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Status and plans of the NA49 pp/pA group

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As explained in our note to the SPSC from September 25th, 2012 [1] the NA49 pp/pA group sees a necessity to inform the committee of our status and plans in a document which is separate from the status report of NA61. This the more so as the physics program of NA49 pp/pA is steadily pursued in an approach which is completely independent of NA61. This is documented in publications in accordance with the plans presented in [1].

1 Recent publications

Two extensive publications concerning very detailed studies of the light-ion p+C interaction have appeared in 2013 [2, 3]. These papers concern baryon and light ion production as well as a first general survey of backward pion and proton production covering the complete range of laboratory momentum and angle for beam momenta from 1 to 400 GeV/c. This constitutes a further step in our systematic approach to the sector of non-perturbative hadronic interactions exploiting analysis methods which are essentially model-independent and exclusively based on a set of precise and complete experimental results with the additional use of basic conservation laws like baryon number and charge conservation as well as isospin symmetry. A further detailed study of kaon production in p+C interactions is in preparation [4].

2 Neutron-proton and deuteron-proton interactions

A unique set of data has been obtained by the NA49 pp/pA group using a deuteron beam incident on a hydrogen target. This beam was derived from a primary Pb beam on a Carbon target, selecting nuclear fragments with Z/A = 0.5 and cutting on charge one particles by dE/dx methods. This beam offers the clean possibility to tag, in the NA49 detector, proton and neutron spectators and thereby to obtain, in addition to d+p collisions, samples of n+p (p spectator) and, as a control, p+p interactions given by identified n spectators [5]. Extensive reference results on p+p collisions have already been published by NA49 pp/pA [6–8].

3 Isospin effects in pion and kaon production

The consequences of the rotation of projectile isospin from 0 (d+p) to -1/2 (n+p) and +1/2 (p+p) on the production of charged pions and kaons are by no means trivial. In fact they depend directly on the respective production mechanisms and thereby the effects on the corresponding particle yields turn out to be substantially different. This is shown in Figs. 1 and 2 for the invariant particle yields per inelastic event as a function of transverse momentum (p_T) at two values of Feynman x (x_F) in the deuteron projectile hemisphere.

For pions the π^+ and π^- cross sections interchange their place completely between proton and neutron fragmentation. As a consequence they become equal for deuteron interactions. For kaons on the contrary they stay to first order unchanged on the level of p+p collisions such that p+p, n+p and d+p interactions result in closely equal kaon yields. This basically different behaviour is clearly borne out by the π^+/π^- and K^+/K^- ratios shown in Fig. 3 where the ratios are shown side by side as a function of p_T for the two x_F values at 0.075 and 0.2.

It is well known, as again shown by us quantitatively for π^- [9], that most if not all pions are produced from resonance decay. We have also shown [7] that about 25% of all K^- mesons are decay products of $\Phi(1020)$ and $\Lambda^*(1520)$ alone. For K^+ the importance of associate Σ/Λ+K^+/K^0 production which in turn stems from heavy N^* decay is well established. These reactions do in fact not result in any dependence on the projectile isospin. It needs the presence of isospin I = 1 mesonic resonances with a decay branching fraction into $K\overline{K}$ pairs as for instance $a_2(1320)$ in order to predict a deviation from the apparent projectile isospin independence. In

