NEW EXPERIMENT ON THE RADIATIVE NEUTRON DECAY

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Annotation

The report is dedicated to the preparation of the new experiment on the neutron radiative decay what is conducted for the last years. We started the experimental research of this neutron decay branch with the experiment conducted at ILL in 2002 [1] and continued in another experiment at the second and third cycles at the FRMII reactor of the Technical University of Munich [2] in 2005. In the first experiment we succeeded in measuring only the upper limit on the relative intensity (B.R.) of the radiative neutron decay and in the second we succeeded in discovering events of radiative neutron decay and measure its B.R.=(3.2±1.6)10-3 (with C.L.=99.7% and gamma quanta energy over 35 keV). The obtained average B.R. value was approximately twice the theoretical value calculated earlier within the framework of the standard electroweak model [3]. However, due to significant experimental error it would be preliminary to deduce that based on this finding a deviation from the standard model has been observed. To prove or disprove the existence of a deviation it is necessary to conduct a new experiment that would allow to measure the radiative peak in timing spectra [2] with precision in the order of 1%. By the present time we have prepared a new experiment the main result of which would be the measurement of B.R. for the radiative branch of neutron decay with this precision

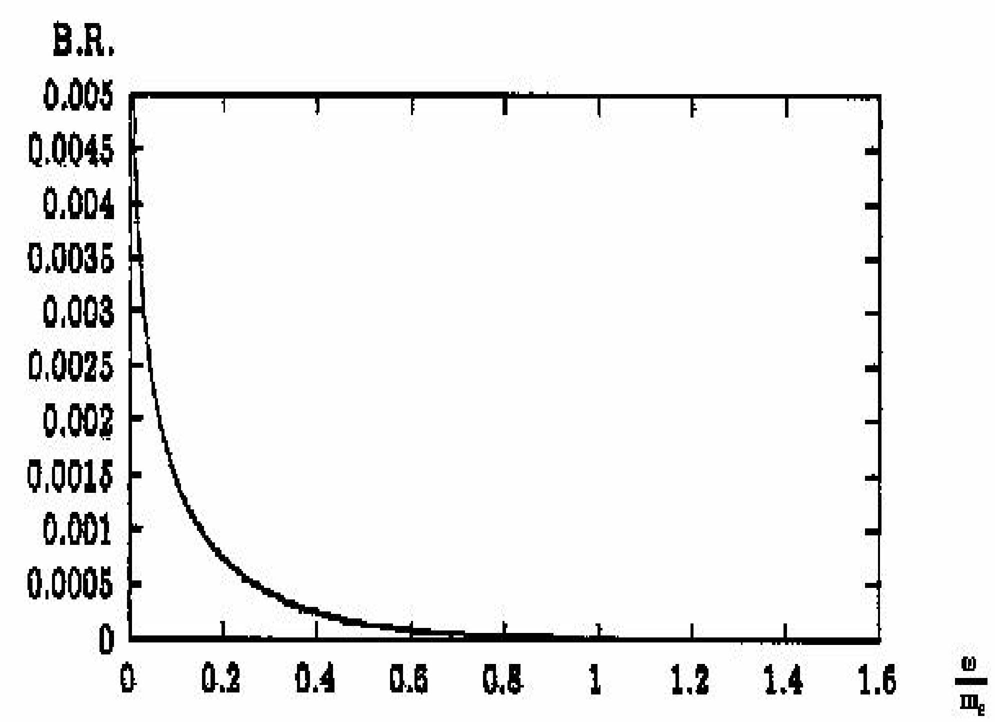
References

[1] M. Beck et al., JETP Letters v. 76(6), 2002, p. 332
[2] R.U. Khafizov et al. JETP Letters, v. 83(1), 2006, p. 5
[3] Yu.V. Gaponov, R.U. Khafizov, Phys. Lett. B 379(1996), p. 7.

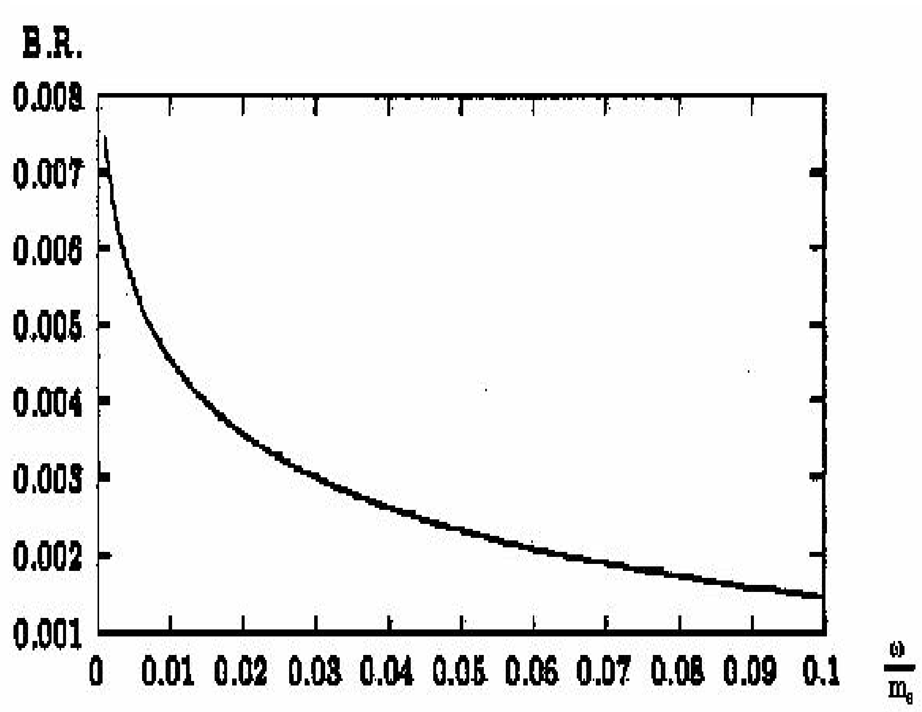
What is radiative branch of decay?

