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Statistics of the pT spectrum from a nonextensive description of particle production

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Outline

01 Physical motivation

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03 Statistical description of the pT spectrum

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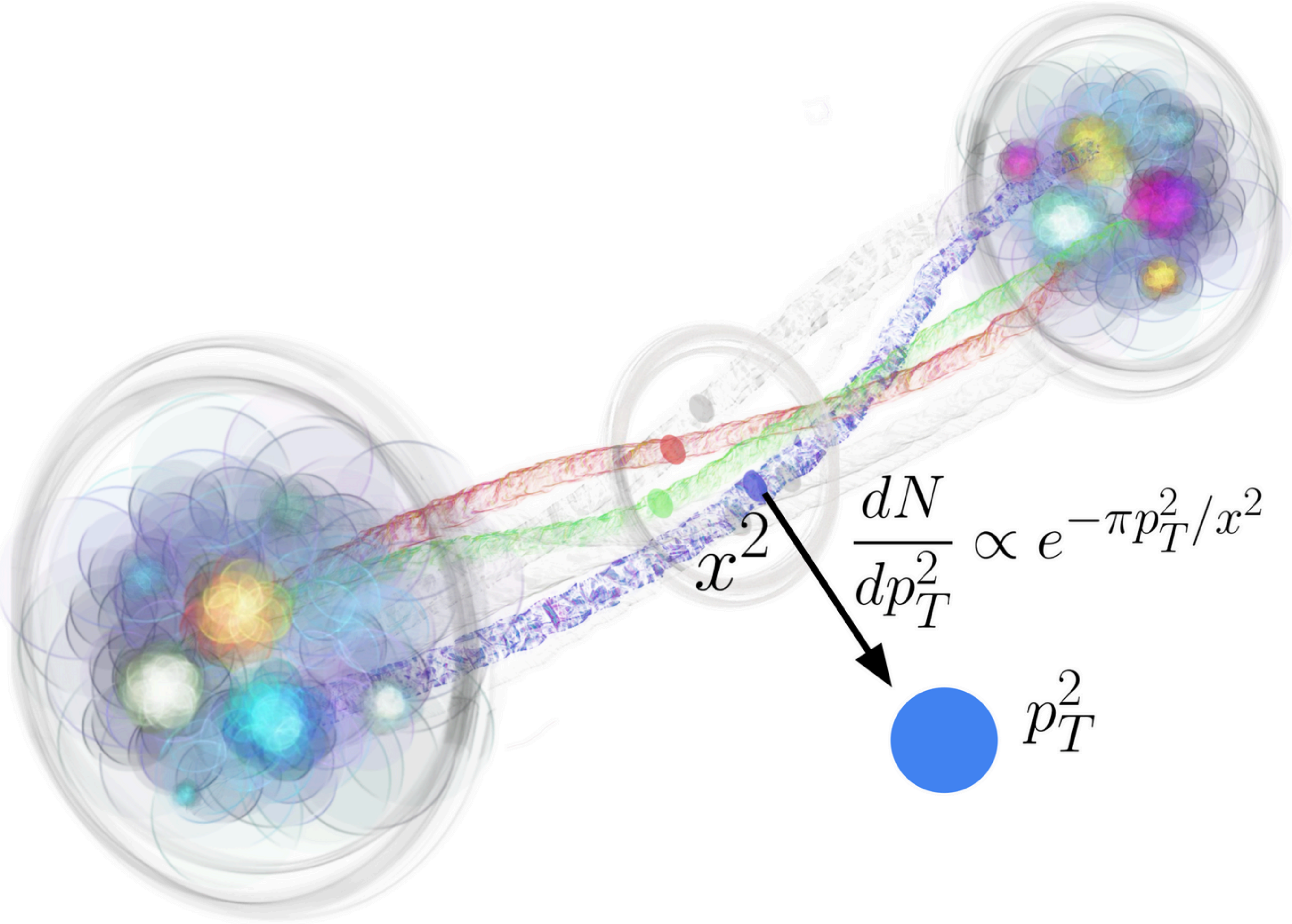
Schwinger mechanism



Gaussian string tension fluctuations

$$P(x) = \sqrt{\frac{2}{\pi \varsigma^2}} e^{-x^2/2\varsigma^2}$$

Thermal distribution

$$\frac{dN}{dp_T^2} \sim \exp\left(-\frac{p_T}{T}\right)$$

with $T = \frac{\varsigma}{\sqrt{2\pi}}$

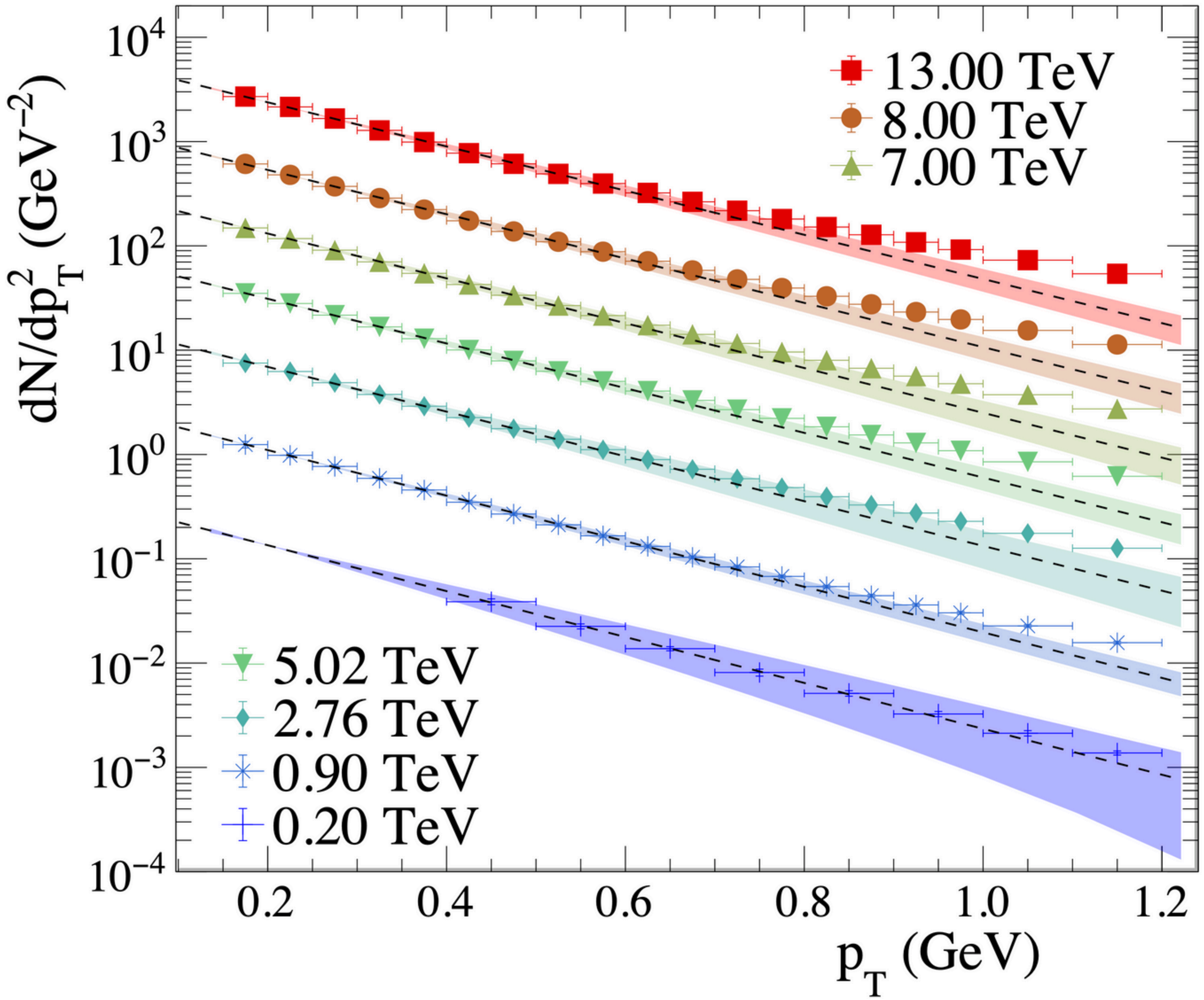
J. Schwinger, Phys. Rev. 128, 2425 (1962).
B. Andersson, The Lund Model (Cambridge University Press, Cambridge, 1998)

