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on Interaction of Neutrons with Nuclei
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Development of neutron detectors for spectrometers of the IBR-2 reactor

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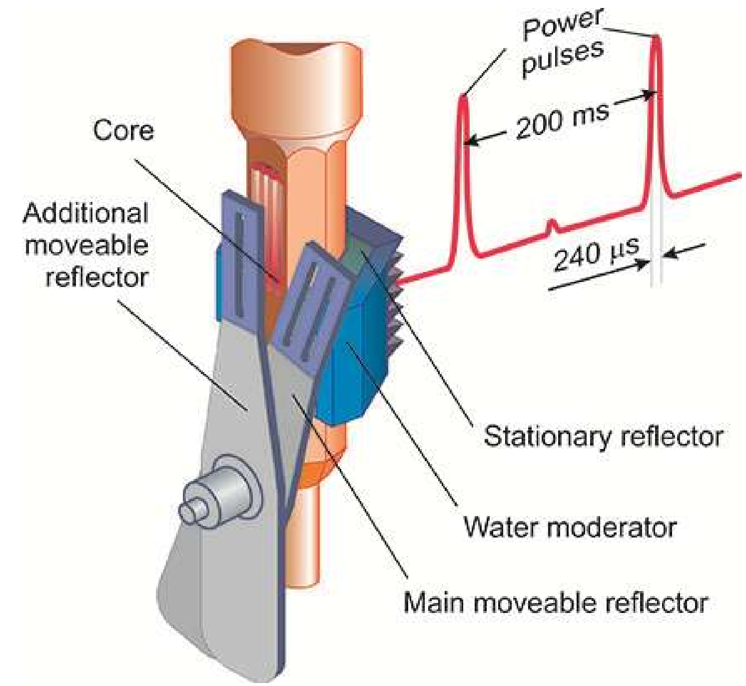
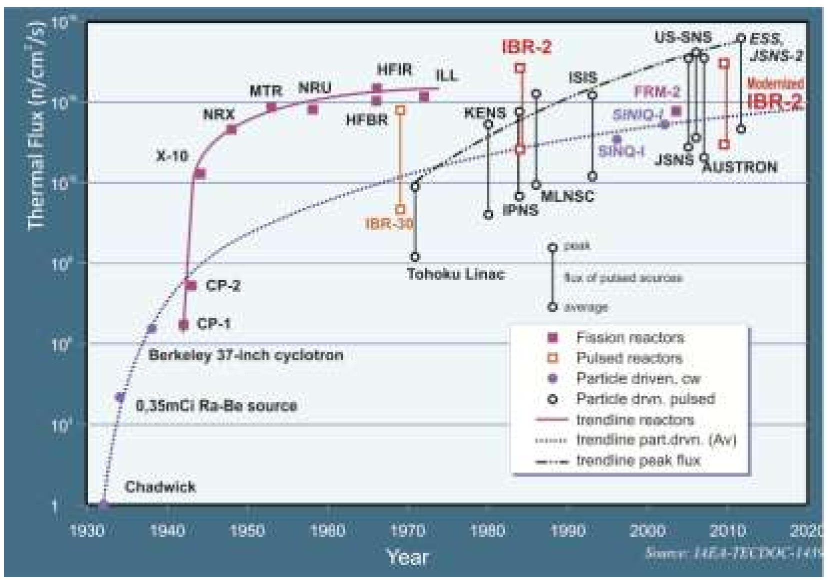


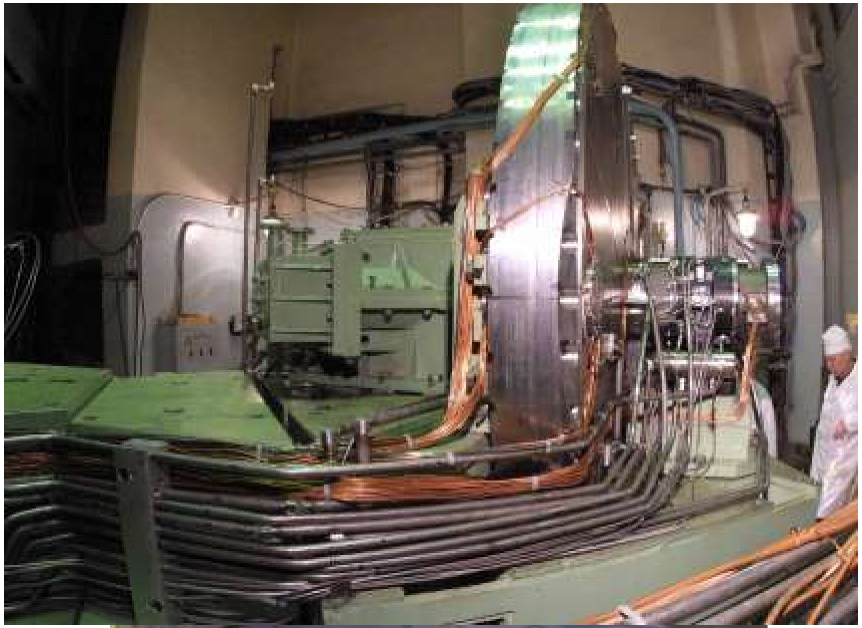
The IBR-2 Reactor

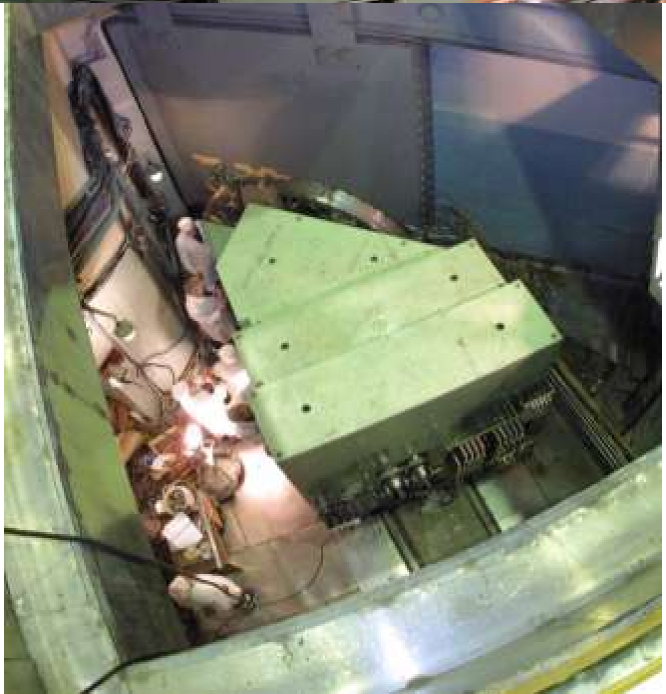
Average power, MW	2
Fuel	PuO_2
Number of fuel assemblies	69
Maximum burnup, %	9
Pulse repetition rate, Hz	5; 10
Pulse half-width, µs: fast neutrons thermal neutrons	 240 340
Rotation rate, rev/min: main reflector auxiliary reflector	 600 300
MMR and AMR material	nickel + steel
MR service life, hours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

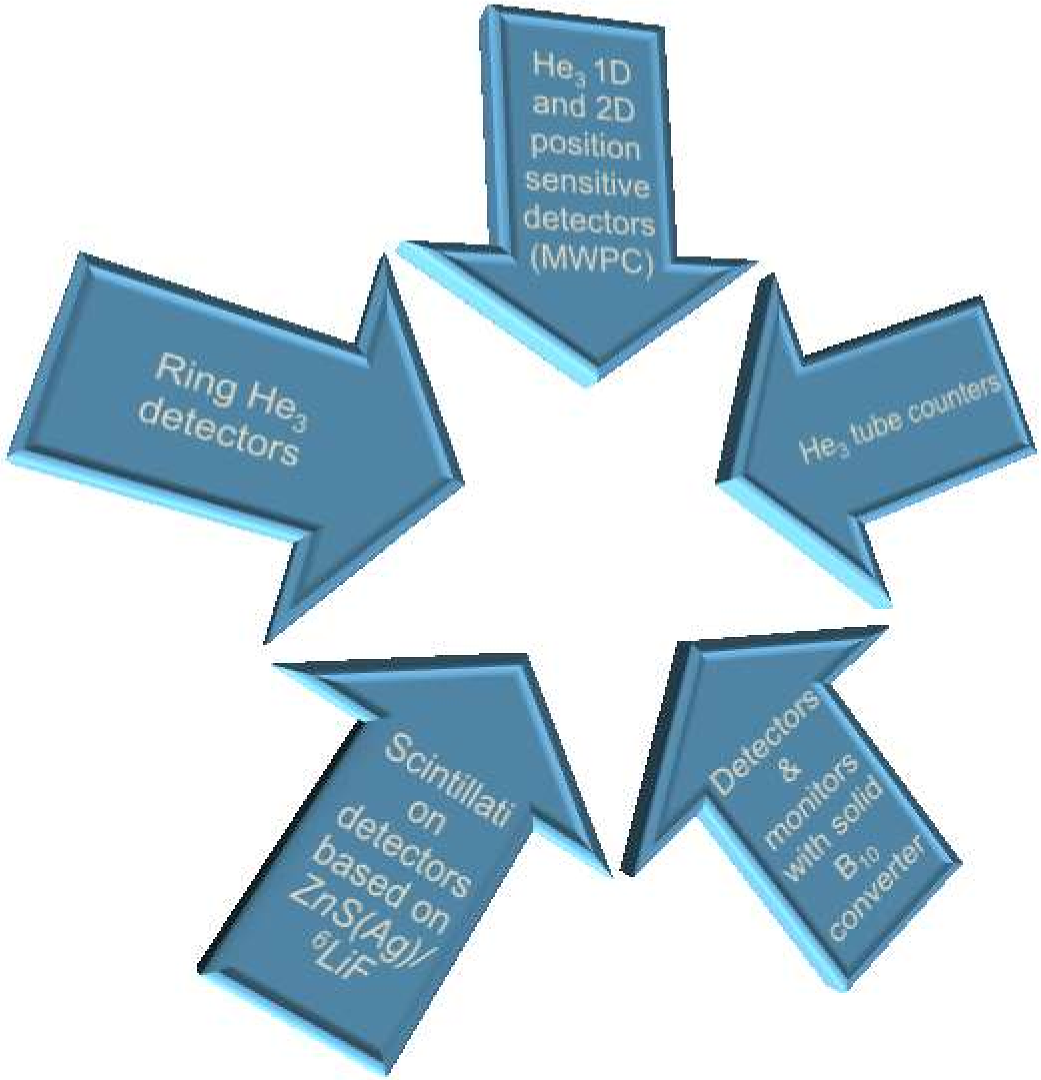
Reaction	Cross-section for E=25 meV, barn	Secondary particles	Particle energies MeV	Energy release, MeV
n + ^{3}He	5333	p^+ ^{3}H	0.57 0.2	0.77
n + ^{6}Li	940	^{3}H ^{4}He	2.74 2.05	4.79
n + ^{10}B	3836	^{4}He ^{7}Li γ	1.47 0.83 0.48 (93%)	2.3
n + ^{235}U	681	Fission fragments		1-2

