

# Key physical quantities in SHE synthesis prediction

Peng-Hui Chen (陈鹏辉)

Yangzhou University

School of Physical Science and Technology

Collaborators : Z. Q. Feng<sup>(SCUT)</sup>, X. J. Bao<sup>(HNNU)</sup>, C. J. Xia<sup>(YZU)</sup>, W. Liu<sup>(YZU)</sup>, H. Wu<sup>(YZU)</sup>,  
J. J. Geng<sup>(YZU)</sup>, Z. H. Wang<sup>(SCUT)</sup>, X. H. Zeng<sup>(YZU)</sup>, L. Ren<sup>(YZU)</sup>, W. Liu<sup>(YZU)</sup>

## ➤ Background

## ➤ Theory model

## ➤ Results and Discussion

- ✓ The prediction cross section of SHE errors caused by different nuclear mass models;
- ✓ The prediction cross section of SHE errors caused by the uncertainty of shell damping factor.

## ➤ Acknowledge

# Periodic table of elements



## PERIODIC TABLE OF ELEMENTS

|                                                                                                                               | 1                                                                  | 2                                                                       | 3                                                                     | 4                                                                  | 5                                                                  | 6                                                                  | 7                                                                  | 8                                                                   | 9                                                                 | 10                                                                  | 11                                                                  | 12                                                               | 13                                                                   | 14                                                                 | 15                                                                  | 16                                                                 | 17                                                               | 18                                                               |                                                                    |
|-------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|-------------------------------------------------------------------------|-----------------------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------|---------------------------------------------------------------------|-------------------------------------------------------------------|---------------------------------------------------------------------|---------------------------------------------------------------------|------------------------------------------------------------------|----------------------------------------------------------------------|--------------------------------------------------------------------|---------------------------------------------------------------------|--------------------------------------------------------------------|------------------------------------------------------------------|------------------------------------------------------------------|--------------------------------------------------------------------|
| 1                                                                                                                             | <div>1</div> <div>H</div> <div>Hydrogen</div> <div>1.008</div>     | <div>Atomic #</div> <div>Symbol</div> <div>Name</div> <div>Weight</div> |                                                                       |                                                                    |                                                                    |                                                                    |                                                                    |                                                                     |                                                                   |                                                                     |                                                                     |                                                                  |                                                                      |                                                                    |                                                                     |                                                                    |                                                                  | <div>2</div> <div>He</div> <div>Helium</div> <div>4.0026</div>   |                                                                    |
| 2                                                                                                                             | <div>3</div> <div>Li</div> <div>Lithium</div> <div>6.94</div>      | <div>4</div> <div>Be</div> <div>Beryllium</div> <div>9.0122</div>       |                                                                       |                                                                    |                                                                    |                                                                    |                                                                    |                                                                     |                                                                   |                                                                     |                                                                     |                                                                  |                                                                      |                                                                    |                                                                     |                                                                    |                                                                  |                                                                  | <div>10</div> <div>Ne</div> <div>Neon</div> <div>20.180</div>      |
| 3                                                                                                                             | <div>11</div> <div>Na</div> <div>Sodium</div> <div>22.990</div>    | <div>12</div> <div>Mg</div> <div>Magnesium</div> <div>24.305</div>      |                                                                       |                                                                    |                                                                    |                                                                    |                                                                    |                                                                     |                                                                   |                                                                     |                                                                     |                                                                  |                                                                      |                                                                    |                                                                     |                                                                    |                                                                  |                                                                  | <div>18</div> <div>Ar</div> <div>Argon</div> <div>39.948</div>     |
| 4                                                                                                                             | <div>19</div> <div>K</div> <div>Potassium</div> <div>39.098</div>  | <div>20</div> <div>Ca</div> <div>Calcium</div> <div>40.078</div>        | <div>21</div> <div>Sc</div> <div>Scandium</div> <div>44.956</div>     | <div>22</div> <div>Ti</div> <div>Titanium</div> <div>47.867</div>  | <div>23</div> <div>V</div> <div>Vanadium</div> <div>50.942</div>   | <div>24</div> <div>Cr</div> <div>Chromium</div> <div>51.996</div>  | <div>25</div> <div>Mn</div> <div>Manganese</div> <div>54.938</div> | <div>26</div> <div>Fe</div> <div>Iron</div> <div>55.845</div>       | <div>27</div> <div>Co</div> <div>Cobalt</div> <div>58.933</div>   | <div>28</div> <div>Ni</div> <div>Nickel</div> <div>58.693</div>     | <div>29</div> <div>Cu</div> <div>Copper</div> <div>63.546</div>     | <div>30</div> <div>Zn</div> <div>Zinc</div> <div>65.38</div>     | <div>31</div> <div>Ga</div> <div>Gallium</div> <div>69.723</div>     | <div>32</div> <div>Ge</div> <div>Germanium</div> <div>72.630</div> | <div>33</div> <div>As</div> <div>Arsenic</div> <div>74.922</div>    | <div>34</div> <div>Se</div> <div>Selenium</div> <div>78.971</div>  | <div>35</div> <div>Br</div> <div>Bromine</div> <div>79.904</div> | <div>36</div> <div>Kr</div> <div>Krypton</div> <div>83.798</div> |                                                                    |
| 5                                                                                                                             | <div>37</div> <div>Rb</div> <div>Rubidium</div> <div>85.468</div>  | <div>38</div> <div>Sr</div> <div>Strontium</div> <div>87.62</div>       | <div>39</div> <div>Y</div> <div>Yttrium</div> <div>88.906</div>       | <div>40</div> <div>Zr</div> <div>Zirconium</div> <div>91.224</div> | <div>41</div> <div>Nb</div> <div>Niobium</div> <div>92.906</div>   | <div>42</div> <div>Mo</div> <div>Molybdenum</div> <div>95.95</div> | <div>43</div> <div>Tc</div> <div>Technetium</div> <div>(98)</div>  | <div>44</div> <div>Ru</div> <div>Ruthenium</div> <div>101.07</div>  | <div>45</div> <div>Rh</div> <div>Rhodium</div> <div>102.91</div>  | <div>46</div> <div>Pd</div> <div>Palladium</div> <div>106.42</div>  | <div>47</div> <div>Ag</div> <div>Silver</div> <div>107.87</div>     | <div>48</div> <div>Cd</div> <div>Cadmium</div> <div>112.41</div> | <div>49</div> <div>In</div> <div>Indium</div> <div>114.82</div>      | <div>50</div> <div>Sn</div> <div>Tin</div> <div>118.71</div>       | <div>51</div> <div>Sb</div> <div>Antimony</div> <div>121.76</div>   | <div>52</div> <div>Te</div> <div>Tellurium</div> <div>127.60</div> | <div>53</div> <div>I</div> <div>Iodine</div> <div>126.90</div>   | <div>54</div> <div>Xe</div> <div>Xenon</div> <div>131.29</div>   |                                                                    |
| 6                                                                                                                             | <div>55</div> <div>Cs</div> <div>Caesium</div> <div>132.91</div>   | <div>56</div> <div>Ba</div> <div>Barium</div> <div>137.33</div>         |                                                                       |                                                                    |                                                                    |                                                                    |                                                                    |                                                                     |                                                                   |                                                                     |                                                                     |                                                                  |                                                                      |                                                                    |                                                                     |                                                                    |                                                                  |                                                                  | <div>86</div> <div>Rn</div> <div>Radon</div> <div>(222)</div>      |
| 7                                                                                                                             | <div>87</div> <div>Fr</div> <div>Francium</div> <div>(223)</div>   | <div>88</div> <div>Ra</div> <div>Radium</div> <div>(226)</div>          |                                                                       |                                                                    |                                                                    |                                                                    |                                                                    |                                                                     |                                                                   |                                                                     |                                                                     |                                                                  |                                                                      |                                                                    |                                                                     |                                                                    |                                                                  |                                                                  | <div>118</div> <div>Og</div> <div>Oganesson</div> <div>(294)</div> |
| <div>119</div> <div>120</div>                                                                                                 |                                                                    |                                                                         |                                                                       |                                                                    |                                                                    |                                                                    |                                                                    |                                                                     |                                                                   |                                                                     |                                                                     |                                                                  |                                                                      |                                                                    |                                                                     |                                                                    |                                                                  |                                                                  |                                                                    |
| <div>For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.</div> |                                                                    |                                                                         |                                                                       |                                                                    |                                                                    |                                                                    |                                                                    |                                                                     |                                                                   |                                                                     |                                                                     |                                                                  |                                                                      |                                                                    |                                                                     |                                                                    |                                                                  |                                                                  |                                                                    |
| <div>57–71</div> <div>89–103</div>                                                                                            |                                                                    |                                                                         |                                                                       |                                                                    |                                                                    |                                                                    |                                                                    |                                                                     |                                                                   |                                                                     |                                                                     |                                                                  |                                                                      |                                                                    |                                                                     |                                                                    |                                                                  |                                                                  |                                                                    |
| 6                                                                                                                             | <div>57</div> <div>La</div> <div>Lanthanum</div> <div>138.91</div> | <div>58</div> <div>Ce</div> <div>Cerium</div> <div>140.12</div>         | <div>59</div> <div>Pr</div> <div>Praseodymium</div> <div>140.91</div> | <div>60</div> <div>Nd</div> <div>Neodymium</div> <div>144.24</div> | <div>61</div> <div>Pm</div> <div>Promethium</div> <div>(145)</div> | <div>62</div> <div>Sm</div> <div>Samarium</div> <div>150.36</div>  | <div>63</div> <div>Eu</div> <div>Europium</div> <div>151.96</div>  | <div>64</div> <div>Gd</div> <div>Gadolinium</div> <div>157.25</div> | <div>65</div> <div>Tb</div> <div>Terbium</div> <div>158.93</div>  | <div>66</div> <div>Dy</div> <div>Dysprosium</div> <div>162.50</div> | <div>67</div> <div>Ho</div> <div>Holmium</div> <div>164.93</div>    | <div>68</div> <div>Er</div> <div>Erbium</div> <div>167.26</div>  | <div>69</div> <div>Tm</div> <div>Thulium</div> <div>168.93</div>     | <div>70</div> <div>Yb</div> <div>Ytterbium</div> <div>173.05</div> | <div>71</div> <div>Lu</div> <div>Lutetium</div> <div>174.97</div>   |                                                                    |                                                                  |                                                                  |                                                                    |
| 7                                                                                                                             | <div>89</div> <div>Ac</div> <div>Actinium</div> <div>(227)</div>   | <div>90</div> <div>Th</div> <div>Thorium</div> <div>232.04</div>        | <div>91</div> <div>Pa</div> <div>Protactinium</div> <div>231.04</div> | <div>92</div> <div>U</div> <div>Uranium</div> <div>238.03</div>    | <div>93</div> <div>Np</div> <div>Neptunium</div> <div>(237)</div>  | <div>94</div> <div>Pu</div> <div>Plutonium</div> <div>(244)</div>  | <div>95</div> <div>Am</div> <div>Americium</div> <div>(243)</div>  | <div>96</div> <div>Cm</div> <div>Curium</div> <div>(247)</div>      | <div>97</div> <div>Bk</div> <div>Berkelium</div> <div>(247)</div> | <div>98</div> <div>Cf</div> <div>Californium</div> <div>(251)</div> | <div>99</div> <div>Es</div> <div>Einsteinium</div> <div>(252)</div> | <div>100</div> <div>Fm</div> <div>Fermium</div> <div>(257)</div> | <div>101</div> <div>Md</div> <div>Mendelevium</div> <div>(258)</div> | <div>102</div> <div>No</div> <div>Nobelium</div> <div>(259)</div>  | <div>103</div> <div>Lr</div> <div>Lawrencium</div> <div>(266)</div> |                                                                    |                                                                  |                                                                  |                                                                    |

