Viscosity Of The Quark Gluon Plasma – Nature's Most Perfect Fluid

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Introduction

- Quark Gluon Plasma [QGP] is a "soup" of matter that exists under extremely high temperatures and pressures.
- QGP can be created through relativistic heavy-ion collisions in the LHC at CERN and the RHIC at BNL.
- Synthesized QGP only exists for 10^{-23} seconds before freezing back into particles which are detected nanoseconds (10^{-9}) after the collision.
- QGP can not be detected directly but instead only "inferred" by the experimental data collected from the collision aftermath.

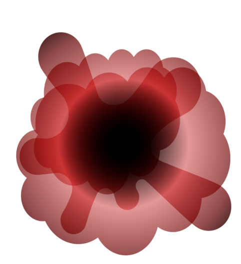
The QGP existed shortly after the Big Bang and is in the heart of Neutron stars!

Using complex models to recreate the steps from the moment of collision until detection, outputs are predicted and compared to measured values, allowing the viscosity of the QGP to be extrapolated.

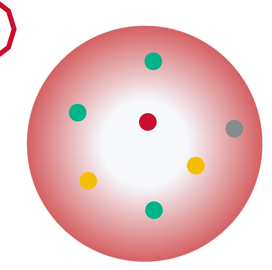
Collision Process

1 

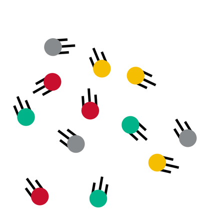
The nucleons collide

2 

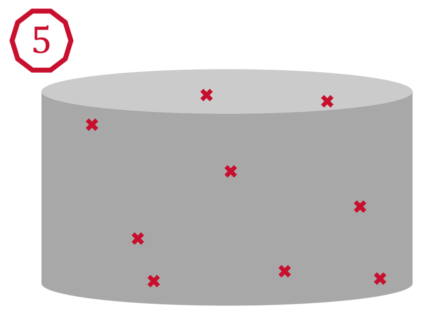
The QGP forms

3 

Matter freezes into particles

4 

The particles interact

5 

The particles are detected

Acknowledgements

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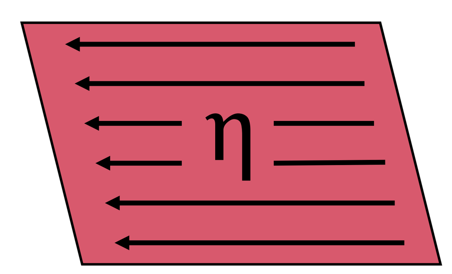
References

J. Moreland, J. Bernhard, S. Bass, Alternative ansatz to wounded nucleon and binary collision scaling in high-energy nuclear collisions. *Physical Review C.* 92 (2015), doi:10.1103/physrevc.92.011901.
H. Song, U. Heinz, Causal viscous hydrodynamics in 2 + 1 dimensions for relativistic heavy-ion collisions. *Physical Review C.* 77 (2008), doi:10.1103/physrevc.77.064901.
S. A. Bass, M. Belkacem, M. Bleicher, M. Brandstetter, L. Bravina, C. Ernst, L. Gerland, M. Hofmann, S. Hofmann, J. Konopka, G. Mao, L. Neise, S. Soff, C. Spieles, H. Weber, L. A. Winckelmann, H. Stocker, W. Greiner, Ch. Hartnack, J. Aichelin and N. Amelin: Microscopic Models for Ultrarelativistic Heavy Ion Collisions
A. Bilandzic, R. Snellings, S. Voloshin, Flow analysis with cumulants: Direct calculations. *Physical Review C.* 83 (2011), doi:10.1103/physrevc.83.044913.
Bernhard, J.E., Moreland, J.S. & Bass, S.A. Bayesian estimation of the specific shear and bulk viscosity of quark–gluon plasma. *Nat. Phys.* **15**, 1113–1117 (2019). https://doi.org/10.1038/s41567-019-0611-8
Anisotropic flow in Xe-Xe collisions at sNN√=**5.44** TeV. Phys.Lett. B784 (2018) 82-95.
J. Bernhard, J. Moreland, S. Bass, *Nature Physics*, in press, doi:10.1038/s41567-019-0611-8.

