NRC "Kurchatov institute"-PNPI

Prospects of the Neutrino-4 experiment on the search for sterile neutrino

Collaboration Neutrino-4:

1. *NRC "KI" Petersburg Nuclear Physics Institute, Gatchina,*
2. *NRC "Kurchatov institute", Moscow,*
3. *JSC "SSC RIAR", Dimitrovgrad, Russia*
4. *DETI MEPhI, Dimitrovgrad, Russia*

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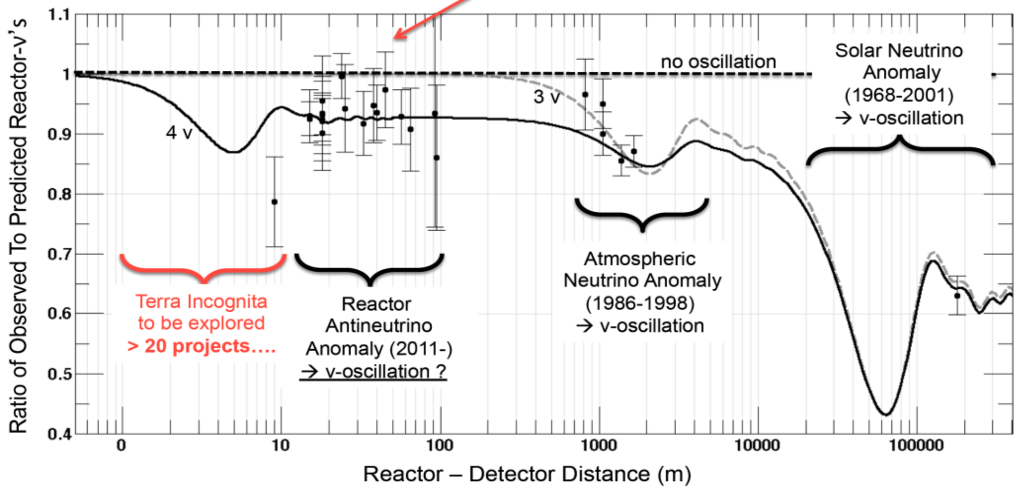
LXXI International conference NUCLEUS – 2021

