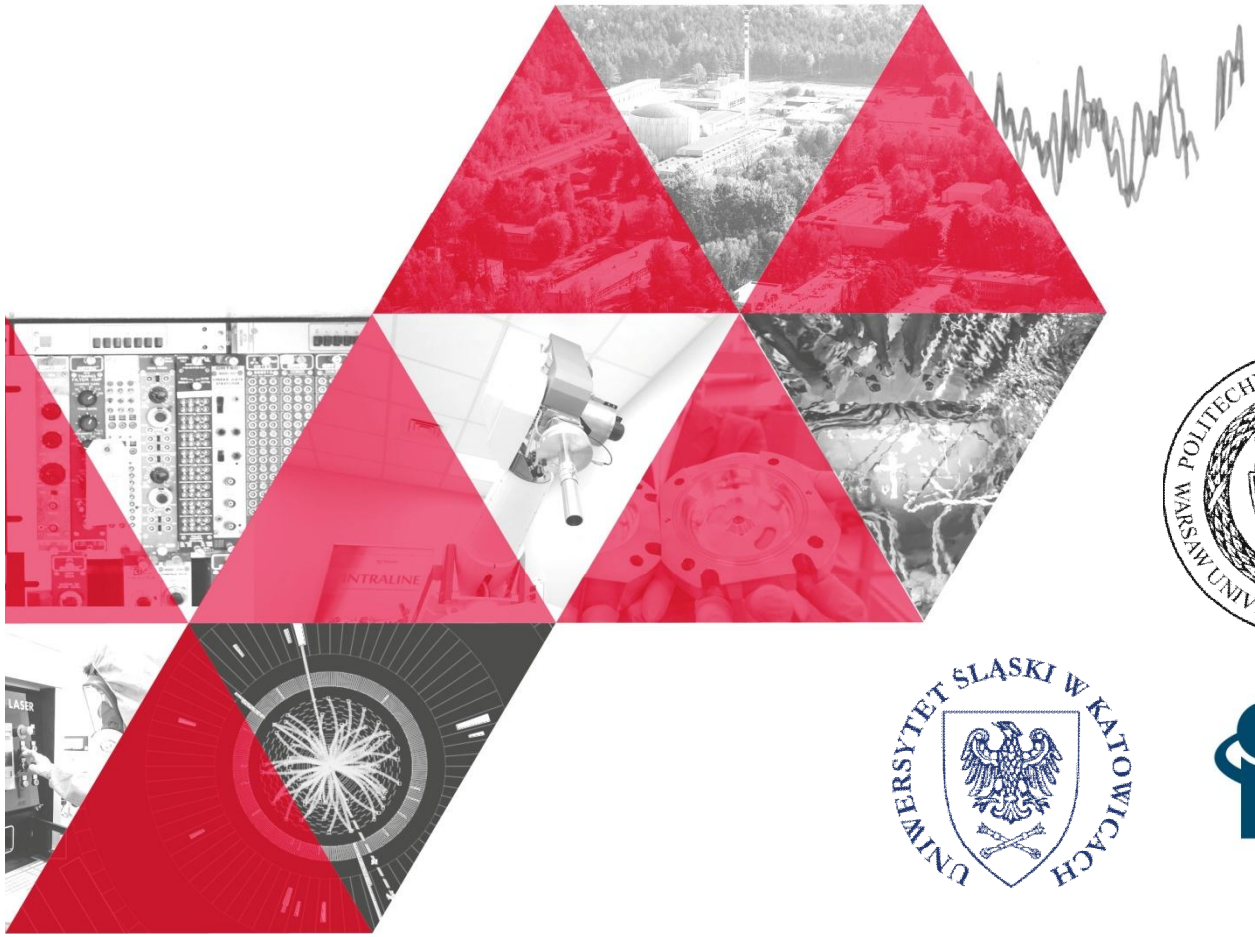
The cosmic ray detector (MCORD) for new NICA-MPD collider

by Polish consortium NICA-PL

Workshop NTNPD, 25-27. Oct. 2021



NARODOWE CENTRUM BADAŃ JĄDROWYCH ŚWIERK

POLITECHNIKA WARSZAWSKA
WARSAW UNIVERSITY OF TECHNOLOGY

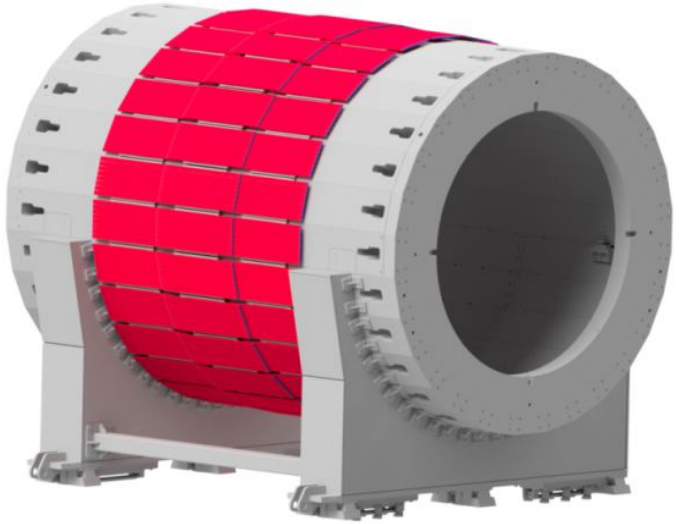
JINR

UNIWERSYTET ŚLĄSKI W KATOWICACH

Uniwersytet Jana Kochanowskiego w Kielcach

Outline

1. Introduction
2. Mechanical Construction and Electronic
3. MCORD present status
4. Laboratory tests
5. Summary

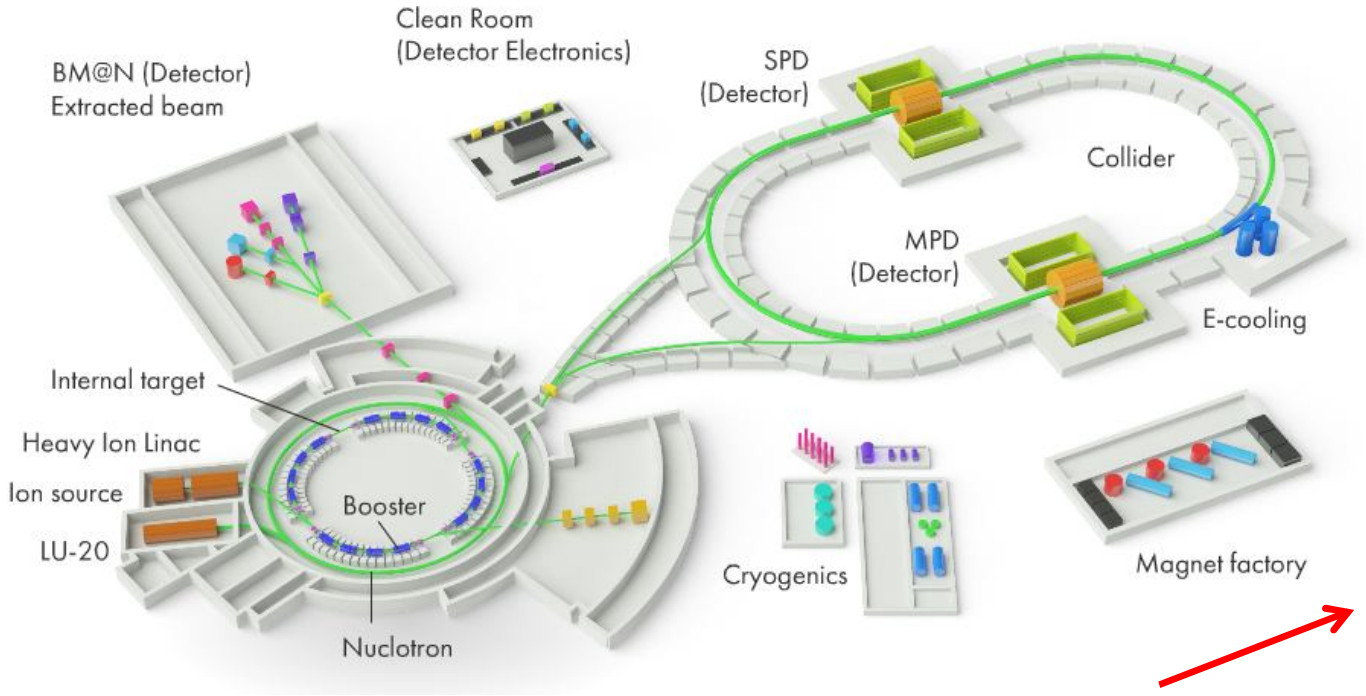


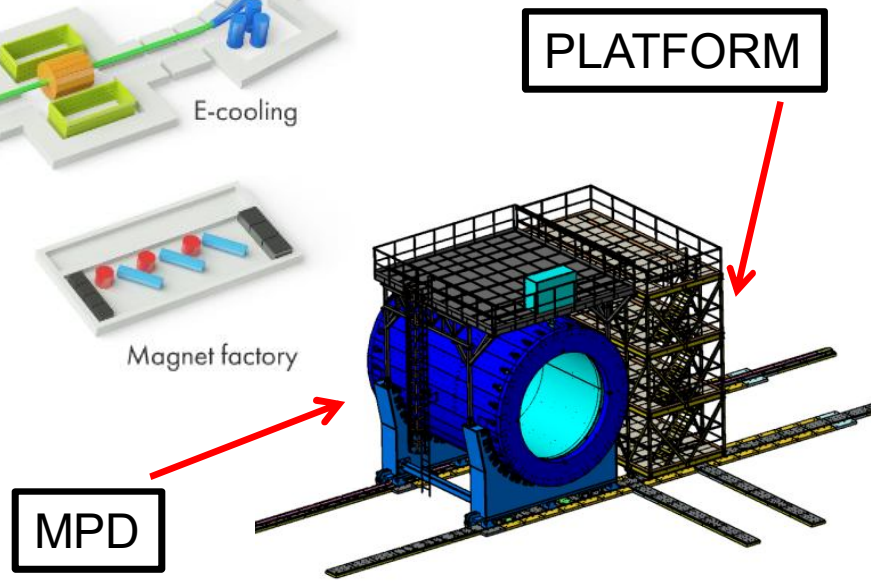
1. Introduction - NICA complex

NICA - **N**uclotron **I**on **C**ollider f**A**cility

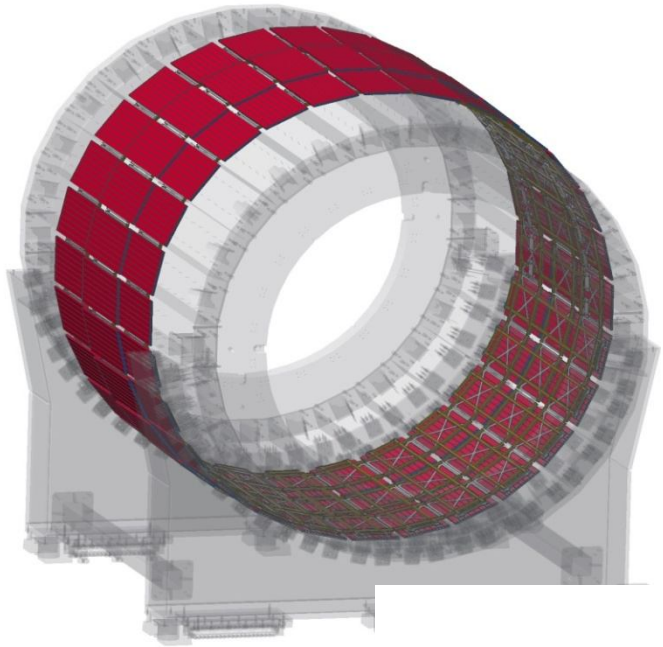
MPD - **M**ulti-**P**urpose **D**etector

