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Temperature fluctuations of the medium formed in pp collisions

HEP Phenomenology Group, BUAP:

D. Rosales Herrera*, J.E. Ramírez, J. R. Alvarado García, A. Fernández Téllez

*diana.rosales.herrera@cern.ch

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PHYSICAL REVIEW C **110**, 015205 (2024)

Nonextensivity and temperature fluctuations of the Higgs boson production

D. Rosales Herrera,[1] J. R. Alvarado García,[1,*] A. Fernández Téllez,[1] J. E. Ramírez,[2,†] and C. Pajares[3]
[1]*Facultad de Ciencias Físico Matemáticas, Benemérita Universidad Autónoma de Puebla, Apartado Postal 165, 72000 Puebla, Puebla, Mexico*
[2]*Centro de Agroecología, Instituto de Ciencias, Benemérita Universidad Autónoma de Puebla, Apartado Postal 165, 72000 Puebla, Puebla, Mexico*
[3]*Departamento de Física de Partículas and Instituto Galego de Física de Altas Enerxías, Universidad de Santiago de Compostela, E-15782 Santiago de Compostela, Spain*

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We determine the temperature fluctuations associated with the Higgs boson p_T spectrum through the derivation of the string tension distribution corresponding to the QCD-based Hagedorn function, frequently used to fit the transverse momentum distribution (TMD). The identified string tension fluctuations are heavy tailed, behaving similarly to the q-Gaussian distribution. After the convolution with the Schwinger mechanism, both approaches correctly describe the entire TMD. This approach leads to the nonthermal description of the particle production in ultrarelativistic pp collisions. By analyzing the data of pp collisions at $\sqrt{s} = 13$ TeV, we found that the average temperature associated with the Higgs boson differential cross section is around 85 times greater than the estimated value for the charged particle TMD. Our results show that the Higgs boson production exhibits the largest deviation from the thermal description.

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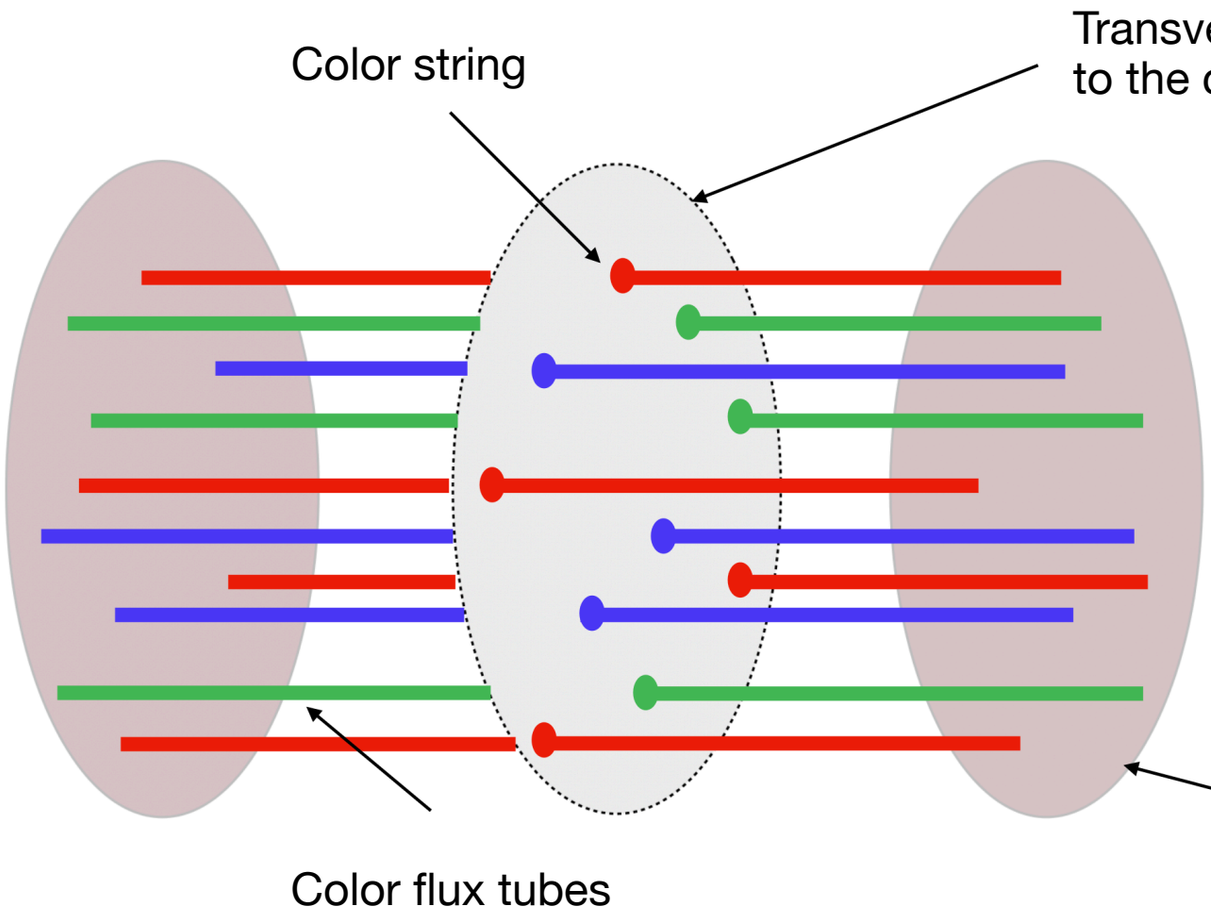
Particle production from Schwinger mechanism



$$\frac{dN}{dp_T^2} \sim \int_0^\infty \exp\left(-\frac{\pi p_T^2}{x^2}\right) P(x)dx$$

Schwinger Mechanism

String tension fluctuations

The Schwinger mechanism represents the probability of observing a particle with transverse momentum p_T produced by the fragmentation of strings with tension x^2.

