ASY-EOS experiment at GSI: constraining the symmetry energy with neutron and proton elliptic flows


and the ASY-EOS collaboration

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Symmetry Energy $E_{sym}(ho_B)$

\[
\frac{E(\rho_B, I)}{A} = E(\rho_B) + E_{sym}(\rho_B) I^2 + O(I^4) + \ldots
\]

\[
I = \frac{N - Z}{N + Z}
\]

Suprasaturation densities
supernovae, nucleosynthesis
(rel. HIC, neutron stars)

From H. Wolter talk at
ASYEOS 2010,
Noto, May 2010
High density symmetry energy in relativistic heavy ion collisions

$\rightarrow$ Au+Au 1AGeV central: phase space evolution in a CM cell

$\rightarrow$ High densities about $2.5 \rho_0$

$\rightarrow$ Non-spherical momentum distribution, non-equilibrium even at highest densities

Observable (qualitative):

Pre-equilibrium emission of $p$, $n$, light clusters

Differential and difference of collective flows

Particle production, $\pi, K$
Constraints on the symmetry energy

Current state at low densities (Fermi energy): various extrapolations, generally consistent with each other, but still uncertainties. More work necessary, also on consistency of codes (see E. De Filippo talk).

Current state at high densities (E/A>100 MeV): Few experimental data on isospin effects, Few extrapolations, inconsistent with each other, Big uncertainties More work necessary on consistency of codes Main example: $\pi^-/\pi^+$ ratio

Ferini, at al., NPA 762 (05) Z. Xiao et al., PRL 102 (09)

Z.Q. Feng, PLB 683 (2010) 459
Pion ratio $\rightarrow$ High densities:
Some increase, some decrease
with increasing stiffness.
Inconsistent with each other!
Understand better mechanism!

Current state at high densities (E/A > 100 MeV):
Few experimental data on isospin effects,
Few extrapolations, inconsistent with each other,
Big uncertainties
More work necessary on consistency of codes
Main example: $\pi^-/\pi^+$ ratio

Constraints on the symmetry energy

Ferini, et al., NPA 762 (05)
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models for symmetry energy (SE)
Transverse and elliptic flow

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

\[ V_1(y, p_t) = \left( \frac{p_x}{p_t} \right) \]

Transverse flow: it provides information on the angular distribution in the reaction plane

\[ V_2(y, p_t) = \left( \frac{p_x^2 - p_y^2}{p_t^2} \right) \]

Elliptic flow: it measures the competition between in-plane \((V_2 > 0)\) and out-of-plane ejection \((V_2 < 0)\)
URQMD simulations (by Qingfeng Li)

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

$$F(u) = \begin{cases} 
F_1 = u^\gamma, & \gamma > 0, \\
F_2 = u \cdot \frac{a-u}{a-1}, & a > 1.
\end{cases}$$

Here, $\gamma$ 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 $F_2$)


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

Coalescence condition:
$\text{DR} < 3 \text{ fm}$ and $\text{DP} < 275 \text{ MeV/c}$

(*) W. Reisdorf et al., NPA 612 493-556 (1997)
UrQMD vs. FOPI data: 
Au+Au @ 400 A MeV 
5.5<b<7.5 fm

squeeze-out more sensitive than the directed flow

inversion of neutron and hydrogen flows


400 AMeV maximum V2
Present constraints on the high density symmetry energy

Au+Au, 400AMeV, FOPI-LAND data (1991)*

π⁺/π⁻ ratio, Feng, et al. (ImQMD)

ρ/ρ₀ S(ρ) (MeV)

Fermi Energy HIC, MSU

result from neut/hydro ratios:
- <γ> = 0.94 ± 0.21
- just below linear

esym = ekin + 22.0*u^{0.95}

HIC isospin diffusion and n/p ratios PRL 102 (2009)
IAS isobaric analog states, Danielewicz and Lee, NPA 818 (2009)
PDR pygmy dipole resonance, Klimkiewicz et al., PRC 76 (2007)

* Y. Leifels PRL 71 (1993) 963
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

FairRoot simulation
(Geant 3-4, Fluka, Montecarlo)

Figure 3: Schematic diagram of experimental setup in Cave C.
Symmetry Energy Project ➔ International collaboration to determine the symmetry energy over a range of density

Require: New Detectors (TPC), travel money, theory support
GSI TEST with $U$ BEAM, September 2009

Quasi-Standard analogical acquisition

$Z=1$

$Z=2$

punching-through

$Z=3$

$\gamma$

$\mathrm{Si}$

$\mathrm{CsI(Tl)}$

$^{73+} U 10^5 \text{ pps} 350 \text{ A.MeV} + \text{Pb}$
GSI TEST with \textit{U} BEAM, September 2009

Digital Pulse Shape acquisition DSPA

U\textsuperscript{73+} 10^5 pps 350 A.MeV + Pb
GSI TEST with $U$ BEAM, September 2009

Digital Pulse Shape acquisition DSPA

$^{9}{\text{Be}}$, $^{7}{\text{Be}}$, $^{7}{\text{Li}}$, $^{6}{\text{Li}}$, $^{3}{\text{He}}$, $^{3}{\text{He}}$ punch-through, $\alpha$, $\alpha$, t, d, p, H punch-through, Fast $p$, $e$, $\gamma$

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

Several heavy Ion reactions observables have been useful in order to get information on symmetry energy at sub-saturation densities (giant and pigmy dipole resonances, isobaric analogue states and masses, isospin diffusion, n/p ratios, $^3$H/$^3$He ratio...). 

Viceversa, more extended data sets and consistency checks $(\pi^-/\pi^+)$ are needed in order to arrive at firm conclusions at supra-saturation densities. Neutron-proton elliptic flow is a promising observable.

In the ASY-EOS experiment at GSI we will try to measure such (and other) crucial observables......

......“a good constraint” of symmetry energy at supra-saturation density?