The 4th Asian Triangle Heavy Ion Conference

ATHIC 2012

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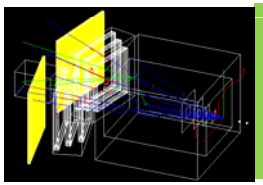
Asymmetrical nuclear EOS study with CEE

XIAO Zhigang

Department of Physics, Tsinghua university



CEE: CSR External target Experiment

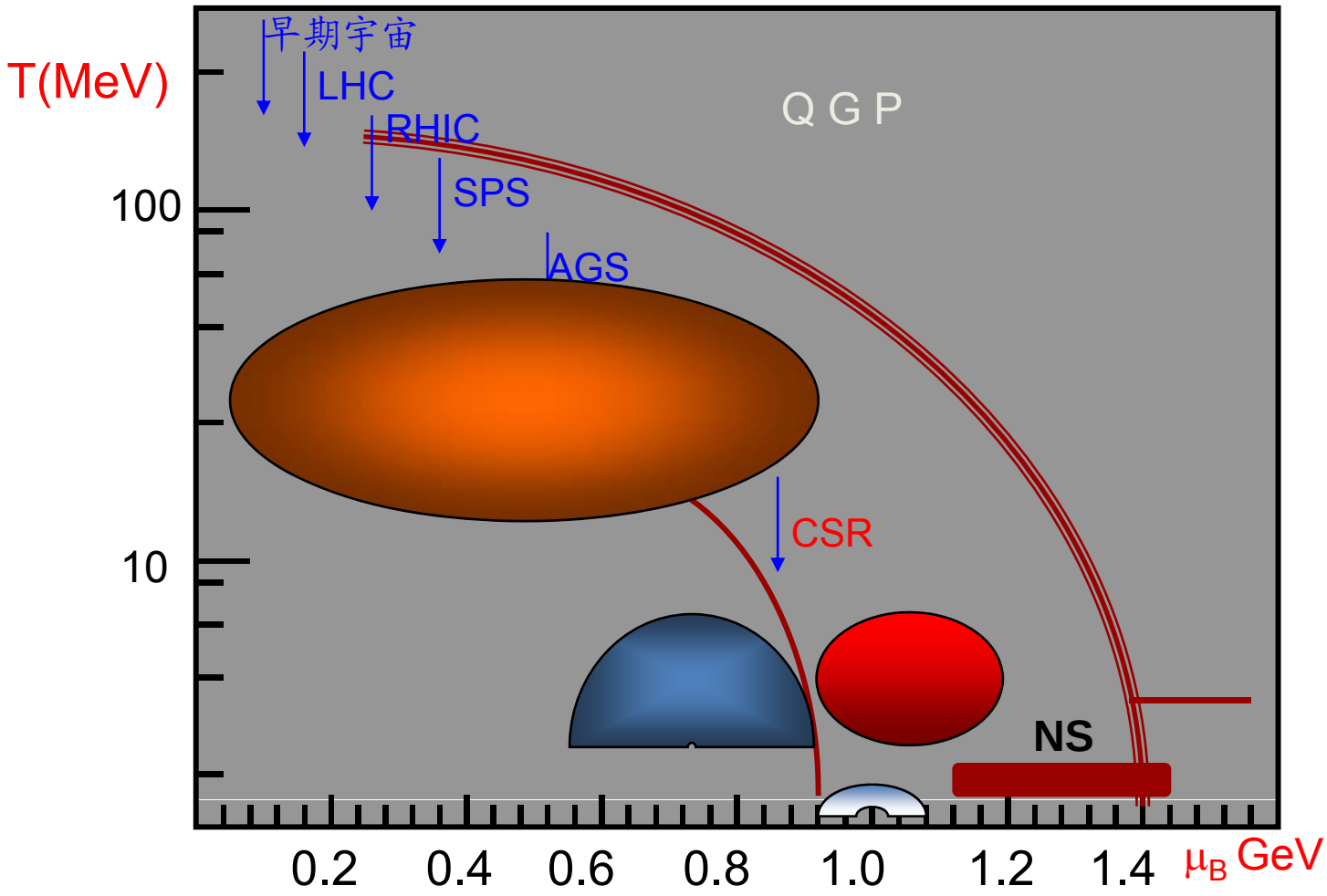
Collaboration institutions:

Peking University
Central China Normal University
Institute of Modern Physics, CAS
University of Science and Technology of China
Shanghai Institute of Applied Physics, CAS
Lanzhou University
Shandong University

Content

- Physics Motivation
- CEE Setup and R&D
- Summary

Nuclear Equation of State



Key Problems:

→To Look for the matter of new degree of freedom

→To understand the properties of QM, HM or NM

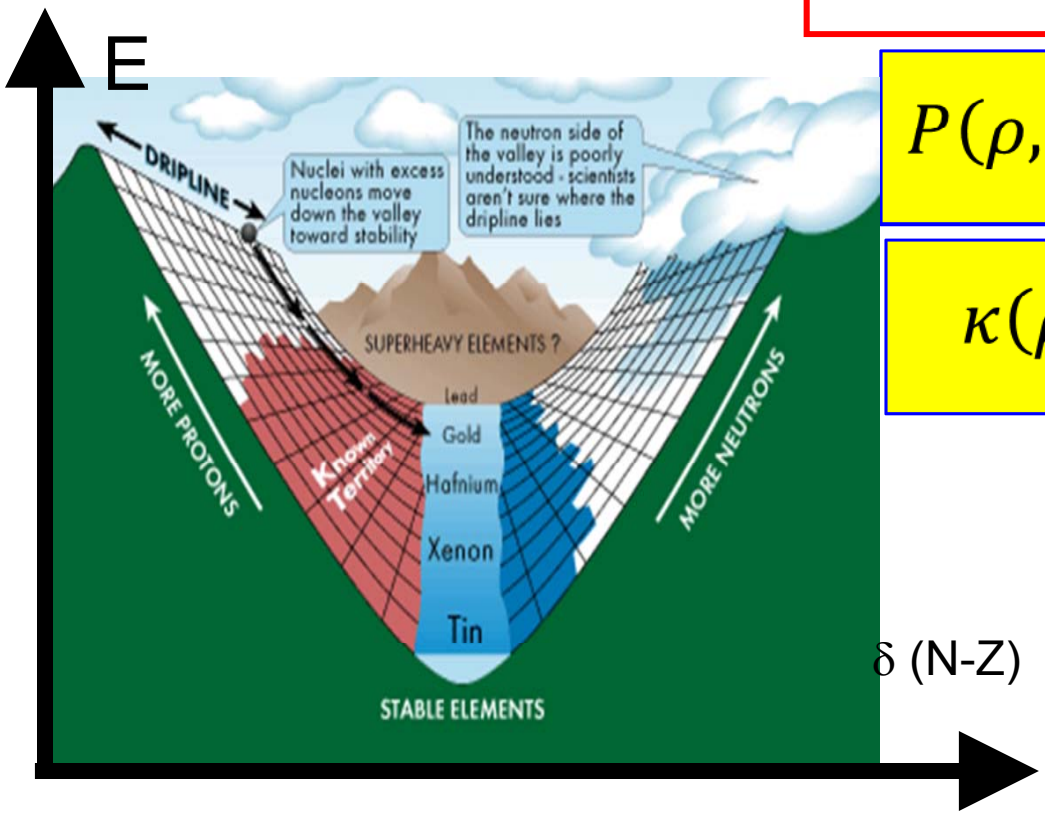
→To Understand the Phase Transition

Equation of State of nucleonic matter:

$$E(\rho,\delta)=E_0(\rho)+\delta^2 E_{sym}(\rho)=a_V+\frac{\kappa}{18}\varepsilon^2-\frac{\kappa^2}{162}\varepsilon^3+\ldots+\delta^2\left(E_{sym}+\frac{L}{3}\varepsilon+\ldots\right)$$

κ:Compressibility

E_{sym}



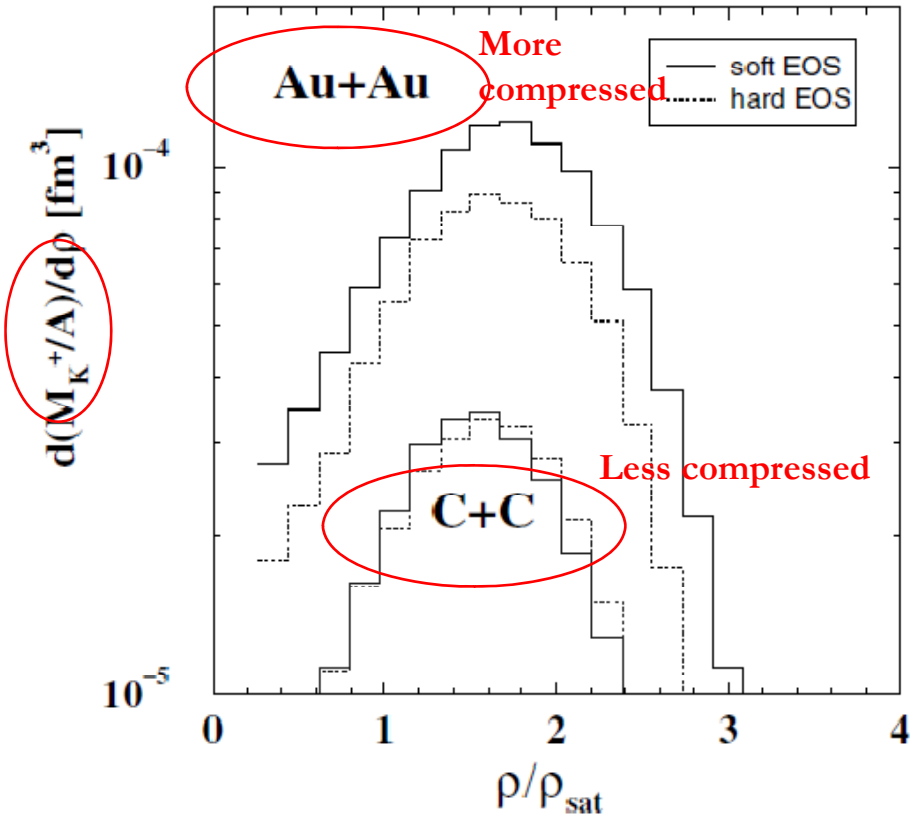
$$P(\rho,T,\delta)=\rho^2\left(\frac{\partial E/A}{\partial\rho}\right)_{T,N=const}$$

