TECHQM Workshop: Breakout session on collective flow

What are the burning issues to be addressed collaboratively?

What work should be done during the next 6-12 months?

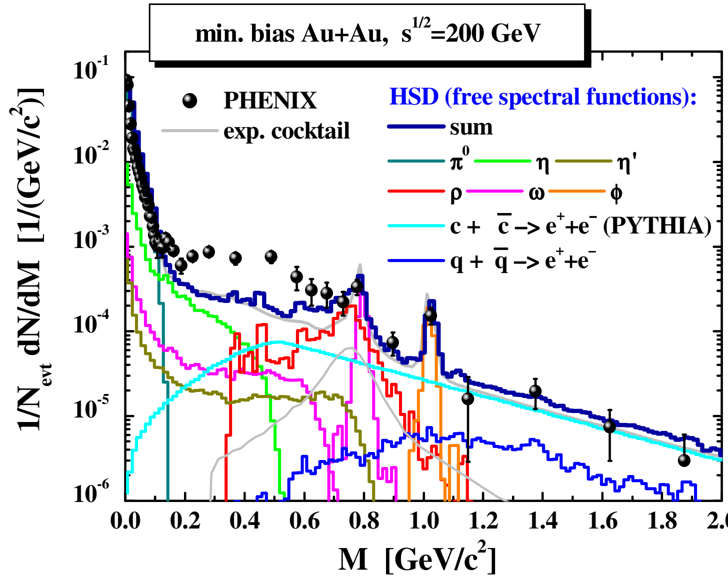
A few slides from prospective European participants who are not here today:

- Giessen (Cassing)
- Frankfurt (Greiner/Rischke)
- Warsaw (Broniowski)
- Bielefeld (Borghini)

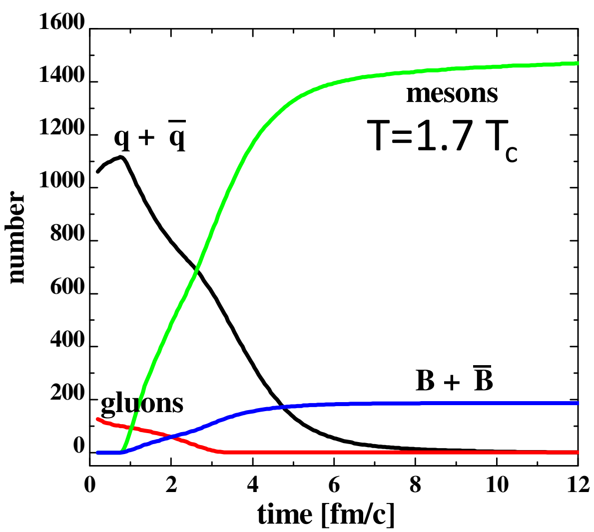
Giessen projects on relativistic nucleus-nucleus collisions within PHSD in 2008/2009

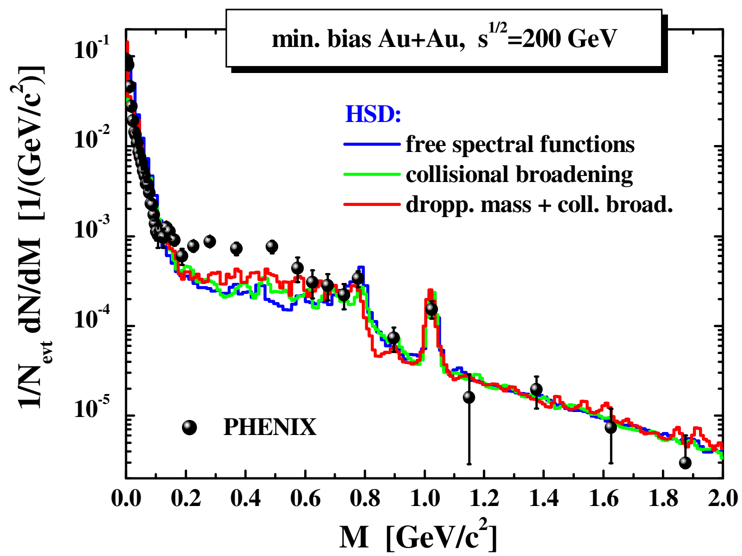
I) Low mass dileptons @ PHENIX
II) Open charm dynamics and intermediate mass dileptons @ RHIC
III) Parton selfenergies and parton v_2
IV) Hadronization of dynamical partons within PHSD

