Rapidity-dependent Dynamics of the Initial State via 3D Multi-system Bayesian Calibration

Andi Mankolli
Vanderbilt University
(on behalf of the JETSCAPE Collaboration)

SFP_300495

Introduction

Experimental measurements at mid-rapidity have driven characterization of the quark-gluon plasma

Bayesian analyses compared mid-rapidity data to 2D initial state and hydrodynamic models

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Editors' Suggestion

Phenomenological Constraints on the Transport Properties of QCD Matter with Data-Driven Model Averaging

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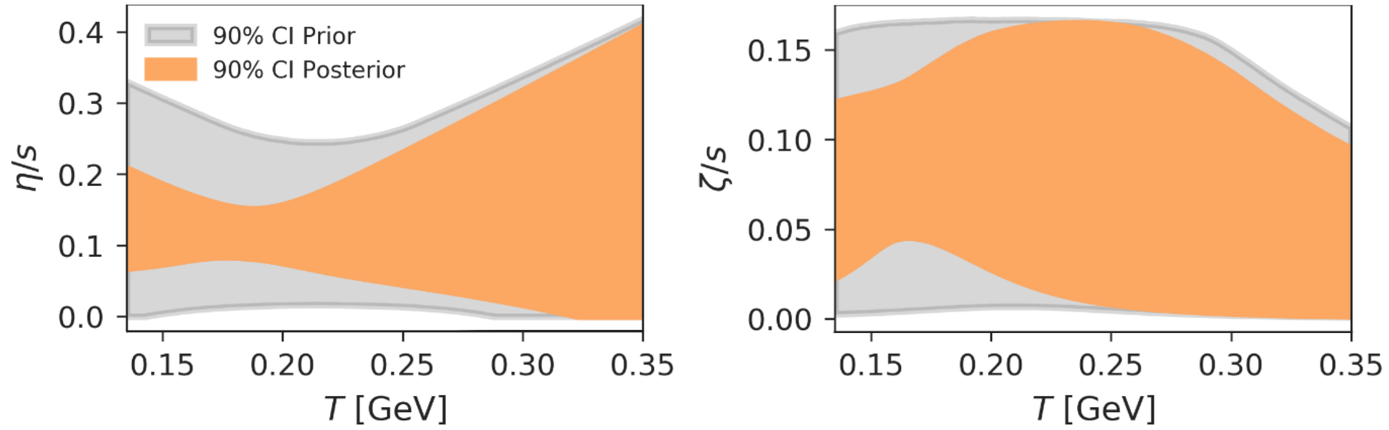

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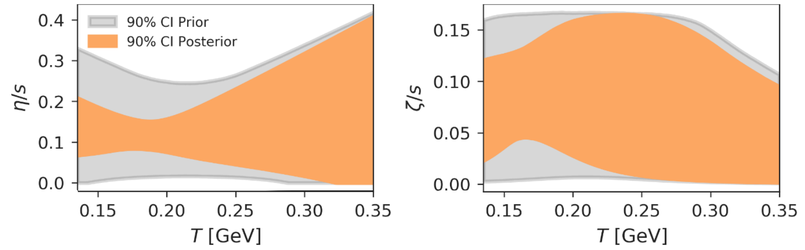

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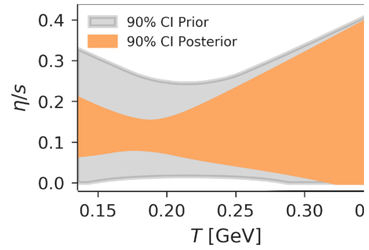

Transverse Momentum Differential Global Analysis of Heavy-Ion Collisions

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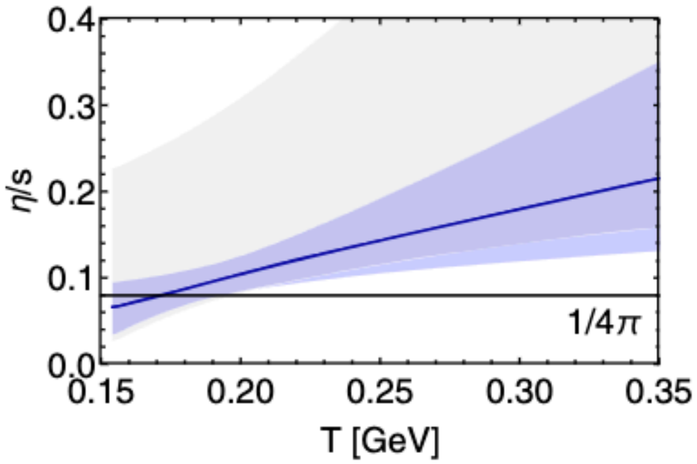

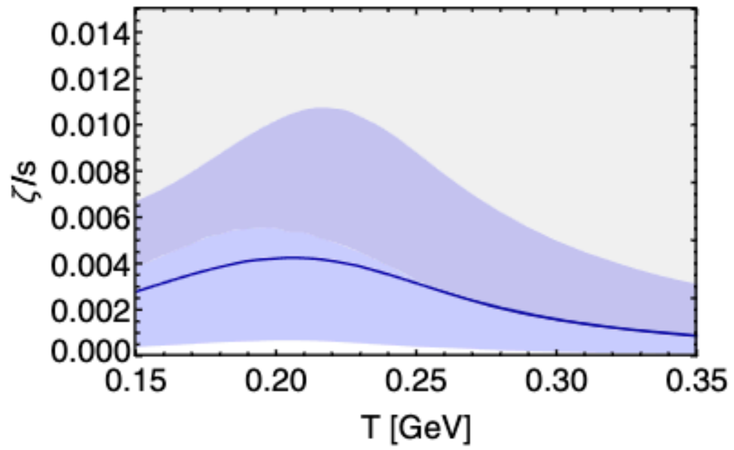

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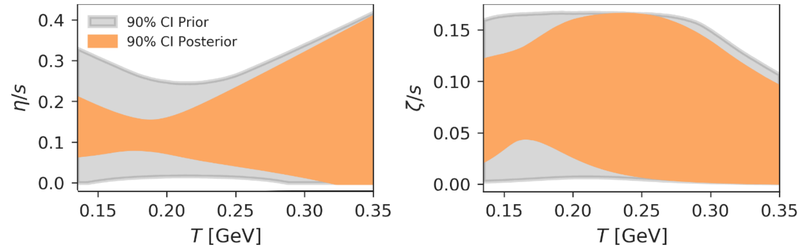

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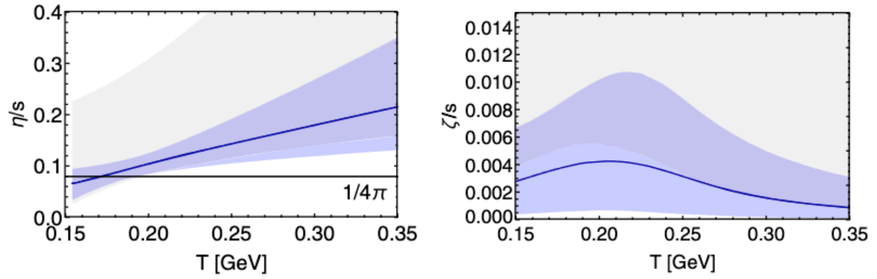

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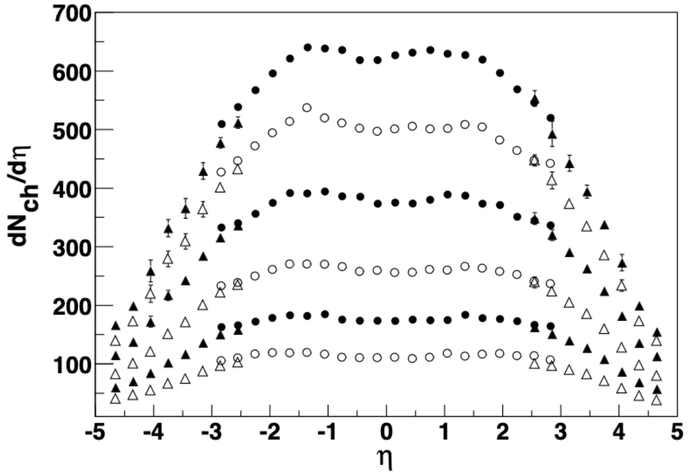

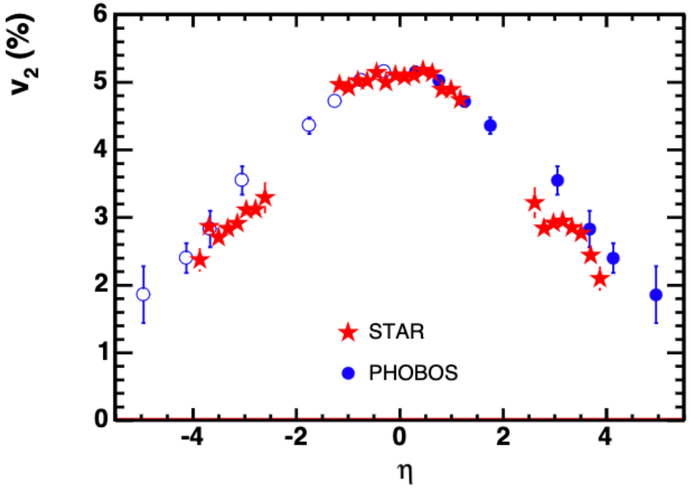

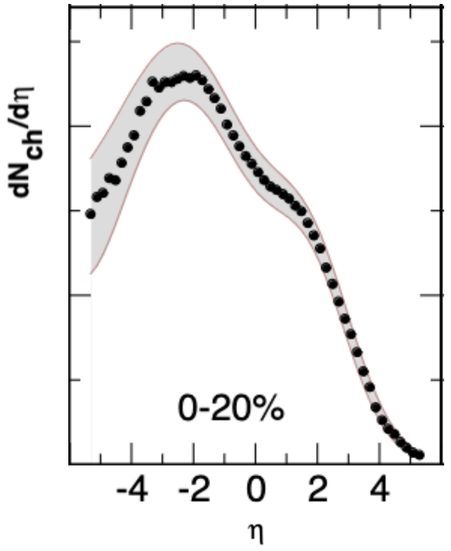

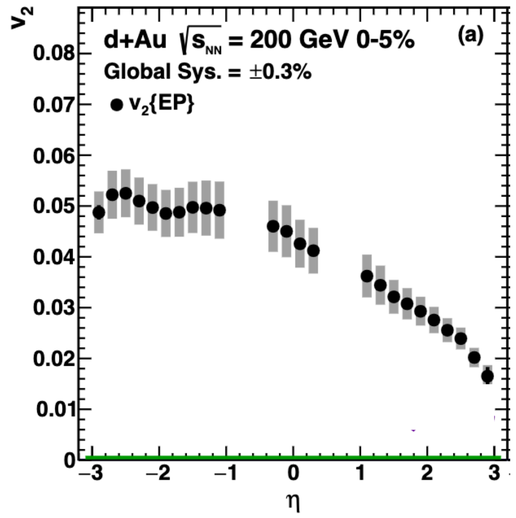

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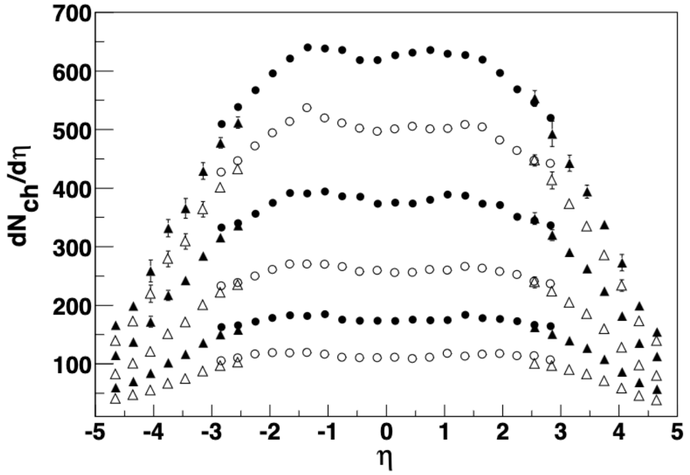
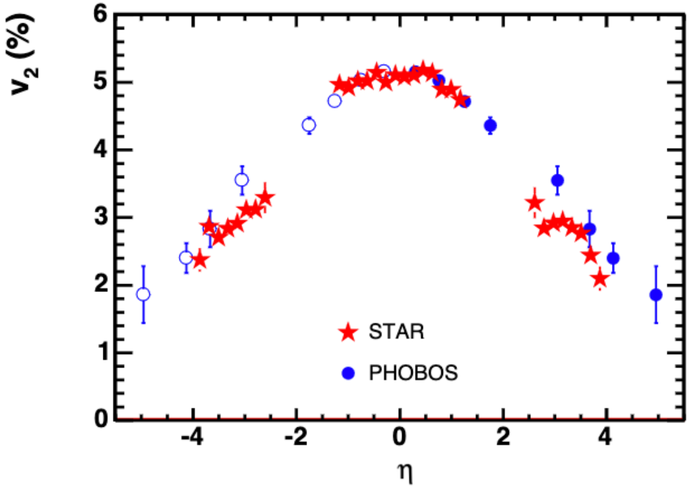
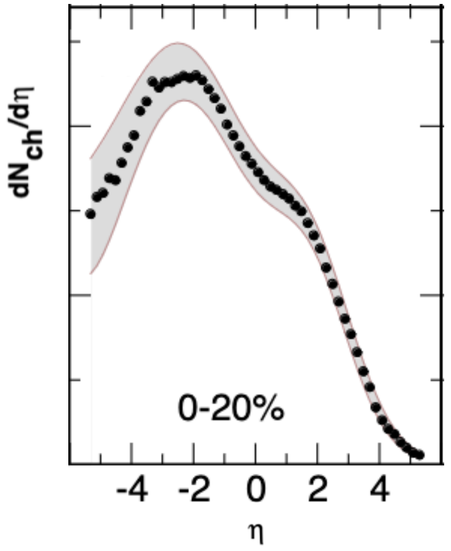


