Strange particle production in relativistic nuclear collisions

UNIVERSITY OF BUCHAREST — VIRTUTE ET SAPIENTIA

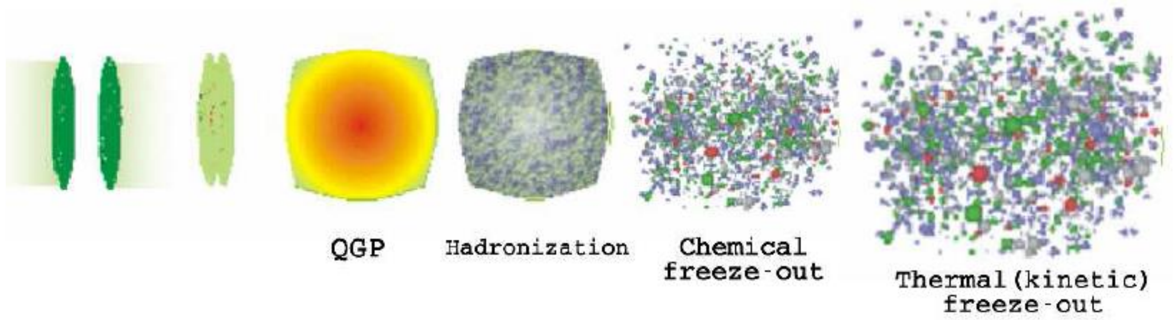
Oana Ristea[1], Catalin Ristea[1,2], Alexandru Jipa[1], Ionel Lazanu[1], Marius Calin[1], Tiberiu Esanu[1,3]

[1]University of Bucharest, Faculty of Physics, [2]Institute of Space Science,

[3]National Institute of Nuclear Physics and Engineering Horia Hulubei, Bucharest-Magurele, Romania

Introduction

High-energy heavy ion collisions provide a unique opportunity to study the nuclear matter under extreme conditions. The hot and dense matter produced in these collisions may evolve through the following scenario: pre-equilibrium, possible formation of QGP, a QGP-hadron gas phase transition, a gas of interacting hadrons, a chemical freeze-out (FO) state when the inelastic processes cease and the particle ratios become fixed and, finally, a thermal freeze-out state when the elastic interactions among the produced hadrons cease and the particles stream freely to detectors.

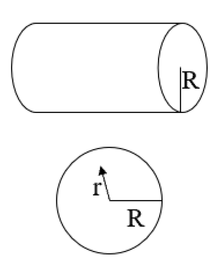


Thermal (kinetic) freeze-out properties of the produced system (i.e. temperature and transverse flow velocity) can be obtained from the analysis of the transverse momentum distributions of the identified charged hadrons.

Blast-wave model

- The model assumes a cylindrical expanding fireball in local thermal equilibrium, in which the particles are locally thermalized at a kinetic freeze-out temperature and are moving with a common transverse collective flow velocity (E. Schnedermann et. al., PRC48 (1993) 2462).
- The p_T spectrum of produced particles is described by:

$$\frac{dN}{p_T\,dp_T} \propto \int_0^R r\,dr\,m_T I_0\left(\frac{p_T \sinh\rho(r)}{T_{\rm kin}}\right) \times K_1\left(\frac{m_T \cosh\rho(r)}{T_{\rm kin}}\right),$$



where T_{kin} is the freeze-out temperature, m_T is the transverse mass, $\rho_T = \tanh^{-1}(\beta)$ and I_0 and K_1 are the modified Bessel functions.

→ The radial flow velocity profile can be parametrized as:

$$\beta = \beta_S (r/R)^n$$

where R is transverse geometric radius of the particle source at freeze-out, β_S is the surface velocity and n is the exponent of flow velocity profile. There are three fit parameters: β_S, T_{kin} and n.