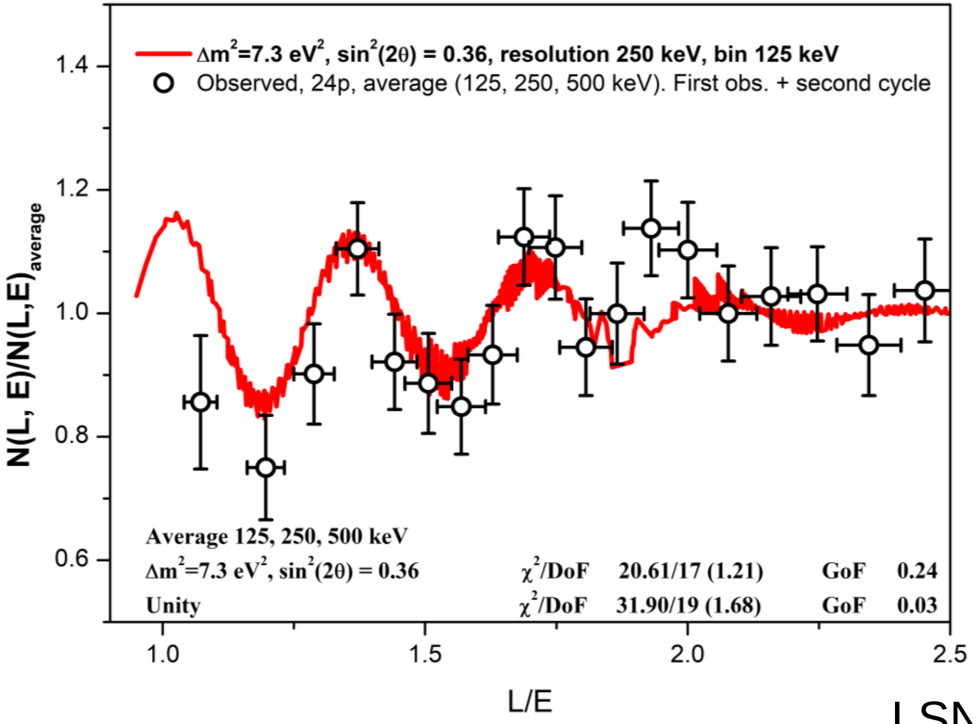
Sterile neutrino search

Reactor antineutrino anomaly

- **Observed/predicted averaged event ratio: R=0.927±0.023 (3.0 σ)**



Experiment Neutrino-4 result

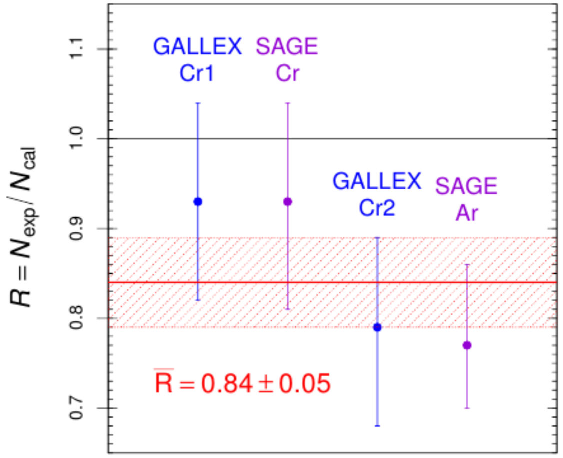


$$\Delta m^2_{14} = 7.3 \pm 1.17 \text{ eV}^2$$

$$\sin^2 2\theta_{14} = 0.36 \pm 0.12$$

CL 2.9σ

Gallium anomaly

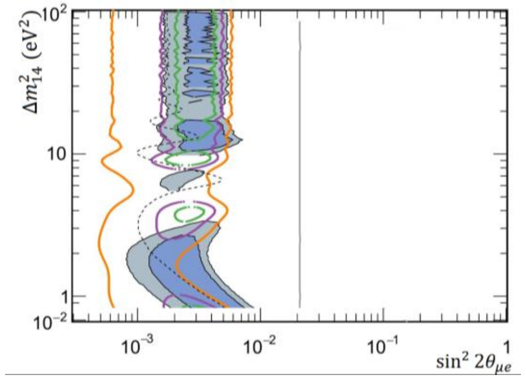


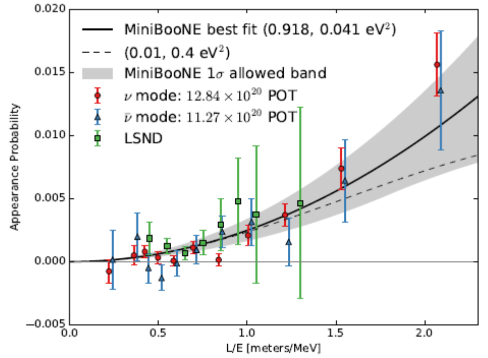
Deficit

R_{avr}=0.84 ± 0.05

CL 3.2σ

LSND, MiniBooNE result



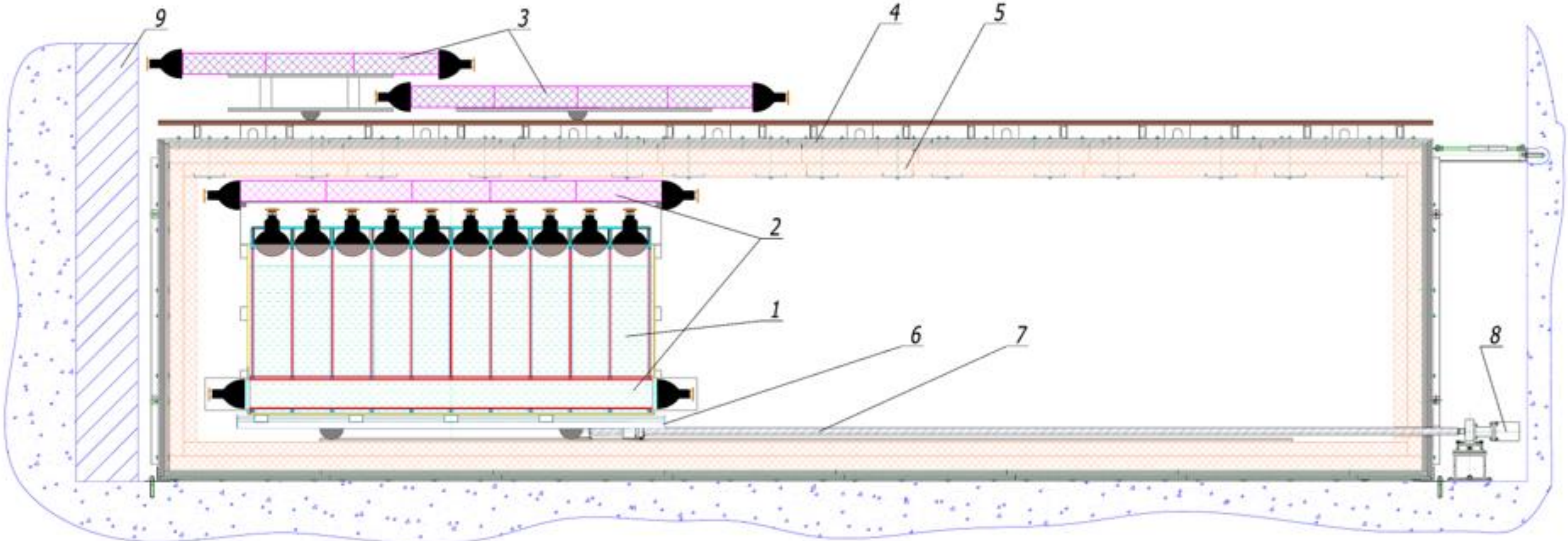


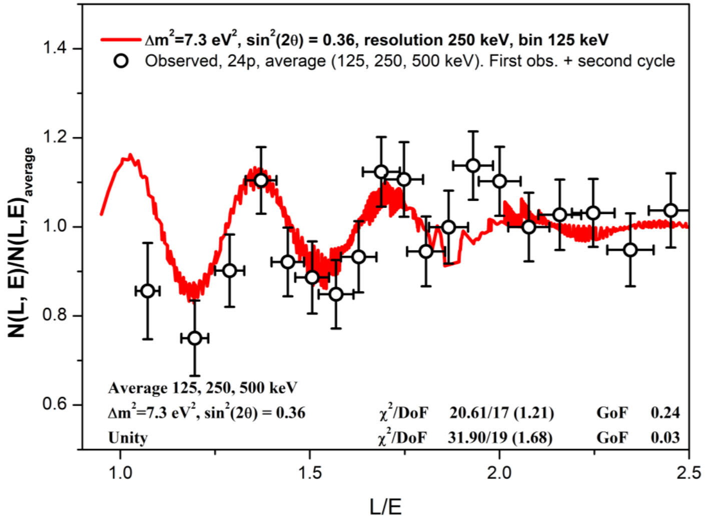
ν_e excess

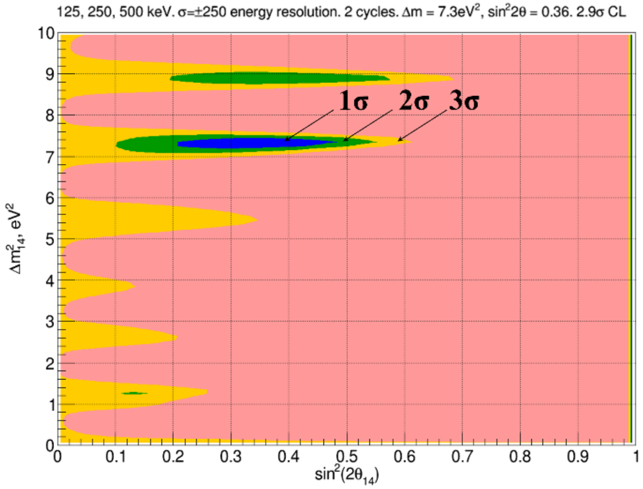
200< E_ν<1250 MeV

CL 6.0σ

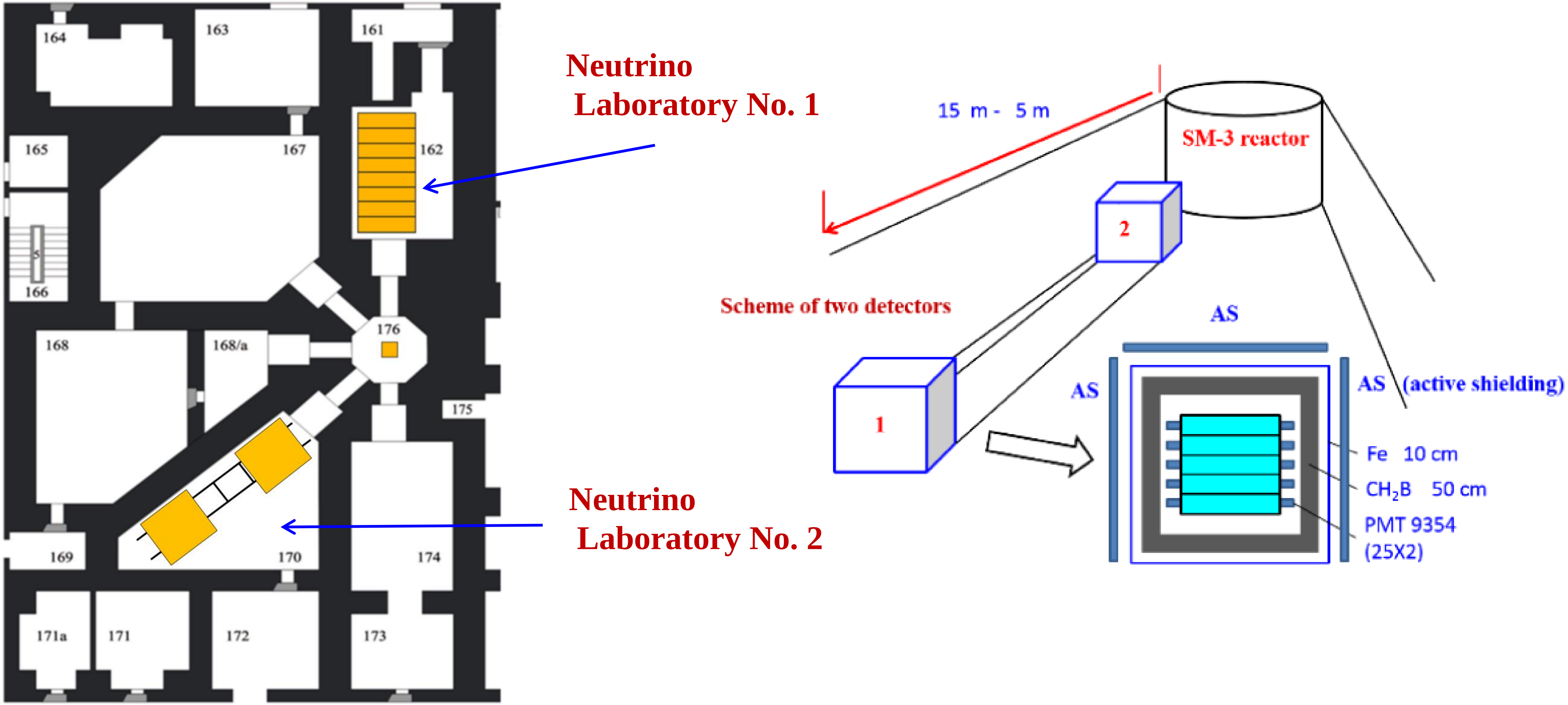
Neutrino-4 result





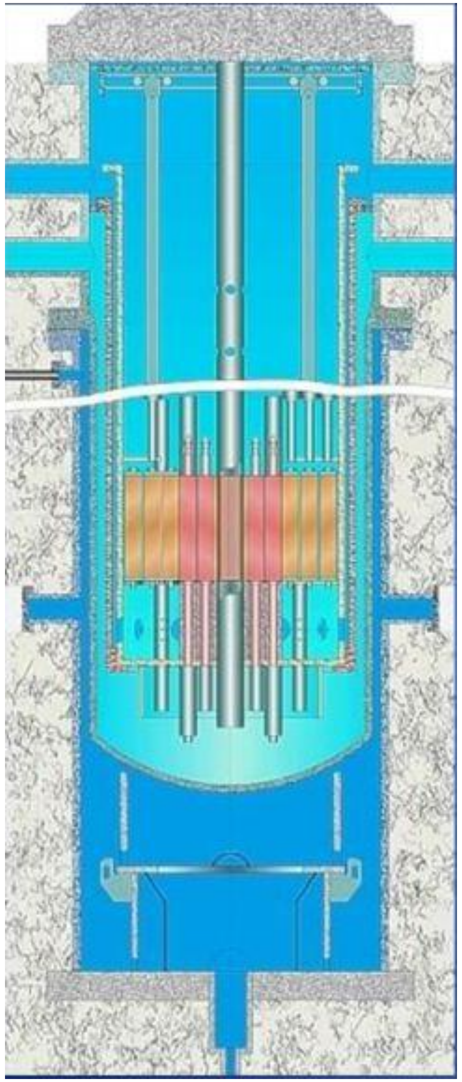


Future of the Neutrino-4 experiment

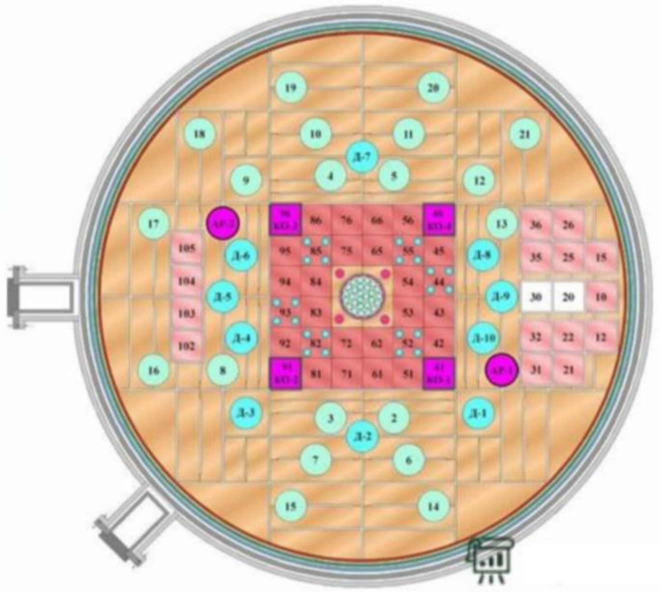


SM-3 research reactor

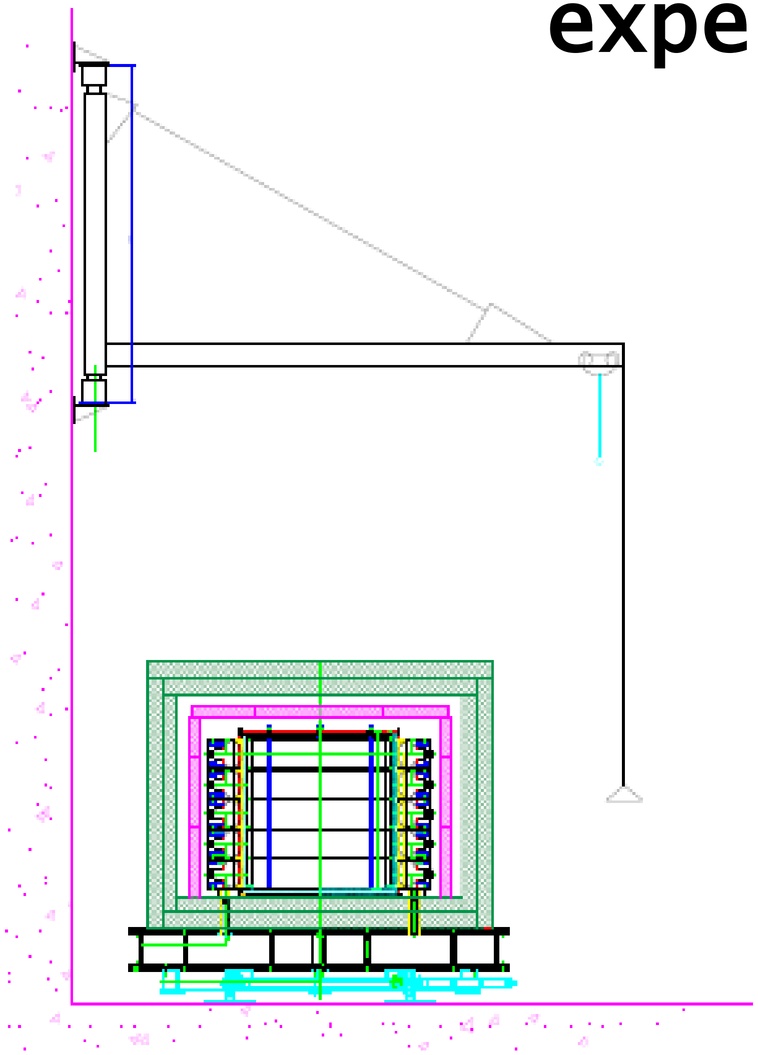
- 100 MW thermal power
- Compact core 42x42x35cm
- Highly enriched ^{235}U fuel
- Separated rooms for experimental setup
- Rooms poorly protected from space radiation

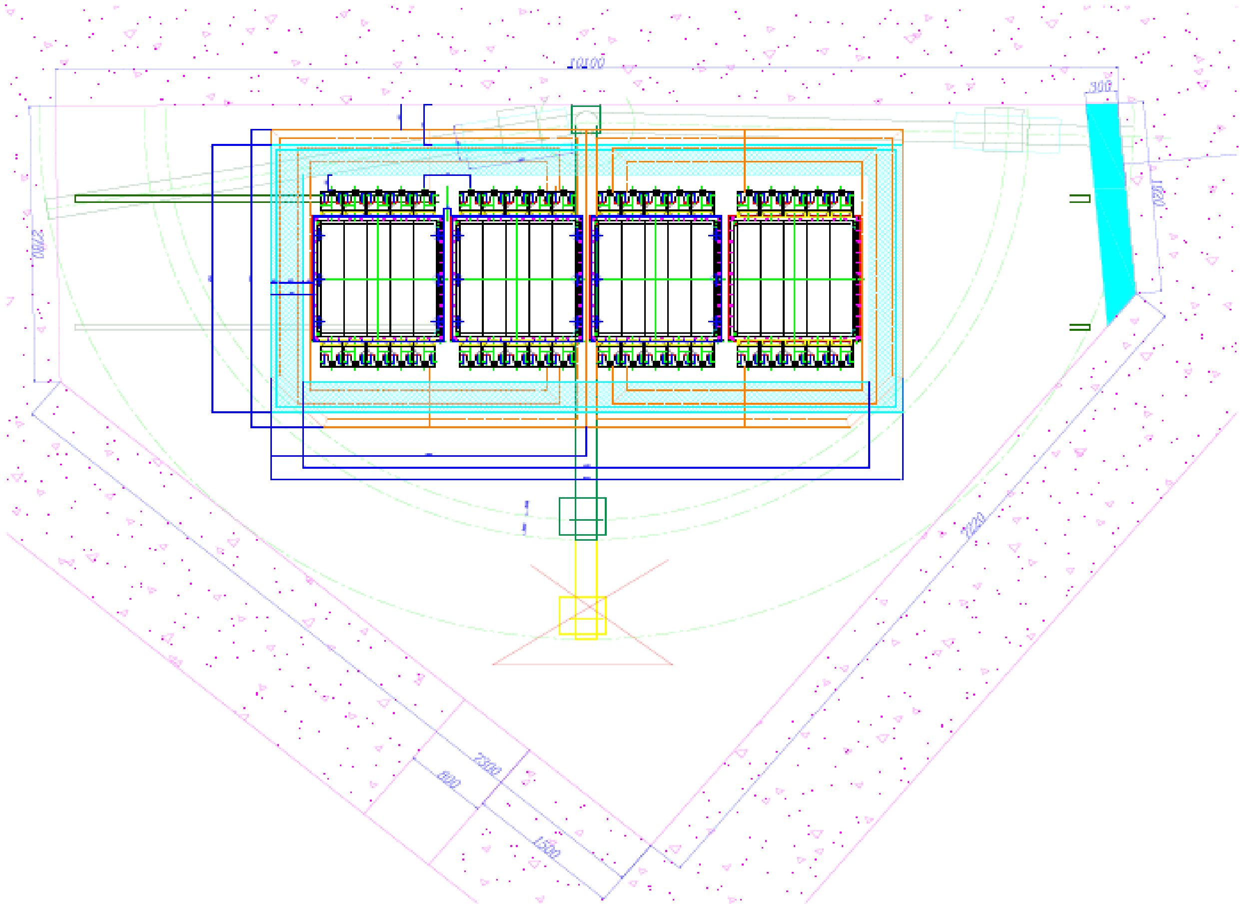


Vertical and horizontal sections of SM-3 reactor



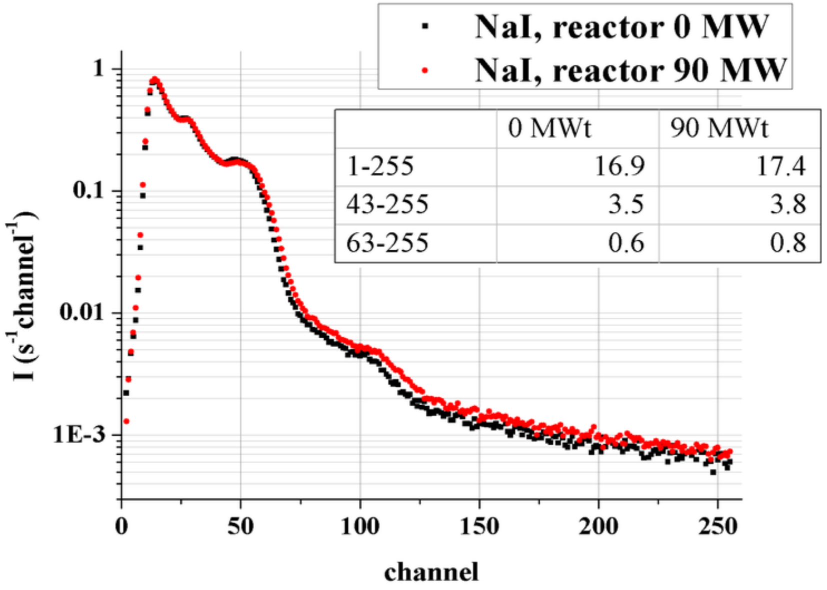
New lab for the Neutrino-4 experiment location

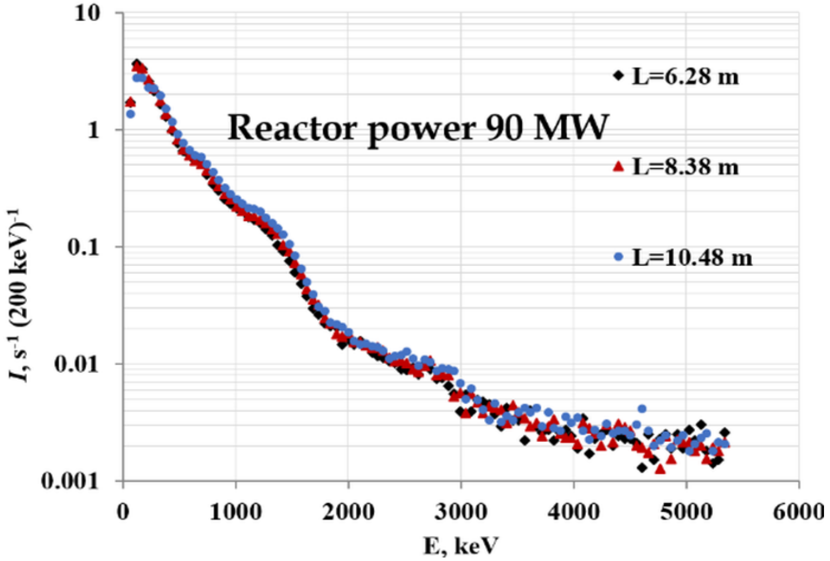


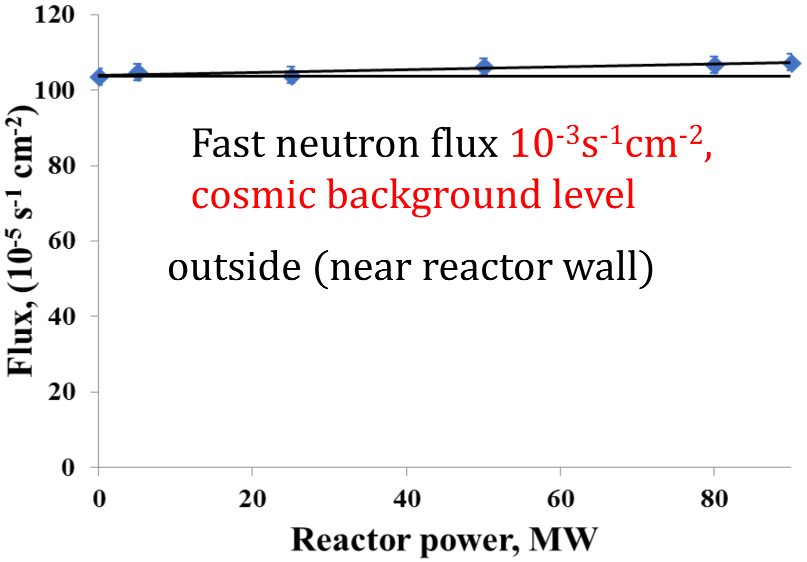


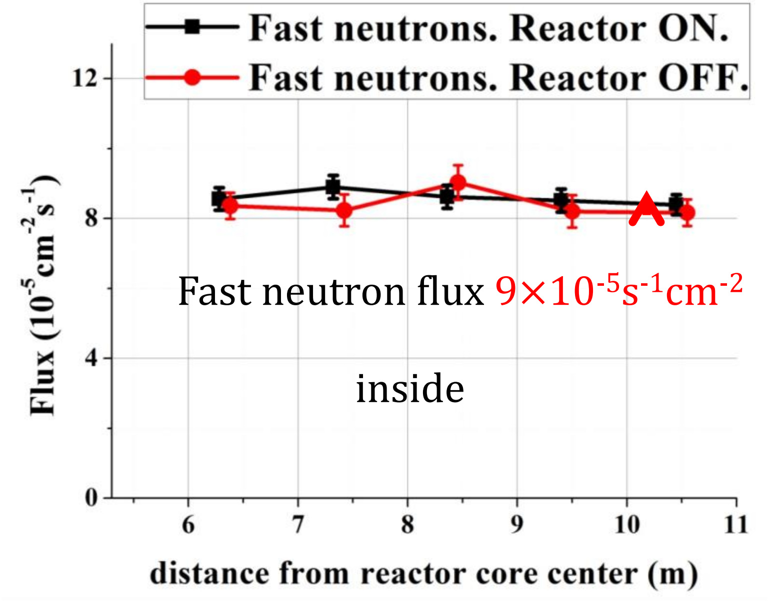
New room, same advantages
and same problems

Gamma and fast neutron backgrounds in passive shielding does not depend neither on the power of the reactor nor on distance from the reactor