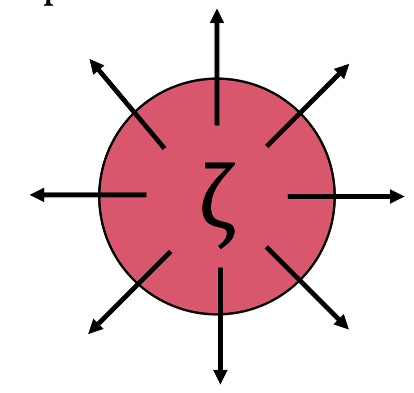
QGP as a fluid

- The QGP's viscosity defines how it evolves with time and impacts the final experimental results.
- Viscosity has two important components: Shear viscosity [η] and bulk viscosity [ζ].

Shear Viscosity is the resistance to pushes and pulls



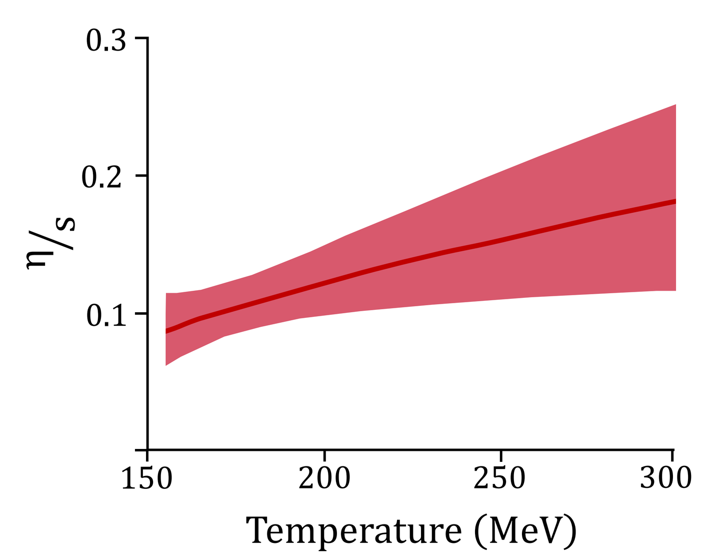
Bulk Viscosity is the resistance to expansion and contraction



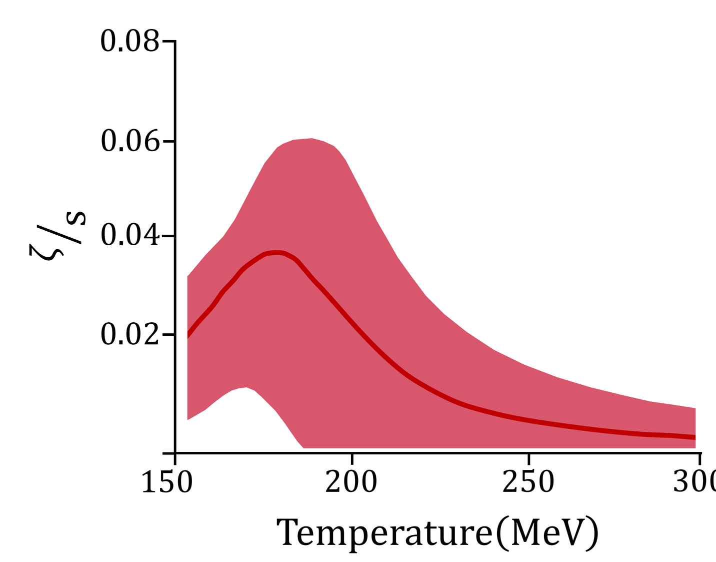
Viscosity

The viscosity is temperature dependent and tuned to lead collisions which have been extensively studied