Intensity of the interaction

Schwinger J 1962 Phys. Rev. 128 2425 // Bialas A 1999 Phys. Lett. B 466 301

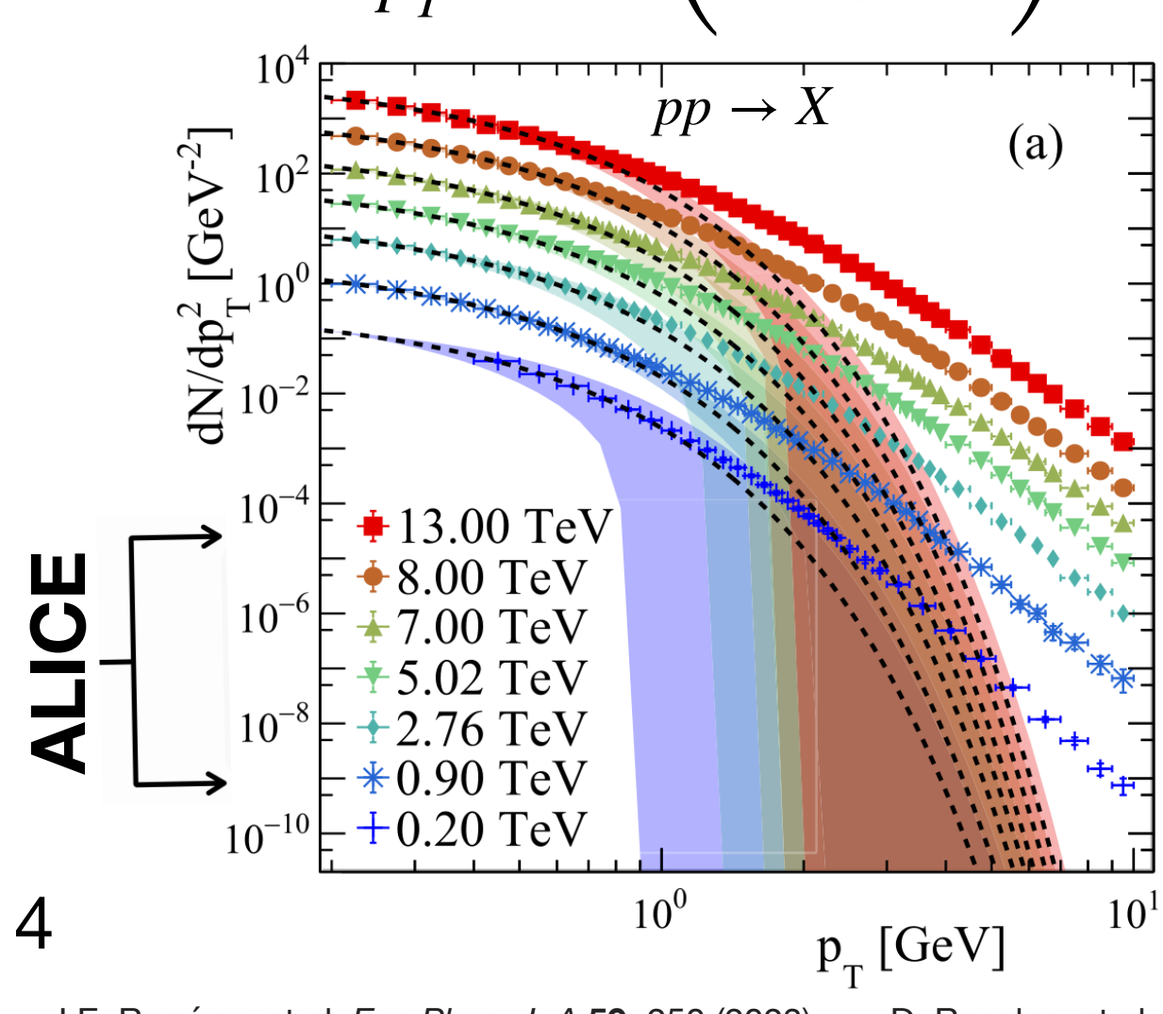
p_T -spectrum descriptions

Gaussian fluctuations

$$P(x) \sim \exp\left(-x^2/2\sigma^2\right)$$

- Thermal distribution

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

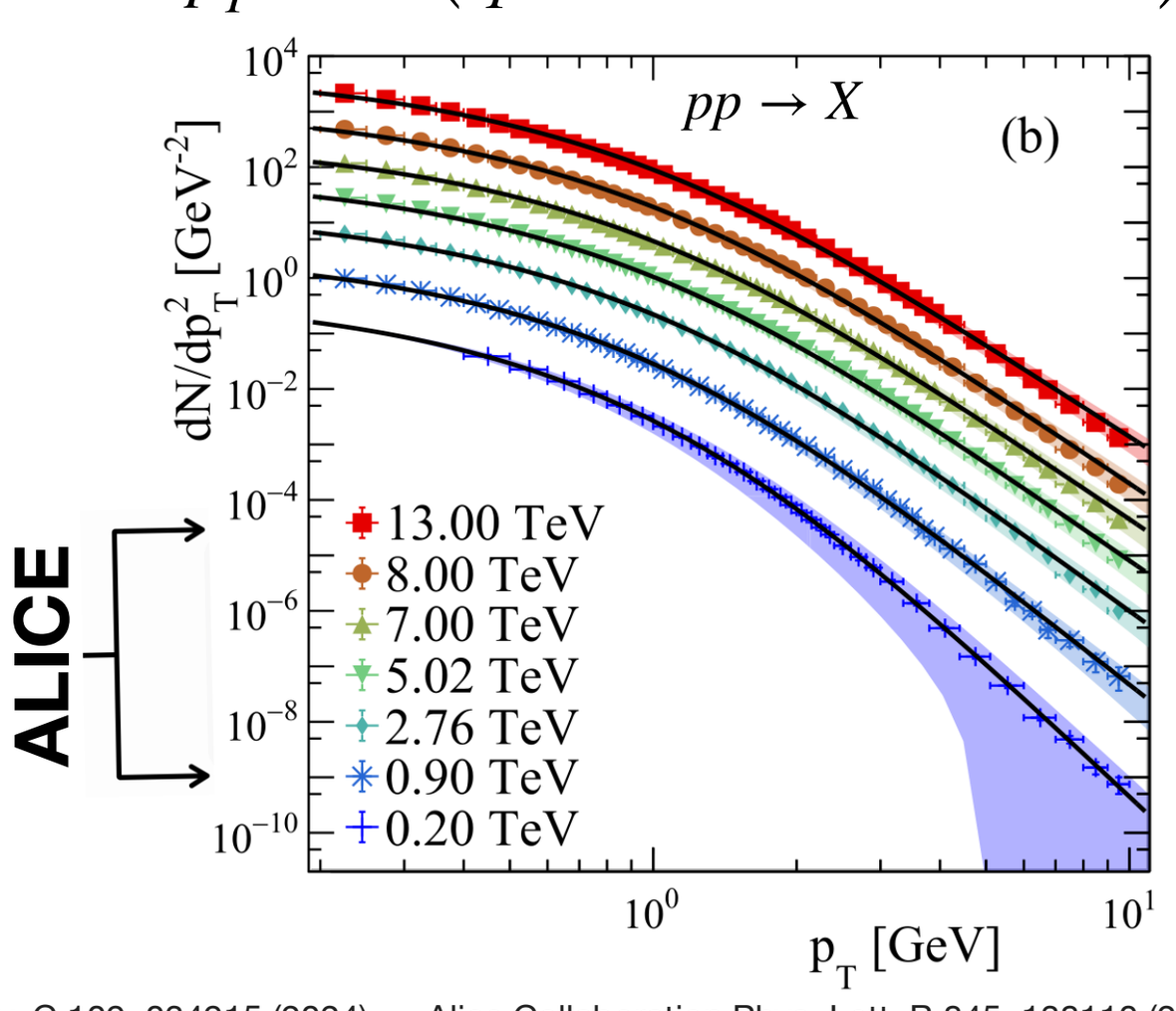


q-Gaussian fluctuations

$$P(x) \sim \left(1 + \frac{(q-1)x^2}{2\sigma^2}\right)^{\frac{1}{1-q}}$$

- Hypergeometric Confluent function

$$\frac{dN}{dp_T^2} \sim U\left(\frac{1}{q-1} - \frac{1}{2}, \frac{1}{2}, \pi p_T^2 \frac{q-1}{2\sigma^2}\right)$$

