ESF PESC Exploratory Workshop:
How to Constrain the High Density Symmetry Energy
Zagreb (Croatia), 15-18 October 2009

Status of the UrQMD predictions

M.Chartier, E.De Filippo, Y.Leifels, R.C.Lemmon, Q.Li, J.Lukasik, A.Pagano, P.Pawlowski, P.Russotto*, W.Trautmann, P.Wu

and the ASY-EOS collaboration

*LNS-INFN and Università di Catania, Italy

0.17 16/10/09

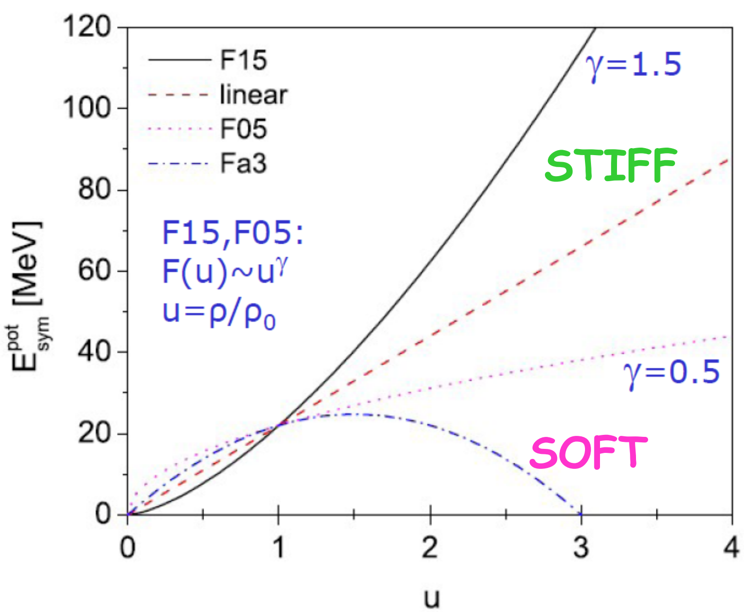
A key problem: The density dependence of the Symmetry Energy

$$\frac{E}{A}(\rho, I) = \frac{E}{A}(\rho, I=0) + \frac{E_{Sym}}{A}(\rho) I^2 + \ldots O(4)$$

$$I = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$$

I is the isospin asymmetry in terms of the neutron and protons density

parameterization in the UrQMD



Qingfeng Li et al., J. Phys. G 31 1359-1374 (2005)

parameterization in the IBUU

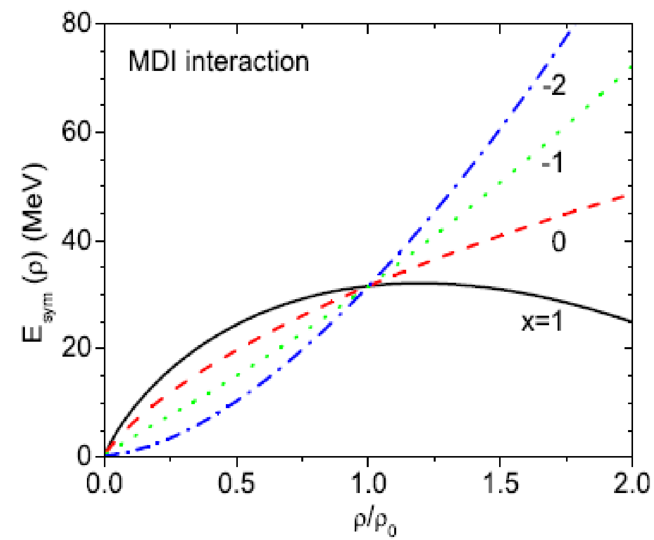


FIG. 2: (Color online) Symmetry energy as a function of density for the MDI interaction with $x = 1, 0, -1$ and -2. Taken from Ref. [109].

B.A. Li et al., Phys. Rep. 464 (2008)

Current Experimental Constraints on the Symmetry Energy

Increasingly stringent constraints at $\rho<\rho_0$:

- Giant and Pigmy Dipole Resonances
- Isospin diffusion and n/p ratios in HICs
- Isobaric analogue states and masses
- Isoscaling in projectile fragmentation

Almost no constraints at $\rho>\rho_0$:

- limited π^-/π^+, K^+/K^0, n-p flow studies

PRL 94, 032701 (2005) PHYSICAL REVIEW LETTERS week ending 28 JANUARY 2005

Determination of the Stiffness of the Nuclear Symmetry Energy from Isospin Diffusion

Lie-Wen Chen,[1,*] Che Ming Ko,[1] and Bao-An Li[2]

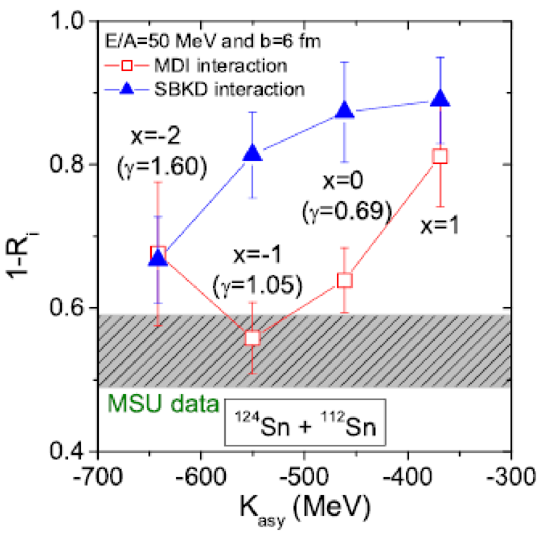


FIG. 4 (color online). The degree of isospin diffusion as a function of K_{asy} with the MDI and SBKD interactions. γ is the parameter for fitting the corresponding symmetry energy with $E_{sym}(\rho) = 31.6(\rho/\rho_0)^\gamma$.

PRL 102, 062502 (2009) PHYSICAL REVIEW LETTERS week ending 13 FEBRUARY 2009

Circumstantial Evidence for a Soft Nuclear Symmetry Energy at Suprasaturation Densities

Zhigang Xiao,[1] Bao-An Li,[2,*] Lie-Wen Chen,[3] Gao-Chan Yong,[4] and Ming Zhang[1]

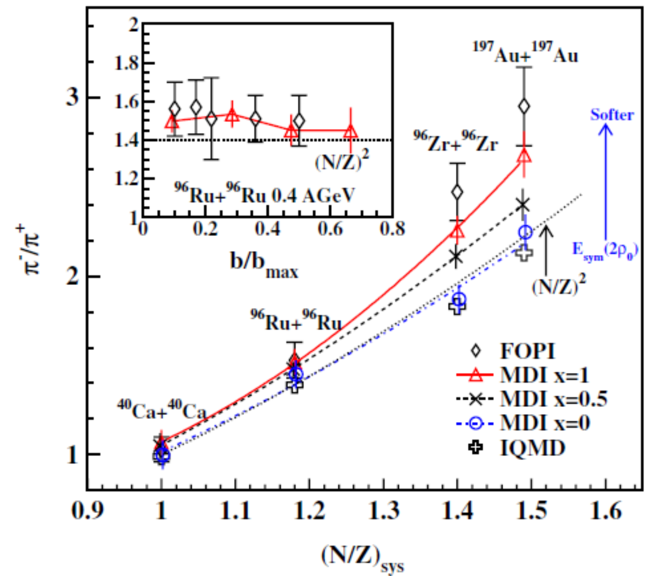
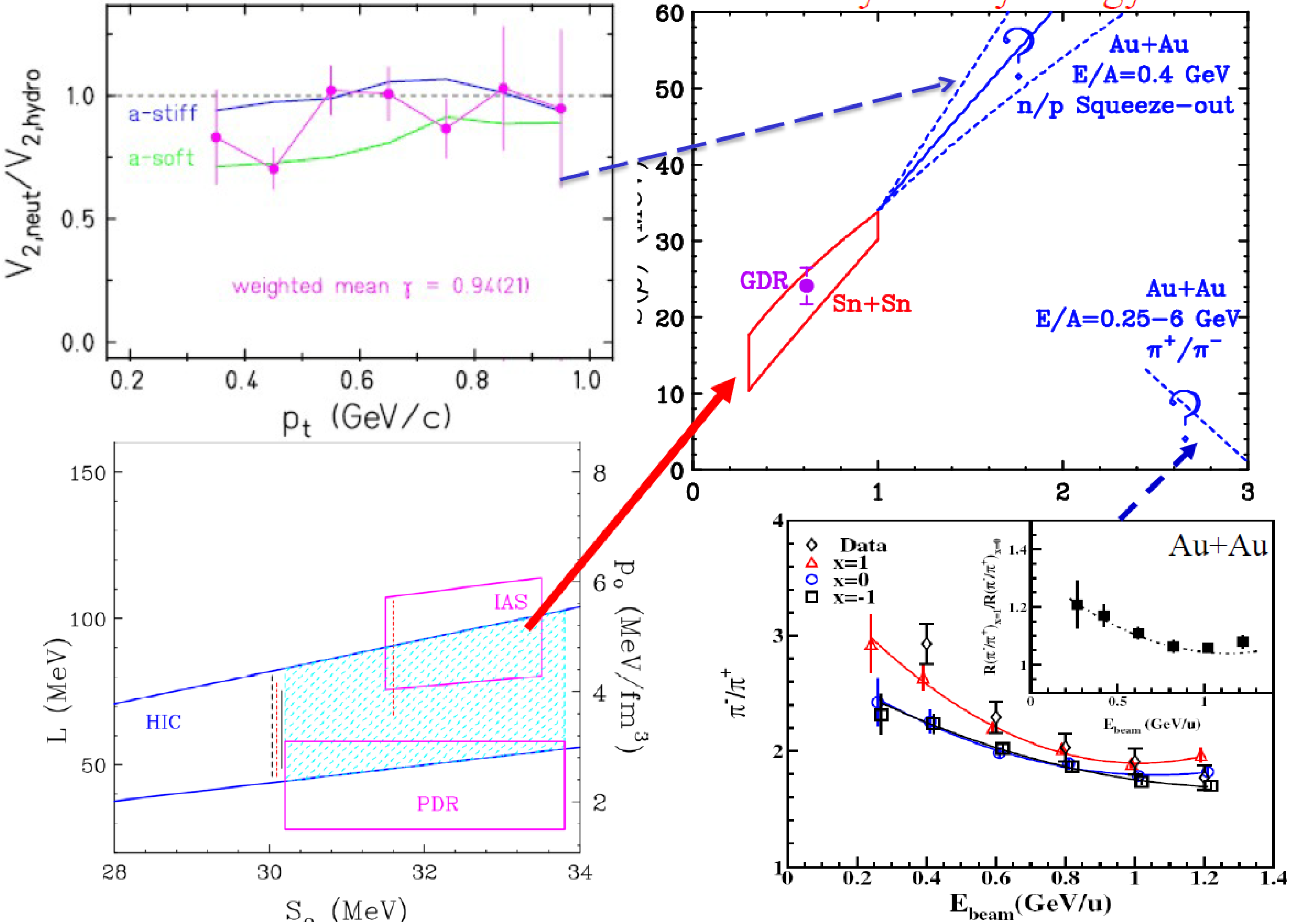


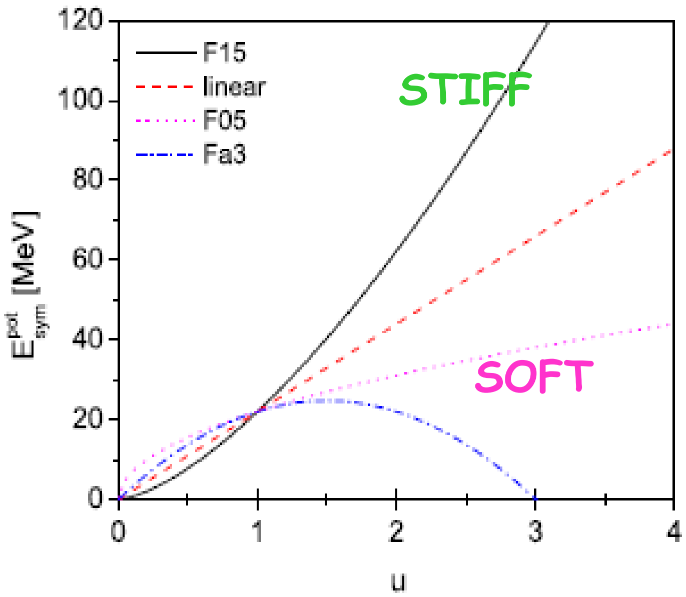
FIG. 2 (color online). The π^-/π^+ ratio as a function of the neutron/proton ratio of the reaction system at 0.4*A* GeV with the reduced impact parameter of $b/b_{max} \leq 0.15$. The inset is the impact parameter dependence of the π^-/π^+ ratio for the $^{96}Ru + ^{96}Ru$ reaction at 0.4*A* GeV.

From B.Tsang NUFRA2009

Constraints on the density dependence of symmetry energy



URQMD simulations (by Qingfeng Li)



symmetry potential energy.

