Practical use of the Modular Cosmic Ray Detector (MCORD)

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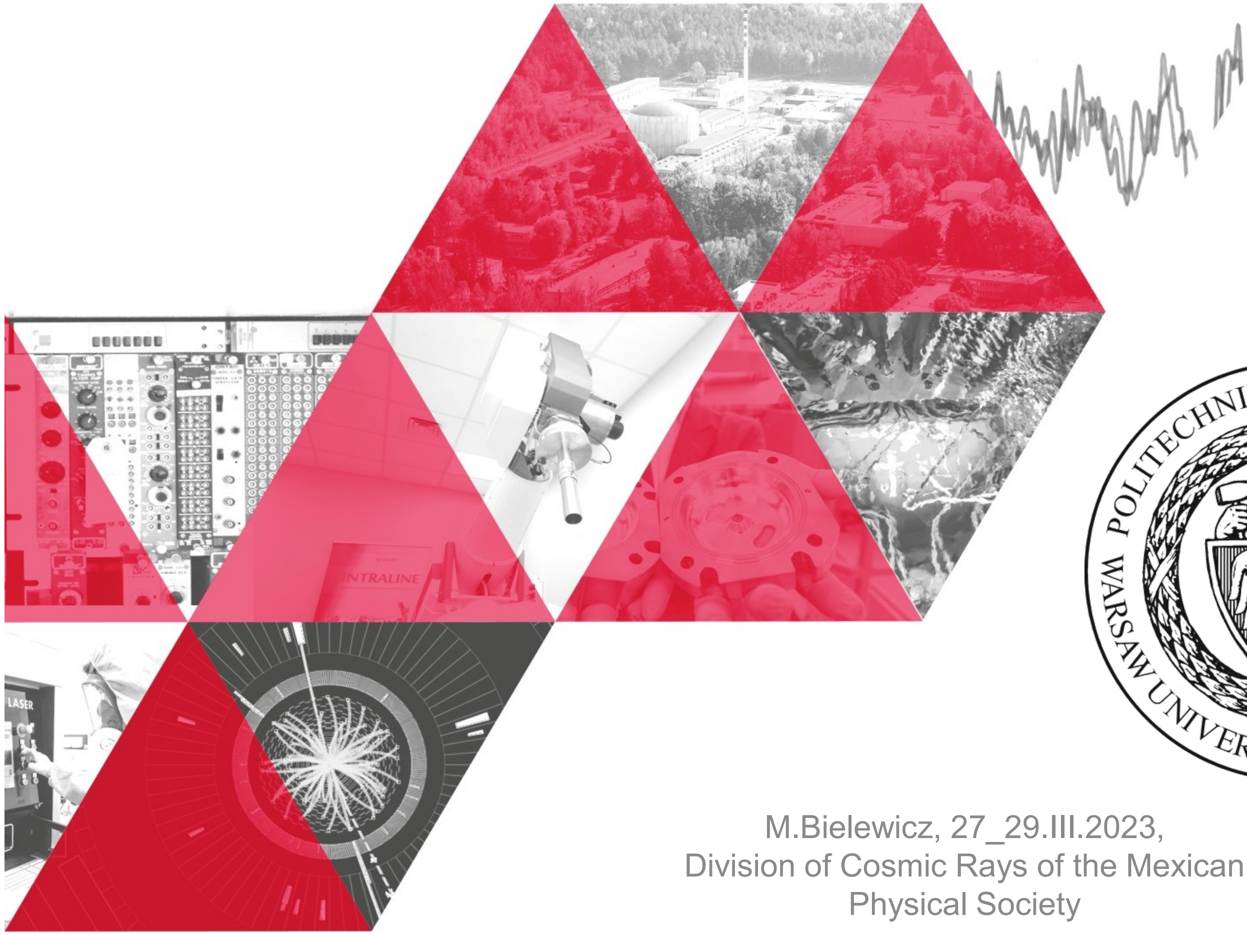
Nacional Centre for Nuclear Research



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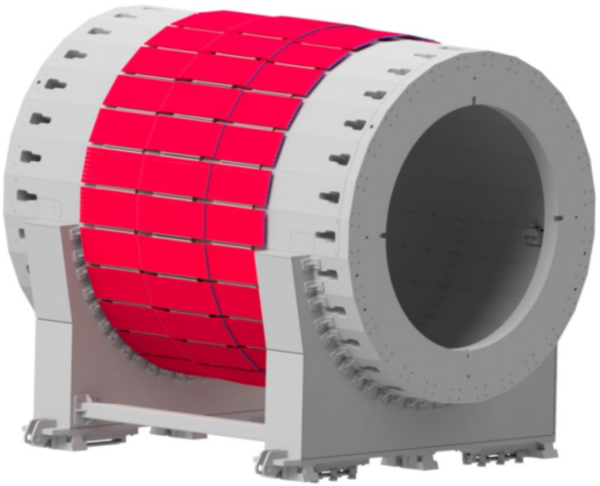
M.Bielewicz, 27_29.III.2023,
Division of Cosmic Rays of the Mexican
Physical Society

Outline

1. Introduction, Genesis, Education
2. Detector
3. Electronics
4. Laboratory tests
5. Cofluxim
6. Practical implementation - Projects
7. Summary

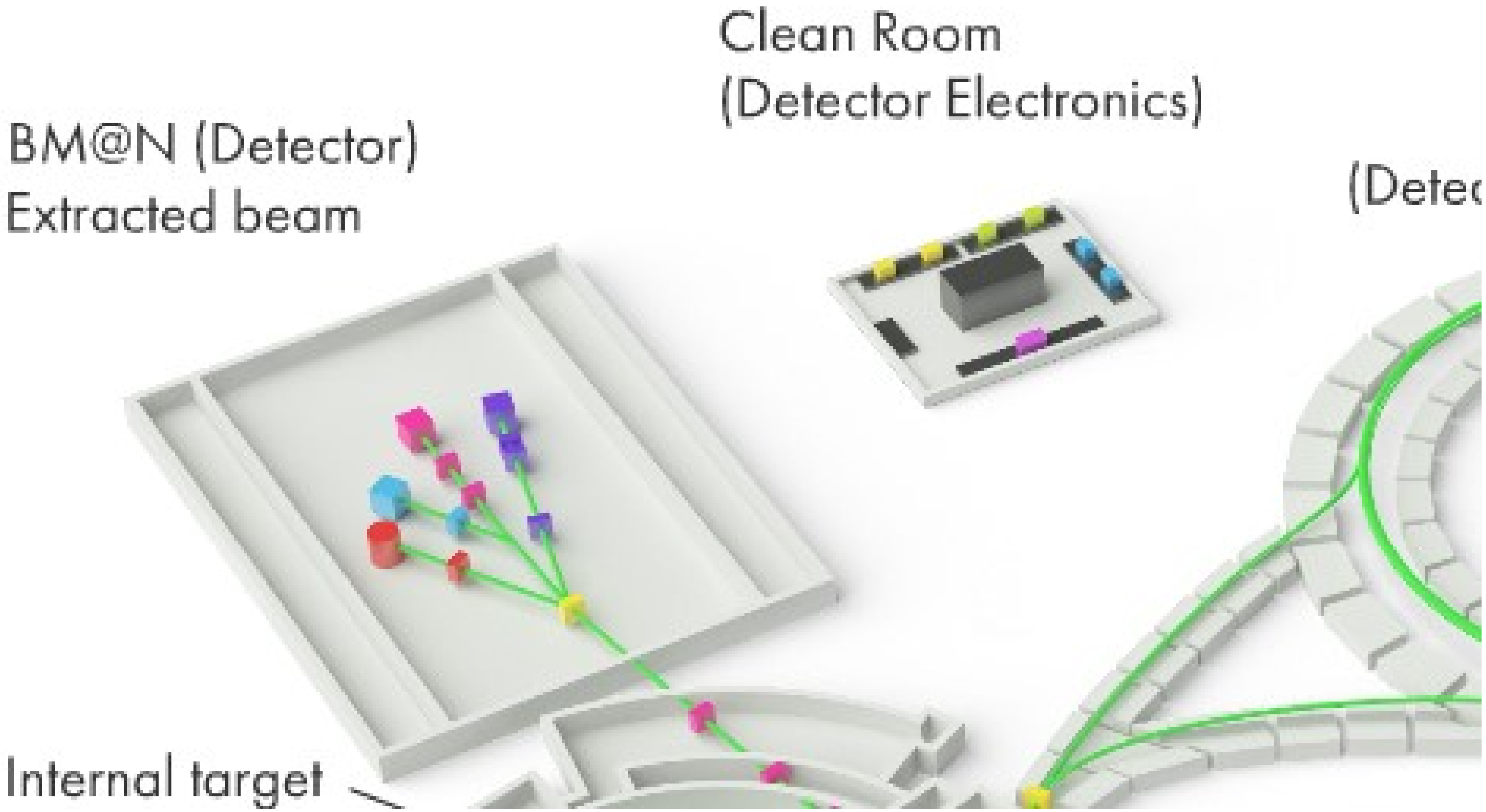


1. Introduction

MCORD applications

1. Trigger for cosmic muons for:
   - laboratory tests of different subsystems (2 separate MCORD sections)
   - Cosmic calibration in off-beam time
2. Muon identifier (from collision):
   - pions and kaons decays
   - rare mesons decays (η, ρ)
3. Astrophysics (muon showers and bundles)
   - Identification of extremely high energy particle sources
   - Sensitivity for horizontal events
   - Earthquake corellation
4. Modular construction – easy upgrade and/or alternative use

1. NICA complex



Light Ions

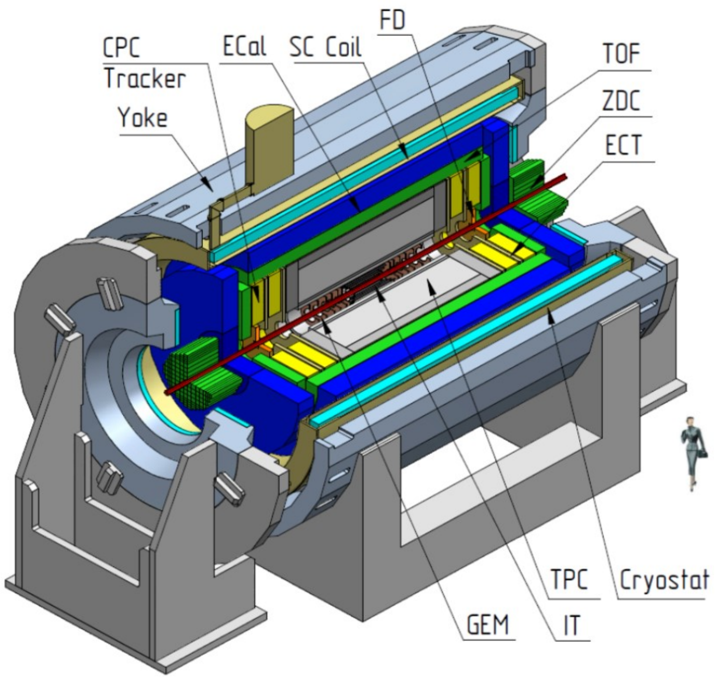
Ion sourse (LU-20)
Light Ion Linac (LILac)
Nuclotron

Heavy Ions

Ion sourse (KRION-6T)
Heavy Ion Linac (HILac)
Booster

Targets: BM@N or NICA ring and MPD

1. MPD detector



- FD Forward detector
- Superconductor solenoid (SC Coil)
- Inner Tracker (IT)
- Straw-tube Tracker (ECT)
- **Time-projection chamber (TPC)**
- **Time-of-Flight system (TOF)**
- **Electromagnetic calorimeter (EMC - ECal)**
- Zero degree calorimeter (ZDC).
- Cosmic Ray Detector (MCORD)

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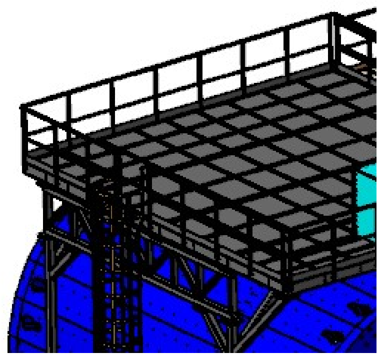
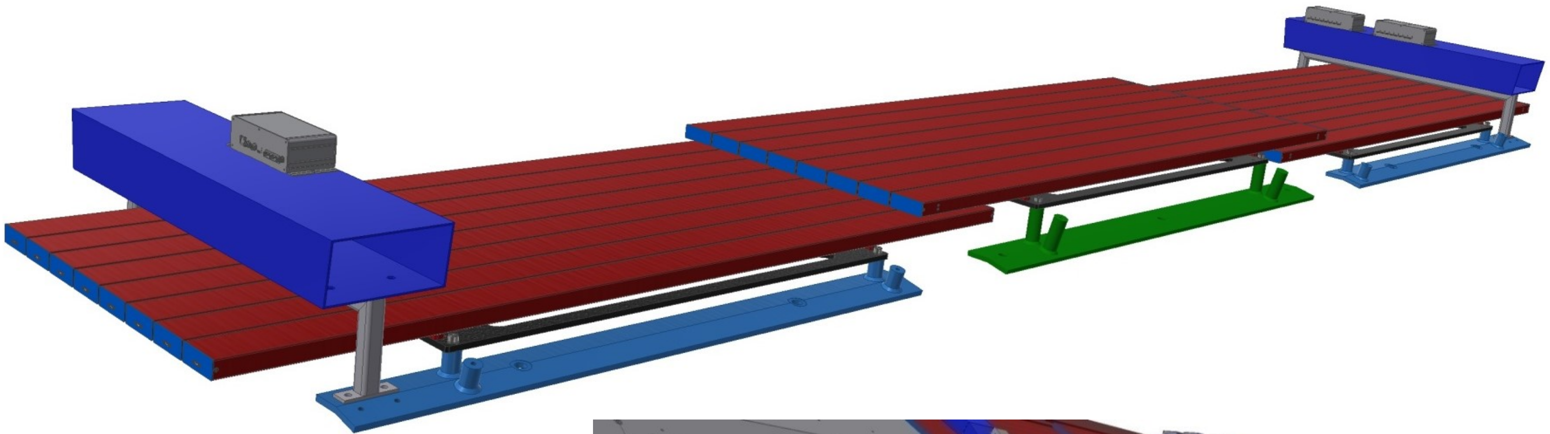
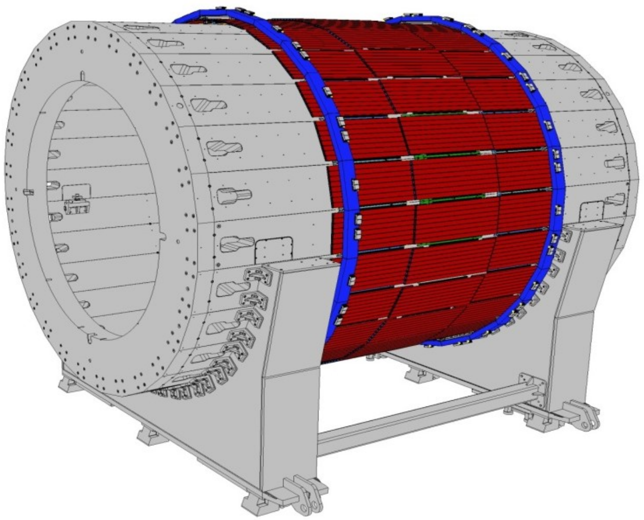
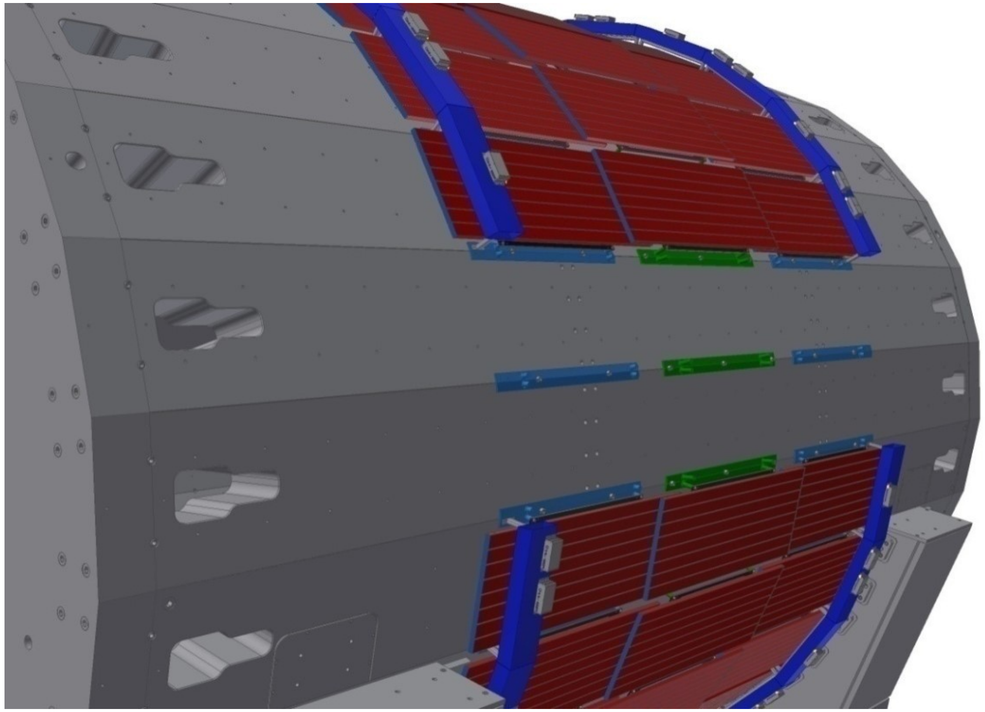


