Constraints on 3D hydro initial conditions from experimental data and systematic predictions of longitudinal observables at the LHC

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I. Introduction

A realistic 3D initial condition for the 3+1D QGP dynamics: understand longitudinal fluctuation in AA, small / asymmetric collision systems, correlation of hard particles and soft particles.

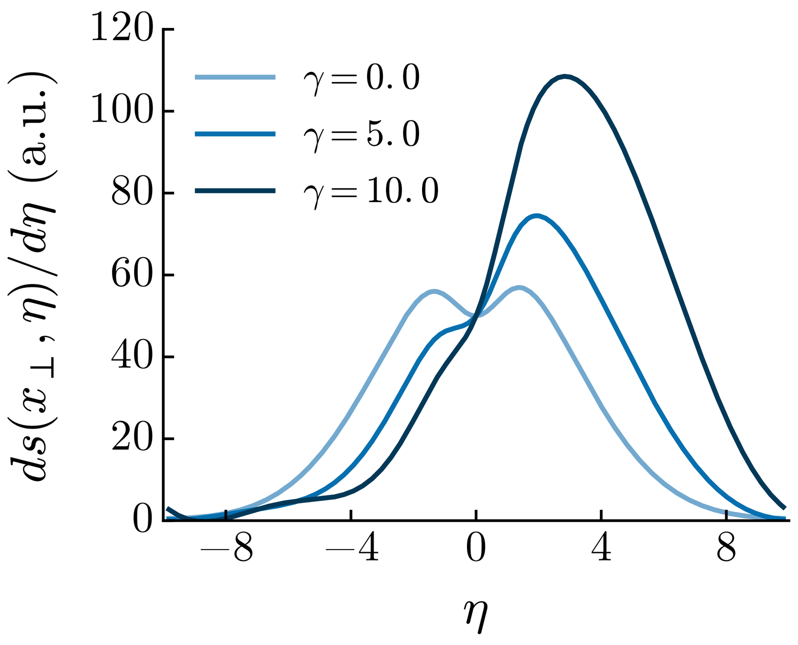
- This work: extend initial condition model (TRENTo) to $\eta \neq 0$. Data-driven Bayesian inference calibrates model parameters with multiplicity observables.
- Validate tuned model by systematic prediction of $v_n(\eta), r_n(\eta), S_{mn}$.

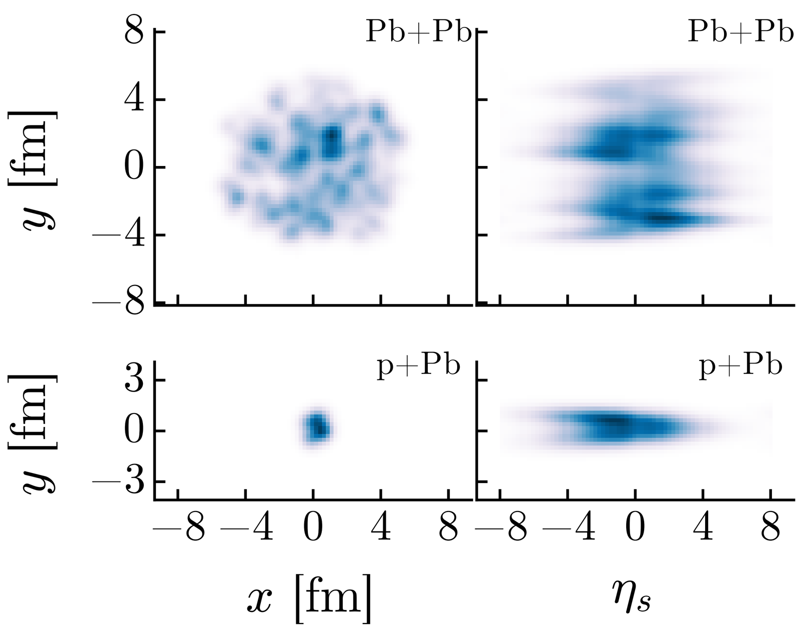
II. Model: from mid-rapidity to finite η

