Cremlin workshop
"Engineering for advanced neutron instrumentation and sample environment"
13-16 of May 2018

Development of neutron detectors for spectrometers of the IBR-2 reactor

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JINR is located in the city of Dubna in ~120 km from Moscow ~700 km from S.Peterburg

Volga River

Sluice

12 meters Dam

Water Power Station

Volga-Moscow Channel

Joint Institute for Nuclear Research is an international intergovernmental organization.
It has at present 18 Member States:

Armenia
Azerbaijan
Belarus
Bulgaria
Cuba
Czech Republic
Georgia
Kazakhstan
D. P. Republic of Korea
Moldova
Mongolia
Poland
Romania
Russian Federation
Slovakia
Ukraine
Uzbekistan
Vietnam

Participation of Egypt, Germany, Hungary, Italy, the Republic of South Africa and Serbia in JINR activities is based on bilateral agreements signed on the governmental level.

Laboratories

Dzhelepov
Laboratory of Nuclear Problems

Veksler and Baldin
Laboratory of High Energy Physics

Bogoliubov
Laboratory of Theoretical Physics

Frank Laboratory of Neutron Physics

Flerov
Laboratory of Nuclear Reactions

Laboratory of
Information Technologies

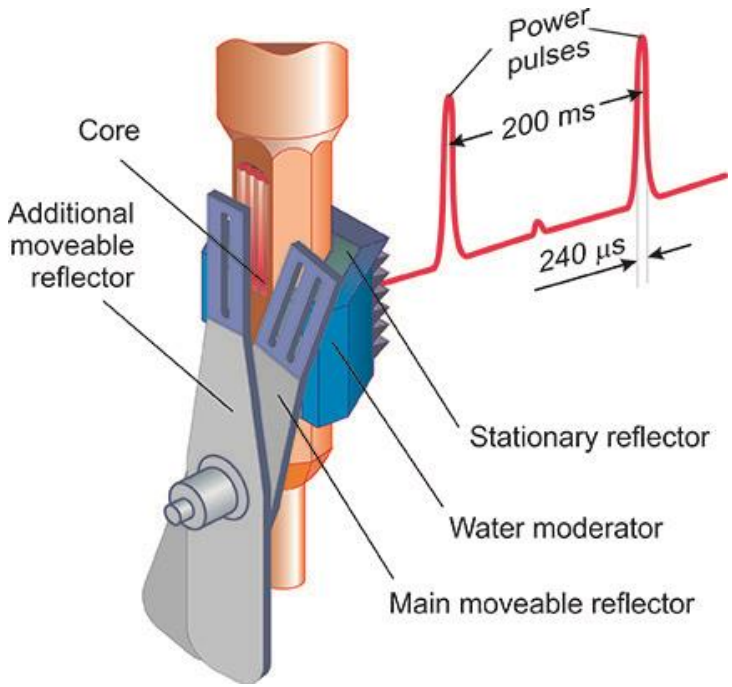
Laboratory of Radiation Biology

Periodic table of elements (2016)

Бор 5 B 10,811 Boron	Углерод 6 C 12,011 Carbon	Азот 7 N 14,0067 Nitrogen	Кислород 8 O 15,9994 Oxygen	Фтор 9 F 18,9984 Fluorine	Неон 10 Ne 20,1797 Neon												
Алюминий 13 Al 26,981539 Aluminum	Кремний 14 Si 28,0855 Silicon	Фосфор 15 P 30,97376 Phosphorus	Сера 16 S 32,066 Sulfur	Хлор 17 Cl 35,4527 Chlorine	Аргон 18 Ar 39,948 Argon												
Никель 28 Ni 58,6934 Nickel	Медь 29 Cu 63,546 Copper	Цинк 30 Zn 65,39 Zinc	Галлий 31 Ga 69,723 Gallium	Германий 32 Ge 72,61 Germanium	Мышьяк 33 As 74,92159 Arsenic	Селен 34 Se 78,96 Selenium	Бром 35 Br 79,904 Bromine	Криптон 36 Kr 83,80 Krypton									
Палладий 46 Pd 106,42 Palladium	Серебро 47 Ag 107,8682 Silver	Кадмий 48 Cd 112,411 Cadmium	Индий 49 In 114,818 Indium	Олово 50 Sn 118,710 Tin	Сурьма 51 Sb 121,757 Antimony	Теллур 52 Te 127,60 Tellurium	Иод 53 I 126,90447 Iodine	Ксенон 54 Xe 131,29 Xenon									
Платина 78 Pt 195,08 Platinum	Золото 79 Au 196,96654 Gold	Ртуть 80 Hg 200,59 Mercury	Таллий 81 Tl 204,3833 Thallium	Свинец 82 Pb 207,2 Lead	Висмут 83 Bi 208,98037	Полоний 84 Po [209]	Астат 85 At [210]	Радон 86 Rn [222]									
Дармштадтий 110 Ds [269] Darmstadtium	Рентгений 111 Rg [272] Roentgenium	Коперниций 112 Cn [277] Copernicium	(Нихоний) 113 (Nh) [286] (Nihonium)	Flerovium 114 Fl Флеровий	(Moscovium) 115 (Mc) (Московий)	Livermorium 116 Lv Ливерморий	(Tennessine) 117 (Ts) (Теннессин)	(Oganesson) 118 (Og) (Оганесон)									

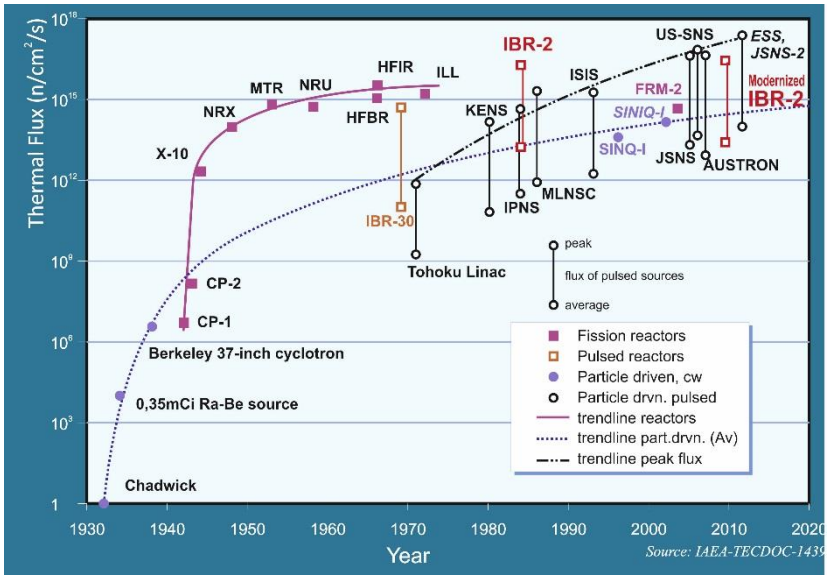
105
Db
Dubnium

Research Triangle Park, NC: On 28 November 2016, the International Union of Pure and Applied Chemistry (IUPAC) approved the name and symbols for four elements: nihonium (Nh), moscovium (Mc), tennessine (Ts), and oganesson (Og), respectively for element 113, 115, 117, and 118.



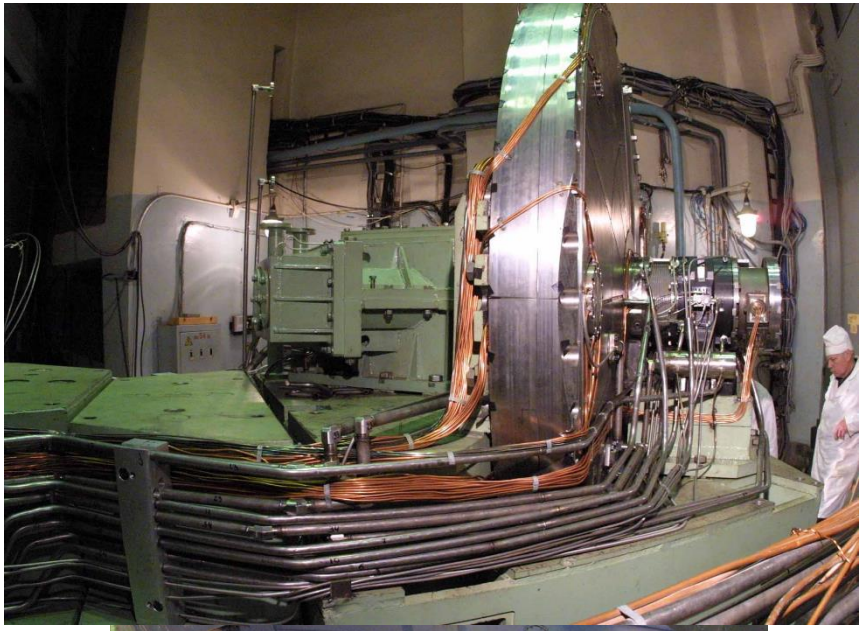
The IBR-2 Reactor

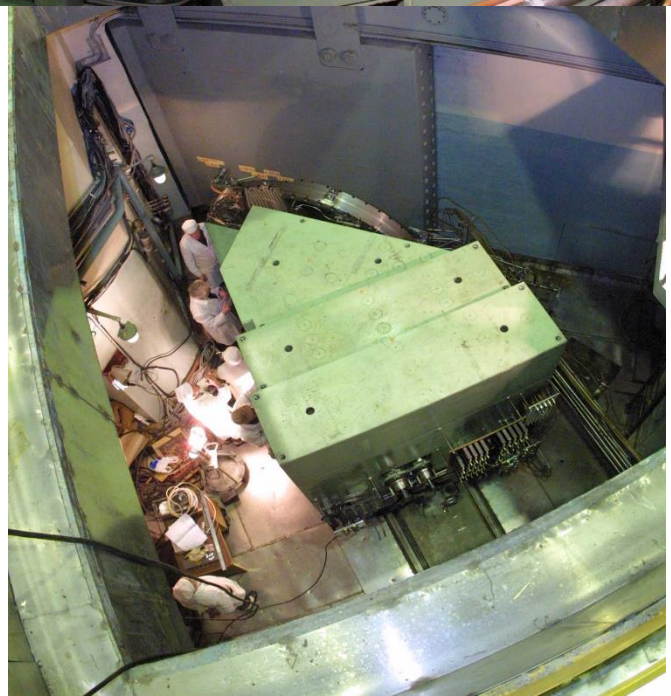
Average power, MW	2
Fuel	PuO_2
Number of fuel assemblies	69
Maximum burnup, %	9
Pulse repetition rate, Hz	5; 10
Pulse half-width, μs:	
fast neutrons	240
thermal neutrons	340
Rotation rate, rev/min:	
main reflector	600
auxiliary reflector	300
MMR and AMR material	nickel + steel
MR service life, hours	55000
Background, %	7.5
Thermal neutron flux density from the surface of the moderator:	
- time average	~ 10^{13} n/cm²·s
- burst maximum	~ 10^{16} n/cm²·s



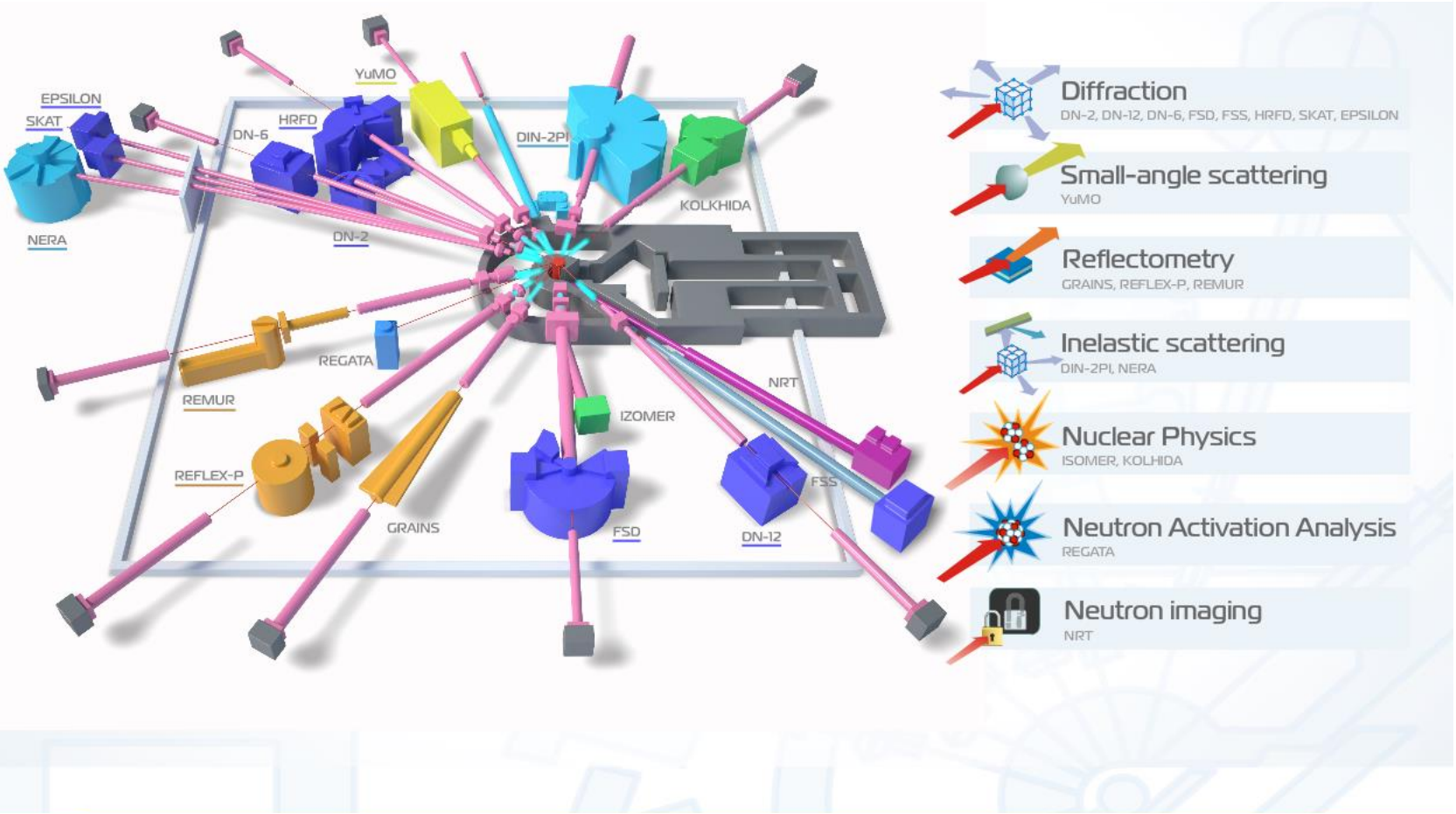
Reactor operation for physics experiments, hr/year ~2500

