Conference Paper

Hadron calorimeter (Projectile Spectator Detector - PSD) of NA61/SHINE experiment at CERN

M. Golubeva[1], F. Guber[1], A. Ivashkin[1], S. Morozov[1,2], and A. Senger[3]
(for NA61/SHINE Collaboration)

[1]Institute for Nuclear Research, Russian Academy of Sciences, 117312 Moscow, Russia
[2]National Research Nuclear University MEPhI, Moscow, Russia
[3]GSI Helmholtzzentrum für Schwerionenforschung GmbH (GSI), Darmstadt, Germany

Abstract

The fixed target experiment NA61/SHINE at the CERN SPS aims to study the onset of deconfinement and search for the critical point of strongly interacting matter. A segmented hadron calorimeter, the Projectile Spectator Detector (PSD), is used in the NA61 experiment to determine the collision centrality and to reconstruct the event plane orientation in collisions of nuclei. The PSD precisely characterizes the event class for the analysis and provides the centrality selection at the trigger level. The wide ranges of beam energies and sizes of the collision system require high dynamic range of the electronic readout. At the same time sensitivity to small signals is needed for the PSD calibration based on minimum ionizing particles. The PSD was also used for particle identification to distinguish electrons and positrons from pions in the 2017 data taking of reference measurements for Fermilab neutrino beam lines. The performance of the PSD for hadrons is discussed as well as a proposal to upgrade the PSD for the NA61 experimental program beyond 2020.

Corresponding Author:
S. Morozov
morozovs@inr.ru

Received: 25 December 2017
Accepted: 2 February 2018
Published: 9 April 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICPPA Conference Committee.

1. Introduction

The NA61/SHINE experiment at the CERN SPS [1], [2] was designed to study the properties of ion-ion collisions, in particular, the onset of deconfinement [3] as well as to search for the critical point of strongly interacting matter. These goals are achievable by investigating p+p, p+A and A+A collisions at different beam energies from 13*A* to 158*A* GeV for ions and up to 400 GeV/c for protons. A schematic view of the NA61/SHINE experiment is shown in Fig.1 (left). An overview of the collision systems and the energies of the physics program is presented in Fig.1 (right).

How to cite this article: M. Golubeva, F. Guber, A. Ivashkin, S. Morozov, and A. Senger, (2018), "Hadron calorimeter (Projectile Spectator Detector - PSD) of NA61/SHINE experiment at CERN" in *The 3rd International Conference on Particle Physics and Astrophysics*, KnE Energy & Physics, pages 379–384. DOI 10.18502/ken.v3i1.1770

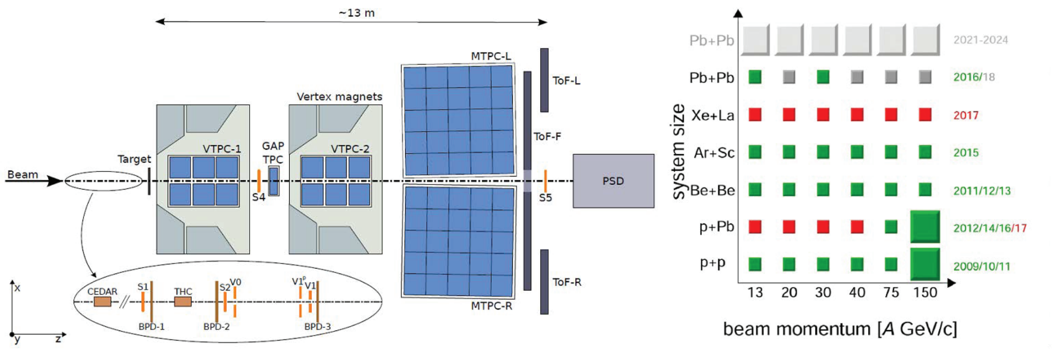

Figure 1: NA61/SHINE experiment (left) and heavy ion physics program (right).

2. Hadron calorimeter (Projectile Spectator Detector - PSD)

The Projectile Spectator Detector (PSD) [4], [5] in NA61/SHINE is a segmented forward hadron calorimeter. It is used to determine the collision centrality as well as orientation of the event plane. The PSD allows to select the collision centrality of events at the trigger level. The modular structure of calorimeter is suitable also for studies of collective flow.

