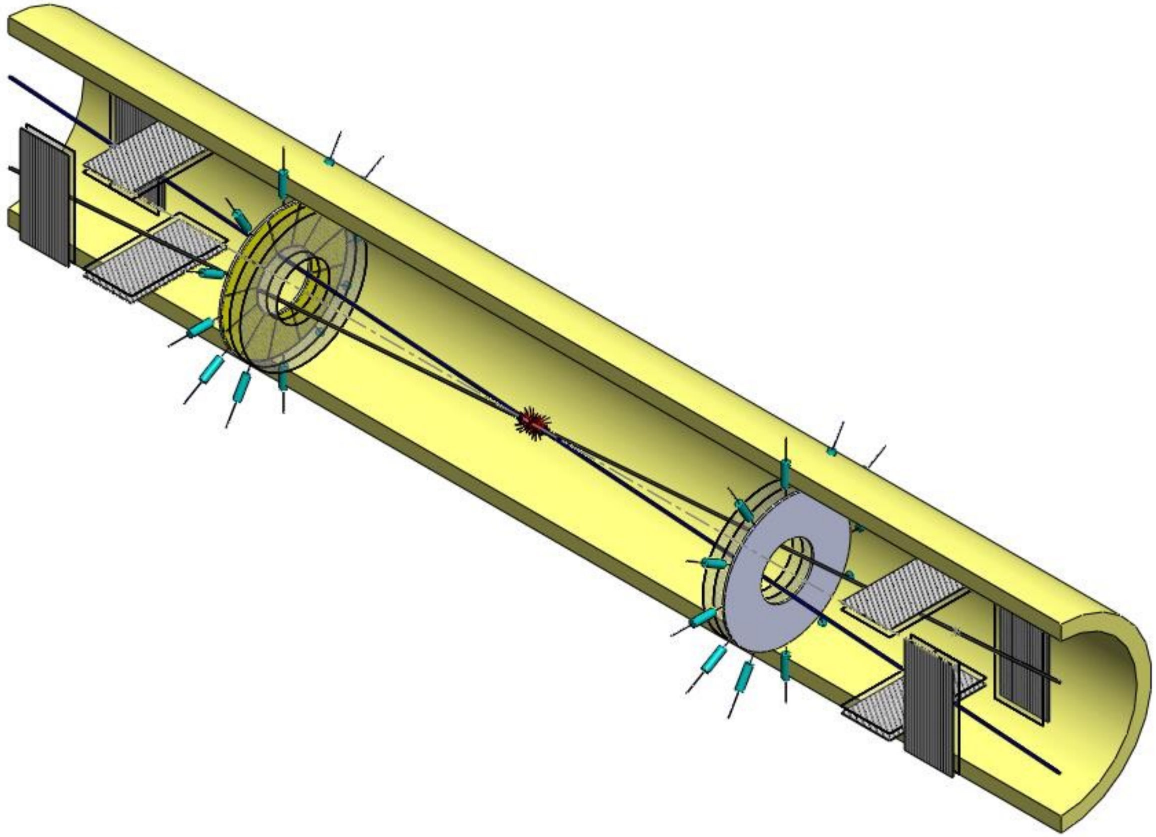


Fast Beam-Beam Collisions Monitor for experiments at NICA

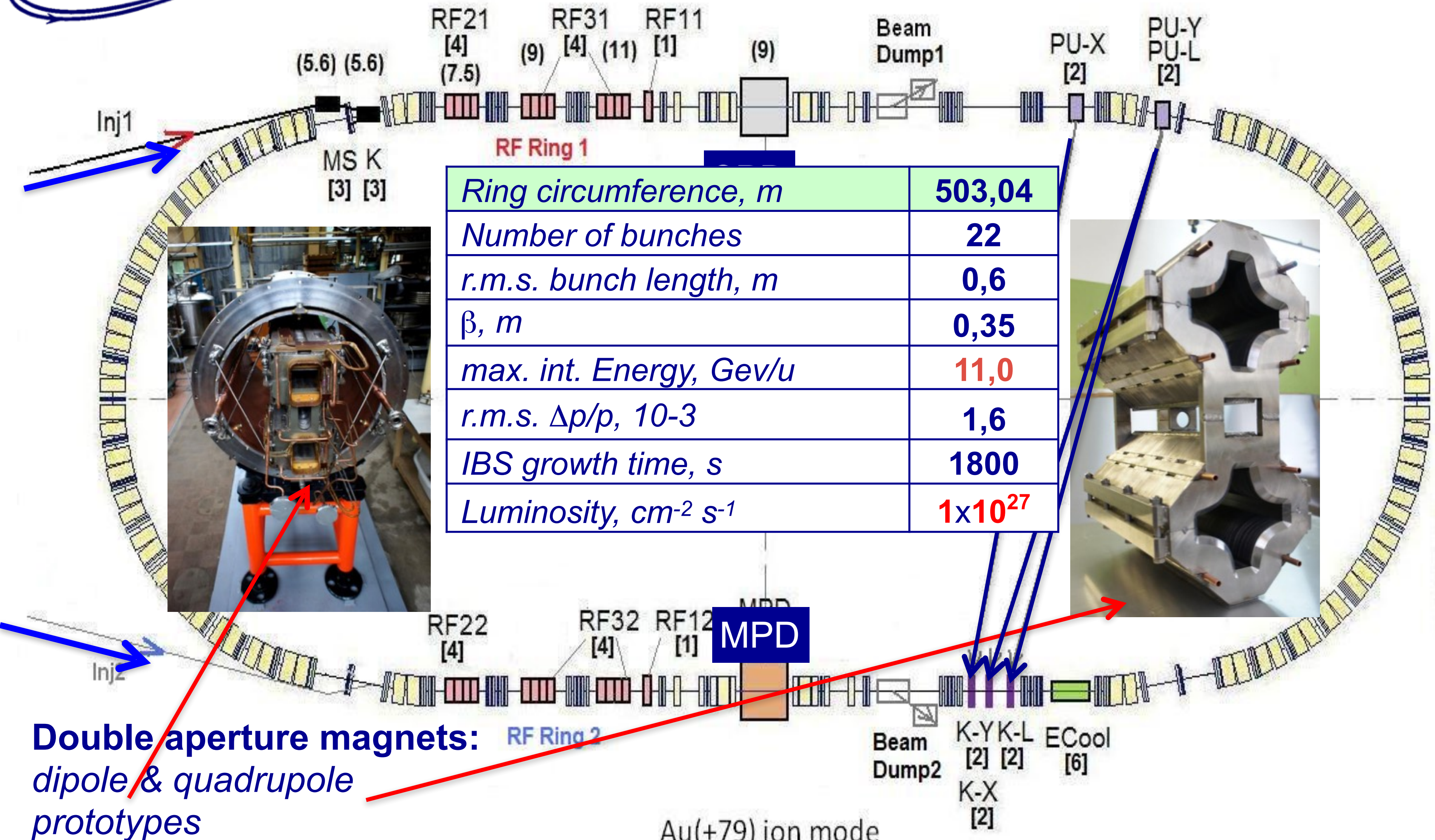
A.A. Baldin (1), G.A.Feofilov*(2), P.Har'yuzov (1), F.F.Valiev (2)
(1) JINR and Institute for Advanced Studies "OMEGA", Dubna, RF
(2) V.Fock Institute for Physics, Laboratory of Ultra-High Energy Physics, Saint-Petersburg State University

Reported by Anton Baldin at the SPD meeting, Thursday, 21.04..2022

*Job is supported by RFBR grant #***18-02-40097-мега**

The Collider

45 T*m, *4.5 GeV/u for* ***Au^{79+}***



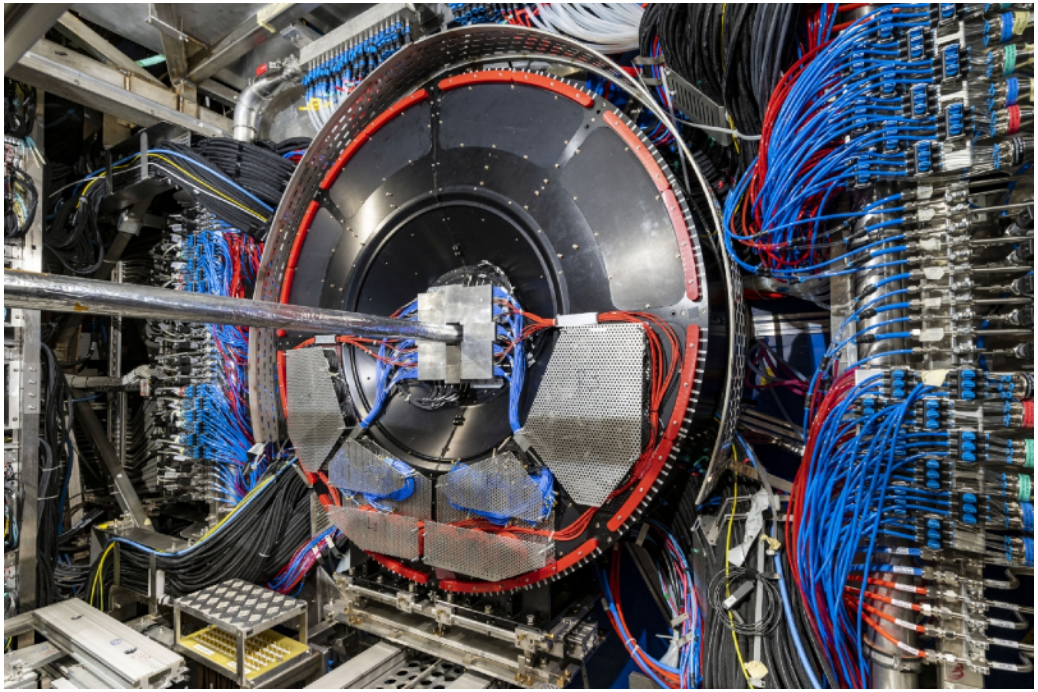
Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
β, m	**0,35**
max. int. Energy, Gev/u	**11,0**
r.m.s. Δp/p, 10-3	**1,6**
IBS growth time, s	**1800**
Luminosity, $cm^{-2}\ s^{-1}$	**$1x10^{27}$**

