The Power of Tsallis-Thermometer as a QGP Indicator for Large & Small Collisional Systems

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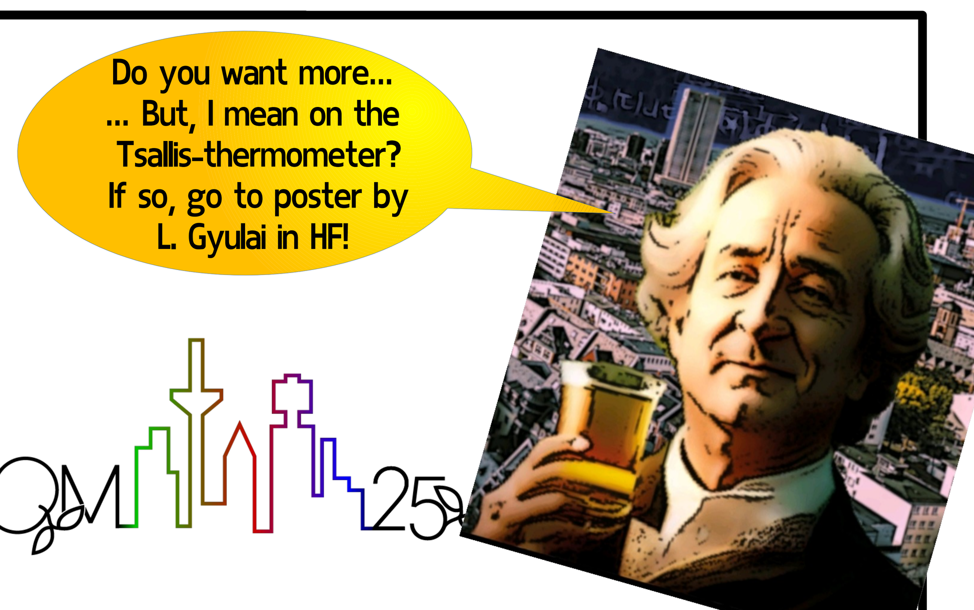


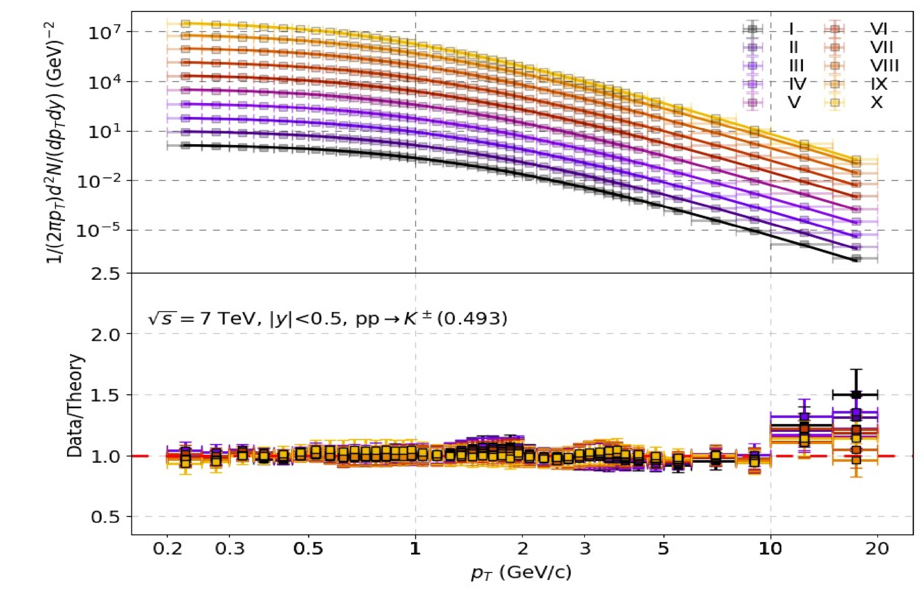
Introduction

Recent experimental results present collectivity also in small systems with high-multiplicity. Today these phenomena are not completely understood: it is an important question whether the presence of the QGP is necessary for the observed collectivity or not. Moreover, the connection between the experimental observables and theories is not trivial. In our phenomenological study we introduce the 'Tsallis-thermometer' as an indicator of QGP, that result in the description of the the smooth transition from small to large collisional systems. The method also works well with geometry-selection of an event and correlates well with spherocity classified events. Results enable us to qualitatively define the underlying event definition beyond the CDF definition.

