Design of the Time-of-Flight System of the MPD

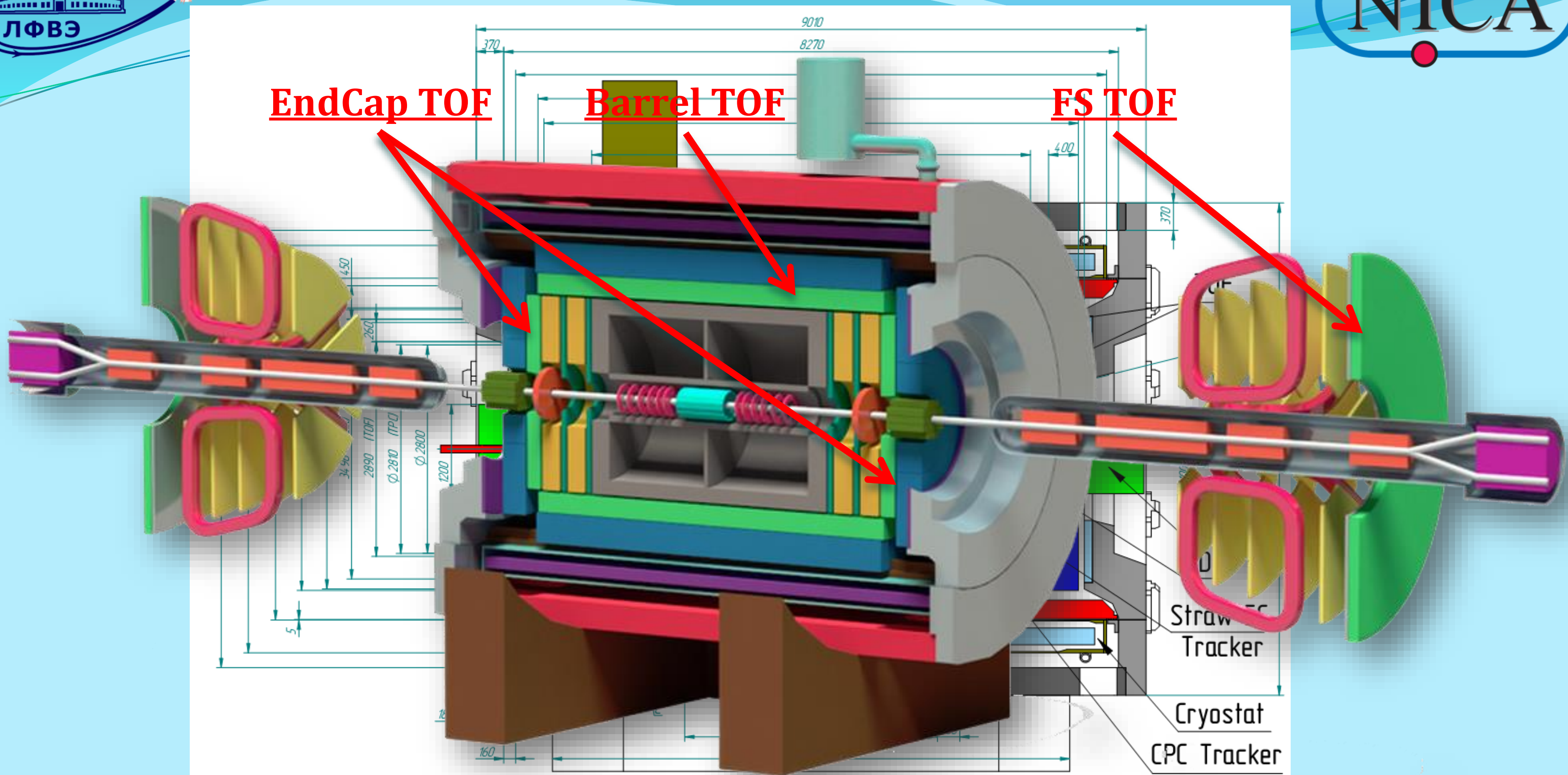
V. Babkin on behalf of the TOF MPD group

Abstract: The Time of Flight system (TOF) of the MPD is one of the elements for particles identification. The TOF MPD has to provide time resolution better 100 ps for effective separation of charged hadrons. The report focuses on the detailed design and technical problems of all the subsystems of the TOF.

Outline

1. MPD layout and design stages
2. TOF identification principle and requirements
3. MRPC principle of operation
4. Barrel TOF design
5. TOF readout electronics
6. Test of the MRPC prototype
7. Service systems (gas system, LV+HV)
8. MPD TOF mass-production area

Three stages of the MPD experiment



First stage: **mid rapidity region**

- Particle yields and spectra (π,K,p,clusters,Λ ,Ξ ,Ω)
- Event-by-event fluctuations
- Femtoscopy involving π, K, p, Λ
- Collective flow for identified hadron species
- Electromagnetic probes (electrons, gammas)

Second stage: **extended rapidity + IT**

- Total particle multiplicities
- Asymmetries study (better reaction plane determination)
- Di-Lepton precise study (ECal expansion)
- Exotics (soft photons, hypernuclei)

Time of Flight (ToF) mass separation (identification)

TPC: momentum & track length determination.

TOF: time-of-flight measurement:

$$t = \frac{L}{v} = \frac{L}{\beta c} = \frac{LE}{pc^2}; \ E = \sqrt{p^2c^2 + m^2c^4}$$

$$t = L\frac{\sqrt{p^2c^2 + (m_0c^2)^2}}{pc^2} = \frac{L}{c}\sqrt{1 + \frac{m_0^2c^2}{p^2}}$$

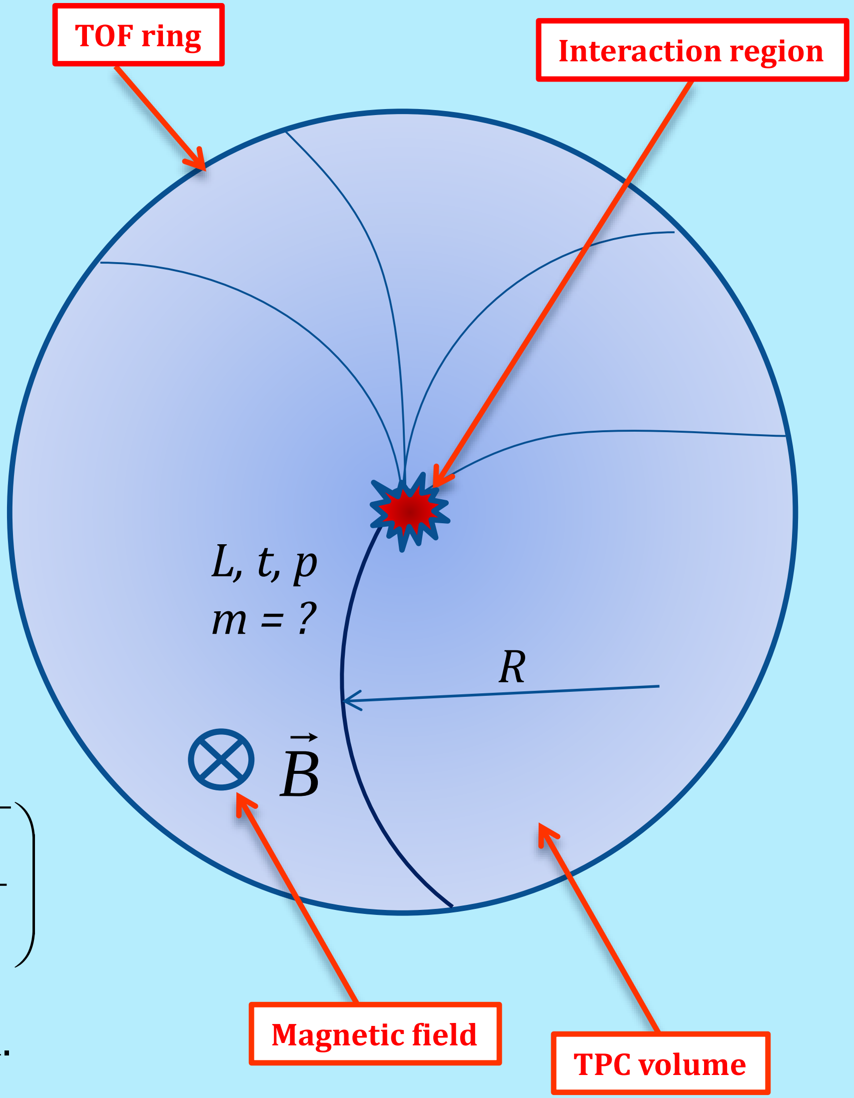
Mass of particle:

$$m_0c^2 = pc\sqrt{\frac{t^2c^2}{L} - 1}$$

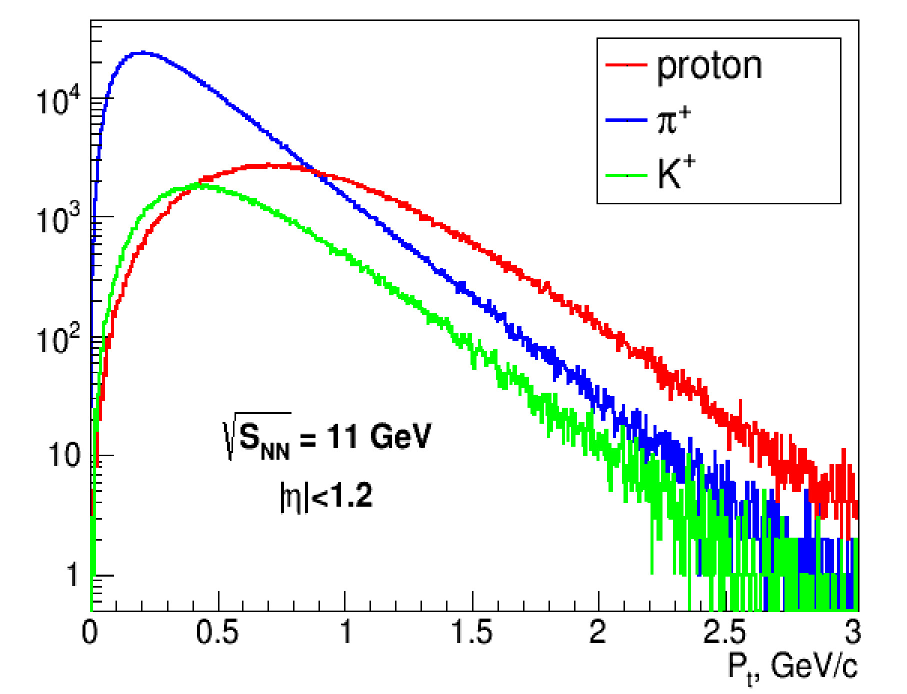
Particles separation power:

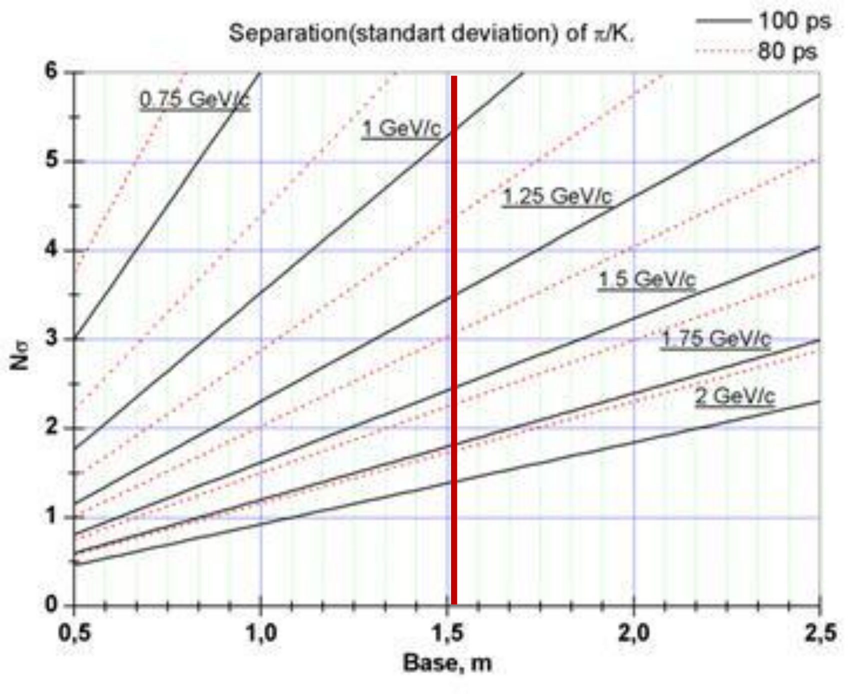
$$N_\sigma = \frac{\Delta t}{\sigma_{TOF}} = \frac{L}{c\sigma_{TOF}}\left(\sqrt{1 + \frac{m_1^2c^2}{p^2}} - \sqrt{1 + \frac{m_2^2c^2}{p^2}}\right)$$

where is $\boldsymbol{\sigma_{TOF}}$ – time resolution of the TOF system.



Requirements to the TOF MPD





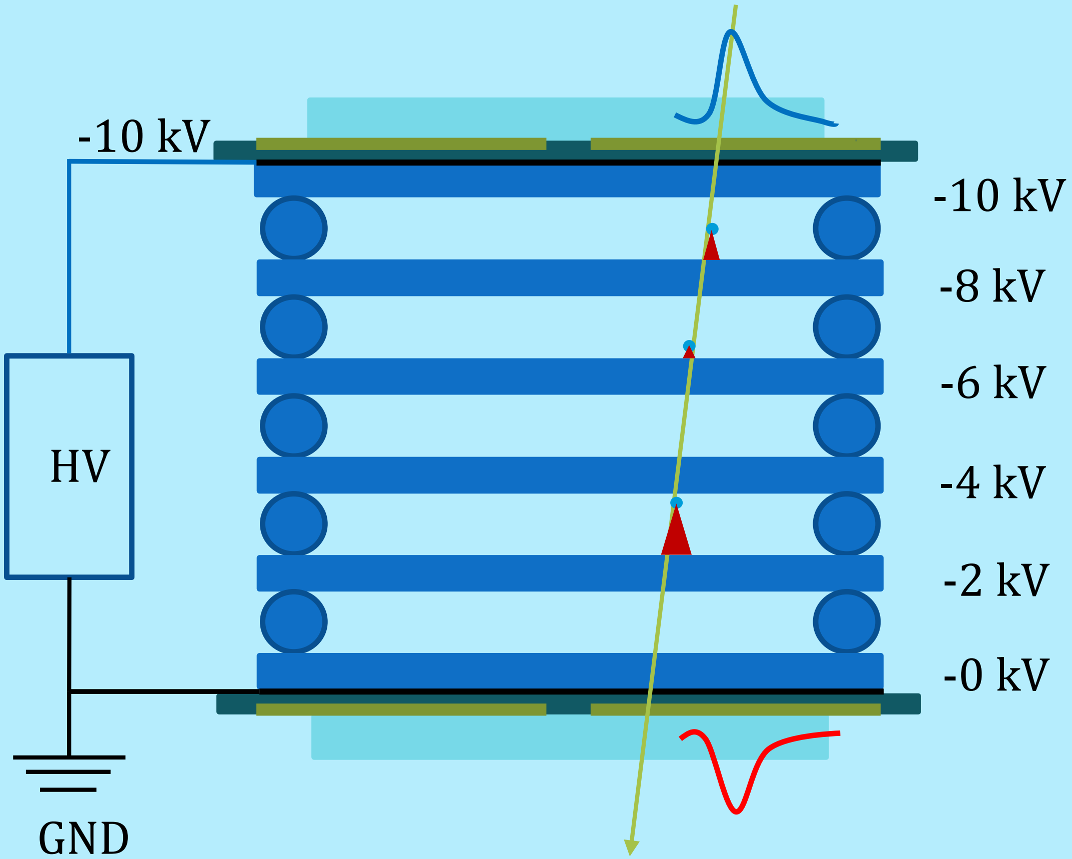
The basic requirements to the TOF system are:

- large phase space coverage **|η| <2**;
- time resolution < **100 ps**;
- high granularity to keep the overall system occupancy below **15%**;
- high geometrical efficiency (better than **95%**);
- identification of pions and kaons with up to p_t **< 1.5 GeV/c**;
- identification of (anti)protons with up to p_t **< 3 GeV/c**;
- rate capability <20 Hz/cm^2

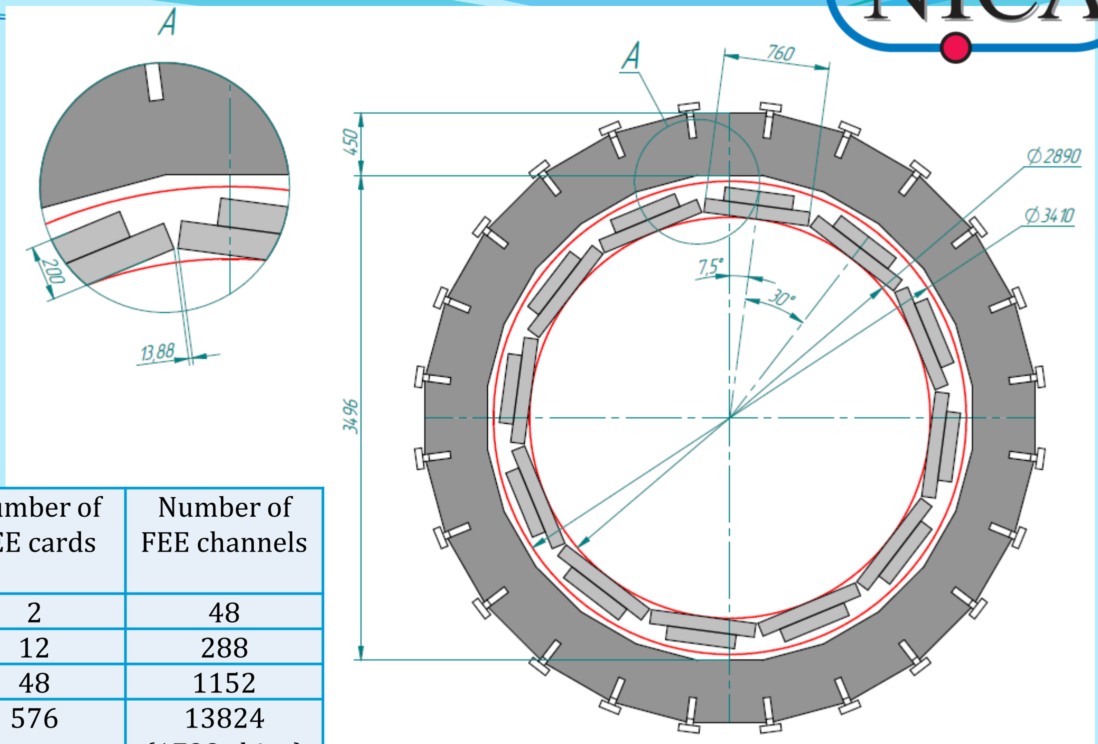
The best choice for this requirements is a **Multigap Resistive Plate Chamber**.

Principle of operation of Multigap Resistive Plate Chamber (MRPC)

The MRPC is a stack of resistive glass plates. A high voltage is applied to the external surfaces of the stack. Further out there are pickup electrodes. A charged particle ionizes the gas and the high electric field amplifies this ionization by an electron avalanche. The resistive plates stop the avalanche development in each gap; they are however transparent to the fast signal induced on the pickup electrodes by the movement of the electrons. So the total signal is the sum of the signals from all gaps (the reason for many gaps is to achieve high efficiency), whereas the time jitter of the signal depends on the individual gap width (the reason for narrow gaps is to achieve good time resolution).

