Strange particle production in proton-carbon interactions at 31 GeV/c

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Abstract. Spectra of positively charged kaons in p+C interactions at 31 GeV/c have been measured with the NA61/SHINE spectrometer at CERN SPS. The analysis is performed on the dataset collected during the 2007 pilot run (about 678×10^3 events). The target is a 2 cm long graphite specimen (4% of a nuclear interaction length λ_I). Charged pion spectra have been already measured with the same dataset [1]. Pion and kaon differential production cross sections are required to improve predictions of the neutrino flux for the T2K long baseline neutrino oscillation experiment in Japan. The knowledge of kaon production is especially important for the precise prediction of the intrinsic electron neutrino component of the T2K beam. The results are presented as a function of laboratory momentum in 2 intervals of the laboratory polar angle covering the range from 20 up to 240 mrad. Kaon spectra as well as K^+/π^+ ratios are compared with predictions of several hadron production models. In addition, first results from the analysis of the high statistics 2009 data taking are shown.

The NA61/SHINE (SPS Heavy Ion and Neutrino Experiment) experiment at the CERN SPS pursues a broad physics program in various fields [2, 3, 4]: hadroproduction measurements for neutrino oscillation experiments (T2K [9]), cosmic ray air-showers simulation (Pierre Auger and KASCADE experiments), study of the properties of the onset of deconfinement and search for the critical point of strongly interacting matter.

First NA61/SHINE physics paper was devoted to measurements of charged pion spectra in p+C interactions at 31 GeV/c [1]. These data have already been used for an accurate neutrino flux prediction in the T2K experiment [10]. The set of measurements on kaon production presented here provide another fundamental ingredient towards a complete flux characterization, in particular in the high energy region where most of the electron neutrino to muon neutrino contamination originates from kaon decays. Hadroproduction measurements are particularly suitable in NA61 thanks to the wide kinematic acceptance and the excellent particle identification based on the information from both drift chambers and time-of-flight detectors.

The NA61/SHINE apparatus ([1]-Sec. II) consists of four large volume Time Projection Chambers (TPCs): two Vertex-TPCs (VTPC-1 and VTPC-2) placed in the magnetic field produced by two super-conducting dipole magnets and two Main-TPC (MTPC) located downstream symmetrically with respect to the beam line (Fig. 2). The setup is complemented with a time-of-flight (ToF) detector array horizontally segmented in 64 scintillator bars read out at both ends by photomultipliers. The time resolution is 115 ps. The magnetic field was set to a bending power of 1.14 Tm (the estimated average momentum resolution $\sigma(p)/p^2$ is about 5×10^{-3} (GeV/c)$^{-1}$). The adopted binning scheme, represented in Fig. 1, was mainly driven

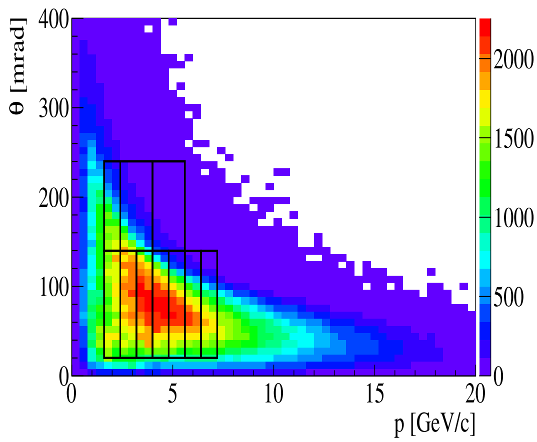

Figure 1. T2K beam simulation: the $\{p, \theta\}$ distribution for K^+ weighted by the probability that their decay produces a neutrino in the acceptance. The binning used in the analysis is superimposed: the maximum kinematic range considered is $1.6 < p < 7.2$ GeV/c and $20 < \theta < 240$ mrad.

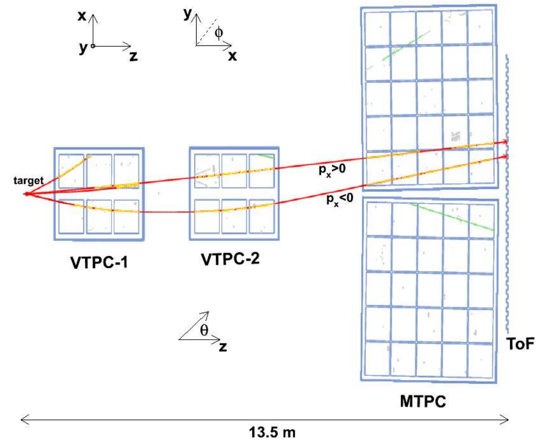

Figure 2. Schematic drawing of the experimental apparatus and a reconstructed p+C interaction event. Yellow (green) points indicate TPC clusters (not) associated to reconstructed primary tracks. Stars correspond to hits reconstructed in the ToF. Red lines are the fitted particle trajectories.

