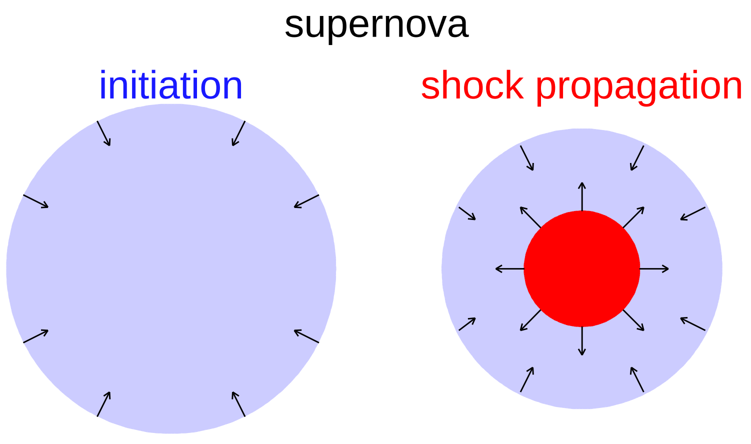
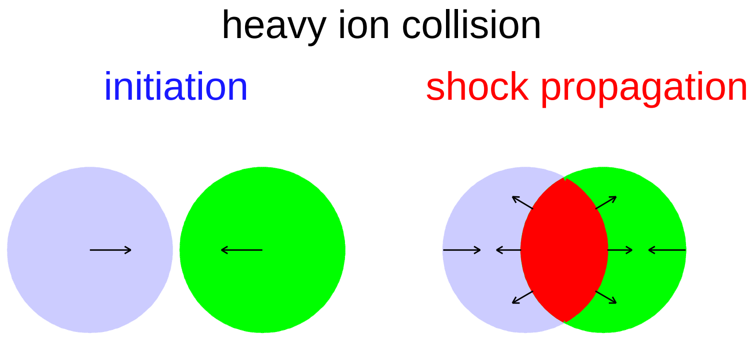
EOS information from HI collisions

- Can we simulate supernova's in the laboratory? Isospin tracing
- How much stopping $\rightarrow$ density is achieved?
- Global sideflow $\rightarrow$ pressure systematics
- Constraining the EOS from global stopping versus sideflow correlation
- More microscopic details: identified particles
  - Flow hierarchy
  - Stopping hierarchy
  - Chemical composition after expansion into vacuum
- Created particles
  - Pions
  - Kaons
- Final remarks

Astrophysical connection:
Supernova vs Heavy Ion Collision



Ejecta from shock
propagation to surface:
H, He



'Green' or Zr right
'Blue' or Ru left

Isospin tracing (Leifels,Rami,Hong,Kim)

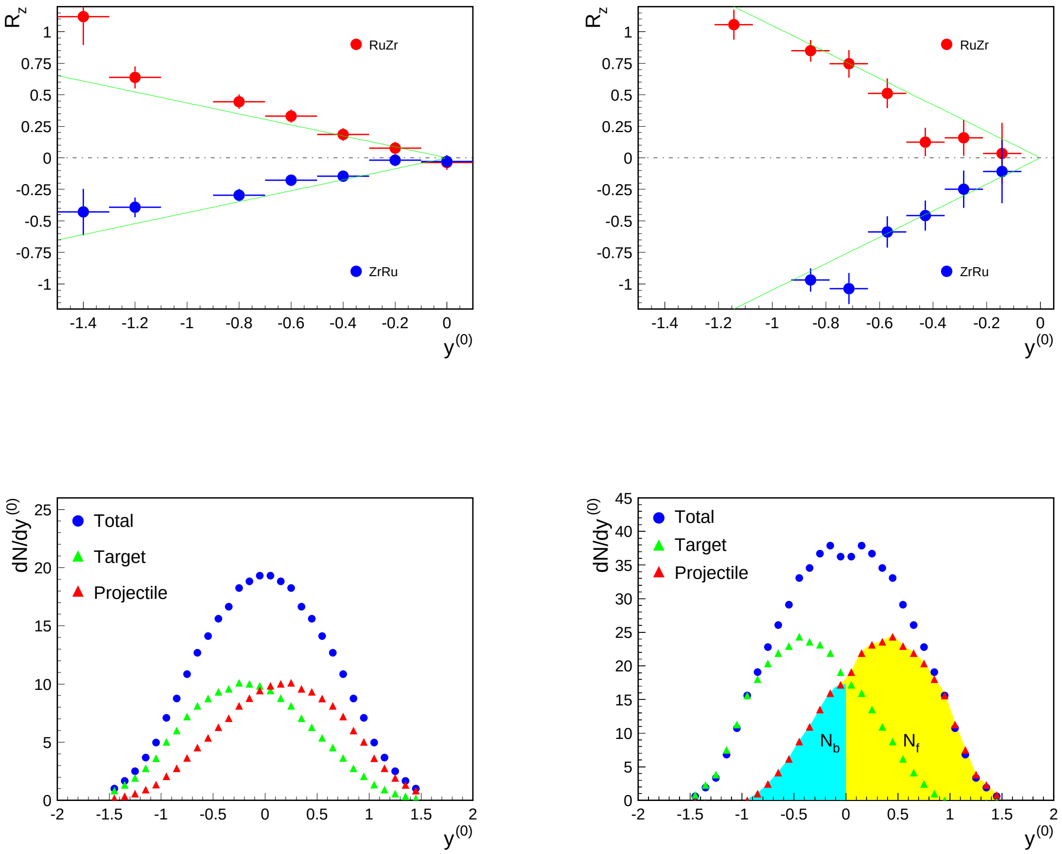
400A MeV   1500A MeV

Mass-symmetric system: A→A

96 → 96

Isospin-asymmetric:

Ru (Z=44) or Zr (Z=40)



Ru → Ru   Zr → Zr

Ru → Zr   Zr → Ru

Observable:

Proton rapidity distribution dN_y

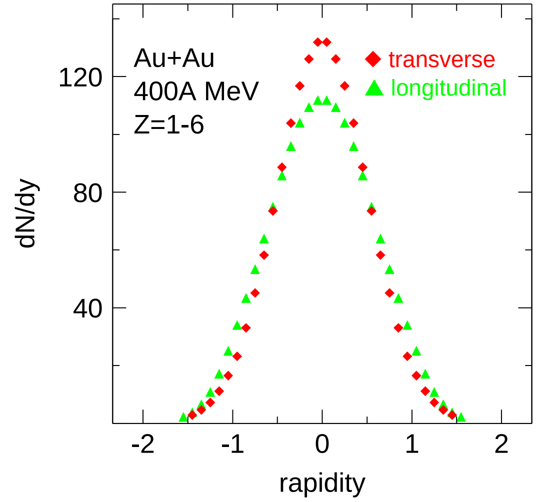
$$R_z = \frac{2 * dN_y(mix) - dN_y(Zr) - dN_y(Ru)}{dN_y(Zr) - dN_y(Ru)}$$

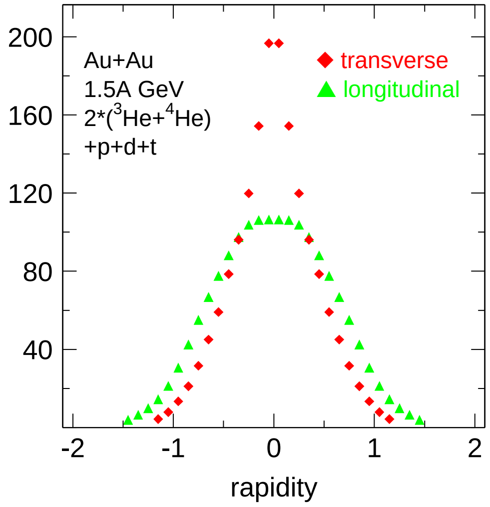
Global stopping systematics

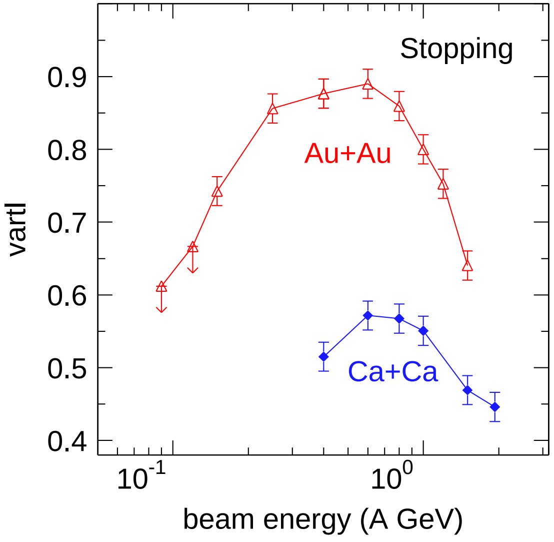
rapidity:

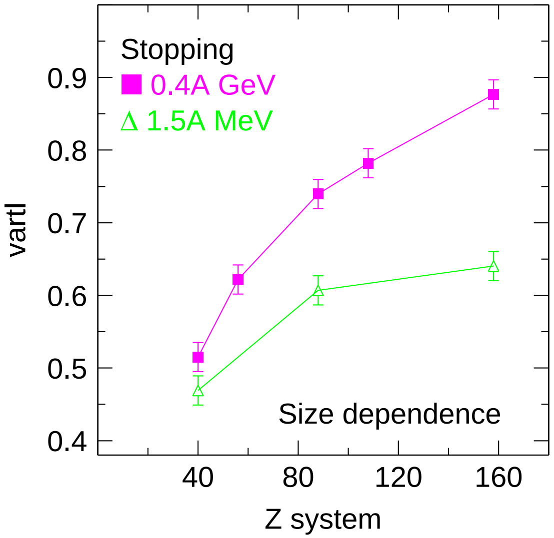
$$y_i = \frac{1}{2} \ln \frac{1+v_i}{1-v_i}$$

$i = x, y, z$ (beam)









"stopping" $\equiv$ *vartl* = ratio of variances transv/long

full event distributions (Z-weighted)

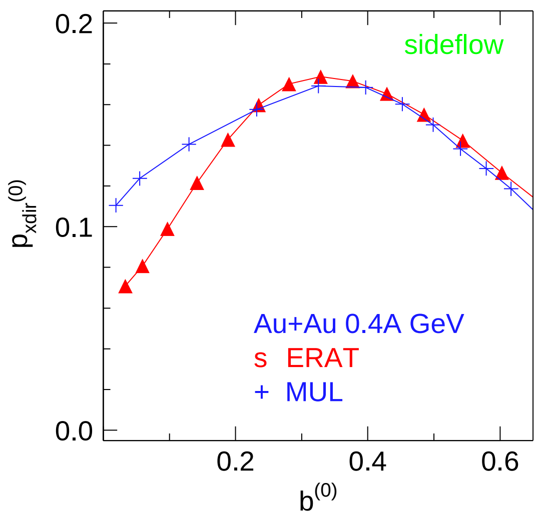
Global sideflow and its correlation to pressure

