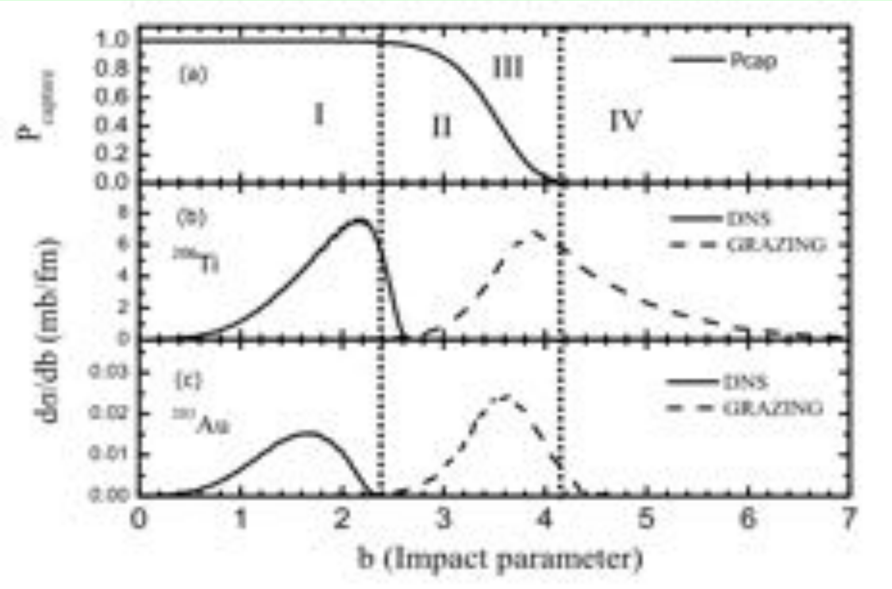
- deals with the nuclei captured with probability Pcap
- transfer or dissipation due to transportation after capture

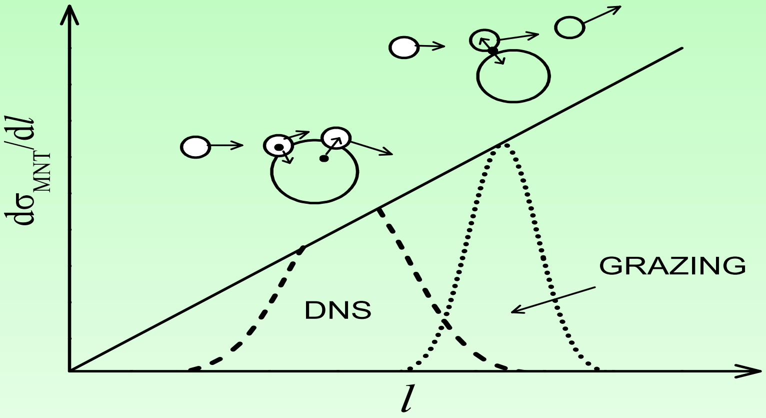
$$\sigma^{tr}_{Grazing}(Z,A,E) = \frac{\pi\hbar^2}{2\mu E}\sum_J (2J+1)(1-P_{cap}(E,J))P^{Grazing}_{trans}(Z,A,E)$$

