Pion Production Cross-section Measurements in p+C Collisions at the CERN SPS for Understanding Extensive Air Showers

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Introduction

Studying high-energy cosmic rays by examining the properties of extensive air showers they induce strongly depends on models of hadronic interactions, which often fail to accurately reproduce experimental data [1] — *e.g.* underestimating the yield of shower muons or showing non-smooth transition from low- to high-energy interactions. Additional phenomenological data is therefore required in order to appropriately tune these models.

It has been demonstrated that for shower energies studied by KASCADE, KASCADE-Grande and the Pierre Auger Observatory, shower hadron production can be accurately reproduced using hadron–light ion collisions in the energy range of the Super Proton Synchrotron (SPS) at CERN [2].

This poster presents the first such results obtained by the NA61/SHINE experiment at the SPS — pion spectra from p+C collisions at 31 GeV.

The NA61/SHINE Experiment

NA61/SHINE is an experiment at the CERN SPS using the upgraded NA49 hadron spectrometer to accomplish a number of physics goals, including providing reference data for cosmic-ray experiments. Its large acceptance, high momentum resolution and good particle-identification capabilities make it an excellent candidate for investigating hadron spectra in the kinematic ranges of KASCADE, KASCADE-Grande and Pierre Auger Observatory (see Figure 1).

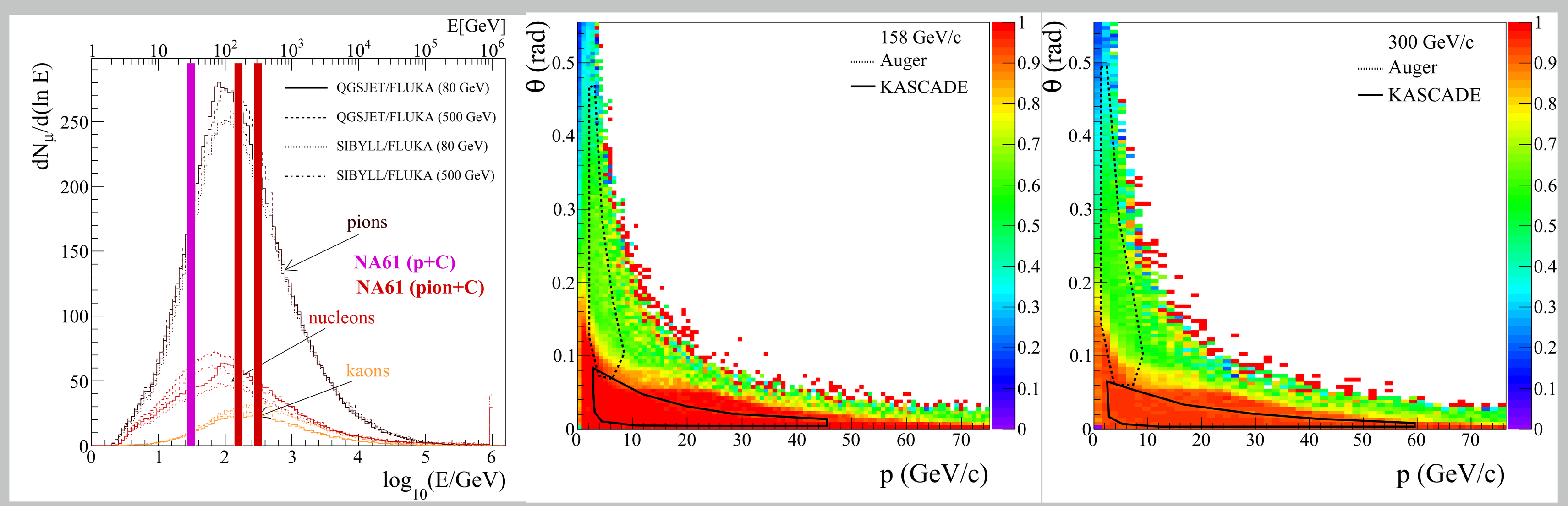

Figure 1: **Left**: Energy distributions, simulated using several models, of the "grandfather" particles in extensive air showers with $E_0 = 10^{15}$ eV, with vertical lines indicating the beam energy in relevant NA61/SHINE runs. **Middle and right**: coverage of NA61 in pion–carbon collisions at 158 (middle) and 300 (right) GeV *vs* that of KASCADE and Auger, with contours indicating the 66-percent level for each.

The following are the main features of the NA61 detector as shown in Figure 2 [3, 4]:

- tracking plus momentum, charge and $\mathrm{d}E/\mathrm{d}x$ measurement with five Time-Projection Chambers;
- three Time-of-Flight walls for additional identification information;
- high-precision downstream Projectile Spectator Detector;
- a number of beam and triggering detectors.

