The asymmetry energy term of the nuclear EOS - *What can FOPI contribute? - Data!*

Yvonne Leifels
GSI

The FOPI detector

Program:

Dynamics of Heavy Ion Collisions

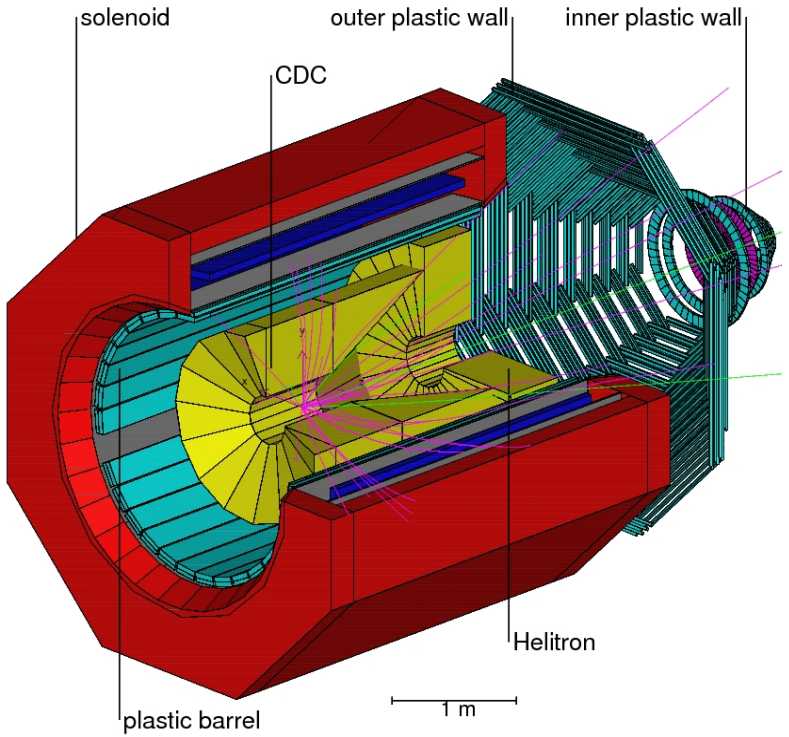
Stopping, collective flow, cluster production

Strangeness in

HI collision (Al+Al, Ni+Ni, Ru+Ru, Ni+Pb)

Pion induced reactions

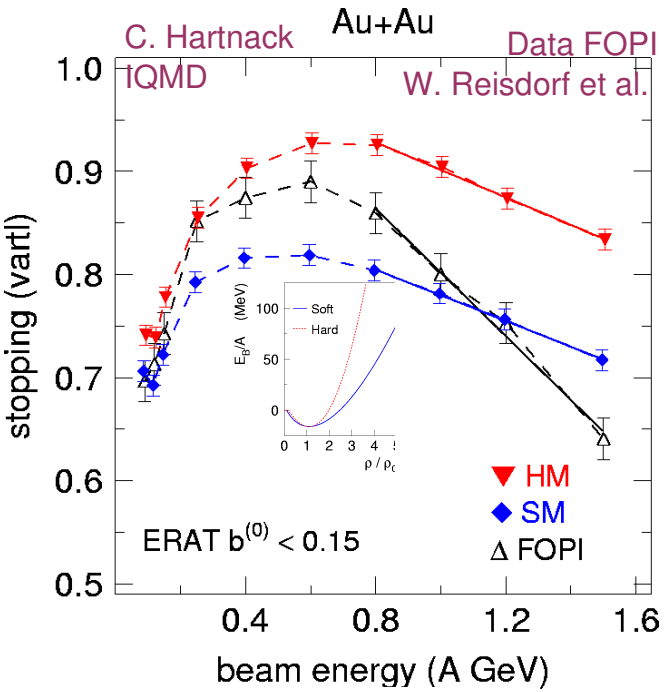
Proton-proton collisions

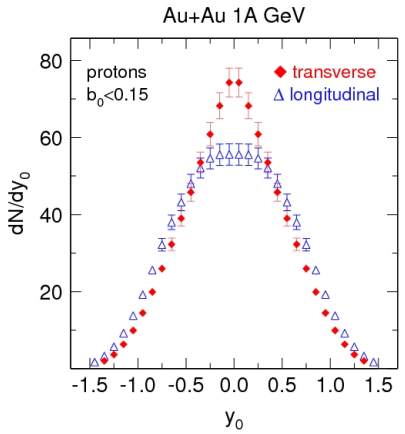


FOPI-Collaboration

A. Andronic, R. Averbeck, Z. Basrak, N. Bastid, M.L. Benabderramahne, P. Bühler, R. Caplar, M. Cargnelli, M. Ciobanu, P. Crochet, I. Deppner, P. Dupieux, M. Dzelalija, L. Fabbietti, F. Fu, P. Gasik, O. Hartmann, N. Herrmann, K.D. Hildenbrand, B. Hong, T.I. Kang, J. Keskemeti, Y.J. Kim, M. Kis, M. Kirejczyk, P. Koczon, M. Korolija, R. Kotte, A. Lebedev, K.S. Lee, Y. Leifels, X. Lopez, J. Marton, M. Merschmeyer, D. Moisa, M. Petrovici, K. Piasecki, F. Rami, V. Ramillien, A. Reischl, W. Reisdorf, M.S. Ryu, A. Schüttauf, Z. Seres, B. Sikora, K.S. Sim, V. Simion, K. Siwek-Wilczynska, K. Suzuki, Z. Tyminski, K. Wisniewski, Z. Xiao, H.S. Xu, J.T. Yang, I. Yushmanov, A. Zhilin, Y. Zhang, J. Zmeskal and J. Aichelin, C. Hartnack, H. Oeschler

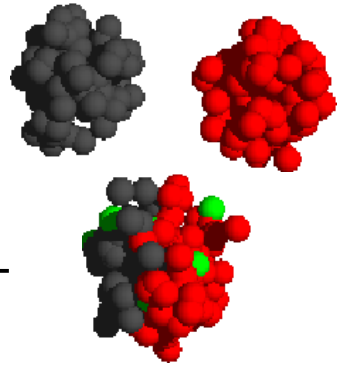
Global characteristics of heavy ion reactions 0.1-2.0 AGeV - Stopping





Investigation of stopping in isospin asymmetric system Zr/Ru

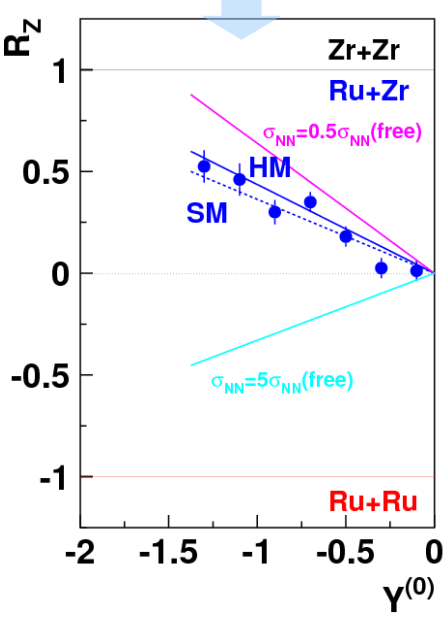
$$R_Z = \frac{2\,M_{Z=1} - (M_{Z=1}^{ZrZr} + M_{Z=1}^{RuRu})}{M_{Z=1}^{ZrZr} - M_{Z=1}^{RuRu}}$$



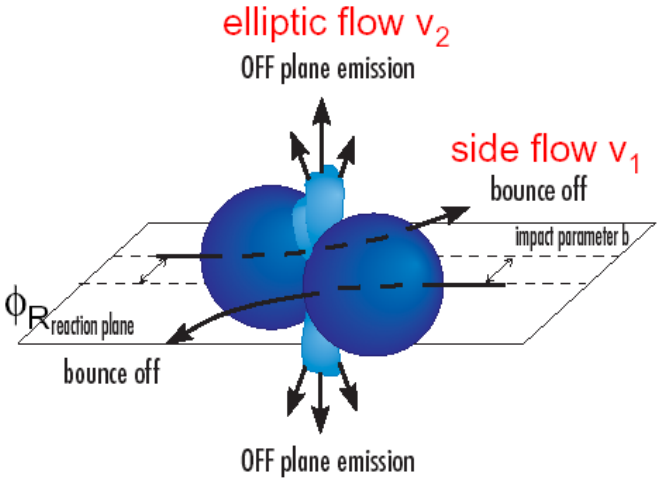
Stopping is an essential observable in relativistic HI collisions