Movable reflector





Facilities at IBR-2 reactor

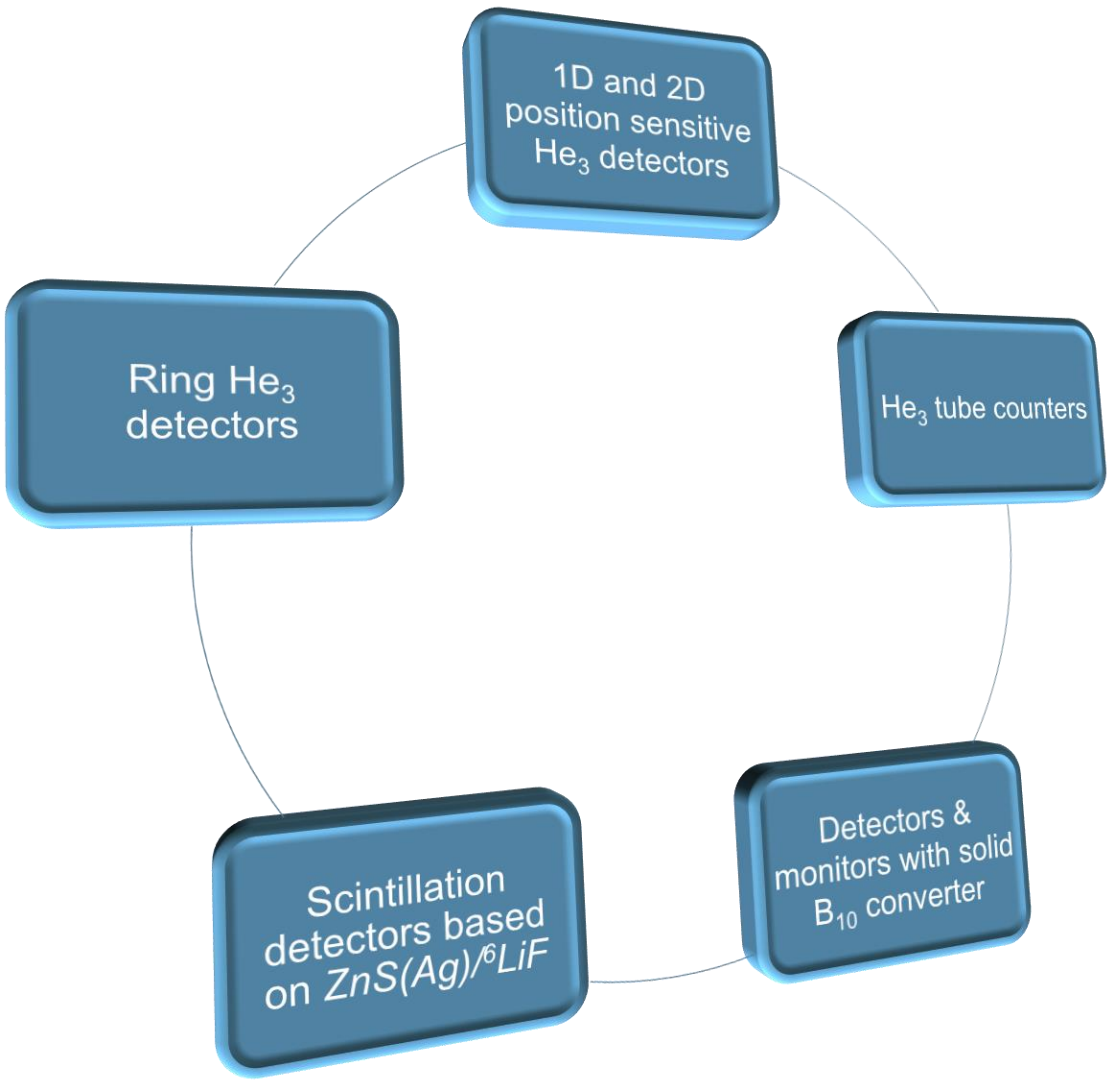


Major nuclear reactions used for registration of thermal neutrons

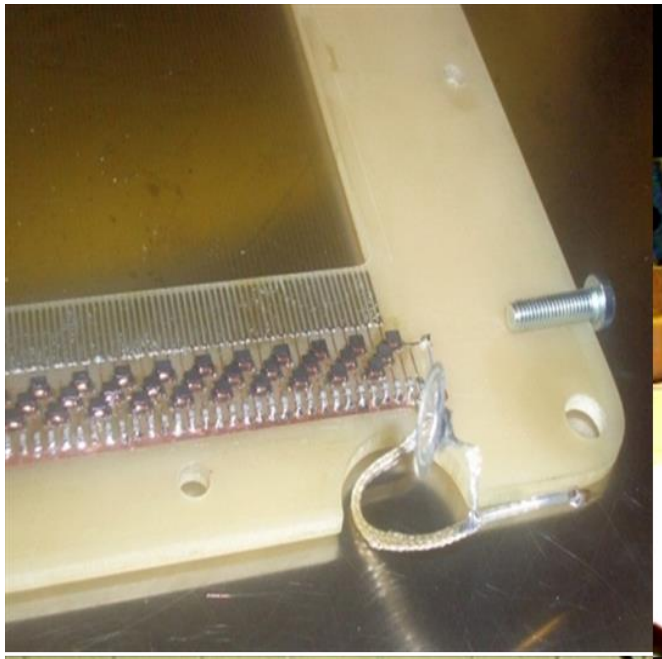
Reaction	Cross-section for E=25 meV, barn	Secondary particles	Particle energies MeV	Energy release, MeV
n + ^{3}He	5333	p^{+} ^{3}H	0.57 0.2	0.77
n + ^{6}Li	940	^{3}H ^{4}He	2.74 2.05	4.79
n + ^{10}B	3836	^{4}He ^{7}Li γ	1.47 0.83 0.48 (93%)	2.3
n + ^{235}U	681	Fission fragments +		1-2

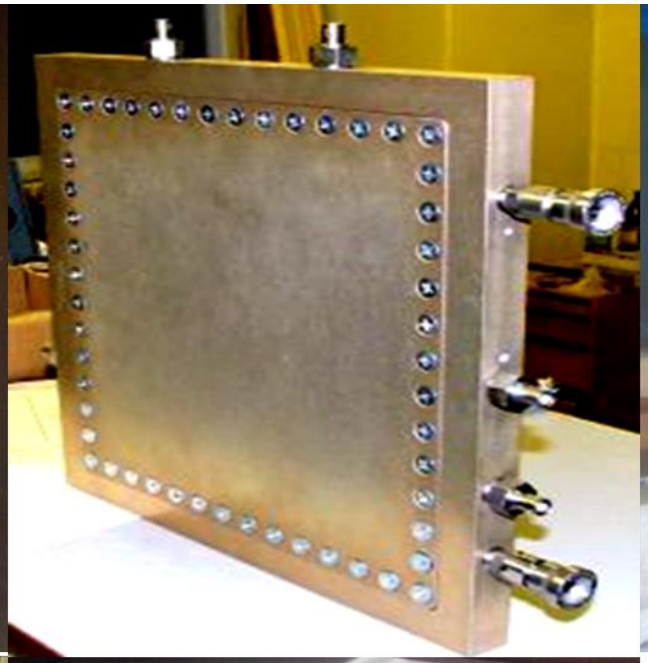
n + ^{155}Gd → Gd* → γ-ray spectrum → conversion electron spectrum
n + ^{157}Gd → Gd* → γ-ray spectrum → conversion electron spectrum

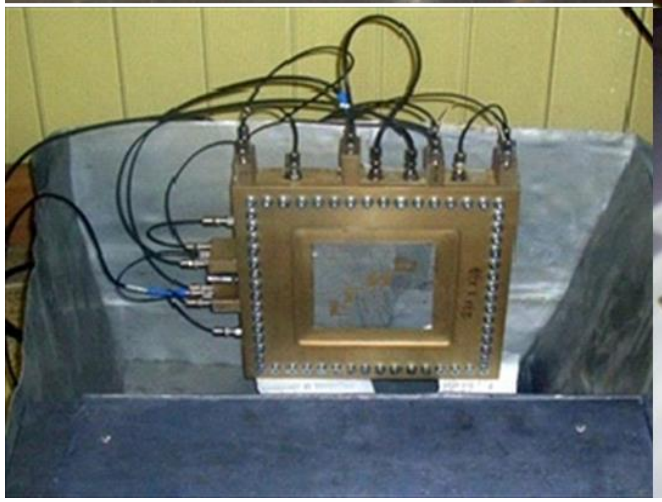
Detectors of instruments of the IBR-2 reactor

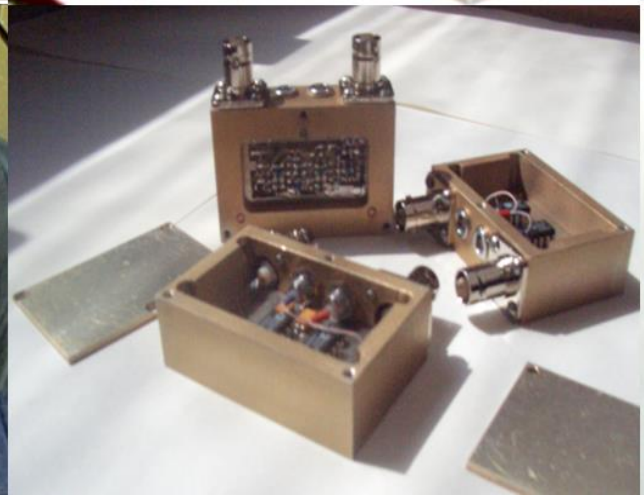


2D and 1D position-sensitive detectors (MWPC)