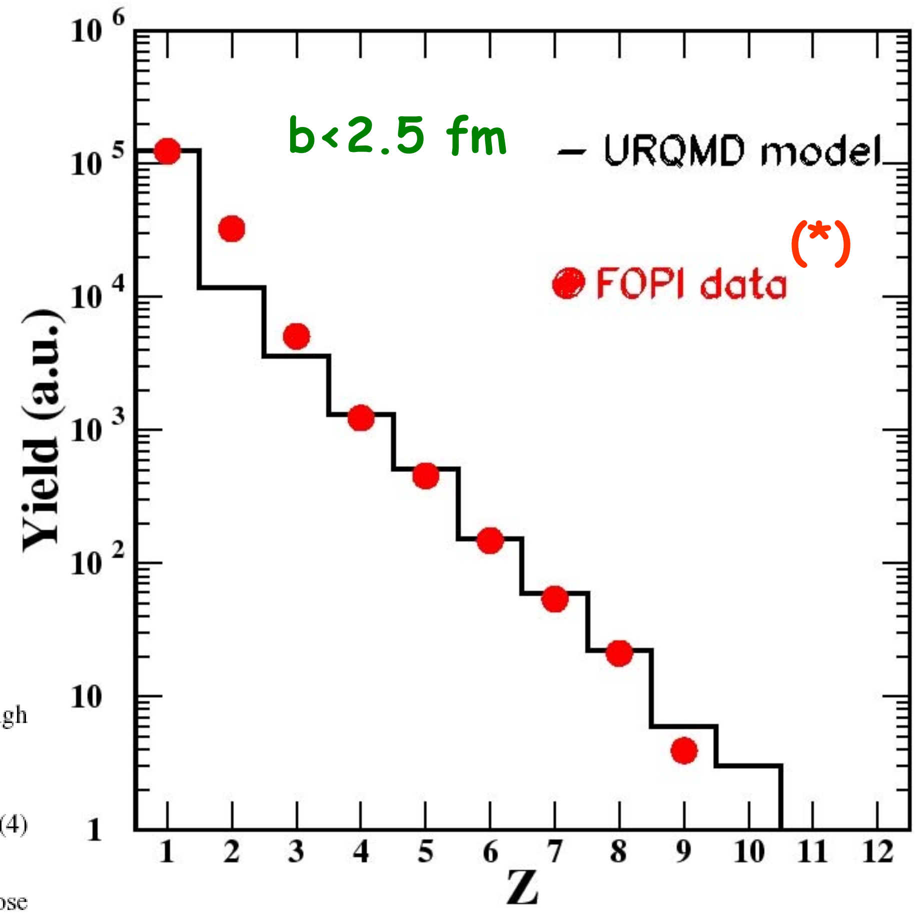
In order to mimic the strong density dependence of the symmetry potential at high densities, we adopt the form of $F(u)$, used in [4], as

$$F(u) = \begin{cases} F_1 = u^{\gamma}, & \gamma > 0, \\ F_2 = u \cdot \dfrac{a-u}{a-1}, & a > 1. \end{cases} \qquad u = \rho/\rho_0 \qquad (4)$$

Here, γ is the strength of the density dependence of the symmetry potential. We choose $\gamma = 0.5$ and 1.5, denoted as the symmetry potentials F05 and F15, respectively. a (in F_2) is

See Qingfeng Li, J. Phys. G 31 1359-1374 (2005) and references therein

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



Coalescence condition:

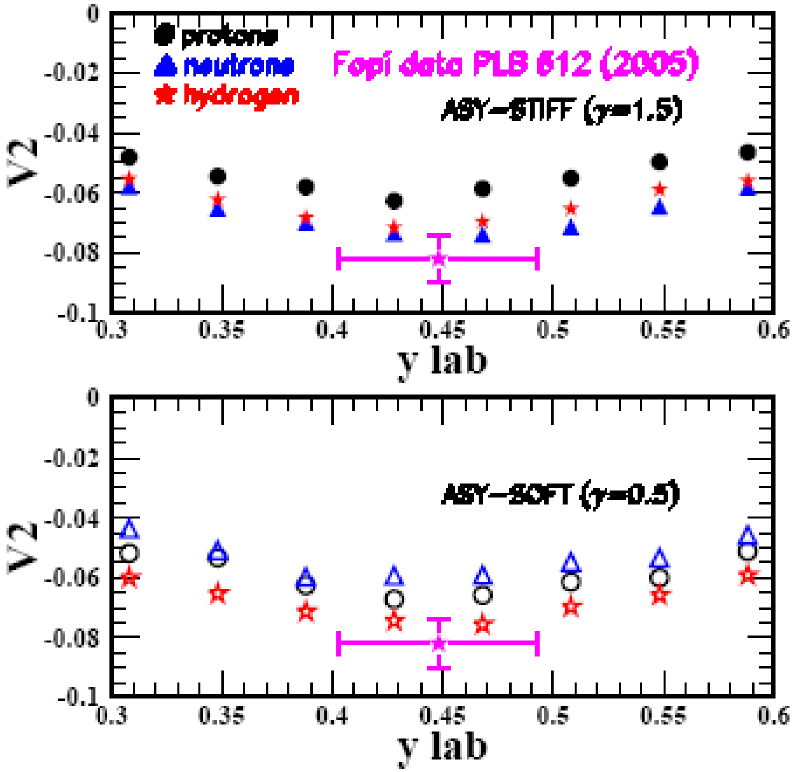
DR <3 fm and DP< 275 MeV/c

(*) W. Reisdorf et al., NPA 612 493-556 (1997)

differential elliptic flow

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

Q.F. Li and P. Russotto



stiff

soft

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

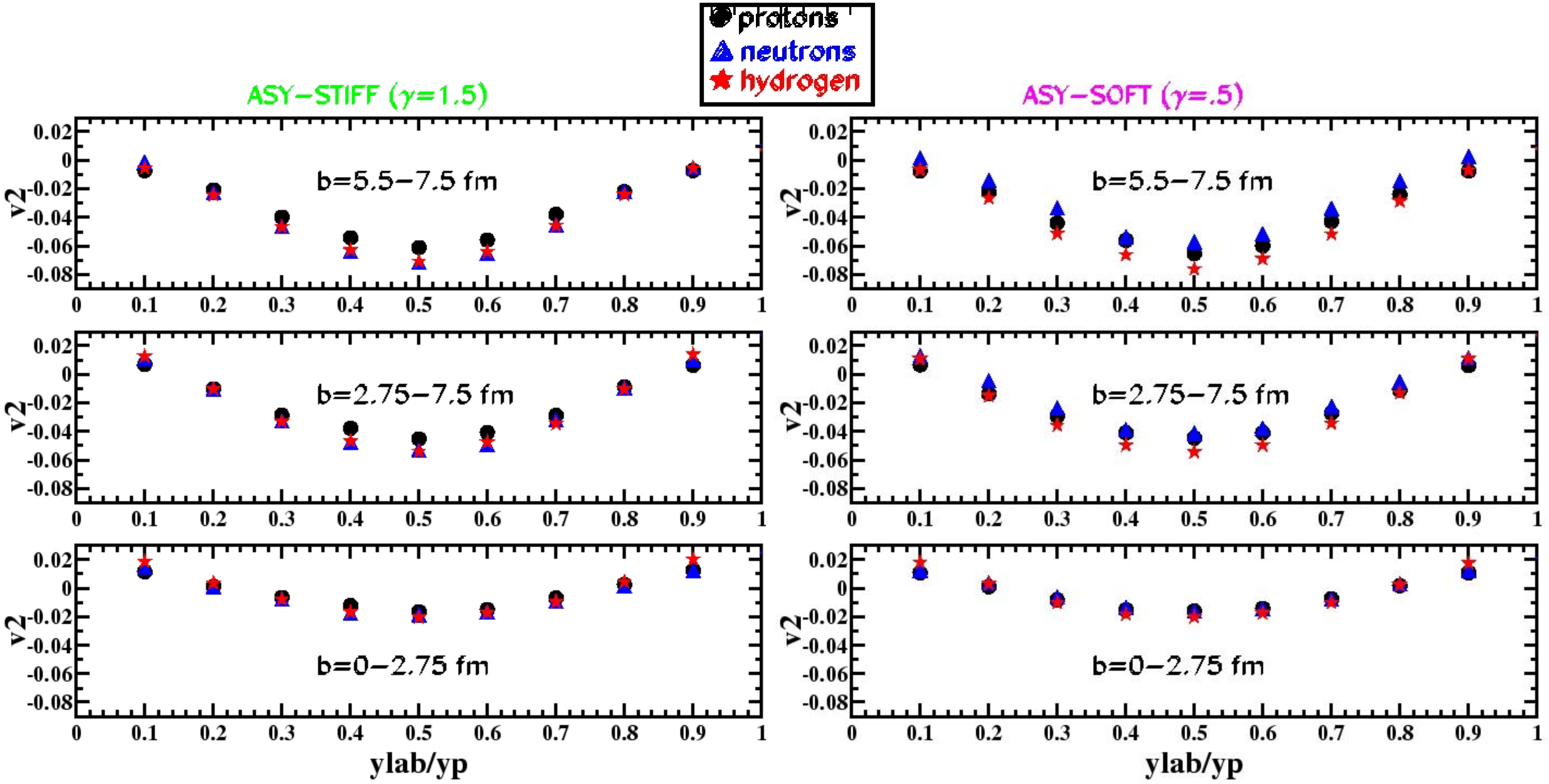
5.5<b<7.5 fm

inversion of neutron and hydrogen flows

squeeze-out more sensitive than the directed flow

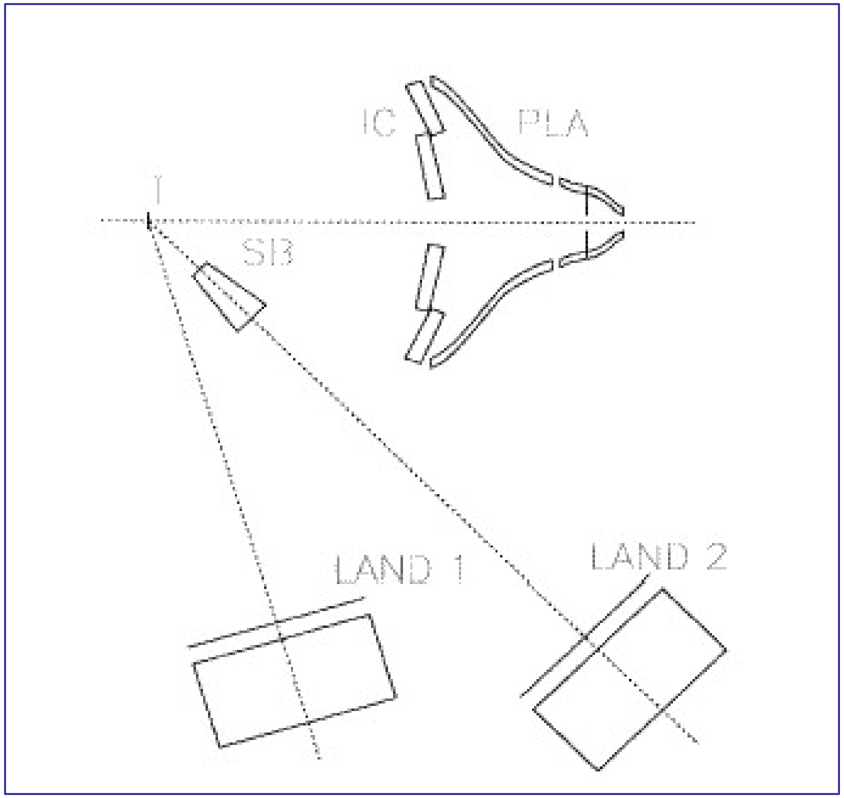
URQMD simulations:Au+Au @ 400 AMeV

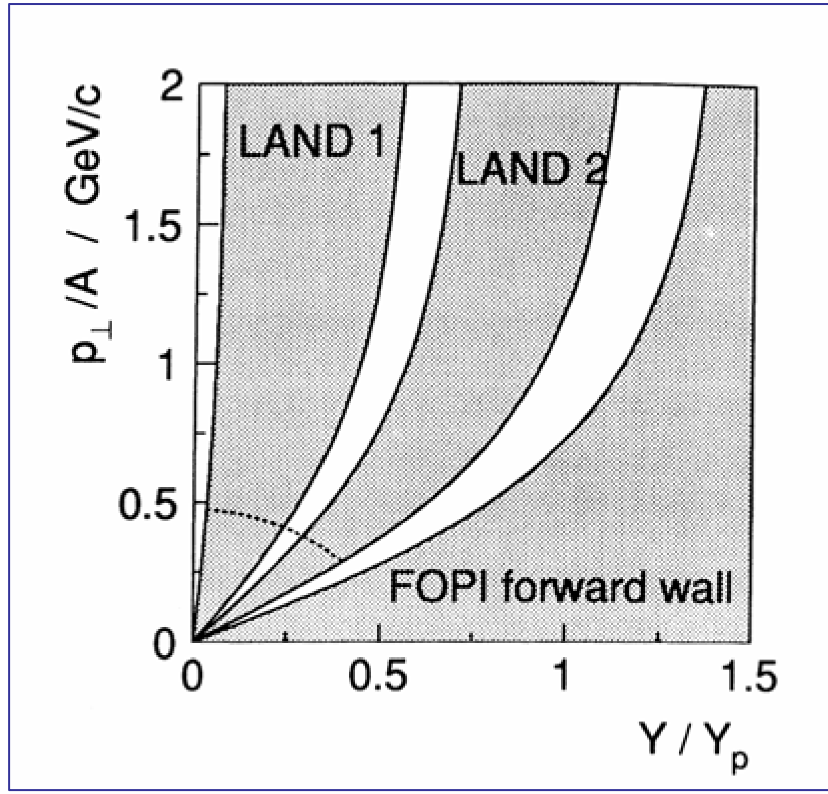
Evolution with impact parameter



FOPI/LAND experiment on neutron squeeze out

Au+Au 400 A MeV





LAND coverage
$37° < \theta_{lab} < 53°$
$61° < \theta_{lab} < 85°$

Y. Leifels et al., PRL 71, 963 (1993)

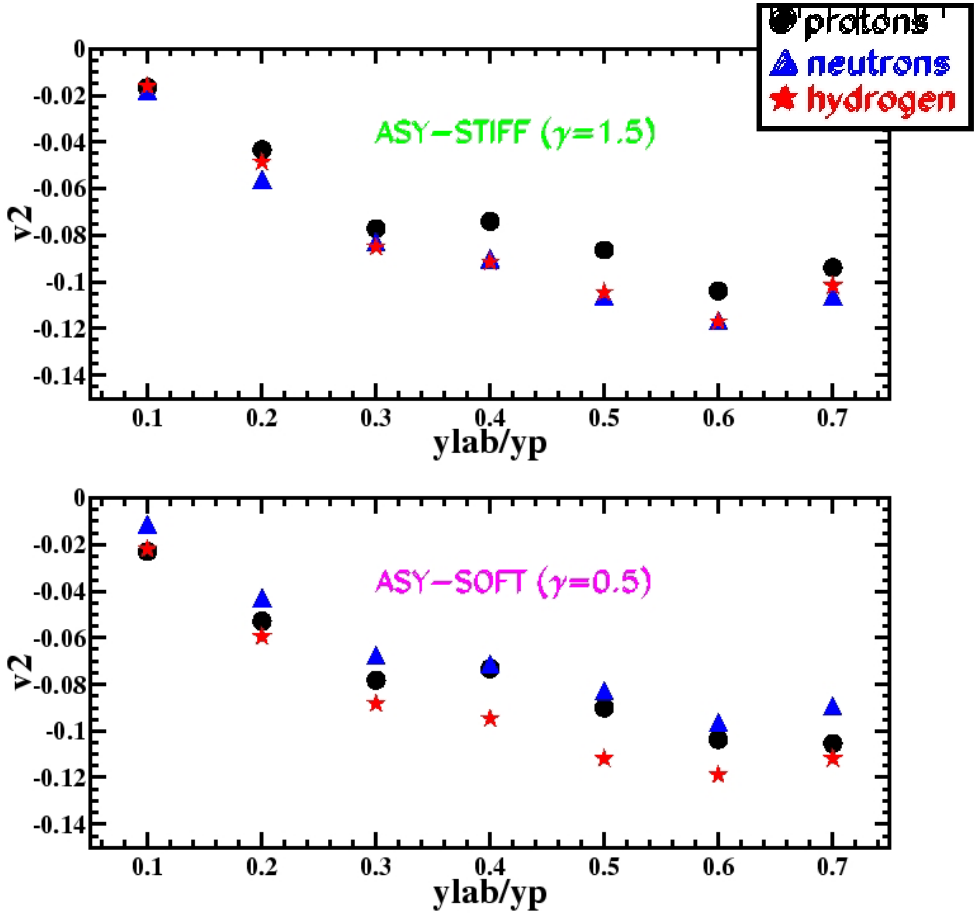
Comparison to experimental data:

