清華大學物理系

Department of Physics, Tsinghua University

NUSYM 2023

September 18-22, 2023

Nuclear equation-of-state studies with the compact spectrometer for heavy-ion experiment (CSHINE)

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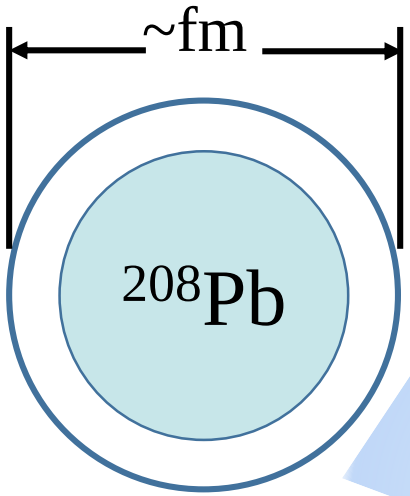
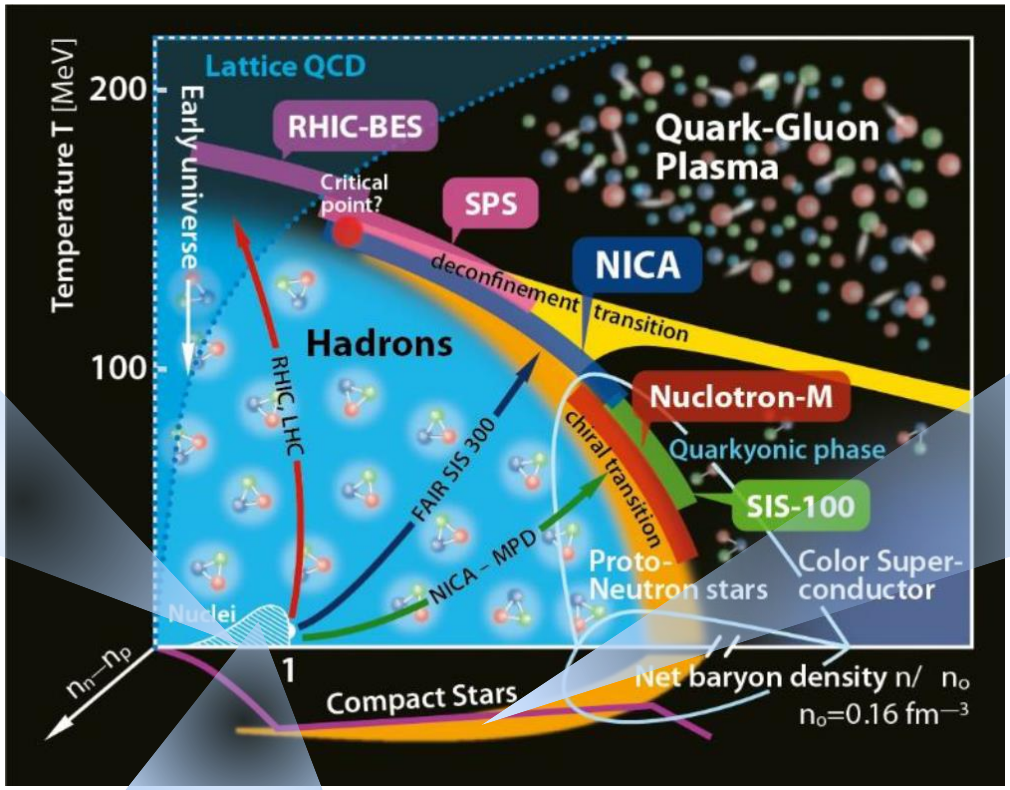
Content

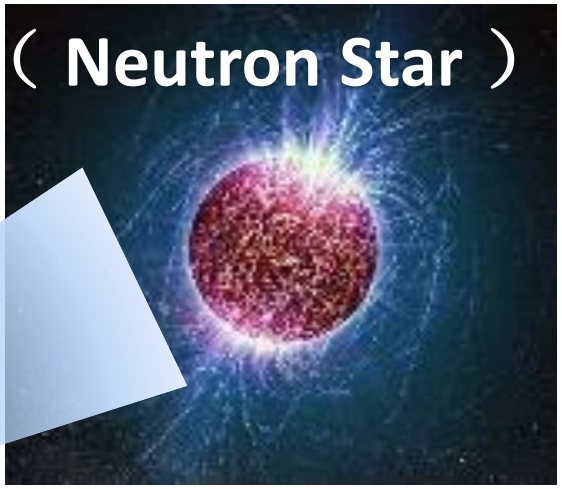
- Research background
- CSHINE detection system
- Result 1： Particle emission order and timescale
- Result 2： ”Ping-pang” emission mode
- Summary



Neutron skin
GMR

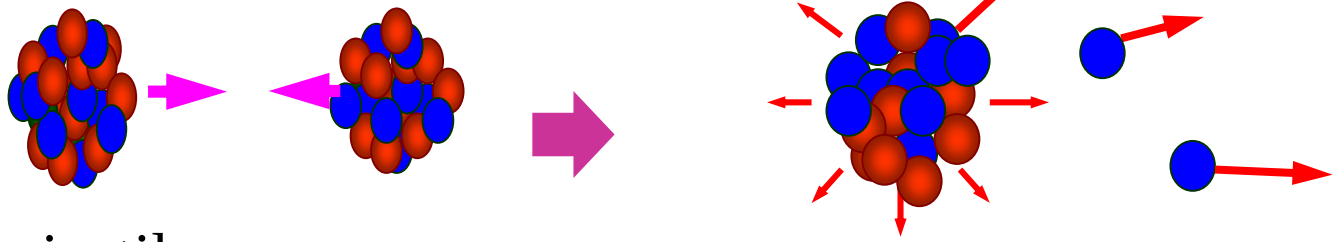


~km



URCA process
R-M Relation

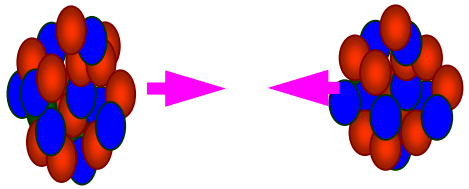
Heavy Ion Collision



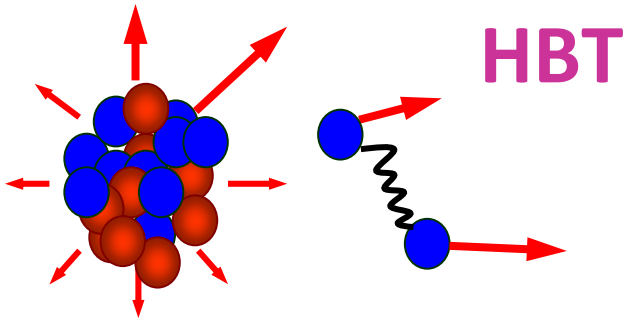
projectile target

Two questions about how symmetry energy influence the particle emission property?

