Isotopic Flows in Au+Au at 400 A MeV

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I. Collective flow and the symmetry energy at supra-saturation density

II. First results from the FOPI (Phase I)-LAND experiment

\[ \gamma = 1.5 \]

\[ \gamma = 0.5 \]
I. why collective flows

elliptic flow

$\Psi$ (azimuthal event) distributions in the plane of directed flow

J. Łukasik et al., PLB 608 (2005)
motivation 1: probes of high-density stage?

probe the early reaction phase with suitable observables like differential neutron-proton flow

\[ \delta = \left( \rho_n - \rho_p \right) / \rho = 0.22 \]

Bao-An Li, PRL 88, 192701 (2002)
motivation 2: can LAND be used to measure differential neutron-proton flows?

neutron and proton detection with the same device and method
motivation 2: can LAND be used to measure differential neutron-proton flows?

neutron and proton detection with the same device and method
motivation 3: high quality of excitation functions of flow

elliptic flow $v_2$

$197\text{Au} + 197\text{Au}$, data from INDRA, FOPI, AGS experiments from A. Andronic et al., EPJA 30 (2006)

$v_1 \equiv \langle \cos(\phi - \phi_R) \rangle$ directed flow

$v_2 \equiv \langle \cos 2(\phi - \phi_R) \rangle$ elliptic flow

$Z=1$ 5.5 – 7.5 fm

in-plane

out-of-plane

$\ell_{im}\mid_{\text{mid}}$

$E_{\text{beam}} \text{ (MeV/nucleon)}$

$\bullet$ INDRA
$\bigcirc$ FOPI
$\blacktriangle$ EOS, E895
$\square$ E877

$10/16/2009$ W. Trautmann, GSI Helmholtzzentrum, HiDeSymE, Zagreb
motivation 4: high density over a long time

\[ \rho \Delta t \text{ maximum here} \]

in the central region of \(^{132}\text{Sn} + ^{124}\text{Sn} \) central collisions

according to the isospin dependent transport model of Bao-An Li, NPA 708(2002)
motivation 5: UrQMD predictions for elliptic flow

Q.F. Li and P. Russotto

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

inversion of neutron and hydrogen flows

survives acceptance cuts of FOPI/LAND experiment
UrQMD: negligible sensitivity to directed flow
UrQMD: negligible sensitivity to directed flow

\[ v_1 \text{ vs. } \frac{y}{y_p} \text{ for PM3} \]

- UrQMD
- stiff neuts
- soft

[Graph showing the relationship between v1 and y/y_p]
II. First results from FOPI/LAND experiment

Au+Au 400 A MeV

SB: shadow bar for background measurement

azimuthal angular distributions for neutrons, background subtracted

\( y/y_p = 0.2 : \)
- near target rapidity
- mostly directed flow

\( y/y_p = 0.5: \)
- mid-rapidity
- strong squeeze-out

\( y/y_p = 0.8: \)
- near projectile rapidity
- mostly directed flow

fitted with:
\[ f(\Delta \phi) = a_0 \times (1.0 + 2v_1 \cos(\Delta \phi) + 2v_2 \cos(2\Delta \phi)) \]
\( \Delta \phi = \phi_{\text{particle}} - \phi_{\text{reaction plane}} \)
negligible sensitivity to directed flow
negligible sensitivity to directed flow
$p_t$ dependence of $v_2$
UrQMD: sensitivity of $v_2$
UrQMD: sensitivity of $v_2$

![Graph showing the sensitivity of $v_2$]
$p_t$ dependence of $v_2$

Data:
- \((PM3-PM5, 0.25<y/y_p<0.75)\)
- $|v_2|$ increases as expected
- reproduced by UrQMD (b<7.5 fm)
- but 15% correction missing

let's look at ratios only:
- large errors at large $p_t$
- UrQMD: decreasing sensitivity at $p_t>0.8$

result from neut/hydro ratios:
- $\langle \gamma \rangle = 0.94 \pm 0.21$
- potential part just below linear
\( e_{\text{sym}} = e_{\text{kin}} + 22.0 \cdot u^{0.95} \)

