

Feasibility of a new polarized active detector for low-energy ν

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- Motivations
- The active target material
 - Polarization related measurements
 - Readout systems
 - Results obtained
- Future developments
- Conclusions

Target polarization

- Useful when it is advantageous to modify the contribution of weak interactions
 - In the presence of new (non standard) couplings in the current
 - CP violation in the leptonic sector (not the same as in ν oscillations)
 - Test for new physics beyond the Standard Model (exotic right handed weak interactions)
 - To improve the sensitivity to magnetic moment of ν 's
- Polarized nucleon structure functions
- Applications in physics not involving ν

$\nu - e$ Scattering

$$1 - \eta_\nu \cdot \mathbf{q}$$

$$\frac{d\sigma^{\nu e}}{dT} = \frac{2G^2 m_e}{\pi} \left[(1 + C_\alpha) \left(g_L^2 - g_L g_R \frac{m_e y}{E_\nu} \right) + g_R^2 (1 - y)^2 \left(1 - C_\alpha + \frac{m_e y C_\alpha}{E_\nu - T} \right) \right]$$

$$T = \frac{2m_e \cos^2 \theta'_e}{\left[1 + \frac{m_e}{E_\nu} \right]^2 - \cos^2 \theta'_e}$$

Kinetic energy of the scattered electron

$$C_\alpha = \eta_e \cdot \mathbf{q}$$

Cosine of the angle between the electron polarization and the neutrino direction

$$\begin{aligned} g_L &= \sin^2 \theta_w - 1/2 \\ g_R &= \sin^2 \theta_w \end{aligned}$$

For ν_μ and ν_τ (NC only)

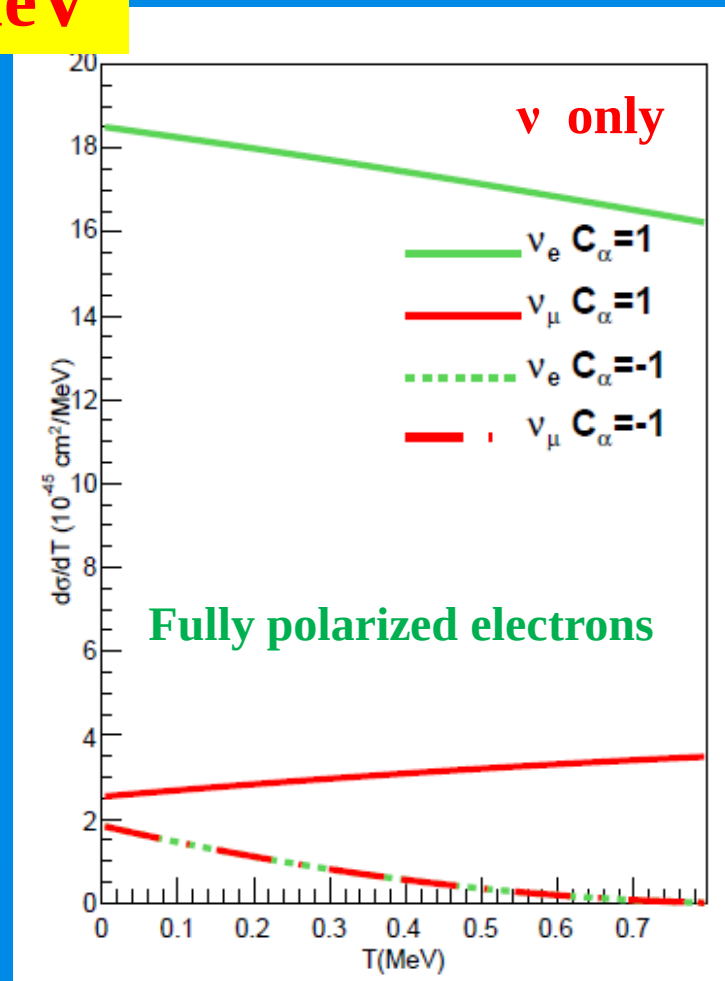
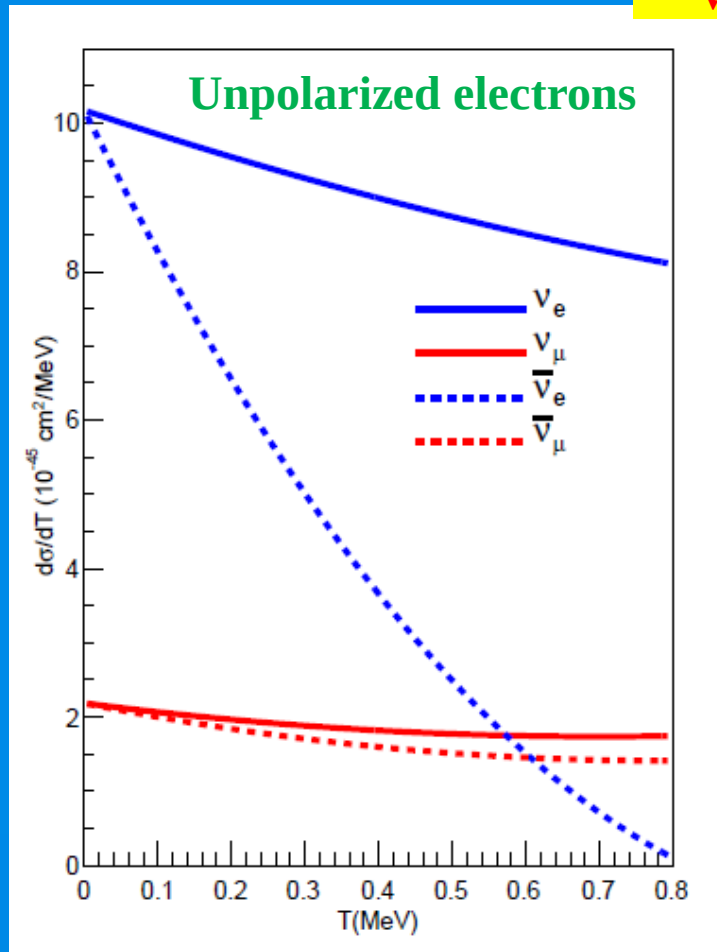
$$\begin{aligned} g_L &= \sin^2 \theta_w + 1/2 \\ g_R &= \sin^2 \theta_w \end{aligned}$$

