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Particle and resonance production rates in pp collisions at 400 GeV/c

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The production rates of mesonic atoms at the CERN SPS energies are expected to be much higher than those available with the present DIRAC setup at the CERN PS with a proton beam momentum of 24 GeV/c. Therefore prolongation of the DIRAC experiment at SPS energies may allow to measure the $\pi\pi$ and Kπ scattering lengths with very high precision thus opening the door to the decisive tests of the low energy QCD predictions. For the corresponding detailed estimates, one needs the Monte Carlo tuned to the measured particle and resonance production rates at such energies. In this note such data measured at pp collisions around a proton beam momentum of 400 GeV/c ($\sqrt{s}$ = 27.5 GeV) are collected and discussed.

The data on particle production rates in pp interactions at a beam momentum of around 400 GeV/c are quite limited. The best results are obtained in the NA27 experiment, performed at CERN with the small Lexan liquid hydrogen bubble chamber (LEBC) serving both as a target and as a vertex detector and the European Hybrid Spectrometer (EHS) for the momentum analysis and the particle identification, exposed to a beam of 400 GeV/c protons coming from the CERN SPS [1]. Some other data on a significantly smaller statistics and essentially restricted to the strange particle production were obtained in the Fermilab experiments with the 15-ft hydrogen bubble chamber at 400 GeV/c [2], the 30-inch hydrogen bubble chamber at 405 GeV/c [3, 4] and in the NA23 experiment at CERN with EHS equiped with the Rapid Cycling Bubble Chamber (RCBC) and exposed to a beam of 360 GeV/c protons from the CERN SPS [5, 6].

The corresponding total inclusive cross sections for the K^0_S, $K^{*+}(892)$, $K^{*-}(892)$, Λ, $\bar{\Lambda}$, $\Sigma^{*+}(1385)$ and $\Sigma^{*-}(1385)$ taken from [2, 3, 5, 6] are collected in Table 1, together with the averaged values of cross sections from these experiments. The results on the Σ^+, Σ^- and $\Delta^{++}(1232)$ from [4] are not included in Table 1. Only 21 and 12 kink candidates identified as Σ^+ and Σ^- respectively with 1C-fit in this experiment, with significant contribution of other competing hypotheses, can not be considered as reliable. An attempt to determine the $\Delta^{++}(1232)$ production rate in [4] can not be justified also since a large background under the broad $\Delta^{++}(1232)$ is peaked just around $\Delta^{++}(1232)$ mass and can not be properly accounted for in this low statistics experiment. The wrong estimate of the $\Delta^{++}(1232)$ production rate in [4] is indeed obvious from the results of experiments with much larger statistics [1, 7] (compare $\sigma(\Delta^{++}(1232)) = (4.42 \pm 1.21)$ mb from [4] with (7.16 ± 0.10) mb from [1]). The attempts of the bubble chamber experiments performed at Fermilab to produce some results in spite of insufficient statistics are indeed quite amazing sometimes. Thus, for example, it

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has been claimed in [2] that "there is little if any ω present" in pp collisions at 400 GeV/c and consequently the upper limits on the ω and η production $\sigma(\omega) < 7\ mb$ and $\sigma(\eta) < 3\ mb$ at 90% confidence level are obtained. These *upper* limits are significantly *smaller* than the ω and η cross sections measured by the NA27 experiment in pp collisions at 400 GeV/c [1] (see Table 2).

Table 1: The total inclusive cross-sections of K_S^0, $K^{*+}(892)$, $K^{*-}(892)$, Λ, $\bar{\Lambda}$, $\Sigma^{*+}(1385)$ and $\Sigma^{*-}(1385)$ measured in pp experiments at 360 GeV/c [5, 6], 400 GeV/c [2] and 405 GeV/c [3] and the averaged values of cross sections from these experiments.

