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INCLUSIVE K^+ PRODUCTION IN PROTON-PROTON COLLISIONS

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Инклюзивное рождение K^+-мезонов в протон-протонных соударениях

В рамках модели однобозонного обмена вычислено сечение инклюзивного рождения K^+-мезонов в *pp*-соударениях. Результаты вычислений удовлетворительно воспроизводят доступные экспериментальные данные и служат основанием для параметризации энергетической зависимости сечения в широком диапазоне энергий от порога реакции до нескольких сотен ГэВ.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Since a long time there has been considerable theoretical and experimental interest in studying K^+-meson production from hadronic and nuclear interactions. Strangeness production has been proposed [1] as a possible signature of the quark-gluon plasma formed in heavy-ion collisions. However, it was discussed [2, 3, 4] that strangeness enhancement may be also simulated by hadronic interactions in nuclear matter under normal conditions. Theoretical models aiming at the to calculation of strangeness production from a pure hadronic phase use the elementary kaon-production processes as an input parameter. One of the important ingredient of such calculations is the kaon production cross-section in baryon-baryon interactions. The latter one can be evaluated from the cross section of the reaction $pp \to K^+X$.

The experimental data on the reaction were collected by Flaminio et al.[5] and cover the beam energy range from around T_p=2.5 to 15 GeV. There are no data close to the reaction threshold at T_p=1.58 GeV as well as at high energies.

Recently with the boson-exchange model we calculated the cross section of the reaction $pp \to NYK$ with K^+, K^0-meson and Λ, Σ-hyperon production. The kaon and the pion exchange graphs were taken into account and the details of the model are described in [6]. In Fig.1 the calculated cross section of the reaction $pp \to p\Lambda K^+$ together with the available experimental data is shown. The sum of the cross sections for the reactions $pp \to p\Sigma^0K^+$ and $pp \to n\Sigma^+K^+$ is shown too. Solid line indicates the contribution from the three body final state reactions to the inclusive K^+-meson production and dots show the experimental results on the inclusive cross section.

It can be seen fromthe figure that the contribution from the Σ-channel becomes dominant at beam energies above 2.5 GeV. Moreover, the contribution from the three-body final state, i.e. reaction $pp \to NYK^+$ to the inclusive K^+-meson production is preponderant at energies below 3 GeV. At high energies one should also take into account the reaction channels with additional meson production.

In this paper we present the cross section of the inclusive K^+-meson production from pp-collisions calculated with the reggeized boson exchange model. The reaction channels with Σ-hyperon production, which significaly contribute to the inclusive K^+ production have been studied.

As was shown by Laget [7] and in our previous analysis [6] contribution from the kaon exchange graphs to Σ-hyperon production is negligible due to the small $g^2_{KN\Sigma}$ coupling constant. We use the reggeized one-pion exchange model. The diagrams are shown in Fig.2 and the relevant cross section is given as [8]

$$\mathrm{d}\sigma(pp \to K^+X) = \frac{64\pi s_1 \lambda^2(s_1, m_N^2, \mu^2)}{\lambda(s, m_N^2, m_N^2)} \frac{\mathrm{d}\sigma}{\mathrm{d}t_1}(\pi N \to YK^+, s_1, t_1)$$
$$\times \lambda(s_2, m_N^2, \mu^2)\sqrt{s_2}\,\sigma_{tot}(\pi N, s_2) F^2(t, s, s_1, s_2) \frac{\mathrm{d}^3P_Y}{(2\pi)^3 2E_Y} \frac{\mathrm{d}^3P_K}{(2\pi)^3 2E_K} \qquad (1)$$

where

$$s_1 = (P_Y + P_K)^2$$

$$s_2 = (P_1 + P_2 - P_Y - P_K)^2$$
$$t = (P_1 - P_Y - P_K)^2$$
$$t_1 = (P_1 - P_Y)^2 \qquad (2)$$

with P_1, P_2, P_Y and P_K being the 4-vectors of the initial protons and the final hyperon and kaon. m_N and μ stand for the nucleon and pion masses respectively.