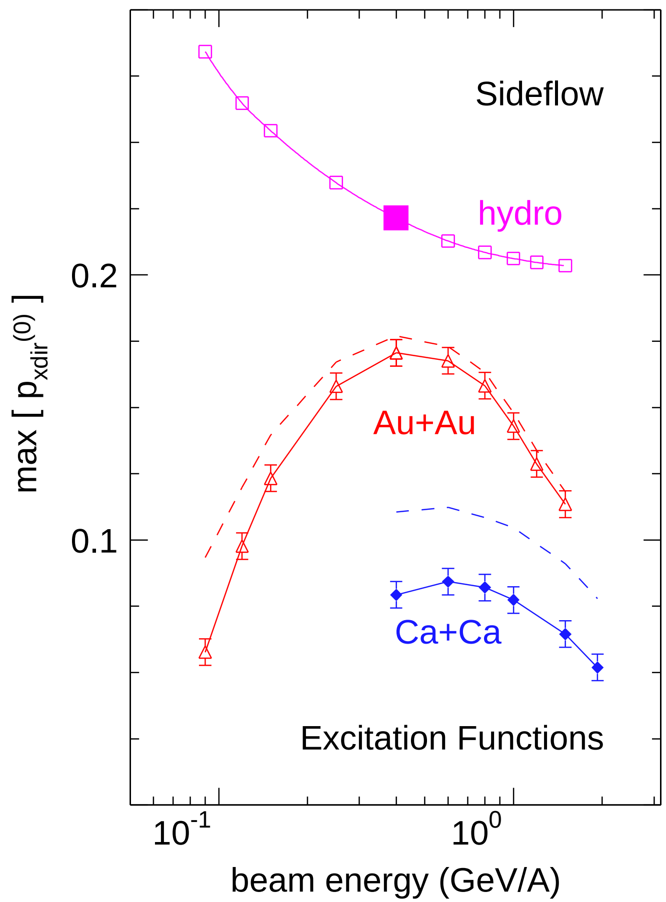
Centrality globals: ERAT$=E^k_{trans}/E^k_{long}$
MUL = particle multiplicity

Global sideflow:

$$p_x^{dir} = \sum sign(y) Z u_x / \sum Z$$

$\vec{u} = \vec{\beta}\gamma$ $\quad y =$ rapidity $\quad$ reaction plane: zx



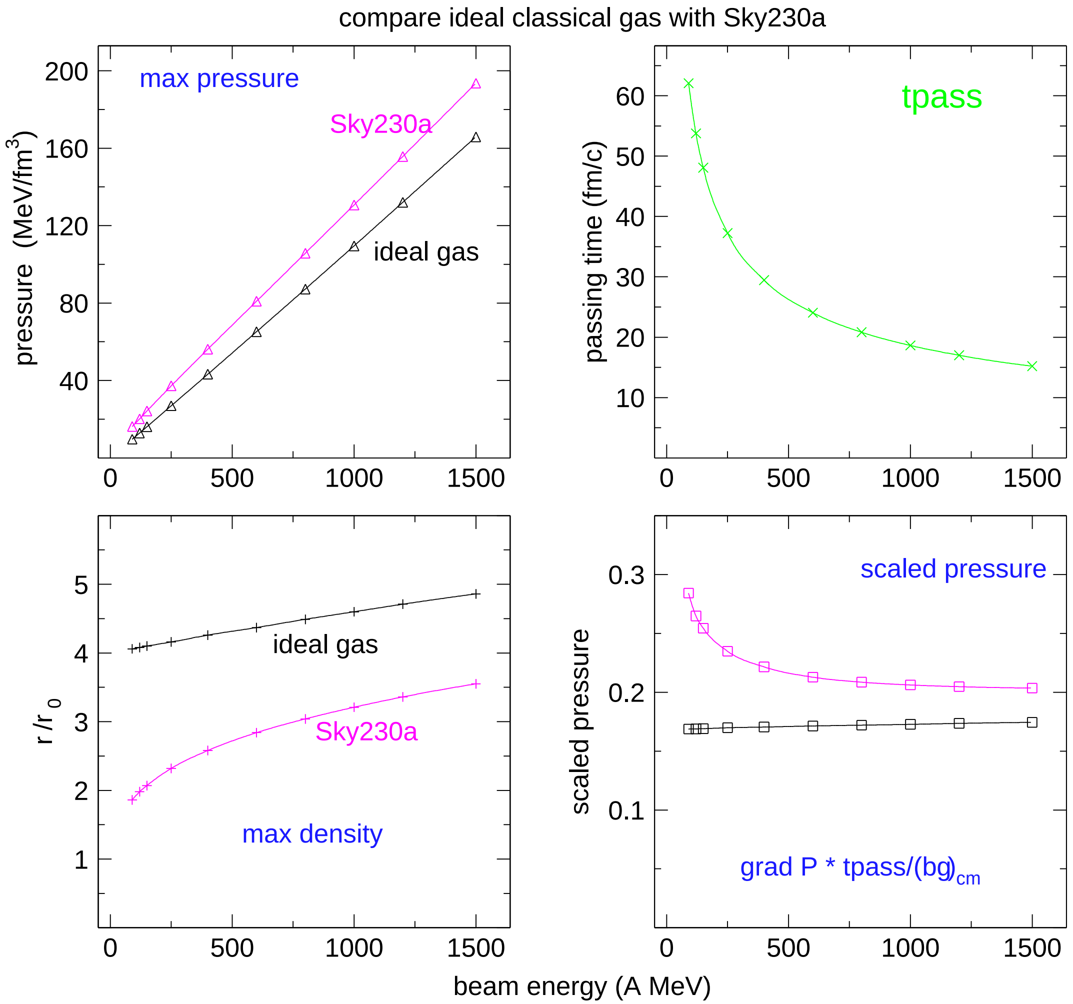


Shock compression: what to expect?

