MCORD detector
Present status

by Polish consortium NICA-PL

MPD Collaboration Meeting, 21-23. Apr. 2021

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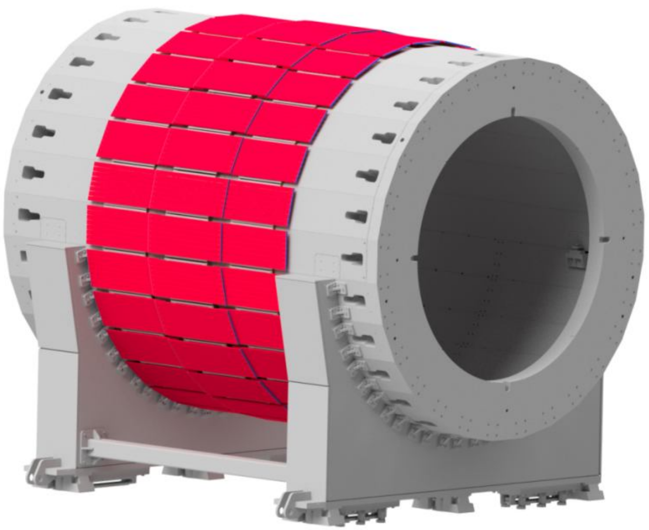
JINR

Outline

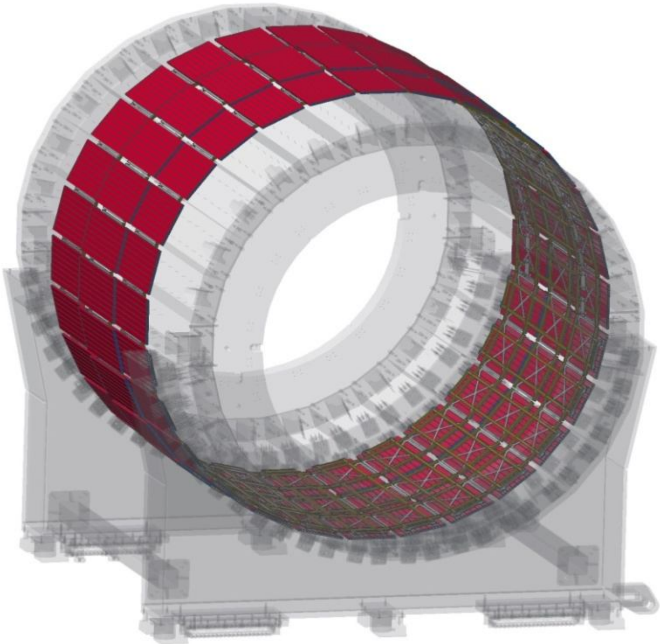
1. Introduction
2. Mechanical Construction upgrade
3. Electronics and software upgrade
4. Trigger
5. Laboratory tests
6. MCORD demonstrator
7. Summary



MCORD applications for MPD

1. Trigger for cosmic muons for:
   - laboratory tests of MPD subsystems
     (2 separate MCORD sections - soon)
   - MPD off-beam calibration in service position
     (6 MCORD modules – about one year)
2. Muon identifier (E > 1 GeV) for:
   - 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
4. Modular construction – easy upgrade and/or alternative use

1. Introduction



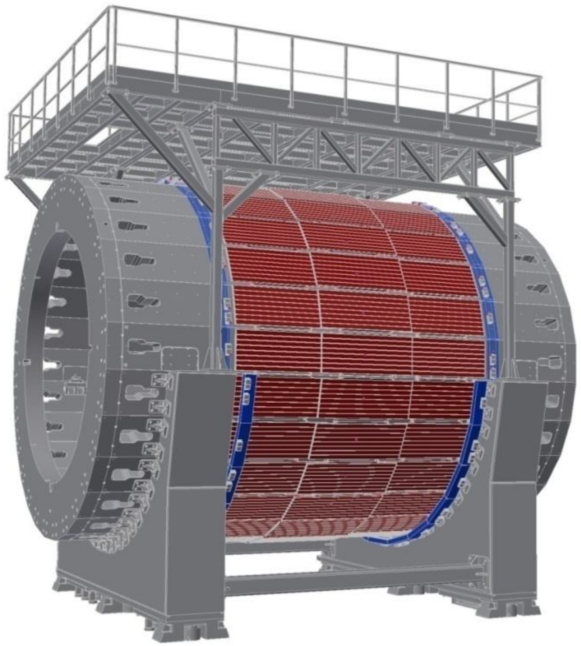
MCORD modules on MPD surface

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

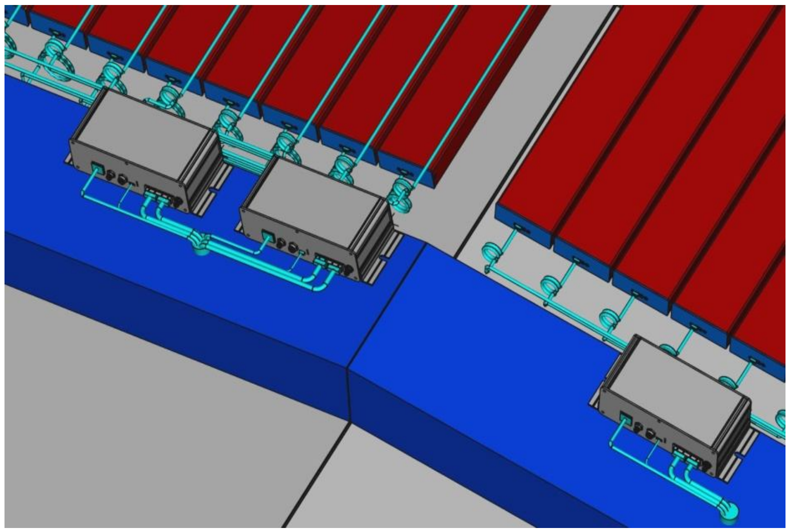
Module size:
4784 x 735 x 140 mm

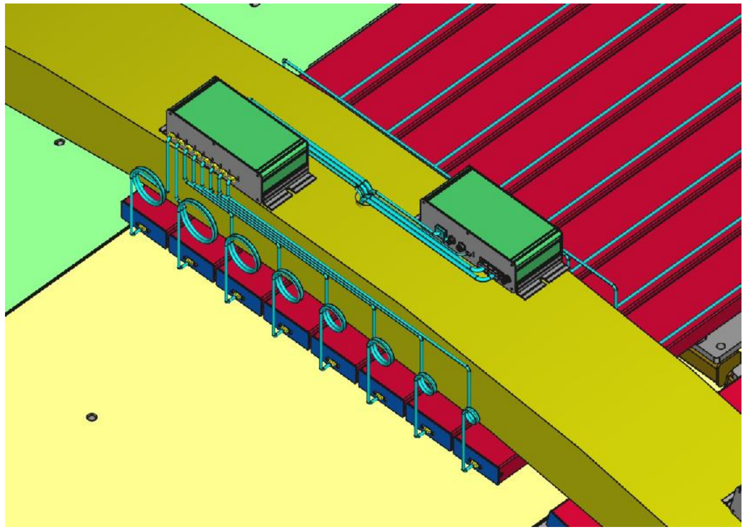
Total number of Scintillators = 672

2. Mechanical construction
Old and new



Old - Cable channels and HUBs are located next to the MCORD modules.

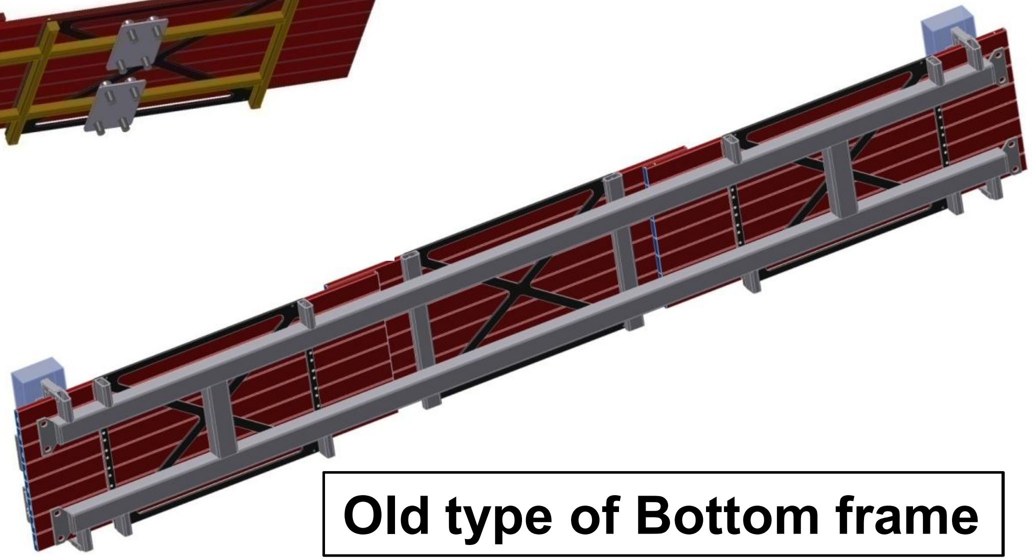




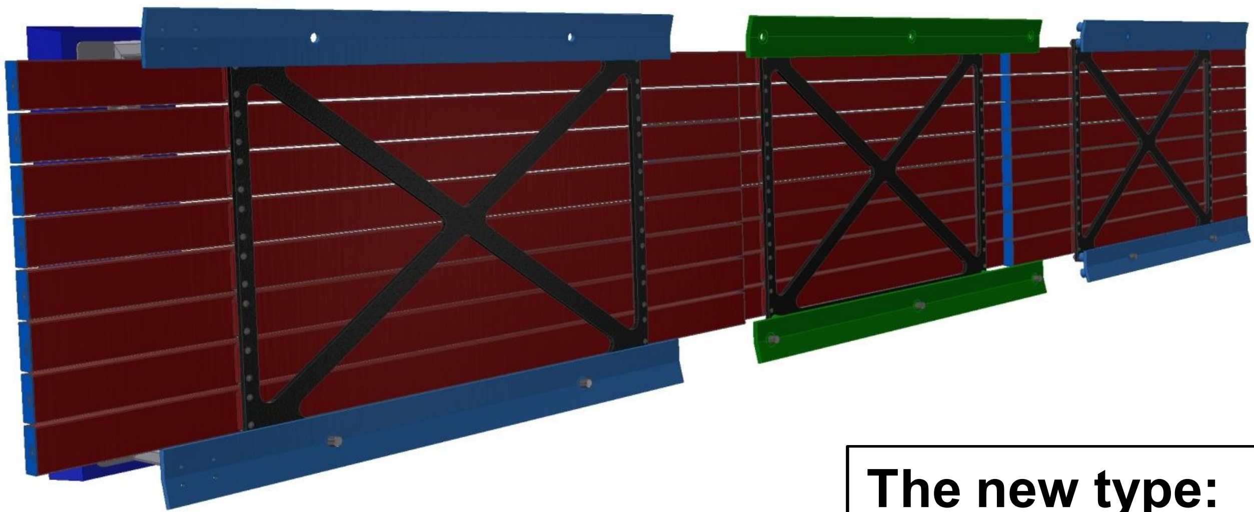
New - Cable channels and HUBs are located on MCORD modules.

2. Mechanical construction

Old type of Upper frame



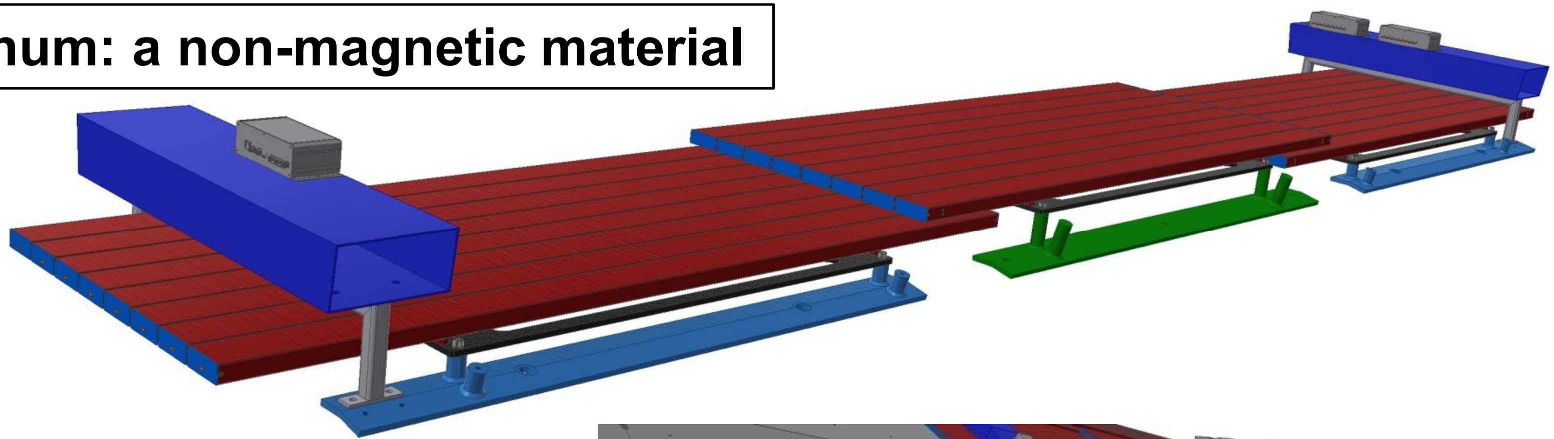
Old type of Bottom frame

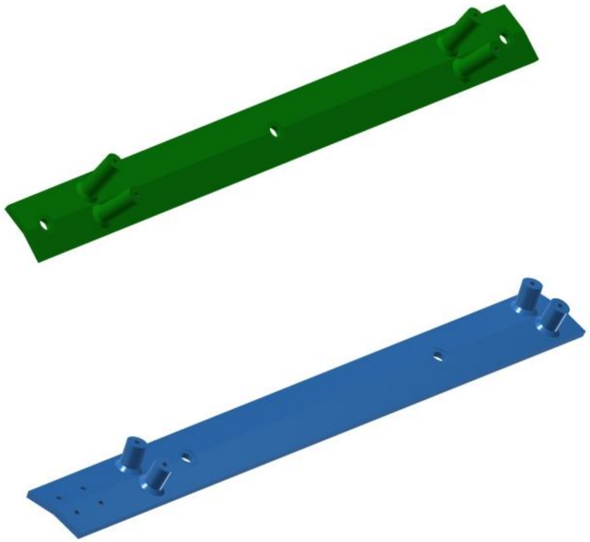


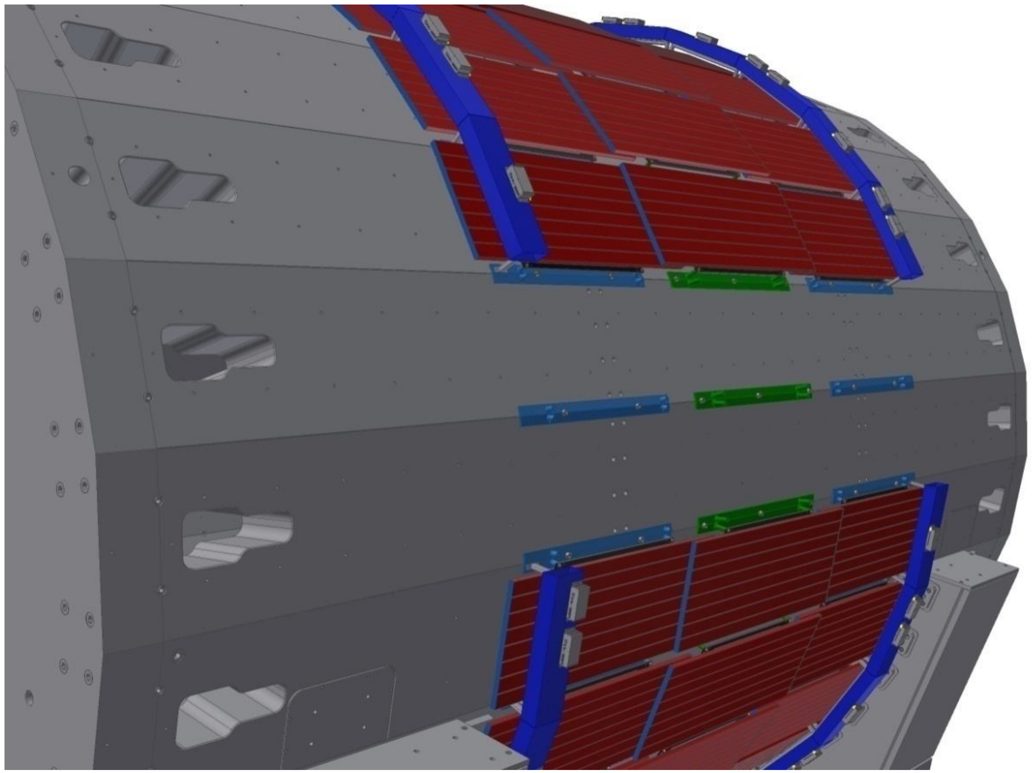
The new type:
6 legs instead of the frame