For ν_e (NC and CC)

Radiative corrections not included but they have been computed

Example: ν - electron cross sections

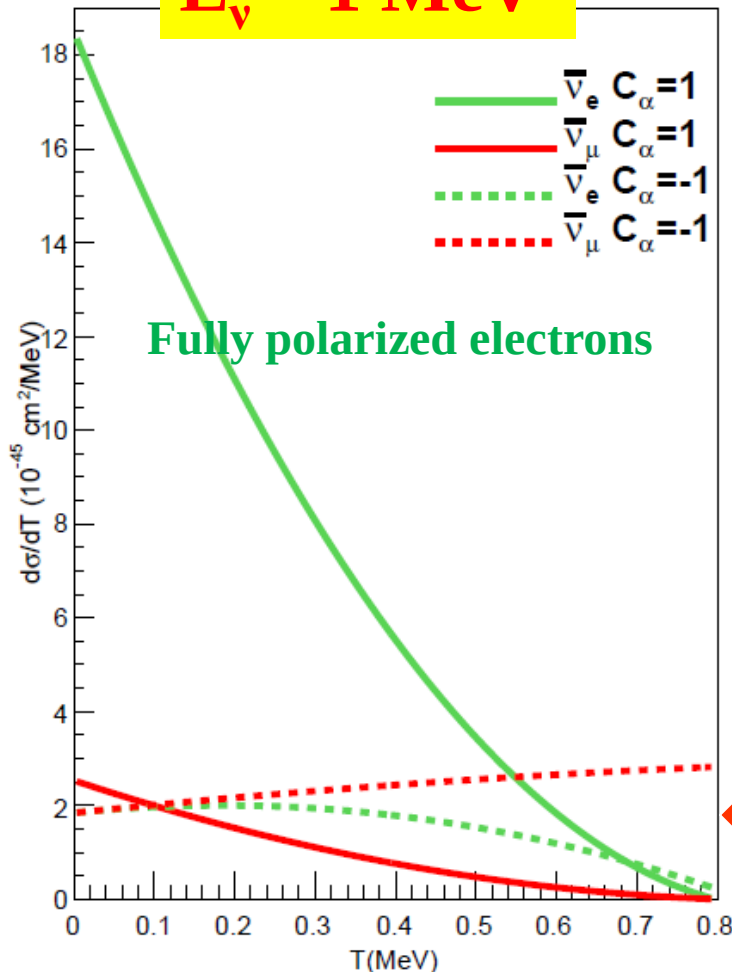
$$E_\nu = 1 \text{ MeV}$$



When $C_\alpha = -1$ σ independent of g_L and $\sigma(\nu_\mu - e) = \sigma(\nu_e - e)$

$\bar{\nu}$ - electron

$E_\nu = 1 \text{ MeV}$



If backgrounds were not a problem.....

antineutrino electron scattering could be used to measure the flavour composition of a $\bar{\nu}_\mu$ beam, (Minkowski and Passera, PLB 541, 151 (2002)).

The difference in cross sections between $\bar{\nu}_\mu$ and $\bar{\nu}_e$ however is large only at low energies ($E \sim m_e$).

Active material: GSO:Ce (*)

