First Results from an Integrated Boltzmann+Hydrodynamics Approach

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Hannah Petersen, Universität Frankfurt

H-QM | Helmholtz Research School
Quark Matter Studies

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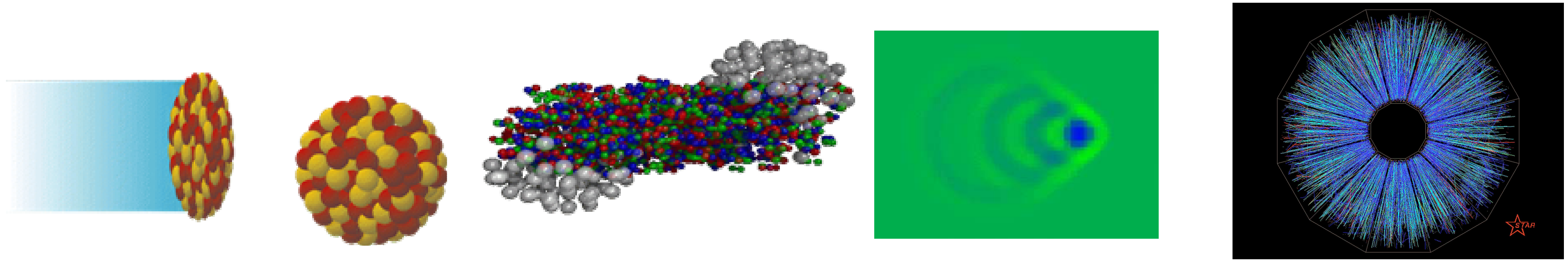
Outline

- Motivation
- Model Description
- Time Evolution
- Multiplicities and Spectra
- <m_T> and Elliptic Flow
  Excitation Function
- Conclusion and Outlook

-> all the information can be found in
H.P. et al., arxiv:0806.1695

Motivation

- Fix the initial state and freeze-out
  → learn something about the EoS and the effect of viscous dynamics



1) Non-equilibrium initial conditions via UrQMD

2) Hydrodynamic evolution **or** Transport calculation

3) Freeze-out via hadronic cascade (UrQMD)

Are differences between hydro and transport as big as expected?

Investigation of differences between

- **UrQMD:**
  - Non-equilibrium (Boltzmann) transport approach
  - Hadron-string and resonance dynamics
- **UrQMD+Hydro:**
  - Non-equilibrium initial conditions
  - Ideal hydrodynamic evolution for the hot and dense phase
  - Freeze-out via hadronic cascade

Initial State I

- Coupling between UrQMD initial state and hydrodynamic evolution at:

$$t_{start} = \frac{2R}{\gamma v} = \frac{2R}{\sqrt{\gamma^2 - 1}} = 2R\sqrt{\frac{2m_N}{E_{\rm lab}}}$$

- Contracted nuclei have passed through each other
  - Initial NN scatterings have proceeded
  - Energy is deposited
- Energy-, momentum- and baryon number densities are mapped onto the hydro grid
- Hadrons are represented by a Gaussian with finite width

$$\epsilon_{\rm cf}(x,y,z) = N \exp -\frac{(x-x_p)^2 + (y-y_p)^2 + (\gamma_z(z-z_p))^2}{2\sigma^2}$$

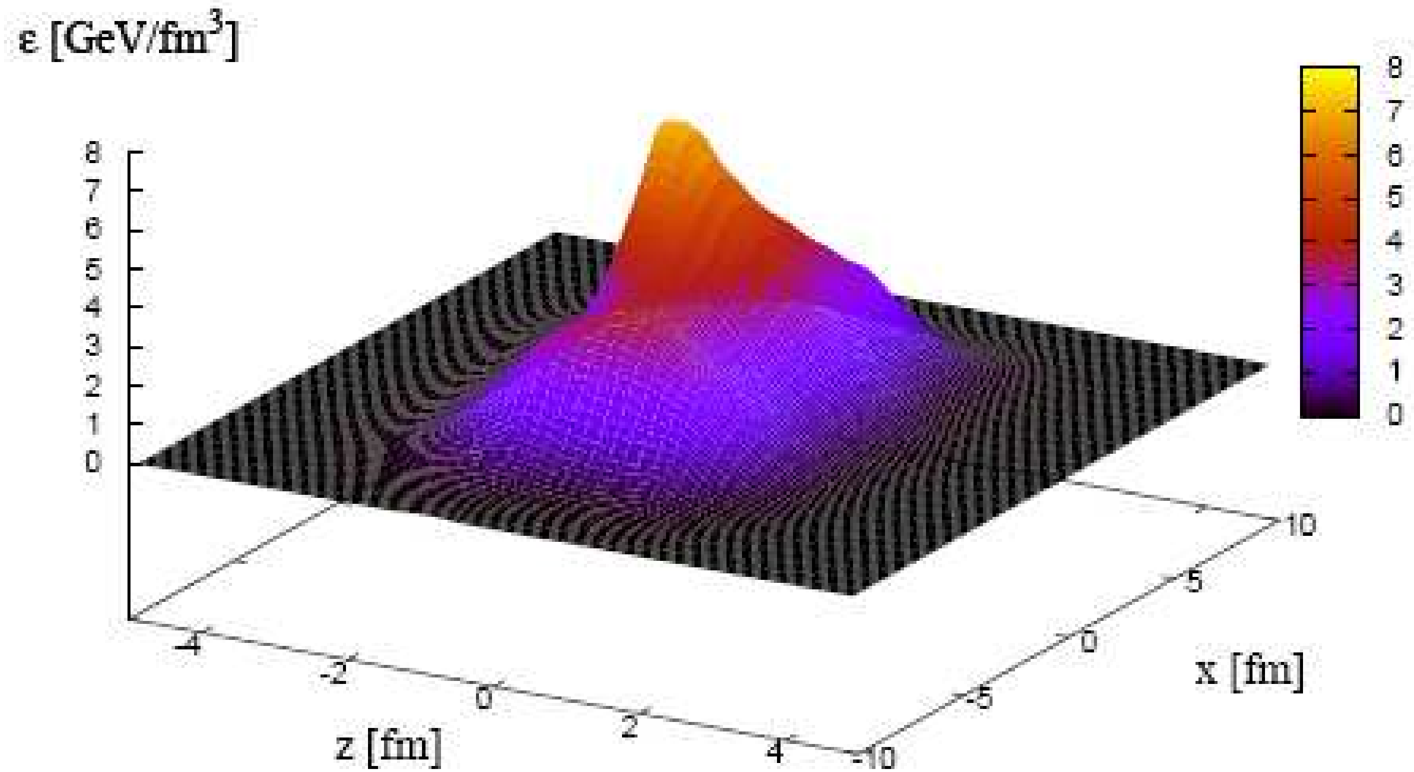
with the proper normalisation $N = (\frac{1}{2\pi})^{\frac{3}{2}} \frac{\gamma_z}{\sigma^3} E_{\rm cf}$

(J.Steinheimer et al., Phys.Rev.C77:034901,2008, arXiv:0710.0332)