In Eq.(1) λ is the Källen function

$$\lambda(x, y, z) = \frac{(x - y - z)^2 - 4yz}{4x} \qquad (3)$$

and $\sigma_{tot}(\pi N)$ stands for the total cross section of the πN interaction.

Function $F(t, s, s_1, s_2)$ accounts for the pion propagator and off-shell modification of the vertices and was taken as has been suggested by Boreskov et al. [9]

$$F(t, s, s_1, s_2) = \exp\left(\left[R^2 + \alpha'_\pi ln \frac{s(p_t^2 + m_K^2)}{s_1 s_2}\right](t - \mu^2)\right) \times \gamma \qquad (4)$$

$$with\ \gamma = \frac{\pi\alpha'_\pi}{2} \frac{1}{\sin(\pi\alpha_\pi(t)/2)}, \quad |t| < |T_0| \qquad (5)$$

$$\gamma = \frac{\pi\alpha'_\pi}{2} \frac{1}{\sin(\pi\alpha_\pi(T_0)/2)} \exp\left[R_1^2(t - T_0)\right], \quad |t| > |T_0| \qquad (6)$$

where p_t and m_K denote the transverse momentum and the mass of the K^+ meson, respectively. The pion trajectory was parametrized as

$$\alpha_\pi(t) = \alpha'_\pi(t - \mu^2) \qquad (7)$$

with α'_π =1. It was assumed that

$$\lambda = \lambda_0 \quad when \quad \lambda = R^2 + R_1^2 + \alpha'_\pi \ln \frac{s(p_t^2 + m_K^2)}{s_1 s_2} \le \lambda_0 \qquad (8)$$

in order to confine function $F(t, s, s_1, s_2)$ at large $|t|$.

The parameters $T_0 = -0.5$ GeV^{-2} and λ_0=0.5 GeV^{-2} were taken from [9], use $R^2 = -0.55$ GeV^{-2} and R_1^2=2.25 GeV^{-2} from [8].

The differential cross section of the reaction $\pi N \to \Sigma K^+$ was parametrized in the center-of-mass system as in [10]

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta^*}(\pi N \to \Sigma K^+) \sim 1 + |\cos\theta^*| \qquad (9)$$

with $s_{\pi N}$ being the squared invariant mass of the πN system. At $s_{\pi N} > 9$ GeV^2 we use the parametrization from [8]

$$\frac{d\sigma}{dt_1}(\pi N \to \Sigma K^+) \sim \exp(-bt_1) \qquad (10)$$

with slope b =9.4 GeV^{-2}.

To normalize the cross section of the reaction $\pi N \to \Sigma K^+$ we use the result from Tsushima et al. [11], which are obtained for the different reaction channels with resonance-model calculations and parametrized as

$$\sigma(\pi N \to \Sigma K^+) = \sum_j \frac{A_j(\sqrt{s_{\pi N}} - \sqrt{s_{th}})^{f_j}}{(\sqrt{s_{\pi N}} - M_j)^2 + B_j^2} \qquad (11)$$

where $\sqrt{s_{th}}$=1.688 GeV and the parameters are shown in Tab.1.

In order to study the dependence of the results calculated with the boson exchange model upon the accuracy of the incorporated πN amplitude we test the reaction $pp \to \Sigma^+ K^+ X$ with parametrizations from [10, 12]. A fit to the experimental data was performed by Cugnon et al. [10] and used in proton-nucleus and heavy-ion simulations as

$$\begin{aligned} \sigma(\pi^+ p \to \Sigma^+ K^+) &= 3.21(\sqrt{s_{\pi N}} - 1.688) \;, \quad \sqrt{s_{\pi N}} < 1.9 \text{ GeV} \\ &= 0.14(\sqrt{s_{\pi N}} - 1.7)^{-1} \; at \;\; \sqrt{s_{\pi N}} \geq 1.9 \text{ GeV} \end{aligned} \qquad (12)$$

where the cross section is given in mb.

