National Research Centre "Kurchatov Institute"
B.P.KONSTANTINOV PETERSBURG NUCLEAR PHYSICS INSTITUTE

NEUTRON DETECTORS AT PNPI

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INSTRUMENTATION FOR PIK REACTOR

1) Condensed-matter physics (CMD) - 22 instruments:
Thermal neutron detectors (counters, 1D, 2D)

2) Nucl. physics & particle physics
10 instruments :
detectors for *n*, *e*, *p*, γ-particles

1st queue	12 units	up to 2019
2nd queue	20 units	2019-2024

CMD Instruments (pcs.)	Counters	PSD (1D/2D)
1. Powder diffractometers (3)	-	3
2. Single-crystal diffractometers (4)	-	5
3. Spectrometers (5)	4	2
4. SANS (6)	1	6
5. Reflectometers (4)	4	6
TOTAL	9	22

POSITION-SENSITIVE DETECTOR PARK OF PIK

Sensitive area, mm	Number	Application
1) ≤ 100×100	2 (more?)	Monitors
2) 200×200 – 300×300	11	Ref., Stress-diff., SCD, …
3) 400×400 – 500×500	3	Ref., SANS
4) 1000×1000	2	SANS, In.Spec.
5) Curved shape “banana-like”	4	Powder Diff., In.Spec.
	TOTAL: 22	

PSD parameters:

- Sensitive area ~100 ÷ 1000 (mm)
- Neutrons wavelength 0.5÷ 20 (Å)
- Position resolution 1 ÷ 10 (mm)
- Counting rate capability 1×10^5 ÷ 1×10^7 (n/sec)

Different technologies should be applied!

THE 1ST QUEUE OF THE INSTRUMENTATION: BEAMS AND DETECTORS (MC - ESTIM.)

Instr.	λ (Å)	Flux (MC sim.) 1) At sample (n/cm2/s) 2) Sample (cm2) 3) Sum flux (n/s)	Detector area, mm	Count rate: 1) full, n/s 2) local, n/cm2/s	Pos. res. (X*Y), mm	Eff., %	Cond.	Note
NERO	5.18	1) 2 E6 (5.18 Å) 2) 3*20 3) 1.2 E8	250×250	1) ~ 1 E6 2) 3 E5	2.5	70	n.c.	1. Beam-stop 2. Beam-monitor 3. He-3 PC
DCD	2.23, 4.43	1) ≥2 E6 (4.43 Å) ≥1.5 E5 (2.23 Å) 2) 3*20 3) 6 E7 (4.43 Å) ≥9 E6 (2.23 Å)	3 * PC	1) (1 ÷10) E5 2) <(1 ÷10) E5	-	>60	Vacuum	1. Beam-stop
SANS-2	3÷20	1) 1.5 E8 (5 Å) 2) 3*3 3) 1.35 E9 (5 Å)	500×500	1) (1 ÷10) E5 2) <(1 ÷10) E4	5	> 60	Vacuum	1. Beam-stop
SANS-3	3÷20	1) 3 E8 (5 Å) 2) 3*3 3) 2.7 E9 (5 Å)	300×300	1) (1 ÷10) E5 2) <(1 ÷10) E4	1.5÷2.0	70÷80	Vacuum	1. Beam-stop
POLDI	1÷3 (1.3, 2.4)	1) No polariz. ~ 3 E8 @1Å, 6.3 E8 @1.5 Å Polariz. (1÷2) E8 @ 1.3 Å 2) 1.5*1.5 3) No polariz. 1.4 E9 @1.5 Å Polariz. (2.3÷4.5) E8 @ 1.3 Å	Banana-like, R 600mm, 80⁰ 780×320	1) (1 ÷30) E5 2) <(1 ÷10) E4	3÷3	70÷80	n.c.	1. He-3 PC 2. Beam-stop
TEX	0.5-3.0	1) n.d. 2) 3*3 3) n.d.	300×300	1) (1 ÷10) E5 2) <(1 ÷10) E4	1.5-2	50÷70	n.c.	1. He-3 PC 2. Beam-stop
ARES	1.5-3.5	1) n.d. 2) 10-30 mm3 (scan) 3) n.d.	300×300	n.d.	1.5-2	50÷70	n.c.	1. 2pcs He- 3 PC

DETECTORS (1ST QUEUE) AND TECHNOLOGIES

Instruments	Counters	PSD (2D)	Main technology
Diffractometers			He-3 Straw Array or
POLDI	1	1	Scint. ZnS/LiF(?)
TEX (stress)	1	1	He-3, MWPC
ARES	2	1	He-3, PC & MWPC
SANS diffractometers			
S3 - DCD	3	0	He-3, PC
S5 - SANS-2	1	1	He-3, Multi-chan. MWPC
S6 - SANS-3	1	1	He-3, Multi-chan. MWPC
Reflectometer		1- PSD,	
NERO	1	1 – 2D Monitor	He-3, PC & MWPC
TOTAL	10	7	

GAS-FILLED DETECTORS PROPOSAL FOR 1ST QUEUE

Gas-filled PSD can be divided into the following classes:

- with aperture:
  1) 2D profilometers, monitors - *prototyping* **Refl., SANS**
  2) up to 300×300 mm - MWPC - *Done!* **TEX (stress), ARES**
  3) ~ 500×500 mm - MWPC - *concept, R&D is planned* **SANS-2**
  4) ~ 1×1 m and Curved PSD **POLDI**

  (Linear-Sensitive Proportional Counters (LSPC) - *prototyping*

- with counting rate capability (per detector)
  1) 100-200 kHz - Delay-line readout - *Done!* **TEX, ARES**
  2) Up to ~ several MHz - MWPC Multi-ch. cathode readout - *concept* **SANS-2**
  3) Multichannel Charge-division (1m^2 and Curved PSD) - *prototyping* **POLDI**

The support of R&D is highly required!

