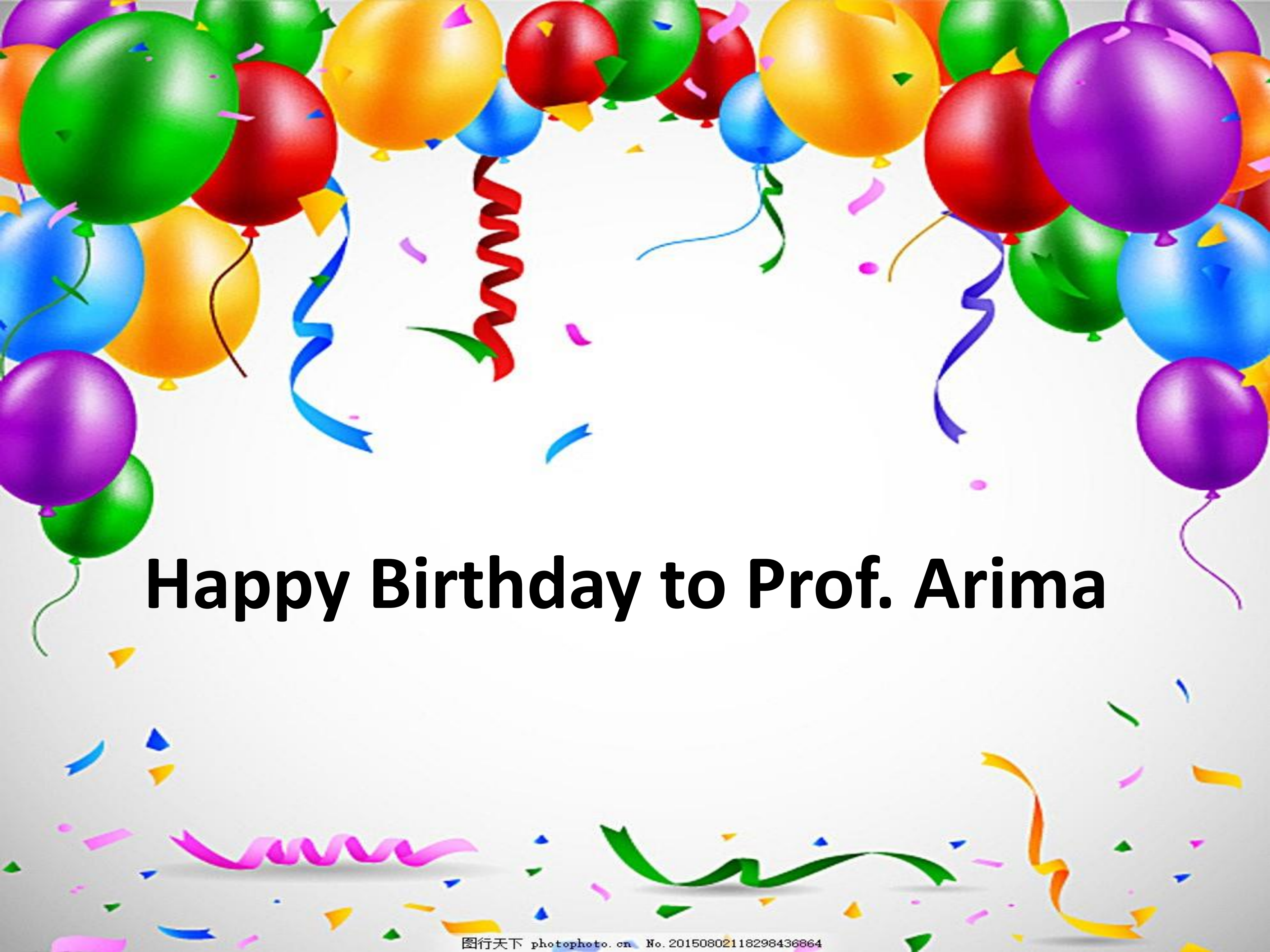


Happy Birthday to Prof. Arima

I met Prof. Arima in 1980 at the international Conference on nuclear physics at Berkeley for the first time. When he knew I was from China he was so kindly to talk to me and encourage me. He talked about the pairing at the conference but I knew not much about the pairing at that time. Later, I listened to several times of his lectures and I learned more about the pairing. Now I understand more deeply of its importance in nuclear structure and also nuclear reaction.

Studies of multi-nucleon transfer reaction with Improved QMD model

1) Introduction
2) Systematic studies of multi-nucleon transfer reactions with Improved Quantum Molecular Dynamics model
3) Conclusion and discussion

Zhuxia Li
China Institute of Atomic Energy

Collaborators: Kai Zhao, Ning Wang, Yinxun Zhang, Junlong Tian, Qingfeng Li, Xizhen Wu

2018 Nov. Shanghai,

Introduction

deep-inelastic reaction
strong-dumped reaction   different term same meaning
multinucleon transfer

Common understanding

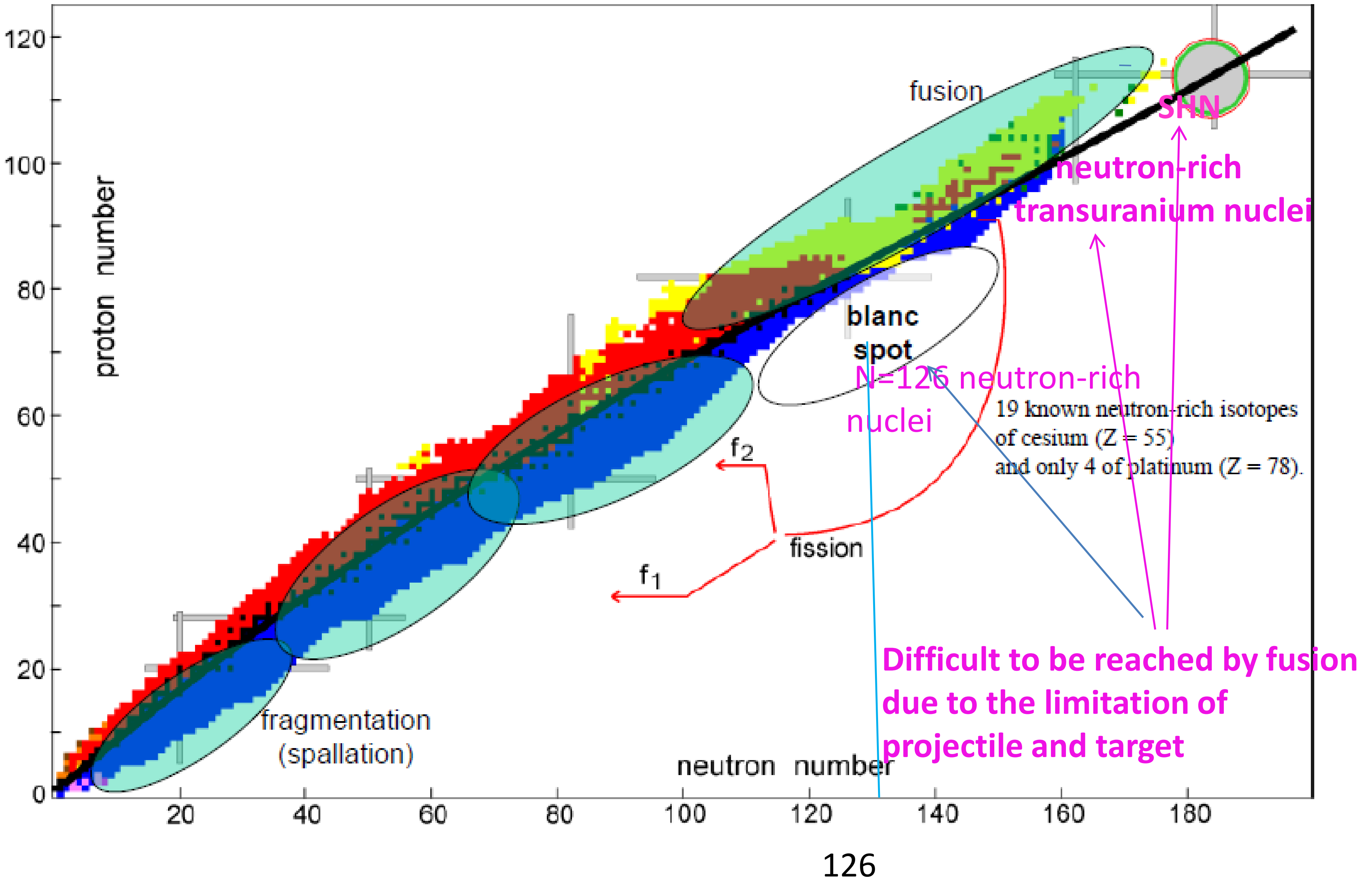
Multinucleon transfer reactions are of great importance