1. MCORD construction on MPD



MCORD - One surface on full circumference

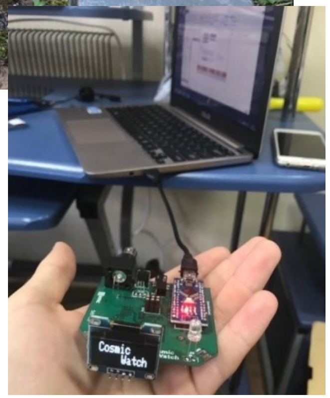


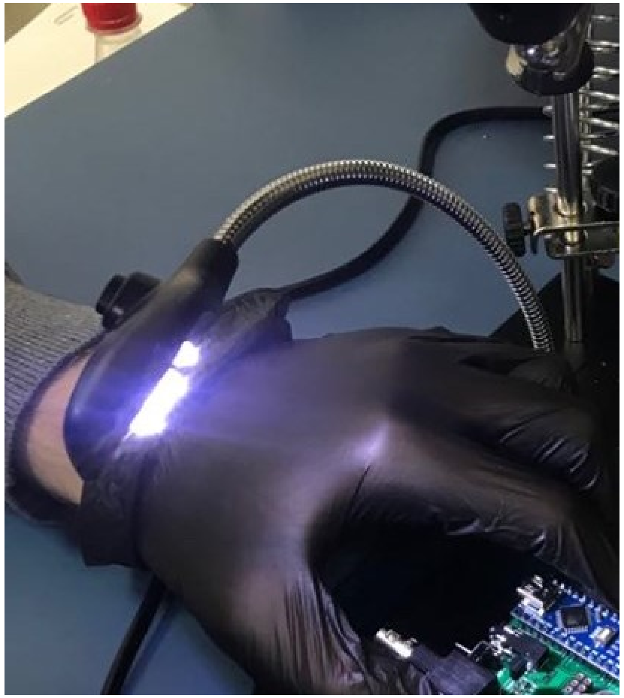


1. Education program

Cosmic Watch

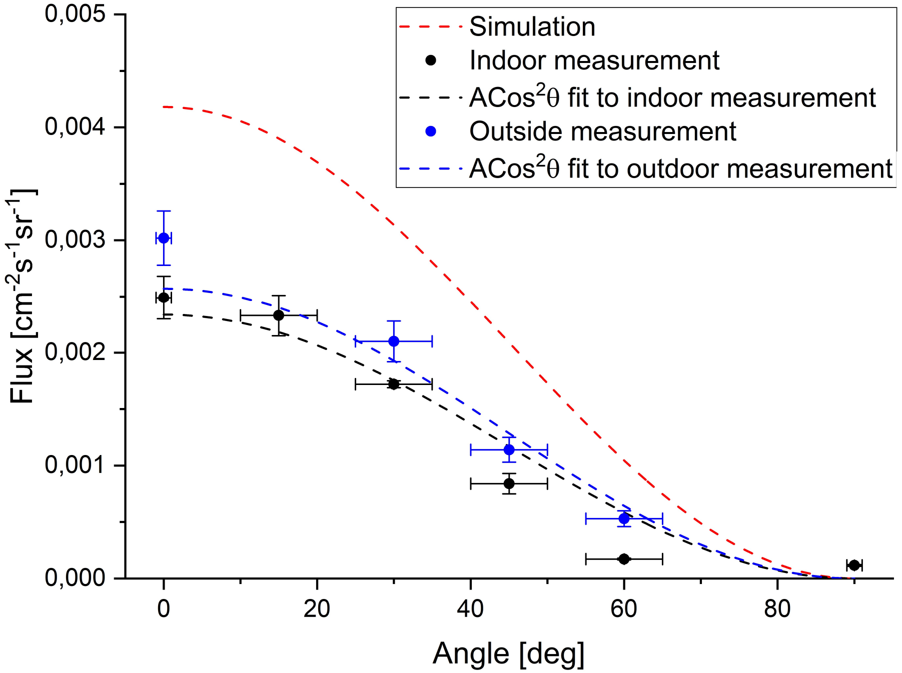
- Cosmich Watch is simple, physics-motivated machine- and electronics-shop project for university students and schools.
- These detectors can be battery powered and used in conjunction with the provided software to make interesting physics measurements.

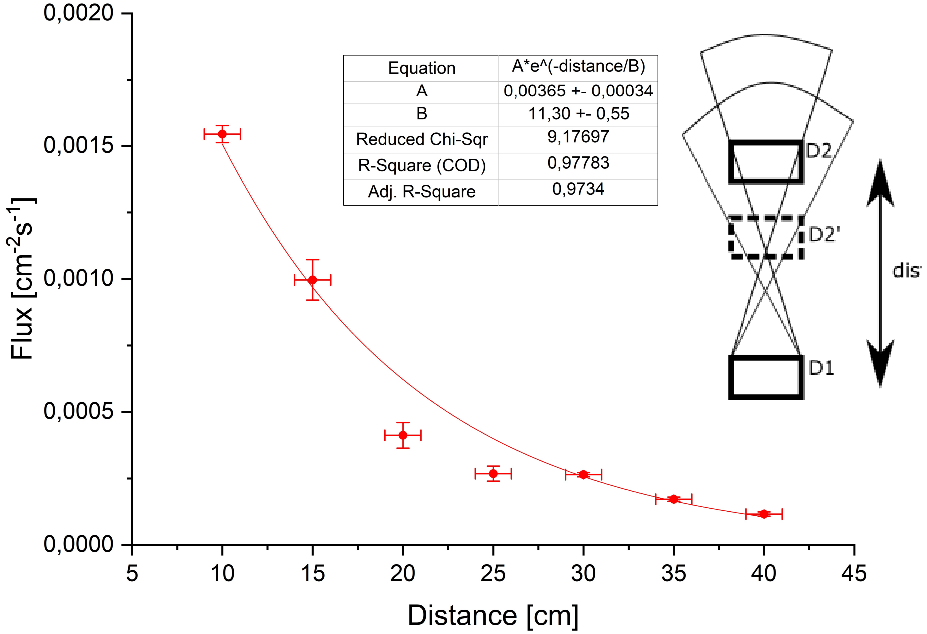





1. Education program

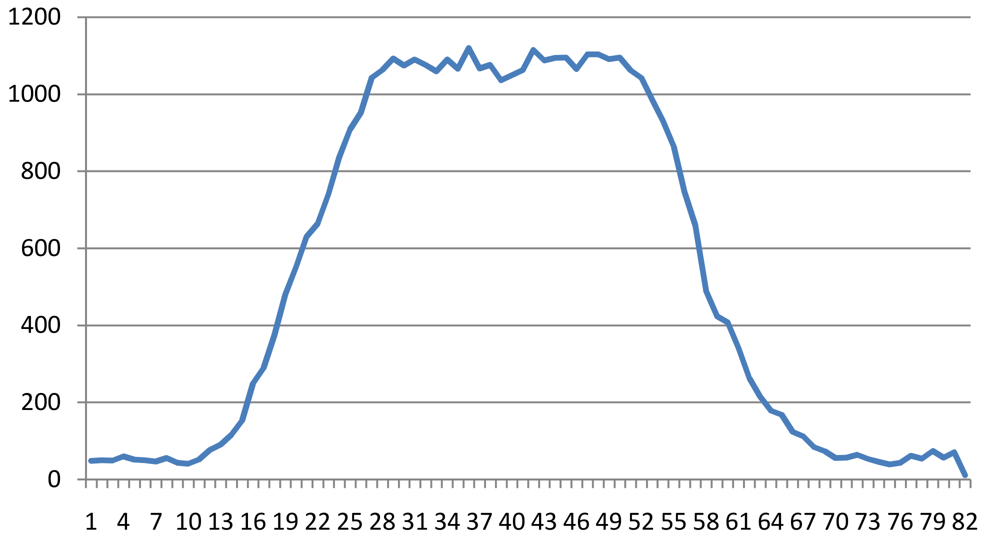
Distance and angle dependence



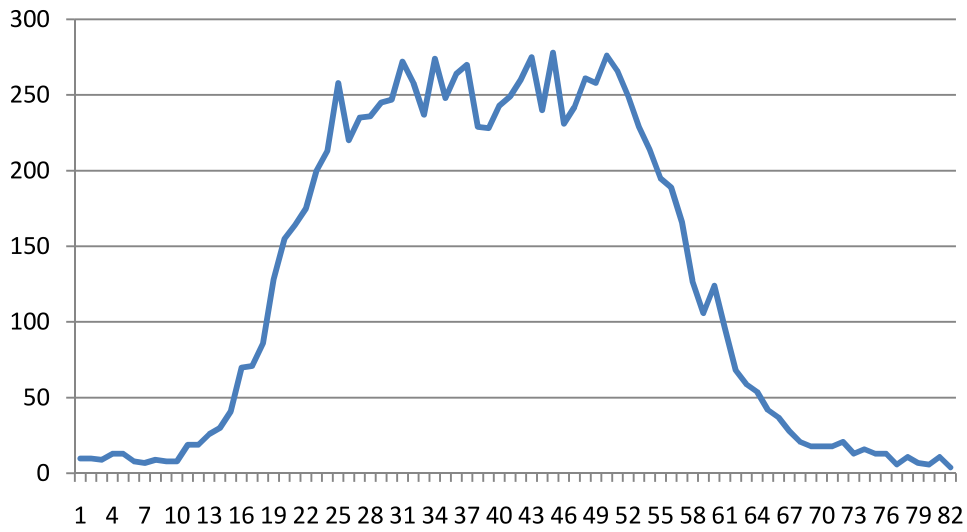


1. Education program

Counts/minutes



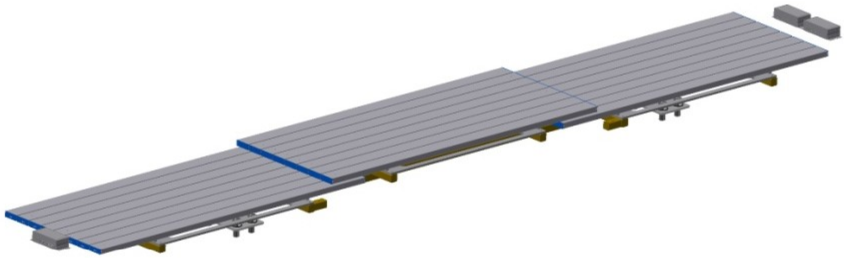
MASTER

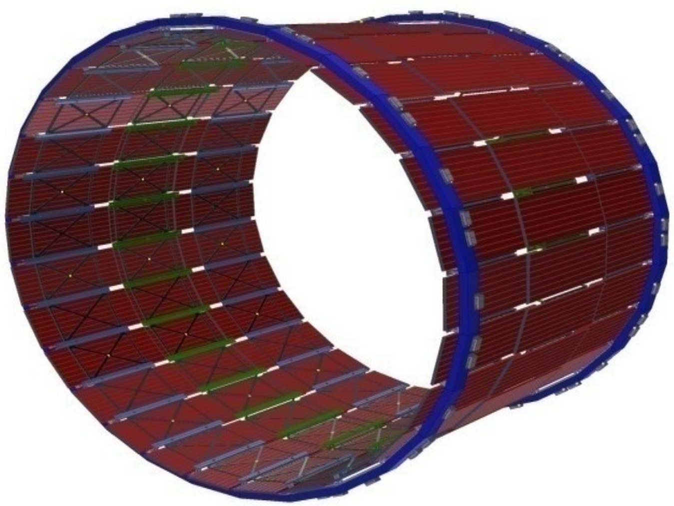


SLAVE

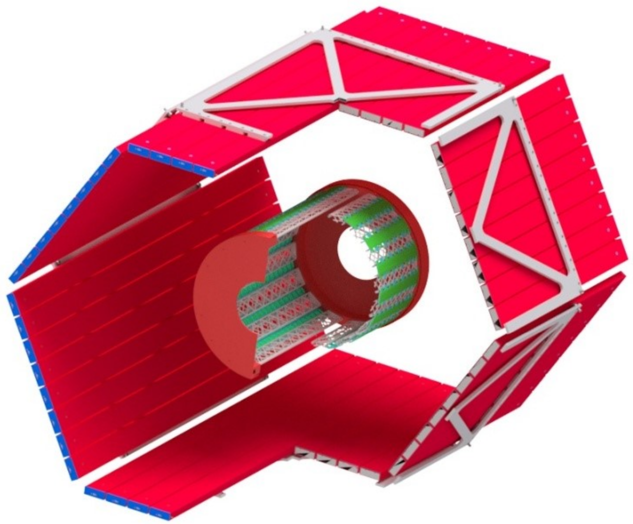
1. Introduction

Big cylindrical detector +
28 Modules (3 section each)
Size: 4784 x 735 x 140 mm

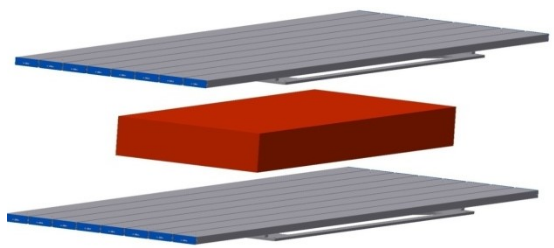




Phase Zero conceptions
6 MCORD section + miniBeBe



2 MCORD section + other detector



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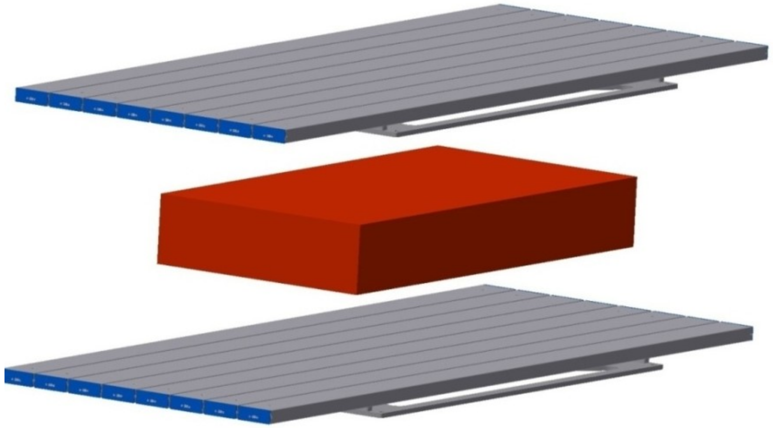
1. Introduction

