Scaling of kinematic and global observables, along with energy and entropy density in pp, pPb and PbPb collisions

(Summited to Phys. Rev. C)

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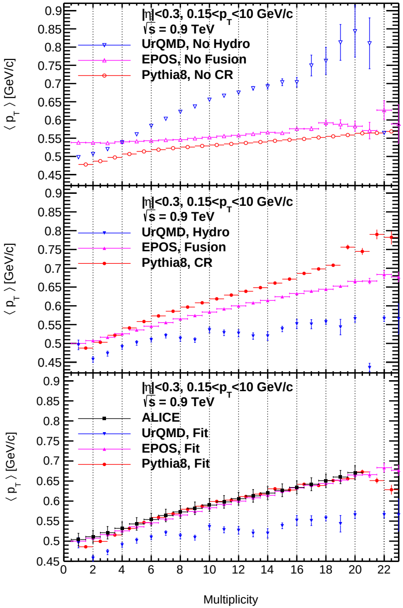
Outline

- Motivation & Main ideas.
- Average transverse momentum and multiplicity.
- Experimental equation of state in $\mathrm{p+p}$ and $\mathrm{p+Pb}$ collisions.
  - Scaling laws: Energy density and $\langle p_\mathrm{T} \rangle$.
- Conclusions & discussion.

Motivation and Main ideas

- The measurements of low-momentum provide information of the non-perturvative QCD.
- High multiplicity $\mathrm{p+p}$ events produce matter that can be describe by thermodynamic where quarks and gluons are degree of freedom.
- The flattening $\langle p_{\mathrm{T}} \rangle$ vs N_{Ch}, allows to study:
  $\rightarrow$ Possible signal for a phase transition in hadronic collisions.
  $\rightarrow$ The EoS (Relation among thermodynamics variables).

$\langle p_{\mathrm{T}} \rangle$, simulation vs data in $\mathrm{p+p}$ collisions

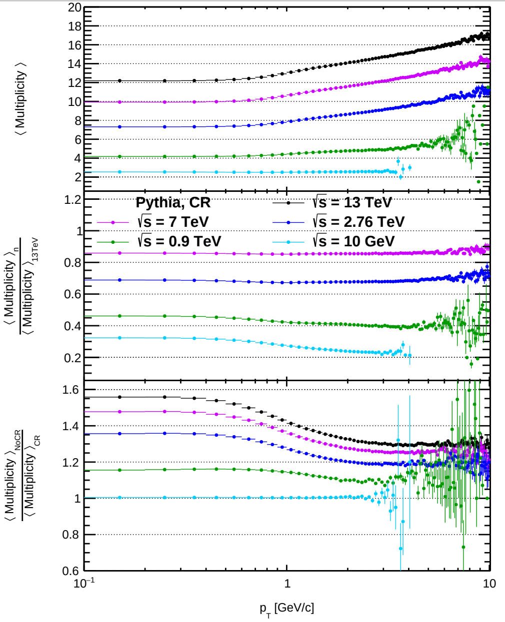


Results show discrepancy among all the Monte Carlo events generators for all p_T ranges.

The distributions withe flow or hydro effects shows an agreement among them at low multiplicity. The disagreement increase when multiplicity does.

The impact parameter affect slightly the results to reproduce ALICE data.

Ratios and mean multiplicity for PYTHIA, $p+p$



- The distributions at lowest energy, 10 GeV, illustrate a flat behavior; meanwhile, when the energy increases, a rising slope appears.

- **EPOS** produces flat ratios for 10 GeV and a positive slope for 900 GeV while **PYTHIA** produces ratios with a negative slope for both energies.

- Large discrepancies are observed in the ratio of average multiplicity calculated with collective effects.

