

# INPC 2013

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

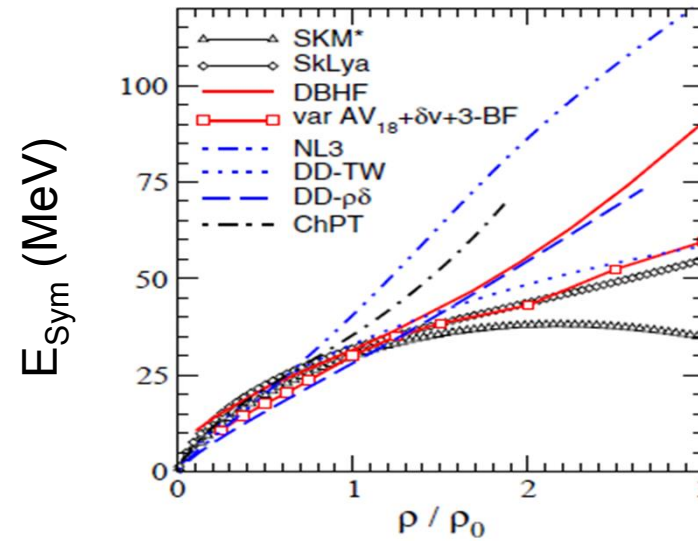
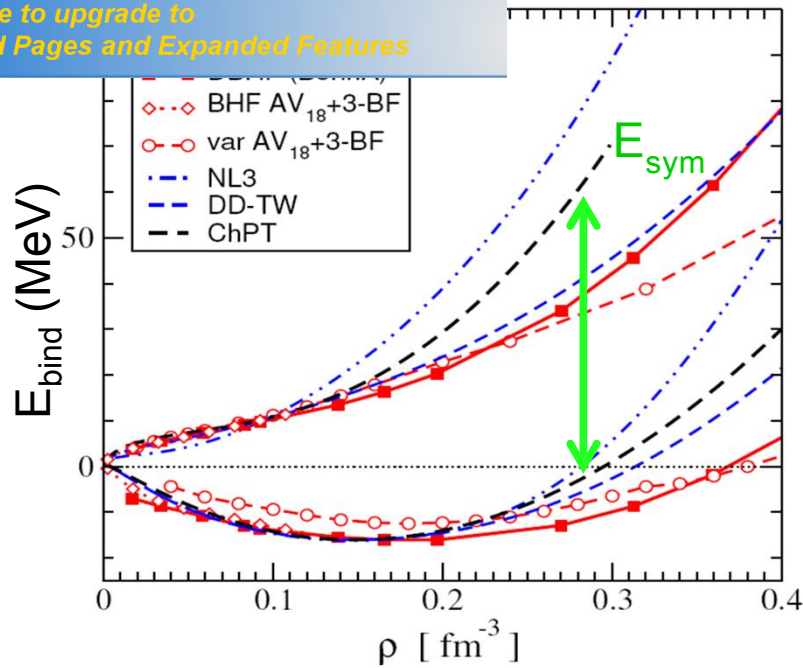
P. Russotto\*

for the ASY-EOS collaboration



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# Symmetry energy



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

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

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

- Relatively large deviations at high densities
- Several constraints (quite consistent among them) around and below  $\rho_0$
- Few constraints above  $\rho_0$

# High densities: flows

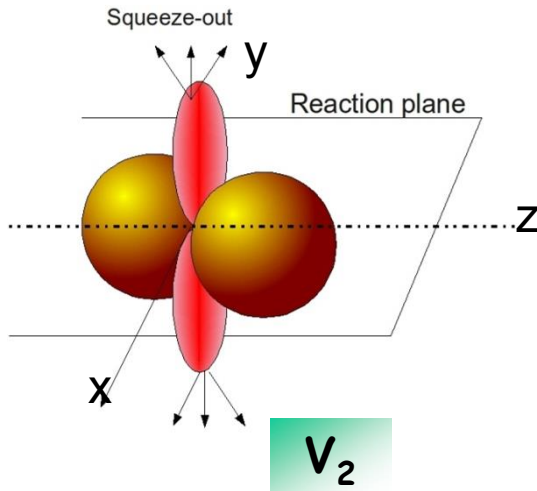
$$\frac{0}{\tau} \left( 1 + 2 \sum_{n \geq 1} v_n \cos n(\phi - \phi_R) \right)$$

Y = rapidity

p<sub>t</sub> = transverse momentum

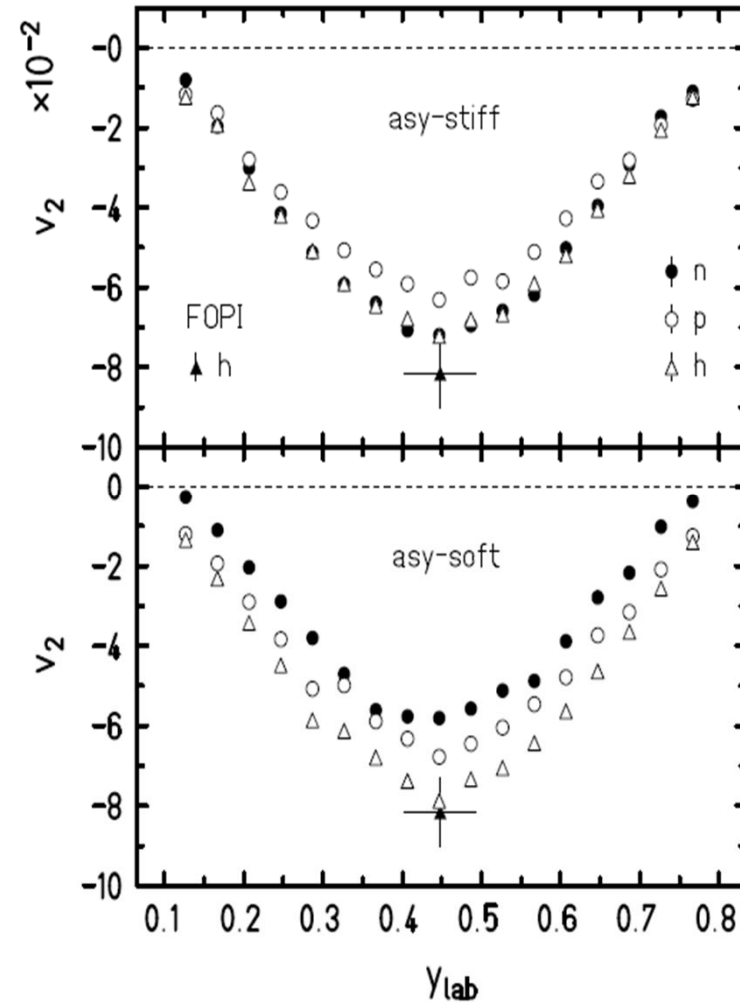
$$V_2(y, p_t) = \left\langle \frac{p_x^2 - p_y^2}{p_t^2} \right\rangle$$