MCORD HUB

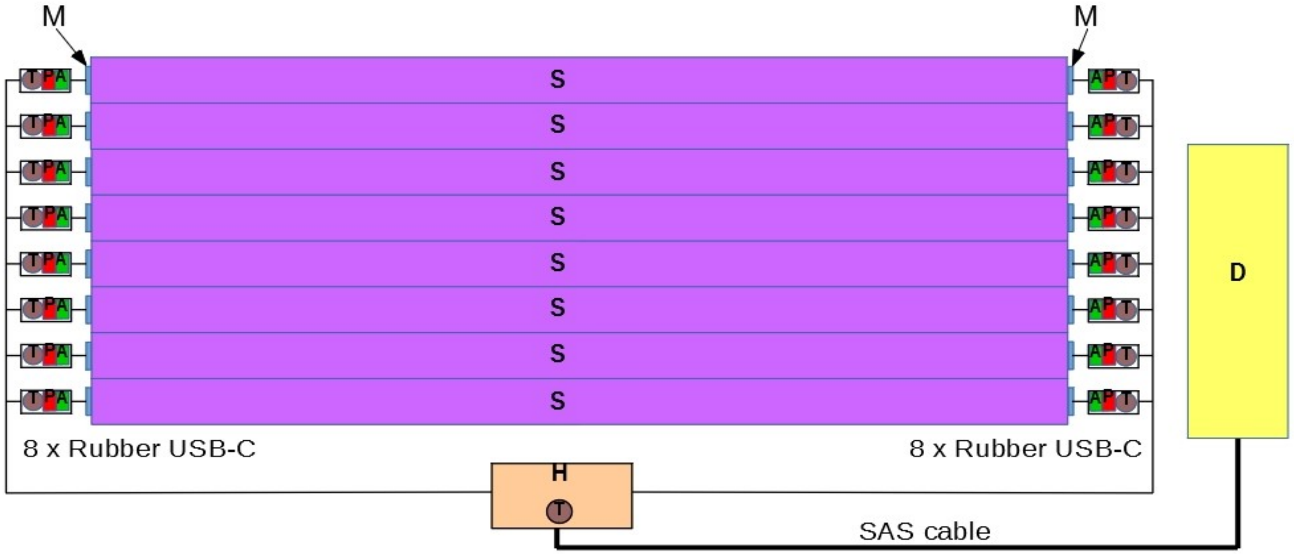
Mini MTCA (FPGA)



2 sections (2 x 8 scintillators) + AFE + DSP + DAQ,

2. Detector

MCORD Section



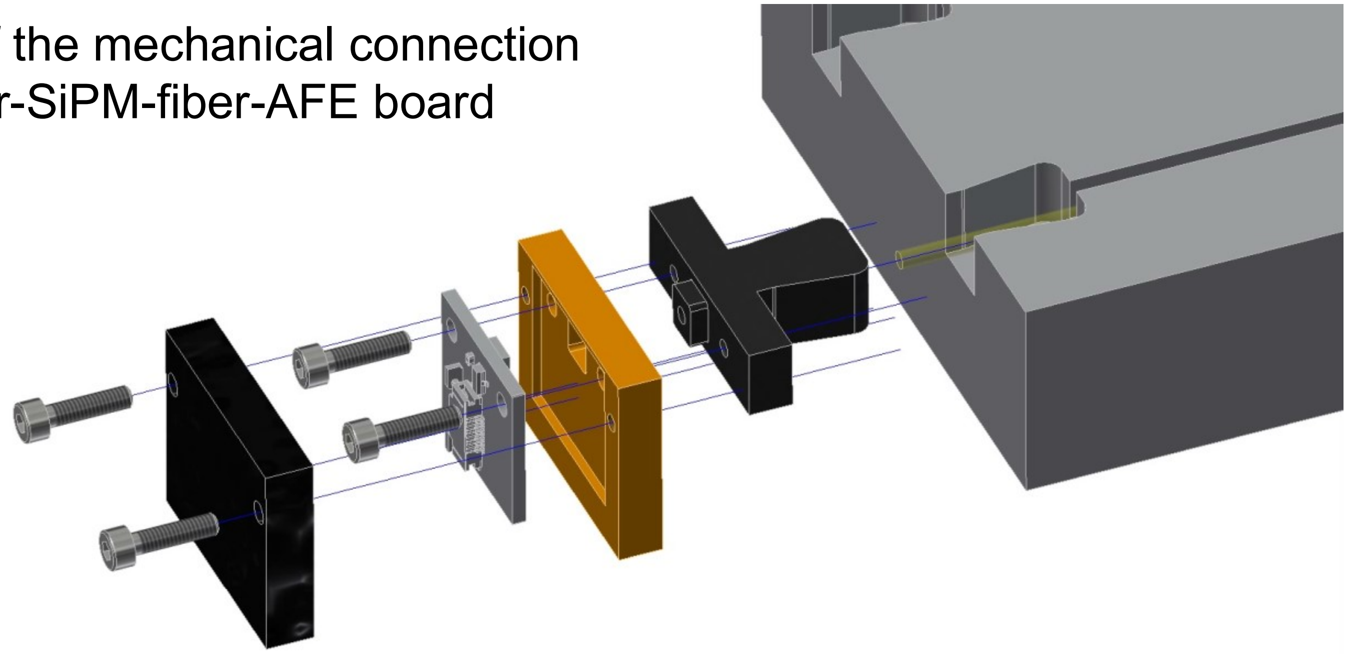
Position resolution
In X axis – up to 5 cm
In Y axis – 5-10 cm

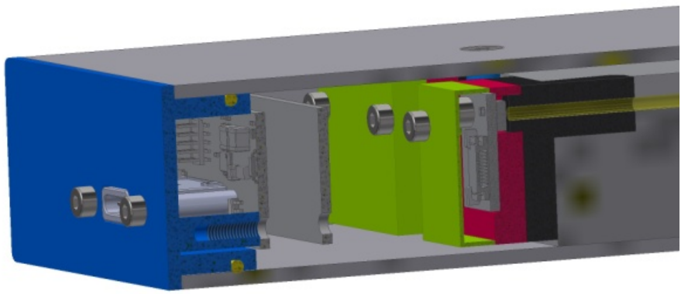
Time Resolution – about 1 ns

Legend: **S** (violet) – plastic scintillator, **M** (blue) – SiPM, **P** (red) – power supply with temperature compensation circuit, **T** (brown) – temperature sensor, **A** (green) – amplifier, **H** (orange) – Passive Signal Hub & Power Splitter, **D** (yellow) – MicroTCA system with ADC boards.

2. Detector

Project of the mechanical connection
scintillator-SiPM-fiber-AFE board





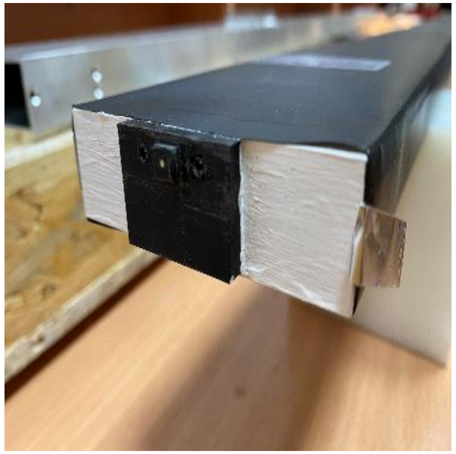
Plastic scintillator: polystyrene (Nuvia)
162 x 7.2 x 2.2 cm

WLS fiber: 1 mm dia. (Kuraray)

SiPM (MPPC): 3x3 mm^2 (Hamamatsu)

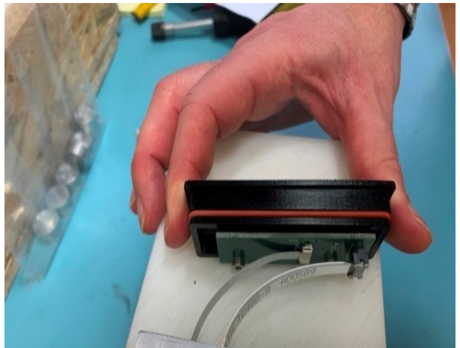
Housing: aluminum profile
174 x 8 x 3 cm

2. Detector Slab manufacturing







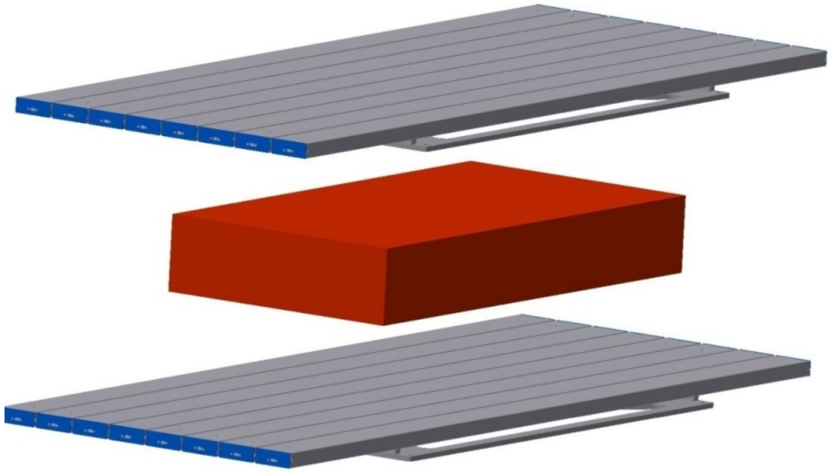



MCORD single detector assembly

2. Detector Slab

MCORD
detector
Slab

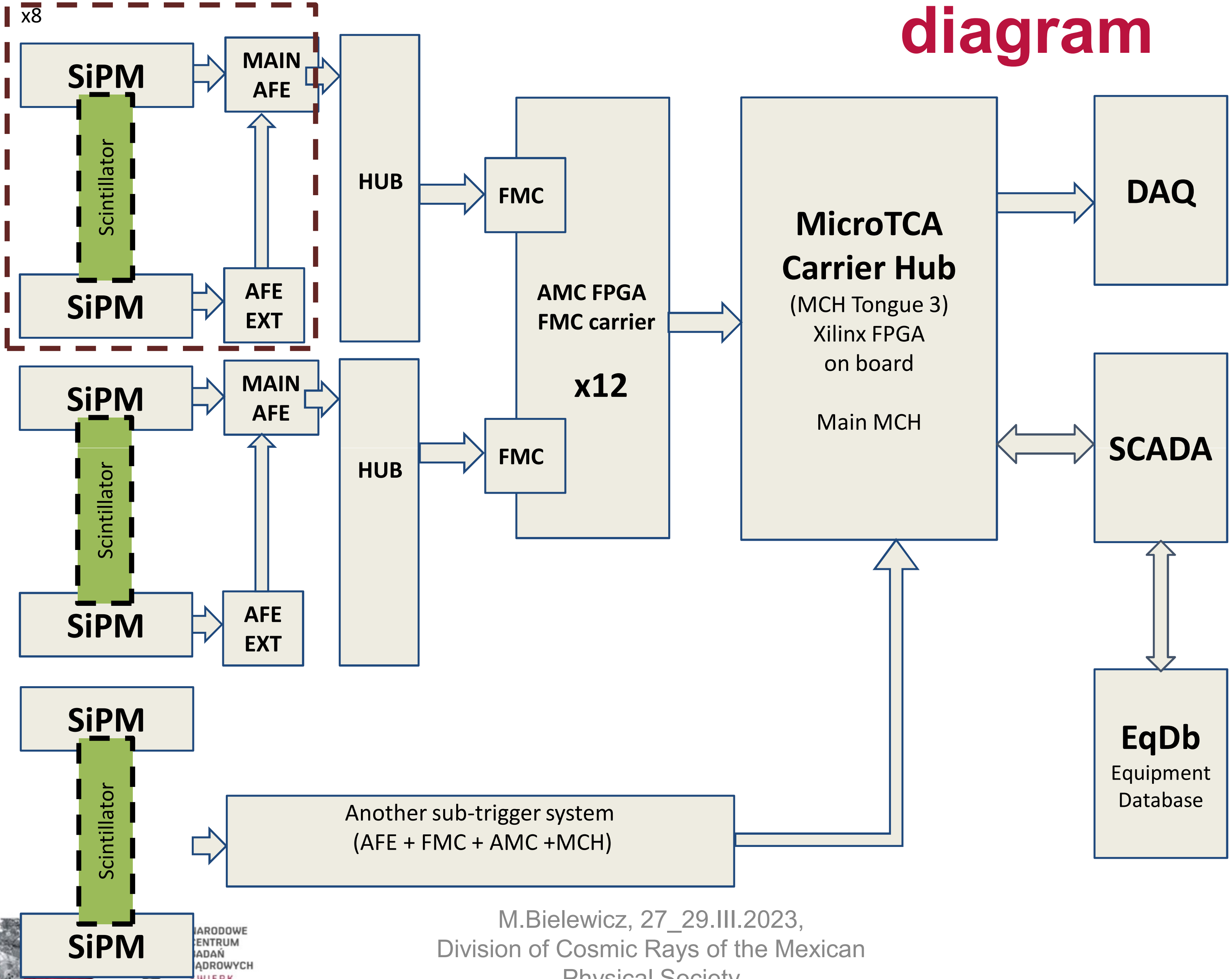
MCORD Sections



Single MCORD section
1744 x 735(675) x 50
[mm]

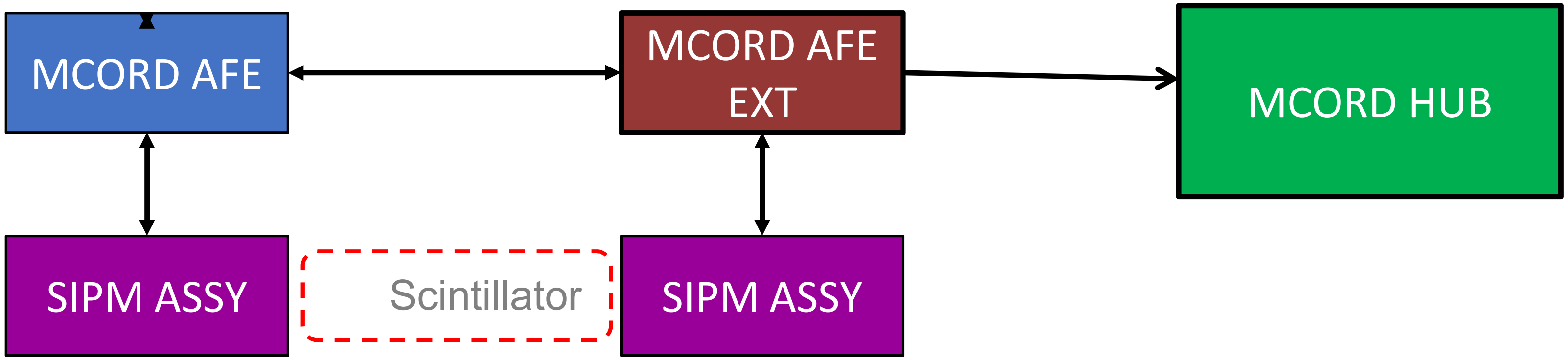
! Feasible for laboratory tests of different subsystems !