Fig.3 shows the experimental cross section of the reaction $\pi^+ p \to \Sigma^+ K^+$ from [5] together with the parametrizations (11) and (12). One can note the difference between the parametrizations at $\sqrt{s_{\pi N}} > 2.5$ GeV. The dashed line in Fig.3 shows the parametrization from [12]

$$\begin{aligned} \sigma(\pi^+ p \to \Sigma^+ K^+) &= 0.1 p^{4.8} \;, \quad 1.05 < p < 1.5 \\ &= 1.48 p^{-1.85} \;, \quad p \geq 1.5 \end{aligned} \qquad (13)$$

where the cross section is given in mb and the incident pion momentum in the laboratory frame p was taken in GeV/c.

With the reggeized one-pion exchange model we calculate the cross section of the reaction $pp \to \Sigma^+ K^+ X$. The solid line in Fig.4 shows the result averaged over the calculations with different parametrizations for the reaction $\pi^+ p \to \Sigma^+ K^+$ and the errorbars demonstrate the corresponding errors due to accuracy of Monte-Carlo integration. We found no difference between the πN parametrizations discussed above. Fig.4 also shows the cross sections of the reactions $pp \to \Sigma^0 K^+$ and $pp \to \Sigma^- K^+$ calculated with (11). Note that the dominant contribution to inclusive K^+-meson production comes from the Σ^+-channel.

The total cross section of the associated $\Sigma K^+ X$ production summed over all final Σ-channels is shown in Fig.5 by the dashed line. The dotted line shows the contribution from the reactions with three body-final states, i.e. $pp \to NYK^+$ with Λ and Σ-hyperon production. The dashed-dotted line shows the result calculated with the pion exchange model for the associated $\Lambda K^+ X$ production. Note, that we did not account for kaon-exchange graphs, which contribute to Λ production.

Fig.5 shows the sum of all reaction channels and the experimental data on inclusive K^+-meson production. The calculations quite reasonably reproduce the

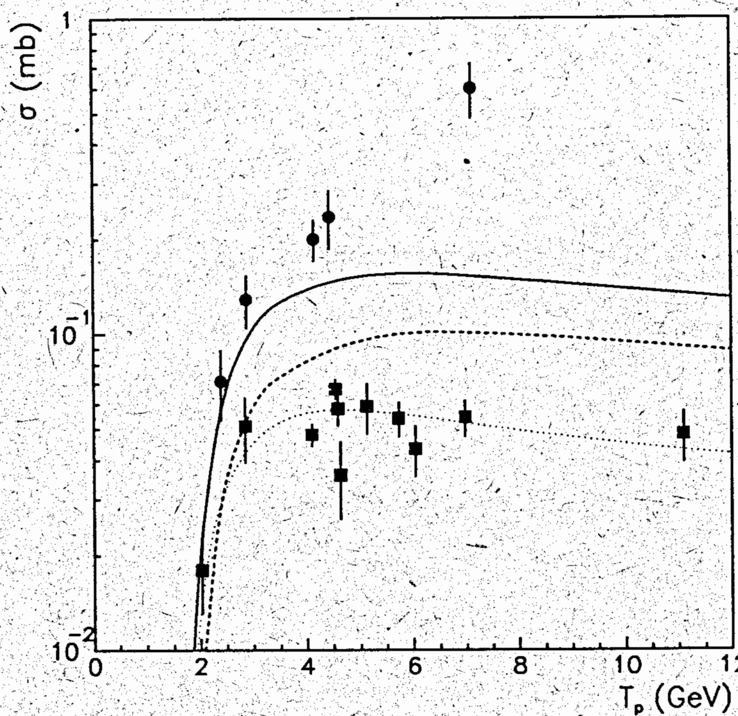

Figure 1: Experimental cross section of inclusive K^+ production (dots) and the reaction $pp \to p\Lambda K^+$ (squares). The lines show contributions from Λ channel(dotted), Σ(dashed) and the sum(solid) calculated with the boson-exchange model for $pp \to NYK^+$ [6].

