Range (muon) System Status and Plans for 2025

G.Alexeev, SPD Collaboration meeting, Dubna 06.11.2024

- **Main result and current activities (after SPD Collaboration meeting, May 2024):**

*** Final calculations of the yoke and support behavior under combined gravitational and magnetic forces are finished. No dangerous moments in terms of material stress and displacement are present. So, this 3D conceptual model opens a door to the next important step – creation of 3D detailed engineering model to be further used for the yoke construction contract**

- RS prototype is mounted in beam position on support/transportation system at Nuclotron test beam area
- Design of detecting plane (new strip board concept) is developing
- Amplifier chip (Ampl-8.53) preproduction at INTEGRAL (Minsk) is being monitored
- Currently working on establishing connection of RS prototype digital module with prototype L1/DAQ concentrator
- Preparations for deployment of equipment for MDTs mass production – area for tuning the equipment is found
- Participation in development of PID algorithms for pion-to-muon separation: DBSCAN clustering algorithm was rewritten in C++ and is integrated into the SPDRoot (in stand alone mode)

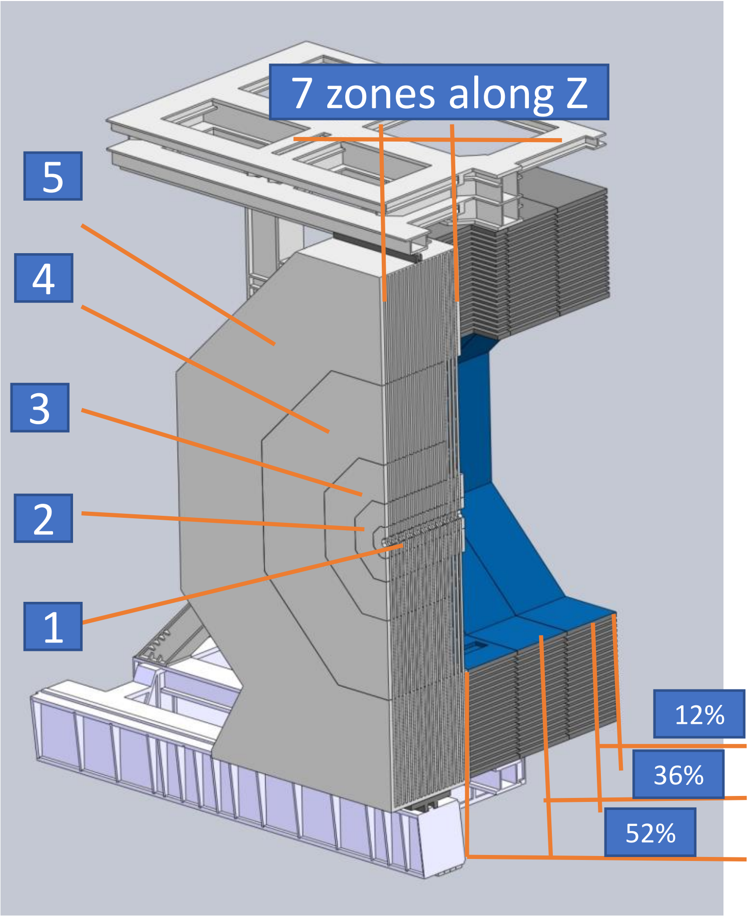
- **Plans for 2025**
- **Conclusion**

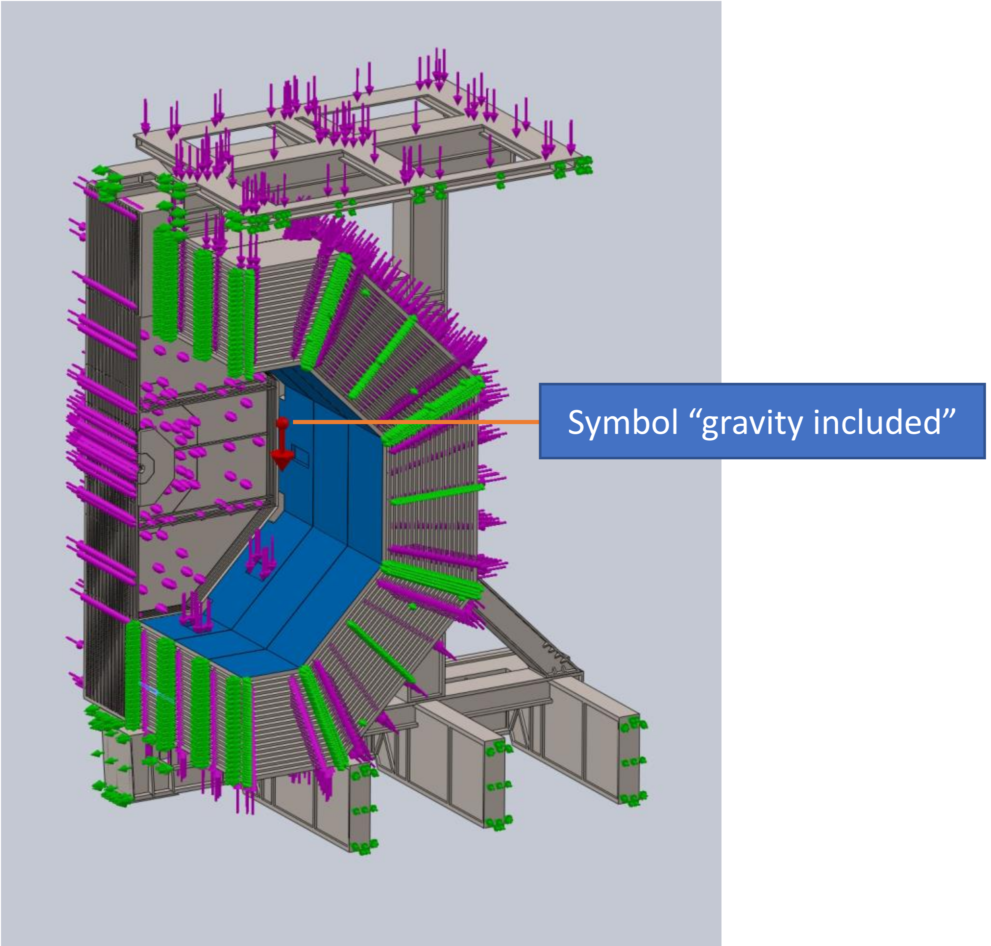
Space distribution /granularity of magnetic forces in the Yoke volume (E.Antokhin/INP & A.Samartsev/JINR) used for final 3D model calculations (program package COSMOS)

Magnetic forces granularity

Final forces (**B + G**) map

Fz/End Cap: 5 radial areas (1-5) *(7 zones along Z: 60mm/3*30mm/4*30mm/4*30mm/4*30mm/4*30mm/60mm)