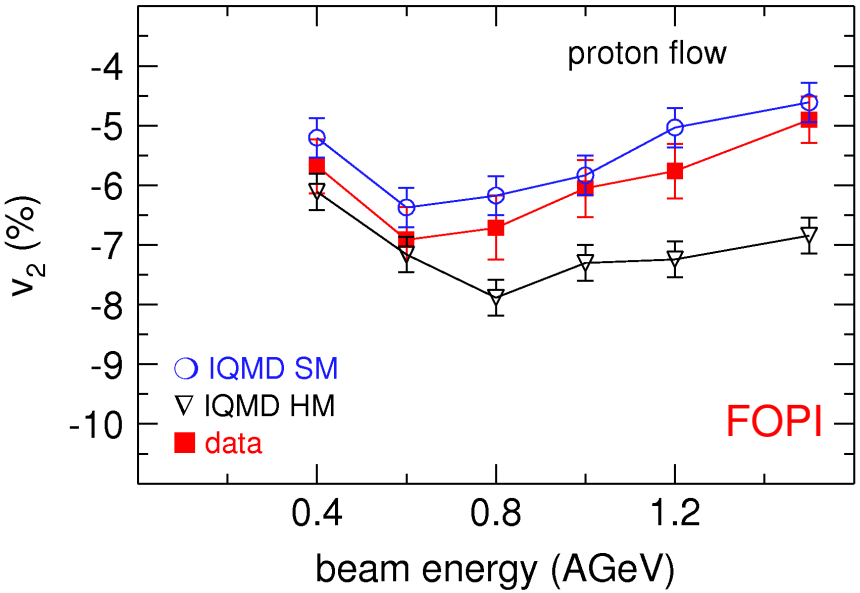
Stopping is sensitive to the equation of state

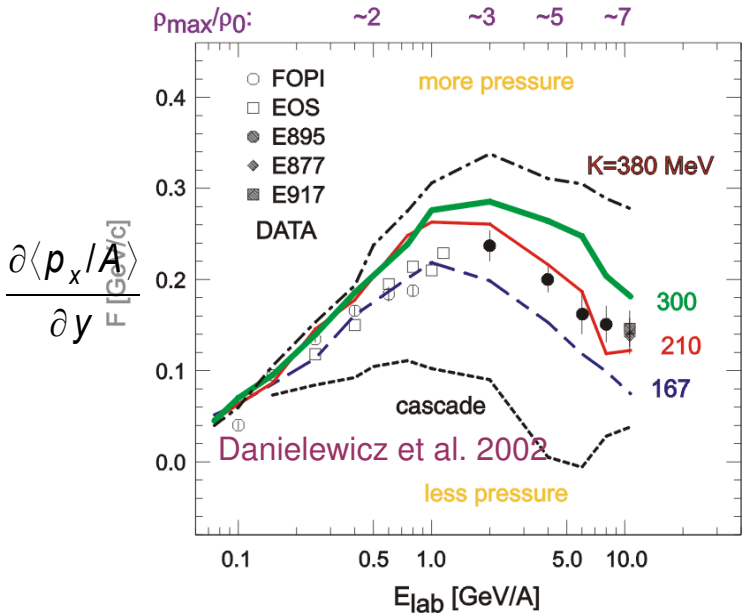
Other stopping observables constrain in-medium σ_{NN}



Collective flow





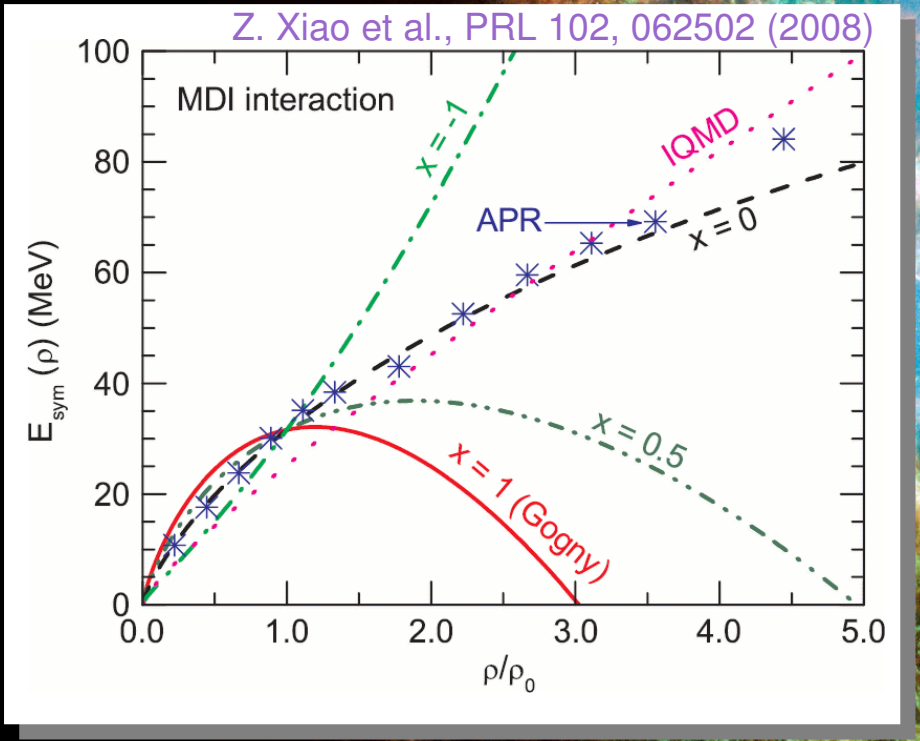


Collective flow sensitive to
EOS
but also
to in-medium cross sections

Probing the EOS of asymmetric nuclear matter at supra-normal densities with heavy ion reactions

$$E/A(\rho,\delta) = E/A(\rho,0) + \delta^2 \cdot S(\rho)\ ;$$

$$\delta = (\rho_n - \rho_p)/(\rho_n + \rho_p) = (N-Z)/A$$

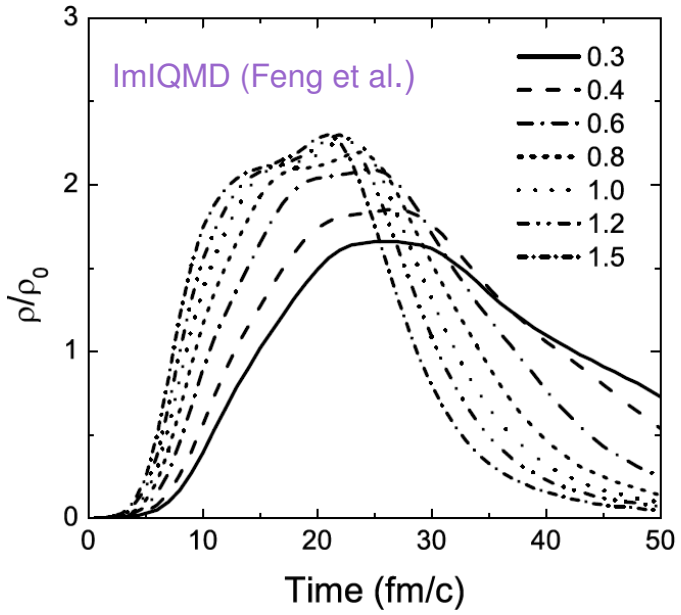


- Heavy ion reactions vs astrophysical objects
  - density regime
  - thermal pressure
  - non-equilibrium
  - importance of asyEOS
- HIC: Difference method
  - vary N/Z at constant mass
  - vary mass at constant charge
  - stay within medium, look at isospin pairs
- FOPI's access to high densities ($\rho \approx 2\rho_0$) :
  - Neutron/proton spectra and flows, t/^{3}He
  - π^+ vs. π^- production, Kaon-, hyperon production.

