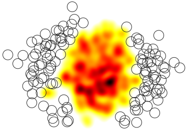


IS2021

The VI[th] International Conference on the

INITIAL STAGES

OF HIGH-ENERGY NUCLEAR COLLISIONS

Rapidity evolution of collision geometry at high energy — an improved TRENTo initial condition model[1]

Weiyao Ke

In collaboration with Derek Soeder, Steffen Bass, and Jean-Francois Paquet

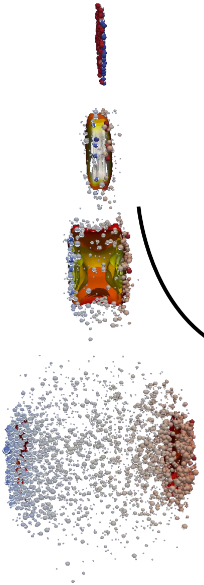
Berkeley UNIVERSITY OF CALIFORNIA

BERKELEY LAB

Duke UNIVERSITY

[1] This work is supported by the UCB-CCNU Collaboration Grant, NSF ACI-1550228 and ACI-1550225 under JETSCAPE, DOE DE-FG02-05ER41367.

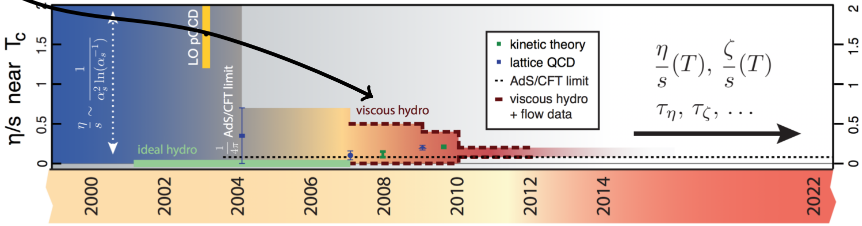
Toward a 3D geometric initial condition model for nuclear collisions



From boost-invariant to a 3+1D evolution of quark-gluon plasma:

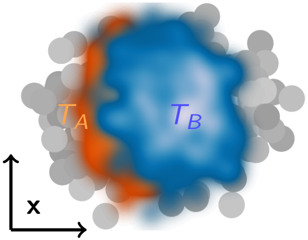
- Achieve a more precise characterization of dynamical quantities.
- Necessary for the study of small collision systems.
- Improve model-data-comparison in the presence of η-gap.

First step: knowledge of three-dimensional initial condition.



A parametric approach to the "initial condition" problem

Current boost-invariant TRENTo model[2]:
"Transverse local": $e(\mathbf{x}) = e(T_A(\mathbf{x}), T_B(\mathbf{x}))$
T_A, T_B: participant density.



[2] JS Moreland, JE Bernhard, SA Bass PRC 92, 011901 (2015)

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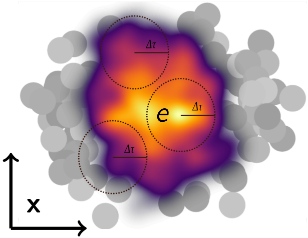

$\Delta\tau \ll$ Transverse length scales

TRENTo: $e(\mathbf{x}) \propto \left[\frac{T_A(\mathbf{x})^p + T_B(\mathbf{x})^p}{2}\right]^{1/p}, \; p \in R$

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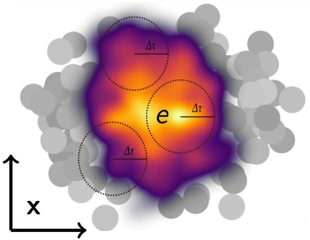

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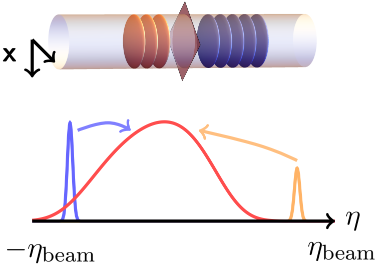
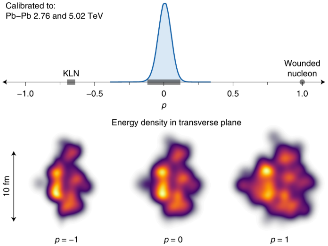
Longitudinal direction:

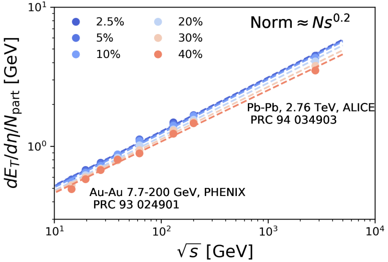


Earlier extension of TRENTo to 3D, WK, JS Moreland, JE Bernhard, SA Bass, PRC 96, 044912 (2017).

★ This study: new parametrization with insights from scaling of energy/particle production with $\sqrt{s}$, T_A, T_B in different η regions.

Scaling of energy production near midrapidity (central fireball)





- Strong evidence from calibrated to data at RHIC and LHC that $p \approx 0$ that[3]

$$e(\mathbf{x}, \eta_s = 0) \propto \left[\frac{T_A(\mathbf{x})^p + T_B(\mathbf{x})^p}{2}\right]^{\frac{1}{p}} \to N\sqrt{s}^{\alpha}\sqrt{T_A T_B}$$

- Extend to finite but small rapidity:

$$e(\mathbf{x}, |\eta_s| \ll y_b) = e(\mathbf{x}, 0)e^{-\frac{(\eta_s - \eta_{c.m.})^2}{2y_b}}$$

$$\langle \eta_{c.m.}(\mathbf{x})\rangle = \frac{1}{2}\ln\frac{T_A(\mathbf{x})}{T_B(\mathbf{x})}$$

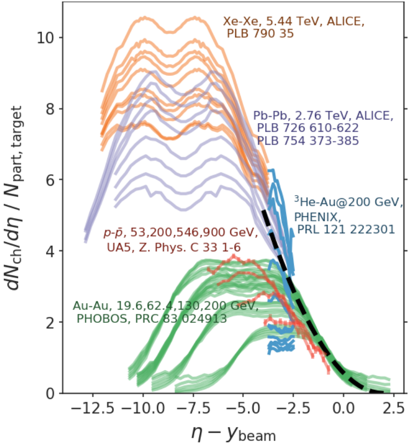
motivated by Landau hydro picture of particle production[4]. Width of the distribution $\sim \sqrt{y_b}$.

[3] JE Bernhard et al PRC 94 024907 and Nat. Phys. 15. 1113–1117. JETSCAPE 2011.01430. $\sqrt{T_A T_B}$ scaling also corroborated by the pQCD+saturation EKRT model PRC 93 024907, or motivated by energy-momentum conservation, C Shen and S Alzhrani PRC 102 014909.

[4] LD Landau, Izv. Akad. Nauk Ser. Fiz. 17 (1953) 51; P Steinberg, Acta Phys.Hung. A24 (2004) 51-57

Scaling of particle production when $y \to y_{\mathrm{beam}}$

Limiting fragmentation assumption[5]: $dN_{ch}/d\eta/N_{part,target} \approx f(\eta - y_b)$



[5] J Benecke, TT Chou, CN. Yang, E Yen Phys. Rev. 188 (1969) 2159. PHOBOS PRL 91 (2003) 052303.

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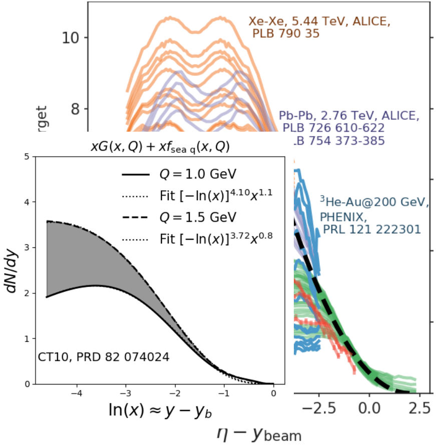

$$f(x) = [-\log(x)]^{\alpha} x^{\beta+1}, x = e^{y_b - |\eta|}$$

- $dN/dy = xf(x)$ of the broken target motivated by parton distribution function[6].

