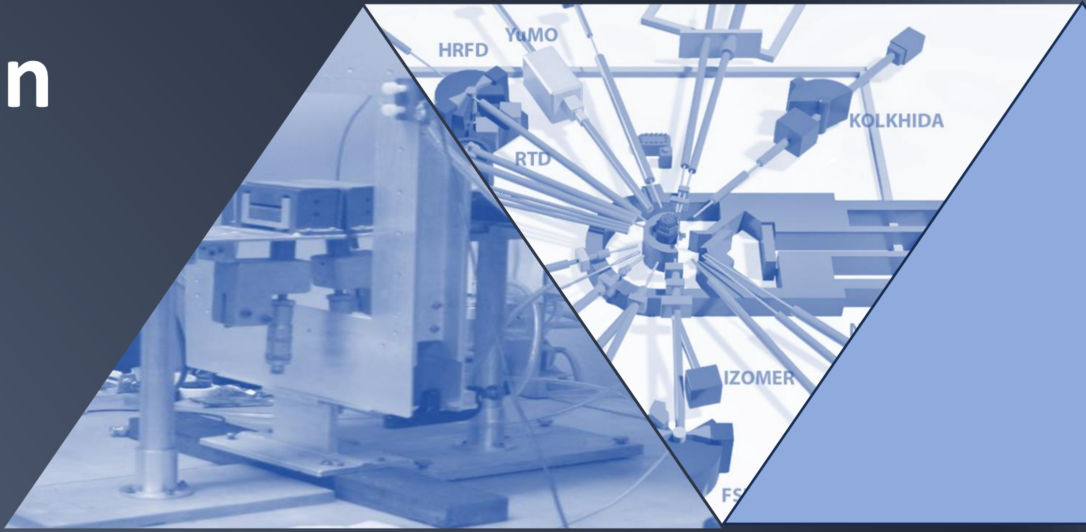
# Development of neutron detectors with boron converter in FLNP JINR




V. Bodnarchuk

# Outline

- **Neutron detectors at instruments at the IBR-2 reactor. Current status**
- **Advances in $B_4C$ deposition technology in FLNP JINR**
- **Projects of new detectors with boron converter**
- **Development of the infrastructure for the production of detectors with boron converters**

# 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

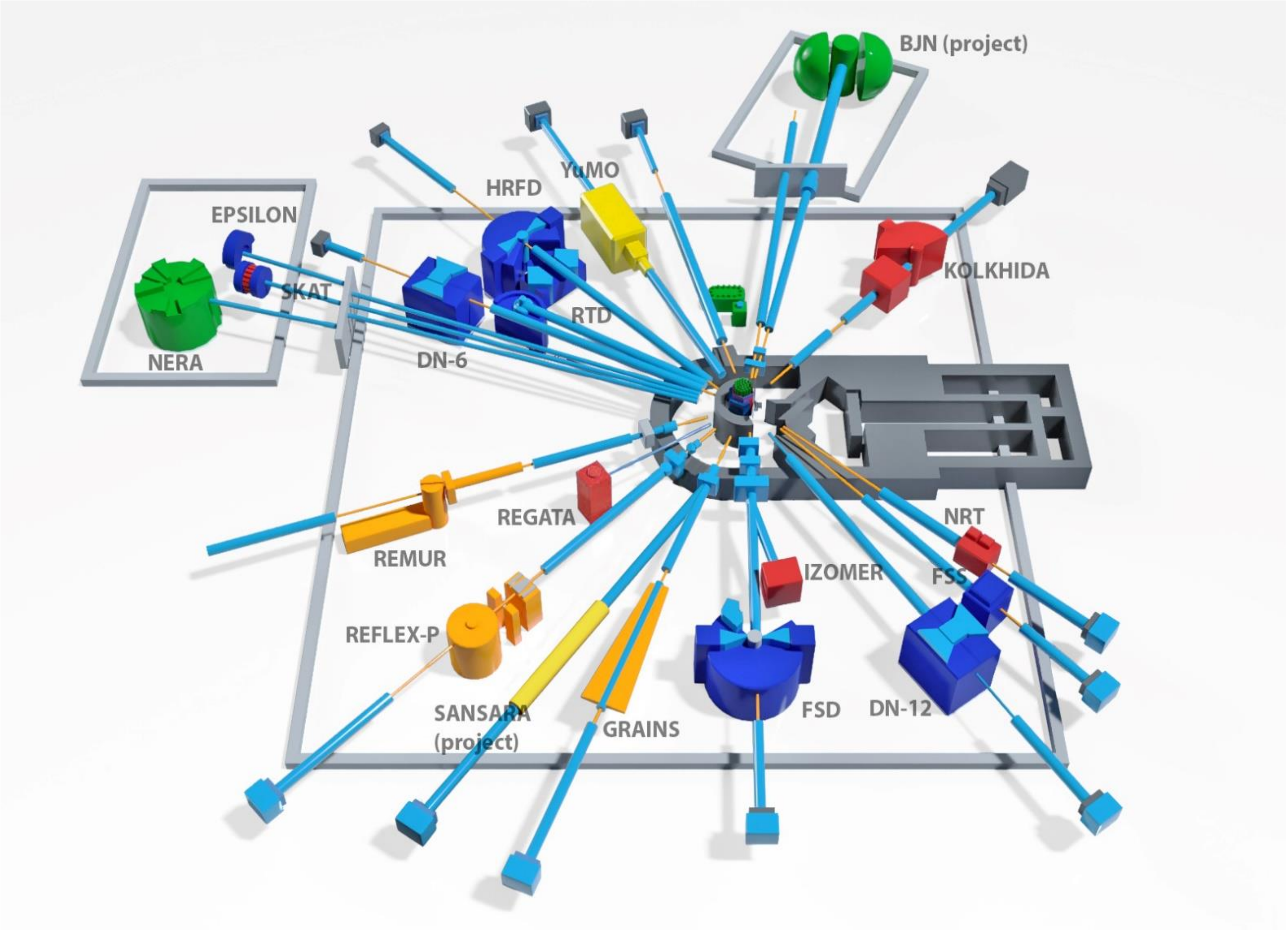
**Inelastic scattering:**
NERA

**NAA:**
REGATA

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

| Detector type | Number |
|---|---|
| $^3$He based detectors | |
| Single counters | > 100 |
| PSD, 200x200 mm$^2$ | 7 |
| Ring detector of different construction | 3 |
| Scintillation detectors | |
| ZnS(Ag)/$^6$LiF | 2 |
| Li-glass | 2 |
| $^{10}$B based detectors | |
| Monitor counter | 1 |

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



# Development of $^{10}B$ based detector technology. Pro and Contra

$$
\begin{aligned}
{}^{10}B + n \rightarrow {}^{7}Li^{*} + {}^{4}He &\rightarrow {}^{7}Li + {}^{4}He + 0.48 MeV\, \gamma\text{-ray} + 2.3\ \ MeV \quad (94\%) \\
&\rightarrow {}^{7}Li + {}^{4}He \qquad\qquad\qquad\qquad + 2.79 MeV \quad (6\%)
\end{aligned}
$$

**$\sigma_B$ = 3840 barns @1.8 Å**

*$n + {}^{3}He \rightarrow {}^{3}H + p + 0{,}77\ MeV$*

**$\sigma_{He}$ = 5328 barns @1.8 Å**

$$\frac{\sigma_B}{\sigma_{He}} \sim 0.7$$

Options for use converter based on $^{10}B$:

1. Gaseous $BF_3$
2. Solid State thin films B or $B_4C$

# Development of $^{10}B$ based detector technology. Pro and Contra

## Gas $BF_3$

**Advances:**
- Easy to access
- Opportunity for mass production of detectors

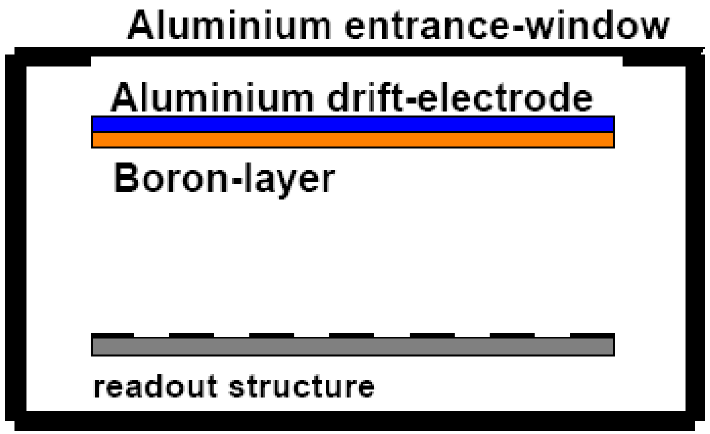
**Drawbacks:**
- Electronegative gas
- Toxic
- 1 counter with $^3He$ = 3 counter with $BF_3$