MCORD - **M**PD **CO**smic **R**ay **D**etector





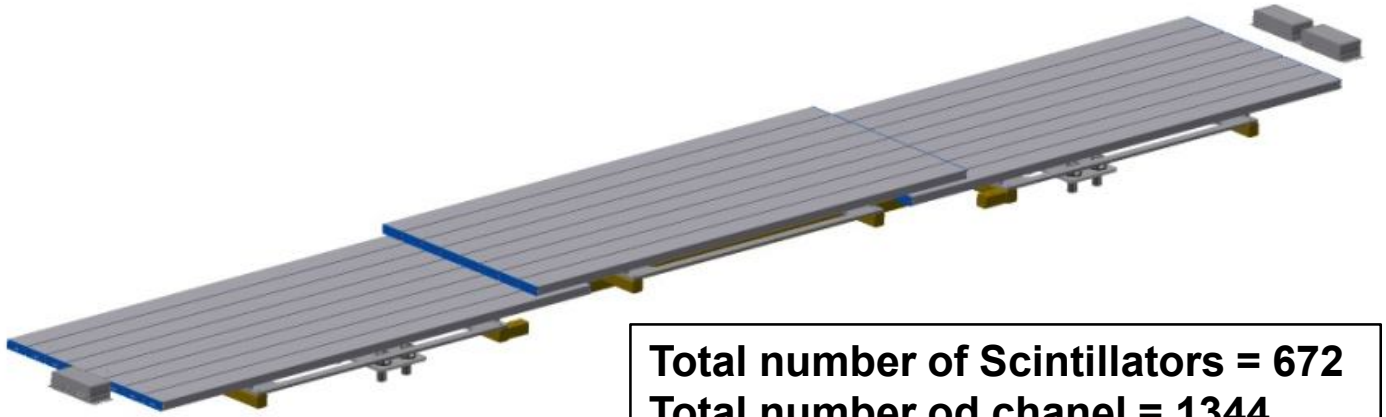
1. Introduction - MCORD



MCORD modules on MPD surface
One circuference

Number of modules: 28
1 module = 3 sections
1 section = 8 scintillators
1 section = 16 chanels

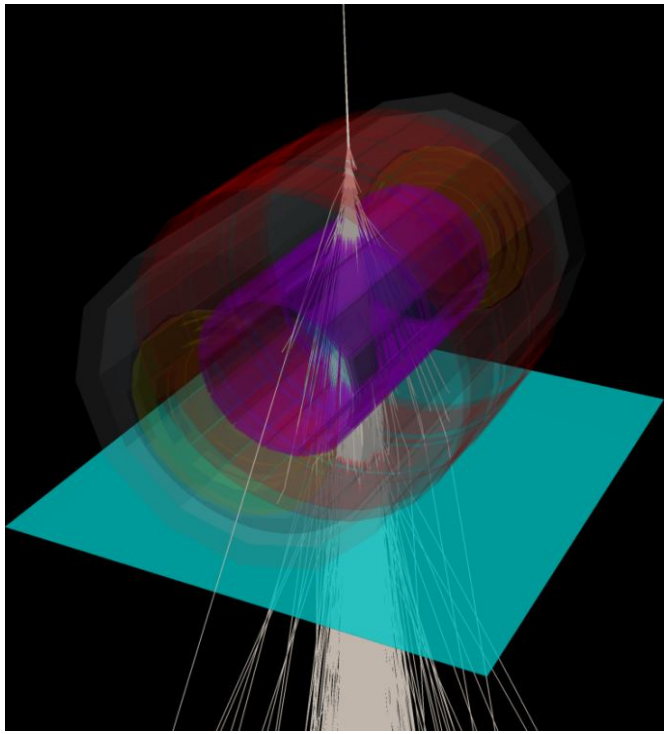
Module size:
4784 x 735 x 140 mm

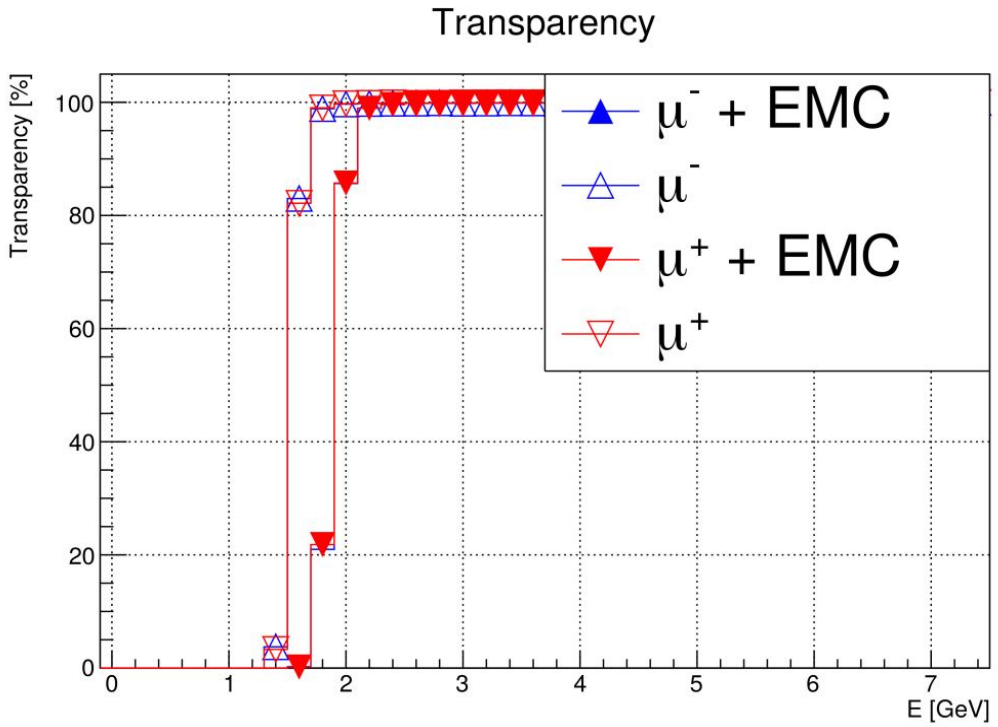


Total number of Scintillators = 672
Total number od chanel = 1344

1. Intyroduction - Simulations (EAS)

Propagation of cosmic muons through the MPD

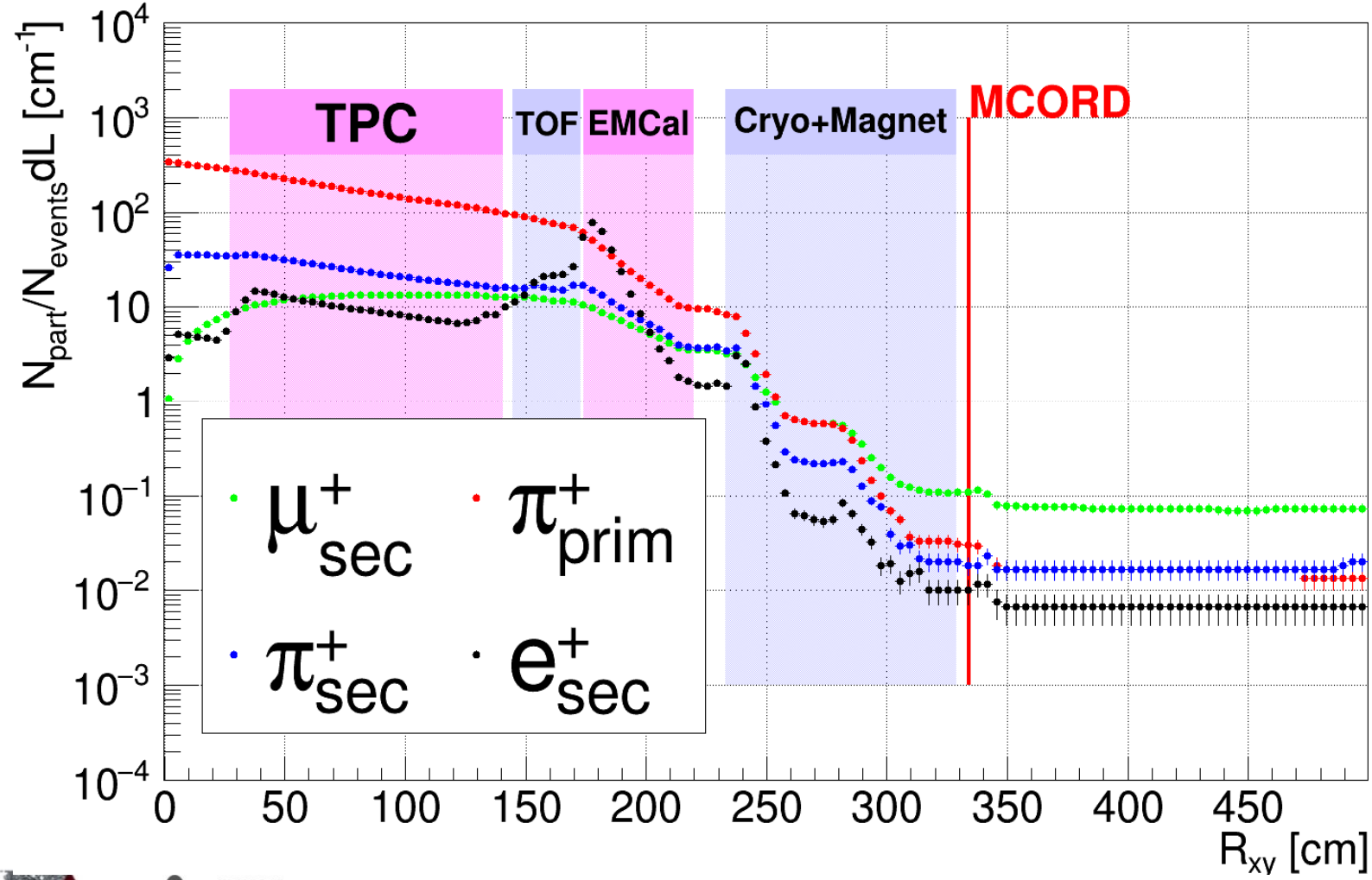




Energy threshold for muons able to pass through the MPD:
with ECal assembled: **2.0 GeV/c²**
without ECal assembled: **1.6 GeV/c²**

1. Introduction - Simulations (Collisions)

Muons and pions distribution from ion-ion collisions inside the MPD.



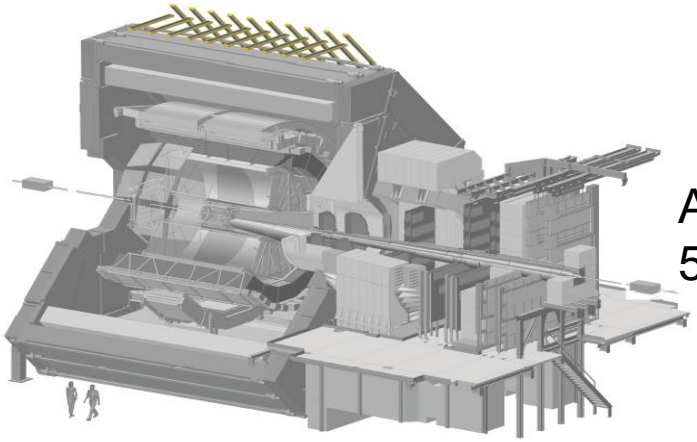
1. Introduction

MCORD applications for MPD

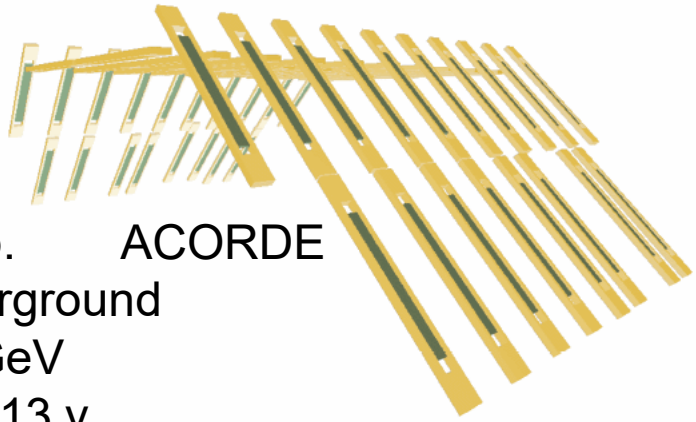
1. Trigger for cosmic muons for:
   - laboratory tests of MPD subsystems
     (2 separate MCORD sections – on site)
   - MPD off-beam calibration in service position
     (6 MCORD modules – about one year)
2. Muon identifier (E > 1 GeV) for:
   - pions and kaons decays
   - ***J/Ψ* particle decay**
   - rare mesons decays (η, ρ)
3. Astrophysics (muon showers and bundles)
   - **identification of extremely high energy particle sources**
4. Modular construction – easy upgrade and/or alternative use

1. Introduction – other experiments

Examples from other experiments



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



ACORDE

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

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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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Astroparticle Physics 28 (2007) 273–286