Phys. Rev. Lett. 88, 202301 (2002)



Phys. Rev. C 72, 014904 (2005)



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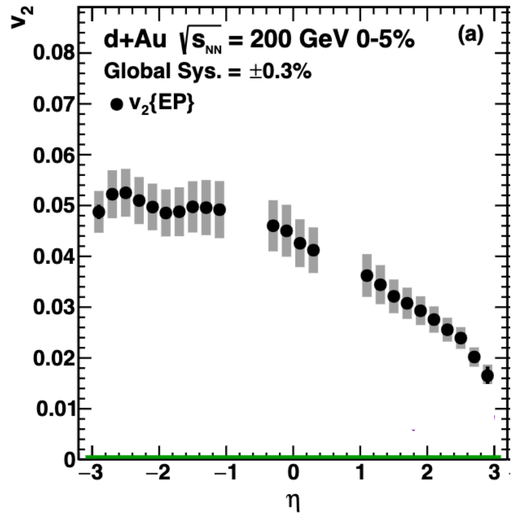

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A 3D model in a Bayesian analysis can utilize the wealth of our experimental knowledge at forward/backward rapidities

Constraining QGP Models: Bayesian Analyses

Likelihood of the parameters given the data

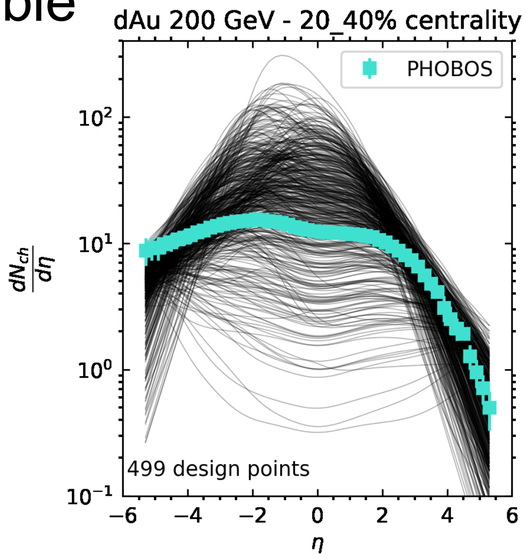
$$P(\vec{\theta}\,|\,\vec{x}) \propto P(\vec{x}\,|\,\vec{\theta})P(\vec{\theta})$$

Posterior

Parameter prior

Observable

Prior



We gain new insight by:

- Taking more (precise) measurements
- Calibrating new models that can describe previously measured data

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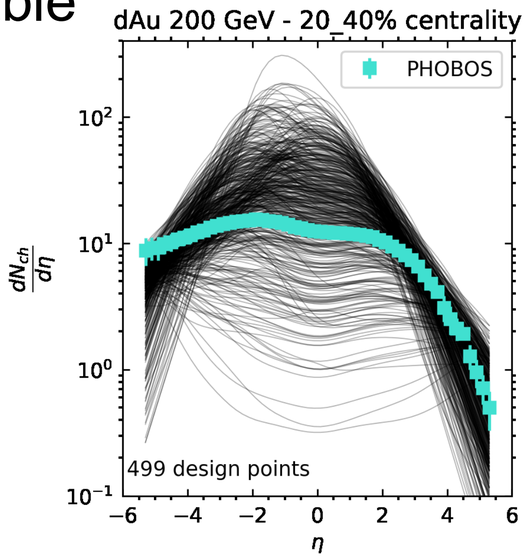
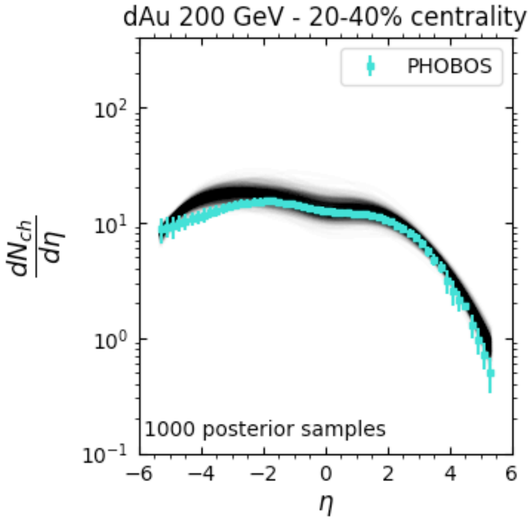
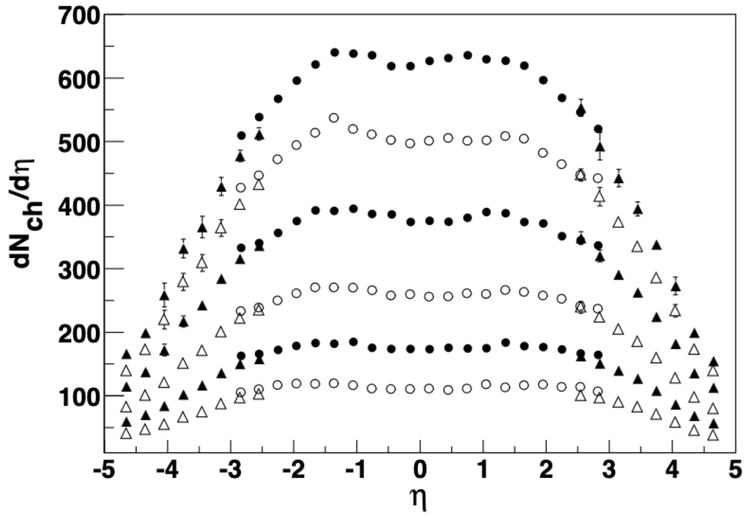
Observable Prior

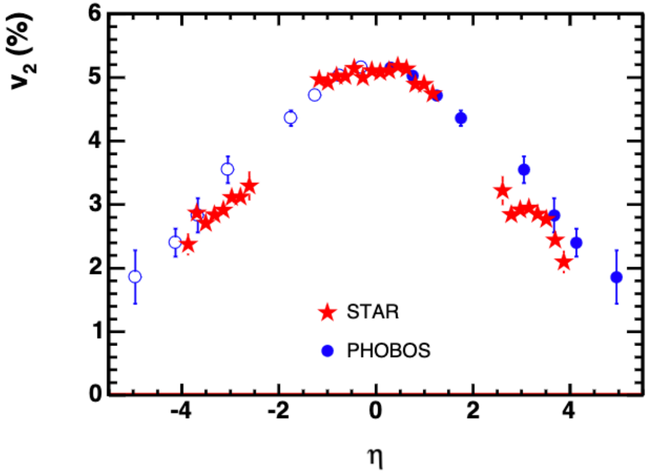


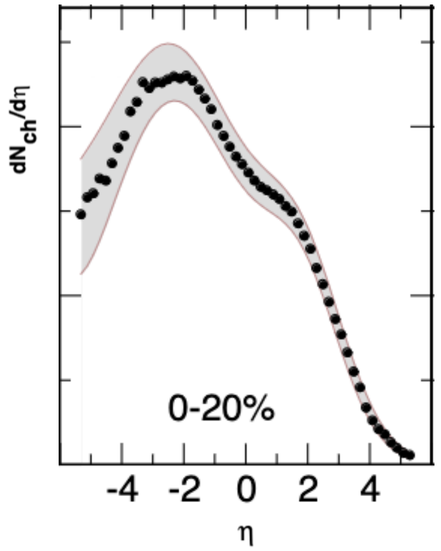
Observable Posterior

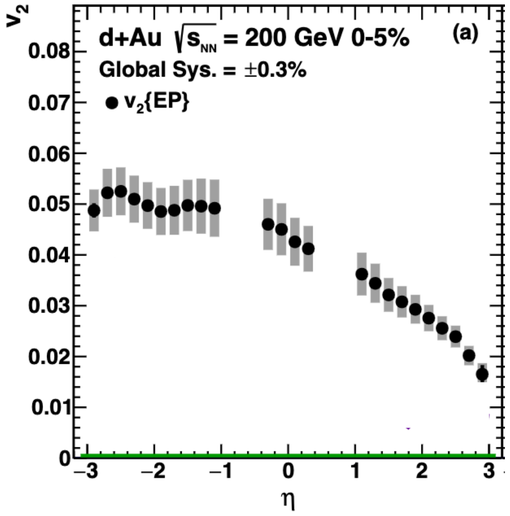


3D Model Constrained on Data at Mid-rapidity









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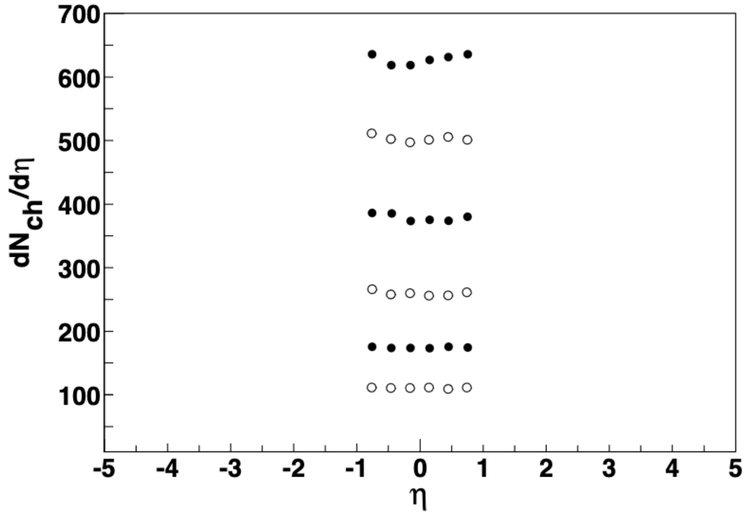
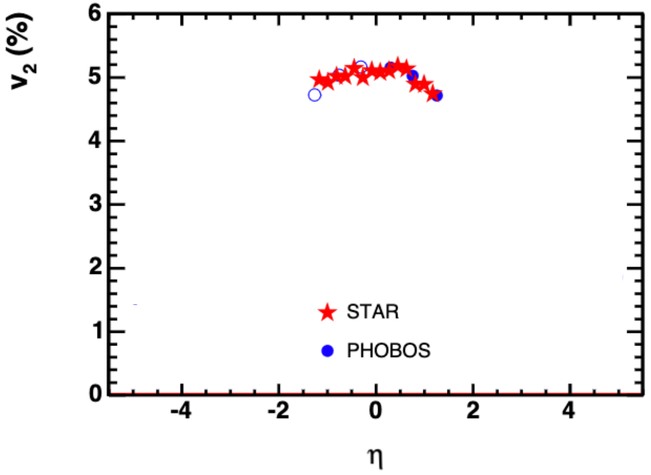
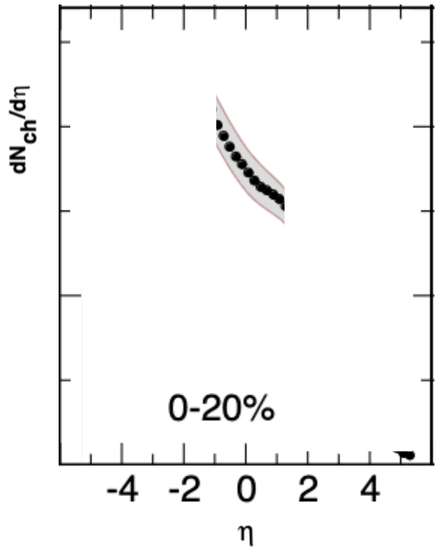
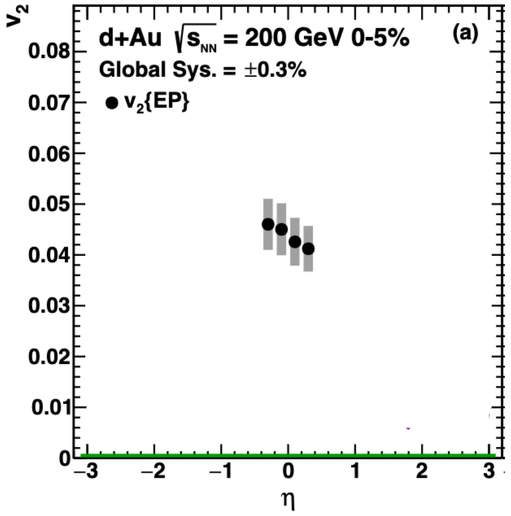


