Bayesian analysis of the *Trajectum* framework

Based on arXiv:2010.15130, 2010.15134 (see also parallel talk by Wilke van der Schee)

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Abstract

We introduce *Trajectum*, a new heavy ion code. We then use *Trajectum* to perform a Bayesian analysis including p_T-differential observables. This leads to a small value of the specific bulk viscosity ζ/s, as well as mild constraints on two second order transport coefficients.

The *Trajectum* framework

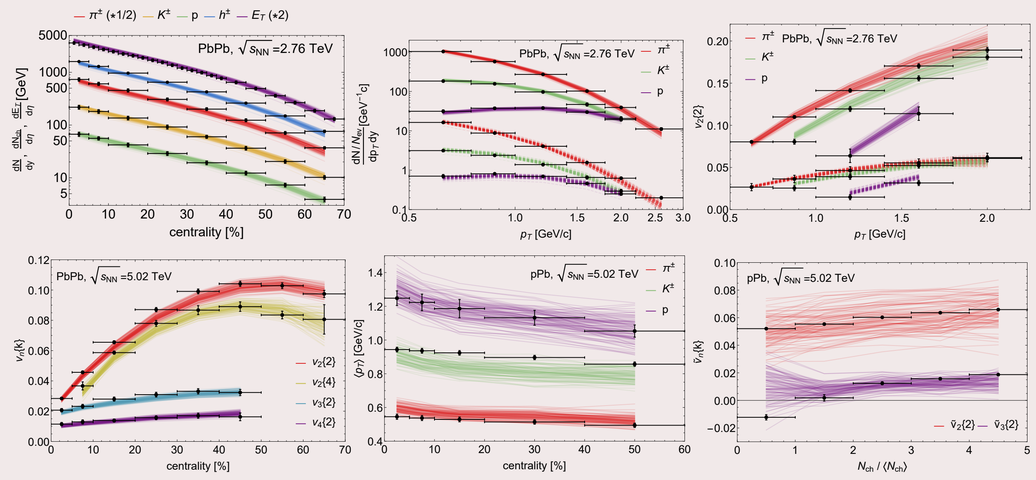
- The *Trajectum* framework is a new hydro code, which simulates the pre-equilibrium stage, the hydrodynamic stage, and freeze-out in a single executable.
- *Trajectum* provides a common interface between these components, allowing each component to be chosen from a list of available ones, while ensuring consistency.

Bayesian analysis of heavy ion collisions

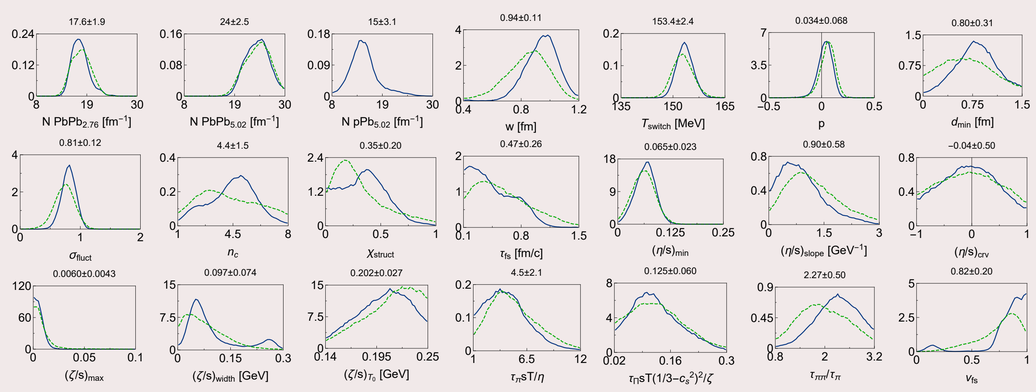
- Models such as *Trajectum* are able to accurately describe experimental observables, but depend on a large number of unknown parameters.
- These parameters include quantities like the shear (bulk) viscosity to entropy density ratio η/s (ζ/s), as well as second order transport coefficients, for which theoretical predictions exist.
- To find the optimal parameters, one evaluates the model at a number of *design points*, and uses the results to train an emulator. Subsequently, one uses the emulator to run a Monte Carlo simulation, resulting in a posterior probability distribution for the parameters [1].

Bayesian analysis with p_T-differential observables

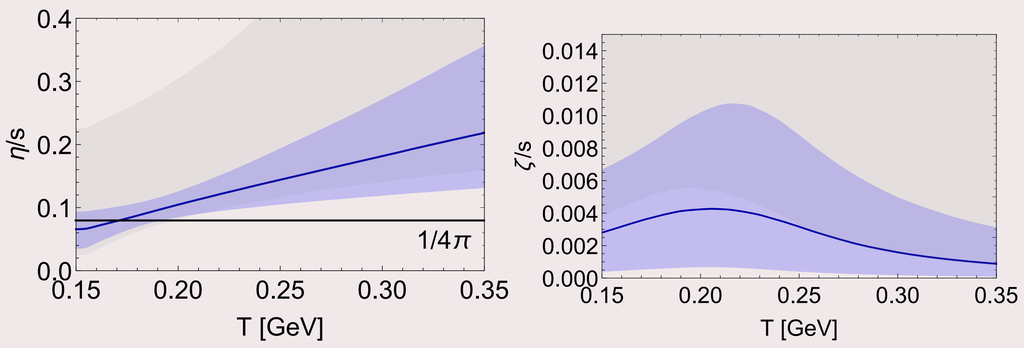
- We performed a Bayesian analysis for both PbPb and *p*Pb data simultaneously, varying 21 parameters.
- We used 1000 design points with 8k events each for PbPb, and 2000 design points with 40k events each for *p*Pb.
- In addition to p_T integrated observables, we also included p_T-differential observables.
- The posterior distributions can be seen to fit data well, although for *p*Pb improvements in emulation accuracy would be useful.