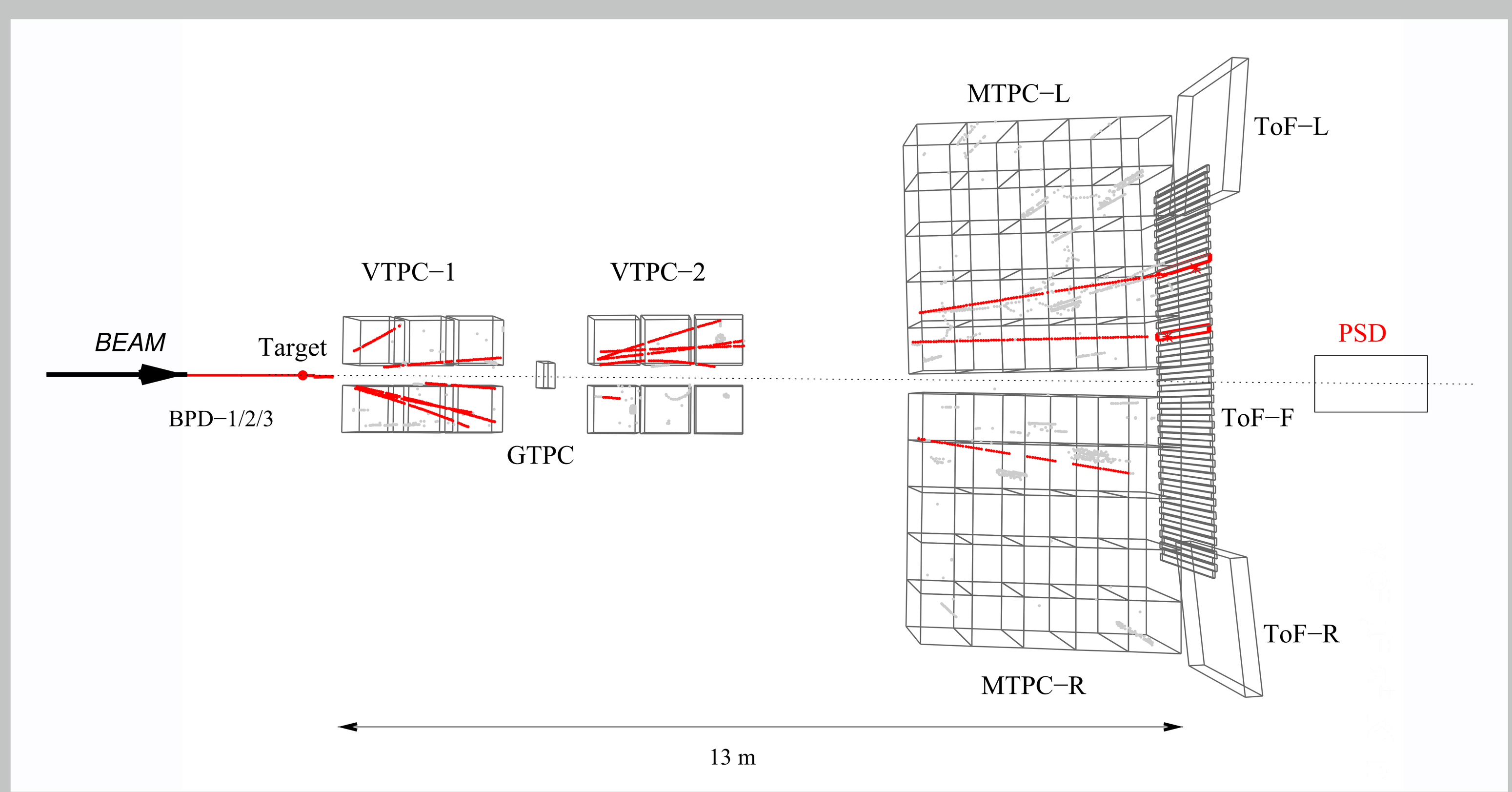

Figure 2: A view of an NA61/SHINE proton–carbon event, showing the general layout of the apparatus.

For the purpose of cosmic-ray studies, SHINE has acquired 4.6 million p+C events at 31 GeV, 3.5 million π^-+C events at 158 GeV and 4.7 million π^-+C events at 300 GeV. The results presented here have been produced from the 600 thousand p+C-at-31 GeV events registered in 2007.

Modus Operandi

The pion spectra presented here have been obtained using three independent analysis techniques:

- The h^- method, in which all negative hadrons produced in a collision are assumed to be pions and the contribution of other species is corrected for using simulations. Pros: simple, high statistics. Cons: stronger model dependence, doesn't work for positive pions;
- $\mathrm{d}E/\mathrm{d}x$ identification of $\pi^\pm$. Pros: explicit identification, still high statistics thanks to NA61 design. Cons: only works at low p where Bethe-Bloch bands do not overlap;
- $\mathrm{d}E/\mathrm{d}x$-plus-ToF identification of $\pi^\pm$. Pros: explicit identification over a wide momentum range. Cons: limited acceptance.

