PROCEEDINGS OF SCIENCE

Statistical hadronization applied to particle yields in p+p collisions at $\sqrt{s}$ = 17.3 GeV

Krzysztof Piasecki[a,*] **and Tomasz Matulewicz**[a]

[a] *Institute of Experimental Physics, Faculty of Physics, University of Warsaw Pasteura 5, Warsaw, Poland*

E-mail: krzysztof.piasecki@fuw.edu.pl

The statistical hadronization model ThermalFist was applied to 17 hadron yields measured in p+p collisions at $\sqrt{s}$ = 17.3 GeV. Recently published yields of ϕ, $K^{\star}(892)^0$, Ξ, $\overline{\Xi}$, and $\Xi(\overline{\Xi})^0(1530)$, measured by the NA61/SHINE Collaboration were accounted for. We consistently used the energy-dependent widths of Breit-Wigner mass distributions of hadronic resonances, as this attempt was found to provide better agreement with experimental data. Several variants of the model were applied to the data, including the canonical treatment of either (i) all the yields or (ii) those with open strangeness, and the grand canonical approach for the rest. For the full data set only the latter approach gave moderately reasonable agreement with data. This result points to the larger volume of strange particles compared to non-strange ones, weakly supported by femtoscopic analyses at higher collision energies. The unjustified removal of the well established experimental ϕ meson yield provided good fit quality for both canonical and strangeness-canonical approaches.

**** Particles and Nuclei International Conference - PANIC2021 ****
**** 5 - 10 September, 2021 ****
**** Online ****

*Speaker

PoS(PANIC2021)242

1. Introduction

Predictions of the statistical hadronization model have been compared to the yields of hadrons emitted from heavy-ion (AA) collisions for over three decades, and the results are marked with great success [1, 2]. To some surprise, this model also describes quite well the hadron yields from elementary collisions like p+p interactions at the top SPS energy [3, 4]. The approach bases on the hypothesis of thermal equilibrium of all hadrons, that at the freeze-out time occupy certain volume. The system is also assumed to conserve all the relevant physical quantities within one of three variants: as an average of events (Grand-Canonical Ensemble, "GCE"), with strict conservation of all the quantities except energy which is constant on average (Canonical Ensemble, "CE"), and without any exceptions (Microcanonical Ensemble). At beam energies ranging from SIS18 to SPS, the production of strangeness is found to be low compared to that of non-strange bulk. Three approaches to the strangeness production have been usually proposed:

- undersaturation of yields of hadrons with strange quarks, parameterized by factor γ (<1 if yields are found to be lower than the values expected at equilibrium). A systematics of γ parameters [5] shows that values are below 1 for p+p collisions at all the energies up to LHC.
- assumption that the volume occupied by strangeness is different than that occupied by the non-strange bulk. The volumes are often represented in terms of effective radii of spheres ("R_C" for the strangeness, and R for non-strange matter).
- "SC" (strangeness-canonical) approach combining the CE applied to hadrons with non-zero strangeness, and GCE for the rest of matter.

2. Analysis

We investigated the yields of hadrons emitted from p+p collisions at available energy of $\sqrt{s}$ = 17.3 GeV, carried out first by the NA49 Collaboration, and then by its successor, NA61/SHINE. We take note of the previous extensive analysis for this system [3]. Since that time, several yields of hadrons emitted from this system were released [6]: ϕ and $K^\star(892)^0$ mesons and Ξ and $\Xi(1530)$ baryons and their antiparticles, K^0_s was submitted for publication.

In this contribution, continuing the statistical hadronization analysis presented in [4], we report on the updated calculation, where all experimental data available now are accounted for. The results concerning the same hadrons, obtained independently by NA49 and NA61/SHINE collaborations, were merged in a consistent procedure described in [4], accounting for the correlations. For the analysis we used the Thermal-FIST code [7]. The list of particles included also the light nuclei up to ^{4}He and their respective hypernuclei. For the calculation of thermodynamical parameters we excluded the charmed hadrons, as their influence was found negligible. We consistently use the energy-dependent widths of Breit-Wigner distributions of masses of hadronic resonances. We found this approach to improve a bit the quality of comparison to the experimental results [4]. This is an important correction compared to the previous analyses devoted to this system.