+

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

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

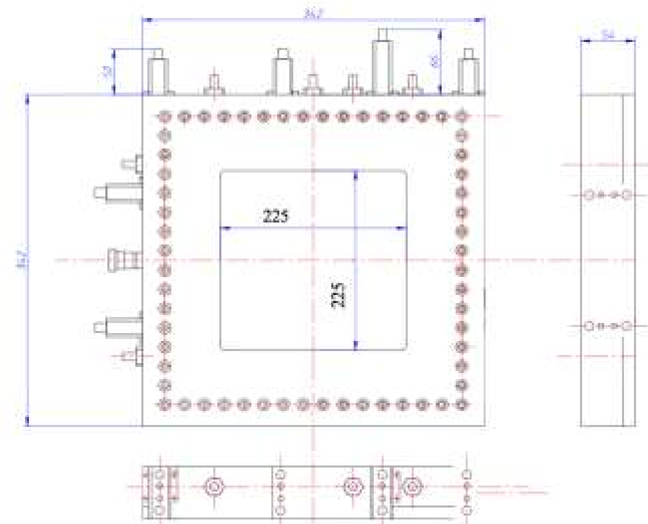
Detectors of instruments of the IBR-2 reactor

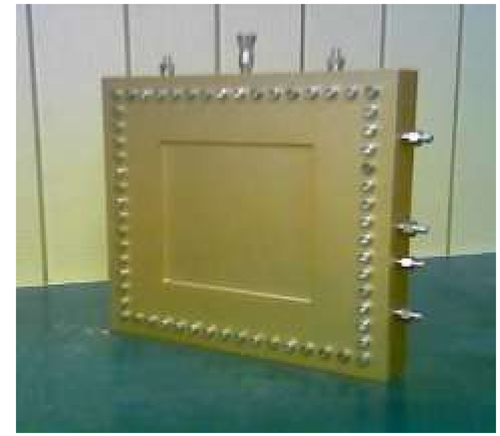


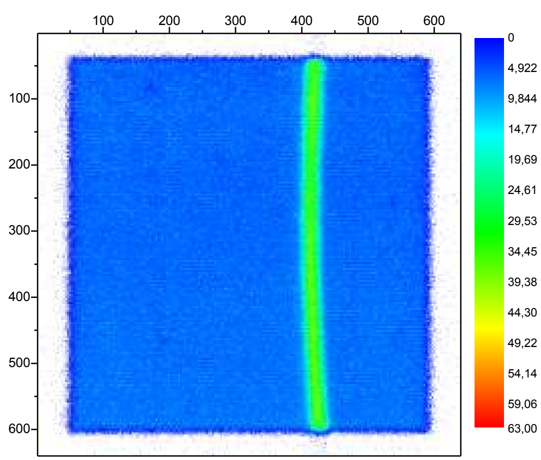
2D and 1D position-sensitive detectors (MWPC)

2D PSD 200 x 200 and 225 x 225 mm^2

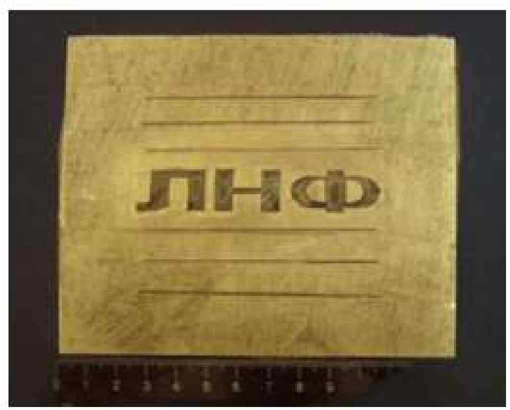
Type	2 – D MWPC
Active area	200x200 mm^2
Position resolution	2,0x2,0 mm^2
Range of neutron wavelength	0,4 - 12 A
Efficiency for thermal neutrons (λ=2 Å)	65%
Position determination	Delay line

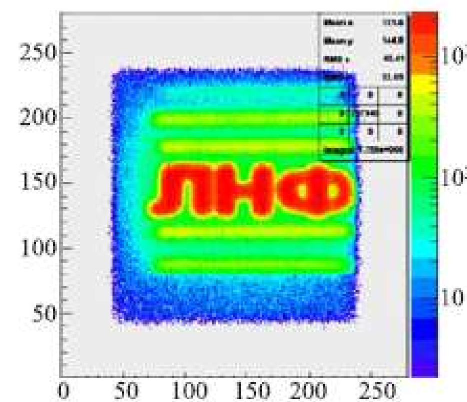






Tests of 2D PSD detectors at Nuclear Physics Institute , NPI ASCR, Řež, Czech Republic





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

DAQ systems for 1D and 2D position sensitive detectorsz

De-Li-DAQ-1 block

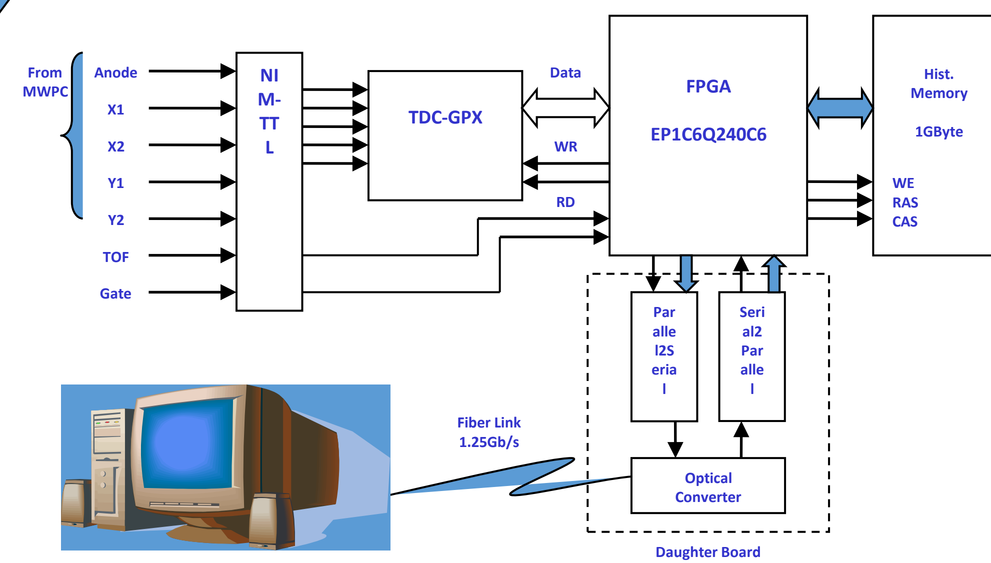
- Counting rate up to 10^5 ev./sec
- Installation in PCI port in PC

- More than 50 boards have been produced.