	Cross sections (mb)			
Particle	pp 360 GeV/c	pp 400 GeV/c	pp 405 GeV/c	Average
K_S^0	8.55 ± 0.51	6.61 ± 0.73	7.43 ± 0.45	7.92 ± 0.34
$K^{*+}(892)$	4.42 ± 0.62	–	4.1 ± 0.1	4.33 ± 0.53
$K^{*-}(892)$	2.54 ± 0.47	–	3.6 ± 0.7	2.87 ± 0.39
Λ	4.08 ± 0.40	3.97 ± 0.54	4.1 ± 0.35	4.06 ± 0.24
$\bar{\Lambda}$	0.43 ± 0.12	0.42 ± 0.16	0.63 ± 0.12	0.51 ± 0.07
$\Sigma^{*+}(1385)$	0.67 ± 0.11	–	0.67 ± 0.12	0.67 ± 0.08
$\Sigma^{*-}(1385)$	0.26 ± 0.07	–	0.45 ± 0.09	0.33 ± 0.06

The K_S^0 production rate from pp experiment at 400 GeV/c [2] (see Table 1) looks also underestimated. It is evident from investigation of the energy dependence of the charged and neutral kaon rates performed in [8] (see Fig. 1). Therefore the K_S^0 cross section at 400 GeV/c was not used in calculating the averaged value of the K_S^0 cross section in Table 1. On the other hand, the $K^{*+}(892)$ and $K^{*-}(892)$ [3, 6], Λ and $\bar{\Lambda}$ [2, 3, 5], $\Sigma^{*+}(1385)$ and $\Sigma^{*-}(1385)$ [3, 6] cross sections measured in different experiments are consistent within errors. Their averaged values given in Table 1 are also reproduced in Table 2 where all other results come from the NA27 pp experiment at 400 GeV/c. The average rates per inelastic collision normalized to the total inelastic cross section $\sigma_{inel}(\mathrm{pp}) = 32.8 \pm 1.0$ mb measured in pp interactions at 405 GeV/c [9] are also given in Table 2.

The η' cross section given in Table 2 was not measured in the NA27 experiment (or any other experiment studying hadronic interactions). It has been estimated following arguments presented in [10] from quite similar ratios $\langle\eta\rangle/\langle\rho^0\rangle$ measured in the NA27 and LEP experiments with the respective values of 0.78 ± 0.06 (see Table 2) and 0.81 ± 0.09 (obtained from the averaged results $\langle\eta\rangle = 1.01 \pm 0.08$ and $\langle\rho^0\rangle = 1.24 \pm 0.10$ of the LEP experiments [11]). Assuming that the ratios $\langle\eta'\rangle/\langle\rho^0\rangle$ would also be the same and using the LEP result $\langle\eta'\rangle = 0.17 \pm 0.05$ [11] one obtains the values $\sigma(\eta')$ and $\langle\eta'\rangle$ given in Table 2.

The results of the NA27 experiment are quite impressive. Notice also that for the Monte Carlo tuning one can use not only the total rates presented here but as well the $\mathrm{d}\sigma/\mathrm{d}x_F$ and $\mathrm{d}\sigma/\mathrm{d}p_T^2$ spectra (where $x_F = p_L^*/(2\sqrt{s})$ is the Feynman variable, p_L^* is the longitudinal momentum in the center-of-mass system and p_T^2 is the transverse momentum squared) of the π^+, π^-, K^+ and K^- also given in [1].

Table 2: The total inclusive cross-sections of particles, $\sigma(particle)$, and their averaged rates per inelastic collision, $\langle particle \rangle = \sigma(particle)/\sigma_{inel}$, measured in pp interactions at 400 GeV/c [1], together with the corresponding results for the K^0_S, $K^{*+}(892)$, $K^{*-}(892)$, Λ, $\overline{\Lambda}$, $\Sigma^{*+}(1385)$ and $\Sigma^{*-}(1385)$ taken from Table 1 and for the η' as estimated in this note.