EXISTING DEVELOPMENTS (IN EXPERIMENTS)

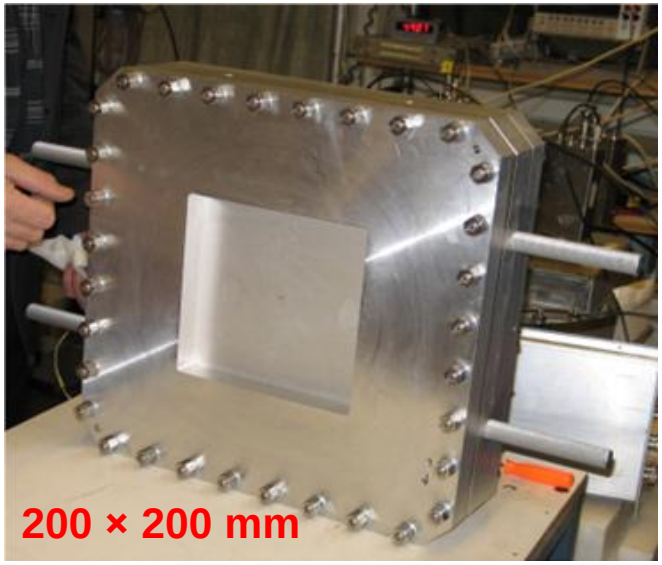
2D PSD

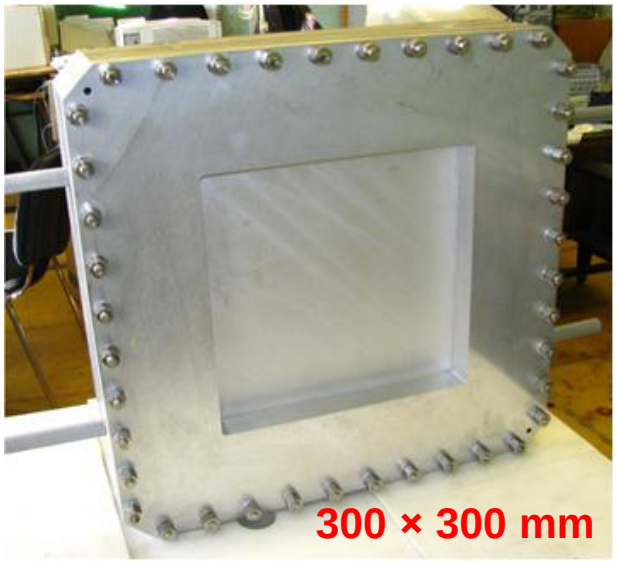
AREAS UP TO 300×300 MM
POSITION RESOLUTION 1.5 * 2 MM (FWHM)
EFFICIENCY 70% (OPTIMIZED)
COUNTING RATE 150 KHZ (OVERALL)
“CLEAN” TECHNOLOGY – EXTENDED LIFETIME

UCN COUNTERS

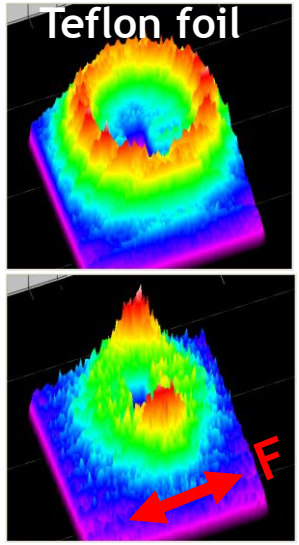
AREA Ø 300 MM
EFFICIENCY >90% (ESTIM.)
OPTIMIZED GEOMETRY OF CELLS
“CLEAN” TECHNOLOGY – EXTENDED LIFETIME

DETECTORS FOR SANS AT VVR-M REACTOR





Parameter	Detector for SANS "Membrane-2"	Detector for SAPNS "Vector"
Window size, mm	200×200	300×300
Mixture composition ($^3He+CF_4$), Bar.	4 + 2	2 + 2
Efficiency (beam optimized), % (λ)	70 (3 Å)	72 (9 Å)
Position res. *FWHM (X×Y)*, mm	1.6×2.0	1.5×2.0
Readout	LC-Delay line	
Dark counting rate, Hz	<0.2	<0.3
Counting capability (10% miscalc.), kHz	125	
γ-sensitivity (^{137}Cs), ×100%	<2 E-8	
Life time (without of gas service), yrs	>5 (since 2008 up to reactor stop in 2015)	