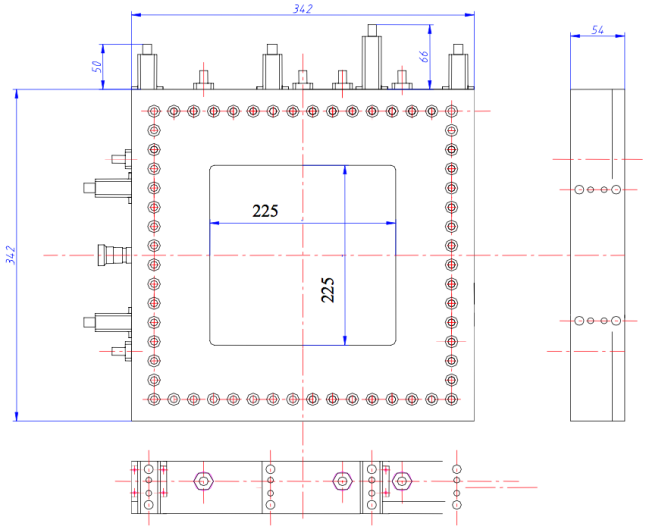


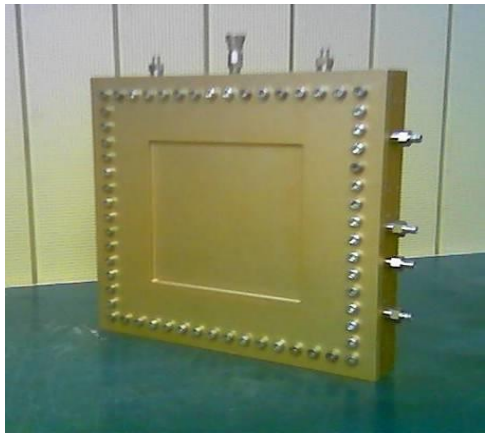


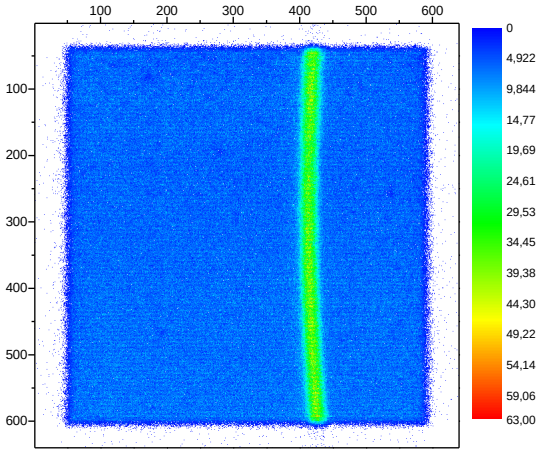


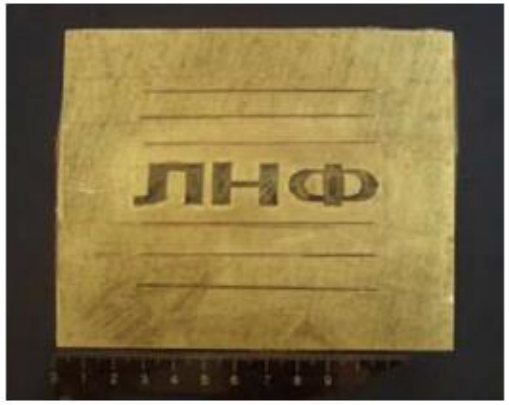
2D PSD 200 x 200 and 225 x 225 mm²

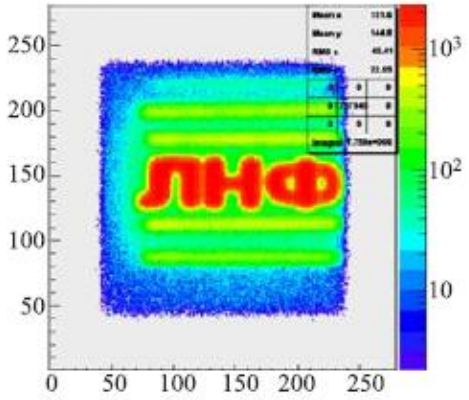
Type	2 – D MWPC
Active area	200x200 mm²
Position resolution	2,0x2,0 mm²
Range of neutron wavelength	0,4 - 12 A
Efficiency for thermal neutrons (λ=2 Å)	65%
Position determination	Delay line











Tests of 2D PSD detectors at Nuclear Physics Institute , NPI ASCR, Řež, Czech Republic

Test measurements with Cd mask «ЛНФ».
50 mbar He_3 + 950 mbar CF_4

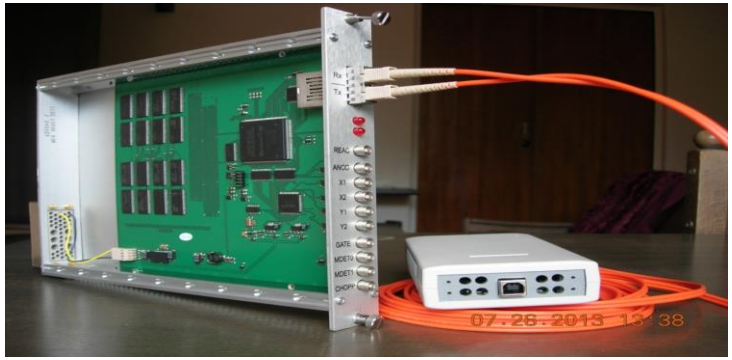
DAQ systems for 1D and 2D position sensitive detectors

De-Li-DAQ-1 block

- Counting rate up to 10^5 ev./sec
- Installation in PCI port in PC

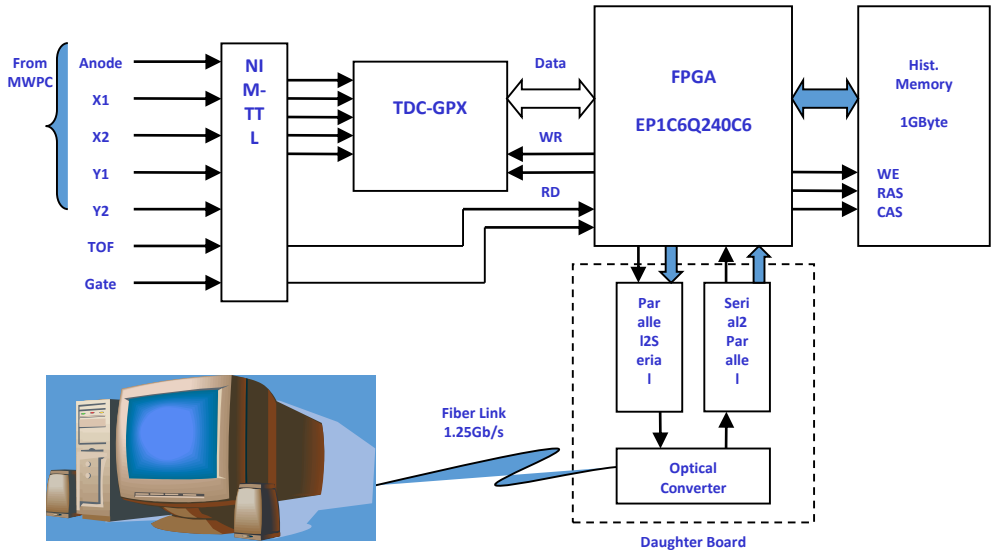
- More than 50 boards have been produced.

They installed in FLNP, HMI (Germany), Rzez (Cheh Republic), Kurchatov inst, Troick etc.

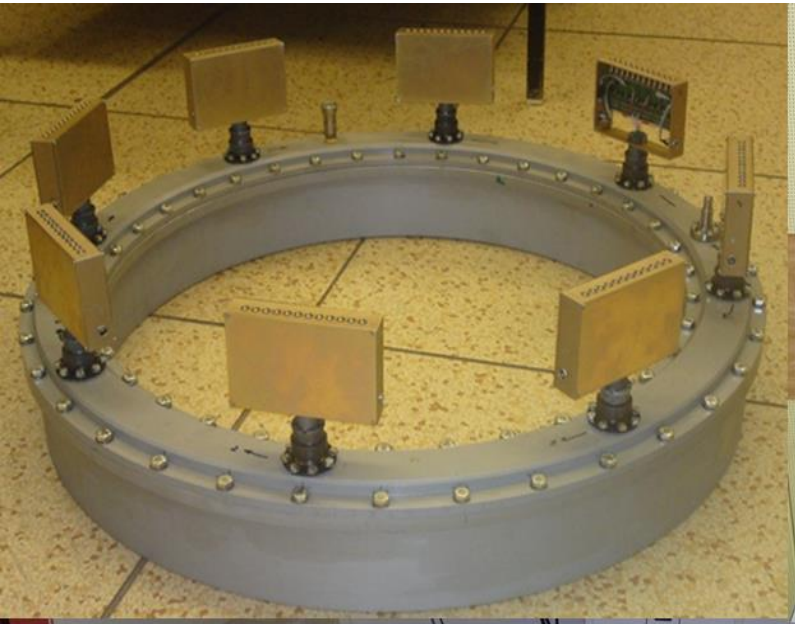


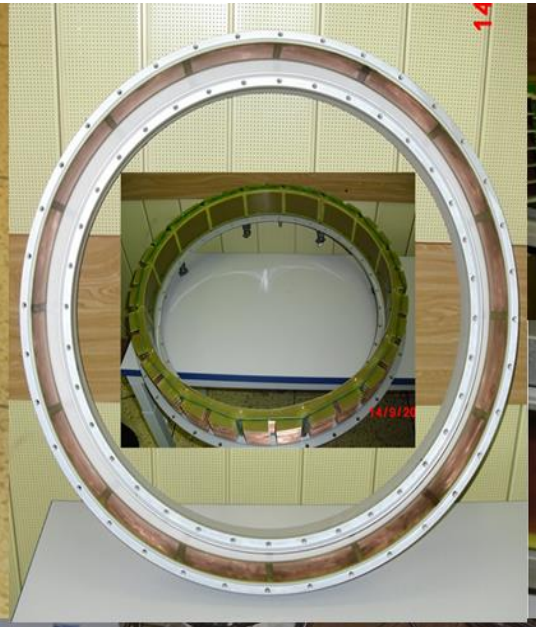
De-Li-DAQ-2 block

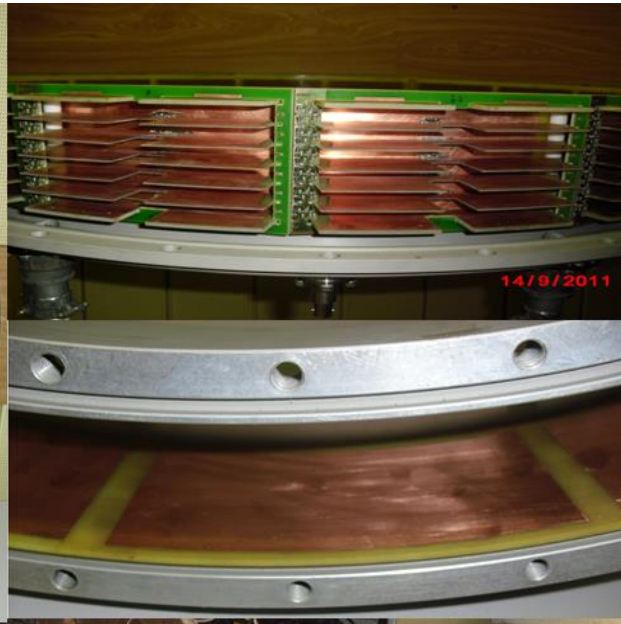
- Counting rate > 10^6 ev./sec
- Standard NIM installation (power supply)
- PC connection via USB

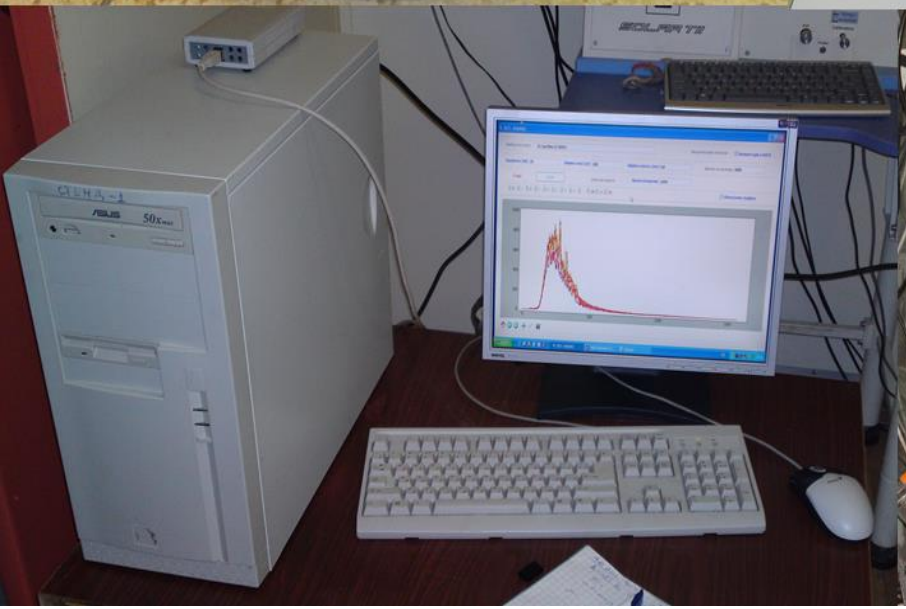


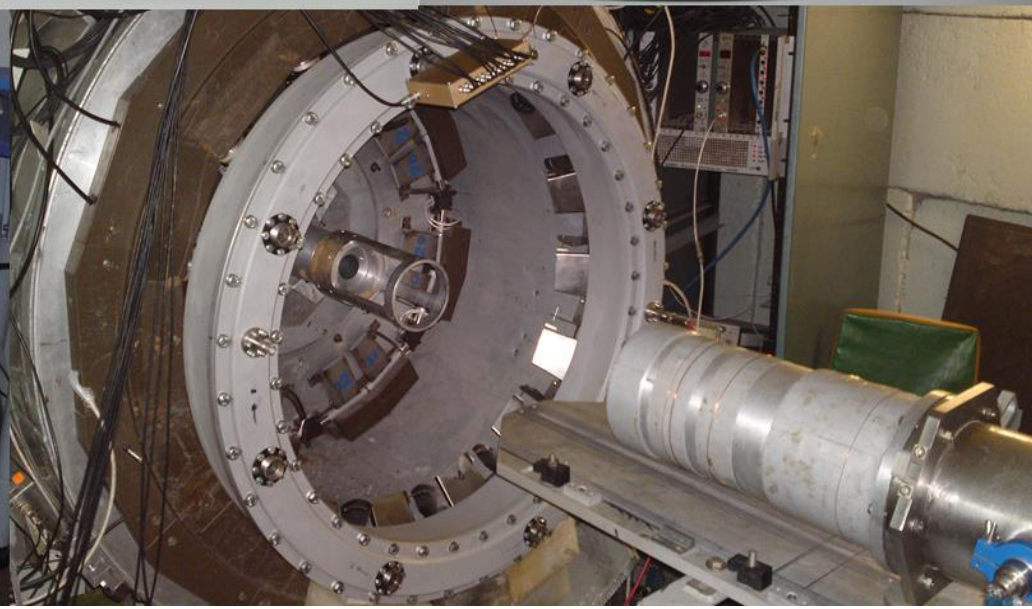
MULTISECTION RING DETECTOR OF THERMAL NEUTRONS FOR DIFFRACTION STUDIES ON MICROSAMPLES IN AXIAL GEOMETRY