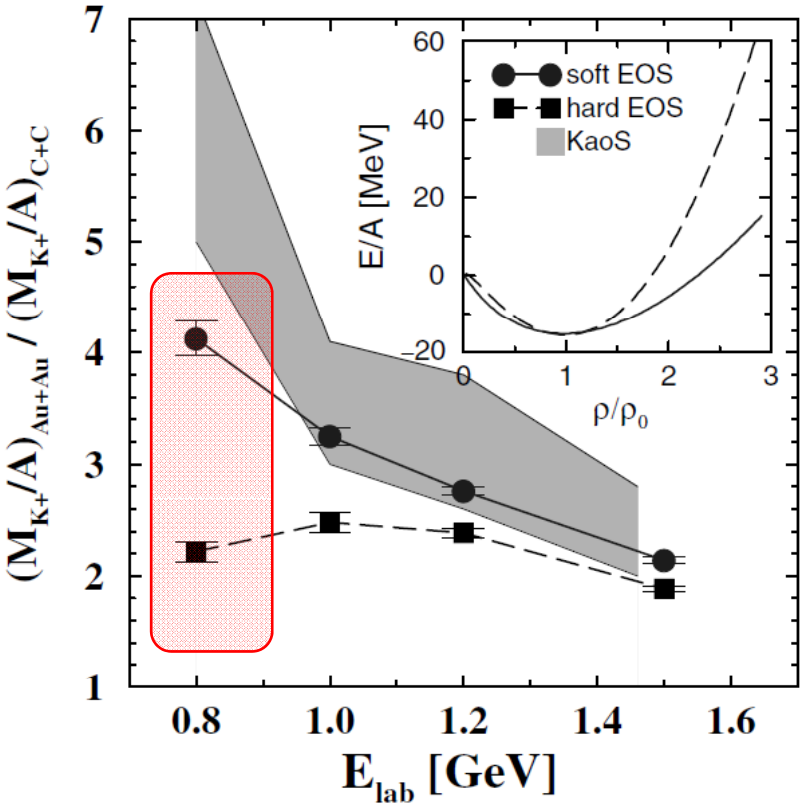
$$\kappa(\rho,T,\delta)=9\left(\frac{\partial P}{\partial\rho}\right)_{T,N=const}$$

$$E_{sym}(\rho)=E_{sym}(\rho_0)\left(\frac{\rho}{\rho_0}\right)^{\gamma}$$

$$\delta=\frac{N-Z}{N+Z}$$

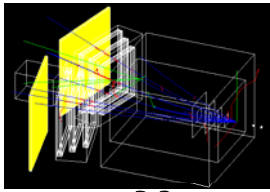
Compressibility of Symm. NM: K+ and κ



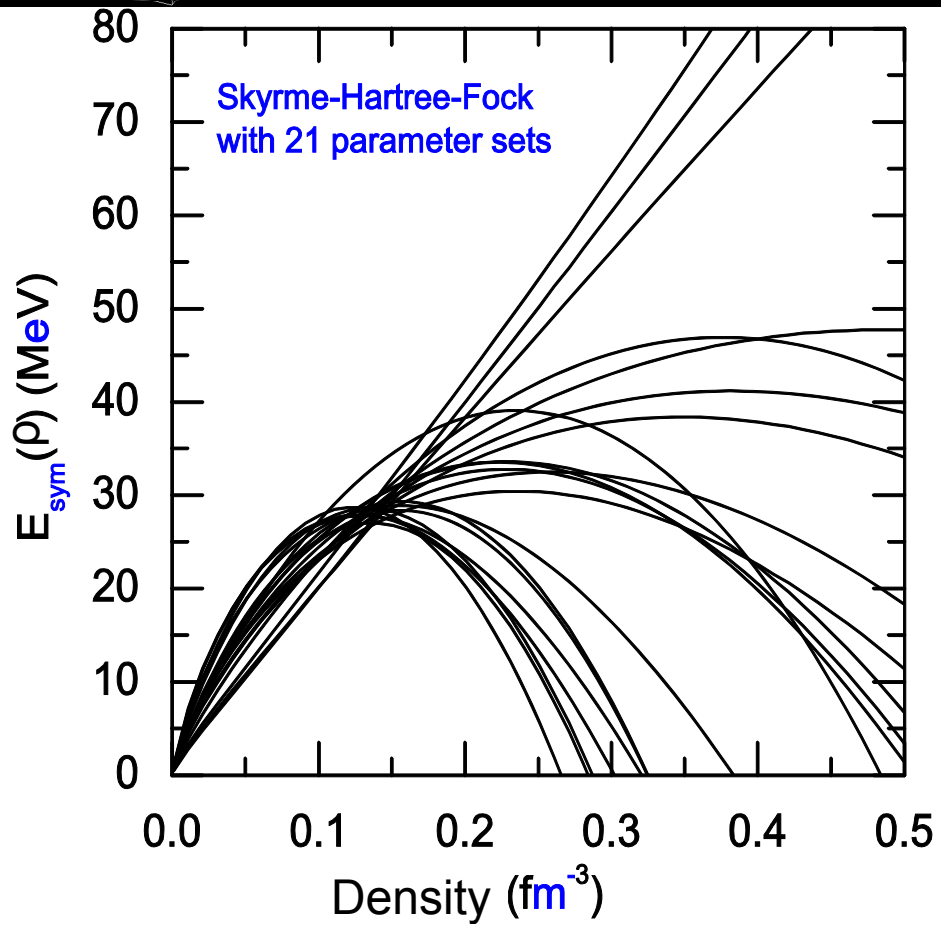


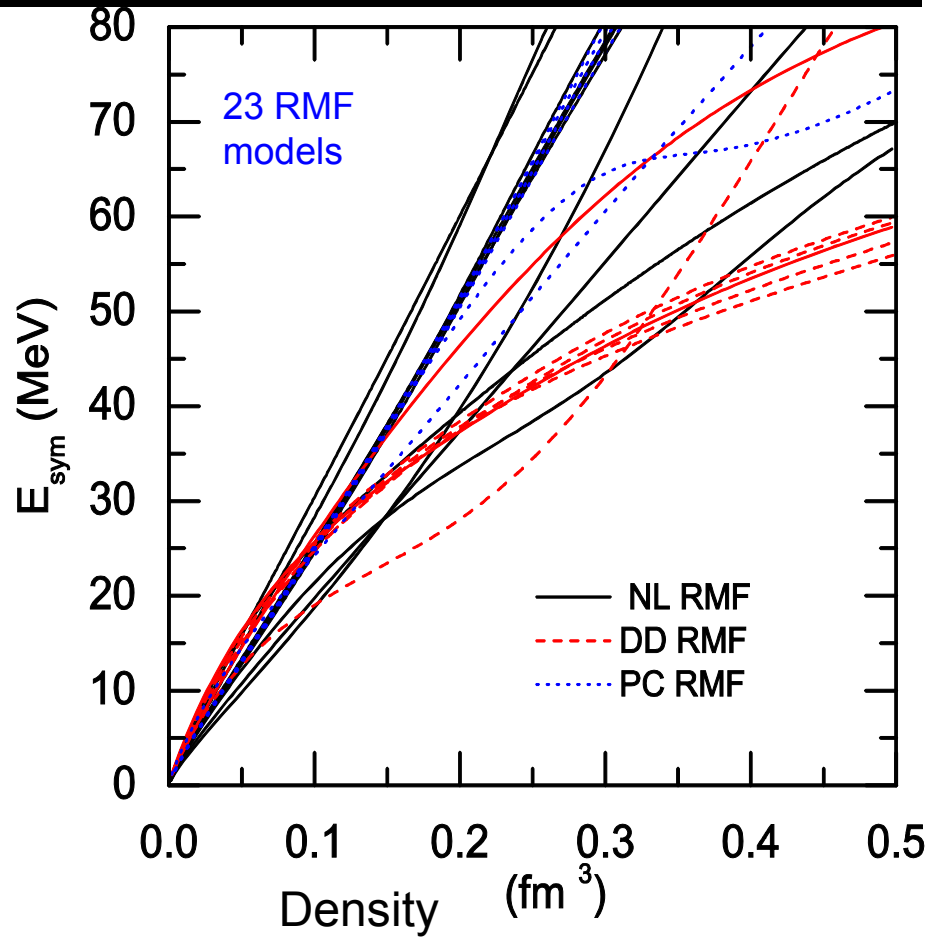
C. Fuchs et al., Phys. Rev. Lett 86, 1974 (2001)

- Nuclear Matter is soft



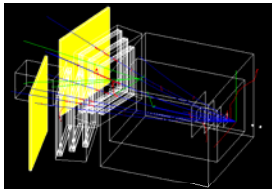
$E_{sym}(\rho)$ very uncertain at $\rho > \rho_0$





L.W. Chen, C.M. Ko and B.A. Li, Phys. Rev. C72, 064309 (2005); C76, 054316 (2007).

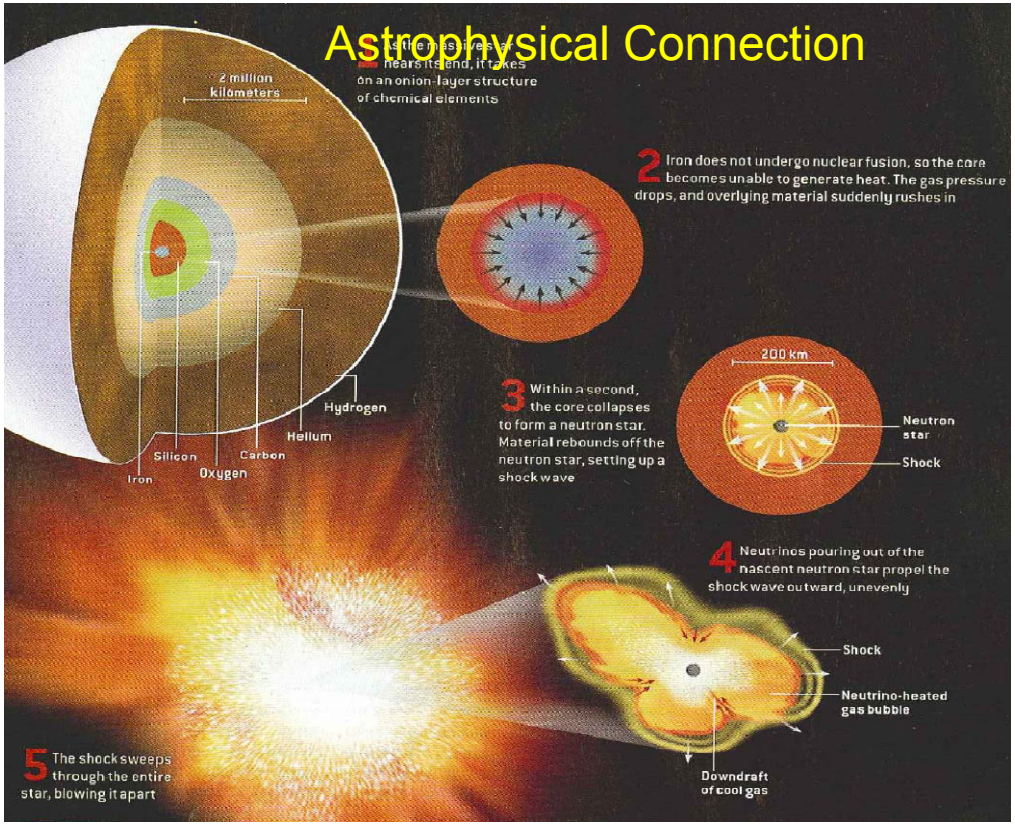
Probes: K^0/K^+, π^-/π^+, n/p differential flow ……

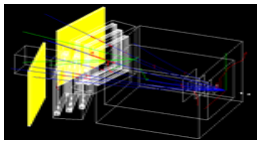


Importance of $E_{sym}(\rho)$ (I): an essential role in astrophysics

- Proton fraction
- M-R relation
- ρ_c for D-Urca
- Transition density
- ……

Phy. Rep. 442(2007) 109; NPA777(2006)479
PRC76(2007),025801; PRC75(2007) 015801
PRC74 (2006),035802; Astro. J. 676 (2008) 1170
Phy. Rep. 411(2005) 325; PLB 642, 436 (2006)
……