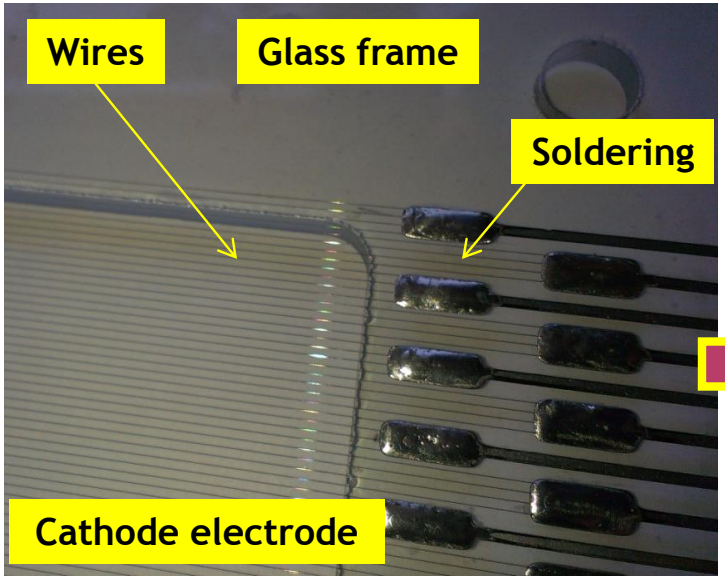


TECHNOLOGY OF MWPC FOR NEUTRON DETECTORS

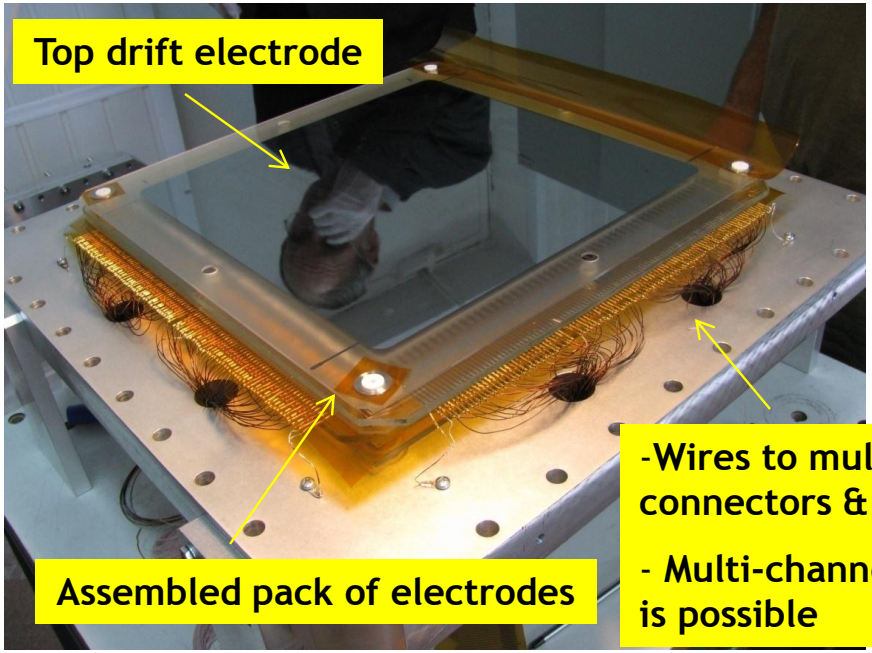
Gas purity + fine technology =
= Detector life-time

1. Initial high purity of gases (He-3, CF4)
2. Materials selection for UHV applications
3. Baking/pumping of assembled detector
4. Low gas leakage (<3% He-3 / year)

Metallic lamellas are sputtered on the glass frame for wire soldering



To Multi-pin connector and Delay-Line



-Wires to multi-pin connectors & DL

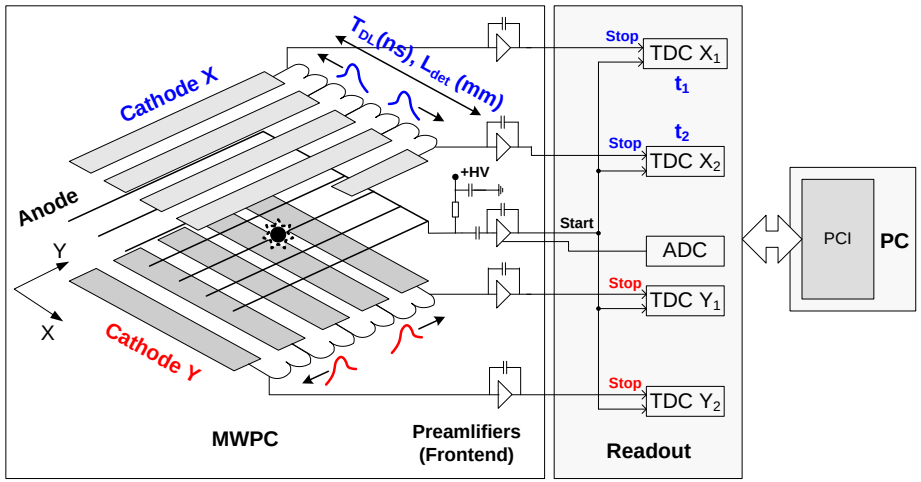
- Multi-channel readout is possible

Robust metal adhesion

Possible to solder wires several times

Thermal annealing up to 120 ^{0}C

Detector design and readout electronics (PNPI)



- **Anode** – central in detector volume, wire space – **2 mm**
- **Cathode distance from anode 3 mm**,
- **Width of cathode strip – 3 mm**
- Two **drift regions** – **12 mm** per each
- Delay line readout.

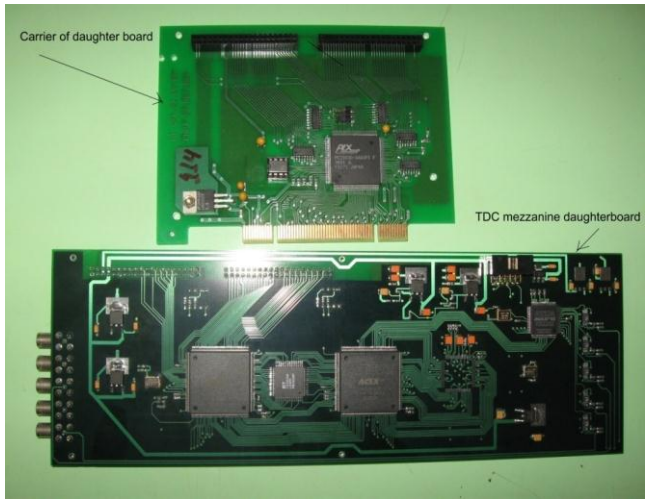
4-Channel TDC (VME-version)

- **TDC range** ~ 600 ns, (150 ps/channel)
- **Diff. nonlinearity** <5%
- **Counting rate** 100 kHz (25% miscalc.)
- **Dead time** ~5 us
- **ADC** 5 V, 1024 ch.

4-Channel TDC (PCI-version)

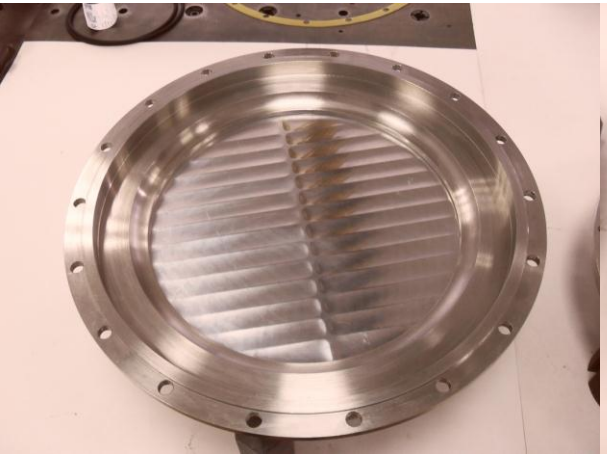
- **TDC range** ~ 1 us, (130 ps/channel)
- **Diff. nonlinearity** <5%
- **Dead time** ~2 us
- **Count rate** capability – **125 kHz** (10% miscalc.)

