Разработка и создание детекторов тепловых нейтронов в ЛНФ ОИЯИ

В. Боднарчук

Outline

- Current status of the IBR-2 reactor

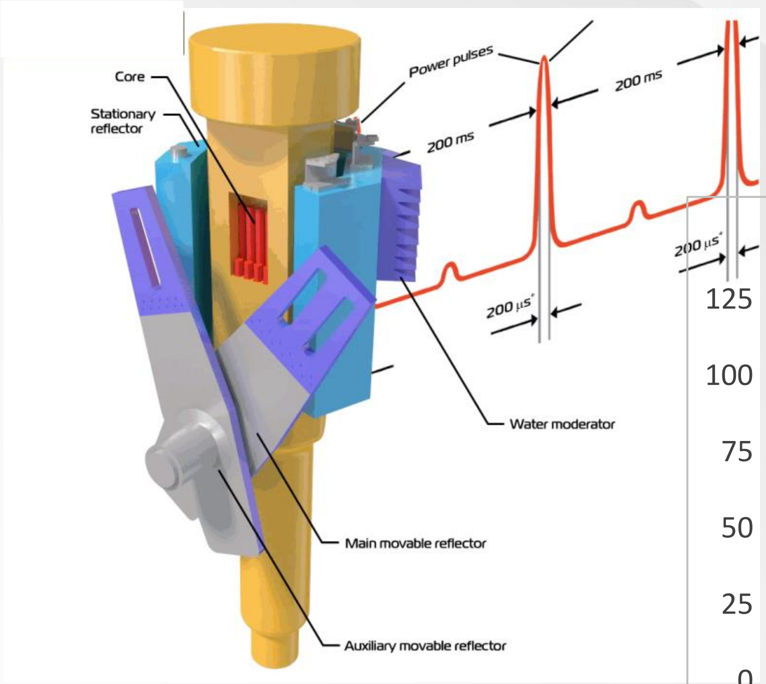
- Neutron detectors at the IBR-2 reactor instrumentation
  - Detectors with ^{3}He converter
  - Scintillation detectors

- Detector electronics

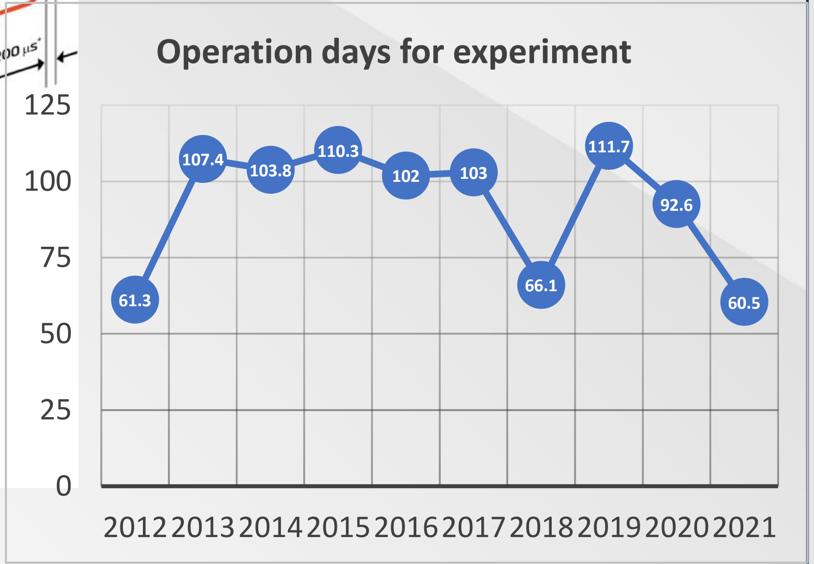
- Development of the technology of thin film B_4C coverage

Pulsed Research Reactor IBR-2

https://flnp.jinr.int/en-us/main/facilities/ibr-2



Operate since 1984



Deep modernization wasdone at 2006-2010

On 2022 the license for the reactor exploitations was expired.
Obtaining the license – beginning of 2024.
Reactor startup – autumn of 2024.

Average power, MW	**2**
Fuel	PuO_2
Number of fuel assemblies	69
Maximum burnup, %	9
Pulse repetiton rate, Hz	5
Pulse half-width, µs: fast neutrons thermal neutrons	 200* 340
Rotation rate, rev/min • Main reflector • Auxiliary reflector	 600 300
MMR and AMR material	Nickel + steel
MR service life, hours	55 000
Background, %	7
Termal neutron flux density from the surface of the moderator • Time average • Burst maximum	 $\sim10^{13}$ n/cm^2 s $\sim10^{16}$ n/cm^2 s

Site of instruments

13 INSTRUMENTS INCLUDE IN USER PROGRAMM

Diffraction:
HRFD
RTD
DN-6
EPSILON
SKAT
DN-12
FSD

Small-angle
YuMo

Reflectometry:
GRAINS
REMUR
REFLEX

Inelastic scattering:
NERA

NAA:
REGATA

Under construction:
- SANSARA – small angle + imaging
- BJN – inelastic scattering

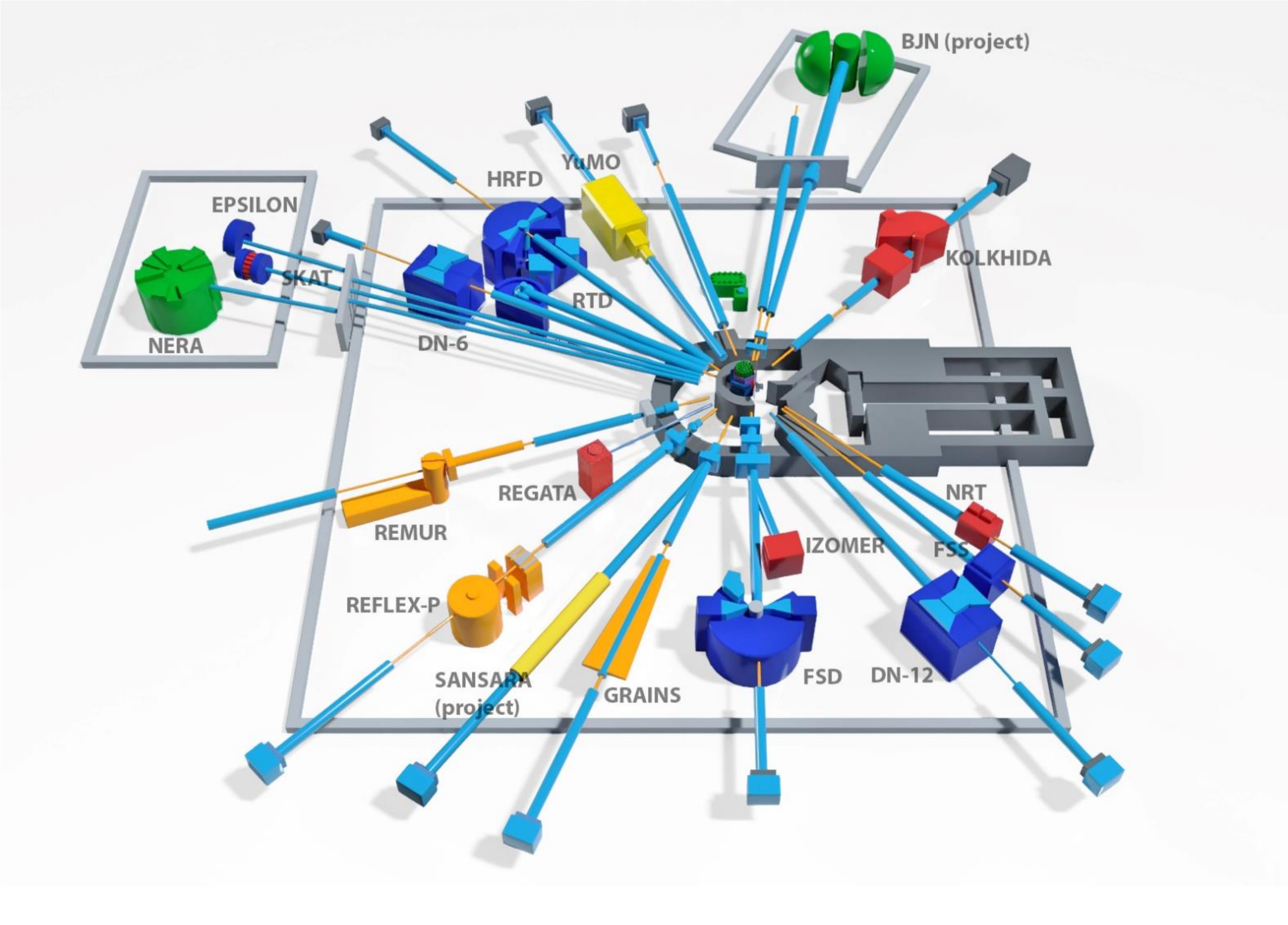
Distribution of the beam time
- **35%** (internal proposals)
- **55%** (external regular proposals)
- **10%** (external urgent beam time requests)

Regular access applications

	First round	Second round
Period for proposal submission	September 1 - October 15	March 1 - April 15
Experiments time	1 half-year	2 half-year

IBR-2 User Club website: https://ibr-2.jinr.ru/

418 users are volume of the community (reregistration since 2020).