- It is a well known scintillator whose properties have been extensively studied
- High density ($\rho = 6.71 \text{ g/cm}^3$)
- Crystals can be grown to large sizes
- Light yield ~ 9000 photons/MeV (at $T = 300\text{K}$)
- Relatively fast scintillator ($\tau_1 = 30\text{-}60 \text{ ns}$, $\tau_2 \sim 300\text{-}400 \text{ ns}$)
- GSO is Gd_2SiO_5 . The “G” stands for Gd and **Gd is Good** ($\text{Gd}^{3+} - 4f^7$, seven unpaired electrons responsible for paramagnetic behaviour. **Observe that at most 7.7% of the total number of electrons can be polarized**)

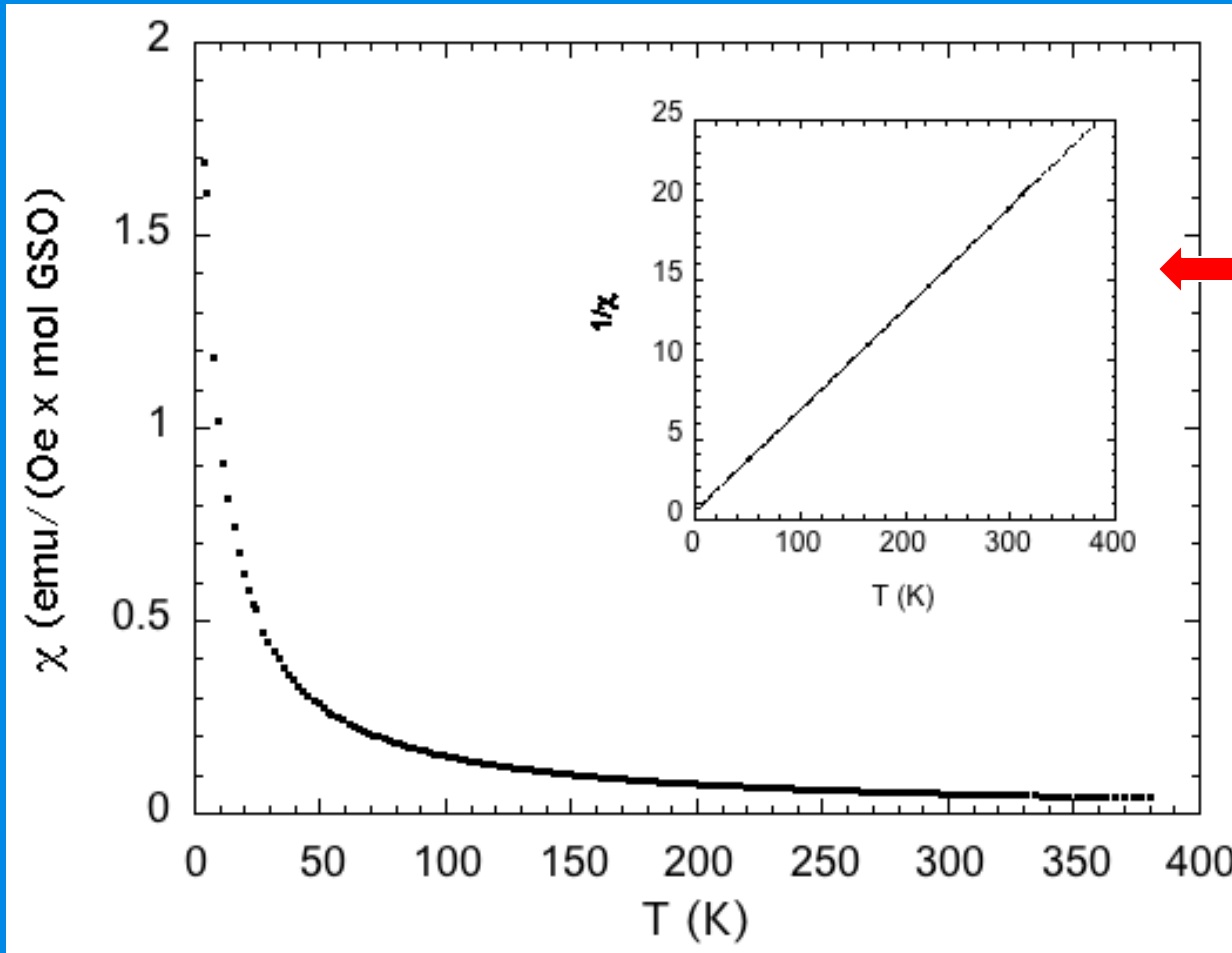
(*) suggested by M. Misiaszek et al. Nucl. Phys. B 734 (2006), 203