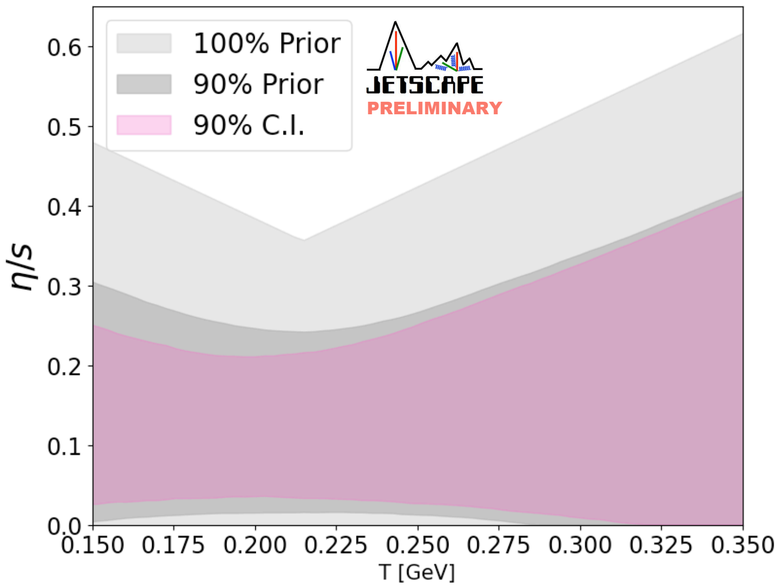


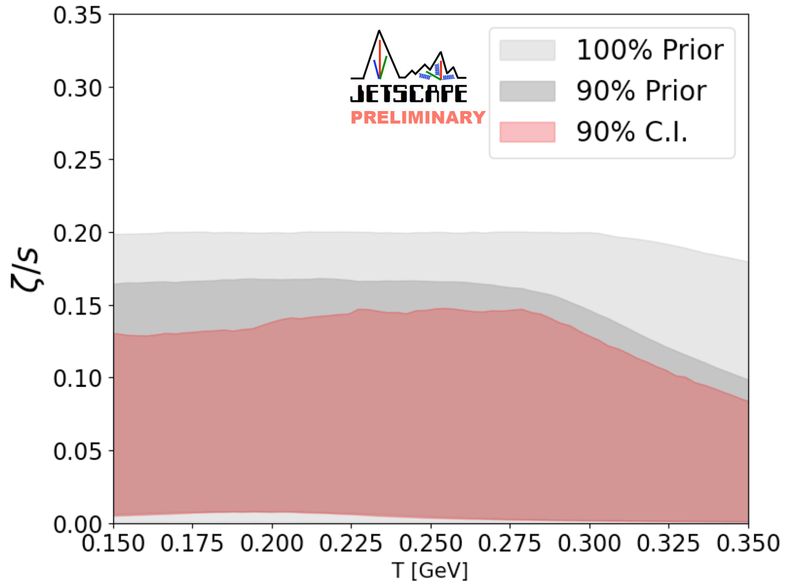




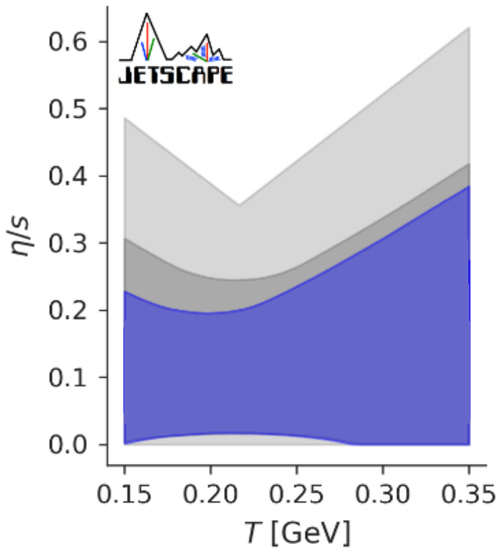
Constraints using only mid-rapidity measurements

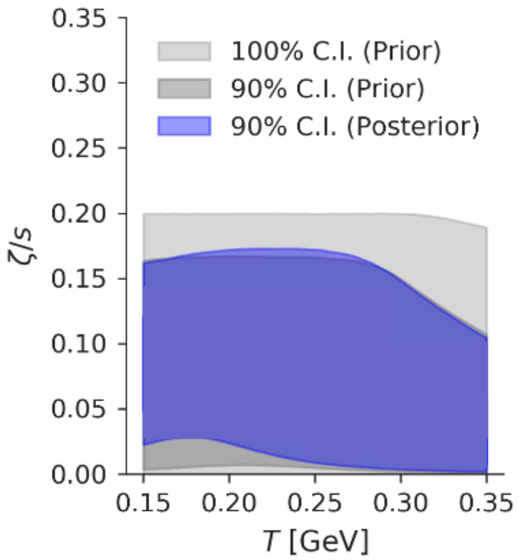
This analysis using only mid-rapidity measurements





Consistent constraints with previous analyses



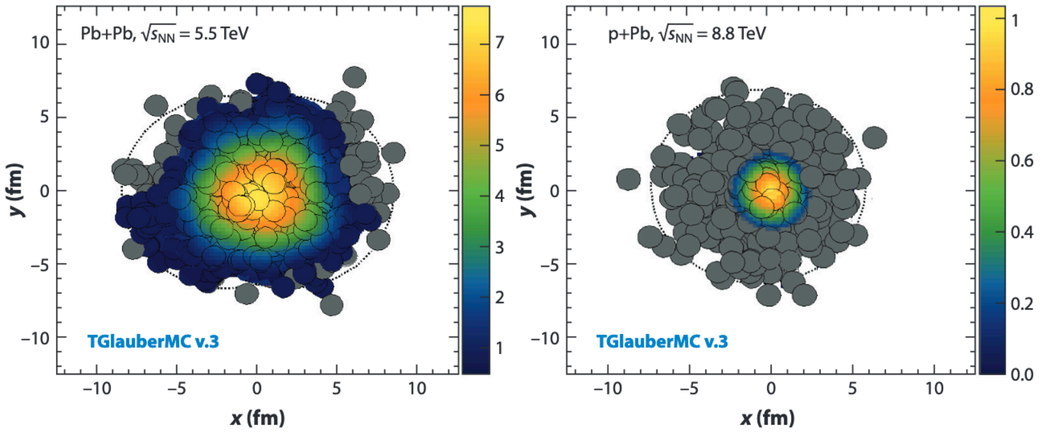


JETSCAPE 2D calibration using only RHIC data at mid-rapidity

The Model: 3D Initial State and Hydrodynamics

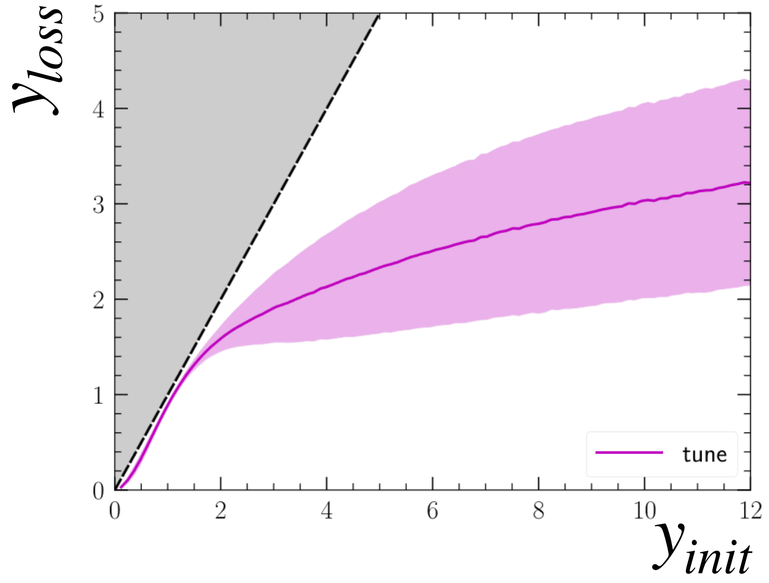
- 3D Monte Carlo Glauber Model
  - Valence quark hot spots
  - Energy deposited along the decelerating string connecting two colliding participants
  - Collision-by-collision fluctuating rapidity loss

2D Glauber density profiles



Ann. Rev. Nucl. Part. Sci. 57 (2007)

Parametrization of rapidity loss function



Schenke, Shen, Zhao.

Phys. Rev. C 105, 064905 (2022)

Phys. Rev. C 97, 024907 (2018)

See talks by B. Schenke and Chun Shen 9/5 !

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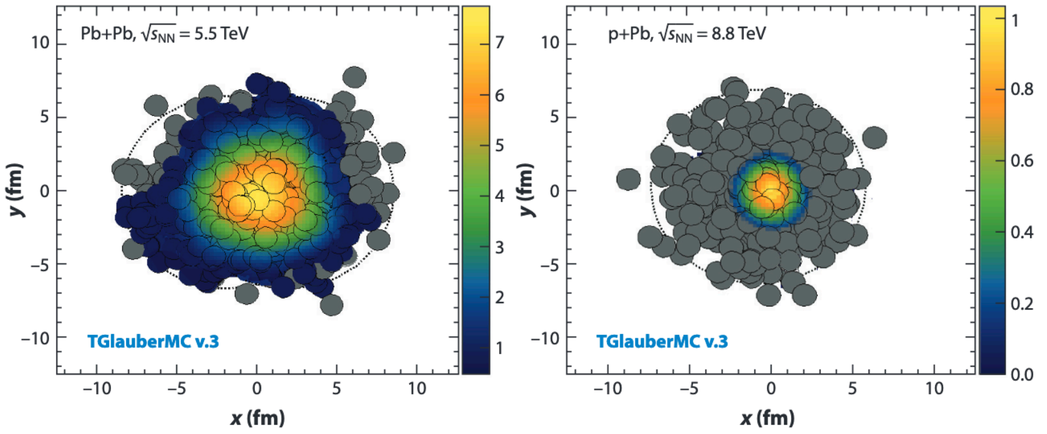

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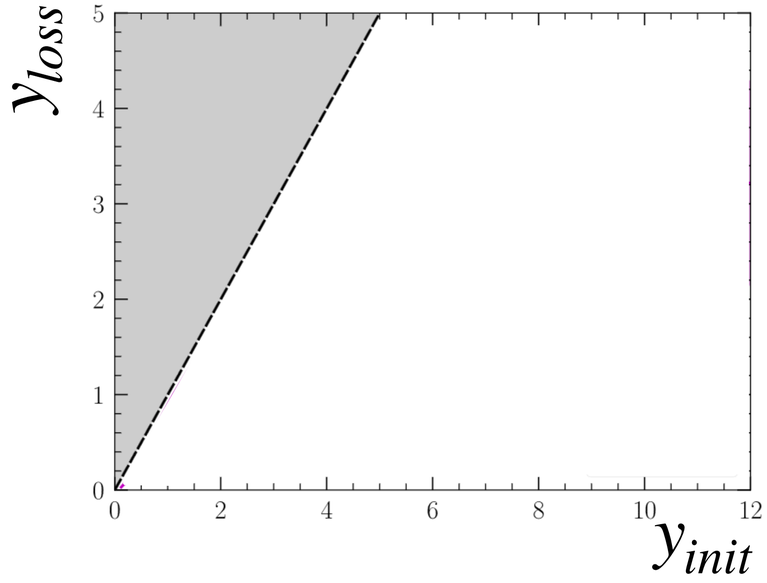

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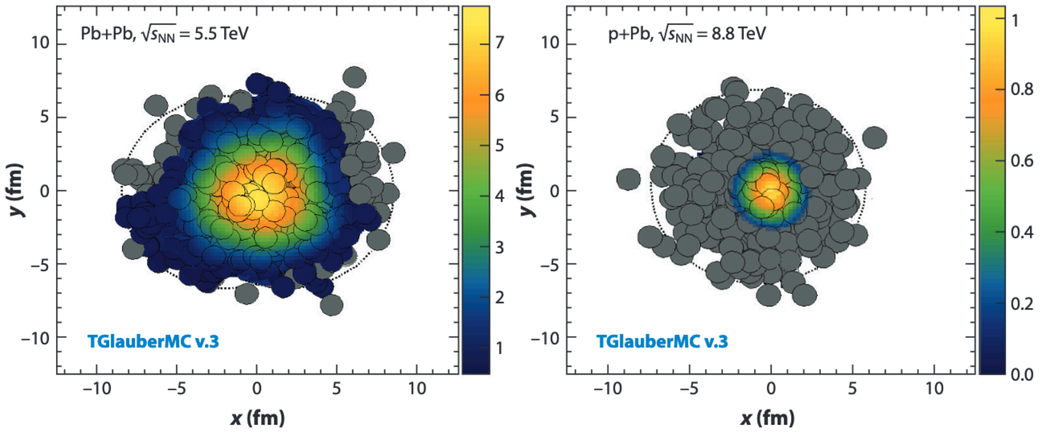

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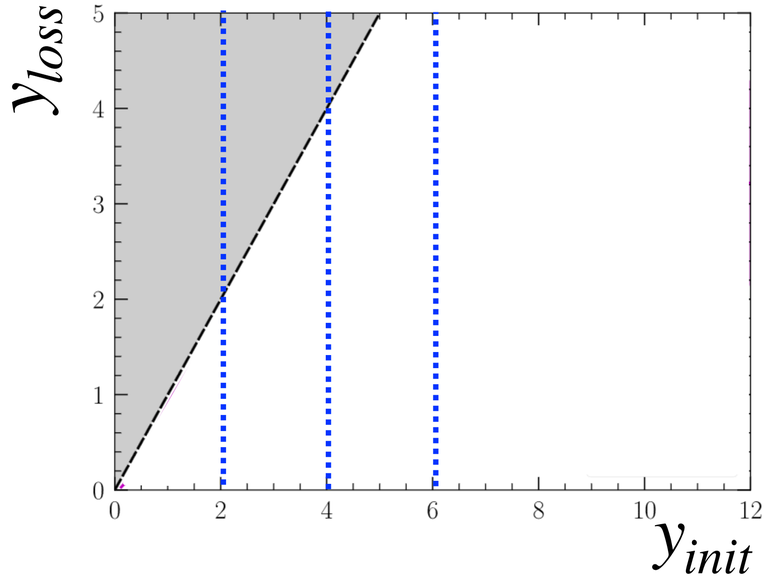