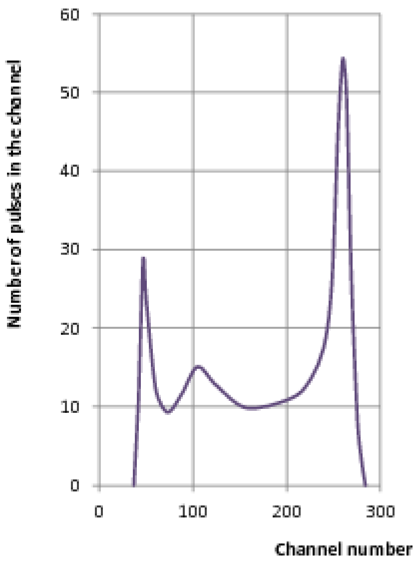
Neutron detectors with He-3 converter

Single counters

Multi counter (19) 90° detector
(SKAT Instrument)

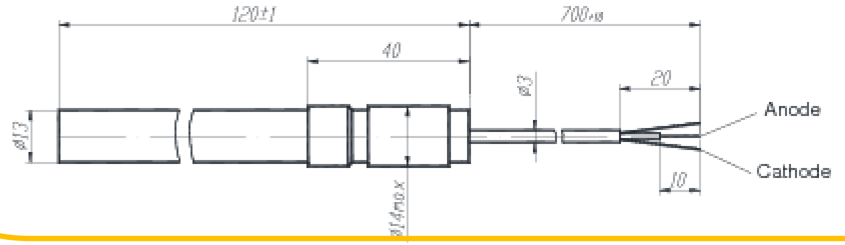
Producer: Scientific-Production Firm "CONSENSUS“
Moscow reg., Zaprudnya

Режим работы / Operating mode	Пропорциональный / Proportional
Эффективная рабочая длина, мм / Effective length, mm	68
Давление ³He, атм / ³He pressure, atm	8,0
Рабочее напряжение (рекомендуемое), В / Operating voltage (recommended), V	1300
Предельно допустимое рабочее напряжение, В / Maximum permissible operating voltage, V	1600
Ширина пика на половине высоты, % / Peak width at half height, %	12 max
Разброс положения пика от среднего значения в партии, % / Variation of the position of the peak of the mean value in a party, %	20 max
Собственный фон, имп/с / Own background, count/s	0,1 max
Разброс чувствительности относительно образца, % / Variation of sensitivity regarding the sample, %	5 max
Рабочий диапазон температур, °С / Operation temperature range, °C	-50 ÷ 60
Масса, г / Weight, g	37



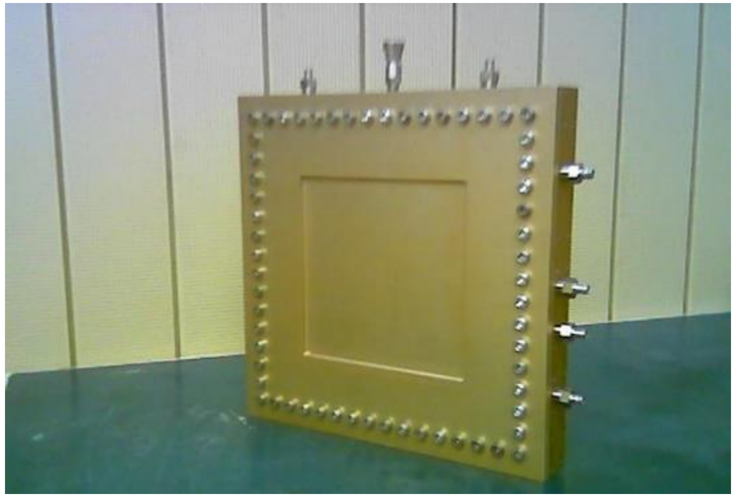
*- При рекомендуемом рабочем напряжении
*- On the recommended operating voltage

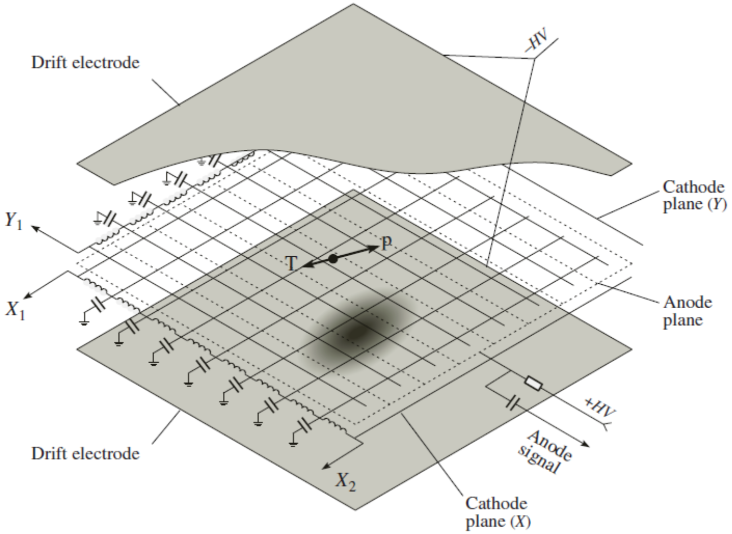
Габариты
Overall dimensions



Gaseous neutron detectors with He-3 converter

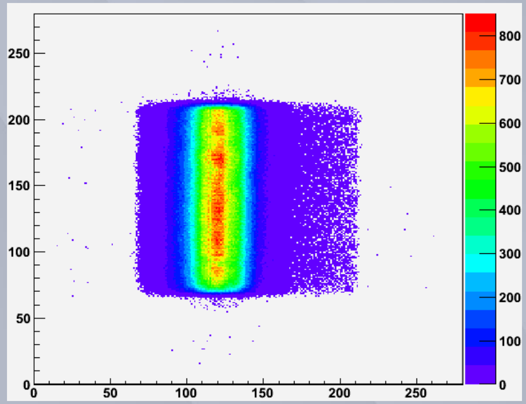
1D/2D PSD MWPC



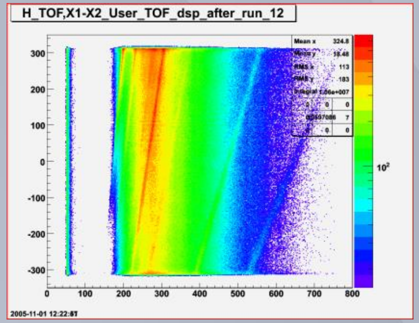


Characteristic	Value		
Detector type	Area monitor	Linear PSD	Area PSD
Operating area, mm^2	100 × 100	200 × 80	225 × 225
Efficiency, %	10^{-2}–10^{-6} (λ = 1 Å)	65% (λ = 2 Å)	65% (λ = 2 Å)
Coordinate resolution, mm^2	4 × 4	2	2 × 2
Load, kHz	Up to 100	Up to 100	Up to 1000
Uniformity of channels, %	No worse that 20% (5%*)	No worse that 5%*	No worse that 15%
Working gas	^{3}He or $N_2 + CF_4$	^{3}He + CF_4	^{3}He + CF_4
Total pressure, 10^5 Pa	1	4.5	4.5

* The result with summation over the channels.

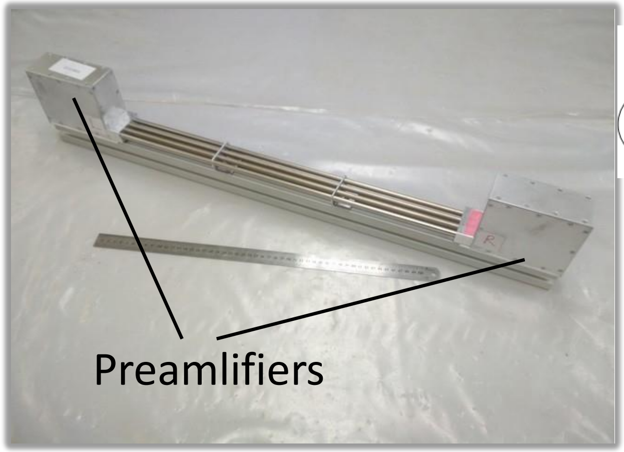


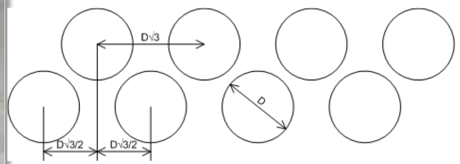
Profile of the beamline 6b of the IBR-2



Diffraction spectra $(La_{0.1}Pr_{0.9})_{0.7}Ca_{0.3}Mn_{0.3}$) at the beamline 5 (HRFD)

Linear PSD with resistive anode

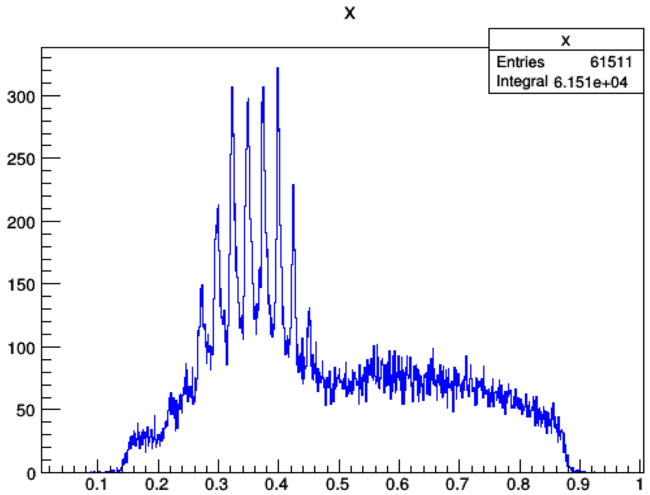




Scheme of tube package

The assemble of 8 tubes of
8 mm diameter, 600mm length

Test of the module at the neutron beam at IR-8 reactor (Kurchatov Institute, Moscow)



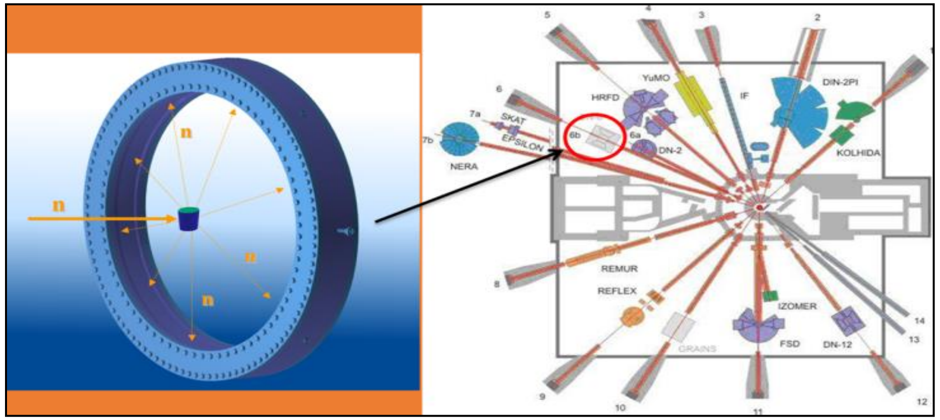
Intensity along 1 tube

Space resolution – 0.5% of the tube length
Average efficiency ~ 55%

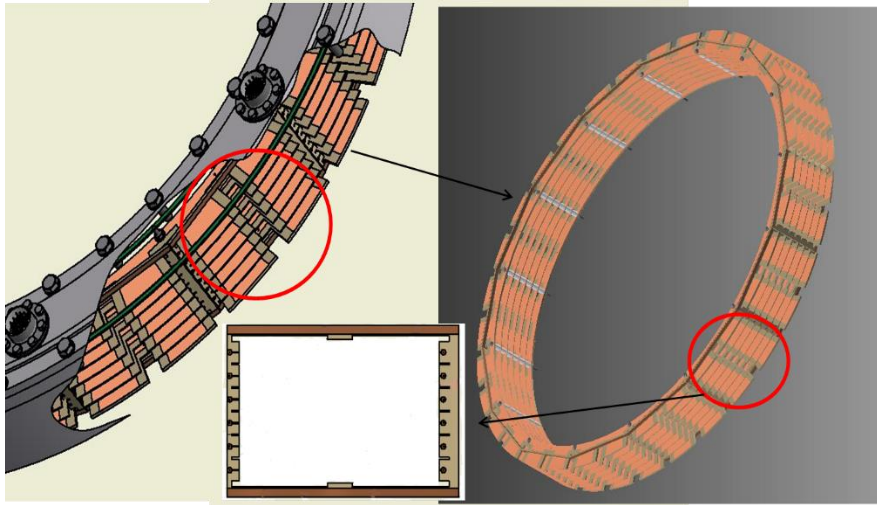
+ CAEN Digitizer

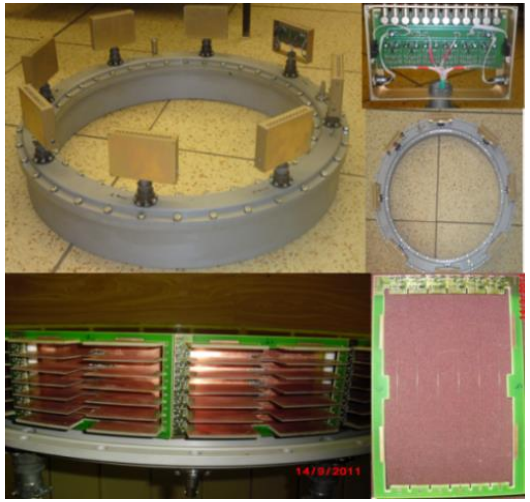
Gaseous neutron detectors with He-3 converter