A. Bialas, Phys. Lett. B 466, 301 (1999).

Transverse momentum distribution description at low pT

The thermal distribution adequately describes the experimental data at low pT values.

However, the experimental results include information on processes occurring during the collision that lead to the creation of the high pT particles.



D. Rosales Herrera, et al, Phys. Rev. C 109, 034915 (2024).

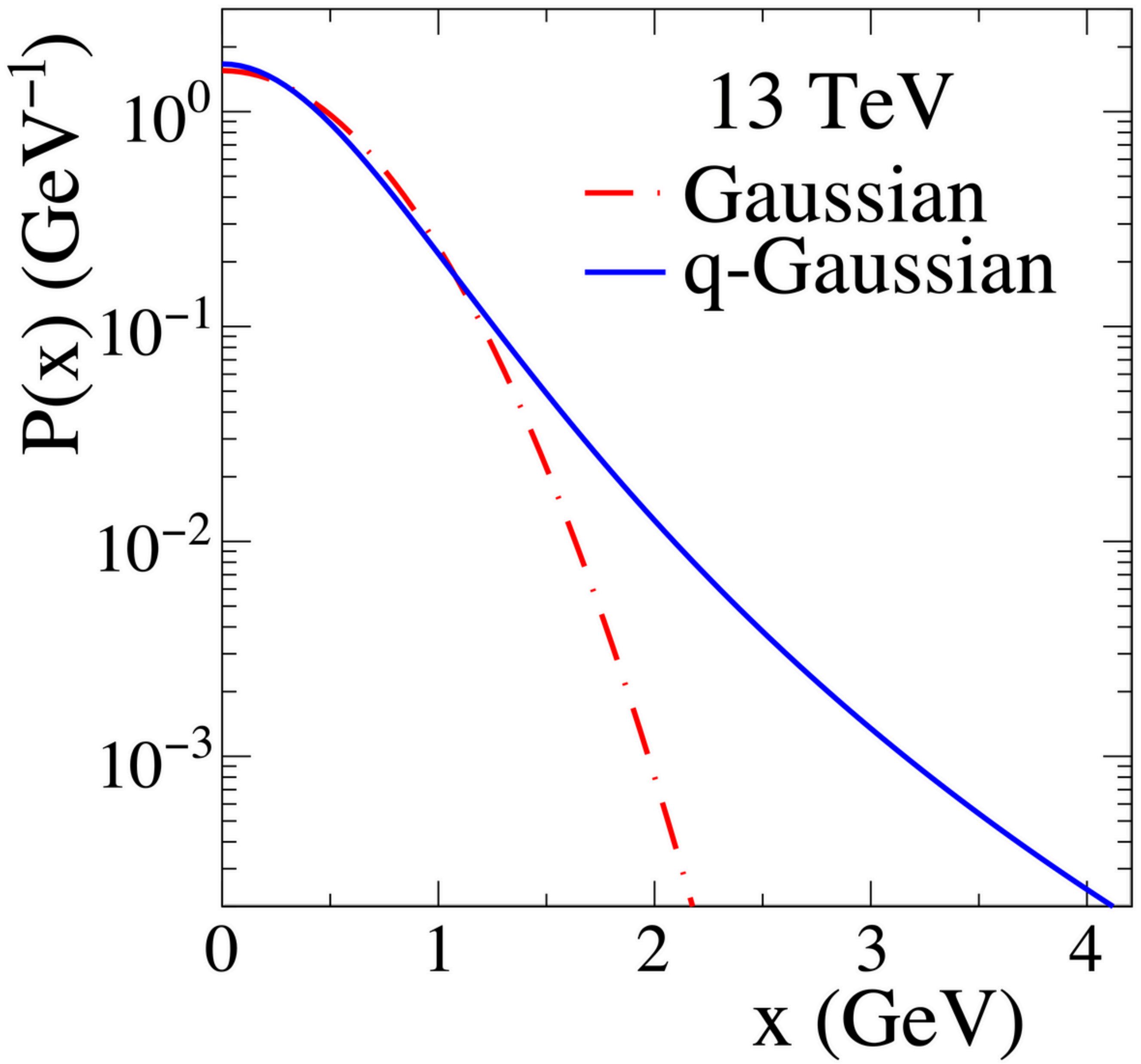
Nonextensive descrption of the particle creation

Taking Bialas' original idea of string tension fluctuations, we incorporate the possibility of observing rare events by

$$P(x) = \mathcal{N}_q \left(1 + \frac{(q-1)x^2}{2\sigma^2}\right)^{\frac{1}{1-q}}$$

Enhancing the probability of having string with higher tension

$$\frac{dN}{dp_T^2} \propto U\left(\frac{1}{q-1} - \frac{1}{2}, \frac{1}{2}, z_0 p_T^2\right)$$