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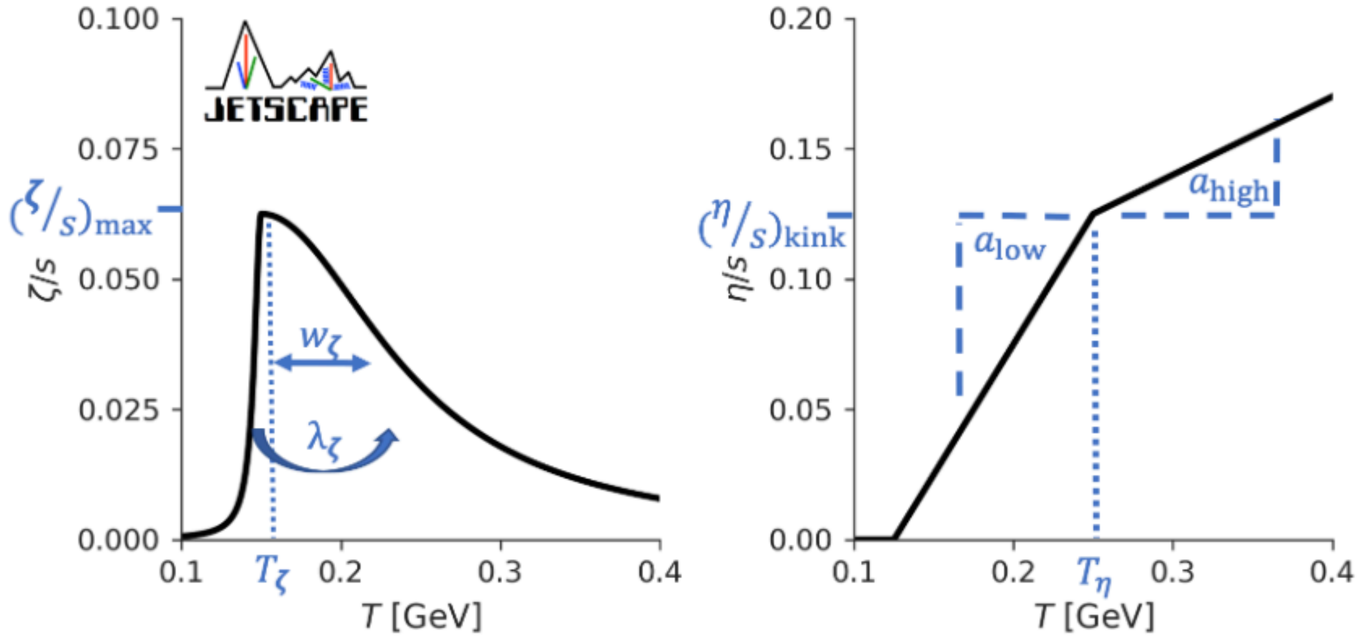
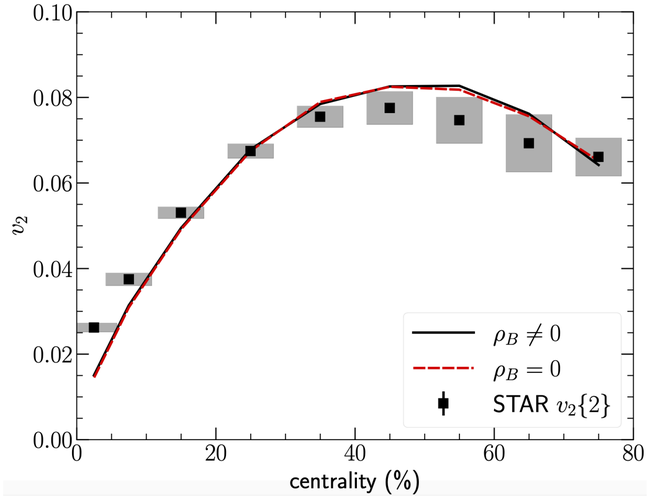
The Model: Hydrodynamics and Hadronic Transport

- (3+1)D Viscous Hydrodynamics
  - Shear and bulk viscosities parametrized as in previous JETSCAPE analyses
- Grad viscous corrections model
- UrQMD to perform hadronic scatterings and decays
- Take ρ_b = 0 (effect on v_2 negligible)

Parametrization of viscosity





Ref: Chun Shen

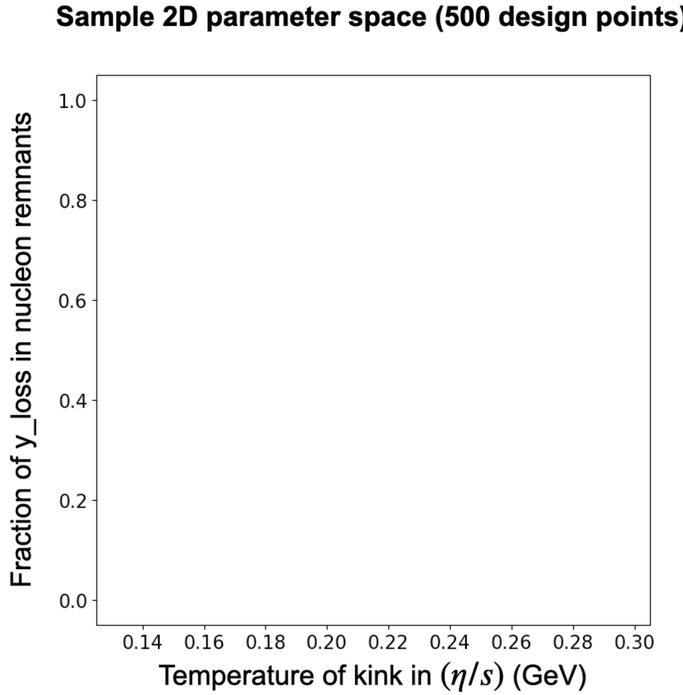
Model Calculations and the Analysis

- Used the following experimental data from RHIC collisions at 200 GeV:

	$AuAu$	dAu
$dN_{ch}/d\eta$	BRAHMS	PHOBOS
v_2	STAR	PHENIX

- Ran simulations across multiple HPC centers through ACCESS (NSF)
- Multivariate-normal distribution used as likelihood function

- Trained a Gaussian process emulator to interpolate between design points:



Covariance matrix of uncertainties

$$P(Y_{exp}|\theta) \propto \left(-[Y_{exp} - Y_{sim}(\theta)]^T[\Sigma_{exp} + \Sigma_{sim}(\theta)]^{-1}[Y_{exp} - Y_{sim}(\theta)]\right)$$

Difference between prediction and data

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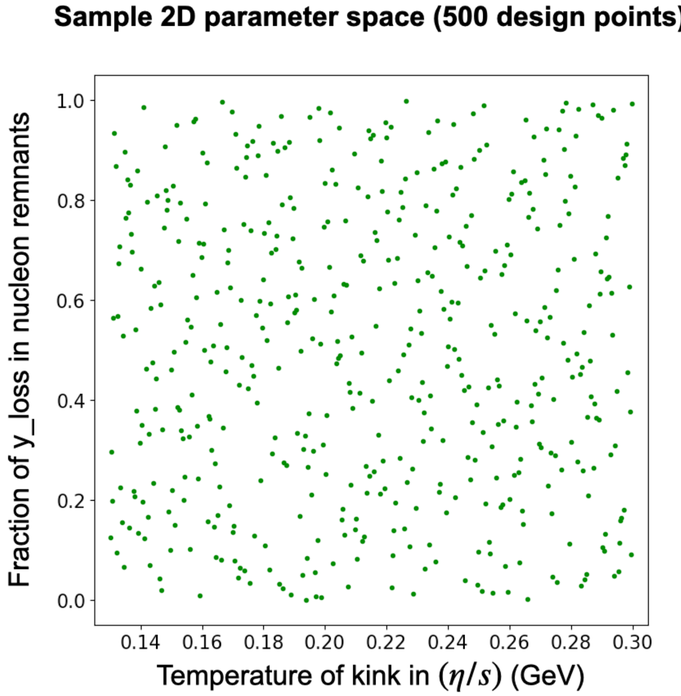

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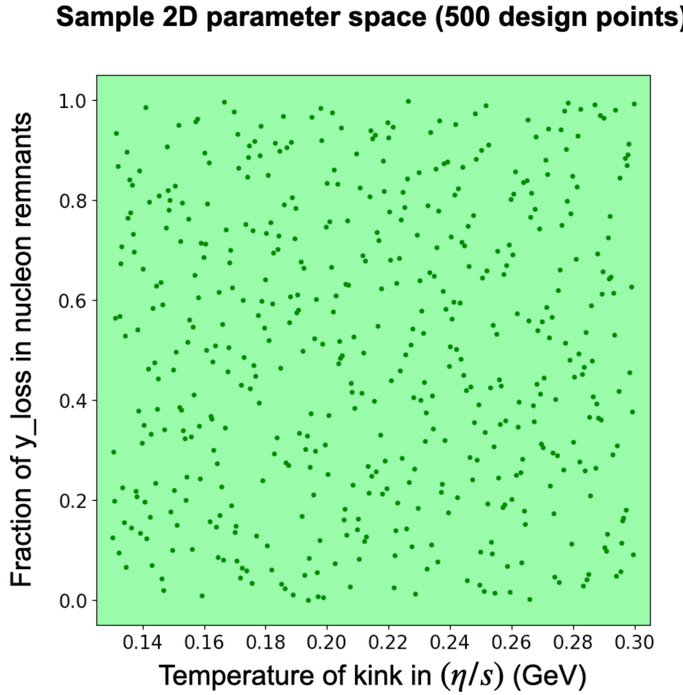

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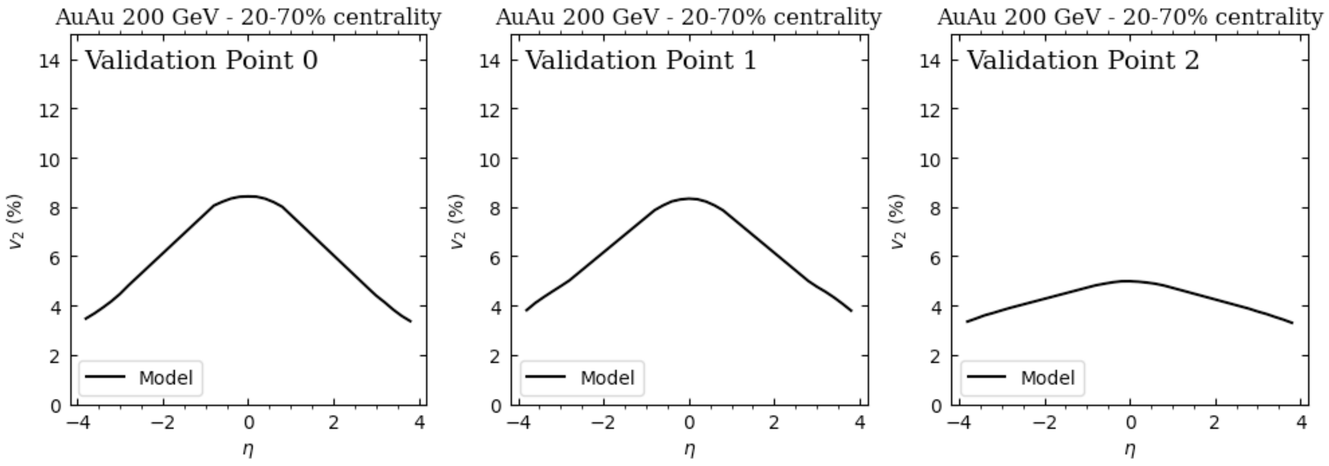
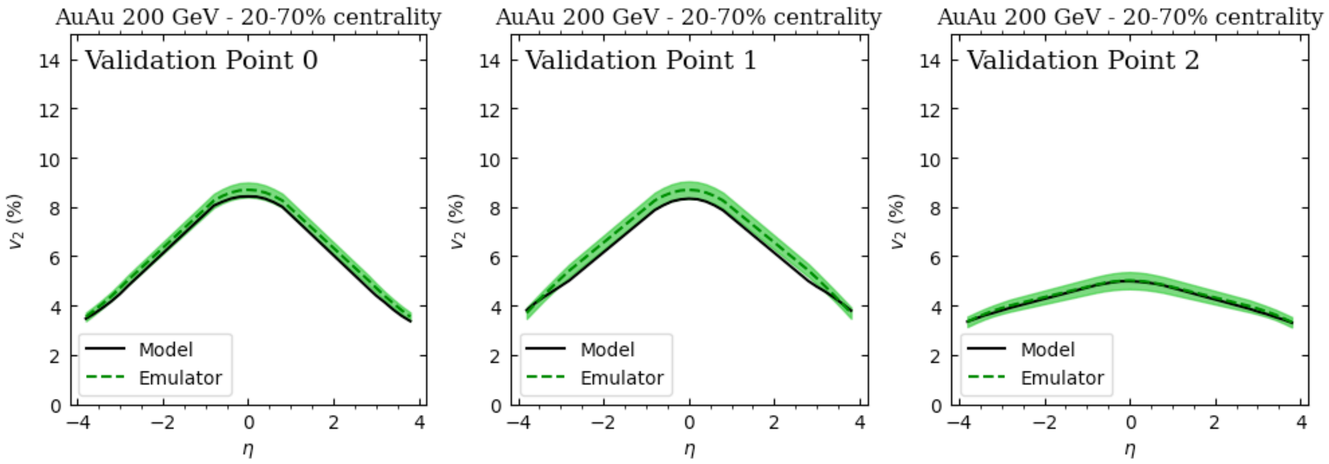
Emulating the Model and Validating the Analysis

- Gaussian Process Emulator: Fast surrogate for slow model



Emulating the Model and Validating the Analysis

- Gaussian Process Emulator: Fast surrogate for slow model



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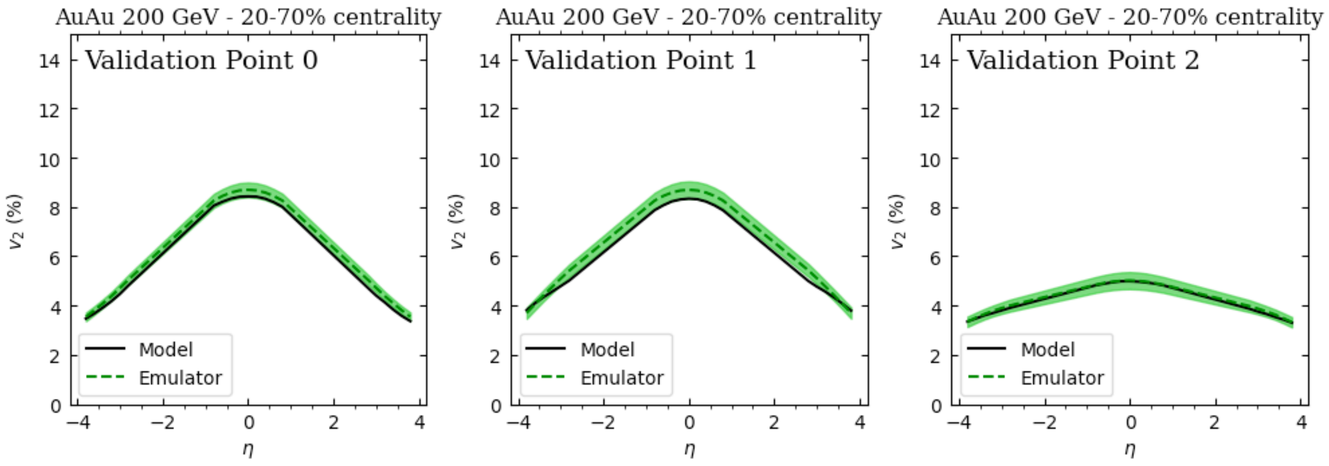

