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Strangeness measurements in NA49 experiment with Pb projectiles

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Abstract. Charged and neutral strange particle production was studied by the NA49 experiment at CERN. Preliminary inclusive spectra are presented for $K^{\pm}$, K^0_S, Φ, Λ, $\bar{\Lambda}$ and $\Xi^{\pm}$ particles, measured in a region close to mid-rapidity, for central Pb+Pb collisions at 158 GeV per nucleon. An enhanced strange particle production relative to properly scaled elementary nucleon–nucleon collisions is observed, but its strength is similar to lighter S + nucleus systems. The enhancement is stronger for multistrange particles.

1. Introduction

The discovery and study of deconfined nuclear matter, the quark-gluon plasma (QGP), is the ultimate goal of the heavy ion experimental programme. One of the proposed signatures of QGP creation is the enhanced strange particle production in A + A relative to the elementary nucleon–nucleon case [1].

The experiment NA49 is a large acceptance hadron detector at the CERN SPS. Four large volume time projection chambers (TPC) record the trajectories of about 2000 charged particles for momentum analysis, figure 1. Two of them (VTPC1,2) are placed inside two superconducting magnets and two are placed further downstream and symmetrically on both sides of the beam line. The set-up also includes four time-of-flight (TOF) walls and a set of calorimeters for triggering and E_T measurements [2].

The acceptance of the detectors relevant to the data presented here, for the different strange particles species, is summarized in table 1. Note that the VTPC2 and MTPC acceptances complement each other around mid-rapidity ($y_{mid} = 2.9$), thus the combination of both detectors covers a major fraction of the available phase-space.

Charged Kaons are identified either by their TOF, energy loss ($\mathrm{d}E/\mathrm{d}x$) or one-prong decays ('kink' topology). Neutral Kaons as well as Lambdas are identified by their characteristic V0-decay topology into charged particles in VTPC2 and MTPC [3–5]. Φ particles are reconstructed in the MTPC (dE/dx) and the TOF via their charged kaon decay mode [6, 7]. Ξ^- ($\bar{\Xi}^+$) are identified by their cascade topology, a primary decay into a charged (pion) and a neutral track (Lambda) followed by the subsequent V0-decay of the Lambda [8, 10]. All

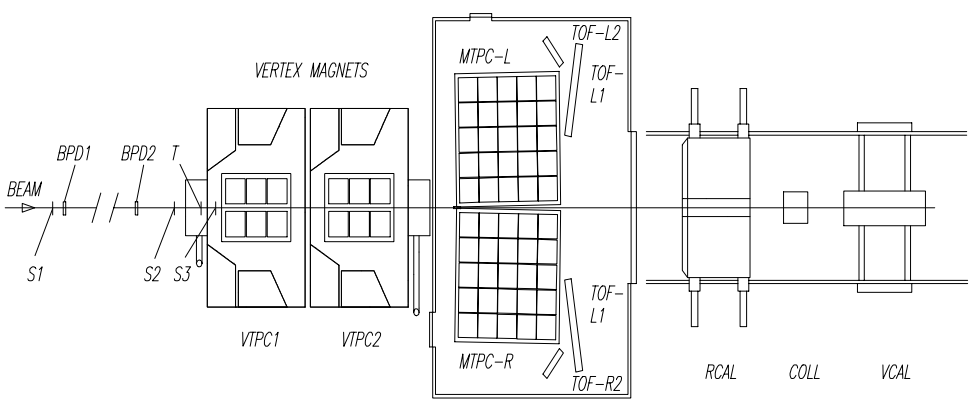

Figure 1. Set-up of experiment NA49.

Table 1. NA49 acceptance for strange particles.

