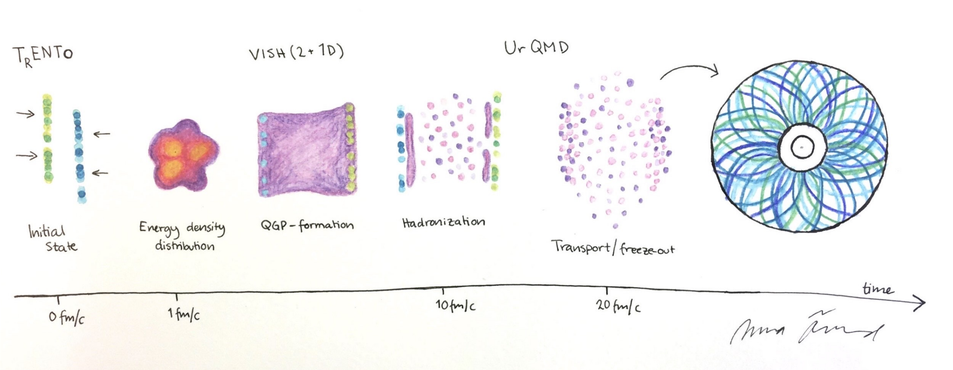
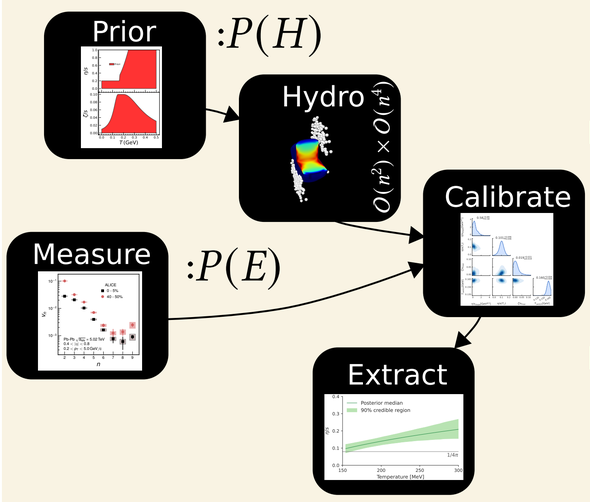
Improving Bayesian parameter estimation of QCD matter with the latest LHC data

Introduction, Based on PRC 104 (2021) 054904, arXiv:2111.08145



- **Goal:** to quantify the transport properties of quark gluon plasma by using an improved global Bayesian analysis and Pb–Pb data at $\sqrt{s_{NN}} = 2.76$ and 5.02 TeV from the CERN Large Hadron Collider.
- **Presenting:** that the uncertainty of the extracted transport coefficients are significantly reduced by including new sophisticated collective flow observables from two collision energies for the first time.

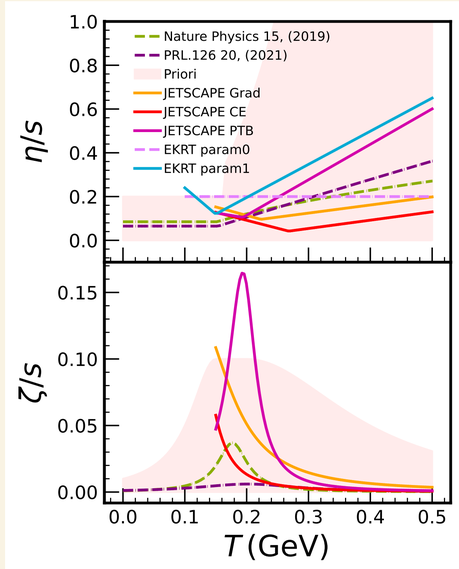
Bayes Theorem



$$P(H|E) = \frac{P(E|H) \cdot P(H)}{P(E)}$$

- Find optimal set of model parameters that best reproduce the experimental data
- Utilize constraints, such as flow observables, to help narrow down the QGP transport properties.

Analysis Steps



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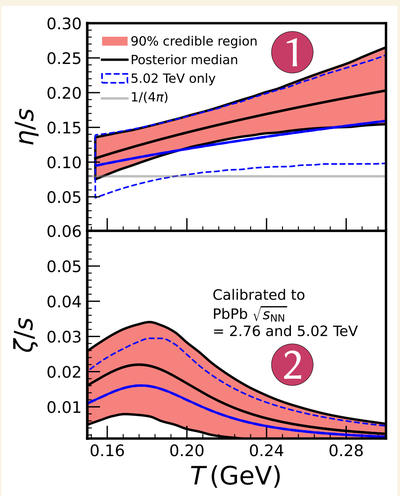
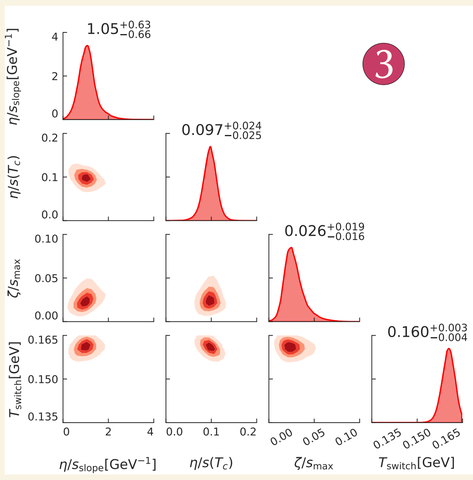
1. Choose prior parameter range based on results from 2019
2. Run hydro TRENTo+VISH(2+1D)+UrQMD for 500 parameterizations, 3-5 million events (×100 previous).
3. Calculate observables using our experimental framework
4. Train emulator and setup/run Bayesian analysis

Testing a single set of parameters requires $O(10^4)$ hydro events, and evaluating eight different parameters five times each requires $5^8 \times 10^4 \approx 10^9$ hydro events.

