

# **Preliminary results of charged pions cross-section in proton carbon interaction at 30 GeV measured with the NA61/SHINE detector.**

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As the intensity of neutrino beams produced at accelerators increases, important systematic errors due to poor knowledge of production cross sections for pions and kaons arise. Among other goals, the NA61/SHINE (SHINE  $\equiv$  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 30 GeV proton beam produced at the SPS with a thin carbon target and a full T2K replica target. Preliminary spectra of  $\pi^-$  and  $\pi^+$  inclusive cross section were obtained from pilot data collected in 2007 with a 2 cm thick target. After a description of the SHINE detector and its particle identification capabilities, results from three different analysis are discussed.

## **1 Physics motivation**

In T2K, neutrinos are produced by a high intensity proton beam of 30 GeV impinging on a carbon target and producing mesons ( $\pi$  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 30 GeV. Thus the NA61/SHINE experiment will provide a precise measurement of meson yield production in carbon at the proton beam energy (30 GeV/c) of interest for T2K. These measurements will be 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<sup>1</sup>.

## **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 inherited from the NA49 experiment<sup>2</sup>. The tracking apparatus consists in four large volume Time Projection Chambers (TPCs), which are capable of detecting up to 70% of all charged particles created in the reactions studied. Two 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 MTPC-R) are positioned downstream of the magnets, symmetrically on the left and right of the beam line. One additional small TPC, so-called gap TPC (GTPC), is installed on the beam axis between the vertex TPCs. 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<sup>1</sup>. 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<sup>3</sup> which provides a  $5 \sigma$   $\pi/K$

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).

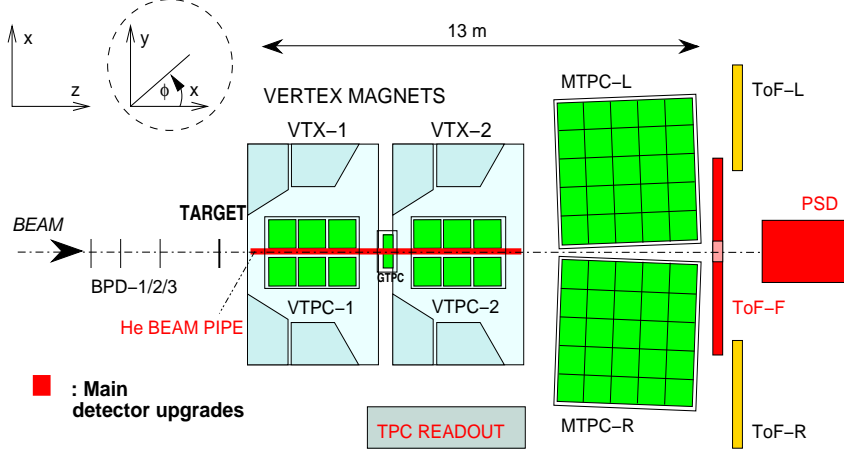


Figure 1: The layout of the NA61/SHINE set-up in the 2007 data taking (top view, not to scale).

For particles within the acceptance of the ToF detectors  $dE/dx$  information from the TPCs is available simultaneously with the time of flight. Fig. 2 shows  $dE/dx$  spectra for positive particles and a mass-squared distribution from the ToF-F. At momenta above  $\sim 4$  GeV/c the separation of  $(e, \pi)$  from  $(K, p)$  is performed essentially by  $dE/dx$ , whereas the ToF measurement is needed to distinguish between kaons and protons. Below 4 GeV/c particle identification can be performed almost exclusively by the ToF while the  $dE/dx$  is needed to separate electrons. By combining both methods pion yields can be extracted with a high purity over the whole momentum range needed for T2K. This is demonstrated in Fig. 2 where particles between 3 and 4 GeV/c of momentum are sorted corresponding to their  $dE/dx$  signal and the mass squared obtained from the forward time-of-flight.

### 3 Preliminary results.

The raw pion yields are corrected step-by-step with the help of the NA61 Geant3 based Monte-Carlo (MC). The following effects have been accounted for: geometrical acceptance of the detector; efficiency of the reconstruction chain; decays before reaching the ToF; ToF detection Efficiency; pions coming from Lambda and K0s decays (called feed-down correction); decays of pions into muons, which are reconstructed as one track (called feed-up correction).