Heavy ion reactions



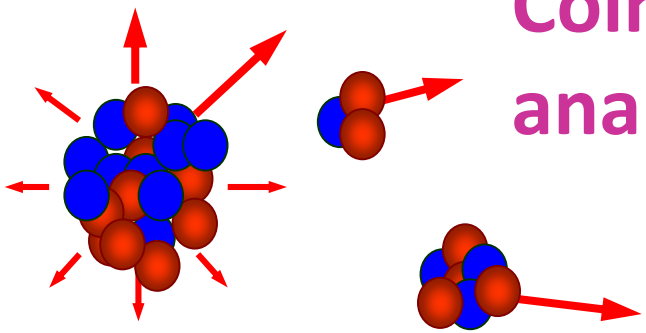
projectile target



HBT method

proton deuteron triton

1, Isospin dependent particle emission order and time scale?



Coincidence analyze

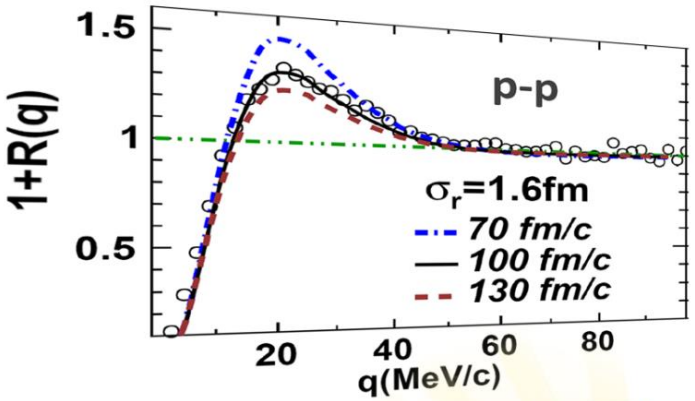
2, Isospin correlation of two coincident emission particles?

Proton , p

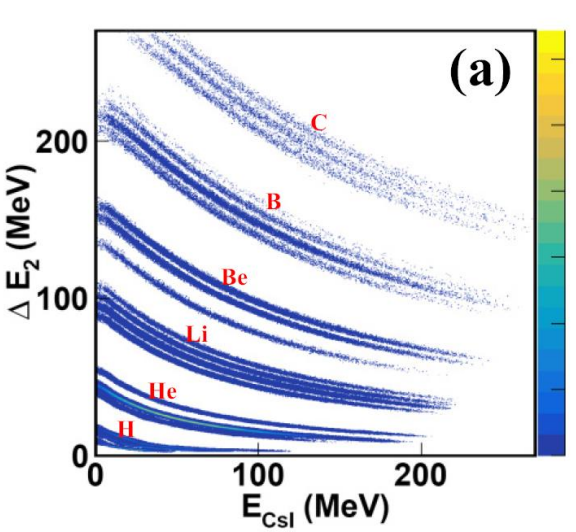
Neutron, n

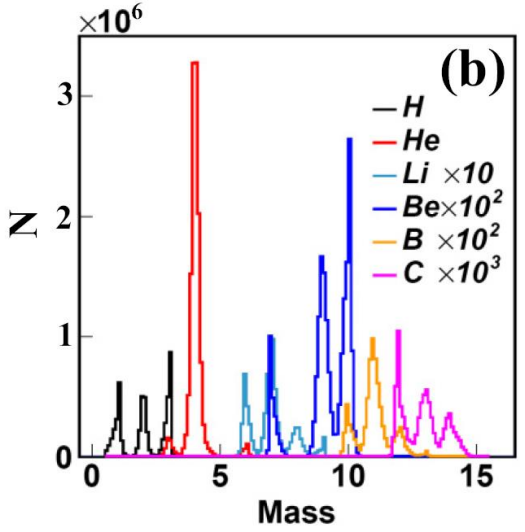
Compact Spectrometer for Heavy IoN Experiments (CSHINE)

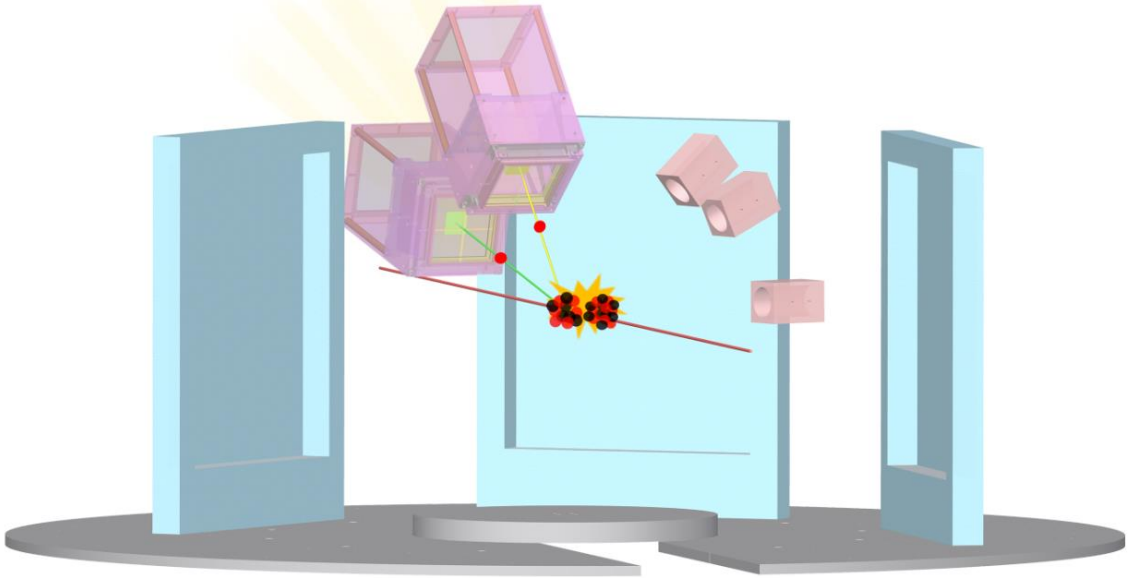
High angular and isotopic resolution!