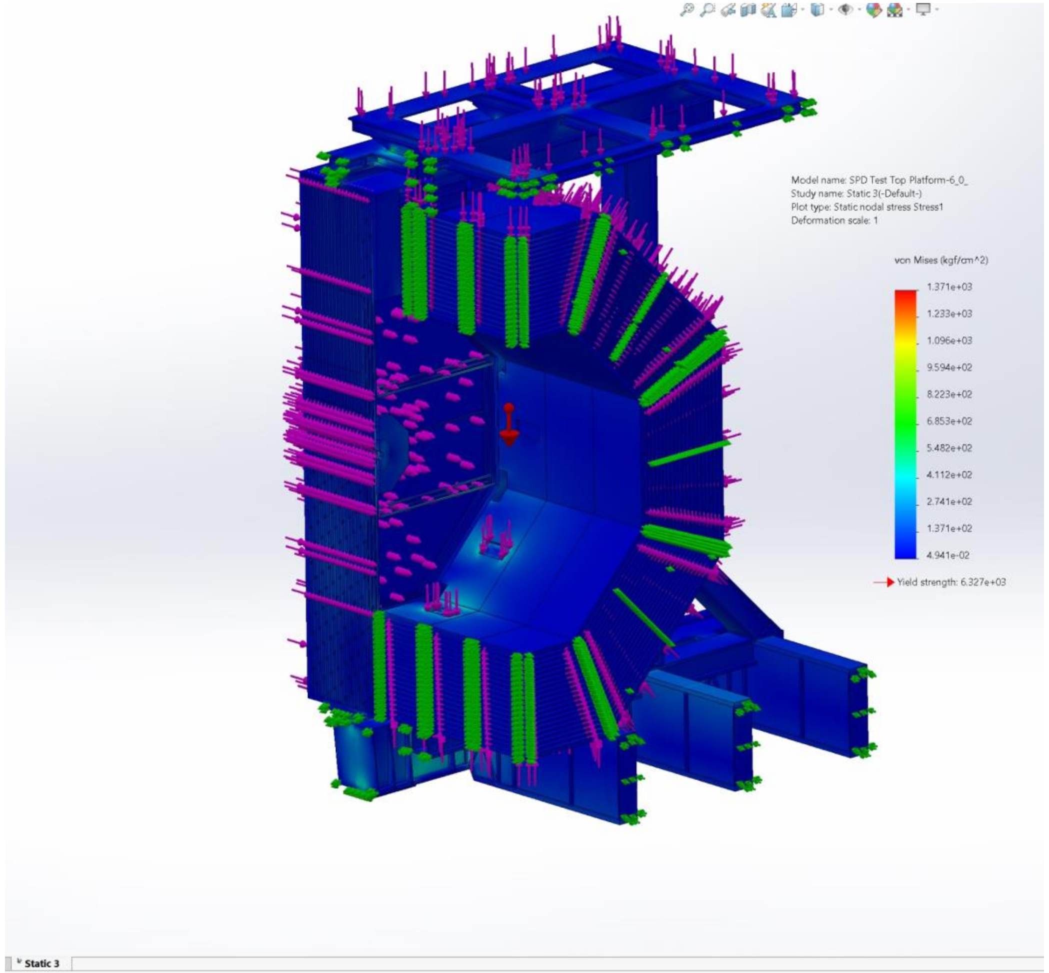




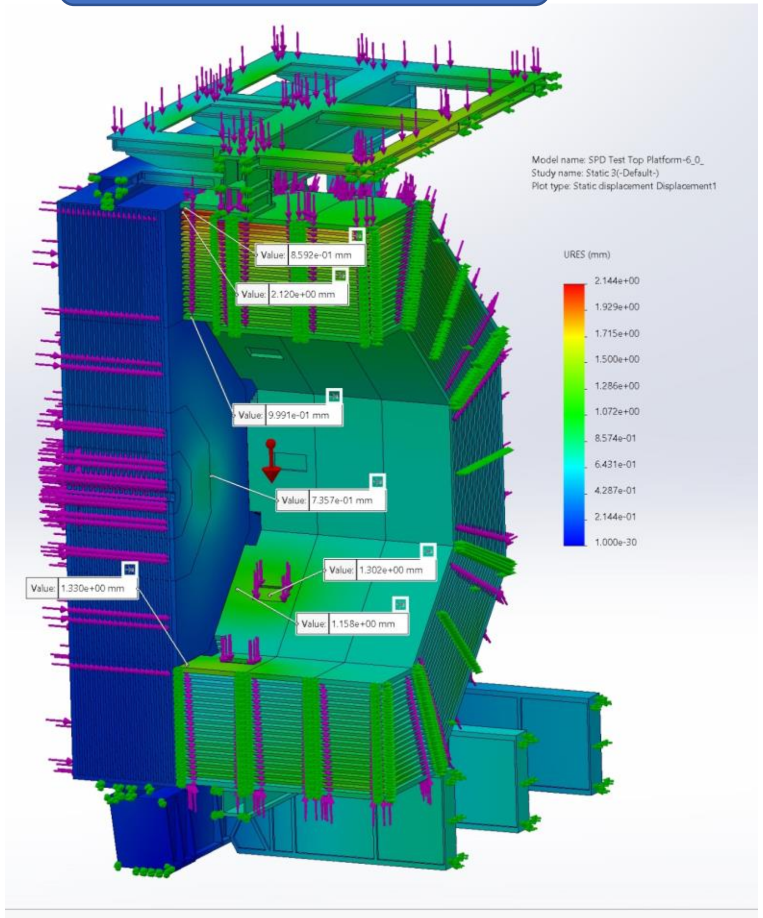
Fr/Barrel: All 21 planes * (3 zones along Z: 12% + 36% + 52%)

Results of stress and displacement calculations in the Yoke system (including support/transportation system and upper platform) demonstrate no dangerous zones. So, 3D conceptual model is practically finalized. After final “polishing” it will be delivered (by the end of 2024) for developing 3D engineering model to VBLSHE

