MCORD

MPD Cosmic Ray Detector for NICA

by Polish consortium NICA-PL

NARODOWE CENTRUM BADAŃ JĄDROWYCH ŚWIERK

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JINR
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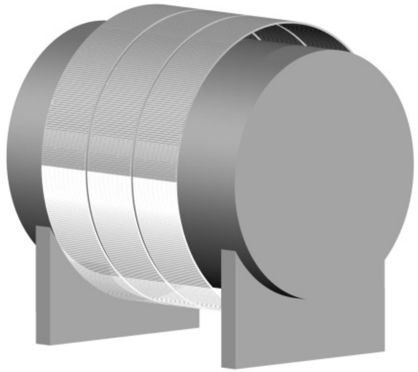
Outline

1. NICA collider
2. Cosmic Ray Detector – Goals
3. Main tasks and schedule
4. Design, modeling proposition
5. Conclusion

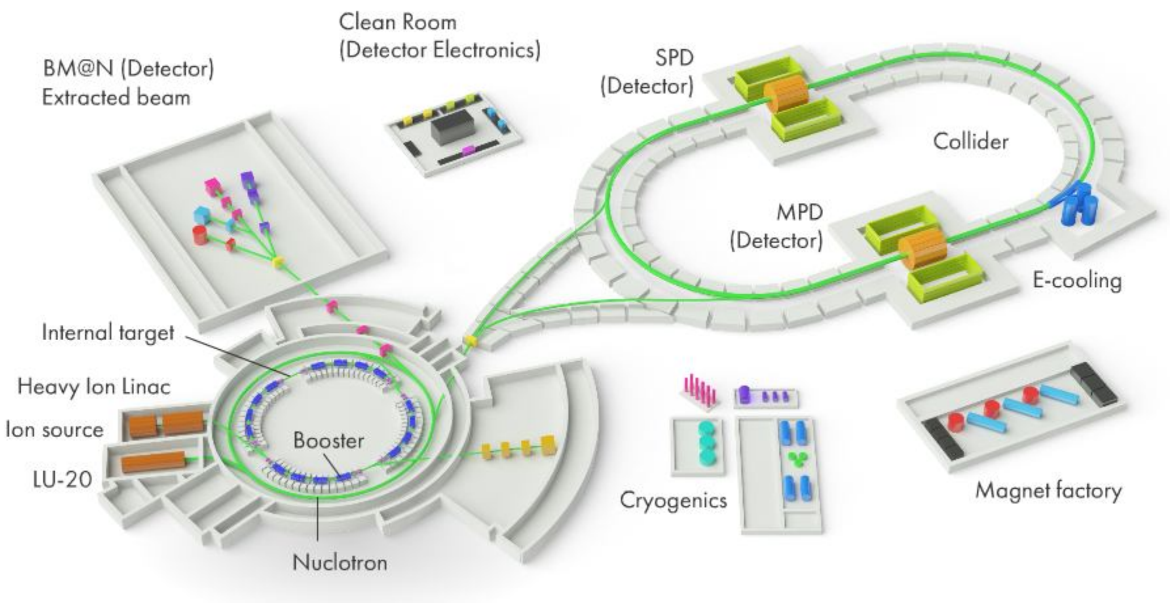


1. NICA complex - Glossary

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

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

MCORD - **M**PD **C**osmic **R**ay **D**etector



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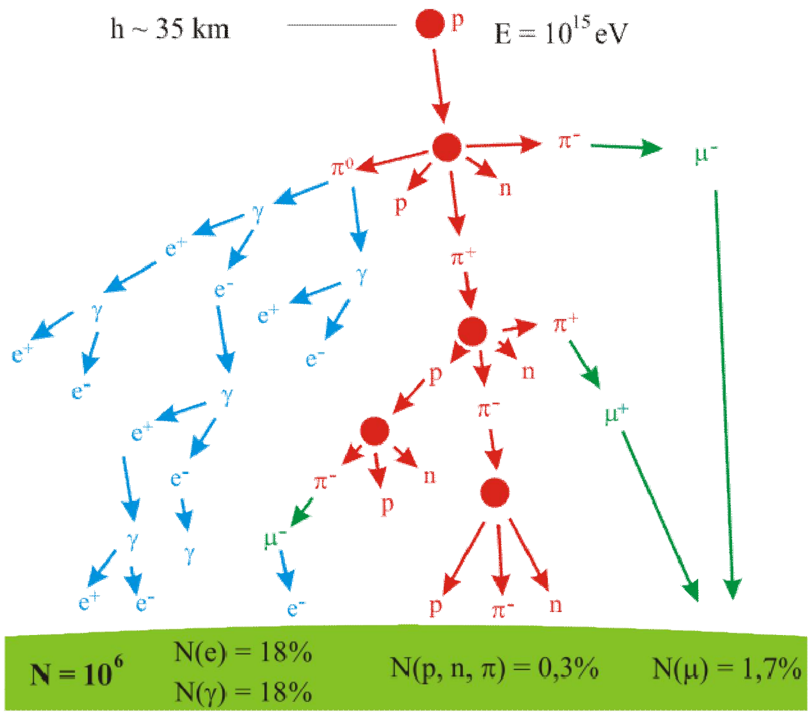
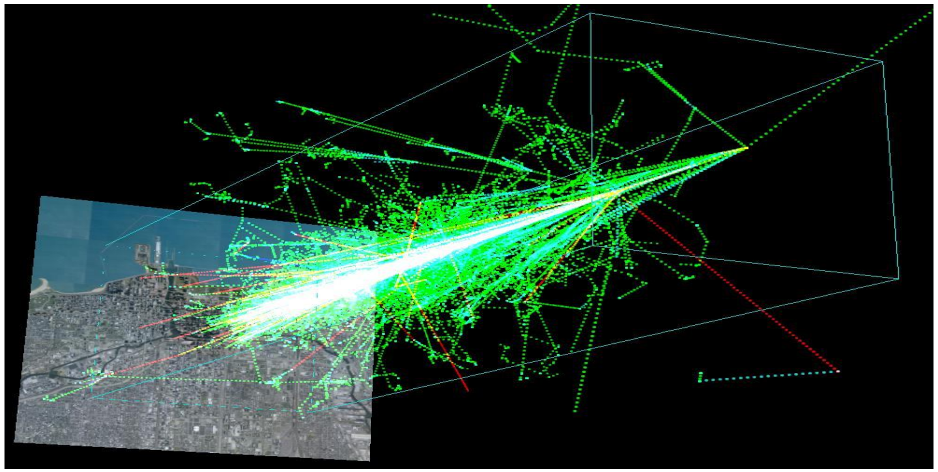
1. NICA complex - Cosmic Ray

PRIMARY PARTICLE

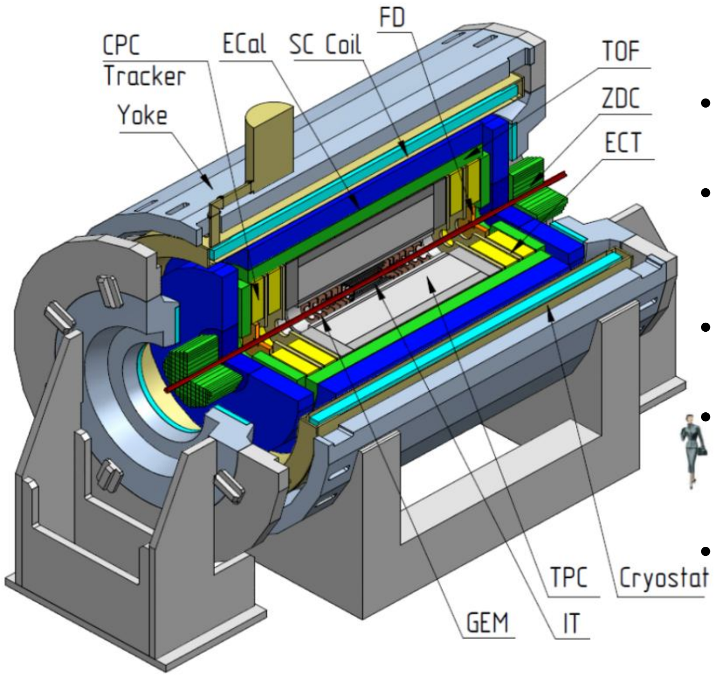


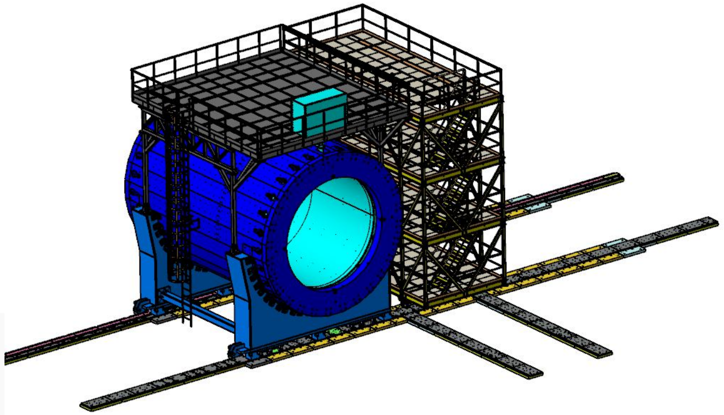
GROUND LEVEL



Cosmic ray air shower created by a 1TeV proton hitting the atmosphere 20 km above the Earth. The shower was simulated using the AIRES package.

1. NICA complex - MPD



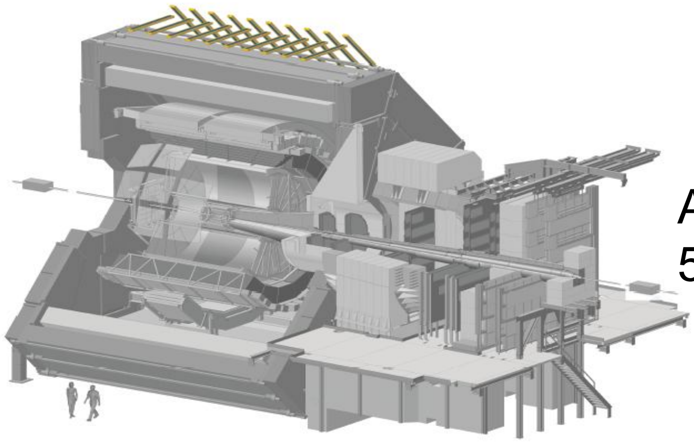


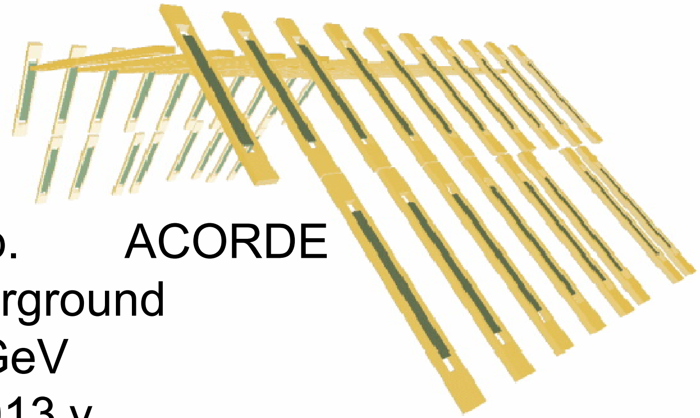
- FD Forward det.
- Superconductor solenoid (SC Coil)
- Inner Tracker (IT)
- straw-tube tracker (ECT)
- **Time-projection chamber (TPC)**
- **Time-of-flight system (TOF)**
- **Electromagnetic calorimeter (EMC - ECal)**
- Zero degree calorimeter (ZDC).