2. Mechanical construction

Aluminum: a non-magnetic material







Central and L-R supports

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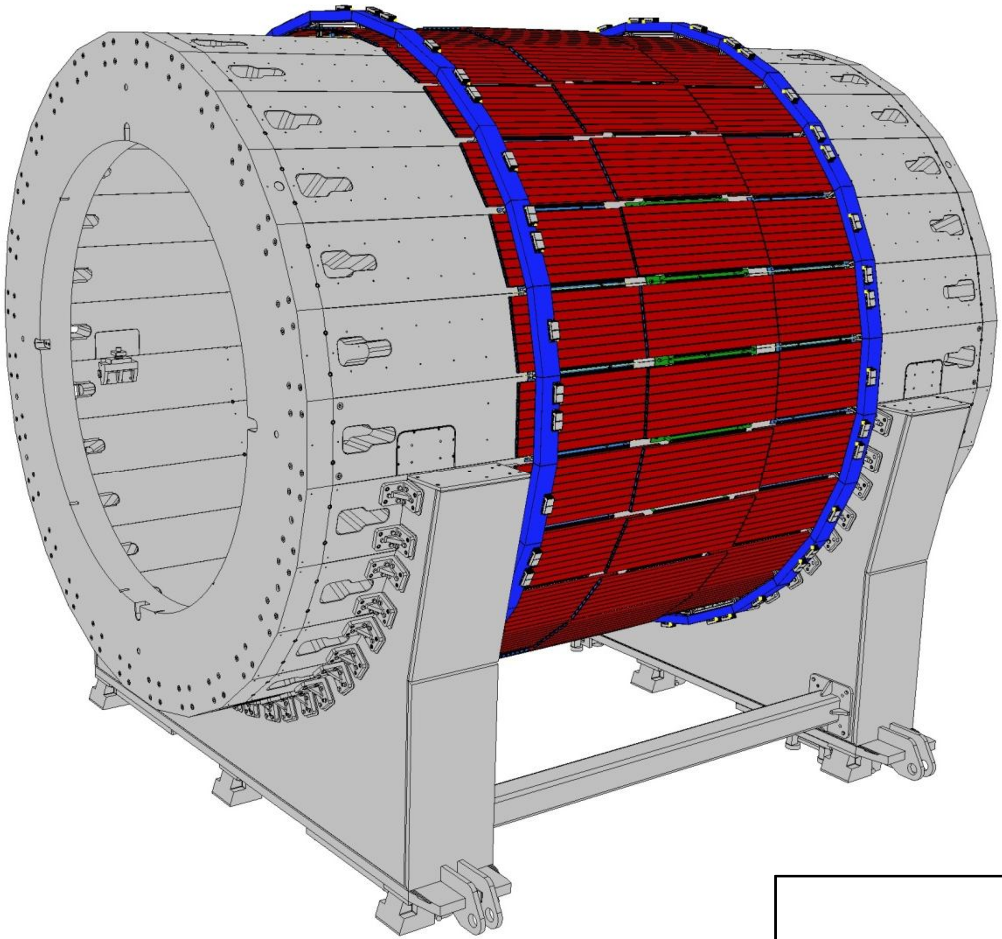
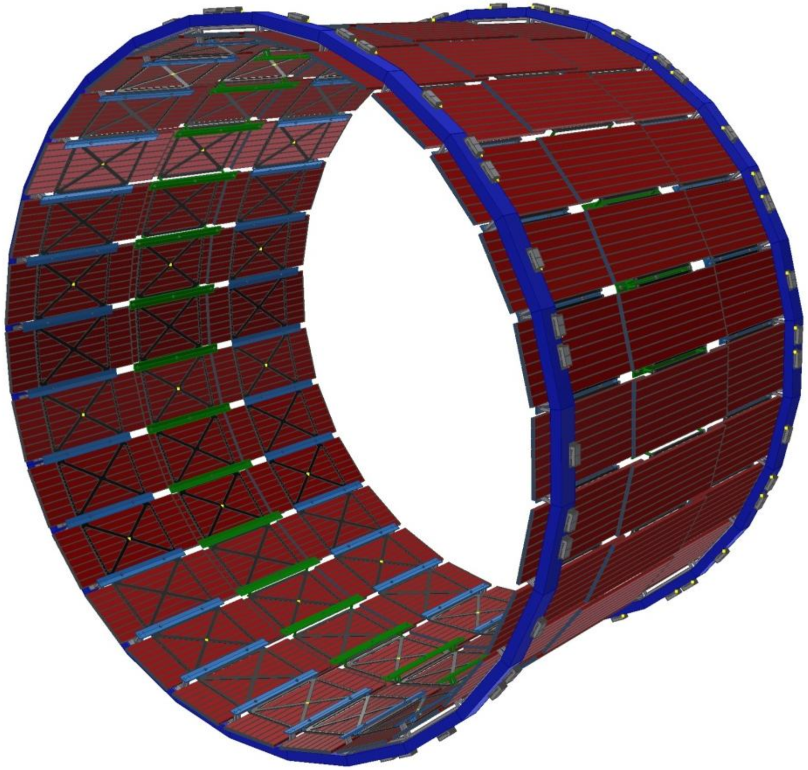
2. Mechanical construction

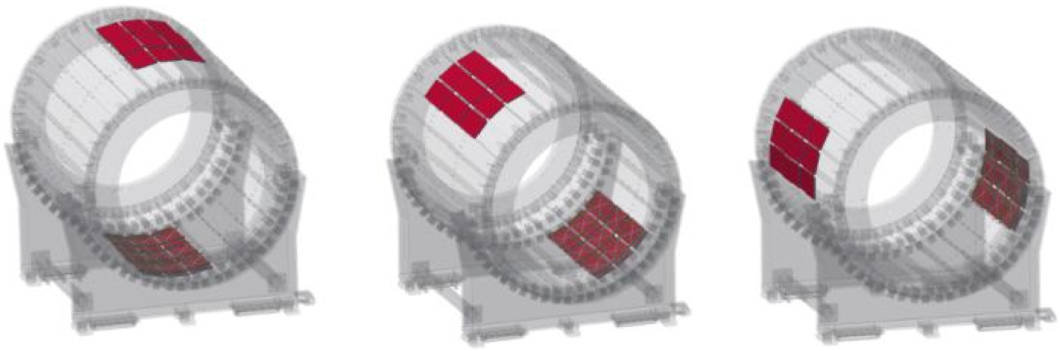




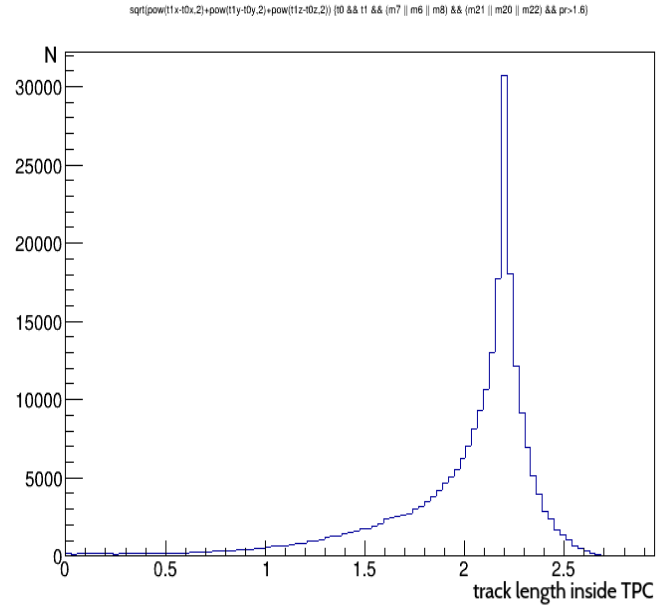
28 MCORD modules
Cable chanels with HUBs – blue
Mounting legs – light blue and green

2. Mechanical construction - advantages

TPC calibration using MCORD trigger.
Faster movement of MCORD elements.



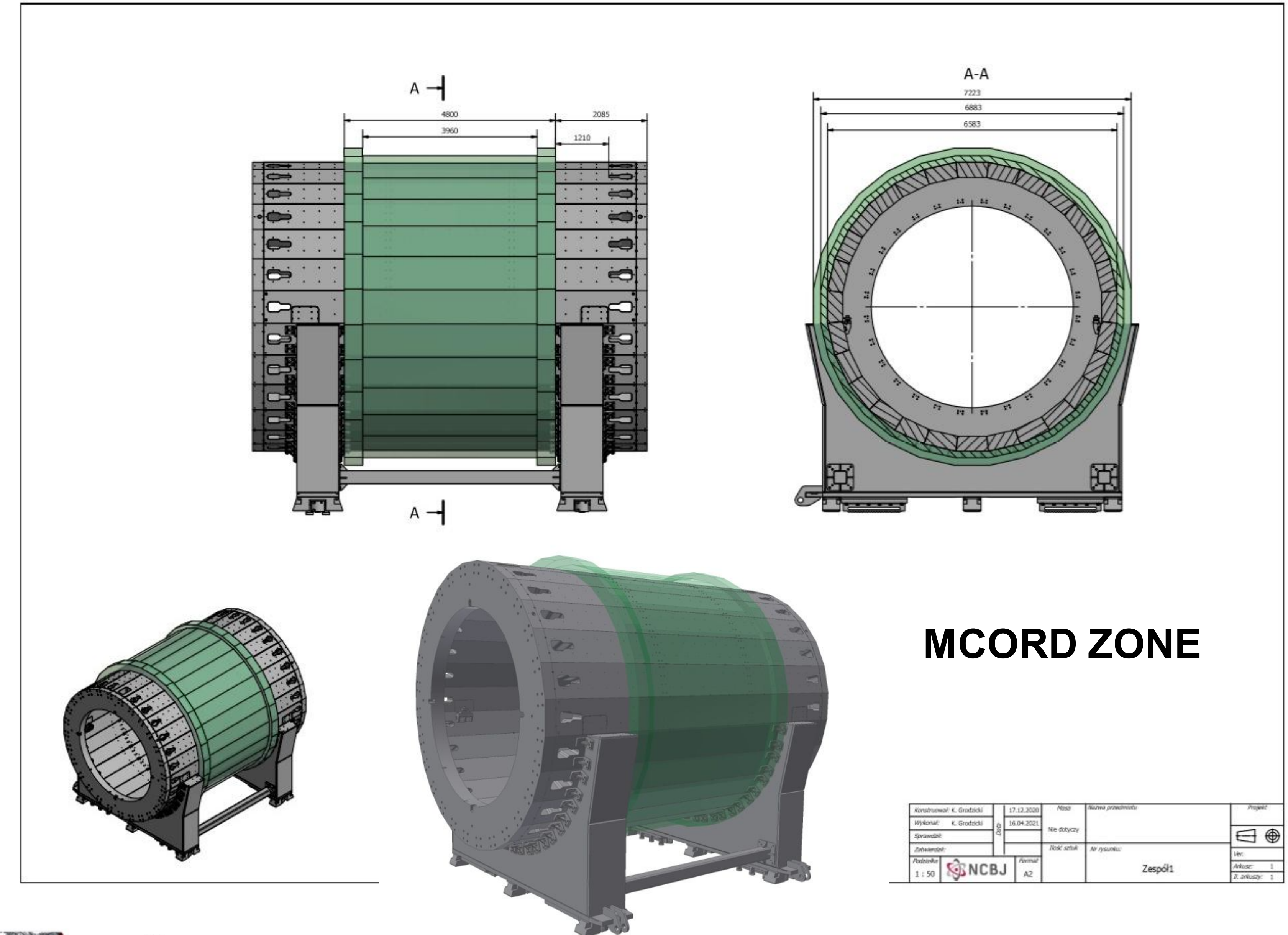
A B C



Calculated for muons with momentum **p > 1.6 GeV/c** by **Cofluxim Program.**

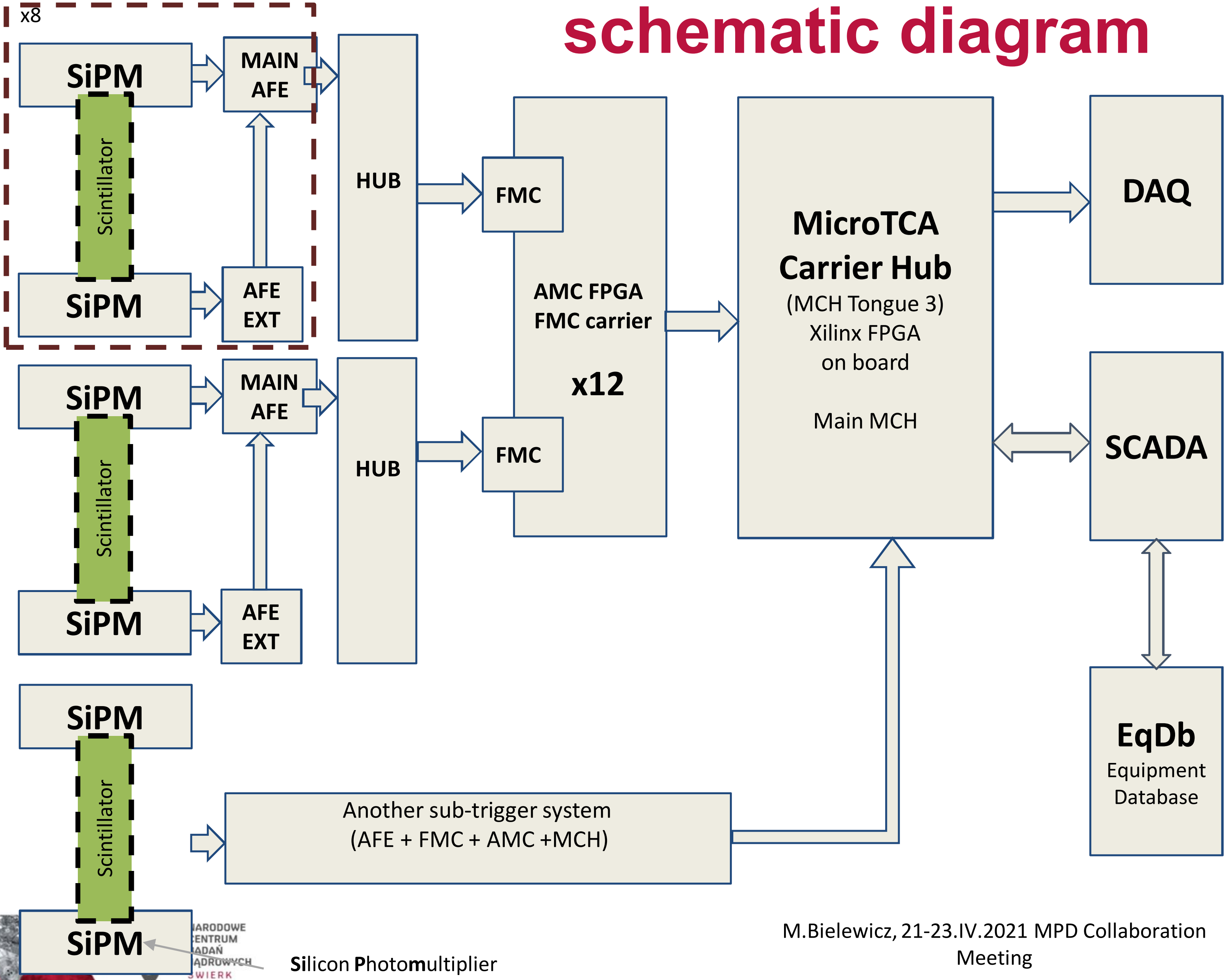
MCORD configuration	MCORD modules ID numbers	MCORD & TPC (tracks per hour)
A	(6 or 7 or 8) and (20 or 21 or 22)	**246 800**
B	(9 or 10 or 11) and (23 or 24 or 25)	**158 262**
C	(12 or 13 or 14) and (26 or 27 or 0)	**20 634**