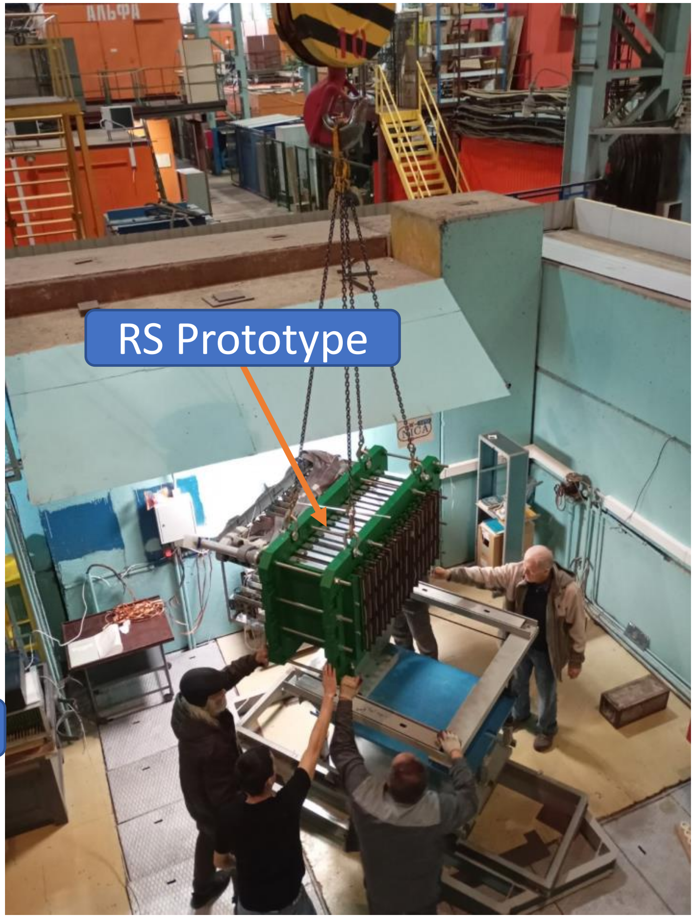
Stress state



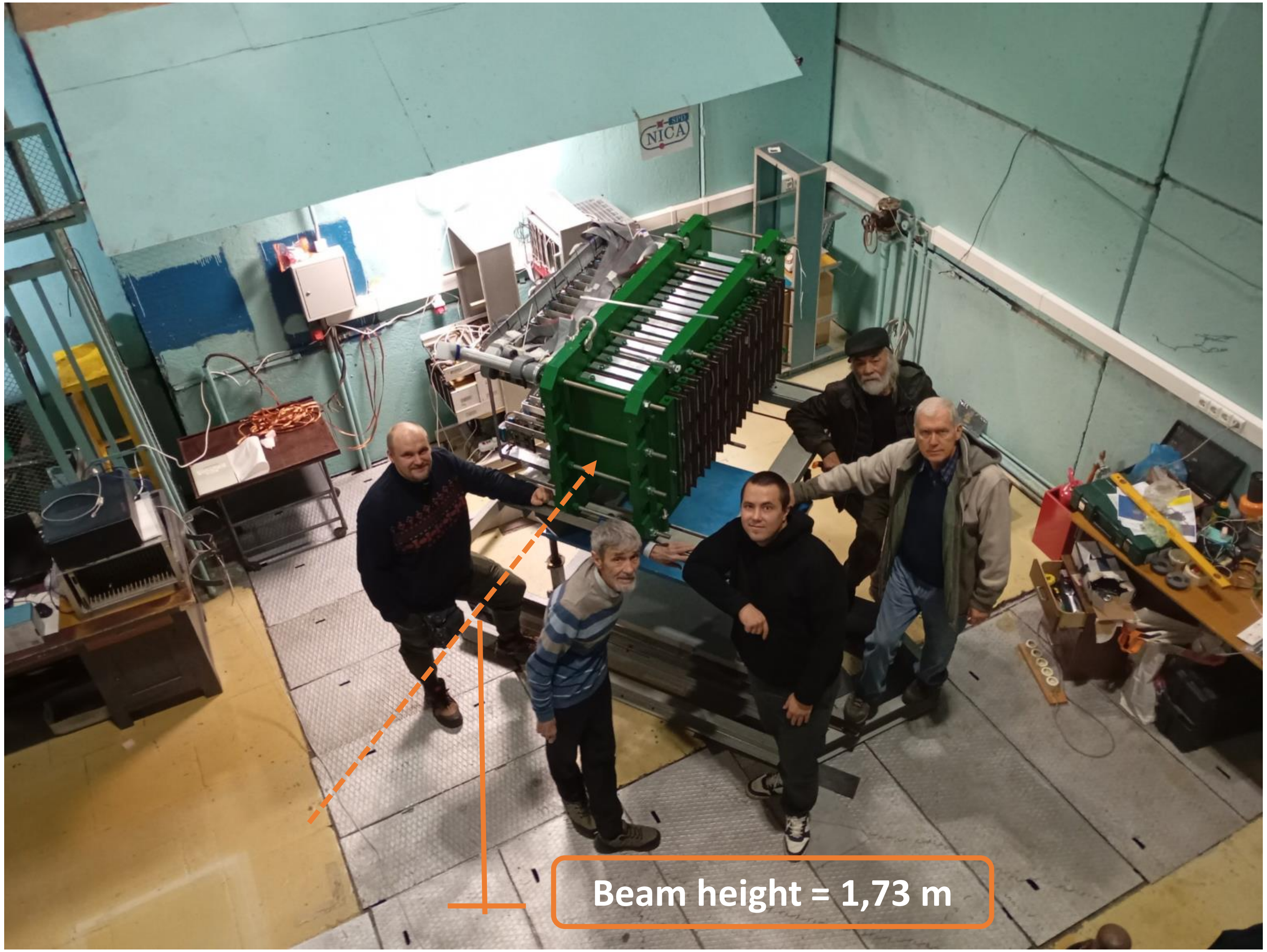
Displacement state



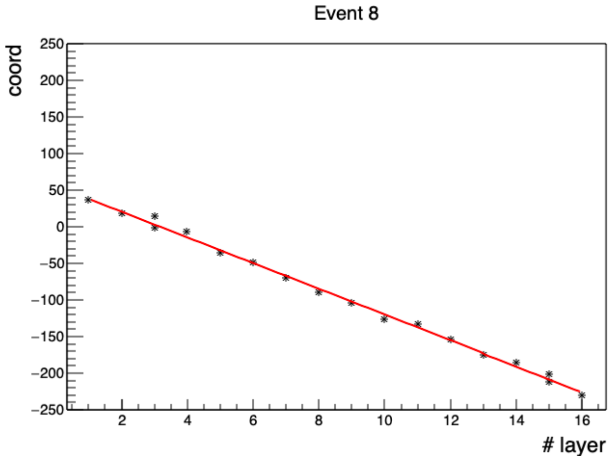
Mounting of RS Prototype at Nuclotron Test Beam Area

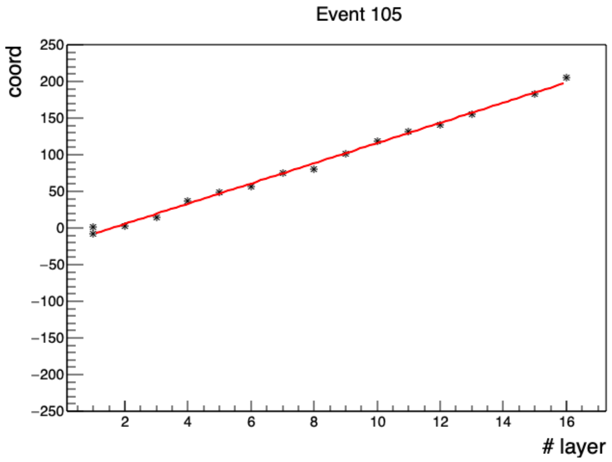


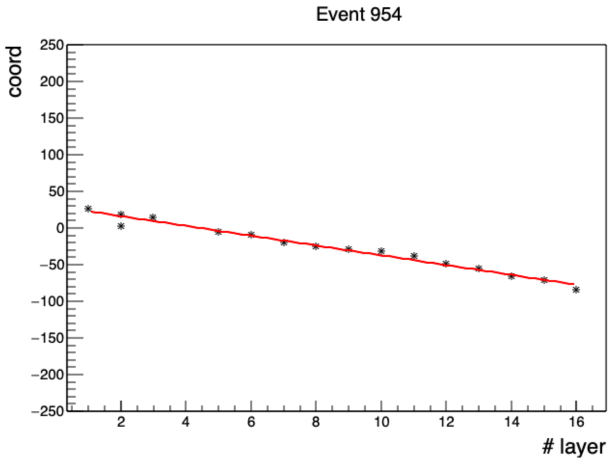
RS Prototype at work position at Test Beam Area



