Extracting symmetry energy information with transport models

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outline

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③ Extracting the $S(\rho)$ with transport model
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  ② in-medium NN cross section effects
  ③ Cluster emission effects
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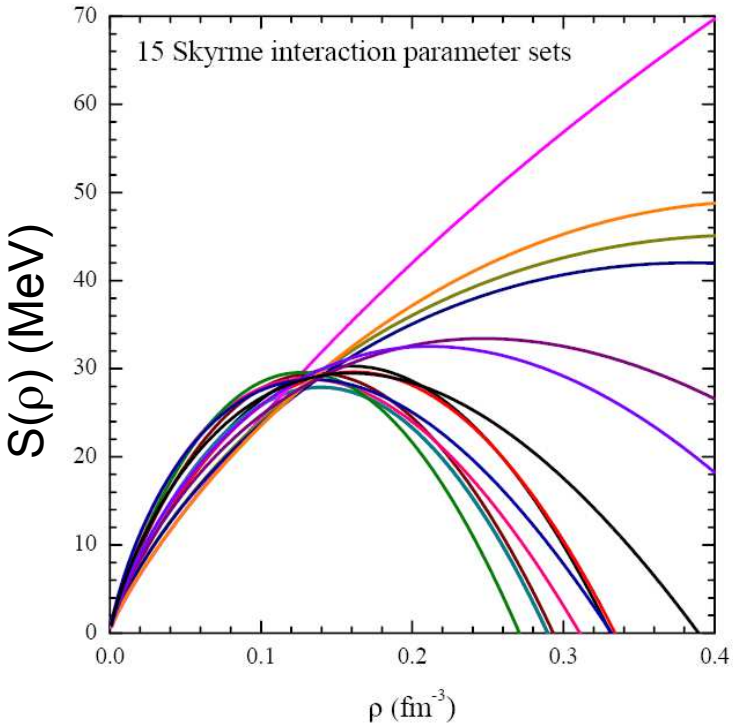
① Introduction

Isospin asymmetric nuclear Equation of State

It is a fundamental properties of nuclear matter, and is very important for understanding

- *masses,*
- *fission barriers,*
- *thickness of the neutron skins of neutron-rich nuclei.*
- *properties of NS, ...*

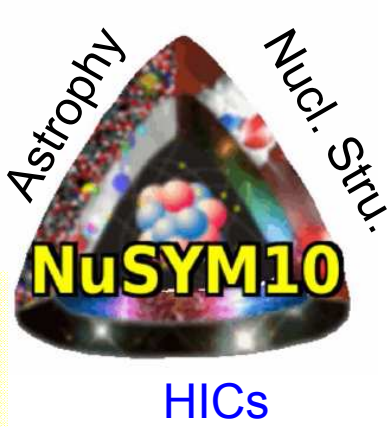
$$E(\rho,\delta)=E(\rho,\delta=0)+S(\rho)\delta^2+O(\delta^4)$$



$S(\rho)$ is the density dependence of symmetry energy, it is a key ingredient of the isospin asymmetric *EOS. However,* $S(\rho)$ uncertainty

- Strategies for constraining the symmetry energy

- *Astrophysical measurements*
- *Nuclear structuer*
- *Heavy Ion Collisions*
  - *large regions of ρ, T, δ,*



- *measure the N/Z ratios of the emitted particles (n/p ratios, isospin diffusion, t/He3, N/Z ratios of IMFs, flow, pi-/pi+, ……)*

- *compare with the prediction from the transport model, in which the different symmetry potential can be used.*

the symmetry energy information can be extracted.
Indirectly! (transport models)

• Uncertainties on constraining the symmetry energy by the transport model

Currently, most of the transport models are based either on BUU or QMD approaches, and there are two main ingredients treated separately:

- *nucleonic mean field (EOS)*
- *the nucleon-nucleon binary scattering*

Especially for the intermediate energy heavy ion collisions !

Theoretical predictions on the isospin sensitive observables depend on:

- *Symmetry potential,*
- *Isospin dependence of in-medium NN cross sectoins*

Therefore, it is very important to understand the influence of in-medium nucleon-nucleon cross sections on the HIC observables as well as symmetry potential

Now, we focus on understanding the influence of symmetry potential, in-medium NN cs on the HIC observables with ImQMD model!

ImQMD (Improved QMD) model

- The different density dependence of symmetry potential can be used in this model

➢ *the mean fields acting on nucleon wavepackets are derived from Skyrme potential energy density functional*

•EOS

$$\dot{\mathbf{r}}_i = \frac{\partial H}{\partial \mathbf{p}_i}, \quad \dot{\mathbf{p}}_i = -\frac{\partial H}{\partial \mathbf{r}_i}. \qquad H = T + U_{\rm loc} + U_{\rm Coul},$$

$$U_{\rm loc} = \int V_{\rm loc}[\rho(\boldsymbol{r})]d\boldsymbol{r}.$$

• Change the symmetry potential in the transport model by varying the γ

potential energy density functional:

$$u_\rho = \frac{\alpha}{2}\frac{\rho^2}{\rho_0} + \frac{\beta}{\eta+1}\frac{\rho^{\eta+1}}{\rho_0^\eta} + \frac{g_{sur}}{2\rho_0}(\nabla\rho)^2 + \frac{g_{sur,iso}}{\rho_0}[\nabla(\rho_n-\rho_p)]^2 + \frac{C_s}{2}(\frac{\rho}{\rho_0})^\gamma\delta^2\rho + g_{\rho\tau}\frac{\rho^{8/3}}{\rho_0^{5/3}}$$

$$\delta = (\rho_n - \rho_p)/(\rho_n + \rho_p)$$

Parameters in U_{loc} are obtained from standard Skyrme interactions parameters

- Isospin dependent nucleon-nucleon cross sections are adopted, the medium corrections are

$$\sigma_{np}^{med} = (1-\eta\ \rho/\rho_0)\sigma_{np}^{free}$$
$$\sigma_{nn,pp}^{med} = (1-\eta\ \rho/\rho_0)\sigma_{nn,pp}^{free}$$

η depend on the beam energy

$\sigma_{np,nn(pp)}^{free}$ *Cugnon, et al., Nucl.Instr.Meth.Phys. B111, 215(1996)*