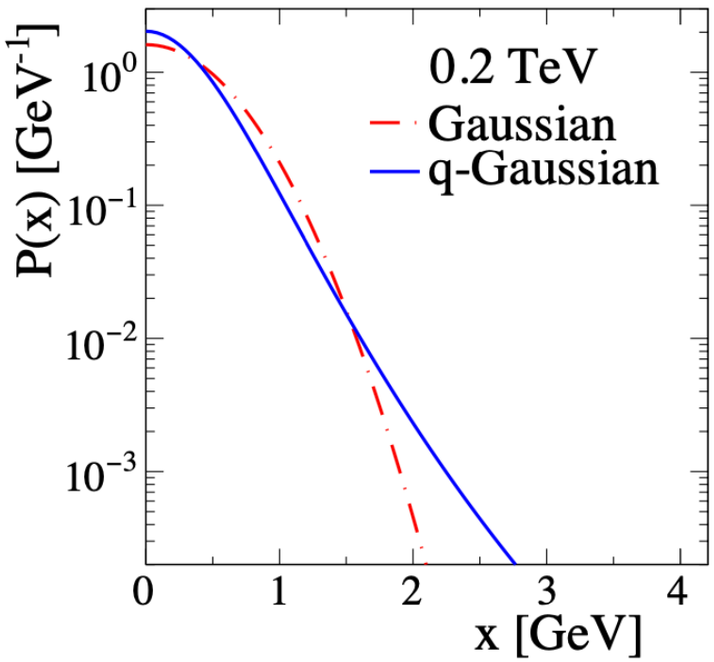


J.E. Ramírez, et al, *Eur. Phys. J. A* **59**, 250 (2023) D. Rosales, et al, Phys. Rev. C 109, 034915 (2024). Alice Collaboration Phys. Lett. B 845, 138110 (2023).

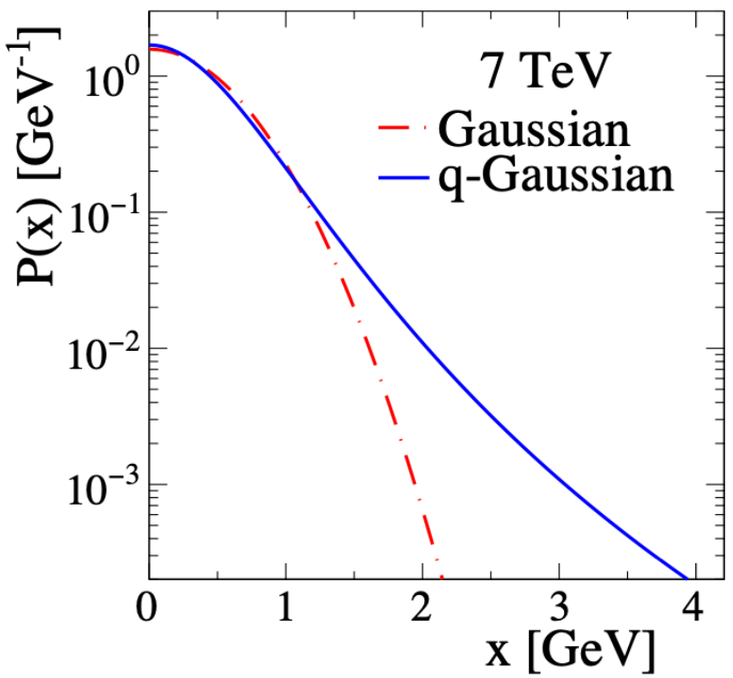
String tension fluctuations

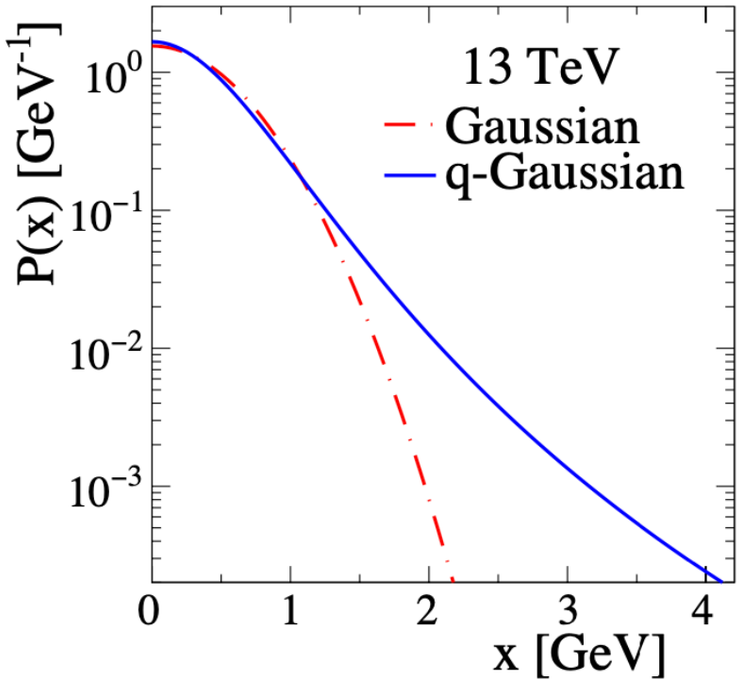
The U functions has an excellent performance