- **Among the many rare branches of elementary decay with charged particles in the final state, the radiative branch, where the decay occurs with the creation of an additional particle – the gamma quantum, is usually the most intensive, as the relative intensity (or branching ratio B.R.) of this mode is determined by the fine structure constant α of 10^{-2} order of magnitude. This decay branch is well established and has been investigated for almost all elementary particles. However, the radiative decay of the free neutron** $n \rightarrow p + e + \overline{\nu} + \gamma$ **had not been discovered, and all the experiments were aimed at the study of the ordinary neutron decay branch**
- **However, the study of radiative branches of elementary particle decay occupies a central place in the fundamental problem of searching for deviations from the standard electroweak model. Characteristics of the ordinary decay mode are currently measured with precision of tenths of a percentage point. Under these circumstances experimental data obtained by different groups of experimentalists can be reconciled only by taking into account the radiative corrections calculated within the framework of the standard theory of electroweak interactions. This means that experimental research of the ordinary mode of neutron decay has exhausted its usefulness for testing the standard model. To test the theory of electroweak interaction independently it is necessary to move from the research of the ordinary decay branch to the next step, namely, to the experimental research of the radiative decay branch.**
- **The main value for radiative decay of neutron that is necessary to measure first of all is the relative intensity or branching ratio**
- **BR = I(radiative decay) / I(ordinary decay) = N(e,p,γ) / N(e,p) =** N_T / N_D **,**
- **where the number of triple** N_T **and double** N_D **coincidences have to be taken directly from the experimental spectra of triple and double coincidences, thus the measurement of BR is really the measurement of the double e-p coincidences spectrum and the triple e-p-γ coincidences spectrum. Without analyzing these experimental spectra it is impossible to say anything about the experimental measurement of the BR value.**
- **So, measurement of BR is a relative experiment, it is not absolute experiment and many uncertainties of this experiment should be canceled.**

Theoretical value of BR calculated in the frameworks of Standard Model (Phys. Lett. 1996, B 379, p.7)



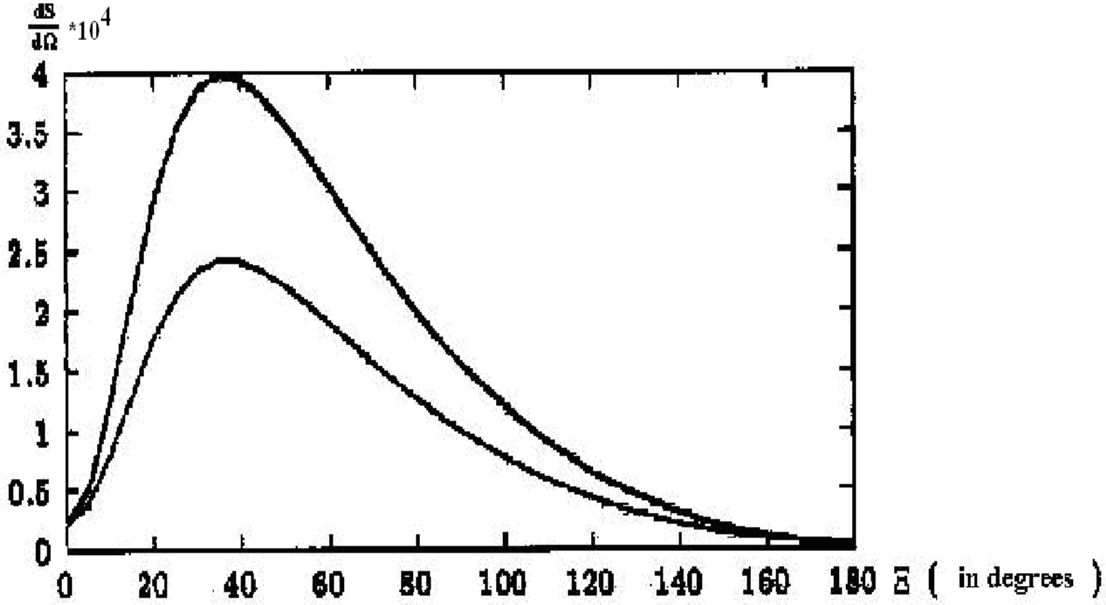
The expected Standard Model branching ratio for radiative neutron beta decay (summed over all gamma energies larger than the threshold gamma energy ω) as a function of ω/m_e.



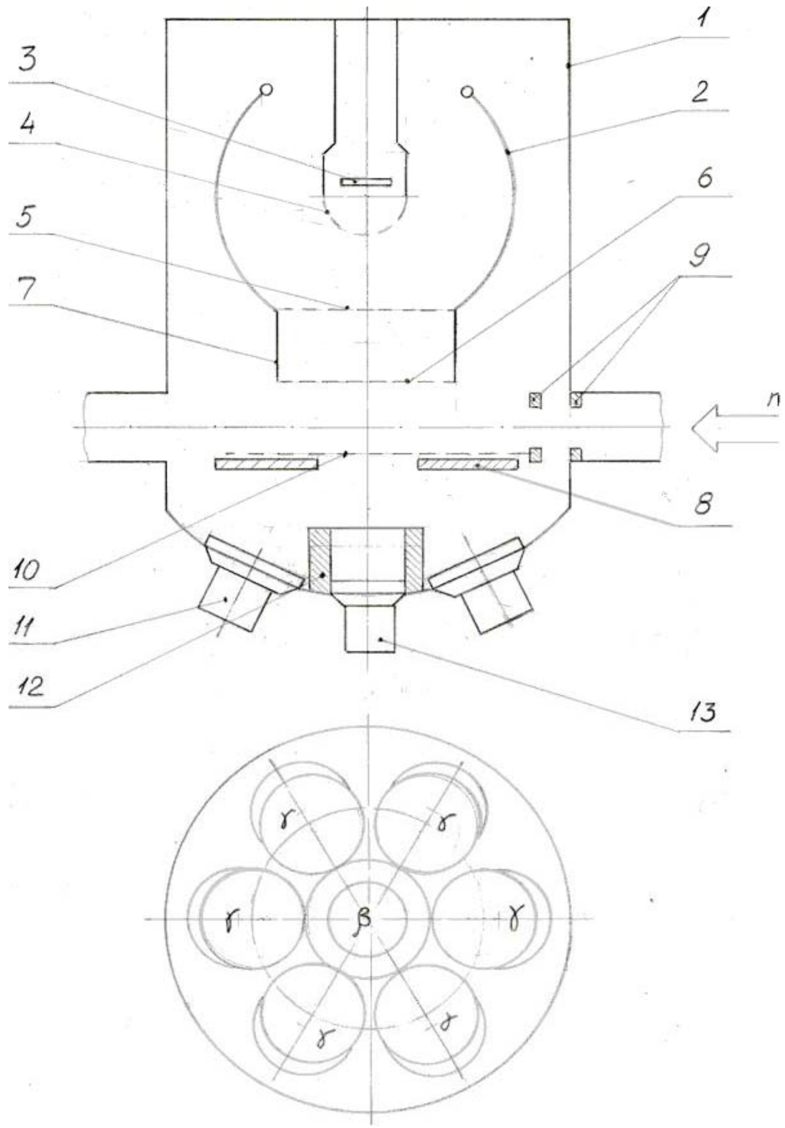
The same but with detail scale for ω/m_e