- isospin independent Momentum dependence interaction

$$u_{md} = \frac{1}{2\rho_0}\sum_{N_1,N_2=n,p}\frac{1}{16\pi^6}\int d^3p_1 d^3p_2 f_{N_1}(\vec{p}_1) f_{N_2}(\vec{p}_2) 1.57\left[\ln\left(1+5\times10^{-4}(\Delta p)^2\right)\right]^2$$

Aichelin, et al., PRL58,1926(1987)

- Clusters are recognized by means of the coalescence model widely used in QMD calculations, DR<=3.5fm, DP<=250MeV/c

Details about ImQMD:

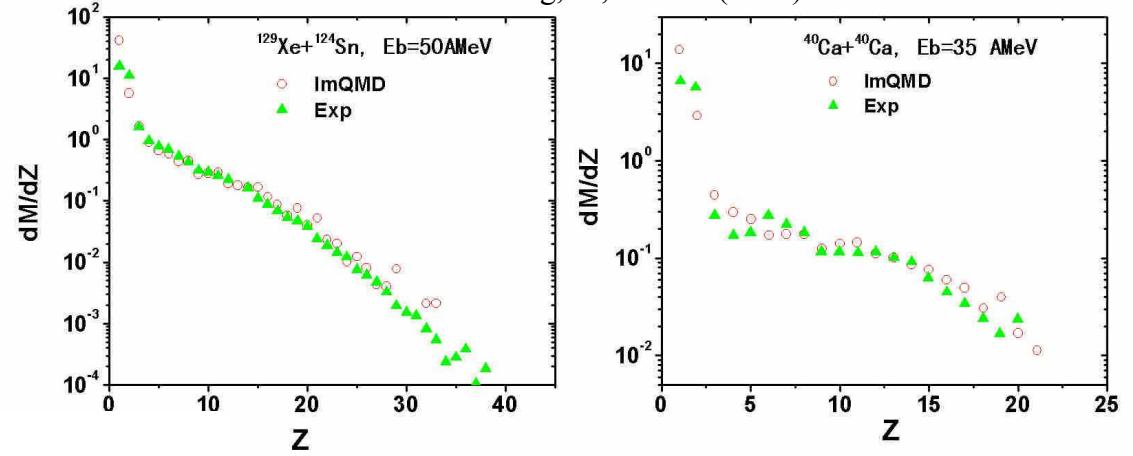
Zhang, et al., PL **B664** (08) 145, PR **C71** (05) 024604, PR **C74** (06) 014602

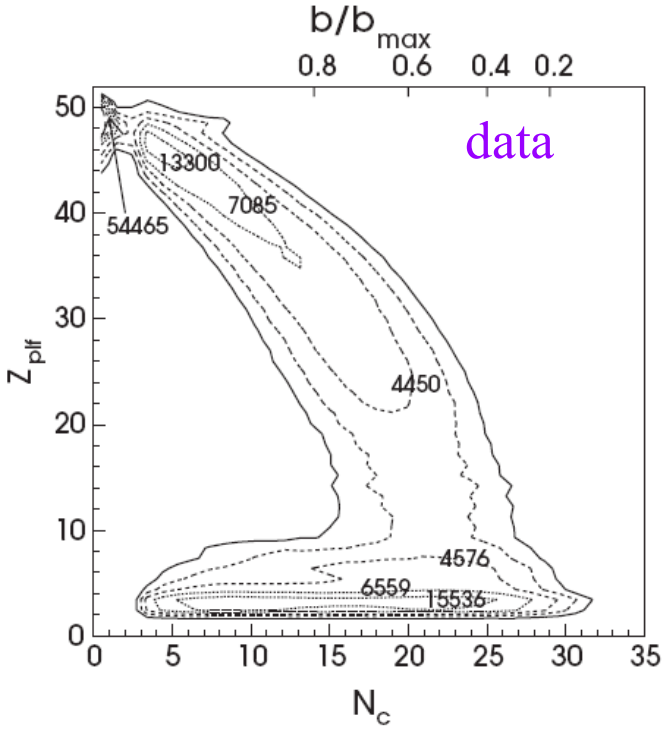
- The symmetry energy (~10%)
- Extracting the symmetry energy information with HICs require model
  - Describe the basic properties of HICs
  - Charge distribution (fragmentation)
  - Flow (EOS)
  - Stopping (in medium NN cross sections)

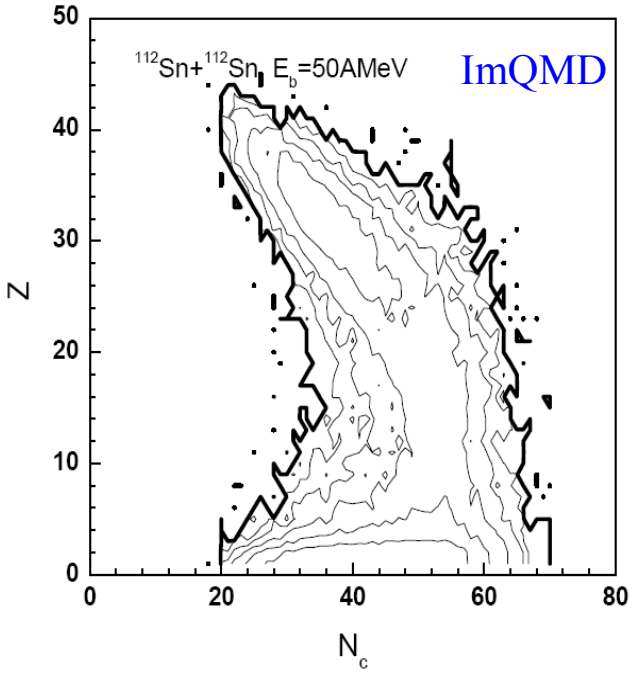
- It describe the charge distribution, flow and stopping power well for the heavy ion collisions for Ebeam=30-400MeV,