### Nation named elements:

钅, Ruthenium, 俄罗斯  
 锗, Germanium, 德国  
 钋, Polonium, 波兰 (居里夫人)  
 钫, Francium, 法国  
 镅, Americium, 美国  
 镱, Nihonium, 日本

### 重离子加速器合成的新元素:

美: Md, No, Lr (101~103), Sg (106)  
 俄 (苏): Rf (104), Db (105),  
 Fl, Mc, Lv, Ts, Og (114~118)  
 德: Bh, Hs, Mt, Ds, Rg, Cn (107~112)  
 日: Nh (113)

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# Nuclide chart



核素图：基态原子核的衰变类型 (NUBASE2020)

Chart of the nuclides: decay mode of the ground state nuclide (NUBASE2020)

有寿命信息但质量未知的核素 (共计239个) Nuclide with half-life information but unknown mass (239)

稳定核素 Stable

$\beta^-$  衰变  $\beta^-$  decay

$\beta^+$  或 EC 衰变  $\beta^+$  or EC decay

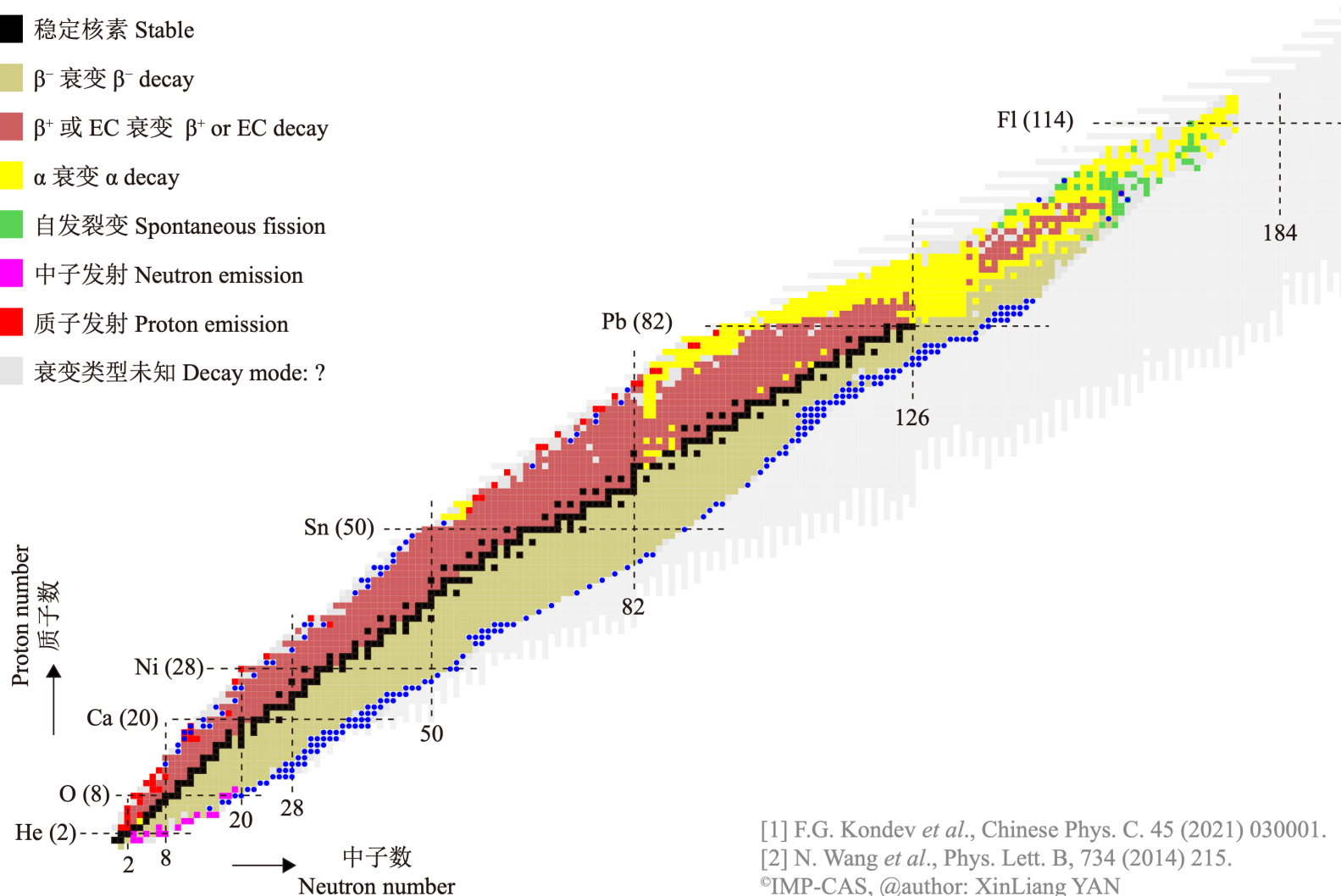
$\alpha$  衰变  $\alpha$  decay

自发裂变 Spontaneous fission

中子发射 Neutron emission

质子发射 Proton emission

衰变类型未知 Decay mode: ?



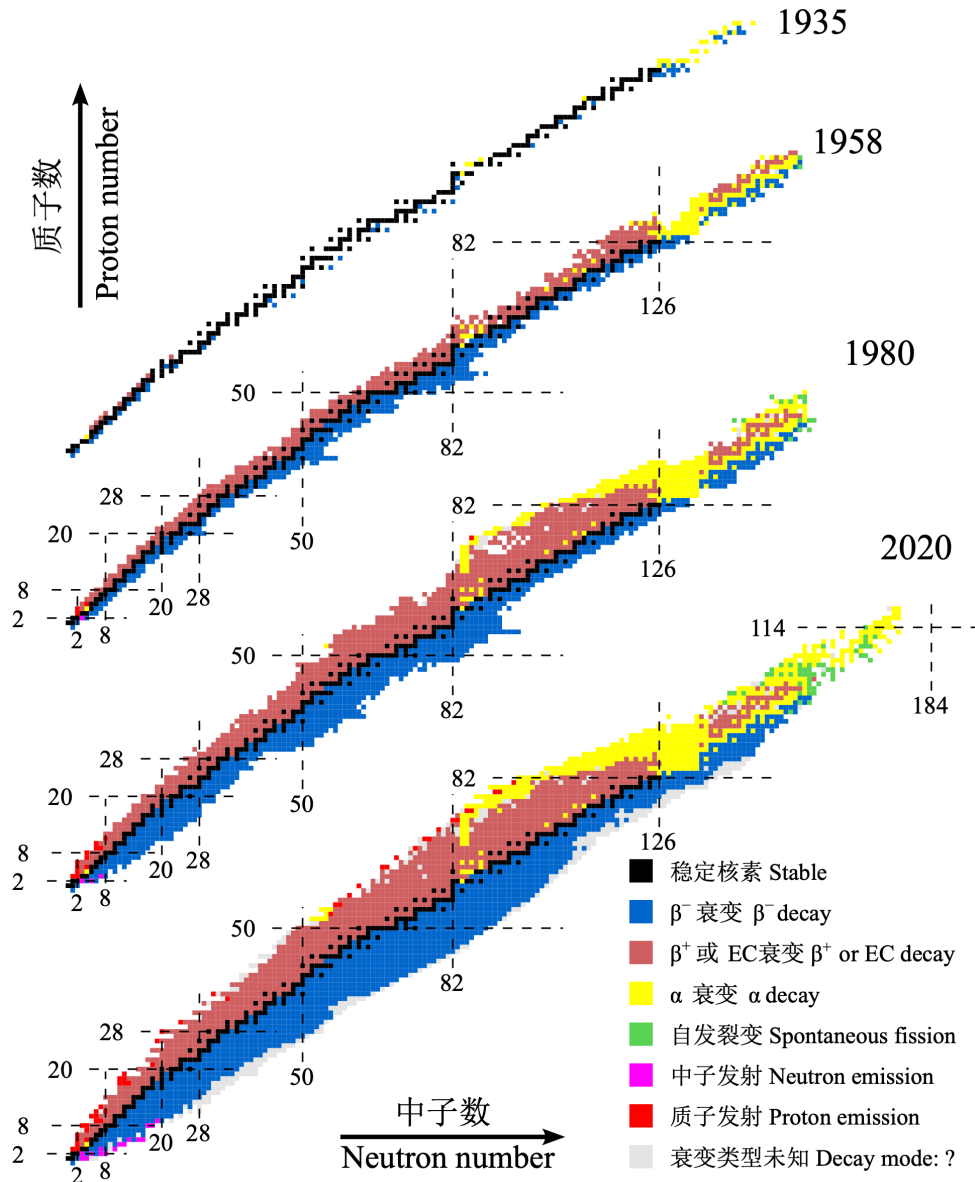
[1] F.G. Kondev *et al.*, Chinese Phys. C. 45 (2021) 030001.

[2] N. Wang *et al.*, Phys. Lett. B, 734 (2014) 215.

©IMP-CAS, @author: XinLiang YAN



# Nuclide chart in history



## ◆ New isotopes in 2020 (4):

$^{235}\text{Cm}$ ,  $^{211}\text{Pa}$ ,  $^{222}\text{Np}$ ,  $^{244}\text{Md}$ .

## ◆ New isotopes in 2021 (15):

$^{101}\text{Br}$ ,  $^{102}\text{Kr}$ ,  $^{105}\text{Rb}$ ,  $^{106}\text{Rb}$ ,  $^{108}\text{Sr}$ ,  $^{110,111}\text{Y}$ ,  
 $^{114}\text{Zr}$ ,  $^{117}\text{Nb}$ ,  $^{13}\text{F}$ ,  $^{214}\text{U}$ ,  $^{249}\text{No}$ ,  $^{150}\text{Yb}$ ,  $^{18}\text{Mg}$ .

## ◆ New isotopes in 2022 (11):

$^{149}\text{Lu}$ ,  $^{207}\text{Th}$ ,  $^{264}\text{Lr}$ ,  $^{166}\text{Pm}$ ,  $^{168}\text{Sm}$ ,  
 $^{170}\text{Eu}$ ,  $^{172}\text{Gd}$ ,  $^{204}\text{Ac}$ ,  $^{251}\text{Lr}$ ,  $^{39}\text{Na}$ ,  $^{286}\text{Mc}$ .