- The average transverse radial flow velocity is:

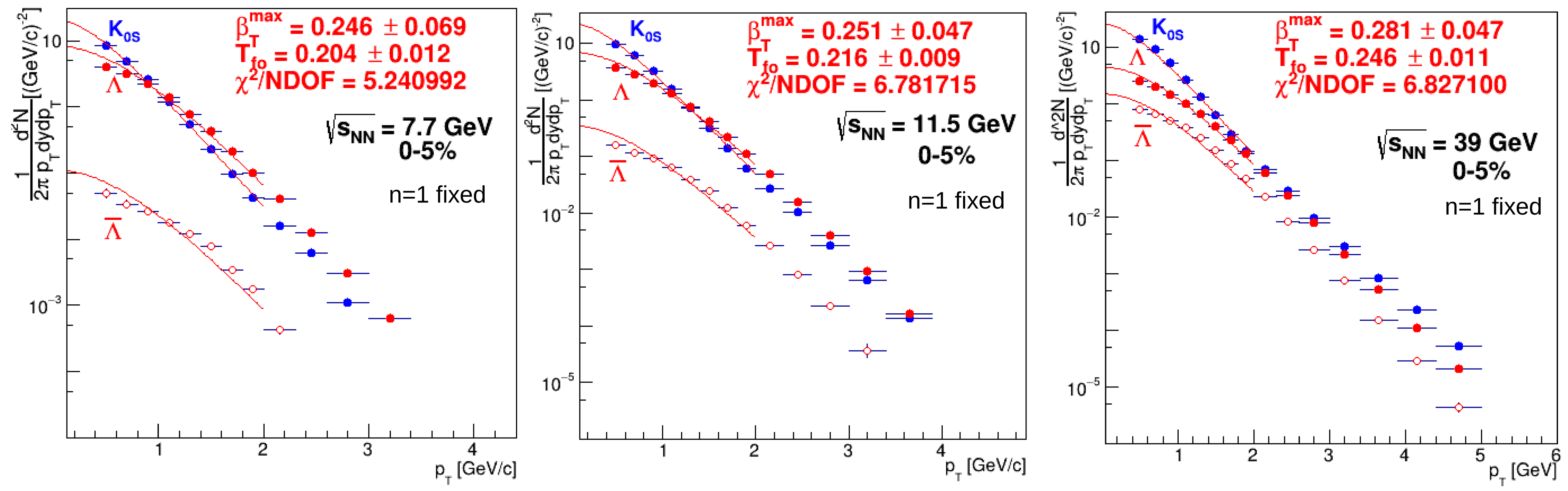
$$\langle\beta\rangle = \frac{2}{2+n}\beta_S$$

- Usually, the p_T spectra of charged pions, kaons and (anti)protons are fitted simultaneously with a single set of parameters → the kinetic freeze-out parameters (T_{kin}, $\langle\beta_T\rangle$, n) of the system.

Blast-wave analysis of strange hadron spectra

The data from SPS and RHIC have shown that the spectra of (multi-)strange particles reflect a higher kinetic freeze-out temperature suggesting an early FO for these particles. This was interpreted as due to diminished hadronic interactions with the expanding bulk matter after chemical FO (NA57 Collaboration, F Antinori et al, J.Phys.G30(2004)823-840; STAR Collaboration, J. Adams et al., Nucl. Phys. A 757, 102 (2005)).

The p_T spectra of K_{0S}, Λ and anti-Λ, produced in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, 27 and 39 GeV from the STAR experiment in the Beam Energy Scan (BES) Program at the Relativistic Heavy Ion Collider (RHIC) were fitted using the BW model (STAR Collaboration, J. Adam et al., Phys.Rev.C 102 (2020) 3, 034909).