CSHINE
Compact Spectrometer for Heavy IoN Experiments



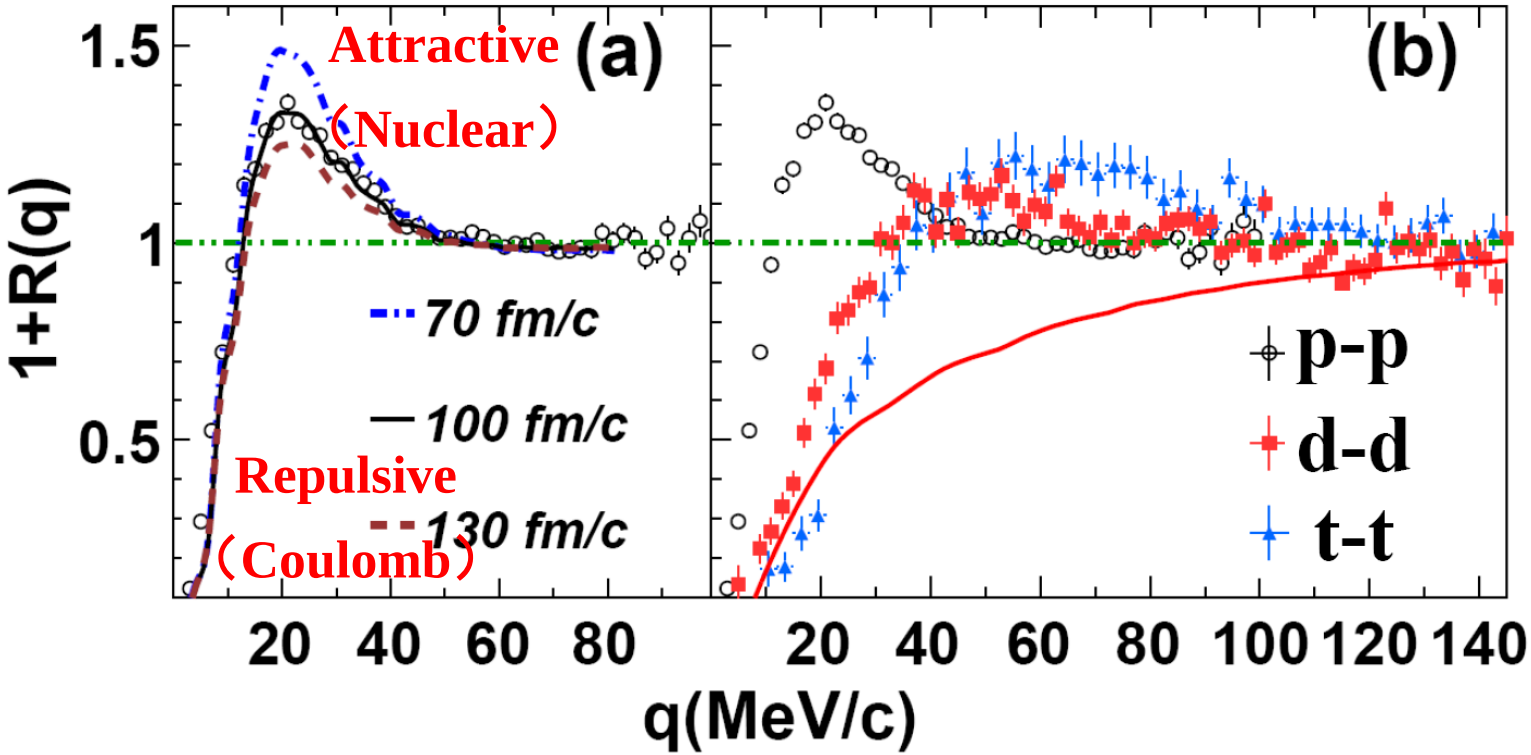


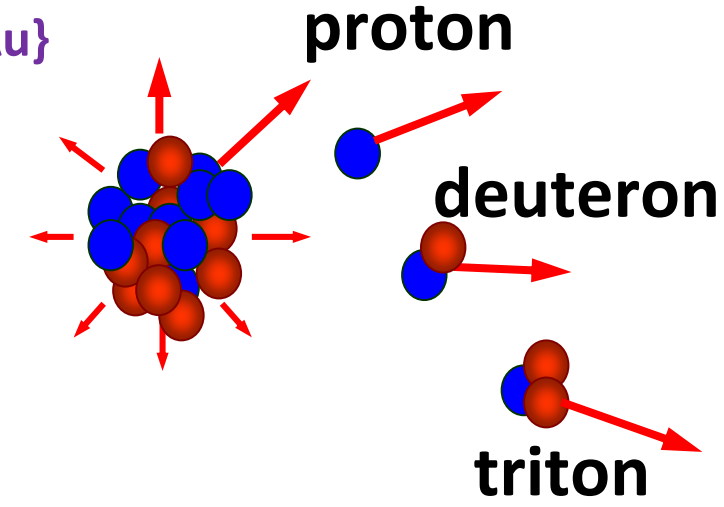


YJW, FHG, QHW et al., Nucl. Sci. Tech. 32, 4 (2021) (cover paper)
FHG, XYD, **YJW** et al., Nucl. Inst. Meth. A, 1011, 165592 (2021)
FHG, **YJW**, XYD et al., Nucl. Inst. Meth. A, 1029, 166461 (2022)
XYD, FHG, **YJW** et al., Nucl. Sci. Tech. 33, 40 (2022)
DG, YHQ, SX, ZQ, **YJW** et al., Nucl. Sci. Tech. 33, 162 (2023)
YHQ, DG, SX, **YJW** et al., NIMA, 1053, 168330 (2023)

