Range (Muon) System Status Report

G.Alexeev, SPD collaboration meeting, Dubna, 10 June 2021

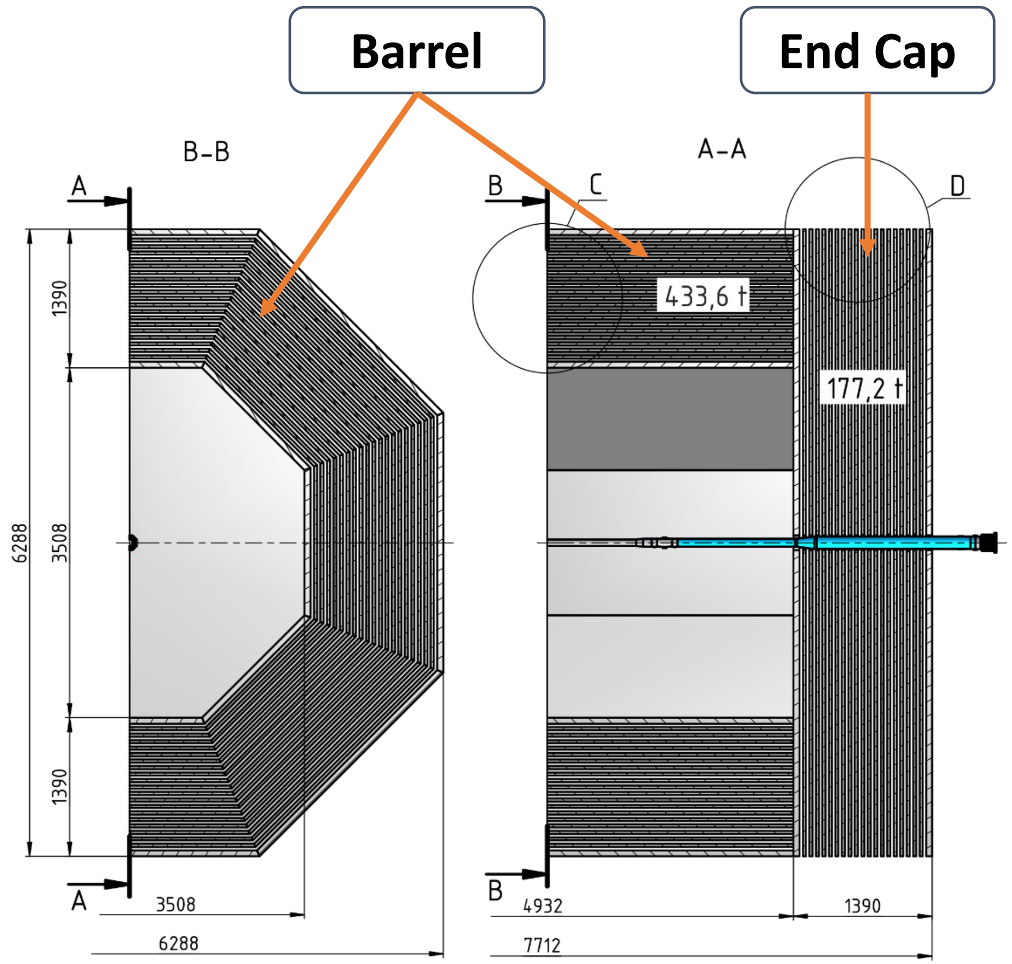
- **Introduction (brief review of RS system)**
- **Mechanical calculations FEA (deformation, stress)**
- **MC model of big prototype, fit to data**
- **Preparation of SPD/RS prototype for Nuclotron test beam (structure/absorber, MDT detectors, analog and digital electronics, Cerenkov counter)**
- **Plans for 2021**
- **Conclusion**

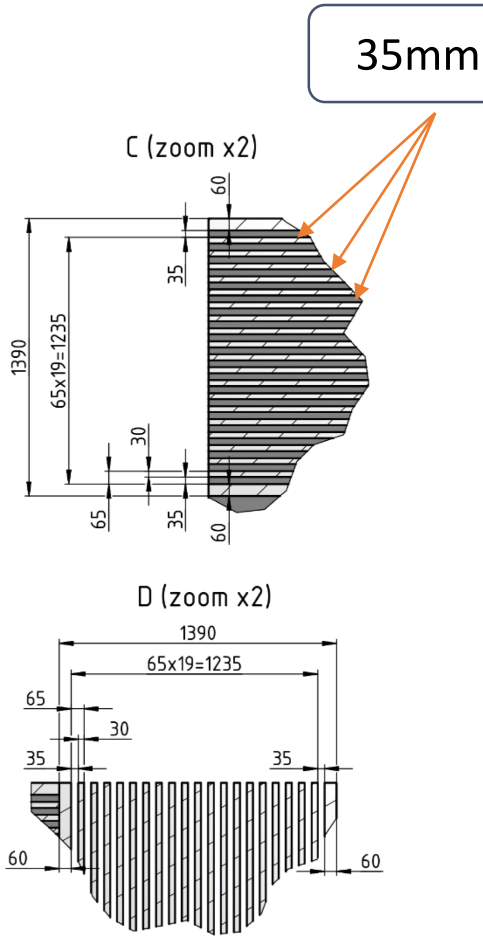
Muon System as PID

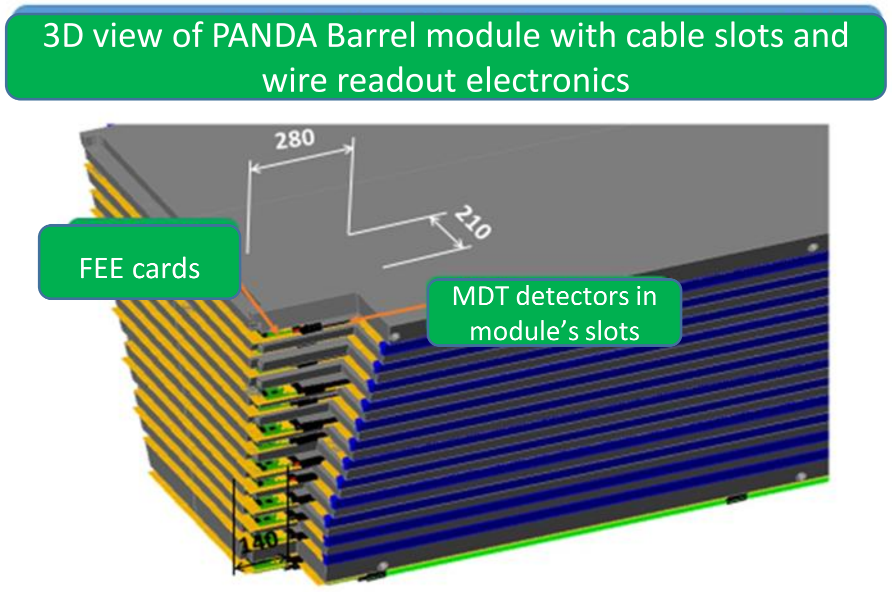
- **SPD/NICA Muon System** based on range system technique is a good PID system for muon-to-hadron separation.
- It works in full energy range of secondary particles at SPD (0.5 ÷ 10 GeV).
- It resolves muons and hadrons with high efficiency (small hadron contamination) above ~ 1 GeV by obviously different response pattern, **separation numerically depends on total λ-thickness**
- Separation of muons vs pions (the main rival) below 1 GeV is less efficient and requires test beam measurements for calibration.
- Important feature of range system is possibility to be used as coarse sampling (30 mm of Fe in our case) **hadron calorimeter – > very important for neutron registration!**

Range System structure

Total weight ~ 800 ton; total thickness 4 λ; structure composition: (60mm + 19 layers*30mm + 60 mm) Fe with 20 gaps*35mm for MDT detectors & strip boards with electronics







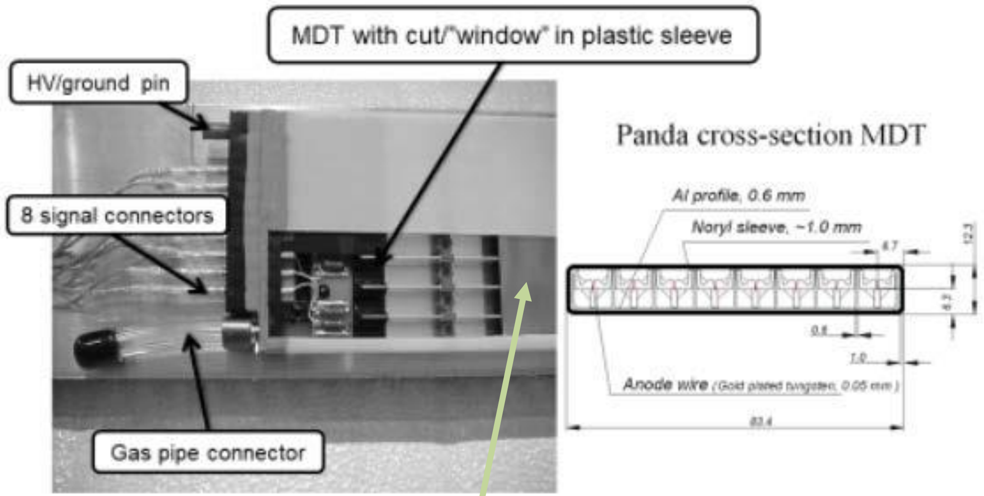
Mini Drift Tube (MDT) detectors

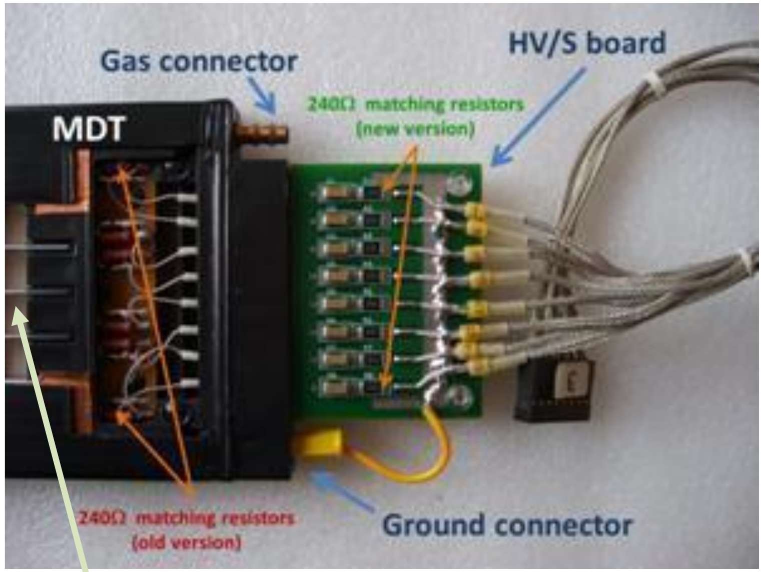
(D0/FNAL&COMPASS/CERN-wire R/O (left),

PANDA/FAIR&SPD/NICA – wire&strip R/O (right)

