The double focalizing magnetic spectrometer at EPFL

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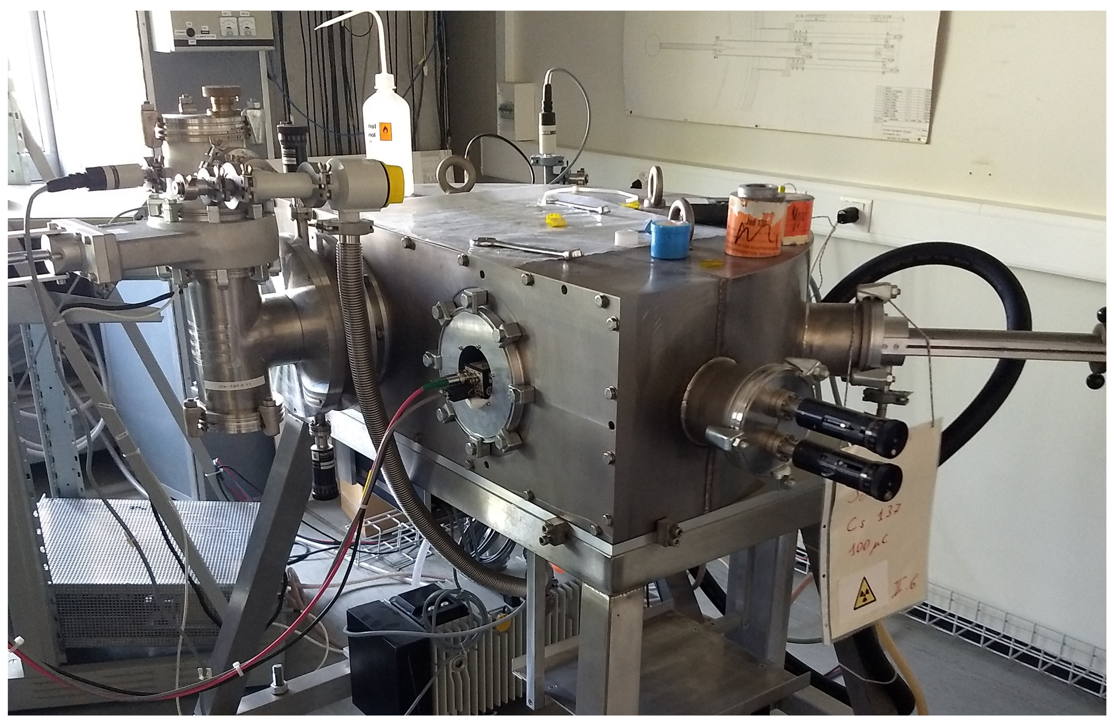
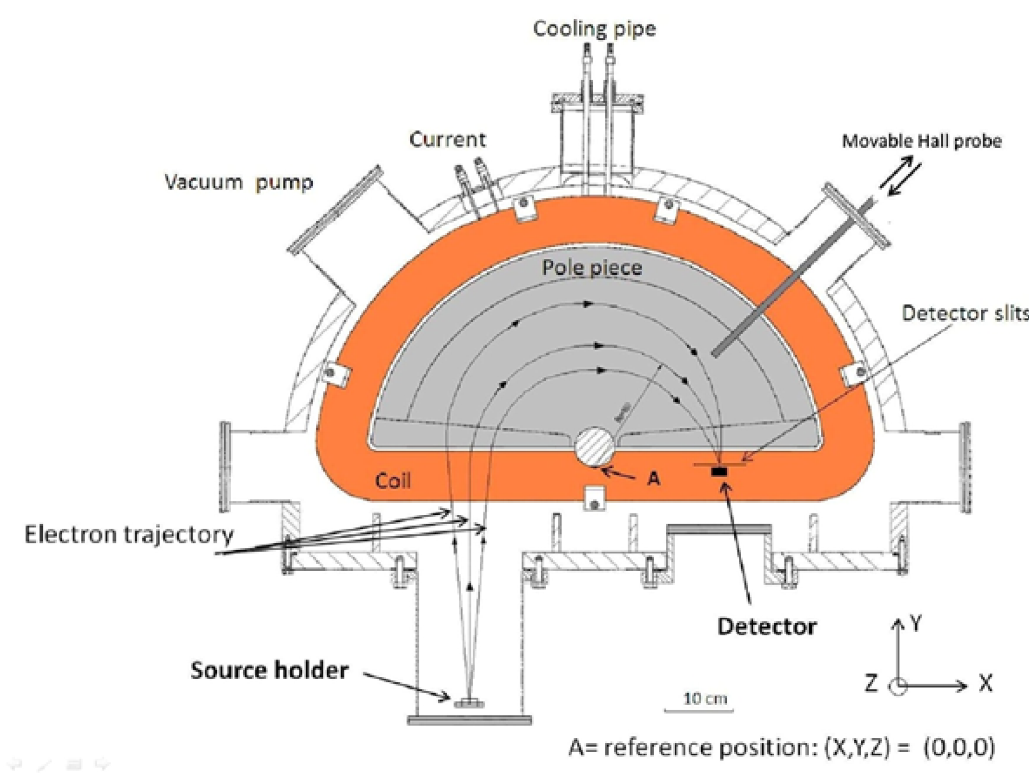
Introduction