Elliptic flow: competition between in plane (V<sub>2</sub>>0) and out-of-plane ejection (V<sub>2</sub><0)



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

**5.5 < b < 7.5 fm**



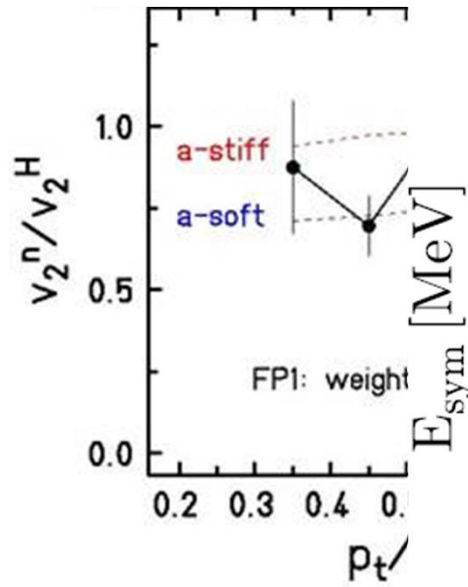
Qingfeng Li, J. Phys. G31 1359-1374 (2005)  
P. Russotto et al., Phys. Lett. B 697 (2011)

FOPI/LAND data (1991)

Au+Au 400 A MeV  $b < 7.5$  fm

Tübingen QMD (momentum dependent)

independent power-law parametrization of the symmetry energy)

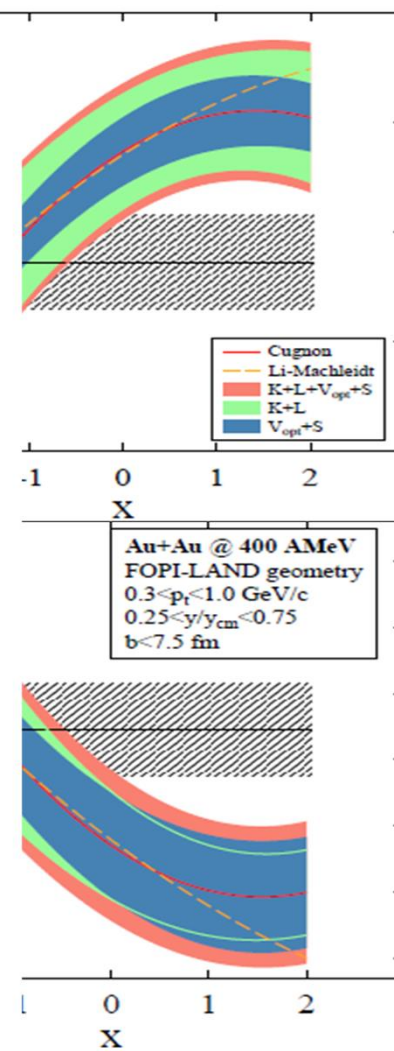
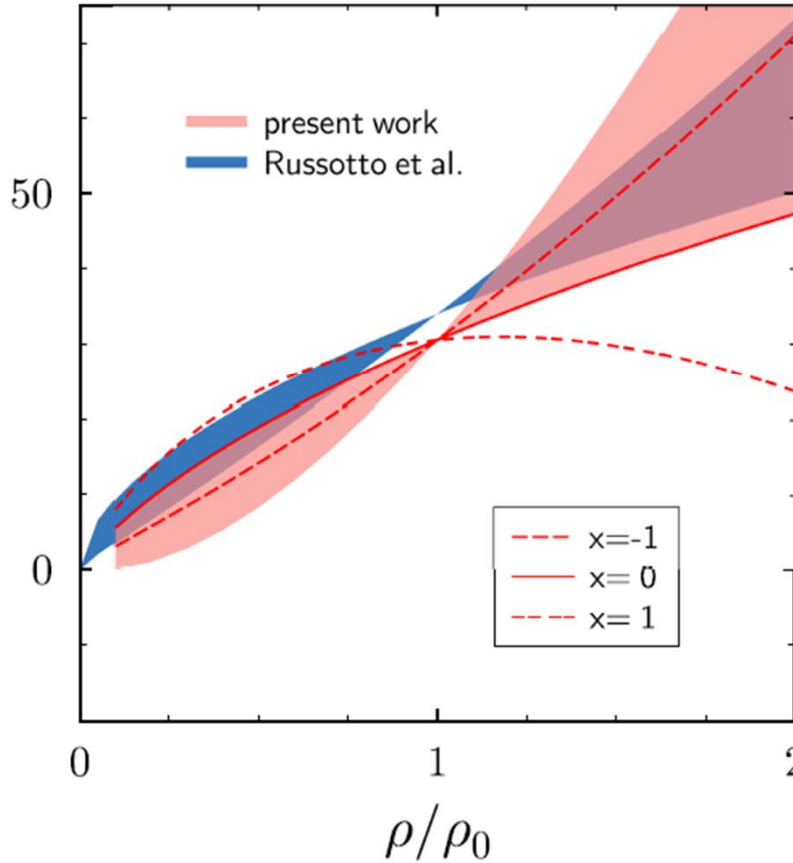


