NA61/SHINE: HADRON PRODUCTION IN p+p/A AND A+A INTERACTIONS AT THE CERN SPS

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The physics motivations, status and plans of NA61/SHINE experiment are presented. Also the first, preliminary results on π^- production, from the pilot run in 2007, are shown. These data are needed by the T2K experiment for precise neutrino beam simulation. It is explained why the precise hadron production measurements are crucial for various fields of physics. Moreover, it is argued that the 2D scan in system size and collision energy is essential for the study of the onset of deconfinement and search for the critical point of strongly interacting matter.

1 Introduction

The NA61/SHINE (SHINE stands for *SPS Heavy Ion and Neutrino Experiment*) is a successor of the well known NA49 experiment in the field of heavy ion collisions. It is a fixed target experiment on primary (ion) and secondary (hadron and ion) beams from the CERN SPS. The proposal [1] was submitted at the-end of 2006, the pilot run was conducted in October 2007 and the first physics run took place in 2009. The collaboration consists of 131 physicists from 25 institutes from 14 countries.

The physics programme regards three different subjects, the neutrino physics (section 3), cosmic ray physics (section 4) and strongly interacting matter physics (section 5). The first goal are precision measurements of hadron production in p/π+C interactions needed by the T2K (neutrino) and Pierre Auger Observatory and KASCADE (cosmic ray) experiments. The second goal are also precision measurements, to study the properties of the onset of deconfinement in nucleus-nucleus collisions, as well as to measure hadron production at high transverse momenta in p+p and p+Pb collisions as a reference for NA49's Pb+Pb results. Finally there is search for the critical point of strongly interacting matter, which is NA61/SHINE's discovery potential.

2 The NA61/SHINE detector

The main part of NA61/SHINE detector, which is sketched in Fig. 1, was inherited from NA49. [2] This includes four large-volume Time Projection Chambers — VTPC-1 and VTPC-2 inside superconducting dipole magnets for momentum determination, MTPC-L and MTPC-R for energy loss (so-called dE/dx) measurement and two time-of-flight detectors — ToF-L and ToF-R.

However, in order to satisfy the experimental programme, some upgrades [1] were needed. First, a new time-of-flight wall, the so-called Forward-ToF (F-ToF), was added in 2007, which gives *2 times larger* ToF acceptance than NA49 had. Second, new Beam Position Detectors

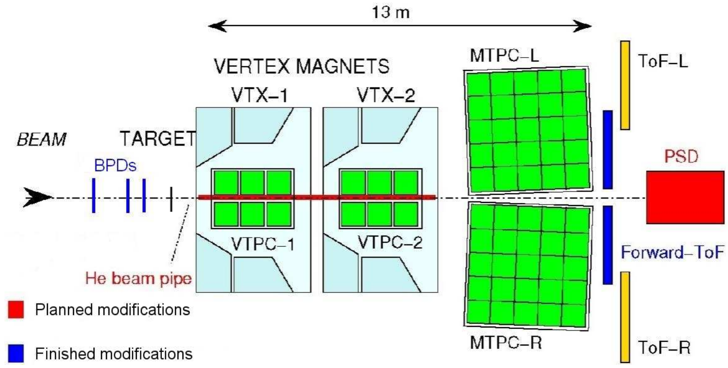

Figure 1: The layout of the NA61/SHINE detector (top-view, not to scale). Blue colour indicates components that were added to original NA49 set-up or upgraded, red indicates elements that will be added.

(BPDs; small Multiwire Proportional Chambers) were built in 2008, which are *2 times bigger* than NA49's. The third finished modification of the original system is a new TPC read-out, commissioned in 2008, which gives *10 times faster* data acquisition than NA49 could have. Moreover two additional upgrades are in progress, the helium filled beam pipe and a new calorimeter, the Projectile Spectator Detector (PSD). The beam pipe will *reduce by a factor of 10* the delta electron background in VTPCs in comparison to NA49. The PSD will in turn have *10 times better* energy resolution than the old NA49's Veto Calorimeter.

Fine performance of the NA61/SHINE detector may be summarized as follows:

- momentum resolution $\sigma(p)/p^2 \approx 10^{-4}\,(\mathrm{GeV/c})^{-1}$,
- time-of-flight resolution $\sigma(tof) \approx 60\,\mathrm{ps}$ for ToF-L and ToF-R and $\sigma(tof) \approx 120\,\mathrm{ps}$ for F-ToF,
- energy loss resolution $\sigma(dE/dx)/ < dE/dx > \approx 4\%$,
- large acceptance $\approx 50\%$ at $p_T \lesssim 2.5\,\mathrm{GeV/c}$.