Ring detectors



№	Parameter	
1.	Detector casing (material)	~ aluminum–magnesium alloy
2.	Inner radius of the detector ring, mm	637
3.	Outer radius of the detector ring, mm	800
4.	The angle of overlap, degrees	360º
5.	Total number of independent detecting elements	96
6.	Single detector element, mm	parallelepiped 123×40×12
7.	At an operating pressure of ^{3}He of 4 atm. the detection efficiency of neutrons with a wavelength of 1.8 Å coming into the detector volume	≈ 89.4 %, (without considering the absorption in the detector wall).
8.	Work pressure max., atm.	7





The multisection ring detector is designed for DN-6 spectrometer at the IBR-2 reactor (channel №6b). The detector is designed to study small-volume samples at high pressure and consists of 16 sections, where each one section is divided into six independent detector elements. The total number of independent detecting elements in the gas ring is 96. 16 sectors with 6 detector

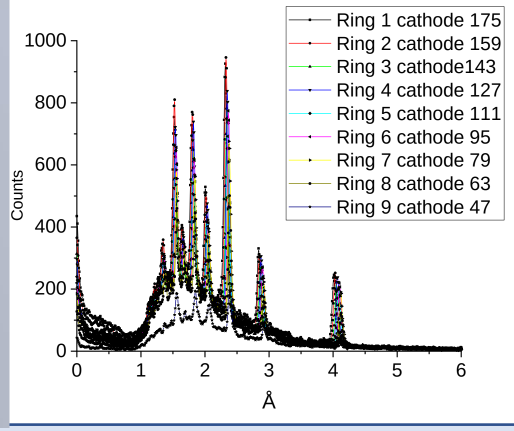
Gaseous neutron detectors with He-3 converter

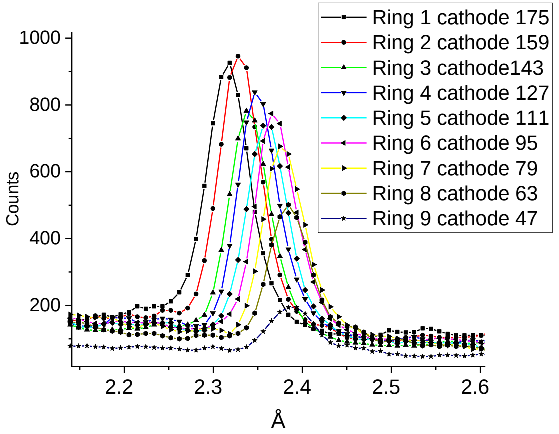
Ring detectors

Efficiency at 1.8 Å ~ 78 %

The ring detector is designed for measure small-angle scattering of thermal neutrons at the IBR-2 reactor (beamline 6a)
instrument: Real-Time Neutron Diffractometer (RTD).

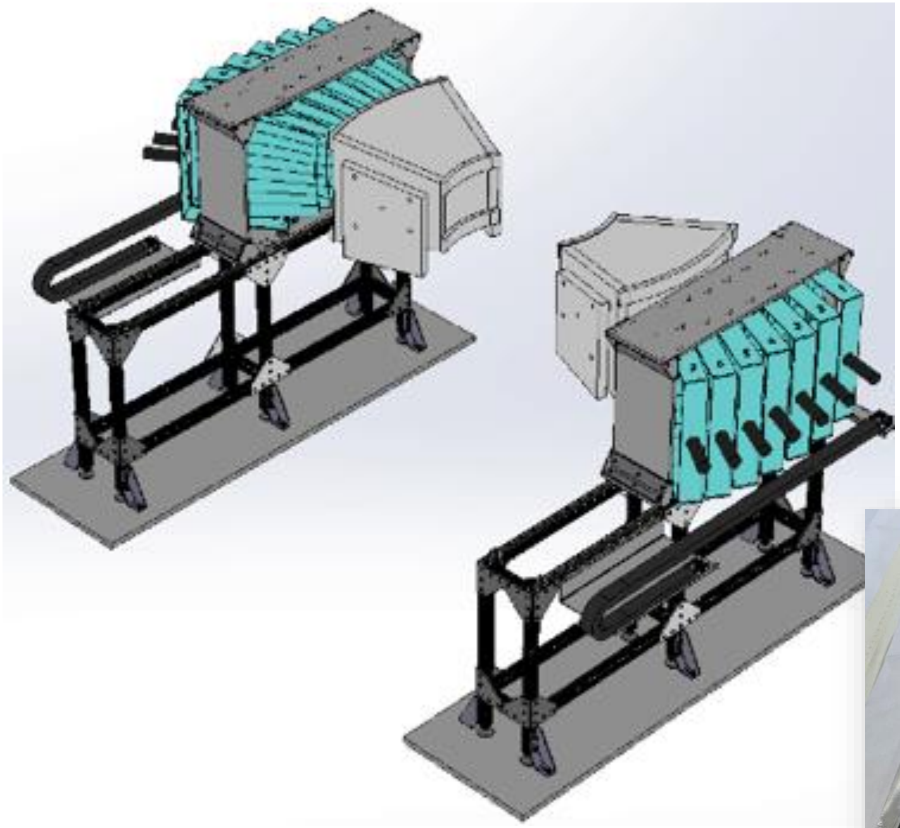
Structurally the detector is divided into 9 independent equidistant coaxial rings. The cathodes of each of the rings are divided into 16 independent sectors, the same for each ring. Registration signals are taken from the anode wires (common for every single ring) and with each of the 16 cathodes - 153 independent detector elements.



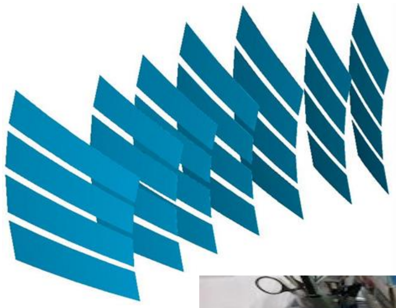


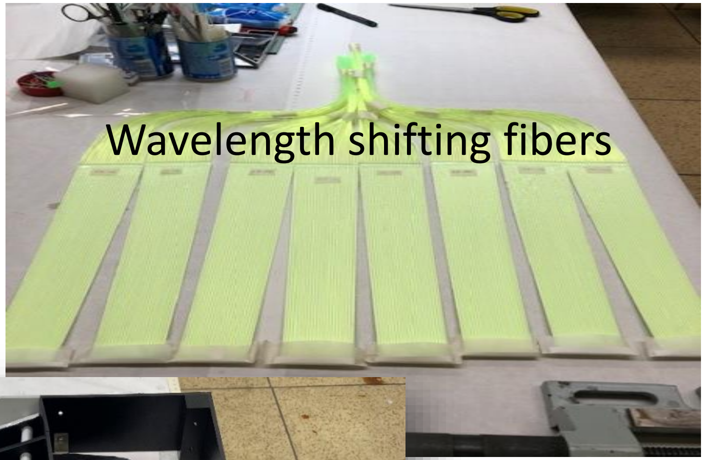
Scintillating detectors based on ZnS(Ag)/^{6}LiF