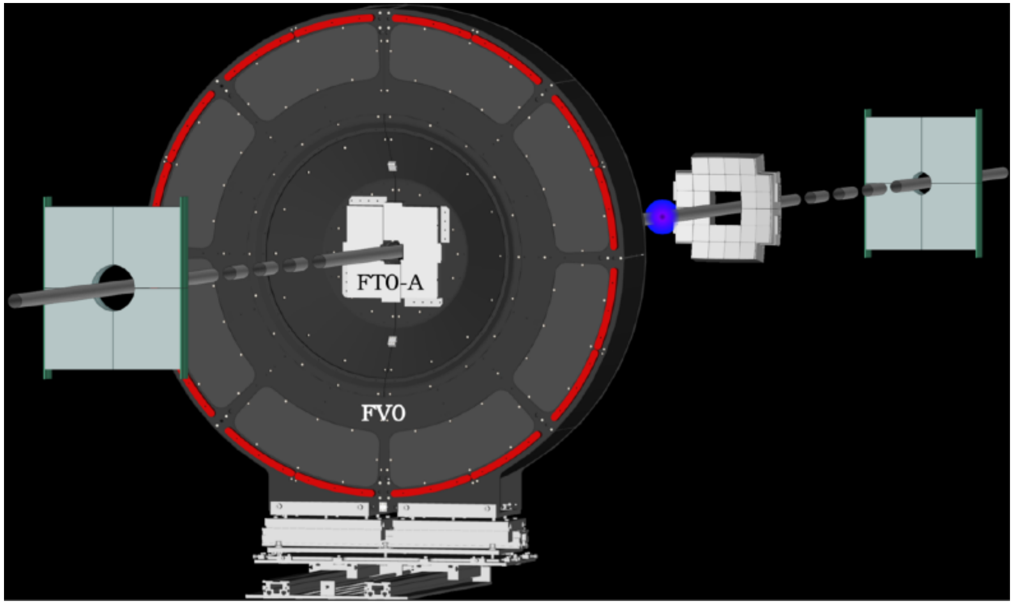
Double aperture magnets:
dipole & quadrupole prototypes

[1] http://nica.jinr.ru/projects/collider.php

The new ALICE Fast Interaction Trigger

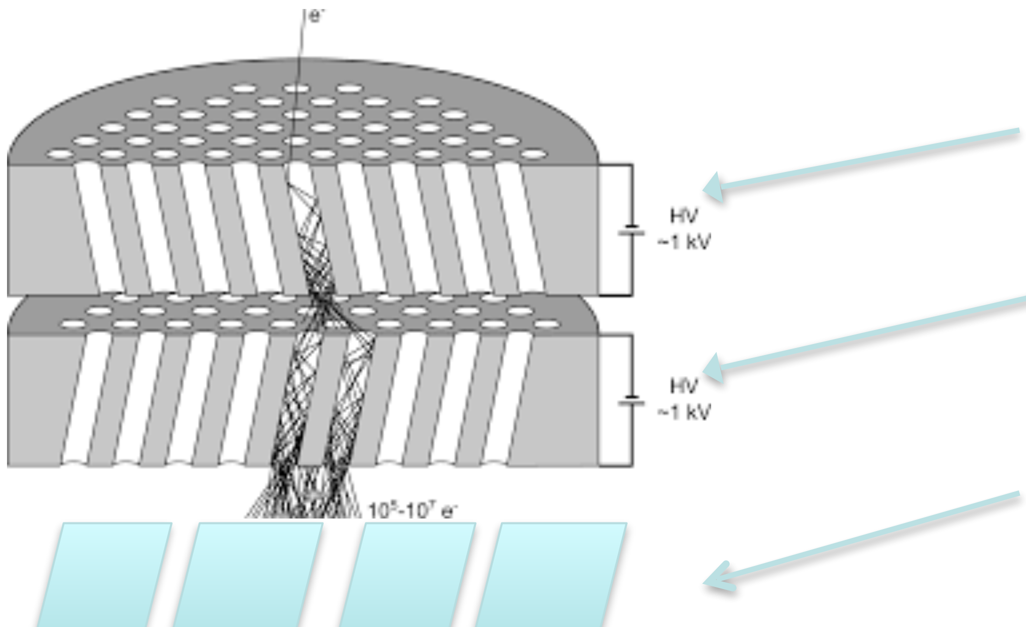
Wladyslaw H. Trzaska (Project Leader of ALICE FIT detector) 23rd Sep 2021





Fast Interaction Trigger (FIT):
FT0. The FT0 comprises two modular Cherenkov detector arrays located on both sides of the interaction point: FT0-A and FT0-C. The FT0-A is composed of 24 modules and the FT0-C of 28. Each module has a Microchannel Plate Photomultiplier Tube (MCP-PMT) photosensor (PLANACON® XP85002/FIT-Q), optically coupled to 4 quartz radiators. The MCP-PMT anode is also divided into 4 matching sectors so that each module delivers 4 independent readout channels/pixels.

Micro Channel Plates (MCPs) as a MIP detector [1,2]



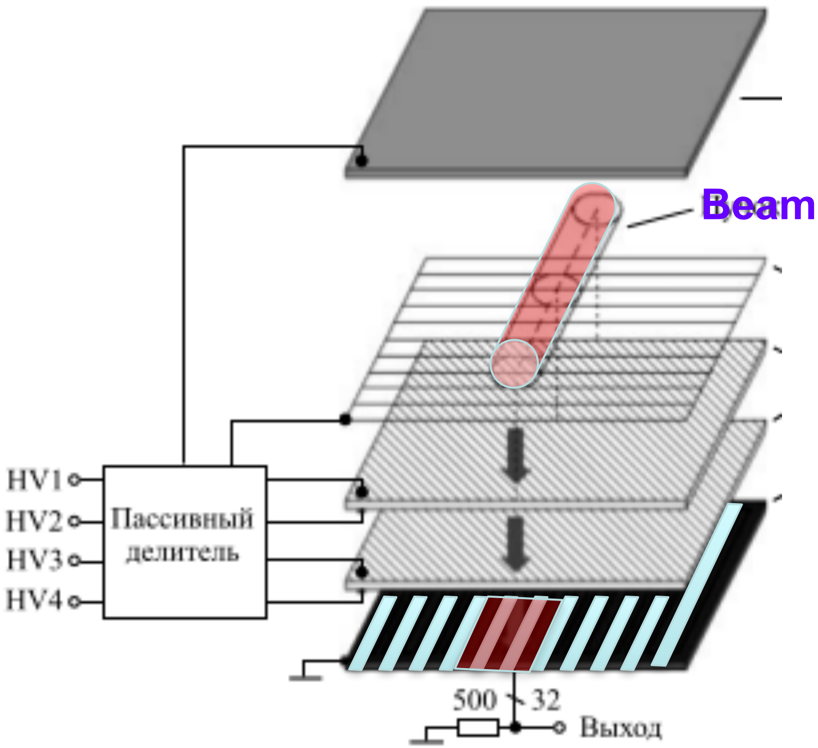
Active target-converter

MCP-Amplifier

Readout anodes

[1]A.Baldin,G.Feofilov,F.F.Valiev et al.
Microchannel plates as a detector for 800 MeV/c charged pions
and protons. // JINR Rapid Communications. 1991. No 4/50/-91. p.27-36.
[2] A.A.Baldin, G.Feofilov,Yu.Gavrilov, A.Tsvinev,F.Valiev,
Proposals for a new type of microchannel-plate-based vertex detector// NIM A32
1992. p. 439-444.

Beam Position Monitor (BPM) [1].



Anode

Gating grid

MCP-1
MCP-2

Strip readout

[1] A.Baldin, A.Berlev, I.Kudashkin, A.Fedorov, Letters to ECHAIA, 2014, vol.11, №2 (186), p.209-218

Layout

- ➢ MicroChannel Plate (MCP) for BBC- Conceptual ideas
- ➢ General requirements to functionality of the beam-beam collisions monitoring at NICA
- ➢ MCP-based solutions for
  - Beam Position Monitor (BPM) and
  - Fast Beam-Beam Collisions counters (FBBC) for NICA
- ➢ First test results and prototyping
- ➢ Some plans

General requirements to functionality of the beam-beam collisions monitoring at NICA

1) To provide the event-by-event measurements of:
   - ➢beam location
   - ➢3D-beam profile (2 dimensional + time structure)
   - ➢luminosity monitoring

2) Additional functionality in determination of:
   - ➢the reaction plane
   - ➢the multiplicity class relevant to the event centrality in nucleus-nucleus collisions
   - ➢T0 --the collision time
   - ➢Location of the Interaction Point (IP)
   - ➢Possible application in local polarimetry

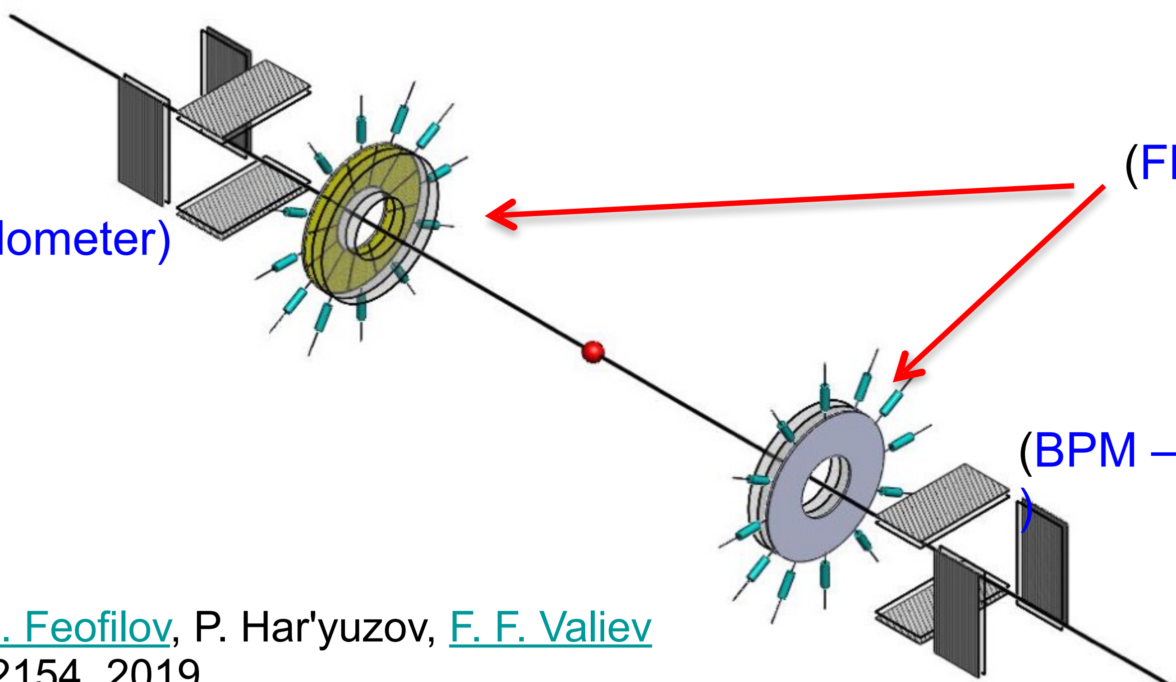
Two compact detector systems are proposed to meet the challenges of the fast beam-beam collisions monitoring, event selection and the precise timing determination in proton-proton and nucleus-nucleus collisions at NICA. Beam Position Monitor (BPM or *Profilometer*) and Fast Beam-Beam Collision (FBBC) monitor are capable to provide the information for each bunch crossing both on the beams location and on the intensity of collisions, as well as on the azimuthal distribution of the particles in the event.