## ◆ New isotopes in 2023(13) :

$^{241}\text{U}$ ,  $^{190}\text{At}$ ,  $^{276}\text{Ds}$ ,  $^{272}\text{Hs}$ ,  $^{268}\text{Sg}$ ,  $^{27}\text{O}$ ,  $^{28}\text{O}$ ,  
 $^{189}\text{Lu}$ ,  $^{191}\text{Hf}$ ,  $^{192}\text{Hf}$ ,  $^9\text{N}$ ,  $^{156}\text{W}$ ,  $^{160}\text{Os}$

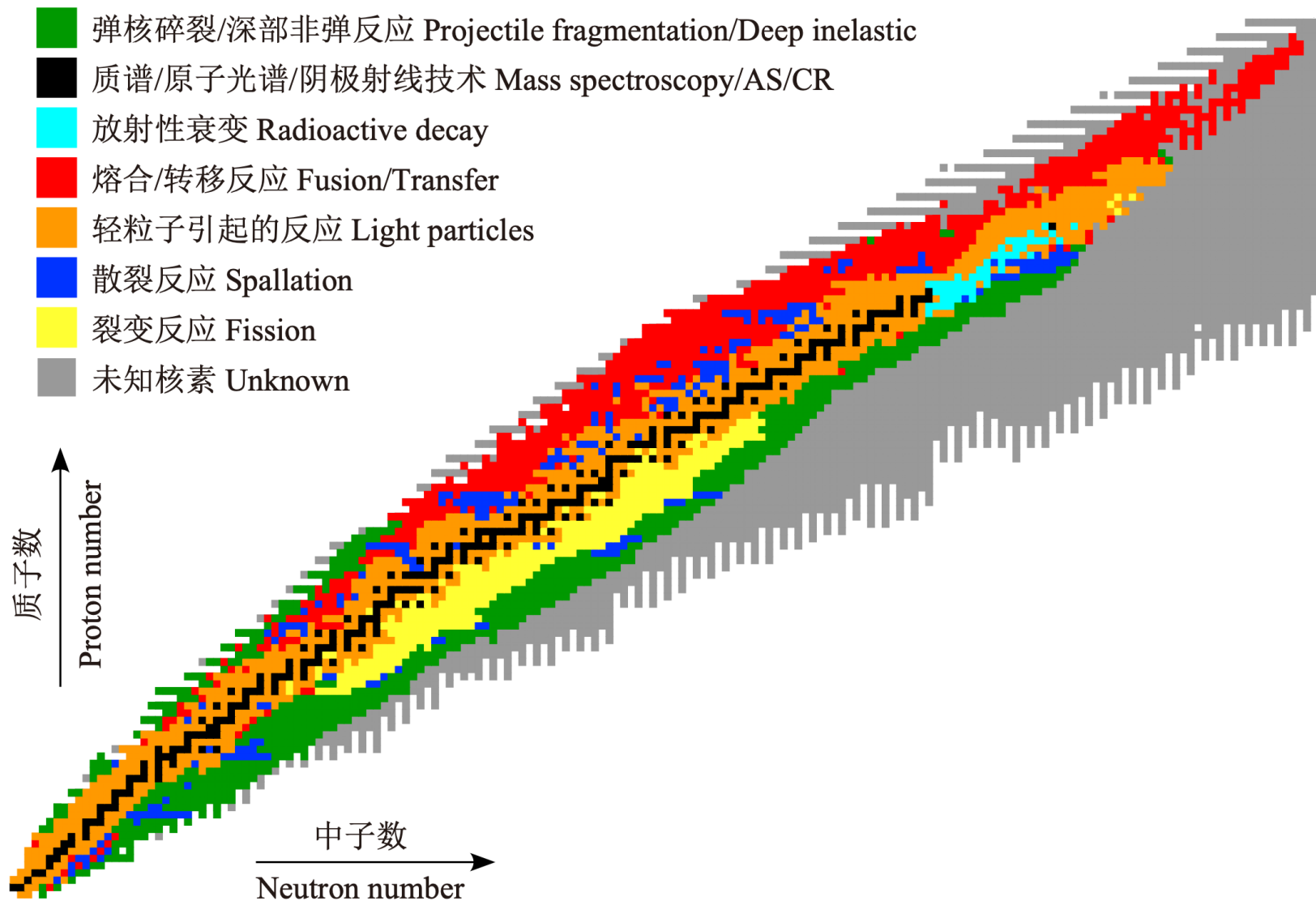
## ◆ New isotopes in 2024(34):

$^{203}\text{Ac}$ ,  $^{275}\text{Ds}$ ,  $^{84}\text{Cu}$ ,  $^{86,87}\text{Zn}$ ,  $^{88,89}\text{Ga}$ ,  $^{45,46}\text{Si}$ ,  $^{227}\text{Pu}$   
 $^{91,92}\text{Ge}$ ,  $^{93,94,95}\text{As}$ ,  $^{96,97}\text{Se}$ ,  $^{99,100}\text{Br}$ ,  $^{103}\text{Kr}$ ,  $^{255}\text{Db}$

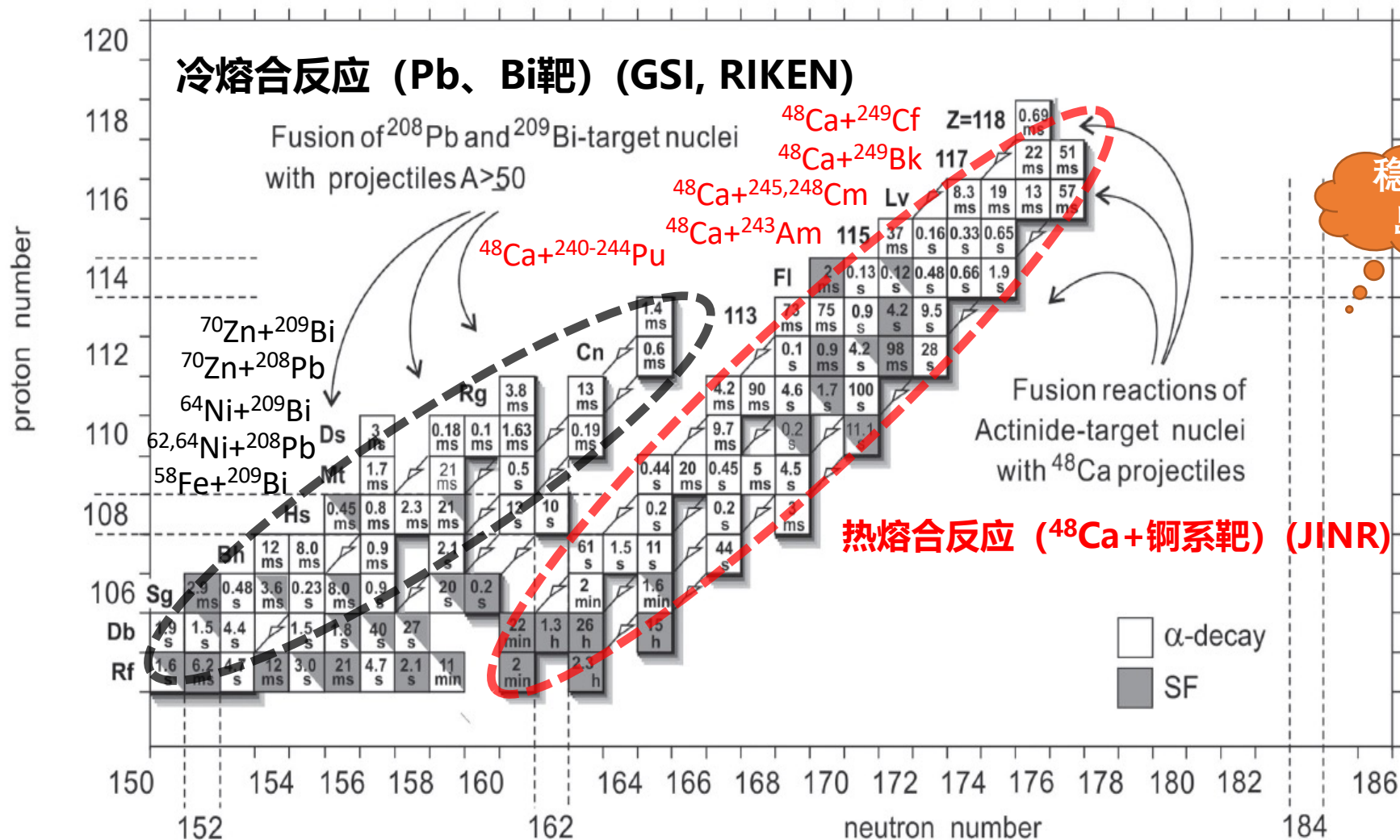
## New isotopes in 2025(3+):

$^{257}\text{Sg}$ ,  $^{98}\text{Sn}$ ,  $^{252}\text{Rf}$ , .....

# Synthesis method



# Experimental progress



# Experimental progress

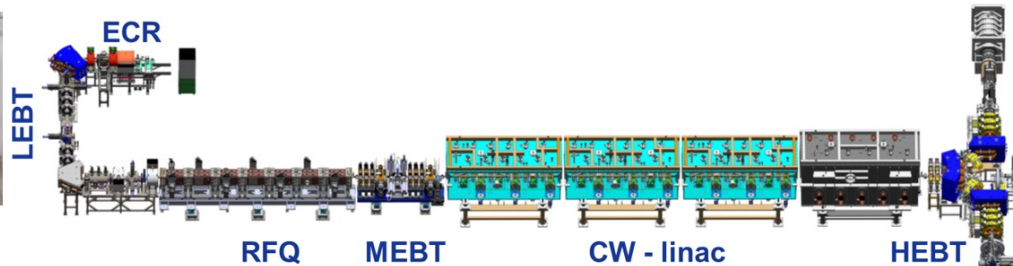


## 中国超重元素研究加速器装置

*China Accelerator Facility for Superheavy Elements (CAFE2)*



电子回旋共振离子源  
(ECR ion source)



| 参数   | 设计指标    | 单位            |
|------|---------|---------------|
| 加速粒子 | Ca ~ Zn | -             |
| 荷质比  | 1/3     | -             |
| 束流能量 | 4.5-7   | MeV/u         |
| 束流强度 | 5-10    | $\mu\text{A}$ |



射频四极聚束器  
(RFQ)



连续波超导直线加速器  
(CW-LINAC)

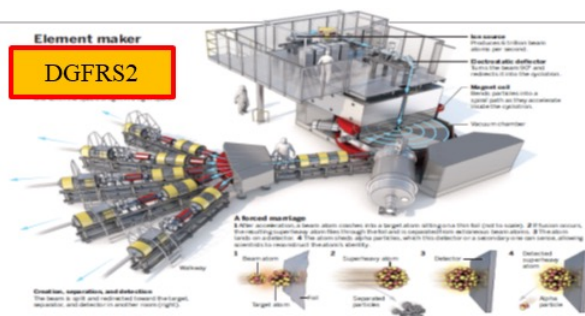


充气反冲核分离器  
(SHANS2)

Russia's JINR, Japan's RIKEN, and China's IMP have all newly constructed experimental facilities, launching plans to synthesize new elements 119 or 120.

