International Workshop on Multi facets of Eos and Clustering

IWM-EC 2014

6th – 9th May 2014 Catania, Italy

The ASY-EOS experiment at GSI: investigating symmetry energy at supra-saturation densities

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5/14/2014 4:17 PM

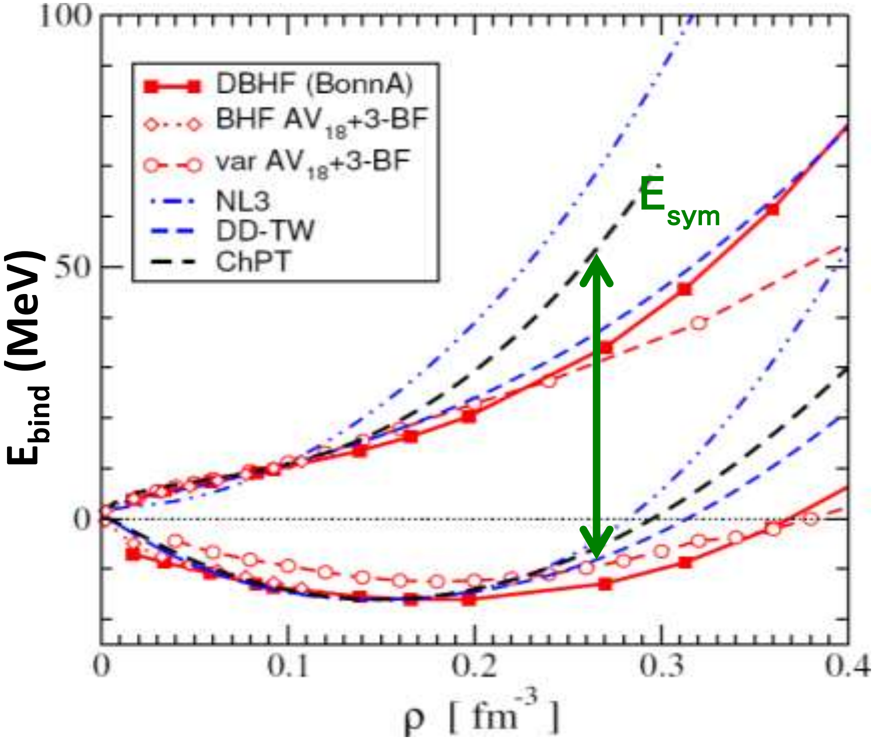
Summary

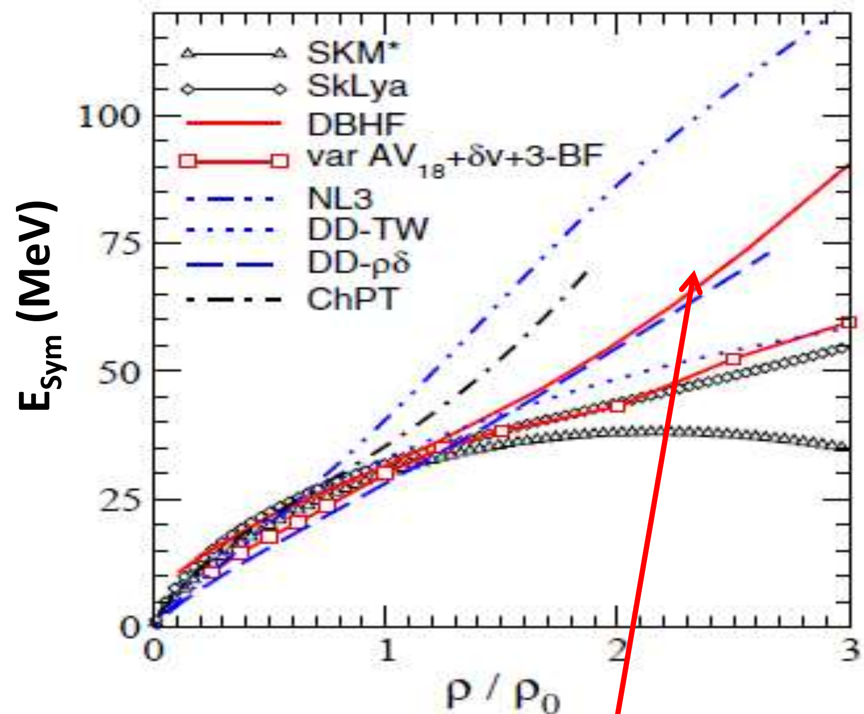
- Brief intro on High Density investigation of Symmetry Energy with H-I
- Suggestion for a route toward model independency…
- First results of the ASY-EOS experiment
- Future possibilities
- Conclusions

Symmetry Energy

$$E_{sym}(\rho) = E(\rho, I=1) - E(\rho, I=0)$$

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





EOS of symmetric nuclear and neutron matter
from
Ab initio calculations (red)
and phenomenological approaches

High density…so important!

Fuchs and Wolter, EPJA 30 (2006)

Constraints of the Symmetry Energy

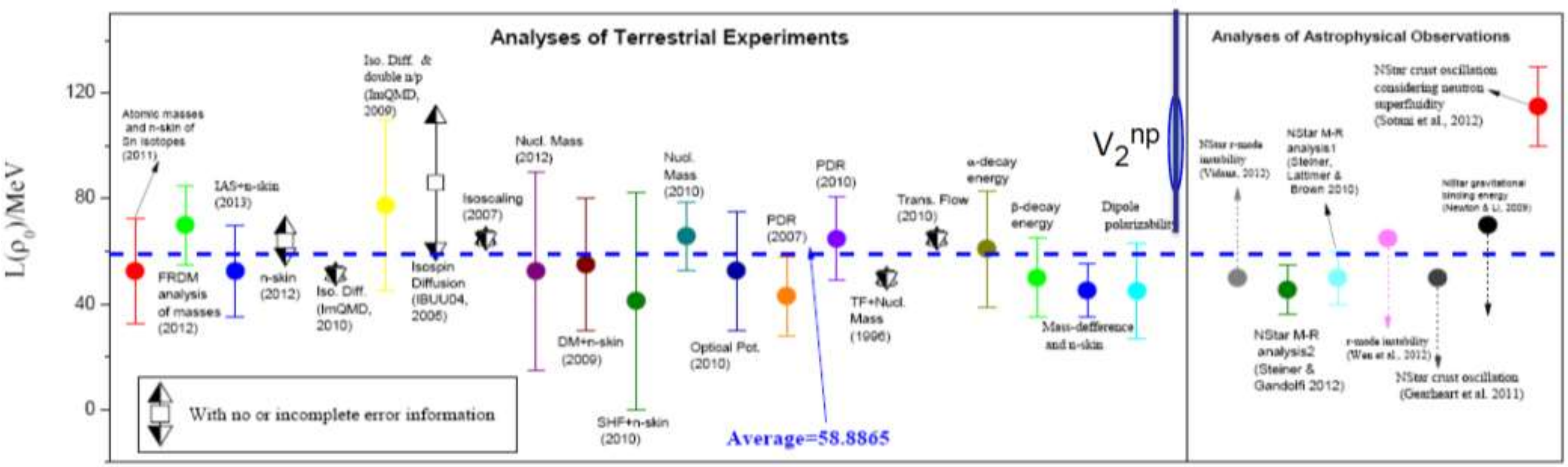
B.A. Li NuSym13 summary talk

$$E_{Sym}(\rho) = S(\rho) = S_0 + \frac{L}{3}\left(\frac{\rho-\rho_o}{\rho_o}\right) + \frac{K_{\rm sym}}{18}\left(\frac{\rho-\rho_o}{\rho_o}\right)^2 + \ldots,$$

Terrestrial laboratories

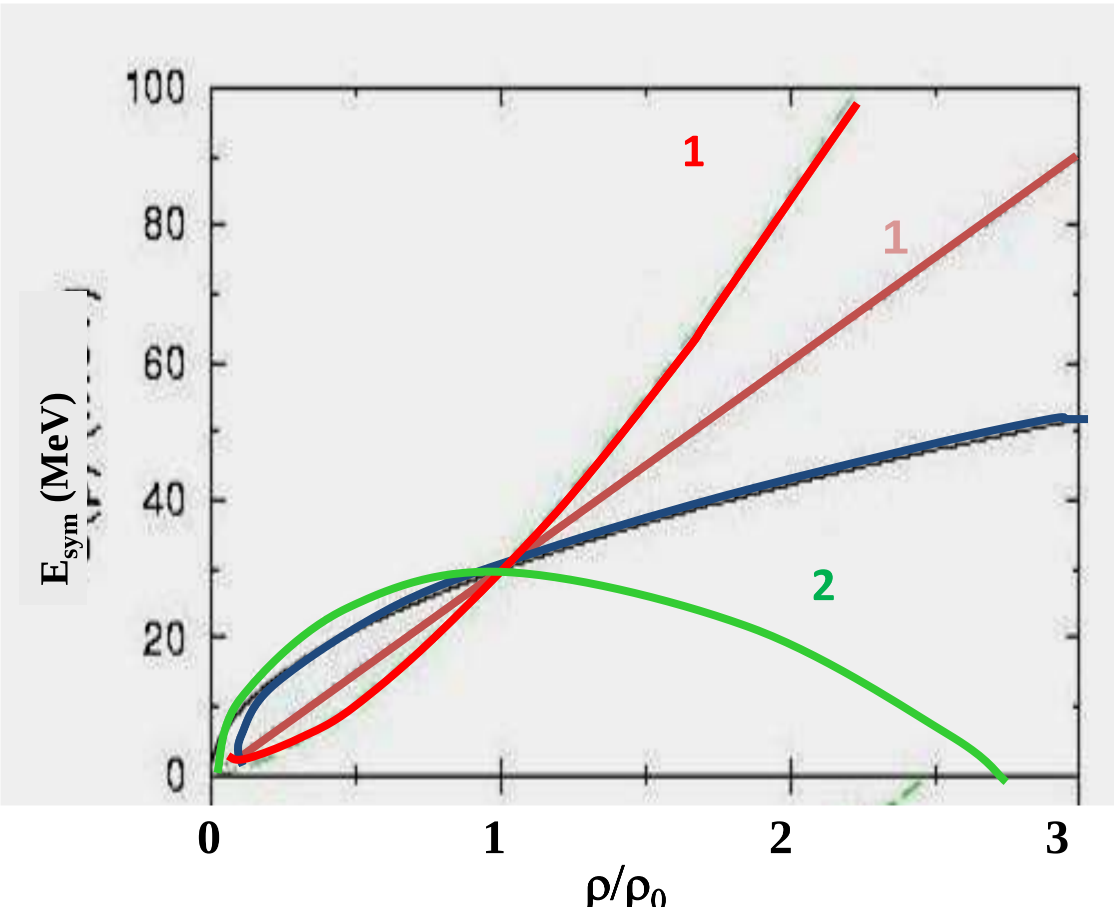
- Several constraints (quite consistent among them) around and below ρ_0
- Few constraints above ρ_0

	S_0	L
average of the means	31.55415	58.88646
standard deviation	0.915867	16.52645



E_{sym} at high density: π^-/π^+ratio

(measured by FOPI, for different systems and energies, as compared to different models)



- Results model dependent
- Density dependence of symmetry energy unambiguously soft or hard

BUT

- symmetry energy → n/p ratio, number of nn, np, pp collisions

$$\text{asystiff} \frac{n}{p} \downarrow \Rightarrow \frac{Y(\Delta^{0,-})}{Y(\Delta^{+,++})} \downarrow \Rightarrow \frac{\pi^-}{\pi^+} \downarrow$$

- medium → effective masses (N, π, Δ), cross sections → thresholds

$$\text{asystiff} \Rightarrow \frac{\pi^-}{\pi^+} \uparrow$$

→ Interpretation of pion data not straight forward

See:

Z. Xiao et al., PRL 102 (2009) **IBUU04**

Z.Q. Feng, PLB 683 (2010) **ImIQMD**

W.J. Xie , et al., PLB 718 (2013) **ImIBL**

G. Ferini, et al., NPA 762 (2005) **RMF**

Ad. from IWM 2011 – Y. Leifels

Kaons:more sensitive probes?

- Higher thresholds
- Weakly interacting in medium
- Freeze-out already at 20 fm/c: more reliable than pions as high ρ probes

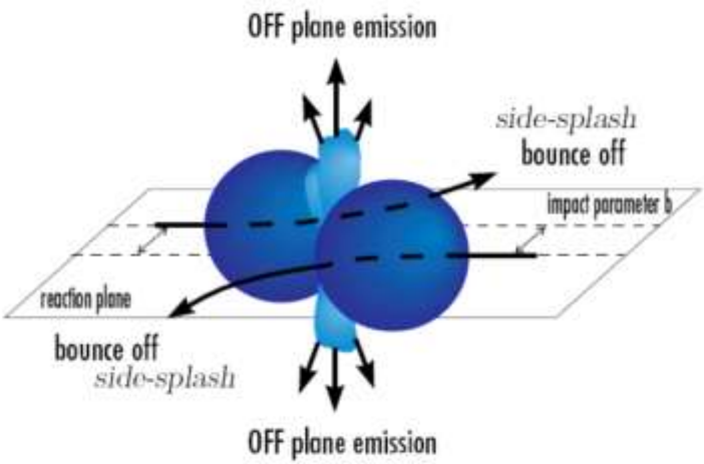
High densities: flows

$$\frac{dN}{d(\phi-\phi_R)}(y,p_t)=\frac{N_0}{2\pi}\left(1+2\sum_{n\geq 1} v_n \cos n(\phi-\phi_R)\right)$$

Y = rapidity
pt = transverse momentum

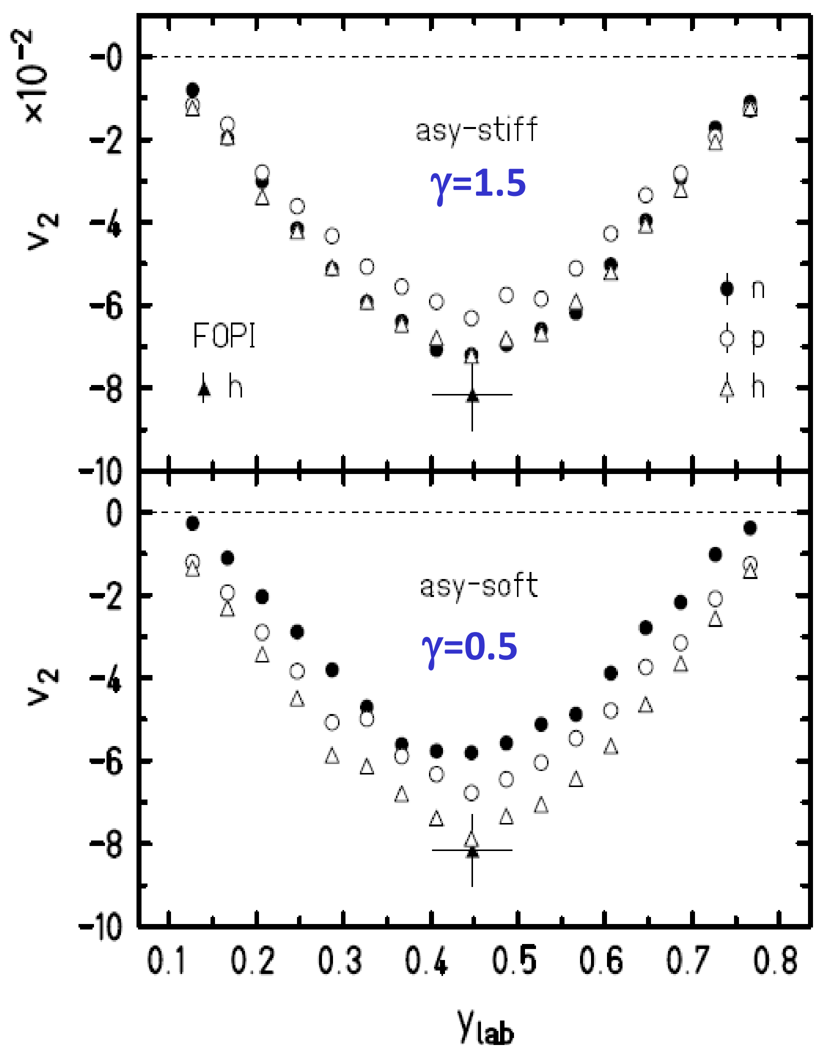
$$V_2(y,p_t)=\left\langle \frac{p_x^2-p_y^2}{p_t^2}\right\rangle$$

Elliptic flow: competition between in plane (V2>0) and out-of-plane ejection (V2<0)