Charge distribution

Zhang, Li, PRC71(2005)24606

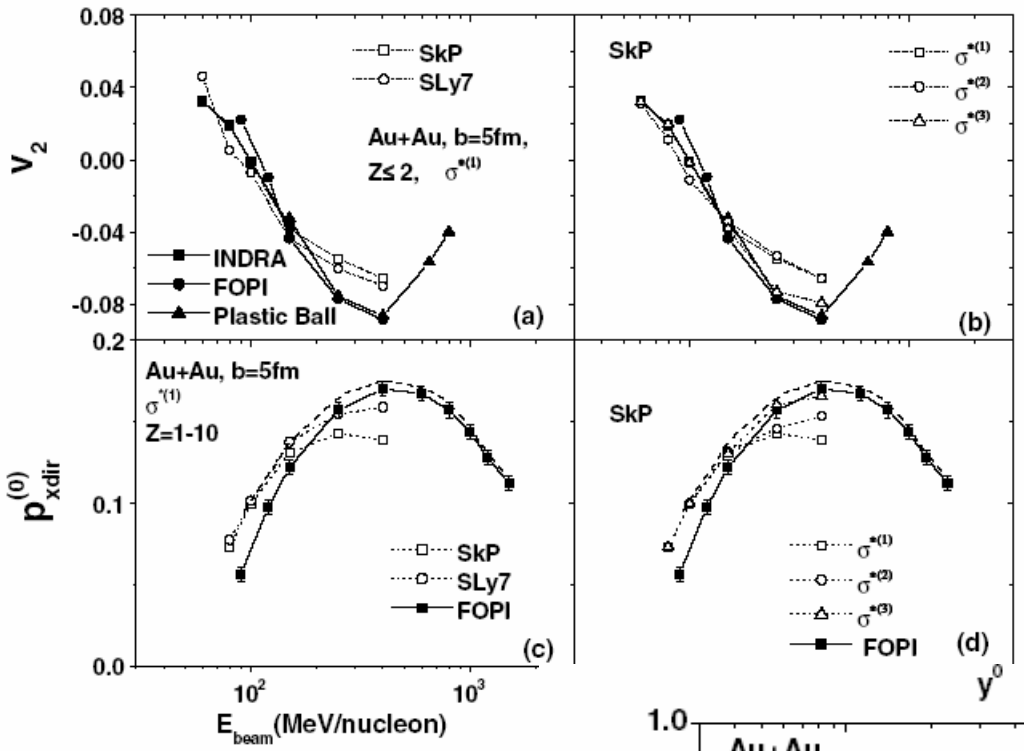




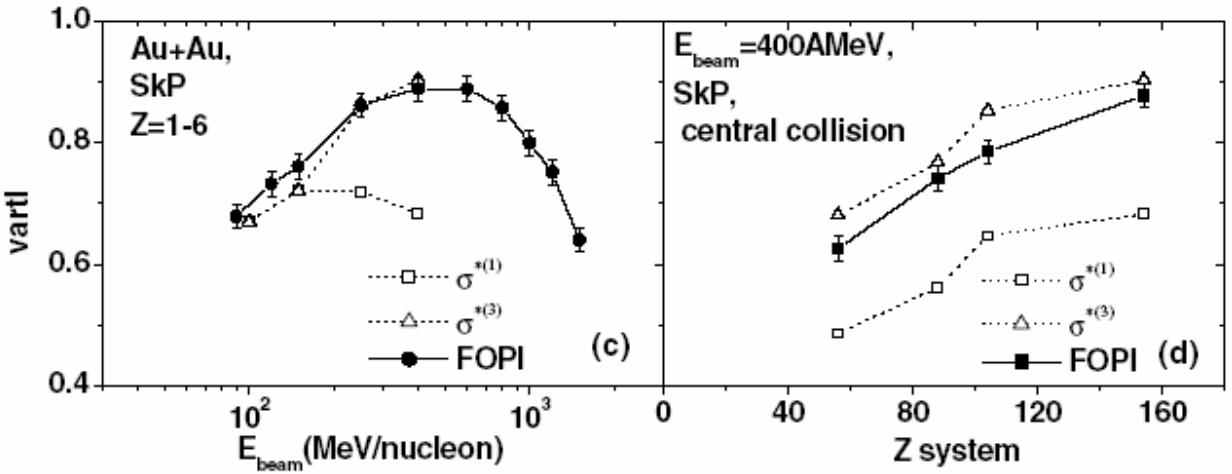


Zhang, Li, PRC74,014602

flow



stopping



Zhang, Li, PRC74,014602 Data: Residorf, PRL 92(2004)232301

- *Give our confidence to study the isospin effects from different symmetry energy case.*

The influence of *Vasy*, and σ* on the HICs observables for Sn+Sn at 50AMeV

- *Varying the potential part of the Symmetry energy in ImQMD*

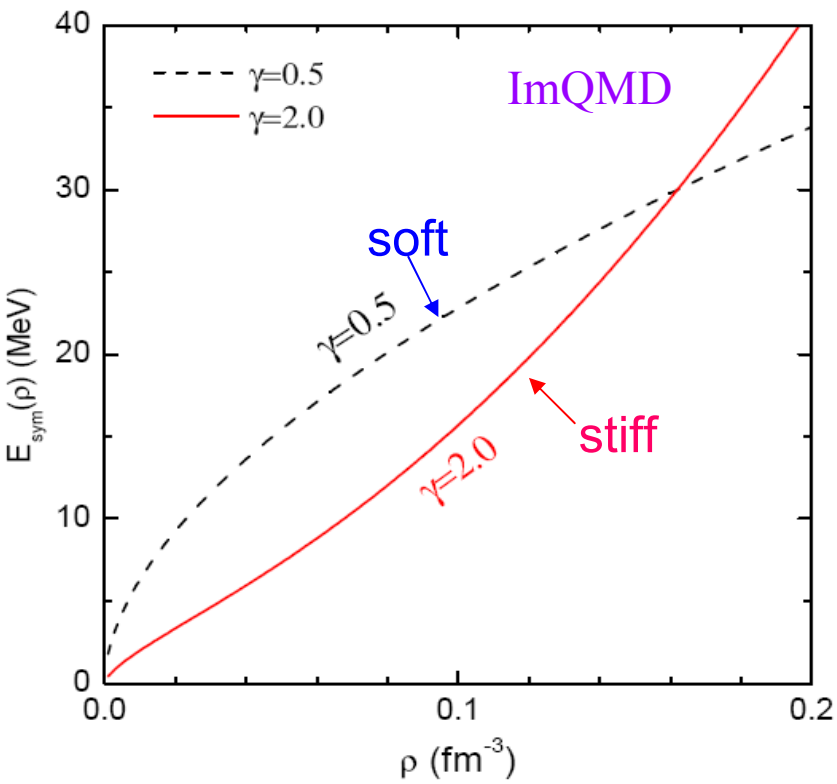
Energy density functional

$$w_{asy}^{pot} = \frac{C_s}{2}\left(\frac{\rho}{\rho_0}\right)^{\gamma}\delta^2\rho$$

