Progress in the MCORD detector

by Polish consortium NICA-PL

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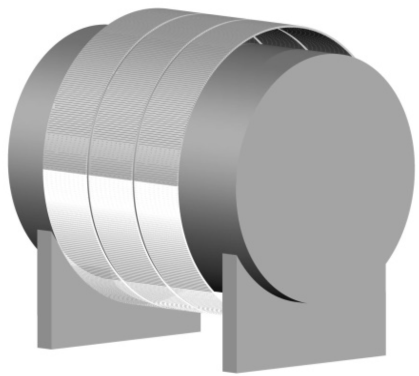
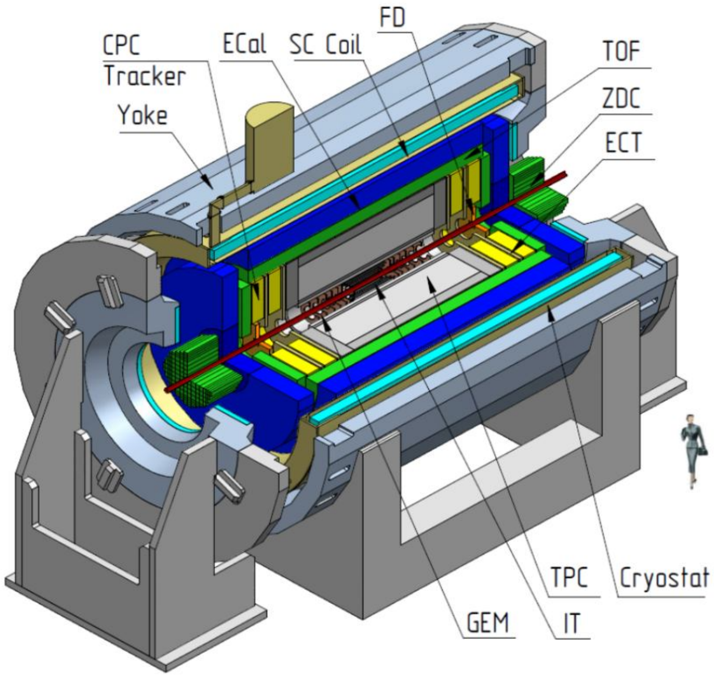
JINR

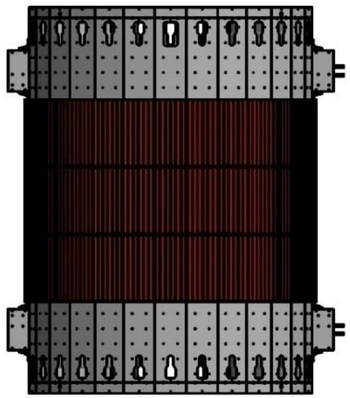
Outline

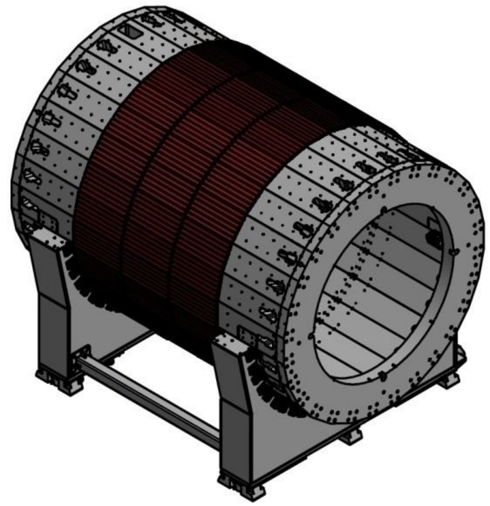
1. Design, modeling proposition - changes
2. Motivation
3. Demonstrator
4. **Present status of work**
5. Conclusions

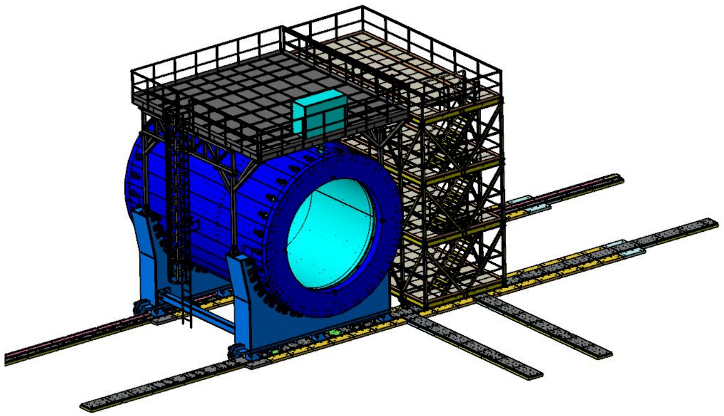


1. MCORD and MPD









MCORD - One surface on full circumference

- 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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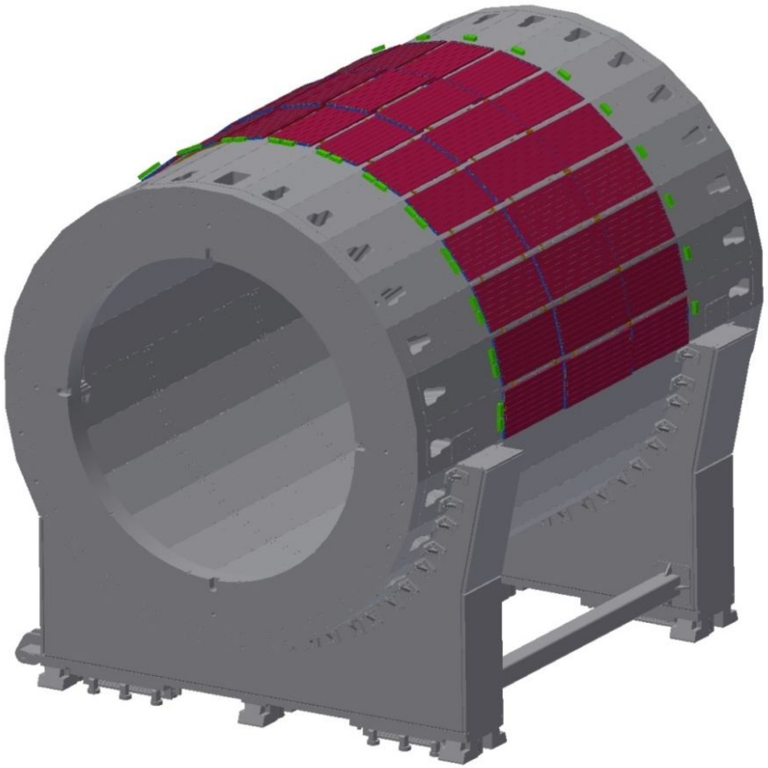
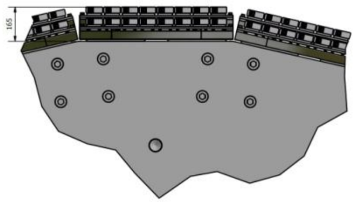
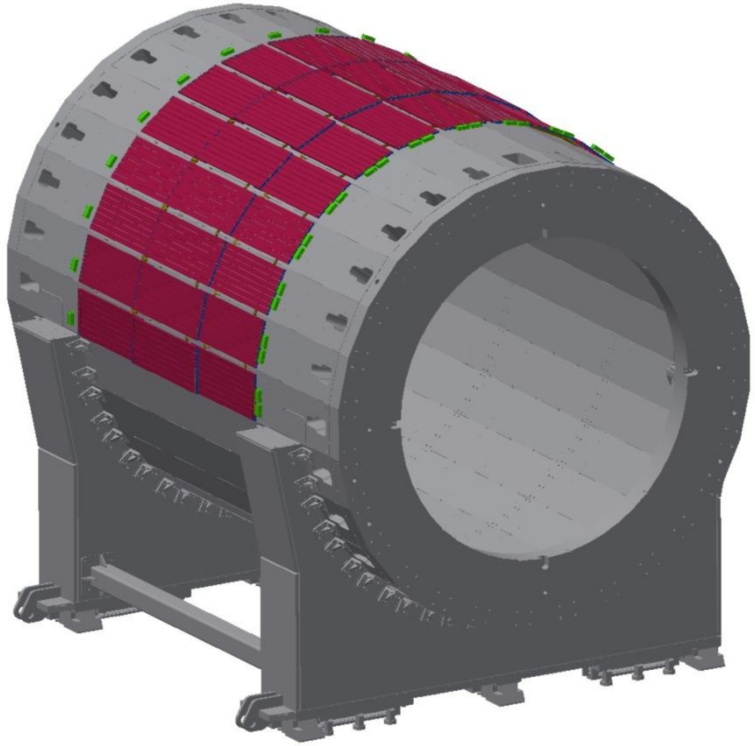
1. MCORD on MPD



A (1 :10)



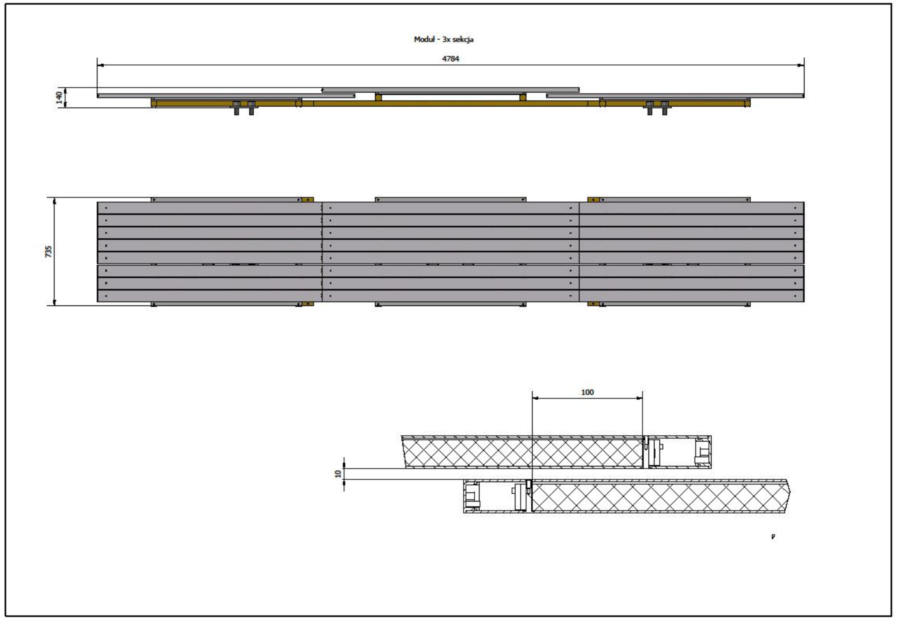


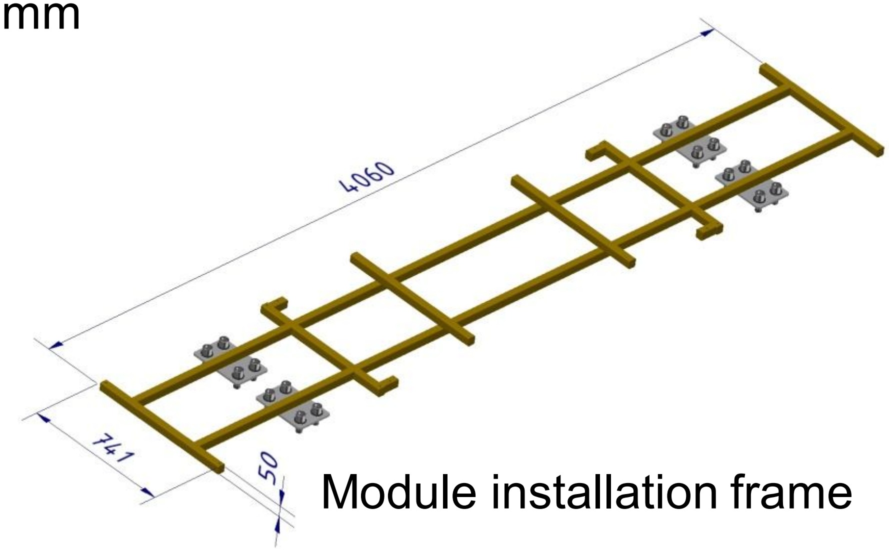
The MCORD modules (new shape) and passive HUB-s on MPD surface.

