Non-extensive statistical distributions of charmed meson production in Pb-Pb and pp($\bar{\mathrm{p}}$)

Yuan Su (苏源)

University of Science and Technology of China

Y. Su, Sun, Zhang, Chen, NUCL SCI TECH 32, 108 (2021)

CLHCP2021 Online

Nov. 26, 2021

- Introduction to non-extensive statistics
- Analyze charmed meson p_T spectra by Tsallis-Pareto distribution
- Results and discussion
- Summary

Non-extensive statistics is a generalization of the traditional Boltzmann-Gibbs statistics.

- Non-extensive entropy (Tsallis entropy 1988)

$$S_q(p_i) = \frac{k}{q-1}\left(1 - \sum_i p_i^q\right) \qquad \xrightarrow{q \to 1} \qquad S_{BG} = S_1(p) = -k \sum_i p_i \ln p_i$$

- Non-additivity

$$S_q(A,B) = S_q(A) + S_q(B) + (1-q) S_q(A) S_q(B)$$

- Invariant transverse momentum distribution (Tsallis–Pareto distribution)

$$\frac{dN}{2\pi p_T dp_T} = A m_T \left[1 + \frac{q-1}{T_q}(m_T - M)\right]^{-\frac{q}{q-1}}$$

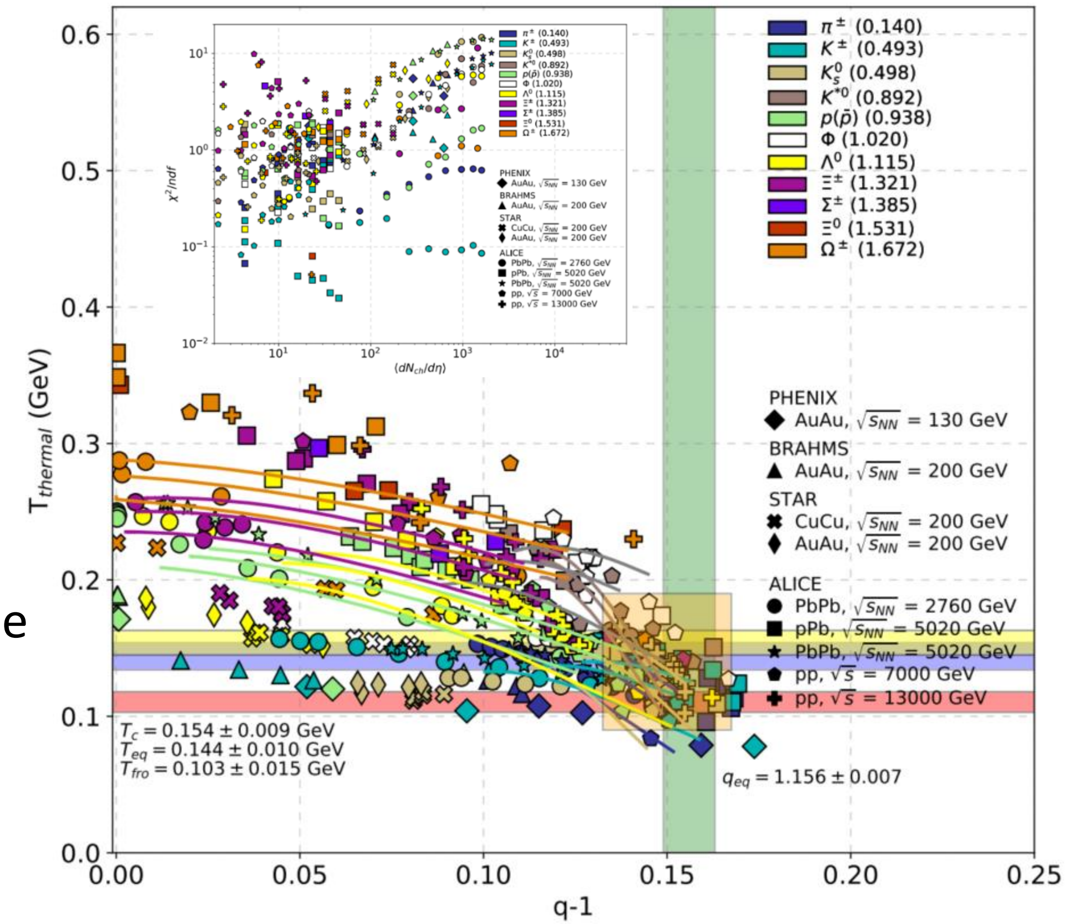
$$m_T = \sqrt{{p_T}^2 + m^2}$$

T_q can differ from T, but its physical meaning should be the same in the limiting case q → 1.