$BR=2\cdot 10^{-3}$ for radiative gamma quanta energy more than 35 keV

Angular distribution of radiative gamma quanta and schematiclay-out of the experimental setup (JETPh Letters, Jan., 2006, vol.83(1), p.5)

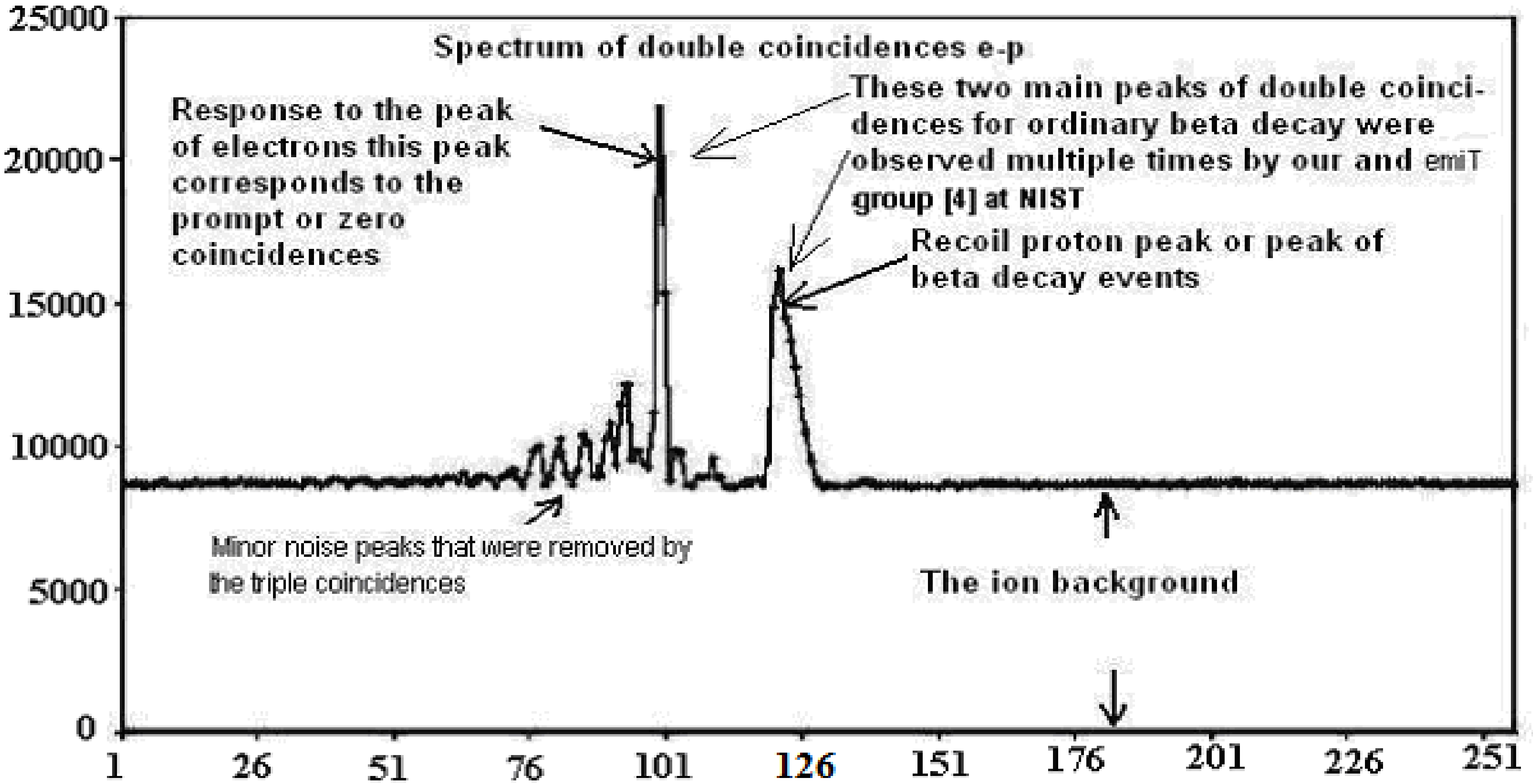


Dependence of the radiative decay spectrum S on the angle Ξ between the photon and the electron momenta (upper curve for a threshold gamma energy of 25 keV, lower curve for a threshold gamma energy of 50 keV)



