Elliptic Flow Results From a Hybrid Model

Workshop on
„Flow and Dissipation in Ultrarelativistic Heavy Ion Collisions"
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Thanks to: Jan Steinheimer, Marcus Bleicher
Dirk Rischke (for providing the hydrodynamics code)

Outline

- Model Description
  - Initial Conditions
  - Equations of State (EoS)
  - Freeze-out Scenarios
- Elliptic Flow
  - Comparison of Initial States
  - Time Evolution
  - Dependence on the EoS
  - Influence of the Transition Criterion
- Conclusions and Outlook

(H.P. et al., PRC 78:044901, 2008, arXiv: 0806.1695)

Hybrid Approaches

- Hadronic freezeout following a first order hadronization phase transition in ultrarelativistic heavy ion collisions.
  S.A. Bass, A. Dumitru, M. Bleicher, L. Bravina, E. Zabrodin, H. Stoecker, W. Greiner, Phys.Rev.C60:021902,1999
- Dynamics of hot bulk QCD matter: From the quark gluon plasma to hadronic freezeout.
  S.A. Bass, A. Dumitru, Phys.Rev.C61:064909,2000
- Flow at the SPS and RHIC as a quark gluon plasma signature.
  D. Teaney, J. Lauret, Edward V. Shuryak, Phys.Rev.Lett.86:4783-4786,2001
- A Hydrodynamic description of heavy ion collisions at the SPS and RHIC.
  D. Teaney, J. Lauret, E.V. Shuryak, e-Print: nucl-th/0110037
- Hadronic dissipative effects on elliptic flow in ultrarelativistic heavy-ion collisions.
  T. Hirano, U. Heinz, D. Kharzeev, R. Lacey, Y. Nara, Phys.Lett.B636:299-304,2006
- 3-D hydro + cascade model at RHIC.
  C. Nonaka, S.A. Bass, Nucl.Phys.A774:873-876,2006
- Results On Transverse Mass Spectra Obtained With Nexspherio
  F. Grassi, T. Kodama, Y. Hama, J.Phys.G31:S1041-S1044,2005
- On the Role of Initial Conditions and Final State Interactions in Ultrarelativistic Heavy Ion Collisions
  K. Werner, T. Hirano, I. Karpenko, T. Pierog, S. Porteboeuf, M. Bleicher, S. Haussler J.Phys.G36:064030, 2009

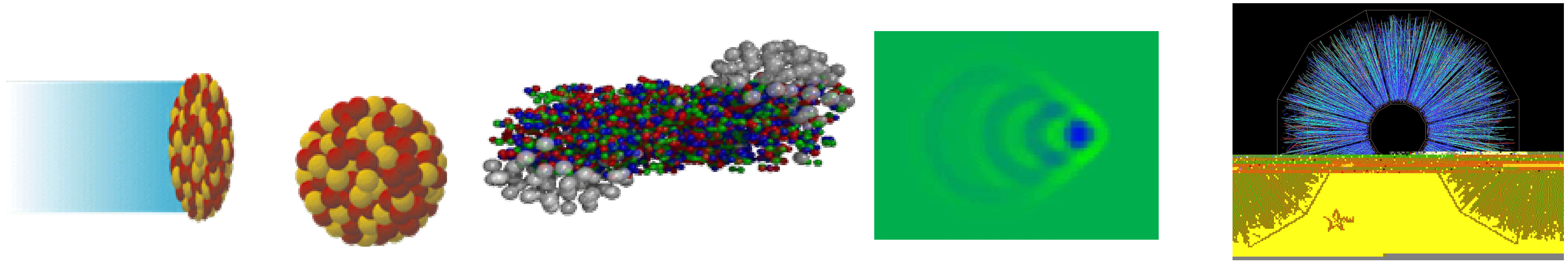
Motivation

- Exploring the differences between transport and hydrodynamics within the same initial conditions and freeze-out
- Calculation with different EoS without adjusting anything else
- Investigate effects of ingredients in a systematic way
- Many observables within the same dynamical approach

→ Here: Concentrate on elliptic flow

Principle Set-Up

- 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)

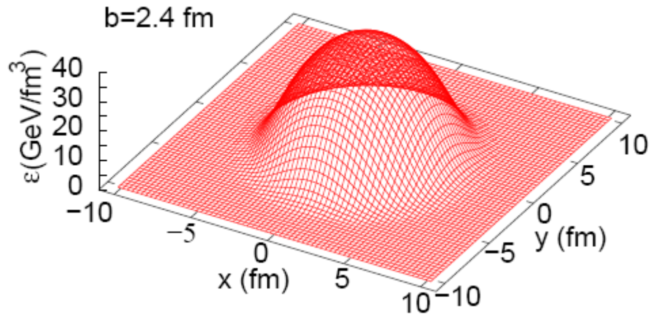
UrQMD-2.3p1 is available at www.th.physik.uni-frankfurt.de/~urqmd

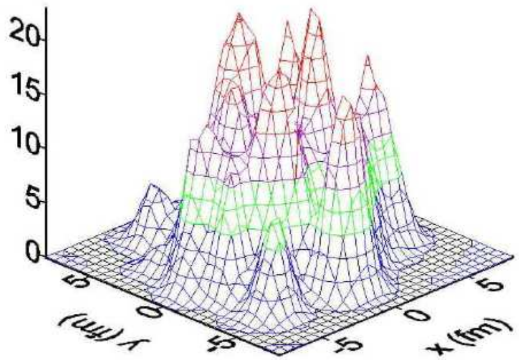
Initial State

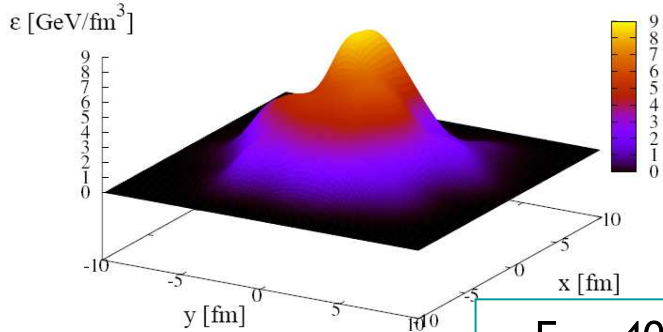
- Contracted nuclei have passed through each other

$$t_{start} = \frac{2R}{\gamma v}$$

  - Energy is deposited
  - Baryon currents have separated
- Energy-, momentum- and baryon number densities are mapped onto the hydro grid
- **Event-by-event fluctuations** are taken into account
- Spectators are propagated separately in the cascade







E_{lab}=40 AGeV
b=0 fm

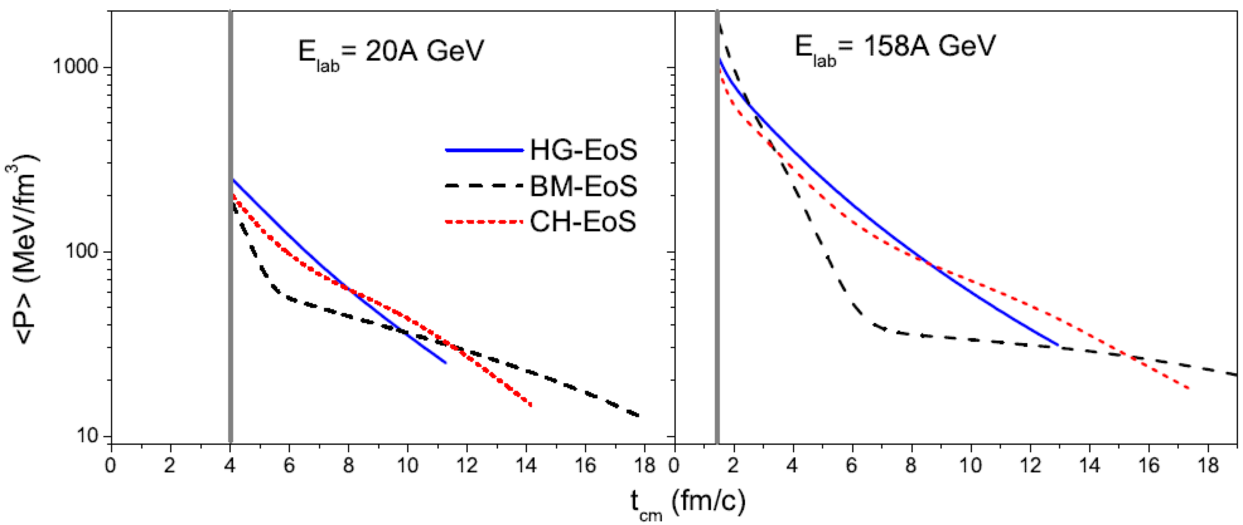
(nucl-th/0607018, nucl-th/0511021)

(J.Steinheimer et al., PRC 77,034901,2008)

(3+1)d Hydrodynamic Evolution

Ideal relativistic one fluid dynamics employing:

- HG: **Hadron gas** including the same degrees of freedom as in UrQMD (all hadrons with masses up to 2.2 GeV)
- CH: **Chiral EoS** from SU(3) hadronic Lagrangian with first order transition and critical endpoint
- BM: **Bag Model EoS** with a strong first order phase transition between QGP and hadronic phase



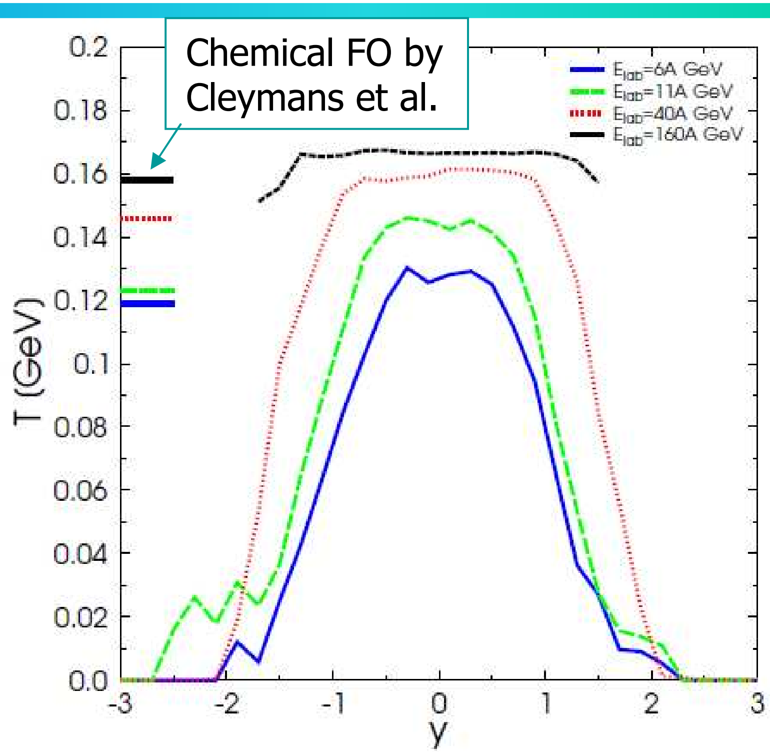
D. Rischke et al., NPA 595, 346, 1995,

D. Rischke et al., NPA 595, 383, 1995

Papazoglou et al., PRC 59, 411, 1999

Freeze-out

1) Transition from hydro to transport when ε < 730 MeV/fm³ ($\approx 5 * \varepsilon_0$) in all cells of one transverse slice (**Gradual freeze-out**, GF)
   → iso-eigentime criterion
2) Transition when $\varepsilon < 5^* \varepsilon_0$ in all cells (**Isochronuous** freeze-out, IF)



