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Measurement of charged pion and kaon production in proton-carbon interaction at 31 GeV/c from NA61/SHINE

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An overview of the recent NA61/SHINE results on determination of charged pion and kaon yields in proton-carbon reactions is presented. The results aim to improve predictions of the neutrino flux in the T2K experiment. The data were recorded during the first physics run of NA61 in 2007 where a proton beam of 31 GeV/c momentum scattered off a graphite target. Thin target, 4% of a nuclear interaction length, was used to determine interaction cross section. Inclusive production cross sections for negatively and positively charged pions and kaons are presented as a function of laboratory momentum and polar angle. The spectra are compared to predictions of hadron production models. In addition the status of the analysis of data recoded by the experiment in 2009 and 2011 (including the T2K replica target data) is presented.

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The NA61/SHINE experiment is situated in the North Area H2 beam-line of CERN SPS. It pursues a rich physics program in various fields [1]. An overview of already published results on determination of $\pi^{\pm}$ yields [2] and preliminary results on K^{+} yields obtained in proton-carbon reactions at 31 GeV/c is presented. The goal of the measurement is to improve predictions of the neutrino flux in the T2K experiment [3]. We refer the reader to [4] for the description of main detector components, software, calibration and analysis methods which were basically inherited from the NA49 experiment. Data used in the analysis were collected during the pilot run in 2007.

For the cross section analysis data obtained in configuration with an isotropic graphite target (thickness of 4% of a nuclear interaction length) were used. The laboratory polar angle covering the range from 0 up to 420 mrad and up to 18 GeV/c in momentum. Depending on the momentum interval, different approaches can be convenient.

1. h^{-} analysis: The analysis is inspired by the fact that more than 90% of primary negatively charged particles produced in p+C interactions at this energy are π^{-}. Thus the analysis of π^{-} spectra can be done without additional particle identification. The Monte Carlo simulation was used to calculate corrections for the contribution of electrons, primary K^{-} and $\overline{p}$. This approach can not be used for π^{+} where non-pion contribution is by far larger.

2. dE/dx analysis at low momentum: The analysis relies on a fact that for momenta below 1 GeV/c the Bethe-Bloch curves of particles of different types do not overlap. Thus particle identification at low momentum can be done via measurements of specific energy loss in the TPCs. The use of TOF at such momenta would decrease the statistics drastically.

3. TOF-dE/dx analysis: Combined TOF and dE/dx analysis provides a high purity particle identification. In addition to that for the momentum range 1–4 GeV/c, where Bethe-Bloch bands overlap, particle identification is in general only possible using the TOF method. The probability density functions for each particle species were parametrized by a product of Gaussian functions in m^2 (TOF) and dE/dx.

For methods (2) and (3) maximum likelihood method was applied to fit yields of π^{+} and π^{-} mesons in each (p, θ) bin. Spectra were compared in overlapping regions to check their consistency. Complementary domains were combined to reach maximum acceptance.

The Monte Carlo simulation was used to calculate corrections for interactions in the detector material and for pions from weak decays. It was also used to correct for the track reconstruction efficiency, resolution and detector acceptance. VENUS 4.12 [5] was chosen to generate interaction in the primary vertex. Bin-by-bin correction factors were calculated as the ratio of all generated primary mesons to all reconstructed and accepted charged particles in a given bin.

In Fig.1 the differential cross sections of π^{+} and π^{-} meson are presented. They are shown as a function of laboratory momentum in different intervals of polar angle. One can see a good agreement of three analyzes in the overlap regions.

Analysis of K^{+} production yields is more complicated due to their small fraction. The kaon signal vanishes over the predominant pion one at smaller momentum range while at larger momentum protons dominate. The interval $1.6 < p < 7.2$ GeV/c has been chosen as an optimal one. For the polar angle the range is $20 < \theta < 240$ mrad. Analysis technique is basically similar to the

