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PROBING INITIAL CONDITIONS WITH RAPIDITY-DEPENDENT DIRECTED FLOW OF IDENTIFIED PARTICLES

IN COLLABORATION WITH

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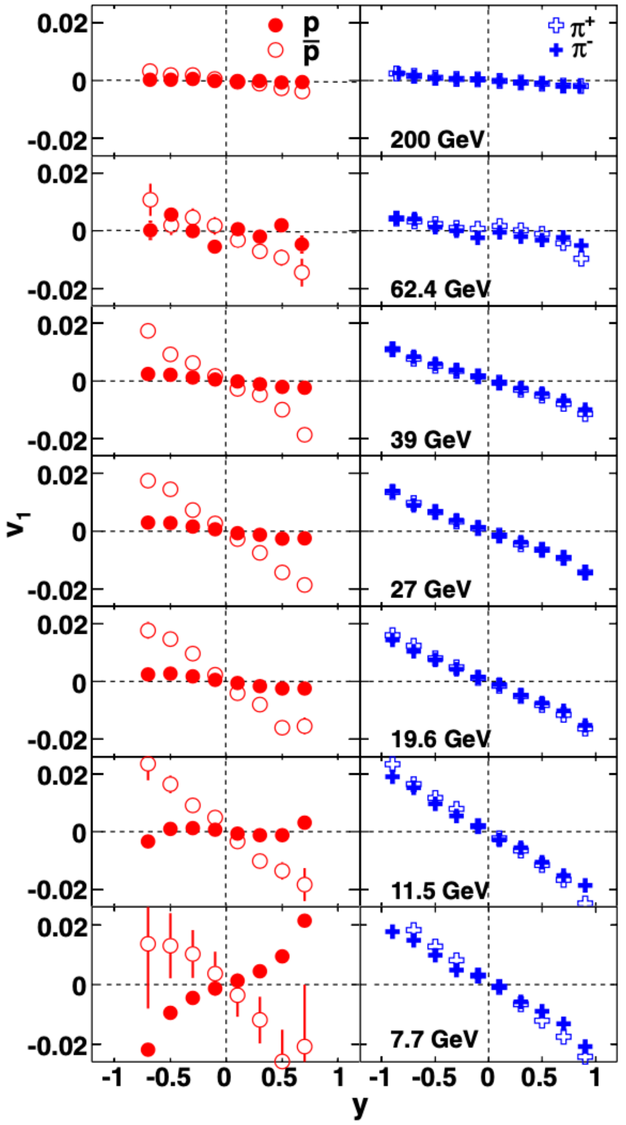
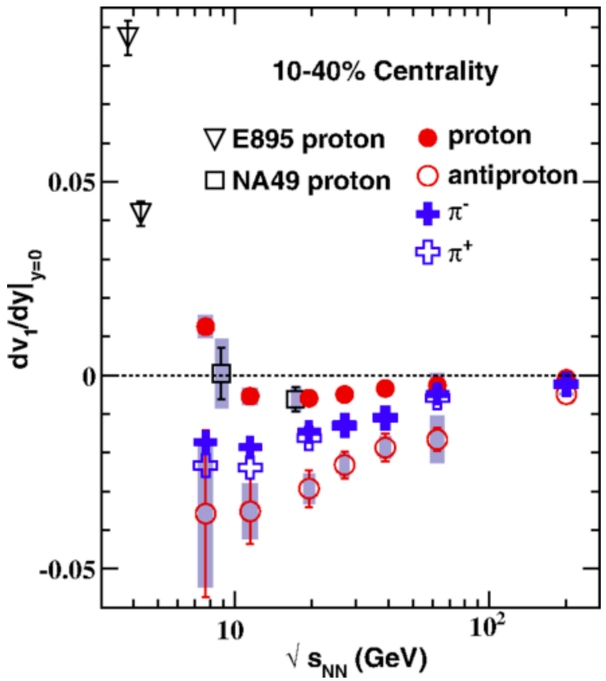
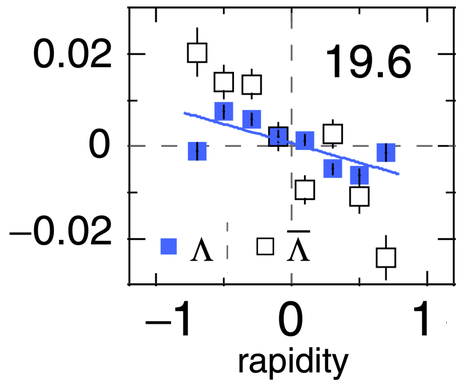
DIRECTED FLOW $v_1(y)$ AT BEAM ENERGY SCAN