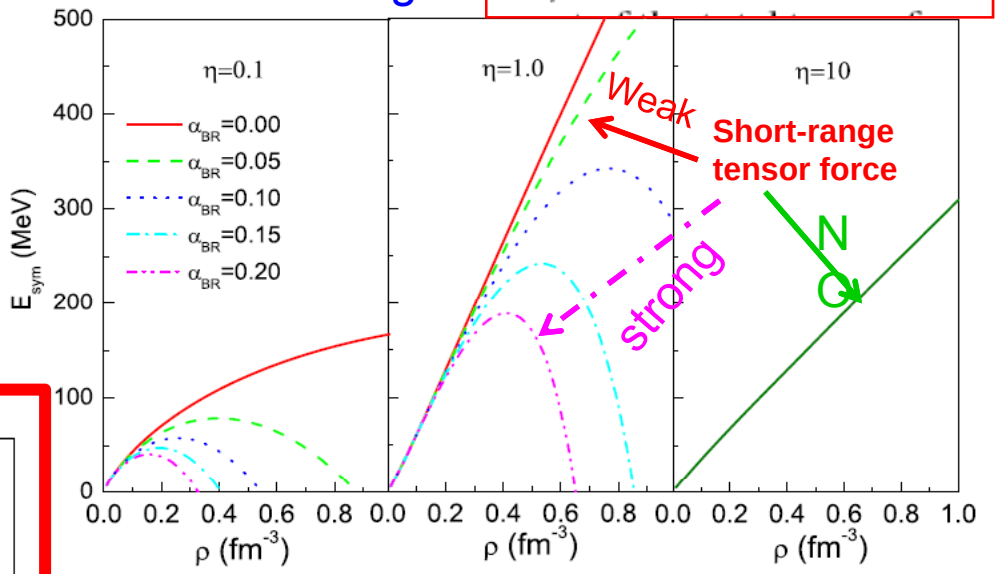


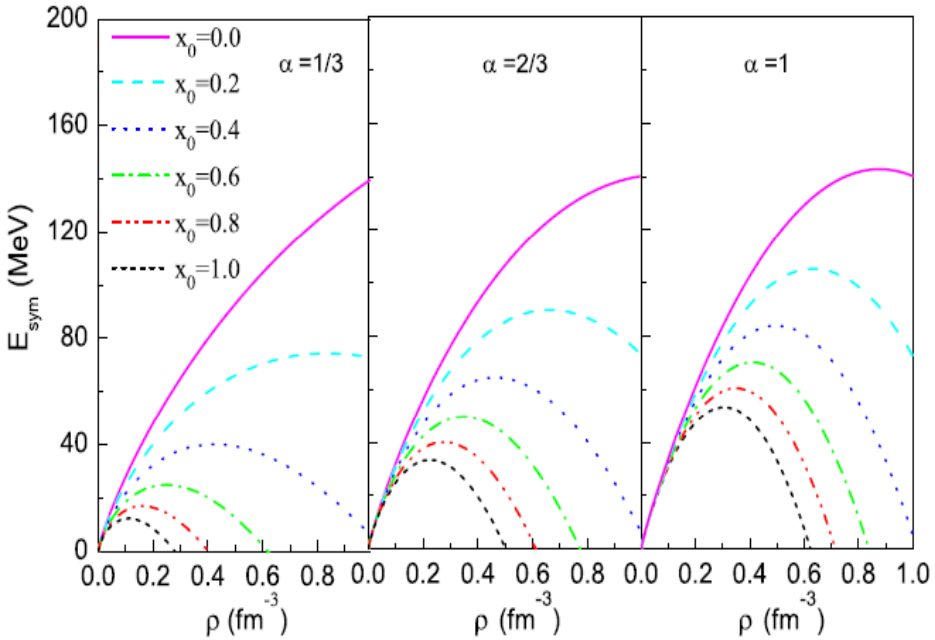
Importance of $E_{sym}(\rho)$ (II): Feature of nuclear force

- Tensor Force at short distance and isospin dependent NN correlation

When the **tensor force** due to ρ exchange in the T=0 channel dominates, E_{sym} is significantly influenced.

Brown Rho Scaling: $m_\rho^\star/m_\rho = 1 - \alpha_{\rm BR}\cdot\rho/\rho_0$



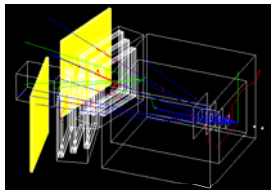


- Three-Body interaction

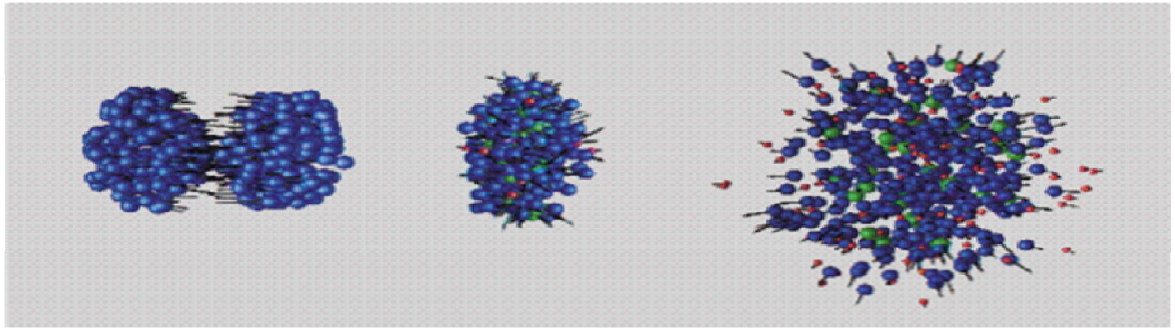
3-body force is reduced to effective 2 body force as:

$$V_d = t_0(1 + x_0 P_\sigma)\rho^\alpha \delta(r),$$

↑ C. Xu and Bao-An Li, PRC81, 064612 (2010).



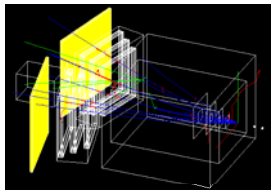
Experimental probes on $E_{sym}(\rho)$ at HICs



Towards to supra-saturation densities

- → π^-/π^+ ratio, K^+/K^0 ratio ……
- → n/p differential flow
- → n/p ratio of the squeezed out nucleons ⊥ the R.P.
- → n/p elliptic flow at high P_T
- → $t/^3He$ differential flow …

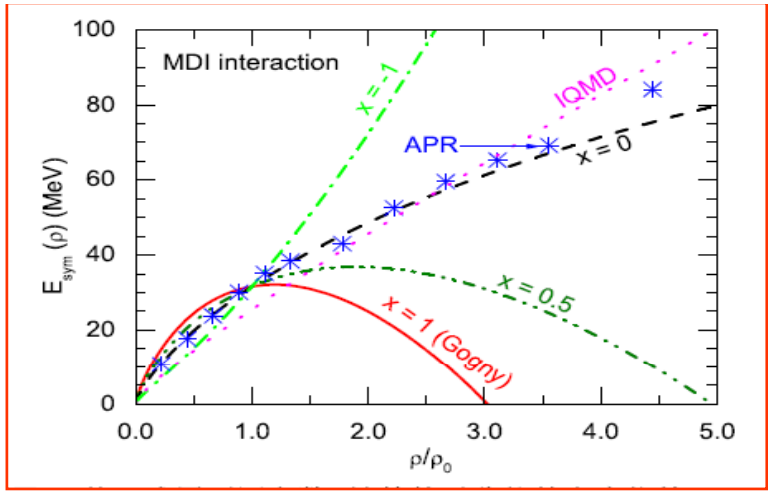
Complementary to each other.

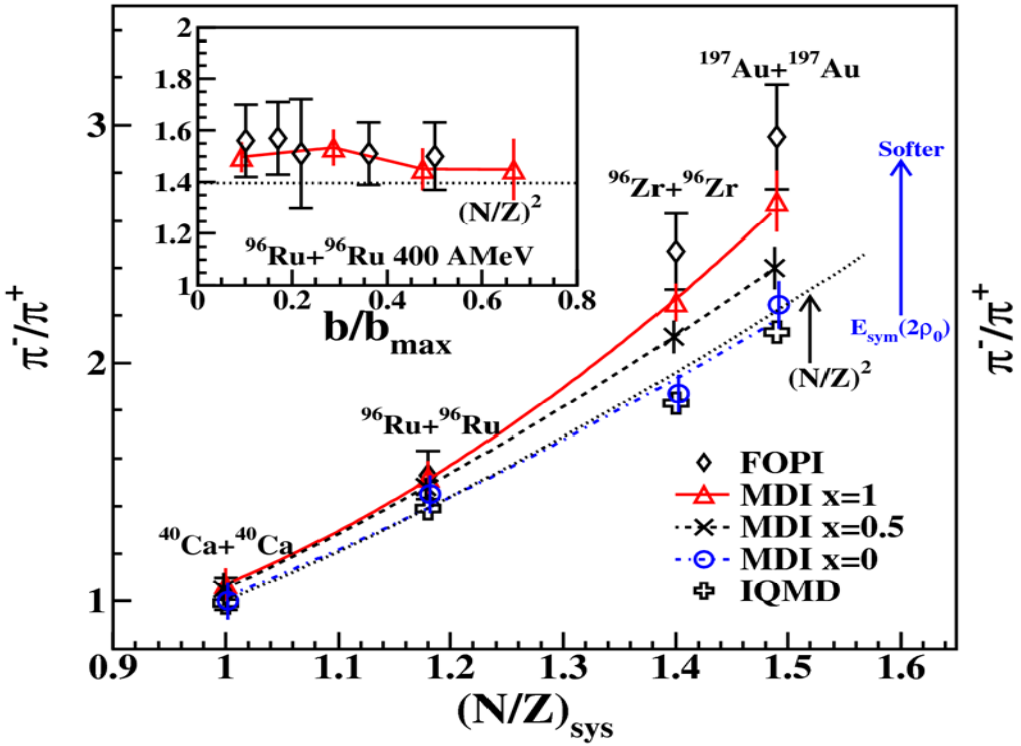


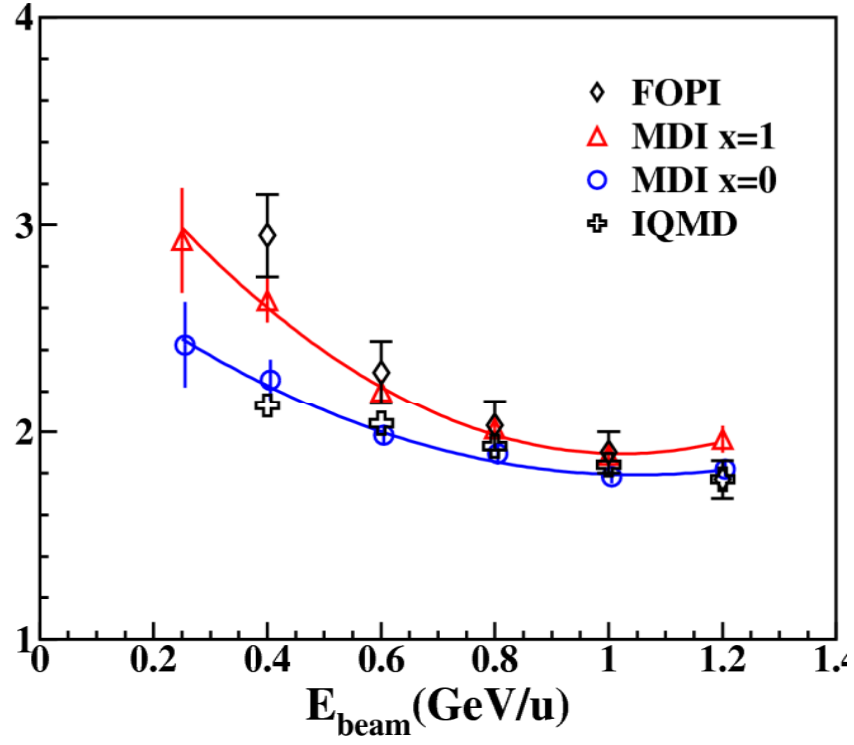
$E_{sym}(\rho)$ is soft?

A rather soft nuclear symmetry energy is more favored by FOPI data!!!