Detector	Particle	Rapidity (y)	p_T (GeV)
VTPC2	K^0_S	3.0–4.2	0.4–2.0
	Λ, $\bar{\Lambda}$	2.8–4.0	0.6–2.4
	Ξ, $\bar{\Xi}$	3.1–4.1	0.5–2.5
MTPC	K^0_S	1.6–2.8	0.4–2.0
	$(\Lambda + \bar{\Lambda})$	1.4–2.4	0.6–2.4
	Ξ, $\bar{\Xi}$	1.7–2.7	1.0–3.0
	$K^{\pm}$	2.6–3.6	0.0–1.5
	Φ	3.2–4.5	0.0–1.6
TOF	$K^{\pm}$	2.5–3.3	0.0–1.5
	Φ	2.9–3.4	0.0–0.8

Table 2. Fitted inverse slope parameters (T) for various particles. For the function form of the fit see text.

Particle	K^+	K^-	K^0	Φ	Λ	$\bar{\Lambda}$	$\Xi + \bar{\Xi}$
Slope (MeV)	224±12	213±6	223±13	284±13	284±15	282±20	298±13

data are corrected for background contamination as well as for geometrical acceptance and reconstruction efficiency [11, 12].

The data reported here represent the most central 5–7% of the total (geometrical) inelastic cross section (calculated to be 7 barns) of Pb + Pb interactions. This corresponds to maximum impact parameters of $b_{max} = 3.5$–4.0 fm and a total number of about 370 participant nucleons. In this report the estimated systematic uncertainty for the fitted inverse slope parameters(see below) is 10% and for yields is 10–20%. In all rapidity distributions presented here, measured points are shown as filled symbols, whereas open symbols are the same points reflected around mid-rapidity (2.9). This is allowed because of the symmetry of the Pb + Pb system.

2. Results and discussion

2.1. Charged and neutral kaons

The transverse mass distributions for $K^{\pm}$ and K^0_S near mid-rapidity are shown in figure 2. Only one measured distribution is shown for each species, but multiple complementary measurements exist, all compatible within their respective errors. We observe that the shape of the distributions is exponential over the full measured range, of m_T, which starts at $p_T = 0$ in the $K^{\pm}$ case. We, therefore, fit the distributions with an exponential function in m_T:

$$\frac{1}{m_T} \cdot \frac{\mathrm{d}^2 N}{\mathrm{d}y \mathrm{d}m_T} = C(T) \cdot \mathrm{e}^{-m_T/T}.$$

The fitted inverse slope parameters (the only free parameter in the fit) are compiled in table 2. All three kaon species have similar slope parameters, in the vicinity of 220 MeV.

The rapidity distributions are obtained by integrating the above function over the full p_T range in individual rapidity intervals. The extrapolated fraction of the yields ranges from a few per cent ($K^{\pm}$) up to about 60% (K^0_S) depending on the rapidity interval. The resulting distributions are shown in figure 3. The left panel shows the $K^{\pm}$ and the right the K^0_S as well as the average charged kaon distribution ($0.5(K^+ + K^-)$). At mid-rapidity a $K^+/K^- \approx 1.8$ ratio is observed indicating a baryon-rich environment. In an isospin symmetric system one