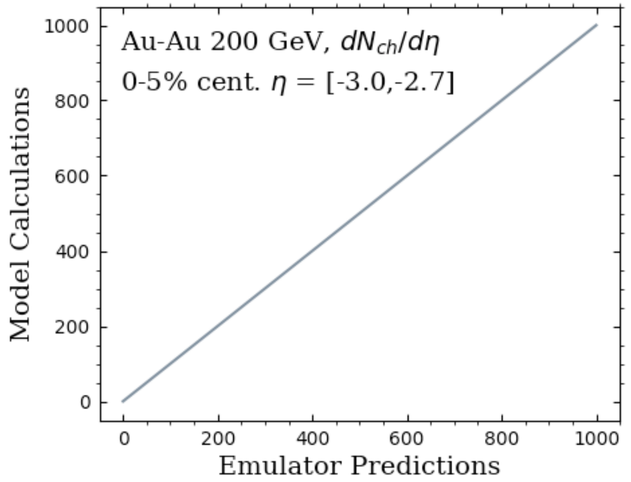

Emulating the Model and Validating the Analysis

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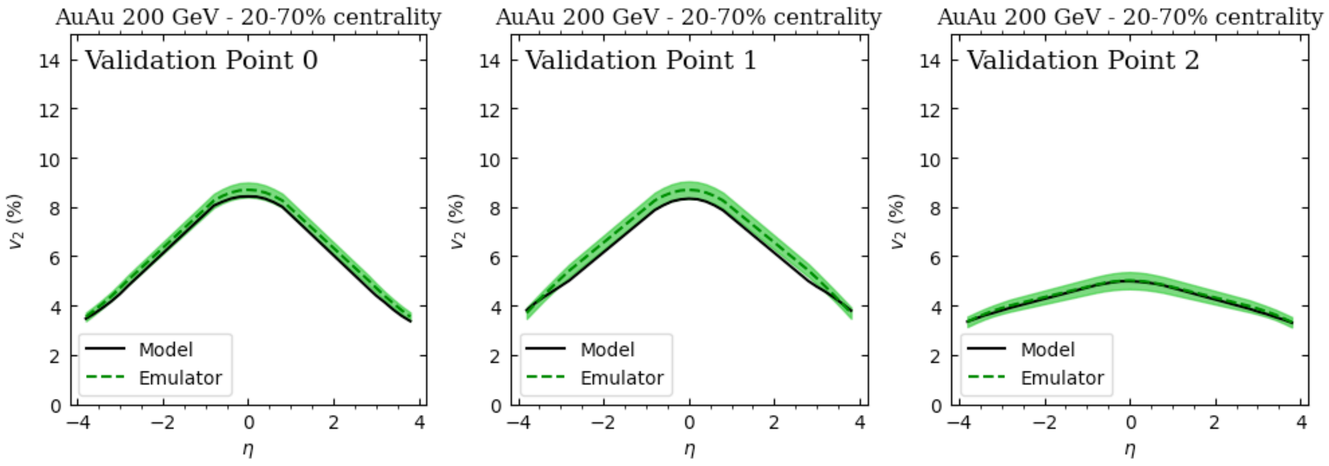

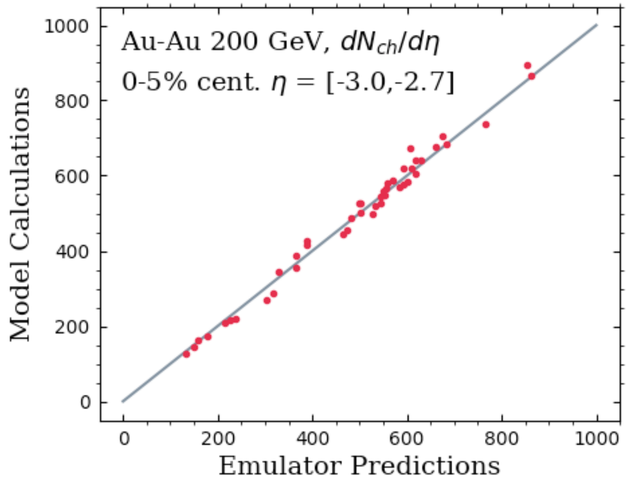

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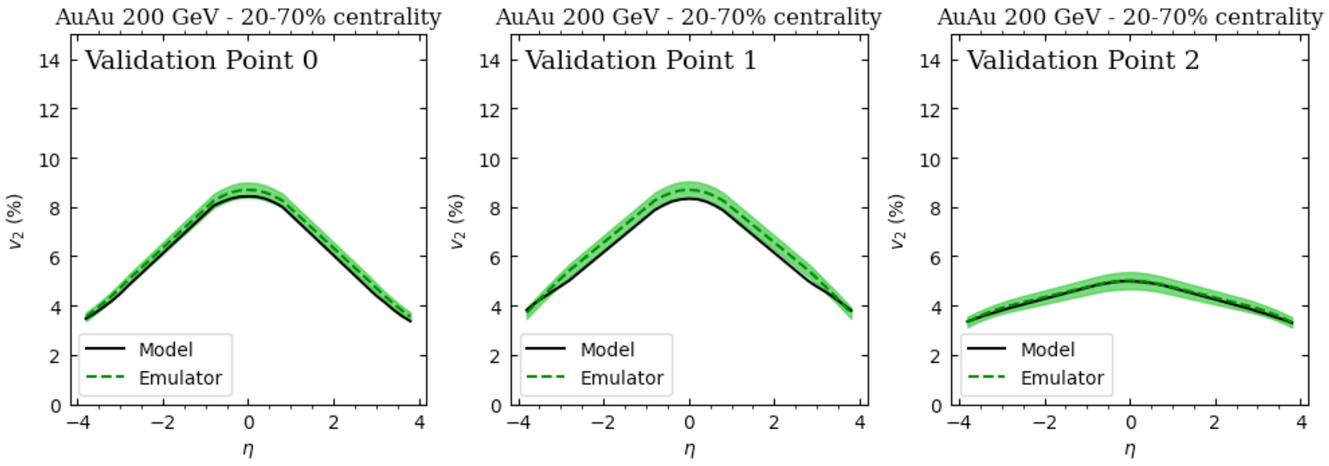
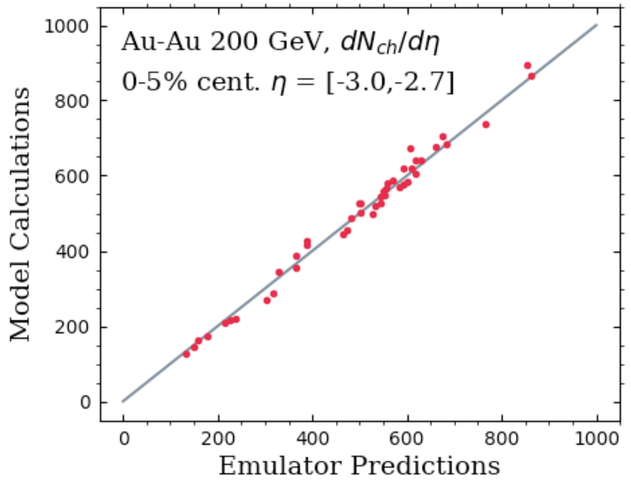
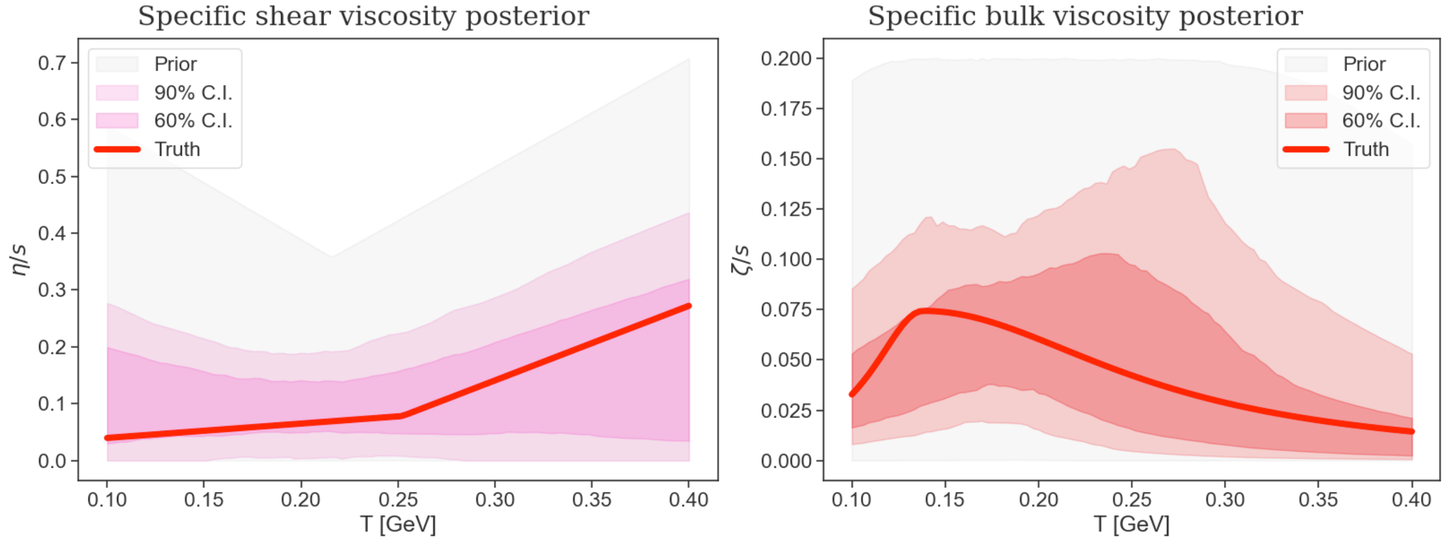


