International Nuclear Physics Conference
Adelaide Convention Centre, Australia
11-16 September 2016

Accessing the long-time isospin drift and the symmetry energy in heavy ion collisions

Zhigang Xiao

Tsinghua University, Beijing, China

Collaborators: Yan Zhang, Rensheng Wang, Jiansong Wang, Junlong Tian et al.

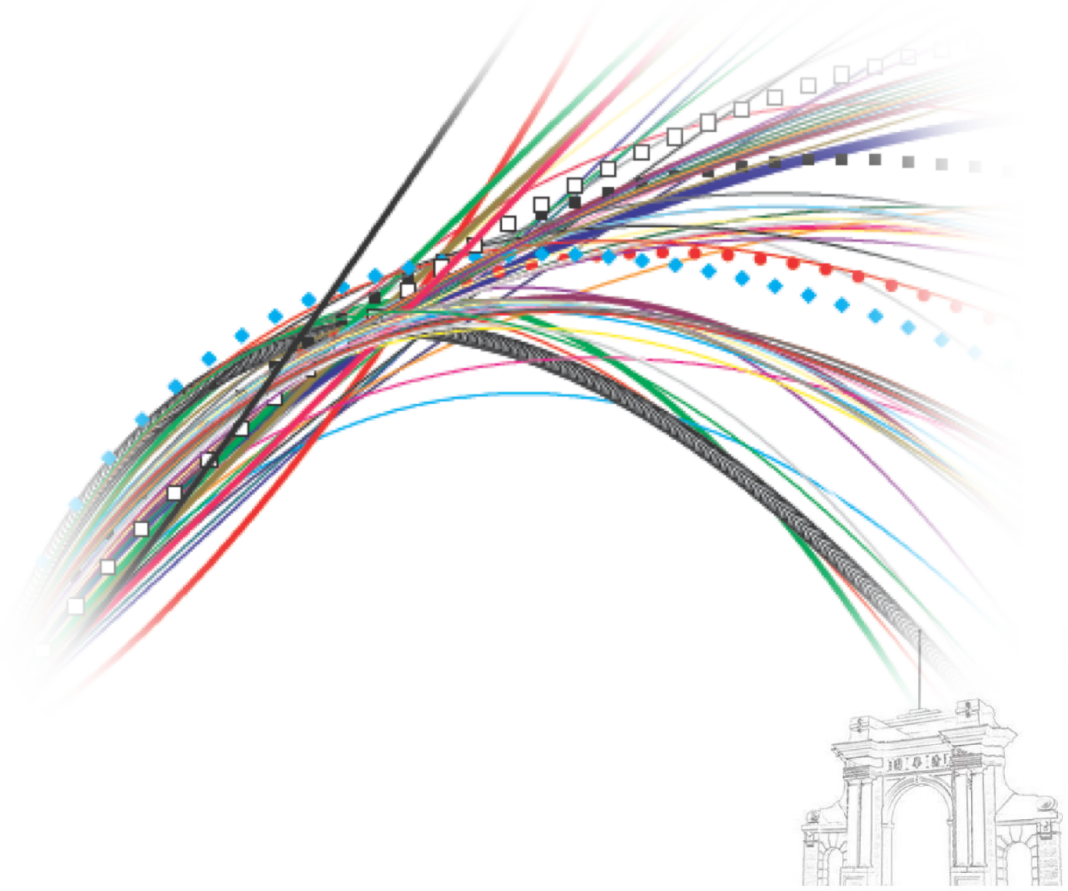
Contents

→ Introduction: Isospin transport and long time $E_{sym}(\rho)$ effect

→ 35 MeV/u Ar+Au fission reactions

→ 30 MeV/u Ar+Au fission reactions

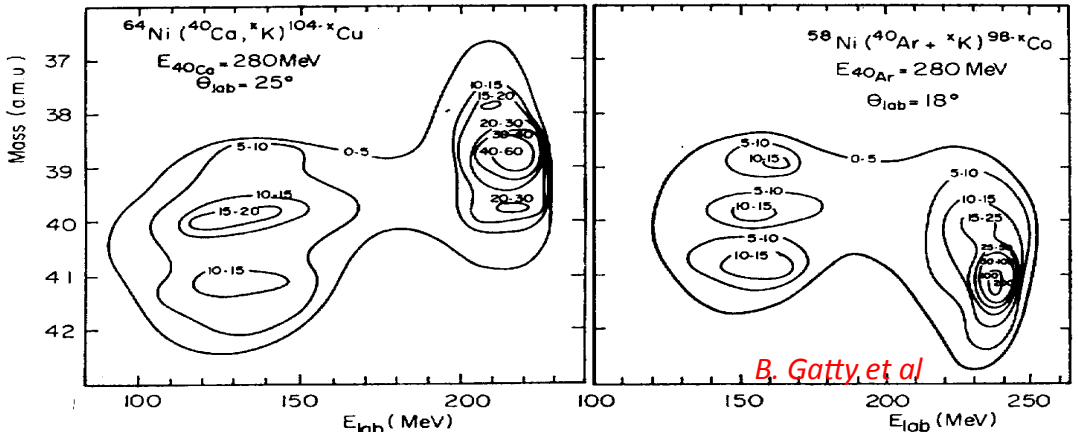
→ Summary



References

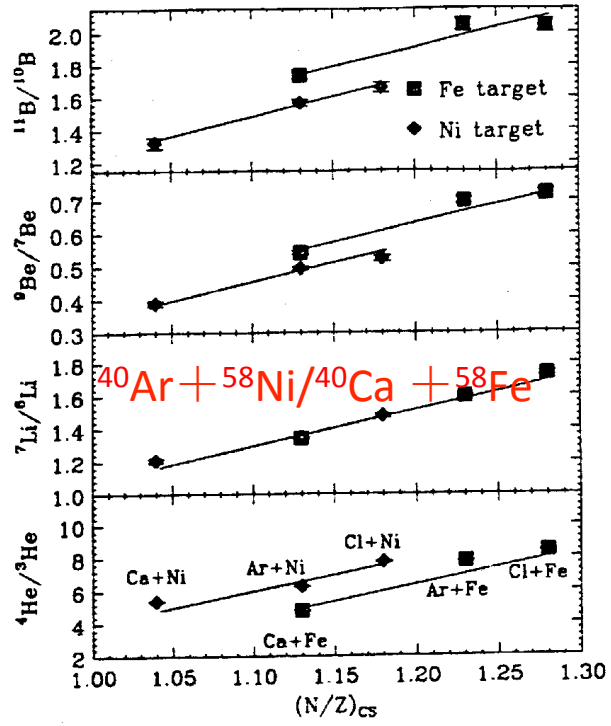
- H. Y. Wu, ZGX, et al. PLB 538 (2002) 39
- R. S. Wang, Y. Zhang, XZG et al., PRC89 064613 (2014)
- Q. Wu, Y Zhang, XZG et al., PRC 91, 014617(2015)
- Y. Zhang, J L Tian, … XZG et al, In Preparation

1. Isospin Transport in HIC at Fermi Energies



→NPA **253**, 511 (1975).
→PRC **20** 1485 (1979).
→PRC **46**, 1996 (1992).
→EPJA **50**,33 (2014).