see W.Trautmann, P.Wu talks

URQMD simulations: Au+Au @ 400 AMeV

5.5<b<7.5 fm

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



Seen by LAND

$37° < \theta_{lab} < 53°$

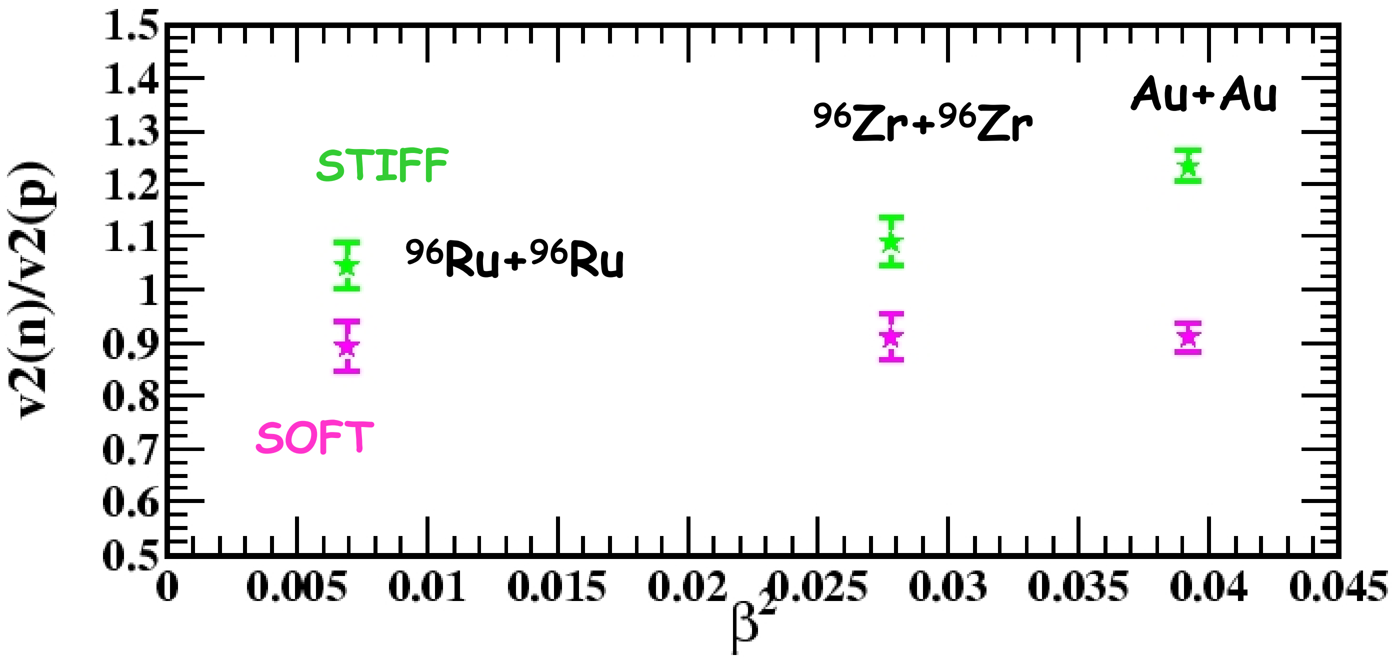
$61° < \theta_{lab} < 85°$

$0.3 < pt < 1.3$ GeV/c

inversion of the relative strengths of the elliptic flow for neutrons, protons, and hydrogen → relative effect!!!!

URQMD simulations: @ 400 AMeV

V2 for |(y/yp)$^{c.m.}$|<0.1

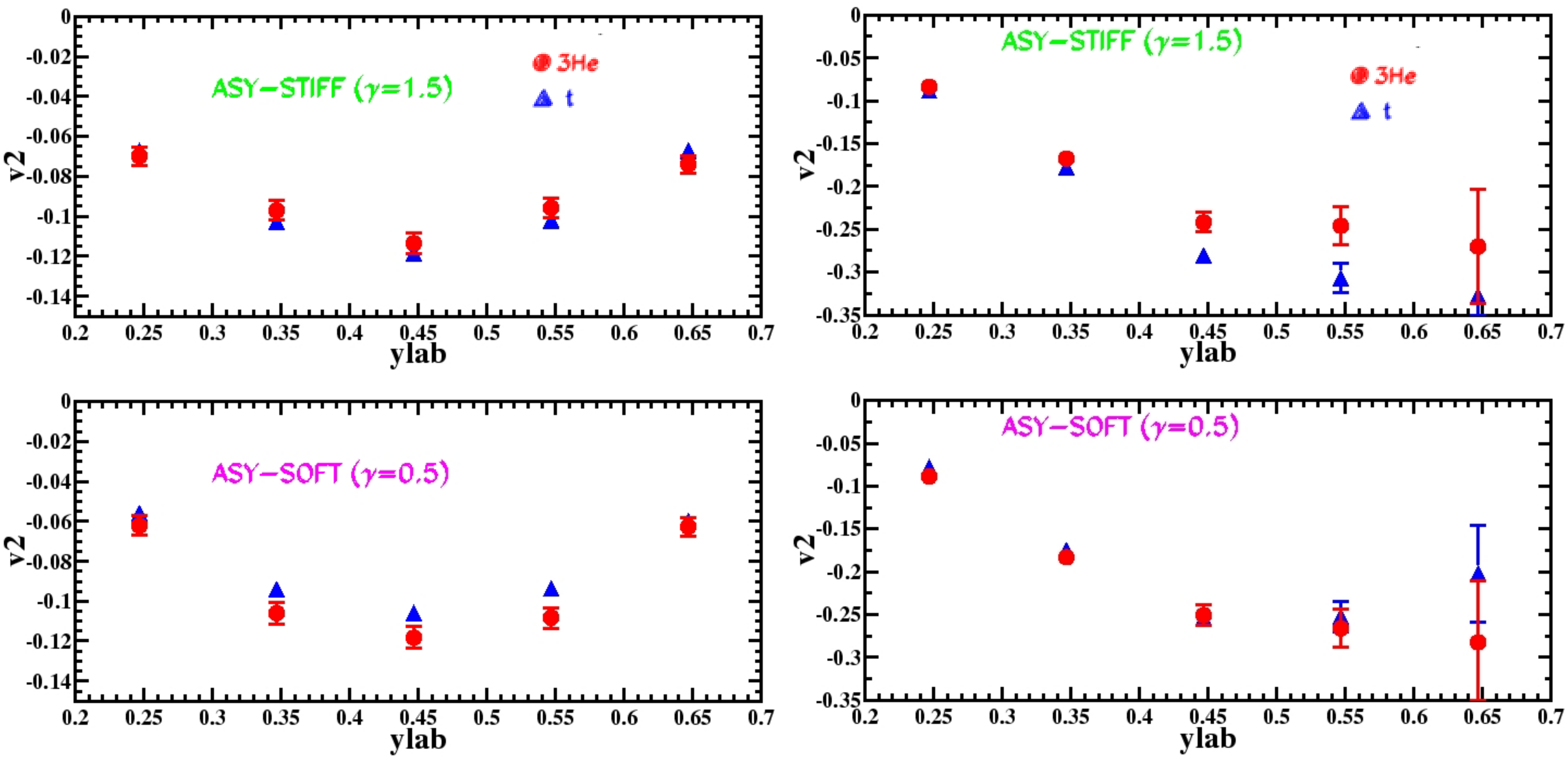


β=(N-Z)/(N+Z)

Au+Au @ 400 AMeV

5.5<b<7.5 fm

preliminar

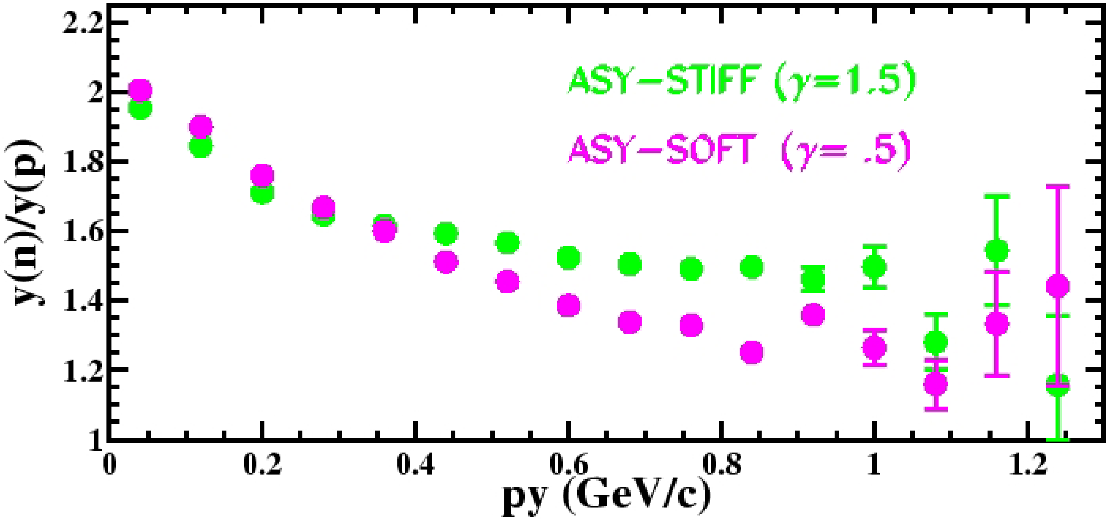


Total

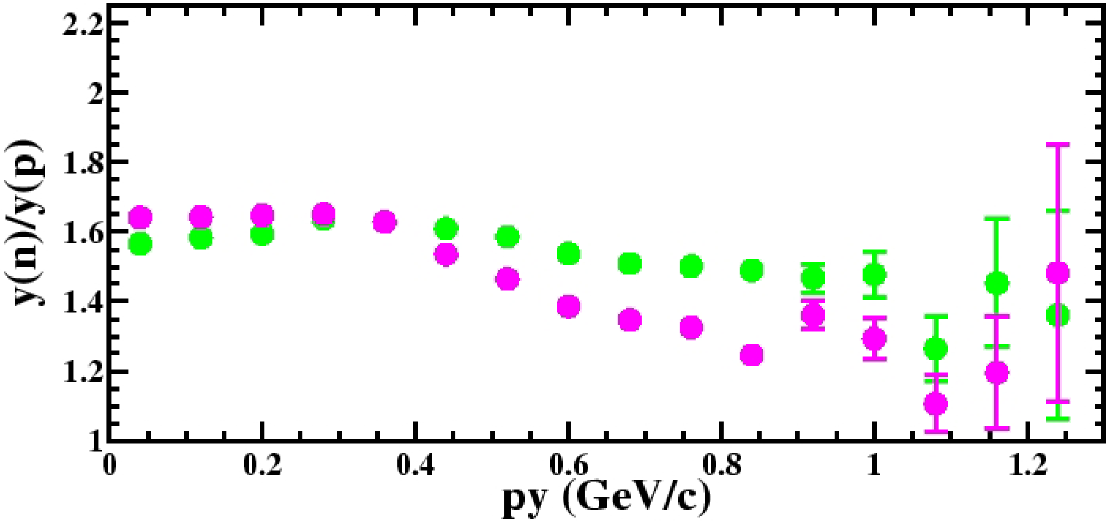
$37° < \theta_{lab} < 53°$

Au+Au @ 400 AMeV

5.5<b<7.5 fm



Total



Seen by LAND

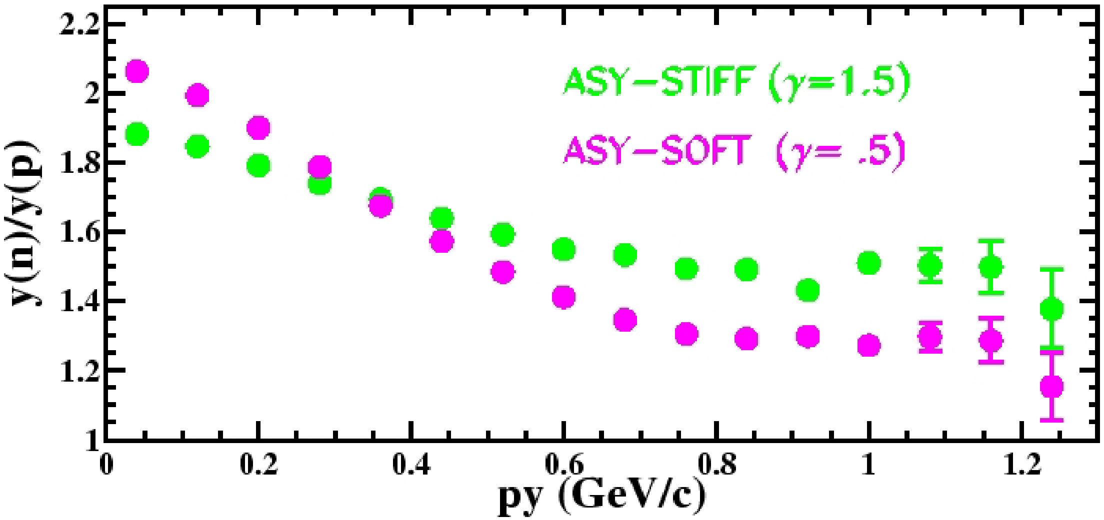
37° < θ_{lab} < 53°

61° < θ_{lab} < 85°

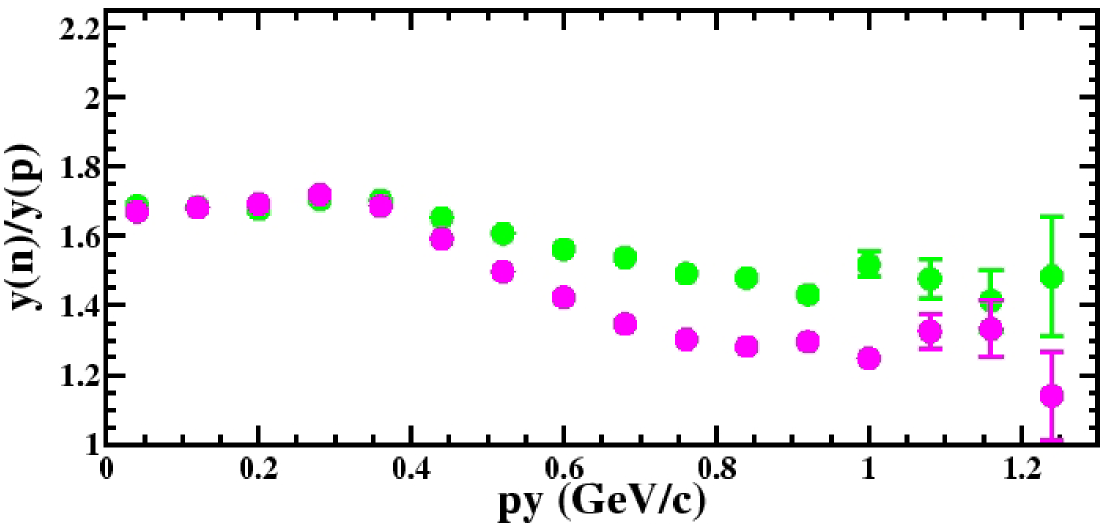
(300<pt<1300 Mev/c)