ZGX, B.A. Li et al., PRL 102 (2009) 062502



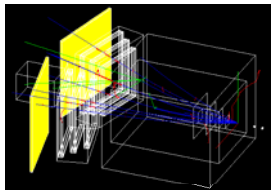




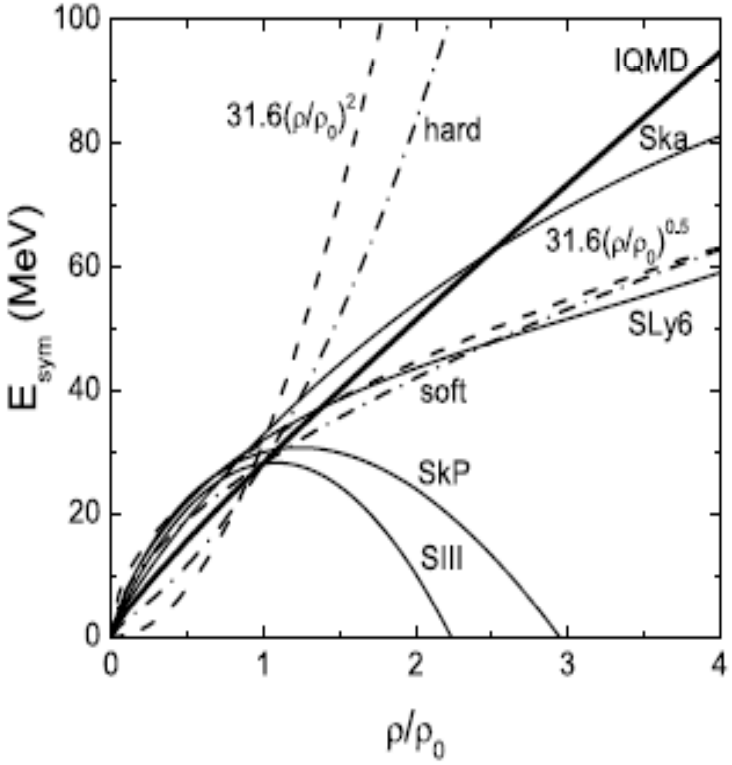
E_b>0.6GeV/u: Undistinguishable

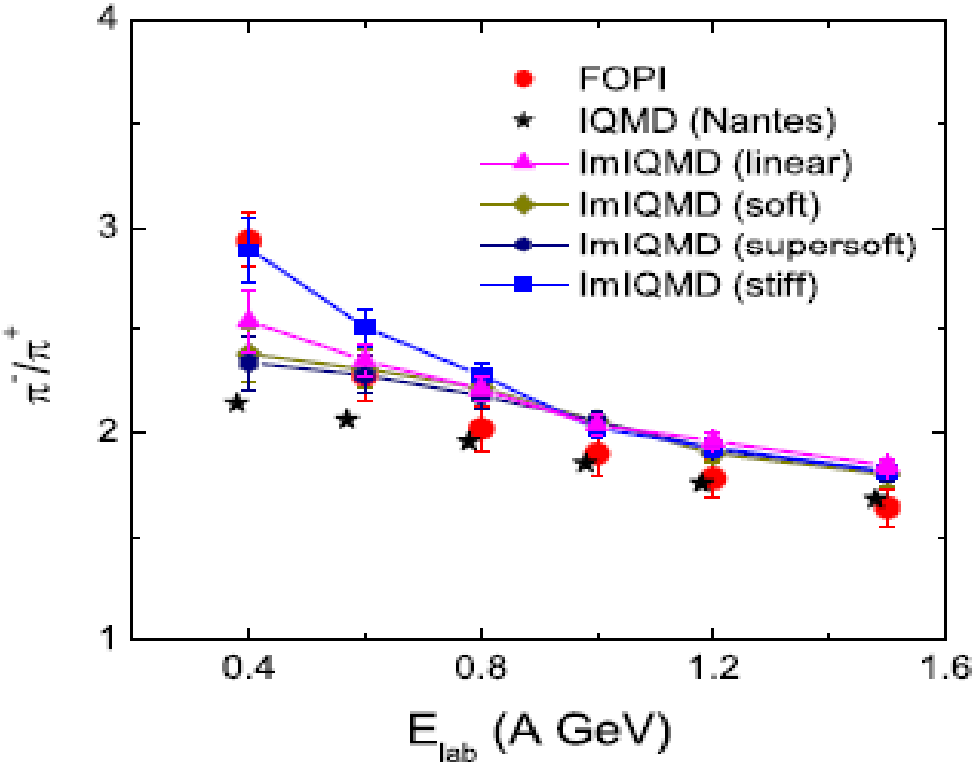
E_b<=0.6GeV/u: Distinguishable

Measurement of pion emissions at CSR energy range (<1GeV for HI) may helps to resolve the $E_{sym}(\rho)$!



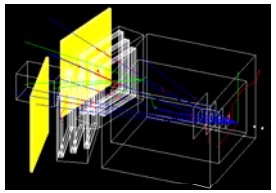
Different conclusion using the same data!





Feng ZQ, Jin GM, Physics Letters B 683 (2010) 140–144

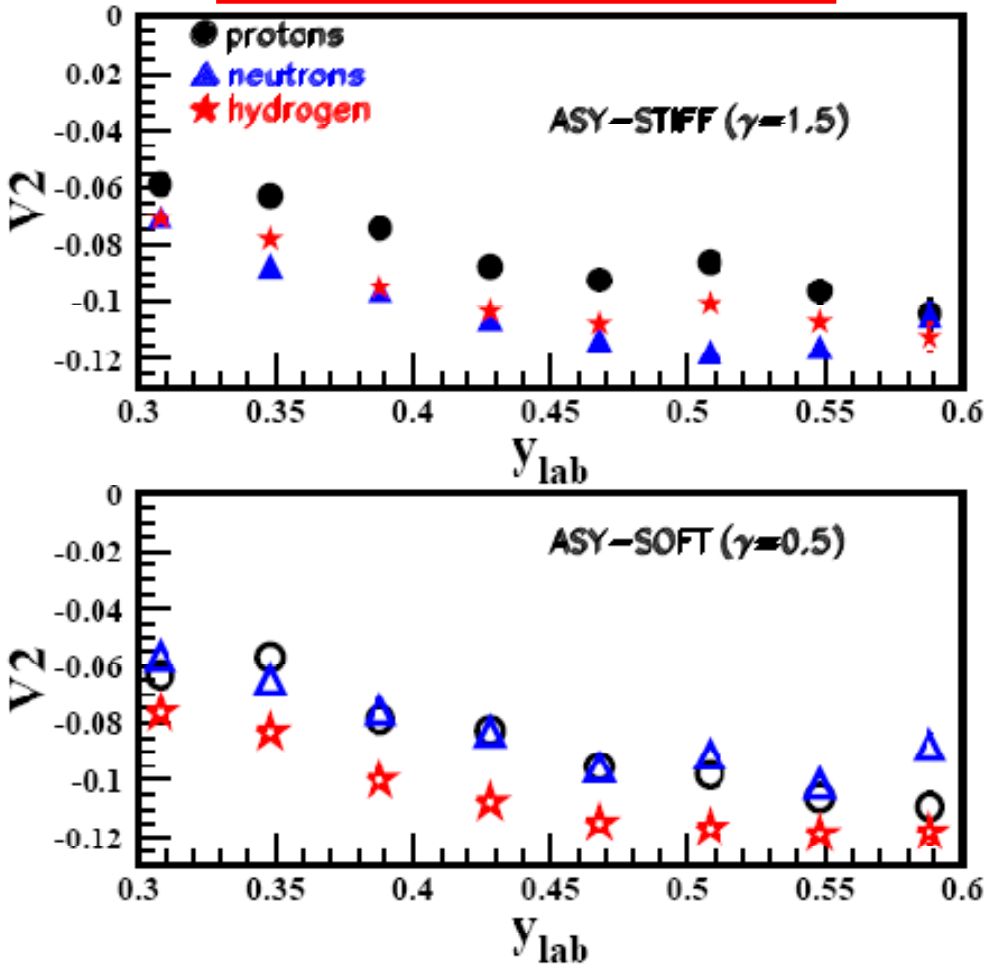
$E_{sym} \sim \rho^2$ Super stiff； Model Dependent Conclusion

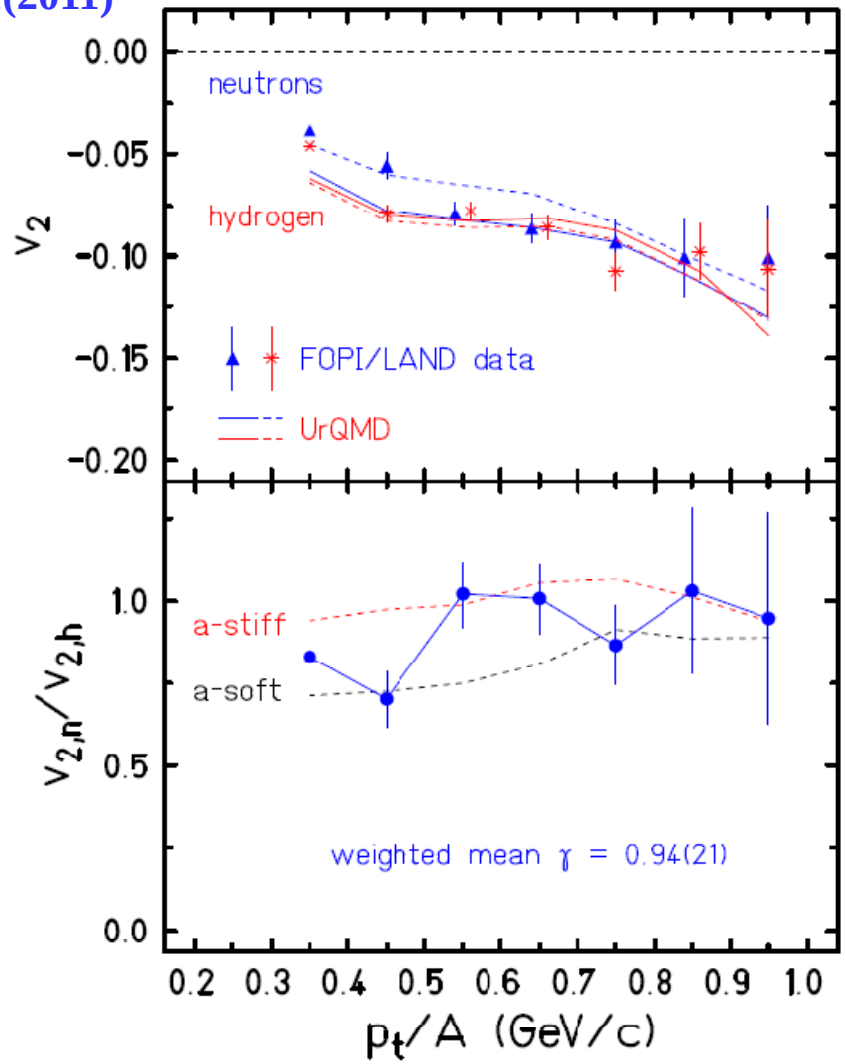


A 3rd conclusion using n/p differential flow

P. Russotto,W. Trauntmann, Q.F. Li et al., PLB697, 471(2011)

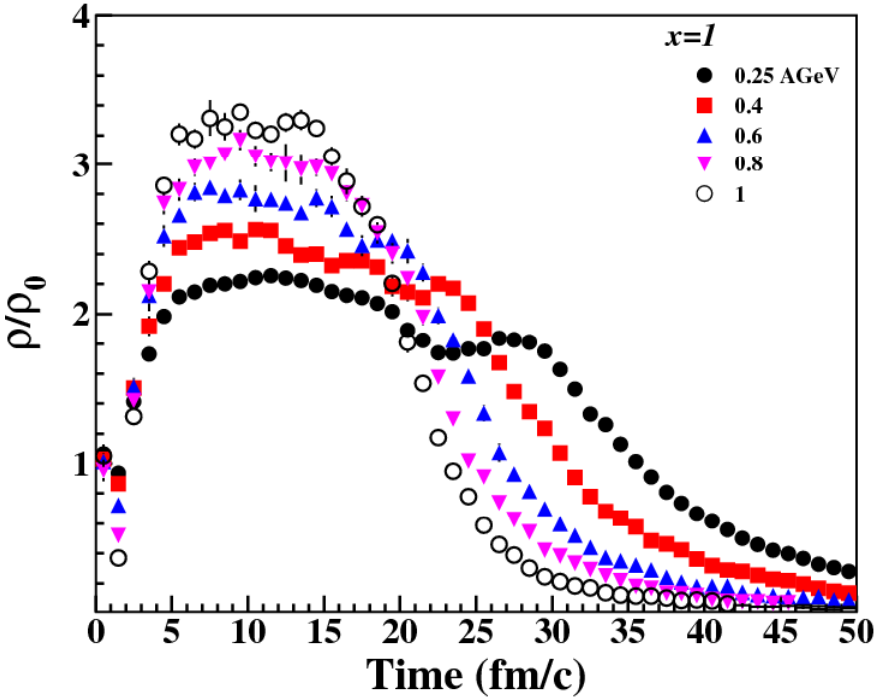
$(\rho/\rho_0)^\gamma$ with $\gamma = 0.9 \pm 0.4$

