Investigation of the heavy-flavour hadronization time-scale using the Tsallis-thermometer

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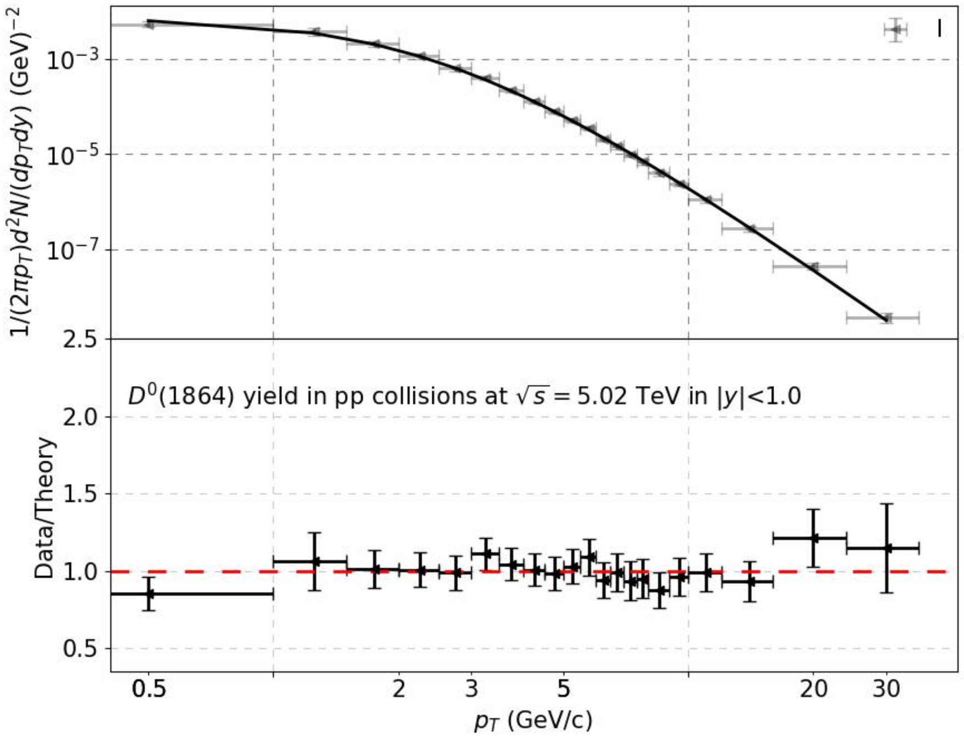
A non-extensive statistical framework

Identified particle spectrum:

- Low-p_T part:
  - soft particle production
  - exponential-like (Boltzmann-Gibbs) distribution
  - stemming from a thermal equilibrium

- High-p_T part:
  - jet-like origin
  - power-law tail distribution
  - described by the perturbative QCD



Tsallis-Pareto distribution smoothly connects the two parts:

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

Motivation for the study

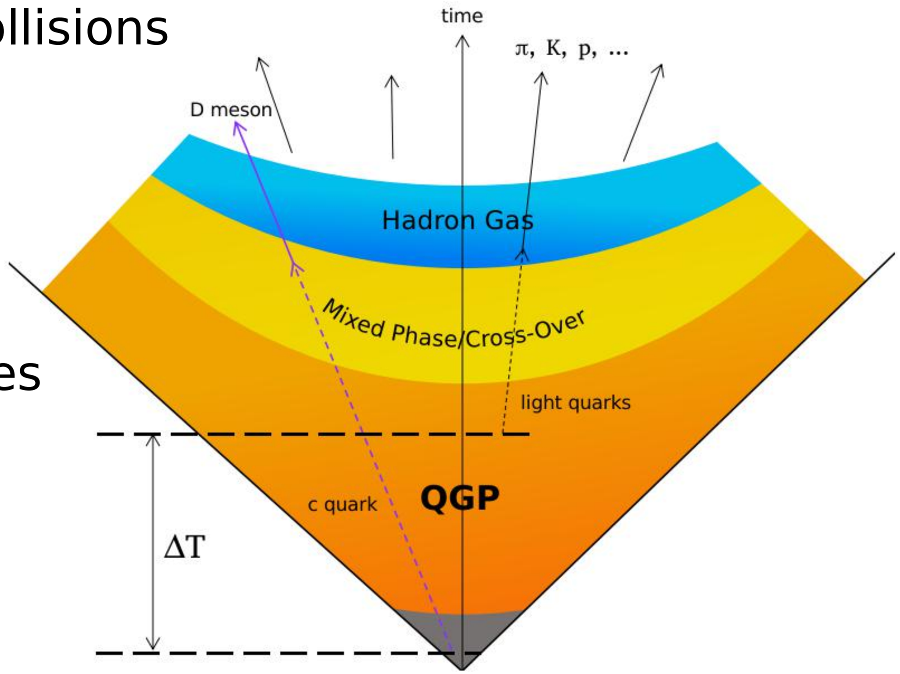
Light-flavoured hadrons (K, π, p, Λ, Φ, Σ, Ξ, Ω) have already been studied in the non-extensive statistical framework in the broad range of collision systems and multiplicities [1]

[1] Arxiv:2003.03278

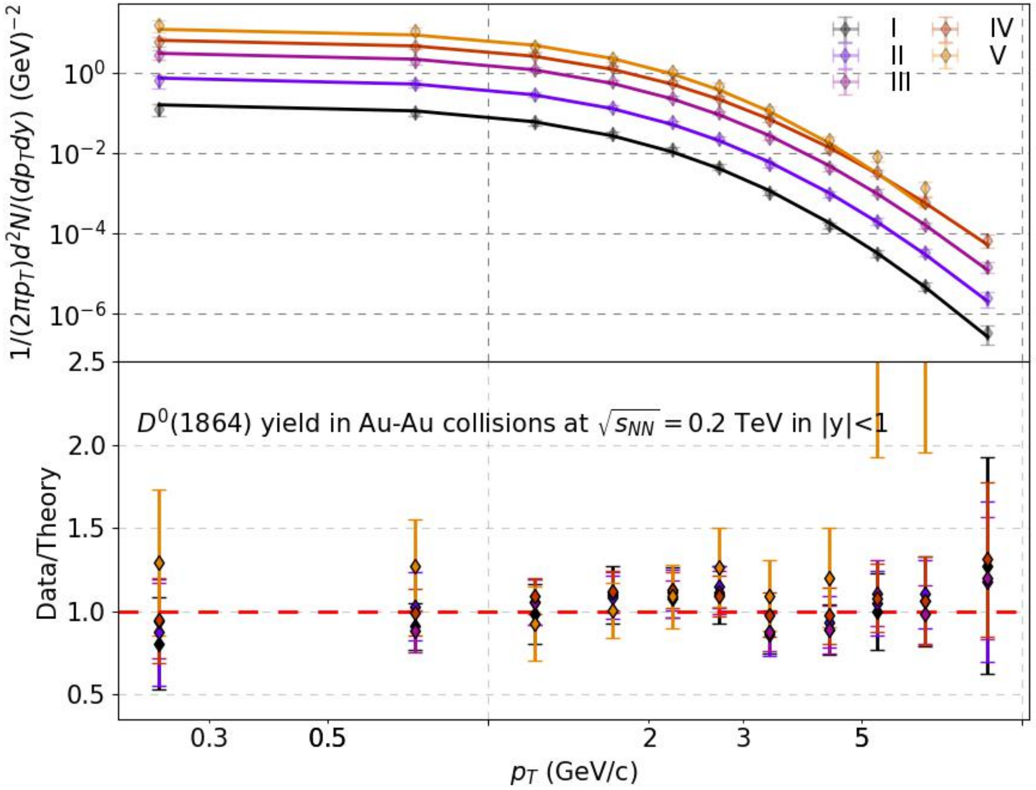
In our study we expand the list of investigated particles with D mesons (containing c quark), which are mostly produced in hard interactions early in the collisions