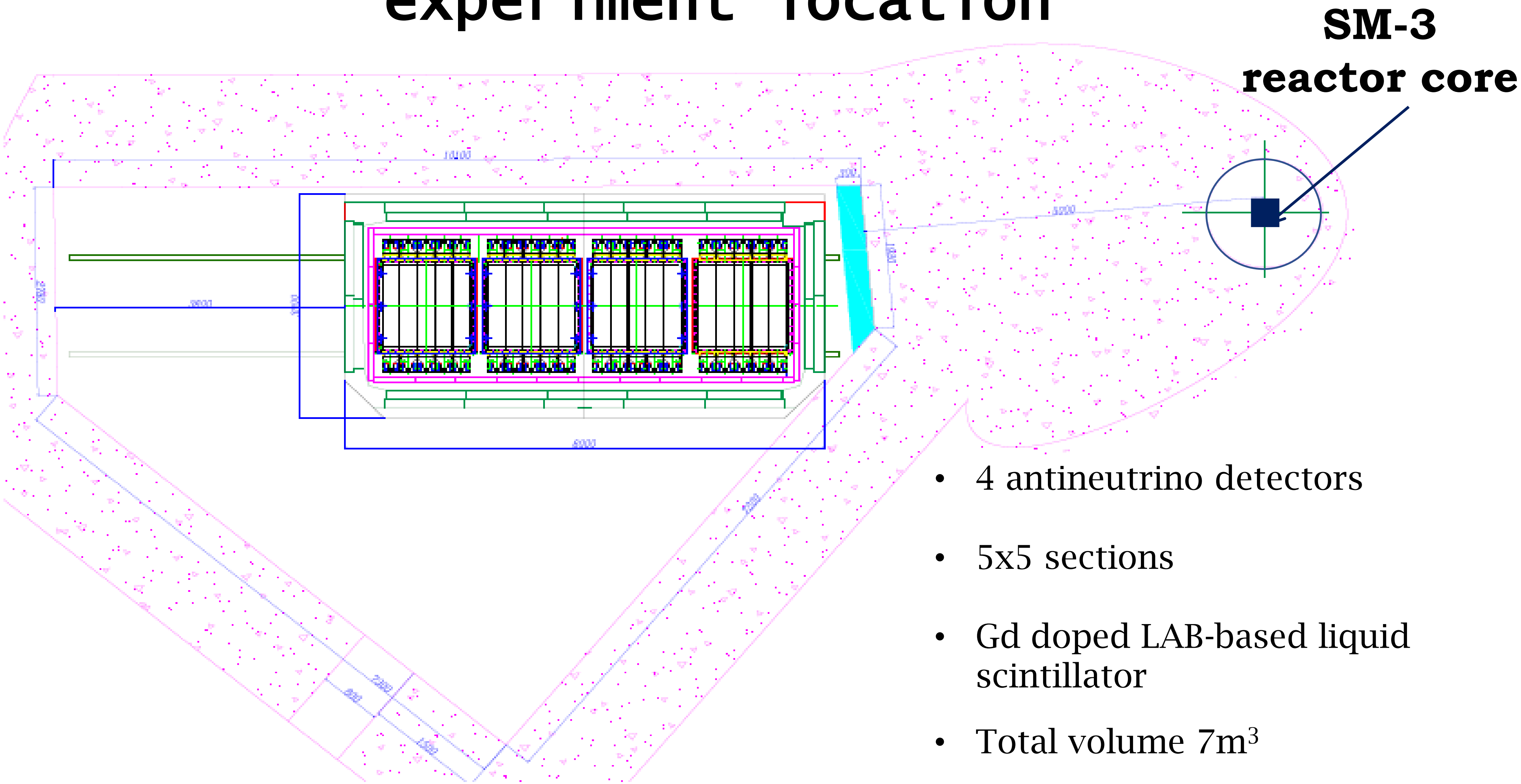






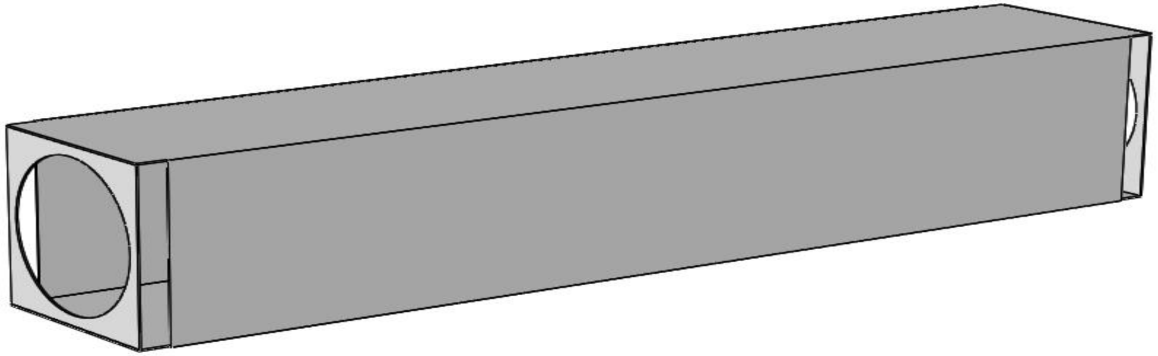


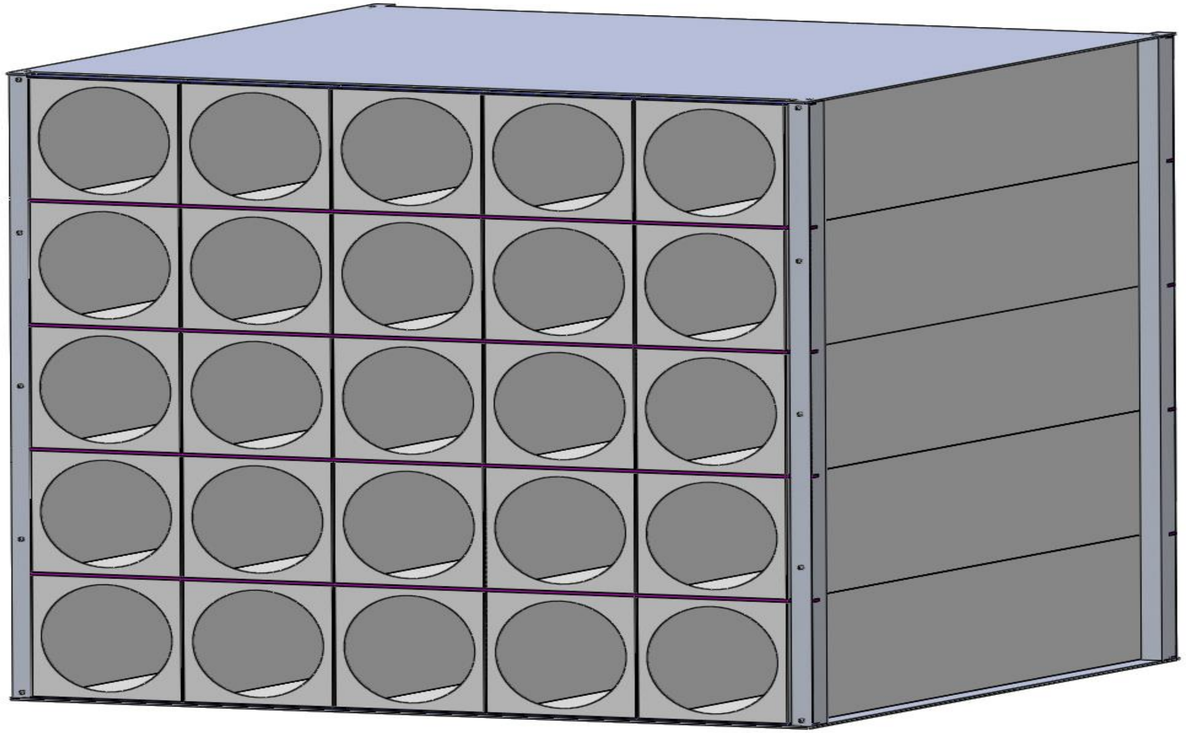
New lab for the Neutrino-4 experiment location



- 4 antineutrino detectors
- 5x5 sections
- Gd doped LAB-based liquid scintillator
- Total volume 7m^3
- 6 – 14m base