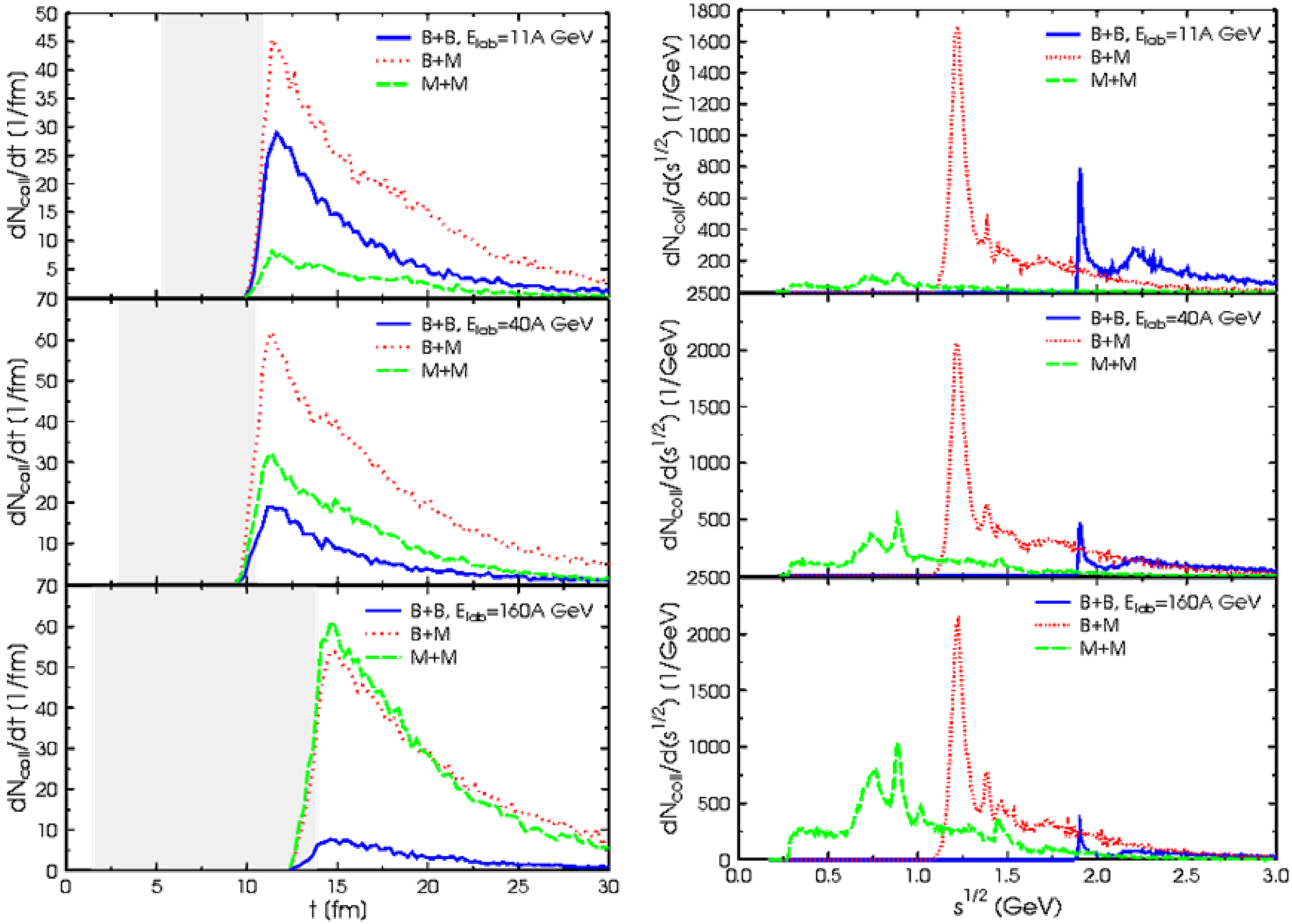
- Particle distributions are generated according to the **Cooper-Frye** formula

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

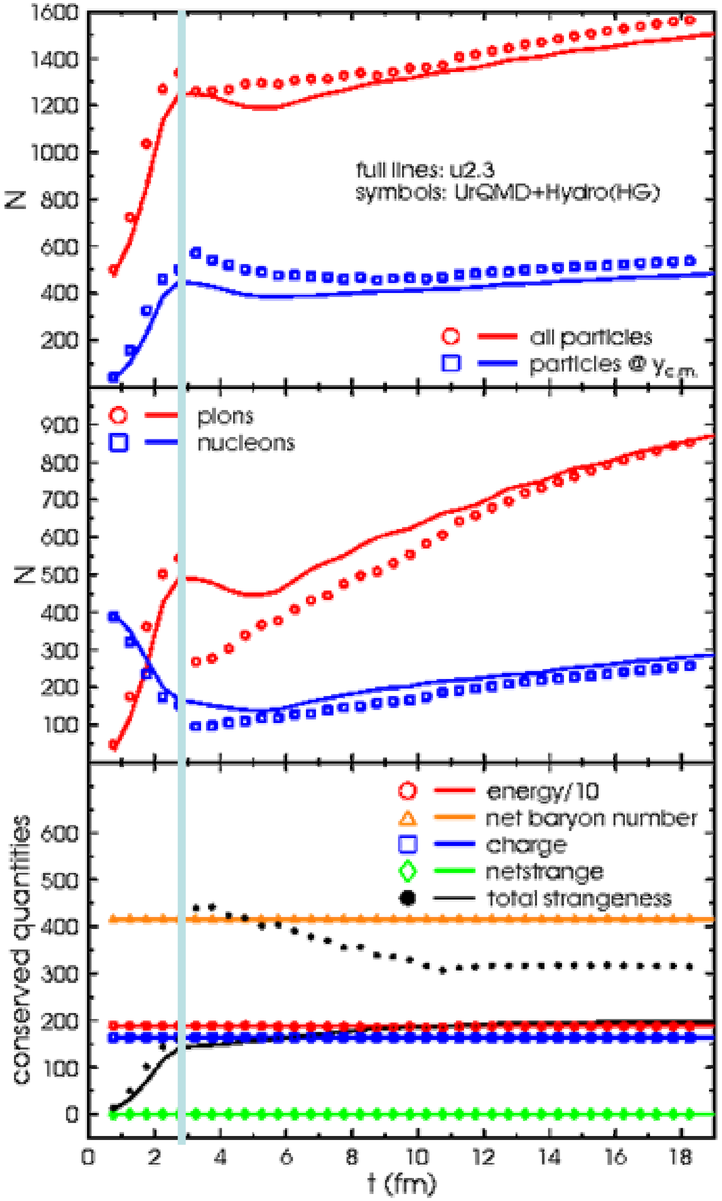
with boosted Fermi or Bose distributions f(x,p) including μ_B and μ_S

- Rescatterings and final decays calculated via **hadronic cascade** (UrQMD)

Final State Interactions



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 vs. Energy

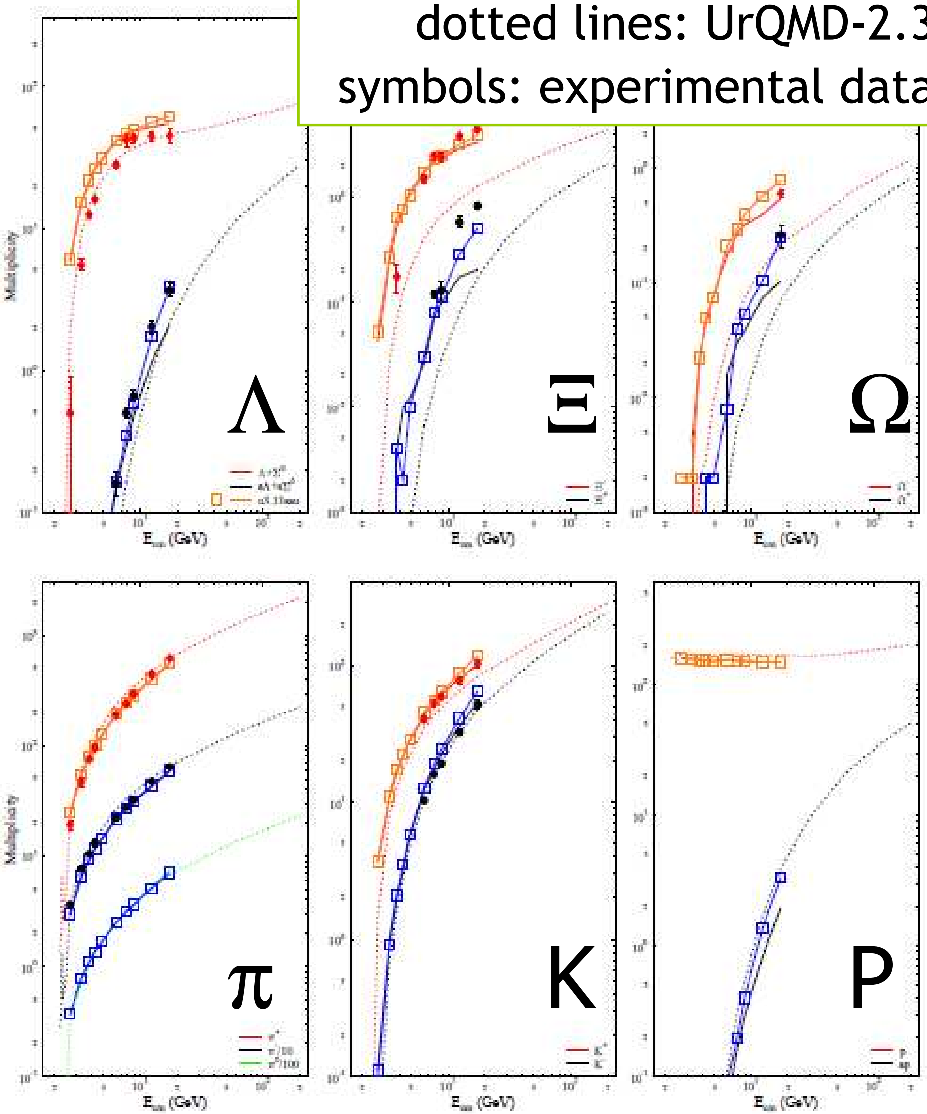
- Both models are purely hadronic without phase transition, **but** different underlying dynamics

→ Results for particle multiplicities from AGS to SPS are **similar**

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

Central (b<3.4 fm) Pb+Pb/Au+Au collisions

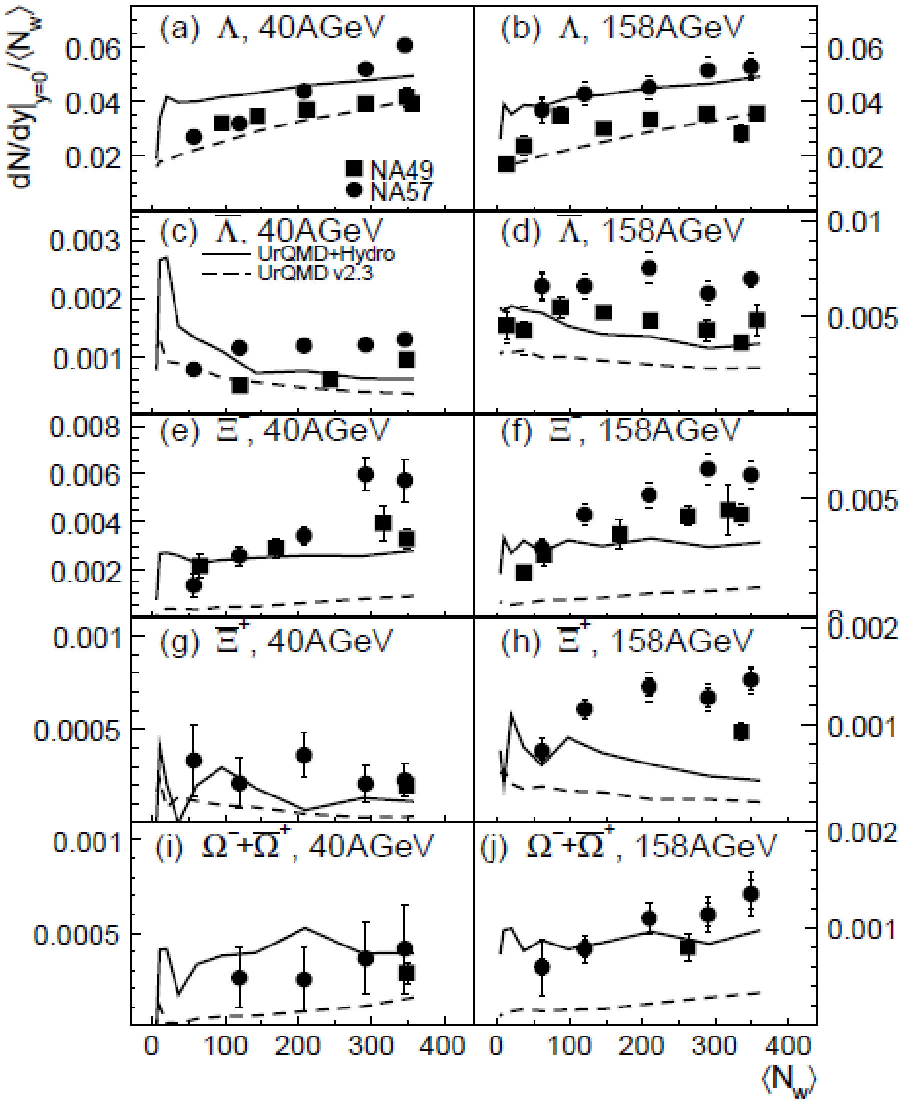
full lines: hybrid model (IF)
squares: hybrid model (GF)
dotted lines: UrQMD-2.3
symbols: experimental data