$$E_{\text{sym}} = E_{\text{sym}}^{\text{pot}} + E_{\text{sym}}^{\text{kin}}$$

$$= 22 \text{ MeV} \cdot (\rho/\rho_0)^k$$

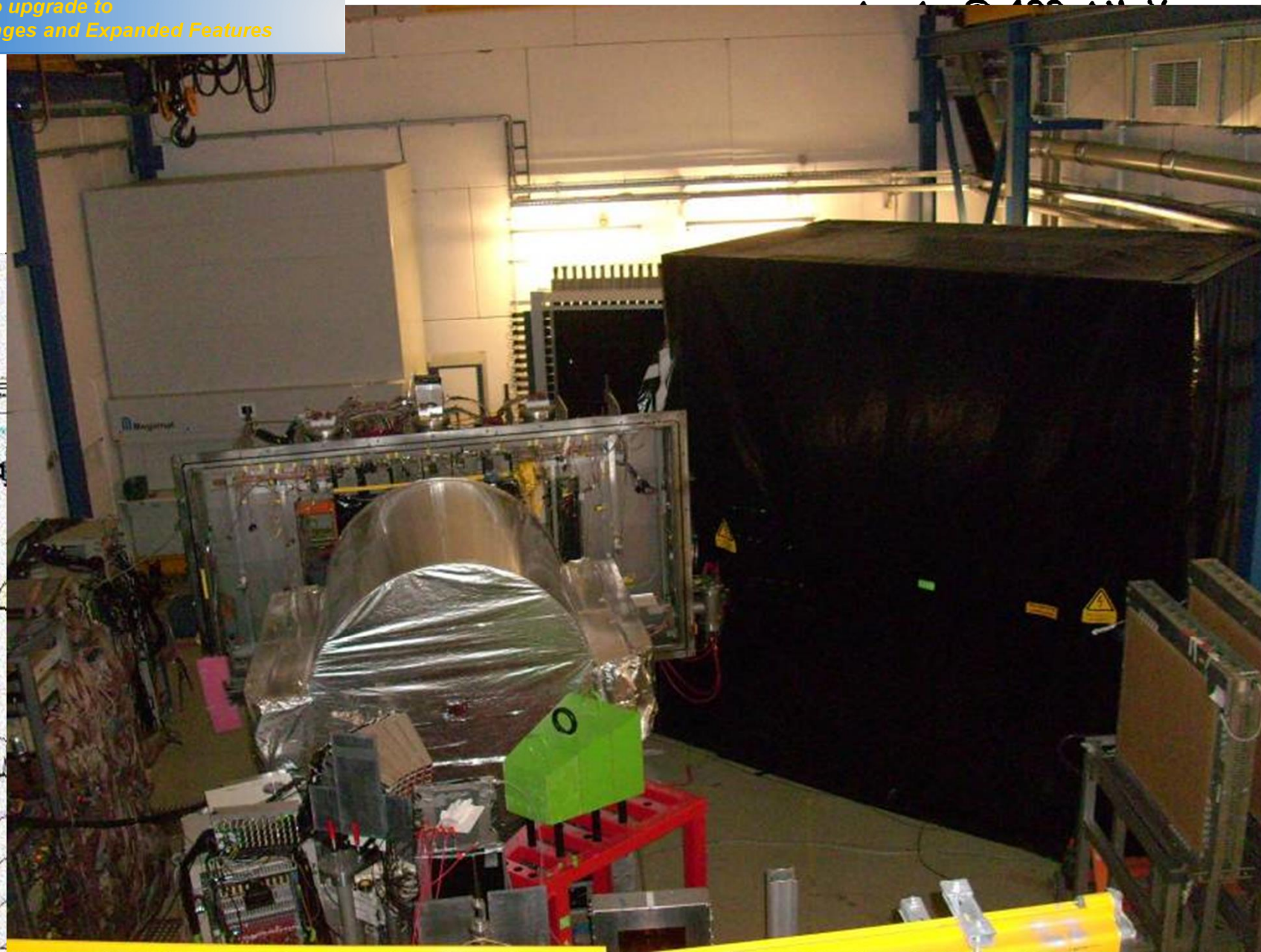
adopted:  $k = 0.9 \pm 0.4$

P. Russotto et al., PLB 697 (2011)



M.D. Cozma et al., Towards a model-independent constraint of the high-density dependence of the symmetry energy [arXiv:1305.5417](https://arxiv.org/abs/1305.5417), sub. to PRC

# 4 experiment @ GSI Darmstadt (Germany)

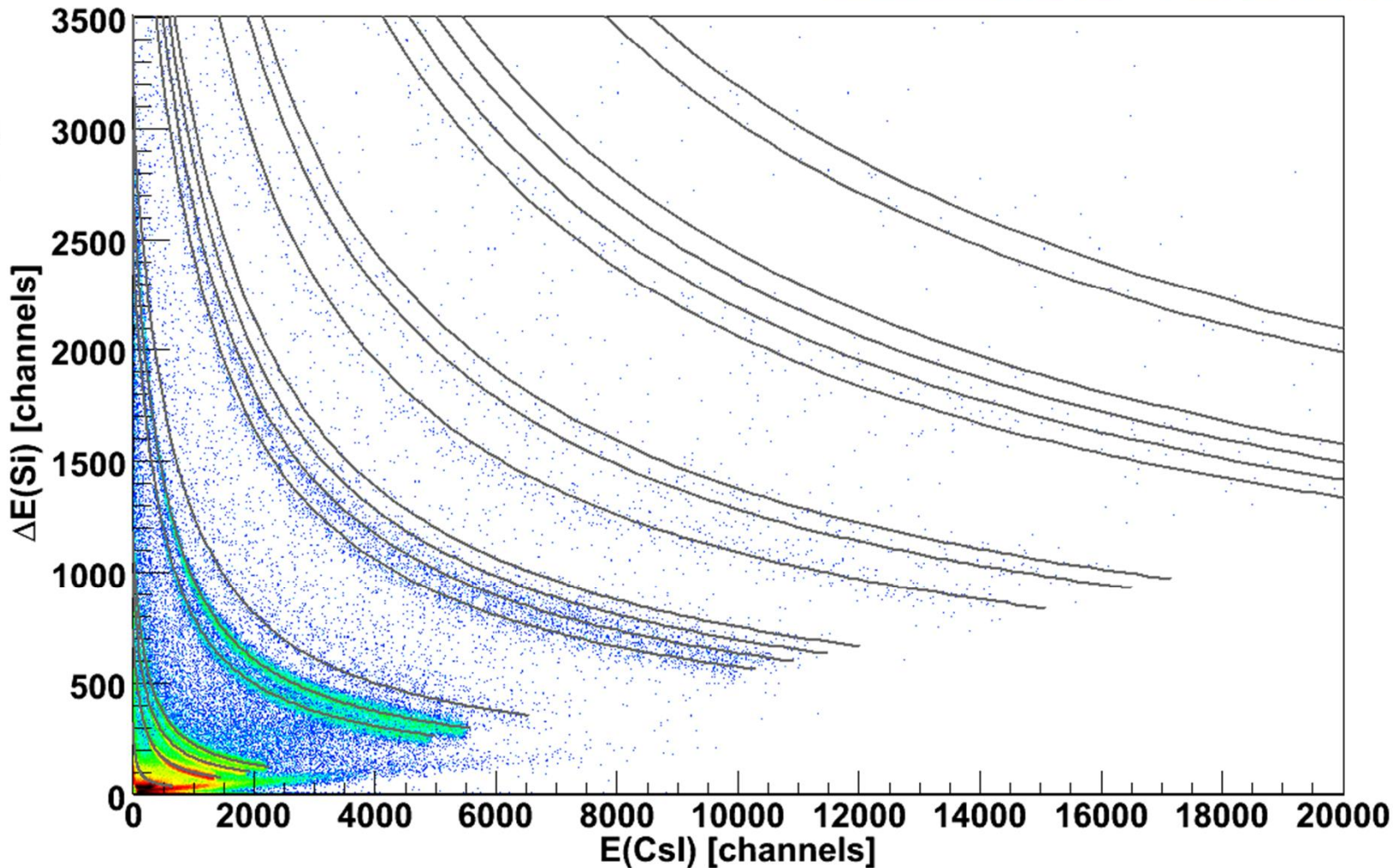
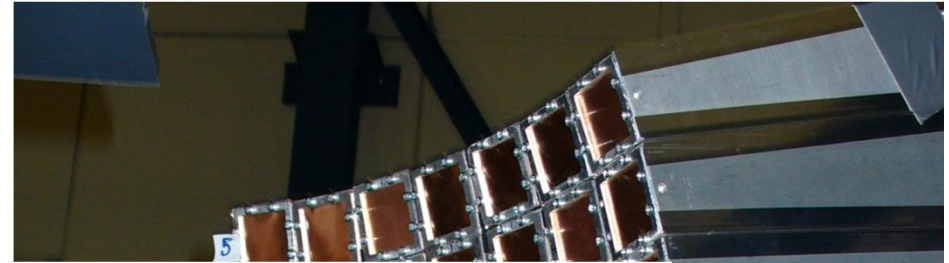