2. Mechanical construction - advantages



MCORD ZONE

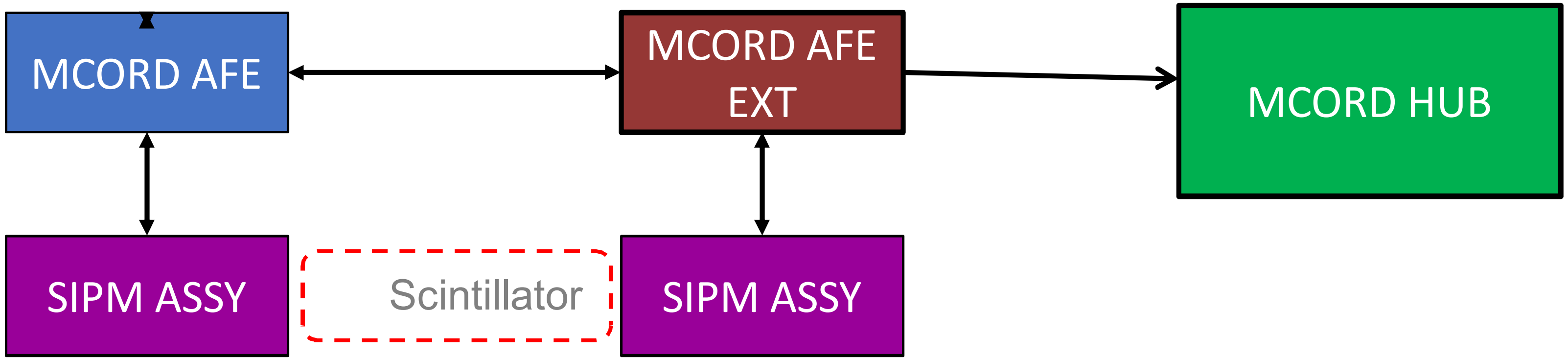
3. MCORD readout system schematic diagram



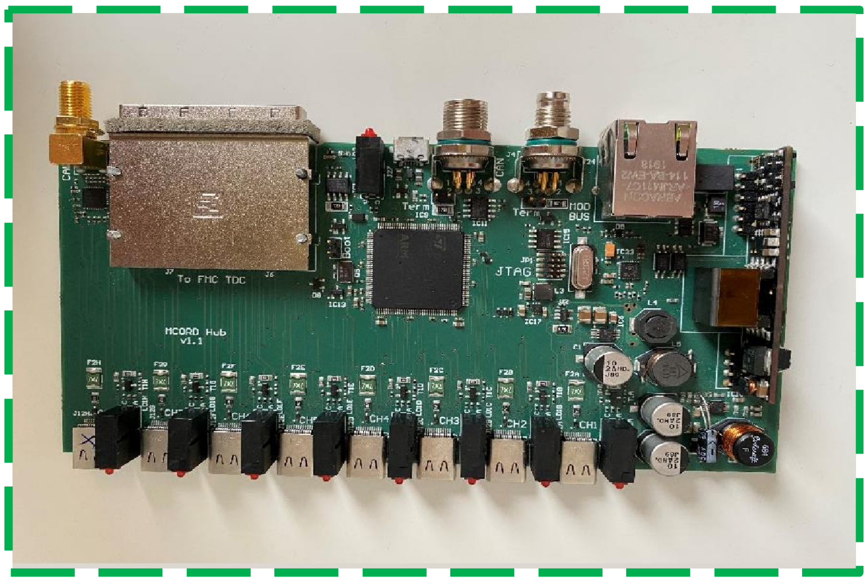
3. Analog Front End – boards ver.3

The main boards ver.3 correction:

1. Gain level   2. Cable checking system   3. Type of some electronic elements





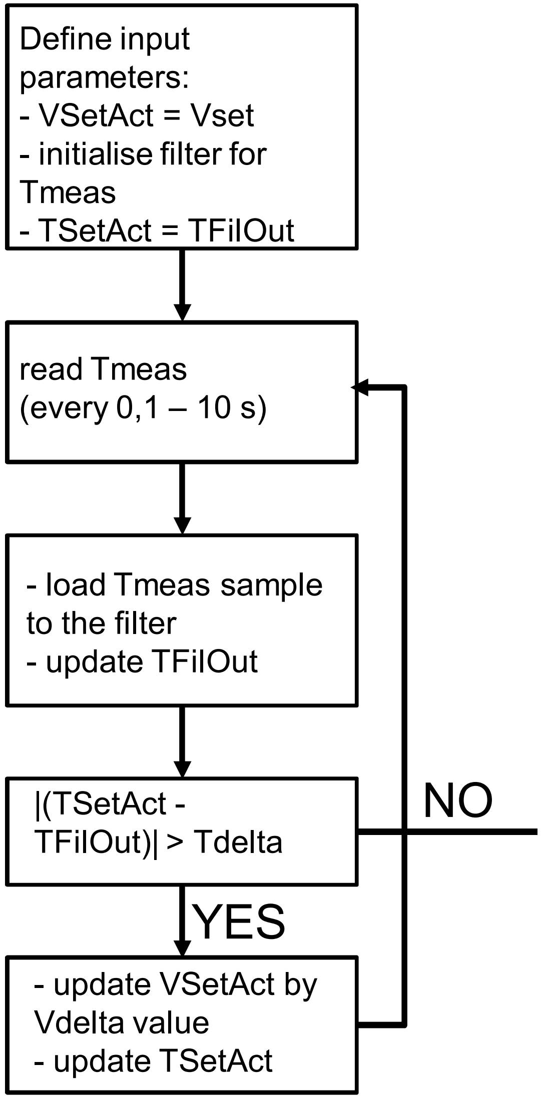



3. The new functionality of AFE

Voltage Control Loop

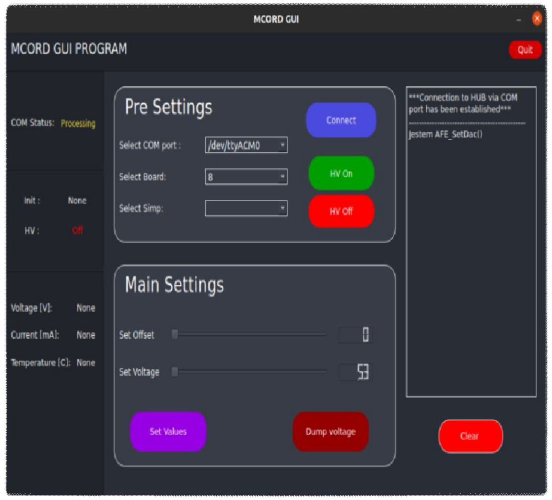
- SiPM Voltage depends on the current temperature
- The controller works in a loop

Input parameters:
- **Vset** - start voltage set point
- **Tdelta** - defines minimal change of the temperature for which the voltage will be updated
- **Vdelta** - defines minimal change of the voltage when temperature changes



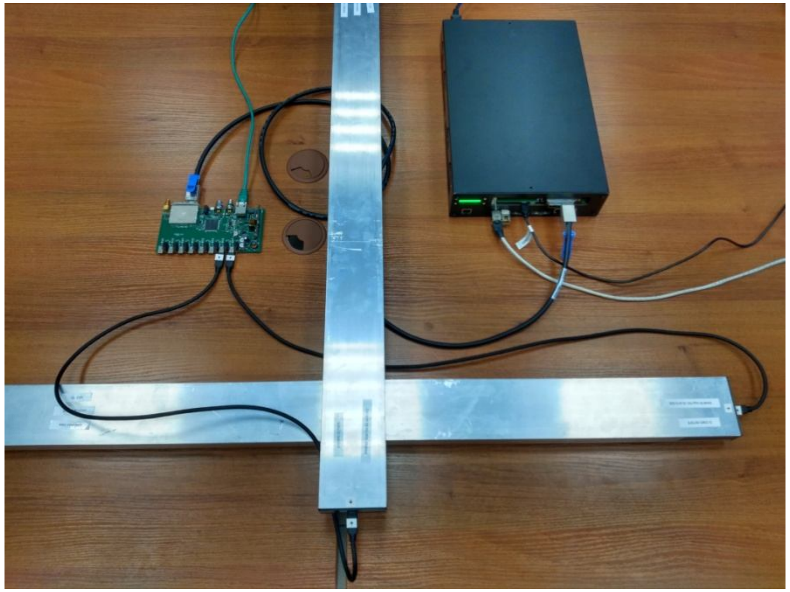
GUI and servis panel

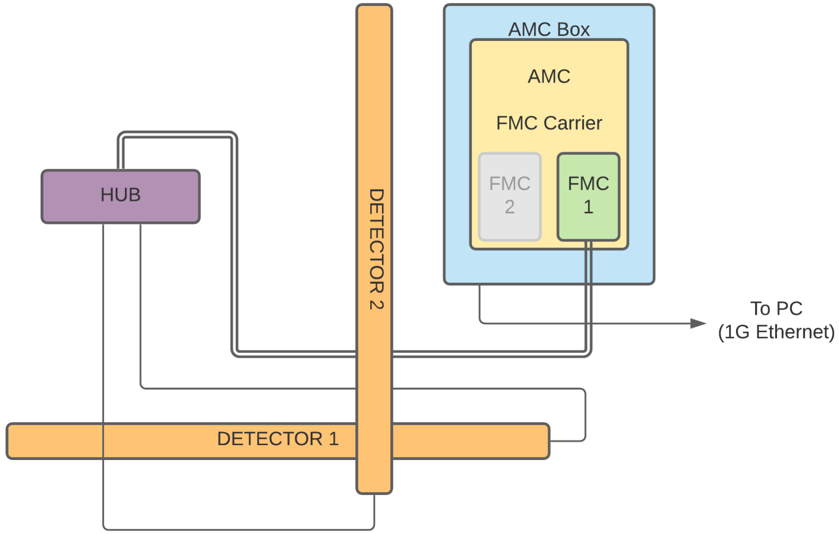
- Using the graphical interface, it will be possible to easily manage the voltage on all photodetectors
- In order to facilitate the use of the layout, a GUI is written using the Qt libraries



3. The FPGA software

MCORD Testing setup for FPGA Software development





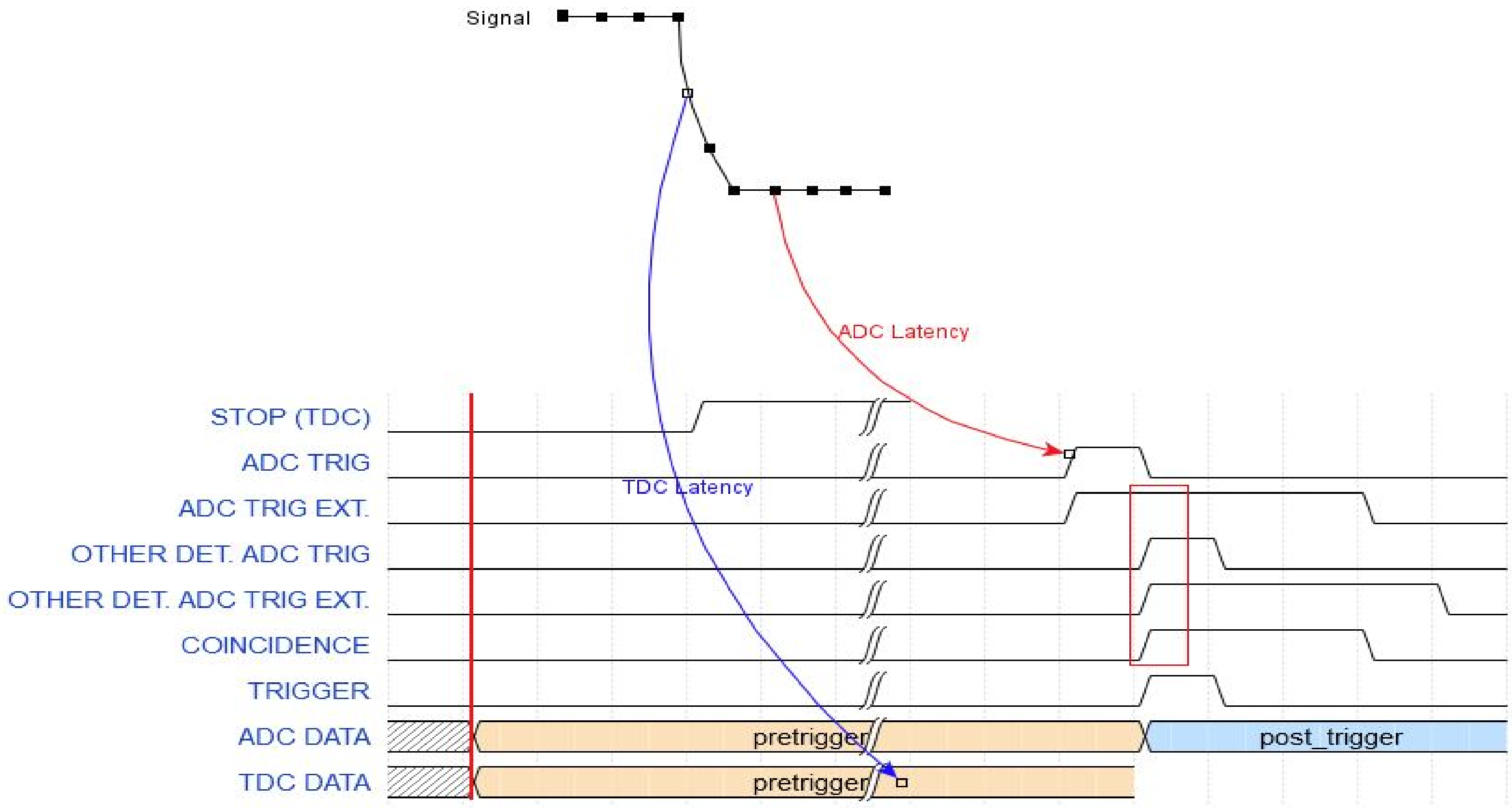
Minimal hardware setup view

The system has one AMC box and up to two MCORD HUBs, up to 16 detectors (2*8)

AMC Box (temporary only for software work and for MCORD Demonstrator
Inside: Single AMC board, up to two FMC card, power suplly)