Data from E895, NA49

(H.P. et al., PRC 78:044901, 2008)

Strangeness Centrality Dependence



Pb+Pb collisions for different centralities

- Thermal production of the particles at transition from hydro to transport
- Centrality dependence of **multistrange hyperons** is improved

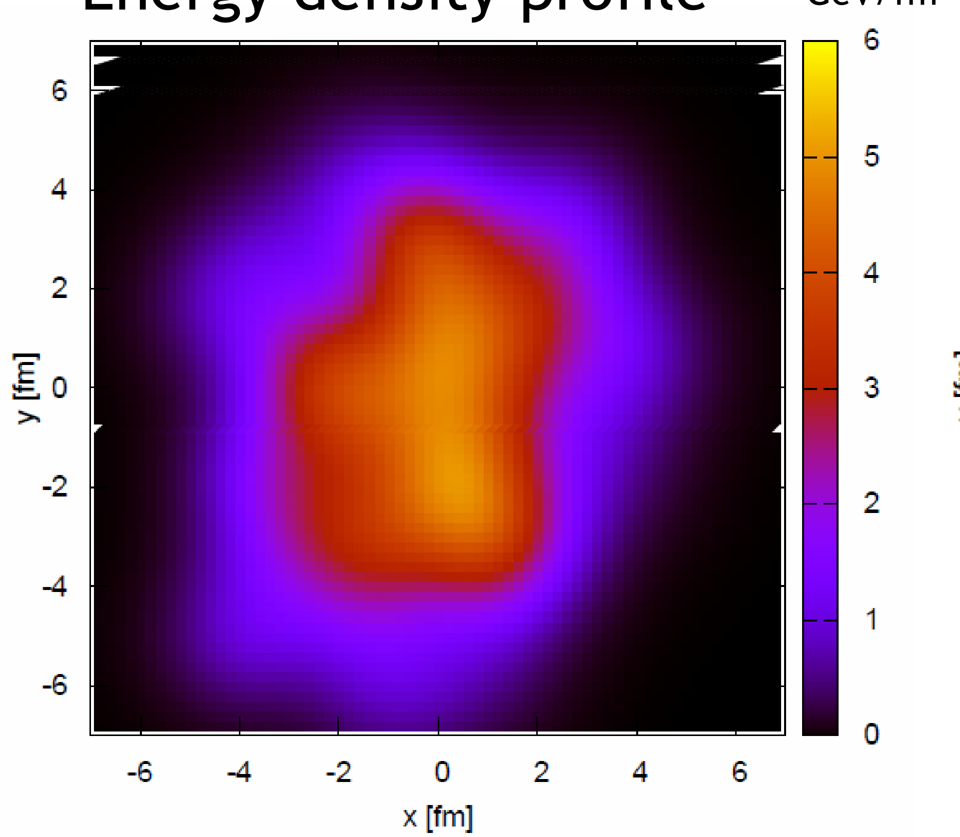
——	hybrid model (GF)
-----	UrQMD-2.3

(H.P. et al., arXiv: 0903.0396)

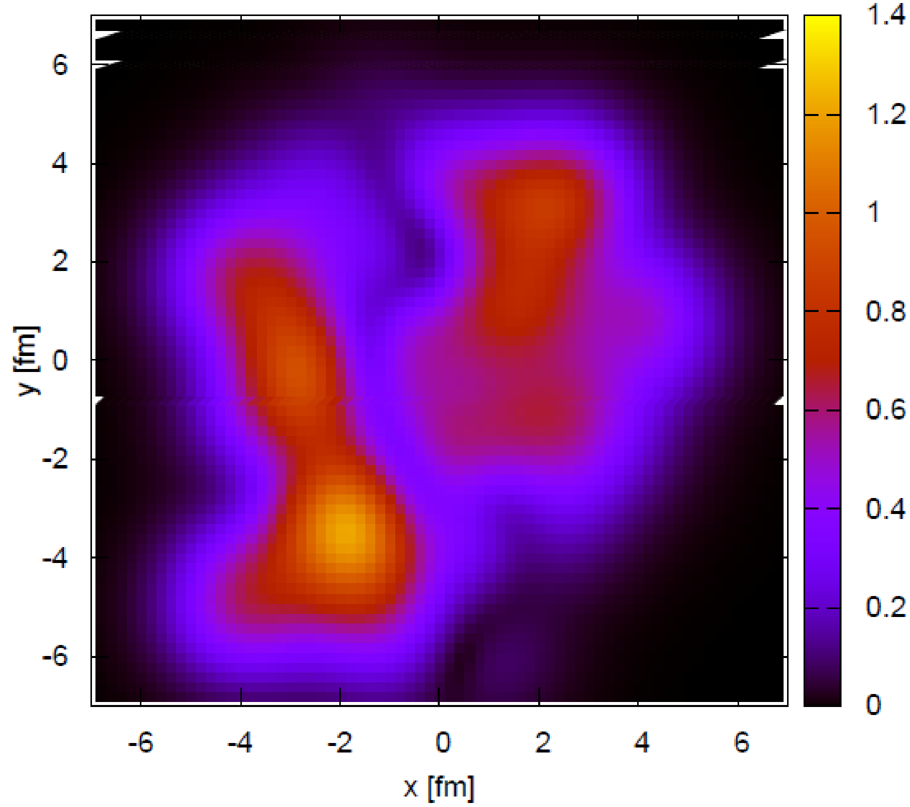
Initial State for Non-Central Collisions

Pb+Pb at E_{lab}=40 AGeV with b= 7fm at t_{start}=2.83 fm

Energy density profile



Weighted velocity profile



→Event-by-event fluctuations are taken into account

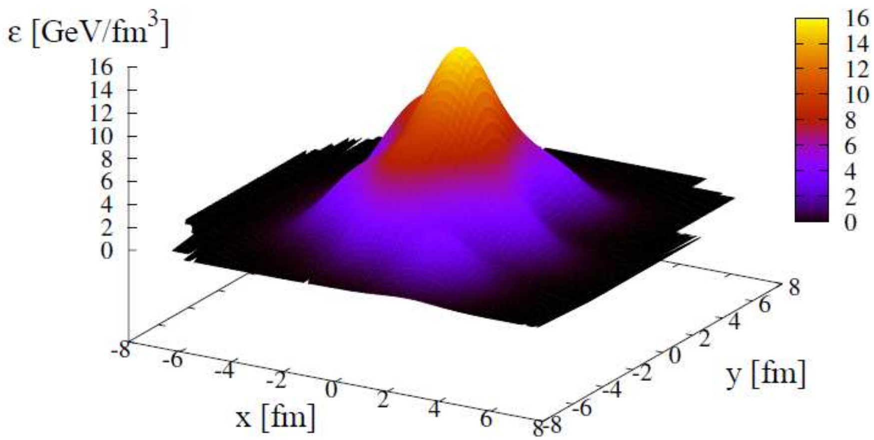
(H.P. et.al., PRC 79, 054904, 2009)

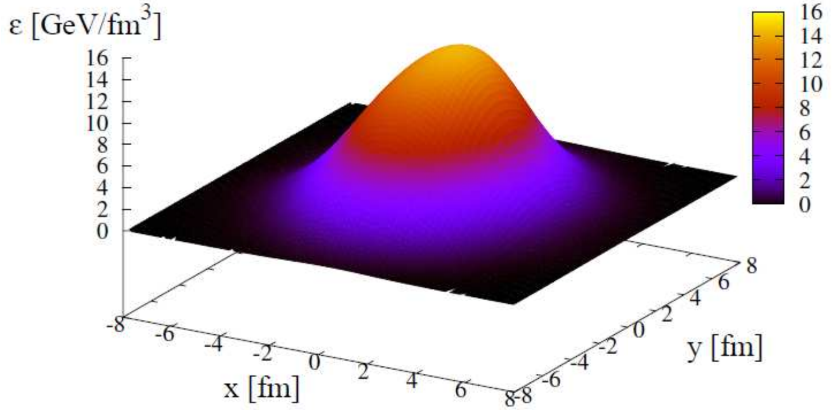
Comparison of Initial Conditions

E_{lab}=160A GeV, mid-central

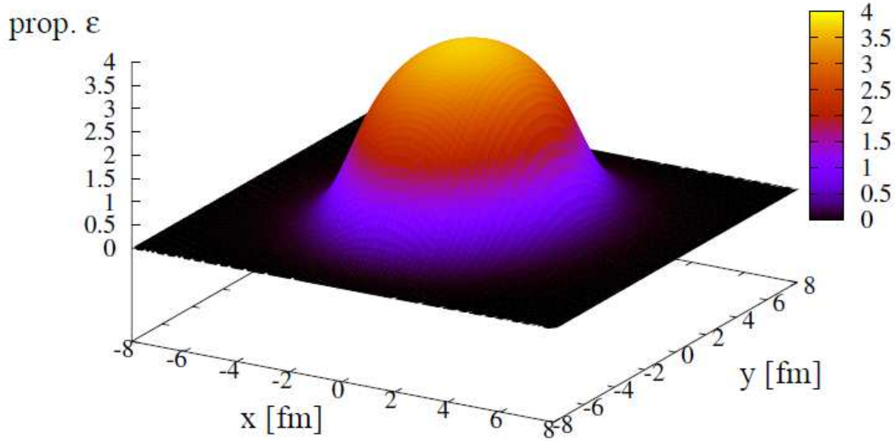
Averaged (over 100 events)

Fluctuating (default)





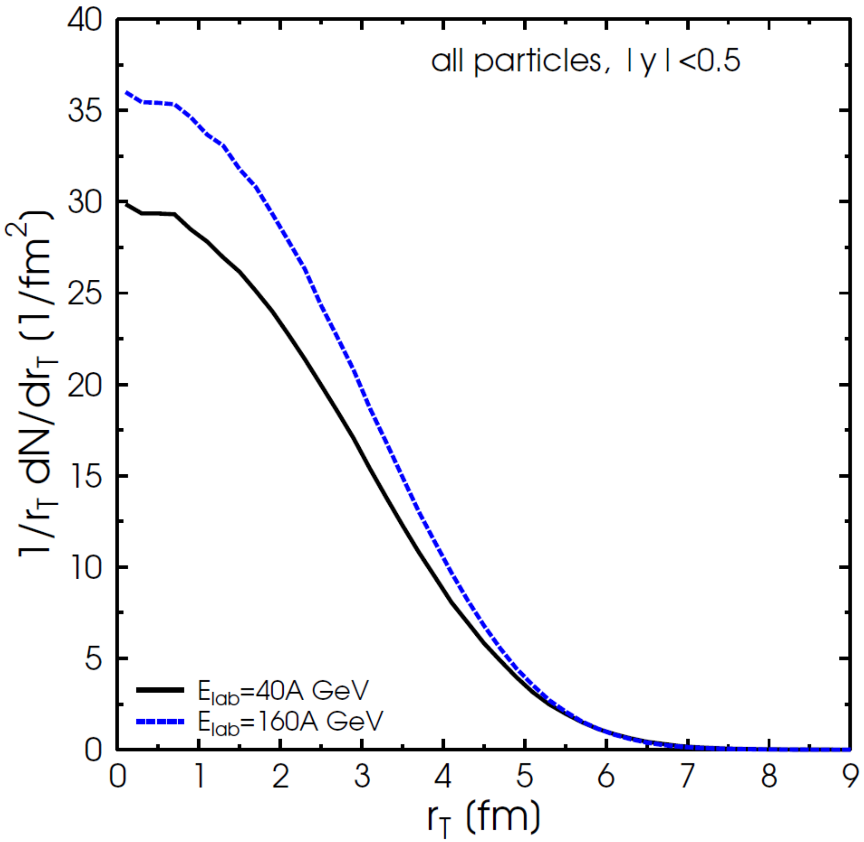
Glauber (N_{part})

