Development of Cryogenic Detectors for the Observation of Coherent Neutrino Nucleus Scattering
Teilprojekt A5

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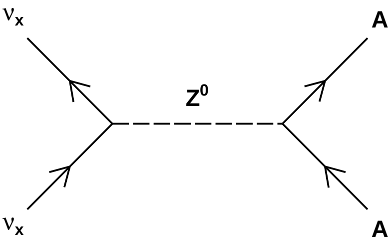
CNNS - A neutral current process



- Neutral current process $\Rightarrow$ CNNS independent of ν-flavor
- For low transferred momenta: Z^0 wave length comparable to radius of nuclei

$\Rightarrow$ ν scatters coherently off all nucleons

CNNS - Cross Section

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

$$\sigma_{tot} = \frac{G_F^2}{4\pi}\left[Z\left(4\sin^2\theta_W - 1\right) + N\right]^2 E_\nu^2$$

with neutrino energy E_ν, scattering angle θ, Fermi constant G_F, Weinberg angle θ_W, proton number Z and neutron number N.

$$\sin^2\theta_W = 0.23 \Rightarrow \sigma_{tot} \sim \frac{G_F^2}{4\pi} N^2 E_\nu^2$$

But recoil energy $E_{rec} \propto \frac{1}{N+Z}$.
$\rightarrow$ Higher neutron number N $\rightarrow$ higher cross section σ_{tot} but also lower recoil energy E_{rec}

Physical potential of CNNS

Standard model predicts CNNS

$\longrightarrow$ Observation of CNNS is a test for standard model

$\longrightarrow$ Investigation of non-standard neutral current interactions

Precise measurement of CNNS cross section

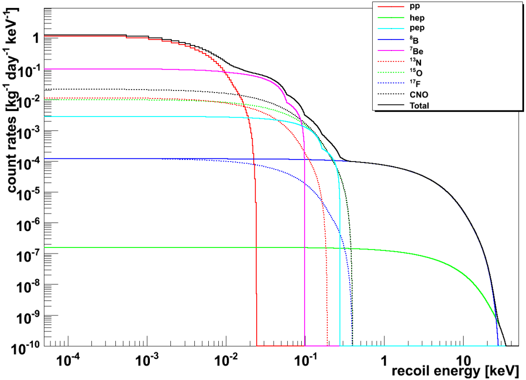
$\longrightarrow$ Weinberg-angle at low energies

$\longrightarrow$ effective radius of weak charge of neutrino

$$sin^2\theta_W \rightarrow sin^2\theta_W \cdot \left(1 - \frac{2}{3} M_W^2 \left\langle r_\nu^2 \right\rangle\right)$$

Expected spectrum for solar neutrinos

- Neutral current interaction ⇒ oscillation independent measurement of solar neutrino flux!



- For ^{7}Be-neutrinos → energy threshold $\lesssim$ 50 eV!

→ Low count rate ~1.1 ton^{-1} day^{-1}

Solar ν: background for direct dark matter search?

- Detectors for direct dark matter search can distinguish between γ's and WIMPs.
- But they can not distinguish between ν's and WIMPS

$\Rightarrow$ solar ν's background for WIMP search?

Target	**Threshold**	ν **- count rate**
Ge	10 keV	$\sim 3.0 \cdot 10^{-8}$ ton^{-1} year^{-1}
$CaWO_4$	10 keV	$\sim$1.1 ton^{-1} year^{-1}
Xe	5 keV	$\sim$3.8 ton^{-1} year^{-1}

$\rightarrow$ No background for Ge

- For $CaWO_4$: ν scatters off Oxygen; WIMP scatters off Tungsten

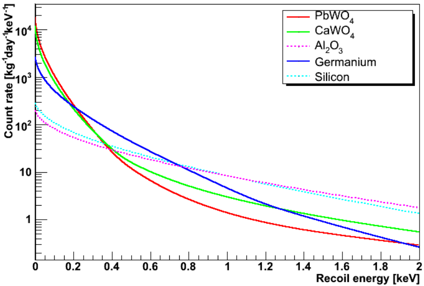
$\rightarrow$ If $CaWO_4$-detectors can distinguish between O-recoils and W-recoils

