Beams of electrons, gammas and fast neutrons at BINP

Viktor Bobrovnikov

v.s.bobrovnikov@inp.nsk.su

The 2024 International Workshop on Future Tau Charm Facilities

14 – 18/01/2024

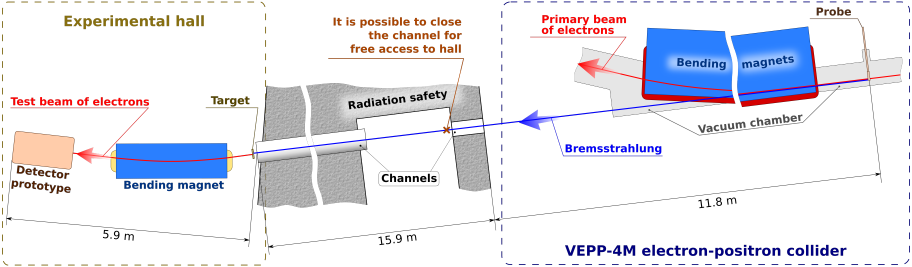
FTCF2024
USTC Hefei

Electron beam

VEPP–4M main parameters	
Perimeter	366 m
Beam energy	1.5÷5.5 GeV
Number of bunches	2×2
Luminosity (1.5÷3.0 GeV)	2×10^{30} cm^{-2}s^{-1}

- The facility is part of VEPP–4M collider

Principle & scheme



1. A special probe is moved into the halo of a primary electron beam of the VEPP–4M collider for generation of Bremsstrahlung.
2. These gammas are converted to electron – positron pairs on a lead target at the entrance to the experimental hall.
3. Electrons with a certain momentum are selected using a bending magnet.

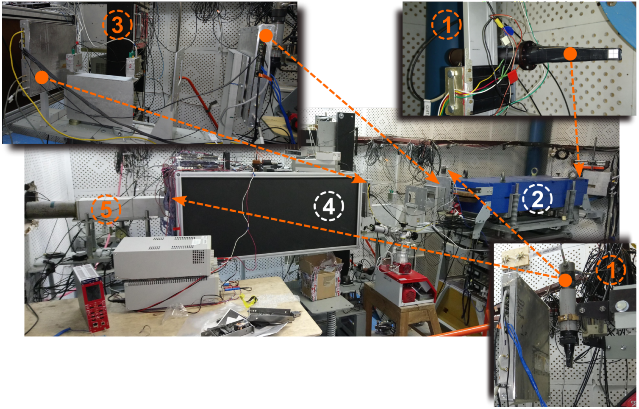
Electron beam: parameters & infrastructure

The beam parameters	
Energy range	0.1÷3.5 GeV
Intensity	50÷100 Hz
Energy spread	7.8% @ 0.1 GeV and 2.6% @ 3.0 GeV

Infrastructure

1. Trigger system based on scintillation counters
2. Mechanical system for setting the position of bending magnet and scientific equipment
3. Tracking system based on GEM detectors ($\sigma_x, \sigma_y \simeq 50\mu$m)
4. Box for the FARICH detector prototype
5. NaI or BGO–calorimeters ($\sigma_E/E = 1.3\%$ @ 3.0 GeV)

- Data acquisition system
- Dedicated system for determining the position of a beam of bremsstrahlung gammas
- MC simulation package (Geant–4)

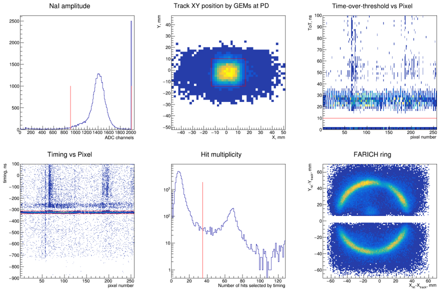


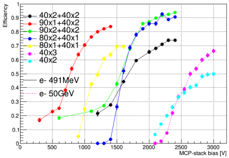
Electron beam: experiments

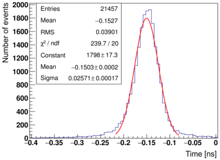
① Development of FARICH (Focusing Aerogel Ring Image CHerenkov), it is a promising particle identification system for future experiments, for example Super Charm−Tau factory

- Since 2011 4 prototypes were tested on the beam
- Focusing effect has been observed:
  – four layers aerogel (30 mm) $\sigma_r = 1.1$ mm
  – single layer aerogel (20 mm) $\sigma_r = 2.1$ mm
- Various samples of aerogel radiators are being studied (multilayer, with various additives), photon detectors with electronics too