Tsallis distributions

Thermodynamically consistent fit function:

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



Investigated experimental data:

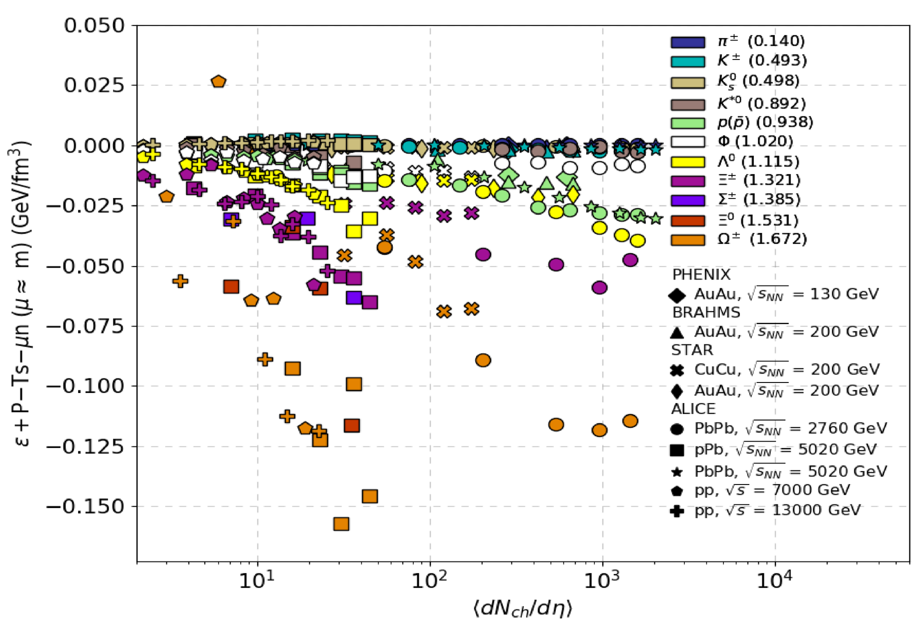
$\pi^\pm, K^\pm, K^0_s, K^{*0}, p(\bar{p}), \Phi, \Lambda^0, \Xi^\pm, \Sigma^\pm, \Xi^0, \Omega^\pm$

