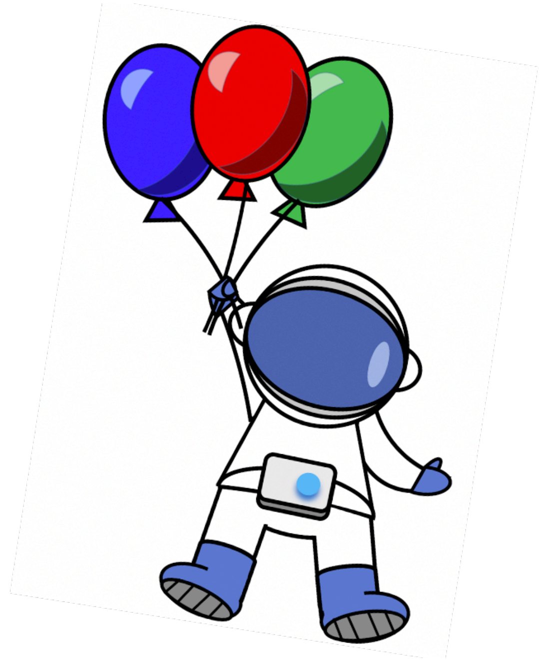


LIPEI DU

DEPARTMENT OF PHYSICS, MCGILL UNIVERSITY

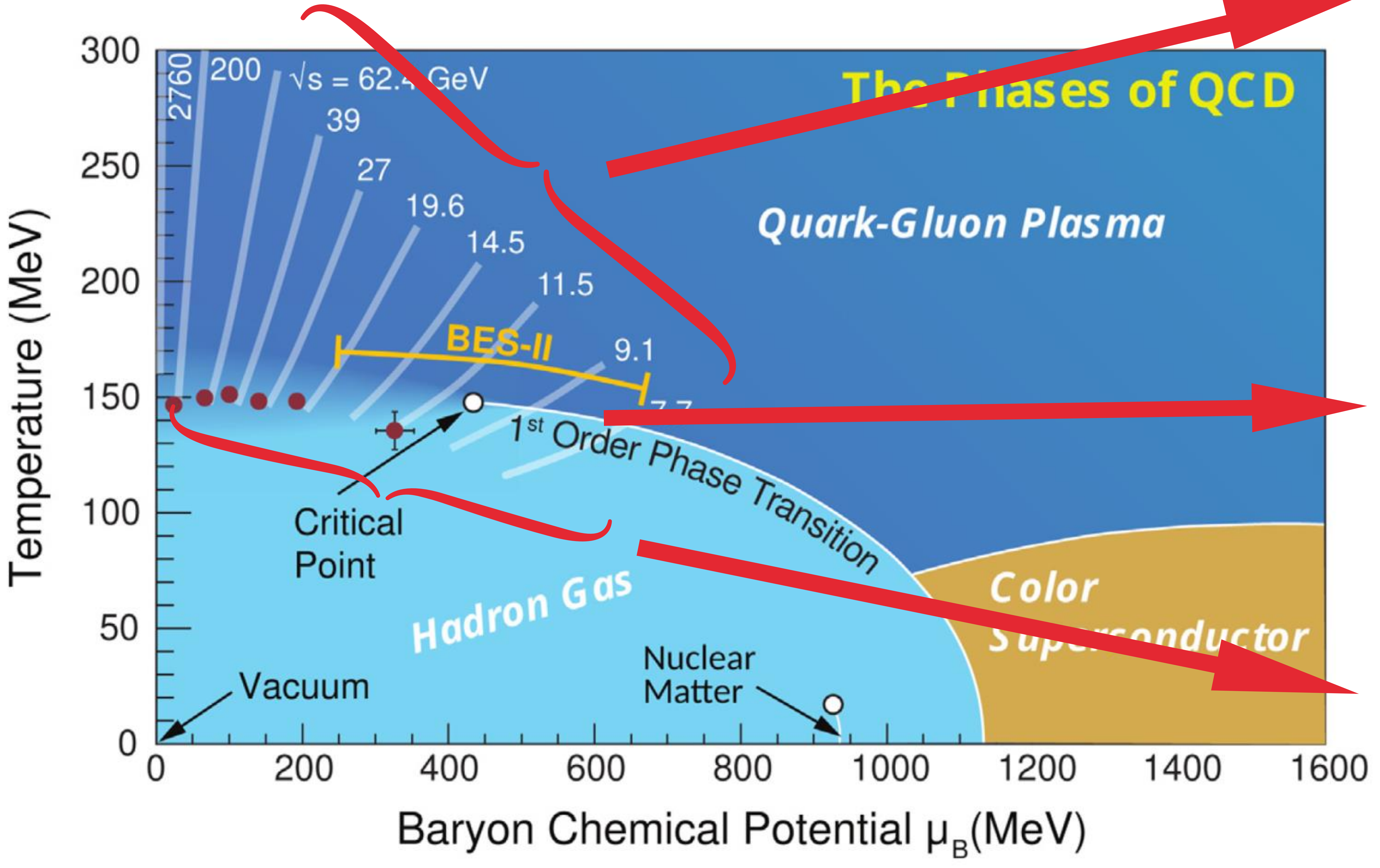
PROBING INITIAL BARYON STOPPING AND EOS WITH $v_1(y)$ OF IDENTIFIED PARTICLES

L. Du, C. Shen, S. Jeon & C. Gale, arXiv:2211.16408

QUARK MATTER 2023

HOUSTON, SEPTEMBER 05, 2023

QCD PHASE DIAGRAM TRAJECTORIES

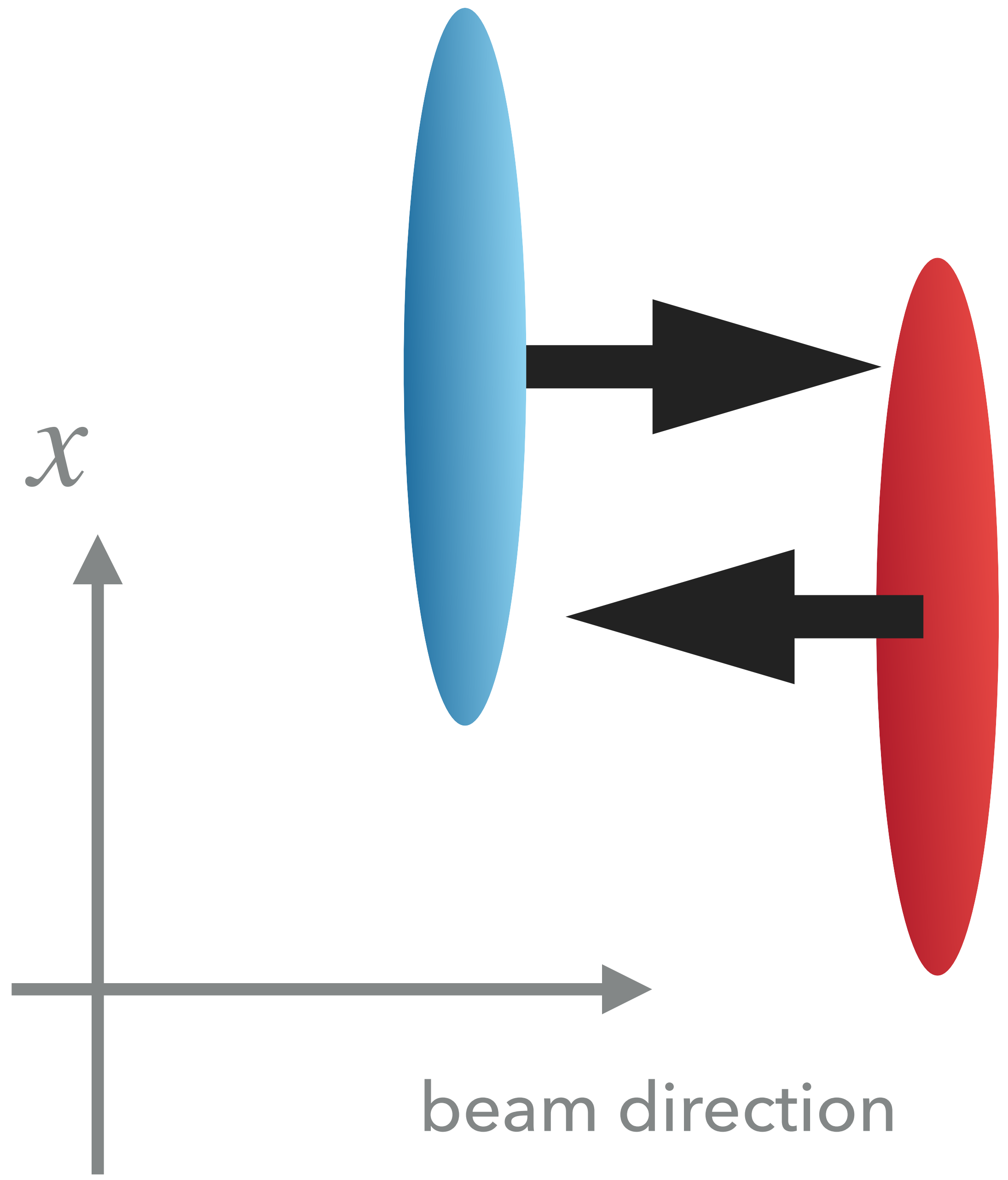


Bzdak, Esumi, Koch, Liao, Stephanov, and Xu, Phys. Rept. 853 (2020)

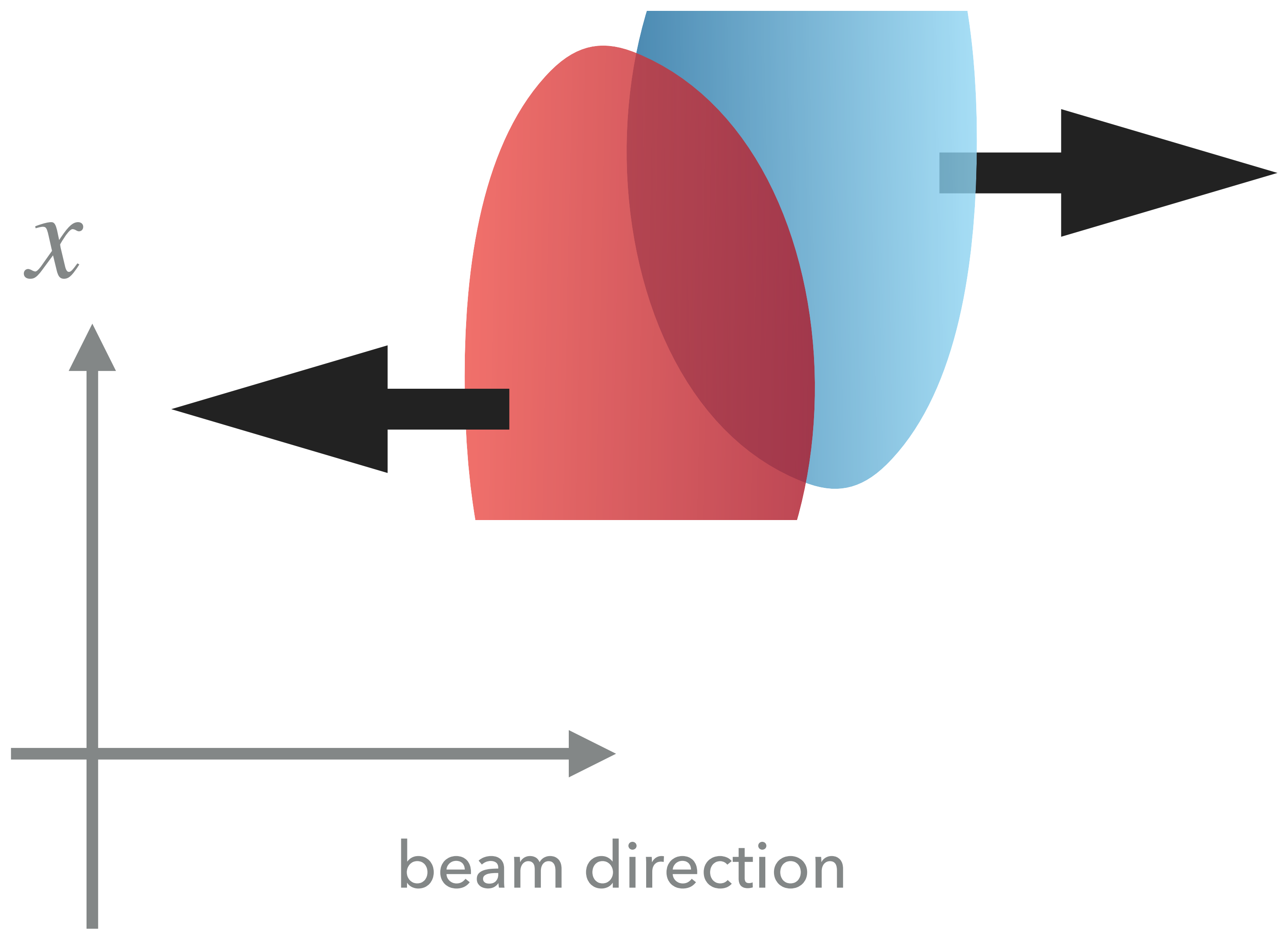
- Starting points:
  - initial baryon this talk
  - initial temperature

  Charles Gale, Tue. 3:10 PM
- Trajectories:
  - hydrodynamic evolution
- Endpoints:
  - chemical potential & temperature at freeze-out

  Han Gao, Tue. 12:00 PM



- From the nucleon deceleration picture, the baryon density profile gets two peaks, naturally giving the double-humped net proton yields in rapidity.