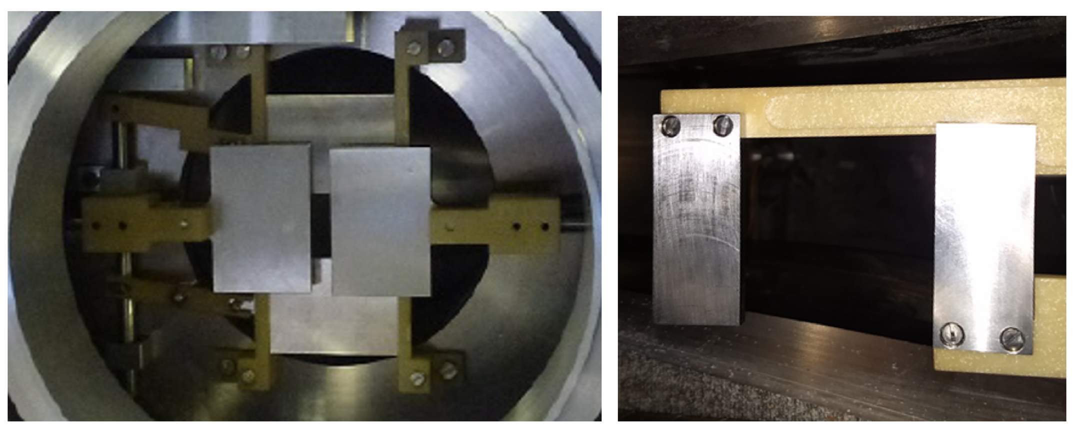


- The double focalizing spectrometer at EPFL [1,2] is a small, hemispherical magnet used for the investigation of the emission spectra of charged particles from radioactive sources.
- The device is principally used for the study of electrons and positrons emitted as a result of beta decay (electron and positron) and electron conversion.