$\sqrt{s_{NN}} \in 130$ GeV, 13 TeV

pp, p-A and AA collisions

Various multiplicity classes

Consistency: $\mathrm{P}=\mathrm{T}s+\mu n-\varepsilon$



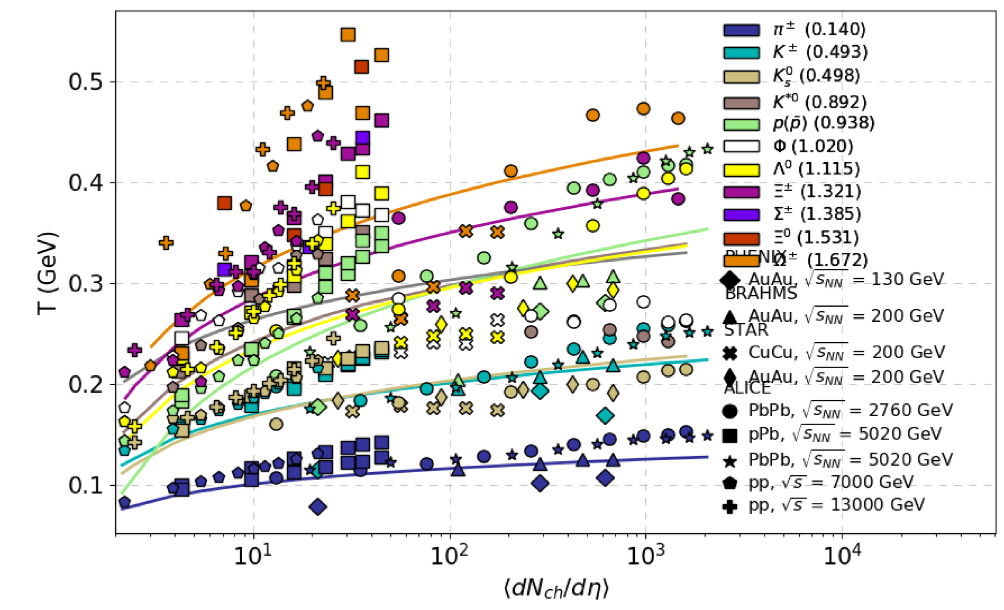
Hadron spectra and multiplicity scaling

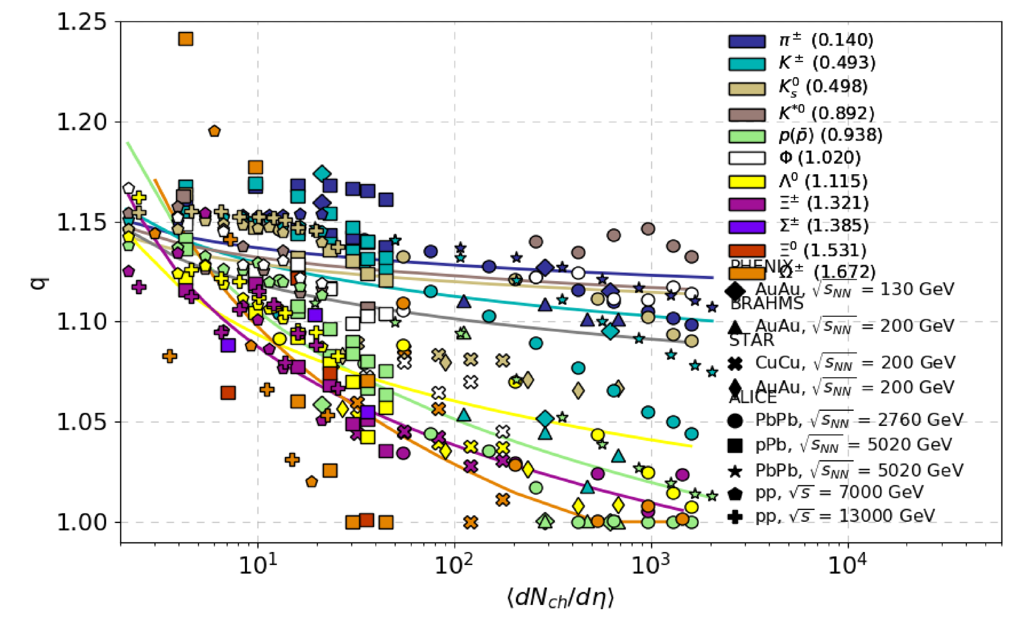
Scaling with multiplicity & center of mass energy

$$T(\sqrt{s_{NN}}, \langle N_{ch}/\eta\rangle, m) = T_0 + T_1 \ln\frac{\sqrt{s_{NN}}}{m} + T_2 \ln\ln\langle N_{ch}/\eta\rangle,$$

$$q(\sqrt{s_{NN}}, \langle N_{ch}/\eta\rangle, m) = q_0 + q_1 \ln\frac{\sqrt{s_{NN}}}{m} + q_2 \ln\ln\langle N_{ch}/\eta\rangle,$$

Strong correlation between the parameters has been recognized as function of multiplicity:

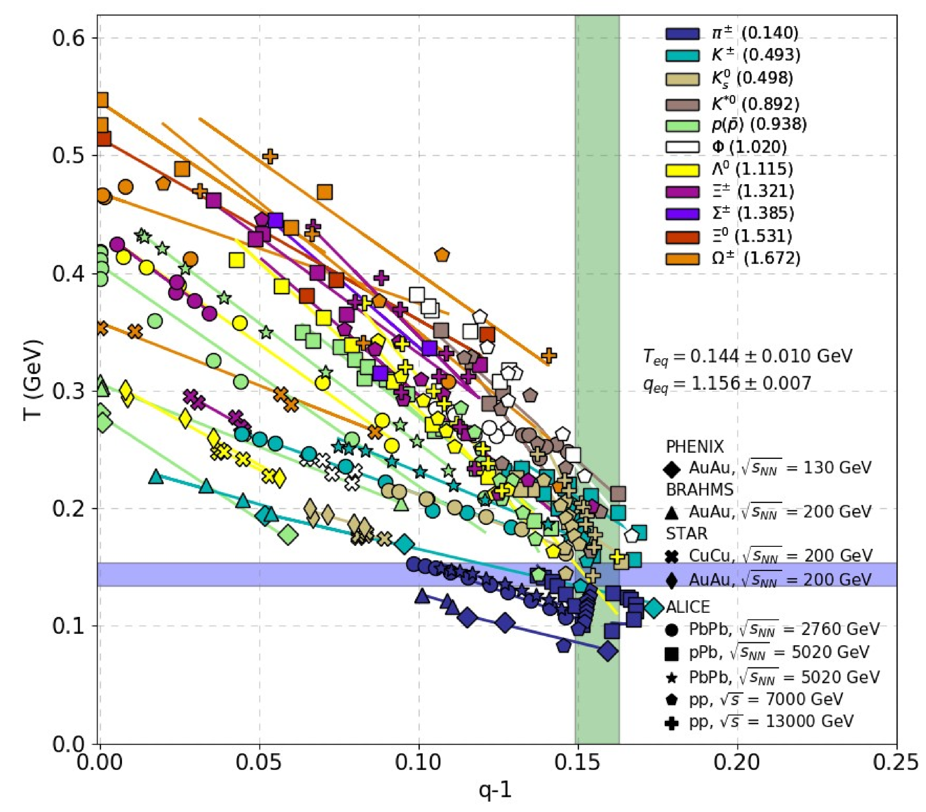


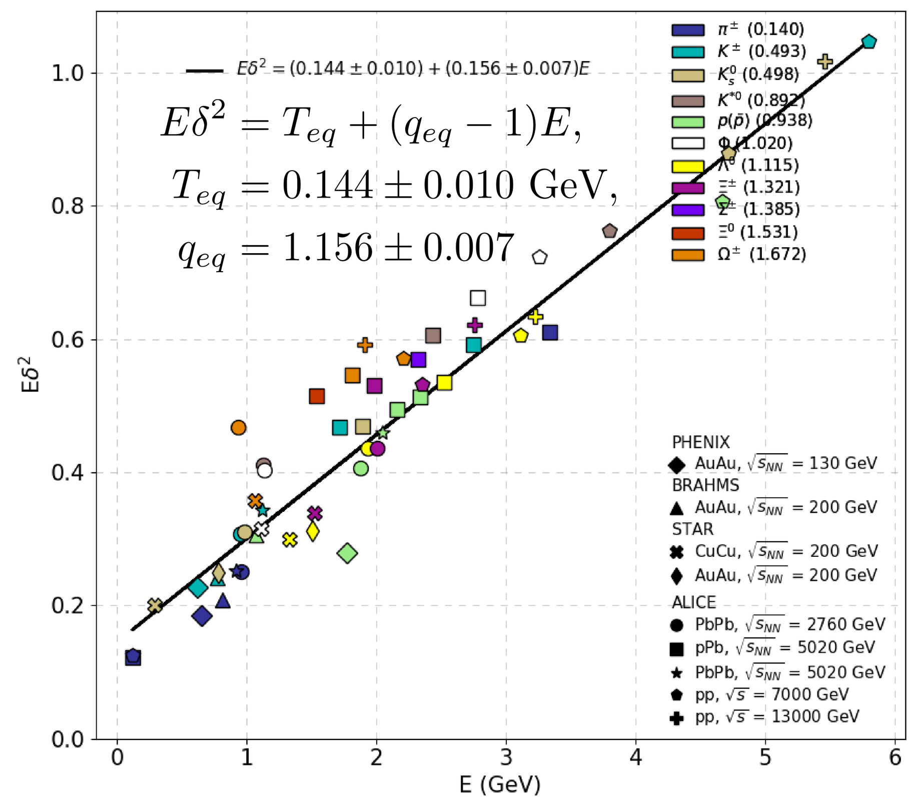


Further correlation with multiplicity fluctuation –

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

THE TSALLIS THERMOMETER ...