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

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

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



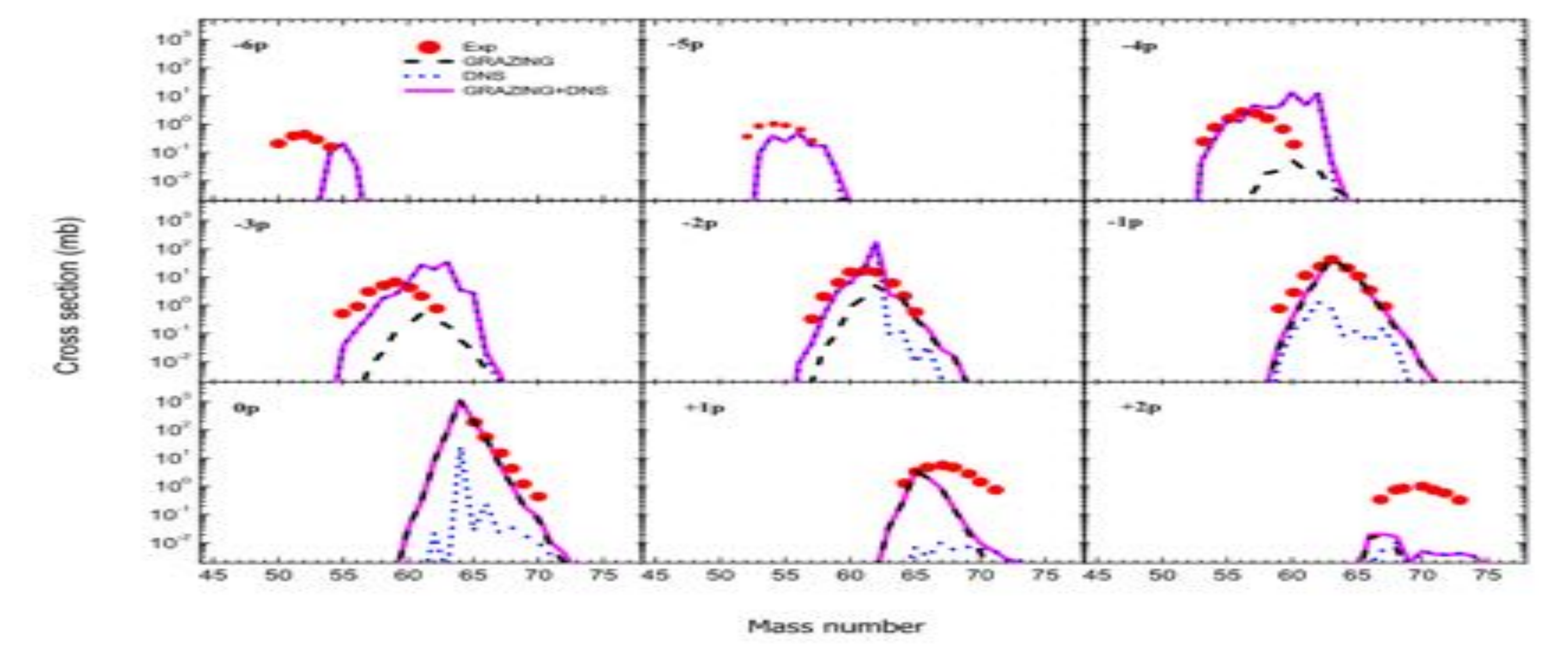


$^{136}Xe+^{208}Pb$ Ecm=450 MeV

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

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

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



Results are also significantly improved by GRAZING+DNS

IOP Publishing Journal of Physics G: Nuclear and Particle Physics
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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[2] Beijing Radiation Center, Beijing 100875, People's Republic of China
[3] Sino-French Institute of Nuclear Engineering and Technology, Sun Yat-sen University, Zhuhai 519082, People's Republic of China
[4] China Institute of Atomic Energy, Beijing 102413, People's Republic of China
[5] Center of Theoretical Nuclear Physics, National Laboratory of Heavy Ion Accelerator of Lanzhou, Lanzhou 730000, People's Republic of China

E-mail: fszhang@bnu.edu.cn

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

OUTLINE

1. Introduction
2. Experimental progress
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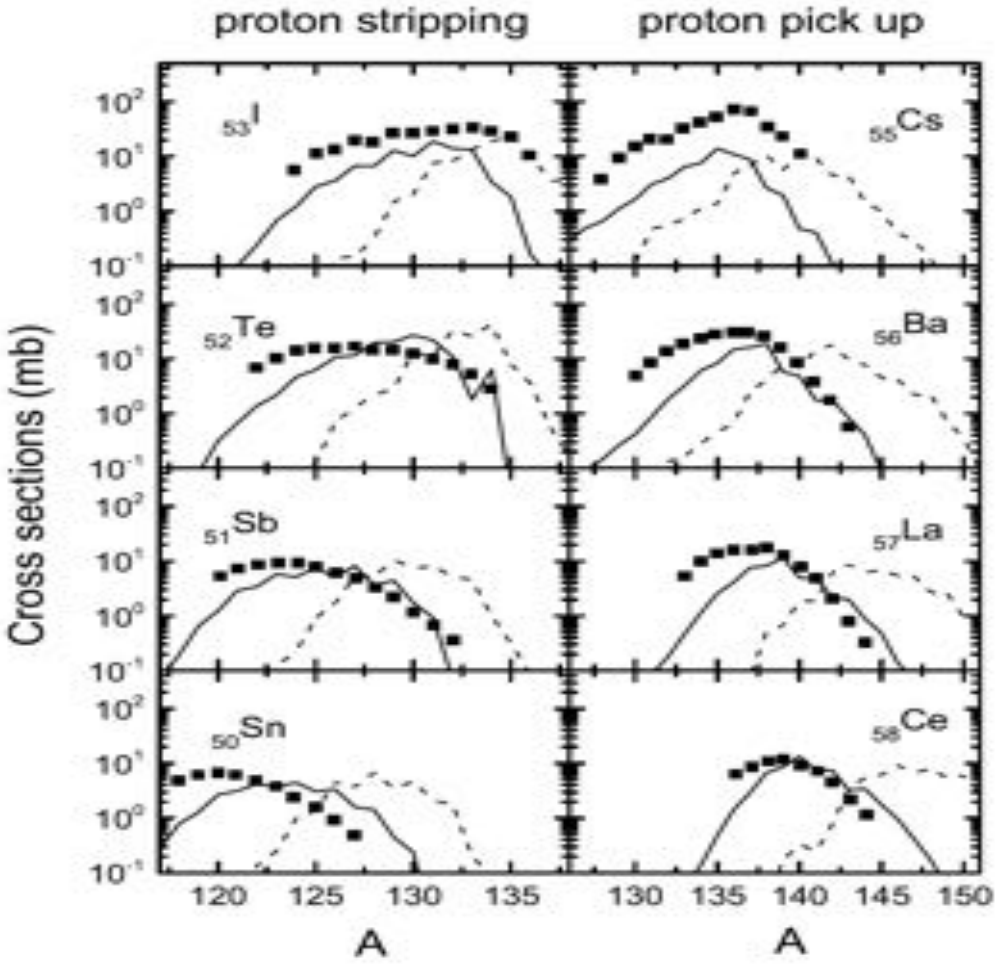
4. RNB induced MNT
5. Summary