Thanks to above parameters, depending on momentum, particle identification (PID) might be done with three methods. For very low momenta of particles (below 1 GeV/c) and high momenta (above 6 GeV/c) the dE/dx is used. For low momenta the time-of-flight measurement might be used. Finally, for medium momenta, where dE/dx Bethe-Bloch curves for various particles' species partially overlap as well as the corresponding tof mass-squared spectra, the combined tof and dE/dx method is used.

3 Neutrino physics - first results

The T2K experiment in Japan aims to study neutrino oscillations. [3] The neutrino beam is mainly produced from decays of products (mainly pions and kaons) of the 31 GeV/c proton beam interactions with a carbon target. The proton beam is created in the J-PARC accelerator in Tokai. Neutrinos first pass through the near detector at a distance of 280 m from the target and then through the far detector, Super-Kamiokande, 295 km away. Both detectors are positioned along a line 2.5° off the beam axis.

The study of oscillations is done by the comparison of the energy spectrum of neutrinos of a given flavour (ν_e or ν_μ) measured at the far detector with that extrapolated from measurements at the near detector with and without oscillation hypothesis. Because of the way the neutrinos are produced, the extrapolation is a non-trivial task. It is done using a Monte-Carlo prediction of the neutrino beam. In order to achieve the T2K physics goals, the extrapolation has to be

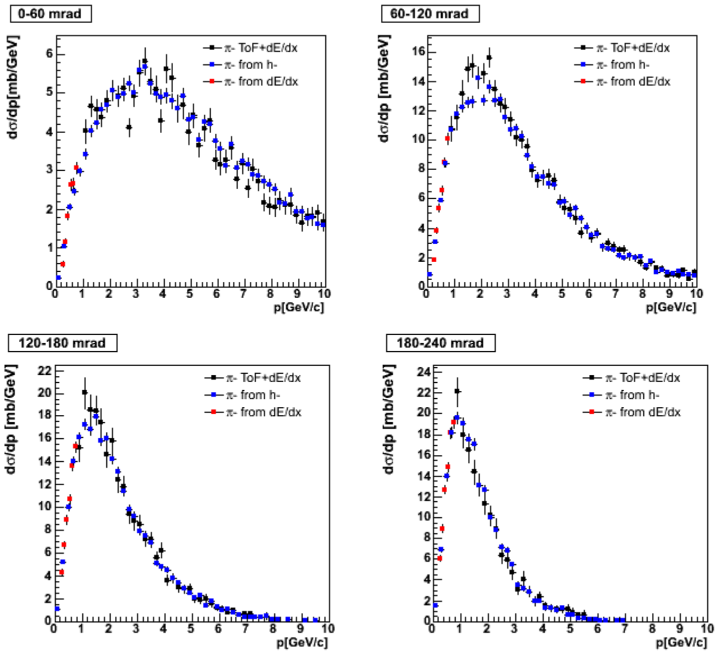

Figure 2: Preliminary cross sections for π^- production in p+C thin target collisions at beam momentum of 31 GeV/c from the pilot run in 2007. Three different methods of analysis (see text) are compared for 4 bins of the production angle. Only statistical errors are plotted.

done with a precision of 2–3%. This implies, that T2K beam MC cannot rely only on hadron production models — it requires *precise knowledge of hadron production* under T2K conditions.[a] This can be provided by the NA61/SHINE measurements.

As there are two strategies to implement the NA61/SHINE data into the T2K beam MC, the measurements are done with two carbon targets — the so-called thin target (4% of nuclear interaction length, λ_I) and the so-called long target (a replica of the T2K target, $1.9\lambda_I$). With the thin target 660k events were taken in 2007 and 6M events in 2009, while with the long target 230k events were registered in 2007 and 4M in 2009.