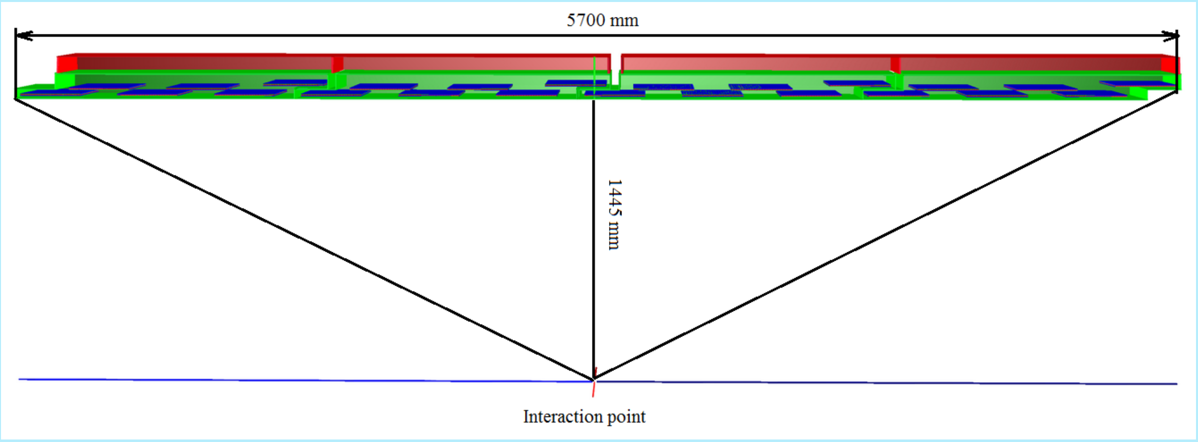


Mechanical design of the TOF barrel

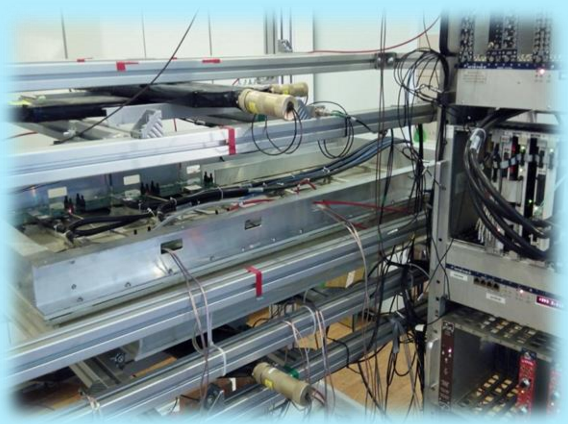


	Number of detectors	Number of readout strips	Sensitive area, m^2	Number of FEE cards	Number of FEE channels
MRPC	1	24	0.2205	2	48
Module	6	144	1.08	12	288
Sector	24	576	4.19	48	1152
Barrel	288	6912	50.3	576	13824 (1728 chips)

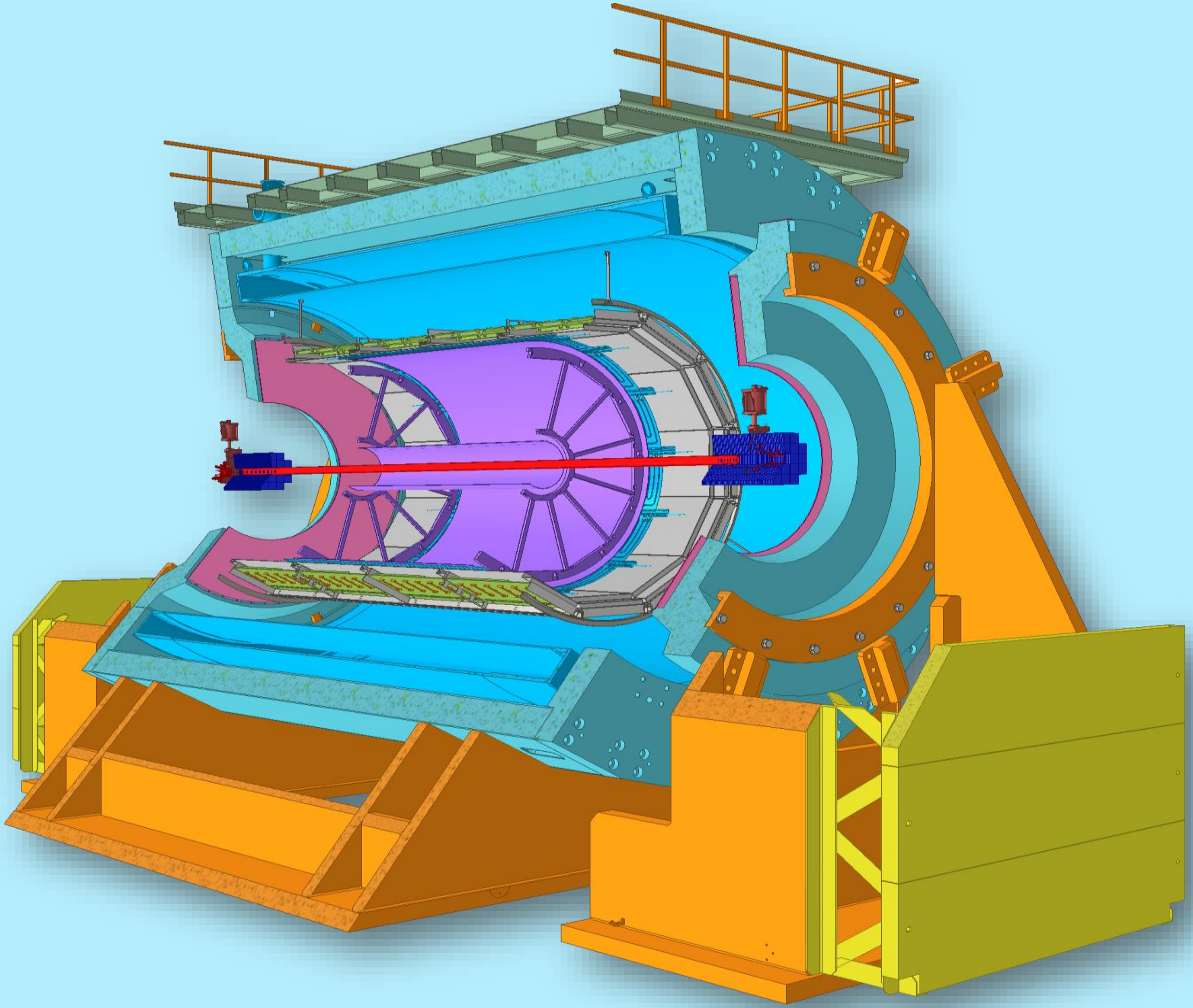
The main sizes of the TOF barrel in φ direction



Modules along the beam direction.

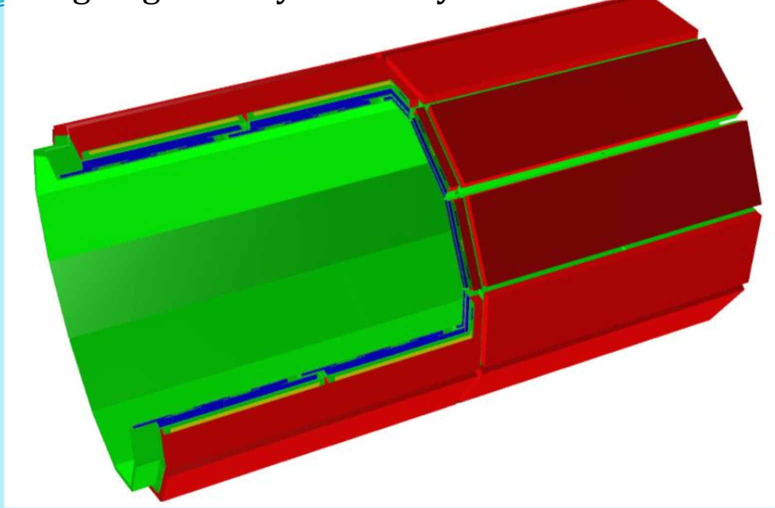


Mechanical design of the TOF barrel

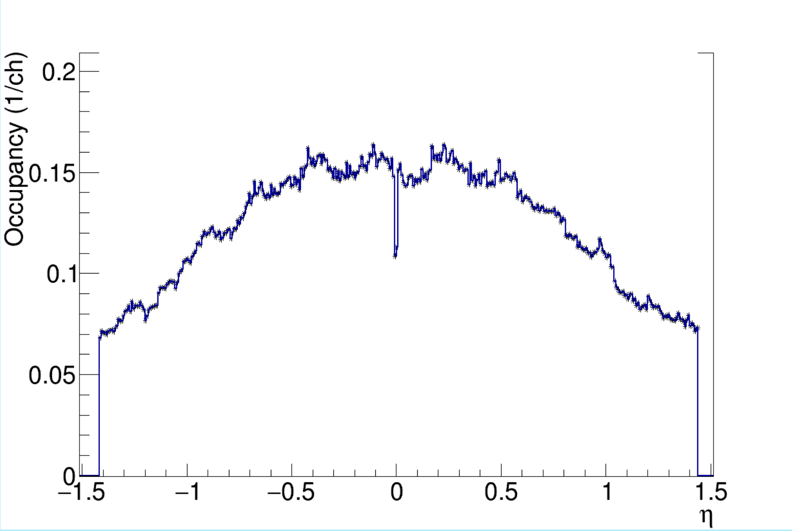


MC simulation results

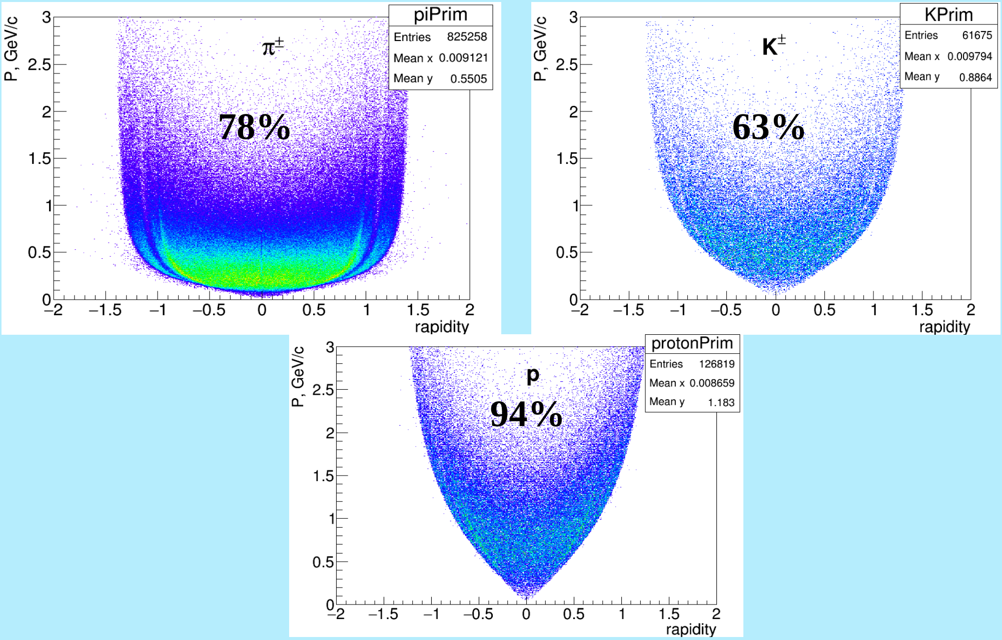
Integral geometry efficiency is ~95%



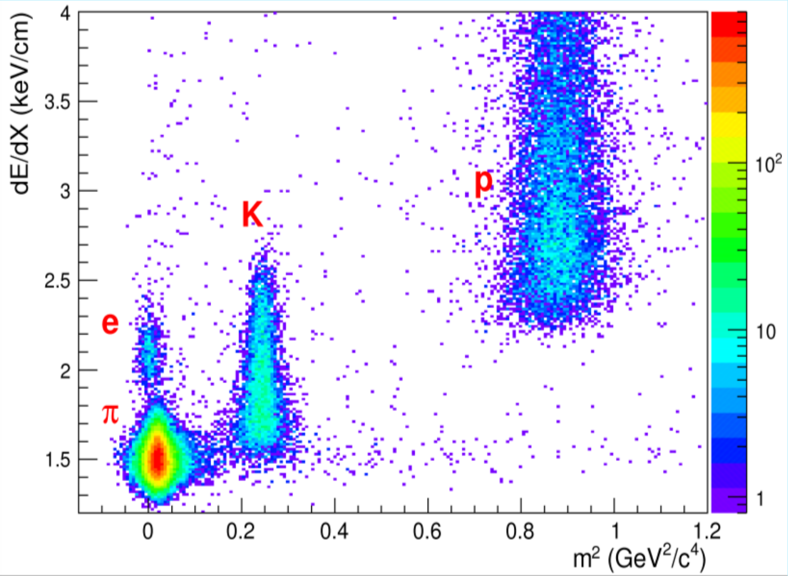
TOF detector layout in MPDROOT framework