4. RNB induced MNT



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

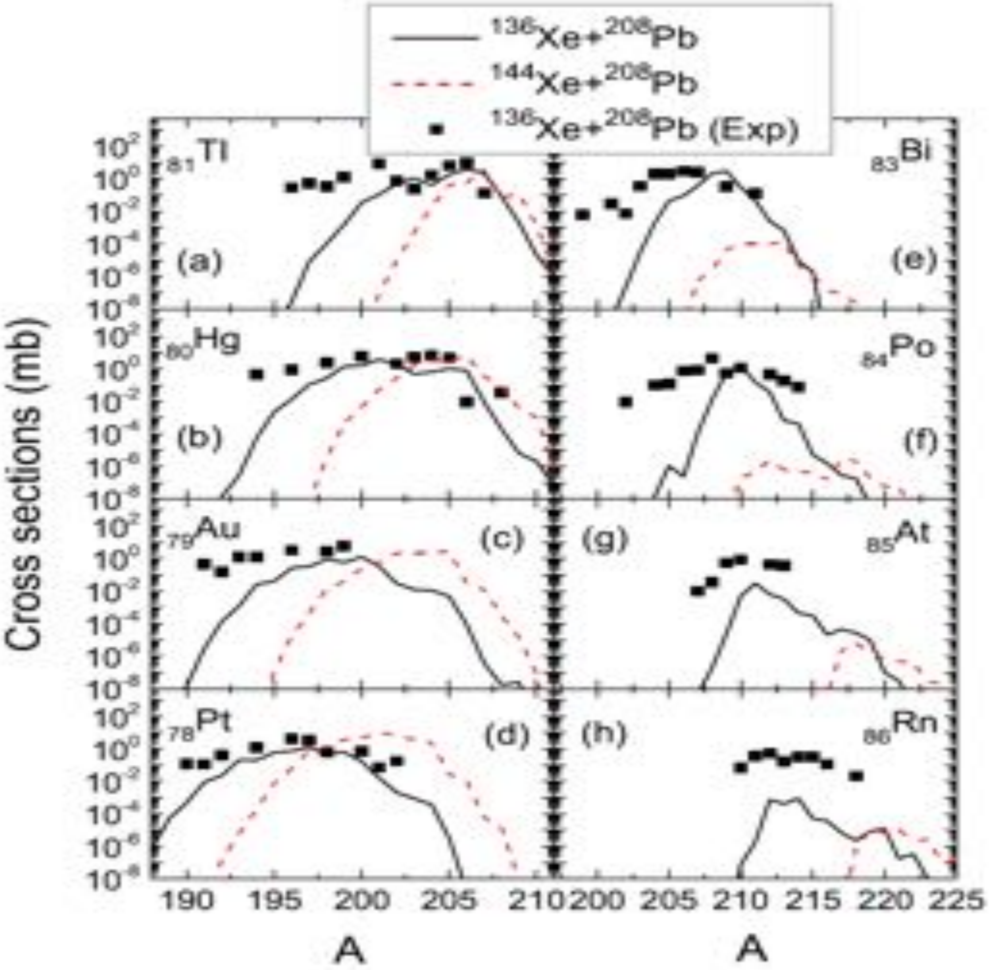
$E_{c.m} = 643$ MeV

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

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

TABLE 1. Expected energy ranges and intensities at the experimental target for some selected radioactive ion beams at RAON.

Beam nuclide	Energy (MeV/u)	Intensity (pps)
^{106}Sn	10–250	$\sim 10^9$
^{132}Sn	5–250	$\sim 10^7$
^{140}Xe	10–250	$\sim 10^8$
^{142}Xe	10–250	$\sim 10^7$

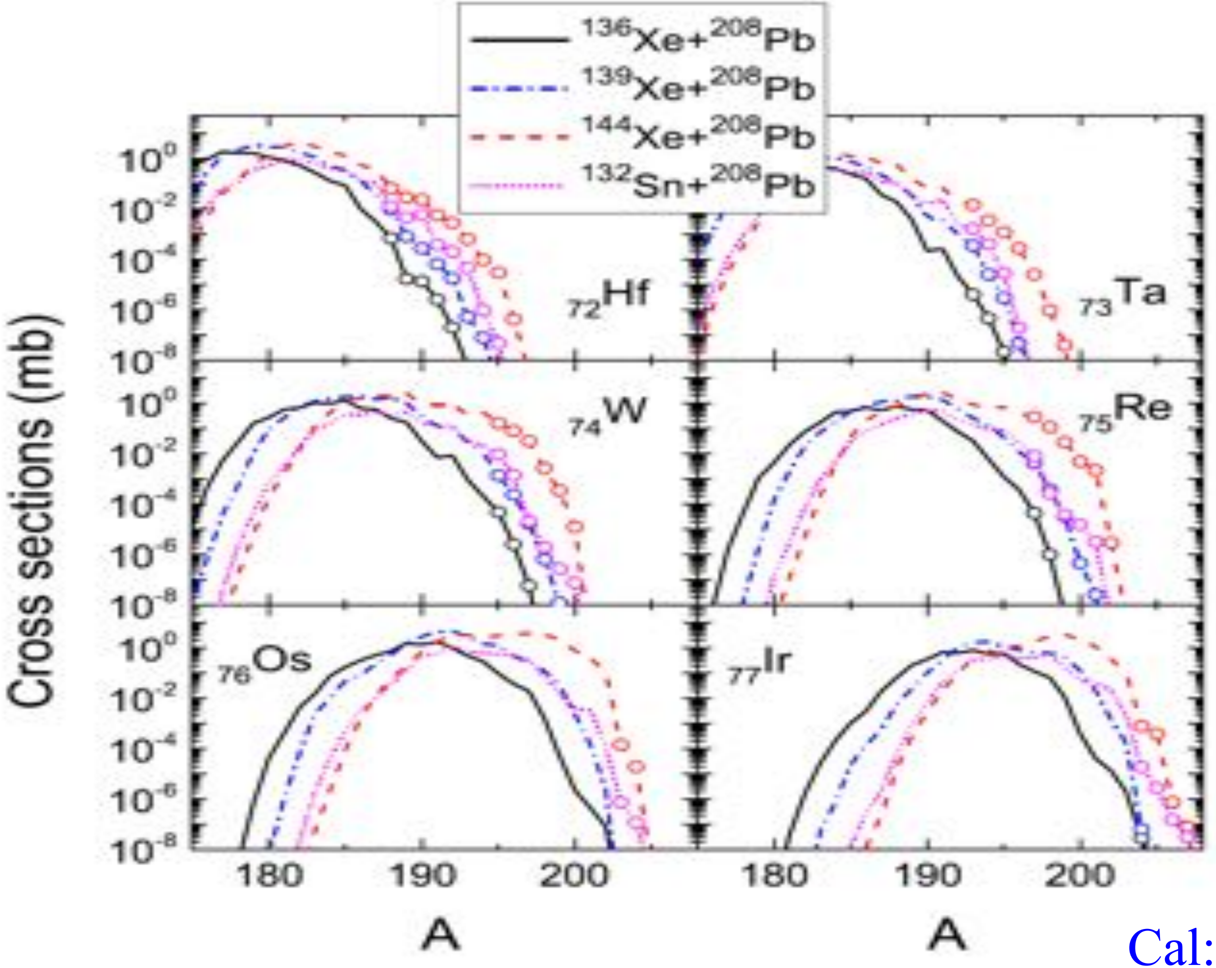


Cal: Zhu, Su, Xie, and Zhang PLB 707, 423 (2017).