Single Event – Initial State

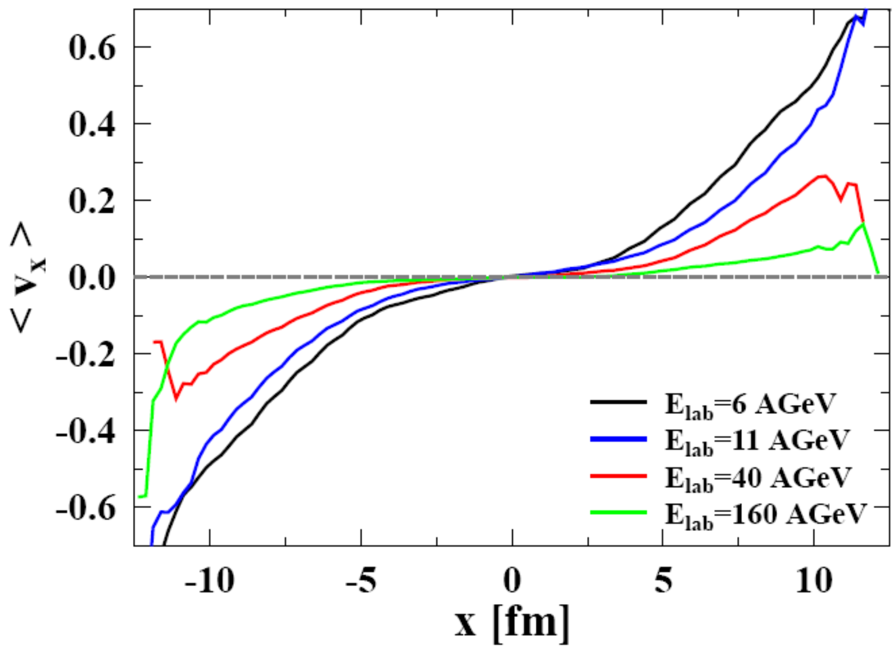
Energy density distribution at E_{lab}=40 AGeV,

$t_{hydrostart}$ = 2.83 fm, $t_{snapshot}$ = 3.07 fm



→ Event-by-event fluctuations are naturally taken into account

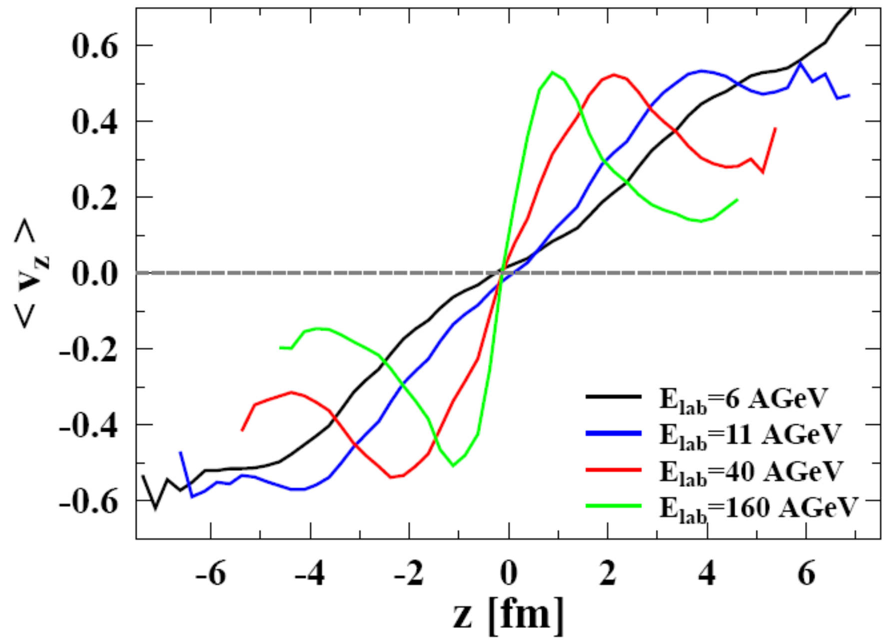
Initial Velocity Distribution



Central collisions at different beam energies

In z-direction:

Effect of Lorentz contraction visible



(3+1)d Hydrodynamic Evolution

- Ideal relativistic one fluid hydrodynamics

$$\partial_\mu T^{\mu\nu} = 0 \quad \text{and} \quad \partial_\mu \left(n u^\mu \right) = 0$$

- Hadron gas equation of state (EoS)
  - No phase transition included
  - Baseline check
  - All hadrons with masses up to 2.2 GeV are included (consistent with UrQMD)

(D. Rischke et al., Nucl. Phys. A 595, 346 (1995))

Freeze-out

- Hydrodynamic evolution until
  - ε < 730 MeV/fm^3 ($\approx 5 * \varepsilon_0$) in all cells
- Isochronous freeze-out is performed via the Cooper-Frye formula

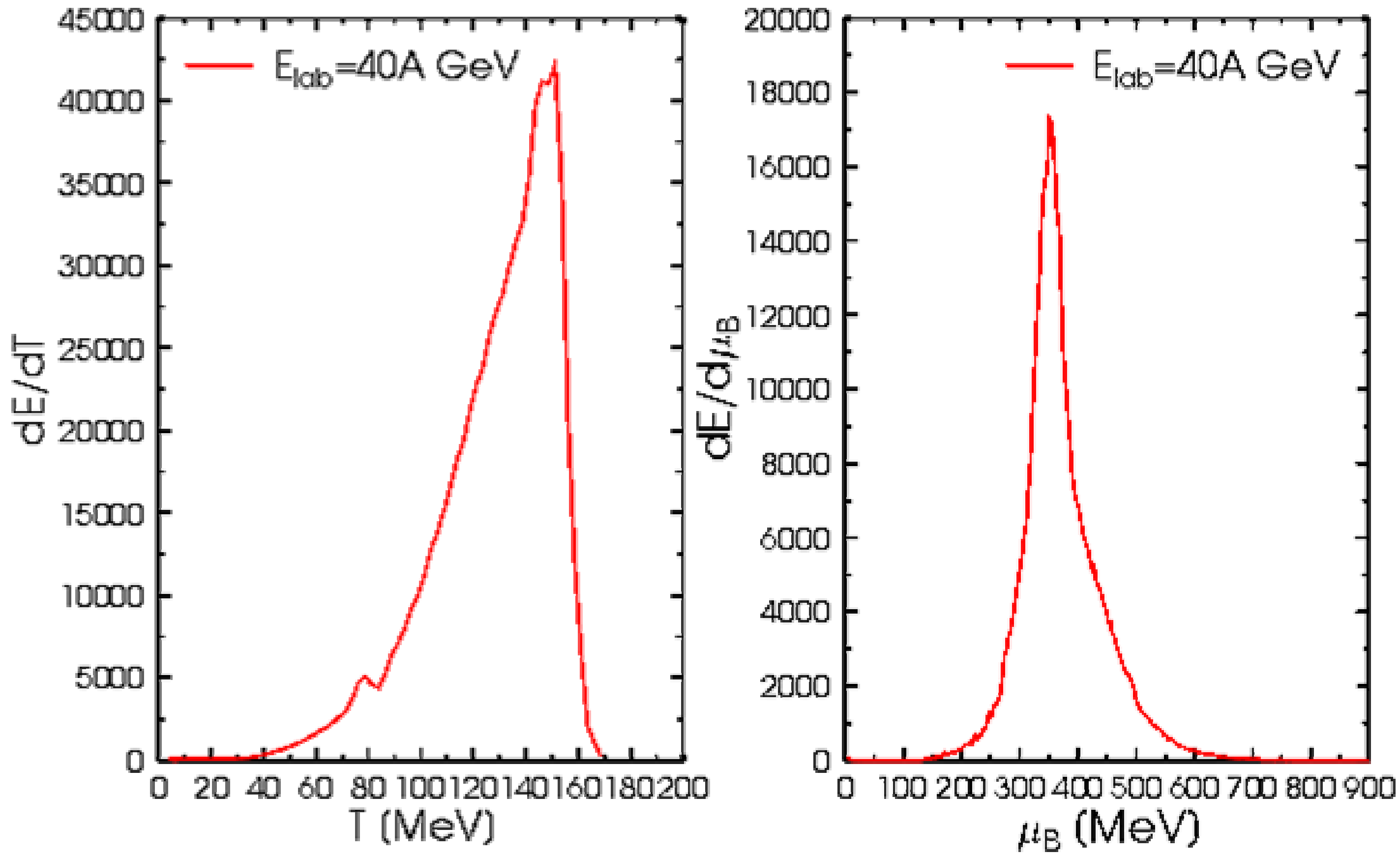
$$E\frac{dN}{d^3p} = \int_\sigma f(x,p)p^\mu d\sigma_\mu \qquad d\sigma_\mu = (d^3x, \vec{0})$$

with boosted Fermi or Bose distributions f(x,p) including μ_B and μ_S

- rescatterings and final decays calculated via hadronic cascade (UrQMD)