C. Pajares and J. E. Ramírez, Eur. Phys. J. A 59, 250 (2023).

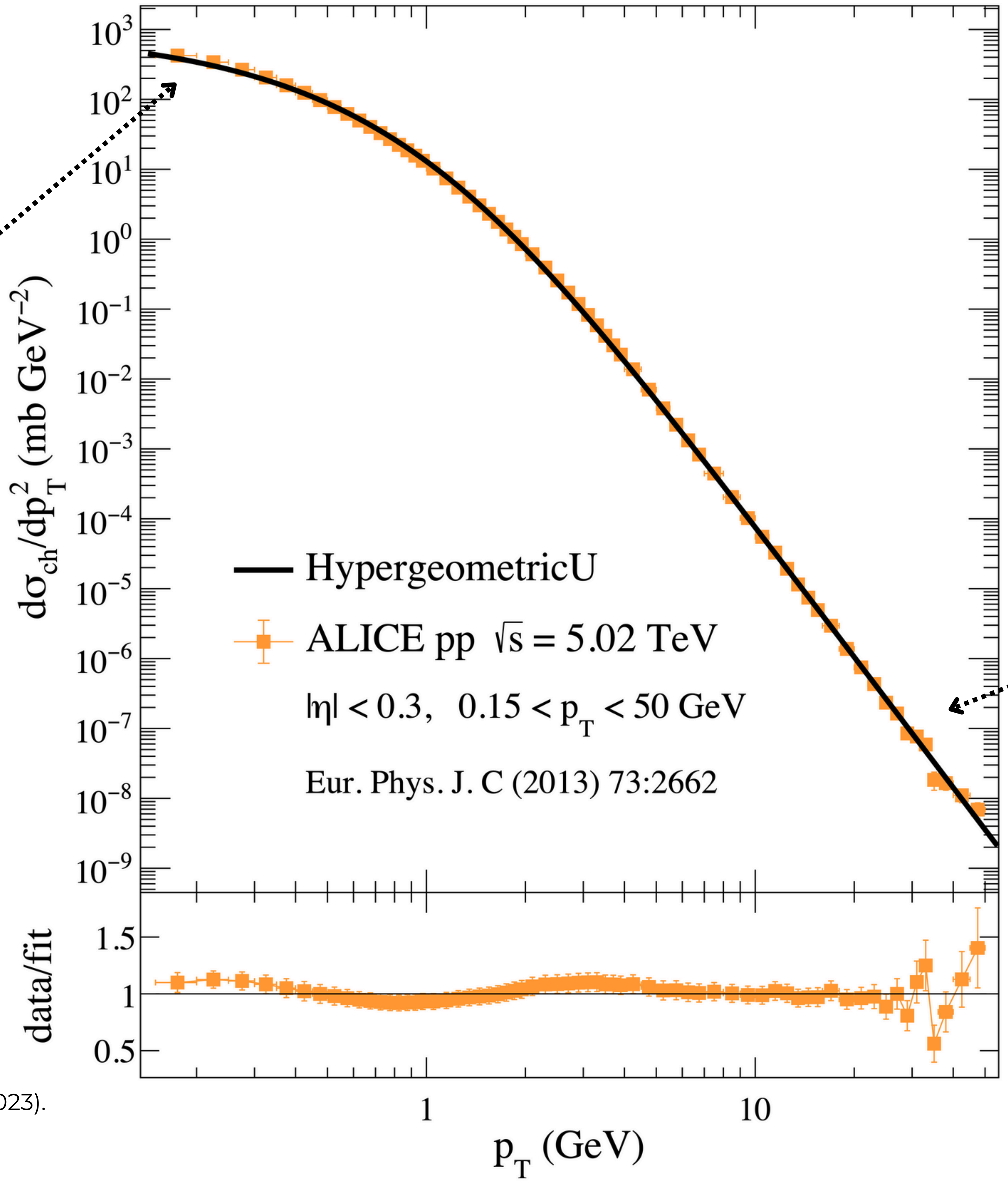
Asymptotic behaviors

pT-exponential decay at low pT

$$\frac{dN}{dp_T^2} \sim \exp\left(-\frac{p_T}{T_U}\right)$$

with temperature

$$T_U = \sigma \frac{\Gamma\left(\frac{1}{q-1} - \frac{1}{2}\right)}{\sqrt{2\pi(q-1)}\Gamma\left(\frac{1}{q-1}\right)}$$