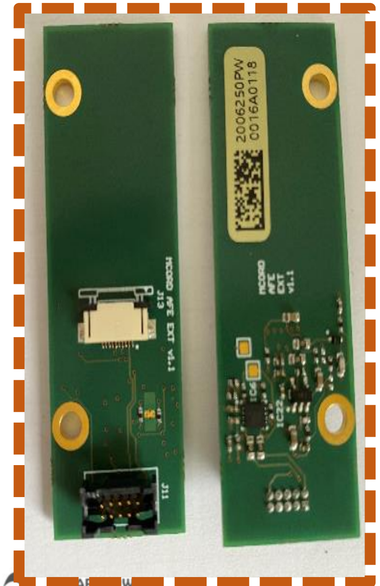
3. MCORD readout system schematic diagram

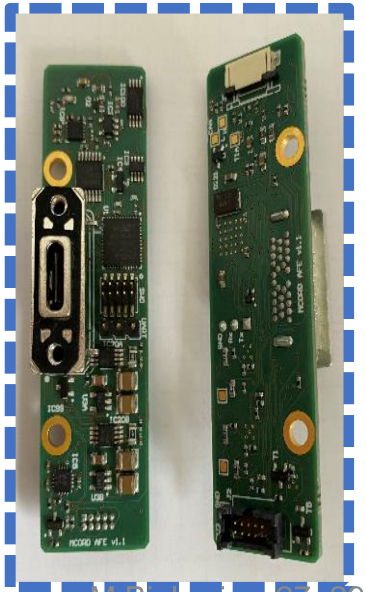


3. Analog Front End and HUB

The main boards ver.3 :

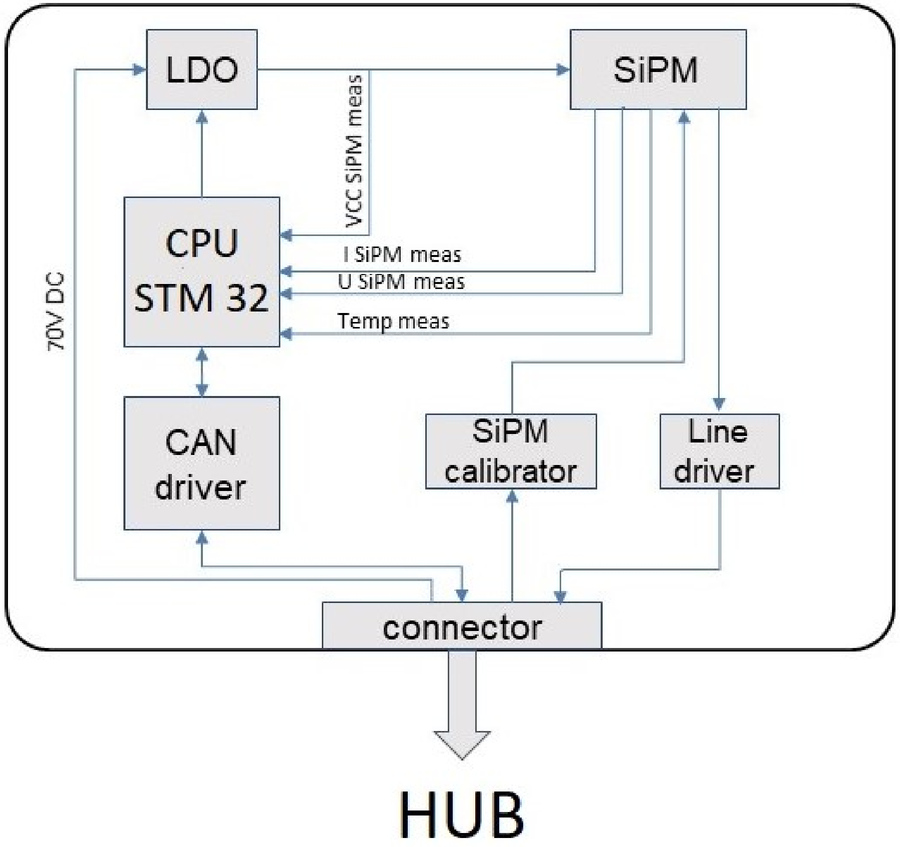






3. Analog Front End - functionality

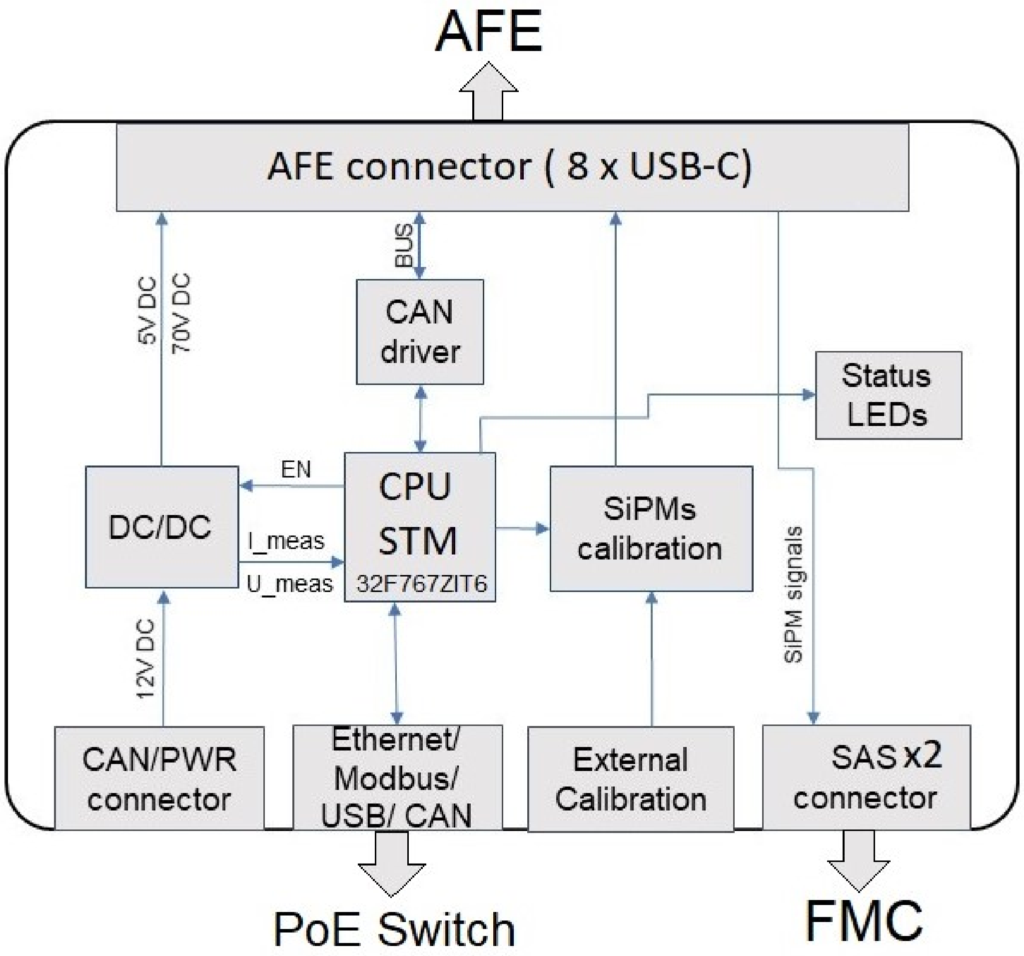
- ➢ Voltage controller for SiPMs and Amplifier physical signal
- ➢ Access to all settings and data from HUB via CAN-bus interface
- ➢ Protection for AFE



- ➢ **Main blocks**
  - ➢ Embedded CPU (STM32F072CBU6)
  - ➢ **Temperature sensor** (LM45)
  - ➢ SiPM voltage controller + LDO (Low Dropout Regulator)
  - ➢ **SiPM calibrator**
  - ➢ SiPM signal transmitter to HUB (differential signal)
  - ➢ **CAN network driver**
- ➢ **Measurements (12 bit ADC)**
  - ➢ 2 x SiPM voltage
  - ➢ 2x SiPM current
  - ➢ 2 x SiPM VCC voltage
  - ➢ 2 x SIPM temperature
- ➢ **Control (8 bit DAC)**
  - ➢ 2 x SiPM voltage

3. HUB - functionality

- **Mikro PYTHON programing**
- PoE supply
- **Generation of 5V and 70V**
- ETH <-> CAN
- Distribution of signals from AFE to SAS cables
- Status LEDs on AFE ASSY and HUB for quick fault identification
- **Generation of calibration signals to AFE**
- STM32 CPU with microPython



3. HUB - microPython

- Development and testing of the control and diagnostic routines may be performed by a physicist
- **The system emulates the USB disk which allows to modify routines in any editor**
- Environment allows to develop interactively control and diagnostic routines
- MicroPython provides the routines to communicate via CAN interface

```
def GetVer(id):
  can = pyb.CAN(1)
  can.init(pyb.CAN.NORMAL,extframe
  can.setfilter(0, 0, 0, (0x00,0x7
  can.send("\x00\x01",id)
  time.sleep(1)
  buf = bytearray(8)
  lst = [0, 0, 0, memoryview(buf)]
  can.recv(0, lst)
  print("ID: ", lst[0])
```

PYBFLASH (

Nazwa

afedrv.py

boot.py

main.py

COM9 - PuTTY

```
ID:  1
RTR:  False
FMI:  0
VerH:  0
VerL:  1
VerD:  2
>>> afedrv.GetVer(1)
ID:  1
RTR:  False
FMI:  0
VerH:  0
VerL:  1
VerD:  2
>>> afedrv.GetVer(1)
ID:  1
```

Data processing

- Latency estimation for **L1 trigger** (event without parameters)

✓ AFE cabling 8ns/m, with 10m cabling latency is 80ns
✓ ADC + SERDES latency: 400ns

Estimated total latency: **about 1us**

Latency estimation for **L2 trigger** (event with parameters)

✓ MGT latency: 500ns
✓ Algorithm latency : 2-5us
✓ Formatter and transmitter latency: 1us

Estimated total latency: **3.5 – 7.5us**

Latency estimation for **L3 trigger** (between MTCA systems)

✓ MGT latency: 500ns
✓ Fiber latency: 500ns + 8ns/m
✓ Algorithm latency : 2-5us
✓ Formatter and transmitter latency: 1us

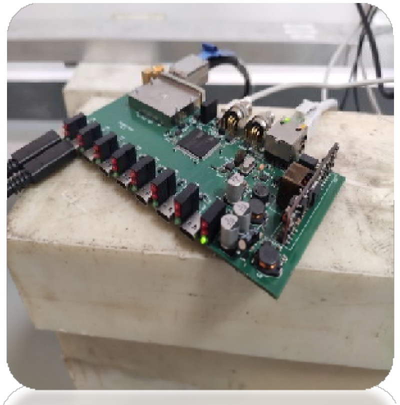
Estimated total latency: **10 – 15us**

4. Laboratory tests

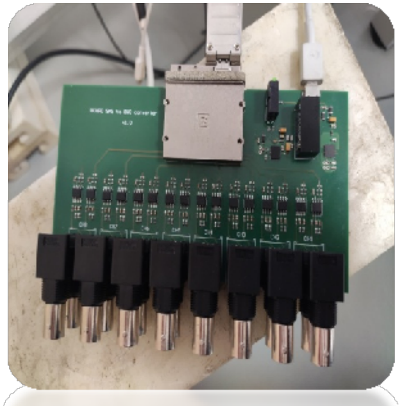
Measuring system

AFE Board → AFE Hub → SAS to BCN converter → Digitizer

Plastic scintillator in an aluminum housing with an AFE amplification system and a Hamamatsu MPPC photodetector



Managed control system for AFE power supplies mounted in boards. Up to 8 boards can be connected once

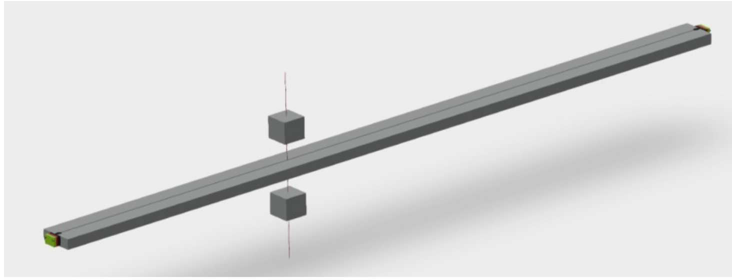


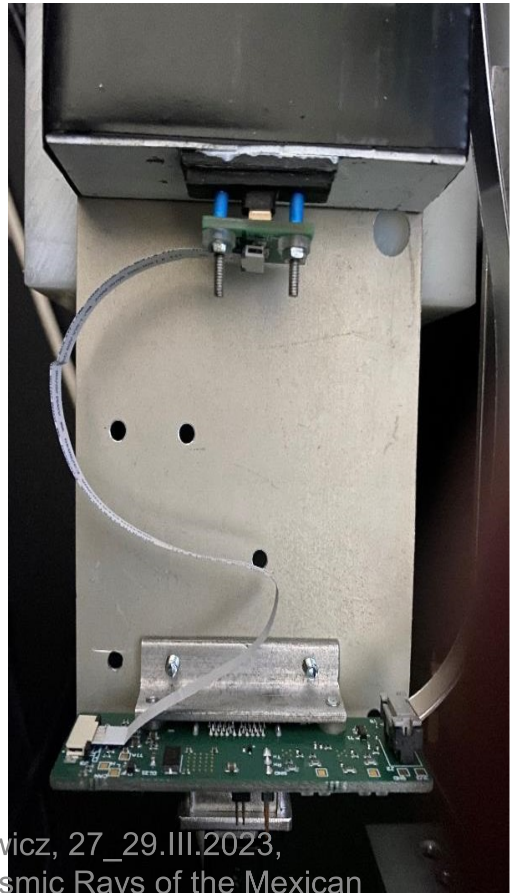
Converter of signals received by SAS cable to appropriate single BNC channels for each MPPC

Digital multi-channel amplitude acquirer by CAEN for analysis of received signals

4. Laboratory tests – 1st step

One Plastic MCORD detector
+ 2 plastic hodoscopes (muon trigger)
+ DAQ: CAEN DT5730

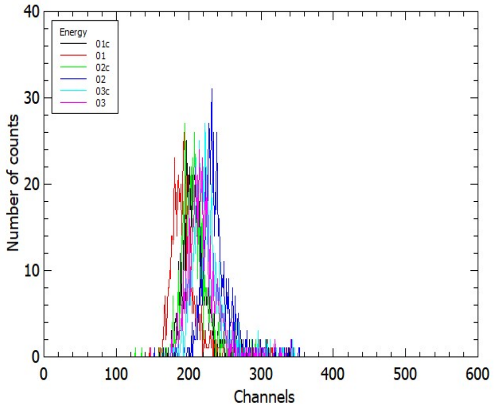




BLACK BOX test setup

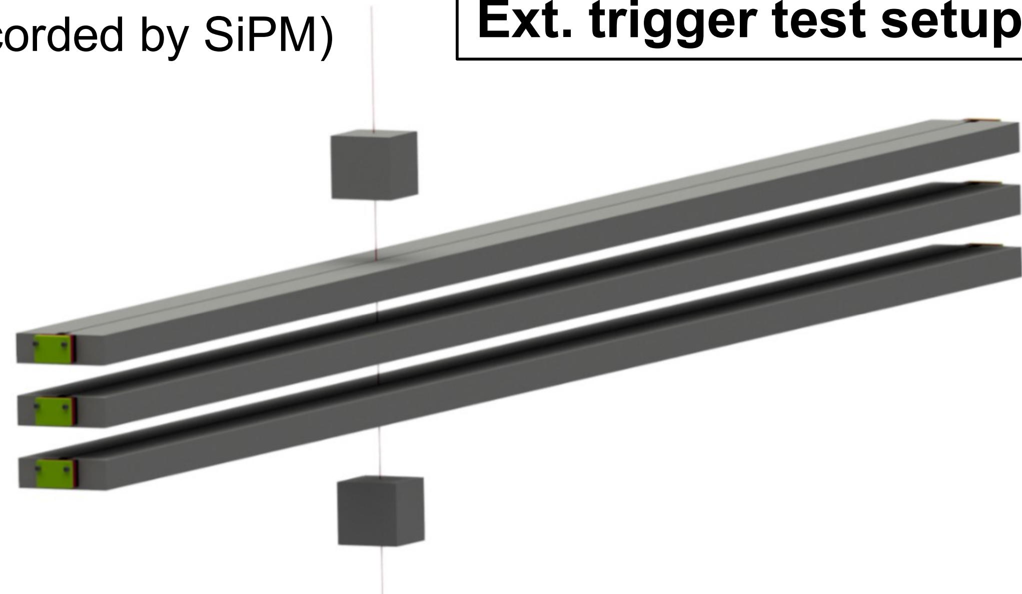
4. Laboratory tests – 2nd step

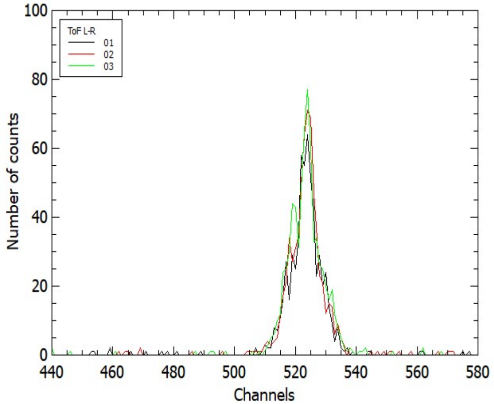
3x plastic MCORD detectors
+ 2x plastic hodoscopes (muon triggers)
+ DAQ: CAEN DT5730



Energy
(amplitude recorded by SiPM)