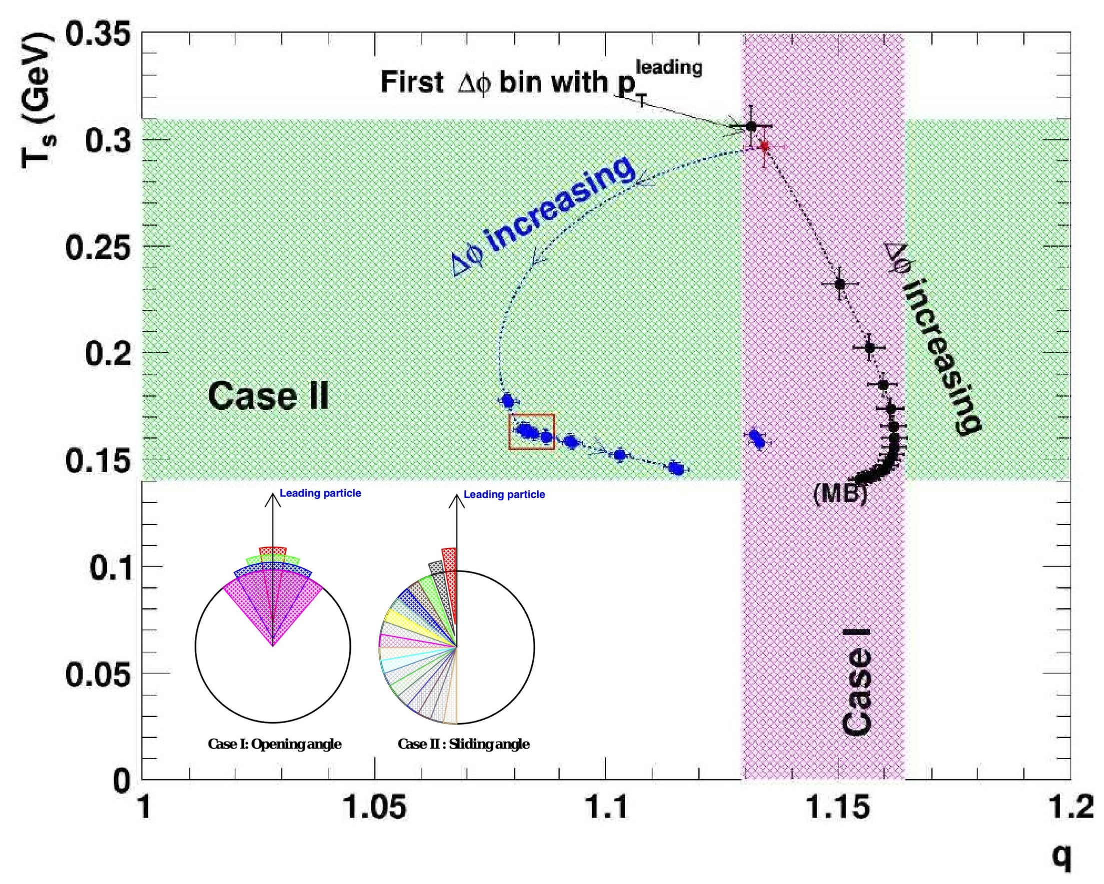
... GIVES YOU MORE:

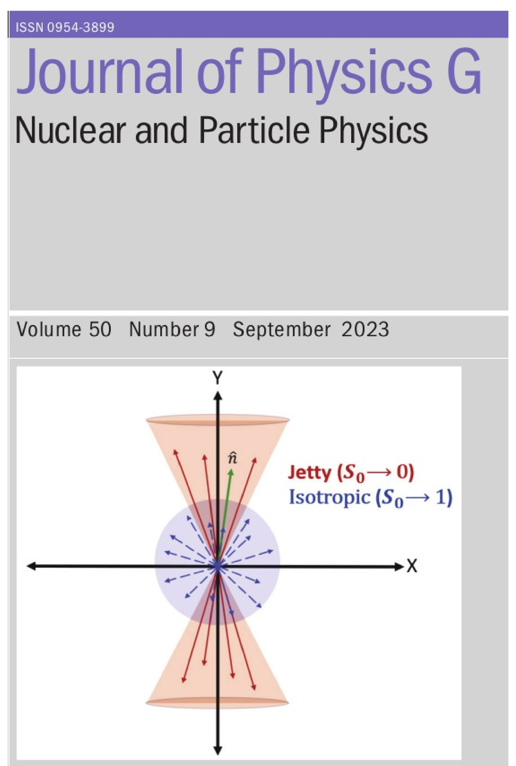
→ TEMPERATURE QUANTITY: *T*

→ INFO ON SYSTEM (SIZE): *q*

Scaling with UE activity

Underlying event activity can be quantitatively seen by the Tsallis thermometer. Geometrical scanning is correlates with spherocity classified events.