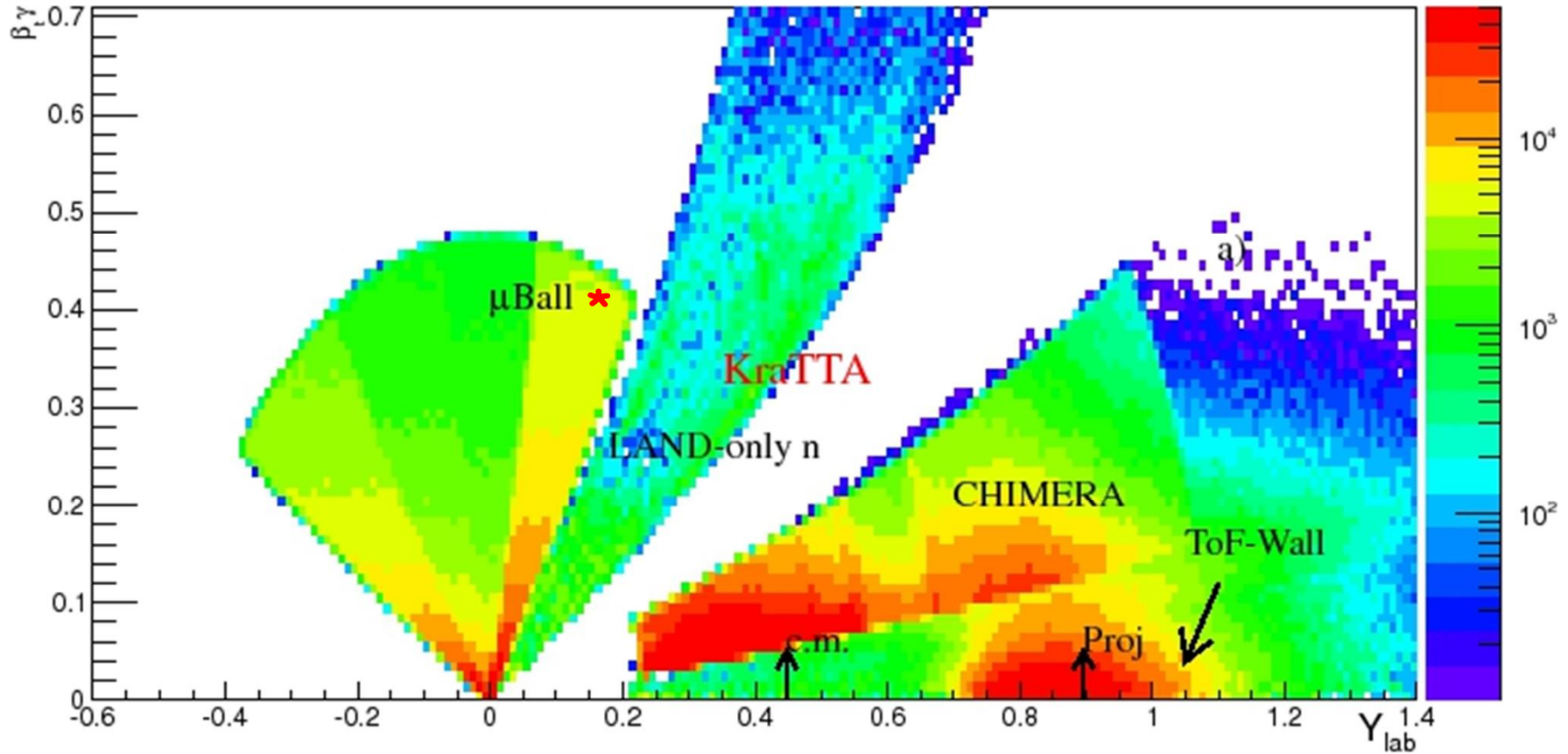
tted)

# Telescopes Array: KRATTA (Poland)

$7^\circ < \theta < 63.5^\circ$   
Aperture: 40 cm.