Isospin dependent particle emission timescale and order, via HBT method

p-p, d-d, t-t Correlation Functions {30MeV/u Ar + Au}



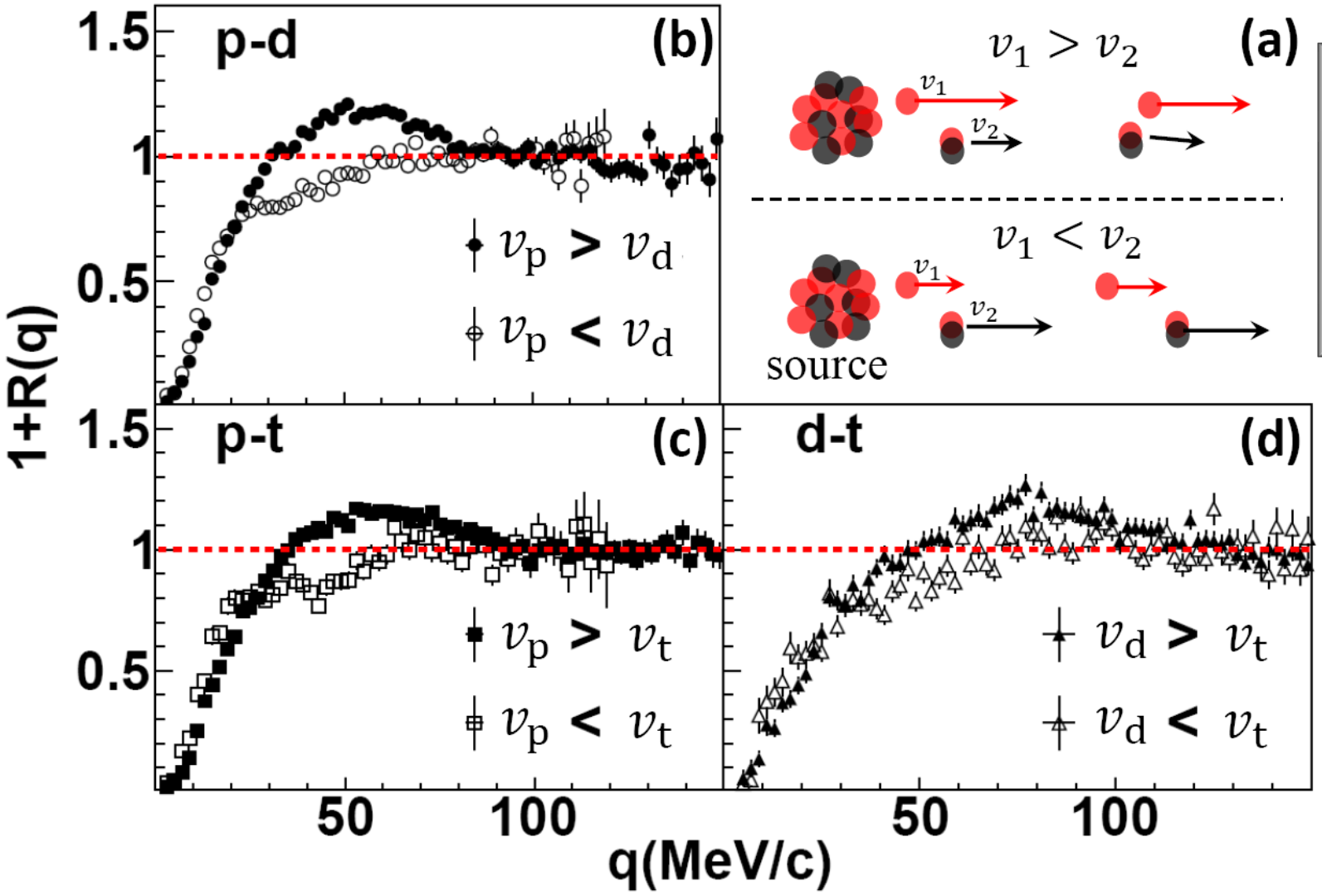


Compared with CRAB calculation, the emission timescale of proton is

$$\tau_p \approx 100\mathrm{fm}/c$$

$$1 + R(q) = C_N \frac{\Sigma \mathrm{Y}_{\mathrm{con}}(\vec{p}_1, \vec{p}_2)}{\Sigma \mathrm{Y}_{\mathrm{mix}}(\vec{p}_1, \vec{p}_2)} \qquad q = \mu\left(\frac{\vec{p}_1}{m_1} - \frac{\vec{p}_2}{m_2}\right)$$