Ext. trigger test setup

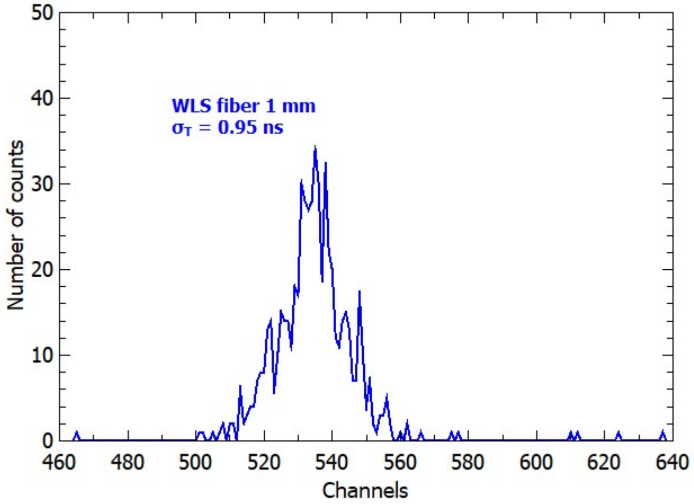




ToF
(between both ends of a scintillator) -> Time rosolution

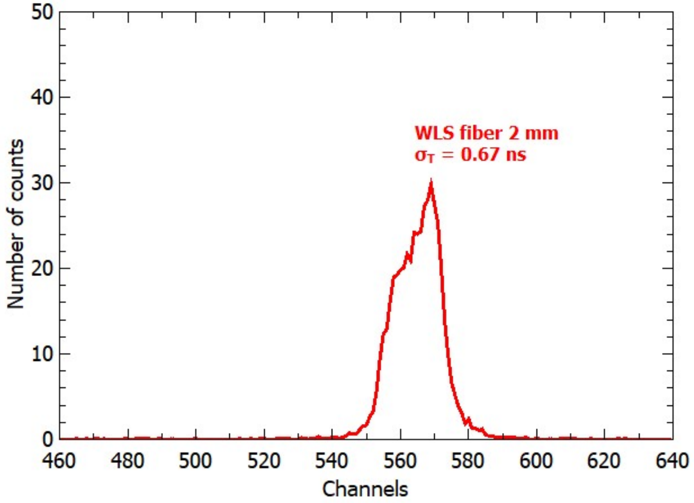
Plastic (162 x 7.2 x 2.2 cm) + WLS fiber (1 mm) + 2x MPPC 3 x 3 mm (pixel size 75um)
Hodoscopes: plastic (5 x 5 x 5 cm) + PMT (2" dia) → **99,5% efficiency**

4. Test procedure



WLS fiber (**1 mm**)

CRT (σ) = 0.95 ns ===> σ_x = 7.1 cm



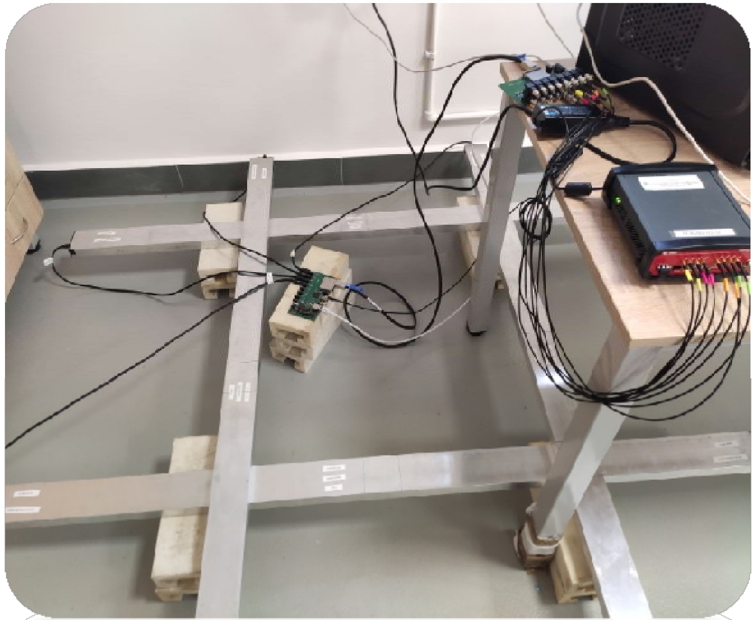
WLS fiber (**2 mm**)

CRT (σ) = 0.67 ns ===> σ_x = 5.1 cm

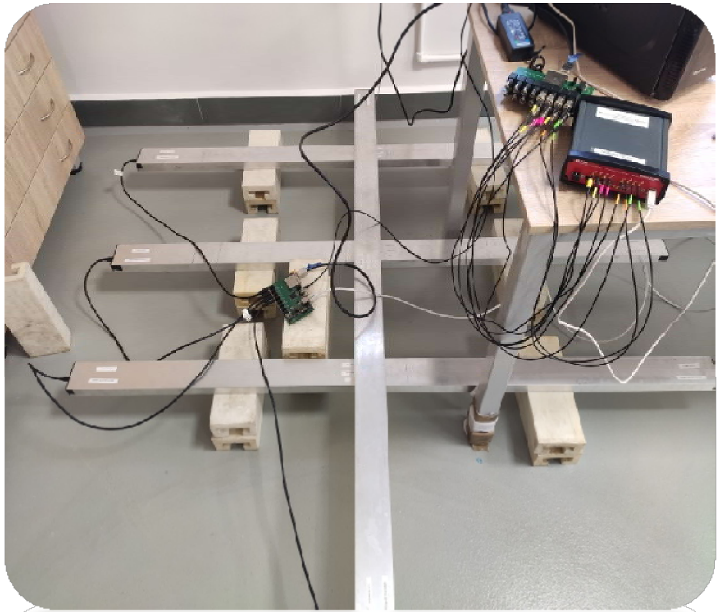
(!) improved timing resolution for 2 mm WLS fiber (!)

4. Laboratory tests – 3rd step

Self trigger multi test setup



Target geometry of the measurement system. There is an area of coincidence between the boards at each crossing of the boards. In this juxtaposition, each board is in a coincidence with two different boards

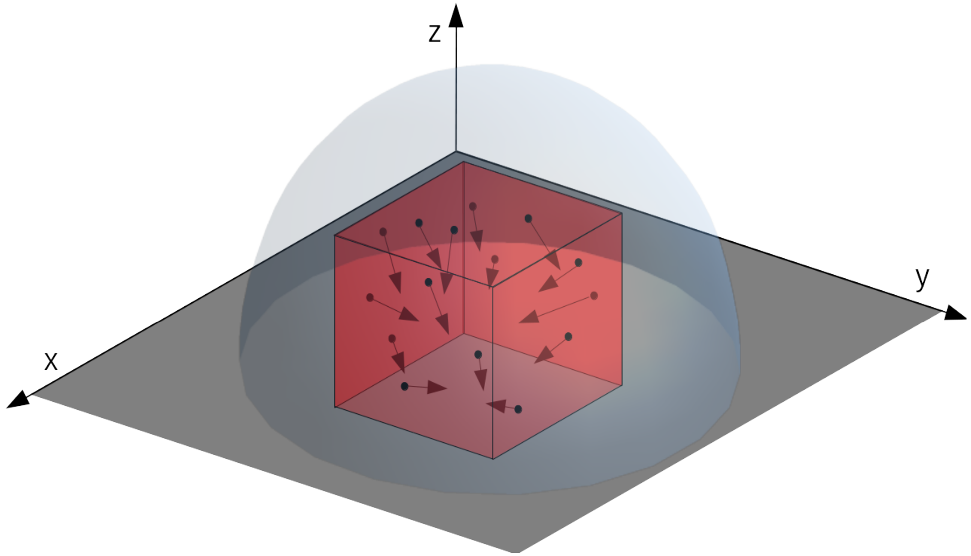


Alternate geometry. One of the boards is responsible for the gate to the others, creating with them appropriate areas of coincidence at their intersections

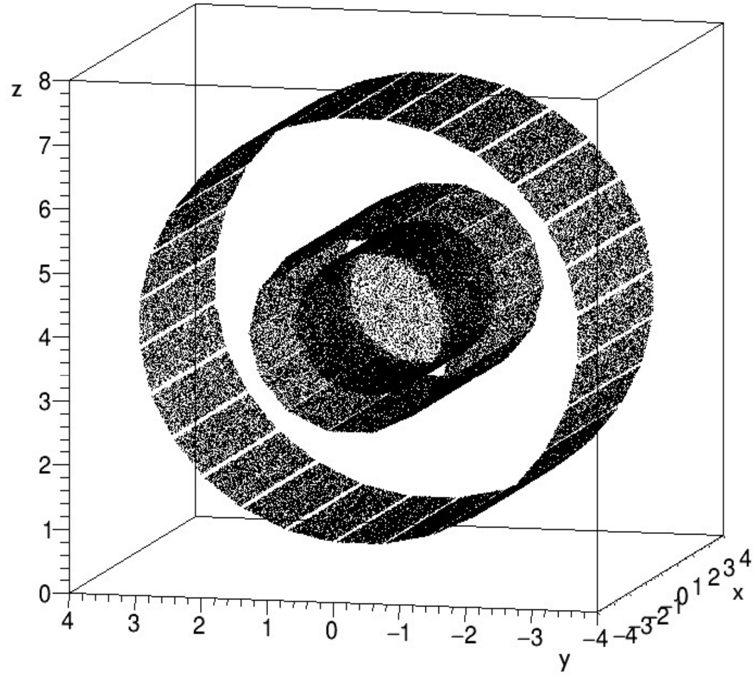
5. Simulations (EAS)

Cofluxim – cosmic ray generator

for MPD subsystems calibration study



The concept of particle generation: drawing particles on the generation cube walls.



Plot of all hits on the surfaces of TPC, ToF and MCORD detectors.

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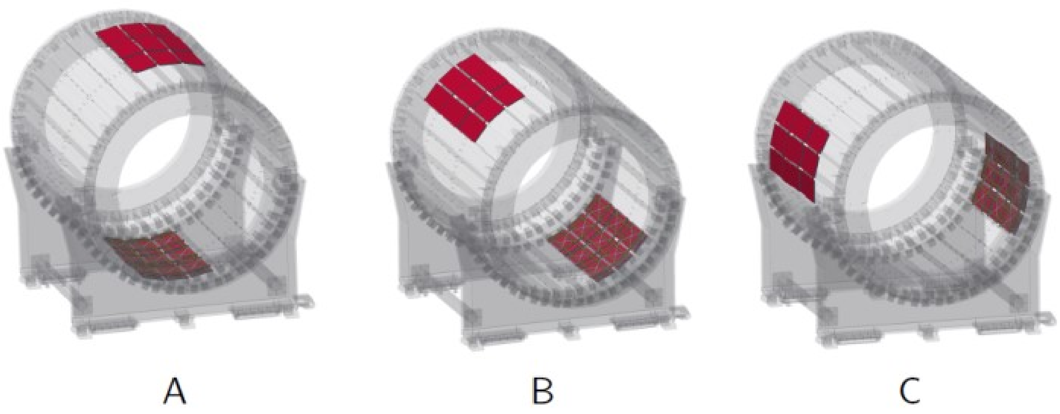
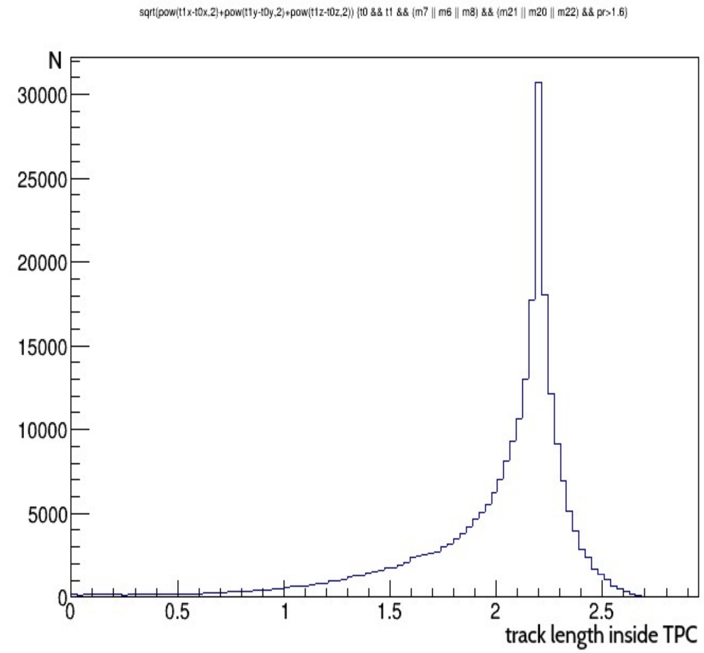
5. Simulations (EAS)

TPC calibration using MCORD triggers



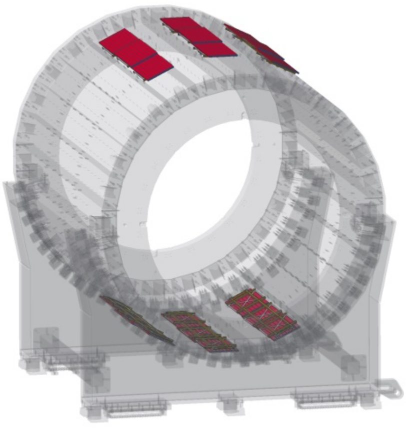


Calculated for muons with momentum
p > 1.6 GeV/c.

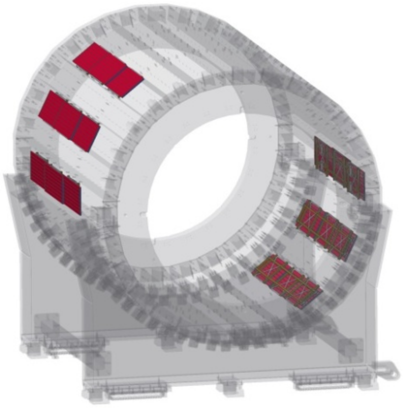
MCORD configuration	MCORD modules ID numbers	MCORD & TPC (tracks per hour)
A	(6 or 7 or 8) and (20 or 21 or 22)	**246 800**
B	(9 or 10 or 11) and (23 or 24 or 25)	**158 262**
C	(12 or 13 or 14) and (26 or 27 or 0)	**20 634**

5. Simulations (EAS)

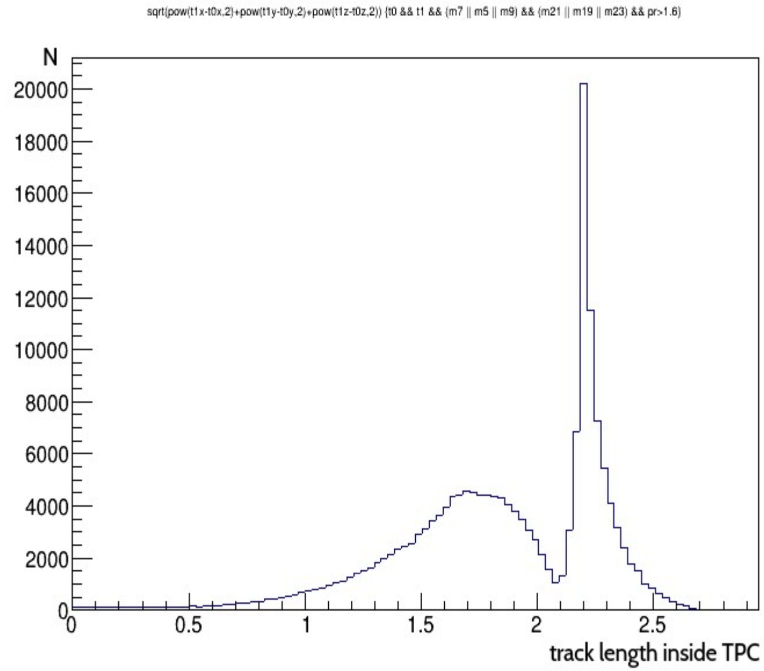
TPC calibration using MCORD triggers



D



E



Calculated for muons with momentum
p > 1.6 GeV/c.