Technical description



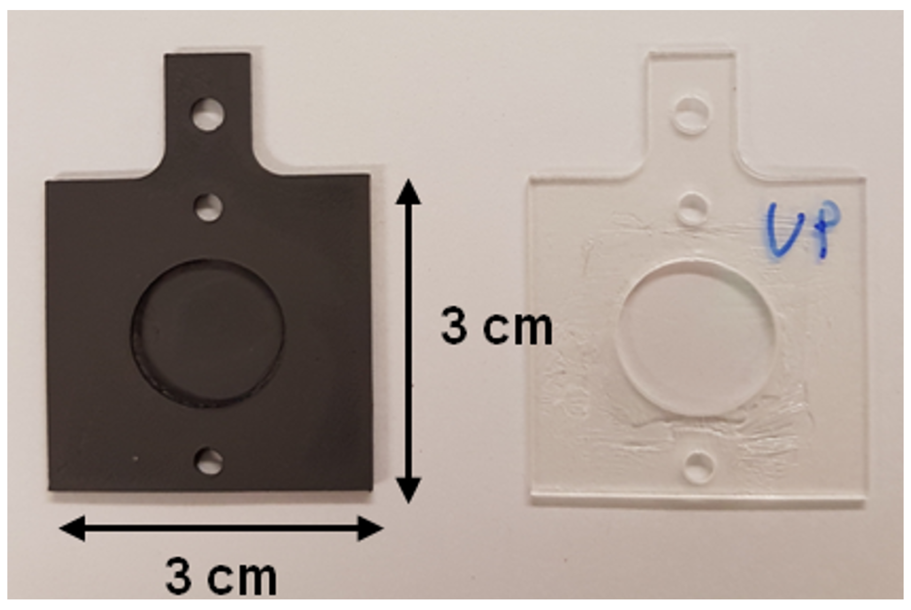
- The device has been laid out with a source holder on the left side, spaced 30 cm from the entrance of the magnetic field.
- The emitted particles are deflected by the magnetic field with a reference radius of 18 cm and are detected by a thin silicon detector with a diameter of 1 cm, operated at 40V, placed in the focal point of the magnetic field.
- All active components are mounted in a vacuum vessel to avoid scattering and energy loss in air.
- To further improve the energy resolution, collimators have been included in the design, allowing for horizontal and vertical collimation at the source and horizontal collimation near the detector.



- The current set in the magnet coils generates the magnetic field, focusing only particles in a narrow momentum range to the detector. The B-field and selected momentum scale linearly (Lorentz force).
- Charged particles deposit their energy in the detector, for particles of reasonably low kinetic energy (below 1 MeV) all or a substantial fraction deposit their full energy in the detector.
- The signals pass through two stages of amplification and are digitized by a National Instruments PCI-6115 DAQ card with LabView.

Sources

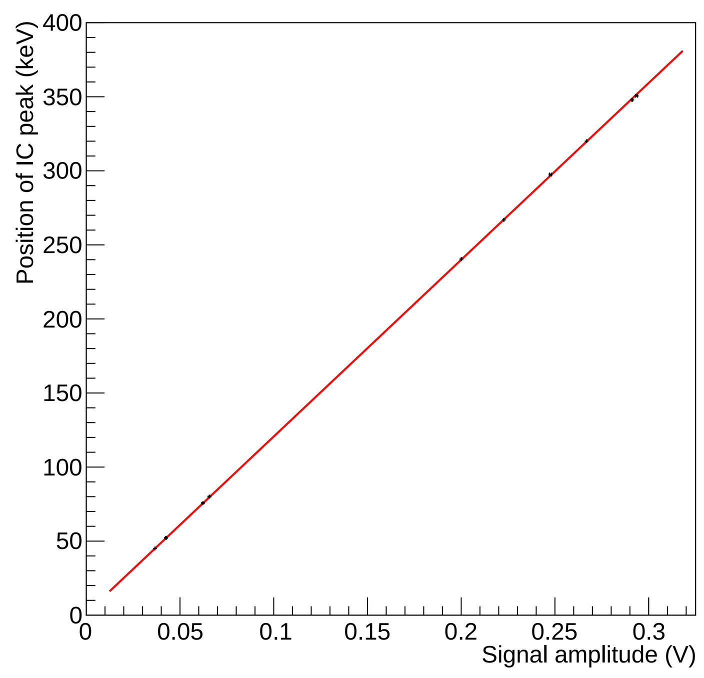
- Sources for the device are specially prepared. A 0.5 μm Mylar foil is glued on a plexiglas support, and coated with graphite. This allows it to remove charge buildup through the long steel rod it will be mounted on. A drop containing the radioactive solution is deposited in the center of the foil and dried.
- Two groups of sources are used. The first emits electrons of discrete energy, so-called conversion electrons, for transitions where photon emission is forbidden or hindered by angular momentum selection rules. These are used for calibration of the device. The second group undergoes beta decay leading to a continous electron energy spectrum.