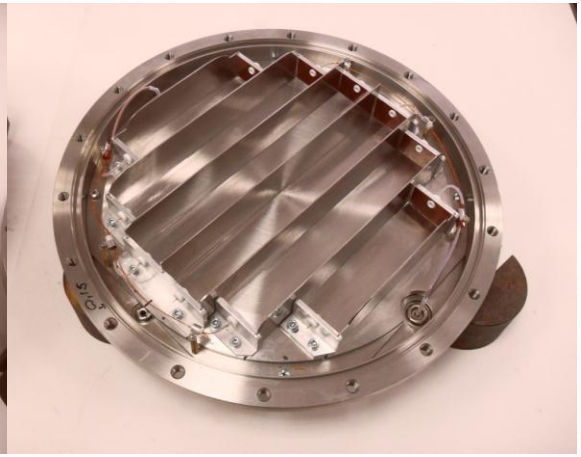
Inputs (NIM):
1) Anode "Start"
2) Cathode "Stop"
(X1, X2, Y1, Y2)

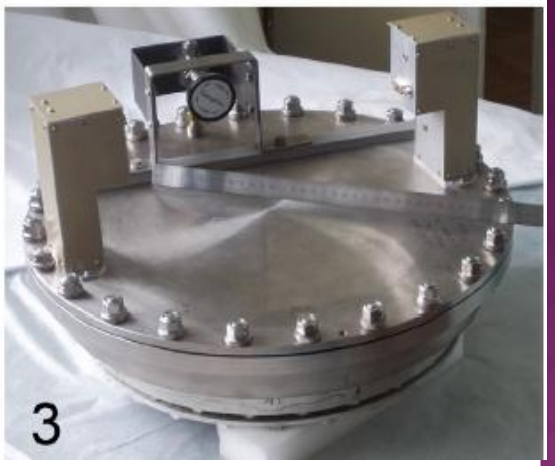


Detector for Ultra-Could Neutrons

Neutron life-time measurements (PF2/MAM, ILL), A.P. Serebrov







Top part

Window: 100 μm Al foil
Foil is supported by metallic grid.
Detector is mounted on neutron guide

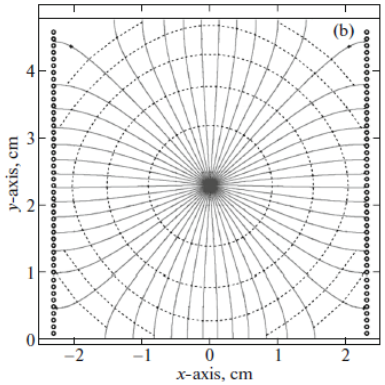
Bottom part

6 PC combined into 2 channels
Anode wires - 25μm.
Gas: 1.0-1.5 % ^{3}He + Ar
1 Atm. Abs.

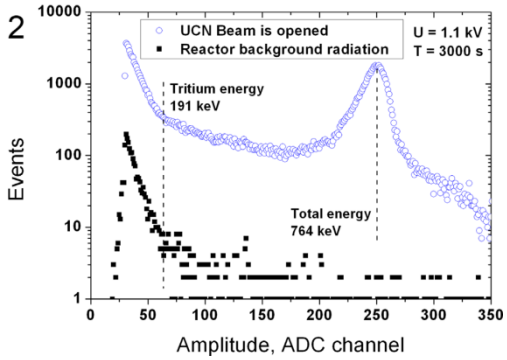
Assembled detector

2 preamplifiers
Gas valve

Electric field, Drift lines (Garfield)



Amplitude Spectra (UCN beam test, ILL)



2 detectors are produced, tested and accepted

New developments and activity

1) Large area detectors (LSPC) - prototyping and tests
2) 2D beam monitor - prototyping
3) B-10 detector prototype – tests
4) Improving of MWPC count rate capability - concept

1) LARGE AREA DETECTORS BASED ON LINEAR-SENSITIVE PC'S

Application:

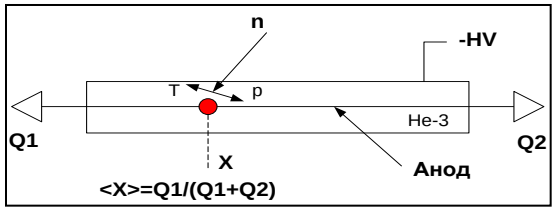
- Large areas >1 m2 (SANS, Inelastic.)
- 1D curvature (Powder.)

Main approaches:

- array of separate counters

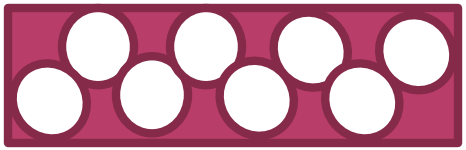
- sub-detectors units: blocks of 8-10 counters with the common gas volume

Charge-division readout for each anode



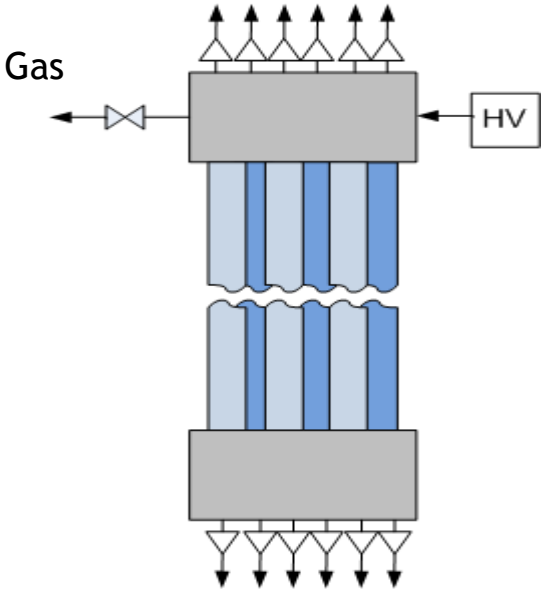
Anode

Single Detector Module of 8th counters



Features

1) **High pressure up to 12-15* bar:**
   High efficiency (60-90%) in the wide range of wavelengths (λ =1 ÷ 20 Å)
2) **Low dead volumes (gas usage)**
3) **Low Scattering and absorption of neutrons**
   (S.S. cathode, wall thickness 200 um)
4) **The gas pressure in each counter is equal:**
   homogeneity of efficiency and gas gain
5) **Scalability principle, quick module replacement**