by the limited available statistics and by the necessity to cover most of the phase space relevant for T2K. Two polar angle θ (cfr. Fig. 2 for the definition) intervals are defined: $20 < \theta < 140$ mrad and $140 < \theta < 240$ mrad. The combination with a 0.8(1.6) GeV/c momentum (p) bin yields a few thousands of selected tracks per $\{p, \theta\}$ interval. Measurements have been performed until 7.2 GeV/c. This choice comes from the fact that in the relativistic rise region (above 4-5 GeV/c) the particle identification is a matter of extracting the vanishing kaon signal over the predominant proton one: with the available statistics of 2007 data the applied procedure turned out to be robust only until about 7 GeV/c. Track selections have been optimized to maximize both acceptance and reconstrucion efficiency. In order to minimize biases in the determination of the kaon ionization energy loss dE/dx (in the TPC's) and the time-of-flight ToF measurement due to the kaon decay in flight, only tracks reconstructed until the downstream edge of the MTPC (close to the ToF detector) are accepted. Such a requirement, given the good efficiency of the reconstruction algorithms in the identification of kink topologies, provide a high purity ($\sim 97\%$) sample of stable kaons. It also reduces the calculation of the corrections to the identified kaon yields essentially to a track-by-track reweighting for the survival probability calculated from the measured momentum and path length (from the primary vertex to the ToF wall); minor corrections ($\sim$ 2-3%) to be applied to take into account the contamination from non recognized kaon decays (i.e. when the decay vertex occurs in between the MTPC and the ToF, cfr.Fig. 2). Kaon identification based only on the dE/dx information is troublesome at the lower considered momenta, until 3-4 GeV/c, since protons and kaons have close values of the specific energy loss in this kinematic range (cfr. Fig. 3). Another approach is to identify particle through the measurement of their mass squared m^2. This method is based on the measurement of the time-of-flight as, along with the track length and momentum, it allows for an indirect measurement of the particle mass. Identification based only on the m^2 information is effective at low momenta, below 3-4 GeV/c, where the separation power is higher. The uncertainty on the mass measurement is in fact dominated by the time resolution, it means the m^2 resolution worsens quadratically with increasing momentum. Given the complementarity of the two approaches the particle identification capability can be improved, over the whole kinematic range, by looking at the combined dE/dx and m^2 information.

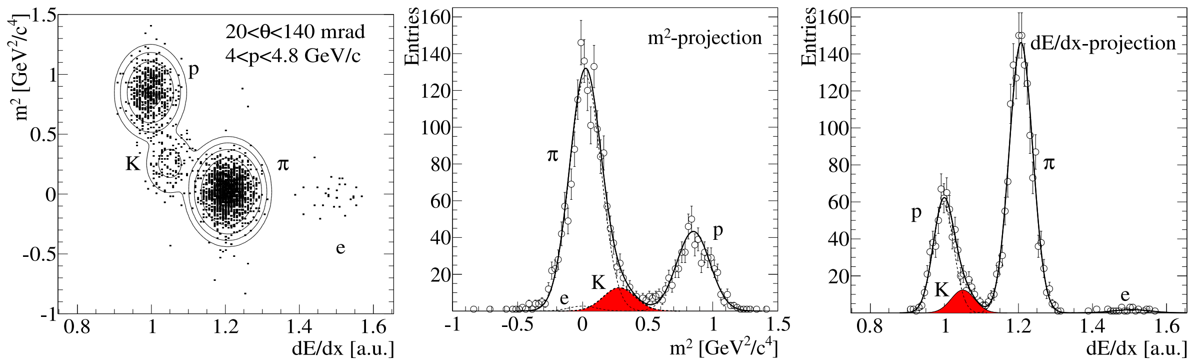

Figure 3. Example of a Maximum Likelihood bidimensional fit to the dE/dx-m^2 distribution. The four contour lines correspond to the 1-σ and the 2-σ levels calculated from the proton (the two innermost) and the kaon (the two outermost) distribution functions. The individual m^2 and dE/dx distributions are also shown superimposed with the results of the fitted functions.