- Measurements from STAR and NA49 for intermediate-centrality collisions show various beam energy dependence of proton and pion $dv_1(y)/dy$ – challenging to explain;
- Transport model UrQMD gives a monotonic trend in proton $dv_1(y)/dy\,|_{y=0}$ at beam energy scan (BES) (STAR, PRL 112, 162301 (2014));
- A hybrid hydrodynamic model generates large positive proton $dv_1(y)/dy$ near mid-rapidity at all beam energies (Shen and Alzhrani, PRC102, 014909 (2020));
- Goal of this study: understand the response of $v_1(y)$ to initial conditions, and in turn constrain initial energy & baryon distributions using $v_1(y)$ of identified particles at BES energies.







Figs: STAR, PRL 112, 162301 (2014); PRL 120, 062301 (2018)

HYBRID MODEL

Parametric initial conditions

Averaged MC-Glauber + longitudinal profile

→

Viscous hydrodynamics with baryon diffusion

MUSIC + NEOS-B

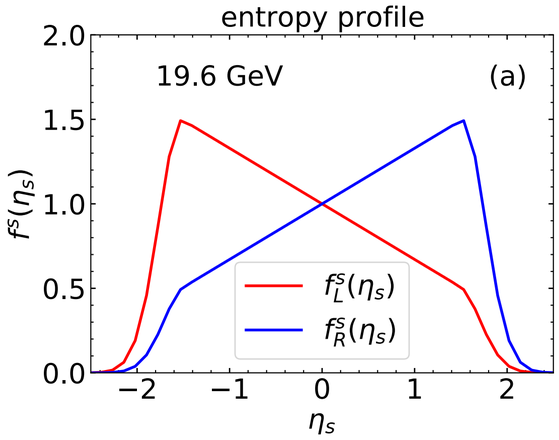
→

Hadronic transport

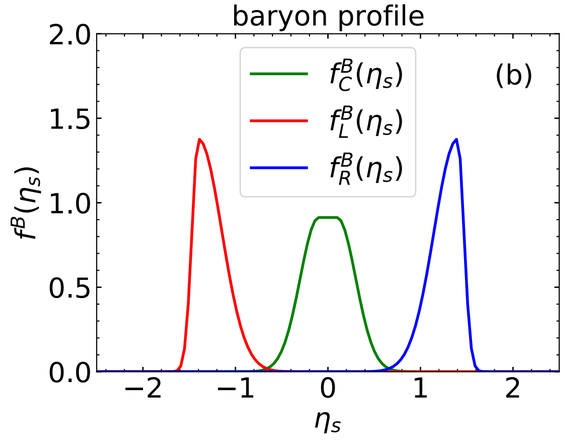
iSS + UrQMD

Multistage framework

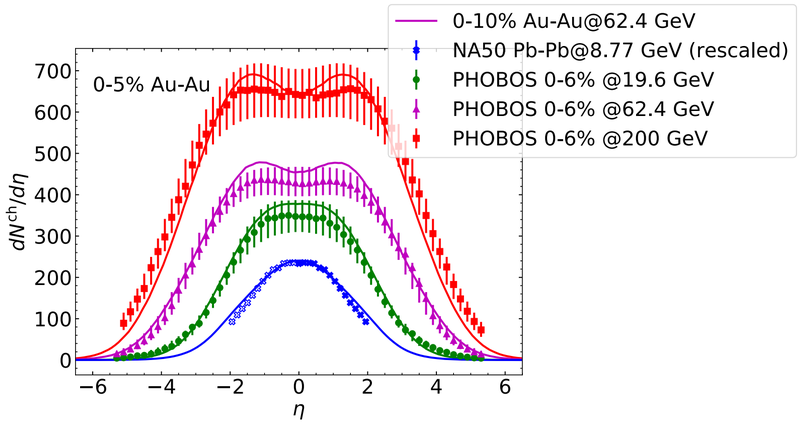
Denicol et al, PRC 98, 034916 (2018); Shen and Alzhrani, PRC102, 014909 (2020); refs therein