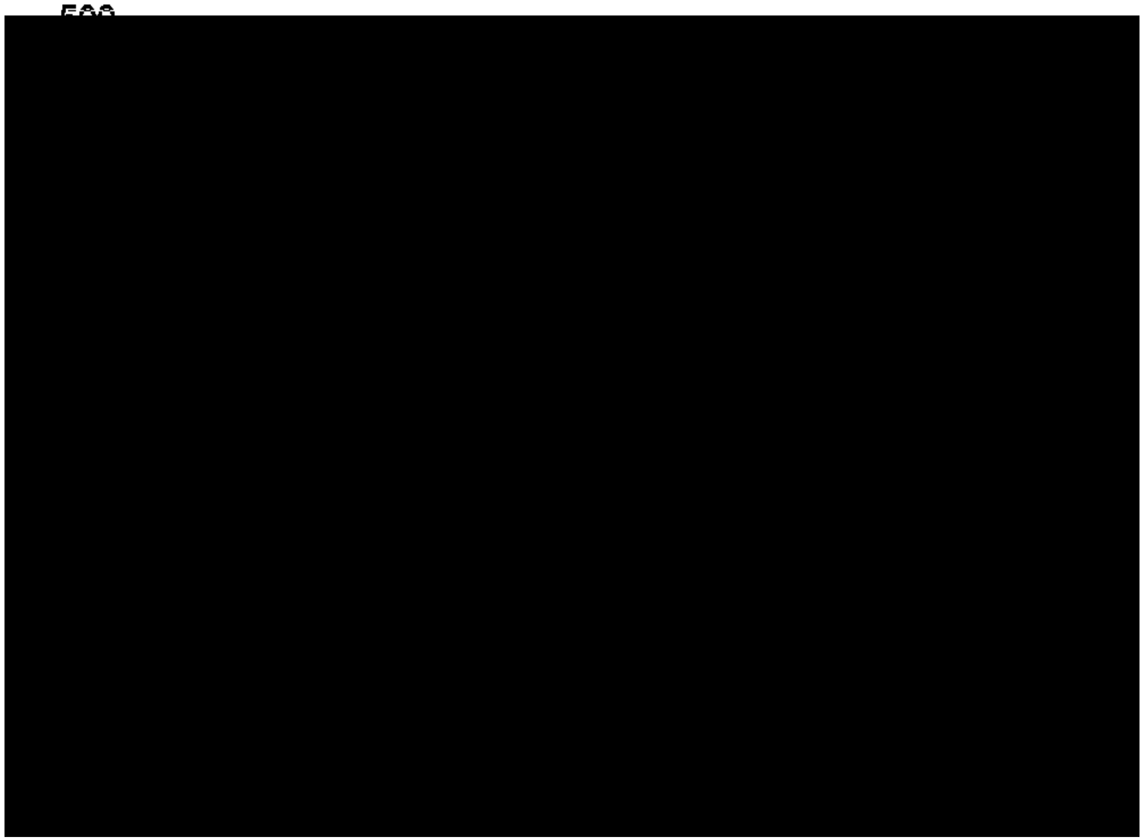
Schematic lay-out:
vacuum chamber, (2) spherical electrodes to focus the recoil protons (at 18-20 kV) on the on the proton detector (3), (4) grid for proton detector (at ground potential), (5) & (6) grids for time of flight electrode, (7) time of flight electrode (at 18-20 kV), (8) plastic collimator (5 mm thickness, diameter 70 mm) for beta-electrons, (9) LiF diaphragms, (10) grid to turn the recoil proton backward (at 22-26 kV), (11) six photomultiplier tubes for the CsI(Tl) gamma detectors, (12) lead cup, (13) photomultiplier tube covered by plastic scintillator of electron detector.

Experimental double coincidences spectrum (JETPh Letters, Jan., 2006, vol.83(1), p.5)

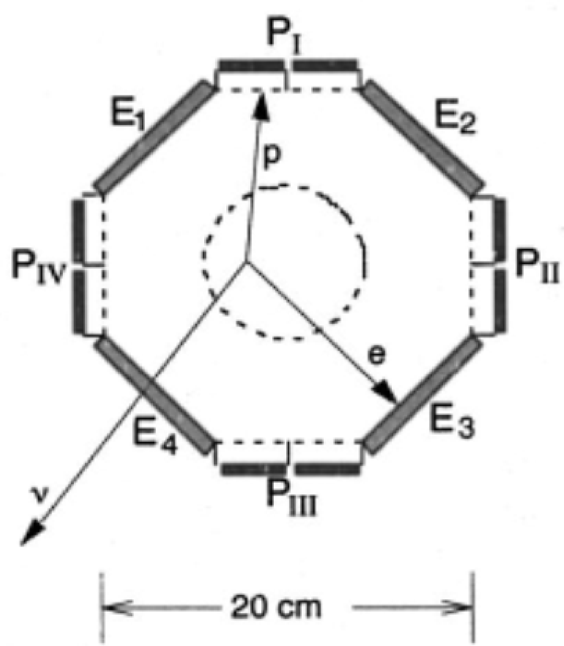


Timing spectrum for e-p coincidences. Each channel corresponds to 25 ns. The peak at channel 99-100 corresponds to the prompt (or zero) coincidences. The coincidences between the decay electrons and delayed recoil protons (e- p coincidences) are contained in the large peak centered at channel 120 (delay time is about 500 ns). This peak gives the number of double coincidences events $N_D=3.75\cdot10^5$ for BR measurement. Minor noise peaks before the peak of zero coincidences were not stable during statistics collection, disappearing at nighttime and on weekends, when the noise in the electric circuits was minimal.

Experimental double coincidences spectrum measured by emiT group at NIST (Phys. Rev. C, 2000, vol.62, p. 055501)