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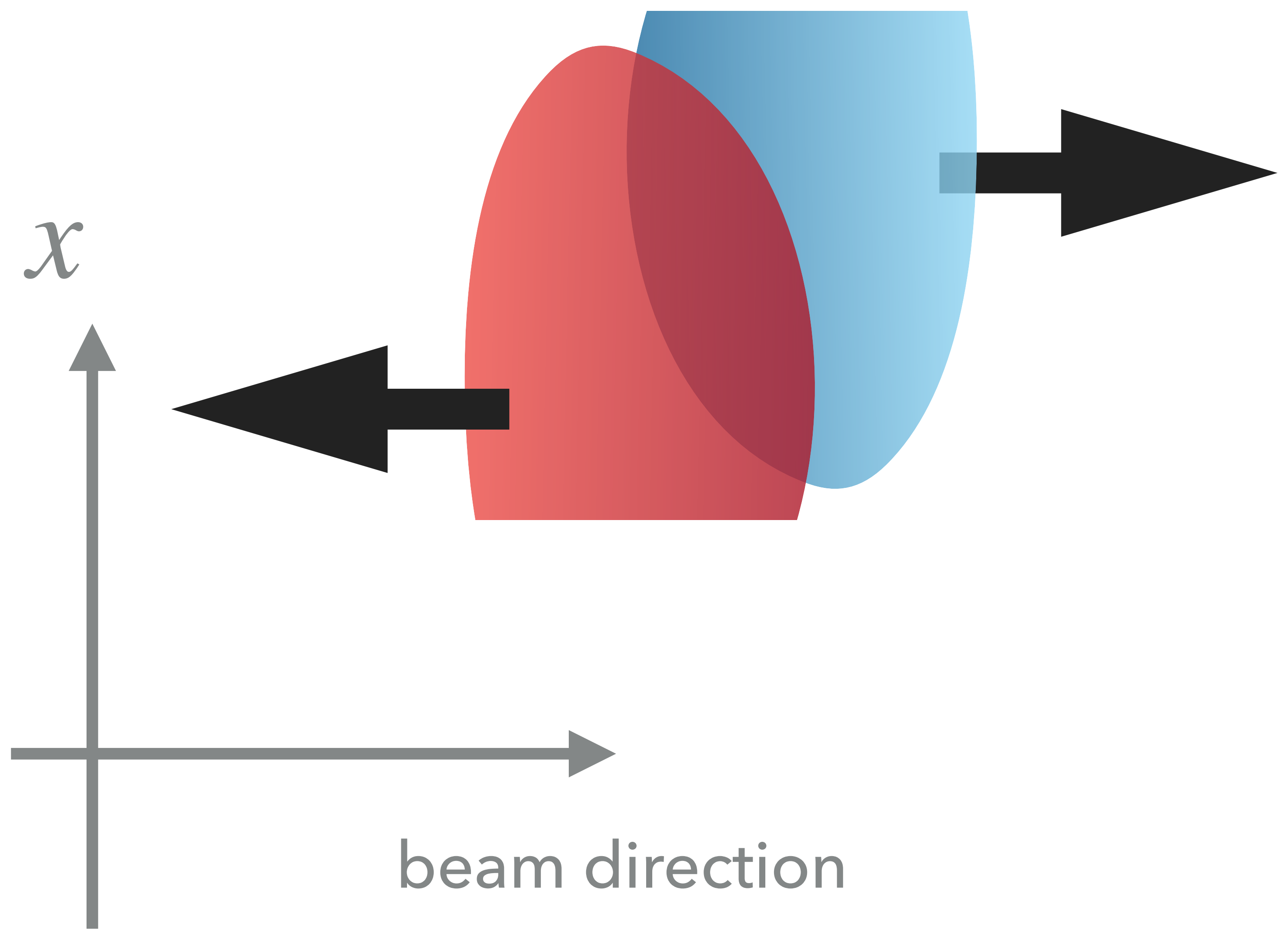
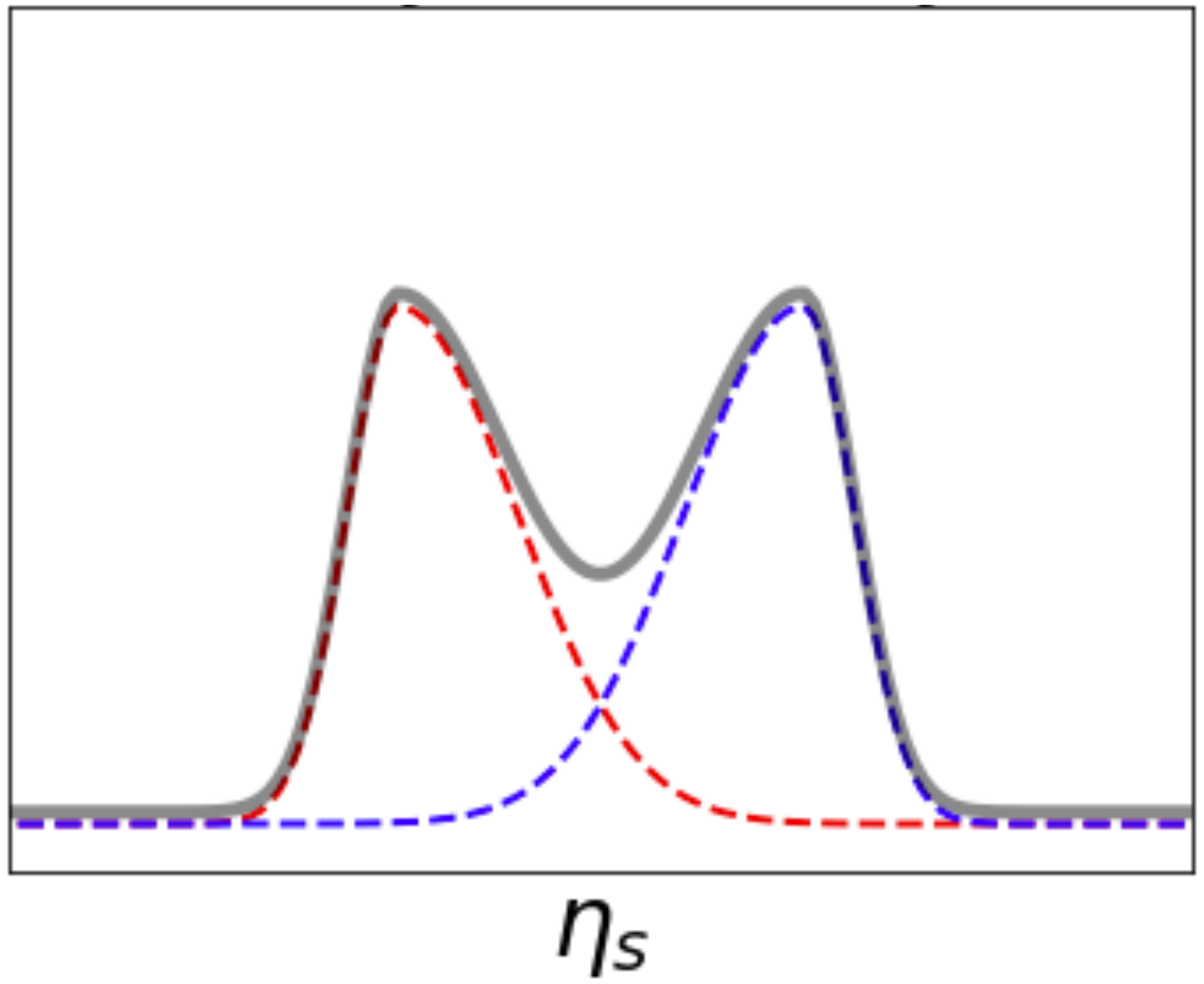
BARYON STOPPING



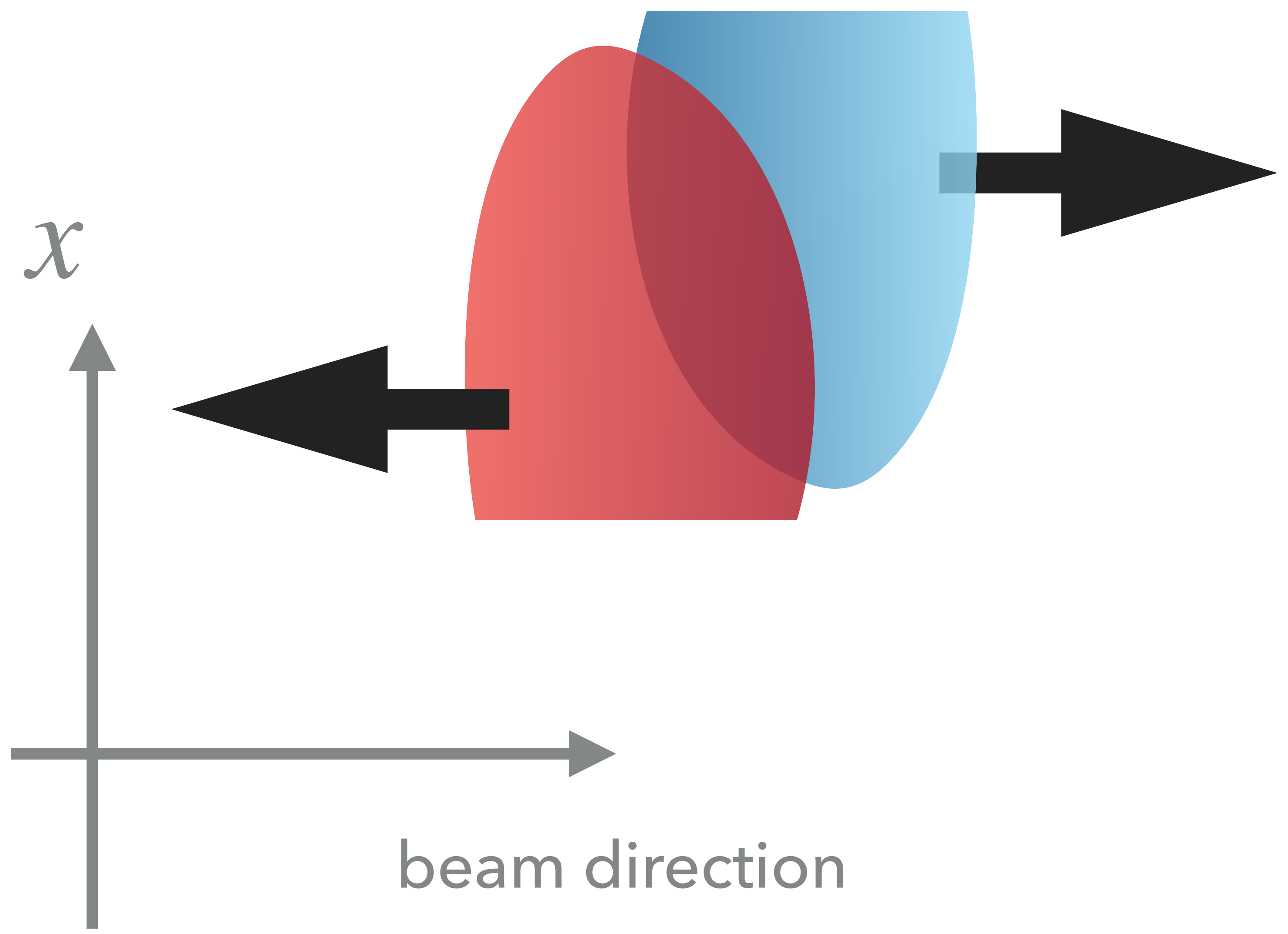


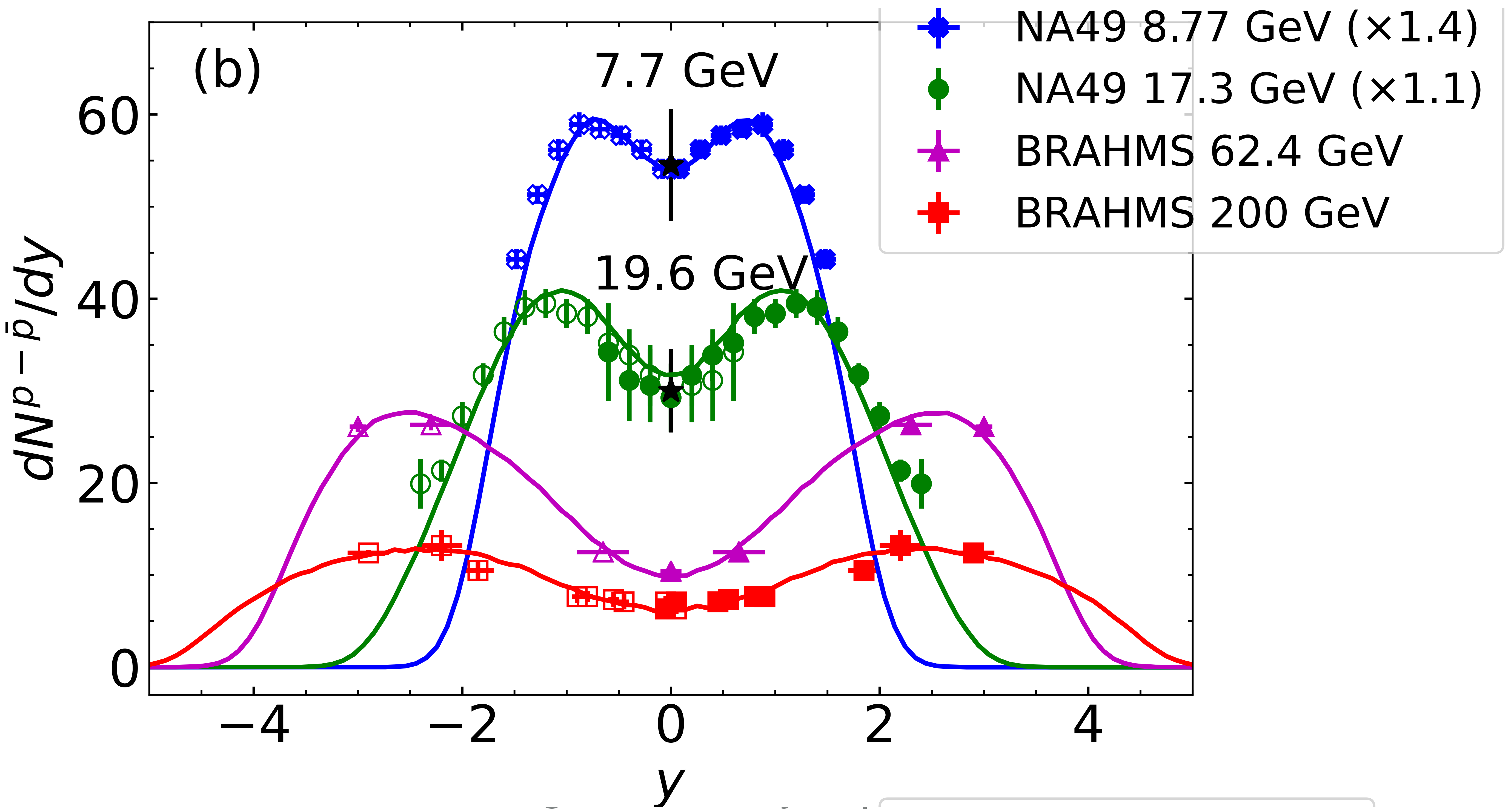
longitudinal baryon profile

- From the nucleon deceleration picture, the baryon density profile gets two peaks, naturally giving the double-humped net proton yields in rapidity.

Denicol et al, PRC 98, 034916 (2018); LD, H. Gao, S. Jeon & C. Gale, arXiv:2302.13852

BARYON STOPPING





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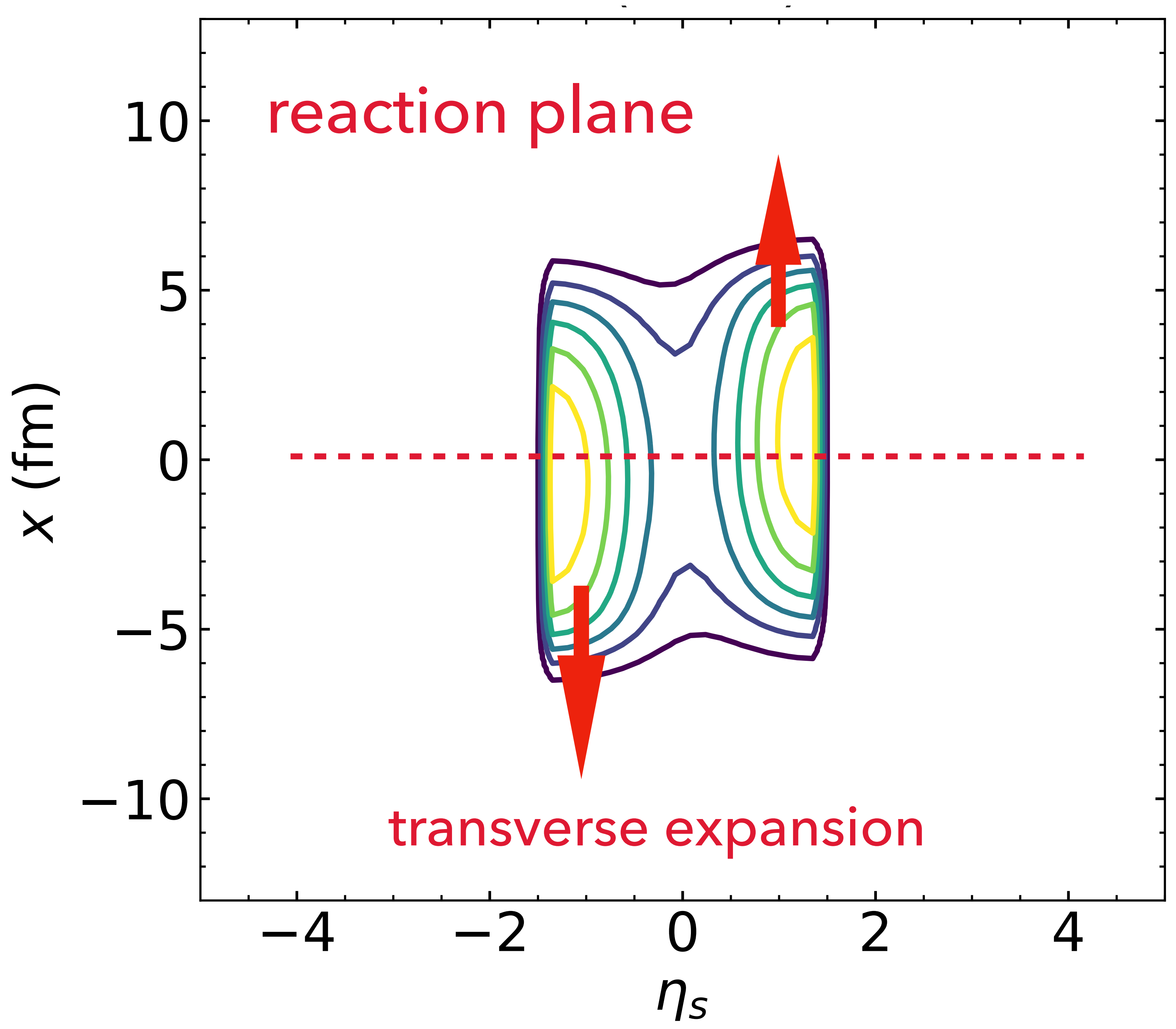
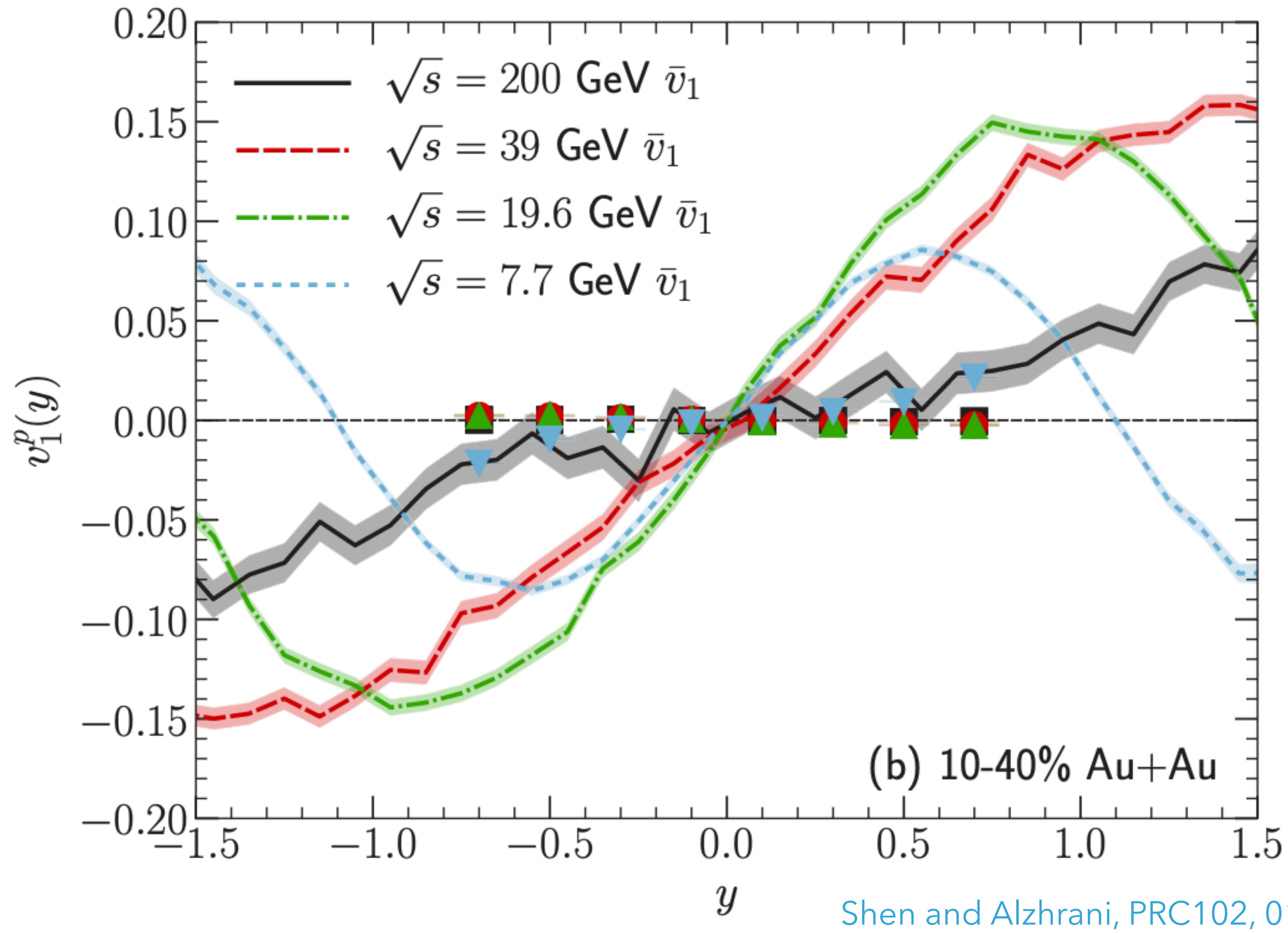
Denicol et al, PRC 98, 034916 (2018); LD, H. Gao, S. Jeon & C. Gale, arXiv:2302.13852