Occupancy of the barrel TOF

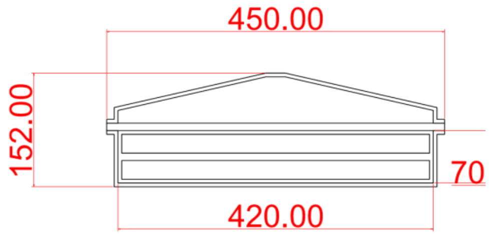


Acceptance estimation

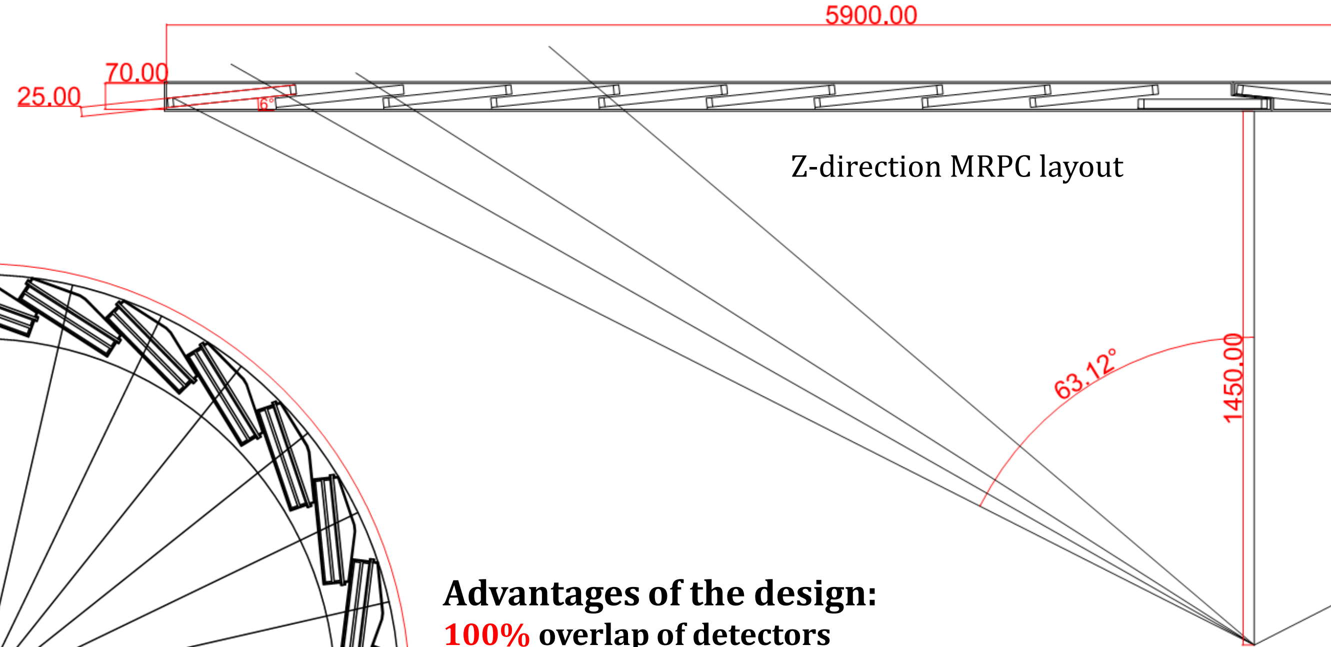


Combined *dE/dx* and TOF particles identification

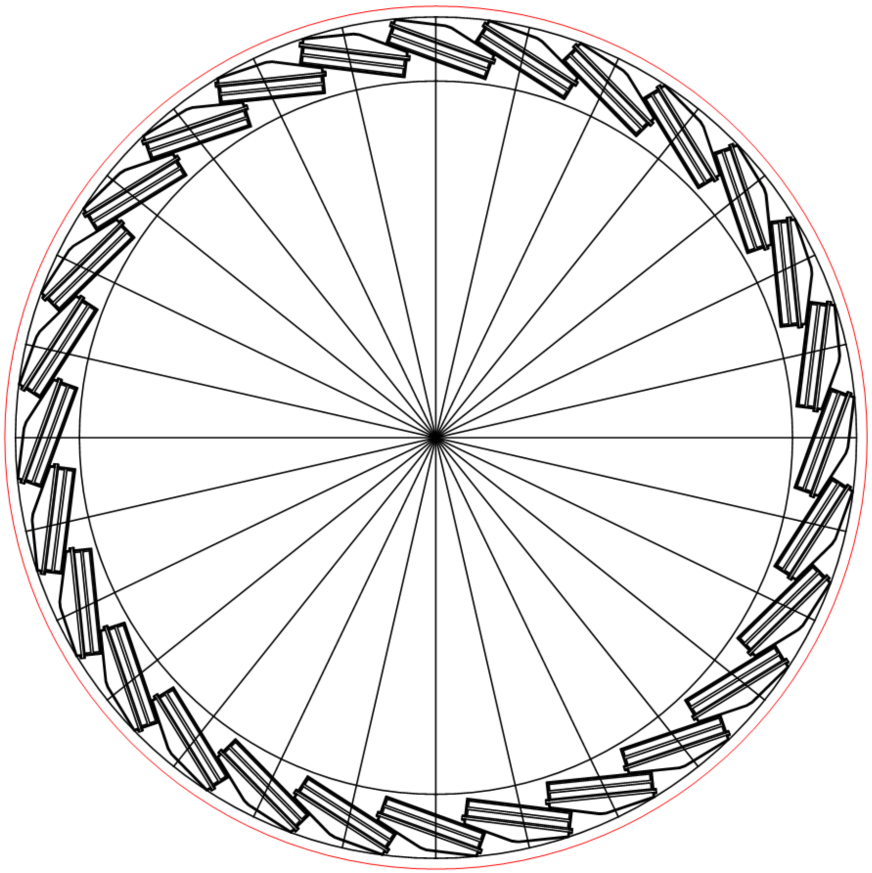
Possible variant of TOF design



TOF module cut view



Z-direction MRPC layout

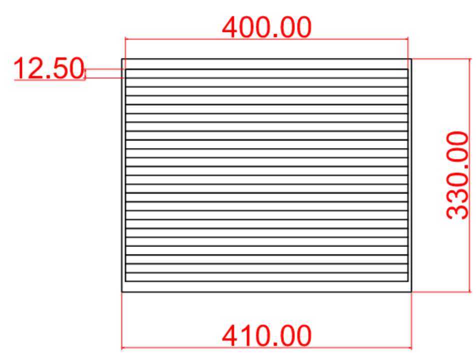


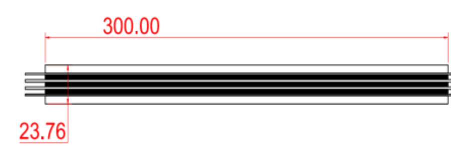
Advantages of the design:

100% overlap of detectors

400x12.5 mm strip: 560x24 = 13440 strips → 26880 el.ch

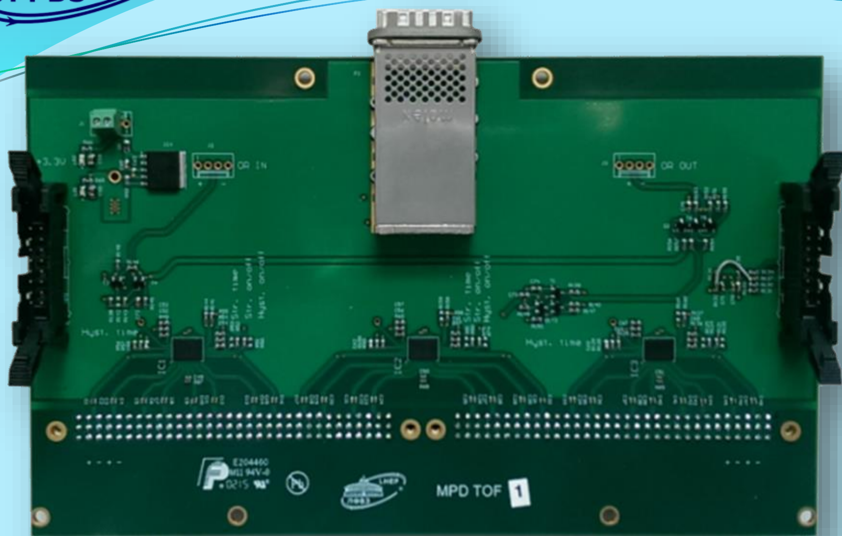
Max. Occupancy = 0.25x50 = 12.5%





MRPC cut view

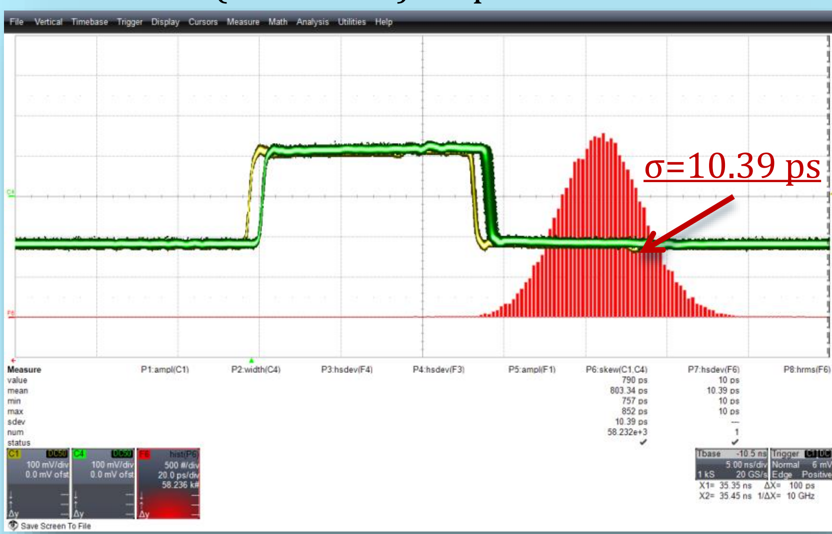
Front-End Electronics



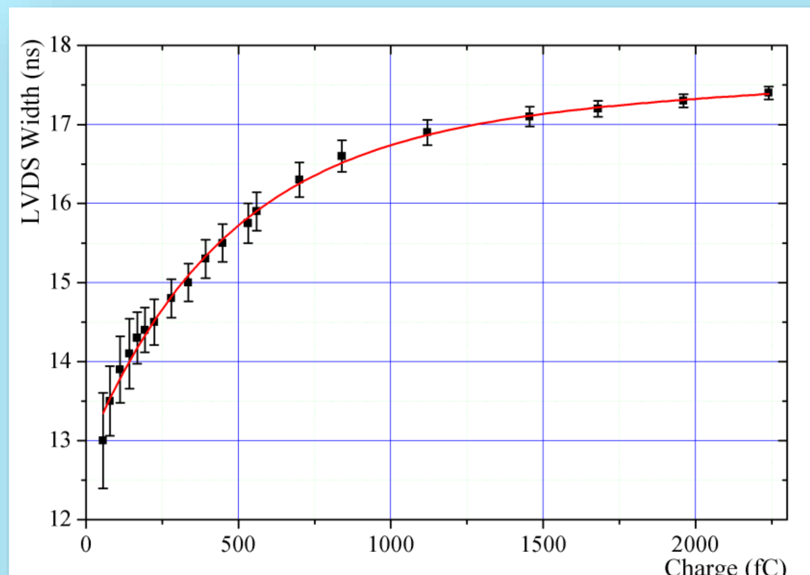
24-channel amplifier based on NINO with CPX (InfiniBand) output connector.

MPD TOF amplifier-discriminator features:

- Stabilized of the voltage (+2.5V);
- Differential input signal; (Z_{diff} = 55 Ohm);
- Overload protection for input channels;
- Capacitors on the inputs for double-end strip readout;
- CPX (InfiniBand) output transmitting line;
- The possibility to use as trigger (series “or” output);
- Controlling and monitoring of the thresholds;
- Time resolution for one channel $10.4/\sqrt{2} = 7.3$ ps;
- Time-over-Threshold correction possibility.

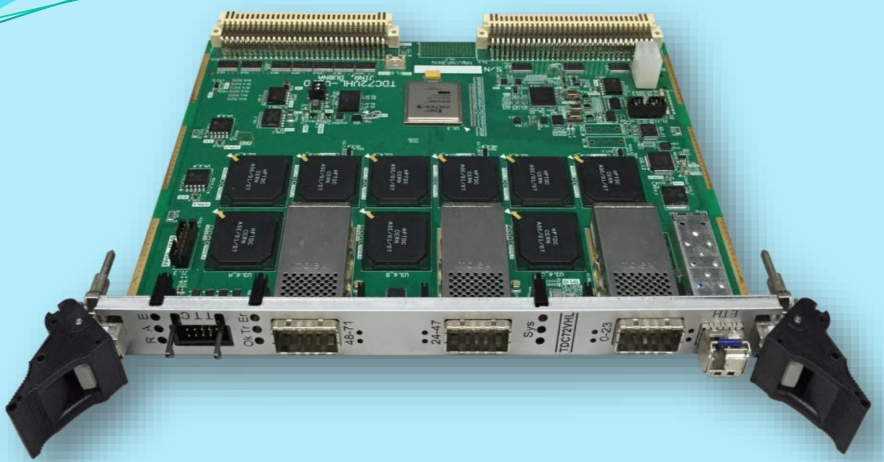


Time difference distribution from two FEE channels

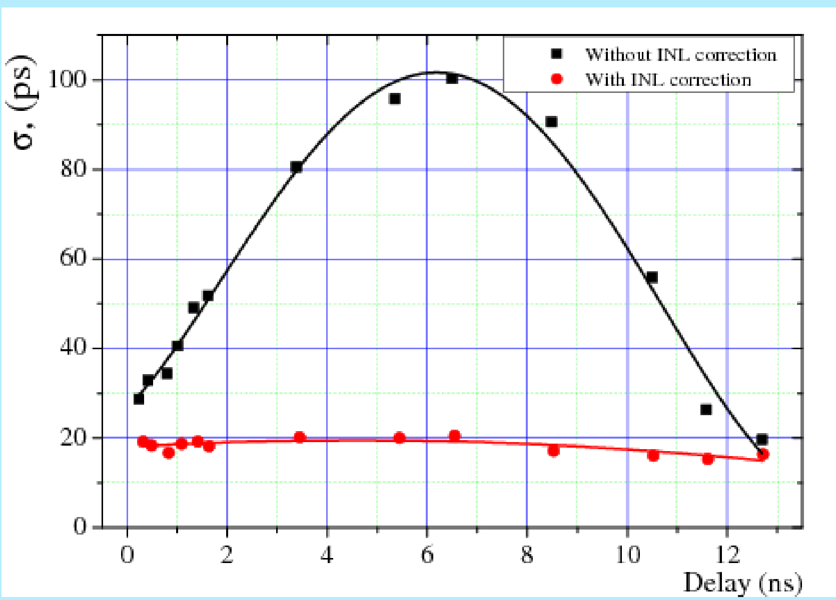


Charge-width dependence for ToT correction

Readout & DAQ



TDC72VHL with CPX(InfiniBand) connector



TDC72VHL time resolution after INL correction

TDC72VHL module specification:

- VME64x interface;
- TDC type: timestamping HPTDC chip;
- Number of input channels: 72;
- Input: differential 100 Ω (LVDS);
- Resolution: ~ 25ps bin size (σ ≈ 20 ps);
- Power consumption: +5 V 0.13 A; +3.3 V 5.6 A.

Standalone mode:

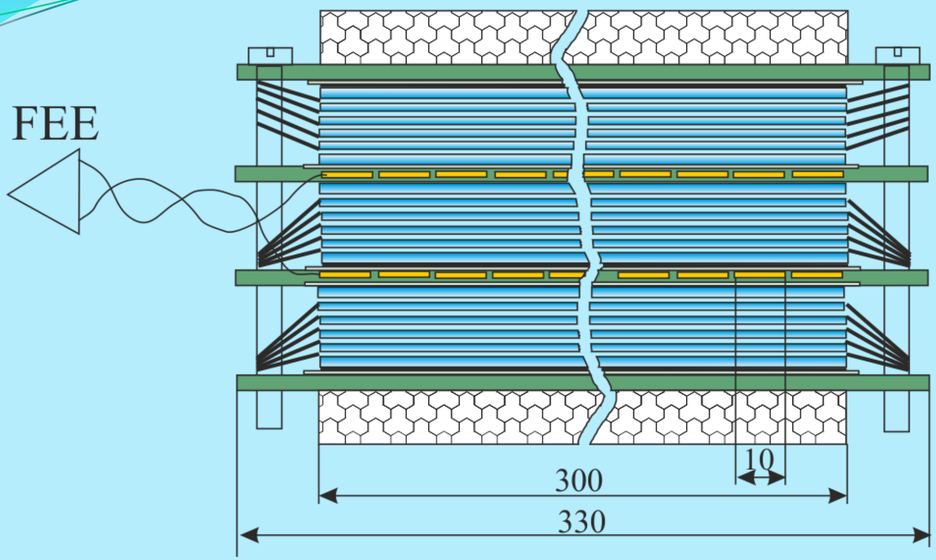
- Ethernet or M-Link data transfer
- Time synchronization by White Rabbit

http://afi.jinr.ru/TDC

TOF DAQ estimation parameters

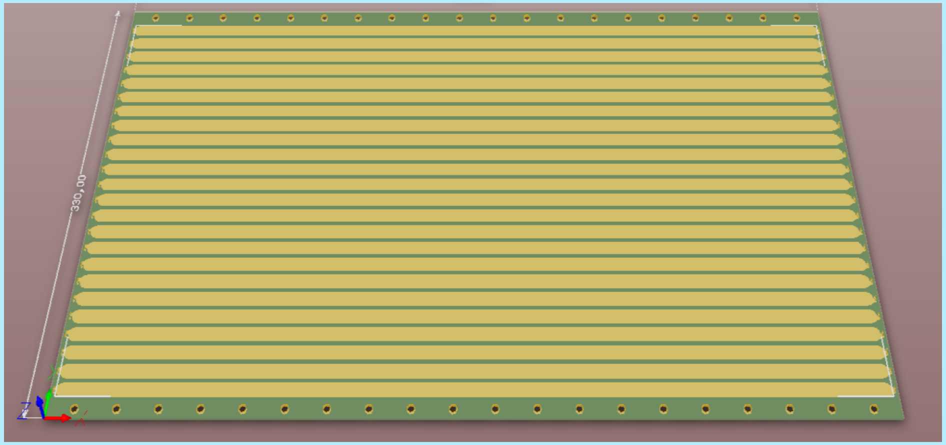
Parameter	Value
Raw data information type	Lead+trail time, 25 ps/bin
Channel size	12 Bytes
Average event size	24 kBytes
Data rate	< 1.5 Gb/s
Number of TDC72VHL	192
Total power	3500 W

Triple-stack MRPC

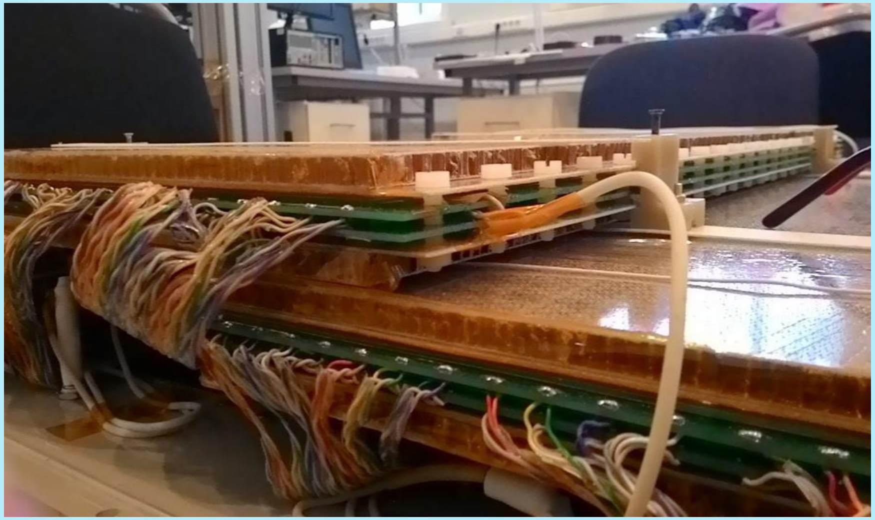


Triple-stack MRPC cut view

Characteristics:	
Overall dimensions	610 x 330 mm^2
Active surface	600 x 300 mm^2
Number of channels	24
Strip pitch	12.5 mm
Dimensions of strips	600 x 10 mm^2
Glass thickness (inner, outer)	280, 400 μm
Gap number (3 stacks)	3 x 5 = 15
Gap width	200 μm