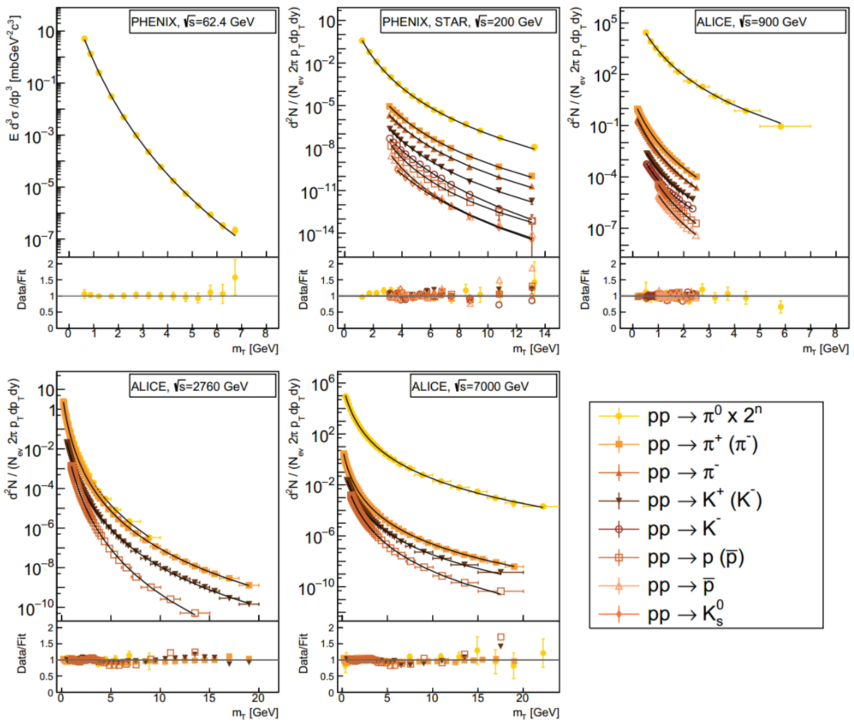
Motivation

- universal description
  - ✓large and small collisional systems
  - ✓center-of-mass energy, $\sqrt{s}$
  - ✓the hadron mass
  - ✓the event multiplicity

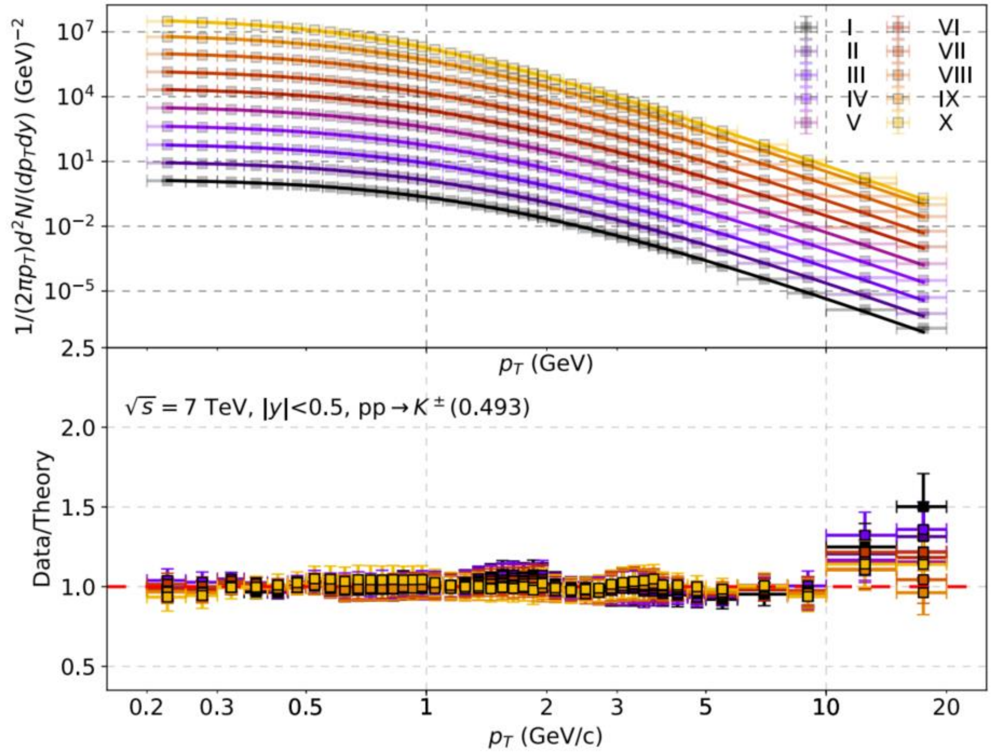
- Strong grouping phenomenon
  - ✓tend to a specific $T_{\rm eq}$ and q_{eq} value
  - ✓ a previously present strongly interacting QCD matter