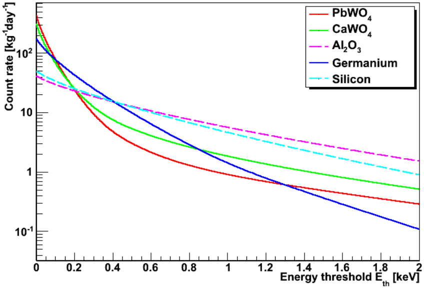
$\Rightarrow$ No background for $CaWO_4$; however important for thresholds < 4 keV

$\rightarrow$ But background for Xe

Expected spectrum for reactor neutrinos

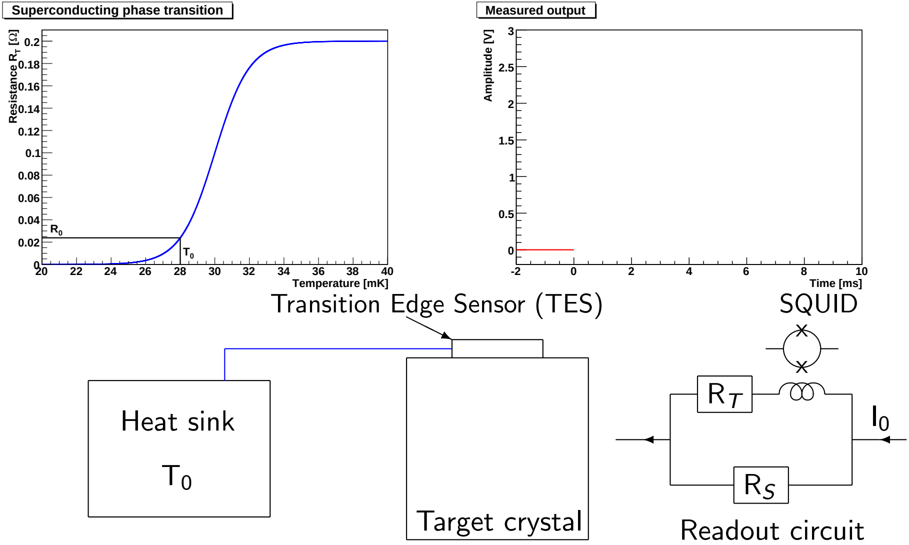
$\longrightarrow$ reactor neutrinos (flux $10^{13}\frac{1}{\mathrm{cm}^2\mathrm{s}}$)





- Small recoil energies (<2 keV) $\Rightarrow$ detectors with low energy threshold ($\approx$ 0.5 keV) needed
- Low event rates $\Rightarrow$ good background suppression needed

Working principle of cryogenic detectors



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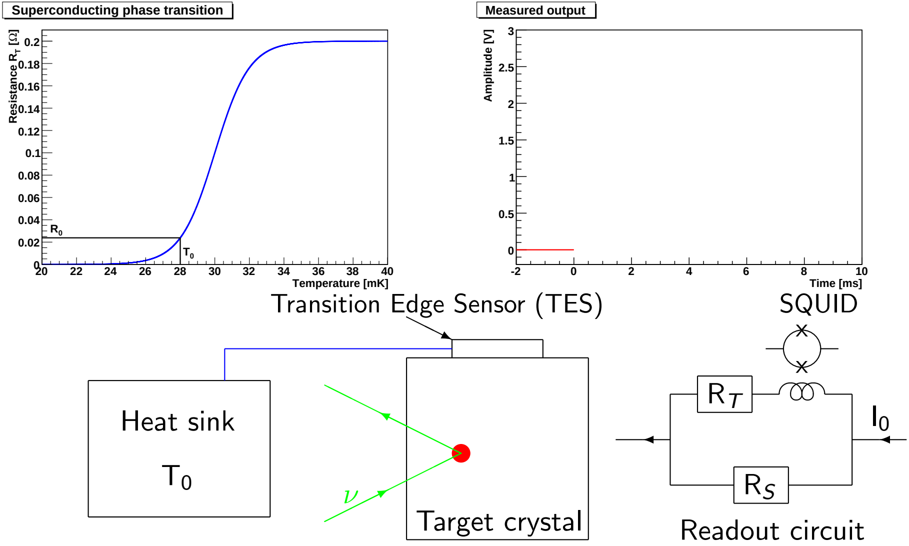