The PSD calorimeter consists of 16 central small modules with size 10x10cm^2 and 28 large modules with size of 20x20cm^2. Each module contains 60 layers of 16 mm lead plates and 4 mm scintillator tiles (sampling ratio 4:1). Wavelength shifting fibers (WLS) are used to collect light from scintillator tiles which is read out by silicon photomultipliers. In total, the PSD has $\sim$ 5.6 hadronic interaction lengths. One short module of 10x10cm^2 is used in front of the PSD to minimize shower leakage for forward going high momentum particles. A photo of the PSD calorimeter and schematic view of the PSD front face are shown in Fig.2.

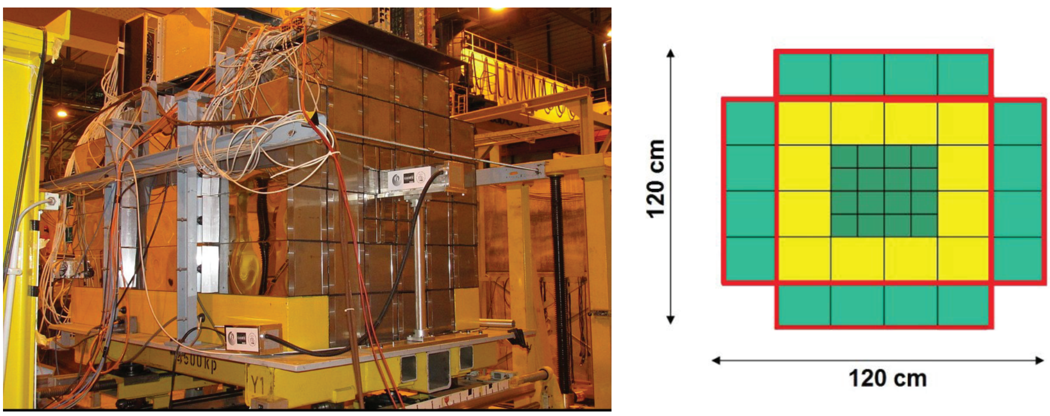

Figure 2: PSD hadron calorimeter installed at NA61/SHINE (left) and schematic view of front face (right).

3. PSD performance.

Calibration has to be performed in order to reconstruct the energy of particles in the PSD. In the first step each module of the calorimeter was exposed to through-going minimum ionizing particles by using a muon beam. The spectrum of one PSD section for muons is shown in Fig.3 (left). Then the response to proton showers was studied at several beam energies to determine the PSD calibration parameters (see Fig.3 (right)). Figure 4 shows results of linearity and energy resolution obtained for proton beams after applying the calibration.

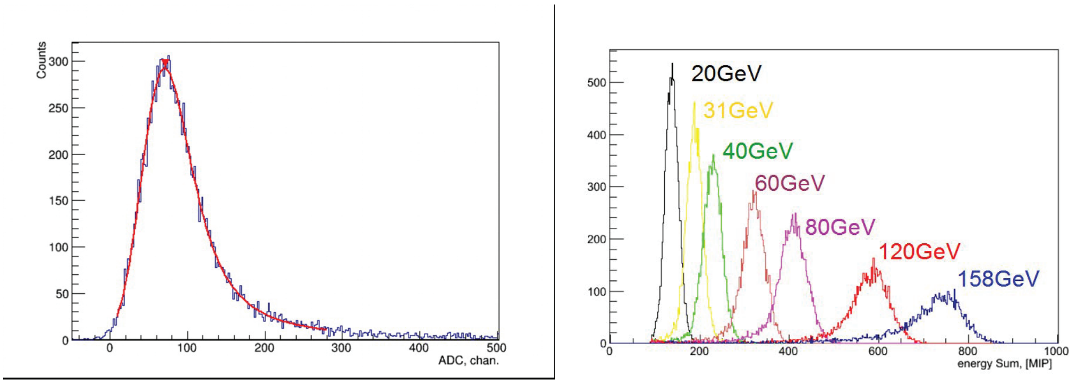

Figure 3: Response to minimum ionizing particle (muon) of a PSD section (left) and spectra of proton showers at different energies measured with the PSD (right).