p-d, p-t, d-t CFs（Velocity discrimination） {30MeV/u Ar + Au}



$$\tau_p > \tau_d > \tau_t$$

Neutron rich particles are emitted relatively earlier ！

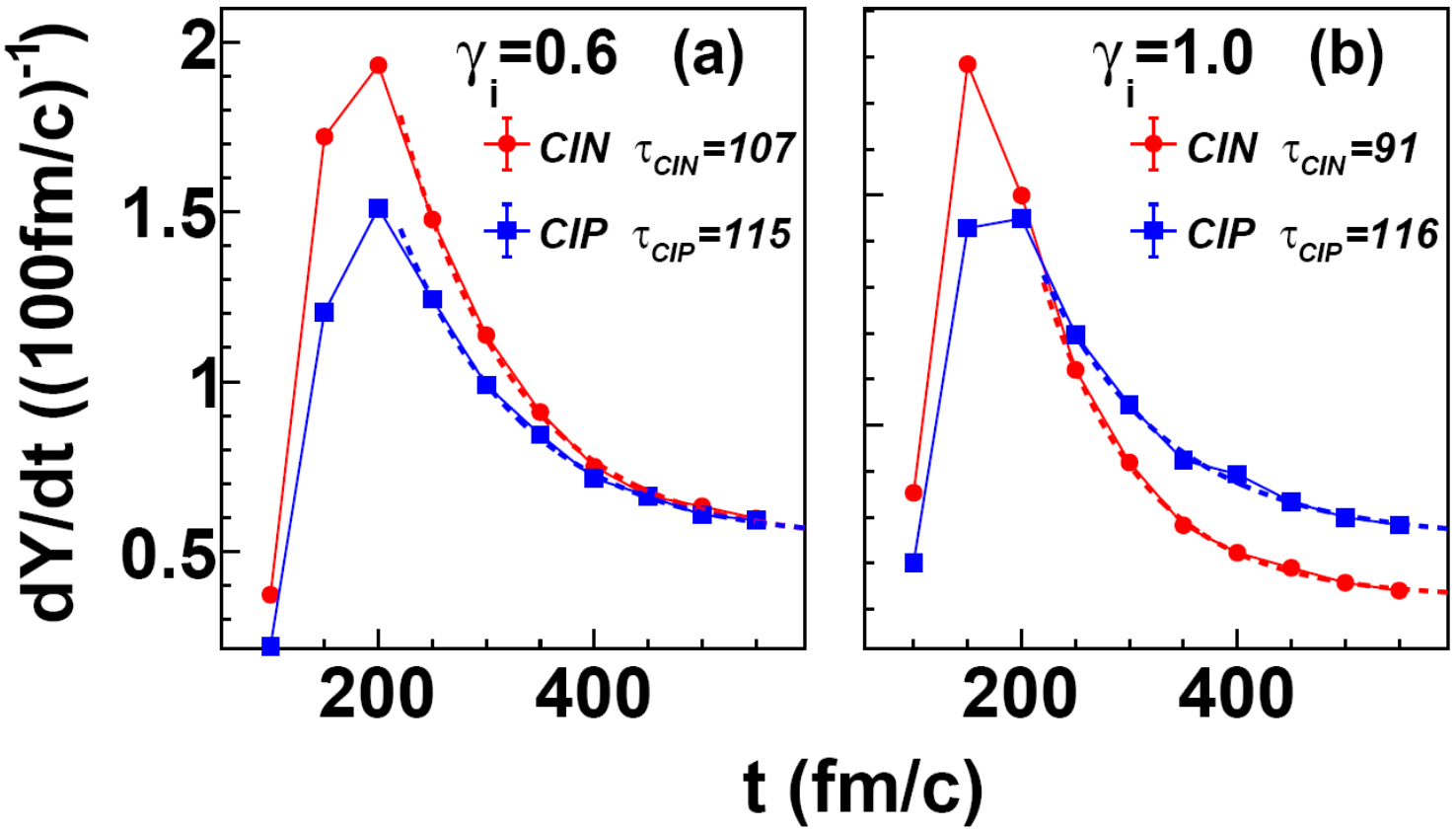
Consistent with the results of R. Ghetti et al.

$$\tau_p > \tau_d > \tau_n$$

Phys. Rev. Lett. 91, 092701 (2003).