DIRECTED FLOW $v_1(y)$ OF PROTONS



initial baryon distribution

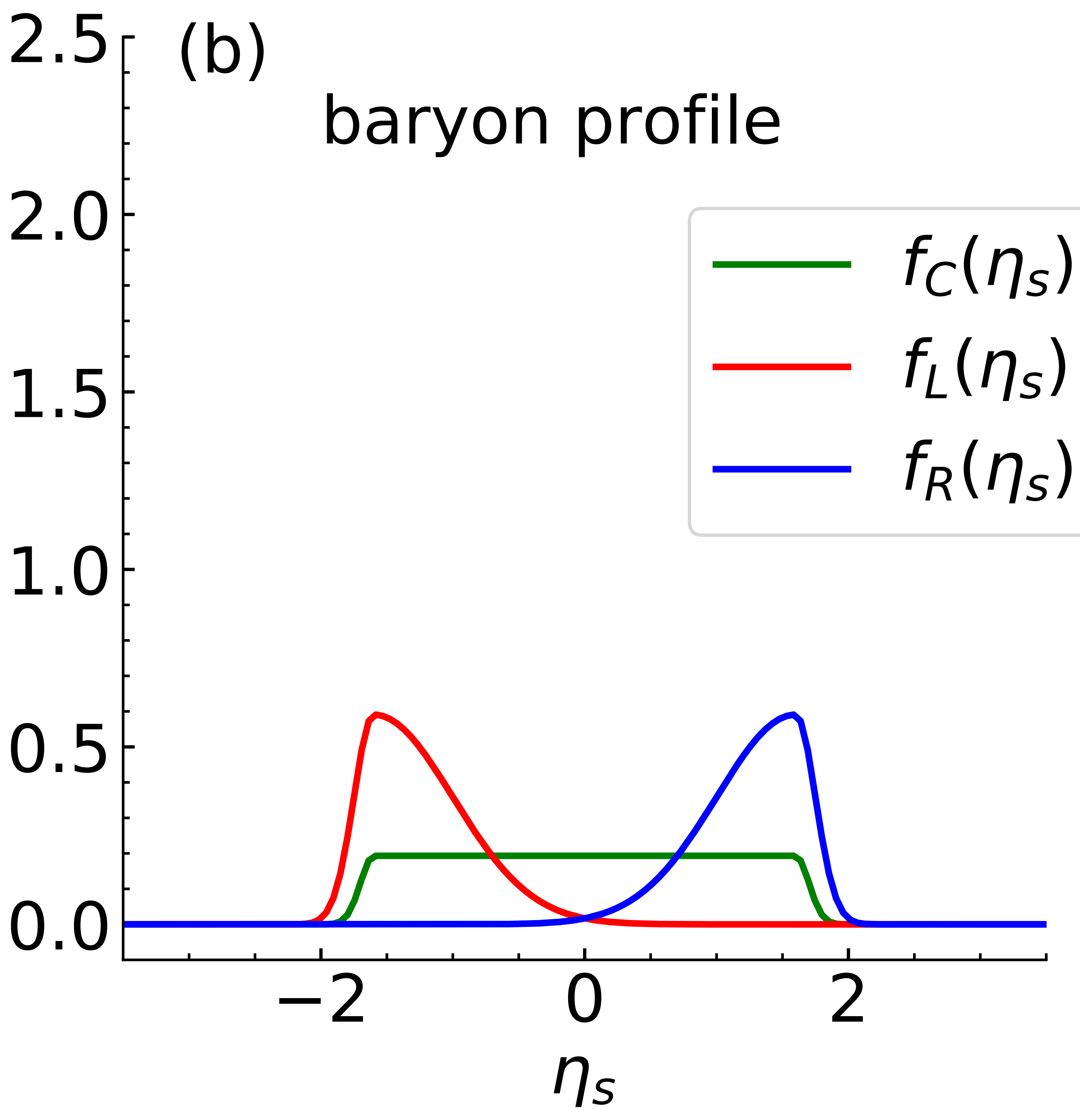


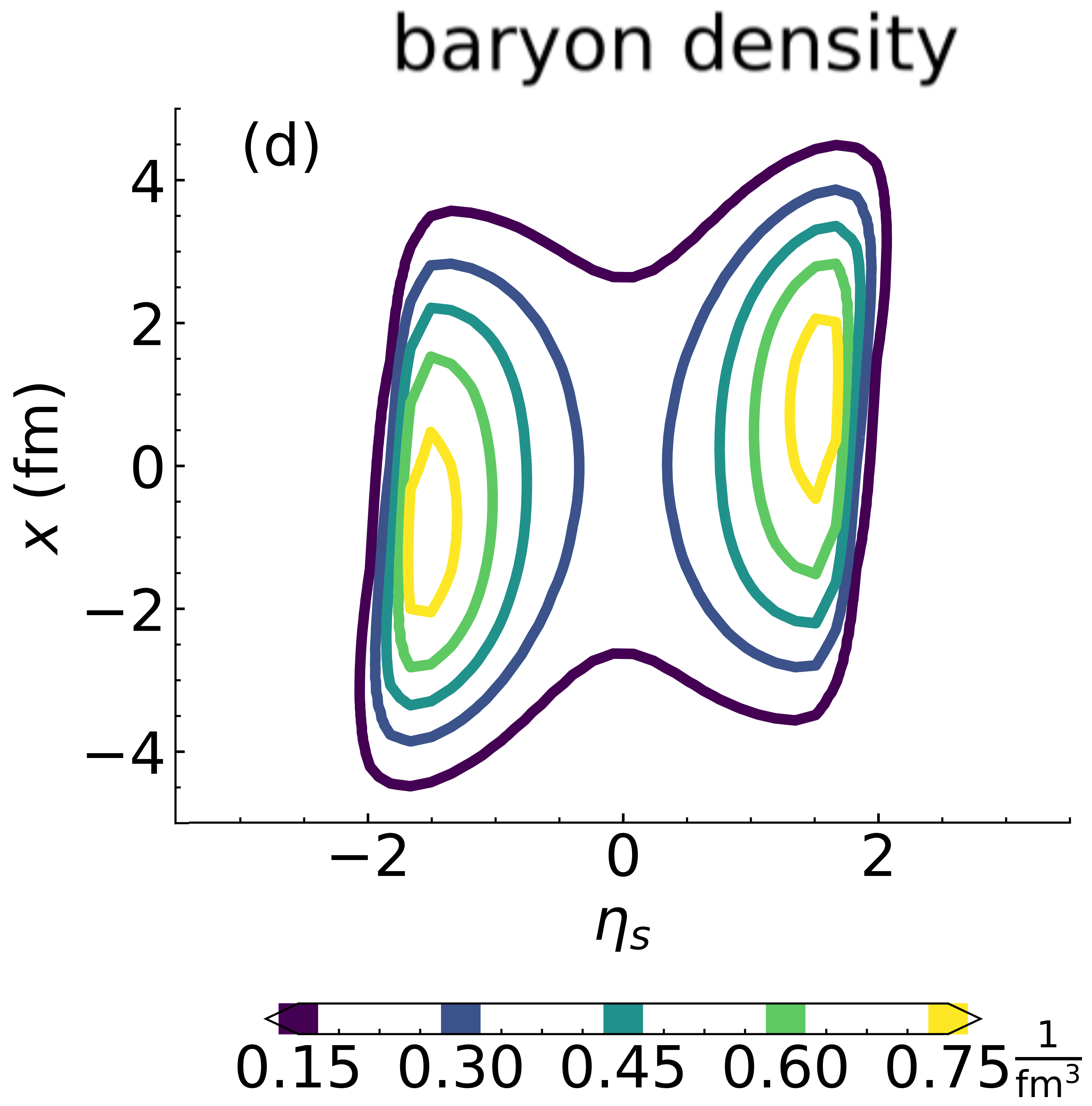
Shen and Alzhrani, PRC102, 014909 (2020)

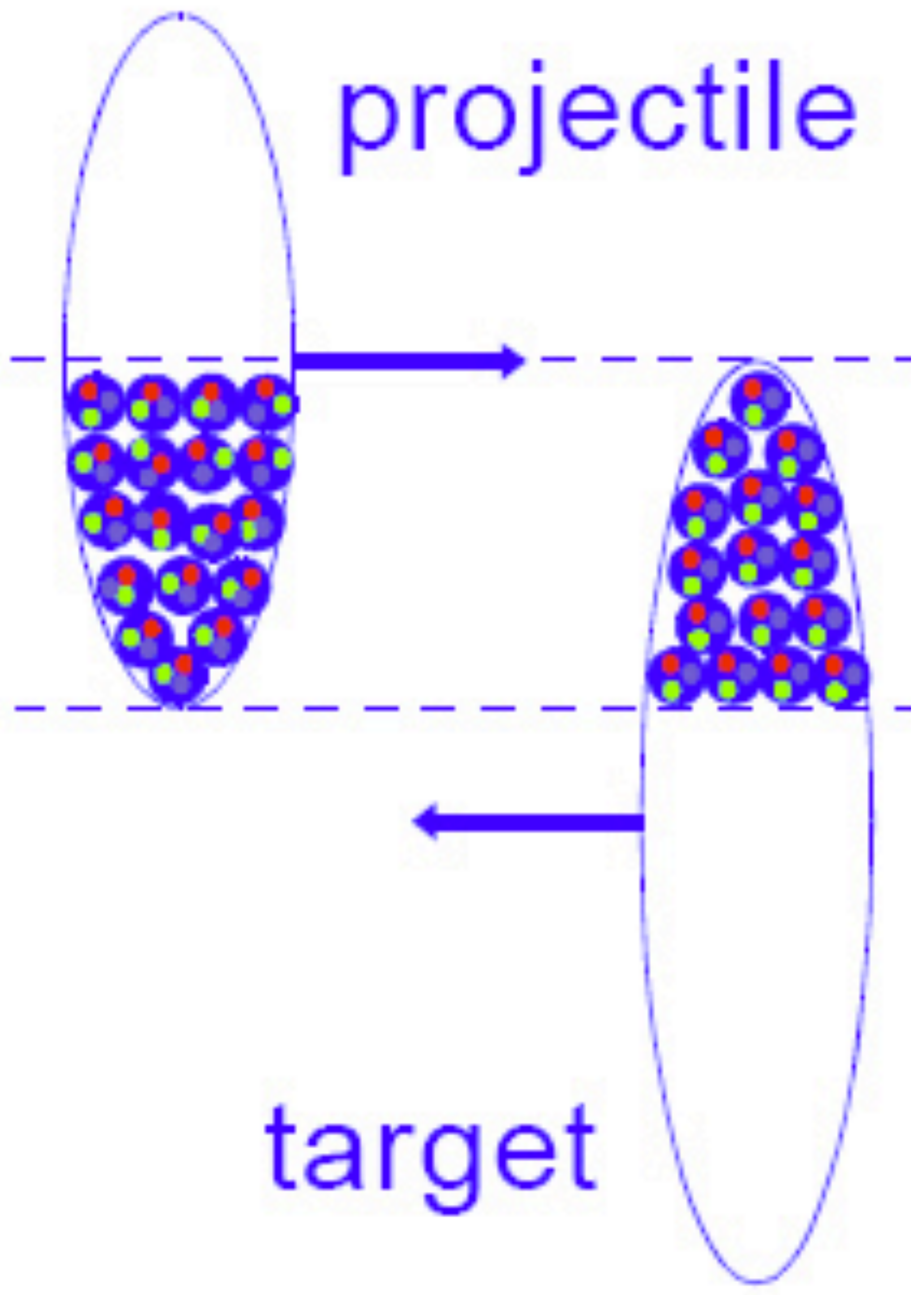
- $v_1(y)$ of baryons is mainly driven by the asymmetric distribution of baryon density with respect to beam axis + transverse expansion;

- The widely used baryon-stopping picture results in $v_1(y)$ strongly overshooting the experimental measurements for protons at all beam energies.