In order to determine the correct number of inelastic interactions among all triggered events some corrections have to be applied<sup>4</sup>. First one has to subtract the contribution of large angle coherent elastic scatterings which pass the trigger conditions. Secondly one needs to take into account a loss of inelastic triggers due to a fact that secondary particle acted as primary proton on the trigger counters. We also have to estimate the rate of the events which take place outside of the carbon target.

The double differential inclusive inelastic cross section  $\frac{d^2\sigma_{inel}}{dpd\theta}$  for  $\pi^+$  and  $\pi^-$  are presented in Fig. 3 and Fig. 4 in four polar angle bins. Only statistical errors are shown and for these preliminary results systematical uncertainties are estimated to be 20% or below. The spectra retrieved with the combined "ToF+ $dE/dx$ " method are compared with 2 other analysis:

- in the  $\pi^+$  case (Fig. 3), another analysis identified particles with  $dE/dx$ -only below 800 MeV/c<sup>5</sup> and corrected the raw spectras with a global MC factor. For ToF acceptance reasons the 2 spectra do not overlap but the results can be checked for continuity.

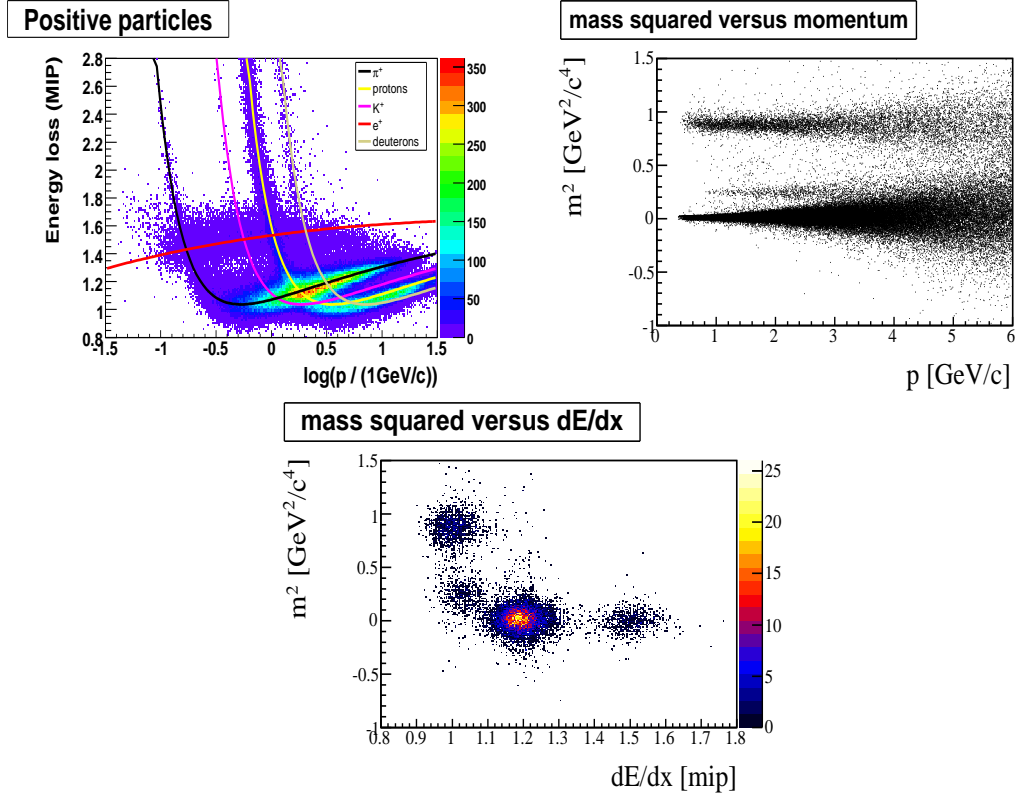


Figure 2: [Top-Left]:  $dE/dx$  versus  $\log(p)$  spectra and Bethe-Bloch parametrization super-imposed. [Top-Right]: mass squared spectra from the Forward Time of flight, protons kaons and pions are visible. [Bottom]: mass squared versus  $dE/dx$  in the momentum range 3-4 GeV/c in which 4 islands corresponding to pions, electrons kaons and protons are clearly defined. High purity samples of pions can be extracted with this method.

- for  $\pi^-$  (Fig. 4) the results have been compared with a so called h-minus analysis in which all negative tracks were selected and yields were extracted from a global MC correction<sup>6</sup>.