Experimental issues addressed

- **Material characterisation**
 - Susceptivity
 - Spectral response and timing (in the presence of magnetic field at various T)
- **Scintillation properties of the (partially) polarized material**
 - Light output
 - Time response
 - Readout systems

$\chi(T)$

Measured at $H=100$ Oe on a small cube shaped crystal

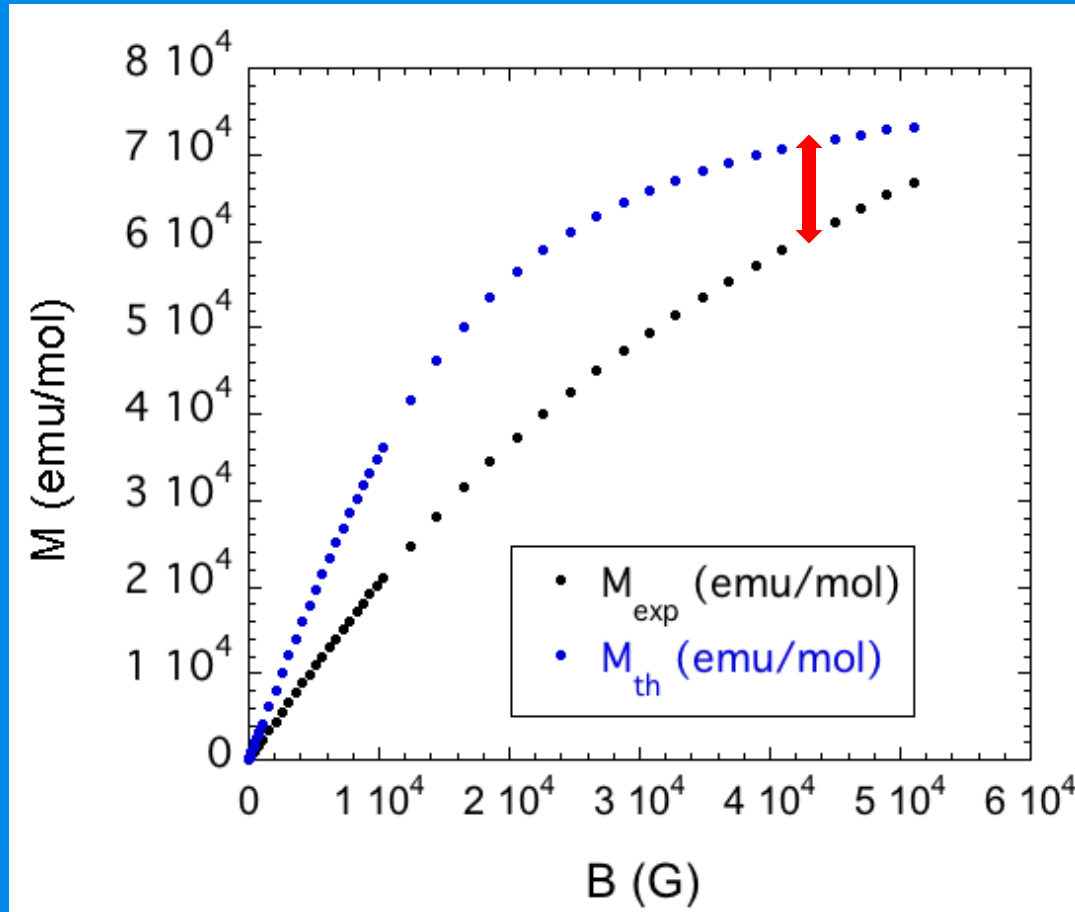


$\chi^{-1}(T)$

Curie-Weiss: $\chi = C/(T-\theta)$
