



Production of the neutron-rich nuclei around N=126

N=126丰中子重核的产生

祝 龙



@snpyga

2022年7月5日



内容提纲



1、背景介绍

2、MNT产生丰中子重核的优势

3、理论模型方法

4、以 ^{238}U 为靶的MNT反应

5、总结与展望

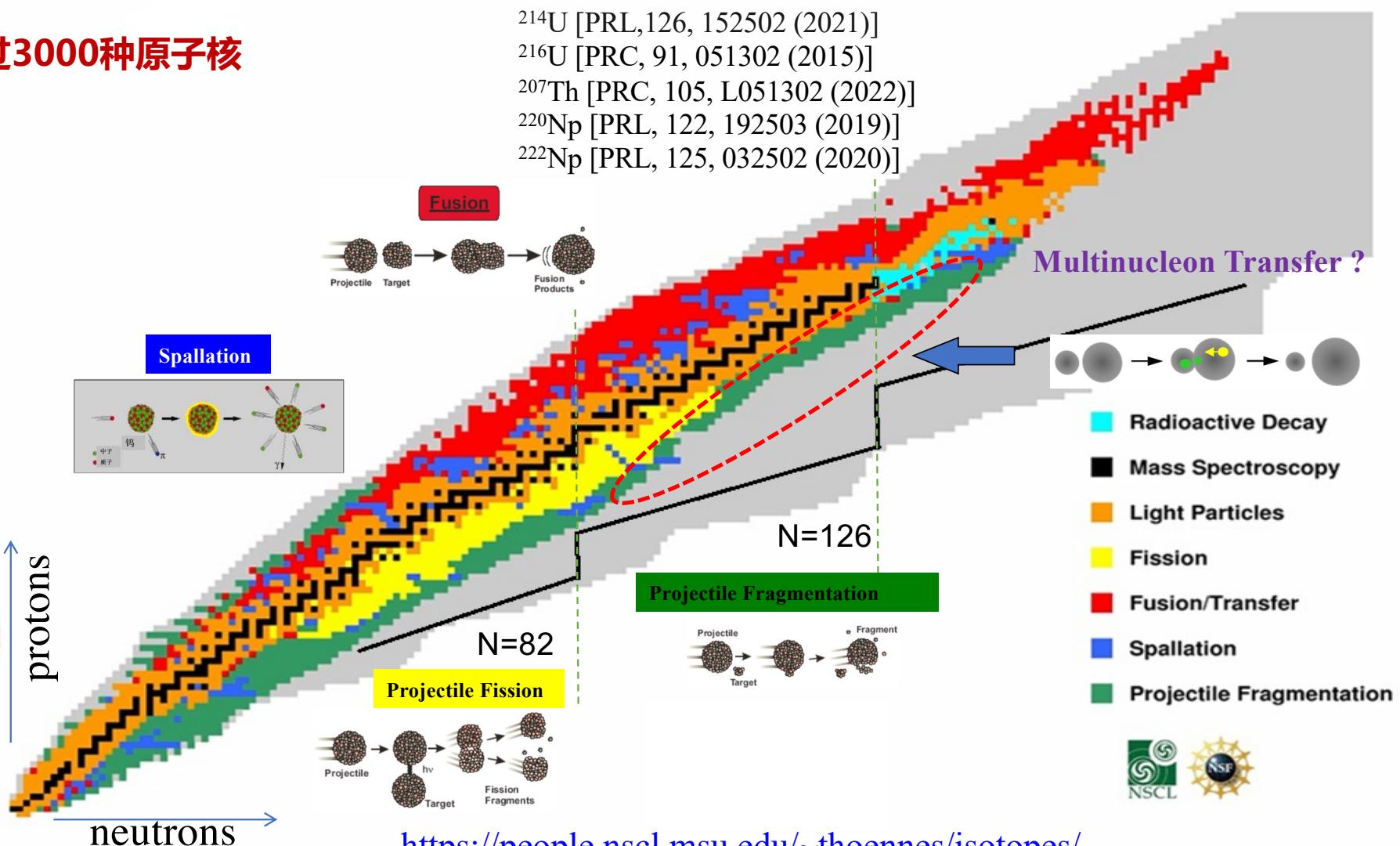
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核素图现状

人工已合成了超过3000种原子核

| Rank | Laboratory | Isotopes |
|------|----------------|----------|
| 1 | Berkeley | 640 |
| 2 | Darmstadt | 445 |
| 3 | Dubna | 221 |
| 4 | Cambridge | 218 |
| 5 | RIKEN | 191 |
| 6 | Argonne | 113 |
| 7 | CERN | 111 |
| 8 | GANIL | 84 |
| 9 | Oak Ridge | 79 |
| 10 | Michigan State | 77 |
| 11 | Orsay | 71 |
| 12 | Los Alamos | 53 |
| | Chicago | 53 |
| 14 | Brookhaven | 46 |
| 15 | Jyväskylä | 43 |
| 16 | Grenoble | 39 |
| 17 | Berlin | 38 |
| 18 | Studsvik | 34 |
| 19 | McGill | 33 |
| | Ohio State | 33 |
| 21 | Lanzhou | 32 |
| 22 | Amsterdam | 29 |
| 23 | Mainz | 23 |
| | Harwell | 23 |
| 25 | Rochester | 22 |
| | Munich | 22 |
| | Michigan | 22 |



<https://people.nscl.msu.edu/~thoennes/isotopes/>

N=126附近新核素的产生是揭示壳演化的关键

PHYSICAL REVIEW LETTERS 126, 152502 (2021)

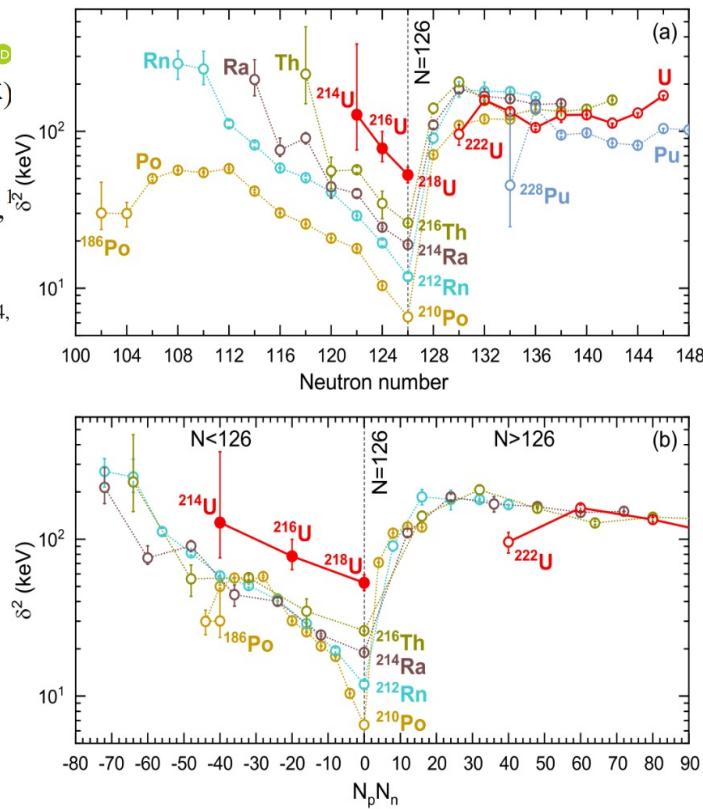
Editors' Suggestion

Featured in Physics

New α -Emitting Isotope ^{214}U and Abnormal Enhancement of α -Particle Clustering in Lightest Uranium Isotopes