Au+Au @ 400 AMeV

b<2.75 fm



Total



Seen by LAND

$37° < \theta_{lab} < 53°$

$61° < \theta_{lab} < 85°$

(300<pt<1300 MeV/c)

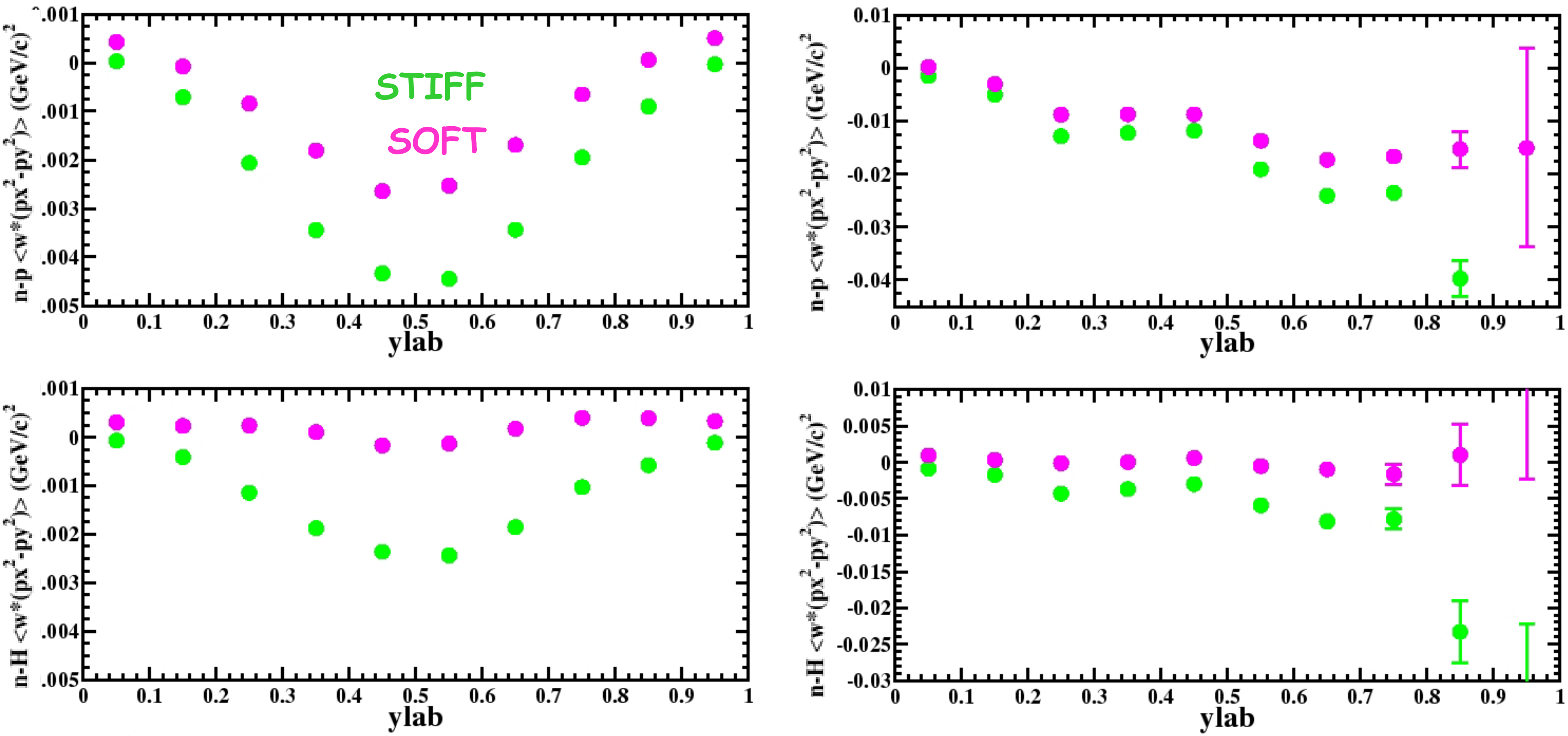
Au+Au @ 400 AMeV

5.5<b<7.5 fm

$$F^x_{n-p}(y) \equiv \sum_{i=1}^{N(y)} (p^x_i w_i)/N(y), \qquad (28)$$

where $w_i = 1(-1)$ for neutrons (protons) and $N(y)$ is the total number of free nucleons at rapidity y. Since

$$F^{x-y}_{n-p}(y) = \sum_{i=1}^{N(y)} [(p^x_i)^2 - (p^y_i)^2] w_i / N(y)$$



preliminar

Total

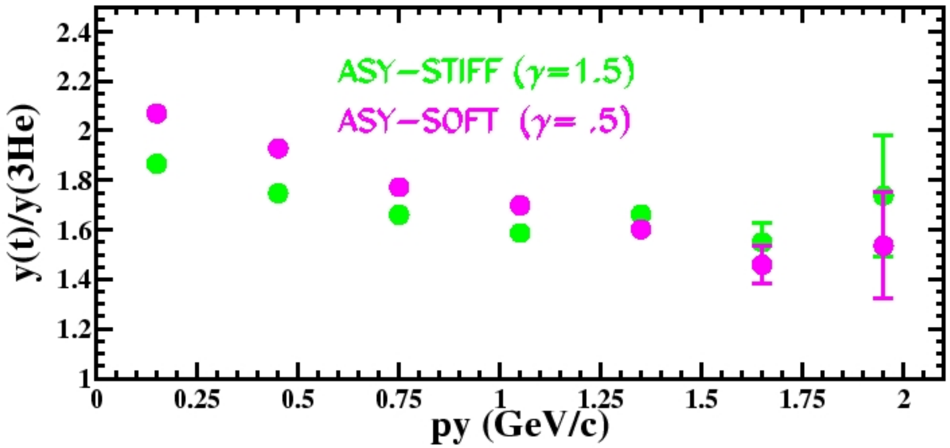
$37° < \theta_{lab} < 53°$
$61° < \theta_{lab} < 85°$
(300<pt<1300 MeV/c)

PB 13/10/09

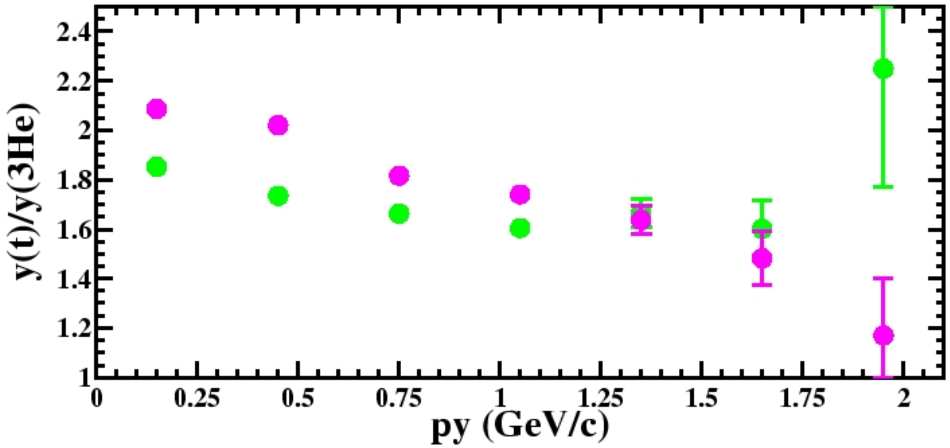
preliminar

Au+Au @ 400 AMeV

5.5<b<7.5 fm



Total

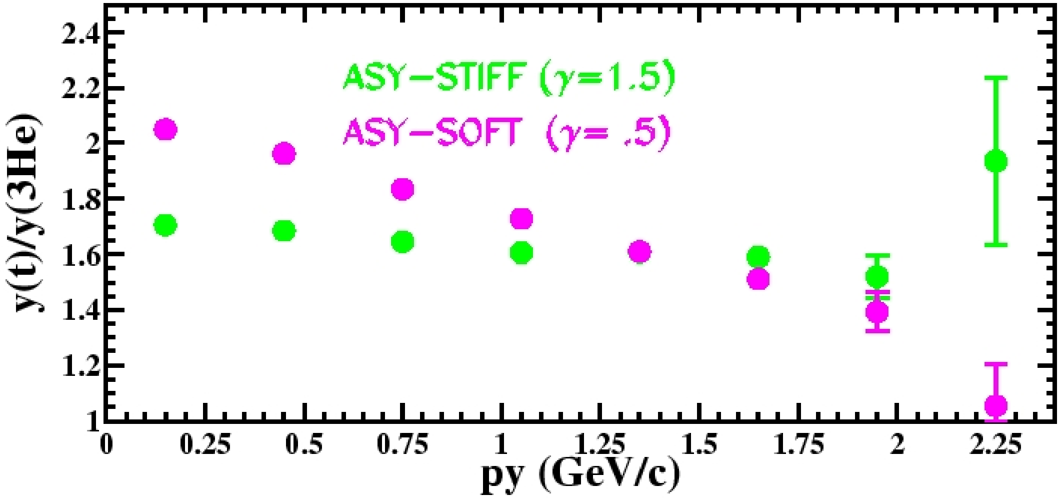


$37° < \theta_{lab} < 53°$

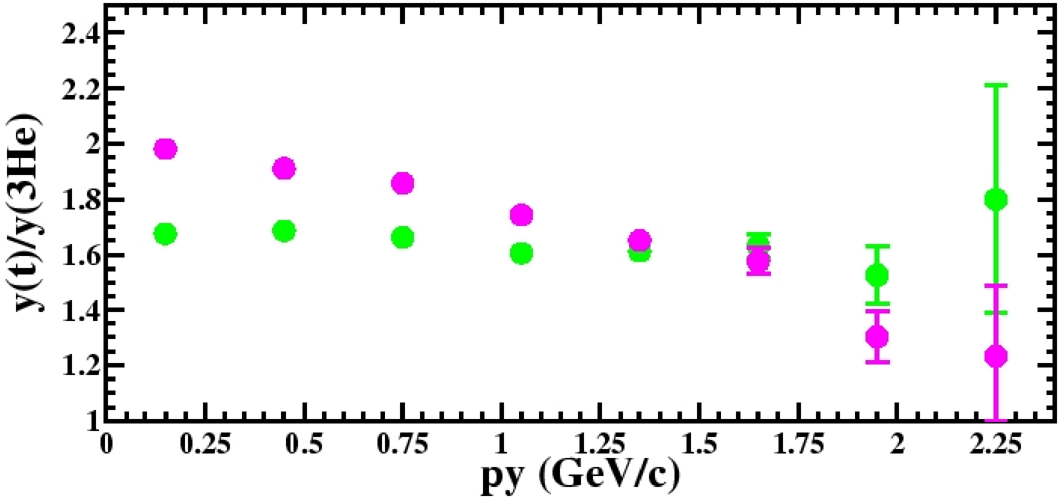
preliminar

Au+Au @ 400 AMeV

b<2.75 fm



Total



37°<θ_{lab}<53°

Double neutron-proton differential transverse flow as a probe for the high density behavior of the nuclear symmetry energy

Gao-Chan Yong,[1,2] Bao-An Li,[3,4] and Lie-Wen Chen[5,6]

$$F^x_{n-p}(y) \equiv \sum_{i=1}^{N(y)} (p_i^x w_i)/N(y), \qquad (28)$$

where $w_i = 1(-1)$ for neutrons (protons) and $N(y)$ is the total number of free nucleons at rapidity y. Since

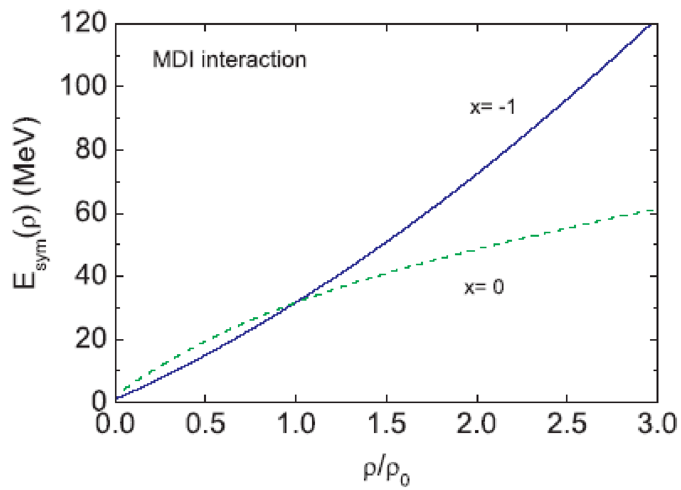


FIG. 1. (Color online) Density dependence of nuclear symmetry energy using the MDI interaction with $x = 0$ and $x = -1$.

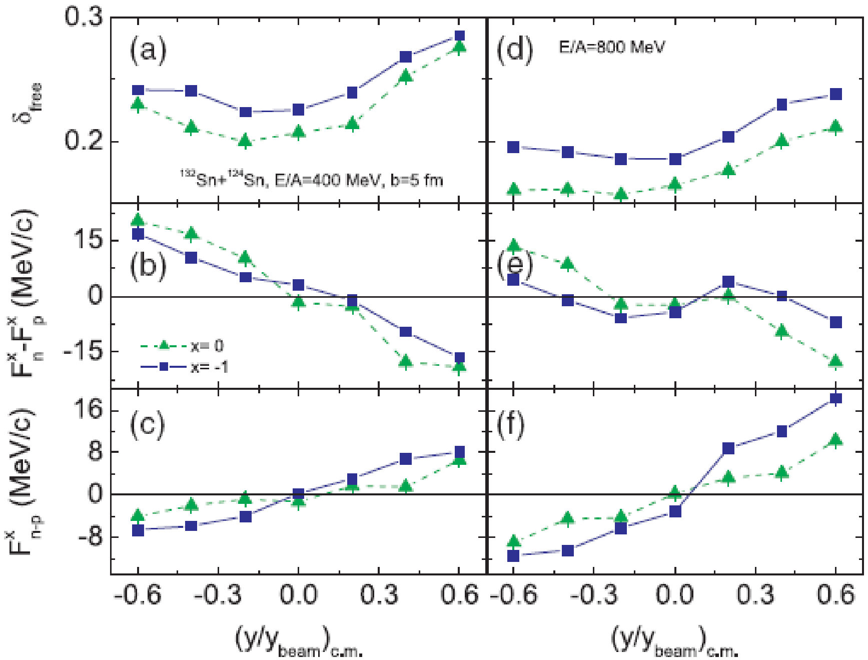


FIG. 3. (Color online) Rapidity distribution of the isospin asymmetry of free nucleons (upper panels), the difference of the average nucleon transverse flows (middle panels) and the neutron-proton differential transverse flow (lower panels) from $^{132}Sn+^{124}Sn$ reaction at the incident beam energies of 400, 800 MeV/nucleon and $b = 5$ fm with two symmetry energies of $x = 0$ and $x = -1$.