1) Important tool for studies of nuclear structure and reaction, nucleon correlation and nuclear fission

2) Important tool for producing new neutron-rich nuclei

3) Prospective approach for synthesizing SHN

“Blanc Spot” on the Nuclear Map



Systematic studies of multi-nucleon transfer reactions with ImQMD model

The quantum molecular dynamics model

A-body dynamics , microscopic approach

- many-body correlation and fluctuation are included
- Large number of degrees of freedom can be considered automatically

excitation, deformation of projectile and target, neck formation, nucleon transfer, different types of separation of composite system, nucleon emission

$^{86}Kr+^{64}Ni$	$^{154}Sm+^{160}Gd$	$^{238}U+^{238}U$
25MeV/u,	Ecm=440MeV	7MeV/u

The reaction mechanism evolves with the size of reaction systems

Intermediate size system
$^{86}Kr+^{64}Ni$ at 25MeV/n

Neutron-rich

understanding the competition between fusion, elastic-inelastic , deep-inelastic and multifragmantation processes

rare-earth region
$^{154}Sm+^{160}Gd$
at Ecm=440MeV

Show the efficiency of MNT on the production of neutron-rich nuclei Z=58-76,neutron-rich reaction system

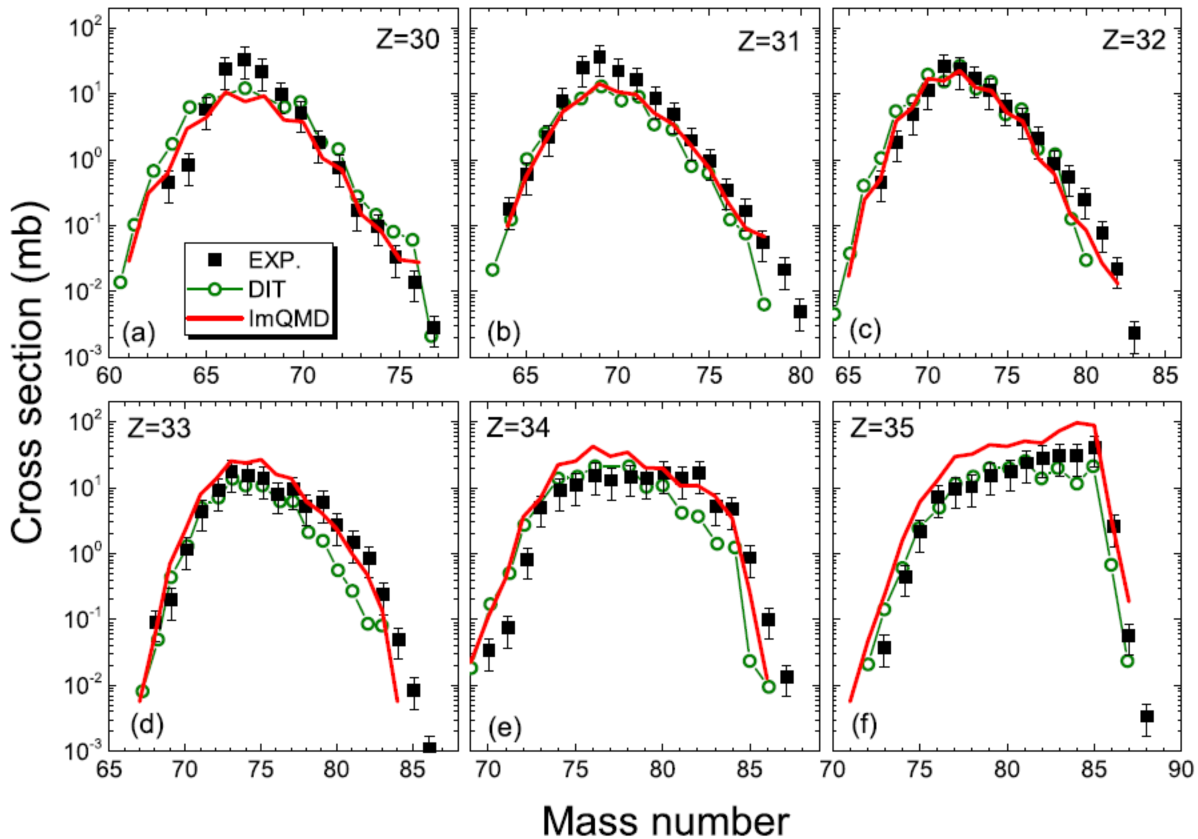
Actinide nuclei
$^{238}U+^{238}U$
at 7 MeV/n

Fusion is completely forbidden
due to strong Coulomb repulsion
Study production of neutron-rich transuranium and light U-like Isotopes by MNT

