# Status and plans of the NA61/SHINE physics program

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One of the NA61/SHINE experiment's goals is to discover the critical point of strongly interacting matter and study the properties of the onset of deconfinement. This is to be achieved by performing a two dimensional phase diagram ($T - \mu_B$) scan – measuring hadron production in collisions of various beam particles and targets at various beam energies. NA61/SHINE also collects data for the T2K experiment, which are just about to be published.

## 1. THE NA61/SHINE PHYSICS GOALS

NA61/SHINE (SPS Heavy Ion and Neutrino Experiment) [1, 2] is a fixed-target experiment located in the North Area of the Super Proton Synchrotron (SPS) accelerator facility at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland. It is the successor of the NA49 experiment [3], which was operating in 1994–2002. The NA61 collaboration consists of 130 physicists from 24 institutes in 13 countries.

NA61/SHINE physics goals are:

- search for the critical point of strongly interacting matter,
- detailed study of the onset of deconfinement,
- study of high $p_{\mathrm{T}}$ hadrons in $pp$ and $p$Pb interactions,
- reference measurements for neutrino physics (T2K experiment) by measuring the hadron production of the T2K target exposed to the proton beam at 31 GeV/$c$ [4, 5],
- reference measurements for cosmic-ray physics (KASCADE-Grande and Pierre Auger Observatory experiments) by measuring $p$C, $\pi$C interactions [6, 7].

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In order to search for the critical point and study the properties of the onset of deconfinement, NA61/SHINE will perform a two-dimensional phase diagram scan. It will measure hadron production in various collisions ($pp$, $p$Pb, BC, ArCa, XeLa) at various beam energies (13, 20, 30, 40, 80, and 158 AGeV) [8]. This new data, together with PbPb reactions recorded by NA49 will allow to cover the region, where the critical point is expected (Fig. 1). According to lattice calculations T = 162 ± 2 MeV and $\mu_B$ = 360 ± 40 MeV [9]. NA61/SHINE will search for the onset of "kink, horn, step" [10] signatures in light nuclei and a maximum of fluctuation signals for systems freezing-out close to the critical point.

## 2. DETECTOR OVERVIEW

The NA61/SHINE detector is a large acceptance hadron spectrometer. The main components of the current detector were constructed and successfully used by NA49. The experimental set-up is shown in Fig. 2.

Transverse positions of beam particles are measured by three Beam Position Detectors (BPD-1/2/3) constructed in 2007. They are 48 × 48 mm$^2$ proportional chambers filled with $Ar/CO_2$ gas mixture with a cathode strip readout (32 strips with 1.5 mm pitch). Each detector consists of two orthogonal wire (15 $\mu$m thick tungsten) planes sandwiched between three cathode planes made of 25 $\mu$m aluminized mylar. A set of scintillation counters are used to trigger data acquisition and to provide precise timing information. Two Čerenkov counters select the desired particle types from the secondary hadron beam. The individual beam particle position measured in the BPDs allows for reconstruction of the interaction point in the target with a precision of 40 $\mu$m for proton and 170 $\mu$m for lead beams.

The main tracking devices are four large volume Time Projection Chambers (TPC) inherited from NA49. Two of them ("vertex" TPCs: VTPC-1 and VTPC-2) are located in the magnetic field, two others ("main" TPCs: MTPC-L and MTPC-R) are positioned downstream of the magnets symmetrically to the beam line. There is also a smaller TPC (GAP TPC) constructed at the end of the NA49 operating period. It is mounted between the two VTPCs, centered on the beam line for measuring particles with the smallest production angles. These detectors allow reconstruction of over 1000 tracks in a single PbPb interaction. Up to 234 track positions and samples of energy loss per track provide high statistics for precise measurement. The VTPCs are located inside two superconducting dipole magnets.

Their field for 158 AGeV beam energy is 1.5 T in the upstream magnet and 1.1 T in the downstream magnet.

Two Time-of-Flight (ToF-L/R) detectors were built for NA49 to improve particle identification at momenta below 5 GeV/$c$. They consist of two arrays of 891 scintillators and cover an area of 2 $\times$ 1.2 m$^2$ each. In order to extend the acceptance of NA61/SHINE to satisfy neutrino physics needs, a new forward detector (ToF-F)was constructed. It is placed between the side ToF arrays, just behind the MTPCs. It consists of 64 scintillator bars with read-out on both sides, and it has a total area of 5.77 $\times$ 1.2 m$^2$.

