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The NA61/SHINE Experiment at the CERN SPS

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Abstract

The physics goals, the detector and its performance as well as status and plans of the NA61/SHINE experiment at the CERN SPS accelerator are presented.

1. Introduction

NA61/SHINE [1] is a fixed-target experiment at the CERN SPS. The main detector components are inherited from the NA49 experiment. These are the two superconducting magnets, the four large volume TPCs and two ToF walls.

The physics program of NA61 is the systematic measurement of hadron production in proton-proton, proton-nucleus, hadron-nucleus, and nucleus-nucleus collisions as a function of $\sqrt{s_{NN}}$ and beam and target nuclear mass number. This comprehensive study has the following main objectives: (1) search for the critical point by an energy (E)- system size (A) scan, (2) study the properties of the onset of deconfinement by the E - A scan, (3) establish, together with the RHIC results, the energy dependence of the nuclear modification factor, (4) obtain precision data on hadron spectra in hadron-nucleus collisions for the T2K neutrino experiment, and for the Pierre Auger Observatory and KASCADE cosmic-ray experiments. In this paper, only the heavy-ion related points (1)-(3) shall be discussed.

To be able to fulfill the demands posed by the physics goals, detector upgrades became necessary. The already implemented and the ongoing detector improvements are shown in Figure 1 and the data taking status and plans are listed in Table 1.

2. Physics goals

Lattice QCD calculations [2] indicate that the phase diagram of strongly interacting matter features a 1-st order phase transition boundary in the temperature - baryochemical potential plane, which has a critical endpoint. This critical endpoint may be located in the energy range accessible at the CERN SPS.

Temperature (T) and baryochemical potential (μ_B) of the freeze-out points may be scanned via a systematic $E - A$ scan [3]. Near the critical endpoint an increase of the scaled variance (ω) of the multiplicity distribution and of the transverse momentum fluctuation measure (Φ_{p_T}) are expected [4]. Thus, the critical endpoint may be discovered by looking at the energy and system size dependence of multiplicity and transverse momentum fluctuations.

To detect an increase of fluctuations related to the critical point, the contribution of possible background fluctuations, in particular the fluctuation of the number of participant nucleons, have

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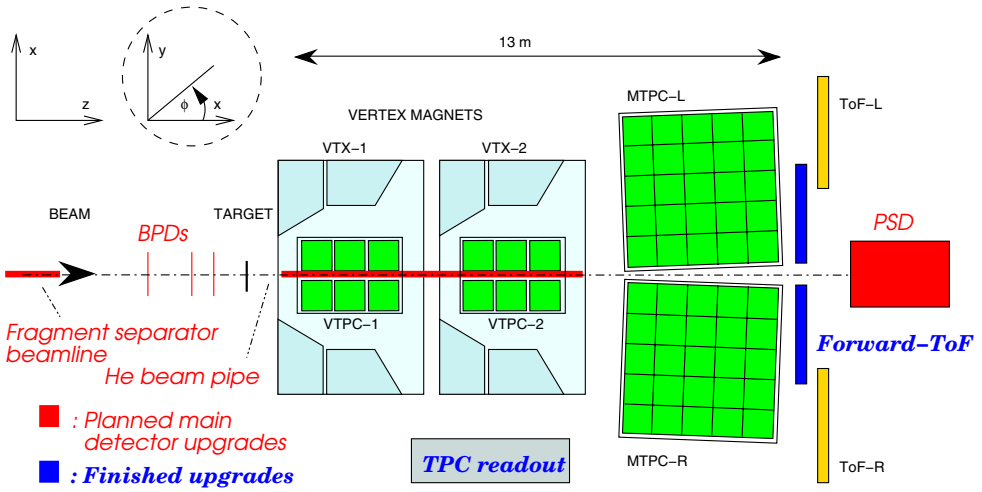

Figure 1: The setup of the NA61/SHINE experiment. The main detector detector upgrades (accelerated TPC readout, forward ToF, improved beam position detectors BPD, new projectile spectator detector PSD, He filled beam pipe, fragment separator beam line) are shown together with the original devices of NA49 (magnets, TPCs, ToF-R/L walls).

to be minimized. As shown in [5] even for a fixed number of projectile participants the number of target participants fluctuates, causing a significant background in a search for fluctuation signals of the critical point and the onset of deconfinement. This can be suppressed by selecting very central collisions of identical nuclei and by considerable improvement of the spectator energy measurement accuracy. To achieve this goal, a new projectile spectator energy measurement facility, the Projectile Spectator Detector PSD is being built (Figure 1), with a resolution of 1 nucleon throughout the energy range of interest.

Another source of background for multiplicity fluctuation measurements is the contamination by spiralling low-energy knock-on electrons (δ-electrons). To minimize this contribution, a Helium beam pipe will be introduced around the beam line inside the sensitive TPC volumes (Figure 1).

The planned systematic scan in energy and system size will allow to study the system size dependence of the anomalies in hadron production observed by NA49 [6] in central Pb+Pb collisions at about 30A GeV. These anomalies were predicted for the onset of deconfinement [7] and their further understanding requires new NA61 data.

A very interesting phenomenon, discovered by RHIC experiments at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ collision energy, is the reduction of high transverse momentum particle yields in nuclear collisions relative to elementary collisions (see e.g. [8]), when assuming scaling of particle spectra by the number of binary collisions. This phenomenon is referred to as 'high p_T particle suppression', and is usually interpreted as the manifestation of parton energy loss in the formed strongly interacting matter. Study of the energy dependence of the suppression phenomenon is required for its further understanding. The idea is that if the collision energy is low enough such that deconfined matter is not formed, the high transverse momentum particle suppression should disappear.