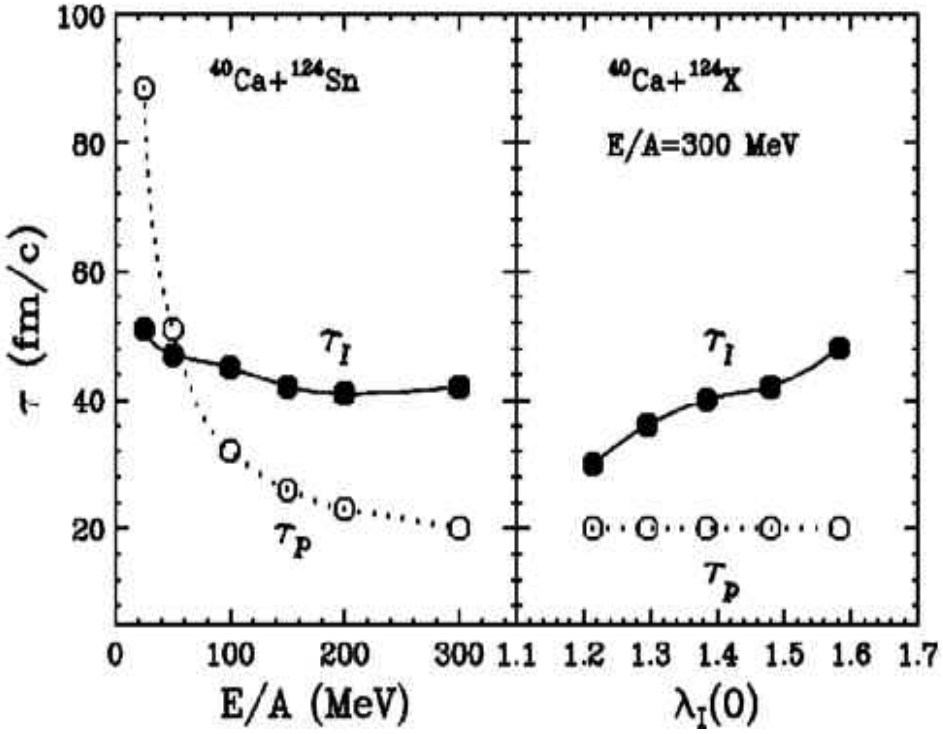
1. **Isospin relaxation equilibrium achieved in low energy**



^{40}Ar + ^{58}Ni/^{40}Ca + ^{58}Fe

→PRC **57**, 2065 (1998).
→ PLB **321**, 15 (1994).
→ J. Phys. G **23**, 211 (1997).
→ PRC **82**, 051603 (2010).

2. However, it is shown that the isopin degree of freedom is not completely equilibrated at higher energies



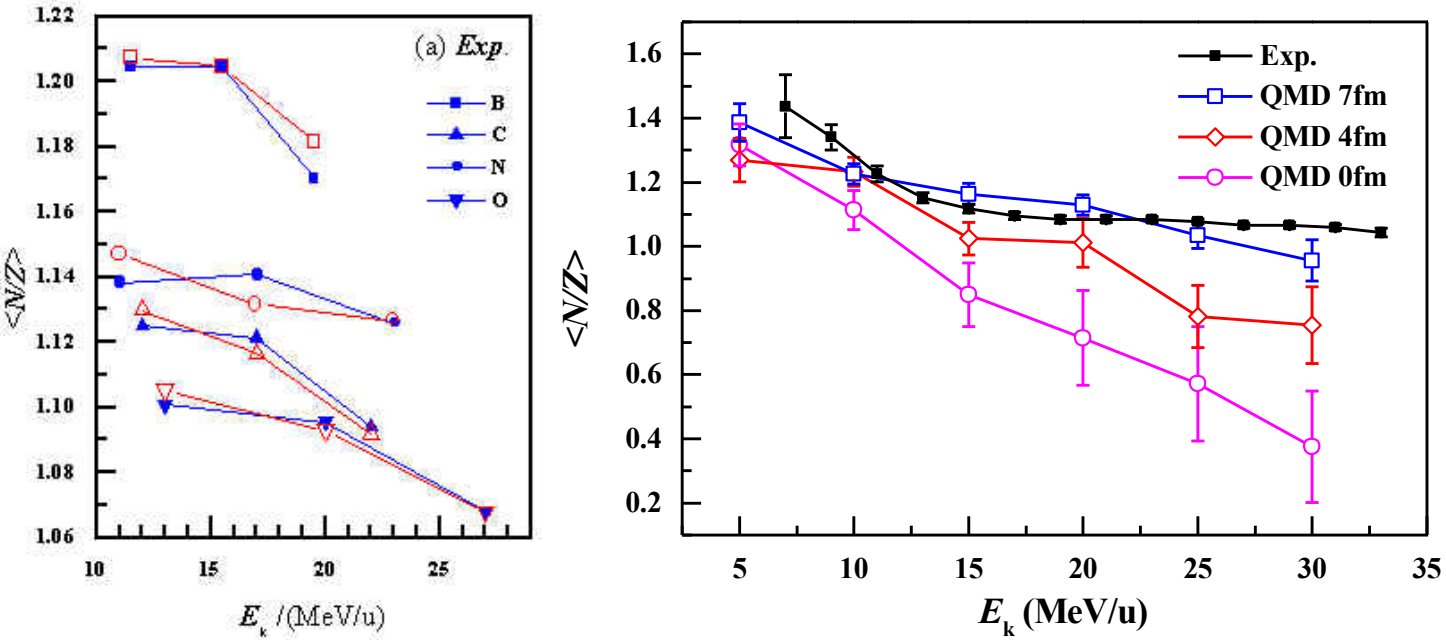
The isospin relaxation time (τ_I) and the momentum relaxation time(τ_p)as a function of incident energy (left) and the isospin asymmetry (right) [LK98]

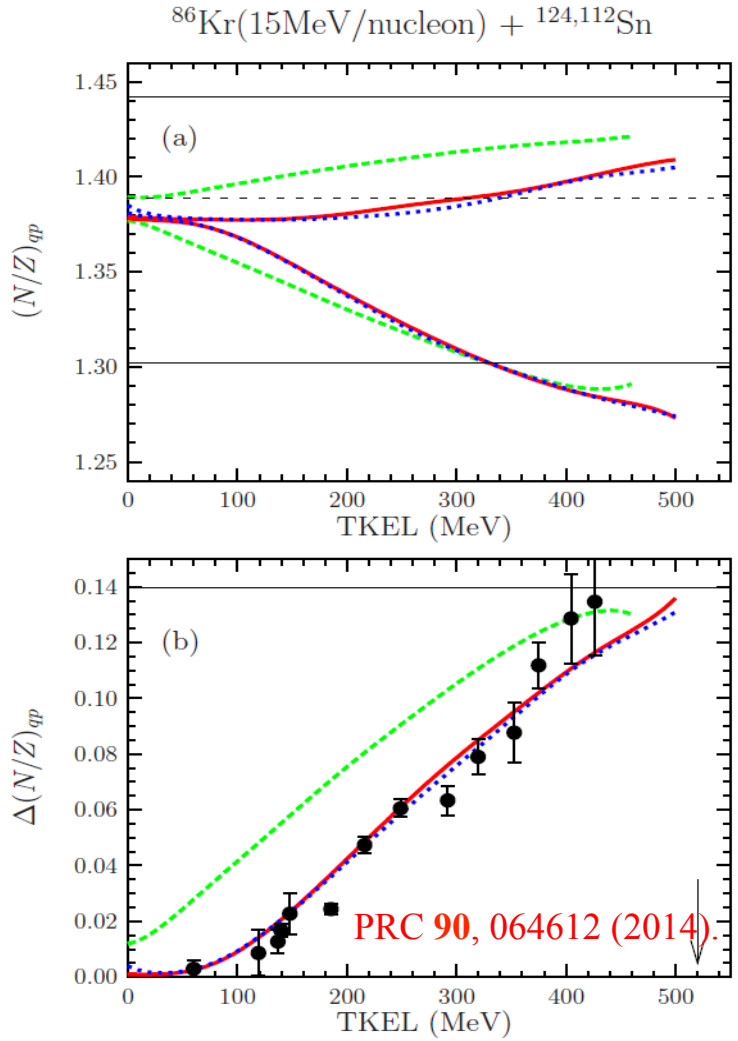
Bao-An Li, C. M. Ko, 1998

3. Isospin relaxation time varies with beam energy …

Isospin transport in non-central collisions

35MeV/u 36Ar + 112,124Sn 5° PLB 538 (2002) 39





→ Clearly, N/Z varies with kinetic energy, The isospin degree of Freedom not equilibrated .