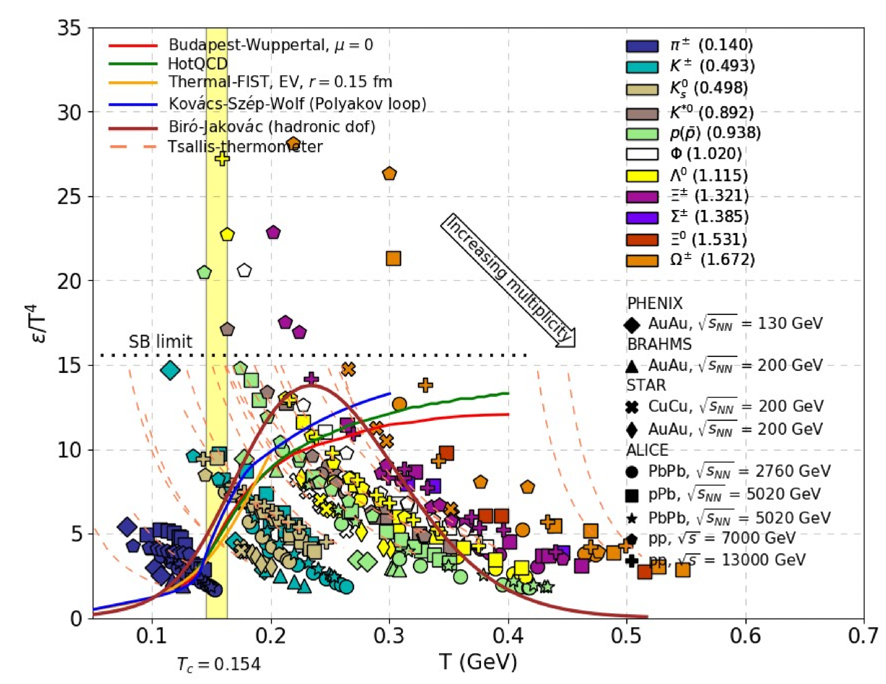


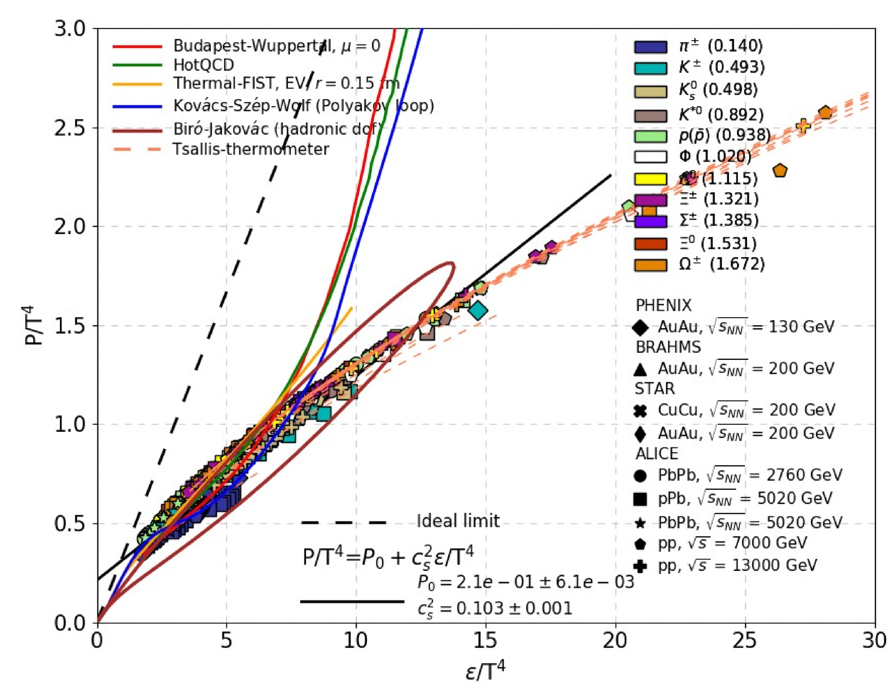


Equation of State

EoS can be obtained, due to the thermodynamical consistency:

→ Hadron mass order
→ Present evolution
→ Branches compatible with hadron d.o.f.





Summary

The Tsallis-thermometer is an excellent measure for locating collective effects in high-energy collisions from small to large system sizes. Scaling behaviors are inherited both from the QCD nature and from system size effects. Thermodynamical consistency helps us to measure EoS more accurately.

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References

[1] G Bíró, GG Barnaföldi, TS Biró, J. Phys. G, 47.10 (2020), 105002.
[2] G Bíró, GG Barnaföldi, K Ürmössy, TS Biró, Á Takács, Entropy, 19(3), (2017), 88
[3] G Bíró, GG Barnaföldi, TS Biró, K Shen, EPJ Web Conf., 171, (2018), 14008
[4] G Bíró, GG Barnaföldi, G Papp, TS Biró, Universe 5 (2019) no.6, 134
[5] AN Mishra, GG Barnaföldi, G Paic, J. Phys.G 50 (2023) 9, 095004