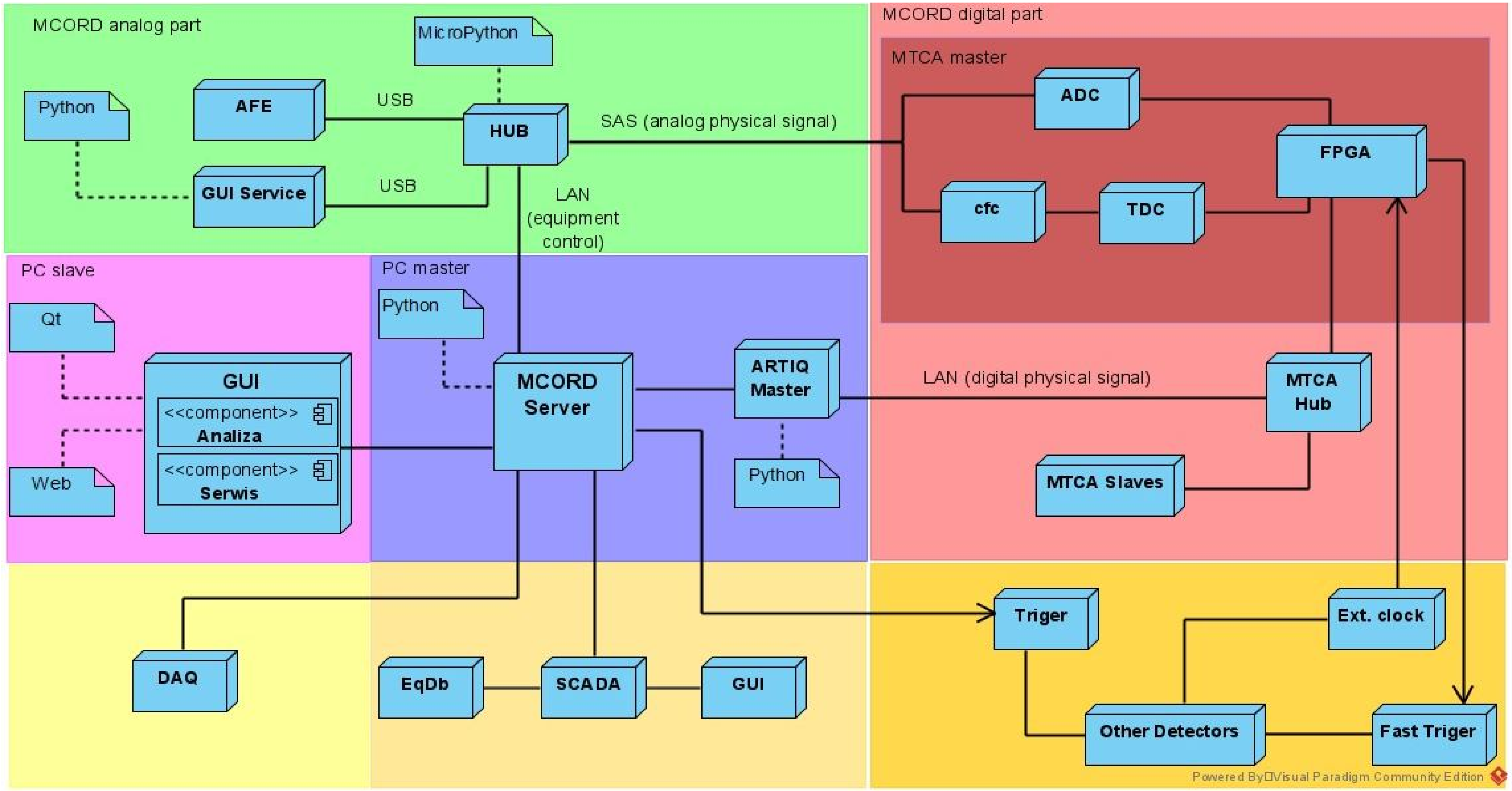
3. The FPGA software

Measurement integration from ADC and TDC electronic systems



When trigger is supplied a specified number of previous samples (pretrigger) and ongoing samples (post trigger) are transfered to the intermediate memory and later to the PC

3. MCORD Software Architecture Description

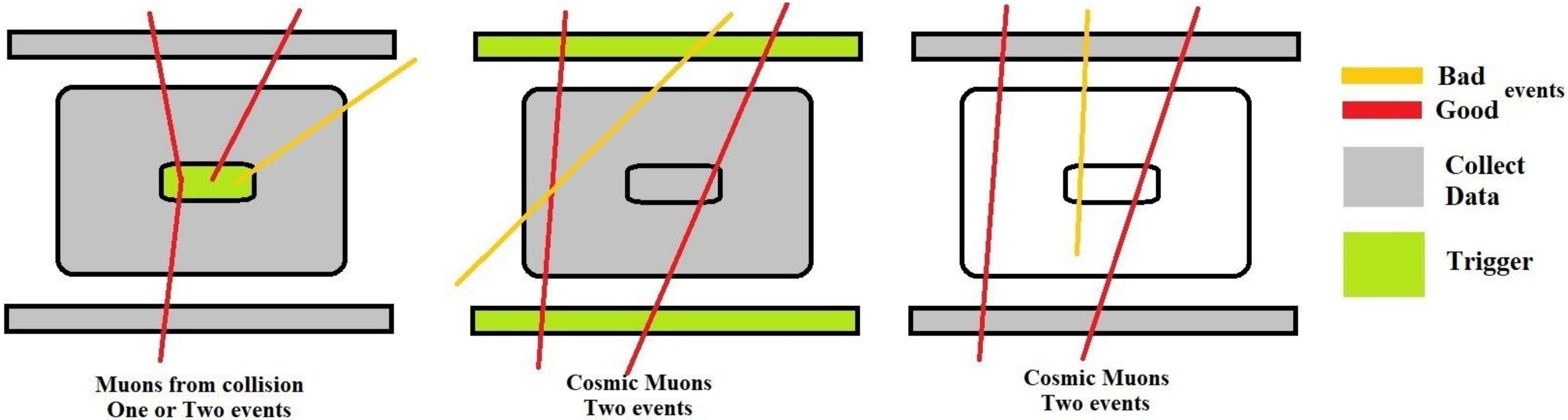


- The system is divided into parts on the basis of their role and implement. platform.
- MCORD Server is a central part controlling system elements
- In this model user interface is totally separated and can be implemented in any way (Web/App/CLI) and changed later on without modifying core MCORD funct.

4. MCORD trigger and acquisition

Three modes of operation:

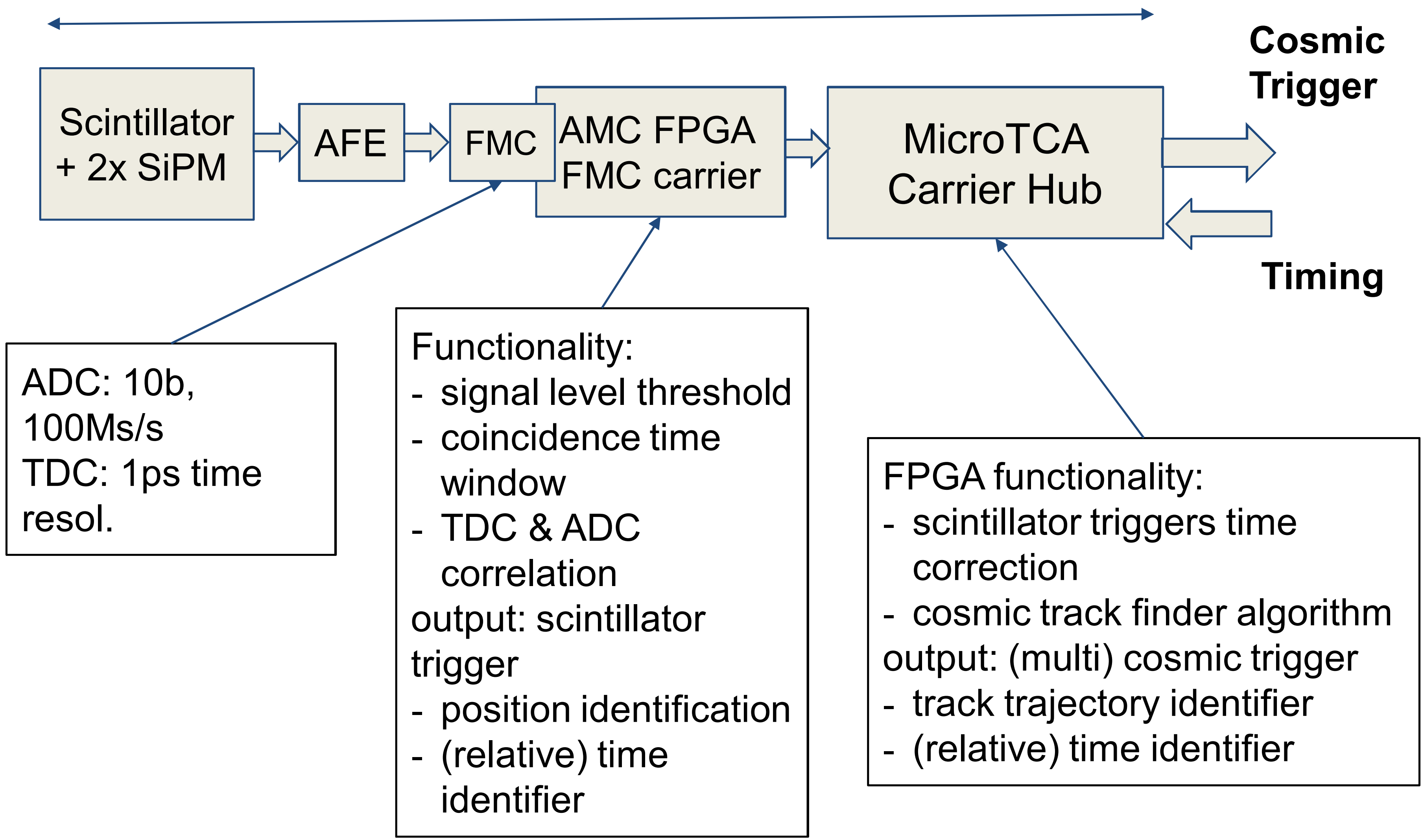
experiment calibration astrophysics



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	
Beam Time	All type in the same time in Beam Time experiment	

4. MCORD Muon Cosmic Trigger

Estimated total trigger latency: 3.5 – 7.5us

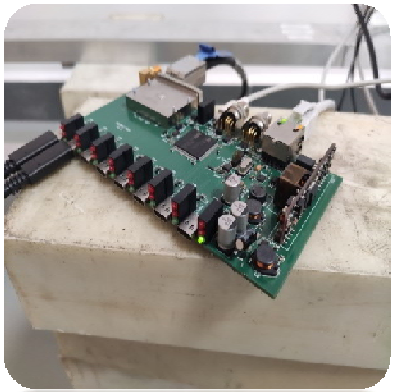


5. Laboratory tests

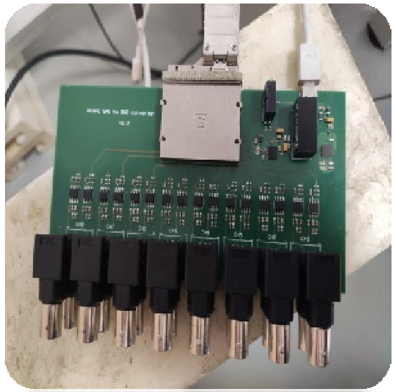
Measuring system

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

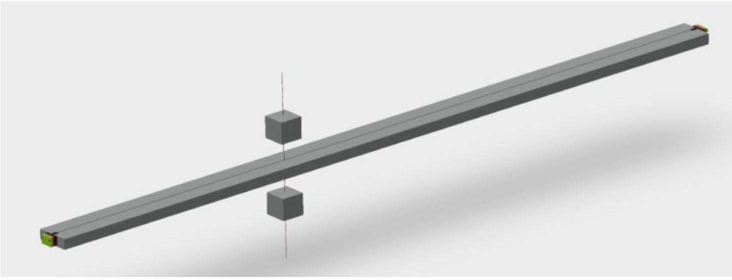


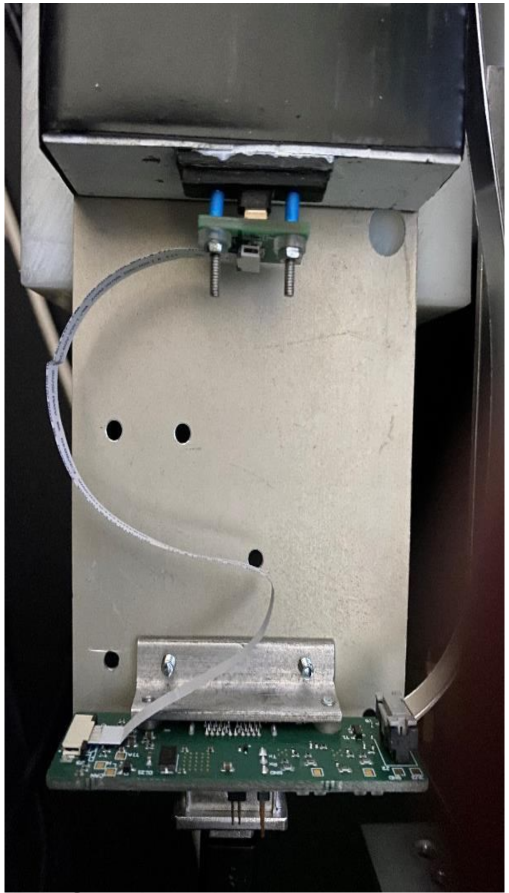
Converter of signals received by SAS cable to appropriate single BNC channels for each MPPC

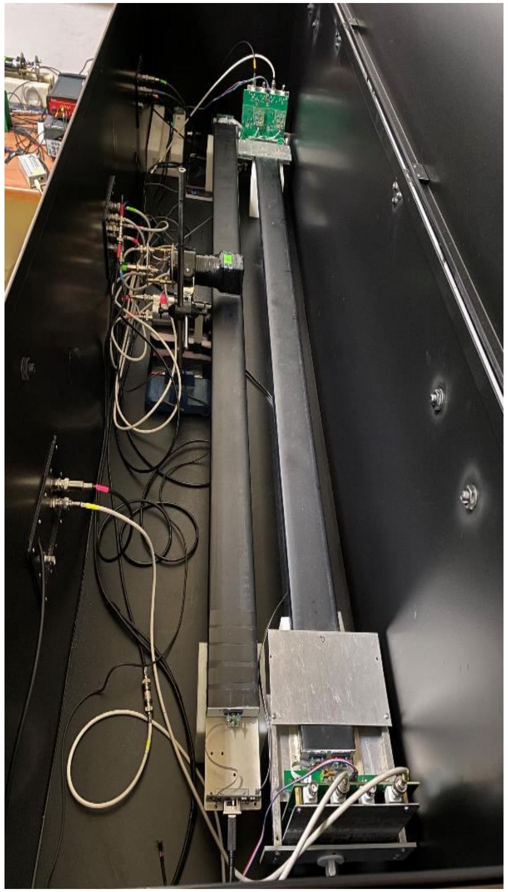
Digital multi-channel amplitude acquirer by CAEN for analysis of received signals