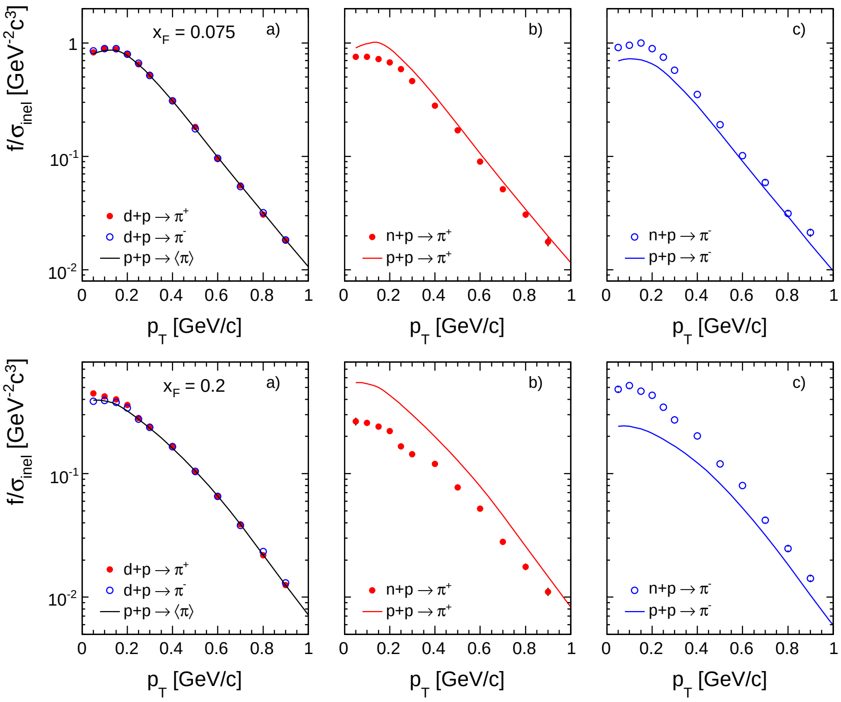

Figure 1: Invariant pion cross sections per inelastic event as a function of p_T for x_F = 0.075 and 0.2. Panel a) π^+ and π^- yields for d+p collisions, b) π^+ yields and c) π^- yields for n+p interactions. The full lines give the respective cross sections for p+p collisions [6]

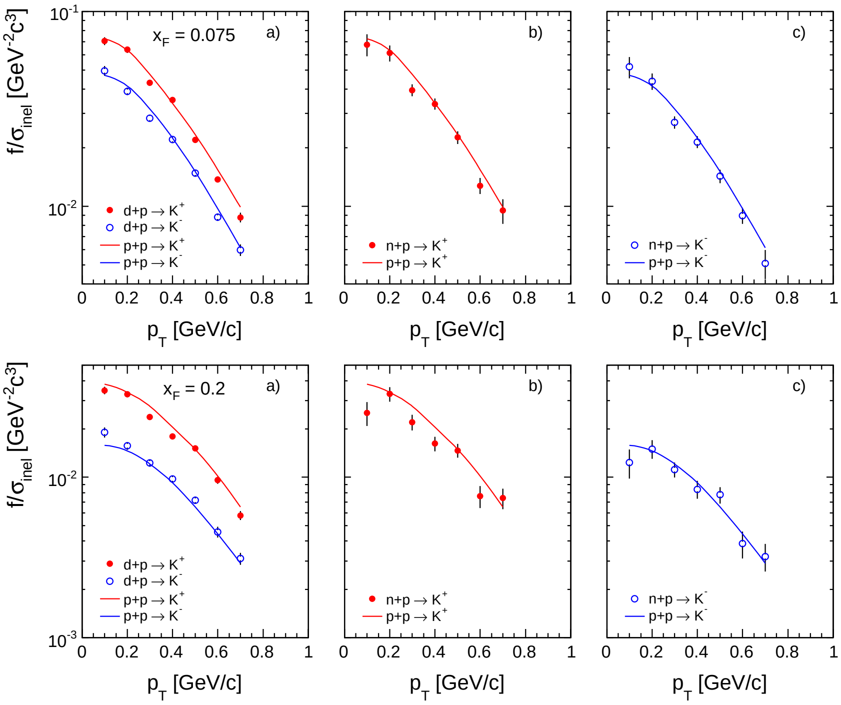

Figure 2: Invariant kaon cross sections per inelastic event as a function of p_T for x_F = 0.75 and 0.2. Panel a) K$^+$ and K$^-$ yields for d+p collisions, b) K$^+$ yields and c) K$^-$ yields for n+p interactions. The full lines give the respective cross sections for p+p collisions [7]