The most downstream detector – the Projectile Spectator Detector (PSD) will be ready for the 2011 run. It is designed to measure the number of non-interacting nucleons from the projectile nuclei on event-by-event basis. The PSD consists of 20 small (10 $\times$ 10 cm$^2$) and 20 large (20 $\times$ 20 cm$^2$) modules, each 120 cm long. The whole detector weighs about 17 tons. Each module consists of 60 consecutive lead (16 mm) and scintillator (4 mm) sandwich layers perpendicular to the beam. High resolution for measurement of the total energy of the projectile spectators ($\sigma(E)/E < 50\%/\sqrt{E}$) in a very broad energy range from 10 GeV to 30 TeV should lead to a low uncertainty in the determination of the number of interacting nucleons even for peripheral collisions of heavy nuclei at low energies.

## 3. DETECTOR PERFORMANCE

During runs in 2007, 2009, and 2010 the excellent detection capabilities of the NA61/SHINE apparatus were confirmed. The most important performance parameters of the detector are:

- large acceptance $\approx 50\%$,
- high tracking efficiency $> 95\%$,
- high momentum resolution: $\sigma(p)/p^2 \approx 10^{-2}$–$10^{-4}$ (GeV/$c$)$^{-1}$,
- good ToF resolution: $\sigma(tof) \approx 60$–$120$ ps,
- good $dE/dx$ resolution $\sigma(dE/dx)/ < dE/dx > \approx 0.04$,
- good invariant mass resolution $\sigma(m_{INV}) \approx 5$ MeV,
- event rate up to 70 Hz.

## 4. DATA TAKING

The data taking plan of NA61/SHINE is shown in Table 1. During the first two years of running over 120 million events have been collected (including data for neutrino and cosmic-rays physics). Also the first steps of the phase diagram scan were accomplished: $pp$ data at various energies were collected. In 2011 first ion runs – energy scan with BC collisions – will take place. The program will be completed by ArCa and XeLa energy scans in 2013 and 2014, respectively.

## 5. FIRST RESULTS

Preliminary results for $p$C collisions at beam momentum of 31 GeV/$c$ collected during the pilot run in 2007 are shown in Fig. 3. These are laboratory momentum distributions of $\pi^-$ mesons produced in different intervals of polar angle ($\theta$) normalized to the mean $\pi^-$ multiplicity in all production $p$C interactions. Also comparison with three different models is shown. Both statistical and systematic errors are plotted. These results are already used by T2K to improve predictions of the initial neutrino flux.

## 6. SUMMARY

NA61/SHINE has the potential to discover the critical point of strongly interacting matter and guarantees systematic data on the onset of deconfinement. Successful 2009 and 2010 runs with high statistics ended with almost 120 million collected events. Also first physics results from $p$C collisions at 31 GeV/$c$ from the 2007 pilot run are available.

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1. The NA61/SHINE web page `http://na61.web.cern.ch`.
2. N. Antoniou *et al.* (NA61/SHINE Collab.), CERN-SPSC-2006-034, SPSC-P-330 (2006).
3. S. Afanasev *et al.* (NA49 Collab.), Nucl. Instrum. Meth. A **430**, 210 (1999).
4. C. Strabel (NA61/SHINE Collab.), arXiv: 1006.0767 [hep-ex].
5. T. J. Palczewski (NA61/SHINE Collab.), PoS EPS-HEP2009, 412 [arXiv: 0911.2800] (2009).
6. M. Unger (NA61/SHINE Collab.), arXiv: 1012.2604 [nucl-ex].

7. N. Abgrall (NA61 and T2K Collabs.), arXiv: 1005.3692 [hep-ex].
8. N. Abgrall *et al.* (NA61/SHINE Collab.), CERN-SPSC-2009-031; SPSC-P-330-ADD-5 (2009).
9. Z. Fodor and S. D. Katz, JHEP **0404**, 050 (2004).
10. M. Gaździcki and M. I. Gorenstein, Acta Phys. Polon. B **30**, 2705 (1999).
11. M. Gazdzicki, M. Gorenstein, and P. Seyboth, arXiv: 1006.1765 [hep-ph].