Particle	$\sigma(particle)$, mb	$\langle particle \rangle$
π^+	134.4 ± 3.4	4.10 ± 0.10
π^-	109.4 ± 2.8	3.34 ± 0.09
π^0	127.2 ± 3.5	3.88 ± 0.11
η	9.78 ± 0.56	0.299 ± 0.017
η'	1.73 ± 0.54	0.053 ± 0.016
K^+	10.85 ± 0.53	0.331 ± 0.016
K^-	7.36 ± 0.35	0.224 ± 0.011
K^0_S	7.92 ± 0.34	0.241 ± 0.010
p	39.5 ± 3.2	1.204 ± 0.097
$\bar{p}$	2.08 ± 0.06	0.063 ± 0.016
Λ	4.09 ± 0.26	0.125 ± 0.079
$\bar{\Lambda}$	0.53 ± 0.08	0.016 ± 0.002
ρ^0	12.6 ± 0.6	0.384 ± 0.018
ρ^+	18.1 ± 2.7	0.552 ± 0.082
ρ^-	11.6 ± 1.9	0.354 ± 0.058
ω	12.8 ± 0.8	0.390 ± 0.024
ϕ	0.62 ± 0.06	0.019 ± 0.002
$K^{*+}(892)$	4.33 ± 0.53	0.132 ± 0.016
$K^{*-}(892)$	2.87 ± 0.39	0.088 ± 0.012
$K^{*0}(892)$	3.92 ± 0.68	0.120 ± 0.021
$\overline{K}^{*0}(890)$	2.96 ± 0.54	0.090 ± 0.016
$f_0(980)$	0.74 ± 0.26	0.023 ± 0.08
$f_2(1270)$	3.02 ± 0.40	0.092 ± 0.012
$\Delta^{++}(1232)$	7.16 ± 0.10	0.218 ± 0.003
$\Delta^0(1232)$	4.62 ± 0.26	0.141 ± 0.008
$\Sigma^{*+}(1385)$	0.67 ± 0.08	0.020 ± 0.002
$\Sigma^{*-}(1385)$	0.33 ± 0.06	0.010 ± 0.002
$\Lambda(1520)$	0.56 ± 0.10	0.017 ± 0.003

As follows from Table 2, the ratio of the K$^+$ and K$^-$ rates is

$$\langle \mathrm{K}^+\rangle/\langle \mathrm{K}^-\rangle = 1.47 \pm 0.10. \tag{1}$$

It is twice smaller than in pp interactions at 24 GeV/c (where $\langle \mathrm{K}^+\rangle/\mathrm{K}^-\rangle = 3.52$ [12]) due to a smaller relative contribution of the proton fragmentation into K$^+$ and strange baryons at higher energy. The ratio of the K^{*+}(892) and K^{*-}(892) rates equals

$$\langle \mathrm{K}^{*+}(892)\rangle/\langle \mathrm{K}^{*-}(892)\rangle = 1.51 \pm 0.28, \tag{2}$$

i. e. the same within errors as (1) as expected (similarly to the situation for pp interactions at 24 GeV/c where $\langle \mathrm{K}^{*+}(892)\rangle/\langle \mathrm{K}^{*-}(892)\rangle = 3.5 \pm 0.8$ [12]).

One may also compare the NA27 results for the K$^+$ and K$^-$ total rates with the estimates performed in [8] and shown in Fig. 1. The K$^+$ and K$^-$ rates corresponding to the smooth lines in Fig. 1 for $\sqrt{s} = 27.5$ GeV amount respectively to $\langle \mathrm{K}^+\rangle = 0.315$ and $\langle \mathrm{K}^-\rangle = 0.215$, very close to the values given in Table 2, and with $\langle \mathrm{K}^+\rangle/\langle \mathrm{K}^-\rangle = 1.47$ as in (1). All this reinforce the confidence in the NA27 results.

Still, in my opinion, the treatment of systematic errors in [1] was far from being perfect and this resulted in serious underestimation of the resulting errors on cross sections[2]. Let me give a couple of examples. The Δ^{++}(1232) and Δ^0(1232) are the broad states sitting on the huge backgrounds with *a priori* not known shapes. It is clearly impossible in such a situation to determine their total cross sections with the inconceivable precision of 1.4% and 5.6%, respectively. Another example can be seen from the values of the measured K$^+$ cross section $5.42 \pm 0.1 \pm 0.8$ mb for $x_F > 0$ and an estimate of the total cross section 10.85 ± 0.53 mb, based on the symmetry of pp interactions, given in [1]. It is obvious that the relative error of the total cross section have to be the same as for the measured one, and not *smaller* by a factor of 3!

This should be kept in mind in tuning Fritiof to the measured particle and resonance rates. In such a tuning, it is important, first of all, to reproduce the total rates (and possibly the spectra) of the π^+, π^-, K$^+$ and K$^-$ as well as those of the η, η', ω and ϕ. Good agreement with other resonances are less critical, in my opinion, since their influence is not expected to be noticeably different from the one of the backgrounds under resonance signals.

[2]I actively participated in preparation of this paper, as it is acknowledged in [1], but eventually refused to sign it just for these reasons.