J. Phys. G: Nucl. Part. Phys. 47 105002 (2020)



AIP Conference Proceedings 1853, 080001 (2017)

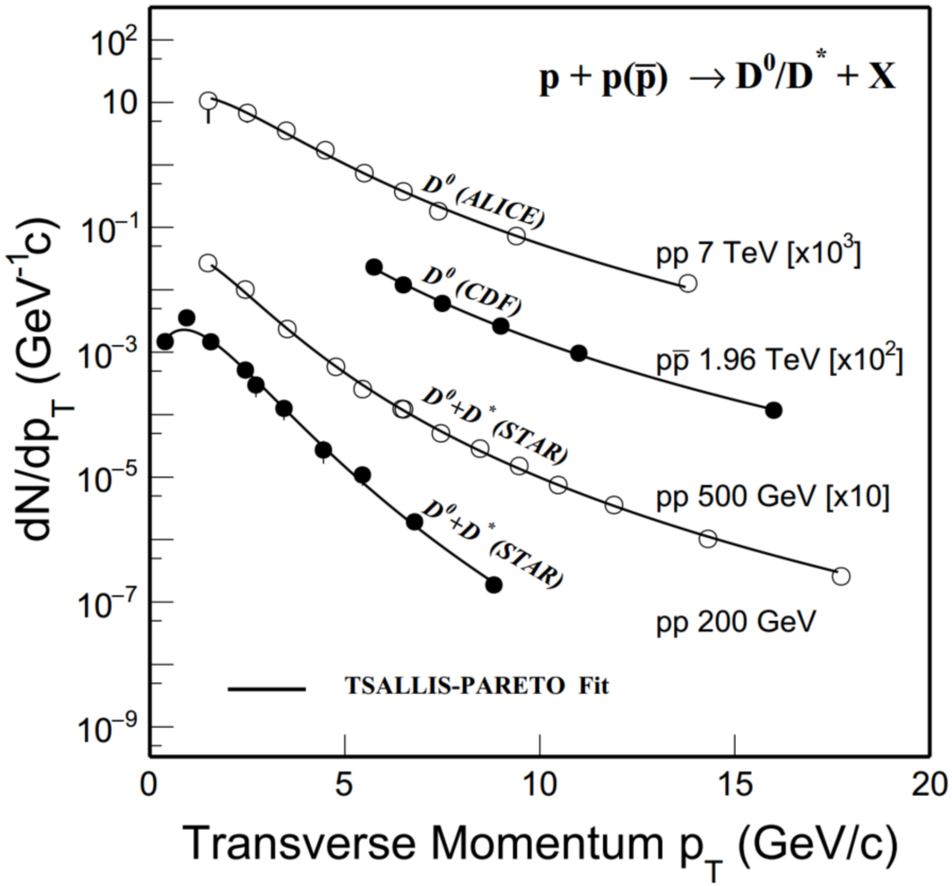


J. Phys. G: Nucl. Part. Phys. 47 105002 (2020)

$$\frac{1}{N_{ev}}\frac{\mathrm{d}^2N}{2\pi p_T \mathrm{d}p_T \mathrm{d}y}\bigg|_{y\approx 0} = A\cdot\left(1+\frac{q-1}{T}(m_T-m)\right)^{-\frac{1}{q-1}}$$

$$\frac{\mathrm{d}^2N}{2\pi p_T \mathrm{d}p_T \mathrm{d}y}\bigg|_{y\approx 0} = A m_T\left[1+\frac{q-1}{T}(m_T-m)\right]^{-\frac{q}{q-1}}$$

- Description in a wide range of collision energies and light hadron transverse momenta
- Exponential and logarithmic functions can be obtained for q → 1
- Non-extensive properties on heavy flavor hadron?



