Viscous QCD matter at RHIC and LHC energies
Results from Viscous Hydrodynamics + Hadron Cascade

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In 2005, BNL announced that RHIC scientists serve up "perfect" liquid. In order to answer how perfect the QGP fluid is, one needs to extract QGP viscosity from experimental data. Viscous hydrodynamics [1] and its hybrid model [2] are such tools to help us to achieve this. In the past years, it was shown that elliptic flow v_2 is very sensitive to the QGP viscosity. The minimum value from string theorists prediction $\eta/s=1/4\pi$ could lead to a 20-25% v_2 suppression, which clearly shows that v_2 can be used to extract the QGP viscosity [1]. However an accurate extraction of the QGP viscosity requires sophisticated theoretical modeling as well as precise experimental data. In this poster, we will report the recent progress on extracting the QGP viscosity at RHIC and LHC energies with the new developed hybrid model (VISHNU) - viscous hydrodynamics + hadron cascade.

Extracting QGP shear viscosity from RHIC data theoretical and experimental status

Sophisticated hybrid model (VISHNU):
viscous hydrodynamics + hadron cascade [2]

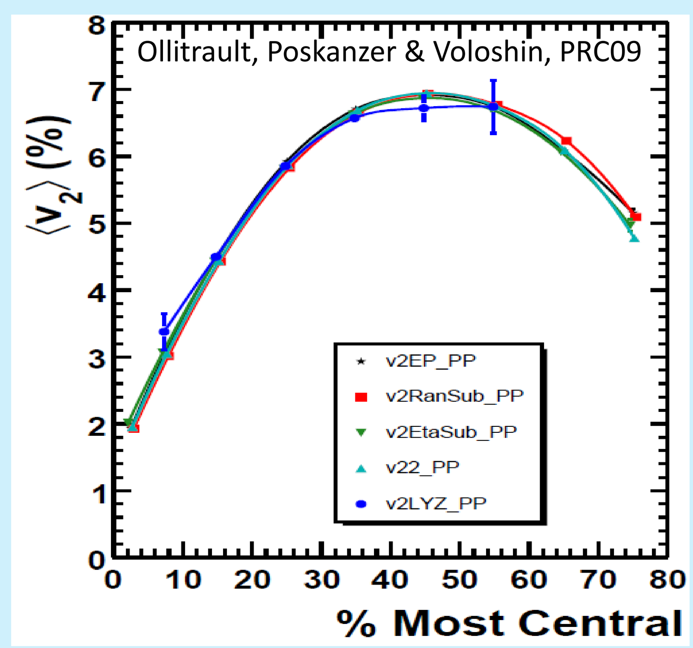
Initial conditions: smoothed initial entropy density profiles averaged from (Monte Carlo) MC-Glauber or MC-KLN initializations by aligning participant plan for each events [3] (largely accounting fluctuation effects)

EOS: constructed from recent lattice data [4]

Hadronic effects: the dissipative and partially chemical equilibrium hadronic effects are well described by hadron cascade (UrQMD) through solving boltzmann eq. with elastic, semi-elastic and inelastic collision rate

Bulk viscosity: only brings less than 20% contaminations for the extracted value of QGP shear viscosity [5]

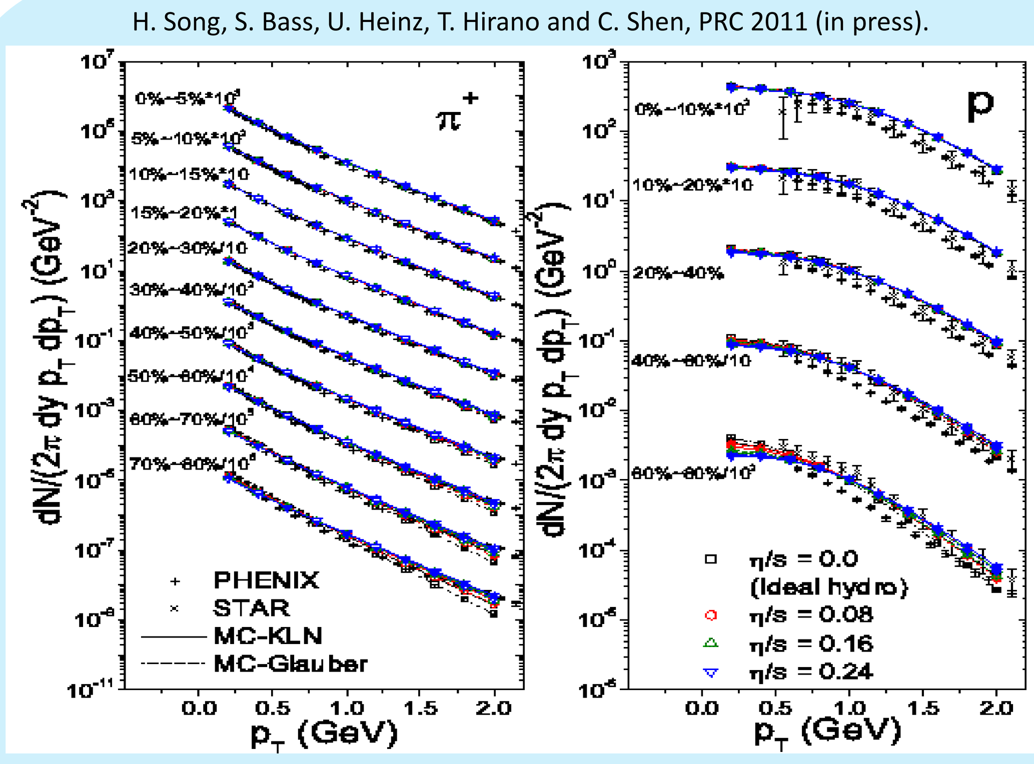
More precise elliptic flow data:
remove non-flow & fluctuation effects