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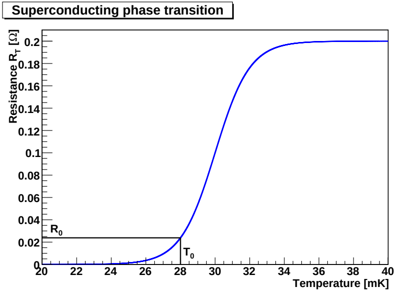

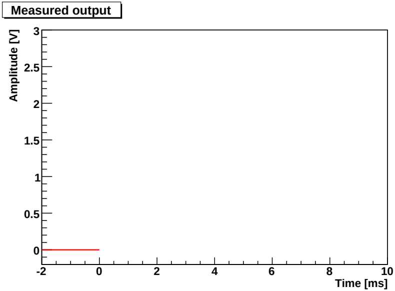

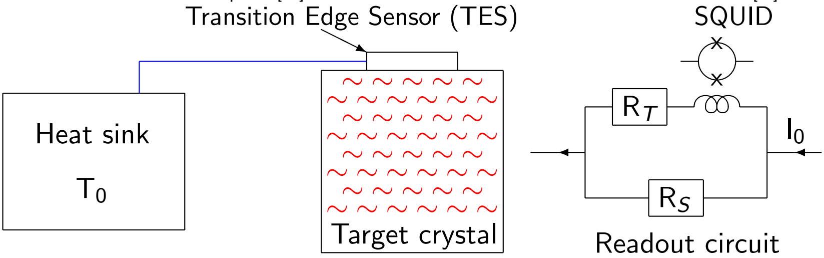

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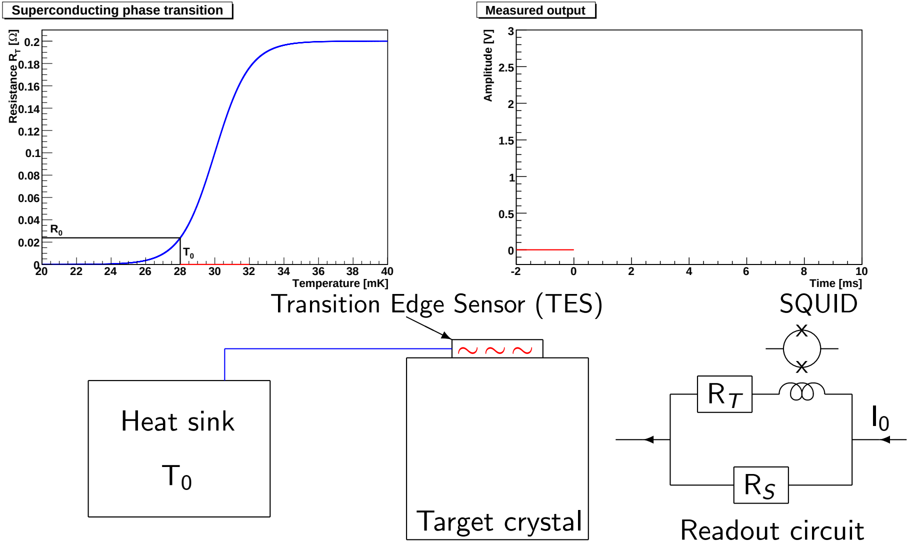