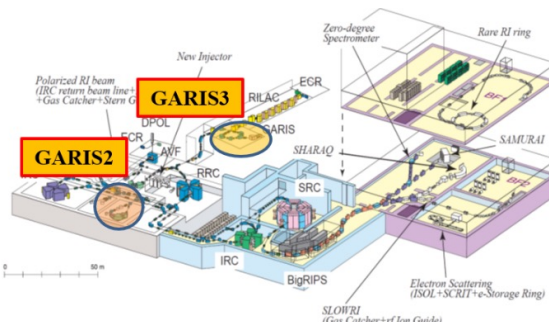


# Experimental progress



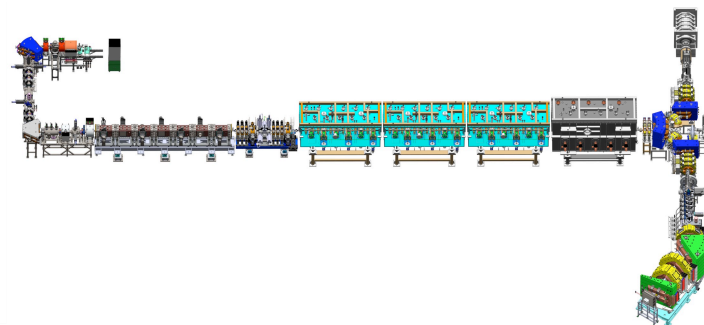
俄罗斯JINR

SHE Factory + DGFRS2



日本RIKEN

RILAC + GARIS3



中国IMP-CAS

CAFE2 + SHANS2

| 国家  | 实验室     | 装置             | 最高流强<br>(粒子微安)       | 充气谱仪传输效率                                  |
|-----|---------|----------------|----------------------|-------------------------------------------|
| 俄罗斯 | JINR    | SHE<br>Factory | ~10                  | ~59% ( $^{48}\text{Ca}+^{206}\text{Pb}$ ) |
| 日本  | RIKEN   | RILAC          | 3~4                  | ~47% ( $^{40}\text{Ar}+^{169}\text{Tm}$ ) |
| 中国  | IMP-CAS | CAFE2          | 目前: 3~5<br>目标: 10~15 | ~58% ( $^{40}\text{Ar}+^{169}\text{Tm}$ ) |

**Key technical challenge:**  
**Element synthesis for fb**  
**cross section generation**

**Higher beam intensity**

**Higher separation efficiency**

# Theory models

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- Phenomenological Models:

- Macroscopic dynamics model: pure dynamical fusion process;

 Swiatecki, *Nucl. Phys. A* **391**, 471 (1982).

- Fluctuation-dissipation model: Fluctuation, shell correction;

 Y. Abe, *Phys. Rev. C* **59**, 796 (1999).

- **Dinuclear system model** (DNS): keep individuality, nucleon transfer;

 G.G. Adamian, *Nucl. Phys. A* **627**, 361 (1997); W. F. Li, N. Wang, et. al., *Eur. Lett.* 64 (2003) 750;

V. V. Volkov, G. G. Adamian, N. V. Antonenko, *Nuovo Cimento A* 110, 1127 (1997)

- Nucleon collectivization model:

 V.I. Zagrebaev, *Phys. Rev. C* **64**, 034606 (2001).

.....

- Microscopic Models:

- Improved quantum molecule model (ImQMD)

 Kai Zhao, *Phys. Rev. C* **94**, 024601 (2016).

- Time-depedent Hartree Fock model (TDHF)

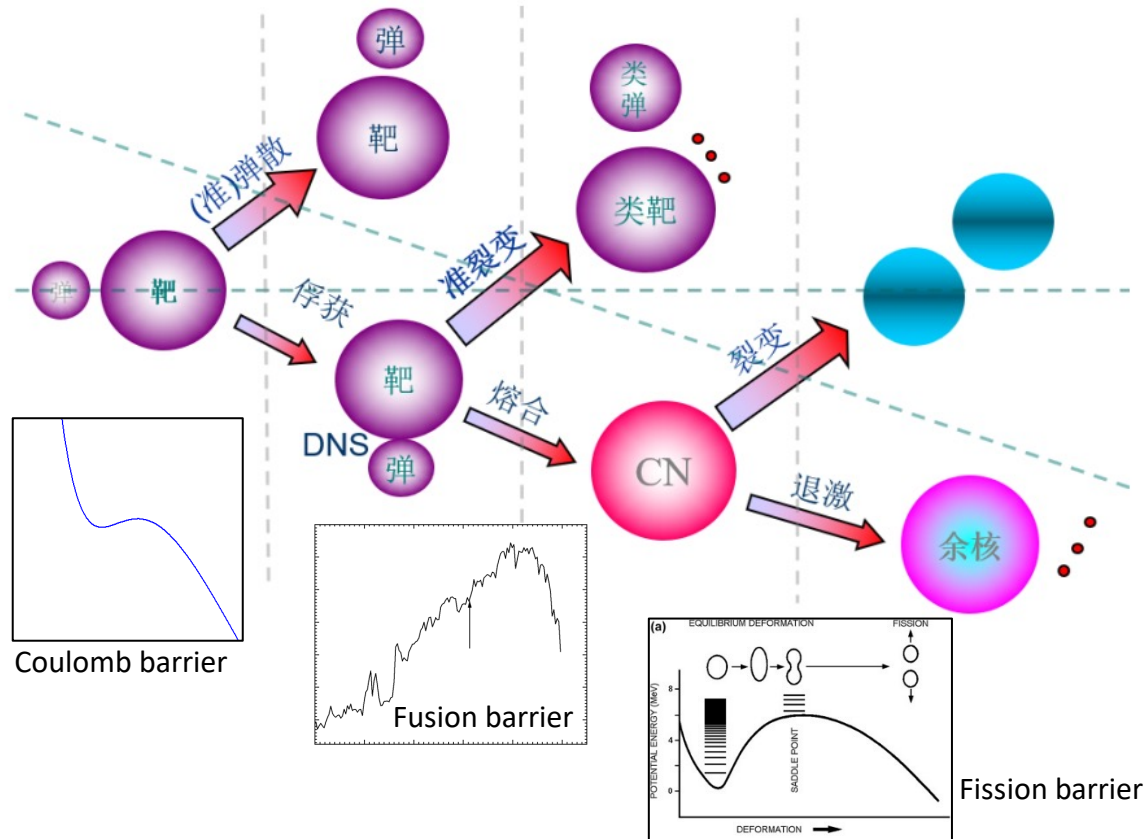
 Lu Guo, *Phys. Rev. C* **90**, 044609 (2014). *Com. Phys. C* 185, 2195 (2014)

.....



# Dinuclear system model (DNS)

- Three stages description of DNS: Phys. Rep. 44(1978)93



- Residual evaporation equation:

$$\sigma_{ER}(E_{c.m.}) = \frac{\pi \hbar^2}{2\mu E_{c.m.}} \sum_{J=0}^{J_{max}} (2J+1) T(E_{c.m.}, J) P_{CN}(E_{c.m.}, J) W_{sur}(E_{c.m.}, J)$$

# Capture stage



- Barrier penetration probability: Hill-Wheeler formula

$$T(E_{\text{c.m.}}, J) = \int f(B) \frac{1}{1 + \exp(-\frac{2\pi}{\hbar\omega(J)}[E_{\text{c.m.}} - B - \frac{\hbar^2}{2\mu R_B^2(J)}J(J+1)])} dB$$

 D.L. Hill, J.A. Wheeler, Phys. Rev. **89**, 1102 (1953).

- Barrier distribution function: Asymmetric-Gauss function

$$f(B) = \begin{cases} \frac{1}{N} \exp[-(\frac{B-B_m}{\Delta_1})] & B < B_m \\ \frac{1}{N} \exp[-(\frac{B-B_m}{\Delta_2})] & B > B_m \end{cases}$$

$$B_m = (B_0 + B_s)/2, \Delta_2 = (B_0 - B_s)/2, \Delta_2 - \Delta_1 = (2 \sim 4) \text{ MeV}$$

- Interaction potential:  $V_N$  double folding,  $V_C$  Wong Formula

$$V(R; \beta_1, \beta_2, \theta_1, \theta_2) = V_C + V_N + \frac{1}{2}C_1(\beta_1 - \beta_1^0)^2 + \frac{1}{2}C_2(\beta_2 - \beta_2^0)^2$$

 Rowley, Phys. Lett. B **254** 25 (1991); Zagrebaev, Phys. Rev. C **64**, 034606 (2001). Feng, et al. Nucl. Phys. A **771**, 56 (2006).

- Master equation *Eur. Lett.* 64 (2003) 750; *Phys. Rev. C* 68 (2003) 034601

$$\begin{aligned} \frac{dP(Z_1, N_1, E_1, t)}{dt} = & \sum_{Z'_1} W_{Z_1, N_1; Z'_1, N_1}(t) [d_{Z_1, N_1} P(Z'_1, N_1, E'_1, t) - d_{Z'_1, N_1} P(Z_1, N_1, E_1, t)] + \\ & \sum_{N'_1} W_{Z_1, N_1; Z_1, N'_1}(t) [d_{Z_1, N_1} P(Z_1, N'_1, E'_1, t) - d_{Z_1, N'_1} P(Z_1, N_1, E_1, t)] \\ & - [\Lambda_{A_1, E_1, t}^{\text{qf}}(\Theta) + \Lambda_{A_1, E_1, t}^{\text{fis}}(\Theta)] P(Z_1, N_1, E_1, t) \end{aligned}$$

- Fusion probability  $P_{\text{CN}}$

$$\begin{aligned} P_{\text{CN}}(E_{\text{c.m.}}, J) = & \int f(B) \sum_{Z=1}^{Z_{\text{BG}}} \sum_{N=1}^{N_{\text{BG}}} \\ & P(Z, N, E_1, \tau_{\text{int}}(E_{\text{c.m.}}, J), B) dB. \end{aligned}$$