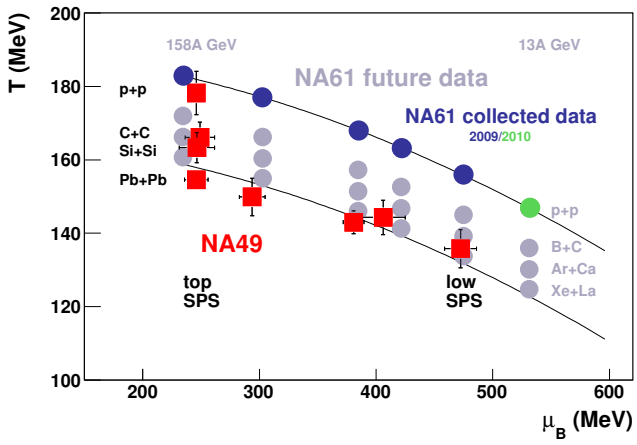


**Figure 1.** Freeze-out points of the planned NA61/SHINE two-dimensional phase diagram scan.

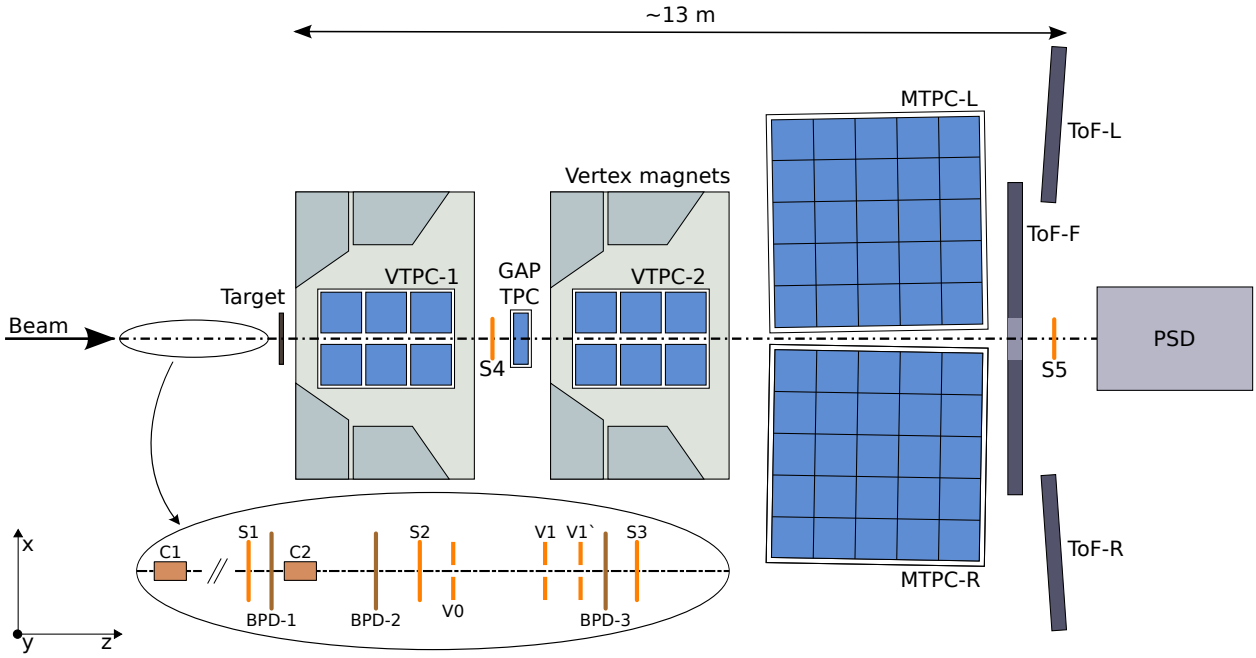


**Figure 2.** The layout of the NA61/SHINE experimental set-up (top view, not to scale).

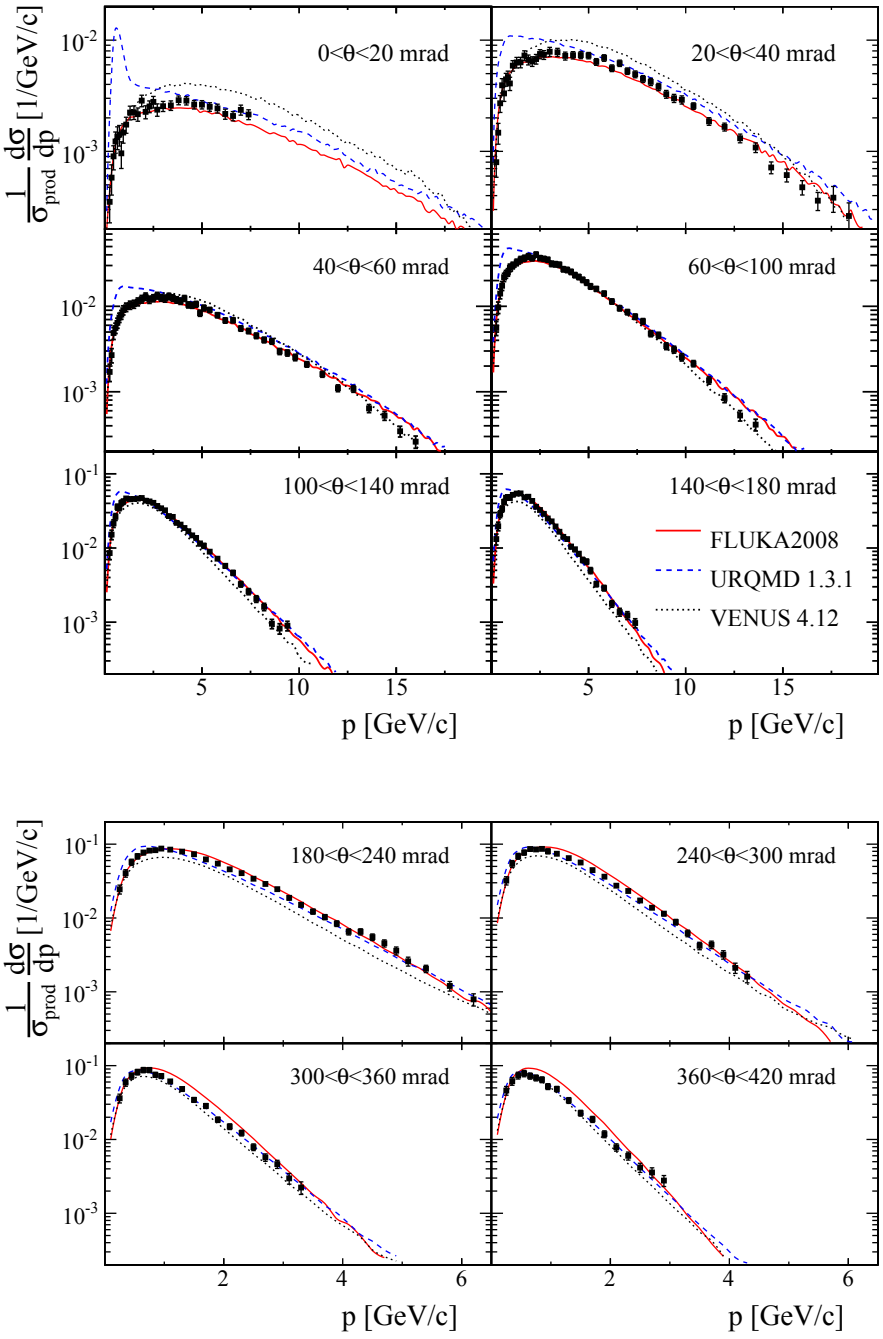


**Figure 3.** Preliminary laboratory momentum distributions of $\pi^-$ mesons produced in $p$C interactions at 31 GeV/$c$ in different intervals of polar angle ($\theta$). The spectra are normalized to the mean $\pi^-$ multiplicity in all production $p$C interactions. Error bars indicate statistical and systematic uncertainties added in quadrature. The overall uncertainty (2.3%) due to the normalization procedure is not shown. Predictions of hadron production models are also indicated.

**Table 1.** The NA61/SHINE data taking plan. CP - Critical Point, OD - Onset of Deconfinement.

| Year | Primary beam | Secondary beam | Target | Energy (AGeV) | Events Collected | Physics |
|---|---|---|---|---|---|---|
| 2009 | $p$ | $p$ | C | 400<br>31 | 10M | Neutrino |
| | $p$ | $\pi^-$ | C | 400<br>158, 350 | 11M | Cosmic-ray |
| | $p$ | $p$ | $p$ | 400<br>20, 30, 40, 80, 158 | 19M | CP & OD |