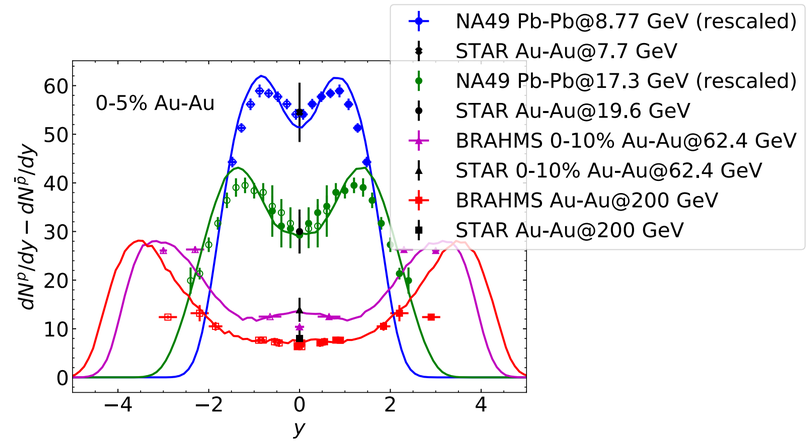
Denicol et al, PRC 98, 034916 (2018)



String junction: Kharzeev, PLB 378, 238 (1996)



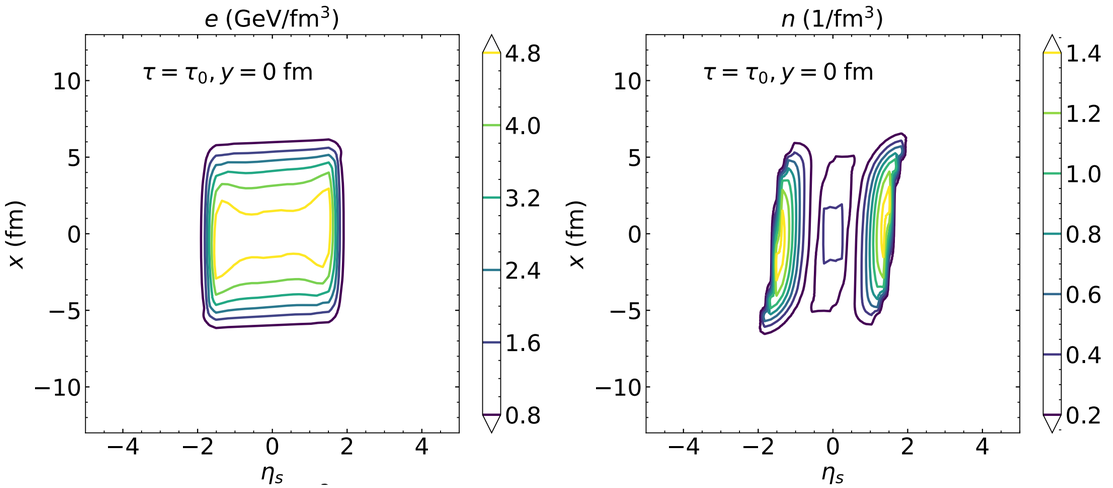
PRELIMINARY



Data: STAR, BRAHMS, PHOBOS, NA49, NA50, Refs [1-16]

