

Proposal to the ISOLDE and Neutron Time-of-flight experiments Committee (INTC):

Collection of Rb-83 at low implantation energy for KATRIN

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Introduction

KATRIN, the KARlsruhe TRItium Neutrino experiment aims to measure the neutrino mass by spectroscopy of the tritium beta decay at the endpoint by means of Magnetic Adiabatic Collimation combined with an Electrostatic filter (MAC-E filter)¹.

The shape of the tritium beta spectrum is given by (with $c=1$):

$$\frac{dn}{dE} = \text{const} \cdot F(2, E) p(E + m_e)(E_0 - E) \sqrt{(E_0 - E)^2 - m(\nu_e)^2}$$

Where: E, p are the momentum and the kinetic energy of the electron

$F(2, E)$ is the Fermi function for helium

E_0 is the endpoint energy (Q-value)

$m(\nu_e)$ is the electron antineutrino mass

Only close to the end point a signature of the massive neutrino can be observed. This is illustrated in fig. 1 where simulated spectra are shown to illustrate that even a slight uncertainty in the energy scale would contest the success of KATRIN. To achieve the anticipated sensitivity of 200 meV (90% C.L.) it is mandatory to stabilize the filter potential of 18.6 kV within ± 60 mV for at least 2 months – an expected KATRIN run. Additionally to conventional HV-measurement (high precision HV divider and voltmeter) this shall be accomplished with the help of a nuclear electron standard measured in the KATRIN main beam line at regular intervals and in a separate monitor beam line continuously. An appropriate isotope appears to be $^{83\text{m}}\text{Kr}$, a short lived daughter ($T_{1/2} \approx 2$ h) of ^{83}Rb ($T_{1/2} \approx 86$ d). The 32.2 keV isomeric transition in $^{83\text{m}}\text{Kr}$ is highly converted, so that mono energetic conversion electrons are emitted. For monitoring of the filter potential mainly the electrons resulting from K-conversion (K-32) are important which have an energy of 17.824 keV. This is close enough to the tritium endpoint of 18.575 keV.

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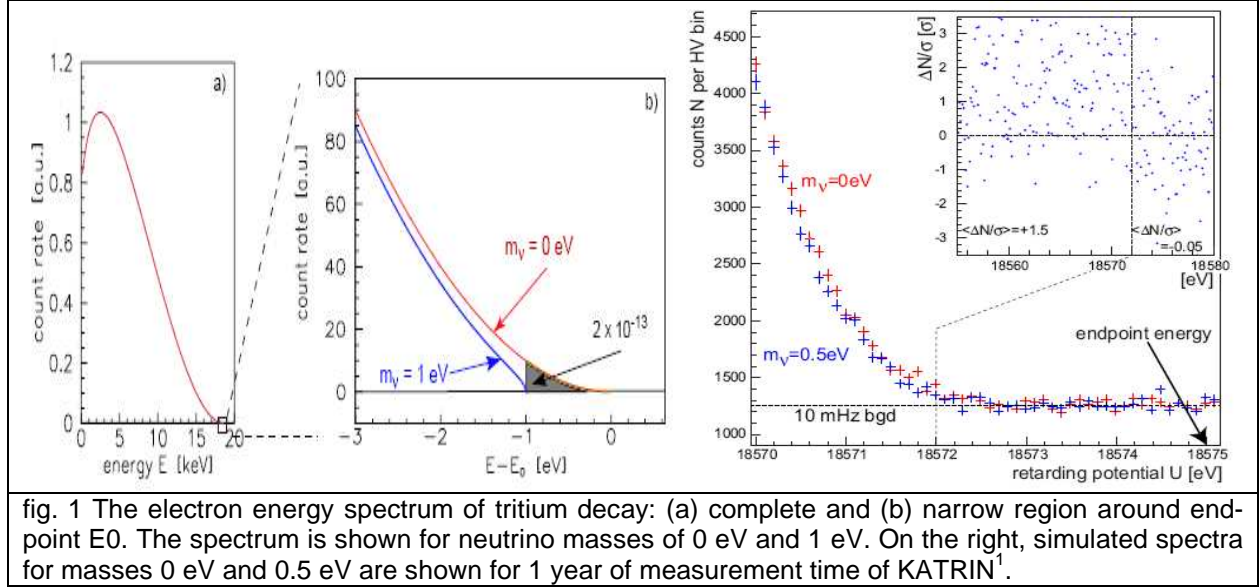
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It is also very important, that the natural line width is only 2.7 eV. A HV-monitoring scheme for KATRIN will look as follows: the filter potential of both the monitor and main spectrometer will be common. Any change of the energy of K-32 electrons measured at the monitor spectrometer will indicate a possible shift of the common retarding voltage reading.