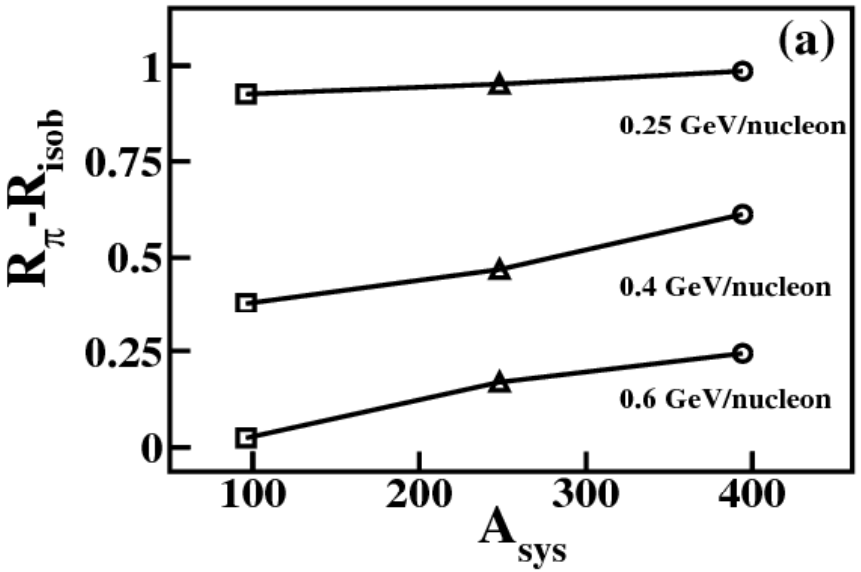


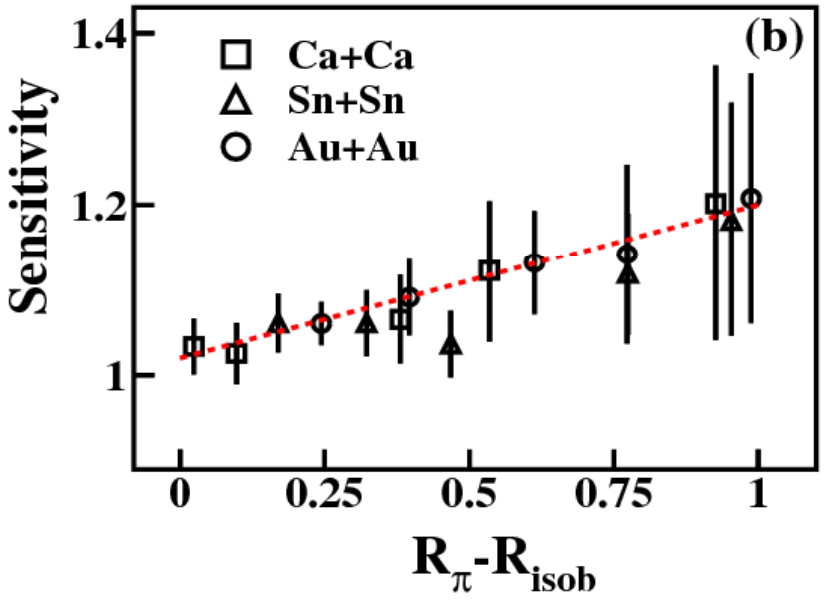


$E_{sym} \sim \rho^{0.94}$ Intermediate； Observable Dependent Conclusion

HIRFL-CSR energy regime: Favors EOS study





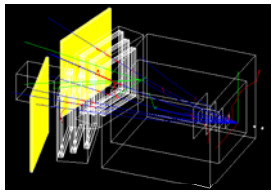


- $2\rho_0$ density achievable
- Sensitivity optimized in CSR energy regime

M. Zhang, ZGX et al., PRC 80 (2009) 034616
F. Fu ZGX et al, PLB 666 (2008) 359

Content

- Physics Motivation
- **CEE Setup and R&D**
- Summary



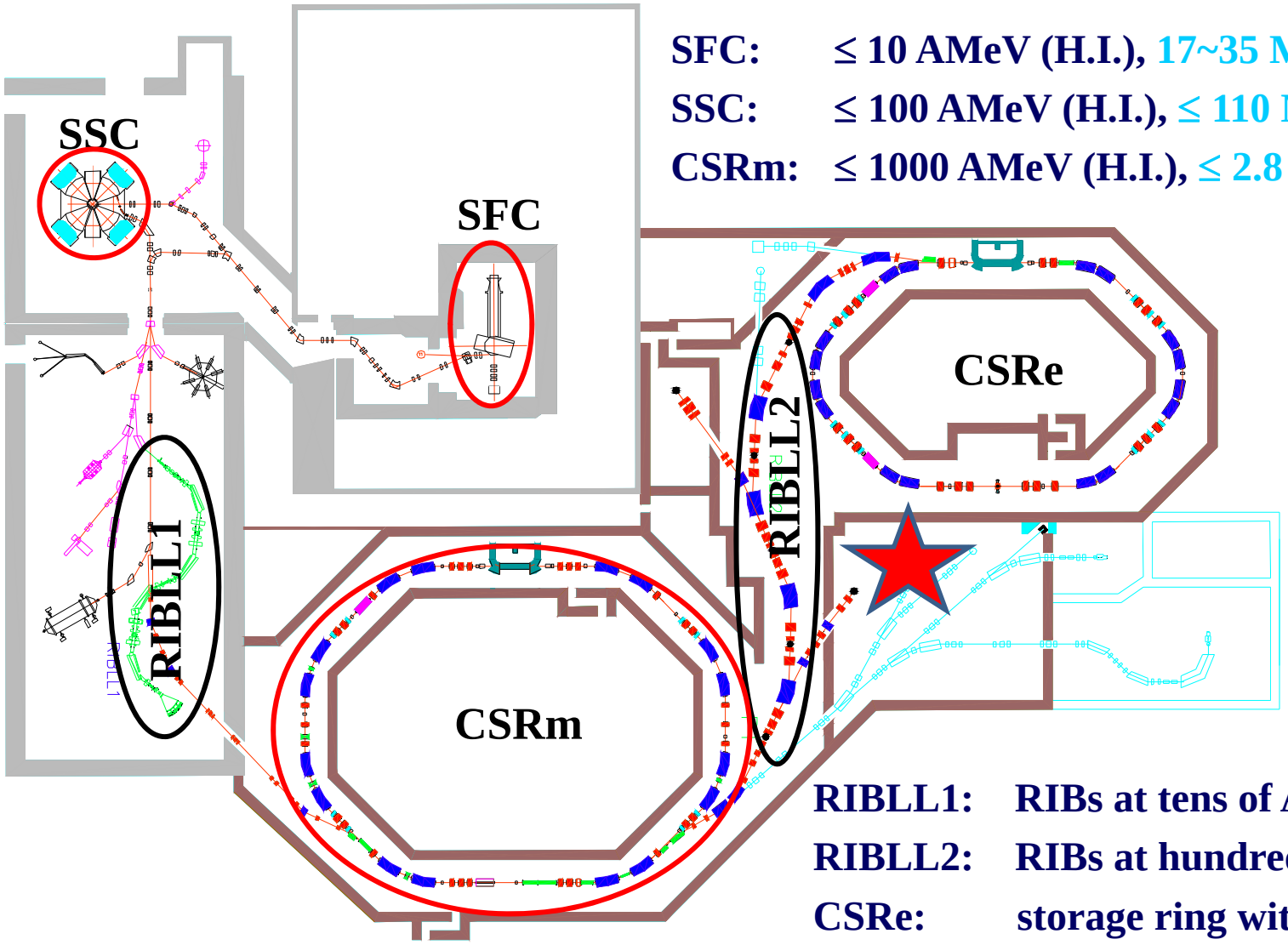
HIRFL-CSR Complex

SFC: ≤ 10 AMeV (H.I.), 17~35 MeV (p)

SSC: ≤ 100 AMeV (H.I.), ≤ 110 MeV (p)

CSRm: ≤ 1000 AMeV (H.I.), ≤ 2.8 GeV (p)

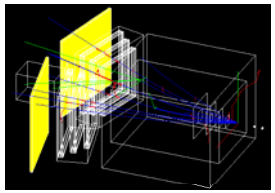
N



RIBLL1: RIBs at tens of AMeV

RIBLL2: RIBs at hundreds of A MeV

CSRe: storage ring with deceleration



Physical Programs at CEE

→ Asymmetrical Nuclear EOS

→ Collision dynamics in sub-GeV regime

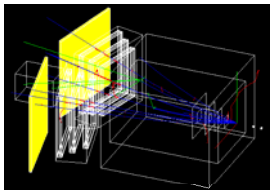
→ Collisions between few nucleon nuclei

→ Elastic Scattering

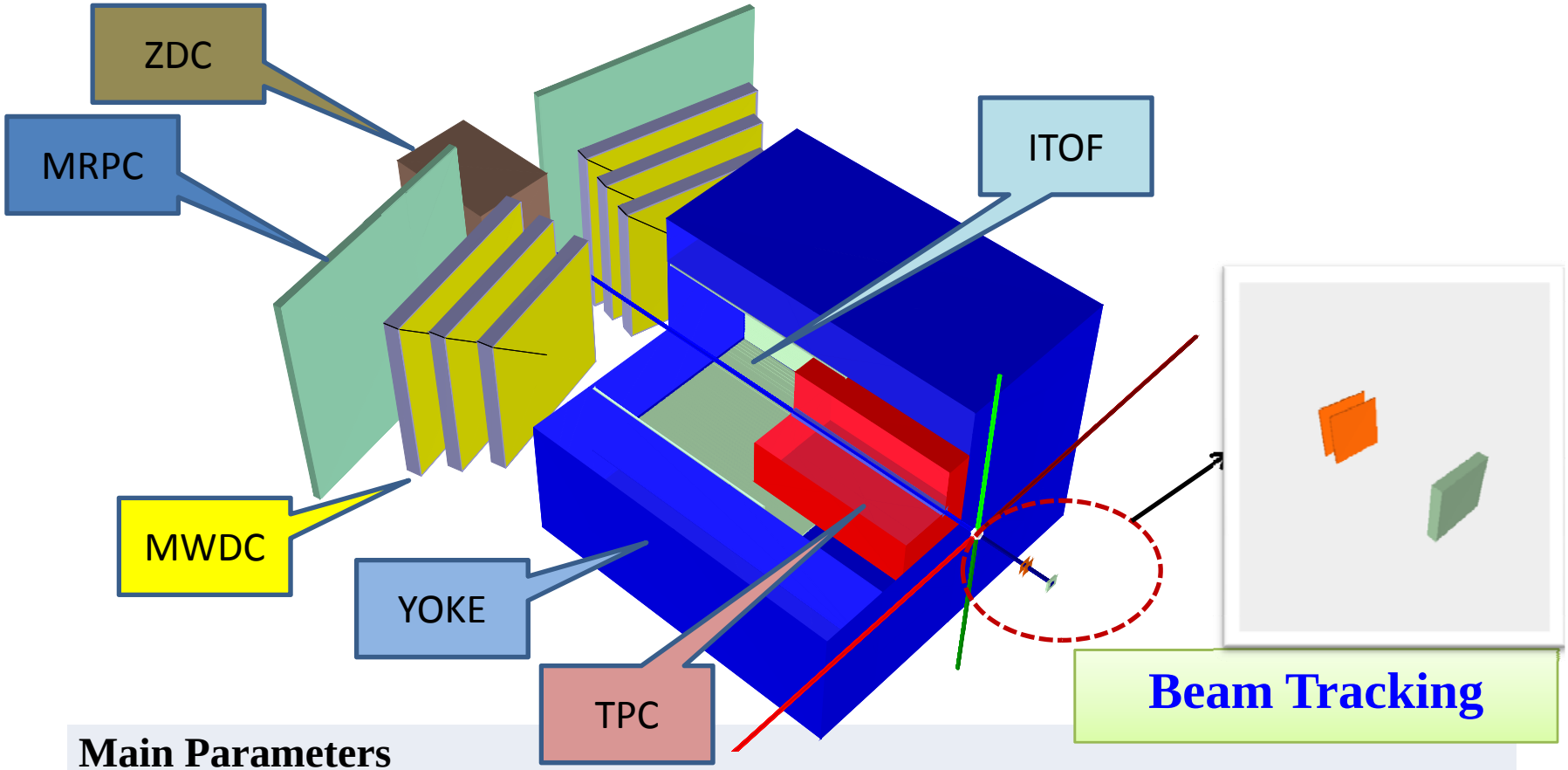
(Short Range correlation, Tensor Force …)