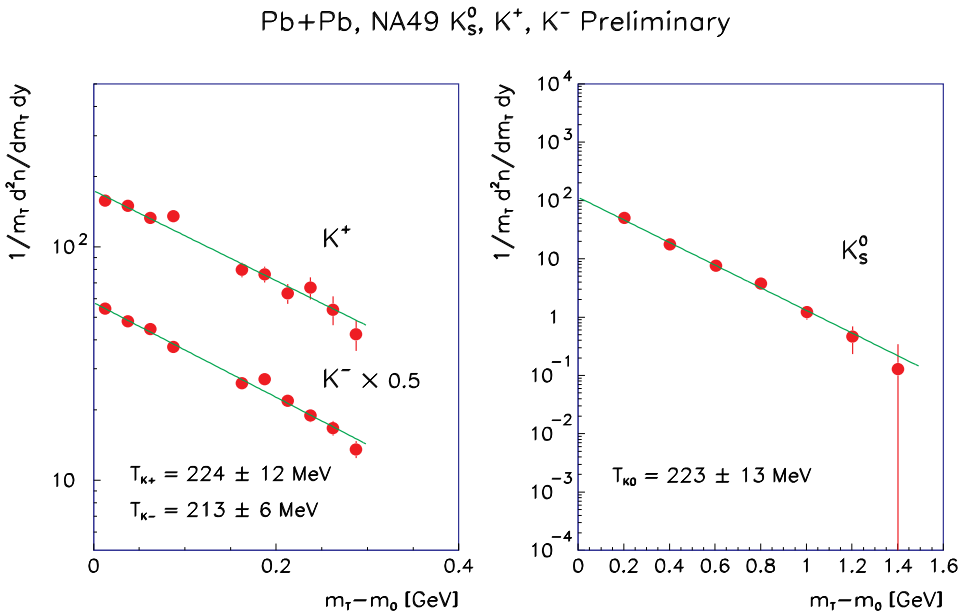

Figure 2. Transverse momentum distributions of K^+, K^- and K^0_S near mid-rapidity.

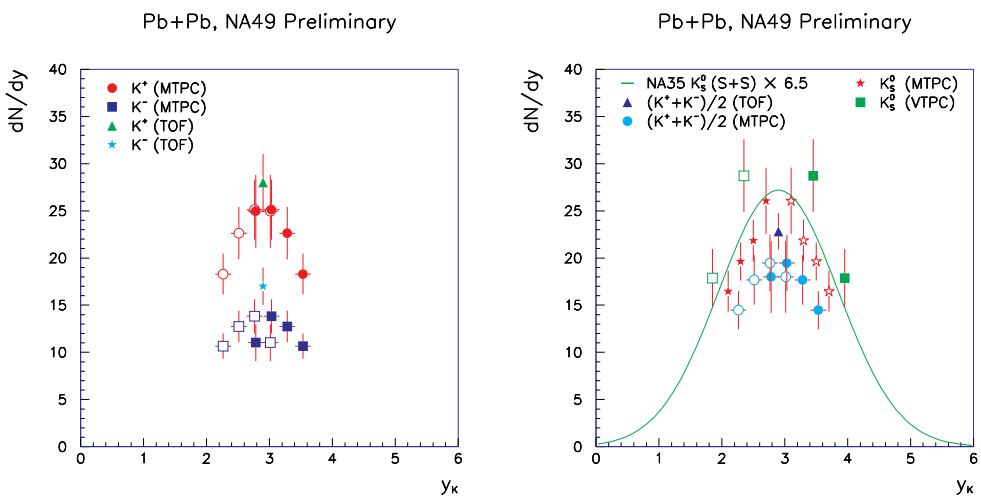

Figure 3. Rapidity distributions of K^+ and K^- (left) and comparison of all kaon species (right). See also text.

expects the K^0_S yield to be equal to half the sum of the $K^\pm$ yields. This should be the case (to within 5%) also for Pb + Pb. The slight excess of K^0_S over $0.5(K^+ + K^-)$ in figure 3 (right panel) is attributed to systematic uncertainties, currently under investigation. In the same figure the solid curve is a fit to the lighter S + S system K^0_S data [13] scaled by the ratio of number of participant nucleons (6.5) in order to take out trivial volume effects. The S + S scaled fit describes well the Pb + Pb K^0_S data.

Integrating the (average) distributions, assuming a Gaussian shape, over all rapidities, one obtains an estimate of the total number of kaons produced. Kaons carry about 70% of all