ImQMD calculation results of particle emission timescale

{30MeV/u Ar + Au}

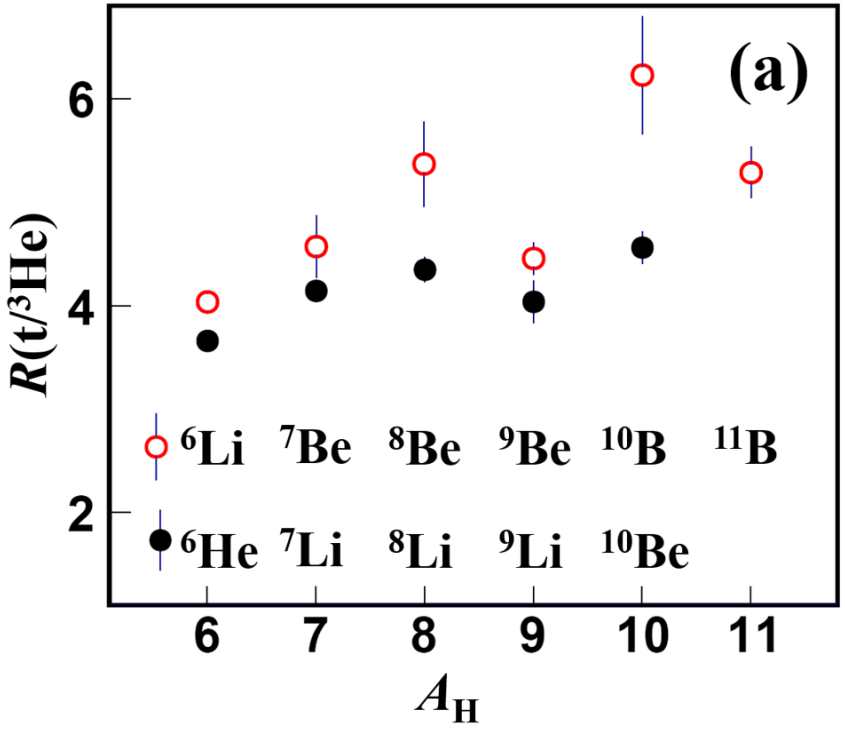


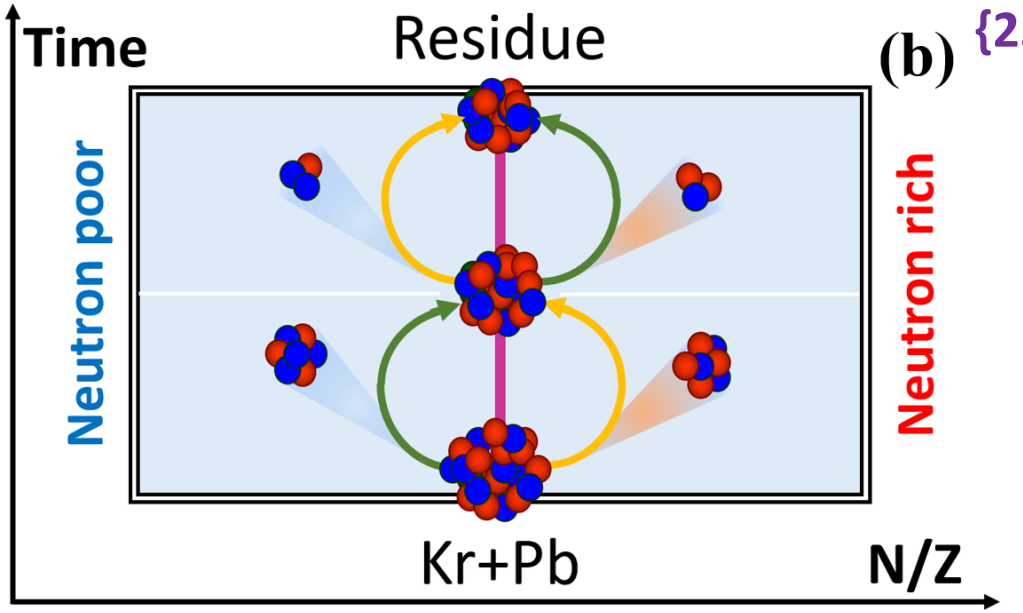
$(\tau_{CIP} - \tau_{CIN})_{\gamma i=1.0}$ is larger than (γi=0.6)

A new way to study $E_{sym}(\rho)$ effect

The Emission Order of Hydrogen Isotopes via Correlation Functions in 30 MeV/u Ar+Au Reactions（Y.J. Wang, et al., Physics Letters B, 825, 136856 (2022)）

Isospin "ping-pang" emission via coincidence analyze





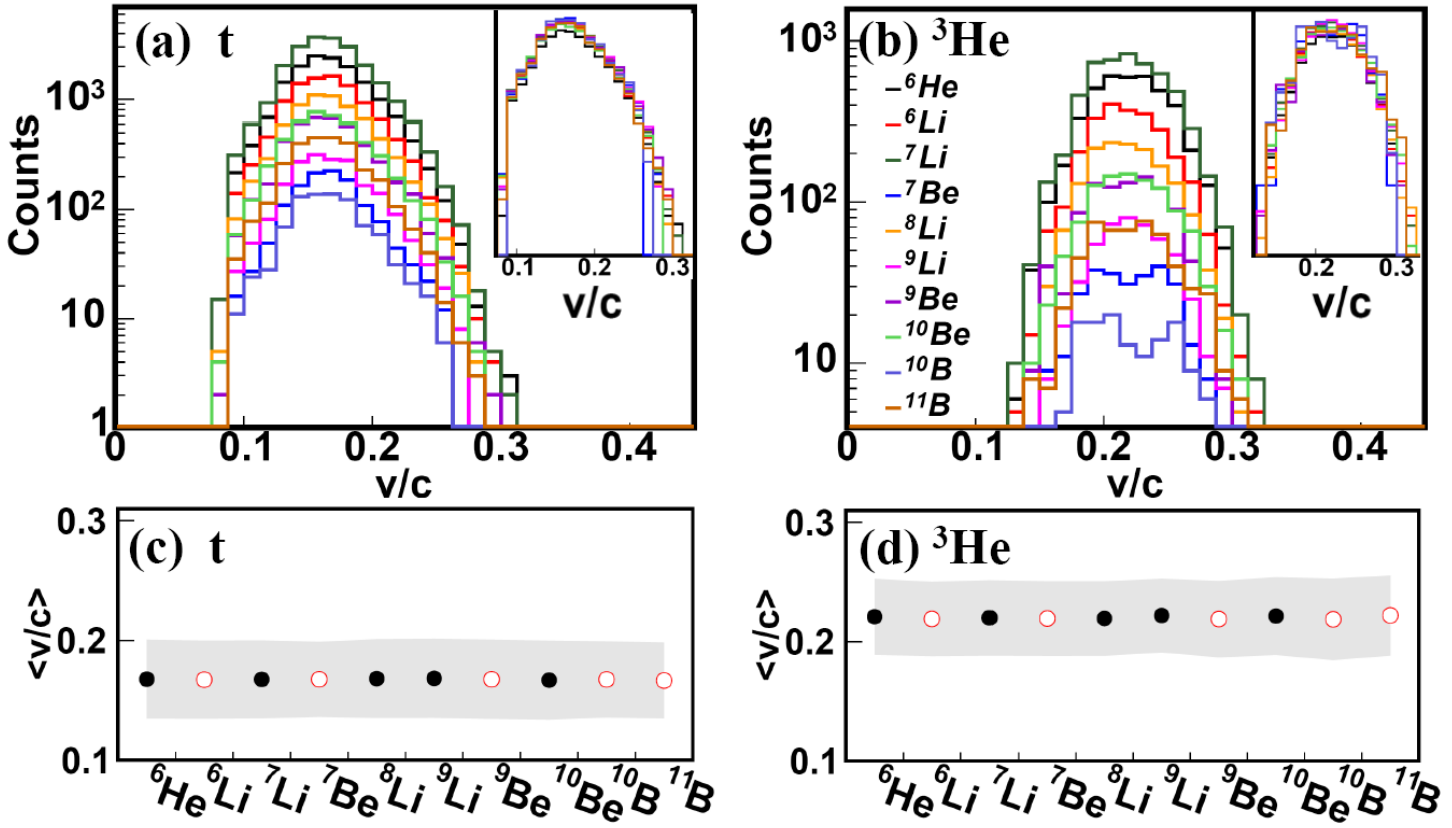
{25MeV/u Kr + Pb}

Same mass and different neutron number for the neutron rich or poor IMFs

Yield ratio of t and ^{3}He R(t/^{3}He) for neutron rich trend of coincident light particles

If a neutron-rich IMF is emitted early, a neutron-poor light particle is more likely to be emitted later.