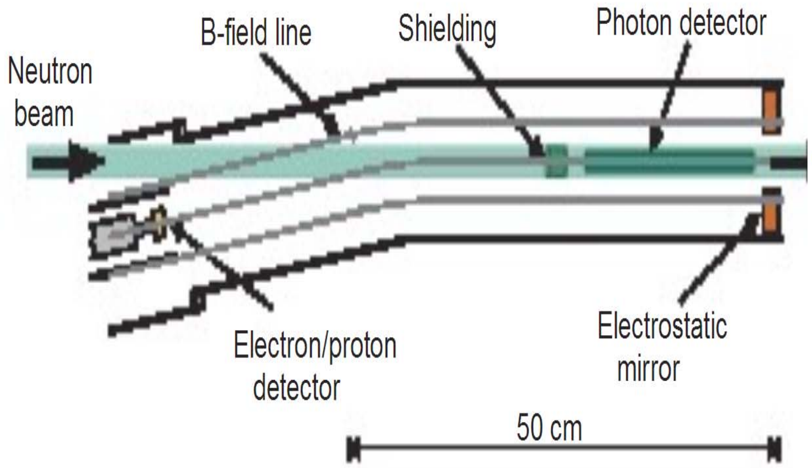


e-p coincidence spectrum with
two main peaks and ion background

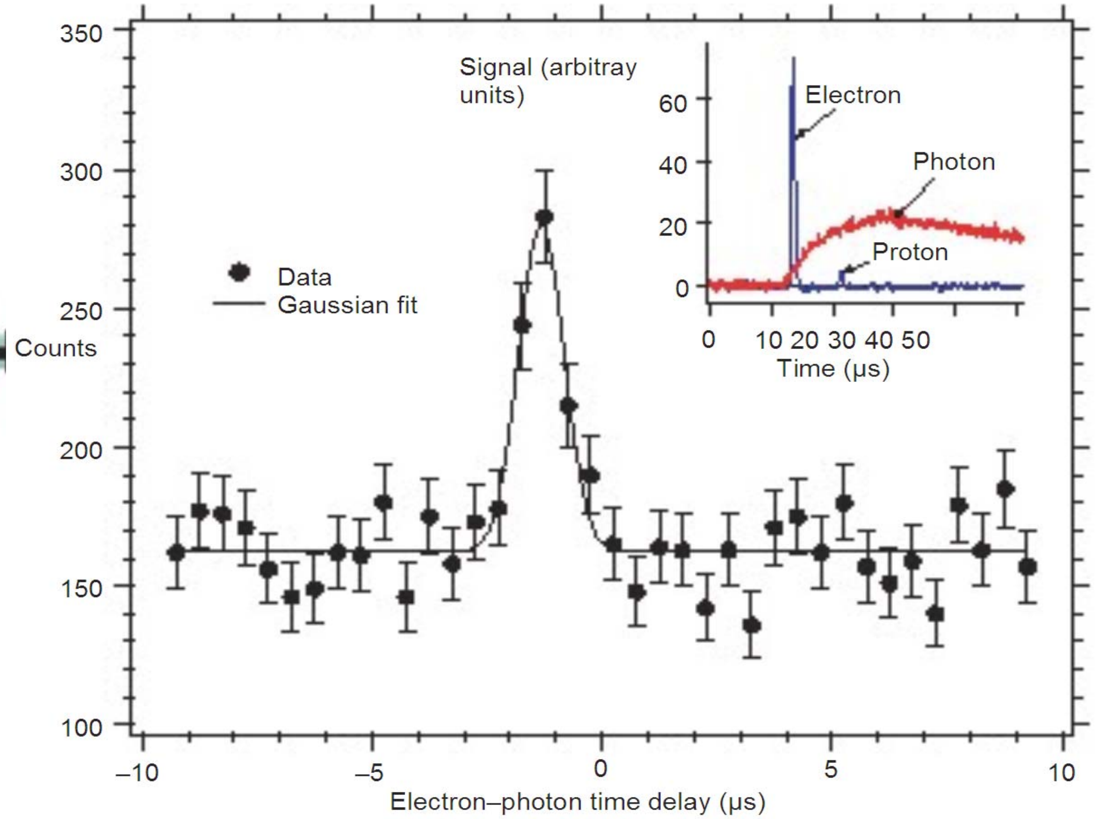


Schematic lay-out of
experimental setup

Experimental setup and double coincidences electron-gamma peak measured by J.S. Nico, M.S. Dewey and T.R. Gentile et al at NIST (Nature v. 444, p.1059 (2006))



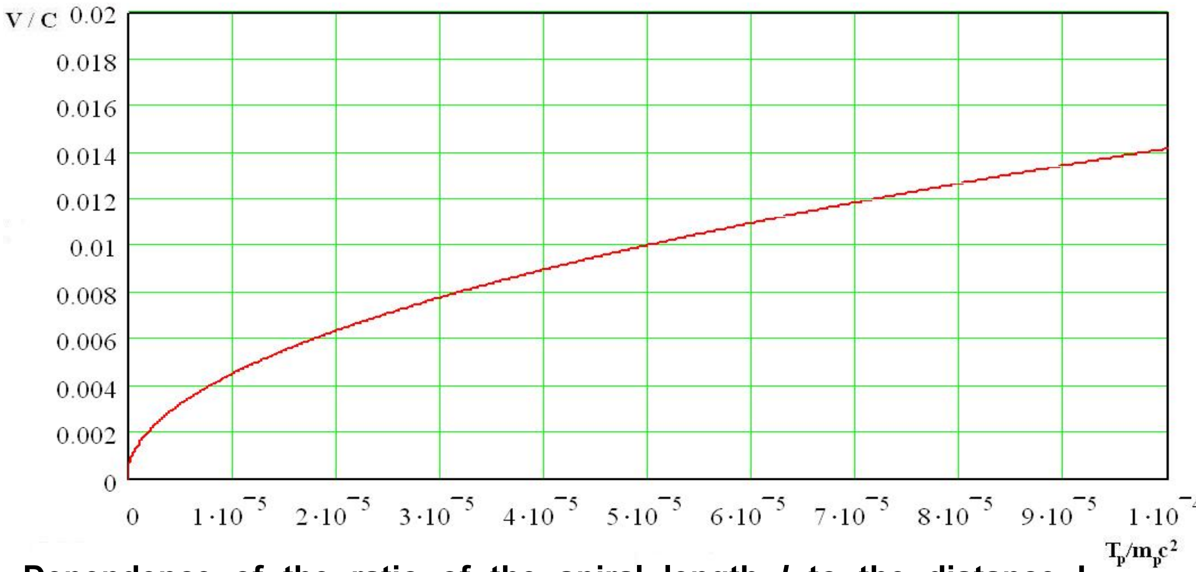
Detection scheme for measuring the radiative decay of the neutron. The cold neutron beam traversed the bore of a superconducting solenoid (4T). The decay zone is surrounded by photon detectors. The combined electron-proton detector was held at a high negative potential 22.5 kV to accelerate the low-energy recoil protons.