For all three approaches, particles passing all the cuts are divided into (p, θ) bins, where p is the total momentum and θ is the polar angle, to account for changing detection and identification properties.

Results

Figures 3 and 4 show the yield and production cross-section of positive and negative pions in two θ bins: 0–60 and 60–120 mrad. All errors are statistical only, systematic effects are being investigated.

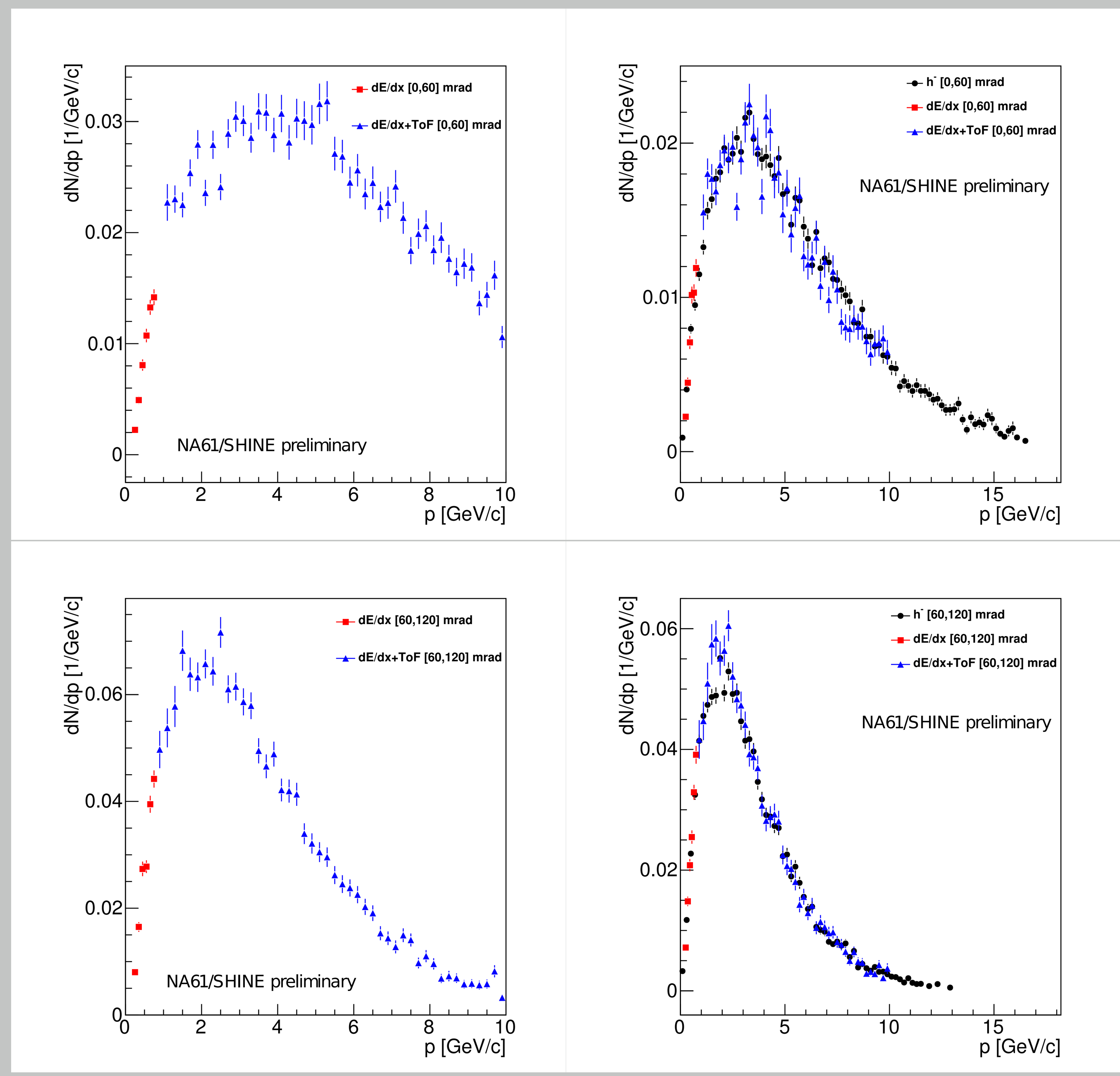

Figure 3: Momentum distribution of the positive (left) and negative (right) pion yield in p+C collisions at 31 GeV/c, in the polar-angle bins of 0–60 and 60–120 mrad. Black circles: h^- analysis (π^- only); red squares: pions identified using $\mathrm{d}E/\mathrm{d}x$; blue triangles: pions identified using combined $\mathrm{d}E/\mathrm{d}x$ and ToF information. All errors are statistical only.