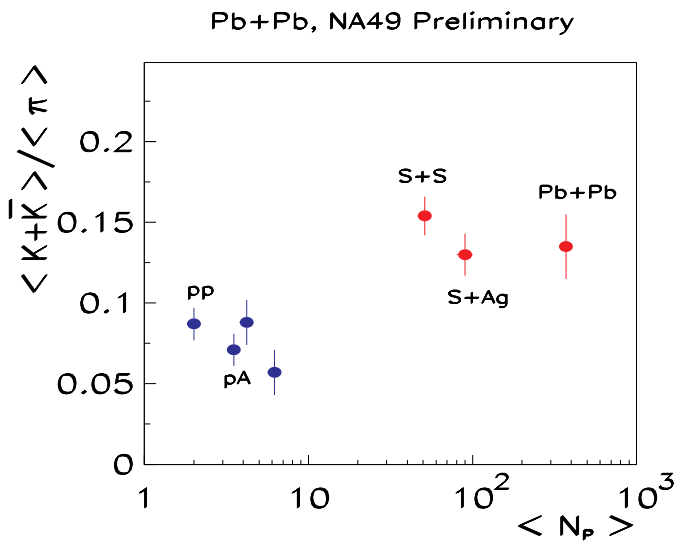

Figure 4. $\langle K + \bar{K} \rangle / \langle \pi \rangle$ ratio per number of participant nucleons.

strangeness, therefore they probe directly the strangeness content of the reaction. Since the production of pions has been found to roughly scale with the number of participants [4], starting with the elementary N + N case, the K/pi ratio as a function of the number of participants would be a direct probe of anomalies in strangeness production in A + A. This is summarized in figure 4 for p + p, p + A and A + A collisions [13, 14]. The ratio refers to the average Kaon multiplicity (all three species as measured in the experiment) divided by the average pion multiplicity (all three species, by estimation based on the π^- measured yields). The p+A data [14] were grouped in three points based on the target mass. The left-most point refers to light masses, the middle to intermediate and the right-most point to heavy targets. We observe that the pp and pA data are clustered around an average value of 0.75 whereas the AA points are about twice as high. The strangeness enhancement first reported for the S + S system [13] is also present in the much larger Pb + Pb system. In the same figure we also observe that the strength of this enhancement remains about the same for the mass range between S + S and Pb + Pb. This has been confirmed recently by experiment WA97 with measurements done at mid-rapidity [15, 16]; analysis of their medium-bias data (40% of total inelastic cross section), in various centrality bins, shows the same saturation effect (their range of number of participants starts from about 10^2 nucleons).

The large acceptance of NA49 allows for an estimate of the K/pi ratio not in an inclusive but single-event manner. Results were reported recently [17] which indicate that the above reported enhancement is present in almost every central event, i.e. the magnitude of the dynamical fluctuations of this quantity is very small.

2.2. Φ mesons

The Φ meson is expected to provide interesting information, not only because it is a doubly strange meson, but also because of recent speculation about its sensitivity to possible chiral symmetry restoration. Details about the reconstruction techniques and procedures can be found in [6, 7]. Figure 5 shows the m_T (left panel) and rapidity (right panel) distribution. An inverse slope parameter of 284 ± 13 MeV and an average (between MTPC and TOF) yield

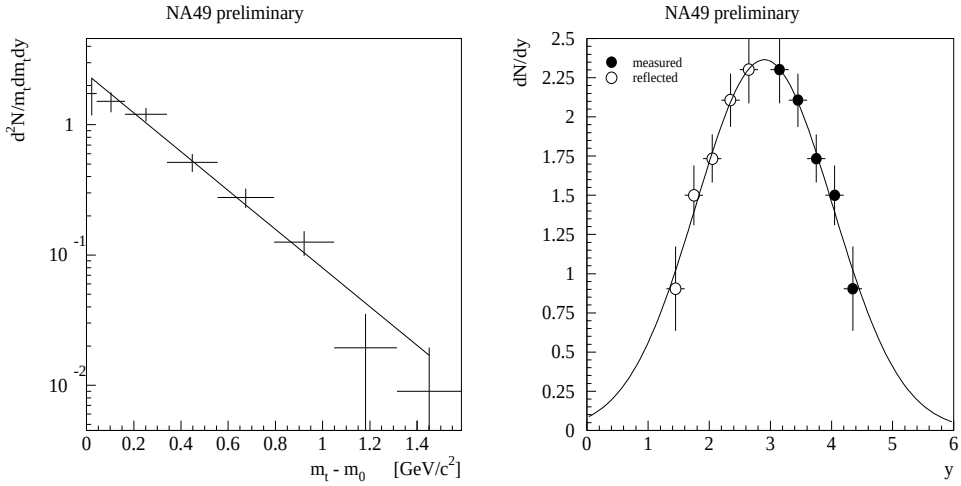

Figure 5. Transverse momentum (left) and rapidity distribution (right) of Φ particles reconstructed in MTPC.