Shear Viscosity

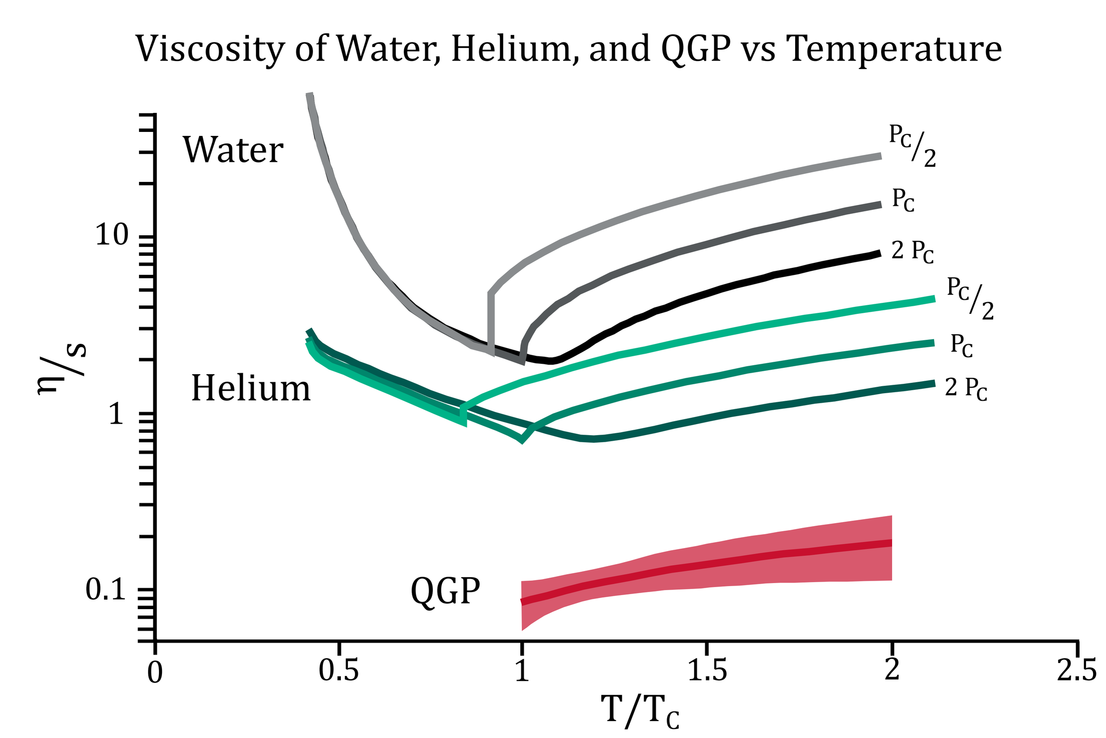


Bulk Viscosity



These viscosities are the lowest measured in nature

String Theory suggests the minimum shear viscosity is $^{1}/_{4\pi}$

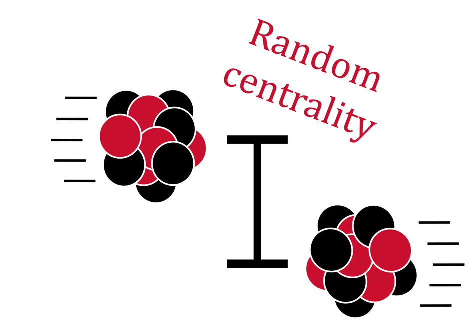


Model Chain

- T_RENTo [step 1]
- Freestream [between steps 1 and 2]
- VISHNu 2 + 1 Hydrodynamics [step 2]
- frzout [step 3]
- UrQMD Hydronic Afterburner [steps 4 – 5]