Reaction	j	A [μb]	f	M [GeV]	B [MeV]
$\pi^+ p \to \Sigma^+ K^+$	1	35.91	0.9541	1.89	124.418
$\pi^+ p \to \Sigma^+ K^+$	2	159.4	0.01056	3.0	970.155
$\pi^0 p \to \Sigma^0 K^+$	1	3.978	0.5848	1.74	81.67
$\pi^0 p \to \Sigma^0 K^+$	2	47.09	2.165	1.905	79.737
$\pi^- p \to \Sigma^- K^+$	1	9.803	0.6021	1.742	81.1357
$\pi^- p \to \Sigma^- K^+$	2	6.521	1.4728	1.94	79.044

Table 1: Parameters of approximation (11) used in our calculations.

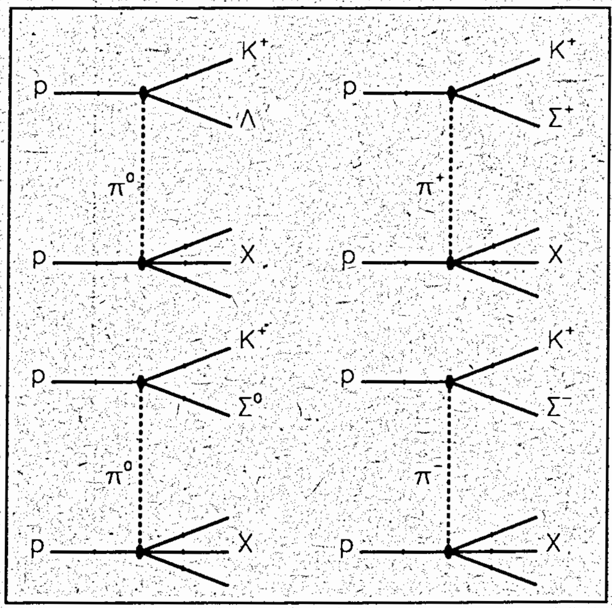

Figure 2: One-pion exchange diagrams for the $pp \to \Sigma K^+ X$ reaction.

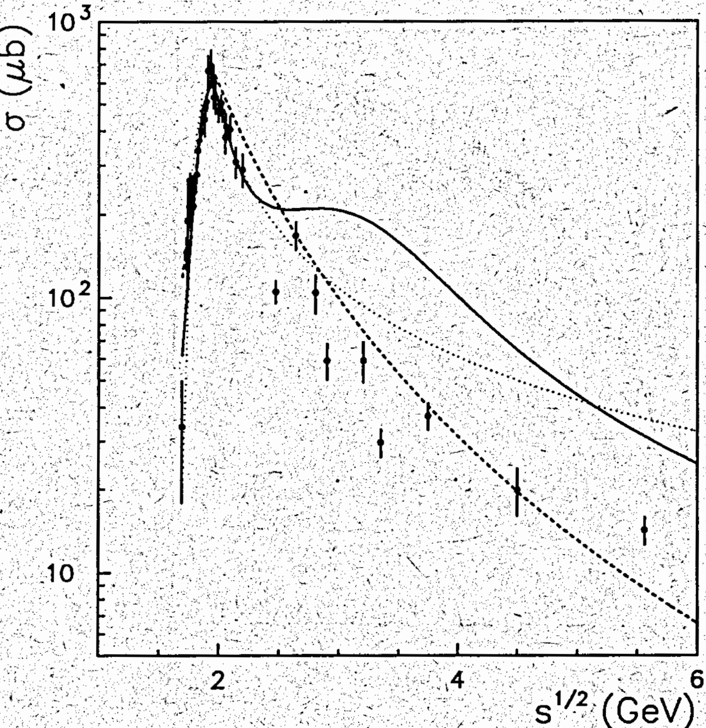

Figure 3: The cross section of the reaction $\pi^+ p \to \Sigma^+ K^+$. Experimental points are from [5]. The lines show parametrizations (11)(solid), (13)(dashed) and (12)(dotted)