NEW PARAMETRIC BARYON INITIAL CONDITION



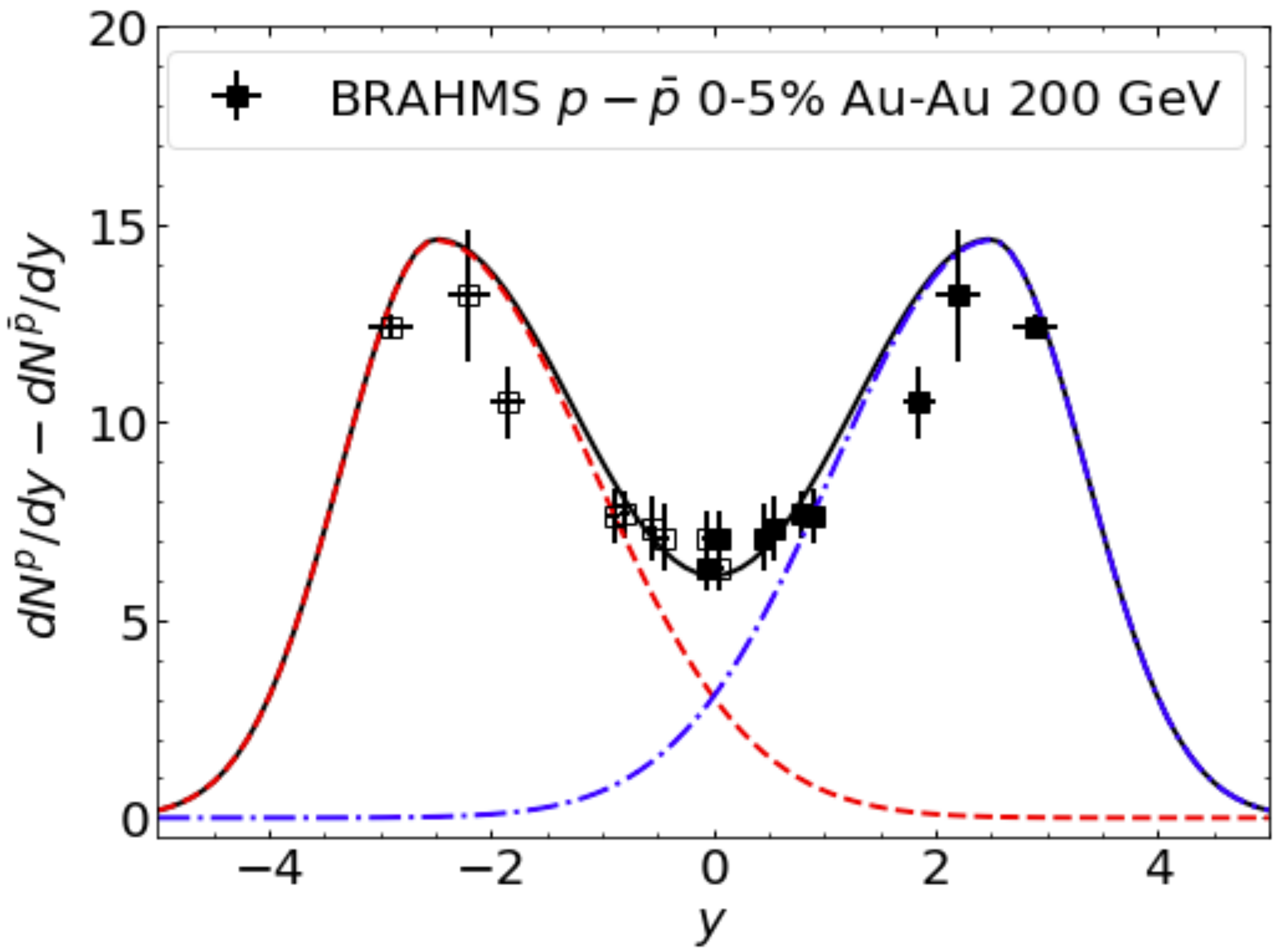


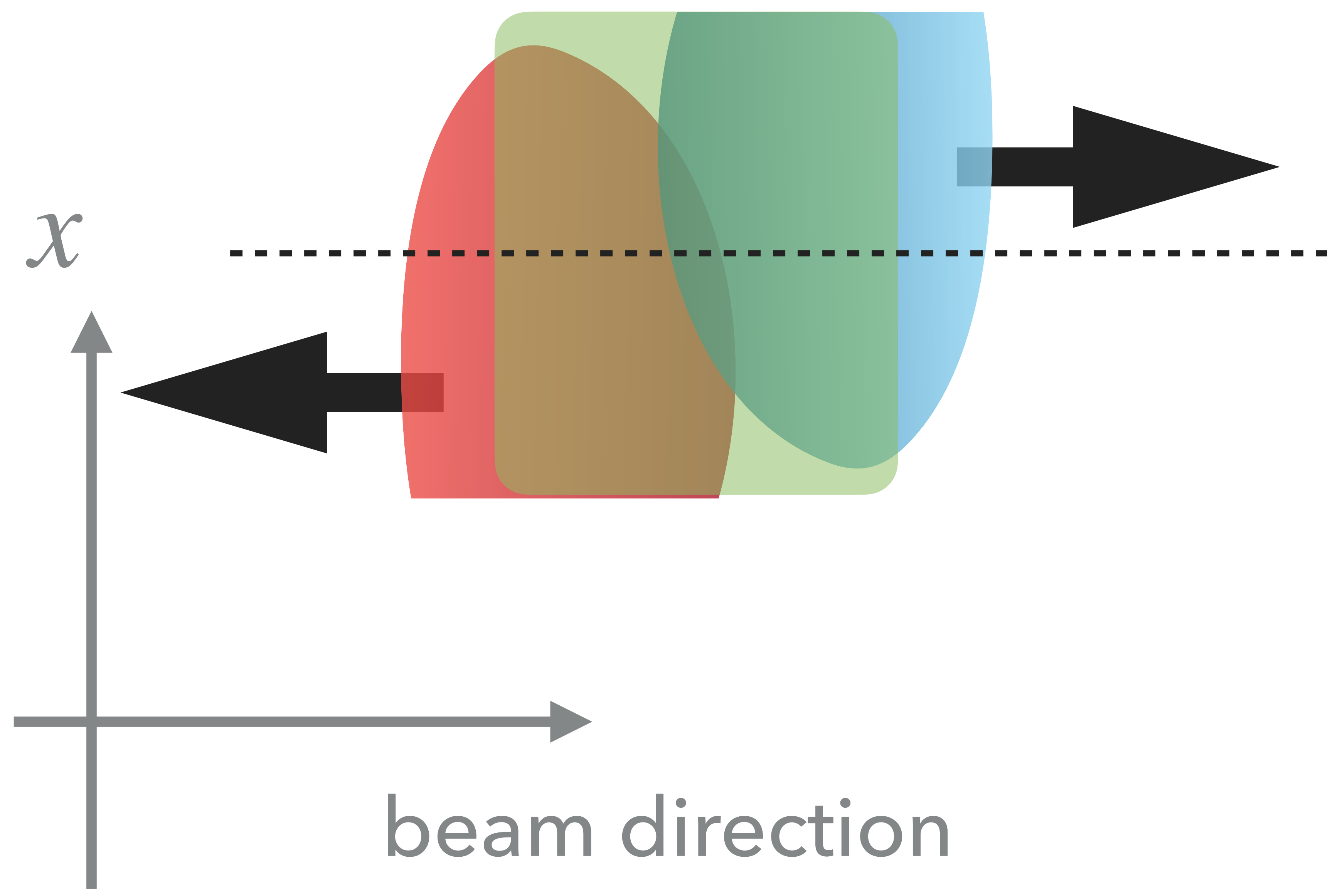


- A rapidity-independent "plateau" component in initial baryon profile & tilted baryon peaks describing the varying baryon stopping in the transverse plane

LD, C. Shen, S. Jeon & C. Gale, arXiv:2211.16408

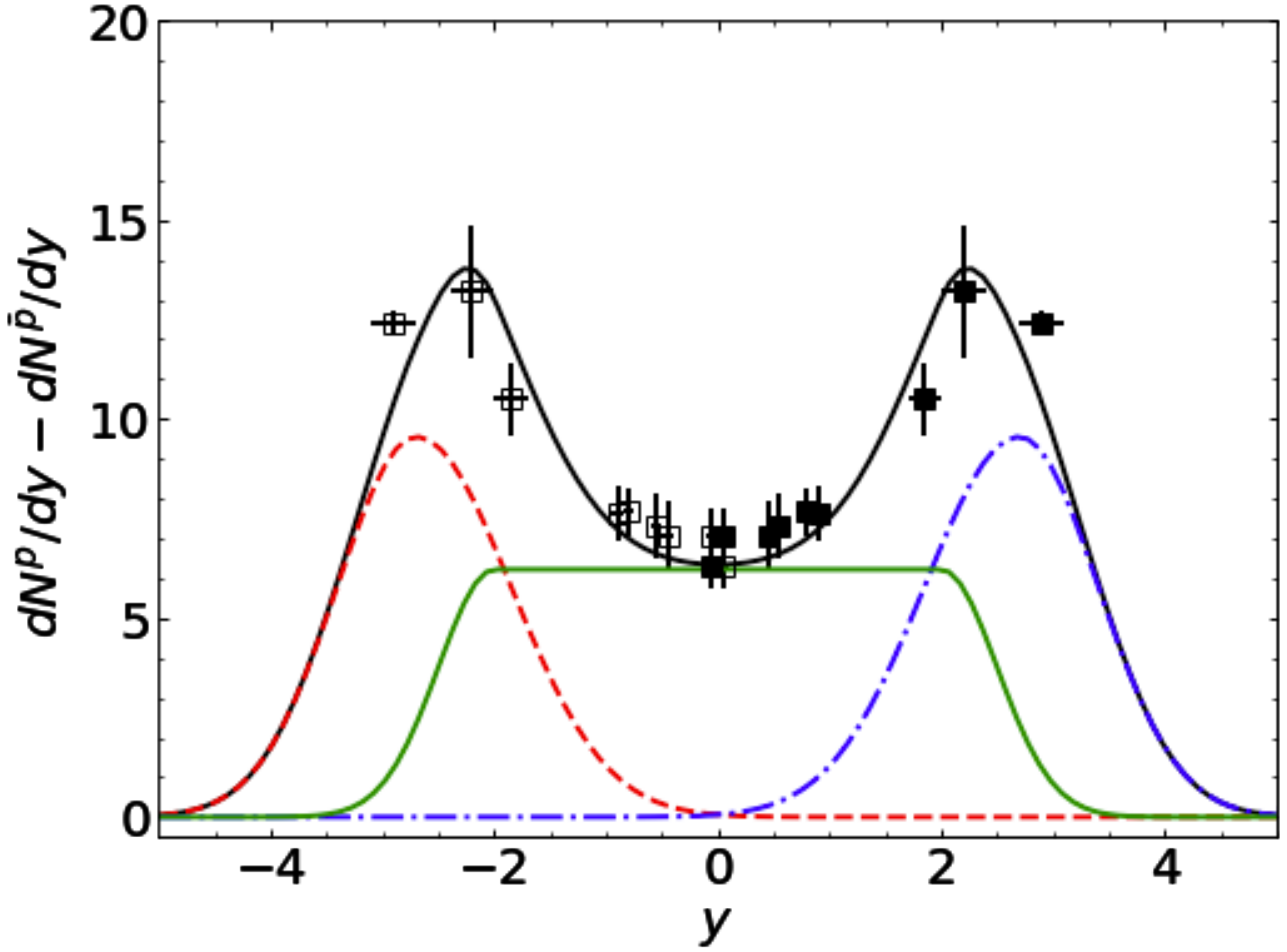
$dN^{p-\bar{p}}/dy$ AND $v_1(y)$ OF PROTONS

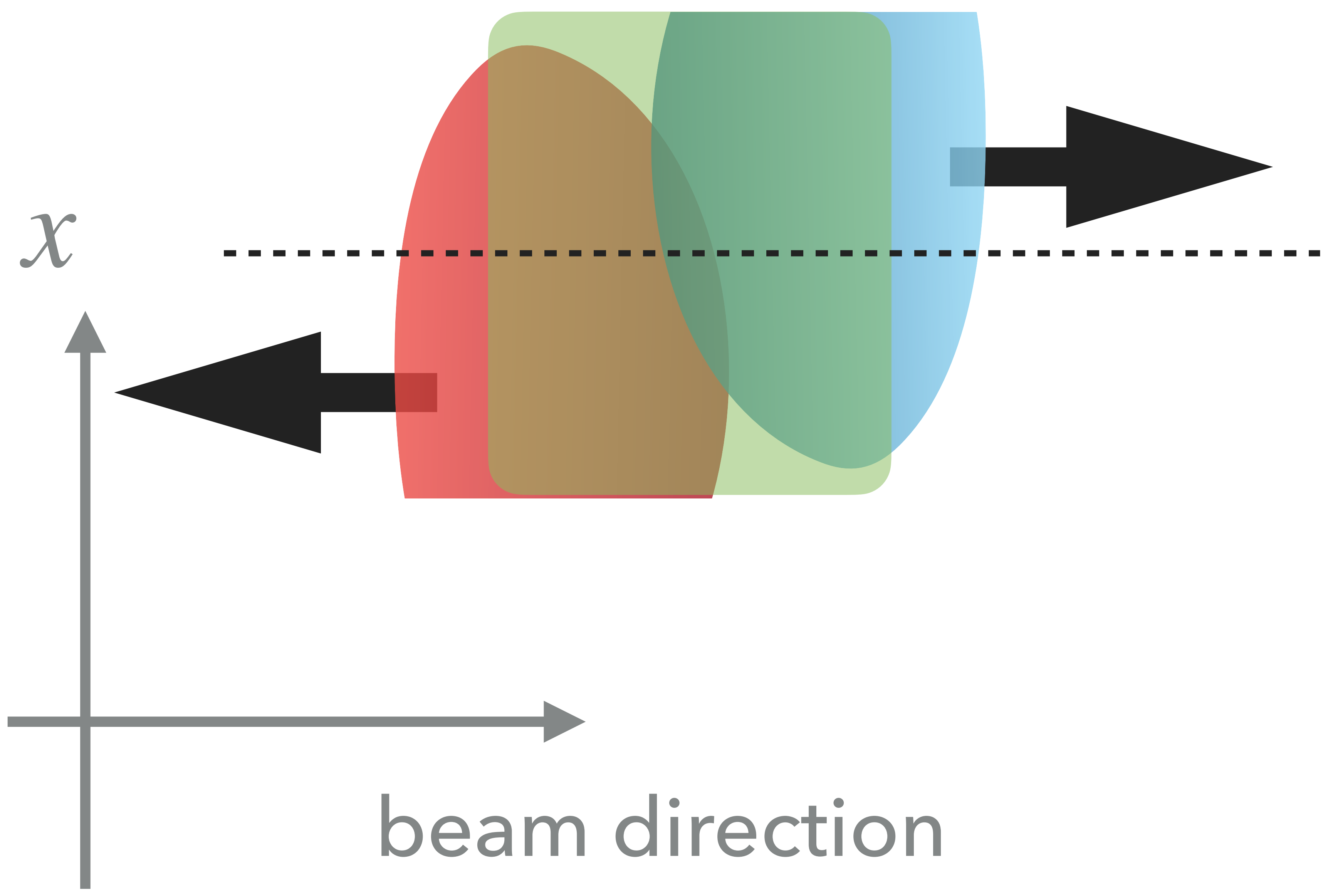




- To explain the rapidity distributions of net proton yields and baryons' directed flows simultaneously, the plateau is favored;
- It helps to reduce baryons' $v_1(y)$ while giving enough net proton yields around midrapidity.