## 4 Conclusion

Preliminary results of pion inclusive cross-section from proton carbon interactions at 30 GeV are now available and used for the T2K flux prediction. Results from 3 different analysis have been presented. Work is currently in progress to reduce the systematic error of 20% to a level below 10% which is required for the T2K physics. Another much larger set of data has been collected at the end of 2009, after a major readout upgrade, an extension of the ToF-F and a new trigger system. This data is currently in the calibration process. With this larger set of statistics the goal, amongst others, is to produce kaon cross-sections results which is crucial for T2K to predict the intrinsic  $\nu_e$  contamination of the neutrino beam. Such results would greatly improve the T2K sensitivity in its search for the last unknown neutrino mixing angle  $\theta_{13}$ .

## 5 References

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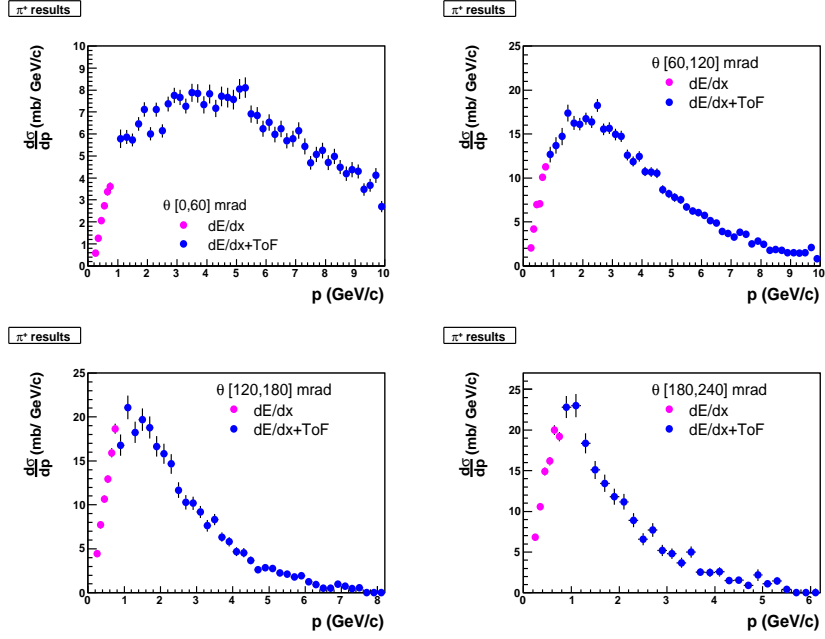


Figure 3: Double differential inclusive inelastic cross section for  $\pi^+$  from collisions of 30 GeV protons on the thin carbon target. Results are shown in 4 bins of polar angle  $\theta$  between 0 and 240 mrad with statistical errors only. The results from ToF + dE/dx in blue are compared with the “dE/dx only” analysis in pink.

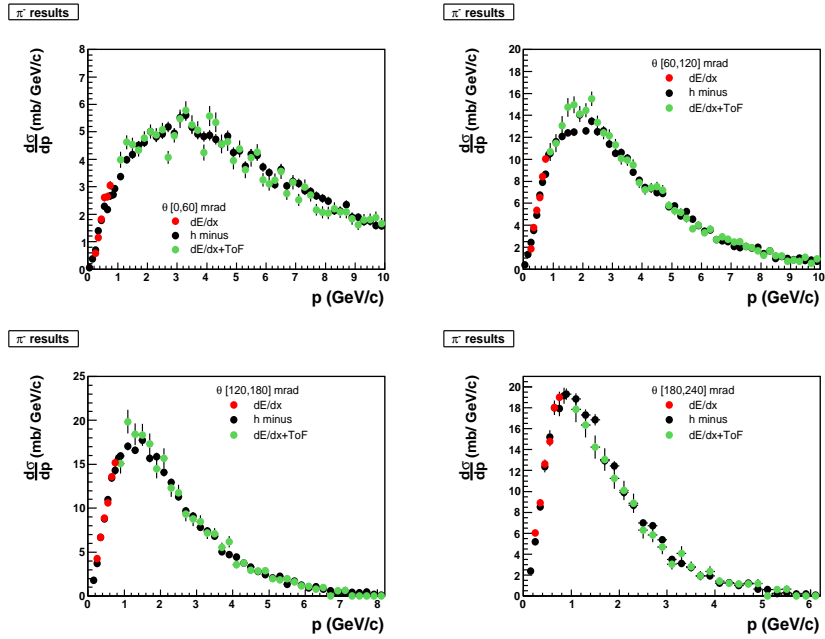


Figure 4: Double differential inclusive inelastic cross section for  $\pi^-$ . Results from 3 analysis are shown with statistical errors only.

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