Our aims are:

- check the feasibility of such a study
- find similarities between light and heavy flavours
- find traces of different production mechanisms and timelines



Investigated datasets



Minimum bias spectra:
- ALICE, pp, 5.02 TeV - D^0, D^+, D^{*+}
- ALICE, pp, 7 TeV - D^0, D^+, D^{*+}
- ALICE, pPb, 5.02 TeV - D^0, D^+, D^{*+}

Centrality (multiplicity) dependent:
- ALICE, PbPb, 2.76 TeV - D^0
  centralities: 0-20%, 40-80%
- STAR, AuAu, 200 GeV - D^0
  centralities: 0-10%, 10-20%, 20-40%, 40-60%, 60%-80%

Tsallis-thermometer

Observation: total charged hadron multiplicity in Tsallis theory follows negative binomial distribution

This is also supported by experimental data

Taking fluctuations of the produced particles n:

$$T = \frac{E}{\langle n \rangle},$$
$$q = 1 - \frac{1}{\langle n \rangle} + \frac{\Delta n^2}{\langle n \rangle^2}$$

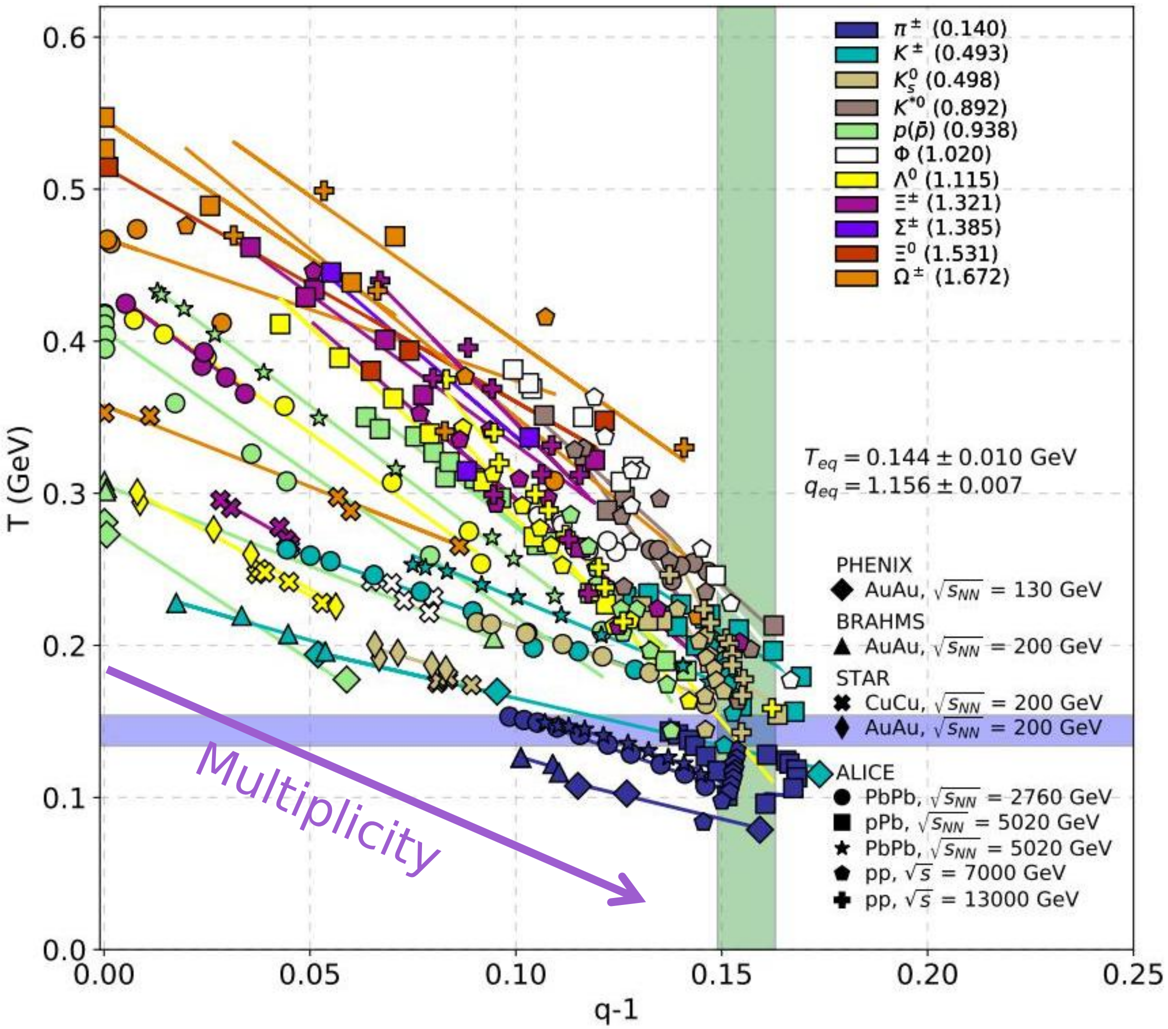
T and q are correlated:

$$T = E\left(\delta^2 - (q-1)\right) \qquad \frac{\Delta n^2}{\langle n \rangle^2} := \delta^2$$