Velocity spectra of LCP coincident with IMF (Thermal Dynamic check)

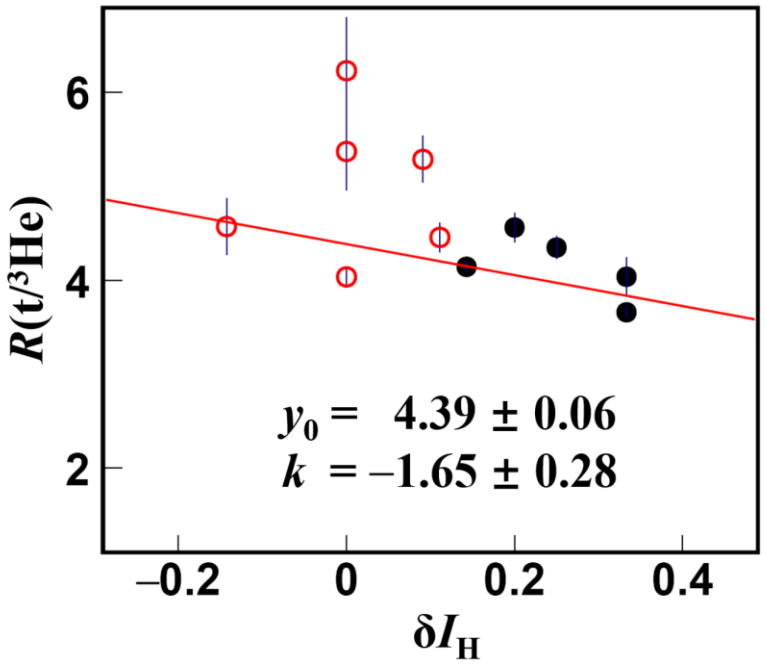


{25MeV/u Kr + Pb}

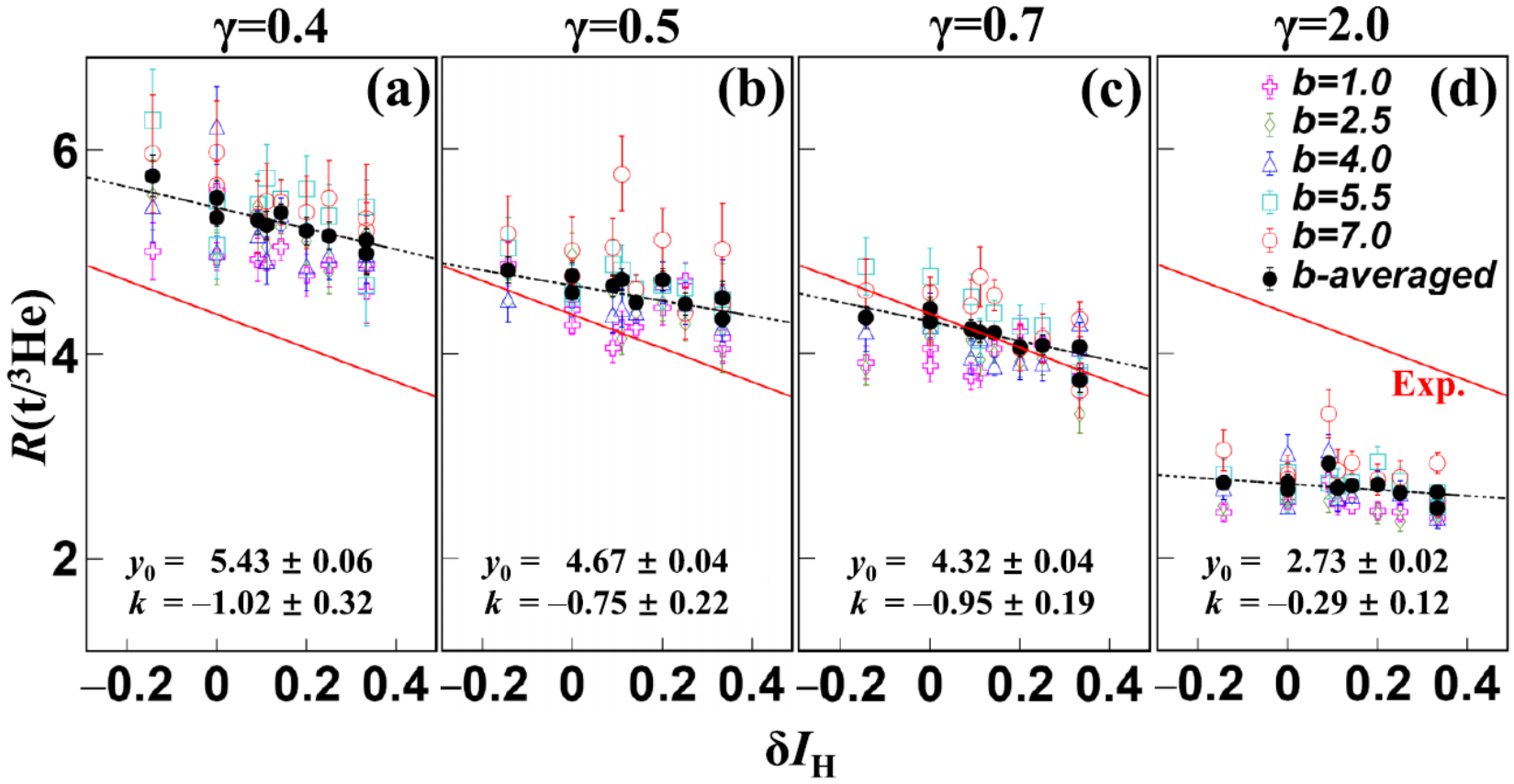
Velocity spectra of both t and ^{3}He exhibit scaling behavior over different IMFs ("Ping-pang" emission is not caused by thermal dynamic process)