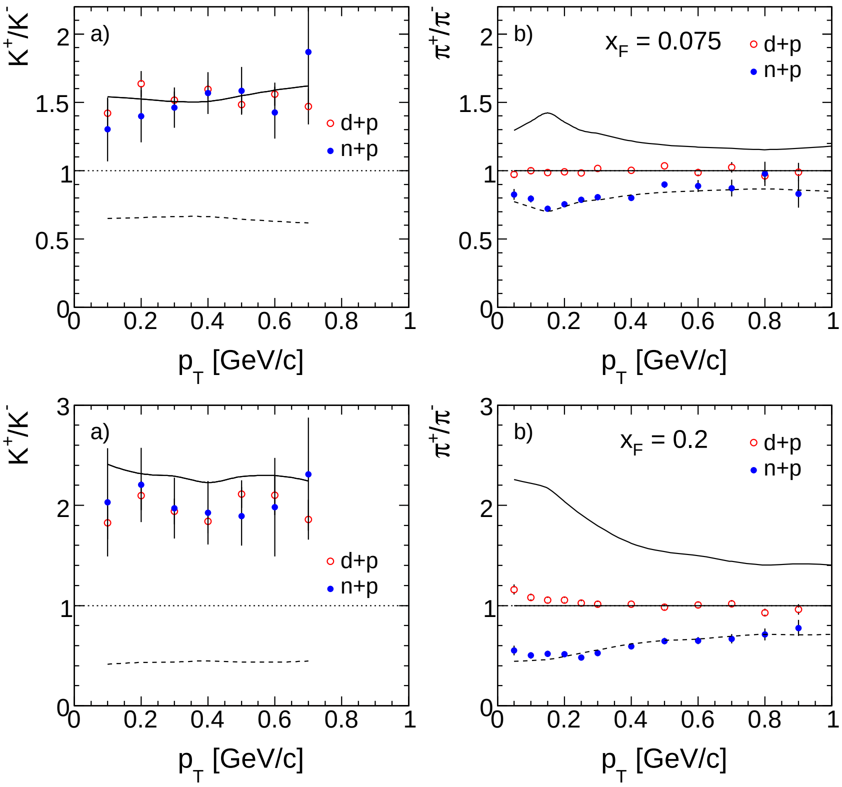

Figure 3: π^+/π^- and K$^+$/K$^-$ ratios as a function of p_T for x_F = 0.75 and 0.2 comparing neutron and deuteron fragmentation to p+p collisions given as full lines. Panel a) K$^+$/K$^-$, panel b) π^+/π^-. Full circles n fragmentation, open circles d fragmentation. Broken lines: inverse p+p π^+/π^- and K$^+$/K$^-$ ratios

this sense the slight deviation from p+p interactions seen in Figs. 2 and 3 may establish an upper limit of I = 1 meson resonance decay as compared to the evidently dominant decay of I = 0 mesonic and I = 1/2 baryonic states.

For pions on the contrary charge exchange reactions at low interaction energy followed by N* excitation and either direct decay into N+π or cascading via intermediate Δ states at higher energy [3] yield a complete interchange of π^+ and π^- in p and n fragmentation. This is also resulting from the decay of I = 1 vector and tensor mesons, whereas the mesonic I = 0 states will reduce the measured π^+/π^- ratios without taking influence on the interchange of π^+ and π^- yields.

4 π^+/π^- and K$^+$/K$^-$ ratios in the target fragmentation of light and heavy ions

The survey of existing data in the backward direction of p+C collisions [3] shows that the π^+/π^- ratios are equal to one at SPS energy, in complete agreement with the new results in d+p interactions shown above. This is also borne out by existing data on the production of pions in the heavy ion p+^{181}Ta interaction at a beam momentum of 400 GeV/c [10]. Here the π^+/π^- ratio turns out to be slightly smaller than unity in the backward direction due to the n/p ratio of 0.6 typical of heavy nuclei.

