TUM E15

SFB/TR 27

Project A05, Poster 1

Development of Cryogenic Detectors for Low-Energy Neutrino Physics

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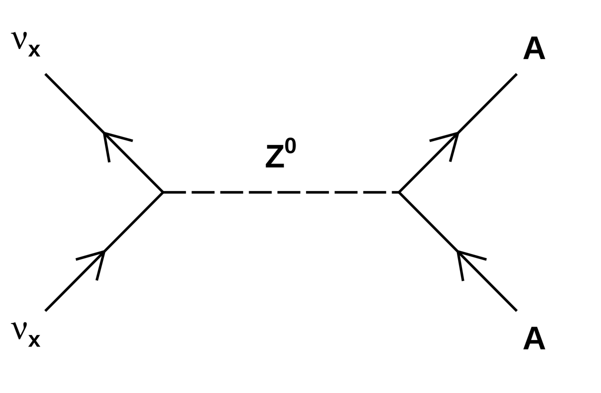
Coherent Neutrino Nucleus Scattering (CNNS)



Feynman diagramm for CNNS

- Neutral current process ⇒ CNNS independent of ν-flavor
- For low transferred momenta: wavelength of Z^0 comparable to radius of nuclei

⇒ ν scatters coherently off all nucleons

→ $\frac{d\sigma}{dE_{rec}} = \frac{G_F^2}{8\pi}\left[Z\left(4\sin^2\theta_W - 1\right) + N\right]^2 M \left(2 - \frac{E_{rec}M}{E_\nu^2}\right)$

⇒ $\sigma_{tot} \approx \frac{G_F^2}{4\pi} N^2 E_\nu^2 = 4.2\cdot 10^{-45} N^2 \left(\frac{E_\nu}{1\,\text{MeV}}\right)^2$ cm^2

→ *G_F: Fermi constant, Z: proton number, N: neutron number, θ_W: Weinberg angle, M: mass of target nucleus, E_{rec}: recoil energy, E_ν: neutrino energy*

Use of cryogenic detectors

- CNNS cross section $\sigma_{tot} \gtrsim 10^{-44}$ cm^2

⇒ High neutrino flux

→ Reactor neutrinos ($\Phi \sim 10^{13}\frac{1}{\text{cm}^2\text{s}}$)

Requirements for the first observation of CNNS:

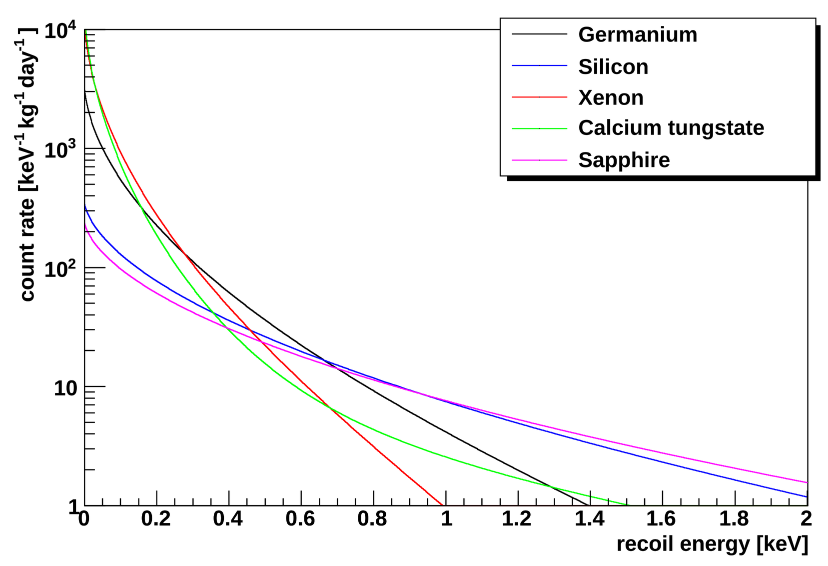
- small recoil energies (a few keV)

⇒ small energy threshold $\lesssim 0.5$ keV

- small count rate ($\sim 10-100$ per day and kg)