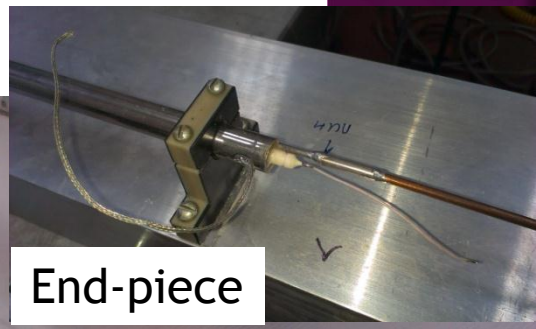


Prototype of Linear Sensitive PC

Cathode – S.S., diam. 10 mm,
Wall – 200 um, L=115 cm

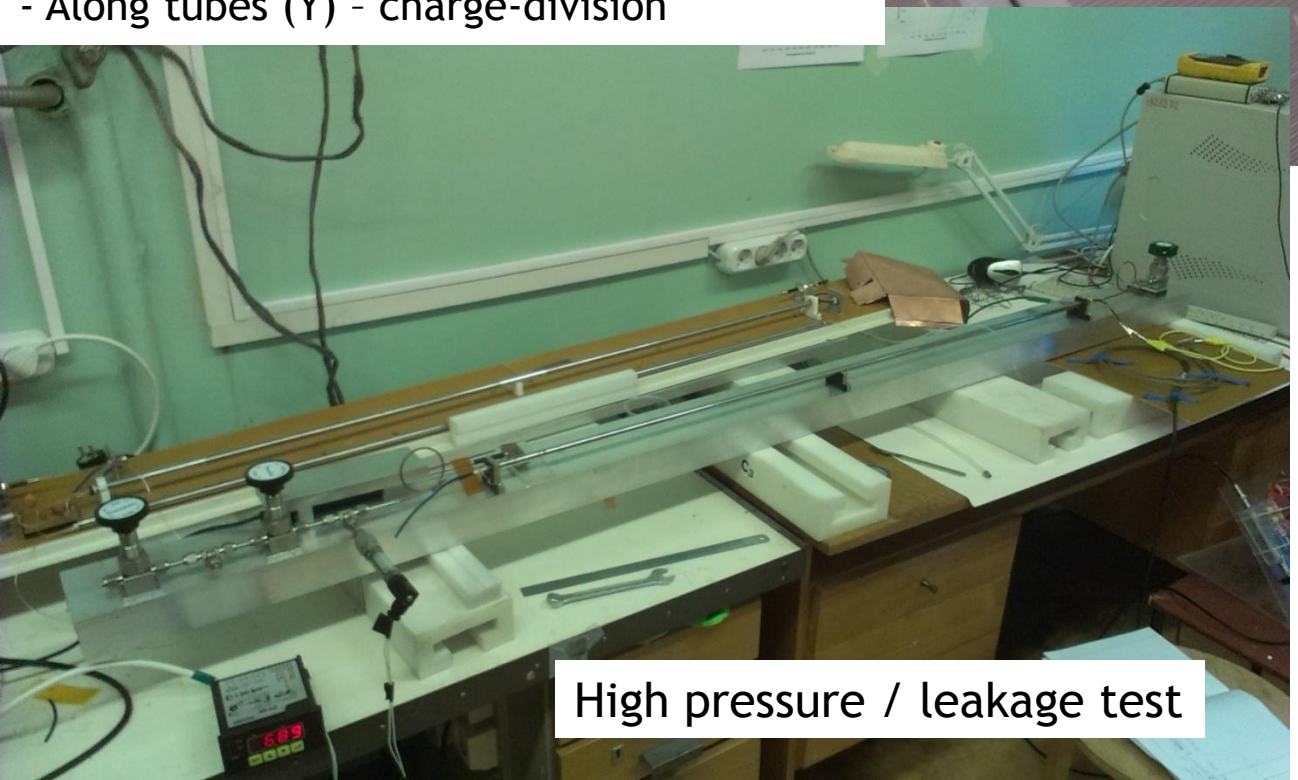
Anode W-Au , diam. 15 or 25 um
• It results in a high radiation resistance much more higher than in case of widely used Ni/Cr wire.

Position readout
- Across the straw tubes (X) – PC number
- Along tubes (Y) – charge-division



End-piece

Single counter



High pressure / leakage test

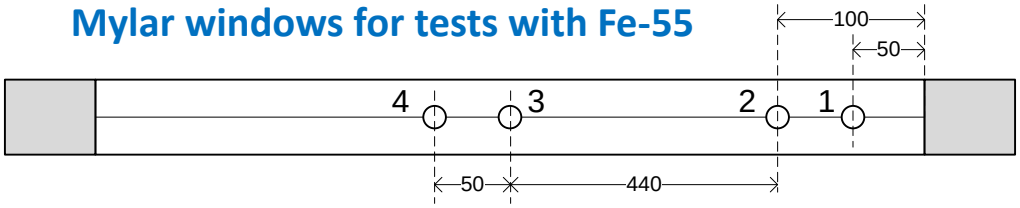
Tests:
• High voltage
• High pressure / leakage

Charge-division position resolution (along wire):