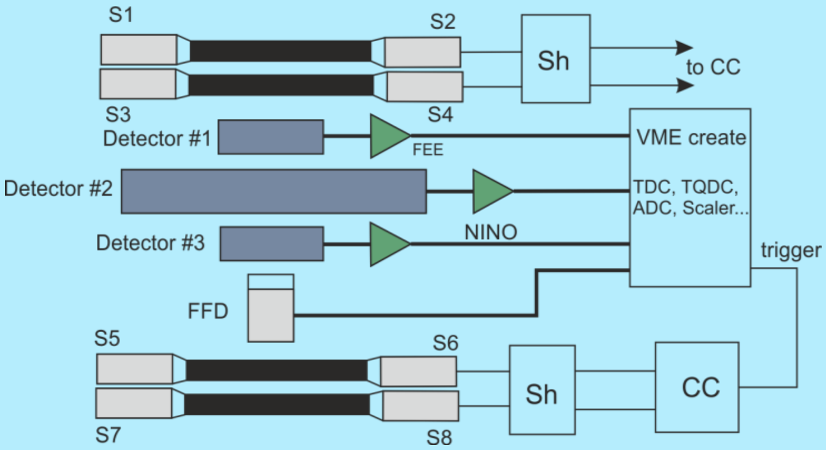


Inner readout board with strips



Assembled triple-stack prototypes in module

Cosmic and beam test facilities

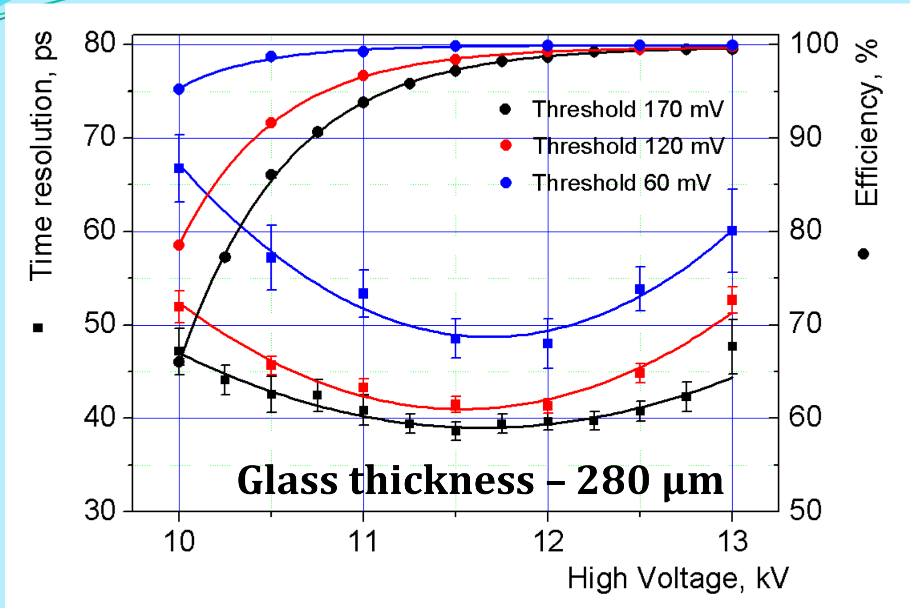
Appearance and schematic diagram of the cosmic test setup

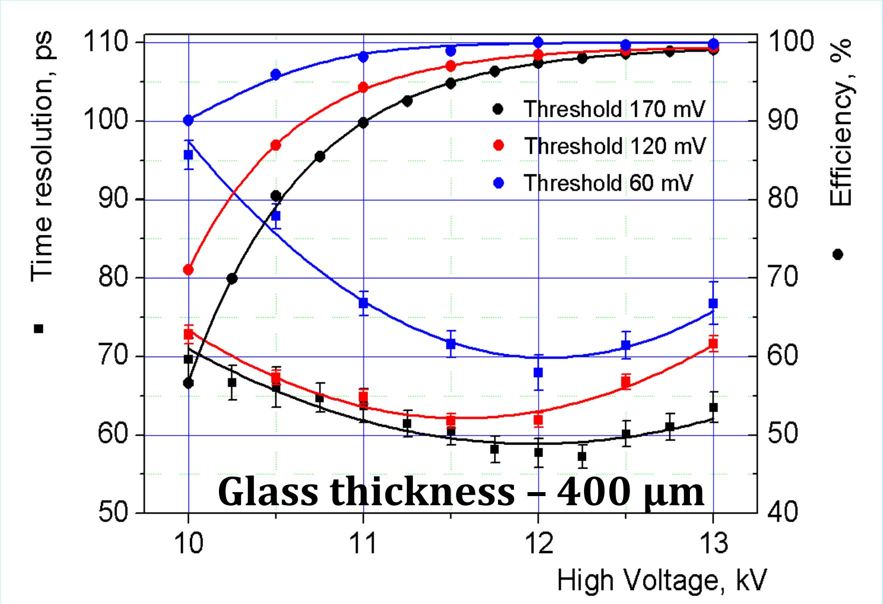
General view of the “Test beam MPD” setup

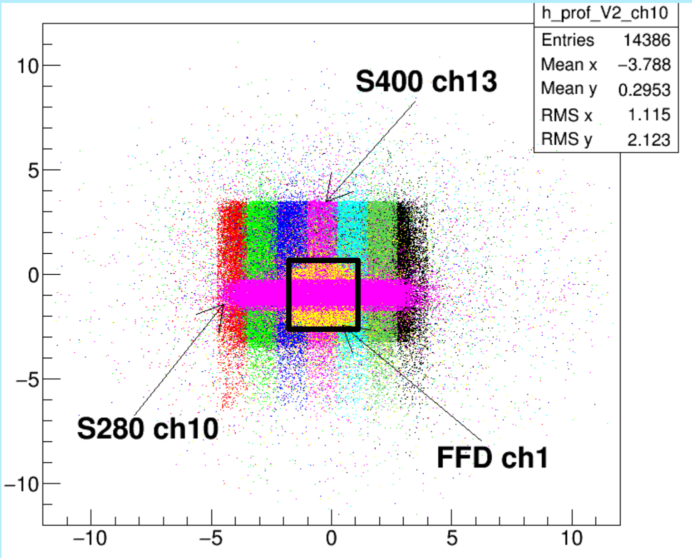
- two platforms made of aluminum profile;
- the precision positioning device;
- three proportional chambers (MWPC 1, 2, 3) with an accuracy of determination of coordinate <1 mm;
- five trigger scintillation counters;
- two independent gas system for various gas-filled detectors with different gas mixtures;
- data acquisition system (DAQ) based on the VME and Ethernet.

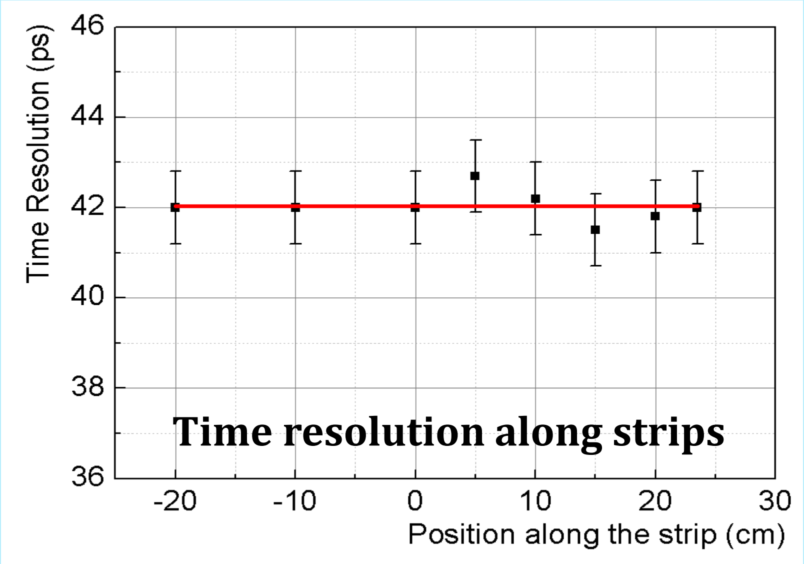
February 2015 beamtest results

Time resolution from the applied high voltage



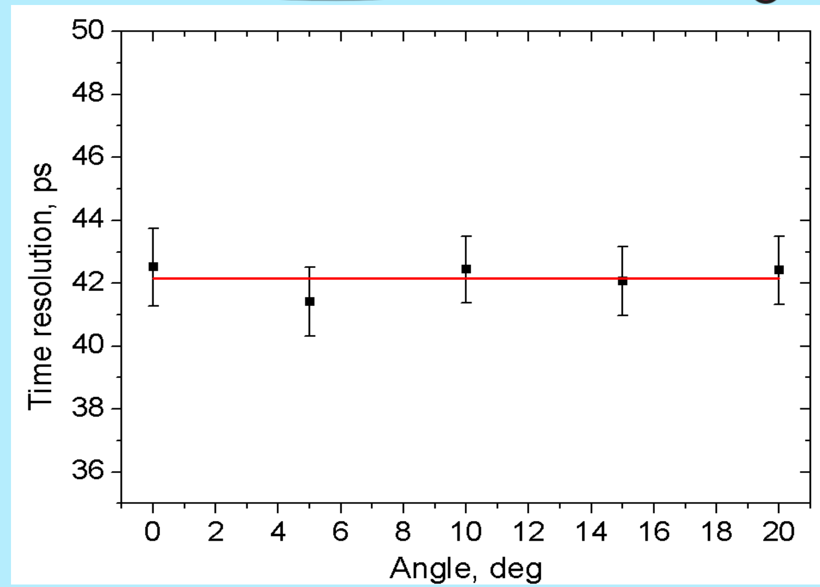




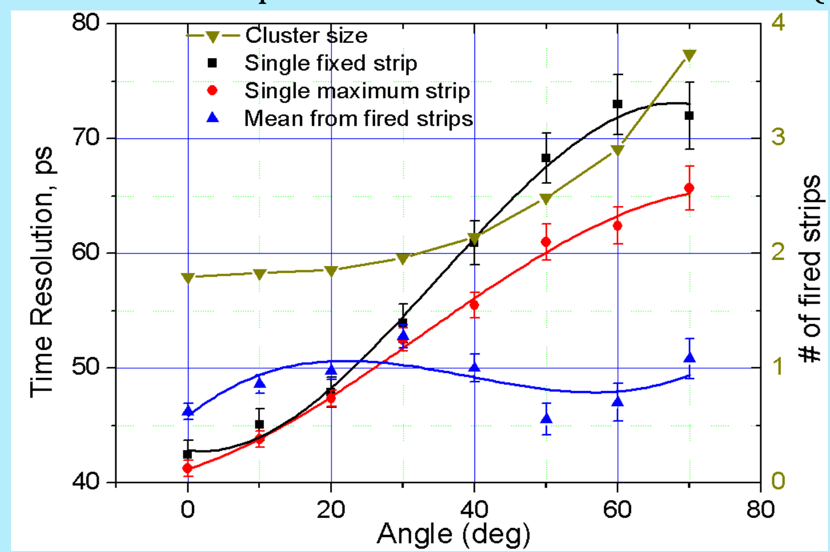


February 2015 beamtest results

MRPC prototype in positioning device



Time resolution in dependence of rotation in surface XZ (along)