5. Laboratory tests – 1st step

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



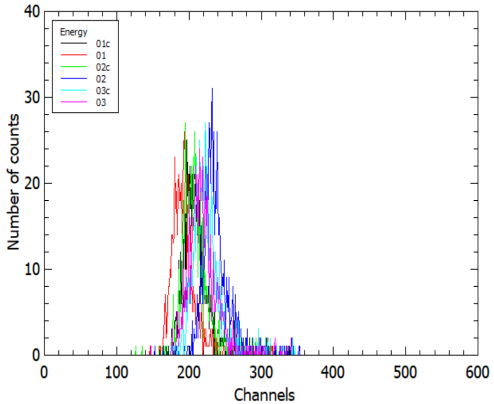




BLACK BOX test setup

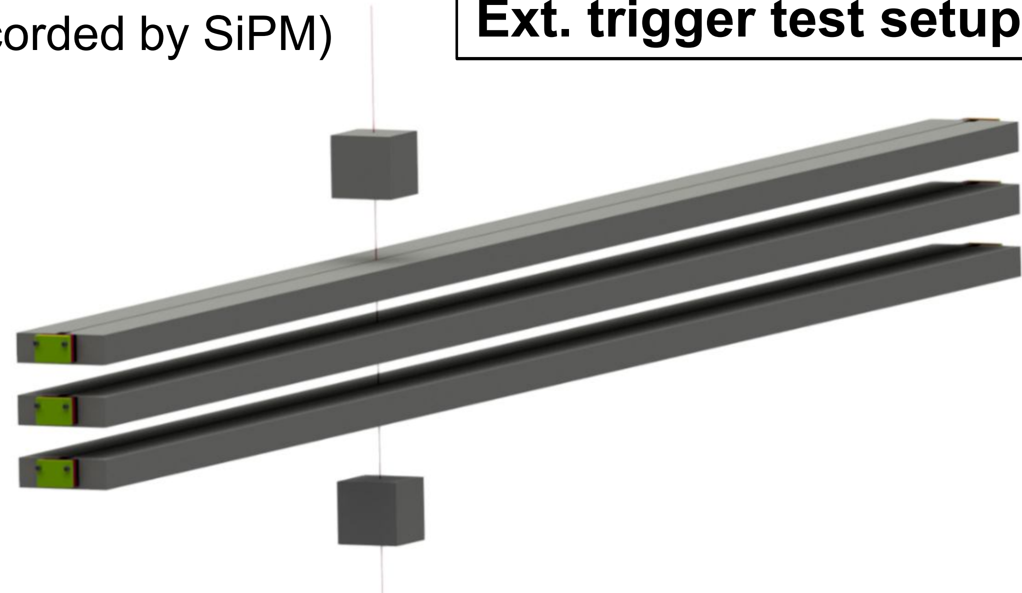
5. Laboratory tests – 2nd step

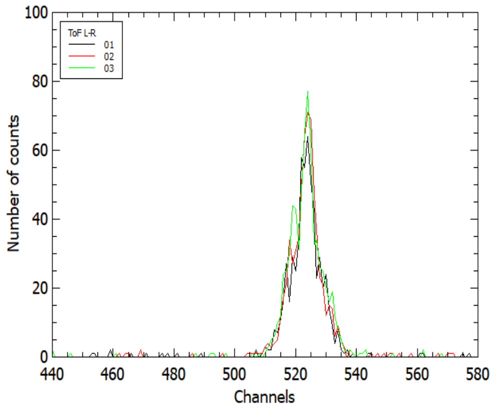
3x plastic MCORD detectors
+ 2x plastic hodoscopes (muon triggers)
+ DAQ: CAEN DT5730



Energy
(amplitude recorded by SiPM)

Ext. trigger test setup



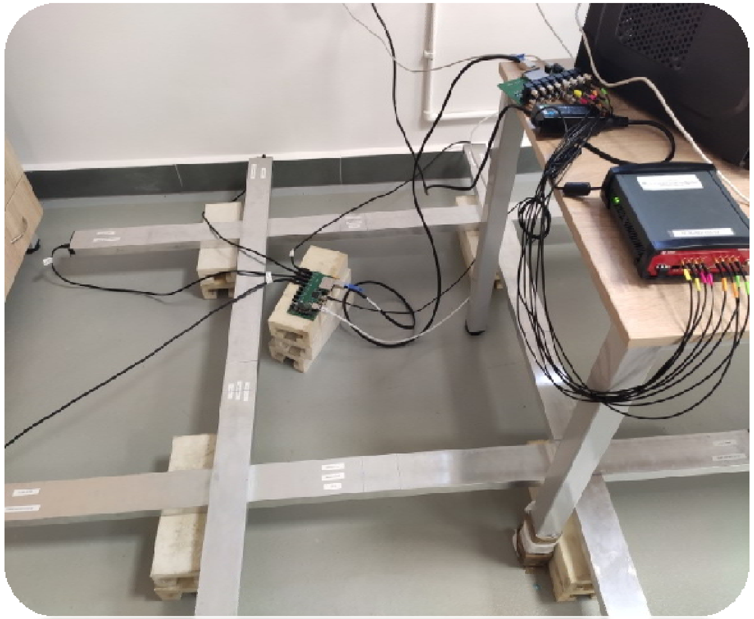


ToF
(between both ends of a scintillator)

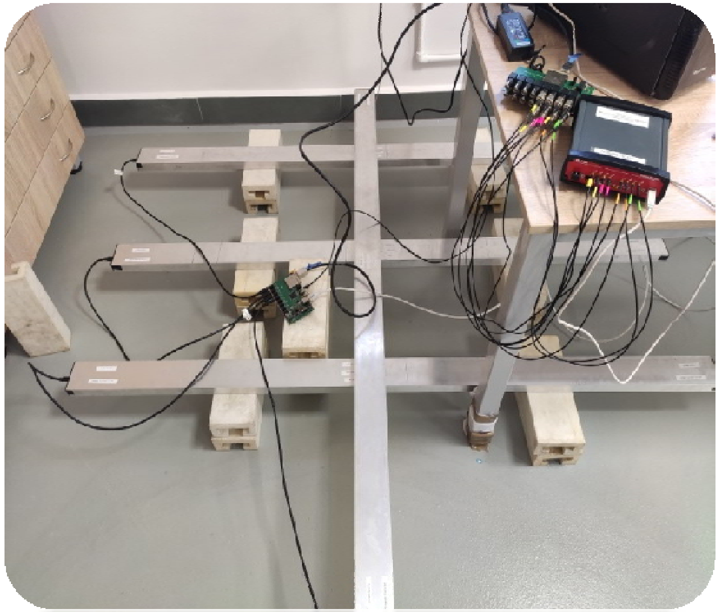
Plastic (162 x 7.2 x 2.2 cm) + WLS fiber (1 mm) + 2x MPPC 3 x 3 mm (pixel size 75um)
Hodoscopes: plastic (5 x 5 x 5 cm) + PMT (2” dia)

5. 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

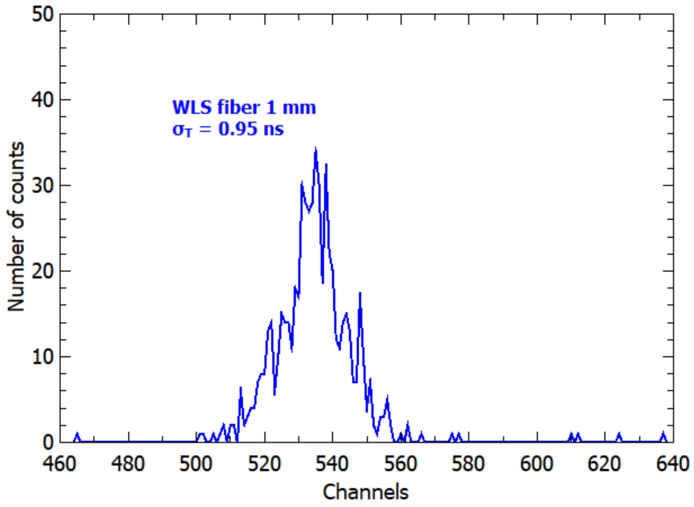
5. Test procedure (from 2nd step)

detector S/N	AFE ID	CRT resolution [ns]
D3036	01	0.95
D3040	02	0.94
D3033	03	0.99
D3047	04	1.00
D3048	05	1.42
D3046	06	1.05
D3042	07	1.03
D3034	08	0.98
D3035	09	0.97
D3044	10	1.09
D3041	11	1.13
D3043	12	0.96
D3038	13	1.08
D3037	14	1.03
D3045	15	0.92
D3039	16	n/a

- 8 out of 16 detectors (ID = 1, 2, 3, 4, 8, 9, 12, 15) show CRT resolution below 1.00 ns,
- 6 out of 16 detectors (ID = 6, 7, 10, 11, 13, 14) show CRT resolution between 1.03 ns and 1.13 ns,
- 1 out of 16 detectors (ID = 5) shows CRT resolution of 1.42 ns,
- 1 out of 16 detector failed to produce acceptable CRT distribution due to low quality of WLS fiber output at one of the ends of the detector,
- 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.

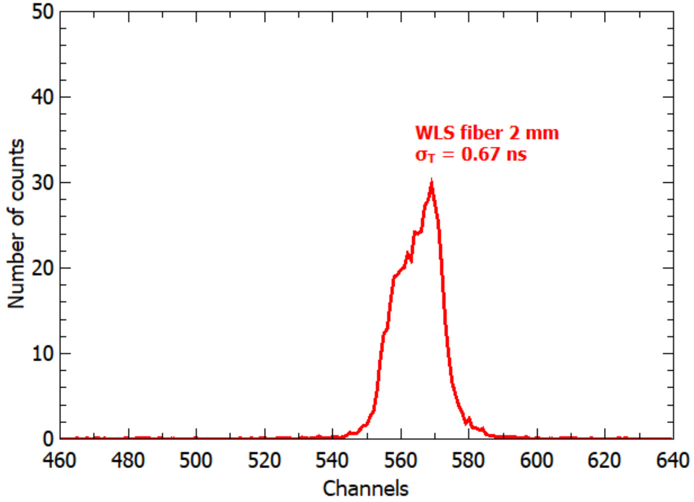
CRT (σ) = 1.0 ns ===> σ_x = 7.6 cm

5. Test procedure



WLS fiber (**1 mm**)

CRT (σ) = 0.95 ns ===> σ_x = 7.1 cm

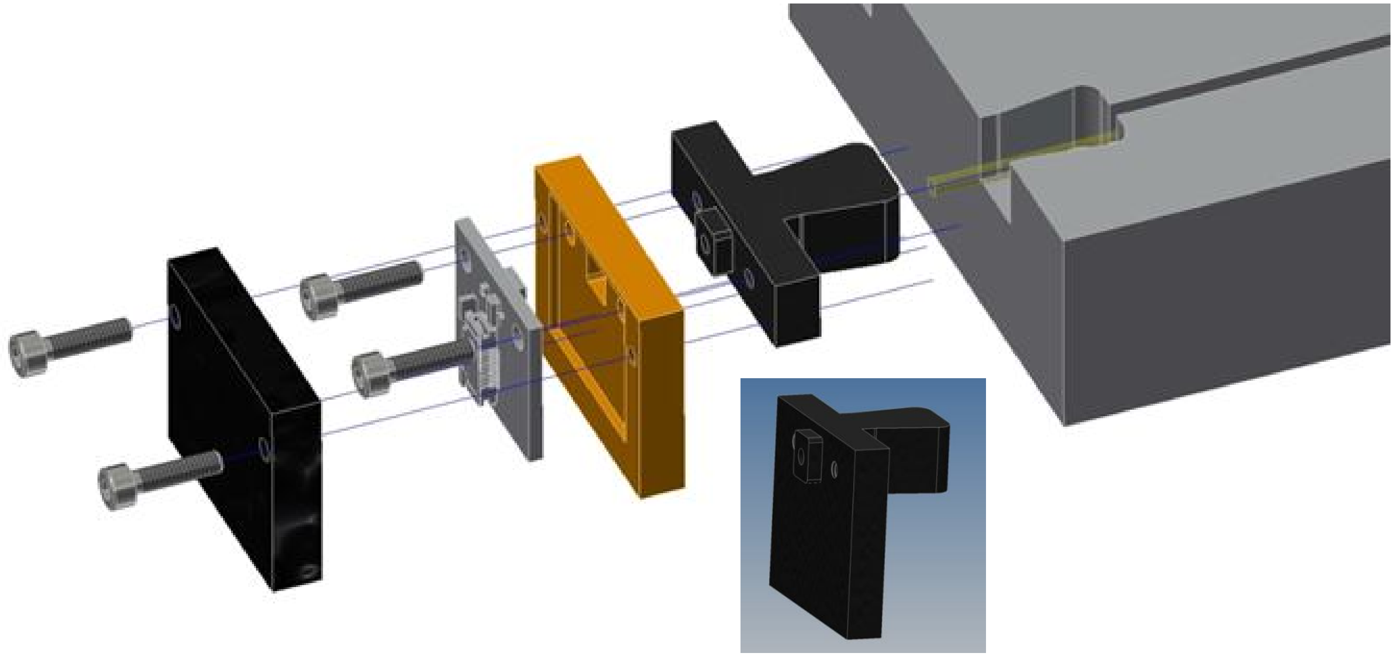


WLS fiber (**2 mm**)

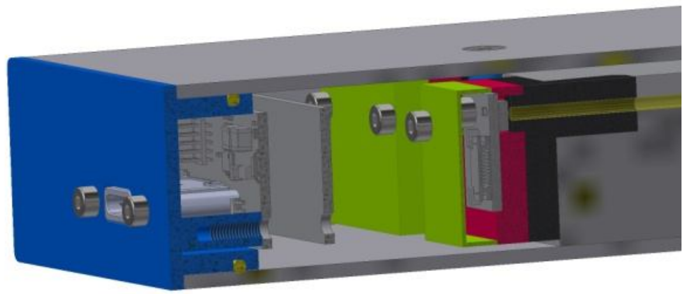
CRT (σ) = 0.67 ns ===> σ_x = 5.1 cm

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

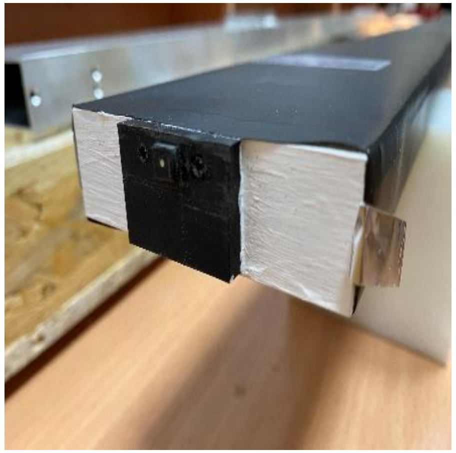
6. Demonstrator manufacturing

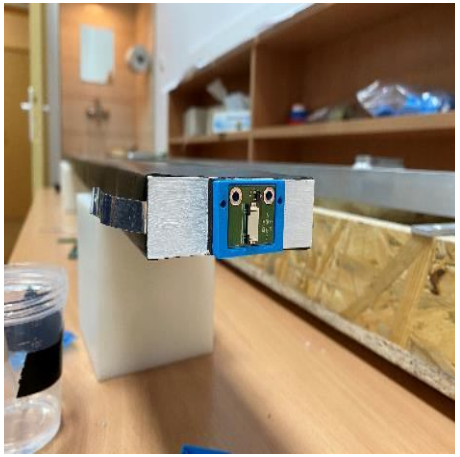


Plastic scintillator:	polystyrene (Nuvia)
	162 x 7.2 x 2.2 cm
WLS fiber:	1 mm dia. (Kuraray)
SiPM (MPPC):	3x3 mm^2 (Hamamatsu)
Housing:	aluminum profile
	174 x 8 x 3 cm
AFE bords	WUT design