Studies of the reaction $^{86}Kr+^{64}Ni$ at 25MeV/n

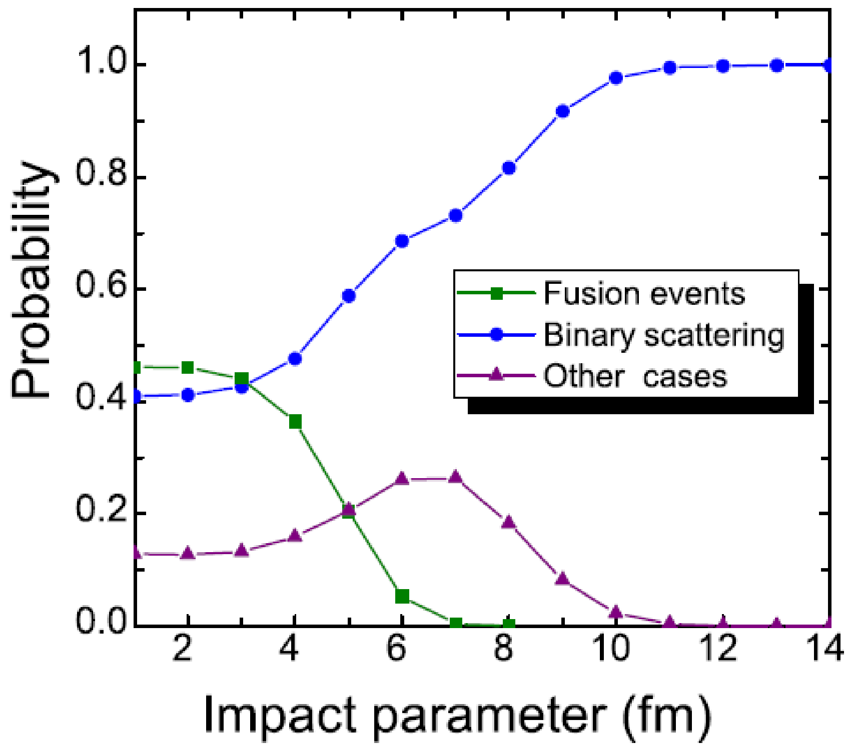
ImQMD +GEMINI calculation

Cross sections of proton removal and neutron pick up isotopes

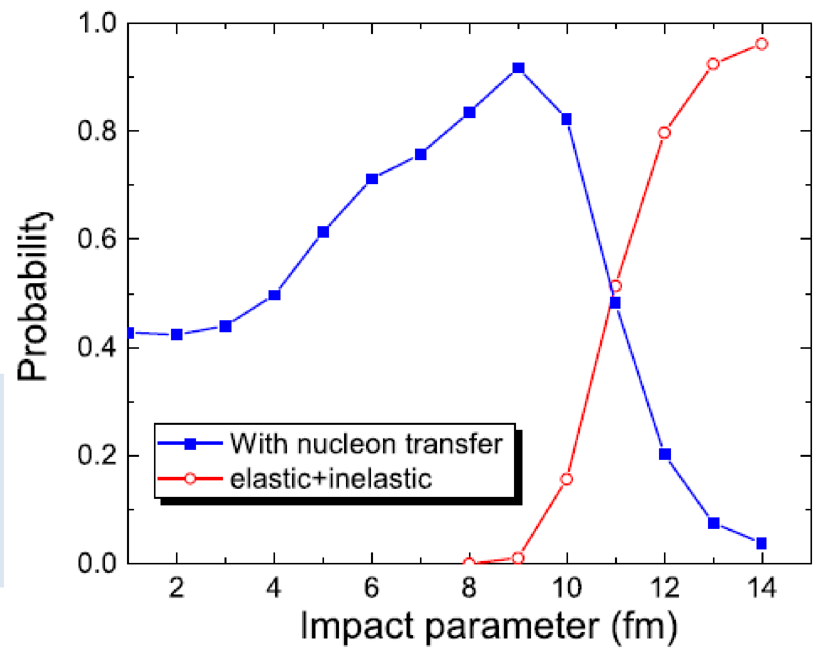


N. Wang , Phys.Rev.C 95,014607(2017)

Exp. Data and DIT/Germini from G.A. Souliotis et.al Phys.Lett. B543,163



Reaction mechanism evolves with impact parameters
fusion: small impact parameter
Binary process: elastic, inelastic, MNT
Others: ternary breakup
and multifragmentation,etc



Binary scattering:
Elastic+inelastic (peripheral)
Deep inelastic(MNT)(peak at 8-9fm)

$^{86}Kr+^{64}Ni$ 25MeV/n

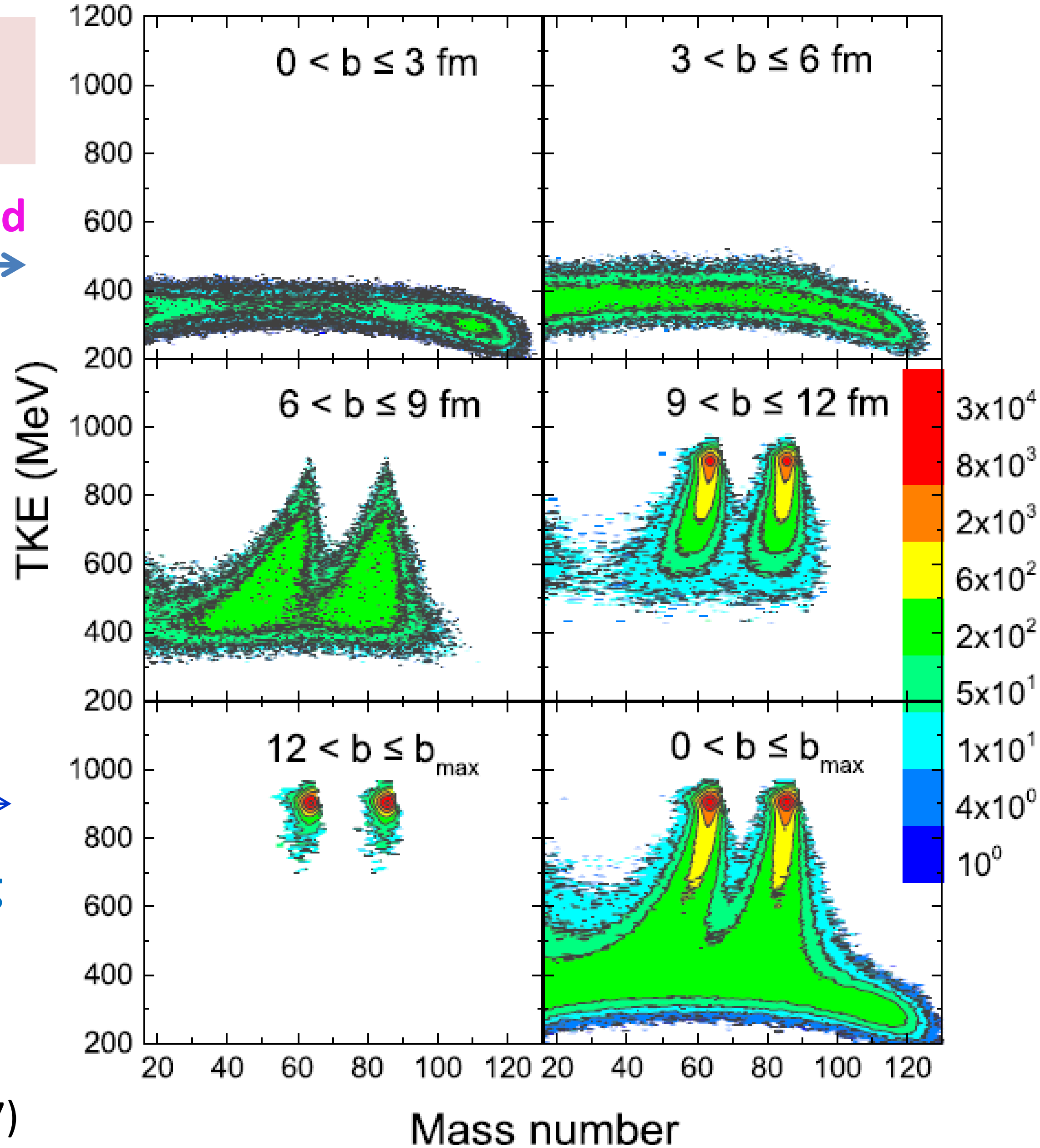
Reaction mechanism evolves with impact parameters

