Charged pion spectra in proton–carbon interactions at 31 GeV/c

Magdalena Zofia Posiadała
on behalf of the NA61/SHINE Collaboration

Faculty of Physics, University of Warsaw, Hoża 69, 00-681 Warsaw, Poland

E-mail: `magdalena.posiadala@fuw.edu.pl`

Abstract. The NA61/SHINE experiment at CERN SPS measured charged pion spectra in p+C interactions at 31 GeV/c. These measurements are necessary to improve predictions of the neutrino flux for the T2K long baseline neutrino oscillation experiment in Japan. Presented analysis was based on the data collected during the first NA61/SHINE run in 2007 with an isotropic graphite target with a thickness of 4% of nuclear interaction length. Three different methods which were used in order to obtain π^+ and π^- spectra are introduced. Differential cross sections for negatively and positively charged pions are presented as a function of laboratory momentum in ten intervals of the laboratory polar angle up to 420 mrad.

1. Introduction

The NA61/SHINE (SHINE = SPS Heavy Ion and Neutrino Experiment) is a large acceptance hadron spectrometer located in the North Area H2 beam line of the European Centre for Nuclear Research (CERN) in Geneva. The experiment uses beams from the Super Proton Synchrotron (SPS). The NA61/SHINE experiment combines a rich physics program in three different fields: auxiliary measurements for neutrino experiments, cosmic-ray simulations, and the behavior of strongly interacting matter at high density (see: [1, 2, 3] for details). In its first stage of data taking (years 2007, 2009 and 2010) NA61/SHINE performed measurements of hadron production in hadron-nucleus interactions. Such data are needed for neutrino (T2K) and cosmic-ray (Pierre Auger and KASCADE) experiments.

This article reports on the measured differential cross sections for negatively and positively charged pions obtained with 31 GeV/c p+C interactions taken during first NA61 pilot run in 2007. All measurements presented here were taken with a 2 cm long target with dimensions 2.5(W)x2.5(H) cm (about 4% of nuclear interaction length) with density $\rho = 1.84 \frac{g}{cm^3}$, so-called thin target. In total, during 2007 data taking we managed to register about 678 k events on thin carbon target.

2. Overview of the NA61/SHINE detector

The main components of the detector have been inherited from its ancestor NA49 [4] which has been designed to handle the most complex hadronic final states like high multiplicity (around 1800) charged particles produced in lead-lead collisions. At the same time it is able to deal with charged multiplicity as low as $\geq 3 - 10$, in elementary hadronic (p+p) as well as proton-nucleus collisions. The layout of the NA61/SHINE setup is shown in Fig. 1. The main tracking
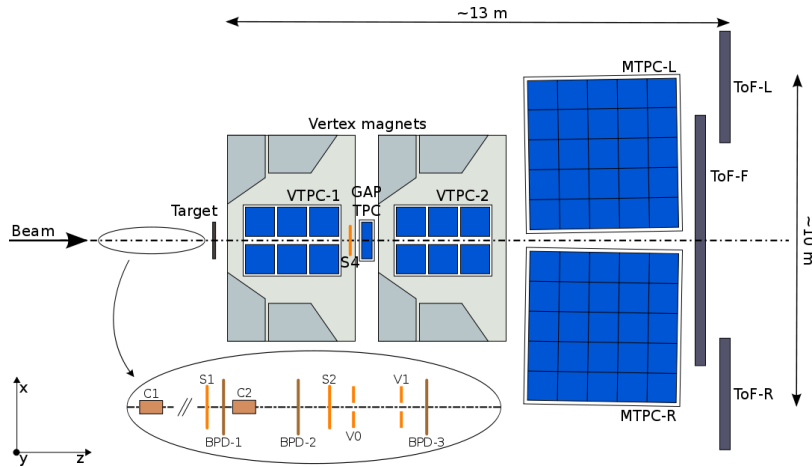
Figure 1. The layout of the NA61/SHINE experiment at the CERN SPS (top view, not to scale). The incoming beam direction is along the z axis. The magnetic field bends charged particle trajectories in the $x - z$ (horizontal) plane. The drift direction in the TPCs is along the y (vertical) axis.

devices are four large volume Time Projection Chambers (TPCs). Two of them, the vertex TPCs (VTPC1 and VTPC2), are located in the magnetic field of two superconducting dipole magnets. Two others MTPC-L and MTPC-R (blue boxes in Fig. 1) are positioned downstream. Two time-of-flight detectors (ToF-L/R) were inherited from NA49 and are able to provide time measurement resolution of $\sigma \approx 60$ ps. In 2007 the experiment has been updated with a new forward time-of-flight detector (ToF-F) in order to extend the acceptance for pion and kaon identification as required for T2K measurements [5]. The ToF-F wall is installed downstream of the main TPCs (black line in Fig. 1), closing the gap between the ToF-L and ToF-R walls. The ToF-F time resolution is $\sigma \approx 115$ ps. More details of the NA61 set-up may be found elsewhere [1, 4].