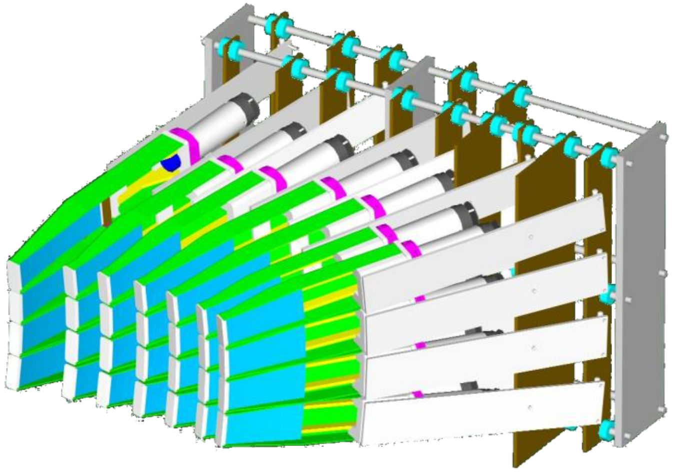
90°- ASTRA detector

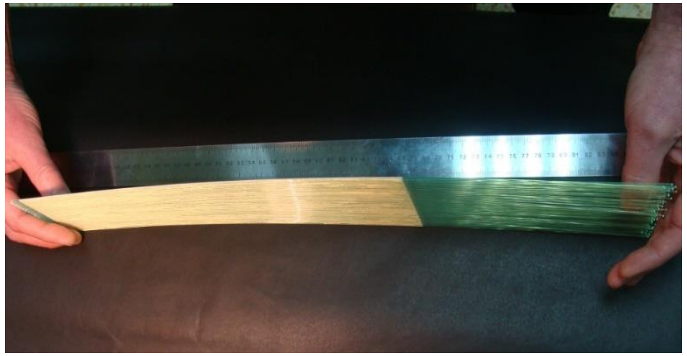


Instrument FSD, beamline 11









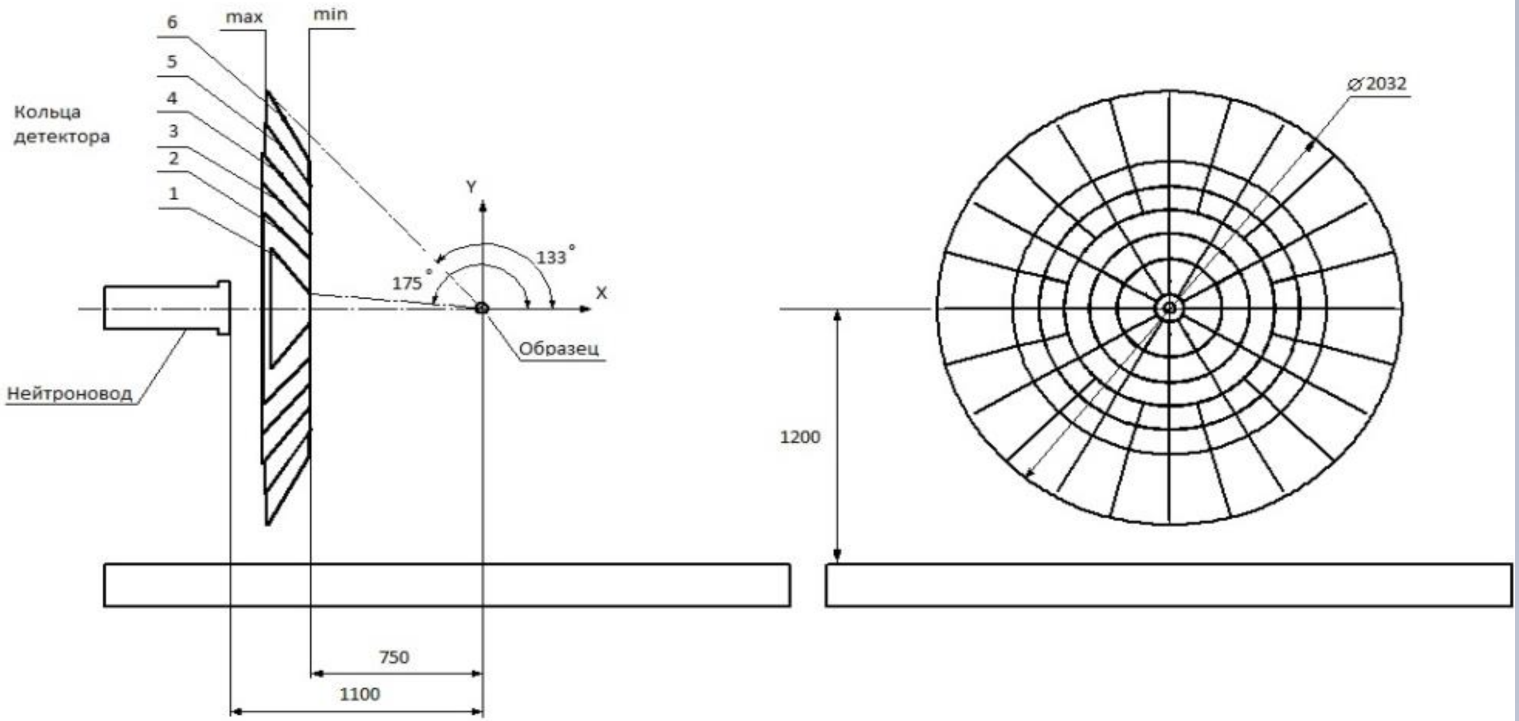
Scintillartor: Scintacor AST-ND 0.42mm

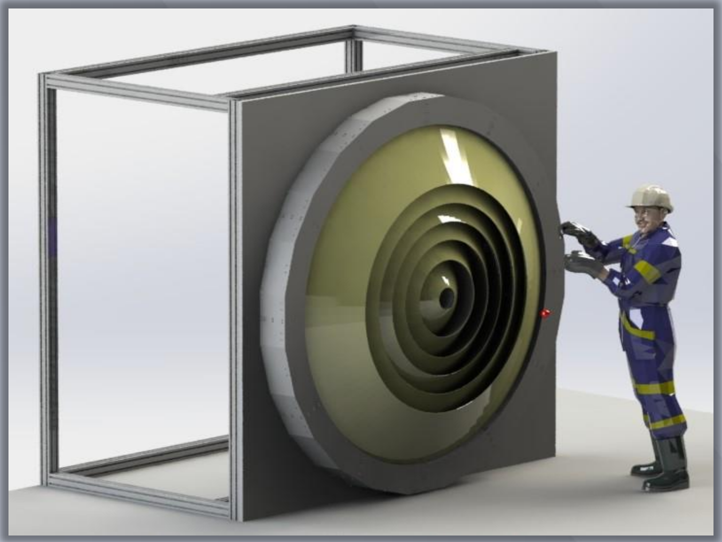
Scintillating detectors based on $ZnS(Ag)/^6LiF$

90°- ASTRA detector

Parameters	ASTRA-M
Ω, sr	0.55
2θ, deg	70-110
ϕ, deg	24
Efficiency (conversion), %	72
Δd/d	8.30E-04
Detector counters	14
Total detector max count rate I (no chopper), s^{-1}	5.03E+06
1 counter max count rate I (no chopper), s^{-1}	3.59E+05
Total detector max count rate I (with chopper), s^{-1}	1.01E+06
1 counter max count rate I (with chopper), s^{-1}	7.18E+04
DAQ electronics	1 MPD-32 or 2 N6730 (8-channel, CAEN digitizer)
Electronic efficiency (1/(1+I*d.t.) for max value n	0,6 for 2 μs dead time

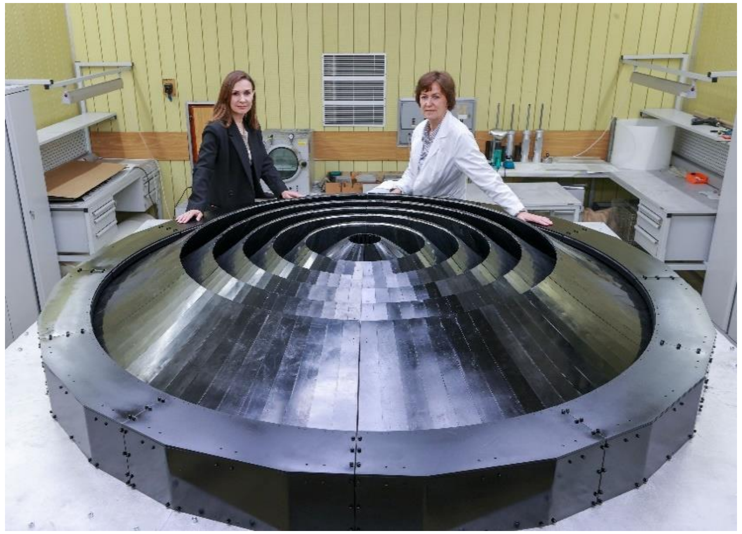
Back Scattering Detector (BSD)



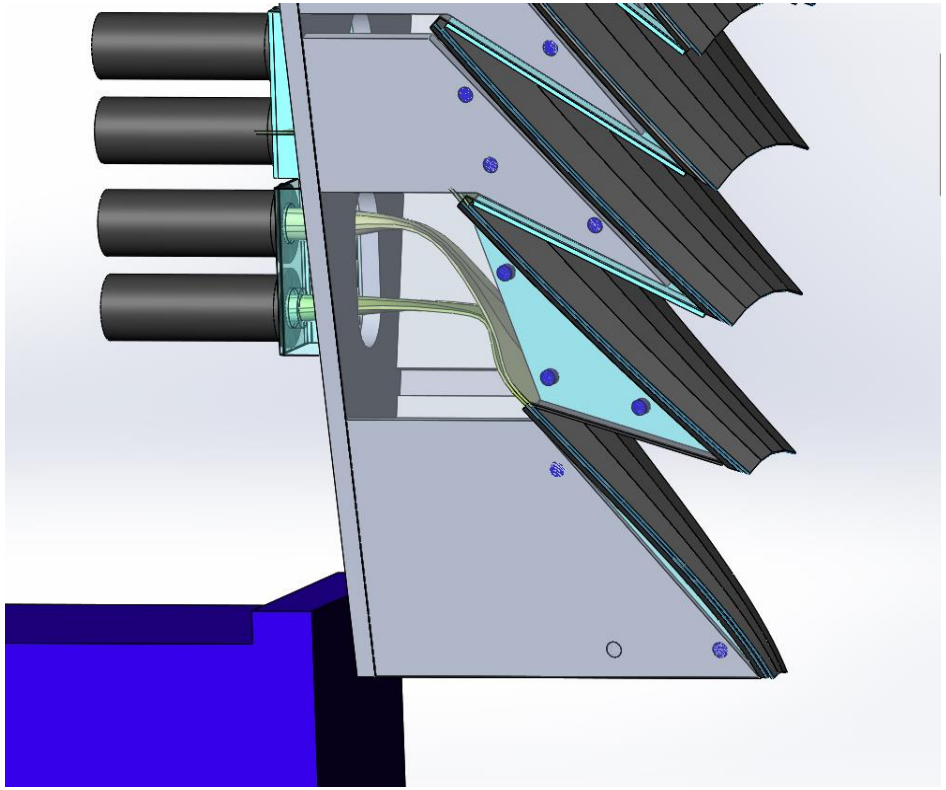


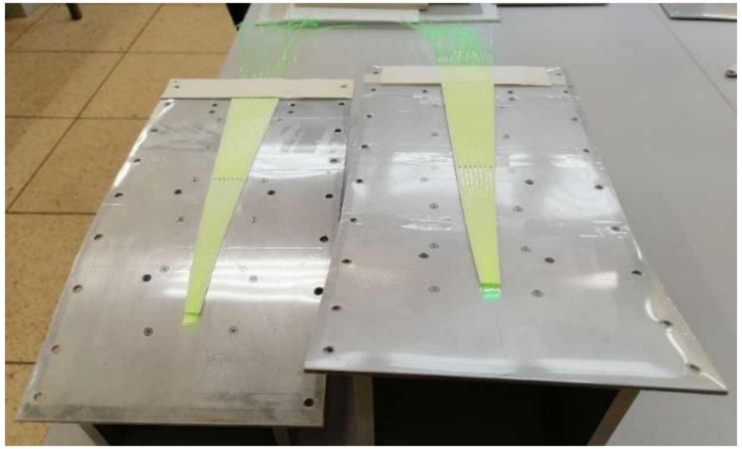
6 rings
Internal 3 rings divided by sectors 30°(12 sec./ring)
External 3 ring divided by sectors 15° (24 sec./ring)

Back Scattering Detector (BSD)