4. the equilibration is not as fast as the separation of the incident partners at very peripheral collisions with small energy damping.

$$j_{n/p} = D_I \nabla I$$

All these diverse conclusions are associated with the isospin diffusion under varying conditions…

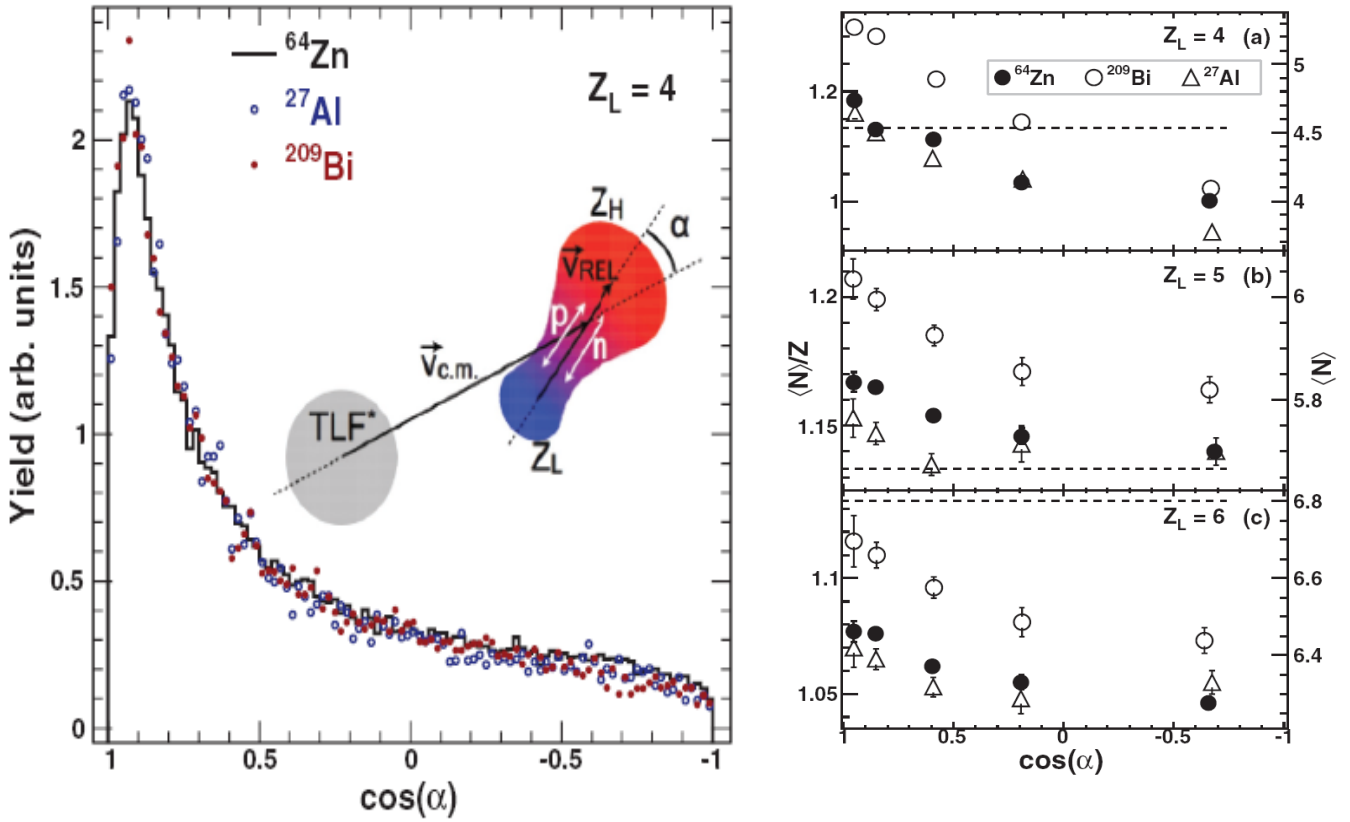
As long as Isospin Drift is at work

As long as isospin drift is at work, more variant pictured can be viewed.

$$j_{n/p} = D_\rho \nabla \rho$$

S. Hudan *et al*., Phys. Rev. C **86**, 021603(R) (2012).
K. Brown *et al*., Phys. Rev. C **87**, 061601(R) (2013).

See Jedele's talk.



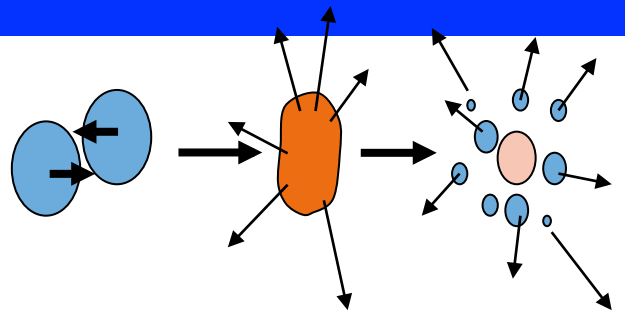
Hudan et al, Phys Rev C87 (2013) 061601(R)

Motivation 1: How long it takes for the IDOF to be equilibrated? How about the longer process? Whether the equilibration shall be associated to a certain process?

A shopping list for sub-saturation density

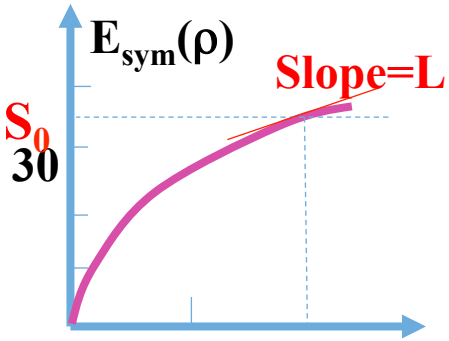
At sub-saturation densities

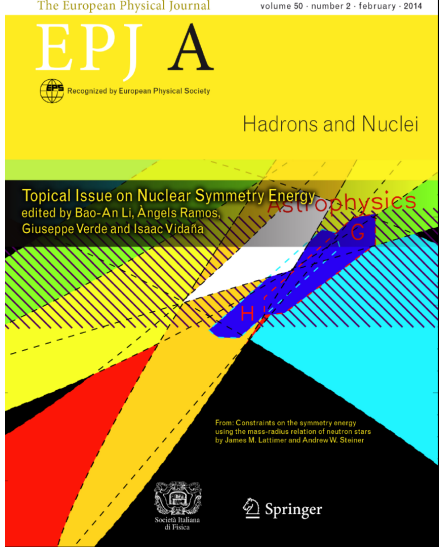
- → **Isospin scalaring and isospin fractionaiton** (MSU…)
- → **Isospin diffusion** (MSU …)
- → **n/p ratio of fast and pre-equilibrium nucleons** (MSU …)
- → **N/Z of the emitted fragments** (LNS, TAMU, MSU, HIRFL …)
- → **GMR strength** (ND …)
- → **HBT correlation function** (KVI, MSU, HIRFL …)
- → …. ….

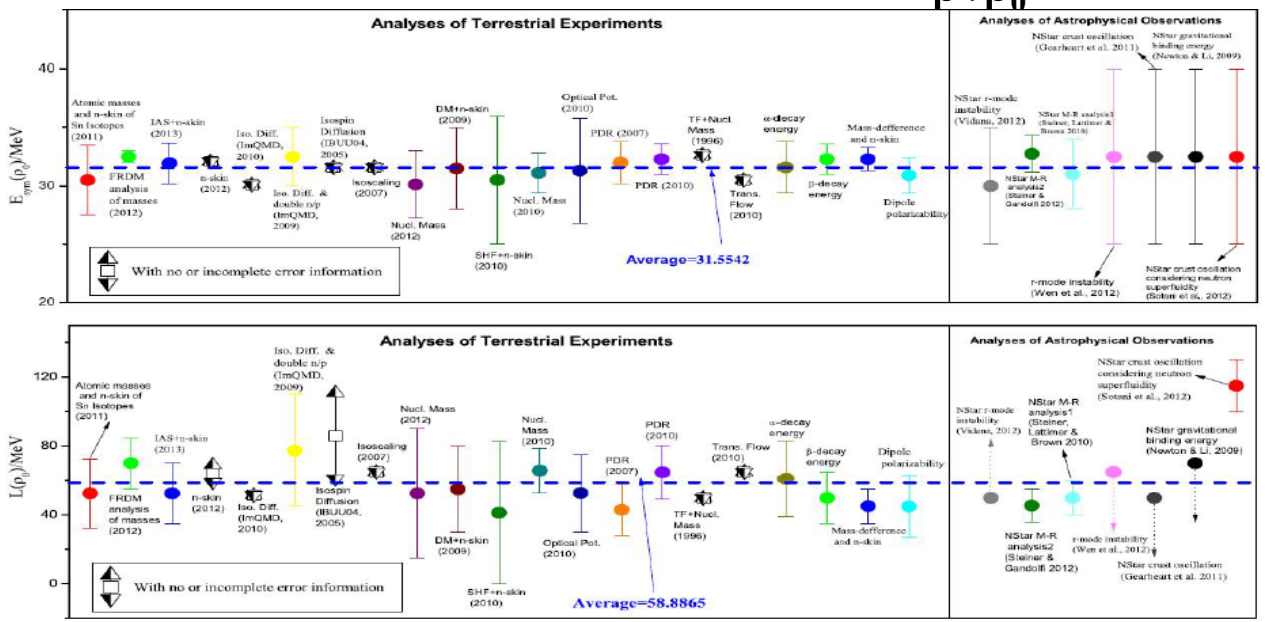


S_0 = 32±3 MeV

L = 55±25 MeV







Motivation 2: To identify an observable in a process where isospin drift is at work to constrain the $E_{sym}(\rho)$?

