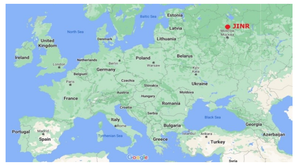
Muon astrophysics with the MCORD detector

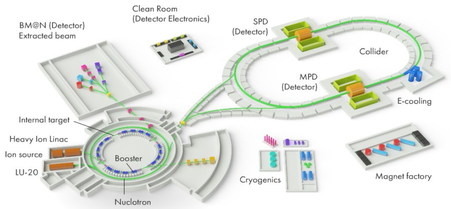
Marcin Bielewicz[1,2,+], Paweł Kankiewicz[3], Maciej Rybczyński[3],
Zbigniew Włodarczyk[3], Łukasz Świderski[1], Elżbieta Strugalska-Gola[1], Kamil Wójcik[4]

[1]Narodowe Centrum Badań Jądrowych, 05-400 Otwock-Świerk, Polska, [2]Zjednoczony Instytut Badań Jądrowych, Dubna, 141980, Rosja,
[3]Uniwersytet Jana Kochanowskiego, 25-406 Kielce, Polska, [4]Uniwersytet Śląski, 40-007, Katowice, Polska,
[+]corresponding author: marcin.bielewicz@ncbj.gov.pl

Introduction

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.

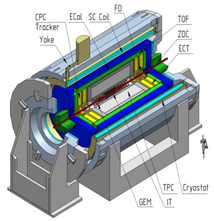


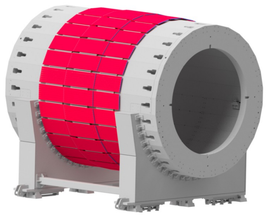


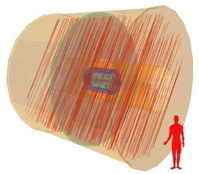
Above: The location of JINR in Europe and the overview of NICA complex with MPD component on collision ring. The MPD is located on the ground level.

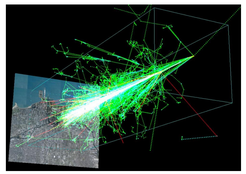
Setup

Our original concept is to surround the MPD detector with an additional cylinder-shaped cosmic ray detector called MCORD (MPD COsmic Ray Detector). The MCORD was designed to recognise inner and cosmic muons, and additionaly can be used for astrophysical observations of extended air showers (EAS).
Below: MPD cutaway, MCORD location on MPD surface (red color), the idea of measuring the directionality of high-energy events by TPC detector (red tracks in the orange cylinder), the example of EAS visualisation.



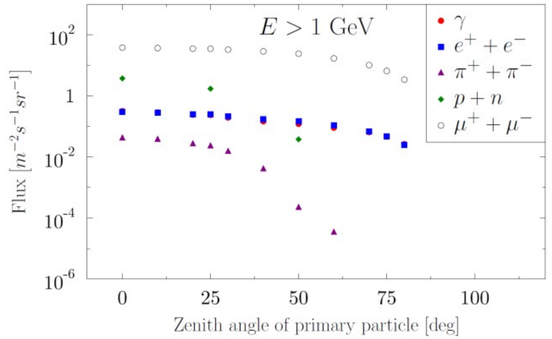




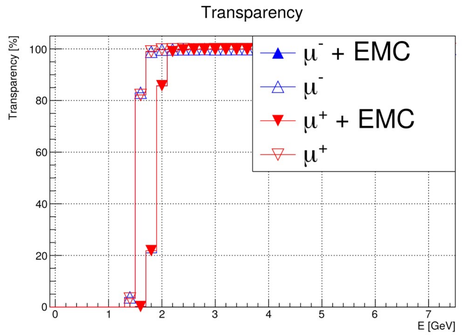


Methodology and data

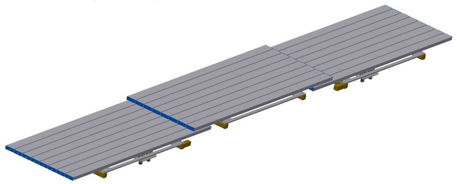
Preliminary simulations show that registration of high-energy events is feasible and can be performed by MCORD at the time of its normal experimental work.



Above: Angular distributions of Extensive Air Shower components. Location near and sea level at Dubna city, with energies above fourth thresholds. Corsika 7.74 code simulation (model QGSJETII-04 + UrQMD). Source: The MCORD CDR.