TECHQM collaboration wishes:
ad III) need support from LQCD (T-dep. corr. fcts.)
ad IV) need support from relativistic molecular dynamics simulations



expanding partonic fireball





BAMPS: **B**oltzmann **A**pproach of **M**ulti**P**arton **S**catterings

Z. Xu and C. Greiner, PRC 71, 064901 (2005); 76, 024911 (2007)

A transport algorithm solving the Boltzmann-Equations for on-shell partons with pQCD interactions

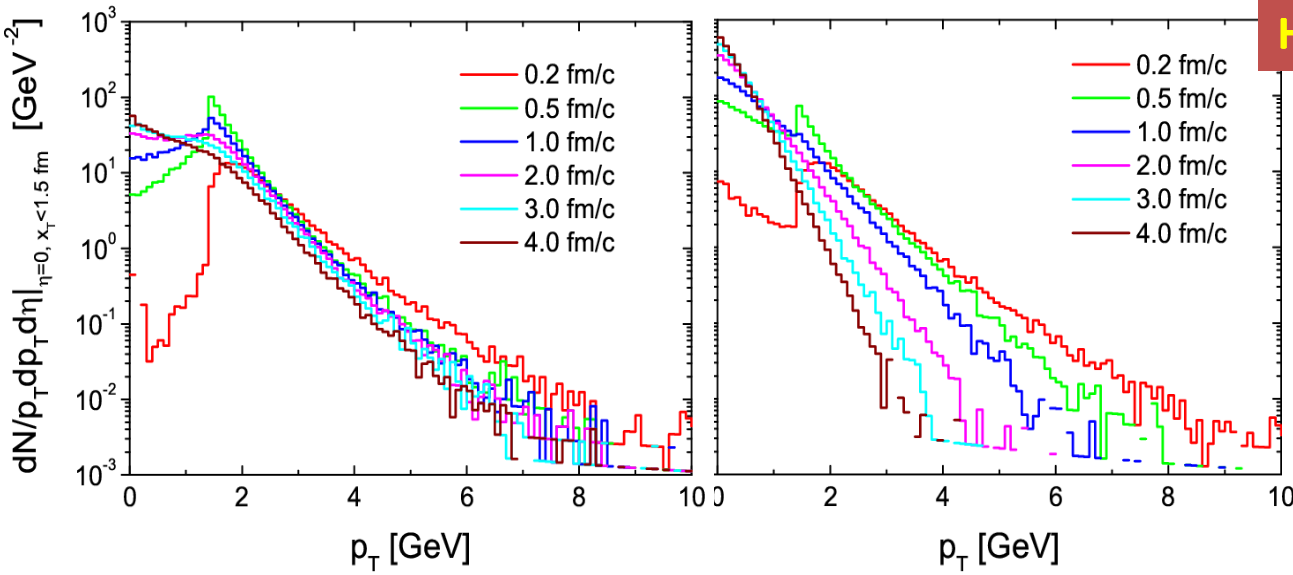
$$p^{\mu}\partial_{\mu} f(x,p) = C_{gg \to gg}(x,p) + C_{gg \leftrightarrow ggg}(x,p)$$

new development ggg ↔ gg, radiative „corrections“

only 2↔2:

simulation pQCD 2-2 + 2-3 + 3-2

3-2 + 2-3: thermalization! Hydrodynamic behavior!