HV on ALU cathode

HV on the wires



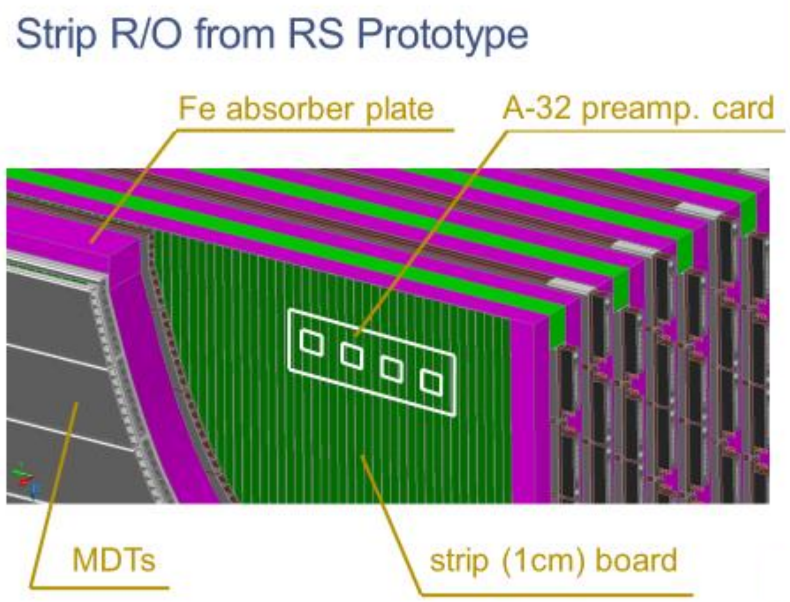


'closed cathode' geometry – with stainless steel cover (0.15 mm thick

'open cathode' geometry – without cover

MDT's strip readout

3D model of prototype with strip R/O

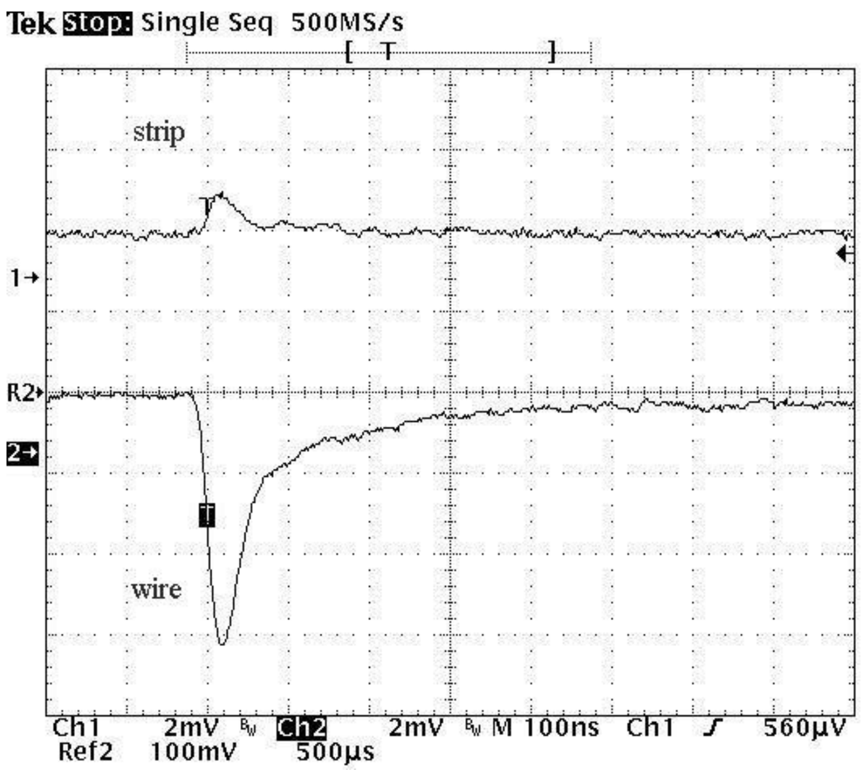


Strip board cut on G10

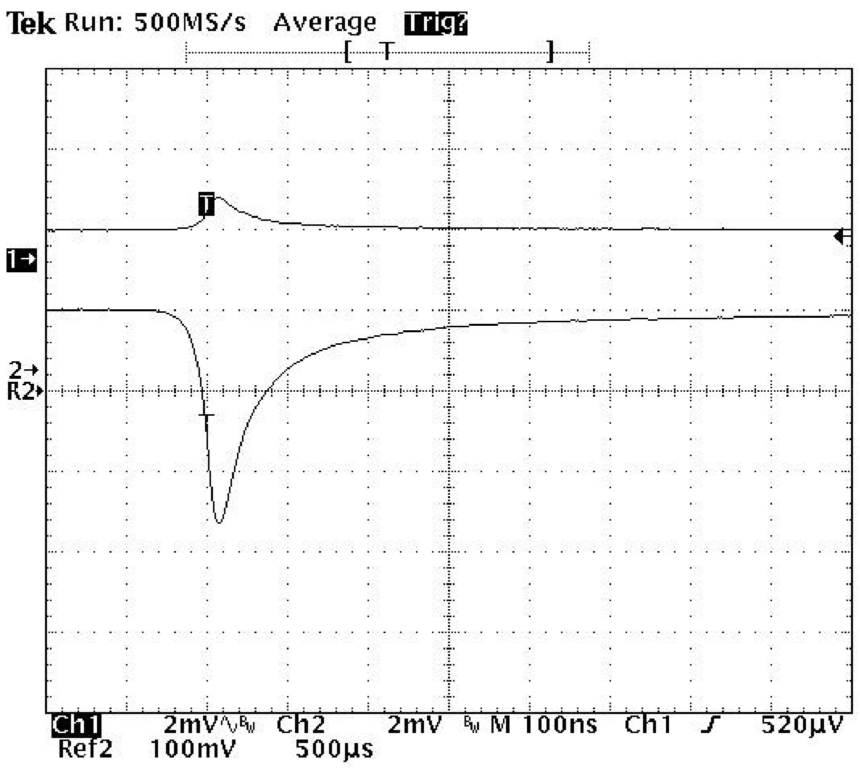
Wire and strip signals

Signals after the AMPL-8.3 on 50 Ohm load

Single event

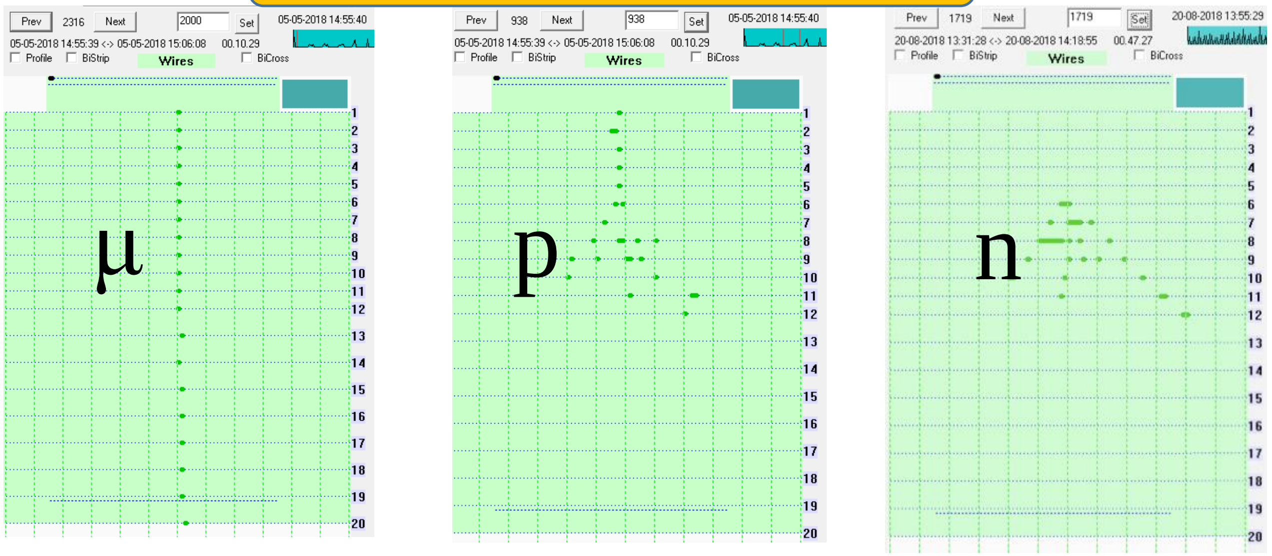


Averaged

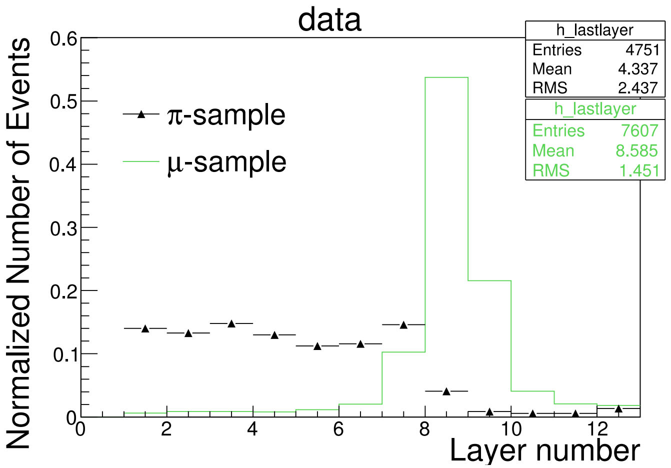


PID Features of SPD Muon System

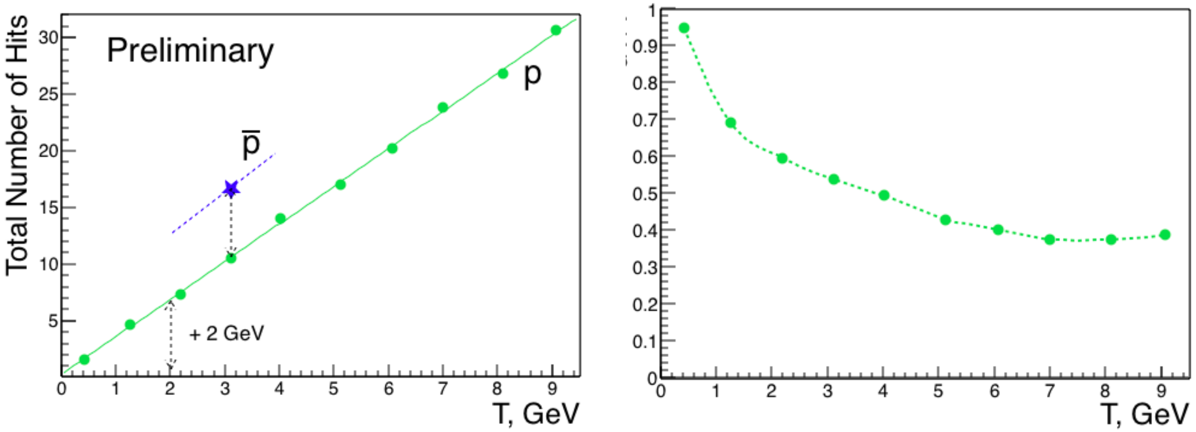
Event examples at 5 GeV/c



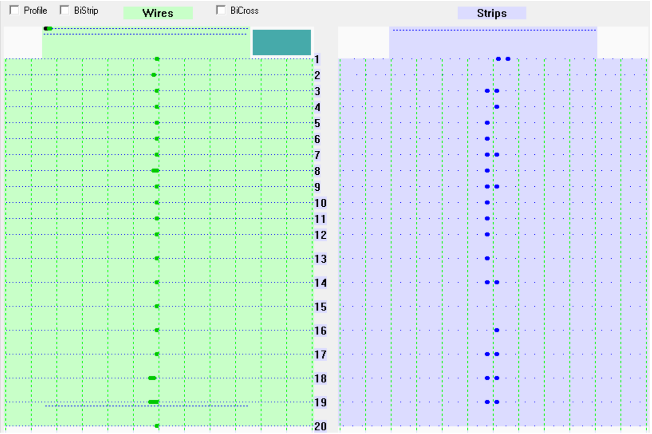
Pion/muon separation at 0.5 GeV/c (~20%)



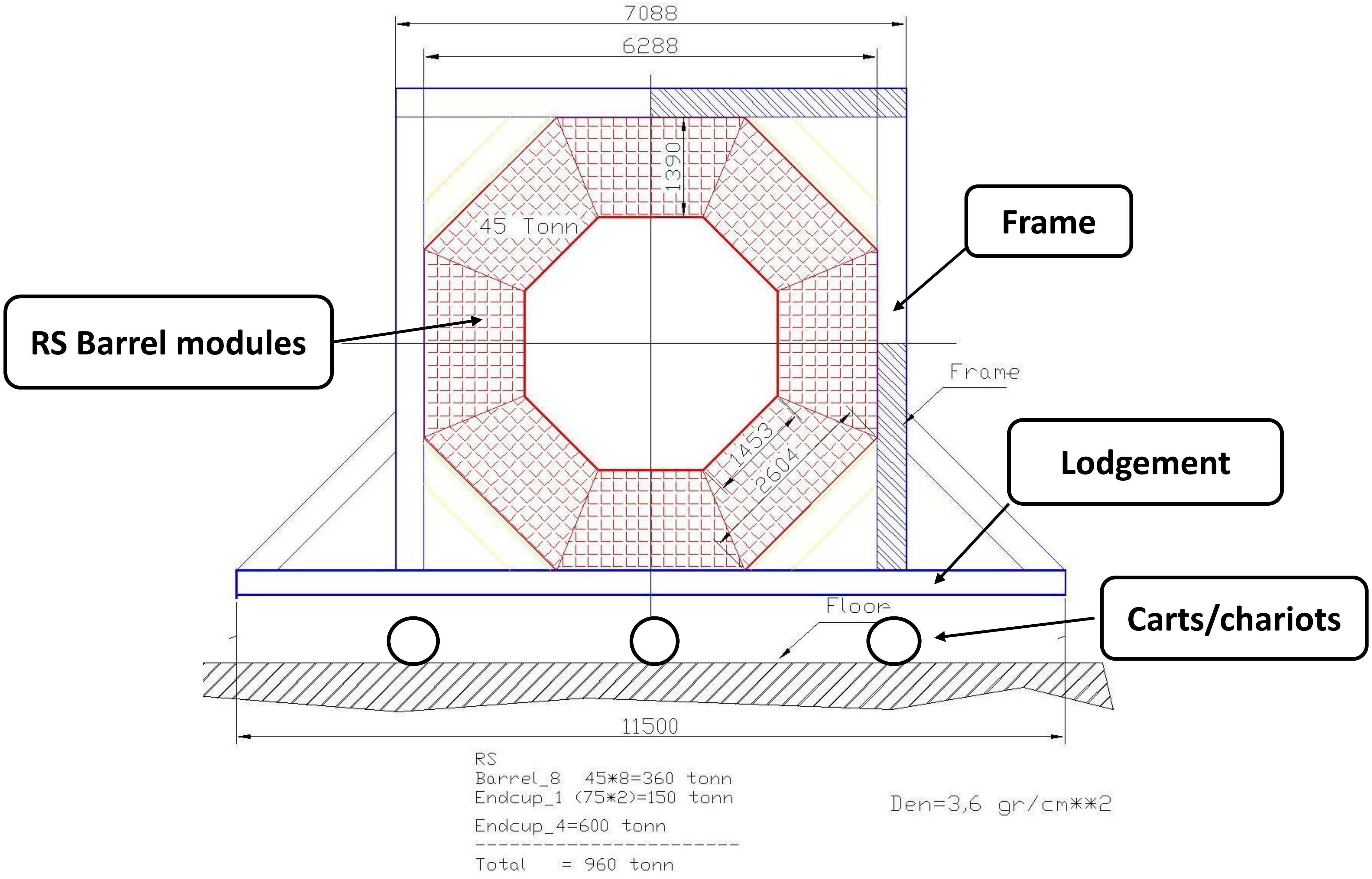
Energy calibration for protons (response and resolution) with antiproton signal



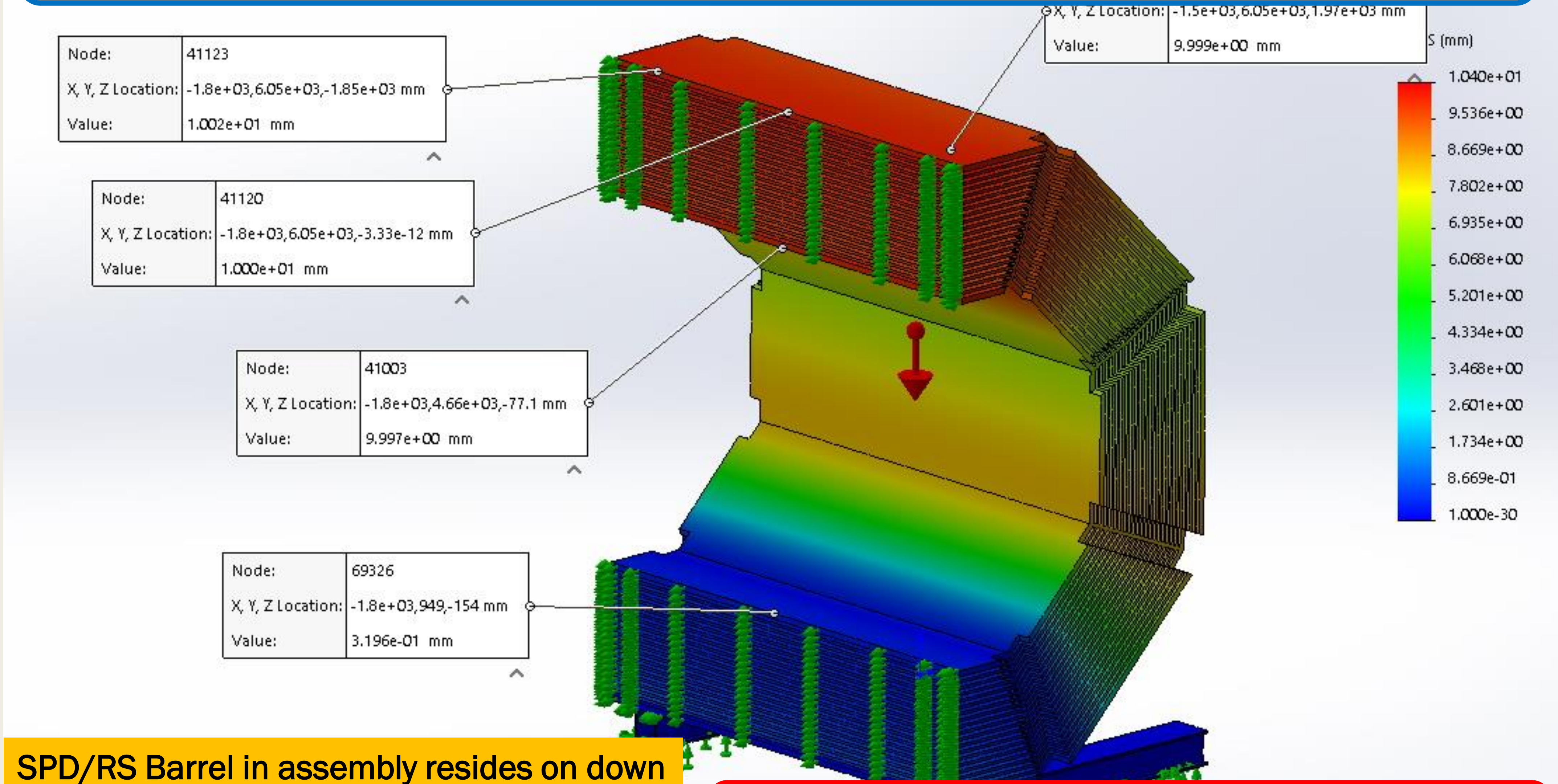
Two-coordinate readout (wires/left and strips/right