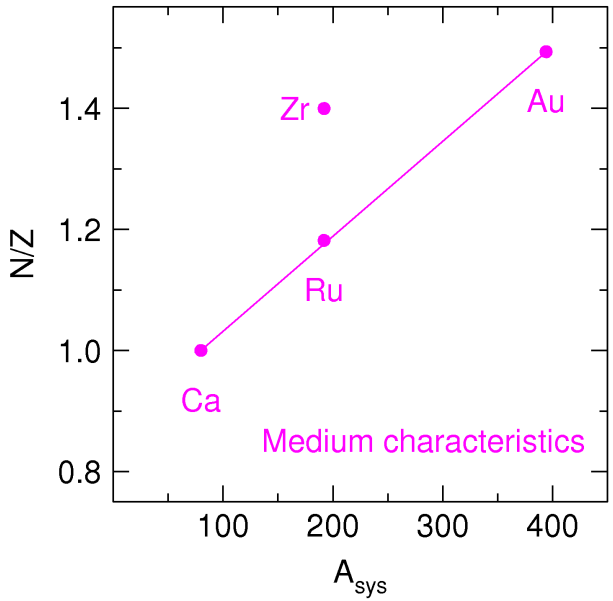
FORS Team, VLT, ESA

FOPI map

Au+Au, central collisions
Maximum density



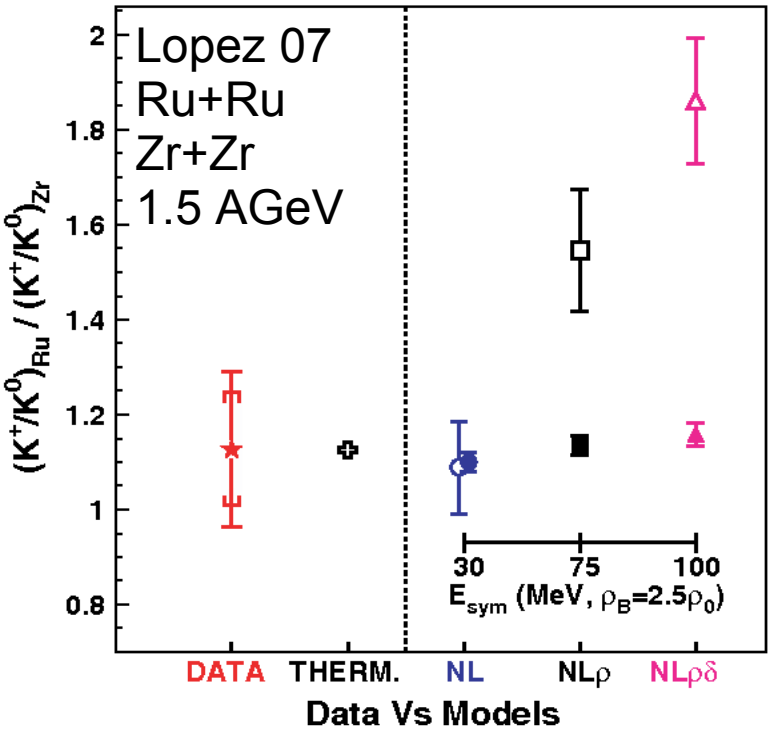
N/Z vs mass



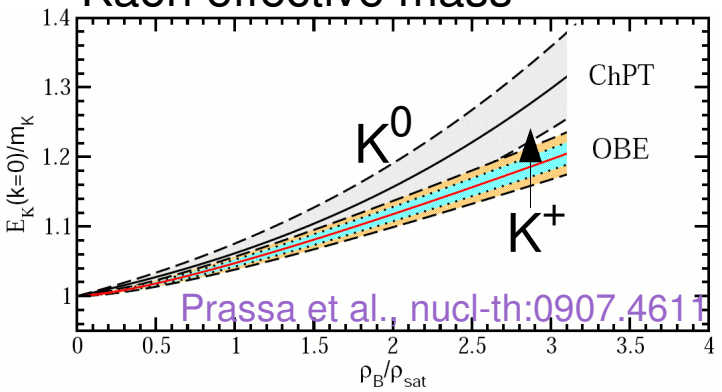
asyEOS from Kaons

- N/Z varied
- Less sensitivity
- No memory effect from

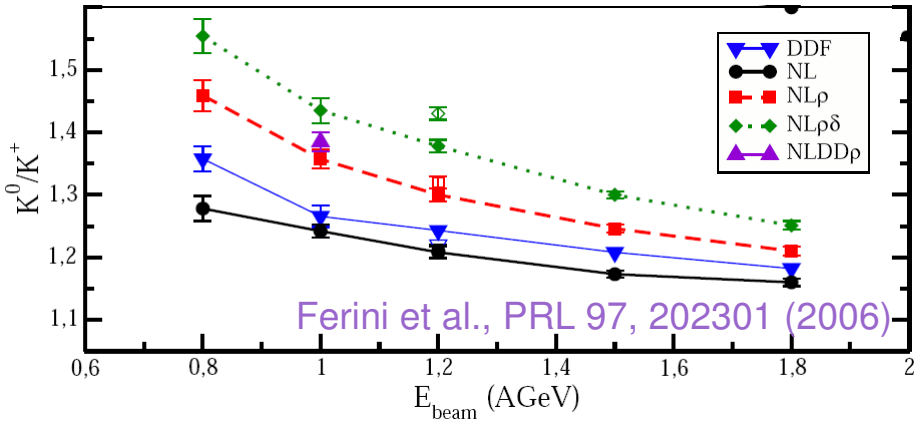
  ρ_{max} at $\rho_{freeze\text{-}out}$



Kaon effective mass



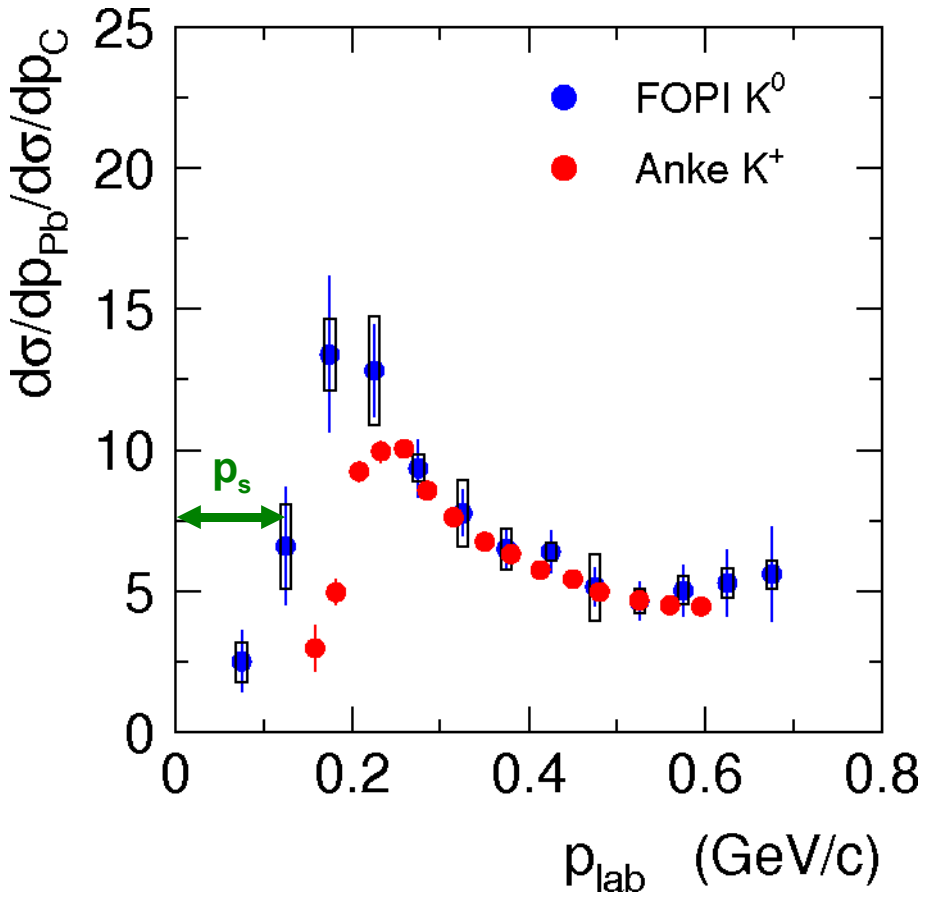
Au+Au, b < 1 fm



- higher sensitivity at lower energies
- requires excellent kaon identification and long beam times

K0/K+ production in p/π induced reactions

Ratio of momentum distributions:



FOPI data @ SIS

M.L. Benabderramahne et al., *PRL* (2009)