all corrected v_2 from different flow measurements converge to unique curves (<v_2> in participant plan)

Results: spectra and elliptic flow

H. Song, S. Bass, U. Heinz, T. Hirano and C. Shen, PRC 2011 (in press).

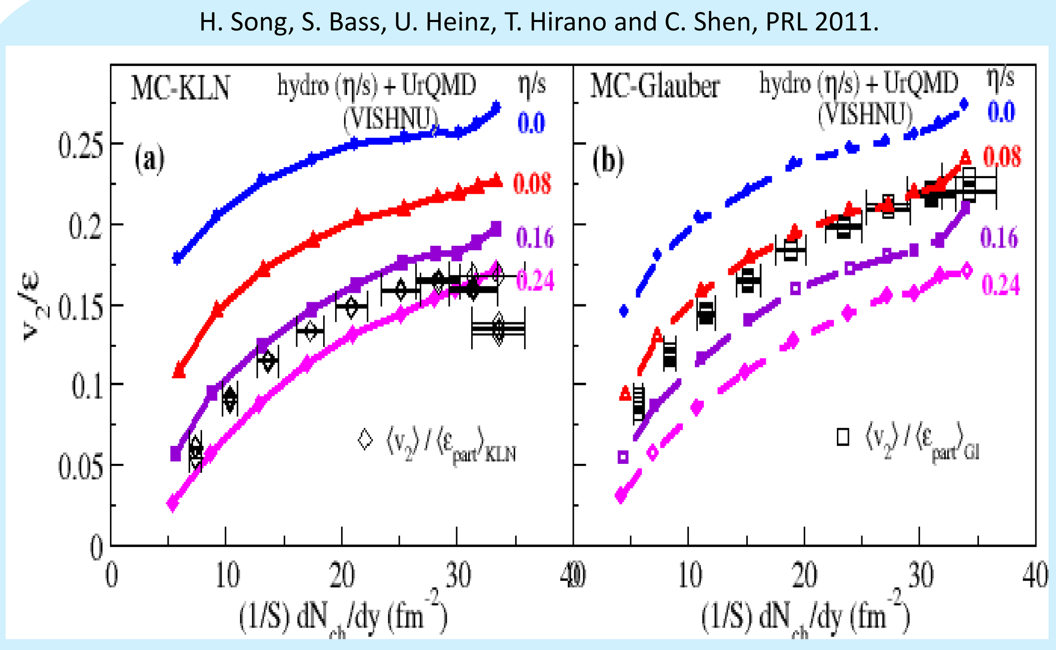


A very nice fit of the p_T spectra for different hadron species from most central collisions to most peripheral collisions

Nice description of proton final multiplicities due to the correct chemical components in the hadron cascade parts of VISHNU

Spectra are insensitive to initializations and the QGP shear viscosity

H. Song, S. Bass, U. Heinz, T. Hirano and C. Shen, PRL 2011.



Uncertainty estimates:

Initial flow: increase v_2 ~5% [7]