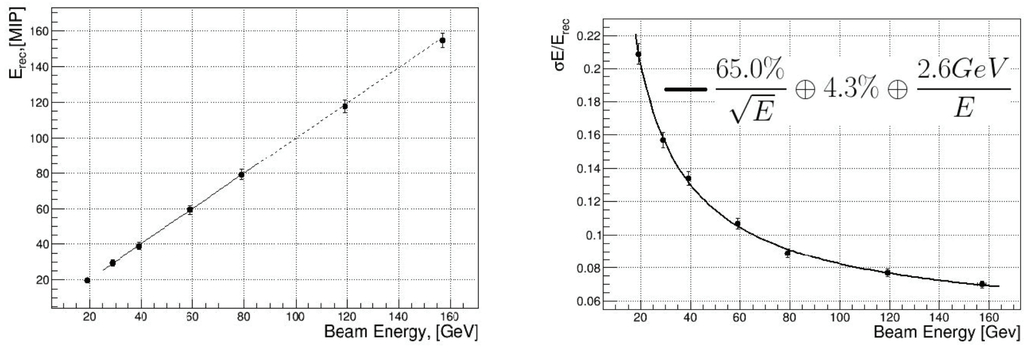

Figure 4: Linearity of PSD response (left) and energy resolution (right) for protons. A fit of the energy resolution curve estimates 65.0% stochastic (a), 4.3% constant (b) and 2.6 GeV noise (c) terms.

In 2016 the PSD was used to study Pb+Pb collisions at maximum SPS ion energy of 150 *A*GeV as well as at intermediate energy 30 *A*GeV. Using the trigger from the PSD the 25% most central events were selected. Figure 5 shows a plot of track multiplicities registered in the TPCs versus energy in the PSD, normalized to the beam energy per nucleon. A linear fit extrapolates to a value close to the atomic number of Pb for very peripheral collisions.

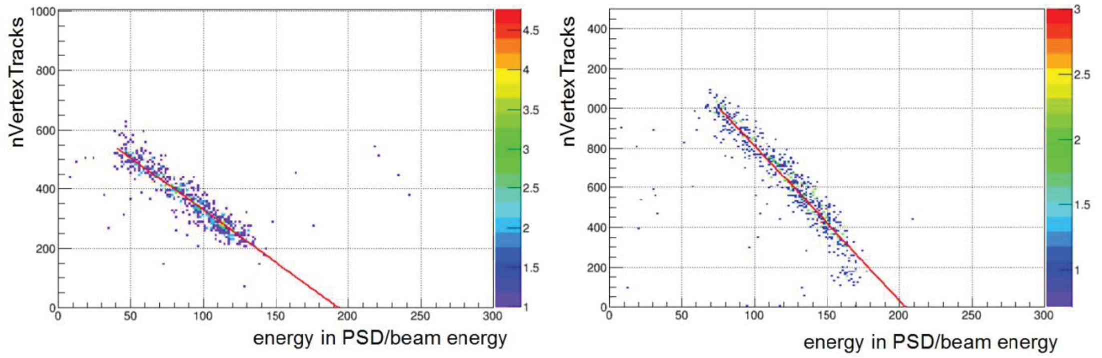

Figure 5: Track multiplicities in the TPCs versus reconstructed energy from the PSD (normalized to the beam energy) for Pb+Pb at 30 *A*GeV (left) and 150 *A*GeV (right). For details on linear fit see text.

4. PSD upgrade for the future continuation of the NA61/SHINE experiment.

A new physics program is under consideration for NA61/SHINE experiments beyond 2020, which includes open charm measurements. The beam rate will be increased by an order of magnitude (up to 5x10^4 ions/sec) for these experiments. To survive in such high radiation conditions the PSD must be upgraded. It is proposed to use two calorimeters instead of the current single one (see Fig. 6). PSD1 is the present calorimeter with the 16 small central modules replaced by 4 new large ones with transverse size of 20x20cm2 and truncated edges to leave a 60mm diameter hole for the beam in the center. The second calorimeter (PSD2) consists of 9 modules of the same large transverse size (20x20cm^2). It will be placed downstream of PSD1. All PSD2 modules have 10 longitudinal readout sections (5.6 interaction lengths,the same as for PSD1) excepting the central module which will have 14 longitudinal readout sections corresponding to 7.8 interaction lengths.

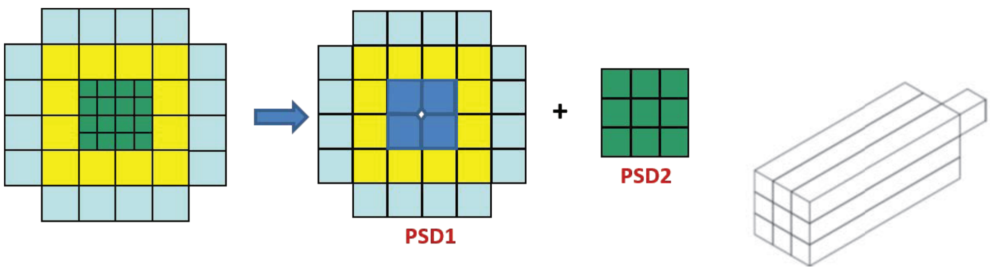

Figure 6: Schematic front view of the proposed new PSD1 and PSD2 configuration (left) and a 3D view of the PSD2 (right).