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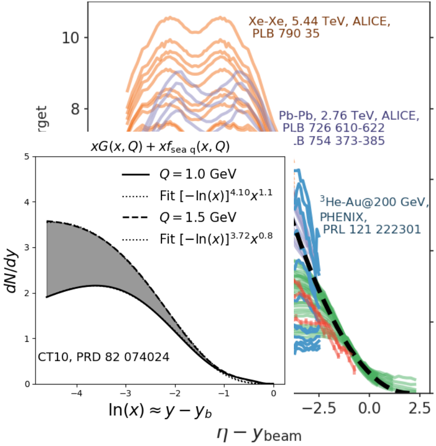

$f(x) = [-\log(x)]^{\alpha} x^{\beta+1}, x = e^{y_b - |\eta|}$

- $dN/dy = xf(x)$ of the broken target motivated by parton distribution function[6].
- Assume energy deposition $y \approx y_b$ scales as

$$\frac{de_{\mathrm{F/B}}}{d\eta} \sim C_{\mathrm{F/B}}\left[T_A(\mathbf{x}) f(y_{\mathrm{b}} - \eta) + T_B(\mathbf{x}) f(y_{\mathrm{b}} + \eta)\right]$$

Interpolate to midrapidty $(N\sqrt{s}^{\alpha}\sqrt{T_A T_B} g(\eta - \eta_{\mathrm{cm}}))$, subject to local energy-momentum conservation.

[5] J Benecke, TT Chou, CN. Yang, E Yen Phys. Rev. 188 (1969) 2159. PHOBOS PRL 91 (2003) 052303.

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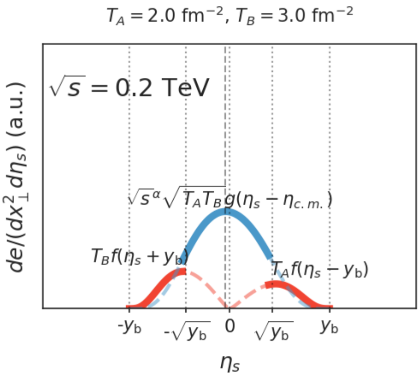
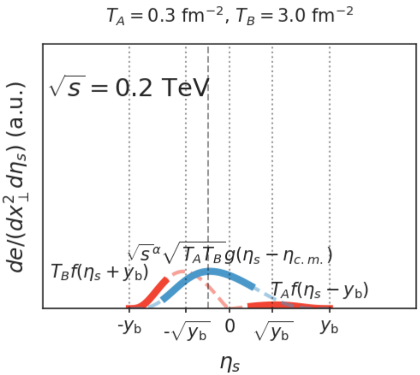
Impact on rapidity-dependent geometric properties

- Geometric properties will evolve from fragmentation region (T_A, T_B) to central region ($\sqrt{T_A T_B}$).
- Central fireball becomes increasingly important at high $\sqrt{s}$.

Typical T_A, T_B for A-A collisions



Typical T_A, T_B for p-A collisions



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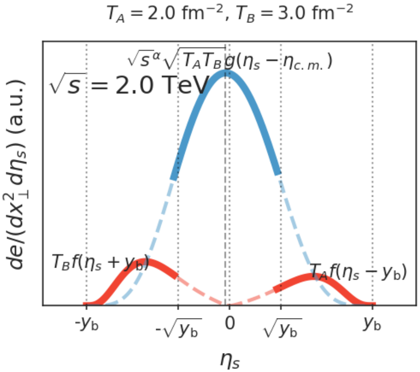