FWHM~1.5 % of L=115 cm

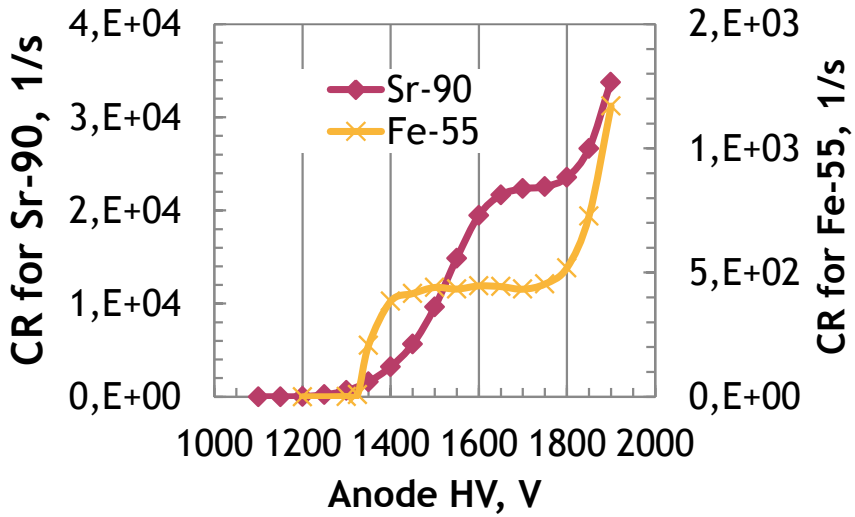
Some results for single LSPC

Mylar windows for tests with Fe-55

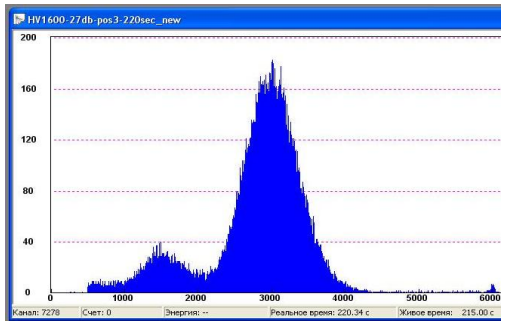


- Cathode diameter 10mm
- W-Au anode 15 um
- Length 115 cm
- Gas: 60%Ar / 30%CO2 / 10%CF4

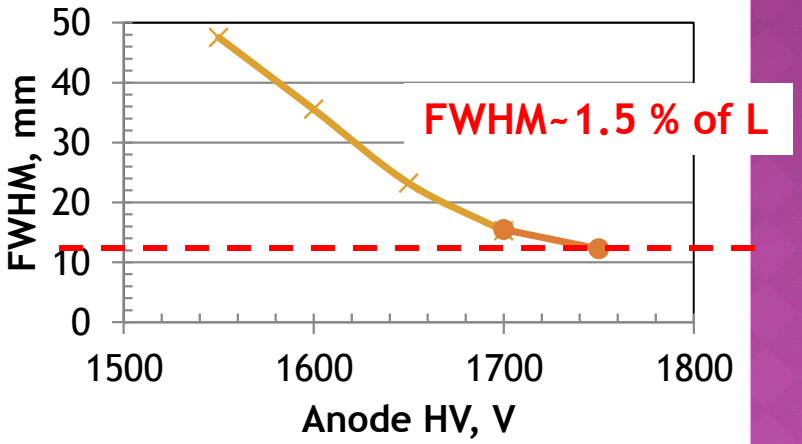
Counting rates for Sr-90 and Fe-55



Amplitude spectrum - Fe-55



Position resolution along straw with Fe-55



Future plans:

- Sealing, end piece construction improvements
- Prototyping of electronics

To push technology in life

Support and collaborative efforts are needed.

2) PSD NEUTRON MONITOR FOR HIGH FLUX BEAMS

Application: Intensity and profile of neutron beam online monitoring

1) Tune of neutron optic elements of instruments
2) Beam parameters monitoring on sample

Estimated needs for PIK ~20-30 pcs.

Technical characteristics

• Neutron transmission	≥ 95-98%
• Area	100 * 100 mm (any)
• Pos. resolution (X,Y)	3-4 mm (1 Bar, limited by window thickness)
• Changeable windows	thickness (100um to ~ mm)
• "Low-cost" DL-readout	4ch-TDC

Adjustable parameters for fluxes

1) Flux up to 10^6 n/cm2/s (VVR-M reactor)

Gas mixture: 50 mBar ^{3}He + 950 mBar CF_4

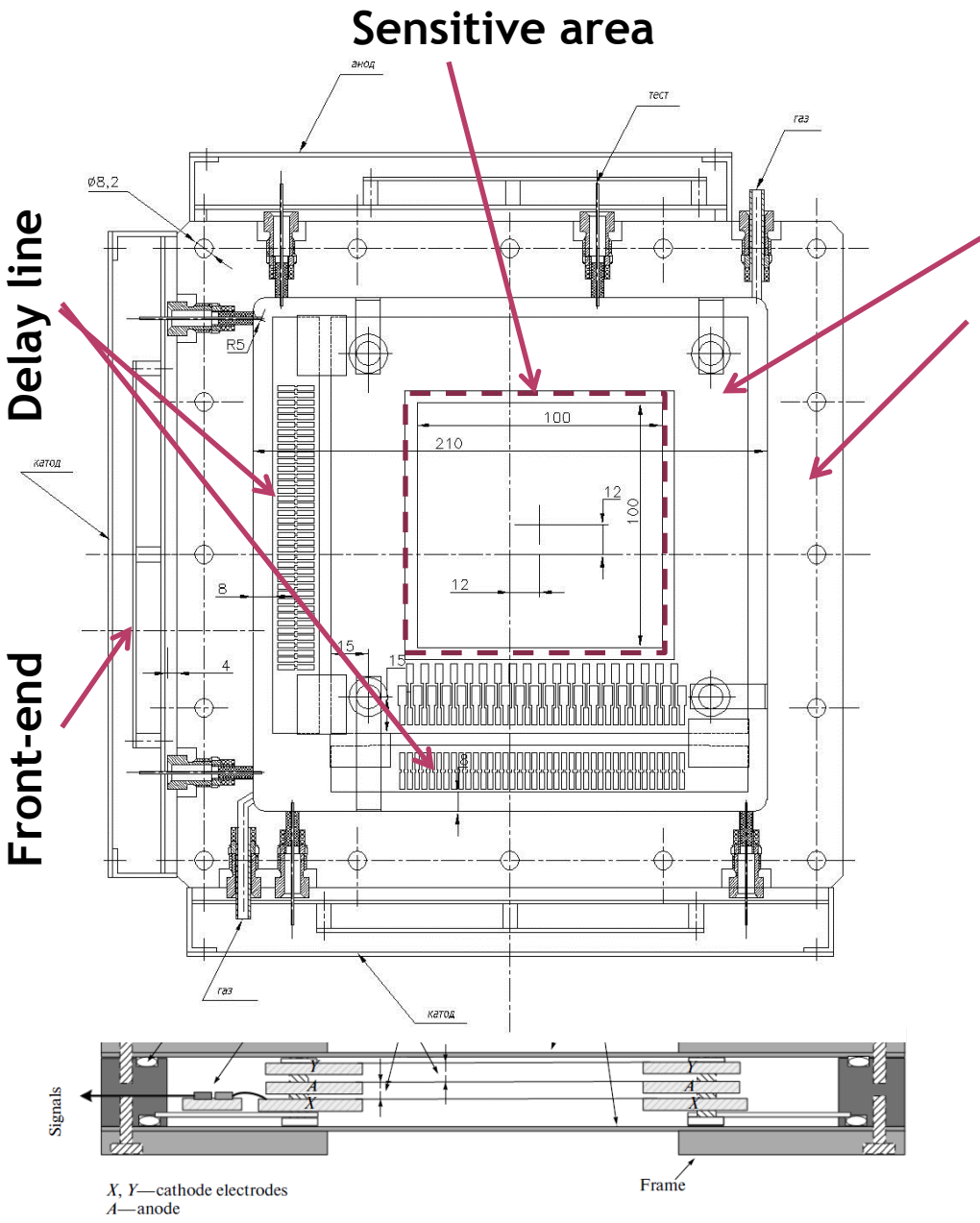
Efficiency: ~1 % (λ=1.8 Å)