✓ For details see presentation by A.Barnyakov "PID R&D status of FARICH option for PID"



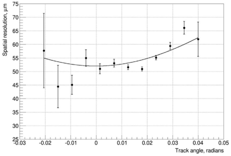




② Testing of devices based on microchannel plates (MCPs) with a CsI photocathode, for time-of-flight systems with excellent times resolution, field of application is identification of particles and suppression of pileup effect in calorimeters at high luminosity, for example, at the LHC

③ Study of coordinate detectors based on GEM. Currently these detectors are actively used in experiments at BINP. Main experiments at the beam are: measuring spatial resolution, selecting operating mode and estimating material quantity on the path of the particle

- Electrons with energy 100 MeV are used to measuring of material quantity. Obtained thickness $0.203 \pm 0.003\%\ X_0$ (the estimate $0.15\%\ X_0$)
- Spatial resolution varies in range 45 – 65 μm.



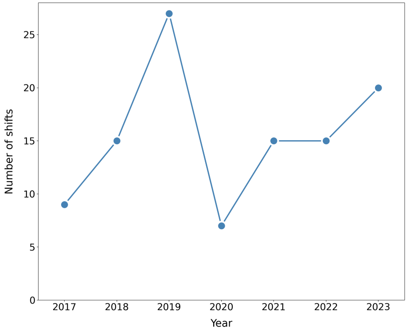
Electron beam: experiments

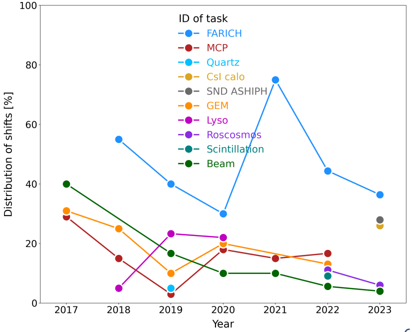
4. Study of the components of Cherenkov light depending on angle of entry of particles into a quartz plate (`Quartz`)
5. Experiments with a LYSO crystal to measure time resolution and Cherenkov component (`Lyso`)
6. Study of the probability of scintillation radiation, in addition to Cherenkov radiation, in aerogels with the addition of zirconium (Zr). The latter makes it possible to increase the optical density of the aerogel radiator while maintaining optical transparency (`Scintillation`)
7. Research of a prototype threshold Cherenkov detector for space dosimetry (`Roscosmos`)
8. Scanning the response of a prototype ASHIPH counter for the SND detector (`SND ASHIPH`)

   ✓ For details see presentation by I.Ovtin ”Status and R&D of ASHIPH option for PID”

9. Technical work on the test beam (`Beam`)

Distribution of the number of shifts and beam time by task

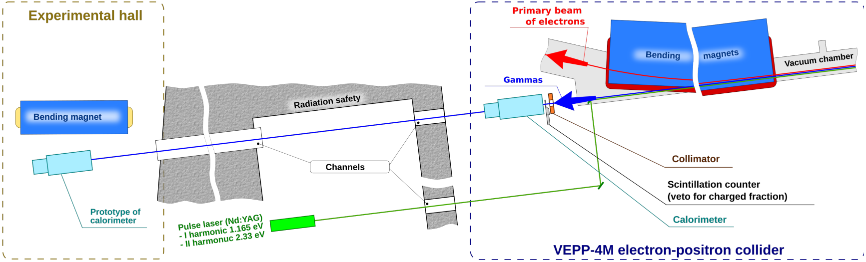




Gammas

Gammas: compton and bremsstrahlung spectra

- Energy spread of the primary electron beam in the VEPP–4M is $\sigma_E/E = 3 \times 10^{-4}$ $\Rightarrow$ it can be used to calibrate scale and energy resolution of calorimeters by edges of spectra compton scattering (laser) and bremsstrahlung (residual gas)
- Principle & scheme



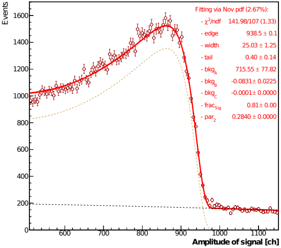
- List of possible calibration points at VEPP–4M collider $\Leftrightarrow$ ω_{max} of compton scattering and bremsstrahlung