- Posterior distributions for the 21 parameters are shown below. We show the result of a fit to both PbPb and *p*Pb (blue, solid), as well as to PbPb alone (green, dashed).

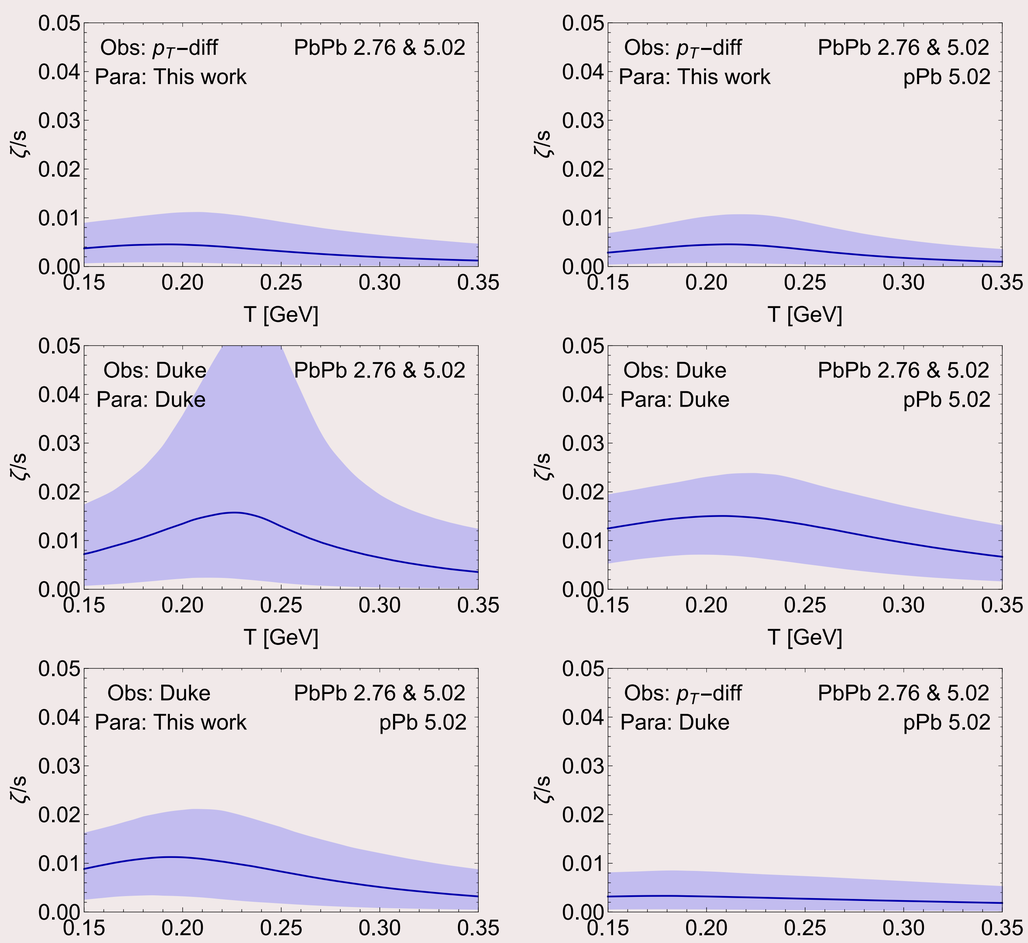


- The posteriors (with 90% confidence bands) of the temperature dependent η/s and ζ/s are given below.



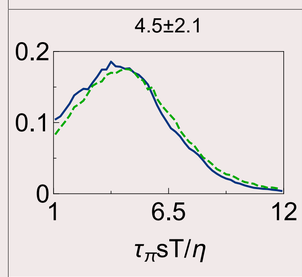
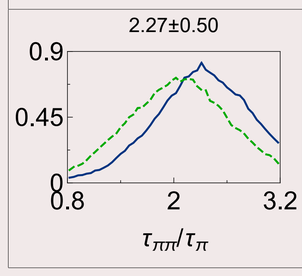
Bulk viscosity

- Differences with earlier studies are the inclusion of p_T-differential observables, as well as an expanded set of parameters.
- The effect on the bulk viscosity of these, as well as of the inclusion of *p*Pb observables, is studied below.
- The inclusion of p_T-differential observables has the largest effect on the smallness of the bulk viscosity.



Second order transport coefficients

- Shear relaxation time τ_π is compatible with both the AdS/CFT and weak coupling results.
- Second order transport coefficient $\tau_{\pi\pi}$ slightly favors the AdS/CFT result over the weak coupling result.

this work	AdS/CFT	kinetic theory
4.5±2.1  $\tau_\pi sT/\eta$	$4-\log(4)\approx 2.61$	5
2.27±0.50  $\tau_{\pi\pi}/\tau_\pi$	$\frac{88}{35(2-\log 2)}\approx 1.92$	$\frac{10}{7}\approx 1.43$

Summary

- We introduced the new heavy ion code *Trajectum*.
- We performed a Bayesian analysis including p_T-differential observables.
- Including p_T-differential observables yields a smaller bulk viscosity compared to the result when using only p_T-integrated observables.
- We obtained mild constraints on two second order transport coefficients, obtaining results compatible with both AdS/CFT and kinetic theory results.

References

[1] Jonah E. Bernhard, J. Scott Moreland, and Steffen A. Bass. Bayesian estimation of the specific shear and bulk viscosity of quark–gluon plasma. *Nature Phys.*, 15(11):1113–1117, 2019.

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