Comparison - BW fit results on π±, K±, p and anti-p p_T spectra:

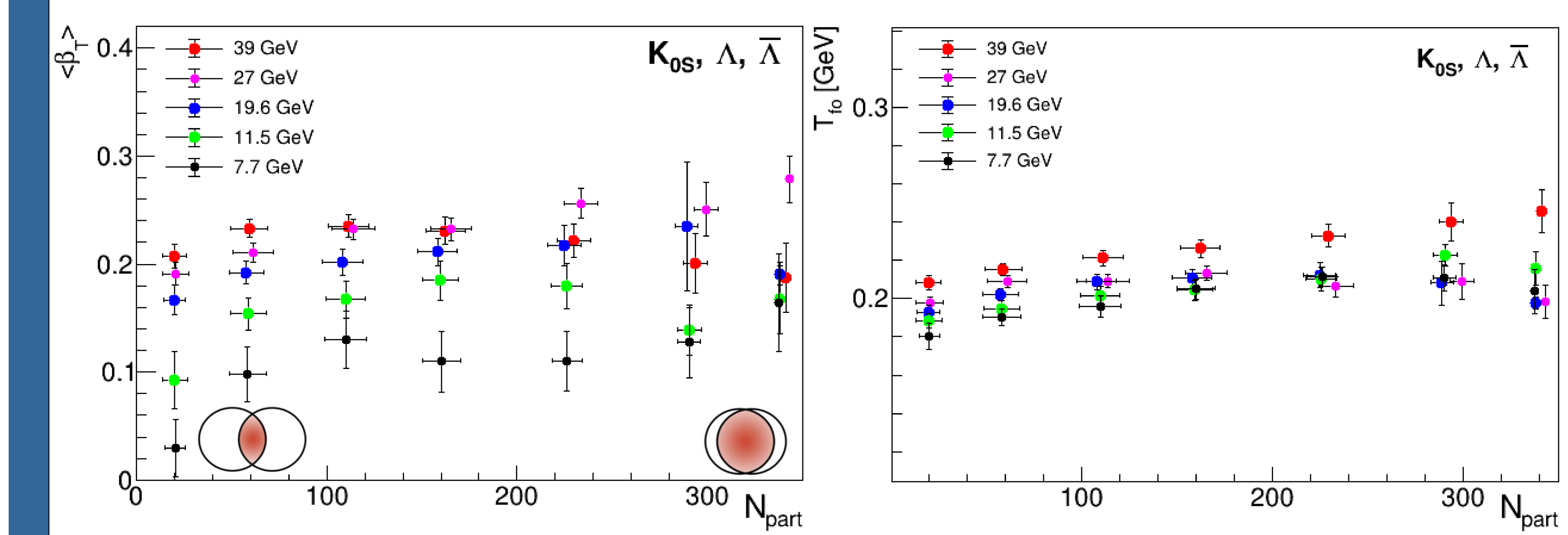
Au+Au, $\sqrt{s_{NN}}$ = 7.7 GeV, 0-5% centrality: T_{kin} = 116 ± 11 , $\langle\beta_T\rangle$ = 0.462 ± 0.043 β_S = 0.578 ± 0.054, n = 0.5

Au+Au, $\sqrt{s_{NN}}$ = 11.5 GeV, 0-5% centrality: T_{kin} = 118 ± 12 , $\langle\beta_T\rangle$ = 0.464 ± 0.044 β_S = 0.580 ± 0.055, n = 0.5

Au+Au, $\sqrt{s_{NN}}$ = 39 GeV, 0-5% centrality: T_{kin} = 117 ± 11 , $\langle\beta_T\rangle$ = 0.492 ± 0.038, β_S = 0.664 ± 0.051, n = 0.7

(STAR Collab. (L. Adamczyk et al.), Phys. Rev. C. 96 (2017) 44904)

Centrality dependence of the BW fit parameters:

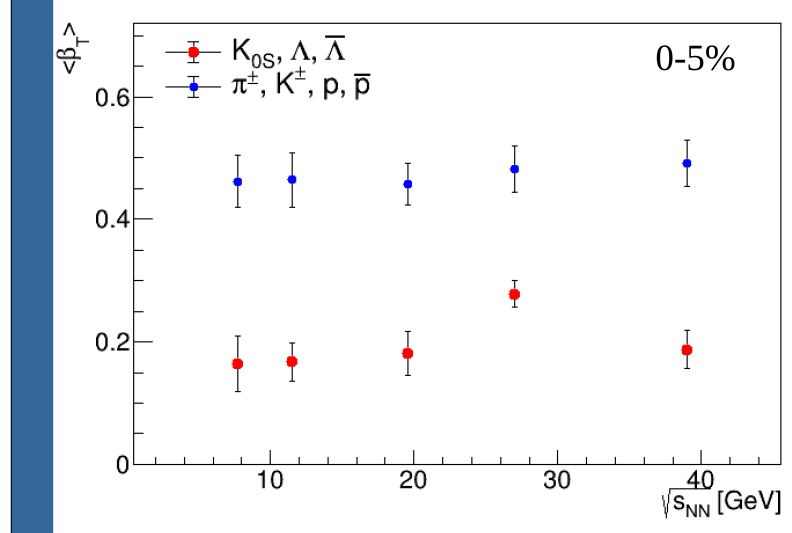


→T_{kin} and average transverse radial flow velocity $\langle\beta_T\rangle$ of these strange hadrons show no sensitivity to the collision centrality

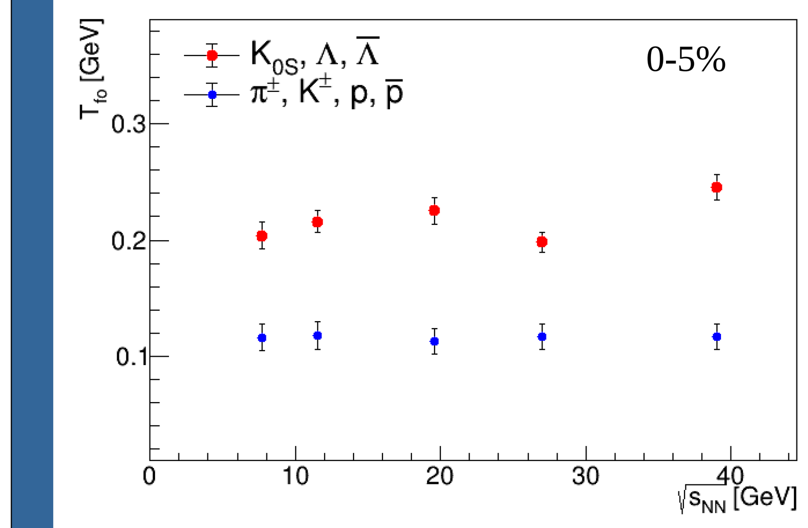
→ for each centrality class, the average transverse radial flow velocity of strange hadrons increases with the energy

→ for a given centrality class, T_{kin} increases very slowly with energy

Energy dependence



→ for all studied energies, $\langle\beta_T\rangle$ obtained from a global BW fit on K_{0S}, Λ, anti-Λ p_T spectra is smaller than $\langle\beta_T\rangle$ obtained by fitting the π±, K±, p and anti-p p_T spectra (STAR Collab. (L. Adamczyk et al.), Phys. Rev. C. 96 (2017) 44904)



→ T_{kin} obtained from K_{0S}, Λ, anti-Λ p_T spectra BW fit is larger than the corresponding value obtained from the π±, K±, p and anti-p p_T spectra fitting, for all energies (STAR Collab. (L. Adamczyk et al.), Phys. Rev. C. 96 (2017) 44904)

→ sequential kinetic freeze-out:

K_{0S}, Λ, anti-Λ → π±, K±, p and anti-p

→ K_{0S}, Λ, anti-Λ decouple earlier in the system evolution than the other particle types (π±, K±, p and anti-p), having a smaller common transverse flow velocity

Conclusions

- This analysis suggests an early decoupling for strange particles (K_{0S}, Λ, anti-Λ) → the system cools and has an expansion of increasing magnitude with energy and a sequential decoupling of particles dictated by their hadronic cross-sections.
- Very weak centrality dependence for Tkin and $\langle\beta_T\rangle$, indicating similar freeze-out conditions in these collisions.
- Transverse flow velocities increase with energy, but the values are smaller than the values from π, K, p BW fits
- Lower thermal freeze-out temperatures are measured at lower beam energies

Acknowledgements

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