The systems use fast Micro Channel Plate detectors (MCPs). The ultra-high vacuum (UHV) compatibility and low-mass compact design of the BPM and FBBC components allow one to consider their application inside the vacuum beam line of the NICA collider. The BPM is based on the effect of the residual gas ionization and provides high accuracy, fast, bunch-by-bunch measurements of the beam position. FBBC uses the concept of the fast isochronous timing for the multi-pad readout of short (~ 1ns) MCP signals, produced by the particles in the collisions of the beams. Studies of the polarization phenomena in light- and heavy-ion interactions at SPD NICA is one of the goals of research at NICA, and FBBC is also considered for the local polarimetry at SPD.

Two configurations are possible: BBC MCP can be installed either in the vacuum volume of the collider chamber or beyond the vacuum beam line in a special vacuumed box. In the case of MCP position out of the collider vacuum volume, the service and replacement of detector elements will be simplified. In this case it is possible to manufacture specialized PEMs with given pad size and geometry for signal readout at VTC “Baspik”.

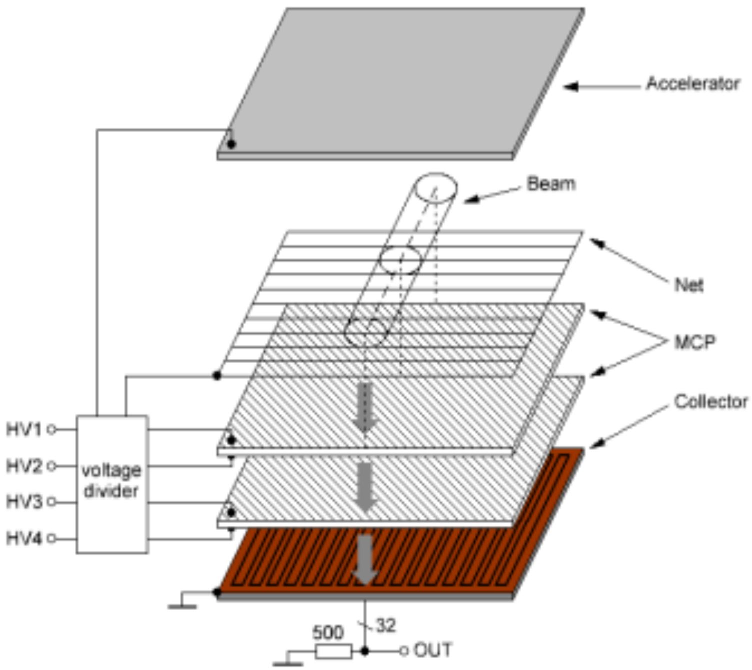
Fast beam–beam collisions monitor for experiments at NICA

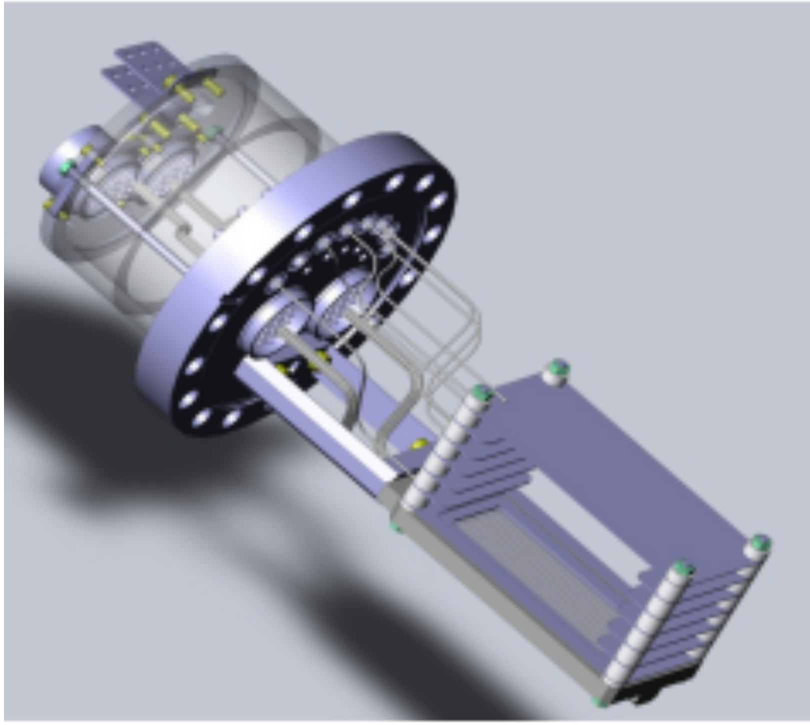
(1) Fast monitoring of the beam position and profile (BPM - Profilometer)
(2) The event-by-event fast monitoring of beam-beam collisions (FBBC)



A. Baldin, G. A. Feofilov, P. Har'yuzov, F. F. Valiev
NIMA, 958, 162154, 2019
Reported at the VCI2019
DOI:10.1016/j.nima.2019.04.108..

Profilometer
at the NUCLOTRON





MCP-based device for fast monitoring of the beam profile (BPM) at the NUCLOTRON [1]

[1] A.Baldin, A.Berlev, I.Kudashkin, A.Fedorov, Space-time characteristics of the circulating beams, Letters to ECHAIA, 2014, vol.11, №2 (186), p.209-218

Profilometer

The question of high vacuum compatibility of MCP based detectors was answered positively during the latest Booster and Nuclotron run in January, 2022. The two-coordinate profilometer based on MCPs was used to monitor the time evolution of the circulating C beam profile and intensity.

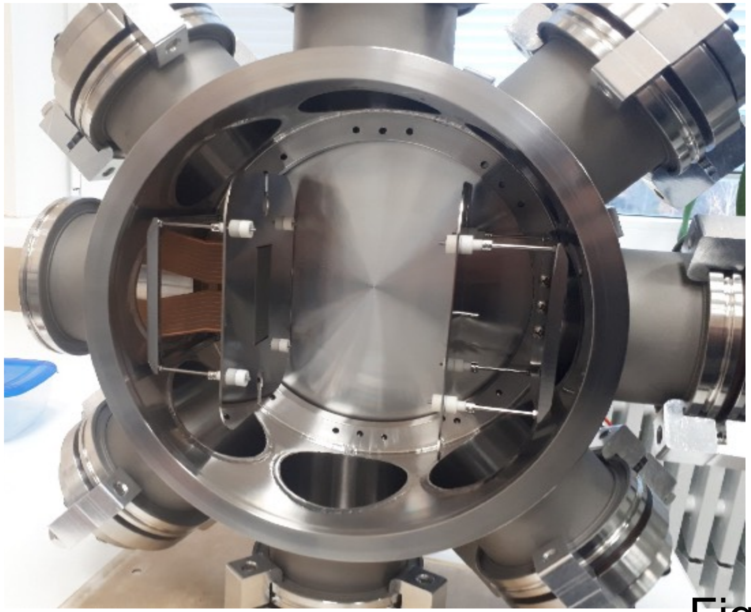


Figure___. Photo of the prototype BBC MCP mounted in a high vacuum chamber.

The profilometer proved capable of operating in ultrahigh vacuum of the beam line and provide information on the circulating beam during the whole cycle from injection into the Booster to transmission into Nuclotron, thus proving that all the applied materials and technologies are appropriate for manufacturing detectors for the NICA collider.

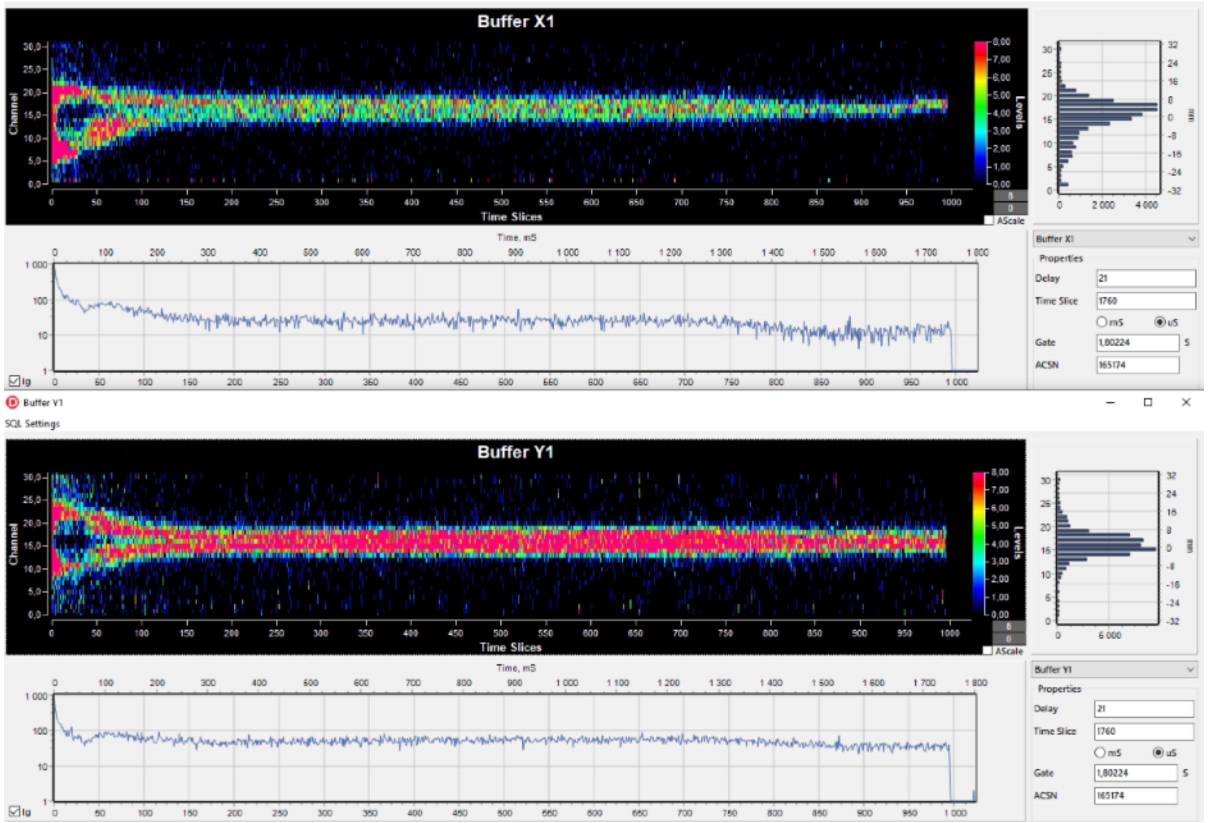


Figure 8 shows an example of C beam acceleration in the Booster from injection to transmission into Nuclotron (a total time of about 1.5 s).