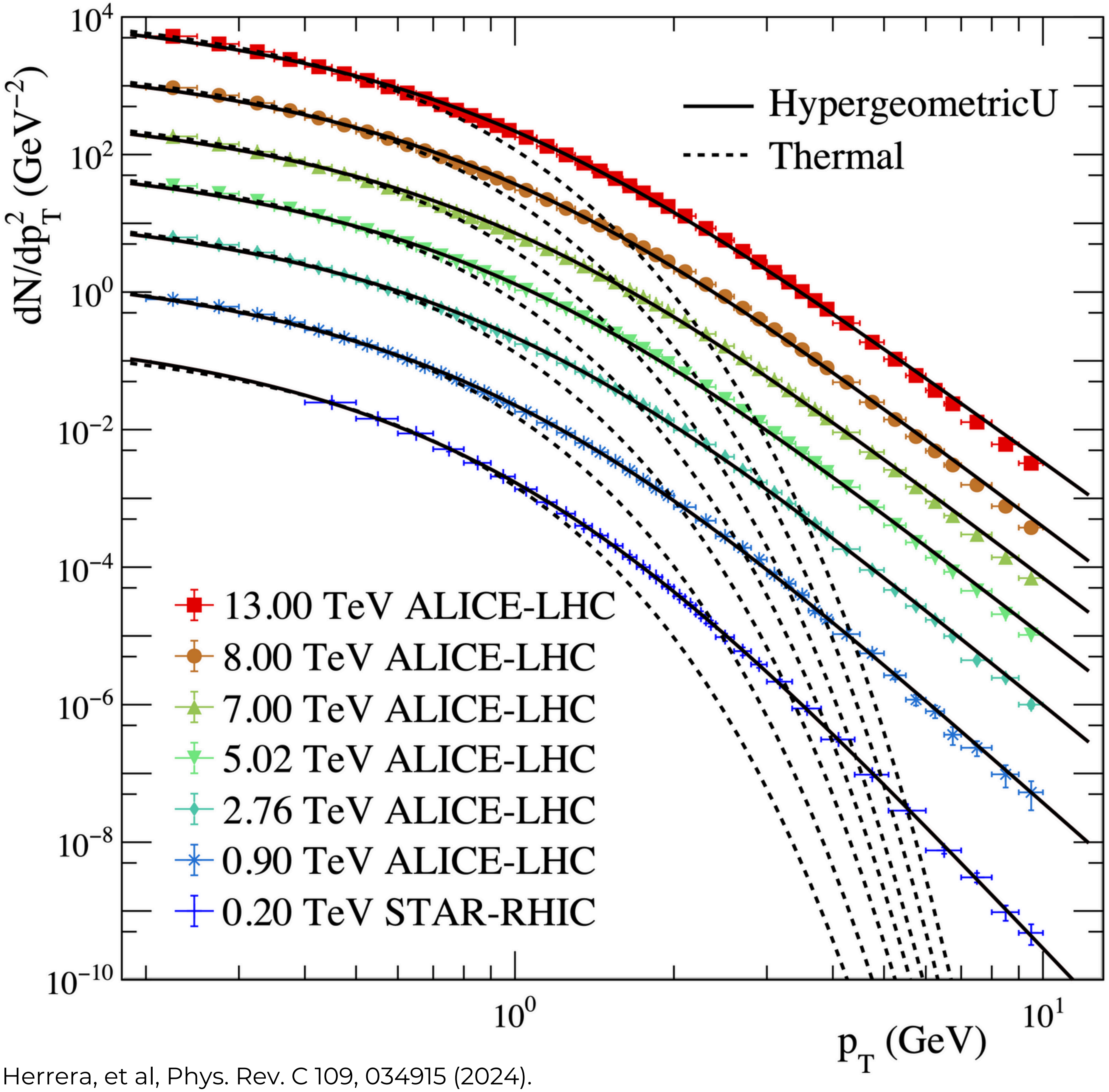


power law at high pT

$$\frac{dN}{dp_T^2} \sim (p_T^2)^{\frac{1}{2} - \frac{1}{q-1}}$$

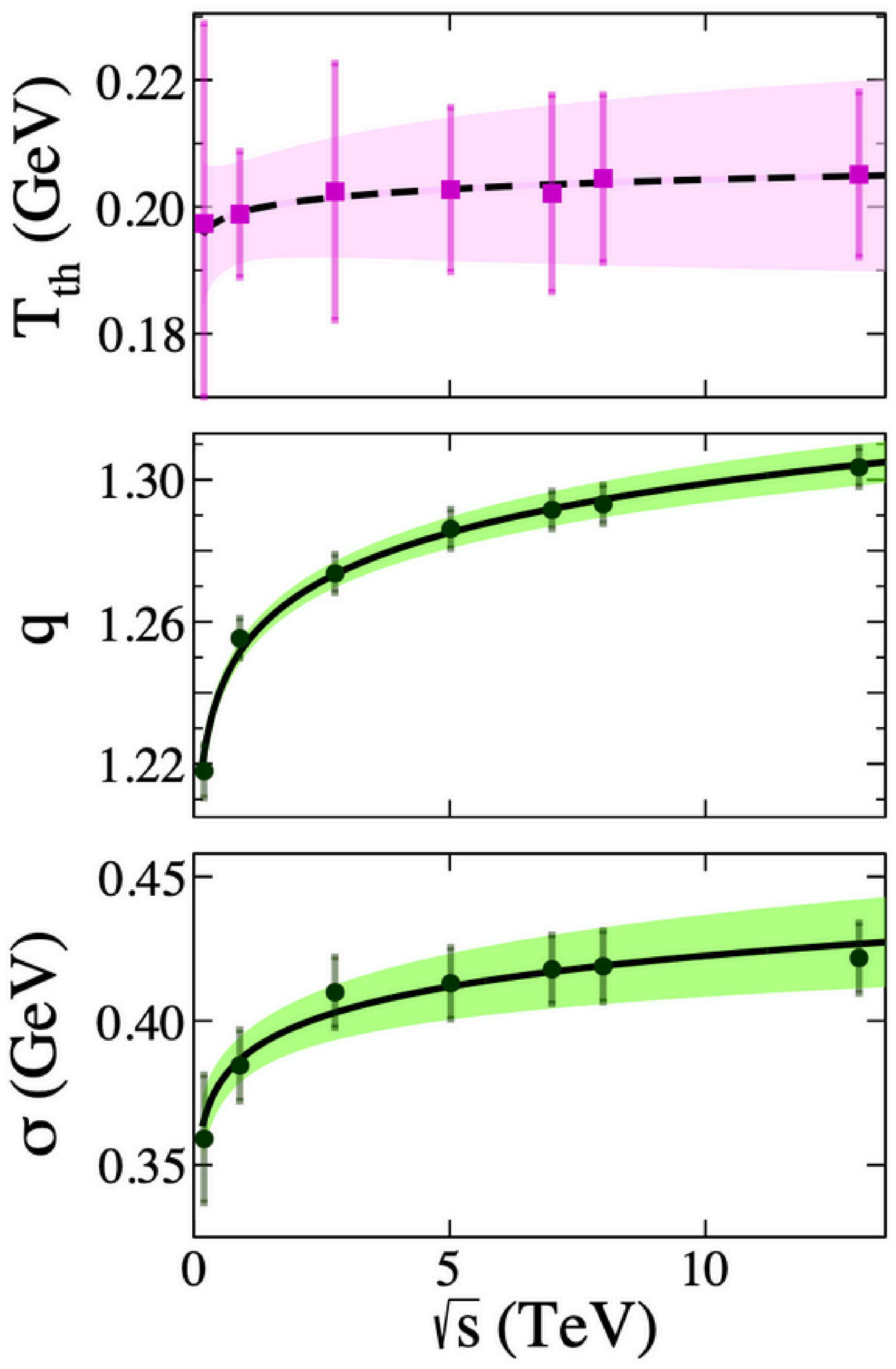
C. Pajares and J. E. Ramírez, Eur. Phys. J. A 59, 250 (2023).