$dN^{p-\bar{p}}/dy$ AND $v_1(y)$ OF PROTONS





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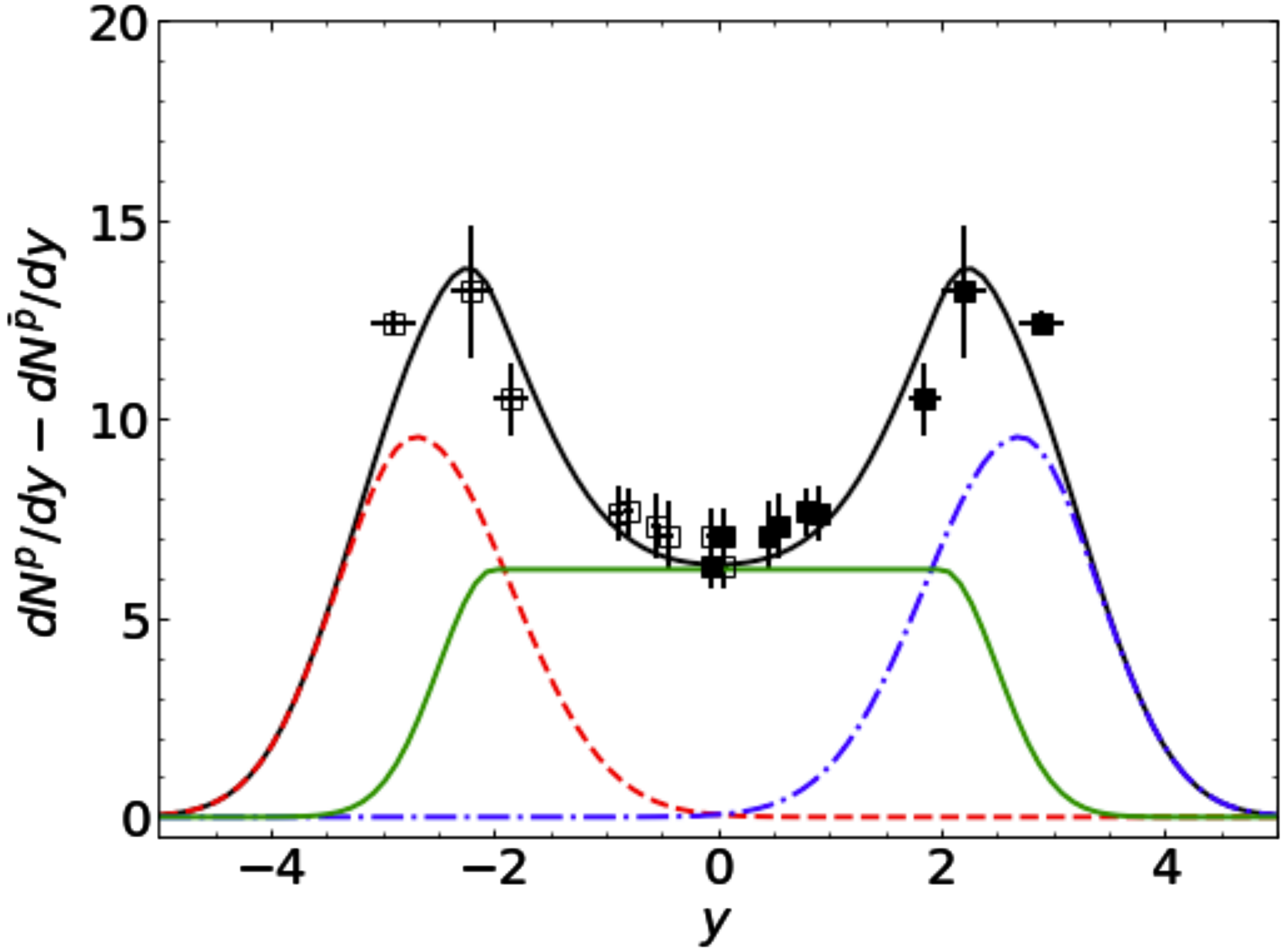
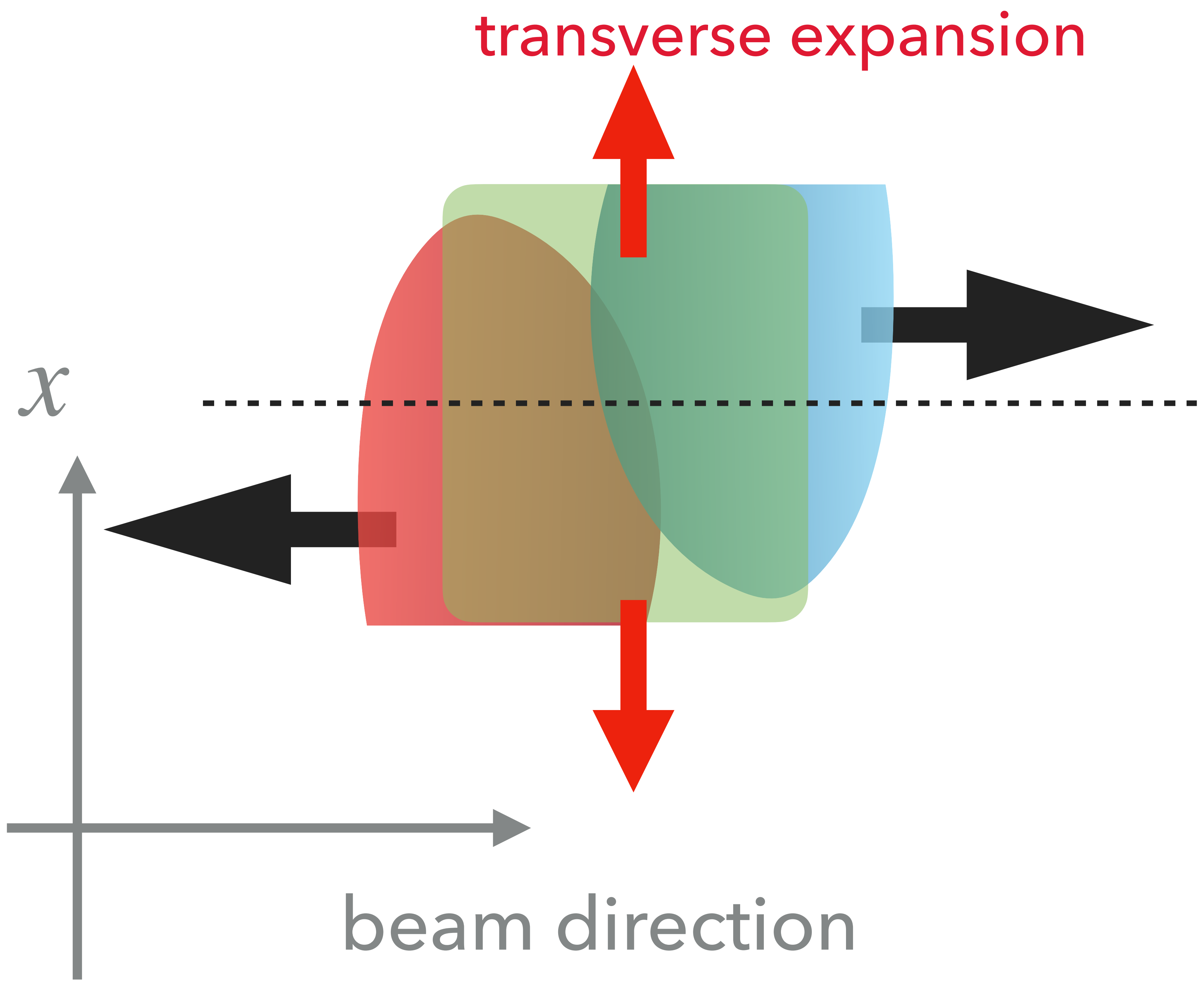
$dN^{p-\bar{p}}/dy$ AND $v_1(y)$ OF PROTONS





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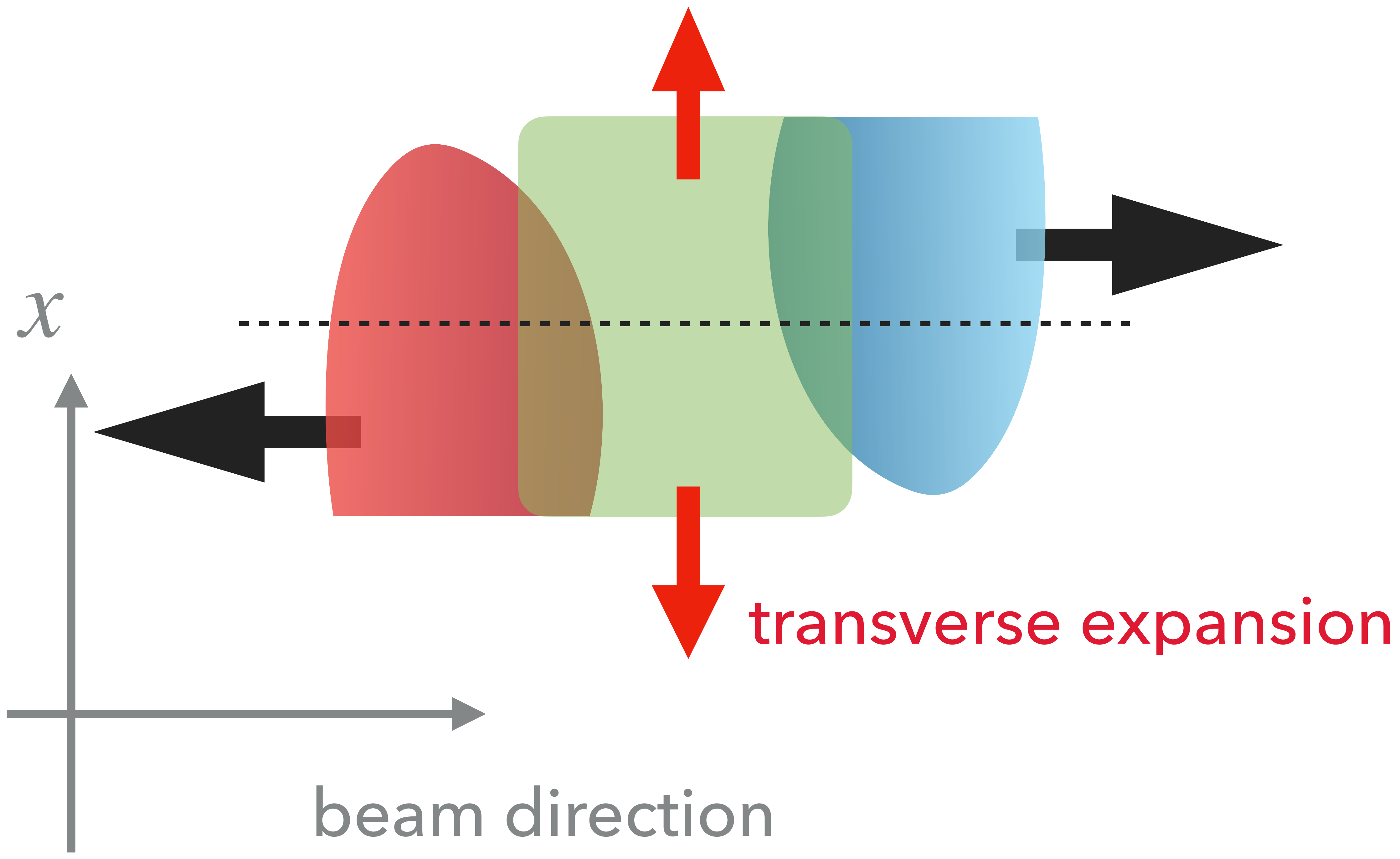
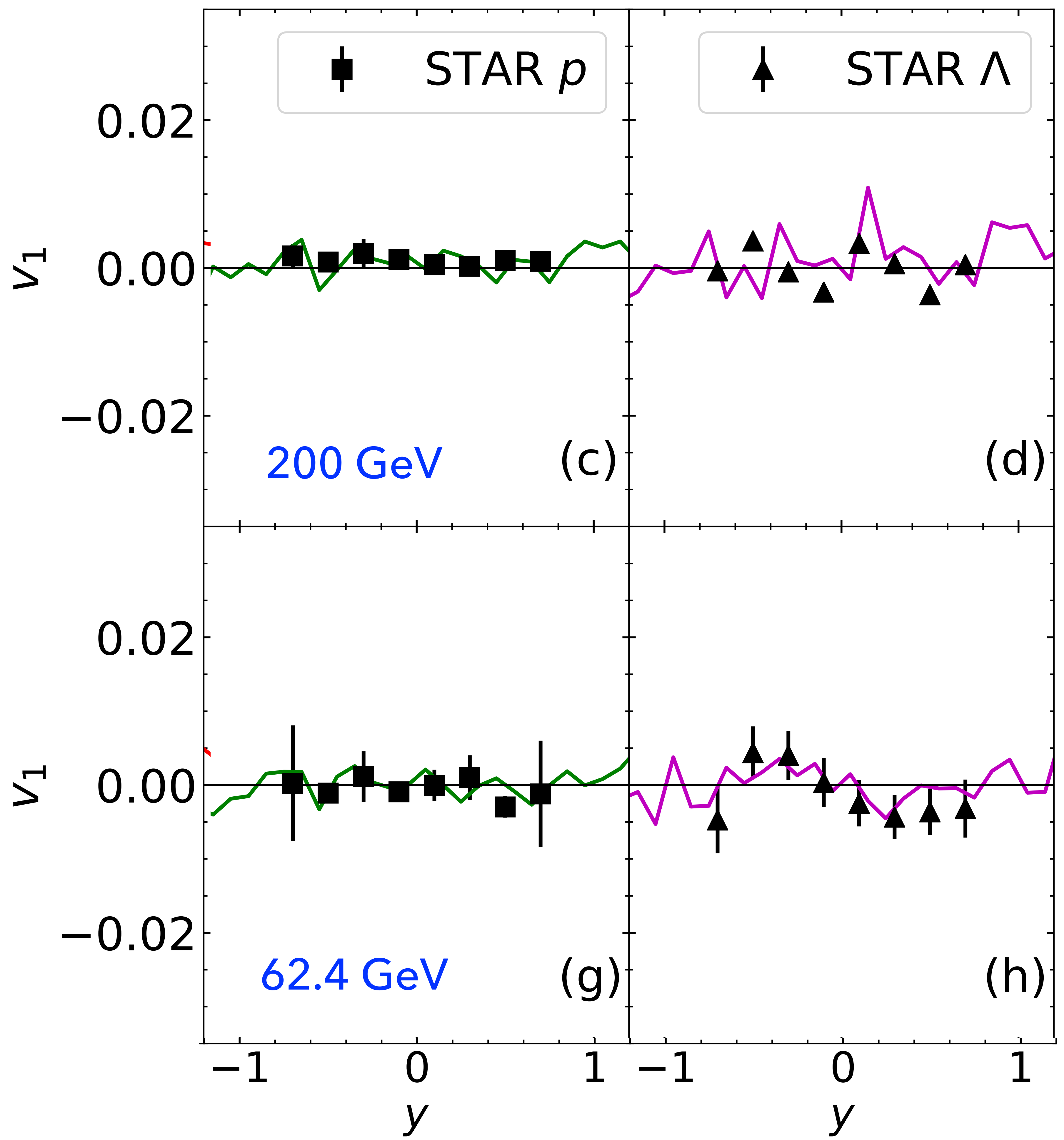
- It helps to reduce baryons' $v_1(y)$ while giving enough net proton yields around midrapidity.