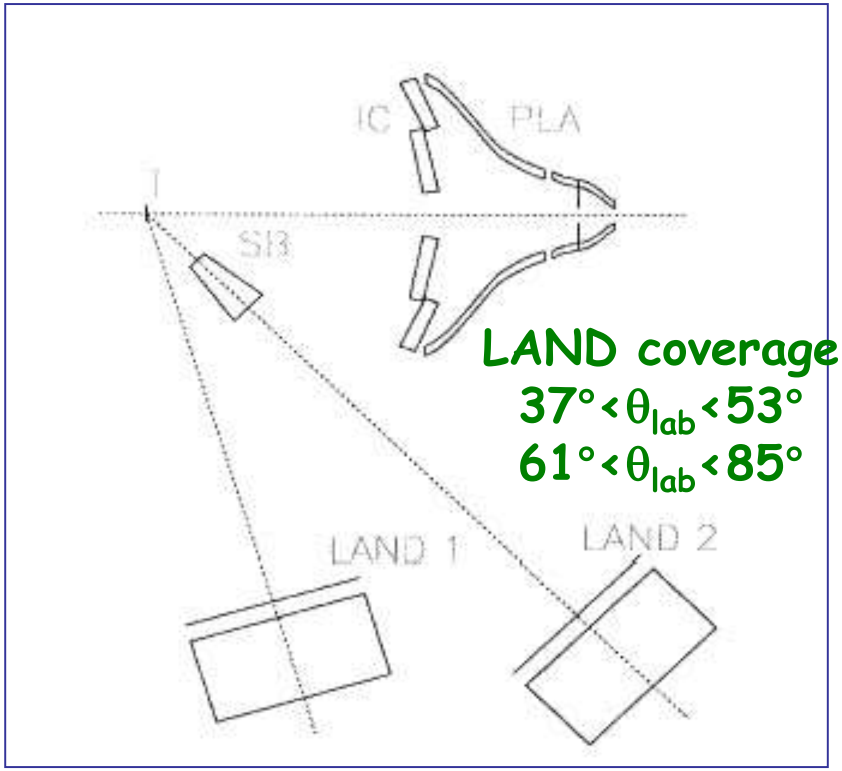
$$E_{sym}=E_{sym}^{pot}+E_{sym}^{kin}$$
$$=22\ \text{MeV}\cdot(\rho/\rho_0)^{\gamma}+12\ \text{MeV}\cdot(\rho/\rho_0)^{2/3}$$

UrQMD :Au+Au @ 400 AMeV
5.5<b<7.5 fm



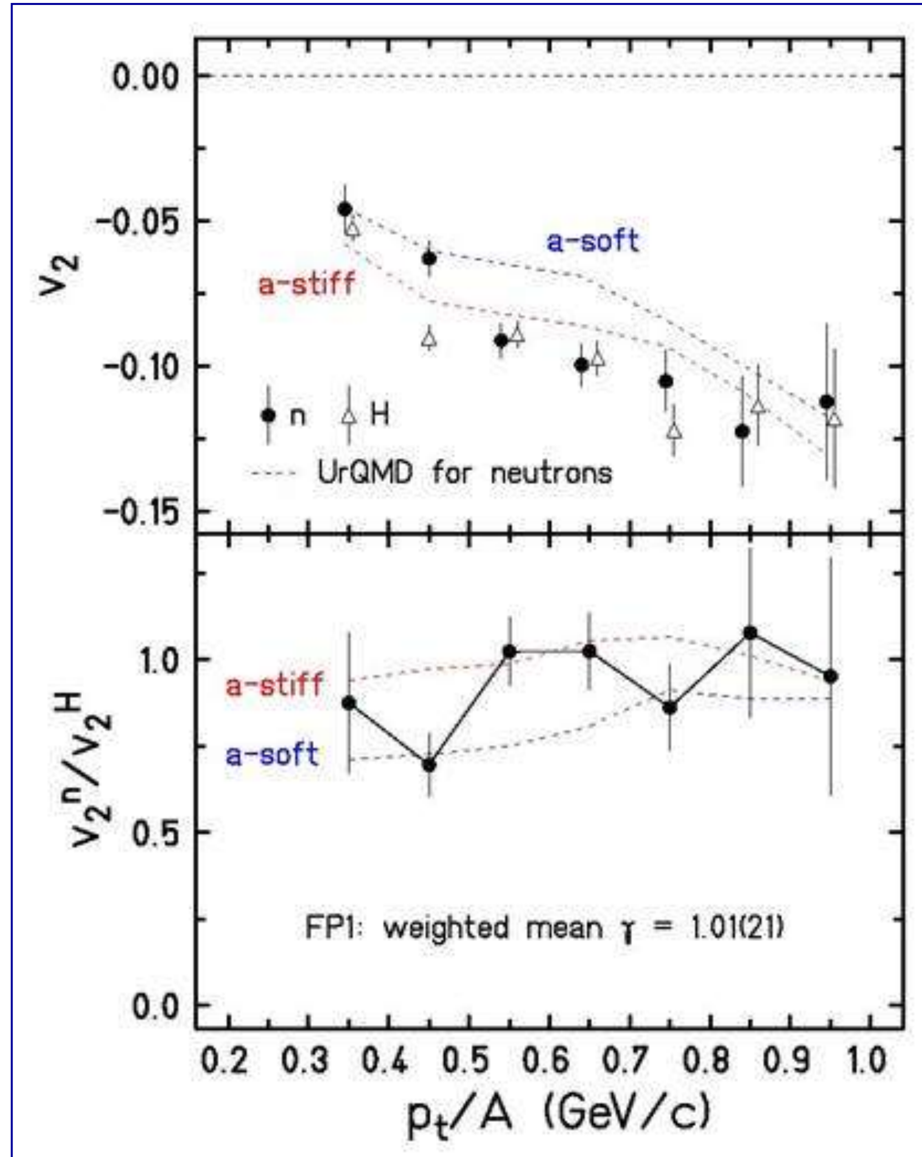
Qingfeng Li, J. Phys. G31 1359-1374 (2005)
P.Russotto et al., Phys. Lett. B 697 (2011)

FOPI/LAND experiment on neutron squeeze out (1991)



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

Au+Au 400 A MeV
b< 7.5 fm



$\gamma = 0.9 \pm 0.4$
$L = 83 \pm 26$

$$E_{sym} = E_{sym}^{pot} + E_{sym}^{kin}$$
$$= 22MeV \cdot (\rho/\rho_0)^{\gamma} + 12MeV \cdot (\rho/\rho_0)^{2/3}$$

Y. Leifels et al., PRL 71, 963 (1993)
P.Russotto et al., PLB 697 (2011)

Results with Tübingen QMD

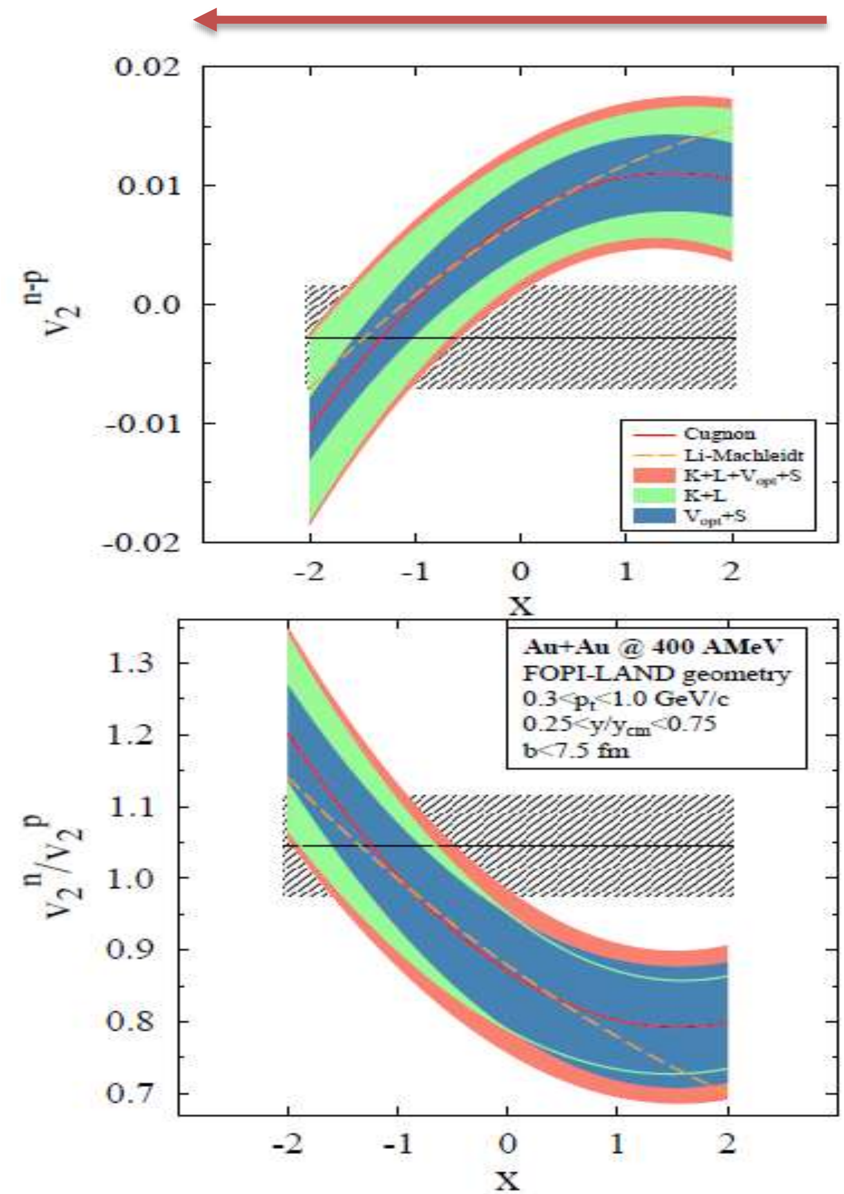
Au+Au 400 A MeV b< 7.5 fm

stiffnes

UrQMD:
momentum dep. of isoscalar field
momentum dep. of NNECS
momentum independent power-law
parameterization of the symmetry energy

Tübingen-QMD:
density dep. of NNECS
asymmetry dep. of NNECS
soft vs. hard EoS
width of wave packets
momentum dependent (Gogny inspired)
parameterization of the symmetry energy

M.D. Cozma, PLB 700, 139 (2011);
arXiv:1102.2728



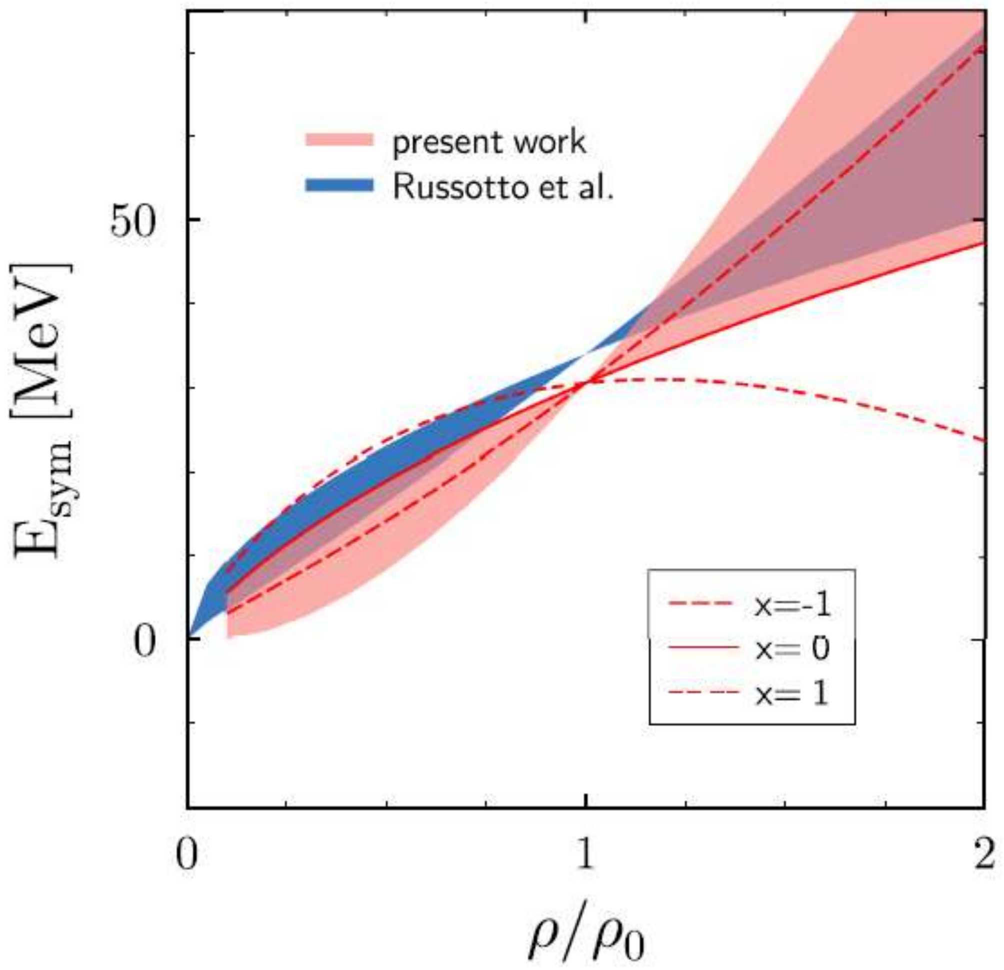
x =-1.35±1.25

FIG. 2: Model dependence of npEFD and npEFR and comparison with FOPI-LAND experimental data, integrated over impact parameter b≤7.5 fm. Sensitivity to the different model parameters, compressibility modulus (K), width of nucleon wave function (L), optical potential (V_{opt}) and parametrization of the symmetry energy (S) are displayed. The total model dependence is obtained by adding, in quadrature, individual sensitivities.

M.D. Cozma et al., Towards a model-independent constraint of the high-density dependence of the symmetry energy,

arXiv:1305.5417 [nucl-th] PRC88 044912 (2013)

Results with Tübingen QMD and UrQMD



x =-1.0±1.0

M.D. Cozma et al., Towards a model-independent constraint of the high-density dependence of the symmetry energy,

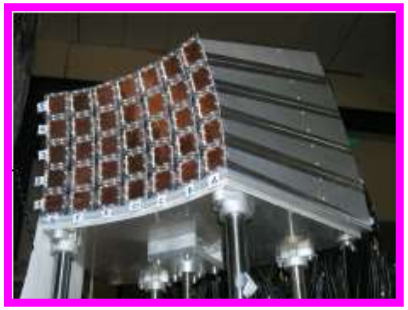
arXiv:1305.5417 [nucl-th]

PRC88 044912 (2013)

ASY-EOS S394 experiment @ GSI Darmstadt (May 2011)

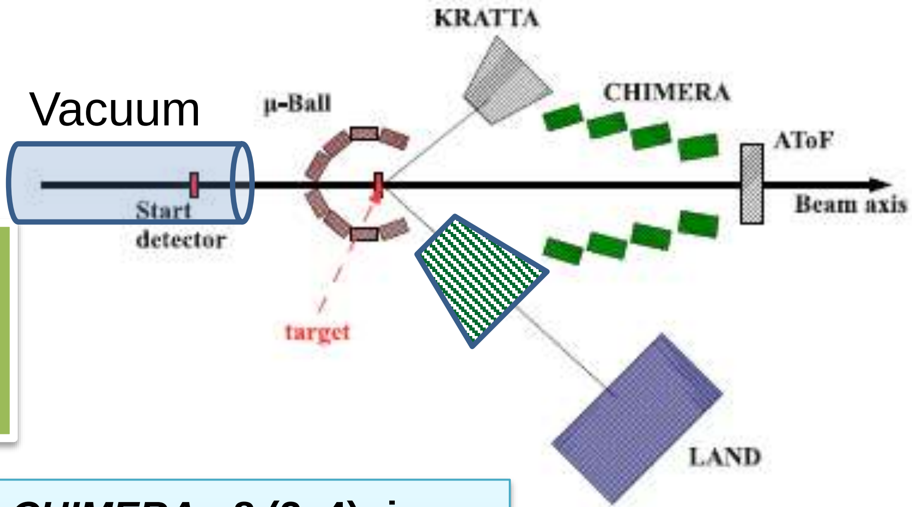
Au+Au, $^{96}Zr+^{96}Zr$, $^{96}Ru+^{96}Ru$ @ 400 AMev

μBall: 4 rings 50 CsI(Tl), Θ>60°. Discriminate target vs. reactions with air. Multiplicity and reaction plane measurements.