Fits to the minimum bias data



Power law dependence of the fitting parameters

$$X(\sqrt{s}) = a_X \left(\sqrt{\frac{s}{s_0}}\right)^{c_X}$$

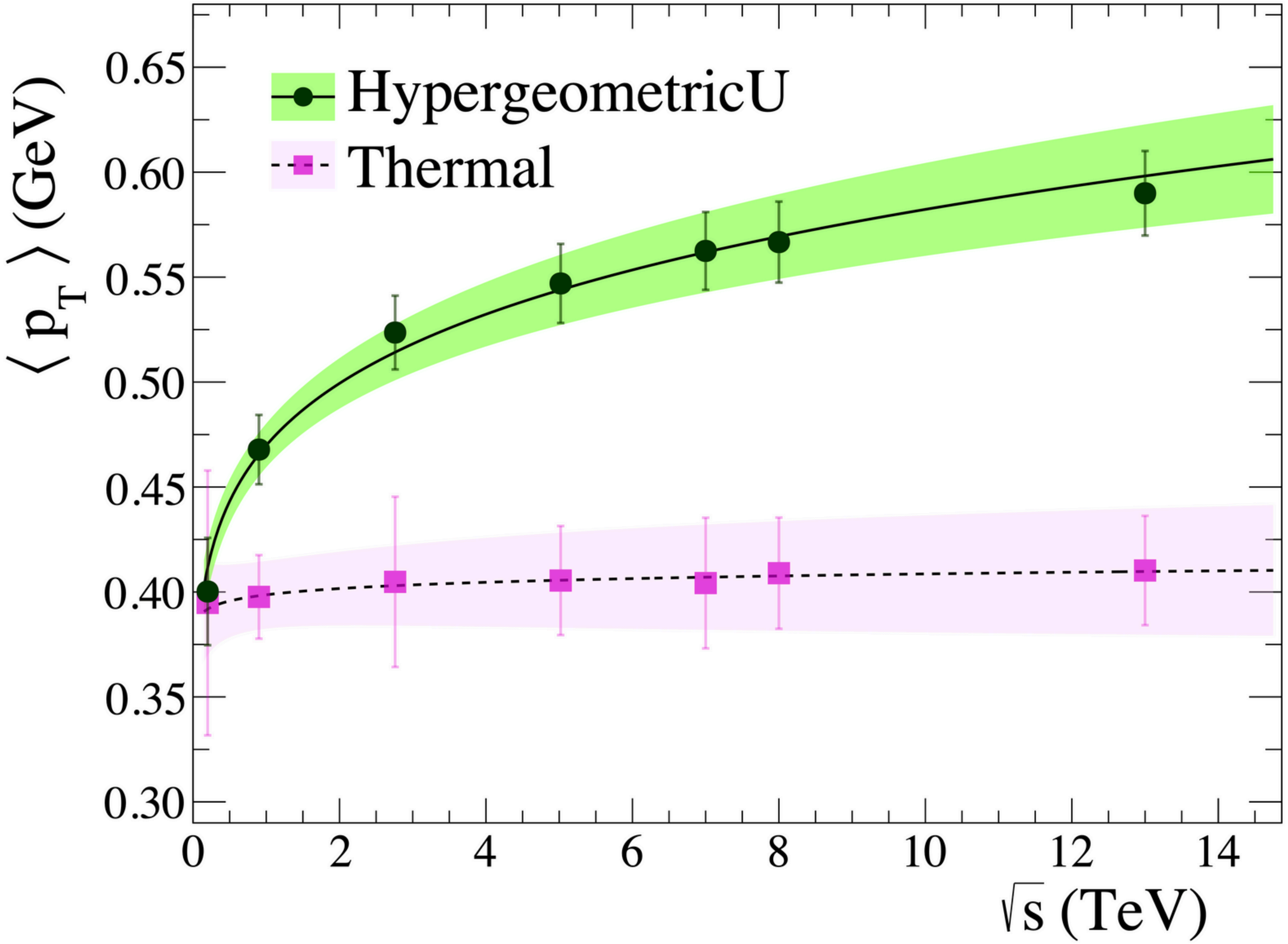


D. Rosales Herrera, et al, Phys. Rev. C 109, 034915 (2024).

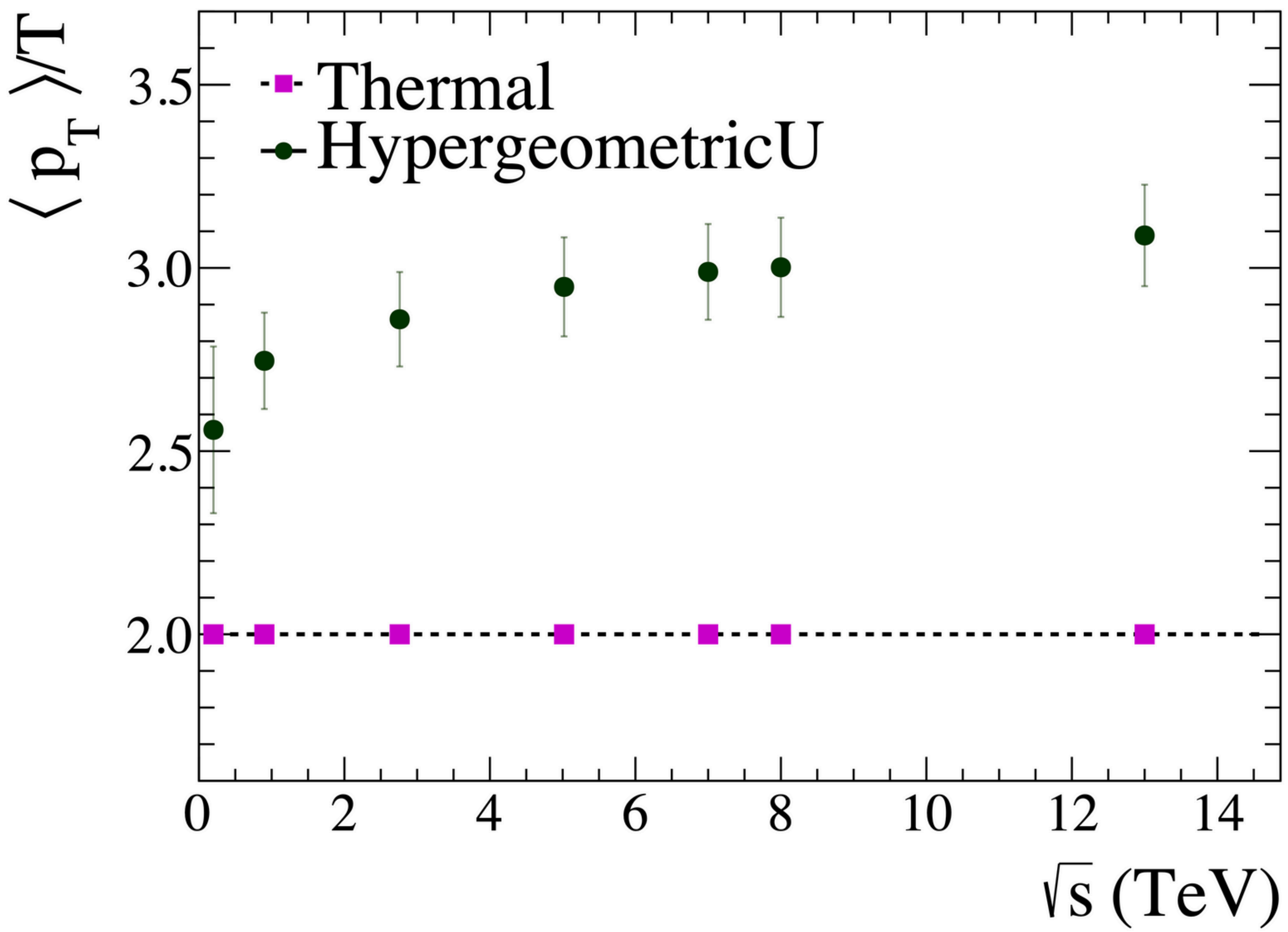
mean pT

$$\langle p_T \rangle = \frac{\int_0^\infty p_T \frac{dN}{dp_T^2} dp_T^2}{\int_0^\infty \frac{dN}{dp_T^2} dp_T^2}$$

$$\langle p_T \rangle_U = \frac{(q-1)(3q-5)}{(2-q)(2q-3)} \left(\frac{\Gamma\left(\frac{1}{q-1}\right)}{\Gamma\left(\frac{1}{q-1} - \frac{1}{2}\right)} \right)^2 T_U$$