 $\theta = -8.9$ K

No differences detected when H is applied along the different edges of the cube

M(B) measured at T = 4 K



Theoretical curve: Brillouin function describing the behaviour of a collection of independent $4f^7$ -ions

80-85% Saturation magnetization induced at $T = 4\text{K}$ and fields of 4-5 Tesla

6.7% of electrons polarized.

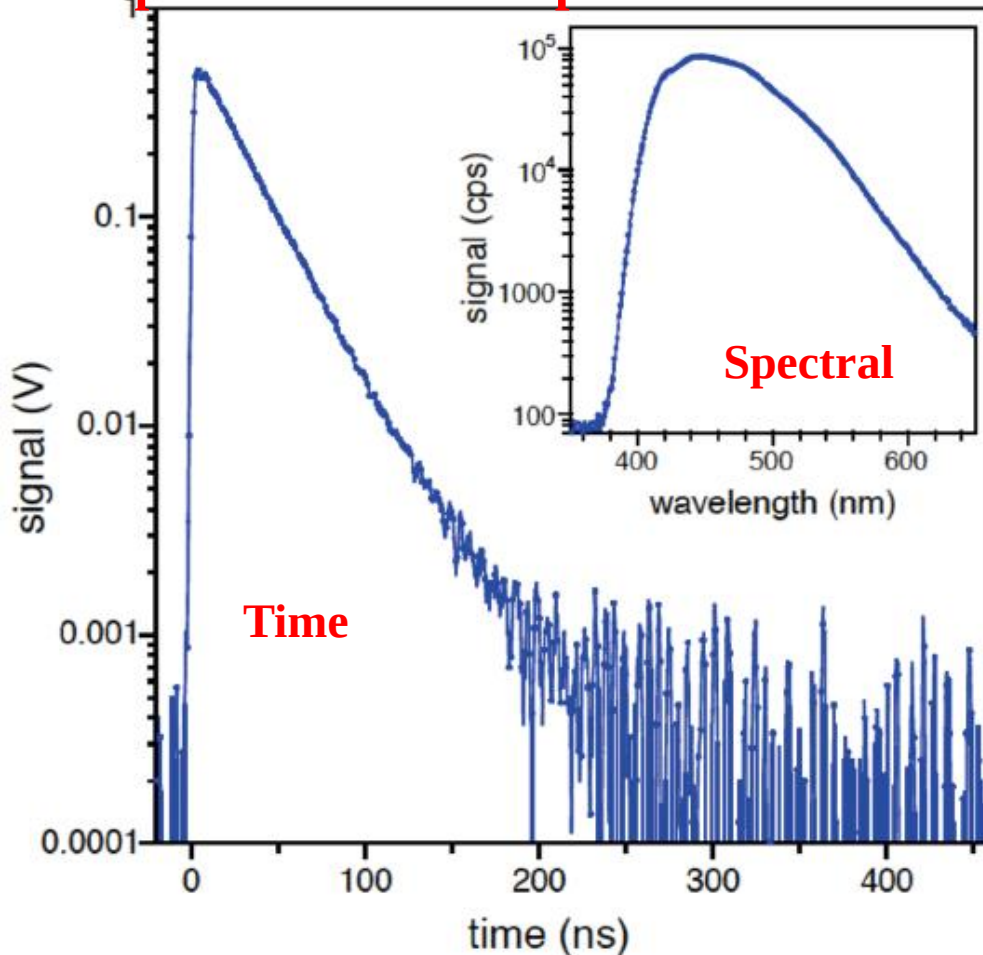
Small but sizeable !