Modules Mounting on MPD surface	
Detector mounted to steel frame	
Steel frame built with square profiles:	40x40 [mm]
Number of Modules:	**28**
Frame mounted to MPD by screws	
Weight of all modules:	~4500 kg

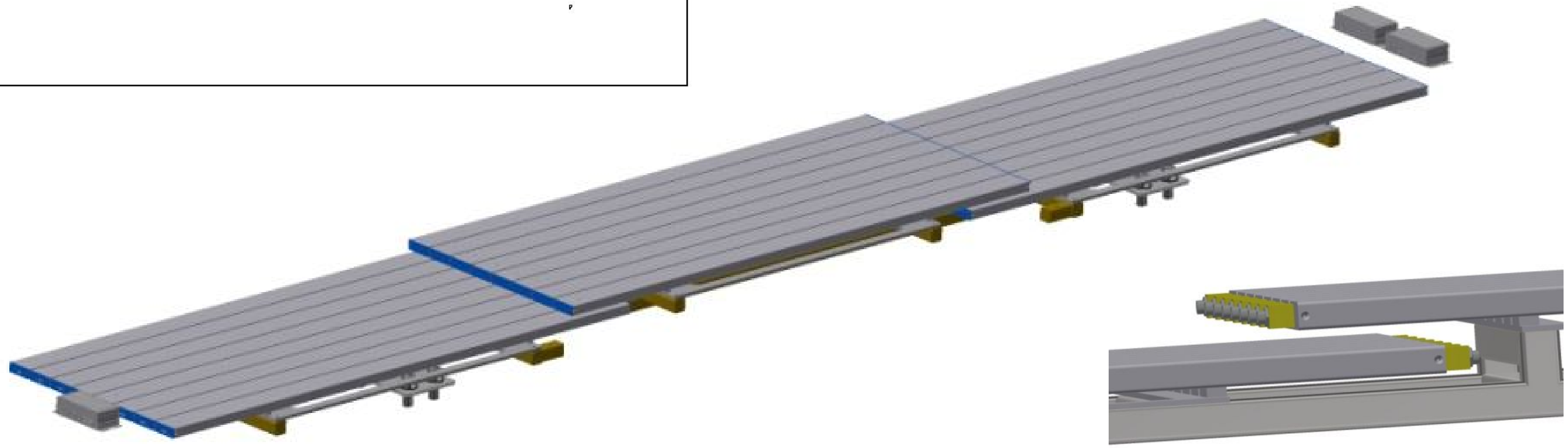
1. MCORD module

Single module on it frame – 4784x735x140mm





Module installation frame



MCORD module consist three sections and installation frame.
Central section is above the first one and third one. No NULL zone.

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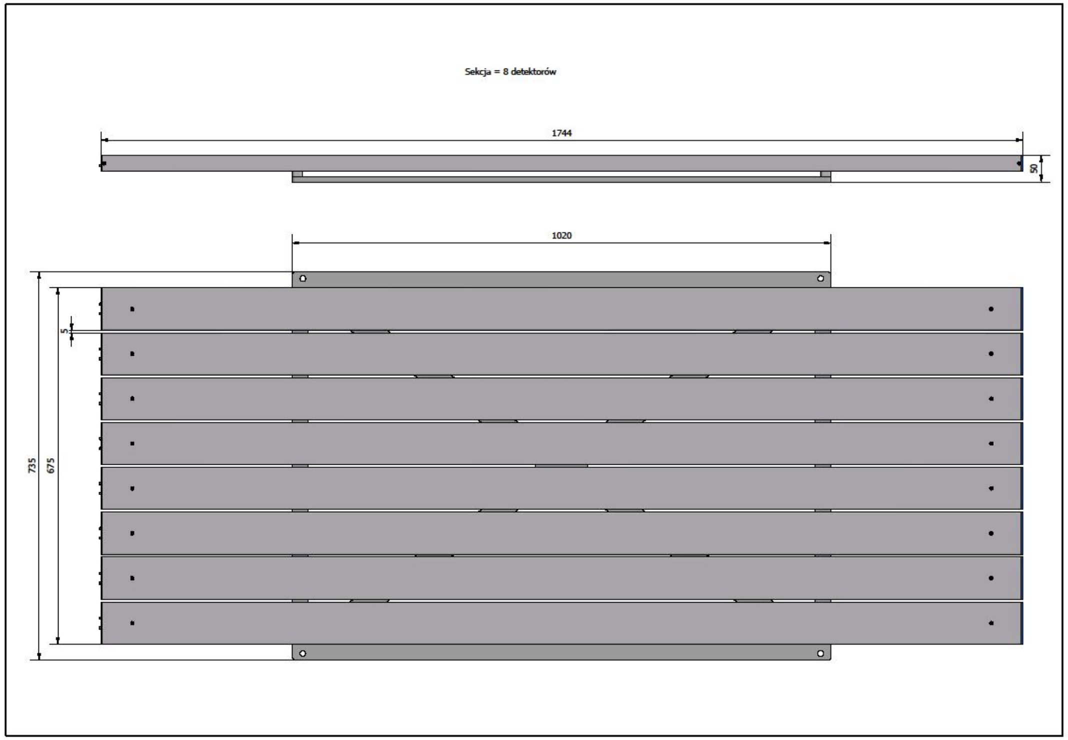
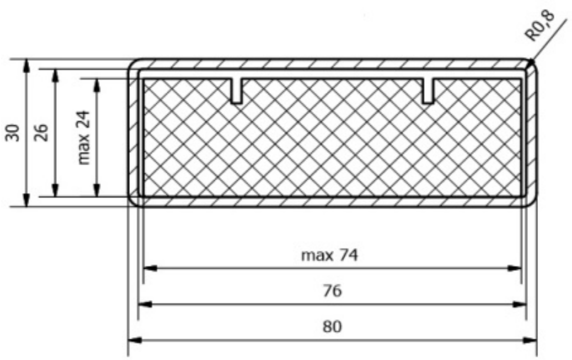
1. MCORD section



Single section – 1744x735(675)x50



Project of scintillator aluminum cover (center).

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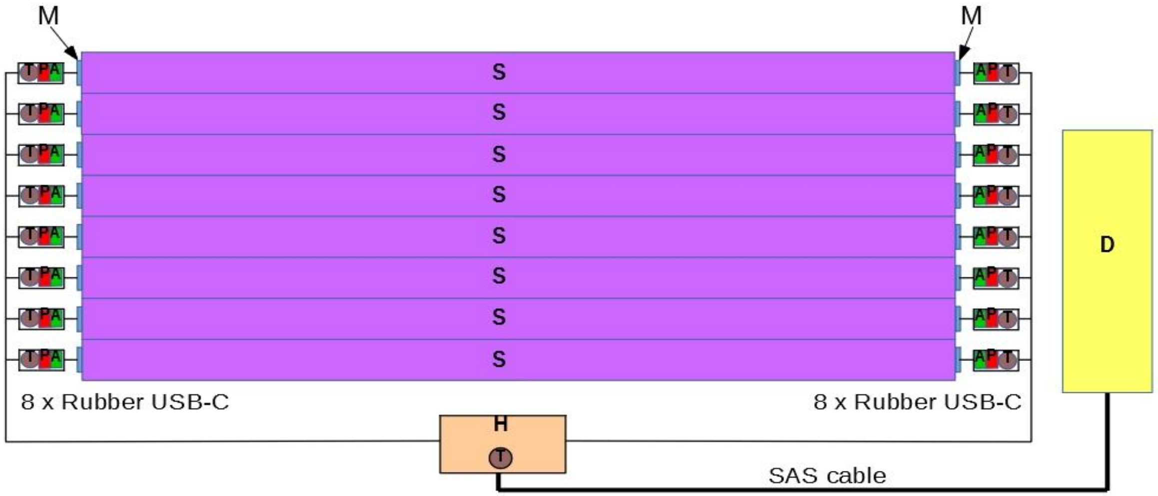
1. Design of detection system

ANALOG SIGNAL PATH OF MUON DETECTOR



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

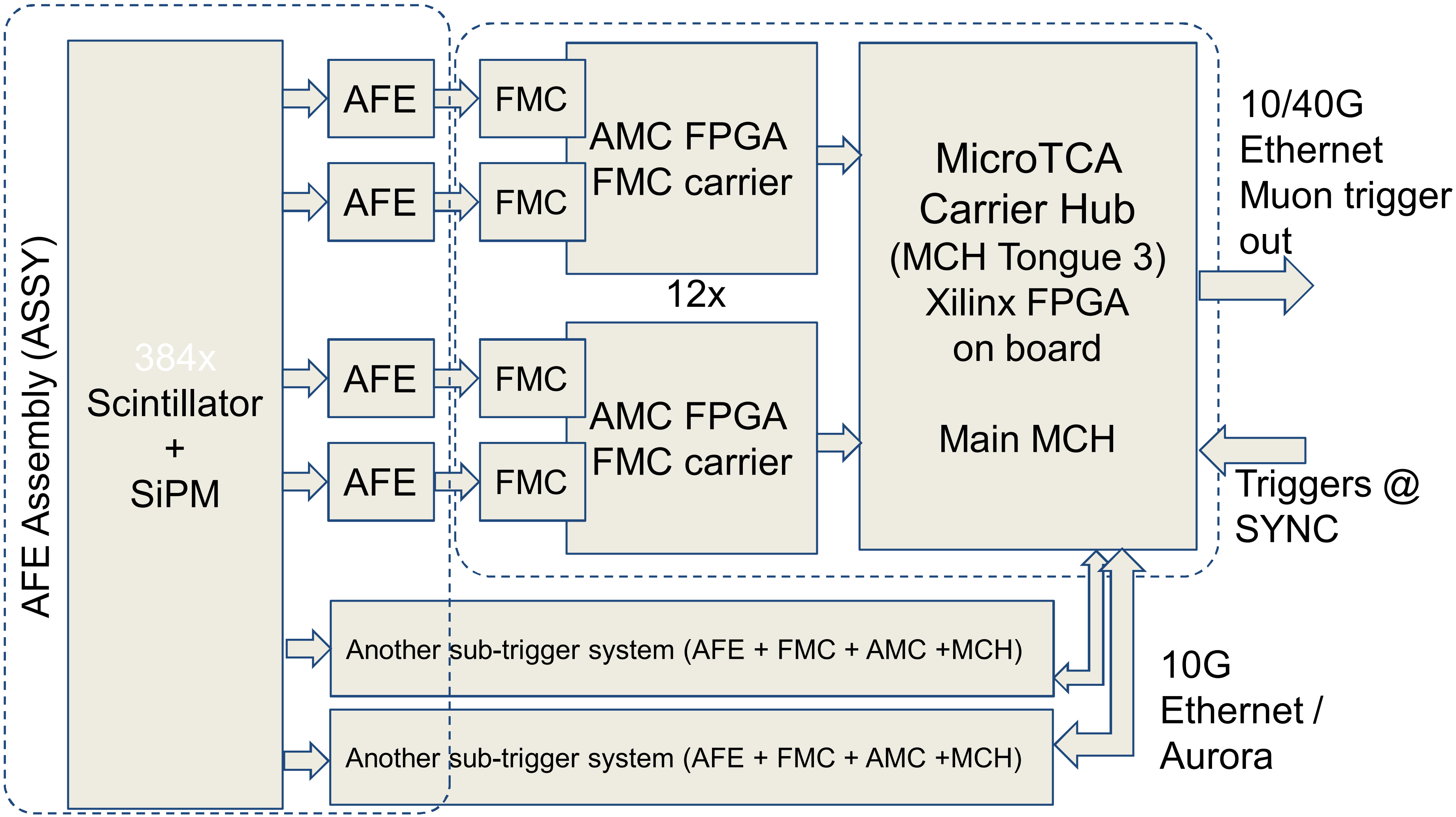
Time Resolution – about 300-500 ps

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.

1. MCORD system overview

uTCA based modular muon trigger (signal flow only) system

ASSY- assembly, AFE- Analog Front End, FMC- FPGA mezzanine card ,AMC- Advance mezzanine card

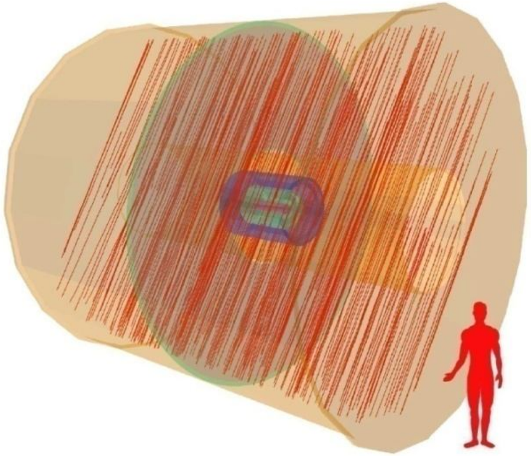


2. Cosmic Ray Detector – Goals

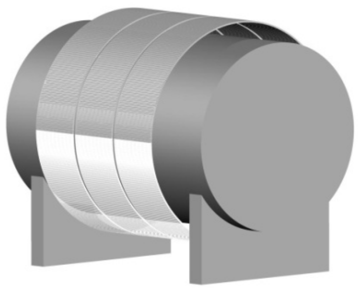
a) Trigger (for testing or/and calibration)
- testing before completion of MPD
(e.g. **two separate MCORD sections or modules**
(testing of TOF, ECAL modules and TPC)
- calibration before experimental session
(e.g. **minimum 2-4 MCORD modules**)

b) Muon identifier (created inside of MPD)
(minimum muon energy: 600 MeV)
- Pions and Kaons decays
- Rare mesons decays (etha, rho)
- Possible decays of new „dark" particles

c) Astrophysics (muon showers and bundles)
- **The position identification of Extremely high energy particle source**
- unique for horizontal events
- working in cooperation with TPC and TOF



Additionally
Veto and Calibration
(normal mode - track and time window recognition)
Mainly for TPC and eCAL



2. Muons detection – dileptons

Motivation for the study of muon production in nucleus-nucleus interactions with MCORD at NICA.