Concept of SPD/RS support structure



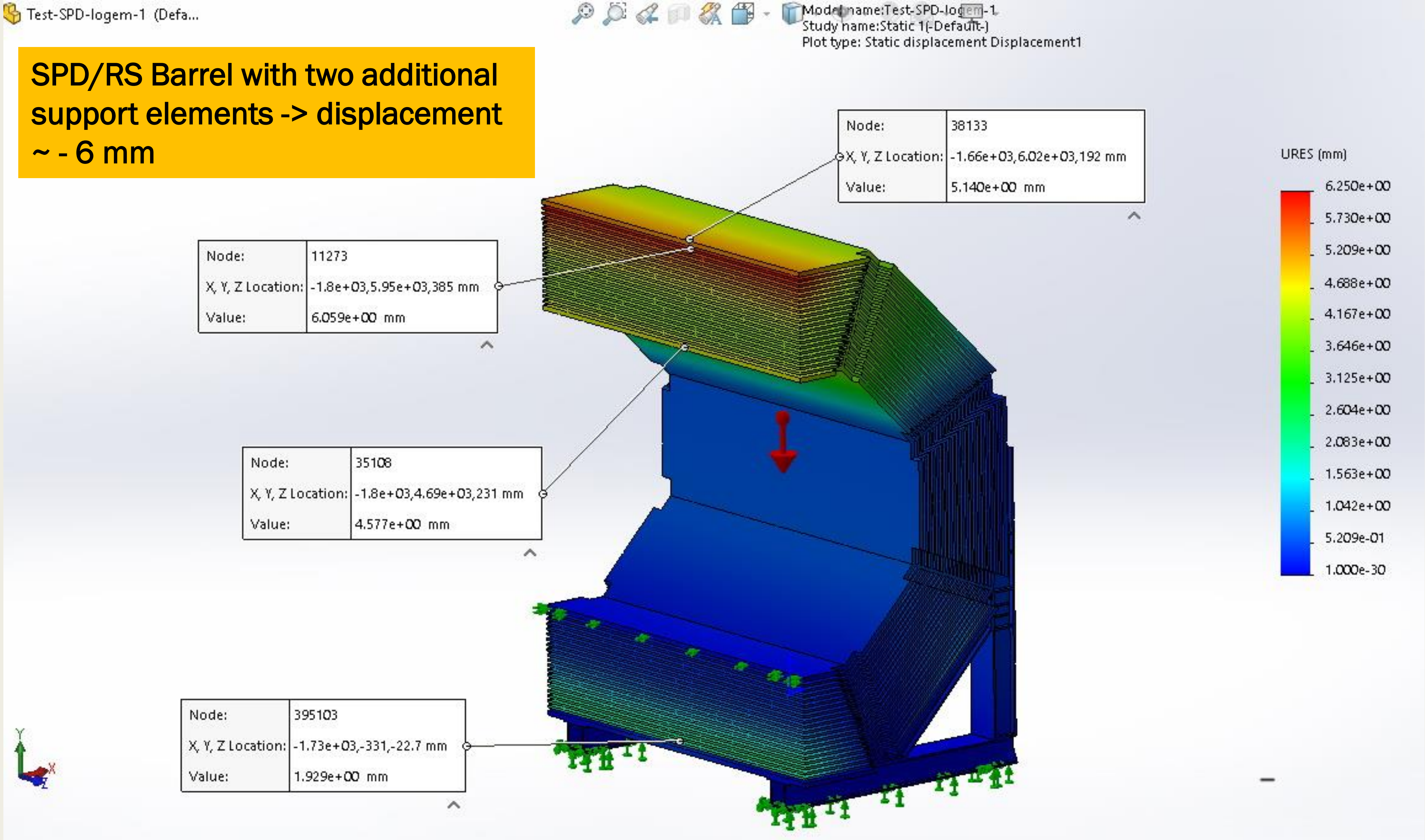
Conditions for the Finite Element Analysis: COSMOS/SolidWorks, standard carbon steel (St.3, St.10) with 7.8 g/cm2 density. Calculations performed for Barrel part of RS.

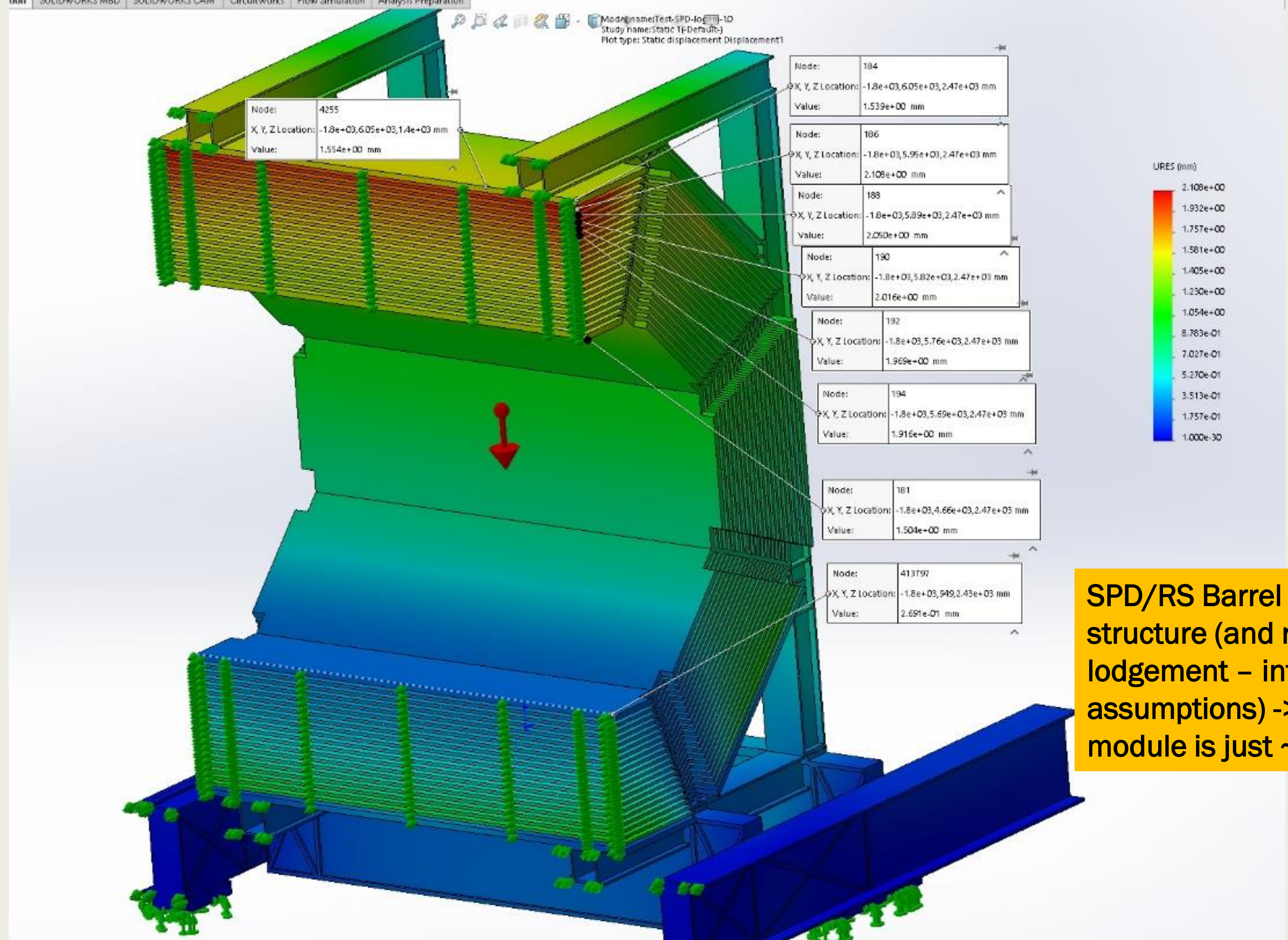


SPD/RS Barrel in assembly resides on down module (on firm ground) -> displacements: -10 mm on “Y” and +/- 5 mm on “X”

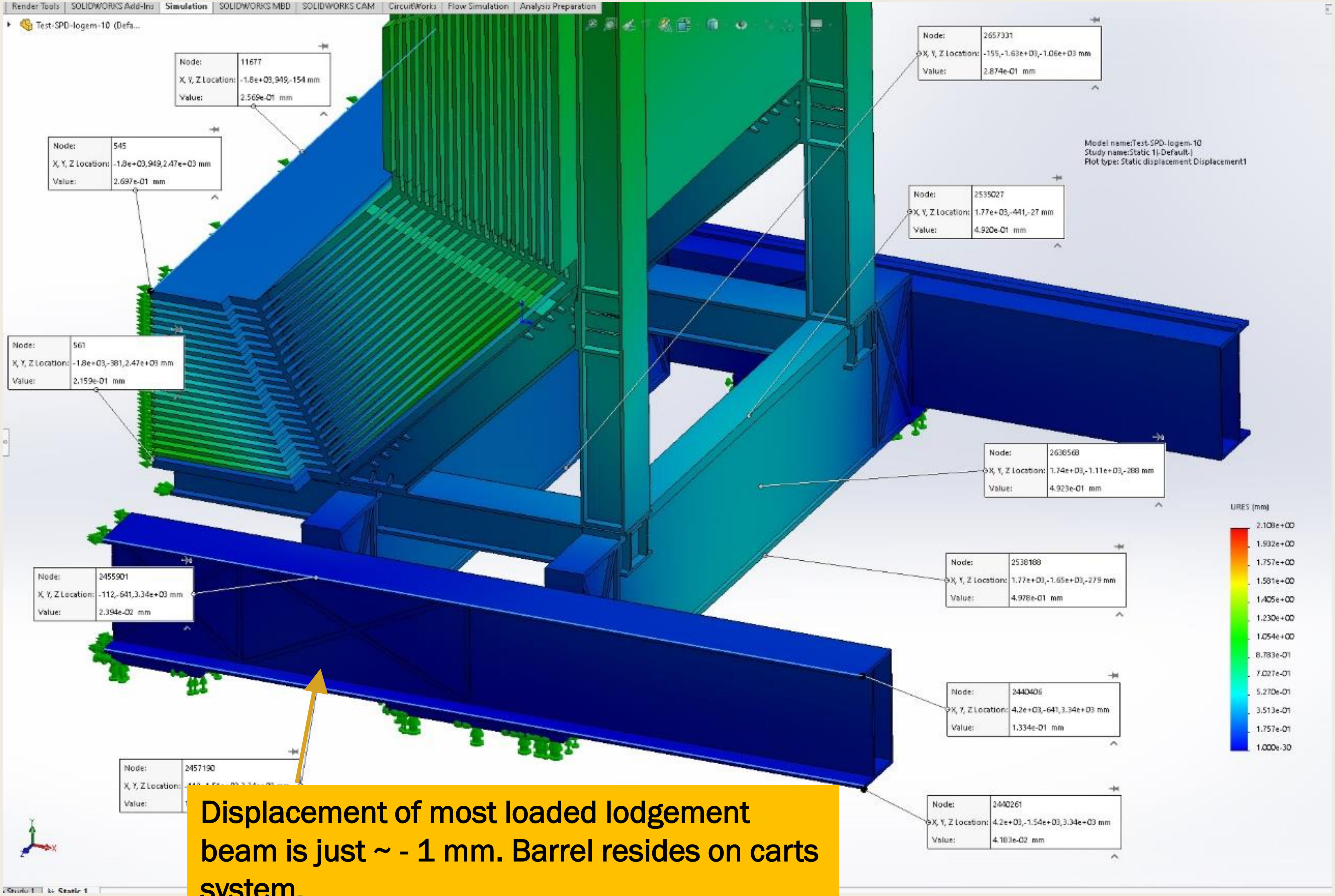
Too big deformation -> comparable with technological gaps for internal equipment of SPD (~ 20 mm)