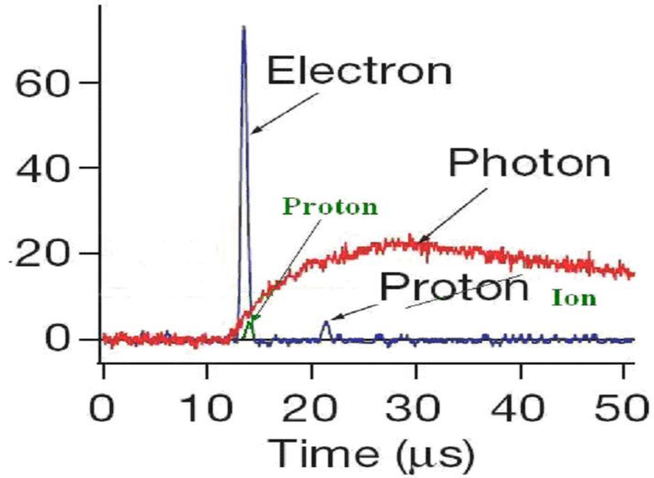


Electron–photon timing spectrum and forms of photon, electron and proton signals.

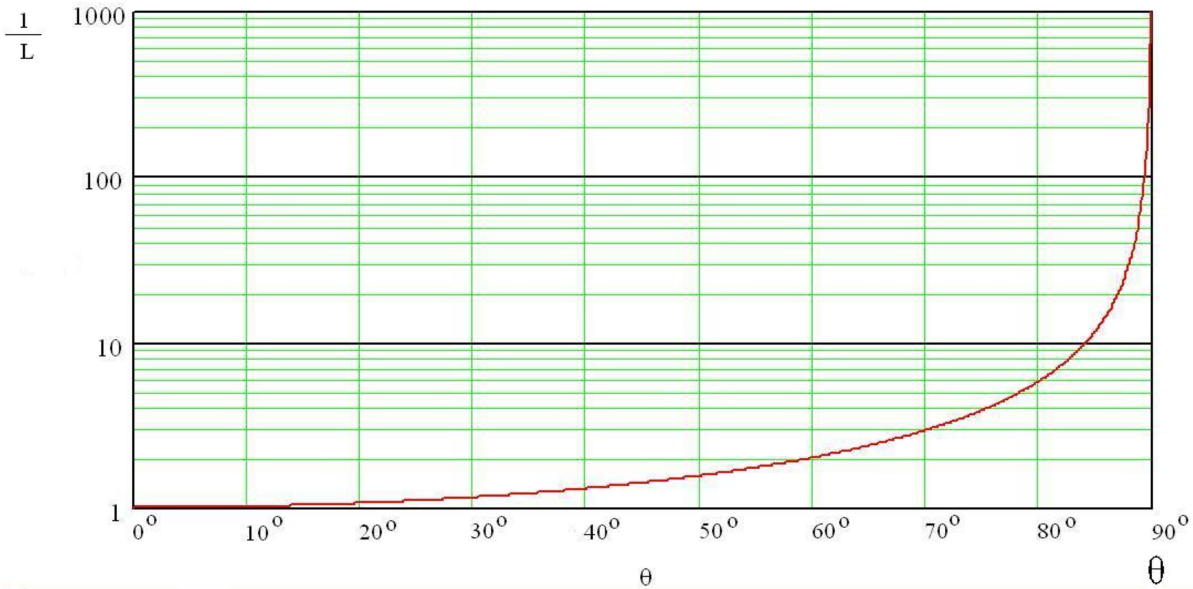
Figures for estimating the time of delay for recoil proton

Dependence of v/c for proton on ratio of its kinetic energy T_p to m_pc^2





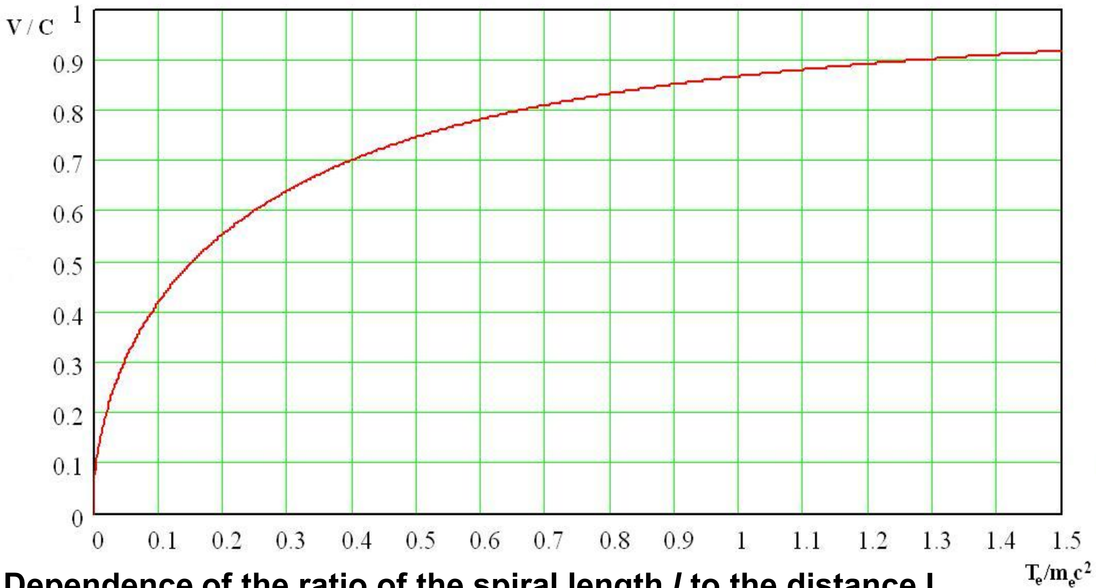
Dependence of the ratio of the spiral length *l* to the distance L between the point of decay and the detector on the angle θ between the velocity of this particle and the direction of the magnetic field.