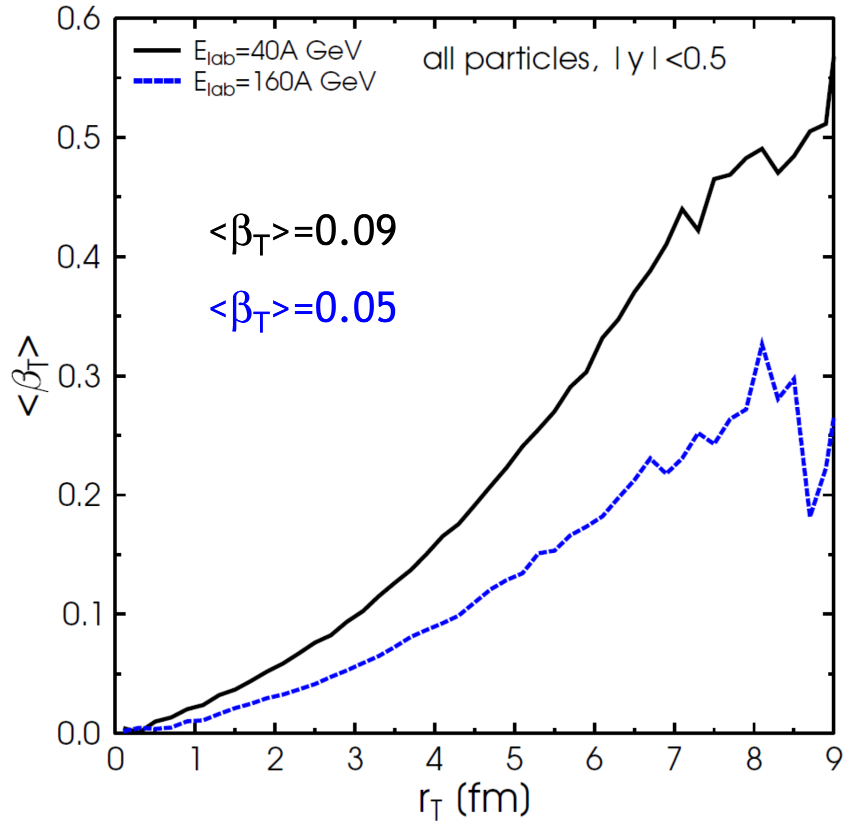


- UrQMD initial conditions have a different shape than the ones from a Glauber model (parameters taken from Teaney et al. nucl-th/0110037)

Initial Transverse Velocity Profile

- The initial velocity is finite in transverse direction

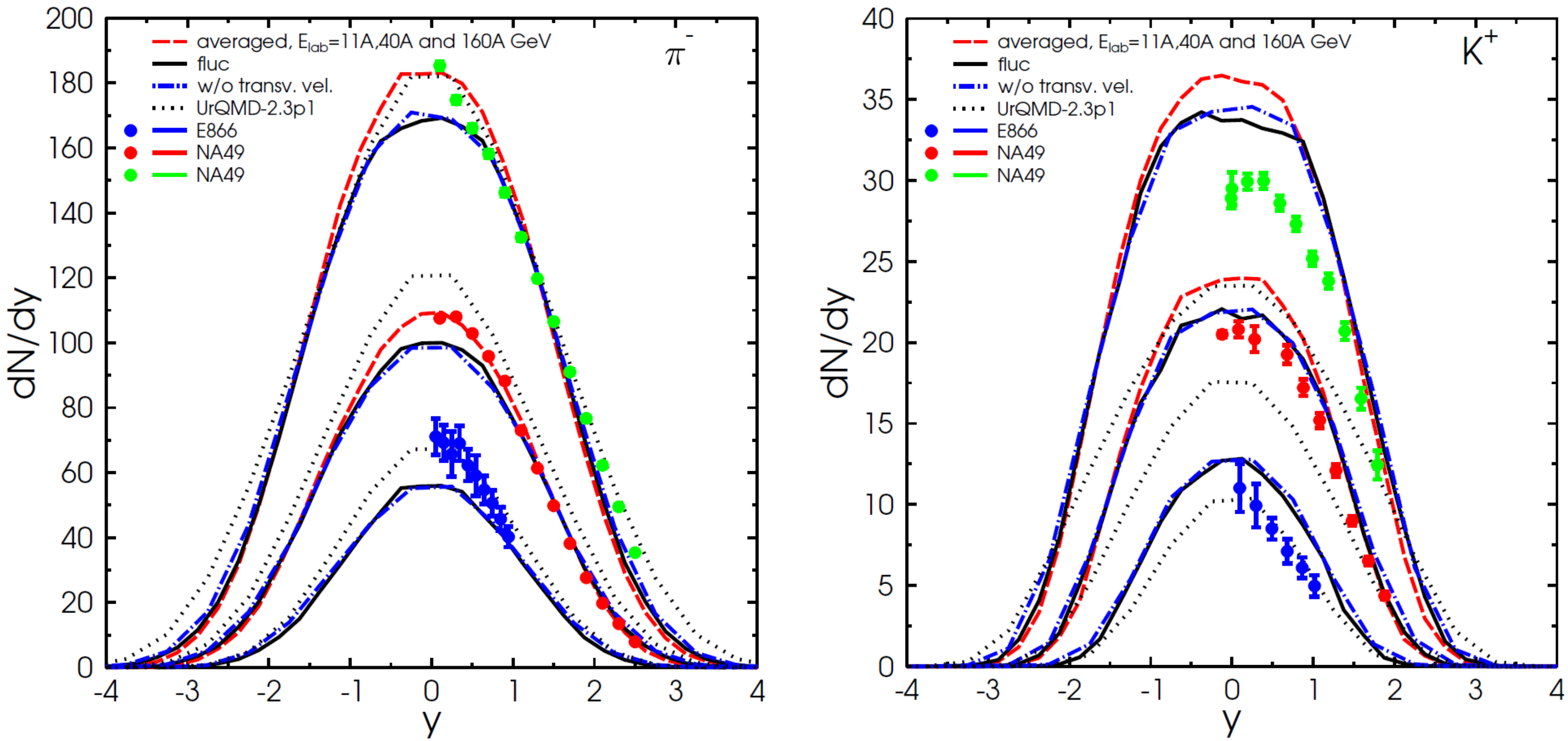




→ Test influence by setting v_x and v_y to zero

Mid-central (b=5-9 fm) Pb+Pb collisions

Rapidity Spectra

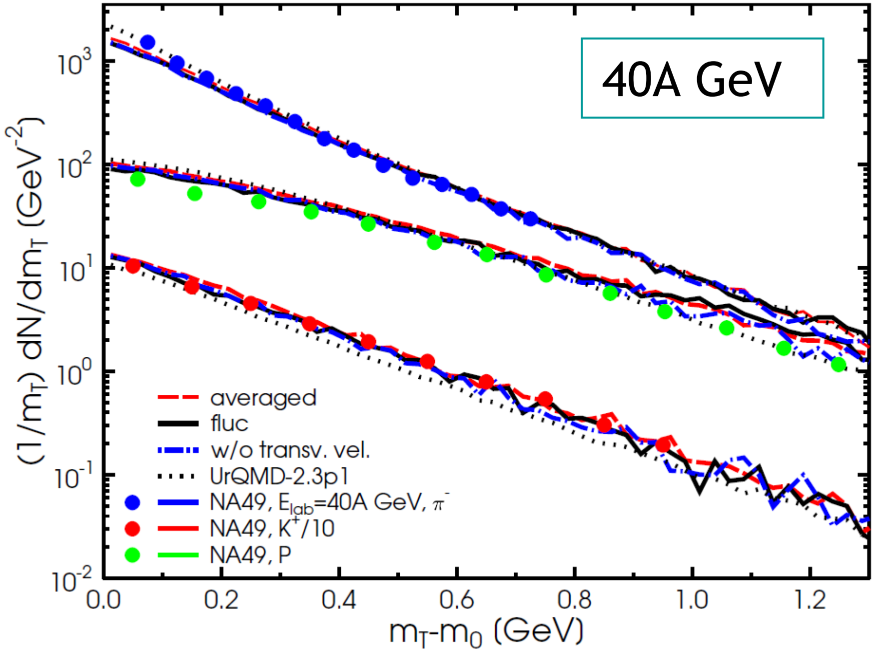


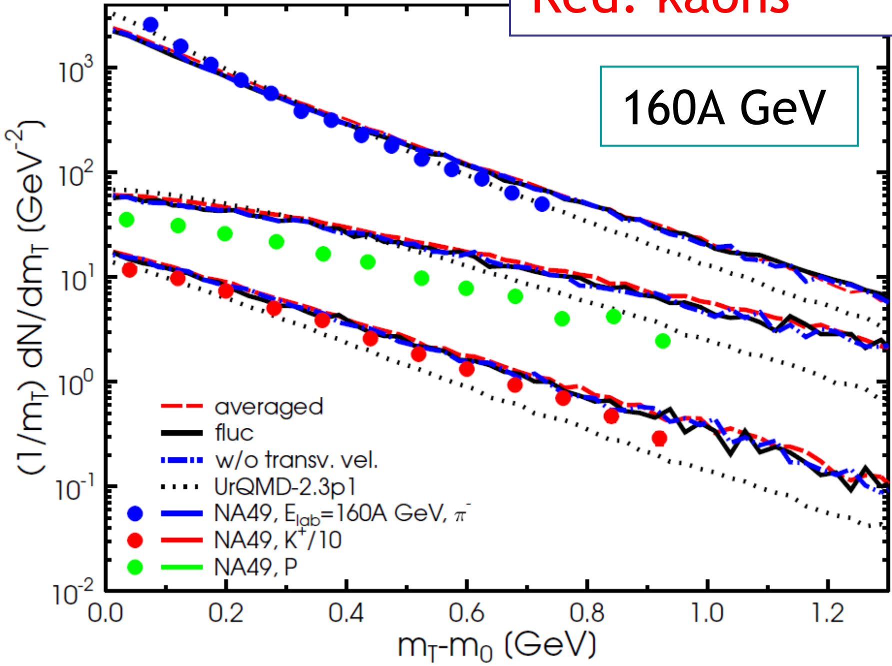
→ Rapidity spectra for pions and kaons are **steeper** for averaged initial conditions and **independent** of the initial transverse velocity profiles

