Muon Astrophysics with the MCORD Detector

Marcin Bielewicz[1,2], Paweł Kankiewicz[3], Maciej Rybczyński[3], Zbigniew Włodarczyk[3], Łukasz Świderski[1], Elżbieta Strugalska-Gola[1] and Kamil Wójcik[4]

1. National Centre for Nuclear Research, 05-400 Otwock-Świerk, Poland
2. Joint Institute of Nuclear Research, Dubna, 141980, Russia
3. Institute of Physics, Jan Kochanowski University, 25-406 Kielce, Poland
4. University of Silesia in Katowice, 40-007, Katowice, Poland

The MPD (Multi-Purpose Detector) complex is the main component of the new NICA (New Ion Collider fAcility) being built at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia. A group of Polish scientists from the NICA-PL Consortium was invited to design and construct an additional cosmic ray detector called MCORD (MPD COsmic Ray Detector). This detector and its standard operation as a muon trigger can also be used for unique astrophysical observations. Its basic features and potential applications will be described below.

1 Introduction

The MPD (Multi-Purpose Detector) as a part of the NICA (New Ion Collider fAcility) is being built at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia (Fig. 1). The experiments conducted at MPD are to complement the research carried out in CERN laboratories but for lower energies. To increase the functionality of MPD, it was proposed to supplement it with an additional muon trigger system. This trigger will be used to calibrate and test other MPD sub-detectors with cosmic ray particles while the accelerator is not producing the experimental beam. The same trigger system can be used as high energy (> 1 GeV) muon identifier during experiments. It was proposed to surround the MPD detector with an additional cylinder-shaped cosmic ray detector called MCORD (MPD COsmic Ray Detector; Fig. 2, left). The MCORD was designed to recognise inner and cosmic muons and additionally can be used for astrophysical observations of extended air showers (EAS), especially for their central part (Bielewicz et al., 2019, 2021). Preliminary simulations show that registration of high-energy events is feasible and can be performed by MCORD at the time of its normal experimental work. It will enable the registration of multi-muon events (Fig. 2, right) like in the past in ALICE, DELPHI and ALEPH experiments. Due to its design (location on the ground surface), it enables the analysis of signals from any direction in relation to the zenith and horizon. This feature makes it a unique tool of this type in the world. The potential goals of these observations may be to try to explain the GZK (Greisen–Zatsepin–Kuzmin) cutoff problem by trying to identify the sources/location of extremely high energy primary particles.

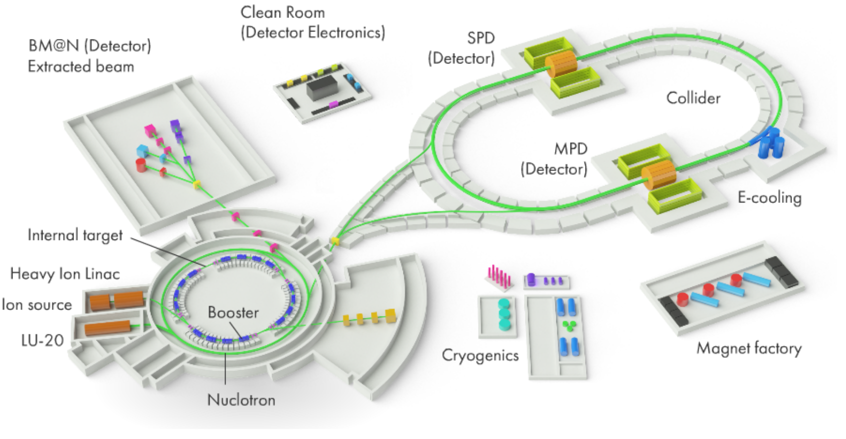

Fig. 1: An overview of the NICA complex with the MPD component on the collision ring. MPD is located on the ground level (MPD collaboration, 2021).

2 Setup

Our original concept is to surround the MPD detector with an additional cylinder-shaped cosmic ray detector consisting of 28 modules, called MCORD (Fig. 2, left; details: MPD collaboration 2017). Details are shown in the MCORD CDR documentation (Bielewicz et al., 2021). One MCORD module includes three MCORD sections containing eight MCORD detectors each. MCORD will be based on long (1.6 m) plastic scintillators with 2 mm fibre with a silicon photomultiplier (SiPM) on both ends for light reading and FPGA (Field Programmable Gate Array) electronics for the analysis of the obtained signals.