$$v_{asy}^{pot}(i) = \frac{\partial w_{asy}^{pot}}{\partial \rho_i}$$

The density dependence of symmetry energy for cold nuclear matter

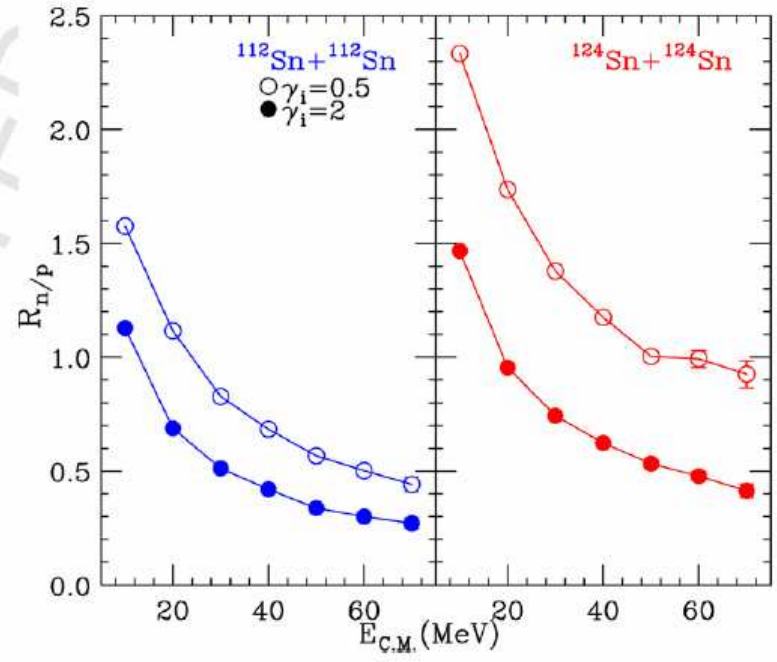
$$E_{sym}(\rho) = \frac{1}{3}\frac{\hbar^2}{2m}\rho_0^{2/3}\left(\frac{3\pi^2}{2}\frac{\rho}{\rho_0}\right)^{2/3} + \frac{C_s}{2}\left(\frac{\rho}{\rho_0}\right)^{\gamma_i}$$



A. n/p ratio and DR(n/p) ratio

• the emitted nucleons directly feel the symmetry potential
• n/p ratio is related to the stiffness of symmetry potential at subsaturation density (BALi, PRL(1997))

b=2fm



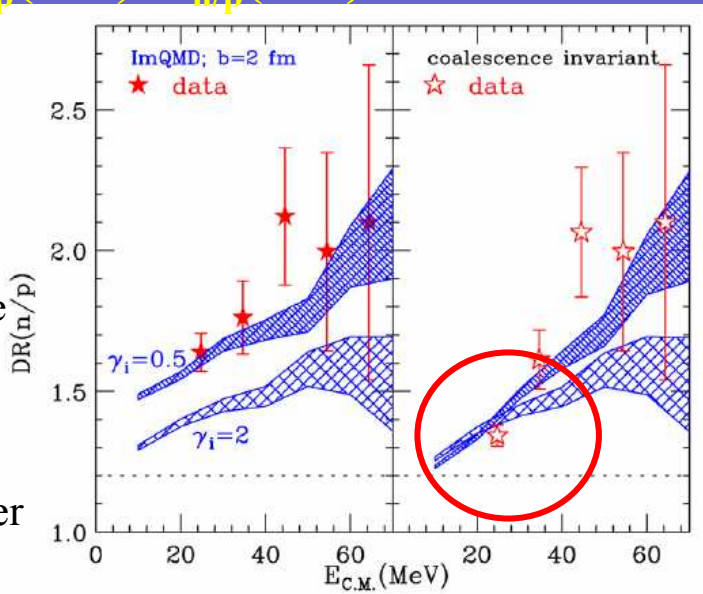
Zhang, P.Danielewicz, et al, PLB664,145(2008)

$$R_{n/p} = \frac{dM_n / dE_k}{dM_p / dE_k}$$

- more pre-equilibrium neutrons get emitted from the neutron rich ^{124}Sn+^{124}Sn system
- relatively more pre-equilibrium neutrons are also emitted in the calculations with softer symmetry energy

$DR(n/p)=R_{n/p}(124)/R_{n/p}(112)$

- Over the whole energy range for both free and coalescence-invariant DR(n/p) the data seem closer to the g_i=0.5 calculation

