(3+1)D Bayesian Analysis at RHIC BES energies with Directed Flow

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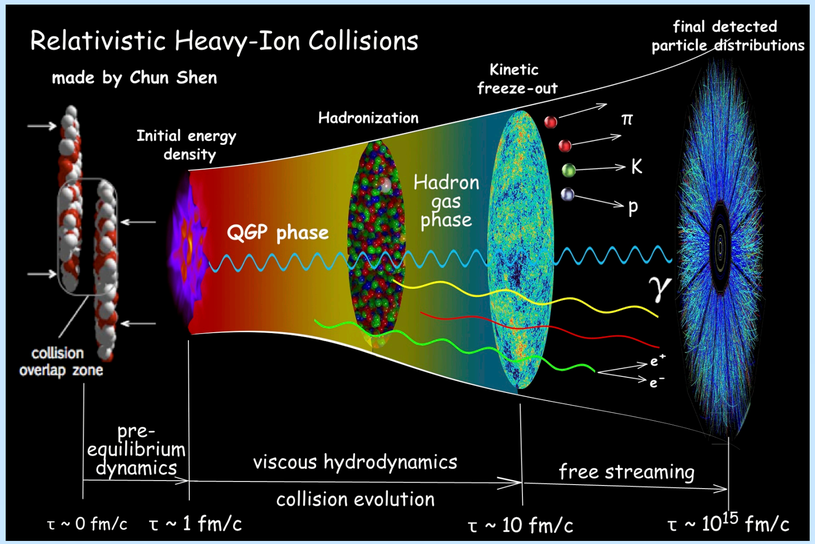
Background:



- Relativistic heavy ion collisions are a multistage process. Patched together phenomenological models.
- To make model predictions with uncertainty qualification Bayesian analysis is the way to go.

Bayes Theorem: $P(\theta \mid Data) = \dfrac{P(Data \mid \theta) P(\theta)}{P(Data)}$

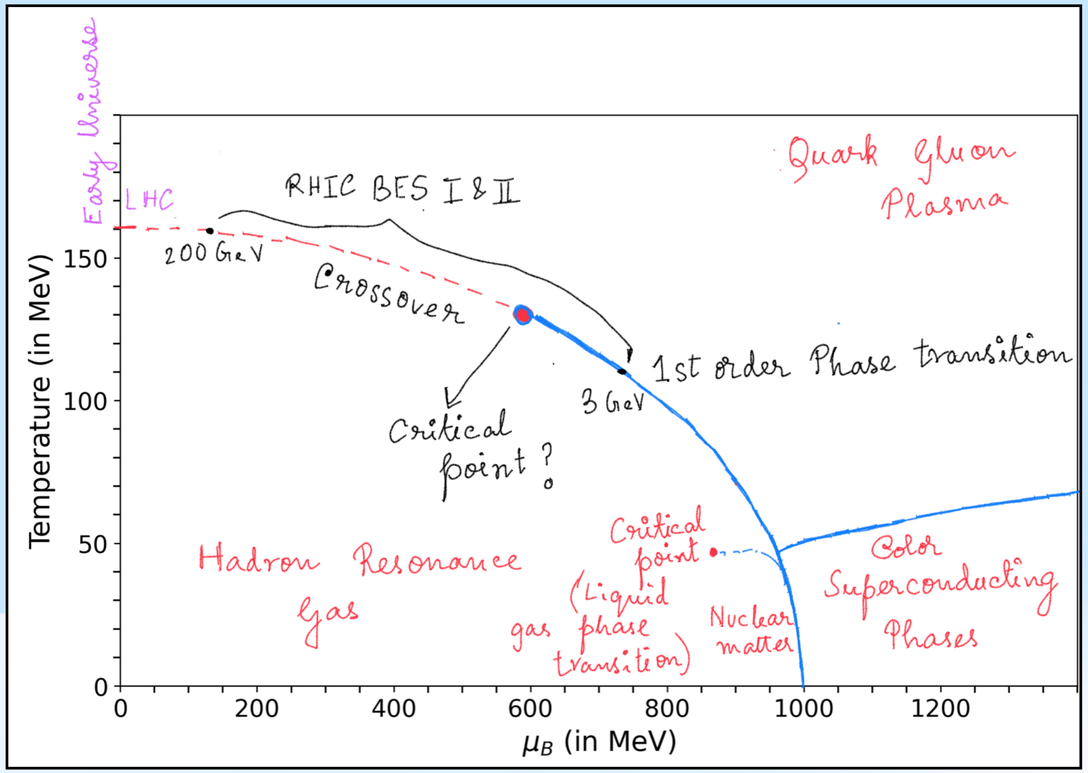
Parameter	Prior	Parameter	Prior
η_0^{ϵ}	$[0, y_{\text{beam}}]$	σ_η	$[0.1, y_{\text{beam}}]$
η_m	$[0, y_{\text{beam}}]$	β	$[0, 1]$
$\eta_0^{n_B}$	$[\max(0, y_{\text{beam}} - 3), y_{\text{beam}}]$	$\sigma_{B,+}$	$[0.1, 1]$
$\sigma_{B,-}$	$[0.1, y_{\text{beam}} - 2]$	ω	$[0, 1]$
η_0	$[0.001, 0.3]$	η_2	$[0.001, 0.3]$
η_4	$[0.001, 0.3]$	T_η [GeV]	$[0.15, 0.3]$
b_1	$[0, 5]$	b_2	$[-5, 0]$
ζ_0	$[0.001, 0.3]$	ζ_2	$[0.001, 0.3]$
ζ_4	$[0.001, 0.3]$	$\sigma_>$ [GeV]	$[0.005, 0.1]$
$\sigma_<$ [GeV]	$[0.005, 0.1]$	T_ζ [GeV]	$[0.15, 0.3]$
e_{sw} [GeV/fm^3]	$[0.1, 0.4]$		