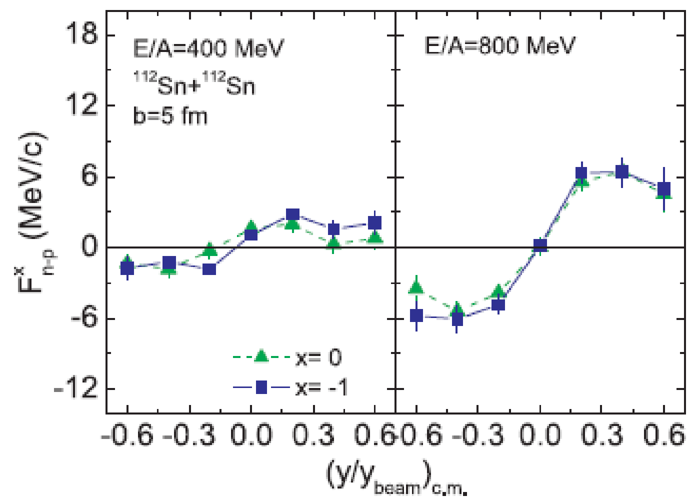


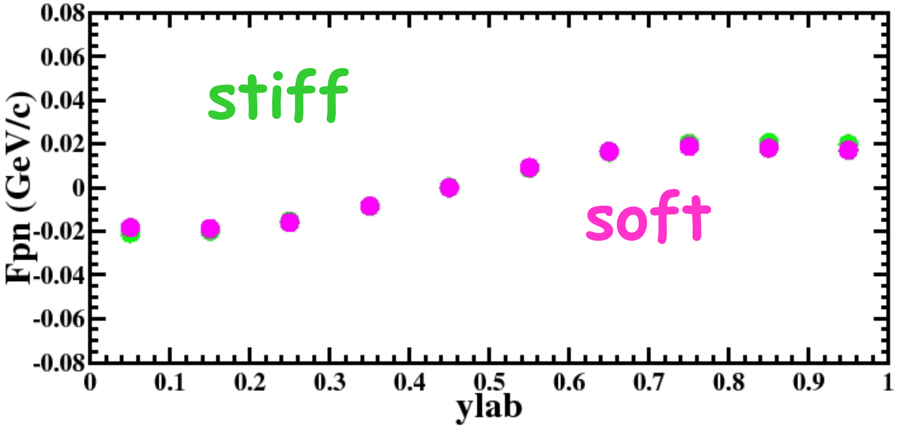
FIG. 4. (Color online) Same as the lowest two panels (c) and (f) of Fig. 3 but for the reaction system of $^{112}Sn+^{112}Sn$.

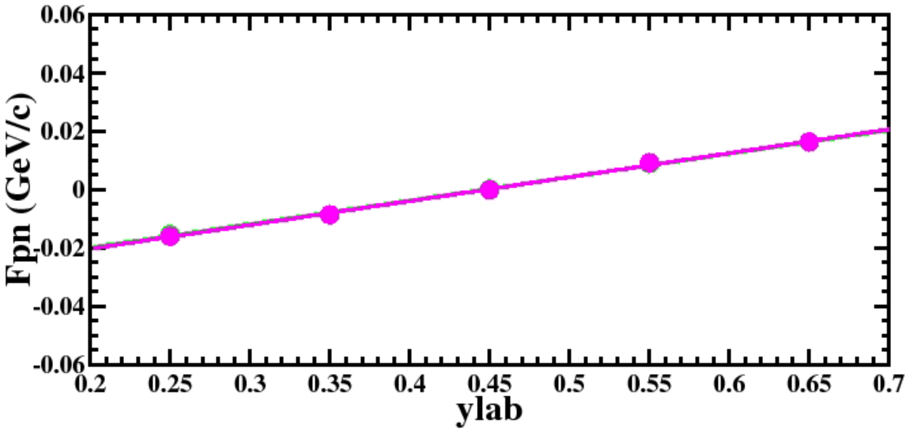
URQMD simulations: Au+Au @ 400 AMeV

$$F^x_{n-p}(y) \equiv \sum_{i=1}^{N(y)} (p_i^x w_i)/N(y), \qquad (28)$$

where $w_i = 1(-1)$ for neutrons (protons) and $N(y)$ is the total number of free nucleons at rapidity y. Since

b=5.5-7.5 fm





Proton and neutron

All pt

Slopes

0.08

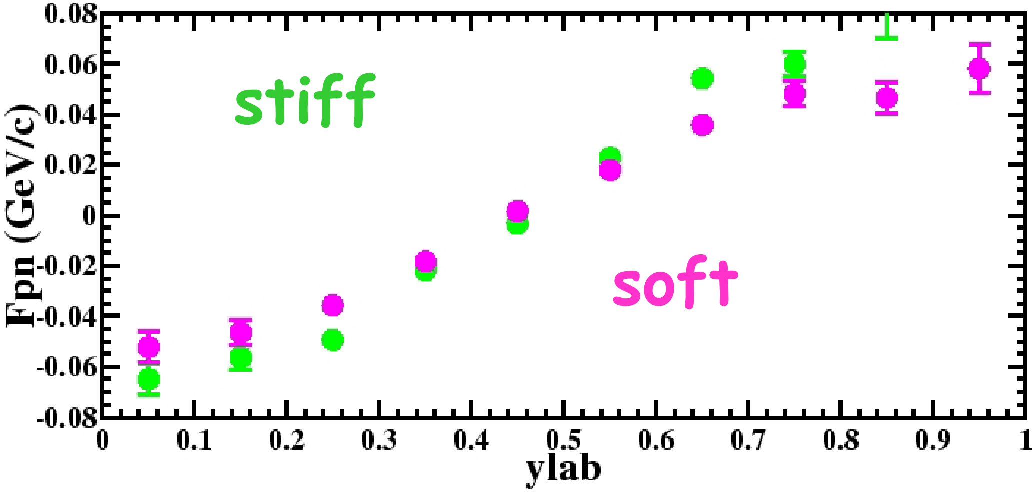
0.08

URQMD simulations: Au+Au @ 400 AMeV

$$F^x_{n-p}(y) \equiv \sum_{i=1}^{N(y)} (p^x_i w_i)/N(y), \qquad (28)$$

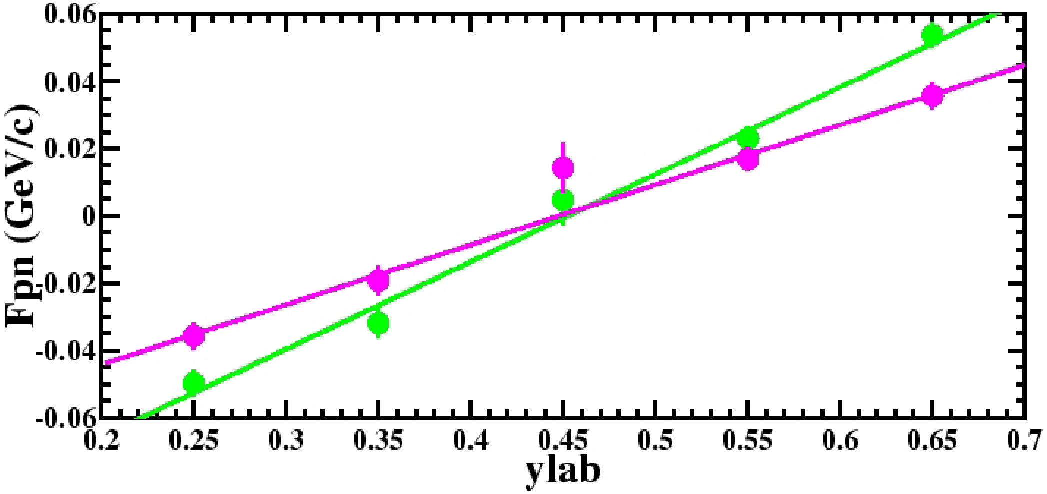
where $w_i = 1(-1)$ for neutrons (protons) and $N(y)$ is the total number of free nucleons at rapidity y. Since

b=5.5-7.5 fm



Proton and neutron

pt>0.75 GeV/c



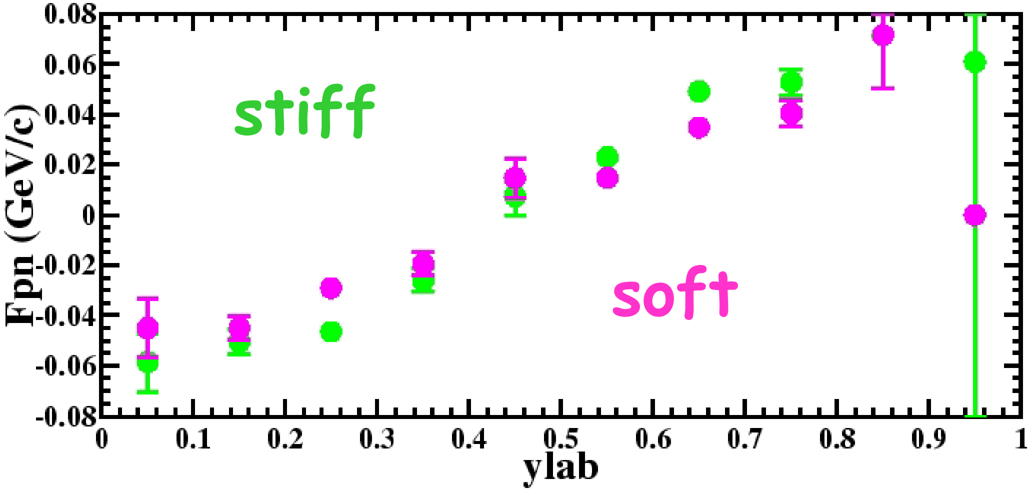
Slopes

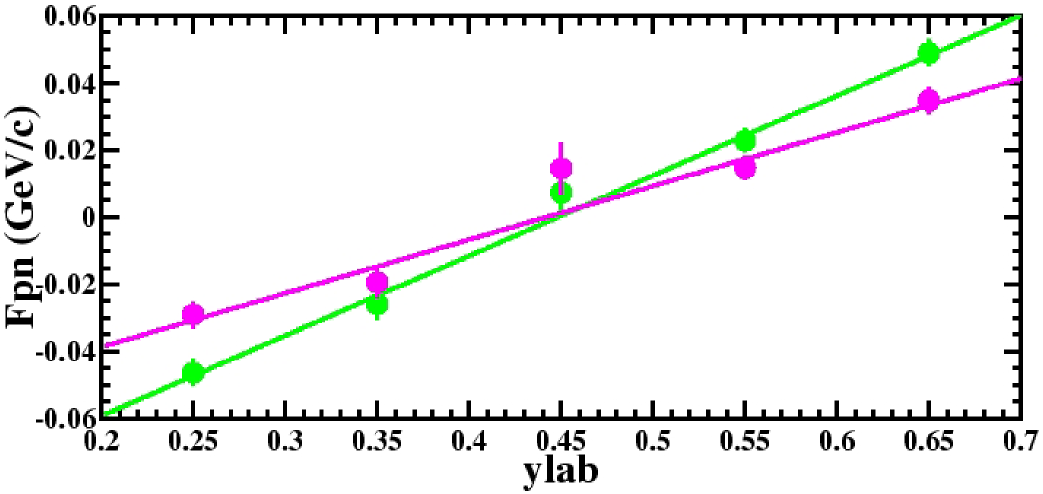
0.25

0.18

URQMD simulations:
Au+Au @ 400 AMeV

b=5.5-7.5 fm





p and neutron

pt>0.75 GeV/c

$37° < \theta_{lab} < 53°$

$61° < \theta_{lab} < 85°$

$\sigma_{rp} = 24°$

Slopes

0.24

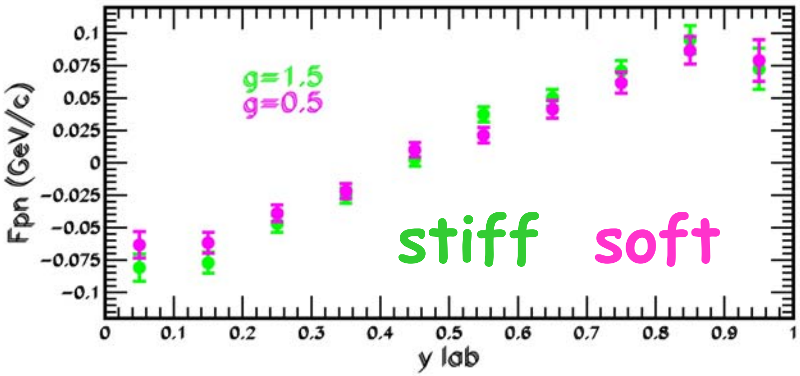
0.16

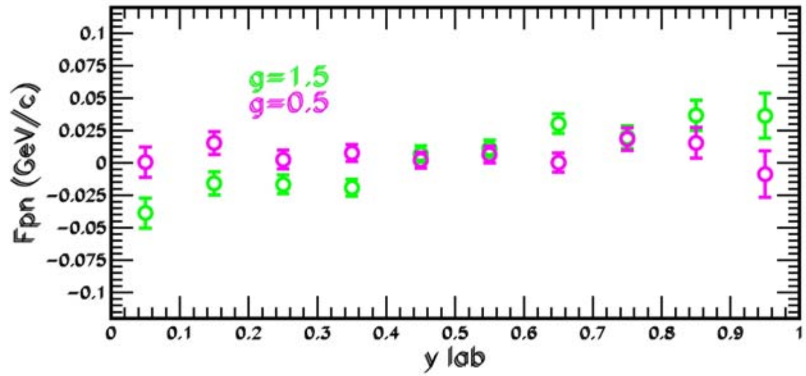
preliminar

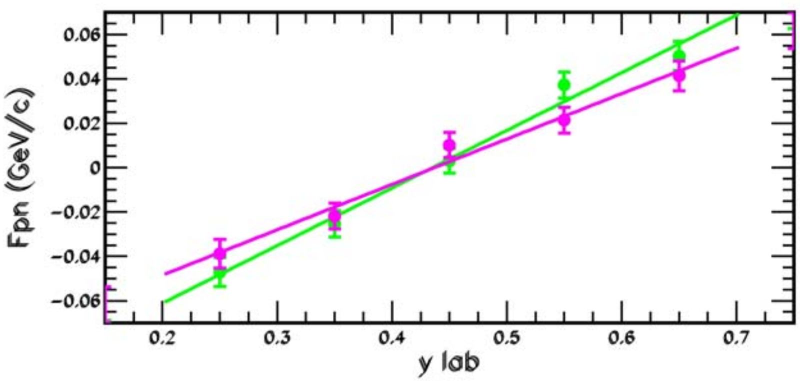
400 AMeV (SMDBHF)

