Bayesian characterization of the initial state and QGP medium

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**Goal**
Perform a systematic model-to-data comparison using an event-by-event heavy-ion collision model. Simultaneously tune all model parameters to optimally reproduce experimental data. Extract probability distributions for each parameter. More information about the methodology.

- J. E. Bernhard et al., PRC 91 054910, 1502.0039.
- S. Pratt et al., PRL 114 202301, 1501.0442.
- J. Novak et al., PRC 89 034917, 1303.5769.

**Input parameters**
- Initial condition normalization $p$
- Entropy deposition parameter $k$
- Nucleon fluctuation parameter $w$
- Gaussian nucleon width $\eta$
- Shear viscosity at $T = 0.154$ GeV $\eta$
- Slope of shear viscosity above $T_c$ $\zeta$
- Bulk viscosity normalization $\zeta$
- Hydro to UrQMD switching temp.

**Posterior distribution**
Diagonals
- Probability distributions of each parameter, integrating out all others
Off-diagonals
- Pairwise probabilities showing correlations between parameters

**Diagonals**
- Posterior mode (labeled for strong peaks)
- Probability of parameters given model and data
- Probability of observing experimental data given prior parameters
- Prior knowledge of parameters

**Posterior samples**
- Draw random samples from MCMC chain
- Gaussian process emulator
  - Non-parametric interpolation / fast surrogate to full model
  - Markov chain Monte Carlo random walk through parameter space weighted by posterior probability

**Model**
Initial conditions
- $T_{\text{ENTo}}$ (parametric model)
- $T_{\text{UrQMD}}$
- $p$ = tunable entropy deposition parameter
- See J. Scott Moreland’s poster

**Experimental data**
- ALICE collaboration
  - Pb+Pb collisions at $\sqrt{s}=2.76$ TeV
  - yields and mean $p_T$
- PRL 107 032301, 1105.3865.
- PRC 88 044910, 1303.0737.

**Key results**
- Determined scaling of initial entropy deposition
- Extracted new measurement of $(\eta/s)_{\text{RHIC}}$; need RHIC data to determine full $T$-dependence
- Found clear preference for nonzero bulk viscosity

**Outlook**
- Combine RHIC and LHC data
- Pre-equilibrium (free streaming) and tunable thermalization time
- Sensitivity analysis

**Flow cumulants**
- Determine full $T$-dependence of $(\eta/s)(\zeta)$; need RHIC data to constrain a linear combination of $\eta/s$ min and slope
- $n/s$ at ~220 MeV appears to be most important at LHC

**Temperature dependence of viscosity**
- $T_c = 0.154$ GeV
- Hydro-to-UrQMD switching temp.
- Slightly below HotQCD EOS, $T_c = 0.154$ GeV
- $\eta/s$ at $220$ MeV appears to be most important at LHC

**Gaussian process emulator**
- Gaussian process emulator
- HotQCD EOS
- UrQMD
- ALICE collaboration
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**Entropy deposition parameter $p$**
- $p = 0$

**Outlook**
- Determine scaling of initial entropy deposition
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**Posterior samples**
- Identified particle yields
- Identified particle mean $p_T$
- Flow cumulants

**Water bag**
- $T_c = 0.154$ GeV
- hydro-to-UrQMD switching temp.
- Slightly below HotQCD EOS, $T_c = 0.154$ GeV

**Model**
Initial conditions
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**Hydro**
- Event-by-event VISH2+1
  - HotQCD EOS
  - T-dependent shear & bulk viscosity

**Paritculation**
OSU Cooper-Frye sampler

**Hadronic phase**
UrQMD

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