Observations for the light flavours

- Strong dependence on event multiplicity
- Mass hierarchy, stronger towards heavier particles
- All points aiming towards $T_{eq} \approx 0.14$ GeV and $q_{eq} \approx 1.15$

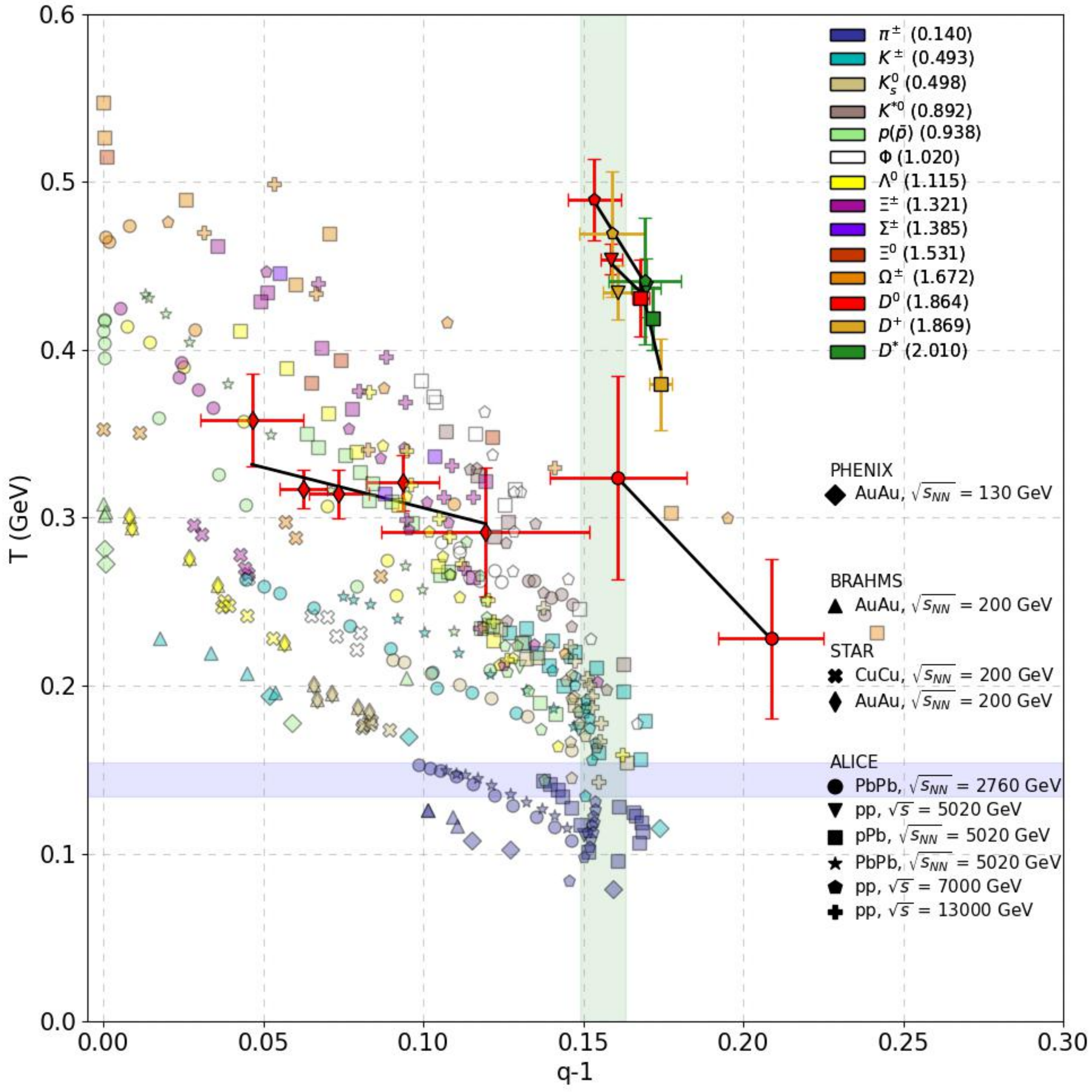
$$T = E\left(\delta^2 - (q-1)\right)$$



D mesons in the Tsallis theory

- Strong dependence on event multiplicity
- Mass hierarchy is even stronger, than for light flavours
- Dependence on the collision energy is more prominent, than for the light hadrons
- A grouping is also present, however the “center” is shifted compared to the light flavours

$$T = E\left(\delta^2 - (q-1)\right)$$



Tsallis-thermometer

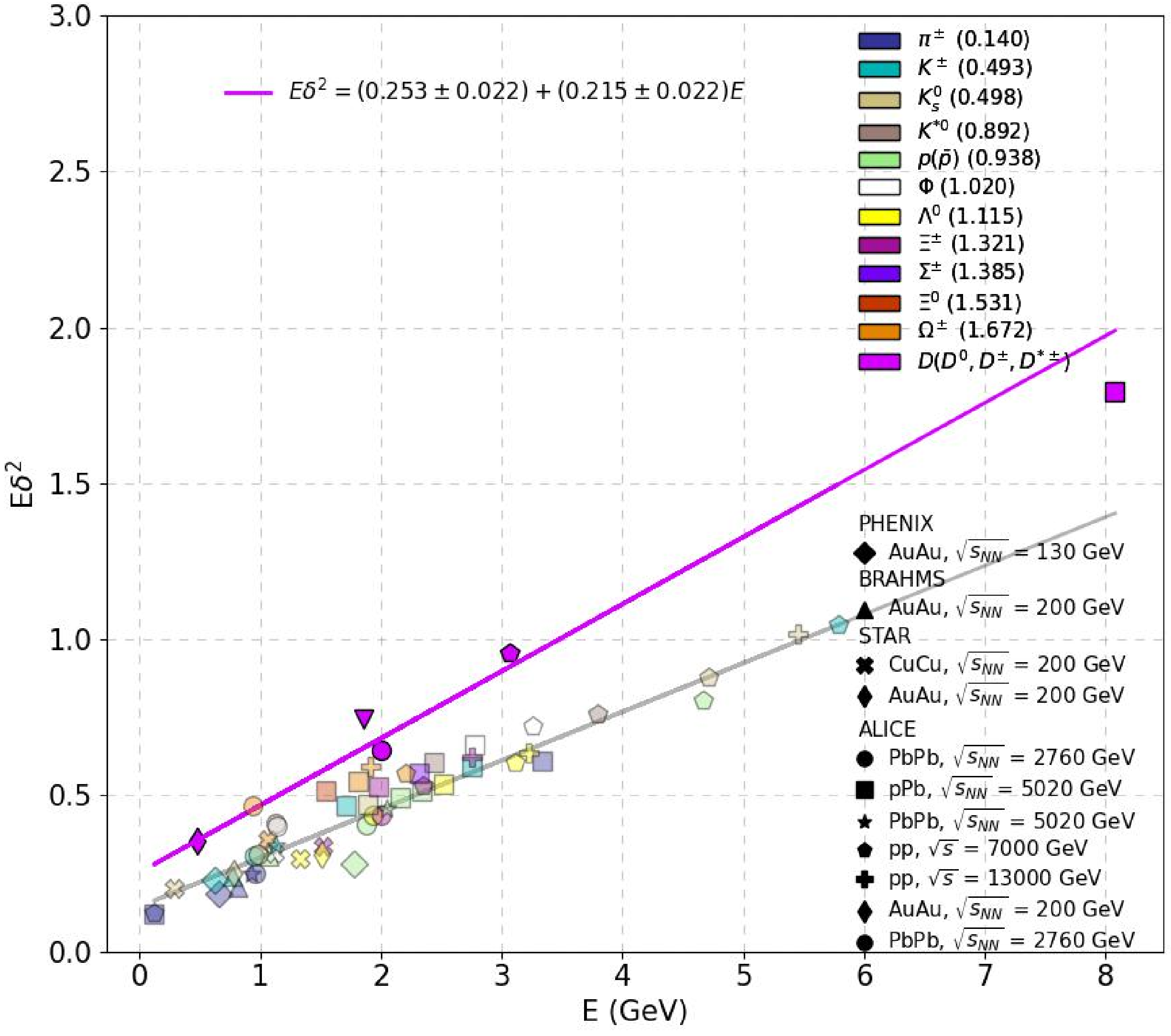
- D mesons reach higher E values
- Fluctuations are stronger on the average