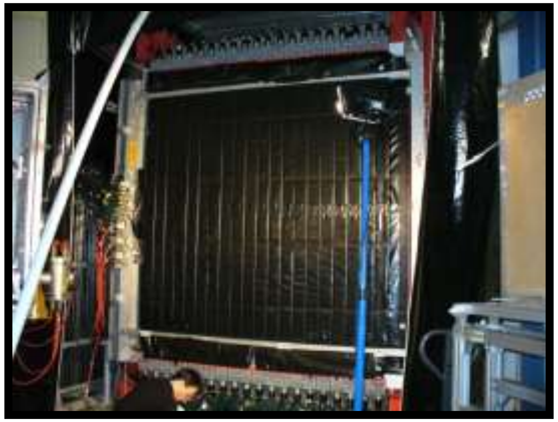
KraTTA: 35 (5x7) triple telescopes (Si-CsI-CsI) placed at 21°<Θ<60° with digital readout . Light particles and IMFs emitted at midrapidity

Shadow bar: evaluation of background neutrons in LAND



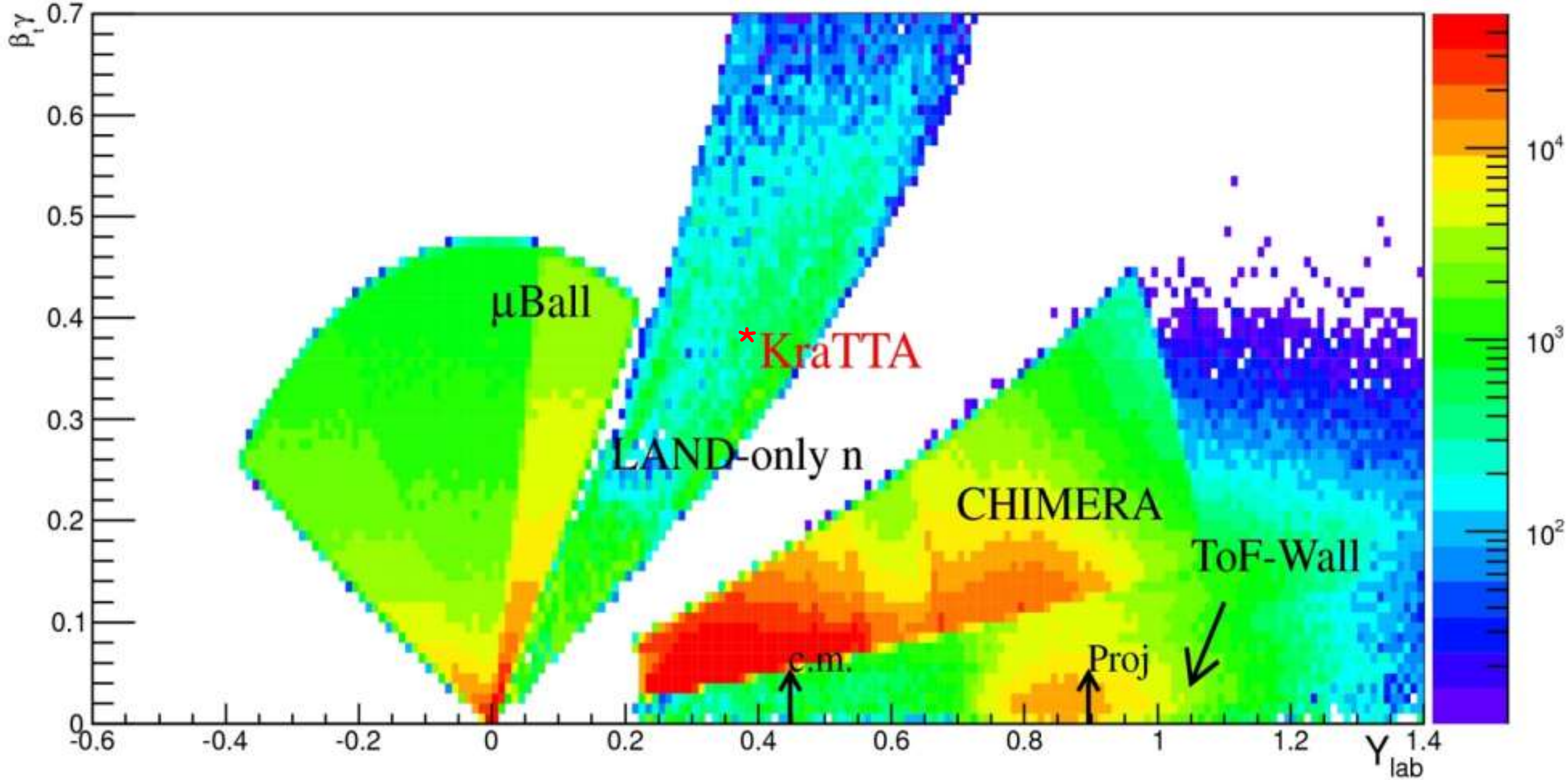
TOFWALL: 96 plastic bars; ToF, ΔE, X-Y position. Trigger, impact parameter and reaction plane determination

CHIMERA: 8 (2x4) rings, high granularity CsI(Tl), 352 detectors 7°<θ<20° + 16x2 pads silicon detectors. Light charged particle identification by PSD. Multiplicity, Z, A, Energy: impact parameter and reaction plane determination

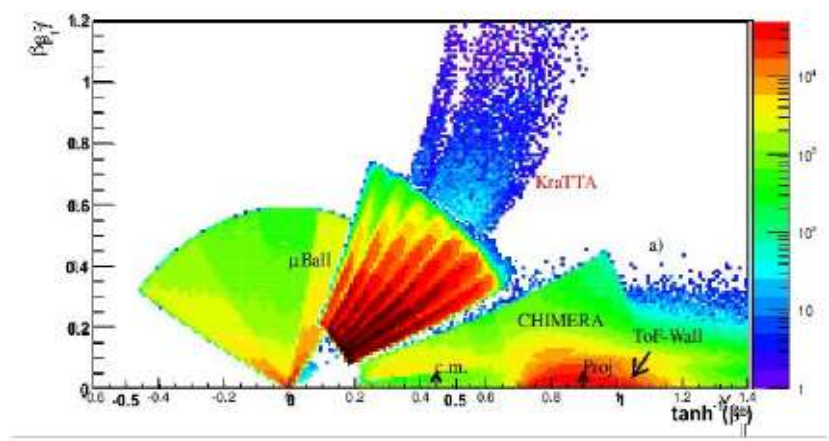


LAND: Large Area Neutron Detector . Plastic scintillators sandwiched with Fe 2x2x1 m^3 plus plastic veto wall. New Taquila front-end electronics. Neutrons and Hydrogen detection. Flow measurements

Au+Au @ 400 A.MeV: Some kinematics

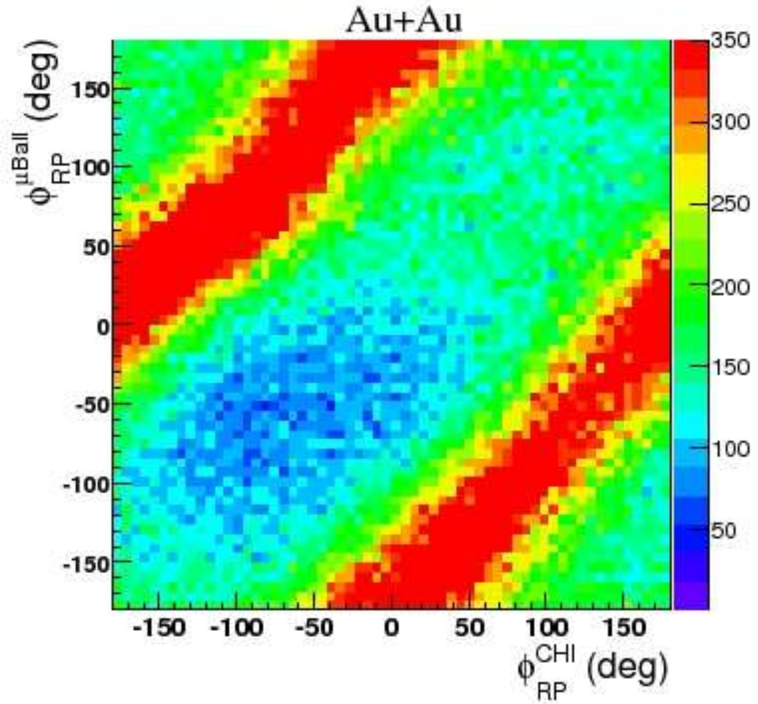


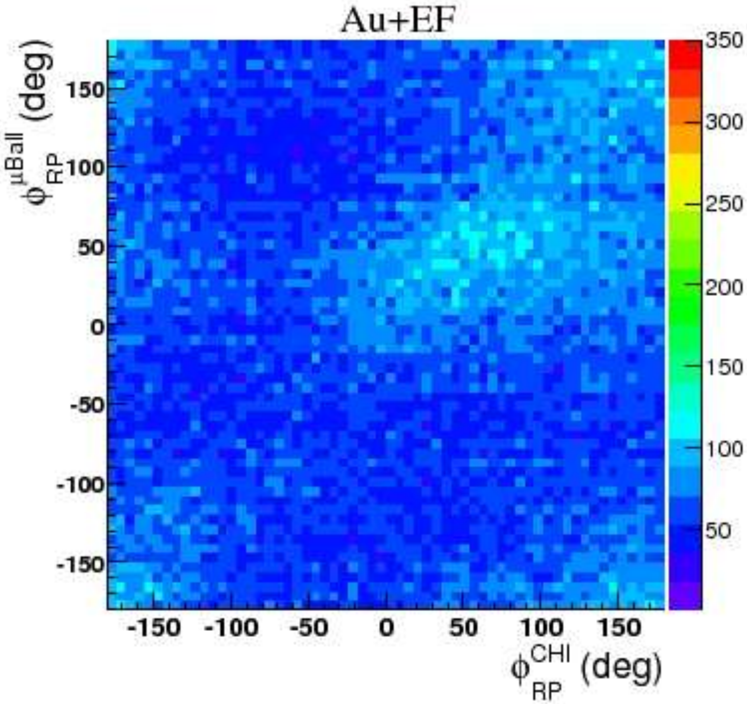
* Random uniform distribution EKin<100 Mev

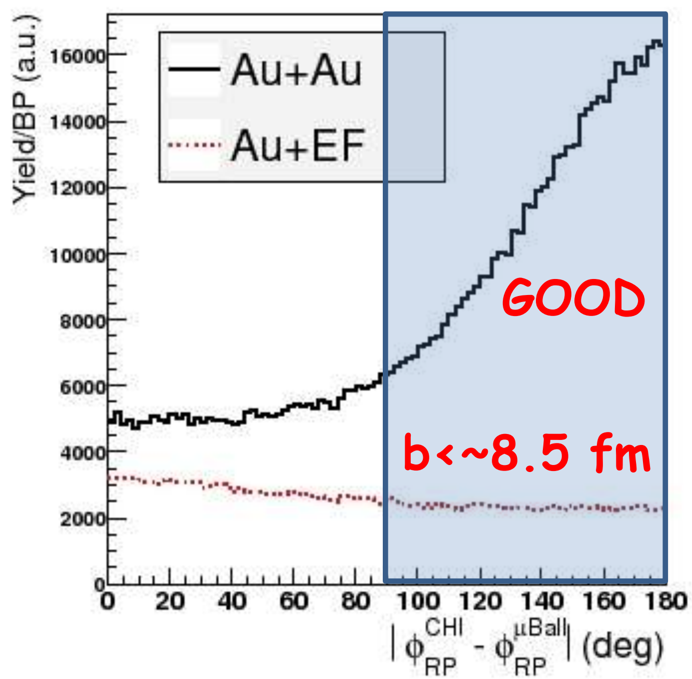


P. Russotto et al., EPJA 50, 38 2014.
P. Russotto et al., Procs. of INPC2013, EPJ Web of Conf.
P. Russotto et al., Journal of Phys. Conf. Series 420, 012092, (2013)

Au+Au @ 400 A.MeV: Background rejection







CHIMERA $M(Y_{c.m}>0.1)\geq 4$

$$\vec{Q} = \sum_{i=1}^{M} w_i Z_i \gamma \vec{\beta}_t^i \qquad w_i = \begin{cases} 1 \text{ for } Y_{cm}>0.1 \\ 0 \text{ for } Y_{cm}<0.1 \end{cases}$$

μBall $M\geq 2$

$$\vec{Q} = \sum_{i=1}^{M} \hat{\beta}_t^i$$

ad. from P. Danielewicz et al., PLB 1985

From MI28022014

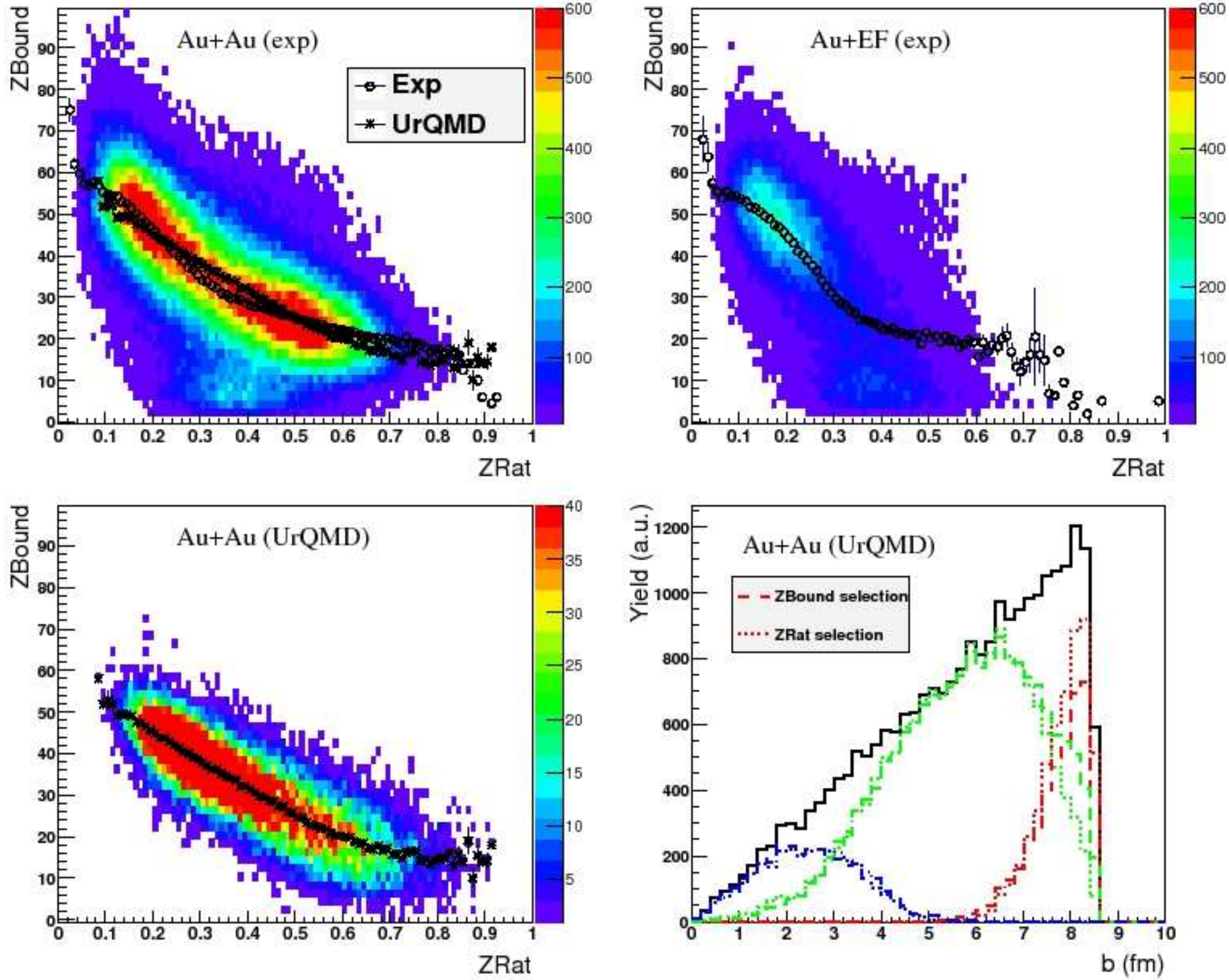
Au+Au @ 400 A.MeV: Centrality selection

$$ZBound = \sum_i Z_i$$

with $Z_i \geq 2$

From
AToF-Wall
and
CHIMERA

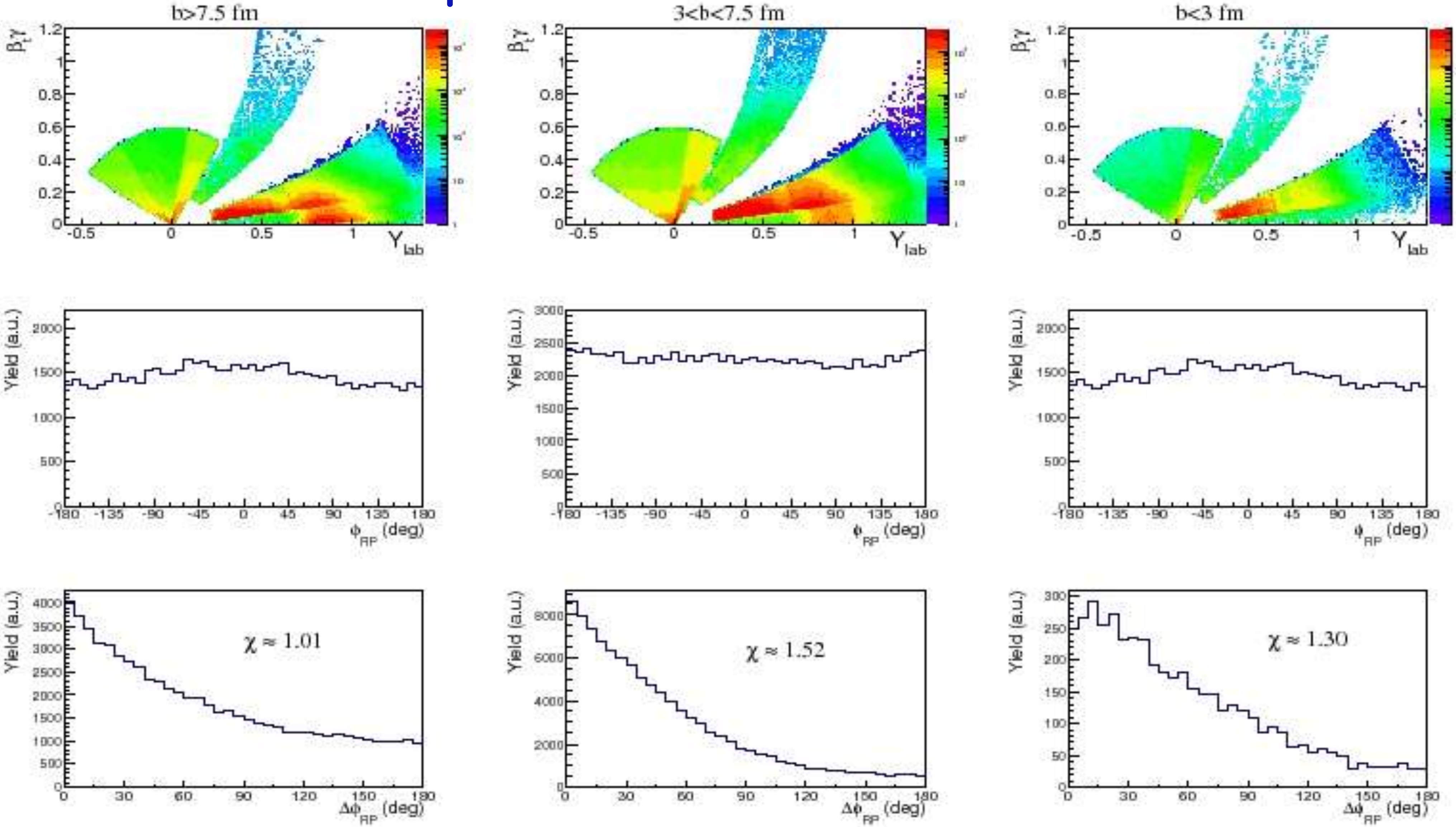
$$ZRat = \frac{Ztrans}{Zlong} = \frac{\sum_i Z_i \cdot \sin^2(\vartheta_i^{lab})}{\sum_i Z_i \cdot \cos^2(\vartheta_i^{lab})}$$