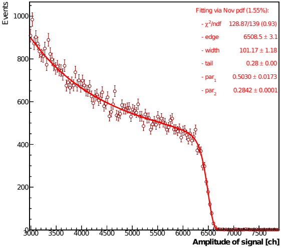
VEPP–4M energy [MeV]	Bremsstrahlung edge [MeV]	Compton edge I harmonic [MeV]	Compton edge II harmonic [MeV]
1850	1850	59	115
2500	2500	111	225
3000	3000	152	290
4000	4000	267	500
4745	4745	402	811

Gammas: compton and bremsstrahlung spectra

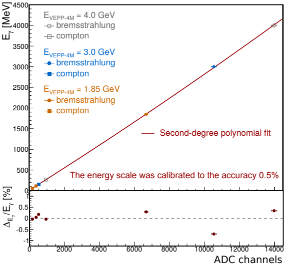
Example of calibration of NaI and BGO calorimeters

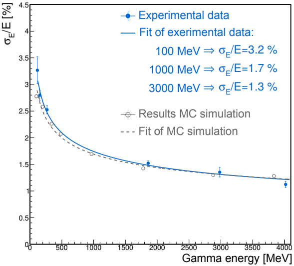
- Examples fitting of spector edges: compton scattering (left) and bremsstrahlung (right)

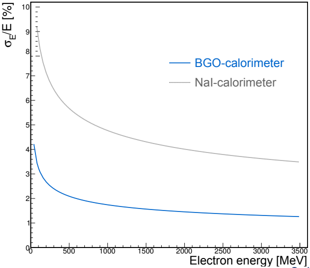




- The result of calibration of the scale (left) and energy resolution of the BGO calorimeter (center), comparison of the obtained energy resolution both calorimeters (right)



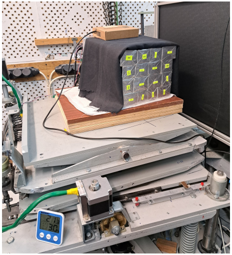


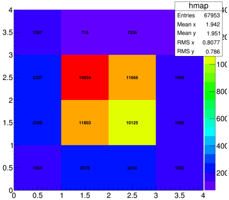


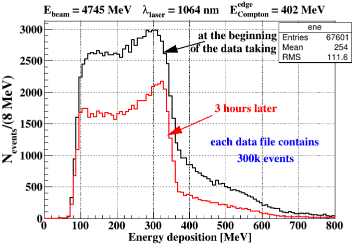
Gammas: compton and bremsstrahlung spectra

Calibrate pure CsI based prototype of calorimeter (July 2023)

- To place the prototype a special table (or platform) was used, capable of handling a weight of up to 400 kg and providing the ability to position the prototype in three axes and two angles (automated control is available)
- The view of matrix of crystals 4×4 (left), an example of the rate of counting events by crystals (center), reconstructed shape of the compton spectrum at one point (right)



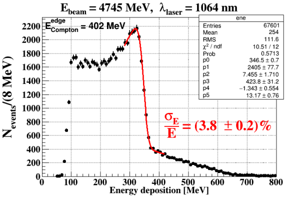


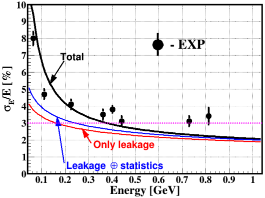


- Temperature control was carried out using 17 DALLAS sensors
- For each crystal, a signal oscillogram (wave) was measured
- The data reading speed was 30 Hz due to the bandwidth limitation of the CAMAC-PC interface

✓ For details see presentation by D.Epifanov "R&D with pure CsI-based prototype of ECAL"

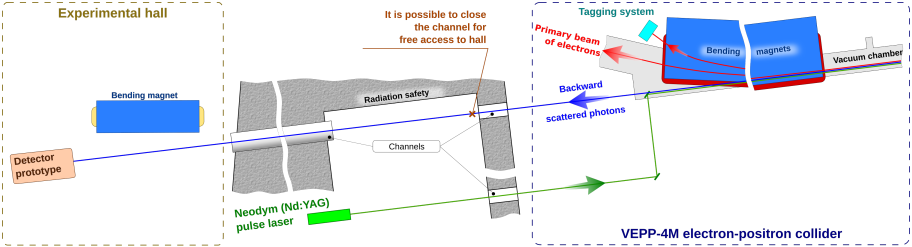
- Preliminary results of fitting the spectrum edge at one of the points (left) and the obtained energy resolution (right)