Estimation of RS prototype coordinate accuracy on cosmic



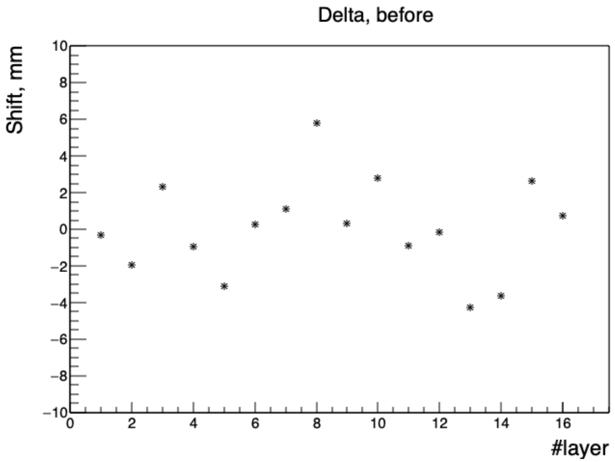


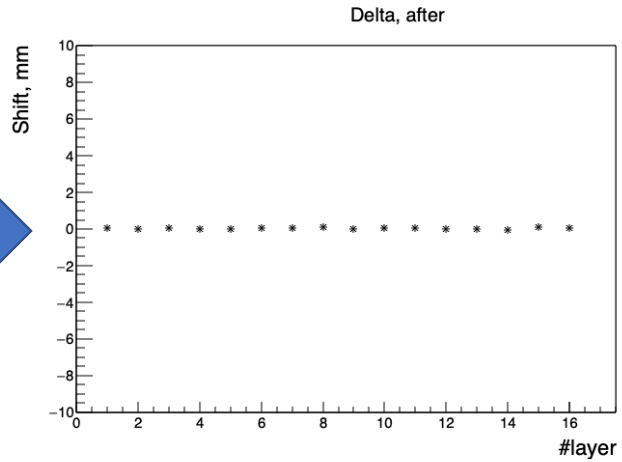


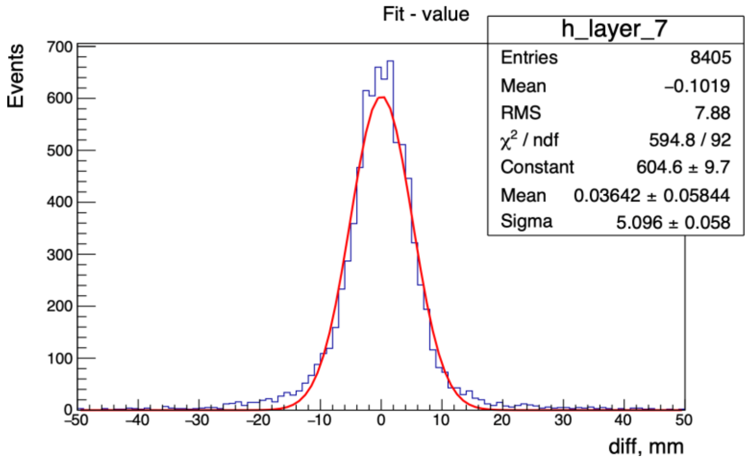
Approximation of straight cosmic tracks by a polynomial in 16 layers.

N_events = 8323
HV = 2300 V

Coordinate alignment







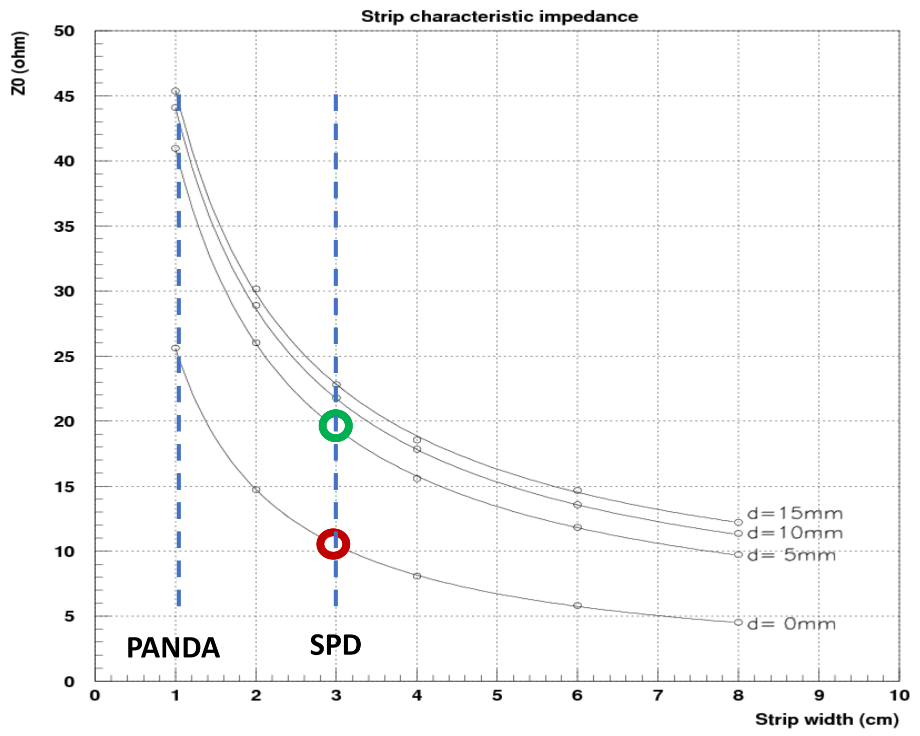
<**σ**> = 5.48 mm

<**σ**> = 5.45 mm

Sigma

New concept of the strip board

Recent idea of a strip board structure is a variation of initial strip R/O concept of the PANDA Moun system design, where the air gap between Fe plate and strip board determined strip parameters (Z_0, C_{max}) -> impossible variant as we need a proper e/m shielding for strip R/O => d (air gap) = 0



Strip wave impedance (Z_0) vs strip width measured for 1,5 mm thick fiberglass stripboard and different air gaps between stripboard and GND plane

In PANDA final design we used 2 mm thick fiberglass (**ε ≈ 4**) and **1 cm** width strips resulting in **Z_0 ≈ 25 Ohm**, **C_{max} ≈ 1÷1,5 nF** (far from optimum but R&D proved that we still within appropriate operation limits if we use low input impedance preamplifiers => Ampl - 8.53, Ampl-8.11R)

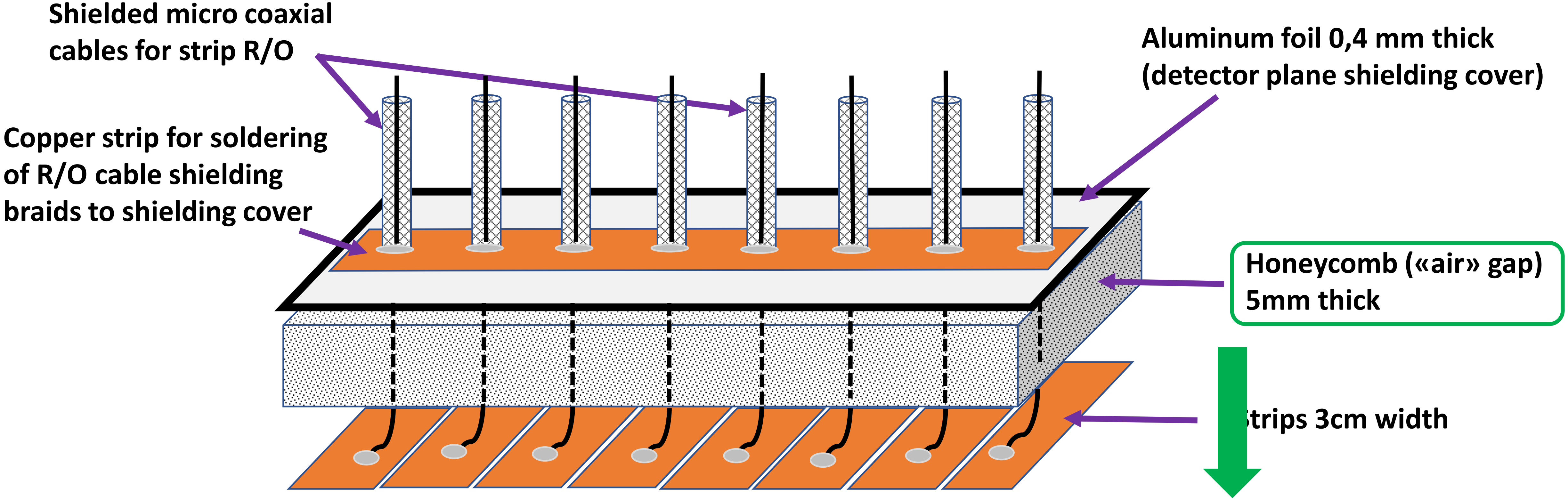
In SPD case due to larger setup dimensions we use 3 cm width strips (to reduce strip R/O channels) and also have longer strips. Application of fiberglass stripboard would mean **Z_0 ≈ 10 Ohm**, **C_{max} ≥ 3nF** resulting in significant

- decrease of strip FEE reliability (no proper HV discharge protection provided by voltage divider formed with wave impedance matching resistor an amplifier input impedance),
- worsening of noise to signal ratio (extremely high detector capacitance),
- decrease of registration efficiency (extremely high detector capacitance).