\( e_{\text{sym}} = e_{\text{kin}} + 18.0 \cdot u^{1.02} \)

\( e_{\text{kin}} = 12.0 \cdot u^{2/3} \)

\( u = \rho / \rho_0 \)
analysis of isospin diffusion and n/p ratios in $^{112,124}$Sn cross bombardments at 50 A MeV
M.B. Tsang et al.,
PRL 102, 122701 (2009)

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)
analysis of isospin diffusion and n/p ratios in $^{112,124}$Sn cross bombardments at 50 A MeV
M.B. Tsang et al.,
PRL 102, 122701 (2009)

flow ratios + UrQMD:
$\langle \gamma \rangle = 0.94 \pm 0.21$
$S_0/L = 34/87 \pm 13$ MeV or $30/79 \pm 10$ MeV
analysis of $\pi^-/\pi^+$ ratios in Au+Au
Zhigang Xiao et al.,
PRL 102, 062502 (2009)
FOPI data, W. Reisdorf et al.
NPA 781 (2007)

$\pi$ ratios + IBUU04: $x=1$ super soft

flow ratios + UrQMD:
$\langle \gamma \rangle = 0.94 \pm 0.21$

nearly linear
Review

Differential neutron–proton squeeze-out

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$\gamma = 0.6 \pm 0.3$

(from PM3 only)
test of systematic uncertainties

<table>
<thead>
<tr>
<th>Physical Parameters</th>
<th>Delta Gamma</th>
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<tr>
<td>impact parameter</td>
<td>$\Delta \gamma = 0.43 \pm 0.32$ (PM3 vs. PM3-5)</td>
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<tr>
<td>transverse momentum</td>
<td>$\Delta \gamma &lt; 0.1$ ($p_t&lt;0.8$ vs. $p_t&lt;1.2$ GeV/c)</td>
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<tr>
<td>rapidity</td>
<td>$\Delta \gamma &lt; 0.15$ (for PM3-5)</td>
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<td>statistics not really sufficient to evaluate errors more precisely</td>
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<tr>
<th>Data Analysis</th>
<th>Delta Gamma</th>
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<tr>
<td>various sorting gates</td>
<td>$\Delta \gamma &lt; 0.1$</td>
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<tr>
<td>include protons separately</td>
<td>$\Delta \gamma$ negligible (protons not sensitive)</td>
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<tr>
<td>background subtraction</td>
<td>$\Delta \gamma = 0.21$ (100% vs. 60% of measured background)</td>
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<th>UrQMD:</th>
<th>Delta Gamma</th>
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<tr>
<td>Pauli blocking (y/n)</td>
<td>$\Delta \gamma = 0.08$ (for PM3-5)</td>
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<tr>
<td>constant $S_0$ ($=a_4$)</td>
<td>$\Delta \gamma = 0.07$ ($S_0=22$ vs. $S_0=18$ MeV)</td>
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test of centratlity

neutrons

$v_2$ in PM5 is not as small as expected, possibly due to lacking experimental impact-parameter resolution
test of cluster algorithm

Q.F. Li and P. Russotto

Z distribution (in arbitrary units) of charged particles in Au+Au at 400 AMeV central collisions (arbitrarily normalized at Z=1)
summary

conclusions:
present elliptic flow result compatible with sub-saturation MSU result
not compatible with result from analysis of pion ratios
impact-parameter dependence barely consistent within errors

crucial for future experiment:
higher statistics
measure fragment data for consistency and check of cluster algorithm
support background measurement with simulations
more precise efficiency of LAND?

UrQMD:
impact parameter dependence
pion ratios

ultimate goal:
theory invariant conclusions
LAND
ALADIN ToF
VETO
Beam
Target
Krakow phoswich
Chimera CsI
ALADIN ToF wall
SIS experiment S394 proposal accepted 2009
calorimeter
impact parameter orientation and modulus
charged particle
Neutron