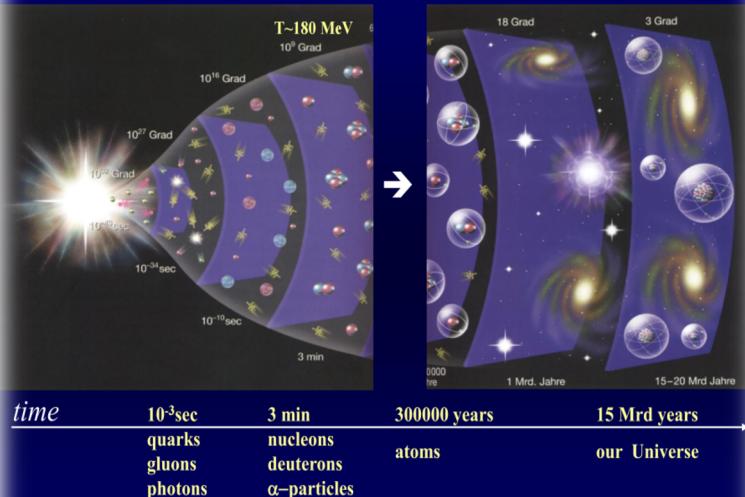
Z. Y. Zhang (张志远)^{1,2} H. B. Yang (杨华彬),¹ M. H. Huang (黄明辉),^{1,2} Z. G. Gan (甘再国),^{1,2,*} C. X. Yuan (袁岑溪)¹ C. Qi (亓冲),⁴ A. N. Andreyev^{1,2},^{5,6} M. L. Liu (柳敏良),^{1,2} L. Ma (马龙),¹ M. M. Zhang (张明明),¹ Y. L. Tian (田玉林) Y. S. Wang (王永生),^{1,2,7} J. G. Wang (王建国),¹ C. L. Yang (杨春莉),¹ G. S. Li (李广顺),¹ Y. H. Qiang (强贊华),¹ W. Q. Yang (杨维青),¹ R. F. Chen (陈若富),¹ H. B. Zhang (张宏斌),¹ Z. W. Lu (卢子伟),¹ X. X. Xu (徐新星),^{1,2} L. M. Duan (段利敏),^{1,2} H. R. Yang (杨贺润),^{1,2} W. X. Huang (黄文学)^{1,2},⁸ Z. Liu (刘忠)^{1,2},⁹ X. H. Zhou (周小红),^{1,2} Y. H. Zhang (张玉虎),^{1,2} H. S. Xu (徐珊瑚),^{1,2} N. Wang (王宁),⁸ H. B. Zhou (周厚兵),⁸ X. J. Wen (温小江),⁸ S. Huang (黄山),⁸ W. Hua (滑伟),³ L. Zhu (祝龙),³ X. Wang (王翔),⁹ Y. C. Mao (毛英臣),¹⁰ X. T. He (贺晓涛),¹¹ S. Y. Wang (王守宇)^{1,2},¹² W. Z. Xu (许文政),¹² H. W. Li (李弘伟),¹² Z. Z. Ren (任中洲),¹³ and S. G. Zhou (周善贵)^{1,2,14}

- alpha衰变的约化宽度在N=126时明显降低，体现了很强的中子壳效应。
- 基于 $N_p N_n$ ，研究发现 $^{214,216}\text{U}$ 的alpha衰变的约化宽度两倍于系统性值。



元素起源一直以来都是物理基本问题

From Big Bang to Formation of the Universe

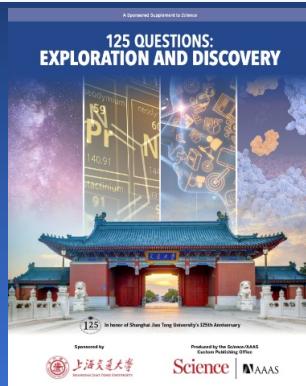


← Can we go back in time ?

| 元素周期表 | | | | | | | | | | | | | | | | | | | | |
|-------|-----------|---------|-------|-----------|-----------|--------|--------|-----------|-------|-----------|--------|-------|-------|-----------|--------|--------|--------|-------|--------|-------|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | | | |
| 0 He | 1 H | 2 He | 3 Li | 4 Be | 5 B | 6 C | 7 N | 8 O | 9 F | 10 Ne | 11 Na | 12 Mg | 13 Al | 14 Si | 15 P | 16 S | 17 Cl | | | |
| 氦 | 氢 | 氦 | 锂 | 铍 | 硼 | 碳 | 氮 | 氧 | 氟 | 氖 | 钠 | 镁 | 铝 | 硅 | 磷 | 硫 | 氯 | | | |
| 4.003 | 1.008 | 4.003 | 6.941 | 9.012 | 10.81 | 12.01 | 14.01 | 16.00 | 19.00 | 20.18 | 22.99 | 24.31 | 26.98 | 28.09 | 30.97 | 32.07 | 35.45 | | | |
| He | H | He | Li | Be | B | C | N | O | F | Ne | Na | Mg | Al | Si | P | S | Cl | | | |
| 2 | 1 | 2 | 3 | 2 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | | | |
| 元素序数 | 原子名称 | 元素符号 | 元素名称 | 元素英文名称 | 相对原子质量 | 主族金属 | 副族金属 | 非金属元素 | 稀有气体 | 人造元素 | 元素序数 | 原子名称 | 元素符号 | 元素名称 | 元素英文名称 | 相对原子质量 | 主族金属 | 副族金属 | | |
| 92 U | 铀 | Uranium | 238.0 | 93 Np | Neptunium | 237.0 | 94 Am | Americium | 243.0 | 95 Cur | Curium | 247.0 | 96 Bk | Berkelium | 247.0 | 97 Cf | Cf | 98 Es | Es | |
| 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | |
| 95 Pu | Plutonium | 244.0 | 96 Am | Americium | 243.0 | 97 Cur | Curium | 247.0 | 98 Bk | Berkelium | 247.0 | 99 Cf | Cf | 251.0 | 100 Cf | 257.0 | 101 Es | 258.0 | 102 Fm | 258.0 |
| 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 |
| 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 |
| 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 |
| 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 |
| 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 |
| 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 |
| 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 |
| 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 |
| 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 |
| 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 |
| 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 |
| 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 |
| 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 |
| 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 |
| 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 |
| 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 |
| 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 |
| 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 |
| 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 |
| 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 |
| 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 |
| 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 |
| 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 | 138 |
| 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 | 138 | 139 |
| 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 | 138 | 139 | 140 |

| | | | |
|-------|---|---------|-------|
| 26 Fe | 铁 | iron | 55.85 |
| 92 U | 铀 | uranium | 238.0 |

?



重大科学问题

Astronomy

Where do the heavy elements in the universe come from?

自然界中的重元素是如何产生的？

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理论预言多核子转移反应产生丰中子重核具有很大的优势

PRL 101, 122701 (2008)