To achieve proper strip parameters and avoid mentioned problems we need new stripboard structure with implemented 5mm «air» gap **(ε -> 1)** under the detector layer shielding cover.

Stripboard with the «air» gap

Instead of the former strip board made of copper laminated fiberglass plate we offer a 5mm thick honeycomb structure with aluminum foil on one side and copper strips on the other.

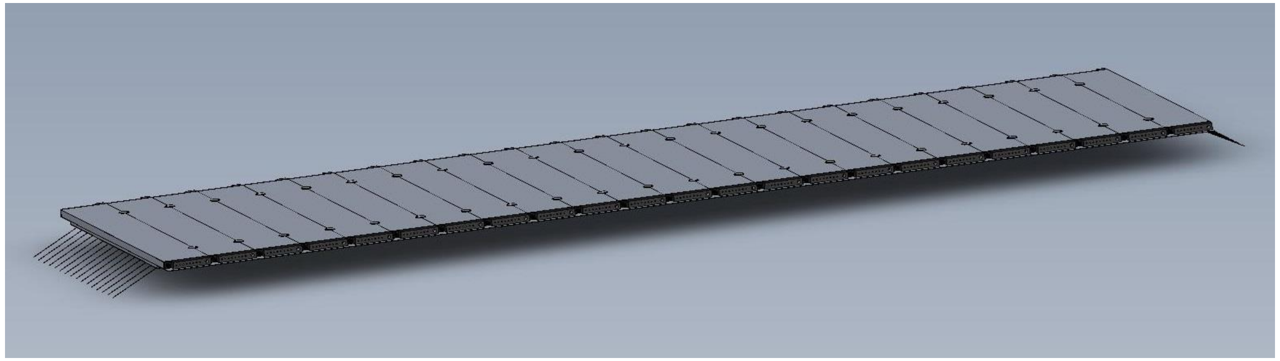


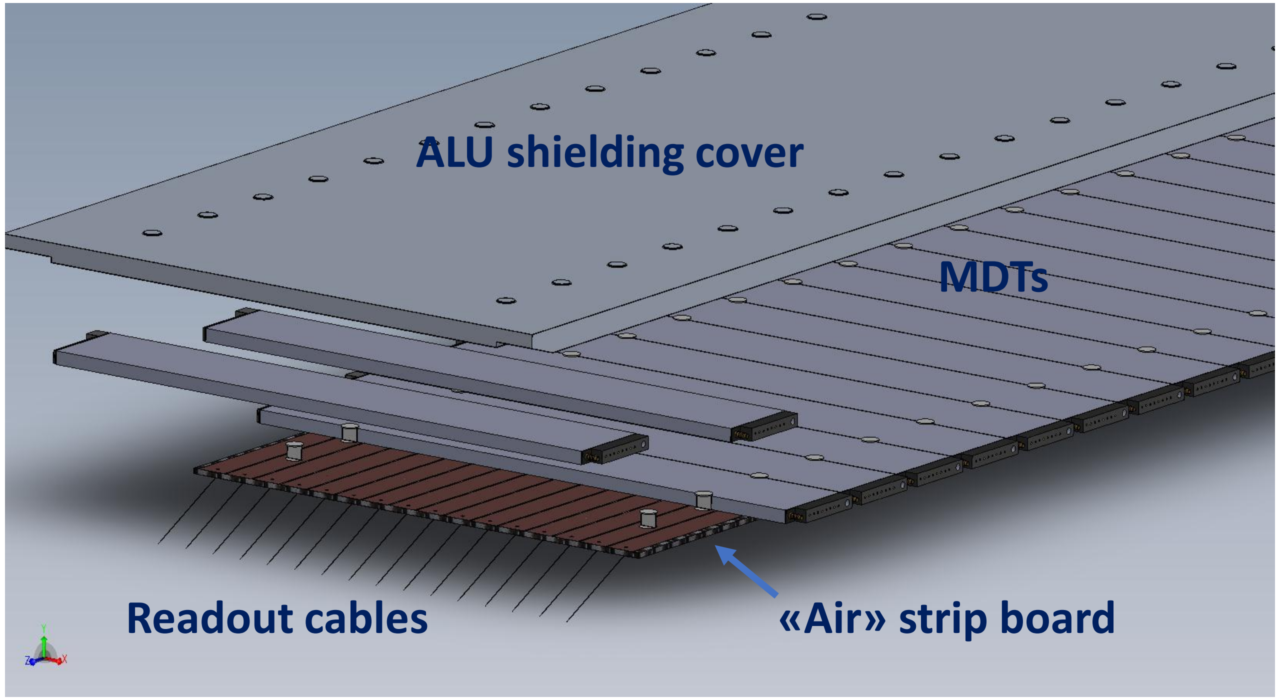
With the «air» stripboard we expect to achieve **Z_0 within 20 ÷ 38 Ohm and $C_{max} \leq 310$ pF**

All parameters of «air» stripboard readout will be studied with Detecting Layer Prototype which is currently at the stage of development and construction

Detecting Layer Prototype (DLP), 3D model

DLP structure consists of 60 cm long MDTs, 2 m long strips (3cm width), 5mm thick honeycomb (air gap) with 3mm cells, new type of blades (cylindrical) and 0,4 mm thick aluminum shielding cover. New design of detecting layer was also intended to minimize its height, as we are using rather thick strip board, providing height of 19,1 mm as a result (vs 21.3 mm of PANDA variant).