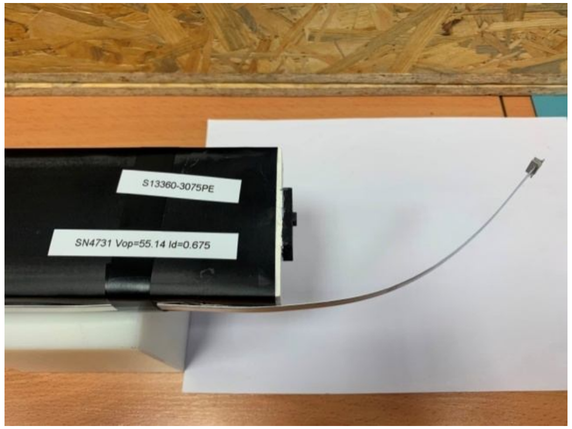
6. Demonstrator manufacturing

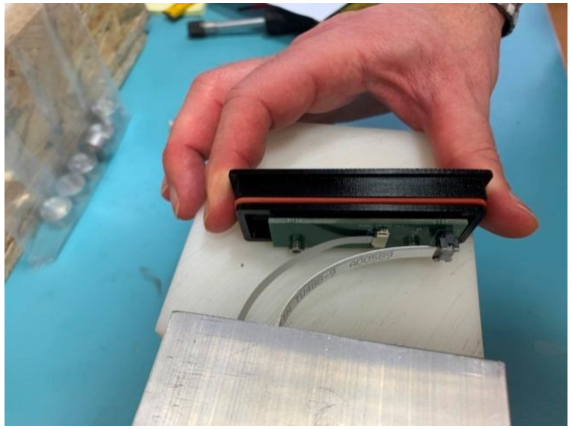





MCORD single detector assembly

6. Demonstrator manufacturing





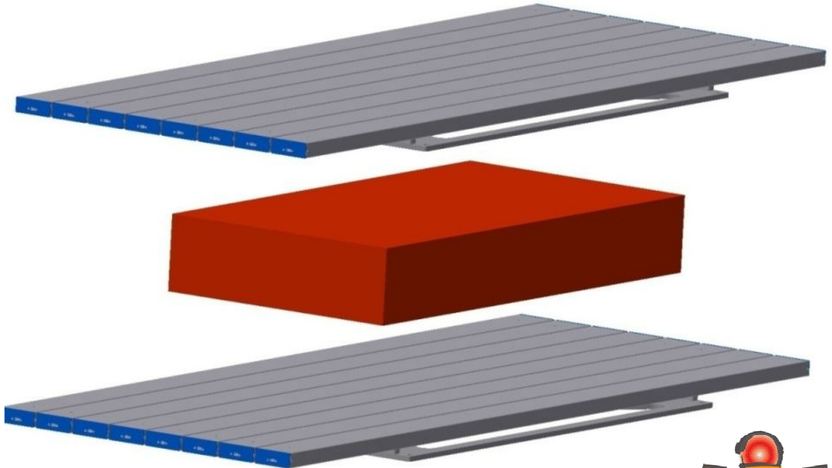
MCORD single detector assembly

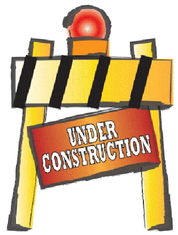
6. Demonstrator manufacturing

MCORD single Section

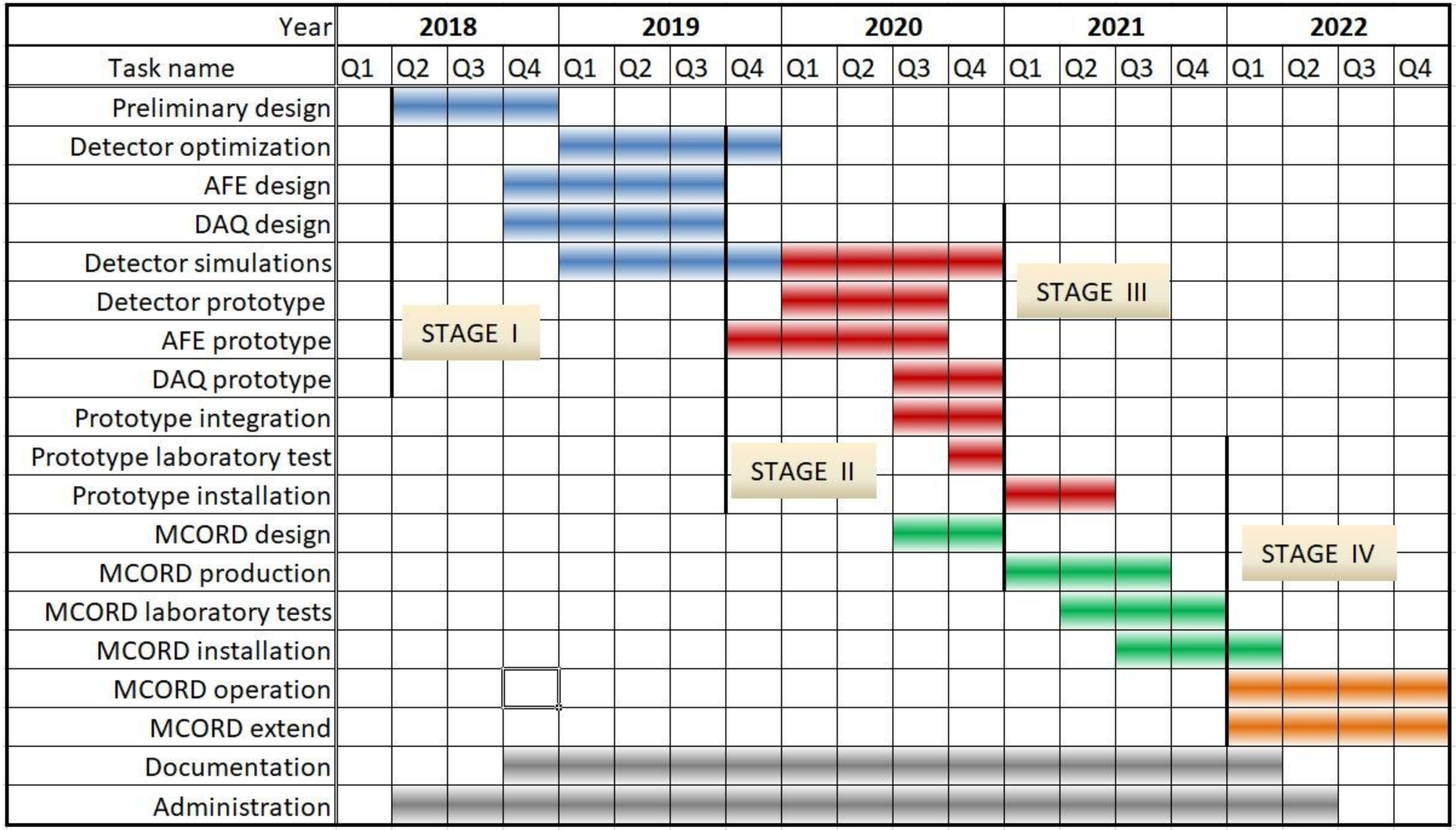
MCORD HUB

Mini MTCA (FPGA)

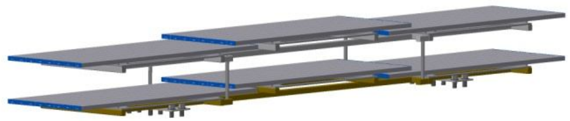




7. Summary



STAGE I – Design and preliminary tests
STAGE II – Demonstrator construction
STAGE III – Construction of the first 6 modules next year
STAGE IV – Construction of additional modules



7. Summary

- MCORD is necessary for calibration of TPC, TOF and ECAL detectors **during off-beam operation of the MPD (during and after installation of other sub-detectors) .**

- The demonstrator (2 MCORD sections) should be ready in the middle of 2021y – **useful for TOF and ECal laboratory characterization**.

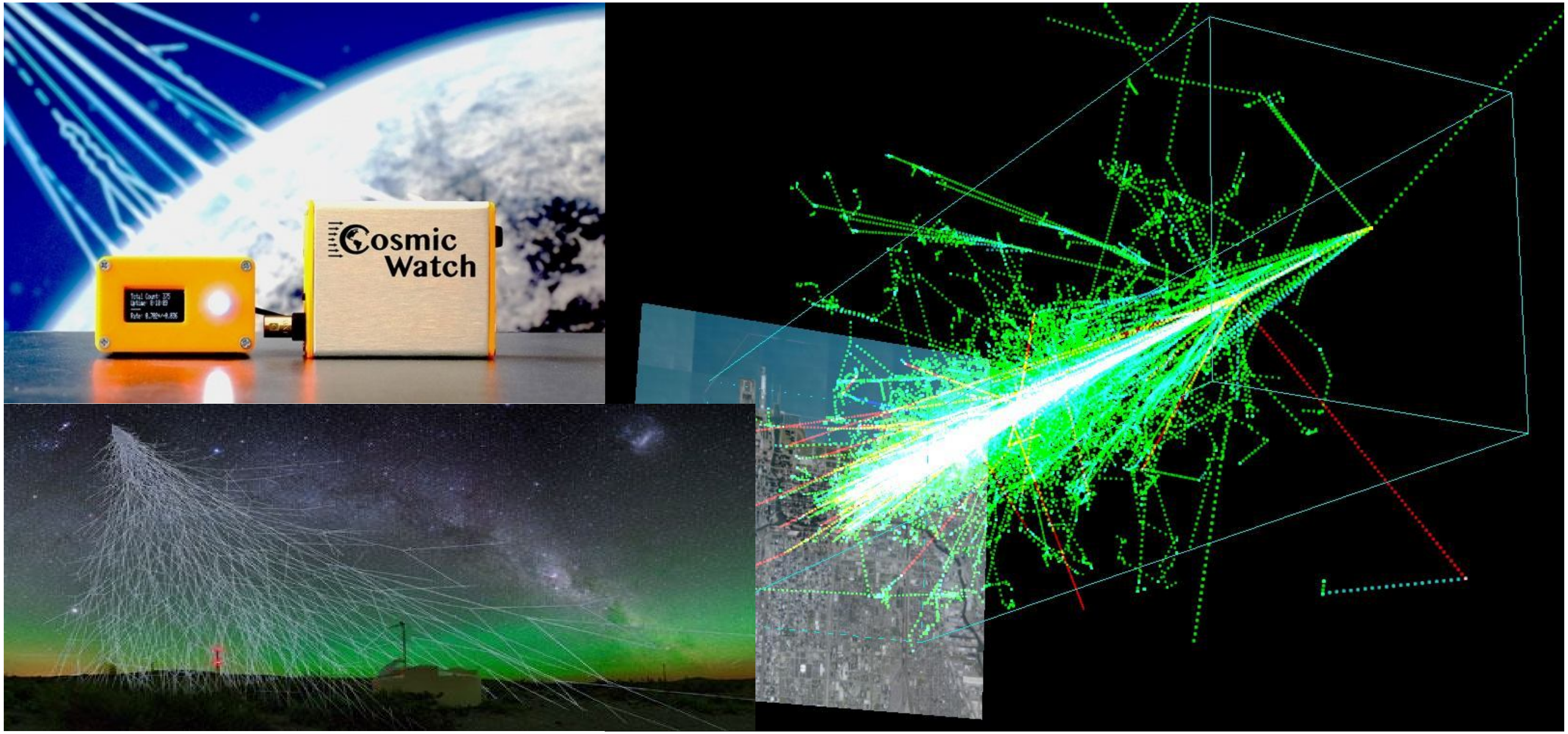
- The first **6 MCORD modules** should be ready by the middle of 2022 for **installation on MPD surface.**

- MCORD can be useful for identification of **high energy muons from ion-ion collisions**.

- MCORD can be used for **unique astrophysics observations** similar to past collider experiments.

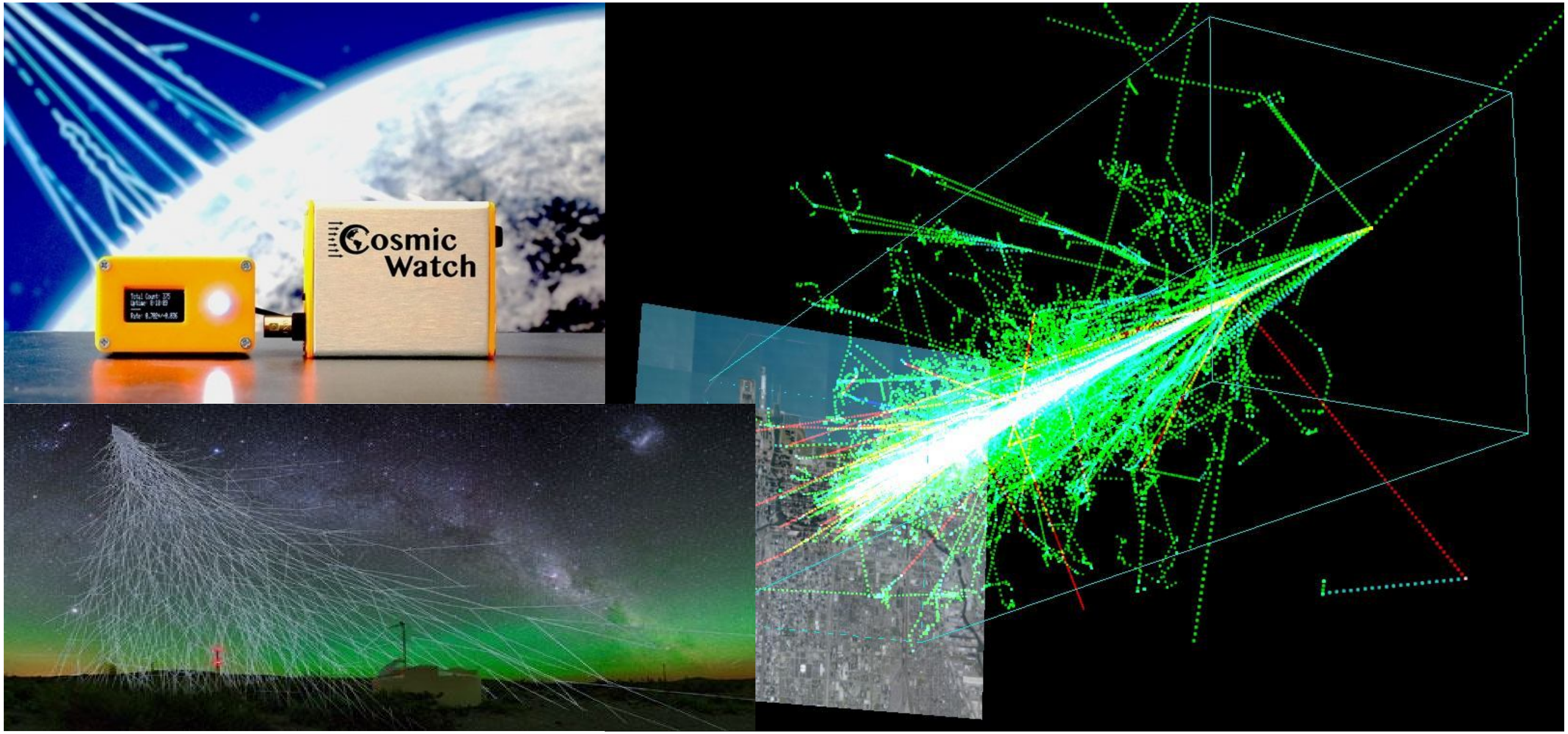
- The cooperation of MCORD trigger system with MPD trigger system should be implemented.

Thank You for Attention!