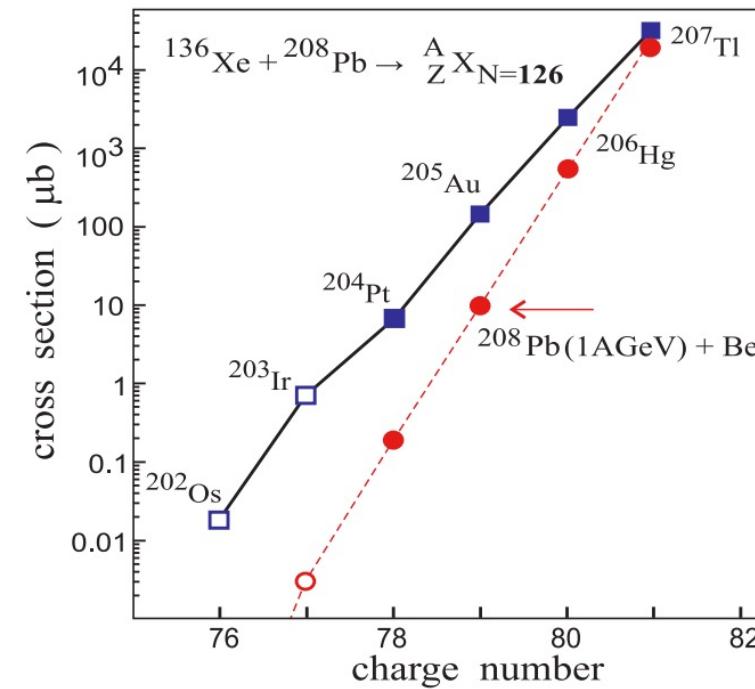
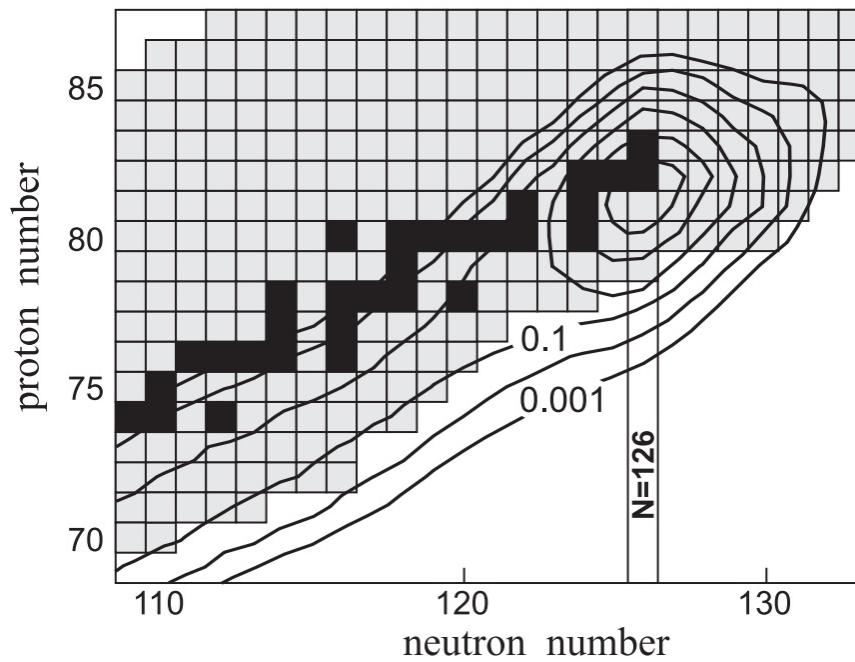
PHYSICAL REVIEW LETTERS

week ending
19 SEPTEMBER 2008

Production of New Heavy Isotopes in Low-Energy Multinucleon Transfer Reactions

Valery Zagrebaev¹ and Walter Greiner²

基于耦合的朗之万公式，预言多核子转移反应 $^{136}\text{Xe} + ^{208}\text{Pb}$ 可以产生近50个丰中子新核素，其截面大于1微靶

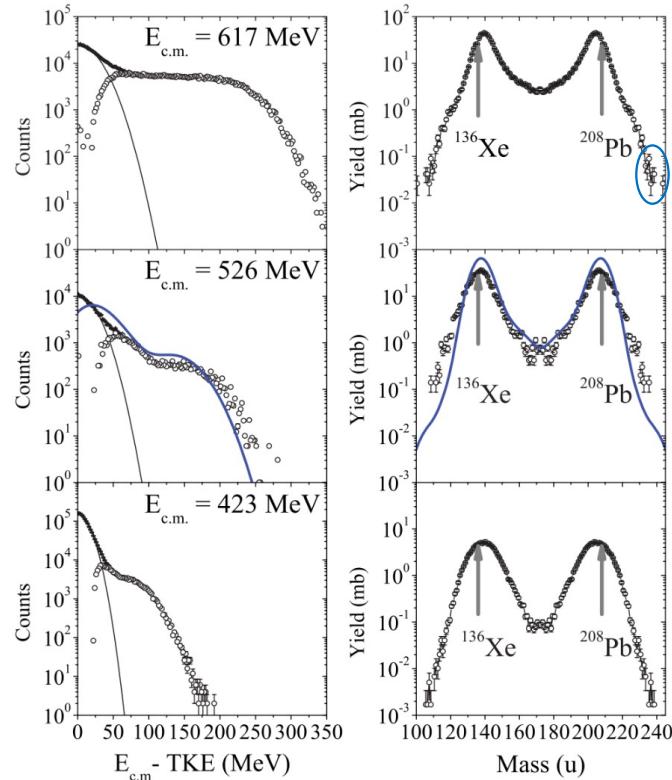


实验观察到多核子转移反应中大量核子净转移

PHYSICAL REVIEW C 86, 044611 (2012)

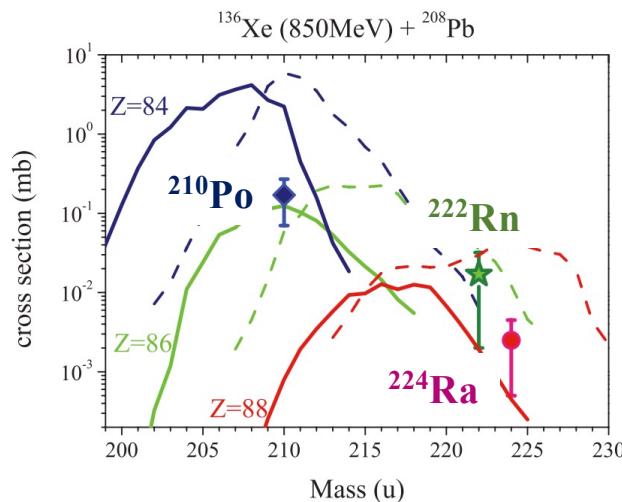
Mass distributions of the system $^{136}\text{Xe} + ^{208}\text{Pb}$ at laboratory energies around the Coulomb barrier: A candidate reaction for the production of neutron-rich nuclei at $N = 126$

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. Zagrebaev¹



没有观测到丰中子新核素

从弹核到靶核转移近20个核子，截面在0.1mb左右。



实验证实多核子转移反应产生N=126丰中子核的巨大截面优势

PRL 115, 172503 (2015)

PHYSICAL REVIEW LETTERS

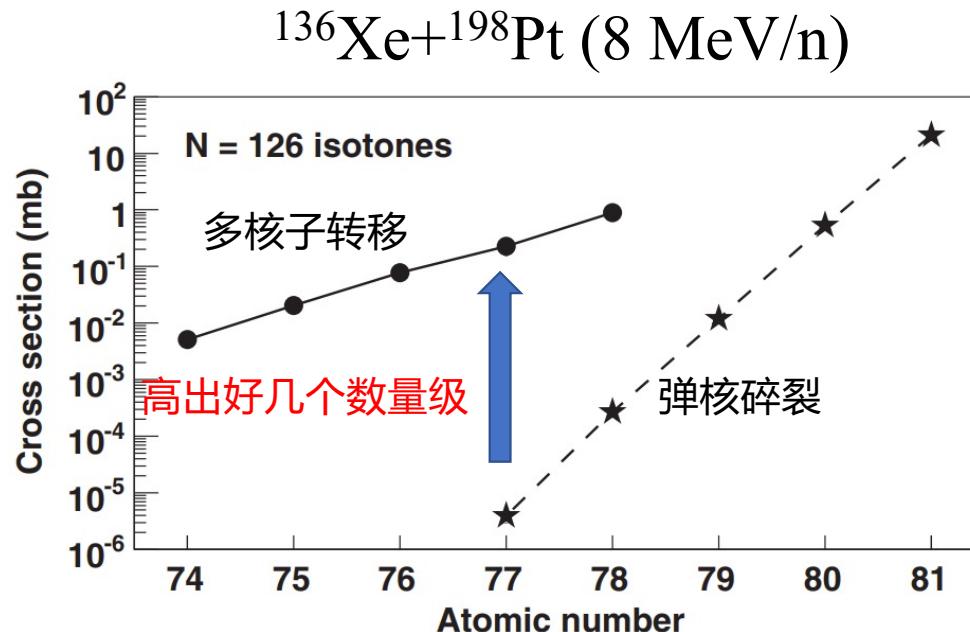
week ending
23 OCTOBER 2015

没有观测到丰中子新核素

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. Takatsu¹⁰

¹Institute of Particle and Nuclear Studies, High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan