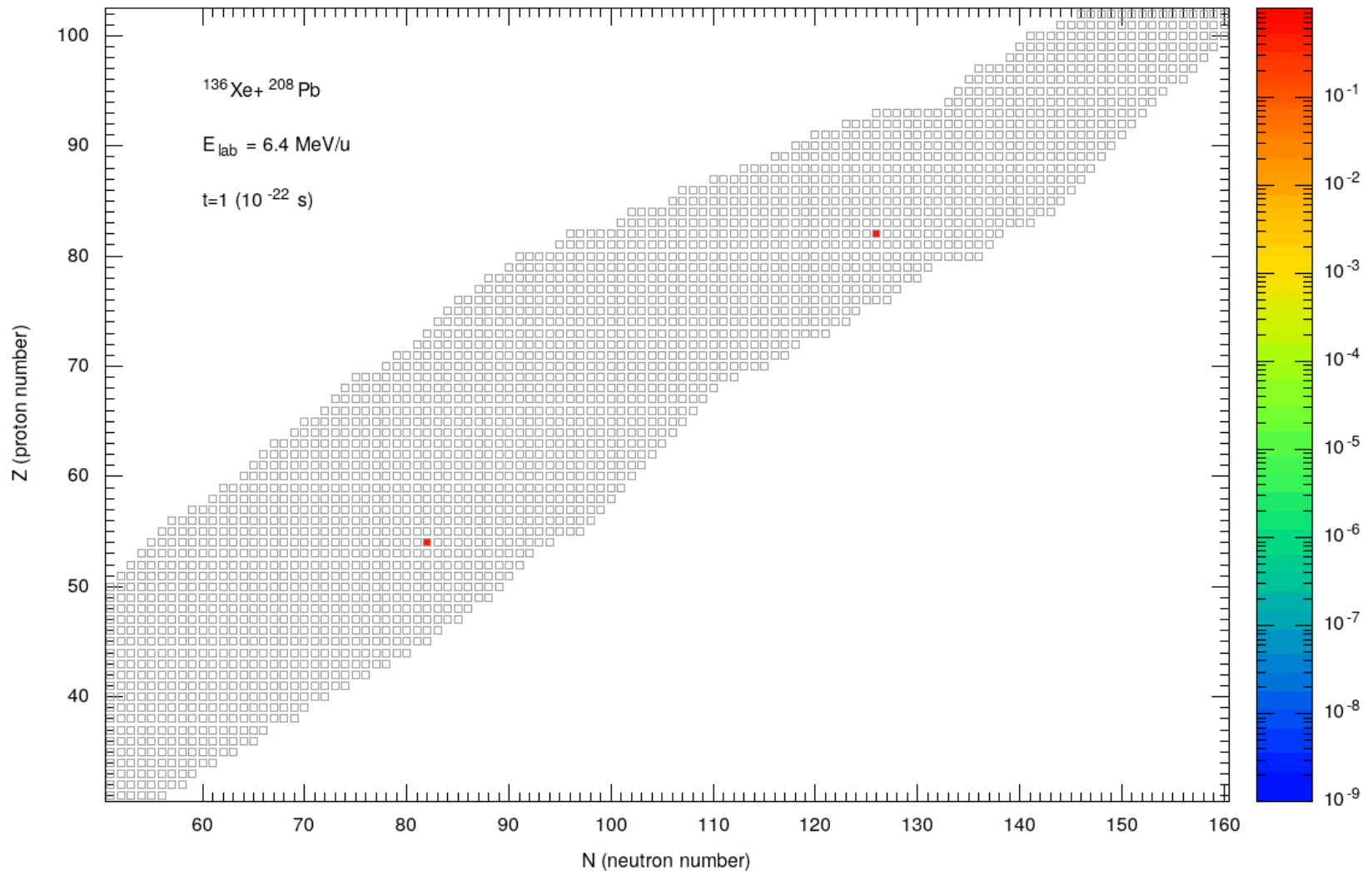
- MNT cross section  $\sigma_{\text{sur}}$

$$\begin{aligned} \sigma_{\text{sur}}(Z_1, N_1, E_{\text{c.m.}}) = & \sum_{J=0}^{J_{\text{max}}} \sigma_{\text{cap}} \int f(B) \\ & \times P(Z_1, N_1, E_1, J_1, B) W_{\text{sur}}(E_1, J_1, s) dB. \end{aligned}$$

- Fusion cross section  $\sigma_{\text{fus}}$

$$\sigma_{\text{fus}}(E_{\text{c.m.}}) = \frac{\pi \hbar^2}{2\mu E_{\text{c.m.}}} \sum_{J=0}^{J_m} (2J+1) T(E_{\text{c.m.}}, J) P_{\text{CN}}(E_{\text{c.m.}}, J)$$

# Probability diffusion process



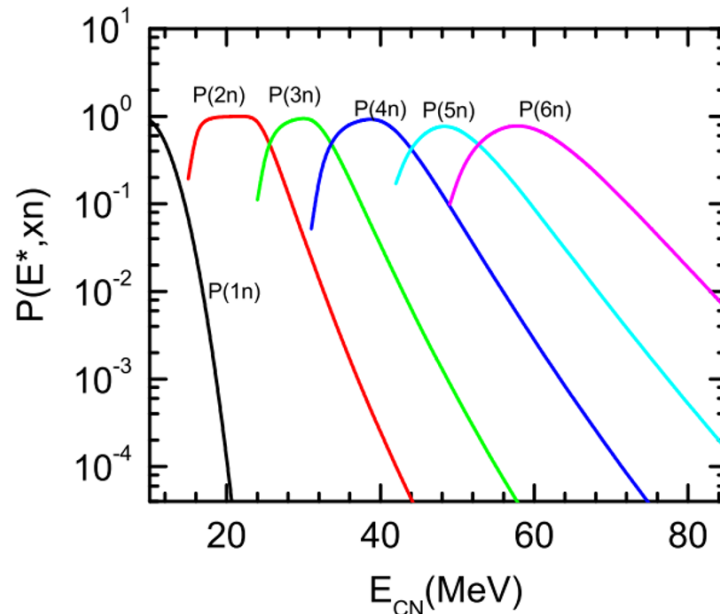
Derived by Master Equation

## ● Survival probability

 V. Weisskopf, *Phys. Rev.* **52**, 250 (1937).

$$W_{\text{sur}}(E_{\text{CN}}^*, x, J) = P(E_{\text{CN}}^*, x, J) \prod_{i=1}^{x_n} \frac{\Gamma_n(E_i^*, J)}{\Gamma_{\text{tot}}(E_i^*, J)} \prod_{j=1}^{x_p} \frac{\Gamma_p(E_j^*, J)}{\Gamma_{\text{tot}}(E_j^*, J)} \prod_{k=1}^{x_\alpha} \frac{\Gamma_\alpha(E_k^*, J)}{\Gamma_{\text{tot}}(E_k^*, J)}$$

## ● Realization probability



$$P(E_{\text{CN}}^*, 1, J) = \exp \left( -\frac{(E_{\text{CN}}^* - B_n - E_{\text{rot}} - 2T)^2}{2\sigma^2} \right)$$

$$P(E_{\text{CN}}^*, x, J) = I(\Delta_x, 2x - 3) - I(\Delta_{x+1}, 2x - 1)$$

$$I(z, m) = \frac{1}{m!} \int_0^z u^m e^{-u} du$$

$$\Delta_x = \frac{E_{\text{CN}}^* - \sum_{i=1}^x B_i^n - E_{\text{rot}}}{T_i}$$

 Feng, *Nucl. Phys. A* **771**, 56 (2006).

 G.G. Adamian, *Nucl. Phys. A* **627**, 361 (1997)





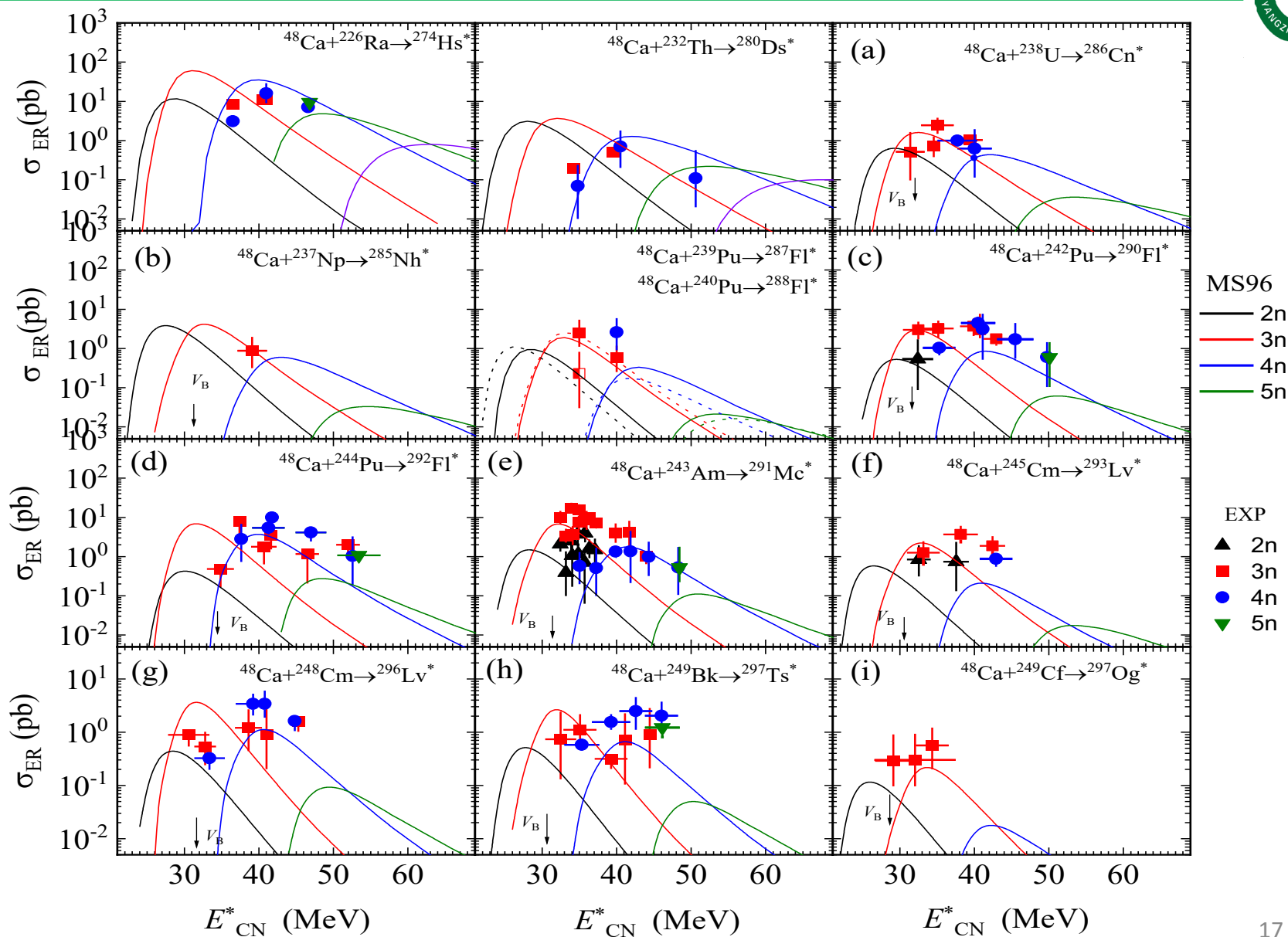
# 1. The prediction cross-section errors caused by different nuclear mass models.

Five nuclear mass models:

- ✓ **FRDM12**, the finite-range droplet model, P. Moller, et.al. ADND 109-110, 1 (2016);
- ✓ **KUTY05**, Koura-Tachibana-Uno-Yamada model, H. Koura, et.al., PTP 113, 305 (2005);
- ✓ **WS4**, Weizsäcker-Skyrme mass models, N. Wang, et.al., PLB 734, 215 (2014);
- ✓ **MS96**, the Little Droplet model, W. D. Myers, et.al. Nucl. Phys. 81, 1 (1966);
- ✓ **HFB02**, Hartree-Fock-Bogoliubov approaches, Y. El Bassem, et.al. NPA 957, 22 (2017).