Running events

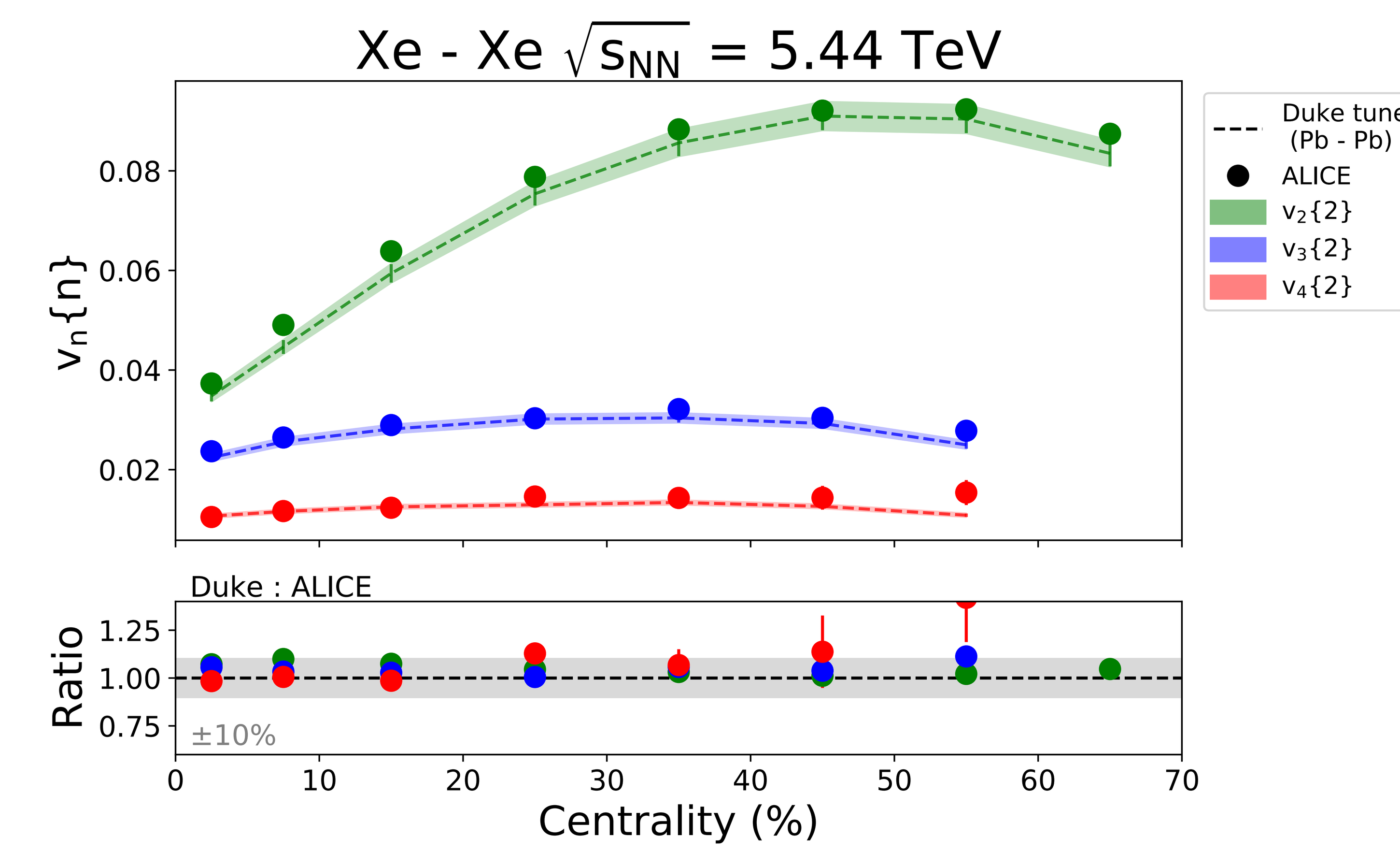
- The particles collide with some random centrality (overlap) that dictates the entire event.
- 40,000 unique events are computed to form a statistically sound basis.