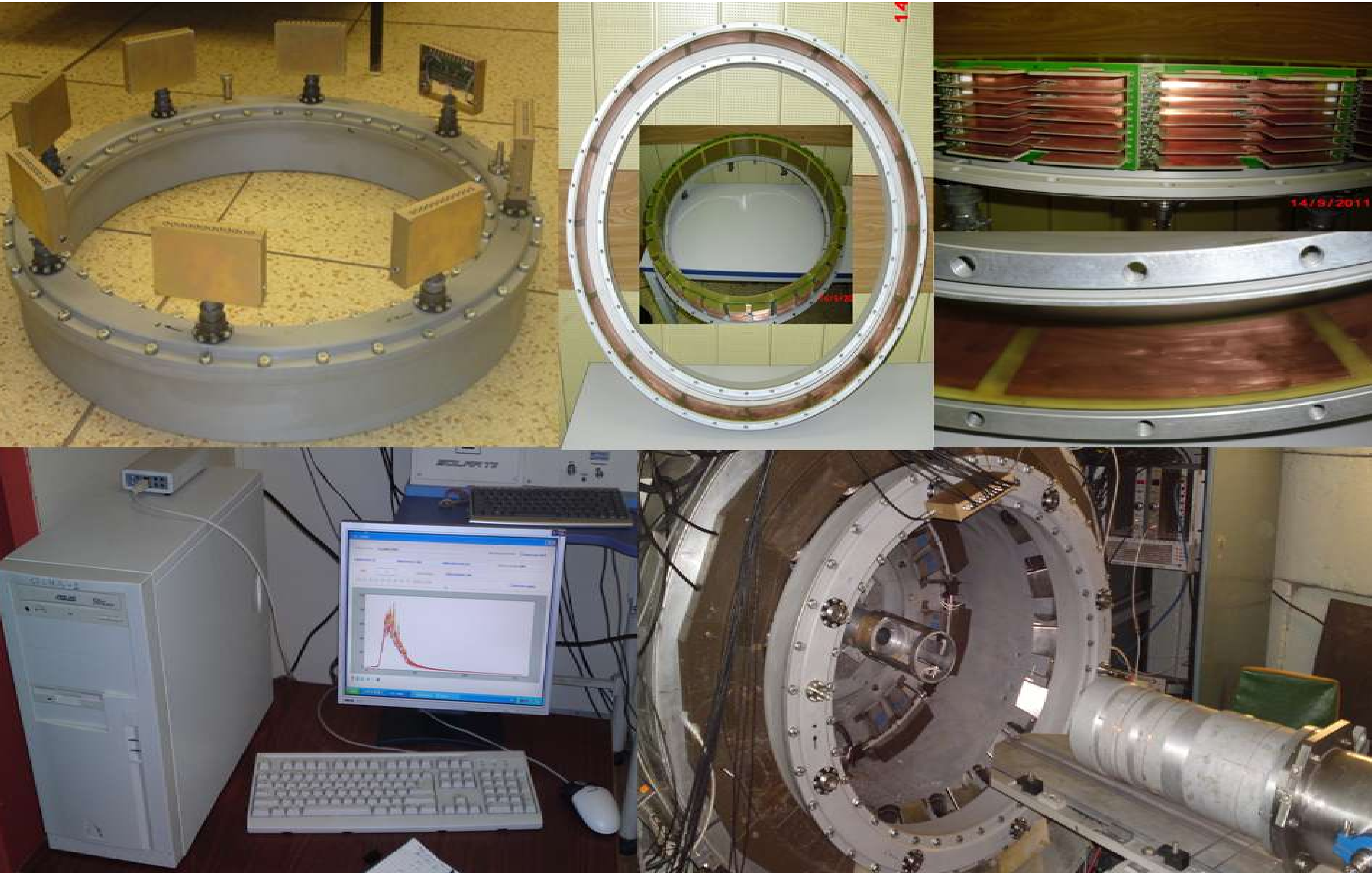
They installed in FLNP, HMI (Germany), Rzez (Cheh Republic), Kurchatov inst, Troick etc.

De-Li-DAQ-2 block

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

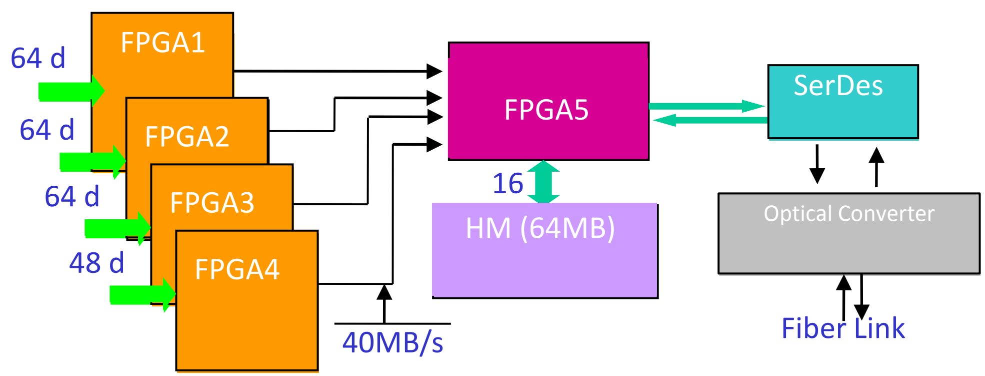


MULTISECTION RING DETECTOR OF THERMAL NEUTRONS FOR DIFFRACTION STUDIES ON MICROSAMPLES IN AXIAL GEOMETRY

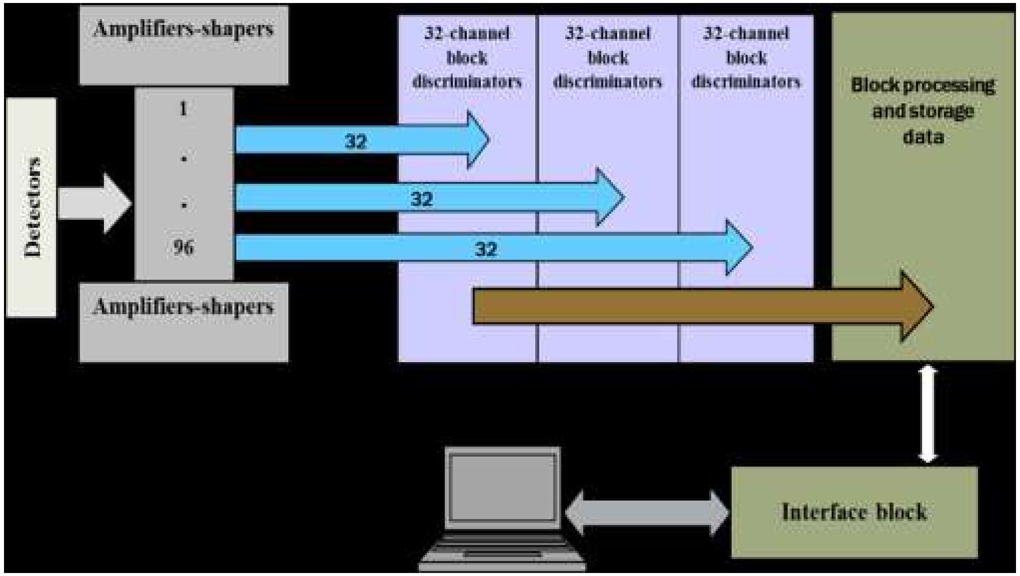


Detector electronics

- **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 chopper;**
- **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

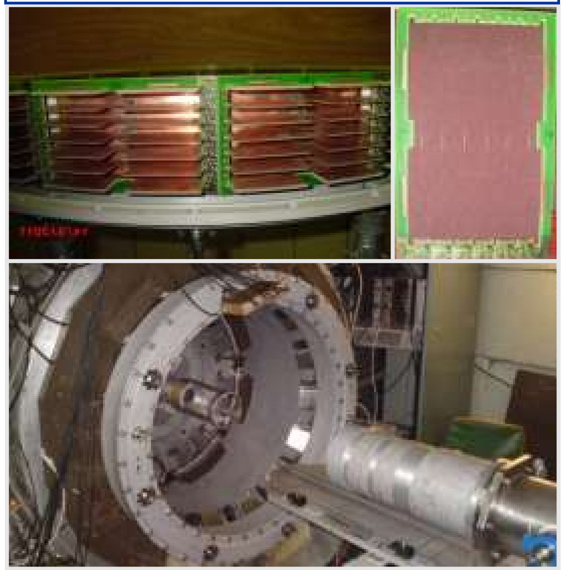


Block of data processing and accumulation:	
Frequency of time sampling of all signals	max. 62.5 MHz
Maximum registration rate	$8 \cdot 10^6$ events/s ($\sim 3 \cdot 10^4$ for one element)
PC interface	USB 2.0
Internal histogram memory	64 Mb
Maximum registration delay relative to reactor burst	0.268 s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