MCORD configuration	MCORD modules (ID numbers)	MCORD & TPC (tracks per hour)
D	(5 or 7 or 9) and (19 or 21 or 23)	**178 822**
E	(10 or 12 or 14) and (24 or 26 or 0)	**50 894**

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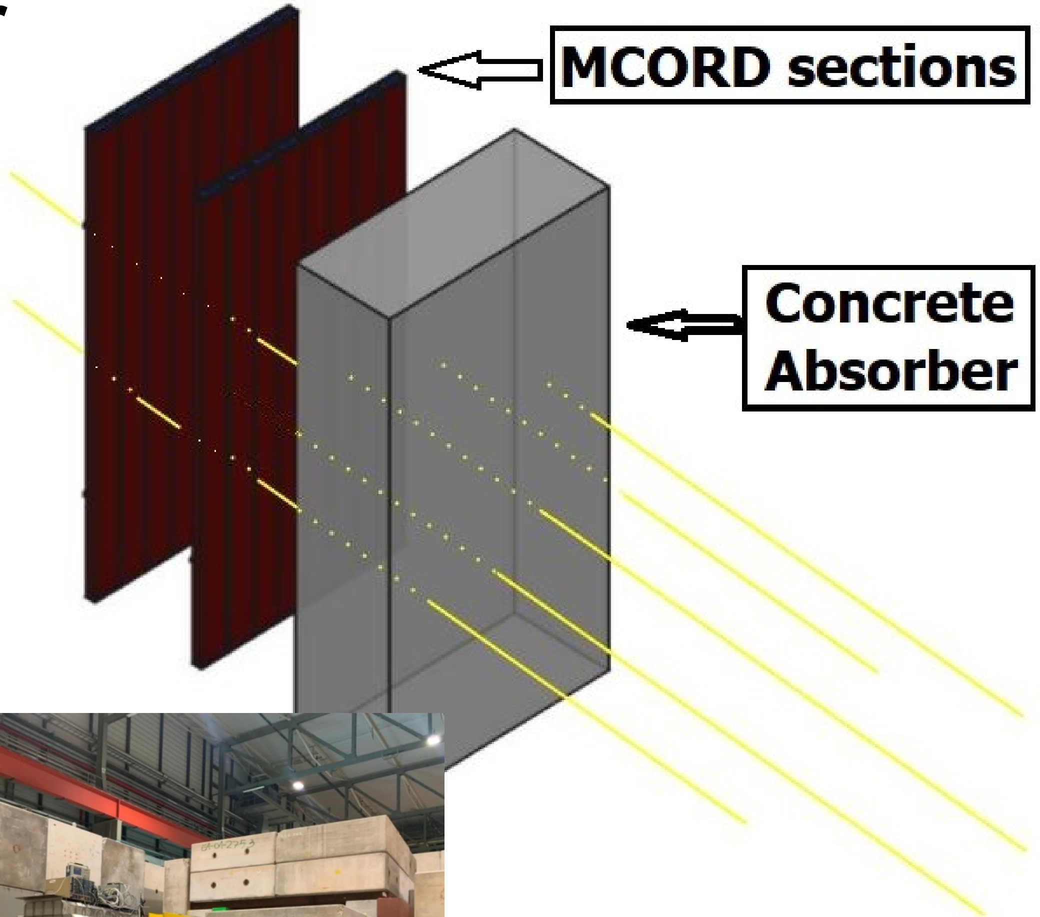
6. Implementation - NA61/SHINE

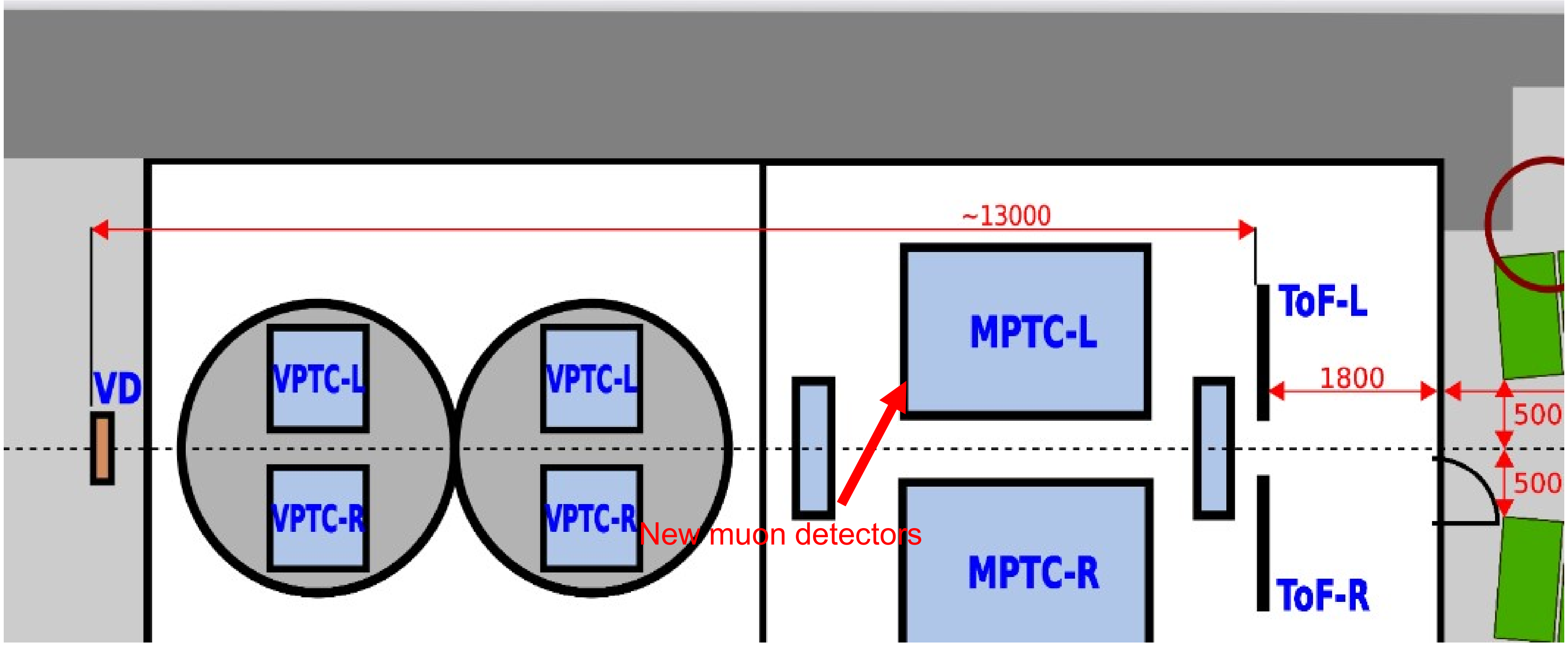
Muon Detector

The absorber will absorb other particles.

The muons will pass through two layers of scintillators, which will give us a vector of their flight path.



6. Implementation - NA61/SHINE



Setup – possible location and configuration of muon detectors

6. Implementation - NA61/SHINE

- **$J/\psi \rightarrow \mu^+\mu^-$**
  - Dileptons are penetrating probes of the dense, hot matter. It permits to study the different stages of interaction before hadronisation.
  - J/ψ meson production is suppressed in heavy nuclei interactions at high energies (STAR,LHC). It is expected in the quark-gluon plasma. Study of evolution of J/ψ absorption on energy and centrality at SPS is of importance. [1]

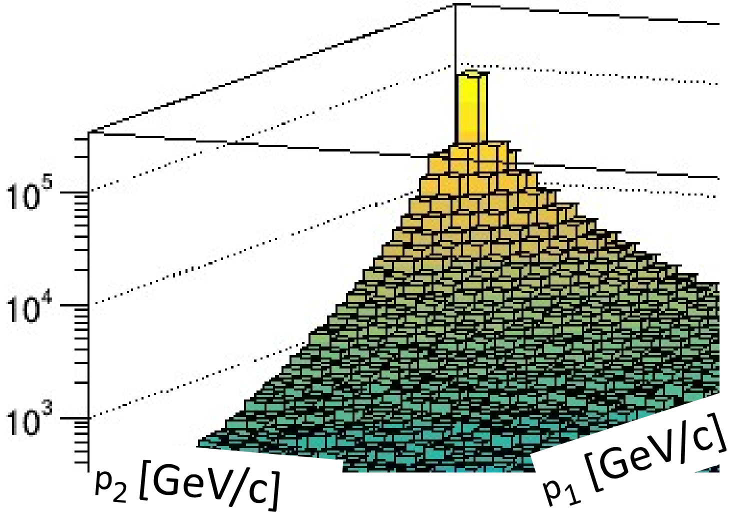
$$\eta \rightarrow \mu^+\mu^-\pi^+\pi^- \quad (\Gamma < 3.6 \times 10^{-4}\ \%)$$
$$\eta \rightarrow \mu^+\mu^-\mu^+\mu^- \quad (\Gamma < 3.6 \times 10^{-4}\ \%)$$

- **$\eta \rightarrow \mu^+\mu^-$**
  - The eta meson is a member of the nonet of the lightest pseudoscalar mesons. It has several decay modes (e.g. gamma-gamma, 3 pions)
  - The rare $\mu^+\mu^-$ decay (Branching Ratio about $6*10^{-6}$) can provide information about the pseudoscalar formfactor needed for light-by-light contribution to the anomalous magnetic moment of the muon (g-2). [2]
  - There is only one experimental BR value in PDG, nevertheless the small maximum was observed by HERA and NA60. No result for BR was extracted.

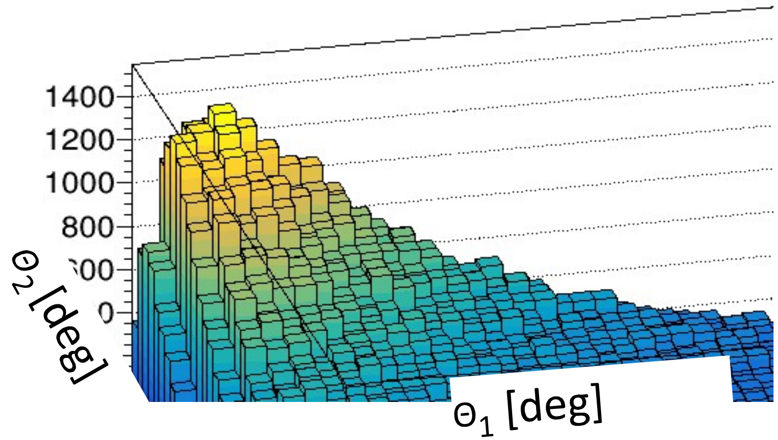
Literature

[1] A. Alessandro [NA50], Eur.J. C 33(2004)31
[2] P. Masjuan and P .Sanchez-Puertas, JHEP 08(2016)108 and references therein

J/ψ → μ⁺μ⁻

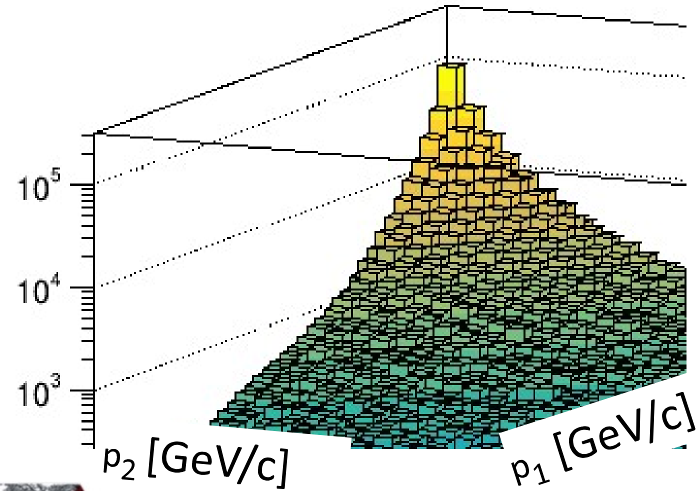


10^5
10^4
10^3
p2 [GeV/c]
p1 [GeV/c]

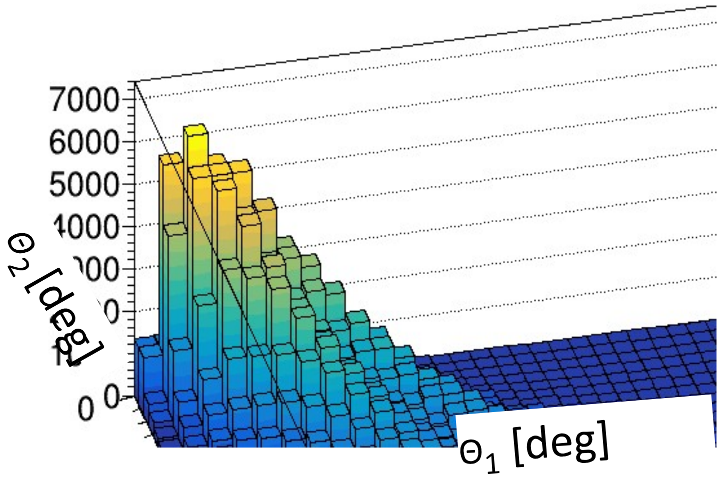


1400
1200
1000
800
Θ2 [deg]
Θ1 [deg]

η → μ⁺μ⁻



10^5
10^4
10^3
p2 [GeV/c]
p1 [GeV/c]



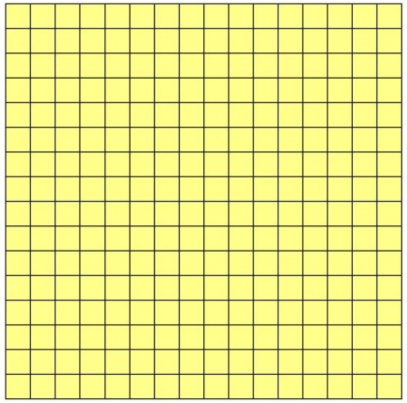
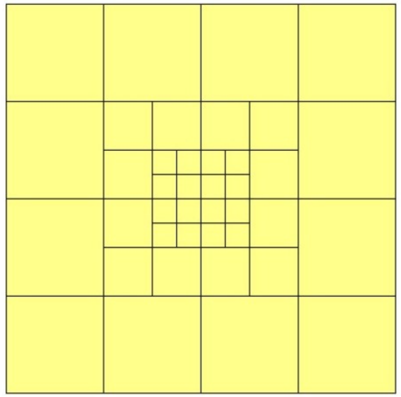
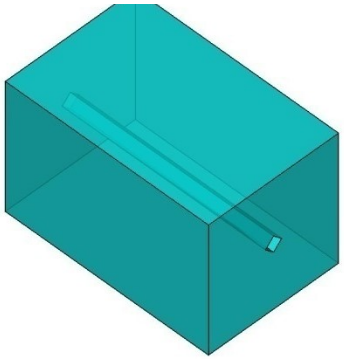
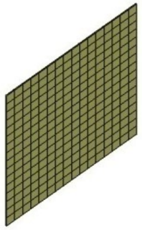
7000
6000
5000
Θ2 [deg]
Θ1 [deg]

6. Implementation - NA61/SHINE

A new detector plane made of scintillators will be placed in front of the MPSD detector, which will obscure the central part of the MPSD detector.

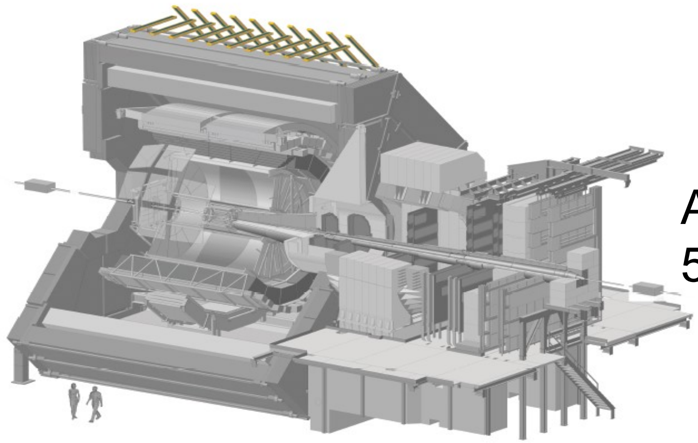
There are various possibilities of dividing the scintillator into smaller, independent fragments.