Central collision: a highly excited composite system, small TKE →
- fusion, MNT,
- ternary breakup
- multifragmentation

MNT dominate →

Peripheral collision: →
Large TKE
Elastic and inelastic scattering

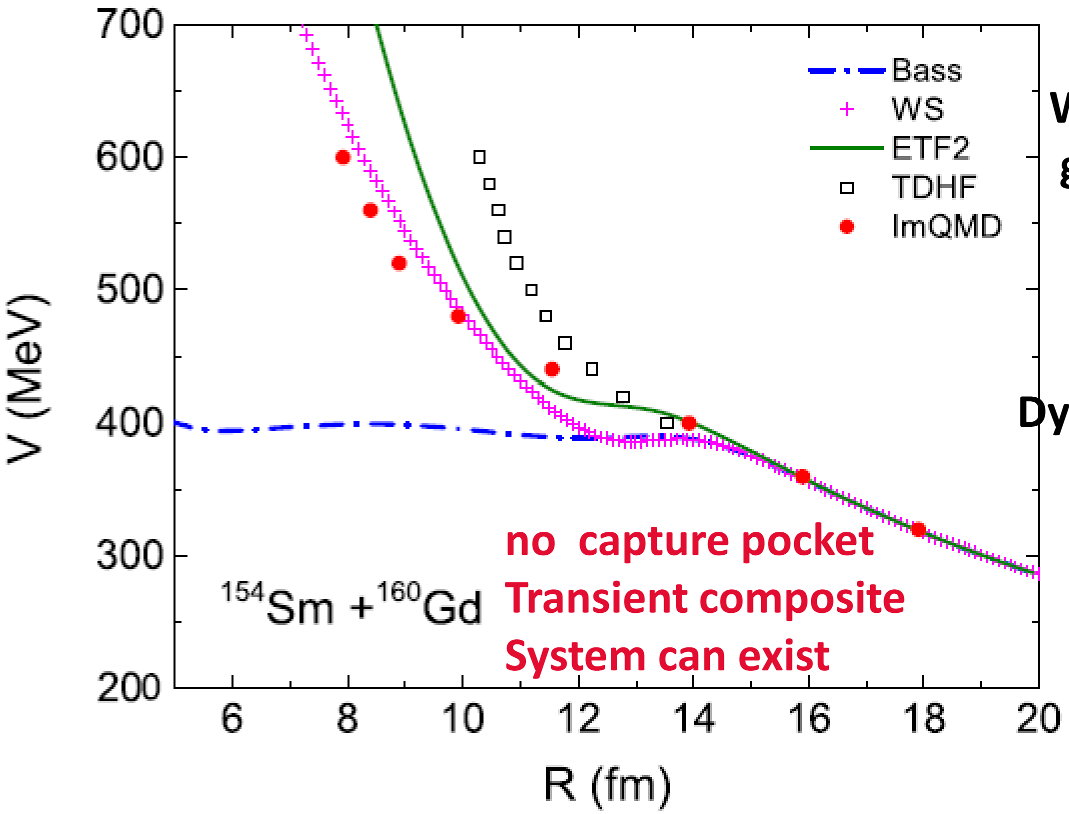
Mass-TKE correlation



N. Wang Phys.Rev.C 95,014607(2017)

MNT in $^{154}Sm+^{160}Gd$ at Ecm=440MeV, production of unknown neutron-rich isotopes

no fusion, MNT dominant at small impact parameters



Nucleus-nucleus potential

WS: woods-Saxon pot. parametrization given by With Broglia and Whither

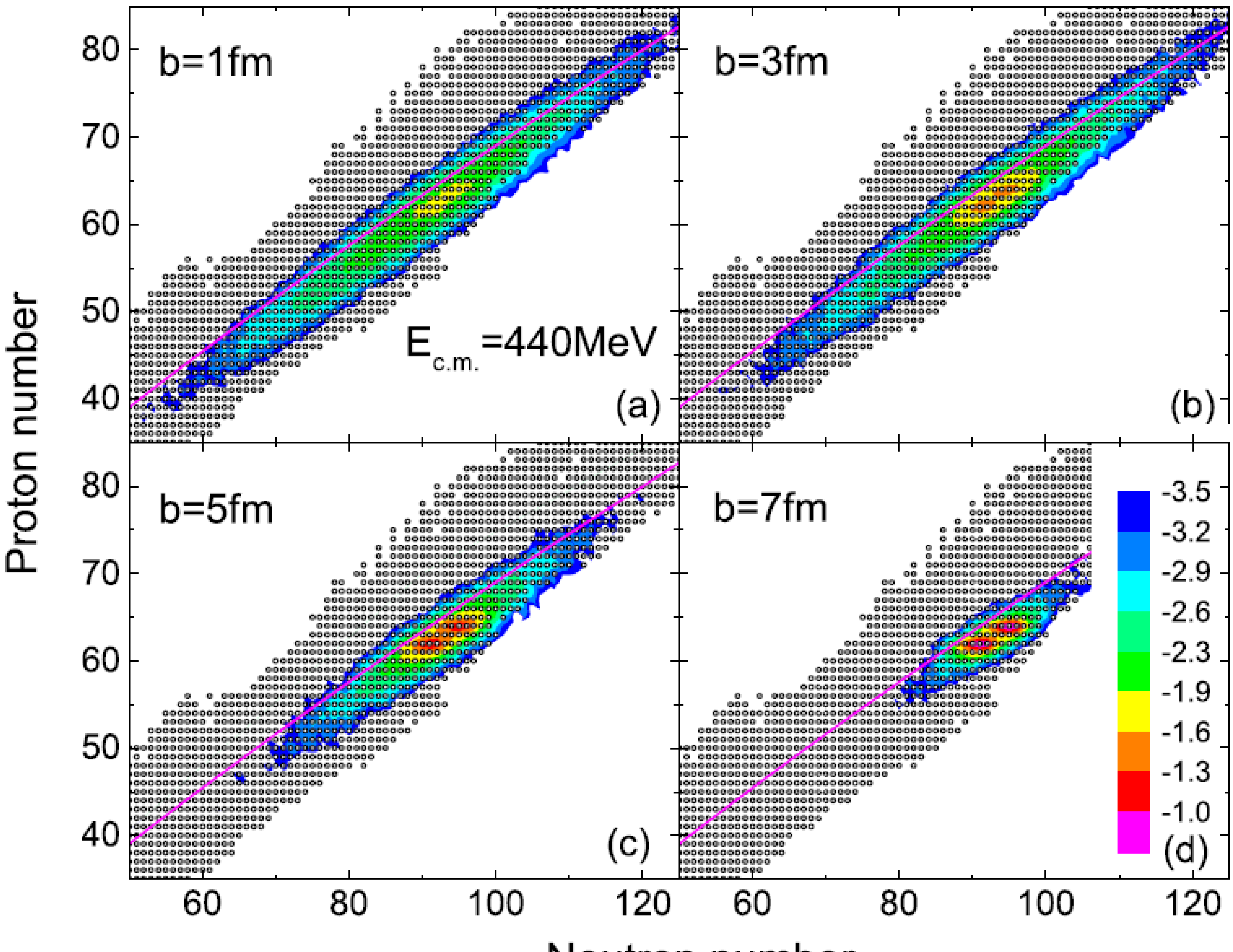
ETF2(given by Ning Wang,et.al.)