Fitting the E-Eδ^2 points with a line defines the equilibrium values for the T (offset) and q (slope) parameters.

$$T = E\left(\delta^2 - (q-1)\right) \qquad \frac{\Delta n^2}{\langle n \rangle^2} := \delta^2$$

Light flavours: $T_{eq} \approx 0.14$ GeV and $q_{eq} \approx 1.15$

Heavy flavours: $T_{eq} \approx 0.25$ GeV and $q_{eq} \approx 1.21$



Production time-scale differences between light and heavy flavours

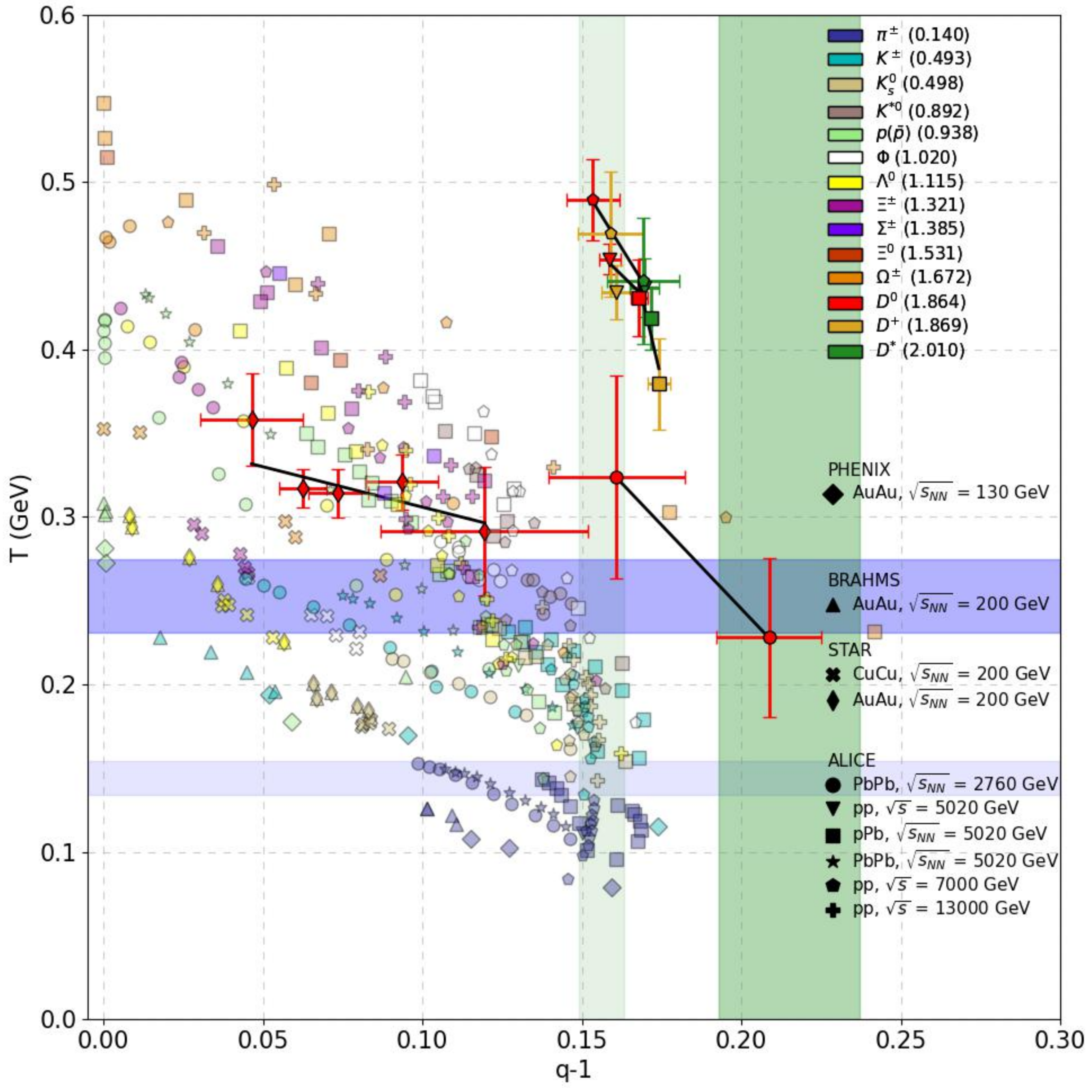
Light flavours: T_{eq}≈0.14 GeV and q_{eq}≈1.15

Heavy flavours: T_{eq}≈0.25 GeV and q_{eq}≈1.21

ΔT_{eq}≈0.11 GeV

pPb 5.02 TeV:
- ΔT(D meson-pion)>0.3 GeV
- ΔT(D meson-proton)>0.2 GeV
- ΔT(D meson-Omega)<0.1 GeV