- A IC model defined at $\eta = 0$ maps participant densities T_A, T_B to entropy density $s_0(\mathbf{x}_\perp)$. Extend to $\eta \neq 0$: $s(\mathbf{x}_\perp, \eta) = s_0(\mathbf{x}_\perp) g(\mathbf{x}_\perp, \eta)$.
- $g(\mathbf{x}_\perp, \eta)$ reconstructed from its cumulant generating function. Parametrise its mean (μ), std (σ), skewness (γ) with $T_A(\mathbf{x}_\perp), T_B(\mathbf{x}_\perp)$.

$$g(\mathbf{x}_\perp, \eta) \sim \mathcal{F}^{-1}\left\{\exp\left(i\mu k - \frac{1}{2}\sigma^2 k^2 - \frac{i}{6}\gamma\sigma^3 k^3 + \cdots\right)\right\} \qquad (1)$$

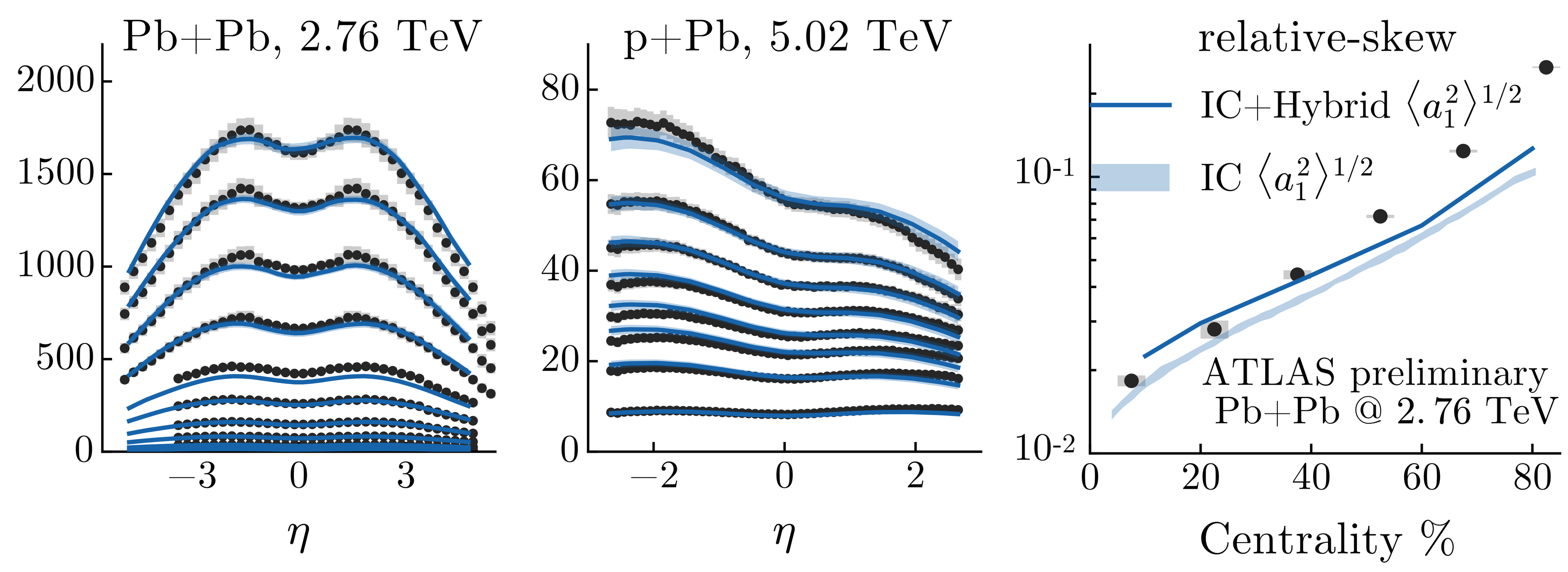
Cumulants	μ	σ	γ
relative-skewness	$\frac{\mu_0}{2}\ln\left(\frac{T_A y_b^2 + T_B}{T_A + T_B y_b^2}\right)$	σ_0	$\gamma_0 \frac{T_A - T_B}{T_A + T_B}$





III. Bayesian model calibration

- Bayesian model-to-data comparison parameter inference. Event-by-event IC+Hydro+UrQMD calculation of $dN_{\text{ch, p+Pb}}/d\eta$. Centrality-averaged-IC+hydro+UrQMD calculation of $dN_{\text{ch, Pb+Pb}}/d\eta$.