Dynamical pot. given by TDHF and ImQMD

$$V(R) \simeq E_{\mathrm{c.m.}} - T(R).$$

PLB 760,216-241 by Ning Wang,et.al.

Primary fragments(ImQMD t=2000fm/c)



cross sections of neutron-rich new isotopes (Z=58-76)

(ImQMD+GEMINI)

154Sm+160Gd at Ecm=440MeV

High efficiency!

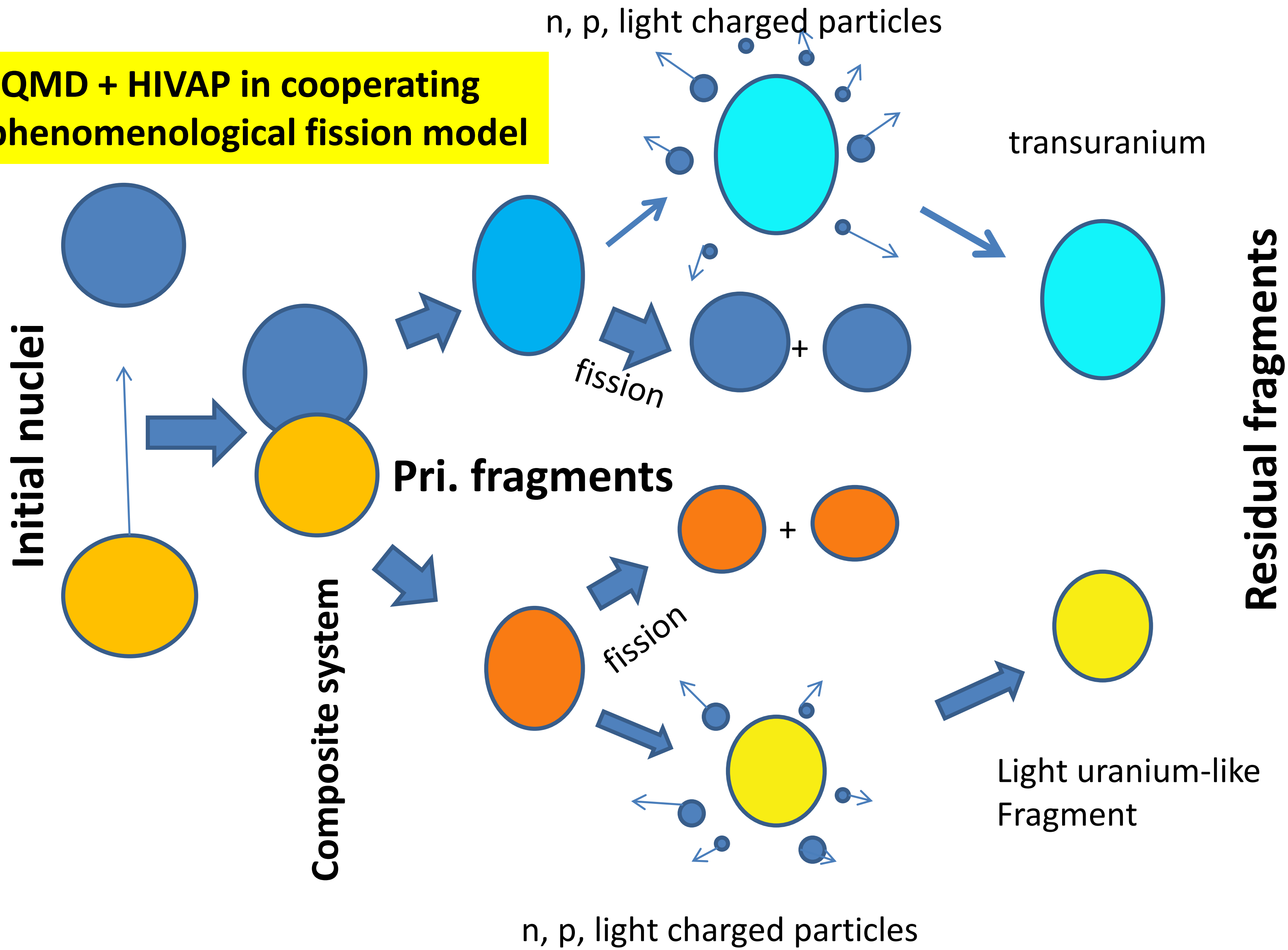
Table 1

Production cross sections of some neutron-rich nuclei with unmeasured masses. The predicted mass excesses of these nuclei from the WS4 model [67] are also listed.