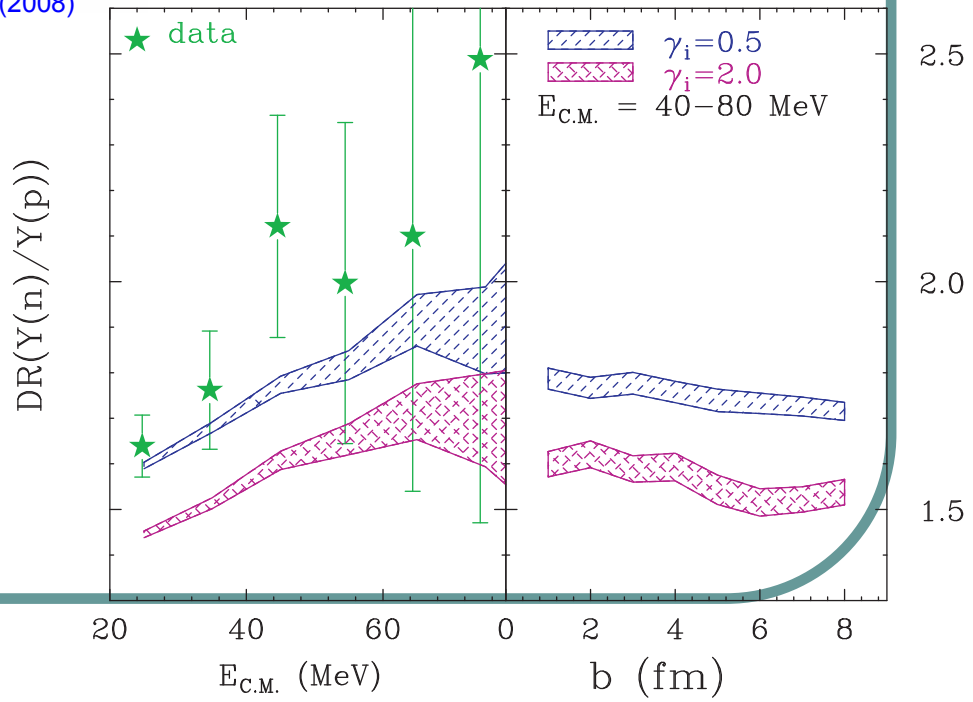


Data from Famiano, PRL97, 052701(2006)

Zhang, P.Danielewicz, et al, PLB664,145(2008)

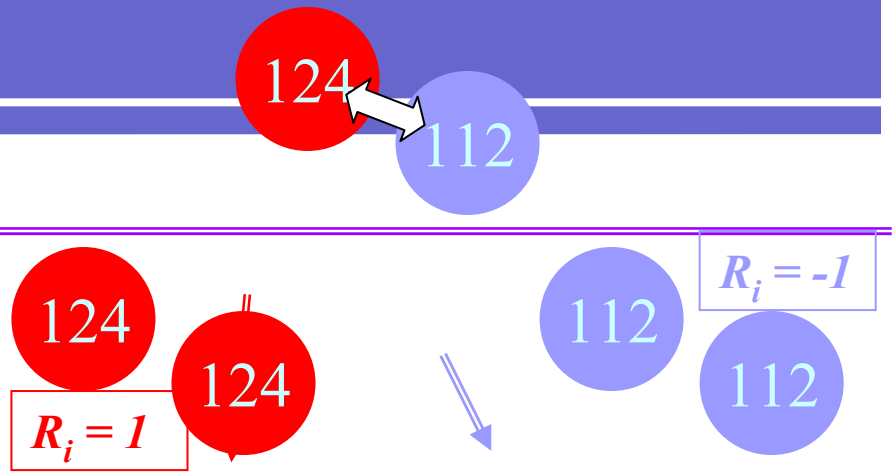
- Significant cluster and sequential decay effects are at low energy!

- *DR(n/p) with higher kinetic energy weakly depend on the impact parameters*



B. isospin diffusion

Isospin diffusion occurs only in asymmetric systems A+B, and diffusion ability depends on the symmetry energy.



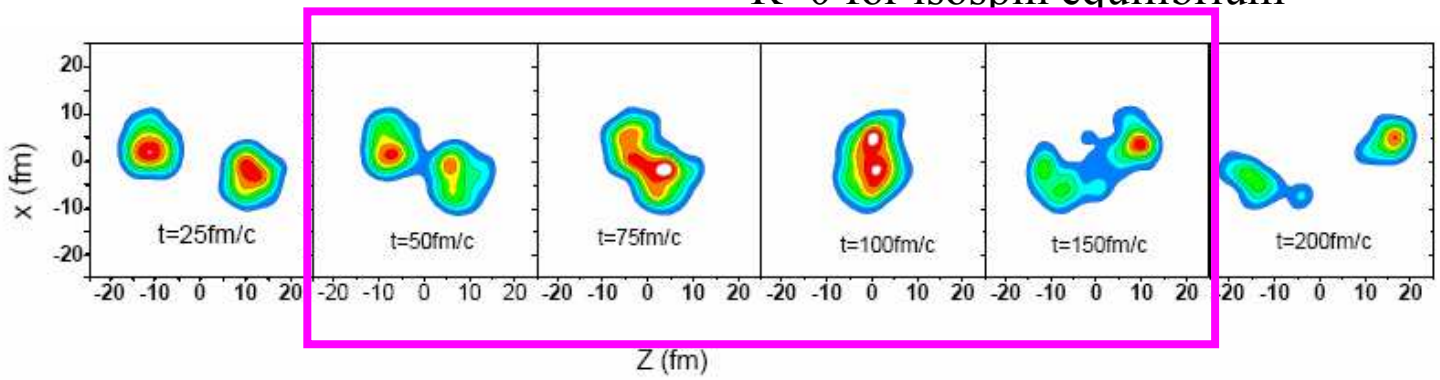
No isospin diffusion between symmetric systems

Isospin transport ratio

$$R_i=(2X-X_{AA}-X_{BB})/(X_{AA}-X_{BB})$$

In absence of isospin diffusion R=1 or R=-1, R~0 for isospin equilibrium

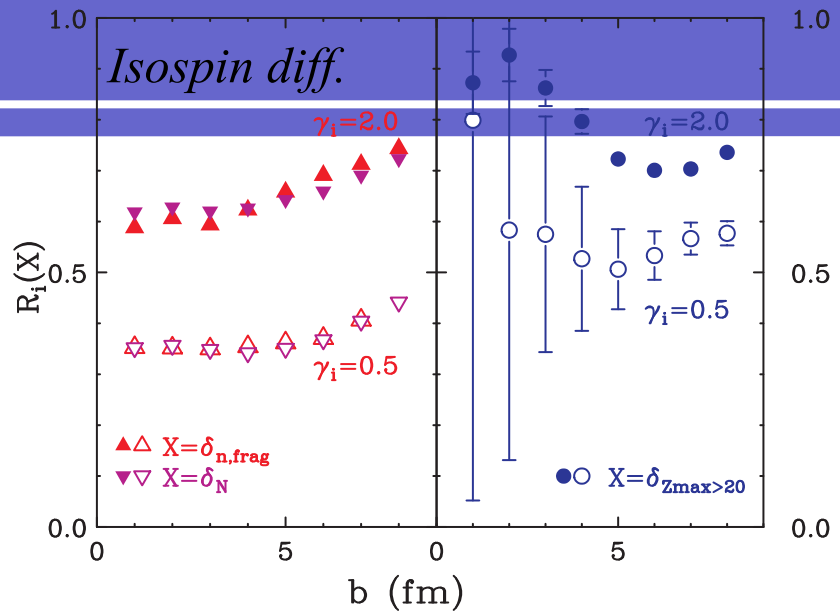
b=6fm



- *Theory: X is the δ, the isospin asymmetry of projectile residues*
- *Exp: X is the isoscaling parameter α (Tsang, PRL)*
- *There is linear relationship between δ and α, So, Ri(δ)=Ri(α)*