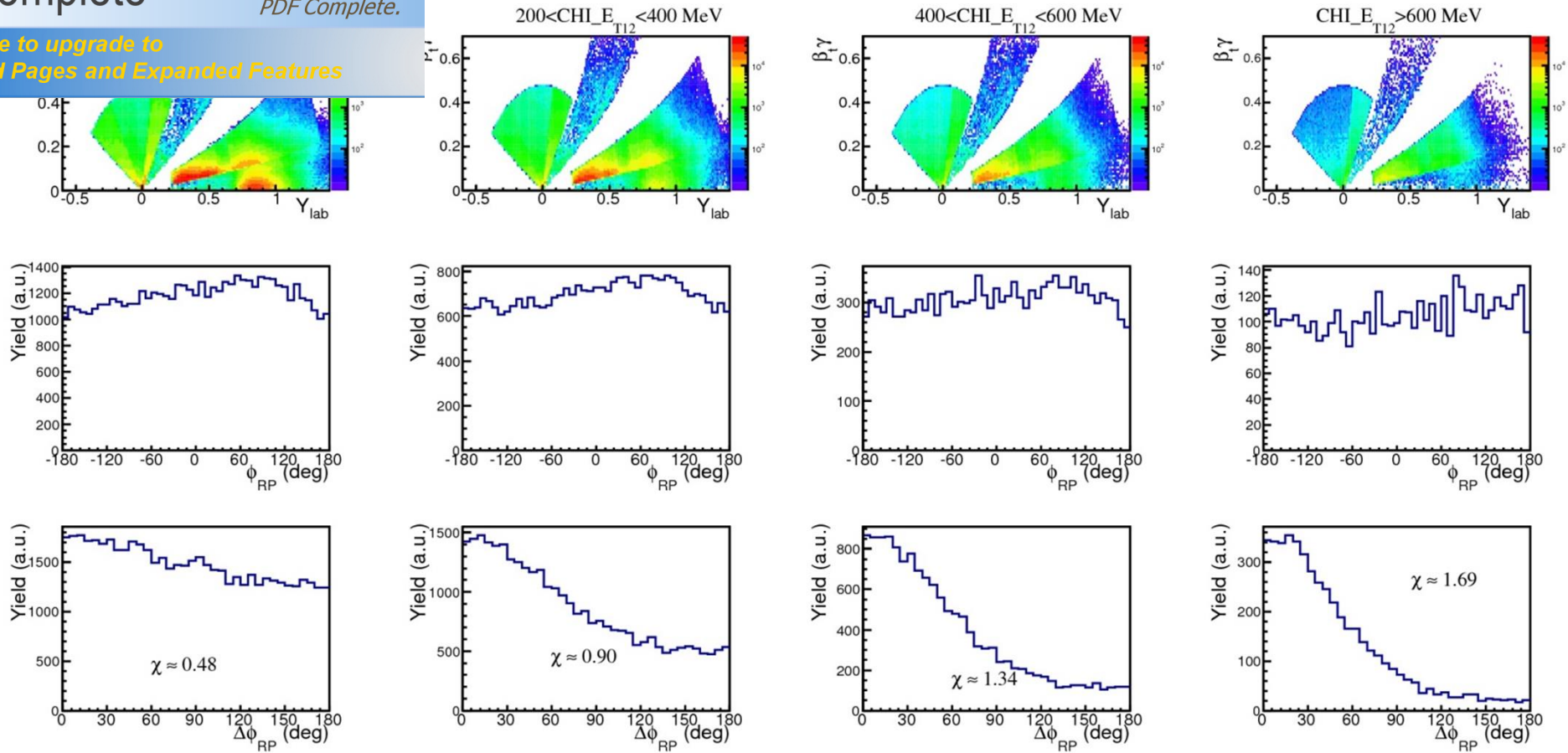
Light particles and IMFs emitted at midrapidity





\* Random uniform distribution  $0 < E_{kin} < 100$  Mev

# and Reaction plane orientation Au+Au @ 400 A MeV



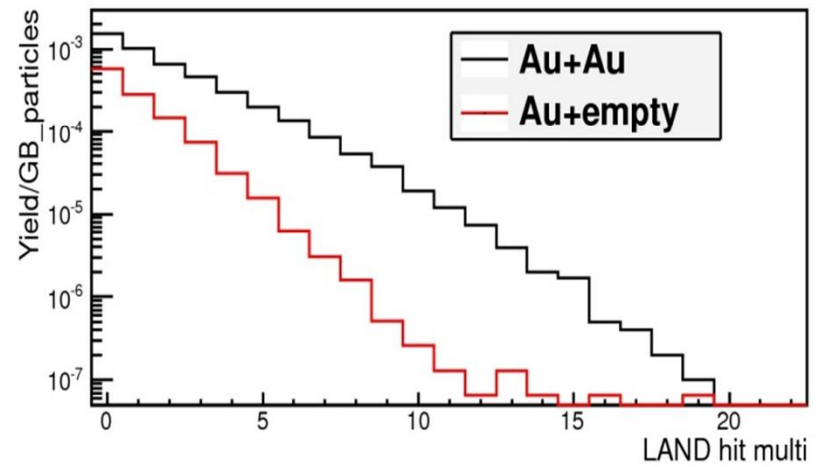
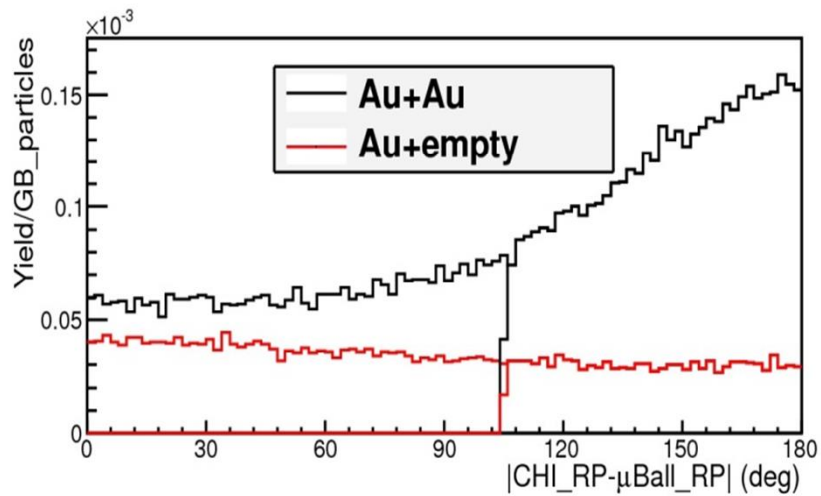
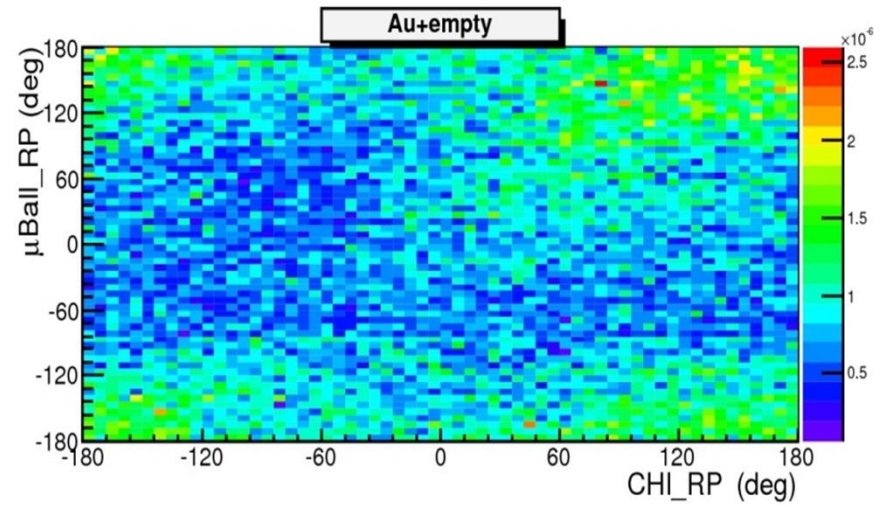
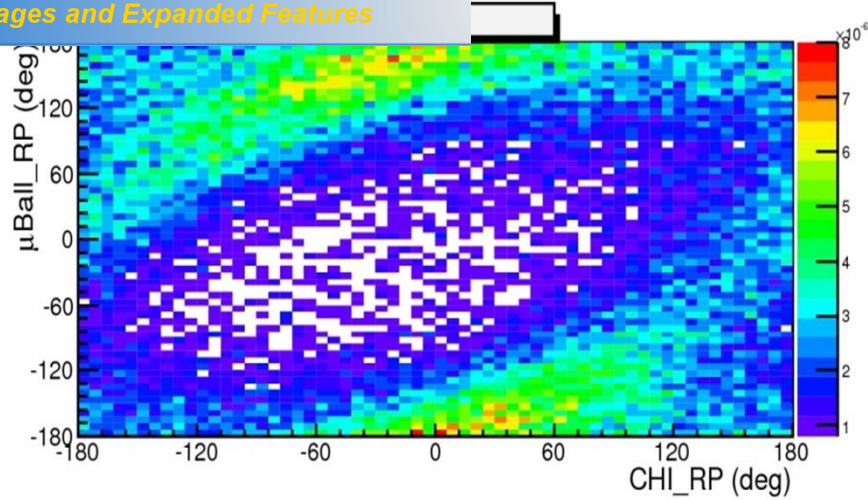
$$\vec{Q} = \sum_{i=1}^M Z \hat{p}_t w \quad w = \begin{cases} 1 & \text{for } Y_{c.m.} > 0.1 \\ 0 & \text{for } Y_{c.m.} < 0.1 \end{cases}$$