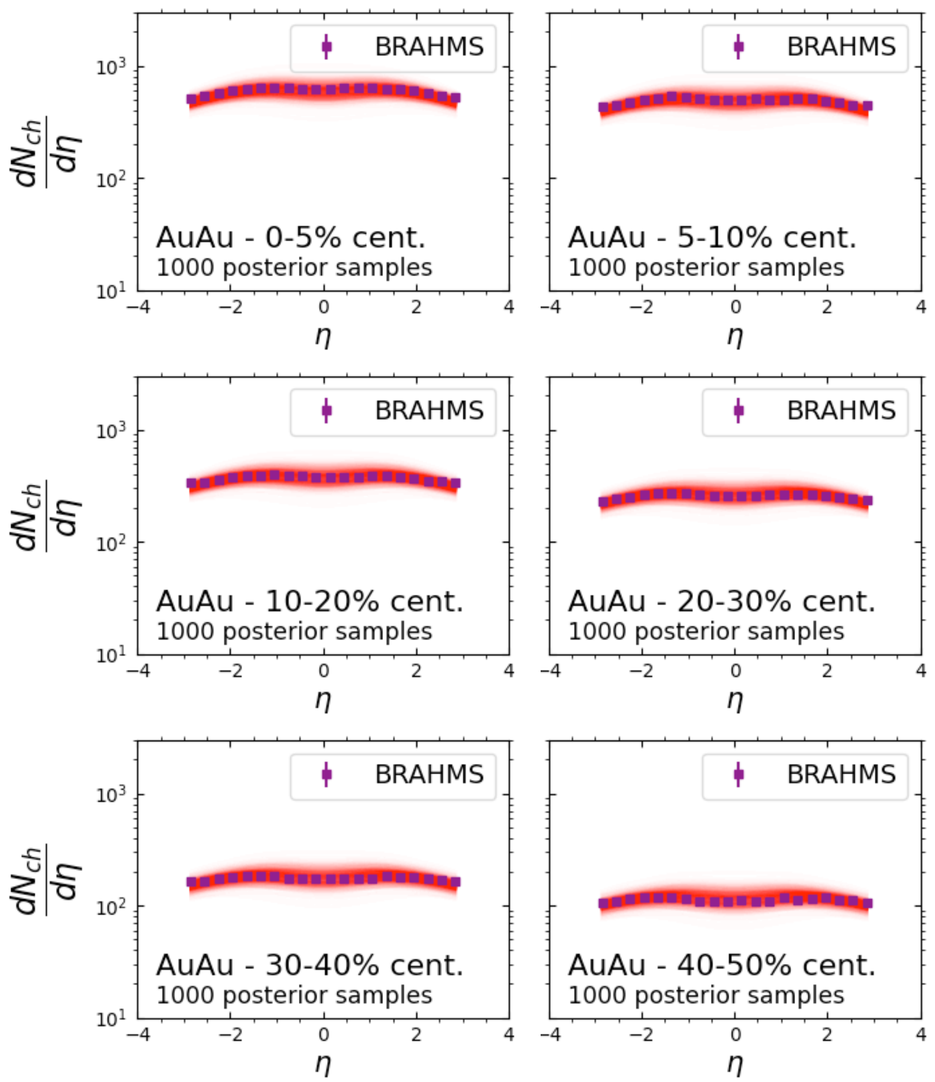


Closure test with the viscosity parameters

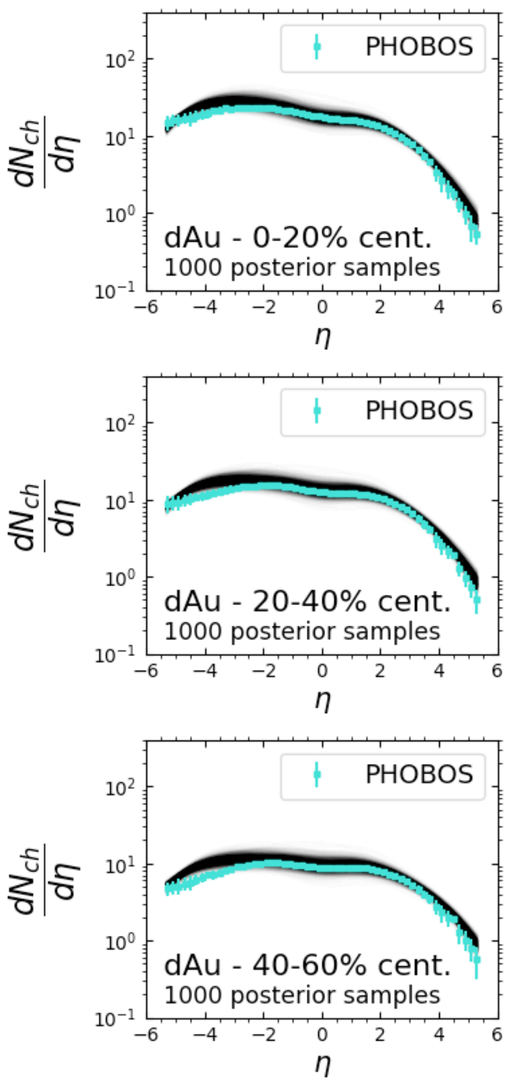


Comparing with Experimental Data

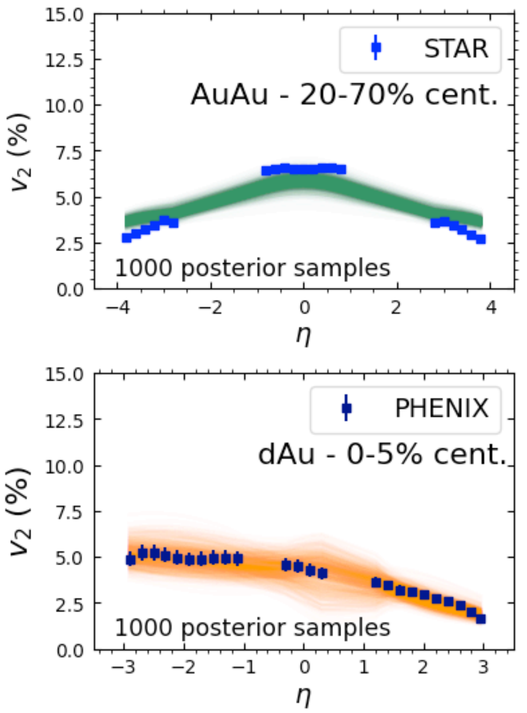
Multiplicity in Au-Au



Multiplicity in d-Au

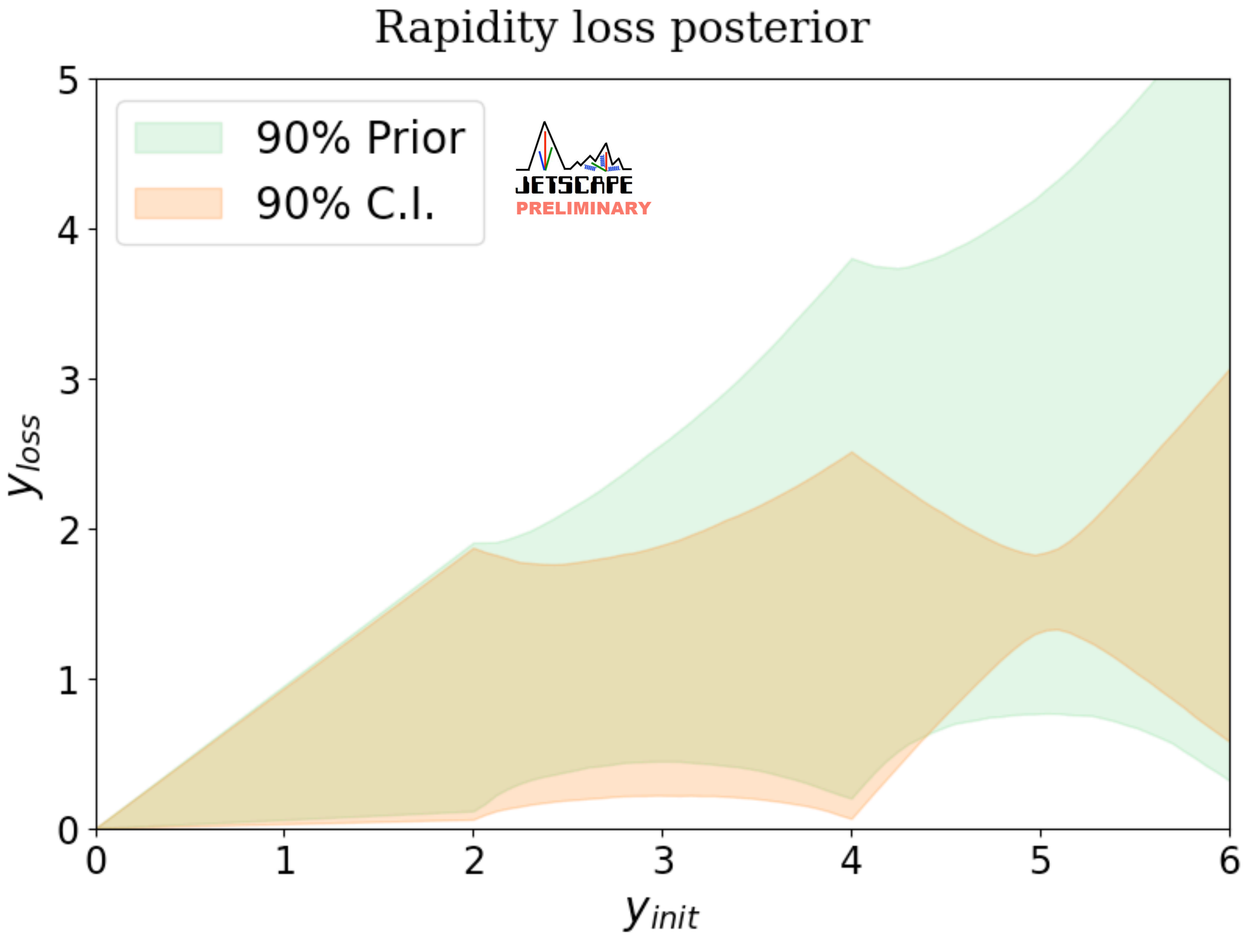


Flow in Au-Au and d-Au



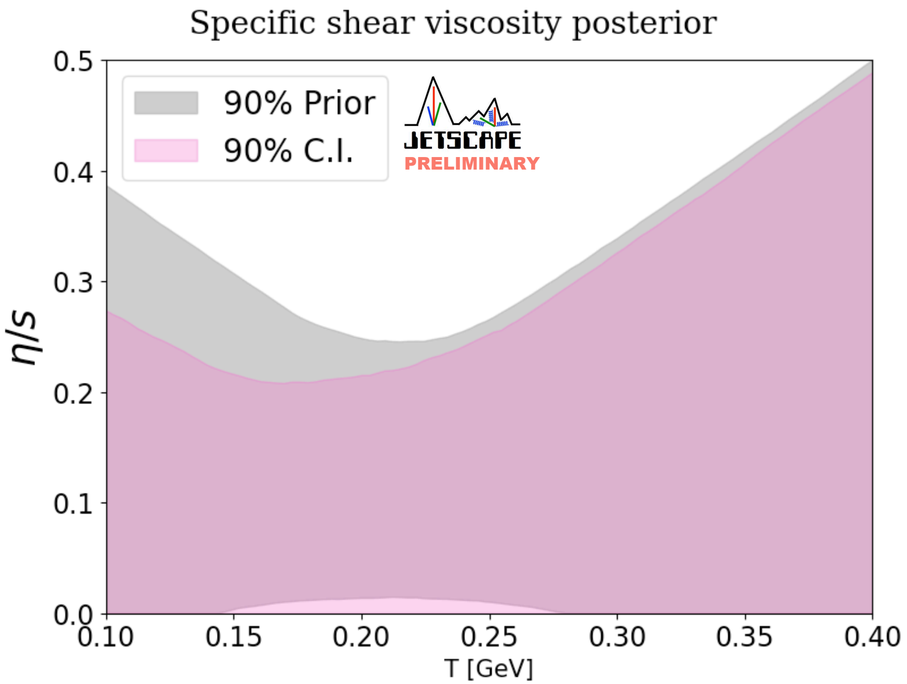
Good agreement with data across systems, observables, pseudorapidity, centrality, and experiment

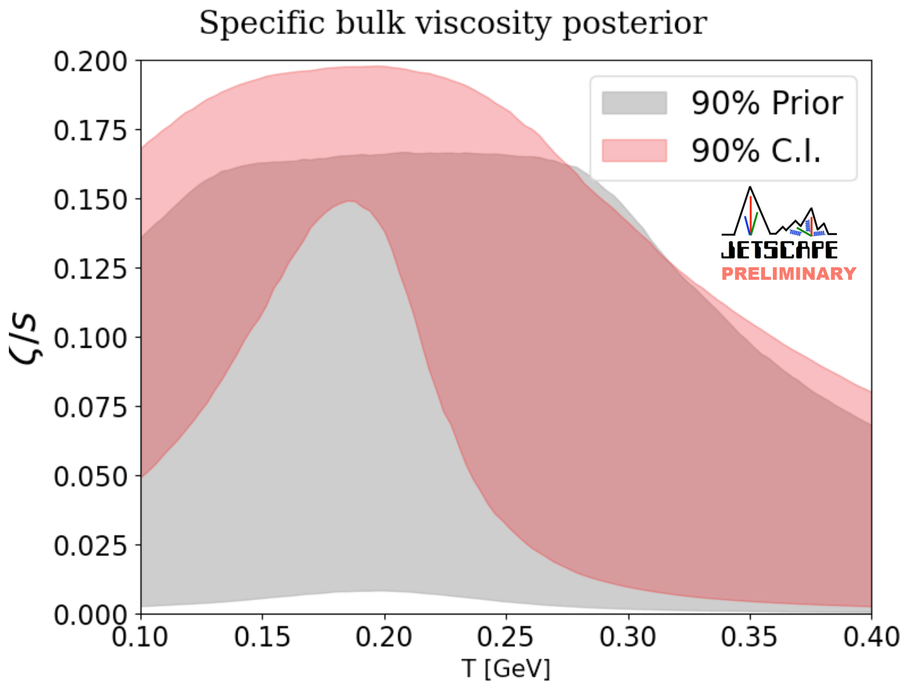
Parameter Posteriors - Rapidity Loss



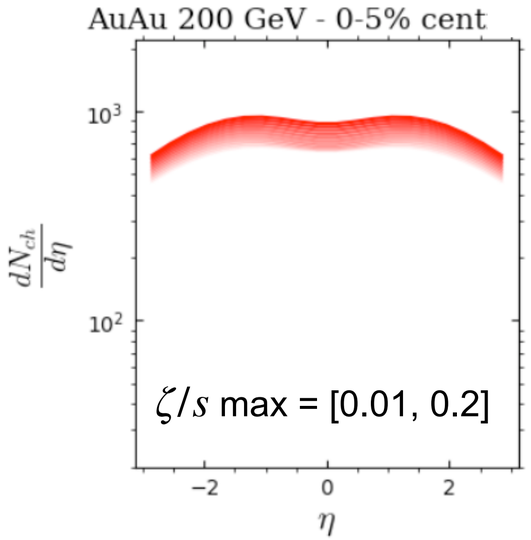
- Initial state energy deposition well constrained, particularly around 5 units of incoming rapidity
- Comparison with data from systems at lower energies may provide stronger constraints in the lower incoming rapidity region

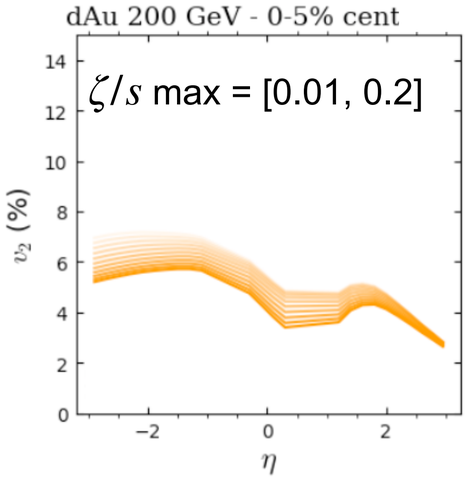
Parameter Posteriors - Viscosity





Sensitivity of observables to the max of the bulk viscosity

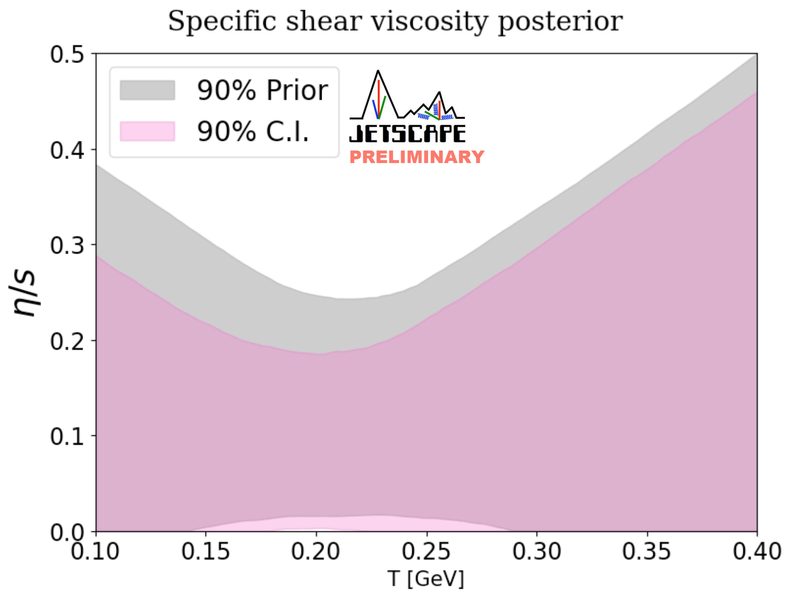


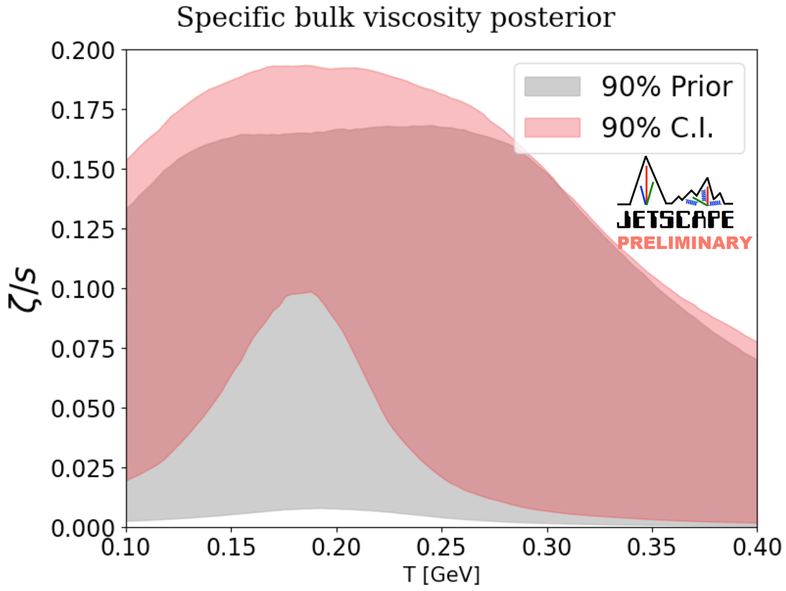


- Strong constraints showing a large bulk viscosity
- Weak constraints on the shear viscosity