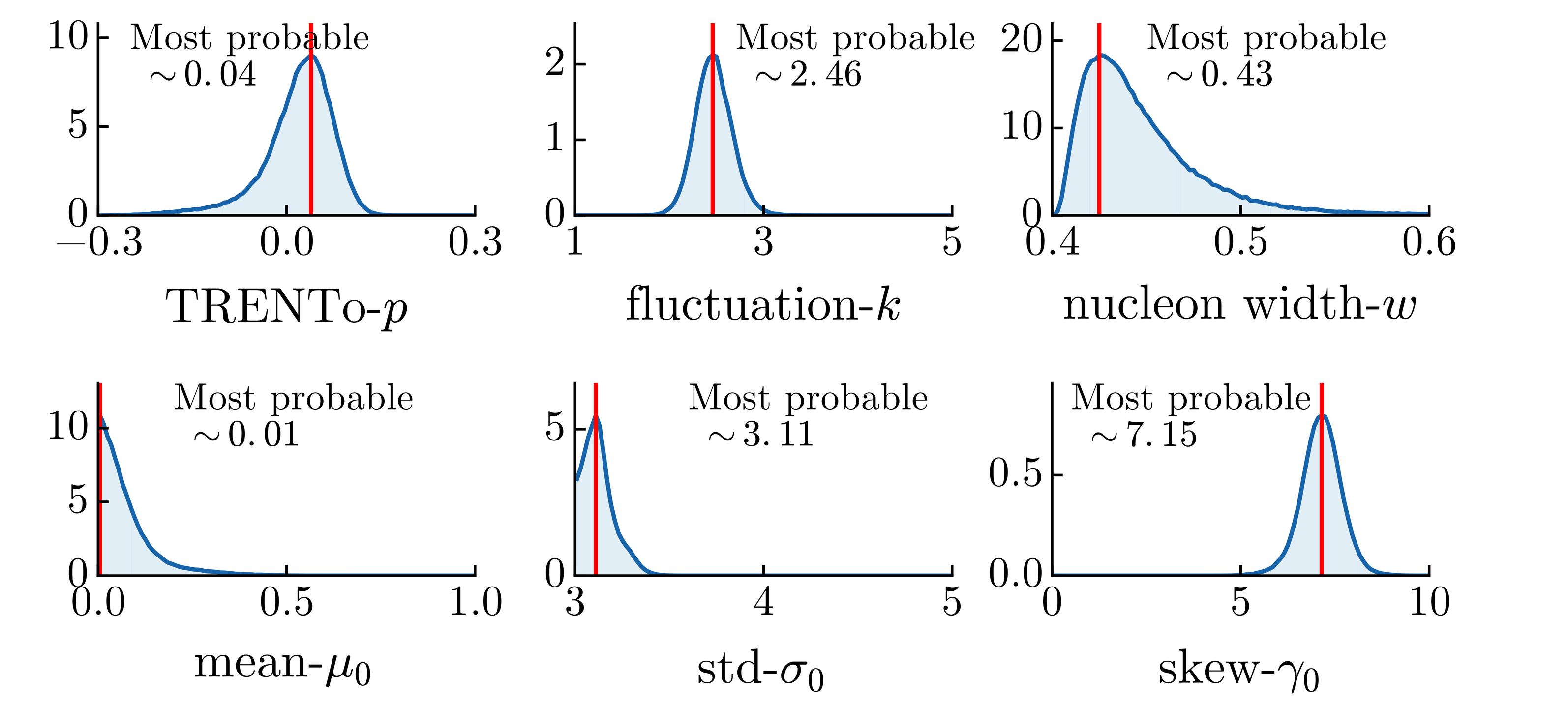


- Calibrated models predict EbE $dN/d\eta$ fluctuation observable $\langle a_1^2\rangle$. $\langle a_1^2\rangle$: event-wise $dN/d\eta$ Legendre decomposition within $[-Y, Y]$.

$$dN/d\eta = \langle dN/d\eta\rangle \left(1 + \sum a_n T_n(\eta/Y)\right). \qquad (2)$$

$\langle a_m a_n\rangle$ extracted from two particle η-correlation $C(\eta_1, \eta_2)$.

- Relative-skewness model reproduces $dN_{\text{ch}}/d\eta$ and describes $\langle a_1^2\rangle$ within 20% up to 50% centrality.