Astroparticle Physics

www.elsevier.com/locate/astropart

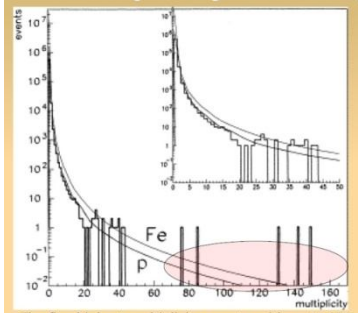
Study of multi-muon bundles in cosmic ray showers detected with the DELPHI detector at LEP

DELPHI Collaboration
J. Abdallah [z], P. Abreu [w], W. Adam [bc], P. Adzic [i], 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 [ae], 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],

1. Introduction

High Muon Multiplicity Events in different experiments

Aleph at Lep : Five high muon multiplicity events (~ 20 days of data)



1) 4.75 μ/m² Zenith(°)=40.8 Primary energy = 3 10^{16} eV

2) 5.3 μ/m² Zenith(°)=37.7 Primary energy = 3 10^{16} eV

3) 8.9 μ/m² Zenith(°)=40 Primary energy = 6 10^{16} eV

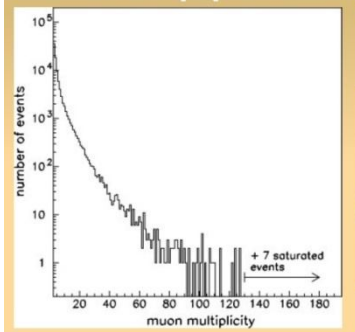
4) 8.2 μ/m² Zenith(°)=48.6 Primary energy = 7 10^{16} eV

5) 18.6 μ/m² Zenith(°)=27 Primary energy = 10^{17} eV

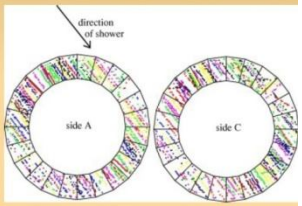
The five highest multiplicity events, with up to 150 muons within an area of 8 m², occur with a frequency which is almost an order of magnitude above the simulation.

Astroparticle Physics 19 (2003) 513–523

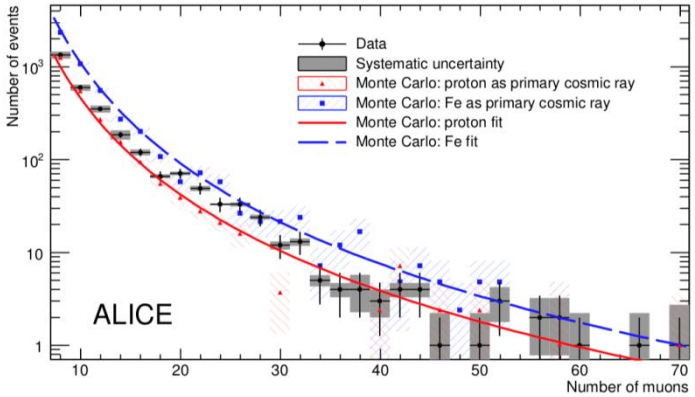
Muon Multiplicity Distribution in Delphi at Lep (~ 18.5 days of live time)

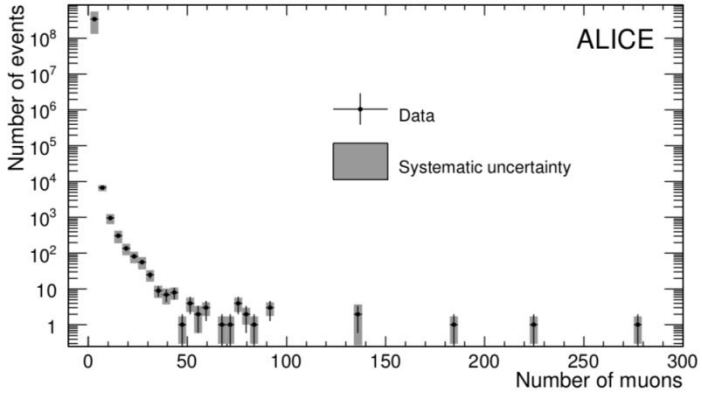


Astroparticle Physics 28 (2007) 273–286



7 high multiplicity events that saturate the detector (HAB)





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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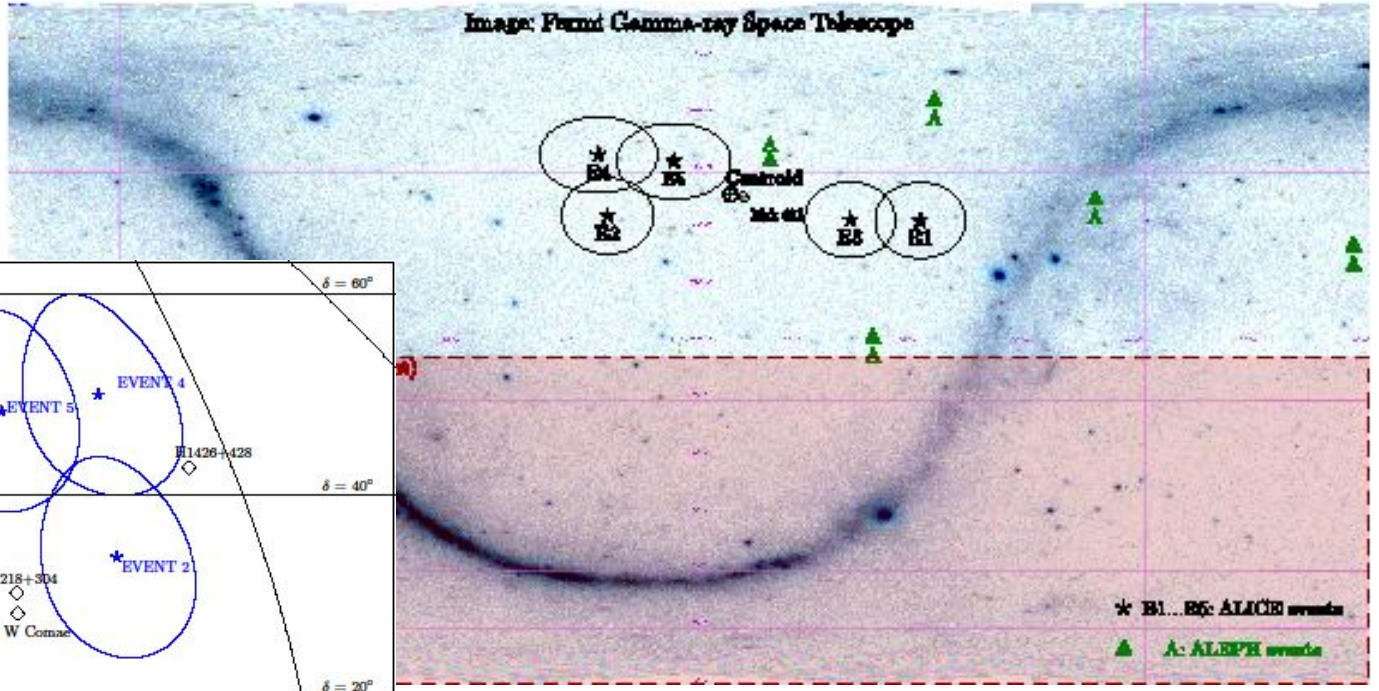
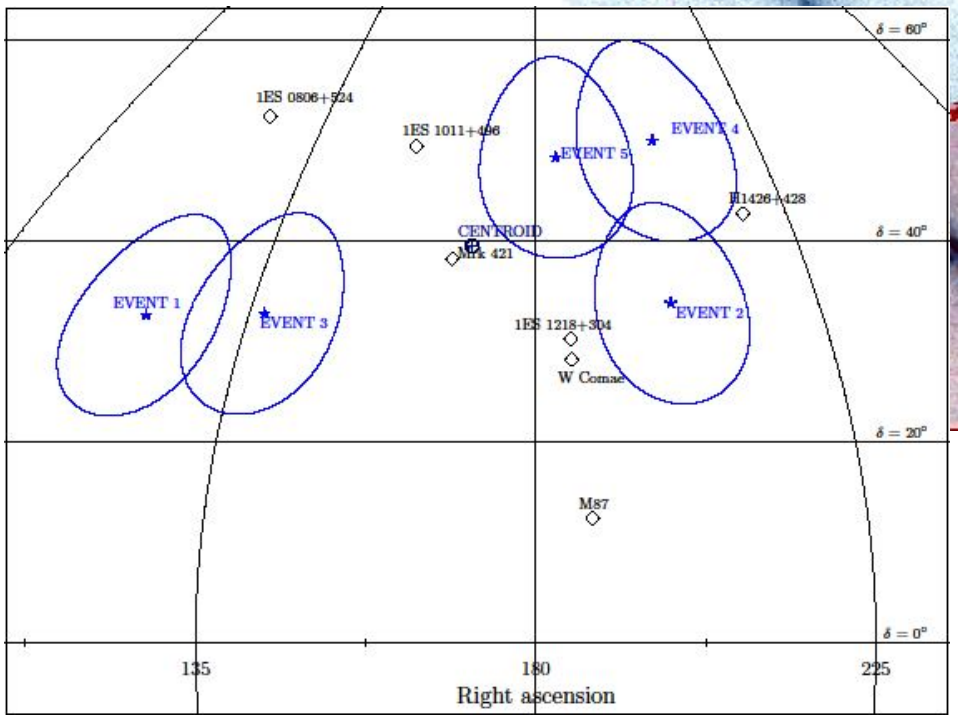
1. Introduction – Astrophysics

The position identification of Extremely high energy particle source

- P. Kankiewicz, M. Rybczyński, Z. Włodarczyk, and G. Wilk. Muon Bundles as a Sign of Strangelets from the Universe. APJ, 839(1):31, April 2017.





ALICE (multi events data) sphere position recognition

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

1. Introduction – Astrophysics

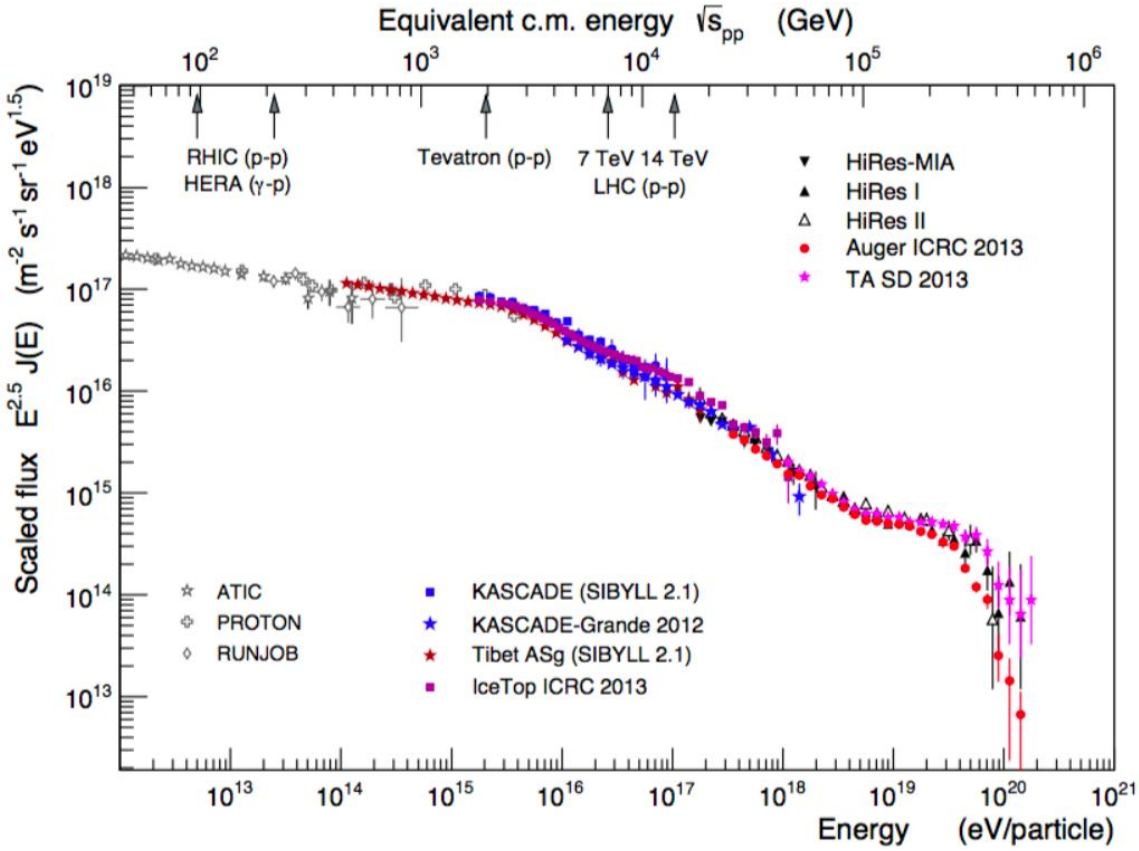
GZK-cutoff problem

- **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)