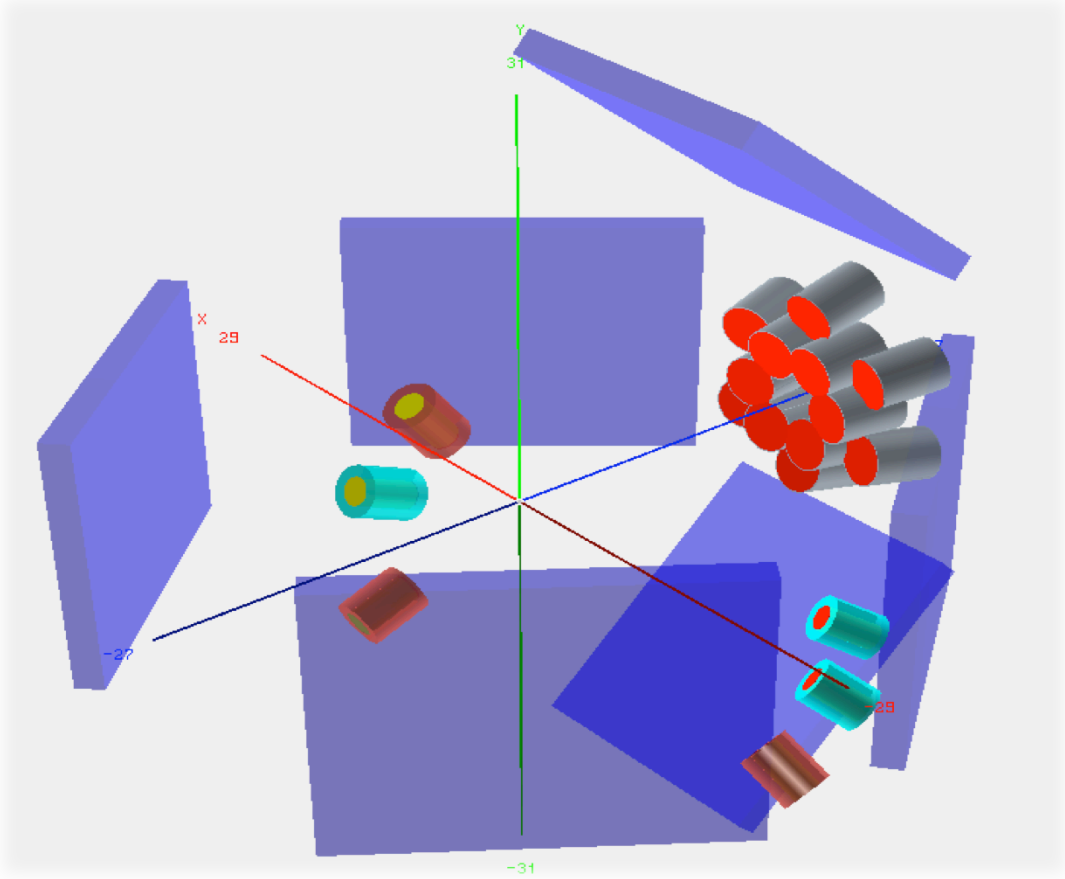
→ Long time accumulation of the work done by isovector force

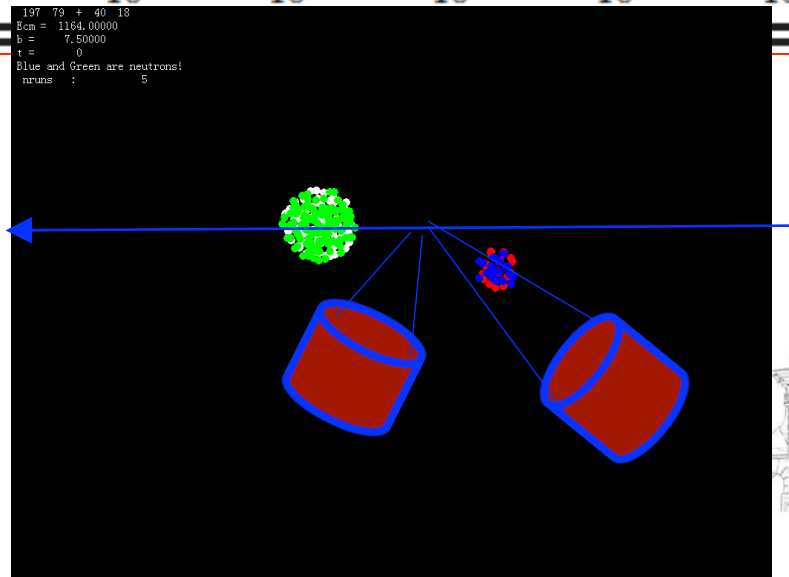
2. 35 MeV/u Ar+Au fission reactions

- 35 MeV/u Ar+ Au.
- Trigger: 2 fold fragments .AND. 1 LCP
- 2 fold fragments .AND. 1 Proj.-like

TABLE I: The parameters of the 6 LCP telescopes

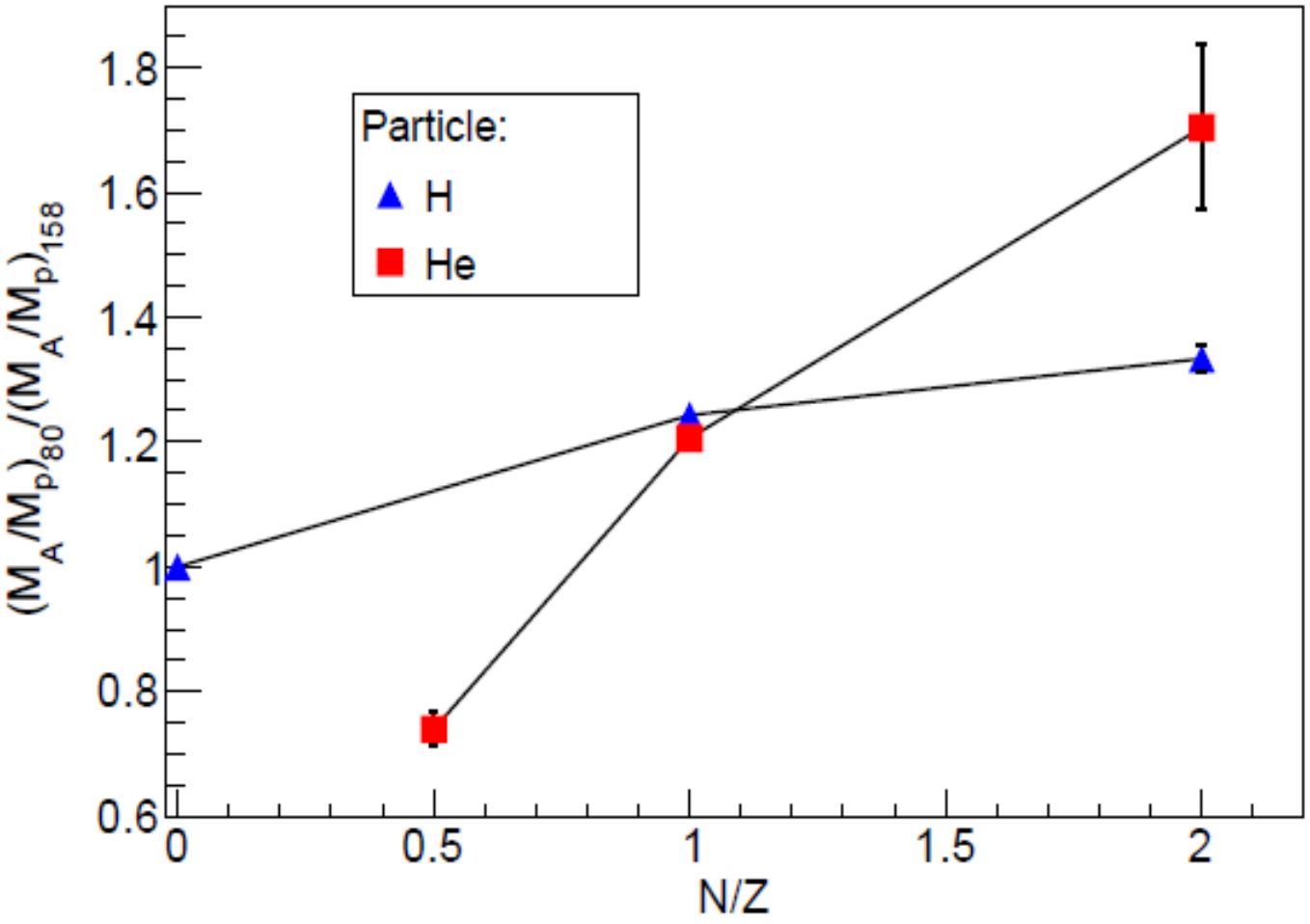
Tele. No.	1	2	3	4	5	6
d (mm)	12.0	10.2	10.4	14.0	14.0	14.0
L (cm)	11.5	11.5	11.5	26.0	21.6	28.5
θ (°)	158	155	127	80	59	44
ϕ (°)	-90	90	90	-145	-139	-133
ΔE_1 (μm)	50	50	50	50	50	50
ΔE_2 (μm)	400	/	400	400	/	/
E_{CsI} (mm)	40	40	40	40	40	40