GEANT4 simulation shows that this new configuration of calorimeters shower leakage decreases from 11% in present PSD to 4% in new PSD1+PSD2 configuration for Pb+Pb reaction at 150 *A*GeV. This will improve the purity of centrality selection for the most central collisions, see Table 1.

Table 1: Purity for the current PSD and for the new PSD1+PSD2 configuration.

Event centrality class [%]	0-5	5-10	10-15	15-20	20-25	25-30
Current PSD	94	87	82	77	71	60
PSD1 + PSD2	96	92	88	88	80	63

The proposed new configuration will help to solve the radiation hardness problems of the forward hadron calorimeter for NA61 experiments beyond 2020. The beam hole in the PSD1 will help to avoid radiation damage of scintillator tiles due to the radiation dose from ionizing particles (see Fig. 7 (left)). The expected neutron flux at the location of silicon photomultipliers in PSD1 and PSD2 will also be at acceptable level for the envisaged beam rates (see Fig. 7 (right)).

PSD2 will measure practically only the energy of heavy fragments and can be operated with reduced voltages on silicon photomultipliers. Only the central PSD2 module will suffer radiation damage in the scintillator tiles which will lead to a decrease of the light yield. However, this effect can be compensated by increasing the bias voltages.

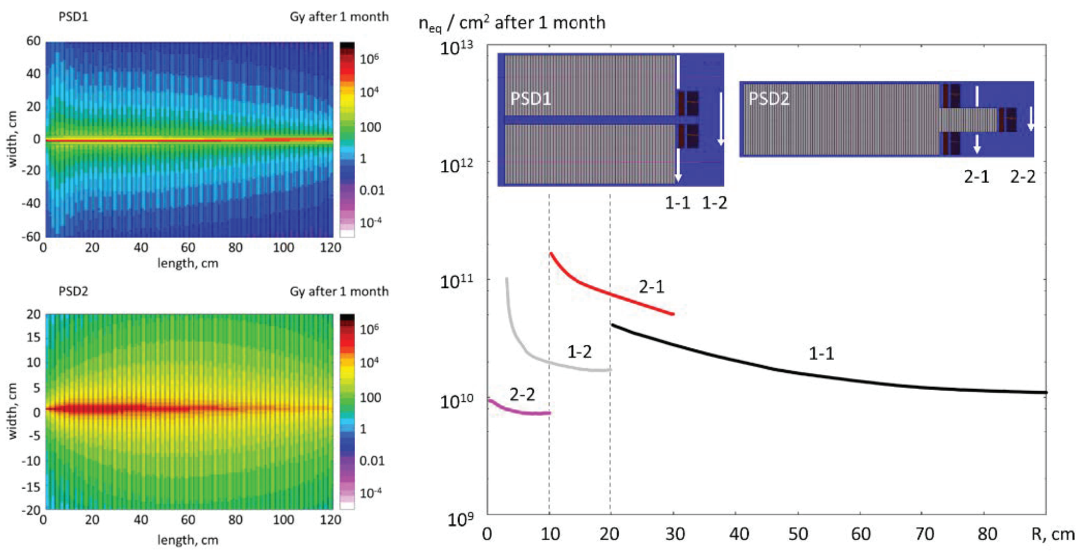

Figure 7: Ionizing radiation doses (left) and neutron flux (right) simulated with FLUKA for PSD1 and PSD2 for Pb+Pb reaction at 150 *A*GeV, Pb beam rate 5x10^4 ions/sec and one month of continuous data taking.

5. Conclusions

Results of performance studies of the existing segmented hadron calorimeter PSD in the NA61/SHINE experiment were reported. Proposed ideas to upgrade the PSD calorimeter system for future heavy ion experiments at the CERN SPS beyond 2020 were presented.

Acknowledgments

This work was partially supported by the Ministry of Science and Education of the Russian Federation, grant N 3.3380.2017/4.6, and by the National Research Nuclear University MEPhI in the framework of the Russian Academic Excellence Project (contract No. 02.a03.21.0005, 27.08.2013).

References

[1] C. Alt et al. 2008 Phys. Rev. C 77 024903

[2] M. Gazdzicki, M. Gorenstein and P. Seyboth, 2008 Acta Phys. Polon. B42, 307

[3] N. Antoniou et al. 2006 [NA61/SHINE Collaboration], CERN-SPSC-2006-034.

[4] A. Ivashkin et al. 2012 arXiv:1205.4864v2

[5] M. Golubeva et al. 2012 Phys. Atom. Nucl. 75 673-675.