## Gas $^3He$

**Advances :**
- Inert gas
- High capture cross section
- Moderate resolution for PSD based on counters with resistive anode

**Drawbacks :**
- High price
- High pressure in chamber ⟹ thick membrane
- Complicated camera cleaning procedure
- For PSD – nonuniformity over the surface
- Gas replacement every 5 years
- Max count rate ~ MHz
- Error in the position defining of neutron capture
- Space resolution limit ~ 1 mm

# Gaseous detectors with solid state converters with $^{10}$B

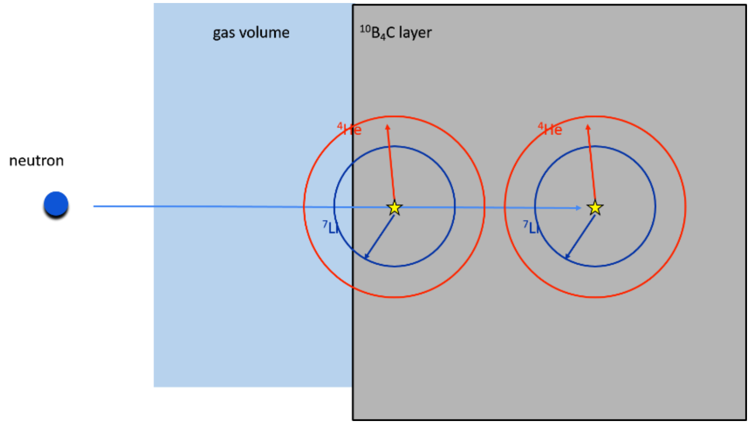



## Advanced:

- Operation at atmospheric pressure
- Gas mixture is blown through the chamber ⟶ no aging effect
- Localization of the neutron capture site
- High temporal ( ns) and space resolution ( $\leq$ 1 mm)
- Easy to produce of a large area detection plane ( $\geq 1m^2$ )
- Reliability of a construction
- Cheapness of materials

## Drawbacks:

- Low registration efficiency (less than 5% for the layer 2 μ)




Free path length of neutron in $^{10}B_4C$ $l_n \sim 30\mu$; $l_\alpha \sim 3\mu$; $l_{Li} \sim 1.3\mu$

R. Hall-Wilton, New Developments in Detector Technology at ESS

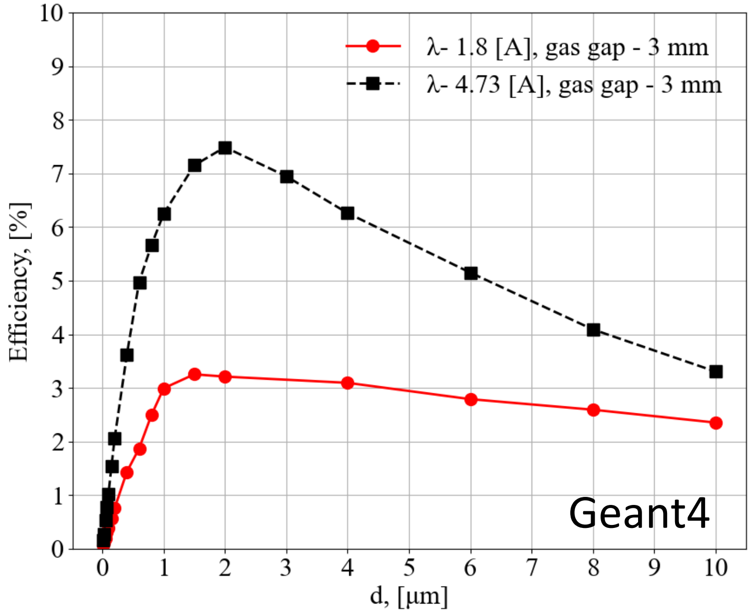
# Efficiency

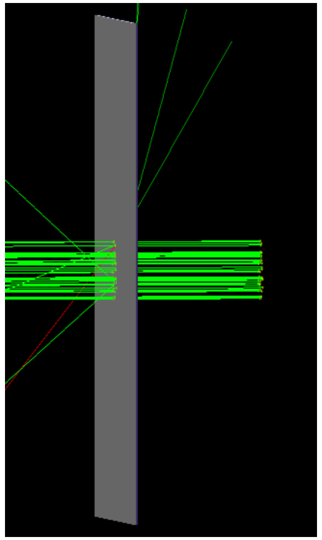
## Efficiency of 1 $B_4C$ layer

$^{10}B + n \rightarrow {}^{7}Li(0.84MeV) + {}^{4}He(1.47MeV) + \gamma\ (0.48MeV)$ (94%)

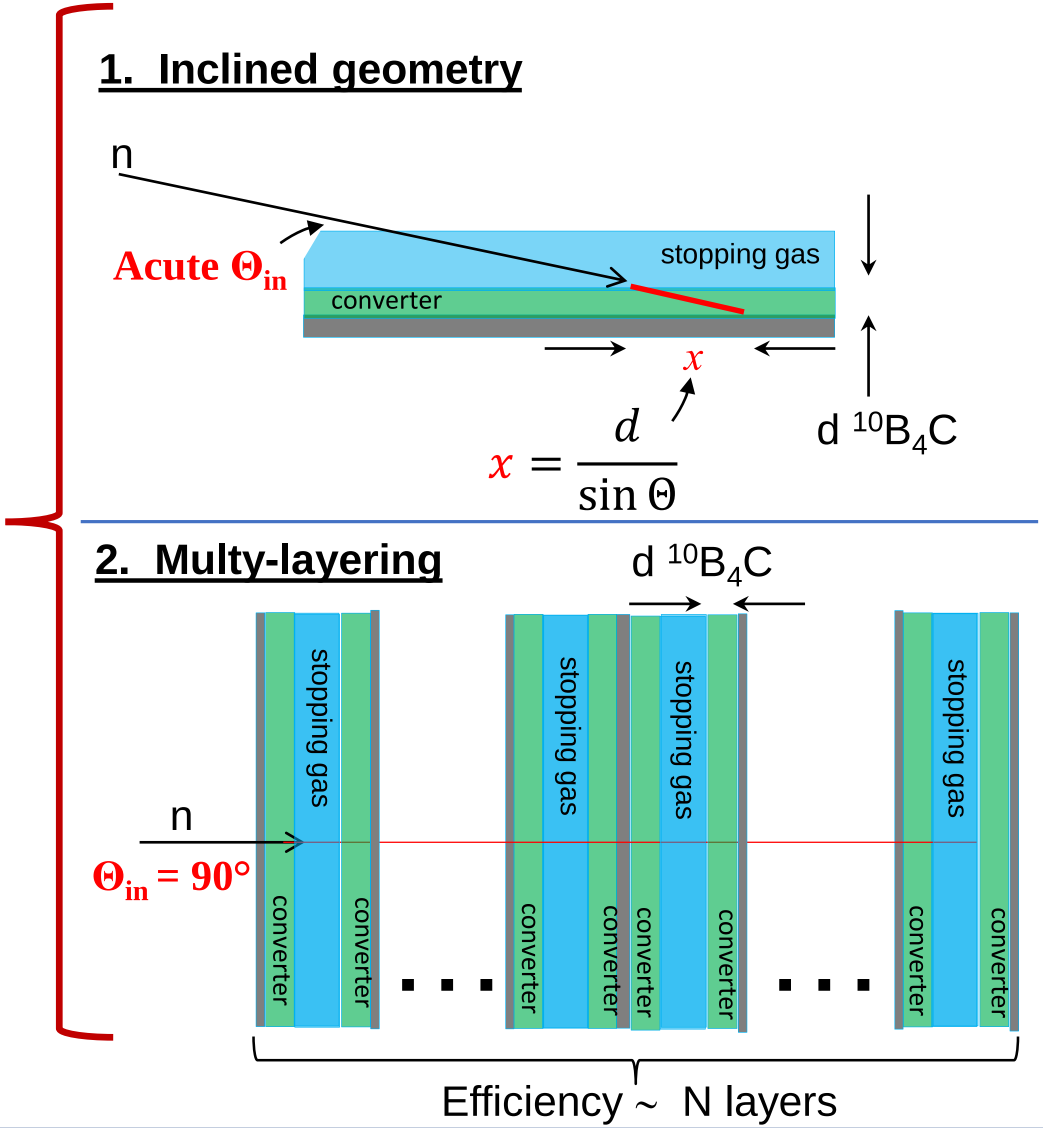
$^{10}B + n \rightarrow {}^{7}Li(1.02MeV) + {}^{4}He(1.78MeV)$ (6%)