This means that.....

On a 1m^3 detector - 20m from a 1 GW reactor - the yield would be about 650 events/day with a $\sim 10\%$ variation between the two orientations of the field (ν – electron elastic scattering only, no efficiencies yet nor backgrounds)

Optical properties (small crystal of 2x2x250 mm³ size, B = 0.9 T)

Response at room temperature

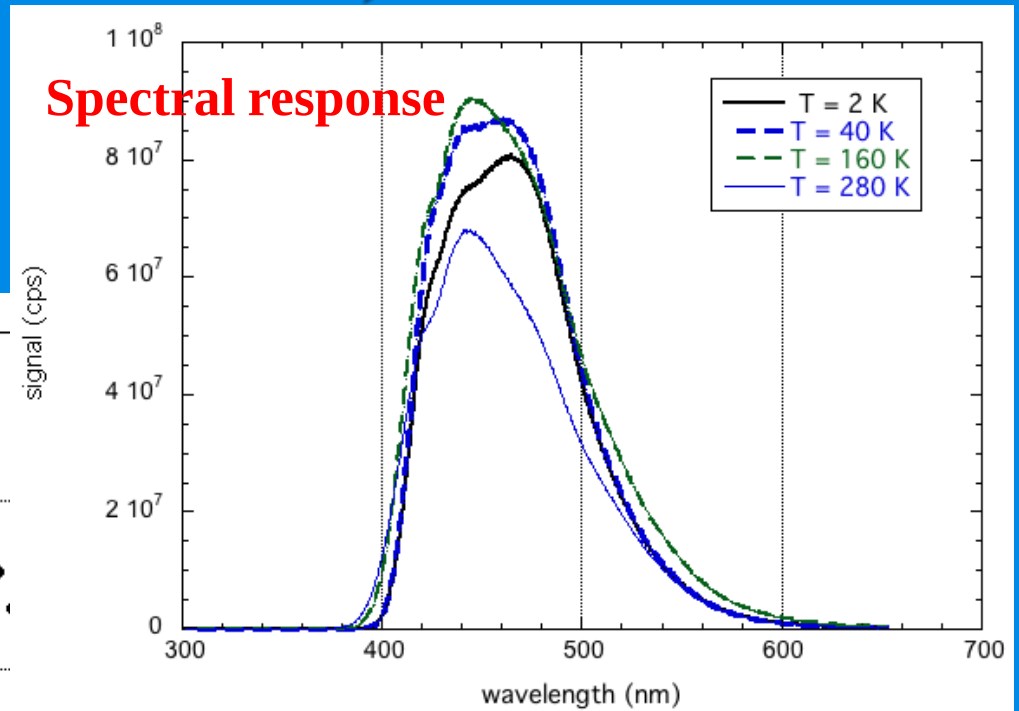
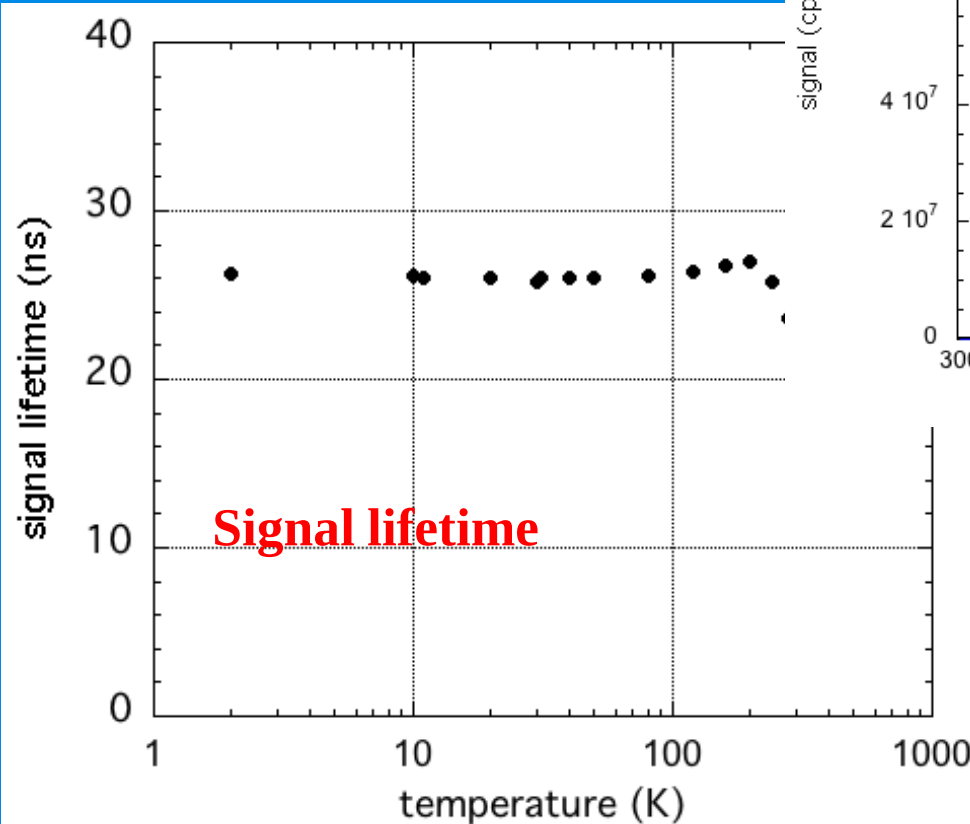