Polish consortium NICA-PL

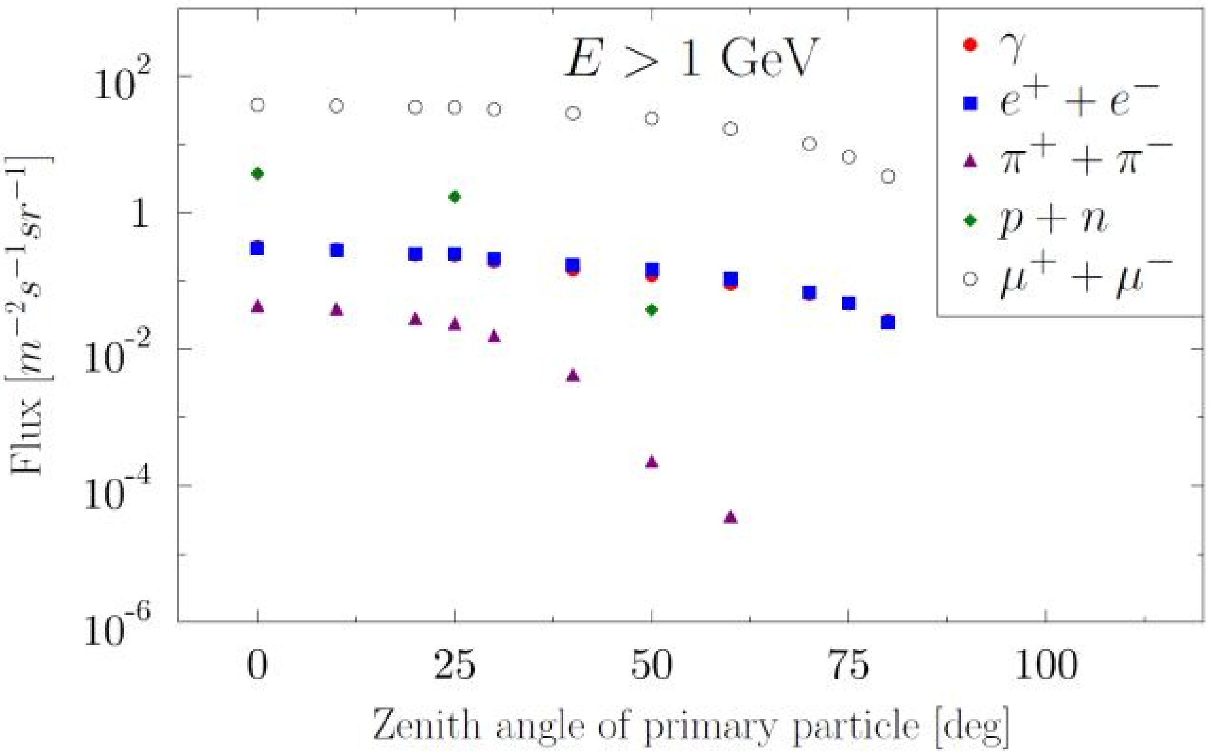
Supplements



Polish consortium NICA-PL

6. Simulations (EAS)

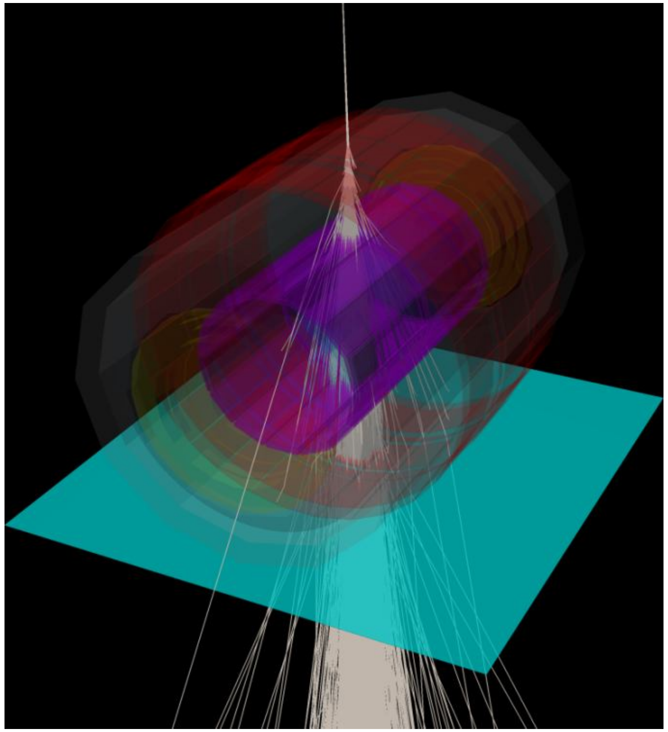
Angular distributions of Extensive Air Shower (EAS) components, calculated for location near Dubna city (at sea level).

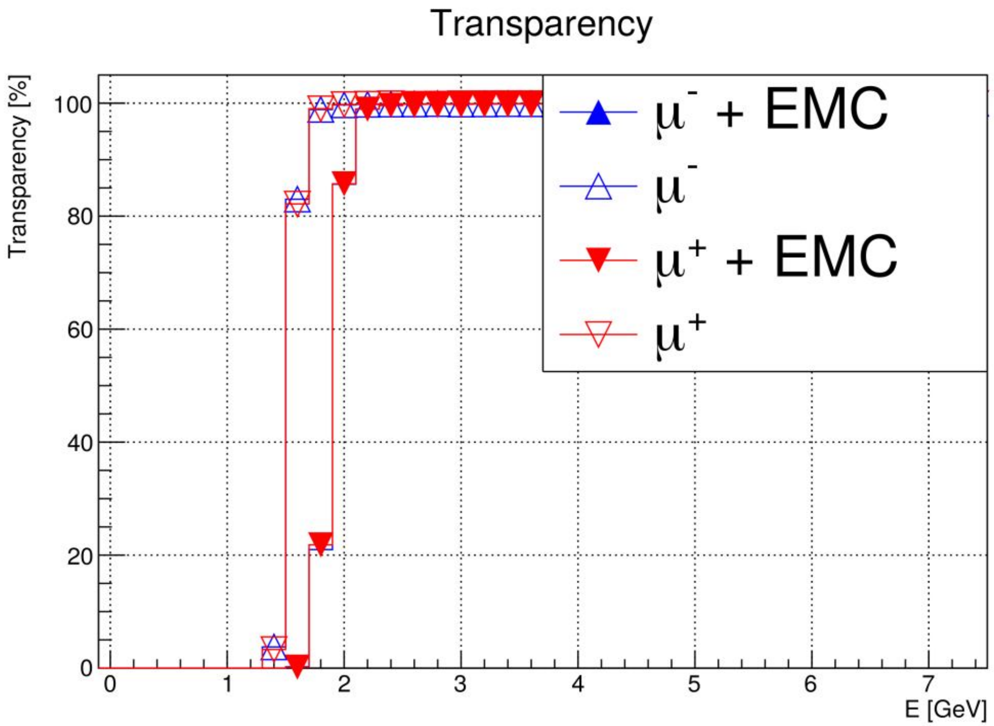


CORSIKA 7.74 code simulation (model QGSJETII-04 + UrQMD).

6. Simulations (EAS)

Propagation of cosmic muons through the MPD



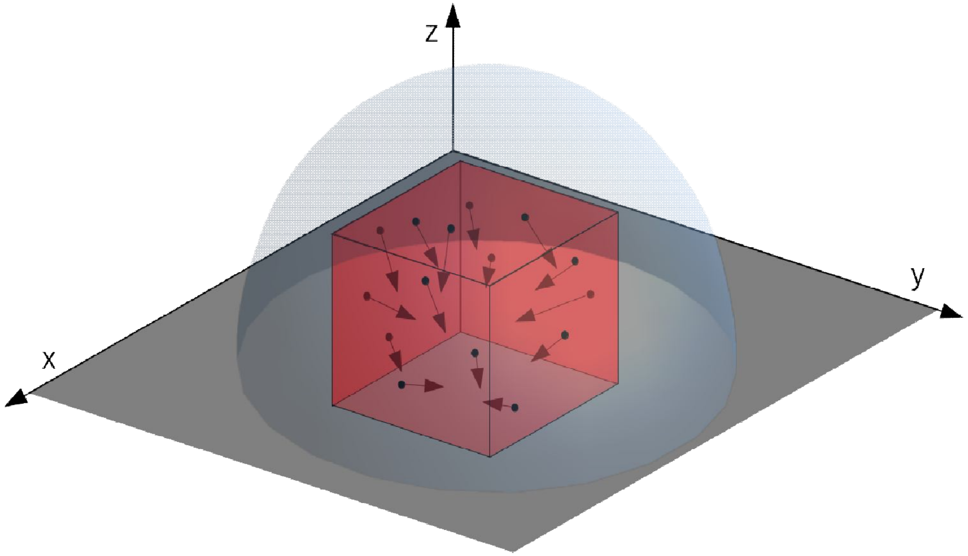


Energy threshold for muons able to pass through the MPD:
with ECal assembled: **2.0 GeV/c^2**
without ECal assembled: **1.6 GeV/c^2**

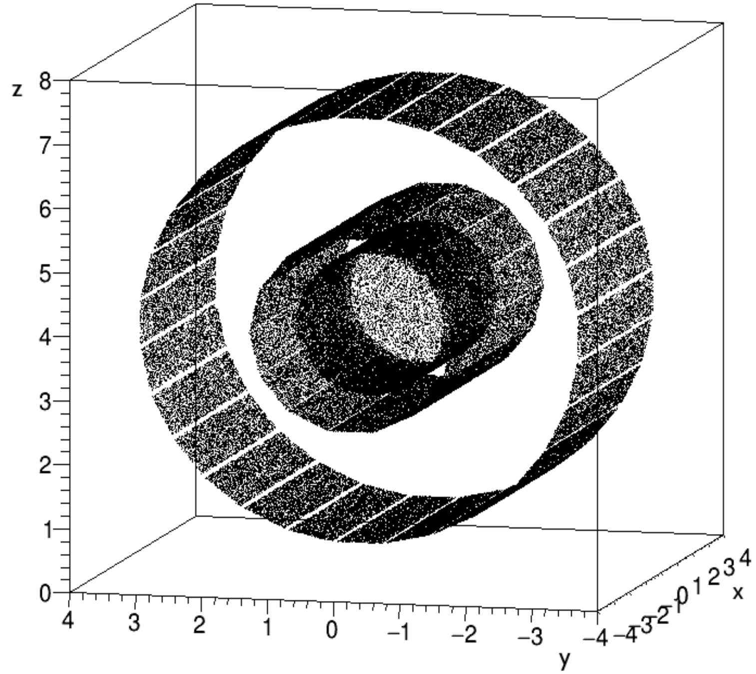
6. Simulations (EAS)

Cofluxim – cosmic ray generator

for MPD subsystems calibration study



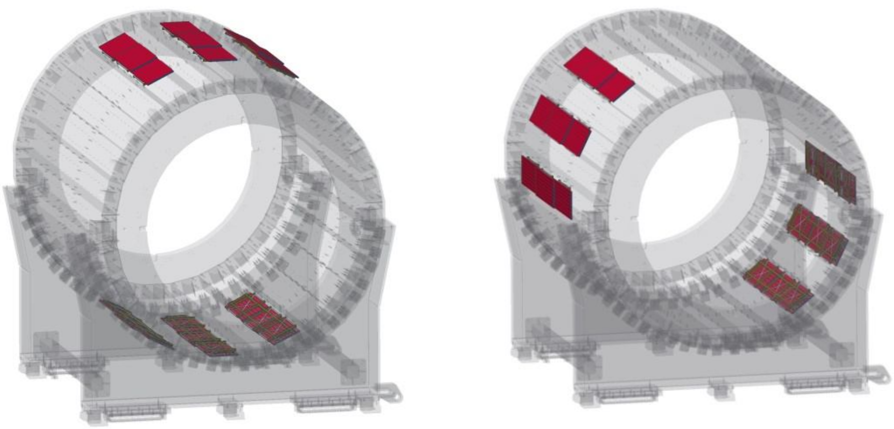
The concept of particle generation: drawing particles on the generation cube walls.



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

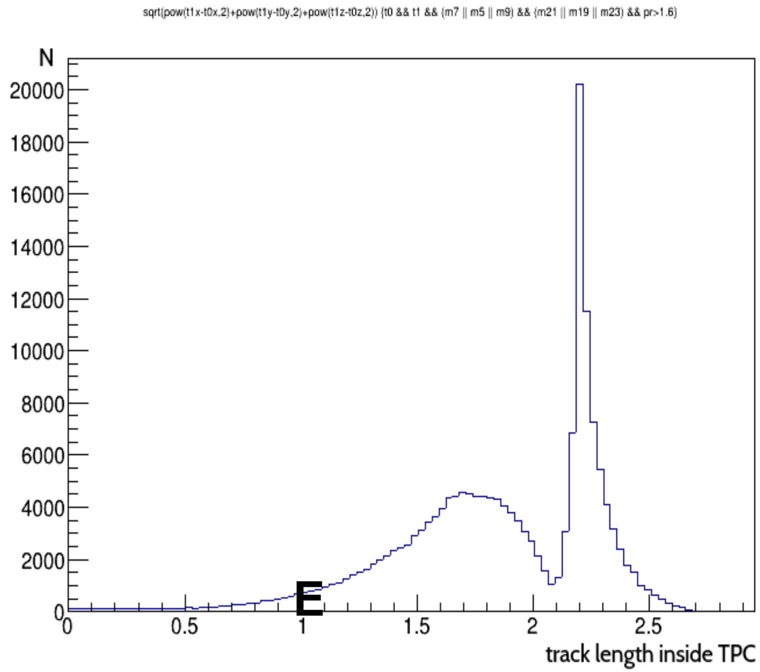
6. Simulations (EAS)

TPC calibration using MCORD triggers



D

E



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

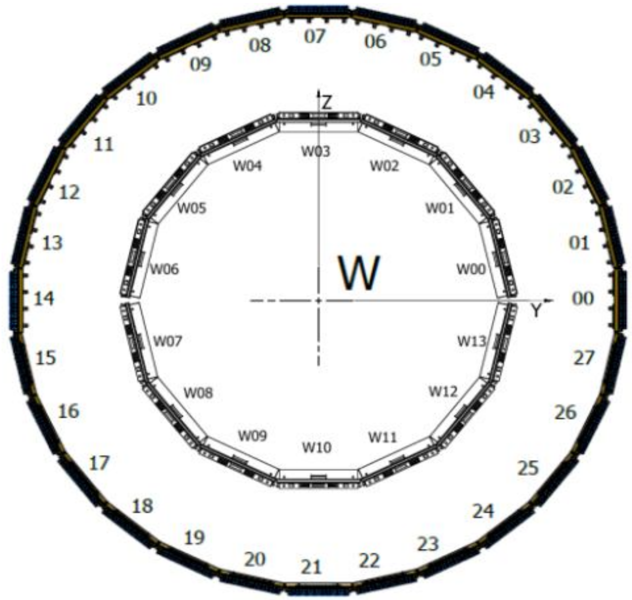
MCORD configuration	MCORD modules (ID numbers)	MCORD & TPC (tracks per hour)
D	(5 or 7 or 9) and (19 or 21 or 23)	**178 822**
E	(10 or 12 or 14) and (24 or 26 or 0)	**50 894**

6. Simulations (EAS)

TPC and ToF calibration using MCORD triggers

MCORD configuration	MCORD modules (ID numbers)	ToF modules (ID numbers)	MCORD & ToF (tracks per hour)	MCORD & ToF & TPC (tracks per hour)
F	(6 or 7 or 8) and (20 or 21 or 22)	3 and 10	43493	**39 768**
G	(4 or 5 or 6) and (18 or 19 or 20)	2 and 9	35554	**32 958**
H	(2 or 3 or 4) and (16 or 17 or 18)	1 and 8	17516	**16 254**
I	(0 or 1 or 2) and (14 or 15 or 16)	0 and 7	3143	**2 932**

Calculated for muons with momentum
p > 1.6 GeV/c



6. Simulations (EAS)

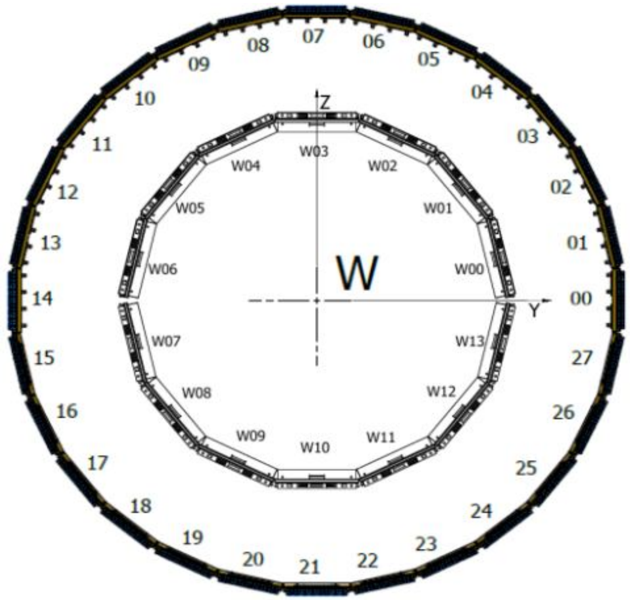
TPC and ToF calibration using MCORD triggers