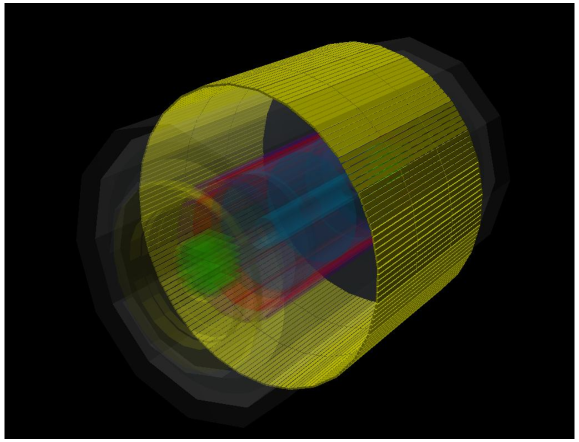
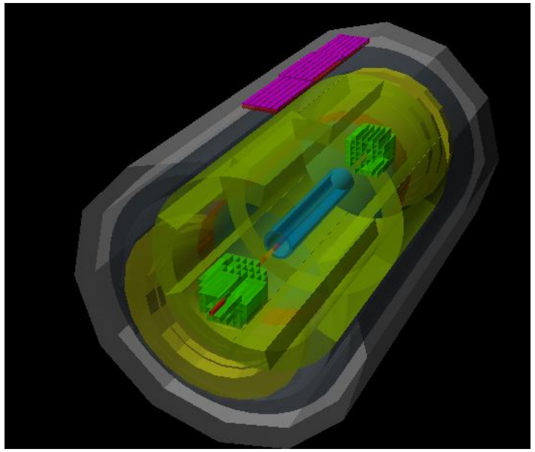
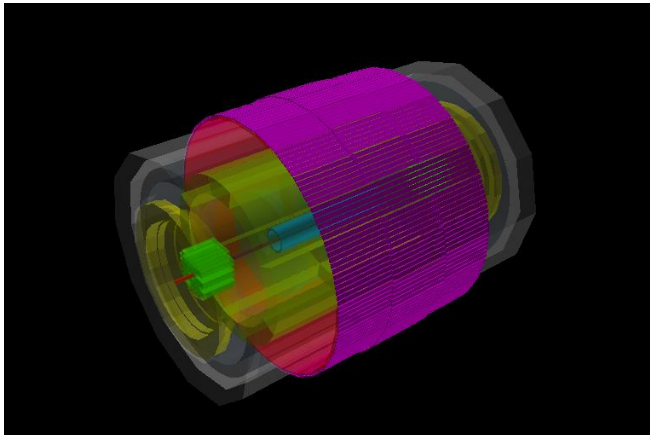
In the existing NICA program the study of e^+e^- dileptons is mentioned as one of important goals. When the available energy in the process is larger than the two muon mass ($2 \cdot 105 = 210$ MeV/c^2), the lepton universality lead to the production of muonic dileptons.

The major sources of dileptons are:

1. The decays of light scalar (η, η' …) and vector (ρ, ω , φ ..) mesons.
2. Open charm meson decays.
3. Drell-Yan processes.
4. Thermal muon pairs from dense, hot matter.
5. Possible decays of new, beyond SM, “dark” particles (dark photon and Higgs-like particles).

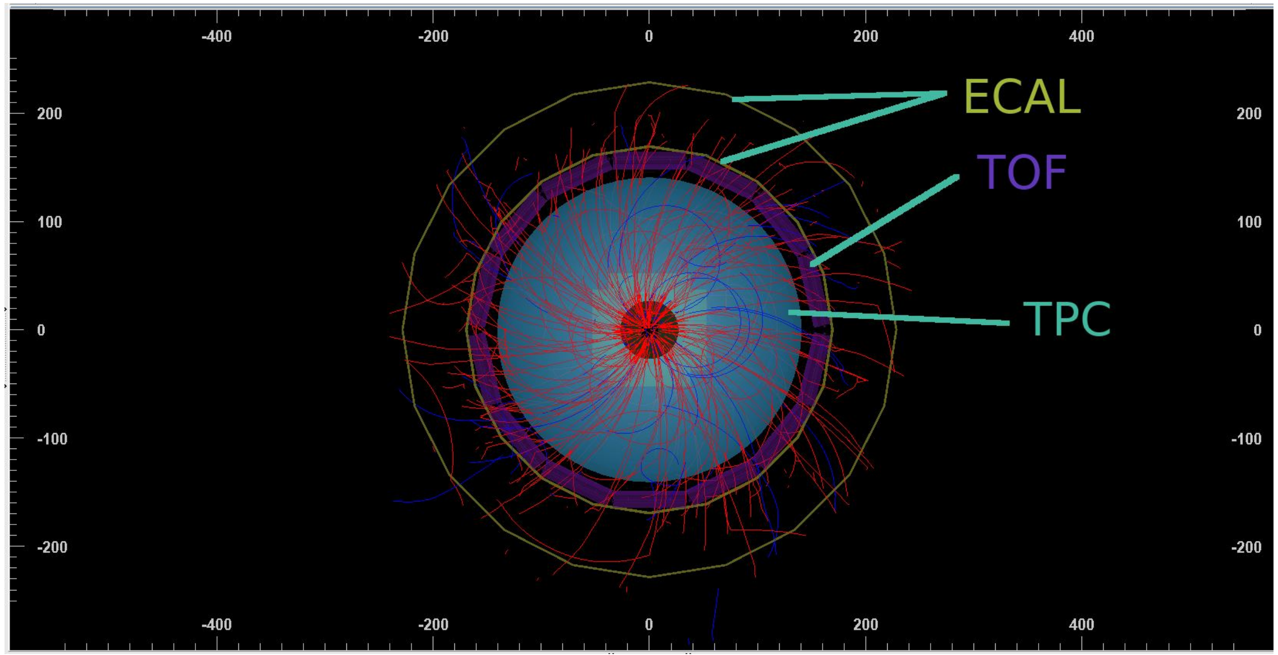
These are very rare processes

2. Muons detection

Simple, older geometry.	More realistic module.	The new MCORD geometry.
		

DATA

- **UrQMD 3.4**
- **Au+Au collisions at 11 GeV**
- **Central collisions (impact parameter < 3.5 fm)**

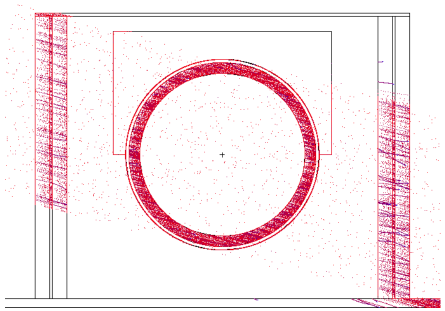


Visualization of central gold-gold collision. Positive pions are marked as red, whereas positive muons are blue. It can be seen that a lot of pions vanish is ECAL without production of muon

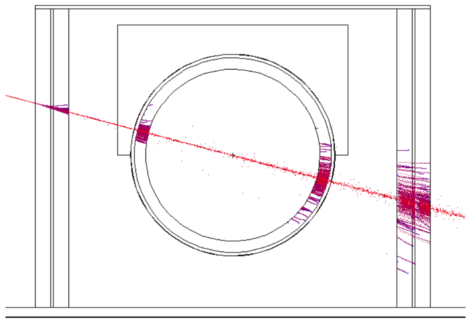
2. Muon detection – simulations

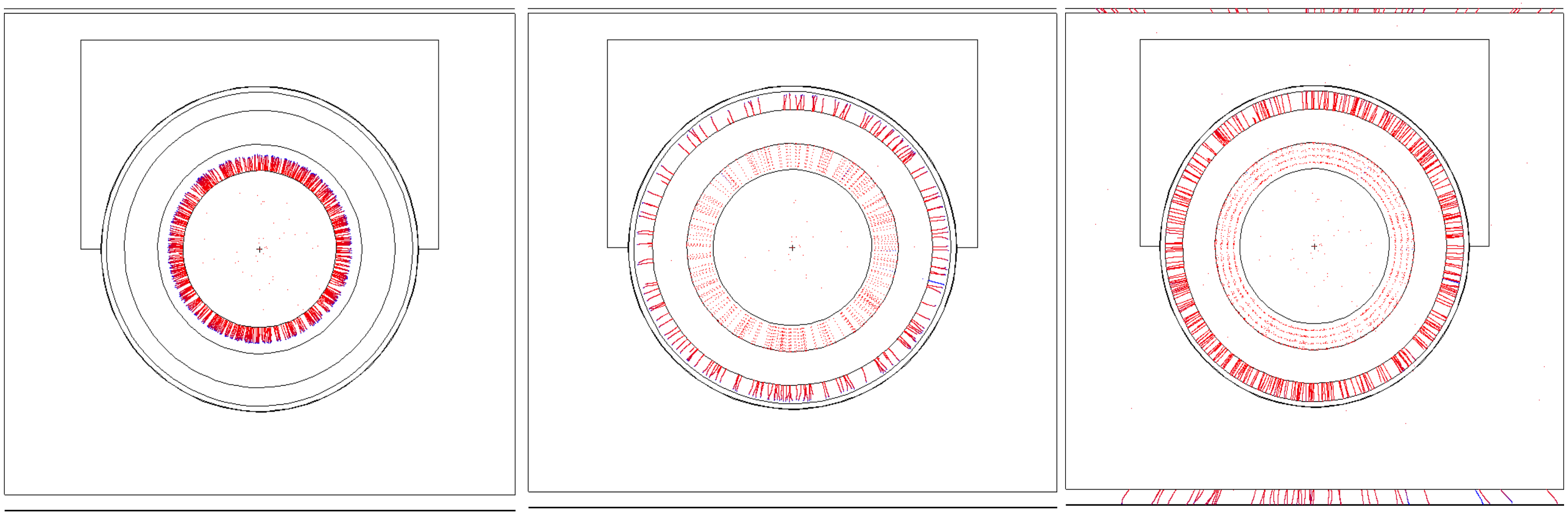
MCNP calculations for MCORD muon detector

(MCNP 6.11, MCNPX 2.7.0. number of iteration 1E9)



Previous simulations
Muons through MPD cross section, 75°





MCNPX calculated central muon transmission through the MPD, MCORD and concrete walls.

Muon energy: Left 100MeV, Central 500 MeV, Right 1000MeV.

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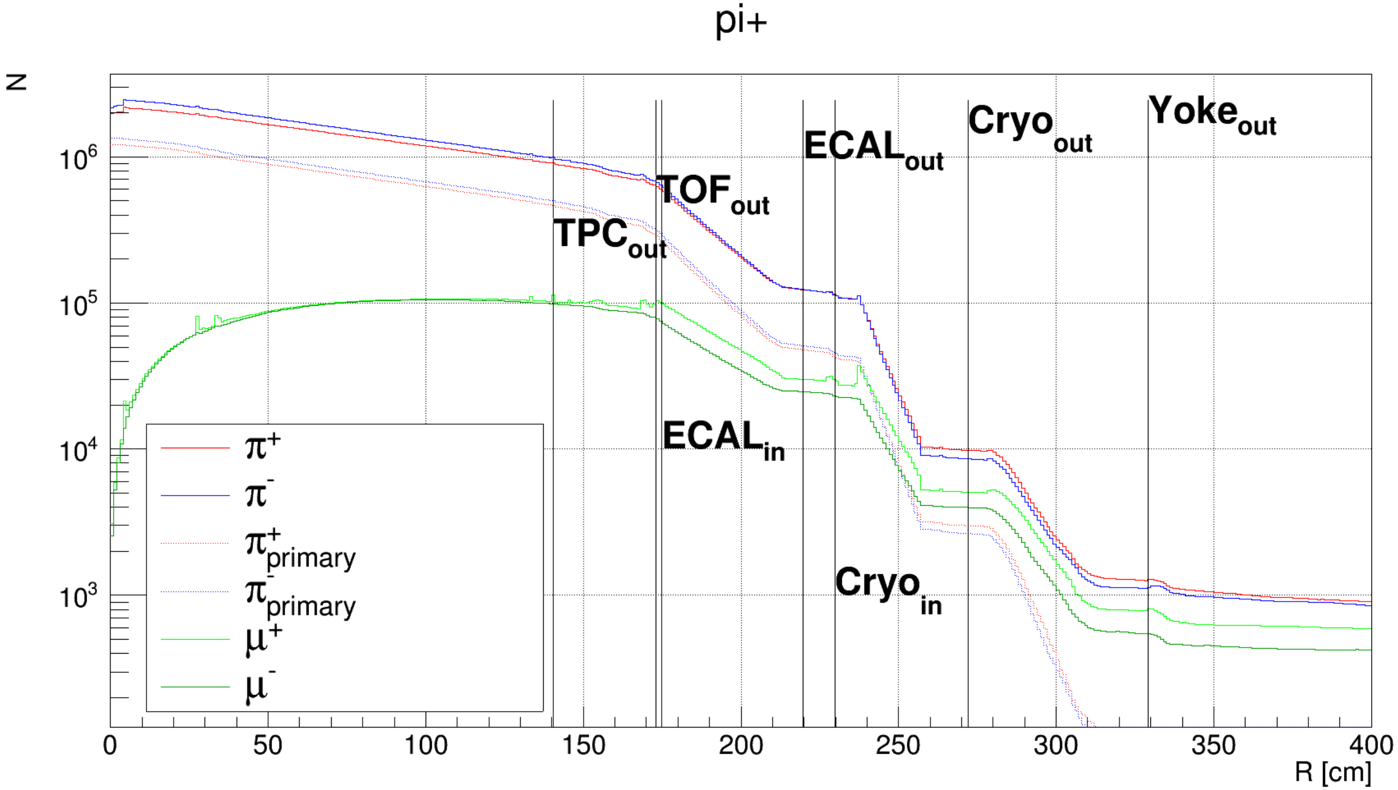
2. Muons detection – Goals