SPD/RS Barrel with two additional support elements -> displacement ~ - 6 mm

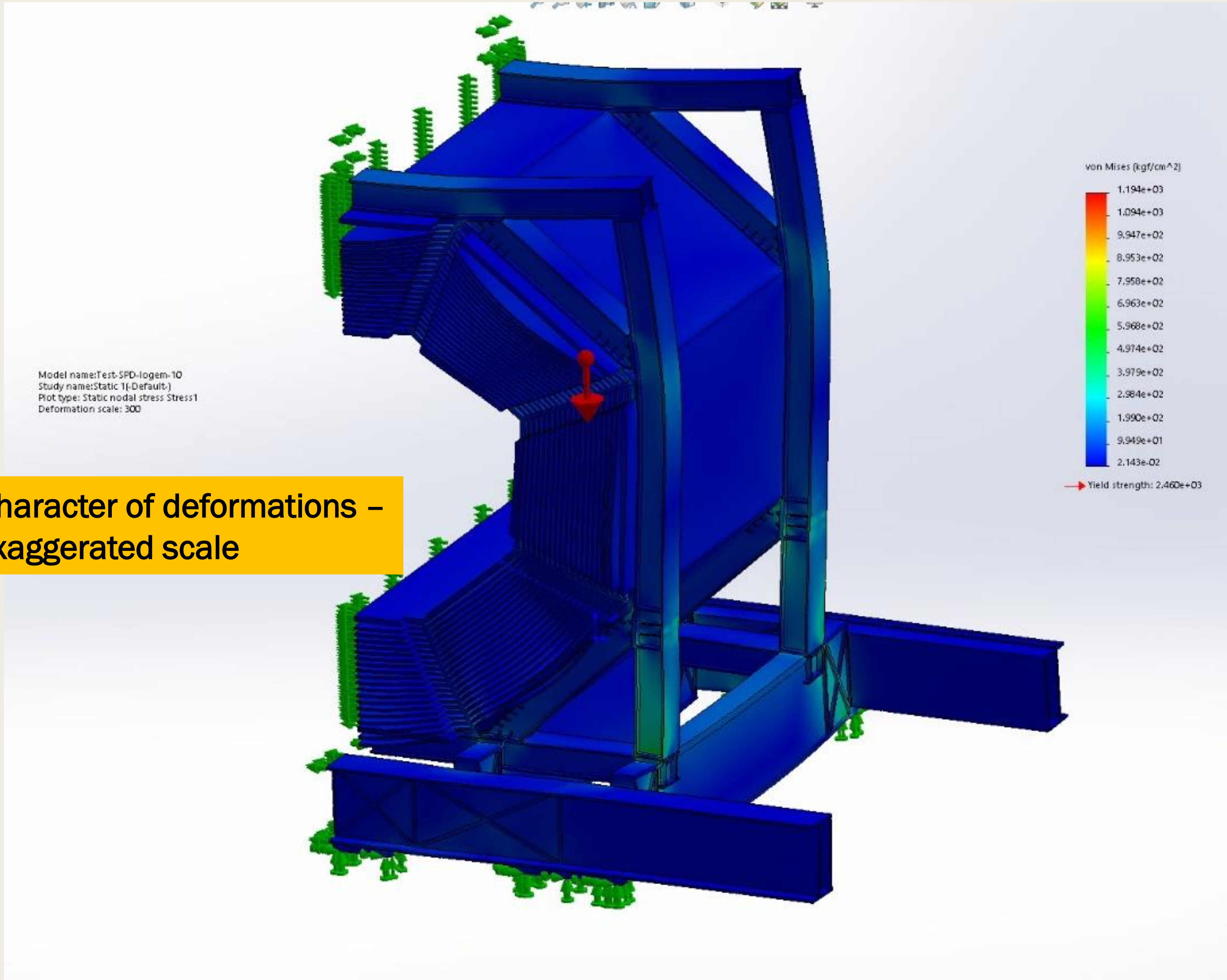




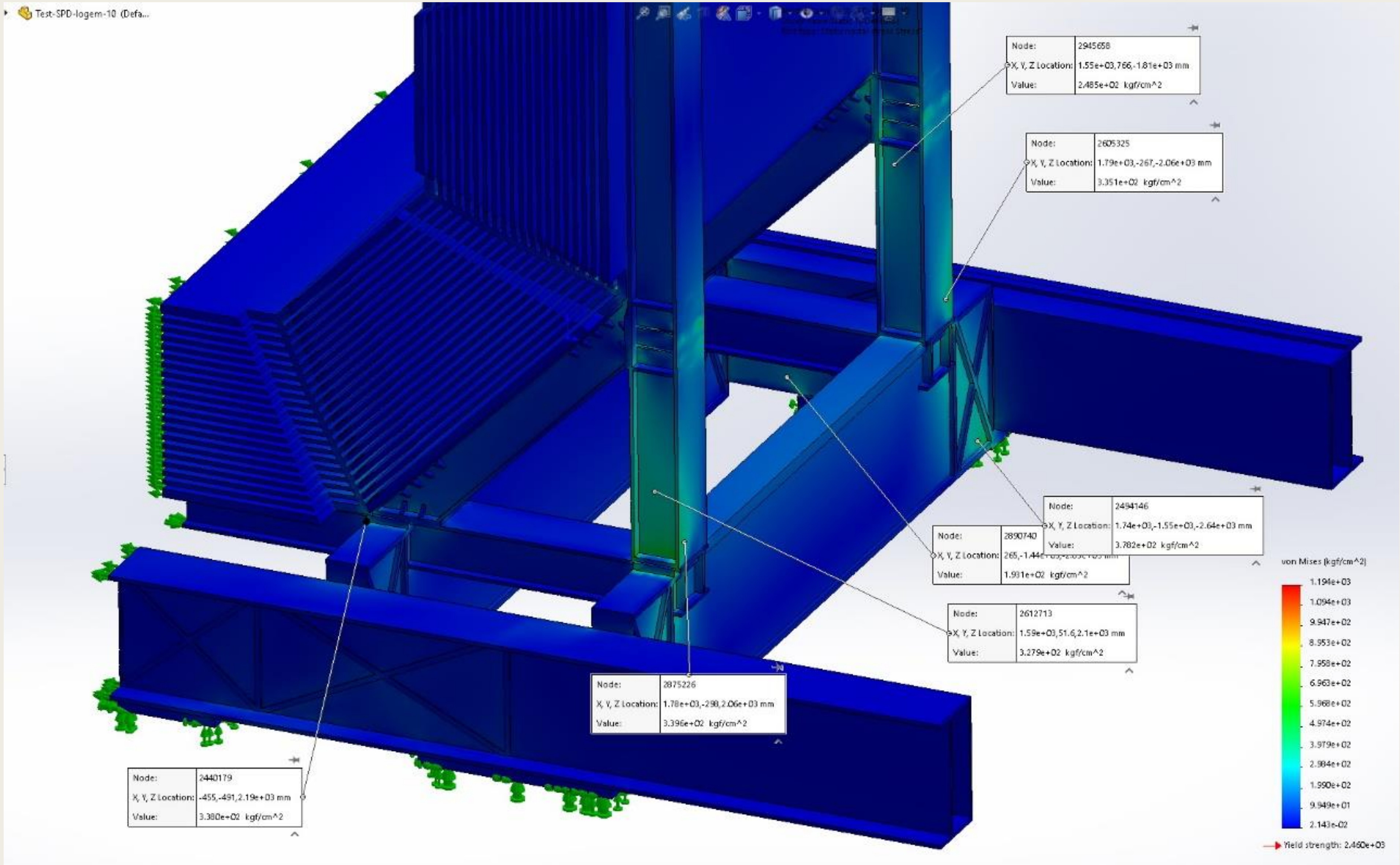
SPD/RS Barrel with full support structure (and residing on "real" lodgement – introduced on some assumptions) -> displacement of top module is just ~ - 2 mm !



Displacement of most loaded lodgement beam is just ~ - 1 mm. Barrel resides on carts system.

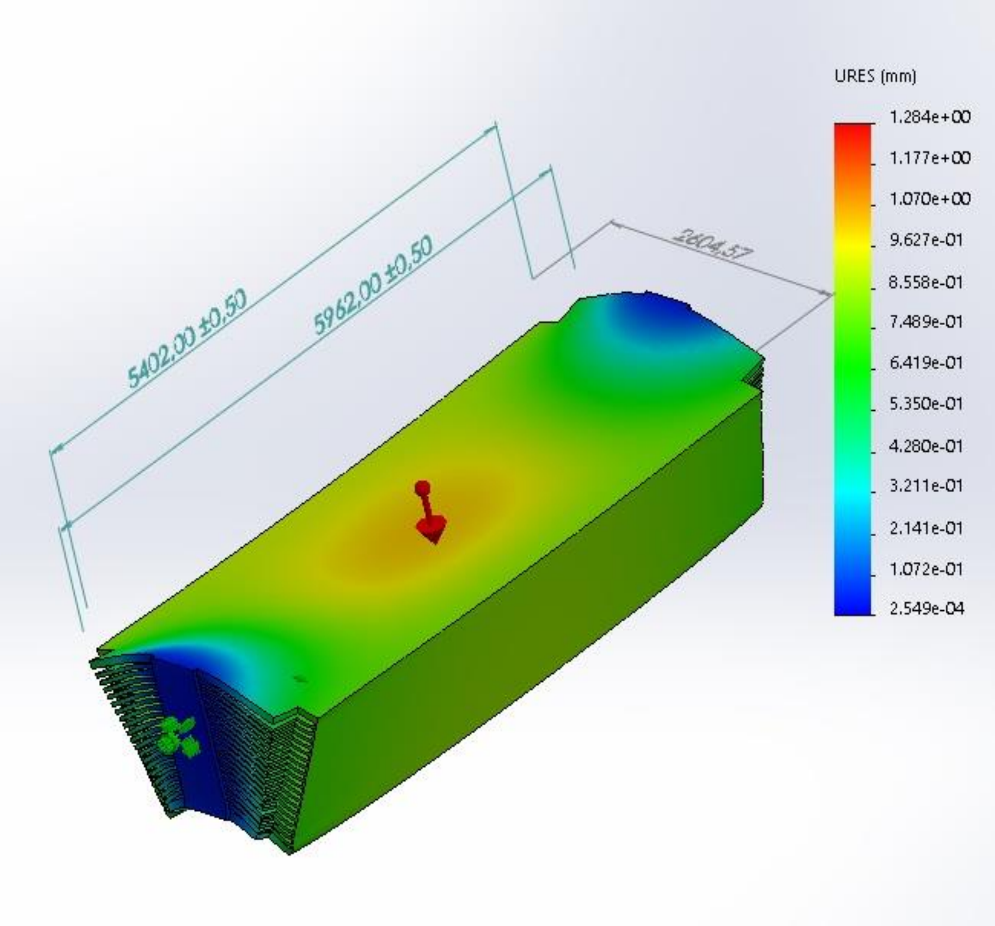


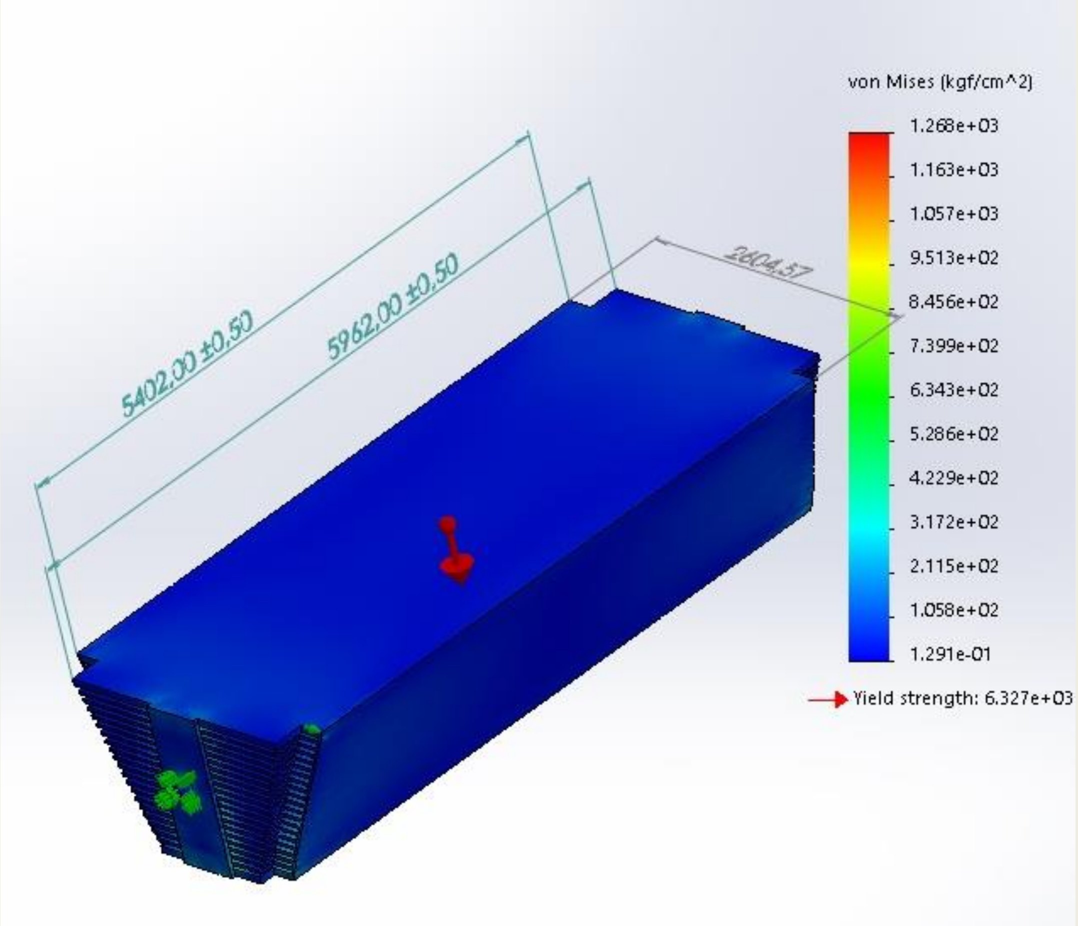
Character of deformations – exaggerated scale



Mechanical stress maximum is < 1100 kg/cm2 –> not a problem !

Displacement and stress for the most loaded Barrel modules – top and bottom – under crane: stress is not a problem, <u>displacement assumes some strengthening of module's mechanical rigidity.</u>





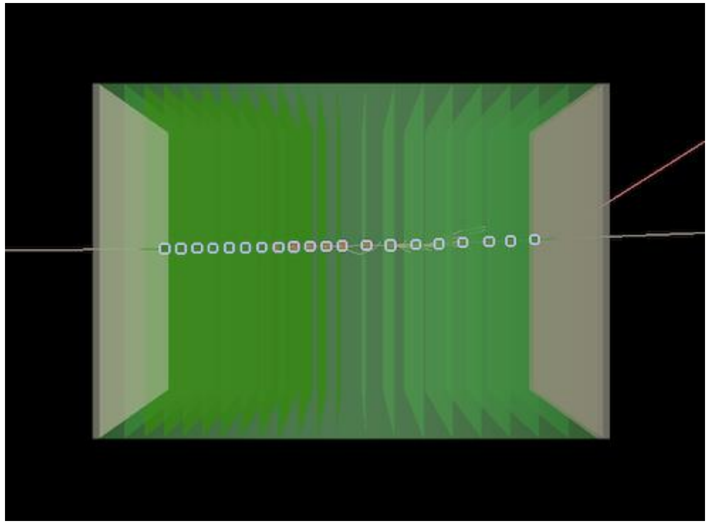
Range System Prototype MC model

Range System Prototype geometry model:

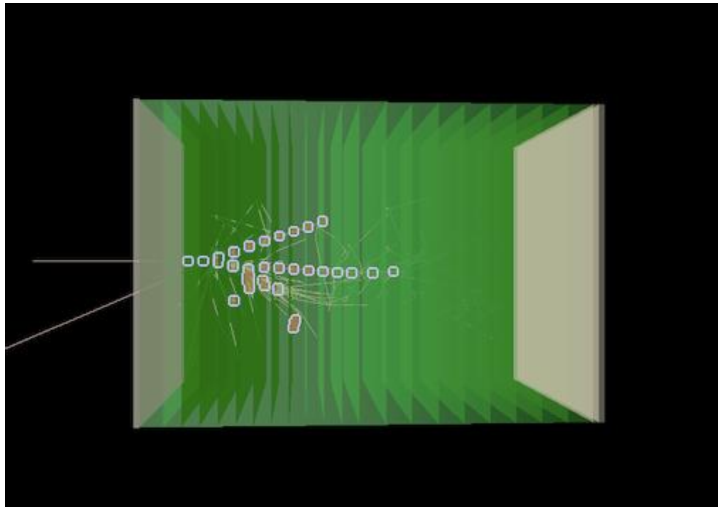
- detailed **RSP model** was created using Root and integrated into **SpdRoot frameworks**;
- MC-point is created/calculated by **Geant4** in a sensitive volume when a particle goes through it;
- **digitization** is used while converting MC-points into MC-hits (detector signal)

An example of hits produced by a single particle passing Range System Prototype:

Muon 6 GeV/c



Proton 6 GeV/c



Digitization of RS signal and MC fit to data at 6 GeV/c

(protons of this energy were selected as they are best identified in test beam with ToF counters

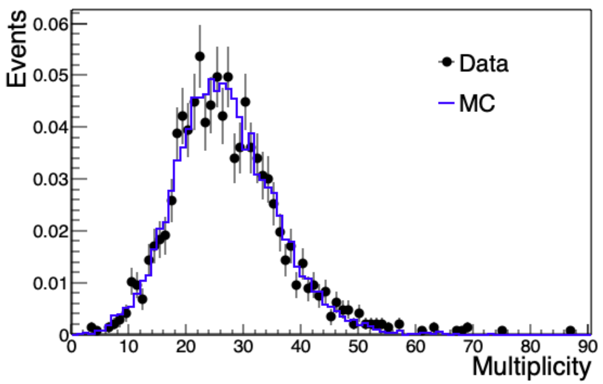
Digitization is based on at least one of two requirements:

***Cut 1*: minimum passage in active volume ≥ 1 cm;**

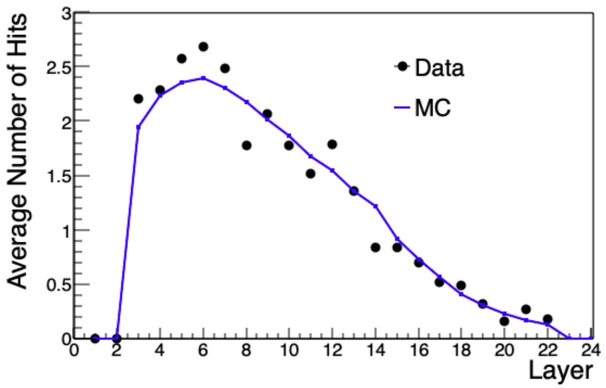
***Cut 2*: minimum energy deposited in active volume ≥ 1 keV**

Protons: 6 GeV/c (calorimetric signal / response)

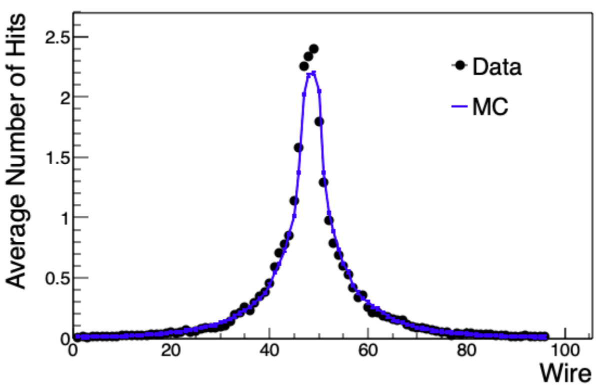
Normalized number of hits in an event (signal)



Average hits per layer (longitudinal shower profile)



Average hits per wire, all layers (transverse shower profile)



Muons/Hadrons separation

Hit profile in RSP corresponding to a particular kind of particles with a certain momentum has a specific pattern (**green points** - wire hits, **blue points** - strip hits).

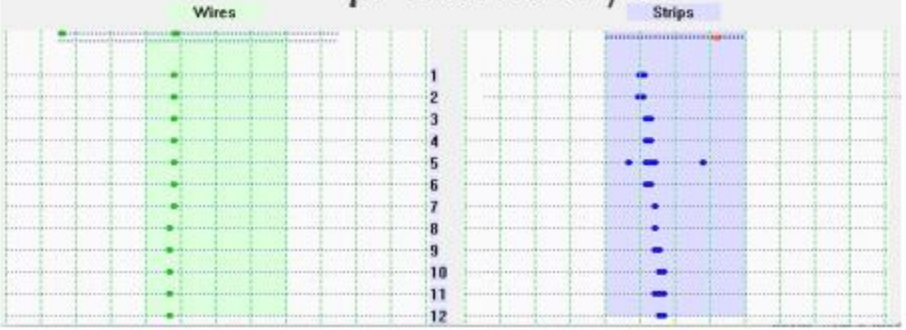
Low momentum pions (**p < 1.0 Ge**V/c) almost indistinguishable from muons with the same momentum.