For KATRIN a sophisticated system has been developed, where krypton gas emanating from a rubidium source is condensed on a clean cold HOPG substrate (25-30 K)². Electron spectra obtained from sources produced this way are reproducible and stable, but the substrate needs to be regenerated in at least weekly intervals. Thus the system is not easy to operate and continuous monitoring is not possible. Solid sources have the advantage of no need for regeneration and should overcome this drawback of condensed sources.

An option for a solid source is the generator type where the isotope ^{83}Rb is embedded and the noble gas krypton is retained sufficiently, but the conversion electrons (at least a significant fraction) get out with no energy loss. The source should also have a chemically inert and robust surface. Especially the work function for electron emission should not change in time.

The technology of production of various radioactive rubidium isotopes by irradiation of krypton gas targets is quite evolved. For the first feasibility studies solid rubidium sources were made by vacuum evaporation of sub-monolayers of ^{83}Rb onto various substrates³. The long term stability and the robustness of sources produced this way are not sufficient for our needs. Ion implanted sources should overcome these problems.

Preliminary results

Four explorative implantations at ISOLDE into platinum and gold foils at implantation energies of 30 keV and 15 keV on the basis of our letter of intend⁴ were already performed. Since stable and efficient ISOLDE operation below 30 keV is not feasible, a retardation setup for the 15 keV sample was used. The setup sketched in fig. 2 was also tested down to an energy of 0.5 keV at KIT. Long term measurements with implanted sources were accomplished at the Mainz MAC-E filter spectrometer.

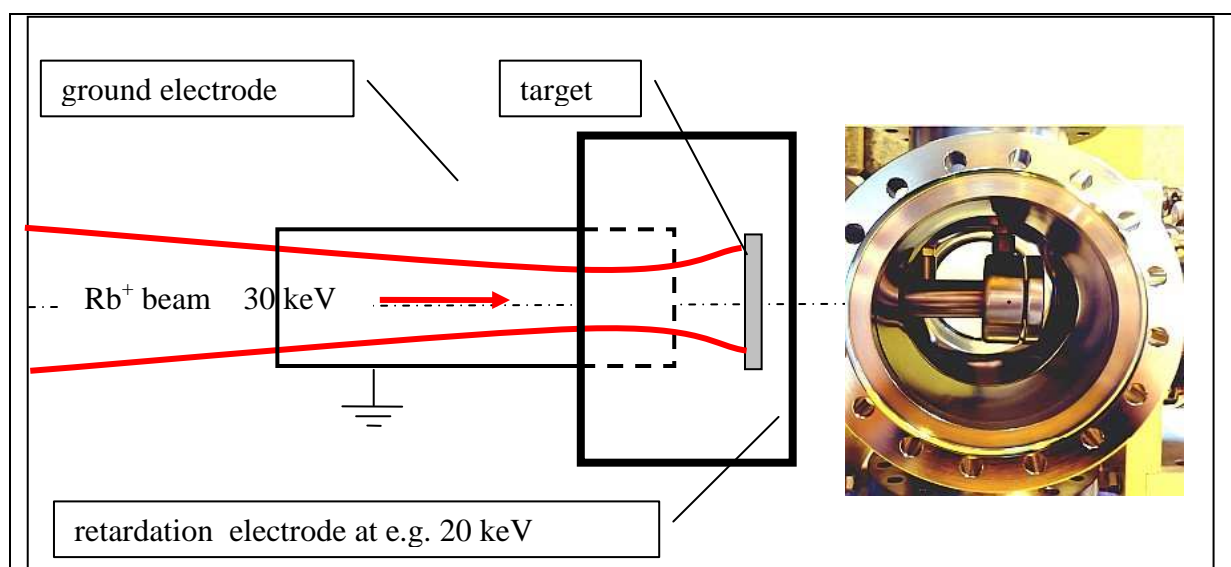


fig. 2: Sketch of the retarding electrodes (left). The incident ions are guided by the ground electrode into the catcher with target at high voltage so that the deceleration takes place only just before the impact. Therefore the spreading of the beam stays within acceptable limits. A photo of the electrodes is shown also on the right.