实验证实多核子转移反应是产生新核素的有希望途径（包括缺中子核）



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Physics Letters B

www.elsevier.com/locate/physletb



Observation of new neutron-deficient isotopes with $Z \geq 92$
in multinucleon transfer reactions **产生了一系列的缺中子核**



H.M. Devaraja ^{a,b}, S. Heinz ^{a,c,*}, O. Beliuskina ^{a,c}, V. Comas ^a, S. Hofmann ^a, C. Hornung ^c,
G. Münzenberg ^{a,b}, K. Nishio ^d, D. Ackermann ^a, Y.K. Gambhir ^b, M. Gupta ^b,
R.A. Henderson ^e, F.P. Heßberger ^a, J. Khuyagbaatar ^a, B. Kindler ^a, B. Lommel ^a, K.J. Moody ^e,
I. Maurer ^a, R. Mann ^a, A.G. Poneko ^f, D.A. Shaughnessy ^e, M.A. Stover ^e, A.V. Yeremin ^f

**216U, 219Np, 223Am
233Bk**

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ABSTRACT

In deep inelastic multinucleon transfer reactions of $^{48}\text{Ca} + ^{248}\text{Cm}$ we observed about 100 residual nuclei with proton numbers between $Z = 82$ and $Z = 100$. Among them, there are five new neutron-deficient isotopes: ^{216}U , ^{219}Np , ^{223}Am , ^{229}Am and ^{233}Bk . As separator for the transfer products we used the velocity filter SHIP of GSI while the isotope identification was performed via the α decay chains of the nuclei. These first results reveal that multinucleon transfer reactions together with here applied fast and sensitive separation and detection techniques are promising for the synthesis of new isotopes in the region of heaviest nuclei.

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我国在多核子转移反应实验探测方面的发展

第34卷第3期
2017年9月

原子核物理评论
Nuclear Physics Review

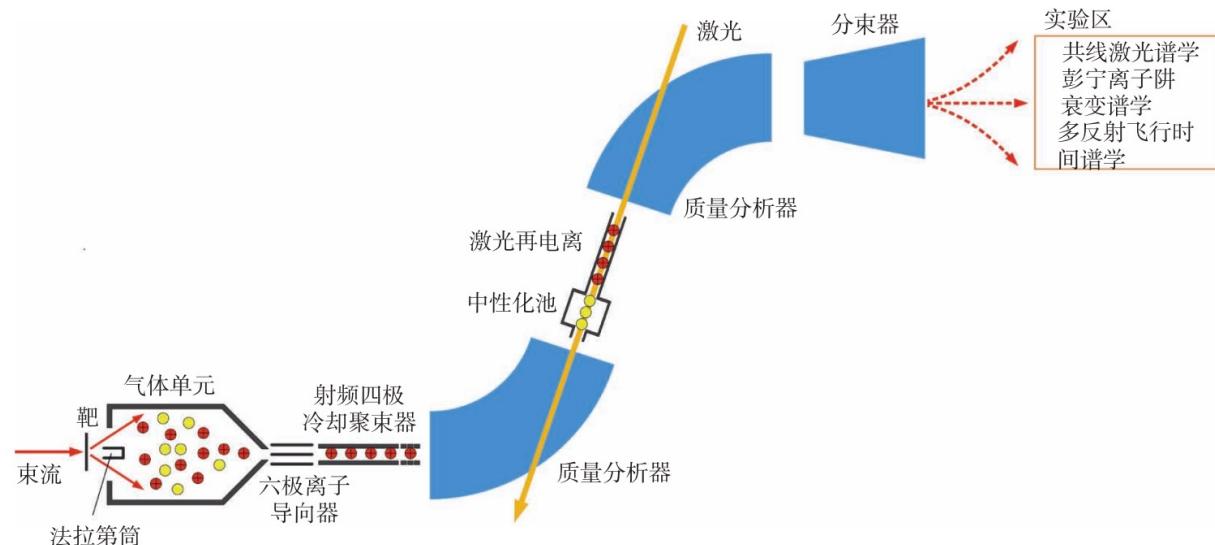
Vol. 34, No. 3
Sep., 2017

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HIAF上基于多核子转移反应的综合谱仪的机遇与挑战

黄文学¹, 田玉林^{1,2}, 王永生^{1,2,3}, 王均英¹, 甘再国¹, 刘忠¹, 杨杰¹, 马新文¹, 周小红¹

- (1. 中国科学院近代物理研究所, 兰州 730000;
2. 中国科学院大学物理科学学院, 北京 100049;
3. 兰州大学核科学与技术学院, 兰州 730000)



不同于熔合蒸发及弹核碎裂反应, 多核子转移反应产物的出射在实验室系并不是 0° 附近的前冲方向, 而是覆盖了 $25^\circ \sim 80^\circ$ 宽范围的圆锥角, 这给收集和分离我们感兴趣的多核子转移反应产物带来了很大的困难。由于多核子转移反应产物分布的特殊性, 专用装置的研发进展缓慢。一旦实现了多核子转移反应产物的高效收集和提取, 我们将可以进入宽广的丰中子核素的蓝海, 极大地推动我国乃至世界的核物理研究。

HIAF提供了一个非常好的机遇, 我们将设计并建造一条专门针对多核子转移反应的综合谱仪。其中气体单元是该谱仪成败的最关键因素, 其必须满足高束流强度、高传输效率、快传输速度的要求, 具有挑战性。我们不得不使用现今离子操纵领域的最新技术来整合整套谱仪, 从而提高谱仪的总效率、传输速度等关键指标。

实验和理论研究多核子转移反应存在困难

实验上

- 对多核子转移反应产物的有效分离和探测。
- 需要发展新方法和探测装置。

理论上

- 对多核子转移反应的机制仍然不清楚。
- 缺乏能统一描述多种反应道的理论模型。
- 缺乏实验数据，限制了理论模型的改进。
- 难以可靠预言。

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4、以²³⁸U为靶的MNT反应

5、总结与展望

常用的理论模型

coupled Langevin-type equations

V. Zagrebaev, W. Greiner, PRL 101, 122701 (2008)

dinuclear system model

Yu.E. Penionzhkevich, G.G. Adamian, N.V. Antonenko, PLB 621 (2005) 119

Z. Q. Feng, *et al*, NPA **836**, 82 (2010)

L. Zhu, *et al*, PRC **98**, 034609 (2018)

X.J. Bao, S.Q. Guo, H.F. Zhang, J.Q. Li, Phys. Rev. C 97 (2018) 024617

quantum molecular dynamics model

K. Zhao, Z. Liu, F.S. Zhang, N. Wang, PLB 815 (2021) 136101

C. Li, J. Tian, F.S. Zhang, PLB 809 (2020) 135697

time-dependent Hartree Fock approach

Z. Wu, L. Guo, Phys. Rev. C 100 (2019) 014612

K. Sekizawa, Phys. Rev. C 96 (2017) 041601

GRAZING

A. Winther, Nucl. Phys. A 572 (1994) 191

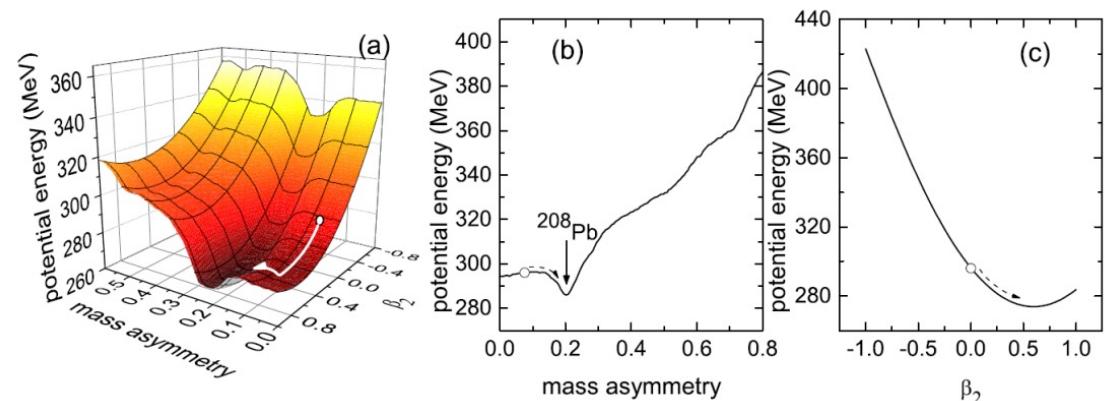
双核系统模型 (DNS-sysu)