nica.jinr.ru/video/general_compressed.mp4

2. Cosmic Ray Detector – Goals

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)

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Astroparticle Physics 19 (2003) 513–523

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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]

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[c] *University of Siegen, Siegen, Germany*

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

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Astroparticle Physics 28 (2007) 273–286

Astroparticle Physics

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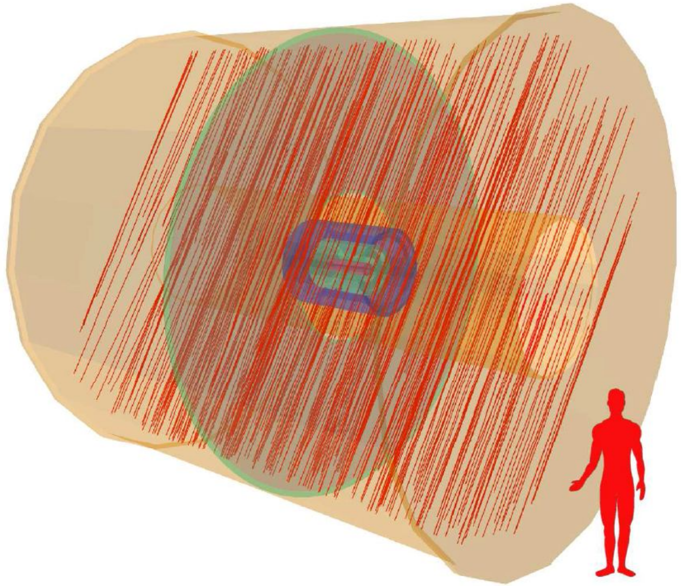
Study of multi-muon bundles in cosmic ray showers detected with the DELPHI detector at LEP

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

2. Cosmic Ray Detector – Goals

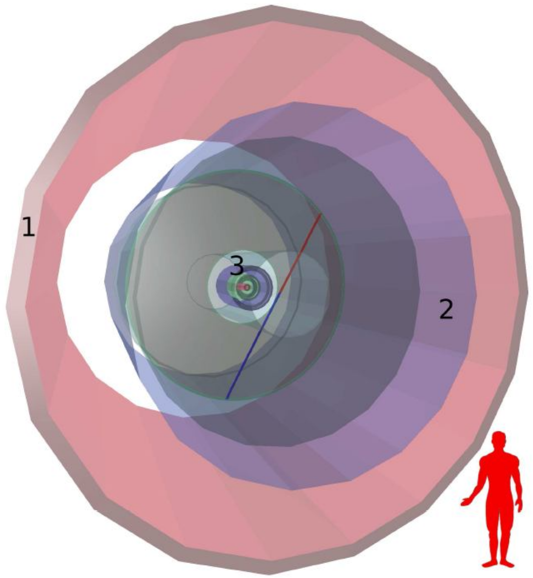


a) Trigger (for testing or calibration)
- testing before completion of MPD
(testing of TOF, ECAL modules and TPC)
- calibration before experimental session

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

Additionally

c) Astrophysics (muon shower and bundles)
- unique for horizontal events
Working in cooperation with TPC

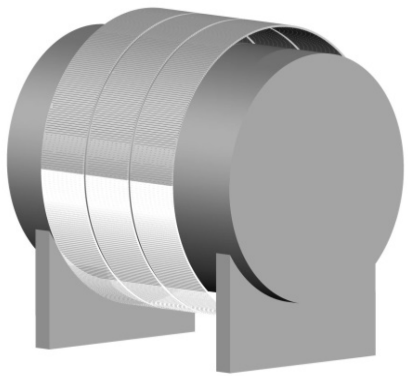


DECOR exp. 2002-2003y (near horizontal observation (60-90 deg. angular range) - 1-10 PeV primary particle)

3. Main tasks and schedule

I. **Conceptual Design** (9-12 months)
(Preliminary Technical and Electronic Design, Market Research, Literature Studies, Cost Estimates, TPC and TOF requirements)

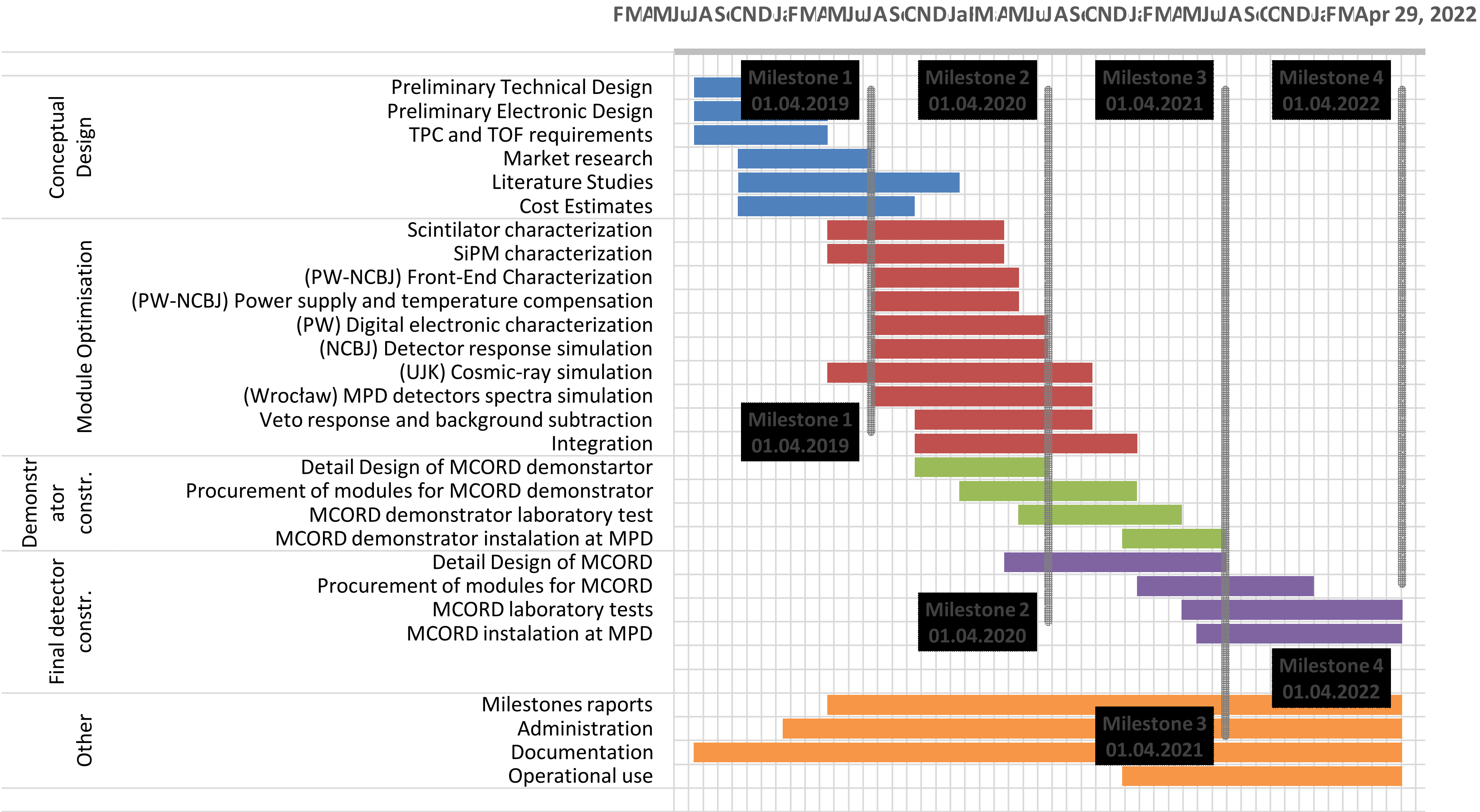
II. **Module Optimization** (9-15 months)
(Scintillator, Power Supply, Front-End and Analog electronics characterization; Detector response, Cosmic-ray and MPD spectra simulation, Veto response, Integration)



III. **Demonstrator constr.** (2-4 ready to use modules) (10-20 months) (Demo. detailed design, Procurement of Modules, Lab. Tests, Installation in MPD

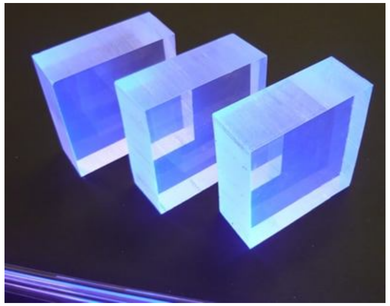
IV. **Final Detector constr.** (procurement of all modules , test installation and integration –12 months)

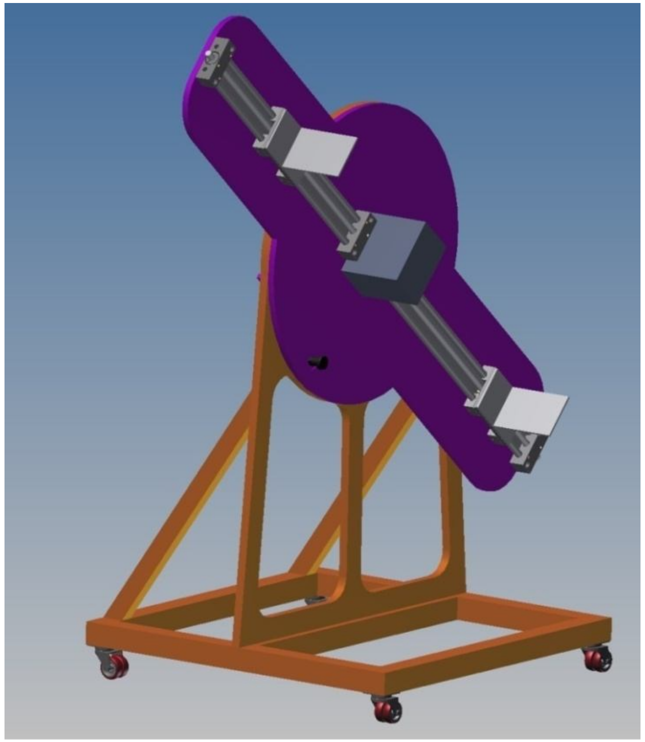
3. Main tasks and schedule

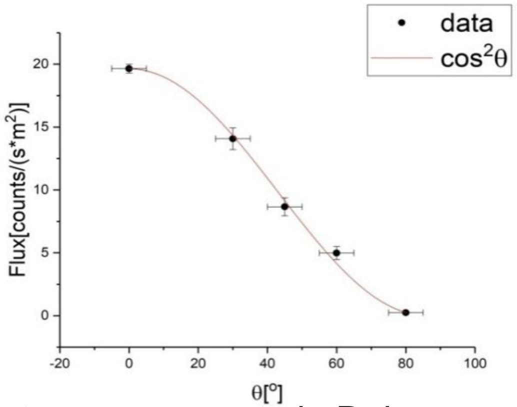


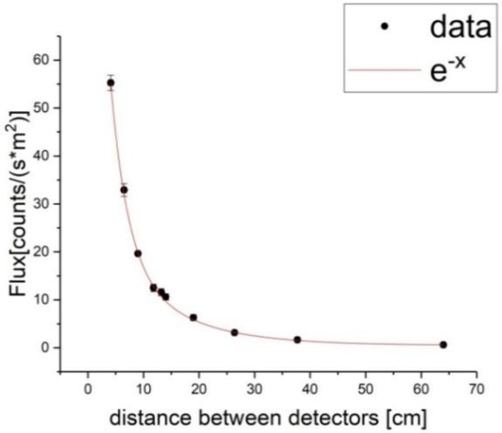
Conceptual design – tasks

1. Measurement of cosmic radiation - azimuthal and horizontal distribution
2. Angular influence of the building (concrete walls and ceiling)
3. Optimization of scintillator shape and light readout method
4. Design of single module and scaling up to full size instrument
5. Simulations (MCNPX, GEANT4 and CORSIKA, Showersim)