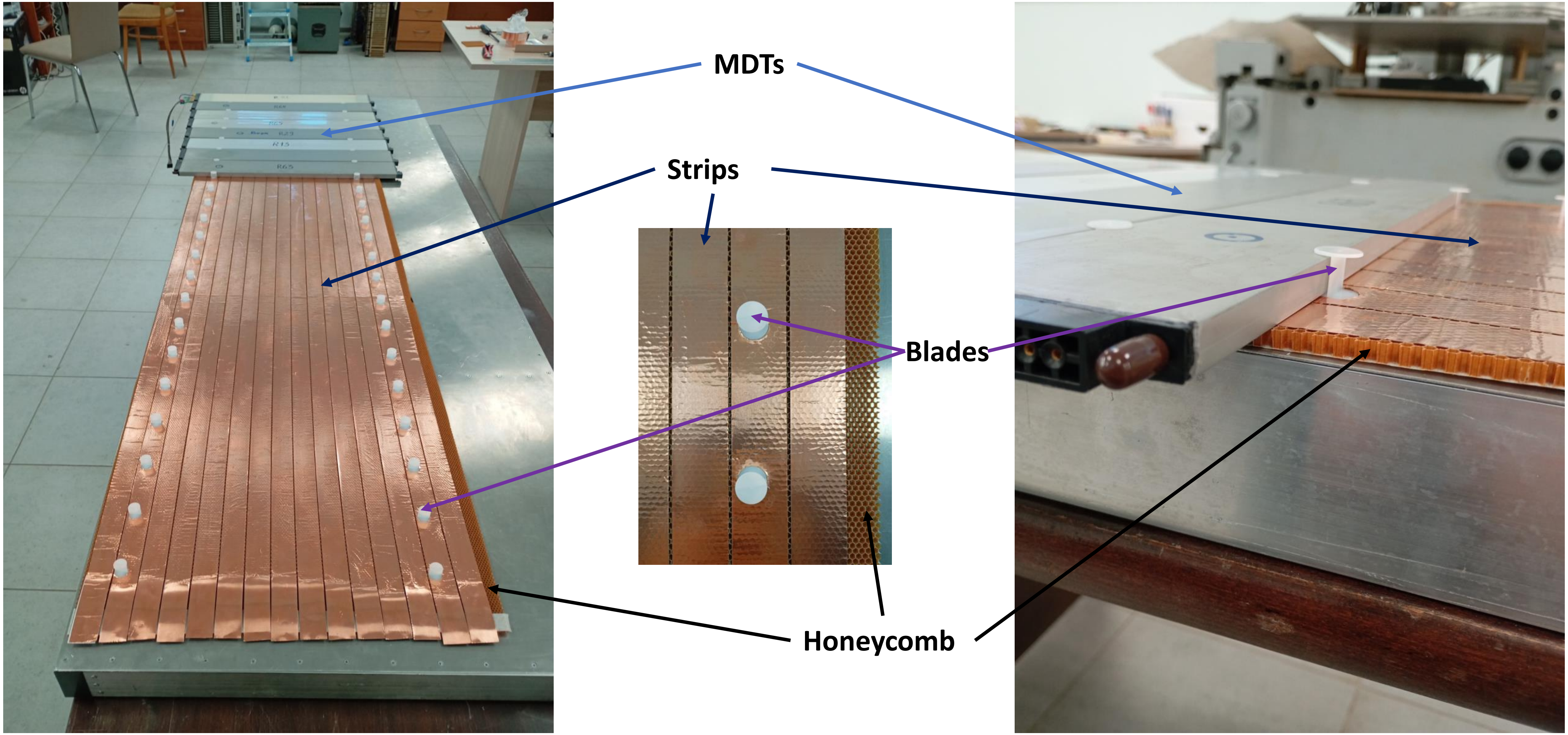




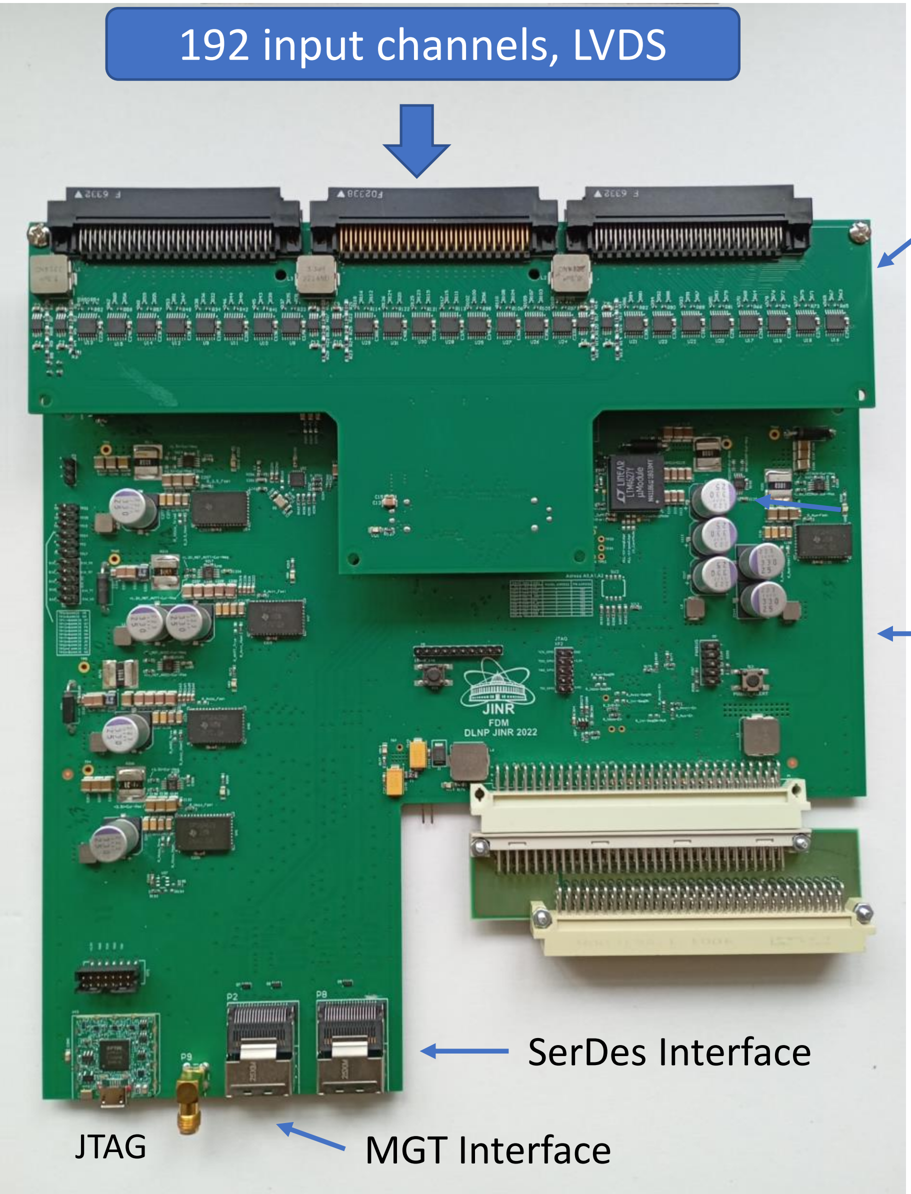
DLP is being created to fulfill two general tasks:

1. **Elaborate technological process** of full scale detecting layer assembly, including
   - list of used materials and tools,
   - consequence of assembly actions and their detailed description,
   - tasks for special tools and assembly table(s) developments.
2. **Study of «air» strip board parameters**, including
   - measurement of strip wave impedance and specific capacitance,
   - signal readout tests,
   - study of strip registration efficiency.

Detecting Layer Prototype (DLP) at test stand



FDM digital module (prototype) for Range System



Mezzanine board

Motherboard

- Mechanics – VME 6U 2M
- **FPGA chip – Xilinx Artix7-200T**
- Number of registered channels -192
- Triggerless mode
- Signals level from analog electronics - LVDS
- Threshold range for input signals - 0 ÷ +3V
- Global Clock – 125 MHz
- Discreteness of digitization the time of the arrival hit signal - 4 ns
- Data interface – SerDes/MGT
- Power consumption - ˜24W

We are currently working on establishing connection with the L1 concentrator.