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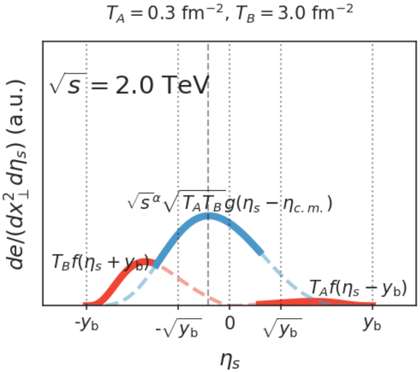
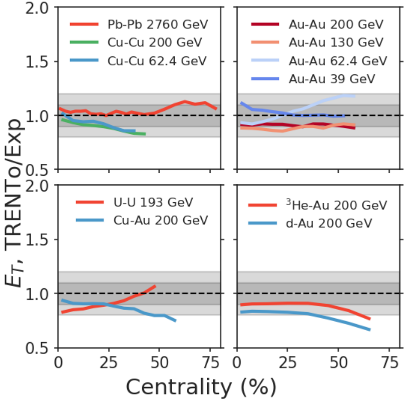
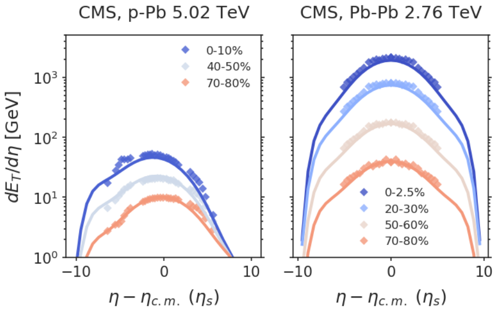


Tune to transverse energy density

- Transverse energy at mid-rapidity over large range of $\sqrt{s}$, collision systems, and centralities.
- Pseudorapidity density of transverse energy for p-Pb (5.02 TeV), Pb-Pb (2.76 TeV).
- Not fine-tuned. A systematic calibration of parameters is underway!



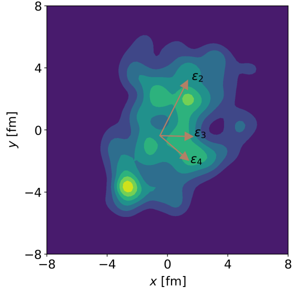


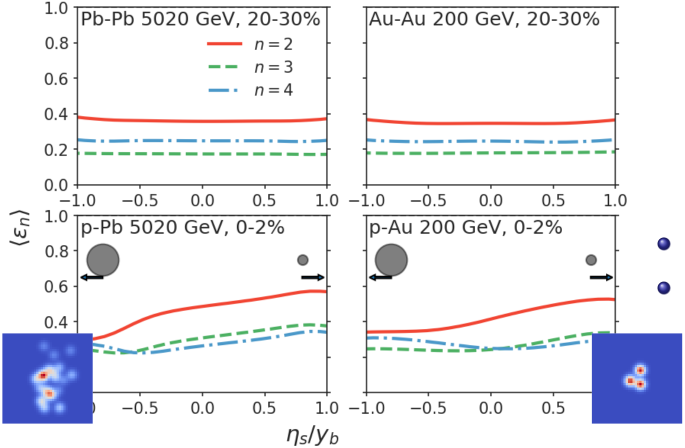
CMS: p-Pb 5.02 TeV, PRC 100 024902, Pb-Pb 2.76 TeV, PRL 109 152303; ALICE: Pb-Pb PRC 94 034903; PHENIX: Cu-Cu, Au-Au, U-U, Cu-Au, d-Au, ^{3}He-Au PRC 93 024901

(Space-time)-rapidity evolution of the event geometry

Rapidity evolution of the eccentricity:

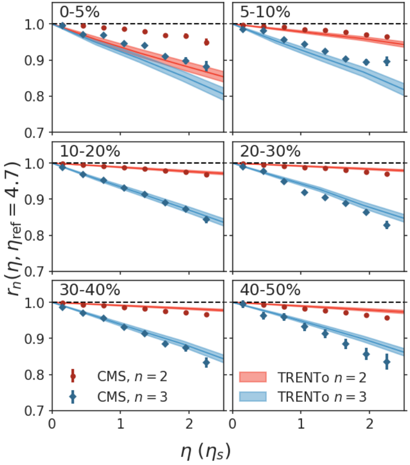
$$\epsilon_n(\eta_s)e^{in\Phi_n(\eta_s)} = \frac{\int dx_\perp^2 r^n e^{in\phi} e(x_\perp, \eta_s)}{\int dx_\perp^2 r^n e(x_\perp, \eta_s)}$$



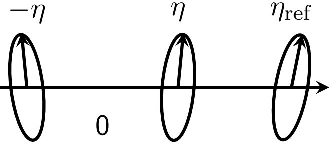


- $\langle\epsilon_n\rangle(\eta_s) \sim \mathrm{const.}$ in AA collisions.
- In p-A collisions, ϵ_n interpolates proton-shape fluctuation, central fireball, and nuclear participant fluctuation.

Longitudinal factorization ratio of participant planes



$Q_n(\eta) = \sum_{i\in\eta} e^{in\phi_i}$



$$r_n = \frac{\langle Q_n(-\eta) Q_n^*(\eta_{\rm ref})\rangle}{\langle Q_n(\eta) Q_n^*(\eta_{\rm ref})\rangle} \approx \frac{\langle \cos(n[\Psi_n(-\eta) - \Psi_n(\eta_{\rm ref})])\rangle}{\langle \cos(n[\Psi_n(\eta) - \Psi_n(\eta_{\rm ref})])\rangle}$$

- Approximate Ψ_n with Φ_n of ϵ_n.
- Agreement for mid-central collisions. TRENTo results in too much decorrelation in 0-5% collisions.

  Other studies: AMPT+hydro, LG Pang et al Eur.Phys.J.A 52 (2016) 97; 3D-Glasma, B Schenke, S Schlichting; Torque Glauber, P Bozek, W Broniowski, PLB 752 (2016) 206-211

Pb-Pb 2.76 TeV, CMS, PRC 92 034911

[7] Pb-Pb 2.76 TeV, CMS, PRC 92 034911. Pb-Pb 5.02 TeV, ATLAS, EPJC 78 142; Au-Au 200 & 27 GeV, STAR Preliminary QM18 (NPA 982 403-406),QM19(2005.03252)

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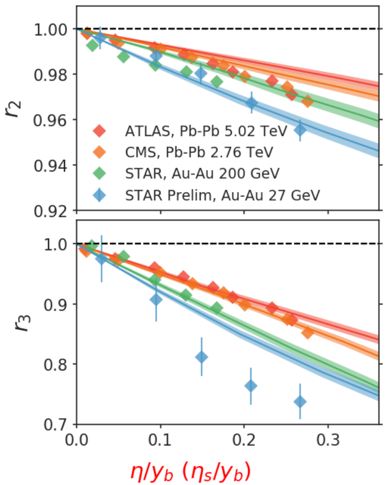

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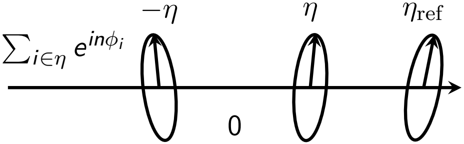

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- $\sqrt{s}$-dependent r_n in 10-40%[7], to be improved with dynamical evolution.

[7] Pb-Pb 2.76 TeV, CMS, PRC 92 034911. Pb-Pb 5.02 TeV, ATLAS, EPJC 78 142; Au-Au 200 & 27 GeV, STAR Preliminary QM18 (NPA 982 403-406),QM19(2005.03252)

Summary

- TRENTo-3D: parametric 3D initial geometric model for nuclear collisions.
- Improvements: incorporate different beam-energy and participant density scaling for
  - Central region ($\eta \sim \eta_{c.m.}$): $e \sim \sqrt{s}^{\alpha}\sqrt{T_A T_B}$
  - Limiting fragmentation region ($|\eta| \sim y_b$): $e \sim T_{A,B}$.