Testing of the prototype MCP detectors for SPD at NICA

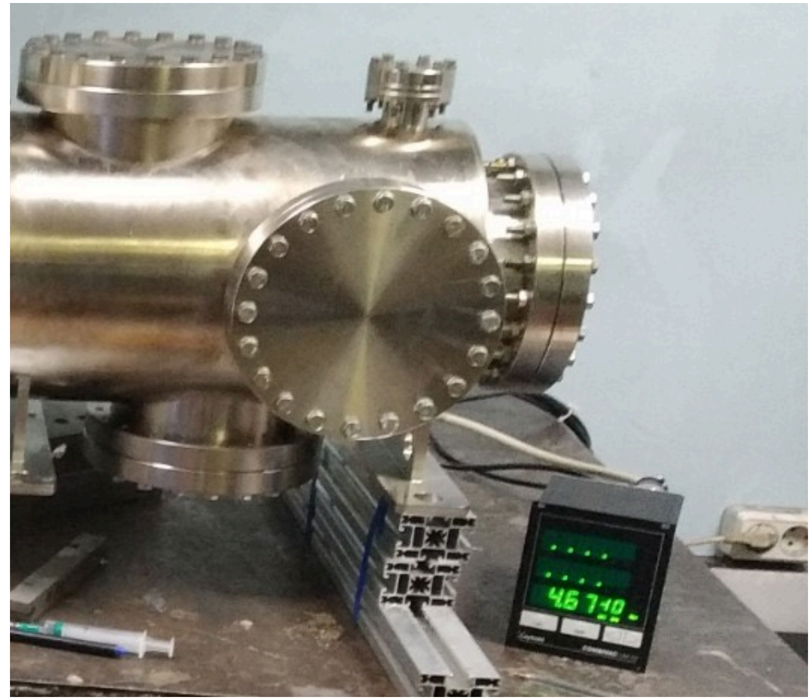
Testing of the prototype MCP detectors for SPD BBC

In 2020% Testing was performed using the system of dynamic diagnostics of the Booster and Nuclotron circulating beams, as well as HILAC beams of the accelerator complex NICA. The objective was to measure the loading characteristics of chevron MCPs with pad-wise signal readout, similar to the design to be implemented in BBC MCP. Signals and loading characteristics of chevron MCP based on PEM TOPAS and PEM SAPFIR were also measured.

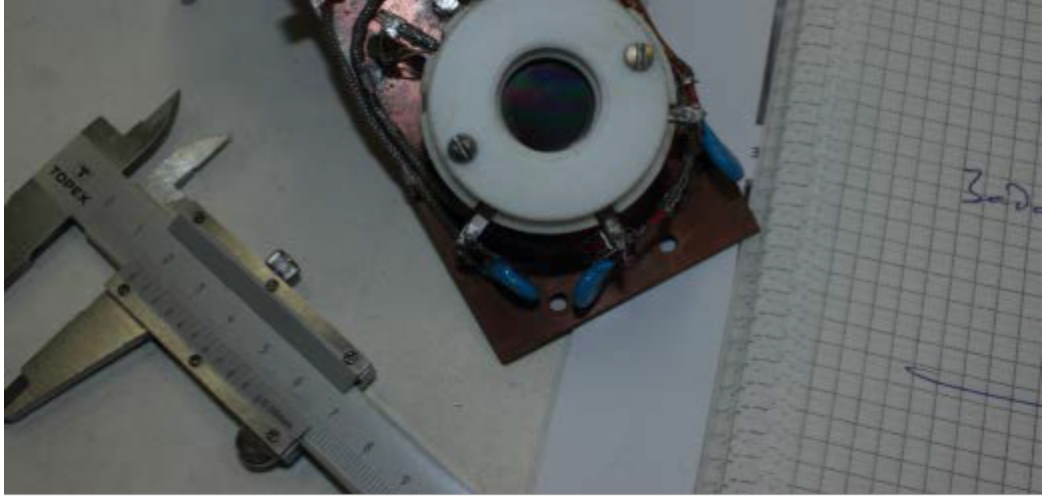
All microchannel plates were manufactured by VTC “Baspik” (Vladikavkaz, Russia). Plates of the following size were chosen for testing: 40×60 mm, 54×54 mm, and circular plates with diameters of 18 mm and 25 mm. The tested plates had different MCP channel diameters: 6, 8, and 12 mkm, and different resistivity in a range from 100 MOhm to 1 GOhm. Signals with a duration not larger than 4 ns and a front of 0.5-1 ns were obtained for all MCP assemblies. Such signals provide a detector time resolution of at least 50 ps.

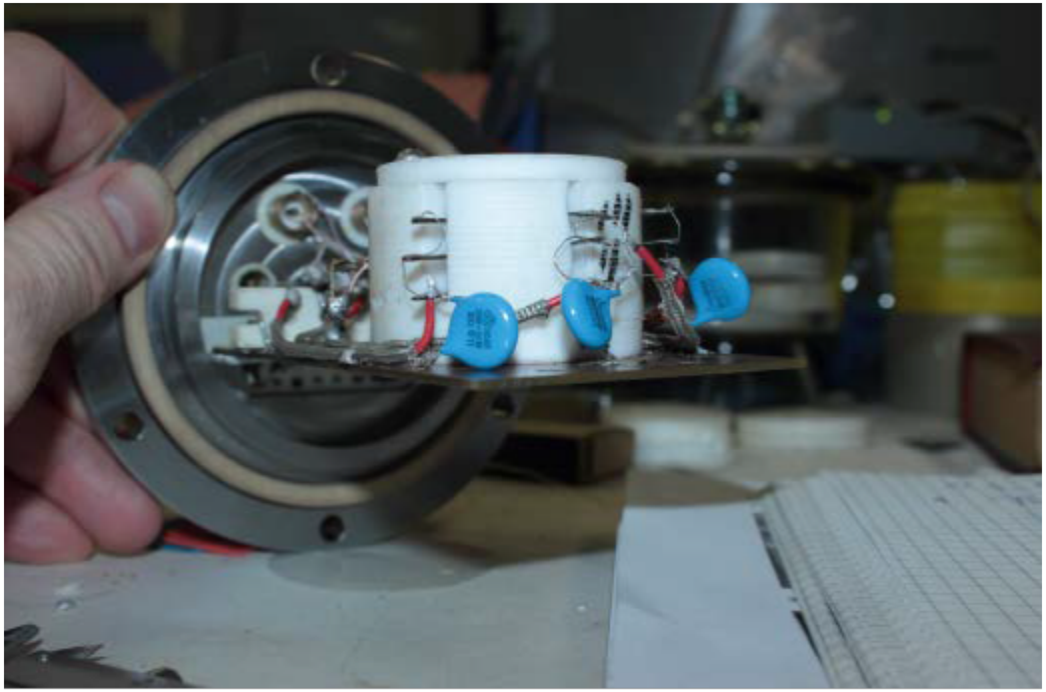
A specialized portable vacuum chamber with thin (50 mkm) Ti windows was manufactured for investigation of particle registration efficiency by chevron MCPs in the case of particles with minimum ionizing power; two independent prototypes of MCP detectors can be installed in this vacuum chamber. It is planned to perform full-scale testing of registration efficiency, time resolution, and loading characteristics of such detectors at extracted beams of Nuclotron and electron beams of the linear accelerator LINAC-200 (LNP JINR).

Figure
shows the photo of the specialized vacuum chamber and its flanges.



Вакуумные испытания камеры с прогревом.
Достигнут вакуум $5*10^{-10}$ Торр


TOPEX



FBBC developments

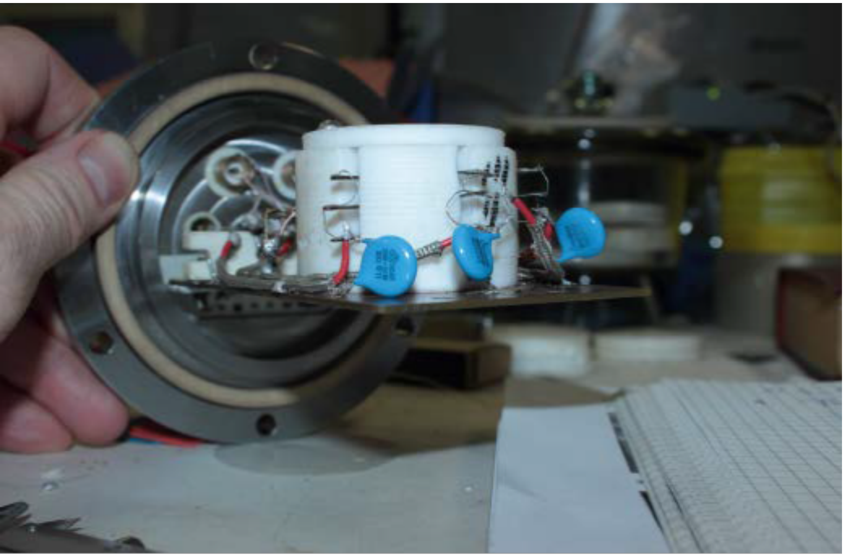


Рис.20. Фотография конструктива для трех детекторов, содержащих по два МКП в шевронной сборке

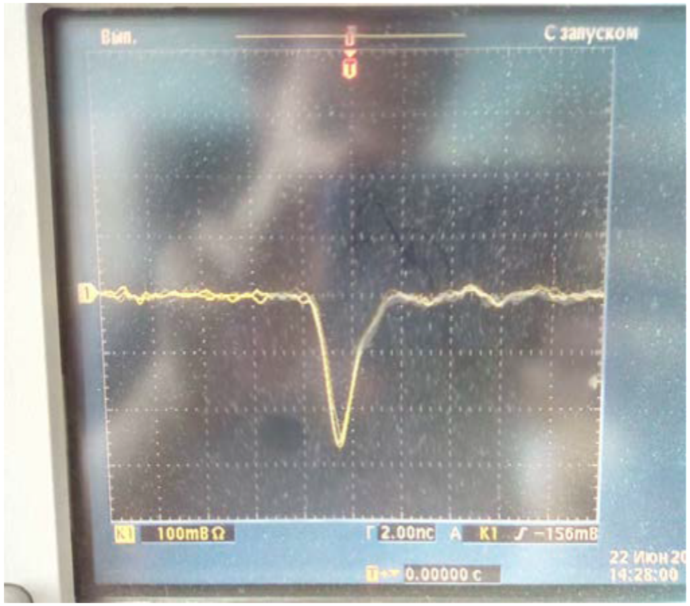


Рис.21. Формы импульсов с детекторов, Напряжение на сборке МКП равно 1.8 кВ. Площадь съемника равна 0.25 см2. Фронт сигнала <1 нсек , амплитуда 300 мВ

FBBC developments: electronics

В результате тестирования детекторов на МКП с разными системами
съема информации для дальнейшего применения
выбран дифференциальный согласованный тракт.
Как уже говорилось выше, такой выбор связан с меньшей чувствительности
к СВЧ наводкам на водные тракты быстрой электроники съема сигналов с МКП.