Time resolution in dependence of rotation in surface YZ (across)

Gas system

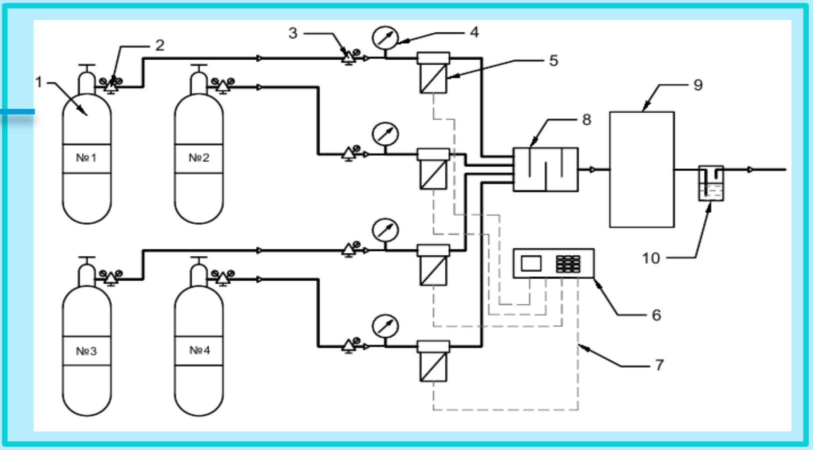
Volumes of the TOF gas-filled elements

	Number of detectors	Gas volume with detectors, l
Module	6	63
Sector	24	252
TOF Barrel	288	**3024,** ~3 м^3

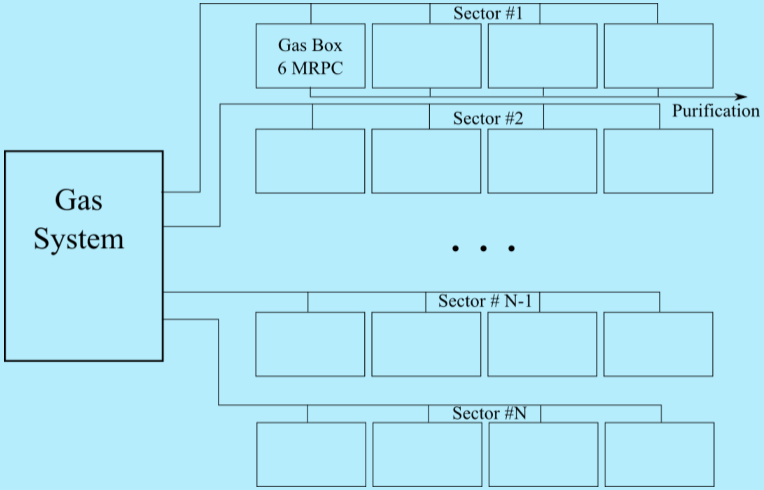
Main requirements to the gas system:

- Typical gas mixture: 90% $C_2H_2F_4$ + 5% i-C_4H_{10} + 5% SF_6
- Recirculation flow rate: 6 – 10 l/min ;
- Fresh gas flow rate: 70 – 100 cc/min;
- Working overpressure: < 3 – 5 mbar;
- Tolerable O_2 content: < 1000 ppm;
- Tolerable H_2O content: < 100 ppm;
- Accuracy of gas flow rate: < 1% of setpoint;

Gas mixture 90% $C_2H_2F_4$ + 5% i-C_4H_{10} + 5% SF_6.



Scheme of a simple mixer system



Gas distribution scheme.

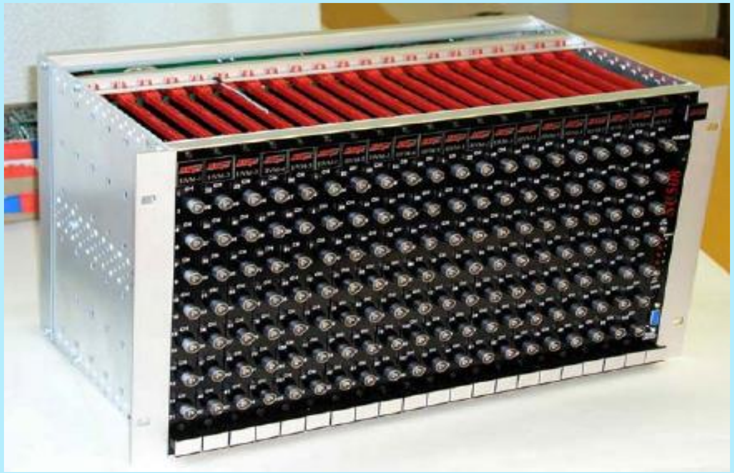
A detailed description of the gas system in the presentation of
Daniel Dabrowski "Gas control system for MPD Time-Of-Flight detector" (Fri 06/11, 11:20)

High Voltage and Low Voltage power supplies

HV system requirements:

Minimum number of differential "±" channels: **48**
Voltage range (one polarity): **2000 – 10000 V**
Total current through the whole system **(~150 μA)**
Precision of the current monitoring: **5 nA**
Multichannel structure
Remote control

http://hvsys.ru/en/



Example of 420-channel HV source in the "Euromechanics" format (TRT ATLAS)

"**HVSys**" HV power supply main characteristics

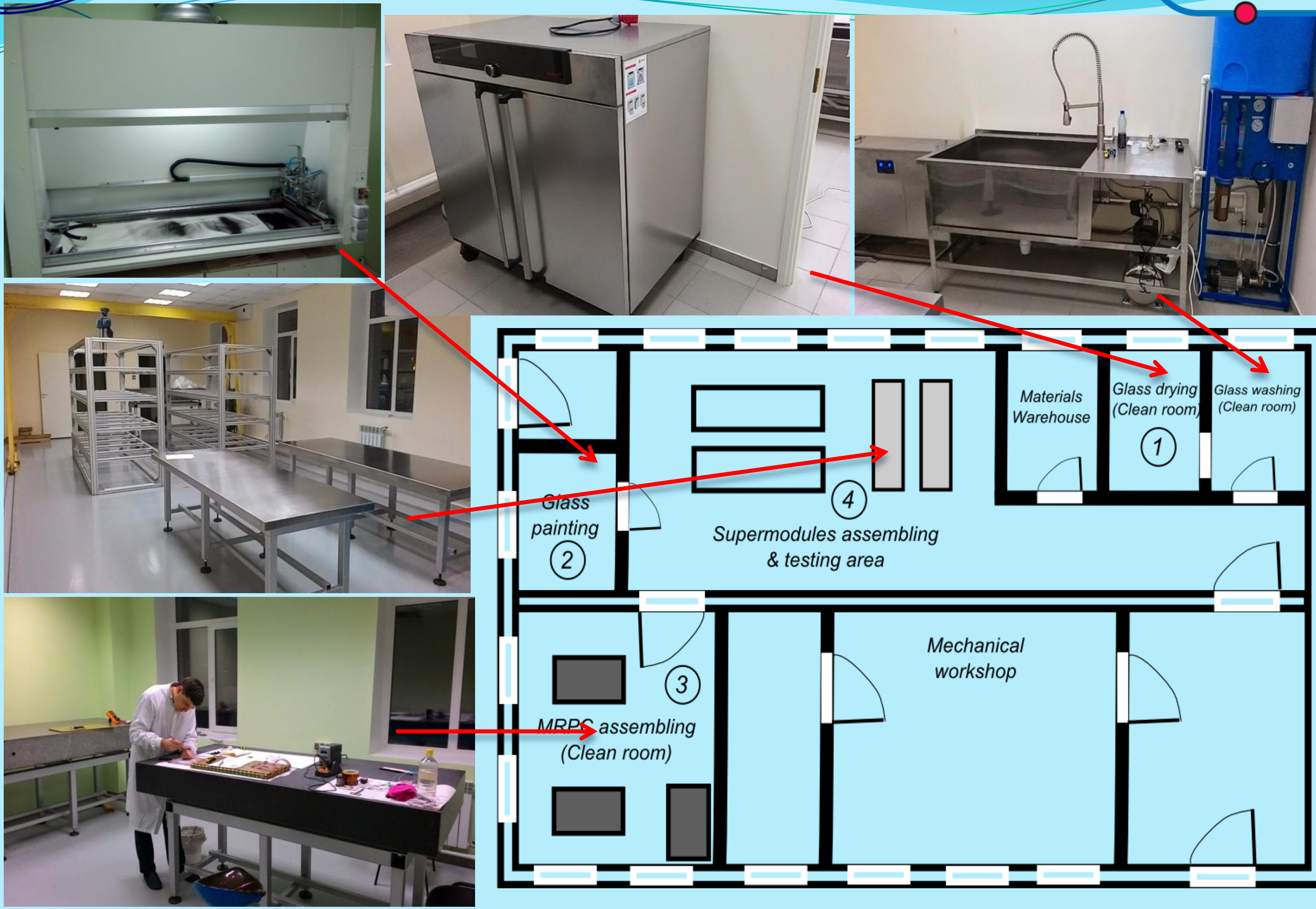
Parameter	Value
Number of channels (pair of ±)	40 (20)
Minimum voltage per channel, V	±1200 (ramp up: 2 – 4 sec)
Maximum voltage per channel, V	±12000
Output voltage ripple at I_{max} (pick-to-pick)	~ 10E-4 (10E-5)
Voltage ramp up speed, V/sec	0.5 – 125
Maximum current per channel, μA	60
Precision of the voltage monitoring	3V (12 bit)
Precision of the current monitoring	12 bit (I ≤ 8 μA: 2 nA) (8 < I < 60: 15 nA)
Output connector	Radiall SHV (RG58/U)
Remote control interface	USB, RS232, Ethernet