Isospin anti-correlation and ImQMD calculation

{25MeV/u Kr + Pb}

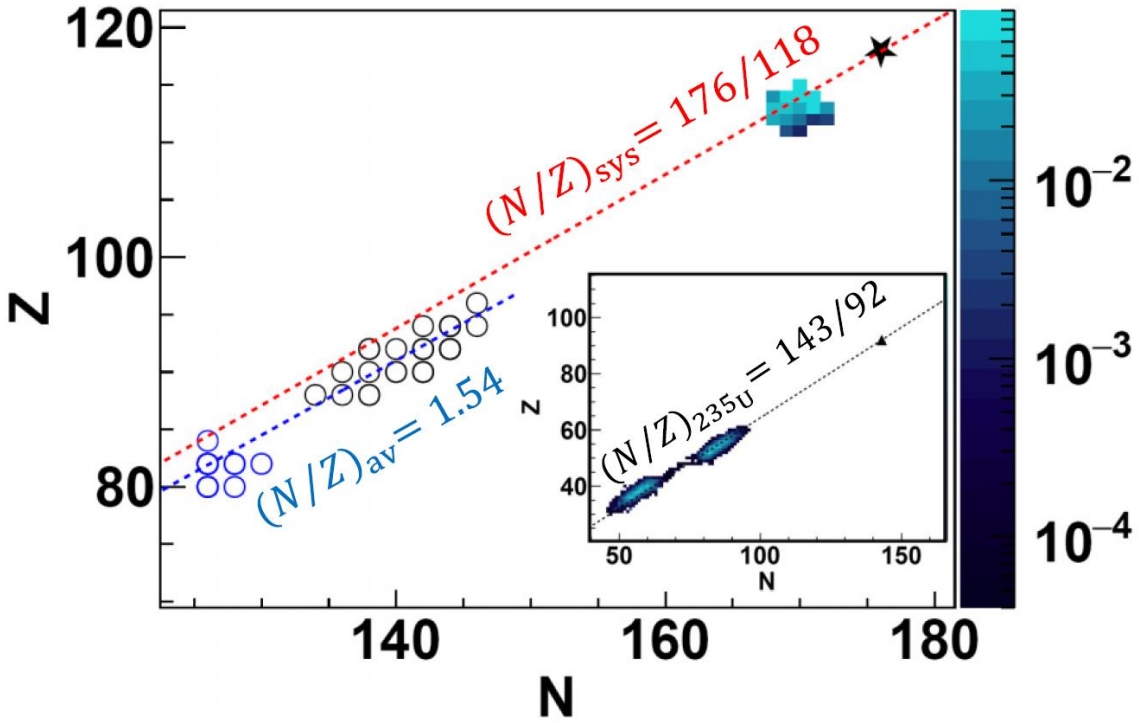


$$\delta I_H = (N_H - Z_H)/A_H$$



Isospin anti-correlation is a precise probe for symmetry energy

Commonality the N/Z of the residues keeps the initial system



{25MeV/u Kr + Pb}

1，“Ping-pang” emission in HIRs

2，Cluster decay in Super-heavy nuclei

3，Fission

Extend isospin balancing effect from ground to highly excited states in HIRs

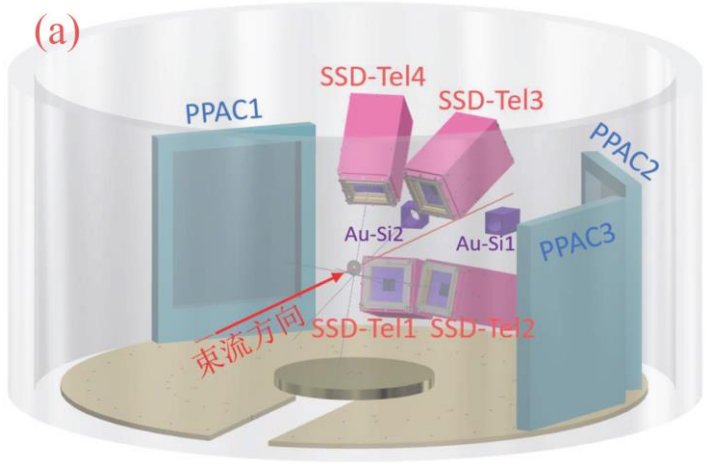
Observing the ping-pong modality of the isospin degree of freedom in cluster emission from heavy-ion reactions（Y.J. Wang, et al., Physical Review C 107, L041601 (2023)）

Summary

①CSHINE, High angular and isotopic resolution

YJW, FHG, QHW et al., Nucl. Sci. Tech. 32, 4 (2021)
FHG, XYD, **YJW** et al., Nucl. Inst. Meth. A, 1011, 165592 (2021)
FHG, **YJW**, XYD et al., Nucl. Inst. Meth. A, 1029, 166461 (2022)
XYD, FHG, **YJW** et al., Nucl. Sci. Tech. 33, 40 (2022)
DG, YHQ, SX, ZQ, **YJW** et al., Nucl. Sci. Tech. 33, 162 (2023)
YHQ, DG, SX, **YJW** et al., NIMA, 1053, 168330 (2023)

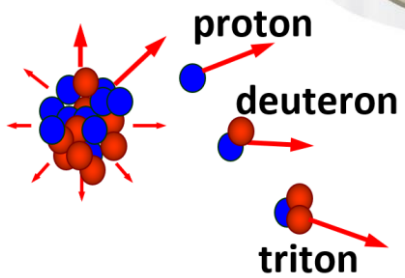
CSHINE
Compact Spectrometer for Heavy IoN Experiments



② Isospin chronology in 30MeV/u Ar+Au:

Neutron-rich particles are emitted earlier, timescale of proton

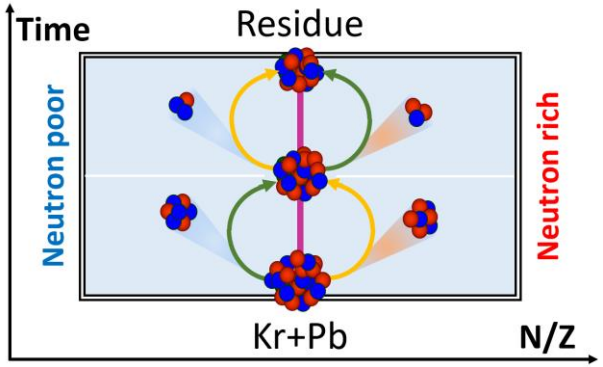
$\tau_p > \tau_d > \tau_t$ $\tau_p \approx 100\mathrm{fm}/c$



Y.J. Wang, et al., Physics Letters B, 825, 136856 (2022)

③ Isospin "ping-pang" emission in 25MeV/u Kr+Pb:

Isospin anti-correlation, isospin balancing effect



Y.J. Wang, et al., Physical Review C 107, L041601 (2023)

Question:

Can transport model describe the triton and ^{3}He energy spectra in large number nucleons reaction in the Fermi energy region?