Radio parametrization and normalized multiplicity

$$R_{pPb,pp} = 1fm \times f_{pPb,pp}(\sqrt[3]{dN_g/dy}),$$
$$\frac{dN_g}{dy} \approx K\frac{3}{2}\frac{1}{\Delta\eta}N_{tracks}.$$

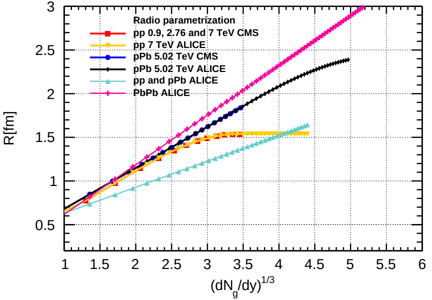
⇒ Radio for $\mathrm{p+p}$ system have a limit in the size. Meanwhile heavier system have a lineal increase.

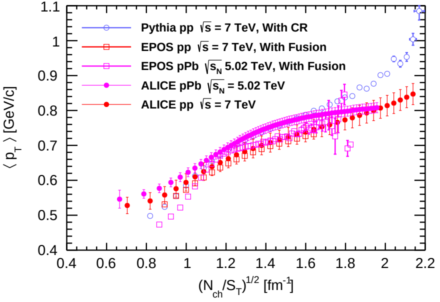
⇒ $\langle p_{\mathrm{T}}\rangle$ has a scaling law when plotted as a function of multiplicity scaled by transverse area.

⇒ Simulation shows a scaling like data.

Nucl. Phys. A 916 (2013), 210-218

Phys. Lett. B 779 (2018), 58-63.

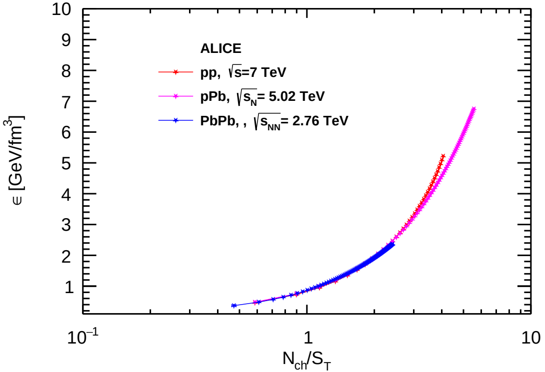




Energy density vs N_{Ch}/S_T

The Bjorken energy density (ϵ_{Bj}) shows scaling laws, it has been used to shows that the enhancement of the strangeness production as a function of ϵ_{Bj} for different colliding systems,

$$\epsilon_{Bj} \simeq \frac{3}{2}\frac{\langle p_T\rangle \frac{dN}{d\eta}}{S_T \cdot \tau}.$$



- A clear scaling law is observed at low multiplicity for all colliding systems.
- $N_{Ch}/S_T \gtrsim 3$ a breaking law appears.

J. D. Bjorken, Phys. Rev. D 27 (1983), 140-151

Energy and entropy for pions, CMS

Phys. Rev. D 33, 3747 (1986)

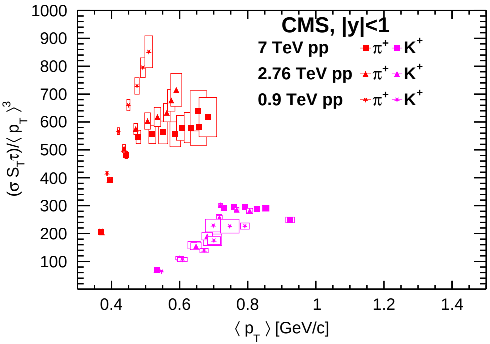
The entropy density (σ) is determined in statistical QCD dynamical quarks as:

$$\sigma \approx \epsilon_{Bj}/\langle p_{\mathrm{T}} \rangle.$$

Considering roughly approximation, $\langle p_{\mathrm{T}} \rangle$ is proportional to the initial temperature **T** , as is deduced in Color string Percolation model.

Eur. Phys. J. C 71, 1510 (2011)

- Kaons show a saturation for higher energy. We can observe a flat behavior for valor higher of $7GeV/c$ for $\langle p_{\mathrm{T}} \rangle$.