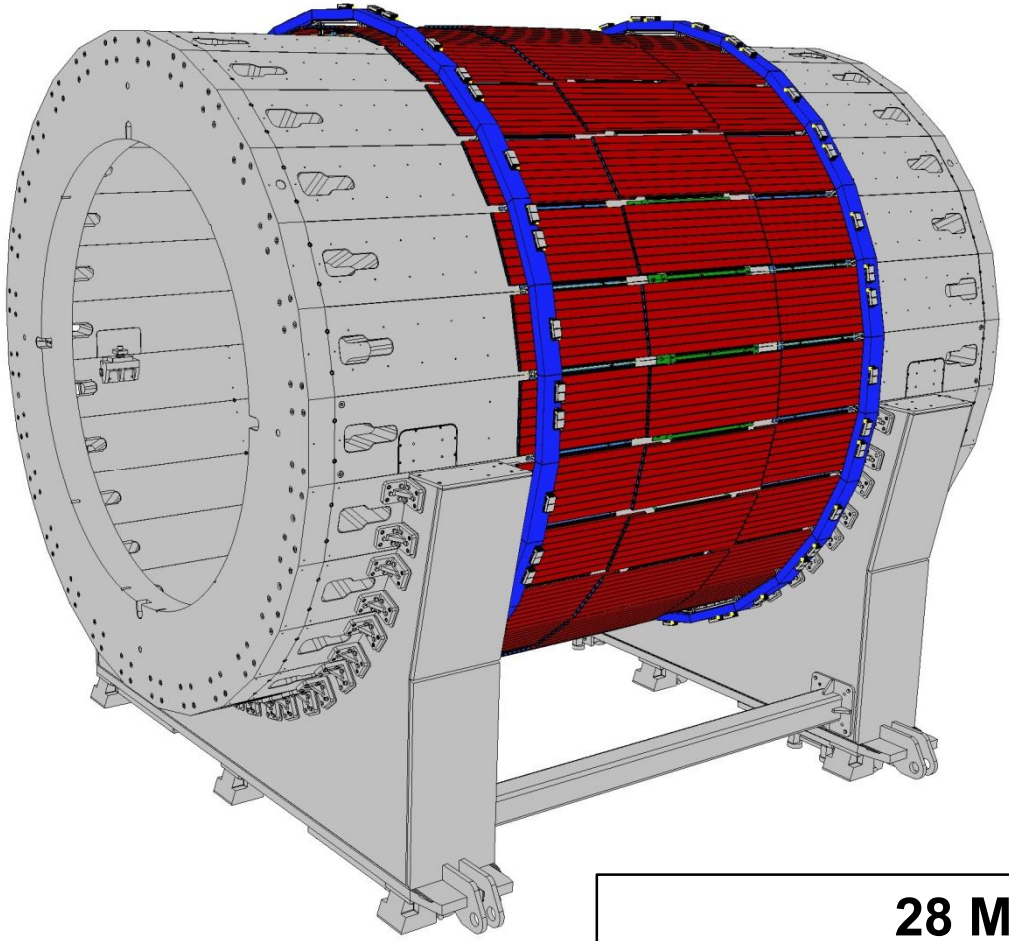
Bibliography:

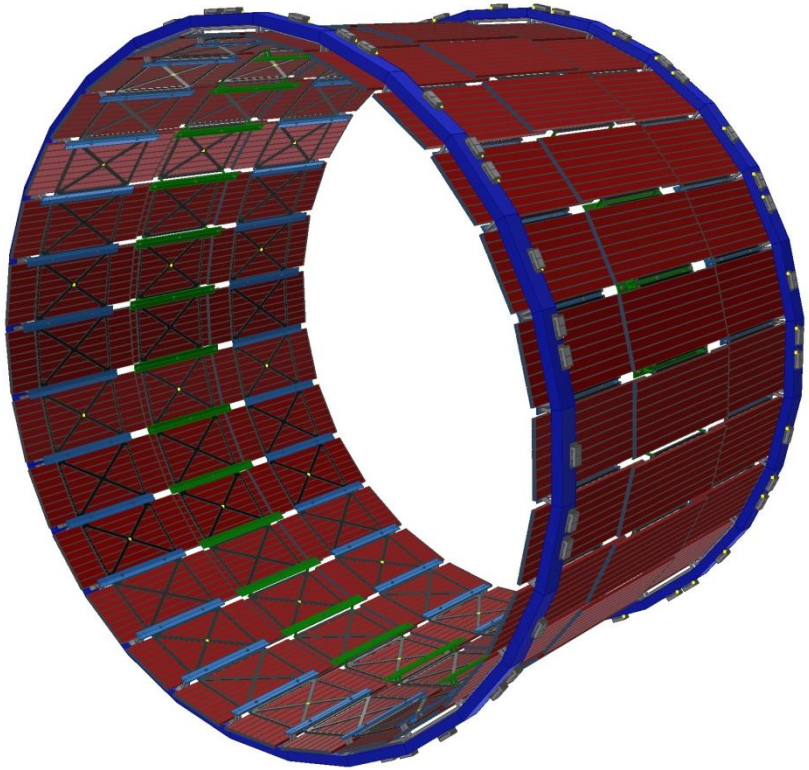
1. Pavluchenko, V. P.; Beisembaev, R. U., Muons of Extra High Energy Horizontal EAS in Geomagnetic Field and Nucleonic Astronomy, 1995 ICRC....1..646P
2. Yashin I. et al., Investigation of Muon Bundles in Horizontal Cosmic, 2005 (28) ICRC p.1147-1150
3. Neronov A. et al., Cosmic ray composition measurements, 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

2. Mechanical construction





28 MCORD modules – red
Cable channels with HUBs – blue
Mounting (support) legs – light blue and green

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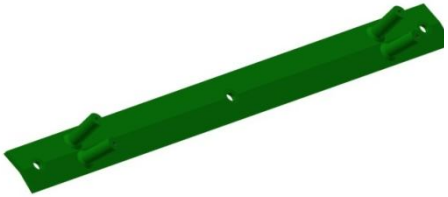
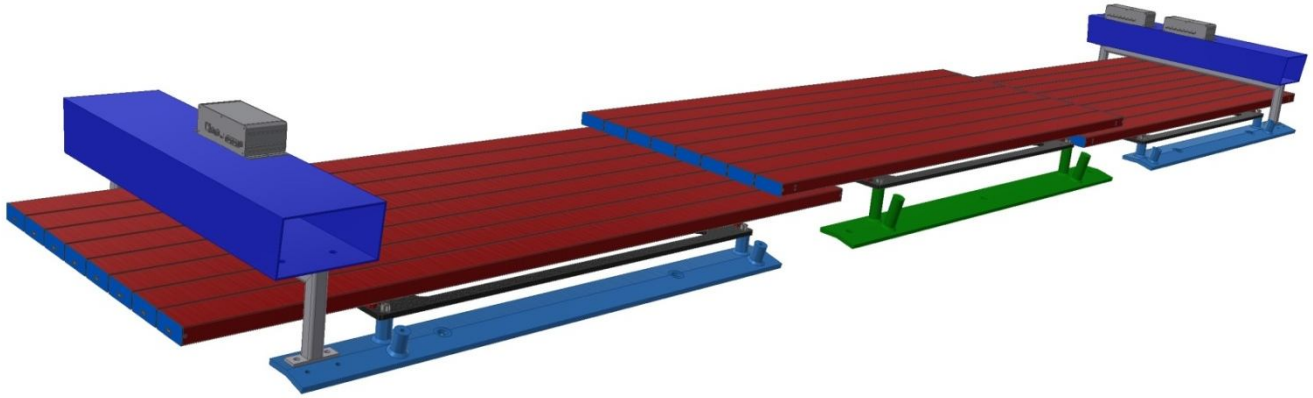
2. Mechanical construction

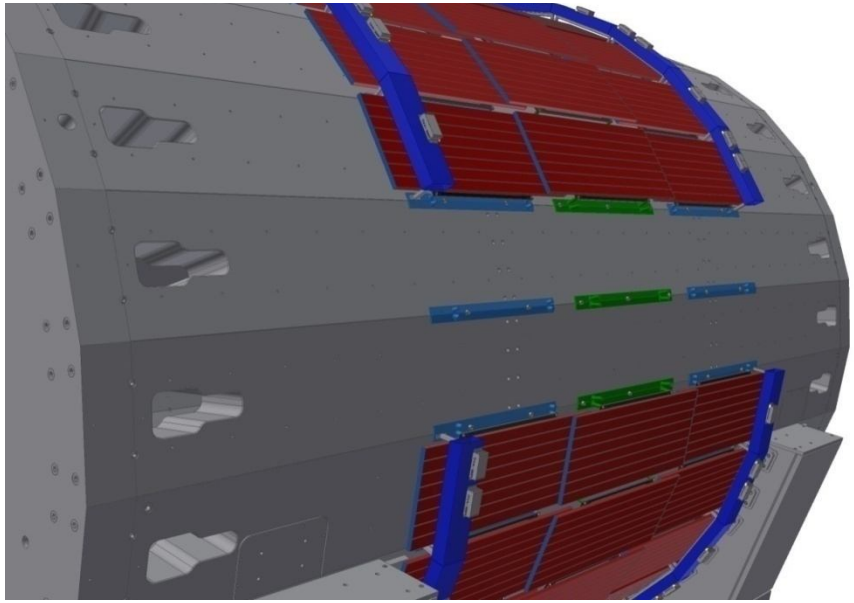
The support legs for MCORD on MPD surface



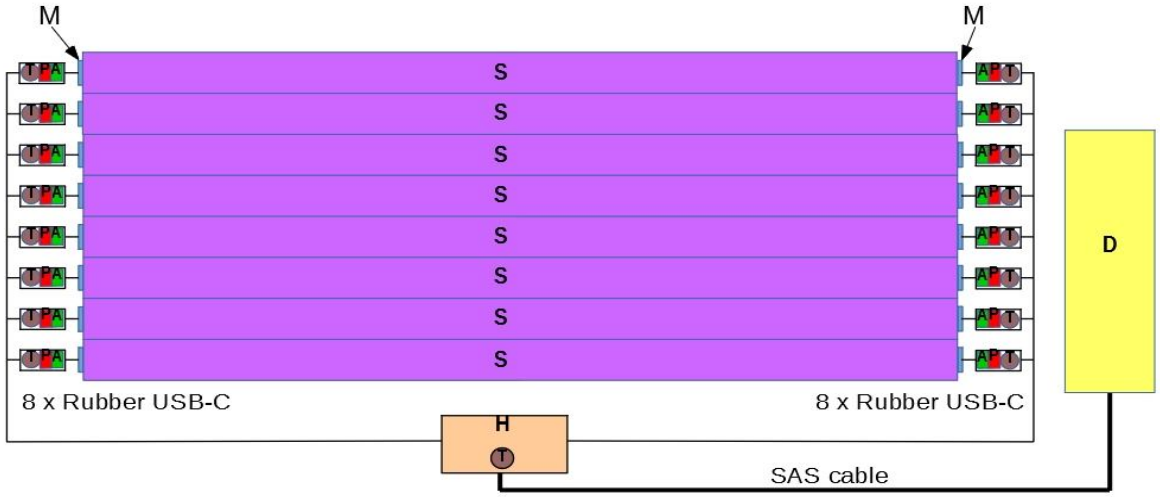
6 legs of two types: central and external



Central (green) and External (light blue) support legs



2. Electronic scheme



Position resolution
In X axis – 5-7 cm
In Y axis – 7 cm

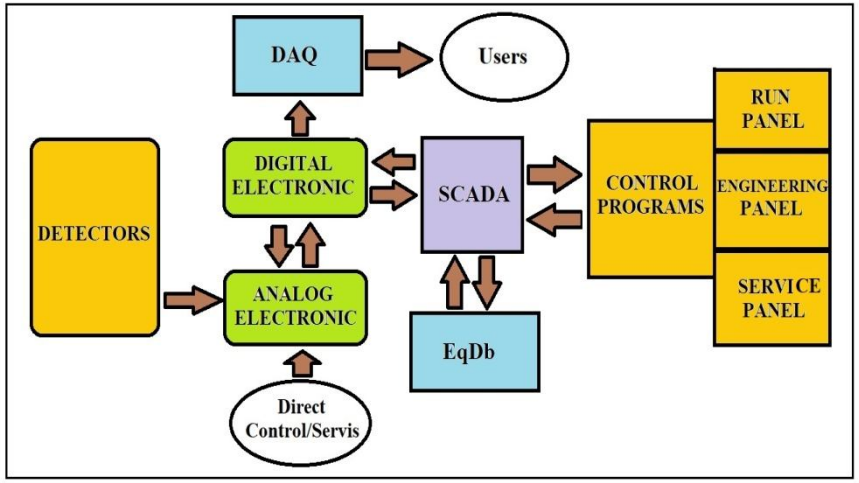
Time Resolution –
< 1ns

Legend: **S** (violet) – plastic scintillator, **M** (blue) – SiPM sensor, **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.