2) Flux up to 10^8 n/cm2/s (PIK reactor)

1) Gas mixture: 50 mBar N_2+ 950 mBar CF_4

2) Efficiency: 2 $\times 10^{-4}$ % (λ=1.8 Å)

2D NEUTRON MONITOR PROJECT



Status today:

- Low outgassing materials selected and tested
- Gas chamber is produced

Future plans:

- MWPC electrodes
- Frontend, Readout

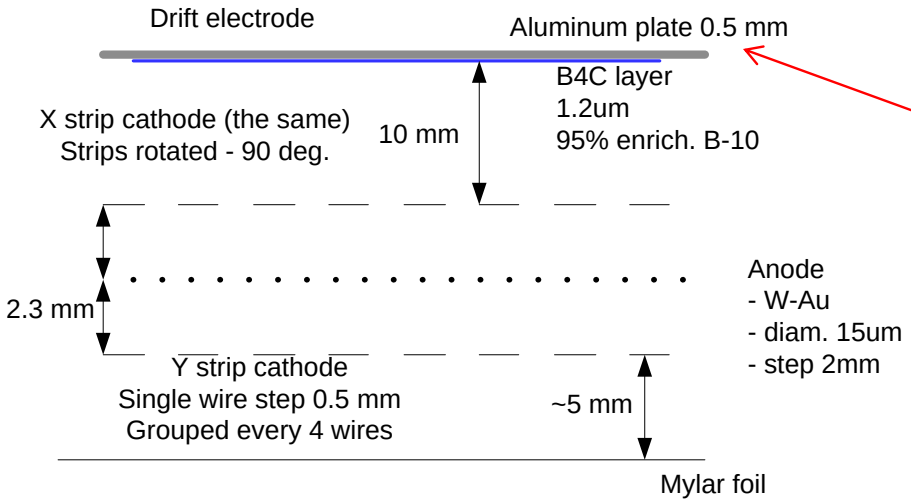
3) GAS-FILLED DETECTORS WITH B_4C CONVERTER

Technology features:

- Various working gases at n.c.	cheap detector construction based on mature technology of MWPC
-Permanent gas flow through detector	cheap and traditional materials for MWPC
-Fast electron/ion collection time	high counting rate capacity
- Inclined & multilayer design for	high efficiency and position resolution, new large aperture detectors
- detectors with 1-2 conv. layers	for beam monitoring

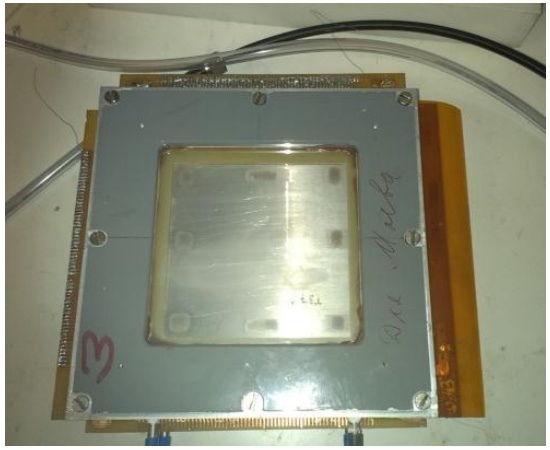
DETECTOR PROTOTYPE WITH SINGLE B_4C LAYER