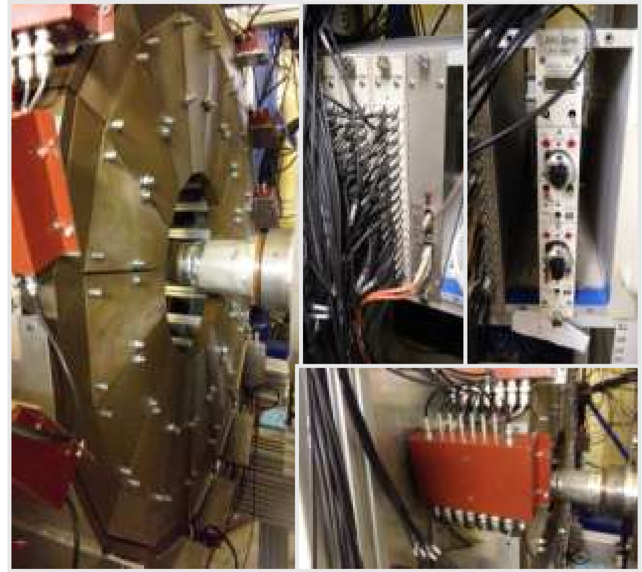
Detector system for DN-6 diffractometer

Multi-section ring neutron detector



- 96 independent detectors in common gas volume;
- 3 modules of 32-channel amplitude discriminators

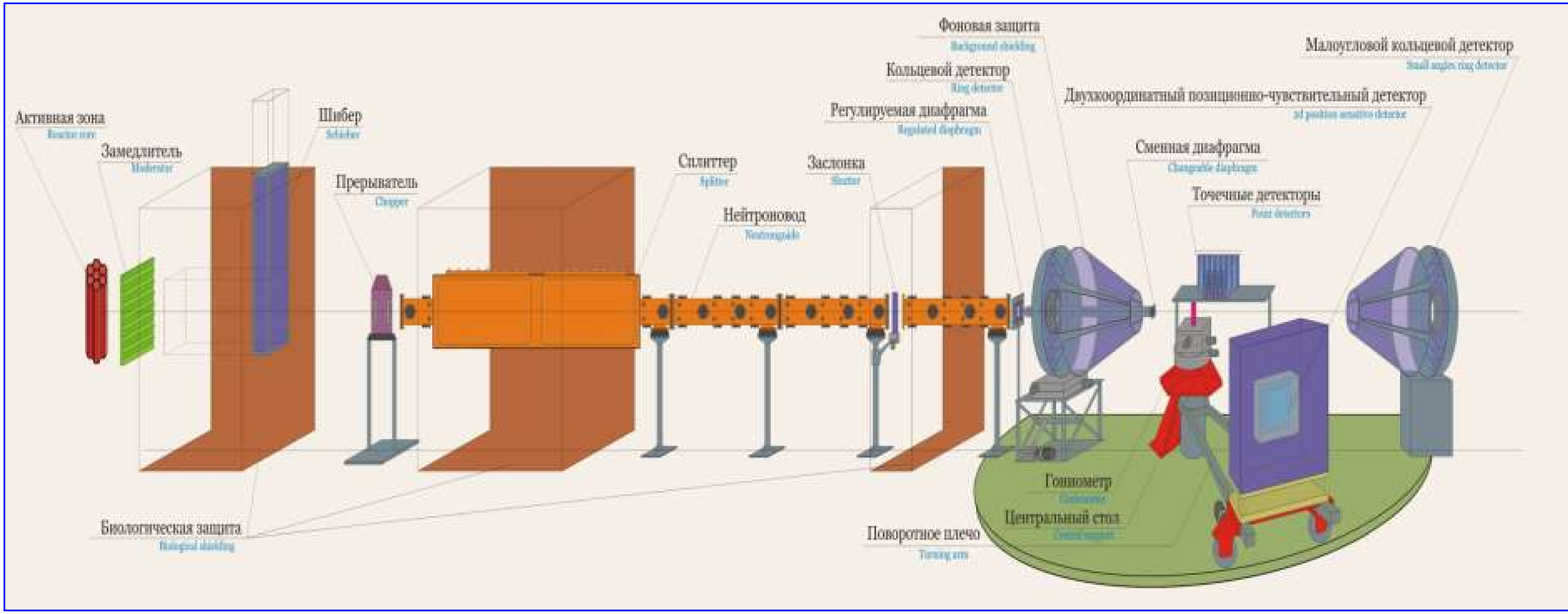
Ring neutron detector



- 96 individual helium-3 proportional counters;
- 3 modules of 32-channel amplitude discriminators

192 – channel data acquisition and accumulation module

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

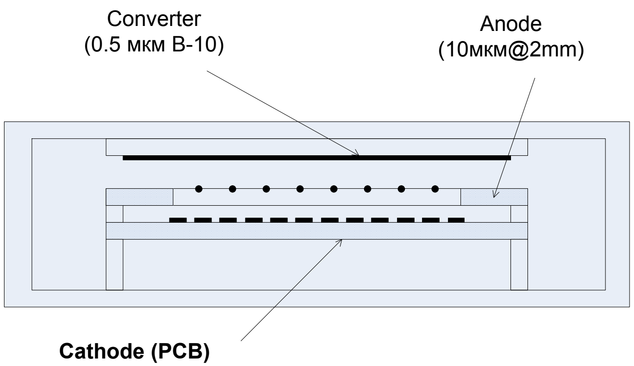
Helium-3 purification facility

New clean room

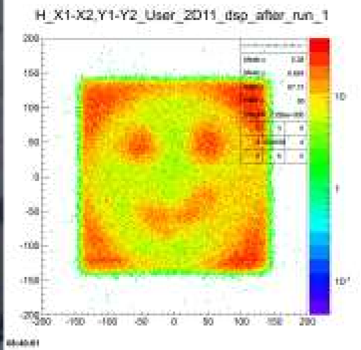
New clean room

Clean area = 48м ^{2}

Prototype with boron converter



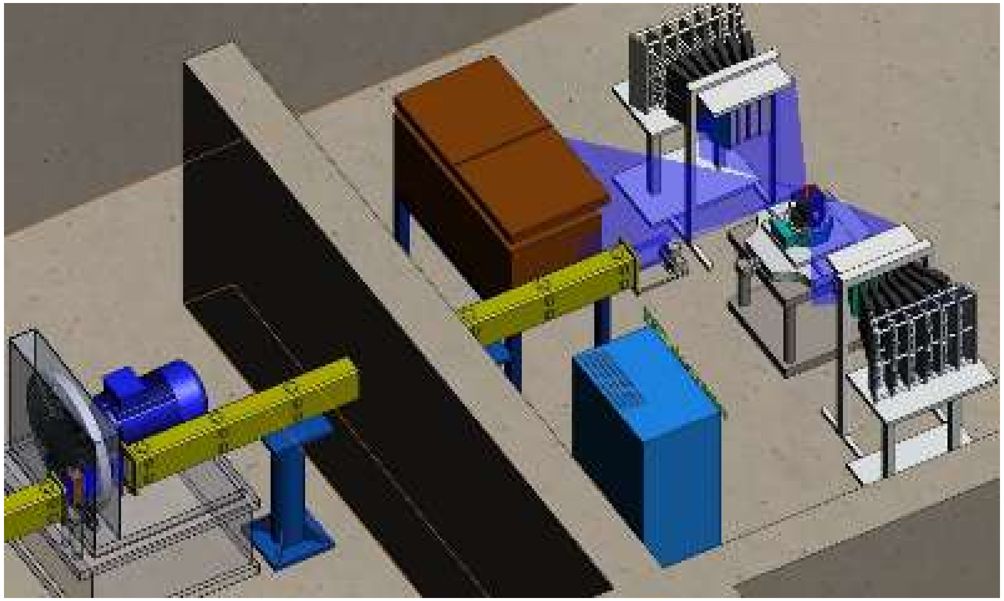
- 200x200 0.5 mkm 10B converter made by ESS.
- MWPC with fiberglass cathode.
- Very good uniformity and stability.



Benefits:

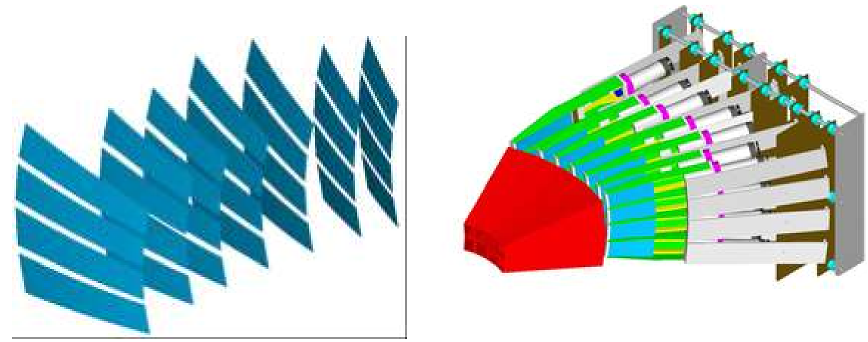
- For cold neutrons counting (thin entrance window)
- To use in vacuum chambers (low pressure)
- For instruments with better resolution (thin layers)
- For higher count speed (multilayers)

Fourier Stress Diffractometer (FSD)