$\mu^{-}: 0.5 GeV/c$

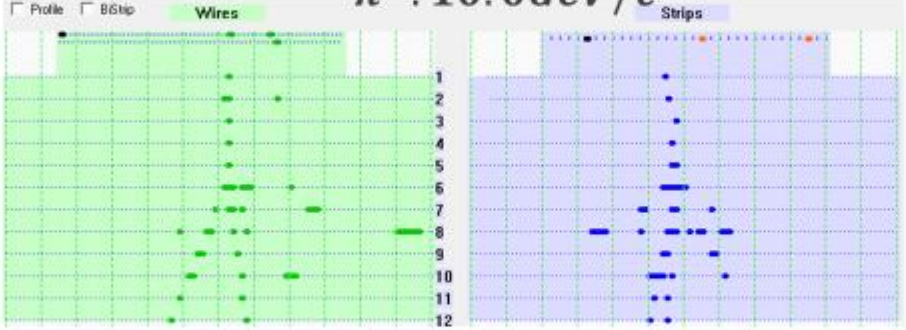
$\pi^{-}: 0.5 GeV/c$

The increasing energy of pions significantly changes the profile of hits, forming a hadron shower of secondary particles for pions with momentum **up to 10.0 GeV/c**.

$\mu^{-}: 10.0 GeV/c$



$\pi^{-}: 10.0 GeV/c$



Muons/Hadrons separation

MC results: muons vs protons

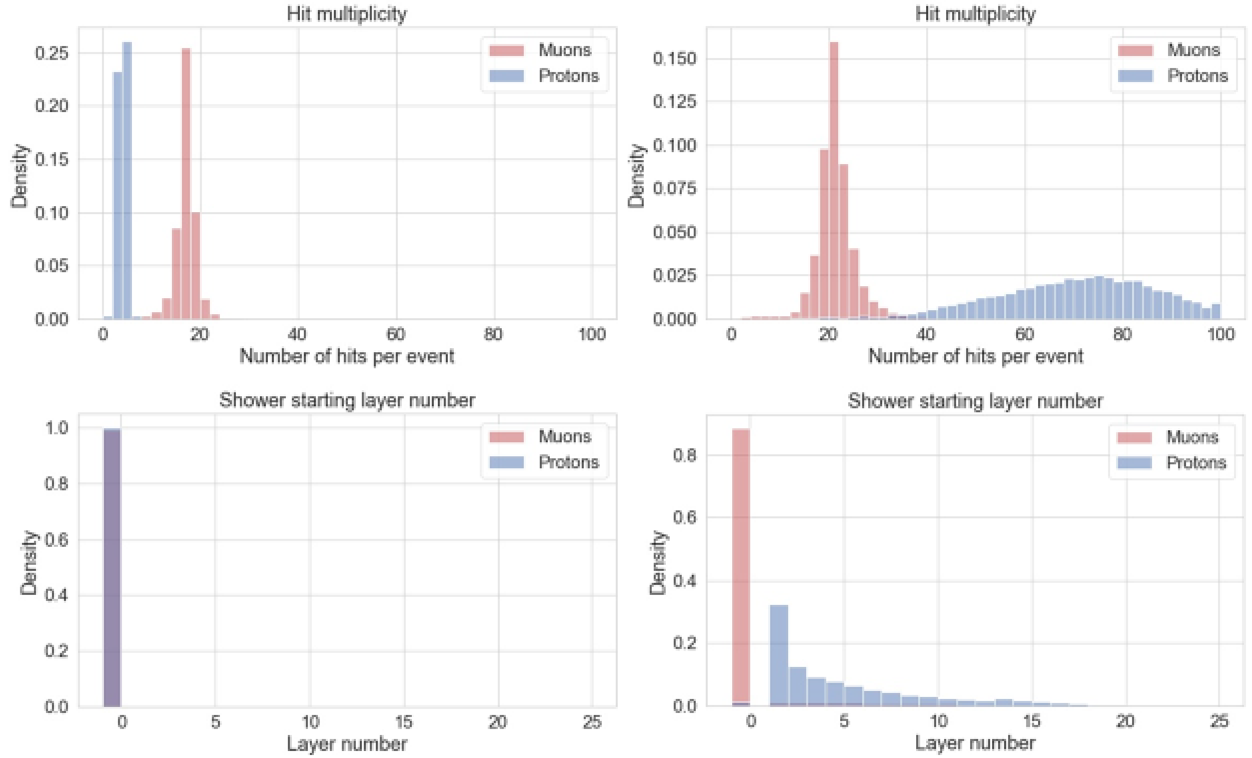
Finding **variables sensitive to differences in such patterns**, is directly related to the efficiency of separation between muons and hadrons.
It can be used as an input to various Machine Learning techniques.

Discriminative Variables:

1. hit multiplicity in an event;
2. last fired layer;
3. shower starting layer number (first layer out of 3 with ≥ 2 hits per layer);
4. first fired layer;
5. number of hits in last layer.

A **Random Forest** classification algorithm (an ensemble of Decision Trees) is used to separate between signal (muon) and background (protons/pions) samples in Data and MC.

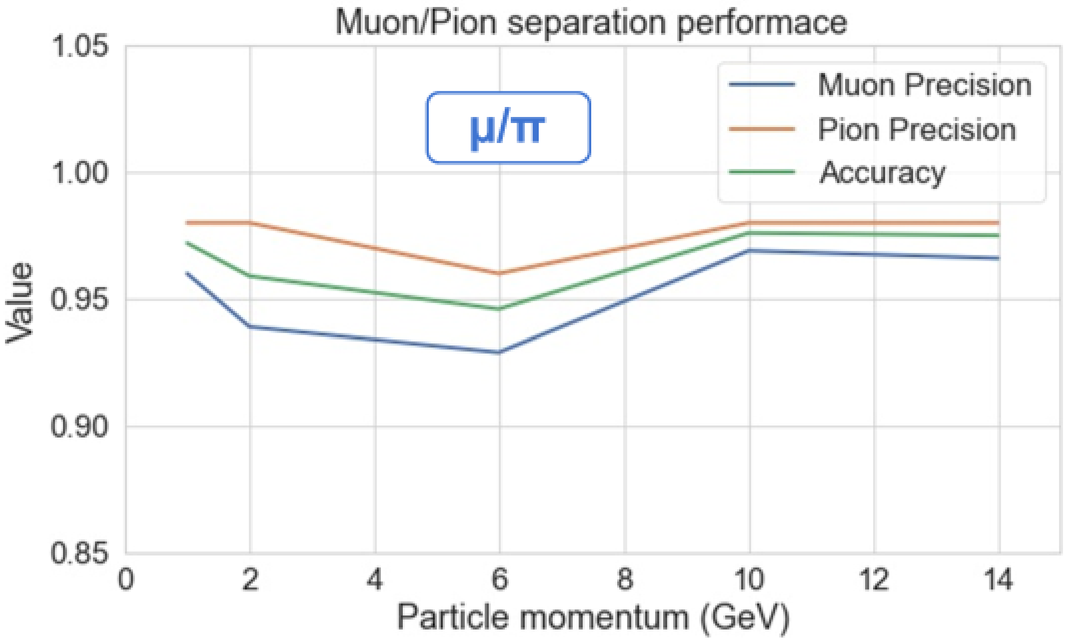
1 GeV/c | **14 GeV/c**

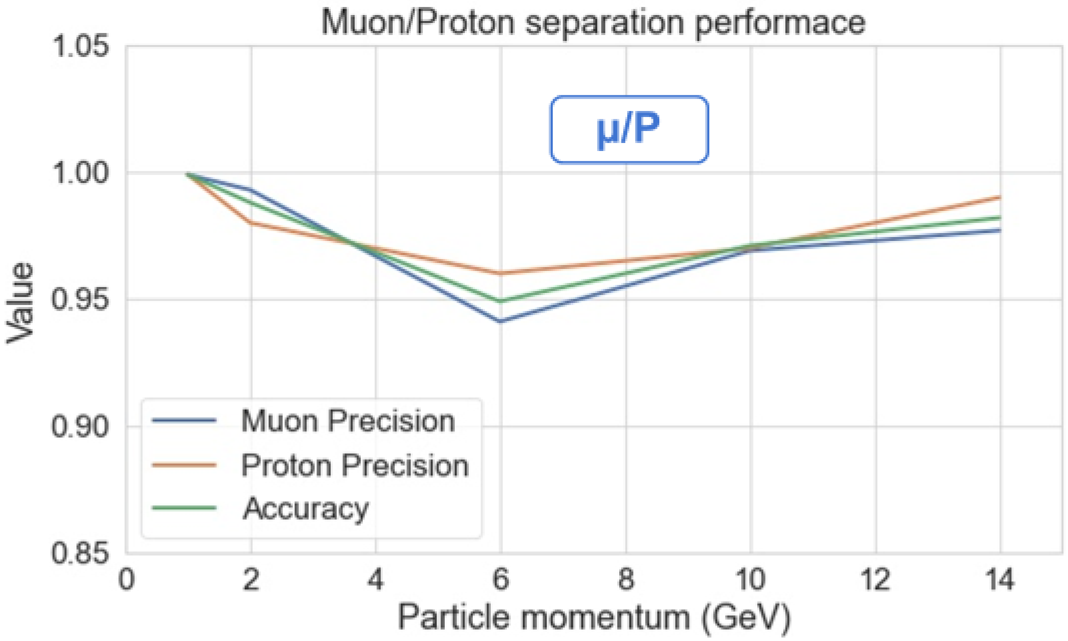


Relative Variable Importance at various momenta

Algorithm performance (MC results: muons vs pions&protons)

$$Precision(\mu) = \frac{True(\mu)}{True(\mu) + False(\mu)} \quad Precision(\pi) = \frac{True(\pi)}{True(\pi) + False(\pi)} \quad Accuracy = \frac{True(\mu) + True(\pi)}{True(\mu) + False(\mu) + True(\pi) + False(\pi)}$$



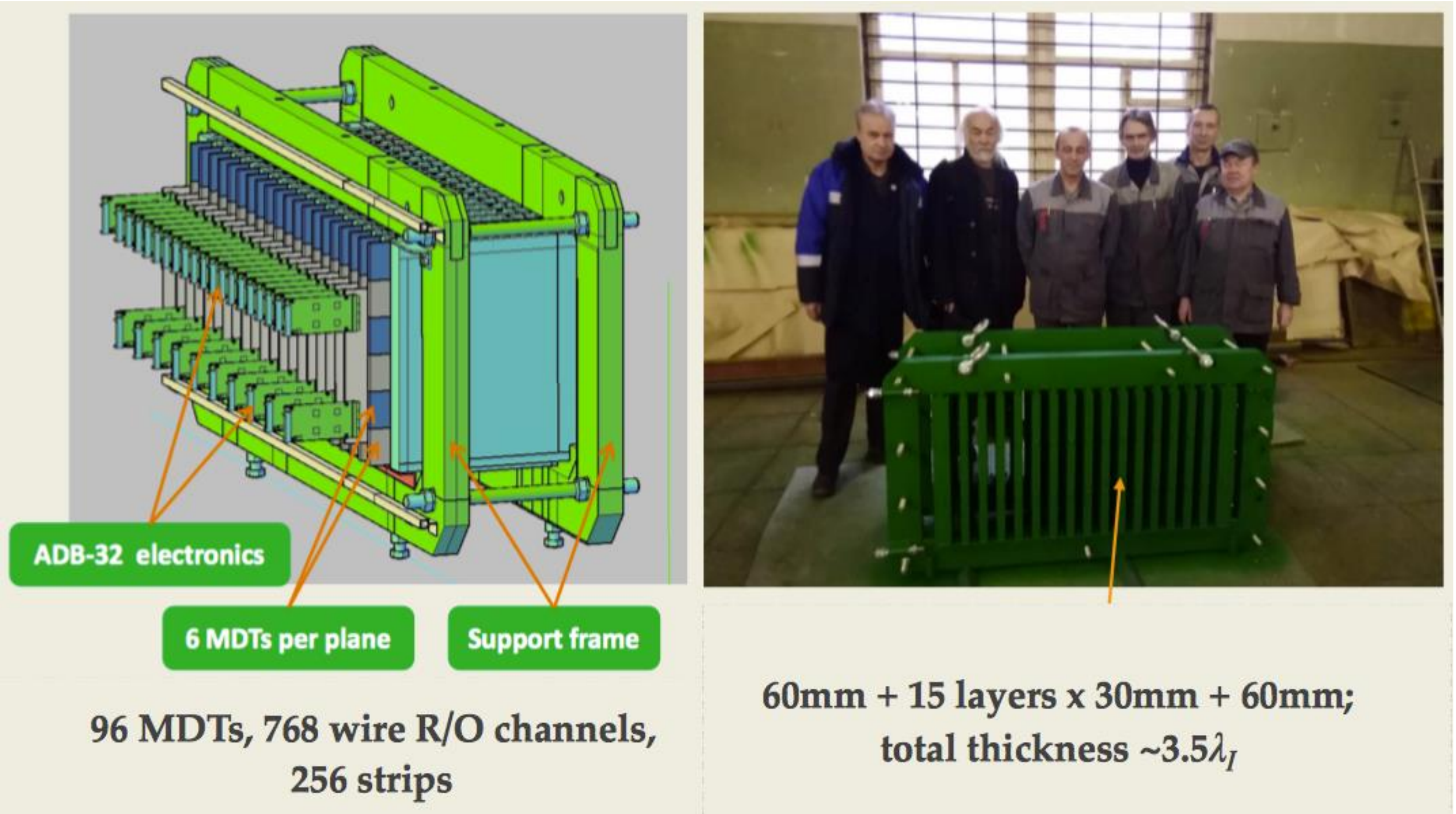


Random Forest algorithm results:

- Hadrons are classified with precision ≥ 97%;
- Muons are classified with precision ≥ 94%;
- **Accuracy of the algorithm ≥ 95%;**
- Almost identical results using *Decision Tree* algorithm;
- **Need more data points for direct MC comparison;**
- **Additional data sample cleaning is needed.**

SPD Range System Prototype:

(a) 3D schematic view of the SPD RSP and (b) manufactured absorber structure with support frame,
total weight ~ 1,5 ton



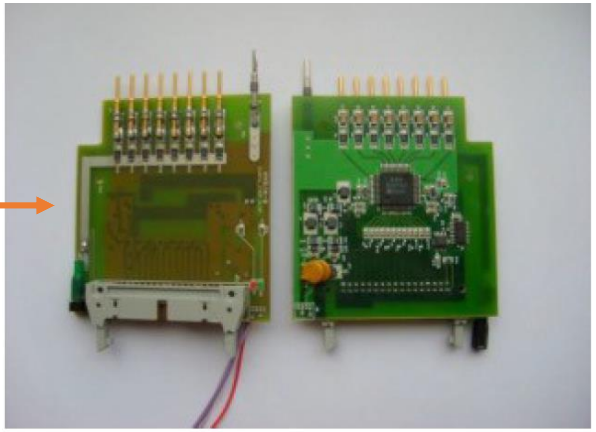
(a) (b)

MAIN FEE cards for Range System

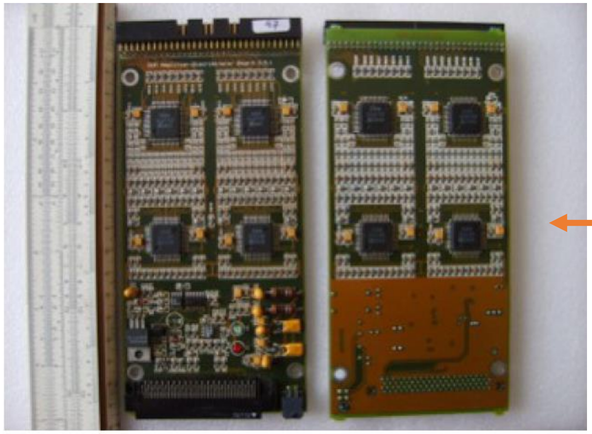
(to be used for and tested with the RS prototype at Nuclotron)