Freeze-out II

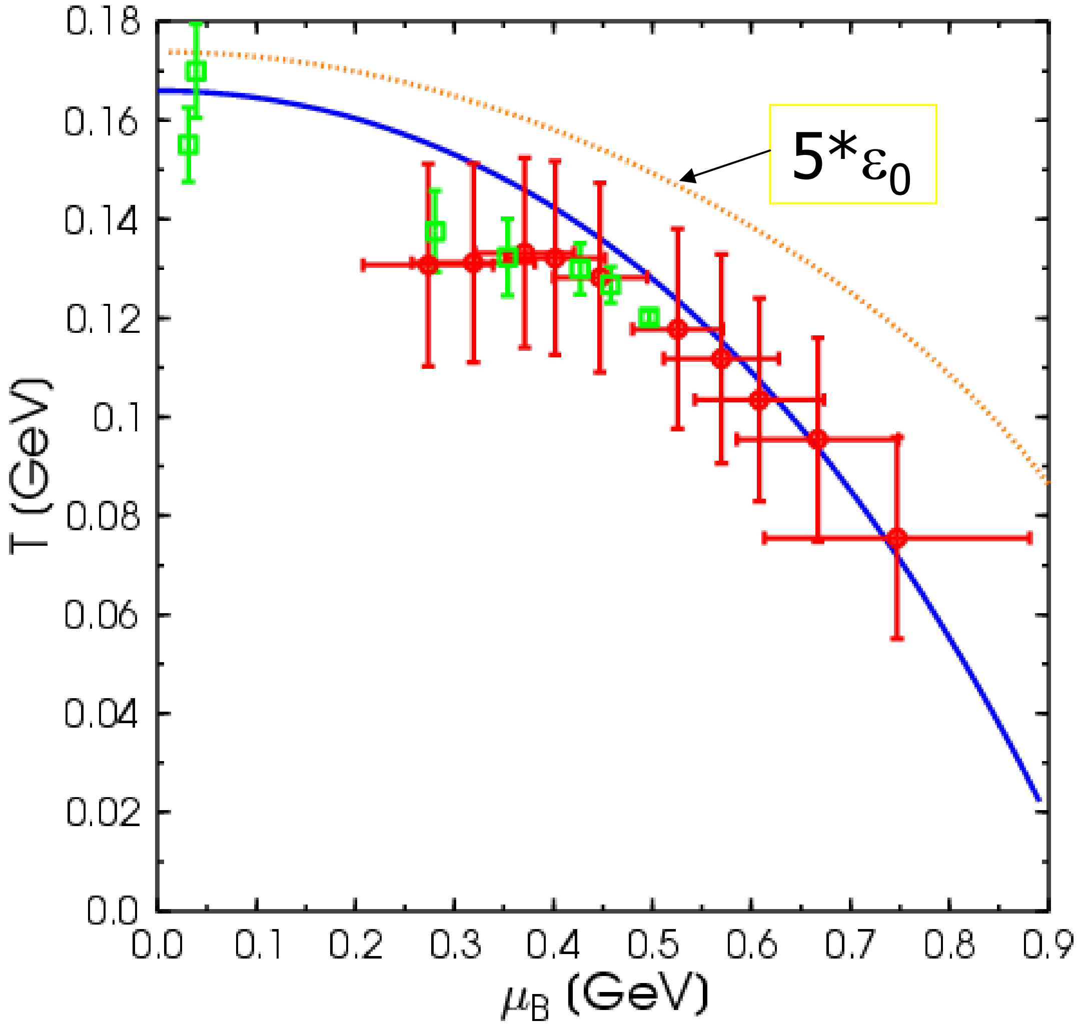
Distribution of the cells at freeze-out at E_{lab} = 40 AGeV



→ Important inhomogeneities are naturally taken into account

(A.Dumitru et al., Phys. Rev. C 73, 024902 (2006))