3. Methods of particle identification

Particle identification in NA61 was possible using energy loss measurements (dE/dx) in active volume of the TPCs and time-of-flight information from the ToF-F detector. If dE/dx is plotted versus a particle's momentum, a clear mass dependence can be seen, as shown in left plot in Fig. 2. When the resolution of the ionization measurement is sufficient, the separation of different species is possible, excluding of course regions where Bethe-Bloch curves cross each others like in momentum range of $1 < p \ [GeV/c] < 3$ for positively charged particles. For negative particles situation in this region of phase space is better as we do not see antiprotons and antideuterons in the data. This momentum range of $1 < p \ [GeV/c] < 3$ is very important for the T2K neutrino predictions which is the reason why measurements were also performed with addition of specially designed ToF-F detector (see middle plot in Fig. 2). As a result, combined analysis with dE/dx and ToF-F measurements was carried out. Example of two-dimensional m^2–dE/dx illustration for positively charged particles for momentum interval $2 < p \ [GeV/c] < 3$ is shown in right plot in Fig. 2.

To conclude, in order to obtain π^+ and π^- yields in broad momentum range, three different analyses were developed. They are as follows:

- energy loss measurements (dE/dx) in the active volume of the TPCs; analysis applicable
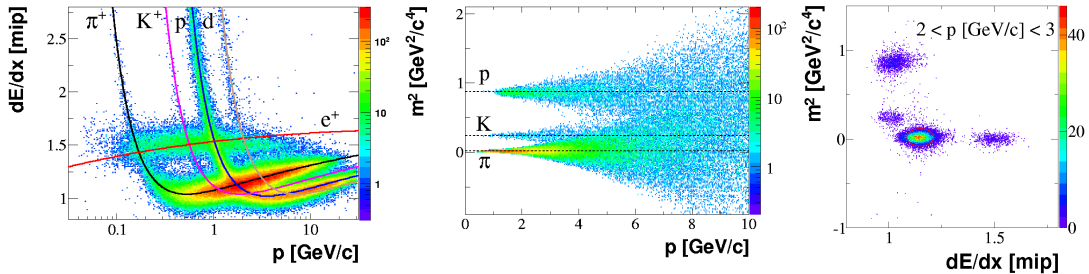
Figure 2. Left: dE/dx as a function of momentum for positively charged particles together with the parametrized Bethe-Bloch curves for positrons (electrons), pions, kaons, protons and deuterons. Middle: Measured mass squared, derived from the ToF-F measurement, versus momentum p. The lines show the expected mass squared values for different particles. Right: Example of two-dimensional m^2–dE/dx plot for positively charged particles for momentum interval $2 < p \, [GeV/c] < 3$. 2σ red contour around fitted pion peak is also shown. Each point in all three plots represents one track detected during 2007 data taking on the thin carbon target.

for low momentum particles *i.e.* $0.2 < p \, [GeV/c] < 1$ for positive and $0.2 < p \, [GeV/c] < 3$ for negative tracks. The topic of this analysis was the subject of the Ph.D. thesis [8, 11].

- combined information from the dE/dx and time-of-flight measurements ($tof - dE/dx$); method used for tracks with the ToF detector acceptance i.e with $p >$0.8 GeV/c. For more details concerning the analysis the reader is referred to [9, 11].

- analysis of negatively charged particles further referred to as h^-. This method is based on the theoretical and experimental premises that negative particles produced by 31 GeV/c protons consist mainly of negative pion mesons with an admixture of electrons, negative kaons and a negligible fraction of antiprotons. The Monte Carlo simulation [6] was used to calculate corrections for the contribution of electrons, primary K^- and $\overline{p}$. Extensive description of the analysis method can be found in [10, 11].

4. Differential cross sections for π^+ and π^- mesons
In Fig. 3 we present differential cross sections for π^+ (left) and π^- (right) meson production obtained in p+C interactions at 31 GeV/c obtained by three methods of analysis. Details of the normalization procedure may be found elsewhere [7].

5. Conclusions
In the 2007 data taking the first physics data on interactions of 31 GeV/c protons on the thin and T2K replica carbon target were registered. The spectra of π^+ and π^- mesons were obtained using different methods: dE/dx, $tof - dE/dx$ and h^-.