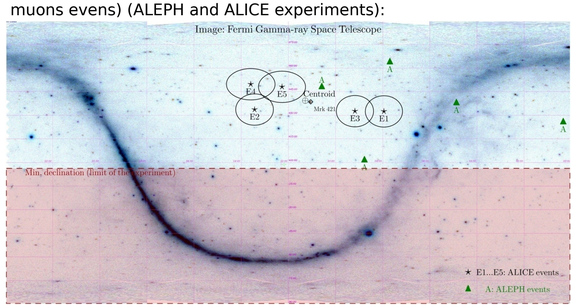
Above: energy dependence of muon transmission coefficient for MPD with and without ECal assembled. Assuming requirement for muon transmission above 95%, the muon cut-off thresholds are 1.6 GeV and 2.0 GeV, respectively (source: The MCORD CDR).



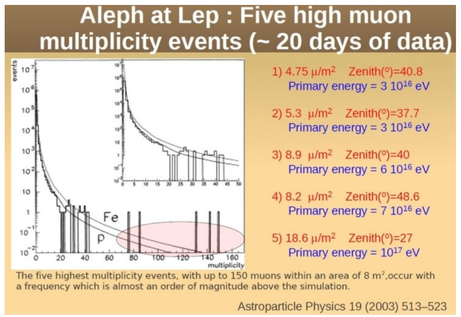
Above: One MCORD module consist three MCORD sections containing eight MCORD detectors. The MCORD will be based on long (1.6 m) plastic scintillators with 2mm fiber with silicon photomultiplier (SiPM) on both ends for light reading and an FPGA electronics for the analysis of the obtained signals.

Early results of other projects

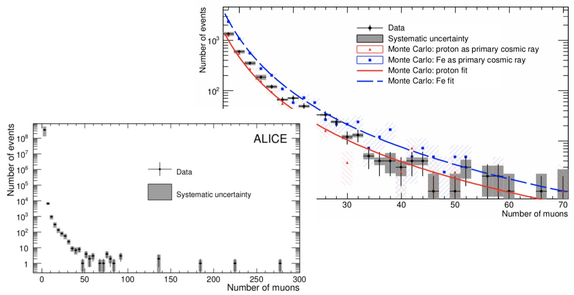
Results of some previous projects on the registration and determination of the directionality of high-energy events (muliti muons evens) (ALEPH and ALICE experiments):



Above: Directionality of high-energy events projected onto the celestial sphere marked as triangles and stars (background: results from the FERMI sky survey). Source: Kankiewicz, Rybczyński, Włodarczyk, Wilk, 2017, ApJ, **839**, 31



Above: Multi muons events registered in ALEPH project with five highest multipliciti events (orange elipse) with can't be explained by simulation. (source: Astroparticle Physics 19 (2003) 513-523).



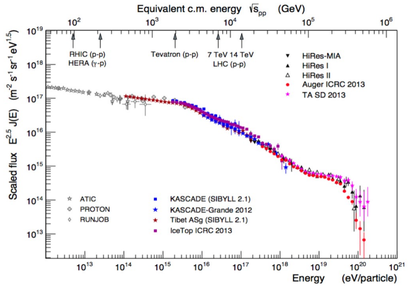
Above: The distribution of multi muons events registered in ALICE project with five highest multiplicity events, which cannot be explained by simulations (source: ALICE Collaboration, JCAP 01 (2016) 032 and K. Shtejer: CERN-THESIS-2016-371).

Summary and conclusion

Known challenges that our project can contribute to solving:

GZK cut-off problem (theoretical upper limit on the energy of cosmic ray protons coming to the Earth):

- 5x10E19 eV (maximum energy limit)
- 50 Mpc (minimum propagation distance)
- Cosmic Microwave Background interaction



Above: All-particle cosmic-ray energy spectrum derived from direct and indirect (air shower experiments) measurements, as well as results from different hadronic models – particles with energies higher than GZK cut-off were observed many times.

- The issues described above can show us problem with current hadronic interaction model for extremely high energy >10E15 eV. This could also be the result of insufficient observational statistics.
- The proposed MCORD detector along with the MPD time projection show the unique opportunity of the very precise measurement of atmospheric muon multiplicity distributions as a function of the zenithal angle of PRC, up to nearly horizontal showers. **Such measurements, up to now, were never possible.**
- The potential goals of these observations may explain the GZK-cutoff problem by trying to identify the sources of primary particles with extremely high energy or collect more data to find other explanation of the described problems.

Bibliography

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