Free path length of neutron in $^{10}B_4C$ $l_n \sim 30\mu$; $l_\alpha \sim 3\mu$; $l_{Li} \sim 1.3\mu$

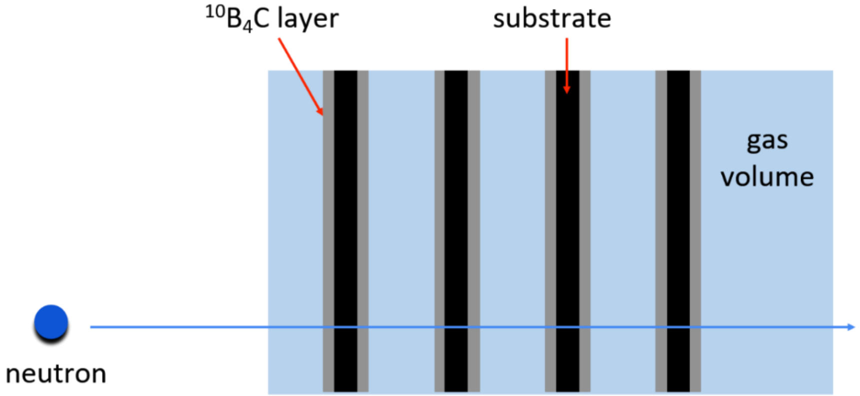


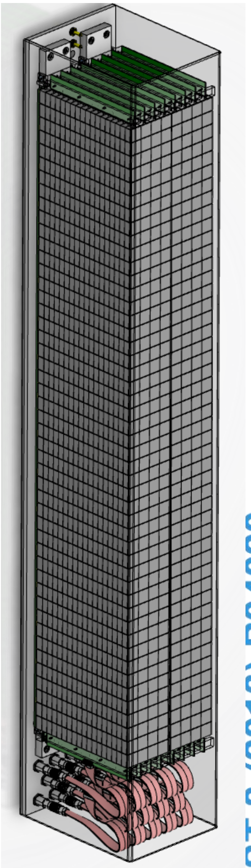
Simulation of the efficiency registration of thermal neutrons by a detector with 1 $B_4C$ layer