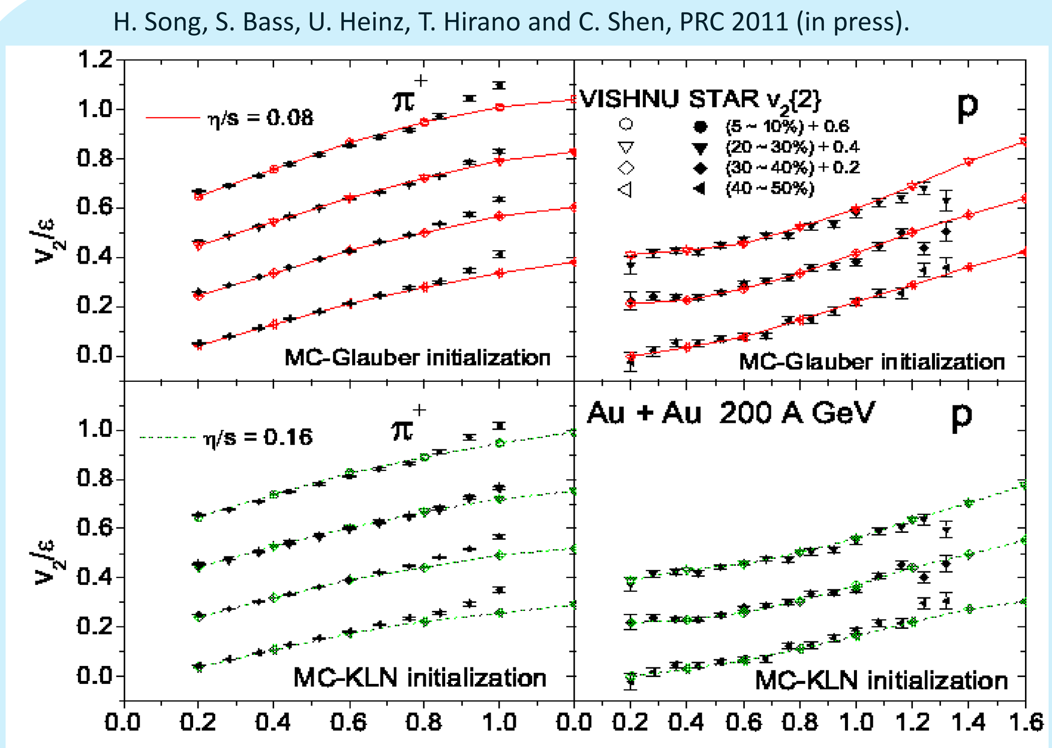
Bulk visc: decrease v_2 <5% [5]

Event by event simulation: decrease v_2/ecc <4-6% [8]

considering the cancelations among the above factors, a further detailed extraction of QGP shear viscosity will only slightly shift the below bands

$\eta/s=(1-2)(1/4\pi)$ for MC-**Glauber** initial condi. (averaged in parti. plane)
$\eta/s=(2-2.5)(1/4\pi)$ for MC-**KLN** initial condi. (averaged in parti. plane)

H. Song, S. Bass, U. Heinz, T. Hirano and C. Shen, PRC 2011 (in press).



STAR $v_2\{2\}$ data are contaminated by non-flow & fluctuation effects

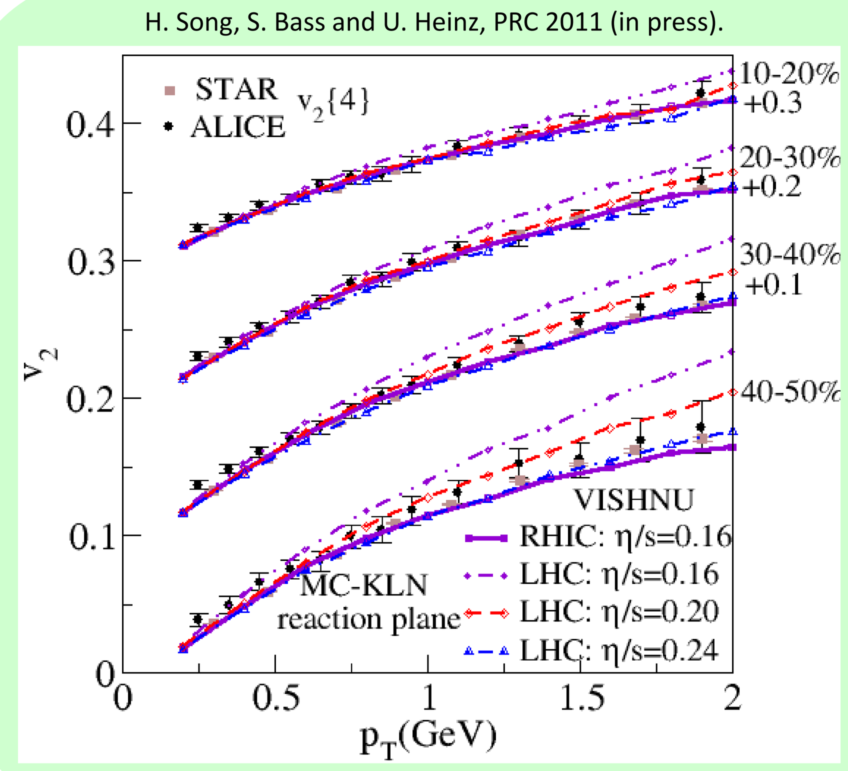
to reduce fluctuation effects
Theory v_2/ε **vs. EXP.** $v_2\{2\}/\sqrt{\varepsilon^2}$