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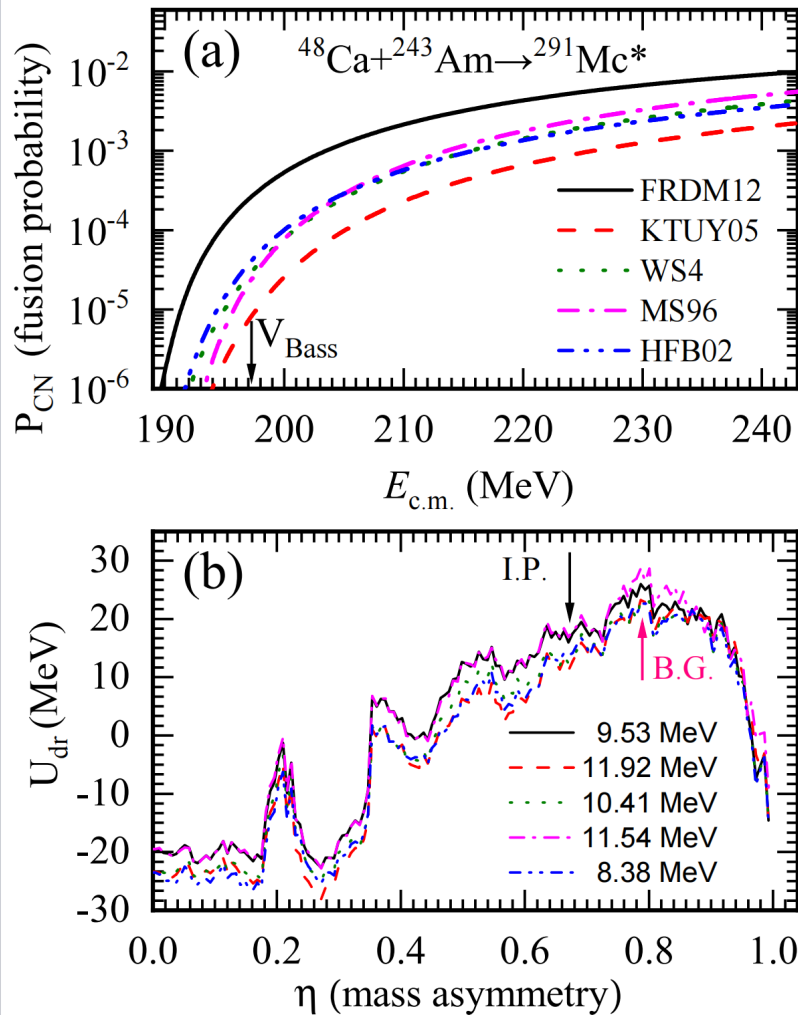
# SHN synthesis cross-section predictions VS Exp. data



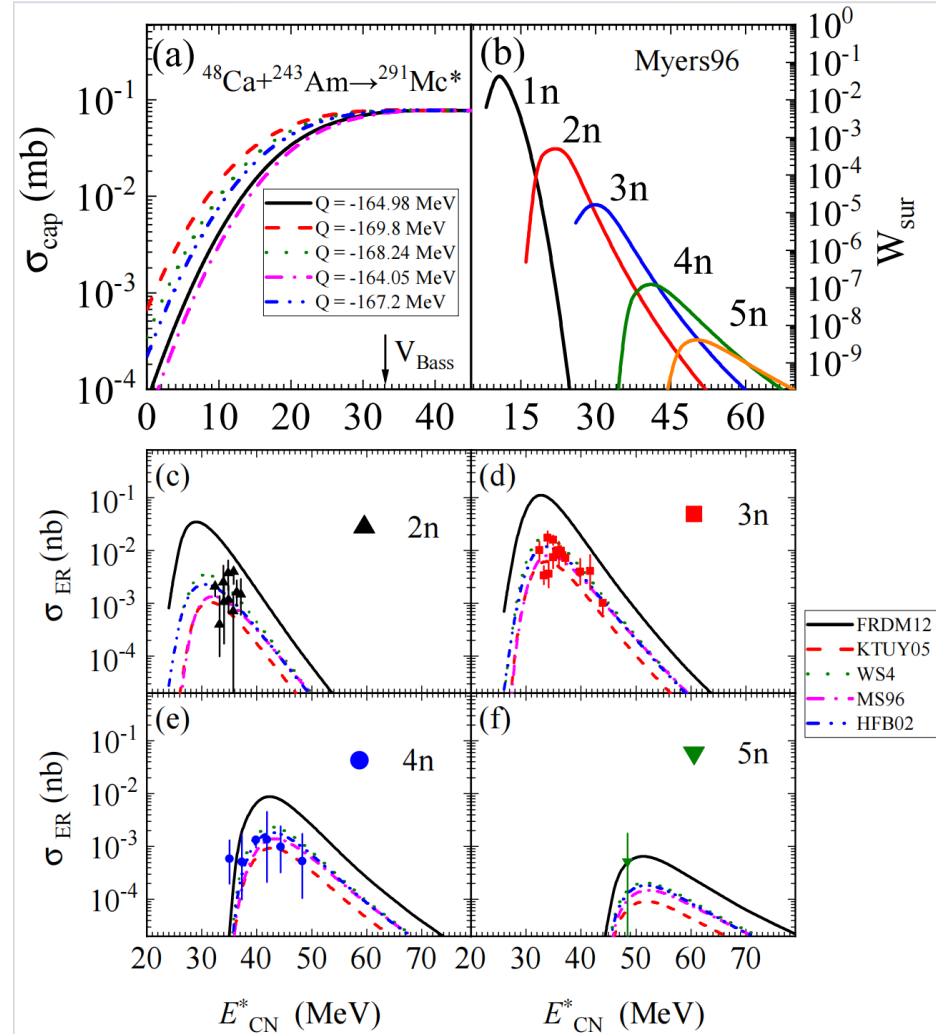
# $^{48}\text{Ca} + ^{243}\text{Am} @ E_{\text{lab}} = 5.6 \text{ MeV/u}$