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

$E_{trans12}$ (MeV)	$\chi \sim$	$\langle \cos(2 \Delta\Phi) \rangle \sim$	$\Delta\Phi$ (deg) $\sim$
< 200	0.48	0.12	41
200-400	0.90	0.34	35
400-600	1.34	0.52	29
> 600	1.69	0.66	24



# Plane orientation II: CHIMERA-MicroBall correlation

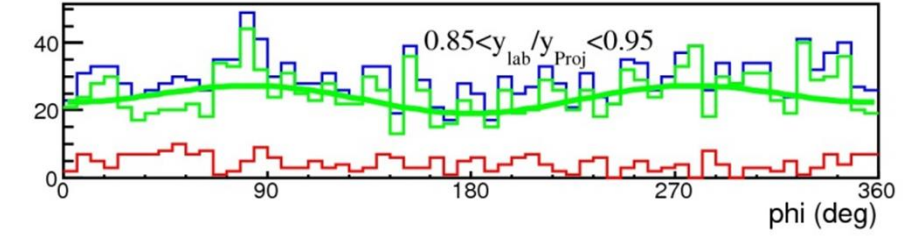
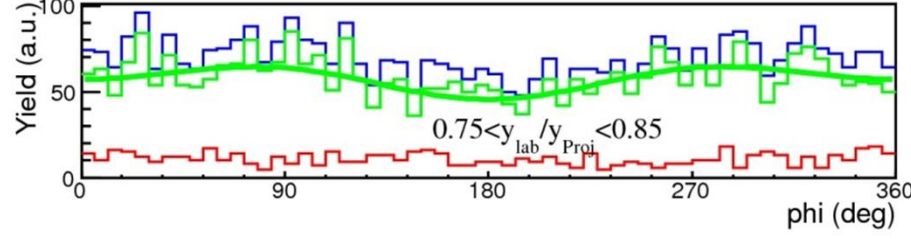
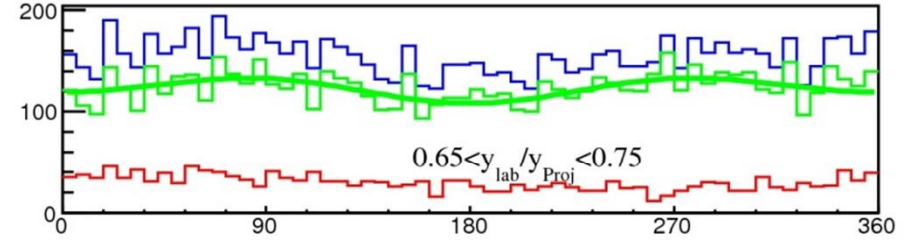
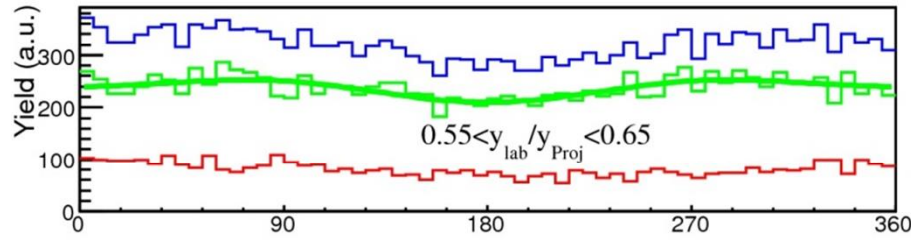
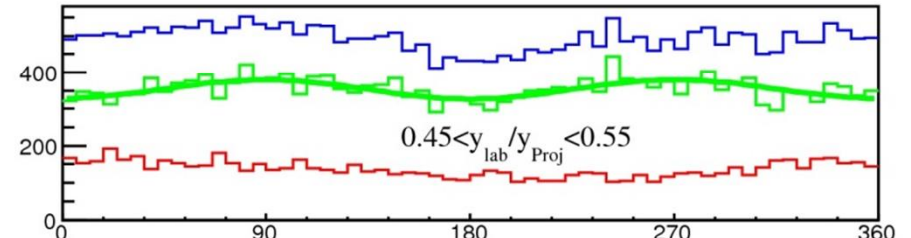
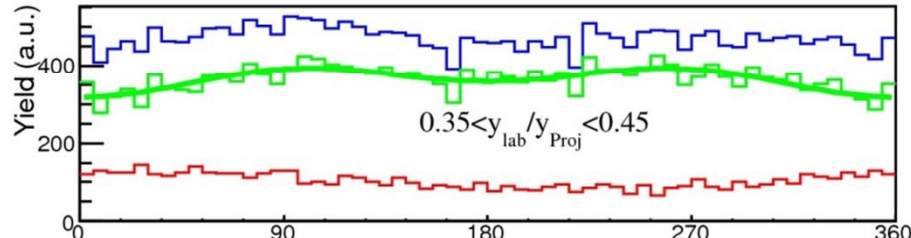
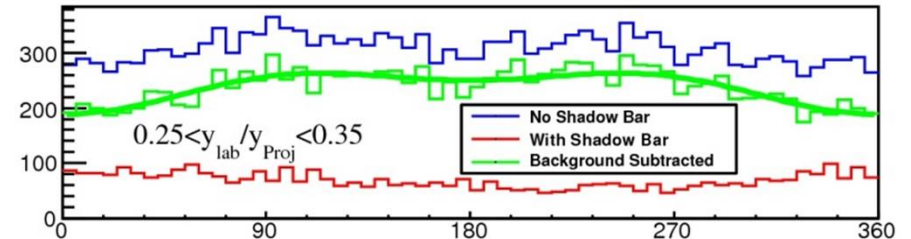
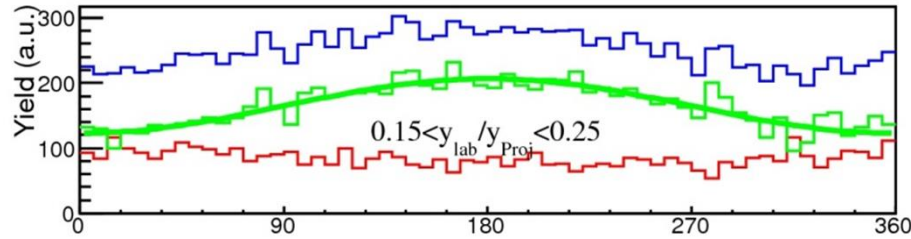