The Flux of pions/muons as a function of distance from the beam axis (not normalized)

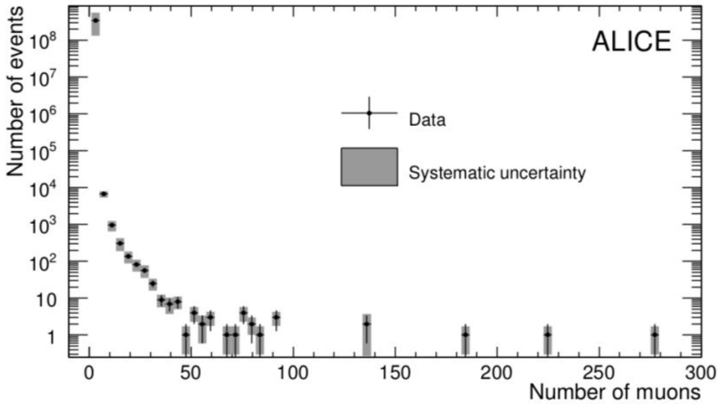


The plot was made by calculation of the total number of particles at |Z|<190 cm and p>1MeV/c as a function of distance from axis beam, simulation was done for 19k Au-Au central collisions (centrality 0-5%) at 11 GeV. The primary particles does not include the particles from strong decays.

2. Astrophysics

• Recently, a new muon data type has been acquired from the extensive air showers (EAS) generated by primary cosmic rays (PRC), in particular multiplicity distribution of muons produced in EAS has been obtained.

• The existing ALEPH, DELPHI, and ALICE cosmic ray data contain information on muon production in EAS only for vertical showers (those with zenith angles not far from zero degree).



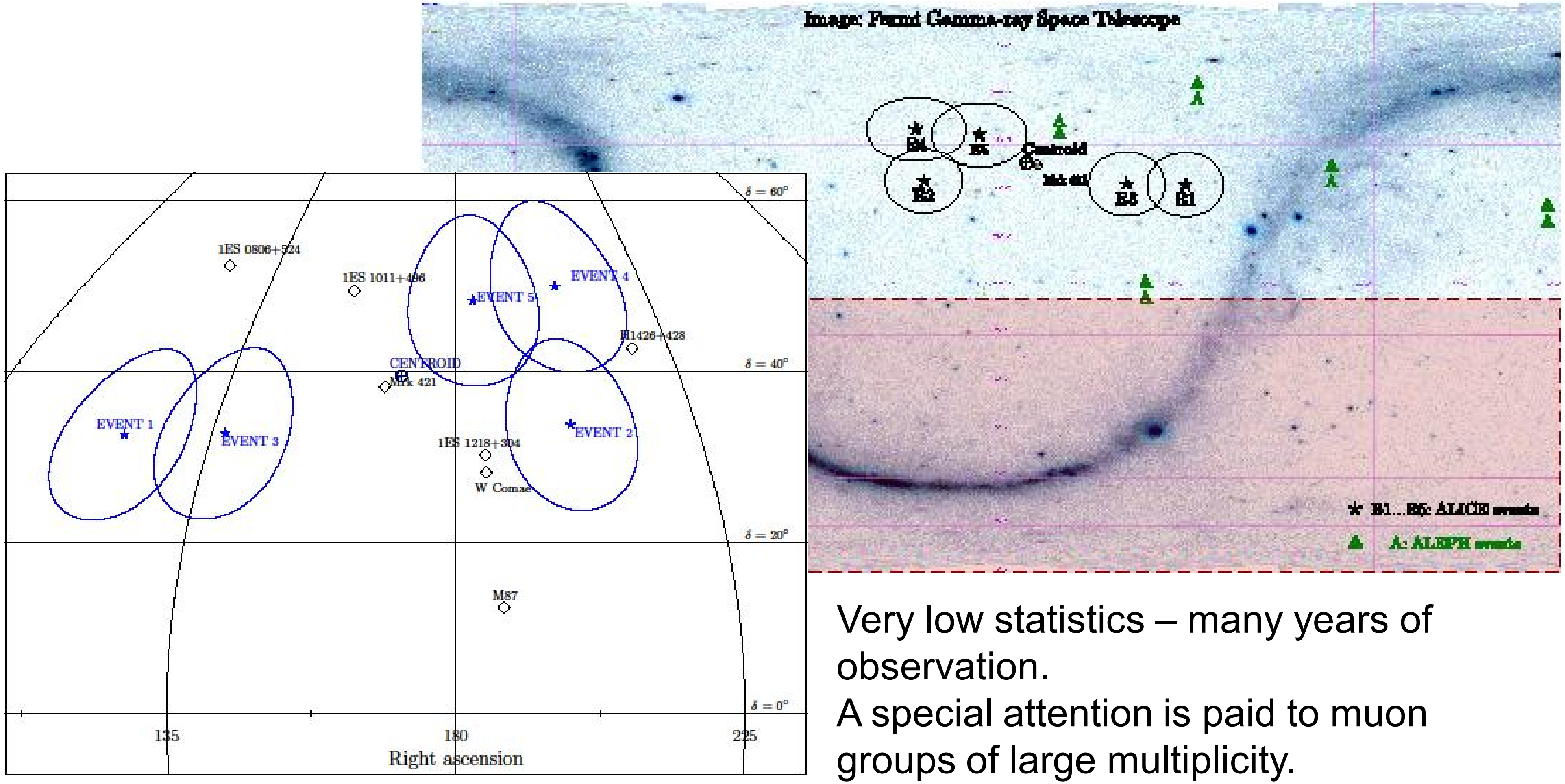
Comparisons with simulation results (KORSIKA+QGSJET) are in agreement for low multiplicities (for low energy). For high multiplicities (only few events) results are almost an order of magnitude above the simulations results.
Problem with current hadronic interaction model for extremely high energy >10E15 eV ???

• 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 zenith angle of PRC, up to nearly horizontal showers. **Such measurements, up to now, were never possible.**

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

3c. Astrophysics

The position identification of Extremely high energy particle source



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.

3c. Astrophysics

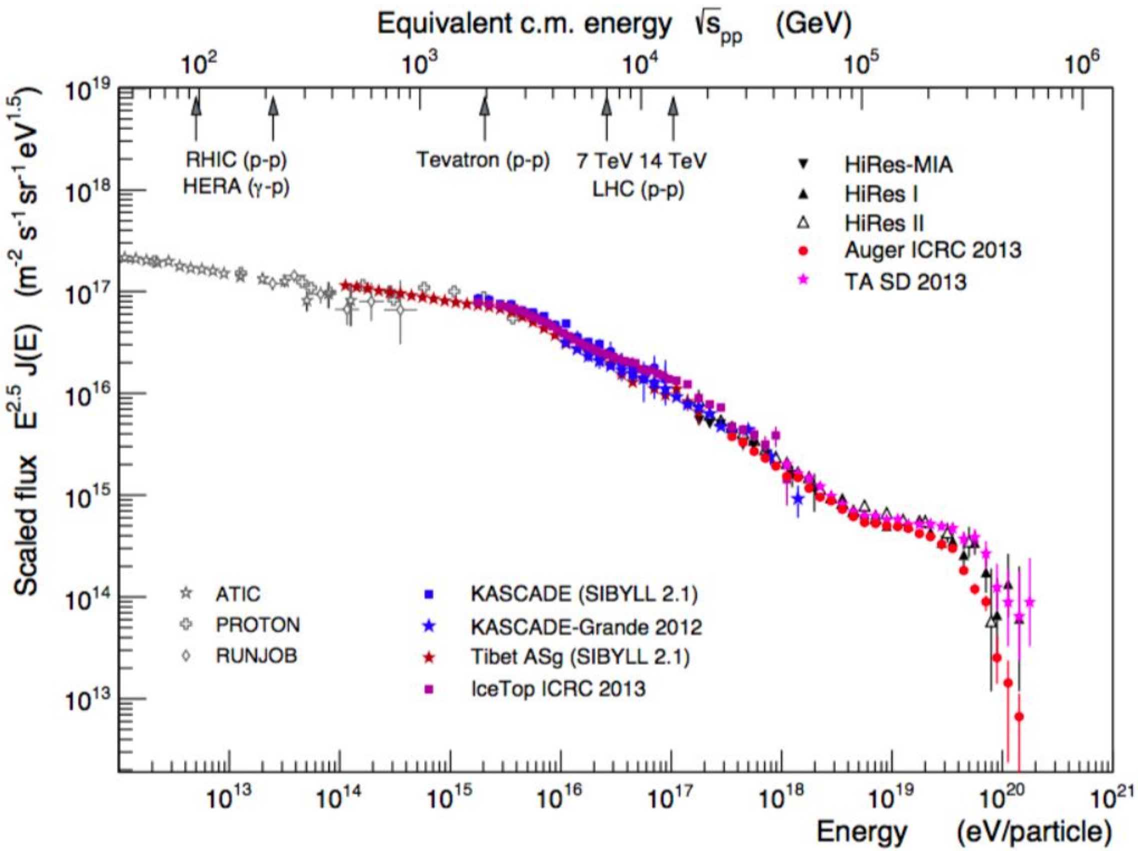
GZK-cutoff problem

- 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:

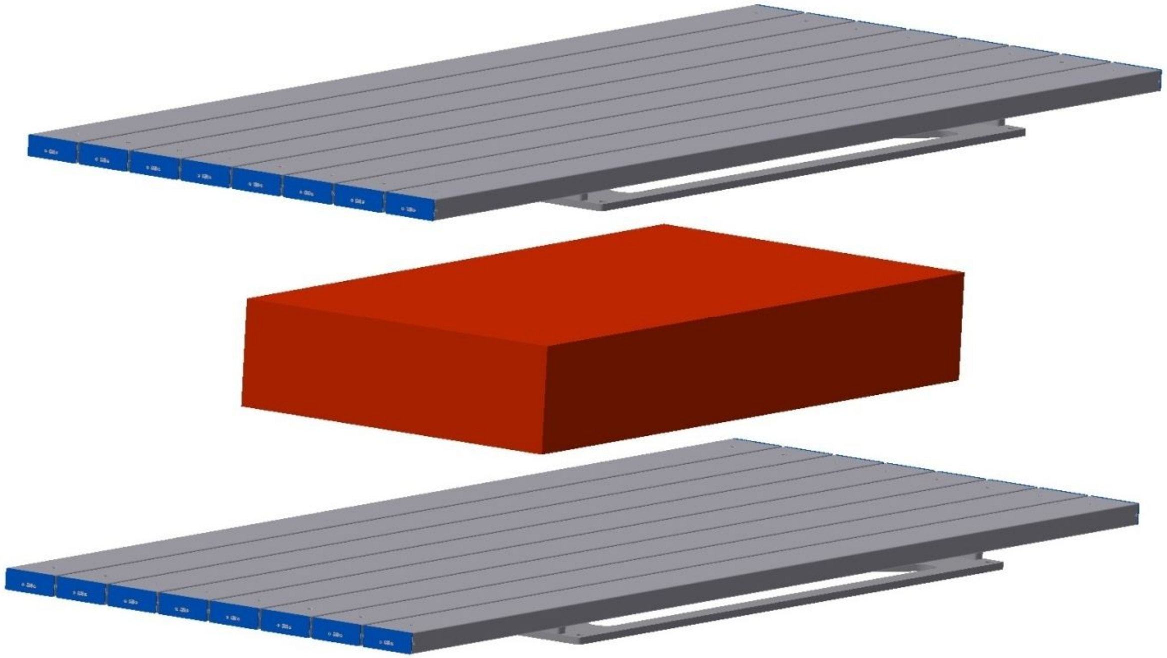
1. Pavluchenko, V. P.; Beisembaev, R. U., Muons of Extra High Energy Horizontal EAS in Geomagnetic Field and Nucleonic Astronomy, 1995 ICRC....1..646P
2. Yashin I. et al., Investigation of Muon Bundles in Horizontal Cosmic, 2005 (28) ICRC p.1147-1150
3. Neronov A. et al., Cosmic ray composition measurements,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

3. Demonstrator

Two sections (2x8 scintillators) will be build with dedicated electronic and full signal analysis.