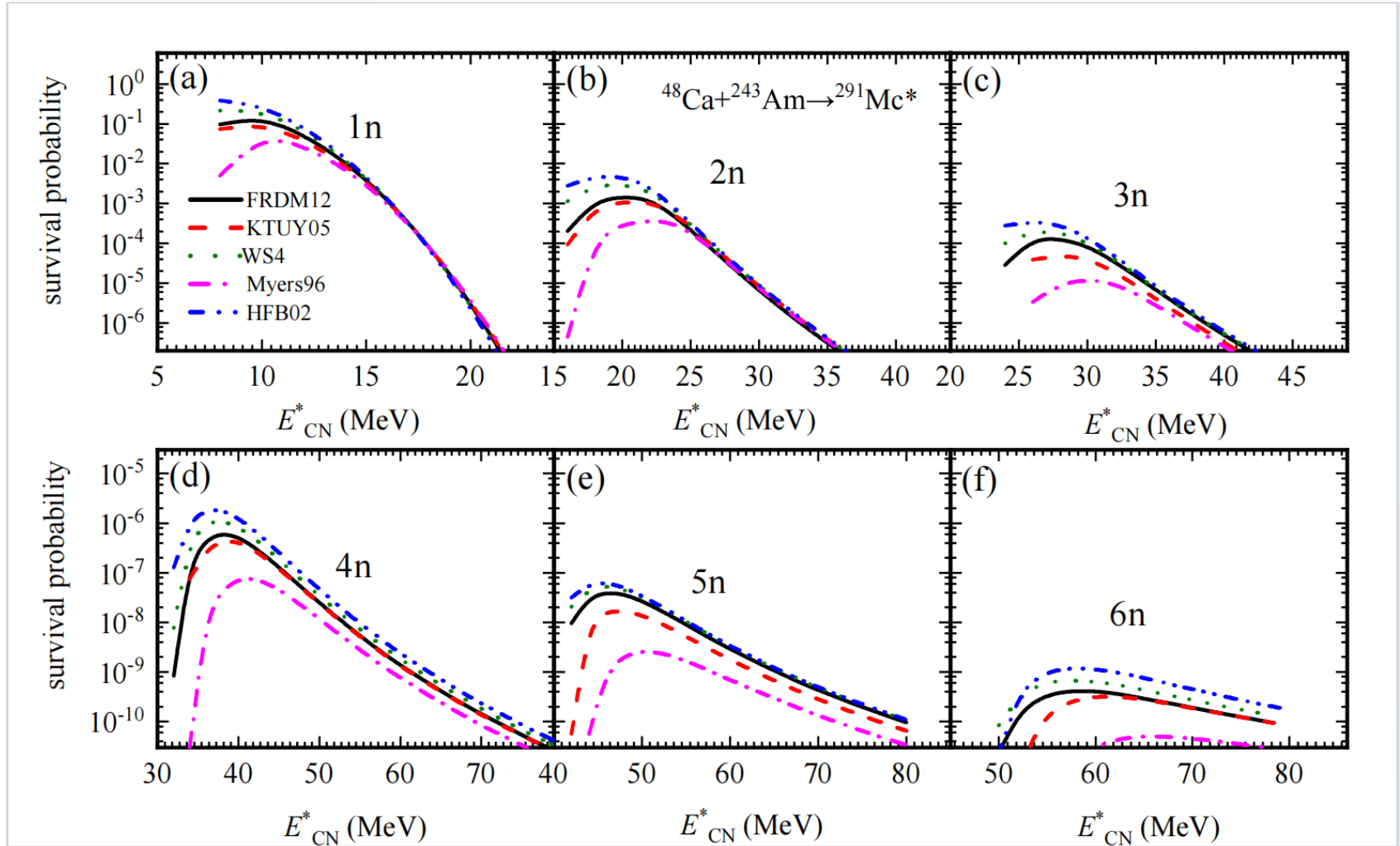
driver potential and fusion probability



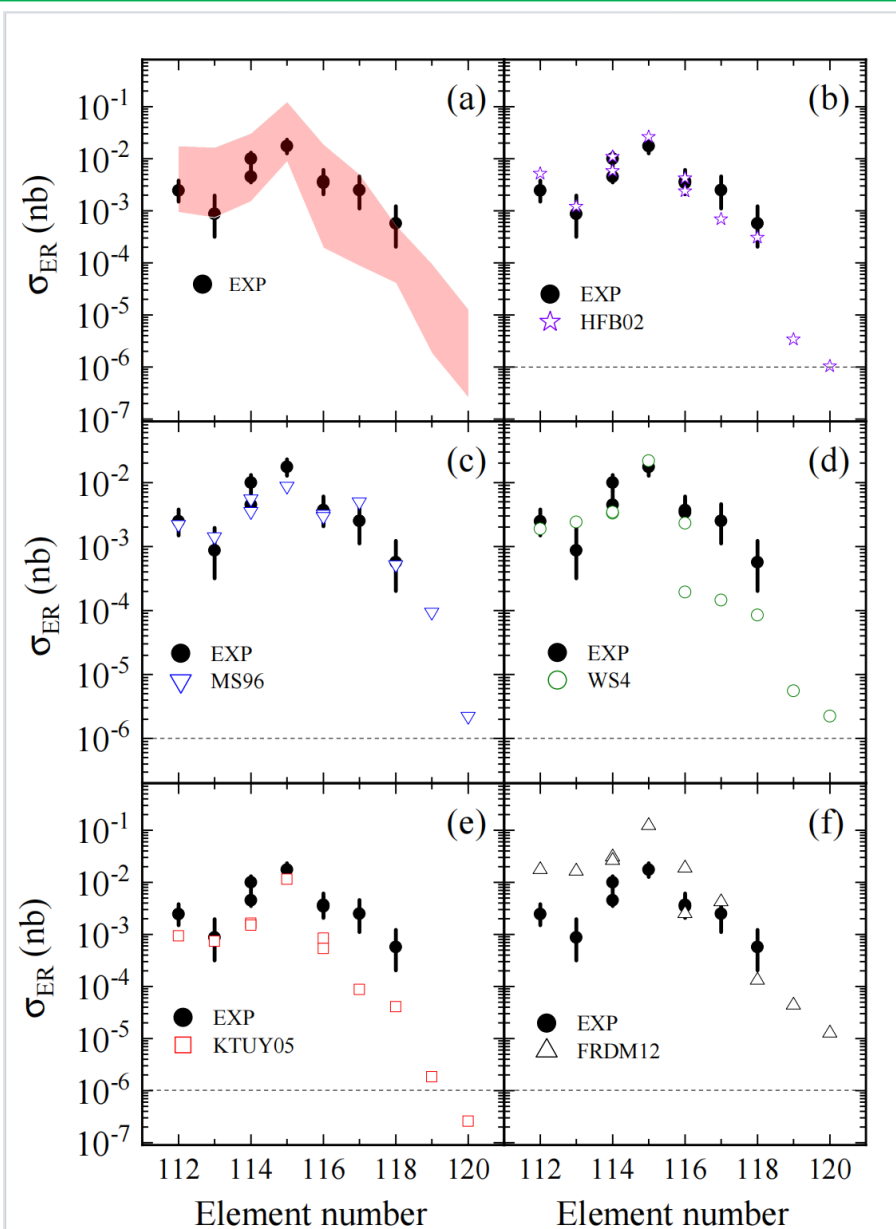
calculation and experimental data



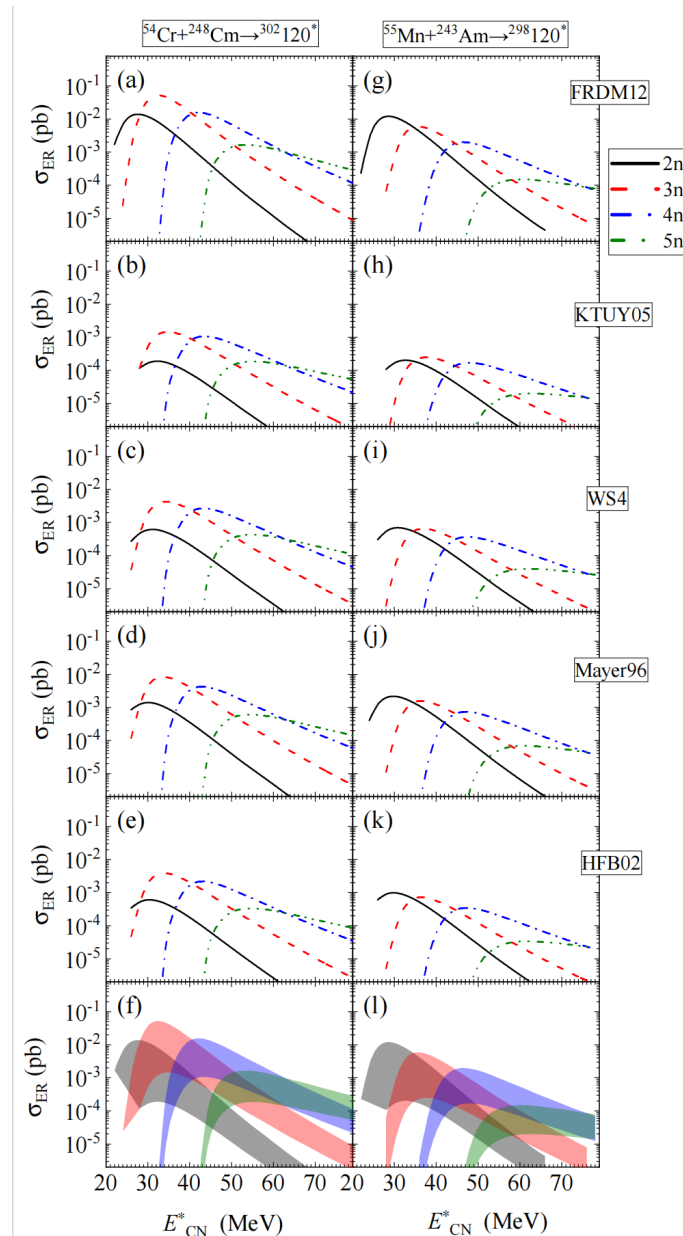
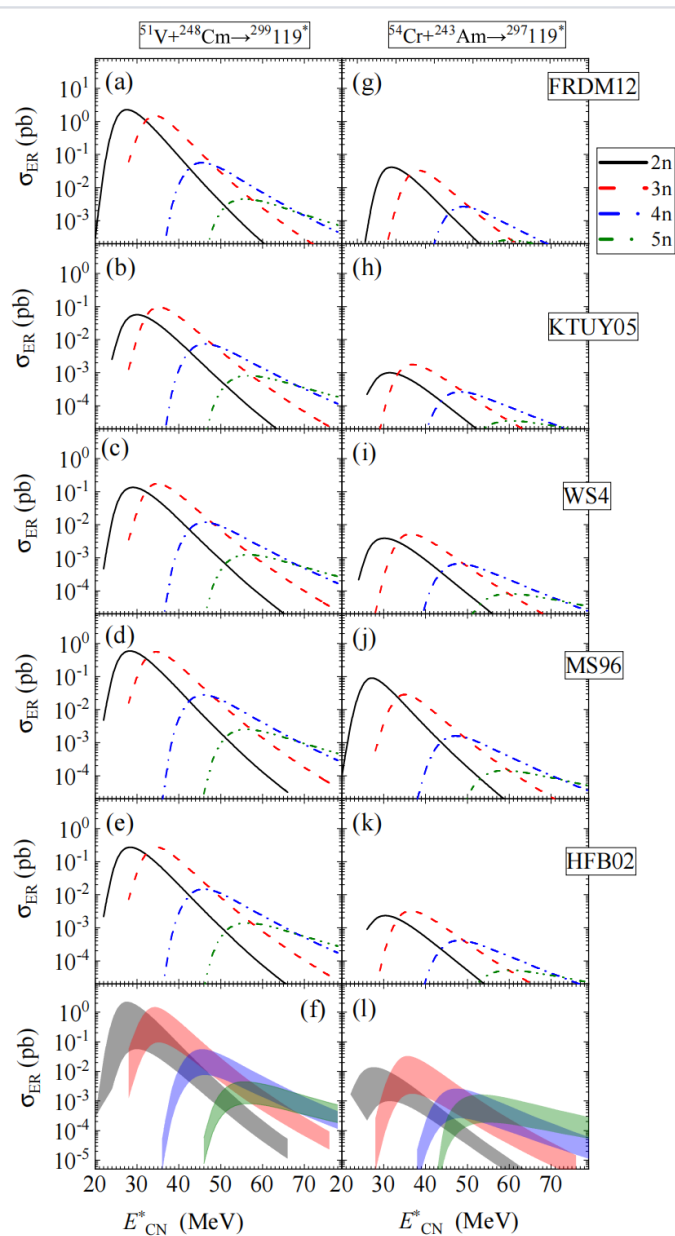
# Evaluate survival probability via different mass models