DIRECTED FLOW OF BARYONS AT 200 AND 62.4 GEV

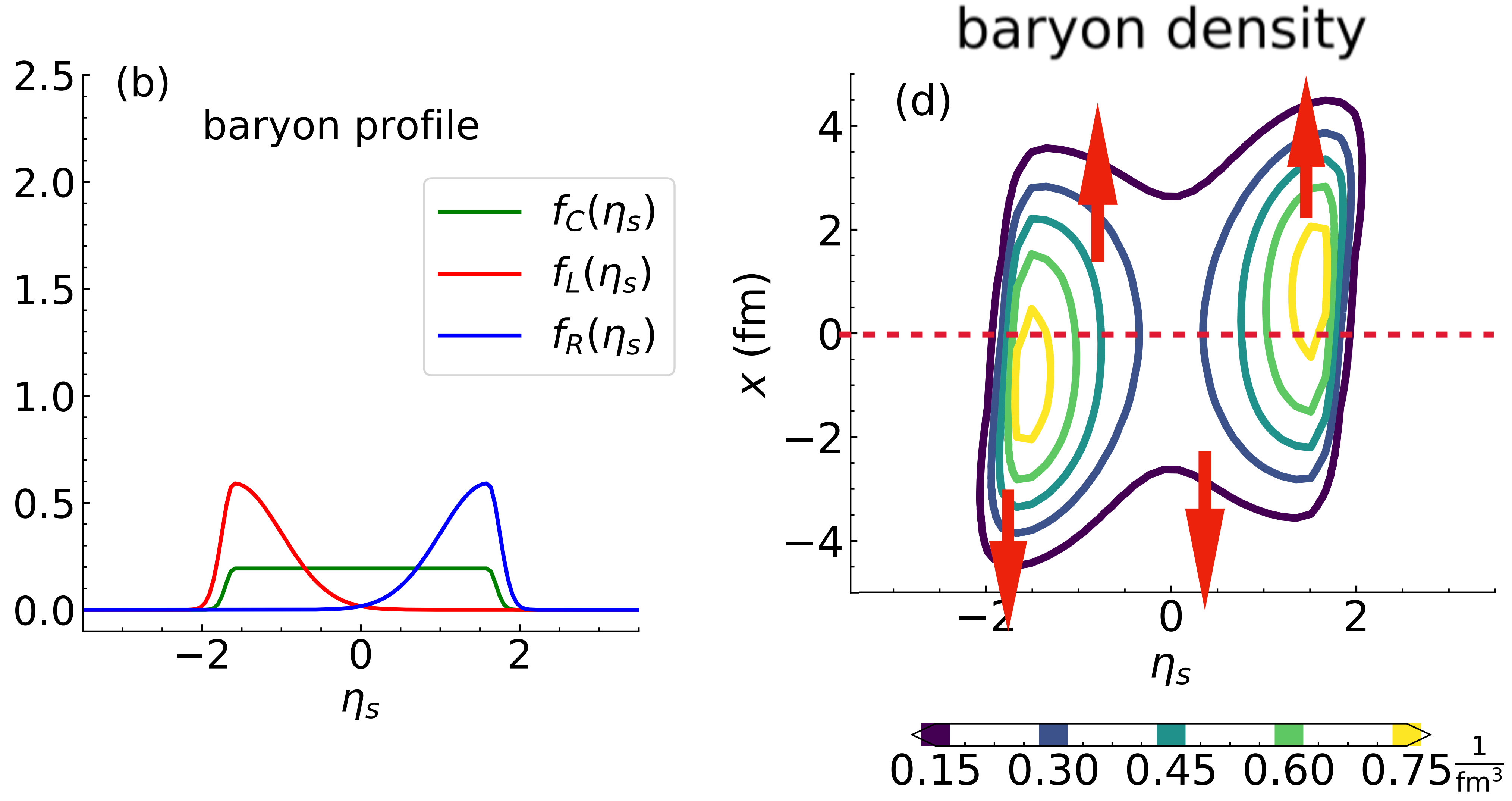




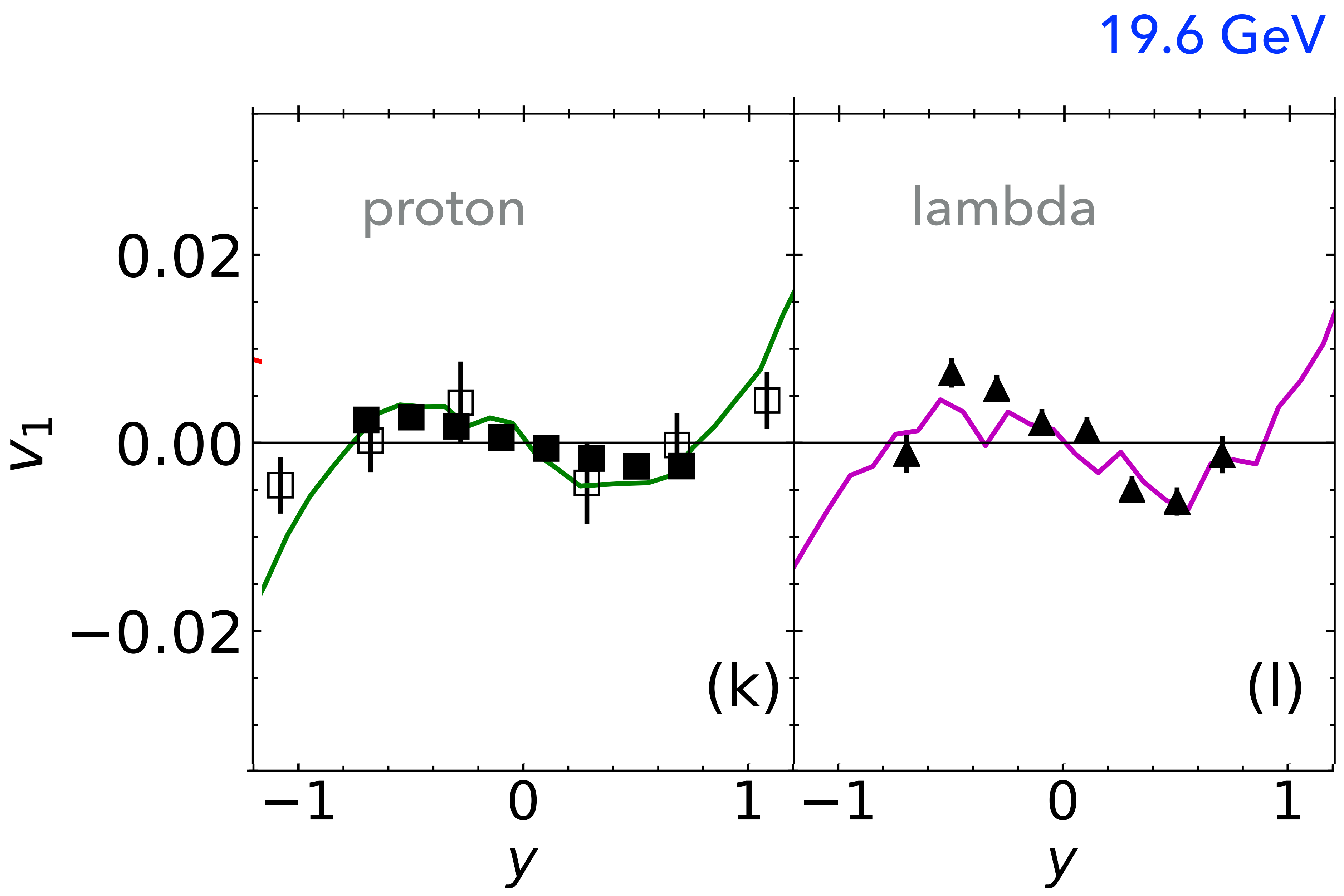
- At high beam energies with large beam rapidities, the plateau dominates and strongly reduces baryons' $v_1(y)$.

Data: STAR, PRL 112, 162301 (2014); PRL 120, 062301 (2018) LD, C. Shen, S. Jeon & C. Gale, arXiv:2211.16408

DIRECTED FLOW OF BARYONS AT 19.6 GEV

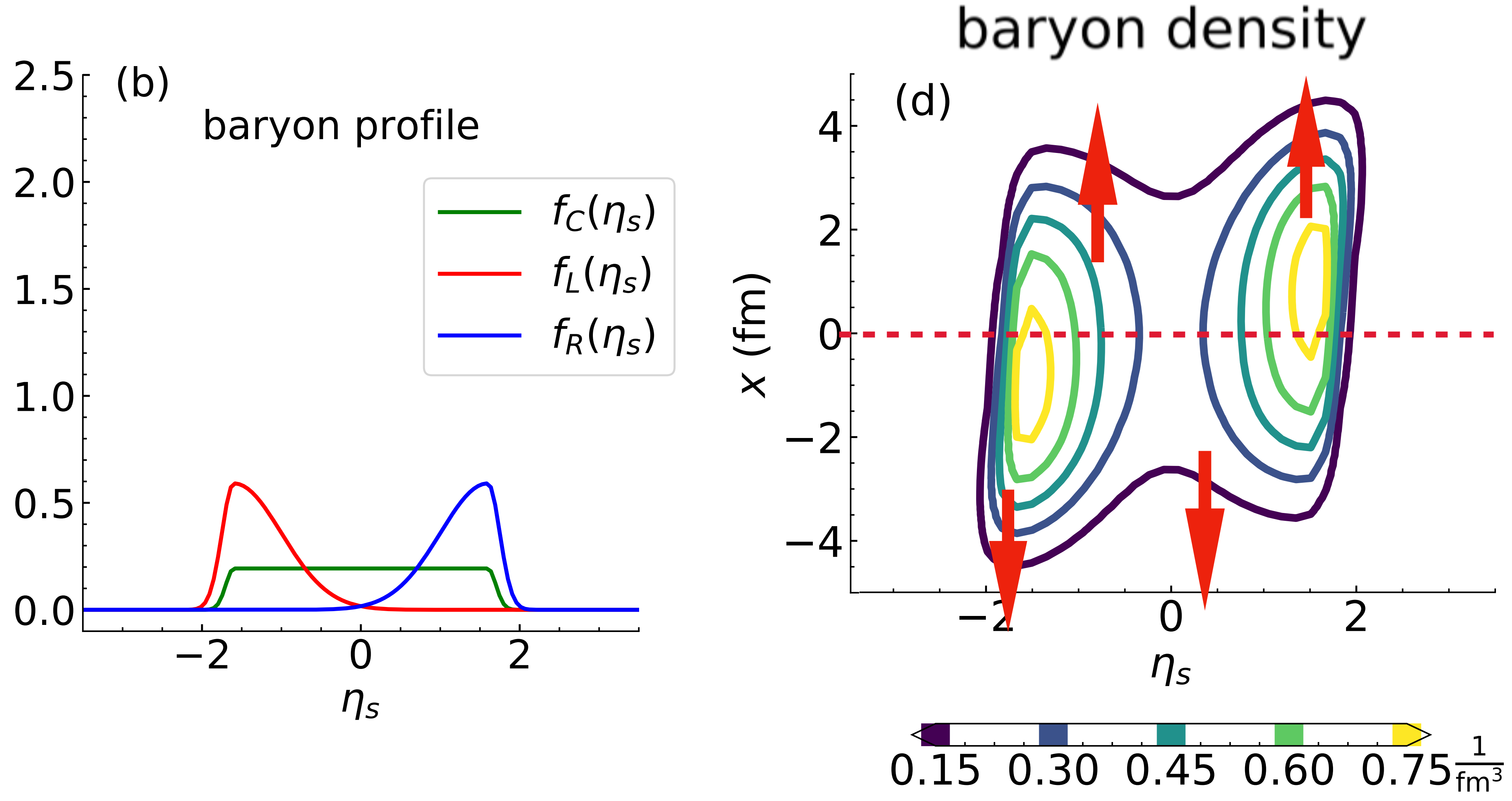


Initial distributions in reaction plane for 10-40% Au+Au@19.6 GeV



- 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
- The sign change of $dv_1(y)/dy\,|_{y=0}$ is naturally reproduced without a 1st-order phase transition.

DIRECTED FLOW OF BARYONS AT 19.6 GEV



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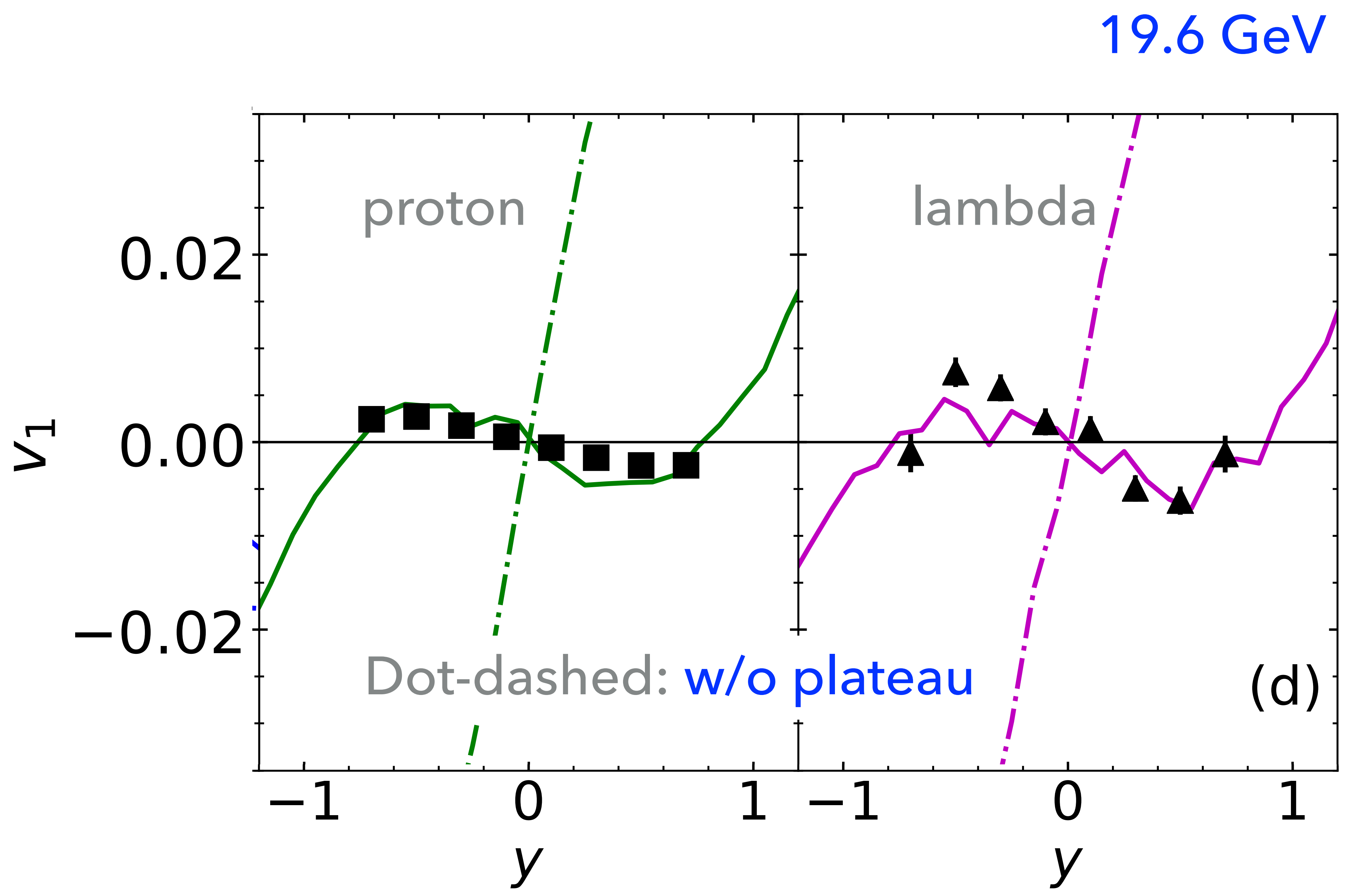

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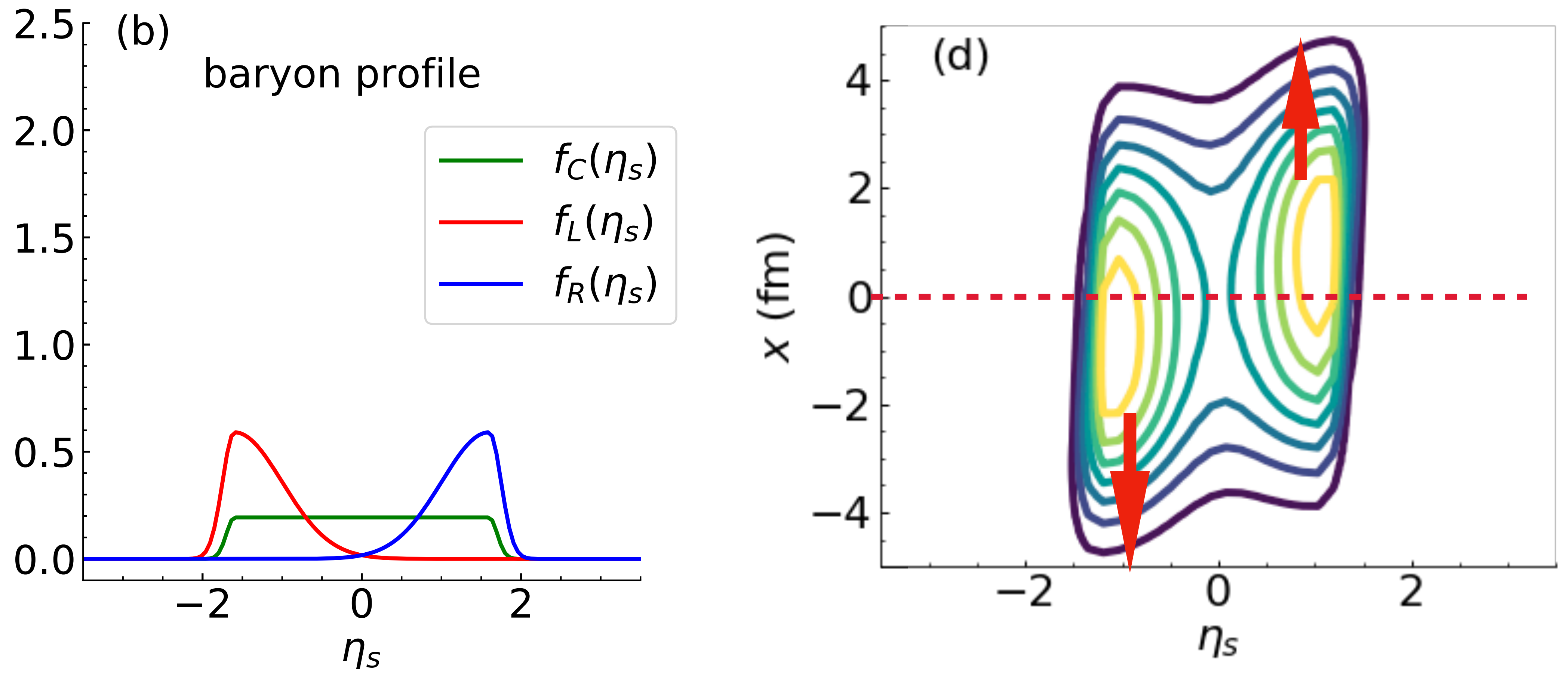
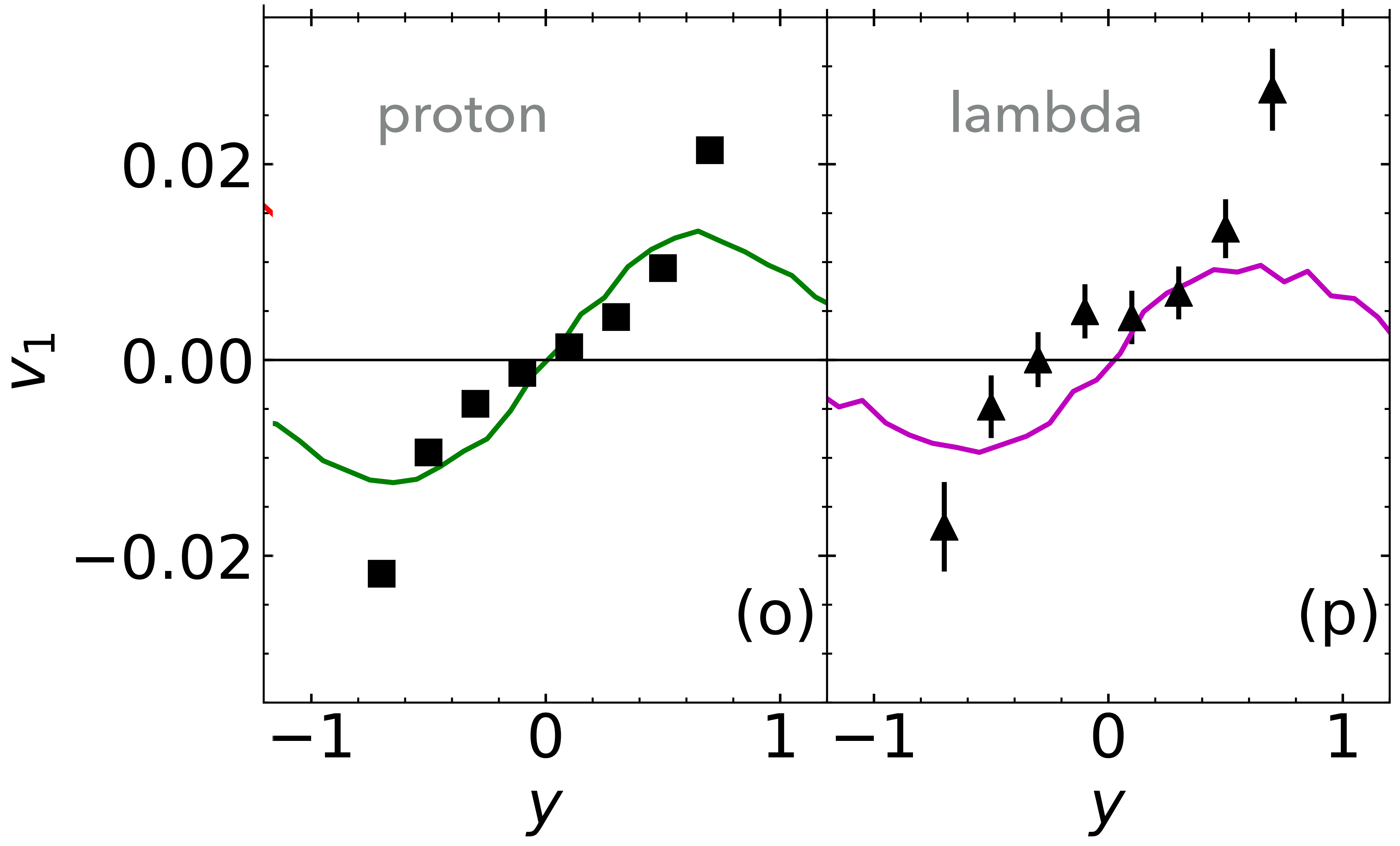
DIRECTED FLOW OF BARYONS AT 7.7 GEV