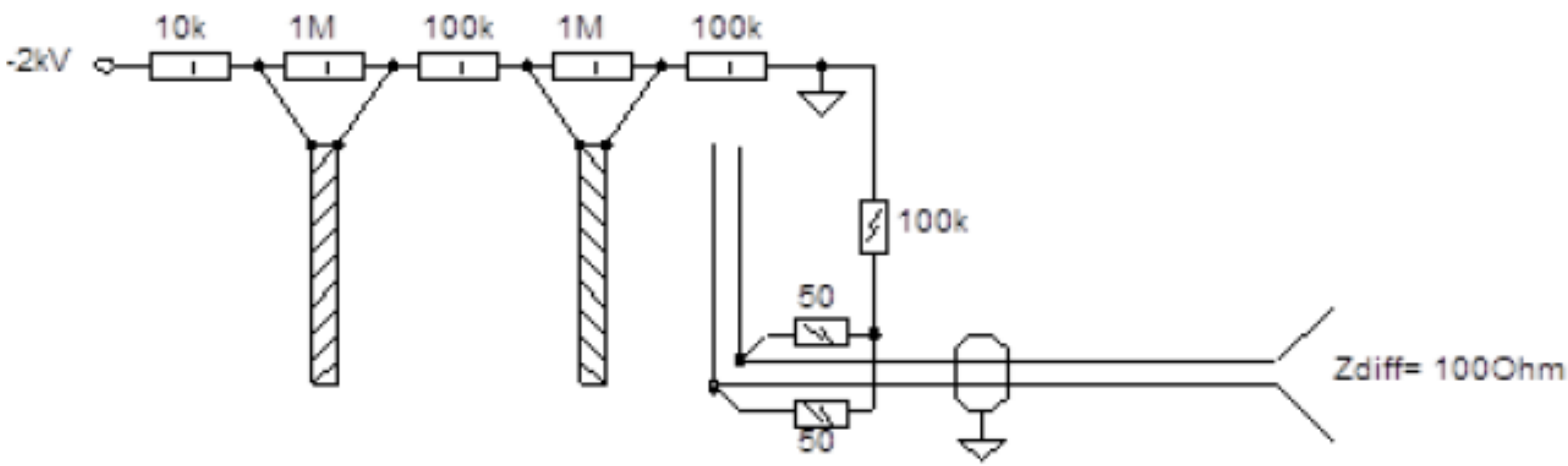


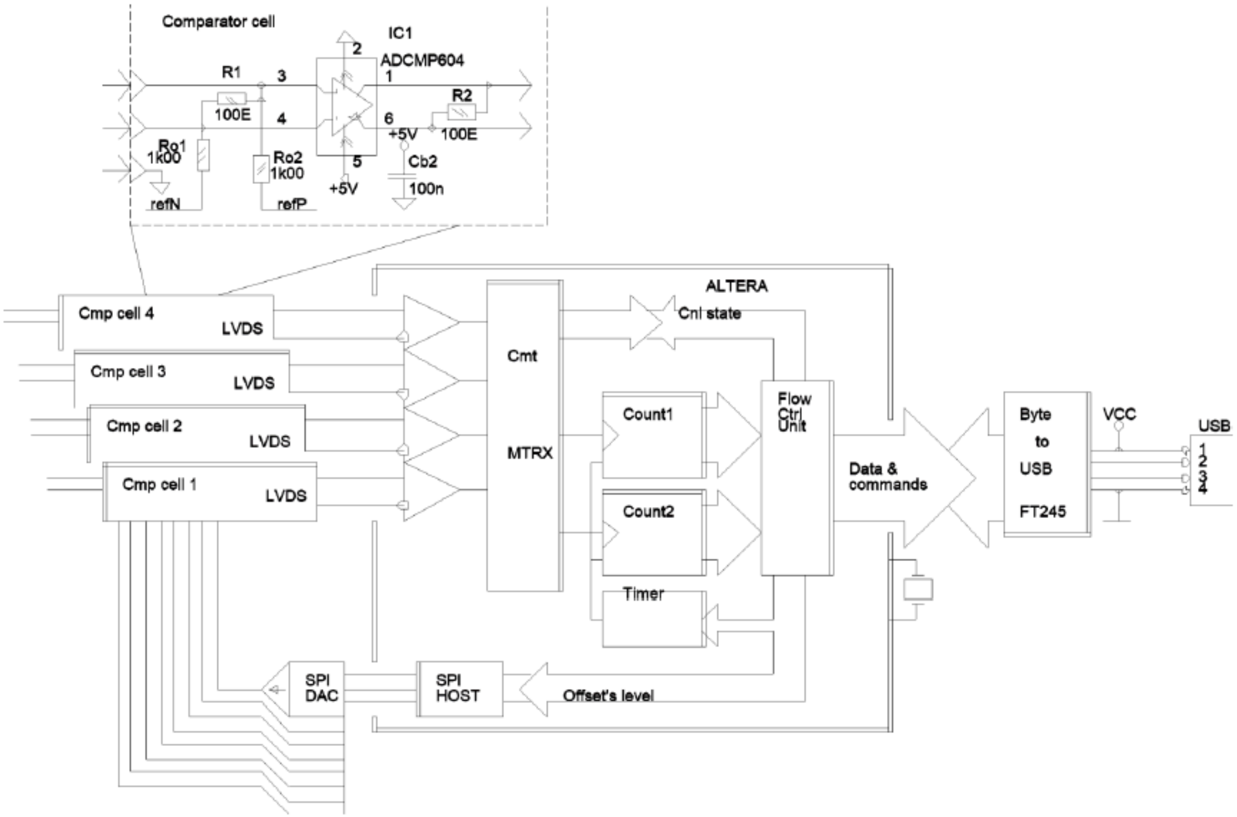
Рис._27. Схема шевронной сборки детектора на МКП с дифференциальным съемом сигнала.

Для сборки телескопа из нескольких детекторов разработаны и изготовлены 3 детектора на МКП. Проверка работоспособности детекторов была проведена на альфа-частицах и космических мюонах. Создан механический конструктив для детекторов с возможностью установки в него от одного до трех детекторов, содержащих от одного до трех МКП каждый.

Данный конструктив обеспечивает быстрый фронт нарастания сигнала (лучше 0.8 нс) и большую амплитуду (несколько сотен мВ). Изучены формы импульсов с детекторов, собранных в СПбГУ.

В детекторах для регистрации сигнала **использовались классический и дифференциальный согласованные вводы.** Испытания детекторов на МКП со съемниками на керамике в классическом исполнении были проведены ранее в ЛВЭ ОИЯИ . Ввиду высокой чувствительности электроники с классической системой съема информации возможна регистрация сверхвысокочастотных внешних наводок. С целью уменьшения внешних наводок на входные тракты регистрирующей электроники сигналов с МКП детекторов на данном этапе **предложен и испытан дифференциальный согласованный тракт.** Кроме того для увеличения амплитуды сигналов с МКП детекторов были изменены съемники сигналов. В результате оптимизации съемников удалось увеличить амплитуду сигналов до нескольких сотен мВ.