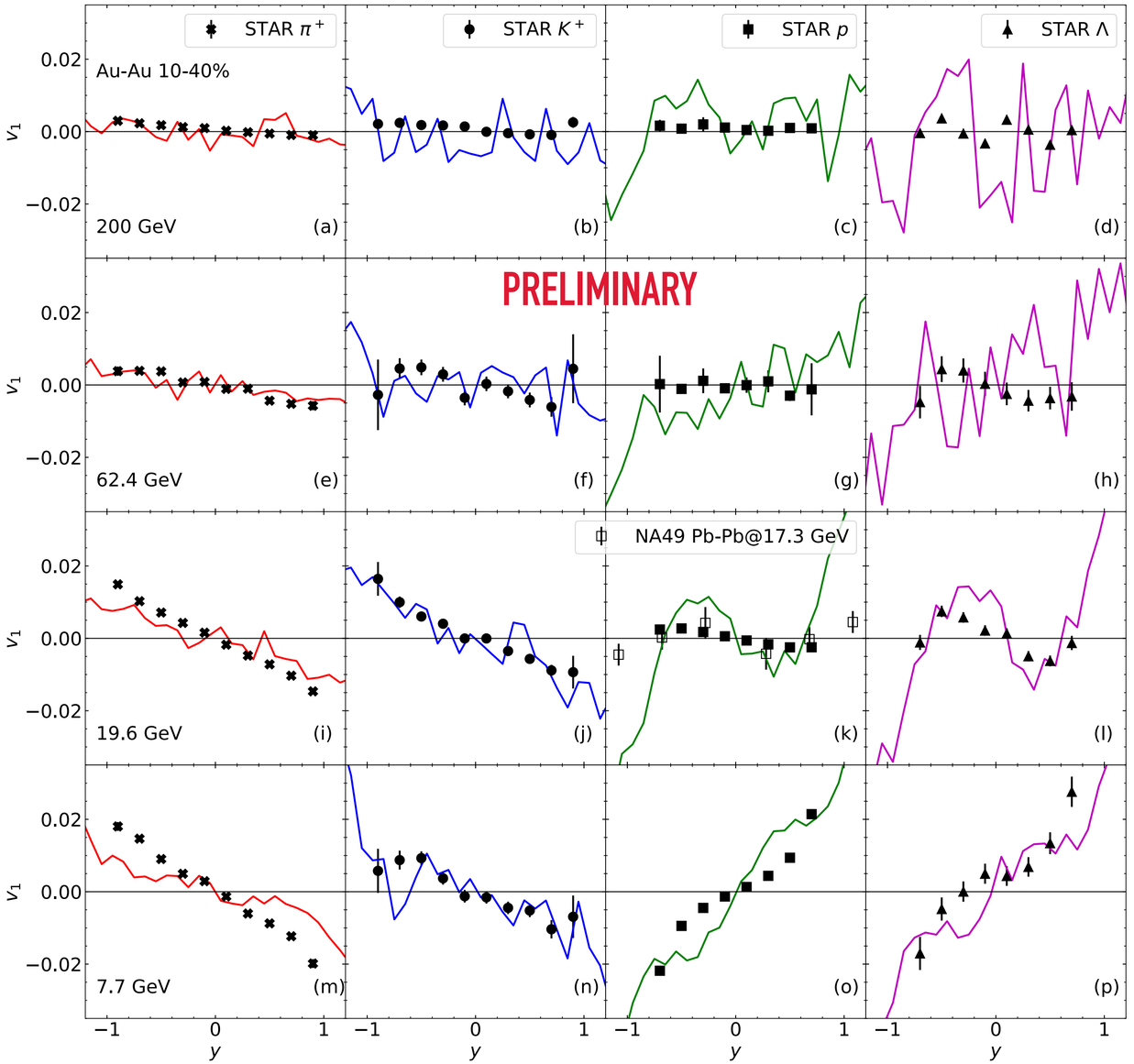
- (Pseudo-)rapidity densities of charged particles and net protons in central collisions to constrain longitudinal profiles.

RAPIDITY-DEPENDENT DIRECTED FLOW OF IDENTIFIED PARTICLES



Initial distributions in reaction plane for 0-5% AuAu@19.6 GeV

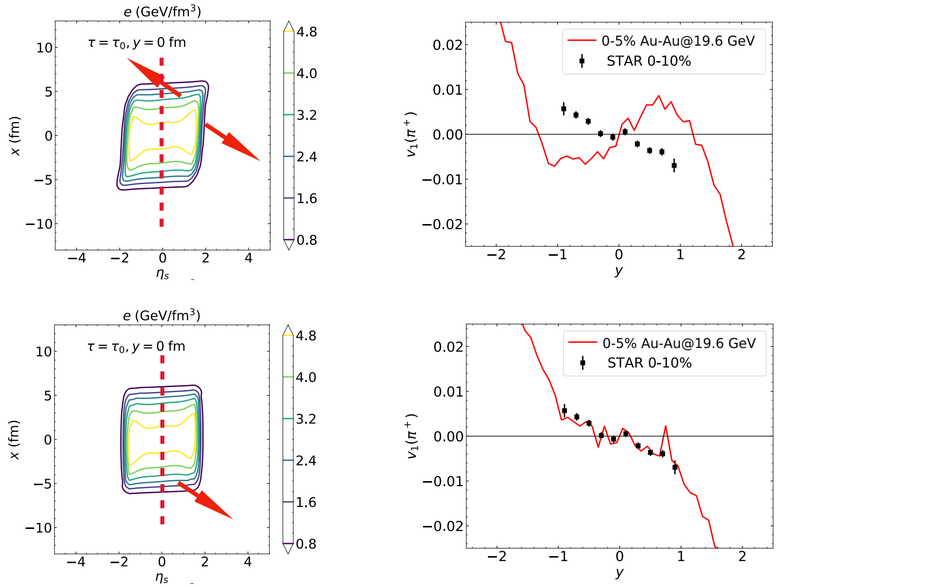
- Slight shift of energy density along $x \Longrightarrow v_1(y)$ of mesons with negative slope at all beam energies;
- Transverse expansion + asymmetric distribution of baryon density along x $\Longrightarrow$ double sign change in the slope of $v_1(y)$ for baryons at 19.6 GeV, and positive slope at 7.7 GeV;
- Central baryon plateau $\Longrightarrow$ small and flat $v_1(y)$ of baryons around mid-rapidity at 200 and 62.4 GeV, and double sign change of proton $dv_1(y)/dy$ at low energies.