Gammas: tagged photon beam

Principle of the beam production



1. A pulsed laser is used to form the photon beam. The special setup of mirrors transported the laser photons to the interaction point of VEPP−4M.
2. After interaction a photon gets part of the primary electron energy and moves along the electron beam direction mainly within a cone with an angle of $1/\gamma$
3. To determinate the photon energy the scattered electron energy is measured by the unique tagging system (part of KEDR detector). The energy resolution of this facility is $\sigma_E/E \sim 10^{-3}$

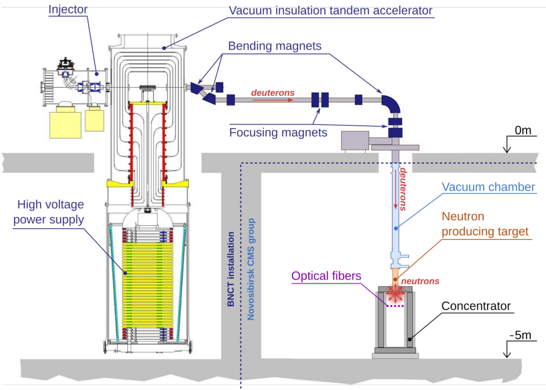
Parameters	
Energy	$(0.39 \div 0.97) \times E$
Intensity	$\sim$1000 Hz

✓ The photon beam was used in 1998 last time for testing BELLE CsI calorimeter prototype. So, it takes some time (about 2-3 months) for its come back.

Fast neutrons

Boron neutron capture therapy (BNCT) facility as source of the fast neutrons

Scheme of the facility

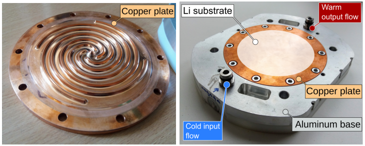


- Hydrogen has been replaced with deuterium in the negative ion source
- Basic nuclear reactions due the interaction of a deuteron beam with lithium target

$$d + {}^{7}Li \rightarrow {}^{8}Be + n + 15.028\ MeV$$

$$d + {}^{7}Li \rightarrow 2\,{}^{4}He + n + 15.122\ MeV$$

Neutron producing target



- Li substrate: thickness 100 mkm, diameter 90 mm
- 9 thermo sensors are located inside for determining position of beam
- water cooling system is necessary part of such kind of device

Lead concentrator

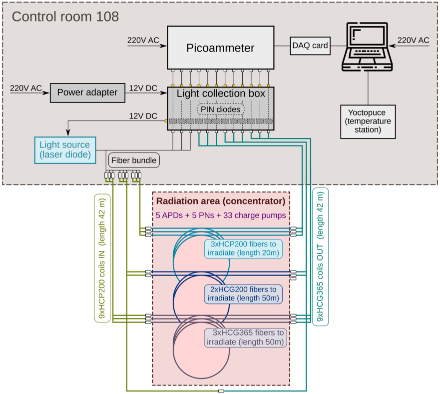
- purpose – first level protection (generation of fast neutrons is performed inside) and raising efficiency of irradiation (part of neutrons are reflected from walls and then are used again)
- inner dimensions $350 \times 350 \times 1000$ mm
- thickness of lead is 100 mm (walls, bottom and top)

Fast neutrons: study of the radiation aging of optical fibers

- The Laser Monitoring system of electromagnetic calorimeter of CMS detector uses optical fibres to inject the light into crystals and reference pin diodes. Under the neutron flux, the fiber darkens due to the destruction of them structure, especially in areas close to the beams, where the radiation background is the biggest. Luminosity and energy of LHC beams will be increased $\Rightarrow$ radiation load on detector systems will be increased too
- Novosibrsk group (NSU) is a member of the CMS collaboration $\Leftrightarrow$ laboratory of hadronic interaction physics, so it is reason to perform such kind of investigation at BINP

Scheme of the test

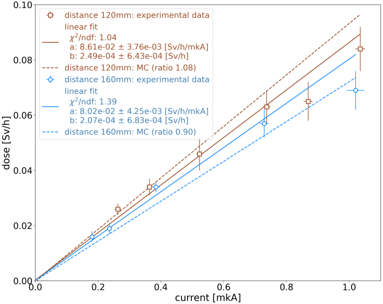
- Measuring equipment and materials were provided by the Saclay team



