

4<sup>th</sup> International Symposium on the Nuclear Symmetry Energy

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

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#### Constraints of the Symmetry Energy

B.A. Li NuSym13 summary talk

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

Terrestrial laboratories •Several constraints (quite consistent

average of the means standard deviation

- **S**<sub>0</sub> **L** 31.55415 58.88646 0.915867 16.52645

among them) around and below  $\rho_{0}$ 

•Few constraints above  $\rho_0$ 



High density symmetry energy in relativistic heavy ion collisions



- N/Z of high density regions sensitive to  $E_{sym}(\rho)$
- High p>p<sub>0</sub>: asy-stiff more repulsive on neutrons



NN collisions in high density regions  $\pi$ -/ $\pi$ + reflecting the (N/Z)<sub>dense</sub>  $\pi$ -/ $\pi$ + sensitive to E<sub>sym</sub>( $\rho$ ) at high  $\rho$ 



#### Esym at high density: pions



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

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

•symmetry energy  $\rightarrow$  n/p ratio, number of nn, np, pp collisions

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

•medium  $\rightarrow$  effective masses (N,  $\pi$ ,  $\Delta$ ), cross sections  $\rightarrow$  thresholds

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

 $\rightarrow$  Interpretation of pion data not straight forward

From IWM 2011 - Y. Leifels



#### High densities: flows

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



Au+Au 400 A MeV b< 7.5 fm

#### Results with Tübingen QMD



parameterization of the symmetry energy

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

#### $x = -1.35 \pm 1.25$



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)

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

Results with Tübingen QMD and UrQMD



 $x = -1.0 \pm 1.0$ 

M.D. Cozma et al., Towards a modelindependent 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, <sup>96</sup>Zr+<sup>96</sup>Zr , <sup>96</sup>Ru+<sup>96</sup>Ru @ 400 AMev



<u>uBall</u>: 4 rings 50 CsI(TI), O>60°. Discriminate target vs. reactions with air. Multiplicity and reaction plane measurements.



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



Shadow bar: evaluation of background neutrons in LAND





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



<u>CHIMERA</u>: 8 (2x4) rings, high granularity CsI(TI), 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<sup>3</sup> 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



#### Au+Au @ 400 A.MeV: Centrality selection





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

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

#### Comparison with UrQMD

#### 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)



### Only charged particles!!!

![](_page_14_Picture_6.jpeg)

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

![](_page_15_Figure_1.jpeg)

#### 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)

preliminary

![](_page_16_Figure_4.jpeg)

#### The analysis is in progress...

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

![](_page_17_Figure_2.jpeg)

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 <sup>208</sup>Pb" Tamii et al., PRL 107, 062502 (2011)

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)

![](_page_17_Picture_10.jpeg)

![](_page_18_Figure_0.jpeg)

## Conclusions

## Symmetry Energy:

- Low densities: several constraints quite consistent
- High density:
  - > pion constraints not consistent
  - n/p flows suggests...a route "Towards a modelindependent 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. <sup>132</sup>Sn) and new detectors (Riken TPC, NeuLand@R3B)
- International collaborations and efforts

## On the road.....

![](_page_19_Picture_10.jpeg)

## The Asy-Eos Collaboration

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