The recently published low energy R_{AA} data on $\pi^{\pm}$ suppression at $\sqrt{s_{NN}} = 17.3\,\mathrm{GeV}$ [9] show a monotonic increase as a function of p_T. Unfortunately there are no data points for $p_T \geq$

2.5 GeV/c. Therefore the existence or non-existence of a suppression at higher p_T is not clear from the present data. The accessible p_T range was limited by the available p+p statistics of the NA49 experiment. The p_T range of the reference p+p (and p+Pb) data will be extended by high statistics NA61 p+p and p+Pb measurements. This program demanded the complete upgrade of the NA61 TPC readout system in order to increase the event rate by an order of magnitude.

3. NA61/SHINE, the upgraded NA49 detector

A pilot run in 2007 showed that the detector fulfills the physics requirements. Its main features are: large acceptance ($\approx$ 50% at $p_T \leq 2.5$GeV/c), good momentum resolution ($\frac{\sigma(p)}{p^2} \approx 10^{-4}(\mathrm{GeV/c})^{-1}$), good tracking efficiency ($\geq$ 95%), good particle identification (resolution ToF-L/R: $\sigma(t) \approx 60$ ps, ToF-F: $\sigma(t) \approx 120$ ps, $\frac{dE}{dx}$: $\sigma(\frac{dE}{dx})\Big/\frac{dE}{dx} \approx 4\%$, V^0 invariant mass: $\sigma(m) \approx 5$ MeV), extended ToF acceptance at low momenta ($\approx$ 1GeV/c), improved event rate (70 Hz).

The still progressing upgrades are: Projectile Spectator Detector with 1 nucleon precision (prototype tested), He beam pipe for reduction of δ-electrons (technical design ready), fragment separator for precise selection of secondary ion beams (pilot simulation ready).

The performance reached in the 2007 pilot run is illustrated in Figure 2.

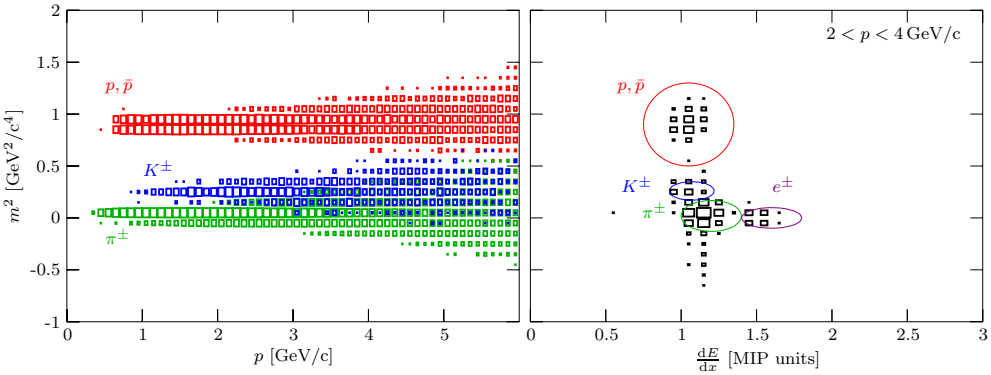

Figure 2: Particle identification performance results form the 2007 pilot run data. Left: ToF mass-square response as a function of momentum. Right: combined ToF + $\frac{dE}{dx}$ particle identification in the $2 < p < 4$ GeV/c momentum range. The size of the boxes indicate the hit population.

The annual beam requests of NA61 are summarized in Table 1, together with the recommendation and approval status assigned by the CERN SPS Committee and Research Board.

For the approval procedure of the NA61 experiment, the following documents are the most relevant: Expression of Interest [10], Letter of Intent [11], Status Report [12], Proposal [13], Addendum-1 [14] and Addendeum-2 [15].

4. Summary

The experiment NA61/SHINE has great discovery potential for the critical point of strongly interacting matter, if it exists.

Important measurements of the nuclear modification factor at the top SPS energy can be performed and the system size dependence of the effects related to the onset of deconfinement can be studied.

Pri. beam	Beam	Target	E [A GeV]	Year	Days	Physics	Status
p	p	C	31	2007	30	T2K, CR	Run completed
p	p	C	31	2008	30	T2K, CR	Interrupted (LHC)
p	p	C	31	2009	21	T2K, CR	Approved
p	π^-	C	158, 350	2009	14	CR	Approved
p	p	p	10 - 158	2009	42	CP&OoD	Approved
p	p	p	158	2010	77	high p_T	Recommended
Pb	S	S	10 - 158	2011	42	CP&OoD	Recommended *
p	p	Pb	158	2011	42	high p_T	Recommended
p	p	Pb	10 - 158	2012	42	CP&OoD	Recommended
Pb	C	C	10 - 158	2012	42	CP&OoD	To be discussed*
Pb	In	In	10 - 158	2013	42	CP&OoD	To be discussed*

Table 1: The beam request of the NA61/SHINE experiment. Abbreviations: CP – search for Critical Point; OoD – study the Onset of Deconfinement; T2K – supplementary spectra for the T2K experiment; CR – measurements for cosmic-ray physics; high p_T – p+p and p+Pb reference spectra for nuclear modification factors. *: Needs implementation of fragment separator beam line as the LHC beam schedule only allows Pb as primary heavy-ion beam in the SPS.

NA61 will provide necessary supporting measurements of hadron production for neutrino and cosmic-ray experiments.

The pilot run in 2007 has been successfully completed, and shows that the detector performance is sufficiently good. The $E - A$ scan starts in 2009 with p+p collisions. Heavy-ion measurements will start in 2011. There are also further projects on nucleus-nucleus collisions in the SPS energy range currently developed at BNL, FAIR and NICA, addressing the discussed physics questions.

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