Simulation

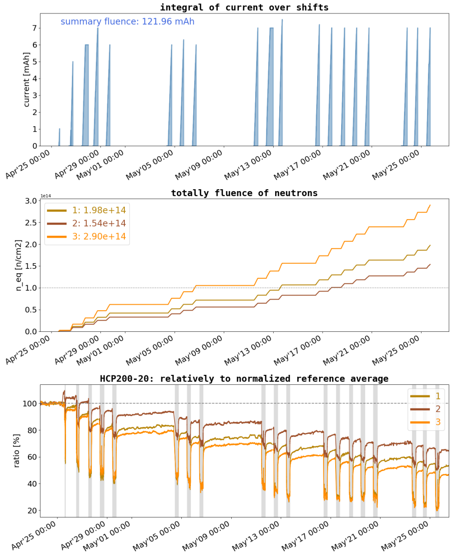
> **!** Direct measurement of the neutron flux (neq/cm2) is impossible due to high doses of the order of 100 Sv/h, at least we do not know such devices which can operating under such conditions

- FLUKA package was used for calculation of neutron flux
- Experimental verification of the simulation was performed



Fast neutrons: results

Example degradation of transparency for HCP200–20 fibers



- The degradation of transparency at level from 20% to 35% (over the full length of the fibres) was obtained for a fluence of 10^{14} neq/cm^2
- Such a drop in the amplitude of the calibration signal can be restored by increasing amplitude level of source light
- Also, since such level of dose will be obtained at CMS within an estimated period of 3 to 5 years, the results obtained are fully satisfactory to the CMS team

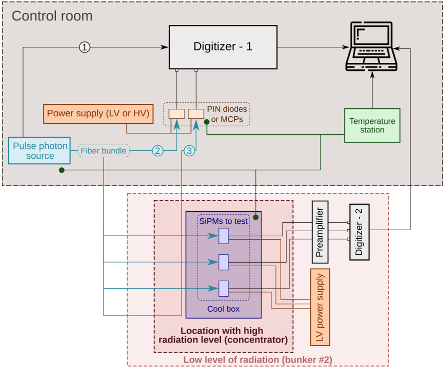
✓

- BNCT facility at BINP SB RAS provides irradiation the dose at level **10^{14} neq/cm^2** (in the case of continuous generation, the time will be about 110 hours), this is quite enough to check the radiation resistance of materials, which are proposed to use in the HEP projects
- The uniqueness of this radiation tests in contrast to irradiation in reactor is the precise control of the accumulated dose with continuous measuring of degradation fiber transparency

Fast neutrons: new stand to test of SiPMs

✓ Next task for our group is developing stand to investigate behaviour of SiPMs under irradiation

- The scheme first version of the stand

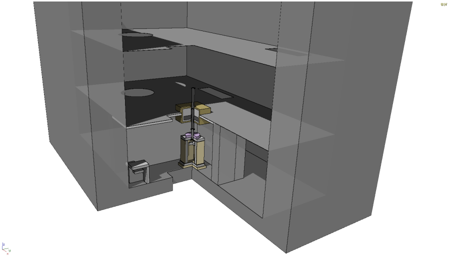


① Synchronization line ② The control stability of light source
③ The control transparency of optical fiber

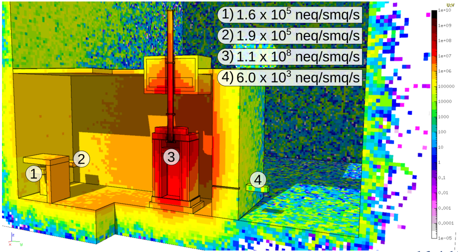
- One of the important question is placement of equipment relative to the concentrator (location to generate fast neutrons)
- Acceptable level of dose is up to 10^6 neq/cmq/s ⇔ info from CAEN

- Estimate of dose level via FLUKA

Example description of geometry of bunker #2

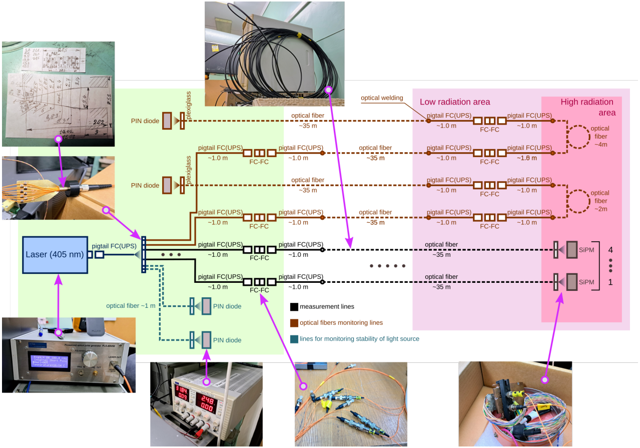


Simulation results ($E_d = 1.5\,\mathrm{MeV}, I_d = 1\,\mathrm{mA}, t = 1\,\mathrm{s}$)