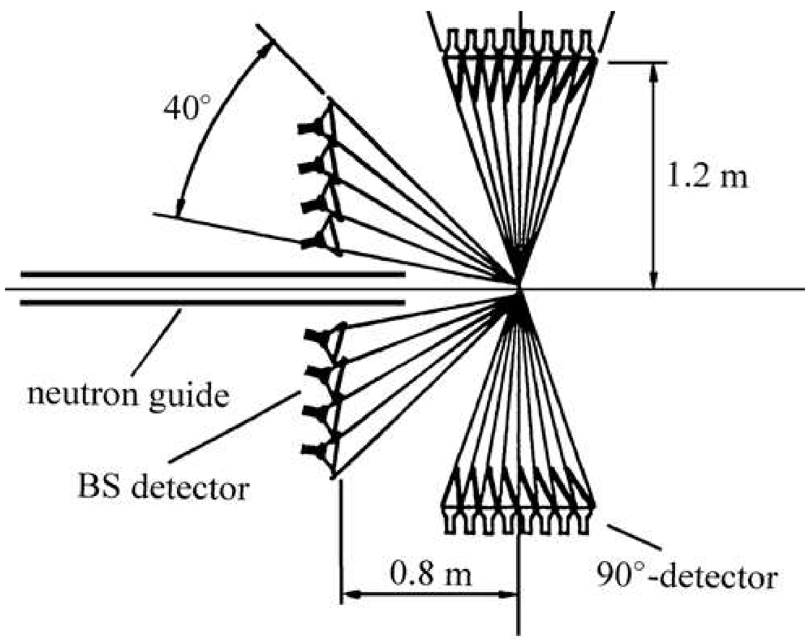


$ZnS(Ag)/^6LiF$ *ND screen, thickness = 0.42 mm*

90°- ASTRA detector



Geometry of the ASTRA detector

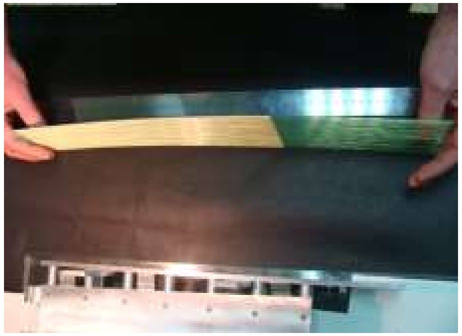


R= 900 mm.
φ= -2.5deg. - +2.5deg.

№	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

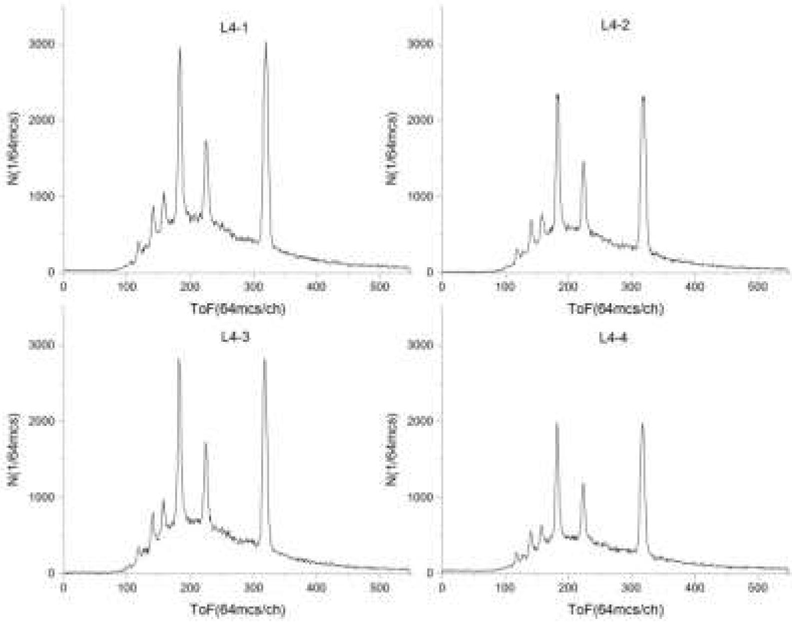
The process of production a scintillation counter