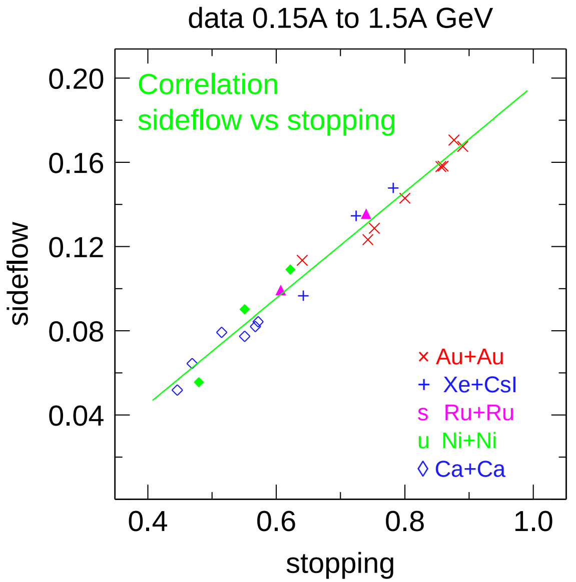
Rankine-Hugoniot-Taub

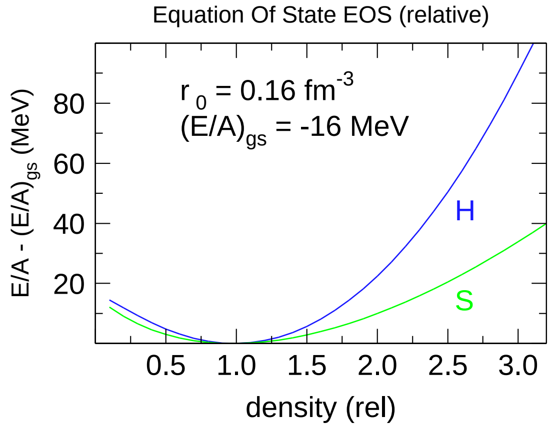
solve 1d shock equations

- The Pressures P are not very different!
- Its the ratio P/ρ that is different
- Pressure $\rightarrow$ sideflow
- Density $\rightarrow$ stopping , Kaons, and/or ?

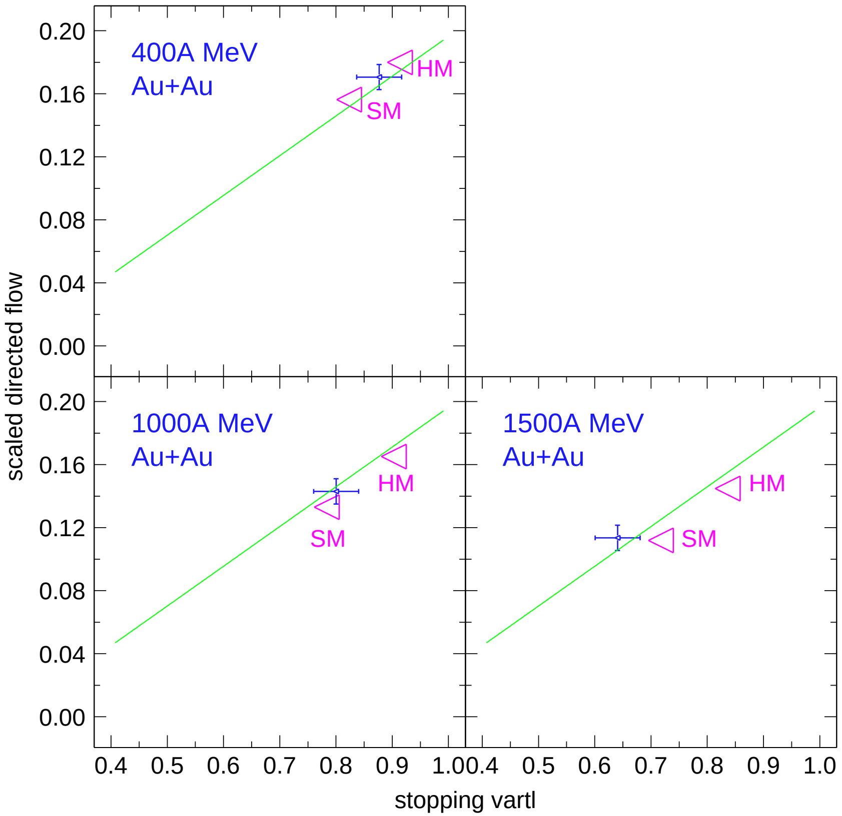


Sideflow (pressure) vs Stopping (density): constraining the EOS





Simulation with transport code IQMD



Flow (pressure) of identified particles

Particle emission is genuinely 3d

$$u = (\gamma, \vec{\beta}\gamma) \; ; \quad u_t = \beta_t \gamma$$

$$\frac{dN}{u_t du_t dy d\phi} = v_0[1 + 2v_1 \cos(\phi) + 2v_2 \cos(2\phi)]$$

$$v_0 = v_0(y, u_t) \; ; \quad v_1 = v_1(y, u_t) \; ; \quad v_2 = v_2(y, u_t)$$

$$v_1 = \langle \frac{p_x}{p_t} \rangle \; ; \quad v_2 = \langle \left(\frac{p_x}{p_t}\right)^2 - \left(\frac{p_y}{p_t}\right)^2 \rangle$$