**Requiring: 4 hits in CHIMERA & 2 hits in MicroBall**

# azimuthal distribution from LAND

Au+Au @ 400 AMeV

$b < 7.5$  fm

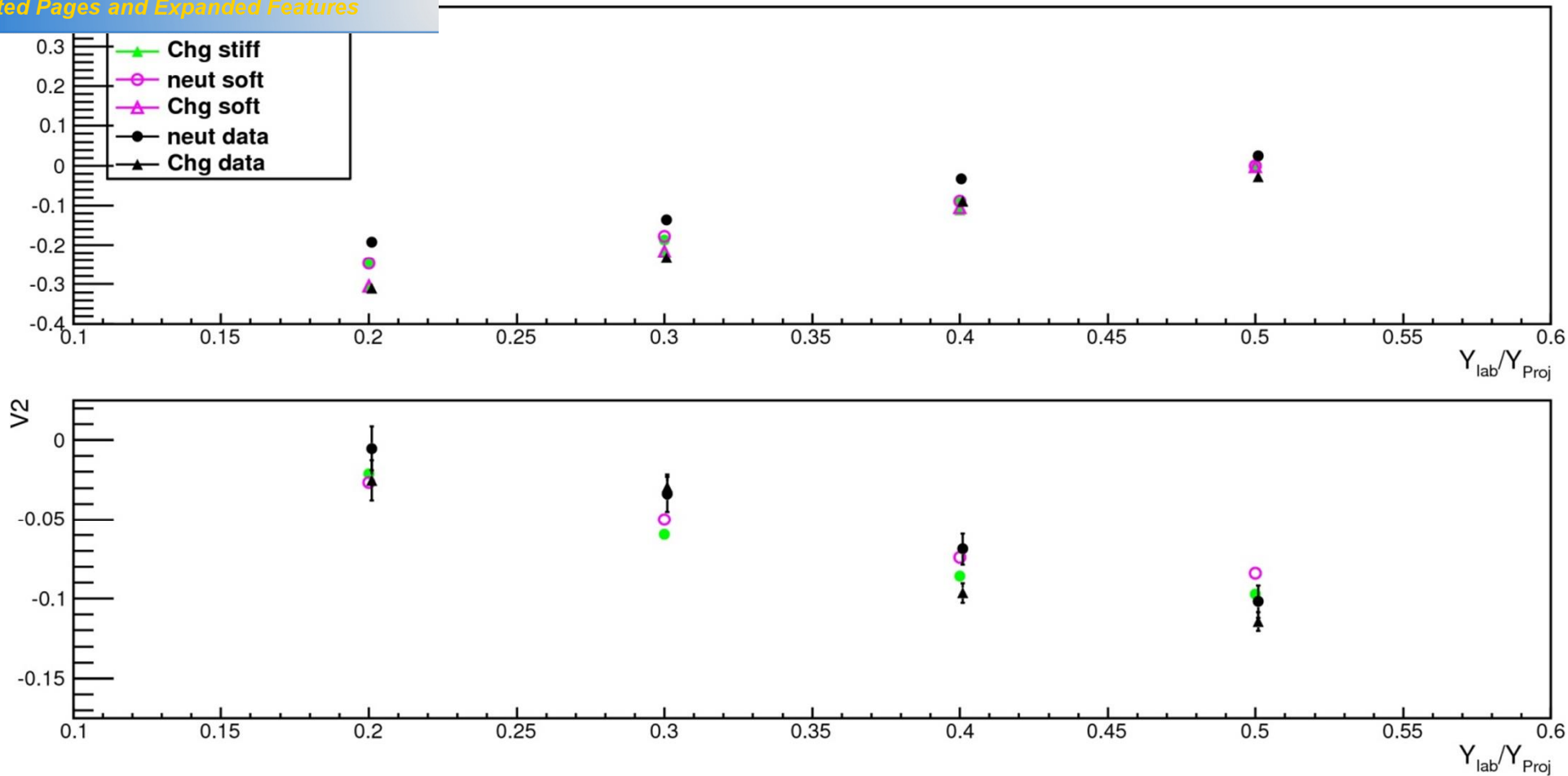


preliminary

# gamma extraction

Au+Au @ 400 AMeV

$b < 7.5$  fm

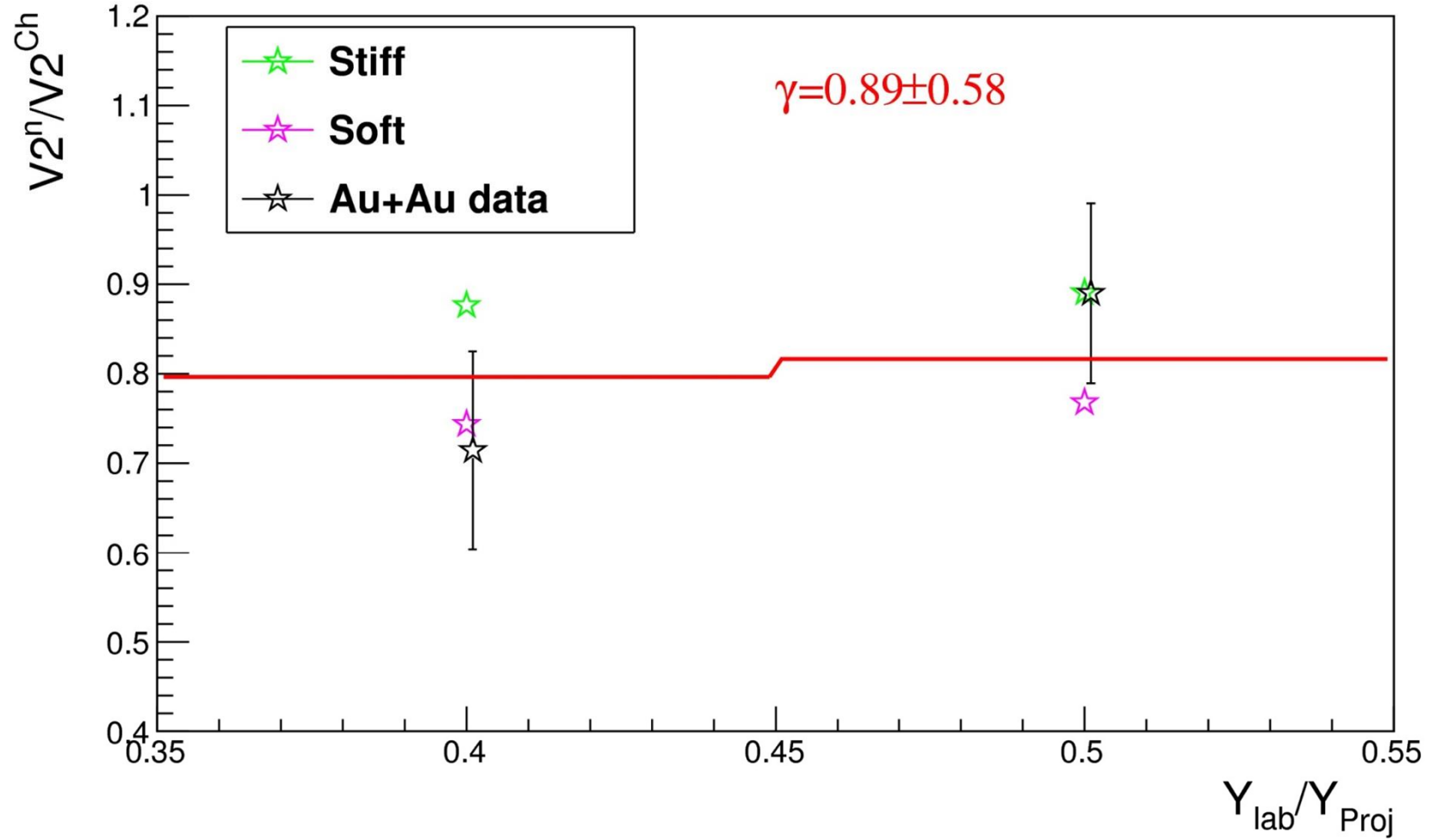


preliminary

# gamma extraction

Au+Au @ 400 AMeV

$b < 7.5$  fm



preliminary

progress...

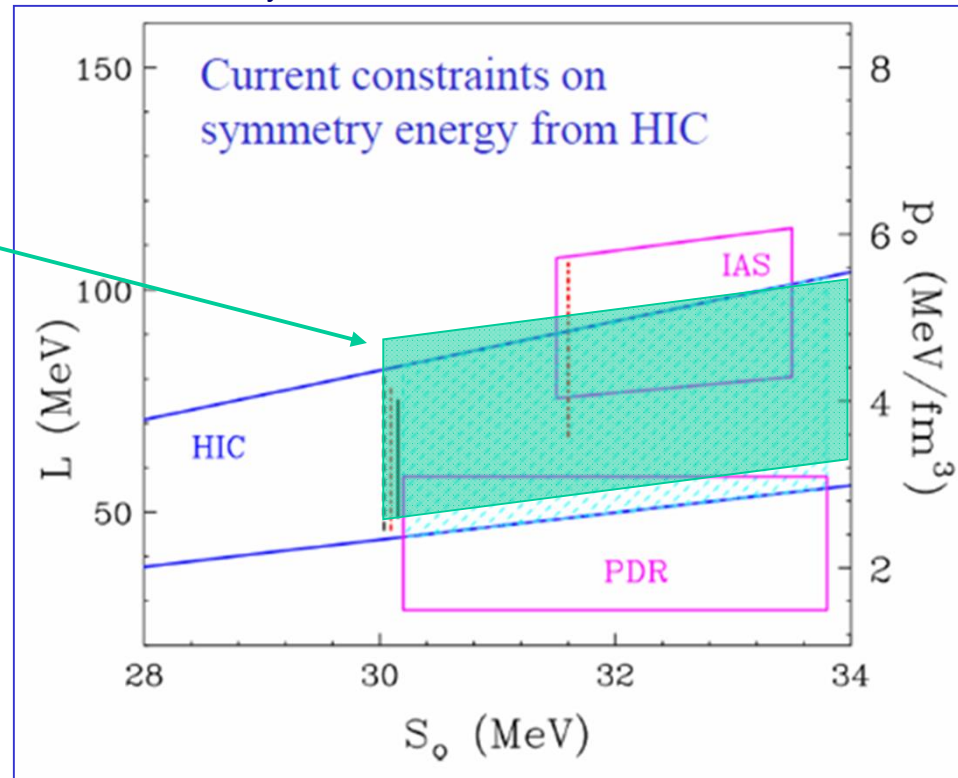
IAS isobaric analog states  
Danielewicz/Lee 2008

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

PDR pygmy dipole resonance  
Klimkiewicz et al. 2007

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

From "old" elliptic n/p flow\*



see also "Complete Electric Dipole Response in <sup>208</sup>Pb" Tamii et al., PRL 107, 062502 (2011)

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

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

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)

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