Freeze-out line



- Parametrization of chemical freeze-out line taken from

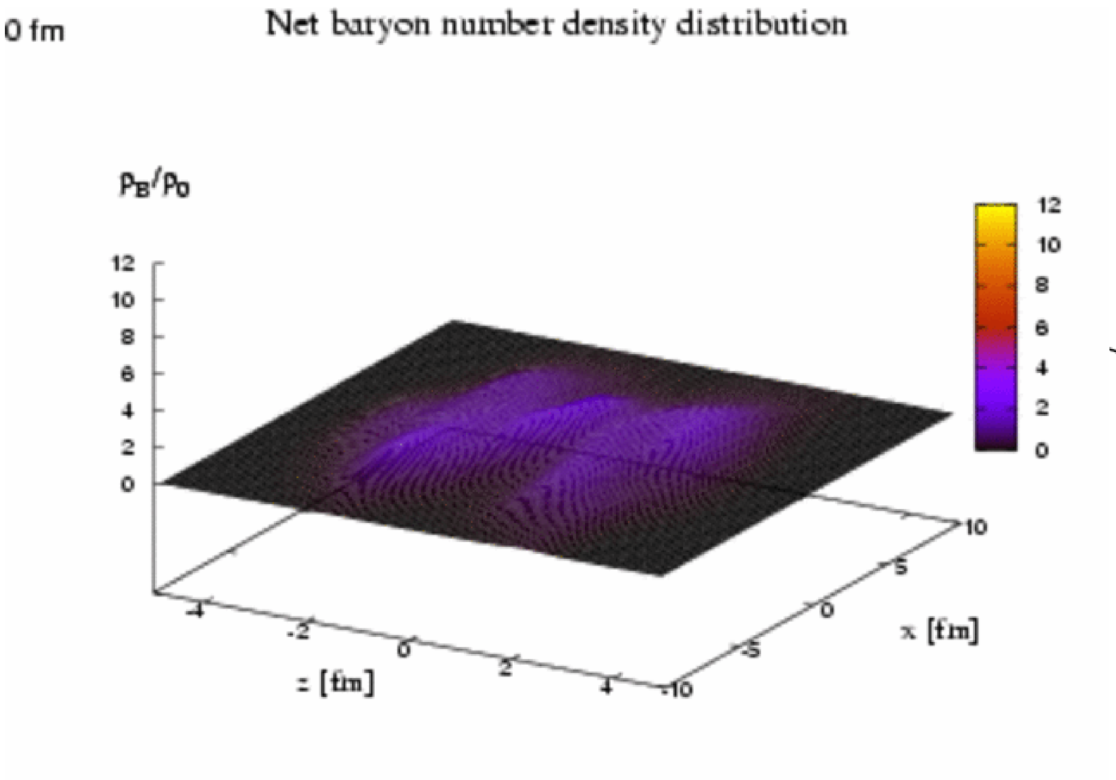
Cleymans et al,

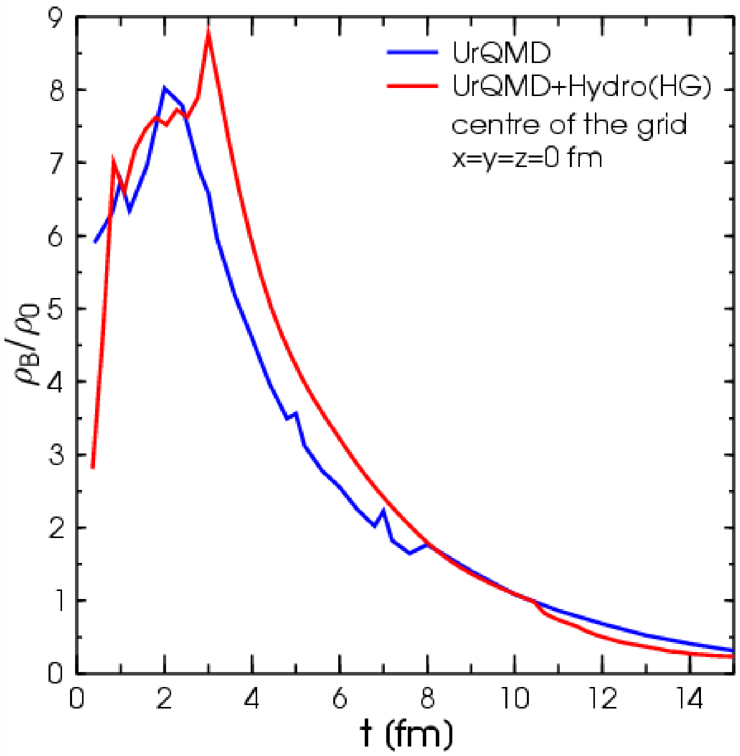
J.Phys. G 32, S165, 2006

→ Mean values and widths are in line with other calculations

Baryon density distribution

Time evolution of the baryon density is smooth

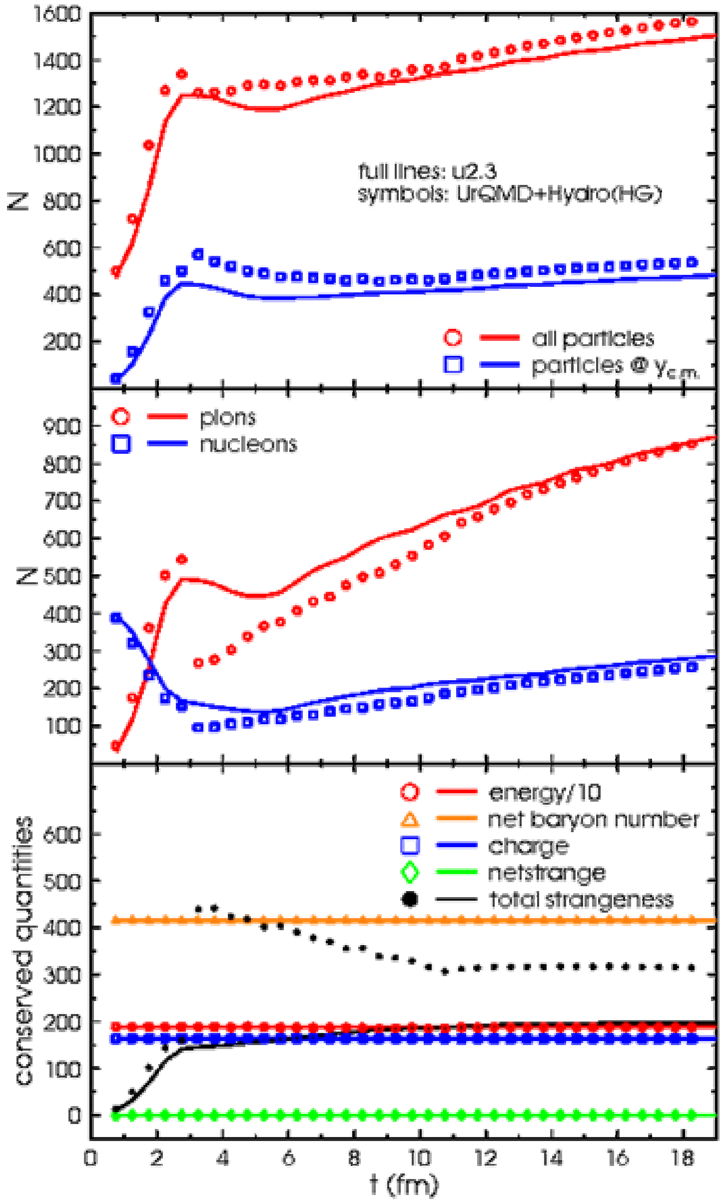




1) in the reaction plane

2) in a central cell

Time Evolution



Central Pb+Pb collisions at 40A GeV:

- Number of particles decreases in the beginning due to resonance creation
- Qualitative behaviour very similar in both calculations

→ UrQMD **equilibrates** to a rather large degree

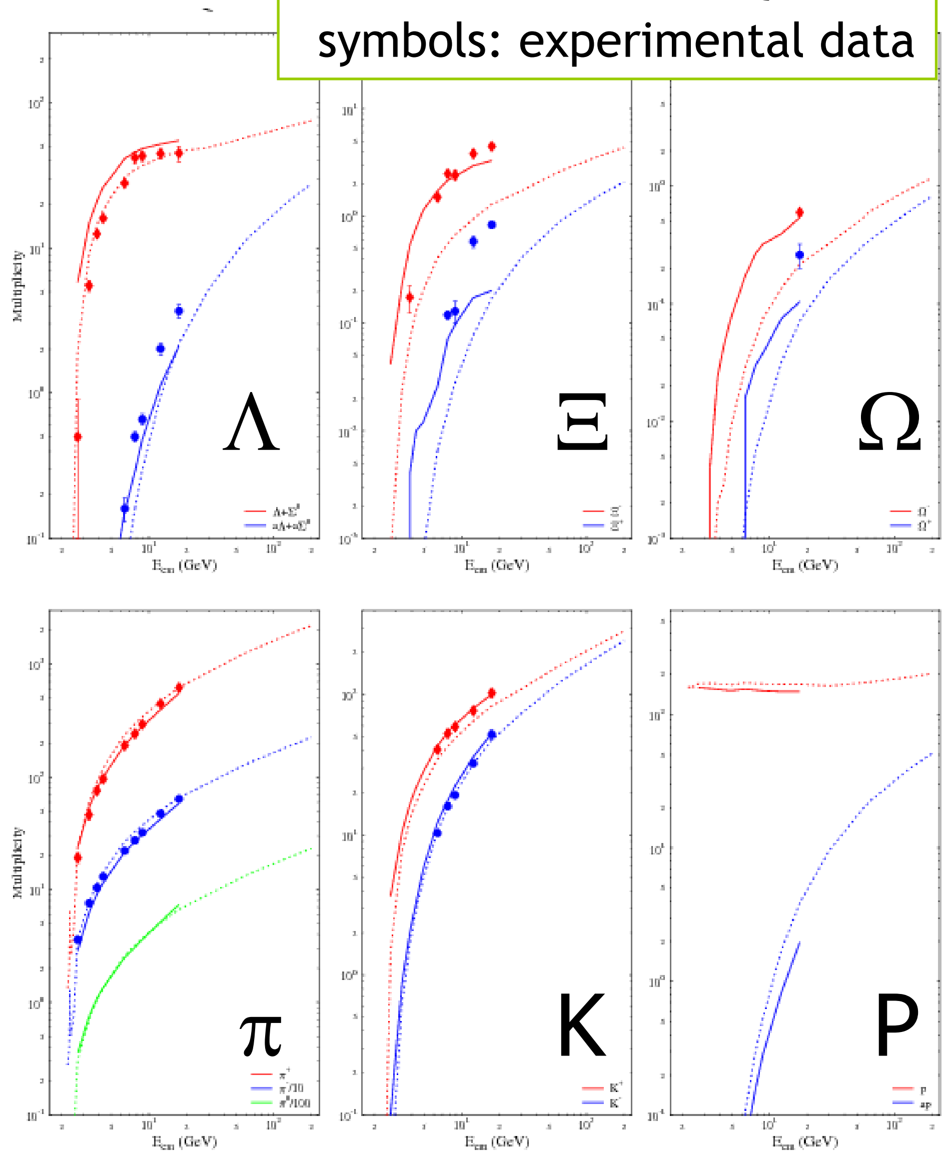
Multiplicities

full lines: hybrid model
dotted lines: UrQMD-2.3
symbols: experimental data

- Both models are purely hadronic without phase transition, **but** different underlying dynamics

