How to constraint the symmetry energy at supra baryonic density?

The symmetry energy at high density: evidences from existing data: models, open problems.

The Asy-EOS-*S394* experiment at GSI: neutron and proton elliptic flows: observables, open problems.

Overview of the last test@GSI. Set-up preparation

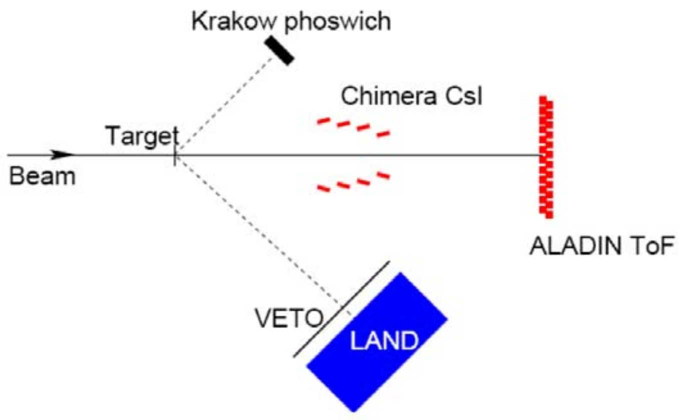
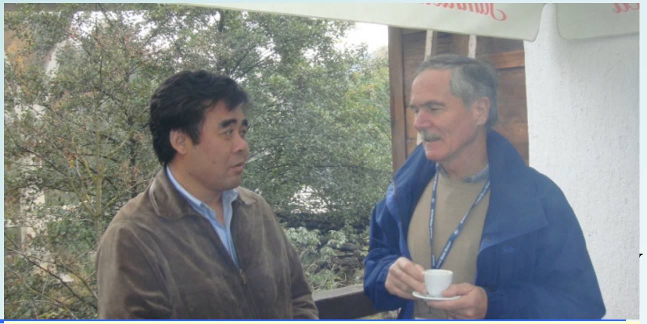


Figure 3: Schematic diagram of experimental setup in Cave C.

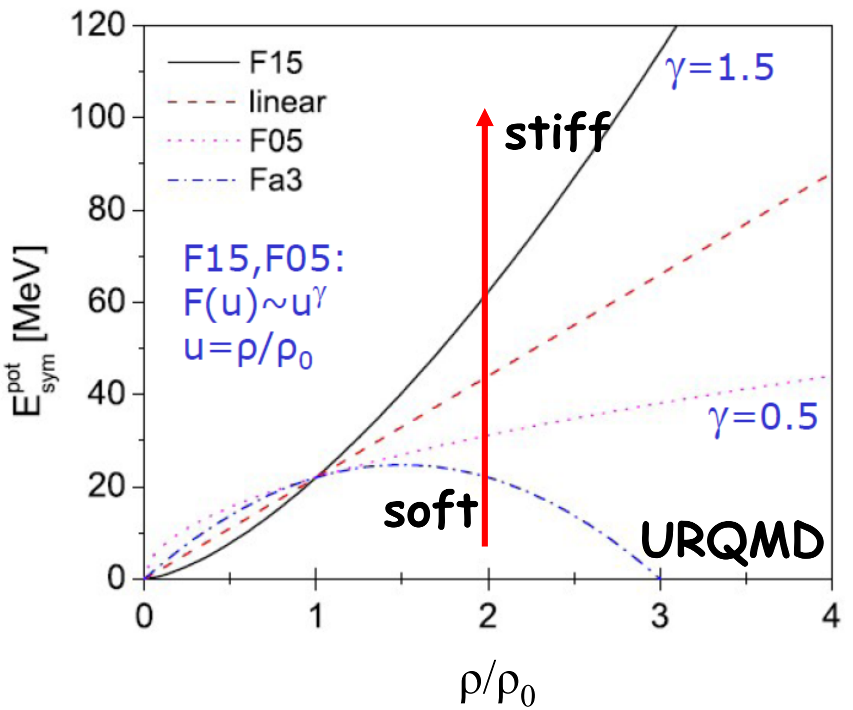
Asy-EOS
2010
Workshop
Noto

The key problem: The density dependence of the Simmetry Energy

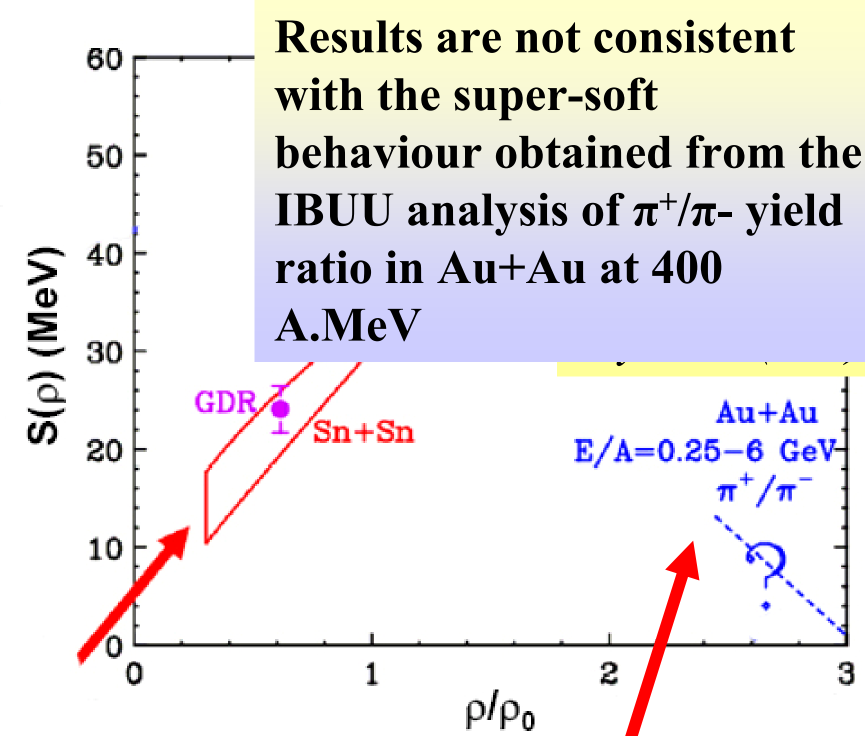
$$E(\rho,\delta)=E(\rho,\delta=0)+E_{sym}(\rho)\delta^2$$



Results are not consistent with the super-soft behaviour obtained from the IBUU analysis of π^+/π^- yield ratio in Au+Au at 400 A.MeV



Q. Li et al. J. Phys. G31 1359 (2005)



B. Tsang IWM2009

$$S(\rho)=C_k(\rho/\rho_0)^{2/3}+C_P(\rho/\rho_0)^\gamma$$

Z Xiao, Bao-An Li et al., PRL 102, 062502 (2009)

Experimental constraint to the symmetry energy

Fragment isotope distribution: isotopic and isobaric yield ratios, isoscaling

Isospin distillation/fractionaction, relative n/p densities

Isospin diffusion: isospin transport ratio R_i

n/p ratio (or double ratio)