$P(Data \mid \theta)$ → Likelihood

$P(\theta \mid Data)$ ← Posterior

$\sqrt{s_{\text{NN}}}$ [GeV]	STAR	PHOBOS
AuAu 200	$\mathrm{d}N/\mathrm{d}y(\pi^\pm, K^\pm, p, \bar{p})$ $\langle p_{\text{T}} \rangle(\pi^\pm, K^\pm, p, \bar{p})$ $v_1(y)(\pi^+, p, \bar{p})$, $v_1^{\text{ch}}(\eta)$, $v_2^{\text{ch}}(\eta)$, v_2^{ch} vs centrality	$\mathrm{d}N_{\text{ch}}/\mathrm{d}\eta$
AuAu 19.6	$\mathrm{d}N/\mathrm{d}y(\pi^\pm, K^\pm, p, \text{net } p)$ $\langle p_{\text{T}} \rangle(\pi^\pm, K^\pm, p, \bar{p})$ $v_1(y)(\pi^+, p, \bar{p})$, $v_1^{\text{ch}}(\eta)$	$\mathrm{d}N_{\text{ch}}/\mathrm{d}\eta$
AuAu 7.7	$\mathrm{d}N/\mathrm{d}y(\pi^\pm, K^\pm, p, \text{net } p)$ $\langle p_{\text{T}} \rangle(\pi^\pm, K^\pm, p, \bar{p})$ $v_1(y)(\pi^+, p, \bar{p})$	

Motivation: Exploring the QCD Phase Diagram



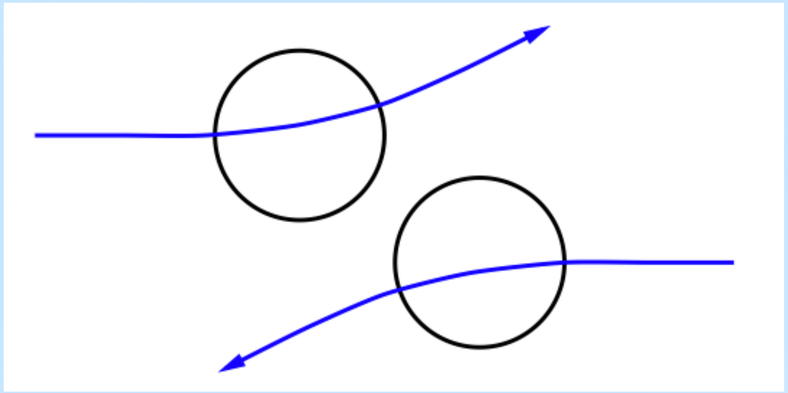
- Nuclear matter can have different phases.
- Different phenomenological theories predict that at finite baryon density it may be become a first order phase transition - a critical point?
- Bayesian analysis at these energies: 200 GeV, 19.6 GeV, 7.7 GeV