First measurements in Dubna

- Azimuthal and horizontal distribution
- Angular influence of the building
- With Pb filter

Conceptual design – laboratory tests

<u>Laboratory tests at NCBJ Swierk - **Plans for 2019**</u>

- **Laboratory tests of plastic tiles with and without wavelength shifting fibers**
- **Readout by PMTs for reference and with silicon PMs for optimization of single detector performance.**
- **We will study light yield and coincidence resolving time for different configurations of scintillator and photodetectors.**
- **The tests will be supported with grant form Polish contribution to JINR.**

Cooperation with scintillators manufacturers and providers:

- **Uniplast (Russia)**
- **Amcrys-H (Ukraine)**
- **Saint-Gobain (FR)**
- **Scionix (Holland)**
- **Nuvia (Czech)**

Cooperation with SiPM vendors:

- **Hamamatsu (Japan)**
- **AdvanSiD (Italy),**
- **Ketek (Germany),**
- **SensL (Ireland)**

Wide range of sizes: 1×1 mm^2 to 51×51 mm^2

Uniplast

NUVIA

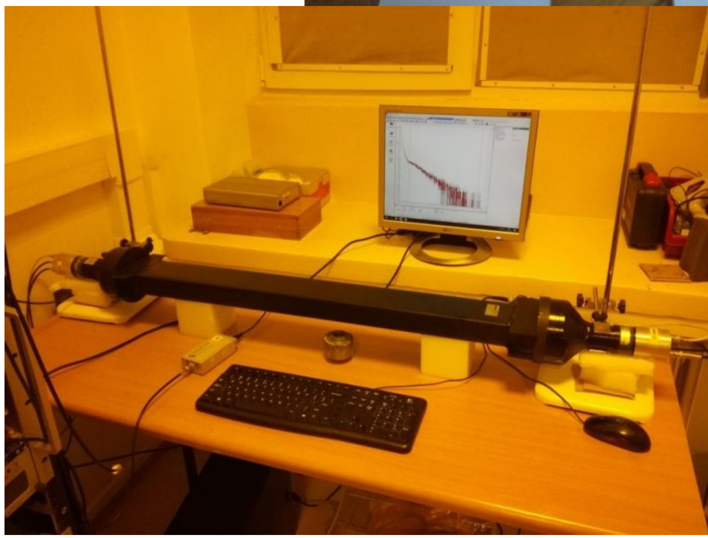
Hamamtsu

Conceptual design – laboratory tests

<u>Laboratory tests at NCBJ Swierk</u>

Available equipment:

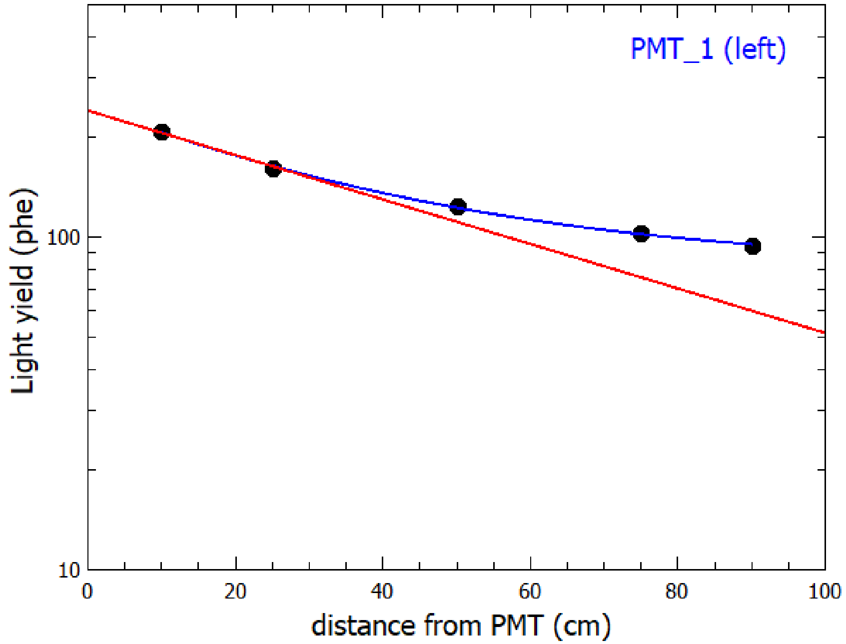
- long tiles (~100-150 cm) from NUVIA (Czech Rep.) and UNIPLAST (Russia) with and without Wavelength Shifting (WLS) fibers
- 5” dia PMTs (XP45D2 and ETL9390)
- medium and small SiPMs (6x6 and 1x1 mm) from Hamamatsu (in future 25x25 mm)
- first measurements of light output and light attenuation along 100x10x5 cm plastic tile
- double-side 5 inches dia PMTs readout
- Co-60 gamma-rays energy calibration



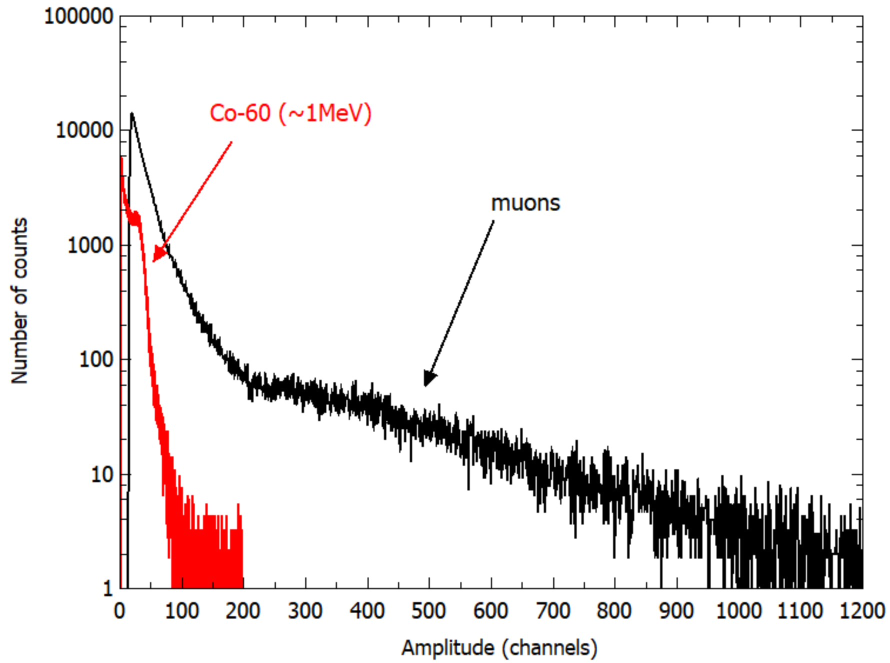
Conceptual design – laboratory tests

Laboratory tests at NCBJ Swierk

- attenuation length in Nuvia plastic (100×10×5 cm)
  λ > 65 cm



- muon energy spectra along entire slab recorded (RT = 1000s)

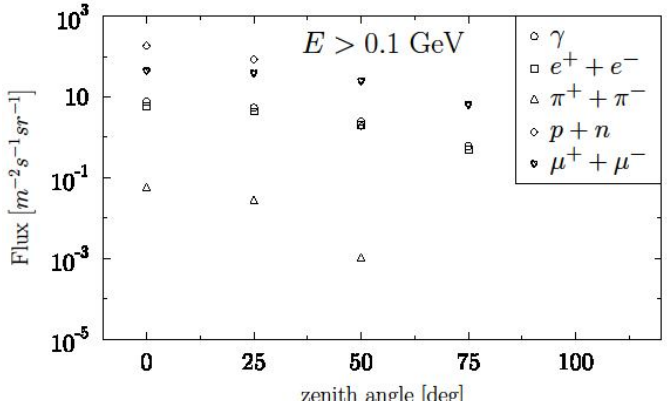


Conceptual design – simulations

CORSIKA simulation of Cosmic Showers

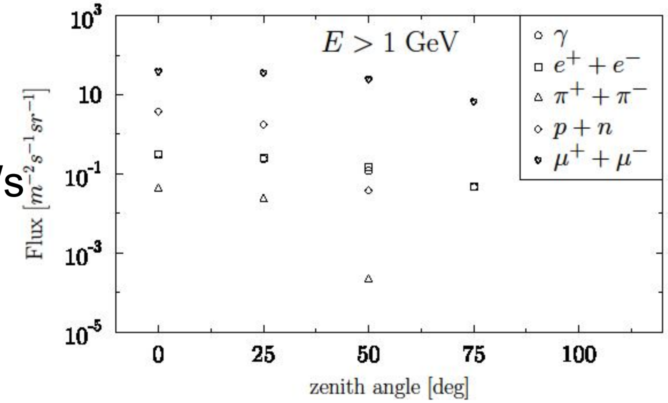
Angular distribution of atmospheric cosmic shower particles

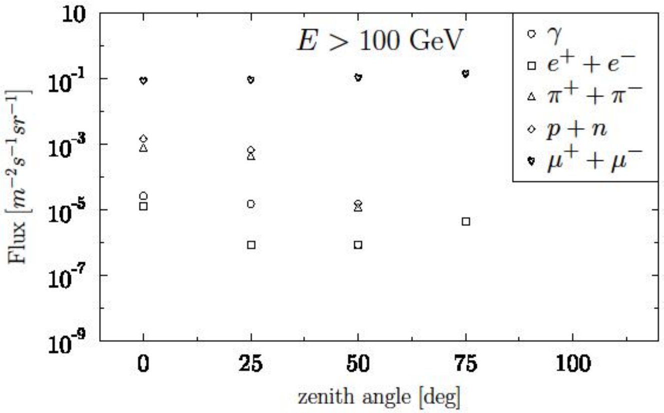
E [GeV]	0	25	50	75
0.1- 1	5.912	3.829	0.612	0
1-10	29.931	26.935	16.637	2.224
10-100	7.976	7.884	7.291	4.186
100~1000	0.087	0.092	0.108	0.142