Projection on rapidity y:

$$v_1(y) = v_{11} y + v_{13} y^3$$

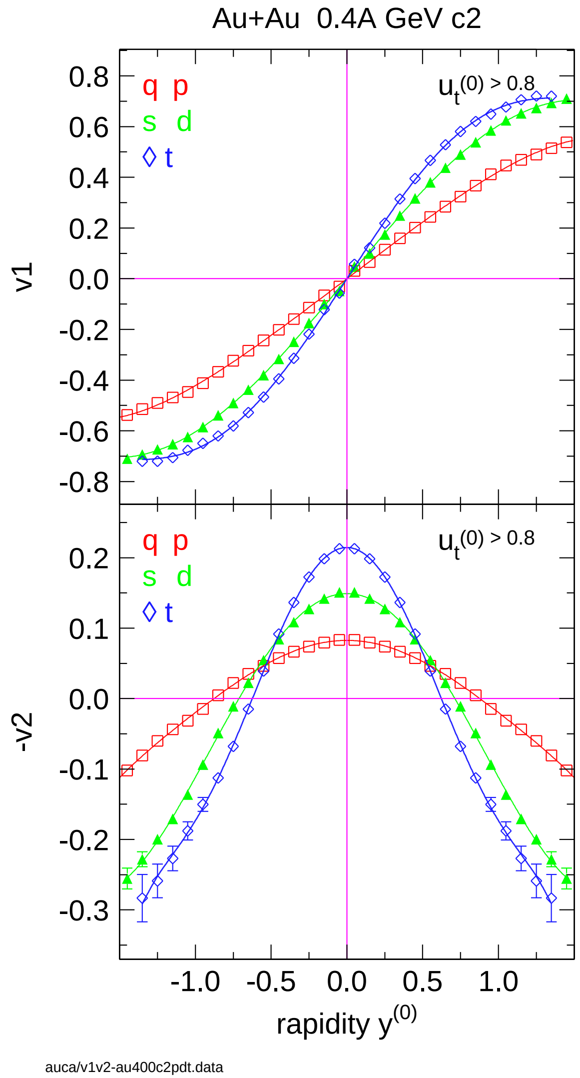
$$v_2(y) = v_{20} + v_{22} y^2 + v_{24} y^4$$

v_1 asymmetric, 'directed' $\qquad$ v_2 asymmetric, 'elliptic'