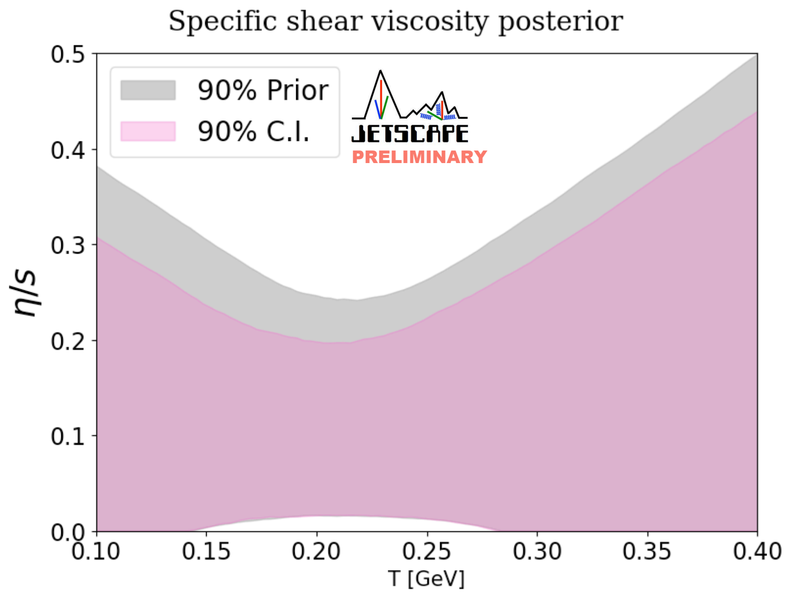
Au-Au vs d-Au constraints

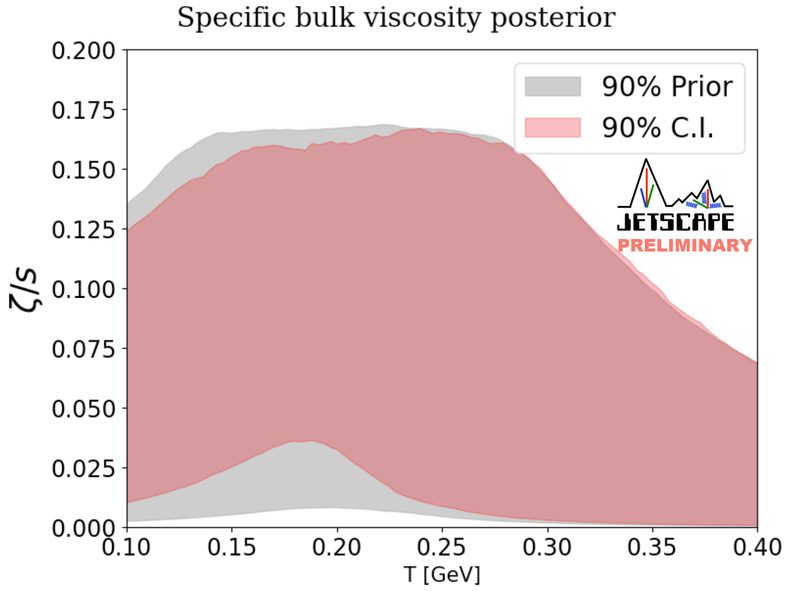
Constrained on *Au-Au only*





Stronger constraints provided on bulk viscosity by Au-Au measurements





Constrained on *d-Au only*

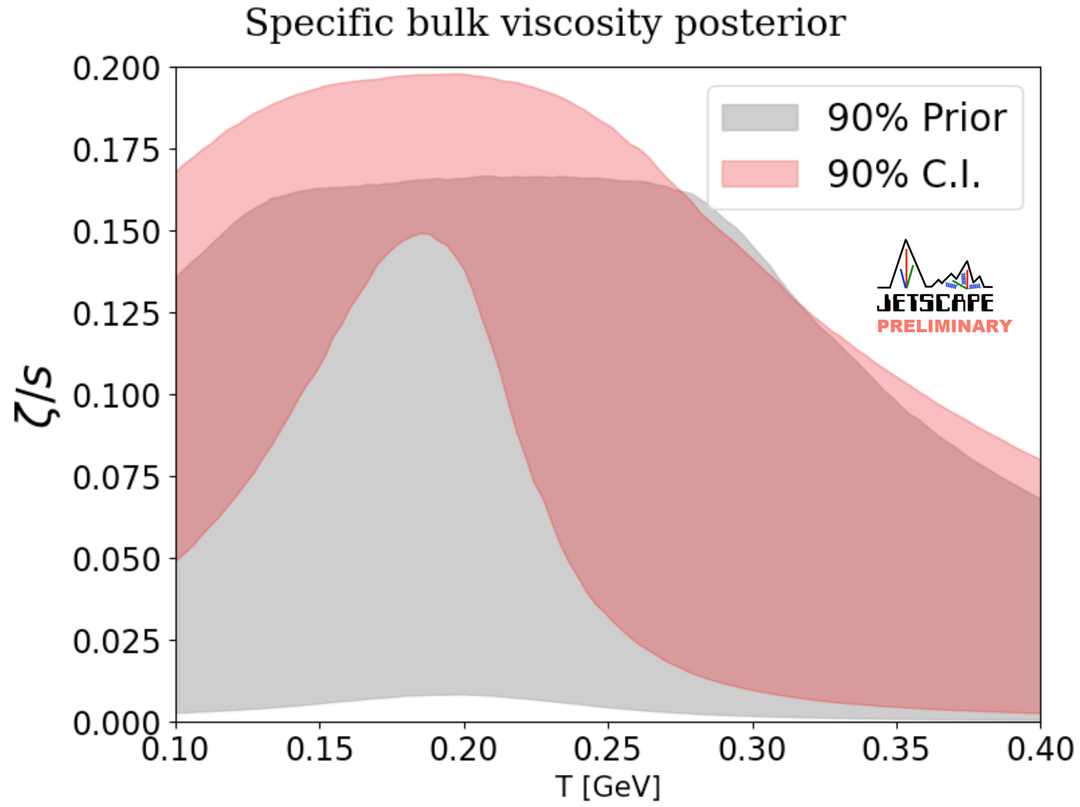
Slight preference for $\zeta/s \neq 0$ in d-Au also

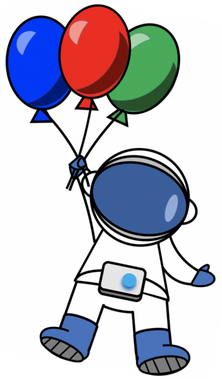
Conclusions and Outlook

- Successfully describe data across pseudo-rapidity for large and small systems at 200 GeV

- Multiplicity and flow measurements at forward rapidities indicate a large bulk viscosity