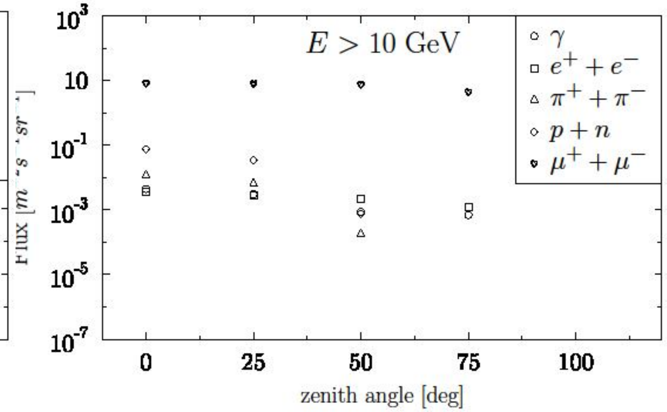


Muon Flux from all angle for E>1GeV is about 100-150 count/m2/s

It gives (6.72m x 4.7m = 31.58m2) about 3000-4500 count/s





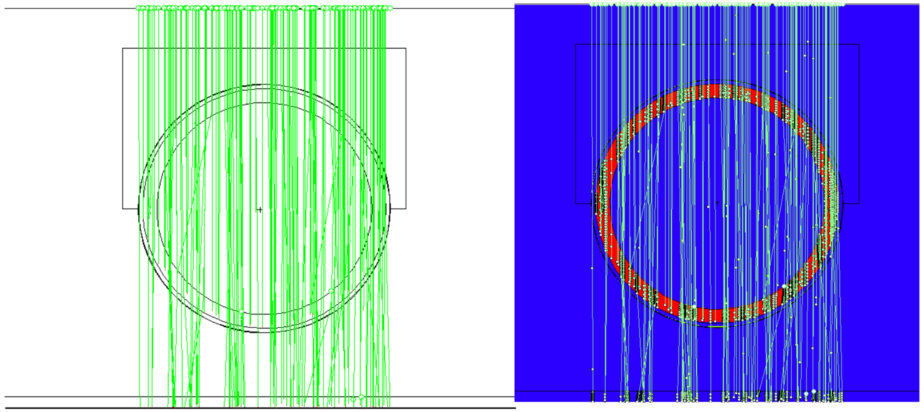


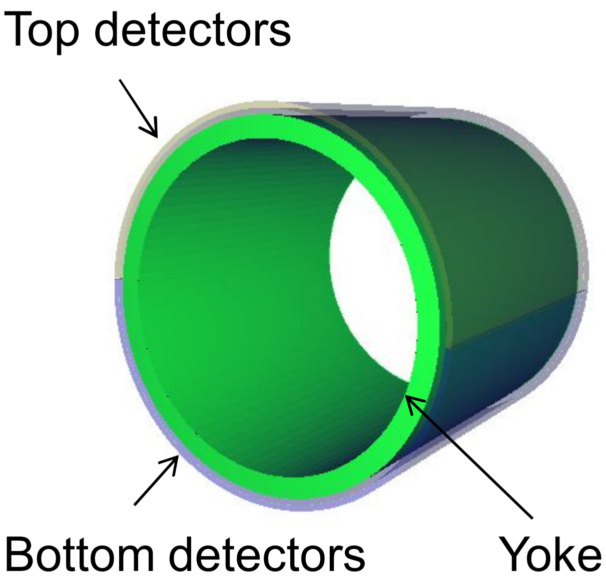
Conceptual design – simulations

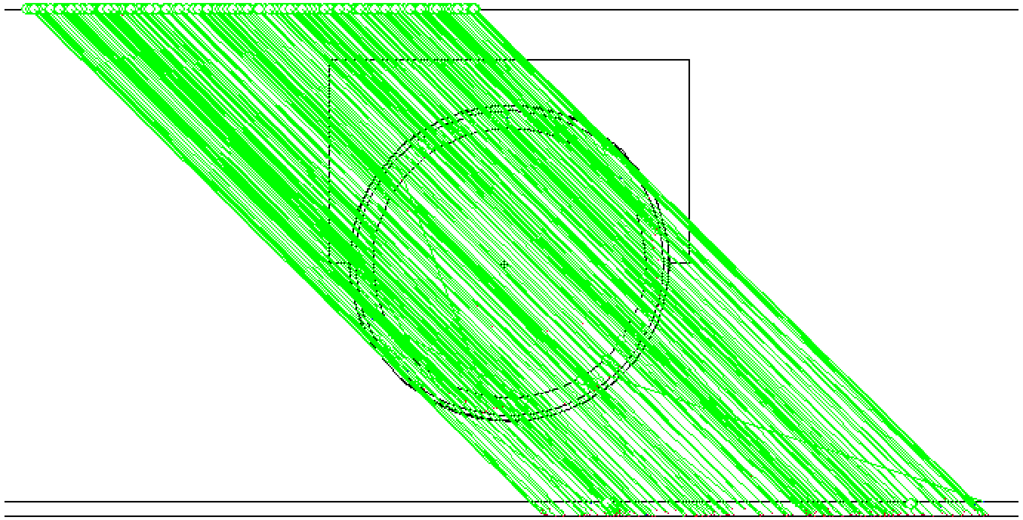
MCNP calculations for MCORD muon detector
(MCNP 6.11, MCNPX 2.7.0. number of iteration 1E9)

Develop the simple model of MCORD detector
divided into top and bottom semicylinder (monolithic) + yoke

- Two half-cylinders of plastic (2.5 cm and 1 cm thick)
- Implemented energy distibution
  as a function of muon incident angle:
    - Angles: 0 and 45 degrees
    - Energy: 0.1 – 1000 GeV
- Implemented surface emission
- Estimated bottom-to-top muon coincidence ratio







Conceptual design – simulations

Pure facts:

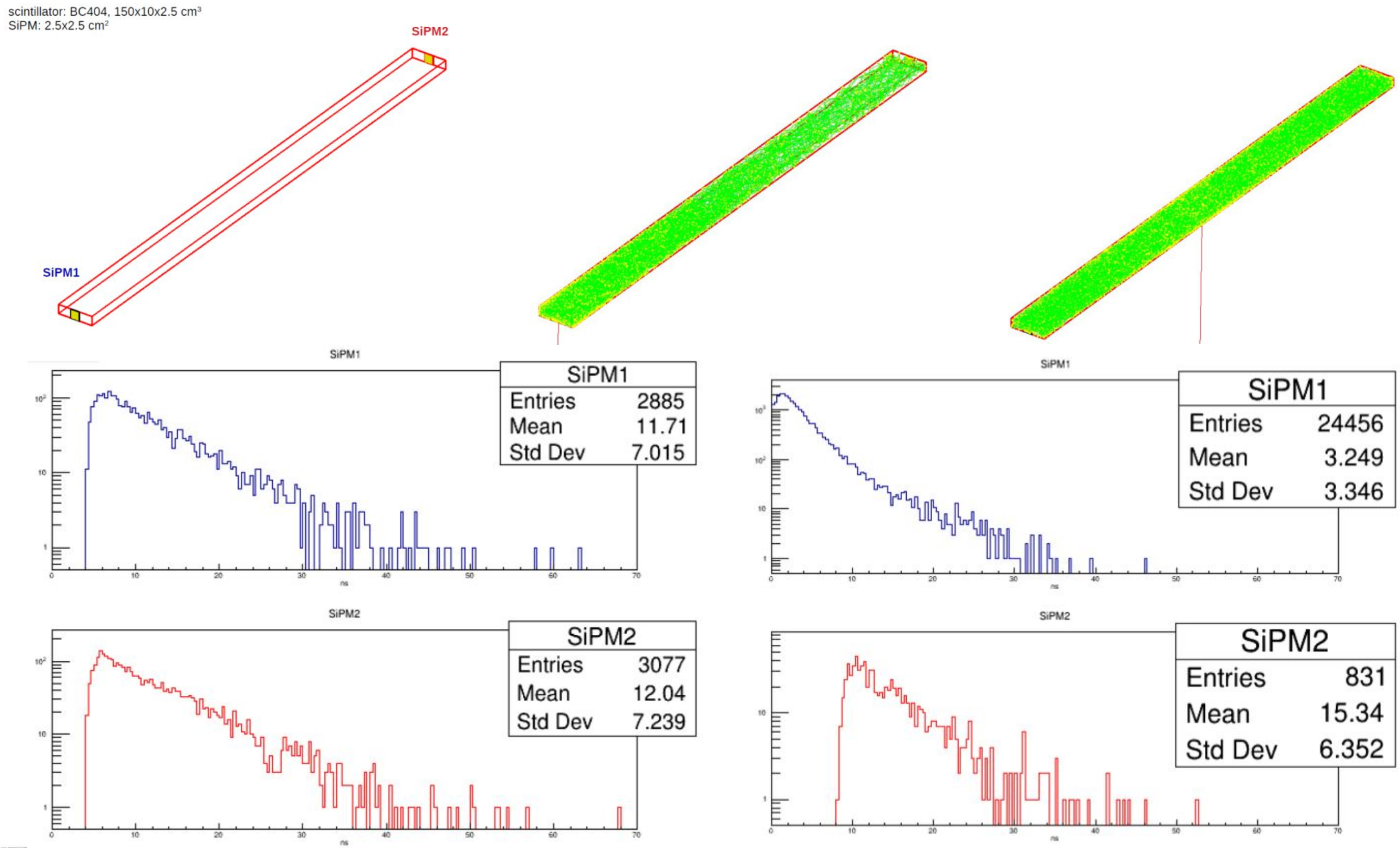
- Coincidence rate: when **both top and bottom detectors detect muon**
- The coincidence rate for two types of detector and for two muon incident degrees:

Detector thickness (cm)	Angle (deg)	Coincidence rate (%)
1	0	98
1	45	98
2.5	0	96
2.5	45	98

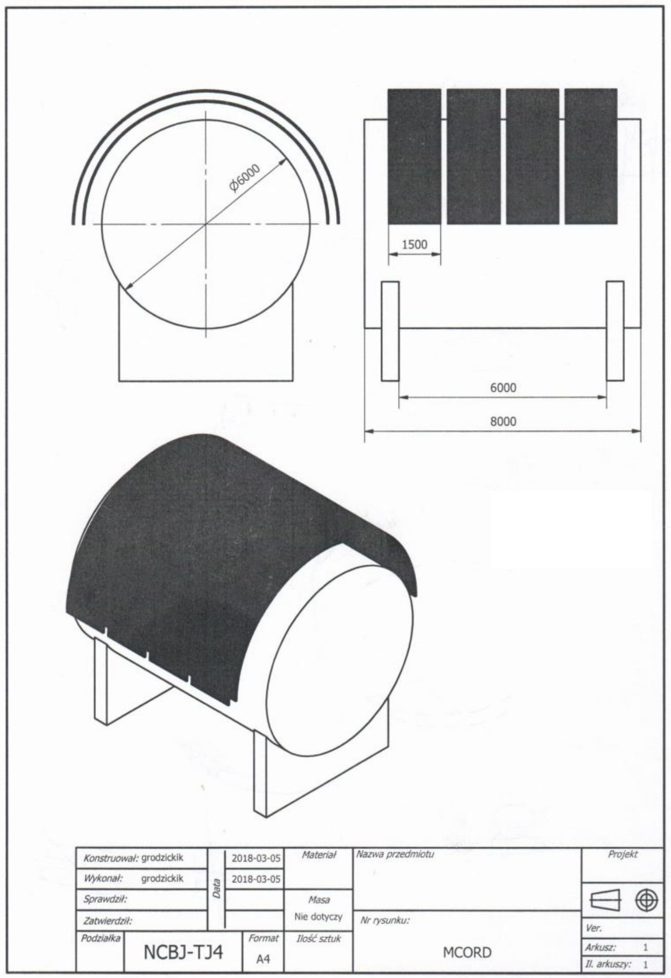
- Coincidence rate lower for thicker detector. Worse coincidence rate for thicker detector and incident muon angle of 0 degree (lower average muon energy) – probably due to muon scattering/glazing on the edge.
- Other muon emission angles are under calculations.