Analog FEE card

HVS/A-8 -> HVS/AD-8
(discriminator with LVDS output will be added at later stage)



(a)



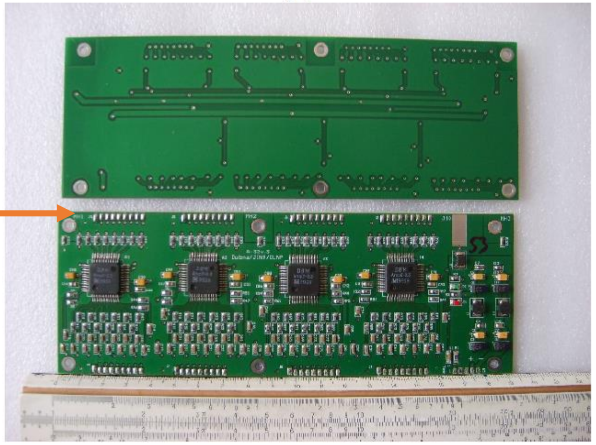
(b)

Analog FEE card

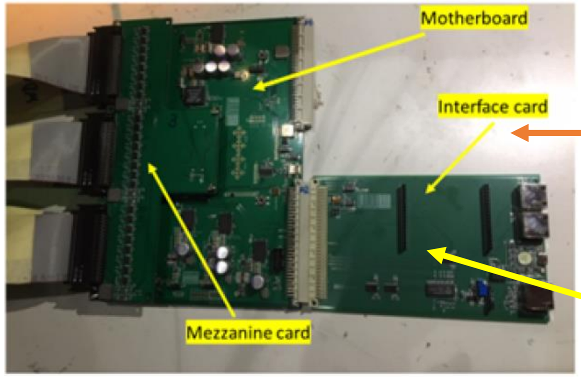
ADB-32 (no principle changes are planned except for replacement of chips)

Analog FEE card

A-32 -> 2AD-32
(discriminator with LVDS output will be added at later stage)



(c)

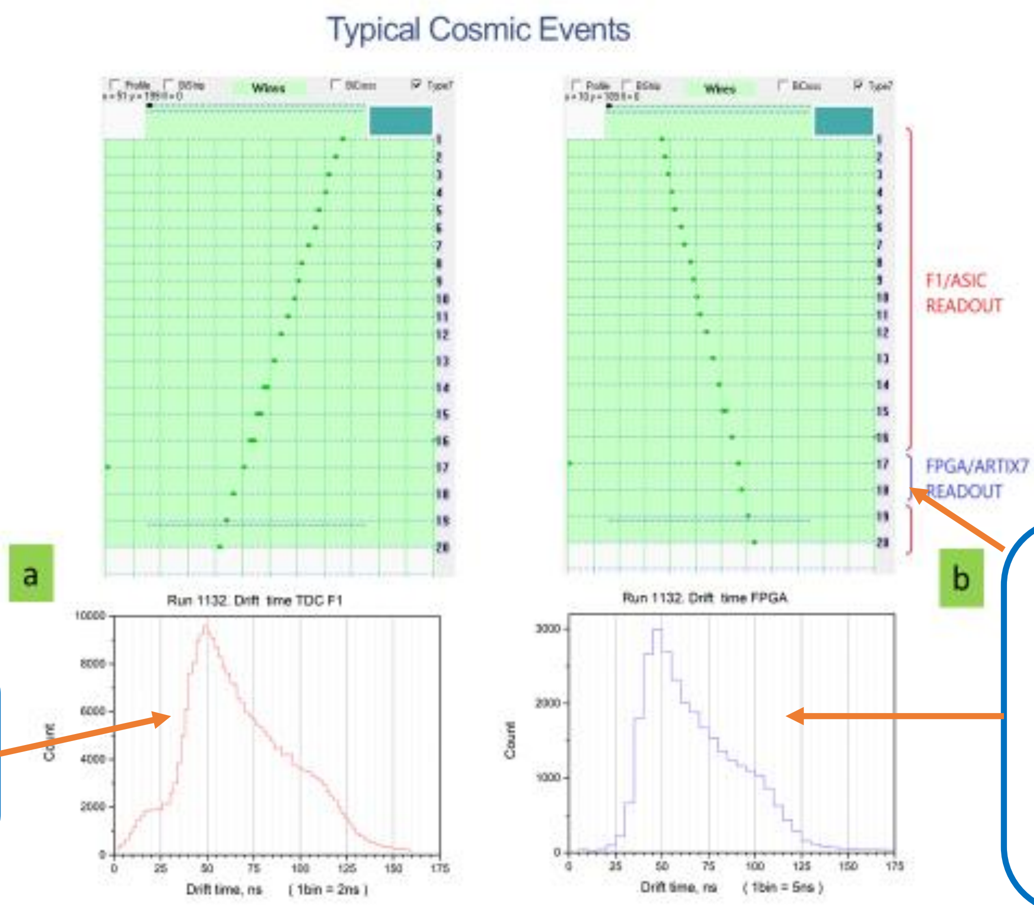


(d)

Digital FEE unit

MFDM-192
(interface card will be adapted/replaced for final SPD/DAQ system

Reults of comparative DAQ studies (ASIC/F1 (a) vs FPGA/Artix7(b)) with RS prototype on cosmic at CERN



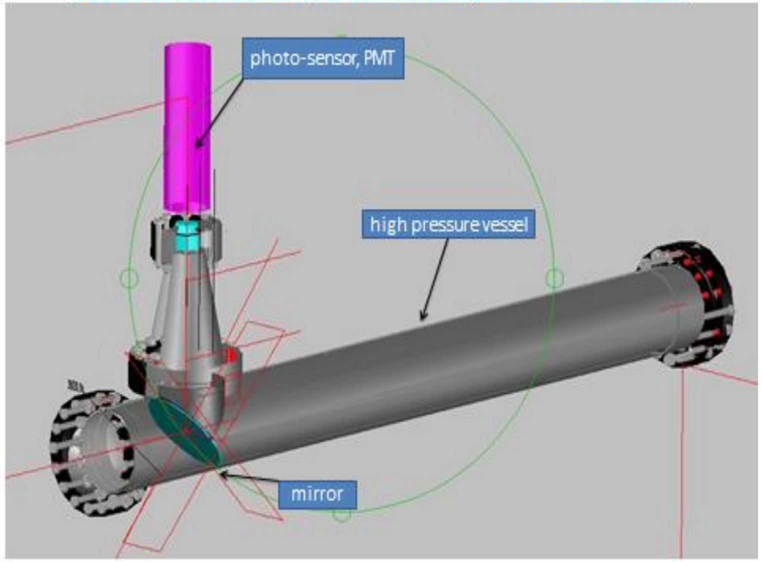
MDT/COMPASS drift time spectrum (2 nsec time bin)

MDT/SPD drift time spectrum (5 nsec time bin, 200 MHz FPGA clock). Thus ~ 150 nsec maximum drift time fits into 32 channels (drift time mode of MDT)

Cerenkov counter for SPD test beam

(main task -> π/μ separation < 1,5 GeV/c; high pressure (up to 60 bar of CO_2)

Čerenkov counter (up to 60 bar), schematic view



3D model/design

Ready device at DLNP test stand, tuning of optics

Parameters of PID devices (ToF, Cerenkov) at SPD/Nuclotron test beam

Time-of-flight difference for π/μ per meter

Calculated Cerenkov counter signal

P, MeV/c	**tπ-tμ**, psec/м	**p**, bar	**e**, photo-electrons	**μ**, photo-electrons	**π**, photo-electrons
600	37.8	60.0	1020	240	0
750	24.7	29.5 51.4 60.0	510 900 1020	0 380 520	0 0 150
1000	13.9	16.7 29.0 41.5	290 500 710	0 220 430	0 0 220
1250	8.9	10.7 18.6 26.6	180 320 460	0 140 280	0 0 140
1500	6.2	7.4 12.9 18.6	130 220 320	0 100 190	0 0 100

Plans for 2021:

- **Continuation of data treatment taken at CERN with big RS prototype**
- **Finalizing mechanical analysis of SPD setup (RS part):**

  - inclusion of End Caps and SPD transport system

  - inclusion of magnetic forces (after selecting the magnet concept)

  - inclusion the load of inner part of SPD (EMC, magnet, etc.)
- **Development of Front End Electronics – analog and digital:**

  - analog FEE: Ampl-8.3 -> Ampl-8.51, Ampl-8.11R; Disc-8.3 -> Disc-8.15

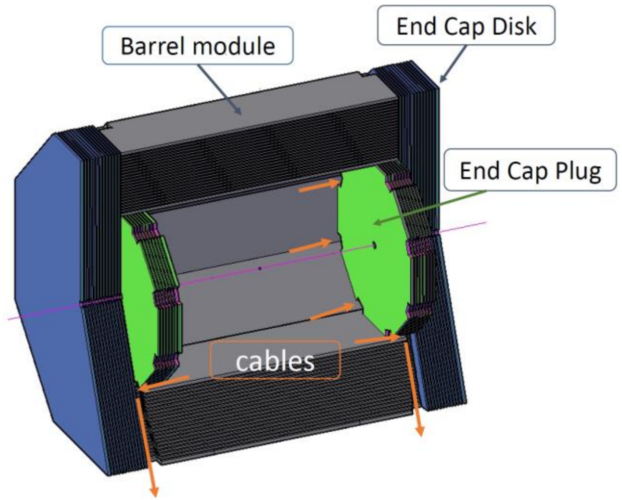
  - digital FEE: tuning of MFDM-192 units based on Artix7/FPGA chip (~ 1300 R/O channels) for test beam
- **Assembly of MDT detectors with analog FEE into iron absorber and connection to digital FEE and test beam DAQ**
- **Make pressurizes Cerenkov counter operation in test beam area**
- **Writing the RS part of SPD Technical Design Report**

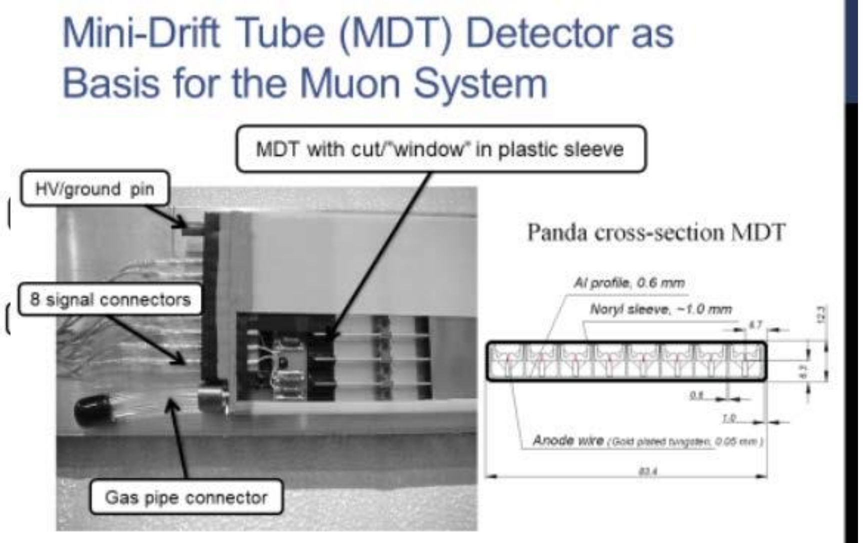
CONCLUSION

The SPD RS project develops with adequate speed to be ready for SPD TDR and its further construction. Presently no critical technical obstacles are identified. The contacts with main industrial partners to be further involved in mass production are reestablished (following the execution of PANDA project having Range System design very close to NICA/SPD). Thus we optimistically look forward!

Backup slides

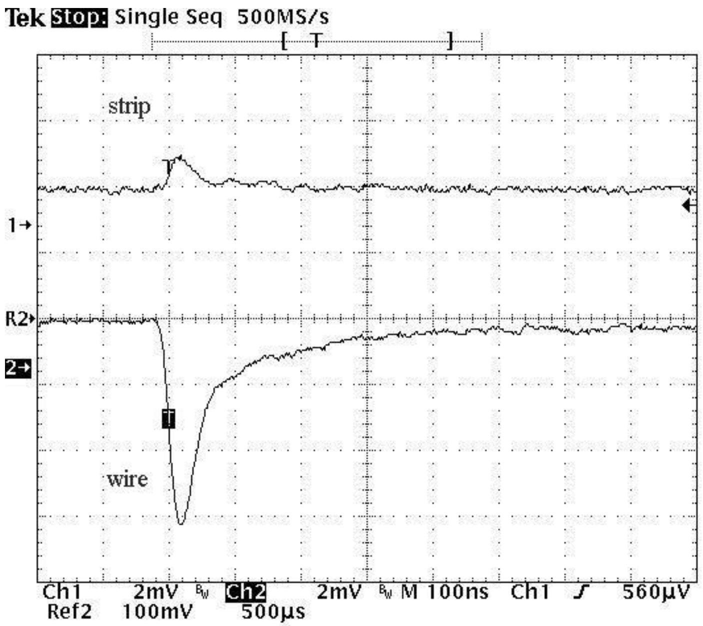
Muon (Range) System of SPD/NICA

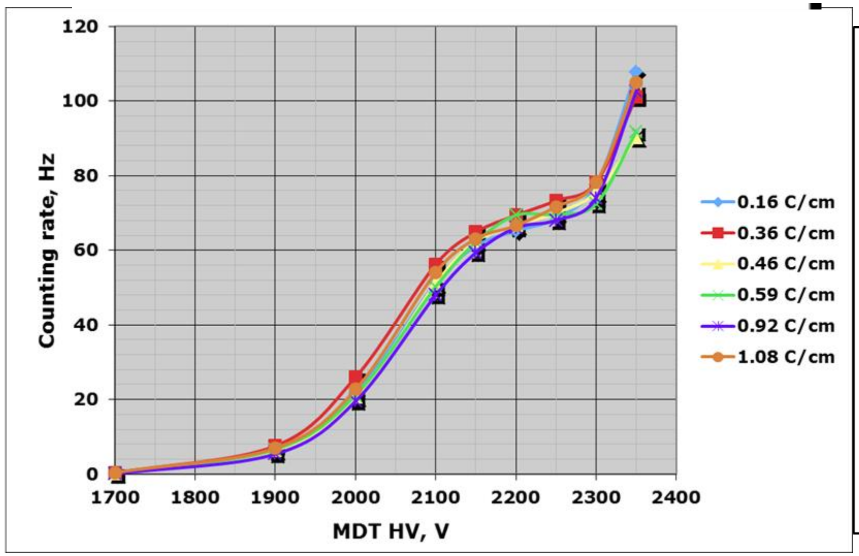


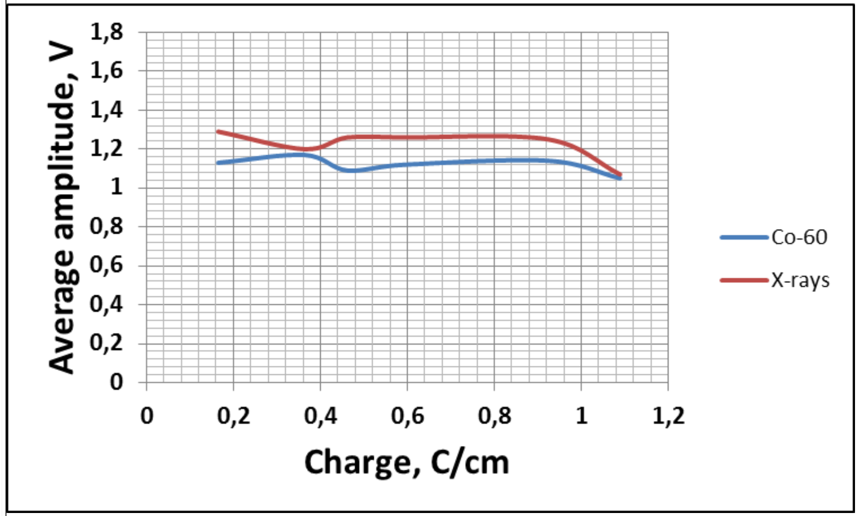


*) MDT detectors represent modification of well-known Iarocci streamer tubes (plastic conductive cathode is replaces by aluminum, and proportional mode of signal is used instead of streamer one).