Neutron Veto


6. Implementation - Astrophysics

Examples from other experiments



ALICE Exp. ACORDE
55 m underground
thr. 16 GeV
2010-2013 y

ALEPH Exp.
140 m under. (thr. 70 GeV) (1997-99y)

N·H
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Astroparticle Physics 19 (2003) 513–523
Astroparticle Physics
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Cosmic multi-muon events observed in the underground CERN-LEP tunnel with the ALEPH experiment

V. Avati [a,*], L. Dick [a,1], K. Eggert [a], J. Ström [a,2], H. Wachsmuth [a,3], S. Schmeling [b], T. Ziegler [b], A. Brühl [c], C. Grupen [c]

[a] European Laboratory for Particle Physics (CERN), Geneva, Switzerland
[b] Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany
[c] University of Siegen, Siegen, Germany

Received 26 July 2002; received in revised form 27 October 2002; accepted 26 November 2002

DELPHI Exp.
100 m under. (thr. 52 GeV) (99-2000y)

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ScienceDirect
Astroparticle Physics 28 (2007) 273–286
Astroparticle Physics
www.elsevier.com/locate/astropart

Study of multi-muon bundles in cosmic ray showers detected with the DELPHI detector at LEP

DELPHI Collaboration
J. Abdallah [z], P. Abreu [w], W. Adam [be], P. Adzic [l], T. Albrecht [r], R. Alemany-Fernandez [i], T. Allmendinger [r], P.P. Allport [x], U. Amaldi [ad], N. Amapane [av], S. Amato [az], E. Anashkin [ak], A. Andreazza [ac], S. Andringa [w], N. Anjos [w], P. Antilogus [z], W-D. Apel [r], Y. Arnoud [o], S. Ask [aa], B. Asman [au], A. Augustinus [i], P. Baillon [i], A. Ballestrero [aw], P. Bambade [u],

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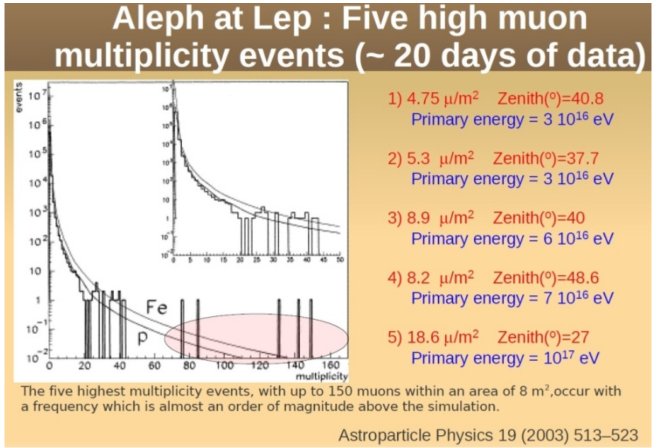
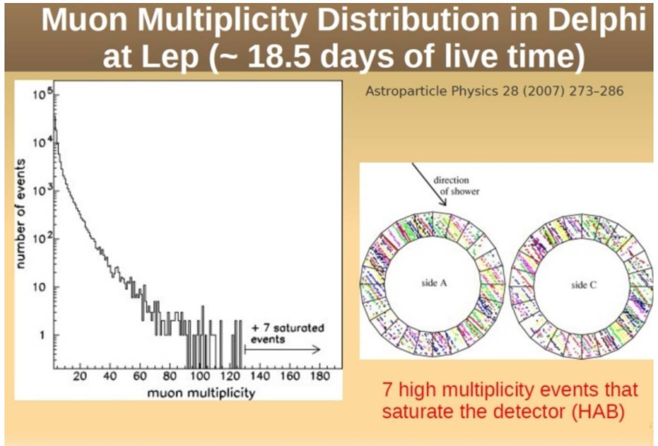
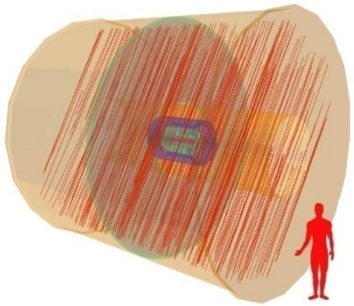
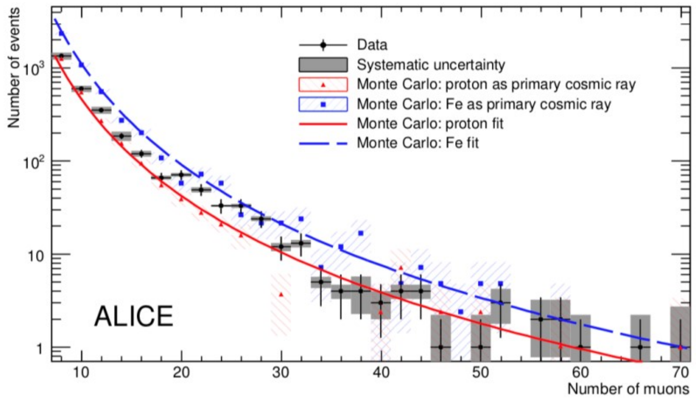
6. Implementation - Astrophysics

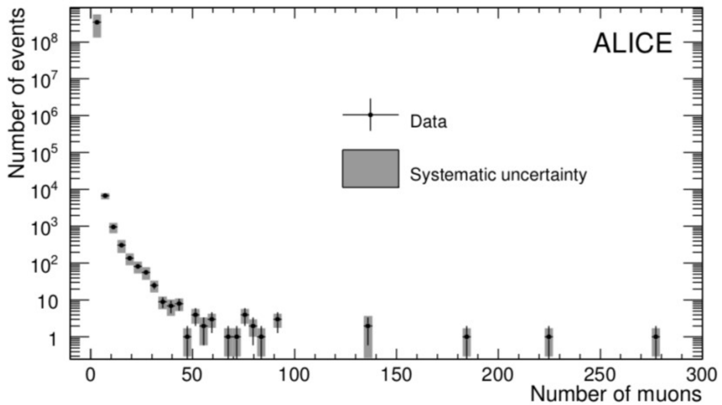
High Muon Multiplicity Events in different experiments











Comparisons with simulation results (KORSIKA+QGSJET) are in agreement for low multiplicities (for low energy). For high multiplicities (only few events) results are almost an order of magnitude above the simulations results.

Problem with current hadronic interaction model for extremely high energy >10E15 eV ???

Bibliography:
Bruno Allesandro prezentation on ALICE collaboration workshop Feb 2013
ALICE Collaboration, JCAP 01 (2016) 032
K. Shtejer: CERN-THESIS-2016-371

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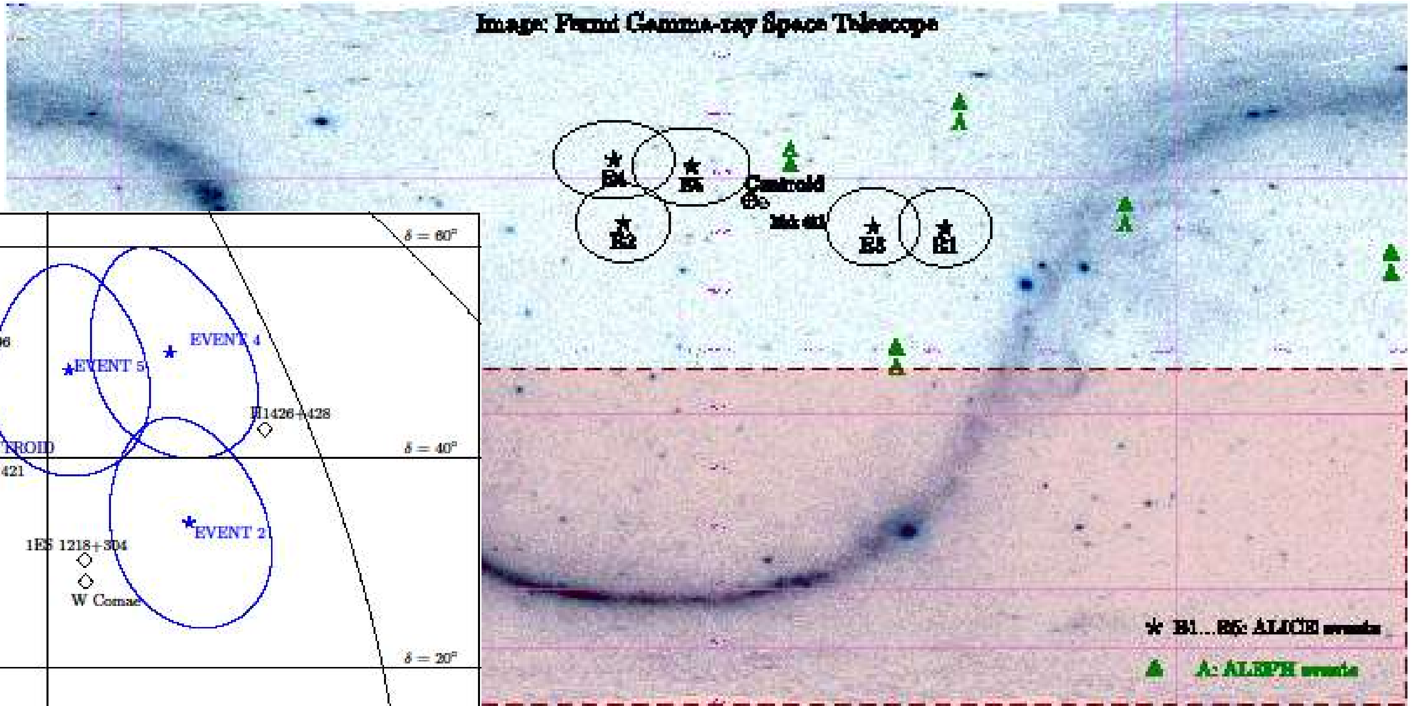
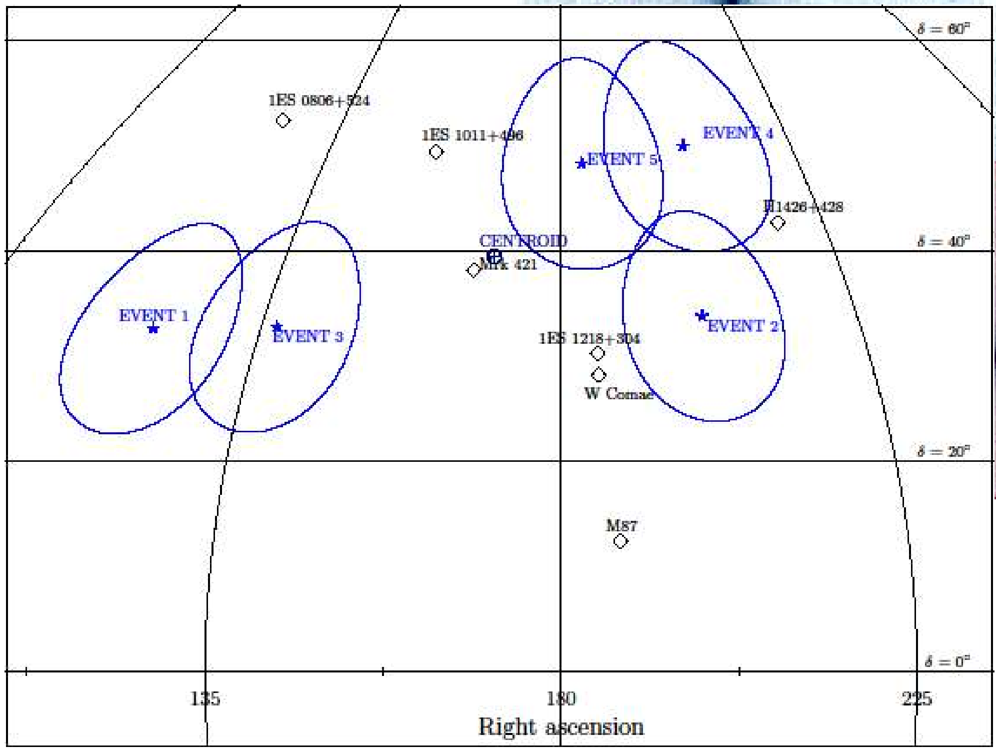
6. Implementation - Astrophysics

The position identification of Extremely high energy particle source

ALICE (multi events data) sphere position recognition





P. Kankiewicz et al., Muon Bundles as a Sign of Strangelets from the Universe, ApJ (2017),vol.839, doi:10.3847/1538-4357/aa67ee

Very low statistics – many years of observation.
A special attention is paid to muon groups of large multiplicity.
Horizontal Events Experiments needs more data.

6. Implementation - Astrophysics

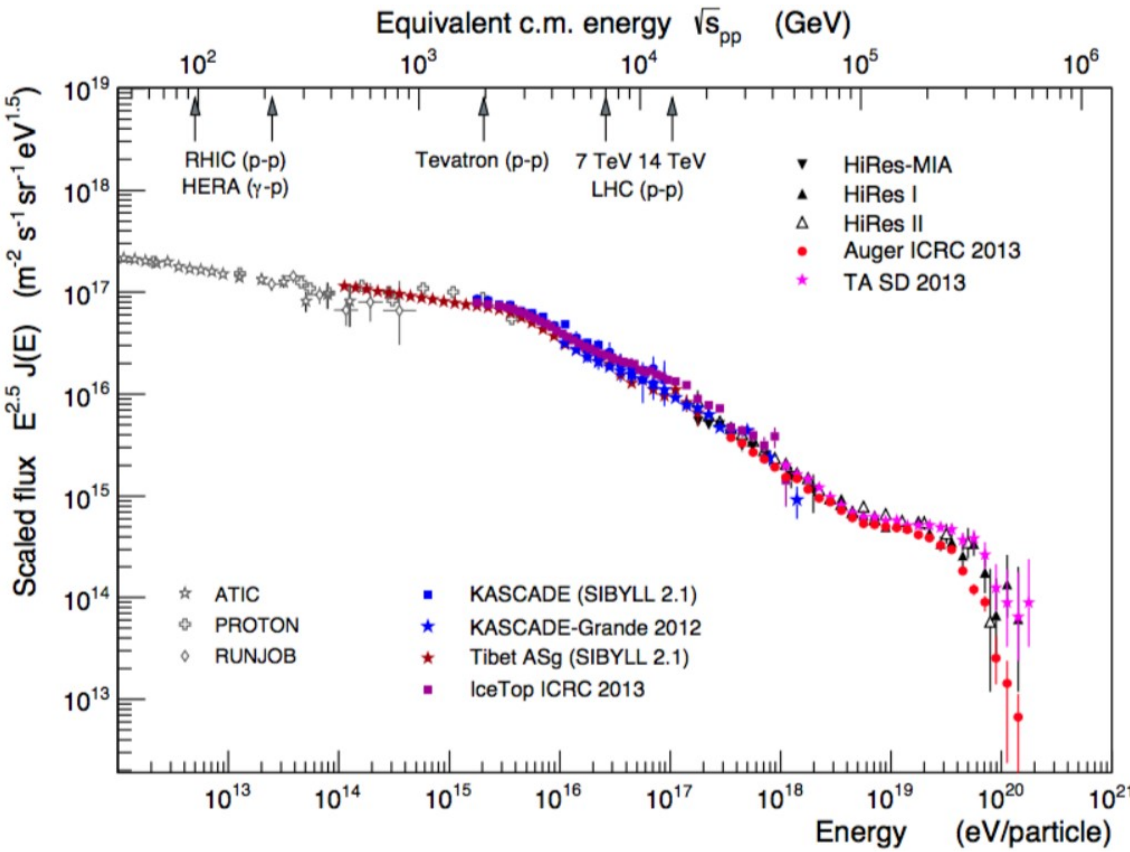
GZK-cutoff problem

- 4x10E19 eV
- 50 Mega Parsec
- Cosmic Microwave Background

Example: DECOR exp. 2002-2003y (near horizontal observation (60-90 deg. angular range)
1-10 PeV primary particle) (see ref. 2)

Bibliography:

1. Pavluchenko, V. P.; Beisembaev, R. U., Muons of Extra High Energy Horizontal EAS in Geomagnetic Field and Nucleonic Astronomy, 1995 ICRC....1..646P
2. Yashin I. et al., Investigation of Muon Bundles in Horizontal Cosmic, 2005 (28) ICRC p.1147-1150
3. Neronov A. et al., Cosmic ray composition measurements, 2017, arXiv:1610.01794v2 [astro-ph.IM]
4. Shih-Hao Wang, 2017_Cosmic ray Detection ARIANNA Station, PoS ICRC2017_358