The numerical values of the final charged pion spectra as well as details concerning the analyses, cross section normalization, systematic errors, model comparisons may be found in [11]. These measurements have already been used by the T2K collaboration in order to tune simulations of the neutrino beam which are very significant for searching of electron neutrino appearance in muon neutrino beam, as stated in [12].
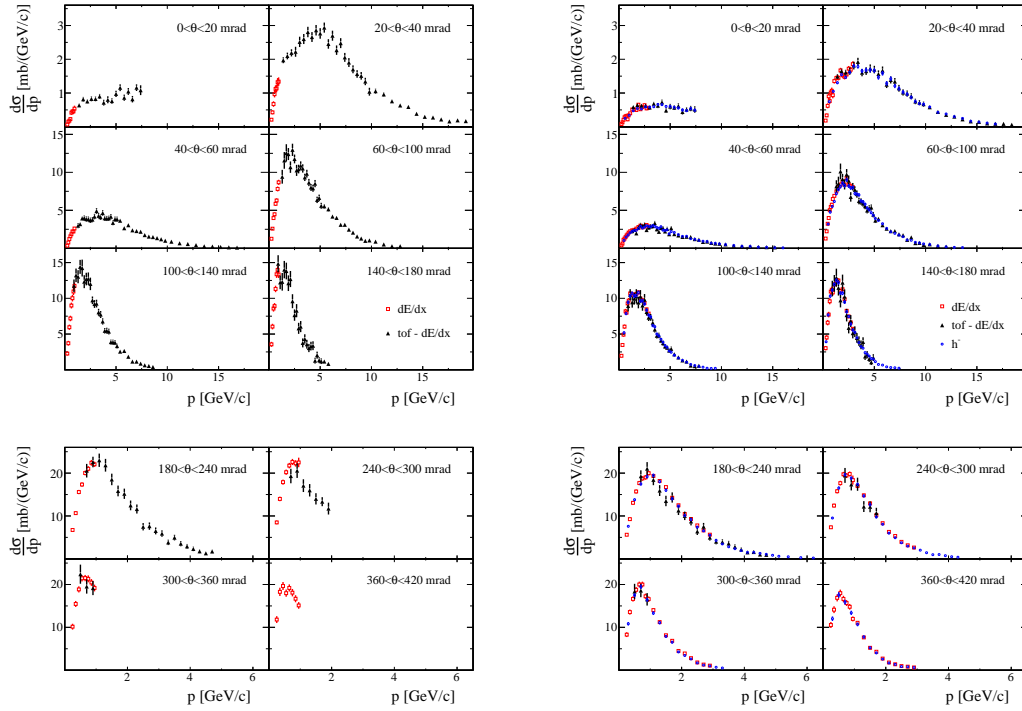
Figure 3. Differential cross sections for π^+ (left) and π^- (right) meson production in p+C interactions at 31 GeV/c. The spectra are presented as a function of laboratory momentum (p) in ten intervals of polar angle (θ). Results obtained using: two analysis methods for π^+ and three for π^- are presented by different symbols: $\square$ - dE/dx analysis, $\bigcirc$ - h^- analysis and $\blacktriangle$ - $tof - dE/dx$ analysis. Error bars indicate only statistical uncertainties.

6. Acknowledgments

References

[1] Antoniou N *et al.* 2006 CERN-SPSC-2006-034
[2] Antoniou N *et al.* 2007 CERN-SPSC-2007-004
[3] Abgrall N *et al.* 2007 CERN-SPSC-2007-019
[4] Afanasev S *et al.* 1999 *Nucl. Instrum. Meth. A* **430** 210
[5] Abgrall N *et al.* 2008 CERN-SPSC-2008-018
[6] Abgrall N 2011 *Constraining neutrino flux predictions with hadron production data: the NA61/SHINE measurements for the T2K experiment* (Geneva: University of Geneva)
[7] Strabel C 2011 *Evaluation of Particle Yields in 30 GeV Proton-Carbon Inelastic Interactions for Estimating the T2K Neutrino Flux* (Zurich: ETHZ)
[8] Posiadała M 2012 *Measurements of Hadronic Cross Section for Precise Determination of Neutrino Beam Properties in T2K Oscillation Experiment* (Warsaw: University of Warsaw)
[9] Murphy S 2012 *Measurement of charged Pion and Kaon production cross sections with NA61/SHINE for T2K* (Geneva: University of Geneva)
[10] Palczewski T 2012 *Ph.D thesis in preparation* (Warsaw: Soltan Institute for Nuclear Studies)
[11] Abgrall N *et al.* 2011 *Phys. Rev. C* **84** 034604
[12] Abe K *et al.* 2011 *Phys. Rev. Lett.* **107** 041801