Results of charged pions cross-section in proton carbon interaction at 31 GeV/c measured with the NA61/SHINE detector.

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Among other goals, the NA61/SHINE (SHINE ≡ SPS Heavy Ion and Neutrino Experiment) detector at CERN SPS aims at precision hadro-production measurements to characterise the neutrino beam of the T2K experiment at J-PARC. These measurements are performed using a 31 GeV/c proton beam produced at the SPS with a thin carbon target and a full T2K replica target. Spectra of π^- and π^+ inclusive inelastic cross section were obtained from pilot data collected in 2007 [1] with a 2 cm thick target (4% of the interaction length). The SHINE detector and its particle identification capabilities are described and the analysis techniques are briefly discussed.

1 Physics motivation

In T2K, neutrinos are produced by a high intensity proton beam of 31 GeV/c impinging on a carbon target and producing mesons (π and K) from the decay of which the neutrinos are produced. There exist so far no measurements of hadron inclusive spectra from p+C at 31 GeV/c. Thus the NA61/SHINE experiment provides a precise measurement of meson yield production in carbon at the proton beam energy of interest for T2K. These measurements are used for the T2K neutrino beam simulation and consequently reduce the systematic uncertainties of the neutrino energy distribution at the needed level for the physics goals of T2K [2].

2 The SHINE detector and combined particle identification

The set-up of the NA61/SHINE is shown in Fig. 1. The main components of the NA61 detector were constructed and used by the NA49 experiment [3]. The tracking apparatus consists in four large volume Time Projection Chambers (TPCs). Two of them, the vertex TPCs (VTPC-1 and VTPC-2), are located in the magnetic field of two super-conducting dipole magnets and, two TPCs (MTPC-L and MTCP-R) are positioned downstream of the magnets, symmetrically on the left and right of the beam line. The TPCs provide a measurement of charged particle momenta p with a high resolution. For the 2007 run a new forward time of flight detector (ToF-F) was constructed in order to extend the acceptance of the NA61/SHINE set-up for pion and kaon identification as required for the T2K measurements [4]. The ToF-F detector consists of 64 scintillator bars, vertically orientated, and read out on both sides with Hamamatsu R1828 photo-multipliers. The resolution of the ToF-F wall is < 120 ps [4] which provides a 5 σ π/K separation at 3 GeV/c. It is installed downstream of the MTPC-L and MTPC-R, closing the gap between the ToF-R and ToF-L walls. The ToF-F provides full acceptance coverage of the T2K phase-space (parent particles generating a neutrino which hit the far detector).

As demonstrated in Fig. 2, high purity particle identification can be performed by combining the tof and dE/dx information over the whole momentum range needed for T2K. Moreover, in the momentum range 1–4 GeV/c, where dE/dx bands for different particle species overlap, particle identification is in general only possible using the tof method. In each (p, θ) bin the bin-by-bin maximum likelihood method was applied to fit yields of π^+ and π^- mesons. The pion yields were calculated summing all particles within 2σ around the fitted pion peak.

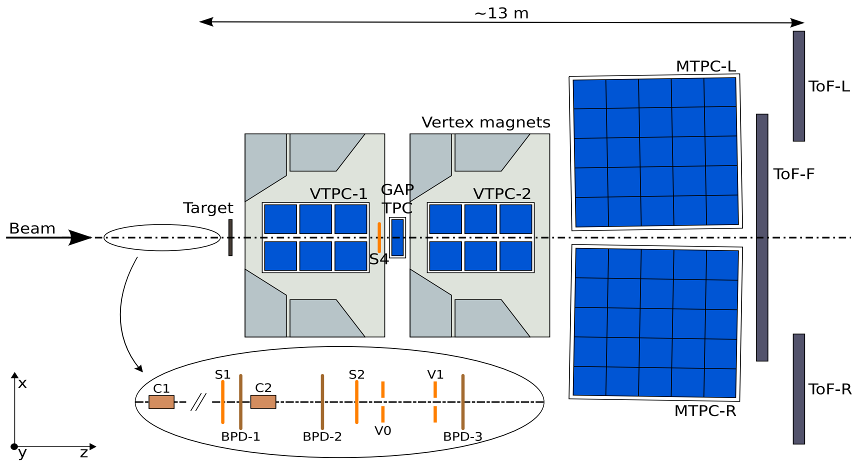

Figure 1: The layout of the NA61/SHINE set-up in the 2007 data taking.

3 Charged pion cross sections

The differential inclusive inelastic cross section $\frac{d\sigma_{inel}}{dp}$ are extracted using three independent analysis:

- π^+ and π^- spectra identified with dE/dx below 800 MeV/c [7].
- π^- spectra from a so called h-minus analysis in which all negative tracks were selected and yields were extracted from a global Monte Carlo factor [6].
- π^+ and π^- yields identified with the combined $tof - dE/dx$ method [8].