As expected, the number of so called “loss” electrons is smaller with decreasing implantation energy, as can be seen from fig. 3. Even the sample implanted at 15 keV retained close to 100% of the Kr so that lower implantation energies should be tested to increase the amount of useful “no-loss” electrons.

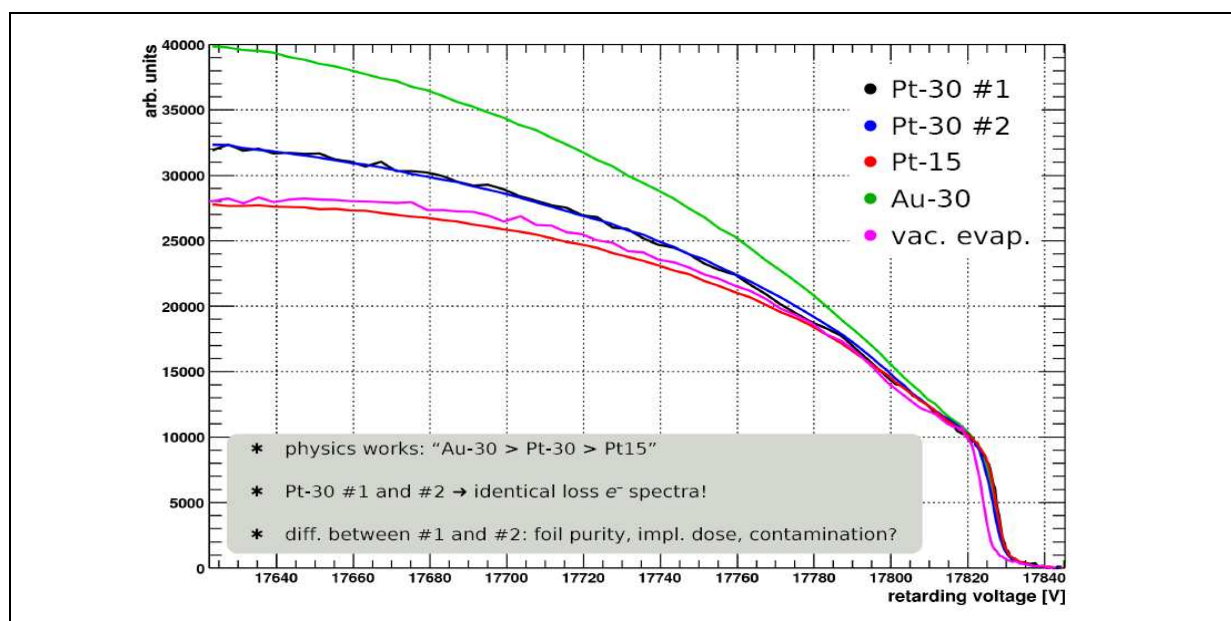


fig. 3: MAC-E filter integral spectra of the K-32 conversion electrons from $^{83\text{m}}\text{Kr}$ taken with a moderate resolution of 2 eV. In addition to the four samples produced at ISOLDE a spectrum of a source produced by vacuum evaporation of ^{83}Rb is also included. If all the electrons would leave the source without energy loss, the spectrum should become more flat at energies below 17.81 keV, but here we observe also electrons with reduced energy.

The precise position of the electron lines from sample to sample is not reproducible. Variations of up to one Volt were observed for all investigated lines. Also a complex line shape different from a Lorentzian curve folded with the spectrometer response function, was ob-

served. Only by introducing an additional Gaussian smearing (Voigt profile) and allowing for a doublet splitting, satisfactory fits were possible. The doublet structure is most easily visible, when the conversion takes place in the outer most N-shell. (see Fig. 4 for details). Also in Moessbauer-spectroscopy of ^{83}Rb implanted into Au some additional broadening was observed, especially after annealing⁵. In contrast to the more indirect hyperfine interaction method, we observe the influence of the environment on the electron binding energies. Since we used much lower implantation energies compared to the Moessbauer studies, we probably observe a mixture of surface and solid state effects.