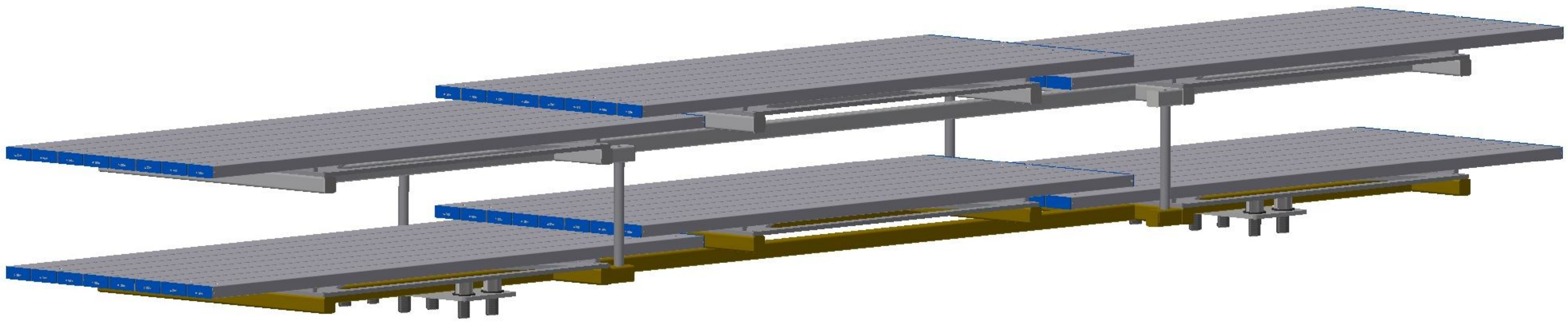
Example: testing of the TOF module

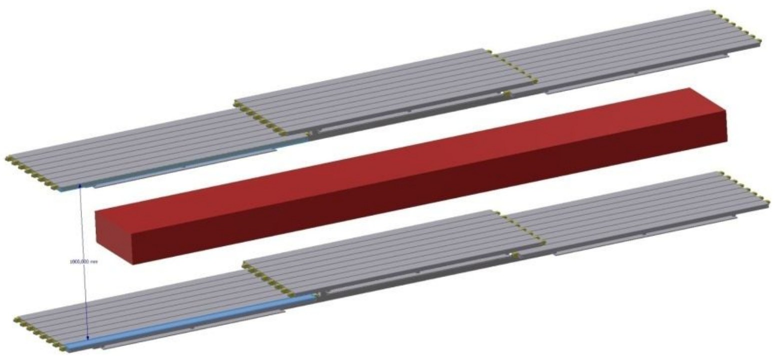
3. Demonstrator

Next step

Six sections 6x8 scintillators (Two MCORD Modules)

It should be ready by the beginning of 2021 year.





4. Present status of work (short view)

A. SiPMs (Hamamatsu) are tested (including different subpixel size)

B. Scintillators (NUVIA) with direct light SiPM redout and with different fiber configuration are tested.

C. Scintillators (NUVIA) for demonstrator – We chosen size and type – waiting for shipment 16 pcs.

D. Electronic (CreoTech) – Prototype AFE, Hub modules and adapters, converter modules , FMC-TDC boards – tests and programing started.

E. Components integration in progress (mechanical and electronic connections, scintillator-SiPM-fiber-AFE integration)

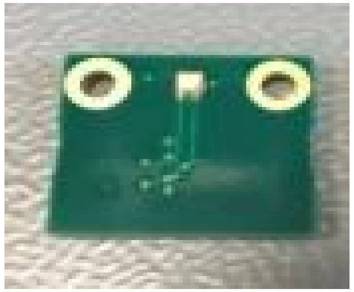
4. Present status of work

SiPMs (Hamamatsu) for test

S13361 – 6050AE – 04	2
S13360 – 1375PE	8
S13360 – 1350PE	8
S13360 – 3050PE	6
S13360 – 3075PE	6
S14160 – 6050HS	2
S13360 – 6050PE	2
Total	**34**

Large and small size SiPMs,
with two sizes of pixels 50, 75um,

24x24mm 2pcs, 6 x6mm 4pcs,
3x3mm 12pcs, 1.3x1.3mm 16pcs



4. Present status of work

Scintillators (NUVIA)

Available scintillators:

- For initial tests: long and short tiles (~50-150 cm) with different thickness (1-5 cm) from NUVIA (Czech Rep.) and UNIPLAST (Russia) companies, with and without Wavelength Shifting (WLS) fibers
- For final tests: 4 tiles from NUVIA (150 x 2 x 7cm) with different WLS (single, double, 1mm and 2mm dia.), with specially designed connectors for easy MPPC coupling

No fiber

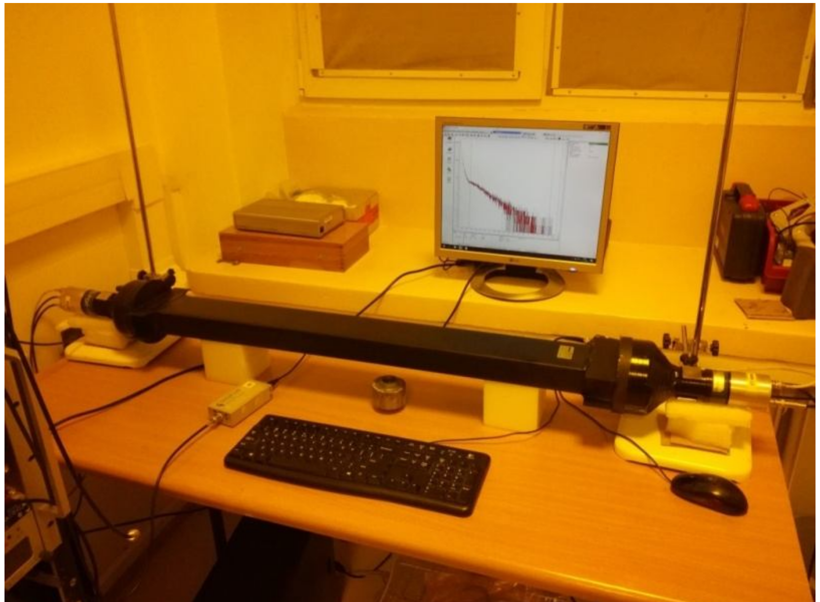
1x1mm fiber

2x1mm fiber

1x2mm fiber

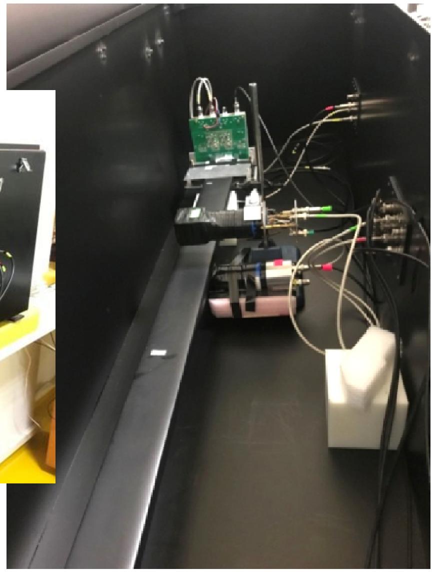
4. Present status of work

<u>Laboratory tests at NCBJ Swierk – two test sites ready to use (standard and BLACK BOX)</u>



Additional equipment:

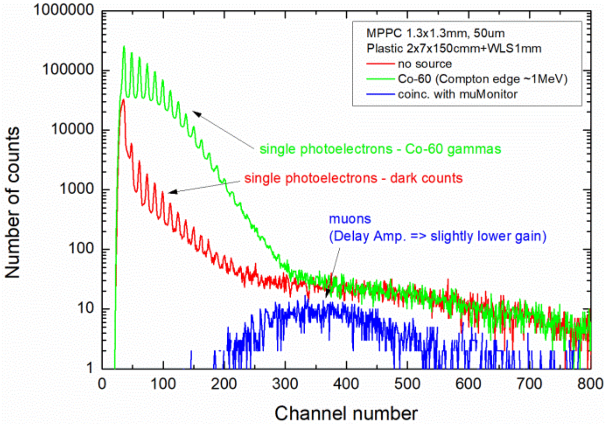
- 5" Ø PMTs (XP45D2 and ETL9390)
- double-side 5 inches dia PMTs readout
- Co-60 gamma-rays energy calibration

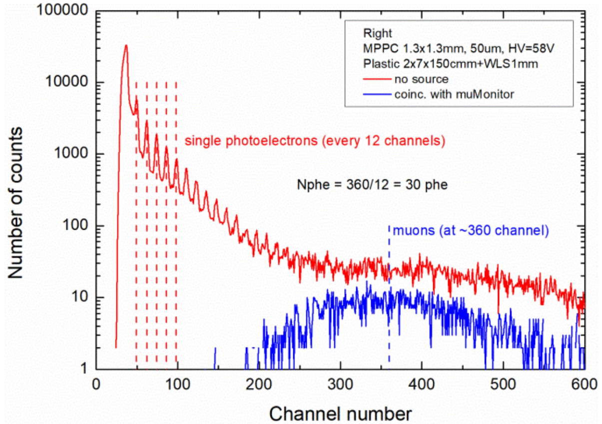


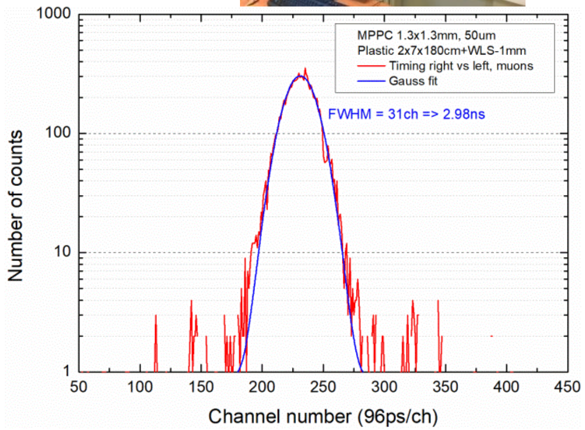
4. Present status of work – NCBJ Swierk

Measurements of Timing Resolution (left vs right) and Number of Photoelectrons:

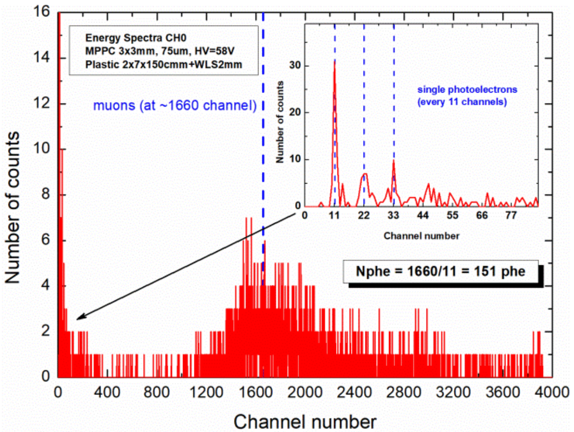
1. NUVIA Plastic 2x7x150cm **with 1mm dia WLS**
   - MPPC 1.3x1.3mm, sub-pixel size 50um, 75um
   - MPPC 3x3mm, sub-pixel size 50um, 75um

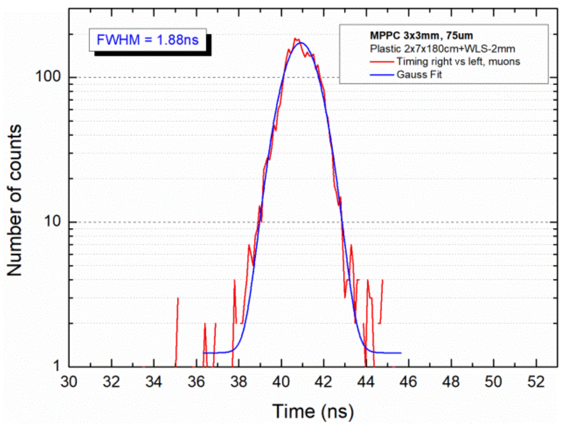






2. NUVIA Plastic 2x7x150cm **with 2mm dia WLS**
   - MPPC 3x3mm, sub-pixel size 50um, 75um





Starting point (analog setup):
Nphe=30phe, Timing=3ns

Present (digital setup):
Nphe=150phe, Timing=1.9ns

Still can be improved!