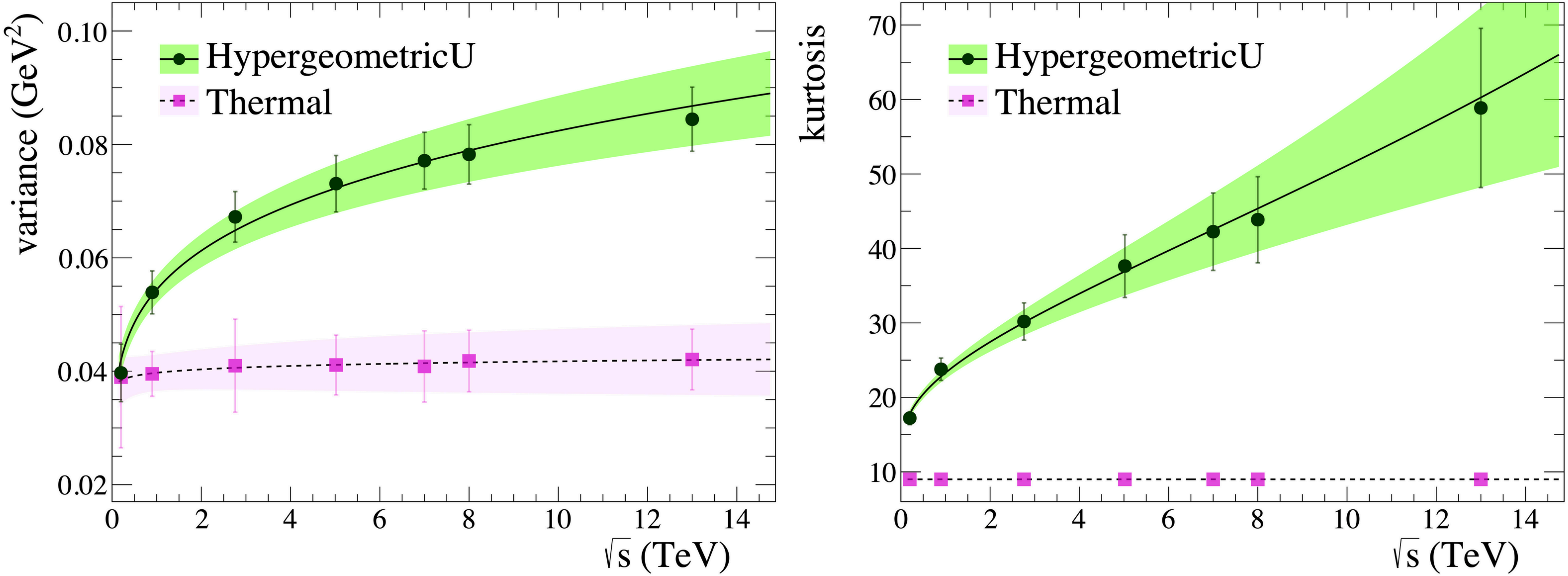
mean pT to temperature ratio



D. Rosales Herrera, et al, Phys. Rev. C 109, 034915 (2024).

Variance and kurtosis

of the invariant yield considering pT as the random variable



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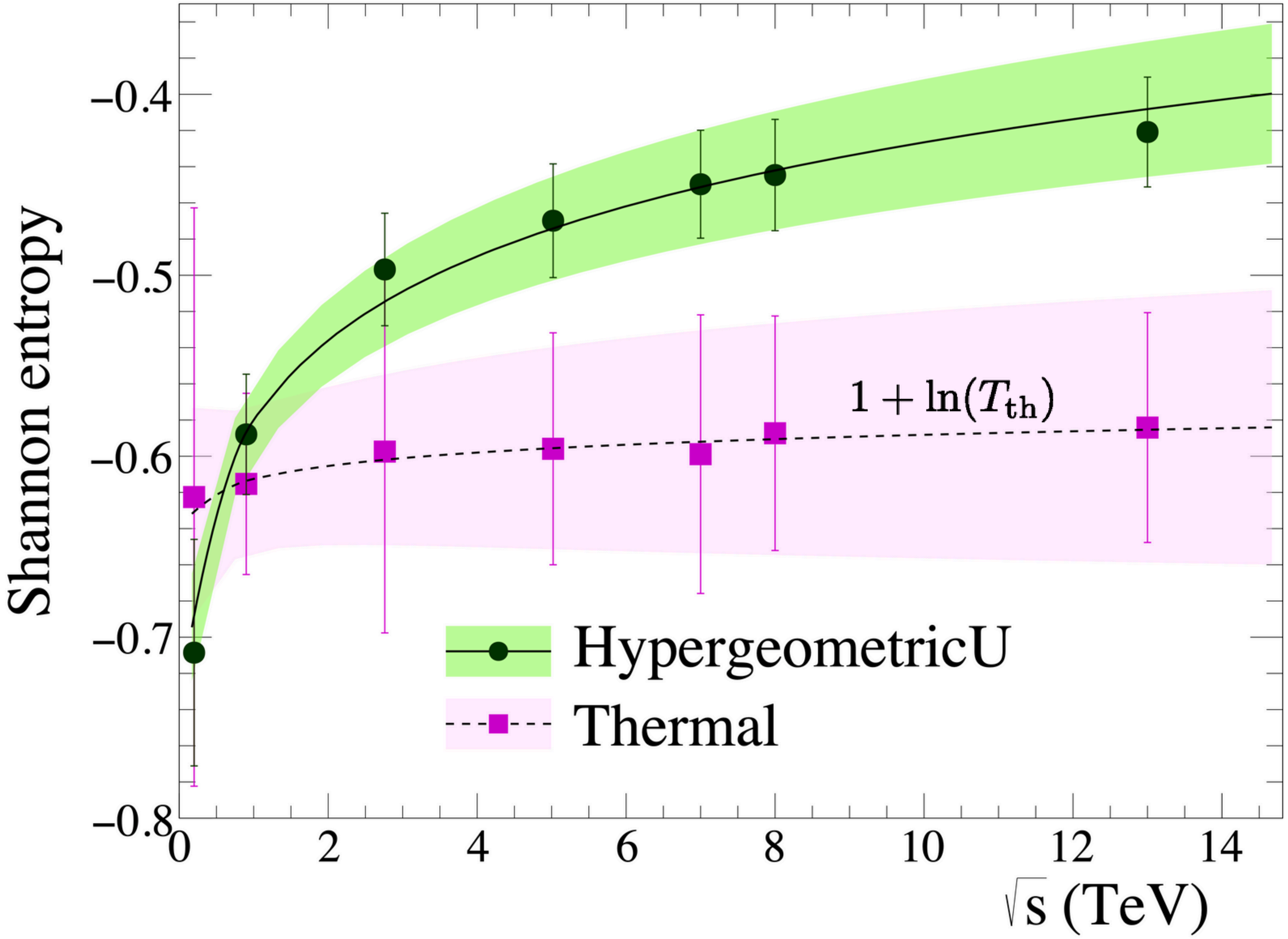
Shannon entropy