STAR Collaboration



ALICE Collaboration

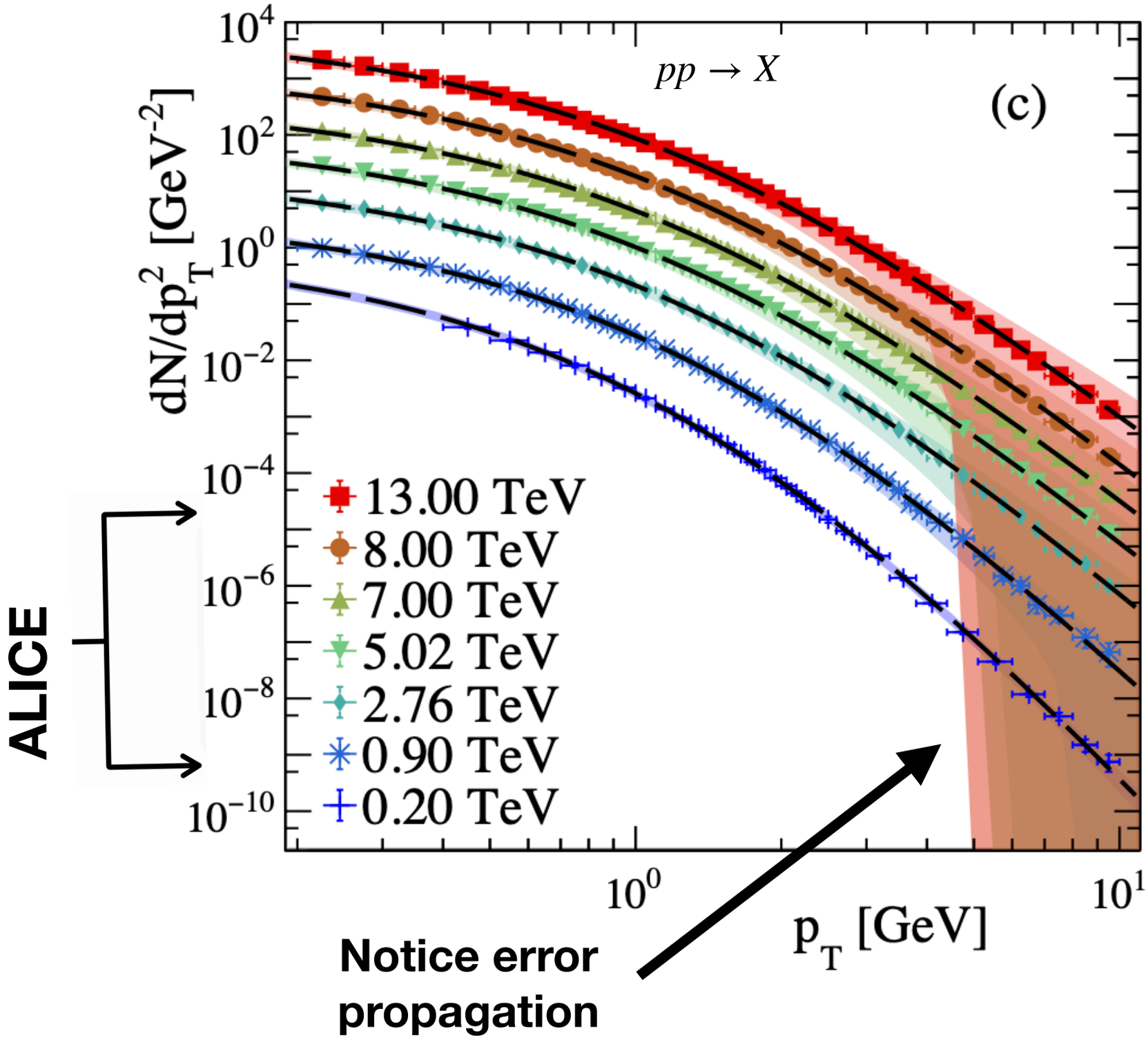




More strings with higher tensions → High p_T particles at higher energies

D. Rosales Herrera, et al 2024 *Phys. Rev. C*, *109*(3), 034915

QCD-based Hagedorn function



$$\frac{dN}{dp_T^2} \propto \left(\frac{p_0}{p_0 + p_T} \right)^m$$

Is it possible to associate the string fragmentation approach to the Hagedorn function?

D. Rosales Herrera, et al 2024 *Phys. Rev. C*, *109*(3), 034915 // R. Hagedorn, Riv. Nuovo Cim. 6N10, 1 (1983)

Hagedorn function string tension fluctuations

$$\text{Hagedorn function} = \int (\text{Thermal dist.})(\text{Temperature fluctuations})\, dT$$

$$T_{th} = \frac{\sigma}{\sqrt{2\pi}}$$

$$= \int \int (\text{SM})(\text{Gaussian string tension fluctuations})(\text{Temperature fluctuations})\, dx dT$$

$$= \int (\text{SM}) \int (\text{Gaussian string tension fluctuations})(\text{Temperature fluctuations})\, dT\, dx$$

$$= \int (\text{SM})(\text{Hagedorn function string tension fluctuations})\, dx$$

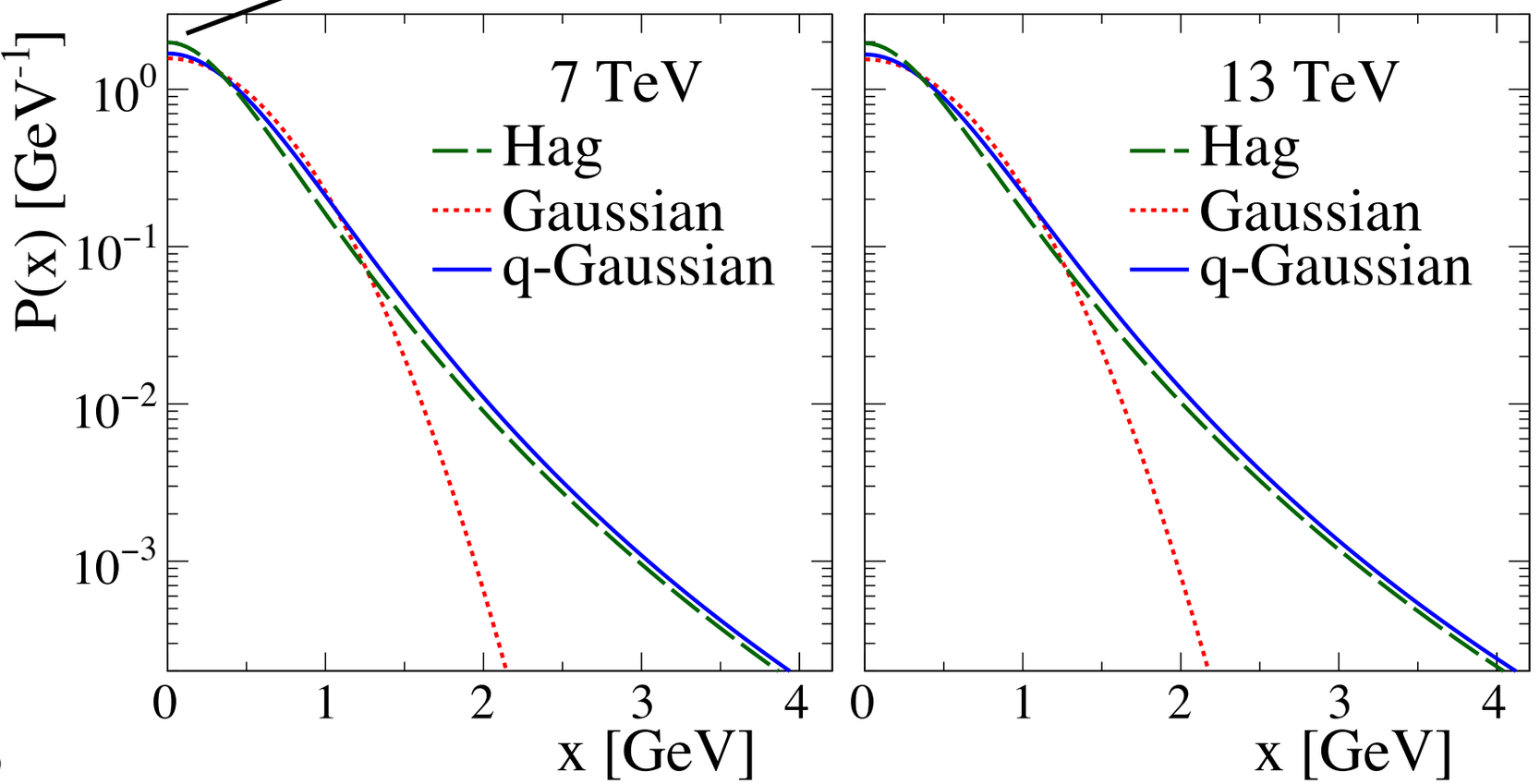
G. Wilk and Z. Wlodarczyk, Phys. Rev. Lett. 84, 2770 (2000