→ Radioactive Ion Beam Physics

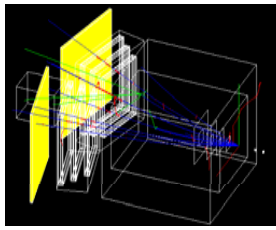
→ ……



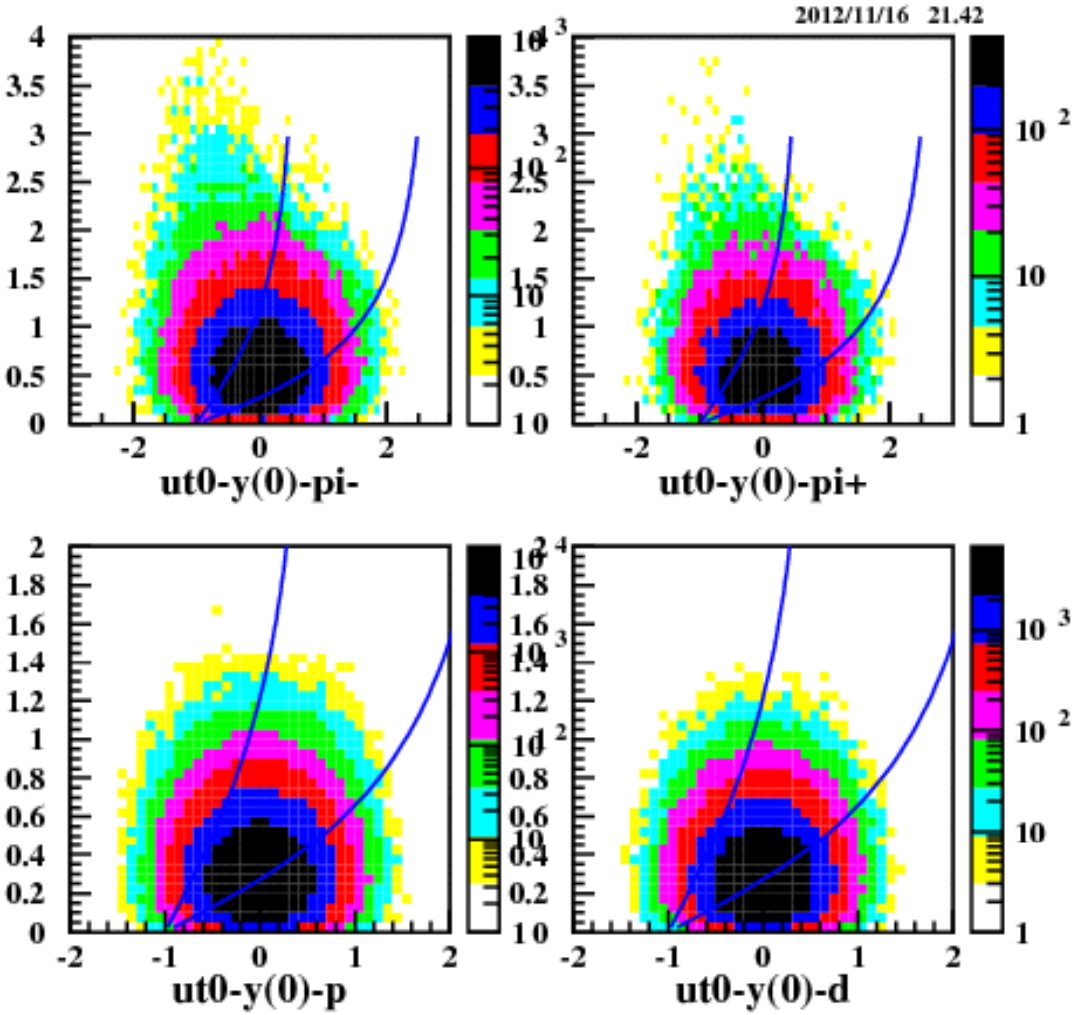
Conceptual Design



Main Parameters	
Total Size(L×B×H)	5 m ×4 m ×3 m
Coverage in C.M.	> 2π
Event Rate	< 10^4~10^5/s
Total Channels	~ 1×10^4
List Mode Data Rate	~ 10^2 MB/s

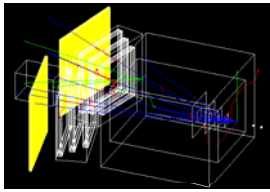


Main Features I: Coverage

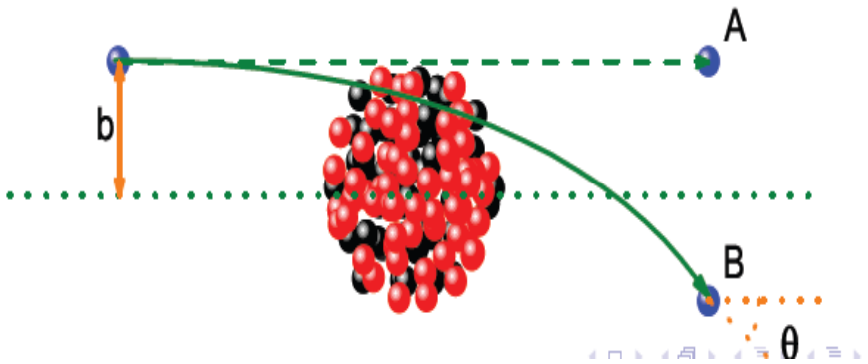


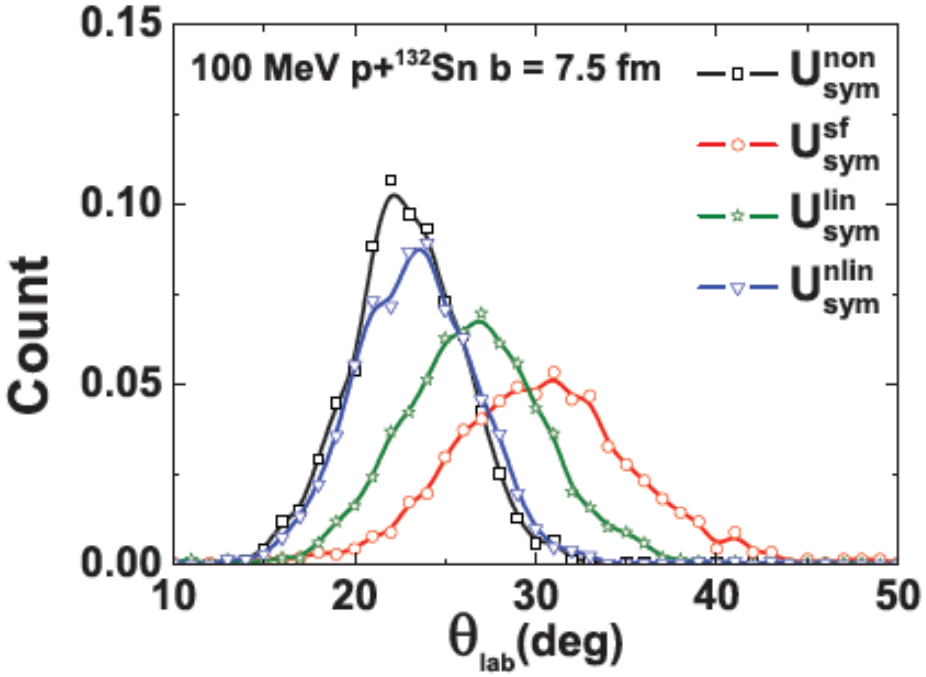
Dipole + MWDC +mTOF ~ 15°

Dipole + TPC + iTOF ~ 45°



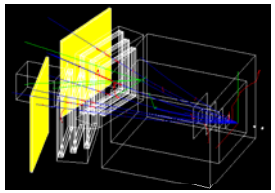
Main Features 2: Dipole + Forward Tracking



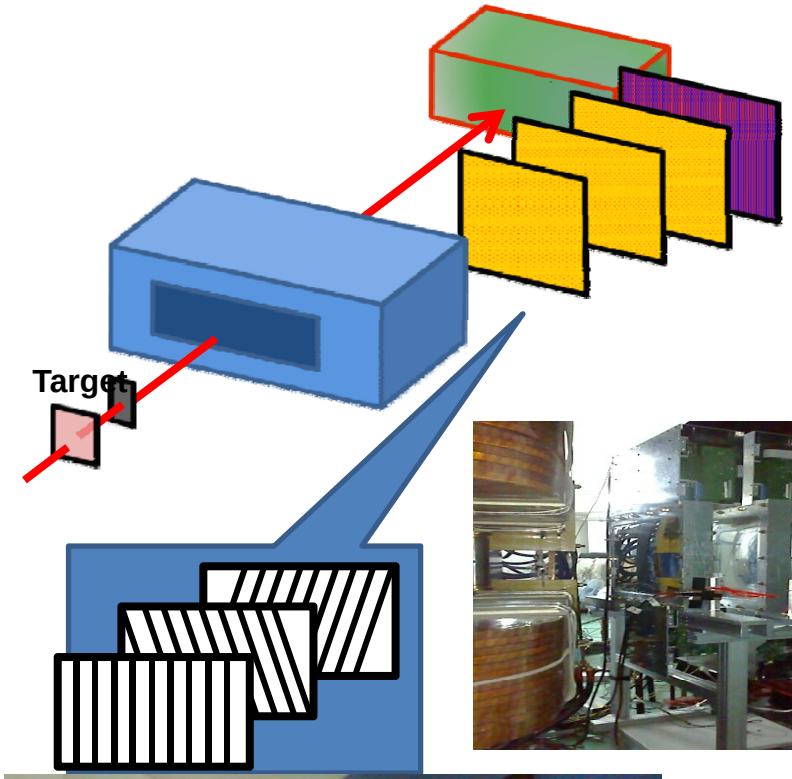


Calculation done by OU Li et al.