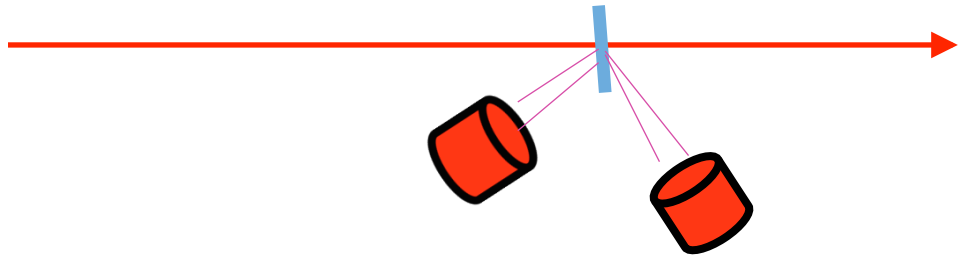




R. S. Wang, Y. Zhang, XZG et al., PRC89 (2014) 064613

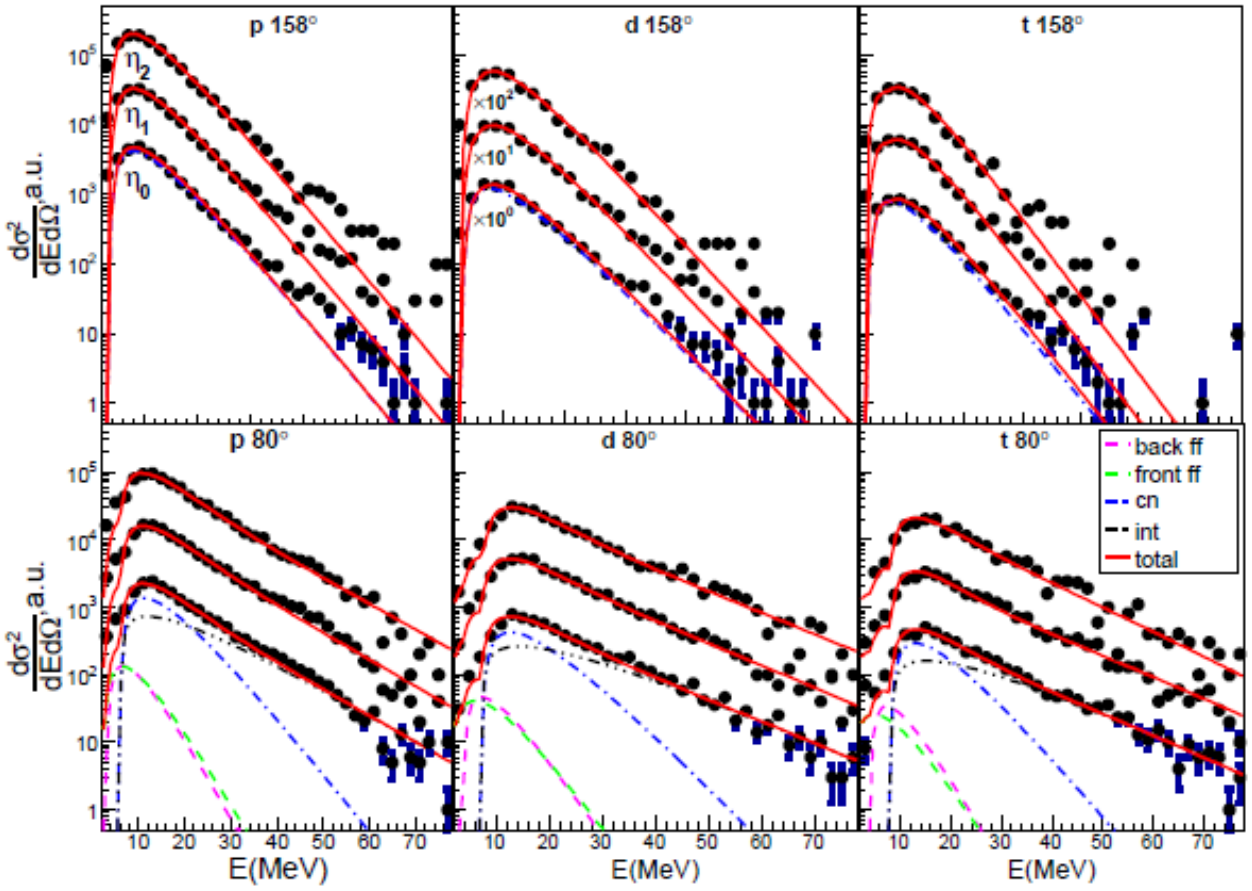
Double angular ratio of particle yield



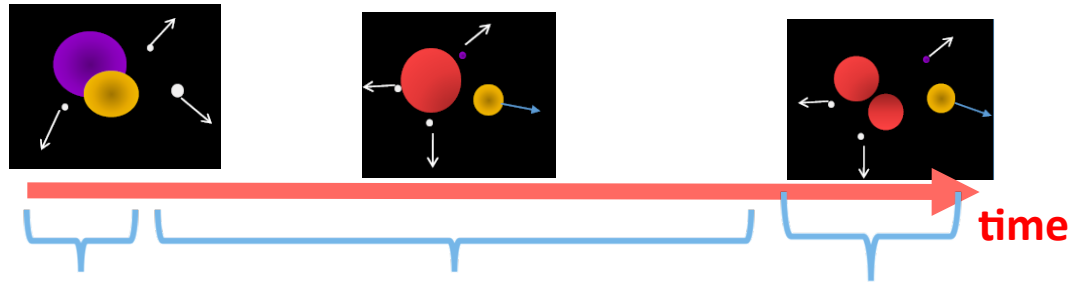


- Model independently, particles emitted at smaller angle are more neutron rich
- Smaller angle emitted particles experience more dynamical contribution