Central (b<3.4 fm) Pb+Pb/Au+Au collisions

Transverse Mass Spectra

Blue: pions
Green: protons
Red: kaons

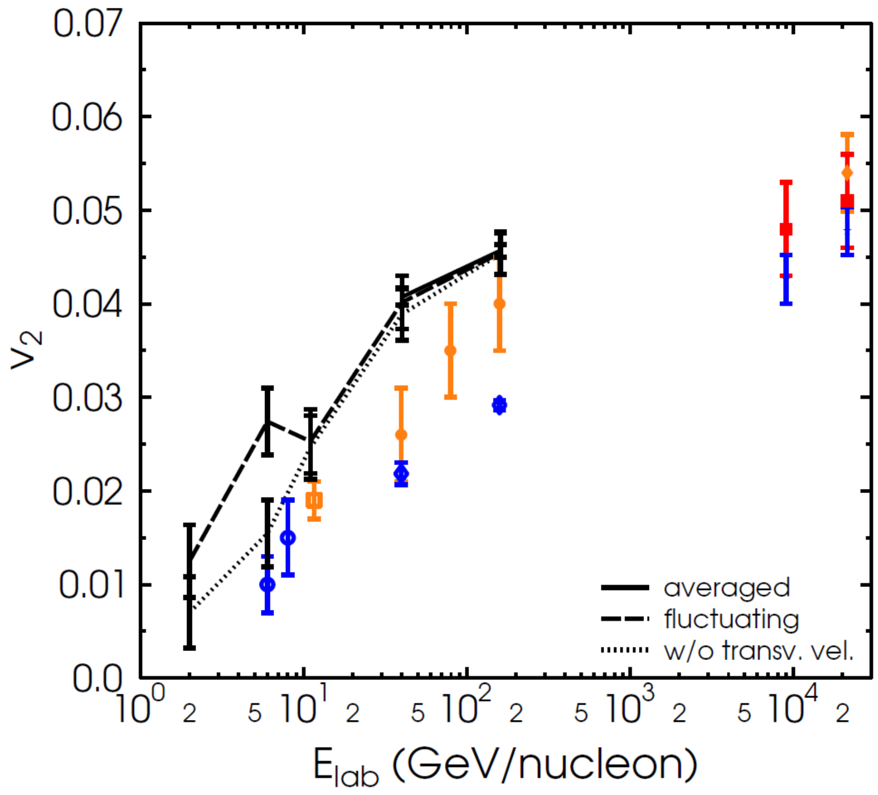


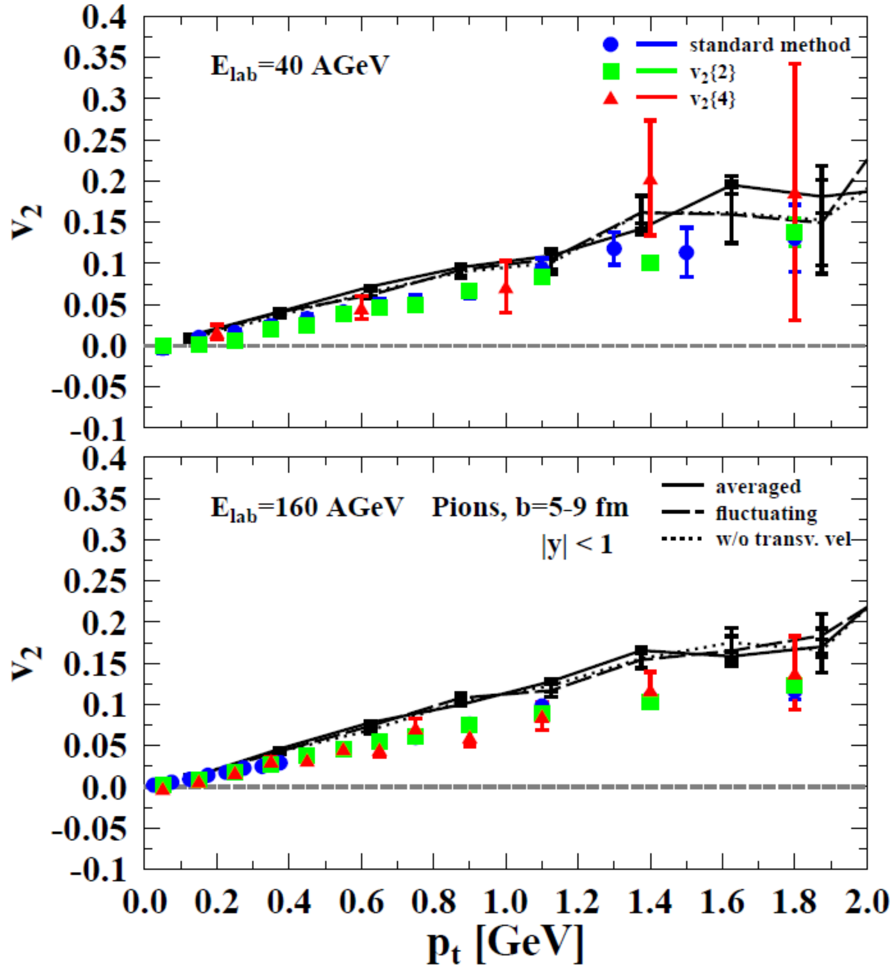


- The **transverse mass** distributions for pions, kaons and protons do not dependent on the initial conditions
- Difference in the **dynamics** between hydro and transport becomes visible at 160A GeV

Central (b<3.4 fm) Pb+Pb collisions

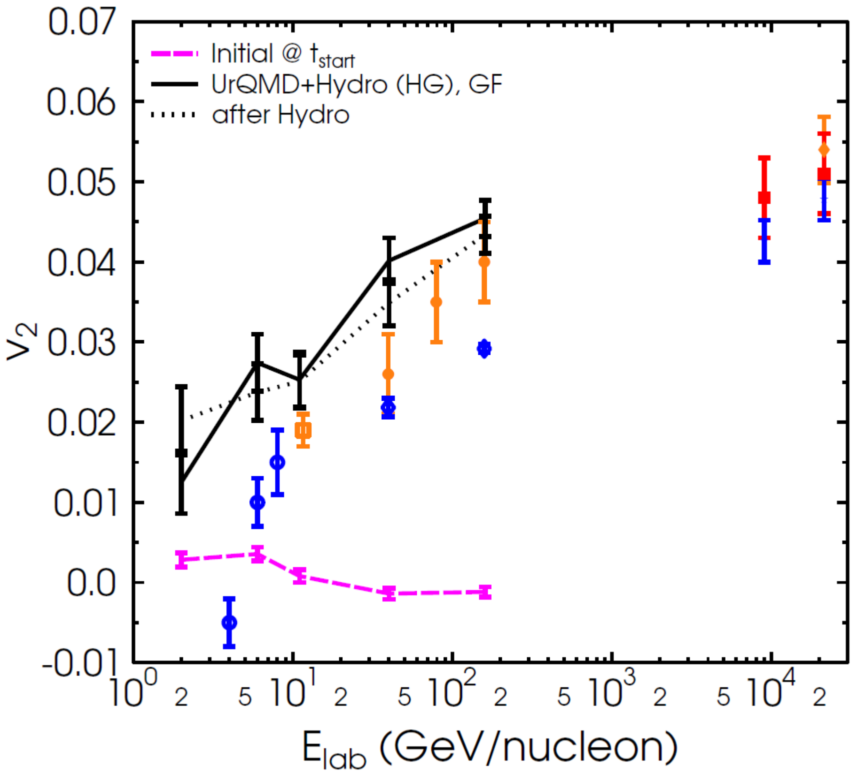
Elliptic Flow-Initial Conditions

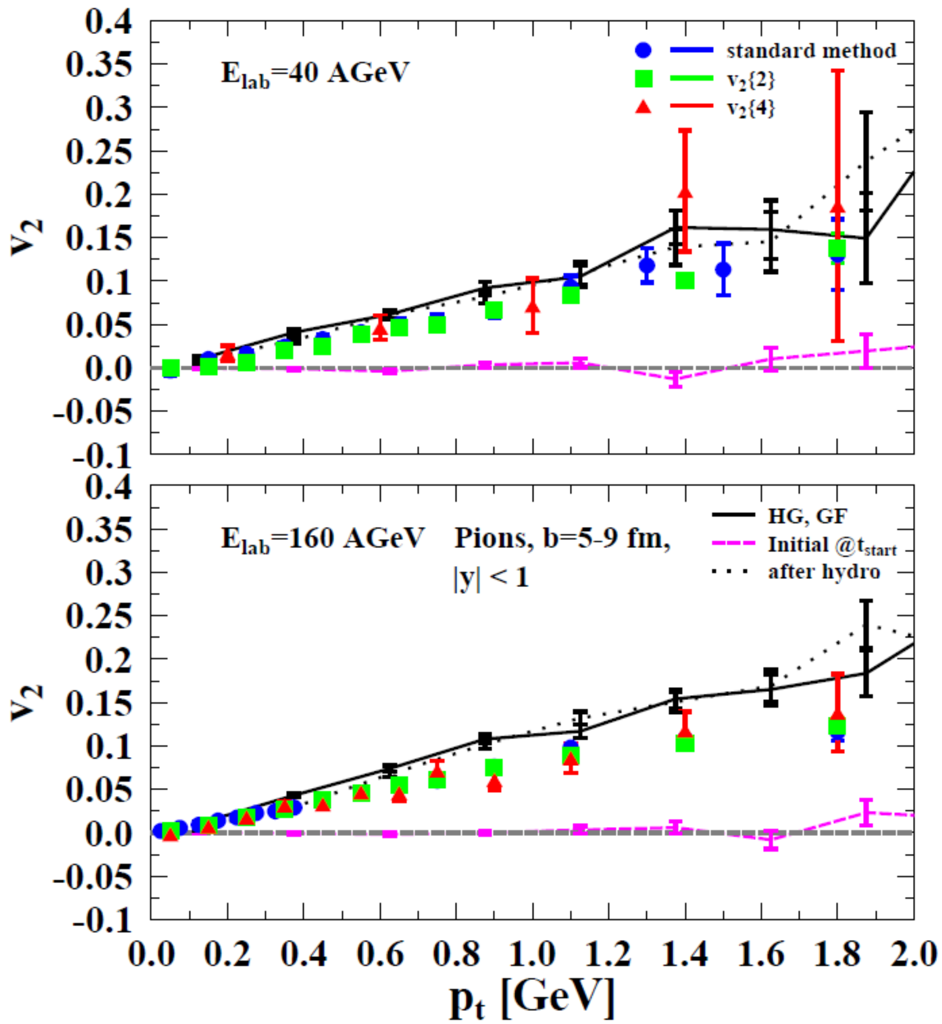




- v_2 is largely insensitive to the initial conditions from **UrQMD** with respect to fluctuations and inital velocity profile