D. Rosales Herrera, et al, Phys. Rev. C 110, 015205 (2024).

Hagedorn also comes from string fragmentation

$$\left(\frac{p_0}{p_0+p_T}\right)^m = \int_0^\infty \exp(-\pi p_T^2/x^2)\,\frac{m p_0^m \pi^{\frac{m-1}{2}}}{x^{m+1}} U\left(\frac{m+1}{2}, \frac{1}{2}, \frac{\pi p_0^2}{x^2}\right) dx$$

Enhance the production of low p_T particles



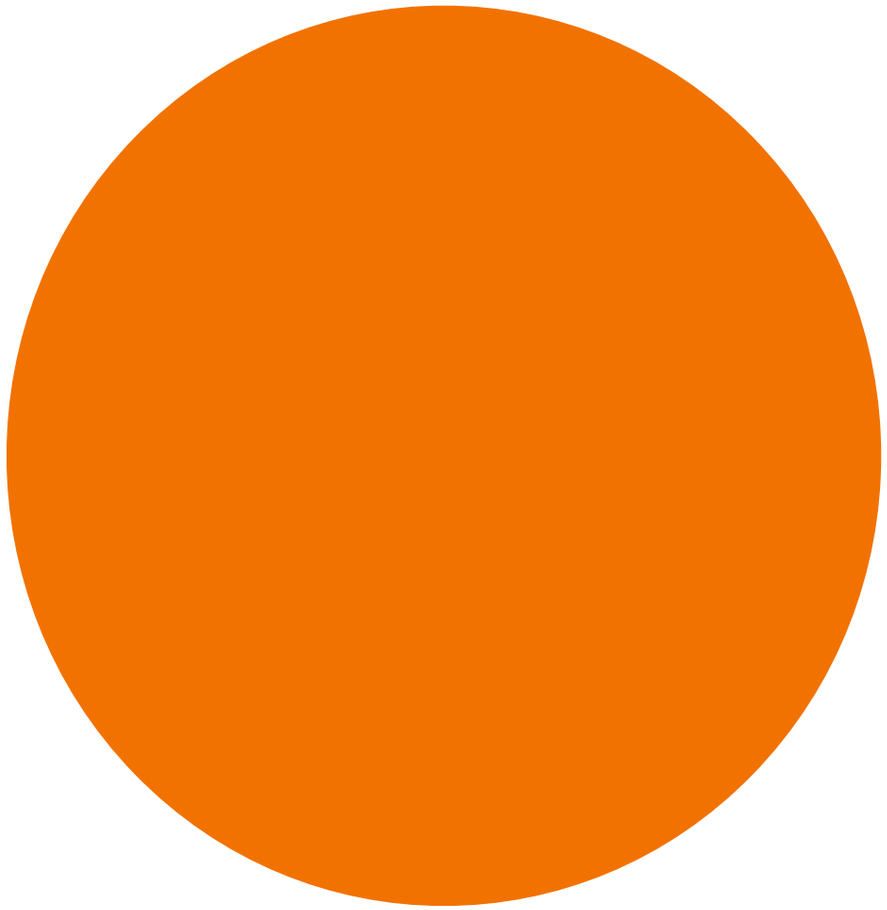
Heavy tailed distributions play an important role in the description of particle production !