Detector's lightguides system

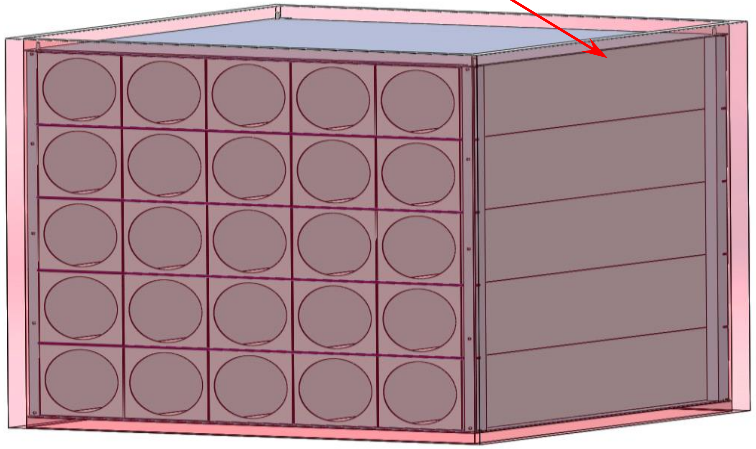


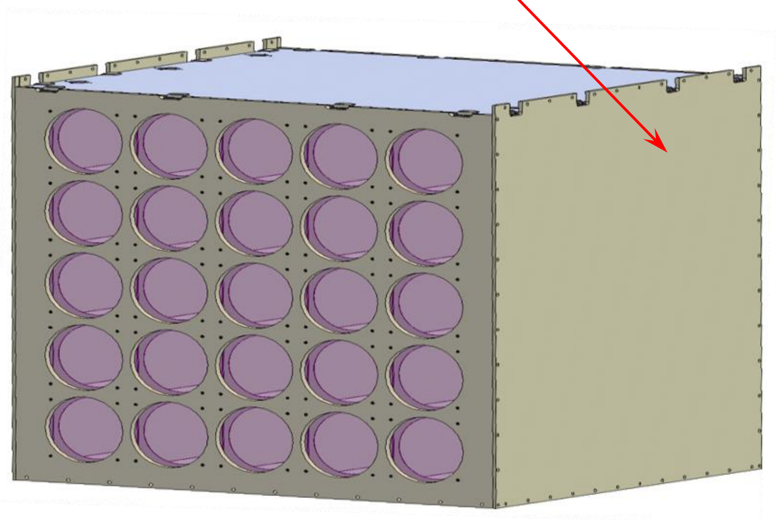


1.2 m length of lightguide
Lightguides are assembled into 5x5 array

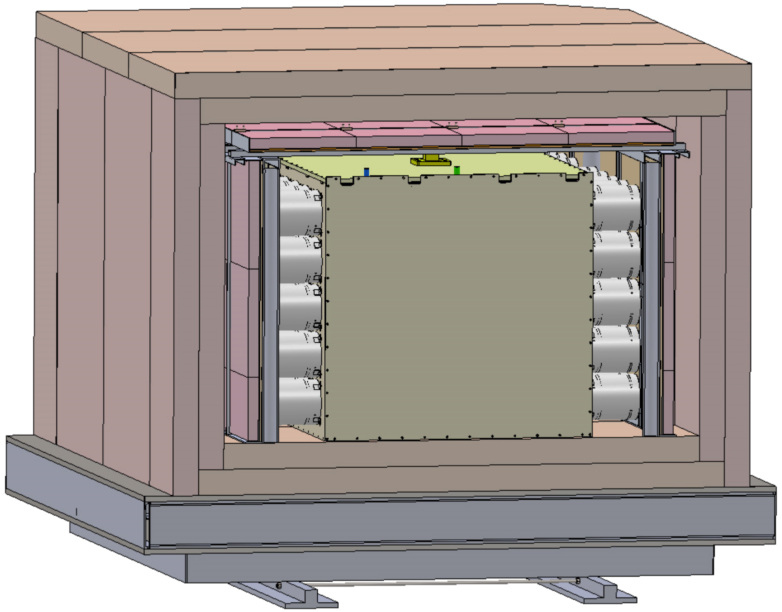
Lightguides system assembling

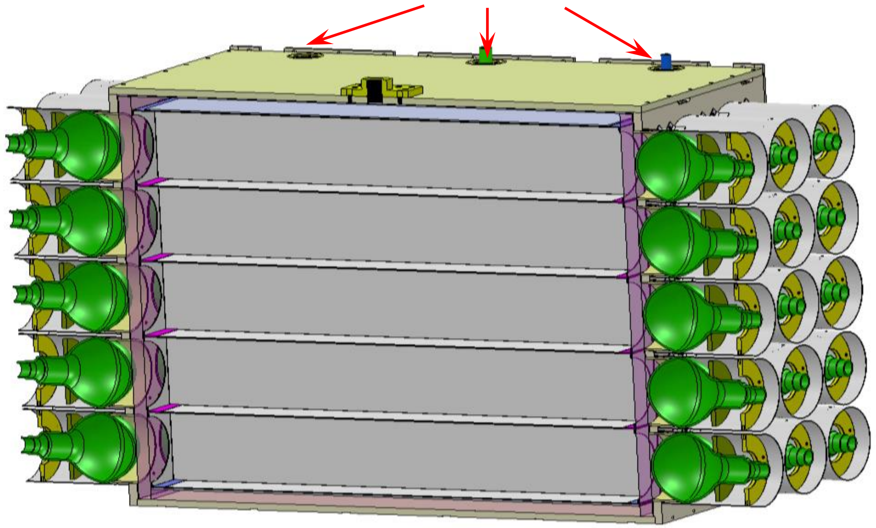
Detector's design. Models

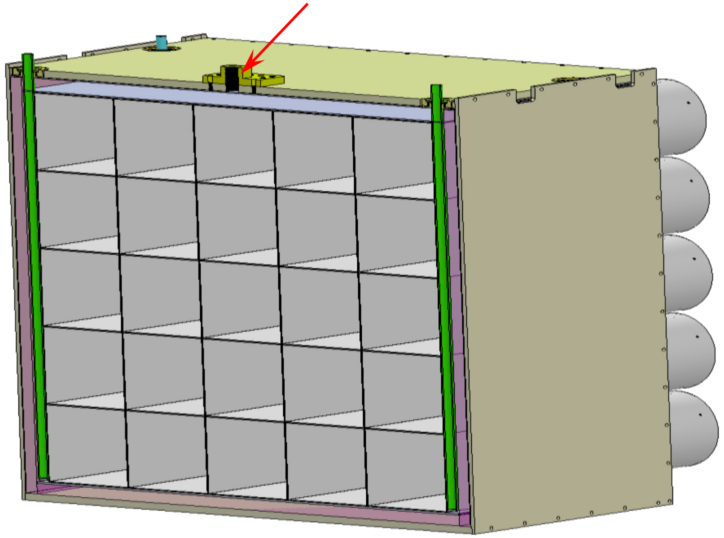




Detector fully assembled



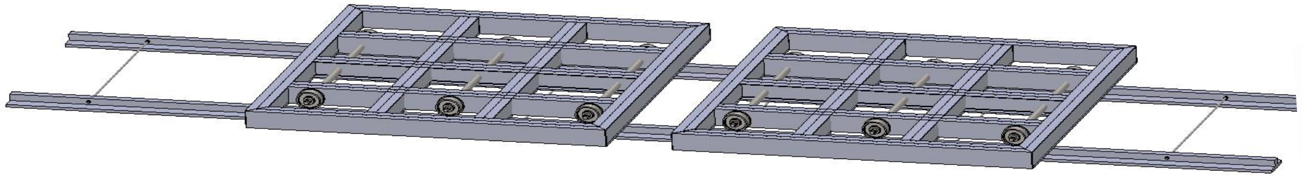




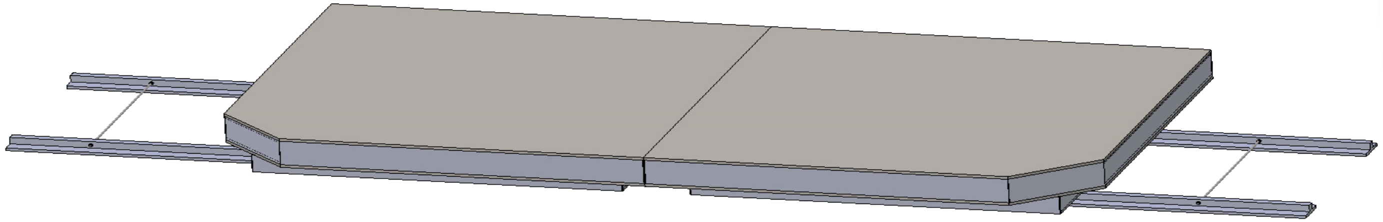
Detector’s design.
Transparent tank

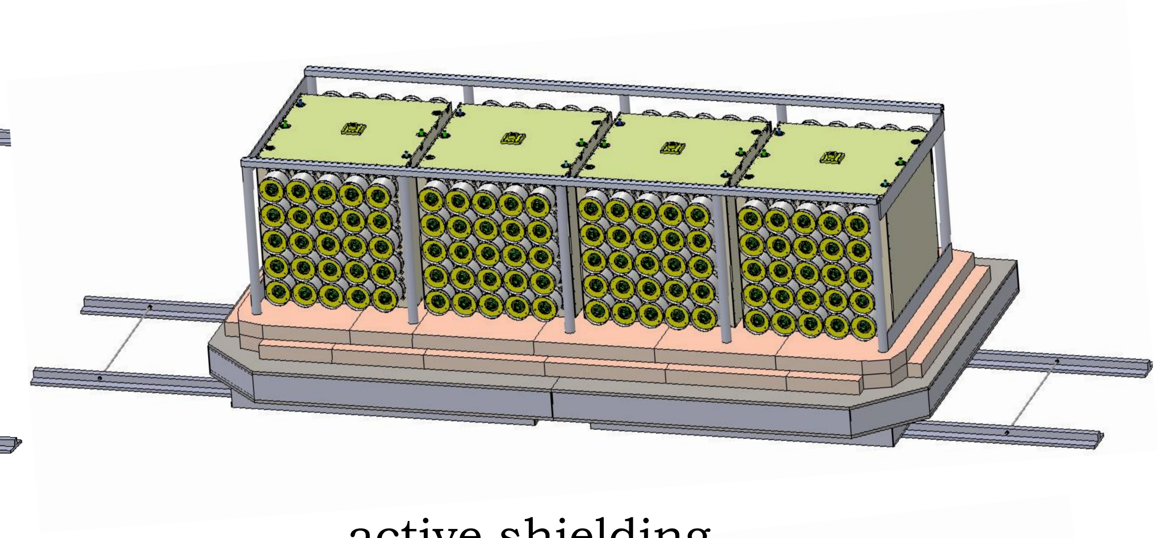
Detector’s design.
Case

Detector’s design.
Transport system

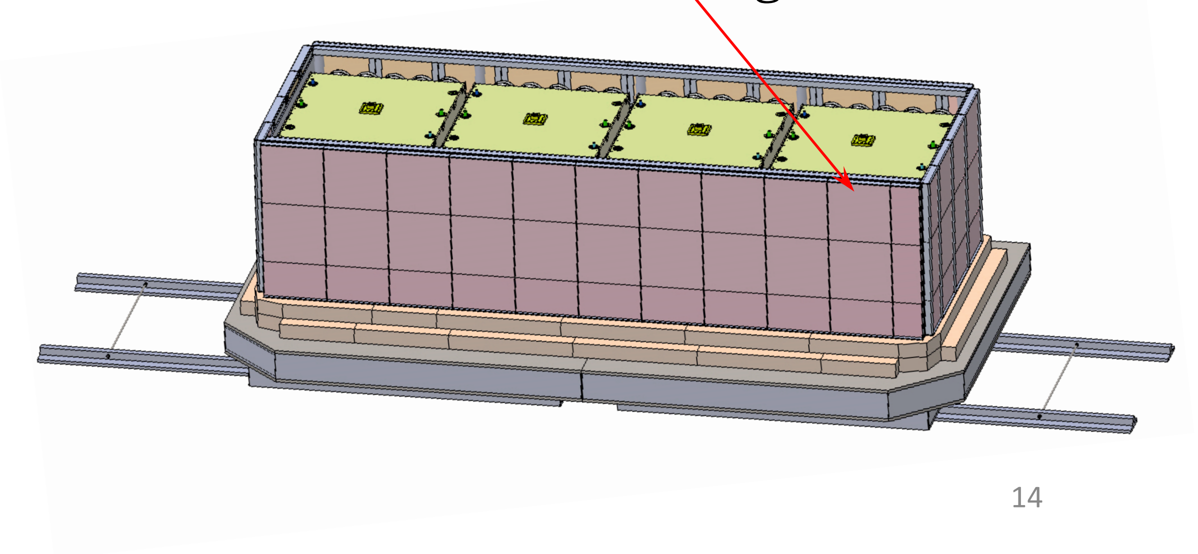


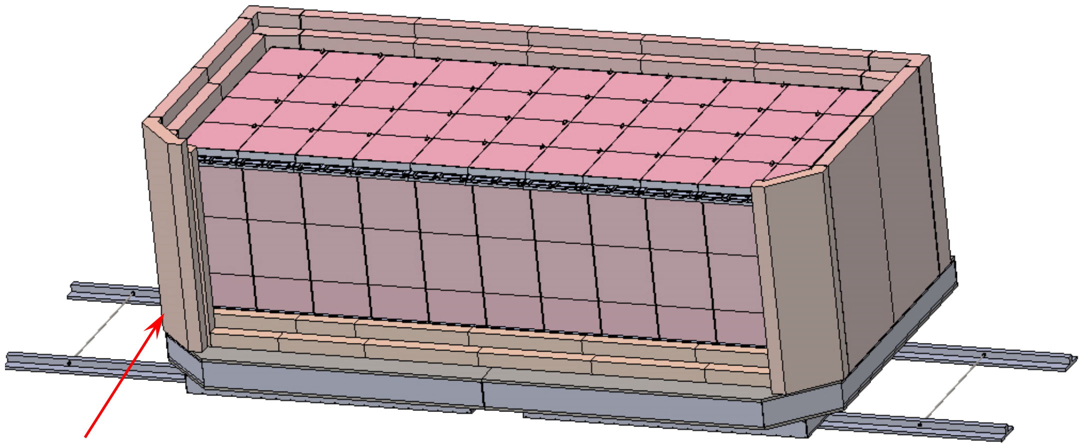
Rails, carts and platforms





active shielding





borated polyethylene

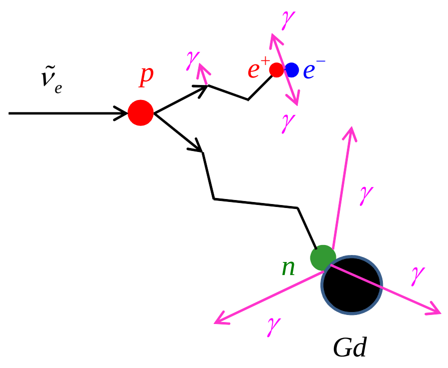
Detector's design. Transport system

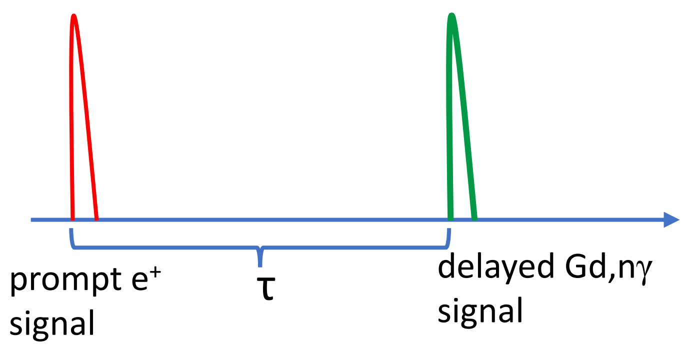
Platforms

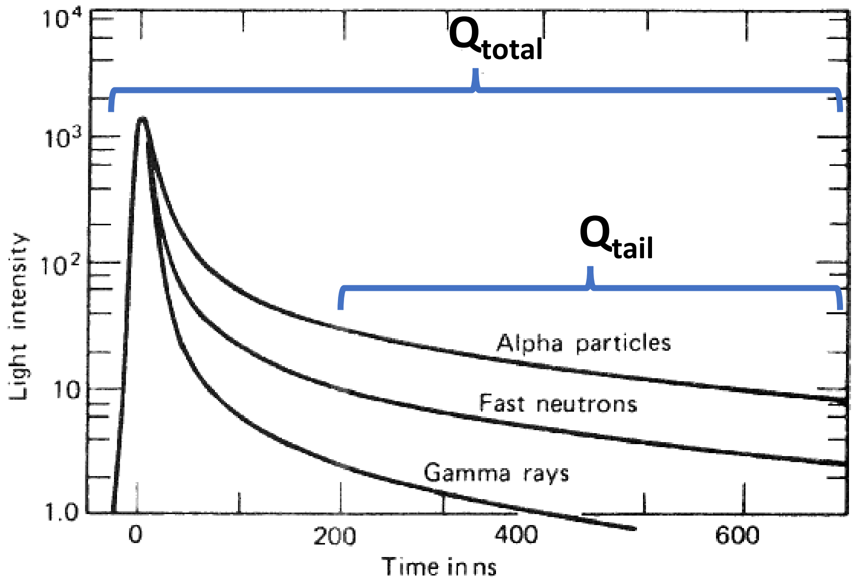
Inner cavities

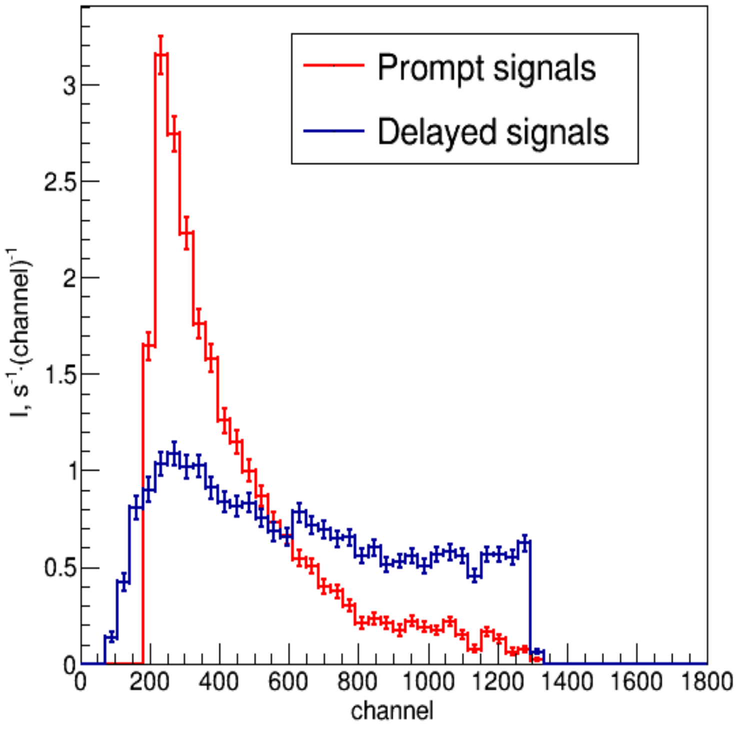
Inverse beta decay events selection

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

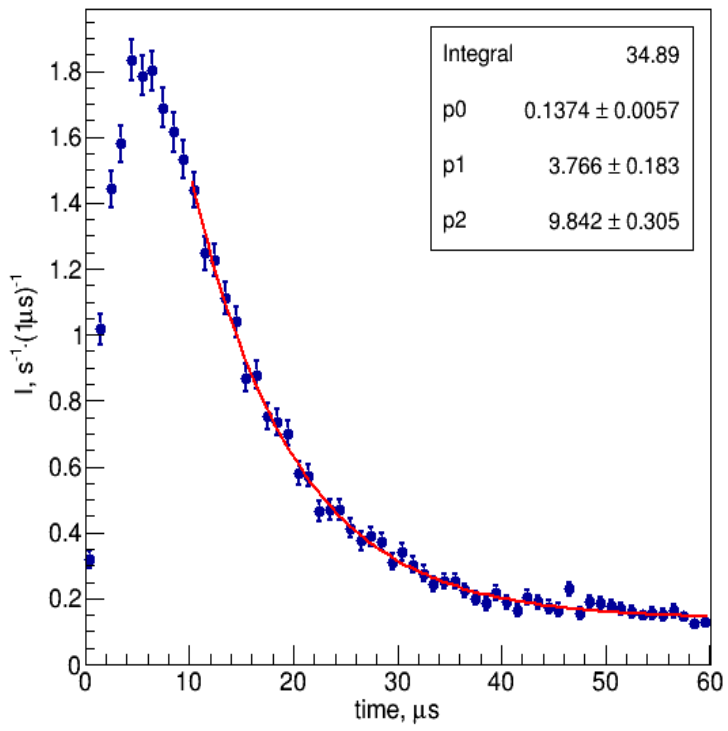




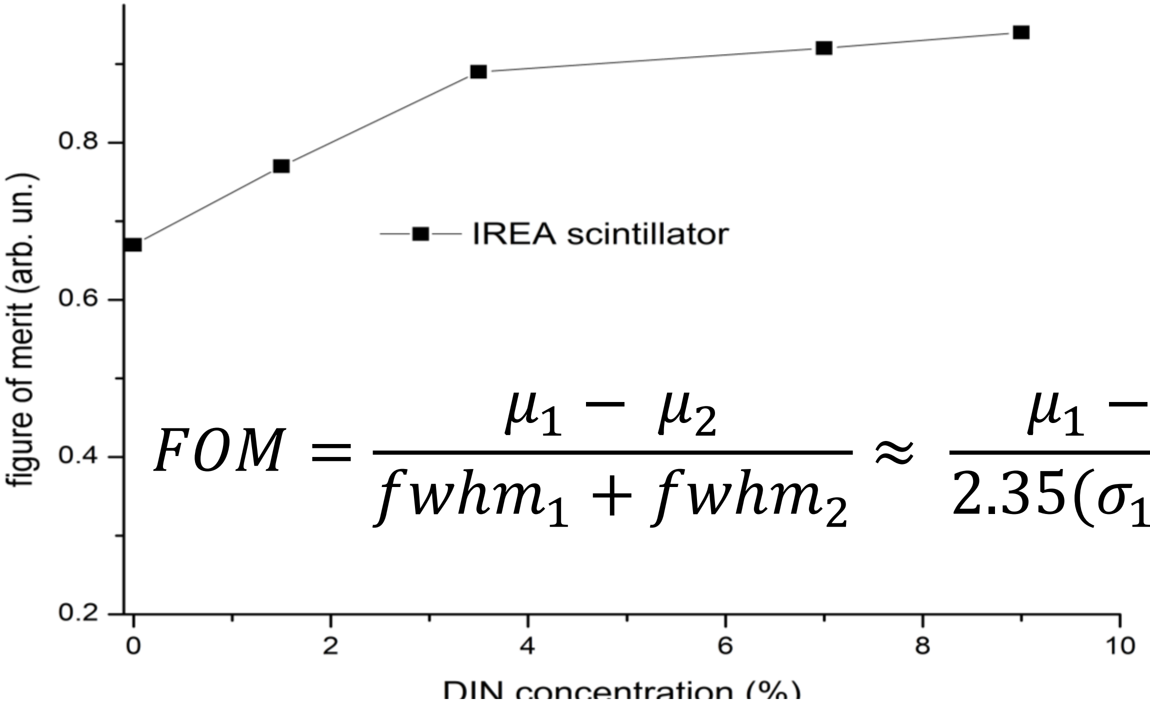




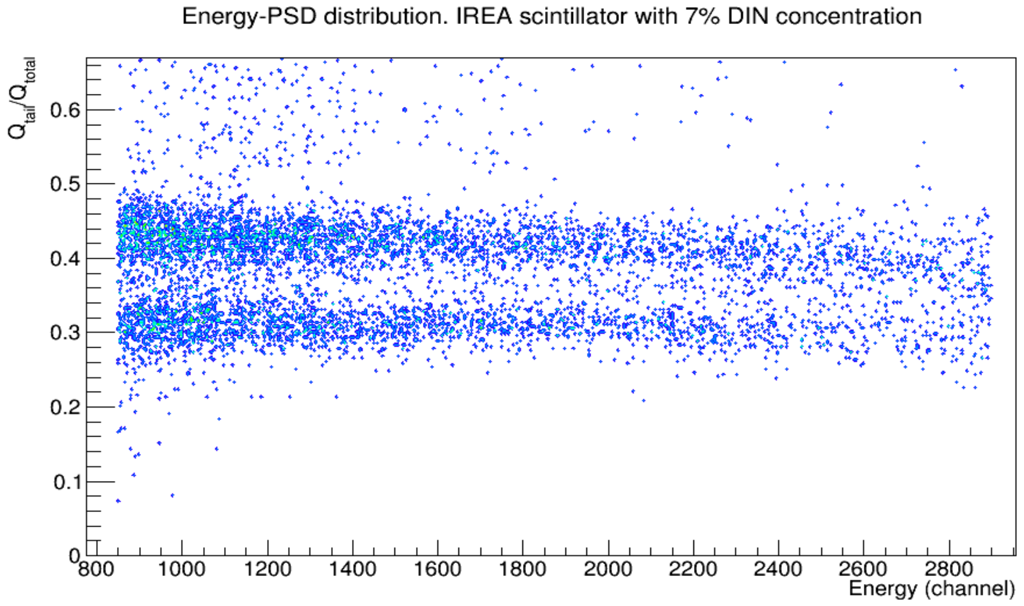
Time spectrum. Cf^{252} at the section center. Trigger mode.



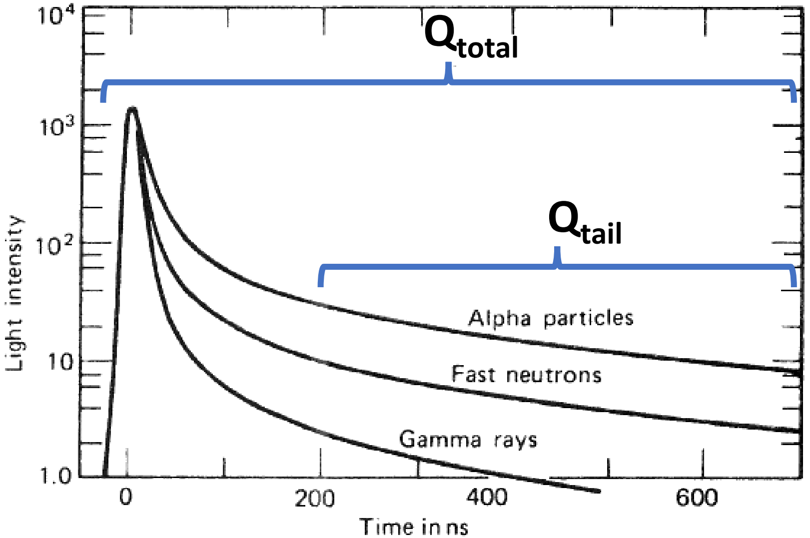
Scintillator PSD capability

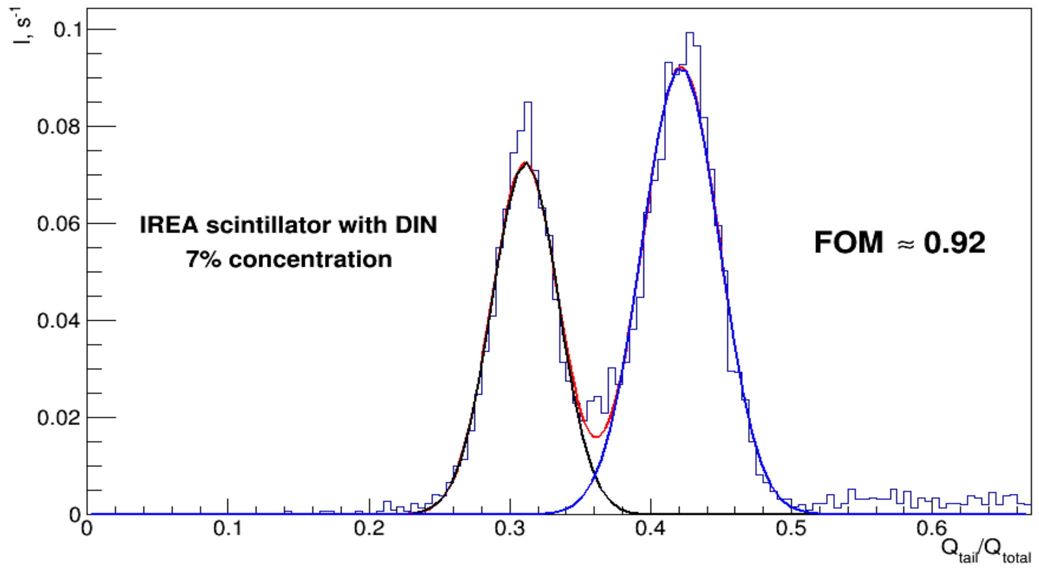


$$FOM = \frac{\mu_1 - \mu_2}{fwhm_1 + fwhm_2} \approx \frac{\mu_1 - \mu_2}{2.35(\sigma_1 + \sigma_2)}$$