$\pi + A \rightarrow K^0 + X$ at 1.15 GeV/c

Anke data @ COSY

M. Büscher et al., *EPJ*, A22, 301 (2004)

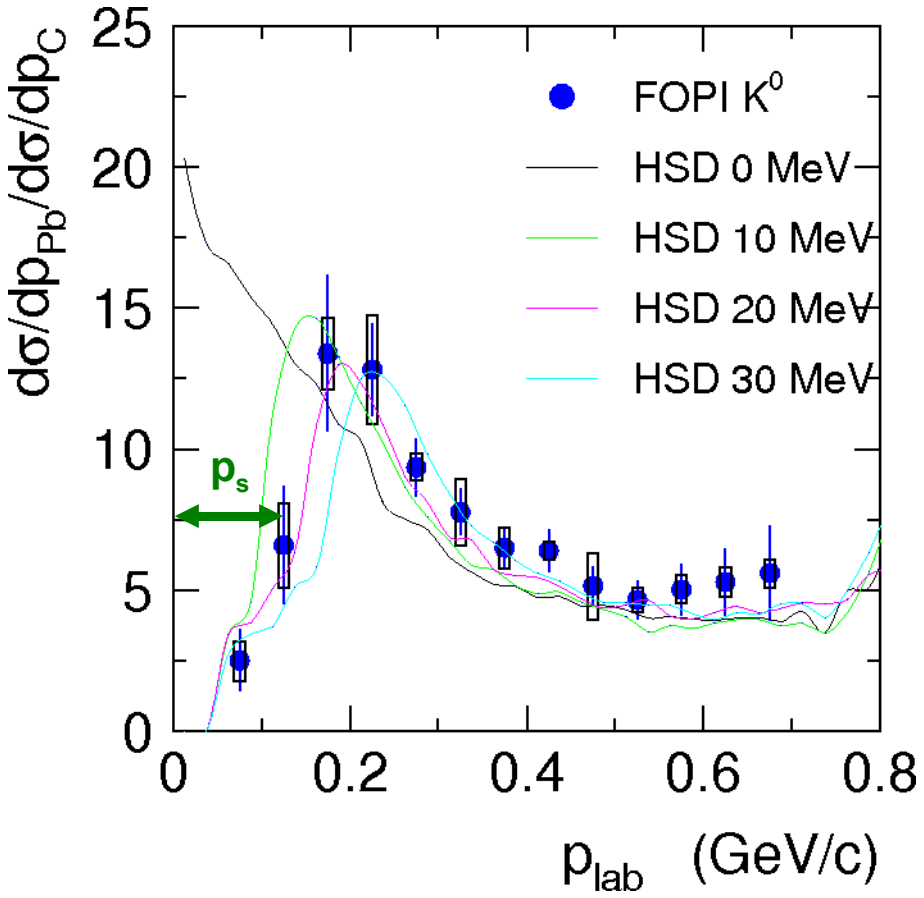
$p + A \rightarrow K^+ + X$ at 2.5 GeV

Model independent interpretation:

$$U_K = \frac{p_s^2}{2m_K} = \frac{(140\,\mathrm{MeV})^2}{2 \cdot 498\,\mathrm{MeV}} = 20\,\mathrm{MeV}$$

K0/K+ production in p/π induced reactions

Ratio of momentum distributions:



FOPI data @ SIS

M.L. Benabderramahne et al., *PRL* (2009)

$\pi^- + A \rightarrow K^0 + X$ at 1.15 GeV/c

Model interpretation with HSD:

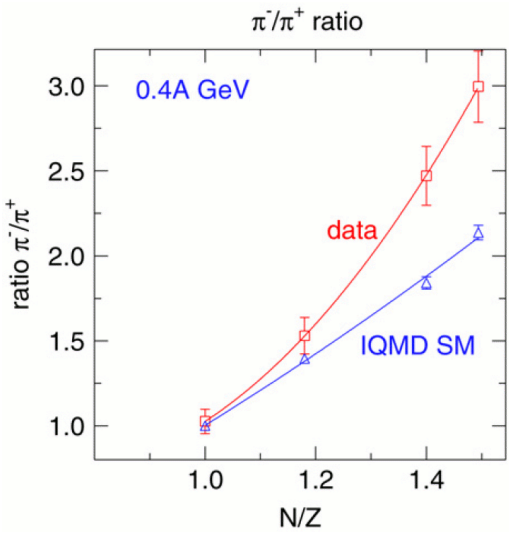
$U(K^0) = +20$ MeV

Model independent interpretation:

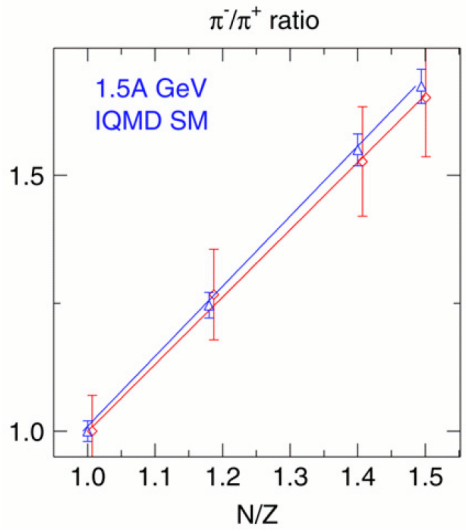
$$U_K = \frac{p_s^2}{2m_K} = \frac{(140\,\mathrm{MeV})^2}{2 \cdot 498\,\mathrm{MeV}} = 20\,\mathrm{MeV}$$

Potential depth: $U(K^0) = +20$ (+/- 5) MeV consistent with heavy-ion data on K^+,
Accuracy (only) statistics limited,
Method applicable to determine isospin dependence of KN – potential (e.g. π^- + ^{x}Sn).

Pion production in heavy ion collisions 0.4-2 AGeV



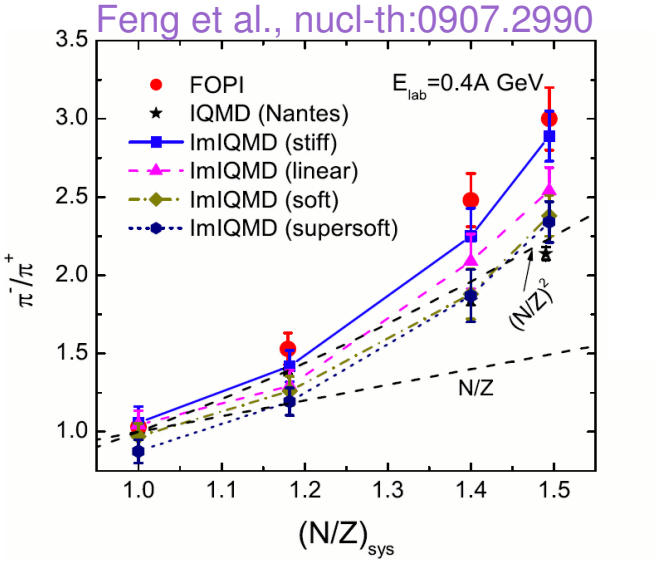
low(er) E/A: perturbative
~ $(N/Z)^2$
as predicted by isobar model