Flow from Different Stages

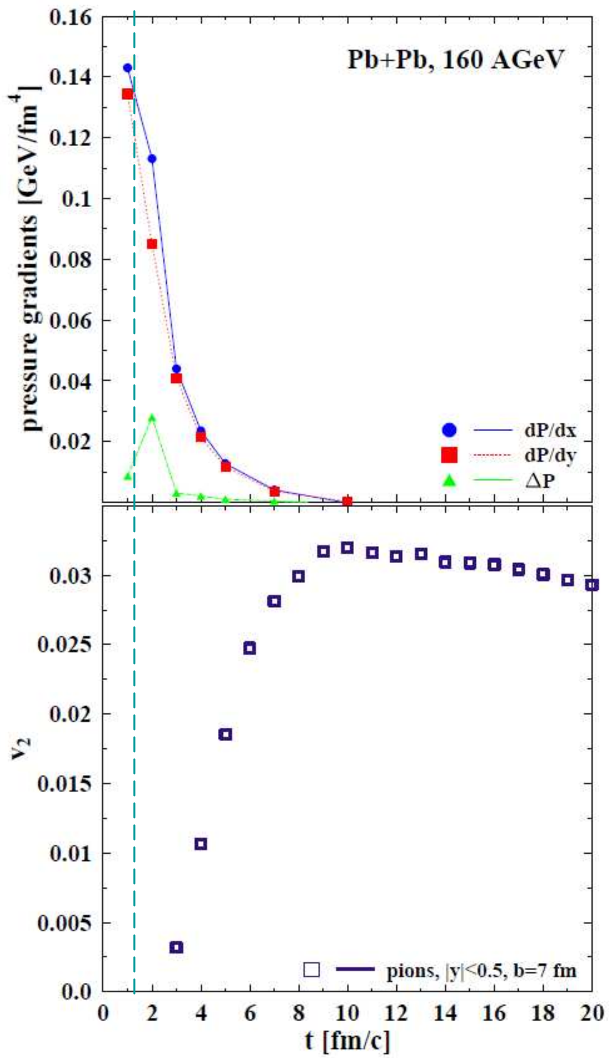


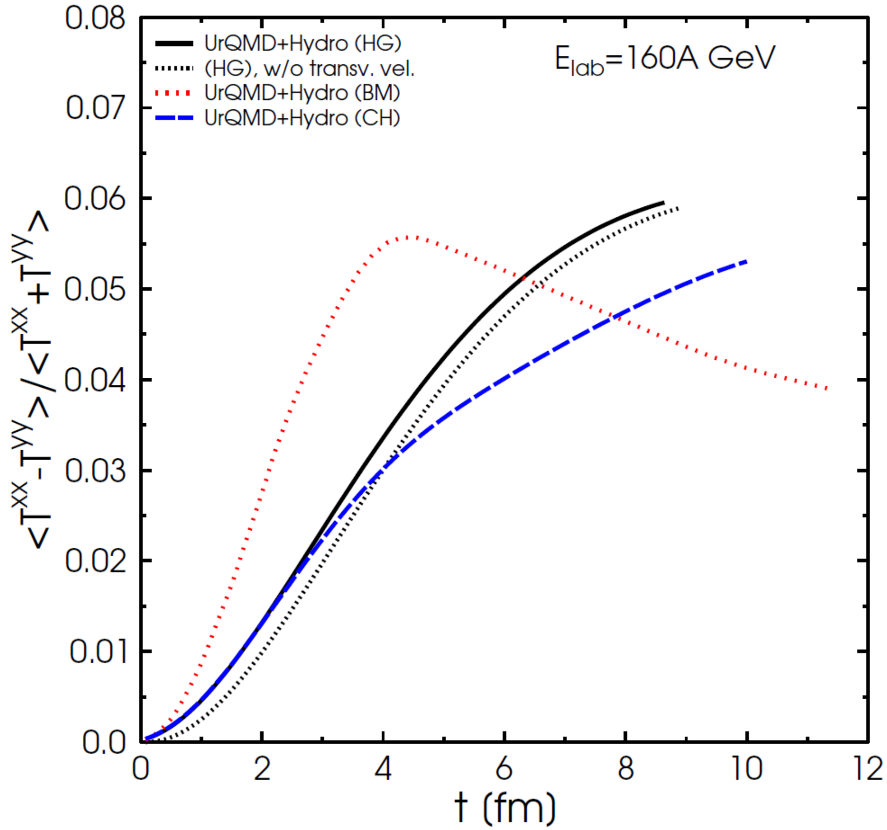


→ v_2 is mostly generated during the **hydrodynamic** expansion

→ **Afterburner** effect might be larger with different transition criterion

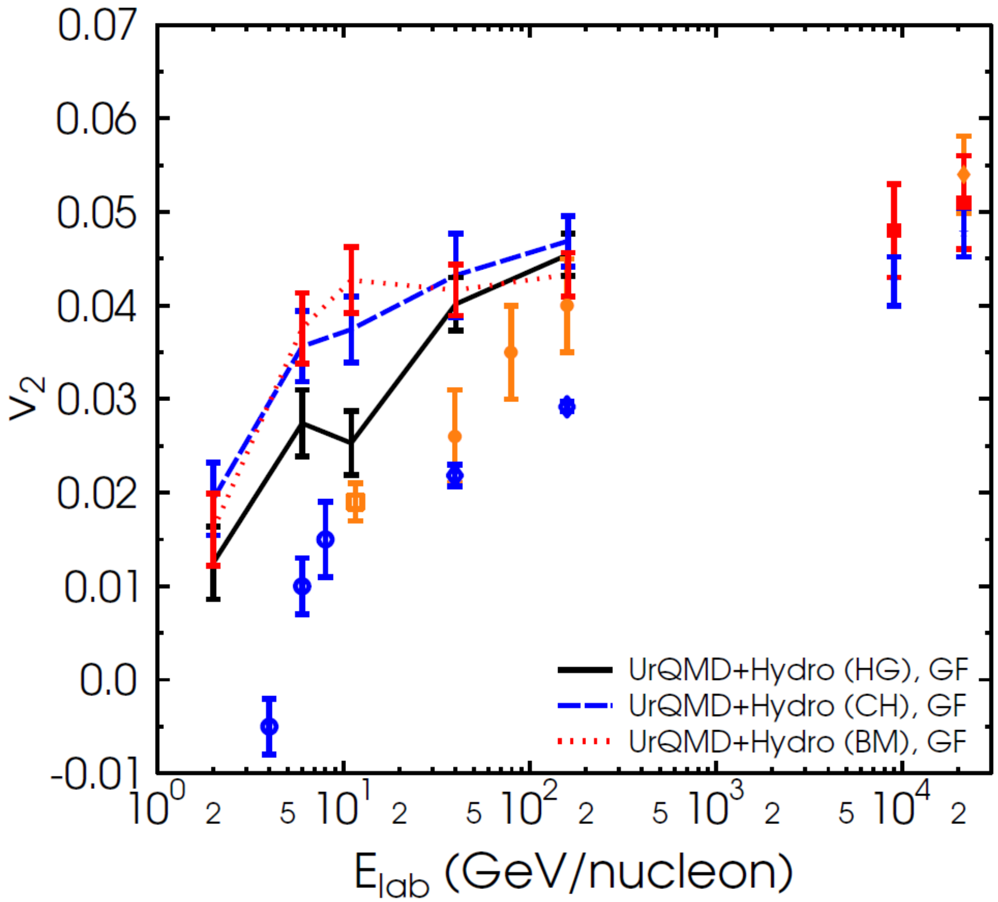
Time Evolution of Elliptic Flow





- Elliptic flow develops after t_{start} in the hadronic **transport** approach
- Different **EoS** lead to very different behaviour

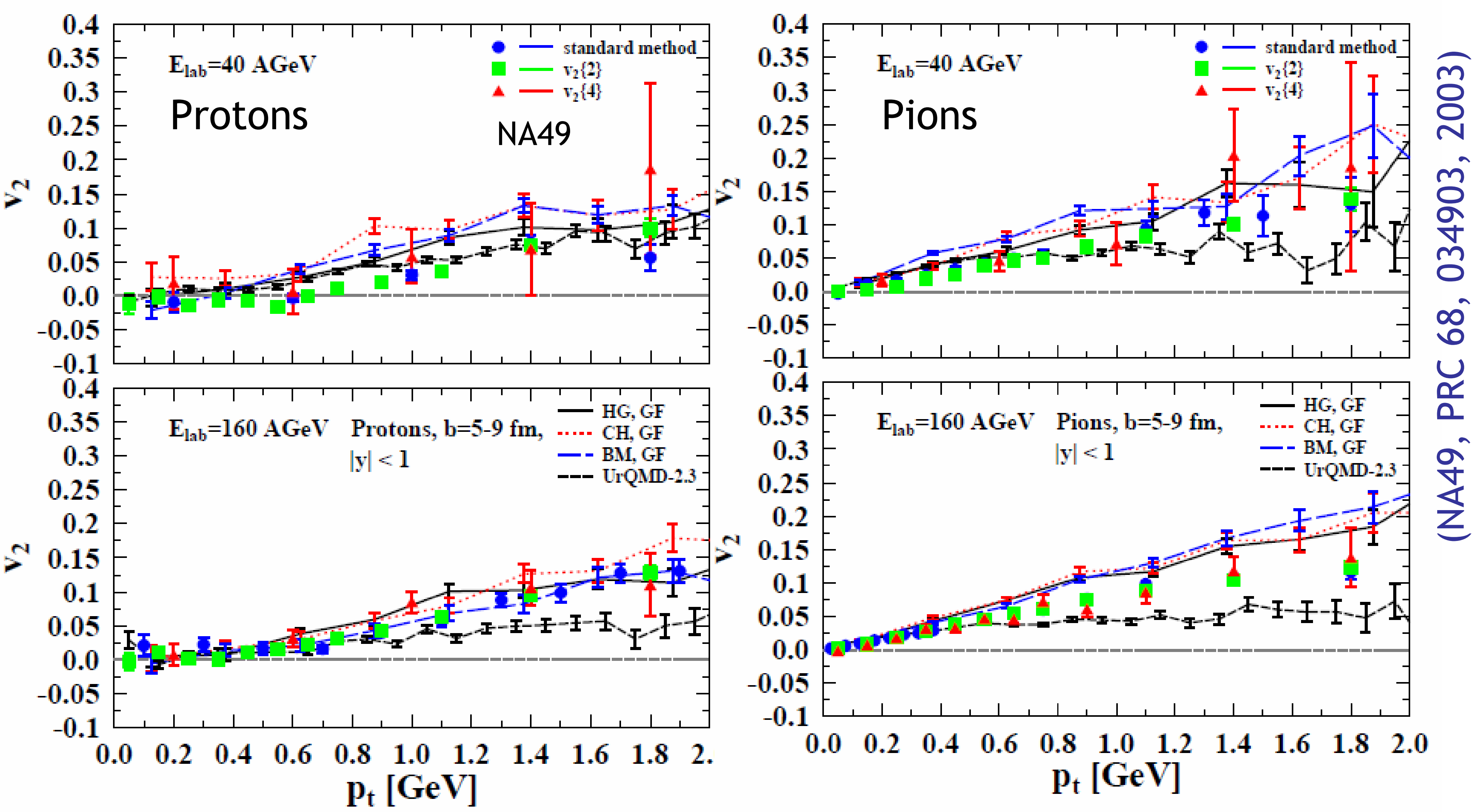
v_2 Excitation Function for Different EoS



- **Final** observable value does not depend on EoS

→ Influence of **transition** criterion

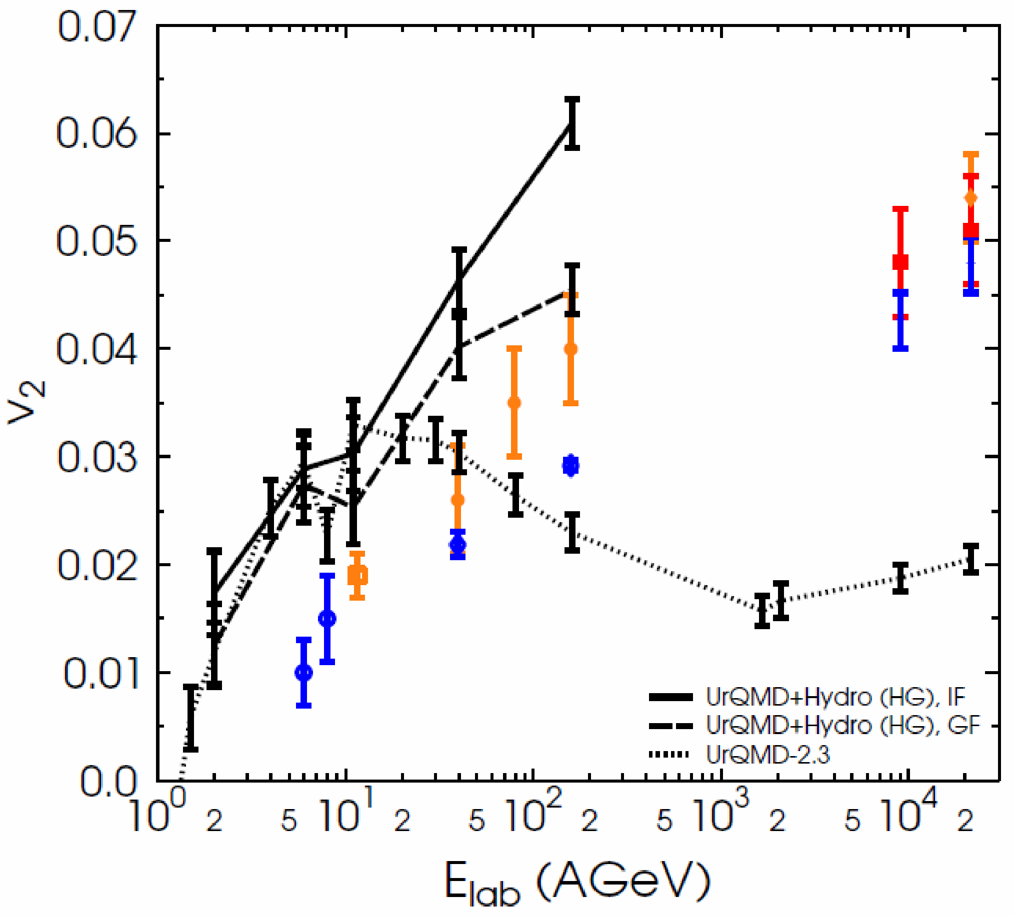
Transverse Momentum Dependence



Hydro phase leads to **higher flow** values, but **weak** EoS dependence

Dependence on Transition Criterion

- 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
- **Gradual transition** leads to a better description of the data



(H.P. et.al., PRC 79, 054904, 2009)

Data from E895, E877, NA49, Ceres, Phenix, Phobos, Star

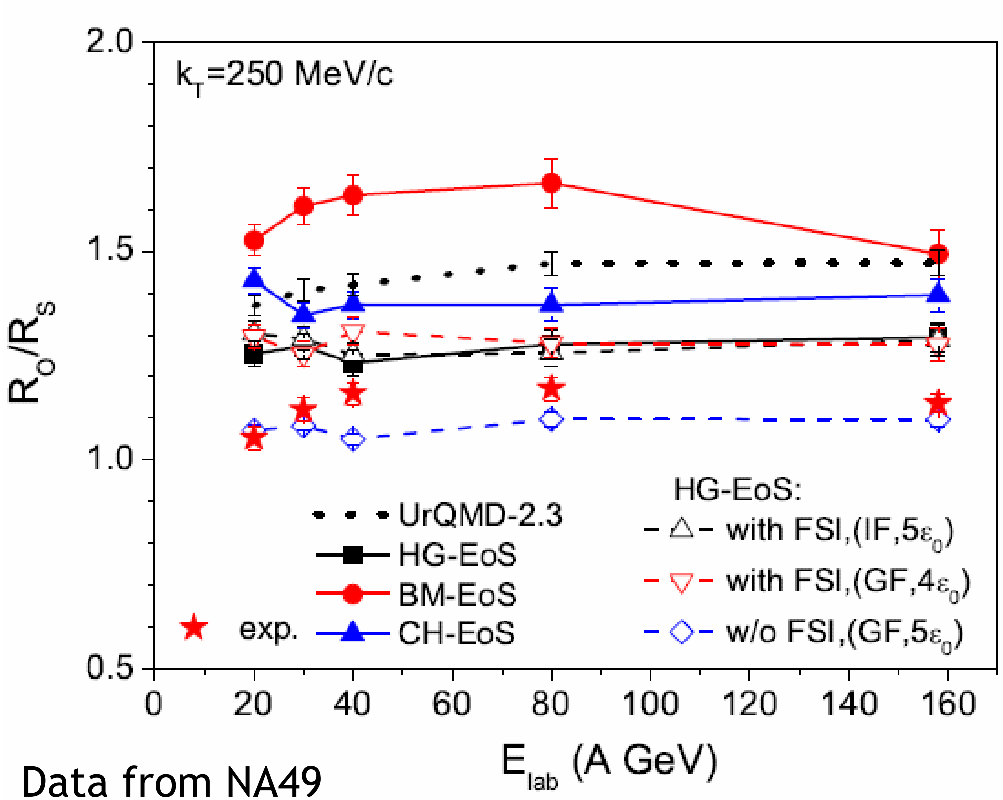
Conclusions and Outlook

- **Integrated approach** with the same initial conditions and freeze-out for different EoS
- v_2 is largely insensitive to the **initial conditions** from UrQMD with respect to fluctuations and inital velocity profile
- Averaged **UrQMD** initial conditions are still different than those from a **Glauber** model
- Final observable flow is rather insensitive to the **EoS**
- Elliptic flow is sensitive to the dynamics (transport vs hydro with the same initial conditions) and therefore to **viscosity**
- Choice of t**ransition criterion** results in a systematic uncertainity on the order of 20 %

- Compare calculations with different initial conditions like e.g. Glauber, CGC, Gaussian ...
- Implement different transition hypersurfaces (iso-T, iso-ρ,..)