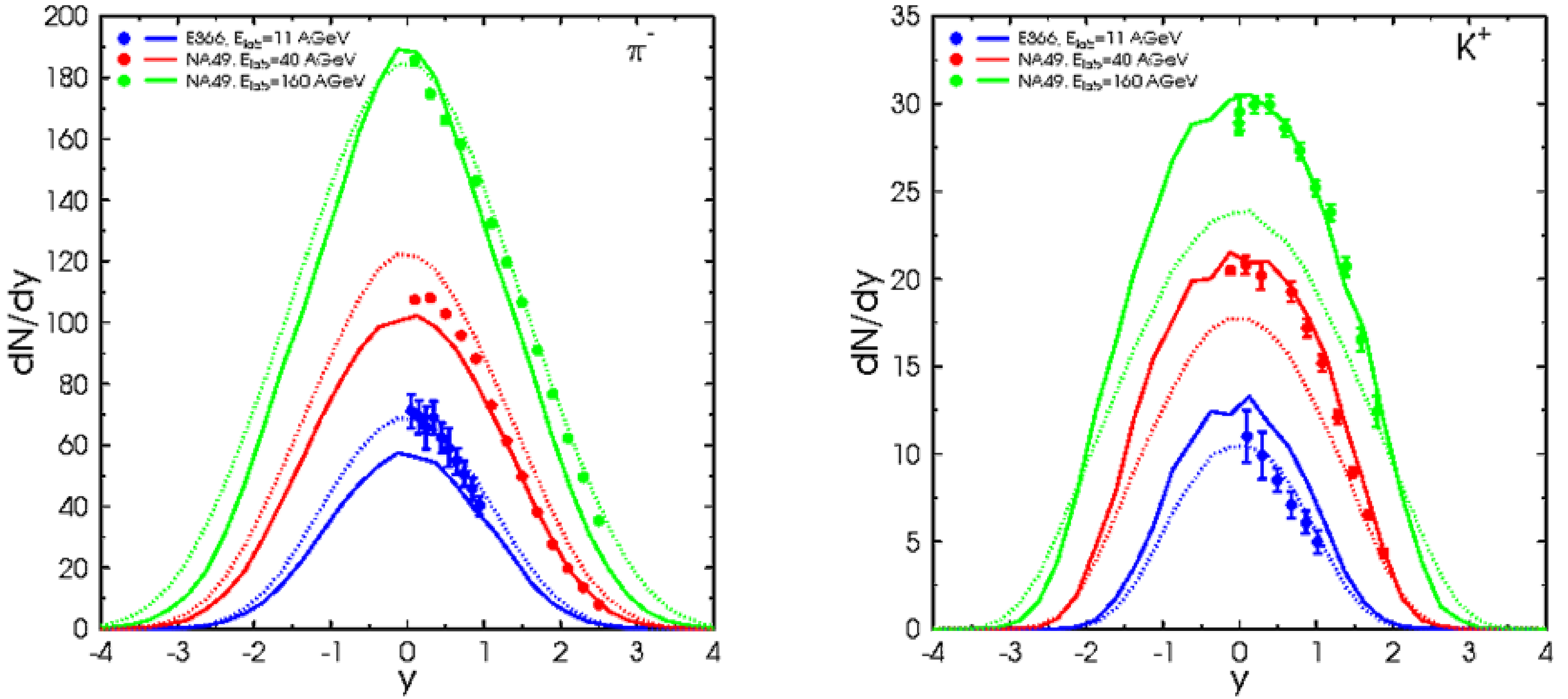
→ results for particle multiplicities from AGS to SPS are surprisingly **similar**

→ **strangeness** is enhanced in the hybrid approach due to local equilibration



Rapidity Spectra

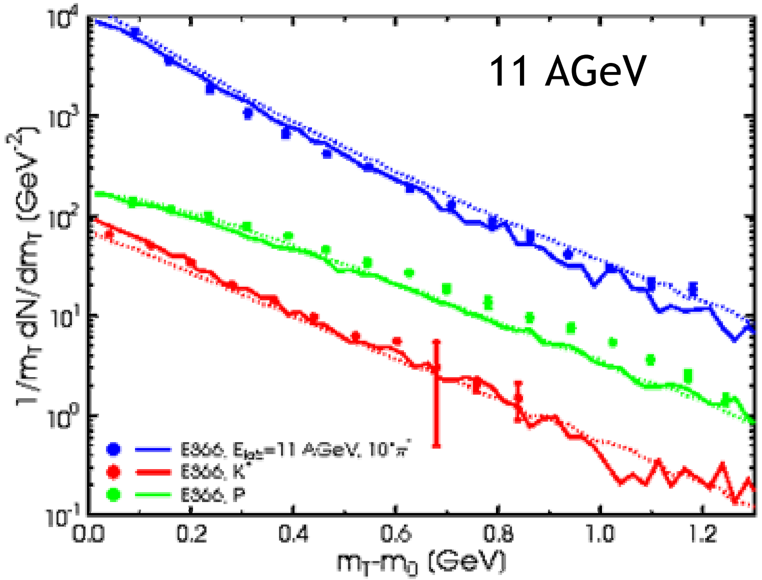
full lines: hybrid model
dotted lines: UrQMD-2.3
symbols: experimental data