主方程：

$$\begin{aligned} & \frac{dP(Z_1, N_1, \beta_2, t)}{dt} \\ &= \sum_{Z'_1} W_{Z_1, N_1, \beta_2; Z'_1, N_1, \beta_2}(t) [d_{Z_1, N_1, \beta_2} P(Z'_1, N_1, \beta_2, t) \\ &\quad - d_{Z'_1, N_1, \beta_2} P(Z_1, N_1, \beta_2, t)] \\ &+ \sum_{N'_1} W_{Z_1, N_1, \beta_2; Z_1, N'_1, \beta_2}(t) [d_{Z_1, N_1, \beta_2} P(Z_1, N'_1, \beta_2, t) \\ &\quad - d_{Z_1, N'_1, \beta_2} P(Z_1, N_1, \beta_2, t)] \\ &+ \sum_{\beta'_2} W_{Z_1, N_1, \beta_2; Z_1, N_1, \beta'_2}(t) [d_{Z_1, N_1, \beta_2} P(Z_1, N_1, \beta'_2, t) \\ &\quad - d_{Z_1, N_1, \beta'_2} P(Z_1, N_1, \beta_2, t)], \end{aligned}$$

势能面：

$$U(Z_1, N_1, \beta_2, R_{\text{cont}}) = \Delta(Z_1, N_1) + \Delta(Z_2, N_2) + V_{\text{cont}}(Z_1, N_1, \beta_2, R_{\text{cont}}).$$



$$\begin{aligned} & W_{Z_1, X; Z'_1, X}(t) = \\ & \frac{\tau_{\text{mem}}(Z_1, X, E_{\text{DNS}}^*(Z_1, X); Z'_1, X, E_{\text{DNS}}^*(Z'_1, X))}{d_{Z_1, X} d_{Z'_1, X} \hbar^2} \times \\ & \sum_{ii'} |\langle Z'_1, X, E_{\text{DNS}}^*(Z'_1, X), i' | V(t) | Z_1, X, E_{\text{DNS}}^*(Z_1, X), i \rangle|^2 \end{aligned}$$

$$\sigma_{\text{pr}}(Z_1, N_1) = \frac{\pi \hbar^2}{2\mu E_{\text{c.m.}}} \sum_{J=0}^{J_{\max}} (2J+1) \sum_{\beta_2} T_{\text{cap}} \times P(Z_1, N_1, \beta_2)$$

- G. G. Adamian, et al, PRC **68**, 034601 (2003).
 M. Schadel, et al. PRL **48**, 852 (1982).
 S. Ayik, et al., ZPA **277**, 299-310 (1976)

- Z. Q. Feng, et al, NPA **836**, 82 (2010)
 L. Zhu, et al, JPG. **42**, 085102 (2015)
 L. Zhu, et al, PRC **98**, 034609 (2018)

DNS-sysu模型对熔合和多核子转移反应的统一描述

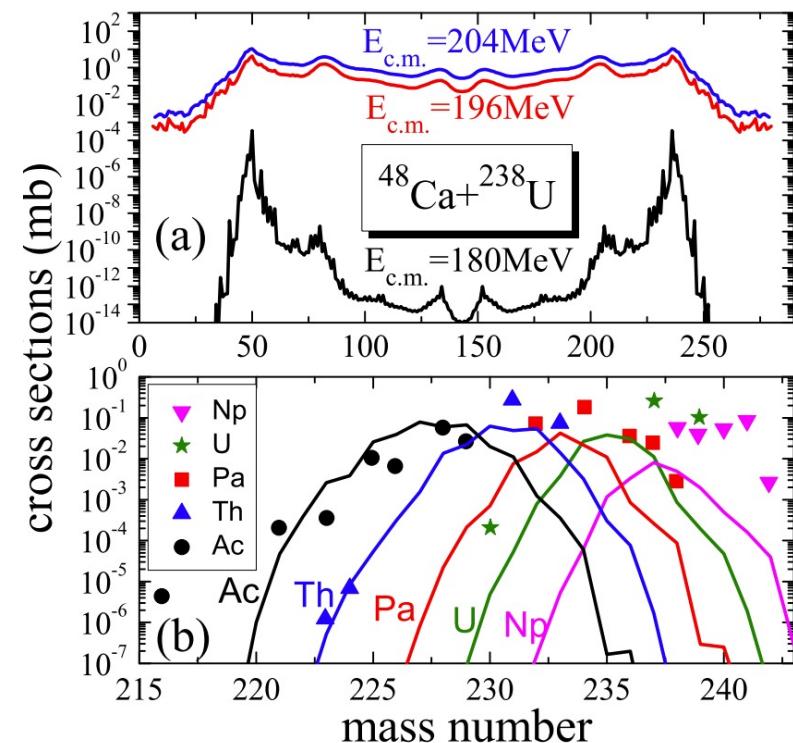
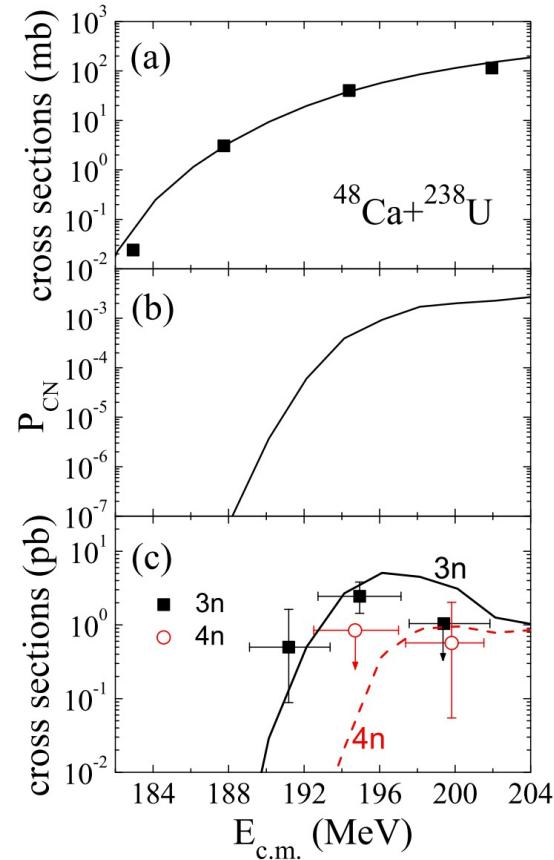
PHYSICAL REVIEW C 104, 044606 (2021)

Unified description of fusion and multinucleon transfer processes within the dinuclear system model

Long Zhu[✉]* and Jun Su

- 主方程中引入形变自由度
- 考虑势能面的温度依赖性
- 建立基于蒙特卡洛方法的统计衰变模型

.....