From MI28022014

Reaction plane orientation

Au+Au @ 400 AMeV



CHIMERA $M(Y_{c.m.}>0.1)\geq 4$

$$\vec{Q} = \sum_{i=1}^{M} w_i Z_i \gamma \vec{\beta}_t^{\,i} \qquad w_i = \begin{cases} 1 & \text{for } Y_{cm}>0.1 \\ 0 & \text{for } Y_{cm}<0.1 \end{cases}$$

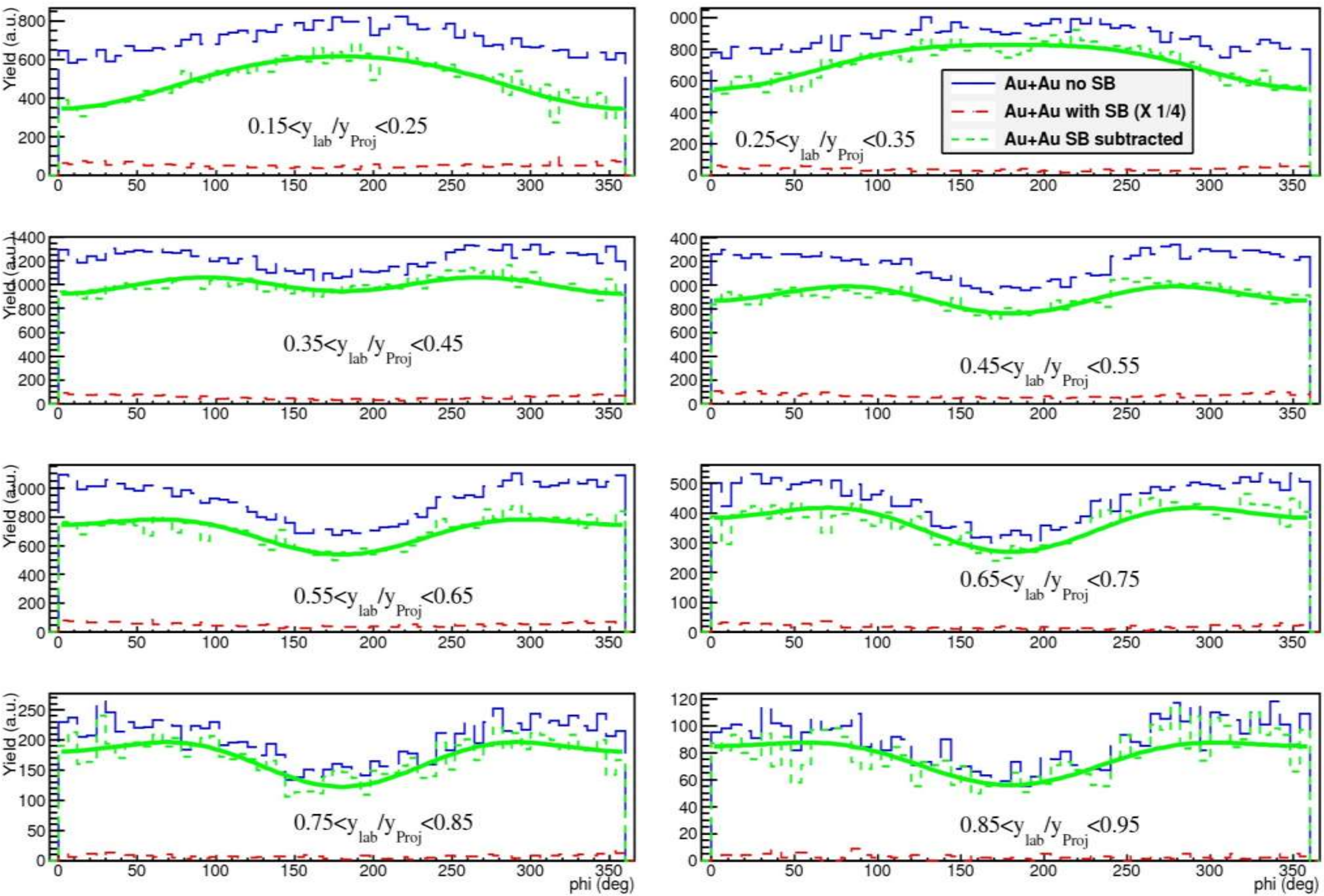
b selection	χ~	<cos (2 ΔΦ) >~	ΔΦ (deg)~
b>7.5 fm	1.01	0.36	34
3<b<7.5 fm	1.52	0.60	26
b< 3 fm	1.30	0.52	29

ad. from P. Danielewicz et al., PLB 1985

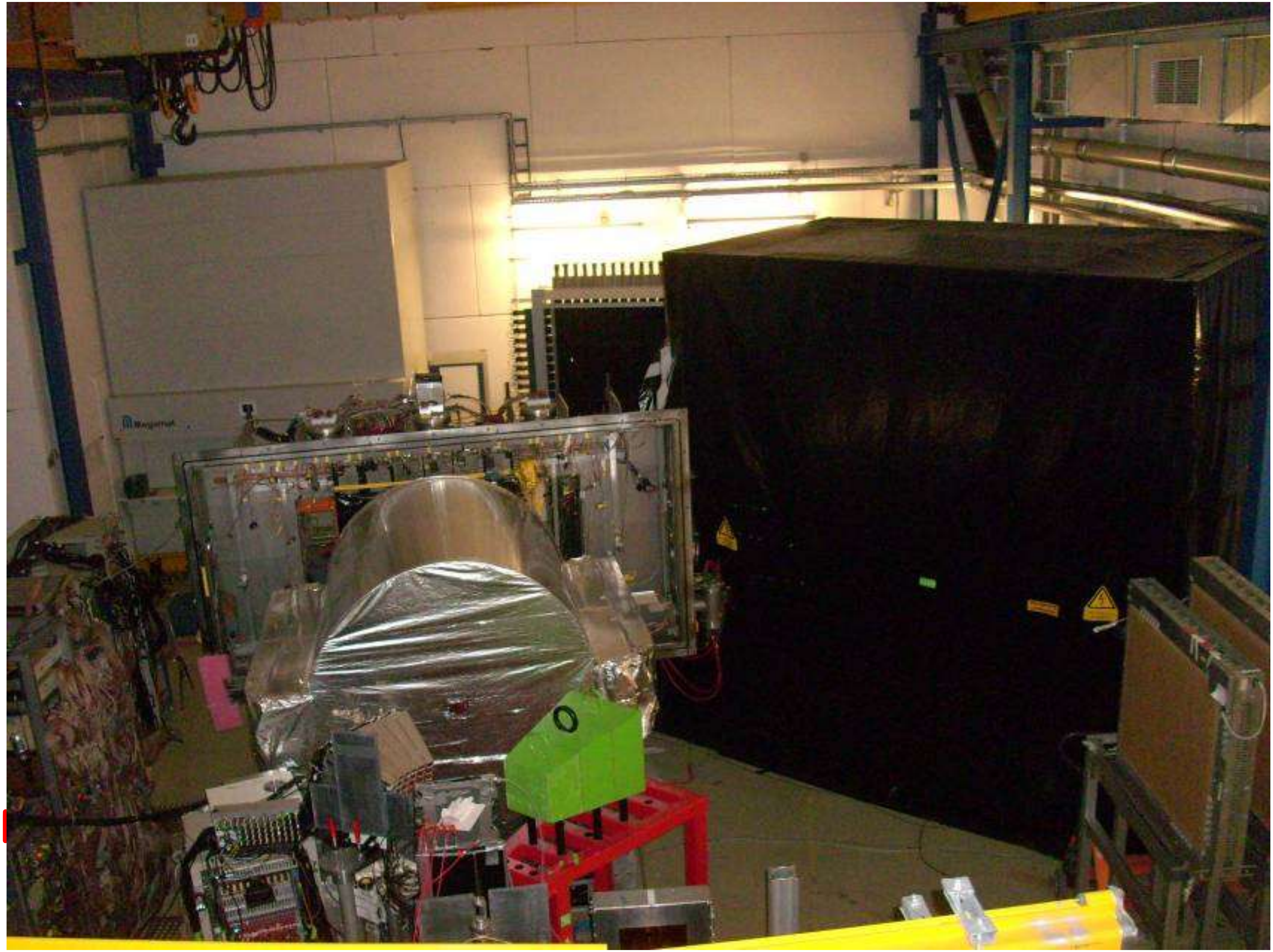
J-Y Ollitrault arXiv:nucl-ex/9711003v2

Neutron azimuthal distributions from LAND

Au+Au @ 400 AMeV
b< 7.5 fm



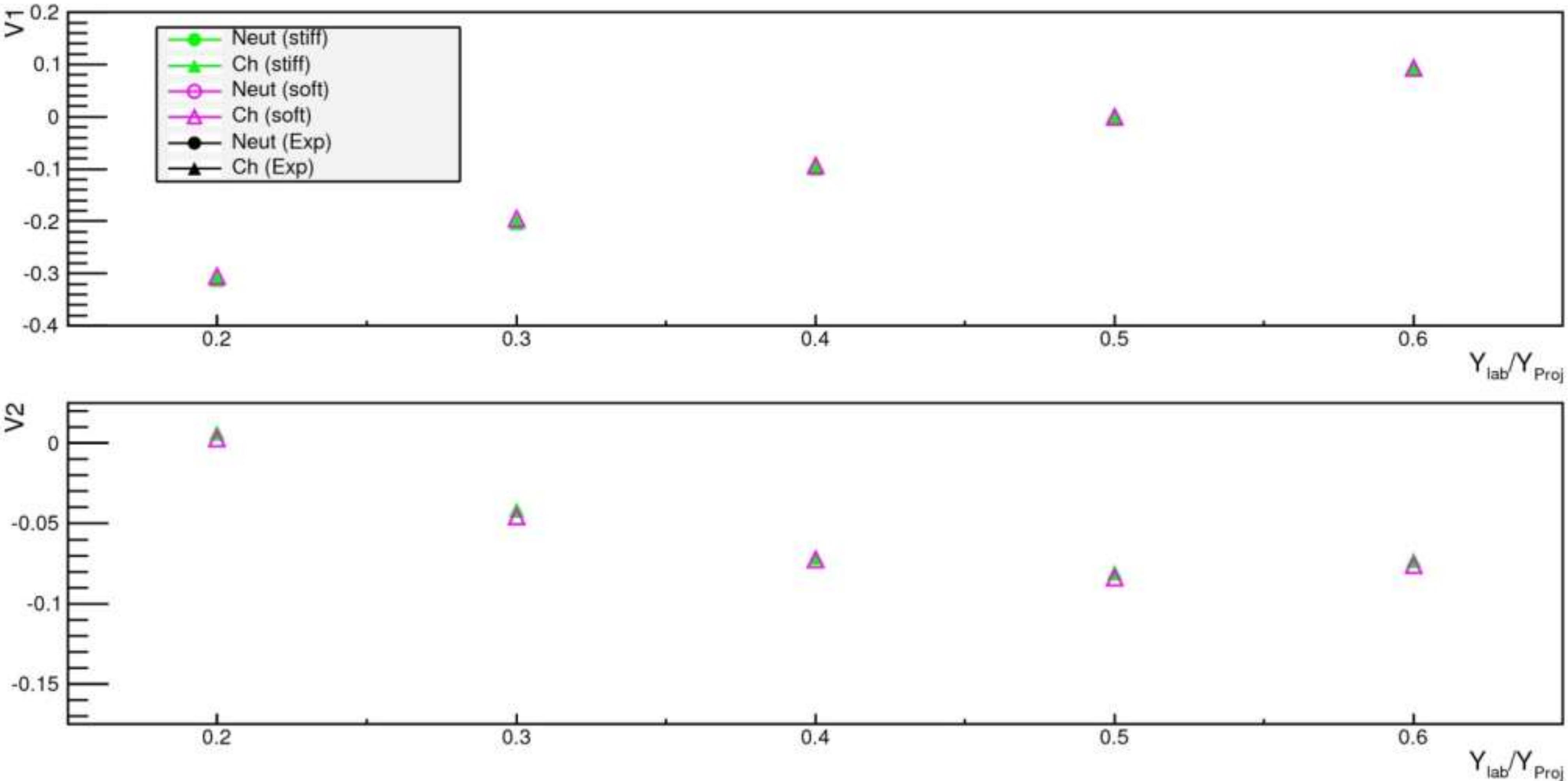
How much background to subtract ?



Comparison with UrQMD

Au+Au @ 400 AMeV b<7.5 fm

Wbg= 110 %



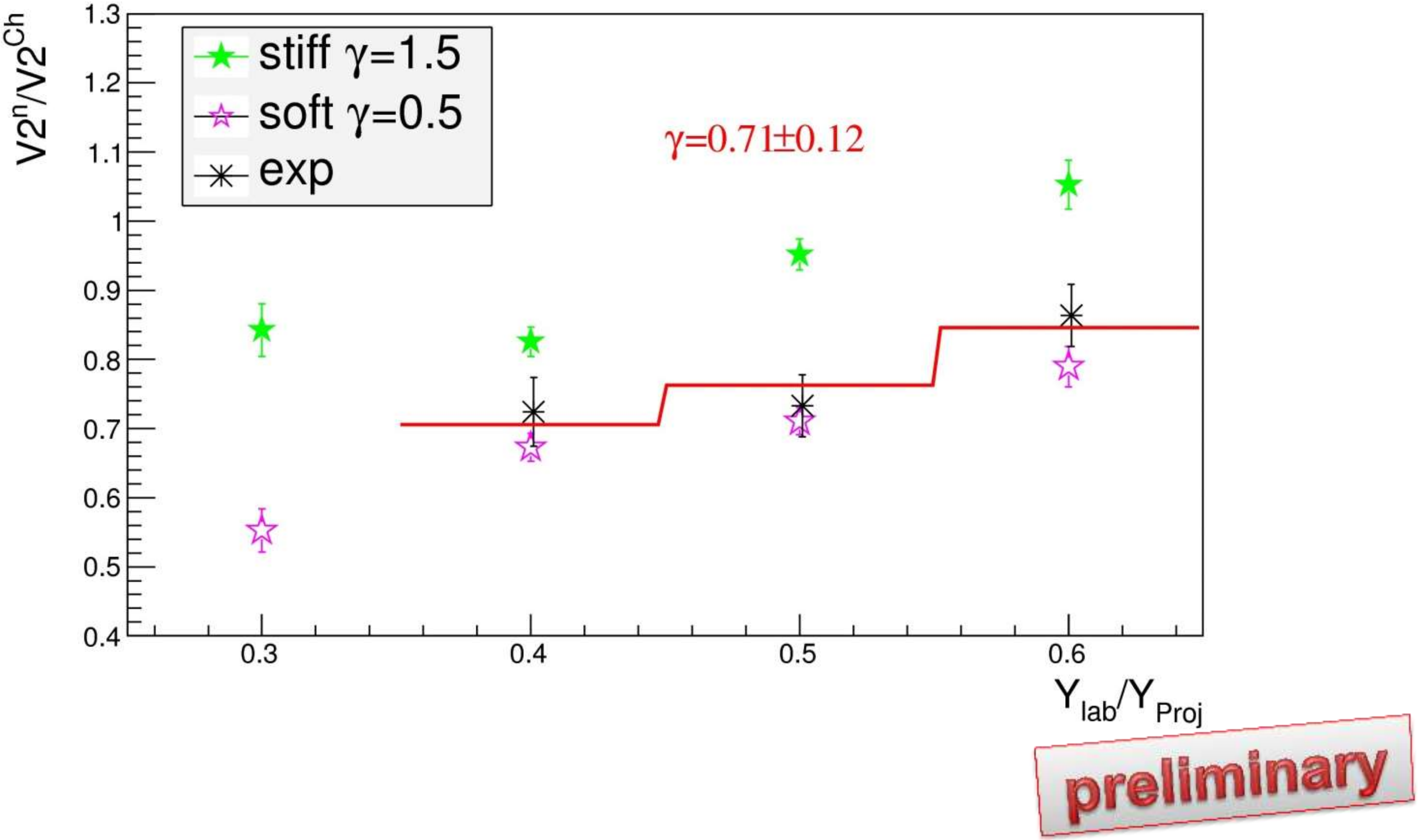
Only charged particles!!!