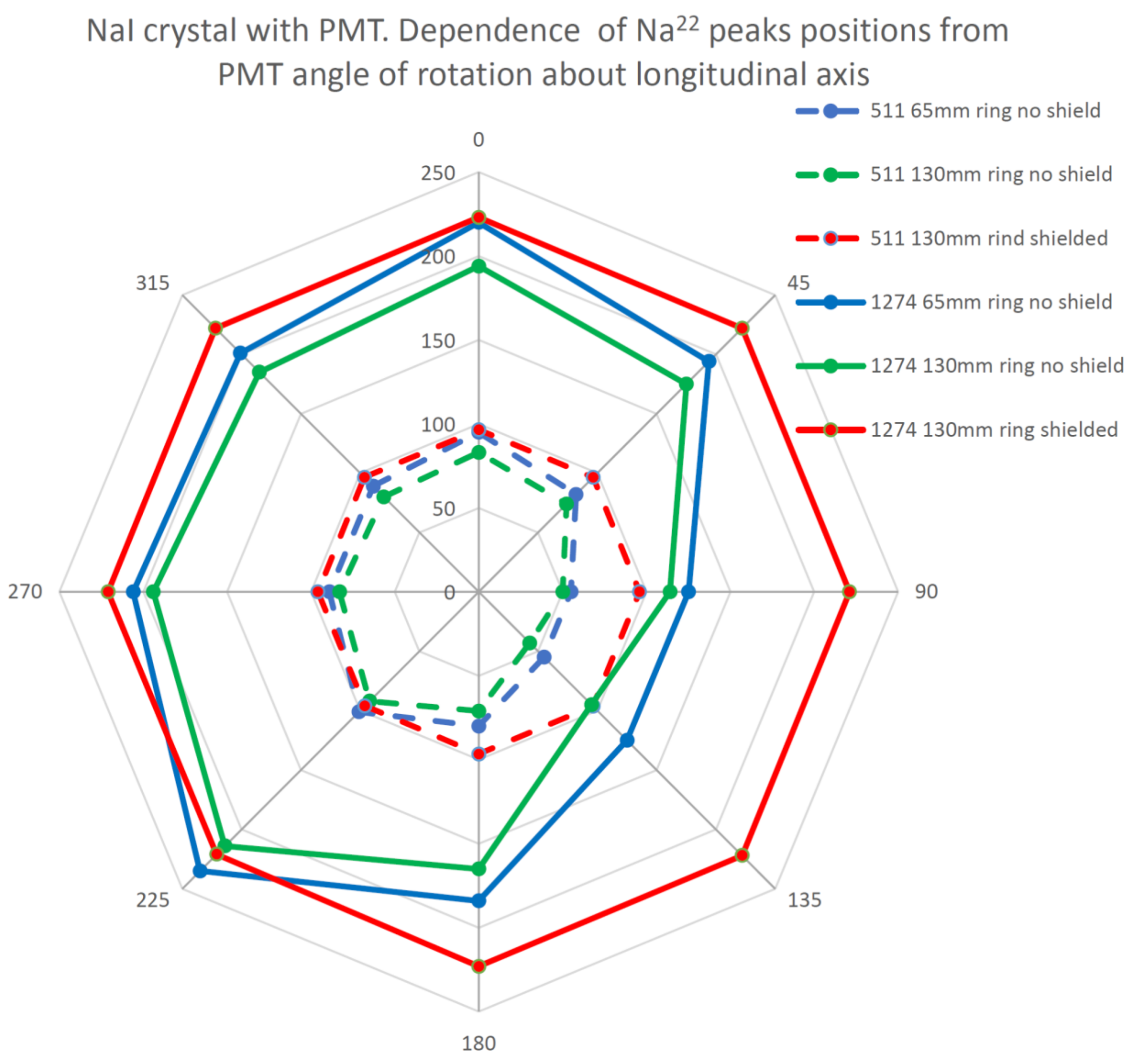


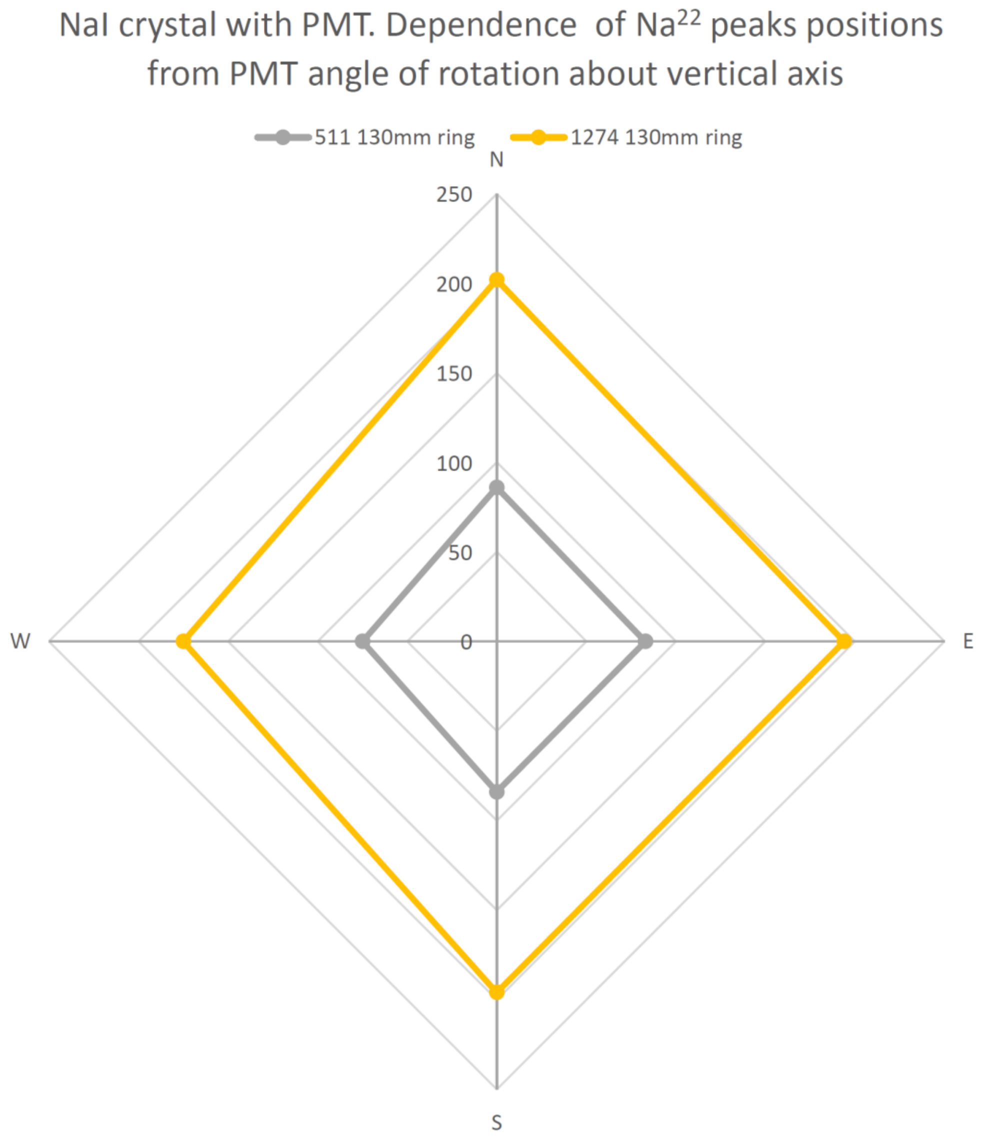
$$\frac{Q_{tail}}{Q_{total}}$$



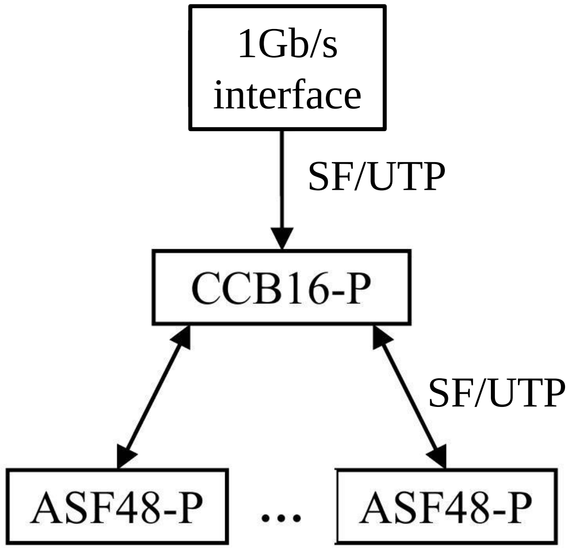


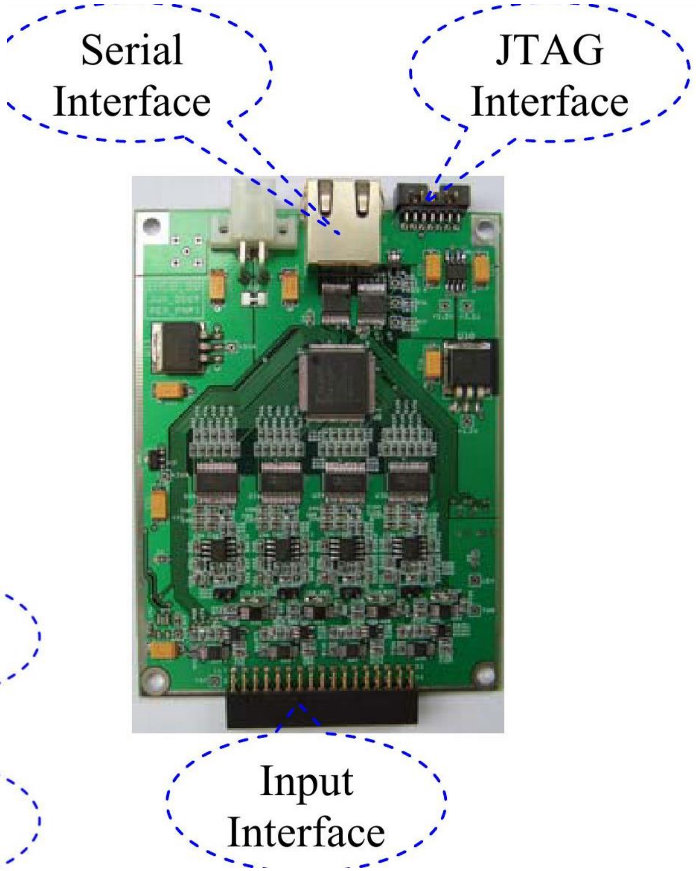
Magnetic shielding



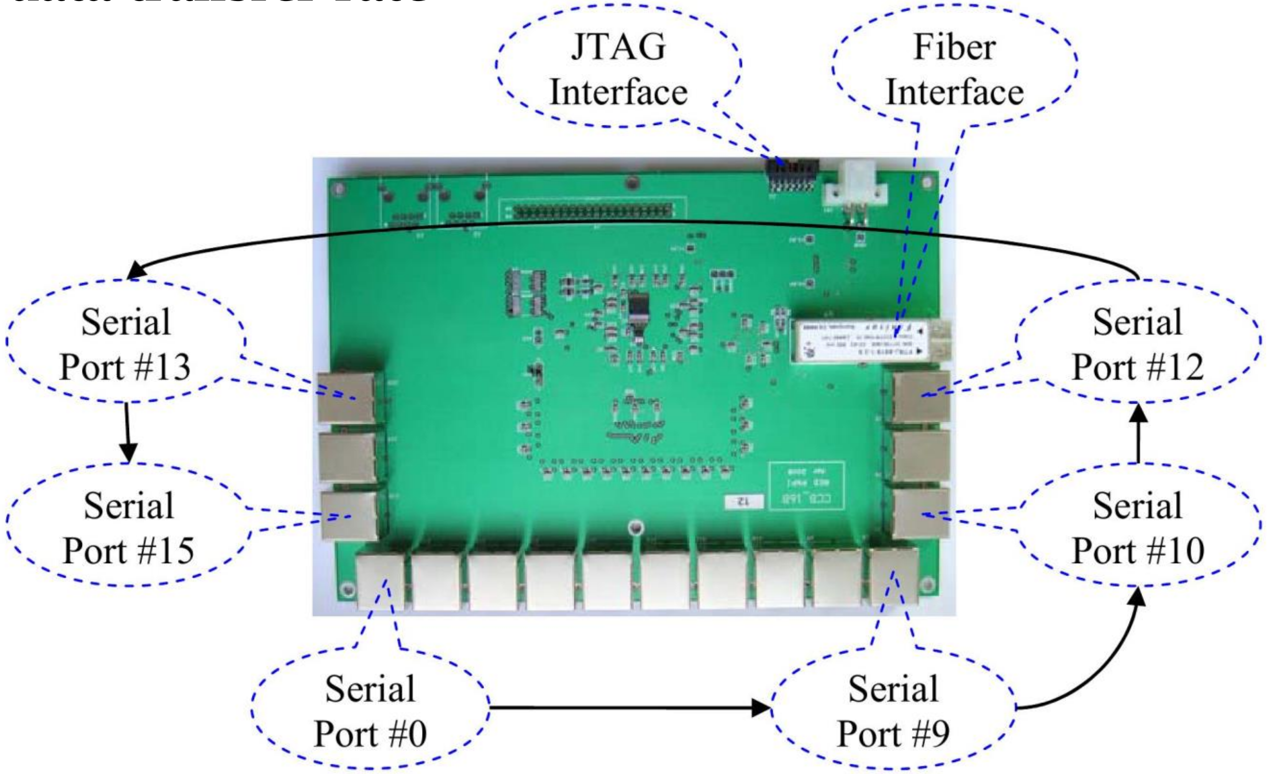


Data acquisition system CROS3

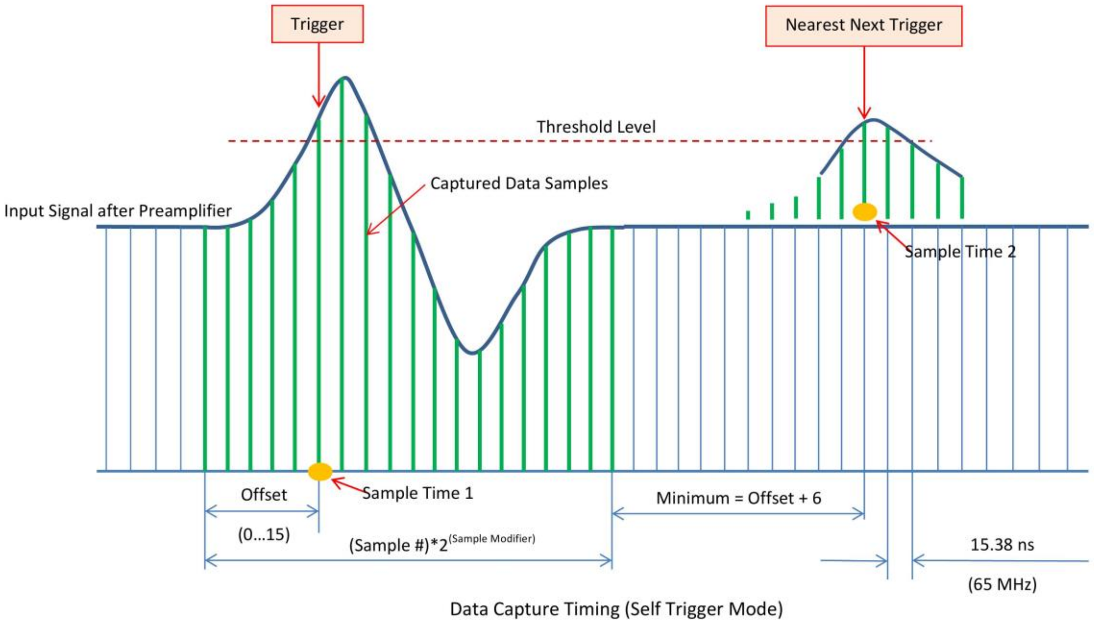




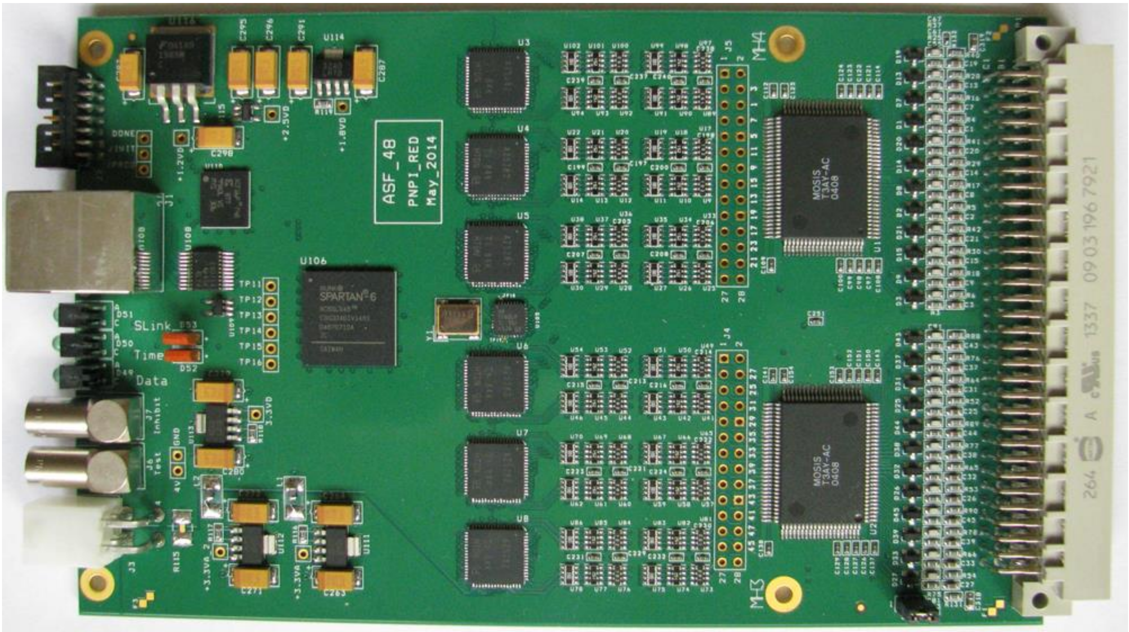
- 3 times faster sampling rate
- 8-10 times higher data transfer rate