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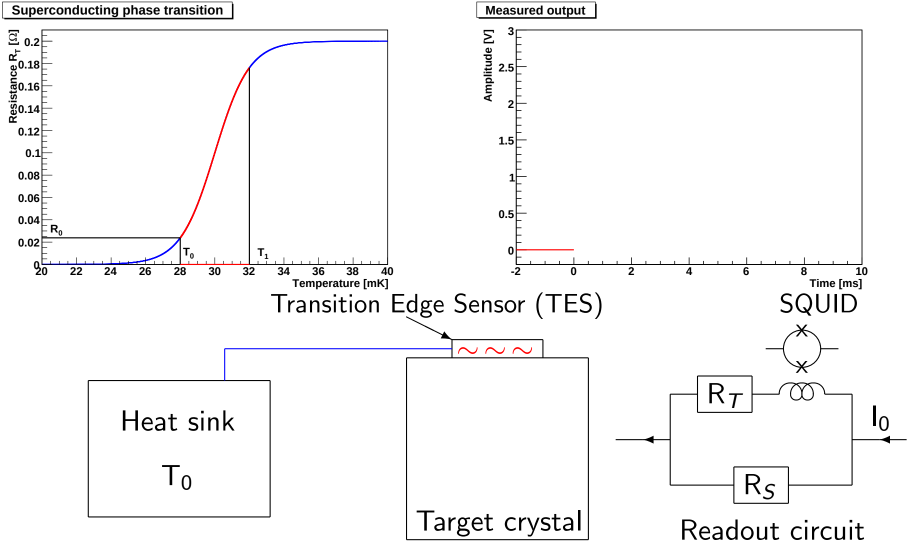

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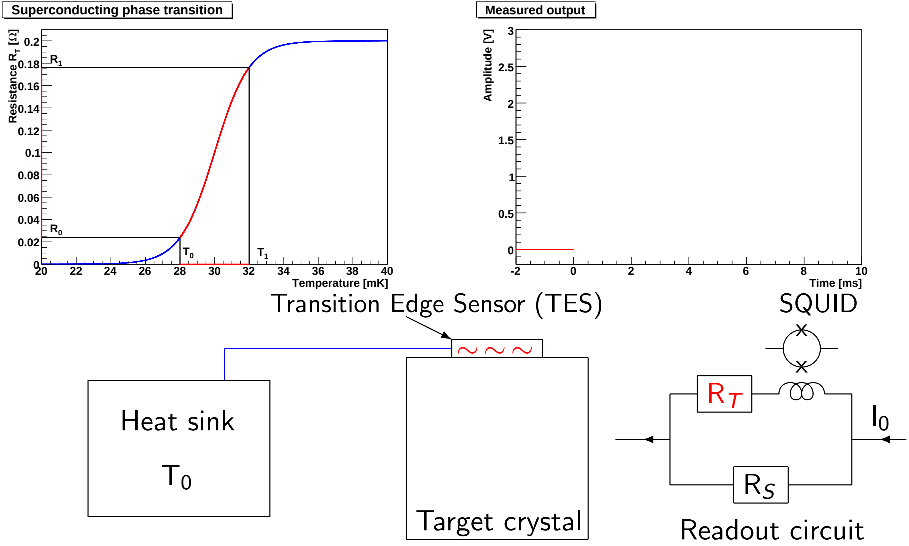

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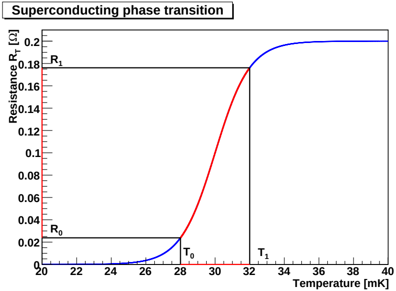