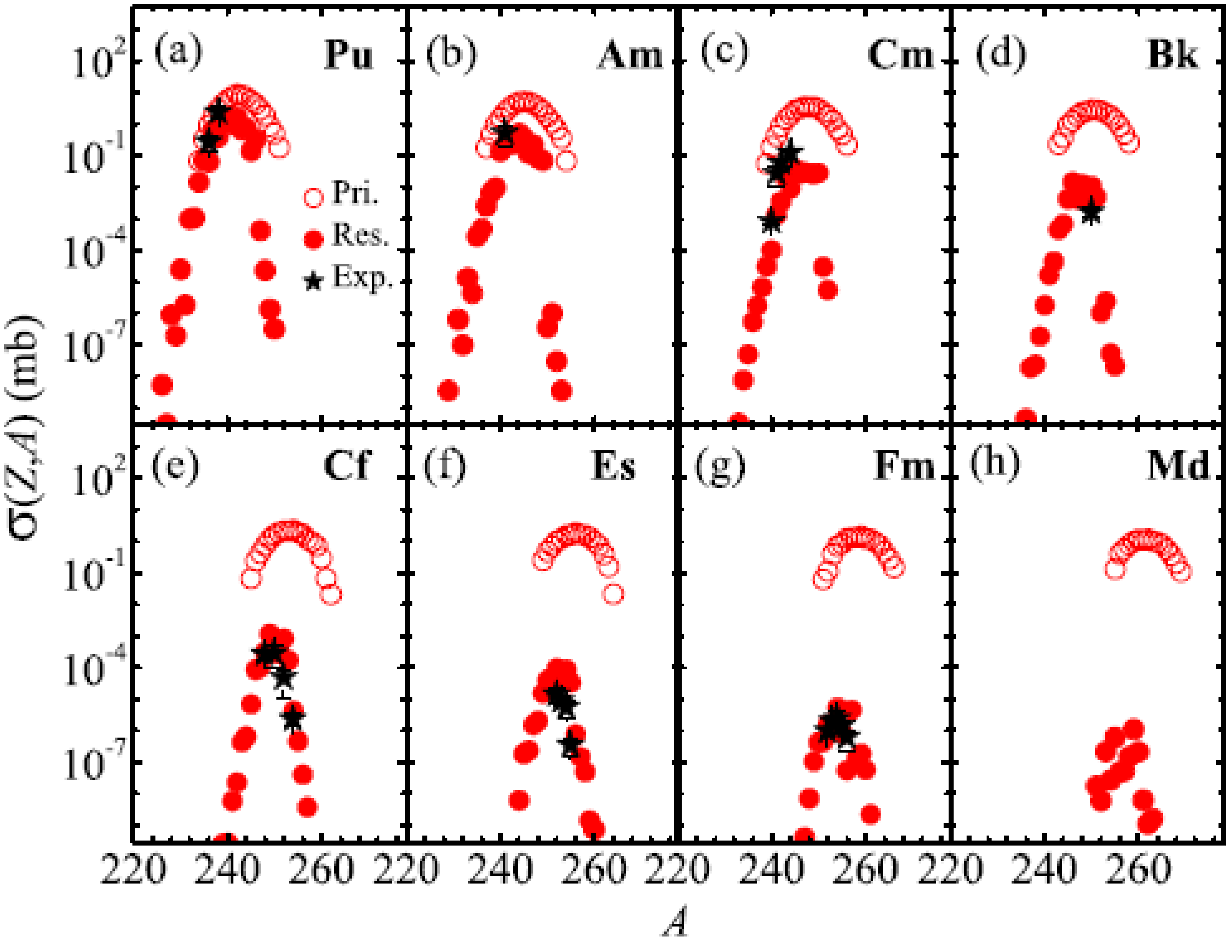
Z	N	σ (μb)	Mass excess (MeV)	Z	N	σ (μb)	Mass excess (MeV)
58	94 -4p,2n	65	−59.33	68	105	975	−53.77
62	100 0p,8n	31	−54.52	68	106	549	−52.31
63	101 1p,9n	256	−52.74	68	107	96	−48.81
63	102 1p,10n	54	−50.36	68	108	186	−46.89
64	100	1543	−59.72	68	109	100	−42.98
64	101	339	−56.29	68	110	44	−40.63
64	102	194	−54.48	69	108	316	−47.63
64	103	104	−50.62	69	109	92	−44.28
65	100	3288	−60.40	69	110	35	−42.02
65	102	806	−55.82	70	109	463	−46.71
65	103	140	−52.53	70	110	186	−44.99
65	104	161	−50.30	70	111	195	−41.38
65	105	46	−46.41	70	112	46	−39.36
66	104	469	−53.98	71	111	153	−41.77
66	105	130	−50.18	71	113	59	−36.45
66	106	117	−47.99	73	105 9p,9n	1639	−50.32
67	105	656	−51.40	73	116 9p,20n	138	−32.46
67	106	203	−49.33	75	119 11p,23n	54	−27.29
67	107	145	−45.76	76	121 12p,25n	180	−25.08

$^{238}U+^{238}U$ 7MeV/u

ImQMD + HIVAP in cooperating a phenomenological fission model



Production of transuranium isotopes



Z=94-101

Features :
Magnitude of cross sections of primary fragments does not change much ,residual fragments decreases exponentially with Z

The most probable residual fragments shift to more less neutron isotopes compared with that of primary fragments as Z increases

K.Zhao, Z.Li, N.Wang, Y.Zhang, Q.Li, Y.Wang, X.Wu, PRC **92, 024613 (2015)**

Exp.data : Phys. Rev. C 88, 054615 (2013)and references there in

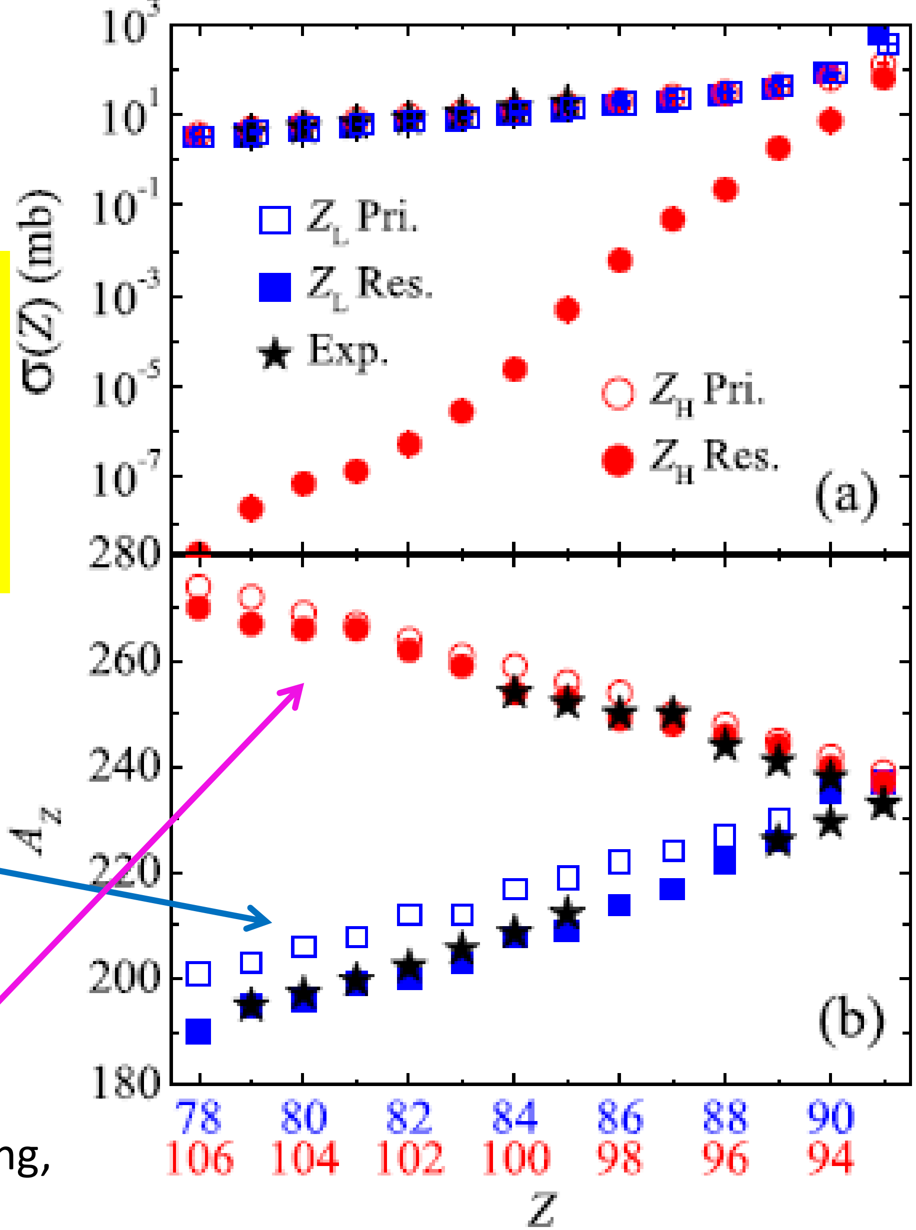
Comparison with experimental data

$\sigma(Z)$ Production cross section of primary and residual fragments with charge Z

light uranium-like fragments
$\sigma(Z)$ primary and residual similar
transuranium fragments
residual fragments decreases exponantialy