New data from NA49 pp/pA on kaon production in the target fragmentation region of p+C interactions [4] show that also here our results from d+p interactions are persisting. In fact the K$^+$/K$^-$ ratio is equal to the one found in p+p reactions. In addition the results on kaon production in p+^{181}Ta follow this trend consistently, as already stated in the paper [10] published about 35 years ago.

The resulting evidence is shown in Fig. 4 both for the π^+/π^- and the K$^+$/K$^-$ ratios.

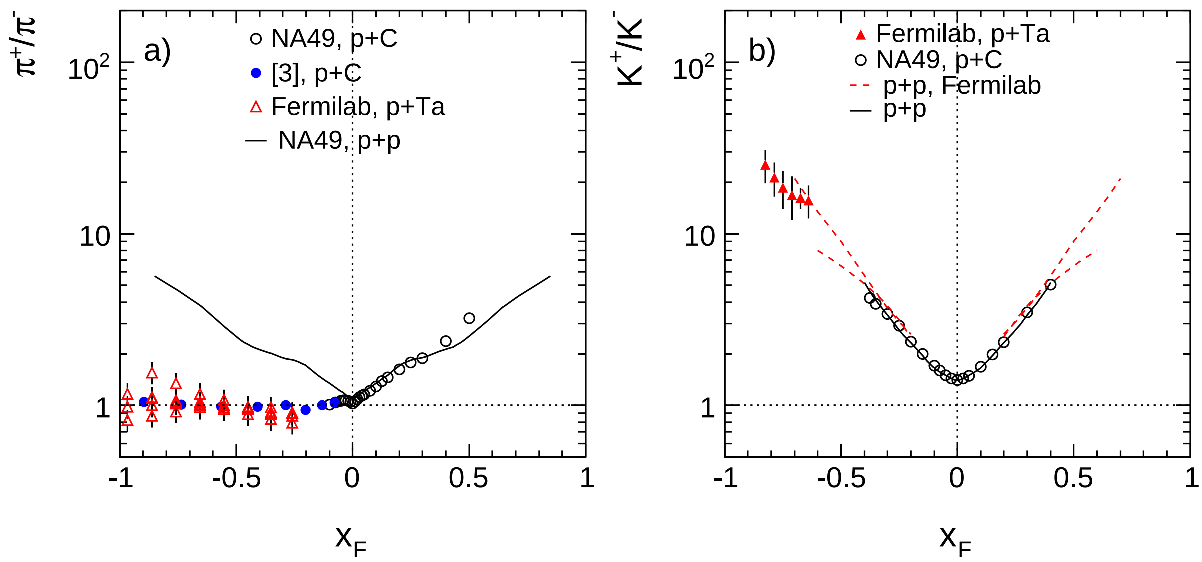

Figure 4: Mesonic charge ratios in the nuclear fragmentation region of p+C and p+^{181}Ta interactions as a function of x_F. Panel a) π^+/π^-, panel b) K$^+$/K$^-$. The results from p+p collisions are shown as full lines for π^+/π^- [6] and K$^+$/K$^-$ ([7] and several Fermilab experiments quoted therein, broken lines)

The important difference between the K$^+$/K$^-$ ratios in excess of 20 in the far backward direction and the π^+/π^- ratios close to unity in the full backward hemisphere is absolutely striking.

5 Consequences for K/π ratios

Given the different dependences of strange and non-strange mesonic cross sections on the isospin of the fragmenting nucleons, it is necessary and mandatory to take great care in the definition and interpretation of particle ratios. This is in particular true for equal-charge ratios like K$^+/\pi^+$ and K$^-/\pi^-$. Whenever the π^+/π^- ratio is greater than unity in the elementary p+p interaction, the former ratio will increase and the latter one decrease when passing from p+p to the nuclear fragmentation region of p+A collisions. This is exemplified for the x_F dependence of the K$^+/\pi^+$ ratio in p+C interactions [4] in Fig. 5.