Conceptual design – simulations

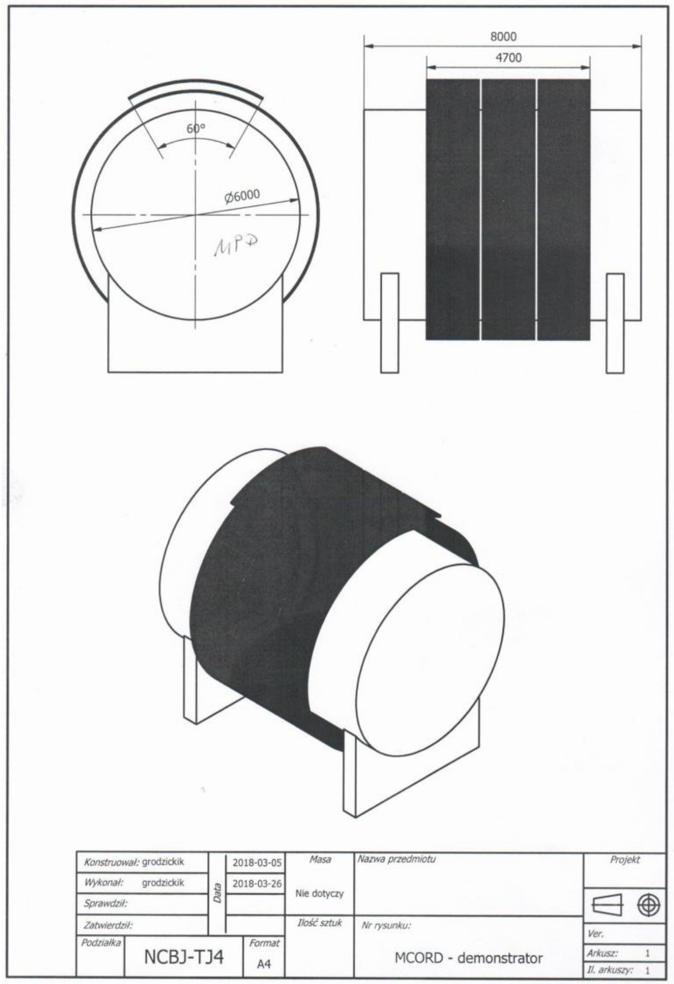
GEANT4 simulation of photon production and distributions in scintillators