preliminary

γ extrapolation from rapidity dependence

Au+Au @ 400 AMeV b<7.5 fm

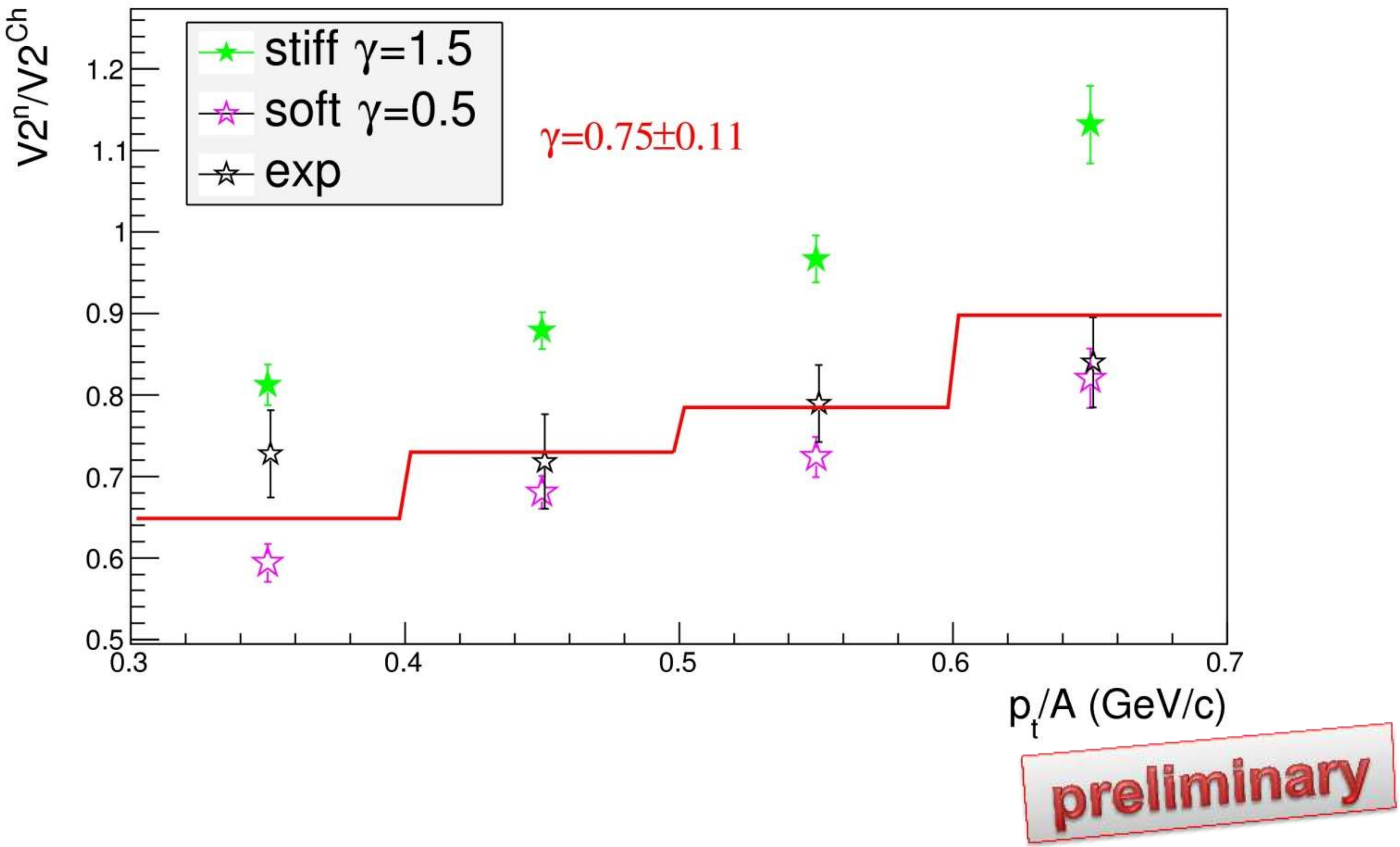
Wbg= 110 %



γ extrapolation from transverse momentum dependence

Au+Au @ 400 AMeV b<7.5 fm

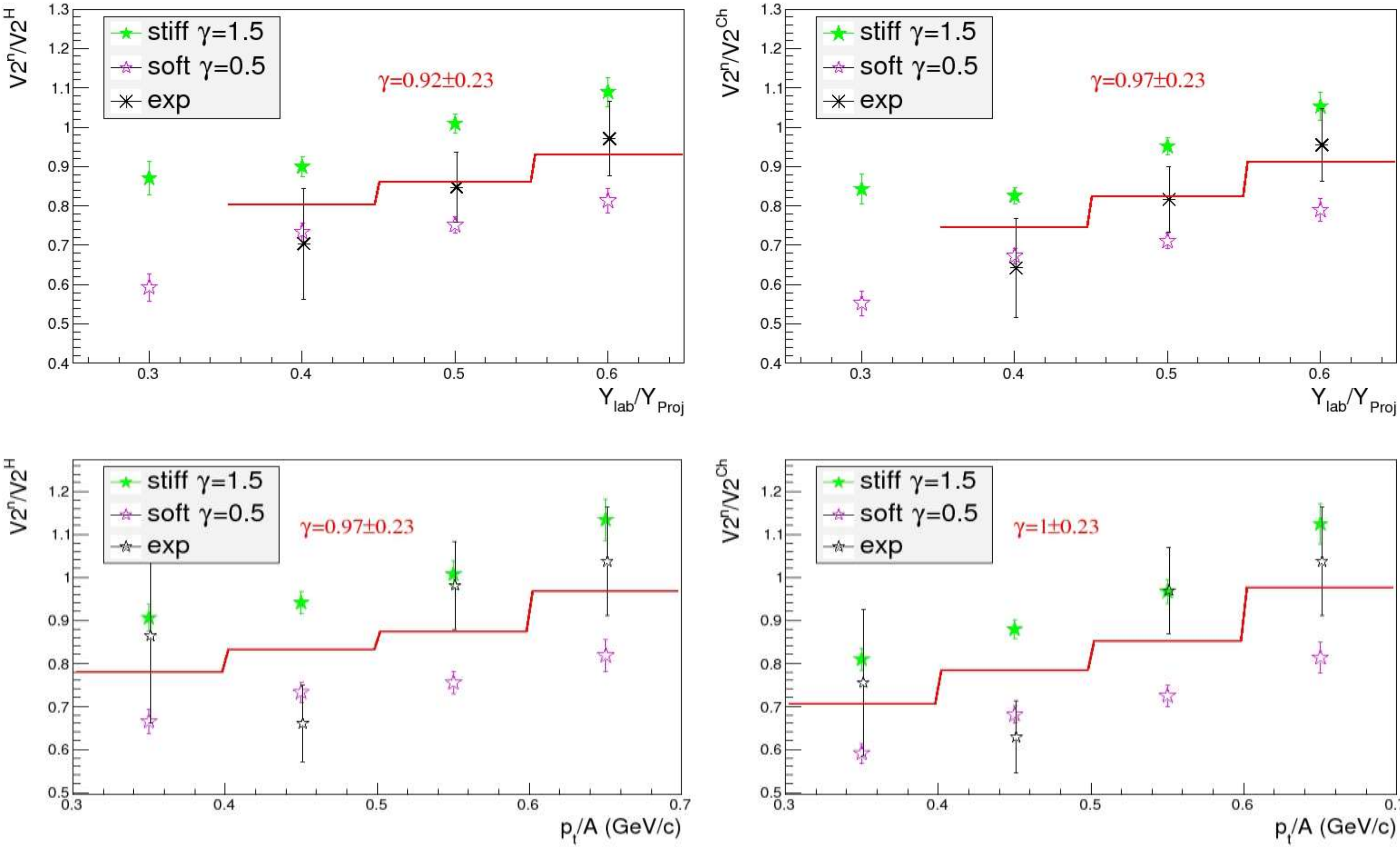
Wbg= 110 %



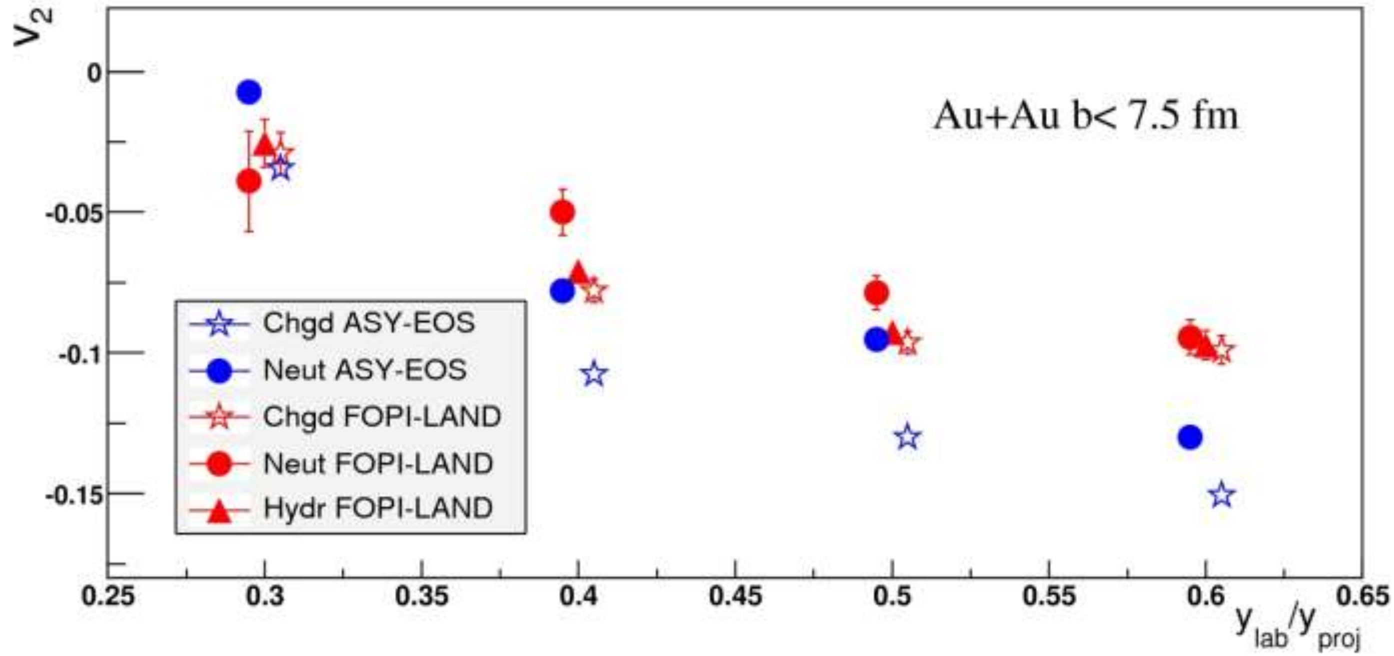
γ extrapolation : v2n/v2ch vs v2n/v2H (FOPI-LAND data)

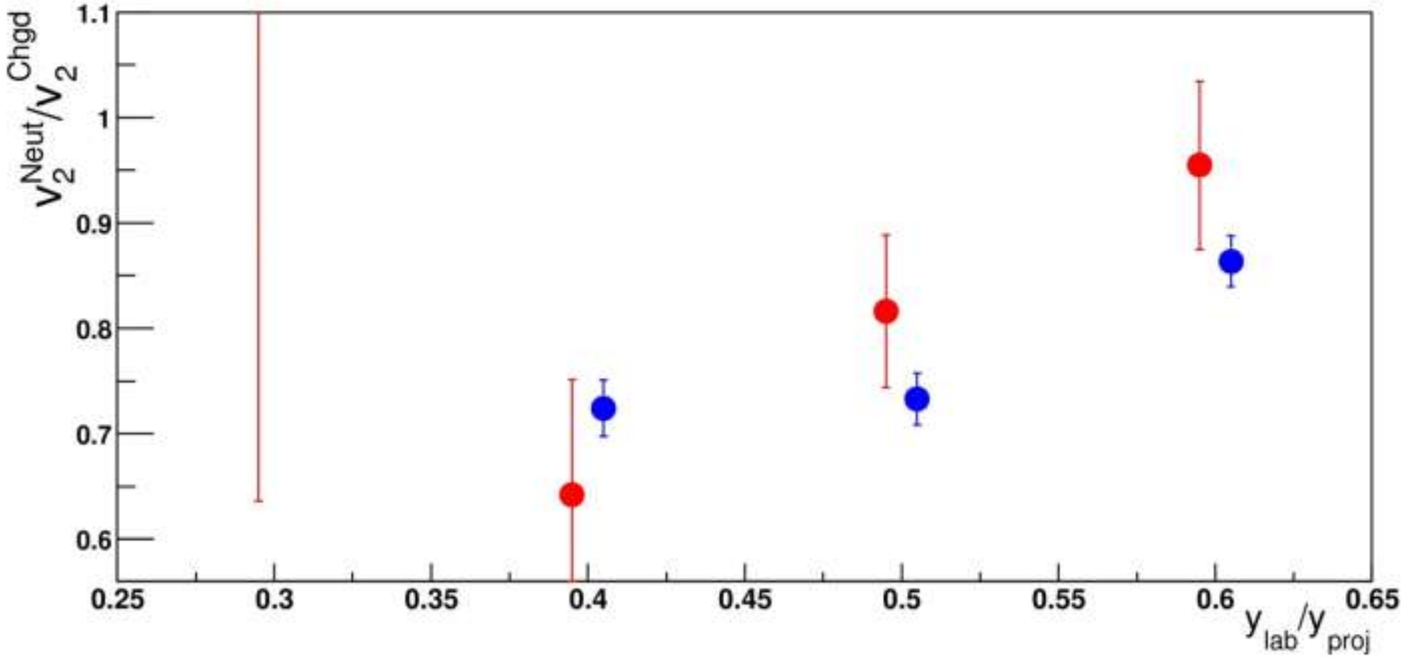
Au+Au @ 400 AMeV
b<7.5 fm

$0.25<y_{lab}/y_{proj}<0.75$
θ_{lab} cut as in ASY-EOS set-up



Comparing ASY-EOS with FOPI-LAND exp: rapidity dependence





Au+Au @ 400 AMeV

b<7.5 fm

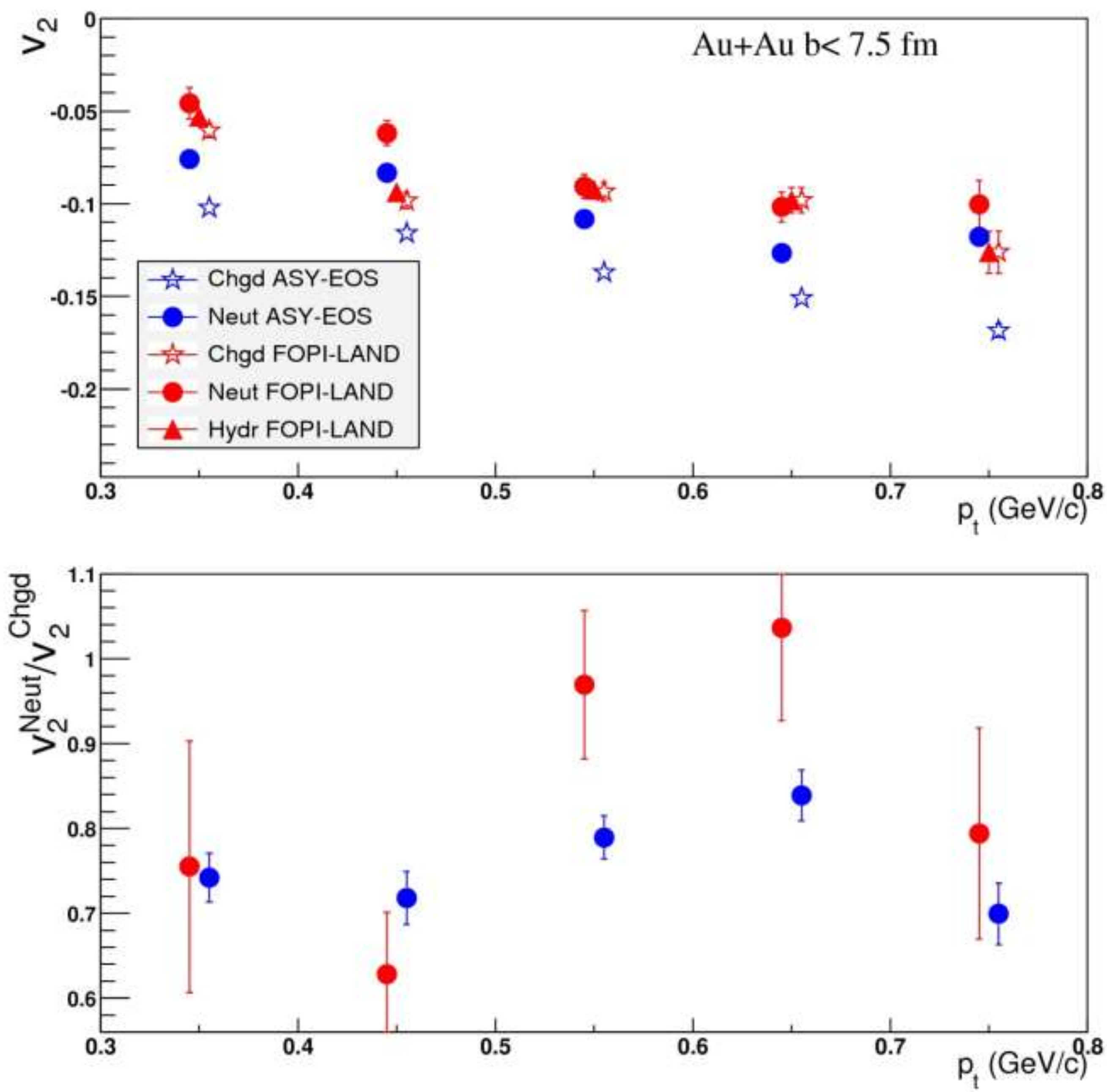
$0.25 < y_{lab}/y_{proj} < 0.75$

θ_{lab} cut as in ASY-EOS set-up

Wbg= 110 %

preliminary

Comparing ASY-EOS with FOPI-LAND exp: transverse momentum dep.