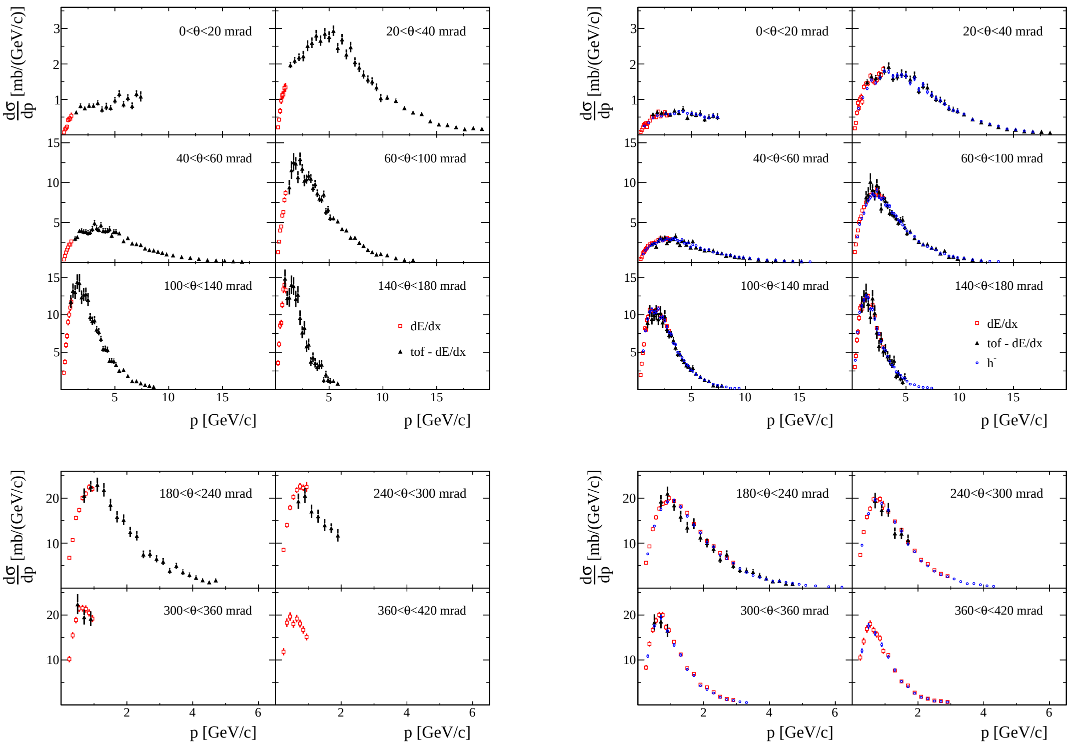

Figure 1: Differential cross sections for π^+ (*left*) and π^- (*right*) meson production. The spectra are presented as a function of laboratory momentum, p, in different intervals of polar angle, θ. Error bars indicate only statistical uncertainties.

TOF-dE/dx one used for pions. The main difference with respect to the pion analysis is in a cut requiring to have the last point of the track in a close vicinity to the TOF detector. This cut enlarges the purity of the kaon sample however it also assumes that the particle travels without decay by about 13 m and thus statistics is decreased. In general statistical error of the K^+ yield measurement is by a factor 3 larger than the systematic one.

In Fig.2 the differential cross section of K^+ production as a function of laboratory momentum in two intervals of θ is shown. The ratio of cross sections K^+ over π^+ is presented in Fig.3. Graphs at both figures are overlapped with predictions of various models. It was found (also true for $\pi^\pm$ analysis) that VENUS 4.12 [5] and FLUKA 2008 [6] models follow the data trend reasonably well.

In the year 2008 important changes have been introduced to the experimental setup of NA61: new trigger logic, TPC read-out and DAQ upgrade, additional sections of TOF-F wall, new beam-telescope detectors. As a consequence of these upgrades the number of events recorded in 2009 for about a same period of time have been increased by an order of magnitude. For both thin target and replica-target configurations we have $\sim$10 M events in 2009 as compared to $\sim$1 M events in 2007. By now the data 2009 have been calibrated and the physics analysis is started.

Additional $\sim$10 M events in the replica-target configuration have been collected by NA61 in 2010. This measurement will make possible a direct prediction of the T2K neutrino flux with precision better than 5%. By parametrizing hadron yields on a surface of the target one predicts up

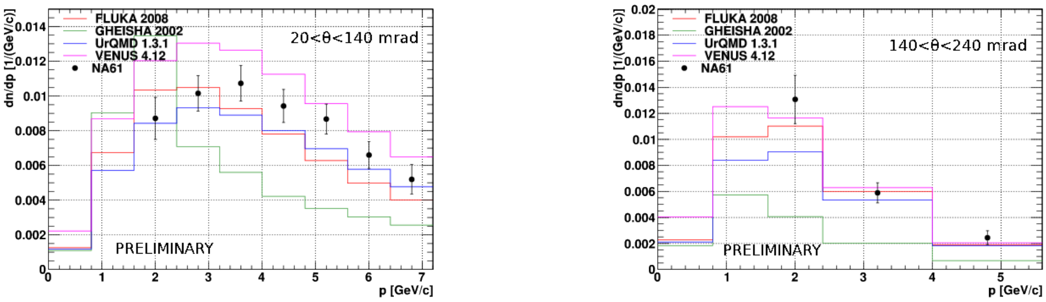

Figure 2: Differential cross section of K^+ production as a function of laboratory momentum in two intervals of polar angle. Lines represent model predictions.

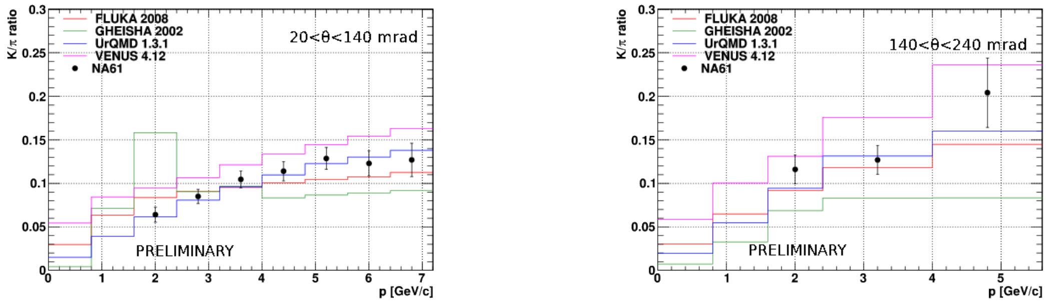

Figure 3: Ratio of cross sections K^+ over π^+ as a function of laboratory momentum in two intervals of polar angle. Lines represent model predictions.

to 90% of the flux for both ν_μ and ν_e components while only 60% of neutrinos coming from the primary interaction vertex.

In conclusion, results of analysis of the 31 GeV proton-carbon data recorded in year 2007 has been presented. Cross sections of charged pions have been published [2] and are used presently by the T2K collaboration for the neutrino flux prediction [7]. Preliminary results for positively charged kaon yields have been presented. Analysis of data collected in 2009 and 2010 is ongoing. They will increase statistics by an order of magnitude.

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