Analog front-end (AFE): custom design (WUT)

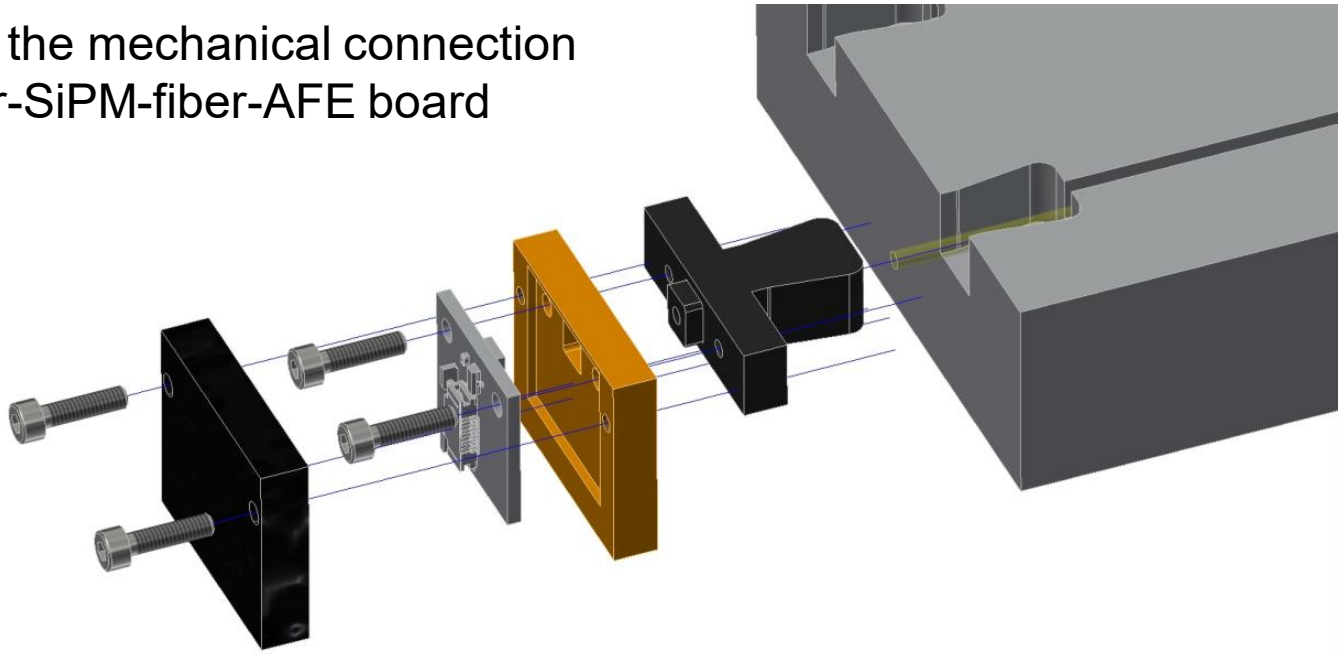
Digital electronics (DSP): custom design (WUT)

Data acquisition (DAQ): MicroTCA



2. Detector

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

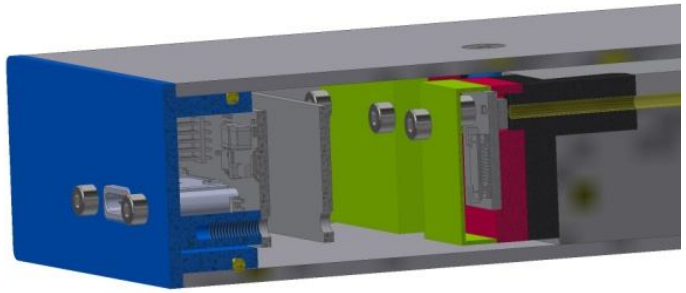


Plastic scintillator: polystyrene (Nuvia)
162 x 7.2 x 2.2 cm

WLS fiber: 1 or 2 mm dia. (Kuraray)

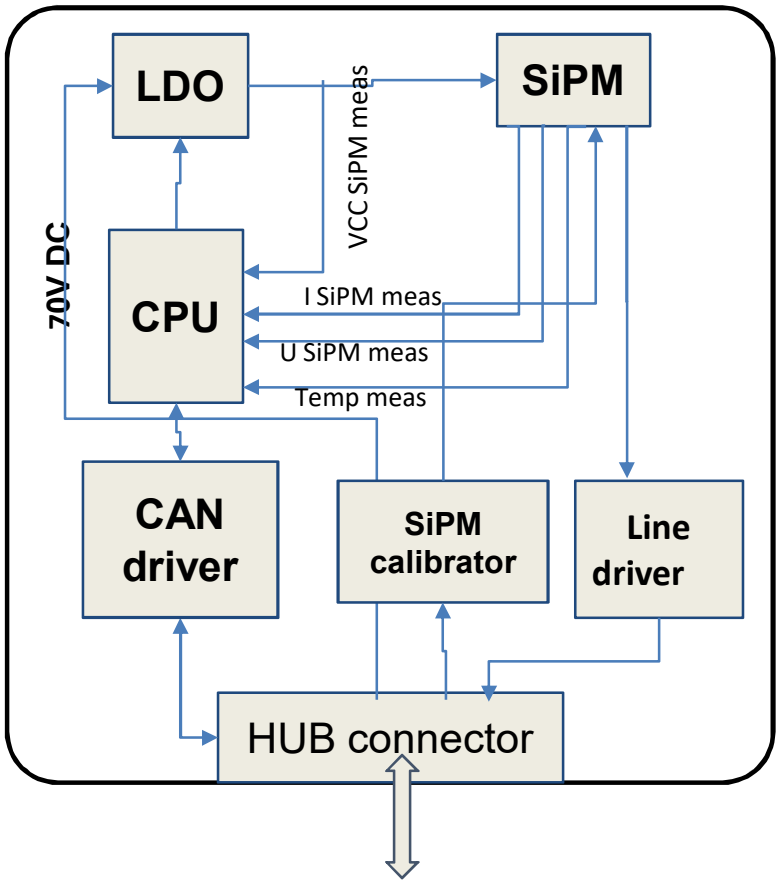
SiPM (MPPC): 3x3 mm^2 (Hamamatsu)

Housing: aluminum profile 174 x 8 x 3 cm



2. Electronic - Analog Front End module

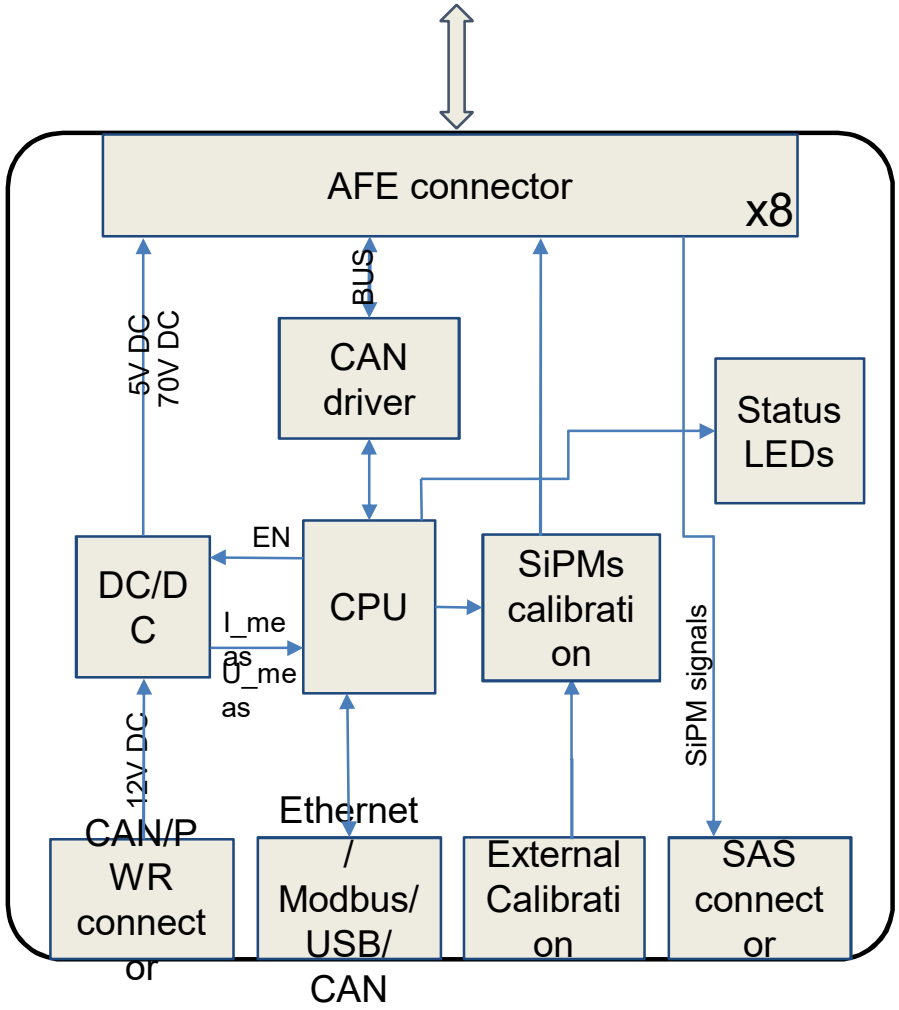
- Voltage controller for SiPMs
- Access to all settings and data from HUB via CAN-bus interface
- Protection for AFE



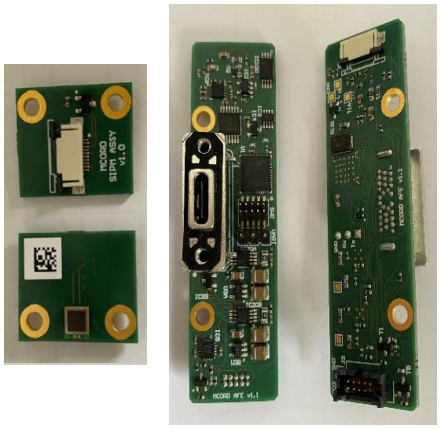
- **Main blocks**
  - Embedded **CPU** (STM32F072CBU6)
  - **Temperature sensor** (LM45)
  - **SiPM voltage controller** + LDO (Low Dropout Regulator)
  - SiPM calibrator
  - SiPM signal transmitter to HUB (differentia signal)
  - CAN network driver
- **Measurements (12 bit ADC)**
  - 2 x SiPM voltage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

2. Electronic - HUB module

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



2. MCORD Electronic



AFE - boards

HUB - front

HUB - board

FPGA mezzanine card (FMC)

AMC FMC carrier board

Standard MTCA crate (8U)