4. Design, modeling variants

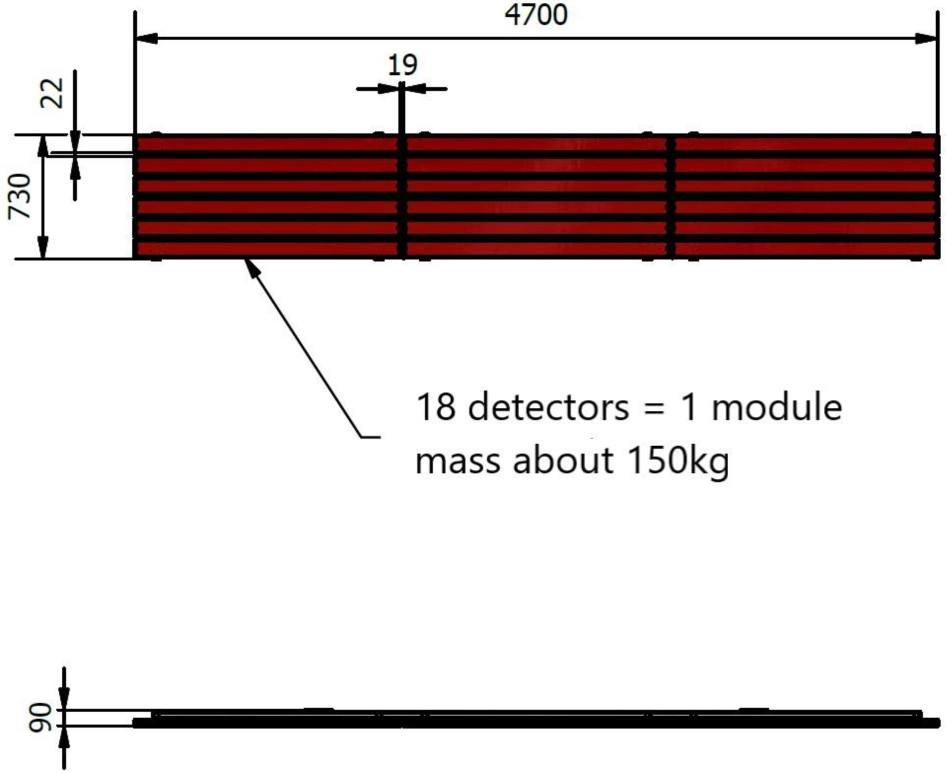


Two surfaces on half circumference

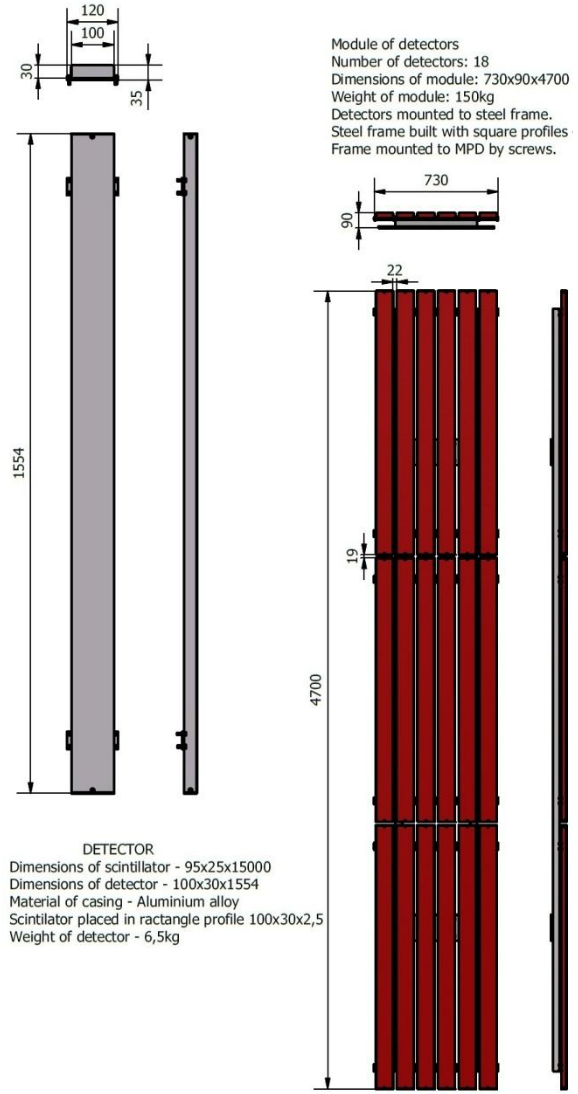


One surface on full circumference

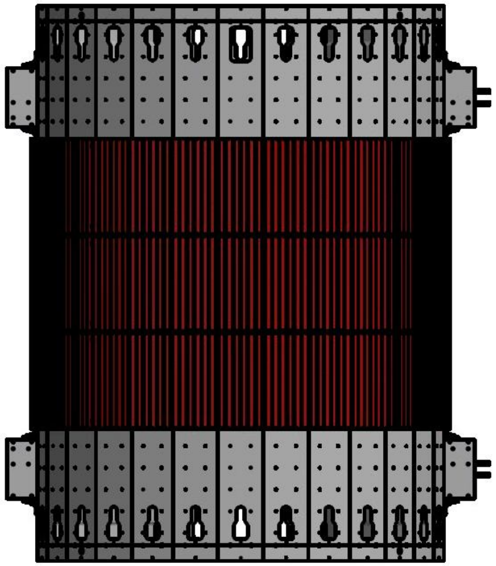
4. Design, modeling variants

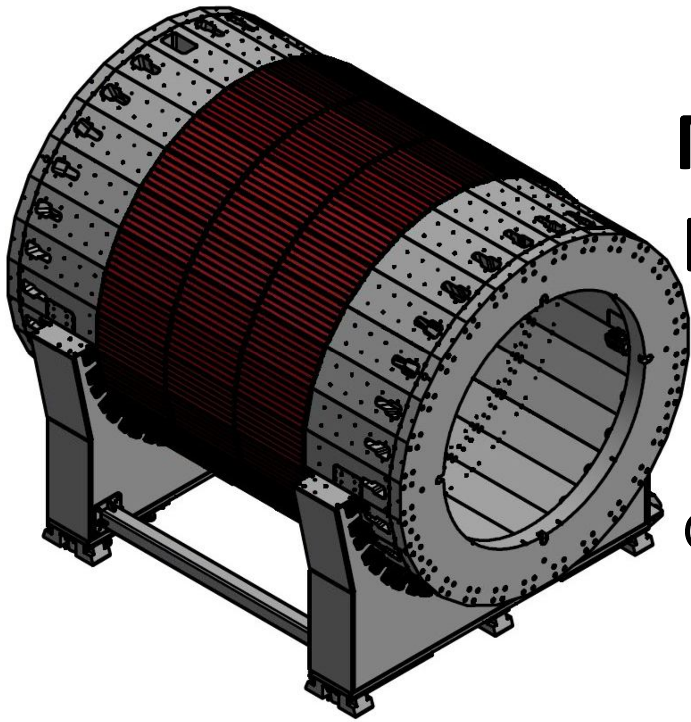


Scintillators and modules



4. Design, modeling variant





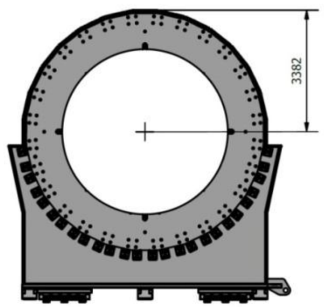
MCORD at MPD scheme Basic variant

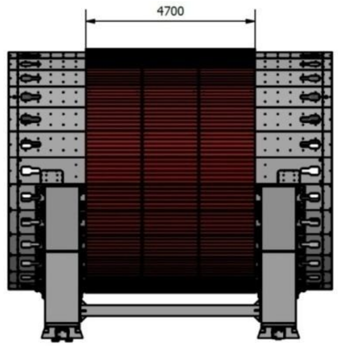
One surface on full circumference

Modules Mounting on MPD surface

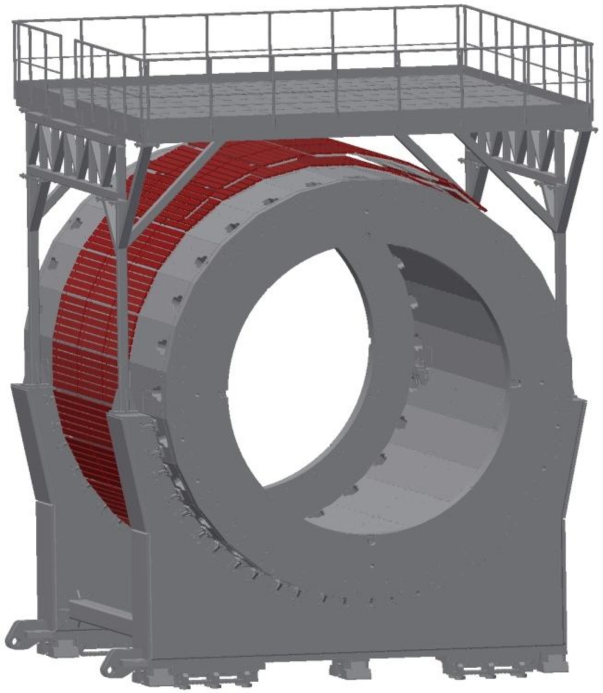
Detector mounted to steel frame

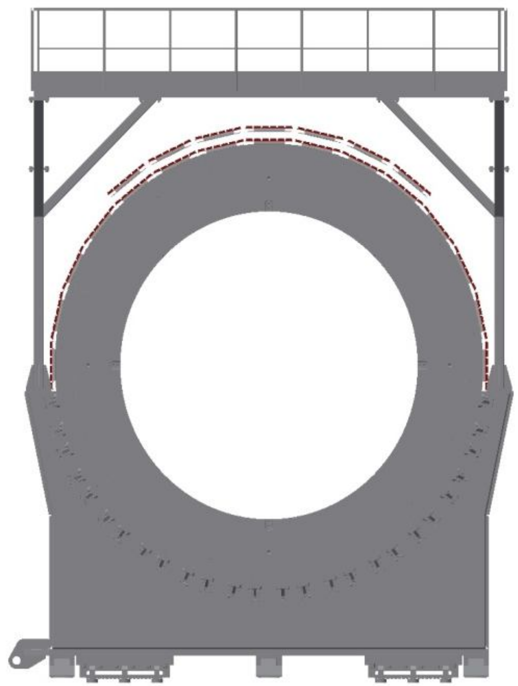
Steel frame build with square profiles:	40x40 [mm]
Number of Modules:	28
Frame mounted to MPD by screws	
Weight of all modules:	4200 kg





4. Design, modeling variants



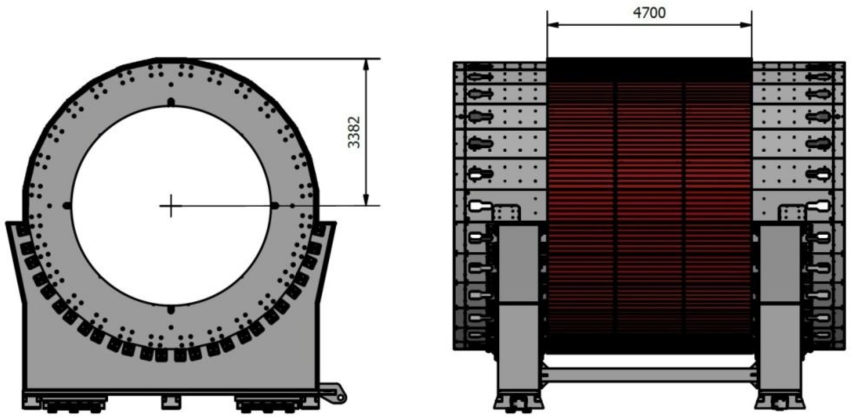


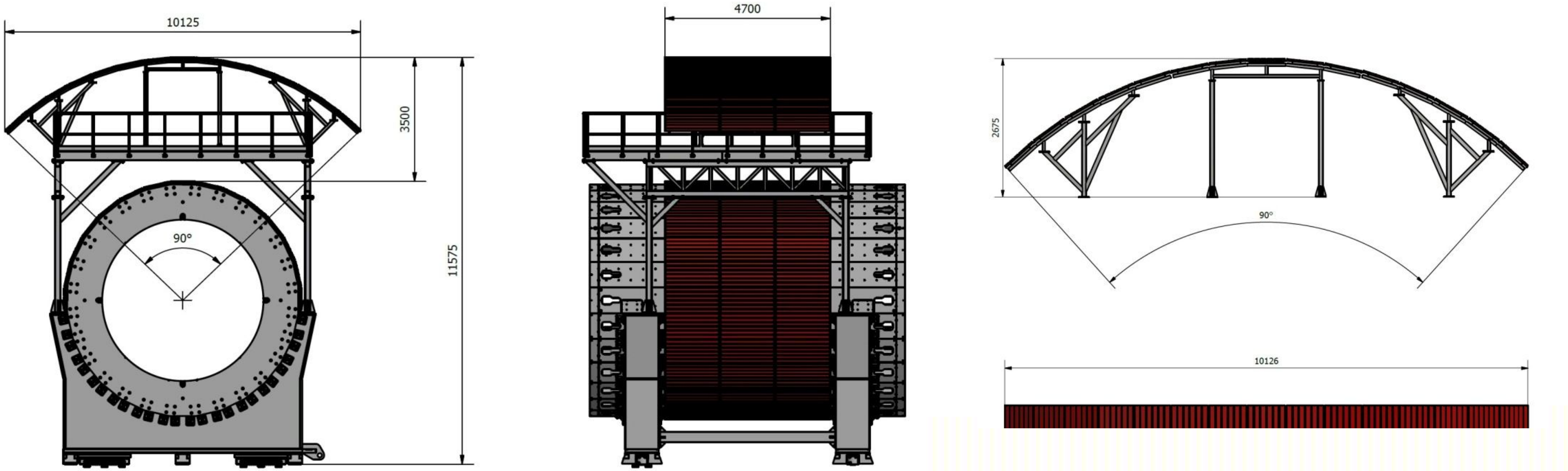
MCORD at MPD scheme

One surface on full circumference + additional surface on the top ver.1

4. Design, modeling variants

MCORD at MPD scheme



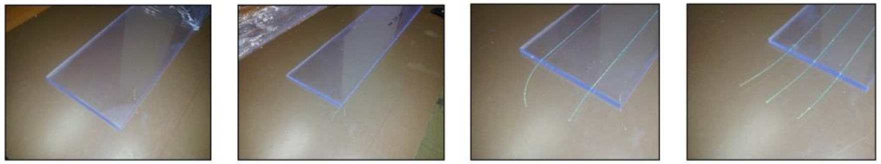


One surface on full circumference + additional surface on the top ver.2

4. Design, modeling variants – FIBER?

OPTION 1

Scintillator: **PVT or PS plastic (no fibers)**
- length: **150 cm**
- width: **10 cm**
- thickness: **2.5 cm**



no fibers | 2 side fibers | 2 up fibers | 3 up fibers

Light Yield estimation — Muon dE/dx = 2 MeV / (g·cm^2) - light production by one particle (muon)

Muon Energy Deposition	Scinti. Light Yield (LY)	Muon LY
~5 MeV	× ~8000 ph/MeV	~40000 ph

Light collection eff.: ~20% (?) **Attenuation length (λ): ~75 cm** Light atten.: LY/[2exp(x/λ)]

LY_{mid}: LY × 0.2 / (2e) ≈ **7000 ph** LY_{end}: LY × 0.2 / (2e^2) ≈ **2500 ph**

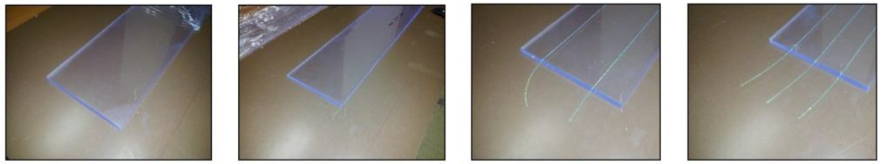
Photodetector: **SiPM** size: **25×25 mm^2** **(¼ scintillators end area)**

Dark Count Rate (DCR): ~50 Mcps (@ 0.5 phe)

DCR @ **5 phe (threshold level): ~10 kcps**

Light Yield (LY)	Photodetector QE: ~25%	Photoelectron Yield (PHE)
	Relative area: 25%	
~7000 ph	×25% ×25%	**~500 phe**
~2500 ph	×25% ×25%	**~150 phe**

4. Design, modeling variants – FIBER?



no fibers | 2 side fibers | 2 up fibers | 3 up fibers

OPTION 2

scintillator: **PVT or PS plastic + WLS (fibers) (fi:1 mm)**

length: **150 cm**

width: **10 cm**

thickness: **1 cm** **(less thickness)**

Light Yield estimation   Muon dE/dx = 2 MeV / (g·cm^2) - light production by one particle (muon)

Muon Energy Deposit	Scinti. Light Yield (LY)	Muon LY
~2 MeV	× ~8000 ph/MeV	~16000 ph

Light collection eff.: ~10% (?)   **Atten. length (λ): ~350 cm**   Light atten.: LY/[2exp(x/λ)]

LY_{mid}: LY × 0.1 / [2exp(75/350)] ≈ **600 ph**   **LY_{end}:** LY × 0.1 / [2exp(150/350)] ≈ **500 ph**

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photodetector: **SiPM**   size: **1 × 1 mm^2** **(100% fiber end area)**

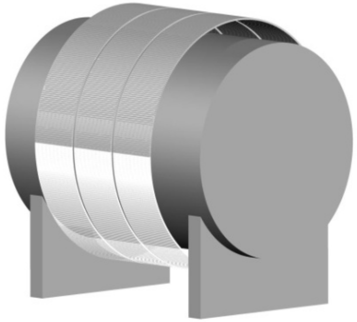
dark count rate (DCR): ~0.5 Mcps (@ 0.5 phe)

DCR **@ 3 phe** **(less threshold level)** : **~10 kcps**

Light Yield (LY)	Photodetector QE: ~25%	Photoelectron Yield (PHE)
	Relative area: 100%	
~600 ph	×25% ×100%	**~150 phe**
~500 ph	×25% ×100%	**~120 phe**

4. Design, modeling variants – FIBER?

Size estimation	**Detector MCORD**
Diameter:	7 m
Length:	4.5 m
Circumference:	22 m
No. of scintillators:	**660 pcs**
No. of SiPM:	**1320 pcs**
No. of mTCA:	**4 crates**



False trigger rate (FTR) estimation

SiPM-SiPM coinc_gate: 20 ns (two ends of one scintillator)

scintillator trigger_gate: 100 ns (two scintillators on MCORD cylinder)

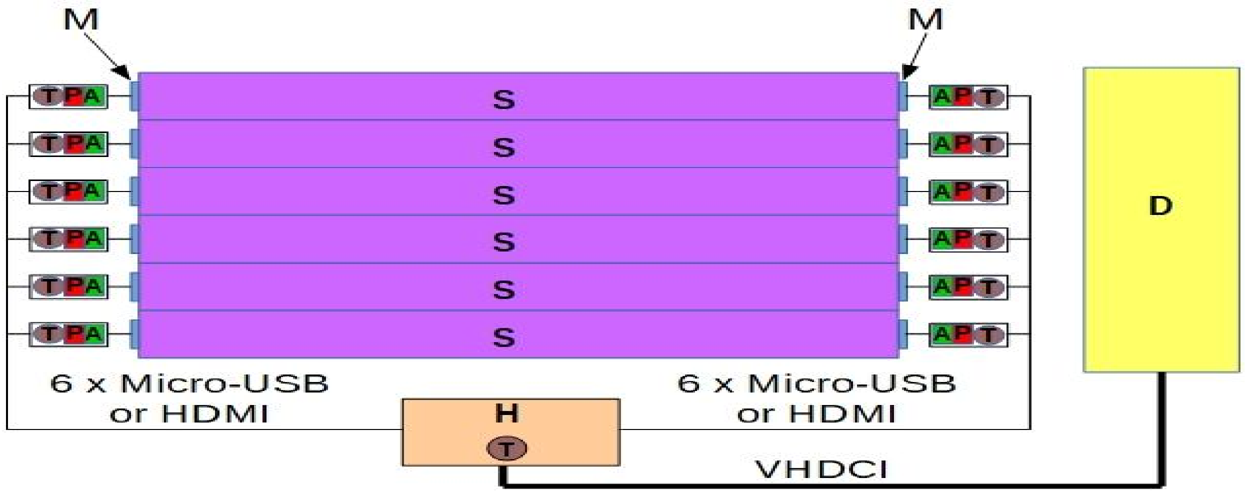
cosmic muon rate: **<150 cps/m2**

DCR (dark count rate)

PVT or PS plastic	(No fiber)	PVT or PS plastic + WLS	
DCR (@ 5 p.e.)	~10 kcps	DCR (@ 3 p.e.):	~10 kcps
noise-noise FTR:	**<0.1 cps (8,67xE-2)**	**noise-noise FTR:**	**<0.1 cps**
noise-cosmic FTR:	**<0.1 cps (7,81xE-2)**	**noise-cosmic FTR:**	**<0.1 cps**

4. Design, modeling variants

THE MUON DETECTOR SCHEME OF ANALOG SIGNAL PATH



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, D (yellow) – MicroTCA system with ADC boards, H (orange) – Passive Signal Hub & Power Splitter.