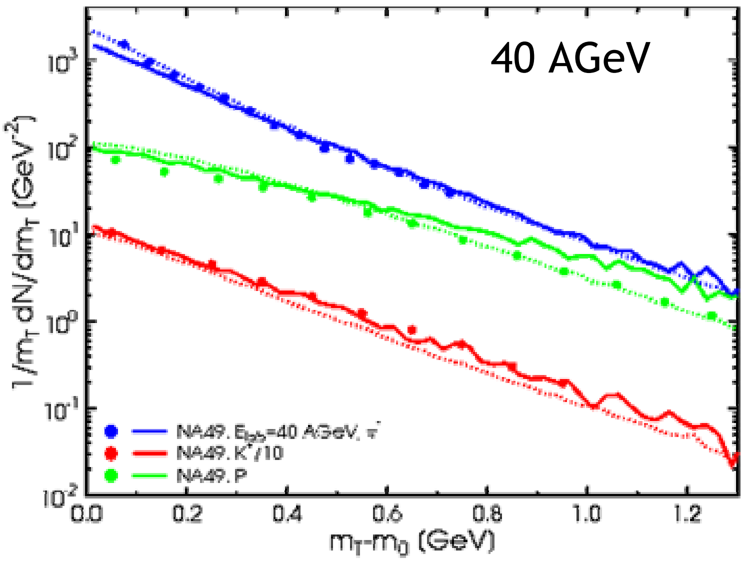


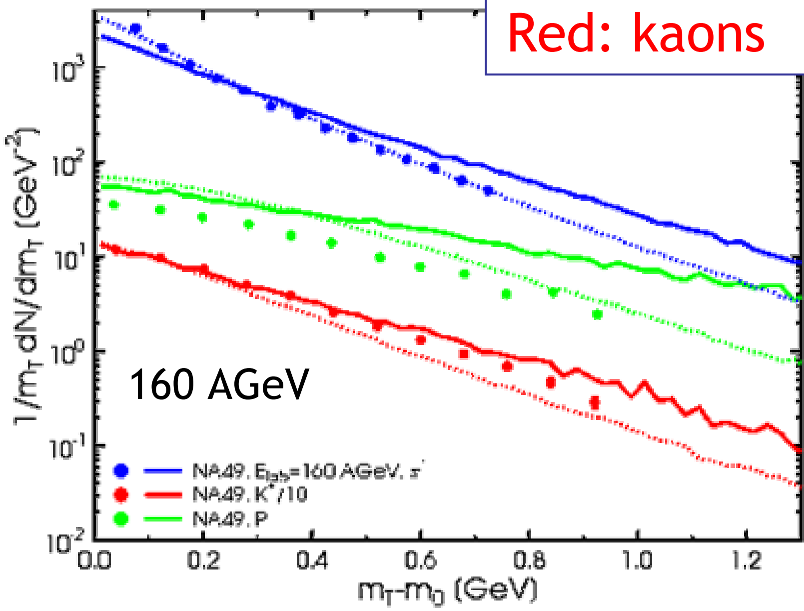
→ Rapidity spectra for pions and kaons have a very **similar shape** in both calculations

m_T spectra

Blue: pions
Green: protons
Red: kaons

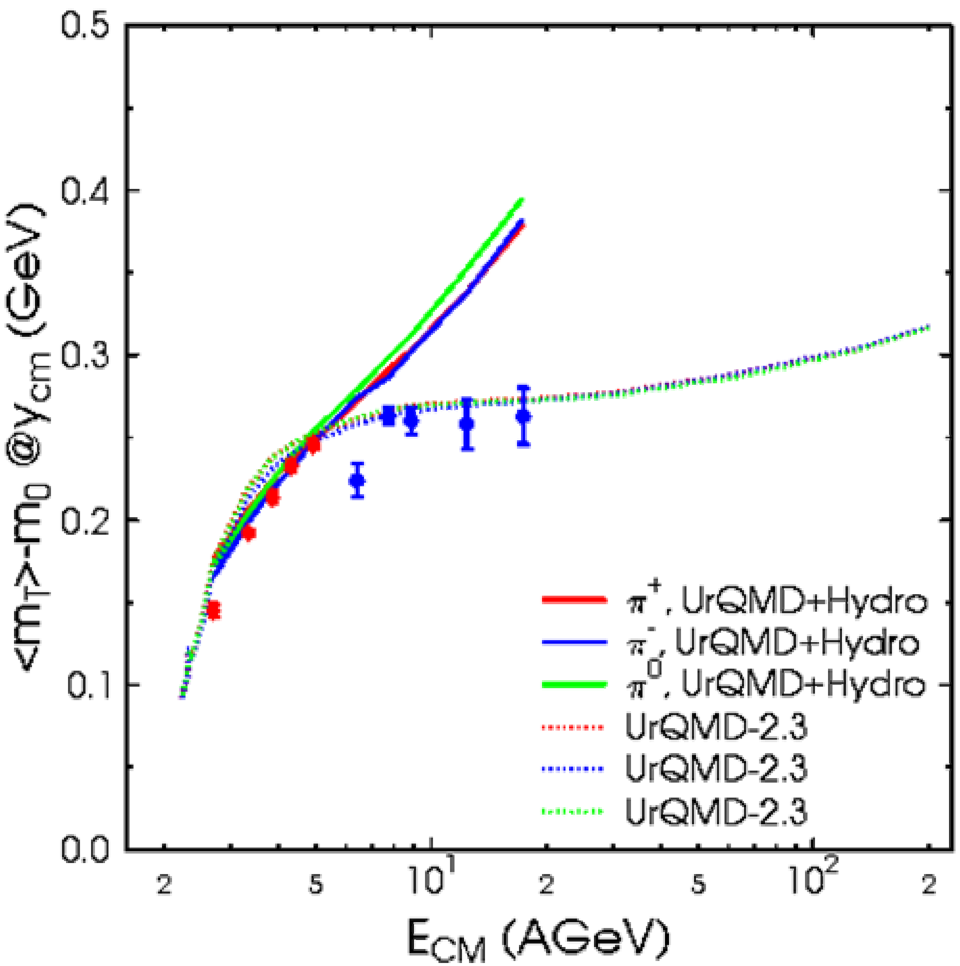






- m_T spectra are very similar at lower energies (11,40 AGeV)
- $<m_T>$ is higher in hydro calculation at E_{lab}=160 AGeV

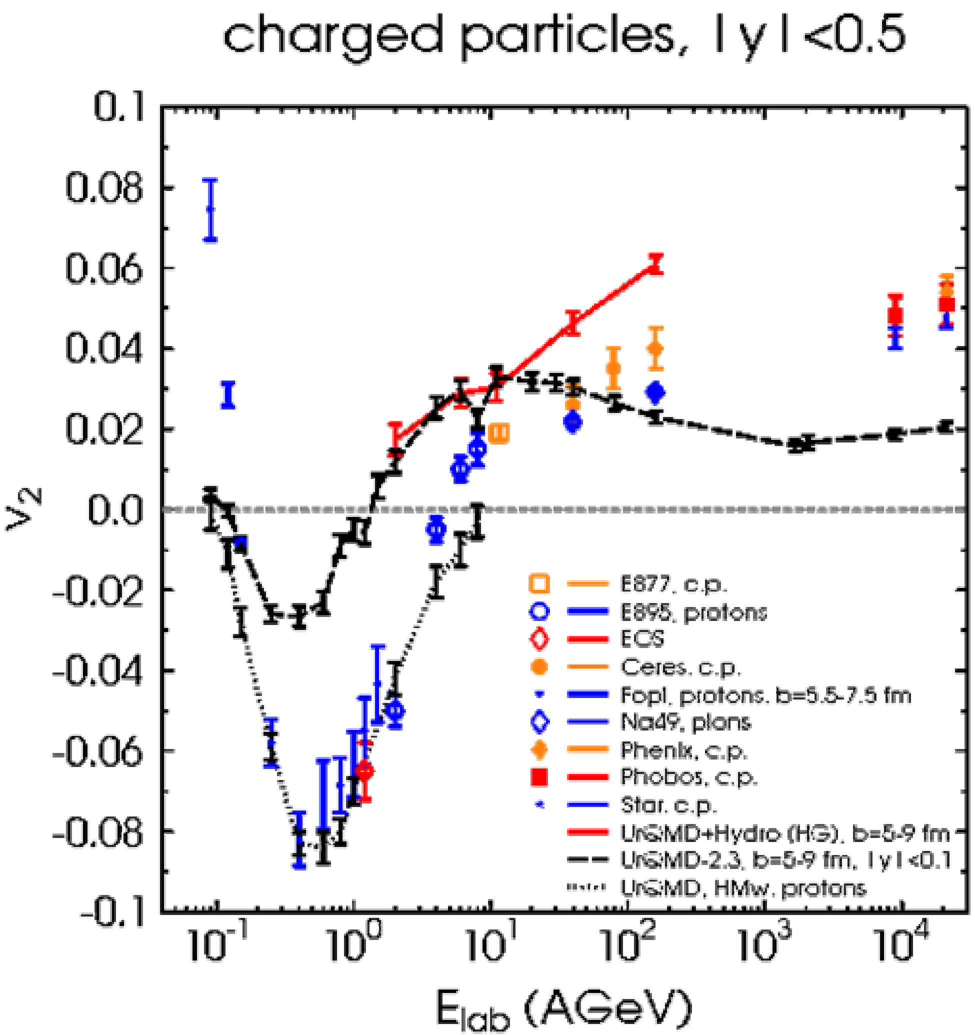
$\langle m_T \rangle$ Excitation Function