Crystal irradiated with a laser
(YAG 355 nm , 25 nJ/pulse, 200 Hz)

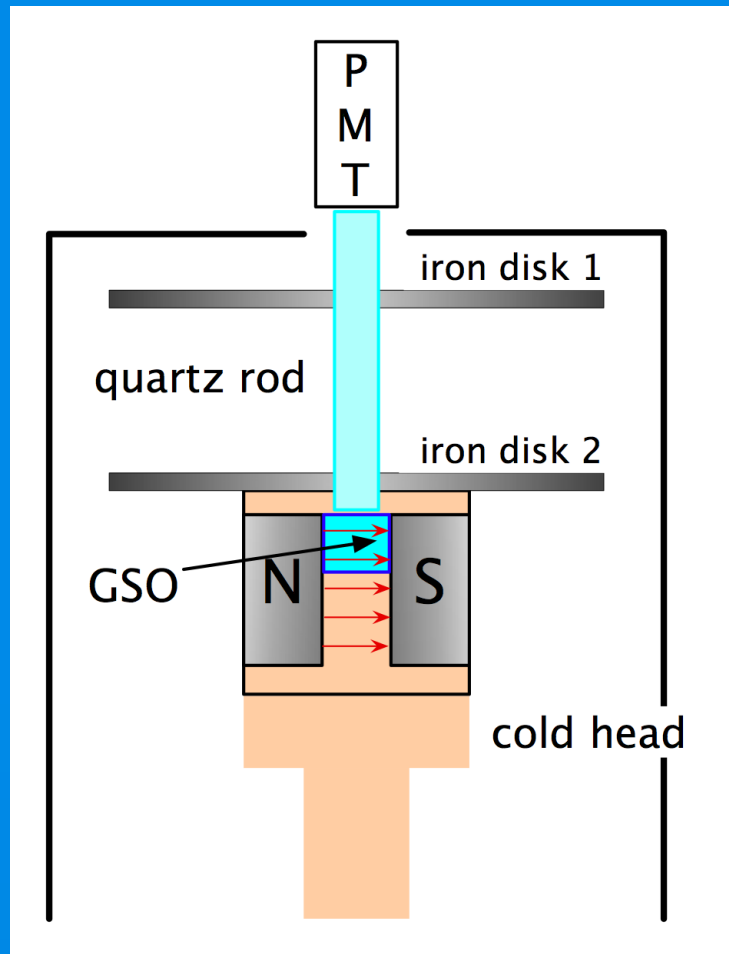
$$\tau = 25.0 \pm 0.8 \text{ ns}$$

(it is known to have a dependence on
energy of exciting radiation and on
the Ce concentration)