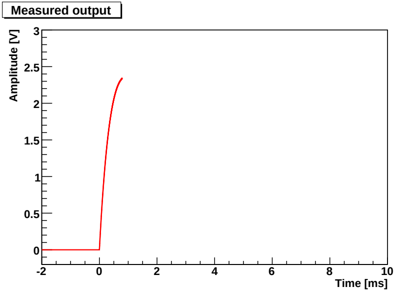

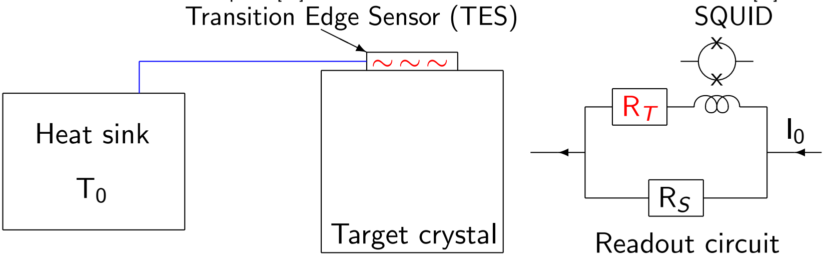

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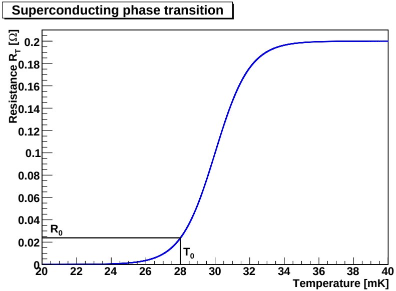
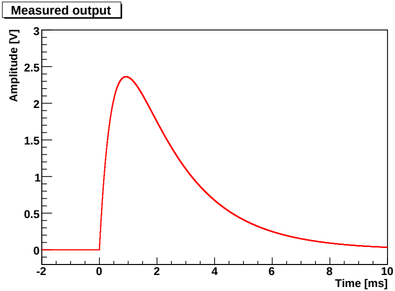
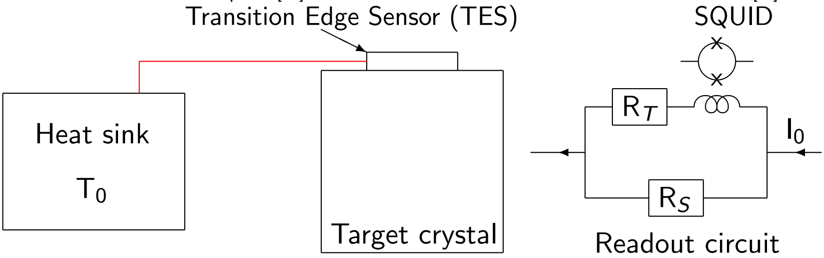
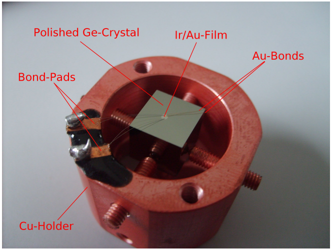
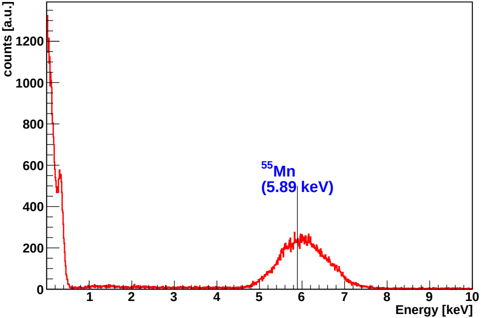






Sample detector



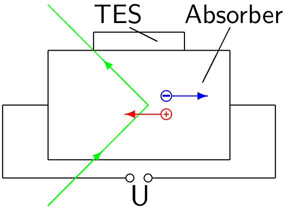


- 3.2 g Ge cube as absorber
- Ir/Au Film as TES

$\longrightarrow$ Energy threshold of $\sim$1 keV

$\Rightarrow$ Energy threshold should be decreased!

Neganov-Trofimov-Luke effect



- Enegy deposition leads in semiconductors to production of phonons and electron-hole-pairs
- Electrons and holes are drifted to electrodes due to applied electric field
- Electrons are producing additional phonons

⇒ Amplification of phonon signal

→ Better signal-to-noise ratio

Phonon collectors

- For a low energy threshold, a high signal-to-noise ratio is needed

$\rightarrow$ High phonon collection efficiency

$\rightarrow$ TES covers large surface

- Problem: large TES has a large heat capacity

$\Rightarrow$ Large heat capacity of TES decreases signal-to-noise ratio

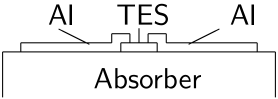
$\rightarrow$ Solution: phonon collectors

- A phonon collector is an Al-structure connected to the TES

$\rightarrow$ Al is superconducting at mK-temperartures $\Rightarrow$ no heat capacity