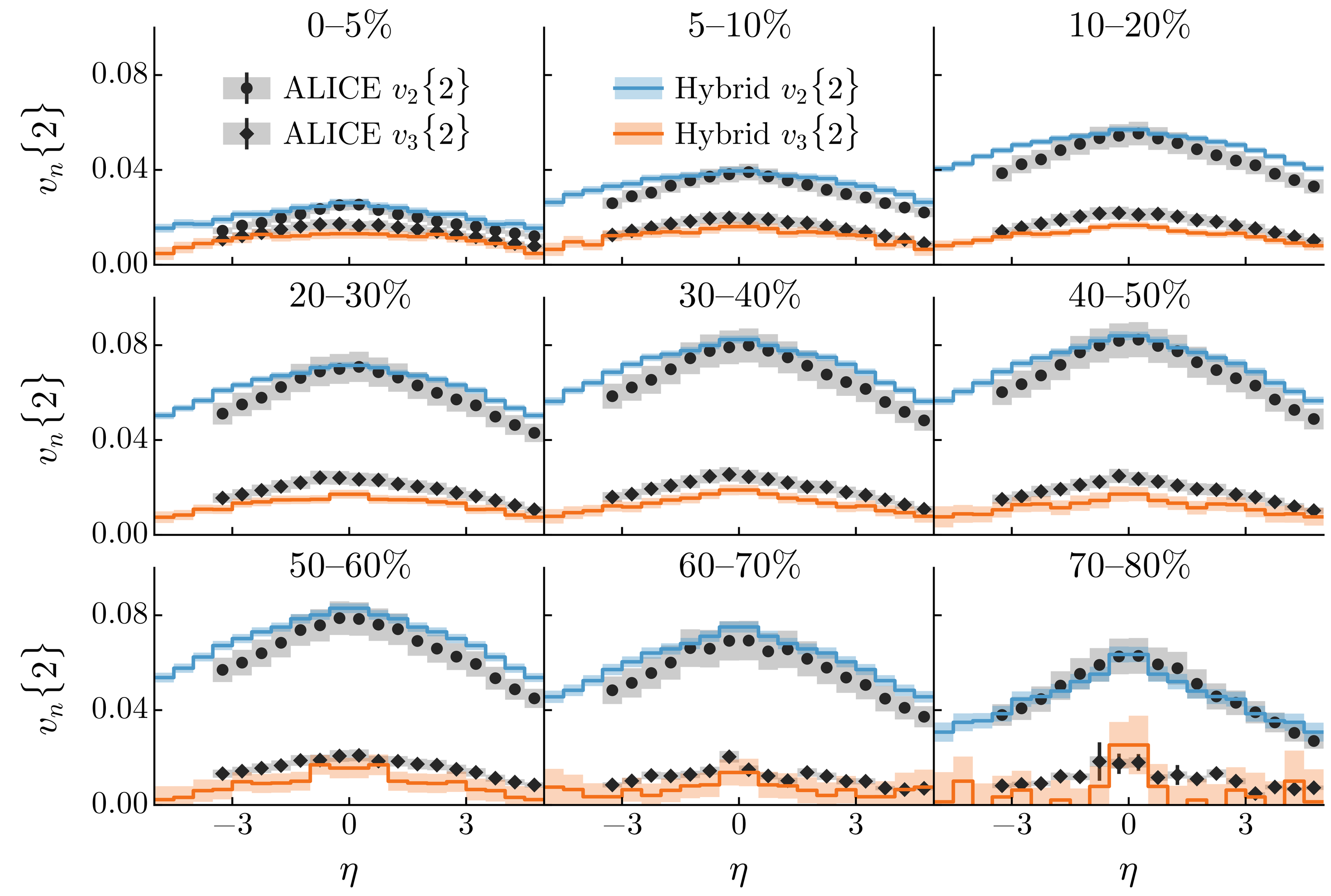


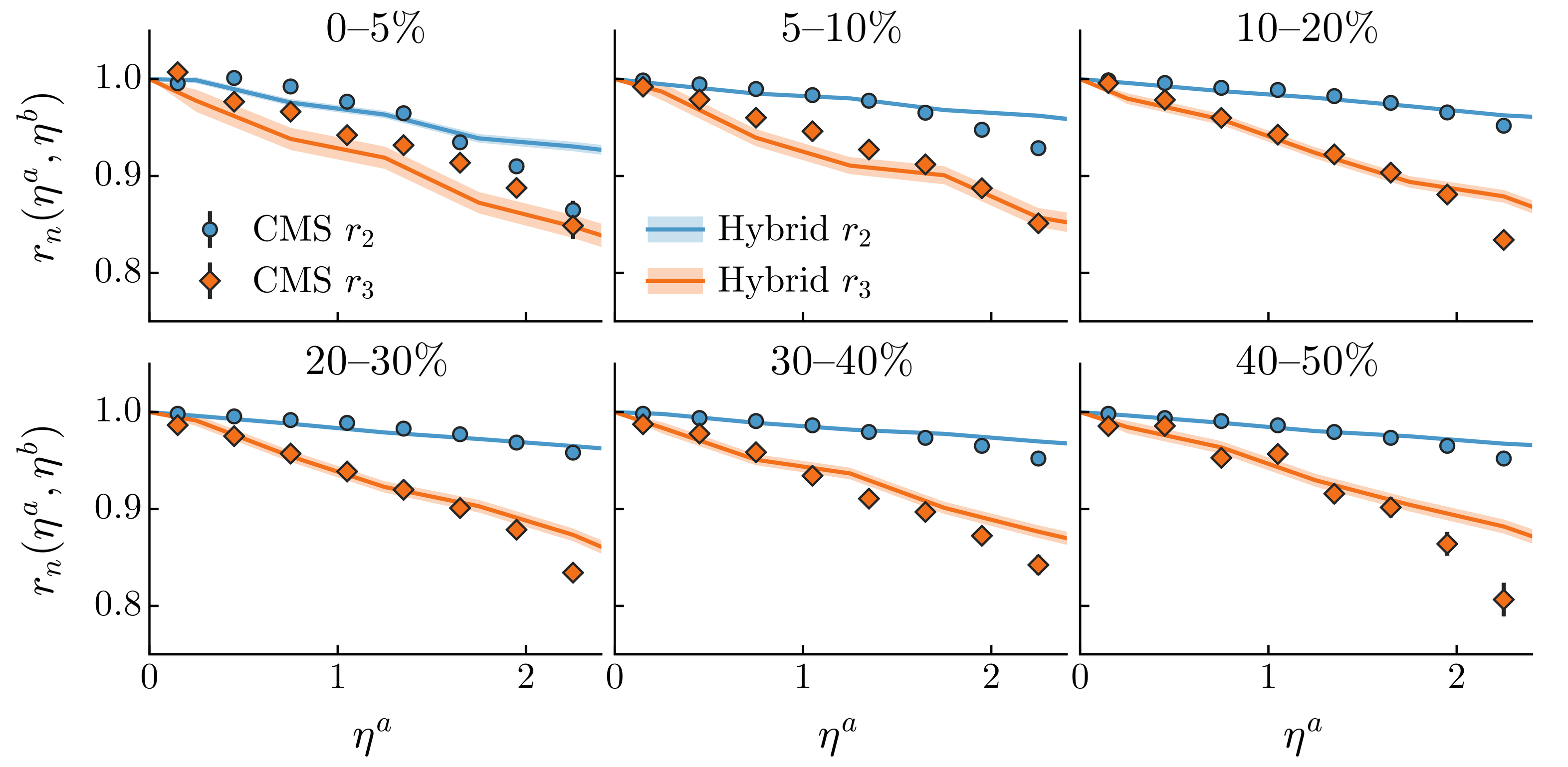
IV. Hydro+UrQMD simulation set-up

3+1 D viscous hydrodynamics (Iu. Karpenko, arXiv:1312.4160). Zero ζ/s; constant η/s for hydro phase, $\eta/s = 0.2 - 0.3$. Transition from hydro to UrQMD at $T_s = 151$ MeV, below critical temperature $T_c \sim 154$ MeV.