# Multi-Grid Detector: example of successful $B_4C$ based detector development

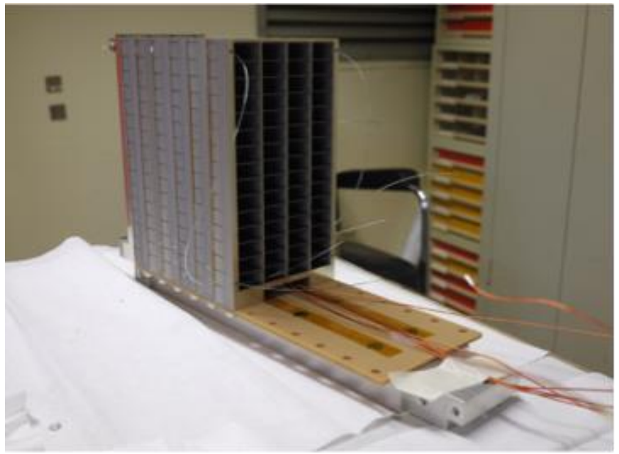


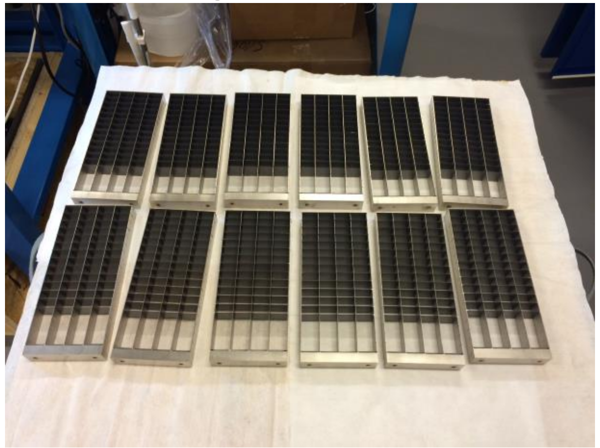


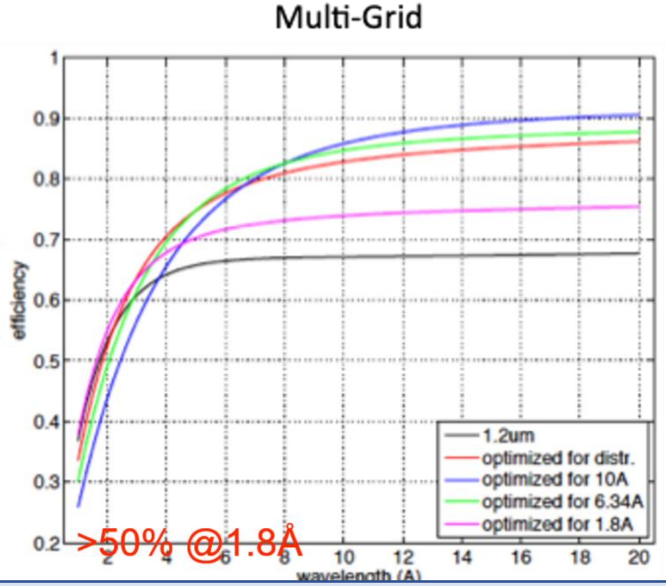


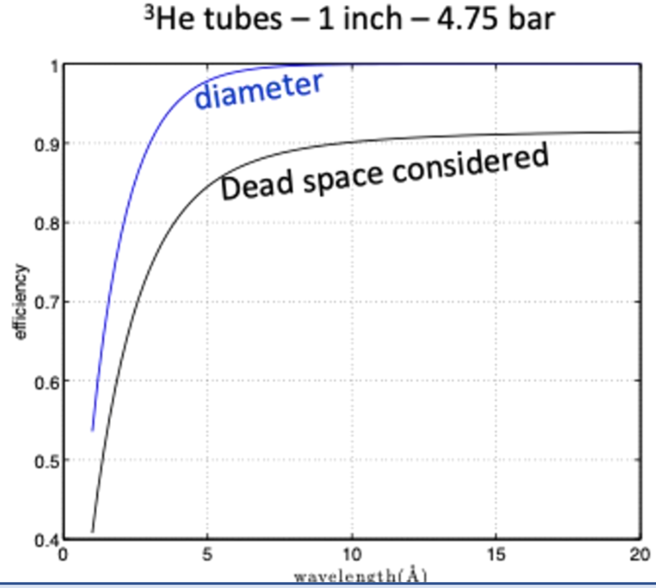
JINST 8 (2013) P04020

Multi-Grid Detector Design





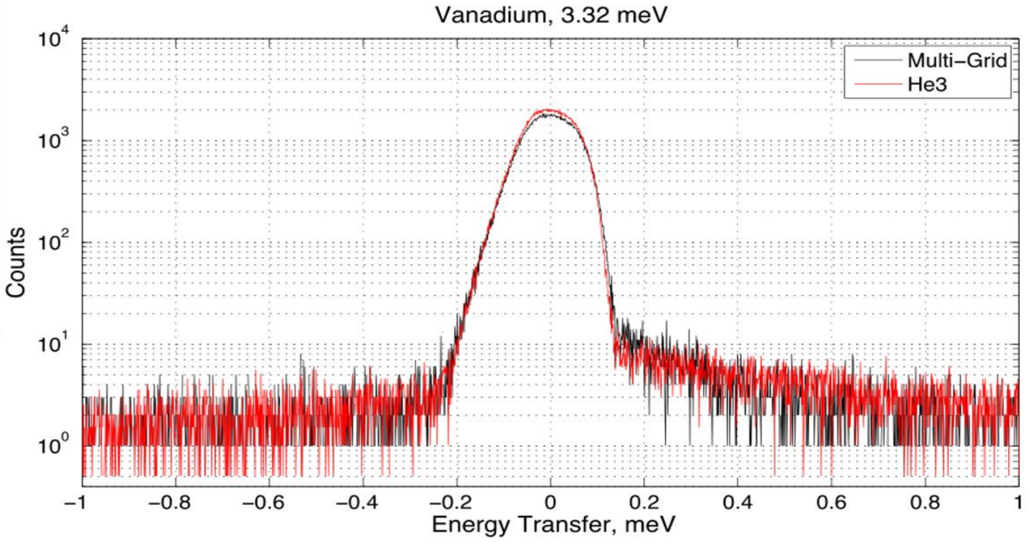


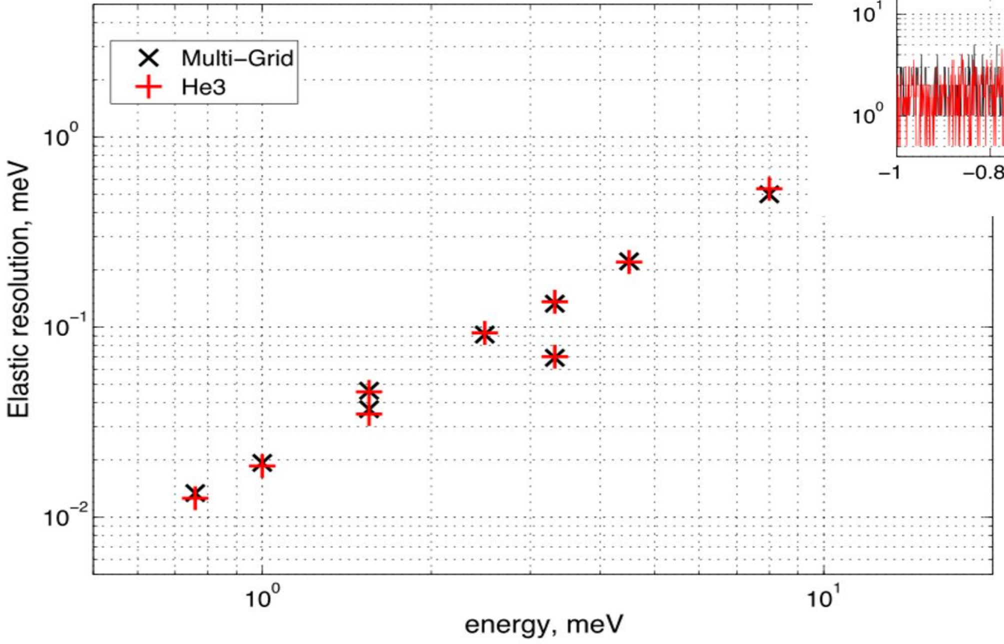



# Multi-Grid Detector: example of successful $B_4C$ based detector development

- Data and instrument resolution identical
- Technology suitable for ESS instruments

Technology demonstrated, ready for deployment



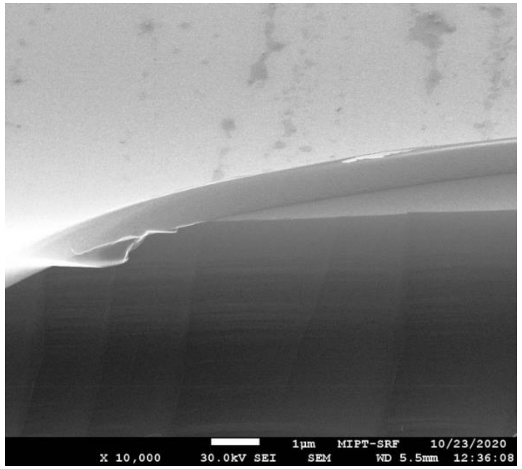

- Advantages over He3 tubes:
  - rate performance
  - fast neutron sensitivity

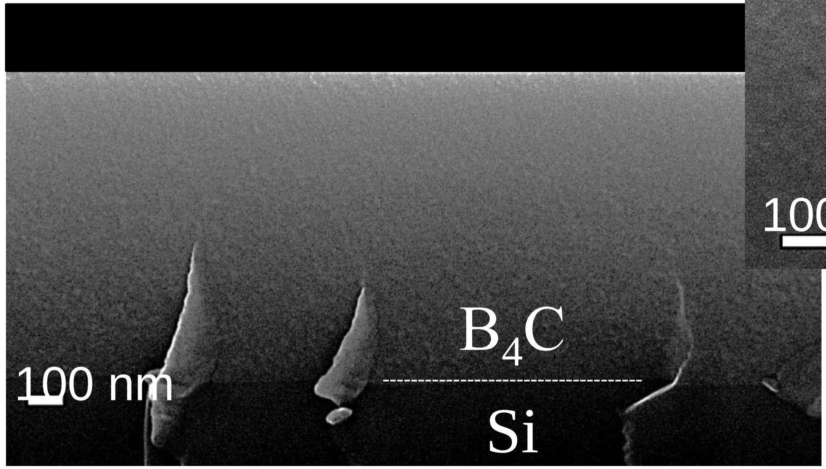
*Anastasopoulos M., et.al. (2017). Multi-Grid detector for neutron spectroscopy: results obtained on time-of-flight spectrometer CNCS. Journal of Instrumentation, 12(04), P04030–P04030. doi:10.1088/1748-0221/12/04/p04030*

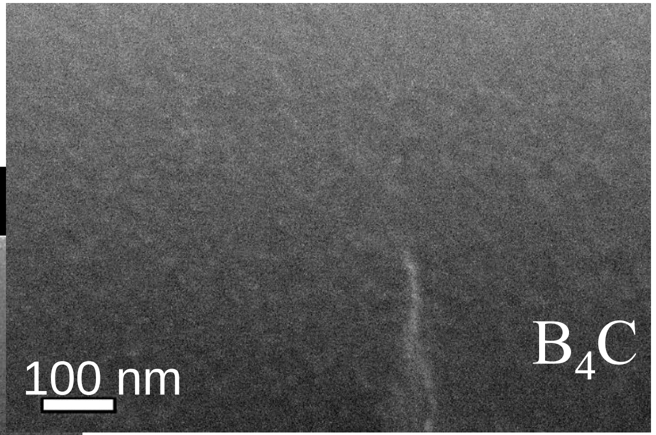
# $B_4C$ thin film production
## in collaboration with State University Dubna

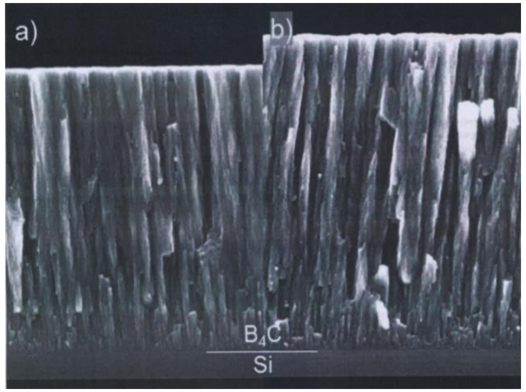
Magnetron sputtering
machine VCR-300
(LLC ROBVAC, Fryazino)

**Amorphous and uniform structure of thin $B_4C$ film**
**With the density 2.4 g/cm$^3$, durable, flexible**



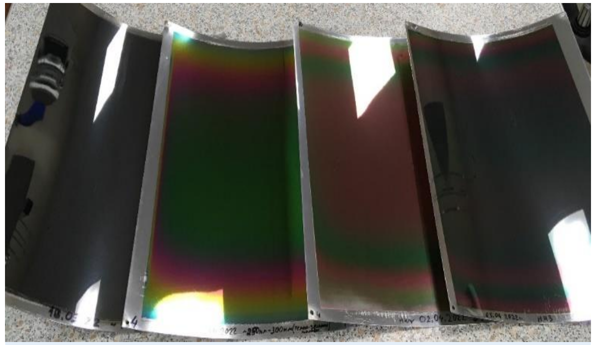




The structure of the thin $B_4C$ film by
Linköping University, Sweden, 450$^0$C

(S.Schmidt et.al., J. Mater Sci (2016) 51:10418–10428,
DOI 10.1007/s10853-016-0262-4)

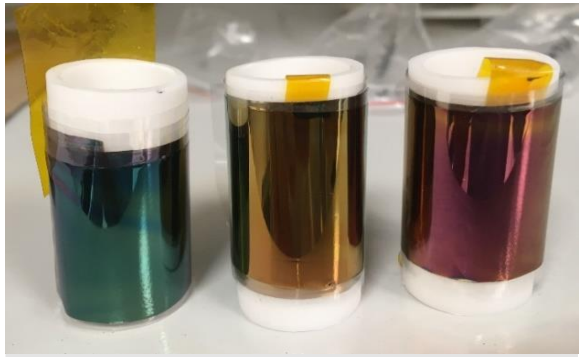
# $B_4C$ thin film production

## in collaboration with State University Dubna



Thin $B_4C$ film (different thickness) on Al plates (0.5mm)
Area of uniform coverage
~ 200 x 300 $mm^2$

Thin $B_4C$ (1μ) on Al foils (20μ)