- Resonance excitations and non-equilibrium effects in intermediate energy regime lead to a **softening** of the EoS in pure UrQMD calculation
- hybrid calculation with hadronic EoS just rises as a function of beam energy

Elliptic Flow

- Smaller mean free path in the hot and dense phase leads to higher elliptic flow
- at lower energies: hybrid approach reproduces the pure UrQMD result
- analysis with different EoS including a phase transition is needed



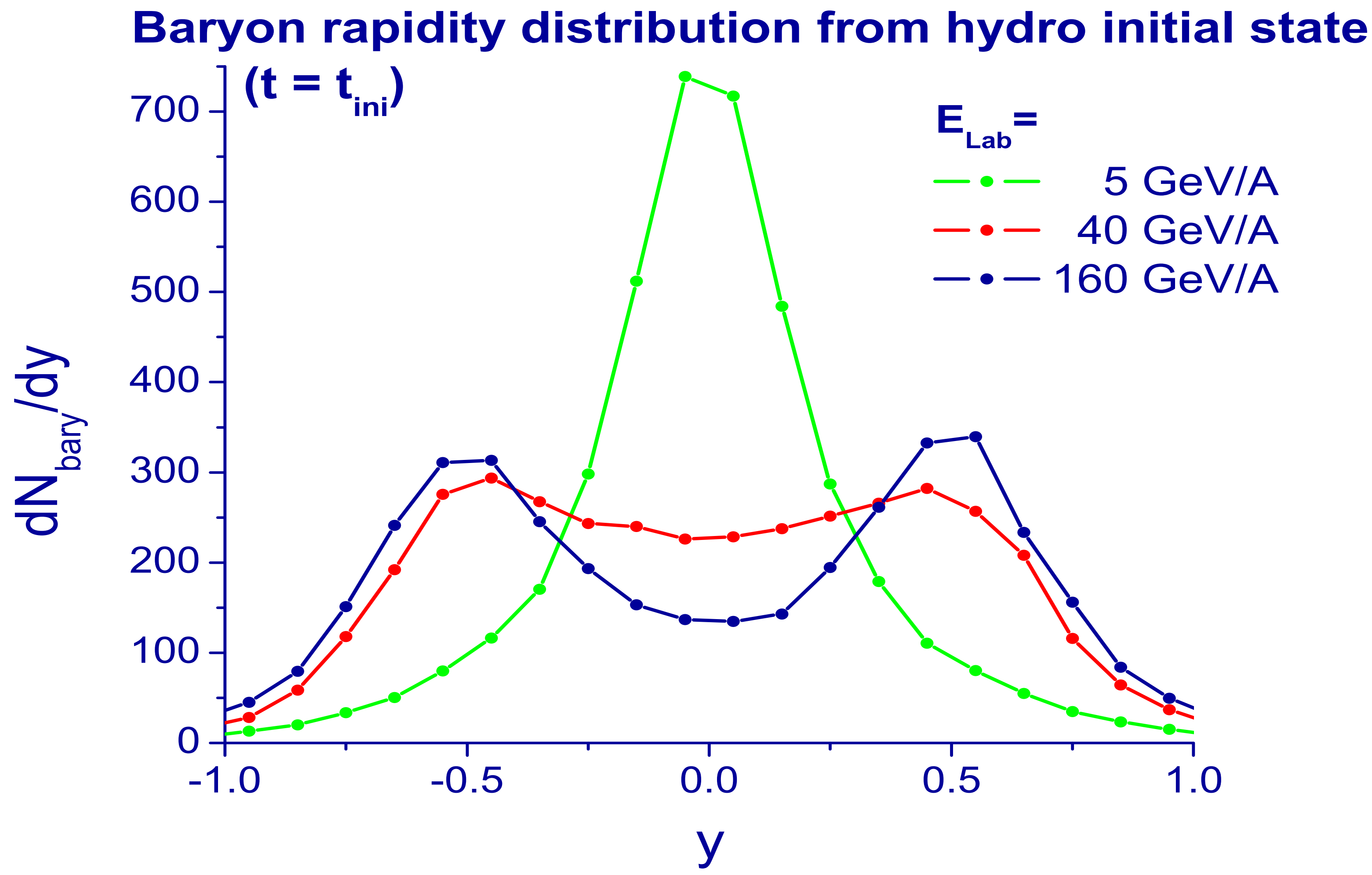
(H.P. et.al., Phys. Rev. C 74, 064908 (2006))

Conclusion and Outlook

- First results from the comparison of a transport and a hybrid calculation with the same initial conditions and freeze-out
  - Multiplicities are surprisingly similar
  - Strangeness is enhanced due to local equilibration
  - $\langle m_T \rangle$ and elliptic flow excitation function is different
- Further studies of different EoS with explicit phase transition are needed
- Calculations at higher energies (RHIC)