- The sources available from the first group include e.g. Cd-109, Ba-133, Bi-207. The second group includes e.g. Na-22, Co-60, Sr-90/Y-90, Tl-204. Cs-137 belongs to both groups since Cs-137 emits a beta spectrum while the populated isomeric level in the Ba-137 daughter nucleus decays subsequently by emission of conversion electrons .
- Recently a source of Tm-171 was made available, for which the spectrum has not yet been experimentally established in literature.

Energy calibration

- Calibration of the device was performed using a long measurement of a Ba-133 source. Scanning the magnet in steps of current and recording the amplitude spectrum for each step allows for the isolation of individual peaks, which then give a direct detector calibration.



- The red line indicates a linear fit to the data. When comparing the found amplitude values input into the fit, all energy peaks are located within ±1 keV kinetic energy in the range shown.

References

[1] F. Juget et al., Appl. Radiat. Isot., **87** (2014), pp. 310-314.
[2] F. Juget et al., NIM A **942** 162384 (2019).
[3] IAEA, LiveChart of Nuclides, accessed: 29-04-2022, https://www-nds.iaea.org/
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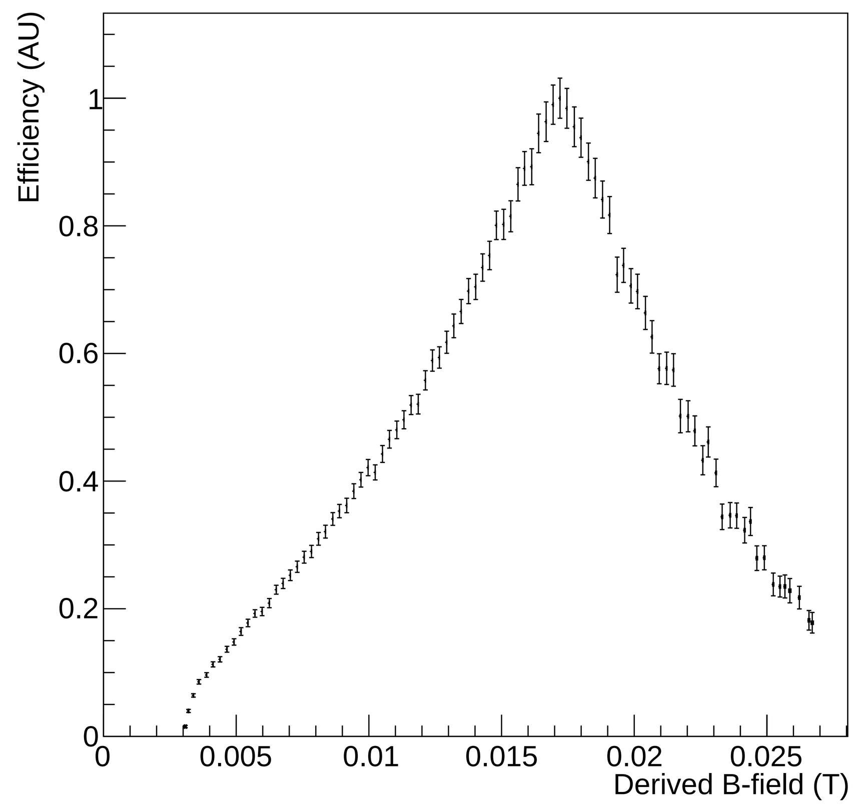
Efficiency calculation