D. Rosales Herrera, et al, Phys. Rev. C 110, 015205 (2024).

Temperature fluctuations

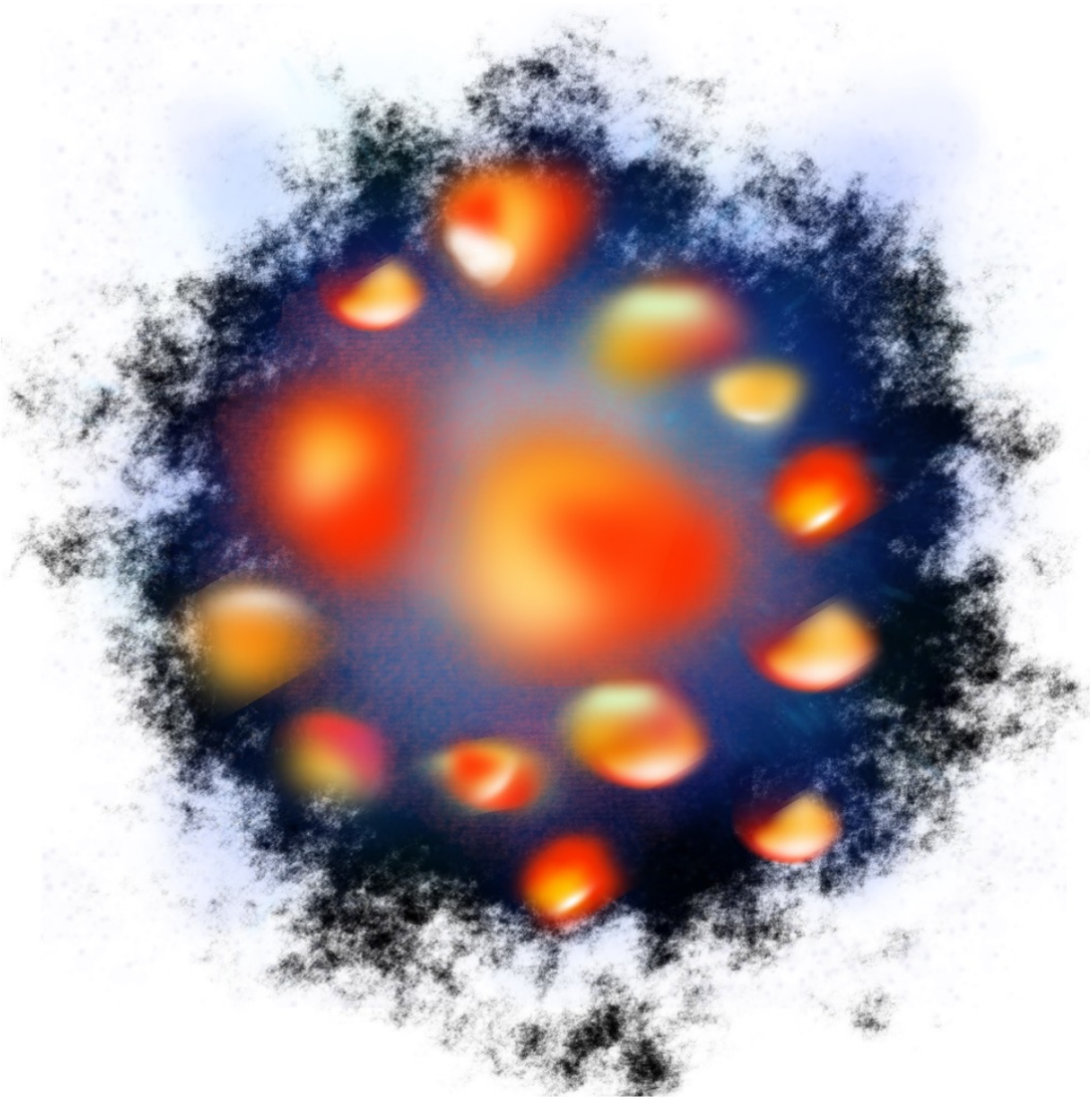
Gaussian fluctuations

$$\mathscr{T}_{th}(T) = \delta(T - T_{th})$$



q-Gaussian fluctuations

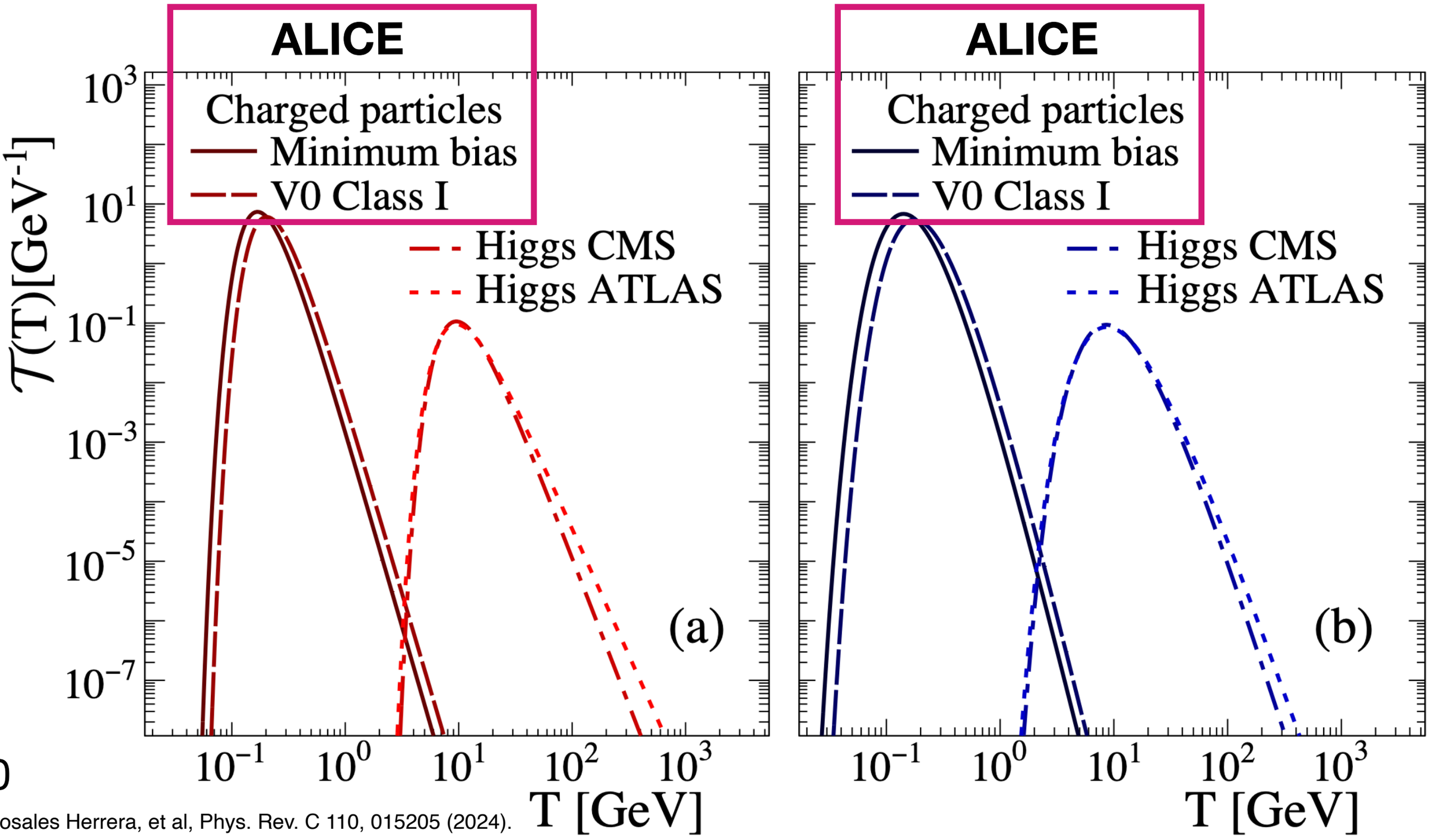
$$\mathscr{T}_{U}(T) = \frac{2}{T^3}\Gamma\left(\frac{1}{T^2}, \frac{1}{q-1} - \frac{1}{2}, \frac{1}{4z_0}\right)$$