The entire shape of the normalized transverse momentum distribution is characterized by this concept from information theory

$$\mathcal{H} = -\int_0^\infty \left(\frac{1}{\mathcal{I}_0}\frac{dN}{dp_T^2}\right) \ln\left(\frac{1}{\mathcal{I}_0}\frac{dN}{dp_T^2}\right) dp_T$$

with

$$\mathcal{I}_0 = \int_0^\infty \frac{dN}{dp_T^2} dp_T$$



This goes hand in hand with the results of the variance and kurtosis

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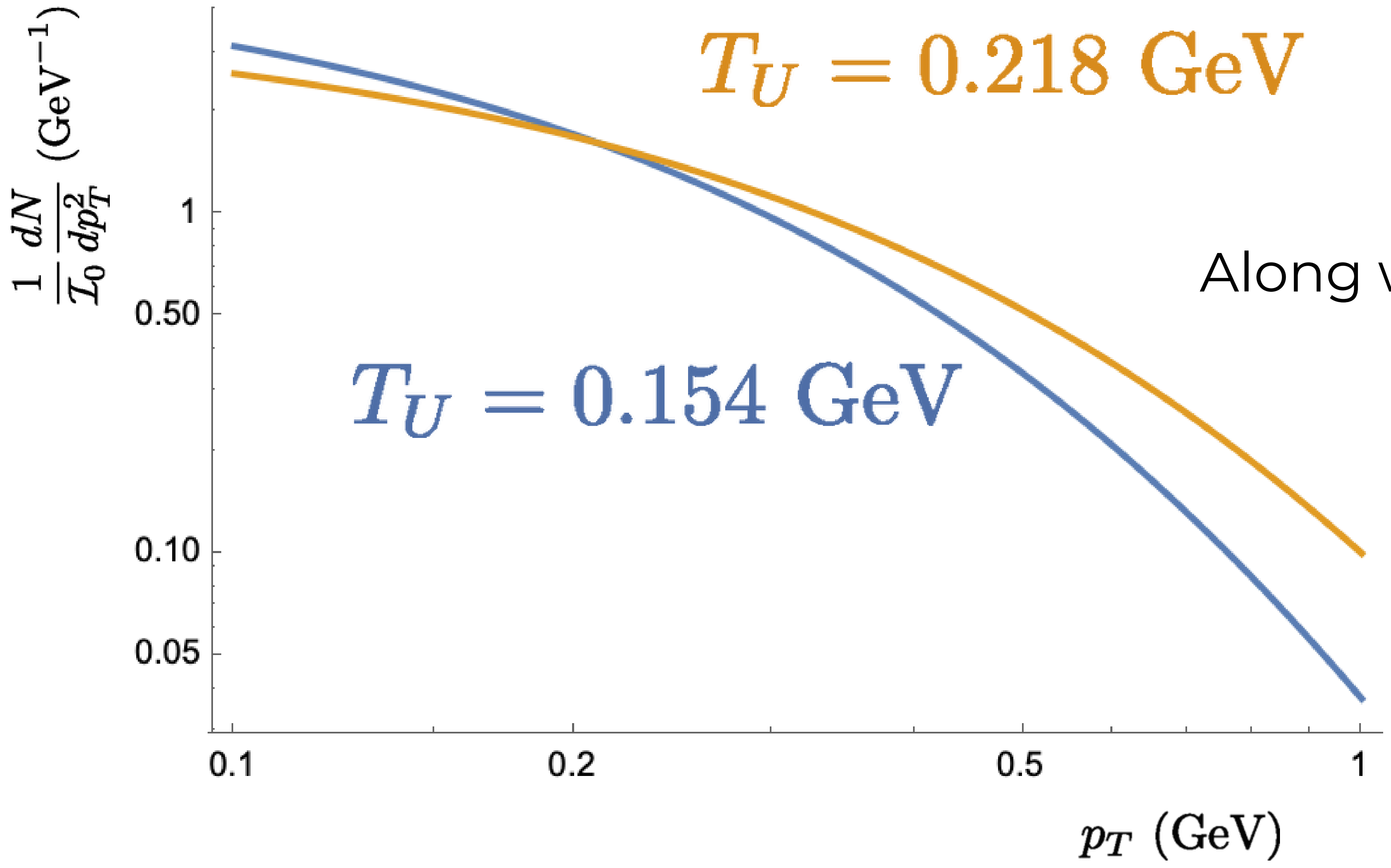
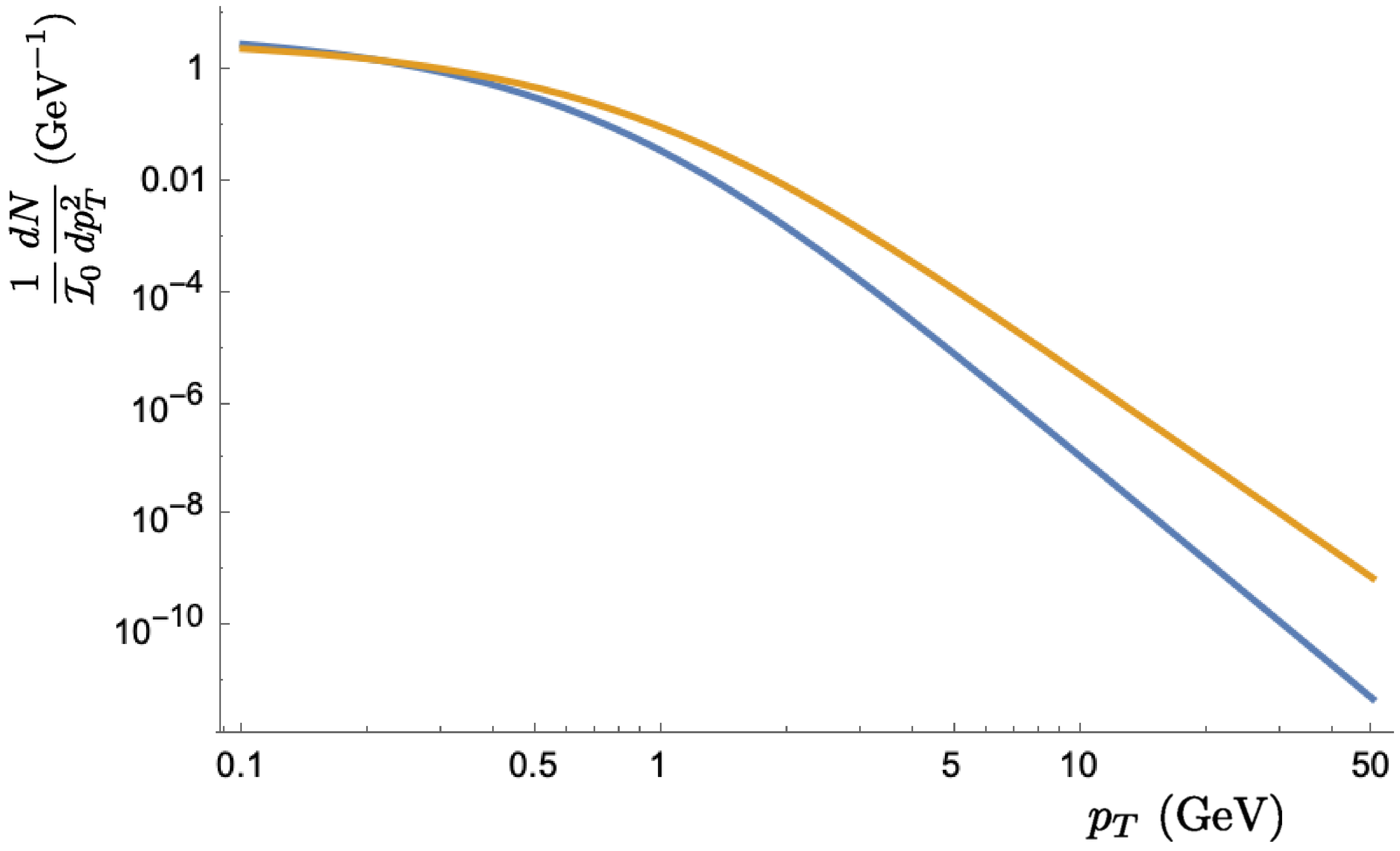
Heating the pT distribution