FBBC developments: electronics



Блок схема быстрой электроники и подробная схема одного канала регистрации

FBBC developments: electronics

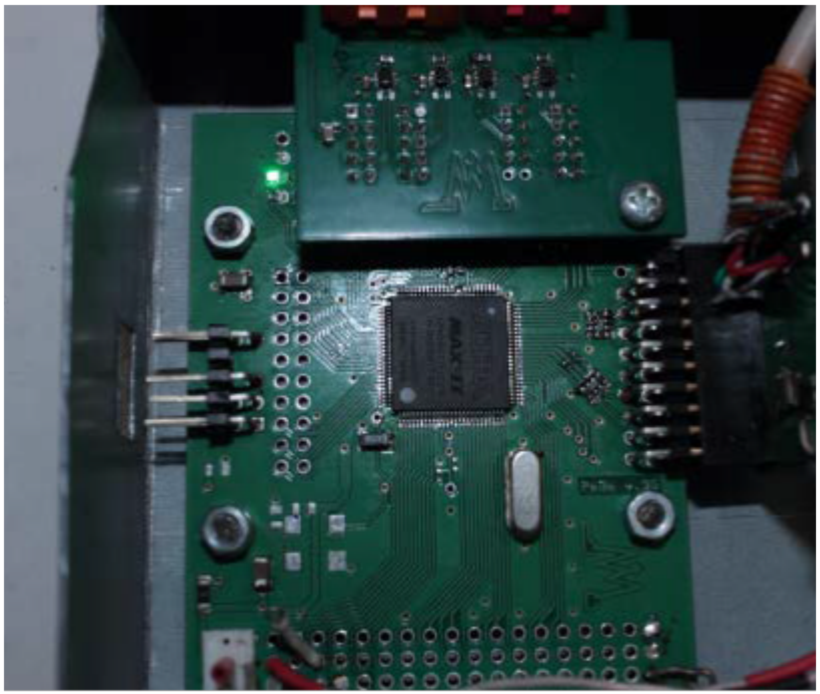
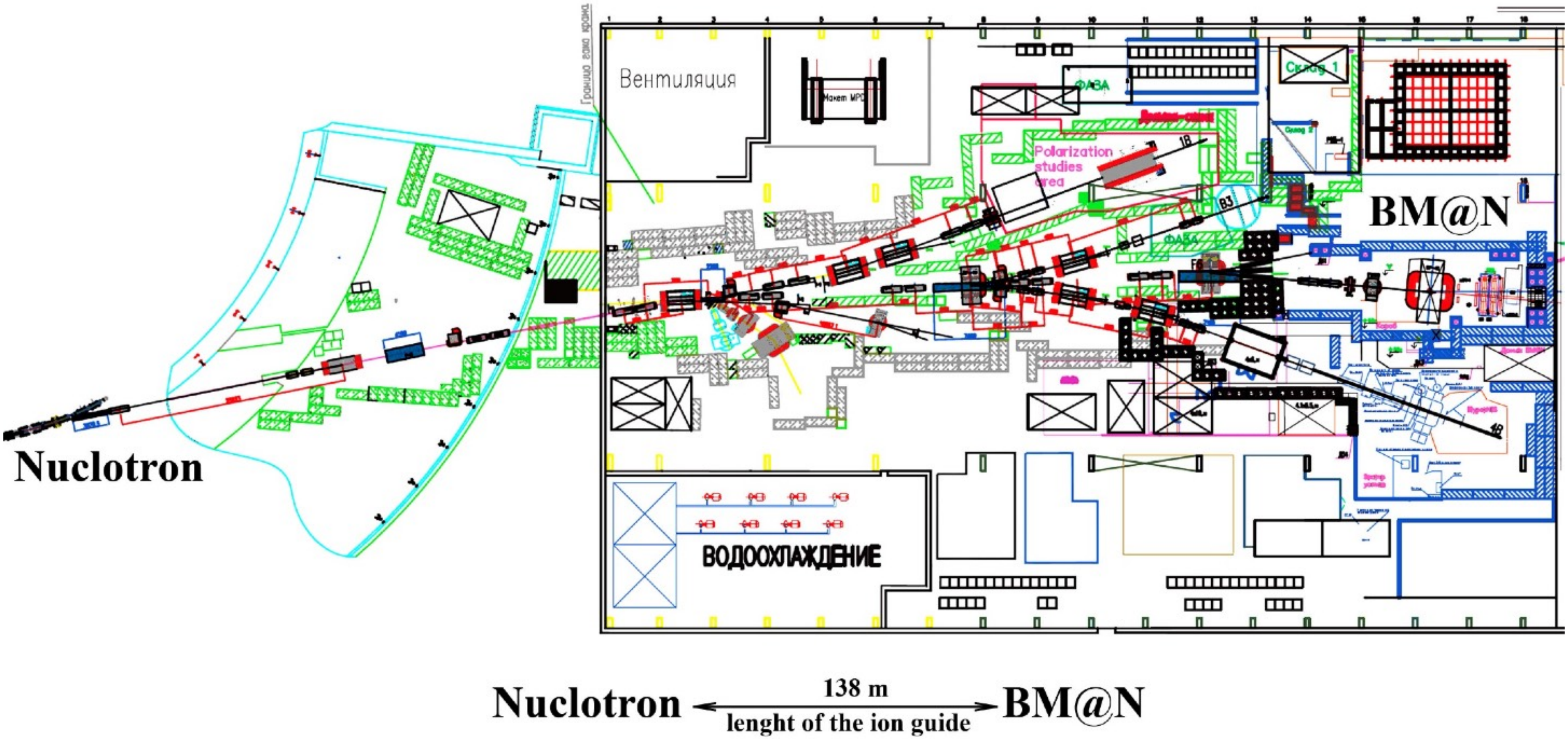


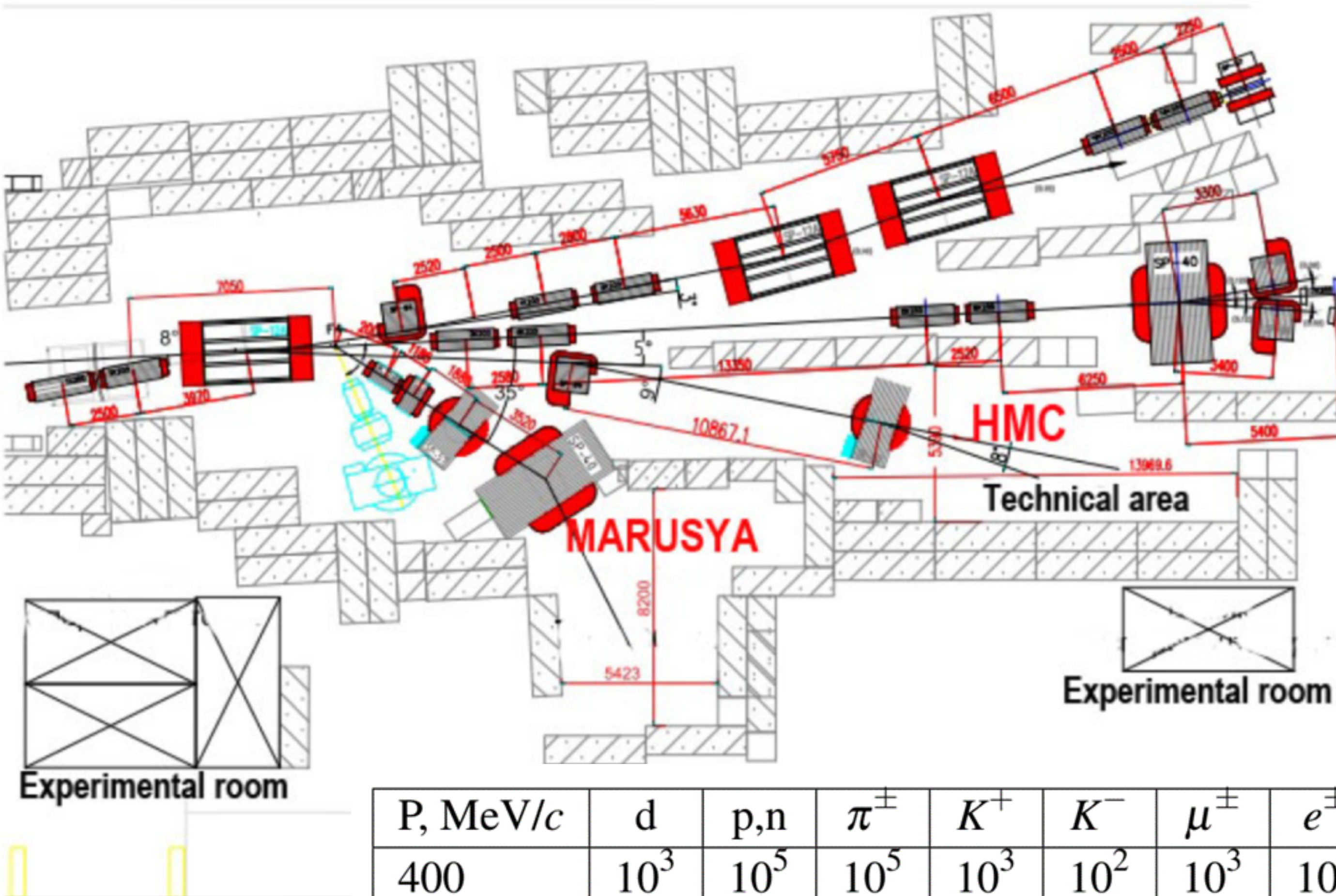
Рис.29. Модуль четырехканальной электроники с дифференциальными входами для проведения временных измерений.

Рис.34. Фотография устройства двухканального модуля быстрой электроники.

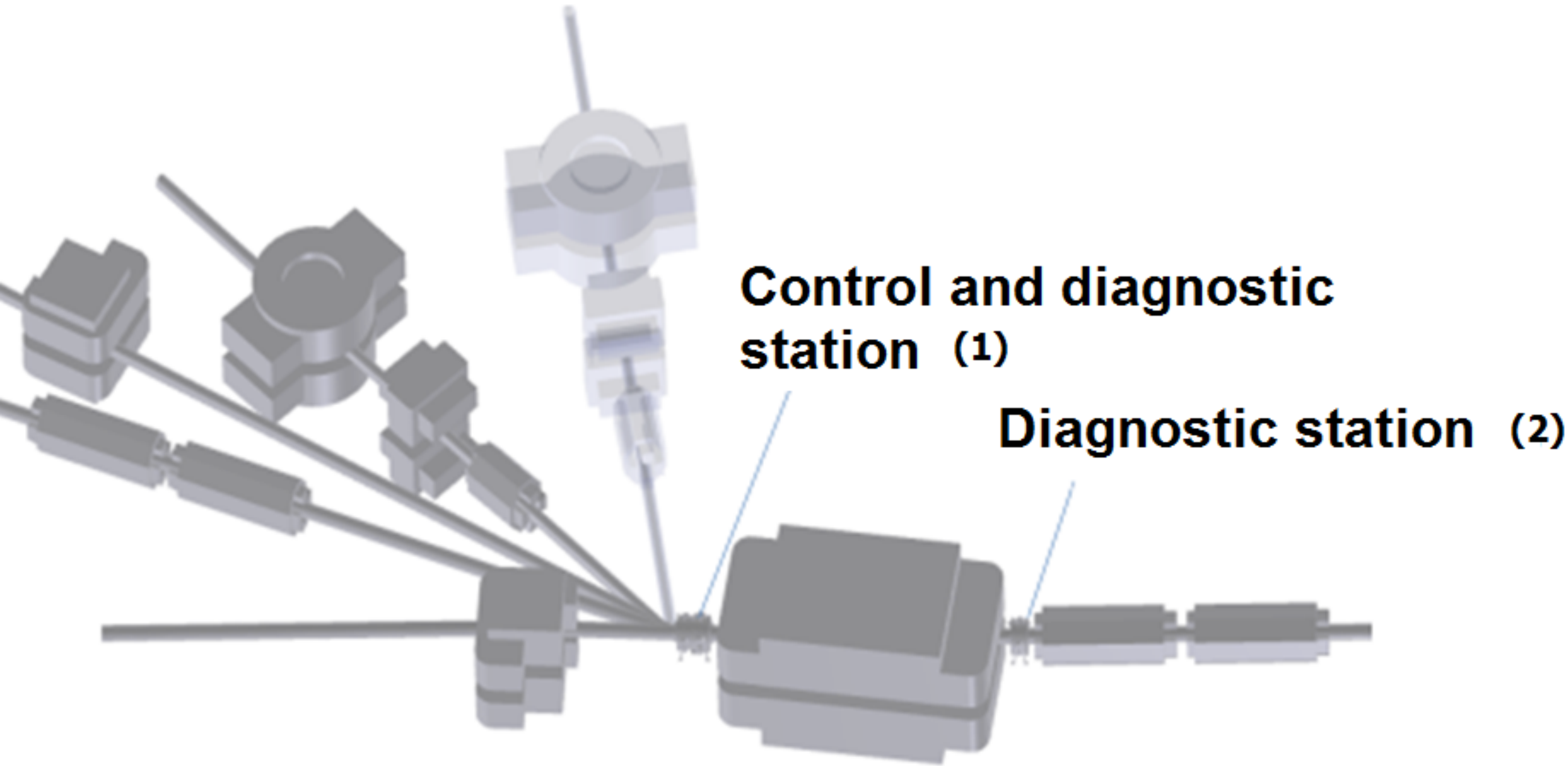


Вентиляция
Макет MPD
ФАЗА
Склад 1
Polarization studies area
1В
В3
4В
BM@N
Nuclotron
ВОДООХЛАЖДЕНИЕ
Nuclotron
138 m
lenght of the ion guide
BM@N