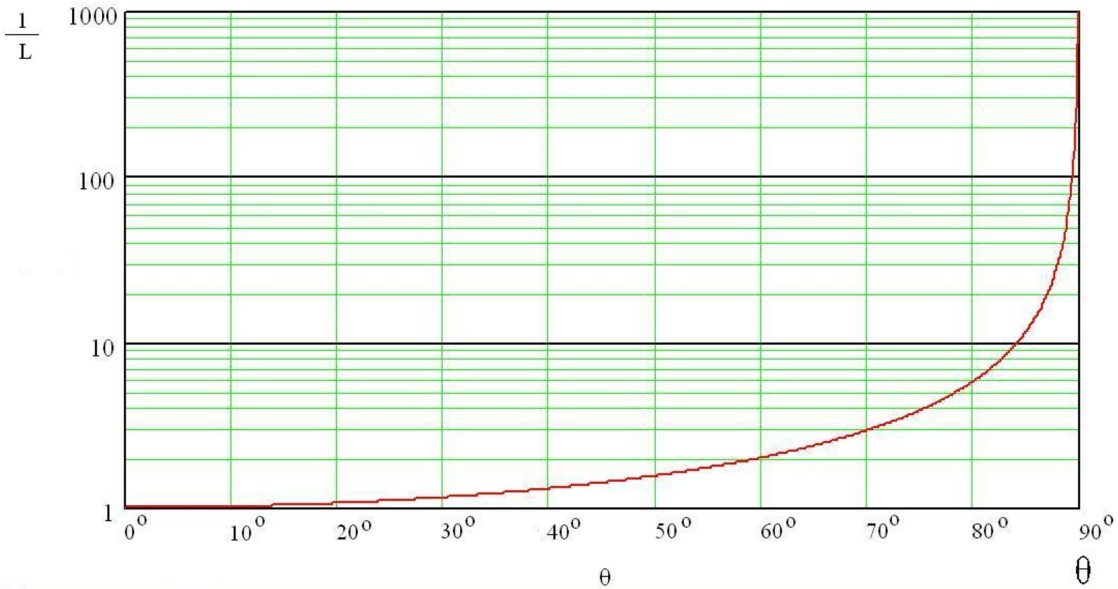
In beta decay, the protons have small initial energy (less than 750eV), therefore the angle θ is determined by angle between the electric and magnetic field lines which is definitely less than 30°. The magnetic field cannot increase the time of delay by several orders of magnitude. As it follows from graph *l*/L, the maximum delay would be increased not more than on 30%. The time of delay about several microseconds should be for background ions only (which also have maximal initial energy 750eV) and for protons the time of delay should be the same as in double coincidences spectra of our and emiT group. The small proton signal should be under the electron one and can not be registered by the combined electron-proton detector. The strong magnetic field can not be used for identification of ordinary beta decay events because it mixes small number of decay protons with large number of background ions and beta decay peak is disappeared on e-p spectrum.

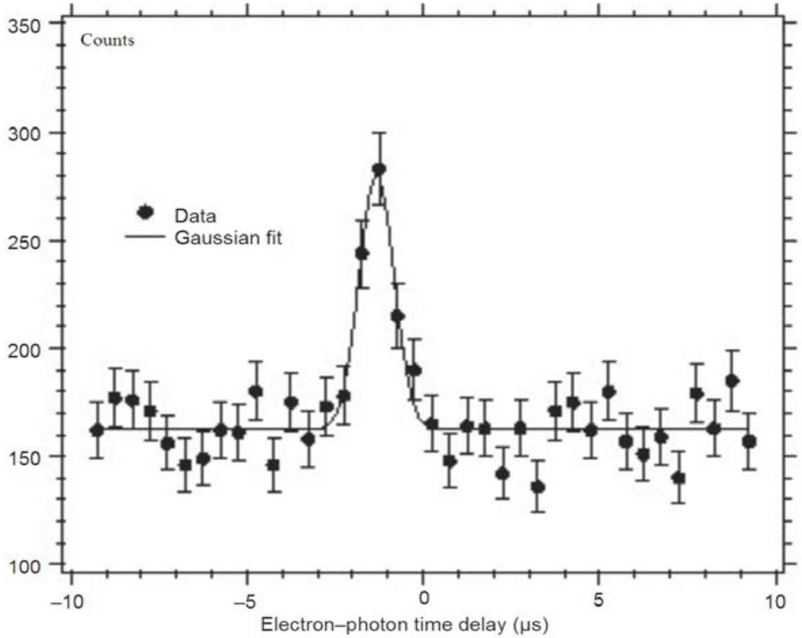
Figures for estimating the time of delay for beta electron

Dependence of v/c for electron on ratio of its kinetic energy T_e to m_ec^2



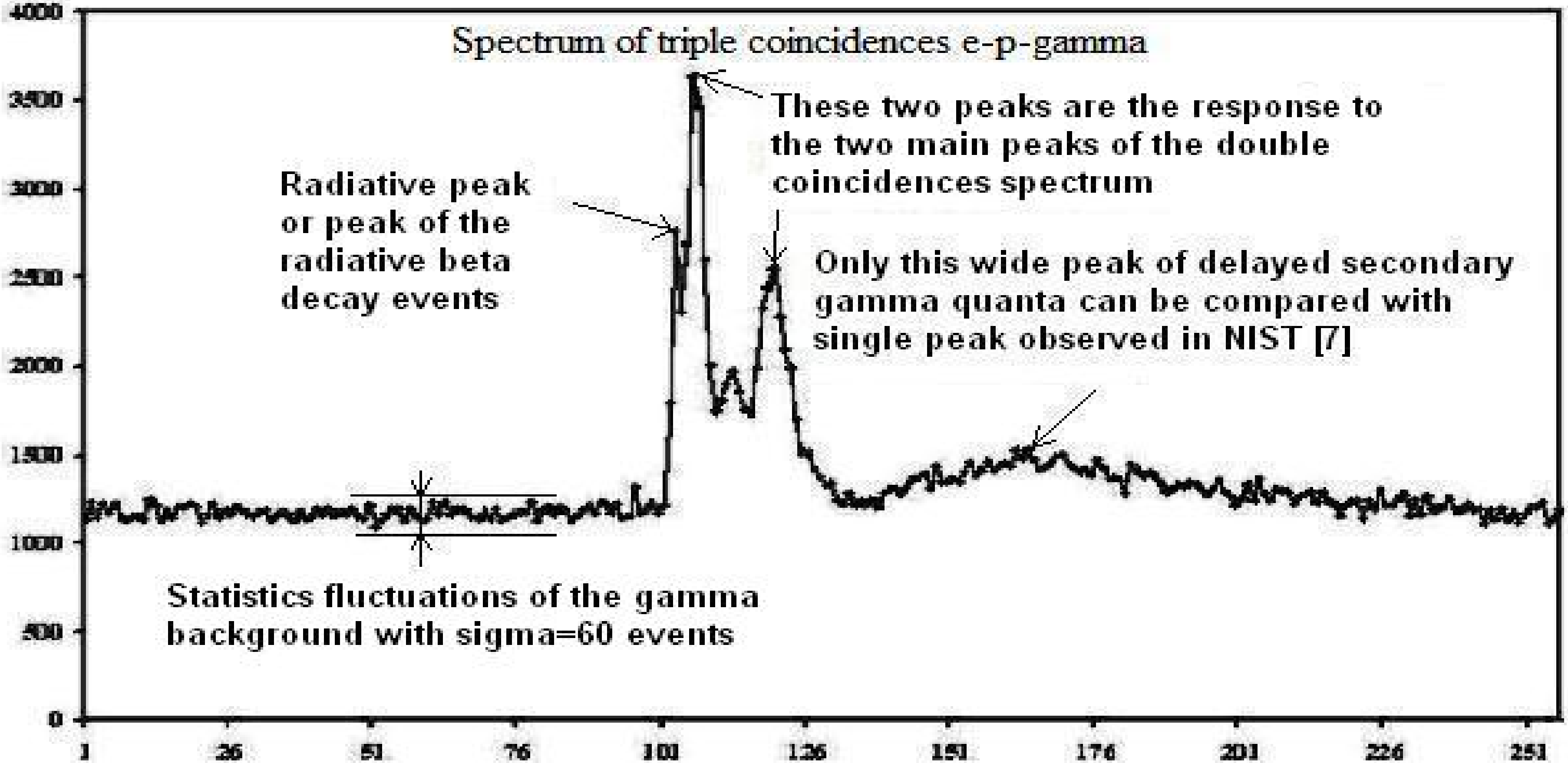
Dependence of the ratio of the spiral length *l* to the distance L between the point of decay and the detector on the angle θ between the velocity of this particle and the direction of the magnetic field.