Fast neutrons: new stand to test of SiPMs

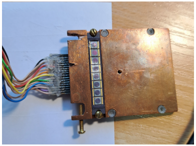
- Realised light distribution system



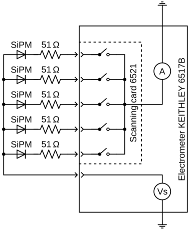
- DAQ and SiPMs

Keithley electrometer 6517B

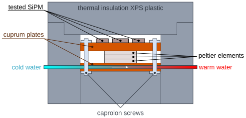
SiPMs by Hamamatsu for the CMS HCAL phase I upgrade

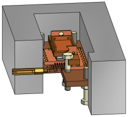


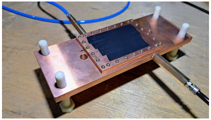
SiPMs readout scheme



- Camera cold and heat: temperature range from -20°C to $+40^\circ$C ($\pm 0.1^\circ$C)



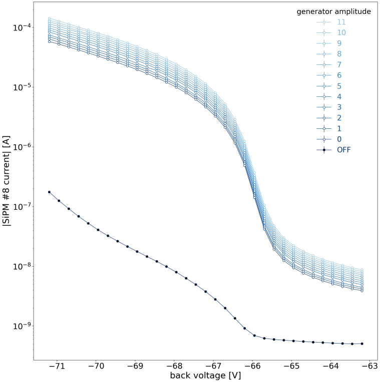




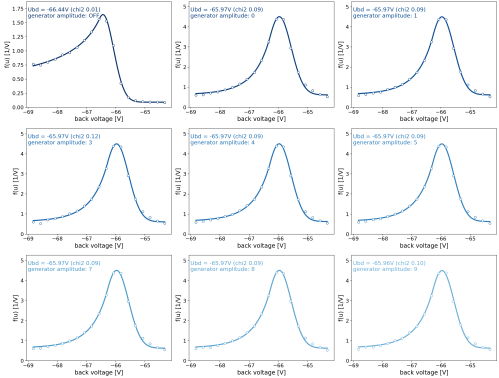
Fast neutrons: new stand to test of SiPMs

- First preliminary results, mainaly to verification performance of DAQ (no irradiation yet)

Example of I-V characteristic



U_{bd} was calculated as maximum of function $f(U) = dI/(I \times dU)$



Our plans to 2024

- First testing irradiation run (dose up to 1.4×10^{13} neq/cm^2) in February – March
- Upgrade of the stand, in particular new DAQ system based on QDC by CAEN (April – September)
- Second irradiation run with other SiPMs from ”real” prototypes or systems (October – December)

Conclusion

- Since 2011 test beam of electron is used to perform various experiments (FARICH, MCP, GEM and other)
- The beam parameters:
  - energy range: $100 - 3500$ MeV
  - energy spread: 7.8% (100 MeV) – 2.6% (3000 MeV)
  - intensity: $50 \div 100$ Hz

- Calibration of energy resolution of calorimeters can be carried out at the edges of the compton scattering ($w_{max} = 60 - 811$ MeV) and bremsstrahlung ($w_{max} = 1900 - 4745$ MeV) spectra
- Tagged photon beam ($w = [0.39 \div 0.97] \times E$) was used in 1998 last time The possibility of its implementation is determined by the presence of corresponding problem with persistent interest on the part of physicists

- BNCT facility provides irradiation the dose at level 10^{14} neq/см^2. It has been demonstrated for the first time that at the BINP SB RAS it is possible to operate with such doses using of neutron beam
- It could be in further used for the wide range of radiation test tasks, related with the development of facilities for HEP
- We are developing new stand on base BNCT facility dedicated to perform investigation irradiation damage of SiPMs right now

✓ **We are open to new cooperation and invite you to Siberia to work with beams of electrons, gammas and fast neutrons !**