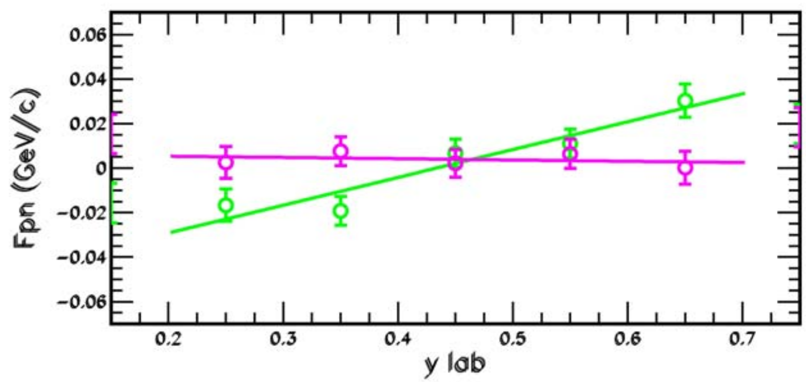
$^{124}Sn+^{124}Sn$ b=4-6 fm

$^{112}Sn+^{112}Sn$ b=4-6 fm







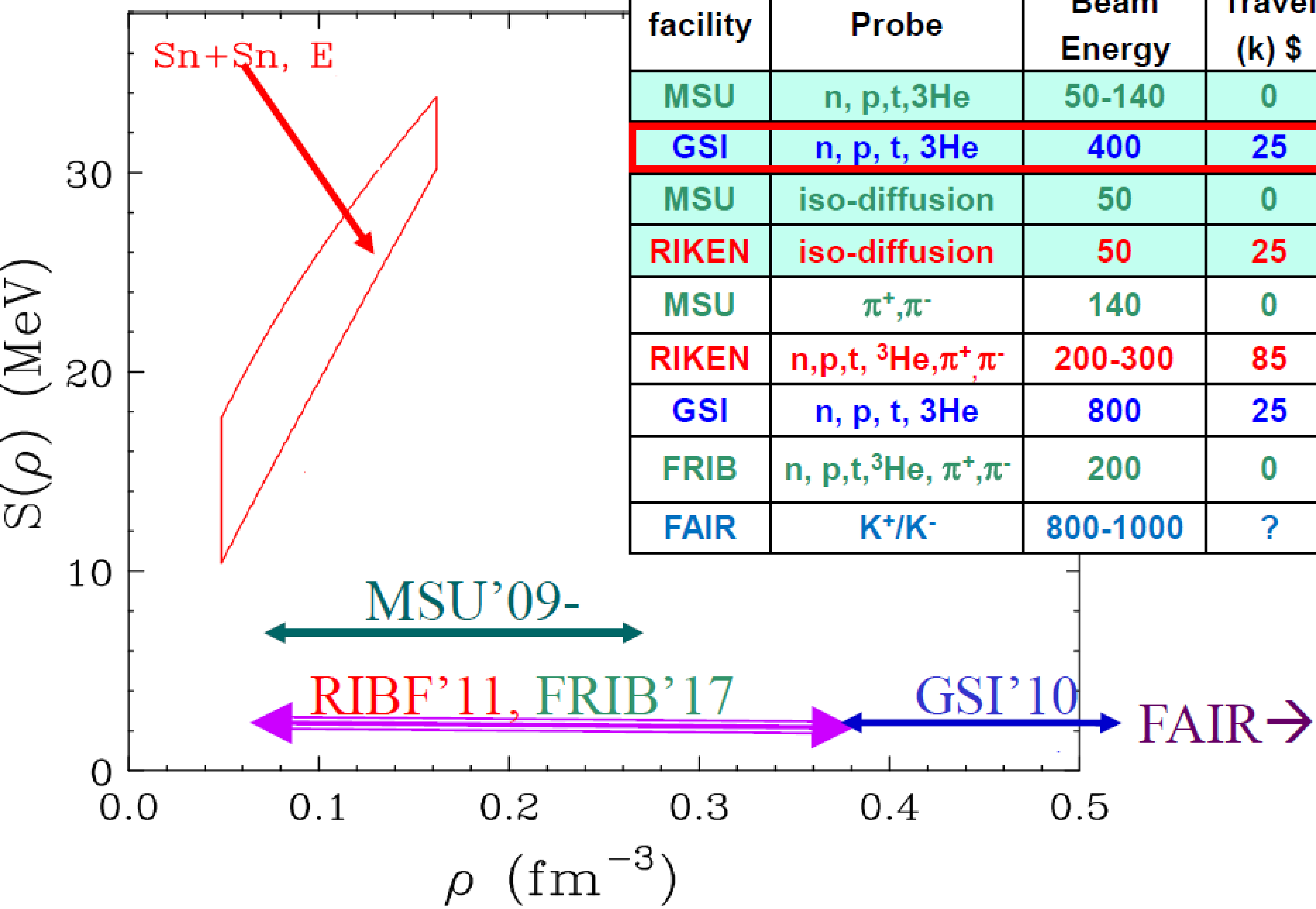


Proton and neutron pt>0.75 GeV/c

→ DFpn and so on….

(02/12/08)

From B.Tsang NUFRA2009



facility	Probe	Beam Energy	Travel (k) $	year	density
MSU	n, p,t,3He	50-140	0	2009	$<\rho_o$
GSI	n, p, t, 3He	400	25	2010/2011	$2.5\ \rho_o$
MSU	iso-diffusion	50	0	2010/2011	$<\rho_o$
RIKEN	iso-diffusion	50	25	2010	$<\rho_o$
MSU	π^+,π^-	140	0	2012-2014	$1\text{-}1.5\ \rho_o$
RIKEN	n,p,t, $^3He,\pi^+,\pi^-$	200-300	85	2012-2014	$2\rho_o$
GSI	n, p, t, 3He	800	25	2014	$2\text{-}3\rho_o$
FRIB	n, p,t,^3He, π^+,π^-	200	0	2018-	$2\text{-}2.5\ \rho_o$
FAIR	K^+/K^-	800-1000	?	2018	$3\rho_o$

Symmetry Energy Project →International collaboration to determine the symmetry energy over a range of density

Require: New Detectors (TPC), travel money, theory support

R.Lemmon, P.Russotto et al.

ASY-EOS experiment approved by GSI-PAC

(possible) 1st phase toward FAIR ???

(e.g. ^{132}Sn, ^{106}Sn beams)

Au+Au @ 400 AMeV

$^{96}Zr + ^{96}Zr$ @ 400 AMeV

$^{96}Ru + ^{96}Ru$ @ 400 AMeV

Other detectors in order to determine reaction plane or measure t, ^{3}He, N/Z of light IMFs…..?????

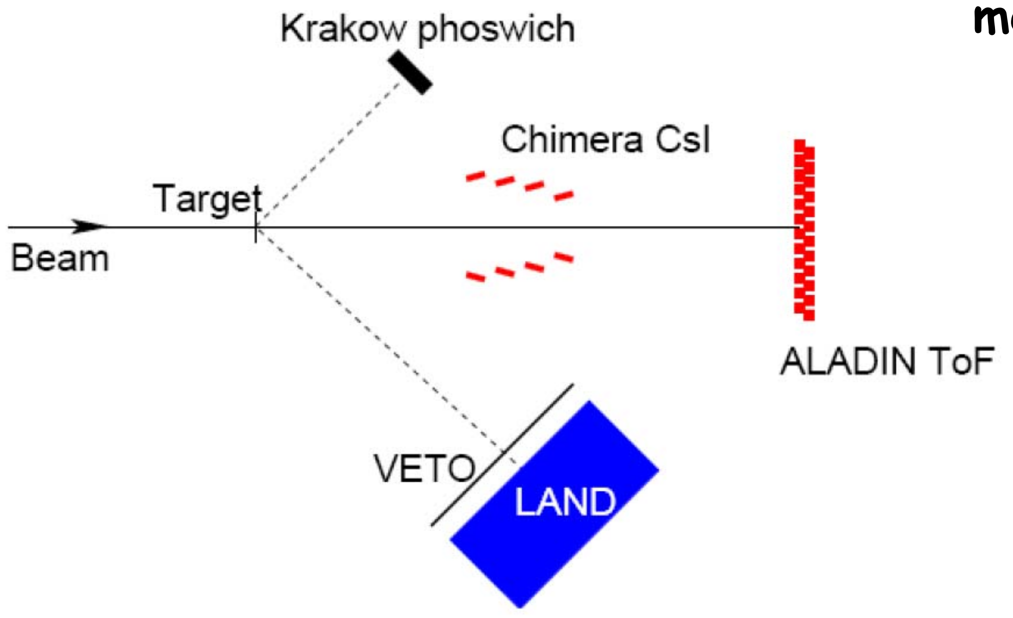
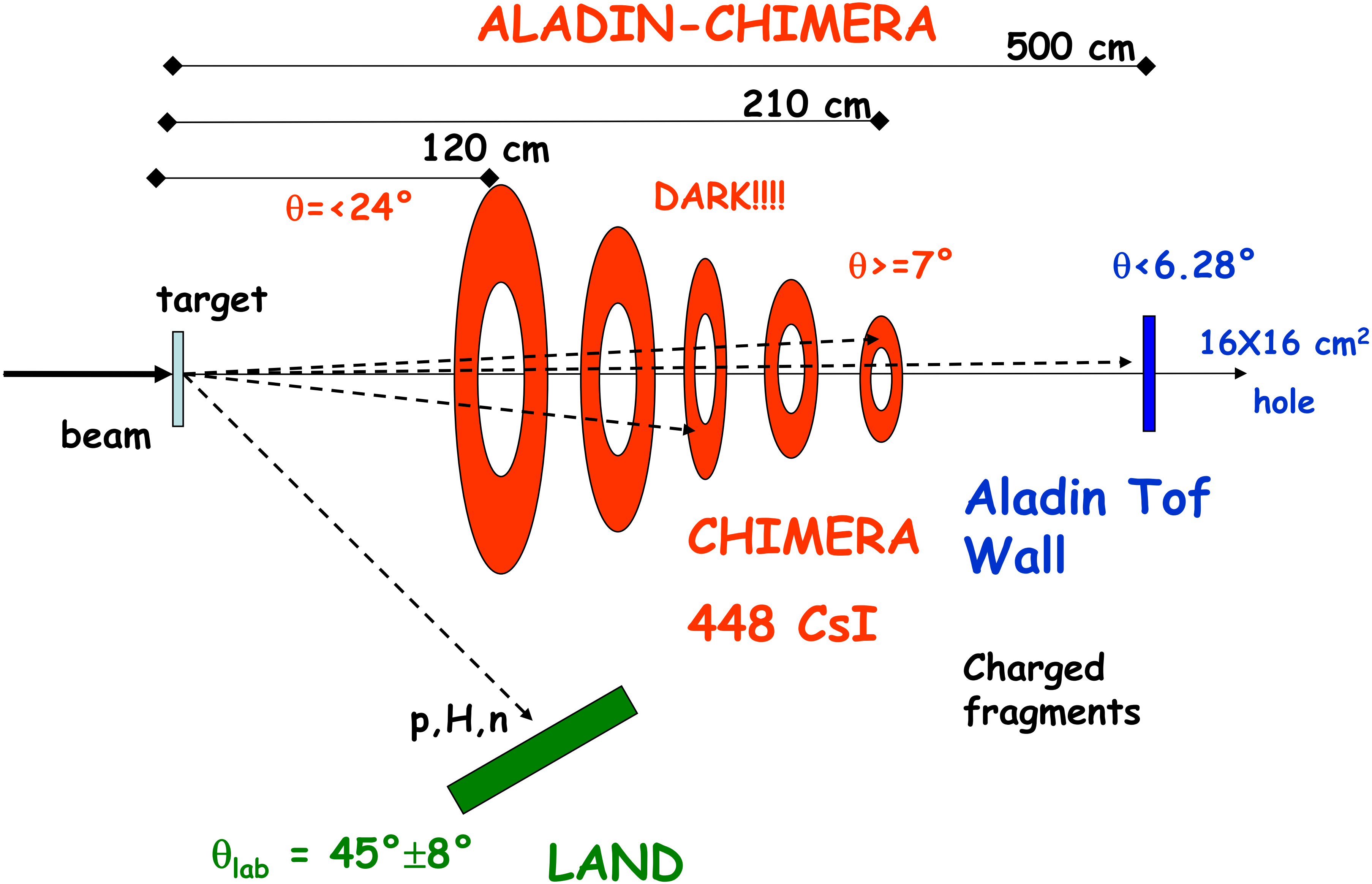


Figure 3: Schematic diagram of experimental setup in Cave C.

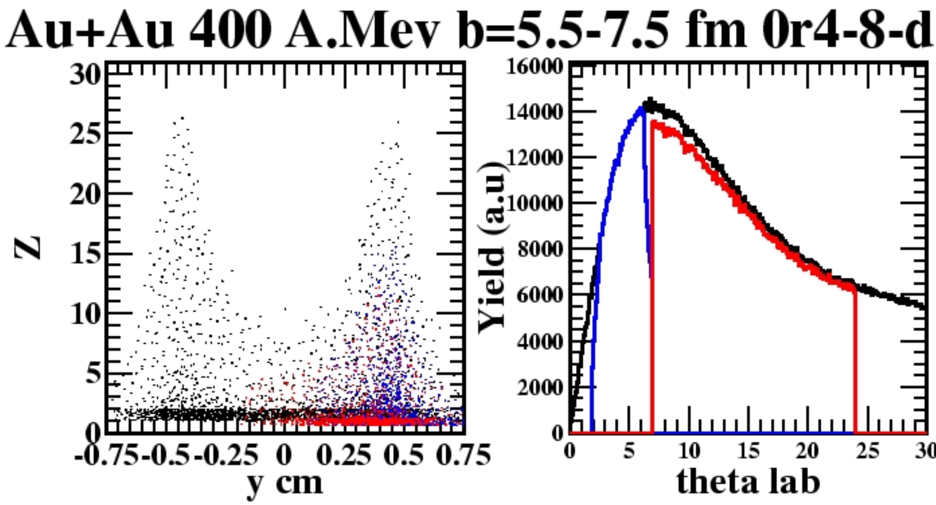
Experiment setup (not in scale)

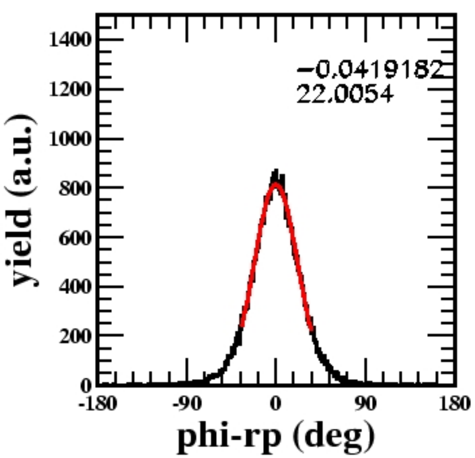


Artistic view (not in scale)

black→all charged particles

blue-red→used in reaction plane reconstrution (Q vector)