Backup

R_O/R_S Ratio

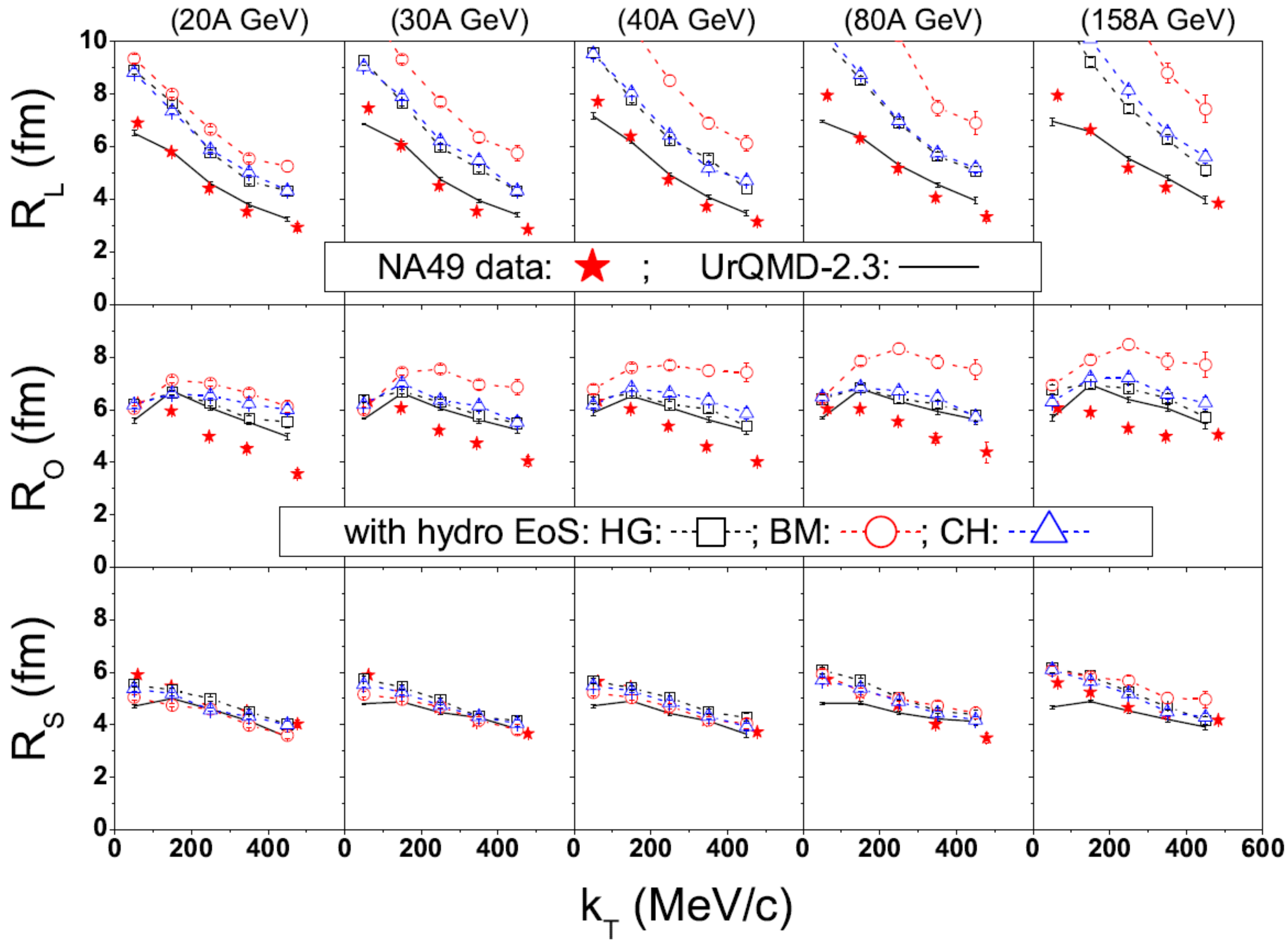


Data from NA49

(Q. Li et al., PLB 674, 111, 2009)

- Hydro phase leads to smaller ratios
- Hydro to transport transition does not matter, if final **rescattering** is taken into account
- **EoS dependence** is visible, but not as strong as previuosly predicted (factor of 5)

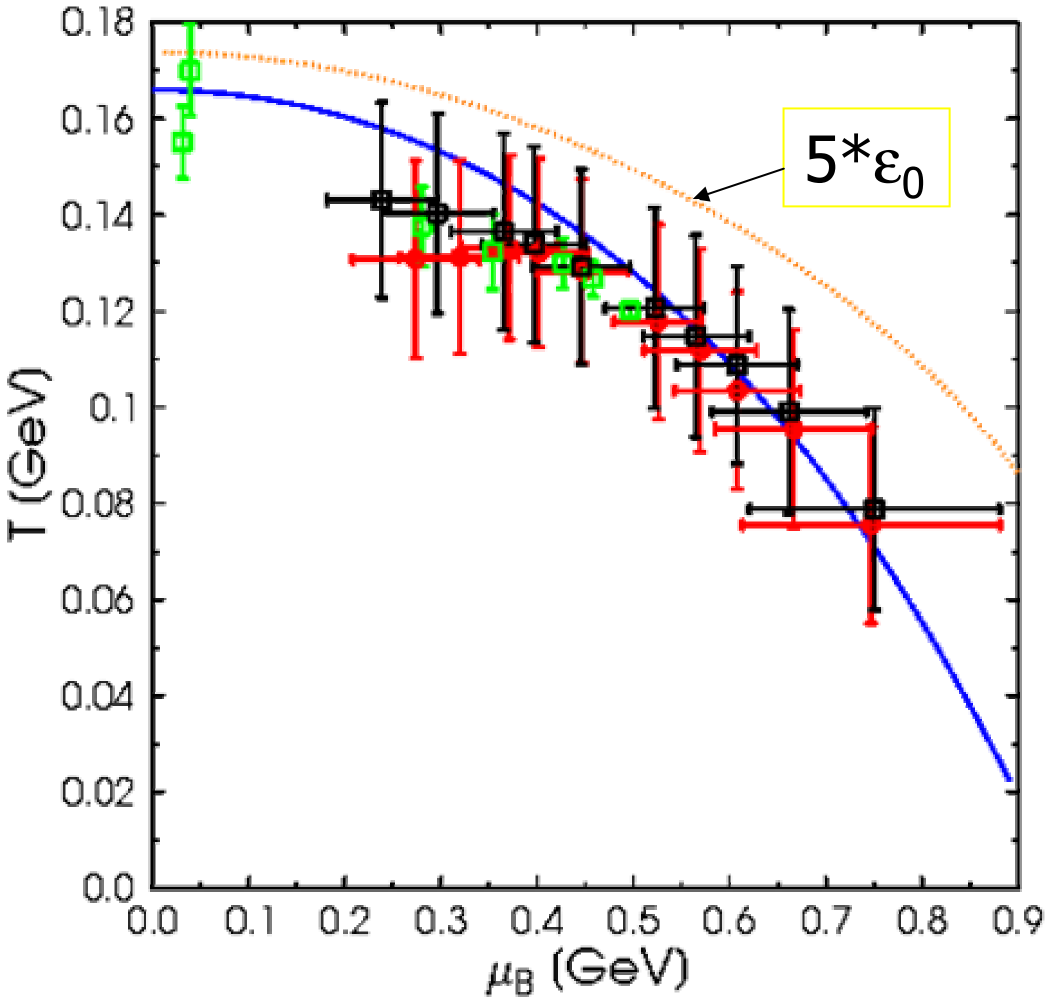
HBT radii



(Q. Li et al., arXiv: 0812.0375, PLB in print)

Hydro evolution leads to larger radii, esp. with phase transition

Freeze-out line



- Parametrization of chemical freeze-out line taken from
Cleymans et al,
J.Phys. G 32, S165, 2006

- Green points are from

A.Dumitru et al.,
PRC 73, 024902, 2006

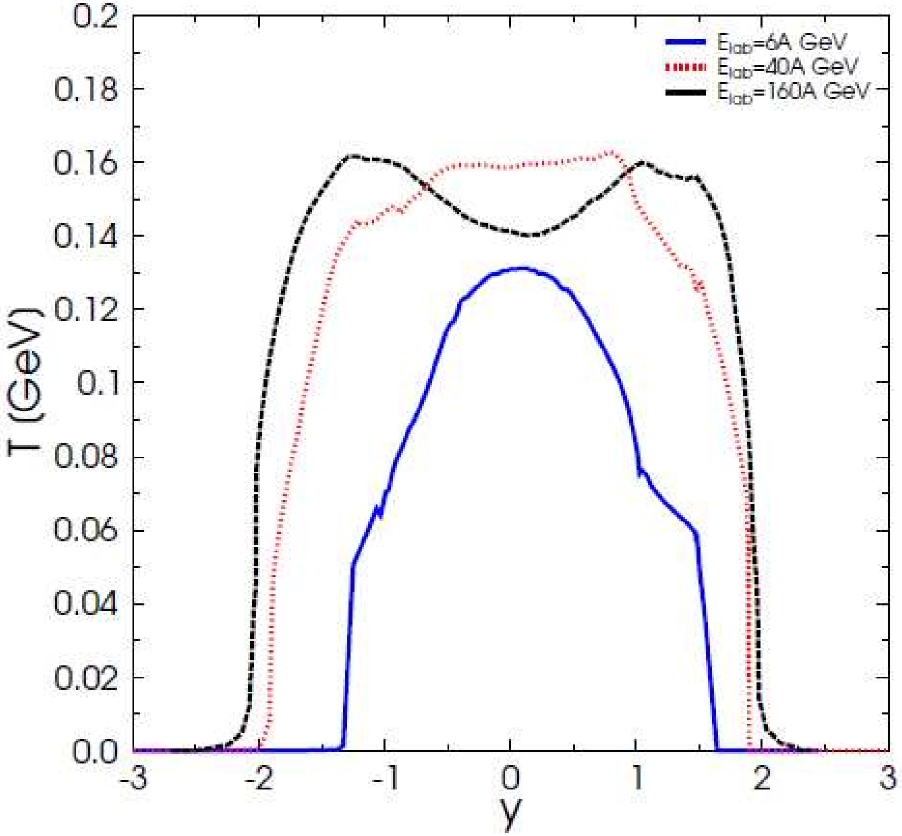
→ Mean values and widths are in line with other calculations

Black: Gradual FO

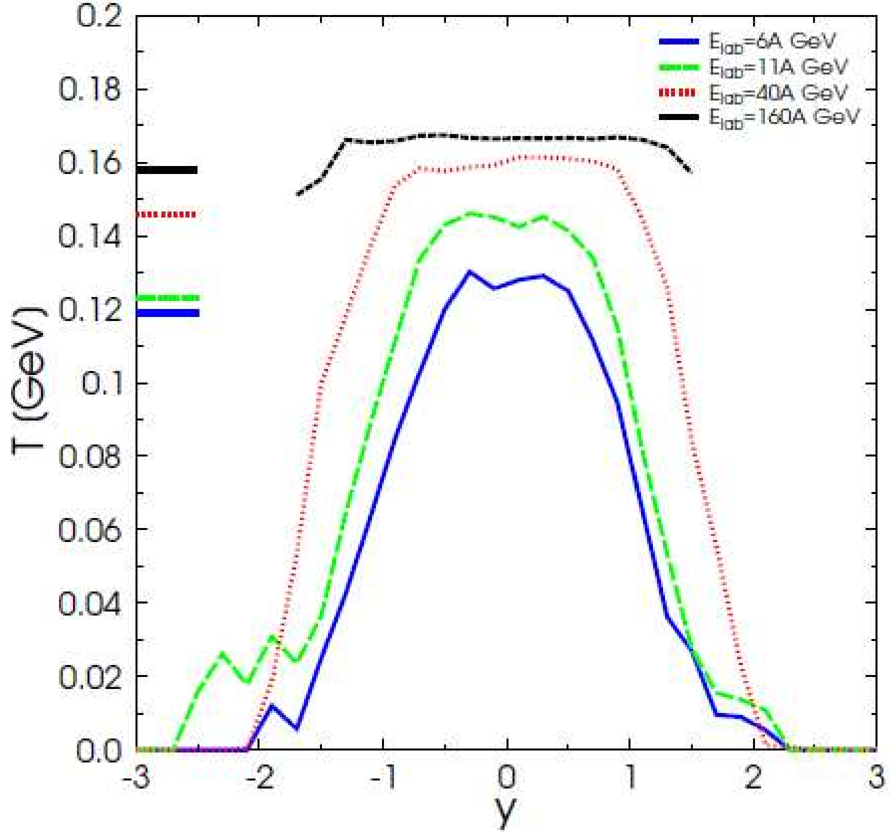
Red: Isochronous FO

Temperature Distributions

Rapidity distribution of the freeze-out temperatures in central Au+Au/Pb+Pb collisions with hadron gas EoS