100nm 300nm 200nm

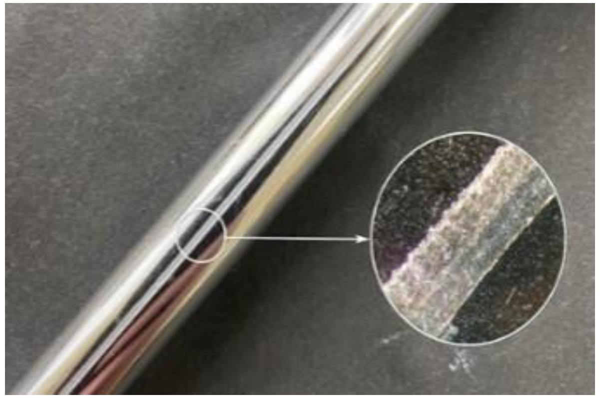
Reels of thin $B_4C$ film on mylar

Thin $B_4C$ (1μ) film on mylar

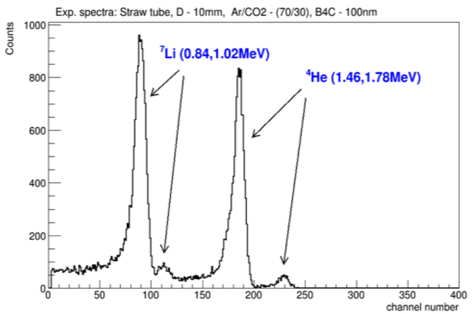
# Straw tubes

## Ultrasound welding machine

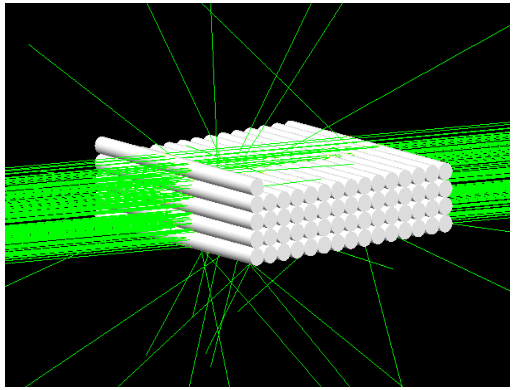
## Welded seam



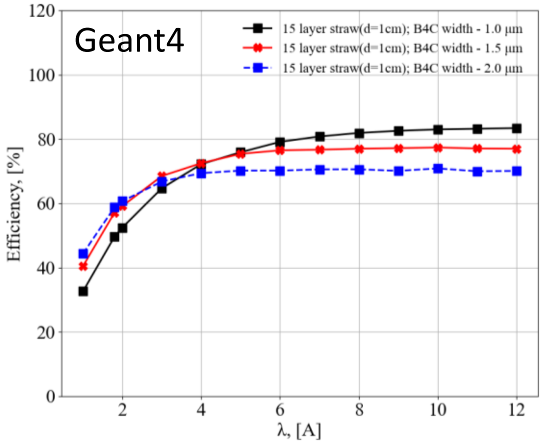
## 1 straw tube detector




## GEANT 4 simulations

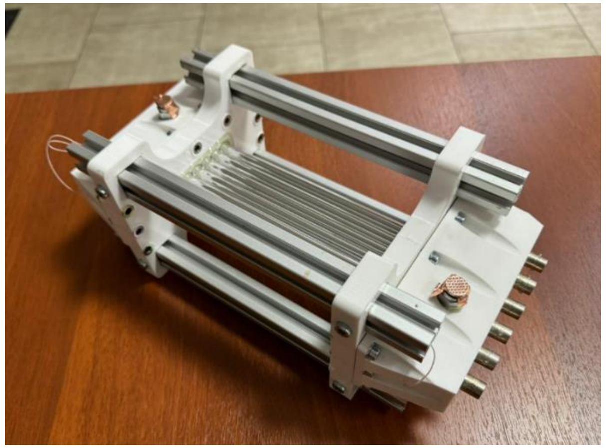


30-layer straw tubes detector(D=1см, converter $^{10}$B)



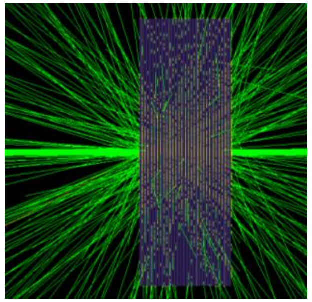

Efficiency of 30-layer straw detector with 90$^0$ beam angle.

## Multi-tube detector

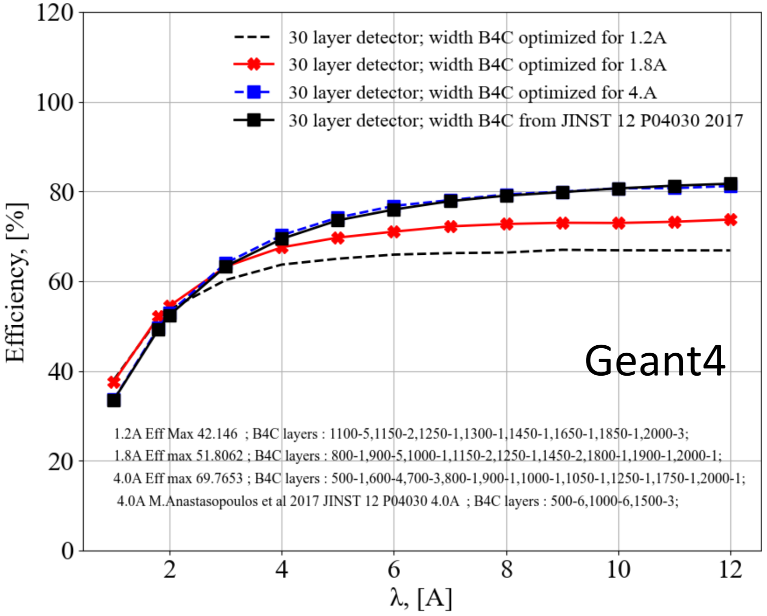


# Multi-layer detector simulation

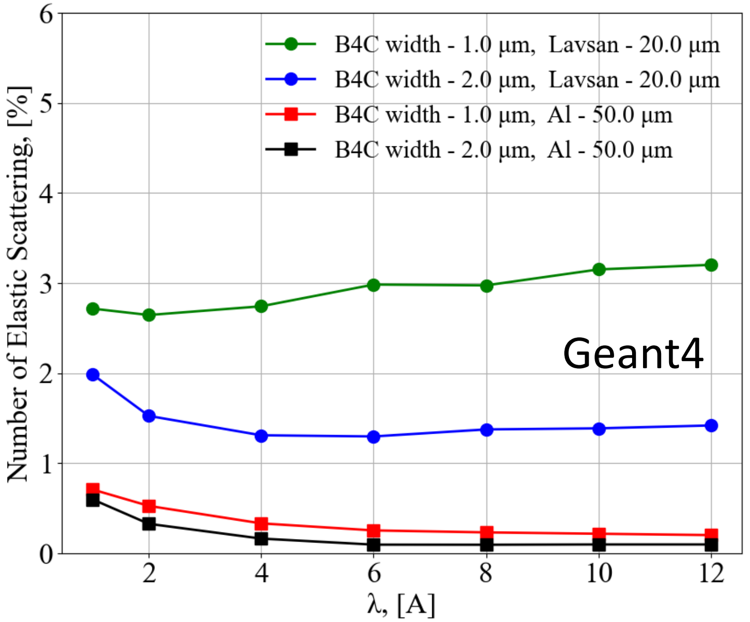
## Efficiency calculation
### of a detector consisting of 15 chambers (30 layers of $B_4C$)



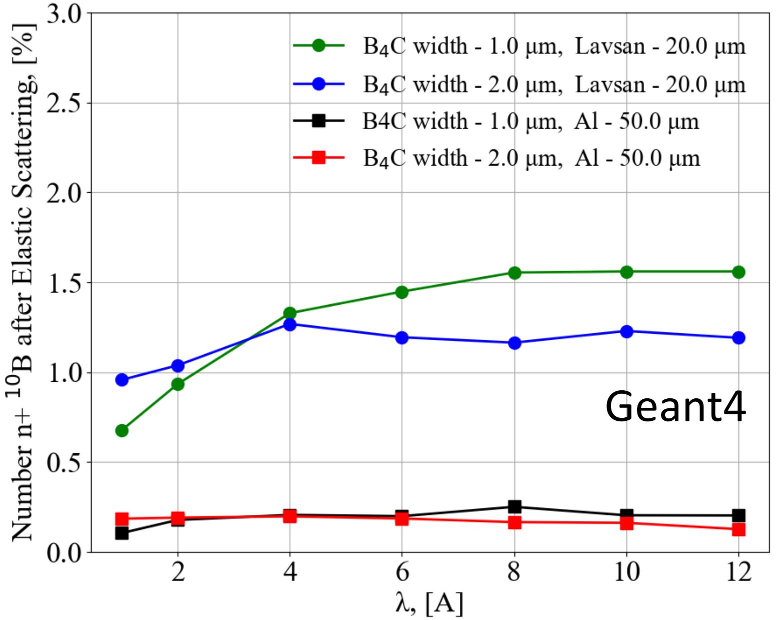
Efficiency




Neutrons are scattered elastically w/o capture in det.