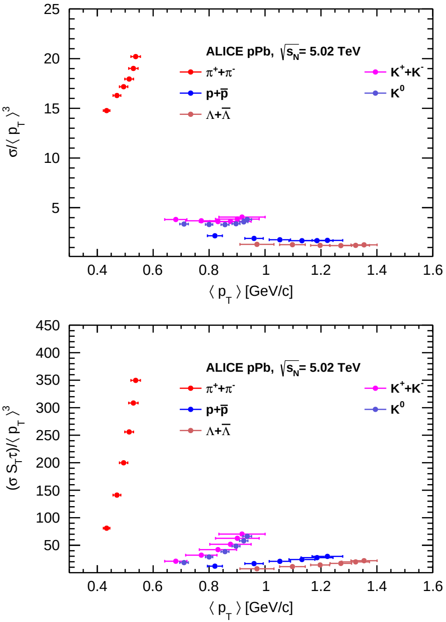


- This entropy ($\sigma S_T \tau$) has a rapid increase for pion at lower energy. If we analyze lower energy we find a saturated behavior in terms of $\langle p_{\mathrm{T}} \rangle$.

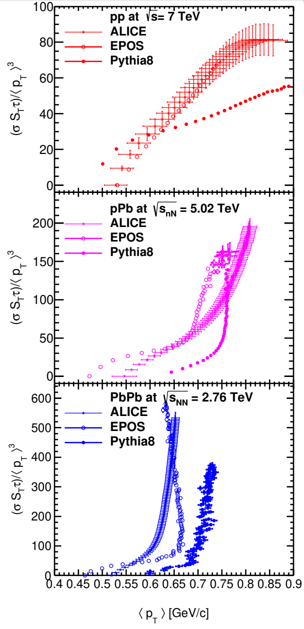
Energy and entropy for pions, ALICE

- $(\sigma/\langle p_\mathrm{T}\rangle^3)$: Heavier hadrons have a flat distribution, meanwhile the lighter meson show a rapid increase.
- $((\sigma S_T \tau)/\langle p_\mathrm{T}\rangle^3)$ a similar trend but a more pronounced growing slopes are observed.

Results are similar for ALICE and CMS for the case of pions, even when there are difference in the multiplicity measure between them.



Ratios and mean multiplicity



- Experimental data from $\mathrm{p+p}$ collisions are well described by **EPOS**, while the **PYTHIA** shows a lower slope with considerable discrepancies when $\langle p_{\mathrm{T}} \rangle$ increase.
- $\mathrm{p+Pb}$ collisions, data and simulation have the same trend, a rapid growth on the slope, around $\langle p_{\mathrm{T}} \rangle \approx 0.7$ for **EPOS** and $\langle p_{\mathrm{T}} \rangle \approx 0.75$ for **PYTHIA** are observed, while data are between both event generators.
- $\mathrm{Pb+Pb}$ colliding system, show a sudden change in the entropy for the data and almost the same trend for the **PYTHIA**, but shifted to higher $\langle p_{\mathrm{T}} \rangle$ values. The **EPOS** event generator produce a larger slope such that distribution cross the data.