We performed the calculations in two scenarios. For the first one (called "CE") the canonical ensemble was applied to all the hadrons. For the second one ("SC") it was used only for hadrons with non-zero strangeness, whereas the rest was described within the "GCE" approach. We have checked the effect of setting the R_C radius free or fixing it at the value of R. For all the calculations, the γ_S undersaturation parameter was fitted freely. As in previous analyses the effect removal of ϕ meson yield, which resulted in a drastic improvement of χ^2 per NDF, was also checked.

For each scenario an inclusion of energy-dependent width of Breit-Wigner distribution resulted in an increase of temperature by about 8 MeV and baryo-chemical potential (μ_B) by about 10 MeV.

The parameters of best fits to the experimental data in different scenarios are shown in Table 1. Variants with R_C fixed to R, as well as the default calculation within the "CE" approach, result in unacceptably high values of χ^2 over NDF. These approaches should therefore be excluded. Default calculation within the "SC" approach results in a χ^2/NDF value of 3.4; too high to claim the agreement, but significantly better compared to other attempts. An interesting feature of this calculation is the value of R_C within 3 standard deviations higher than R. This scenario is currently unrejectable by all three available femtoscopic analyses from p+p collisions, although they were obtained at higher available energies ($\sqrt{s} \in [27.4 - 900]$ GeV) (see the discussion and references in [4]). We confirm that also for the present analysis an exclusion of ϕ meson yield results in a clear drop of χ^2/NDF to the value of 2.0, close to be accepted. The ϕ meson yield has been consistently measured by NA49 and NA61/SHINE collaborations. Without any known theoretical arguments to treat this meson in a specific manner, we are not in a position to distinguish this result among all others. Therefore we chose the default "SC" scenario, for which we present the comparison of measured and calculated multiplicities and best-fit parameters in Figure 1. It is worth to notice four orders of magnitude span in multiplicites between pions and doubly-strange baryons (they apparently manifest the largest deviations).

Scenario	T (MeV)	μ_B (MeV)	R (fm)	R$_C$ (fm)	γ_S	χ^2/NDF
			Grand Canonical - Strangeness Canonical (SC)			
Default	173.6 ± 2.7	245.3±3.9	1.35 ± 0.06	1.70 ± 0.09	0.418±0.010	41 /12 = 3.4
$R_C = R$	169.9 ± 2.8	245.7±3.8	1.46 ± 0.07		0.454±0.009	140 /13 =10.8
no ϕ	179.9 ± 3.0	252.7±4.4	1.21 ± 0.06	1.21 ± 0.06	0.90 ±0.10	21.6/11 = 2.0
			Canonical (CE)			
Default	177.3 ± 3.2		1.37 ± 0.07	1.38 ± 0.07	0.424±0.009	129 /13 = 9.9
$R_C = R$	177.9 ± 3.1		1.36 ± 0.07		0.423±0.008	130 /14 = 9.3
no ϕ	184.5 ± 3.1		1.22 ± 0.06	1.20 ± 0.06	0.504±0.011	23.9/12 = 2.0

Table 1: Values of best fits of statistical model to the experimental yields of hadrons from p+p collision at $\sqrt{s}$ = 17.3 GeV evaluated in different scenarios within SC and CE approaches (see text for details).

3. Summary and conclusions

Several yields (ϕ, $K^\star(892)^0$, Ξ, $\overline{\Xi}$, and $\Xi(\overline{\Xi})^0(1530)$) from p+p collisions at $\sqrt{s}$ = 17.3 GeV, recently reported by the NA61/SHINE Collaboration, were incorporated in statistical hadronization model ThermalFist, aiming to reproduce the multiplicities of 17 hadrons. Several variants of the model were applied to the data. The unjustified removal of the well established experimental ϕ meson yield provides a good fit quality for both canonical and strangeness-canonical approaches.