All pion yields were corrected with the help of the NA61 Geant3 based Monte-Carlo. The following effects have been accounted for: geometrical acceptance of the detector; efficiency of the reconstruction chain; decays and secondary interactions; ToF detection efficiency; pions coming from Lambda and K0s decays (called feed-down correction). The inverse corrections applied to the spectra for one angular bin in the tof+dE/dx analysis are shown in Fig. 3 as an example. The Systematic error associated with each correction and with the particle identification are also shown. The dominant systematic come from the uncertainty in the correction for weak decays and secondary interactions (30% of the correction value). In addition to several track quality cuts, maximum acceptance regions were selected by applying a cut on the azimuthal angle, thereby assuring tracks have a large number of measured points, and a very high reconstruction efficiency. This minimizes the systematical errors arising from possible differences in geometry between data and Monte-Carlo.

The spectra normalized to the inclusive cross section [5] are shown in Fig. 4 for positively charged pions. The spectra are presented as a function of particle momentum in ten intervals of the polar angle. The chosen binning takes into account the available statistics of the 2007 data sample, detector acceptance and particle production kinematics. The negatively charged pion cross sections are given in [1] along with details on all three analysis.

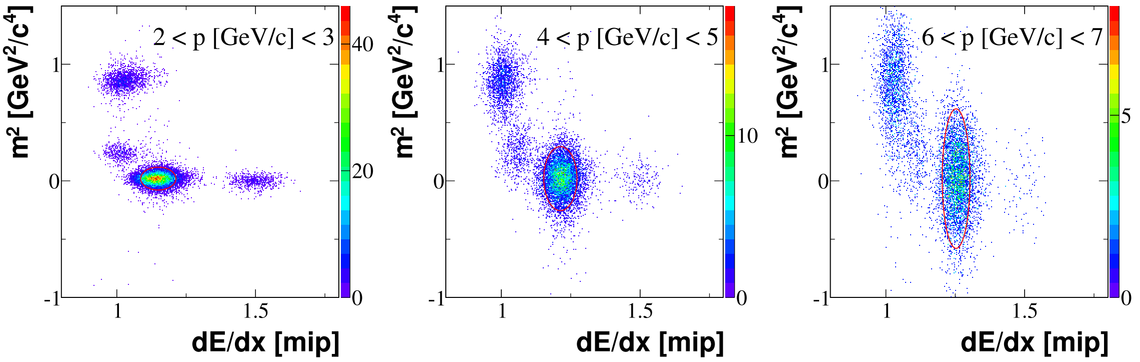

Figure 2: Examples of two-dimensional m^2–dE/dx plots for positively charged particles in three momentum intervals indicated in the panels. 2σ contours around fitted pion peaks are shown. The left and middle plots correspond to the dE/dx cross-over region while the right plot is at such a high momentum that the ToF-F resolution becomes a limiting factor. The combination of both measurements provides close to 100% purity in the pion selection over the whole momentum range.

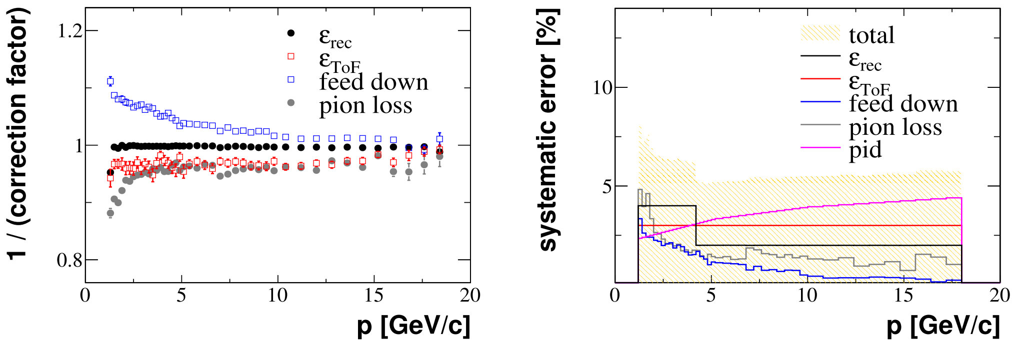

Figure 3: Example of momentum dependence of the inverse correction factor (left) and systematic errors (right) for the $tof - dE/dx$ analysis for positively charged pions in the polar angle interval [40,60] mrad. ϵ_{rec} and ϵ_{tof} are the efficiencies of the reconstruction and of the ToF-F, respectively. The feed-down correction accounts for pions from weak decays which are reconstructed as primary particles, while the pion loss accounts for pions lost due to decays or secondary interactions.