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4. Present status of work

Laboratory tests at NCBJ Swierk

Summary of Tests of Silicon Photomultipliers for MCORD

Measurements performed:

Light output measurements of cube 5x5x5cm NUVIA plastics

Tests of large area MPPC arrays in readout of NUVIA plastics (without WLS) :

- 2x2inches MPPC array and 5x5x5cm plastics
- 2x2inches MPPC and 5x10x100cm plastic– good results of timing resolution
- 2x1inches MPPC - very poor performance due to short attenuation length

Photoelectron number and timing resolution

- 1mm WLS read by **1.3x1.3, 50um** MPPC – only around **30 phe** for muons,
  poor timing resolution of almost 3ns
- 1mm WLS read by **1.3x1.3, 75um** MPPC–almost **50phe** for muons, improved timing resolution
- 1mm WLS read by **3x3, 75um** MPPC –to almost **60phe** for muons, improved timing resolution
- 2mm WLS read by **3x3, 75um** MPPC – timing resolution at the level of 1.85ns (FWHM)

Measurements to be performed:

Photoelectron number and timing resolution for a setup consisting of small area (1.3x1.3mm and 3x3mm) MPPCs and 2x7x150cm plastics with WLS:

Double, 2mm diameter WLS read by**, 75um sub-pixel size MPPC**

I invite you cordially for tomorrow's first part of our detector show.
Buil.215 **room 247** (Seminar Hall) **Wednesday, 15:00**
Presentation of a single detector mod with double sided MPPC readout

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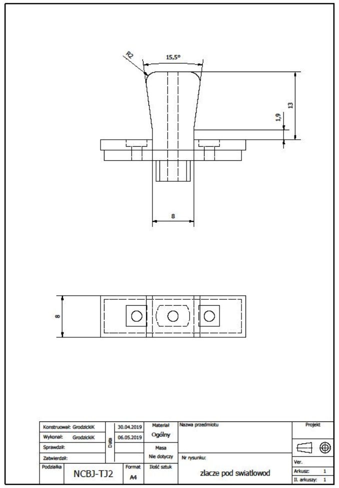
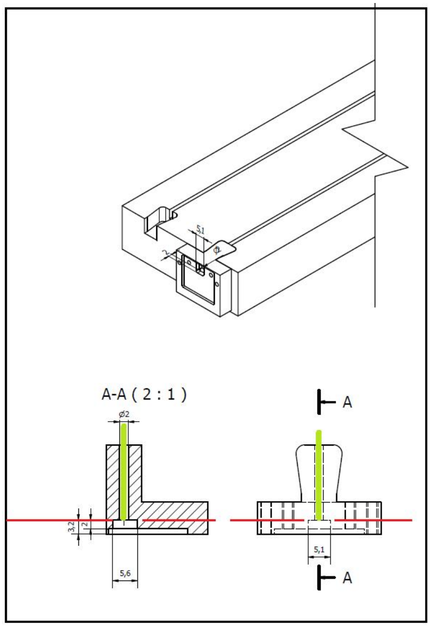
4. Present status of work

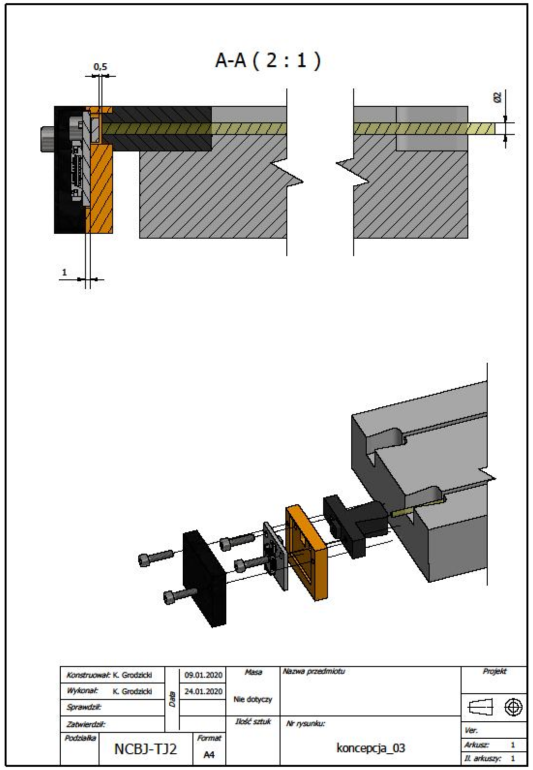
Project of the mechanical connection
scintillator-SiPM-fiber-AFE board