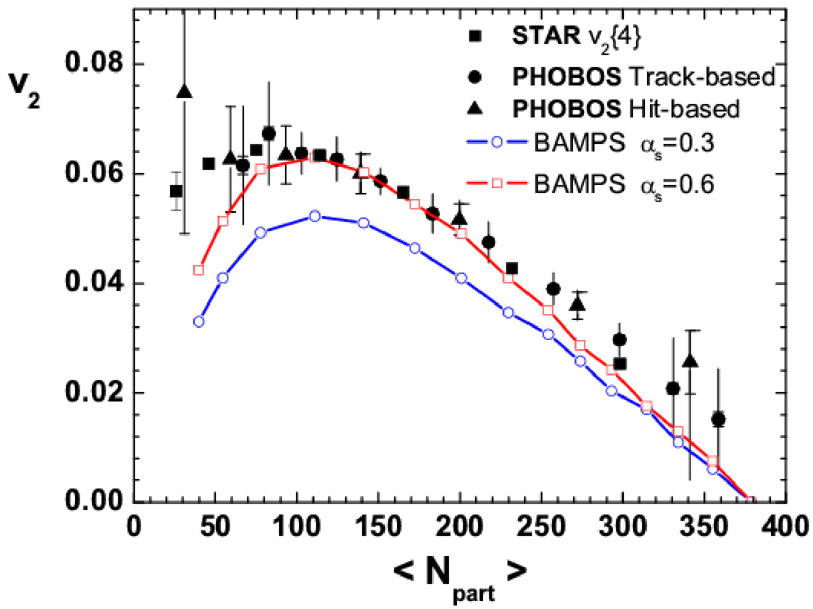


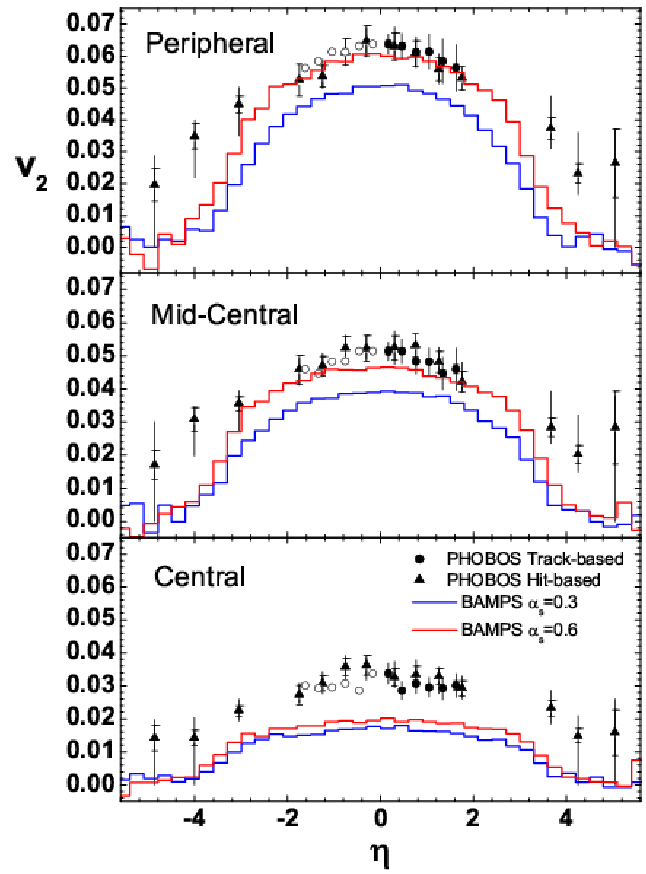
Elastic scatterings are ineffective in thermalization !
Inelastic interactions are needed !

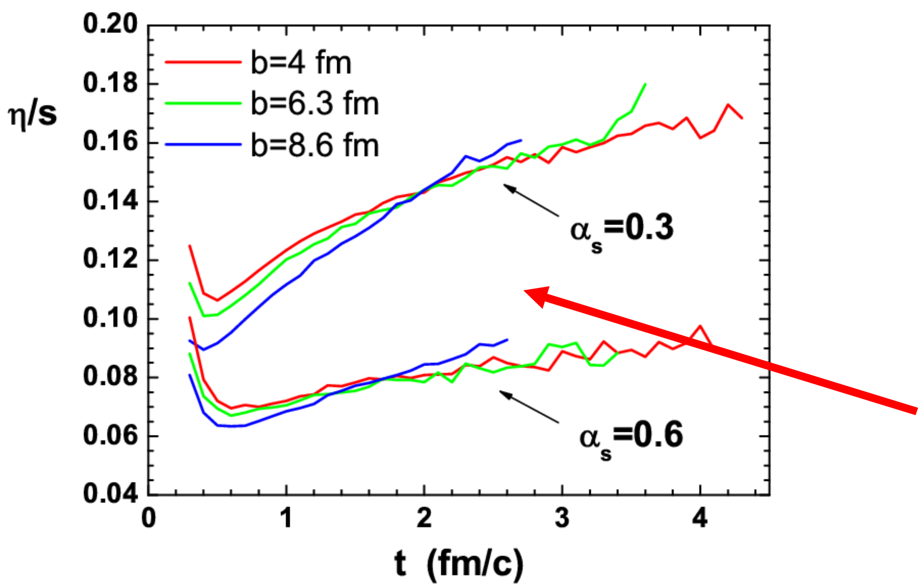
Elliptic Flow and Shear Viscosity in 2-3 at RHIC

2-3 Parton cascade BAMPS

Z. Xu, CG, H. Stöcker, arXiv: 0711.0961 [nucl-th]







$$\eta = \frac{1}{5} n \frac{\left\langle E\left(\frac{1}{3} - \frac{p_z^2}{E^2}\right)\right\rangle}{\frac{1}{3} - \left\langle \frac{p_z^2}{E^2} \right\rangle} \frac{1}{\sum R^{tr} + \frac{3}{2} R_{23} - R_{32}}$$