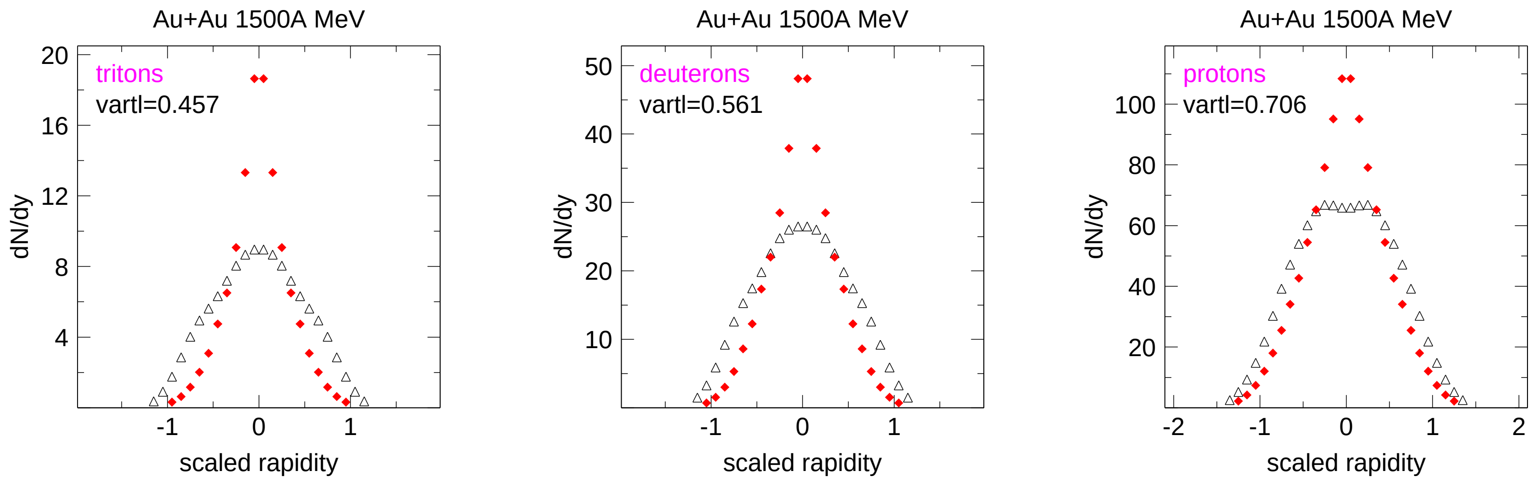
→ flow of clusters is more focussed

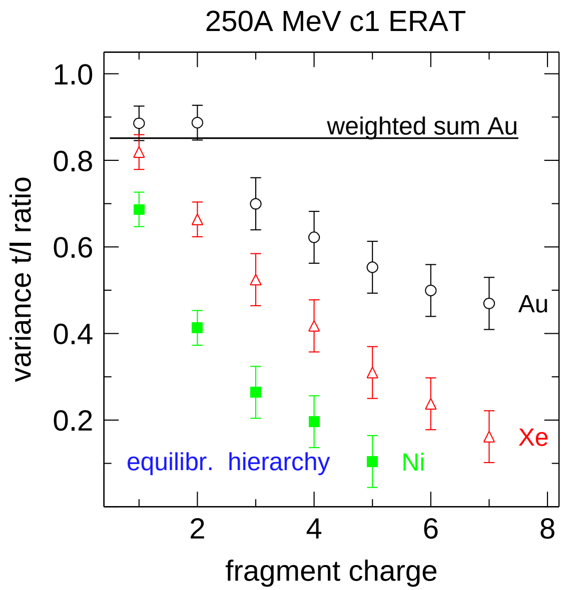
Derivable from nucleon flow by coalescence models?

→ requires common collision history



Stopping (density) hierarchy of identified particles





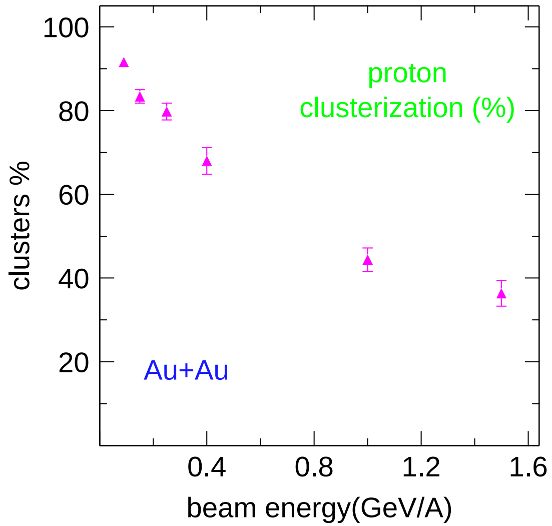
There is a hierarchy of stopping histories

Single nucleons, on average, have undergone a more complex collision scenario

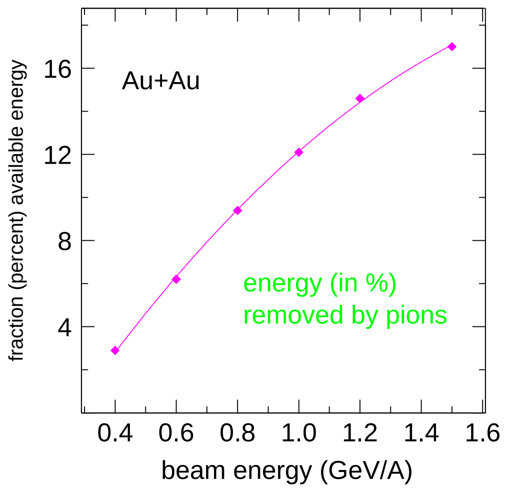
→ protons have seen more density and pressure