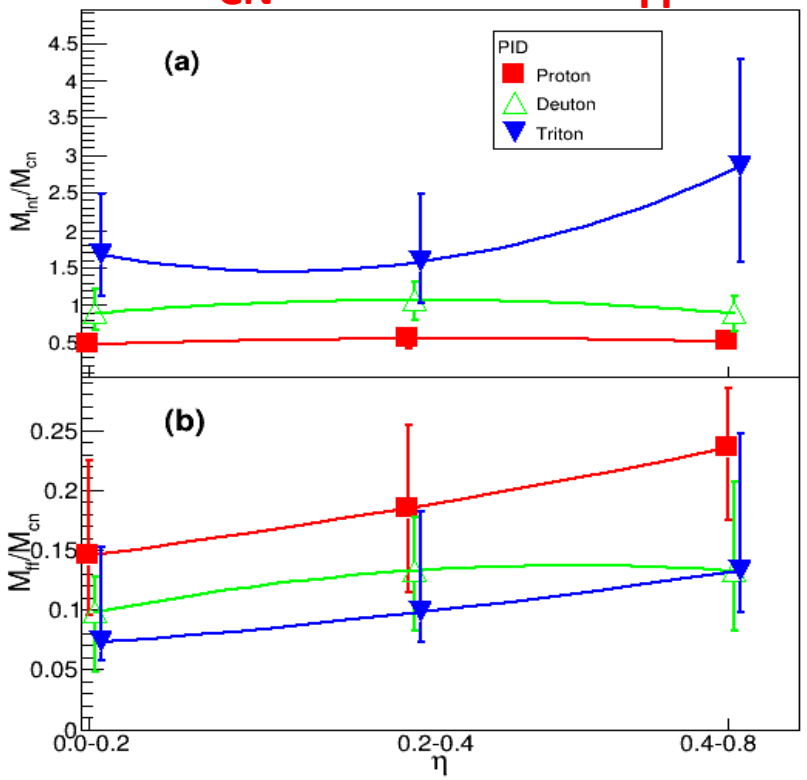
Energy spectra analysis vs mass asymmetry



- Three moving source: Int. Velocity, CN, FF



Int. Velo. CN FF



→ M_{ff}/M_{cn} vs. M_{inv}/M_{cn}

→The two ratios show different hierarchy

→ **The particles emitted in early stage are neutron rich!**

Translate the time evolution into angular distribution

time

counts

1

2

$\tau_1 < \tau_2$

$V_1^{cm} > V_2^{cm}$

Time

$$\langle\tau\rangle = n\downarrow 1\ \tau\downarrow 1 + n\downarrow 2\ \tau\downarrow 2\ /\ n\downarrow 1 + n\downarrow 2$$

<τ>

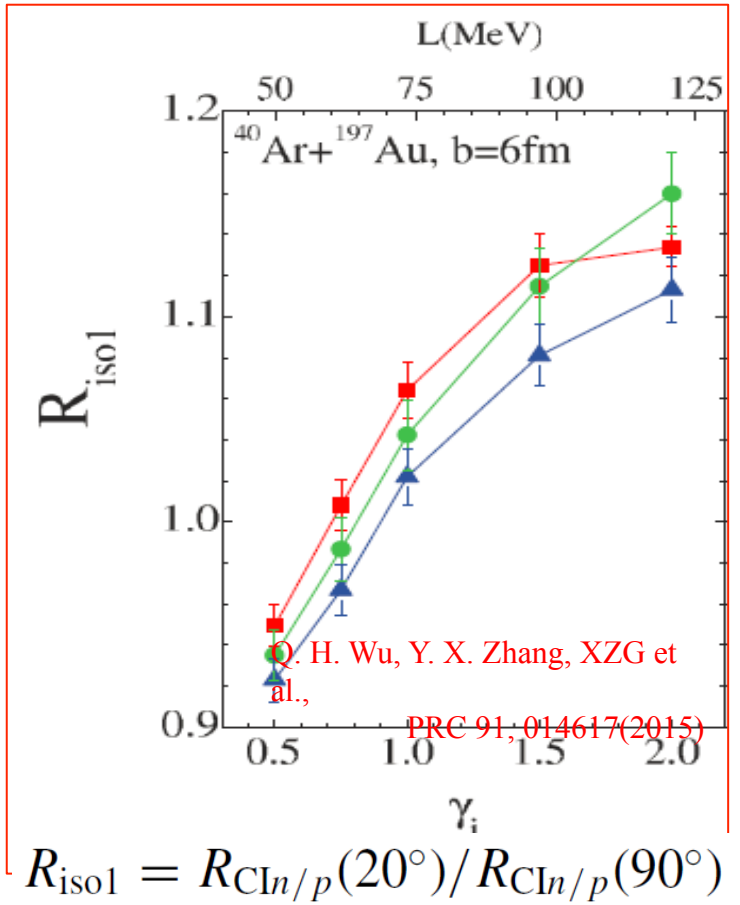
θ_{LAB}

counts

θ_{LAB}

<N/Z>

θ_{LAB}



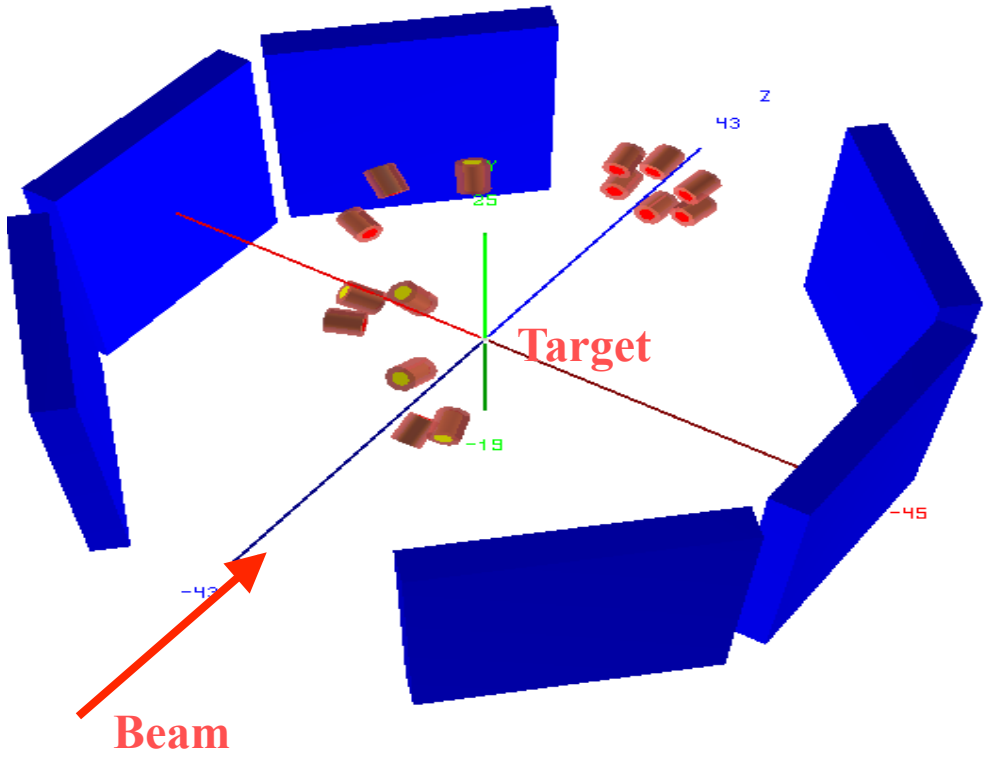
Q. H. Wu, Y. X. Zhang, XZG et al., PRC 91, 014617(2015)