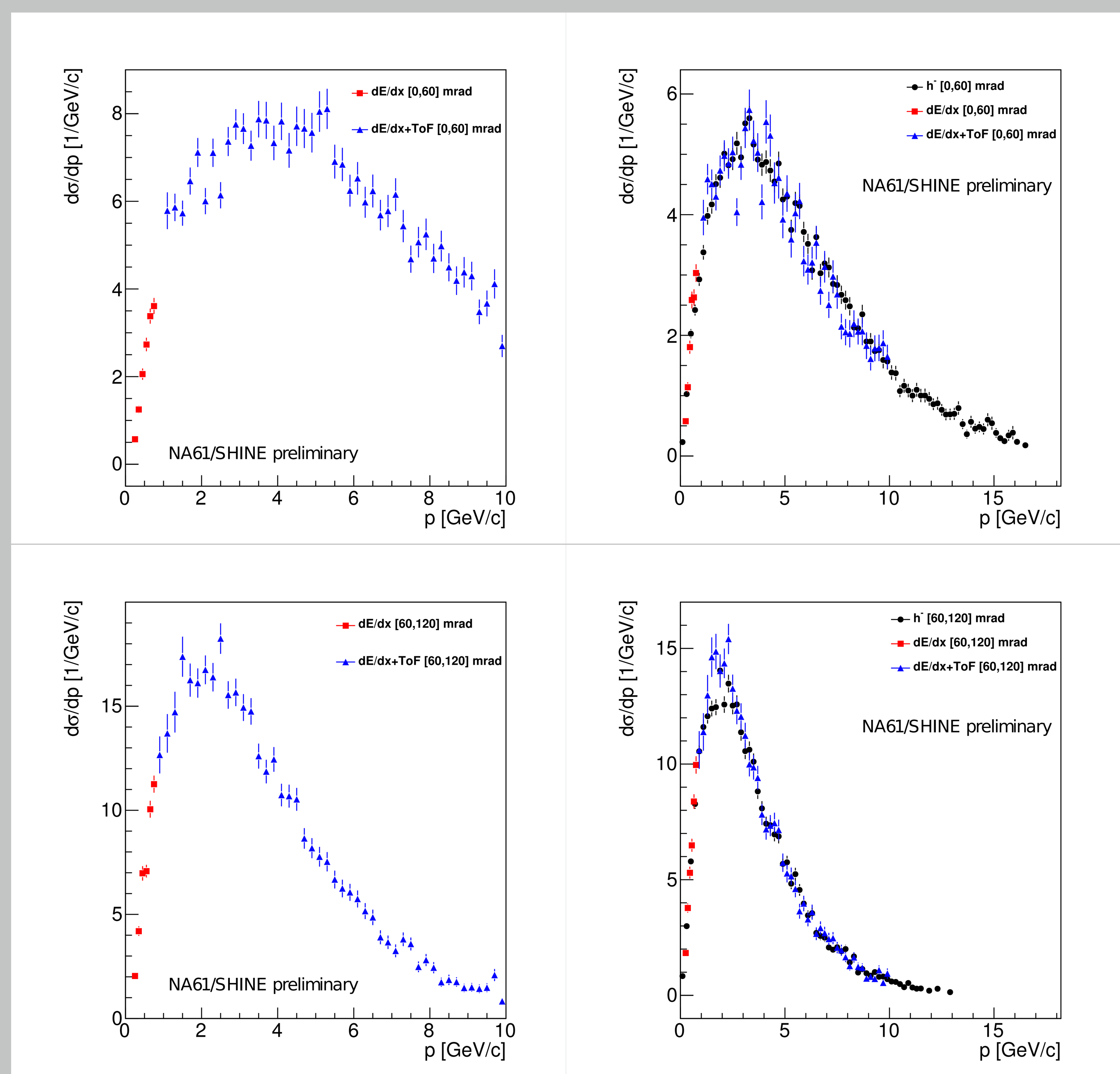

Figure 4: Momentum distribution of positive (left) and negative (right) pion production cross-section in p+C collisions at 31 GeV/c, in the polar-angle bins of 0–60 and 60–120 mrad. Black circles: h^- analysis (π^- only); red squares: pions identified using $\mathrm{d}E/\mathrm{d}x$; blue triangles: pions identified using combined $\mathrm{d}E/\mathrm{d}x$ and ToF information. All errors are statistical only.

Summary

NA61/SHINE has produced its first results relevant to tuning models of hadron production in extensive air showers: preliminary $\pi^\pm$ spectra from p+C collisions at 31 GeV. The spectra were obtained using three different methods, with good agreement observable between them. Work is ongoing to finalise and publish these results, as well as to analyse the large-statistics p+C and π+C runs from 2009.

Bibliography

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