Data: STAR, PRL 112, 162301 (2014); PRL 120, 062301 (2018)

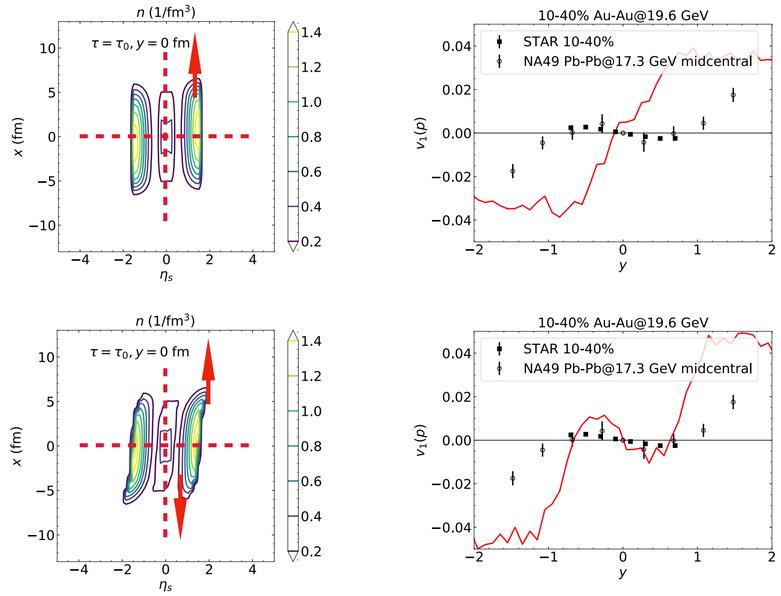
CONSTRAINING INITIAL DISTRIBUTION WITH $v_1(y)$

energy distribution & pion $v_1(y)$



0-5% see also: Bożek & Wyskiel Phys. Rev. C 81, 054902 (2010)

baryon distribution & proton $v_1(y)$



- By tuning initial profile parameters, different features of the rapidity-dependence of $v_1(y)$ slopes of mesons and baryons can be obtained;
- An alternative method to hydrodynamic calculations with a first-order phase transition;
- Some transport approach can fit $v_1(y)$ at mid-rapidity, but not rapidity density of net protons.

SUMMARY

- Using a parametric initial condition, we were able to reproduce the (pseudo-)rapidity densities of charged particles $dN^{\mathrm{ch}}/d\eta$ and net protons $dN^{p-\bar{p}}/dy$, and the rapidity-dependence of directed flow of identified particles $v_1(y)$, simultaneously, from high to low beam energies at RHIC.

- Within our framework, the directed flow of baryons is mainly driven by transverse expansion and asymmetric baryon distribution along x-direction.

- We introduced a plateau component in the initial baryon distribution, which has no preference to target or projectile nucleus, and it may originate from string junctions. The plateau is useful for explaining small and flat $v_1(y)$ around mid-rapidity of baryons, compared to that of mesons.

- Our model reproduced the fact that $dv_1(y)/dy$ of baryons has a double sign change in Au-Au@19.6 GeV by RHIC and Pb-Pb@17.3 GeV by NA49. When it goes to even lower beam energy at 7.7 GeV, our model gave positive $dv_1(y)/dy$ of protons naturally.