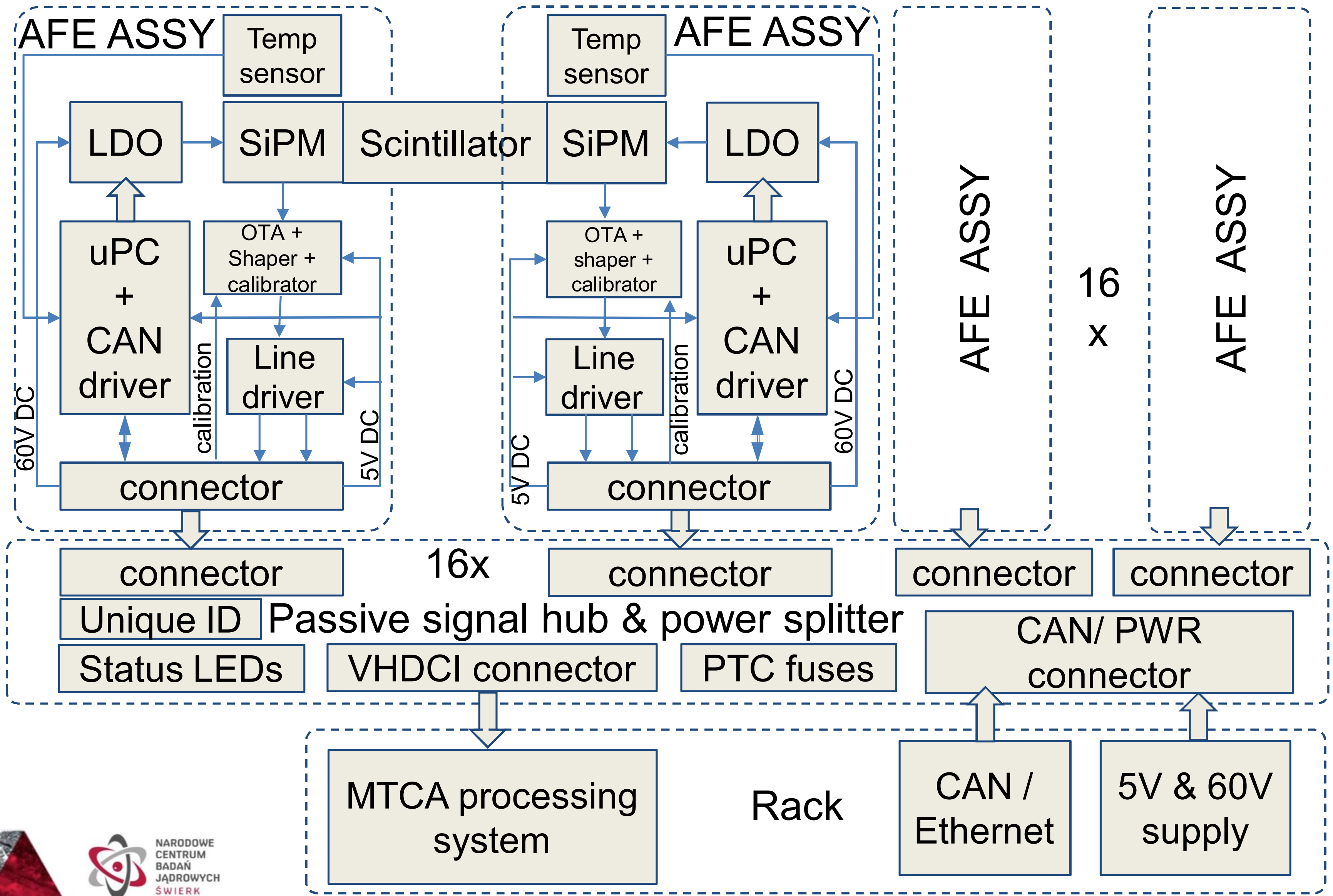



Connector type examples:

1. Rugged Micro-USB
2. C3 HDMI Rugged
3. HDMI Industrial
4. HVCDI

4. Design, modeling variants

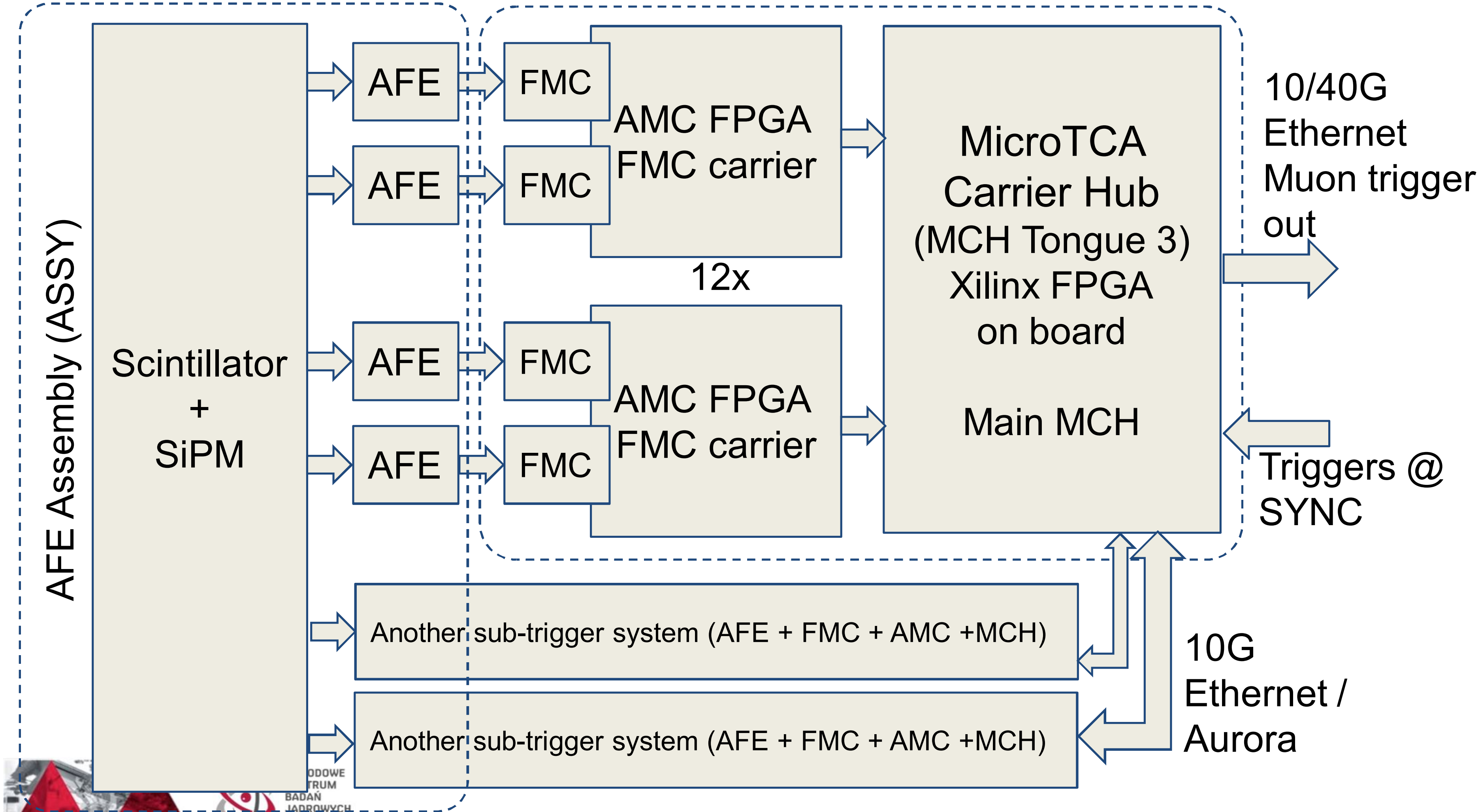
THE MUON DETECTOR SCHEME OF Analog Front END



4. Design, modeling variants

THE MUON DETECTOR SCHEME OF DIGITAL SIGNAL PATH

uTCA based modular muon trigger (signal flow only)

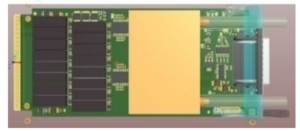


Analog Front End configuration

- Dedicated AFE Assembly per SiPM
- Embedded uPC + temperature sensor + LDO for SiPM set point adjust
- CAN network connectivity with unique ID chip as CAN address
- Unique ID in every hub for VHDCI cabling checking and identification
- Hardware ID for every AFE ASSY
- Low cost LDO instead of expensive switching power supply. No inductors required and lowers EMI.
- SiPM voltage, AFE current monitoring, latchup detection & protection for AFE
- Low cost shielded VHDCI cables – COTS components available as 1-10m length and custom versions
- Local passive hub with PTC fuses for 5V and 60V rails, distribution of power, CAN and signals from 16 AFE ASSY to single VHDCI cable
- Status LEDs on AFE ASSY and hub for quick fault identification
- Central power supply – custom built 2U rack box with COTS resonant 5V SMPS, 60V flyback SMPS, IEC outlets and fuses.
- CAN to Ethernet converter – standard COTS component.

MicroTCA (MTCA) configuration

Analog Front-End module



FPGA mezzanine card (FMC)

AMC FMC carrier board

MTCA Carrier Hub

- Standard MTCA crate (14U)
(cable fi1,5cm 24 channels +8)
(additional cable for 5V and 40V power)
- Crate number depends on channel count and sampling speed

At 250MS/s: 192 channels / crate
At 125MS/s: 384 channels / crate
(16 cables)
At 80MS/s: 576 channels / crate
At 50MS/s: 768 channels / crate

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

Data processing

- Latency estimation for L1 trigger (event without parameters)

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

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

5. MCORD Detector

SCINTILLATORS

Number of scintillators:	660 pcs
Dimensions of scintillators:	95x25x1500 [mm]
Dimensions of detector:	100x30x1554 [mm]
Scintillators are placed in the rectangle profile	10x30x2.5 [mm]
Weight of detector:	6.5 kg
Material of scintillators casing:	Aluminum alloy

MODULES

Number of detector in one module:	18
Number of Modules:	28
Dimensions of module:	730x90x4700 [mm]
Weight of one module:	150 kg

SiPM/MMPC

Number of SiPMs (Chanels)	1320
Number of SiPMs (with two fibers)	2640

RESOLUTION

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

Time Resolution – about 300-500 ps

Number of events (particles): about 100-150 per sec per m2

Calculated Coincidence factor: about 98%

5. MCORD Team

30 people
Including
18 scientists (professors and doctors)
12 engineers
from
2 universities and 3 science institutes

With knowledge and experience in digital and analog electronics, scintillators and photodetectors, nuclear and astrophysics, data acquisition and analysis, simulation and experiments.