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

$E_{c.m}$=450 MeV

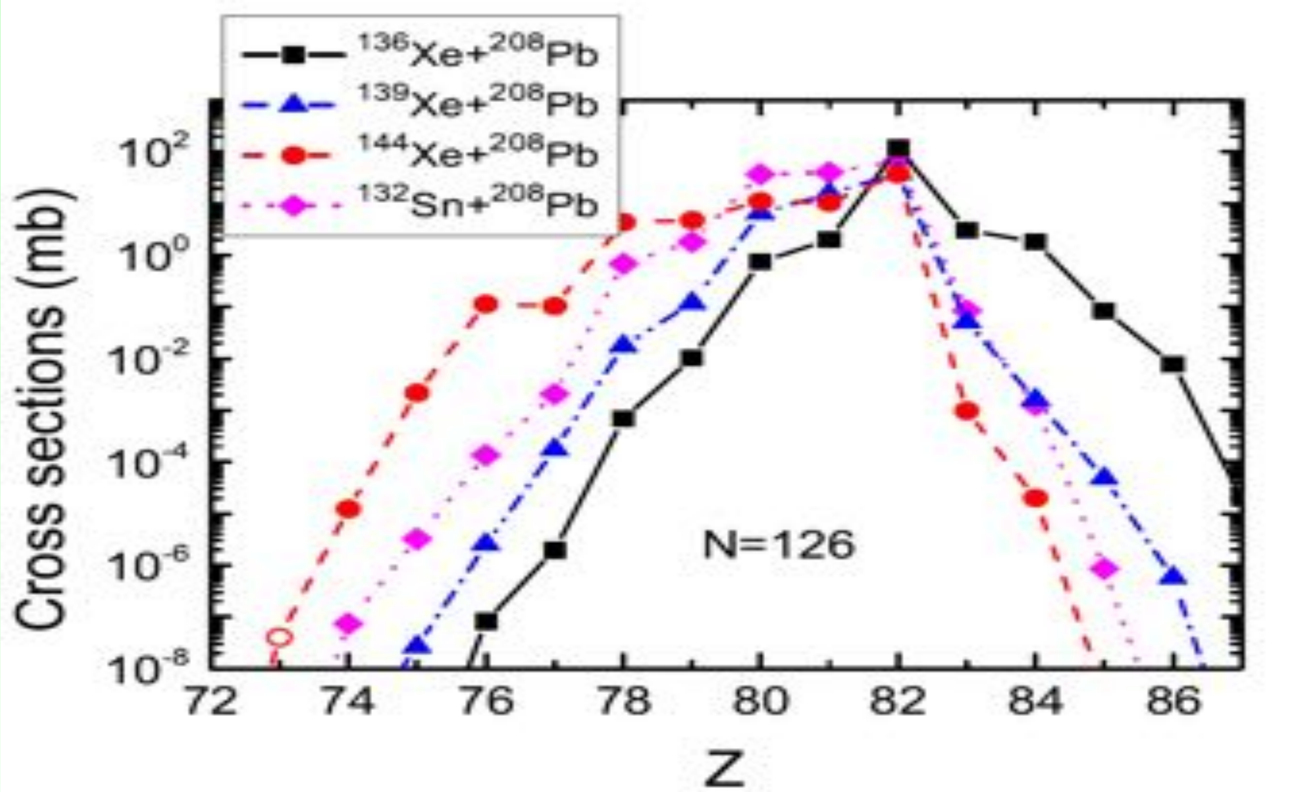
Date: Y. X. Watanabe et al. PRL 115, 172503 (2015).



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.

Cal: 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

Long Zhu [a,*], Jun Su [a], Wen-Jie Xie [b,c], Feng-Shou Zhang [d,e,f]

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[b] Department of Physics, Yuncheng University, Yuncheng 044000, China
[c] Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China
[d] 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
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[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