of 2.0 ± 0.3 particles has been measured at mid-rapidity. The integral of the shown rapidity distribution results in a estimated yield of 5.7 ± 0.7 Φ mesons in 4π. This, in turn, results in a Φ/π ratio of $(9 \pm 1) \times 10^{-3}$ which indicates an enhancement relative to p+p interactions by a factor 2.5–3.0 [7]. This is stronger than the enhancement observed with Kaons, mesons containing only one strange quark†.

2.3. Λ *and* $\bar{\Lambda}$

Figure 6 (left panel) shows the transverse mass distribution for Λ and $\bar{\Lambda}$ particles reconstructed in the VTPC2. Both Λ and $\bar{\Lambda}$ have similar slope parameters (280–285 MeV). This is close to the Φ measured slope, but significantly higher than the pion and the Kaon slopes. A compilation of all hadron slope parameters measured in NA49 is shown in figure 7 (left panel) [10]. An increasing slope parameter with the particle mass is observed in the Pb + Pb system, an indication of presence of transverse collective motion (and perhaps early pressure [18]). This effect was also reported by the NA44 Collaboration [19]. Note that this effect is absent in the elementary N+N collisions [19].

In figure 7 (right panel) are shown the fitted slope parameters of the combined Λ + $\bar{\Lambda}$ from MTPC in different rapidity bins. It shows an increase in the slope parameter closer to mid-rapidity. Note that this figure is compatible with the presented individual slope parameters from VTPC2 in figure 6 (left panel) near mid-rapidity.

The rapidity distribution, obtained by integration in m_T, is shown in the right panel of figure 6. Data reconstructed in VTPC2, together with new data from the MTPC using independent analysis procedures, are shown. The MTPC data allowed the extension of the measurements to lower values of rapidity. The sharp peak of the distribution at mid-rapidity, first reported in [5], is more pronounced in this wider-acceptance results, but note that both data (VTPC2 and MTPC) are not corrected for the contributions of Lambdas originating from cascade decays ('feed-down' lambdas). Direct correction is now possible since we have our own measurement of cascade production [10]. The magnitude of the correction can be

† We note here that there is lack of good quality Φ data in p + p collisions at the same energy.

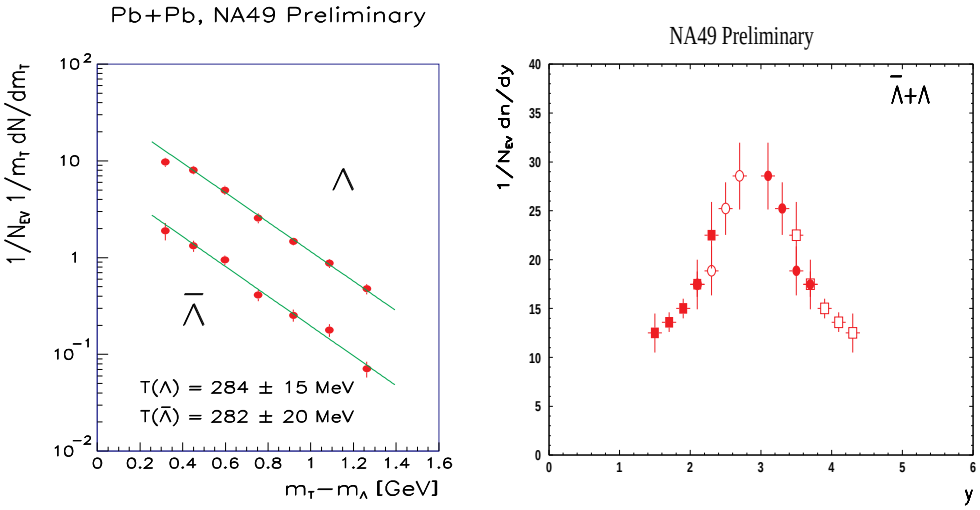

Figure 6. Transverse mass spectra (left) and rapidity distribution (right) of Λ and $\bar{\Lambda}$. See also text for an explanation of the symbols.