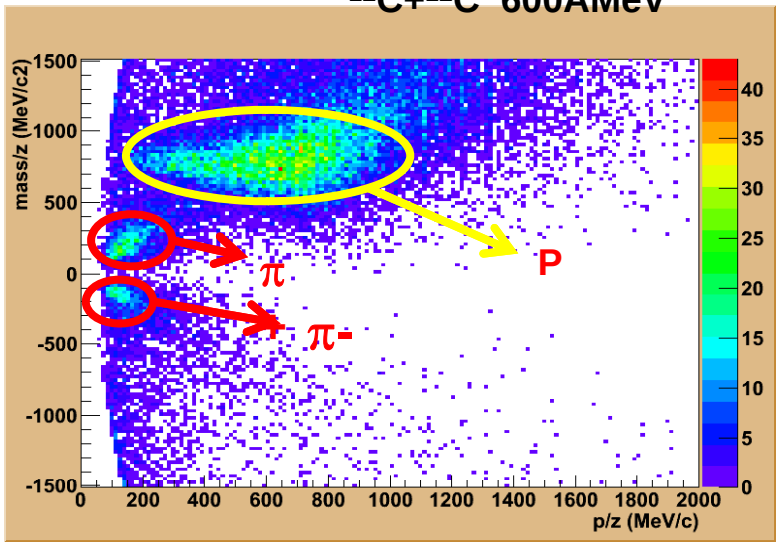
Dipole + Forward Tracking
RIB Physics
Low P_t Physics → Peripheral Reactions, Collision Dynamics
Neutron Measurement with ZDC

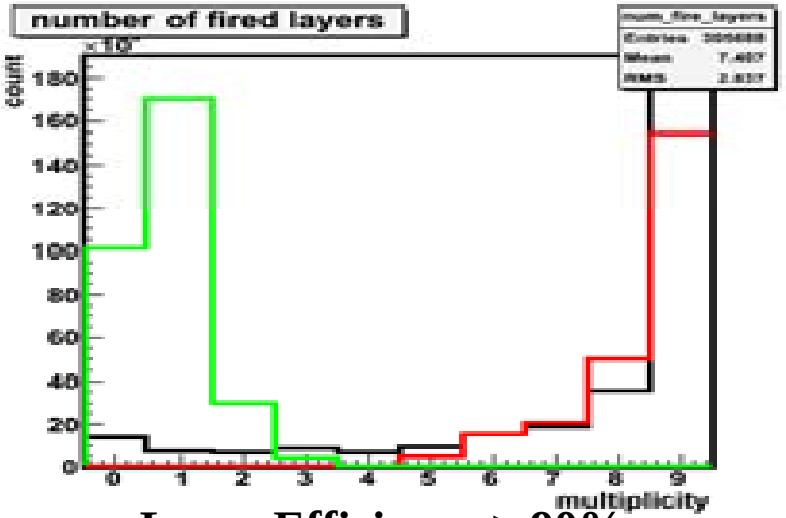


R&D I: Phase 1 Beam Test

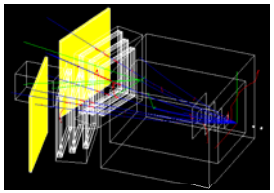


$^{12}C+^{12}C$ 600AMeV

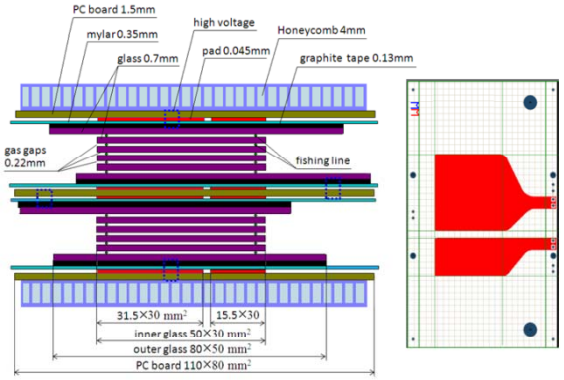




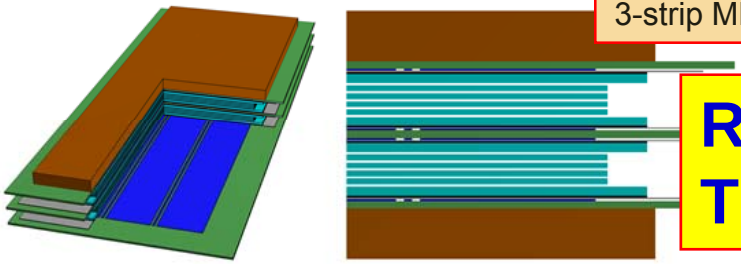
Layer Efficiency > 90%



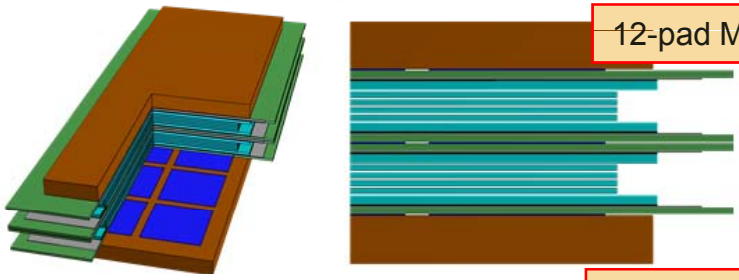
R&D II: MRPC



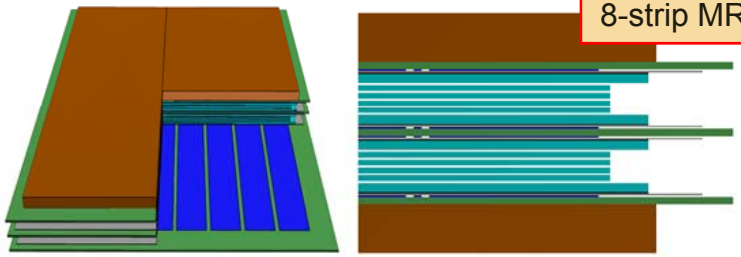
2-pad MRPC



3-strip MRPC

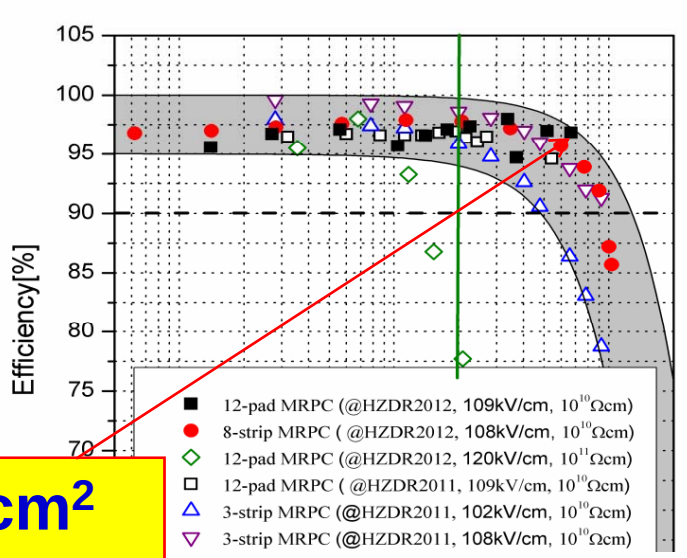


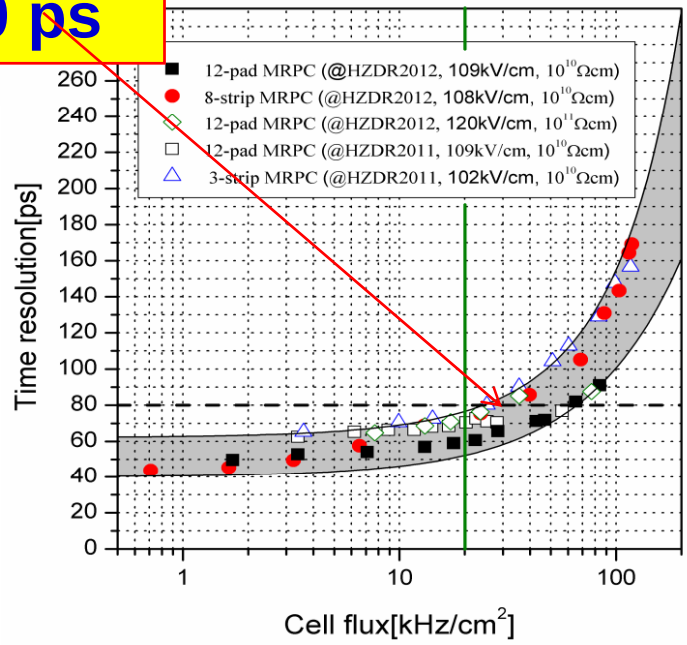
12-pad MRPC

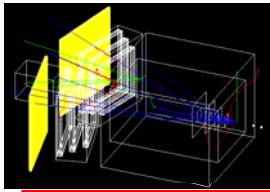


8-strip MRPC

Rate: 100kHz/cm²
Time resol.: 40 ps



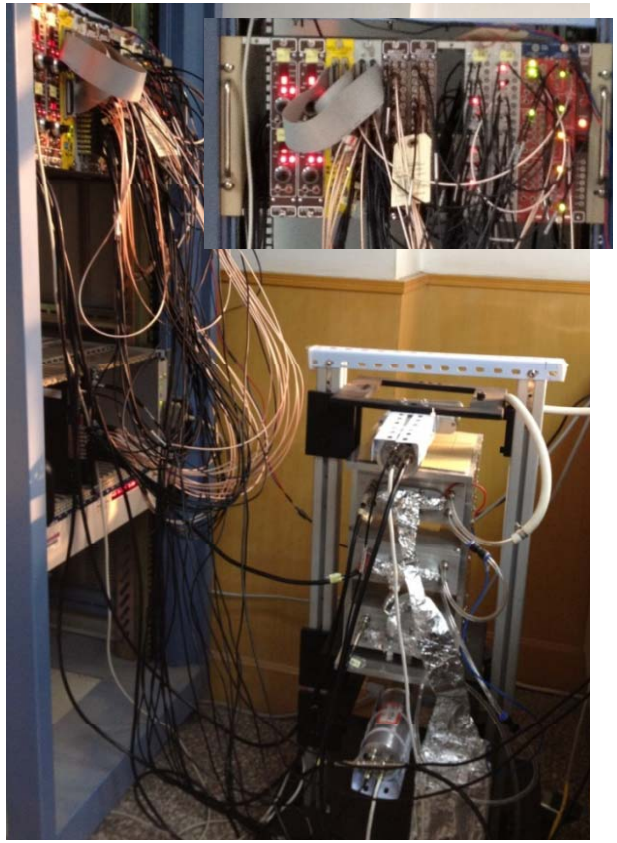




R&D III： MWDC test



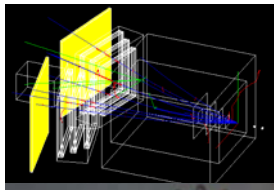

Dimension (cm)	114×76×13	98×86×13	64×49×13
Sensitive Size (cm)	96×50	80×60	48×32
Anode Layers	6	6	6
Max. Drift Len.	5mm	5mm	5mm