In LHC energies of TeV we consider the nuclei to be pancakes

At RHIC BES energies we want to consider dynamics in the beam direction too

Hence, a (3 + 1)D Bayesian analysis

Inclusion of directed flow $v_1(y)$



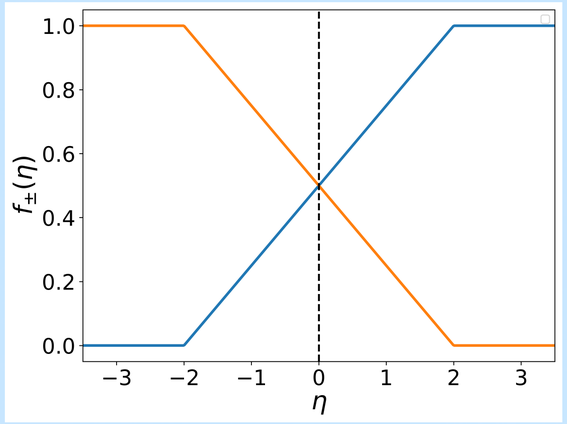
$$\frac{dN}{d\phi} = \frac{N}{2\pi}[1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\phi - \Psi_n))]$$ Flow Coefficients

$$v_1 = \langle \cos(\phi - \Psi_n) \rangle$$ Directed Flow

$$y = \log \frac{t+z}{t-z}$$ Rapidity

- We want to constrain the longitudinal structure and Equation of State.
- Using rapidity dependent observables like $v_1(y)$ gives us information about the longitudinal dynamics, thus we can obtain robust constraints on the shear and bulk viscosity.
- In our initial state model, we use a generalized form for the energy density.

Our Work: New Parameterization for Energy Density in 3D Glauber Model



$$\epsilon_{\text{tilt}} = \epsilon_{0t} f_\eta(\eta, \eta_0, \sigma_\eta) T_A^{f_+} T_B^{f_-}$$

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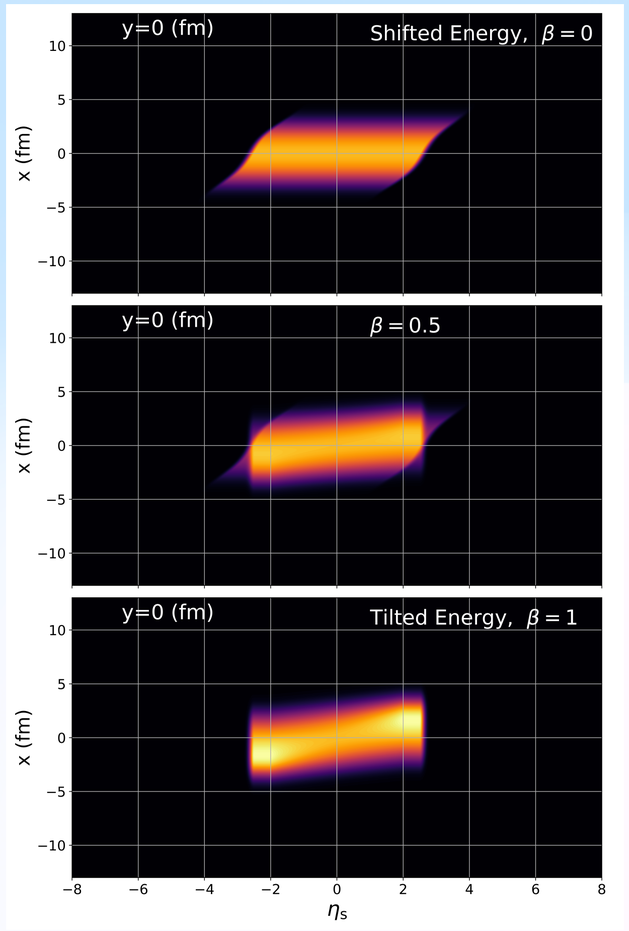
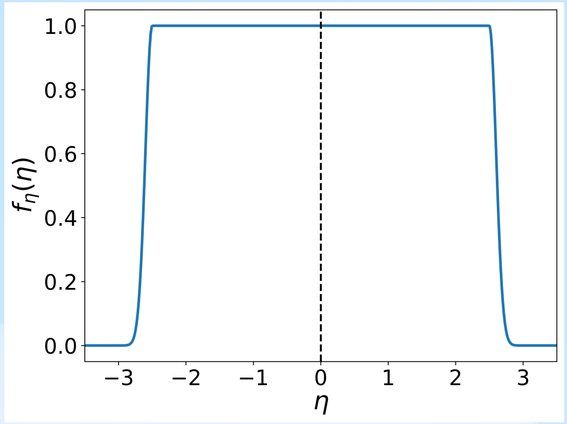
Depending on forward and backward rapidity, projectile A or target B is chosen