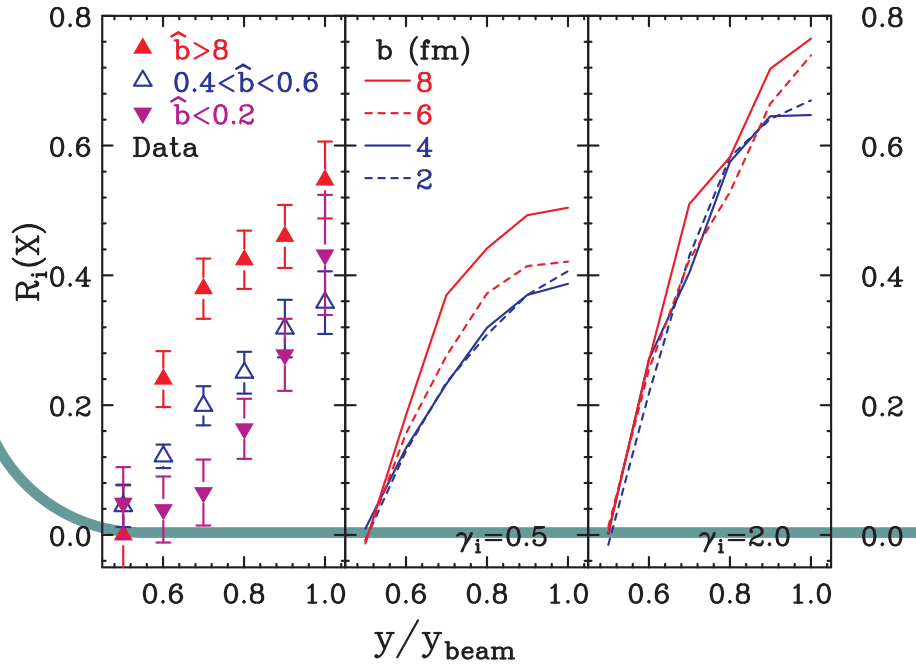
• *Ri as a function of impact parameters*

Zhang,, et.al.,



• *larger symmetry energy at subsaturation density leads to smaller Ri*

• *Ri depend on the X tracer. The differences reflect the isospin diffusion mechanism for peripheral collisions. Isospin diffusion mainly occurs around neck region.*



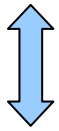
• the rapidity dependence of *Ri* also sensitive to the density dependence of symmetry energy

•*Isospin dependence of in-medium NN cs*

•*The isospin dependence of in-medium NN cs also influence the isospin sensitive observables*

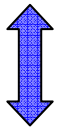
- *the influence of medium correction*
- *the influence of isospin dependence* $\sigma^*_{np}/\sigma^*_{nn}$