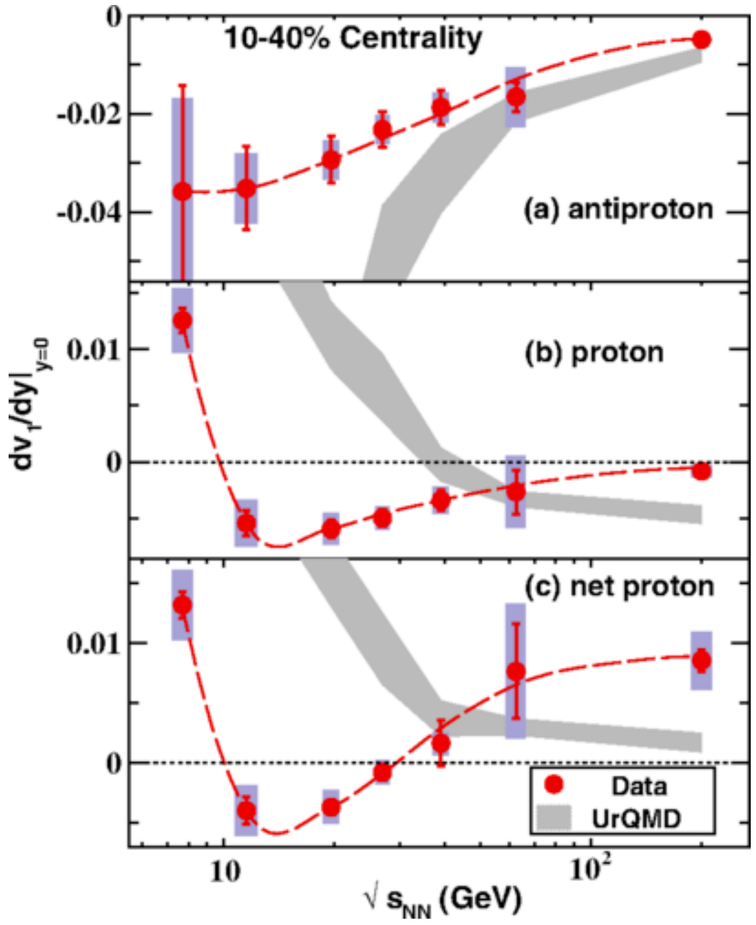
- Our results indicated that $v_1(y)$ of identified particles is sensitive to details of the early collision stages and has constraining power on initial conditions, especially on the initial baryon distribution.

- Outlook: Bayesian inference on the central baryon plateau and baryon diffusion.