Low Voltage power distribution

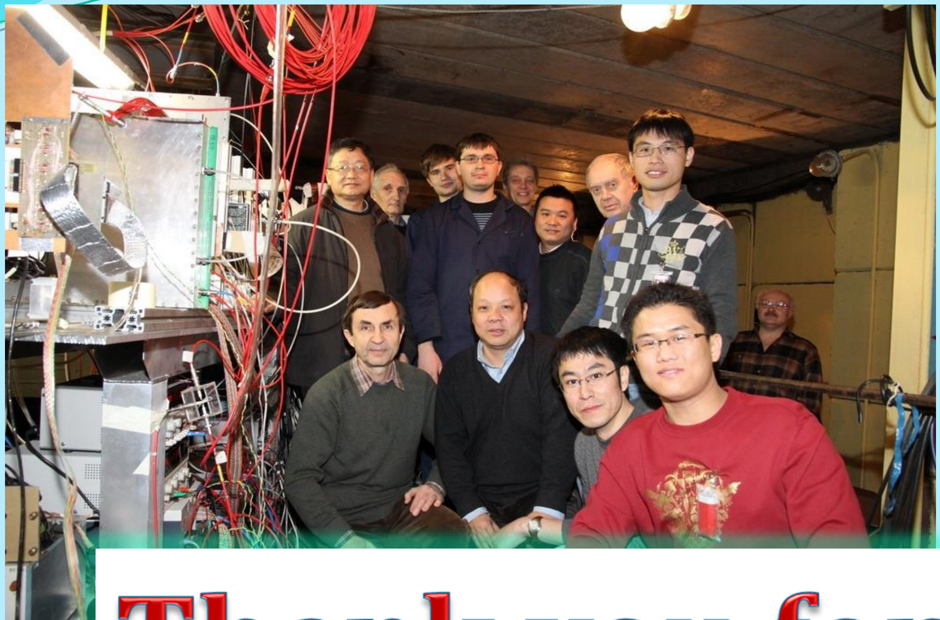
The power consumption of one FE card is 1.35 W. The total power consumption of the TOF is less than **800 W**. Such a small power allows using a simple and cheap power supply scheme. Two options are considered to supply LV power to the electronics:

1. Power supplies located immediately outside the MPD magnet, in the experimental hall, delivering the needed voltage and current directly to the load.
2. DC-to-DC converter placed inside the magnet as close as possible to the load. Such converters must operate in a high magnetic field (possibly up to 0.5 T) and substantial radiation environment.

Area for mass-production of the TOF MRPC



We are open for collaboration



Thank you for the attention!

<u>**We are invite for cooperation:**</u>

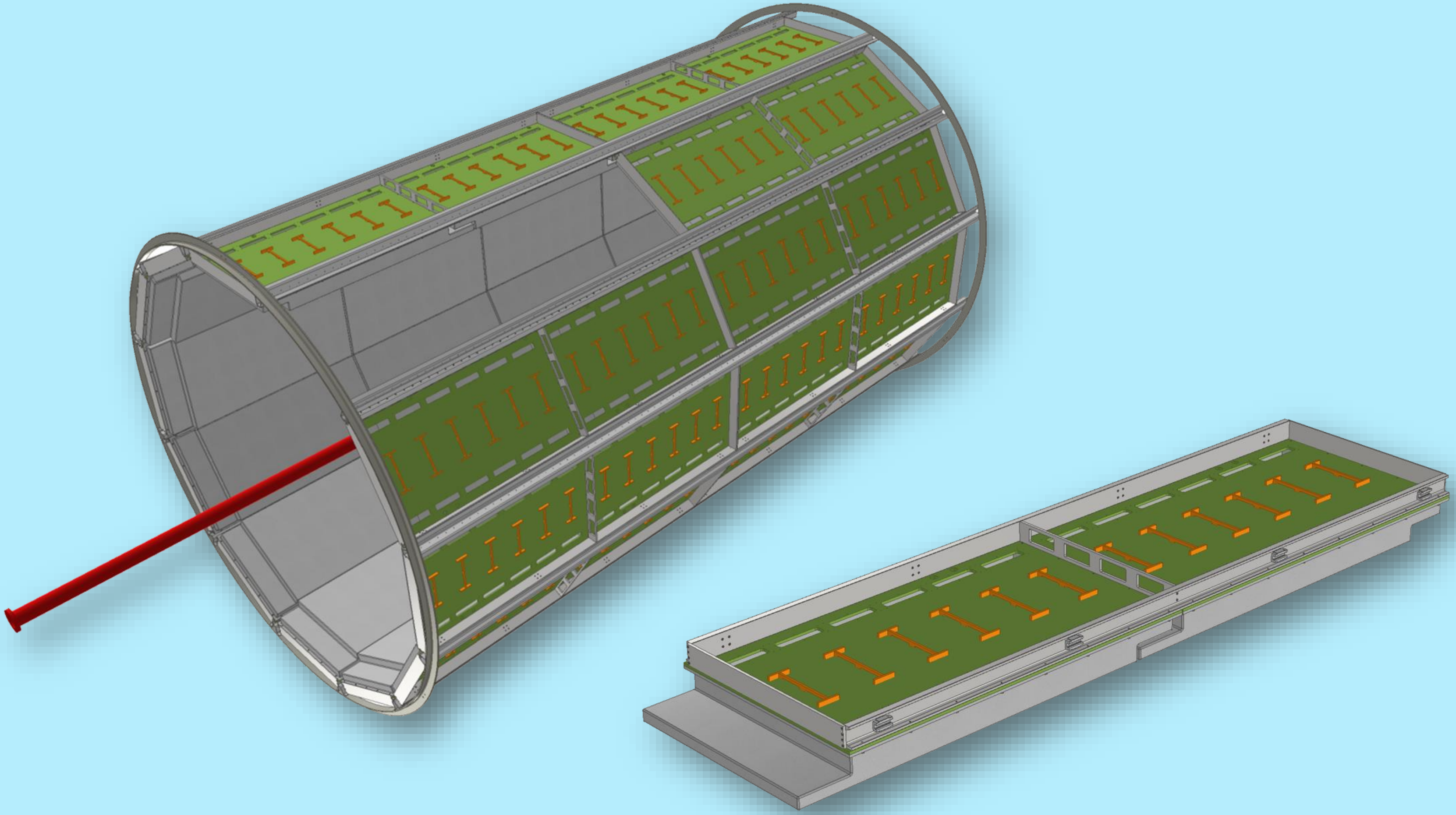
Design engineers

Electronics engineers

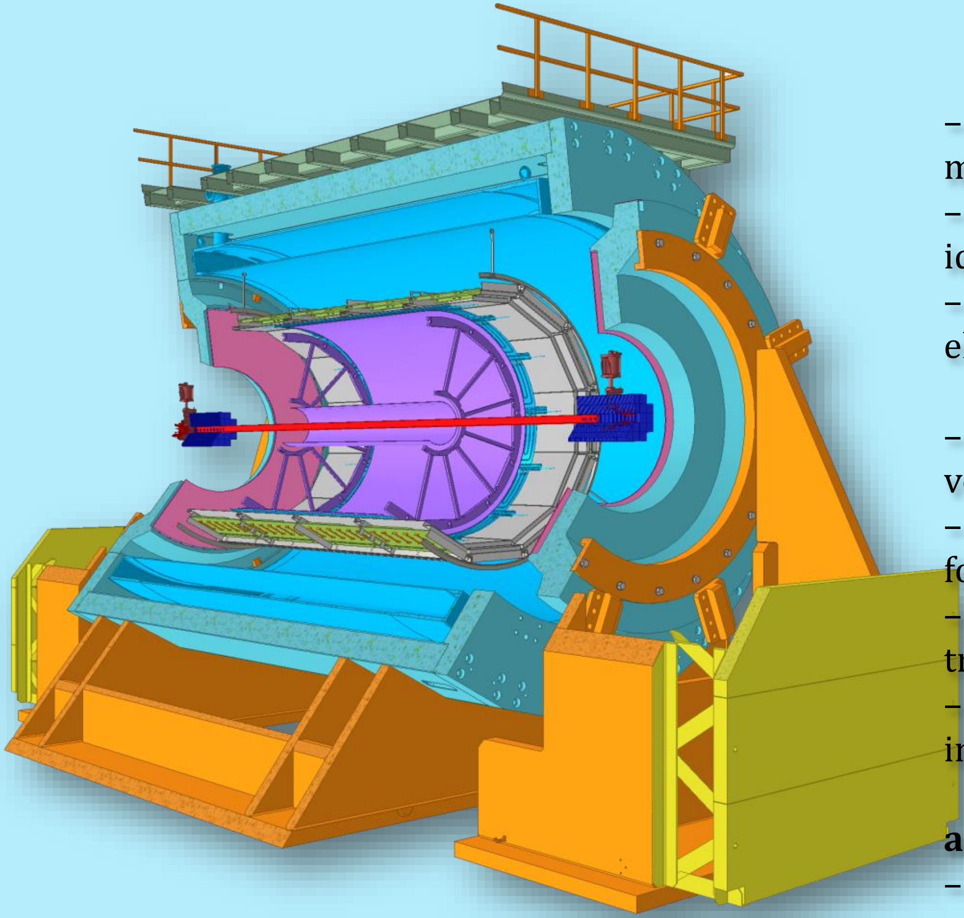
Software developers

Physicists

Mechanical design of the TOF barrel



MPD setup design



The main systems of the MPD detector:

1. Particles Identification (PID) system:

– Time Projection Chamber (**TPC**) is measure momentum and *dE/dx* of charged particles;
– Time of Flight (**TOF**) for charged particles identification by time-of-flight;
– Electromagnetic Calorimeter (**ECal**) to identify electrons and photons and measure their energy.

2. Tracking system:

– Inner Tracker (**IT**) provide precise tracking and vertex determination;
– Time Projection Chamber (**TPC**) is the main device for tracking;
– Endcap Straw Tracker (**ECT**) and (**CPC**) are provide tracking for particles travailing in forward direction;
– **TOF** & **ECal** can used for additional tracking information.

3. Trigger system used for trigger definition, T0 and centrality determination:

– Fast Forward Detectors (**FD**);
– Zero Degree Calorimeters (**ZDC**).