PoE Switch

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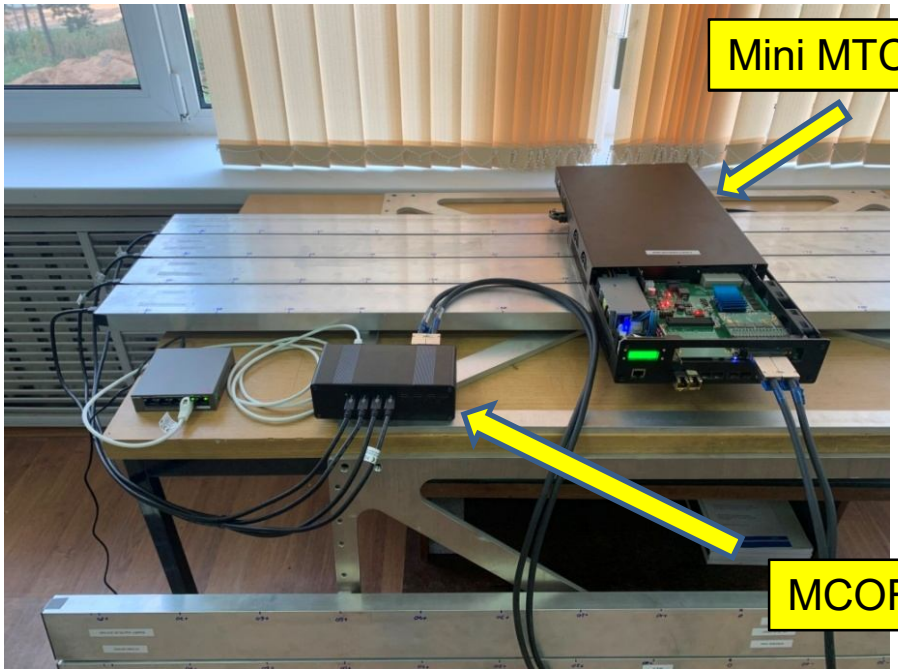
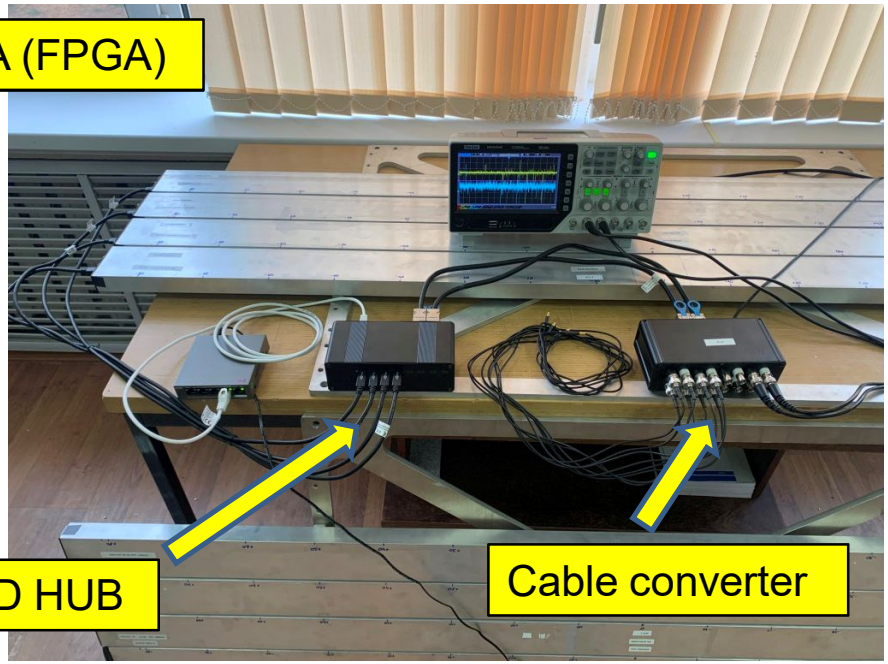
3. Present status - Demonstrator

The first shipment reached Dubna

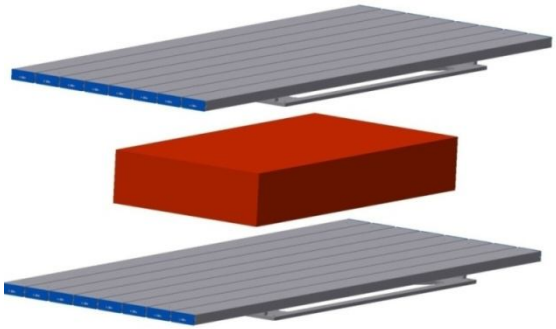




Standard mode: signal from scintillators (silver) to MCORD HUB and then to digital signal analysis system.

Laboratory mode: signal from the scintillators (silver) to the MCORD HUB and then to the cable converter. The analog signal can be sent from the converter to an oscilloscope or other digital analyzer (e.g. TOF).

3. Present status - Demonstrator

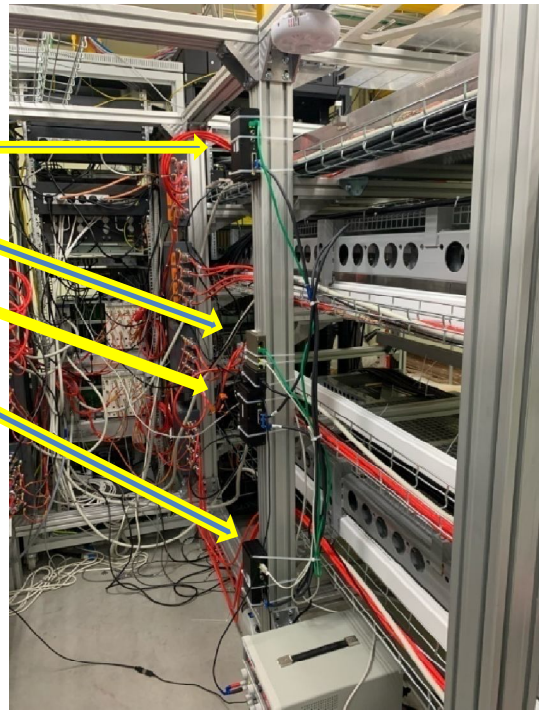


MCORD section

TOF module

MCORD section

MCORD electronic

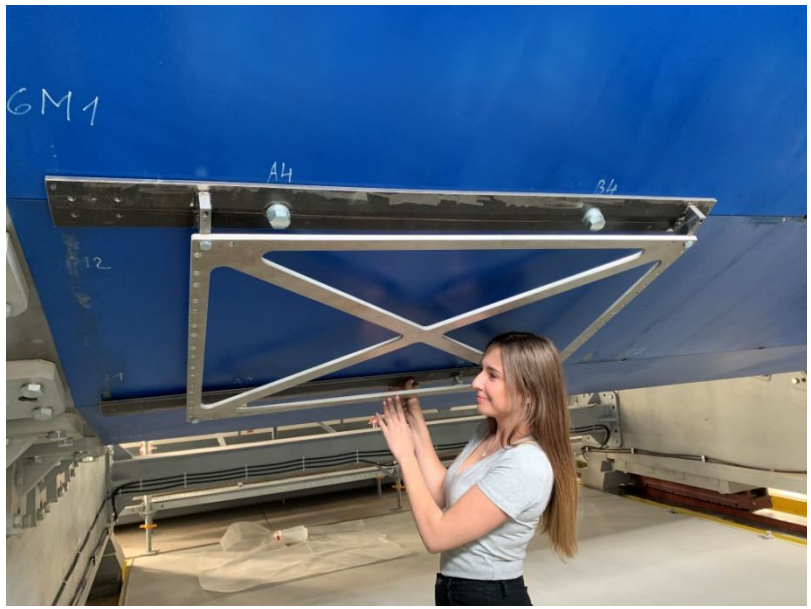


MCORD two section as a trigger for TOF test

3. Present status – MPD surface

Test installation of support legs and frames for the MCCORD section.

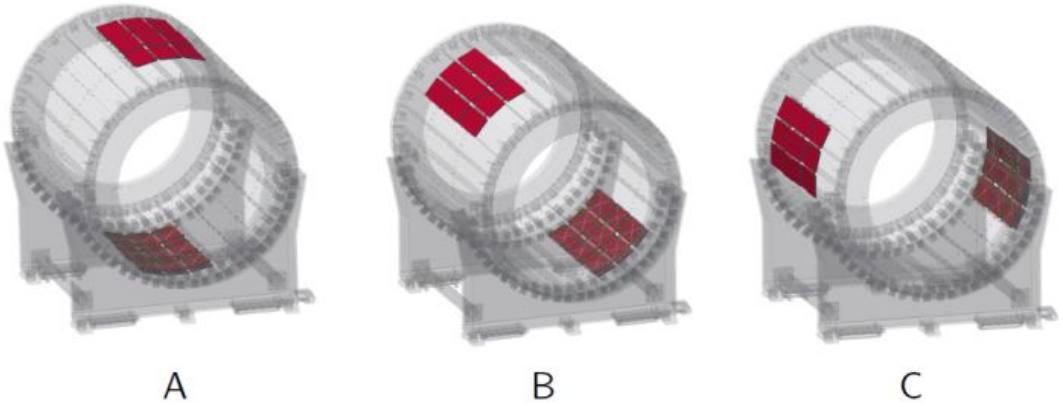
Test OK.
Support elements made correctly.
Now they will be painted

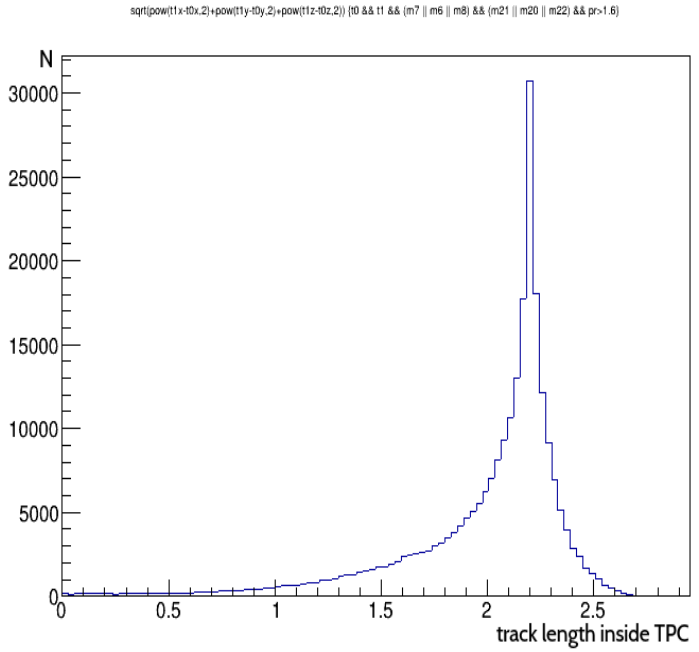


A total of 12 pieces were made:
- 8 external pieces
- 4 central pieces
Enough for the installation
of 6 MCORD sections.
Production of the next ones soon.

3. Present status – 6 modules

TPC calibration using MCORD triggers





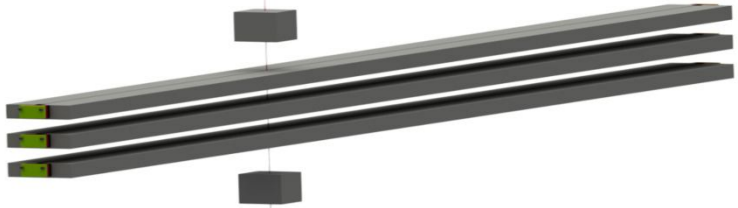
Calculated for muons with momentum
p > 1.6 GeV/c.

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**

4. Laboratory Test

detector S/N	AFE ID	CRT resolution [ns]
D3036	01	0.97
D3040	02	0.99
D3033	03	1.05
D3047	04	0.96
D3048R	05	1.49
D3046	06	1.06
D3042	07	1.17
D3034	08	1.04
D3035	09	1.01
D3044	10	1.11
D3041	11	1.03
D3043	12	1.00
D3038	13	1.19
D3037	14	1.03
D3045	15	0.92
D3039R	16	1.40

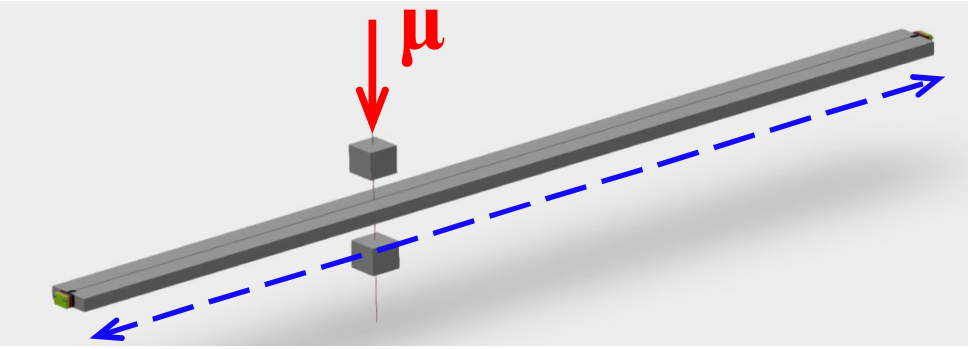
- 4 out of 16 detectors (ID = 1, 2, 4, 15) show CRT resolution below 1.0 ns,
- 7 out of 16 detectors (ID = 3, 6, 8, 9, 11, 12, 14) show CRT resolution between 1.0 ns and 1.1 ns,
- 3 out of 16 detectors (ID = 7, 10, 13) show CRT resolution between 1.1 ns and 1.2 ns,
- 2 out of 16 detectors (ID = 5, 16) show CRT resolution between 1.4 ns and 1.5 ns, despite repair by the manufacturer,
- 4 out of 16 detectors (ID=5, 10, 11, 14) show shifts in CRT distribution centroids in the range between 1 ns and 4 ns, the reason for this will be studied further on.