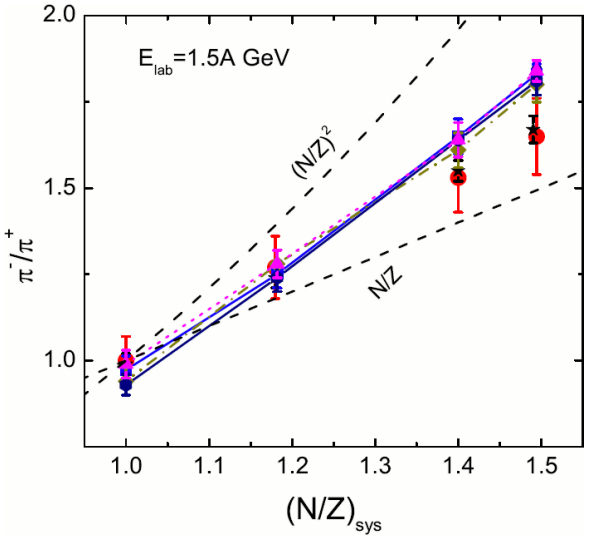


high(er) E/A: back-flow
~ (N/Z)
has to measure π^-/π^+ and n/p

$(N/Z)_{final} < (N/Z)_{init}$

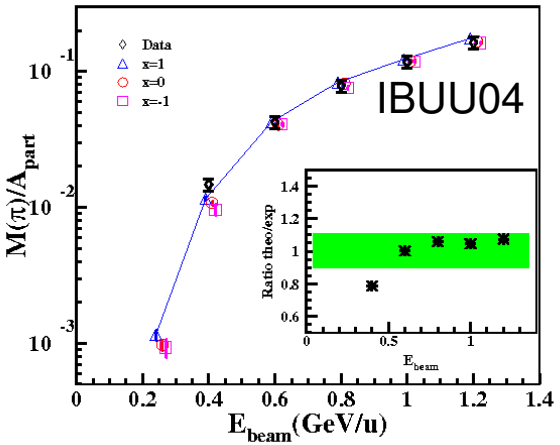
Feng et al., nucl-th:0907.2990





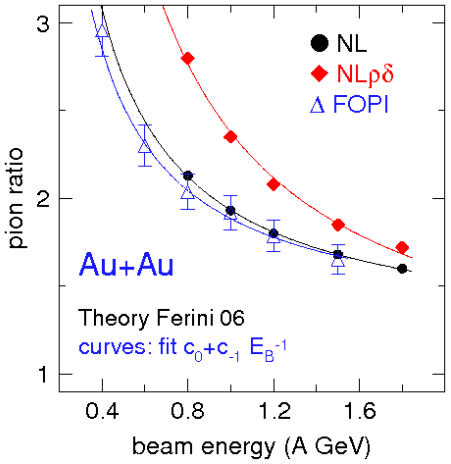
Pion production and the symmetry energy

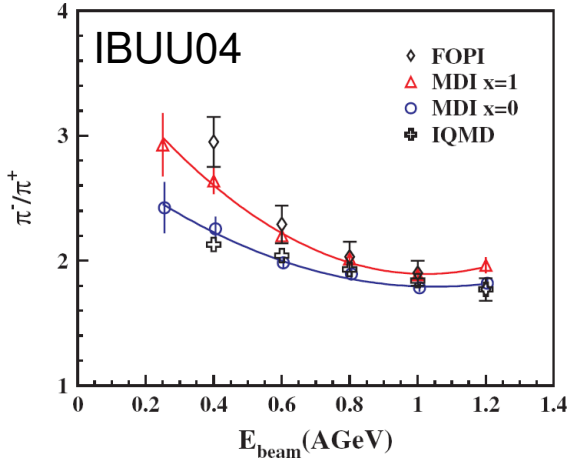
Z. Xiao et al.
PRL 102 (2009) 62502

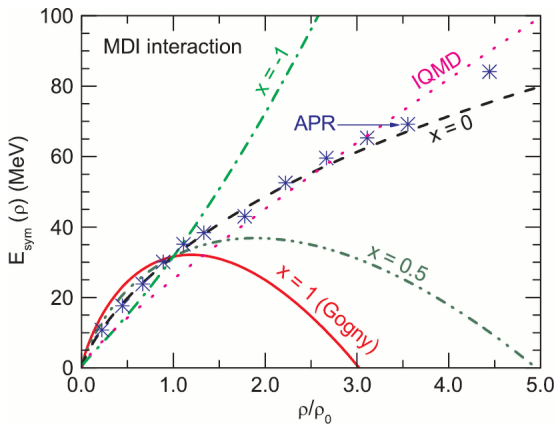


π-/π+ ratio
Au+Au central

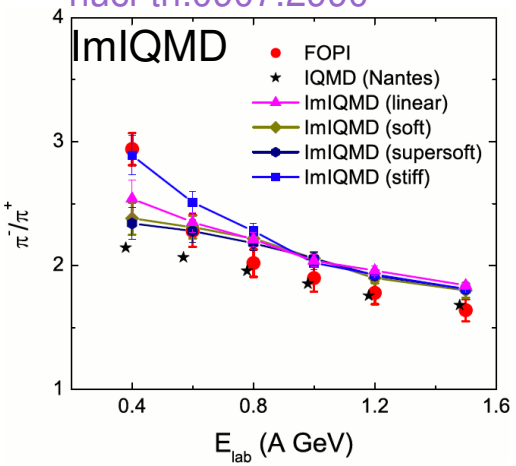
- Sensitivity?
- No sensitivity of total pion multiplicity!
- Described reasonably!





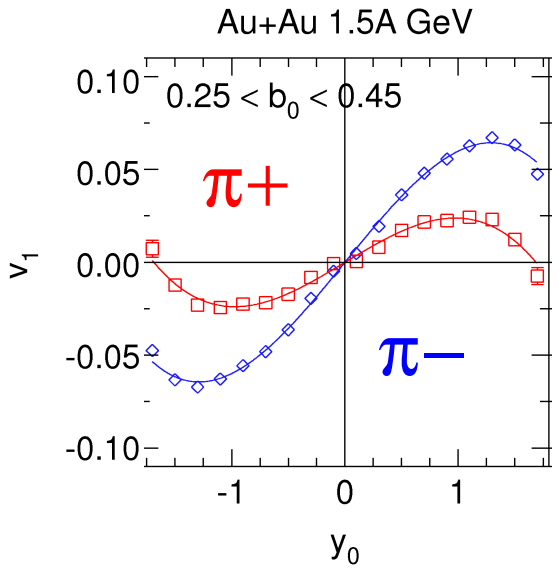


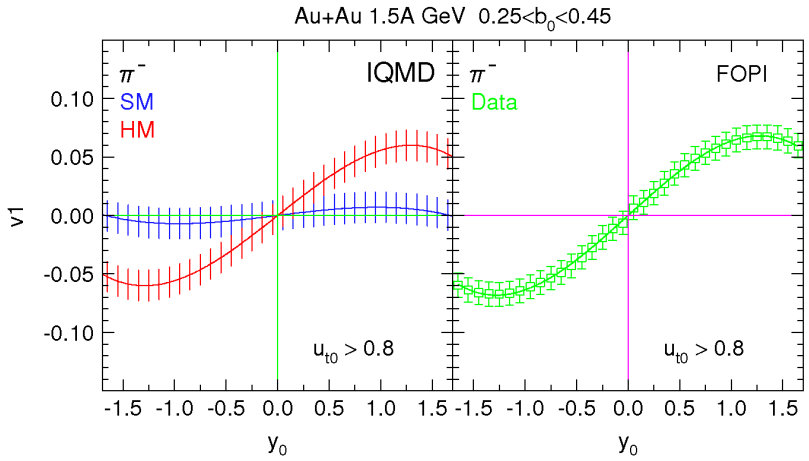
Feng et al.,
nucl-th:0907.2990



Pion flow

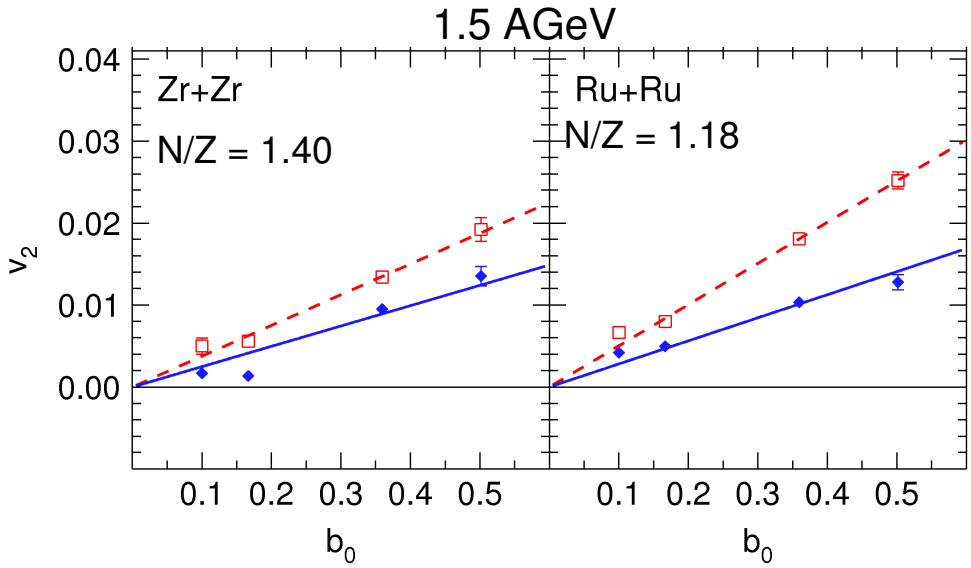
v1





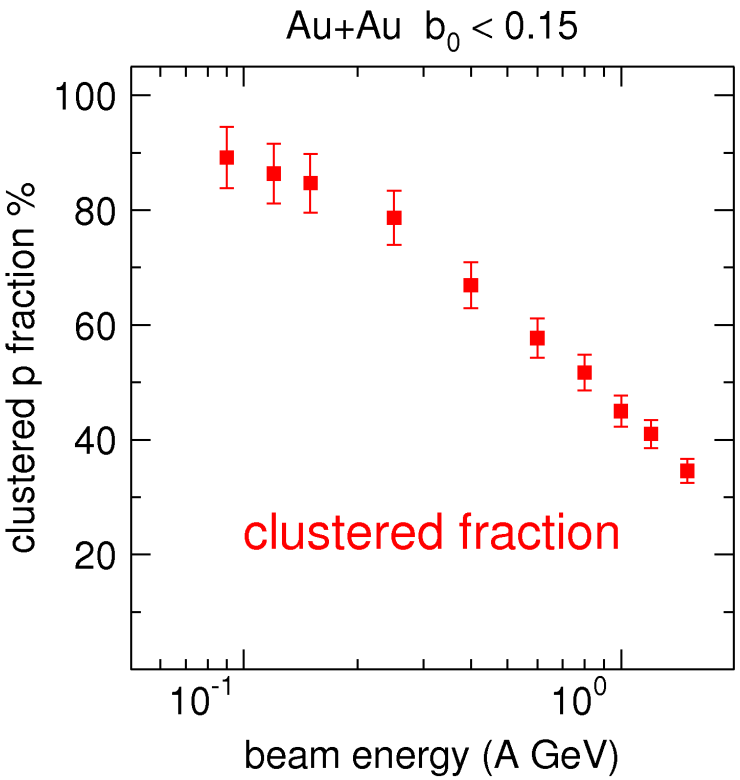
Hard EOS?