Test beam facility at LHEP JINR
Experiment SPD

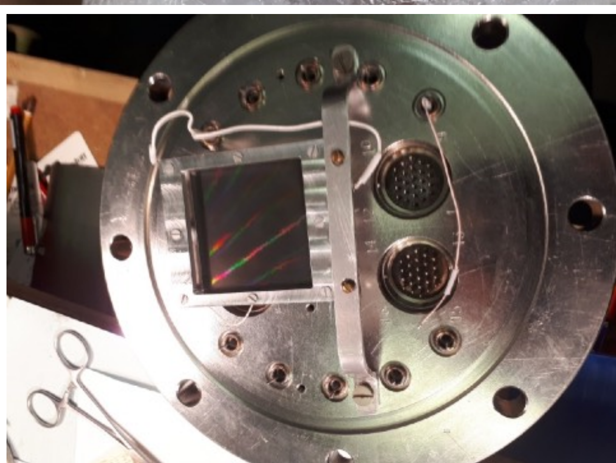


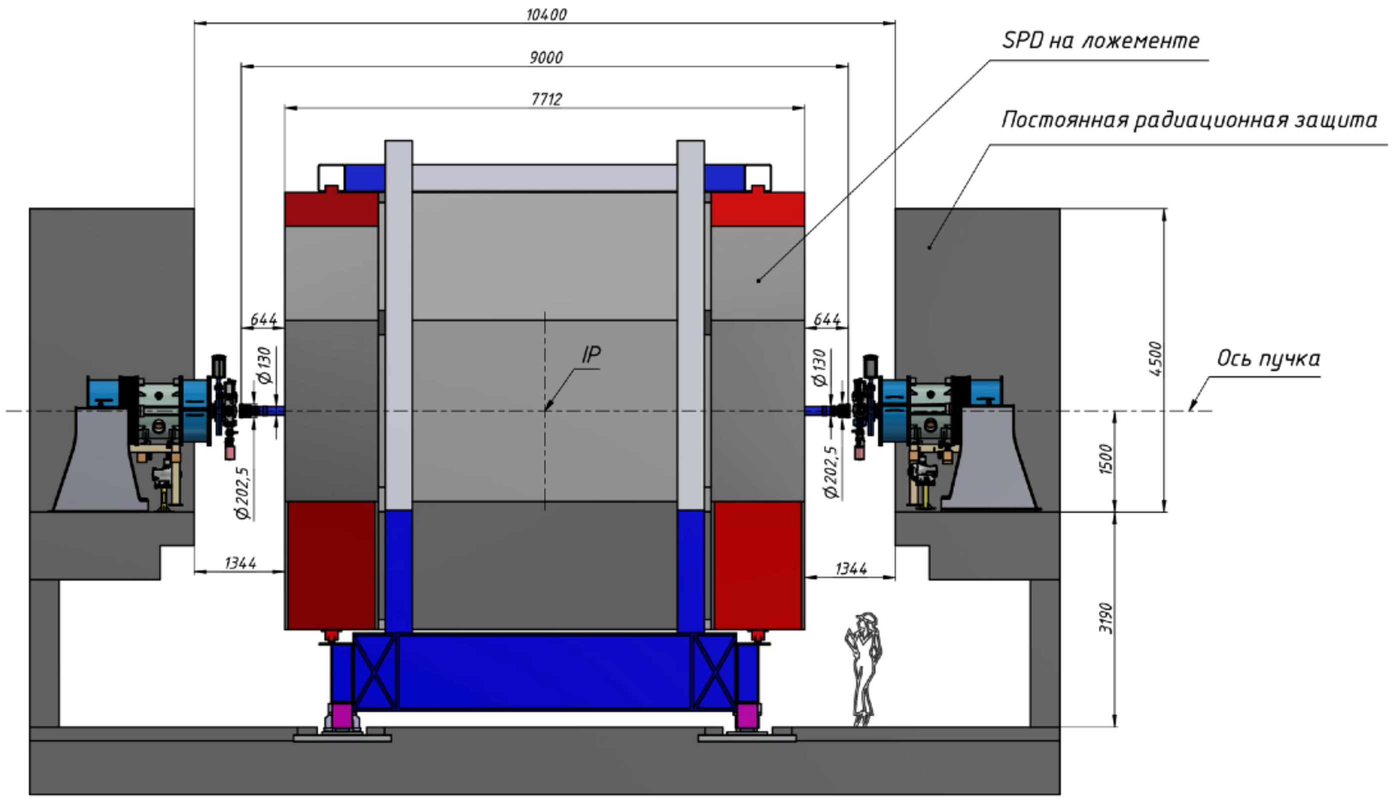
P, MeV/c	d	p,n	$\pi^{\pm}$	K^{+}	K^{-}	$\mu^{\pm}$	$e^{\pm}$
400	10^3	10^5	10^5	10^3	10^2	10^3	10^3
800	10^3	10^4	10^4	10^3	10^2	10^3	10^3
1500	10^2	10^4	10^4	10^3	10^2	10^2	10^2
2000	10^4	10^5	10^4	10^3	10^2	10^2	10^2
7000	10^4	10^6	10^3	10^3	10^2	10^2	10^2


Control and diagnostic station (1)
Diagnostic station (2)

SPD Test zone
Target station 2

BBC MCP Prototype




10400
9000
7712
SPD на ложементе
Постоянная радиационная защита
644
644
Ø 130
Ø 130
IP
Ось пучка
4500
Ø 202,5
Ø 202,5
1500
1344
1344
3190

FBBC developments

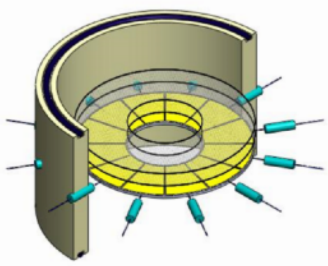
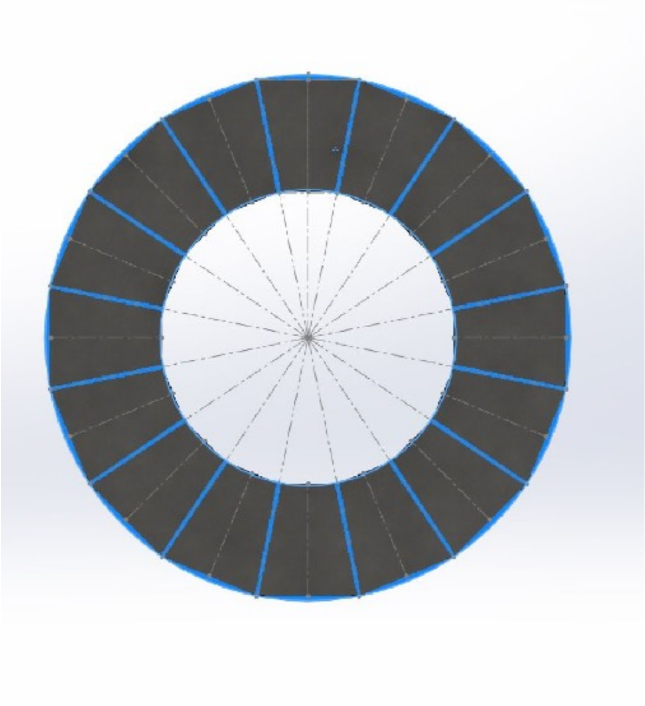
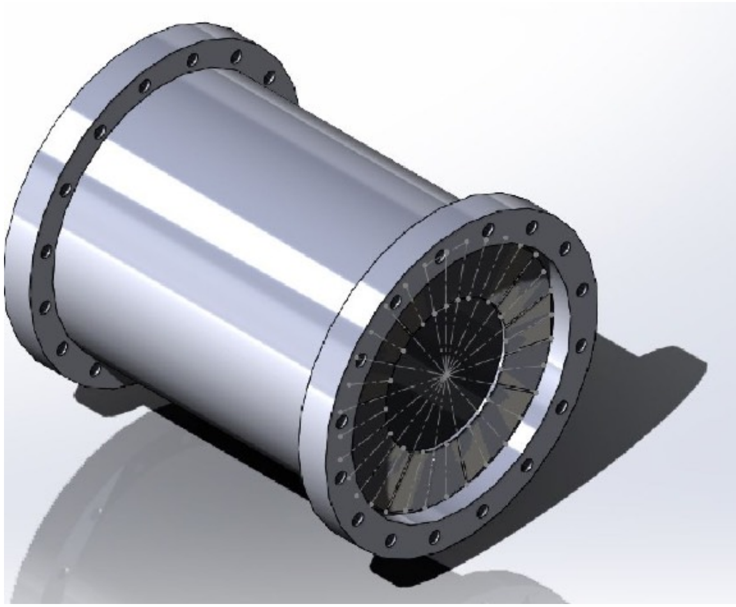


Figure : Compact module of the Fast Beam-Beam Collision Monitor (FBBC) based on the circular MCPs. Sector cathode readout pads and two MCP set-ups are embedded into a separate flange with hermetic 50 Ohm signal feedthroughs
and
HV feedthroughs (the last ones are not shown).

FBBC developments

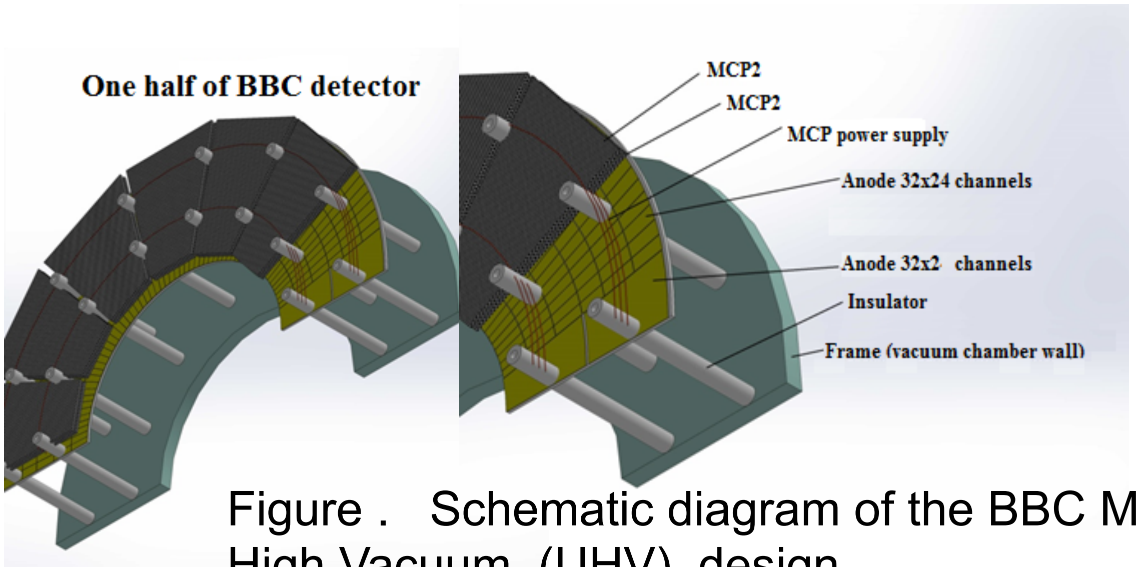


Figure . Schematic diagram of the BBC MCP detector in the Ultra-High Vacuum (UHV) design.