PoS(PANIC2021)242

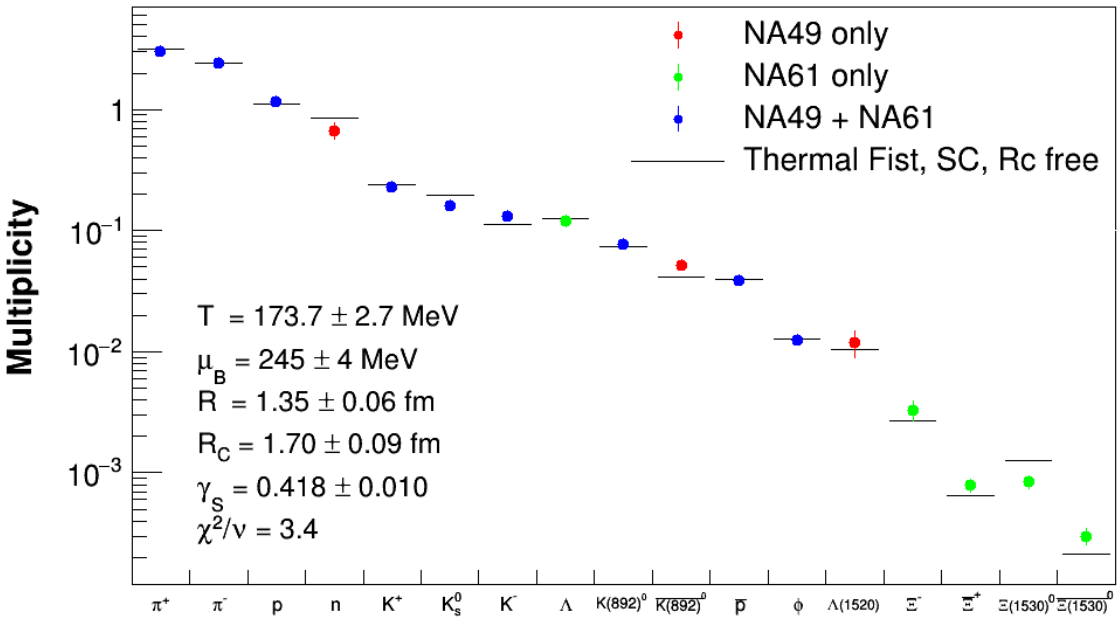

Figure 1: Results of statistical hadronization model fit (black lines) to the experimental yields (full dots) of hadrons from p+p at $\sqrt{s}$ = 17.3 GeV. The "SC" scenario was used, see text for details.

We find that without removal of this yield the only possibly appropriate variant is the strangeness-canonical approach, where the R_C radius is not fixed to R. This result points to the larger volume of strange particles compared to non-strange ones, weakly supported by femtoscopic analyses at higher collision energies. The femtoscopic analysis of $\pi\pi$ and KK pairs from p+p collisions measured by the NA61/SHINE Collaboration at $\sqrt{s}$ = 17.3 GeV is therefore welcome. The p+p measurements provide an important insight into the thermodynamic properties of A+A collisions. Therefore extensive p+p measurements at $\sqrt{s}$ = 11 GeV at CERN SPS and their thermodynamical analysis might be an important contribution to the physics planned at the NICA collider.

References

[1] A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, Nature **561** 321 (2018).

[2] J. Cleymans, H. Oeschler, K. Redlich, S. Wheaton, Phys. Rev. **C73** 034905 (2006).

[3] V.V. Begun, V. Vovchenko, M.I. Gorenstein, H. Stoecker, Phys. Rev. C **98**, 054909 (2018).

[4] T. Matulewicz, K. Piasecki, J. Phys. G: Nucl. Part. Phys. 48 085004 (2021).

[5] P. Castorina, S. Plumaria, H. Satz, Int. Jour. Mod. Phys. E **26**, 1750081 (2017).

[6] NA61/SHINE Collaboration: Eur. Phys. J. **C80** 199 (2020); **C80** 460 (2020); **C80** 833 (2020); **C81**, 911 (2021); arXiv:2106.07535 .

[7] V.Vovchenko, H. Stoecker, Computer Physics Communications **244** 295 (2019).