*) MDTs were used at high quantities in the D0/FNAL and COMPASS/CERN experiments, and also accepted for the Muon System at PANDA/FAIR project







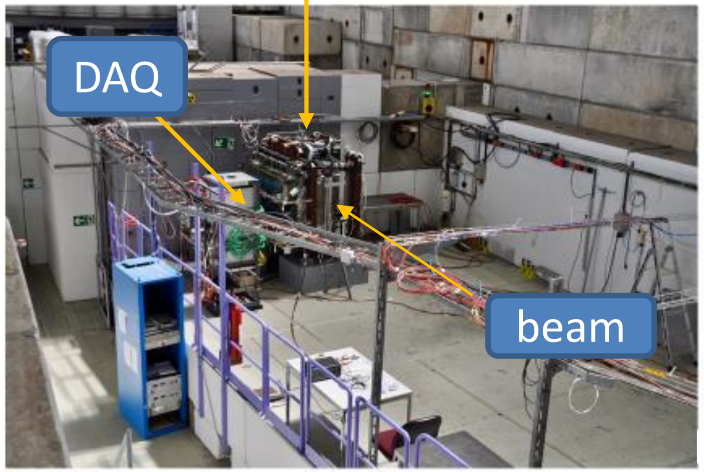
Range System Prototype at CERN

(~10 ton/Fe absorber plates; 276 MDTs; ~ 3000 R/O channels: 2200 wires + 672 strips)

beam position (horizontal)

PROTOTYPE @ PS/T9 BEAM LINE

May 2017 – September 2018

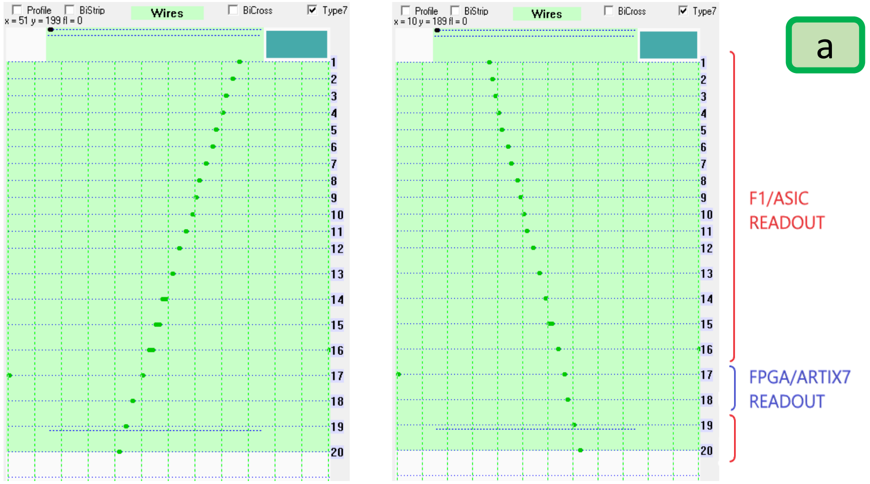


cosmic test position (vertical)

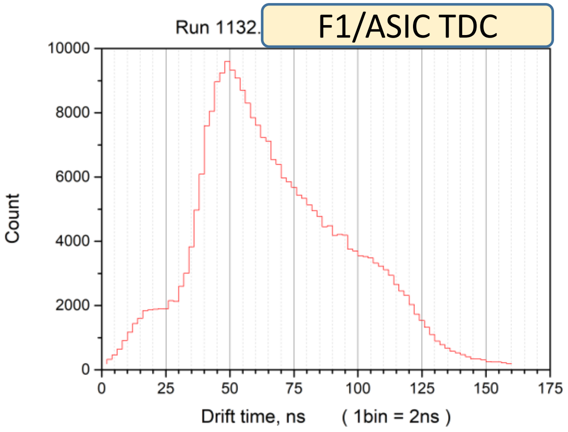
FPGA digital readout test

(a) - prototype's wires R/O, (b) - VME/FPGA R/O unit, (c,d) – comparison of time spectra (ASIC vs FPGA)

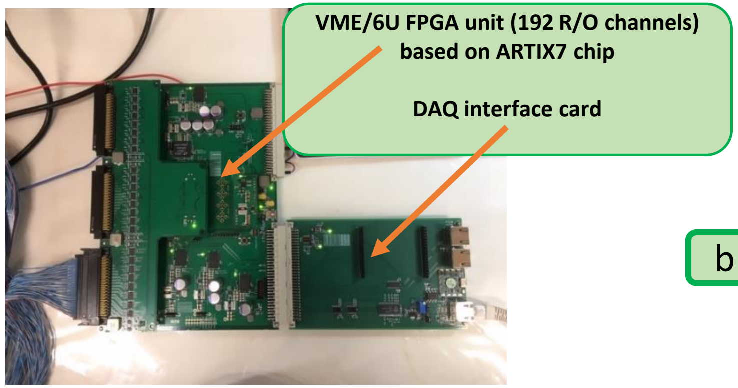
Typical cosmic events



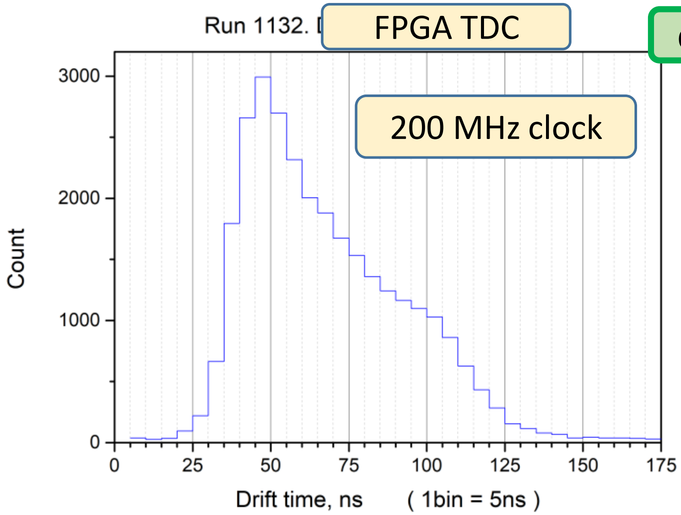
a



c

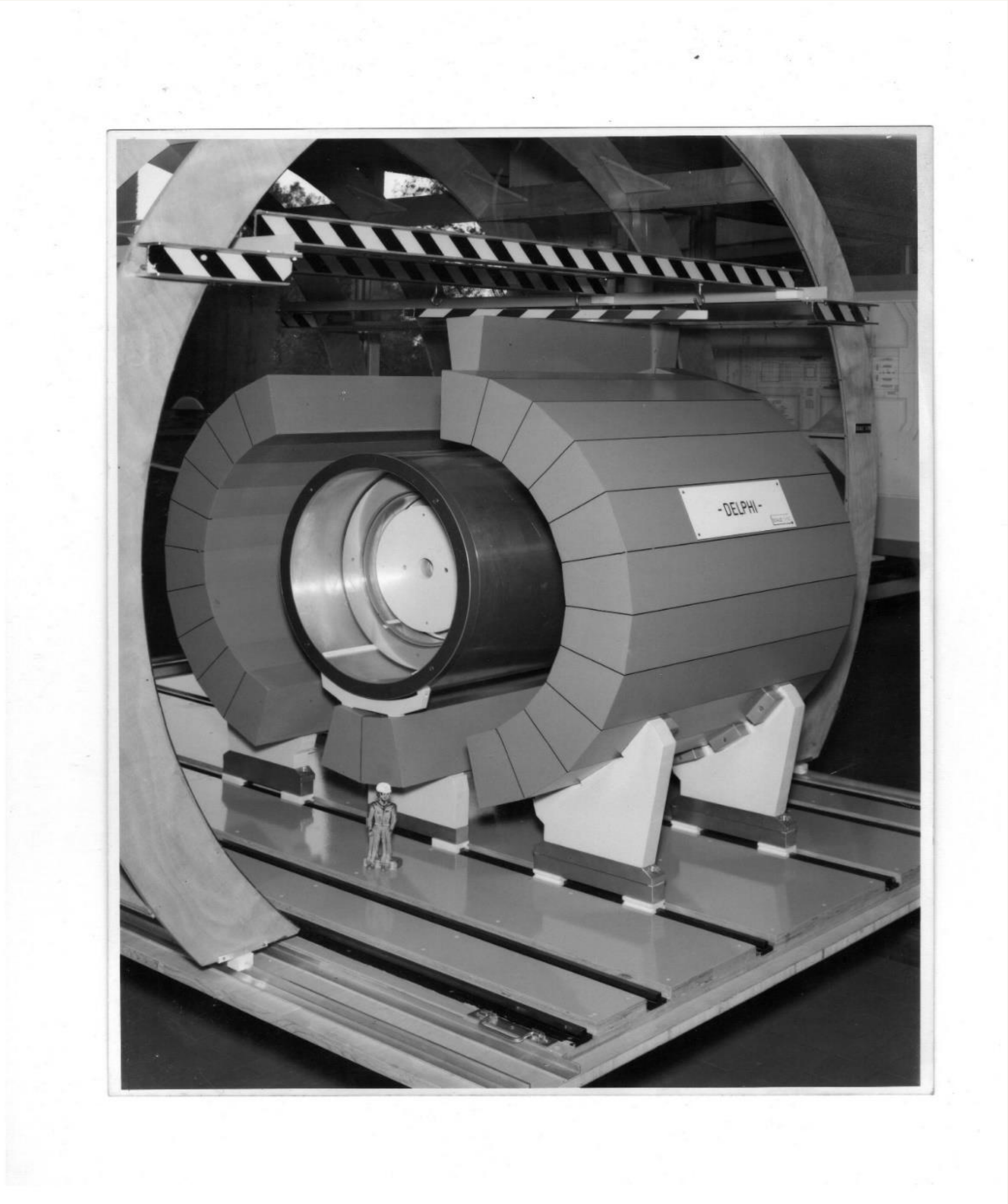


b



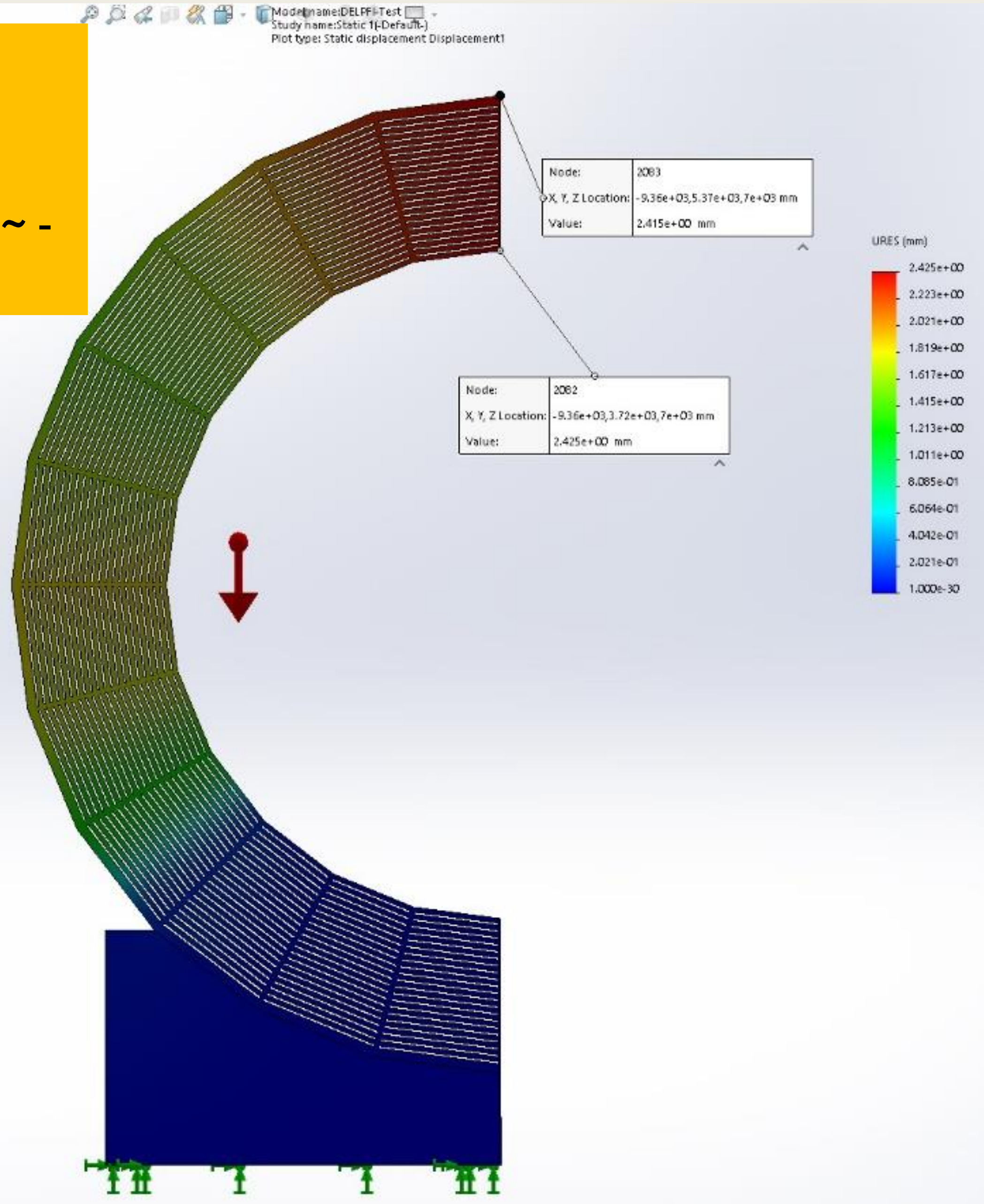
d

Example of DELPHI Barrel (CERN/LEP) residing on 2 lodgements (mockup).