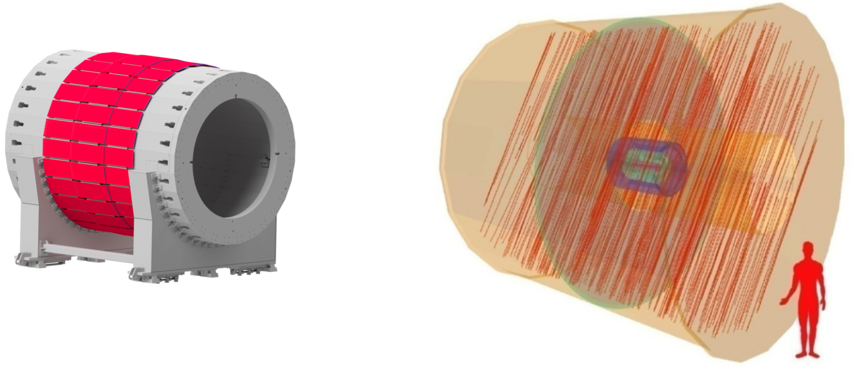

Fig. 2: *Left*: MCORD location on the MPD surface (red color). *Right*: Multi-muon event at the ALICE TPC (Time Projection Chamber) detector (ALICE Collaboration, 2016).

3 Early results of other projects

Results of some previous projects on the registration and determination of the number and directionality of high-energy events (multi-muon events in ALEPH, DELPHI and ALICE experiments, see Fig. 3), in case of the few highest ones (> 70 muons) so far, have not been explained by any modelling and simulation (Avati et al., 2003; ALICE Collaboration, 2016; Shtejer, 2016). Their possible directionality is intriguing and requires further research and extended material for statistics (Kankiewicz et al., 2017). The biggest obstacle in explaining this and similar problems is the very small number of observed events. This was the case for all the three experiments and shows that it is necessary to conduct further observations on similar experimental sets, but in a way that gives a chance to collect much better statistics of similar events.

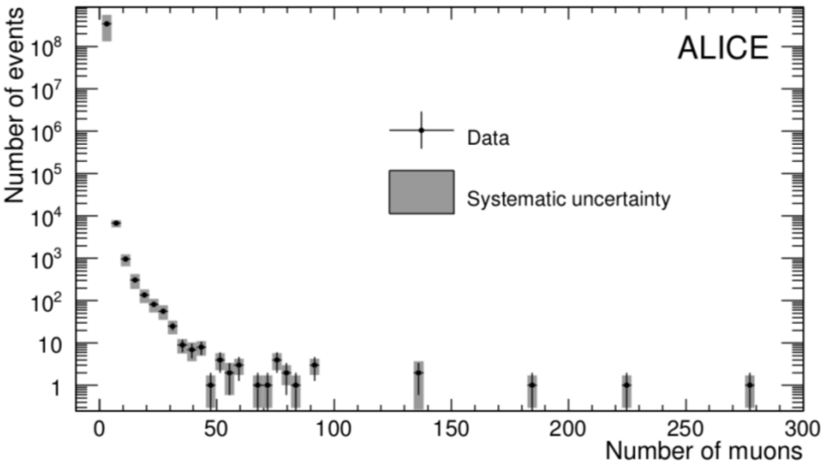

Fig. 3: Multi-muon event distributions from ALICE experiments (ALICE Collaboration, 2016).

4 Summary and conclusion

Carrying out similar long-term observations using a similar experimental setup may contribute to the collection of data that will allow us to explain or get closer to clarifying several long-known problems like the GZK cutoff problem. This latter issue is the theoretical upper limit on the energy (5×10^{19} eV) of cosmic ray protons coming to the Earth from a distance farther than 50 Mpc (minimum propagation distance) due to the Cosmic Microwave Background interaction. However, in numerous observations, we detect particles with greater energy, which we cannot explain. Among the potential goals of current observations is to explain the GZK cutoff problem by identifying the sources/position of primary particles with extremely high energy or collect more data to find other explanations of the described problems. The issues described above can point to the problem with the current hadronic interaction model for extremely high energy (above 10^{16} eV). This could also be the result of insufficient observational statistics. The proposed MCORD detector, along with the MPD time projection, shows the unique opportunity for the very precise measurement of atmospheric muon multiplicity distributions as a function of the zenithal angle, up to nearly horizontal showers. Such measurements, up to now, have never been possible.

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