The increase of K$^+/\pi^+$ at negative x_F, which might be erroneously interpreted as "strangeness enhancement" also in target fragmentation, is entirely due to the isospin effects on the pion yields described above. Using instead the K$^+/\langle\pi\rangle$ ratio, Fig. 5b, the increase at $x_F < 0$ vanishes and the real strangeness enhancement in projectile fragmentation at $x_F > 0$ stays evident. This enhancement in a light ion collision with an average of only 1.6 intranuclear projectile collisions is demonstrated here for the first time.

6 Consequences for A+A collisions

The symmetry of nucleus-nucleus collisions superimposes as a matter of course the different components constituting the final state particle yields which are available and separable

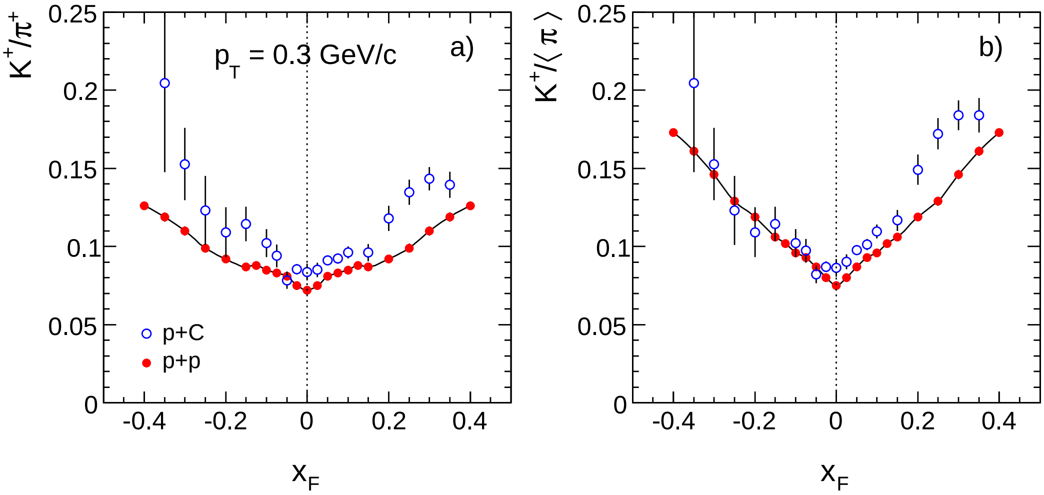

Figure 5: a) K^+/π^+ ratio as a function of x_F for p+C collisions in the target fragmentation region ($x_F < 0$) and the projectile fragmentation region ($x_F > 0$), b) the same for the $K^+/\langle\pi\rangle$ ratio

in the asymmetric p+A interactions. The one additional aspect of A+A collisions consists of the fact that here most colliding participant nucleons will have undergone preceding collisions thus modifying the part of target fragmentation in p+A interactions. Nevertheless there is no reason to believe that the basic isospin dependences mentioned above will not be present in A+A reactions. Therefore also here it is absolutely necessary to avoid argumentations exclusively based on equal-charge particle ratios. These arguments should be carefully repeated by using instead, in the case of K/π ratios, the average pion yields. This is especially true for any dependence on interaction energy. It has been shown [3] that the π^+/π^- ratio increases very strongly with decreasing $\sqrt{s}$. Hence a strong increase of the corresponding isospin effect at low energy where the yields are governed by charge exchange [3]. In contrast the isospin independence of kaons will remain untouched as associate kaon-hyperon production prevails close to the production threshold. The corresponding K^+/π^+ ratios will therefore increase with decreasing $\sqrt{s}$ until the kaon threshold will finally suppress this increase. The NA49 collaboration has claimed [11] the discovery of a "phase transition" in exactly this region of the interplay of isospin and threshold effects, based on the s-dependence of the K^+/π^+ ratio. This claim is consistently repeated by the NA61 collaboration [12] although it has been demonstrated repeatedly [13, 14] that the corresponding effect can be attributed to a combination of isospin and threshold effects.

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