A_Z The mass number of the most probable primary and residual fragments

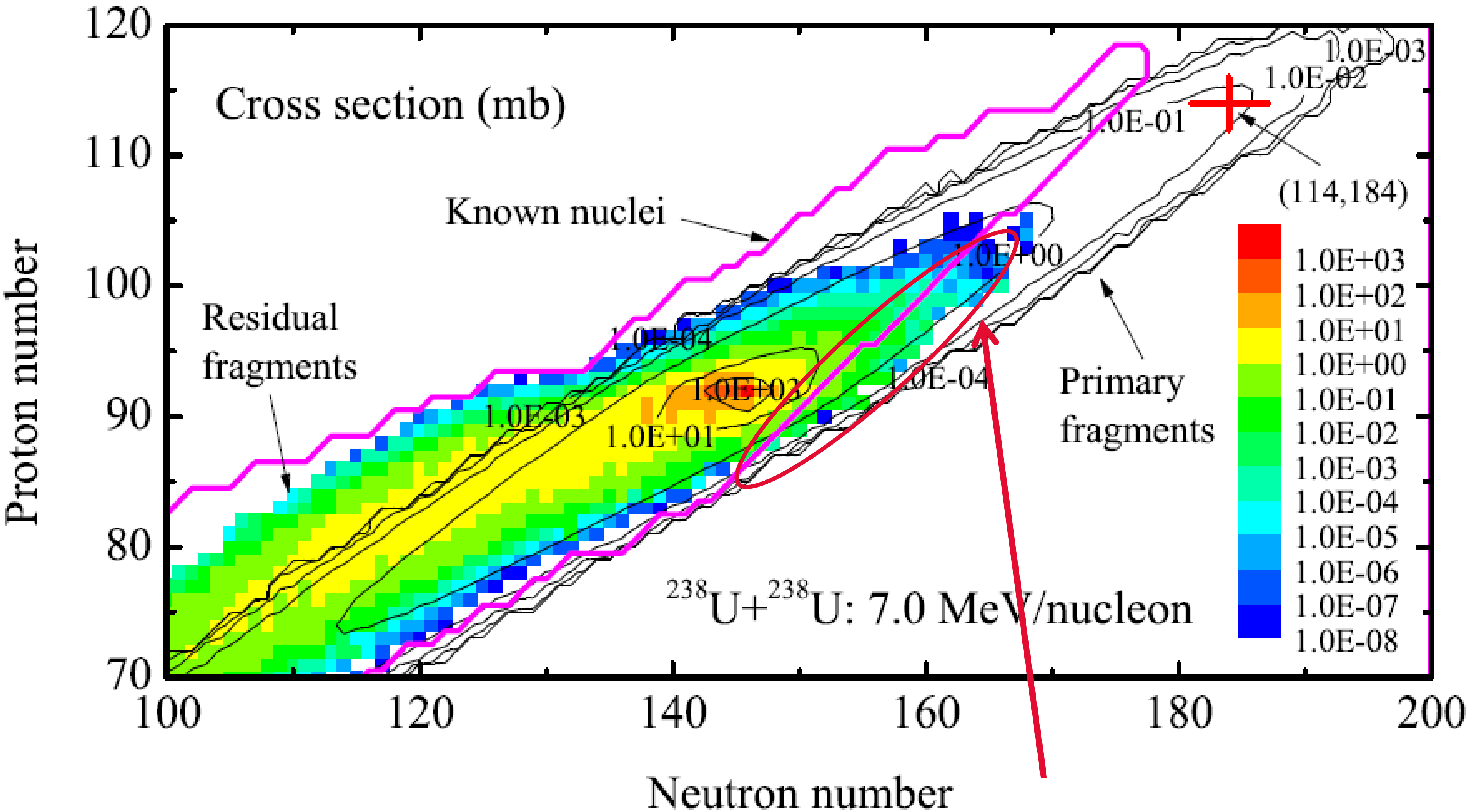
Light uranium fragments
Az pri. fragments is larger than residual fragments
Transuranium fragments Az pri. and resi. Fragments are close



K. Zhao, Z. Li, N. Wang, Y. Zhang, Q. Li, Y. Wang, X. Wu,PRC **92, 024613 (2015)**

Exp.data : Phys. Rev. C 88, 054615 (2013)

Produced primary and residual fragments in $^{238}U + ^{238}U$ compared with known nuclei



K. Zhao, Z.Li, etc PRC94,024601

New neutron-rich transuranium nuclei
Better trand towards SHN

Key factors influencing the formation of residual fragments useful for finding best reaction system for synthesizing heavy neutron-rich transuranium isotopes

Peak isotopes of res.frag. ^{214}Rn， ^{249}Cf, and neutron -rich isotopes $^{254-256}$Cf