Detector layout

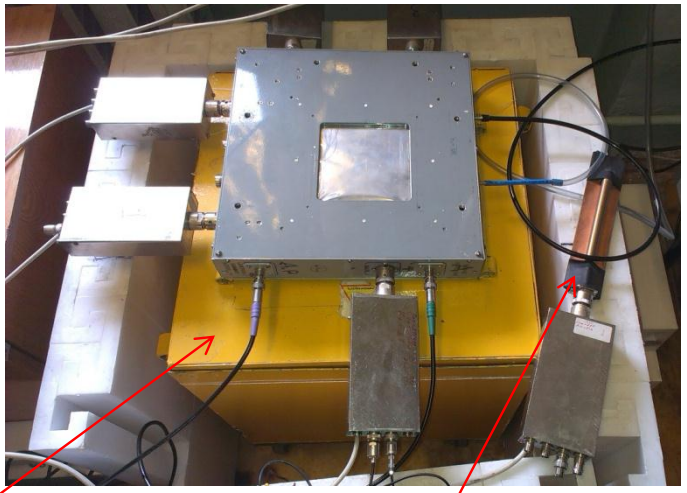


Launched with converter from HGZ

Assembled prototype



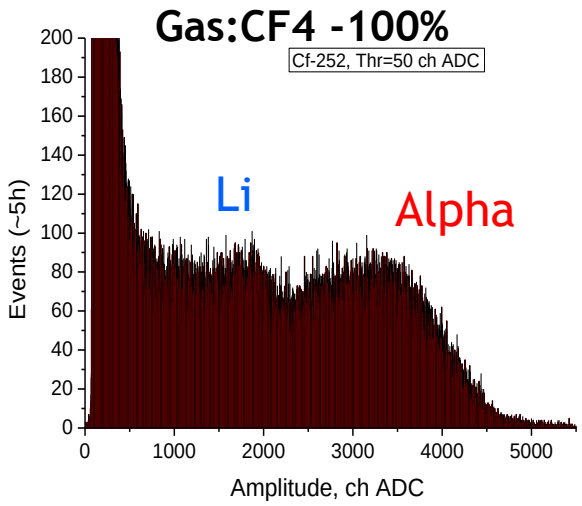
LC-delay line readout

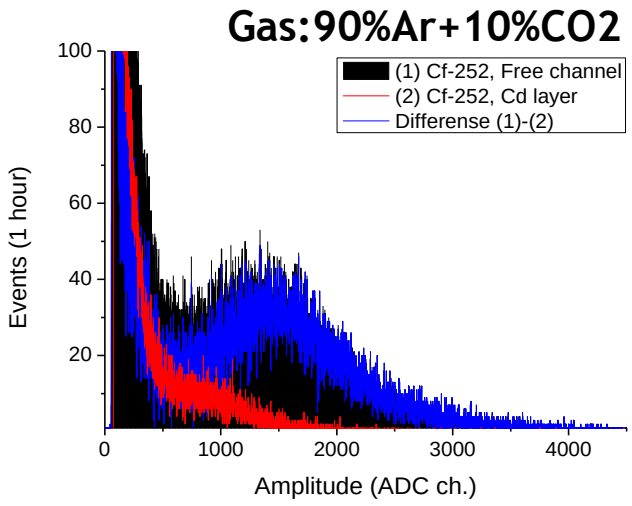


Some tests

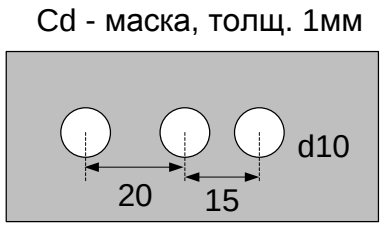
B(10) + n -> α + Li(7)* -> α (1.47 MeV) + Li (0.84 MeV) + γ (0.48 MeV) -93.7%
-> α (1.78 MeV) + Li (1.02 MeV) -6.3%

1) Amplitude spectra (Cf-252)



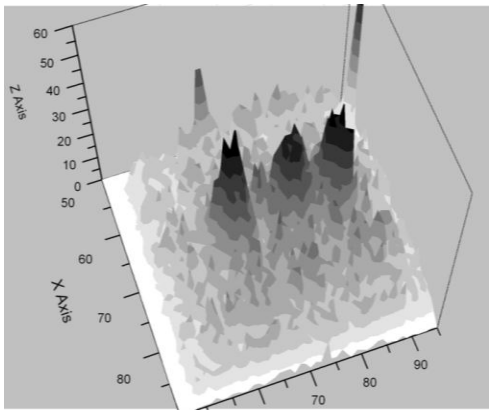


2) 2D spectra (Pu-Be)

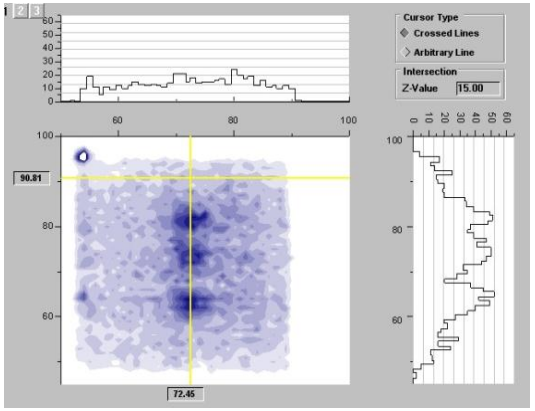


Cd-mask

Isomeric view



Cross-section



4) INCREASING THE COUNT RATE CAPABILITY OF MWPC-BASED DETECTOR - PROPOSAL

- Delay-line readout (+TDC) limits count rate capability to 200-300 kHz

- Our technology of MWPC allows to increase
  the counting rate capability to ~1 MHz
  by signal pick-up from each cathode strip
  without modernization of the detector design

Multi-channel readout system CROS3

Radio Electronics Department, HEPD, PNPI

96-channel Digitizers (CDR96) with 16ch-Amplifiers cards

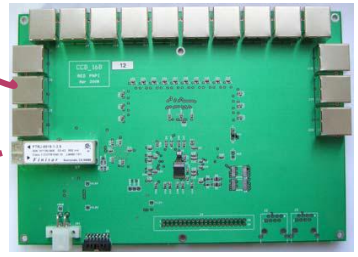
AD_16:
16-ch Amplifier/Discriminator
Based on a CMP_G ASIC

Peaking time 30 ns
Minimum threshold 7 fC
Double pulse resolution 80 ns
Power dissipation ~35 mW/ch

Digitization and Readout
Xilinx Spartan-3 FPGA

Up to 6 AD_16 cards
Programmable Delay 10 ns step
Programmable Gate 10 ns step
100 MHz 10-bit ADC
Power Consumption 500 mW

STP CAT5 cable (copper): 100 Mb/sec



CCB16 – Concentrator

Up to 16 Digitizers
Optical fiber transceiver 2.0 Gb/sec

Optical link: 2Gb/s

CBS - System Buffer

↔ PCI(Express) System Interface

DAQ

4 versions are used:

- CROS-3G for GSI (Drift Chamber option)
- CROS-3M for PNPI HEPD, OLIMPUS DESY (MWPC option)
- CROS-3B for RFWU PI (Drift Chamber option)
- CROS-3L for PNPI HEPD (TS for LHCb Drift Chambers)

+ experiments: “Neutrino-4”, “DP DD-Fusion”

CONCLUSION

1. He-3 detectors is still the base technology: ~70% of planned detectors for CMP at PIK

- Basic requirements of modern neutron instruments are met by modern ^{3}He-detectors
- ^{3}He is available in sufficient quantity and at a reasonable price in Russia!

2. PNPI has the technology of neutron detectors with apertures up to 300×300 mm and counting rates up to 125-150 kHz (n/s)

- To reach counting capability up to 1MHz (n/s) we propose to apply the multichannel readout electronics, for example CROS3 system

3. According to the PIK requirements our efforts are directed to the new technologies

- Monitors, profilometers
- PSD with medium areas up to 500 x 500 mm
- Large area PSD (1 m^2 and higher) based on LSPC arrays

All other technologies (scintillators, solid converters) are highly needed for the efficient combination with He-3-technologies.

4. Requirements for future successful work

- Permanent work of Scientific and technical Council (detectors and electronics) are required: strategy, planning, distribution of responsibilities, technical projects (CDR)
- The official team of neutron detectors & electronics for PIK and the budget for R&D work

THANKS!