$$\sigma^*_{nn/np} = \sigma^{free}_{nn/np}$$



The influence of medium correction

$$\sigma^*_{nn/np} = (1 - 0.2\rho/\rho_0)\sigma^{free}_{nn/np}$$

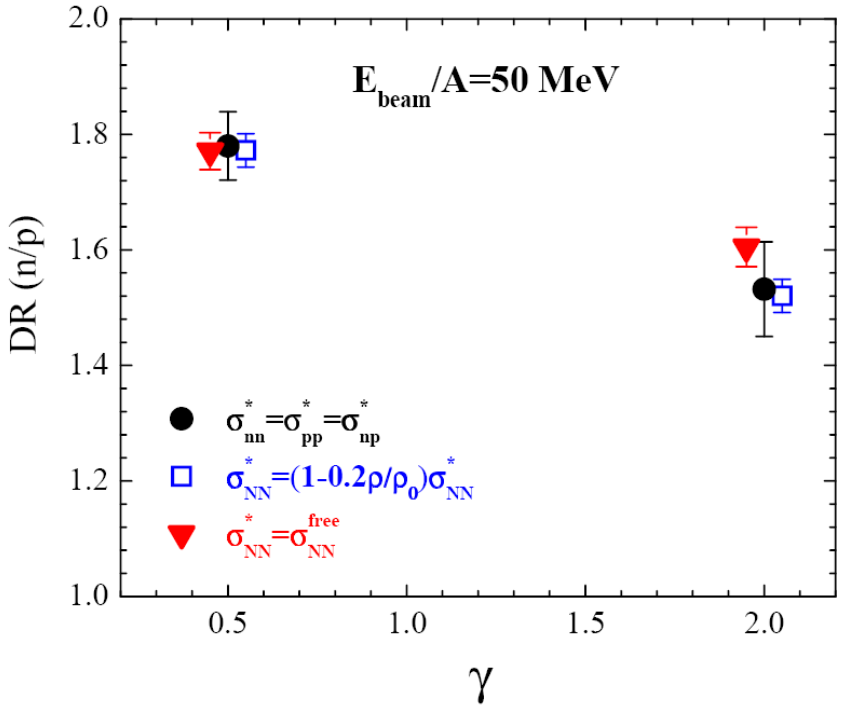


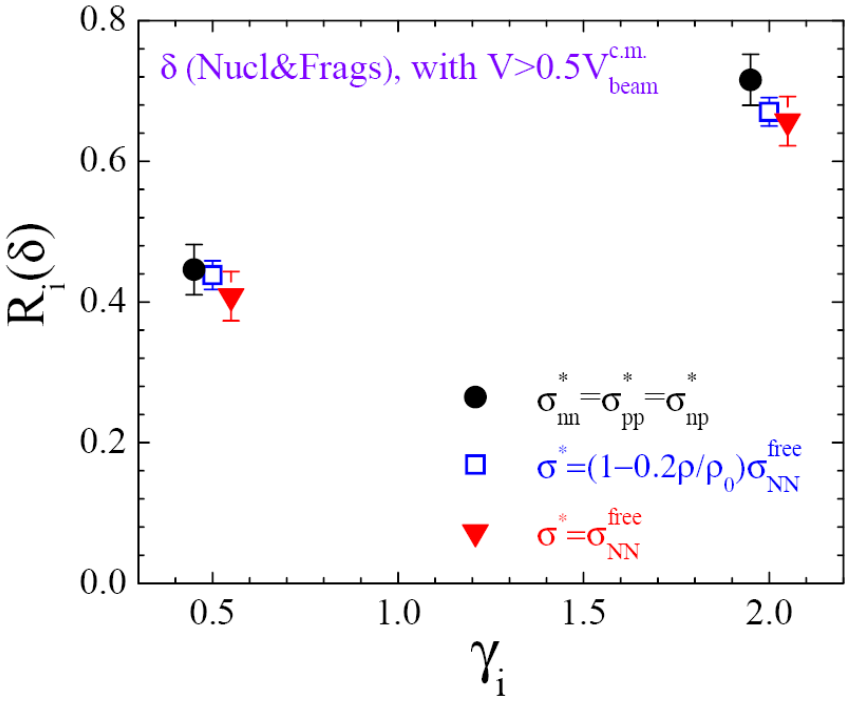
The influence of $\sigma^*_{np}/\sigma^*_{nn}$

$$\sigma^*_{nn} = \sigma^*_{pp} = \sigma^*_{np}$$

Keep the collision number same

The influence of the in-medium NN cs on DR and Ri

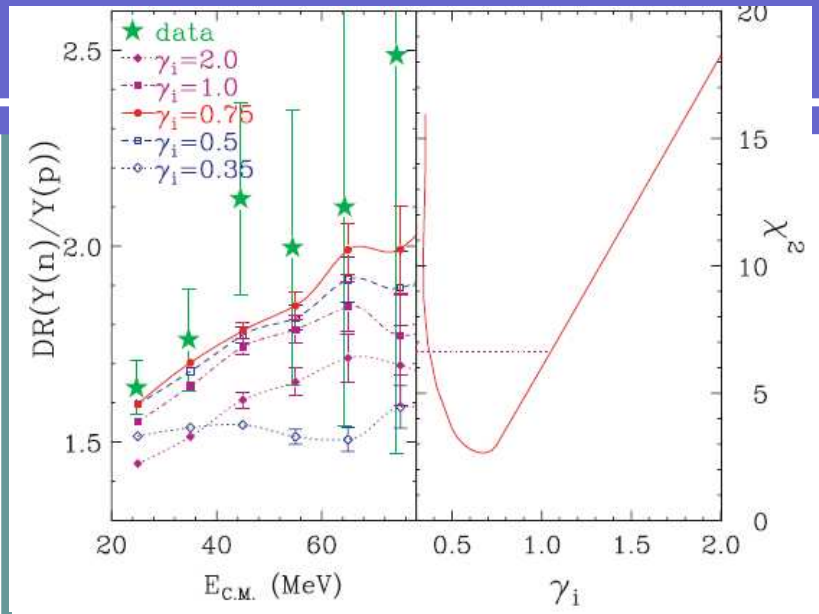


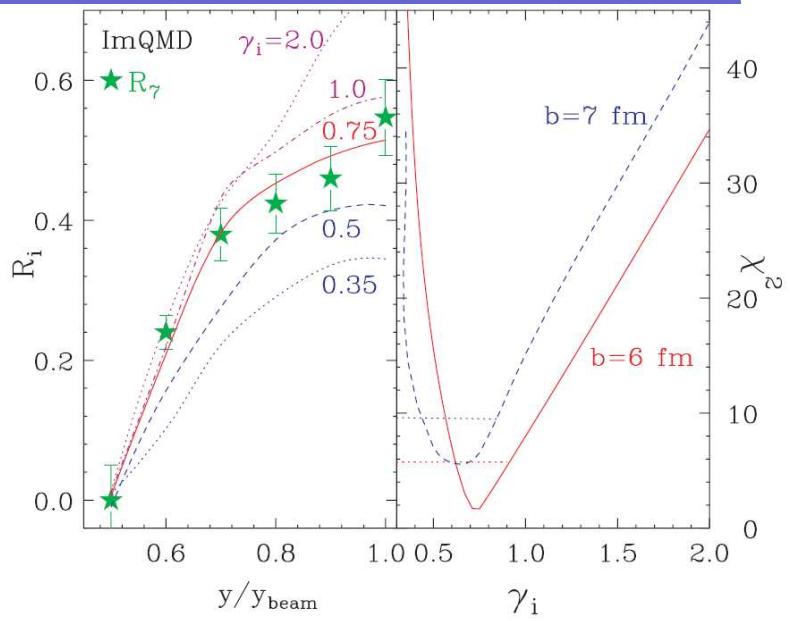


- DR(n/p) with Ek>40MeV

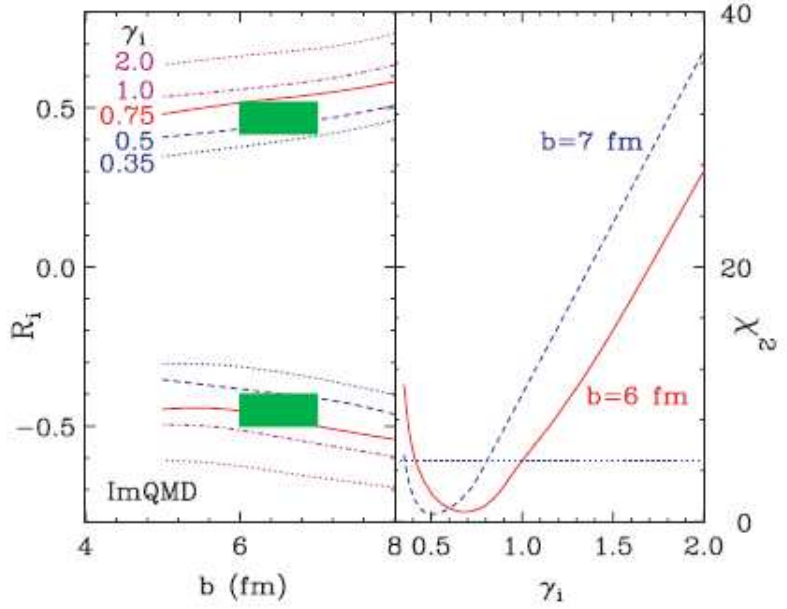
- *DR(n/p) and Ri sensitive to the density dependence of symmetry energy rather than in-medium NN cs for Sn+Sn at E/A=50MeV*