AuAu 200 GeV:
- ΔT(D meson-light flavour)≈0.10-0.15 GeV

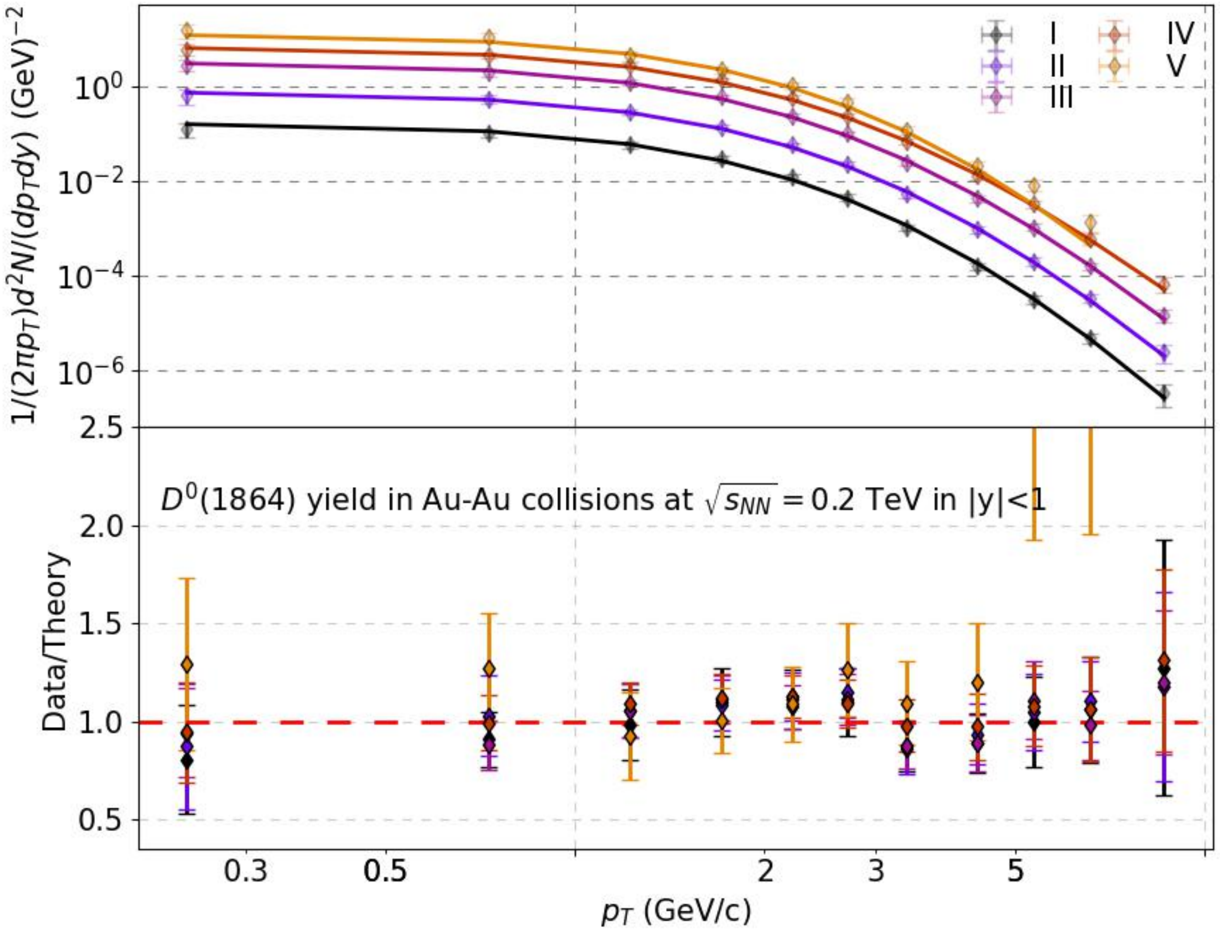


Conclusion

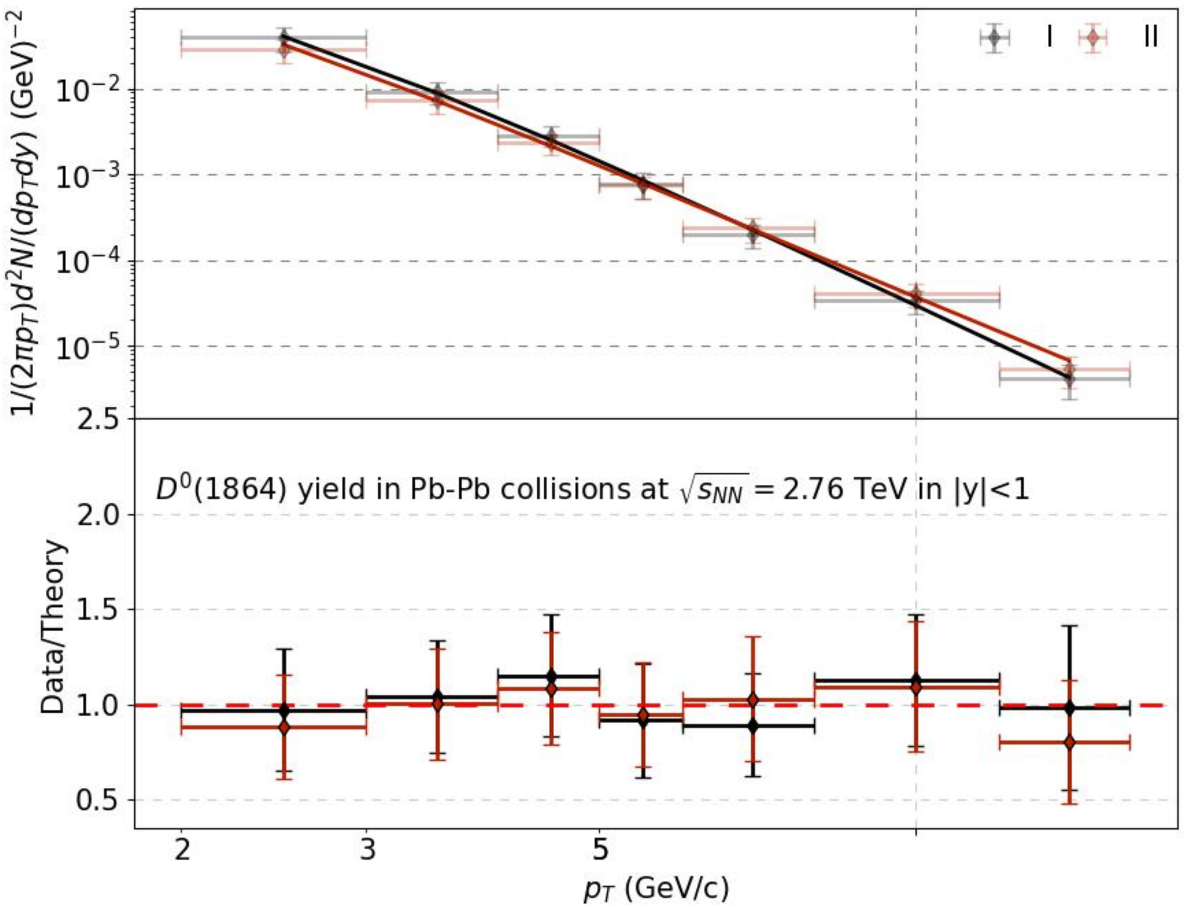
- We extended the non-extensive statistical framework beyond the light flavours
- Broad range of D meson data from ALICE and STAR experiments was used, consisting of 5 different collision systems: from pp to AA, from 200 GeV to 7 TeV, from minimum bias to low and high centralities
- The Tsallis-Pareto fits of the D meson spectra describe precisely both the low-p_T and the high-p_T regions
- Lot of similar trends to the light-flavour hadrons, however having different scale:
  - dependence on multiplicity and collision systems
  - mass hierarchy
  - overall grouping
- The results show that D mesons indeed interact with a hot medium after being produced in the initial stages of a collision