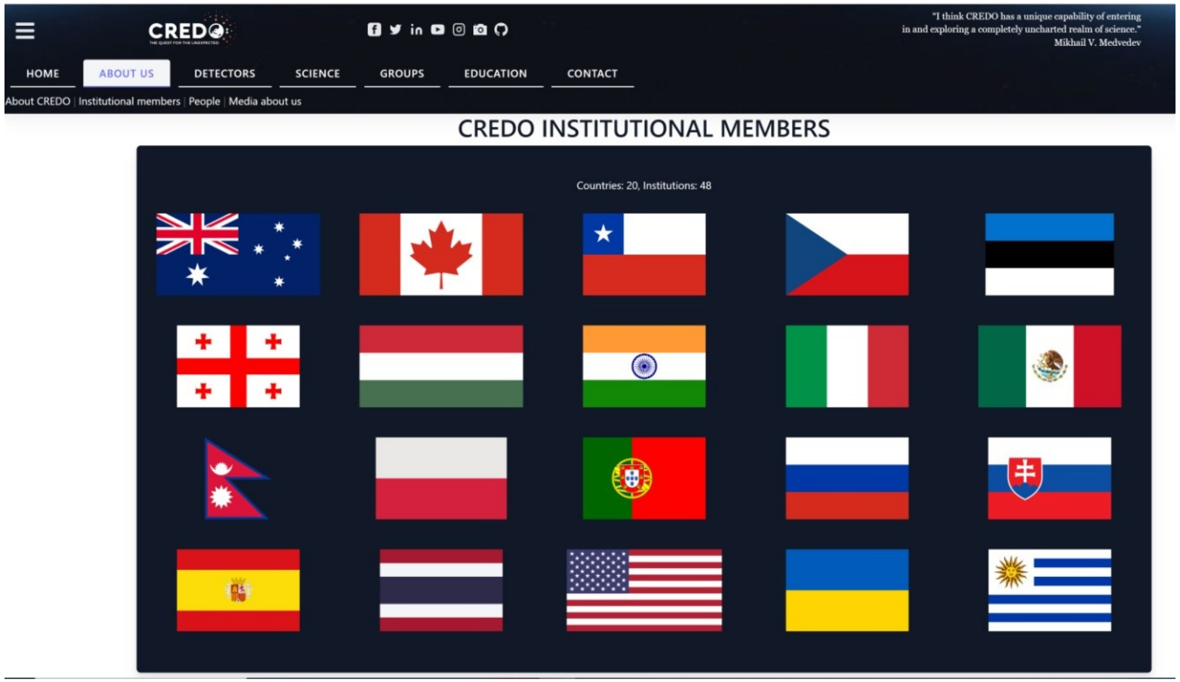


All-particle cosmic-ray energy spectrum derived from direct and indirect (air shower experiments) measurements, as well as results from different hadronic models

6. Implementation - CREDO program

International project Cosmic-Ray Extremely Distributed Observatory (CREDO), initiated in 2016 at the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Krakow by prof. IFJ PAN Dr. hab. Piotr Homola.

https://credo.science



20 Countries
40 institutions

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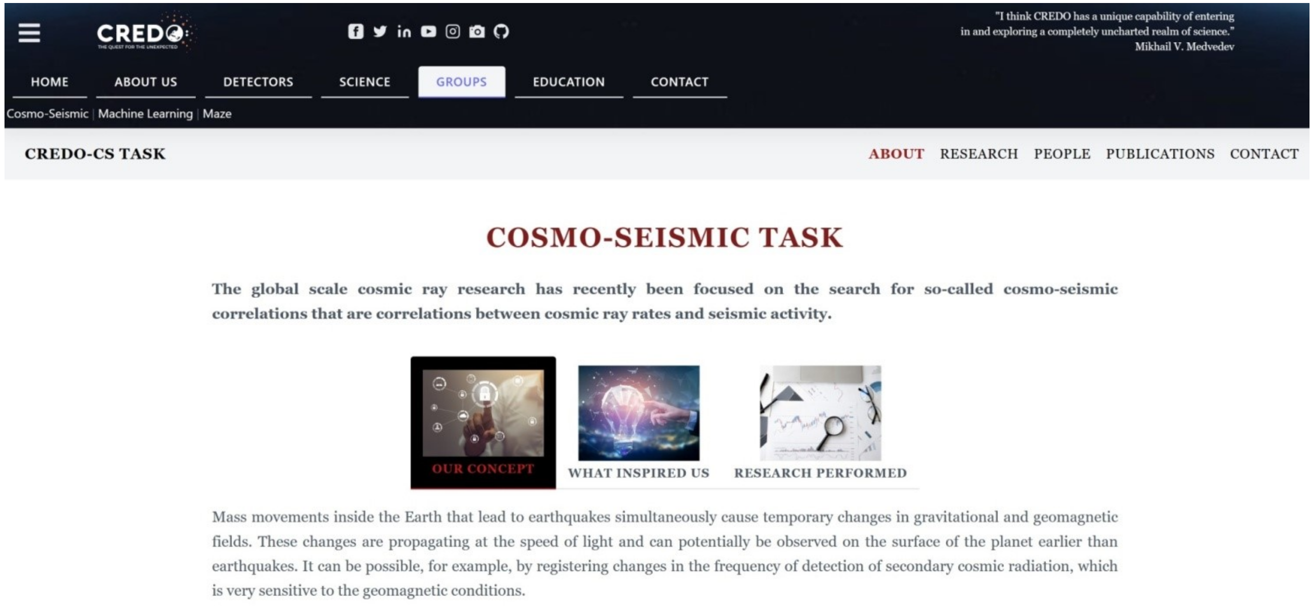
Earthquake Precursors

Large scale correlations between cosmic rays and earthquakes presumably related to earthquakes precursors has been observed. The found periodicity is rather similar to the sun spots solar cycle.

Cosmic ray data correspond to the measurements at the Pierre Auger observatory in Malargüe, Argentina, whereas seismic data is taken from Moscow and Oulu stations located in Russia and Finland, respectively.

A 6σ correlation effect has been observed in a period of about 4.5 years. Details can be found in a publication being peer reviewed at the moment and soon to be publicly available

6. CREDO-MEXICO program



The use of the Mexican cosmic ray observatory + several MCORD coincidence detectors installed in universities + several smaller detectors for schools etc. - Creation of a measurement network collecting data simultaneously with seismographic stations.

The scope of research and the list of institutions are discussed. Currently, we are preparing the text of the **Memorandum of Understending**, which will become the basis for obtaining the grant.

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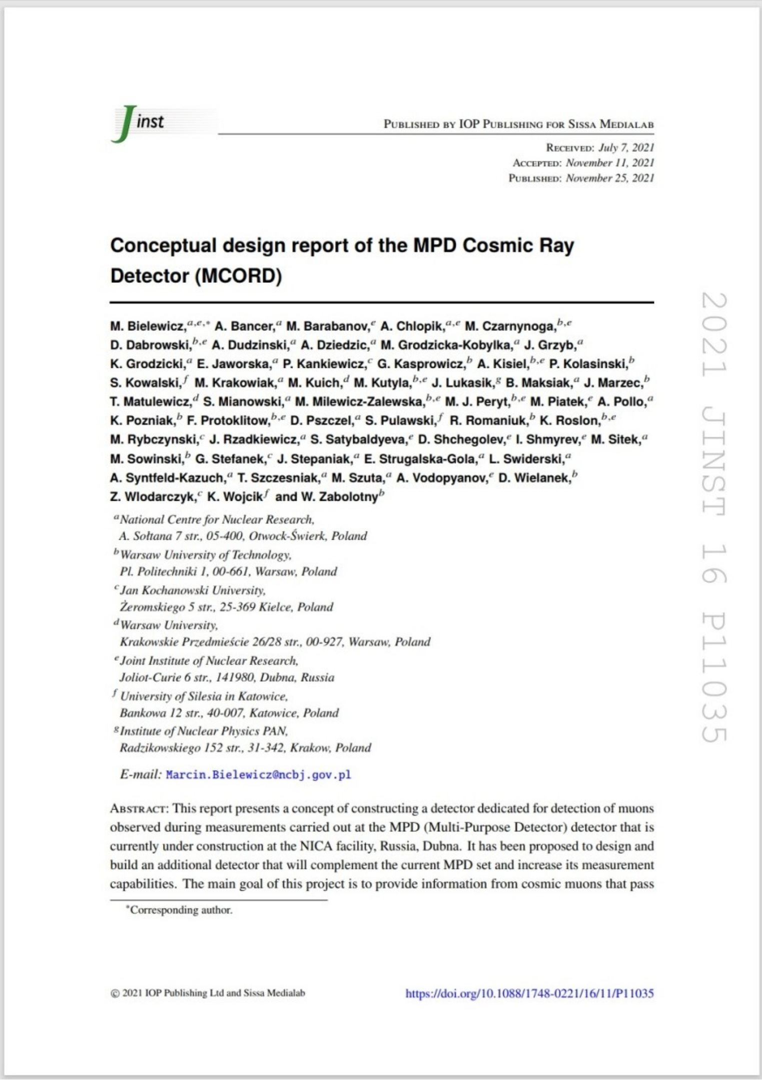
7. CDR publictation

Conceptual design report of the MPD Cosmic Ray Detector (MCORD)

Published 25 November 2021 • © 2021 IOP Publishing Ltd and Sissa Medialab

Journal of Instrumentation
Volume 16 November 2021

https://doi.org/10.1088/1748-0221/16/11/P11035



Jinst — Published by IOP Publishing for Sissa Medialab
Received: July 7, 2021
Accepted: November 11, 2021
Published: November 25, 2021

Conceptual design report of the MPD Cosmic Ray Detector (MCORD)

M. Bielewicz,[a,e,*] A. Bancer,[a] M. Barabanov,[e] A. Chlopik,[a,e] M. Czarnynoga,[b,e] D. Dabrowski,[b,e] A. Dudzinski,[a] A. Dziedzic,[a] M. Grodzicka-Kobylka,[a] J. Grzyb,[a] K. Grodzicki,[a] E. Jaworska,[a] P. Kankiewicz,[c] G. Kasprowicz,[b] A. Kisiel,[b,e] P. Kolasinski,[b] S. Kowalski,[f] M. Krakowiak,[a] M. Kuich,[d] M. Kutyla,[b,e] J. Lukasik,[g] B. Maksiak,[a] J. Marzec,[b] T. Matulewicz,[d] S. Mianowski,[a] M. Milewicz-Zalewska,[b,e] M. J. Peryt,[b,e] M. Piatek,[e] A. Pollo,[a] K. Pozniak,[b] F. Protoklitow,[b,e] D. Pszczel,[a] S. Pulawski,[f] R. Romaniuk,[b] K. Roslon,[b,e] M. Rybczynski,[c] J. Rzadkiewicz,[a] S. Satybaldyeva,[e] D. Shchegolev,[e] I. Shmyrev,[e] M. Sitek,[a] M. Sowinski,[b] G. Stefanek,[c] J. Stepaniak,[a] E. Strugalska-Gola,[a] L. Swiderski,[a] A. Syntfeld-Kazuch,[a] T. Szczesniak,[a] M. Szuta,[a] A. Vodopyanov,[e] D. Wielanek,[b] Z. Wlodarczyk,[c] K. Wojcik[f] and W. Zabolotny[b]

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E-mail: Marcin.Bielewicz@ncbj.gov.pl

Abstract: This report presents a concept of constructing a detector dedicated for detection of muons observed during measurements carried out at the MPD (Multi-Purpose Detector) detector that is currently under construction at the NICA facility, Russia, Dubna. It has been proposed to design and build an additional detector that will complement the current MPD set and increase its measurement capabilities. The main goal of this project is to provide information from cosmic muons that pass

*Corresponding author.

https://doi.org/10.1088/1748-0221/16/11/P11035

2021 JINST 16 P11035

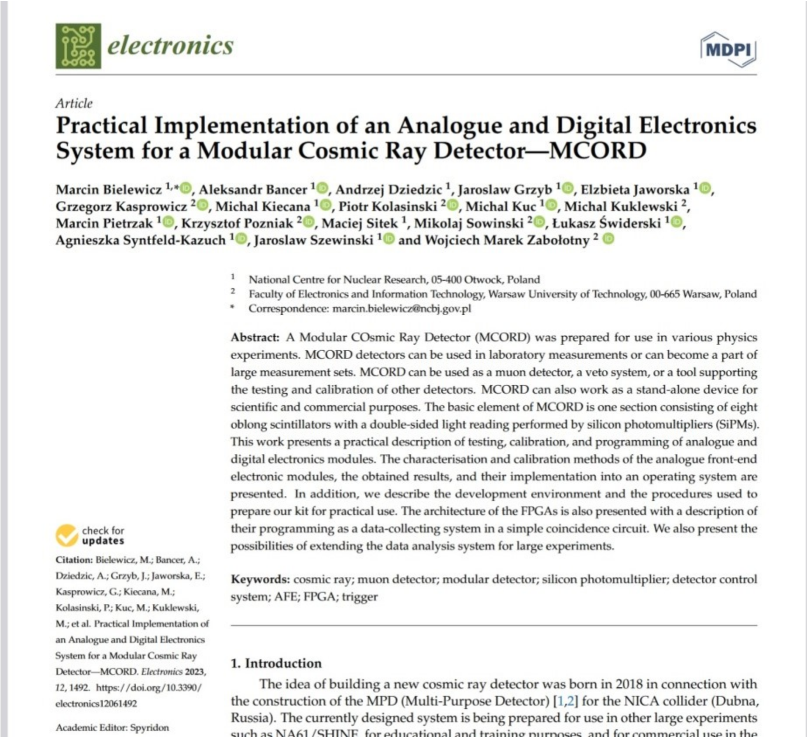
7. Electronic analysis publication

Practical Implementation of an Analogue and Digital Electronics System for a Modular Cosmic Ray Detector—MCORD

Published 22 March 2023

Electronics **2023**, *12*(6), 1492;

https://doi.org/10.3390/electronics12061492



electronics MDPI

Article

Practical Implementation of an Analogue and Digital Electronics System for a Modular Cosmic Ray Detector—MCORD

Marcin Bielewicz [1,*], Aleksandr Bancer [1], Andrzej Dziedzic [1], Jaroslaw Grzyb [1], Elzbieta Jaworska [1], Grzegorz Kasprowicz [2], Michal Kiecana [1], Piotr Kolasinski [2], Michal Kuc [1], Michal Kuklewski [2], Marcin Pietrzak [1], Krzysztof Pozniak [2], Maciej Sitek [1], Mikolaj Sowinski [2], Łukasz Świderski [1], Agnieszka Syntfeld-Kazuch [1], Jaroslaw Szewinski [1] and Wojciech Marek Zabołotny [2]

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2 Faculty of Electronics and Information Technology, Warsaw University of Technology, 00-665 Warsaw, Poland
* Correspondence: marcin.bielewicz@ncbj.gov.pl

Abstract: A Modular COsmic Ray Detector (MCORD) was prepared for use in various physics experiments. MCORD detectors can be used in laboratory measurements or can become a part of large measurement sets. MCORD can be used as a muon detector, a veto system, or a tool supporting the testing and calibration of other detectors. MCORD can also work as a stand-alone device for scientific and commercial purposes. The basic element of MCORD is one section consisting of eight oblong scintillators with a double-sided light reading performed by silicon photomultipliers (SiPMs). This work presents a practical description of testing, calibration, and programming of analogue and digital electronics modules. The characterisation and calibration methods of the analogue front-end electronic modules, the obtained results, and their implementation into an operating system are presented. In addition, we describe the development environment and the procedures used to prepare our kit for practical use. The architecture of the FPGAs is also presented with a description of their programming as a data-collecting system in a simple coincidence circuit. We also present the possibilities of extending the data analysis system for large experiments.

Keywords: cosmic ray; muon detector; modular detector; silicon photomultiplier; detector control system; AFE; FPGA; trigger

check for updates

Citation: Bielewicz, M.; Bancer, A.; Dziedzic, A.; Grzyb, J.; Jaworska, E.; Kasprowicz, G.; Kiecana, M.; Kolasinski, P.; Kuc, M.; Kuklewski, M.; et al. Practical Implementation of an Analogue and Digital Electronics System for a Modular Cosmic Ray Detector—MCORD. *Electronics* **2023**, 12, 1492. https://doi.org/10.3390/electronics12061492

Academic Editor: Spyridon

1. Introduction

The idea of building a new cosmic ray detector was born in 2018 in connection with the construction of the MPD (Multi-Purpose Detector) [1,2] for the NICA collider (Dubna, Russia). The currently designed system is being prepared for use in other large experiments

Thank You for Attention!