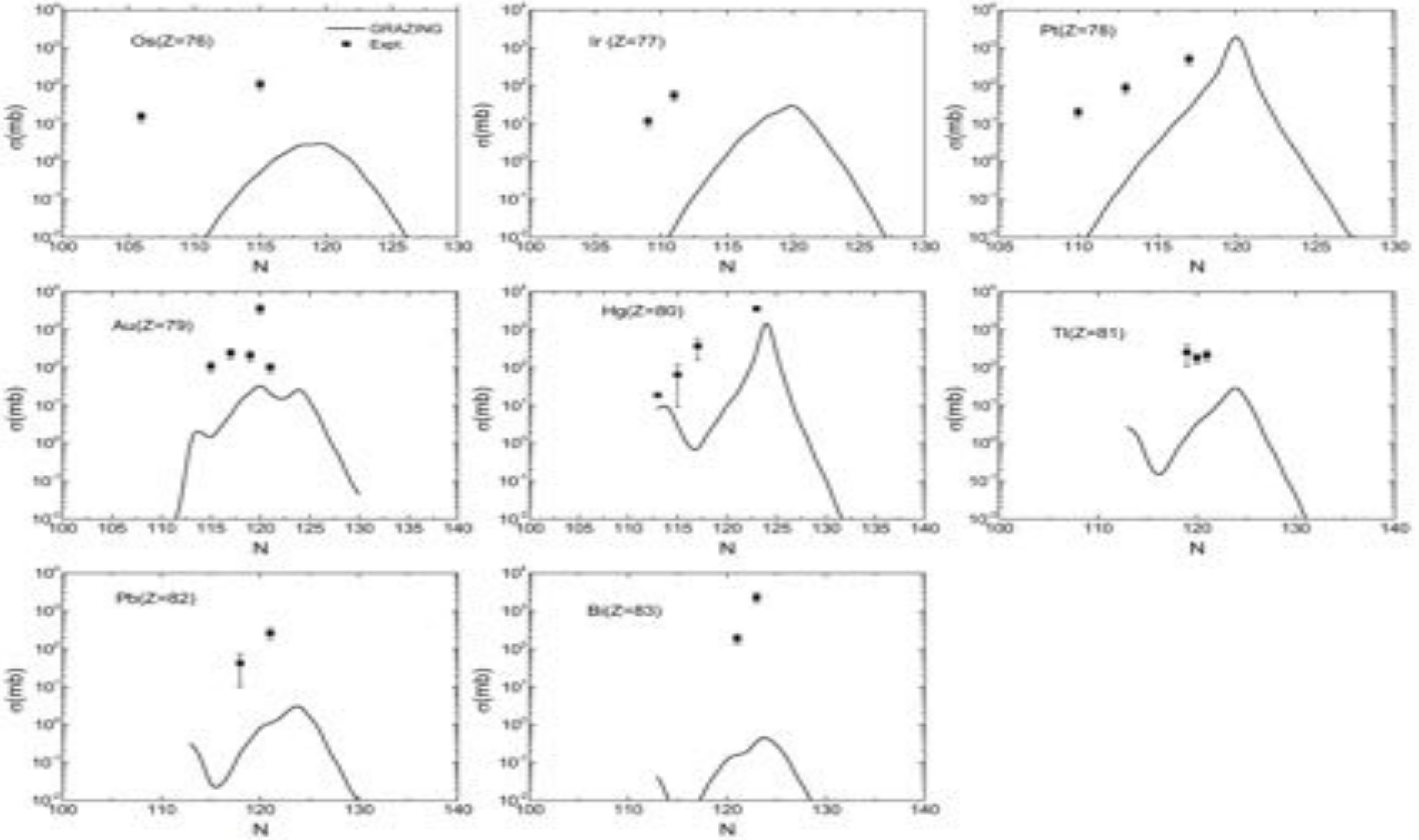

Fig. 1. The observed fragment yields for the $E_{c.m.}$ = 619 MeV ^{204}Hg + ^{198}Pt reaction compared to the predictions of the GRAZING model.

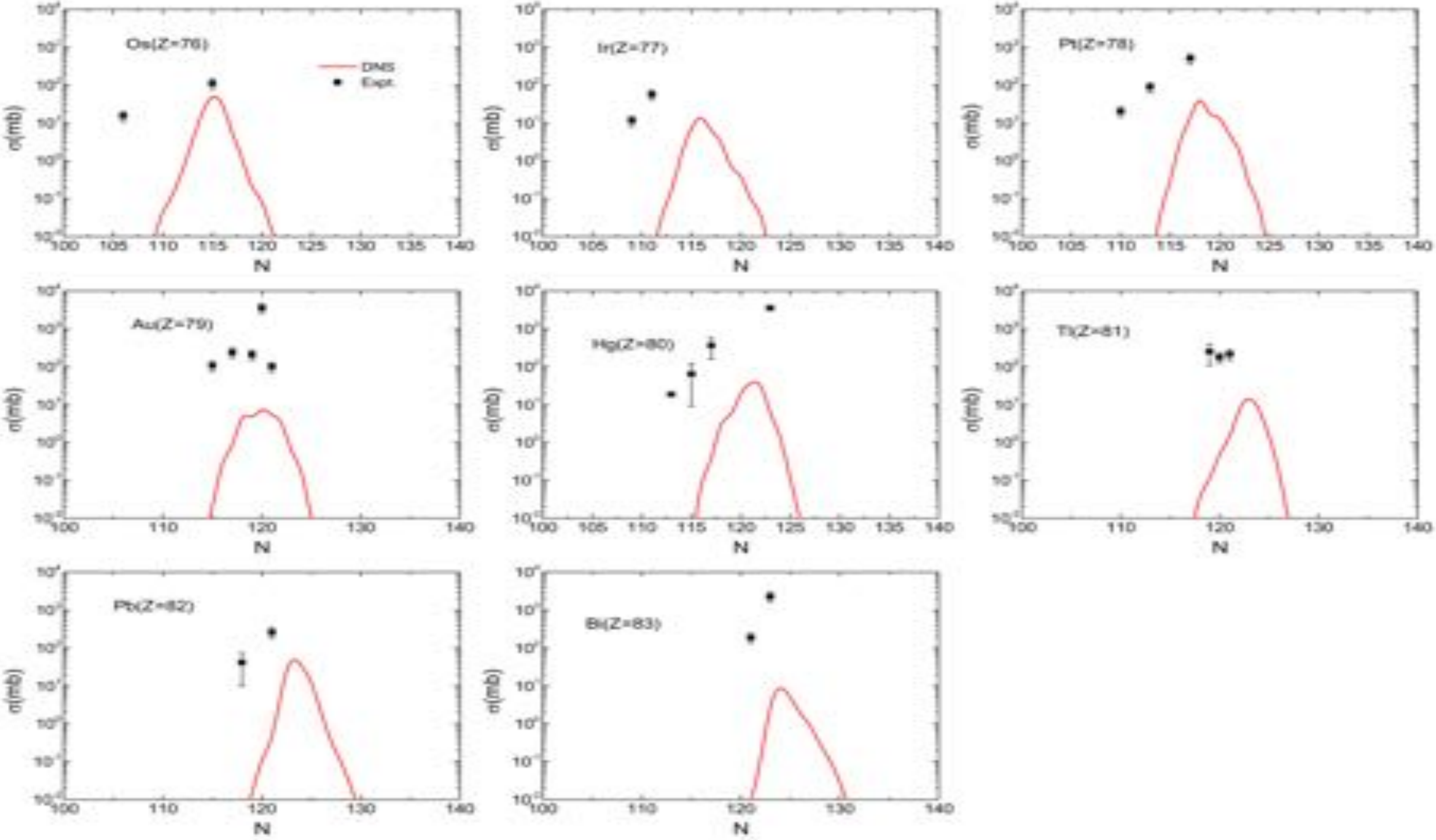

Fig. 2. The observed fragment yields for the $E_{c.m.} = 619$ MeV $^{204}Hg + ^{198}Pt$ reaction compared to the predictions of the DNS model.