Initial distributions in reaction plane for 10-40% Au+Au@19.6 GeV

7.7 GeV



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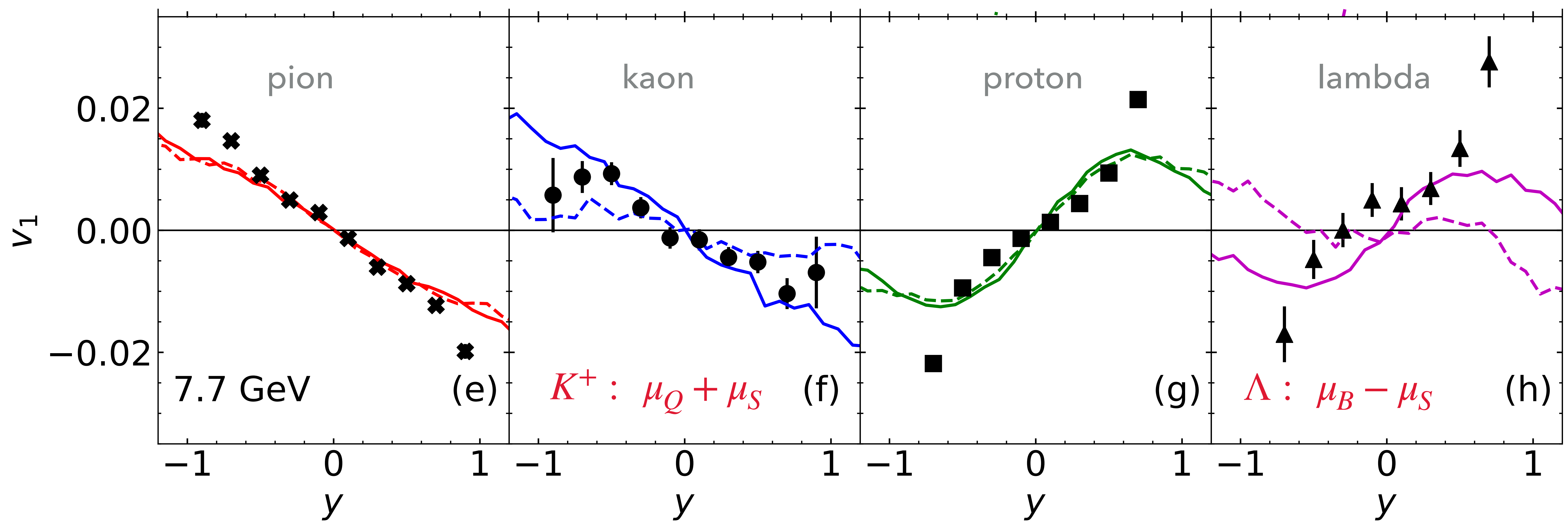
- The sign change of $dv_1(y)/dy\,|_{y=0}$ is naturally reproduced without a 1st-order phase transition.

PROBING EOS AT FINITE CHEMICAL POTENTIALS



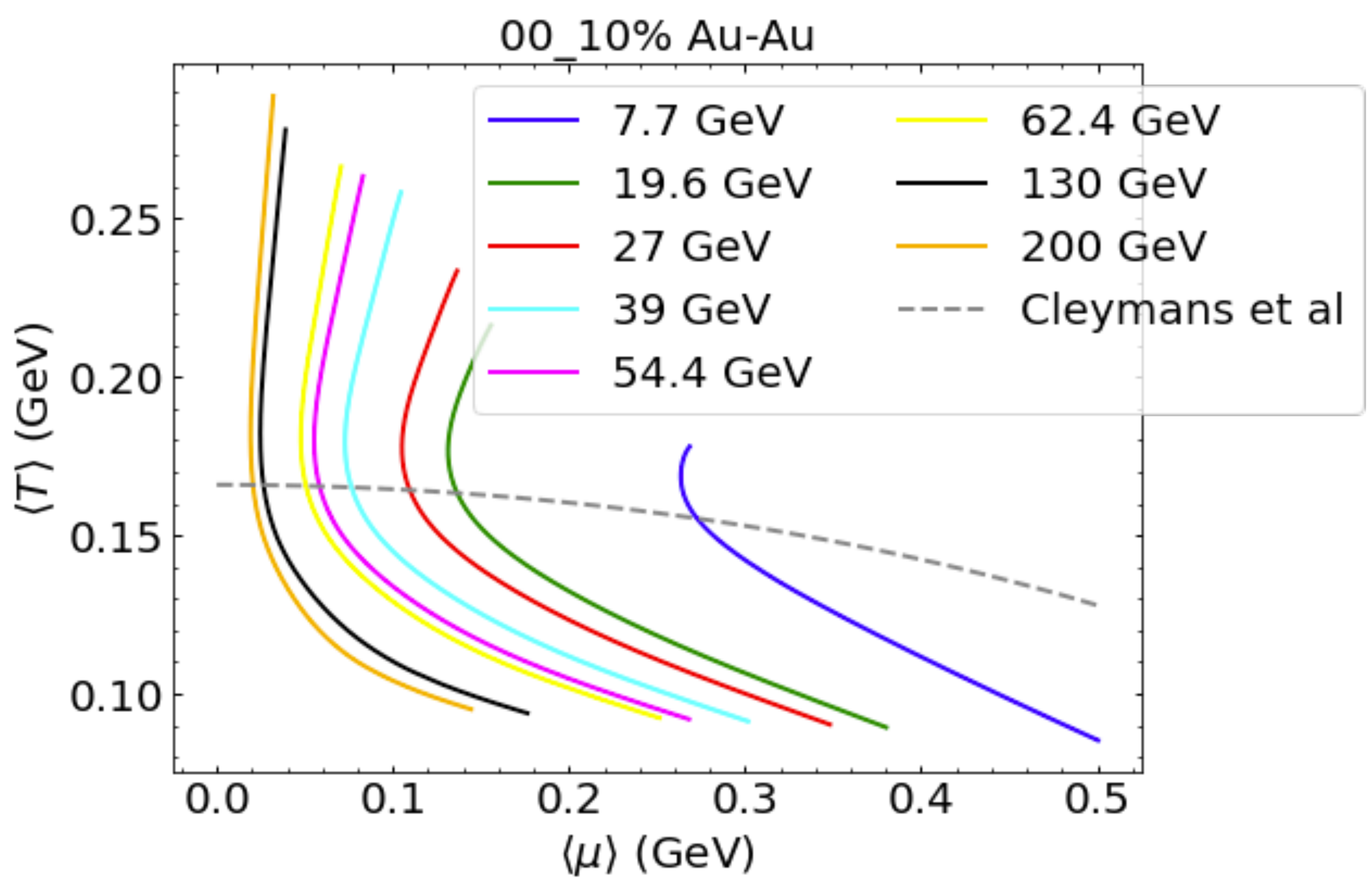
Solid: NEOS-B

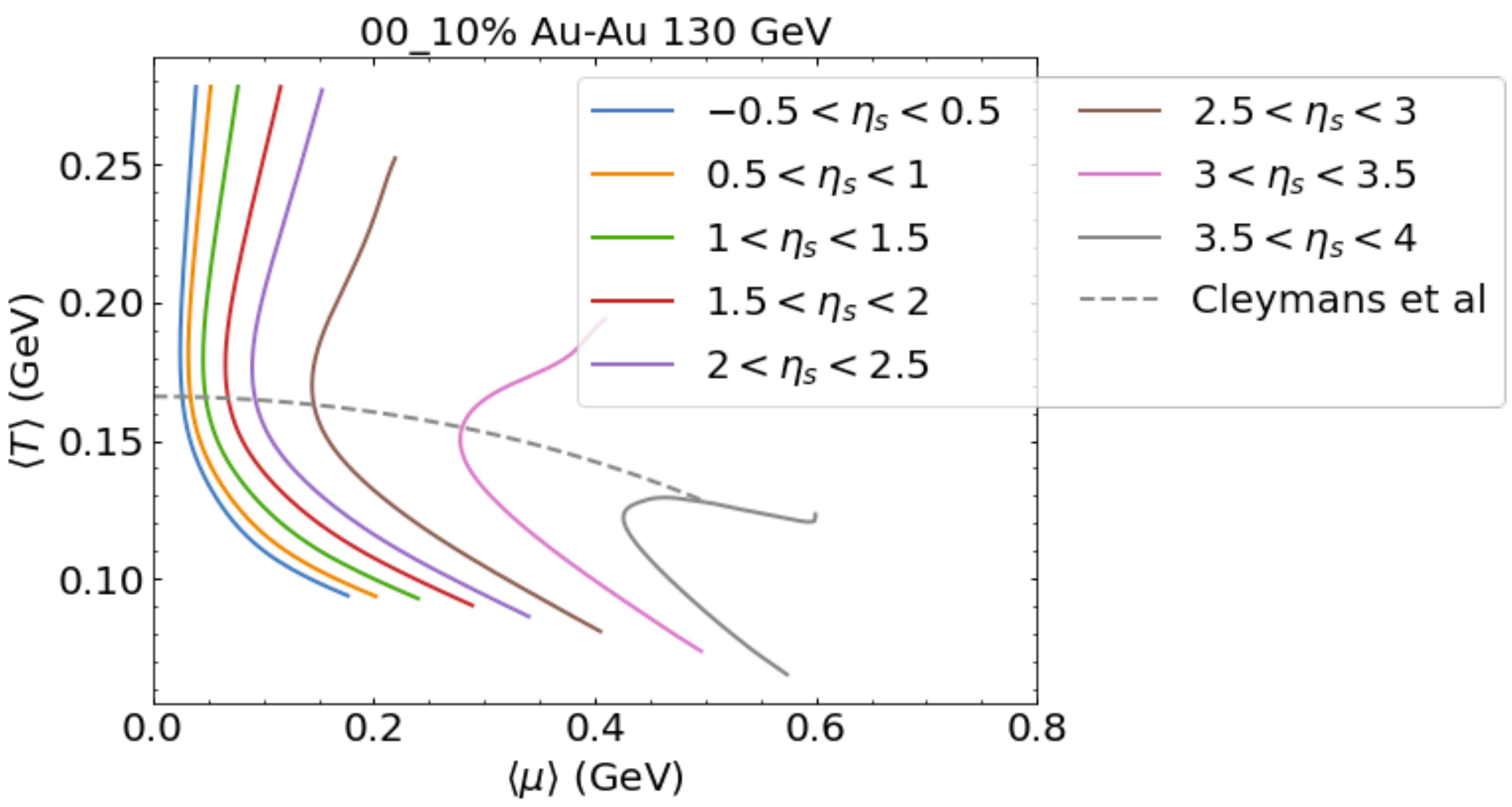
Dashed: NEOS-BQS

NEOS: Monnai et al, PRC 100, 024907 (2019)

- Two limits of EoS: NEOS-B, $\mu_S = \mu_Q = 0$ and NEOS-BQS, $n_S = 0, n_Q = 0.4 n_B$ (2D projection of a 4D EOS)
- Local strangeness neutrality suppresses the $v_1(y)$ of K^+ and Λ around midrapidity, and even alters the sign of Λ's $v_1(y)$ beyond $|y| \gtrsim 0.6$
- The $v_1(y)$ of identified particles can be used to probe EoS at finite chemical potentials.

BEAM ENERGY SCAN VS. RAPIDITY SCAN





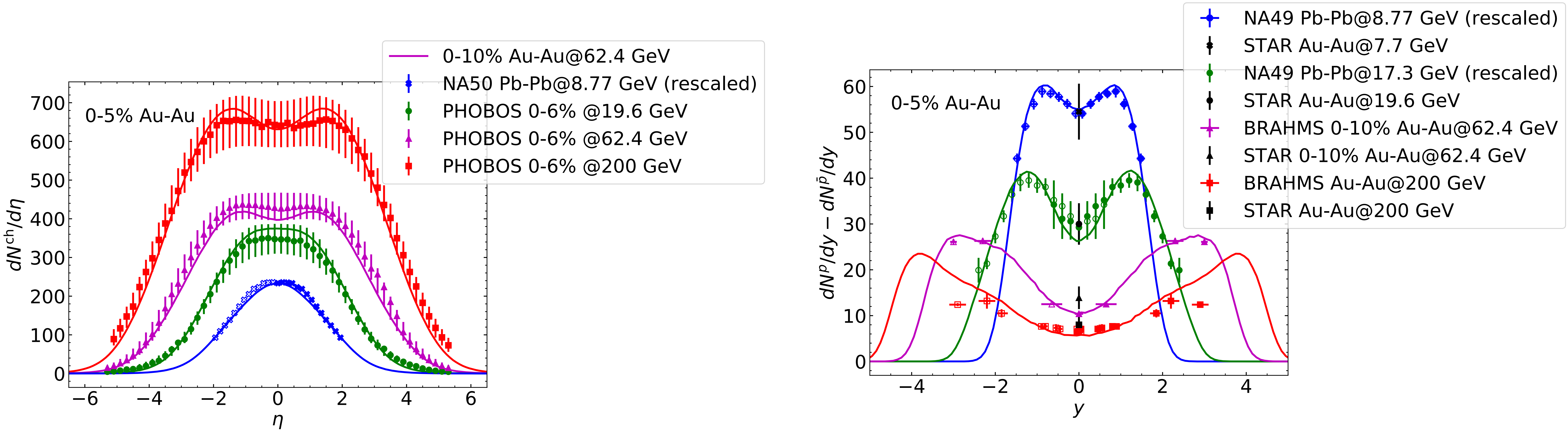
- Left: expansion trajectories at midrapidity in heavy-ion collisions with different beam energies;
- Right: expansion trajectories for different rapidities of the fireball in a collision with a fixed beam energy ($\sqrt{s_{\rm NN}} = 130$ GeV)

SUMMARY

- The $v_1(y)$ of identified particles, together with $dN^{p-\bar{p}}/dy$, have strong constraining power on the initial baryon stopping.
- A central plateau component in the initial baryon distribution is essential for explaining characteristic features of $v_1(y)$ at various beam energies.
- The sign change of $dv_1(y)/dy\,|_{y=0}$ is naturally reproduced without a 1st-order phase transition.
- The $v_1(y)$ of identified particles can be used to probe EoS at finite chemical potentials.