Z. Xu and CG, arXiv: 0710.5719 [nucl-th]

η/s at RHIC > 0.08

Present and future developments with parton transport

Inelastic/radiative pQCD interactions (23 + 32) explain:

- **fast thermalization**
- **large collective flow (… much more to investigate)**
- **small shear viscosity of QCD matter at RHIC**
- **realistic jet-quenching of gluons (… will come soon)**

Future/ongoing analysis :

- **light and heavy quarks have to be implemented**
- **dissipative hydrodynamics via realistic 3-dim parton transport:**

  advantage: initial conditions are taken into account early on;

  disadvantage (at present): ideal equation of state
- **hadronisation and afterburning (UrQMD) needed to determine**

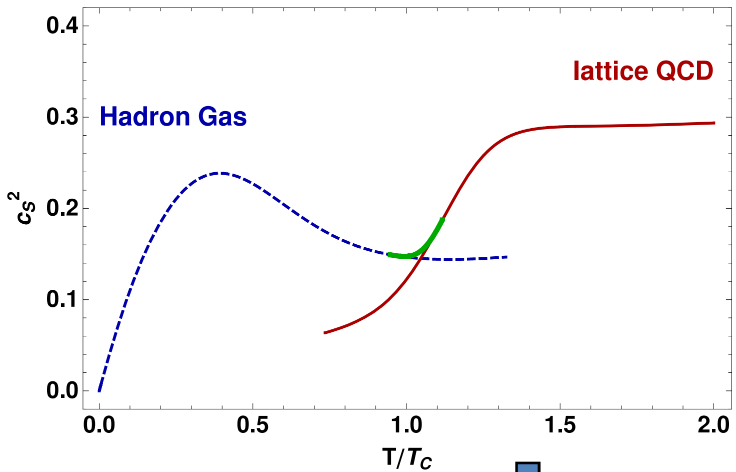
  how imperfect the QGP at RHIC and LHC can be

  … and dependence on initial conditions (Glauber, CGC, …)

  …particle spectra and correlations, e.-m. signals

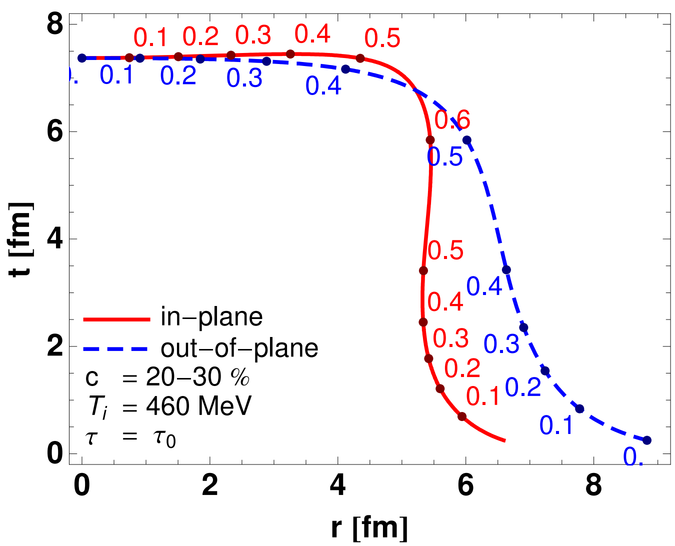
Cracow group – participation in developments of tests and benchmarks

equation of state (sound velocity)