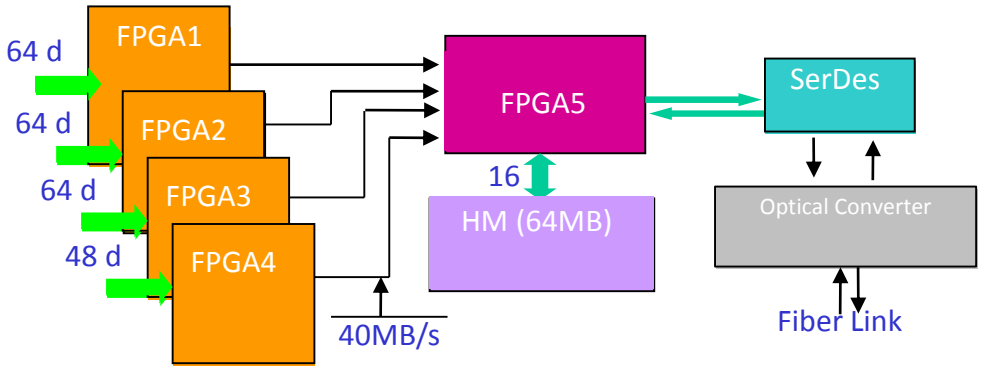




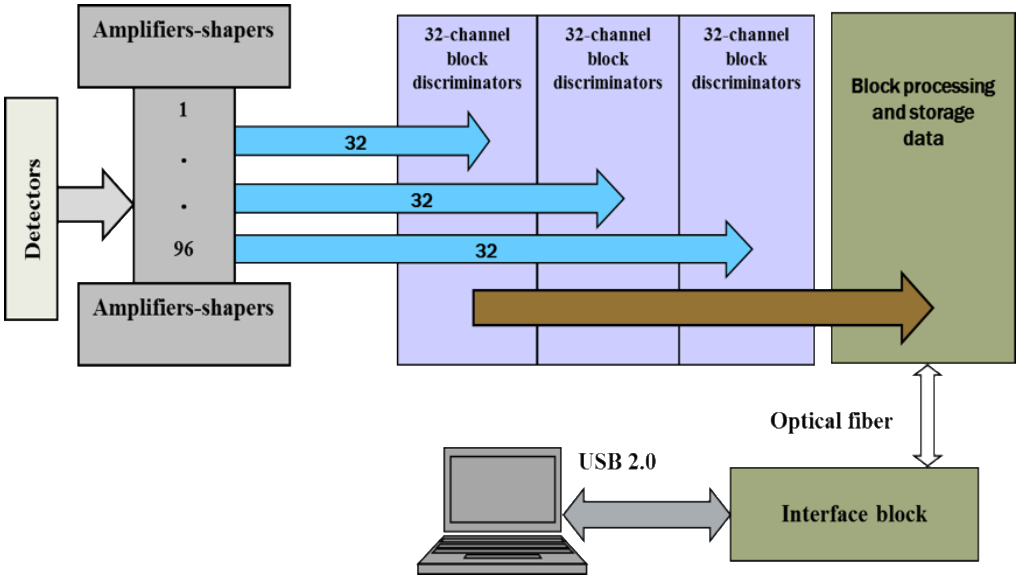


Detector electronics

- **The number of detector elements</= 240;**
- **The total throughput of system is $8x10^6$ [ev./s] at 240 detectors in the system or 3 x 10^4 [ev./s] for one detector element;**
- **The frequency of sampling time is 62.5 [MHz] (16 [ns]) and the stability of the generator is 1 [ppm];**
- **Events are registered in the absolute time of the experiment, max. time exposition is $4.5x10^6$ [s];**
- **Register signaling with the same accuracy as the detector elements: the start of the reactor, the beginning / end of the time window, the end of exposure, etc .;**
- **Registering an additional 6 external signals (falling and growing front): for example PICK-UP signal from Fourier diffractometer;**
- **Histogram memory (64MB) for visualization and operational control of data collection.**
- **Data transfer between the data acquisition electronics and PC USB interface is performed through a fiber optic line at a rate of 1.25 [Gbit /s].**



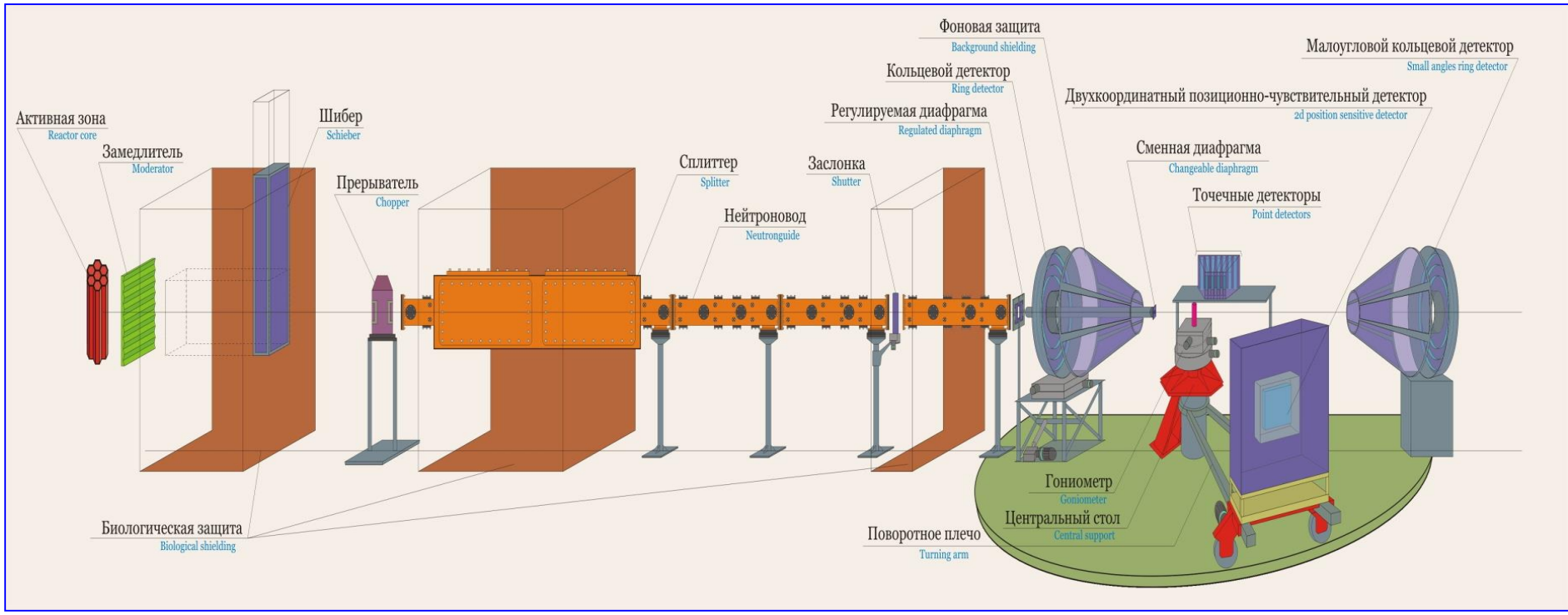
Detector electronics



Block of data processing and accumulation:	
Frequency of time sampling of all signals	max. 62.5 MHz
Maximum registration rate	$8 \cdot 10^6$ events/s ($\sim 3 \cdot 10^4$ for one element)
PC interface	USB 2.0
Internal histogram memory	64 Mb
Maximum registration delay relative to reactor burst	0.268 s
Accuracy in specifying the channel width for the histogram memory and the time window duration	16 ns

3×32-channel discriminators	NIM standard
Preamplifiers and amplifiers:	
Preamplifier type	charge-sensitive
Power	± 12 V
Gain	40
Signal shaping time	1 μs
Output signal polarity	positive
Connectors	LEMO
High voltage	- 1000 V

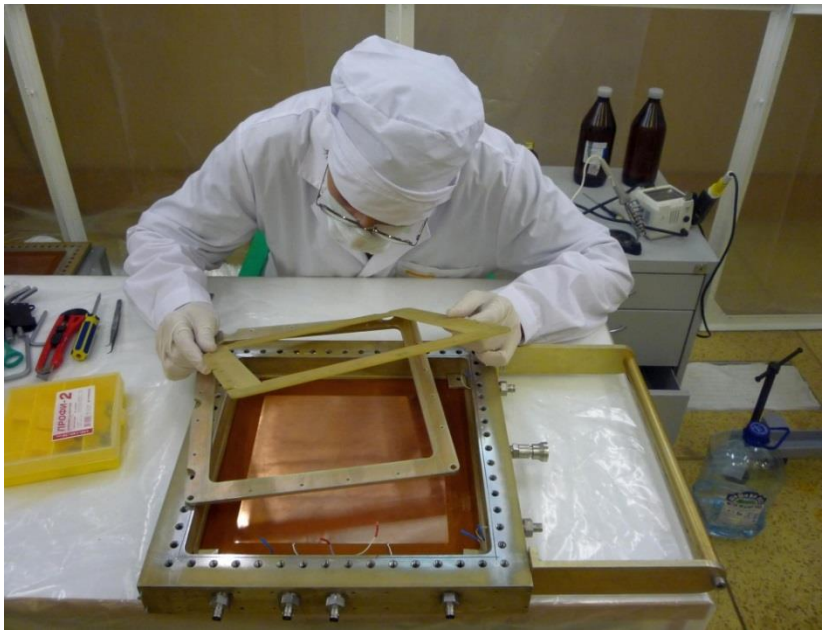
Real time diffractometer (RTD)



Detector for small angle neutron scattering at Real Time Diffractometer

The detector is divided into 9 independent equidistant coaxial rings. The cathodes of each ring are divided into 16 independent sectors. The signal pickup is performed from anode wires (shared by all rings) and from each of the 16 cathodes. Thus, this detector system consists of 144 + 9 independent detectors.

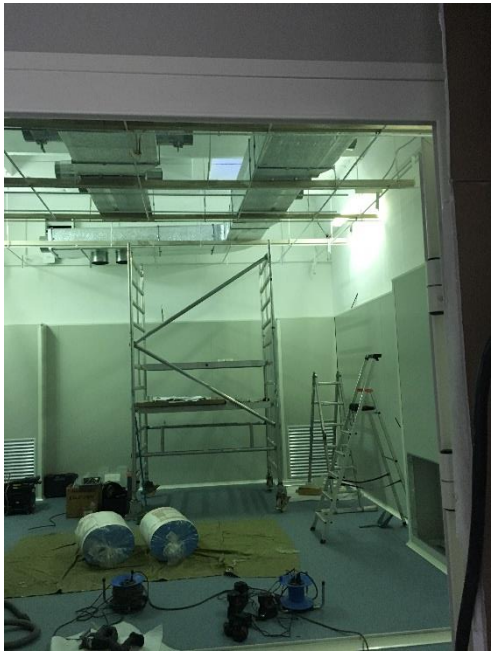
Infrastructure



Clean room

Helium-3 purification facility

New clean room

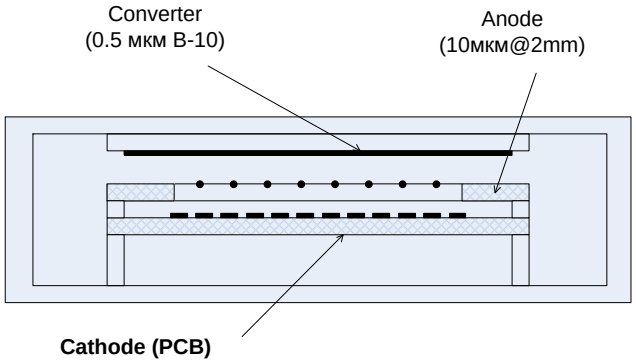


New clean room

Clean area = 48м ^{2}

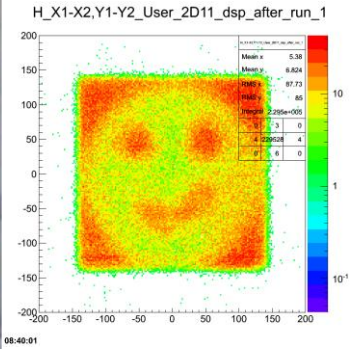
Prototype with boron converter

- 200x200 0,5 mkm 10B converter made by ESS.
- MWPC with fiberglass cathode.
- Spatial resolution 0,9x1,3 mm.
- Very good uniformity and stability.