Рис._ Концептуальная схема кольцевого модуля детектора на МКП в высоковакуумном исполнении. Керамические элементы изоляторов обеспечивают общую конструкцию шевронной сборки системы МКП, многоанодная сегментированная платформа должна монтироваться внутри кольцевого фланца с сигнальными вакуумными выводами и высоковольтными вводами (на схеме не показаны)

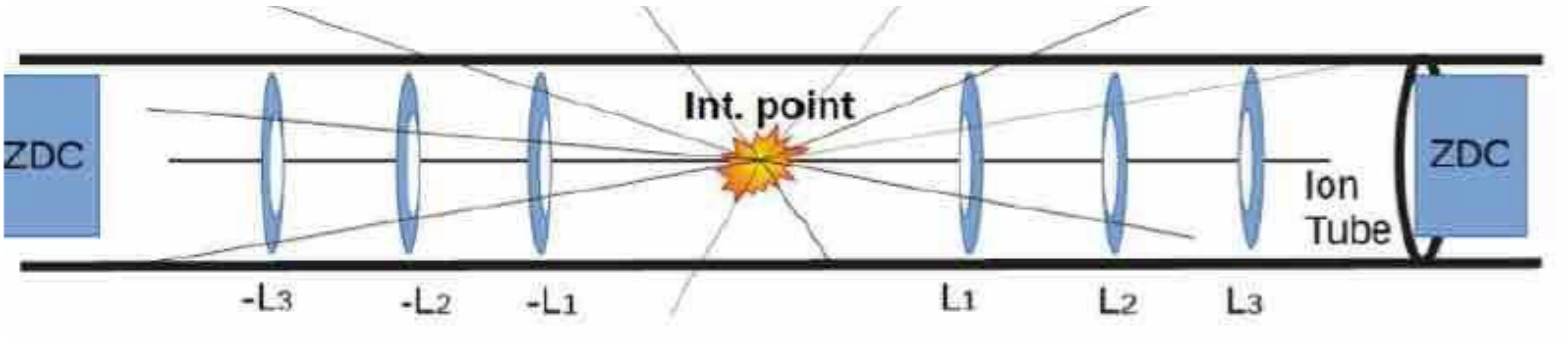
Software for data processing

An important part of experiment preparation at NICA SPD is the development of an adequate software for event reconstruction and analysis.

The possibility of application of MCP-based FBBC for determination of the coordinate Z (ion interaction point in an event) by the difference of the times of flight of particles from the symmetrically situated MCP detectors was studied numerically. The Monte Carlo event generator DQGSM was used. One million events of Au+Au collisions at $\sqrt{s}$=11 GeV were simulated. A special library FBBClib was applied. The efficiency of charged particle registration by MCP was taken equal to 90%, the time tagging precision was 50 ps. The Z coordinate of a vertex event was reconstructed using machine learning, in particular neural networks and the algorithm of gradient boosting on decision trees XGBoost. These methods of machine learning are widely used and have proved quite efficient. Learning samples included the following parameters: average times of particles arrival at separate MCPs, time of first particle arrival at separate MCPs, multiplicity of charged particles, ratios of multiplicities at separate MCPs and total event multiplicity. The neural network included 6 layers: the input layer, the normalization layer, three inner layers with the number of neurons equal to the number of parameters, one summing inner layer, and an output layer. The maximum decision tree depth in XGBoost was equal to 6. All possible detection configurations were considered with an ideal time resolution (σ = 0 ps) and a realistic time resolution (σ = 50 ps and 100 ps).

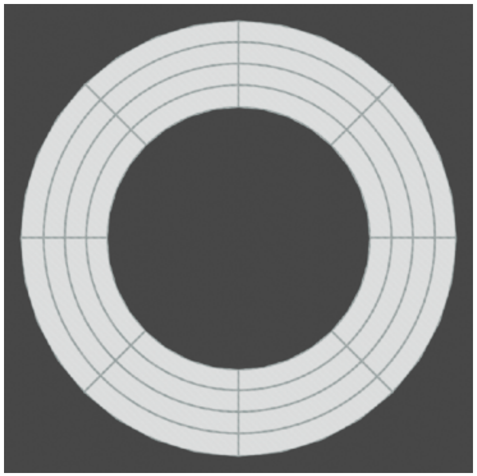
The numerical study showed that the root mean square deviation of event vertex coordinate is on a level of 7 mm and the maximum RMS does not exceed 12 mm even for MCP time resolution σ = 100 ps.

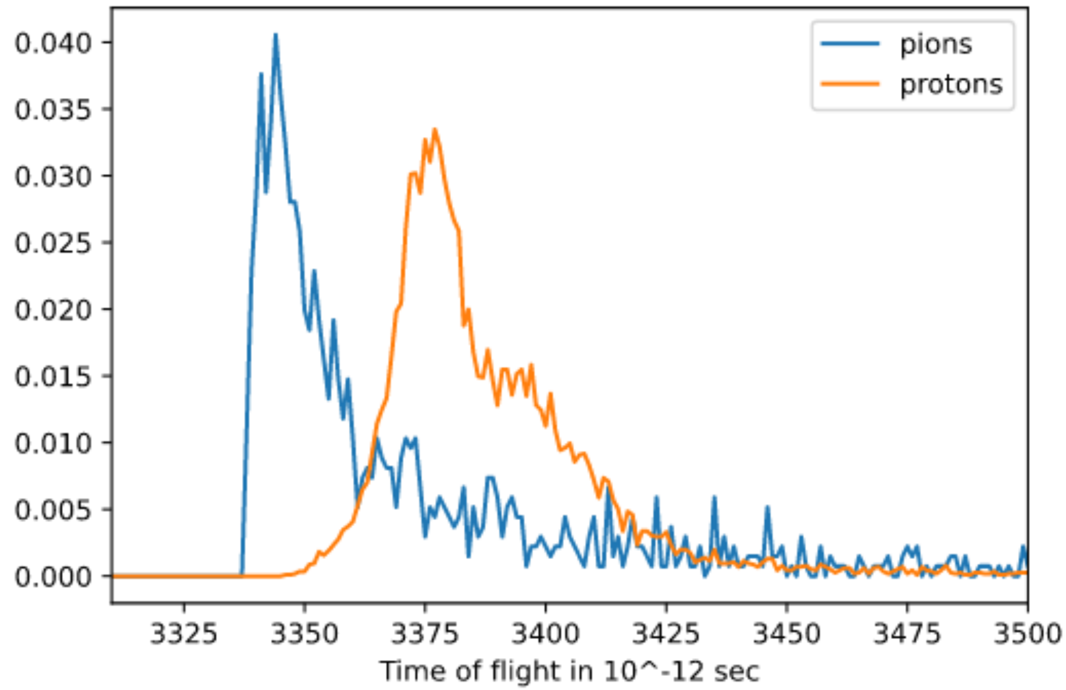
Моделирование сборок микроканальных пластин (МКП) с многоанодной системой для beam-beam collisions monitor/T0 детектора с использованием генераторов LAQGSM, SMASH, UrQMD и пакета GEANT.



Концепция компактного быстрого детектора столкновений FBBC на кольцевых МКП с сегментированными многоанодными системами. (“внутренний вариант” расположения) [Доклад 21.10.2020 на конференции «RFBR Grants for NICA”, G.Feofilov et al., Investigation of initial states and development of methods for their analysis in proton and nucleus collisions at energies of NICA collider’]

Application of neural networks for event-wise evaluation of the impact parameter





(_а)_ _Сегментация _по _углу _и _радиусу _кольцевого _МКП _детектора._ _(_б)_ _Временная _информация,_ _получаемая _с _детекторов._ _

Conclusions-1

- We propose to use the MCP-based Beam Profilometer and the Fast Beam-Beam Collisions counters (FBBC) as devices potentially capable to extend the performance and the physics outreach of the SPD experiment at NICA.
- This includes the event-by-event measurements of:
  - Beam-beam IP location in z-coordinate
  - 3D-beam profile (2 dimensional + time structure)
  - Luminosity
  - Reaction plane
  - Event centrality class in A-A collisions
  - T0 -- the collision time
  - Beam-gas events suppression
  - Polarimetry

Conclusions-2

- We evaluated the effectiveness of the conceptual design of the proposed FBBC system using Monte Carlo simulation based on event generators SMASH, LAQGSM and UrQMD
- We show the possibility of increasing the acceptance of the SPD setup up to 6 units of pseudorapidity by using several MCP-based ring detectors located inside the beam pipe of the NICA collider. This also provides an extension of the possibilities for physical measurements.
- The Beam Profilometer was succesfully tested at the NUCLOTRON beams,
- At the end of December 2020, the first test of a prototype multi-anode detector of the MCP system, made in the design of ultrahigh vacuum, was carried out on the line of the circulating helium ion beam of the NICA collider booster

Conclusions-3

- ➢ The technology for ultra-high vacuum (UHV) design of MCP detectors was tested. It allows the application of the MCP detectors inside the vacuum beam line.
- ➢ The first prototypes were prepared in the UHV and UHF design. The in-lab and in-beam tests show subnanosecond MCP signal rise time (<800 ps)
- ➢ We produced, using modern high-speed discrete comparators, the prototype of a multichannel fast electronics module for time reference to signals from MCP detectors
- We proposed to develop a next prototype of a registration system basing on high-speed discrete comparators of the **ADCMP572 / ADCMP573 type** as primary recorders in a multichannel time-code converter based on the FPGA. These ADCMP572 / ADCMP573 type comparators feature a high switching rates (35 ps) with jitter of the order of 15 ps with a minimum signal duration of 85 ps.
- ➢ We applied the machine learning method using event-by-event information from MCP detectors in our studies of event-by-event selection of the primary collision vertex and for the fast selection of collision centrality class. We show the method to be feasible for the bunch-by-bunch crossing analysis at NICA.

BACK-UP SLIDES

Micro Channel Plates (MCPs) as a MIP detector

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