Au+Au @ 400 AMeV
b<7.5 fm
$0.25<y_{lab}/y_{proj}<0.75$

θ_{lab} cut as in ASY-EOS set-up

Wbg= 110 %

preliminary

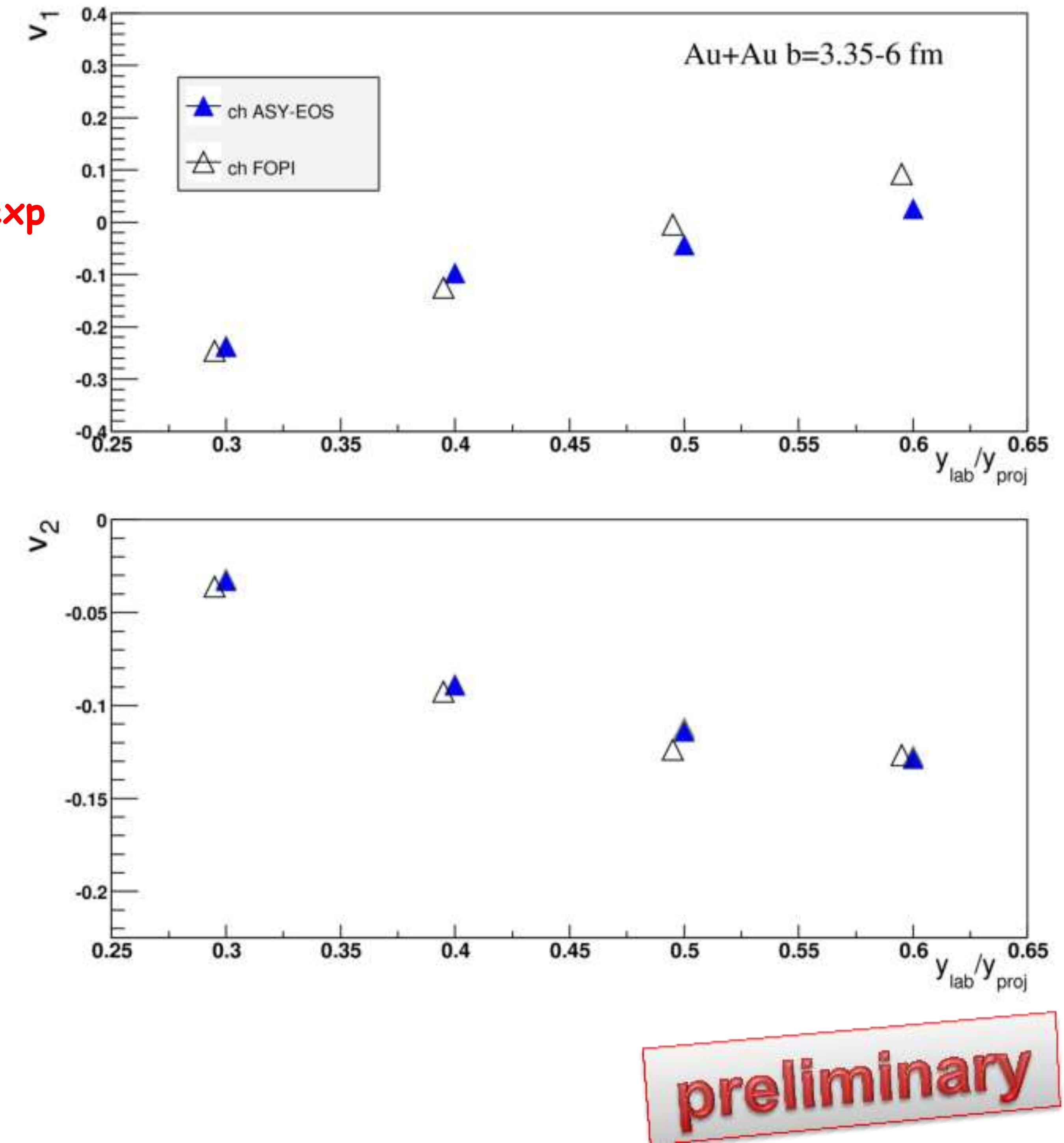
Comparing ASY-EOS with FOPI: rapidity dep. of charged particles

Au+Au @ 400 A.MeV

3.35<b<6 fm (c2)

θ_{lab} cut as LAND in ASY-EOS exp

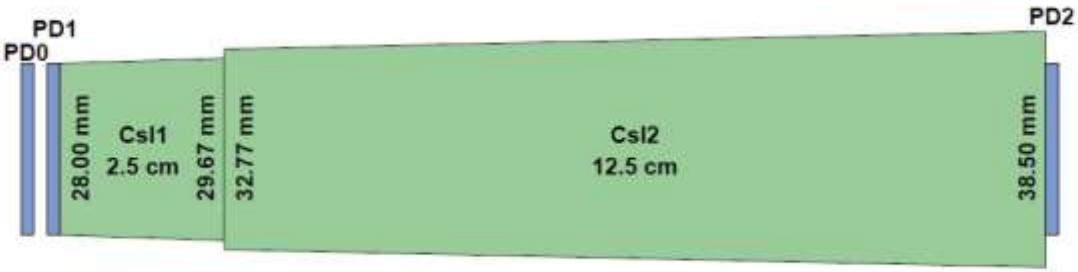
Courtesy of W. Reisdorf

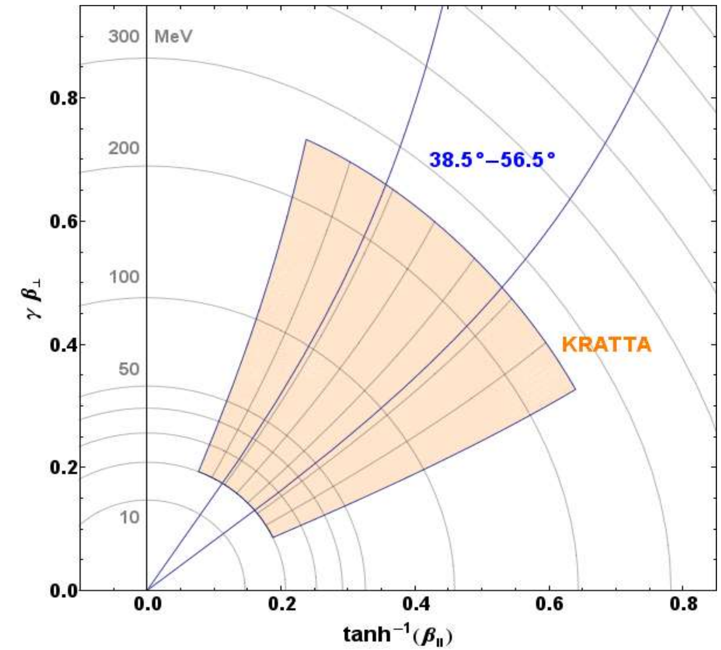


Good agreement between v2 of charged particles of FOPI and ASY-EOS exps …good benchmark for us

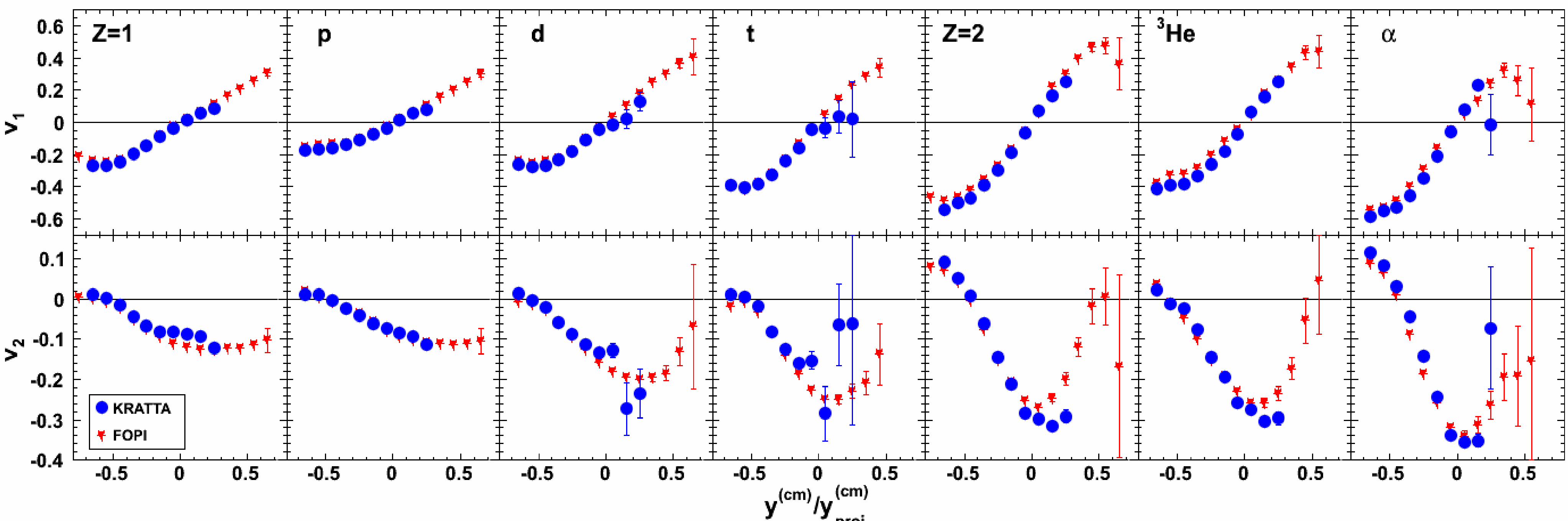
Comparing KraTTA* with FOPI: rapidity dep. of isotopes

35 modules (5 x7), 20.7°<θ<63.5°
40 cm from target.
Digitized with 100 MHz, 14 bits Flash ADCs





Au+Au @ 400 A.MeV
3.35<b<6 fm (c2)
θ_{lab} cut as LAND



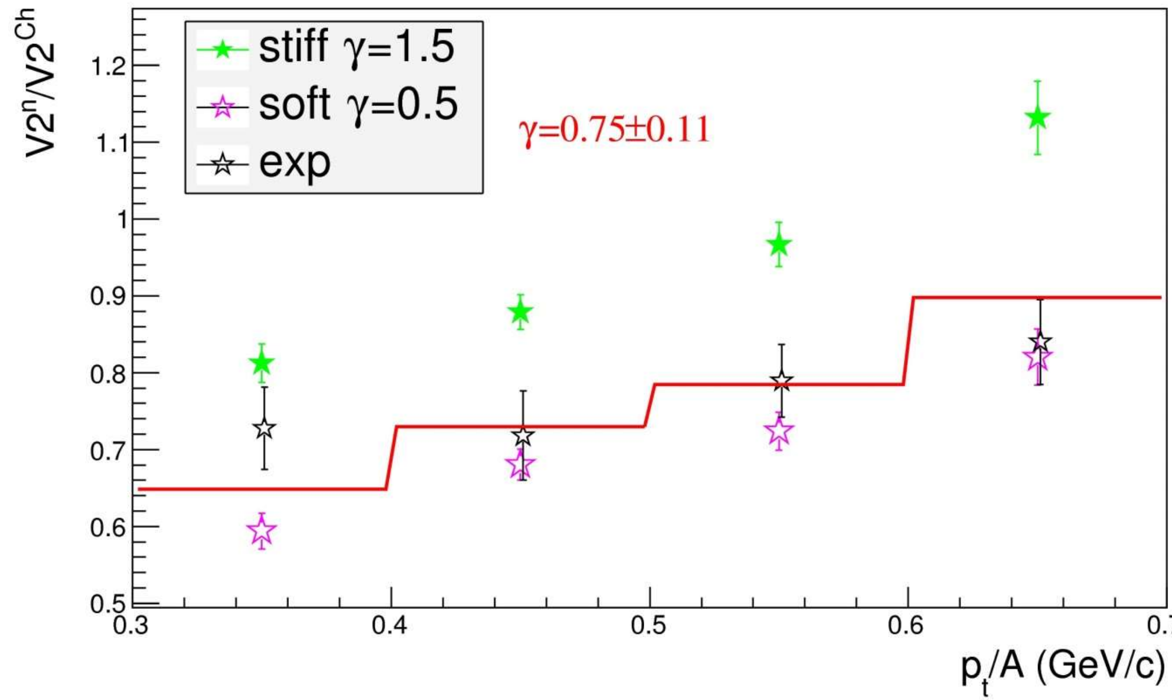
*J. Lukasik et al., NIM A 709, 120 (2013)

see S. Kupny poster

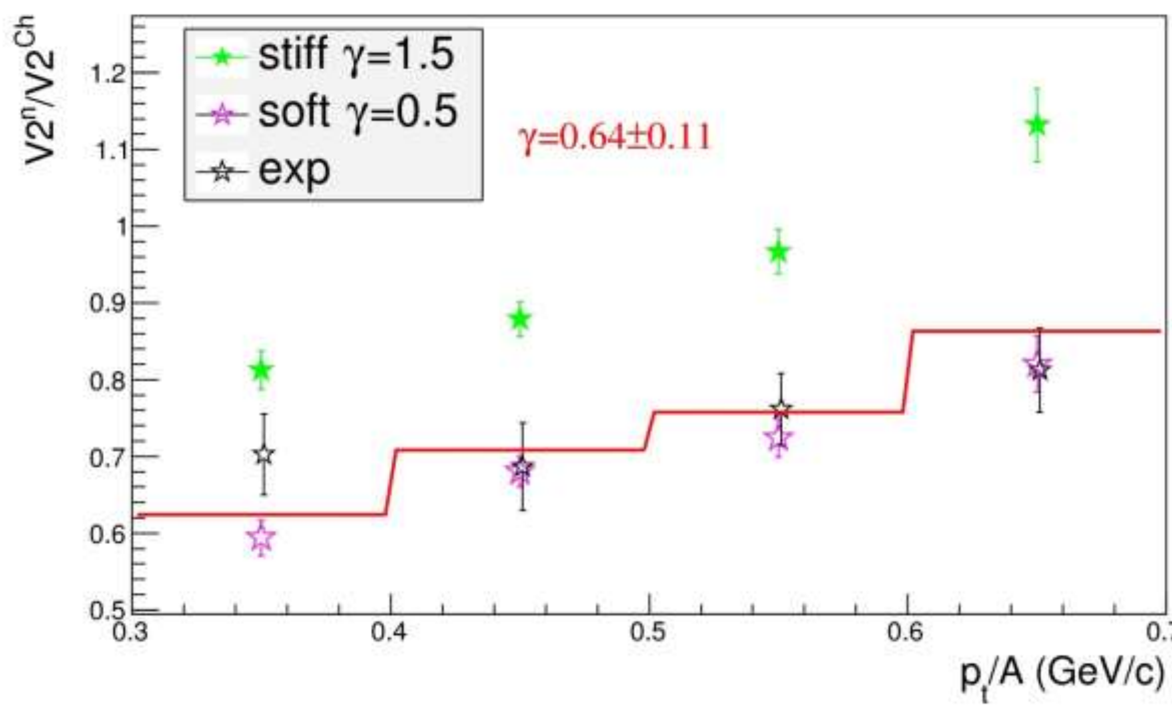
γ extrapolation from transverse momentum dependence : Wbg influence

Au+Au @ 400 AMeV
b<7.5 fm

Wbg= 110 %



Wbg= 100 %

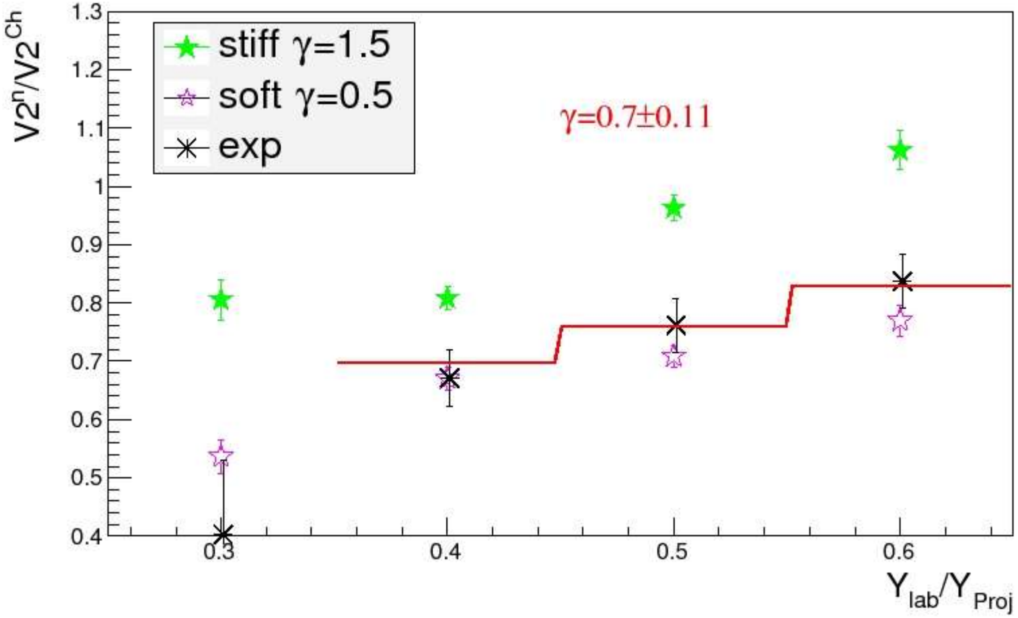


preliminary

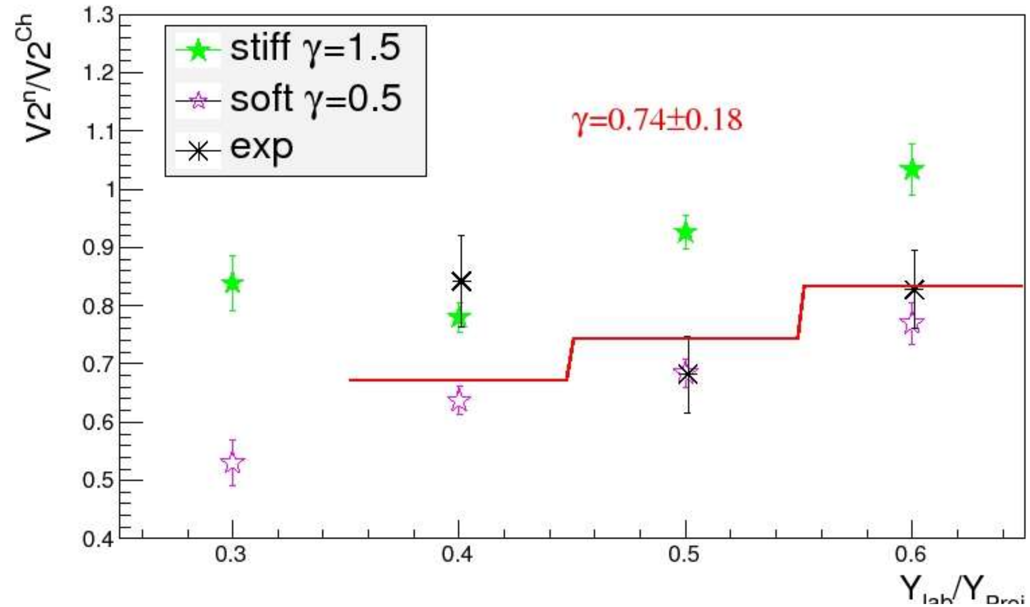
γ extrapolation: impact parameter selection influence