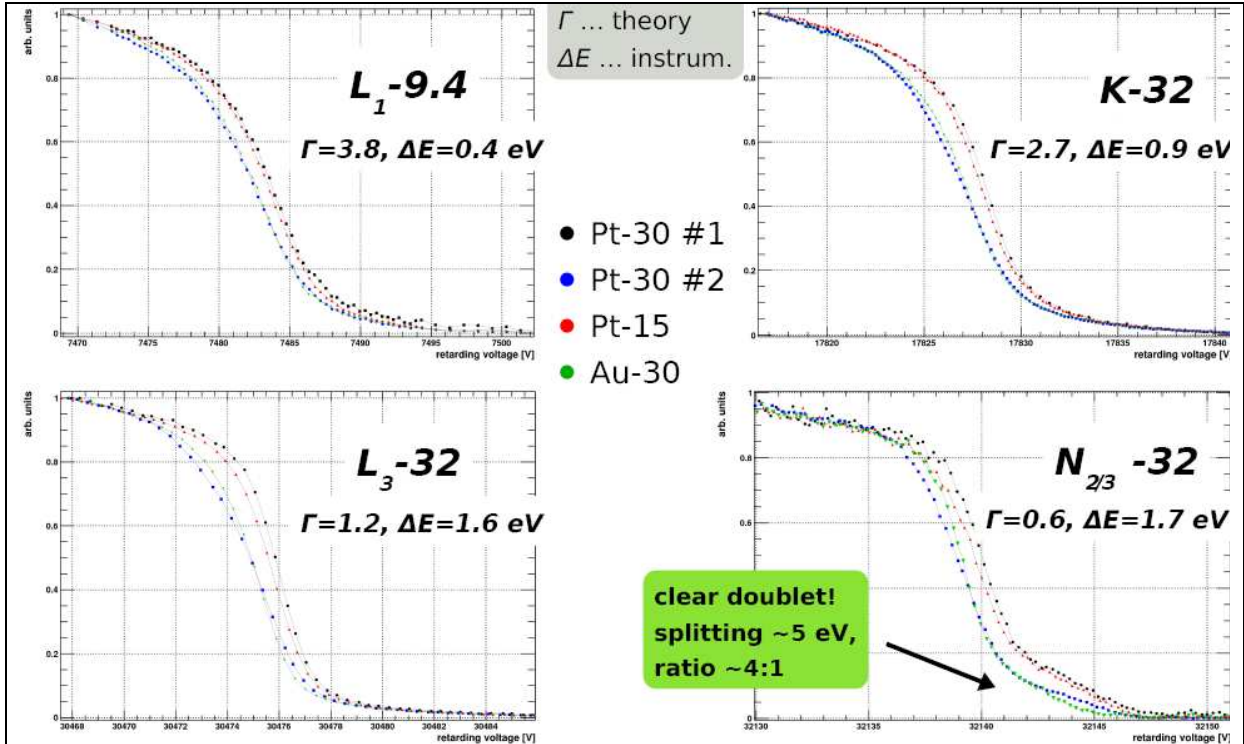


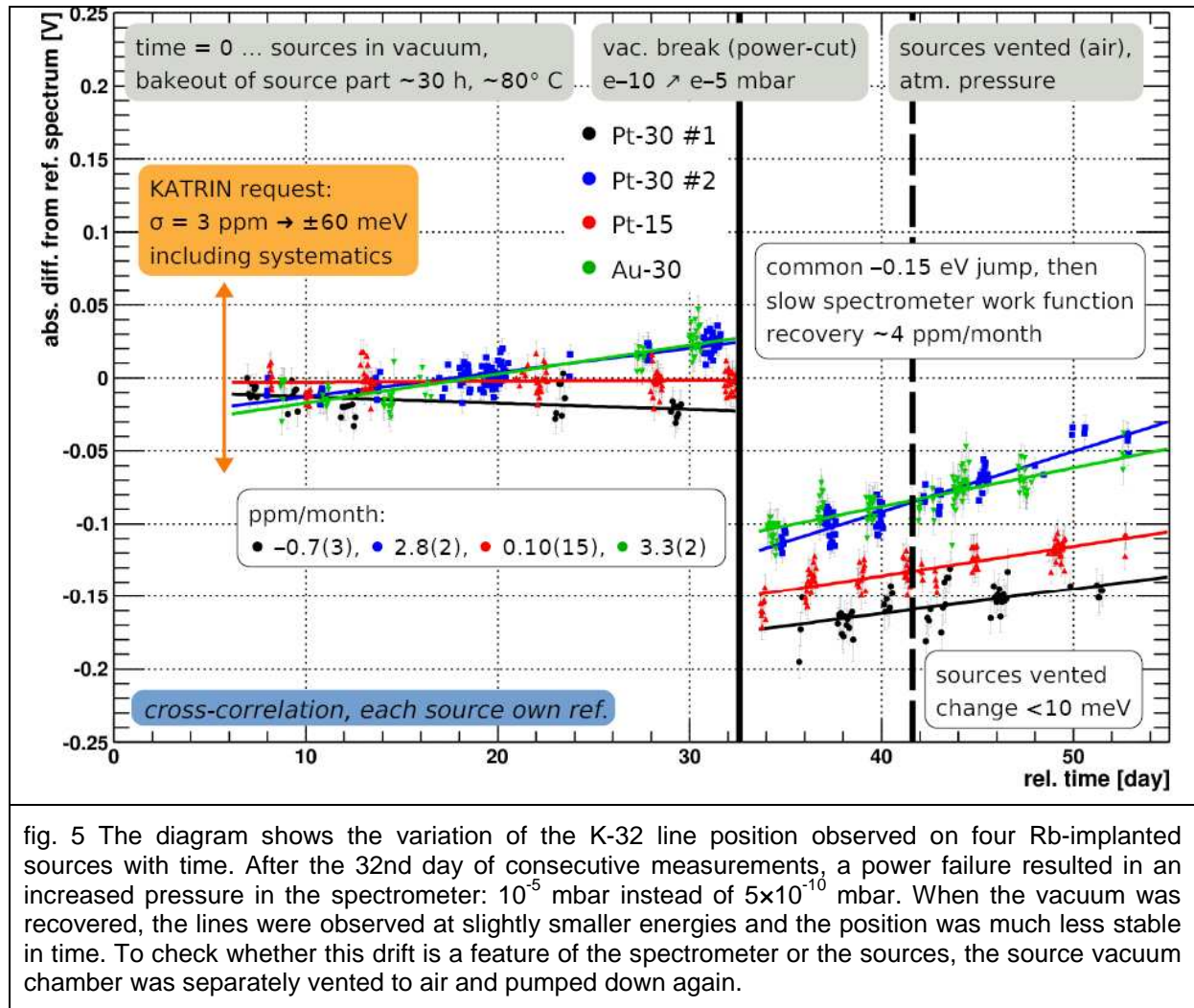
Fig. 4: Spectra of various conversion electron lines of implanted sources. For comparison, the count rates were normalized with respect to each other. Γ is the natural line width and ΔE is the instrumental resolution. It can be seen from the diagrams that both, the line position and its shape vary from source to source. When the outer most atomic N-shell is involved, a splitting of about 5 eV, much larger than the difference in binding energies of N_2 and N_3 , is observed.

To test whether the implanted samples are useful for monitoring we have measured spectra of K-32 line of all implanted sources for many days (the sources were mounted together on a moveable holder which enabled us to set each source into the measuring position within several minutes). To account for the complex line shape, we established for each source one of the measured spectra as reference. In the subsequent fits of a given spectrum only intensity, background and line position shift relative to reference were allowed as free parameters.

The K-32 line position of all the samples produced at ISOLDE proved to be stable within the specifications of KATRIN (3 ppm) over a period of a month. One source, namely the Au sample showed a critical trend. (see fig. 5) The jump in line positions after day 32 is caused by a failure of the vacuum system due to a power cut in the building. It is assumed, that the increased pressure changed the work function of the spectrometer. We tested also, that all the sources themselves are very robust against exposure to air as for the electron line positions.