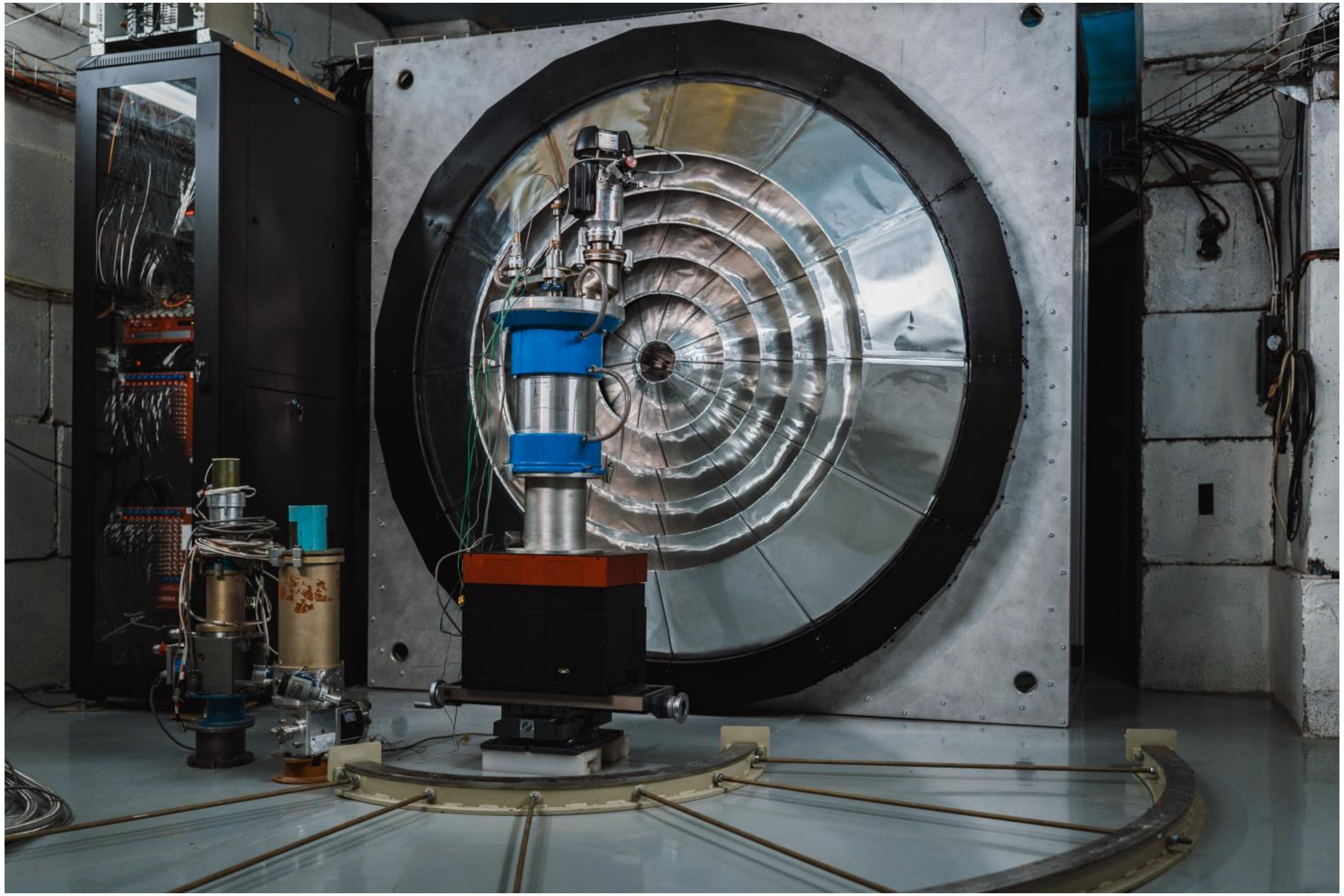
Optical fibers: Saint-Gobain Crystals (BFC-91A)
PM – Hamamatsu R3998-02
Scintillartor: Scintacor AST-ND 0.42mm

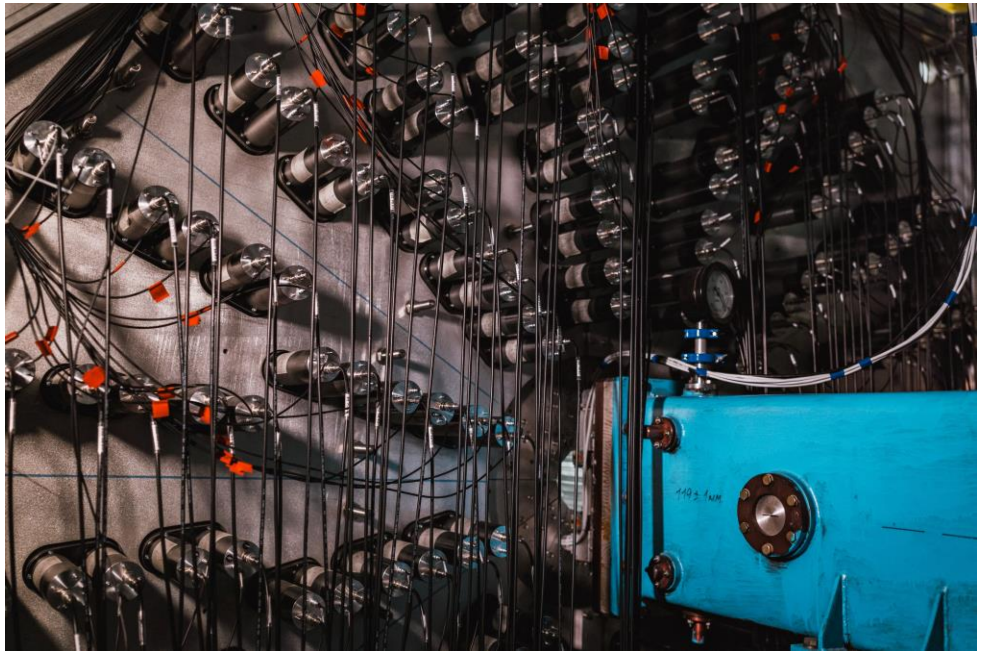




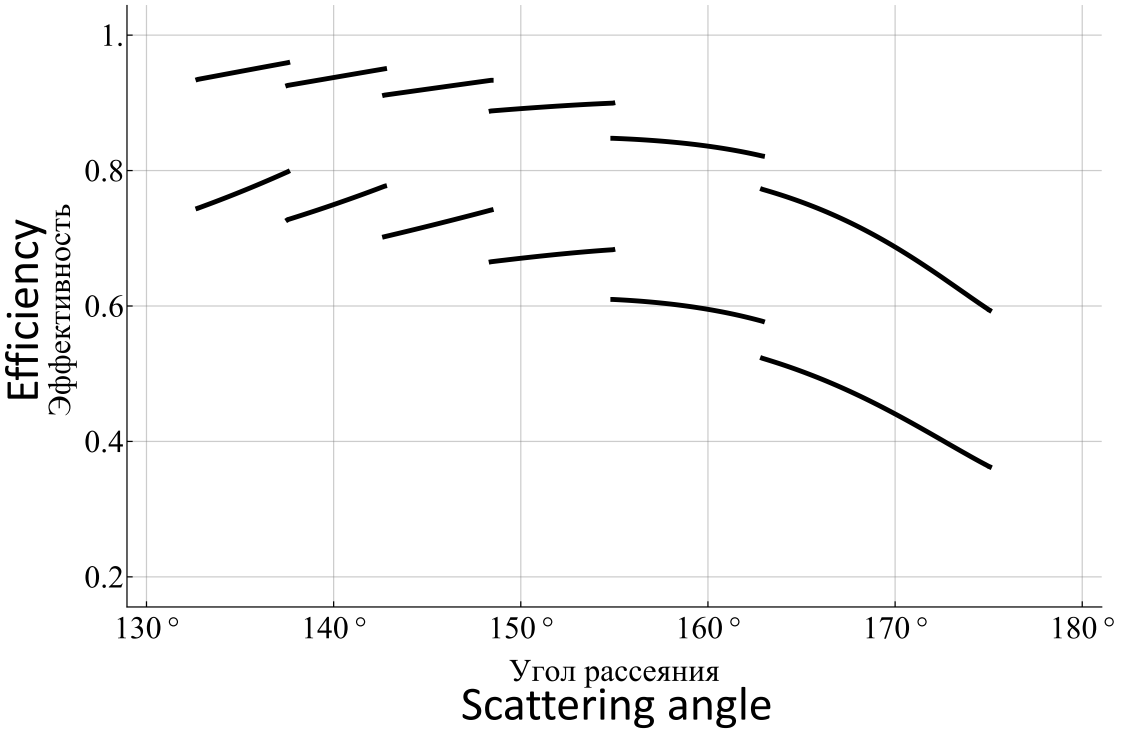
Scintillating detectors based on ZnS(Ag)/^{6}LiF

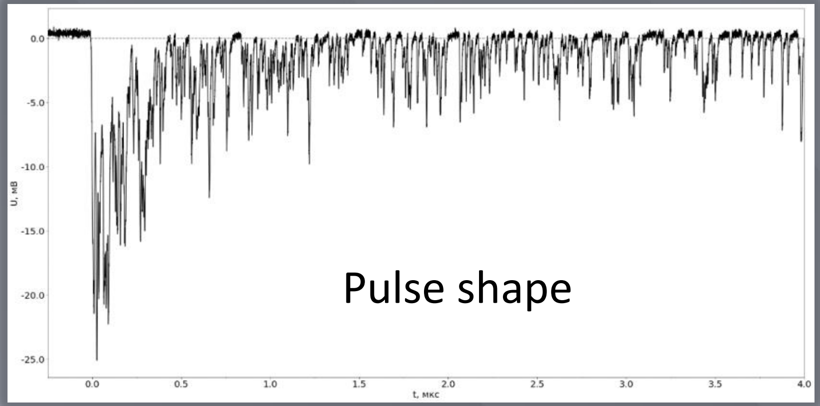
Back Scattering Detector (BSD)



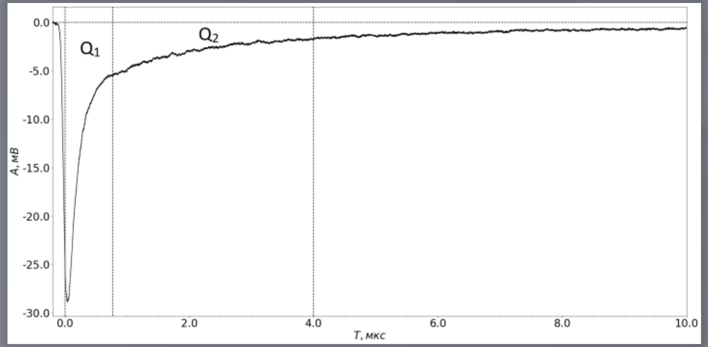


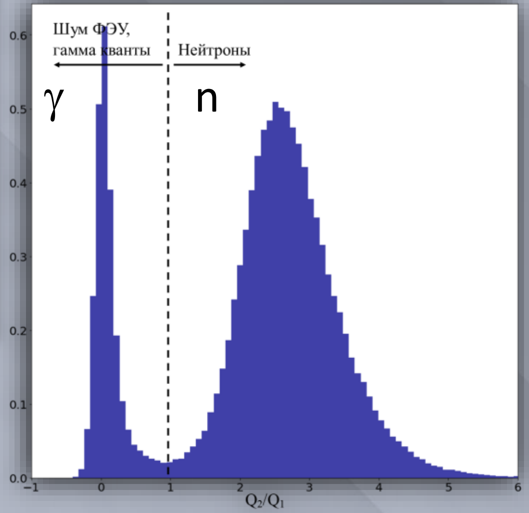
Back Scattering Detector (BSD)