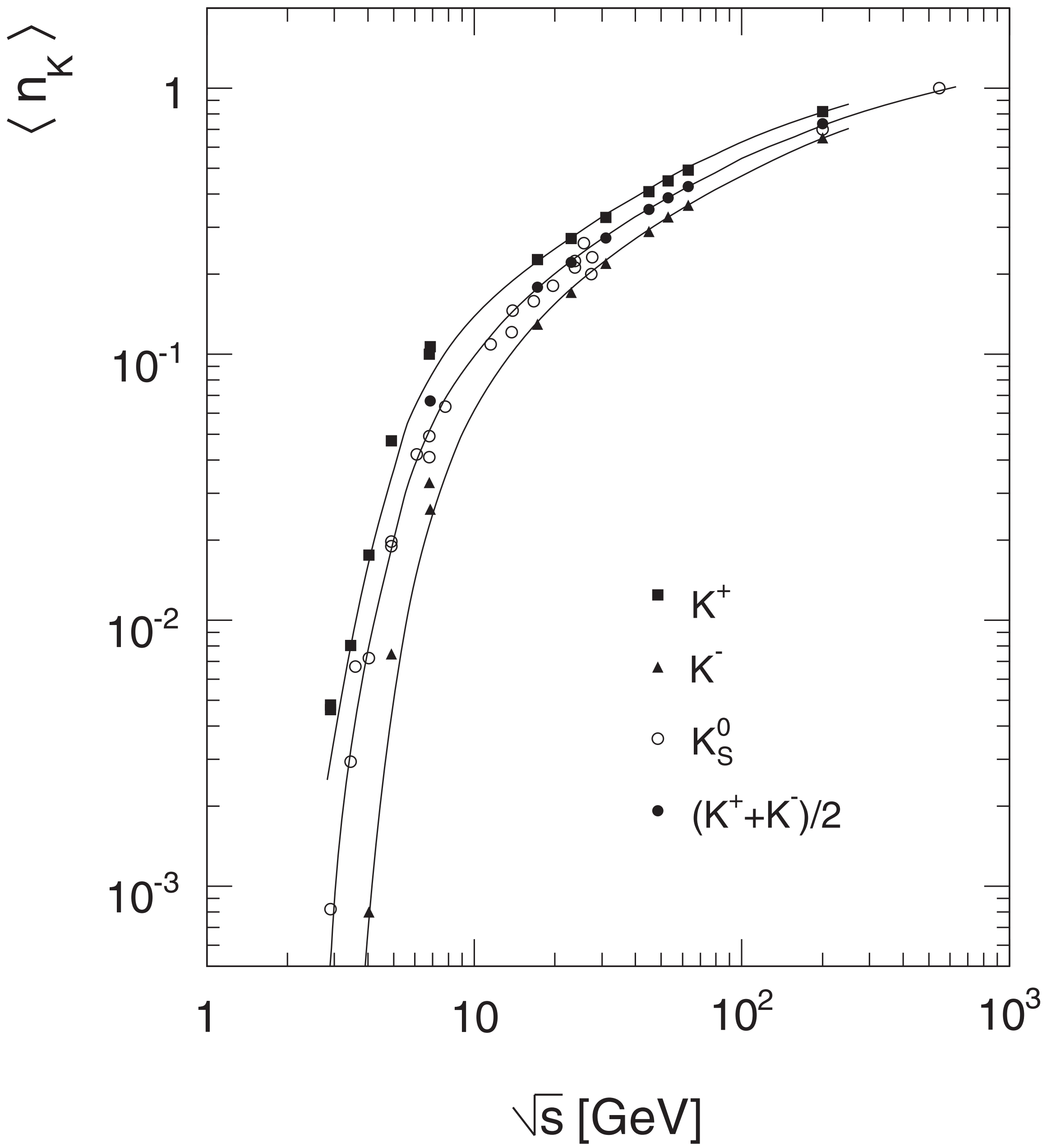

Figure 1: Fig. 130 taken from [8]: total yields $\langle \mathrm{K}^+ \rangle$, $\langle \mathrm{K}^- \rangle$ and $\langle \mathrm{K}^0_S \rangle$ as a function of $\sqrt{s}$. The full circles in the K^0_S data correspond to $0.5(\langle \mathrm{K}^+ \rangle + \langle \mathrm{K}^- \rangle)$ established at corresponding $\sqrt{s}$ values. The full line through the K^0_S results is eyeball fit. The lines through the K^+ and K^- data are derived in [8] from eyeball fit to the energy dependence of the $\langle n_{\mathrm{K}^+} \rangle / \langle n_{\mathrm{K}^0_S} \rangle$ and $\langle n_{\mathrm{K}^-} \rangle / \langle n_{\mathrm{K}^0_S} \rangle$ ratios.

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