In beta decay, electrons can fly out under any angle θ, therefore the magnetic field can increase the time of delay by several orders of magnitude only for a negligible portion of the charged particles. Even this negligible number of particles that flew out at an almost 90 degree angle to the direction of the magnetic field that coincides with the direction of the narrow neutron guide will most likely end up on the walls of the neutron guide rather than reach and hit the detector due to the presence of the strong electrostatic field. Because the distance between the point of decay and the detector is about 0.5 meter and electron velocity is comparable with speed of light the electron time of delay the electron time of delay should be less by two orders than microseconds.

Experimental triple coincidence spectrum e-p-γ (JETPh Letters, Jan., 2006, vol.83(1), p.5)



Timing spectrum for triple e-p-γ coincidences. In this spectrum, three main peaks in channels 103, 106 and 120 can be distinguished.The leftmost peak in 103 channel among these three main peaks is connected with the peak of radiative decay events. This peak gives the number of triple coincidences events N_T for BR measurement. This peak was always stable, it never "migrated" to a different channel and it grew at a stable rate, regularly collecting the same number of events during the same stretch of time. The final value of radiative events, namely the value of triple coincidences N_T, in our experiment with an error of 3σ was equal to N_T =360±180 events. After we obtained the number of beta-decay events forming the beta decay peak on the spectrum of double coincidences $N_D=3.75 \cdot 10^5$ and calculated the geometric factor of our experimental equipment k=3.3, we obtained the BR= k · N_T /N_D value of B.R. = (3.2+-1.6) 10^{-3} (with C.L.=99.7% and gamma quanta energy over 35 keV).

Next experiment on the radiative neutron decay and conclusions

- The main result of our experiment is the discovery of the radiative peak namely in the location and of the width that we expected. The location and the width of the radiative peak correspond to both estimates and the detailed Monte Carlo simulation of the experiment.
- Thus, we can identify the events of radiative neutron decay and measure its relative intensity, which was found to be equal B.R. = (3.2+-1.6) 10-3 (with C.L.=99.7% and gamma quanta energy over 35 keV).
- At the same time, the average experimental B.R. value exceeds the theoretical value by 1.5 times. However, due to a significant error we cannot use this result to assert that we observe a deviation from the standard model.
- Therefore, our most immediate goal is to increase experiment precision, which we can improve by several percents according to estimates.
- For last two years we were preparing this new experiment and conducted number of tests for our new electronics. We constructed multi channel generator what can generate the pulses with the same forms as our electron, proton and gamma detectors. During these tests we got the same responses as during our last experiment on real neutron beams at FRMII. It means that all additional peaks on our spectra have no any physics reasons and It proves once more that we were absolute correct when applied the response function method for explaining these peaks as response ones and for developing our experimental spectra.
- We created and tested our new electronic system for obtaining experimental spectra. By using this new programmable electronics we can significantly reduce the influence of response peaks on peak with radiative decay events. Now we can get this peak almost isolated from responses.
- On our estimations all these allow us to reach accuracy for our new experiment about 1%
- So, on the base of our new electronics we can confirm or refuse the deviation of our average experimental value of BR from the standard model one.
- As concerning the comparison of our experimental results with others we can make the following two main conclusions.
- The main parameters of our spectrum of double electron-proton coincidences identifying the events of ordinary neutron decay fully coincide with an analogous spectrum published by emiT group in Phys. Rev. C, 2000, vol.62, p. 055501
- Unfortunately we cannot say same for another experiment measuring the radiative neutron decay published in Nature v. 444, p.1059 (2006). Particularly vexing is the authors' unsubstantiated assertion that they observe their only wide peak of gamma quanta before the registration of beta-electrons. Both the position and the width of this peak are located in sharp contradiction to both the elementary estimates, and the results of our experiment. In the course of our entire experiment we did not observe such a wide peak in the triple coincidences spectrum, located before the arrival of electrons at a huge distance of 1.25 ms. However, it is possible to reconcile our spectra of triple coincidences with the one isolated peak observed at NIST if we assume that at NIST, the gamma-quanta were registered after the beta electrons. Only in this case does the NIST peak almost completely coincide with the peak we observed in the spectra of triple coincidences with the maximum in channel 163, both in terms of the huge delay of 1.25 ms and in terms of its huge width. This peak is created by the delayed secondary radioactive gamma-quanta, arising from the activation by beta electrons of the media inside experimental chamber, which was the real object of the NIST experimentalists' observation.