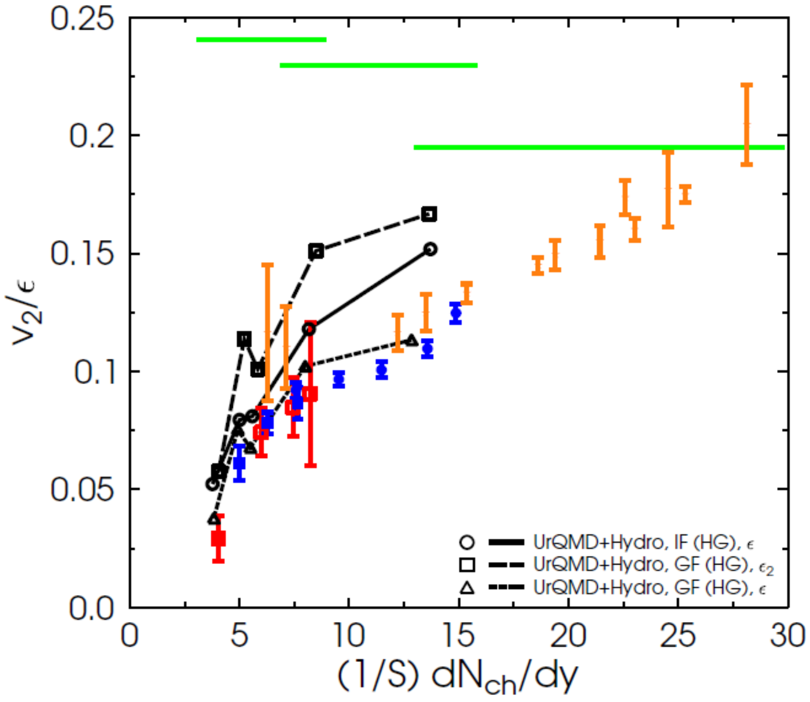


Isochronuous freeze-out



Gradual freeze-out

v_2/ε Scaling



- More realistic initial conditions and freeze-out

→Qualitative behaviour nicely reproduced

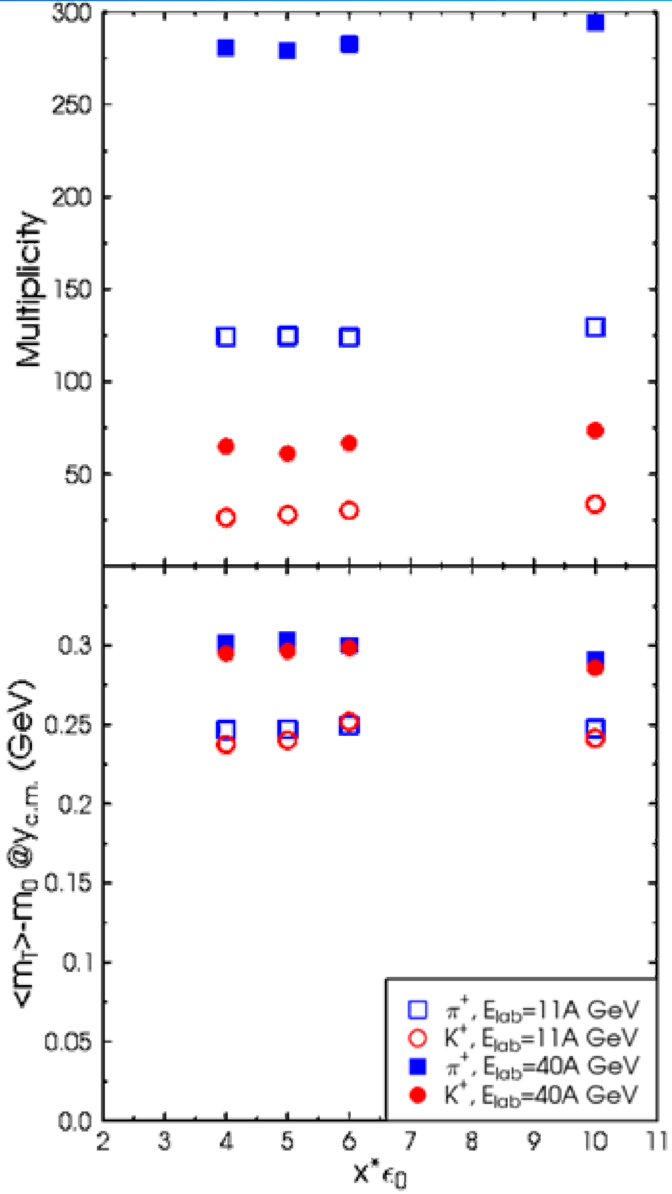
- Uncertainty due to eccentricity calculation

$$\epsilon = \frac{\langle y^2 \rangle - \langle x^2 \rangle}{\langle y^2 \rangle + \langle x^2 \rangle} \qquad S = \pi \sqrt{\langle x^2 \rangle \langle y^2 \rangle} \qquad \epsilon_2 = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

Avaraged over particles and events at the same time

Averaged first over particles and then over events

Dependence on Freeze-out

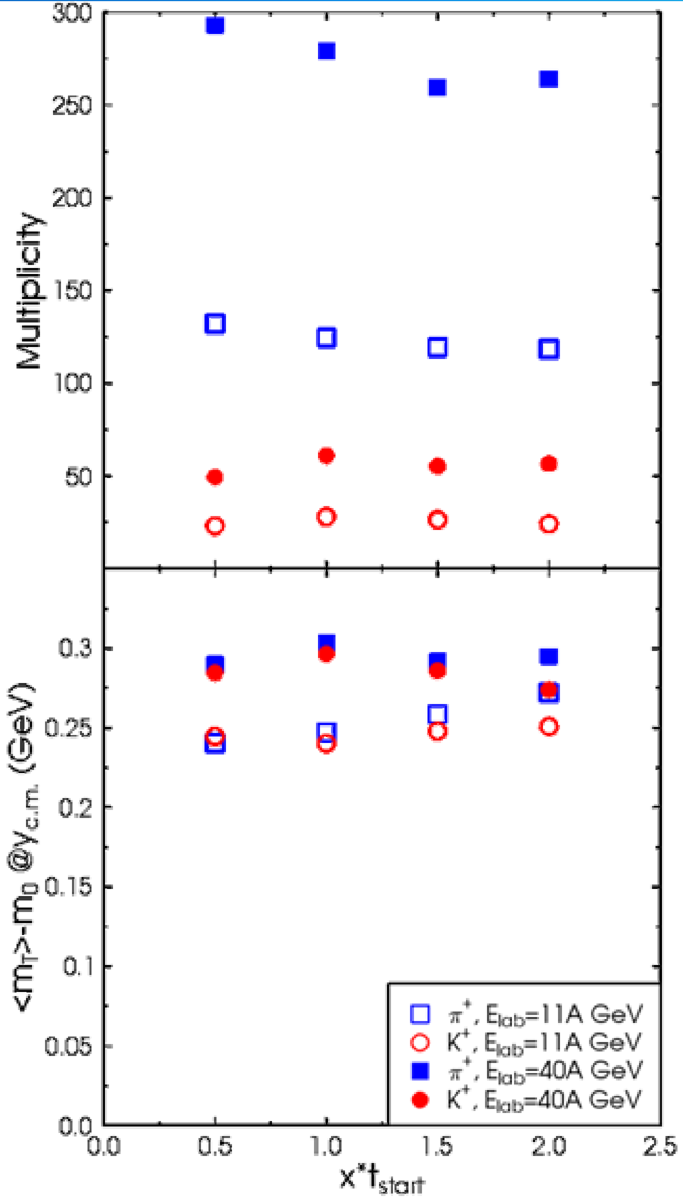


- Variation of the freeze-out criterium does not affect the meson multiplicities and mean transerve masses

Full symbols: 40 AGeV

Open symbols: 11 AGeV

Dependence on t_{start}

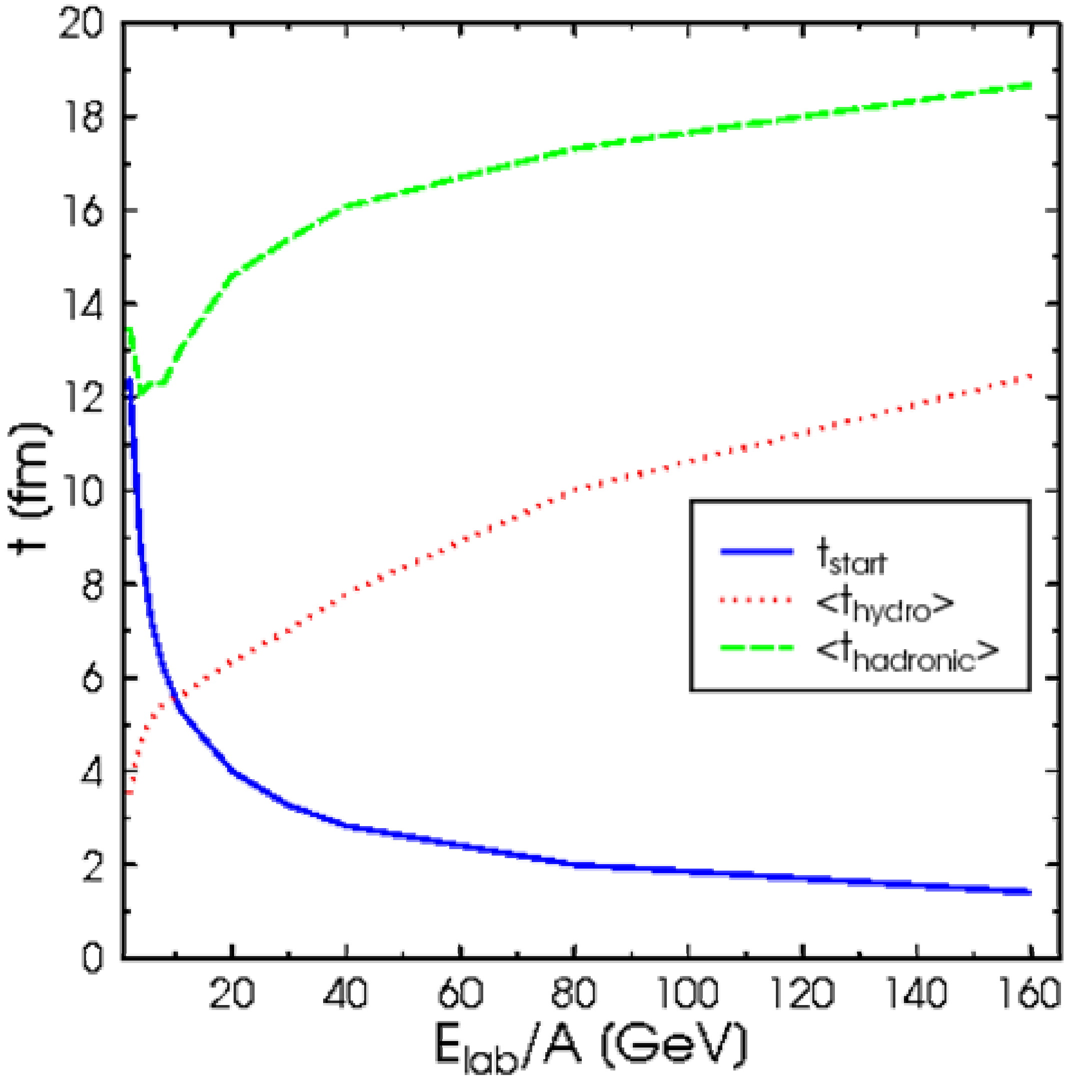


Variation of starting time by a factor 4 changes results only by 10 %

Full symbols: 40 AGeV

Open symbols: 11 AGeV

Time scales



t (fm)
20
18
16
14
12
10
8
6
4
2
0
20
40
60
80
100
120
140
160
E_lab/A (GeV)
t_start
<t_hydro>
<t_hadronic>