Comparision with experimental work in ANL

Physics Letters B 771 (2017) 119–124

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ELSEVIER

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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[b] National Data Center, Brookhaven National Laboratory, Upton, NY 11973, USA
[c] Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA
[d] Dept. of Chemistry and Biochemistry, Univ. of Maryland, College Park, MD 20742, USA
[e] Dept. of Physics, UMass Lowell, Lowell, MA 01854, USA

Acknowledgements

We thank Prof. F. S. Zhang and co-workers for making the DNS and ImQMD calculations cited in this paper and R.V. F. Janssens for helpful comments. This work was supported in part by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the US Department of Energy under Grant DE-SC0014380 (OSU), Grant Number

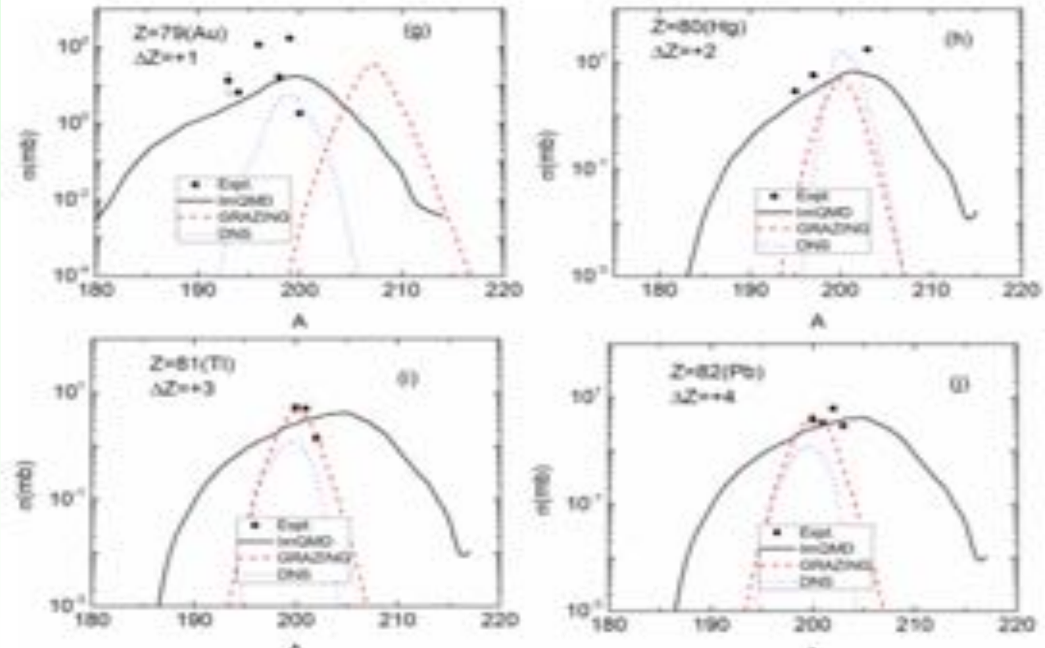
PHYSICAL REVIEW C 99, 044604 (2019)

The ^{136}Xe + ^{198}Pt reaction: A test of models of multi-nucleon transfer reactions

V. V. Desai, W. Loveland, K. McCaleb, and R. Yanez
Department of Chemistry, Oregon State University, Corvallis, Oregon 97331, USA

G. Lane, S. S. Hota, M. W. Reed, and H. Watanabe
Department of Nuclear Physics, Research School of Physics and Engineering, The Australian National University, Canberra, Australian Capitol Territory 2601, Australia

S. Zhu, K. Auranen, A. D. Ayangeakaa,* M. P. Carpenter, J. P. Greene, F. G. Kondev, and D. Seweryniak
Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA



(d) The DNS model underestimates the yields of the PLFs and most TLFs.
(e) The ImQMD model adequately predicts the magnitude of the PLF and TLF yields and is superior to the GRAZING and DNS models.

We hope to improve the experimental characterization of the 760 MeV ^{136}Xe + ^{198}Pt reaction by measuring the yields of those species formed in beam in a future experiment.

ACKNOWLEDGMENTS

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

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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.