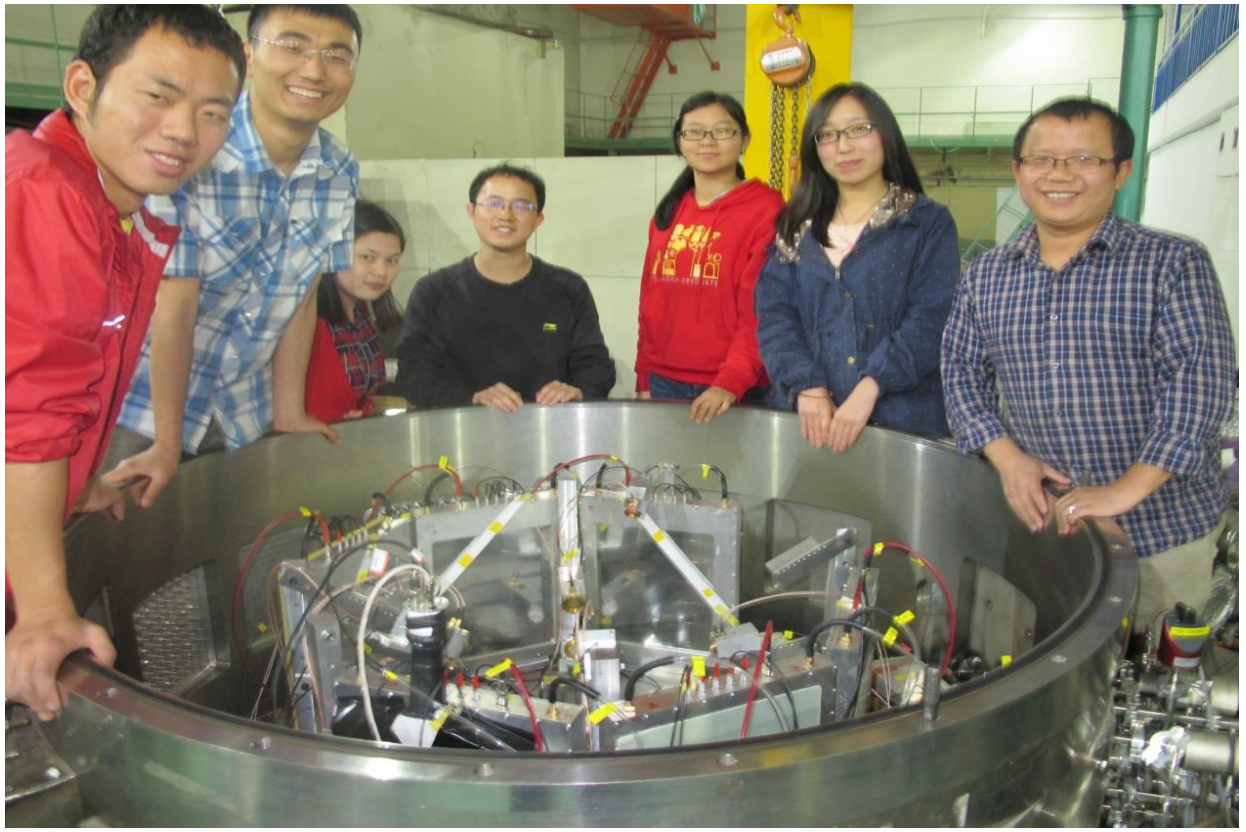
$$R_{iso1} = R_{CIn/p}(20°)/R_{CIn/p}(90°)$$

1 Angular Distribution Reflects the Average Emission Time

2 Stiffer $E_{sym}(\rho)$ results in faster N/Z fractionation → Stiffer angular distribution

3. 30 MeV/u Ar+Au fission reactions

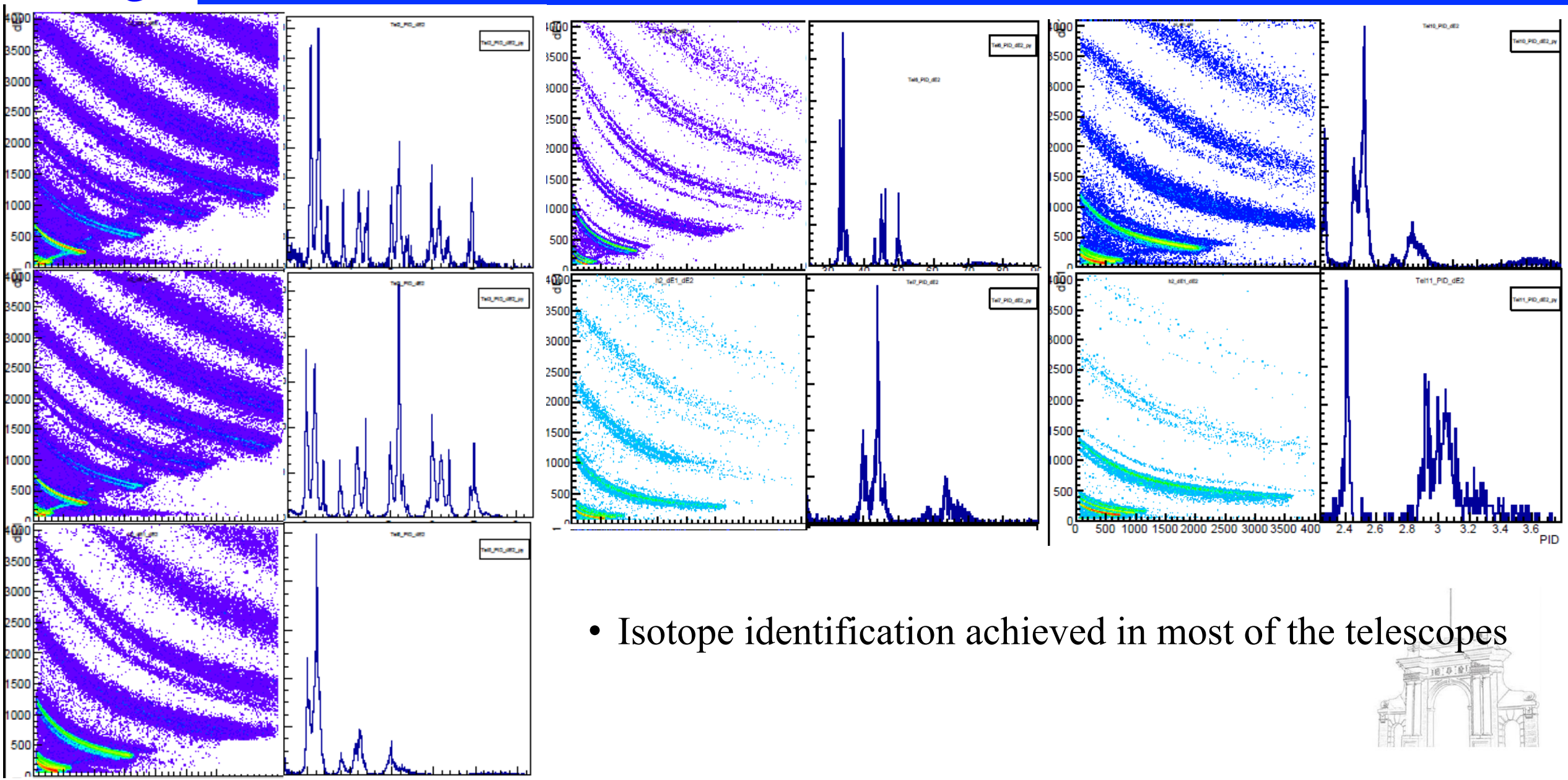




- **Complete in June 2014.**

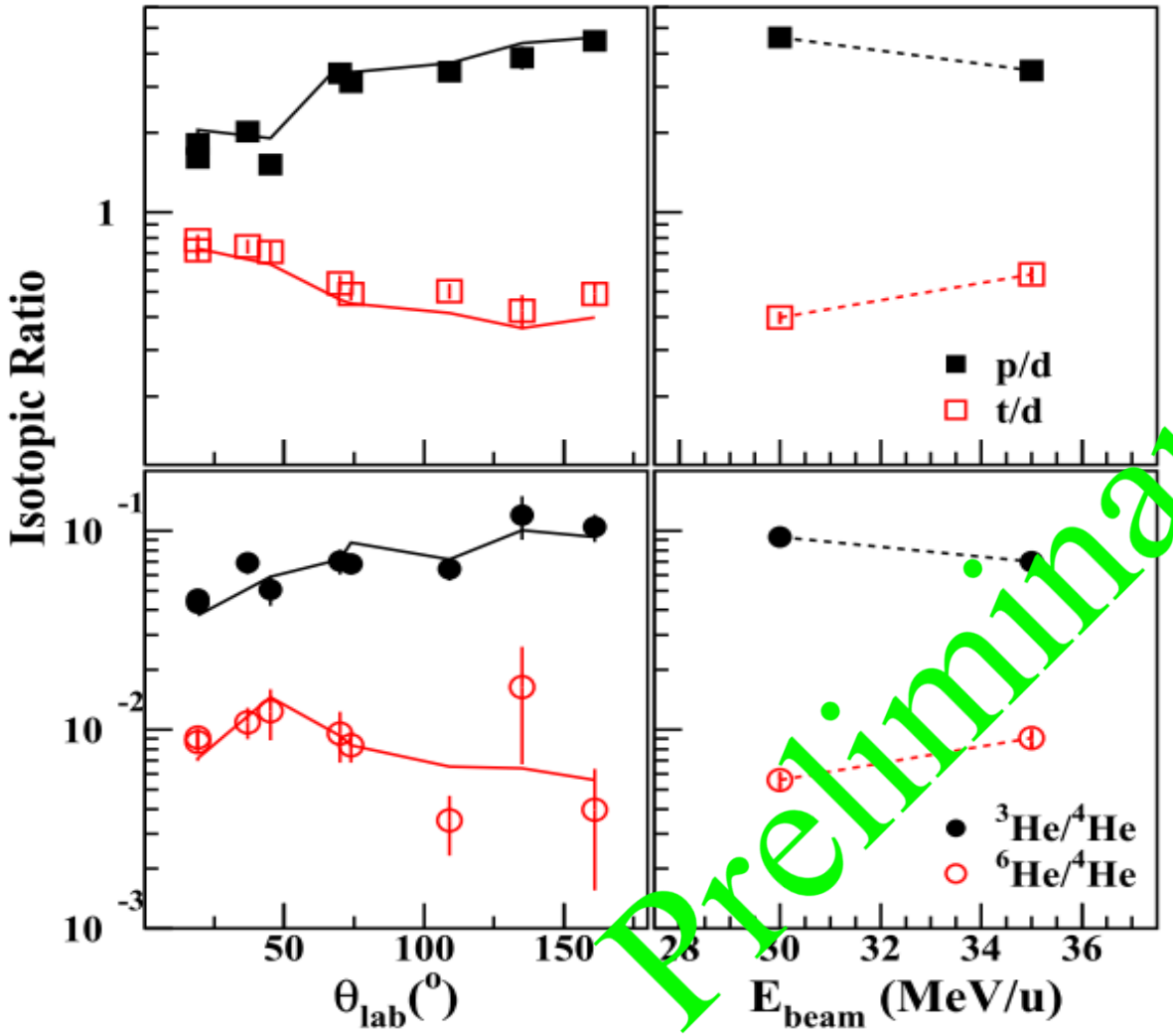
1. Improved PID by using H.Q. telescopes
2. Lower energy threshold
3. More Detectors(> 5 positions)