# Prediction cross section of SHN via different mass models, Exp. data

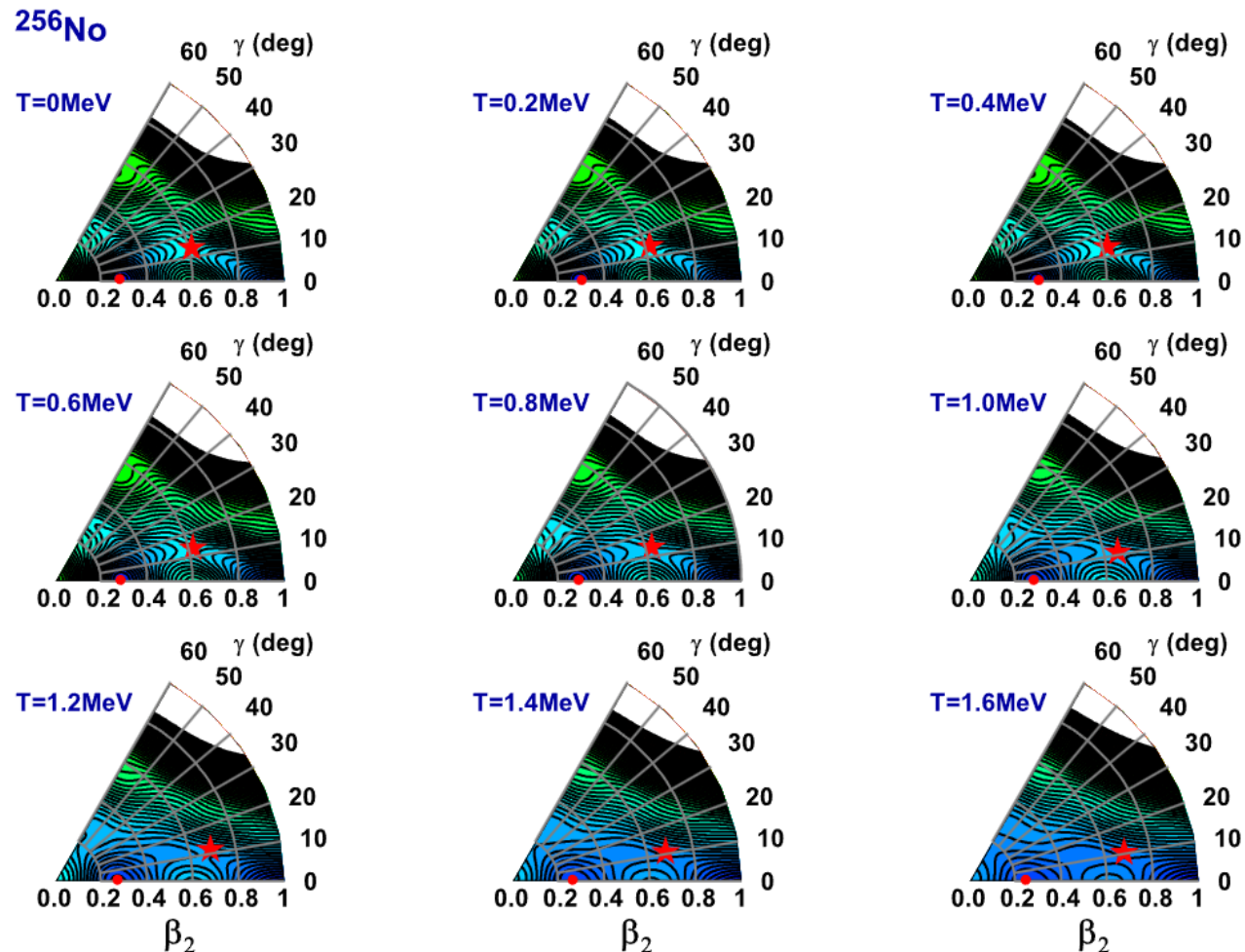


# Prediction cross section of SHE with Z=119-120 via different mass models

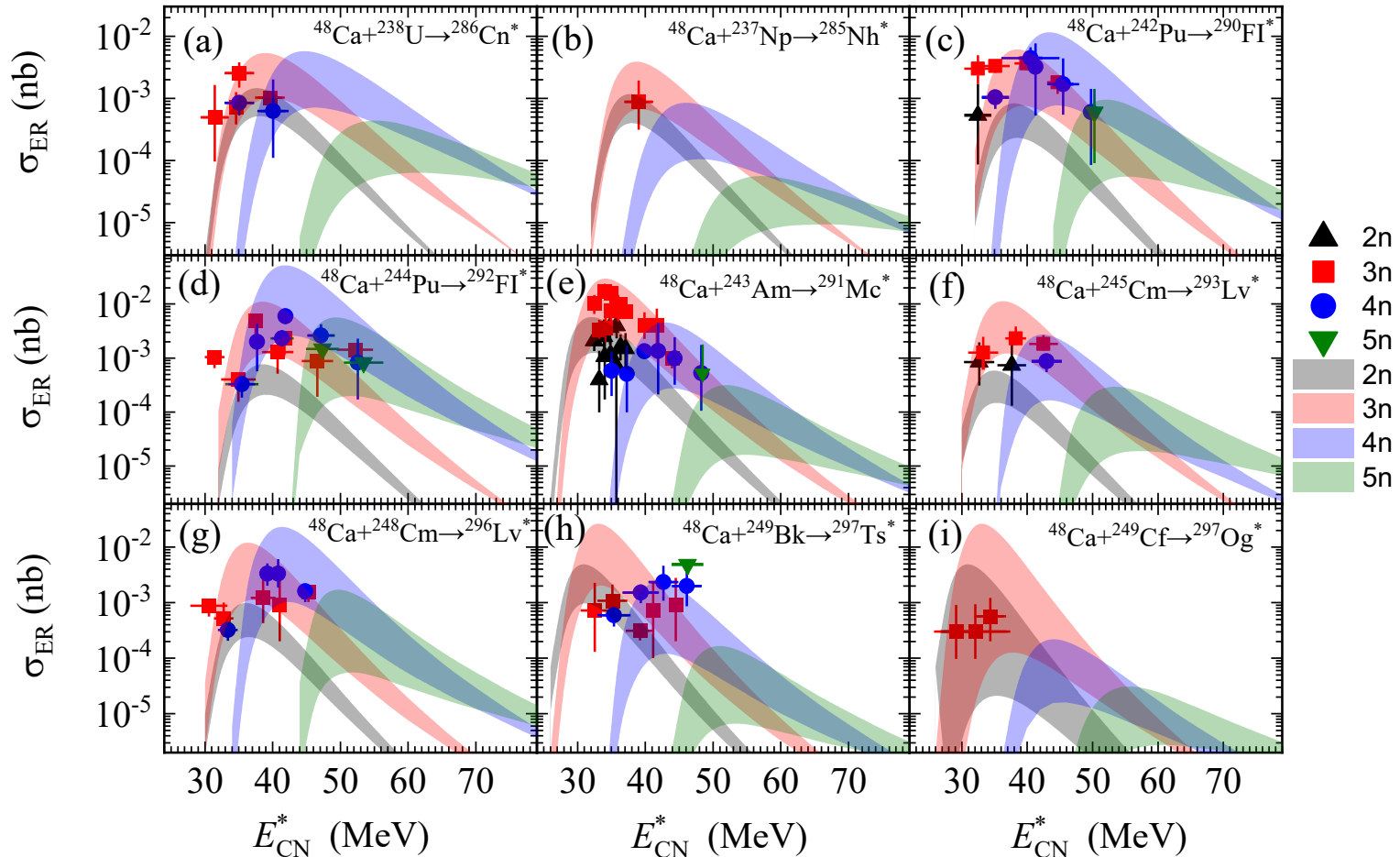




## 2. The prediction cross-section errors caused by shell damping factor



# Constraint $E_D$ from Exp. data



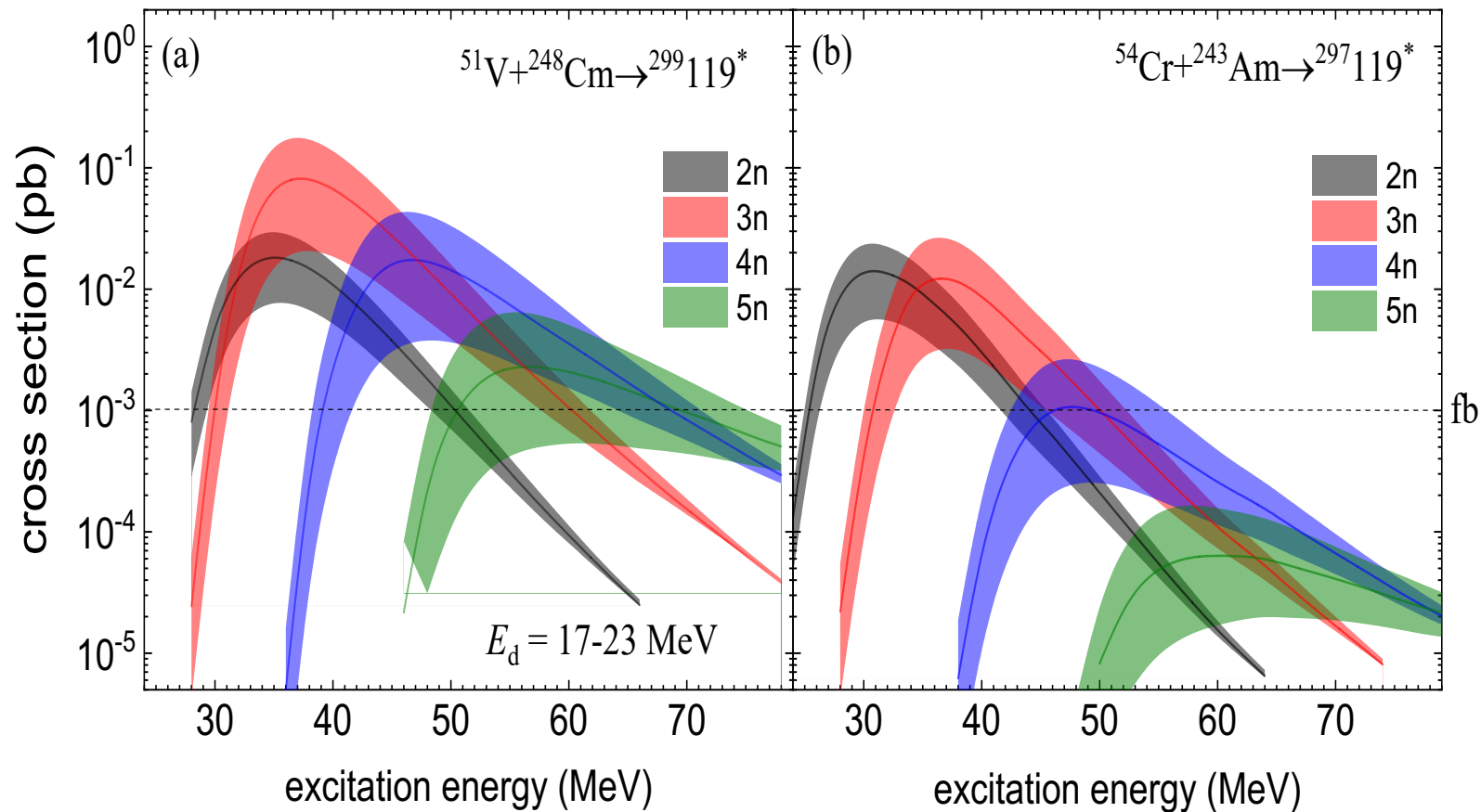
$$B_f(E^*, J) = B_f^{\text{Mac}} + B_f^{\text{Mic}}(E^* = 0, J) \exp(-E^*/E_D),$$

$E_D = 13-25$  MeV



$E_D = 17-23$  MeV

# Predict cross section of new SHE with Z=119



$E_D = 17-23$  MeV

# Summary and prospect



## ■ Summary:

- The calculated cross-sections using different nuclear mass tables can reasonably reproduce the experimental data of hot fusion reactions;
- The predicted synthesis cross-sections show strong dependence on nuclear masses, with uncertainties within one order of magnitude;
- $Z=119$ :  $^{54}\text{Cr}(^{243}\text{Am}, 3n)^{294}119 \sim 2\text{-}35 \text{ fb}$ ,  $^{51}\text{V}(^{248}\text{Cm}, 3n)^{296}119 \sim 0.1\text{-}1 \text{ pb}$ .
- $Z=120$ :  $^{55}\text{Mn}(^{243}\text{Am}, 3n)^{295}120 \sim 0.2\text{-}6 \text{ fb}$ ,  $^{54}\text{Cr}(^{248}\text{Cm}, 3n)^{299}120 \sim 1\text{-}55 \text{ pb}$ .

## ■ Prospect:

- In the DNS model, Systematic evaluation of model parameter effects on superheavy nucleus synthesis cross-section predictions;
- In the DNS model, develop a dynamical potential energy surface based on the multi-dimensional adiabatic approximation.

C. Geng, P. H. Chen\*, X. H. Zeng, Z. Q. Feng, *Phys. Rev. C* **109**, 054611 (2024)  
P. H. Chen\*, H. Wu, Z. X. Yang, X. H. Zeng, Z. Q. Feng, *Nucl. Sci. Tech.* **34**, 7 (2023)  
P. H. Chen\*, Chang. Geng, Z. X. Yang, X. H. Zeng, Z. Q. Feng, *Nucl. Sci. Tech.* **34**, 160(2023)  
P. H. Chen\*, F. Niu, X. H. Zeng, Z. Q. Feng, *Phys. Rev. C* **105**, 054601 (2022)  
P. H. Chen\*, C. Geng, X. H. Zeng, Z. Q. Feng, *Phys. Rev. C* **106**, 034610 (2022)

# Group members at YZU





# Acknowledge



Thank you for your attention !  
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