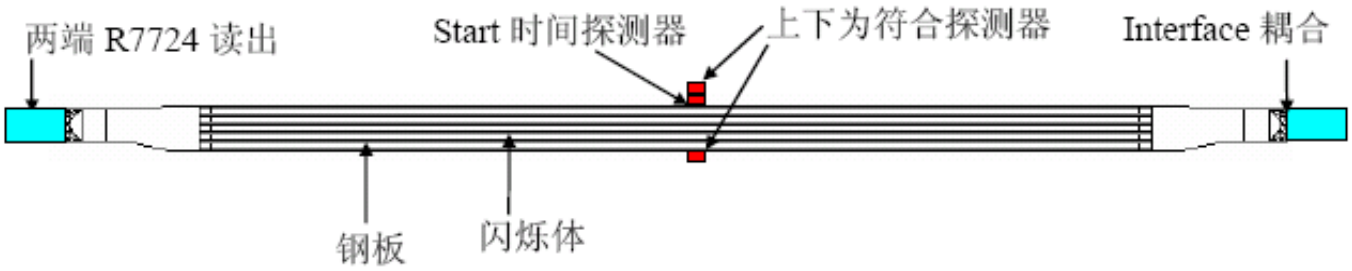
Position Resolution: σ＝200 ~ 260μm

MIP Efficiency 95% ~ 97%，

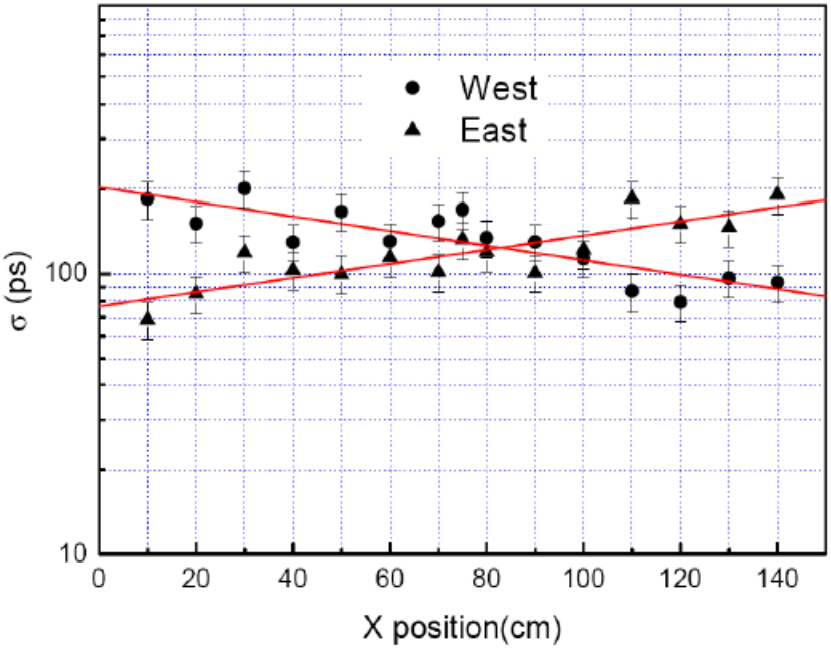
Max. Rate : 10^4 HZ/wire

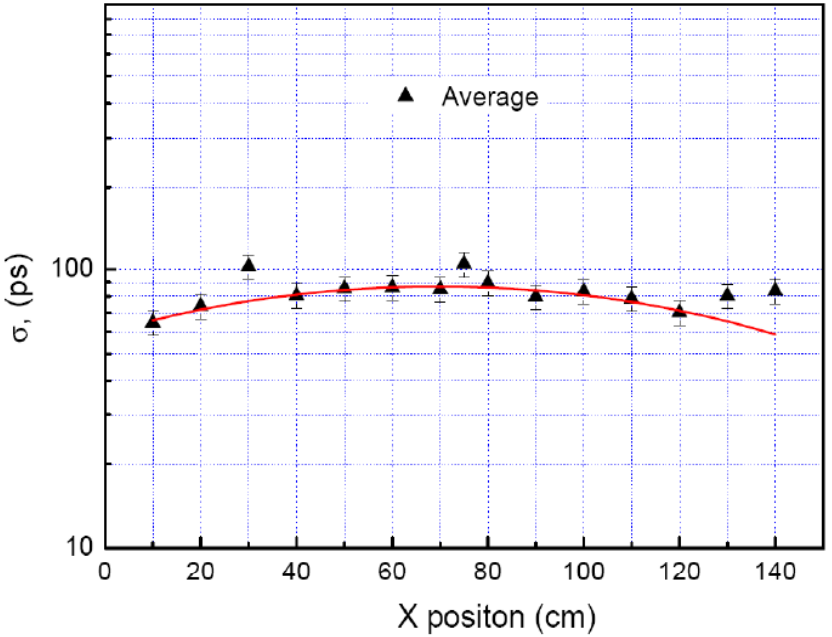


R&D IV： ZDC

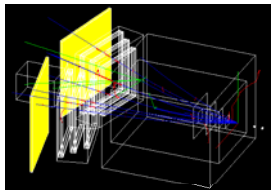


Time Resolution: <100ps, ε_{tot}>90% for 400MeV neutron

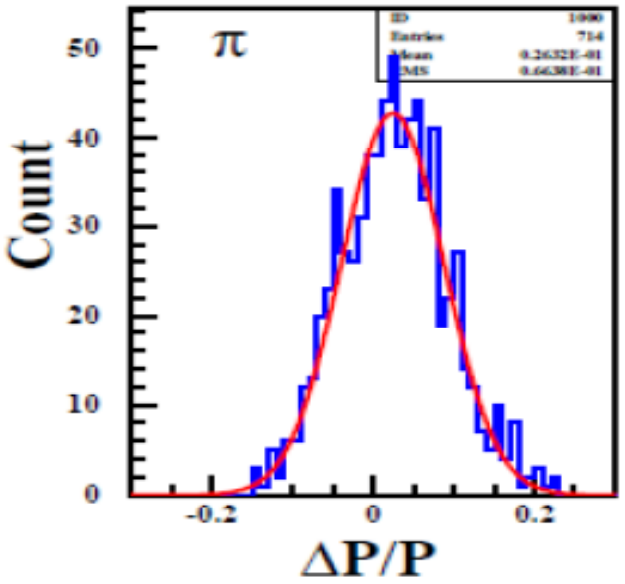


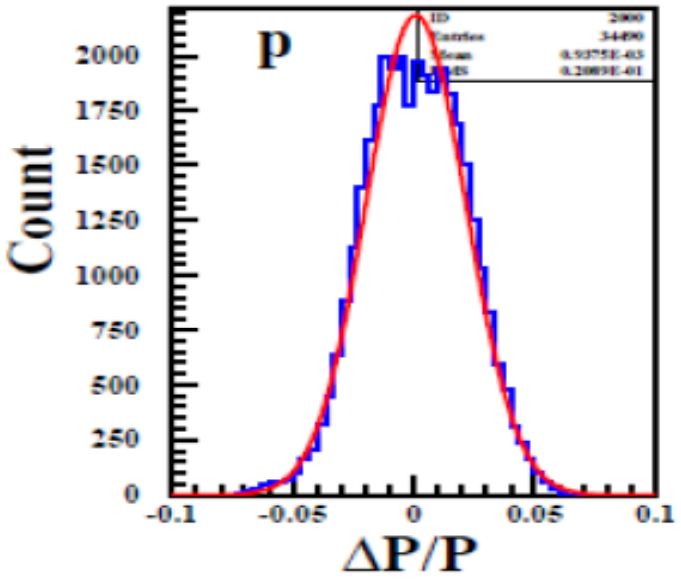


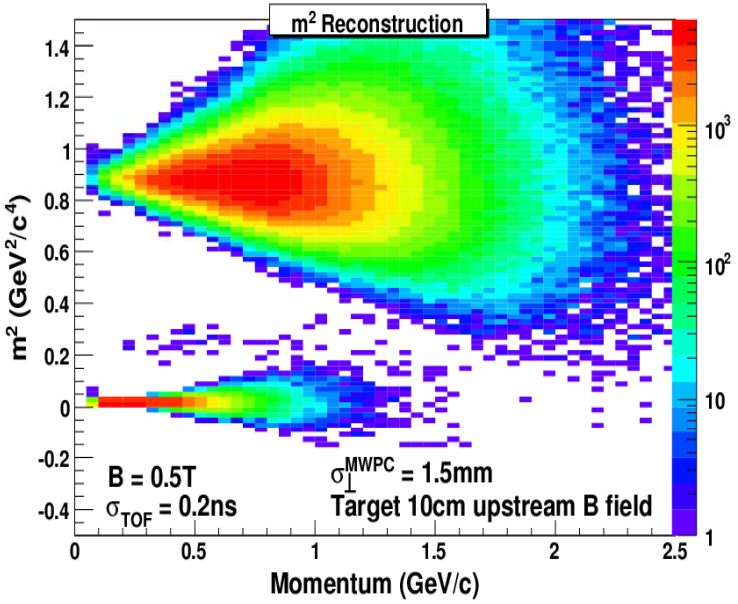
XU H. G, Doctoral Thesis, IMPCAS, 2006

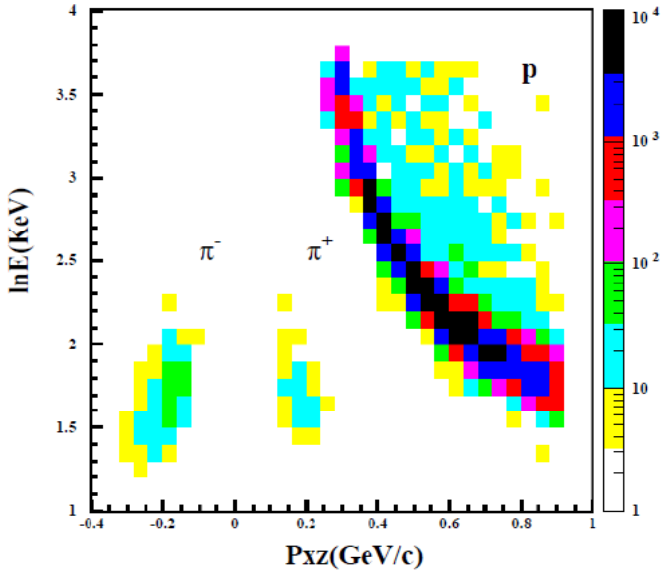


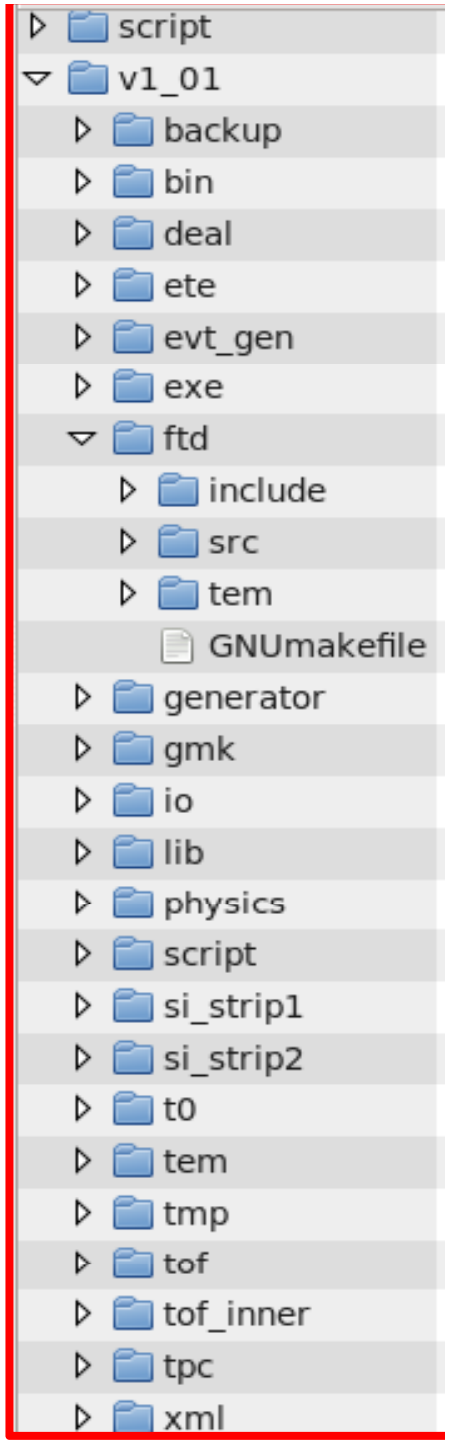
R&D V： Simulation

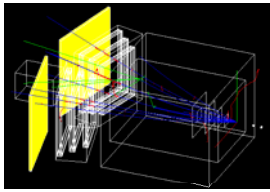












Summary

- Density dependence of $E_{sym}(\rho)$ at $\rho>\rho_0$ is an open question, one of the most uncertain quantities in nuclear physics.
- Heavy ion collisions at sub-GeV/u are favored to constrain $E_{sym}(\rho)$ at $\rho>\rho_0$ for the large degree of ispsoin fractionation.
- HIRFL-CSR, equipped with CEE as proposed, may hopefully provides an opportunity to contribute to the issue.

Thank you !