Plans for 2025

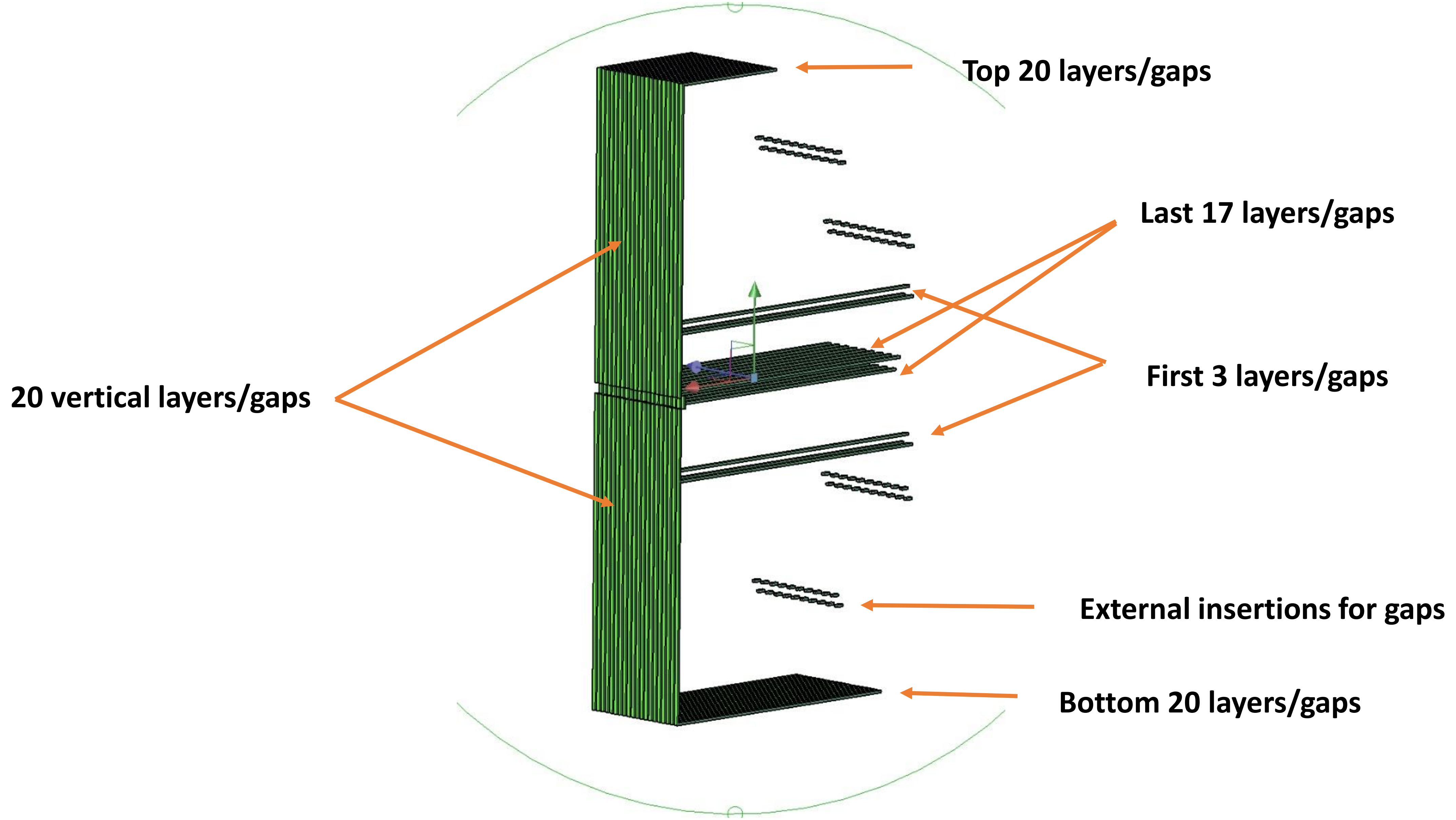
- Start preparing/equipping the MDT assembly and test areas at DLNP (old cyclotron zone)
- Continue cooperation in developing of 3D engineering model of the Yoke (and around)
- Study of the first set of amplifier chips from Integral/Minsk
- Signing of the contract with Minsk on FEE chips (Ampl-8.11R-G5, Disc-8.17)
- Development of strip readout technology (analog cards and strip boards)
- Tests of Cherenkov counter at electron beam of DLNP linac
- Participation in tests of digital FDM-192 units with L1/DAQ prototype (step forward final DAQ design)
- Detailing of 5 year planning for RS construction (preliminary)
- Participation in development of PID algorithms for pion-to-muon separation

CONCLUSION

- **Range System at present has reached serious milestone – 3D conceptual model of the Yoke is finished**
- MDTs preproduction (DLNP)and production (VBLSHE) areas are found
- Still we have a lot to do for development of final technologies (mostly for strip readout)