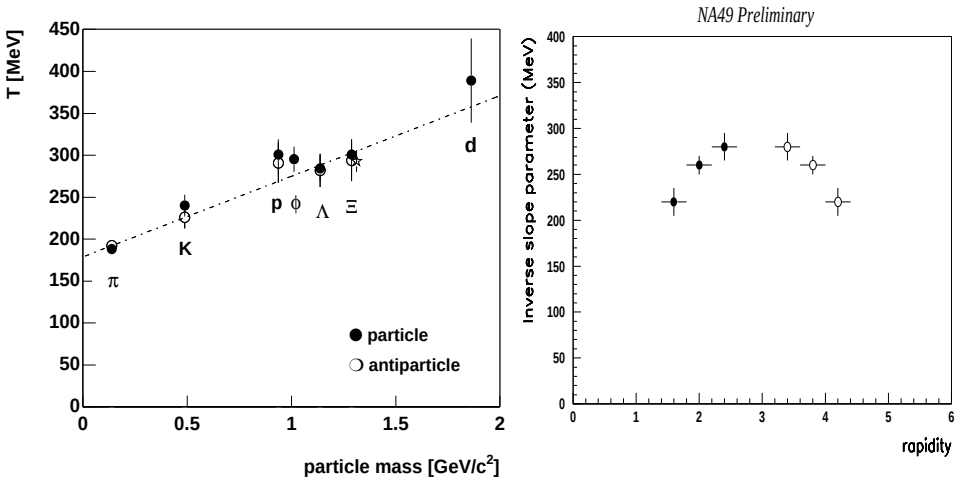

Figure 7. Fitted inverse slope parameters as a function of particle mass (left panel) and fitted inverse slope parameters as a function of rapidity for $\Lambda + \bar{\Lambda}$.

substantial since the lambdas from cascade decays will be over-corrected due to their apparent long lifetimes (the double decay of the cascade). This correction is estimated to be around 20% for the MTPC data but it might be higher in the VTPC2 data (where most of the 'peak' is contained). We have to perform the cascade correction before we can evaluate the magnitude and significance of the effect (if any).

2.4. Cascades

The cascade analysis in VTPC2 [10] and MTPC [8] has been completed. The results were reported at this conference by F Gabler and are included in these proceedings. An important

ratio one should note here is the hyperon ratio of $(\Xi + \bar{\Xi})/(\Lambda + \bar{\Lambda})$. When calculating this ratio we have to keep in mind that the lambdas are not corrected for the cascade feed-down. The resulting ratio in the rapidity interval $3.1 < y < 4.1$ is calculated to be:

$$\frac{\Xi + \bar{\Xi}}{\Lambda + \bar{\Lambda}} = 0.13 \pm 0.03$$

in agreement with our earlier report [8]. It is expected to slightly increase after the 'feed-down' correction is done for the lambdas. This ratio is enhanced relative to the elementary e^+e^- and pp collisions [9]. This is in line with the WA97 observation of an even stronger enhancement of cascade particles (as opposed to the lambda and kaon enhancement) relative to pA collisions [15, 16].

3. Summary

Strangeness measurements in NA49 indicate a strangeness enhancement in Pb + Pb interactions, relative to the elementary nucleon–nucleon and nucleon–nucleus collisions. It appears that the magnitude of the enhancement is similar in Pb + Pb and S + nucleus collisions. The enhancement is present in almost every central Pb + Pb collision, the dynamical fluctuations (in strangeness) appear to be minimal. The magnitude of the enhancement increases with the strangeness content of the particle species. The inverse slope systematics indicate the presence of transverse flow in the system. The cascade/lambda ratio is increased relative to elementary collisions.

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