Thank you for your attention!

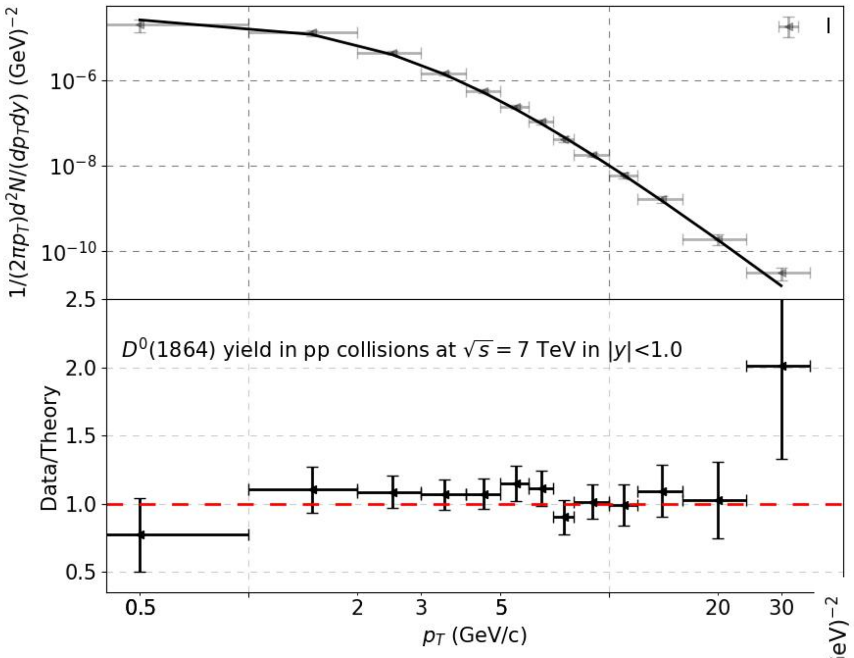
Back-up

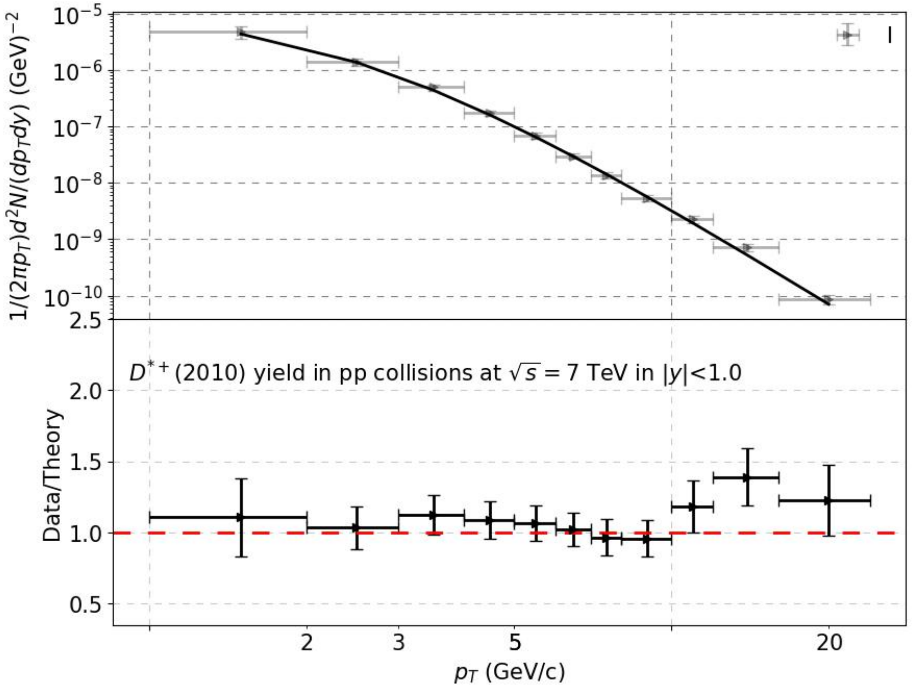


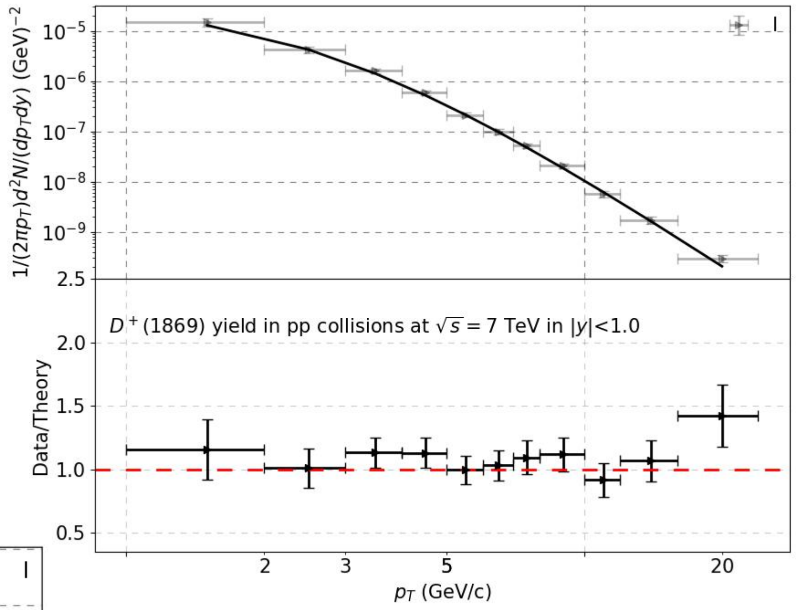
$1/(2\pi p_T)d^2N/(dp_T dy)$ (GeV)$^{-2}$
I
II
III
IV
V
Data/Theory
$D^0(1864)$ yield in Au-Au collisions at $\sqrt{s_{NN}} = 0.2$ TeV in |y|<1
p_T (GeV/c)