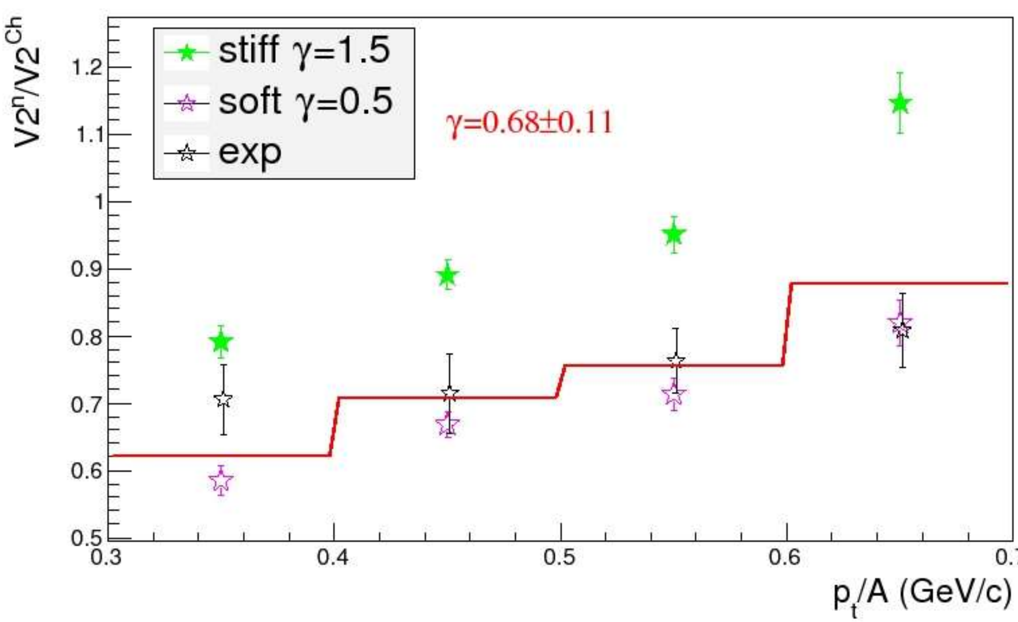
Au+Au 3<b<7.5 fm | **Au+Au 3.35<b<6 fm**

Wbg= 110 %

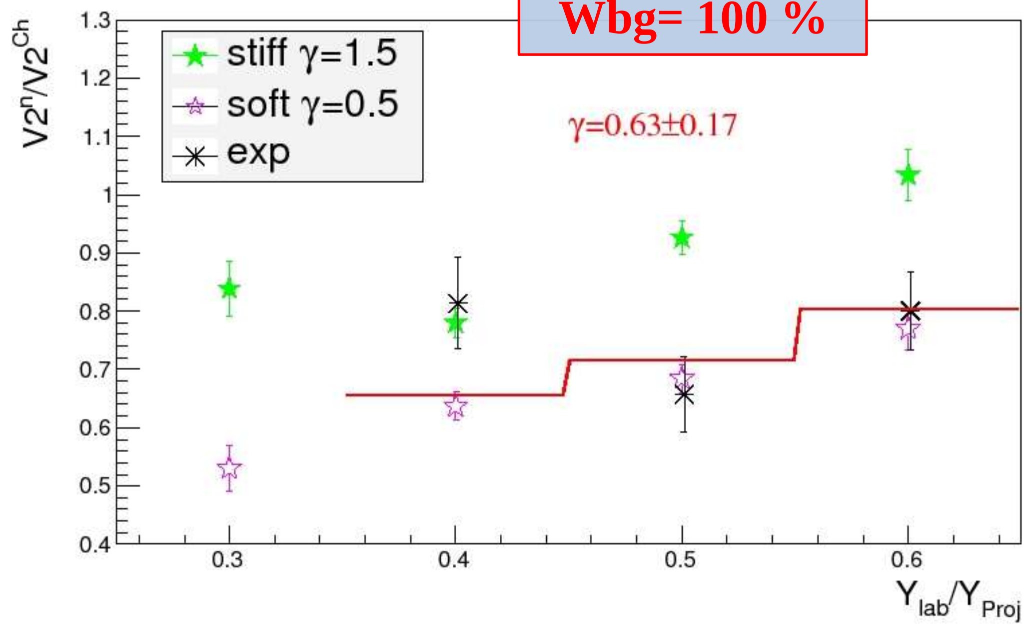


Wbg= 110 %





Wbg= 100 %

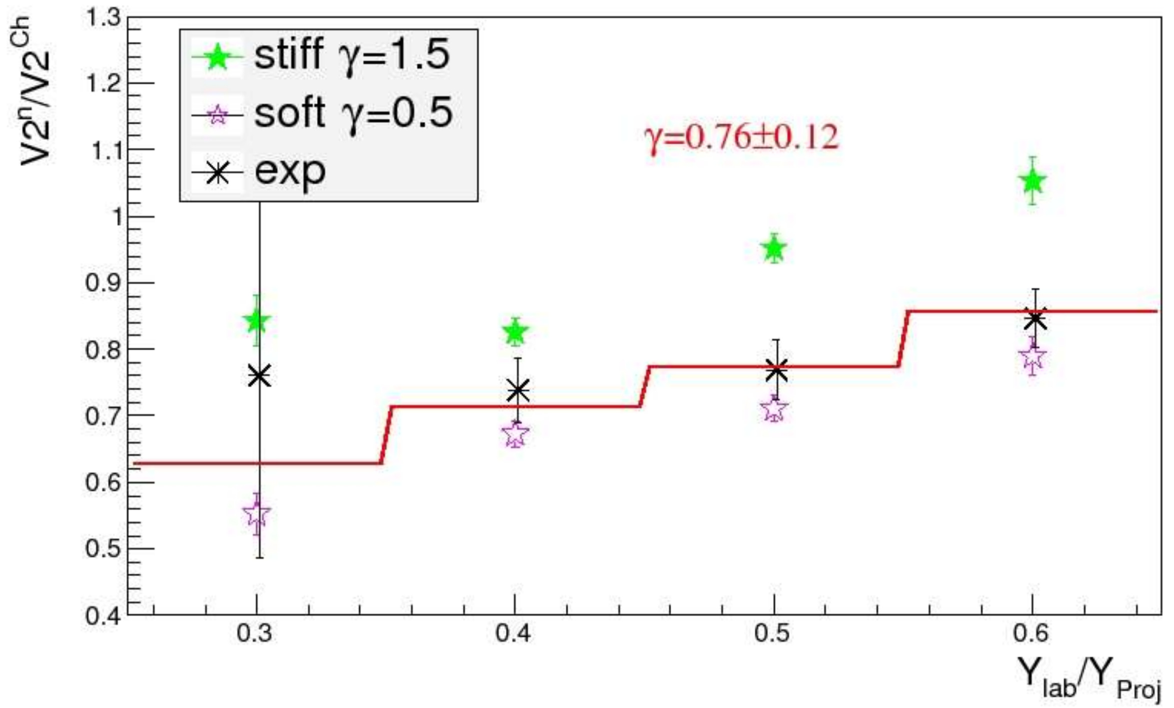


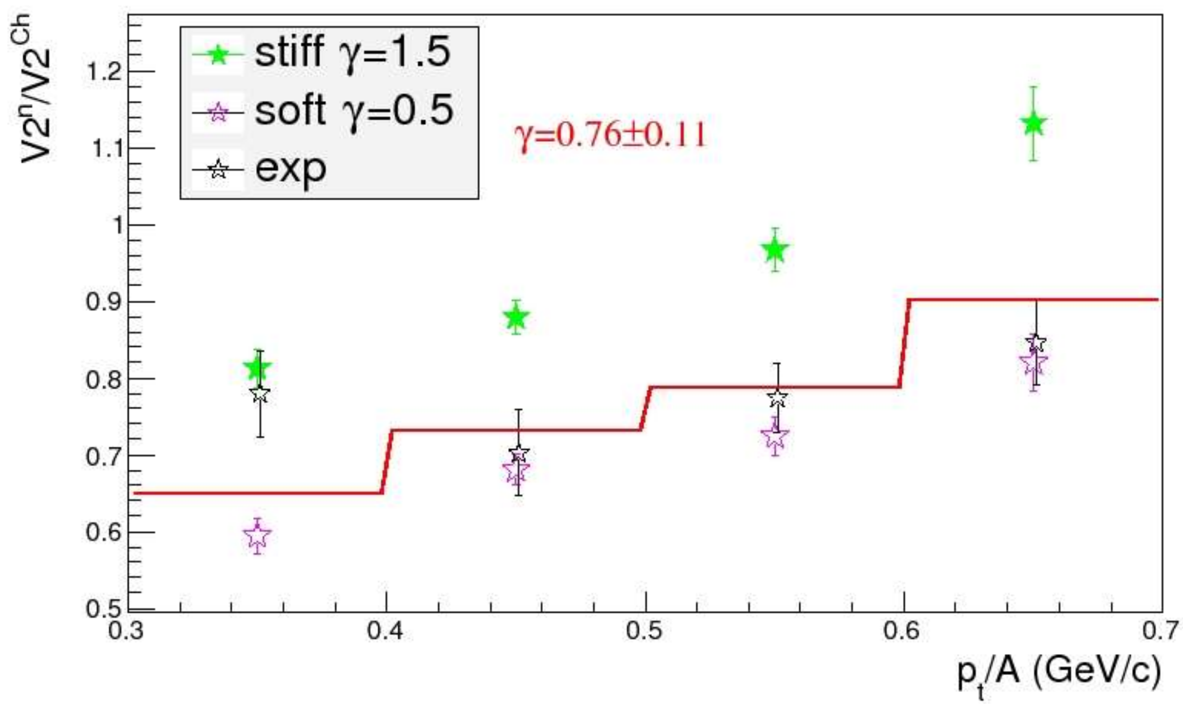
Last result: improved background evaluation

Au+Au @ 400 AMeV
b<7.5 fm

Neutrons:
(Au+Au)-(Au+Au with SB)+
-(Au+EF)+(Au+EF with SB)

Charged Particles:
(Au+Au)-(Au+EF)





The analysis is in progress…

$$S(\rho) = S_0 + \frac{L}{3}\left(\frac{\rho-\rho_o}{\rho_o}\right) + \frac{K_{\rm sym}}{18}\left(\frac{\rho-\rho_o}{\rho_o}\right)^2 + \ldots,$$

$L=3\rho_0\cdot\partial E_{sym}/\partial\rho$

IAS — isobaric analog states, Danielewicz/Lee 2008

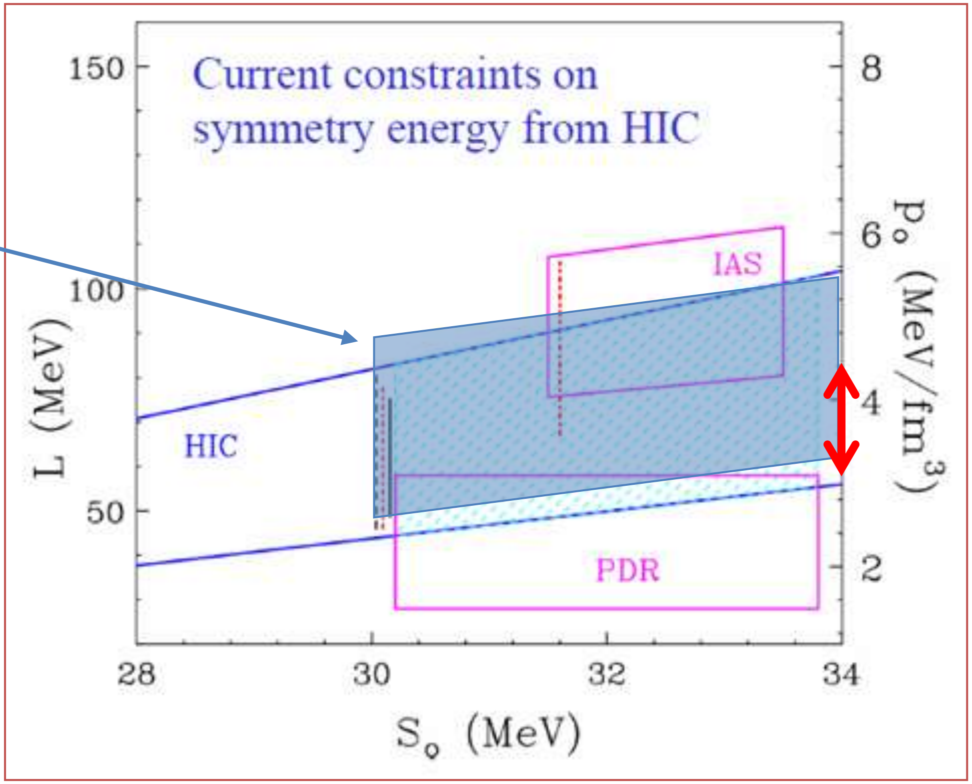
HIC — heavy-ion collisions, isospin diffusion, n/p ratios, Tsang et al., 2009

PDR — pygmy dipole resonance, Klimkiewicz et al. 2007

see also "Complete Electric Dipole Response in ^{208}Pb" Tamii et al., PRL 107, 062502 (2011)

From "old" elliptic n/p flow*

γ=0.7±0.2
L=70±13 (FP1)



symmetry pressure
$P_0=(L/3)\rho_0$

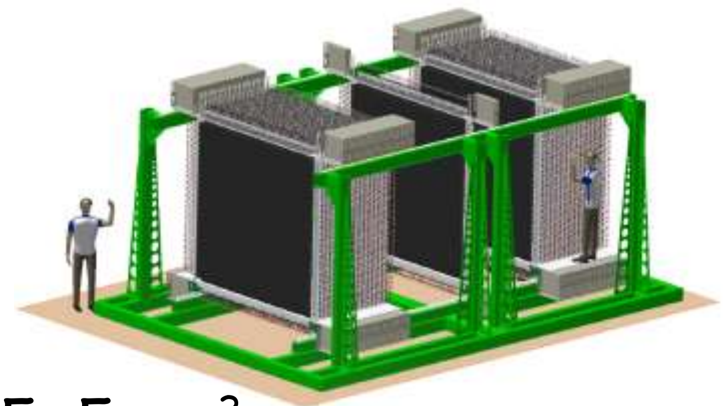
$S_0=E_{sym}(\rho_0)$

from M.B. Tsang et al., PRL 102, 122701 (2009)
vertical lines: analyses with ImQMD (Zhang et al.) and IBUU04 (Li and Chen)

*P.Russotto et al., Phys. Lett. B 697 (2011)

preliminary

NeuLAND @ FAIR/GSI

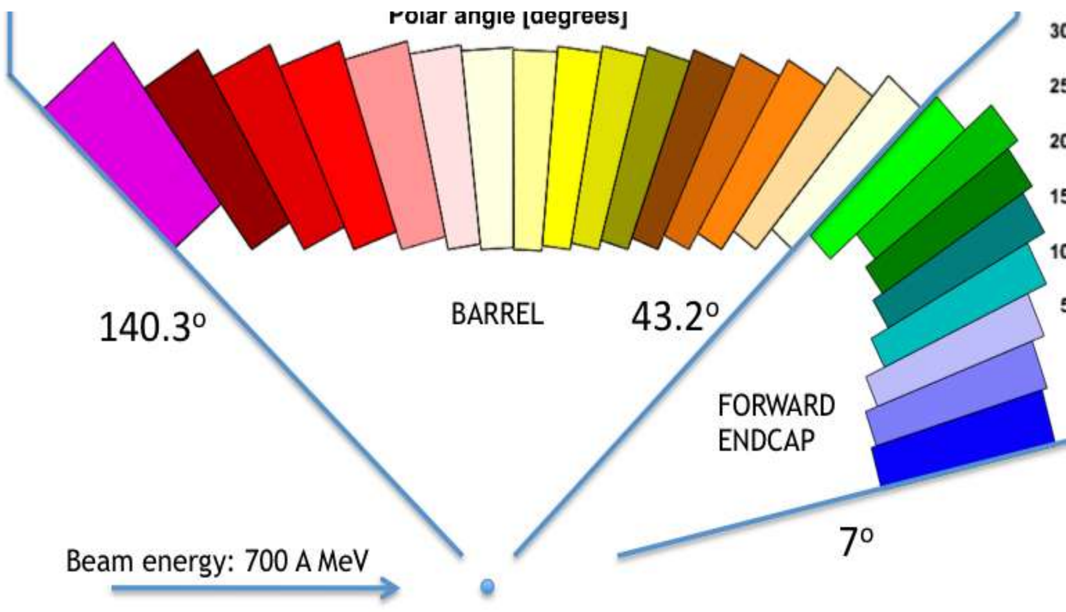


TDR finalized in Oct 2011 and submitted
total volume 2.5x2.5x3 m^3
each bar readout by two PMT
3000 modules (plastic scintillator bars) 250x5x5 cm^3
30 double planes with 100 bars each, bars in neighboring planes mutually perpendicular
$\sigma_t \leq 150$ ps and $\sigma_{x,y,z} \leq 1.5$ cm
one-neutron efficiency ~95% for energies 200-1000 MeV
multi-neutron detection capability