⇒ large target mass of ~ 1 kg

⇒ **Use of cryogenic detectors for first observation of CNNS**



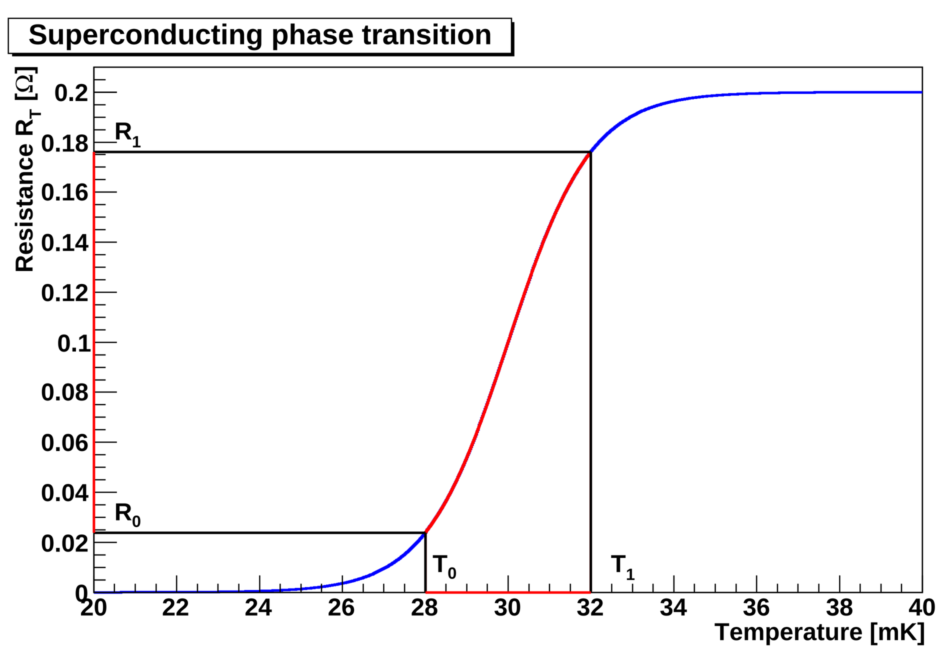
Recoil spectra of reactor neutrinos for different target materials

Detector development

Working principle of cryogenic detectors

- Deposited energy is converted into phonons
- Phonons enter Transition Edge Sensor (TES, superconducting thin film) and thermalize there

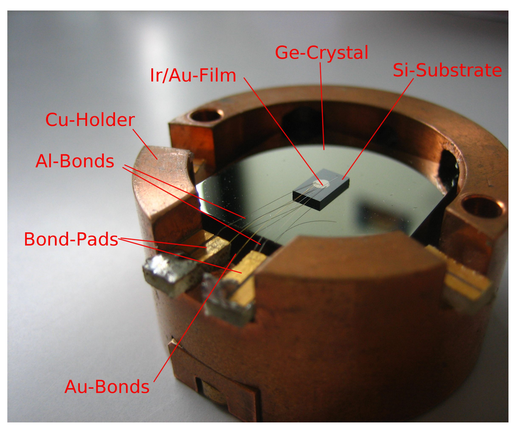
⇒ Temperature rise of the TES leads to resistance rise of the superconducting film



0.8 g germanium absorber

(A. Gütlein, et al., J. Low. Temp. Phys. **151** (2008) 629)

- Absorber: germanium substrate (20×20×0.5 mm^3)
- Silicon substrate (5×3×0.5 mm^3) with deposited Ir/Au-TES (⌀=2mm) is glued onto absorber substrate.



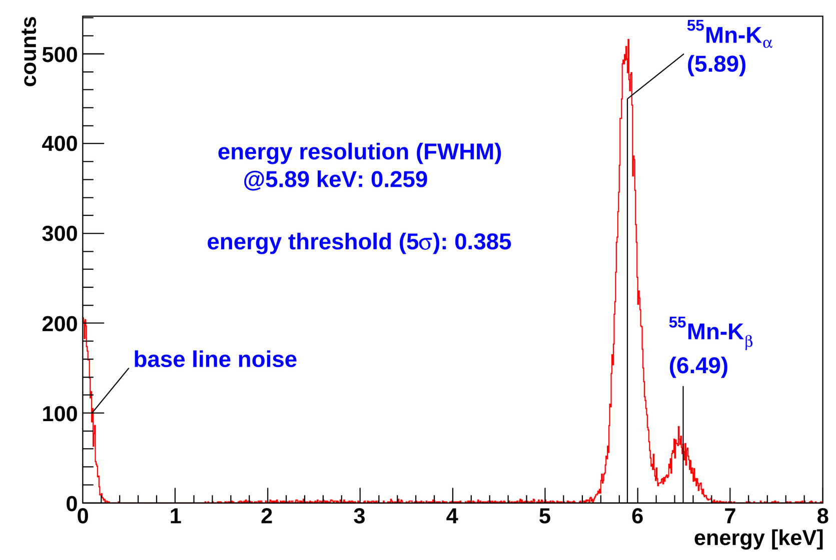
Composite detector with germanium absorber

^{55}Mn x-ray spectrum (see picture on the right) measured with this detector (see photo on the left):

