Correlations of net-charge, net-kaon and net-proton in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with ALICE

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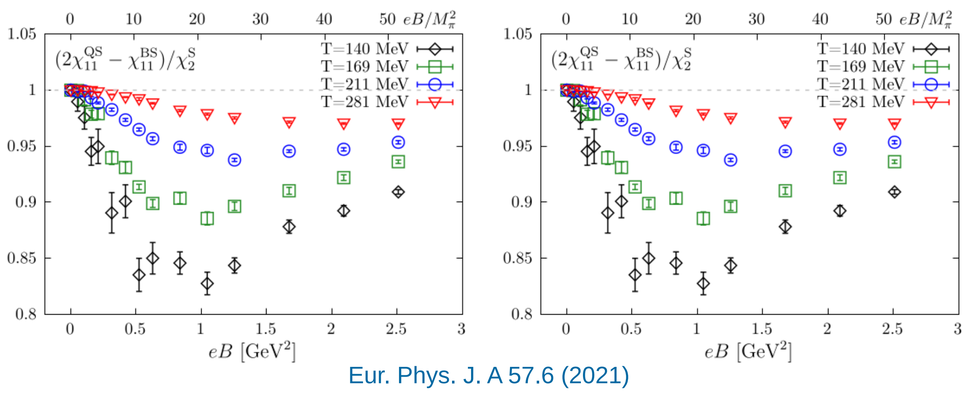
1. Motivation

- Correlations between net-conserved quantities such as net-baryon (*B*), net-charge (*Q*), and net-strangeness (*S*) number show characteristic changes in the crossover region between the low- and high-temperature phases of QCD, which are correlated with changes in the relevant degrees of freedom [1,2].
- They are sensitive probes for the equation of state and can be directly related to the thermodynamic susceptibilities, calculable within the lattice QCD (LQCD) framework [3,4].

$$\chi^{lmn}_{\mathrm{B,S,Q}} = \left[\frac{\partial^{(l+m+n)}(P(\hat{\mu}_\mathrm{B},\hat{\mu}_\mathrm{S},\hat{\mu}_\mathrm{Q})/T^4)}{\partial\hat{\mu}^l_\mathrm{B}\partial\hat{\mu}^m_\mathrm{S}\partial\hat{\mu}^n_\mathrm{Q}}\right]_{\vec{\mu}=0}$$

- Theoretical calculations suggest that the measurement of these correlations can help better constrain the freeze-out parameters [3].

- LQCD computation in the presence of external magnetic fields showed certain combinations of susceptibilities of *B*, *Q,* and *S* can be useful probe for isospin symmetry breaking [5].
- Centrality dependence study of the observables can probe the possible existence of a magnetic field in the early stage of heavy-ion collisions.



Eur. Phys. J. A 57.6 (2021)

2. Observables

- The susceptibilities are related to the cumulants (σ) of the event-by-event distribution of the associated conserved charges.

$$\chi^{lmn}_{\mathrm{B,S,Q}} = \frac{1}{VT^3}\sigma^{lmn}_{\mathrm{B,S,Q}}$$

- Due to the limitation in detecting all baryons and strange hadrons experimentally, net-proton (p) and net-kaon (K) are considered as proxies for the net-baryon and net-strangeness.
- The second-order ($m + n + l = 2$) diagonal and off-diagonal cumulants of *Q*, p, and K multiplicity distributions are expressed as (where α and β can be *Q*, p, or K):

$$\sigma^2_\alpha = \langle(\delta N_\alpha)^2\rangle, \quad \sigma^{11}_{\alpha,\beta} = \langle(\delta N_\alpha)(\delta N_\beta)\rangle$$
$$\delta N_\alpha = (N_{\alpha^+} - N_{\alpha^-}) - \langle(N_{\alpha^+} - N_{\alpha^-})\rangle$$

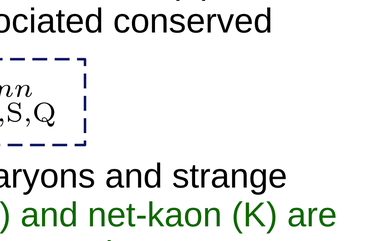
- The correlations of *Q*, p, and K are finally defined as:

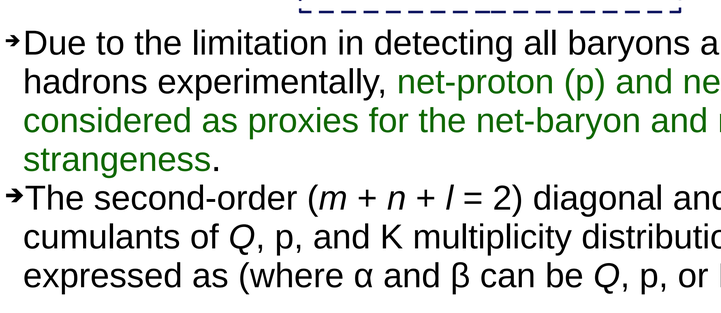
$$C_{\mathrm{p,K}} = \sigma^{11}_{\mathrm{p,K}}/\sigma^2_\mathrm{K},\ C_{\mathrm{Q,K}} = \sigma^{11}_{\mathrm{Q,K}}/\sigma^2_\mathrm{K},\ C_{\mathrm{Q,p}} = \sigma^{11}_{\mathrm{Q,p}}/\sigma^2_\mathrm{p}$$

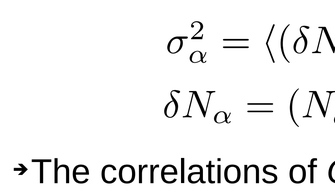
3. ALICE detector

Run 2 data: Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

- V0 (V0A +V0C): trigger and centrality estimation.







- ITS: tracking and vertexing.

- Pions, kaons, and protons are selected using information from TPC and TOF.

4. Correlations between *Q*, K and p

** *Q*: net-charge, K: net-kaon and p: net-proton

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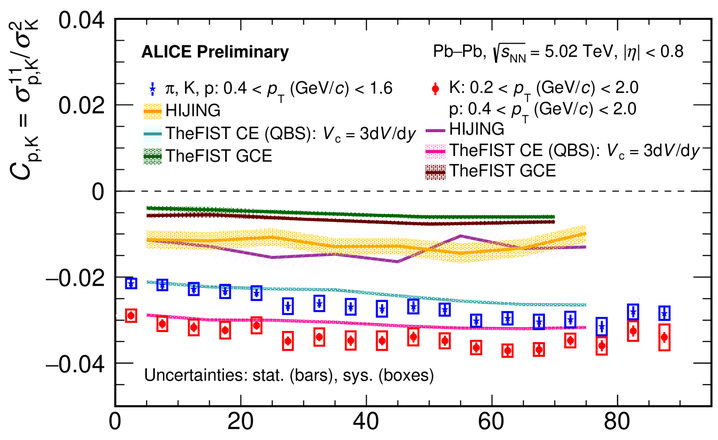
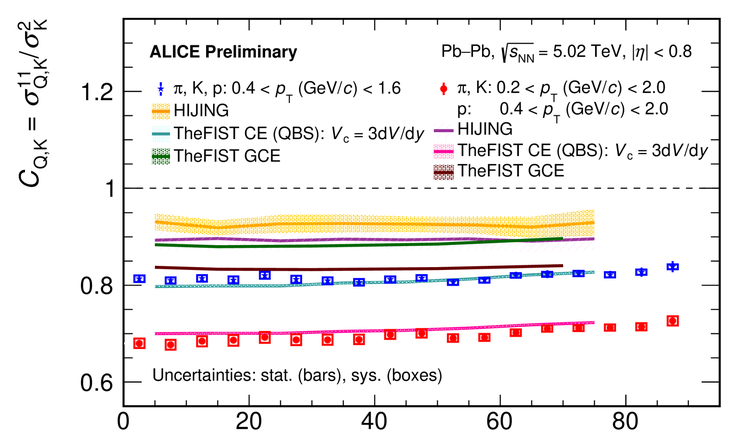


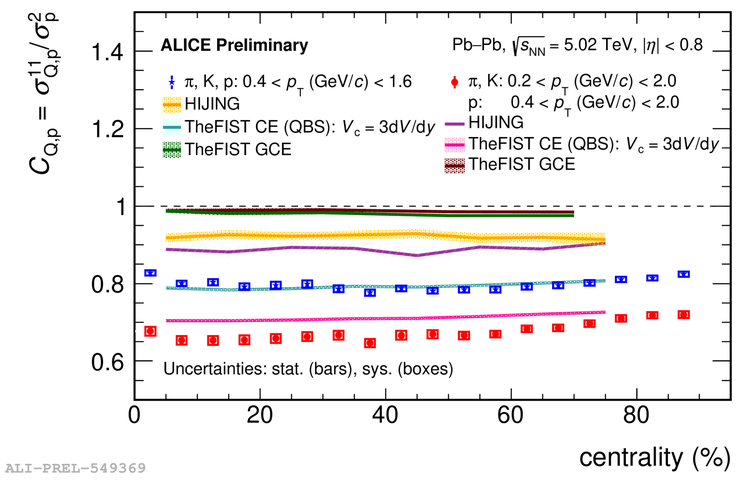


- $C_{\mathrm{p,K}}$, $C_{\mathrm{Q,K}}$ and $C_{\mathrm{Q,p}}$ vs. centrality changes with p_T acceptance.