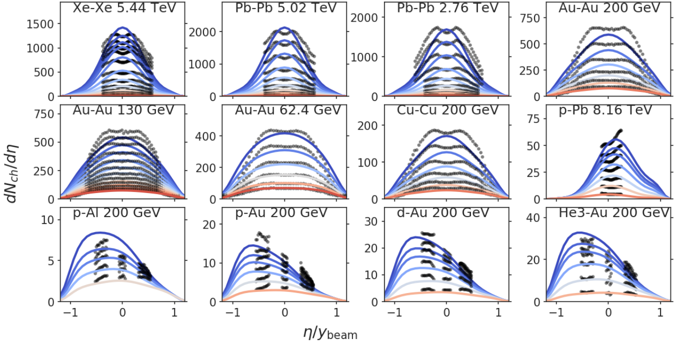
  lead to systematic $\sqrt{s}$ & η-dependent participant plane decorrelations.
- Systematic description of E_T & N_{ch} for different $\sqrt{s} \bigotimes$ collision systems $\bigotimes$ centralities.

Ongoing works:

- Systemic tuning parameters, comparing initial-condition level "observables" to data.
- Facilitate large-scale 3+1D dynamical simulation in the future (JETSCAPE).

Back-up: pseudorapidity density of charged particle multiplicity

- TRENTo initial condition yields initial energy distribution, not directly comparable to charged particle multiplicity.
- Apply the relation $\langle N_{ch} \rangle \sim 1.5 \langle E_T \rangle / \sqrt{s}^{0.05}$ motivated by fitting the measured E_T v.s. N_{ch} at middle rapidity.



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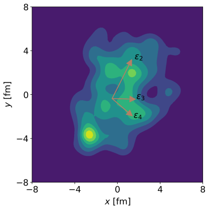

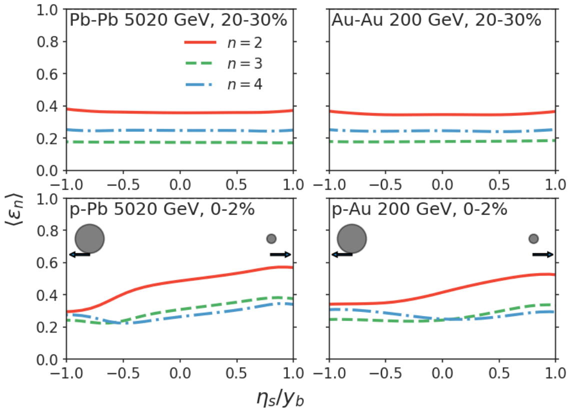

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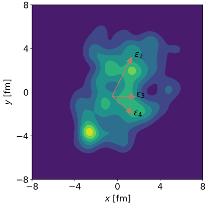

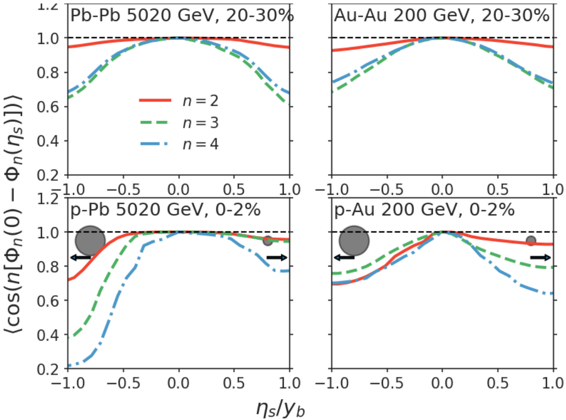

Participant-plane decorrelation $\langle \cos[n(\Phi_n(\eta_s) - \Phi_n(\eta_s'))] \rangle$

- High energy: central fireball dominates, slowly-evolving participant-plane orientation.
- Low energy: limiting-fragmentation becomes important, faster-evolving participant-plane orientation.