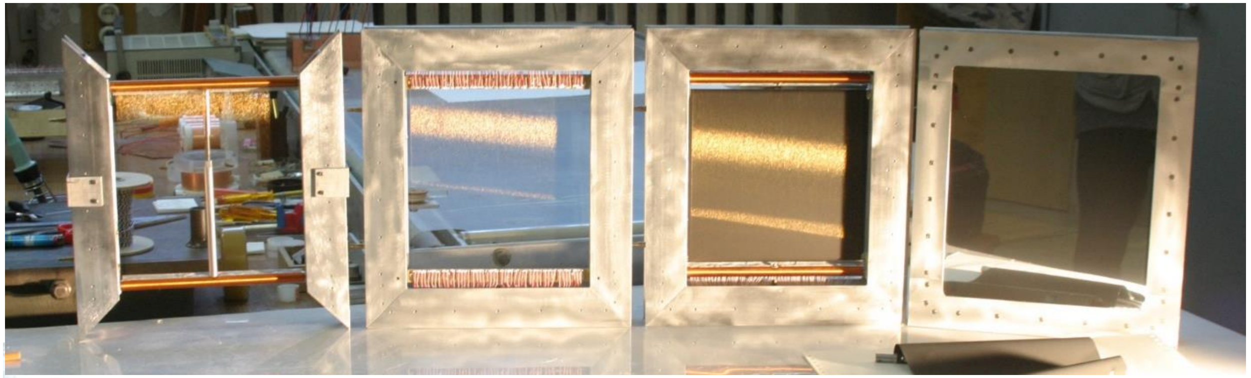



Neutrons are scattered elastically and captured in det.

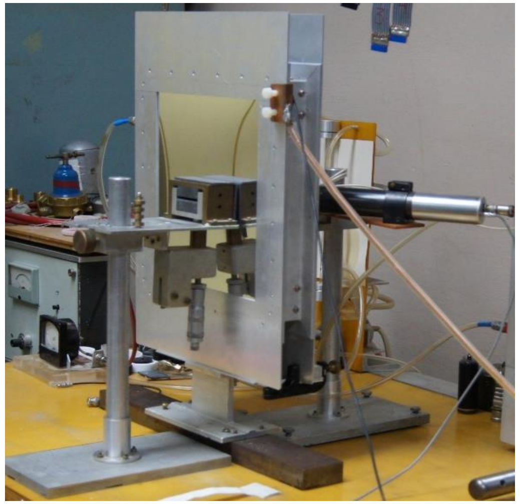


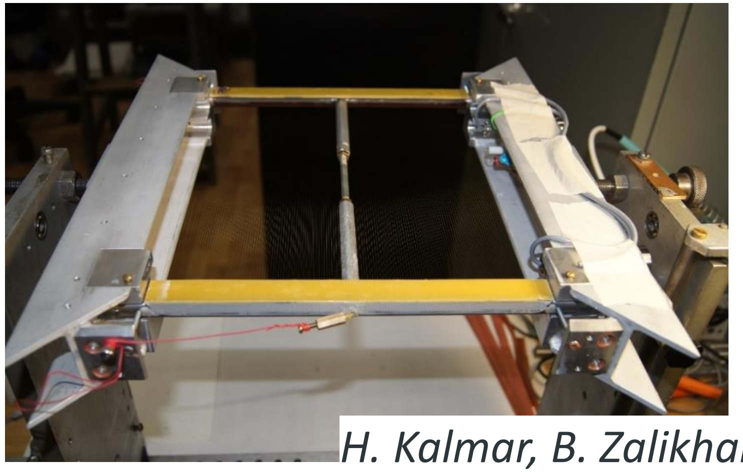
# Multi-wire detector project

## Zalikhanov's (DLNP JINR) narrow gap chamber



| 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 |





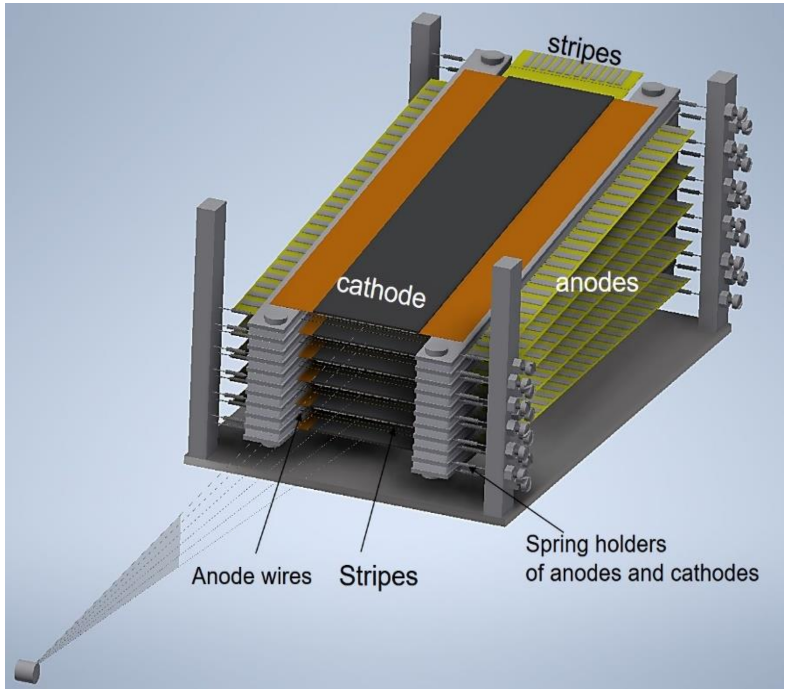
Assembly and testing of a detector with an entrance window of 200x200 mm,
Wire-pitch 1.5 mm,
Gap anode-kathode 2 mm, 128 channels,
Detector speed - 8.4 ns (FWHM),
Operating voltage – 2450 V

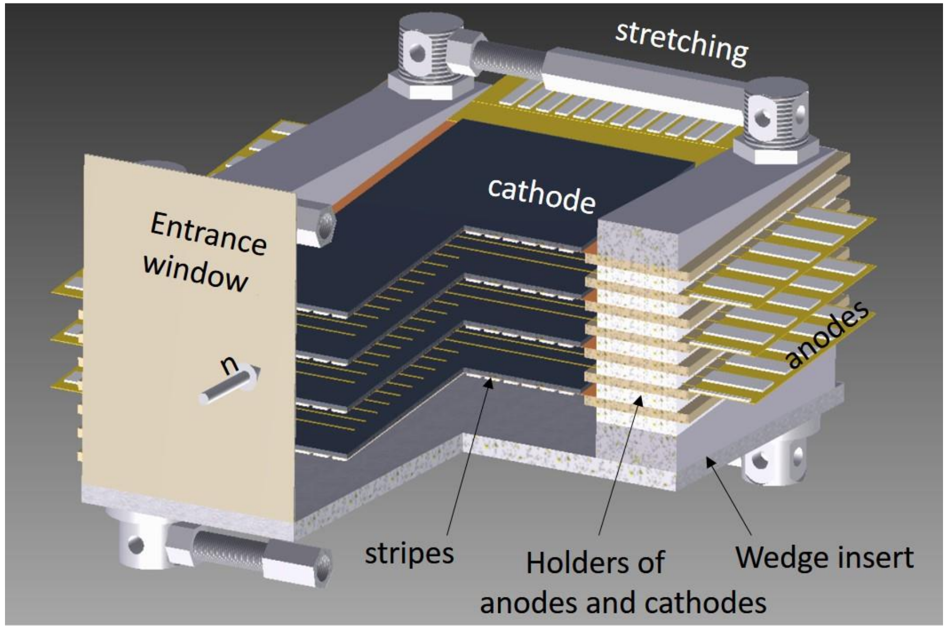
*H. Kalmar, B. Zalikhanov et al. New method for constructing Multiwire chambers, Nucl. Inst. and Meth., A307, 1991. p.279*