η/s here hits the lowest bound of the above extraction, mostly due to non-flow effects, which raises exp v_2 data, leading to smaller η/s

corrected differential v_2 data (remove non-flow & fluc. effects) are needed for future detailed extraction of QGP viscosity

Viscous QCD matter at LHC energies

H. Song, S. Bass and U. Heinz, PRC 2011 (in press).



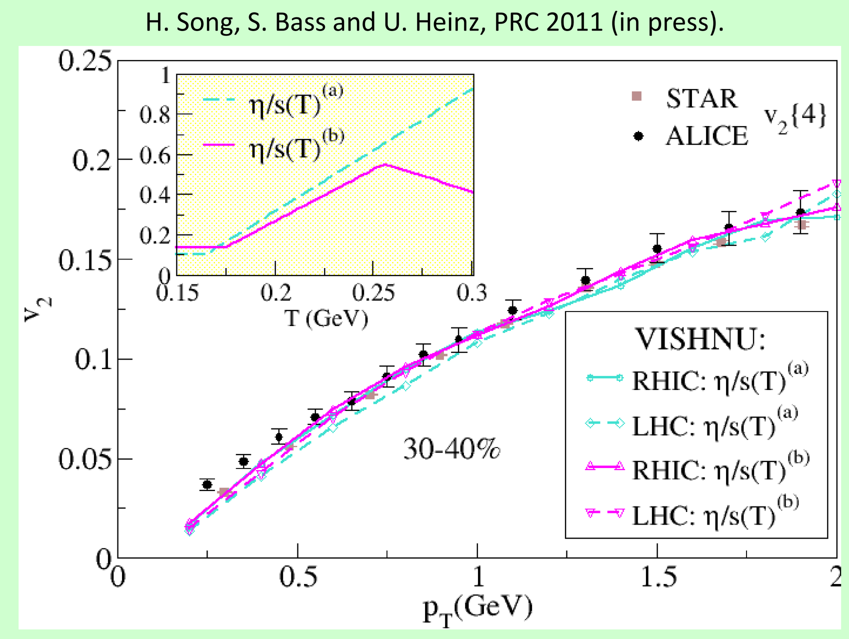
Assuming constant specific QGP viscosity $\eta/s=const.$ during the QGP fireball evolution at RHIC and LHC energies

One needs larger "averaged" (constant) specific QGP viscosity to fit the ALICE data than the one used to fit STAR data

However, using one constant η/s to for the QGP fluid (T_c-$2T_c$) created at RHIC energies, and then another constant η/s for the QGP fluid (T_c-$3T_c$) created at LHC energies is not logically consistent

One should try $\eta/s(T)$ for both RHIC & LHC energies

H. Song, S. Bass and U. Heinz, PRC 2011 (in press).



One can not constrain the form of $\eta/s(T)$ by fitting the spectra and v_2 at RHIC and LHC energies

At this moment, it is an open issue on whether QGP fluid is more viscous or perfect in temperature regime covered by LHC (from our phenomenological approach).

Summary and Concluding Remarks

Using new developed hybrid model VISHNU, we make an extraction of QGP viscosity from the RHIC integrated v_2 data that removes non-flow and fluctuation effects. We find:

$$(\eta/s)|_{QGP}=(1-2.5)(1/4\pi)$$

This is a robust extraction of $(\eta/s)|_{QGP}$ with reliable uncertainty estimates. The uncertainty is dominated by the undetermined initial conditions, especially for the initial eccentricity ε. Relatively small uncertainties are from bulk viscosity, initial flow, lacking of real event by event simulation, ect.

After studying the differential & integrated V_2 for 200 A GeV Au+Au collisions & 2.76 A TeV Pb+Pb collisions. We find that the average ("constant") QGP specific shear viscosity slightly increases from RHIC to LHC energies. However, a further study with different $(\eta/s)|_{QGP}(T)$ shows that one can not constrain the form of $(\eta/s)|_{QGP}(T)$ by fitting spectra and v_2 alone, based on our current understanding, the question on whether the QGP fluid is more viscous or more perfect in the temperature regime reached by LHC energies is still open .

References

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