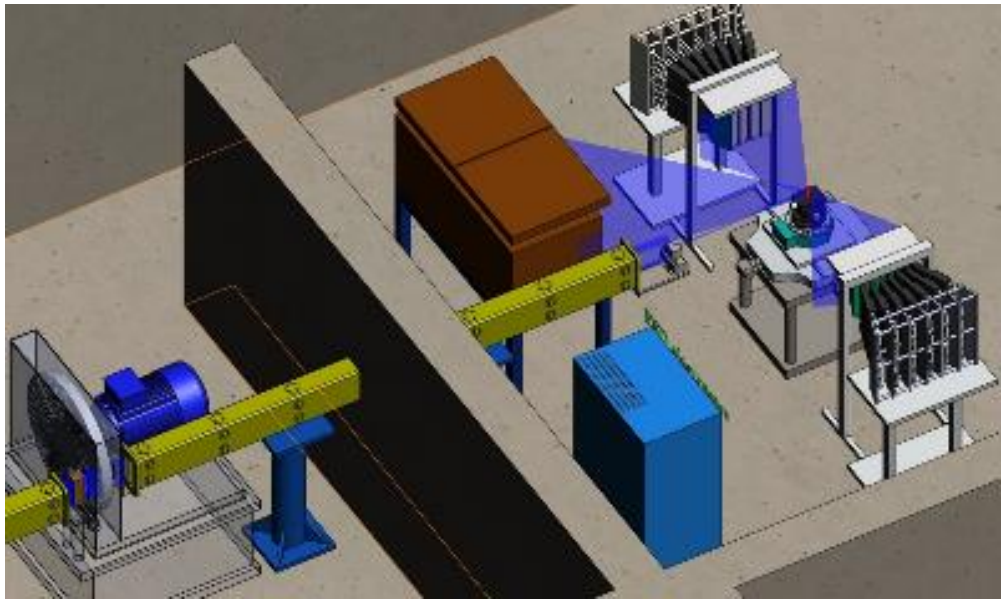


Benefits:

- For cold neutrons counting (thin entrance window)
- To use in vacuum chambers (no pressure)
- For instruments with better resolution (thin layers)
- For higher count speed (multilayers)

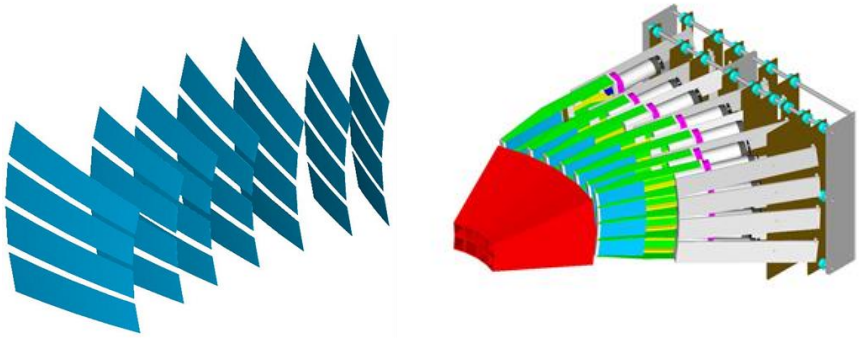


Fourier Stress Diffractometer (FSD)

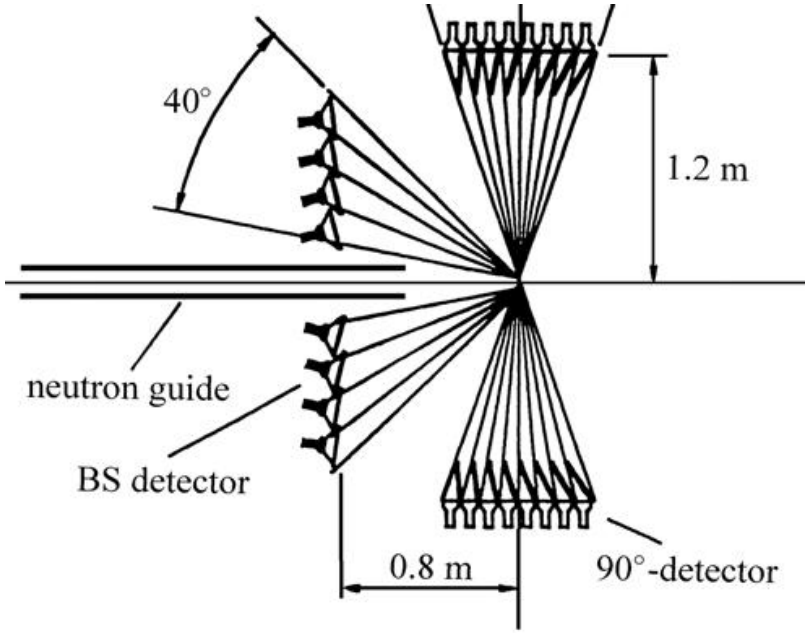


ZnS(Ag)/^{6}LiF *ND screen, thickness = 0.42 mm*

90°- ASTRA detector



Geometry of the ASTRA detector



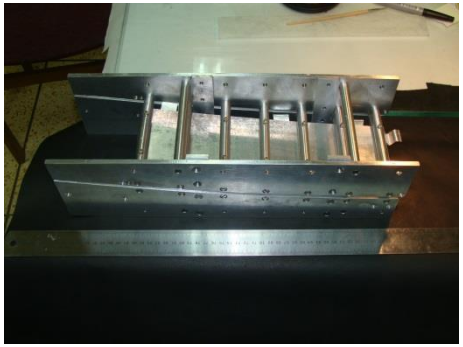
R= 900 mm.
φ= -2.5deg. - +2.5deg.

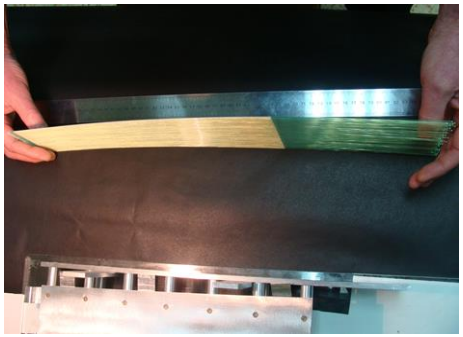
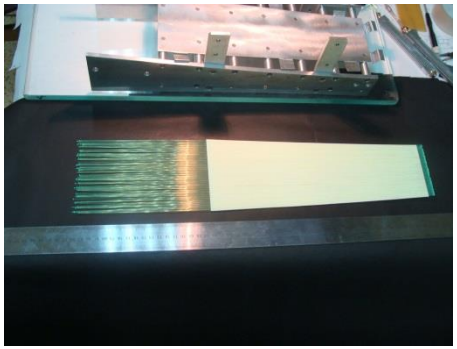
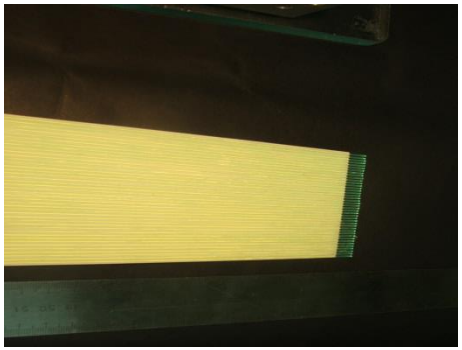
№	Angle range ϑ , deg.
1	110.000 - 103.000
2	101.000 - 96.031
3	95.531 - 91.000
4	89.000 - 84.031
5	83.531 - 79.000
6	77.000 - 73.639
7	73.139 - 70.000

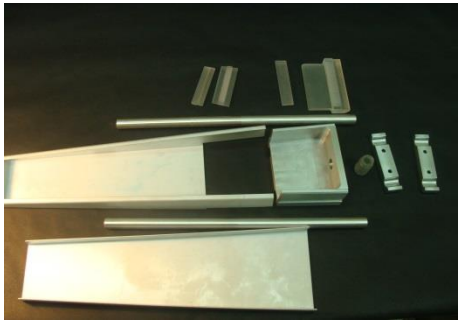
Fourier Stress Diffractometer FSD

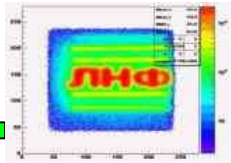
The process of production a scintillation counter