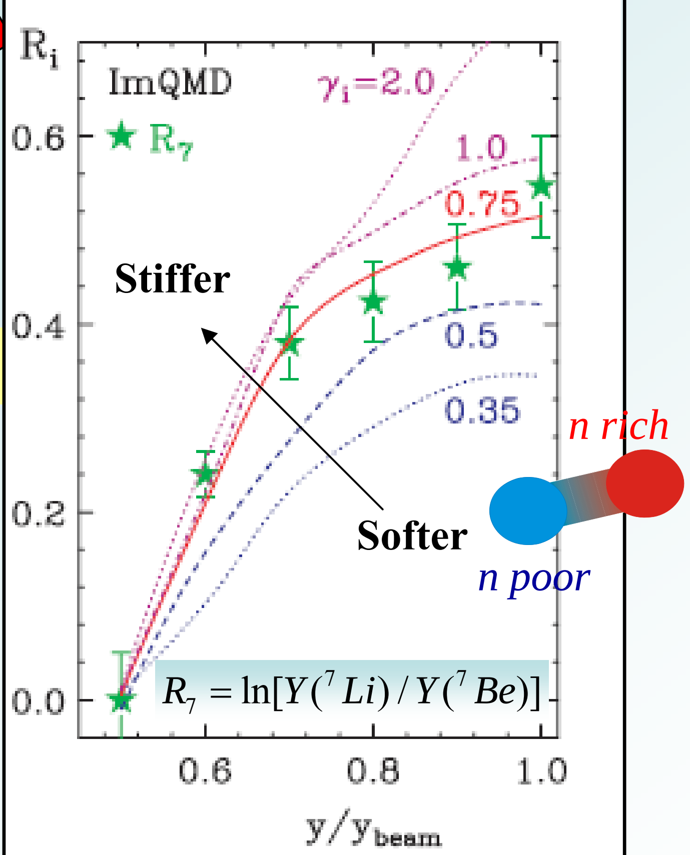
Particle – Particle correlations

Light cluster production

Mid-rapidity emission

Pygmy resonances in exotic nuclei

Mostly at $\rho<\rho_0$



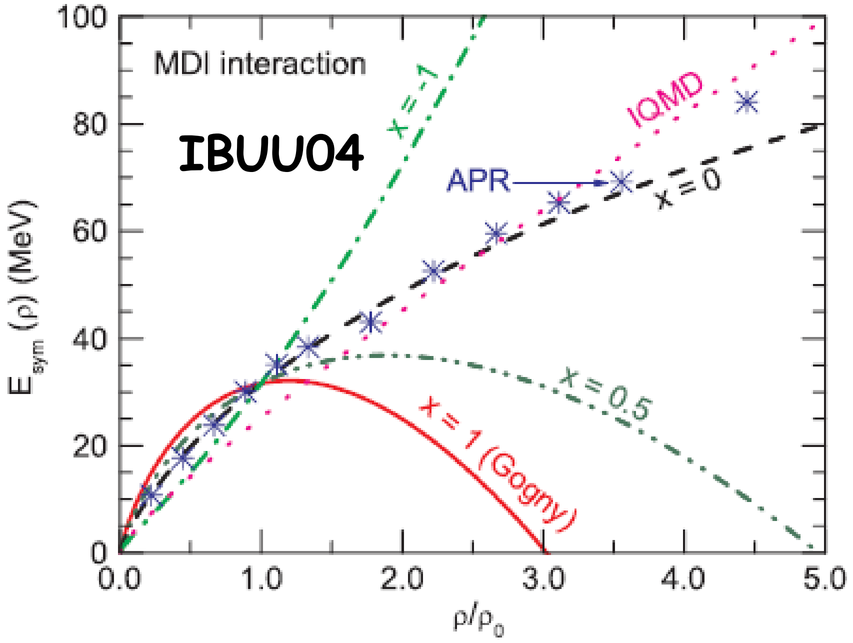
B. Tsang et al. PRL102 (2009)

Collective flow (n-p elliptic flow, n-p differential transverse flow

Charged pions π^+/π^-, K^+/K^0 ratio, etc.

Generally uncostrained especially above saturation density due to limited data available and theoretical predictions are very different

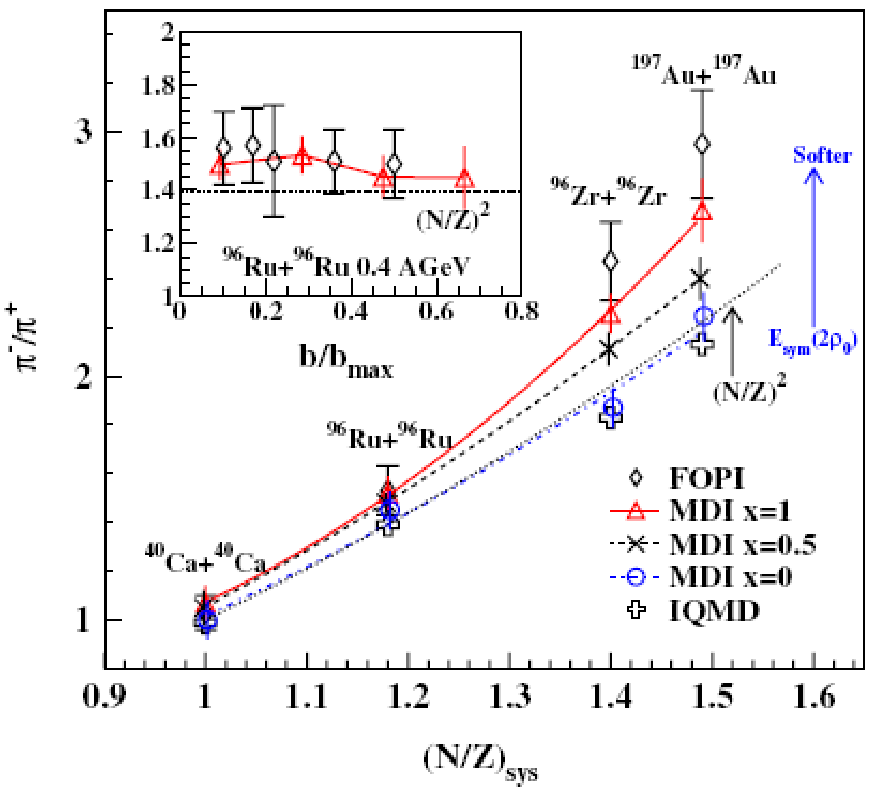
Two cases study using pion emission in heavy ion collisions. IBUU / ImIQMD



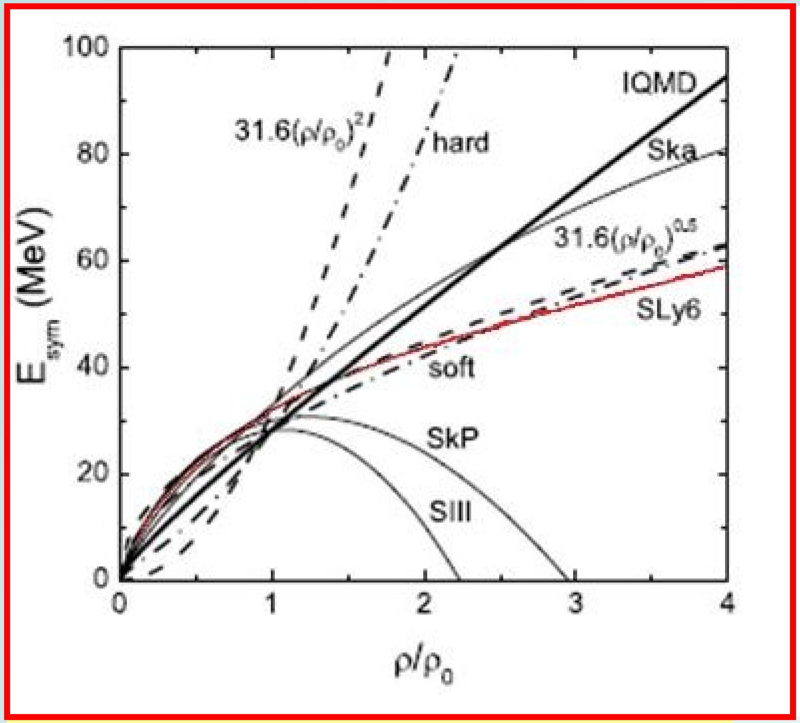
Z. Xiao, Bao-An Li et al., PRL 102, 062502 (2009)