Selection of events: Pulse shape discrimination method - PSD

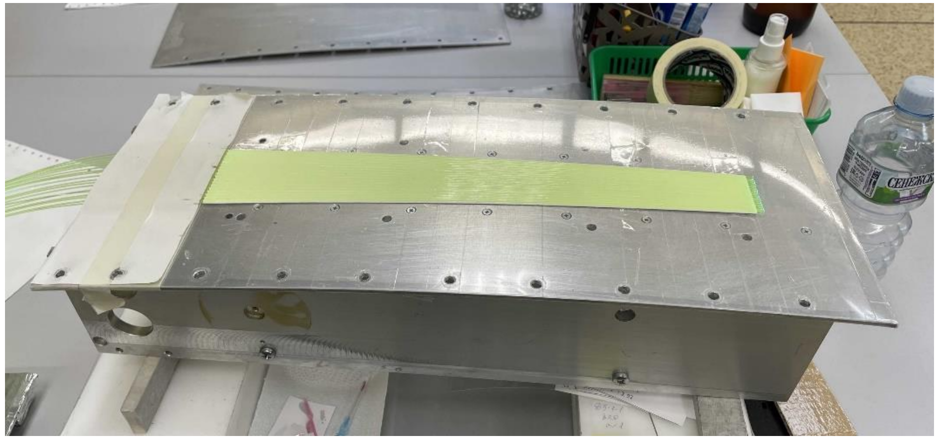




Scintillating detectors based on ZnS(Ag)/^{6}LiF

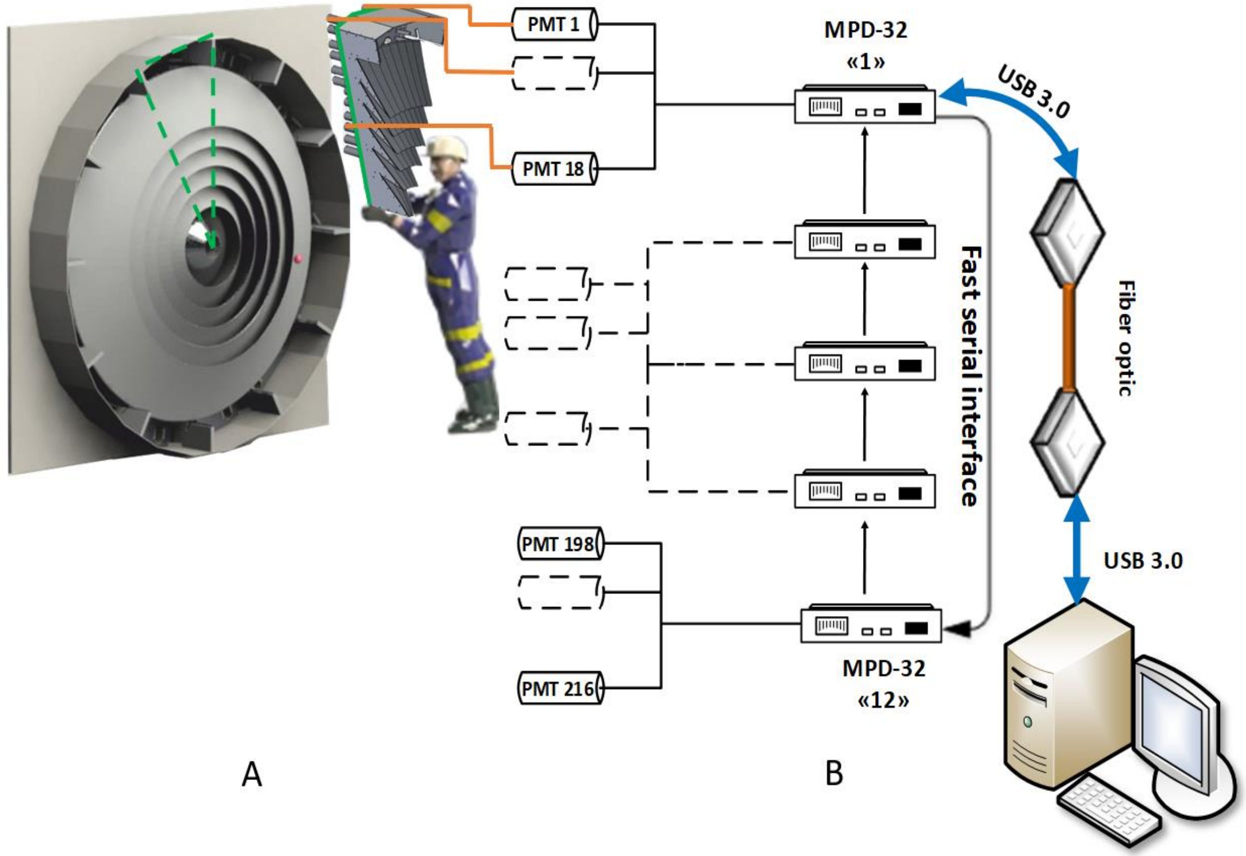
Back Scattering Detector (BSD)

- Photomultipliers : 216
- The surface of scintillator S > 10 m^2
- The approximate length of fibers L=36000 m
- High voltage (CAEN)
- 2 NIM creates
- Pre-amplifiers and 216 independent detectors of the Data Acquisition and Accumulation System. The system is designed in the NIM standard. In its full configuration, it consists of 8 units of amplifiers-discriminators with 32 inputs.

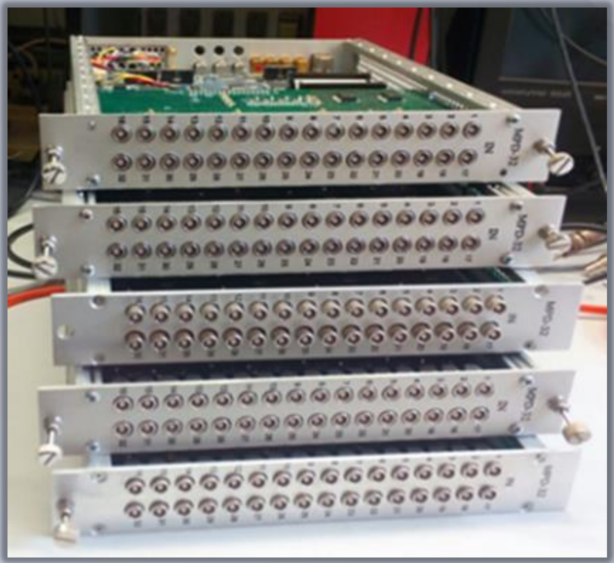


An element of the scintillation screen (white plate) together with the optical wavelength shifting fibers glued to it on both sides.

Back Scattering Detector (BSD)



Experimental example of MPD32-USB3



- **MPD-32 combines a discriminator and an encoder for 32 analog inputs**
- **Digital logic on 2 FPGA (Altera Cyclone IV)**
- **USB3.0 interface with optical fiber extender**
- **Maximum data rate $6 \cdot 10^7$ event/sec**
- **High speed (2.5 Gb) interunit interface for linking several MPD-32 to common USB3.0 port.**

Back Scattering Detector (BSD)

Parameters	BSD
Ω, sr	2
2θ, deg	133-175
ϕ, deg	360
Efficiency (conversion), %	85
$\Delta d/d$	2.62E-04
Detector counters	216
Total detector max count rate I (no chopper), s^{-1}	1.30E+08
1 counter max count rate I (no chopper), s^{-1}	6.02E+05
Total detector max count rate I (with chopper), s^{-1}	4.69E+07
1 counter max count rate I (with chopper), s^{-1}	2.17E+05
DAQ electronics	8 MPD-32 or 8 DT5560SE (32-channel, CAEN digitizer)
Electronic efficiency 1/(1+I*d.t.) for max value n	0,5 for 2 μs dead time

DAQ Electronics for 1D or 2D PSD

DeLiDAQ 2

Design and production FLNP JINR

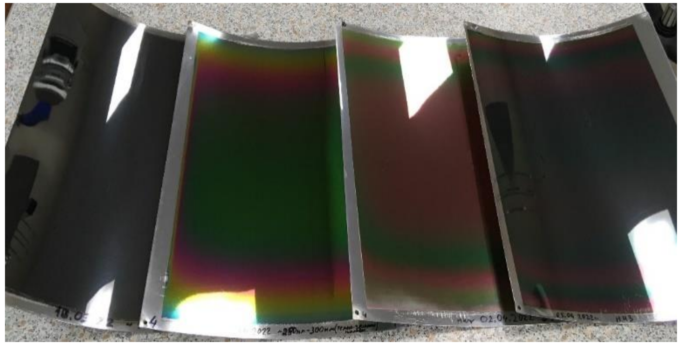
The DeLiDAQ-2D provides two basic options of data acquisition: histogramming with
on-line sorting and collection of spectra in the module memory, and list mode.

8-channel TDC-GPX 80 ps res.
Digital logic baded on FPGA (Altera Cyclone III)
Count rate together with data transfer and writing to PC is no less than 10^6 events/s.
Data transfer between the DAQ and USB computer via a serial optical fiber line at a rate of 1.25 Gbit/s.
The maximum distance between DAQ electronics and computer is up to 100 m.
Data transfer rate through USB 2.0 port is 32 MB/s.