- Phonons produce quasi particles in Al; quasi particles diffuse into TES

$\Rightarrow$ Small heat capacity and large covered surface



Background sources

Energies of neutrino events are below 2 keV

$\Rightarrow$ Events with higher energy deposition are background

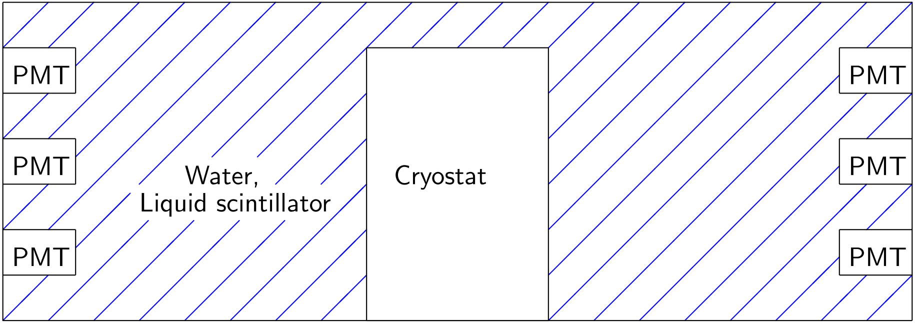
Remaining background sources:

- Neutrons
- Compton events with small energy deposition ($\rightarrow$ forward scattering)
- Surface radioactivity
- Low energetic γ's ($E_\gamma < 2$ keV)

Neutrons

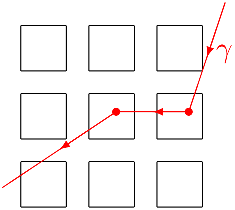
- Thermal Neutrons (E $\sim$ 25 meV) are far below energy threshold
- Fast neutrons (E $\sim$ 10 keV) leading to similar events as ν's

Neutron shielding:

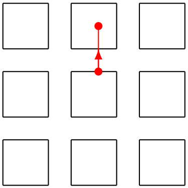


Compton events, Surface radioactivity

Potential of a detector array to reject Compton scattering events and surface radioactivity



Detection of Compton scattering

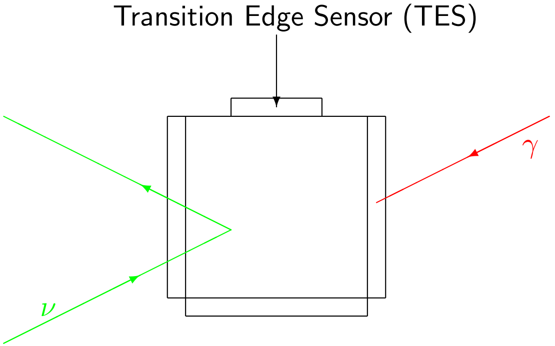


Detection of surface radioactivity

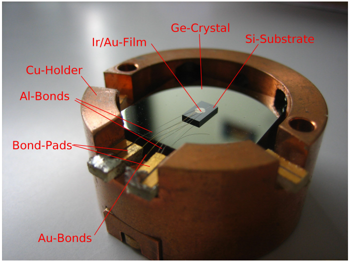
Low energetic γ's

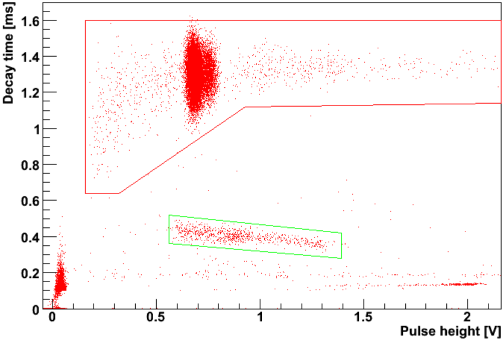
- γ's with energies below 2 keV are absorbed within $\sim$ 1 mm.
- ν's can scatter off any nucleus in the target

$\Rightarrow$ Surface events for γ's, but bulk events for ν's



Low energetic γ's





$\rightarrow$ surface events can be detected via pulse shape analysis due to longer decay times of events in glued substrates.

Conclusion and Outlook

Conclusion

Cryogenic detectors have a high potential to observe CNNS for the first time, due to ...

- low energy threshold ($\rightarrow$ sapphire crystal with 260 g and 0.5 keV energy threshold)
- different absorber materials ($\rightarrow$ multi target experiment)
- background suppression

Outlook

- Investigations on low energetic background and its suppression (measurements and simulations)
- Development of cryogenic detectors with low energy threshold ($\sim$ 0.1 keV) and a mass of $\sim$ 100 g