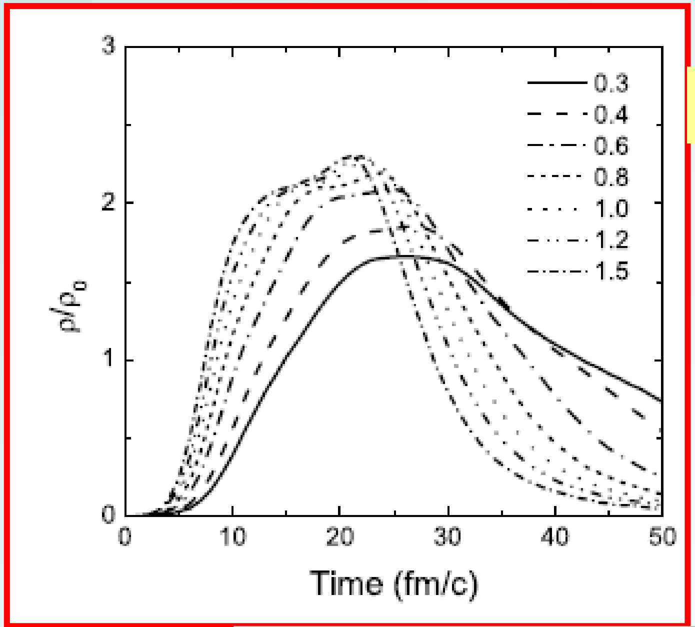
$Y(\pi-)/Y(\pi+) \approx (N/Z)^2$

Comparison of IBUU04 $Y(\pi^-)/Y(\pi^+)$ ratio from FOPI data evidence a super soft (x=1) E_{sym} for the most neutron rich reactions.



Z.Q. Feng et al., PLB 683 140 (2010)





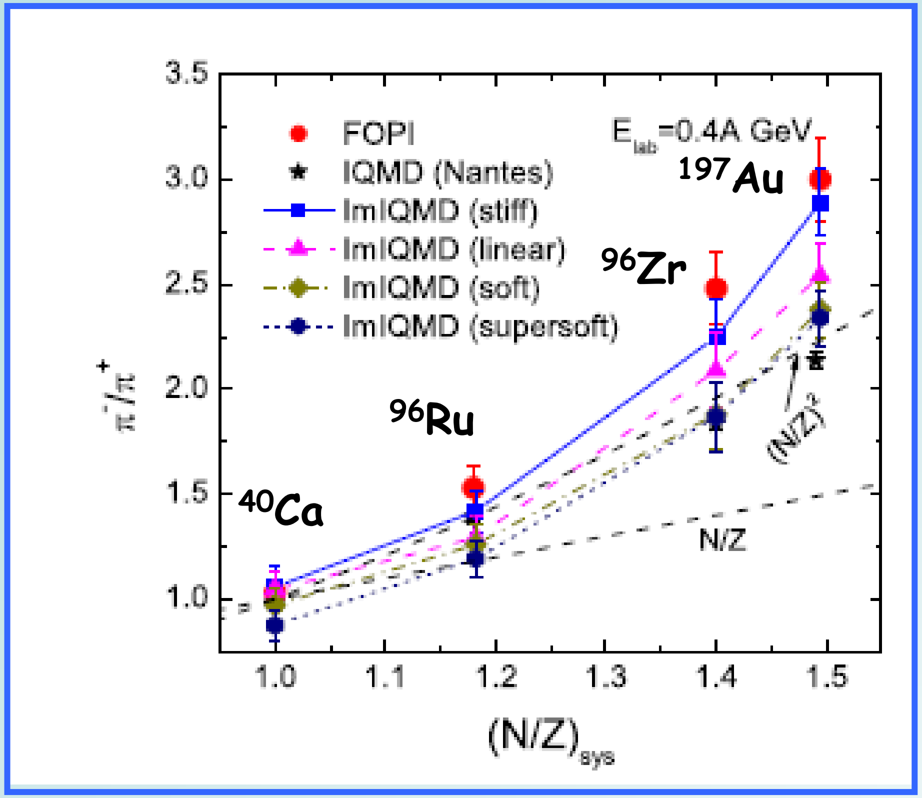
A.GeV

The ImIQMD model is used with different parametrization of the stiffness of symmetry energy and effective interaction

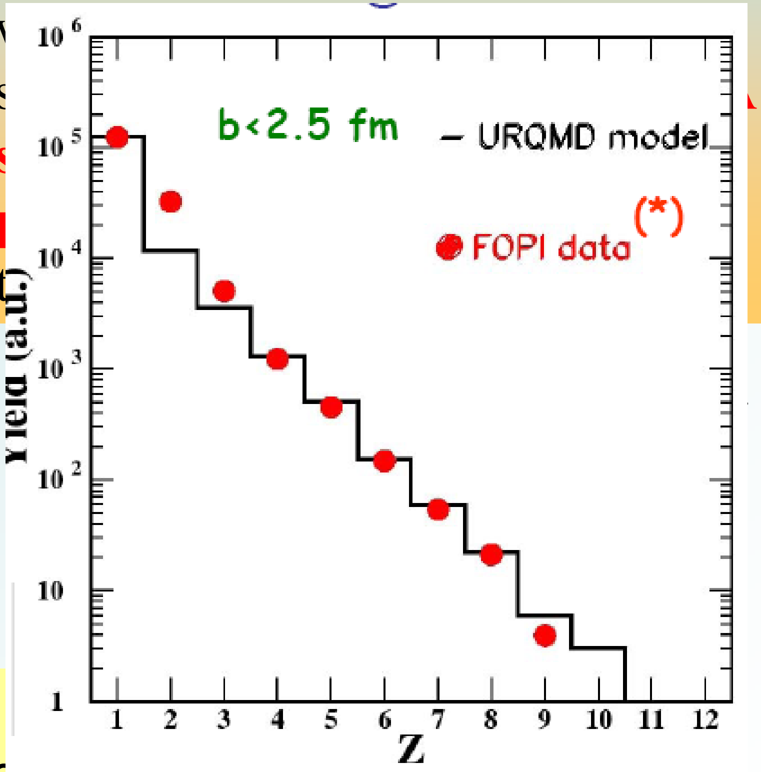
Evolution of central densities reached at different incident energies

<u>A question</u>: which densities are really probed from a given observable (pions in this case) ?

Two cases study using pion emission in heavy ion collisions. IBUU / ImIQMD



The dependence of the π^-/π^+ ratio on *N/Z* of reaction systems at energy 0.4 A GeV are compared



Coalescence condition:

DR <3 fm and DP< 275 MeV/c

A question: UrQMD vs IQMD SMF vs ImIQMD…… what is the "ingredient", for example in the here, that make comparisons dif

Constraining the Symmetry Energy at Supra-Saturation Densities With Measurements of Neutron and Proton Elliptic Flow