We define a vector constructed from the transverse momenta $p_\nu^\perp$ of detected particles:

$$Q = \sum_{\nu=1}^{M} \omega_\nu p_\nu^\perp , \qquad (1)$$

$\omega_\nu = 1$ for $y_\nu > y_c + \delta$, $\omega_\nu = -1$ for $y_\nu < y_c - \delta$, and $\omega_\nu = 0$ otherwise. For symmetric collisions it is nat-

Using only θ, φ, Z information

$$\vec{Q} = \sum_{\nu=1}^{M} \omega_\nu Z_\nu{}^\perp$$

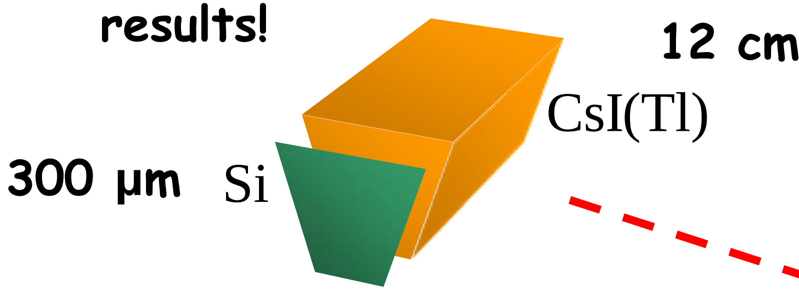
Only y_{cm}>0.1

CHIMERA

Δt (Csi) =10 ns

ΔE/E (CsI) =10 %

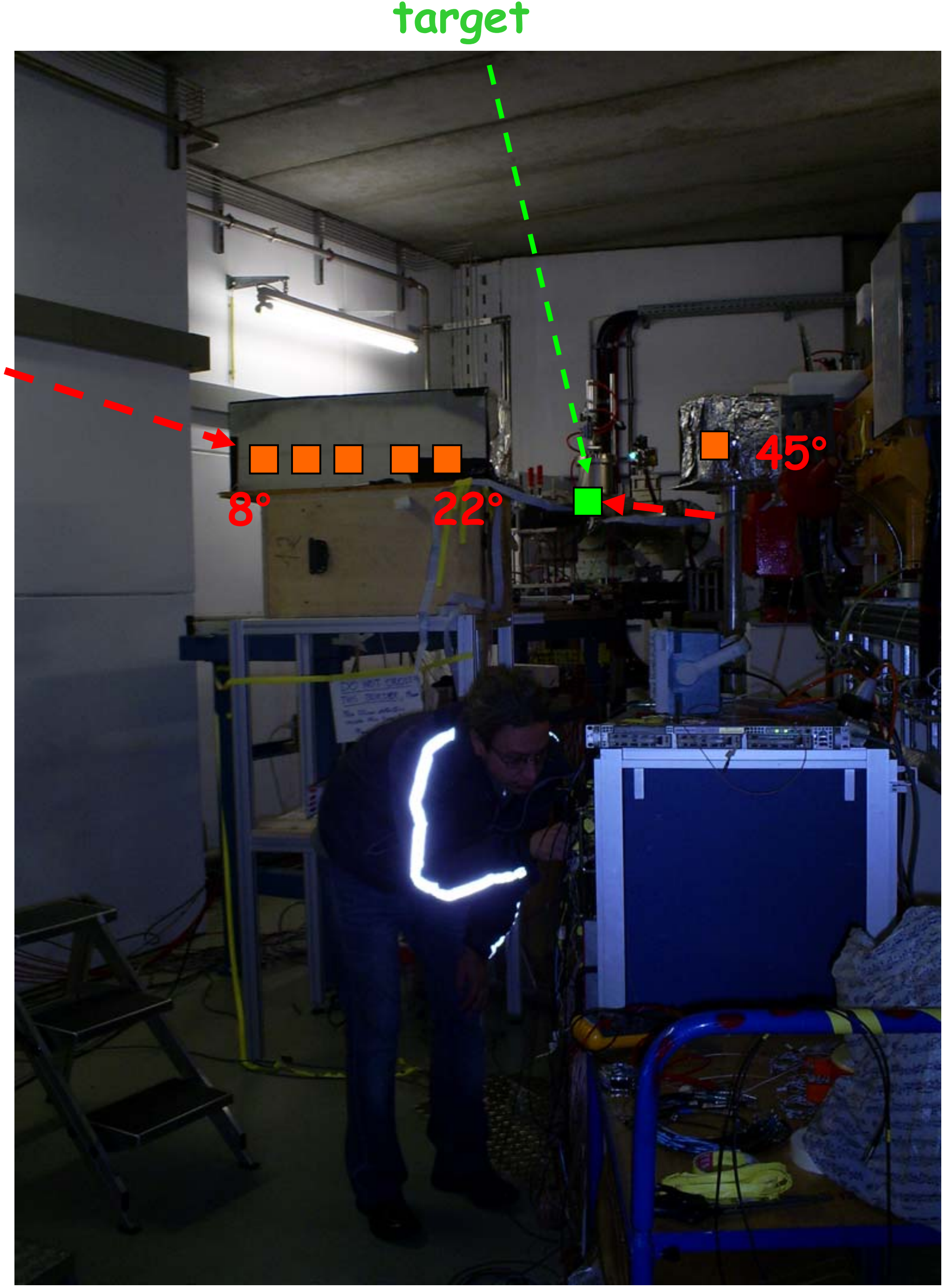
Last month results!

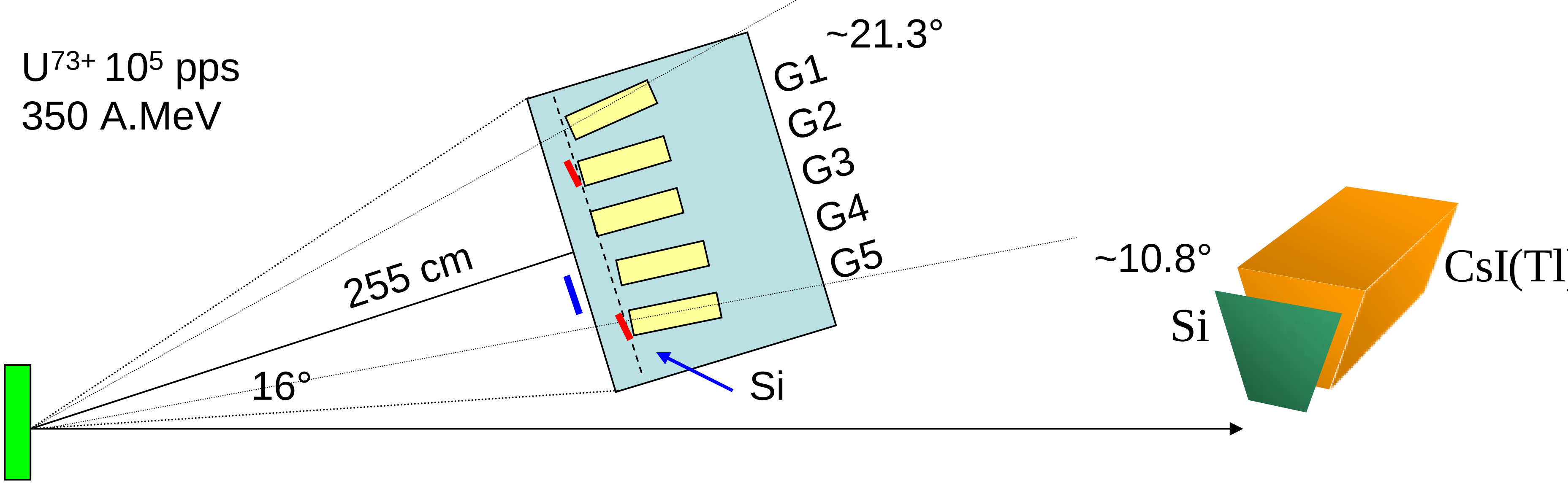


U+Pb 350 AMeV

In air @ GSI

Cave C

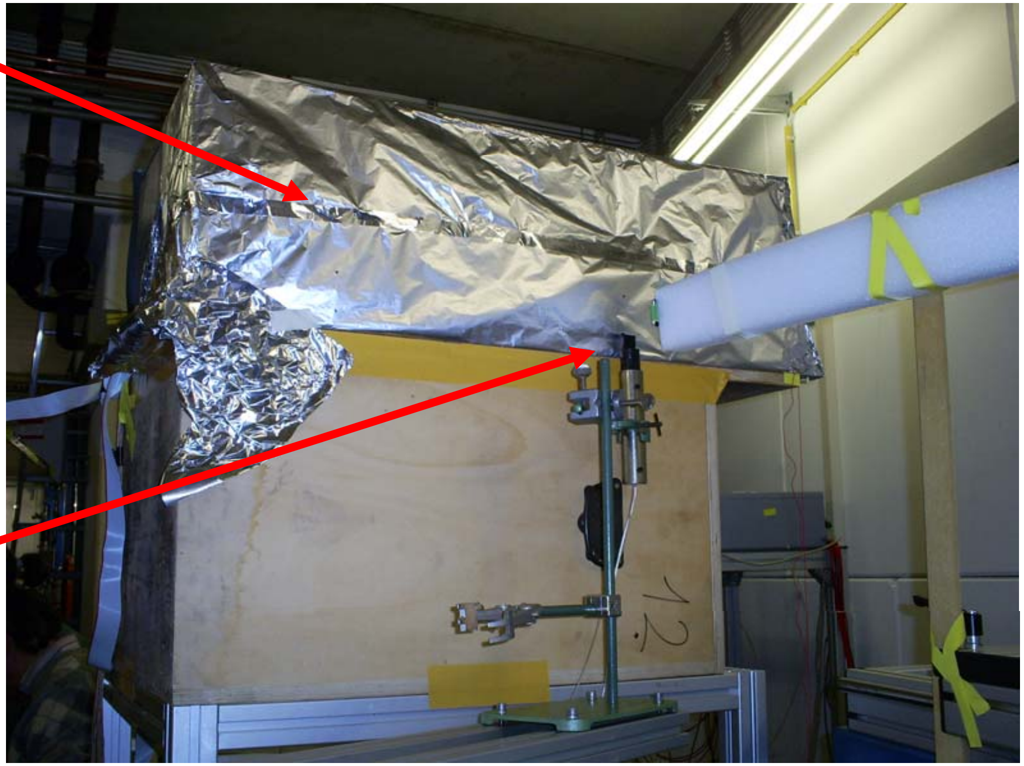




Pb (3% target)
run 22-23

GSI TEST
GEOMETRY

Big Box



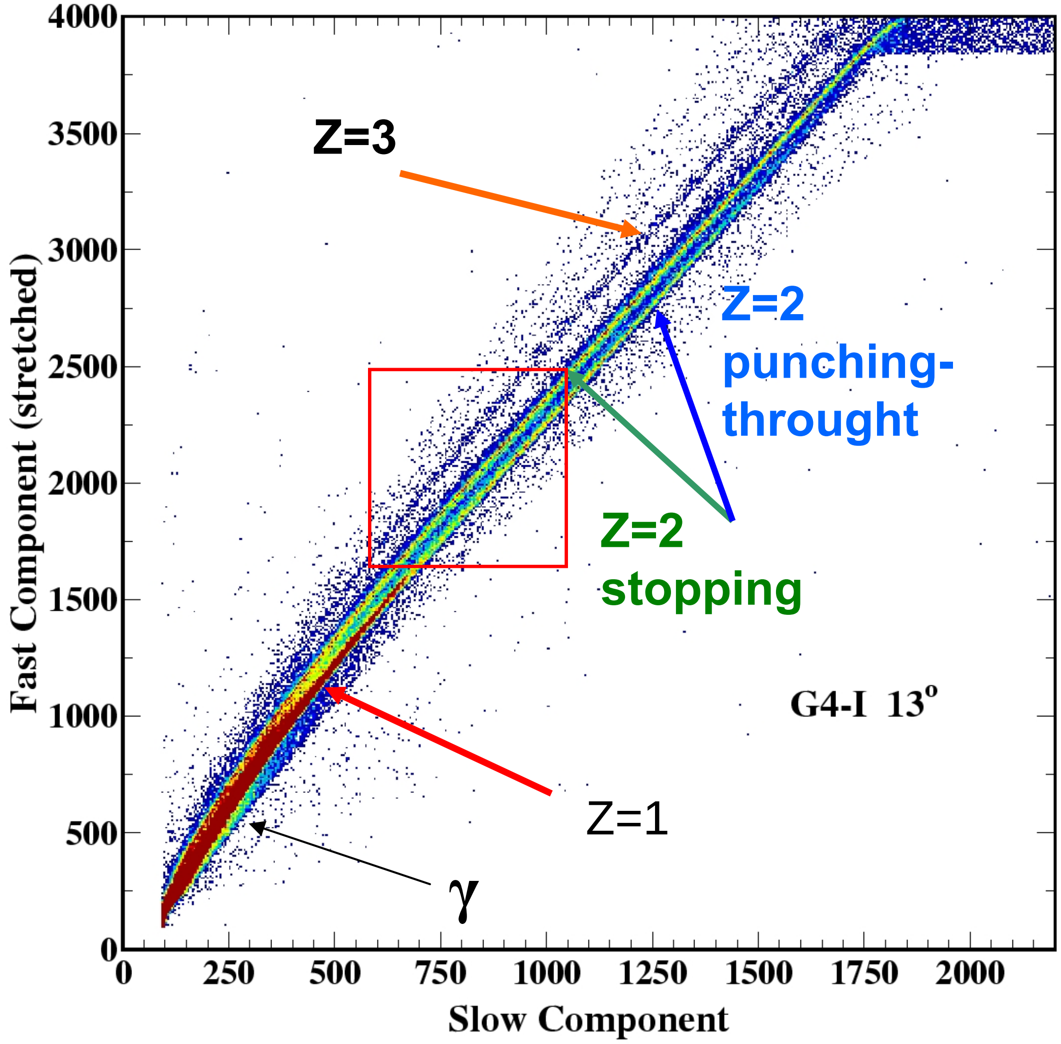
Silicons
in front of G5 and G2

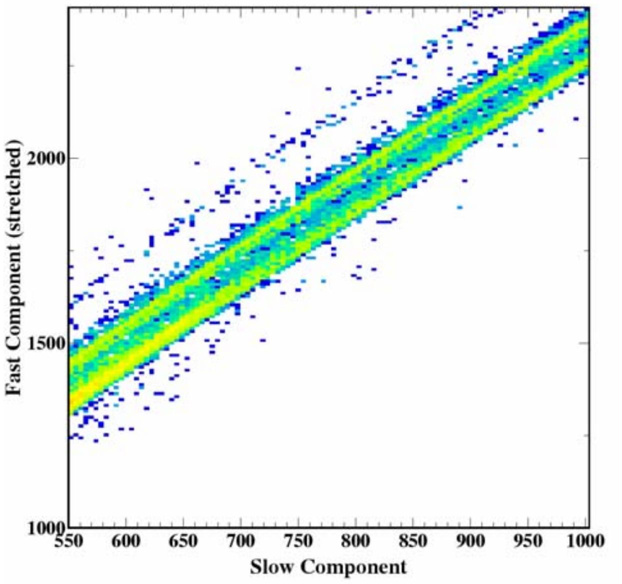
0.5 Plastic
detector
(front of
G4I)