4 Conclusion

The presented results are essential for precise predictions of the neutrino flux in T2K and are currently used as input to the neutrino beam simulation. In 2009 and 2010 another much larger set of data has been collected with both the thin and a T2K replica carbon target and is presently being analysed. For both these data sets the ToF-F was extented yielding a higher detector acceptance, the TPC readouts were upgraded and a new trigger system was implemented. This new data will provide results of charged pion cross-section with a higher precision and will allow the measurements of other hadron species such as charged kaons, protons or K_s^0. Knowledge of kaon production is crucial for T2K to predict the intrinsic ν_e contamination of the neutrino beam.

5 References

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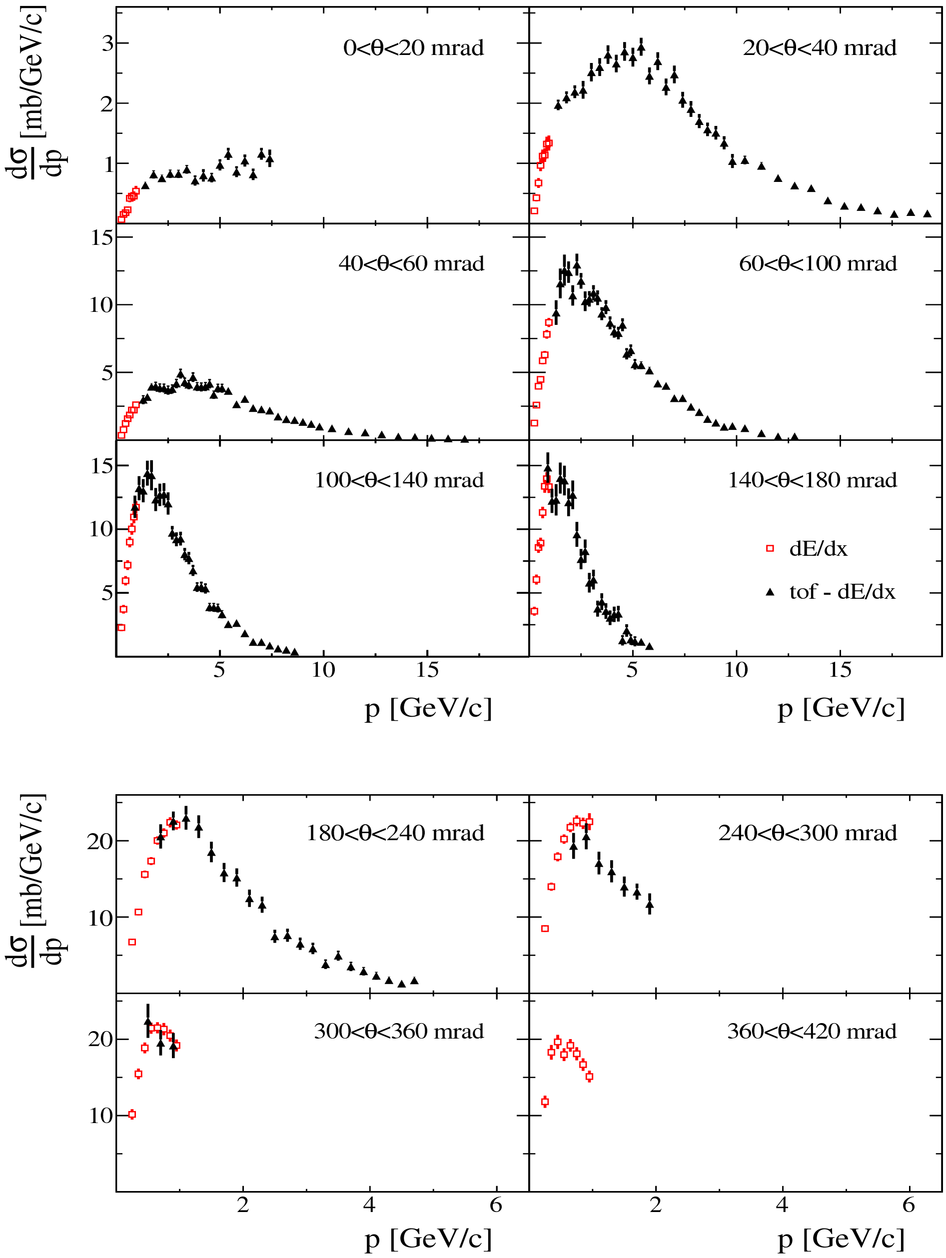

Figure 4: Differential cross sections for π^+ meson production in p+C interactions at 31 GeV/c. The spectra are presented as a function of laboratory momentum (p) in different intervals of polar angle (θ). Results obtained using two analysis methods are presented by different symbols: red open squares - dE/dx analysis and black full triangles - $tof - dE/dx$ analysis. Error bars indicate only statistical uncertainties.

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