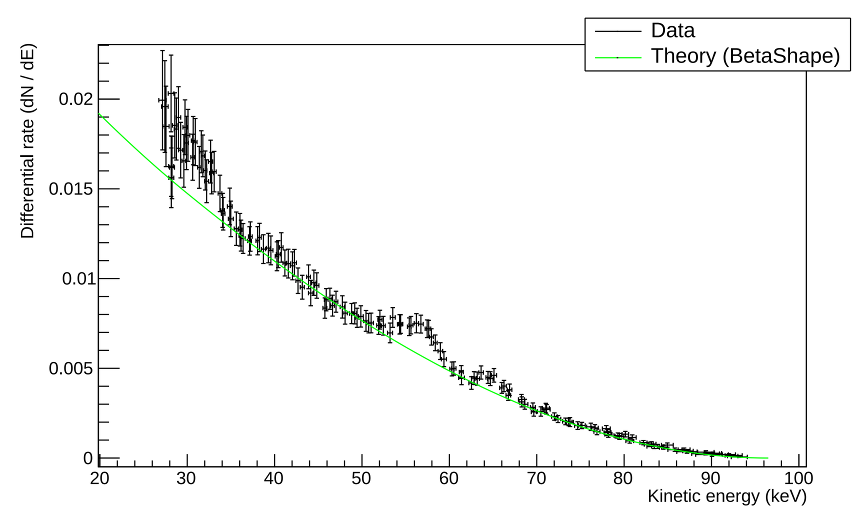
- The B-field is measured for each current step using the full energy deposition peak. With the calibration of energy to amplitude known, the efficiency of the device is derived using a Sr-90/Y-90 source for which the kinetic energy spectrum is well known (calculated using BetaShape [4]).

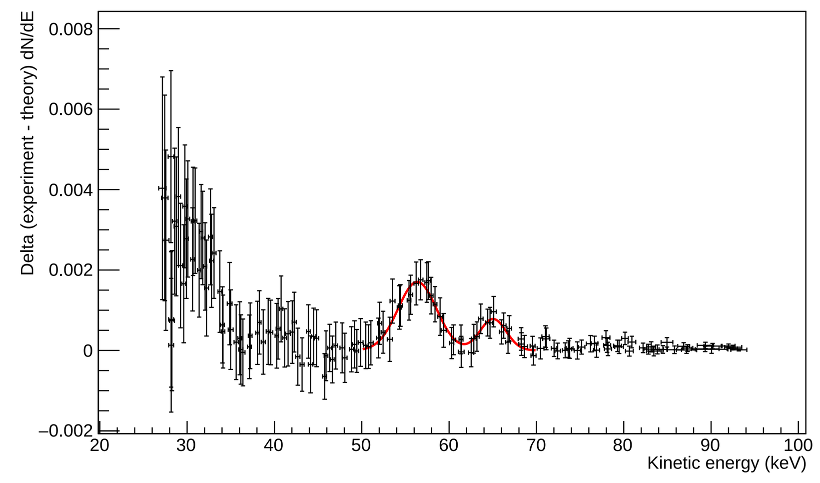


- The background is subtracted by taking a separate run without a source, and subtracting the resulting amplitude spectrum from the measurement to be analysed. At low energies (below 30 keV of so) the detector efficiency drops because the signal merges into the detector noise. Then, for some distance the efficiency increases close to linearly, as the selected (fractional) energy window increases linearly with the B-field. The efficiency finally starts dropping when particles punch through the detector and don't always deposit their full energy.

Tm-171 measurement

- Using all of the above calibrations, a measurement was made of the kinetic energy spectrum of electrons emitted by a 50 kBq Tm-171 source prepared at PSI. Tm-171 had been produced by irradiation of enriched Er-170 in the V4 high-flux position of the ILL reactor in Grenoble. The produced short-lived Er-171 decays to Tm-171 that was radiochemically separated at PSI, leading to non-carrier-added Tm-171 [5].
- The expected continuous beta curve was calculated with BetaShape, and is shown here together with the data. The difference between the two is also calculated, clearly showing two (expected) internal conversion peaks.





- A fit to the two internal conversion peaks gives 56.4±0.3 keV and 65.1±0.4 keV, comparing favourably to the expected values of 56.2-57.8 keV and 64.3-65.2 keV.