- energy resolution: 0.259 keV at 5.9 keV
- energy threshold: 0.385 keV

Good energy threshold, but small target mass

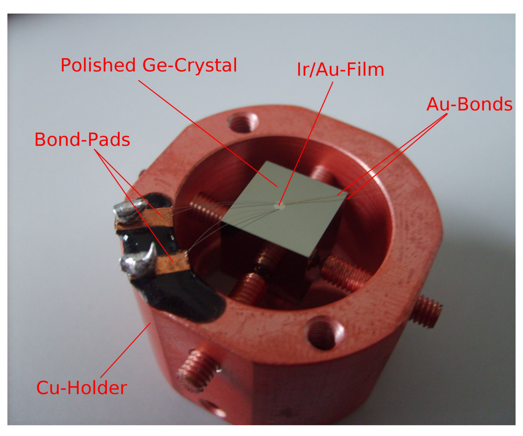
→ **next step: larger target mass**



^{55}Mn x-ray spectrum recorded with 0.8 g detector (see left picture). Separation of the Mn-K$_\alpha$ and Mn-K$_\beta$ line can clearly be seen. Energy threshold: 0.385 keV, resolution @ 5.9keV: 0.259 keV

3.2 g germanium absorber

- Absorber: 10×9×9 mm^3 germanium cube with polished surfaces
- TES (Ir/Au Film) evaporated directly onto the absorber crystal
- ^{55}Mn x-ray spectrum (see picture on the right) measured with this detector (see photo below):

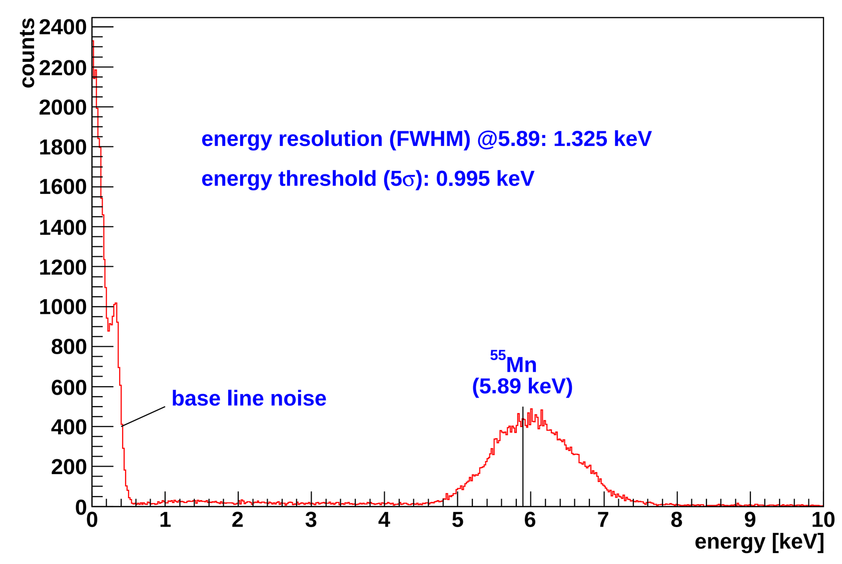


Cryogenic detector with 3.2 g germanium absorber

Comparison of this detector with two other detectors with a similar absorber, but with rough surfaces and composite design (see 0.8 g detector above):

- surface properties have no effect on energy threshold
- glue in the composite design has no effect on energy threshold

⇒ **Large energy threshold is due to small TES area (small phonon collection efficiency)**



^{55}Mn x-ray spectrum recorded with 3.2 g detector (see left picture). Energy threshold: 0.995 keV, resolution @ 5.9keV: 1.325 keV

Future developments

- Development of detectors with 10 g target mass (~100 10 g detectors for 1 kg target mass) and an energy threshold below 0.5 keV
- Use of **Neganov-Luke amplification** in semi-conducting target materials (see also figure below):
  - Incident particle produces phonons and electron-hole pairs
  - Charges are drifted by an electric field applied to the absorber crystal
  - Additional phonons are produced by drifting charges
  - Amplification of the phonon signal proportional to applied field