v2

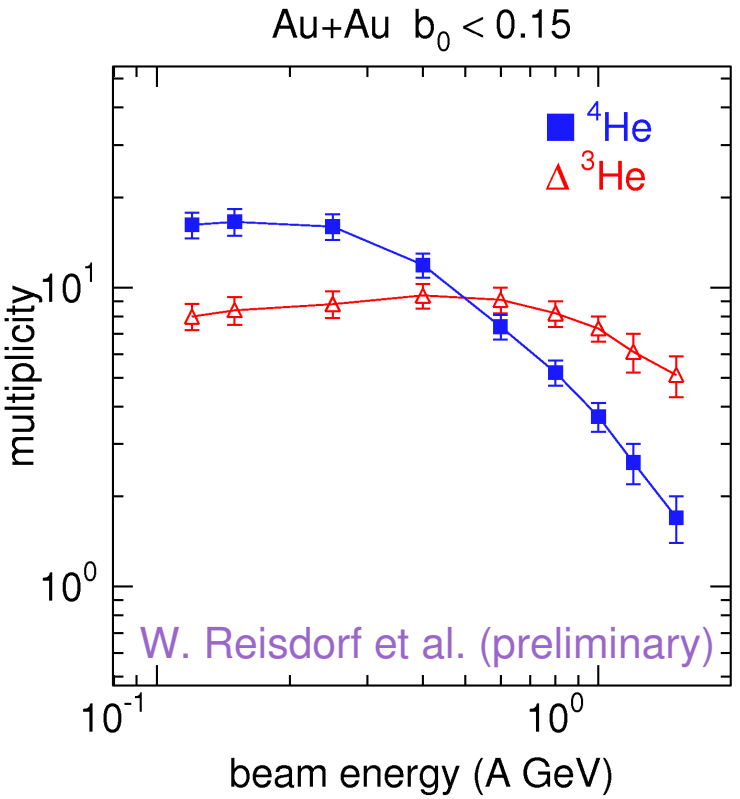


The system with the larger N/Z has the smaller effect
Coulomb?
Potential?

Nucleons and light fragments



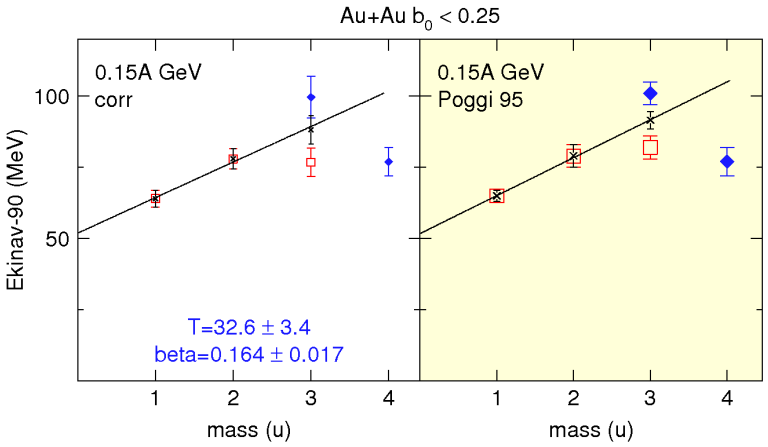
Large amount of nucleons are bound in clusters
Clusterization important!

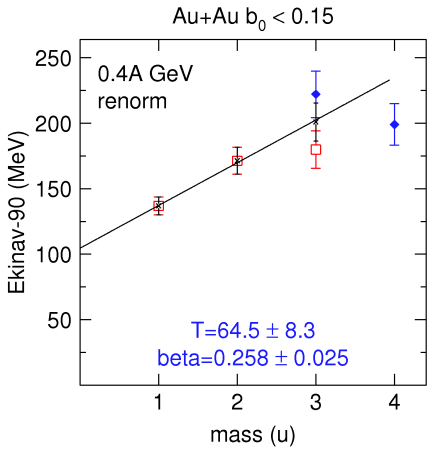


Production mechanism for clusters are changing

t/3He spectra in Au+Au collisions

scaled kinetic energy
in transverse direction

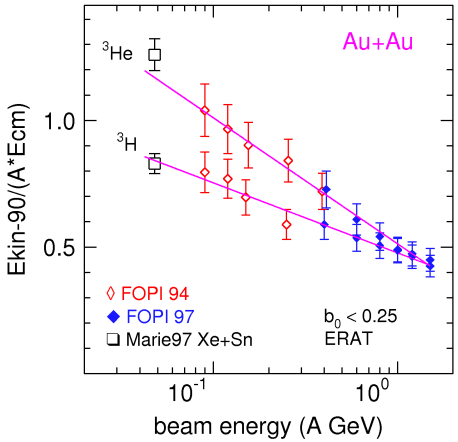




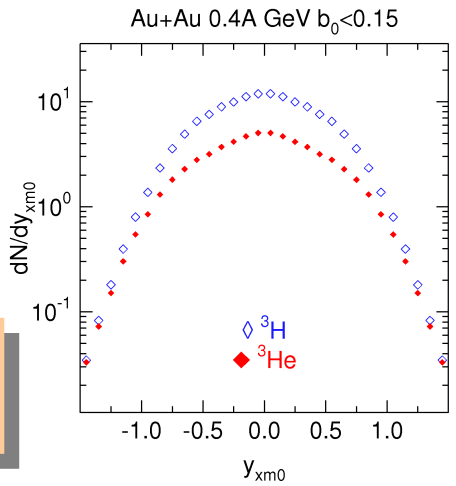
Ekin grows with mass:
radial flow

Low momentum 3He
removed from spectra?