Constraints on the density dependence of symmetry at subsaturation density





Tsang, Zhang, et al., PRL102,122701(2009)



Detailed comparison with data by varying γ_i

$$E_{sym}(\rho)=12.5(\rho/\rho_0)^{2/3}+17.5(\rho/\rho_0)^{\gamma_i}$$

Consistent χ^2 analysis of these observables within ImQMD model provides

with gamma_i=[0.45,0.95]

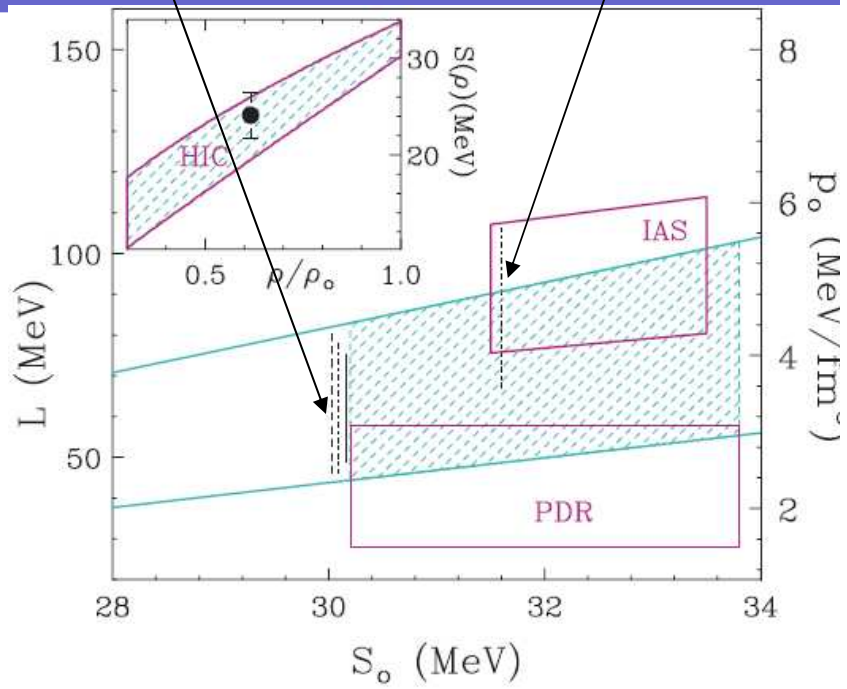
Conclusion and outlook

- The DR(n/p), isospin diffusion, rapidity dependence of R sensitive to the density dependence of symmetry energy
- At E_{beam}=50MeV per nucleons, the isospin sensitive observables strongly depend on the density dependence of symmetry energy rather than the isospin dependence of in medium NN cross section.
- Cluster effects are important for n/p ratios and isospin transport ratios, it can provide another observables to constrain the symmetry energy and understand the reaction mechanism
- By comparing the transport model predictions to the NSCL data, the very stiff and very soft symmetry energy case are ruled out.

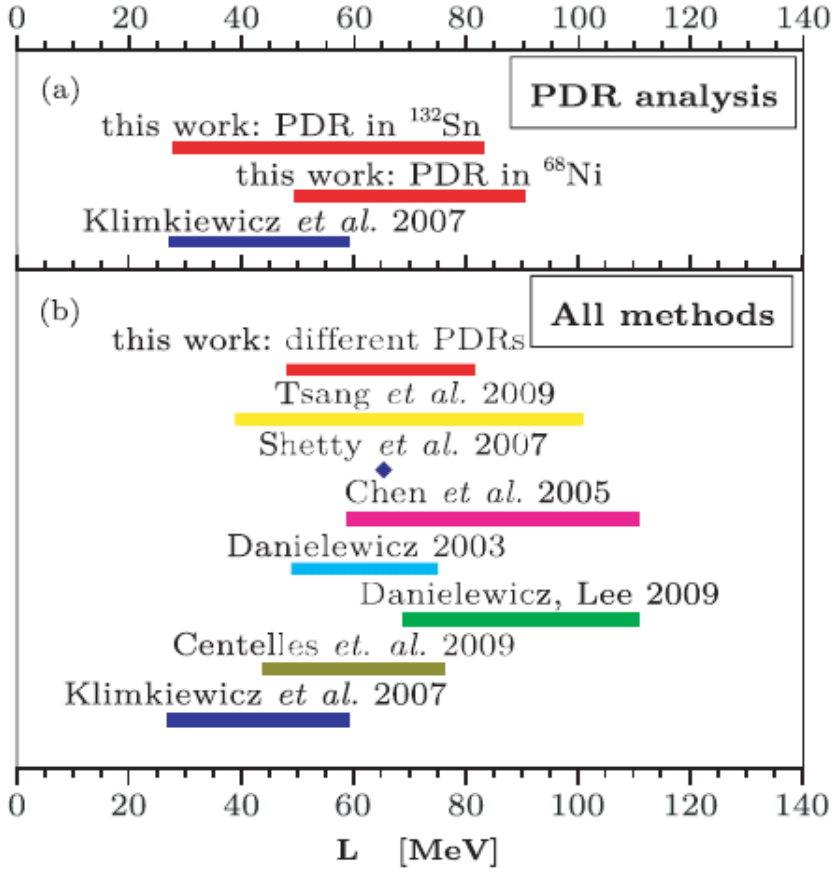
ImQMD, DR(n/p), Ri, R_7

IBUU04, R_i

Tsang, Zhang, et.,PRL102



$$S = S_o + \frac{L}{3}\left(\frac{\rho_B - \rho_0}{\rho_0}\right) + \frac{K_{sym}}{18}\left(\frac{\rho_B - \rho_0}{\rho_0}\right)^2 + .$$



A. Carbone, et.al., PRC81,014301(2010)

- Still within large room, more work necessary

- *Need more data,*
- *Systematic study the isoscalar and isovector observables, to reduce the uncertainties in the transport model*

Thanks for your attention!