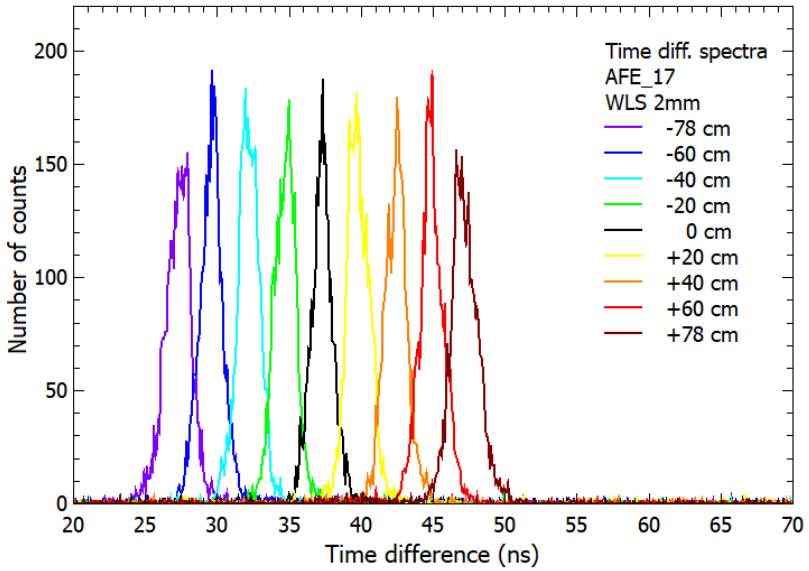
CRT (σ) = 1.0 ns ==> σ_x = 7.6 cm

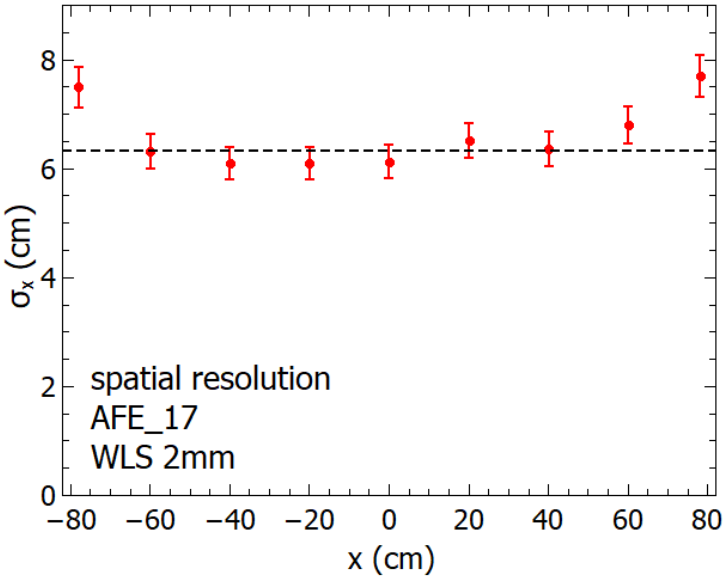
4. Laboratory tests

Muon response (CRT measurements):
improved timing resolution
for 2 mm WLS fiber



WLS fiber (**2 mm**)
CRT (σ) = 0.87 ns ===> σ_x = 6.3 cm

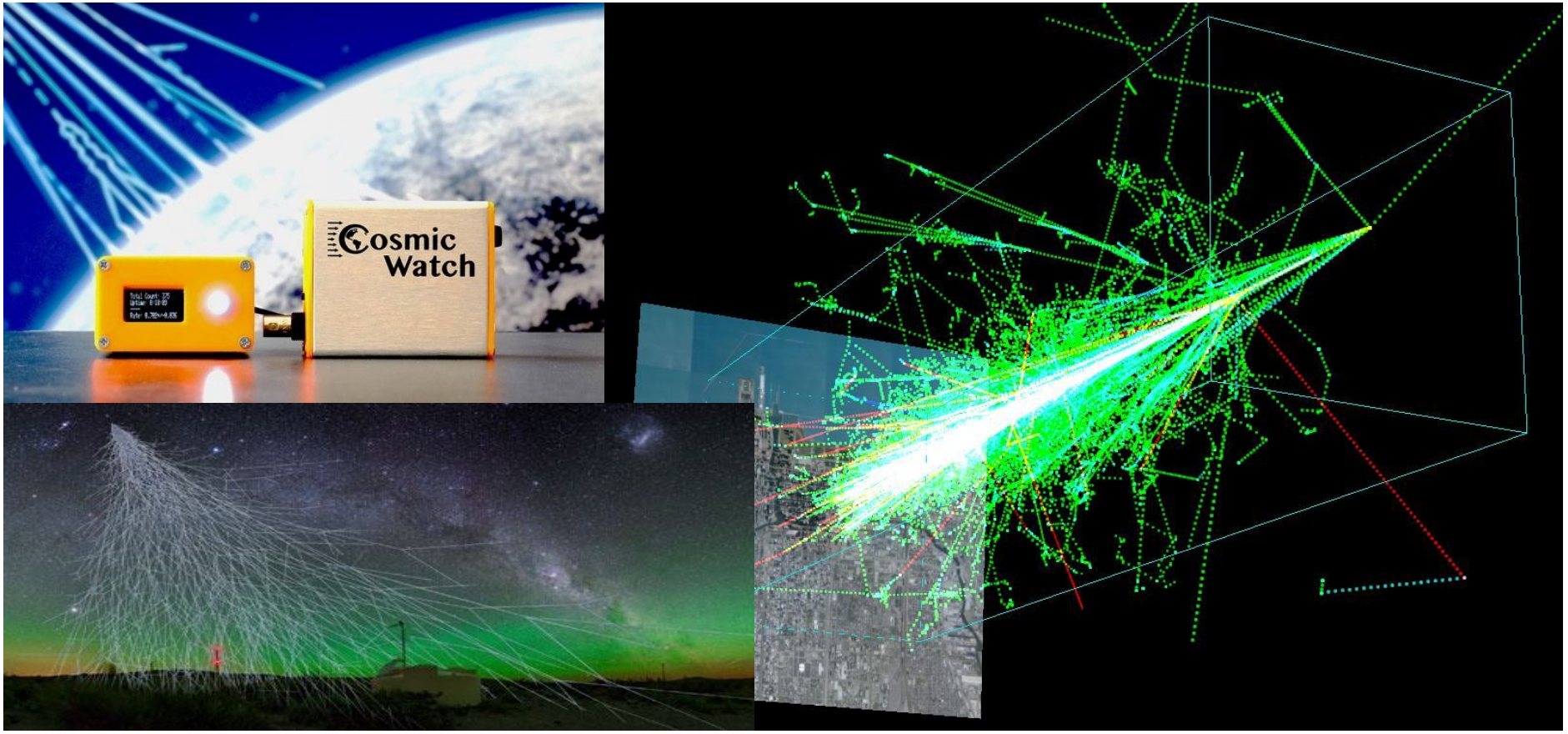




7. Summary

- MCORD is useful for calibration of TPC, TOF and ECAL detectors **during off-beam operation of the MPD** (during and after installation of other sub-detectors).
- MCORD demonstrator (STAGE 2: 2 sections = 16 scintillators) assembled and tested, 1 section delivered to JINR – **ready for TOF laboratory characterization**.
- The first **6 MCORD modules** (STAGE 3: 18 sections = 144 scint.) should be ready by Q4 2022 for installation on MPD surface.
- MCORD eligibility for identification of high energy muons from ion-ion collisions will be verified for **J/Ψ production**.
- MCORD can be used for **unique astrophysics observations** similar to past collider experiments.

Thank You for Attention!



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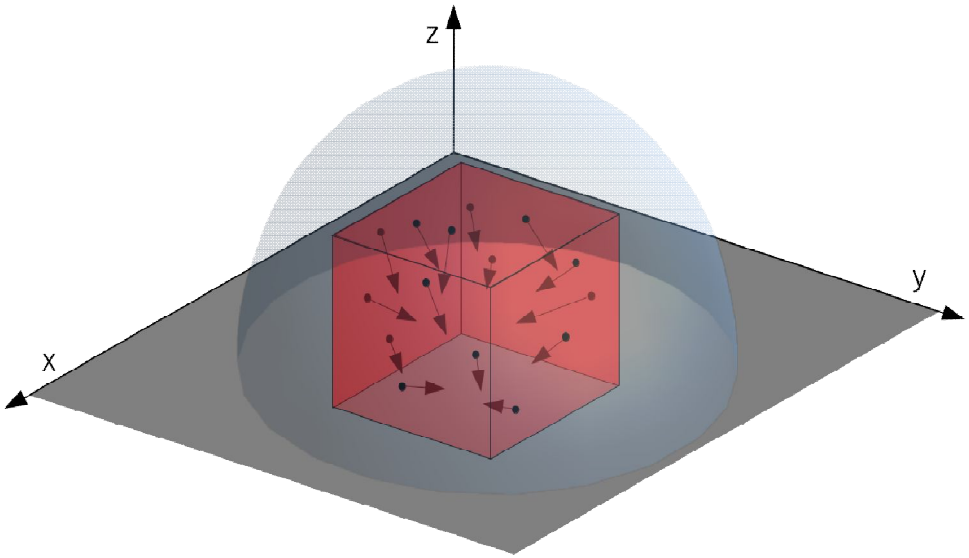
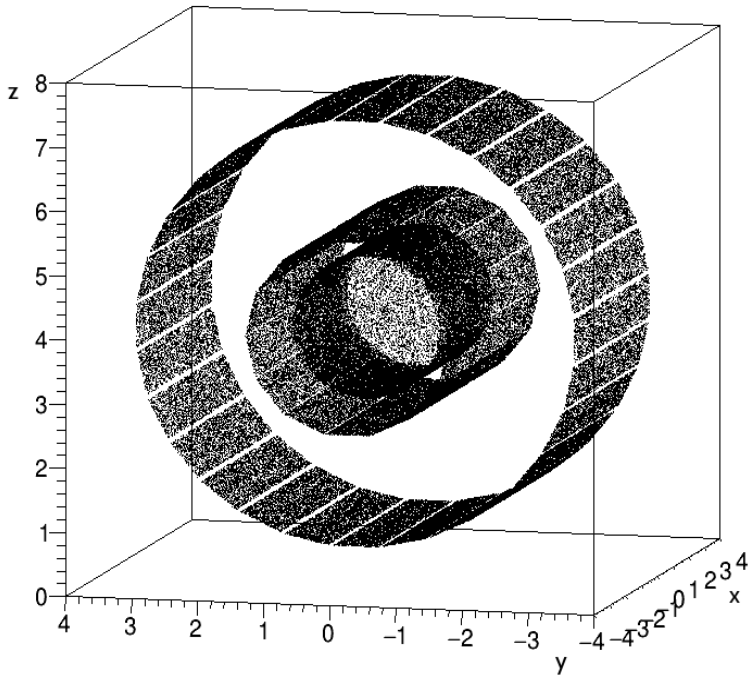
6. Simulations (EAS)

Cofluxim – cosmic ray generator

for MPD subsystems calibration study



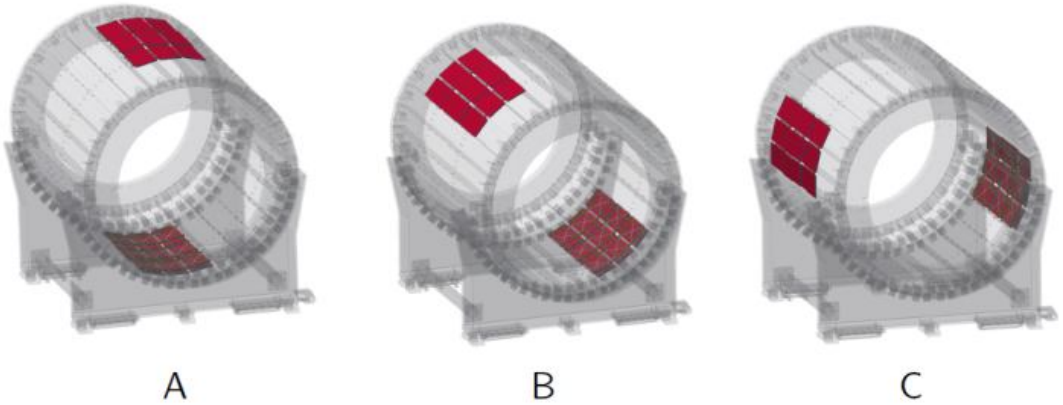
The concept of particle generation: drawing particles on the generation cube walls.