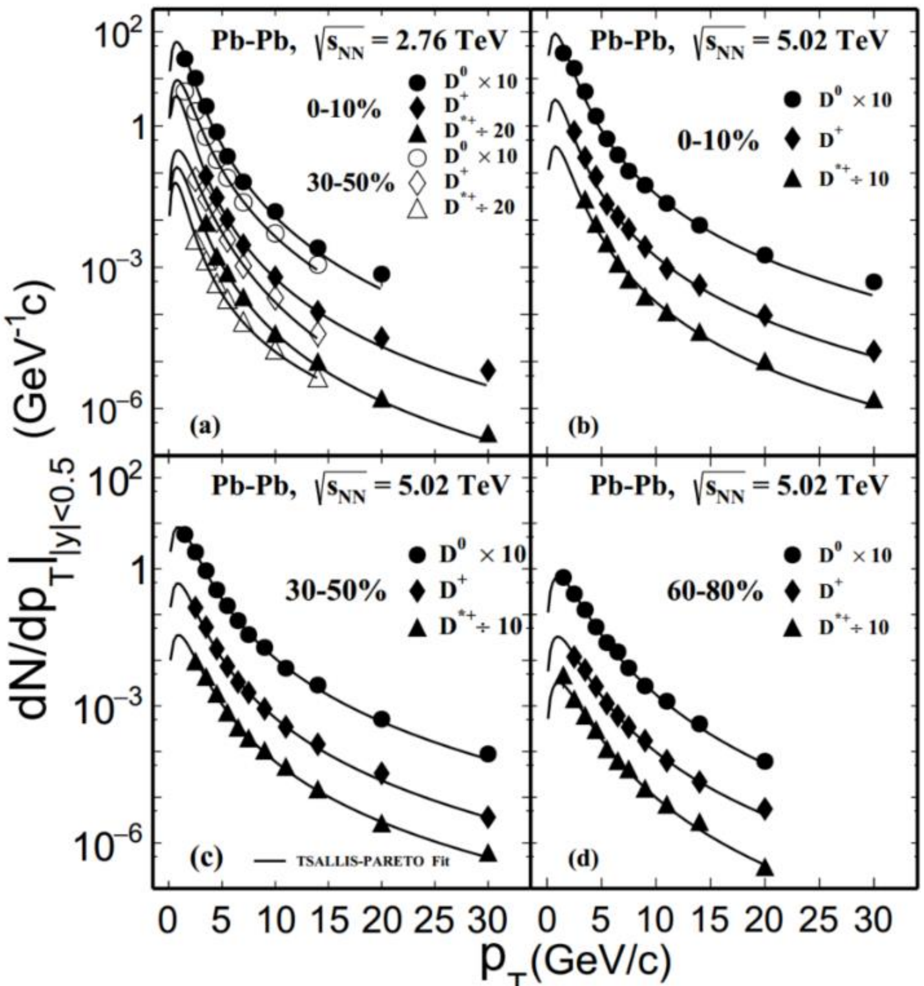
J. High Energ. Phys. 2012, 128 (2012)

Phys. Rev. Lett. 91, 241804

J. Phys.: Conf. Ser. 509 012078 (2014)

Phys. Rev. D 86, 072013

- Well description in a wide range of collision energies and charmed meson transverse momenta
- The results of pp($\bar{p}$) provide a reference for PbPb collisions, especially for peripheral collision.



$$\frac{dN}{2\pi p_T dp_T} = A m_T \left[1 + \frac{q-1}{T_q}(m_T - M)\right]^{-\frac{q}{q-1}}$$