D. Rosales Herrera, et al, Phys. Rev. C 110, 015205 (2024).

Temperature fluctuations

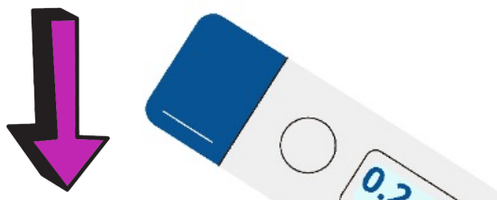
$$\mathcal{T}_U(T) = \frac{2}{T^3}\Gamma\left(\frac{1}{T^2}, \frac{1}{q-1} - \frac{1}{2}, \frac{1}{4z_0}\right) \qquad \mathcal{T}_{Hag}(T) = \frac{\Gamma(1/T, m, p_0)}{T^2}$$



D. Rosales Herrera, et al, Phys. Rev. C 110, 015205 (2024).

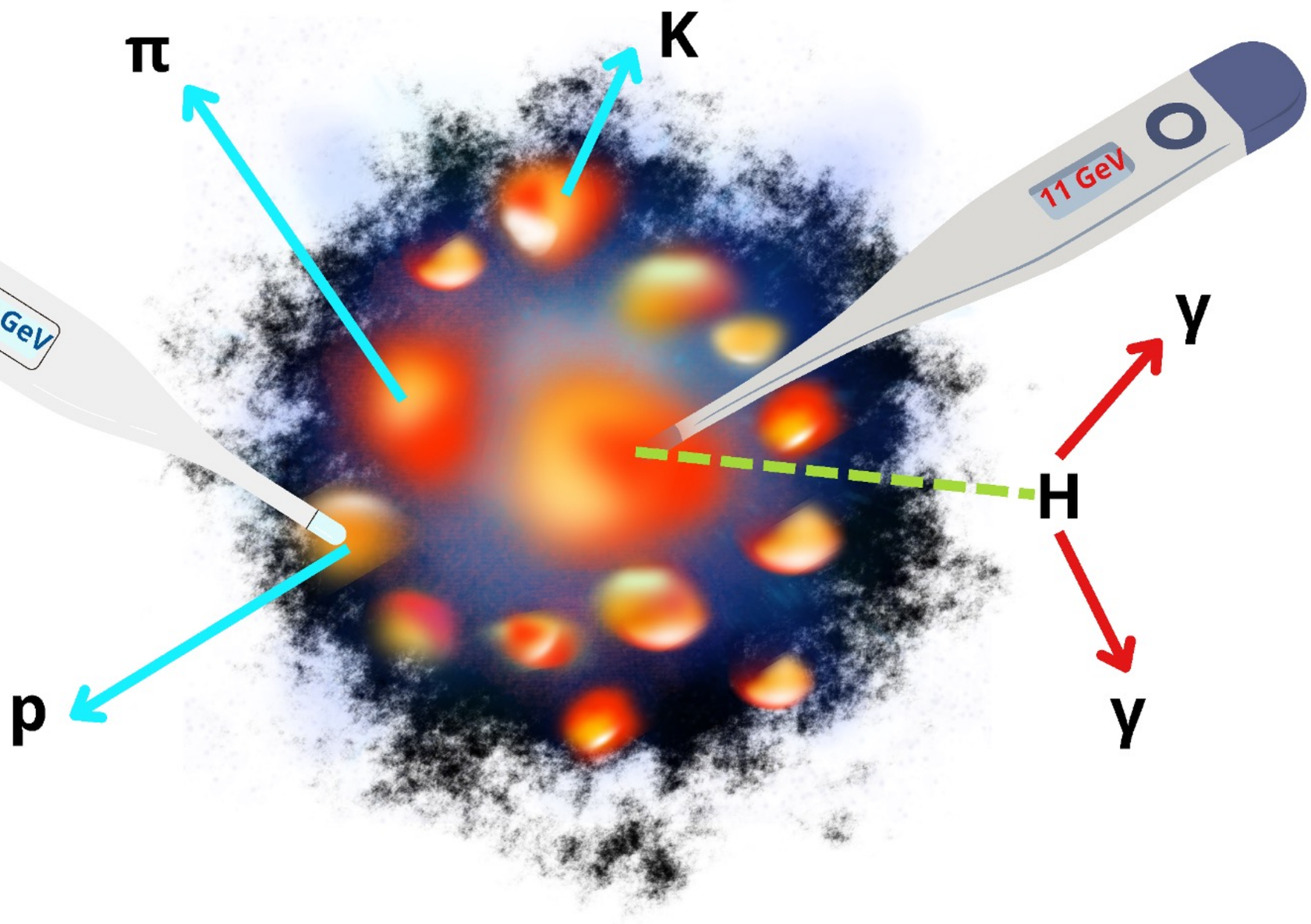
In summary

Heavy tailed distributions describing string tension fluctuations



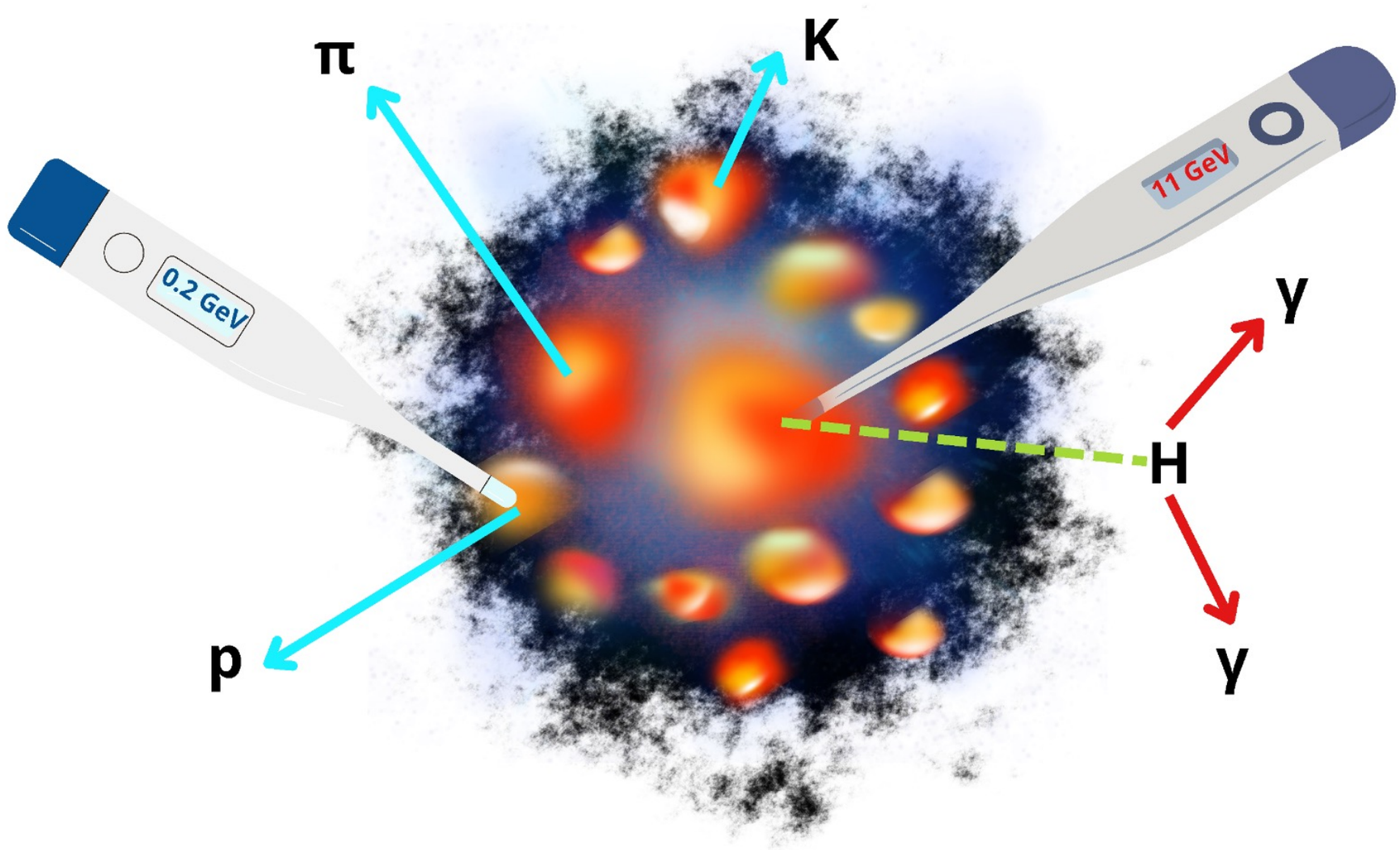
Nonextensive particle production

Nonthermal description of the system