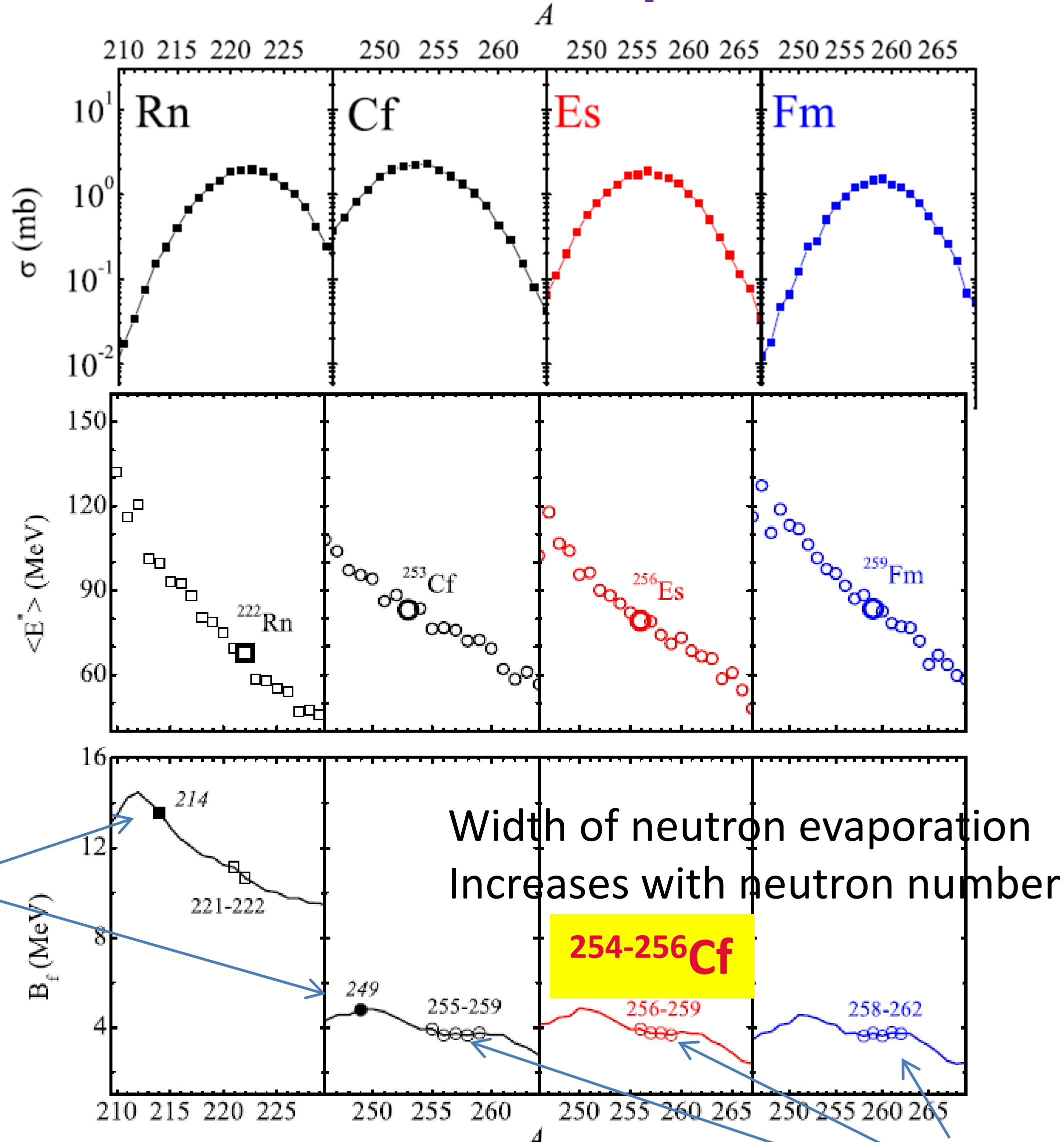
Cross sections of pri.frag.

+

Excitation of pri.frag.

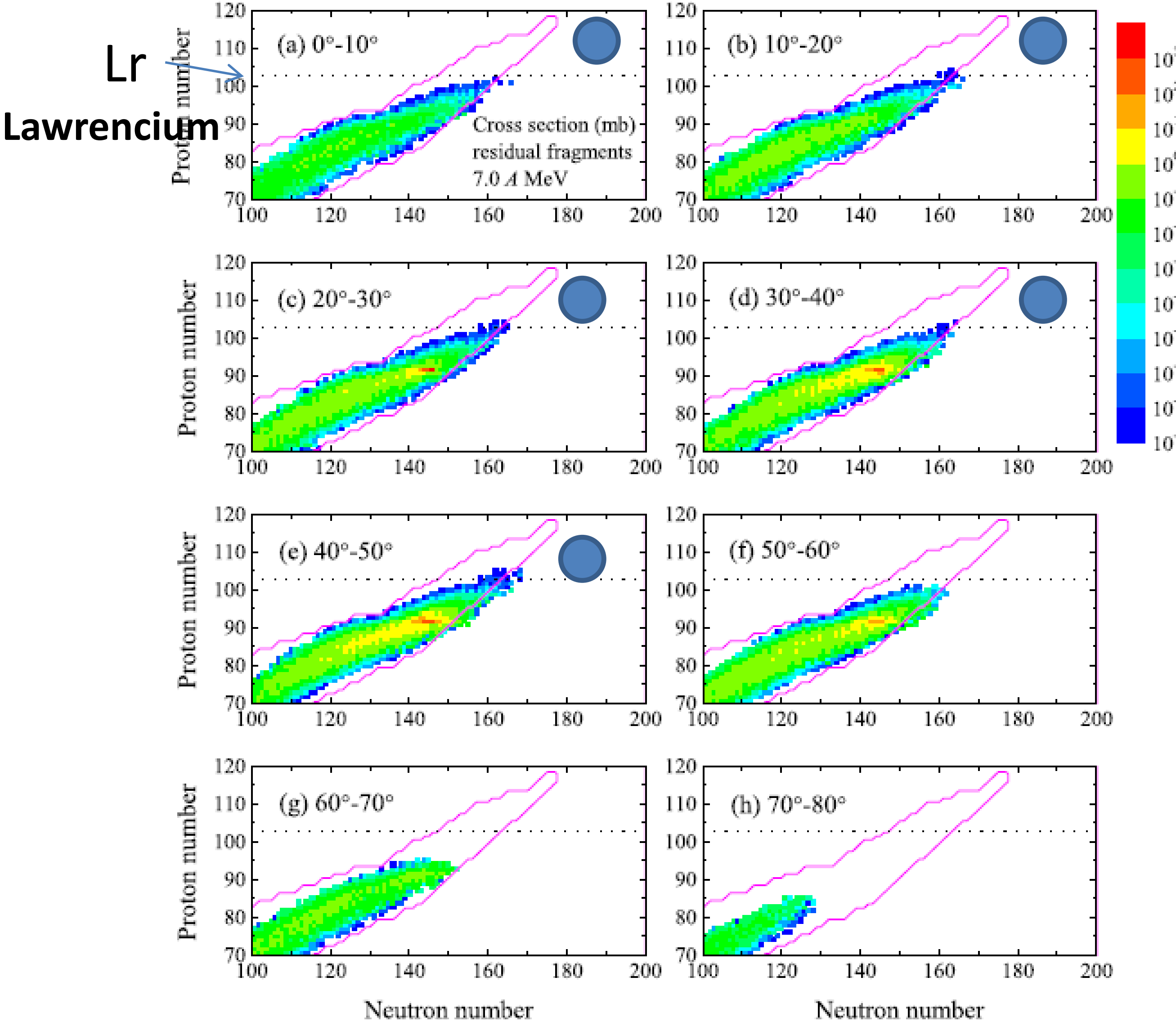
+

Isotope distribution of fission barrier



Competition between fission and evaporation neutrons

Outgoing angle distribution of residual fragments



outgoing angles (lab) of heavy transuranium residual fragments

Useful for experimental measurement

Summary and discussion

MNT reactions in three reaction systems from intermediate size nuclei to actinide nuclei are studied

- It shows the reaction mechanism evolves with reaction system size and reaction impact parameters
- The MNT reactions of neutron-rich nuclei are very efficient for producing very neutron-rich nuclei
- The key factors that influence the formation of neutron-rich transuranium nuclei are studied which will be useful for finding the best reaction systems for synthesizing extreme neutron-rich transuranium nuclei and possibly the SHN

Thanks for attention

Congratulations to Prof. Arima 88’th birthday

Introduction I: What are rare isotopes?