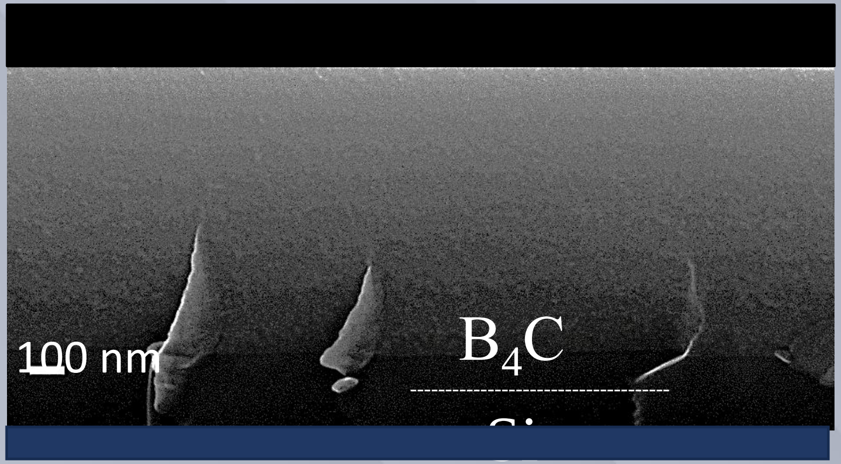
Development of detectors based on solid state convertors

B4C coverage technology

Collaboration
FLNP JINR & State University Dubna

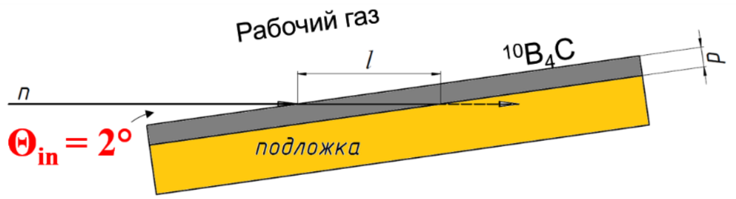


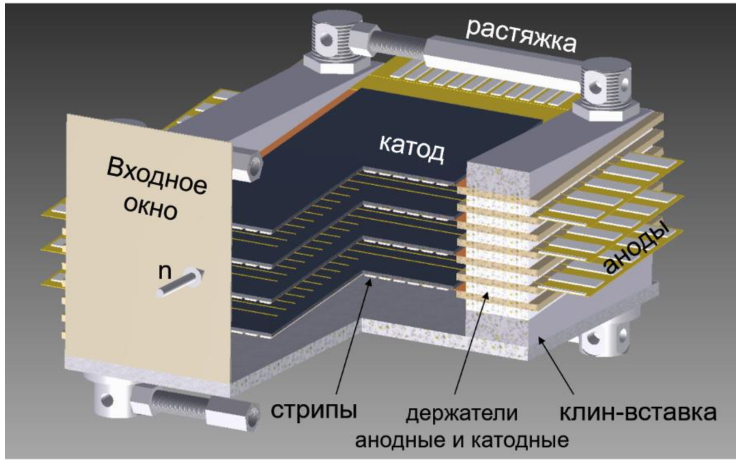
Magnetron sputtering machine VCR-300

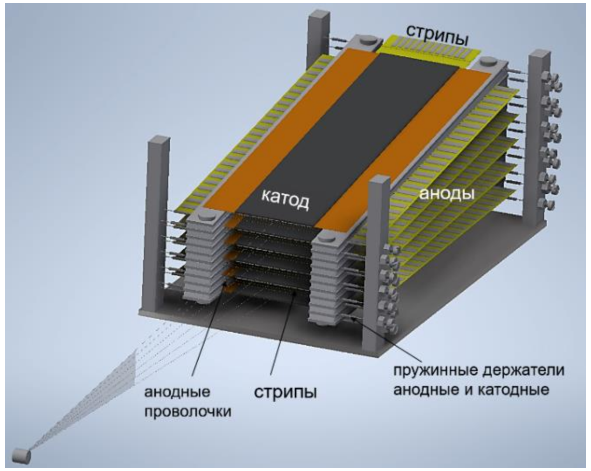


Neutron detector design with B_4C convertor

«Multi-foil detector project

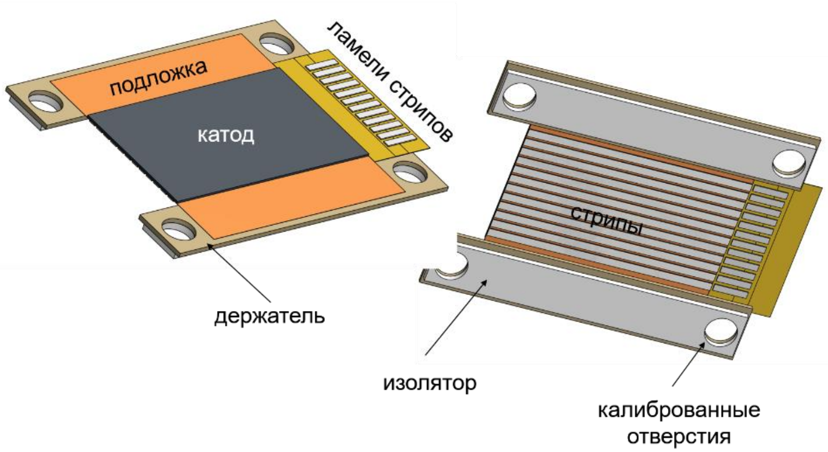


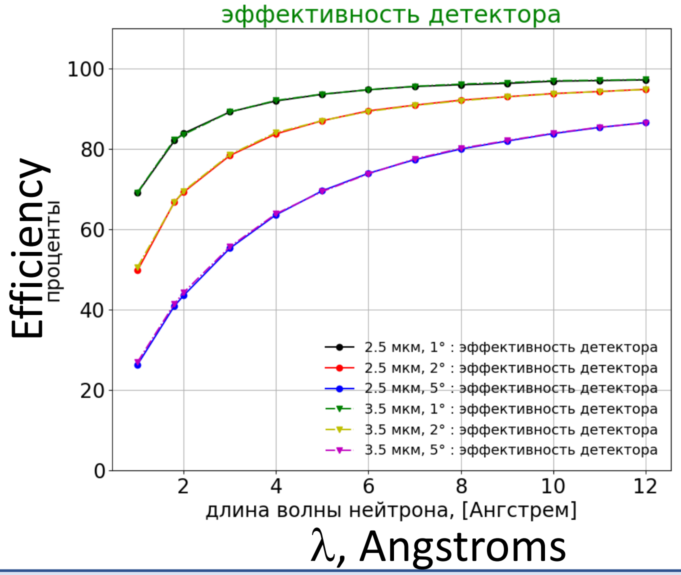




Advantages

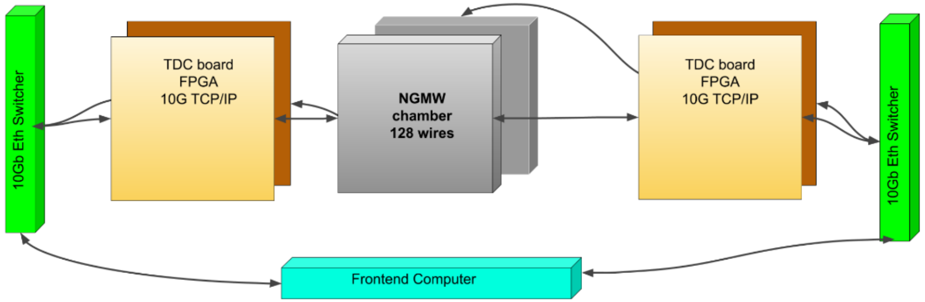
1. High efficiency
2. Space resolution ~ 1 mm
3. Time resolution ~ 1 нс