Preliminary results [4] for p+C thin target collisions at beam momentum of 31 GeV/c from the pilot run in 2007 are shown in the Fig. 2. These are differential cross sections for π^- production, for 4 bins of the production angle (the angle between beam and particle track). In the plot, 3 analysis methods are compared. The first uses combined tof and dE/dx information for momenta above 1 GeV/c, the second assumes that all negatively charged hadrons are π^- and then an MC correction is applied, finally the third one uses solely dE/dx measurement for momenta below 1 GeV/c. Only statistical errors are plotted and systematic ones are less than 20%. Still there is some work in progress to lower them. As one can see, results of these 3 methods are consistent, proving that the detector and analysis is well understood and that NA61/SHINE is ready to analyse a large amount of data collected in 2009.

4 Cosmic rays physics

Modern detectors, like KASCADE and Pierre Auger Observatory, measure composition of cosmic rays, which is of key importance for understanding sources of these particles and exciting structures (*knee, ankle*) in their energy spectrum. The problem is, that the measurement is done indirectly. Really observed are fragments of extensive air showers — cascades of billions of

[a] The same reasoning applies also to prediction of the energy spectrum of neutrinos at the near detector for neutrino cross section measurements.

particles produced in collisions of the primary cosmic ray with a nucleus in the atmosphere and subsequent collisions caused by products of the initial collision. So, a simulation of the shower is needed to say what particle started the shower. This causes a strong model dependence, due mainly to simulation of muon production. This in turn can be related to hadronic interactions at fixed-target energies, where muons are created in decays of products of these interactions. This again means that *a precise knowledge of hadron production* under certain conditions is needed.

For cosmic rays part of the programme, 5M collisions of 158 GeV/c pion beam with a thin carbon target were collected in 2009, along with 6M events with 350 GeV/c pion beam.

5 Physics of strongly interacting matter

Similarly to commonly known substances as water, strongly interacting matter may be found in various phases; there might be phase transitions between them, which may end in critical points. However, the difference is, that the experimental study for the case of strongly interacting matter is indirect. What we actually have access to, are freeze-out points of hadrons created in collisions, in the space of the temperature T and baryochemical potential μ_B. It has been shown, [5] that T and μ_B may be brought into one-to-one correspondence respectively with the system size A and energy E of nuclear collisions.

Lattice QCD calculations predict a first order phase transition between confined and deconfined matter. The idea for the study of the onset of deconfinement is that when the early stage of the collision hits the transition line, one expects to see certain signals in collision energy dependence of hadron production, e.g. the so-called kink, horn and step. These signals were predicted by Gaździcki and Gorenstein [6] and then actually observed by NA49 experiment [7] in central Pb+Pb interactions. Now NA61/SHINE aims to study how these signals develop when the system size is scanned.

There is also a prediction that the mentioned 1^{st} order phase transition ends in a critical point somewhere in the energy range covered by the CERN SPS. The idea for the search for the critical point, given by Stephanov *et al.* [8], is that if freeze-out is close to critical point and system is large enough, when one does a scan in A and E (T and μ_B), then one expects a hill in event-by-event fluctuations of multiplicity and transverse momentum. Important for the search is that one has to take into account fluctuations not related to the critical point. Huge contribution comes from fluctuations in number of participants, so one has to consider only central collisions. This is why *the first 2D (A and E) scan in the history of nucleus-nucleus relativistic collisions* started by NA61/SHINE, [9] is crucial for this search.

For this part of programme, about 19M p+p collisions were registered in 2009 with beam momenta of 20, 31, 40, 80 and 158 GeV/c.

References

1. N. Antoniou *et al.* [NA61 Collaboration], CERN-SPSC-2006-034, SPSC-P-330, (2006). `http://na61.web.cern.ch/`
2. S. Afanasiev *et al.* [NA49 Collaboration], *Nucl. Instrum. Methods* A **430**, 210 (1999).
3. Y. Itow *et al.*, “The JHF-Kamiokande neutrino project”, [arXiv:hep-ex/0106019].
4. S. Murphy [NA61 Collaboration], proceedings of the EW session.
5. F. Beccatini, J. Manninen, M. Gaździcki, *Phys. Rev.* C **73**, 044905 (2006).
6. M. Gaździcki, M. Gorenstein, *Acta Phys. Pol.* B **30**, 2705 (1999).
7. C. Alt *et al.* [NA49 Collaboration], *Phys. Rev.* C **77**, 024903 (2008).
8. M. A. Stephanov, K. Rajagopal and E. V. Shuryak, *Phys. Rev.* D **60**, 114028 (1999).
9. N. Abgrall *et al.* [NA61 Collaboration], CERN-SPSC-2009-031, SPSC-P-330-ADD-5, (2009).