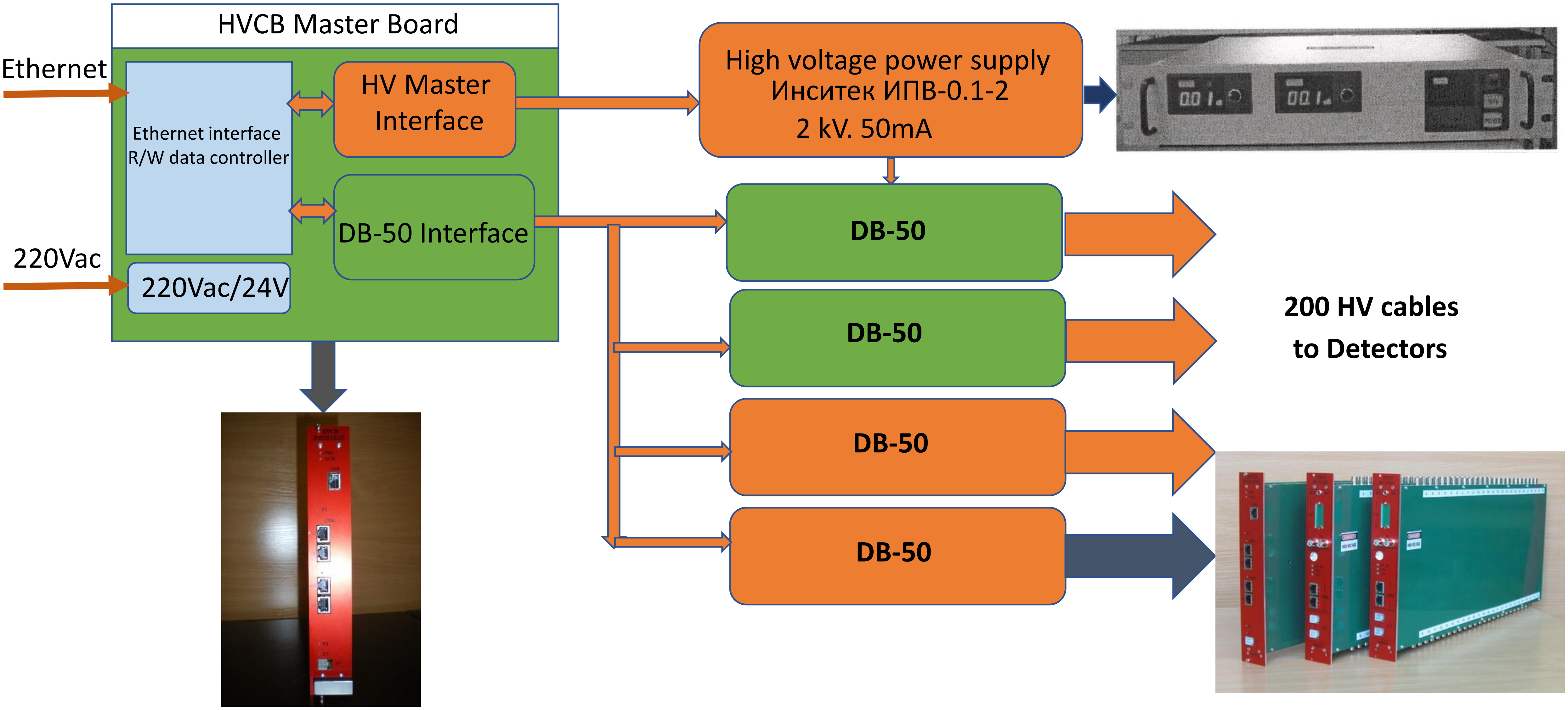
ASF48 card with FADC



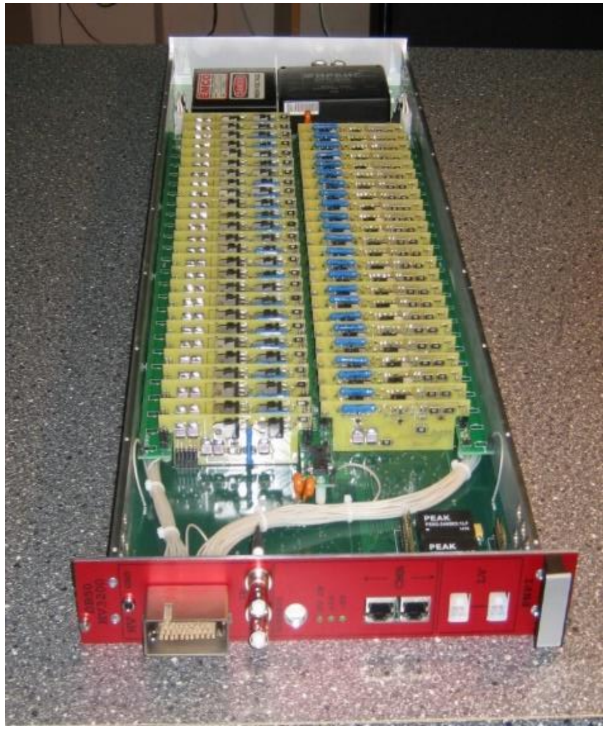
Channels / Card	48/24/12
Channels / System maximum	48 x 16 = 768
Target DAQ System	CROS-3: • CCB16-B Top Level Concentrator • CBS-B CROS-3 System Buffer (PCI Card)
Sampling Rate	(10, 20, 40, 50, 80, 100, 160, 200, 400) MHz
Sampling to discriminator delay	Sampling Period * 14
ADC resolution	10/12 bit
Sample Number / Trigger	(1 – 31), (2 – 62), (4 – 124), (8 – 248), (16 – 496), (32 – 992)
Offset Before Trigger	0…15 / 0…30 / 0…60
Self Trigger Mode	Individual for each channel
Threshold	Individual for each channel (0x000…0xFFF)
Sampling Mode Only for non-interleave modes	Individual for each channel Sampling Rate / 2, Sampling Rate / 4, Sampling Rate / 8
External Trigger Mode	Common for all channels
Distance between nearest triggers	(Sample Number + 6) * 15.38 ns (for each channel) (If a channel has enough memory space for next event)
Channel's L1 FIFO	48 x 1024 / 24 x 2048 / 12 x 4096 - 16-bit words
Output L2 FIFO	16384 16-bit words
Sample Timer	44-bit, 100 MHz, 48 hours (Common for all channels)
Serial Link (signal levels, bit rate)	LVDS, 100MBPS
Card size	100 x 160 mm
Power supply	Single + 3.8V, 2.7A (10,3W)

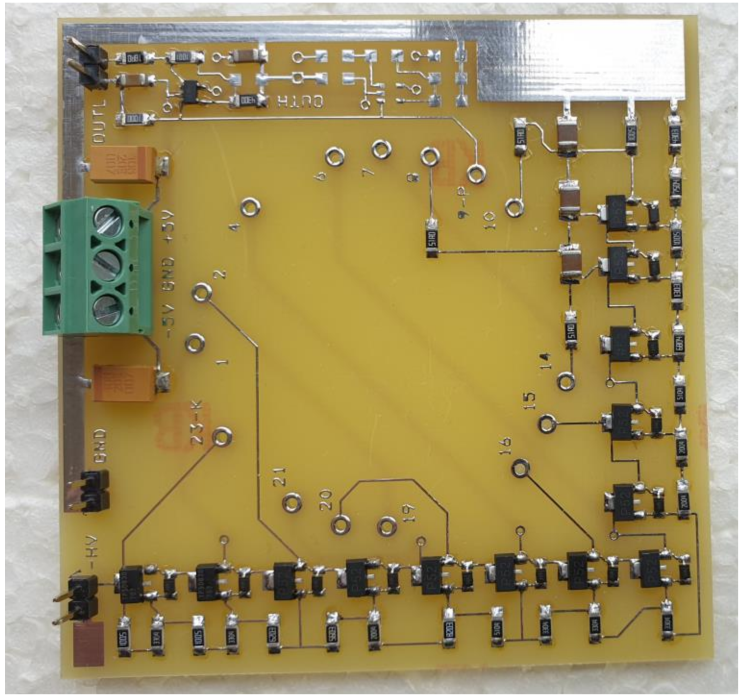


High Voltage Distribution System HVDS3200 and active voltage-dividers



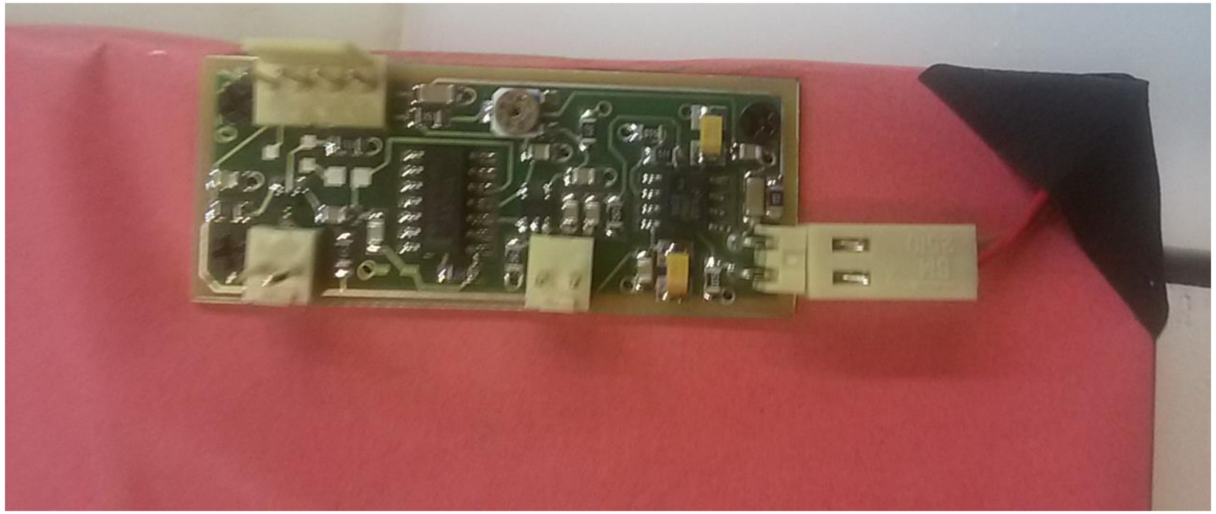
High Voltage Distribution System And active divider for PMT





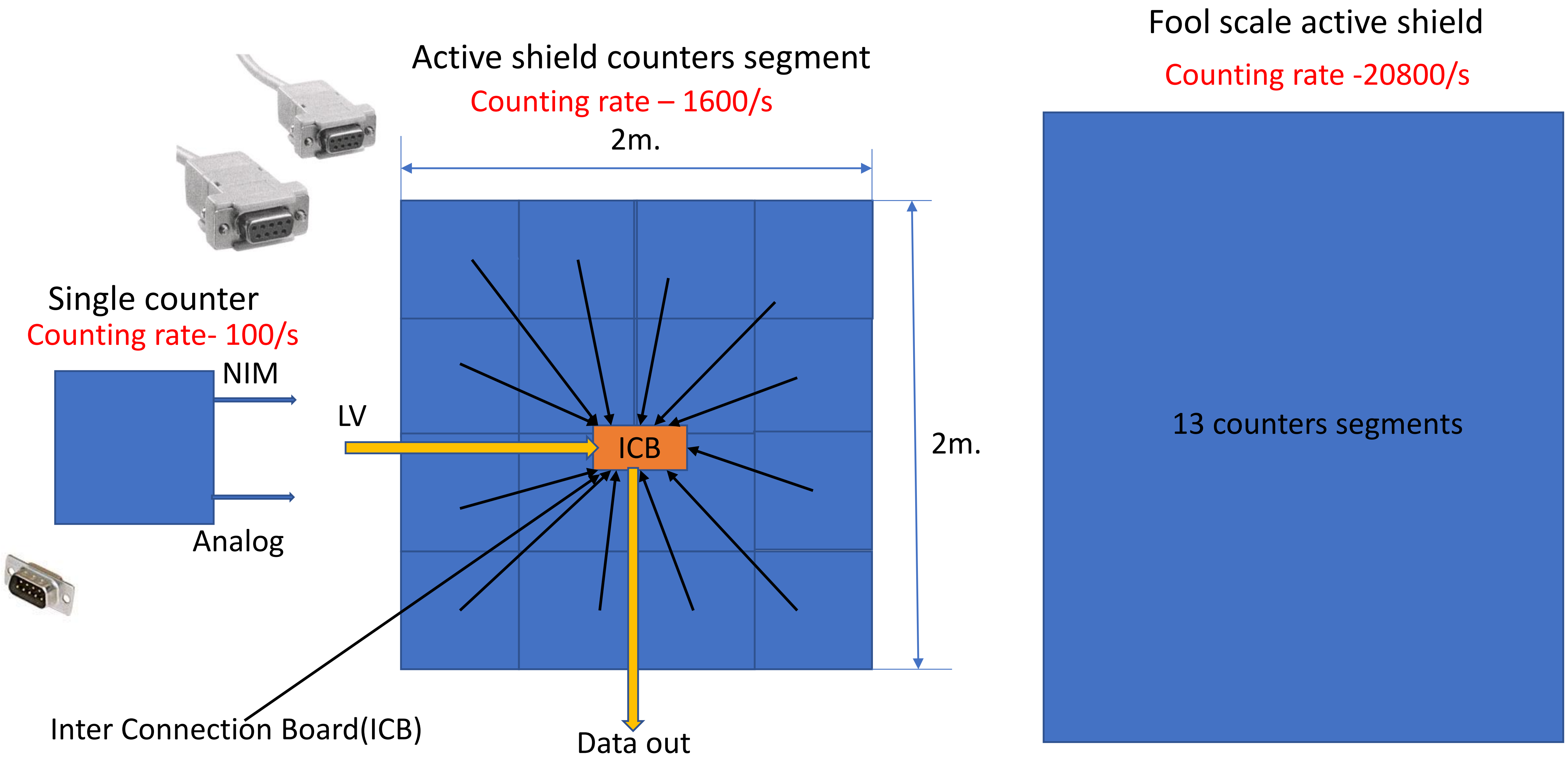
- Voltage adjustment 0…1500 V; 0.1%
- Maximum current 0.5 mA
- Current monitoring 0.1%
- Voltage monitoring 0.1%
- Stability (during 1 day) 0.1%

Active shielding



- Polysterene based scintillator
- Optical fibers with SiPM are used
- “Spectral” or “logical” operating modes