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

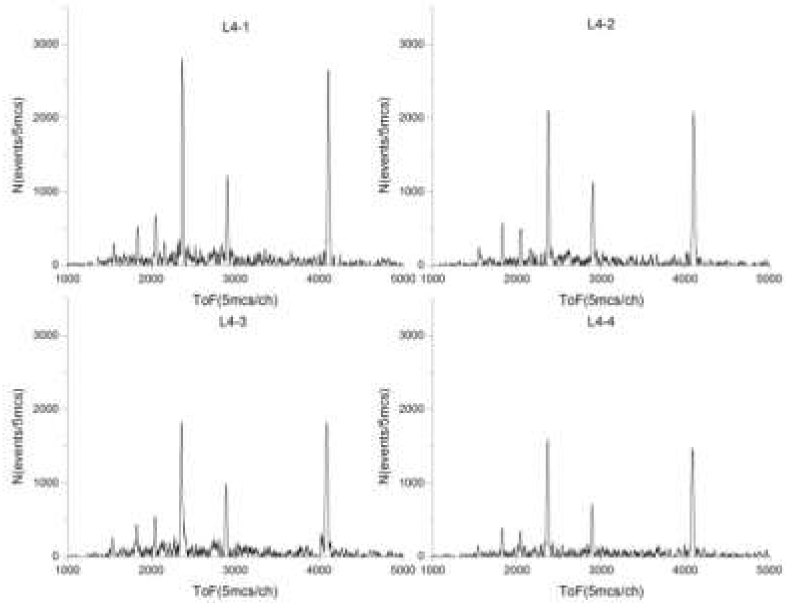


Fourier Stress Diffractometer FSD

The detector system ASTRA

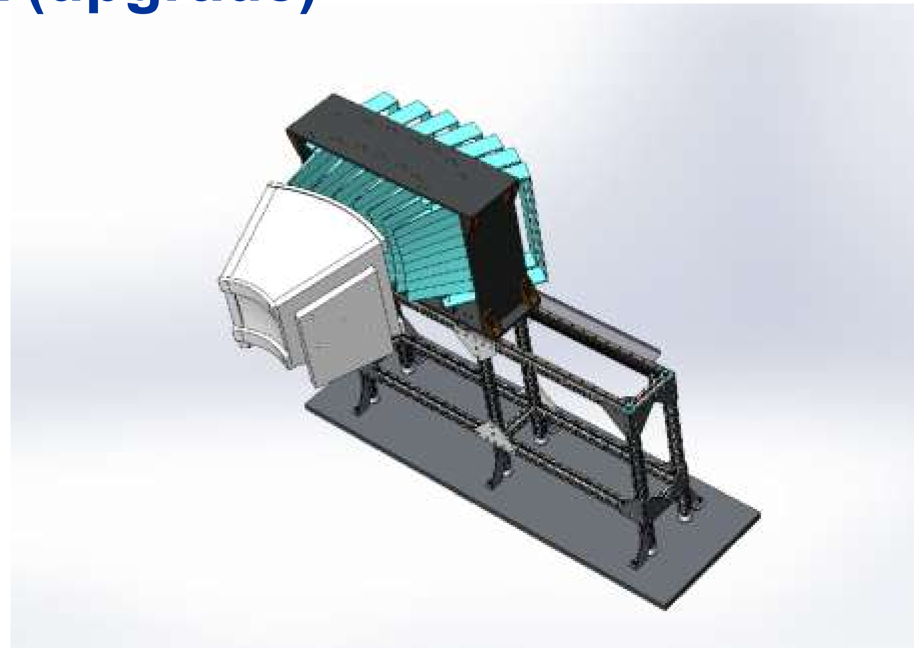


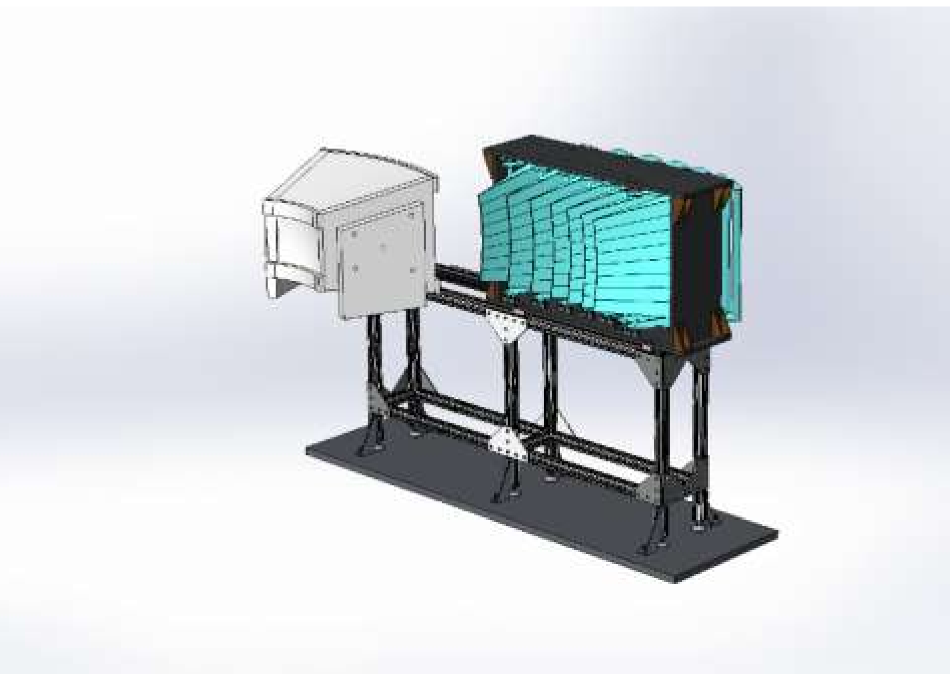
ToF- spectra of low resolution

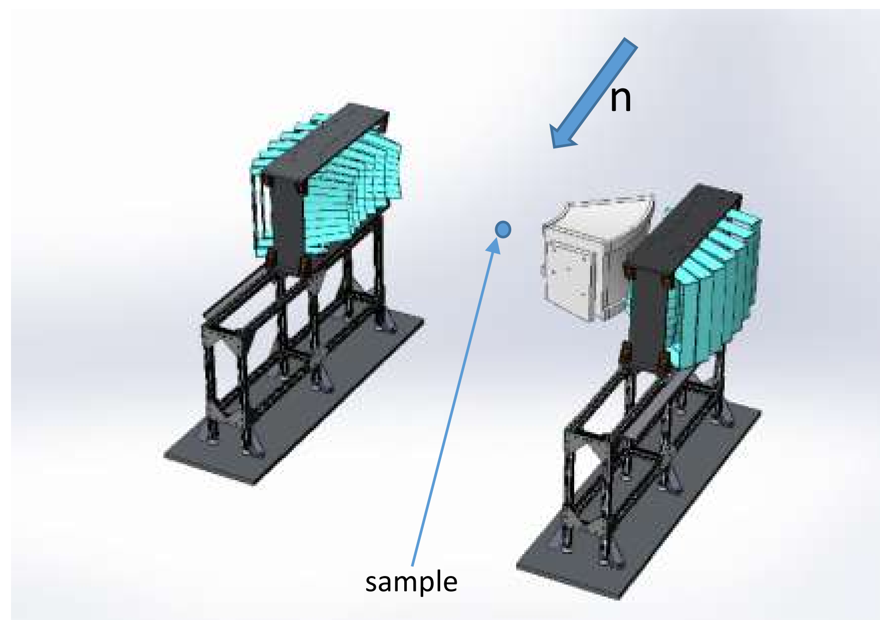


ToF- spectra of high resolution

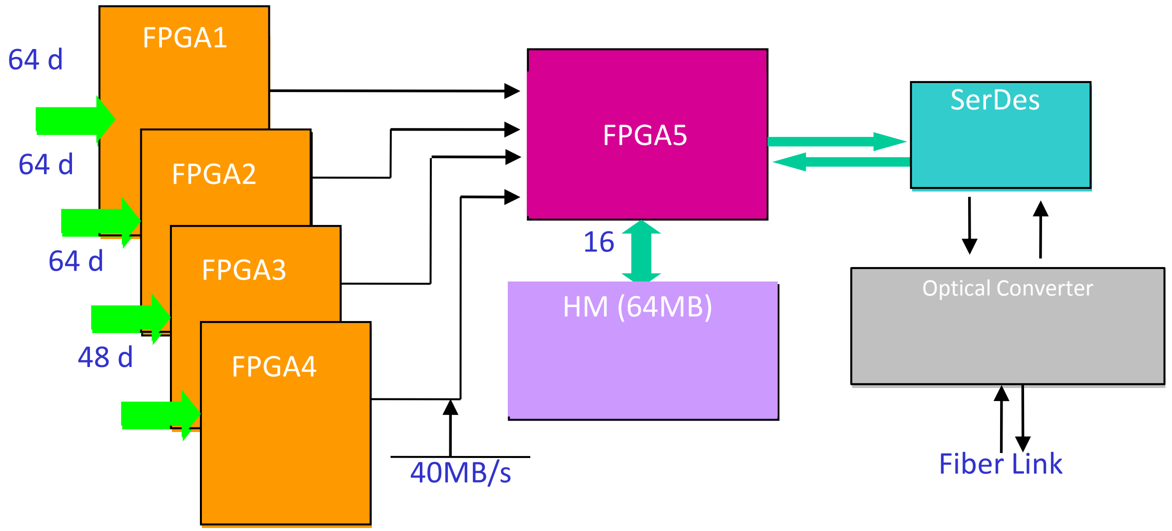
The detector system ASTRA (upgrade)





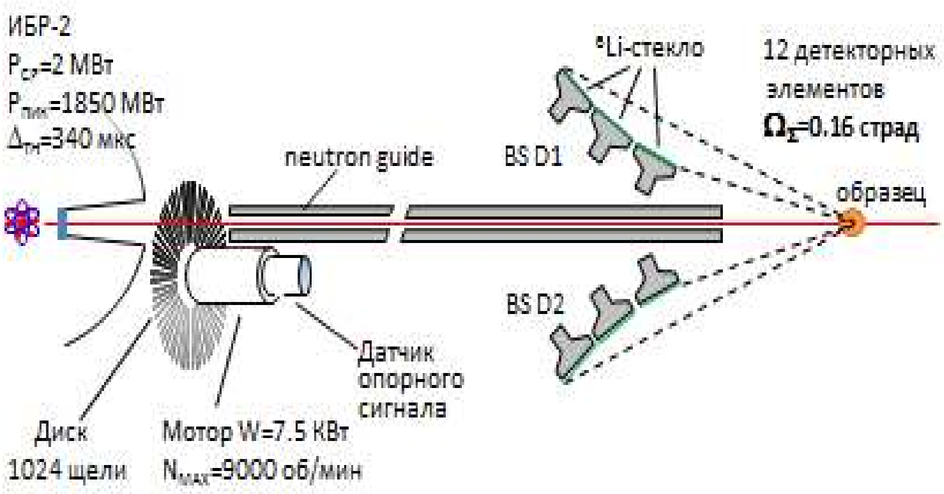


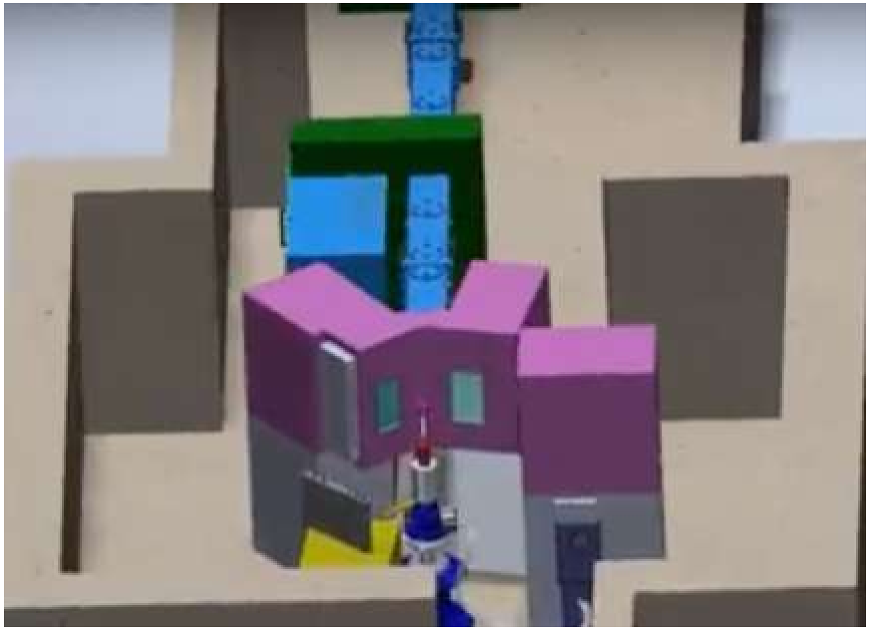
DAQ electronics for multi-point detector (MPD)