Pulse-shape **G4I**

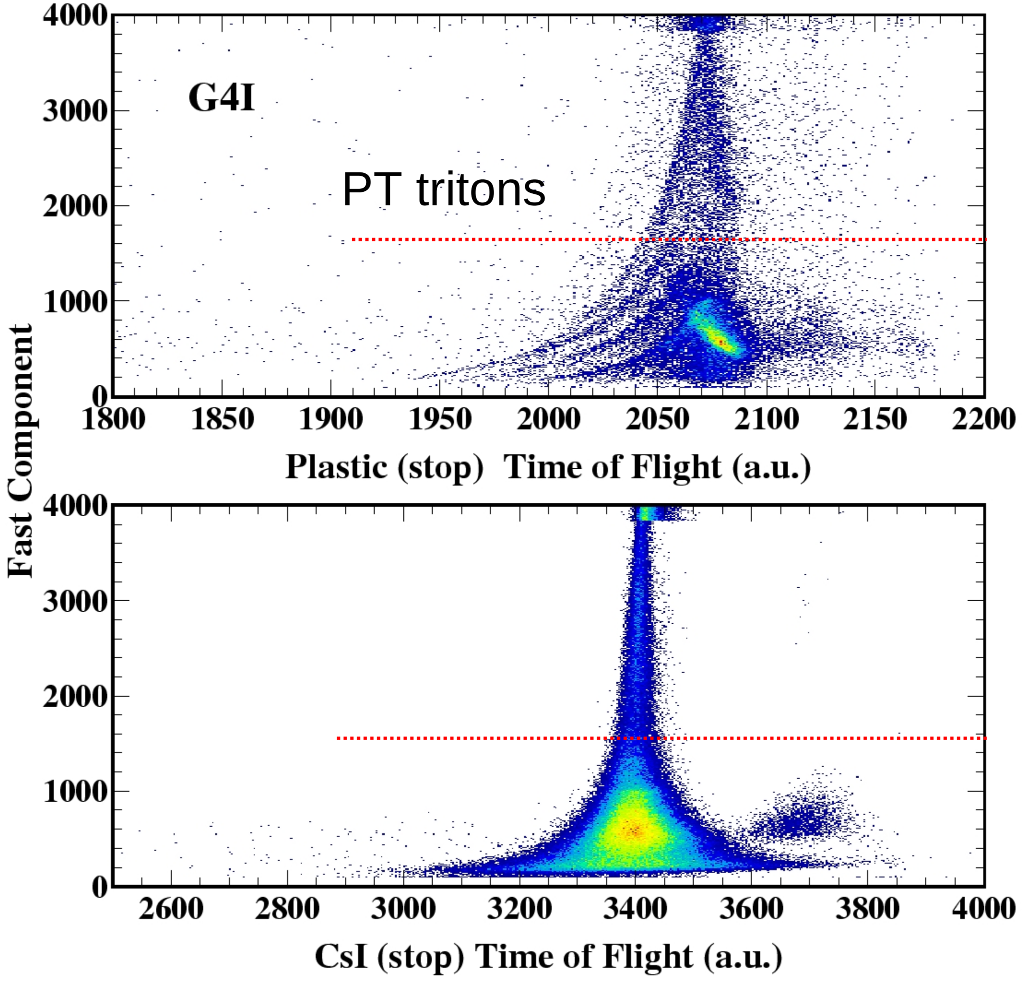
Gates (stretched and slow) = 50 ns (QDC V792, 50 Ohm impedence input / 400pC range)

Standard preamplifier 45 mV/MeV





0.5 cm plastic scintillator (phototube readout) in front of G4I CsI(Tl). Time-of-Flight respect to the beam start detector



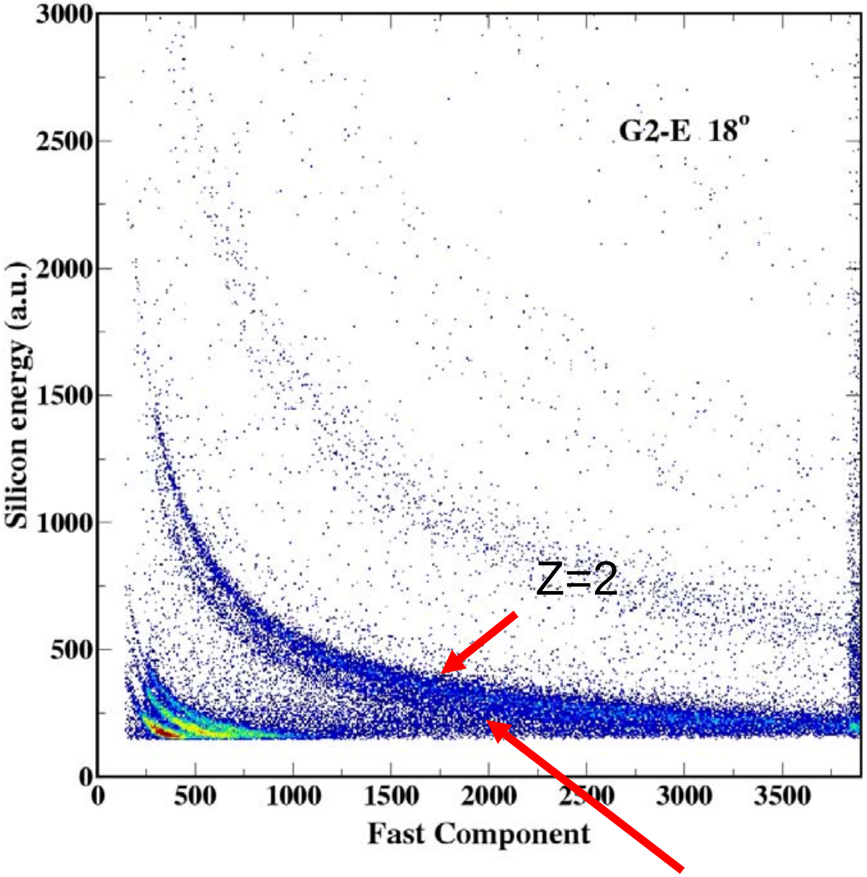
Useful to determine CsI average time resolution

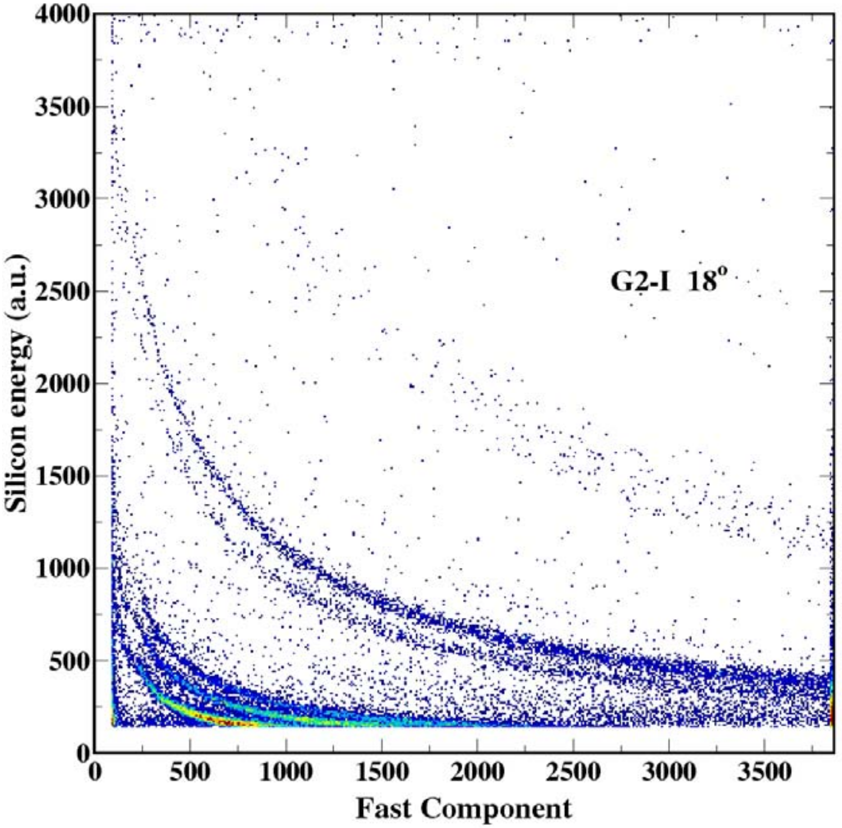
Estimeted CsI time resolution ~ 8-11 ns.

G2-E – G2-I

Gates (stretched and slow) = 500 ns (QDC V792, 1.1 kOhm impedence input*)

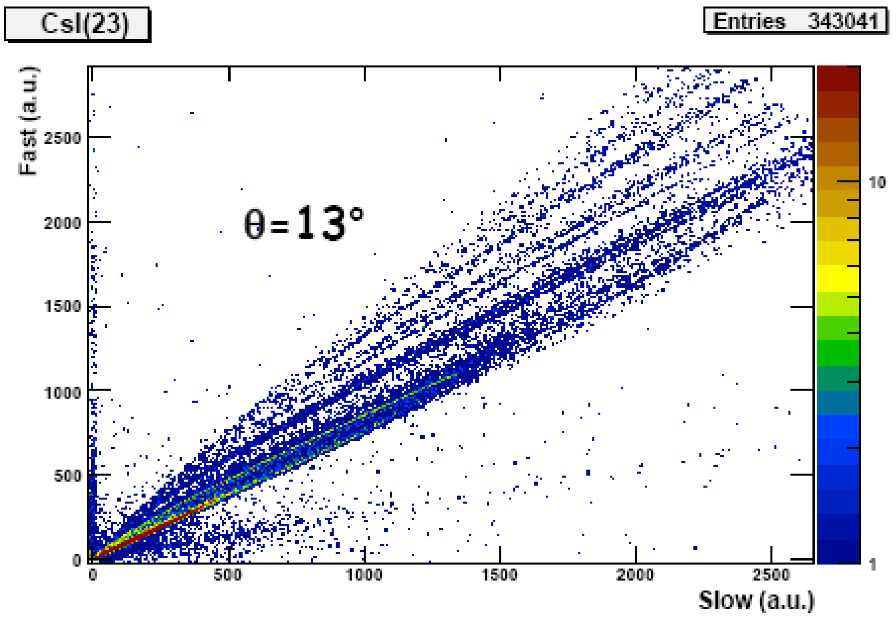
Standard preamplifier 45 mV/MeV (Standard Si-Csi Chimera telescope)

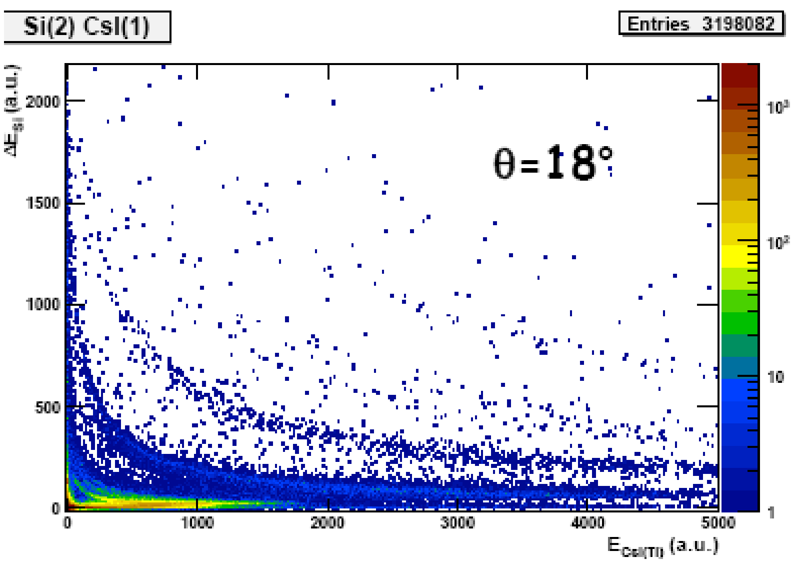


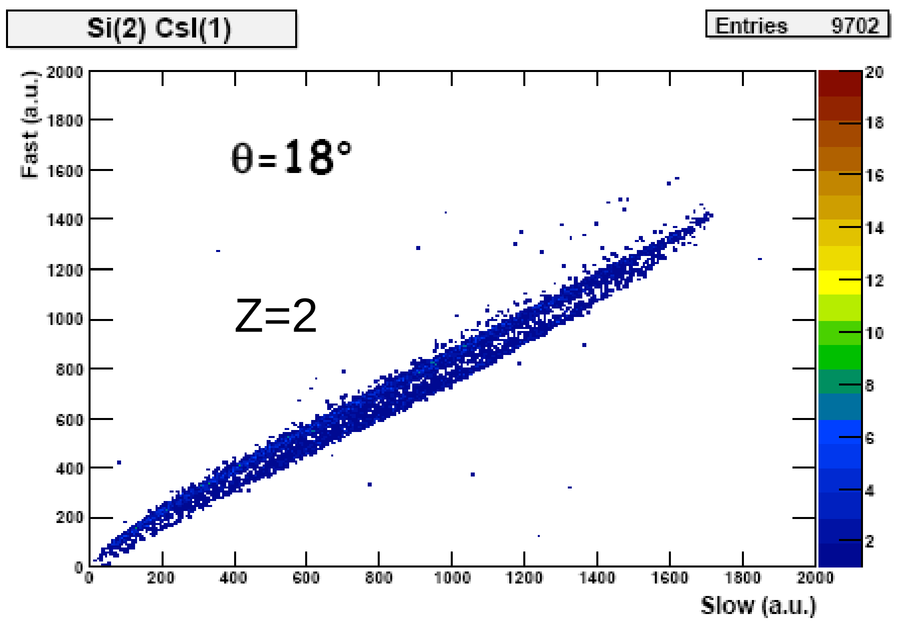


* 1.1 kOhm in series resistors at input channels.

DPSA: almost all Si and CsI signals splitted for digital analysis







Conclusions

Several heavy Ion reactions observables have been proposed in order to get information on symmetry energy (giant and pigmy dipole resonances, isobaric analogue states and masses, isospin diffusion, π^-/π^+, K^+/K^0, n/p ratios, neutron/proton differential flow, v2, $^3H/^3He$ ratio…).

More extended data sets and consistency checks are needed in order to arrive at firm conclusions especially at supra-saturation densities

Even if there are a lot of open questions (N-N cross section, effective masses,…) in the ASY-EOS experiment at GSI we will try to measure crucial observables……….

……"a good constraint" of symmetry energy at supra-saturation density ???

The high density behaviour of the nuclear symmetry energy $E_{sym}(\rho)$ is very important for understanding both high density nuclear matter and many interesting astrophysical objects, but it is also subject to the large uncertainty.