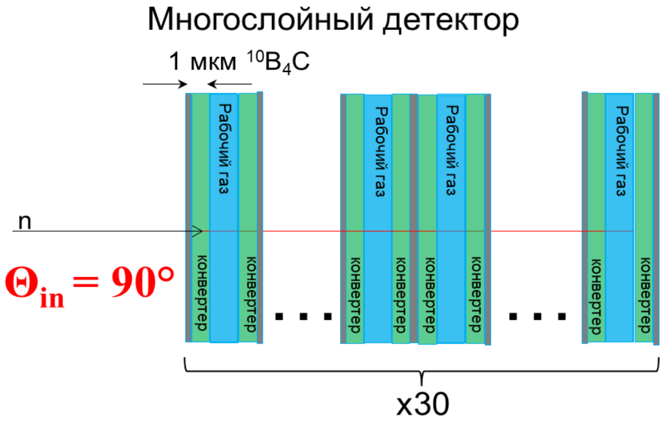


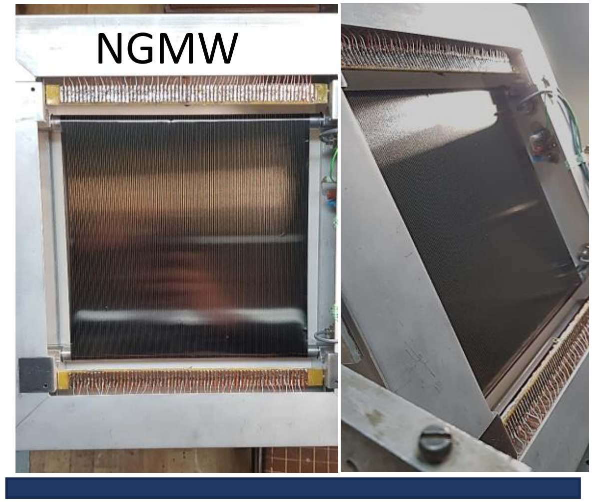


Neutron detector design with B_4C convertor

Multi-layer detector project





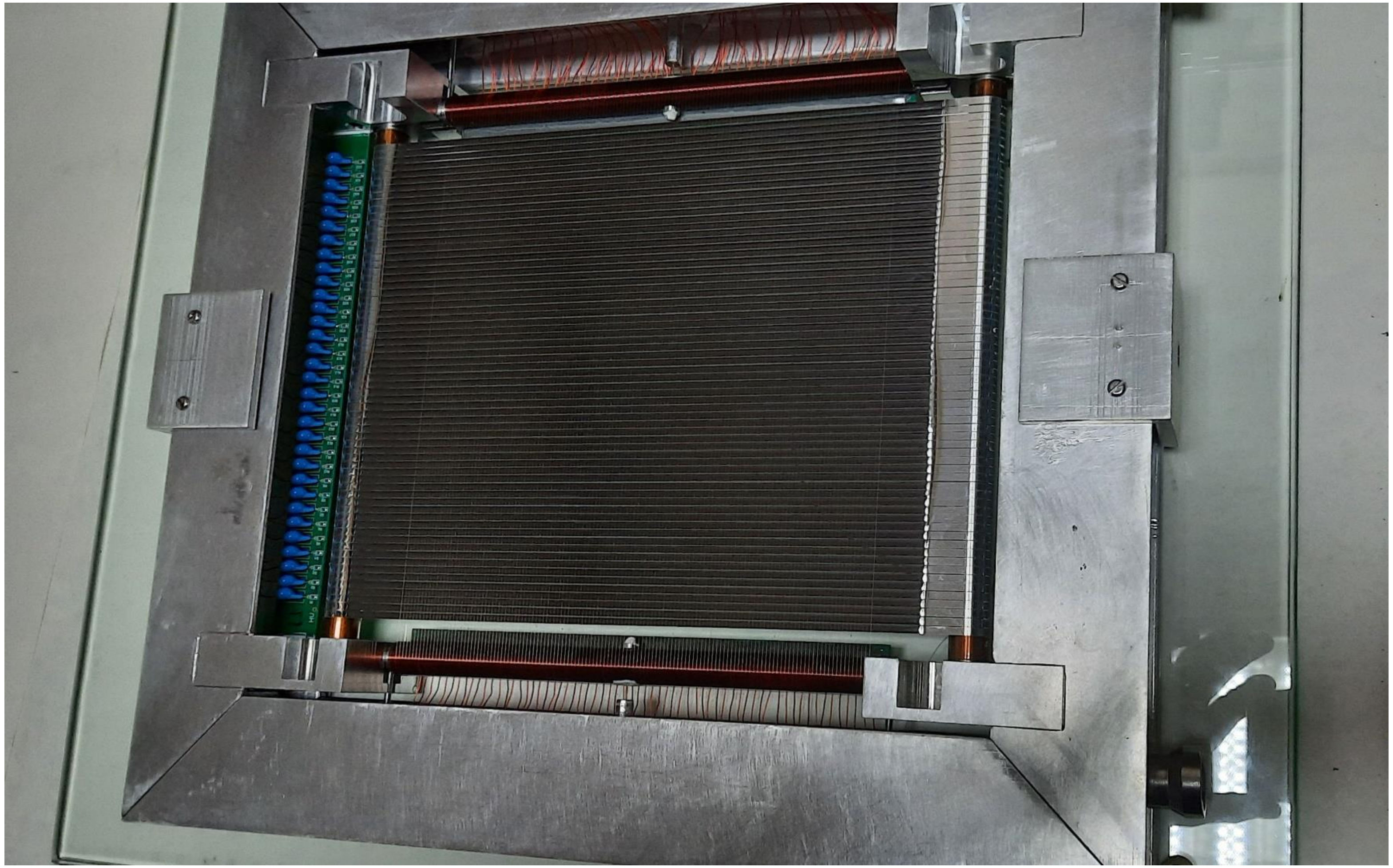


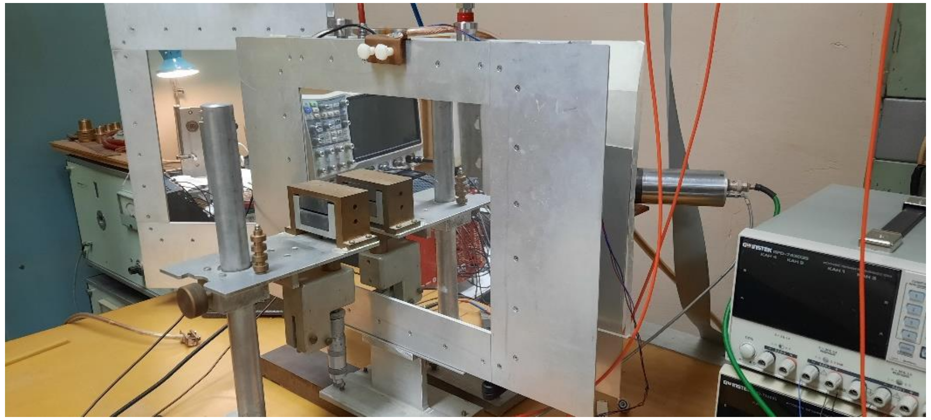
64 ch TDC, 1nc res.

32 ch. AmpDisc, 7ns res.

Parameters	Narrow gap detectors	MWPC
	Proportional mode	
Gas amplifier	10^5	
Anode-cathode distance, mm	1 - 2	5 - 10
Anode wire step, mm	≤1	≥ 2
Radius of avalanche area, mm	0,3 – 0,5	0,06 – 0,2
Current of electron avalanche, μA	0,5	0,5
Anode signal duration (in base), ns	20	100
Amplitude spread, ΔA/A, %	100	100
Time resolution (FWHM), ns	5	40
Limit of count rate, $c^{-1}cm^{-2}$	10^8	$5*10^5$
Radiation resistance, Кл/см	10	0,2

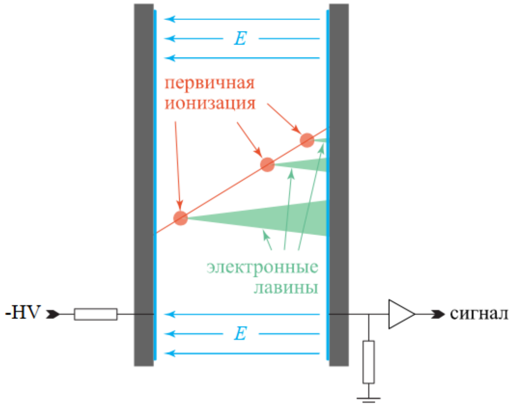
Neutron detector design with B_4C convertor

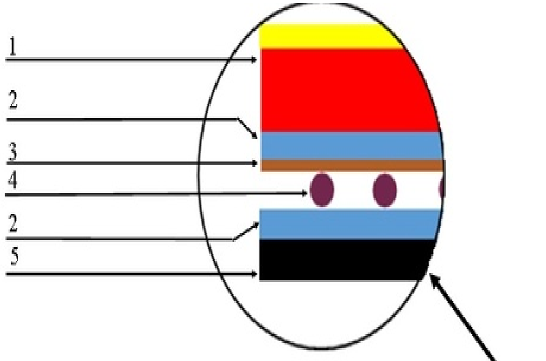


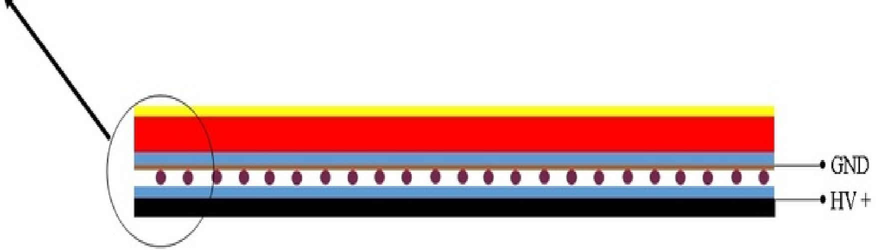


Neutron detector design with B_4C convertor

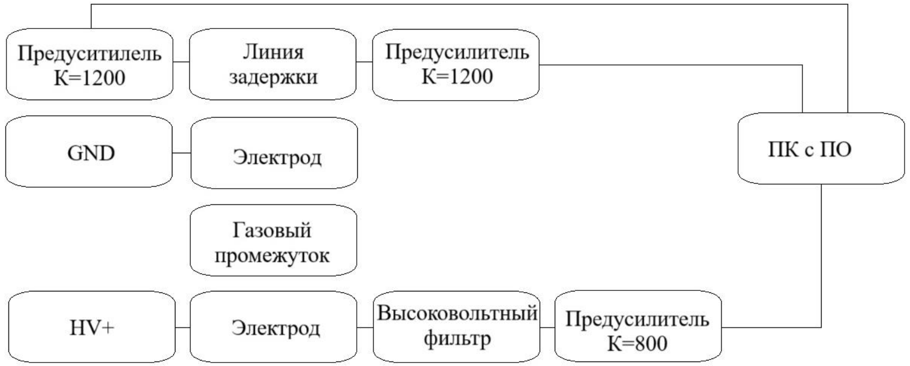
Плоская камера с $^{10}B_4C$

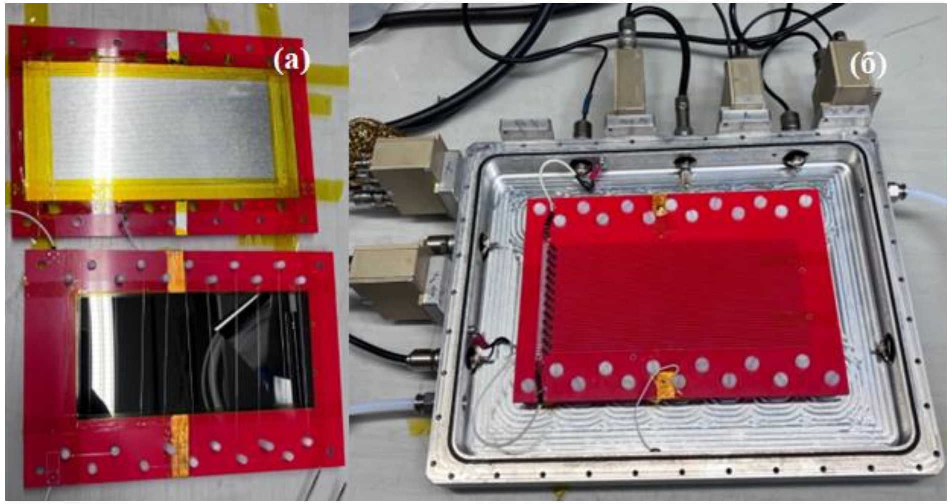






Структура плоской камеры для регистрации медленных нейтронов: 1 - печатная плата со стрипами, 2 - термополированное стекло, 3 - карбид бора, 4 – спейсер (~ 400μ), 5 - алюминиевая фольга.



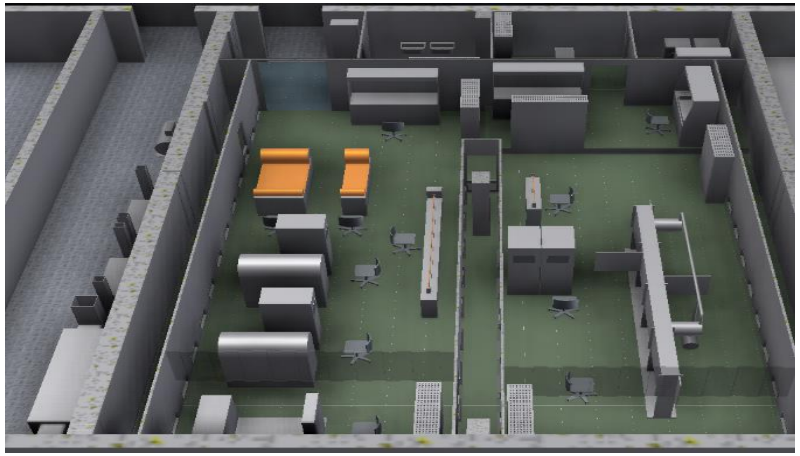


Development of infrastructure

With financial support of Russian Federation Ministry of Education and Science, Grant № 075-10-2021-115 from 13.10.2021

Building of experimental site for detector production

ALUMICA
ЗАВОД ЧИСТЫХ ПОМЕЩЕНИЙ



ЗАО «Ламинарные системы», г. Миасс

Development of infrastructure

With financial support of Russian Federation Ministry of Education and Science, Grant № 075-10-2021-115 from 13.10.2021

Building of experimental site for detector production

Spattering machine for B_4C coverage

Ferry Vatt company, Kazan, Russia

Max. coverage square 400x1200 mm^2

Initial stage of building

Today: modern equipment and engineer systems

Thank you for the attention!

CONTACT US:

The Frank Laboratory of Neutron Physics, JINR, Joliot-Curie str. 6,
Dubna, Moscow reg., Russia, 141980

bodnarch@nf.jinr.ru