- 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



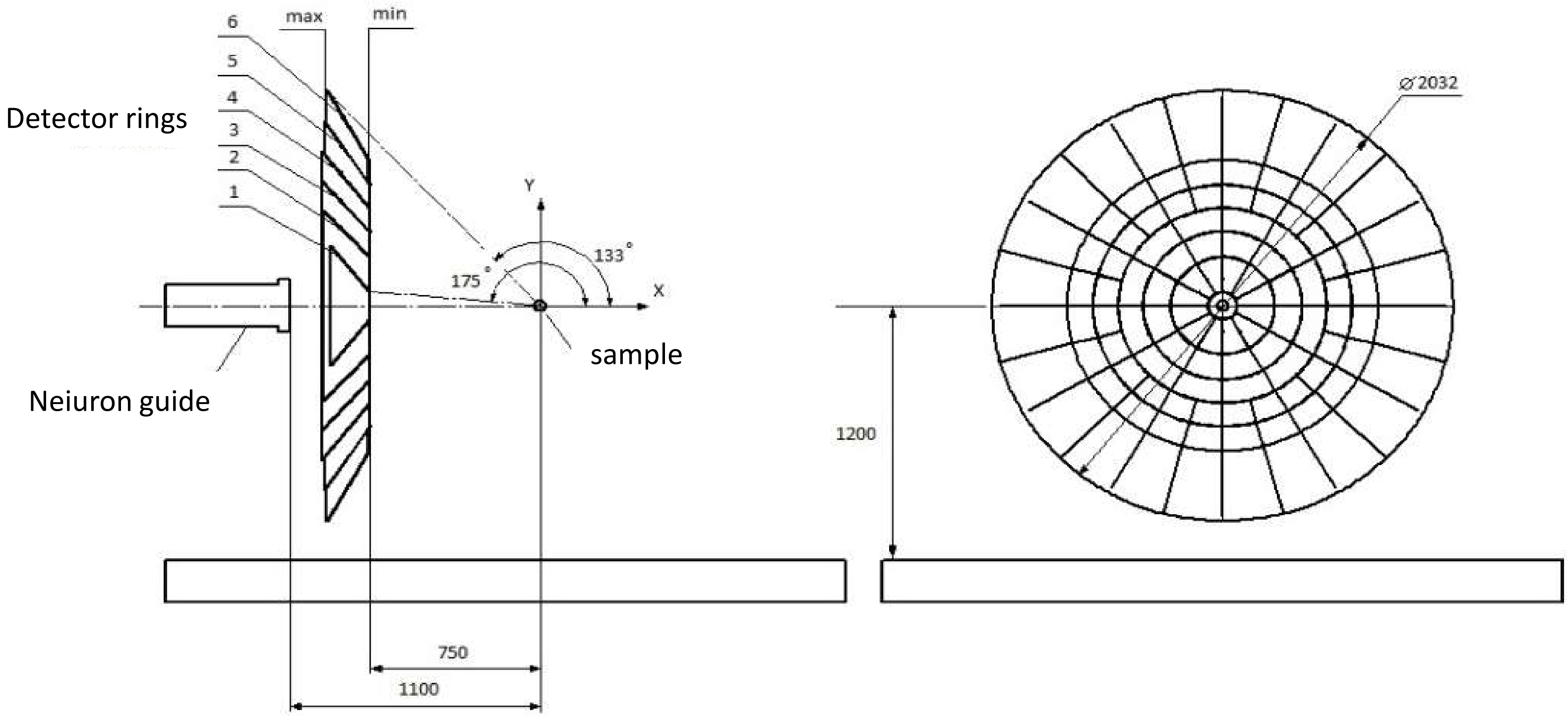


R= $\Delta d/d \approx 0.001$

Disadvantages of current back scattering detector:

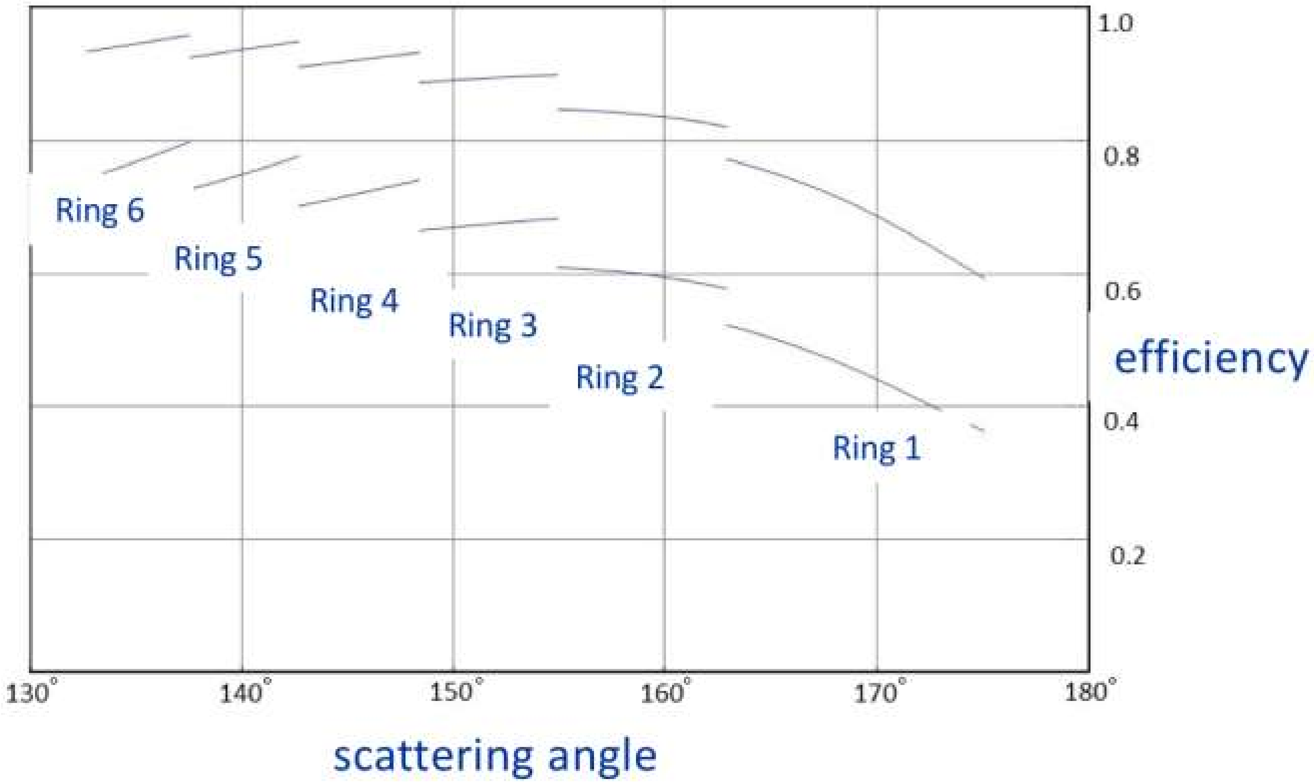
- current solid angle of detector ~0.16 sr;
- a high sensitivity to γ-background (^{6}Li glasses).

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

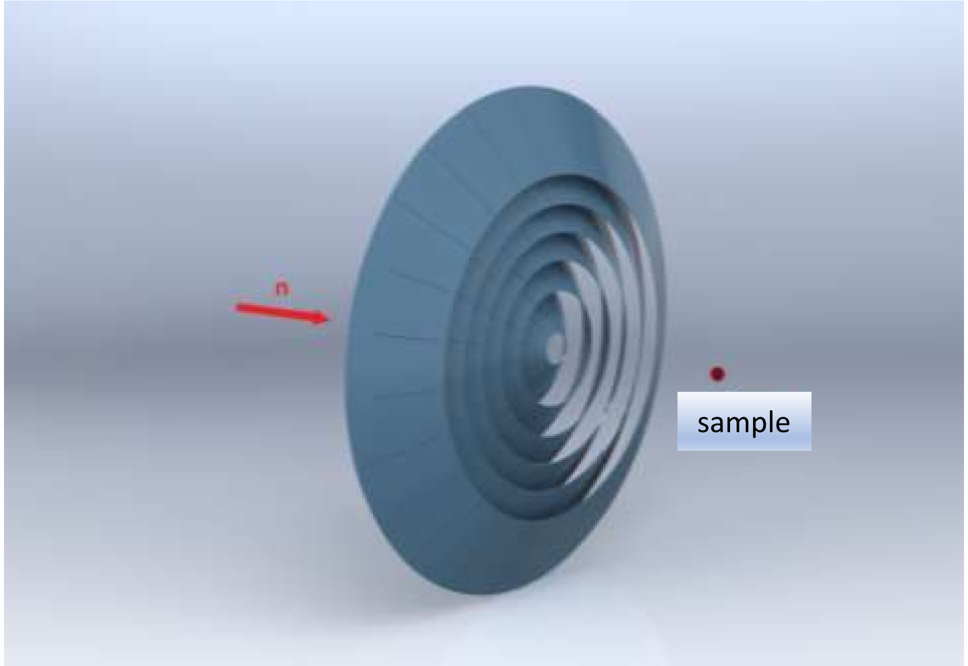


- Solid angle: $\Omega_{\Theta} \sim 2.0$ sr. (more ~12.5 times).
- 0.42 mm, $ZnS(Ag)/^{6}LiF$. (with wavelength shifting fibers)
- 216 independent elements

Dependence of the detector efficiency on the scattering angle



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



$\Delta d/d \approx 0.001$

$\varnothing_{samp}$, 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.