内容提纲



1、背景介绍

2、MNT产生丰中子重核的优势

3、理论模型方法

4、以²³⁸U为靶的MNT反应

5、总结与展望

^{238}U 为靶的多核子转移反应产生丰中子重核的优势

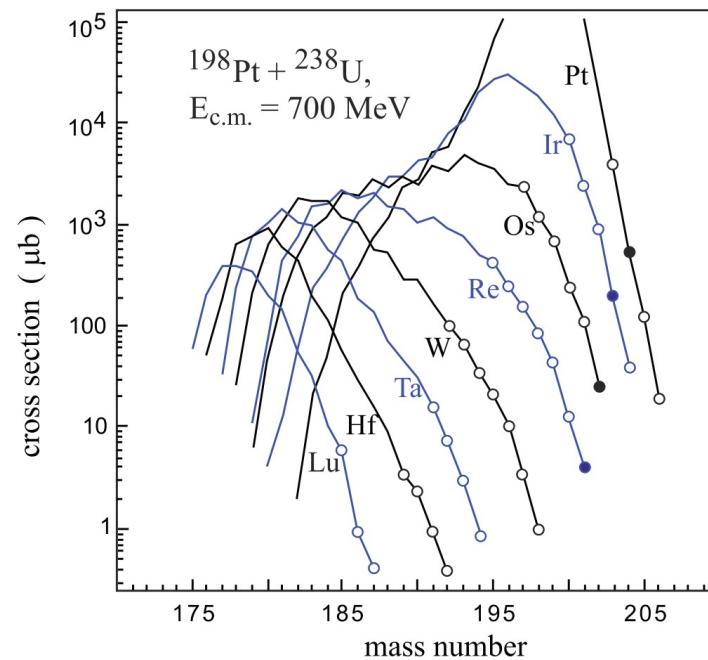
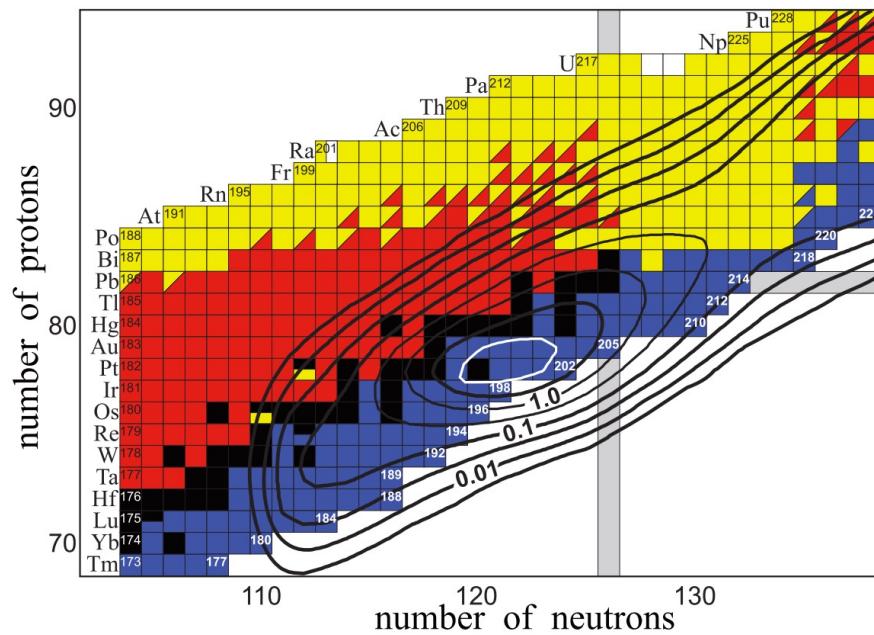
PHYSICAL REVIEW C 87, 034608 (2013)



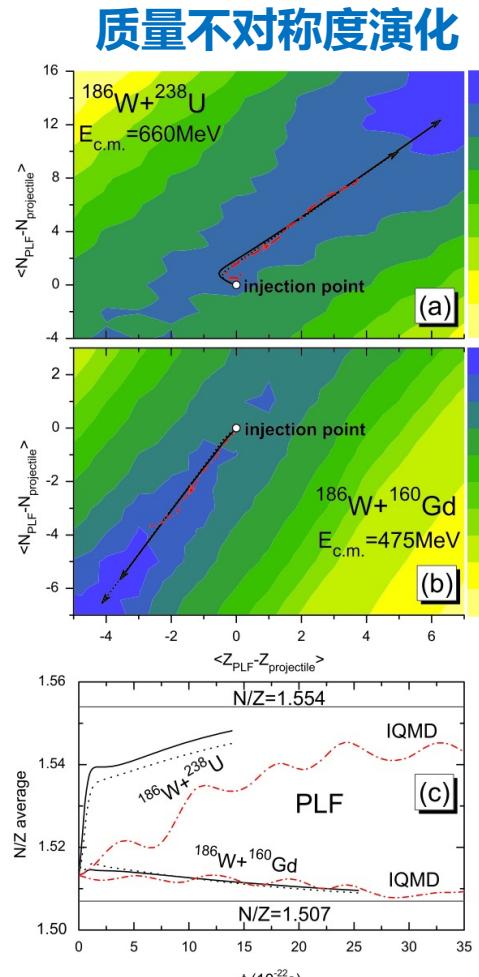
Production of heavy trans-target nuclei in multinucleon transfer reactions

V. I. Zagrebaev¹ and Walter Greiner²

基于耦合朗之万方程的方法最早计算了基于 ^{238}U 靶的反应，但是没有分析并提出 ^{238}U 靶的优势性



^{238}U 为靶的多核子转移反应产生丰中子重核的优势



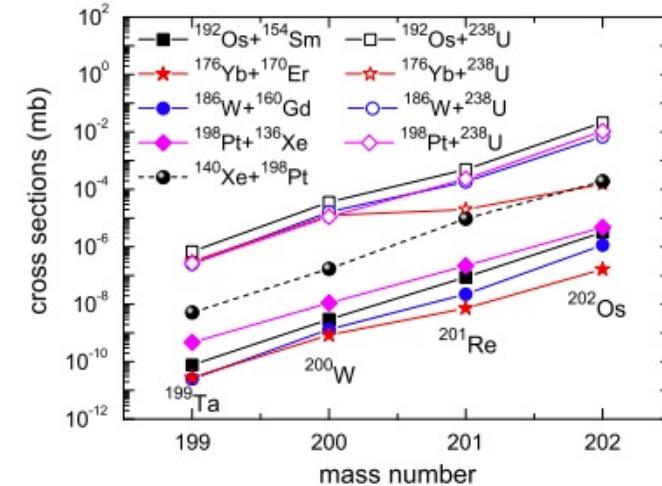
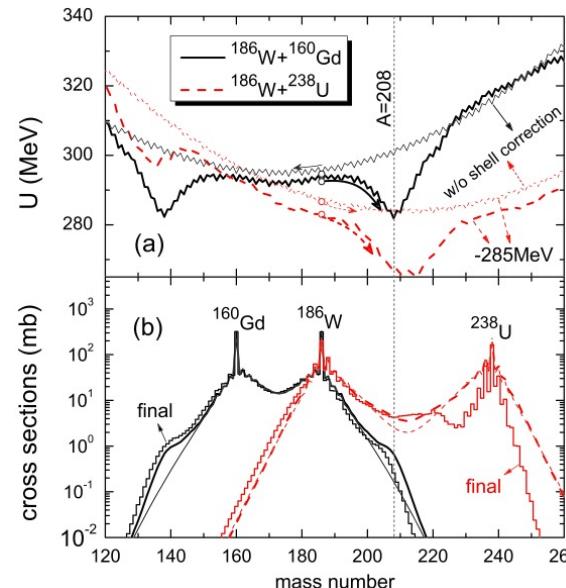
Physics Letters B

www.elsevier.com/locate/physletb

Physics Letters B 791 (2019) 20–25

Advantages of the multinucleon transfer reactions based on ^{238}U target for producing neutron-rich isotopes around $N = 126$