| 2010 | $p$ | $p$ | $p$ | 400<br>158 | 44M | High $p_T$ |
| | $p$ | | | 400 | | CP & OD |
| | | $p$ | $p$ | 13 | 700k | |
| | $p$ | $p$ | C | 400<br>31 | 10M | Neutrino |
| 2011 | $p$ | $p$ | $p$ | 400<br>158 | | High $p_T$ |
| | Pb | | | 13, 20, 30, 40, 80, 158 | | CP & OD |
| | | $^{11}$B | C | 13, 20, 30, 40, 80, 158 | | |
| 2013 | $p$ | $p$ | $p$ | 400<br>158 | | High $p_T$ |
| | Ar | | Ca | 13, 20, 30, 40, 80, 158 | | CP & OD |
| 2014 | $p$ | $p$ | Pb | 400<br>13, 20, 30, 40, 80, 158 | | CP & OD |
| | Xe | | La | 13, 20, 30, 40, 80, 158 | | CP & OD |

## FIGURE CAPTIONS

Fig. 1: Freeze-out points of the planned NA61/SHINE two-dimensional phase diagram scan.

Fig. 2: The layout of the NA61/SHINE experimental set-up (top view, not to scale).

Fig. 3: Preliminary laboratory momentum distributions of $\pi^-$ mesons produced in $p$C interactions at 31 GeV/$c$ in different intervals of polar angle ($\theta$). The spectra are normalized to the mean $\pi^-$ multiplicity in all production $p$C interactions. Error bars indicate statistical and systematic uncertainties added in quadrature. The overall uncertainty (2.3%) due to the normalization procedure is not shown. Predictions of hadron production models are also indicated.