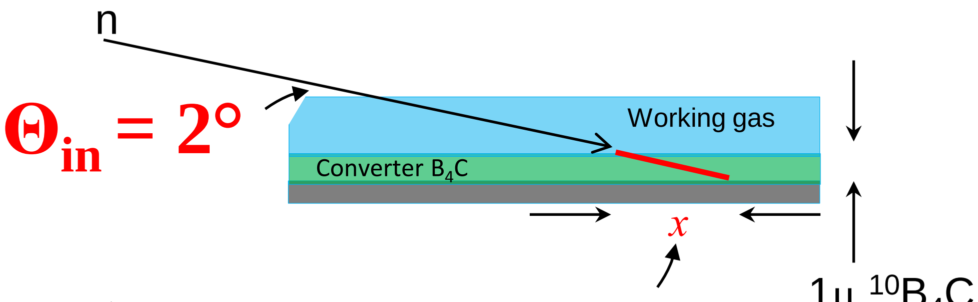
# Multi-foil detector project

## Project of the neutron detector based on Zalikhanov's (DLNP JINR) narrow gap chamber

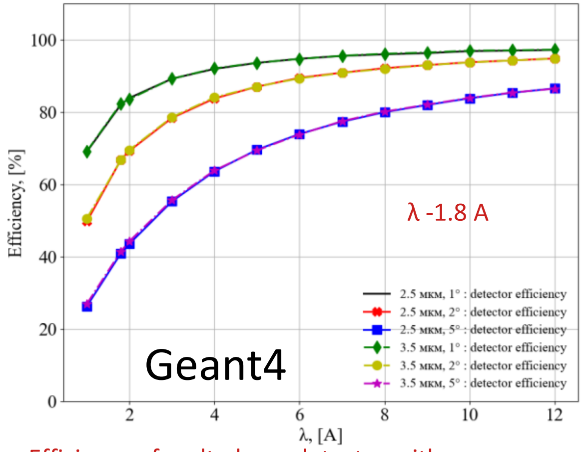
*H. Kalmar, B. Zalikhanov et al. New method for constructing Multiwire chambers, Nucl. Inst. and Meth., A307, 1991. p.279.*



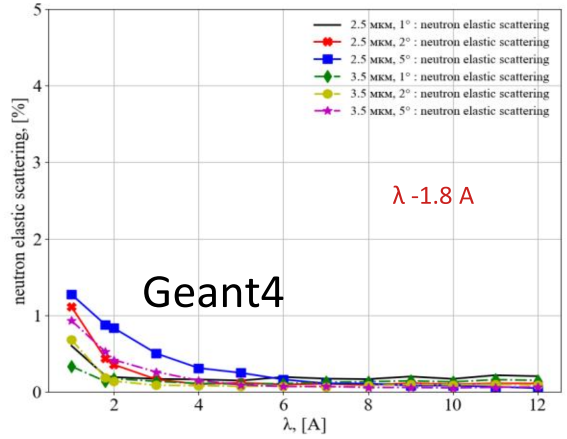




$$x = \frac{1\mu}{\sin(2^{\circ})} = 28.6\mu \quad (71.5\ \mu \text{ at } 2.5\mu\ B_4C \text{ thickness})$$




Efficiency of multy-layer detector with inclination 1,2,50 (material - Al foil 0.5 mm)




Number of elastically scattered neutrons with inclination1,2,5$^{0}$ (material - Al foil 0.5 mm)

# Multi-foil detector project

## Expected performance

Anode pulse width (in base) – ≥ 20 ns

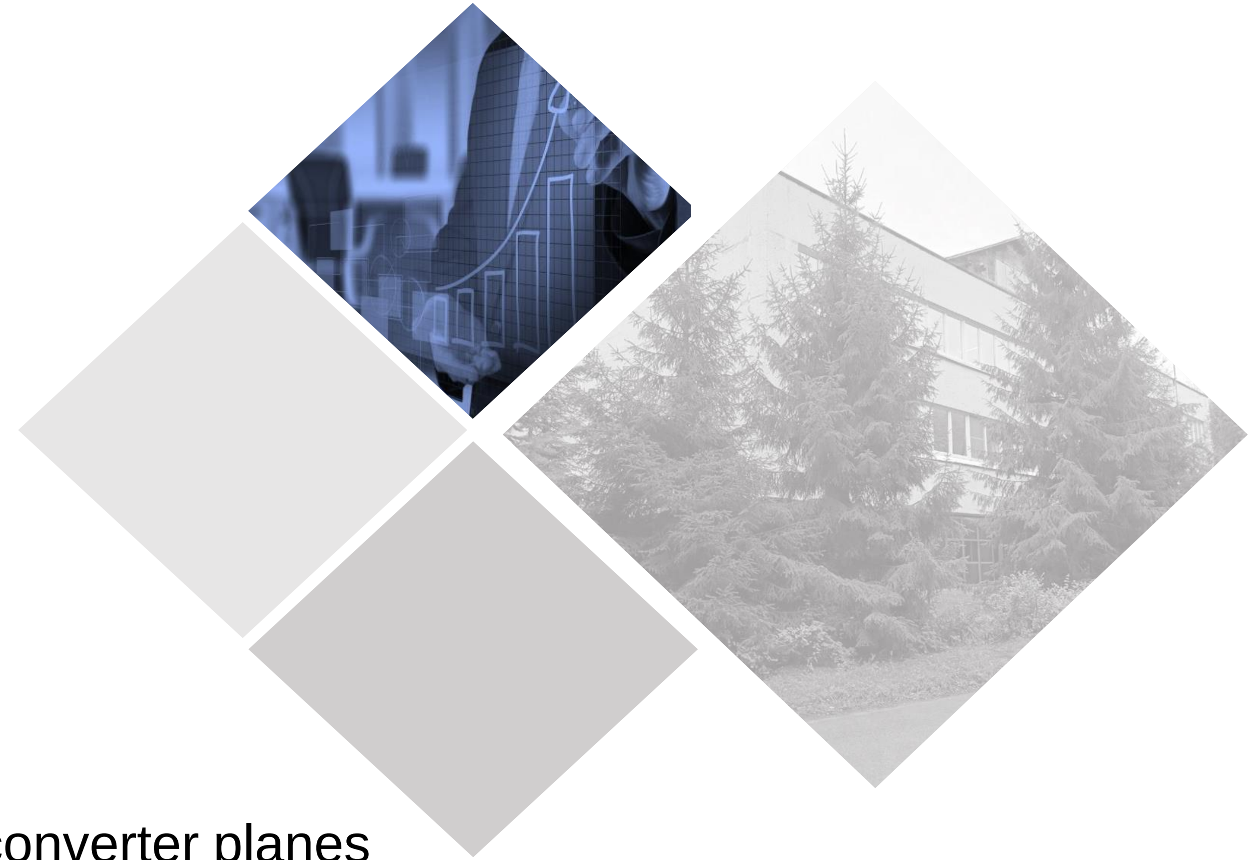
Temporal resolution (FWHM) – ≥ 5 ns

Count rate – ≤ $10^8$ $s^{-1}sm^{-2}$

Space resolution – 0,2x2,5 $mm^2$

Converter thickness $^{10}B_4C$ – 2,5μ

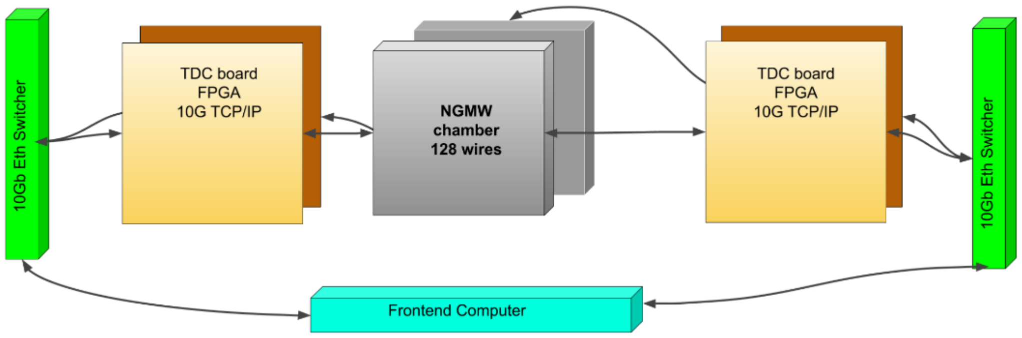
Efficiency at 1,8 Å ~ 65%

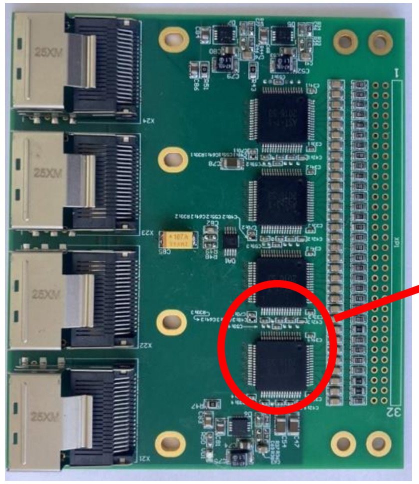


## Drawbacks:

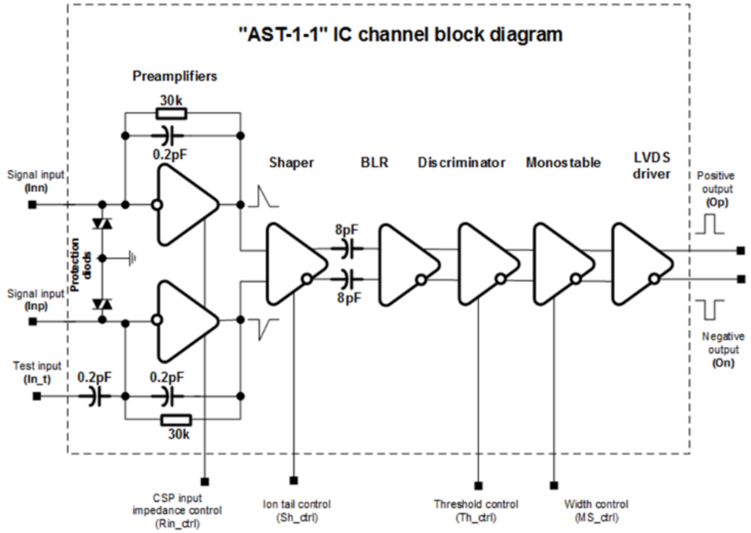
The precise positioning of the detector is needed
to provide the value of 2° of incident angle to the converter planes