Long Zhu^{a,*}, Cheng Li^b, Jun Su^a, Chen-Chen Guo^a, Wei Hua^a



壳效应

^{238}U 为靶的多核子转移反应是产生丰中子重核的新途径



Physics Letters B

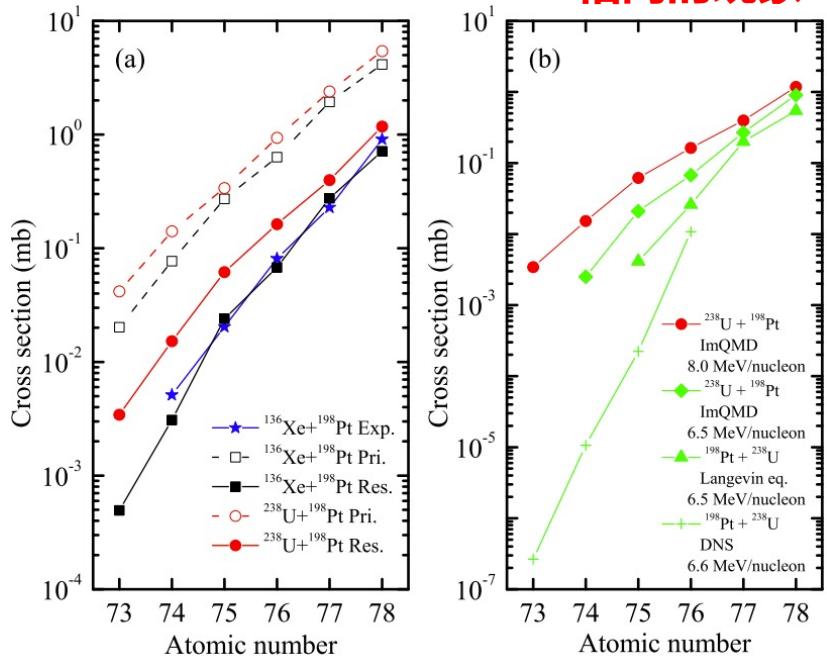
www.elsevier.com/locate/physletb

Physics Letters B 815 (2021) 136101

Production of neutron-rich $N = 126$ nuclei in multinucleon transfer reactions: Comparison between $^{136}\text{Xe} + ^{198}\text{Pt}$ and $^{238}\text{U} + ^{198}\text{Pt}$ reactions

K. Zhao ^{a,b,*}, Z. Liu ^{c,d,*}, F.S. Zhang ^{e,f,g}, N. Wang ^{b,h}

ImQMD模型发现了
相同的现象



Eur. Phys. J. A (2020) 56:224
<https://doi.org/10.1140/epja/s10050-020-00229-2>

THE EUROPEAN
PHYSICAL JOURNAL A

Regular Article - Experimental Physics

New studies and a short review of heavy neutron-rich transfer products

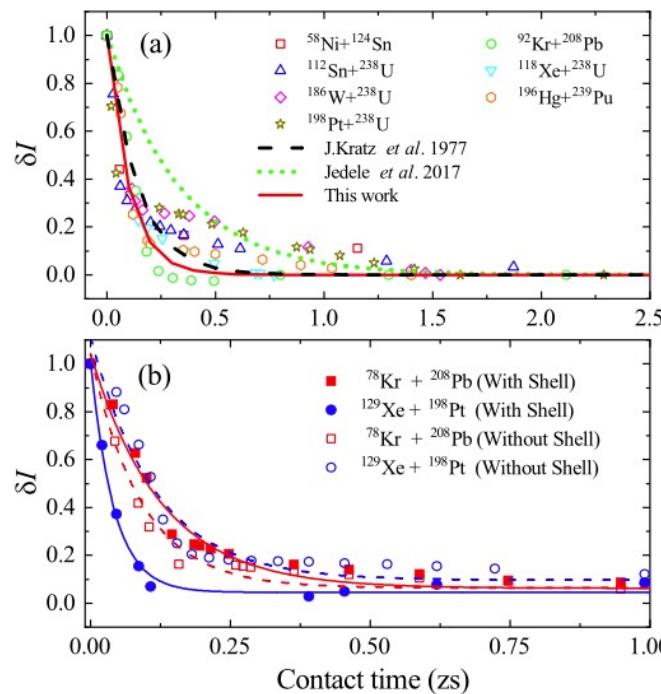
H. M. Devaraja ^{1,2,a}, S. Heinz ^{1,2}, D. Ackermann ³, T. Göbel ¹, F. P. Heßberger ^{2,4}, S. Hofmann ², J. Maurer ², G. Münenberg ², A. G. Popeko ⁵, A. V. Yeremin ⁵

ants. An interesting alternative approach of the DNS model is the suggestion to use uranium targets instead of Pb or Pt to populate nuclei along $N = 126$. With Pb or Pt targets