THANK YOU VERY MUCH!

CONSTRAINING LONGITUDINAL PROFILES

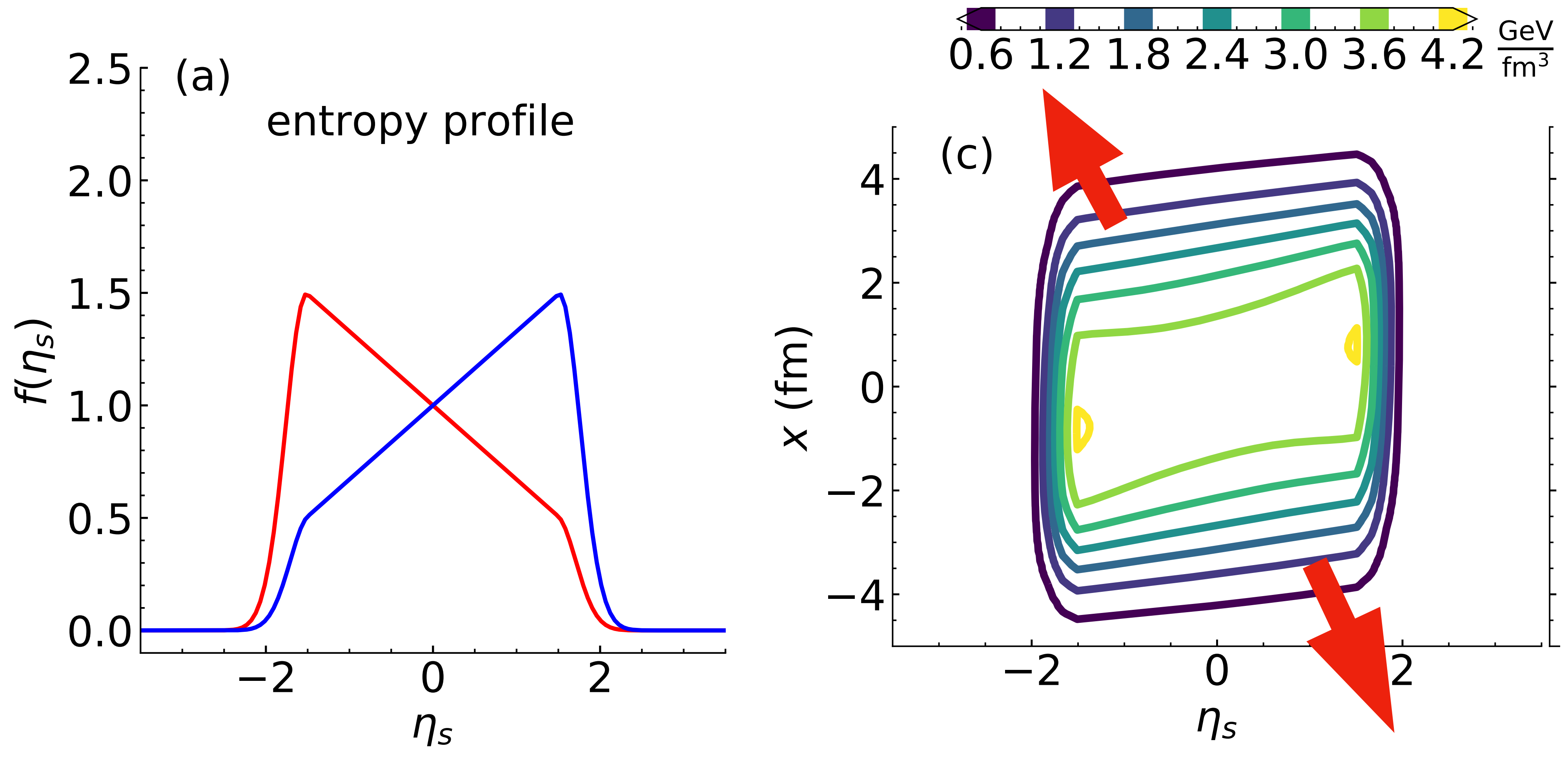


Data: STAR, BRAHMS, PHOBOS, NA49, NA50

- (Pseudo-)rapidity densities of charged particles and net protons in central collisions to constrain longitudinal profiles.
- The plateau component contributes flat net proton yields in rapidity.

L. Du, C. Shen, S. Jeon & C. Gale, arXiv:2211.16408

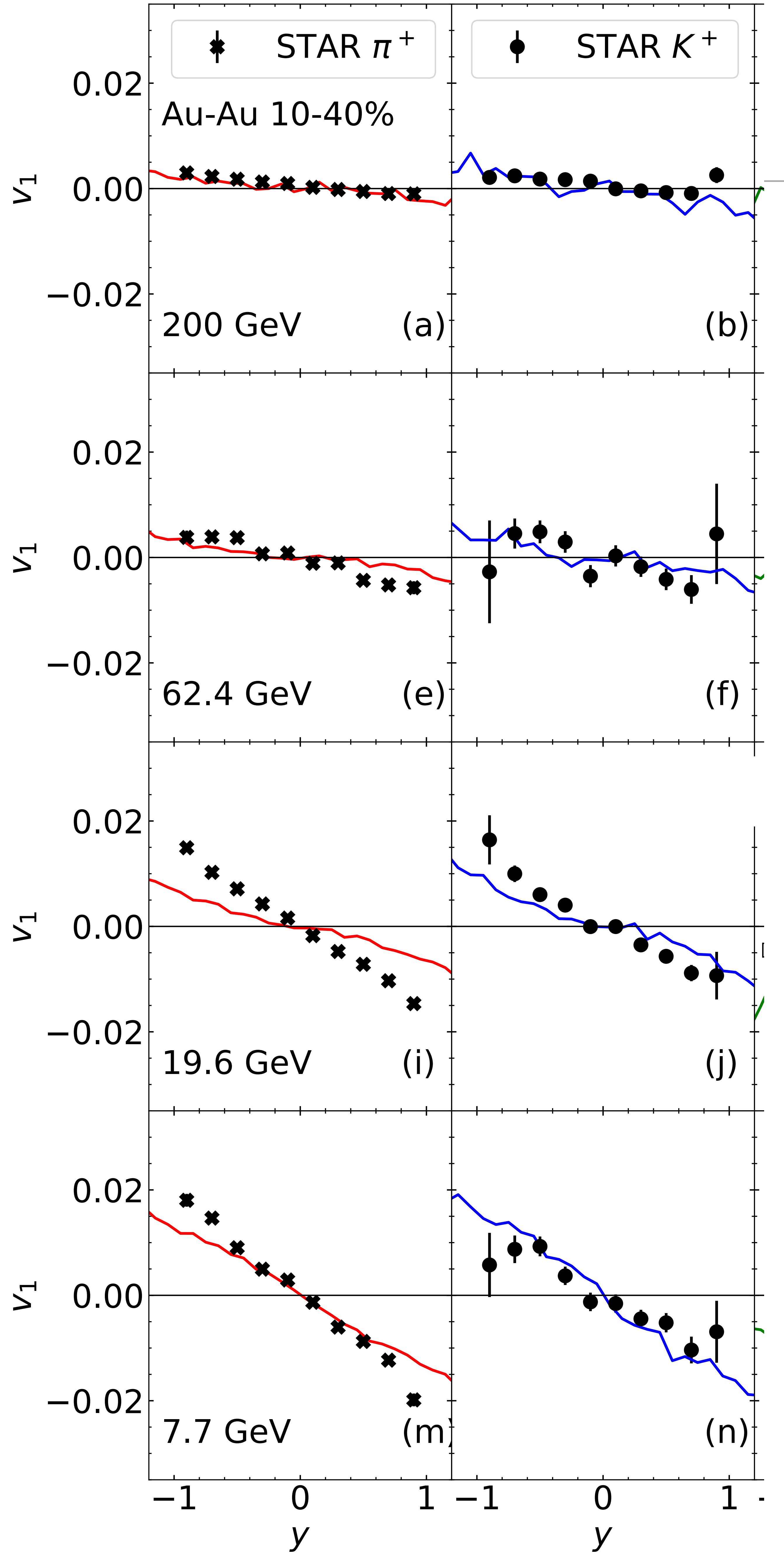
DIRECTED FLOW OF MESONS



Initial distributions in reaction plane for 10-40% Au+Au@19.6 GeV

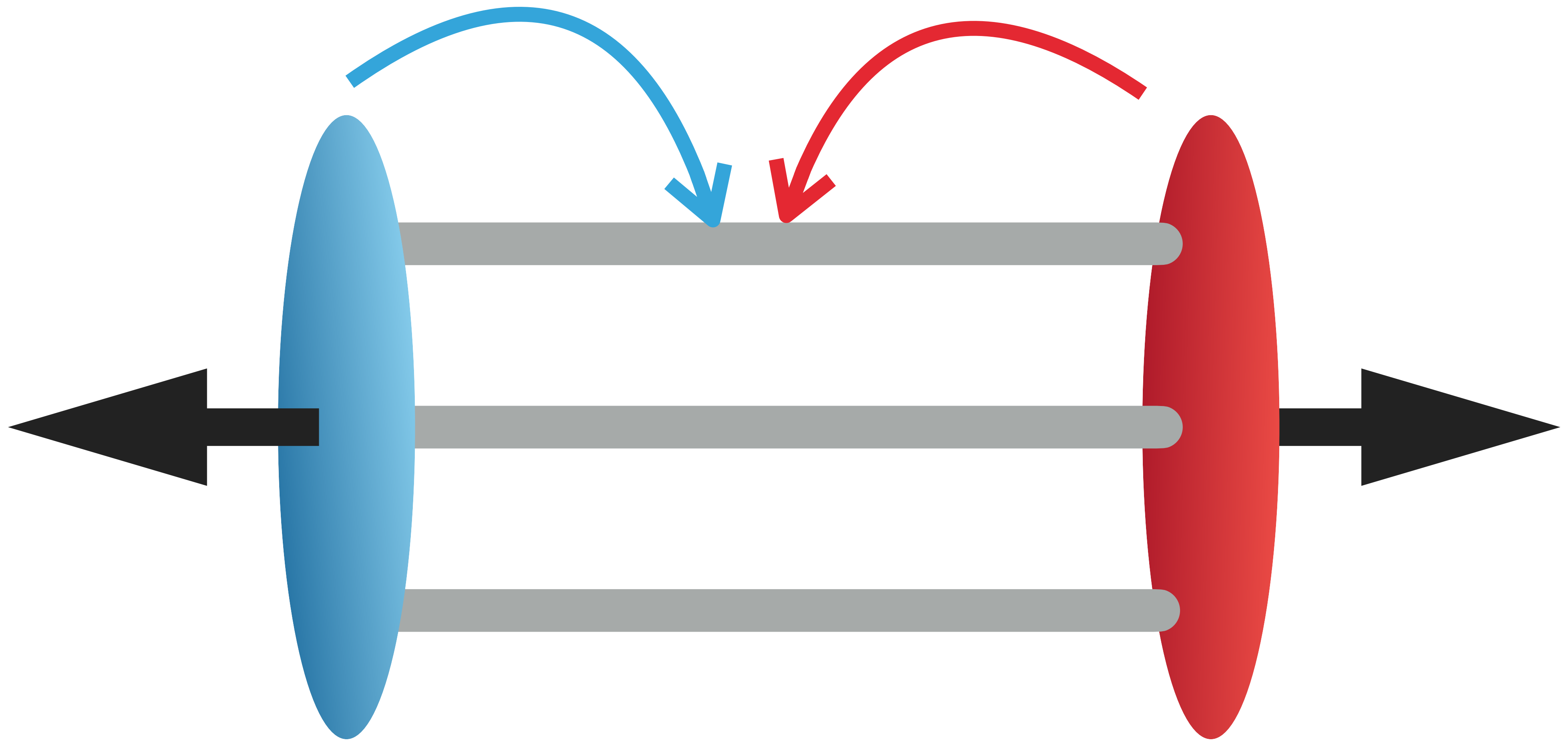
- $v_1(y)$ of mesons with negative slope at all beam energies; slope increases when beam energy decreases
- Slight shift of energy density along x (tilted structure) generates sideward pressure gradient

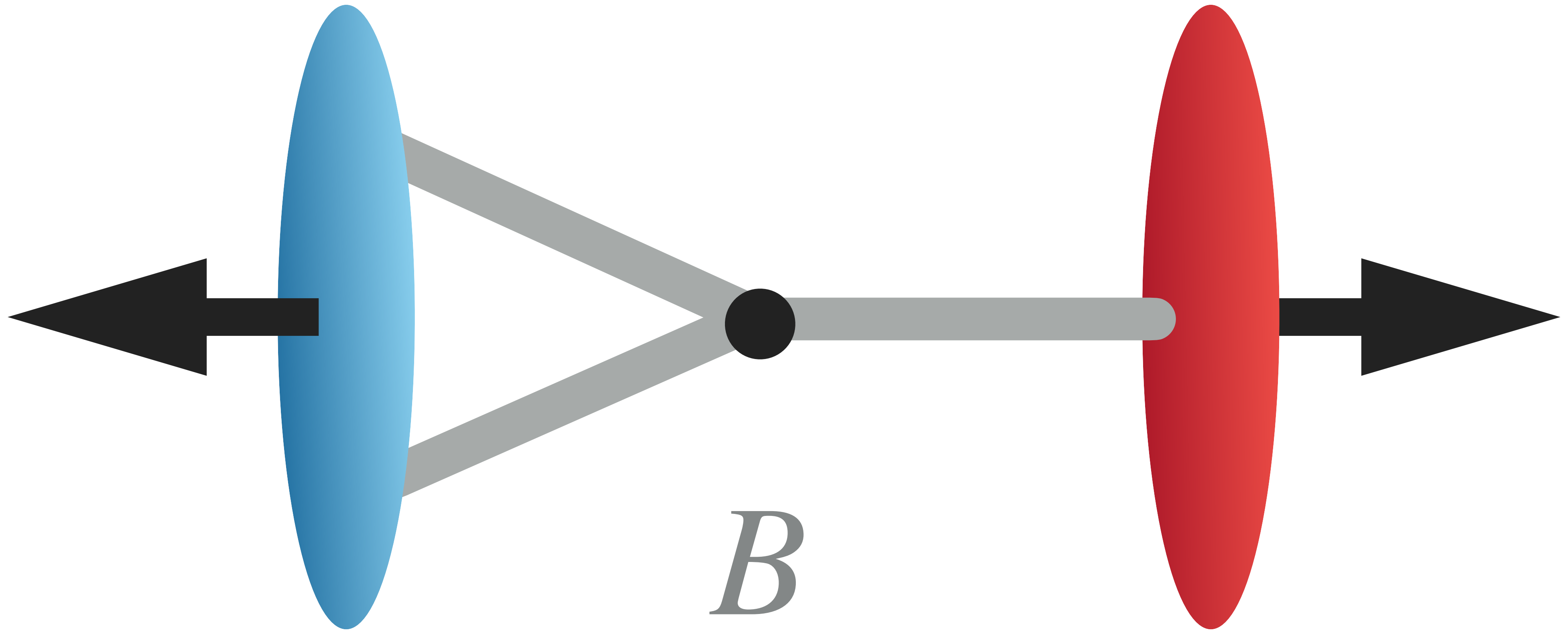
see also: Bożek & Wyskiel Phys. Rev. C 81, 054902 (2010)



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

INITIAL BARYON "STOPPING"





Baryons get distributed in rapidity by deceleration of the incoming nucleons

Baryons get distributed in rapidity through string junction breaking

- Profound impact on understanding initial baryon distribution and energy loss
- How to differentiate "baryon deceleration" and "string junction breaking" in the initial baryon distribution?

String junction: Kharzeev, PLB 378, 238 (1996); Lund string model

J. D. Brandenburg, N. Lewis, P. Tribedy, and Z. Xu, arXiv:2205.05685