x 40,000

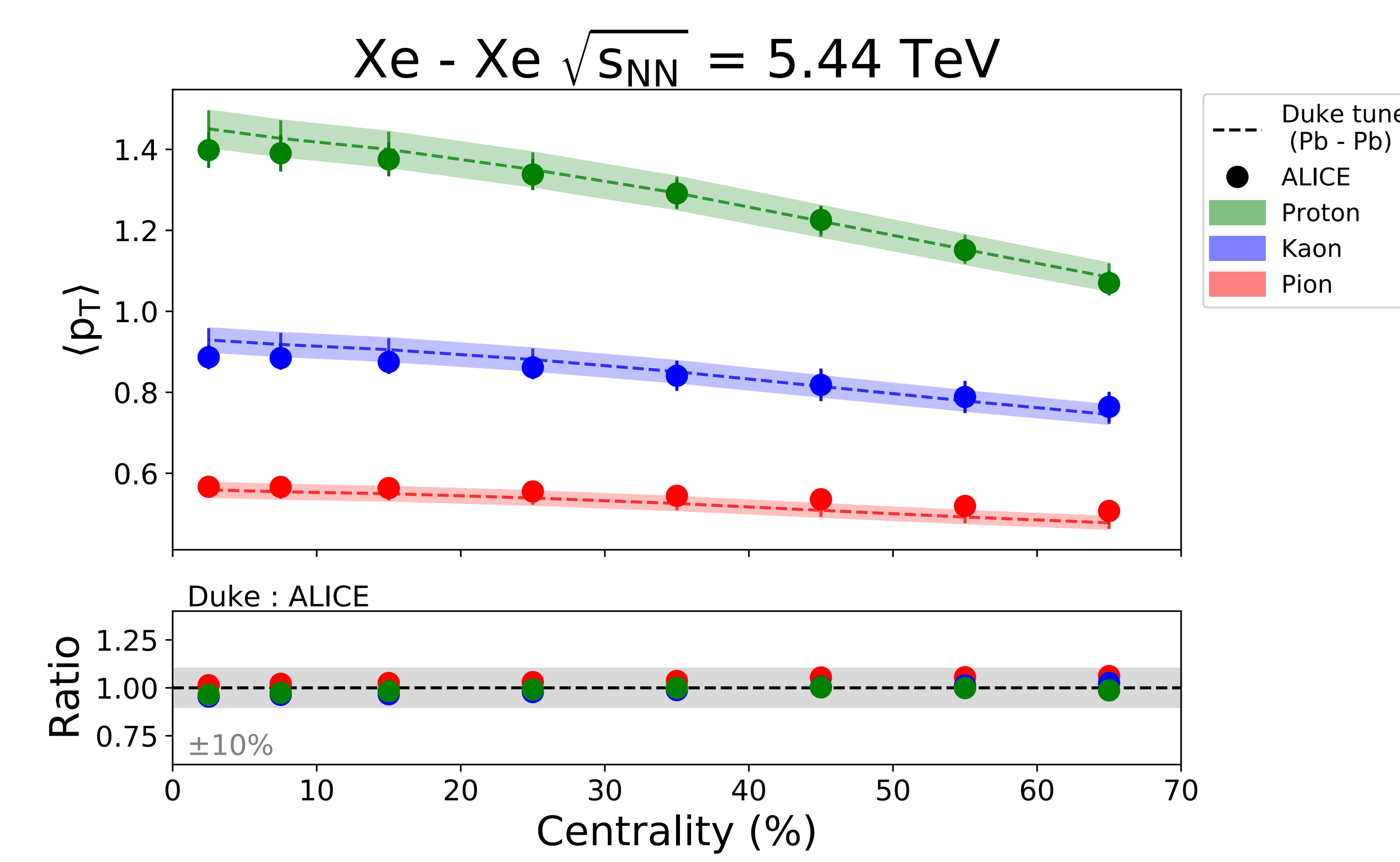
Results

shear viscosity is inversely influenced by the flow coefficients $v_n\{n\}$



The predictions match the data, thus the shear viscosity is well constrained

bulk viscosity is inversely influenced by the Transverse momentum $\langle p_T \rangle$



The bulk viscosity is also well constrained

Conclusion

- The lead-tuned parameters for the heavy-ion collision model chain have been verified for xenon nuclear collisions.
- The shear viscosity and bulk viscosity describing the quark gluon plasma are consistent for both lead and xenon, providing further evidence it is nature's most perfect fluid