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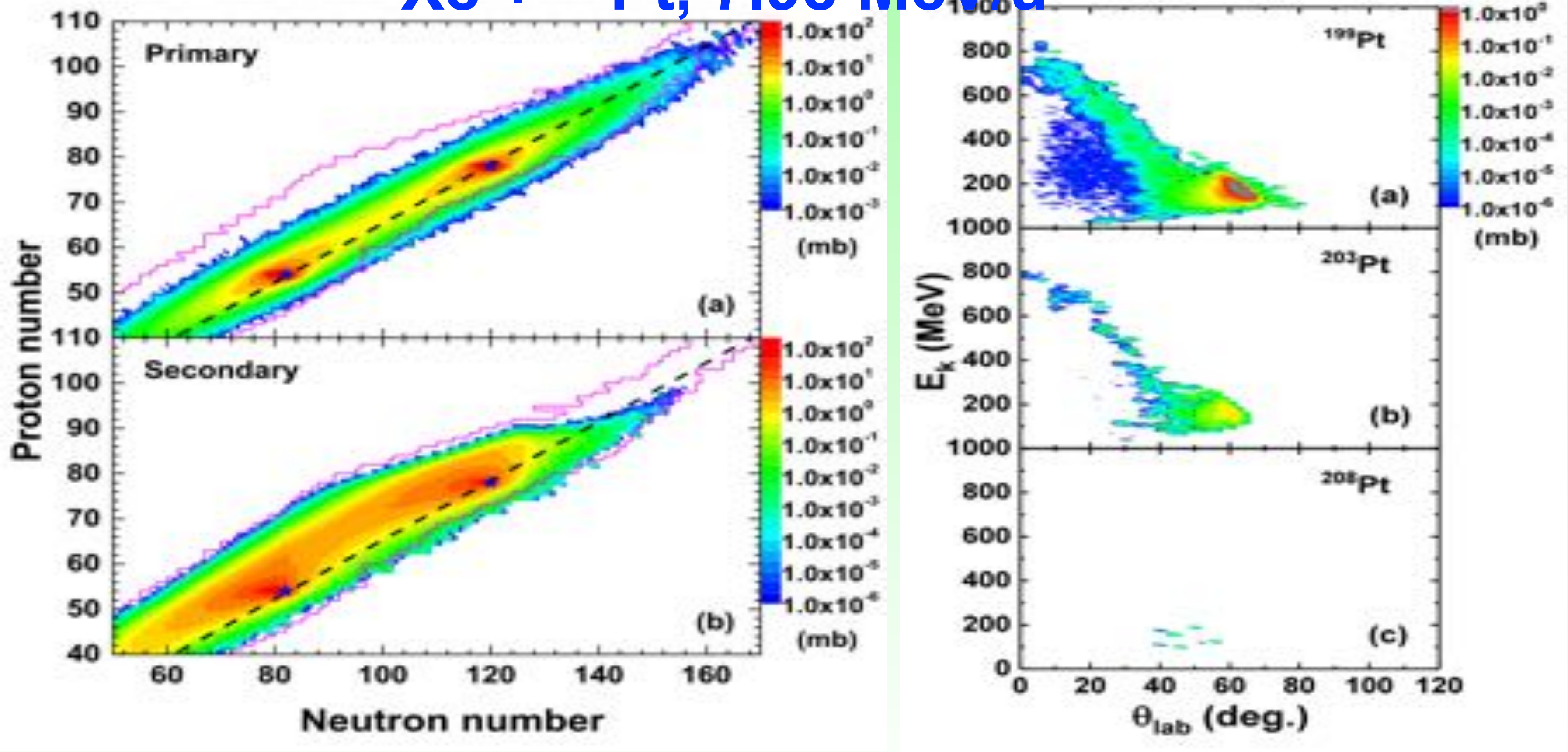
Isotope production cross sections for ^{199}Pt, ^{203}Pt, and ^{208}Pt

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



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

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

PHYSICAL REVIEW C 98, 014613 (2018)

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

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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

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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(Received 9 February 2018; revised manuscript received 20 June 2018; published 31 July 2018)

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 $^{280-283,290-292}$Fl isotopes

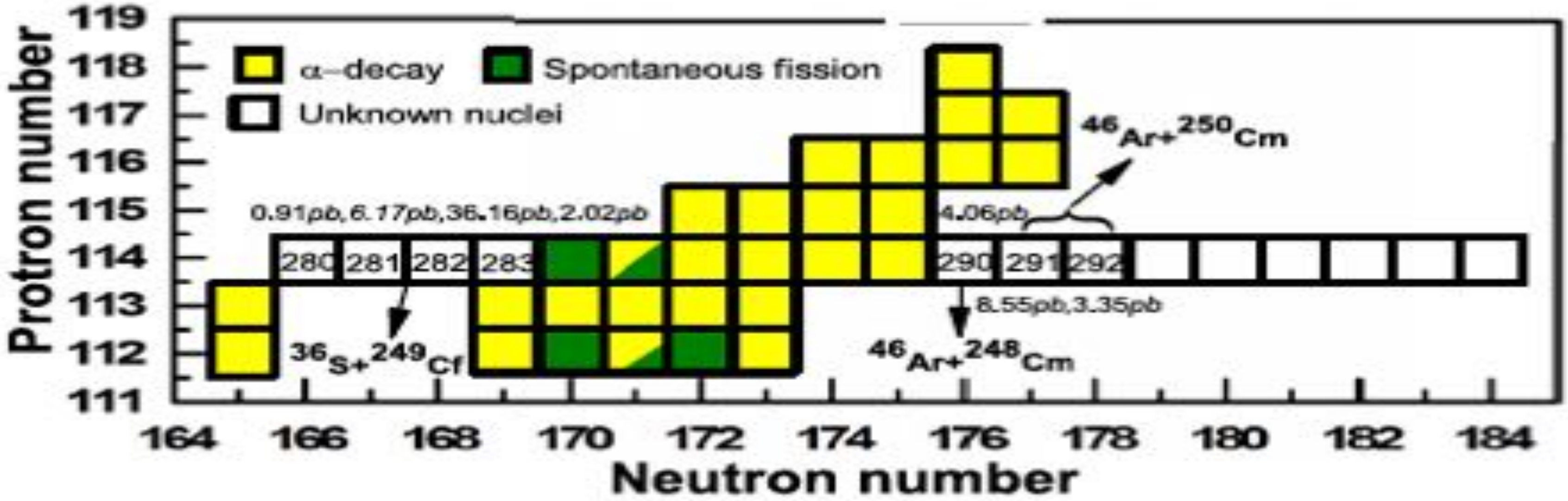

FIG. 5. Superheavy nuclei ($Z > 112$) region at the top-right part of the nuclear map. The filled squares and open squares denote the known nuclei and the predicted ones, respectively. Yellow and olive indicate the α decay and SF, respectively. The optimal reaction systems and the corresponding production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

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

PHYSICAL REVIEW C 95, 054612 (2017)

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

Jingjing Li,[1,2] Cheng Li,[1,2] Gen Zhang,[1,2] Long Zhu,[3] Zhong Liu,[4] and Feng-Shou Zhang[1,2,5,*]
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(Received 28 February 2017; published 15 May 2017)

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

α−decay properties of $^{283\text{-}339}$Og isotopes

Eur. Phys. J. A (2019) **55**: 166
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THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Theoretical Physics

Theoretical predictions for α-decay properties of $^{283-339}$Og using a shell-effect induced generalized liquid-drop model