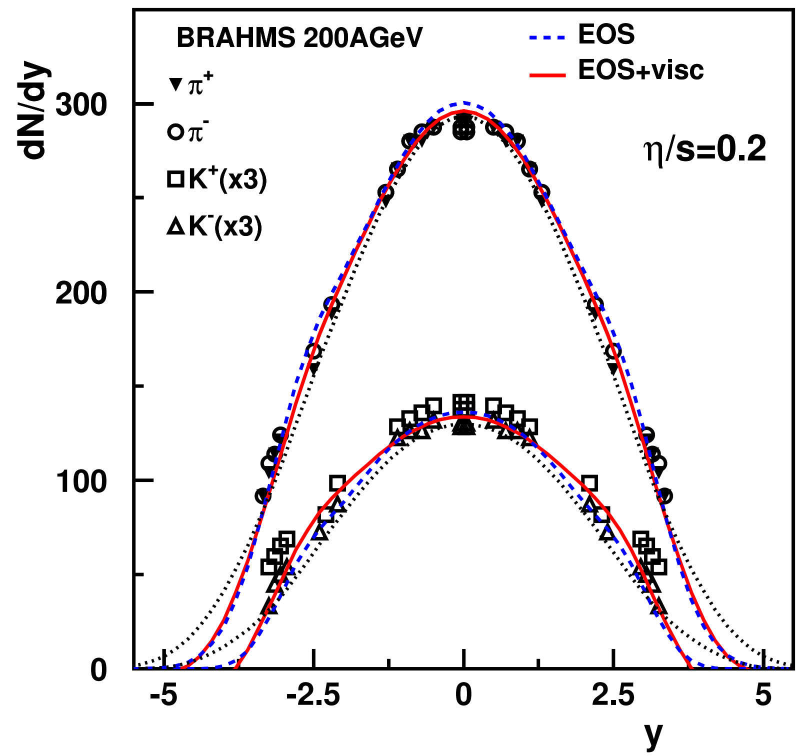
inviscid 2+1 boost-invariant hydro

freeze-out at T=145MeV



[Broniowski, Chojnacki, Florkowski, Kisiel, arXiv:0801.4361]

viscous hydro (initial energy density is reduced from 14 to 5 GeV/fm^3 with viscosity included to reproduce BRAHMS) [Bozek 2007]



All codes should obviously give the same!

Input and output can be given in tabulated form, some standards needed

~~Elliptic~~ Anisotropic flow

The anisotropy in particle production is not entirely described by v_2 !

☞ higher harmonics v_4, (v_6 ...)*.

No obvious reason (symmetry considerations...) why these harmonics should reflect different aspects (initial geometry, time scales...) of the collisions ⇒ should be studied together with v_2.

Kolb, Sollfrank & Heinz; Huovinen; Borghini & Ollitrault; Ko, Chen & Zhang

- Theorists:
  - v_2 predictions should be accompanied by v_4 predictions;
  - do not omit the STAR v_4 when fitting your favorite model(s) to "anisotropic flow data".
- Experimentalists: please provide us with further data (easy request...) (what has become of PHENIX preliminary results, nucl-ex/0506019?)

* The physics behind v_1 might be different...

Experimentalists are from Mars, theorists are from Venus

(J.Nagle & T.Ullrich, Cargèse 2001)

Theorists know the reaction plane, experimentalists do not measure it
⇒ mismatch between

- what theorists compute within a given model ≡ v_n ("true" flow);
- what experimentalists extract from their data: estimates ($v_n\{\mathrm{EP}\}$, $v_n\{2\}$, $v_n\{4\}$, $v_n\{\infty\}$...), obtained using various methods of analysis that have different sensitivities to "parasitic" effects;
  ("nonflow" correlations between particles, fluctuations of flow itself...).

☞ my wish: that theorists analyze the outcome of their models using the methods used by experimentalists.

Codes implementing various methods (cumulants, Lee–Yang zeroes...) (soon) available at http://www.physik.uni-bielefeld.de/~borghini/Software/.

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Short solicited contributions

- J. Kapusta
- M. Lisa
- V. Koch
- S. Gavin
- C. Gale (UH)

Each contribution max. 5 minutes, followed by 10 min. of discussion from the floor

Afterwards unsolicited contributions (<=2 slides, < 5 min.) from the floor + discussion

McGill/Gale:
TECHQM: Some issues

- Photons and other hard probes (e.g. jets) can and should be theoretically treated together and consistently
- What is the effect of the evolution model on the hard probe signals? (2D vs 3D, ideal vs. viscous, any difference in the photon spectra (for example)?)
- The need to quantify reliably collisional energy loss, and its influence(s) on the observables.
- Same as above, replace “collisional eloss” with “viscosity”.
- Recent comparisons in theory (e.g. S. Bass’ talk @QM) and in experiment-theory (e.g. statistical analysis by PHENIX (J. Nagle)) of different models is useful. These two exercises could form the basis of TECHQM sub-working groups.
- Above goals could be realized in year-1 (or 2…)

Charles Gale, McGill

TECHQM: Some suggestions

- Constitute working groups (theory + experiments)
- Regular events: workshops, summer schools, conferences
- Mark milestones with equivalent of CERN Yellow Reports
- Define “standard candles”: idealized situations and results with alternate formalisms
- Maintain a web repository (in the spirit of OSCAR) with source codes
- Draw from current and past experiences (CTEQ, OSCAR, HEPDATA (Durham))…
- TECHQM postdocs?