Conclusions drawn from our explorative studies

- HOPG (highly oriented pyrolytic graphite) as a low Z substrate should be tested.
- The effect of the sample annealing on line position drift should be investigated .
- Lower implantation energies should be tested.
- The vacuum system of the spectrometer will be improved, so that vacuum breakdowns are prevented.
- The out baking hardware must be upgraded for its more frequent use



Status of monitor spectrometer

The MAC-E filter in Mainz has been dismantled and moved to KIT in order to serve as the KATRIN monitoring spectrometer. The reassembling will also include some improvements and modernizations. Installation is expected to last a couple of months, so with spring time the first measurements can be started. In fig. 6 the spectrometer is shown, just before the tank was closed again at KIT

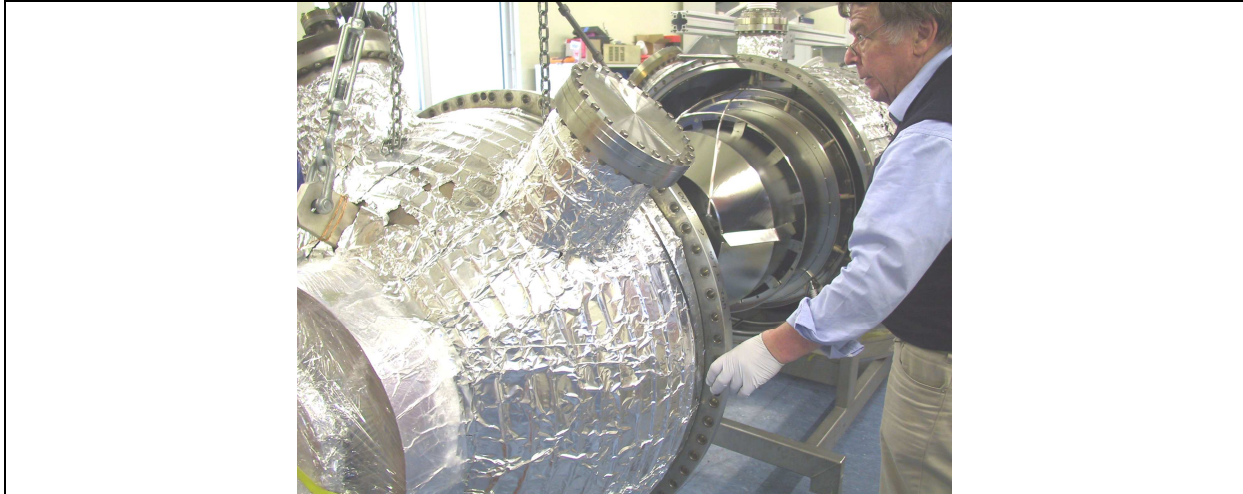


fig. 6: Installation of the monitoring spectrometer at KIT.

Beam time requirements

To monitor the HV-system of the KATRIN-setup, we would need one or two ^{83}Rb sources roughly every half a year. Depending on the producible activity an annual replacement of the source might be sufficient also. For the initial test phase, the first ISOLDE run in 2010 should give us three samples of about 3 MBq each. Up to three sources could be produced within a shift, if the yield is above $3 \cdot 10^9$ ions of ^{83}Rb per second.

Beam time requirements	Two shifts per year, one in spring and one in autumn
Ion Source	surface ionization at 30 keV
Suitable Targets	Uraniumcarbide, Niobium (powder), Zirkonium (metal foil) or Thoriumcarbide

References:

- ¹ KATRIN Design Report 2004, Report NPI ASCR Řež, EXP-01/2005, FZKA Scientific Report 7090, Karlsruhe Institute of Technology (KIT). MS-KP-0501
- ² B. Ostrick, PhD thesis, University of Münster, 2008
- ³ D. Véros, M. Zbořil, J. Kašpar, O. Dragoun, J. Bonn, A. Kovalík, O. Lebeda, N.A. Lebedev, M. Ryšavý, K. Schloesser, A. Špalek, Ch. Weinheimer, Izmeritelnaya Technika, 2010, in press.
- ⁴ CERN-INTC-2009-001/I-080
- ⁵ G.J. Kemerink, S. Bukshpan and H. de Waard, Hyperfine Interactions 7(1979)339-351