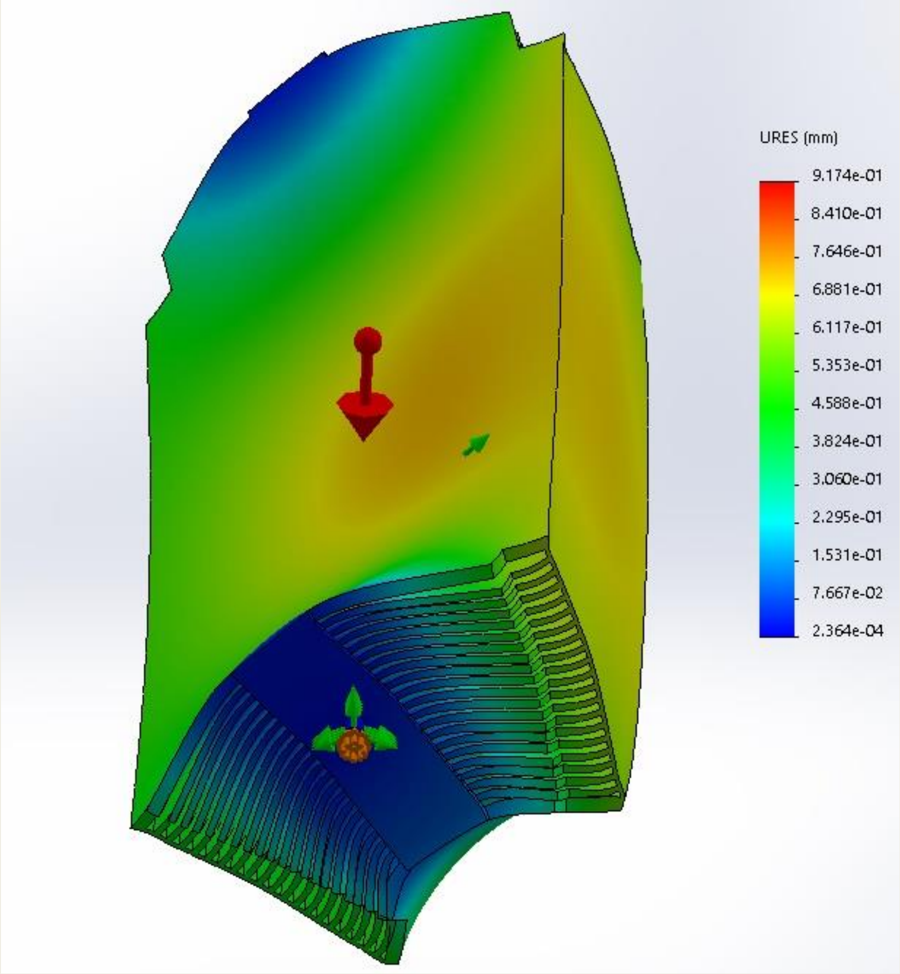


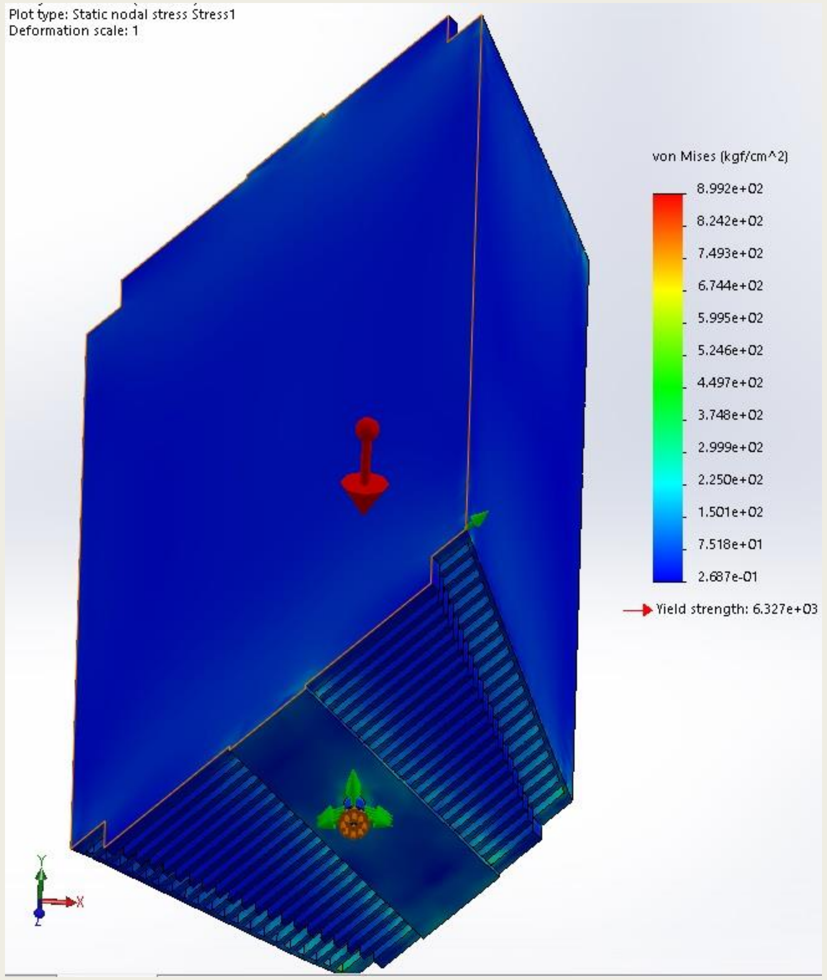
CERN/LEP/DELPHI/Barrel – full assembly without support structures

Example of DELPHI (24 modules with bigger sizes) shows why it is self-supporting, thanks to its almost cylindrical shape: displacement is just ~ -2.5 mm for 10 m outer diameter!

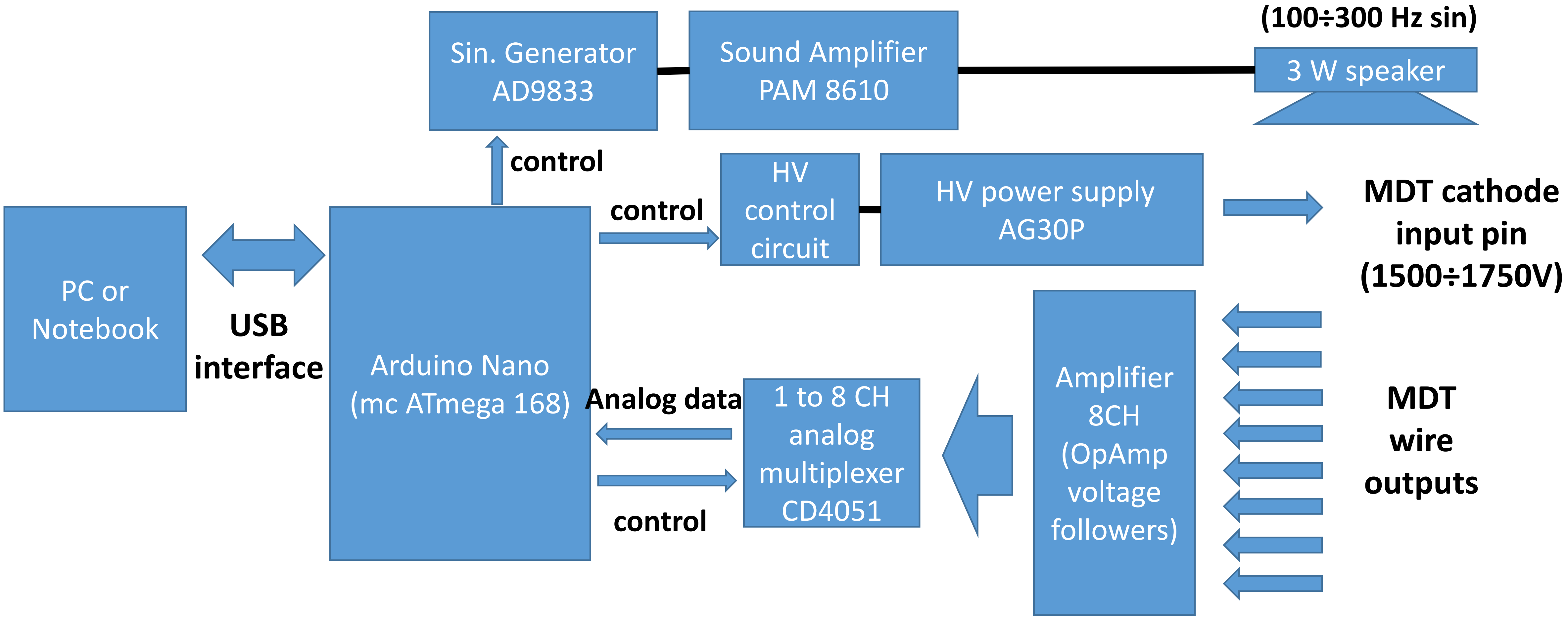


SPD/RS Barrel side modules under crane (displacement and stress)



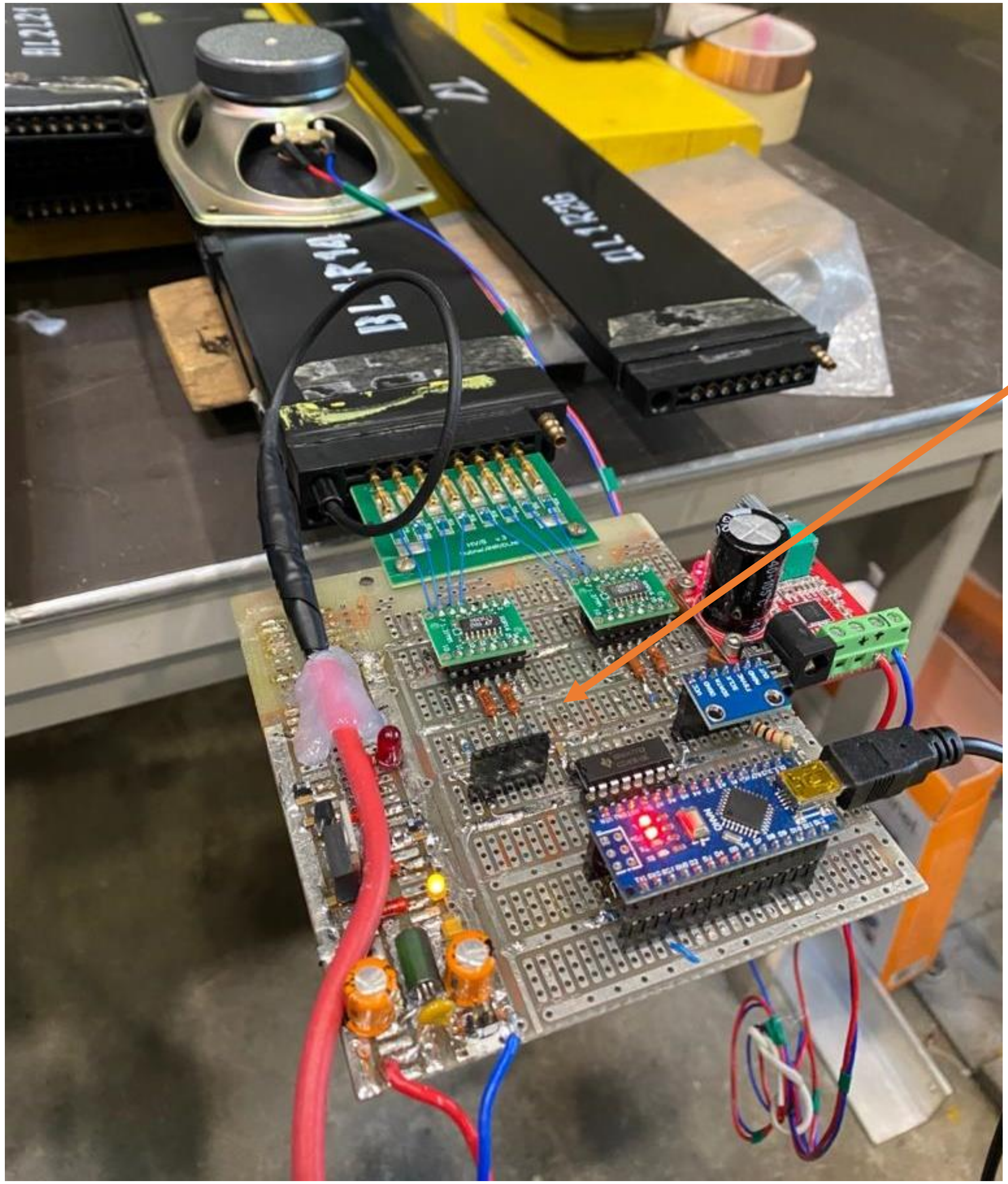


Wire Tension Test Module
block diagram



WTTM is designed to check tension of MDT wires during detector mass production (or repairs) by determining their vibration resonance frequencies

WTTM prototype

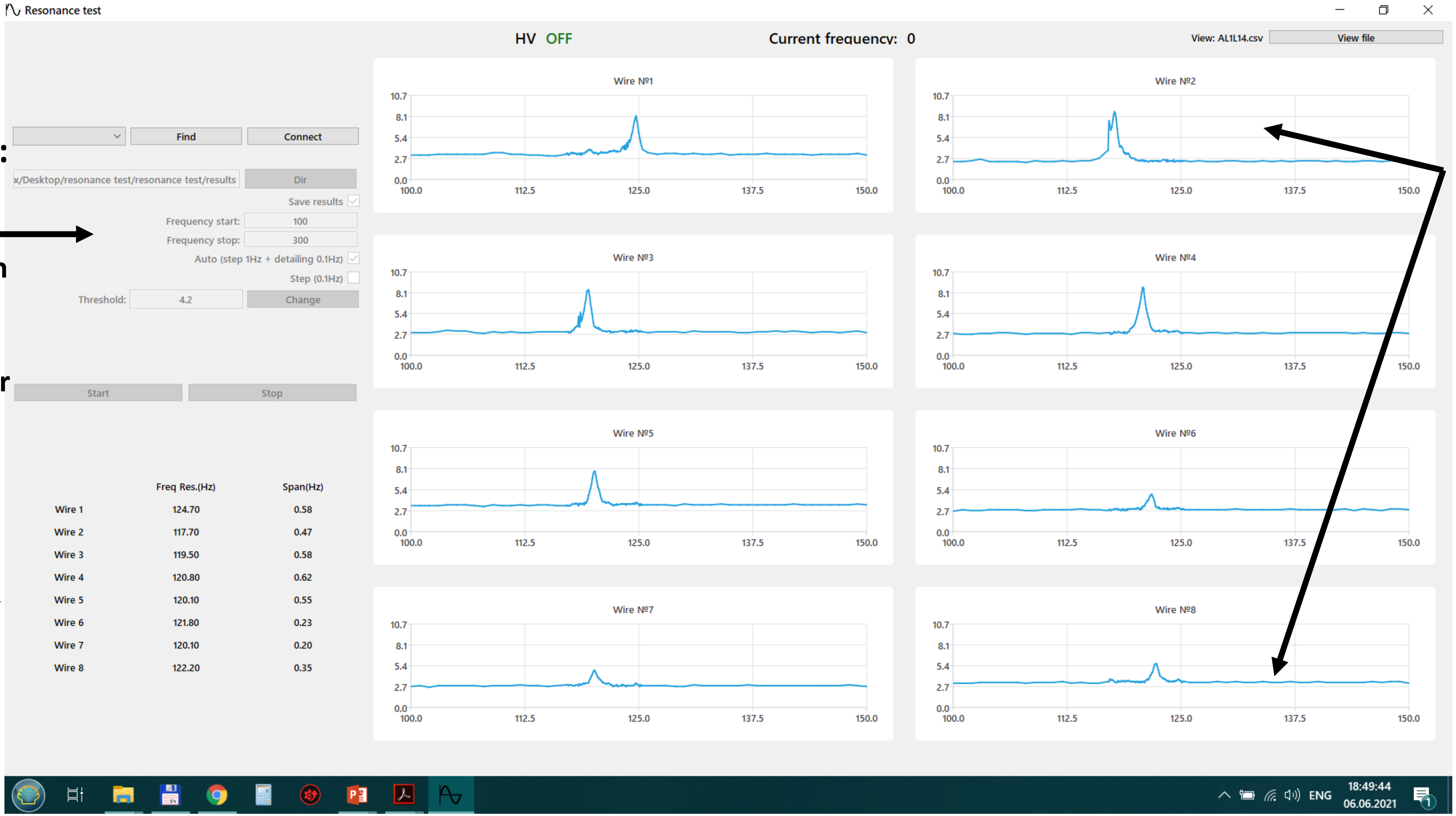


Prototype of the Wire Tension Test Module (WTTM) together with corresponding software were well tested during production of MDTs for the SPD/RS prototype and repair works of the COMPASS/CERN RichWall MDTs.

WTTM soft interface

Program setup:
- File saving option
- Scanning frequency diapason
- AutoDetect or continuous mode
- Threshold level for AutoDetect mode

Measured resonance frequencies



Plots of 8 MDT wires frequency responses

Tension test shows good uniformity of frequencies around 200 gram

HV electrical breakdown test

Breakdown test is intended to determine the HV level of individual wire current breakdown for MDT filled with air (when wire current exceeds the preset threshold level).

Test defines presence of any significant wire (MDT channel) defect (when breakdown HV level is more then 3% below the average value)

Test stand consists of 4 channel HV module CAEN N1470 and notebook with control software.