Our group is a member of Polish consortium NICA-PL

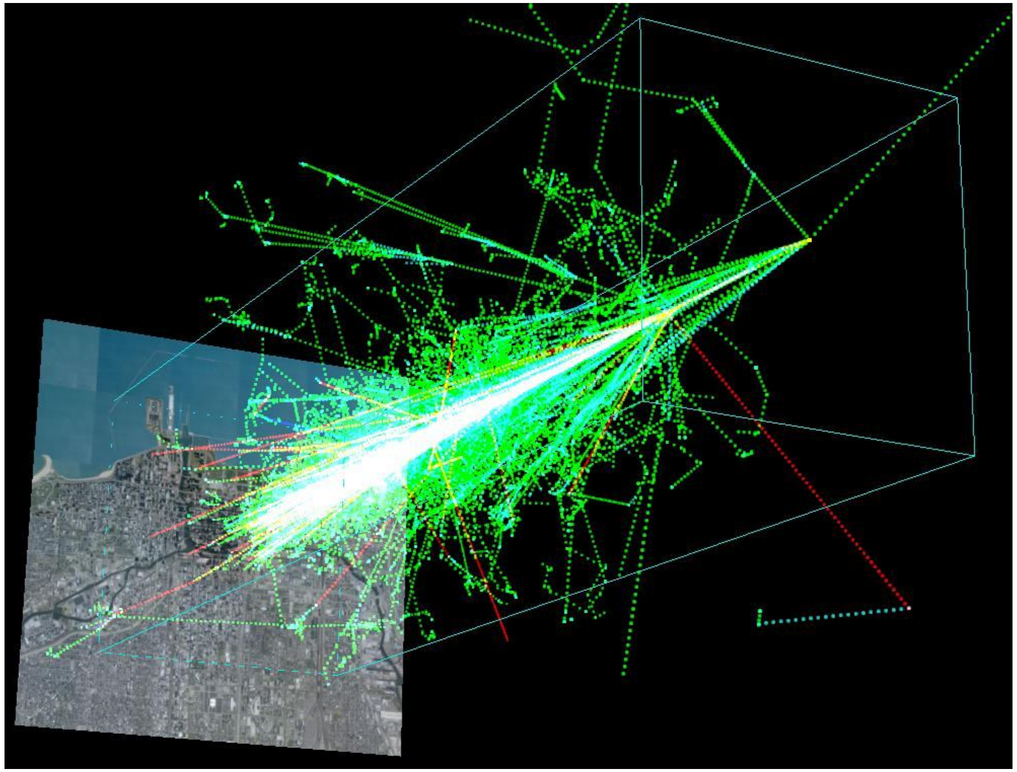
5. Conclusions

1. Cosmic Ray Detector is necessary for good calibration of TPC, TOF and ECAL, MPD detectors before completion of MPD .
2. Cosmic ray detector is helpful for better calibration of TPC TOF, before each experimental session.
3. Additionally MCORD can be used for astrophysics observations similar to past collider experiments. In our case, especially for investigations of near horizontal muon bundles (research of main trivial mechanism of multi-muon event generation (EAS muons).
4. Our team has a realistic plan and is capable of building this detector.
5. Projected cosmic ray detector will be designed to have required time resolution and position accuracy

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

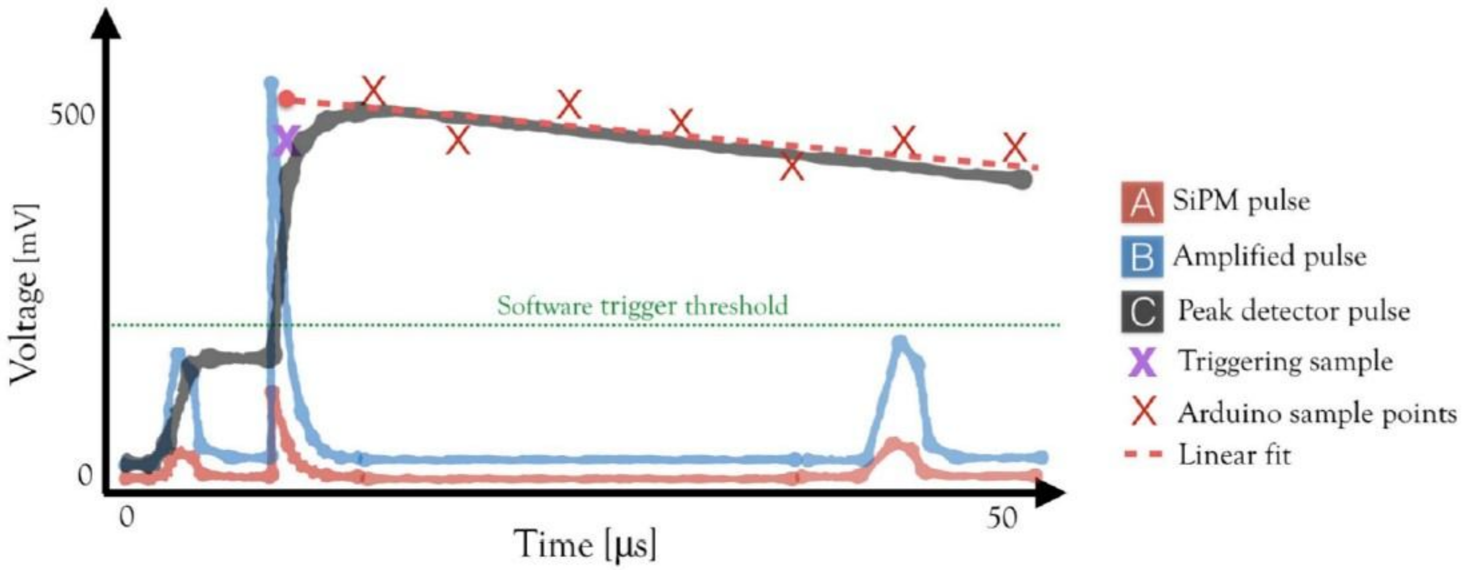
Polish consortium NICA-PL

Thank You for Attention

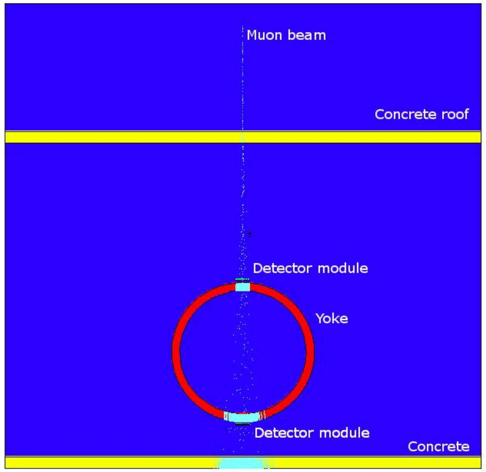


Data processing

- FPGA gateware:
- ✓ Time synchronisation: White Rabbit–based sub-ns
- ✓ Pulse position estimator (advanced DSP processing)
- ✓ Local triggering
- ✓ Data quality monitoring
- ✓ Data acquisition
- ✓ Data formatter and transmitter

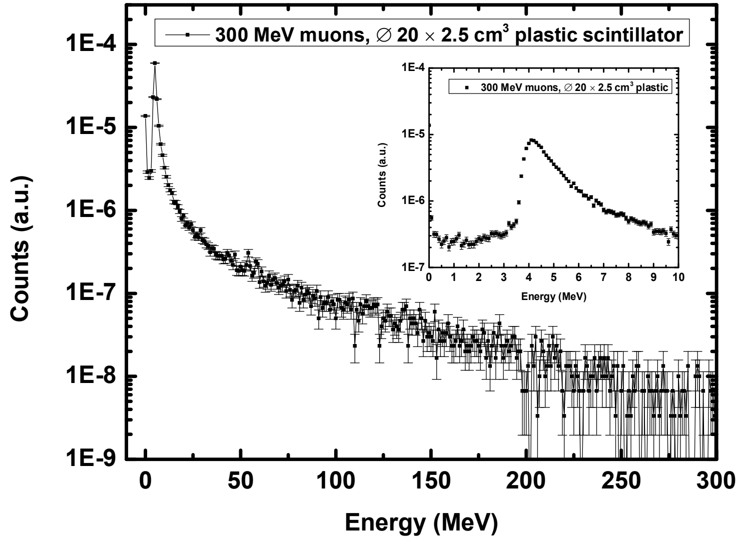


Conceptual design – simulations

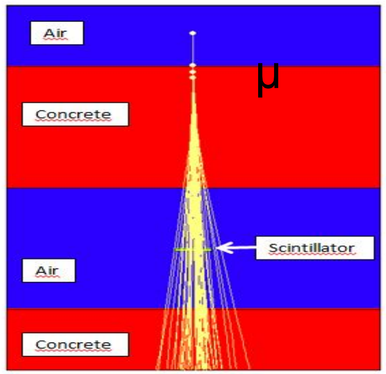


The first MCNPX simulation of muon energy deposition in plastic scintillator for NICA Energy spectrum reconstruction

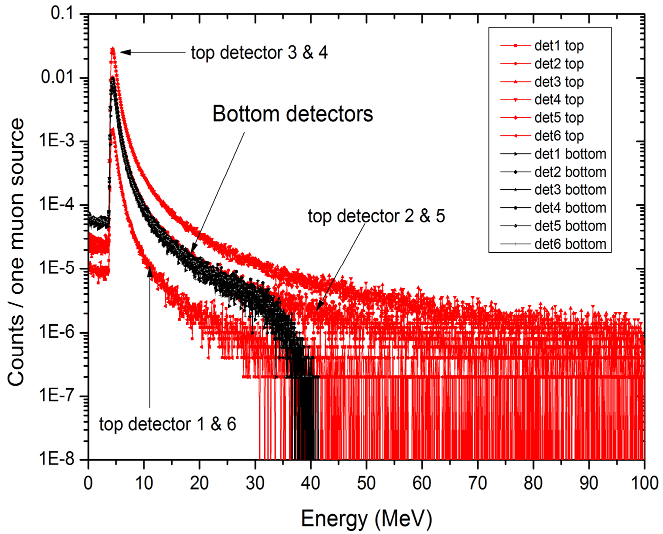
- Cylindrical plastic scintillator Ø20 × 2.5 cm^3 – the same used for experiment at NCBJ
- The maximum energy deposition centroid is around 4 MeV - reasonable result, assuming 2 MeV/cm dE/dx energy loss for muons in organic scintillator. Light generation due to ionization in plastic scintillator will be implemented in the near future.



Energy deposition spectrum



Geometry used (40000 tracks)



Energy deposition spectra of 2 GeV monoenergetic muons

5. MCORD – estimated cost

4. Design, modeling variants

MicroTCA and other in the Slow Control Racks