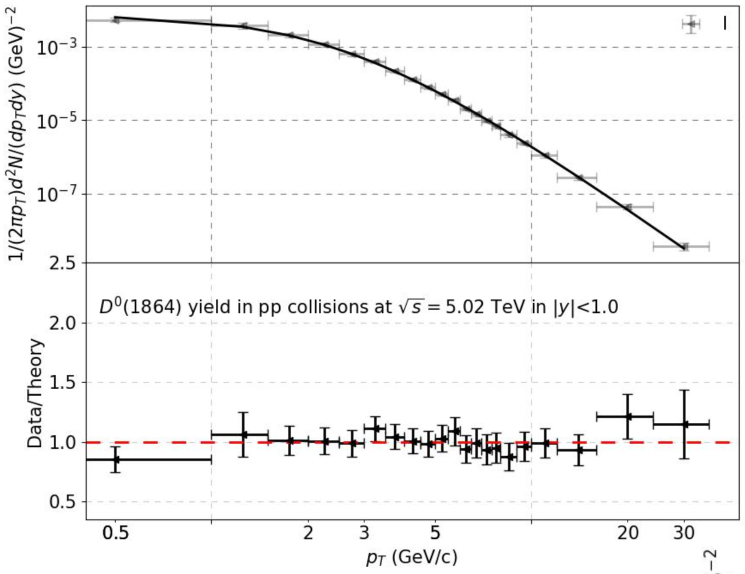


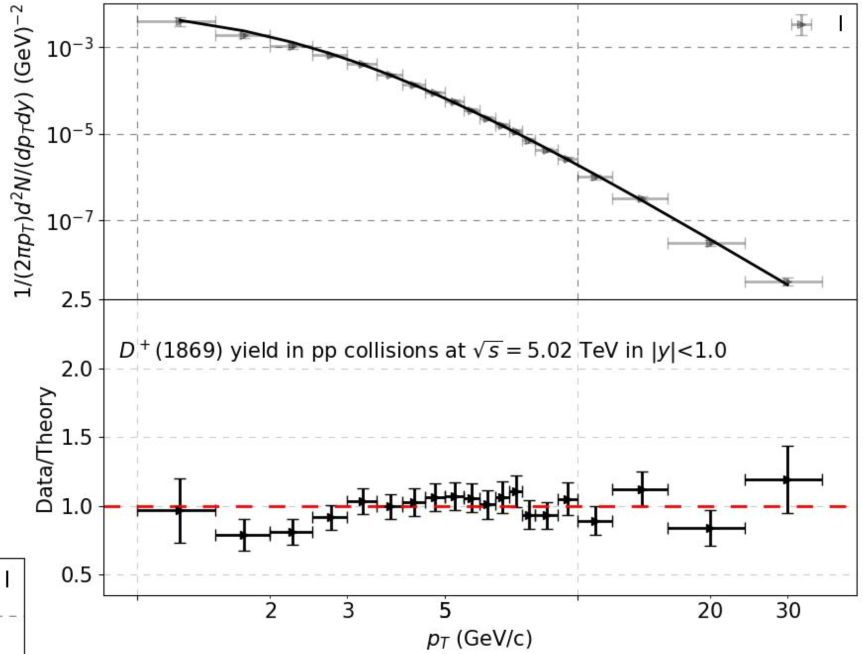
$1/(2\pi p_T)d^2N/(dp_T dy)$ (GeV)$^{-2}$
I
II
Data/Theory
$D^0(1864)$ yield in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in |y|<1
p_T (GeV/c)


$1/(2\pi p_T)d^2N/(dp_T dy)$ (GeV)$^{-2}$
$D^0(1864)$ yield in pp collisions at $\sqrt{s} = 7$ TeV in $|y|<1.0$
Data/Theory
p_T (GeV/c)


$1/(2\pi p_T)d^2N/(dp_T dy)$ (GeV)$^{-2}$
$D^{*+}(2010)$ yield in pp collisions at $\sqrt{s} = 7$ TeV in $|y|<1.0$
Data/Theory
p_T (GeV/c)


$1/(2\pi p_T)d^2N/(dp_T dy)$ (GeV)$^{-2}$
$D^{+}(1869)$ yield in pp collisions at $\sqrt{s} = 7$ TeV in $|y|<1.0$
Data/Theory
p_T (GeV/c)