BACKUP

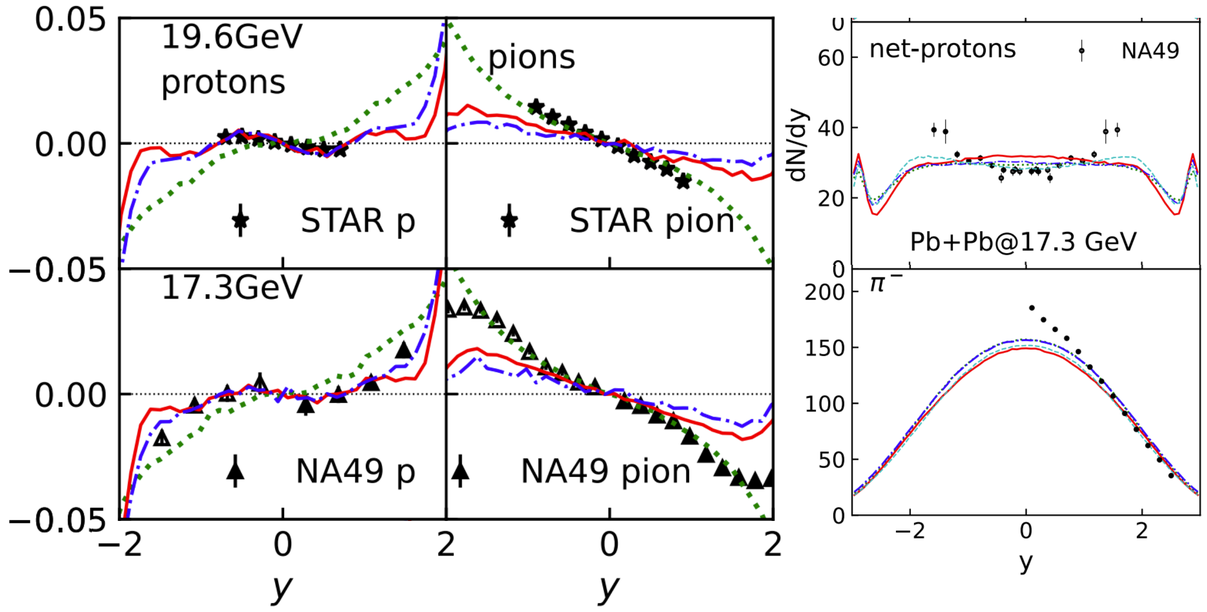
TRANSPORT APPROACHES

UrQMD



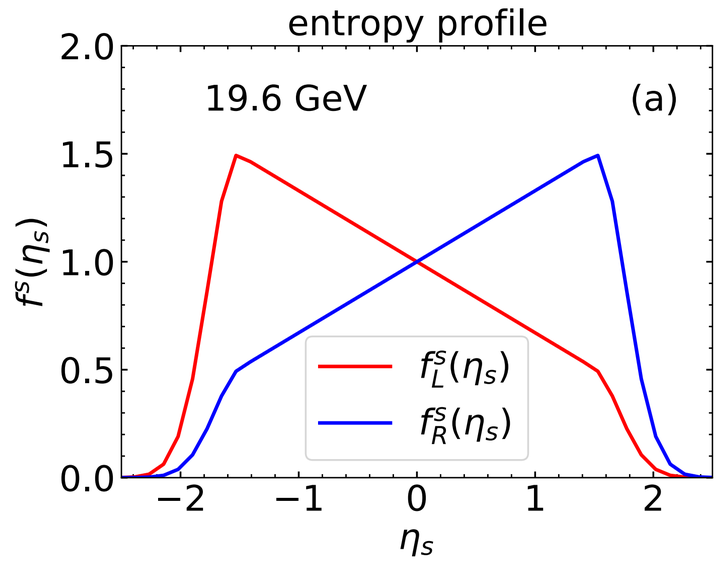
STAR, PRL 112, 162301 (2014)

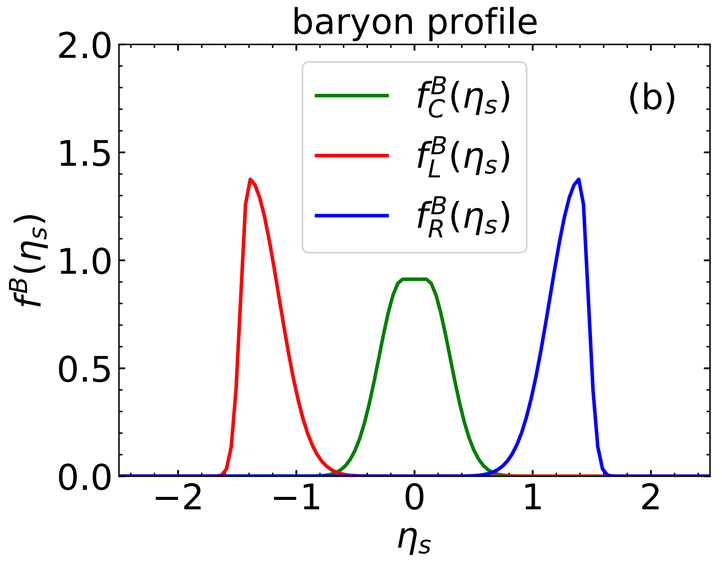
JAM



Nara and Ohnishi, PRC 105, 014911 (2022)

INITIAL PROFILE PARAMETERS





	$\sqrt{s_{NN}}$(GeV)	y_b	τ_0(fm)	N_s	η_0^s	σ_η^s	N_B	η_0^B	σ_+^B	σ_-^B	N_{frac}^B	η_0^B	σ_η^B	N_{tot}^B
0	7.7	2.11	3.6	2.45	1.5	0.18	0.93	1.0	0.07	0.2	0.285	0.25	0.05	1.20
1	19.6	3.04	1.8	5.85	3.0	0.25	0.72	1.4	0.07	0.18	0.4	1.1	0.2	1.01
2	62.4	4.20	1.0	12.5	4.6	0.3	0.71	3.0	0.2	1.0	0.17	1.2	0.22	0.83
3	200	5.36	1.0	16.0	4.8	0.55	0.7	3.5	0.3	1.1	0.12	1.5	0.25	0.78

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