- Suppressed correlations observed compared to the Poissonian baseline.

- HIJING model predictions overestimate the data.

- Canonical ensemble (CE) treatment of conserved charges in the thermal model is required to explain data.



- V_c = 3dV/dy in Thermal-FIST (TheFIST) [6,7] with *Q*, *B*, *S* conservation seems to favor data.

5. $(2C_{\mathrm{Q,K}} - C_{\mathrm{p,K}})/\sigma^2_\mathrm{K}$ and $(2C_{\mathrm{Q,p}} - C_{\mathrm{p,K}})/\sigma^2_\mathrm{p}$

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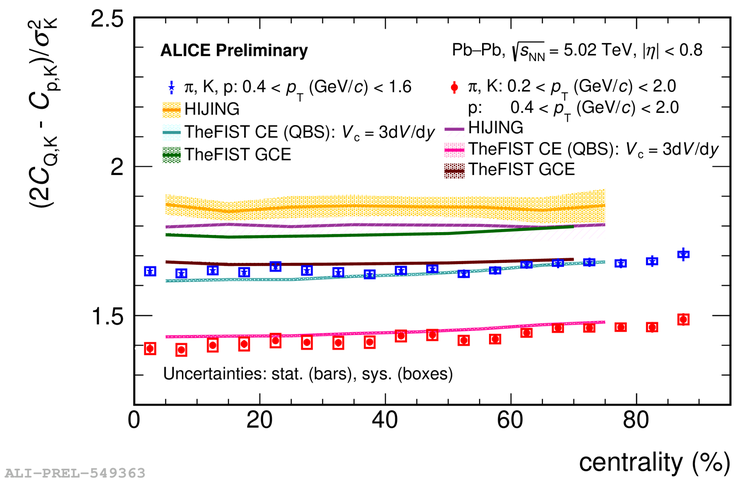

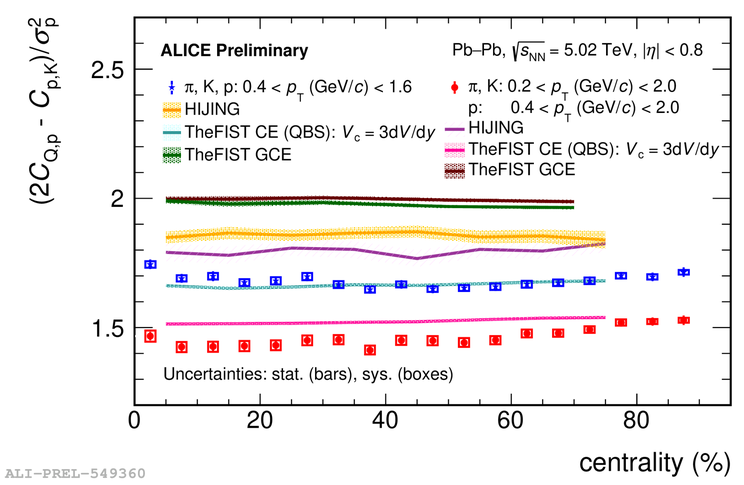

- HIJING, which is based on the Lund string model with a much smaller correlation length, fails to describe the data.

- CE predictions from the thermal model with V_c = 3dV/dy and *Q*, *B*, *S* conservation are in good agreement with the data.

- Slight indication of an increase in the peripheral collisions (70–90 % centrality).

6. Summary

- First measurement of cross-correlations betweeen net-charge, net-kaon, and net-proton ($C_{\mathrm{p,K}}$, $C_{\mathrm{Q,K}}$, and $C_{\mathrm{Q,p}}$) at LHC energies.

- The correlations, $C_{\mathrm{p,K}}$, $C_{\mathrm{Q,K}}$, and $C_{\mathrm{Q,p}}$ are suppressed compared to the Poissonian baseline and expectations from grand-canonical ensemble calculation in the thermal model.

- HIJING model calculations overestimate the data.

- Thermal model (γ_s- CSM in TheFIST) calculations for the charge, baryon, and strangeness number conservation with V_c = 3dV/dy seems to describe data.

References:

[1] B. Friman et al., Eur. Phys. J. C 71 (2011).
[2] F. Karsch et al., Phys. Lett. B 695 (2011).
[3] A. Bazavov et al., Phys. Rev. D 86, 034509 (2012).
[4] S. Gottlieb et al., Phys. Rev. Lett. 59, 2247.
[5] H. T. Ding et al., Eur. Phys. J. A 57.6 (2021).
[6] V. Vovchenko et al., Phys. Rev. C 100, 054906.
[7] V. Vovchenko et al., Comput. Phys. Commun. 244, 295 (2019).