Flattening of the soft part



Along with

Enhancement of the pT distribution tail



Rising the probability of producing high pT particles

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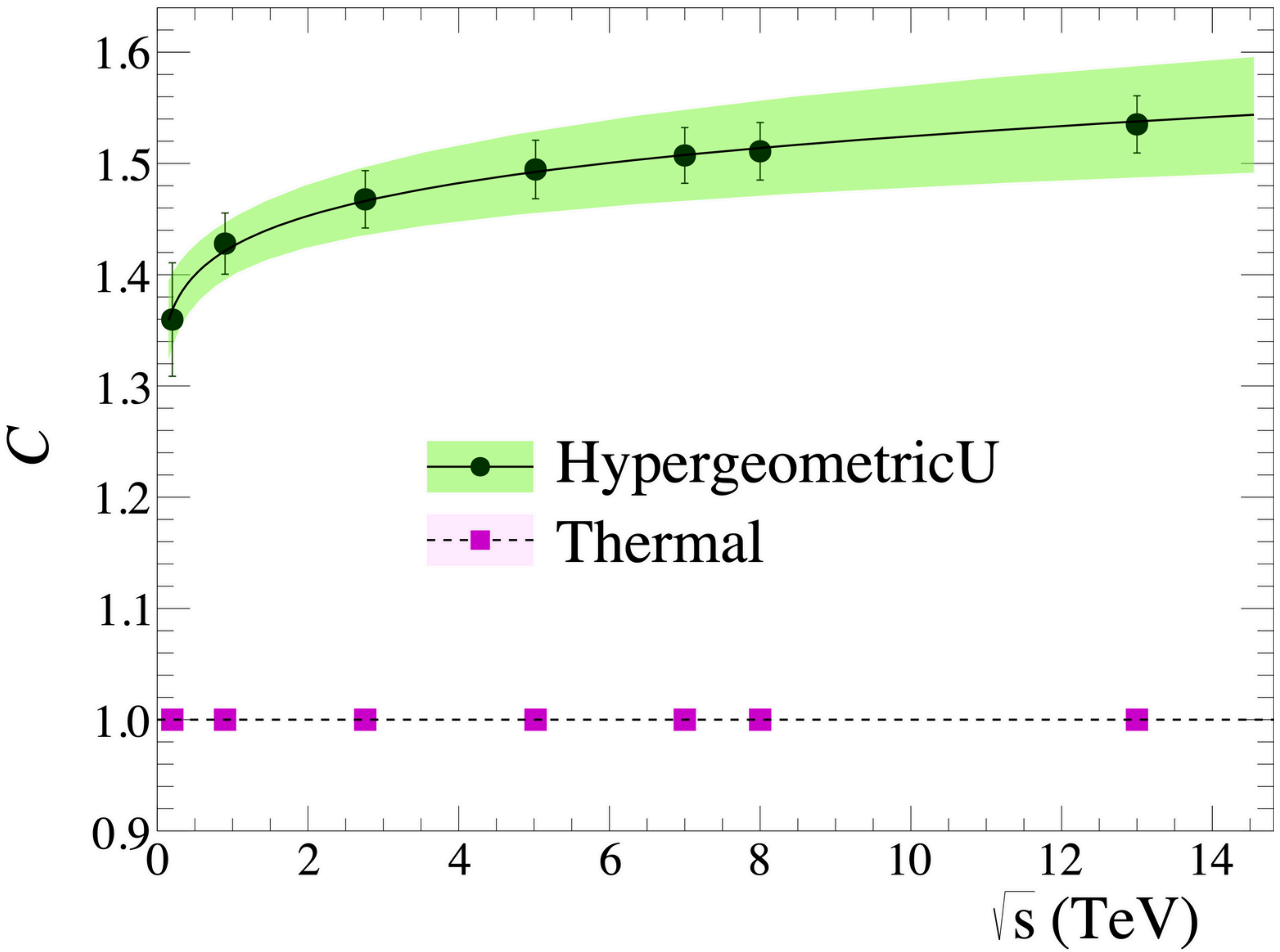
Heat capacity

By definition

$$C = \frac{1}{T}\frac{d\mathcal{H}}{dT}$$

The heat capacity gives the energy necessary to heat up the transverse momentum distribution.

The heat capacity increases as the center of mass energy does.



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Conclusions

The nonextensive description of particle production captures the information in the whole pT spectrum.

The mean pT, the variance, and the kurtosis of the invariant yield grow as the system's center of mass energy increases.

The latter is consistent with an increment of the Shannon entropy.

The results of the heat capacity suggest that more energy is required to heat the pT distribution as the center of mass energy increases. Implying that it is more difficult to increase the width of the distribution and the probability of having more high pT particles.

Thank you