$\sqrt{s_{NN}}$ (GeV)	Centrality	Charmed meson	T	q
Pb-Pb, 2760	0–10%	D^0	0.239 ± 0.030	1.166 ± 0.014
		D^+	0.201 ± 0.024	1.180 ± 0.013
		D^{*+}	0.240 ± 0.031	1.179 ± 0.012
	30–50%	D^0	0.278 ± 0.041	1.169 ± 0.020
		D^+	0.322 ± 0.055	1.151 ± 0.025
		D^{*+}	0.250 ± 0.049	1.205 ± 0.025
Pb-Pb, 5020	0–10%	D^0	0.240 ± 0.020	1.187 ± 0.008
		D^+	0.245 ± 0.025	1.190 ± 0.008
		D^{*+}	0.258 ± 0.026	1.184 ± 0.010
	30–50%	D^0	0.328 ± 0.026	1.175 ± 0.008
		D^+	0.311 ± 0.024	1.179 ± 0.007
		D^{*+}	0.331 ± 0.034	1.185 ± 0.008
	60–80%	D^0	0.427 ± 0.042	1.151 ± 0.012
		D^+	0.402 ± 0.043	1.170 ± 0.013
		D^{*+}	0.430 ± 0.069	1.156 ± 0.017
pp, 200		$D^0 + D^*$	0.322 ± 0.022	1.081 ± 0.011
pp, 500		$D^0 + D^*$	0.310 ± 0.020	1.132 ± 0.006
p($\bar{\text{p}}$), 1960		D^0	0.386 ± 0.058	1.143 ± 0.011
pp, 7000		D^0	0.494 ± 0.062	1.139 ± 0.023

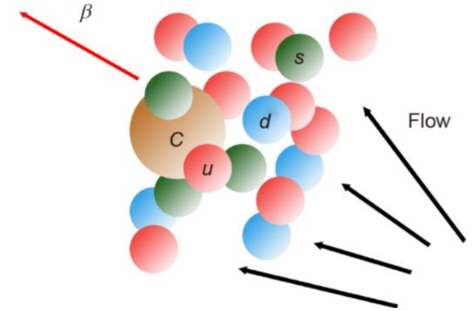
- Universal description for different centralities at 2.76 and 5.02 TeV
- Base on the T-P distribution, non-extensive parameters(T, q) can be extracted.

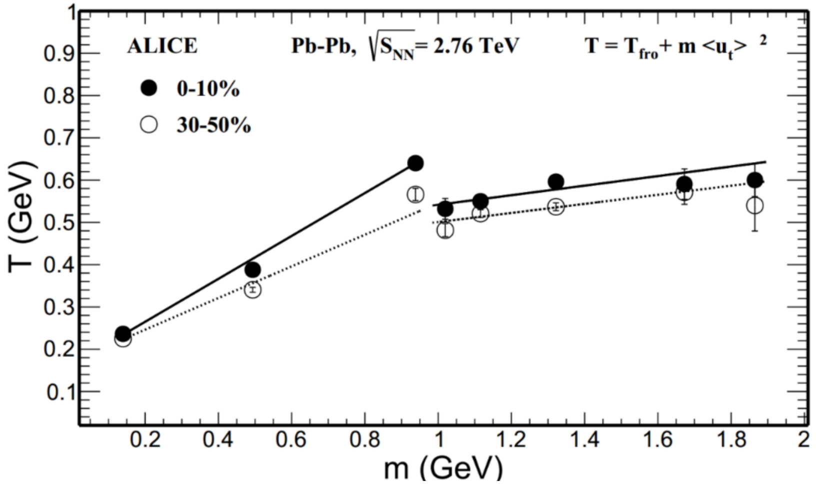
mass dependence of the effective temperature