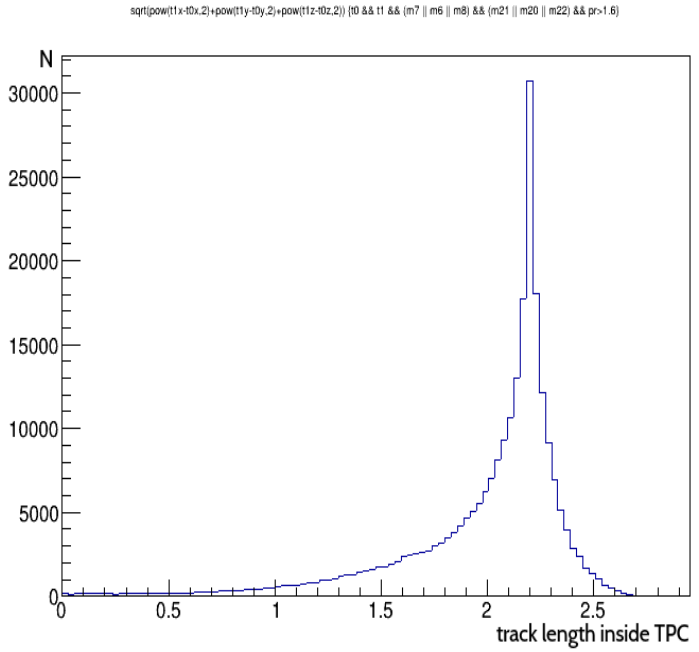


Plot of all hits on the surfaces of TPC, ToF and MCORD detectors.

6. Simulations (EAS)

TPC calibration using MCORD triggers



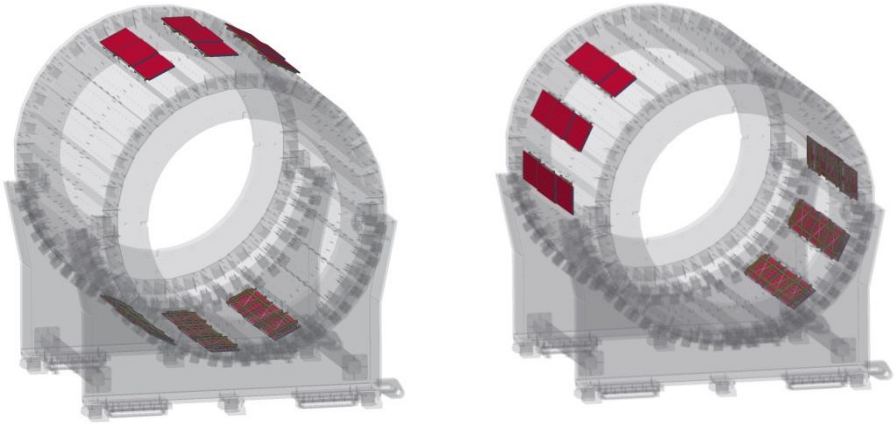


Calculated for muons with momentum
p > 1.6 GeV/c.

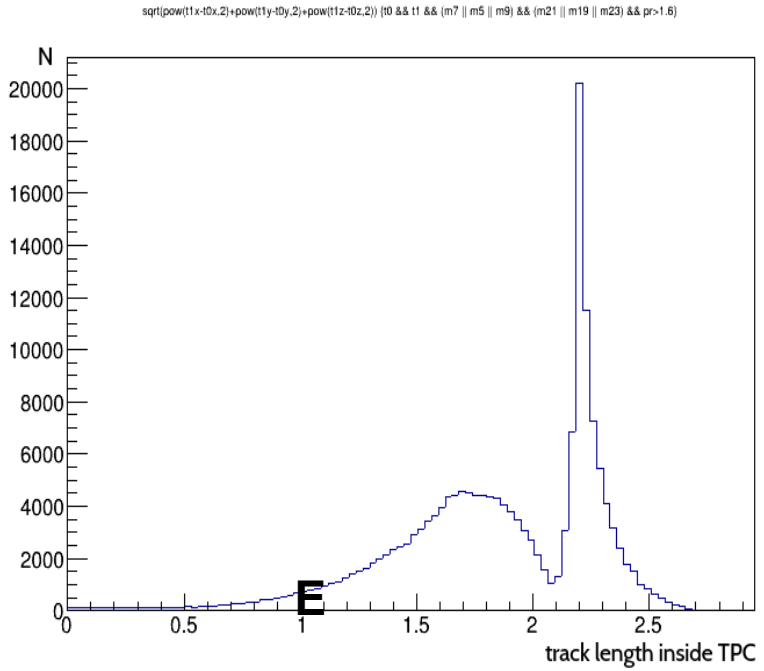
MCORD configuration	MCORD modules ID numbers	MCORD & TPC (tracks per hour)
A	(6 or 7 or 8) and (20 or 21 or 22)	**246 800**
B	(9 or 10 or 11) and (23 or 24 or 25)	**158 262**
C	(12 or 13 or 14) and (26 or 27 or 0)	**20 634**

6. 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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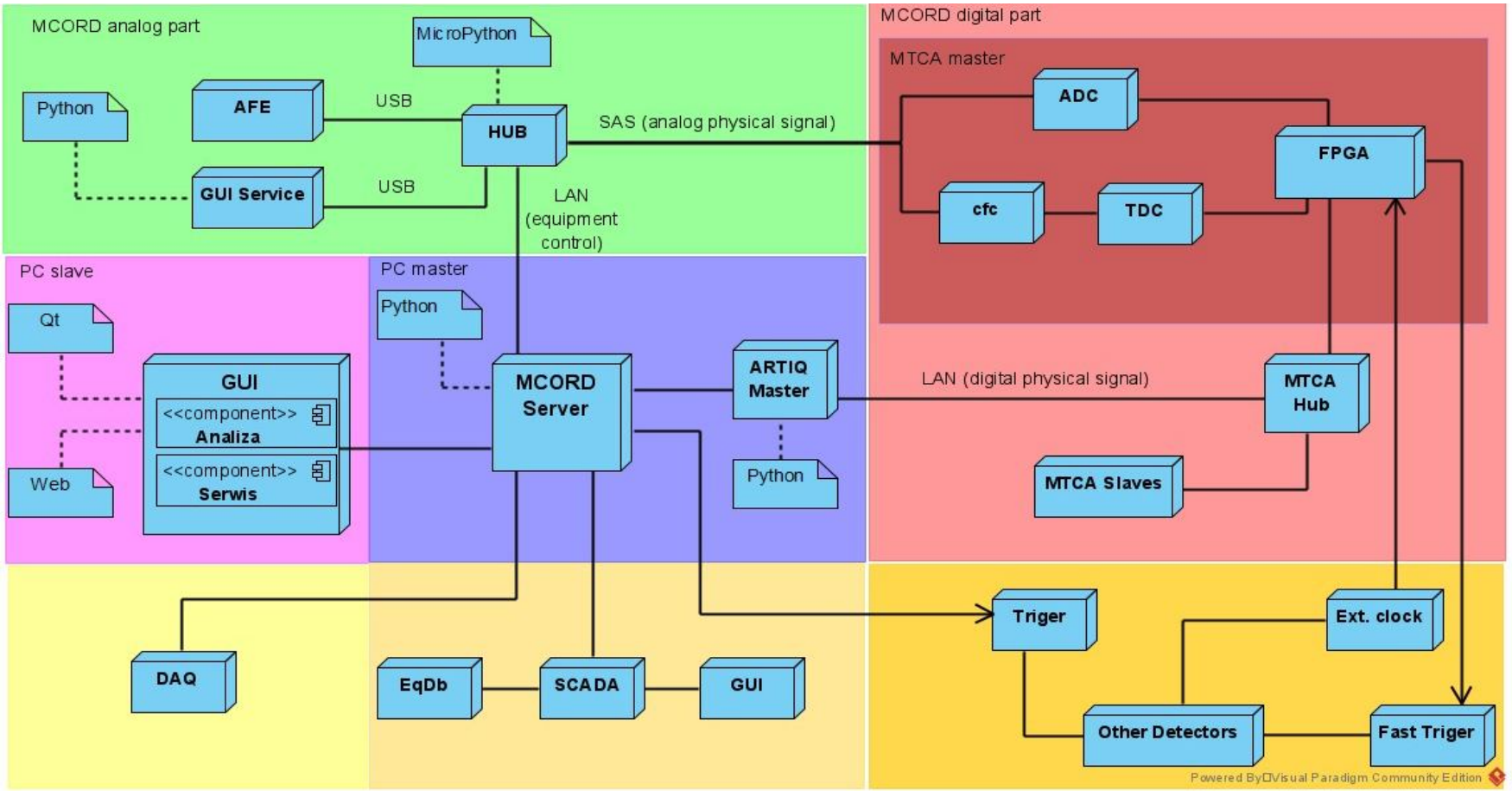
3. Present status - Software



- The system is divided into parts on the basis of their role and implement. platform.
- MCORD Server is a central part controlling system elements
- In this model user interface is totally separated and can be implemented in any way (Web/App/CLI) and changed later on without modifying core MCORD funct.

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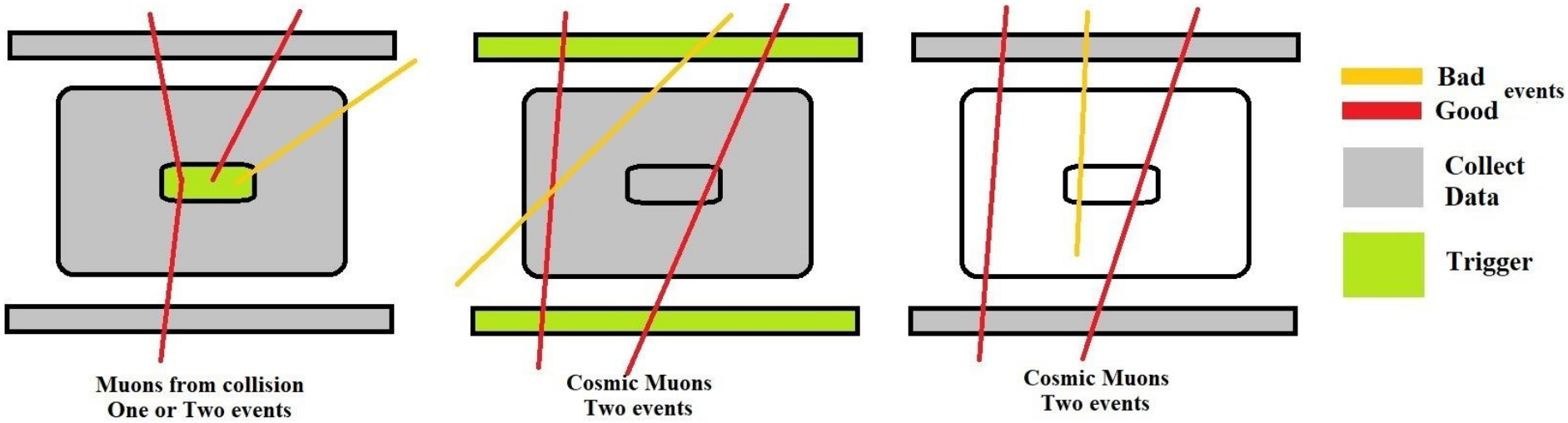
2. MCORD trigger and acquisition

Three modes of operation:

experiment	calibration	astrophysics



Collect data after collision inside MPD	MCORD trigger	MCORD collect Data
Single or dual muons E > 1GeV	Energy threshold for cosmic muons E > 2 GeV	

Estimated total trigger latency: 3.5 – 7.5us (max 15us)

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