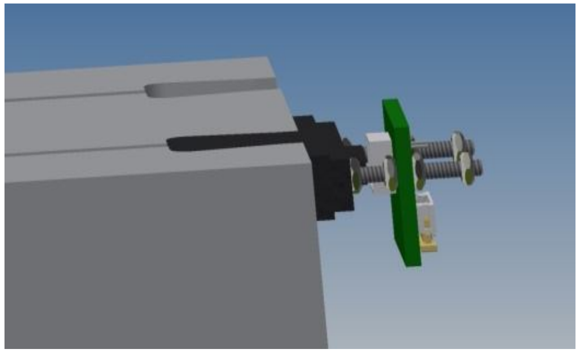
The first version

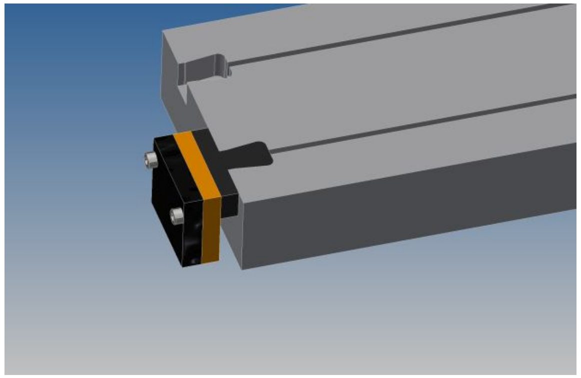


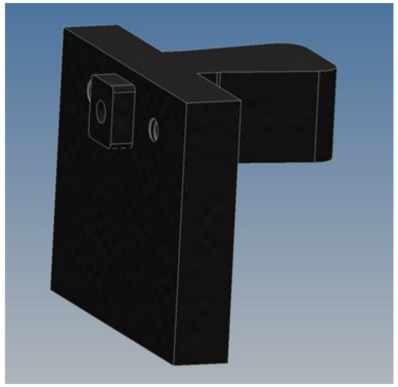
The second version



The last version

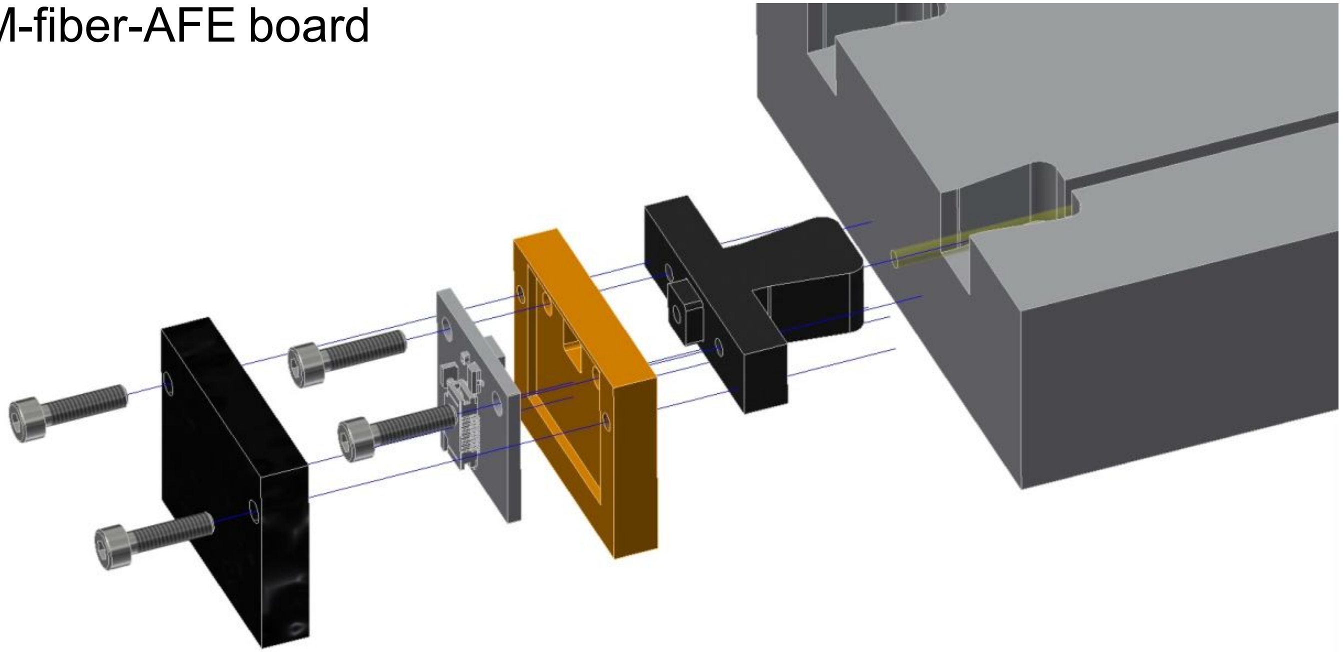


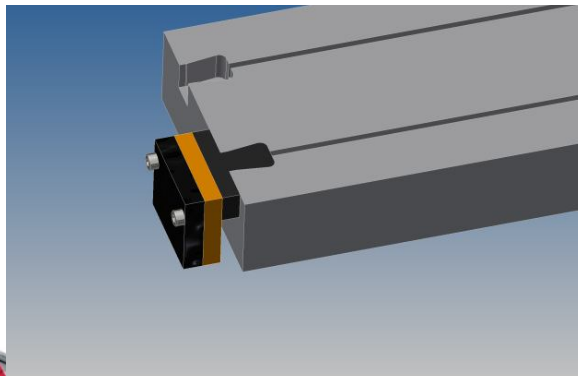


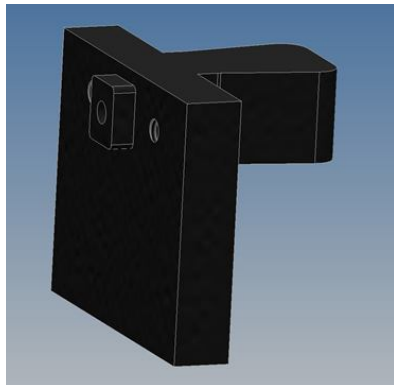


4. Present status of work

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





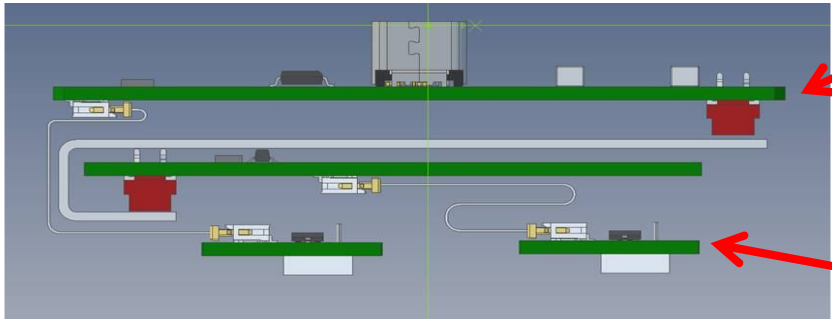


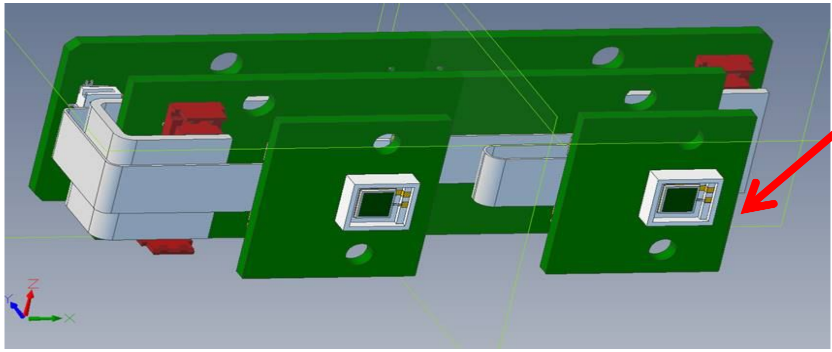
4. Present status of work

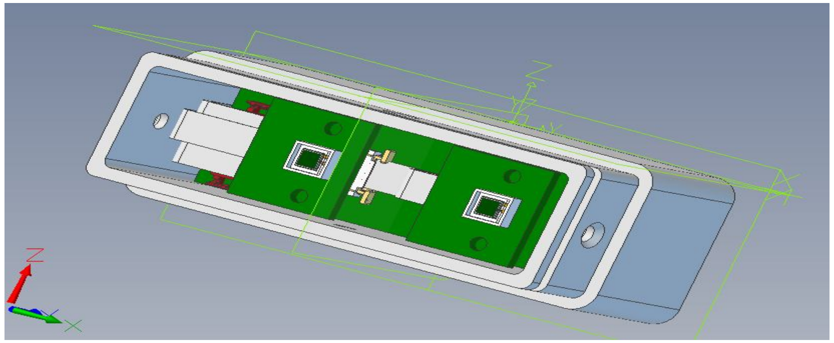
Connection SiPM-AFE

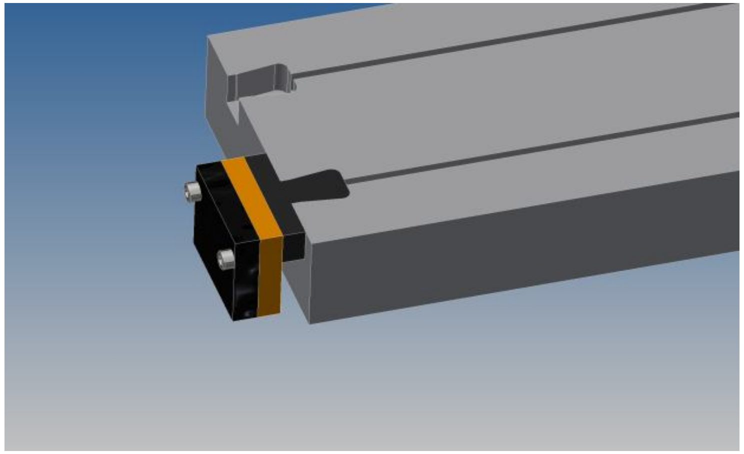
Amplifier & Power supply

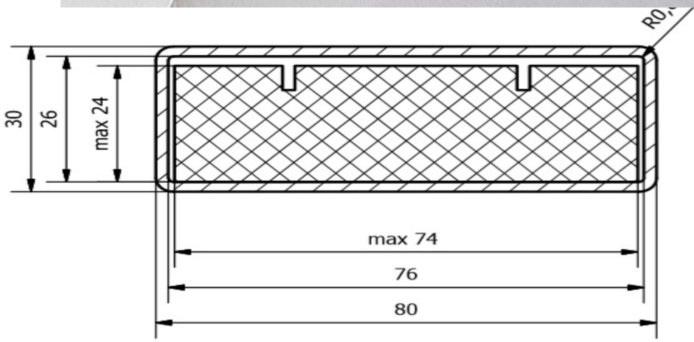
SiPM











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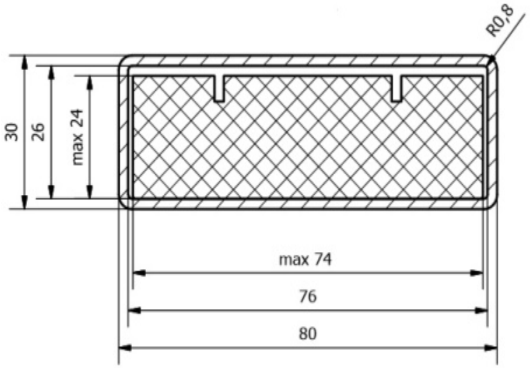
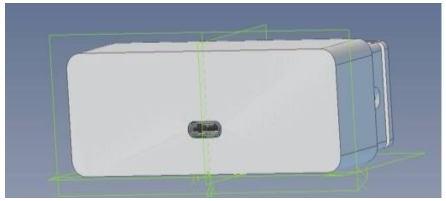
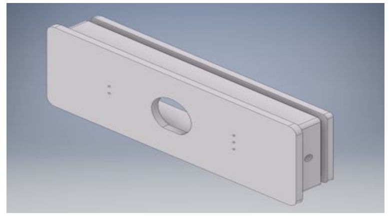
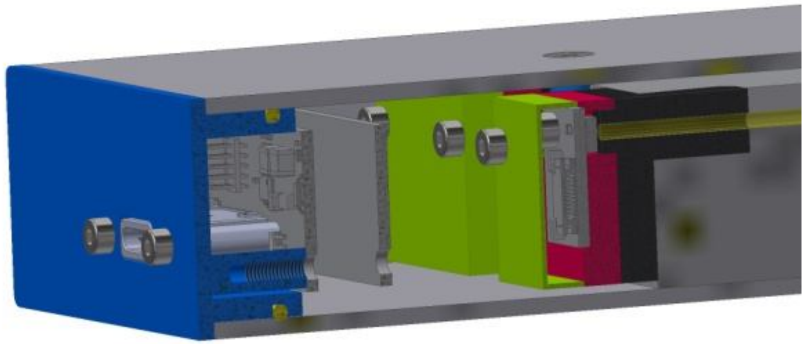
4. Present status of work

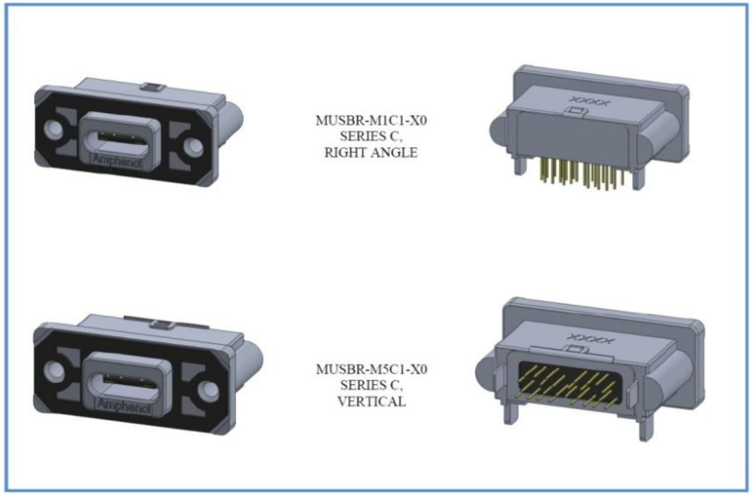
Project of the End-Cup (with USB port) to install on both ends of aluminum scintillators cover



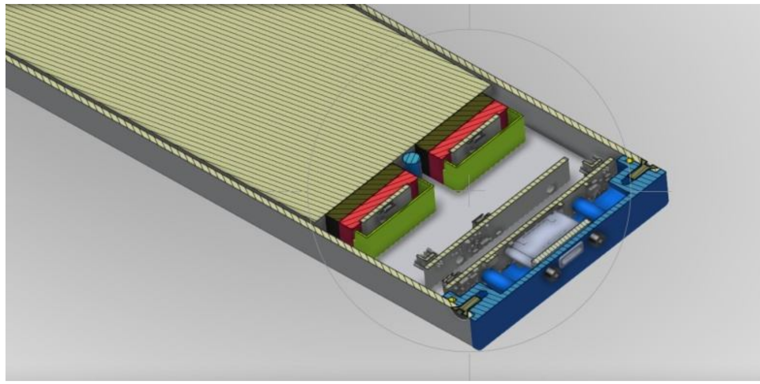








View of the area between the end of scintillator and End-Cap



Rugged USB Type C, Input Output Connector, IP67, Vertical, Metric Thread,
No Dust - cover and No Light - cover

MicroTCA (MTCA) configuration

Standard MTCA crate (8U)
Crate number depends on channel count and sampling speed At 125MS/s:384 chan/crate

Dedicated Analog Front-End module

FPGA mezzanine card (FMC)

AMC FMC carrier board

2xSAS-external cable + 1xEthernet cable for one section (8 scintillators) SAS cable fi 8mm (16 chanels), Etchernet cable 5mm (other signals and 60V power)

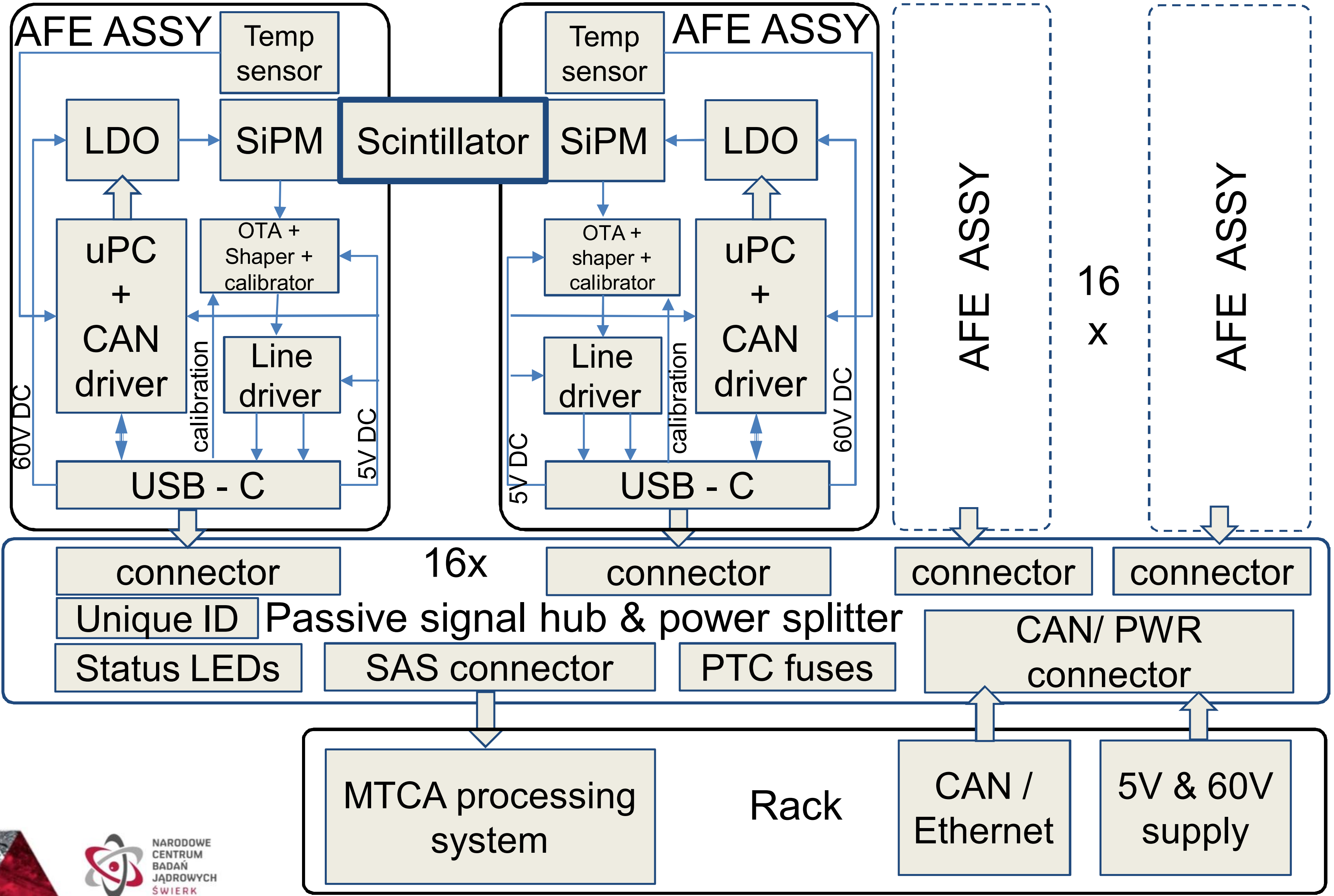
MTCA Carrier Hub

For several MTCAs one main MCH concentrates data from slave MCHs to generate the final muon trigger

We need cabling system that provides near 1GHz bandwidth and very low crosstalk <30dB@1GHz to maintain sub-ns precision of pulses time-of-arrival measurement.