## Read-Out Electronics

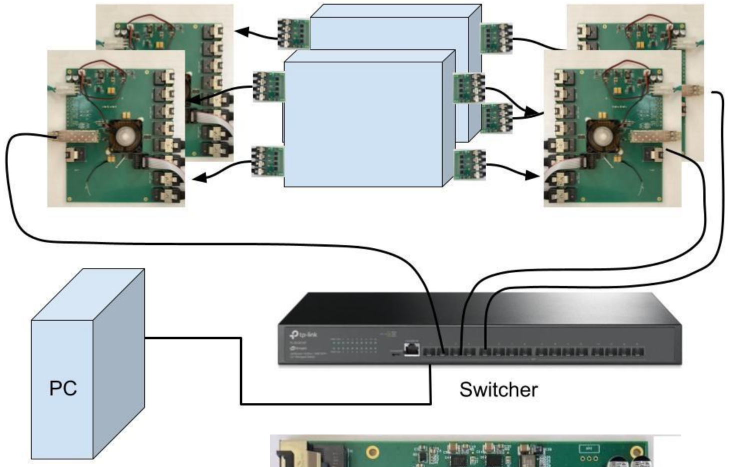


32 ch. Amp.Disc., 7ns res.

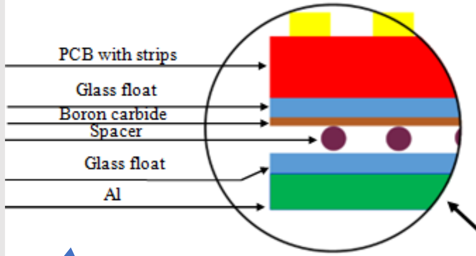


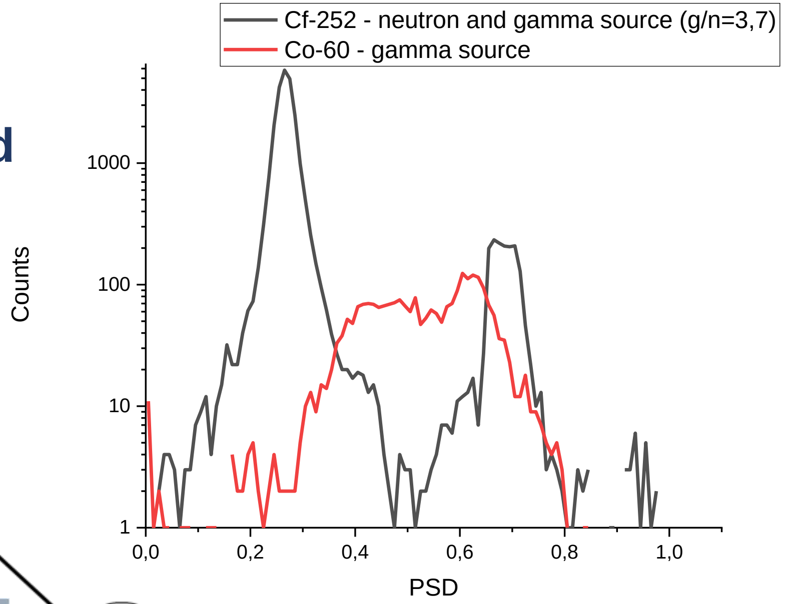

AST-1 chip - 8-ch. ASIC,
developed by Institute of Nuclear Problem,
Belarussian State University

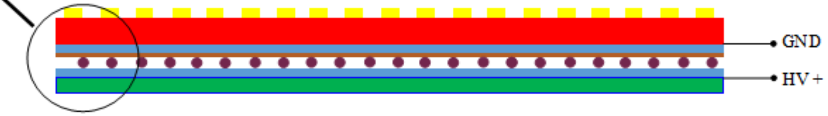



64-ch. TDC, 1ns res.

## Resistive plane chamber 1D $^{10}$B-RPC with delay line and digitizer CAEN 6730 based read-out

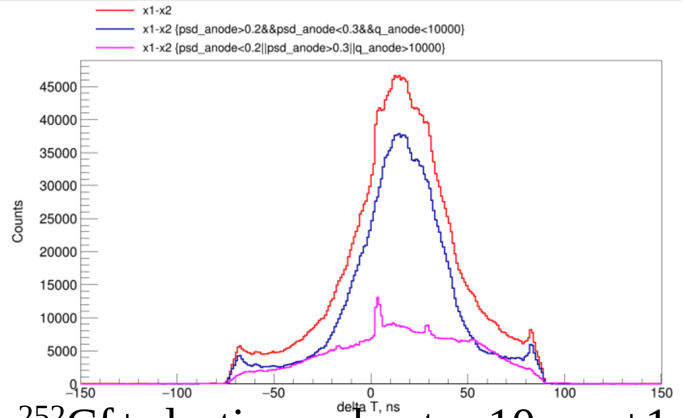


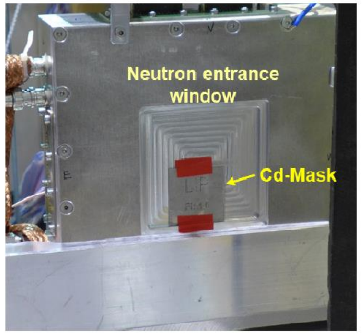



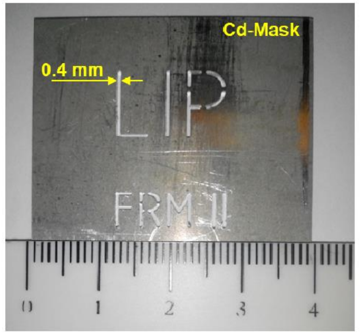

Pulse shape discrimination (PSD) is parameter for difference in the waveform shapes PSD $=\frac{Q_{long}-Q_{short}}{Q_{long}}$

PhD student Maria Petrova holds the experimental module of RPC




$^{252}$Cf+plastic moderator 10 cm +1 cm Cd slit




L. M. S. Margato, et. al.
Multilayer 10B-RPC neutron imaging detector
Journal of Instrumentation 15(06):P06007-P06007,
DOI:10.1088/1748-0221/15/06/P06007

# 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

- Modular machine straight through type with continuous operation
- Substrate size 650x1200 mm, vertical orientation
- Possible option is two side coverage deposition with uniformity of 3% on the square 400 x 1200 mm$^2$
- Single and multilayer coverage possibility
- Operation mode – “there and back”
- Possibility of upgrading with additional technological modules

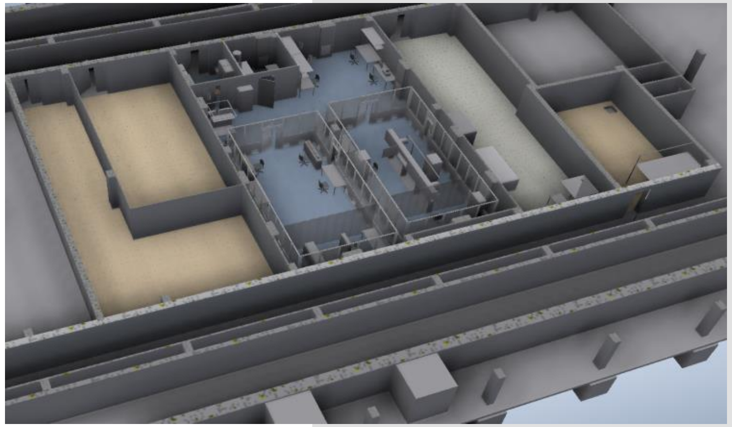
Spattering machine for $B_4C$ coverage
Ferry Vatt company, Kazan, Russia
Max. coverage square 400x1200 mm$^2$

# 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



# Thank You

**for your attention**

CONTACT US:

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

bodnarch@nf.jinr.ru