Zhishuai Ge[1], Gen Zhang[1,2], Shihui Cheng[1,2], Yuling Li[3], Ning Su[3], Wuzheng Guo[3], Yu.S. Tsyganov[4], and Feng-Shou Zhang[1,2,5,a]

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Communicated by F. Gulminelli

Abstract. The α-decay half-lives of synthesized superheavy nuclei (SHN) from seaborgium to oganesson are calculated by employing the generalized liquid-drop model (GLDM), the Royer formula and the universal decay law (UDL) with experimental α-decay energies Q_α. For the GLDM, we consider 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 known SHN. The decay-modes of known nuclei on the ^{294}Og decay-chain are also consistent with the experiments. For the unknown nuclei, the α-decay half-

α−decay properties of $^{280\text{-}305}$Fl isotopes

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

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

Zhishuai Ge,[1,2] Cheng Li,[1,2] Jingjing Li,[1,2] Gen Zhang,[1,2] Bing Li,[1,2] Xinxin Xu,[1,2] Cheikh A. T. Sokhna,[1,2] Xiaojun Bao,[3] Hongfei Zhang,[4] Yu. S. Tsyganov,[5] and Feng-Shou Zhang[1,2,6,*]

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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

Review article: MNT

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.

Keywords heavy-ion collisions, multinucleon transfer reactions, exotic nuclei, GRAZING model, DNS model, ImQMD model

PACS numbers 25.70.Hi, 25.70.-z, 24.10.Cn, 25.60.Je

Frontiers of Physics

Contents

heavy nuclei, the limitations of fusion-evaporation reactions have led to an exploration of multi-nucleon transfer (MNT) reactions between projectile and target at energies around the Coulomb barrier [12–23].

MNT reactions happen in quasi-elastic scattering process, deep inelastic scattering, and partly quasifission reactions. The mechanisms of these reactions are totally different. Deep inelastic scattering was discovered in 1960s. This new mechanism, accompanied with the discovery of quasifission mechanism, greatly promoted the development of heavy ion nuclear reactions. The 70s and 80s of the last century is one of the rapid develop-

frontiers in Physics

ORIGINAL RESEARCH
published: 08 March 2019
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W. Loveland, frontiers in Physics

The Synthesis of New Neutron-Rich Heavy Nuclei

*Walter David Loveland**

Chemistry Department, Oregon State University, Corvallis, OR, United States

All the known isotopes of the elements Fm through Og are neutron-deficient relative to β-stability. In this contribution, I discuss two methods of producing more n-rich heavy nuclei, i.e., the use of radioactive nuclear beams (RNBs) and the use of multi-nucleon transfer (MNT) reactions. In the former case, I discuss recent studies of the interaction of $^{39,46}K$ with ^{181}Ta and their implications for the synthesis of more n-rich isotopes of Bh and Hs. In the case of MNT reactions, I discuss recent results for the reaction of ^{136}Xe with ^{208}Pb, $^{204}Hg + ^{198}Pt$, and $^{136}Xe + ^{198}Pt$. I compare measured distributions of the target-like fragments (TLFs) and projectile-like fragments (PLFs) with current models of MNT reactions.

Keywords: heavy ion collisions, multi-nucleon transfer reactions, GRAZING model, DNS model, ImQMD model, TDHF model, radioactive nuclear beams

PACS numbers: 25.70.Hi, 25.70.-z,24.10.Cn, 25.60.Je

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Edited by:
Angela Bonaccorso,
Istituto Nazionale di Fisica Nucleare,
Sezione di Pisa, Italy

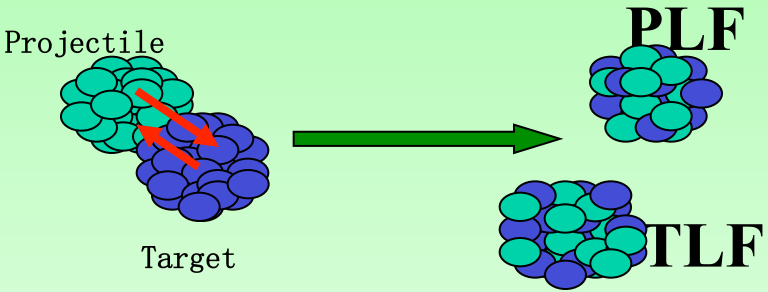
INTRODUCTION

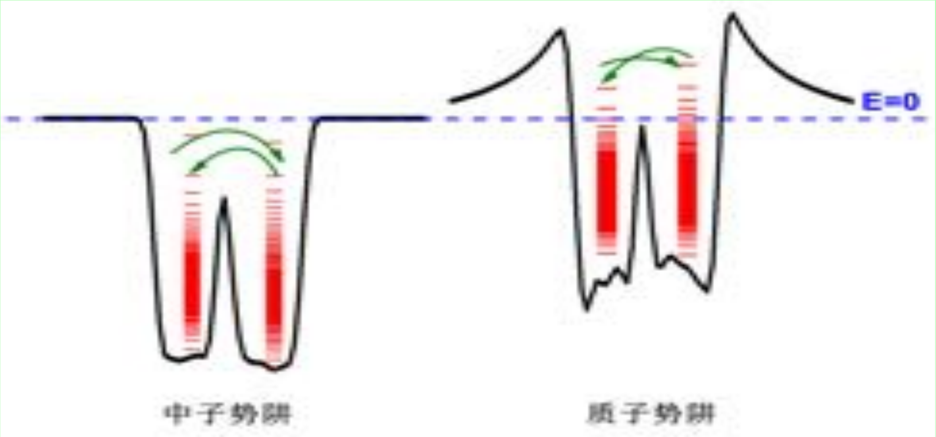
All known isotopes of the elements Fm through Og are neutron deficient relative to β-stability. While there is some dispute as to the next proton magic number beyond 82 (with proponents of $Z = 114$, 120, and 126) [1] there is little doubt that the next neutron magic number beyond $N = 126$

OUTLINE

1. Introduction
2. Experimental progress
3. Theoretical models
4. RNB induced MNT
5. Summary

多核子转移反应中的若干问题





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