Chemistry: small, expanding systems

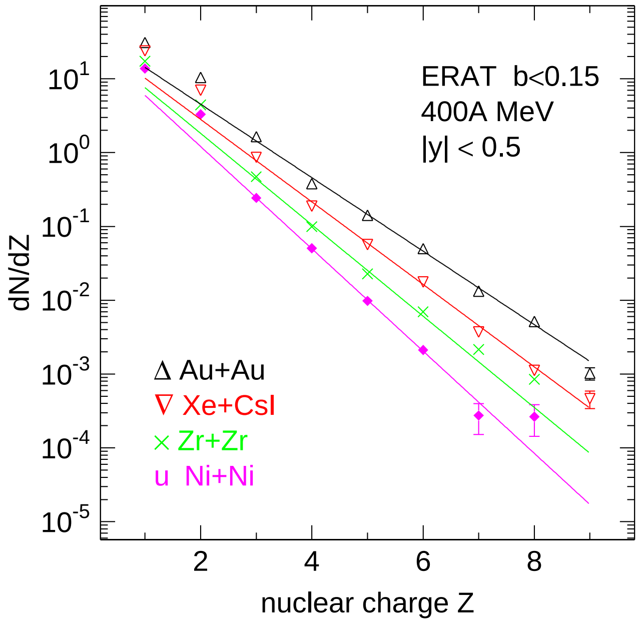
Clusterization



Pionization



Droplet formation
nucleosynthesis
in (small) exploding systems



$\longrightarrow$ system-size dependences

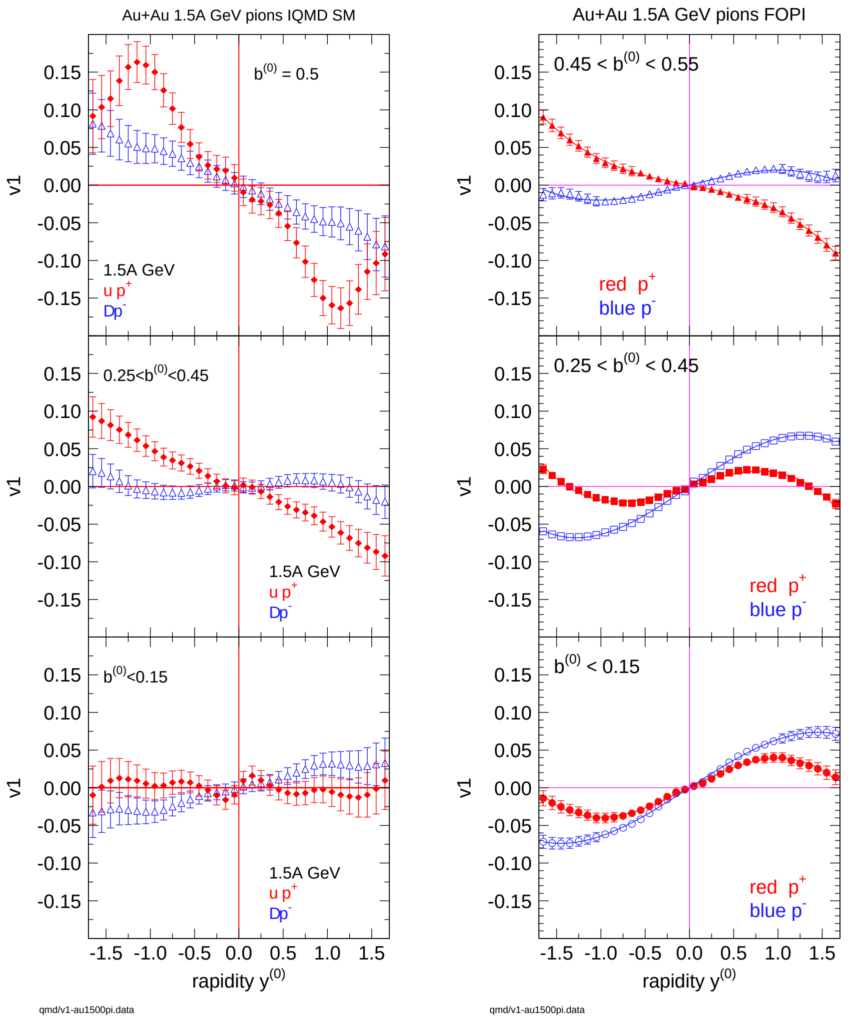
Pion information: pion condensates?

Simulation Data

π^+/π^- flow $v_1(y)$
Au+Au 1.5A GeV
vary centrality

Δ propagation in the medium?

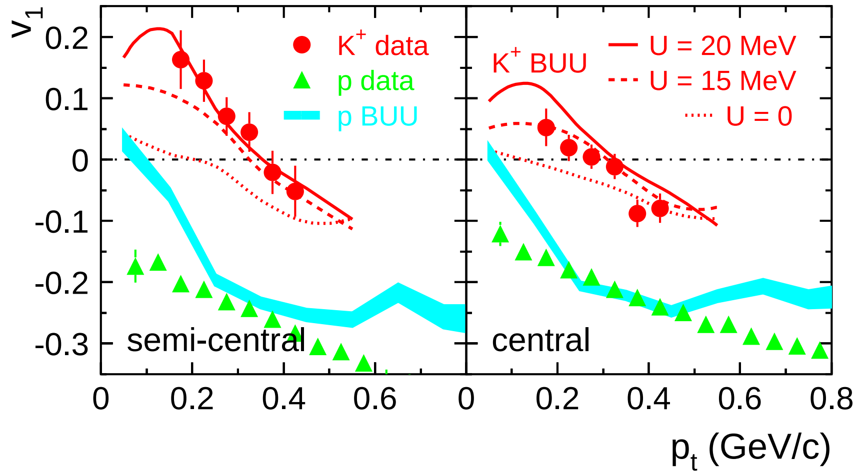
Antiflow: repulsion or absorption?
$\rightarrow$ Asymmetric systems (Ni+Pb)

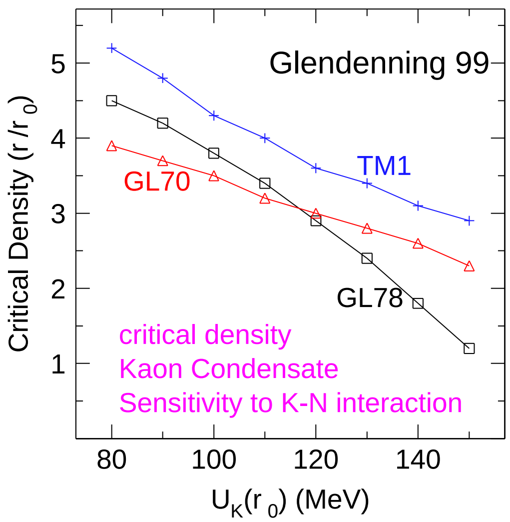


Kaon information: K- condensates, K- nuclei?

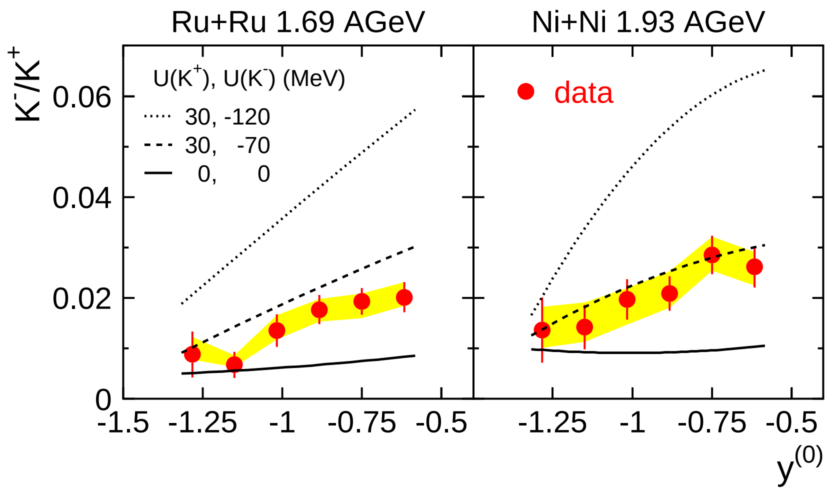
K-N, K-nucleus interaction?