GSI S394

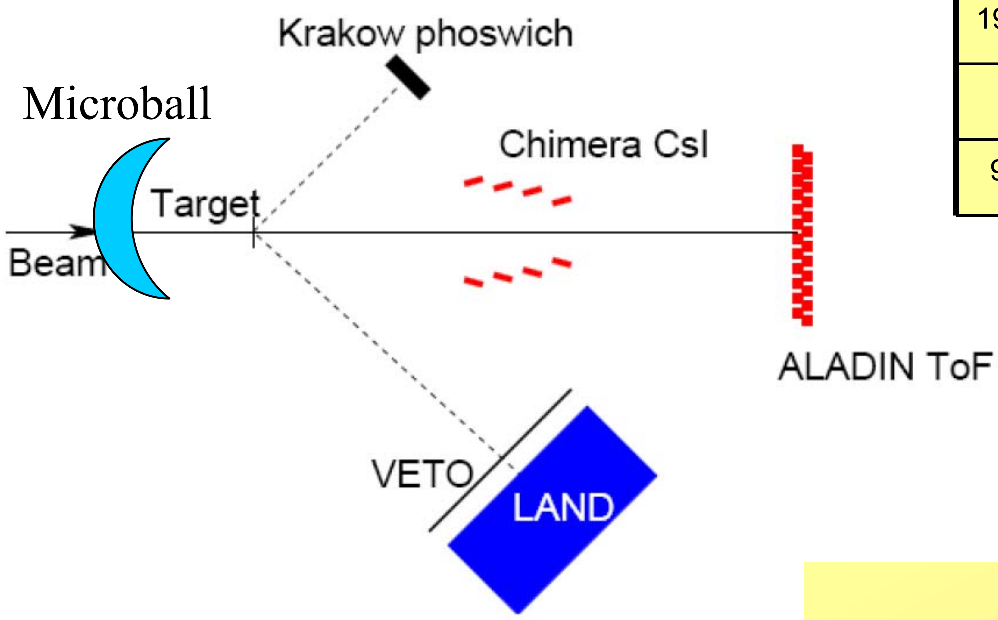


Figure 3: Schematic diagram of experimental setup in Cave C.

Reaction	Energy (AMeV)	
$^{197}Au+^{197}Au$	400	N/Z=1.50
$^{96}Zr+^{96}Zr$	400	N/Z=1.40
$^{96}Ru+^{96}Ru$	400	N/Z=1.18

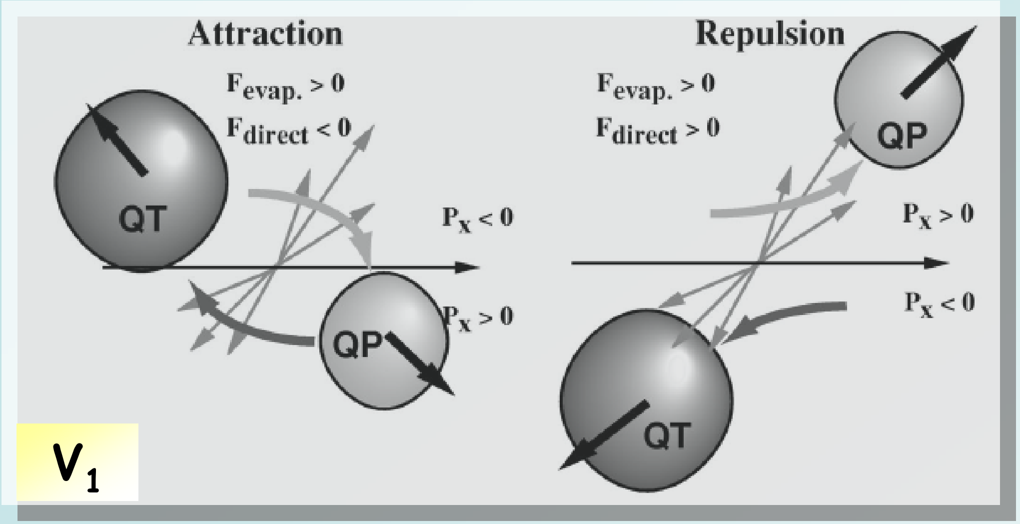
The proposal was presented on 27th-28th February 2009 at GSI PAC: spokepersons:

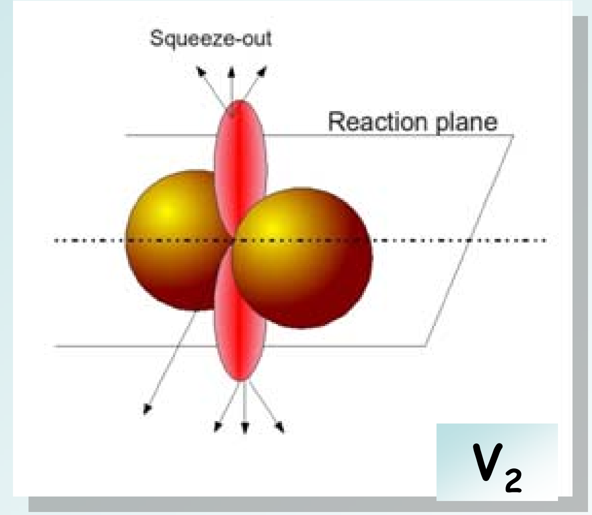
R. Lemmon and P. Russotto

(Asy-EOS collaboration)

- **LAND calorimeter positioned to cover the mid-rapidity kinematic region**
- **CHIMERA and TOF wall will give modulus and orientation of impact parameter**
- **Krakow/R3B telescope arrays used for light fragment detection**
- **Back-angle target hodoscope as reaction trigger (WU Microball)**
- **Califa prototype (LCP/light fragments)**

Transverse and elliptic flow



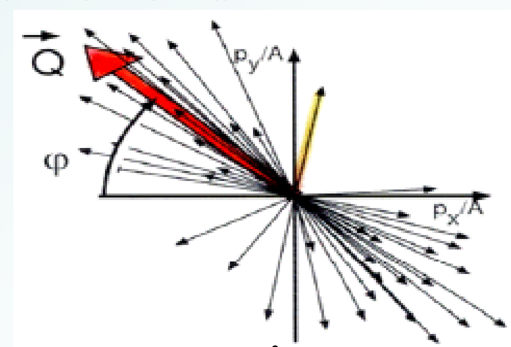


Some definitions:

Y = rapidity

p_t = transverse momentum

$$\frac{dN}{d\phi}(y, p_t) = 1 + V_1 \cos(\phi) + 2V_2 \cos(2\phi)$$



Reaction plane

$$V_1(y, p_t) = \left\langle \frac{p_x}{p_t} \right\rangle$$

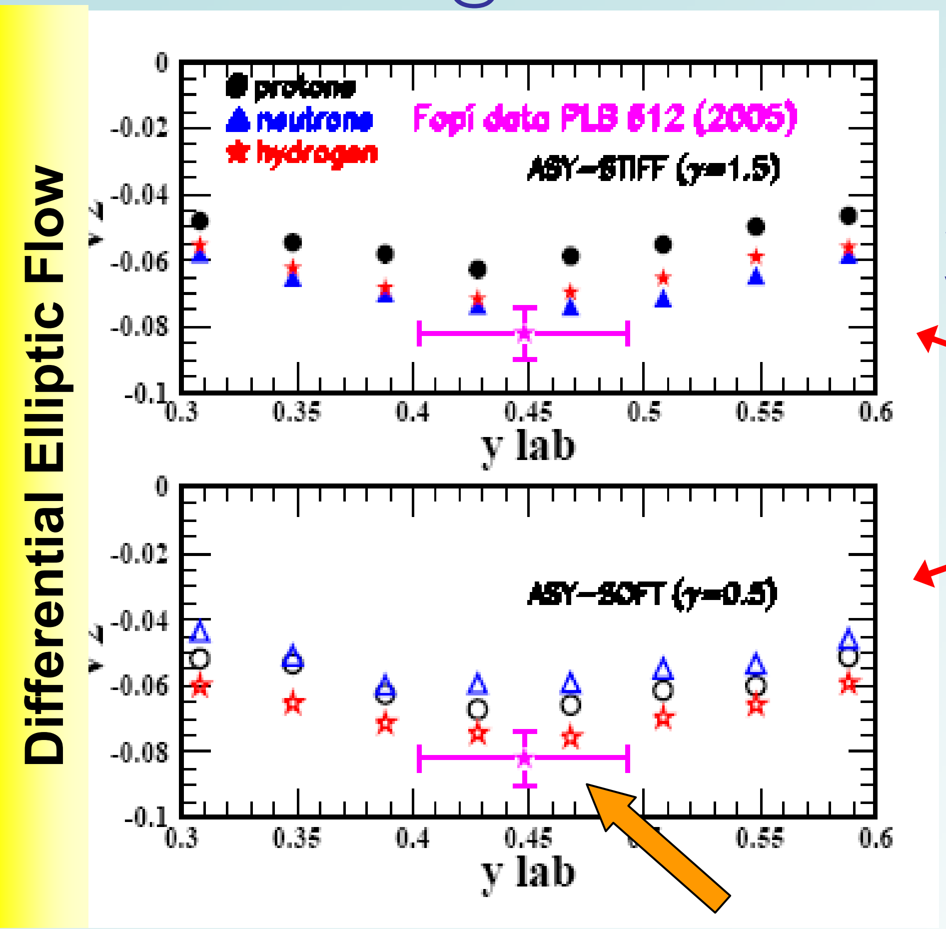
Transverse flow: *it provides information on the azimuthal anisotropy in the reaction plane*