D. Rosales Herrera, et al, Phys. Rev. C 110, 015205 (2024).

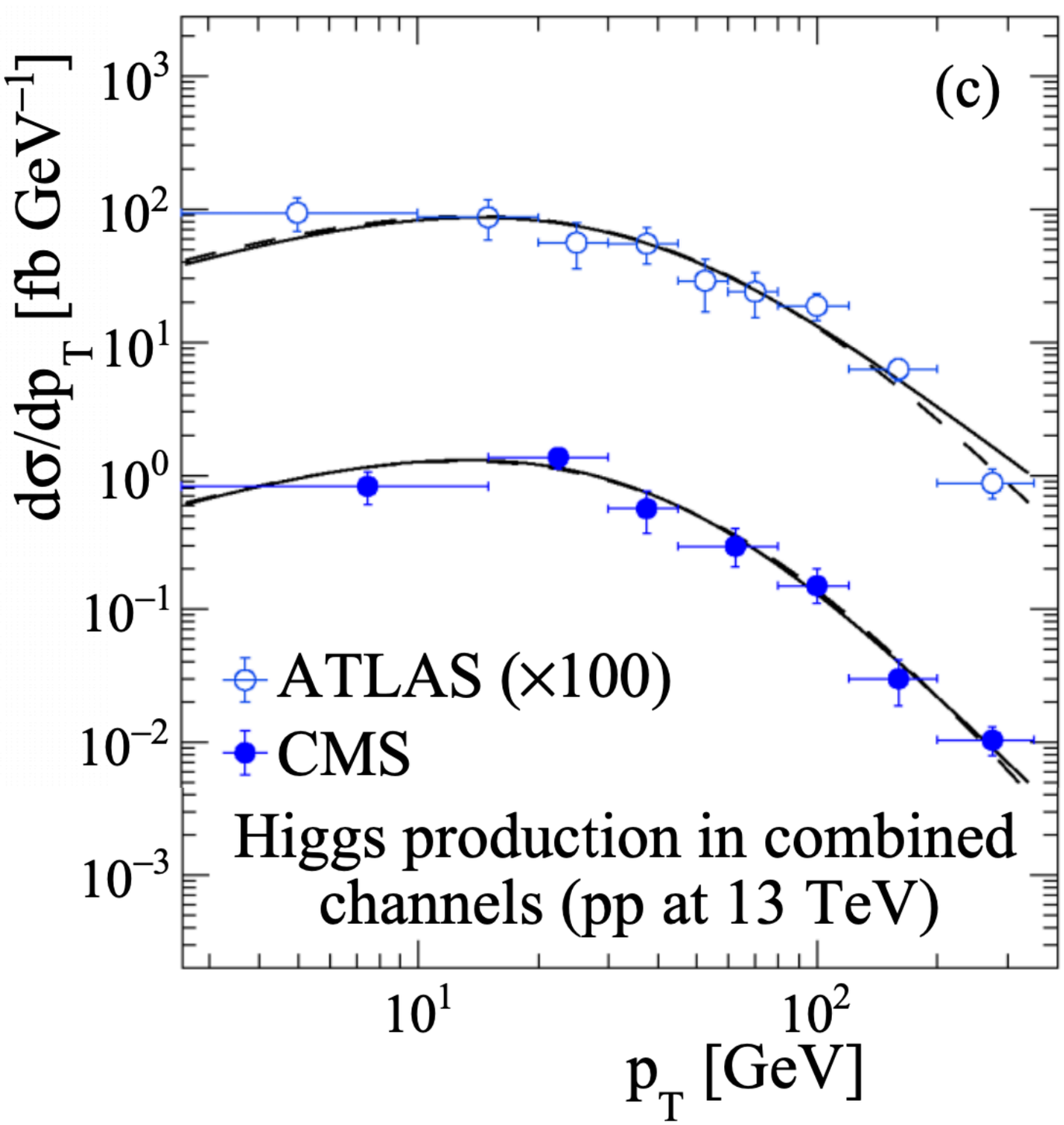
Thank you



For more details:

[1] D. Rosales Herrera, et al, Phys. Rev. C 110, 015205 (2024)
[2] D. Rosales Herrera, et al, Phys. Rev. C 109, 034915 (2024)
[3] J. R. Alvarado García, et al, J. Phys. G: Nucl. Part. Phys. 50, 125105 (2023)
[4] J. E. Ramírez, et al, Eur. Phys. J. A 59, 250 (2023)

Backup slide



Higgs boson production in the combined channels $H \to \gamma\gamma$, $H \to ZZ^*$, and $H \to b\bar{b}$ (only CMS)

Higgs boson is not produced through soft processes. However, we can fit with a pT-exponential up to 30 GeV