W. Reisdorf et al. (preliminary)



transverse rapidiy

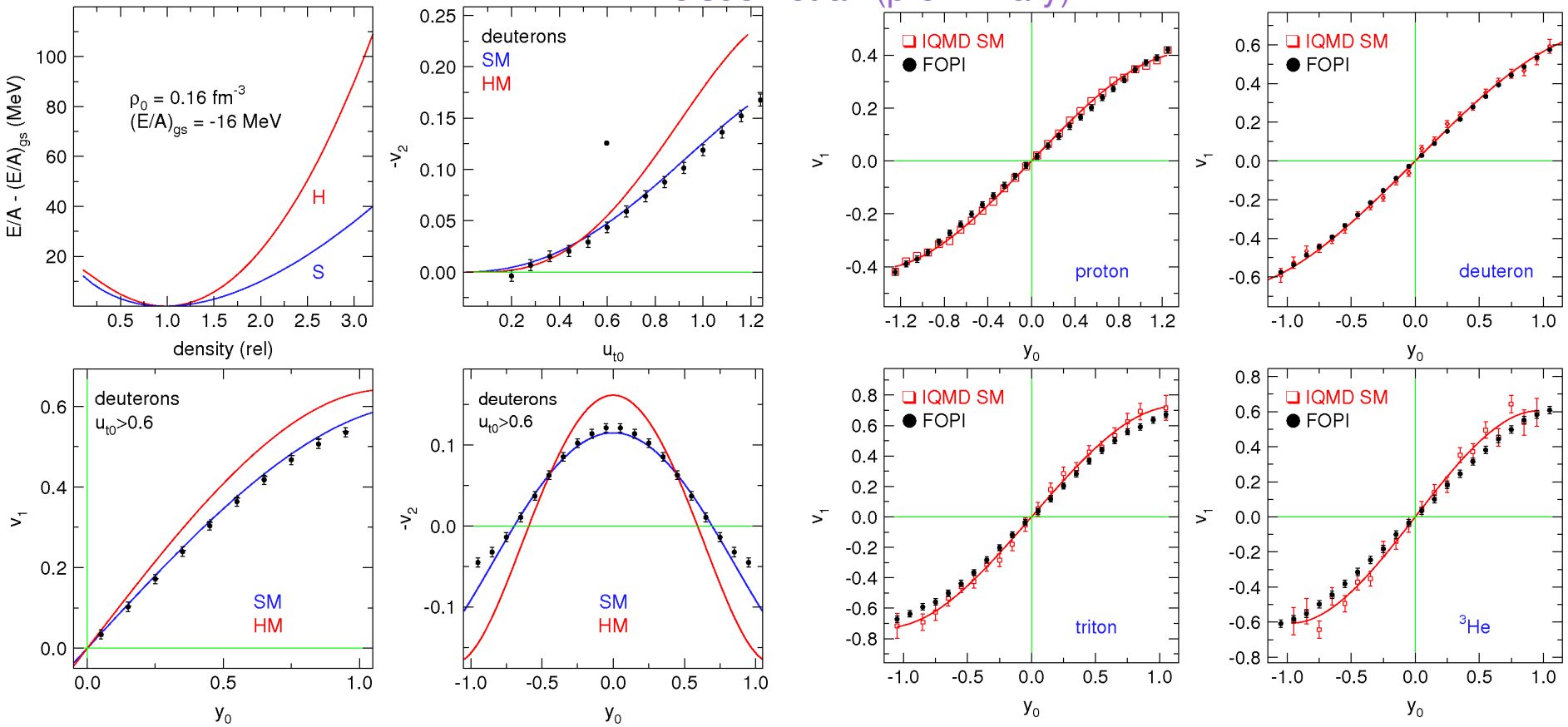


Directed flow of light fragments
Sensitivity to EOS

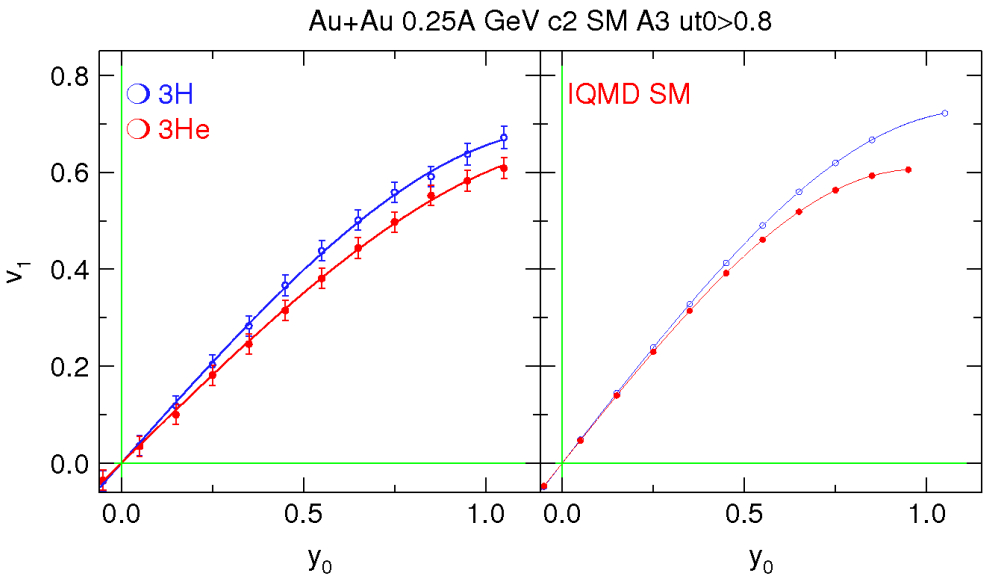
Au+Au 0.4A GeV 0.25<b_0<0.45

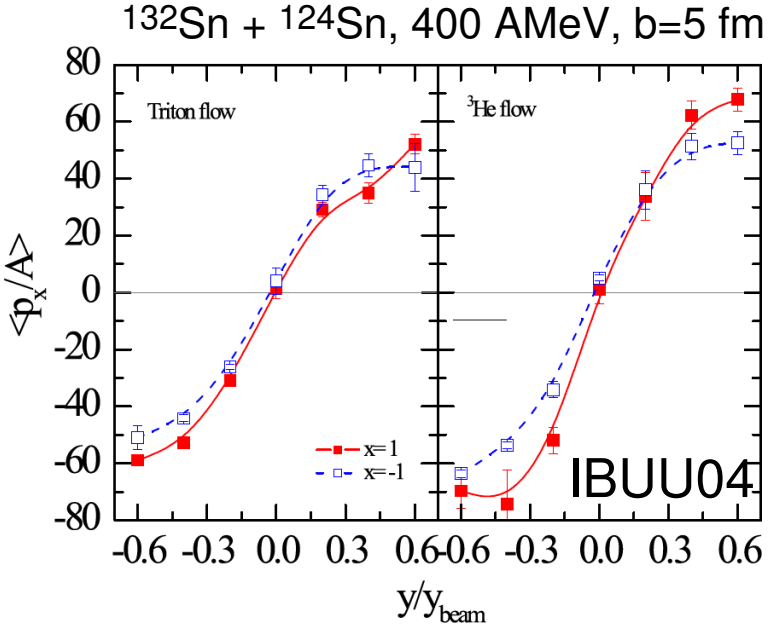
W. Reisdorf et al. (preliminary)

Au+u 0.25A GeV c2 ut0>0.8



Directed flow of t/^{3}He

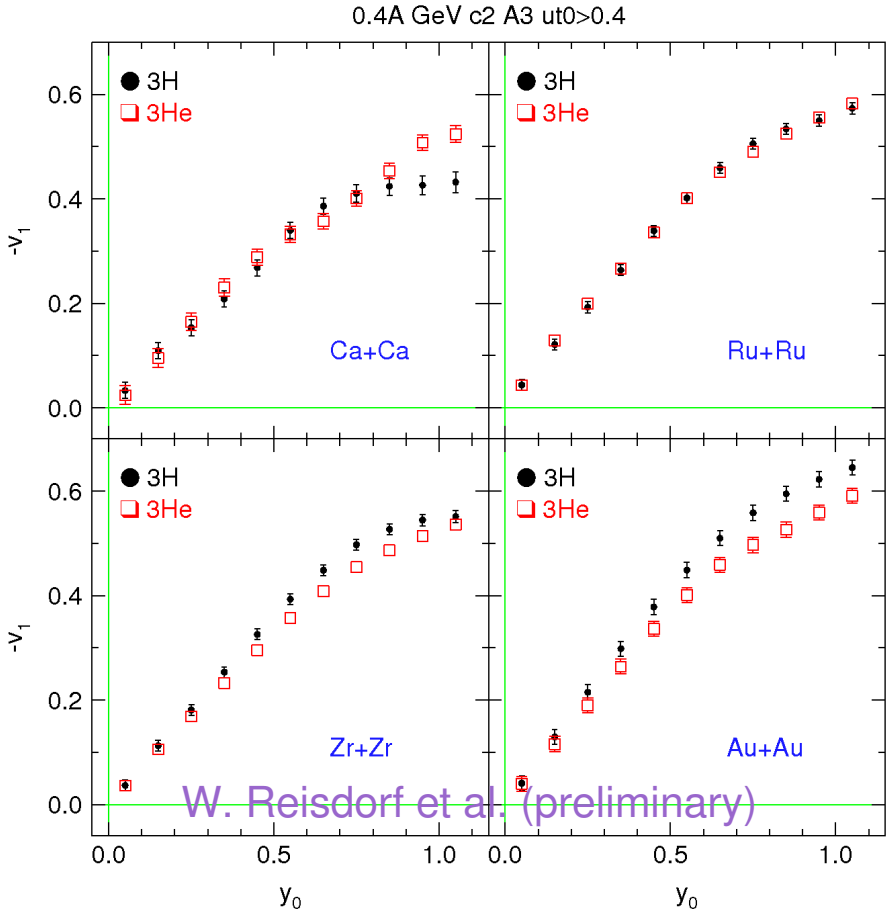




- Effect small
- IBUU4 including isospin dependent potentials predicts opposite effect
- Systematic errors (detector efficiencies) on the order of the difference between t and ^{3}He