$$V_2(y, p_t) = \left\langle \frac{p_x^2 - p_y^2}{p_t^2} \right\rangle$$

Elliptic flow: *it measures the competition between in plane (V_2>0) and out-of-plane emission (V_2<0)*

Constraining the Symmetry Energy at Supra-Saturation Densities With Measurements of Neutron and Proton Elliptic Flow

UrQMD vs. FOPI data:
Au+Au @ 400 A MeV



5.5<b<7.5 fm

Fopi-Land exp

stiff $\gamma = 1.5$

Soft $\gamma = 0.5$

At supra-saturation densities our knowledge about $E_{sym}(\rho)$ is poor because of very limited data available and few model analysis carried out … (Bao An Li)

inversion of neutron and hydrogen flows

Extensive investigations of nucleon flow observables with *UrQMD* (see. IWM2009 P. Russotto talk)

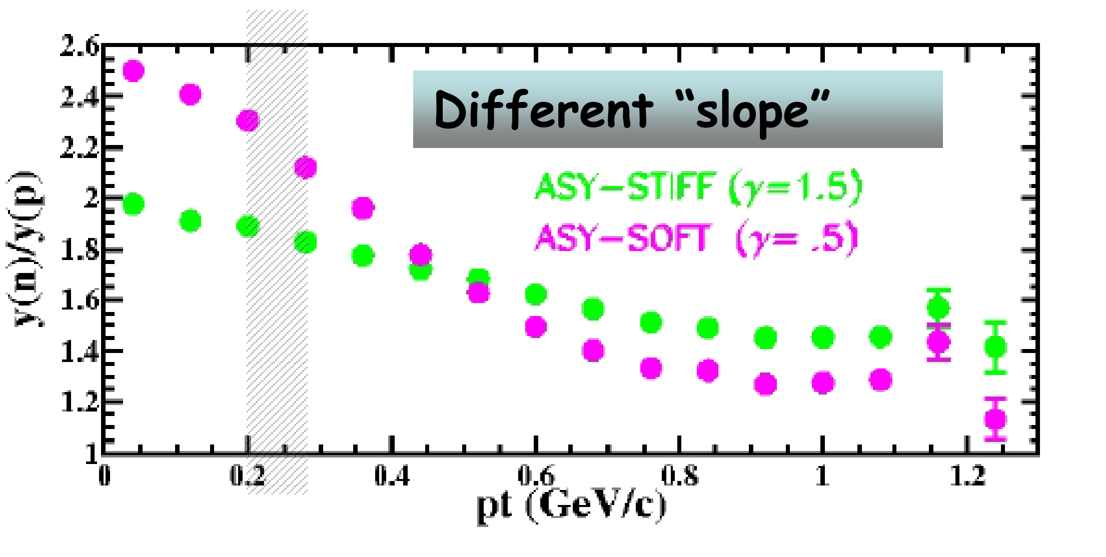
Elliptic flow more sensitive than directed flow

P_t dependence on V2:

The P_t dependence of v2 is sensitive to the high density behaviour of the EOS since highly energetic particles originate from the initial compressed and out-of-equilibrium phase of the collision

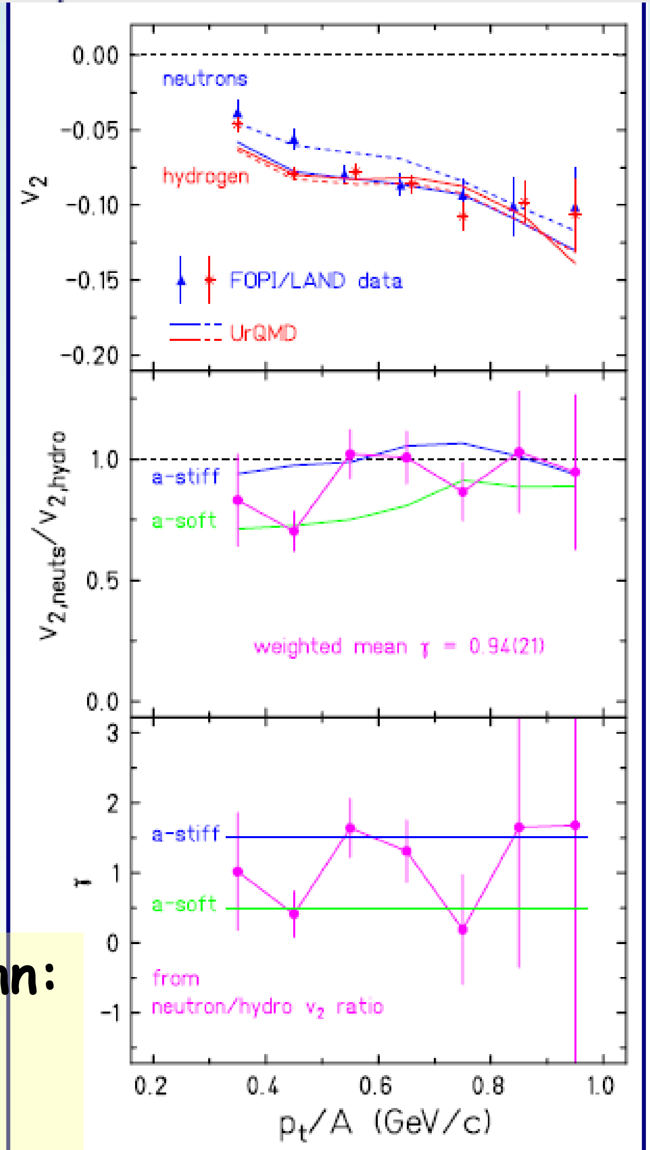
P_t dependence on V2: analysis on Au+Au @ 400 A.MeV (Land + Fopi)

UrQMD simulation
P. Russotto and Q. Li



n/p yield ratio as a function of p_t for Au+Au central collisions.

result from neut/hydro ratios
- $<\gamma> = 0.94 \pm 0.21$



Experiment problems:

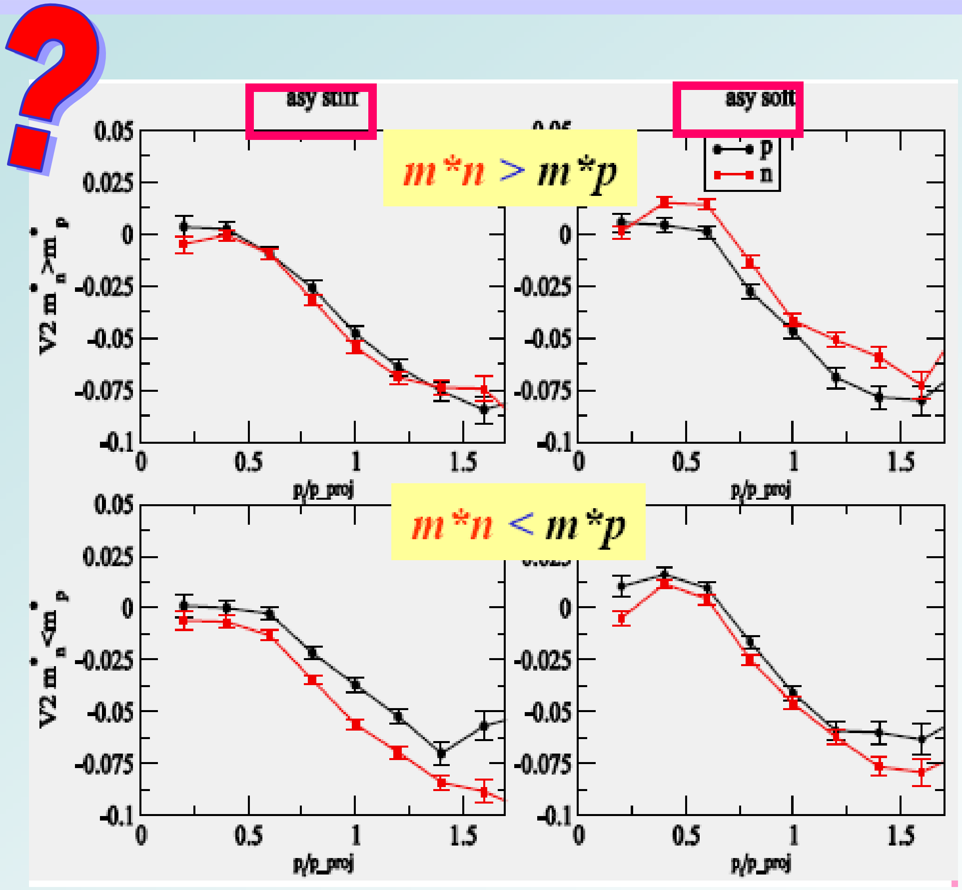
Limited statistics
LAND configuration not optimized for V2 studies

W. Trautmann:

HiDeSymE, Zagreb 2009

Open problems:

Statistics on previous "flow" experiments not sufficient
Not consistent results on the potential term of symmetry energy when comparing data on pi-/pi+ ratio with different models.
Results of the analysis are model dependent
How results evolve with isospin asymmetry of entrance channel?
. . . .



M. Di Toro: HiDeSymE, Zagreb 2009:

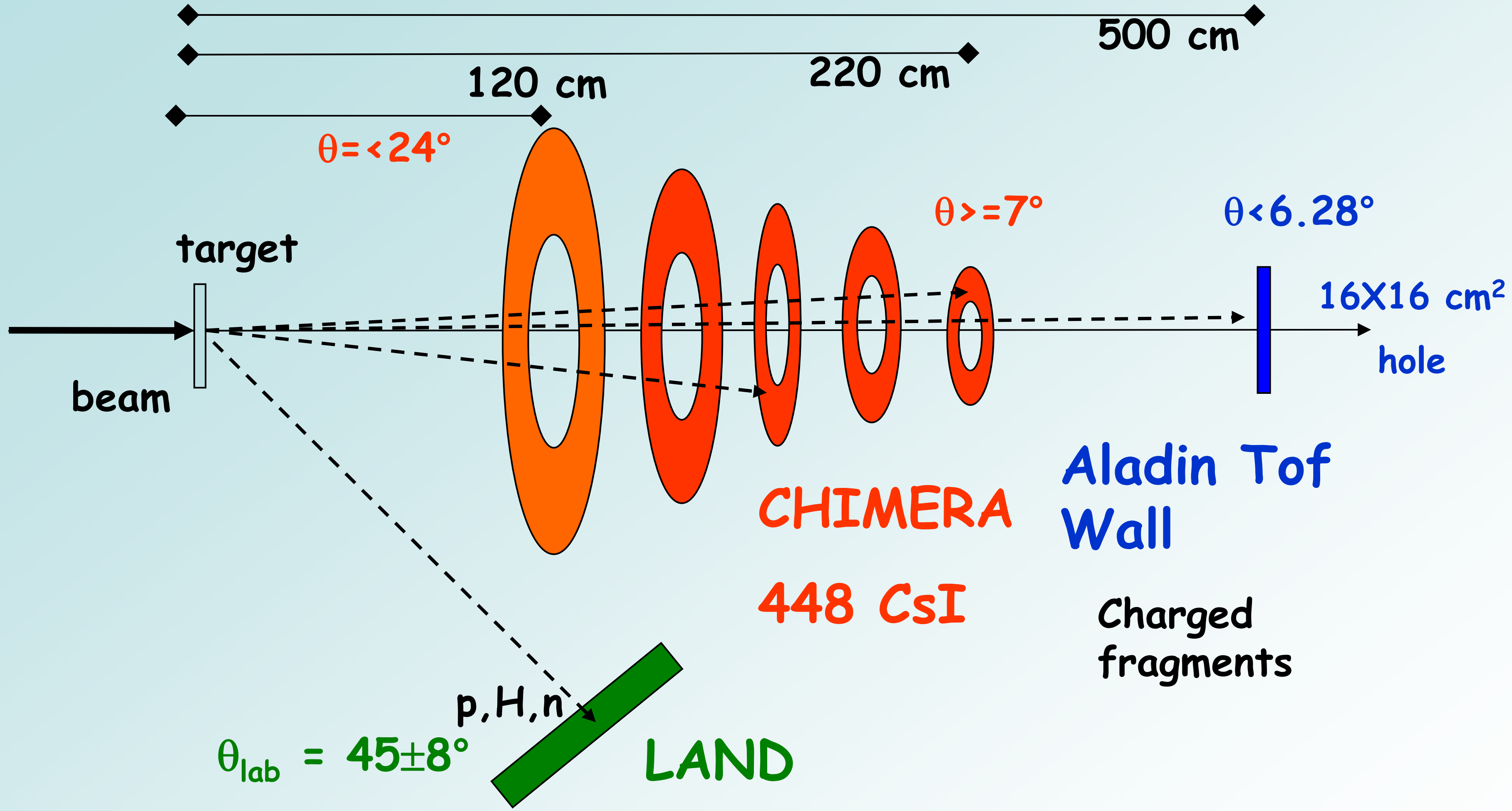
SMF calculations:

$m^*_n < m^*_p$: effect of mass splitting on elliptic flow: larger neutron repulsion for asy-stiff, larger neutron squeeze-out at midrapidity. Could be comparable to effects due to the symmetry energy.