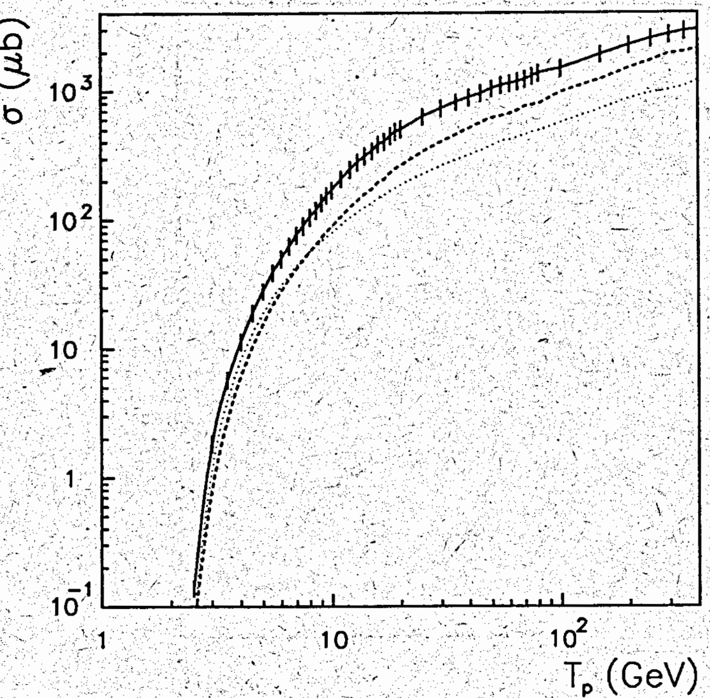

Figure 4: Calculated cross sections of the reactions: $pp \to \Sigma^+ K^+ X$ (solid line), $pp \to \Sigma^0 K^+ X$ (dashed) and $pp \to \Sigma^- K^+ X$ (dotted).

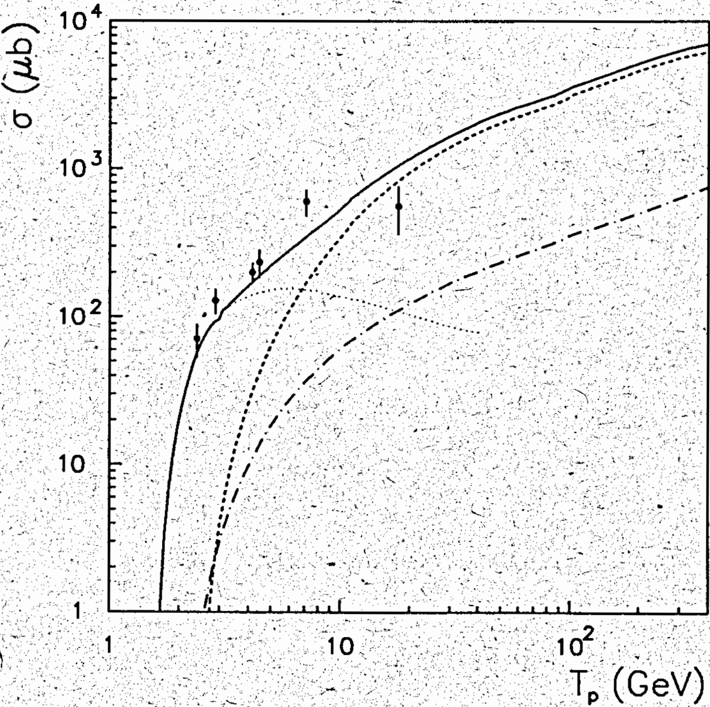

Figure 5: Total cross section of inclusive K^+ production. The dots show experimental data from [5]. The lines show the contribution from associated Σ (dashed) and Λ production (dashed-dotted), reaction $pp \to NYK^+$ (dotted) and their sum (solid).

data and there is no much room for contributions from kaon-exchange graphs. We found that dominant contribution to the inclusive K^+ production comes from the reaction channels with Σ-hyperon production.

The total cross section of the inclusive K^+-meson production from pp-collisions we parametrizy as

$$\sigma(pp \rightarrow K^+X) = a(1 - 6.48/s)^b (s/6.48)^c \tag{14}$$

with $a = 2.021$ mb, $b = 1.829$, $c = 0.6$ at $s < 15$ GeV^2 and $a = 0.494$ mb, $b = 2.03$, $c = -1.294$ at $s > 15$ GeV^2 where s is the squared invariant mass of the initial protons in GeV^2. The parametrization is valid from the reaction threshold up to beam energy of 400 GeV.

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