Gao-Chan Yong et al., nucl-the:0906.0939

System size dependence of directed t/^{3}He flow

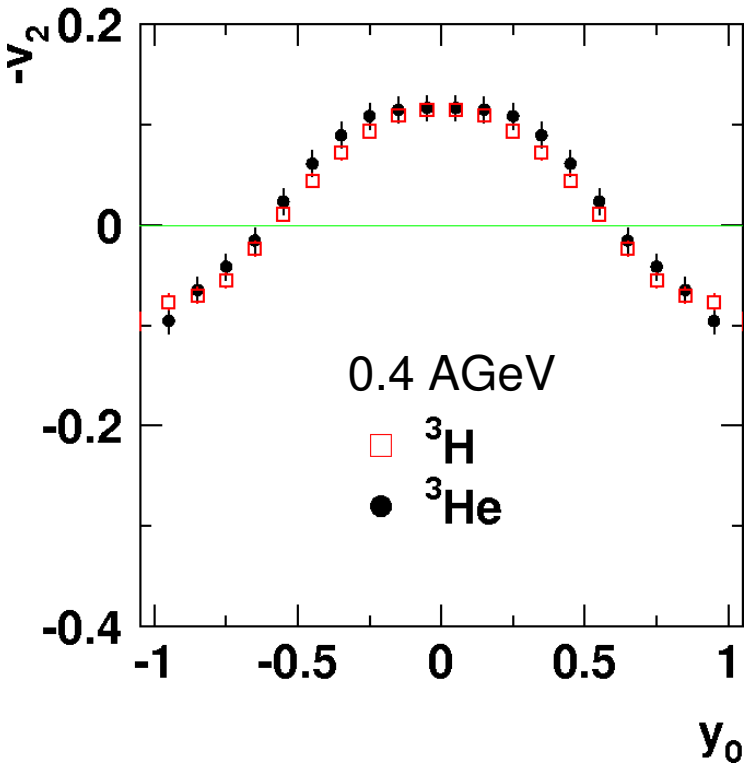


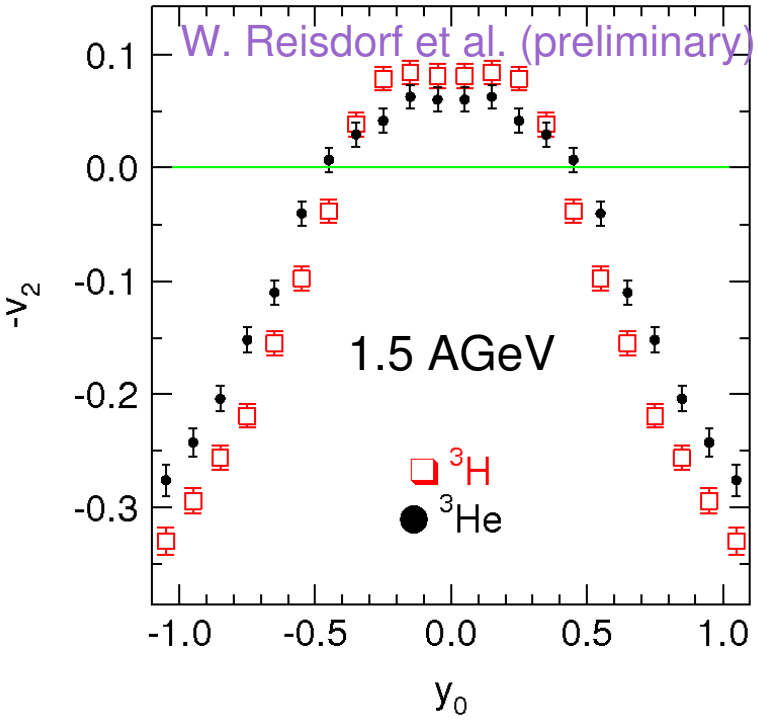
W. Reisdorf et al. (preliminary)

Larger difference between t and 3He for systems with larger N/Z

Elliptic flow of t/^{3}He

Au+Au 0.25<b_0<0.45





Increasing difference of t/3He elliptic flow with energy

Summary and conclusions

In general:

Clusterization important

promising results on flow, yields

Pion production cannot be ignored

at energies > 1AGeV not a perturbation

Constrain other model input

e.g. cross sections and angular distributions

Isospin pairs t/^{3}He and π^-/π^+:

Sensitivity of pion ratio to asyEOS at low energies

not settled

t/^{3}He yields and flow

effects tiny (systematic errors, corrections)

at high energies (>1 AGeV) differences get larger

need confirmation by models

Summary and conclusions

The short term future:

Publication of experimental data on the way

Comparisons to model predictions

IQMD (C. Hartnack), URQMD (Qinfeng Li), BUU (T. Gaitanos)

The long term future at energies 0.4-2 AGeV:

Detectors

with excellent particle identification properties

high efficiency, large acceptance

Pion (and Kaon) identification

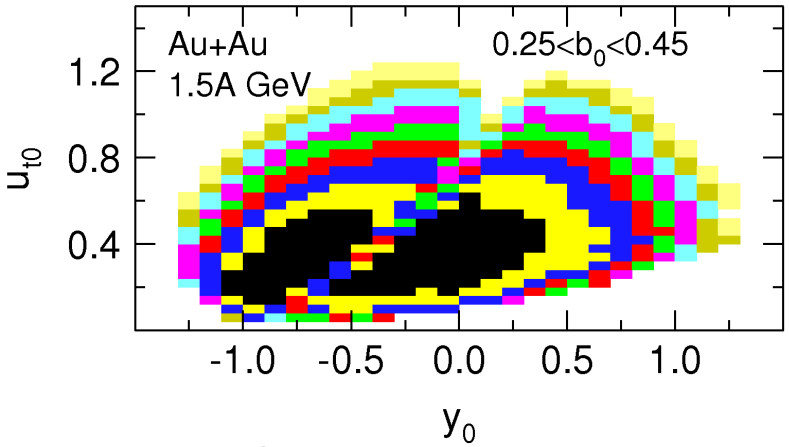
FOPI (?), HADES, LAND @ GSI

Systematic measurements

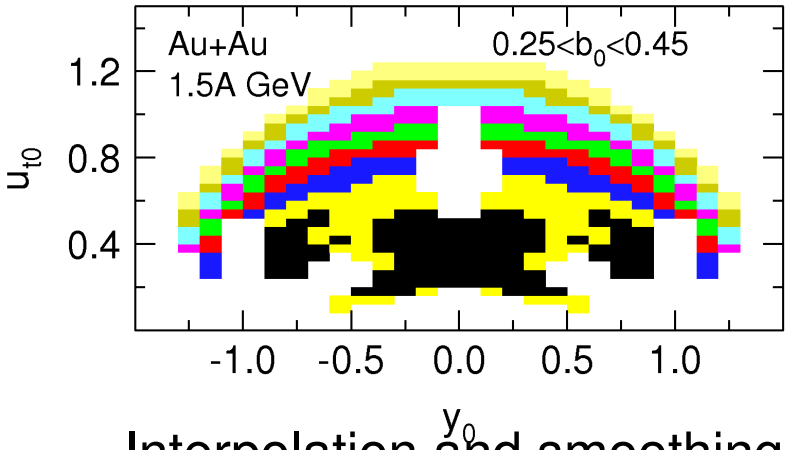
disentangle surface/volume effects

Analysis details of FOPI data

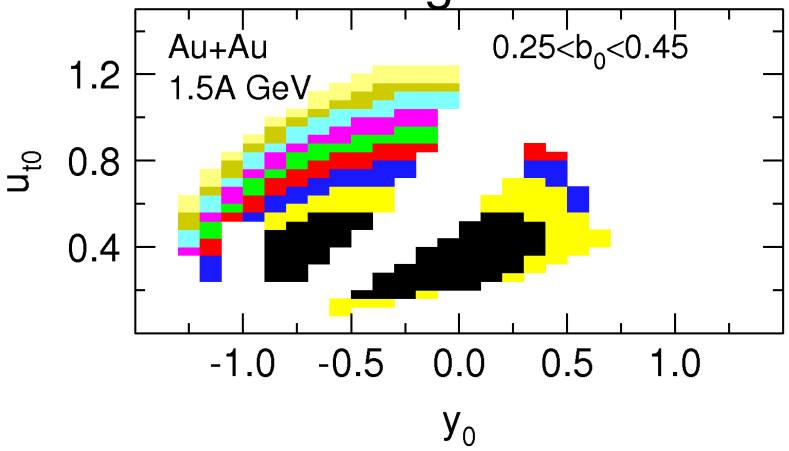
Measured data



Reflection and Symmetrization



Cleaning cuts



Interpolation and smoothing