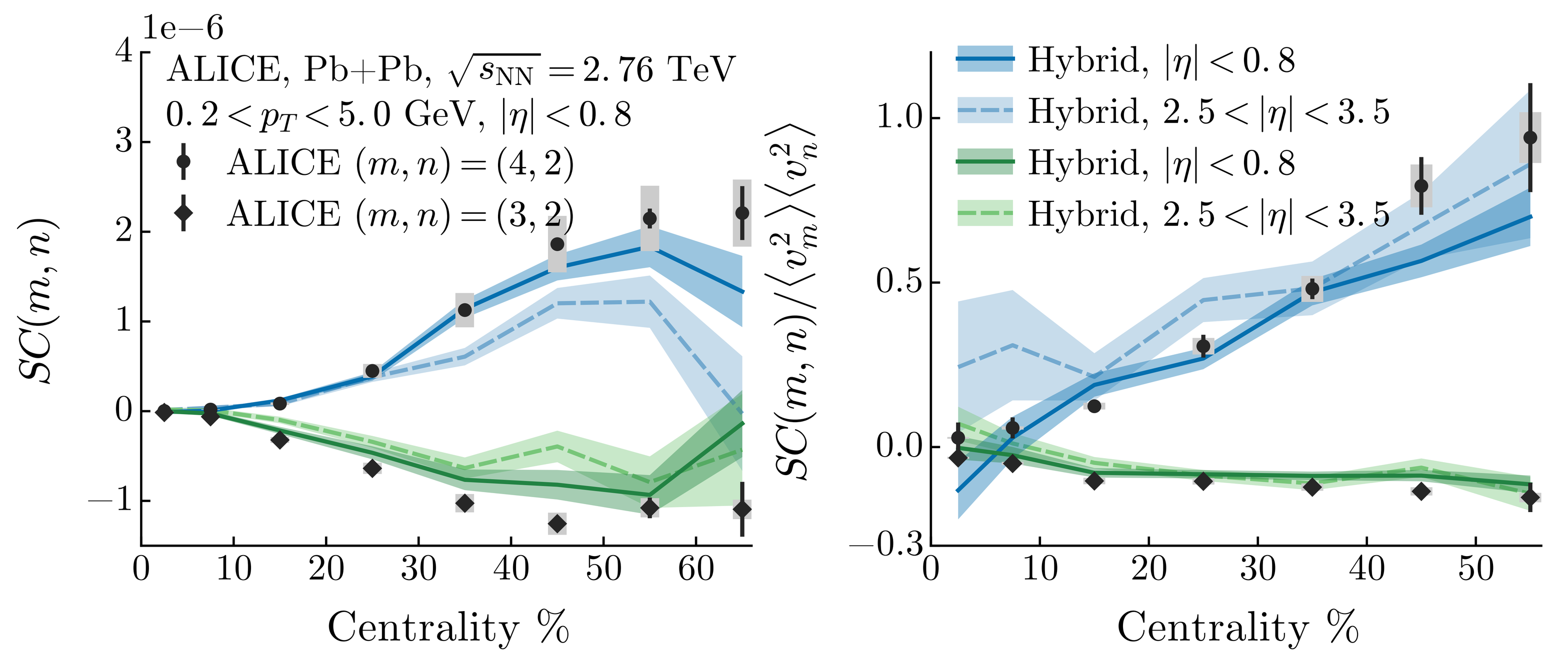
V. Validate with other η-dependent observables

Calibrated relative-skew model predicts η-differential flows (ALICE $p_T > 0, \eta/s = 0.3$) and event-plane decorrelations (CMS, $3 < |\eta^b| < 4$).





Symmetric cumulants are calculated at mid-rapidity and compared to ALICE data. Also shown are the prediction of S_{mn} at the forward rapidity.



VI. Conclusion

- Initial $ds(\mathbf{x}_\perp, \eta)/d\eta$ is modelled by parametrising its first 3 cumulants in terms of nuclear participant densities $T_A(\mathbf{x}_\perp), T_B(\mathbf{x}_\perp)$.
- The model calibrated on multiplicity observables also predicts $v_n(\eta)$, r_n that agree with data. Unlike multiplicity observables, $v_n(\eta), r_n$ are sensitive probes to longitudinal evolution of transverse structures.
- It suggests the present optimized parametrisation is a reasonable model of the 3D entropy deposition at the beginning of hydrodynamic evolution.
- We use the present model to further predict the symmetric cumulants at the central and forward rapidity.

Acknowledgement

We thank Jiangyong Jia for providing the ATLAS preliminary data. This work has been supported by DOE grant # DE-FG02-05ER41367-A.