S394 SETUP SUMMARY

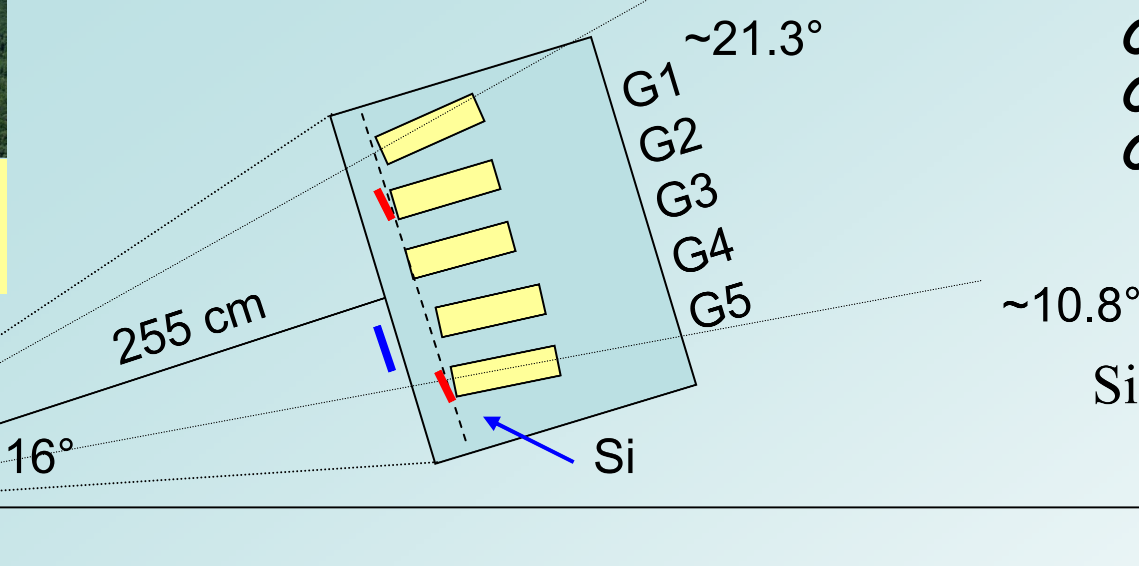
- Characterization of collision events - Chimera & ToF Wall:
  - Impact parameter
  - Reaction plane
- Squeeze-out and directed flow – LAND neutron and proton detection
- Yields of complex fragments (t/^{3}He) - charged particle array (CPA, Califa)
- Charged particles at backward angles - Microball (USA contribution)

S394 PARTIAL: CHIMERA SETUP

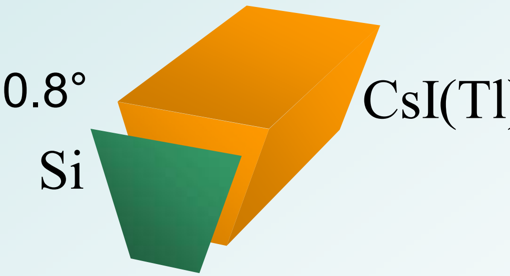


modulus and orientation of the impact parameter→ detection system with high effective granularity at forward angles
CsI rings of the CHIMERA multidetector

U^{73+} 10^5 pps
350 A.MeV



Chimera CsI
Cracow Array
Califa prototype



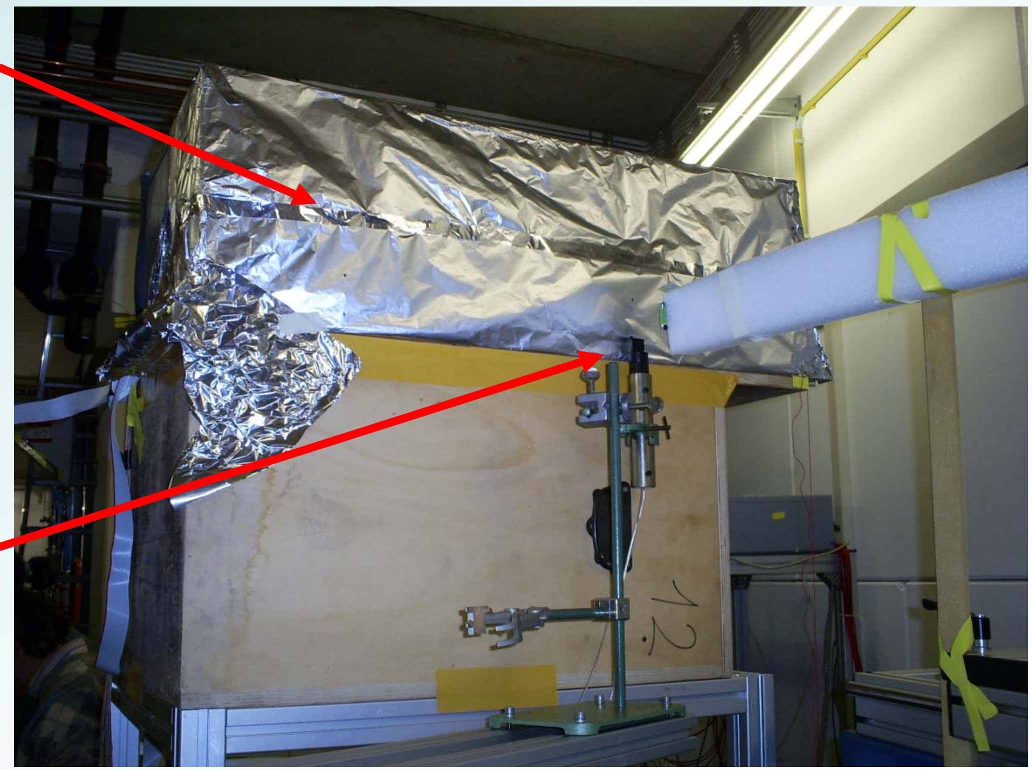
Pb (3% target)
run 22-23

Big Box

GSI TEST GEOMETRY

Silicons
front of G5 and G2

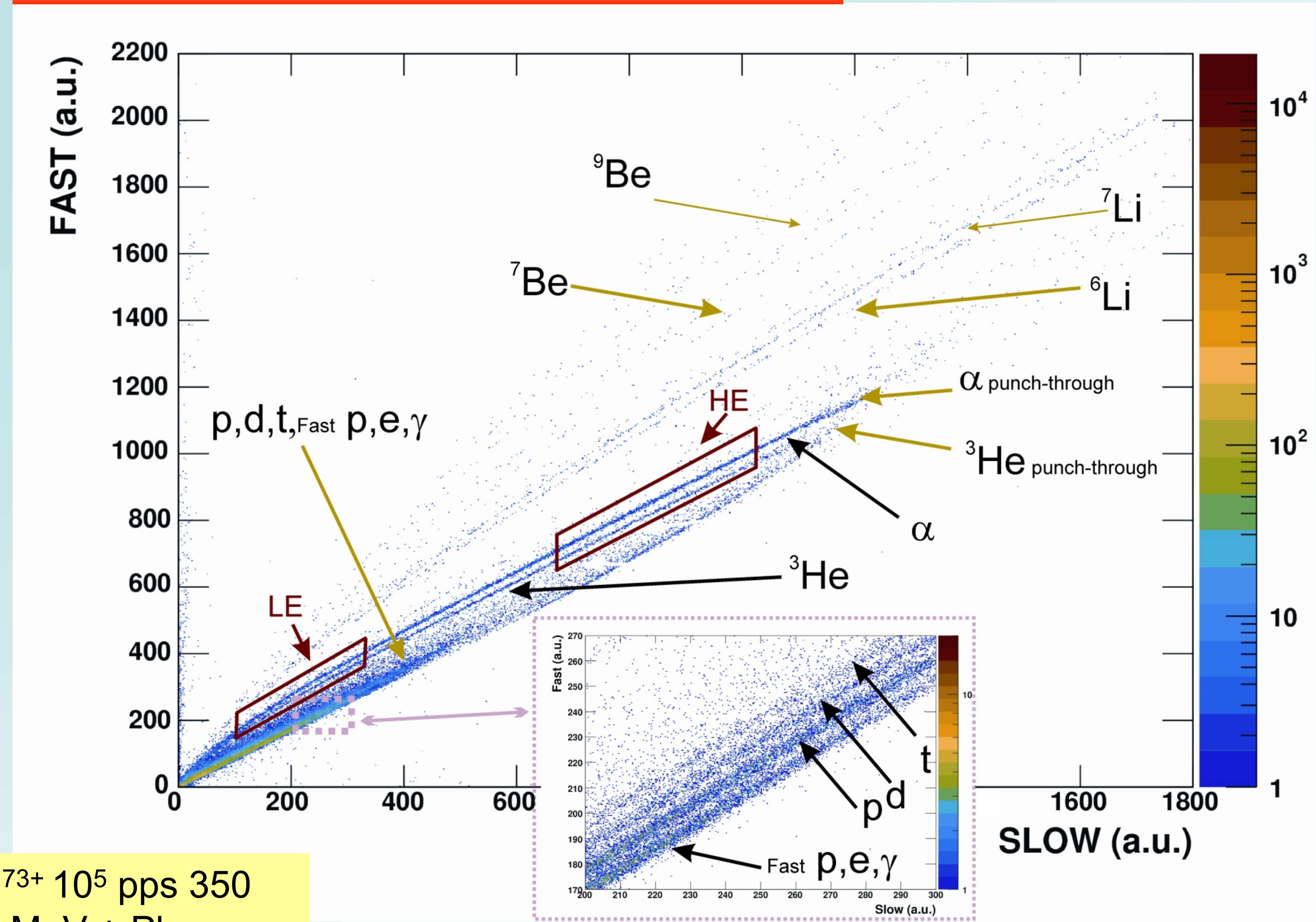
0.5 Plastic detector (front of G4I)