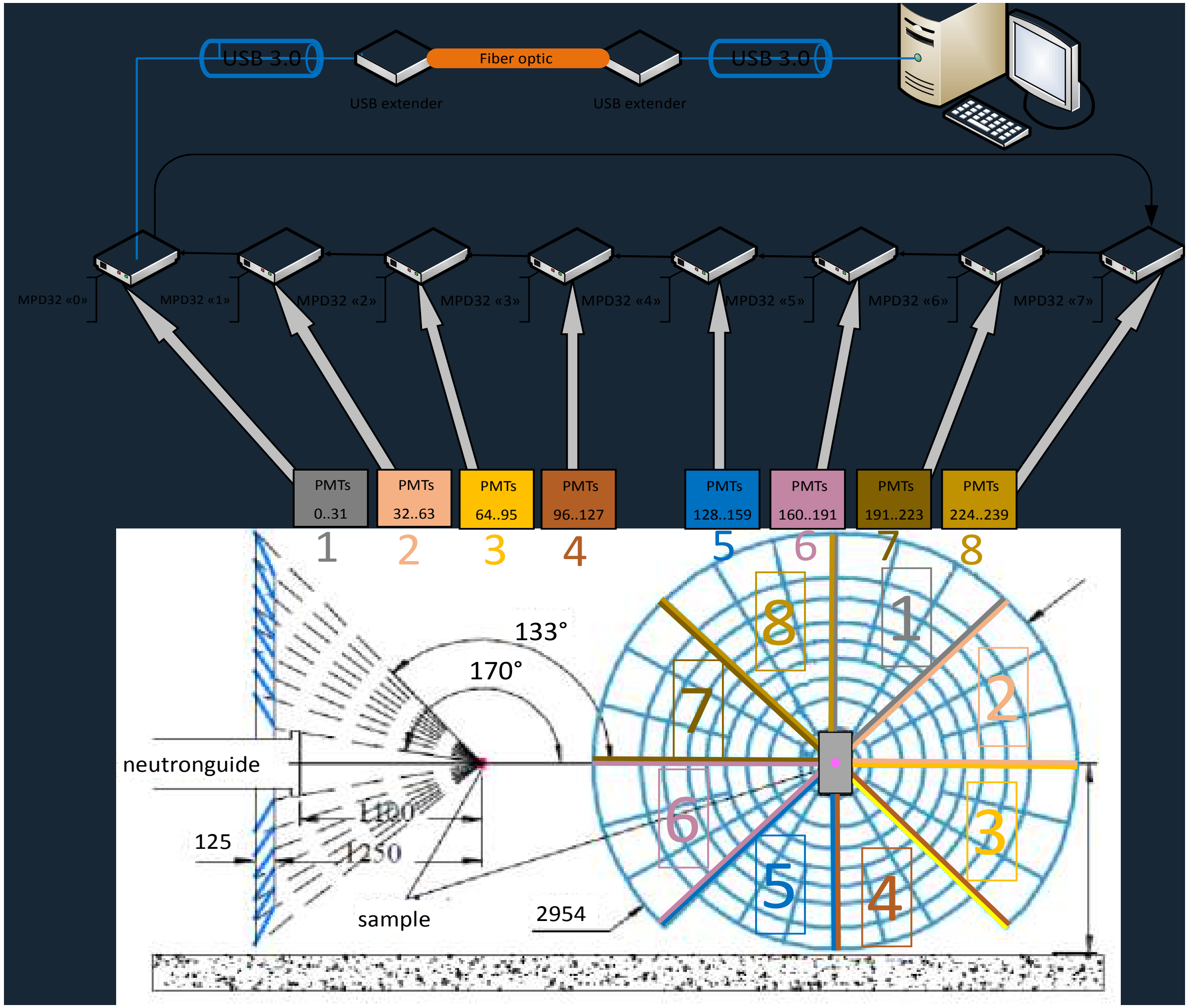
$<\Delta_i>=2.36\sigma_i$ – error value for the i-th ring of the detector.

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.**

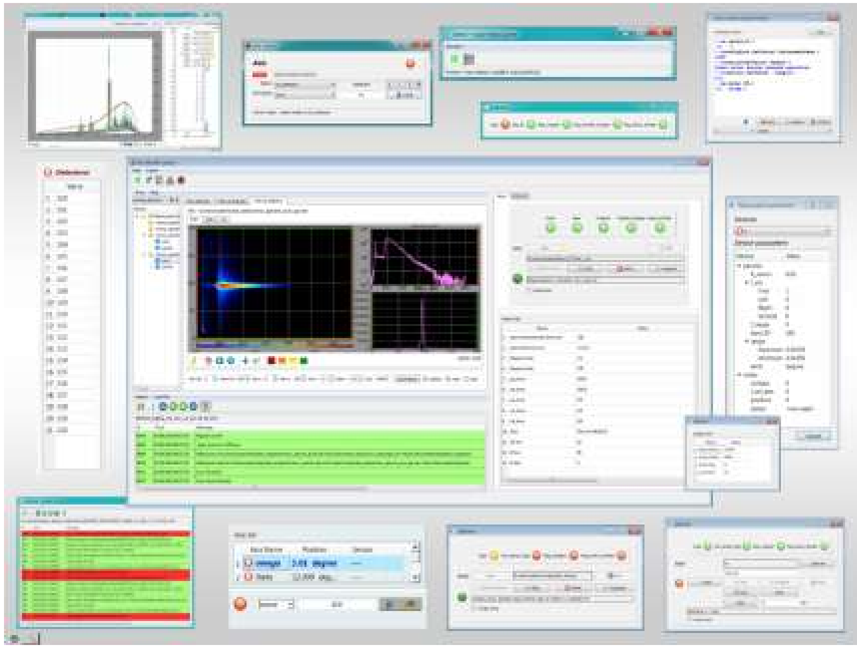
Element of the scintillation screen (white plate) together with the optical wavelength shifting fibers glued to it on both sides.

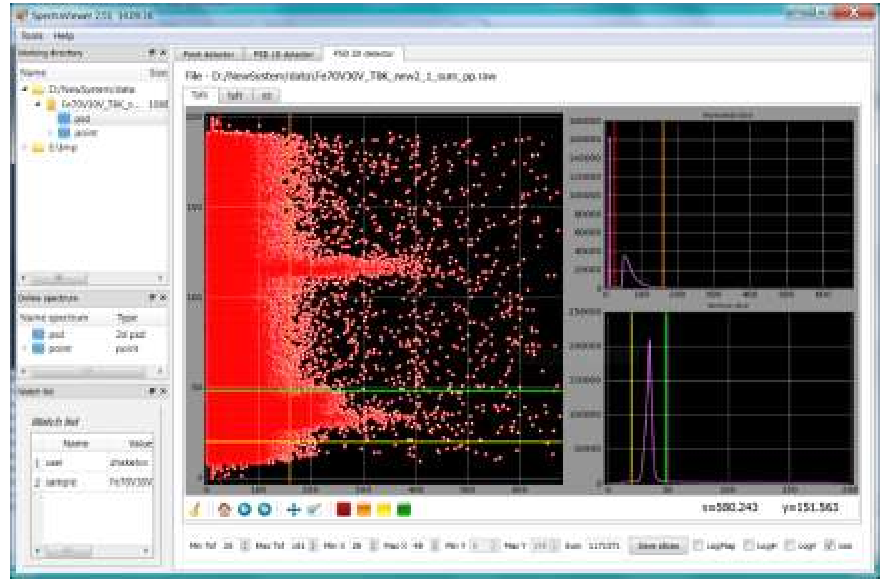
DAQ electronics for multi-point detector (MPD)



- 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.

Software Sonix+ and Web remote system



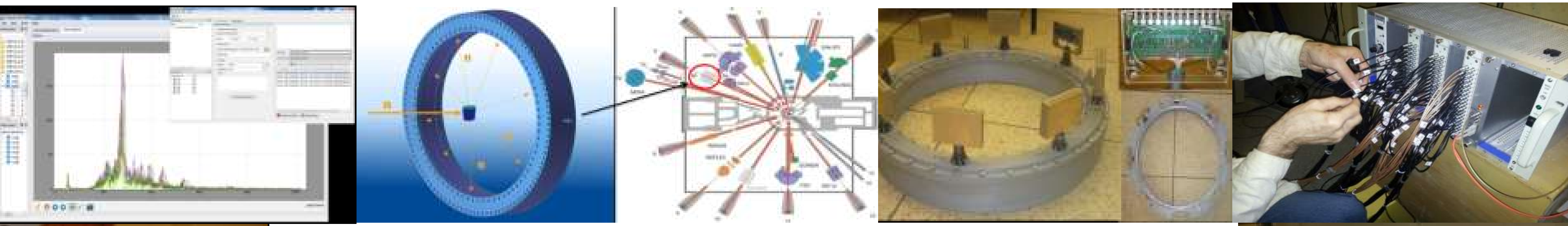


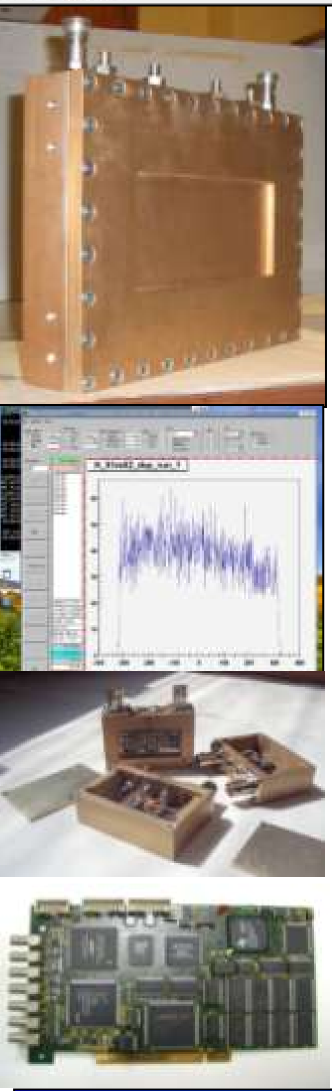
The control over experiments and the visualization of neutron data are realized in a single user interface of the software package based on the software tool kit Sonix+ together with a specialized graphical interface developed using PyQt and Matplotlib.

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 to Dubna





Thank you for your attention!