Blue shift correction PRC 48, 2462 (1993)

$$T = T_{fro} + m\langle u_t \rangle^2$$

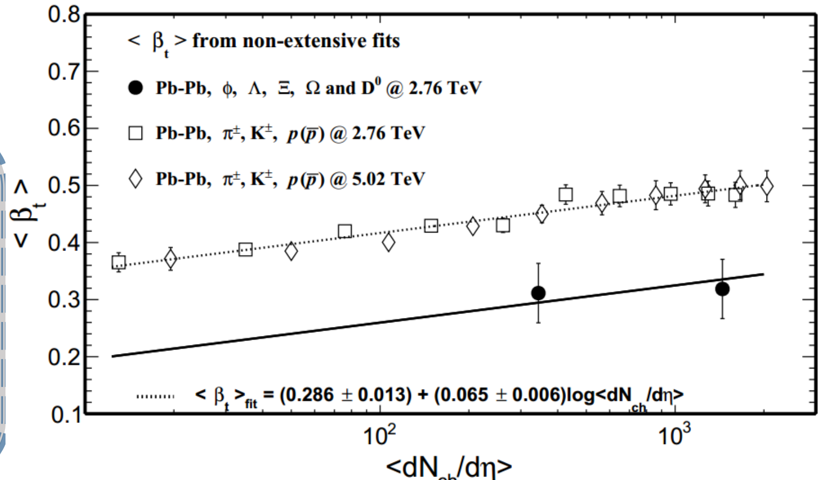
$$\langle \beta_t \rangle = \frac{\langle u_t \rangle}{\sqrt{1+\langle u_t \rangle^2}}$$