D^0(1864) yield in pp collisions at $\sqrt{s} = 5.02$ TeV in $|y|$<1.0
$1/(2\pi p_T)d^2N/(dp_T dy)$ (GeV)$^{-2}$
Data/Theory
p_T (GeV/c)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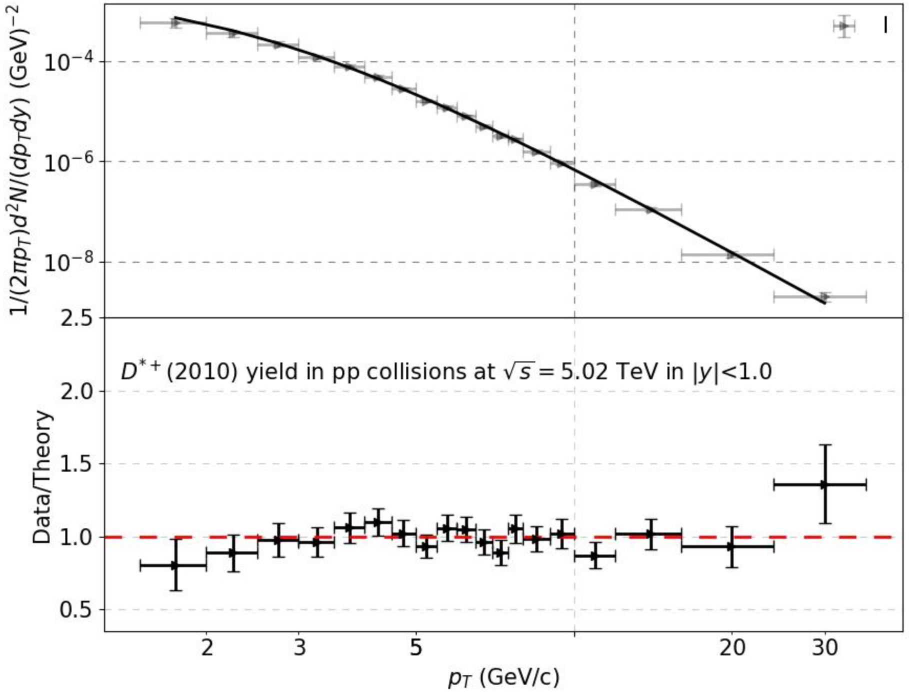
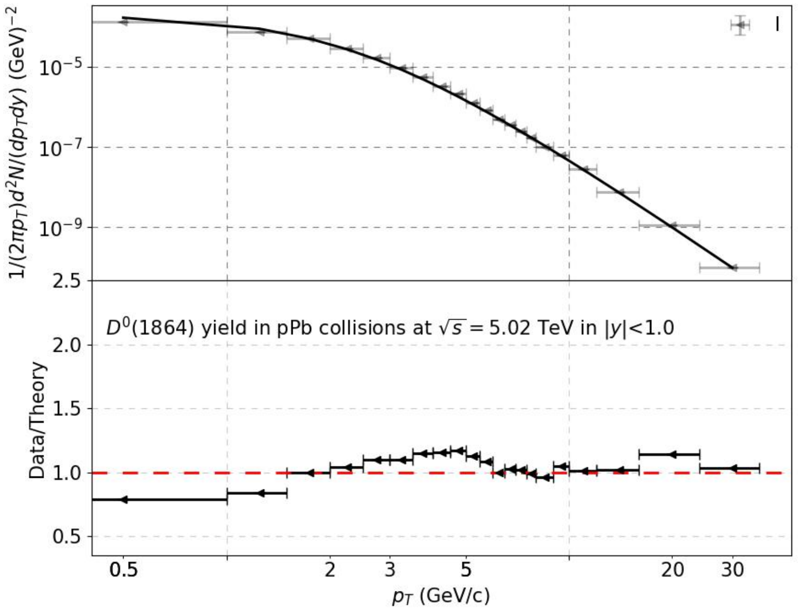
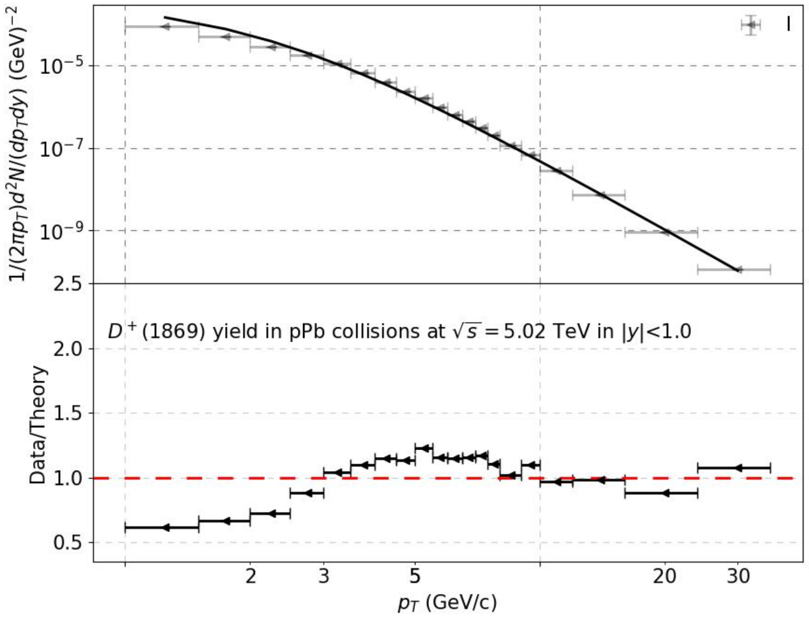

D^{*+}(2010) yield in pp collisions at $\sqrt{s} = 5.02$ TeV in $|y|$<1.0
$1/(2\pi p_T)d^2N/(dp_T dy)$ (GeV)$^{-2}$
Data/Theory
p_T (GeV/c)


D^0(1864) yield in pPb collisions at $\sqrt{s} = 5.02$ TeV in $|y|$<1.0
$1/(2\pi p_T)d^2N/(dp_T dy)$ (GeV)$^{-2}$
Data/Theory
p_T (GeV/c)


D^+(1869) yield in pPb collisions at $\sqrt{s} = 5.02$ TeV in $|y|$<1.0
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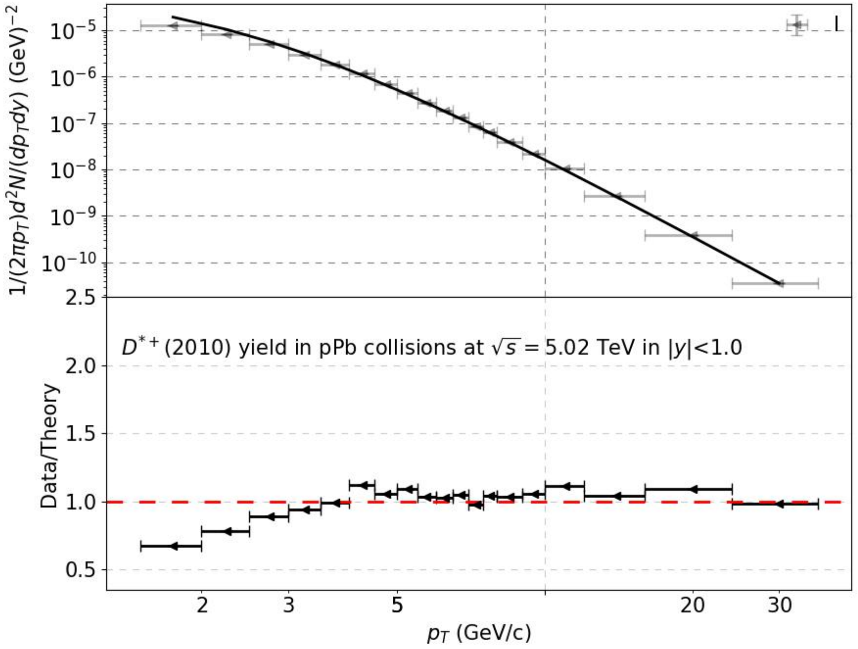
Data/Theory
p_T (GeV/c)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Data/Theory
p_T (GeV/c)

Thermodynamical consistency