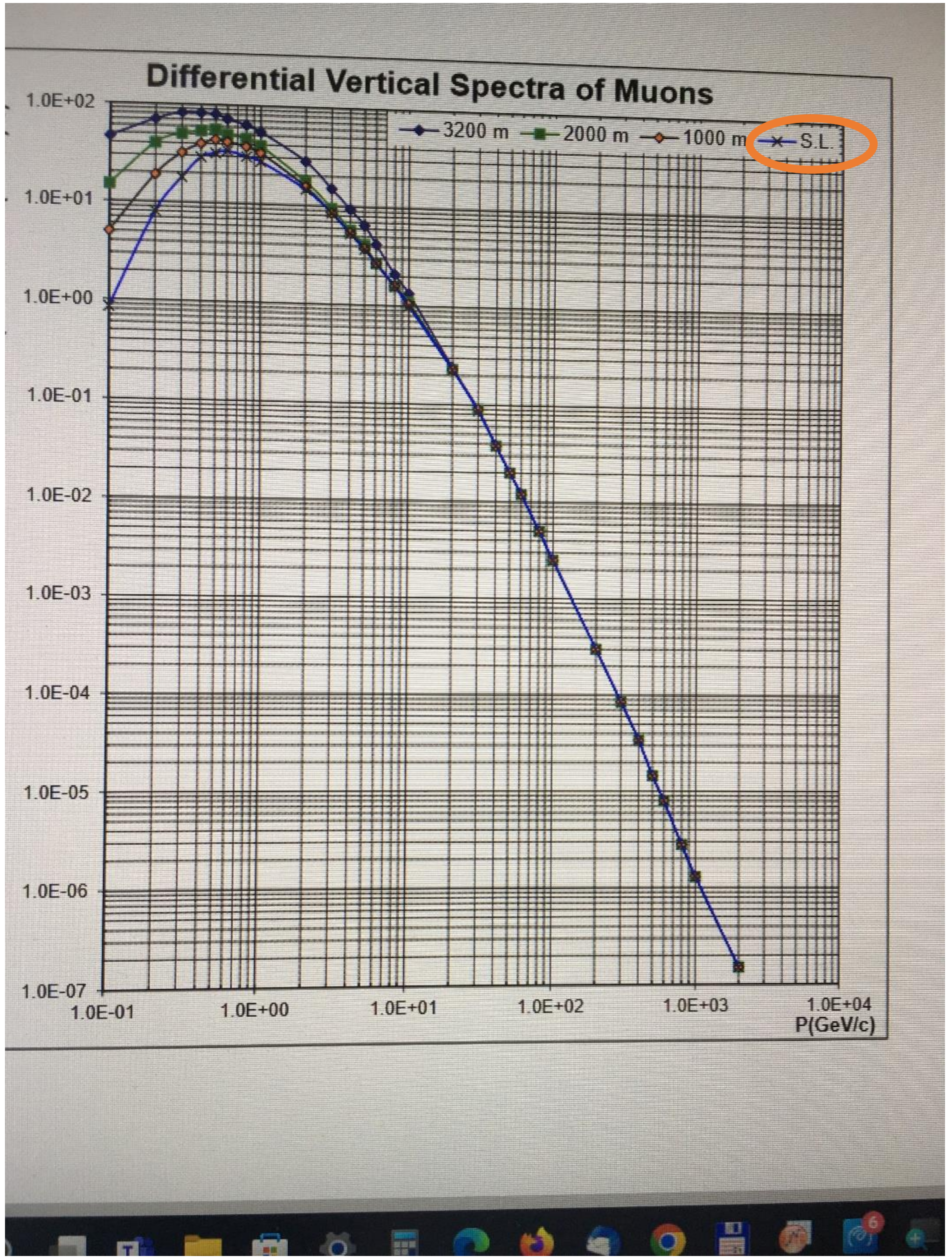
BACKUP SLIDES

Strengthening bars (withstanding magnetic forces) in volume/gaps of End Cap



RS Prototype at Nuclotron SPD test beam area -> waiting for the beam…

Usefull information on cosmic muons



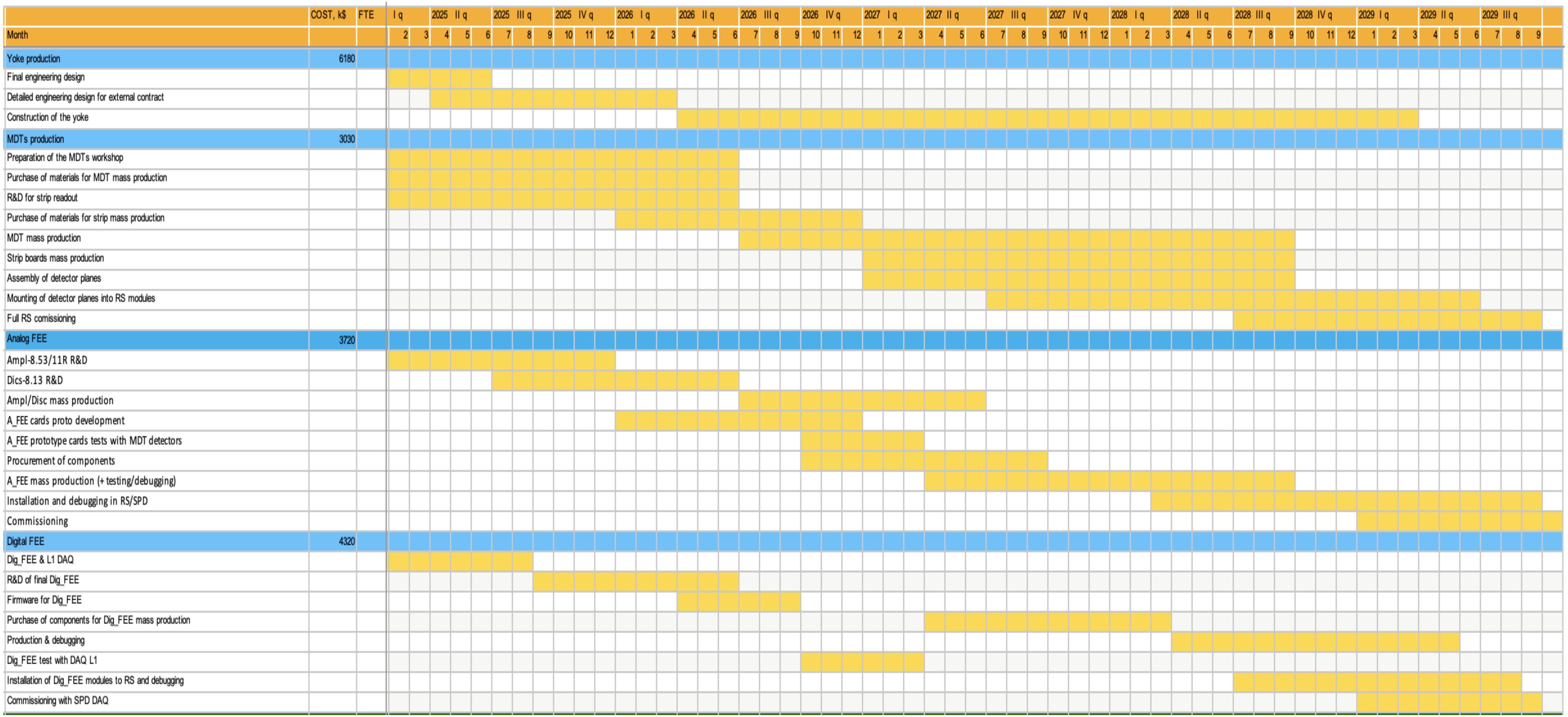
30.3 Cosmic rays at the surface

30.3.1 *Muons*

Muons are the most numerous charged particles at sea level (see Fig. 30.5). Most muons are produced high in the atmosphere (typically 15 km) and lose about 2 GeV to ionization before reaching the ground. Their energy and angular distribution reflect a convolution of the production spectrum, energy loss in the atmosphere, and decay. For example, 2.4 GeV muons have a decay length of 15 km, which is reduced to 8.7 km by energy loss. The mean energy of muons at the ground is ≈ 4 GeV. The energy spectrum is almost flat below 1 GeV, steepens gradually to reflect the primary spectrum in the 10–100 GeV range, and steepens further at higher energies because pions with $E_\pi > \epsilon_\pi$ tend to interact in the atmosphere before they decay. Asymptotically ($E_\mu \gg 1$ TeV), the energy spectrum of atmospheric muons is one power steeper than the primary spectrum. The integral intensity of vertical muons above 1 GeV/c at sea level is $\approx 70\ \mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$ [67, 68], with recent measurements [62, 69, 70] favoring a lower normalization by 10-15%. Experimentalists are familiar with this number in the form $I \approx 1\ \mathrm{cm}^{-2}\ \mathrm{min}^{-1}$ for horizontal detectors. The overall angular distribution of muons at the ground as a function of zenith angle θ is $\propto \cos^2\theta$, which is characteristic of muons with $E_\mu \sim 3$ GeV. At lower energy the angular distribution becomes increasingly steep, while at higher energy it flattens, approaching a $\sec\theta$ distribution for $E_\mu \gg \epsilon_\pi$ and $\theta < 70°$.

Figure 30.6 shows the muon energy spectrum at sea level for two angles. At large angles low energy muons decay before reaching the surface and high energy pions decay before they interact, thus the average muon energy increases. An approximate extrapolation formula valid when muon decay is negligible ($E_\mu > 100/\cos\theta$ GeV) and the curvature of the Earth can be neglected ($\theta < 70°$)

RS production schedule (Yoke, MDT detectors, analog and digital electronics



Manpower of Range (muon) System project

Project leaders	**JINR: G.Alexeev**
Magnet yoke design and MDT detecting planes assembling and mounting into slots of the yoke	JINR: A.Samartsev, E.Boltushkin, S.Kakurin, S.Gerasimov
Gas system (as part of DCS)	MSU: K.Korolev + 1
Analog and digital electronics	JINR: N.Zhuravlev + 4 Minsk: M.Baturitsky + 3, A.Solin +1 MSU: A.Chepurnov, A.Nikolaev, A.Aynikeev + 3
MDT detectors and strip boards production and assembling	JINR: V.Abazov, A.Piskun, S.Kutuzov, I.Prokhorov, Yu.Vertogradova
Software and analysis	JINR: A.Verkheev, L.Vertogradov MEPhI: A.Osetrov