- Stay tuned for 3D calibration using broader set of experimental data



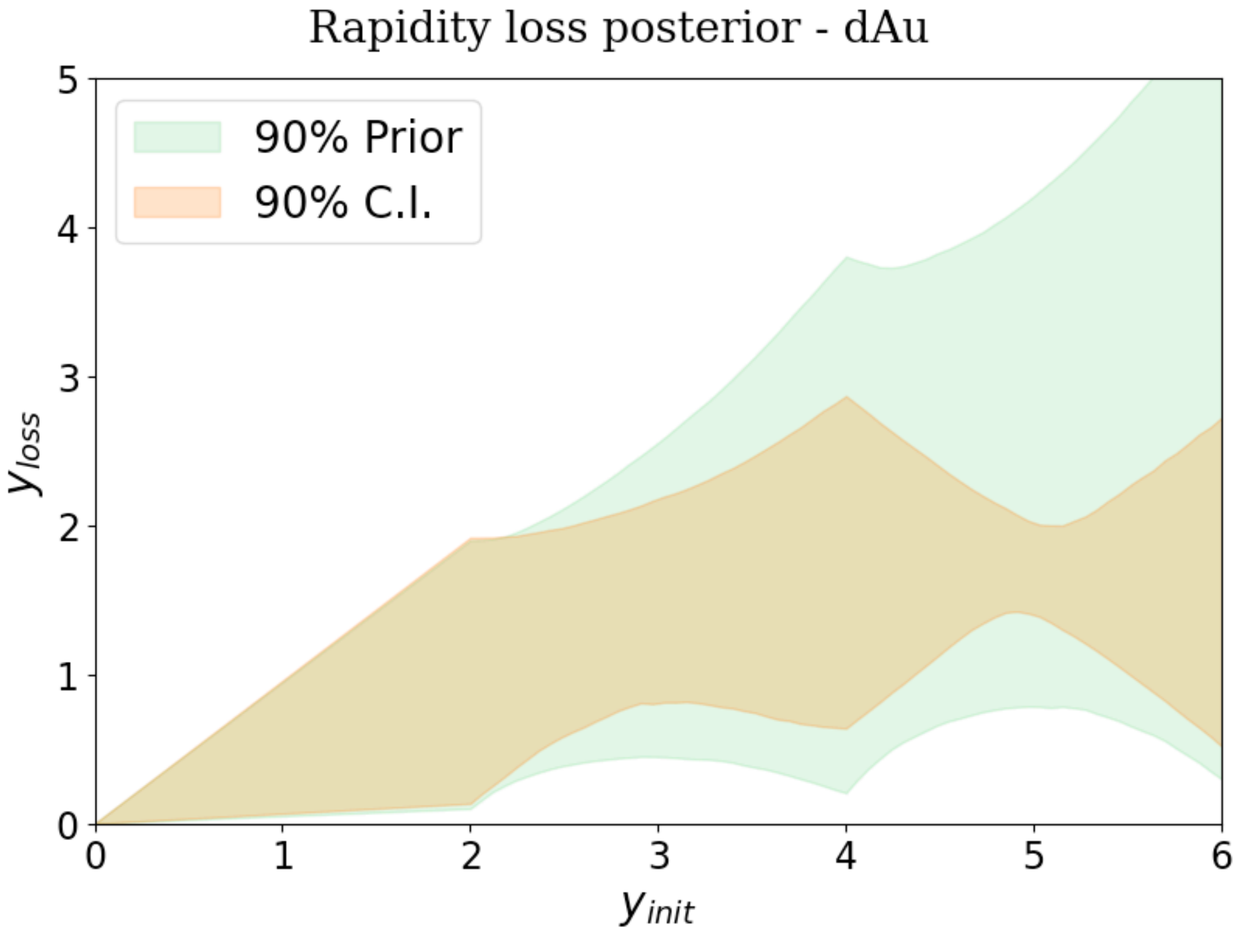


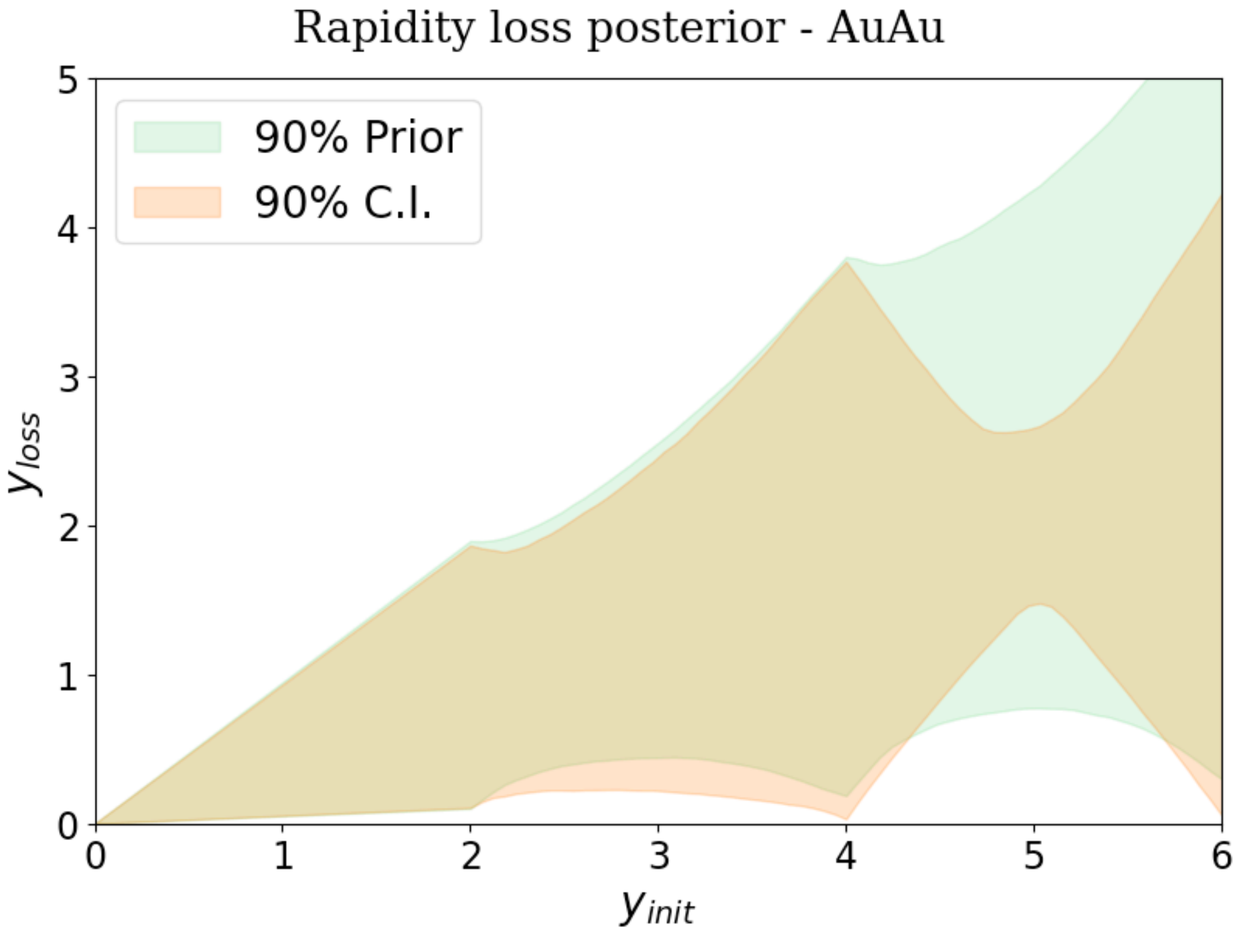
THANK YOU!

Acknowledgements

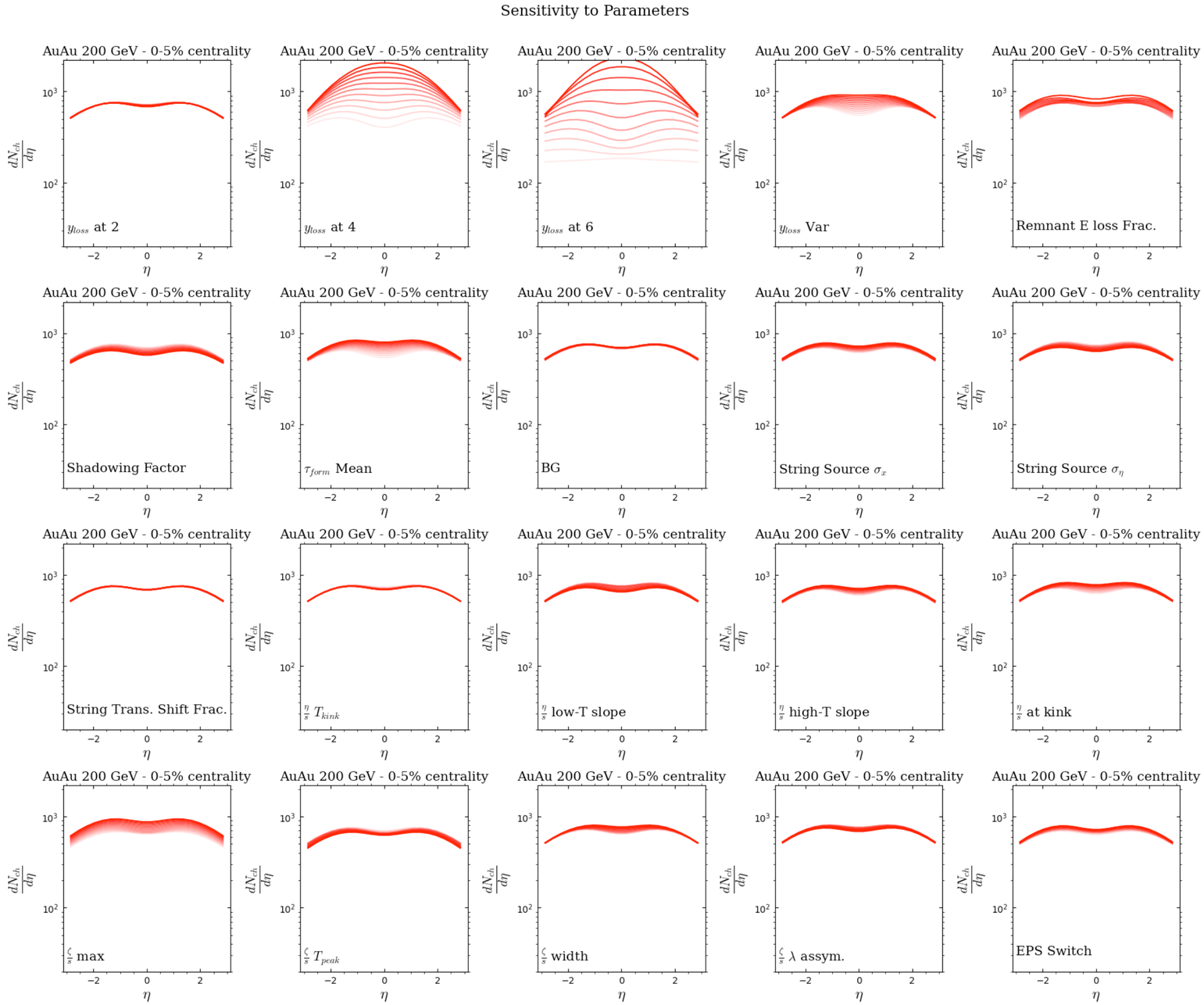
JETSCAPE COLLABORATION

Constraints on rapidity loss from dAu or AuAu only





Sensitivity of AuAu $dN_{ch}/d\eta$ to parameters



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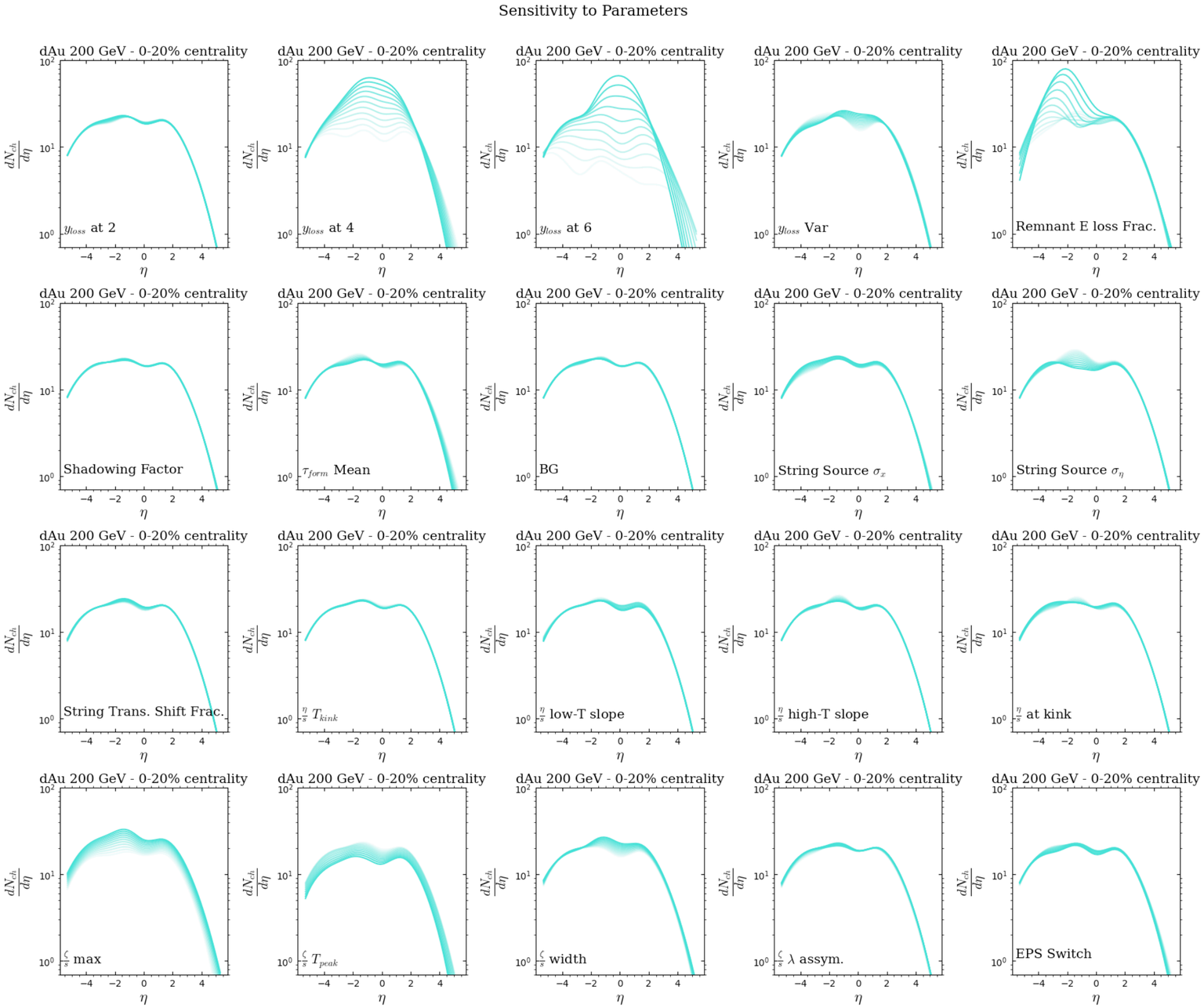
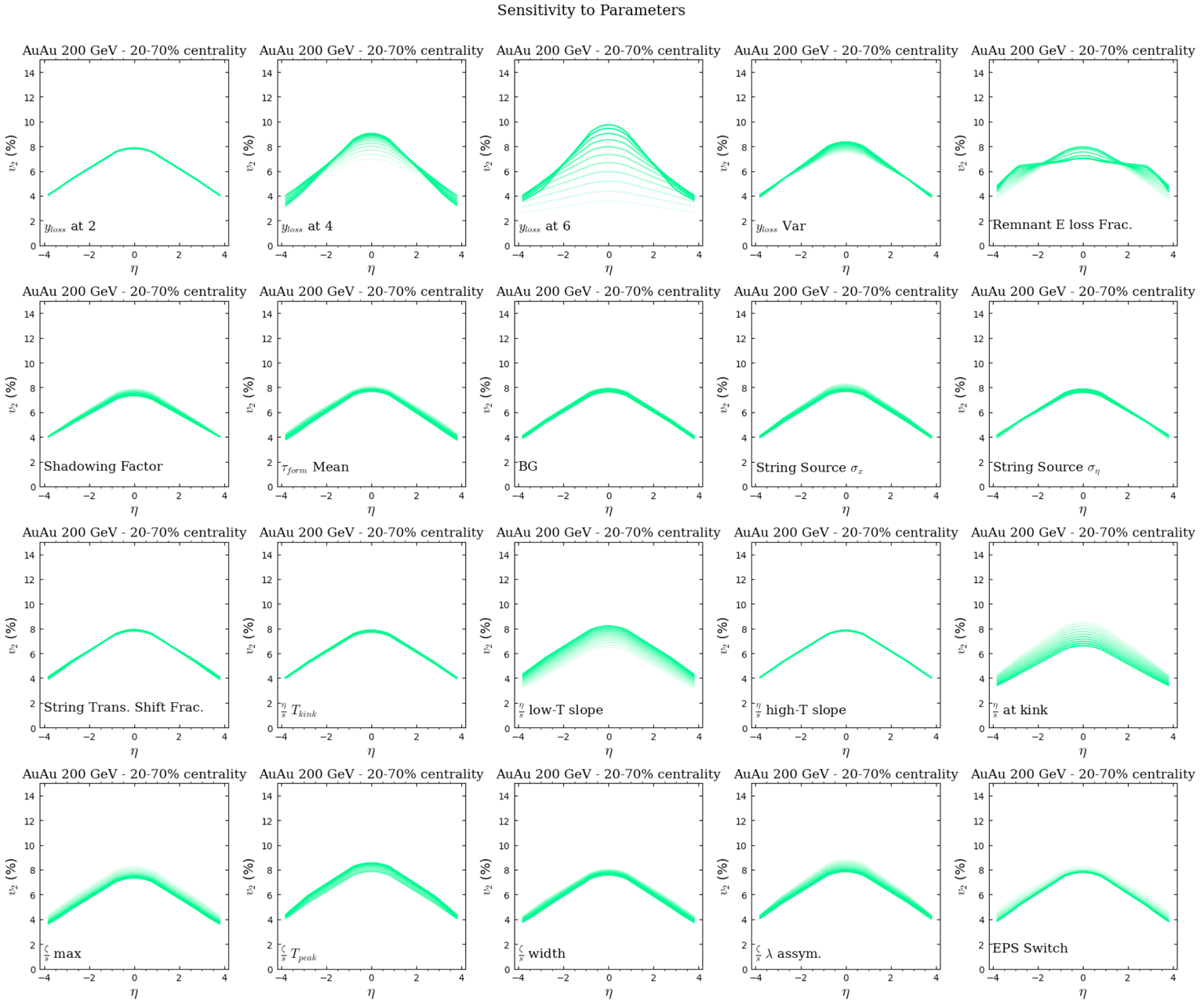


Sensitivity of AuAu v_2 to parameters



Sensitivity of dAu v_2 to parameters