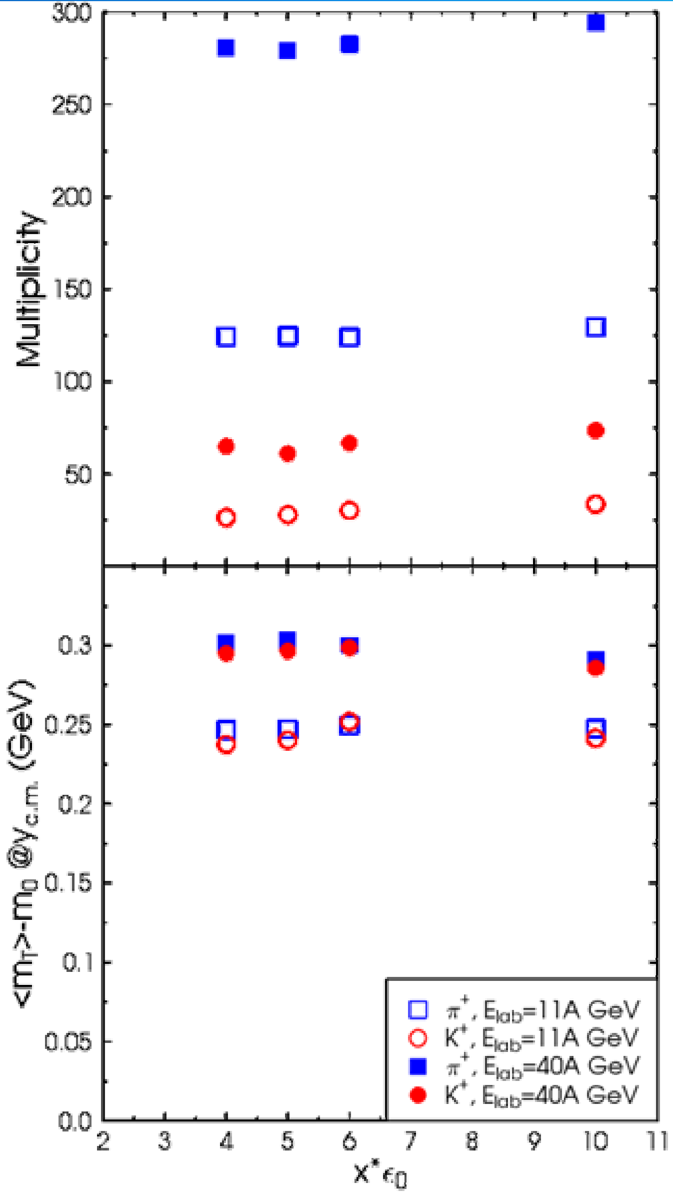
Backup

Initial State Baryon Density



Averaged over 10 events

Dependence on Freeze-out

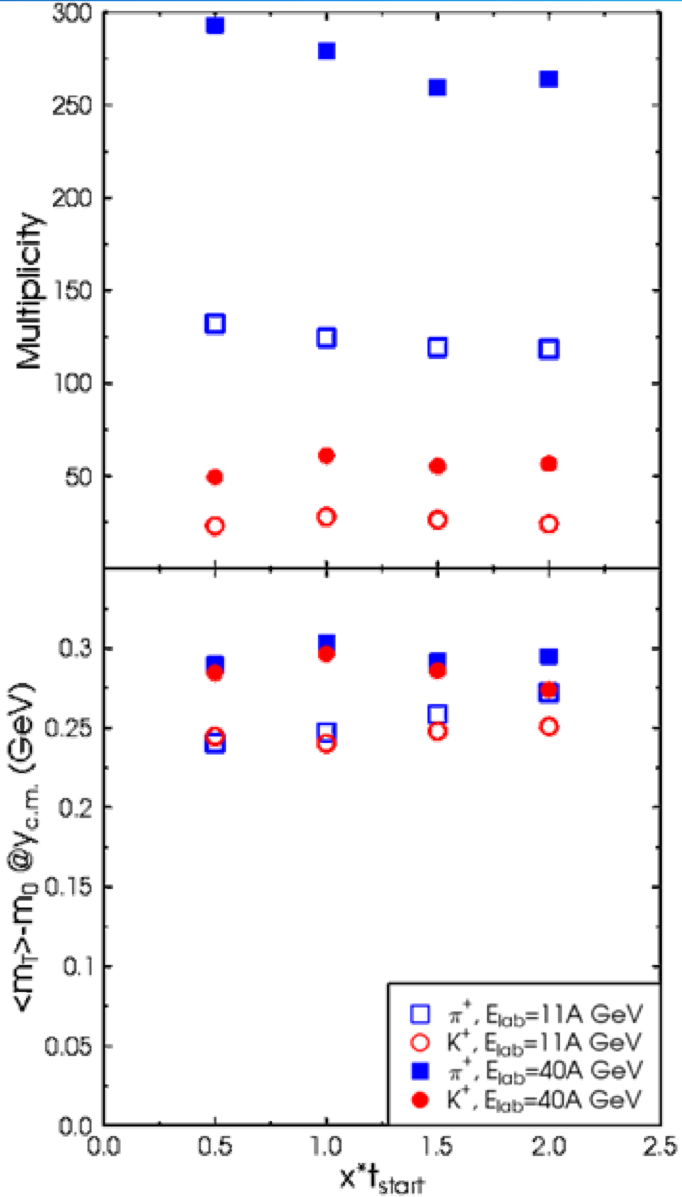


- Variation of the freeze-out criterium does not affect the meson multiplicities and mean transerve masses

Full symbols: 40 AGeV

Open symbols: 11 AGeV

Dependence on t_{start}

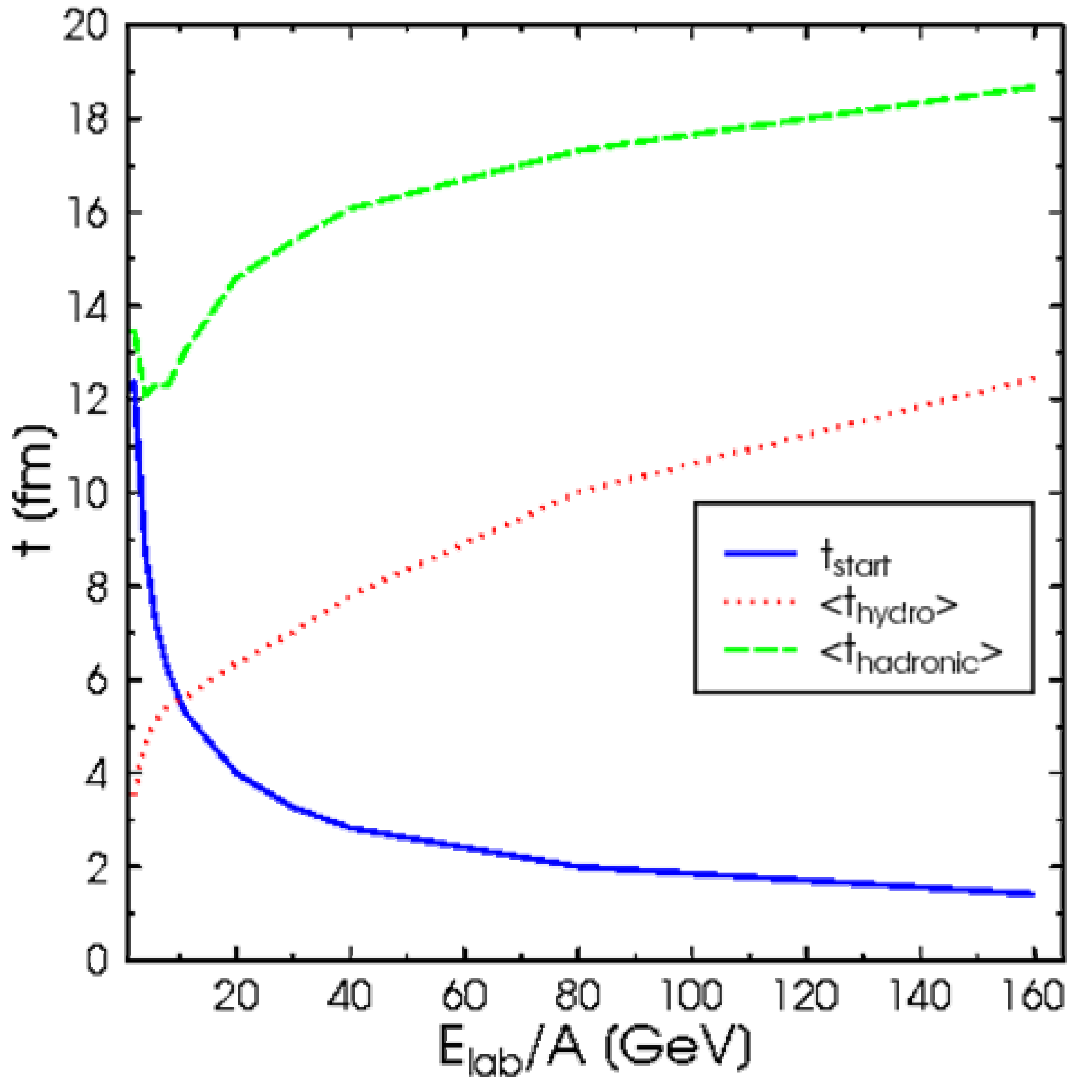


Variation of starting time by a factor 4 changes results only by 10 %

Full symbols: 40 AGeV

Open symbols: 11 AGeV

Time scales



20
18
16
14
12
10
8
6
4
2
0
t (fm)
20
40
60
80
100
120
140
160
Elab/A (GeV)
tstart
<thydro>
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Final State Interactions