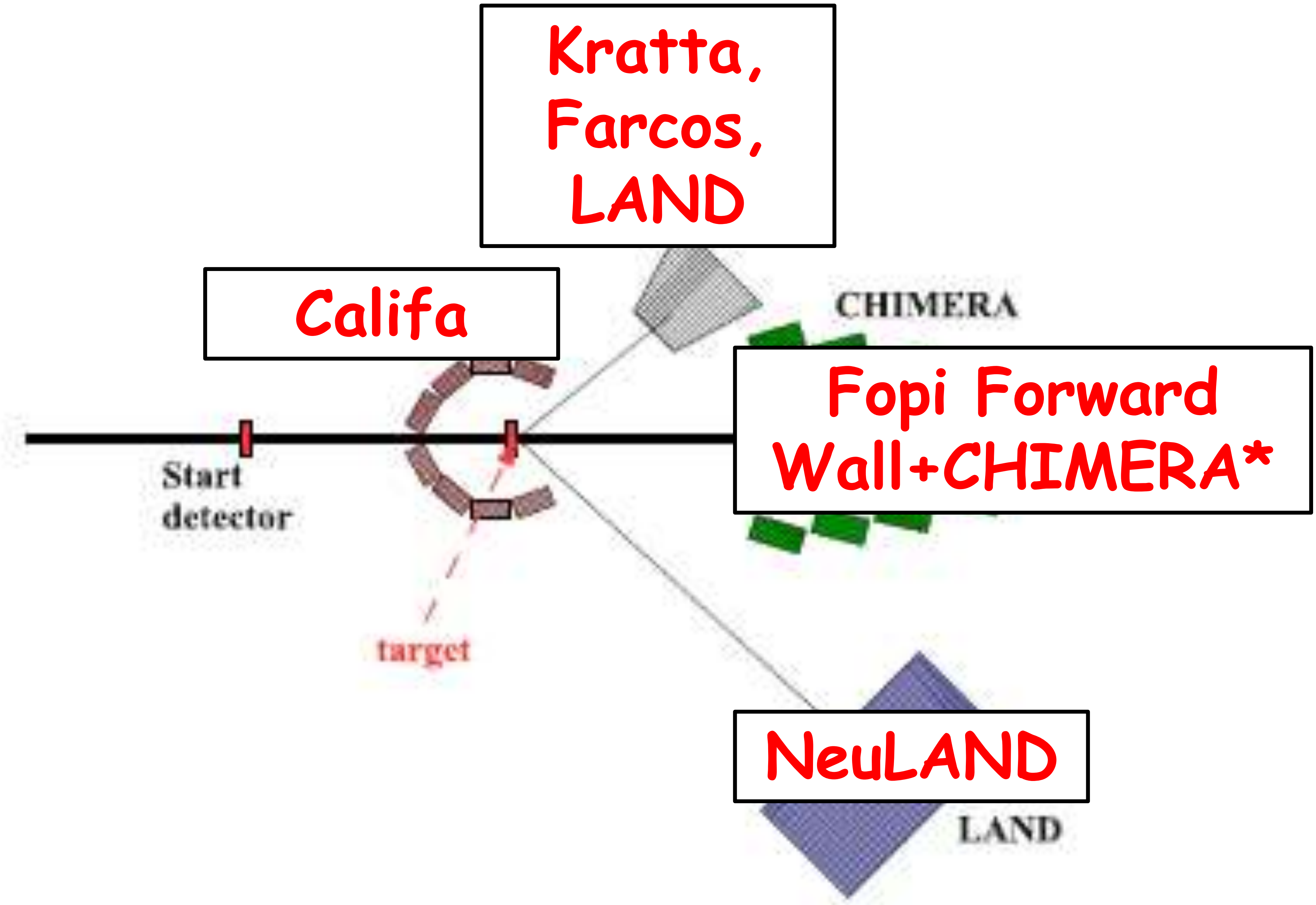
I. Gasparic AsyEOS2012 workshop, 6.9.2012, Siracusa, Italy

Califa
CALorimeter for the In Flight detection of γ rays and light charged pArticles

CsI(Tl) read by APD
with digital read-out

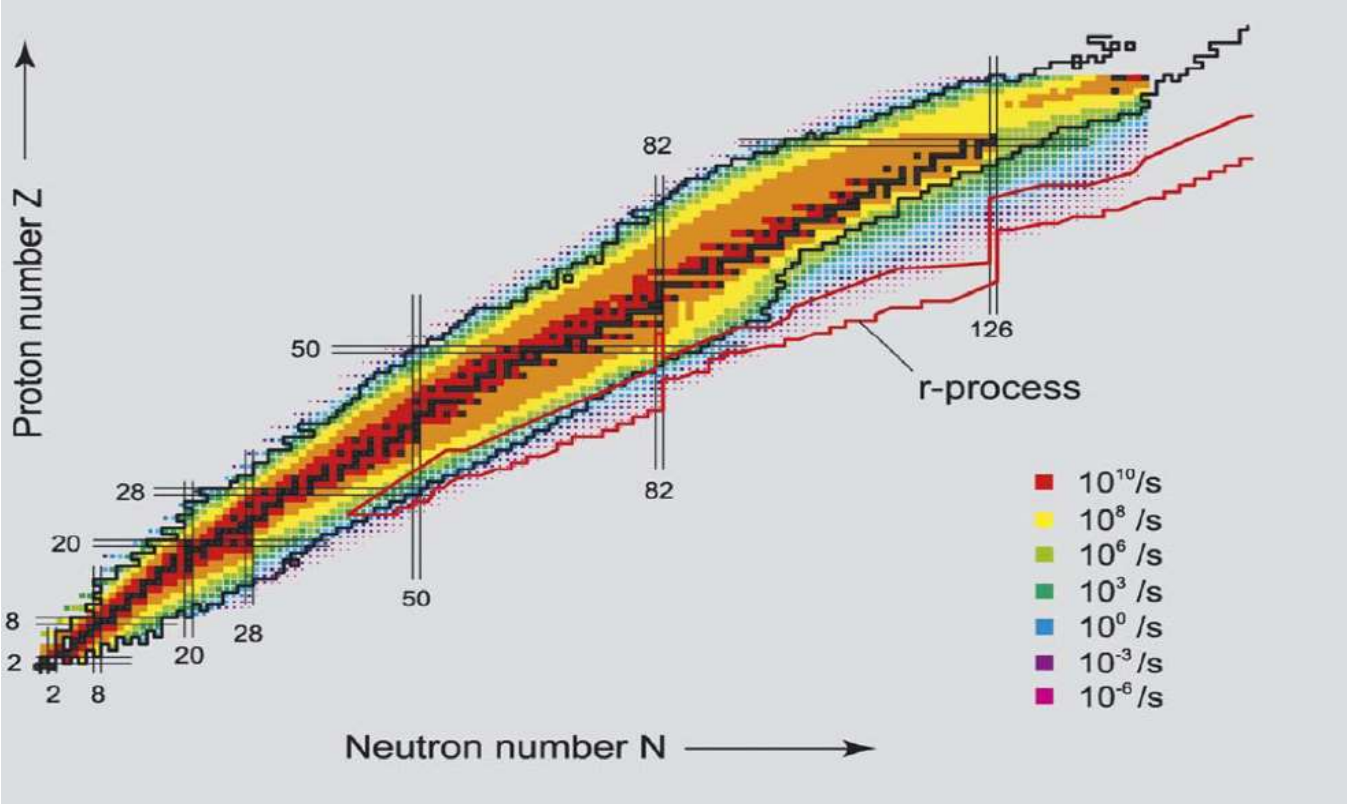


ASY-EOS future set-up?



* Ring 1-2-3 (θ<7°)

FAIR rates



Some interesting beams (and I^2)

^{197}Au+^{197}Au @ 600,800,1000 AMeV (0.039+0.039)

^{132}Sn+^{124}Sn @ 400, 800, 1000 AMeV (0.059+0.037)

^{106}Sn+^{112}Sn @ 400, 800, 1000 AMeV (0.003+0.011)

Why ^{132}Sn?

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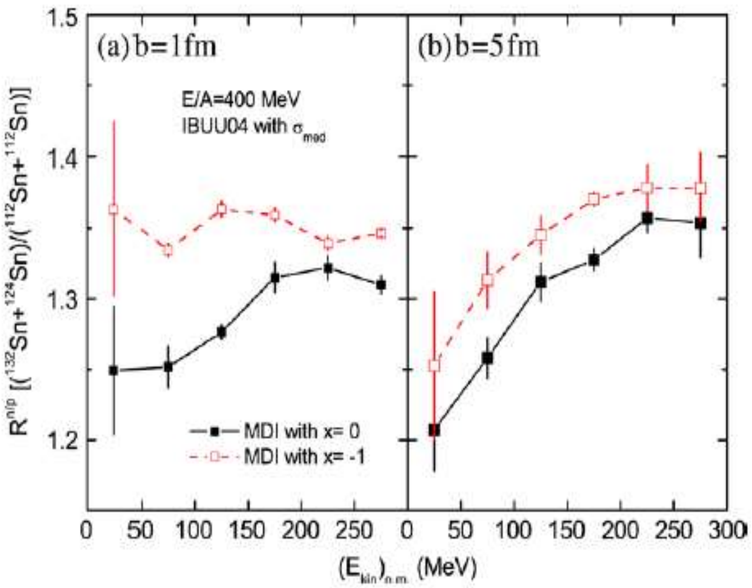

atio of free nucleons taken from the reactions of ^{132}Sn + ^{124}Sn and ^{112}Sn +
m (right panel). Taken from Ref. [67].

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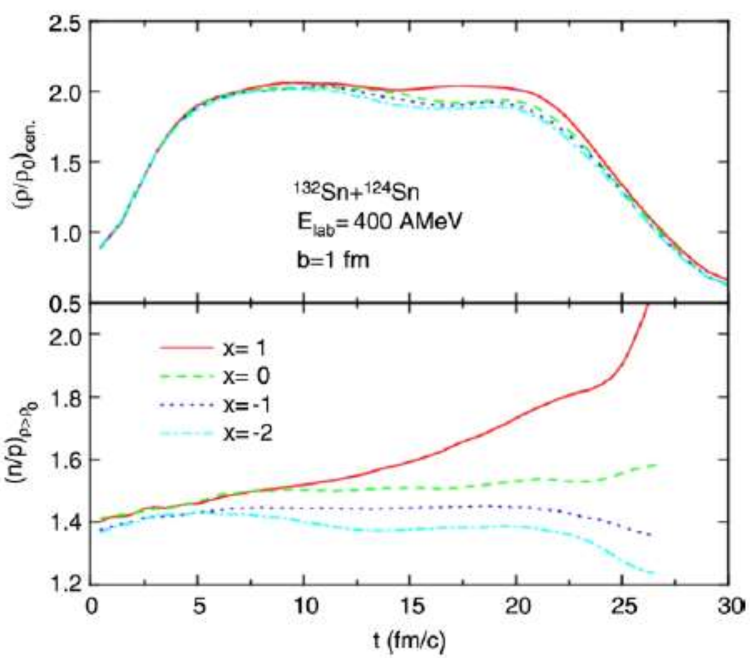

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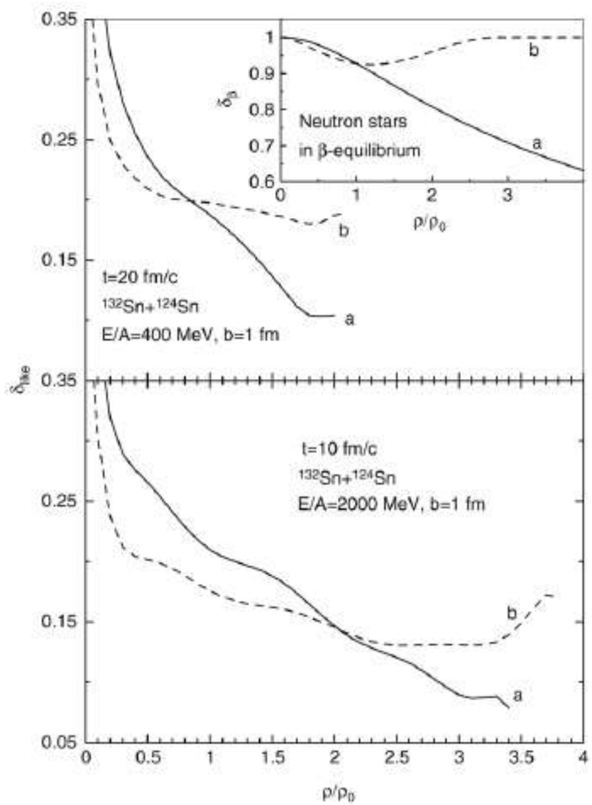

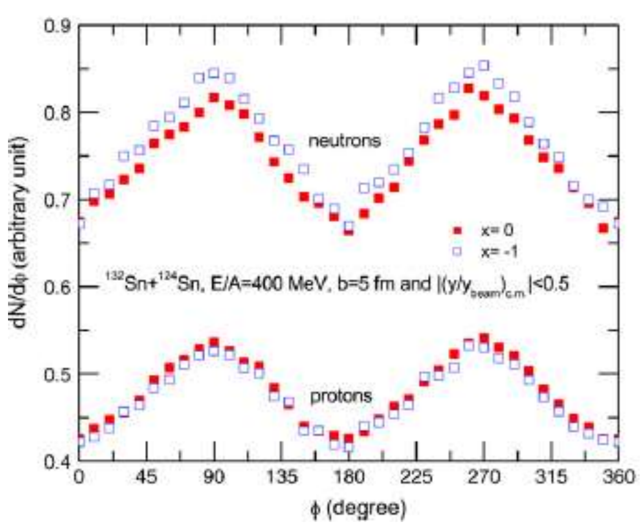

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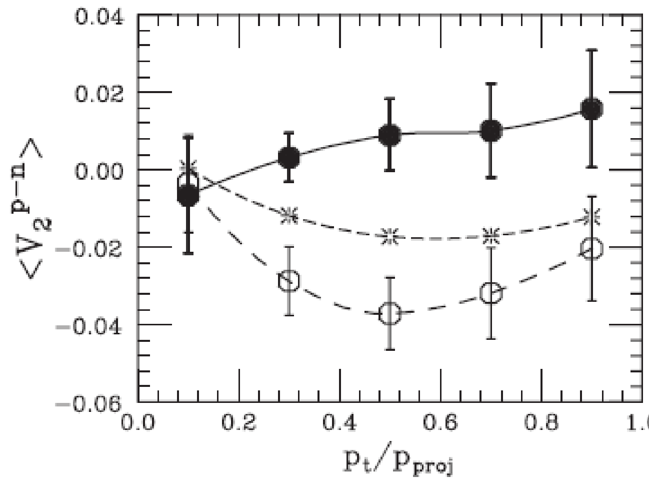

1.5 A GeV ($b = 6$ fm) from the three different models f
ll circles and solid line: $NL\rho\delta$. Open circles and dashe
ext and the previous caption.

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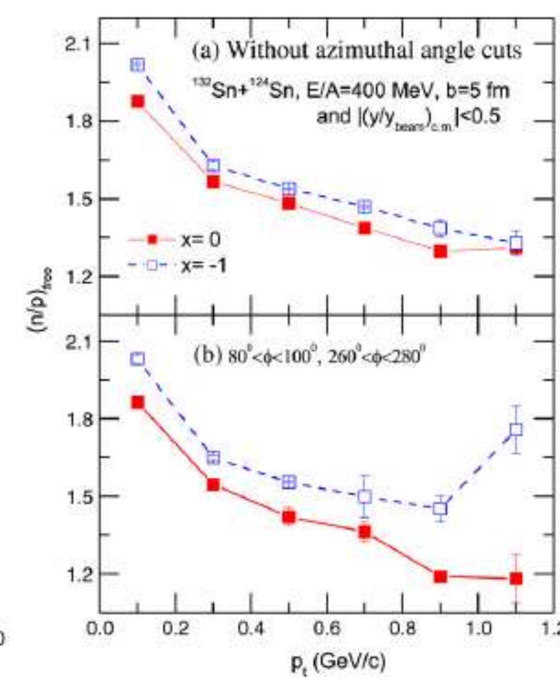

Conclusions

Symmetry Energy:

- Low densities: several constraints quite consistent
- High density:
  - pion constraints not consistent
  - n/p flows suggests…a route "Towards a model-independent constraint of the high-density dependence of the symmetry energy"
  - Finalizing ASY-EOS data analysis is in progress
- Work on code consistency needed…everywhere
- New and better experiments on n,p flows and ratio, pions and kaons, also with high asymmetric beams (e.g. ^{132}Sn) and new detectors (Riken TPC, NeuLand@R3B)
- International collaborations and efforts

On the road…..

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THANKS!