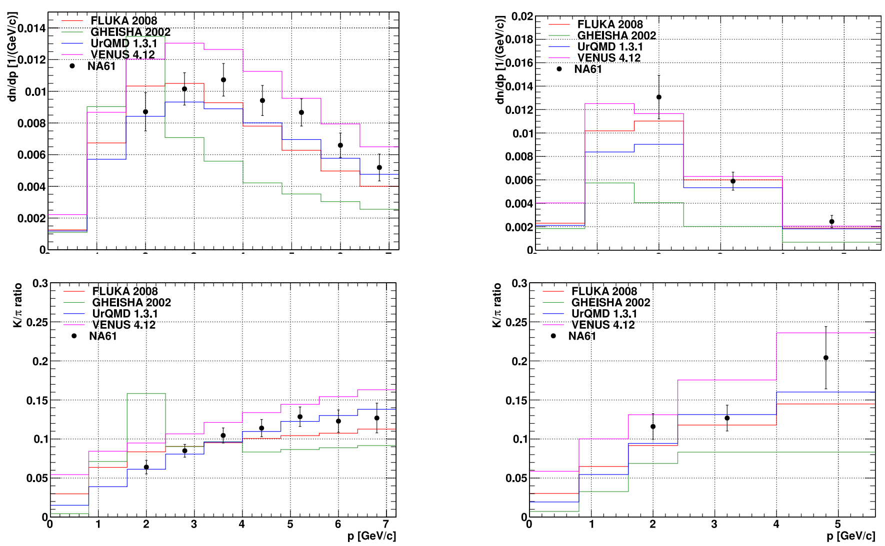

Figure 4. *Top*: Differential cross sections for K$^+$ production in p+C interactions at 31 GeV/c as a function of the laboratory momentum, p (left: 20< θ <140 mrad, right: 140< θ <240 mrad). Errors are statistical and systematic uncertainties added in quadrature. The overall uncertainty (2.5%) due to the normalization procedure is not included. *Bottom*: Ratio of K$^+$ over π^+. Errors are statistical only. Curves from several model prediction are superimposed.

Fig. 3 shows the correlation between the measured dE/dx and m^2 for one of the analysed $\{p, \theta\}$ bin: accumulations corresponding to the different particle types are resolvable if compared to the individual dE/dx and m^2 distributions. The functional model used to fit the yields of protons (p), kaons (K^+), pions (π^+) and positrons (e^+) to the data is a superposition of four bidimensional gaussians. A dedicated Monte Carlo simulation has been used to validate the accuracy of the simple gaussian shape approximation so as to avoid biases related to the definition of the particle distribution functions. Given the small K/p and K/π production rate and the signals overlapping at higher momenta, a dedicated procedure has been conceived for the precise determination, directly from the data, of the expected dE/dx and m^2 mean value and of the m^2 variance as well. This allows to narrow the variability range of the fitted peak positions and widths on both dE/dx and m^2 axis. Moreover, considering the $\beta\gamma=p/m$ dependence of the dE/dx expected value, the relative peak distances between the different particle accumulations have been fixed: this further reduce the number of degrees of freedom and improve the stability of the fit. Measured K^+ spectra and ratio of K^+ over π^+ cross sections are presented in Fig. 4 compared with the prediction of different simulation model (e.g. VENUS 4.12 [5, 6] and FLUKA 2008 [7, 8]). Errors are dominated by the statistical uncertainty ($\sim 10-15\%$) except for the highest momentum interval where the systematic error associated to the fit procedure rises up to $6-7\%$ After the 2009 data taking campaign an order of magnitude more events have

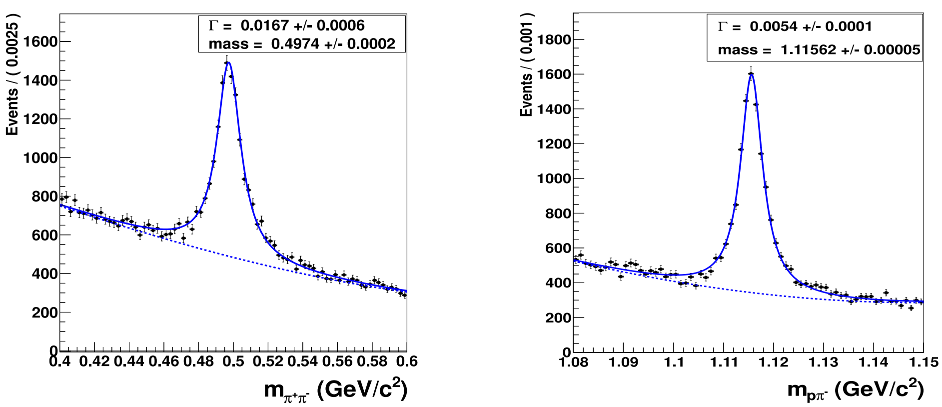

Figure 5. Data quality assessment for the 2009 dataset: invariant mass distribution in the regions of K^0_S (left, $p_T < 0.2$ GeV/c, $1 < y < 1.5$) and Λ (right, $0.4 < p_T < 0.6$ GeV/c, $-1.25 < y < 1$) peak.

been recorded, also thanks to important upgrades in the TPC readout and DAQ system. The data have been calibrated and the physics analysis is started. Data quality plots based on the invariant mass distribution of V^0-like topologies are shown in Fig. 5.

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