Readout for active shielding

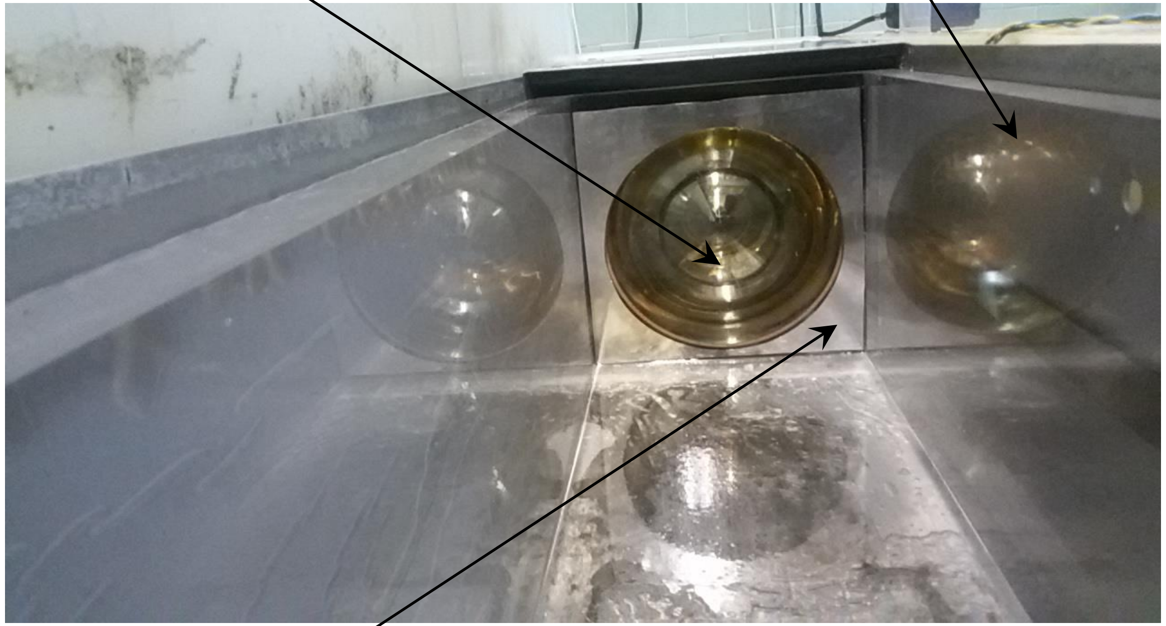


Measurements with section model

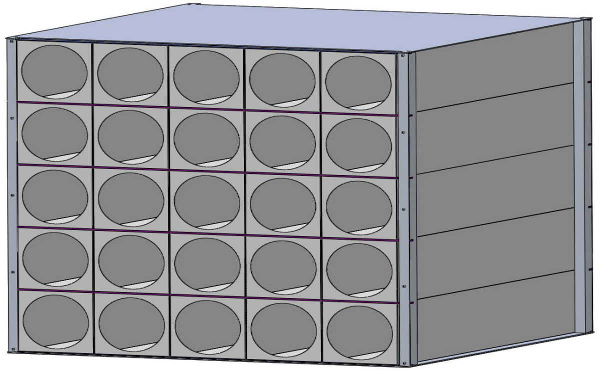
Single section model

PMT

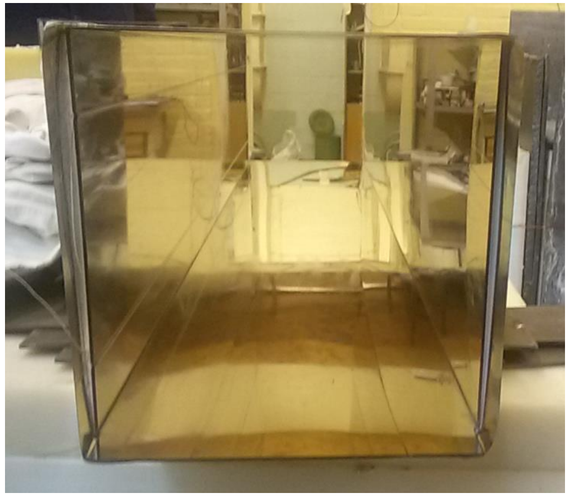
Plex 30mm width tank



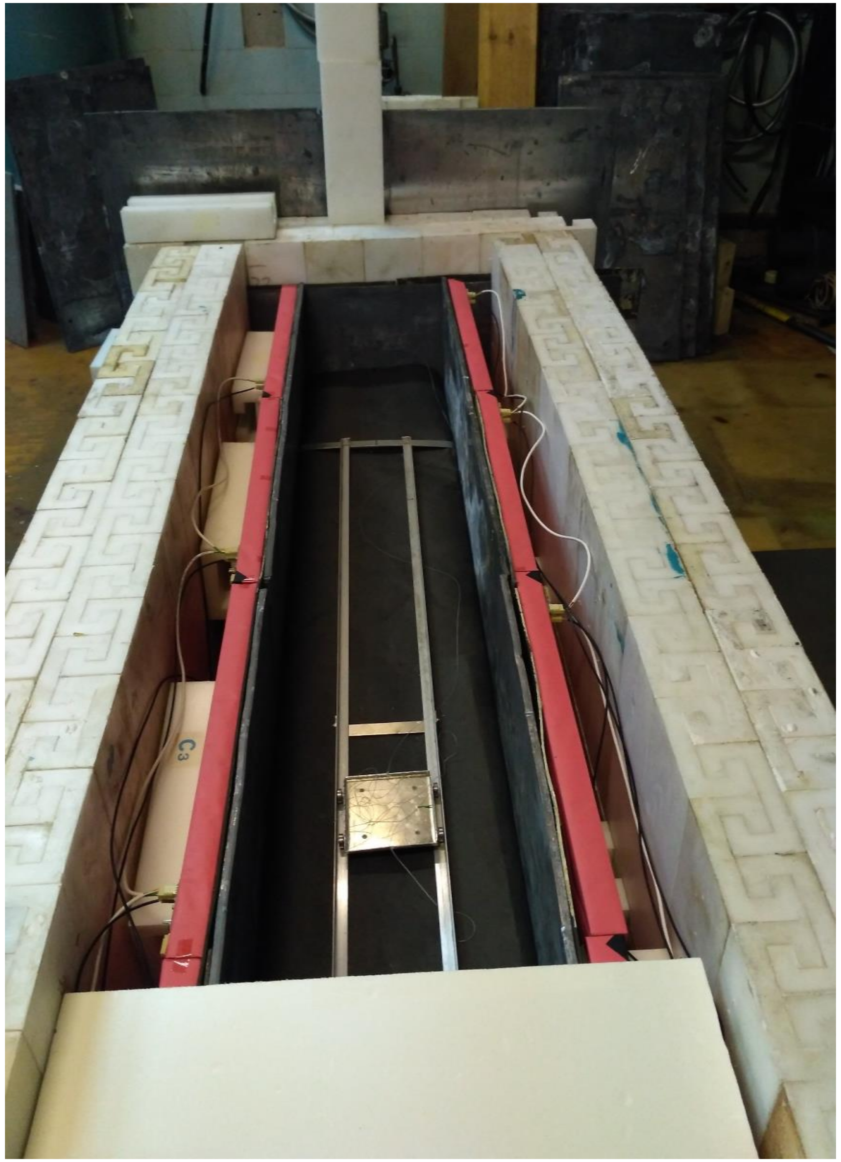
aperture



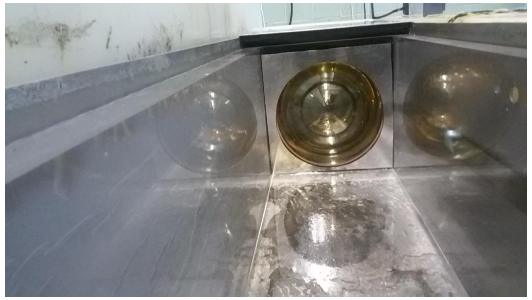
Mirror plex lightguide

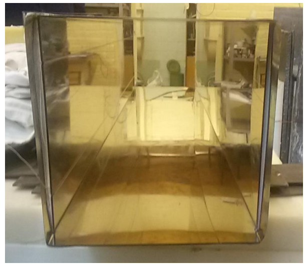


Section with NEOS scintillator inside shielding



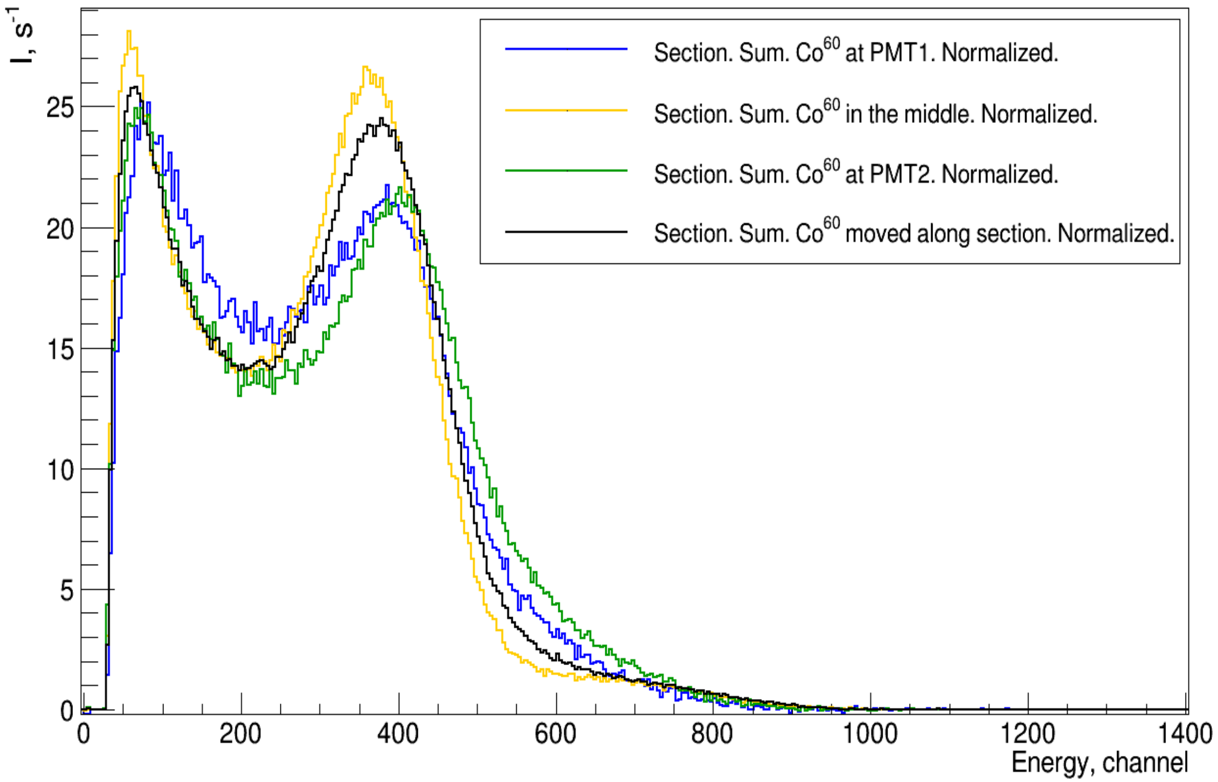
Scintillator volume ~55 liters





Section with NEOS scintillator inside shielding

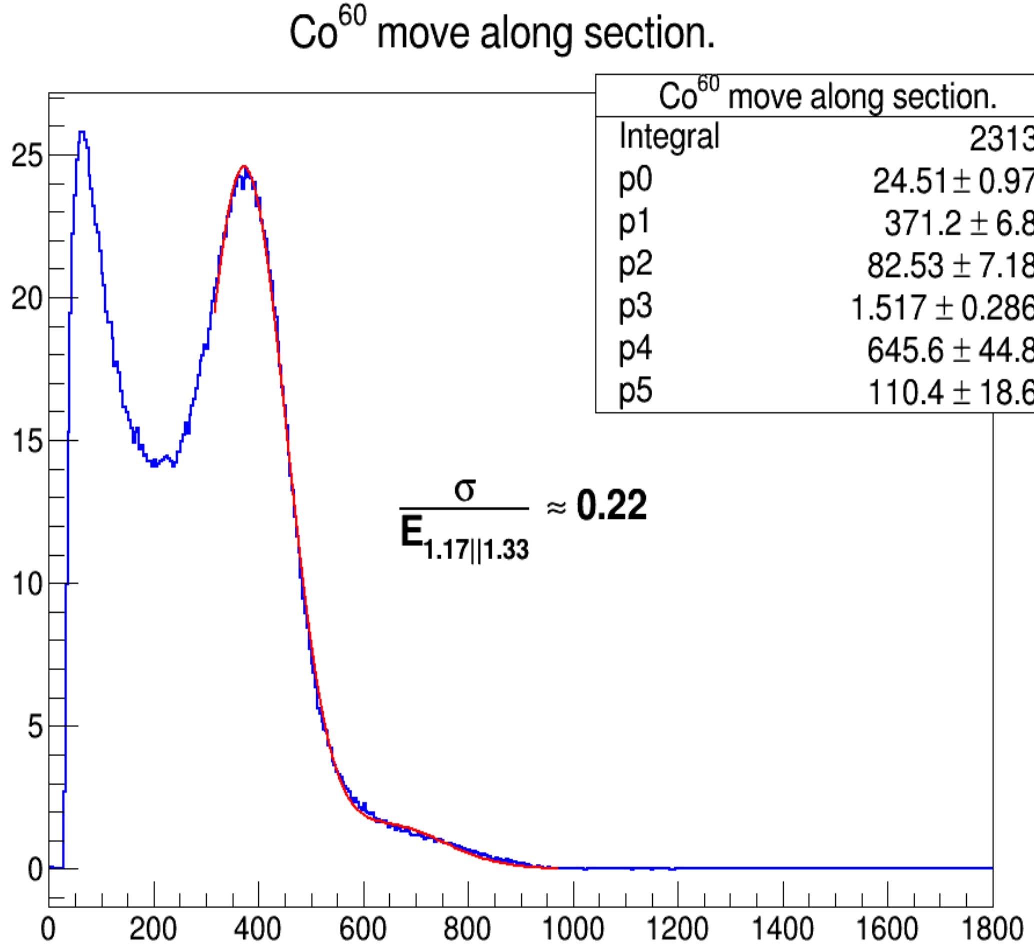
Calibration with Co^{60}



Maximum deviation from "average" peak (scanning mode) is less than **6%**

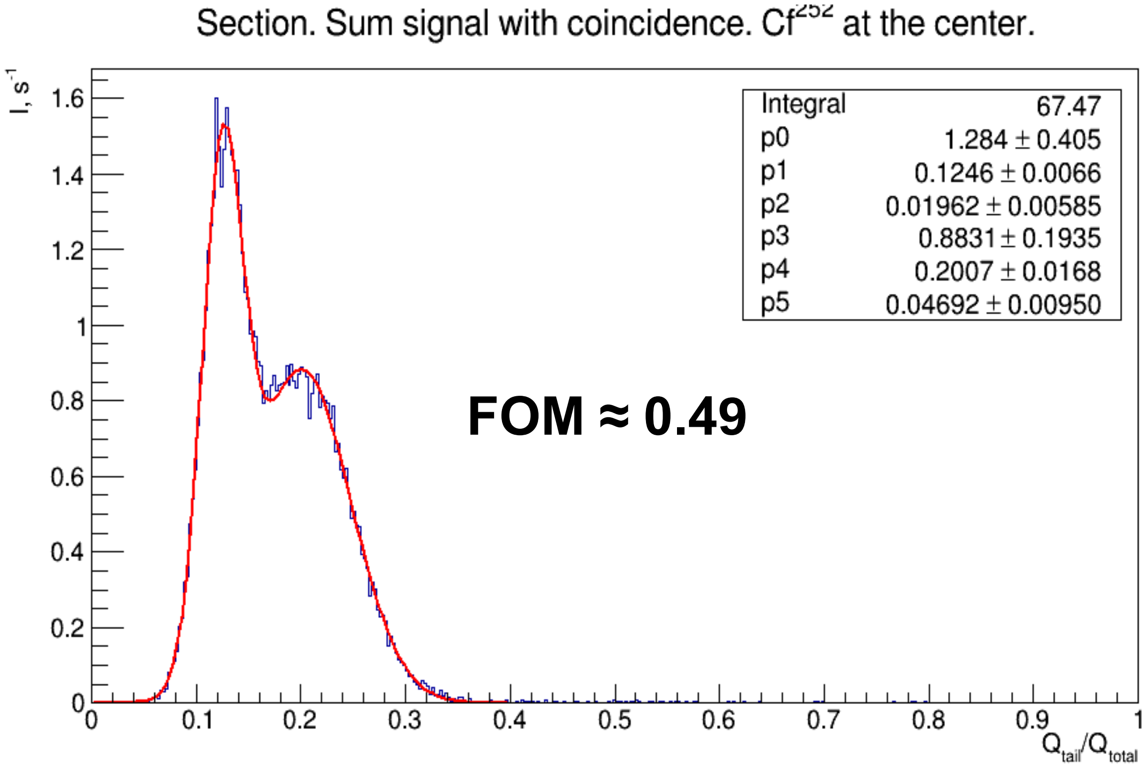
Energy resolution for Co^{60} line

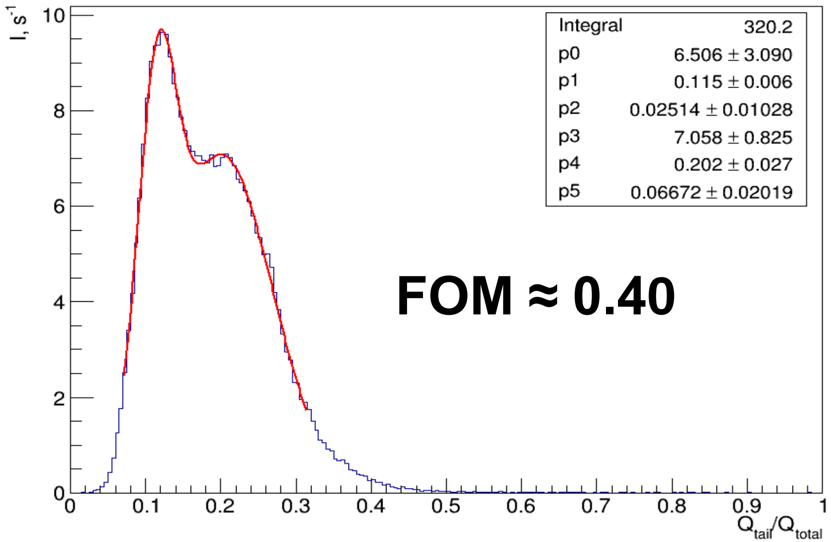
± 300 keV

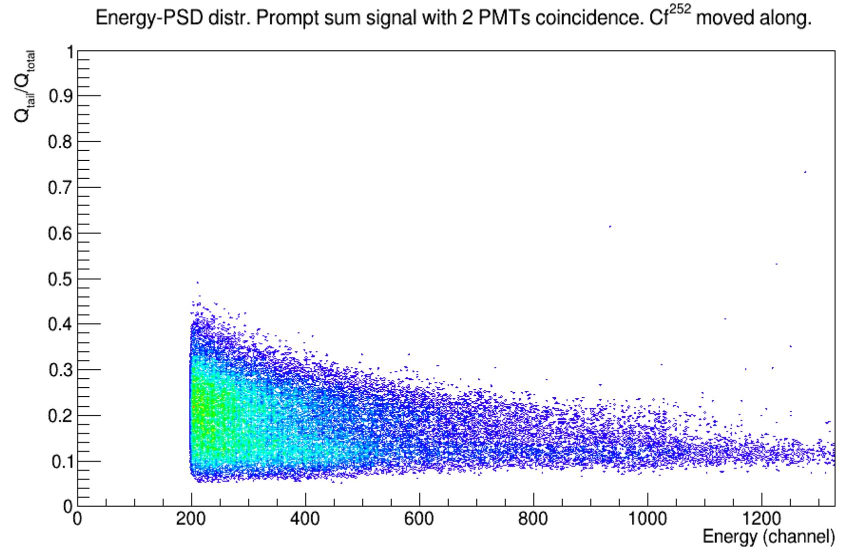


Section with NEOS scintillator inside shielding

PSD capability

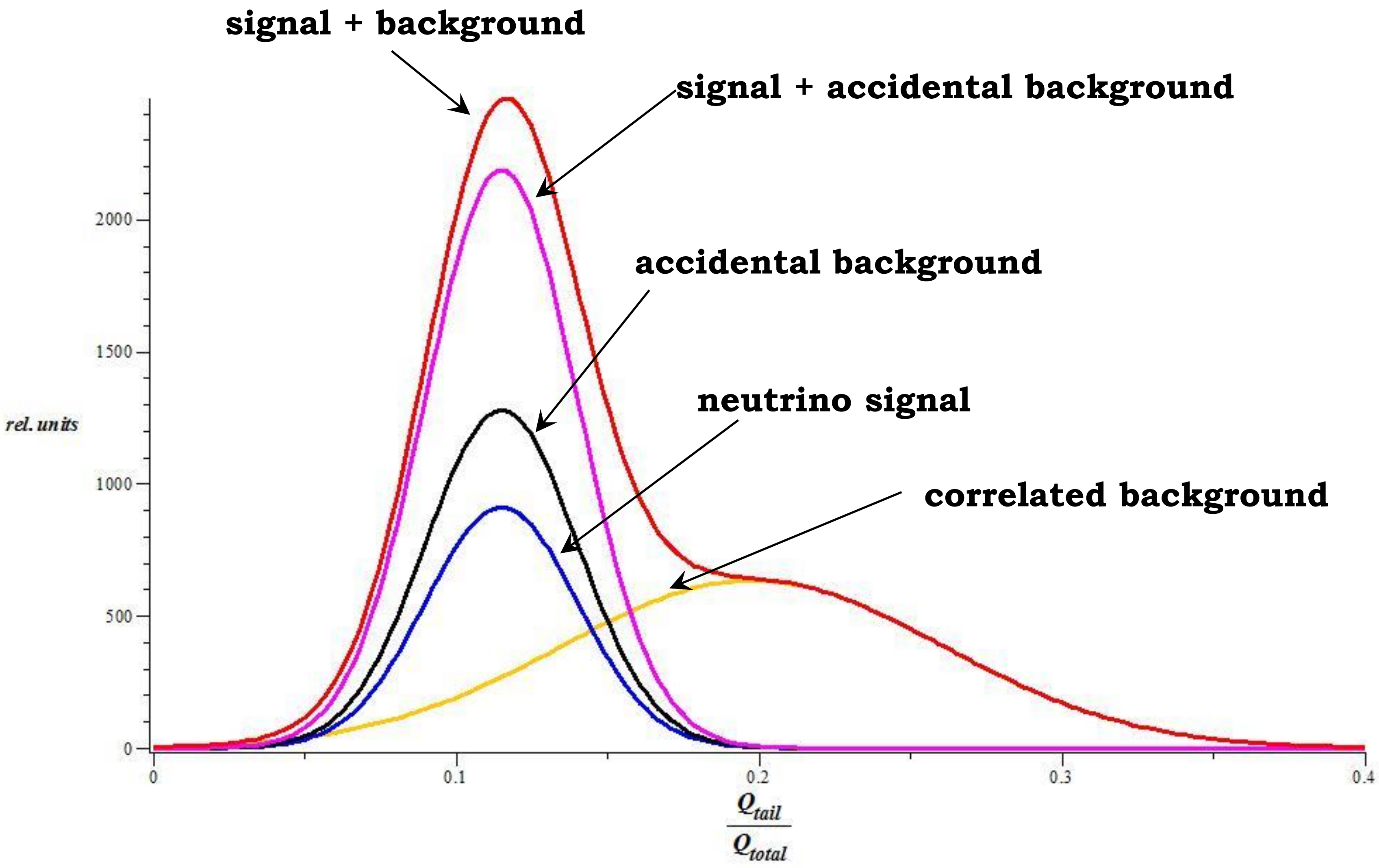






PSD for prompt signals of correlated events from Cf^{252} fast neutrons in “scanning” mode

PSD distribution prediction for detector at SM-3

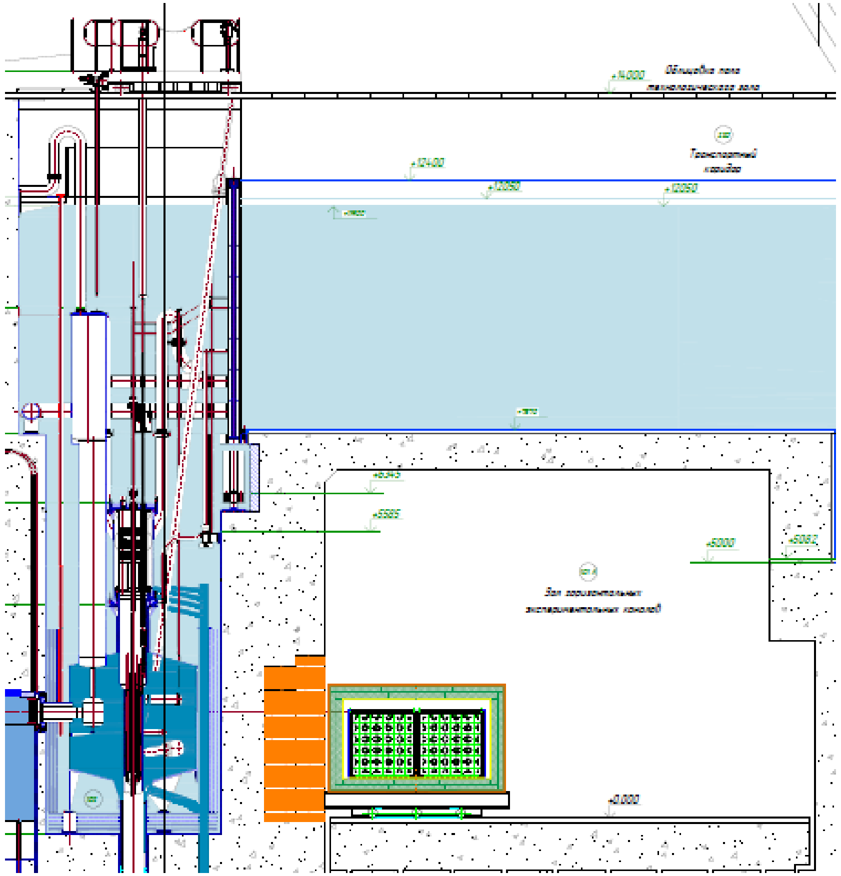


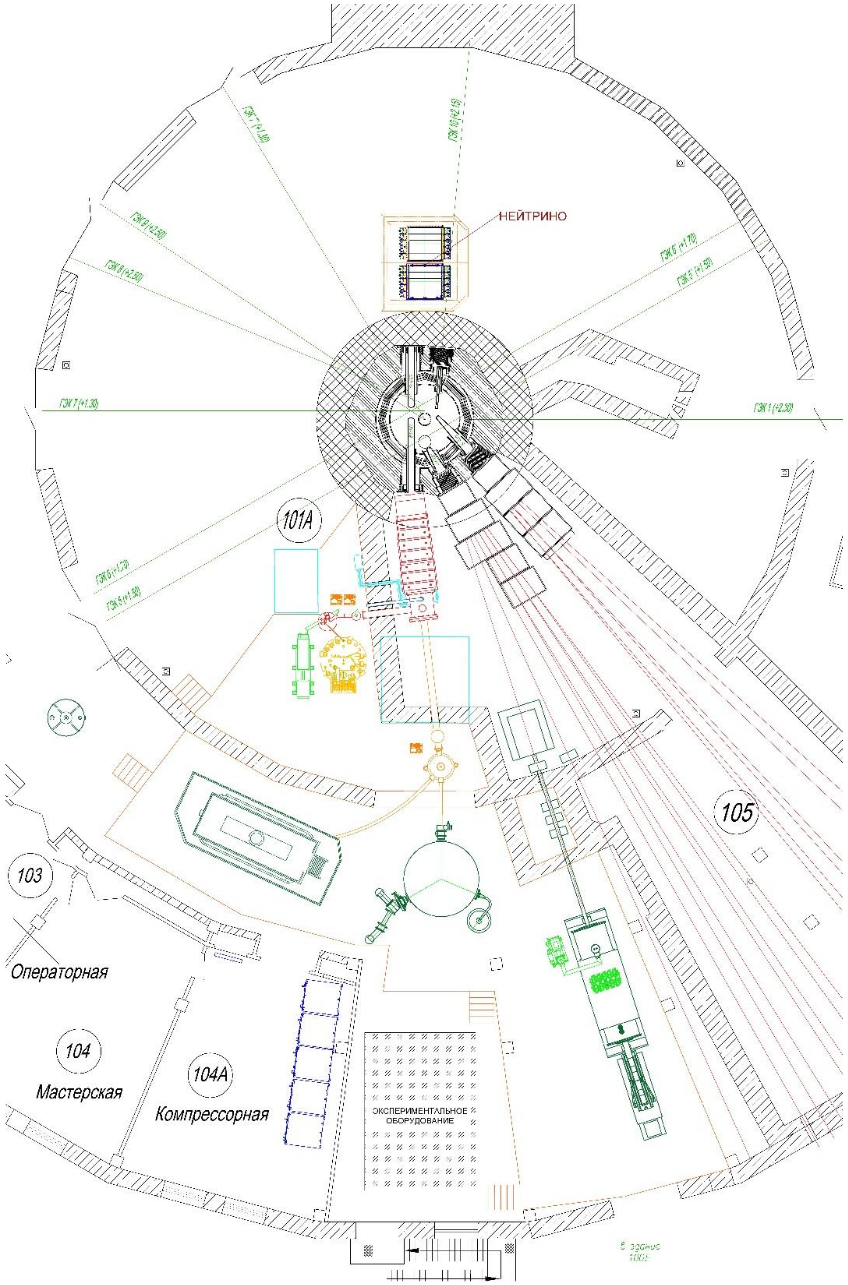