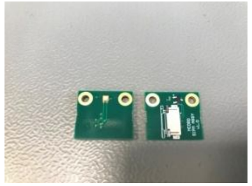
4. Scheme of Analog Fron-End electronic

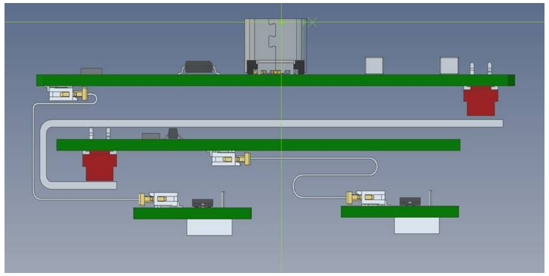
Dedicated Analog Front-End module: CAN network connectivity with unique ID chip as CAN address, Unique ID in every hub for cabling checking and identification of Hardware ID

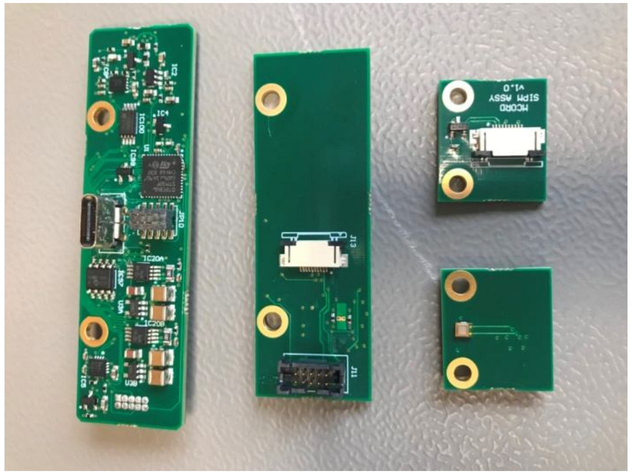


4. Present status of work

Fron-End electronic equipments and PCB bords

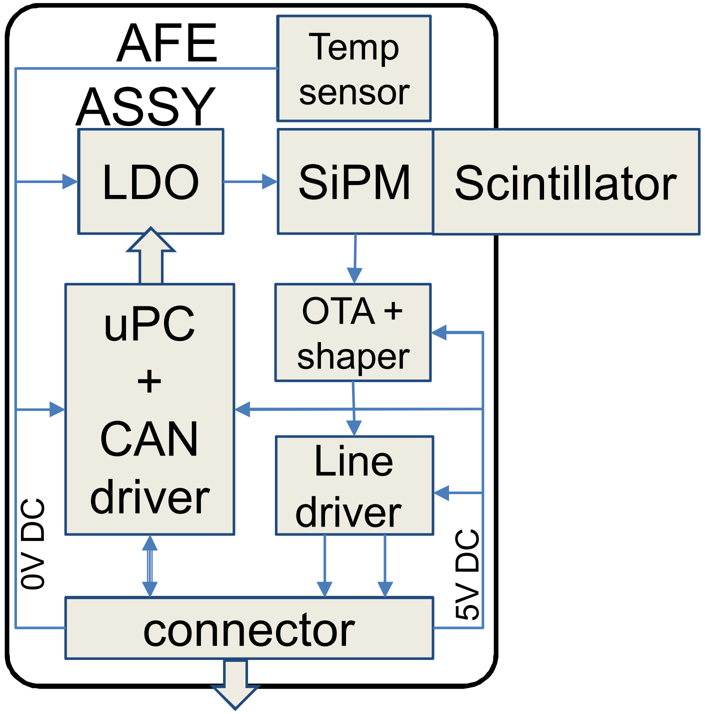


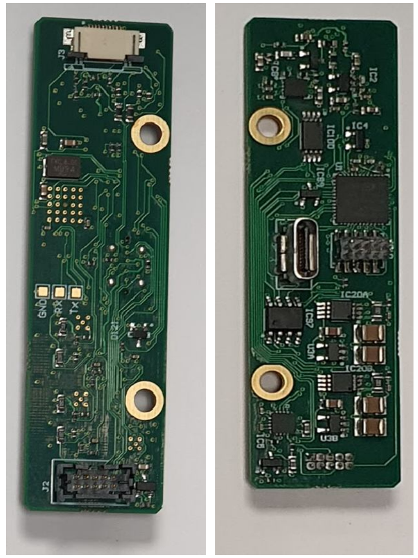




Analog Front-End configuration

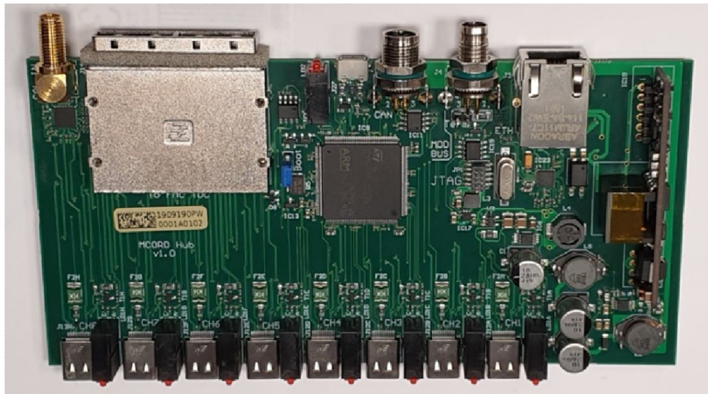
- Dedicated AFE Assembly per 2 SiPM detectors
- Embedded uPC + temperature sensor +dual LDO for SiPM set point adjust
- CAN network connectivity with unique ID chip as CAN address
- Low cost LDO instead of expensive SMPS power supply. No inductors required and lower EMI.
- SiPM voltage, AFE current monitoring, latchup detection & protection for AFE





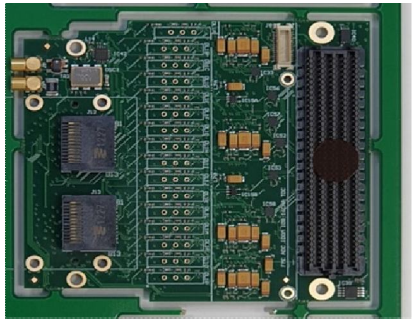
Hub & supply

- ➢ Local supply hub with PTC fuses for 5V and 70V rails
- ➢ PoE supply, Generation of 5V, 70V
- ➢ ETH <-> CAN
- ➢ distribution of signals from AFE to SAS
- ➢ Low cost shielded SAS cables – COTS components available as a custom versions length, 10GHz BW
- ➢ Status LEDs on AFE ASSY and hub for quick fault identification
- ➢ STM32 CPU with uPython - quick local diagnostics using easy to use tools, just any computer/smartphone with USB is needed
- ➢ Supply and communication from standard PoE switch



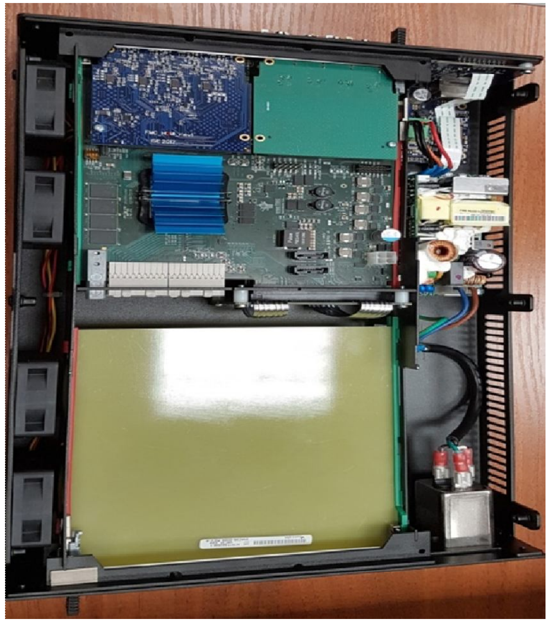
FMC/TDC

- ➢ 16 channel TDC with 10ps resolution and 50MS/s rate
- ➢ simultaneous ADC and TDC operation
- ➢ flexible clocking system with internal/external clock
- ➢ dual SAS cable input for ultra-wide BW

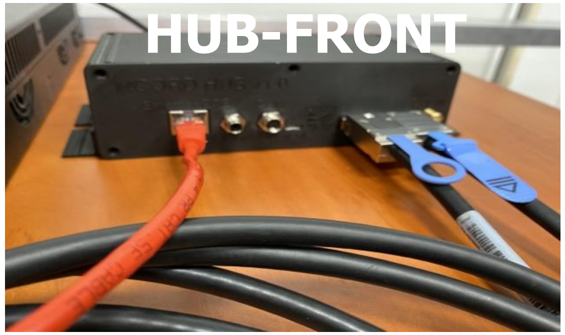


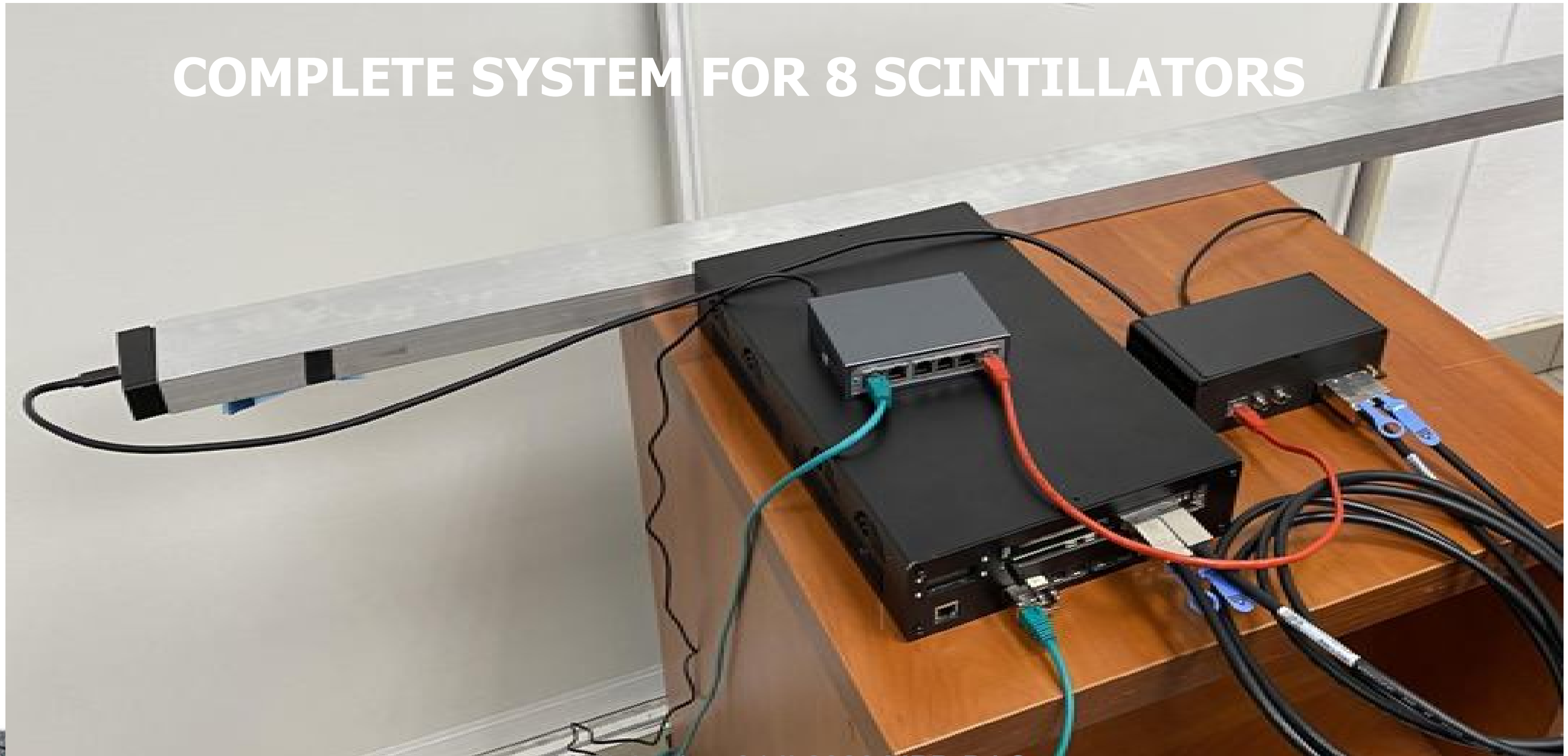
uTCA processing box

- ➢ 32 channels per AMC board
- ➢ sub-ns timing synchronization, board-to-board thanks to WR/DRTIO protocol
- ➢ Low cost, portable alternative to large uTCA crate
- ➢ Ethernet + 10Gbit interfaces



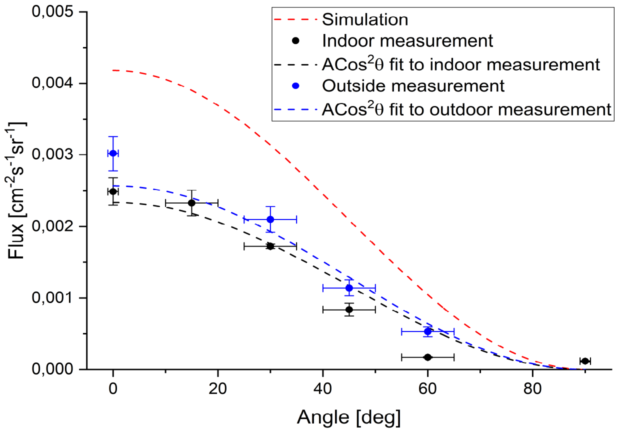
MCORD hardware prototype





4. Present status of work

Cosmic Ray Measurement Assembly with two Cosmic Watch detectors on two arms.



The Cosmic Watch detectors measurement results at Dubna (July 2019y). Flux dependence on the direction with respect to the azimuth (coincident mode).

5. Conclusions

1. Cosmic Ray Detector is necessary for good calibration of TPC, TOF and ECAL, MPD detectors **before completion of the MPD .**
2. MCORD can be useful for detection of rare processes of **muonic dilepton production.**
3. Additionally MCORD can be used for unique astrophysics observations similar to past collider experiments.
4. Cosmic ray detector might be helpful for better calibration of TPC TOF, before each experimental session.
5. The First demonstrator (two MCORD sections) should be ready by half of 2020 and can be use to calibration measurements.
6. The first two MCORD modules should be ready on the beginning 2021 y, and can be install on MPD surface

Our group is a member of the Polish consortium NICA-PL

Polish consortium NICA-PL

Thank You for Attention!