ZnS(Ag)/^{6}LiF *ND screen, thickness = 0.42 mm*

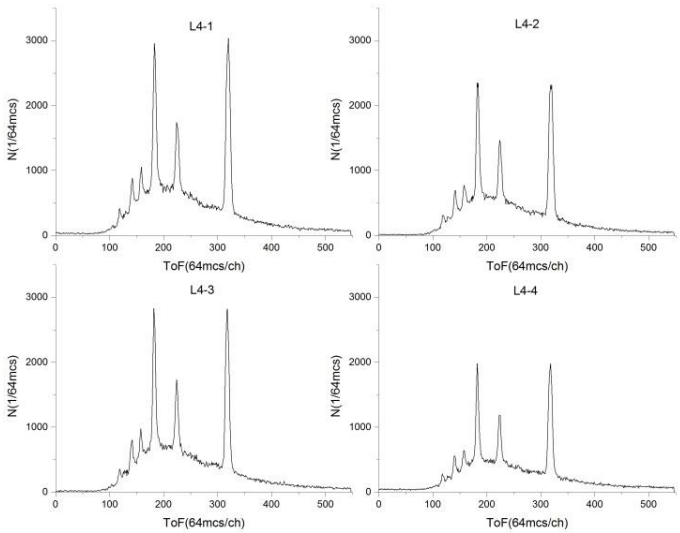


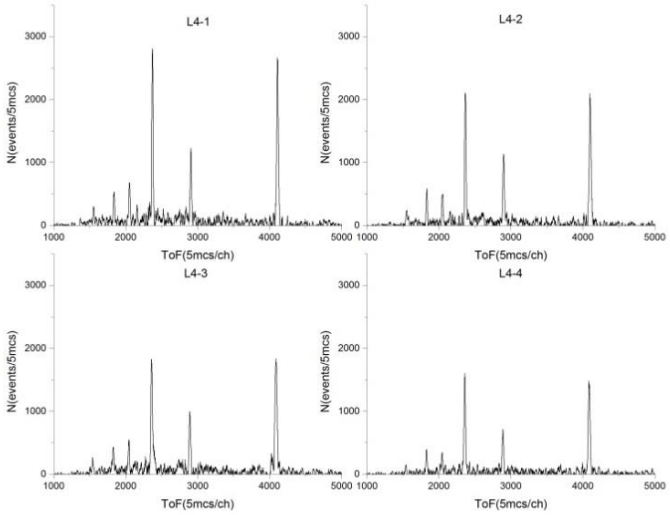




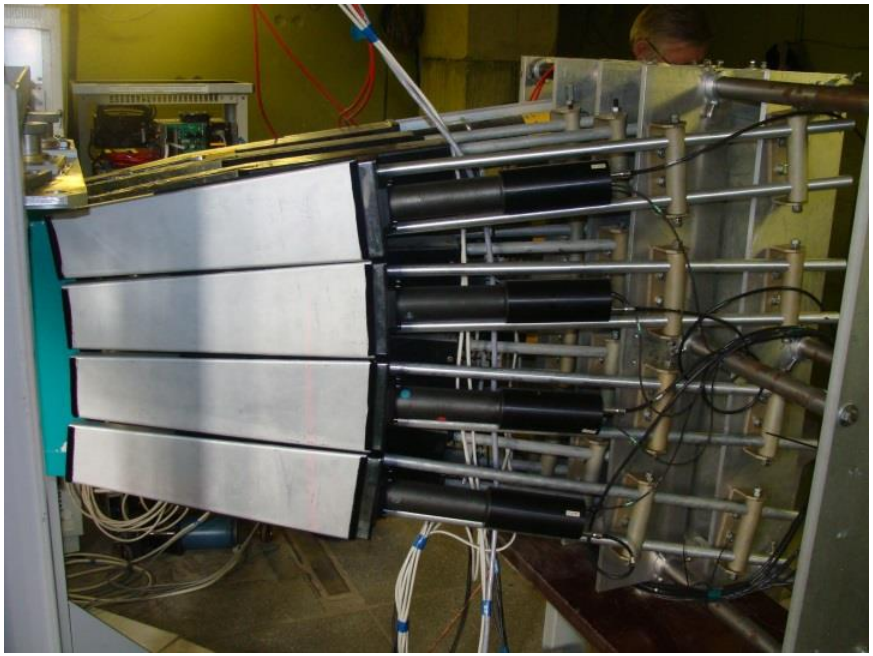
The detector system ASTRA



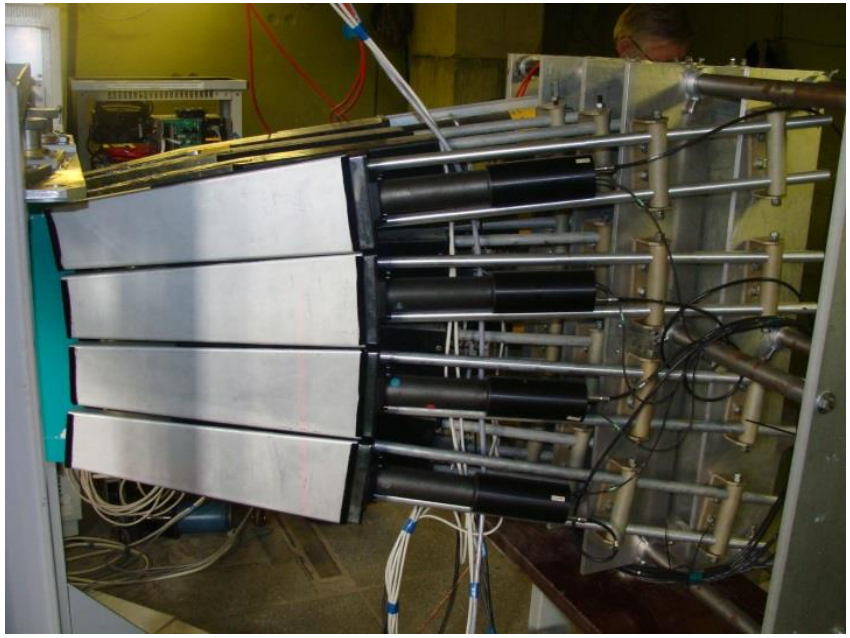
ToF- spectra of low resolution

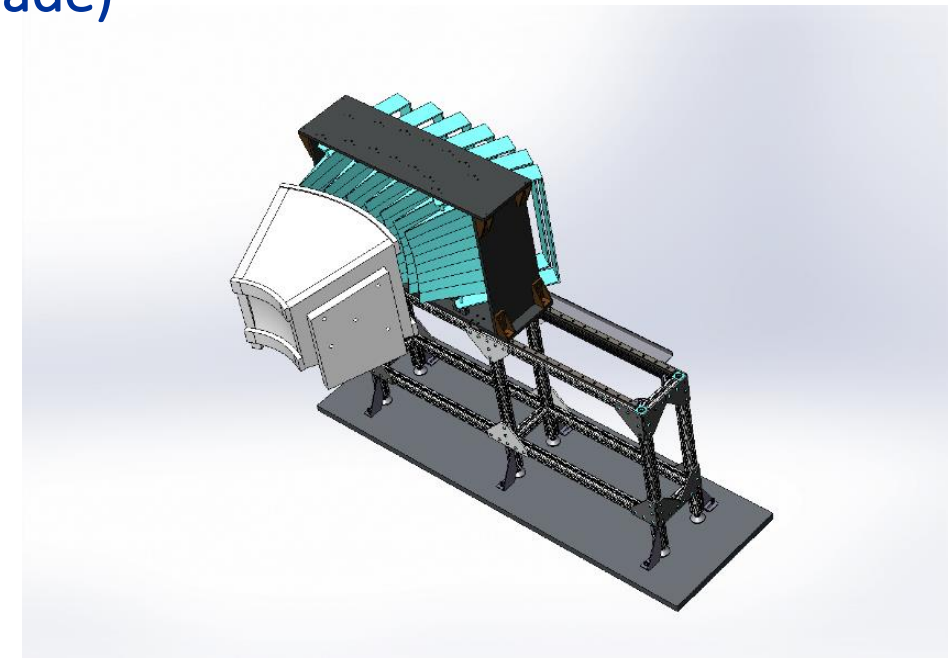


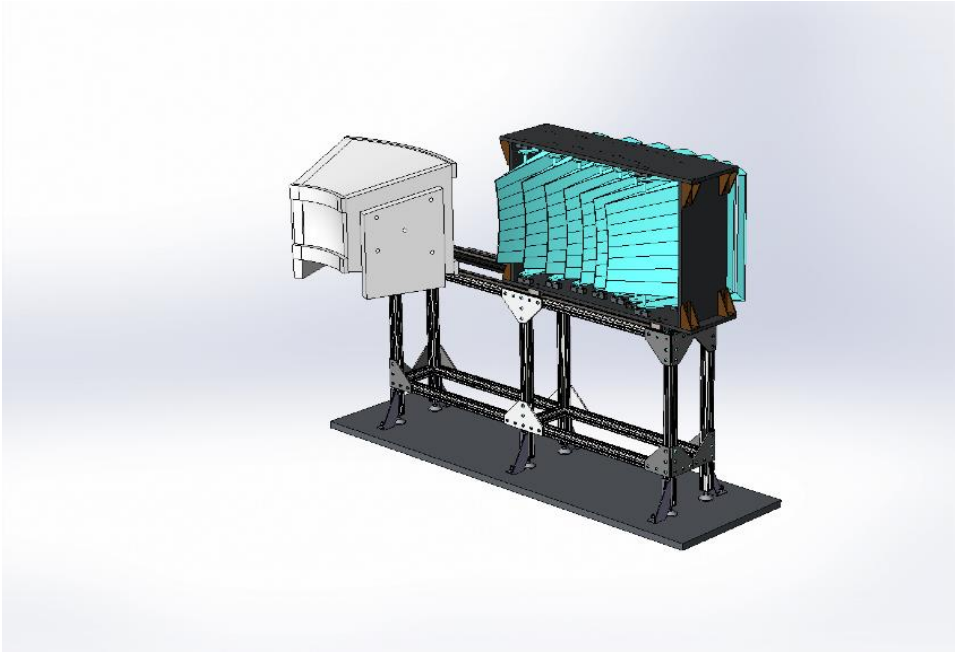
ToF- spectra of high resolution

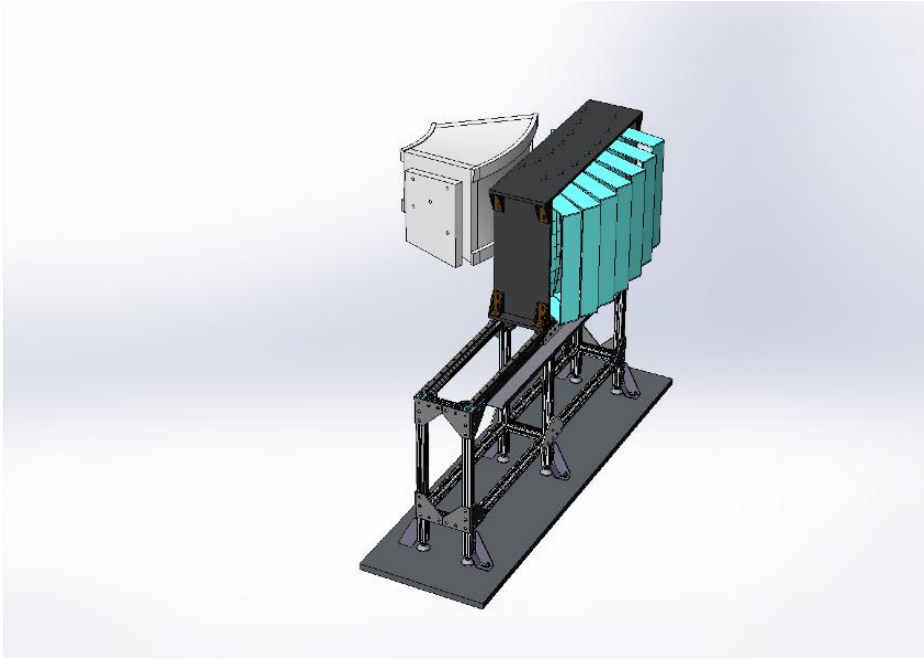


The detector system ASTRA (upgrade)

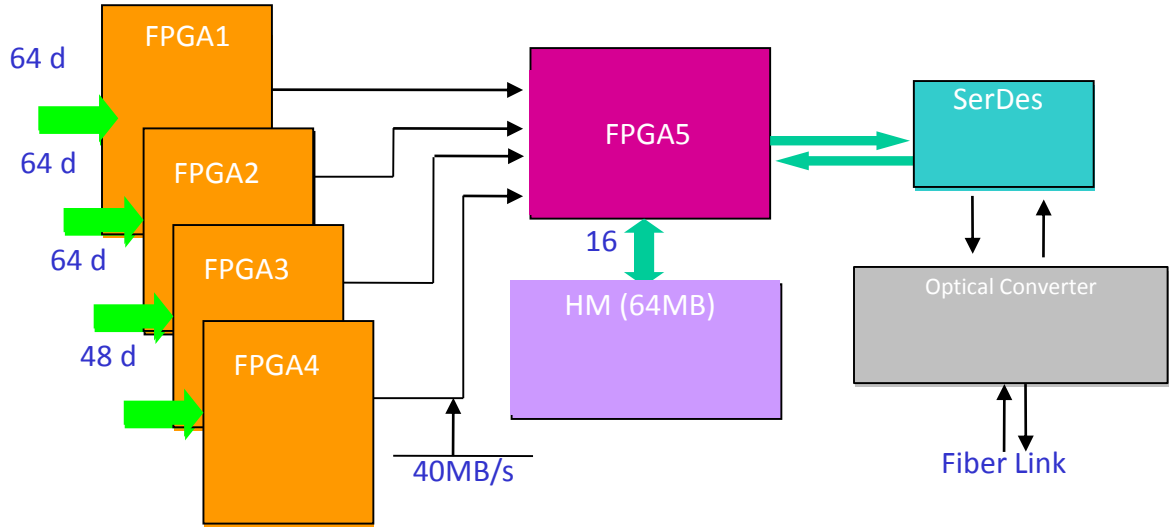






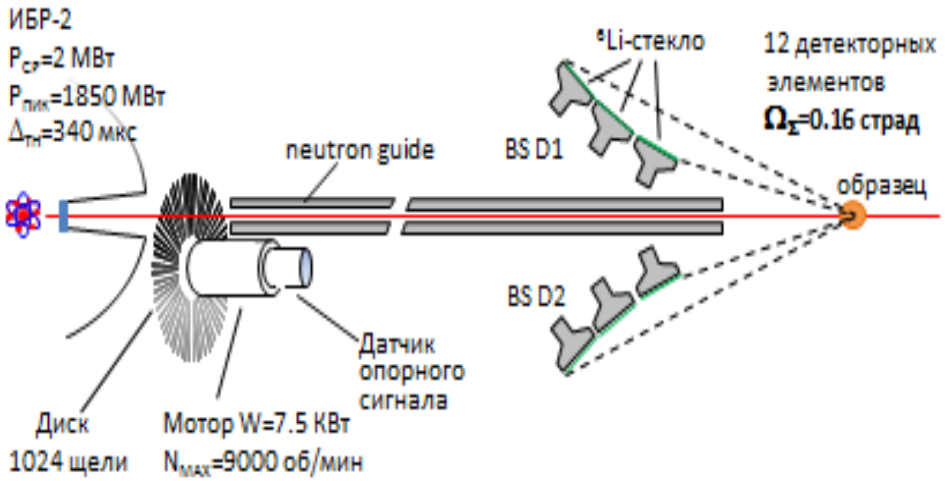


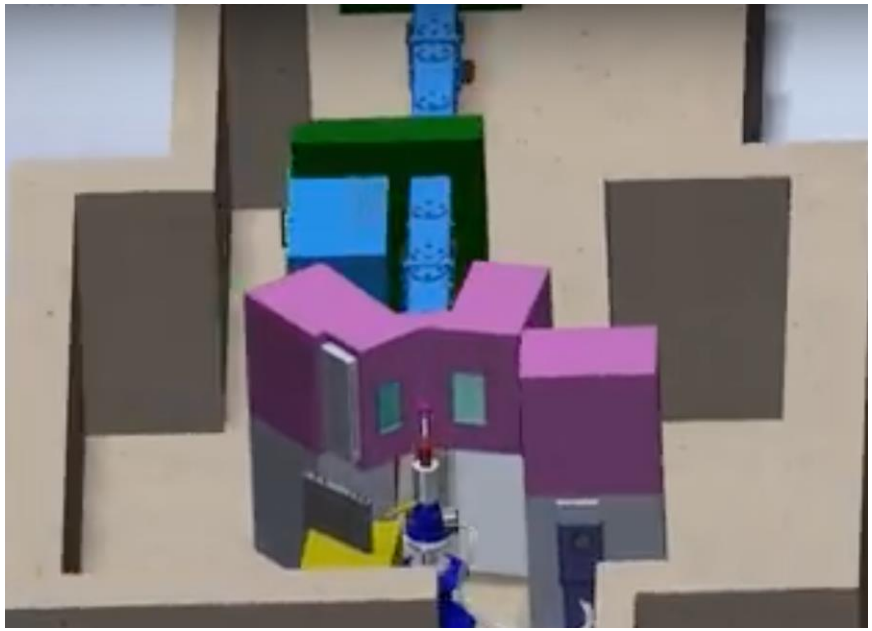
DAQ electronics for multi-point detector (MPD)