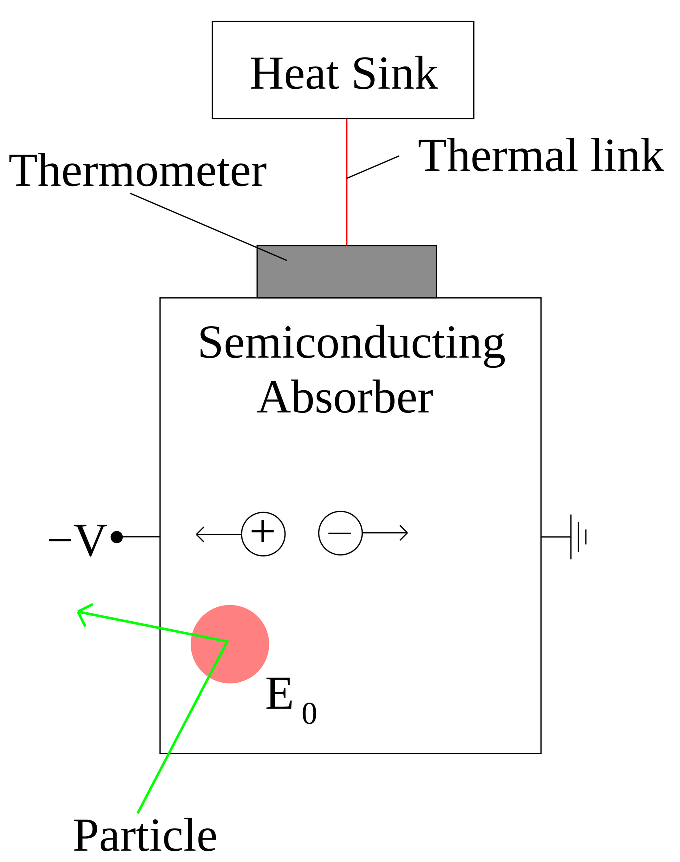
⇒ **Reduction of energy threshold**

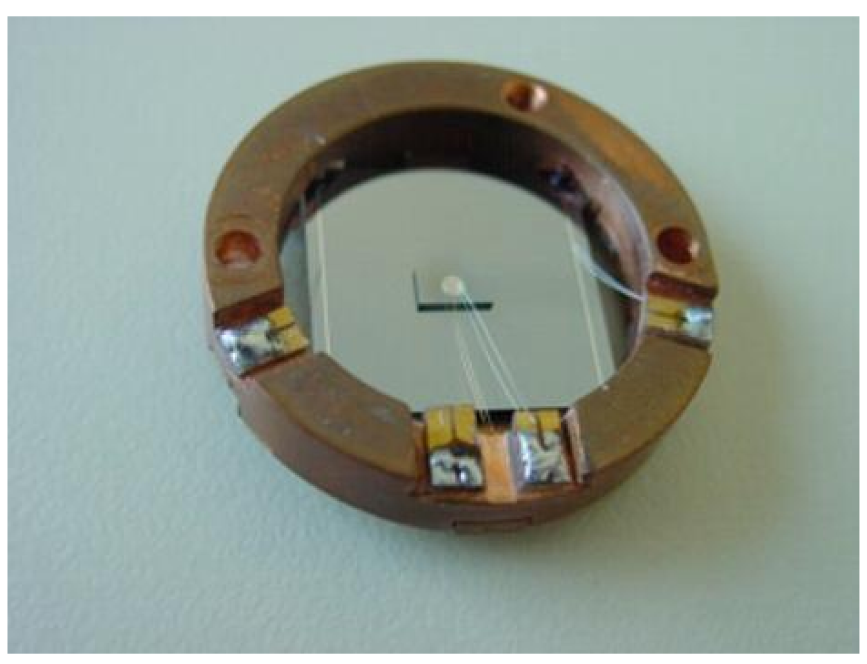
→ Use of Neganov-Luke amplification with neutrons for the first time

- Use of **phonon collectors** (superconducting aluminum structures connected to the TES, see figure below)
- **Solar neutrinos** as **background** for the direct dark matter search (see second poster)

Future improvements

Neganov-Luke Effect





Detector with Al-electrodes

Amplification is given by:

$$E_{tot} = \left(1 + \frac{eU}{\epsilon}\right)\cdot E_0$$

E_{tot}: total energy deposited in the absorber, e: charge of electron, U: applied voltage, ϵ: energy needed to produce one electron hole pair, E_0: energy deposited by incident particle

ϵ is given by:

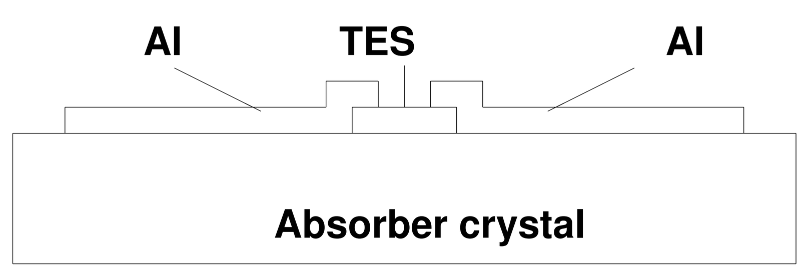
$$\epsilon = \frac{E_0}{\eta}$$

η: quatum efficiency for the production of electron hole pairs

→ Typical value for x-rays for Si:

$$\epsilon = 3.64\,\text{eV}$$

Phonon collectors



- Superconducting structures (Al) do not increase the heat capacity of the TES and thus do not deteriorate the sensitivity of the phonon detector
- Phonons entering the phonon collector (Al) produce quasi particles by breaking up cooper pairs
- Quasi particles drift to the TES and thermalize there

⇒ Phonon collection area is increased without an increase of the heat capacity

⇒ **Reduction of energy threshold**