That's roughly 10^5 CPU years!

Results: Combined Collision Energy

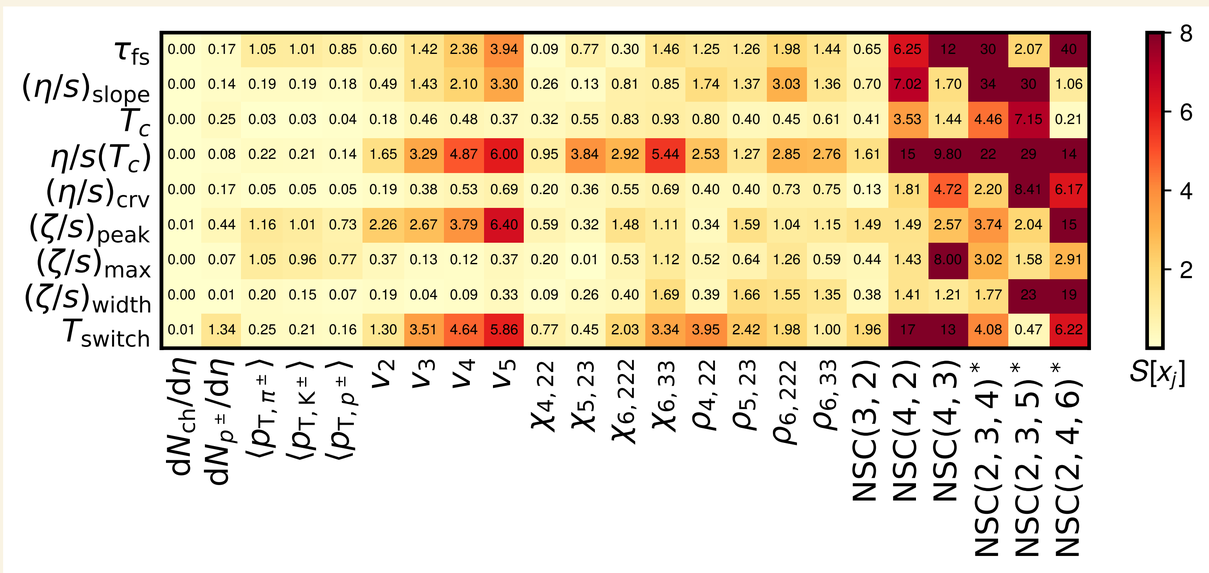




1. Significantly improved $\eta/s(T)$ uncertainty
2. Non-zero $\zeta/s(T)$
3. Overall better convergence for parameter components

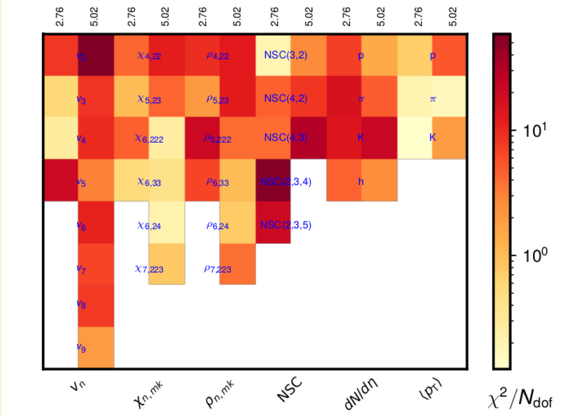
Together with two collision energies and added observables, the uncertainty has reduced!

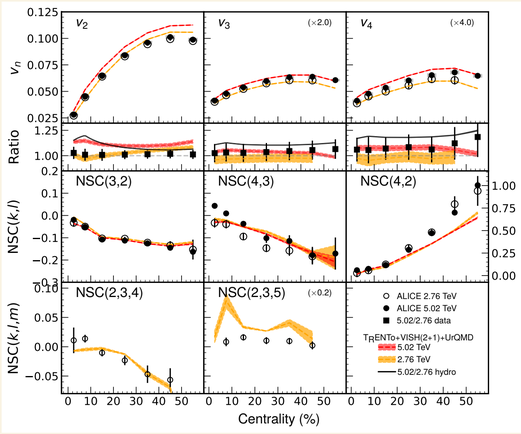
Sensitivity of observables to parameters



- Symmetric cumulants, especially NSC(n,m,k) among the most sensitive observables followed by v_n and $\chi_{n,mk}$.
- The precision measurements of observables, reflecting mostly non-linear hydrodynamic responses, are crucial.

Remaining Concerns





- overestimated v_n for 5.02 TeV by $\sim 10\%$
- still underestimated NSC(4,2)
- overestimated NSC(2,3,5)
- PID multiplicity (especially $\pi^{\pm}$)

Summary

Success:

- Higher harmonic orders and non-linear flow observables. → better constraints.
- Improved the overall uncertainty by a factor of two by combining two beam energy data.
- As a bonus, sensitivities of the observables are now quantified → precision measurements of observables, reflecting non-linear hydrodynamic responses.

Challenges:

- Small discrepancy for description of few observables
- Improving the initial state model, with dynamical collision model or subnucleon structure à la IP-Glasma, might help us to improve the results.

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