- Maximal amount of detectors – 240;
- Maximal counting rate - 8·10^6 ev./sec.;
- Standard NIM installation (power supply)
- List mode
- PC connection via USB 2.0

High resolution Fourier Diffractometer HRFD



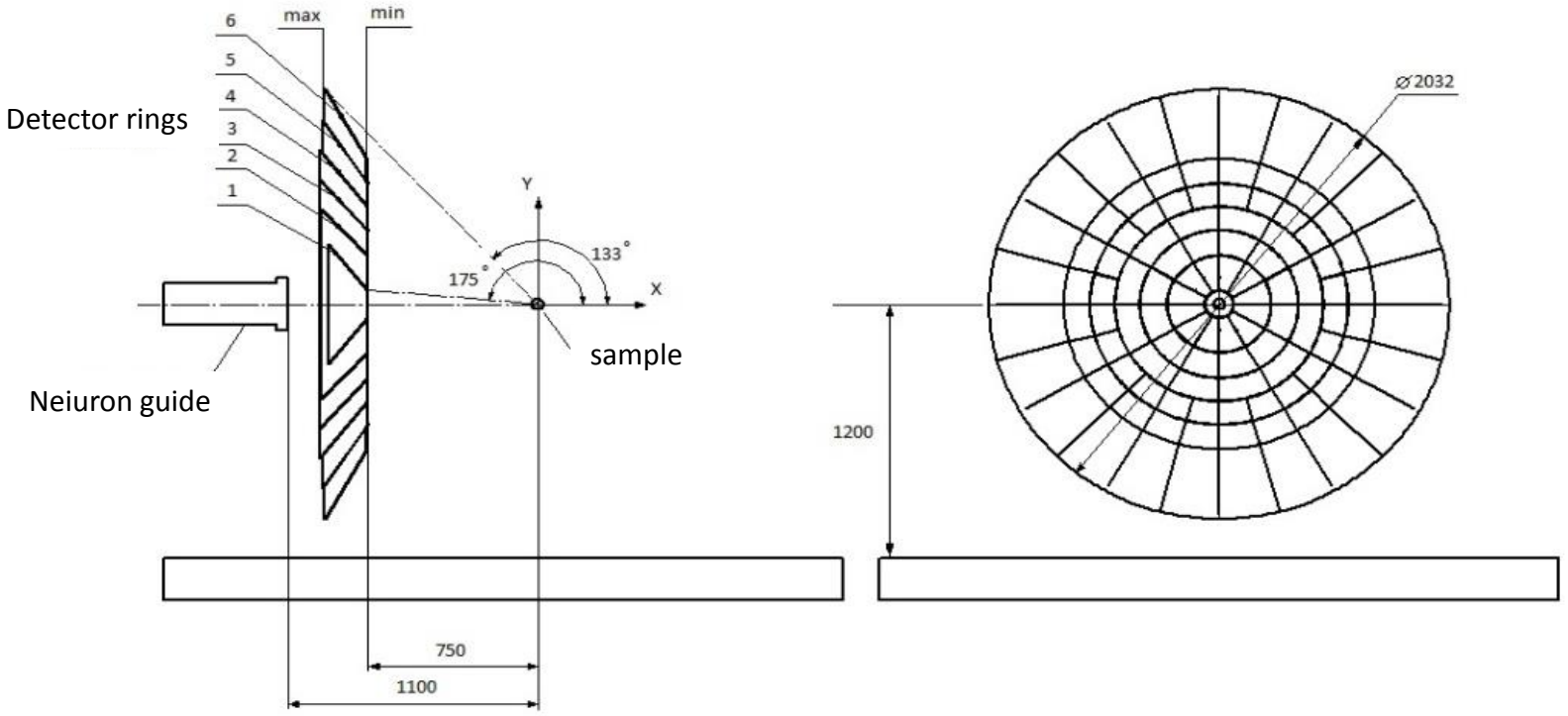


R= Δd/d≈0.001

Disadvantages of current back scattering detector:

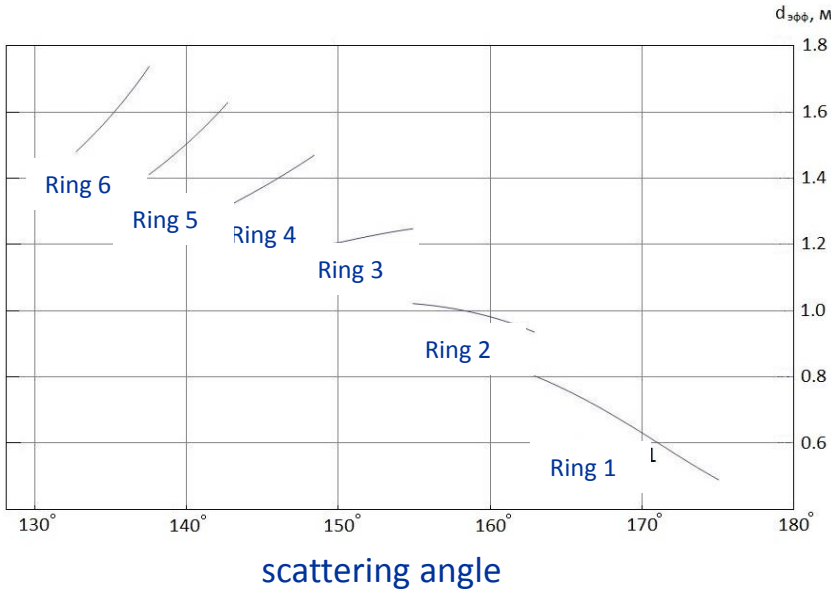
- current solid angle of detector ~0.16 sr;
- a high sensitivity to γ-background (^{6}Li glasses).

Development of a wide-aperture backscattering detector (BSD) for the HRFD diffractometer

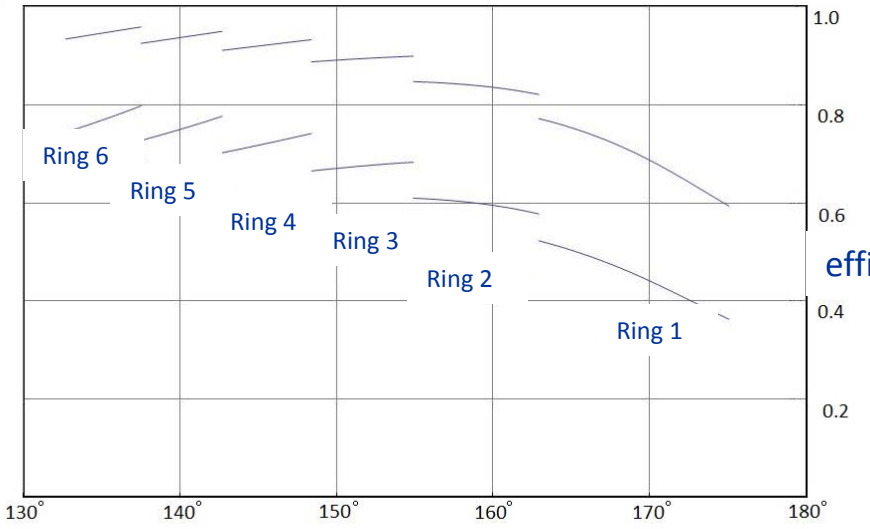


- Solid angle: Ω_{Θ} ~ 2.0 sr. (more ~12.5 times).
- 0.42 mm, ZnS(Ag)/^{6}LiF. (with wavelength shifting fibers)
- 216 independent elements

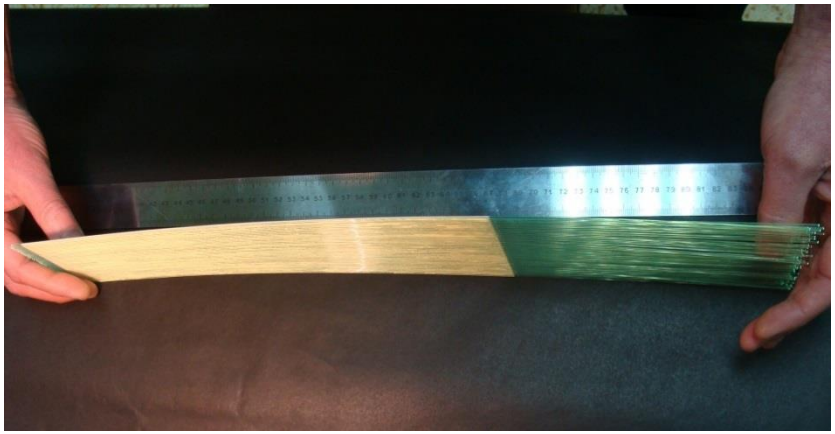
Dependence of the detector efficiency on the scattering angle



scattering angle

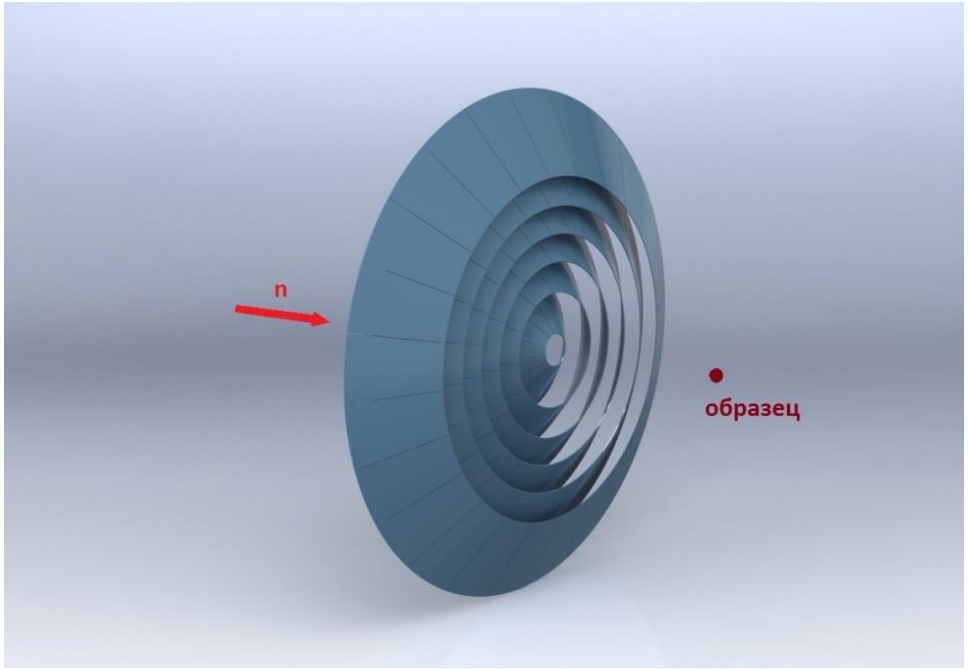


scattering angle



Element of the scintillation screen (white plate) together with the optical wavelength shifting fibers glued to it on both sides. The curved shape of the screen is determined by the requirement of space-time focusing

3D graphic presentation of a large-aperture backscattering detector.