Kaon (K^+) Flow
Crochet





K^-/K^+
rapidity distr.
Wisniewski



EOS from subthreshold kaons?

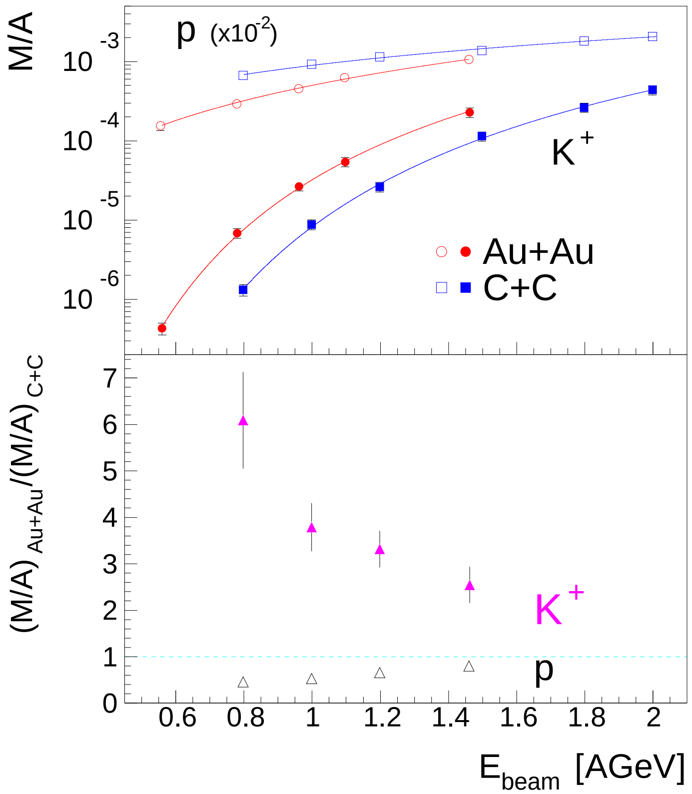
Observable: Ratio K^+ production C+C vs Au+Au

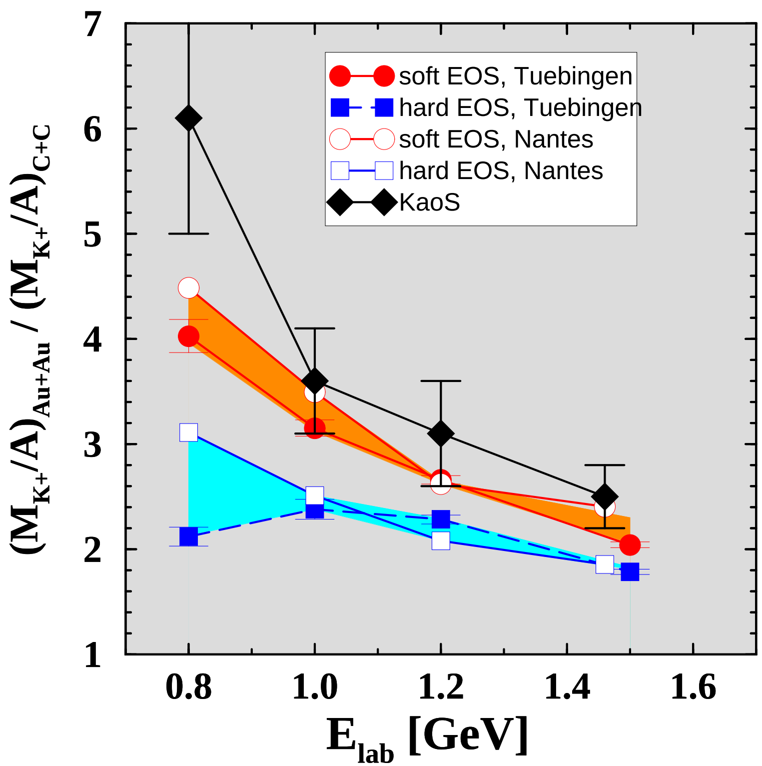
experiment: KaoS

Sturm (Darmstadt)

simulations: $\rightarrow$ soft EOS

Fuchs,Hartnack (Tuebingen,Nantes)





Some final remarks

Colliding nuclei → small system → finite-size effects in all observables:

- Stopping (density) → partial transparency → density
  Momentum dependence of fields & transport properties important
- Sideflow & Elliptic flow → pressure, sound velocity, medium effects
- Chemical composition → hadron- and nucleo-synthesis

Link to 'fundamentals' therefore requires

- establishing a complete and systematic data basis A-A (like n-n)
- microscopic simulations that
  - avoid equilibrium assumptions (even local)
  - avoid being in conflict with facts and symmetries in nuclear physics
  - avoid being programmer and CPU dependent
  - reproduce the ENSEMBLE of reaction data → credibidility