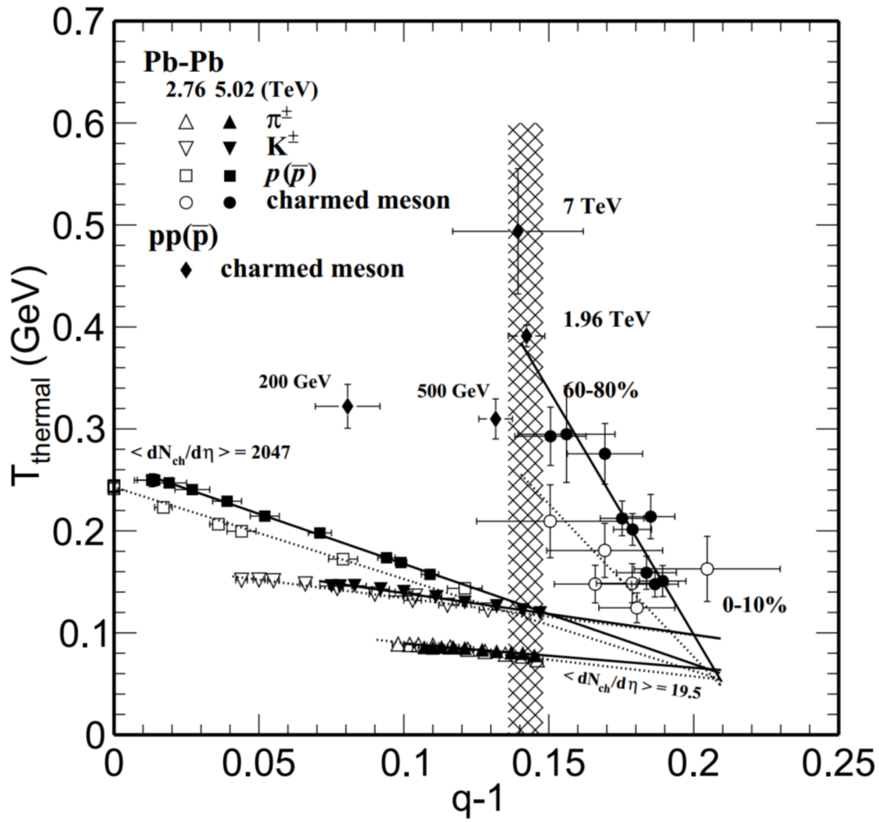


collectivity of charmed mesons

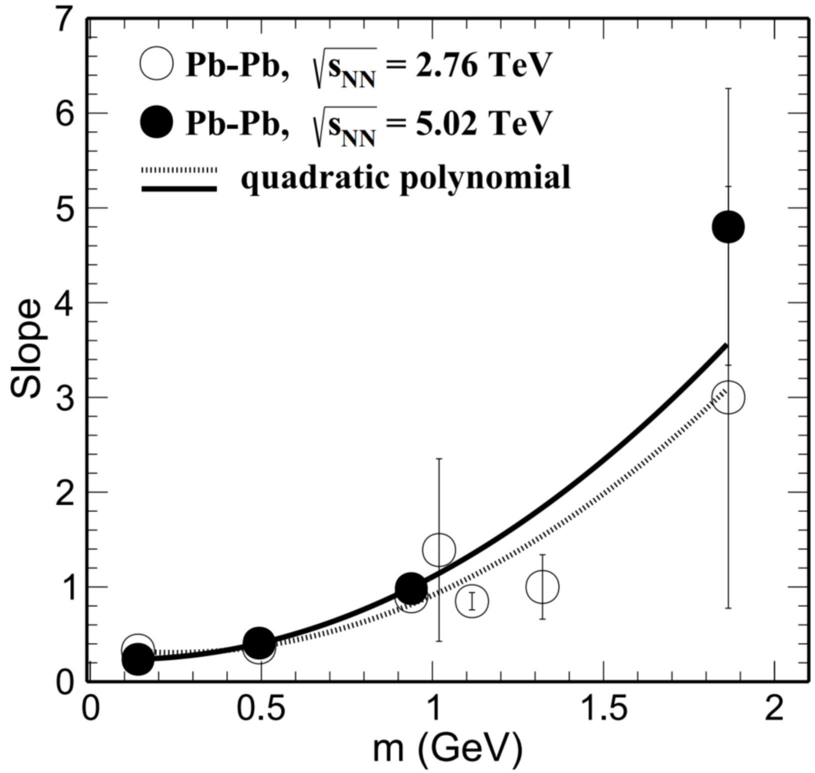
$$\frac{d^2N}{2\pi m_T dm_T dy} = \frac{dN/dy}{2\pi T(m_0+T)} e^{-(m_T - m0)/T}$$



- Light hadrons and strangeness, charmed hadrons clearly follow different grouping
- Charmed and strangeness hadrons may freeze out earlier
- Gain less collective velocity



- Significant linear relationship between $T_{thermal}$ and q-1 parameter
- A higher $T_{thermal}$ required for charmed meson to reach the same degree of non-extensivity as light flavor hadrons in HIC
- For pp($\bar{p}$), $T_{thermal}$ increases with collision energy, but q stops at q-1 = 0.142±0.010
- More peripheral in HIC are less affected by the medium and more similar to pp($\bar{p}$)
- Maybe have grouping phenomenon, more precise data are needed.



- The slope is positively correlated with the hadron mass
- Weakly dependent of the system energy (2.76 and 5.02 TeV).

- Describe charmed meson spectra in pp($\bar{p}$) and PbPb system at a wide p_T range by Tsallis-Pareto distribution

- Extract $T_{thermal}$ by blue shift correction, a higher $T_{thermal}$ required for charmed meson to reach the same degree of non-extensivity as light flavor hadrons

- The slope of T~(q-1) is positively correlated with the hadron mass.

- Describe charmed meson spectra in pp($\bar{\text{p}}$) and PbPb system at a wide p_T range by Tsallis-Pareto distribution
- Extract $T_{thermal}$ by blue shift correction, a higher $T_{thermal}$ required for charmed meson to reach the same degree of non-extensivity as light flavor hadrons
- The slope of T~(q-1) is positively correlated with the hadron mass.

Thank you!

More detailed references are listed below:

Backup

4/14 C. Tsallis, J. Stat. Phys 52, 479 (1988)

5/14 C. Tsallis, Introduction to Nonextensive Statistical Mechanics: Approaching a Complex World. (Springer, 2009)

J Stat Phys 72, 879 (1993)

8/14 Phys.Rev. C 31, 81 (2020)

9/14 J. High Energ. Phys. 2016 81 (2016) ~ 2.76 TeV

J. High Energ. Phys. 2018, 174 (2018) ~ 5.02 TeV

Backup

$$\langle \beta_t \rangle = (0.286 \pm 0.013) + (0.065 \pm 0.006) \log \langle dN_{ch}/d\eta \rangle . \quad (10)$$

The linear dependence for charmed mesons is

$$\langle \beta_t \rangle = (0.129 \pm 0.037) + (0.065 \pm 0.000) \log \langle dN_{ch}/d\eta \rangle . \quad (11)$$

$$T_{thermal} = T \sqrt{\frac{1 - \beta_t}{1 + \beta_t}}$$