$\Delta d/d \approx 0.001$

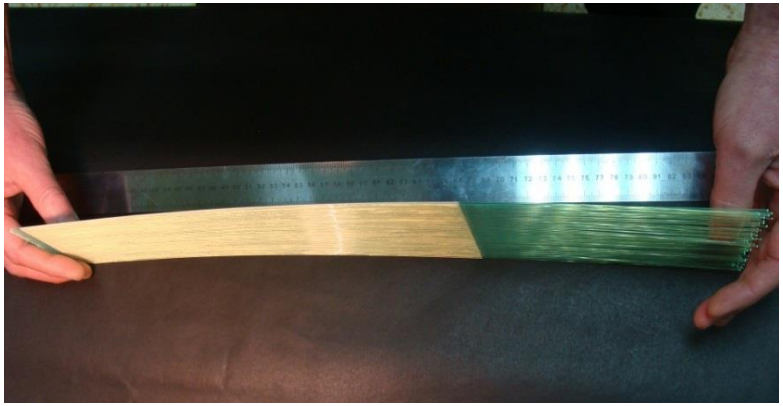
$\emptyset_{samp}$, mm	1	2	3	4	5	6	7	8
$<\Delta_1>$	4.0×10^{-5}	6.9×10^{-5}	1.0×10^{-4}	1.3×10^{-4}	1.7×10^{-4}	2.0×10^{-4}	2.3×10^{-4}	2.6×10^{-4}
$<\Delta_2>$	4.6×10^{-5}	7.3×10^{-5}	1.0×10^{-4}	1.3×10^{-4}	1.7×10^{-4}	2.0×10^{-4}	2.3×10^{-4}	2.6×10^{-4}
$<\Delta_3>$	5.1×10^{-5}	7.6×10^{-5}	1.1×10^{-4}	1.4×10^{-4}	1.7×10^{-4}	2.0×10^{-4}	2.3×10^{-4}	2.6×10^{-4}
$<\Delta_4>$	5.5×10^{-5}	7.9×10^{-5}	1.1×10^{-4}	1.4×10^{-4}	1.7×10^{-4}	2.0×10^{-4}	2.3×10^{-4}	2.6×10^{-4}
$<\Delta_5>$	5.8×10^{-5}	8.1×10^{-5}	1.1×10^{-4}	1.4×10^{-4}	1.7×10^{-4}	2.0×10^{-4}	2.3×10^{-4}	2.6×10^{-4}
$<\Delta_6>$	6.1×10^{-5}	8.2×10^{-5}	1.1×10^{-4}	1.4×10^{-4}	1.7×10^{-4}	2.0×10^{-4}	2.3×10^{-4}	2.6×10^{-4}

Geometric contribution to the total resolution of the diffractometer.

$<\Delta_i> = 2.36\sigma_i$ – error value for the i-th ring of the detector.

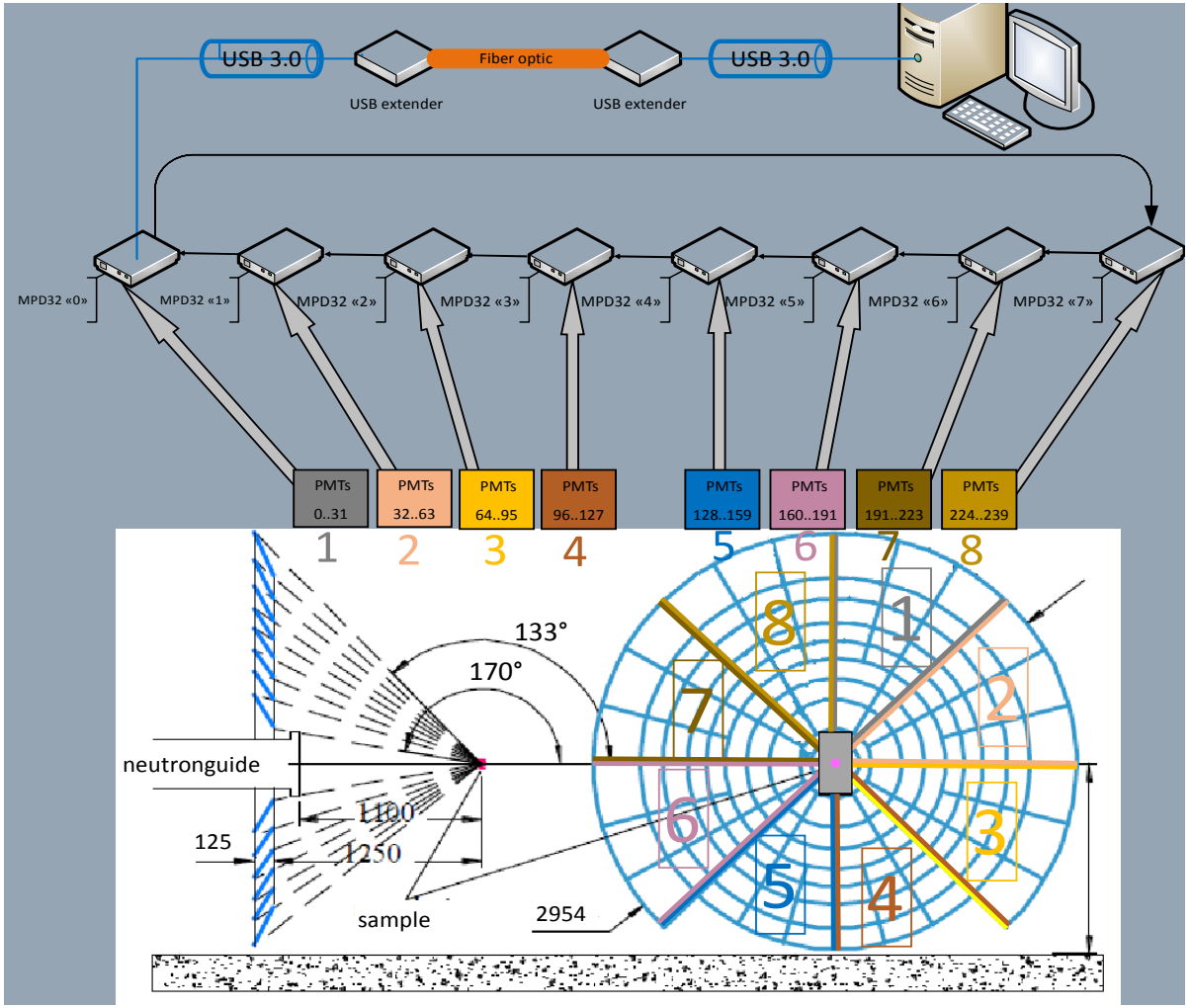
The main materials and equipment

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



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

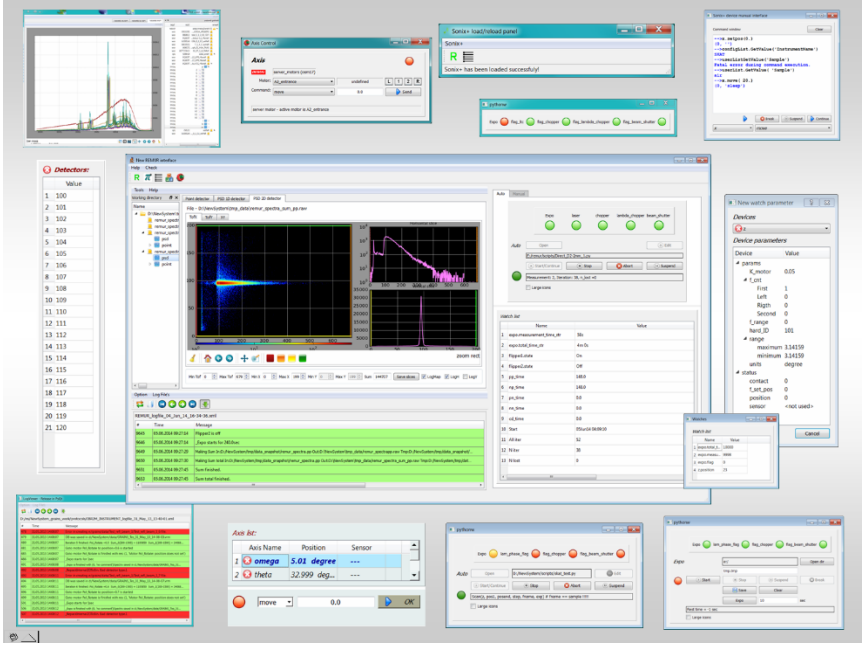
DAQ electronics for multi-point detector (MPD)

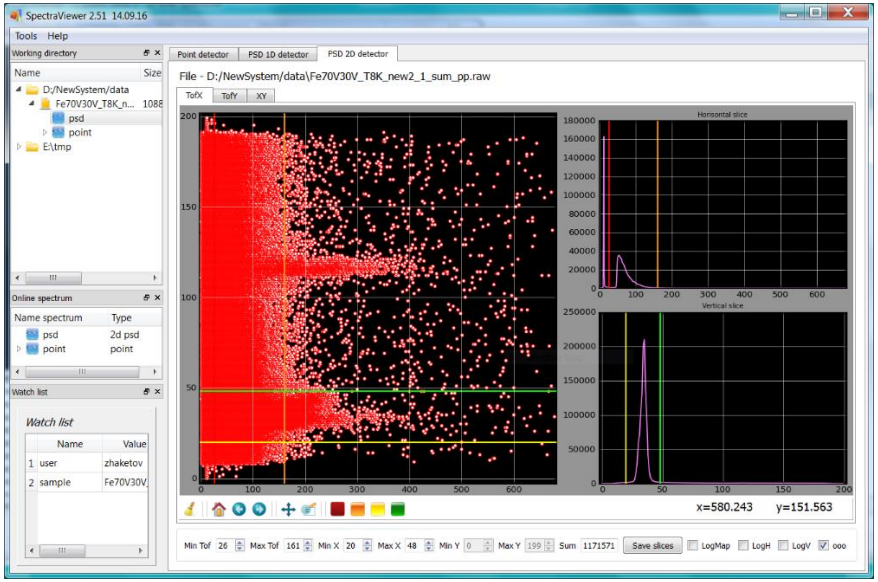


- MPD-32 combines discriminator and encoder for 32 analog inputs
- USB3.0 interface with optical fiber extender
- maximum data rate $6*10^7$ event/sec
- high speed (2.5 Gb) interunit interface for linking several MPD-32 to common USB3.0 port.

*) More information on the poster of V. Drozdov

Software Sonix+ and Web remote system



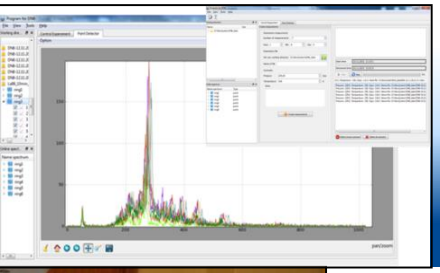
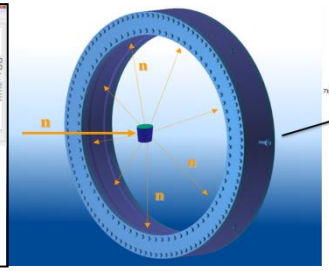
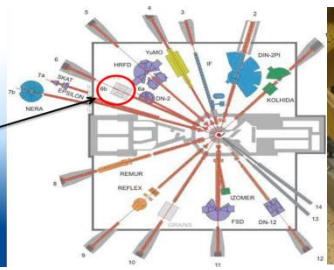
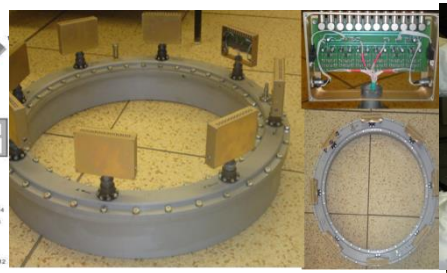


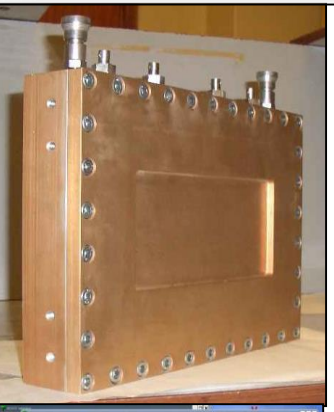
The control over experiments and the visualization of neutron data are realized in a single user interface of the software package based on the software tool kit Sonix+ together with a specialized graphical interface developed using PyQt and Matplotlib.

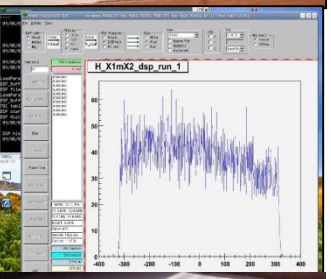
The software package includes:

- modules for controlling experiments (start, stop, start a sequence of experiments);
- the module for visualization of accumulated data;
- the module for input of data on an experiment or a series of experiments;
- additional software for summarizing data on various series of experiments and individual rings of the gas detector, for converting raw data into ASCII text data format.

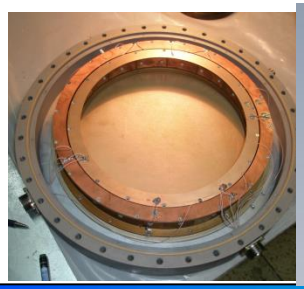
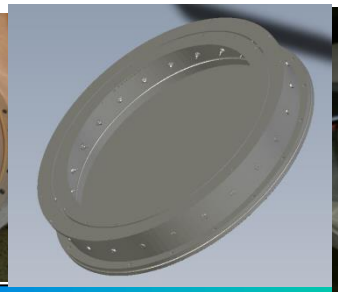
Welcome Dubna

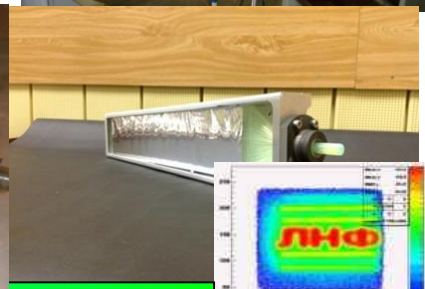











Thank you for your attention!