GSI TEST with *U* BEAM, September 2009

Digital Pulse Shape acquisition DSPA

NIM A To be submitted

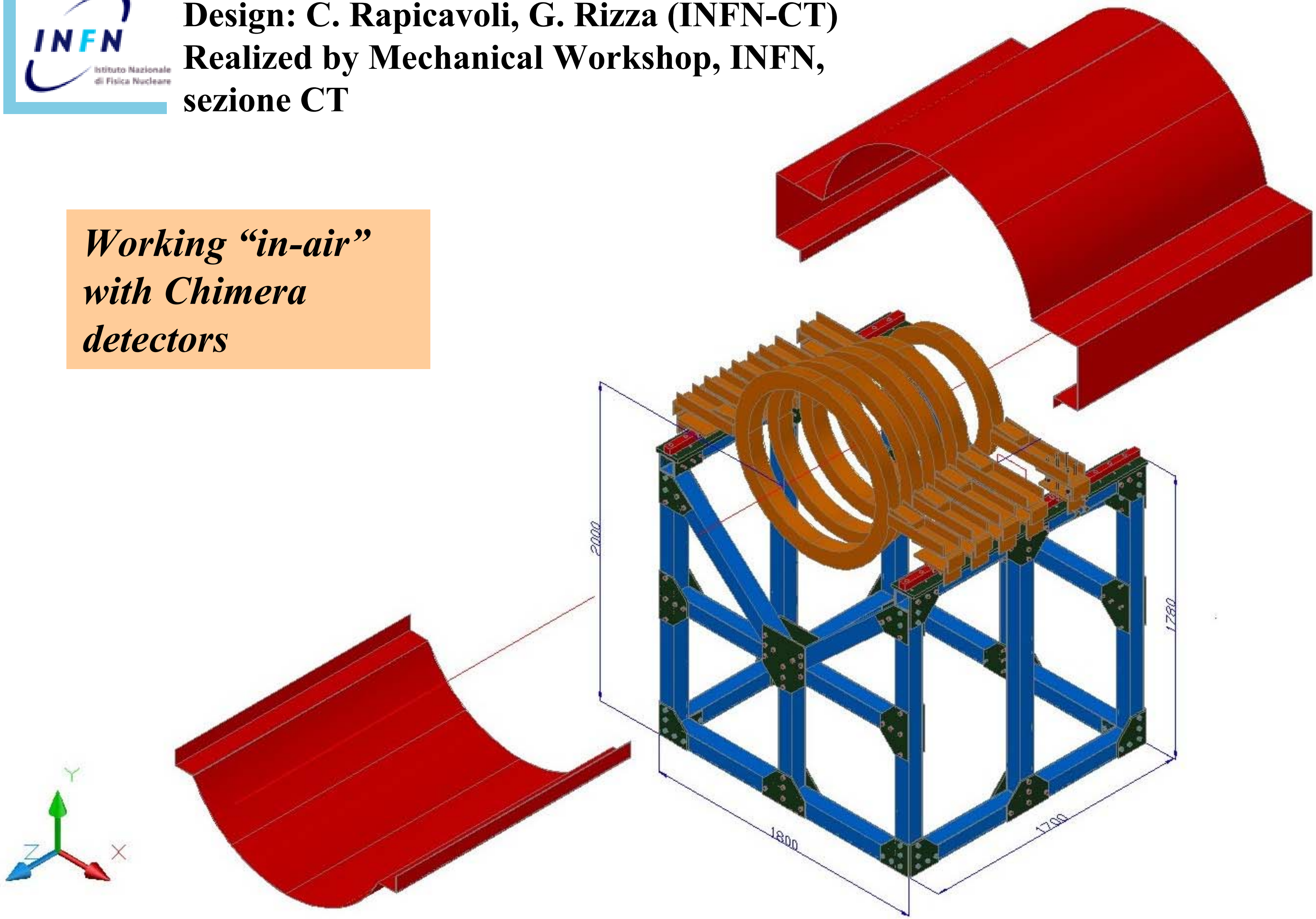


U^{73+} 10^5 pps 350 A.MeV + Pb

New mechanical setup for CHIMERA@GSI rings

Design: C. Rapicavoli, G. Rizza (INFN-CT)
Realized by Mechanical Workshop, INFN, sezione CT

Working "in-air" with Chimera detectors



CONCLUSIONS

Constraining the symmetry term of EOS**: The new experiment proposed at GSI by the Asy-EOS collaboration is a challenge. It is a unique occasion to get new data with high statistics in order to measure different observables sensitive to the symmetry energy at supra-saturation densities.**

UrQMD simulations have shown that proton-neutron flows constitute a crucial observable to probe the symmetry energy. Experimental setup is configured in order to obtain the maximum information possible from this experiment.

This is also an important experimental step to get new ideas towards the study of EOS in regions not only far from normal density but also with the use in the future of new radioactive beam facilities (extreme isospin asymmetry) such as FAIR (GSI), FRIB (USA), RIBF (Riken) SPIRAL2 (France), SPES (Italy), etc..

S394 experiment/ Asy-EOS collaboration

Constraining the Symmetry Energy at Supra-Saturation Densities With Measurements of Neutron and Proton Elliptic Flows

Co-Spokespersons: R.C. Lemmon[1]and P. Russotto[2]

Collaboration

F. Amorini[2], A. Anzalone[17], T. Aumann[3], V. Avdeichikov[12], V. Baran[23], Z. Basrak[4], J. Benlliure[13], I. Berceanu[11], A. Bickley[14], J. Brzychczyk[8], B. Bubak[22], G. Cardella[7], S. Cavallaro[2], J. Cederkall[12], M. Chartier[5], M.B. Chatterjee[16], A. Chbihi[6], M. Colonna[17], D. Cozma[11], E. De Filippo[7], K. Fissum[12], D. Di Julio[12], M. Di Toro[2], J.D. Frankland[6], E. Galichet[18], I. Gasparic[4], E. Geraci[15], V. Giordano[2], P. Golubev[12], L. Grassi[15], A. Grzeszczuk[22], P. Guazzoni[21], L. Isaksson[12], B. Jacobsson[12], A. Kelic[3], M. Kis[4], S. Kowalski[22], E. La Guidara[20], Y. Leifels[3], Q. Li[9], I. Lombardo[2], J. Lukasik[10], W. Lynch[14], A. Pagano[7], M. Papa[7], P. Pawlowski[10], M. Petrovici[11], S. Pirrone[7], G. Politi[15], A. Pop[11], F. Porto[2], W. Reisdorf[3], E. Rosato[19], M.V. Ricciardi[3], F. Rizzo[2], W. Trautmann[3], M.B. Tsang[14], G. Verde[7], M. Vigilante[19], J.P. Wielczko[6], P.Z. Wu[5], L.Zetta[21], W. Zipper[22]