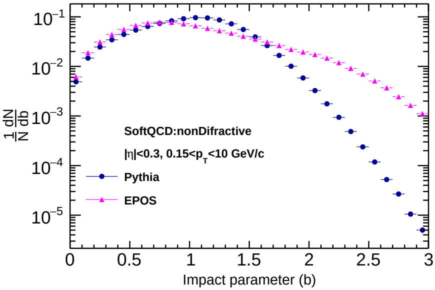
Conclusion & discussion

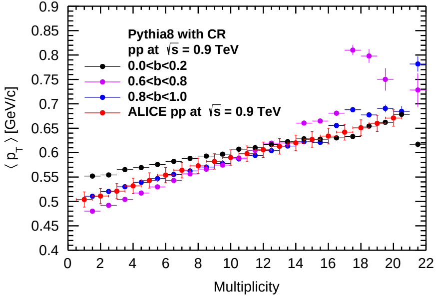
- $\langle p_{\rm T}\rangle$ can be described for the Monte Carlo generators (**EPOS** and **PYTHIA**), using the collective effects.
- Multiplicity is one piece of the puzzle that can not be matched with both generators, using the same inputs that describe the $\langle p_{\rm T}\rangle$.
- Multiplicity distribution normalized to the interaction transverse area is an excellent variable to see a scaling law of the $\langle p_{\rm T}\rangle$ and energy density at lower energies for different colliding systems and energies.
- The abrupt change in $(\sigma S_T \tau)/\langle p_{\rm T}\rangle^3$ when they are plotted as a function of $\langle p_{\rm T}\rangle$, reveals possible phase transitions, however only the $\rm p{+}p$ results from **ALICE** show kind of saturation and the identify for **CMS** in the case of the pions.

Backup

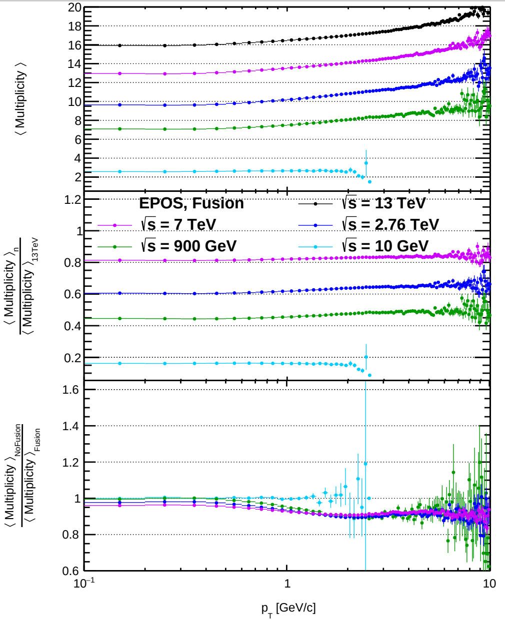
Impact parameter & mean transverse momentum

- Impact parameters of p+p collisions incorporated in two event generators, **EPOS** and **PYTHIA**.
- different ranges of impact parameter produce a slight change in the slope of the $\langle p_T \rangle$.
- However, ranges on the impact parameter by themselves do not allow reproduction of data, and it is worst events with high multiplicity.





Ratios and mean multiplicity for EPOS, p+p

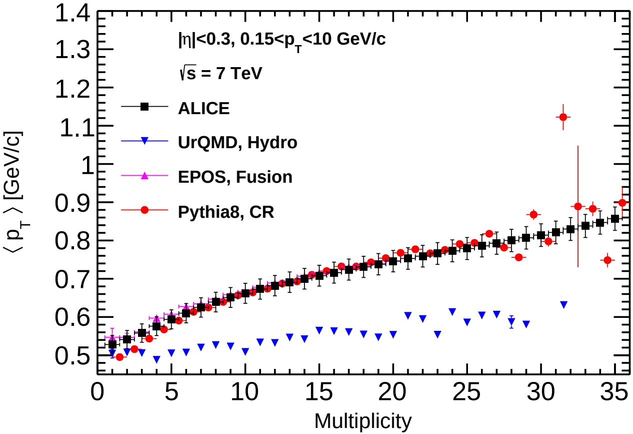


- The distributions at lowest energy, 10 GeV, illustrate a flat behavior; meanwhile, when the energy increases, a rising slope appears.

- **EPOS** produces flat ratios for 10 GeV and a positive slope for 900 GeV while **PYTHIA** produces ratios with a negative slope for both energies.

- Large discrepancies are observed in the ratio of average multiplicity calculated with "effects".

Transverse mean momentum, charge particles ALICE, $\mathrm{p+p}$



Higher energy show a little bit of more of discrepancy for **PYTHIA** and **EPOS** for low and high multiplicity.

The same distribution where each event generator includes flow or hydro effects (middle) shows a better agreement among them at low multiplicity; nevertheless, the disagreement increase when multiplicity does, and larger disagreement for **UrQMD** is seen.