Telescope Performance



- Isotope identification achieved in most of the telescopes

Angular Distribution



- Angular Distribution:

→Smaller angle corresponds to earlier emission

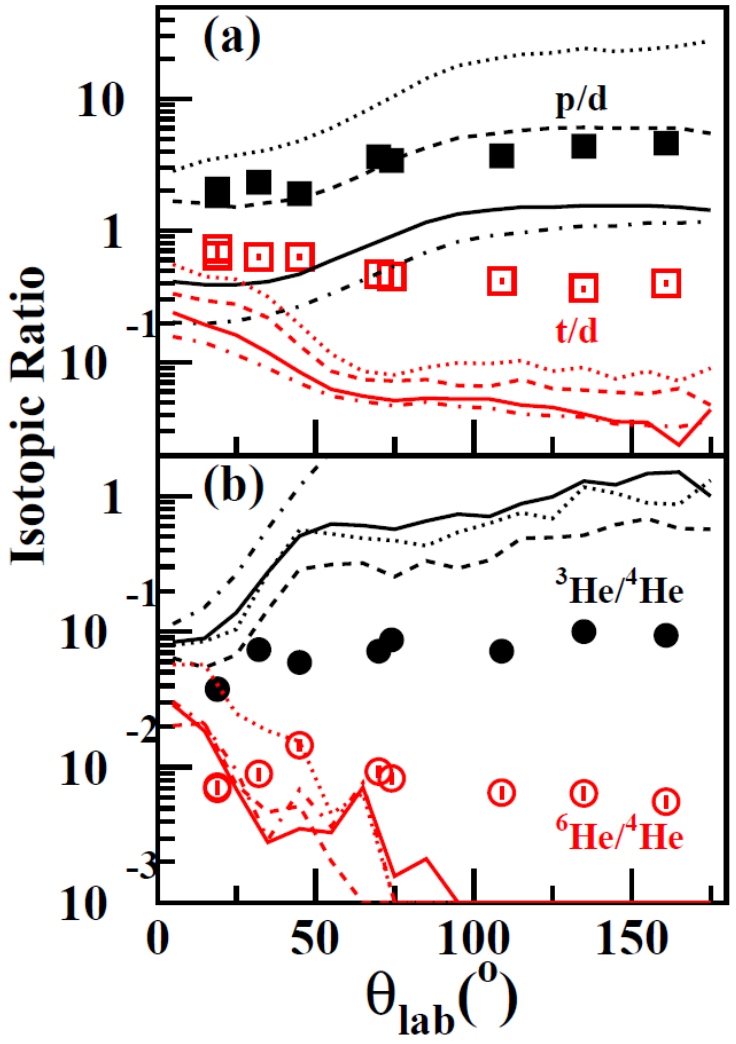
→Higher neutron richness at small angles

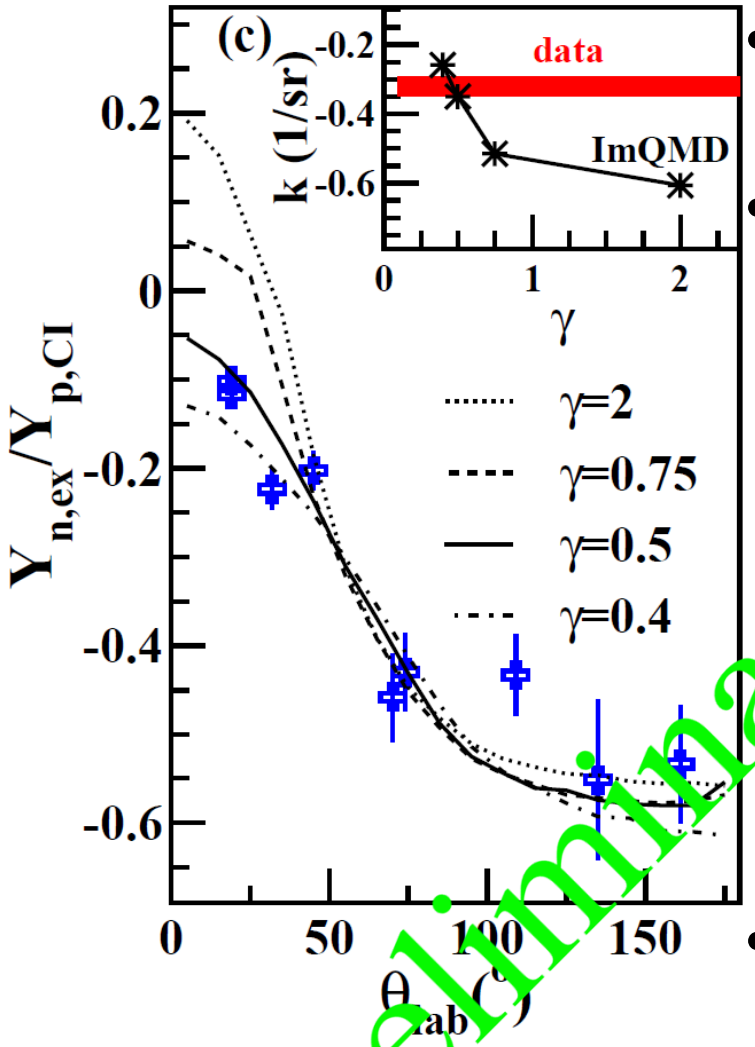
→Long time scale of isospin drift is evidenced.

→ Neutron richness in gas higher than liquid drop, and with the temperature decreasing, the neutron richness decreases.

Yan Zhang， Junlong Tian et al., in preparation

ImQMD Calculations





- →Trend of Angular distribution is reproduced.
- →Relative decreasing rate of the neutron richness with angle can differentiate $E_{sym}(\rho)$.

$$\frac{Y_{n,ex}}{Y_{p,CI}} = \frac{\sum y_i (N_i - Z_i)}{\sum y_i Z_i}$$

- →A soft $E_{sym}(\rho)$ with γ=0.45-0.5, or L=45-50 MeV, is favored by the data.

Preliminary

4. Summary

- Confirmed in 35 MeV/u Ar+Au: the effect of $E_{sym}(\rho)$ persists to long time, and an isospin-dependent emission hierarchy is observed as neutron rich particles are emitted relatively earlier.

- In 30 MeV/u Ar+Au reaction: the neutron richness of the LCPs decreases with the emitting angle in laboratory over a wide range accessible in experiment and with the beam energy at large angle, underlining the long timescale of isospin drift process which refers to the transport of IDOF from the high density region (liquid phase) to the low density region (vapor phase)..

- Detailed comparison with transport model IMQMD+GEMINI calculation reveals that a soft $E_{sym}(\rho)$ with γ=0.5 or L=45-50 MeV is favored.

Thank you for your attention!