$$\epsilon(x, y, \eta_s, t) = (1-\beta)\epsilon_{\text{shift}} + \beta\epsilon_{\text{tilt}}$$



From shifted to tilted energy density



$$\epsilon_{\text{shift}} = \epsilon_{0s} f_\eta((\eta - y_{\text{cm}}), \eta_0, \sigma_\eta)$$

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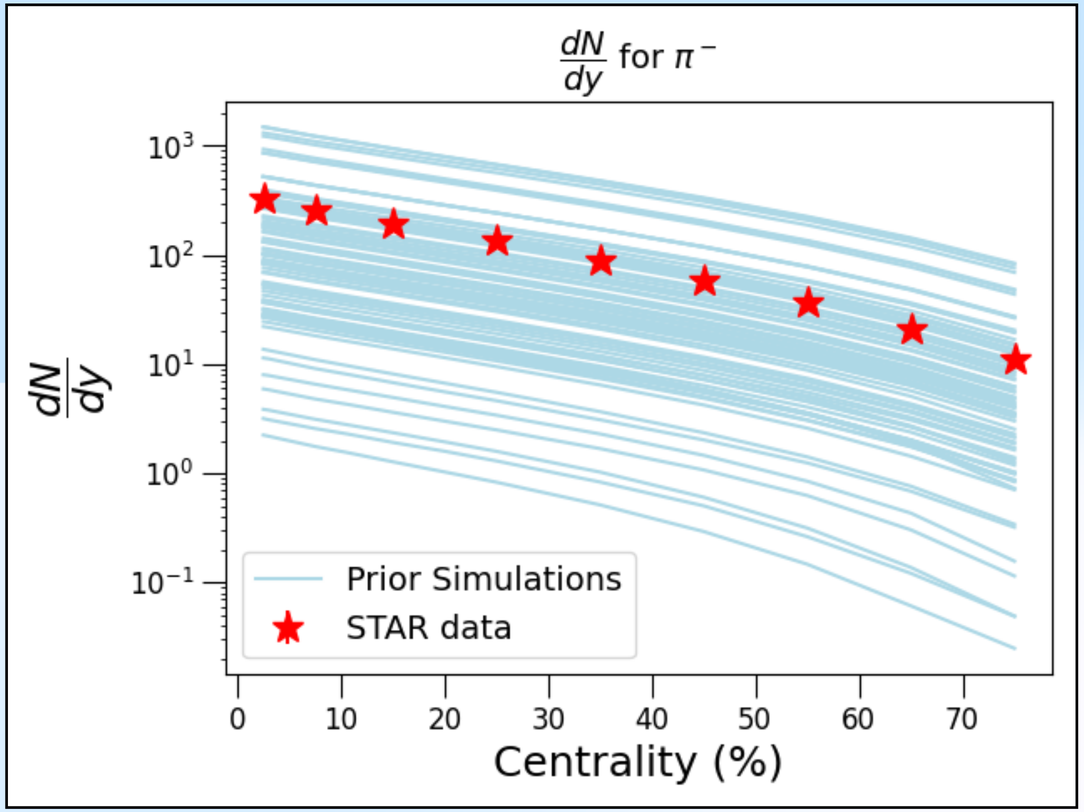
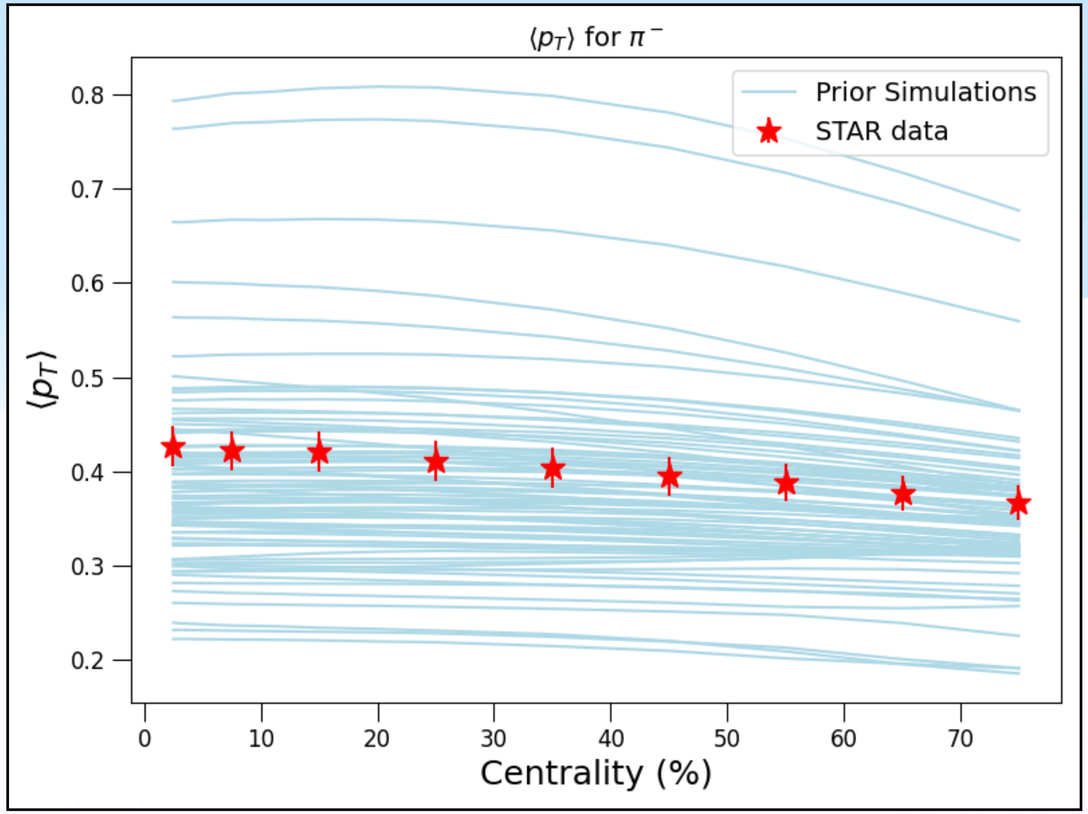
The energy density is shifted by the center of mass of the fireball determined by $T_A - T_B$

Preliminary Results

- Our first step is to compare experimental data with simulations from the prior range.





Our next step is to train the emulators i.e the surrogate models on the design points.

Summary

- We have made a Bayesian framework which will use the observable directed flow to constrain longitudinal structure. Rapidity dependent directed flow has not been used in any previous Bayesian analysis.
- We have also employed a generalized parameterization for the initial energy density.
- We have obtained reasonable predictions from our simulations. We are currently setting up the Bayesian analysis.

Bonus Slides