MCORD configuration	MCORD modules (ID numbers)	ToF modules (ID numbers)	MCORD & ToF (tracks per hour)	MCORD & ToF & TPC (tracks per hour)
F	(6 or 7 or 8) and (20 or 21 or 22)	3 and 10	6648	**6 069**
G	(4 or 5 or 6) and (18 or 19 or 20)	2 and 9	5590	**5 196**
H	(2 or 3 or 4) and (16 or 17 or 18)	1 and 8	2713	**2 503**
I	(0 or 1 or 2) and (14 or 15 or 16)	0 and 7	480	**445**

Calculated for muons with momentum

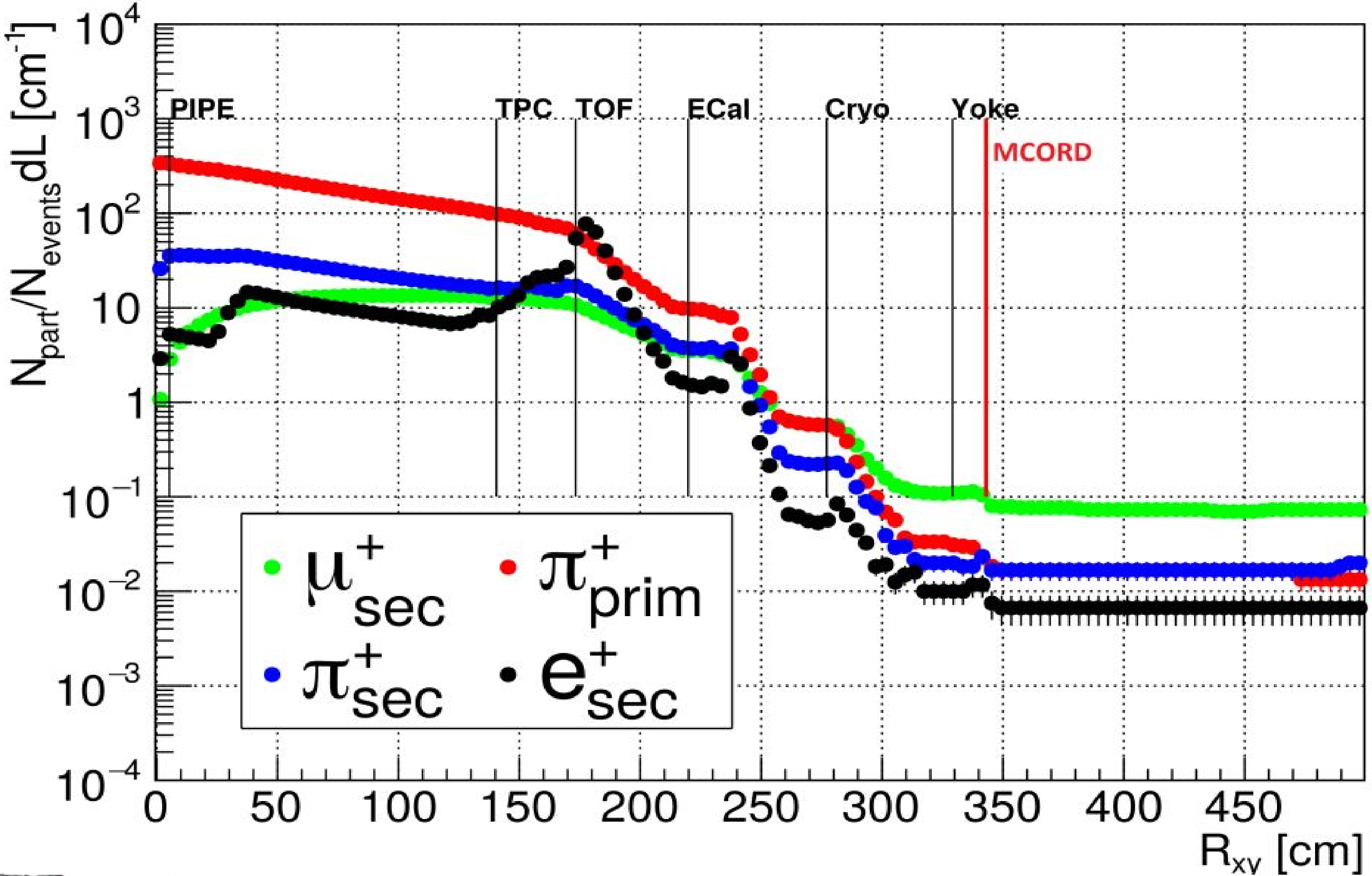
p > 10 GeV/c

(minimum of rescattering angel)



6. Simulations (Collisions)

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



Analog Front End – CAN protocol

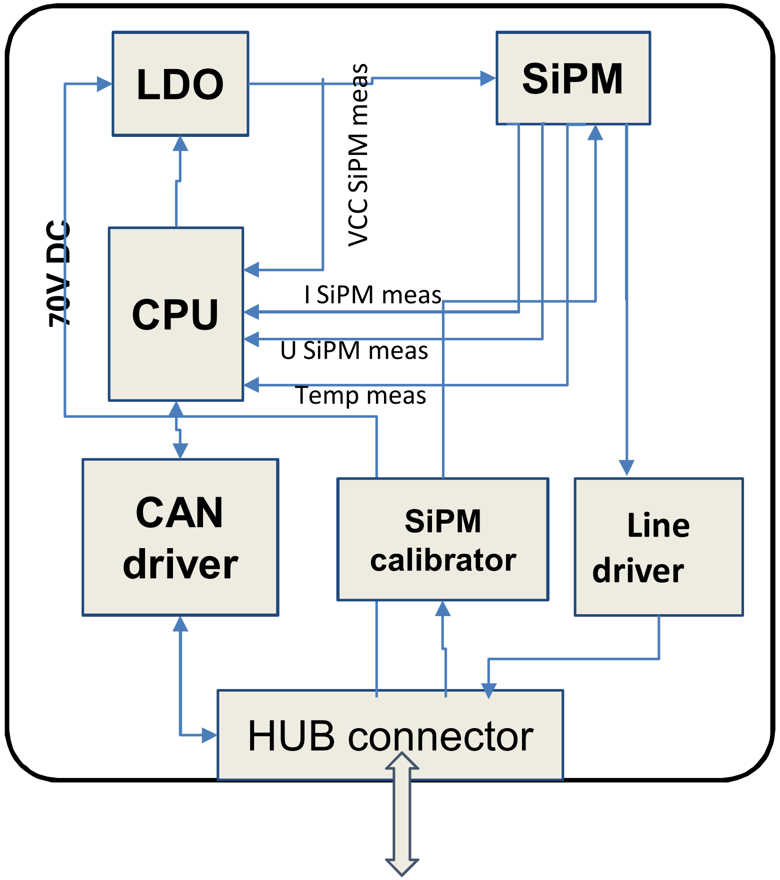
- CAN (protocol 2.0A) network
- CAN address (CAN ID) based on unique ID of CPU (STM32) chip (96 bits)
- Communication protocol defines all transactions between AFE and HUB
- HUB is always a master in a communication and AFE always responds to any request
- In the CAN frame, first two data words define request and others define arguments if needed

Examples of CAN transactions between HUB and AFE.

Function	Function individual code	Arguments	Return data
Get version	0x0001	--	Firmware version
Get ADC data Reg. 1	0x0010	--	Data of 3 adc channels
Get ADC data Reg. 2	0x0011	--	Data of 3 adc channels
Set SiPM voltage 1 & 2	0x0012	ADC values	--
Set bits in a Control Register	0x0040	Bits to set	
Clear bits in a Control Register	0x0041	Bits to clear	
Get bits in a Control Register	0x0042	--	Bit values in the Register

Analog Front End - functionality

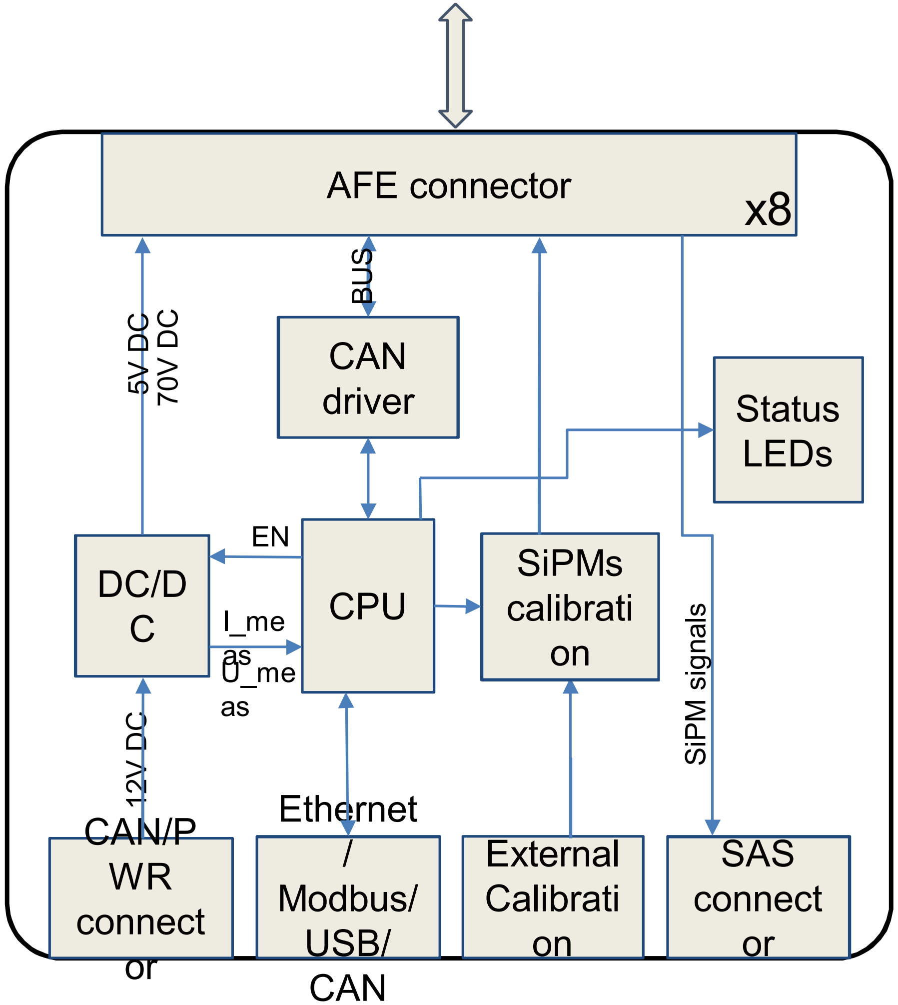
- Voltage controller for SiPMs
- Access to all settings and data from HUB via CAN-bus interface
- Protection for AFE



- **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

HUB - functionality

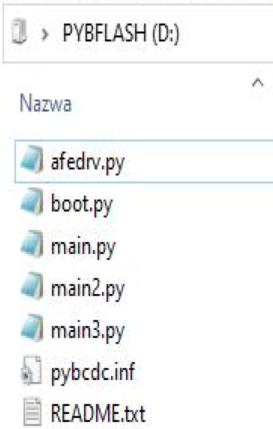
- PoE supply
- Generation of 5V and 70V
- ETH <-> CAN
- Distribution of signals from AFE to SAS cables
- Status LEDs on AFE ASSY and HUB for quick fault identification
- Generation of calibration signals to AFE
- STM32 CPU with microPython



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=False,prescaler=8,sjw=1,b                    True)
  can.setfilter(0, 0, 0, (0x00,0x7ff))
  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])
  print("RTR: ", lst[1])
  print("FMI: ", lst[2])
  VerH = (lst[3][2] << 8) | (lst[3][3] & 0xff)
  print("VerH: ", VerH)
  VerL = (lst[3][4] << 8) | (lst[3][5] & 0xff)
  print("VerL: ", VerL)
  VerD = (lst[3][6] << 8) | (lst[3][7] & 0xff)
  print("VerD: ", VerD)
```

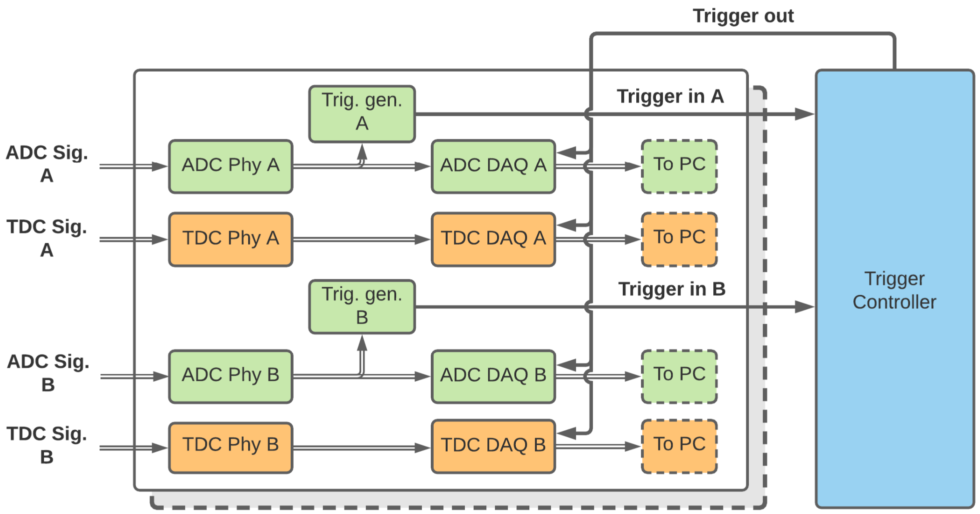


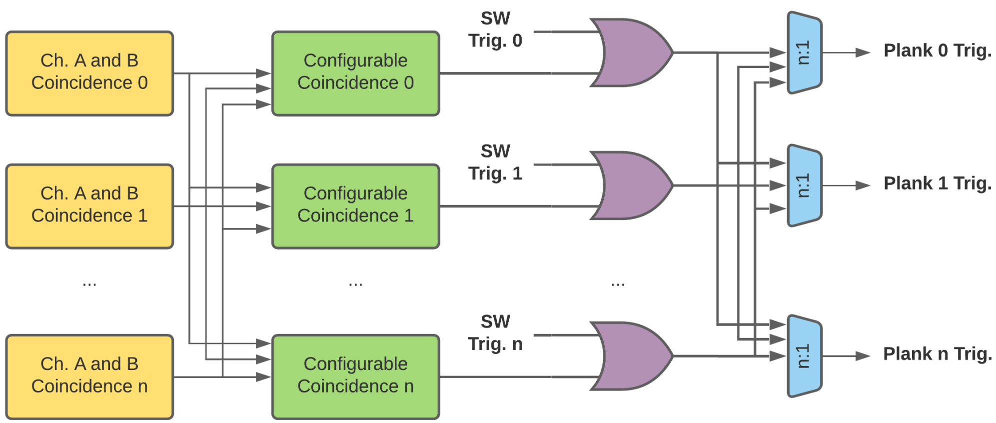
COM9 - PuTTY

```
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
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
>>>
```

3. The FPGA software

A single detector with two channels, one for every end of the plank.





Signals from ADC and TDC chips are connected to HDL (Hardware Description Language) modules (FPGA). These are responsible for interfacing with ADC/TDC data ports.

Then raw data from the converters is passed to Trigger Generators (level or baseline deviation based) and DAQs (Data AcQuisition modules).

Signals from triggers are passed to coincidence detection block.

3. MCORD Muon Data Acquisition