PSD parameter distribution for 10 sections providing that new detectors efficiency is not worse than working now, correlated background is the same and accidental coincidence background is suppressed at least 3 times due to 5 times gadolinium concentration

Expecting improvements of statistical accuracy for the Neutrino-4

Method	Consequence	Increasing accuracy factor
4 detectors	3x larger volume	**1.6**
Gd concentration	4x less accidental background	**1.5**
PSD	4x less correlated background	**1.3**
Total		**3.1**

Neutrino-4 experiment at the PIK reactor





Conclusions

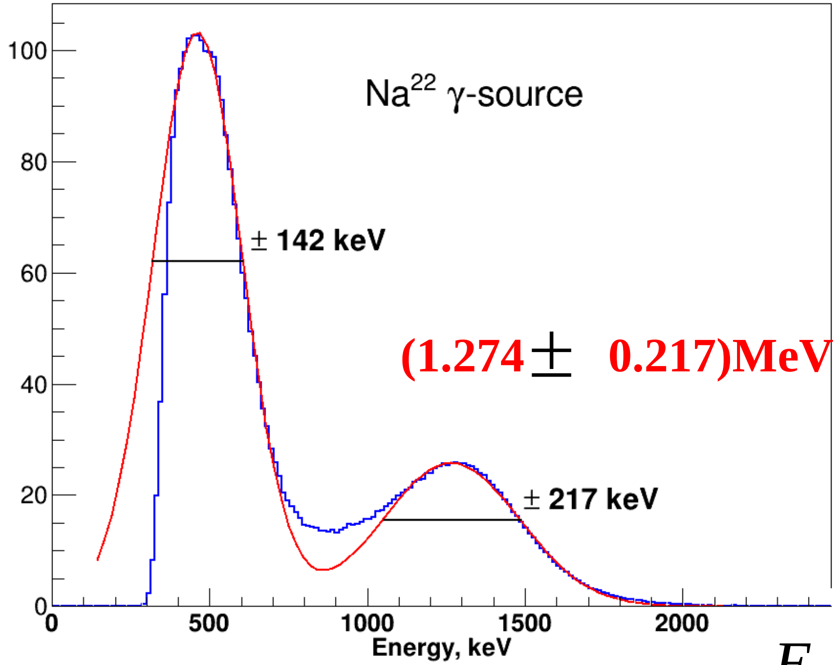
- New measurements with detector Neutrino-4 and new scintillator with more high concentration of Gd and with PSD capability
- Creation of the second neutrino laboratory at the reactor SM-3
- Creation neutrino laboratory at the reactor PIK
- The development and manufacture of a new detector Neutrino-4 with a sensitivity of 3.1 times higher

Thanks for your attention!

Energy calibration of the full-scale detector

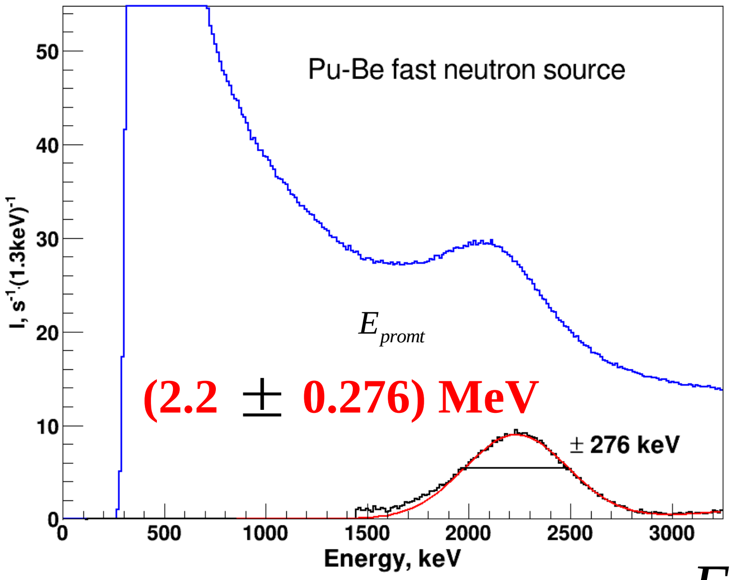
(0.511 ± 0.142) MeV

$$E_\nu = E_{promt} + 0.8 MeV$$



(1.274 ± 0.217)MeV

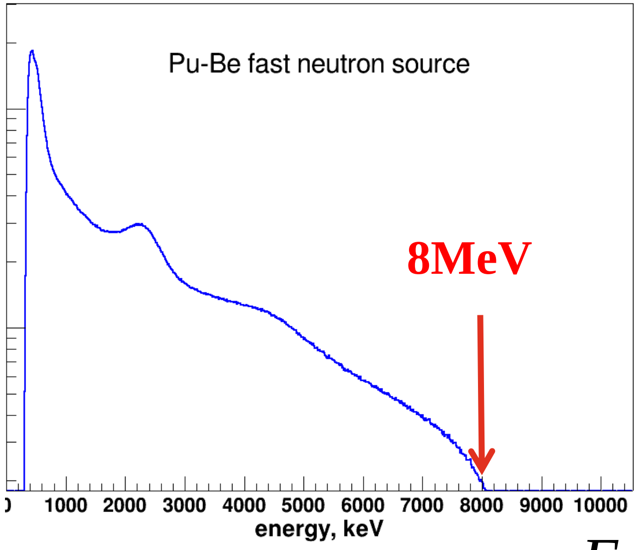
E_{promt}



E_{promt}

(2.2 ± 0.276) MeV

E_{promt}



E_{promt}

$$\Delta E_\nu / E_\nu (2MeV) = 21\%$$

$$\Delta E_\nu (2MeV) = 440 keV$$

$$\Delta E_\nu / E_\nu (3MeV) = 18\%$$

$$\Delta E_\nu (3MeV) = 550 keV$$

$$\Delta E_\nu / E_\nu (6MeV) = 14\%$$

$$\Delta E_\nu (6MeV) = 830 keV$$