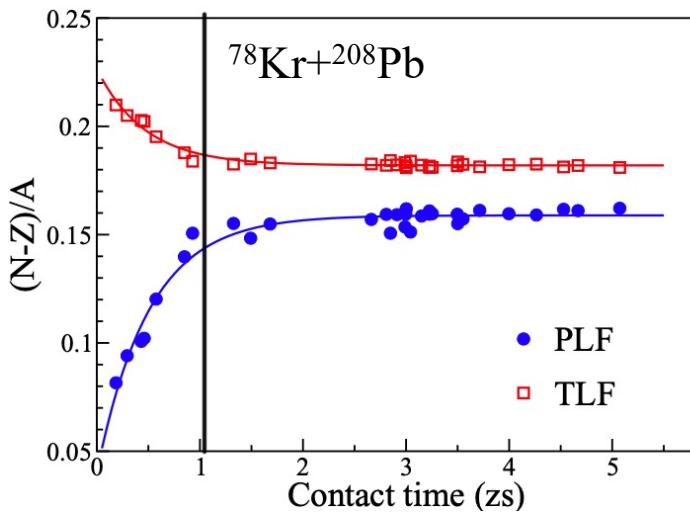
GSI实验学家认为我们提出的方法是产生N=126丰中子重核的新途径。

电荷平衡的特征

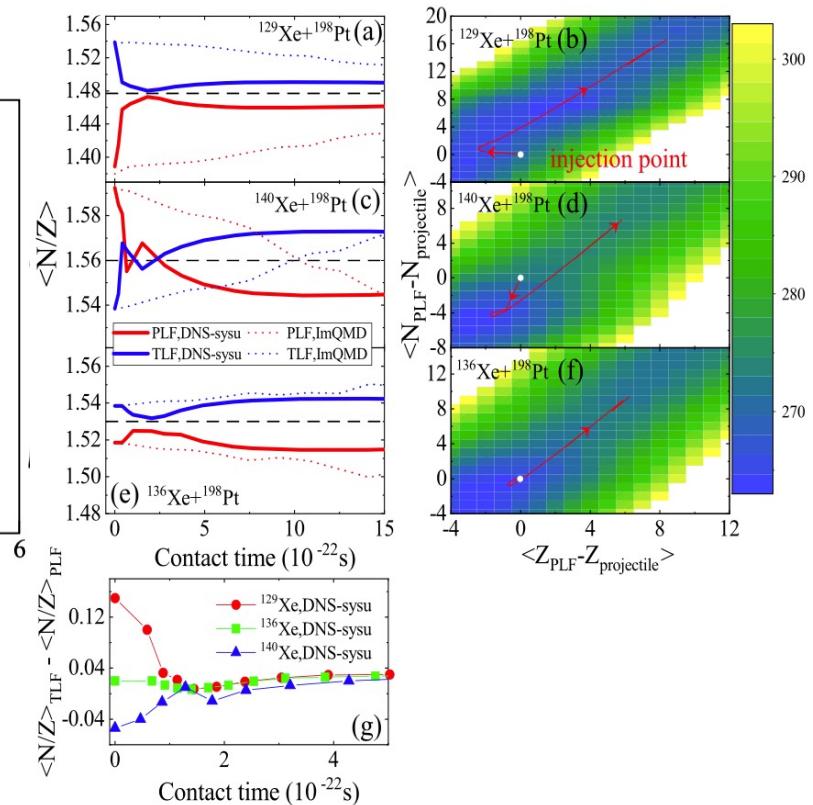
电荷平衡是个快过程 0.1~1.0 zs



非完全电荷平衡



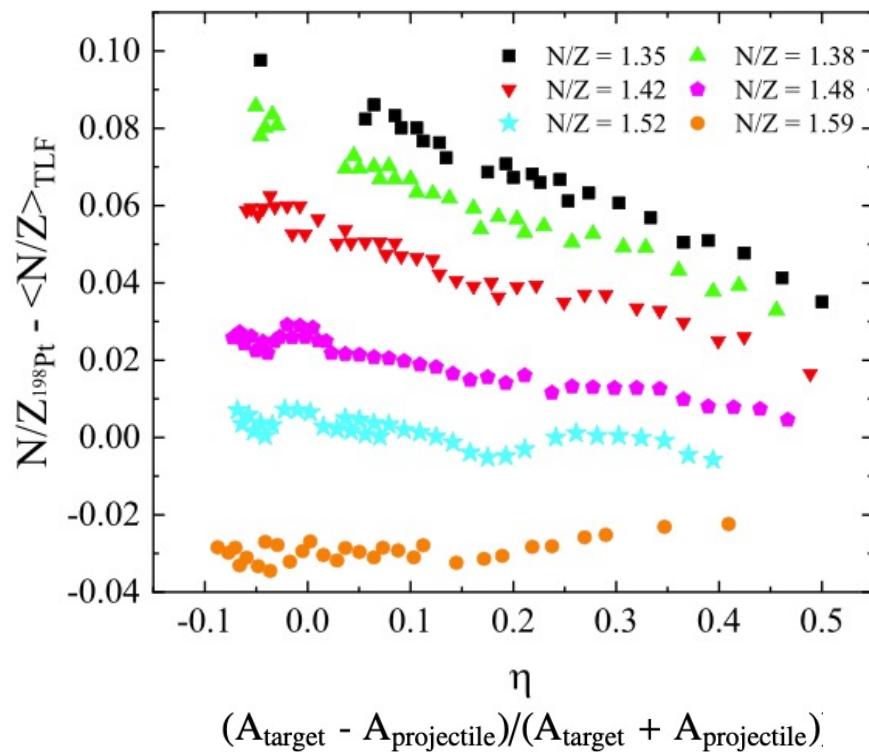
非完全电荷平衡；逆电荷平衡



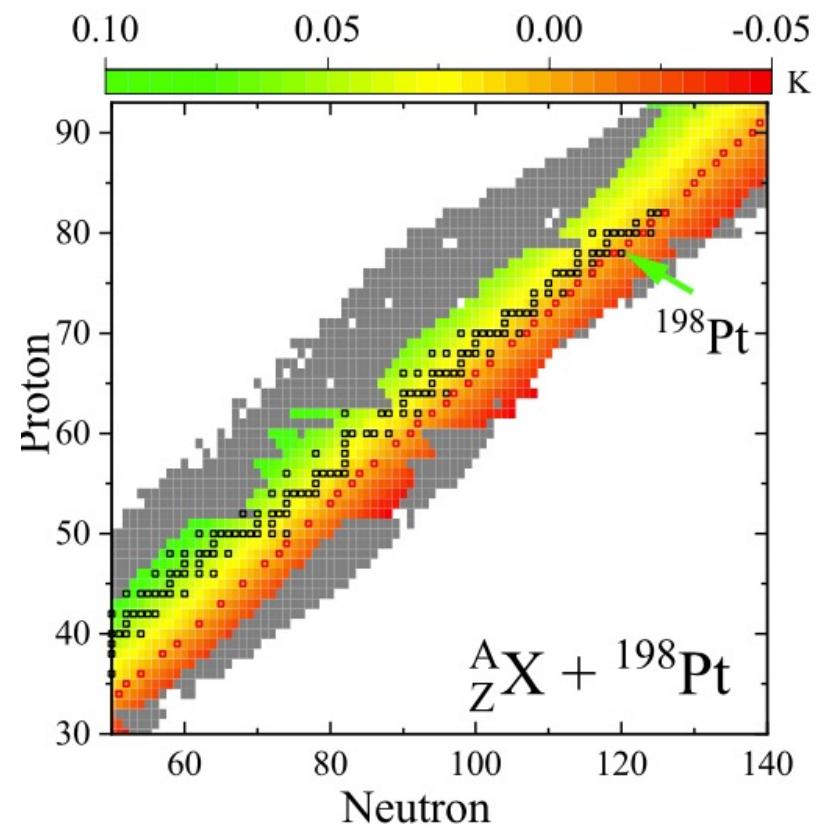
Ze-Hong Liao, Long Zhu*, et al., submitted to PLB

电荷平衡与质量不对称度的关联，解释了电荷平衡的重要规律

电荷平衡过程强烈地依赖于反应体系的质量不对称度

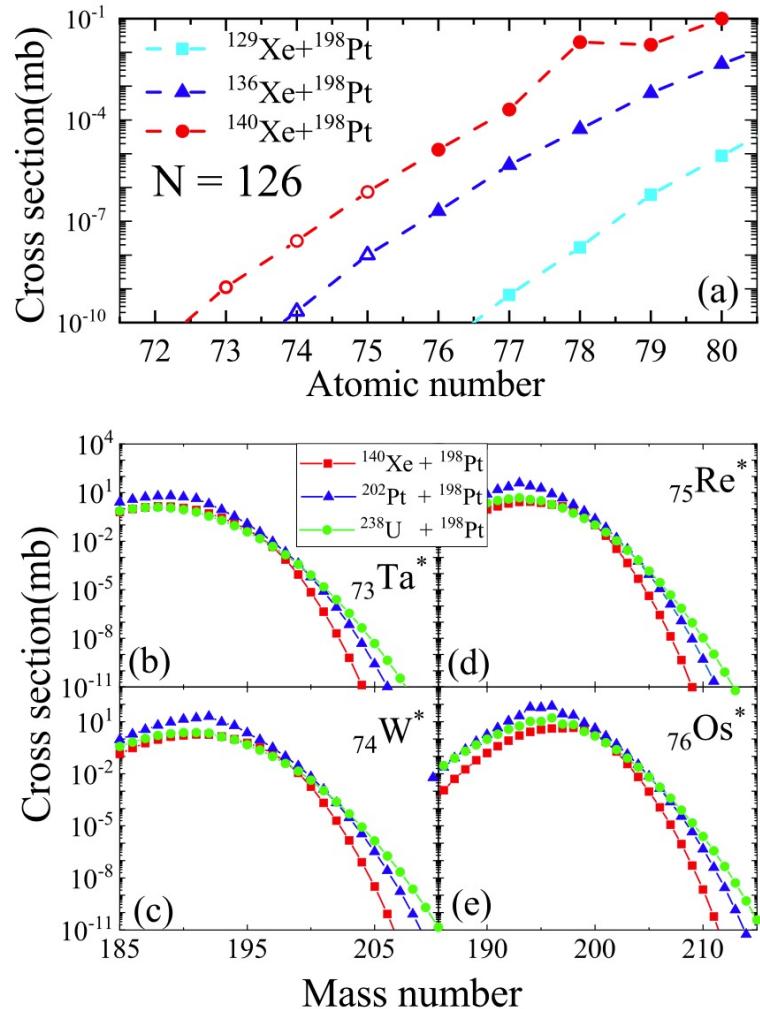


$$K = \frac{(N/Z)_{\text{target}} - \langle N/Z \rangle_{\text{TLF}}}{(N/Z)_{\text{CN}}}$$



Ze-Hong Liao, Long Zhu*, et al., submitted to PLB

电荷平衡与质量不对称度的关联，解释了 ^{238}U 的优势



即使放射性束流 ^{140}Xe 比 ^{238}U 有更高的N/Z值。但是，
基于其产生丰中重核的截面低于 ^{238}U 引起的反应。
并且 ^{140}Xe 的束流强度很低。

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总结与展望

总结

- 多核子转移反应是产生丰中子重核有希望途径。
- 实验上还未基于MNT反应直接观测到丰中子新核素的产生。
- ^{238}U 为靶的MNT反应是一条有希望的可选途径。

展望

- 发展能探测A~200及以上的高效探测方法。目前利用gamma谱学的方法，受限于丰中子核的寿命和已知的gamma跃迁。
- 发展能统一描述多种反应道的理论模型，深入揭示多核子转移反应机制
- 理论实验相结合，有效产生丰中子新核素。

THANKS



谢谢大家