No significant differences when varying the temperature (liquid He bath)



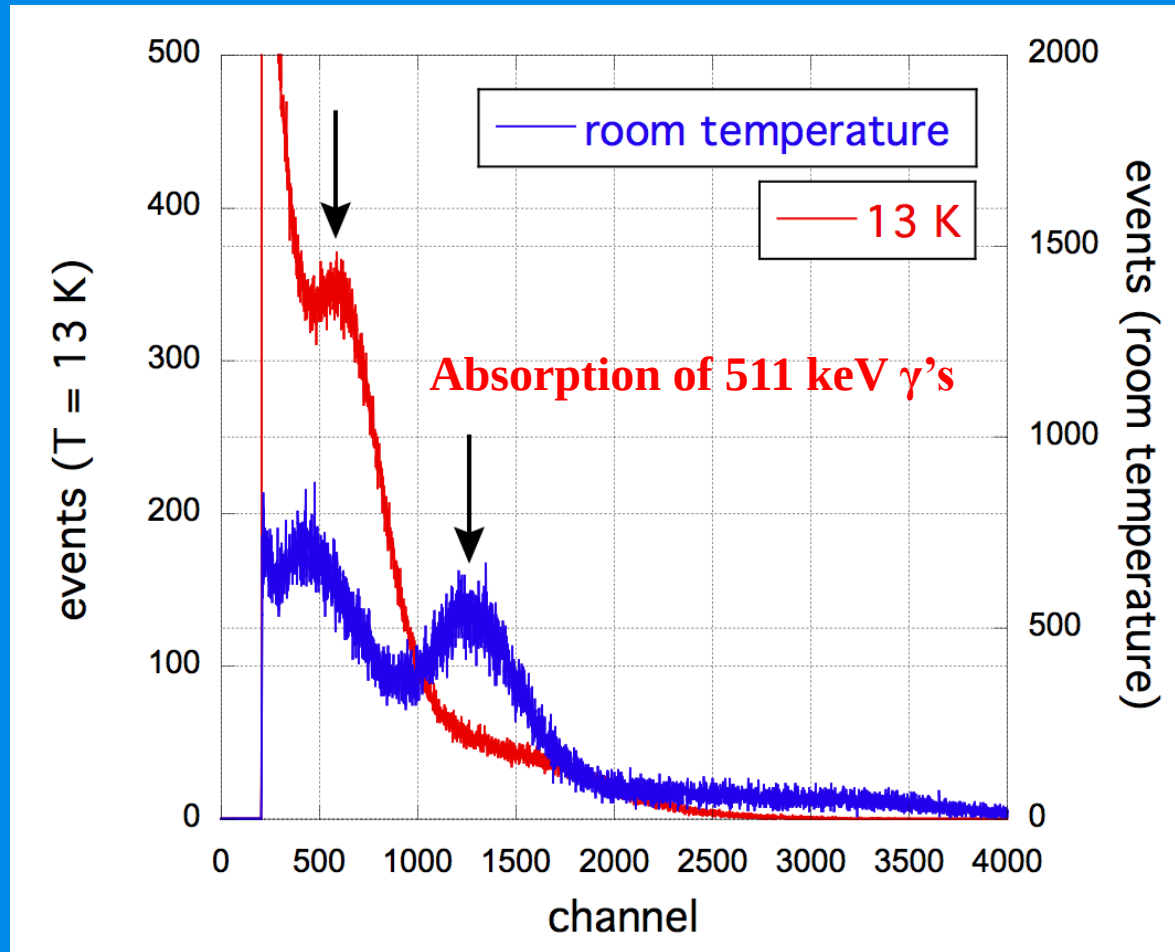
Irradiation with 511 keV γ 's



A 1 cm³ crystal placed in a *cryocooler* ($T \sim 14$ K) within a permanent magnet generating $B \sim 1$ T

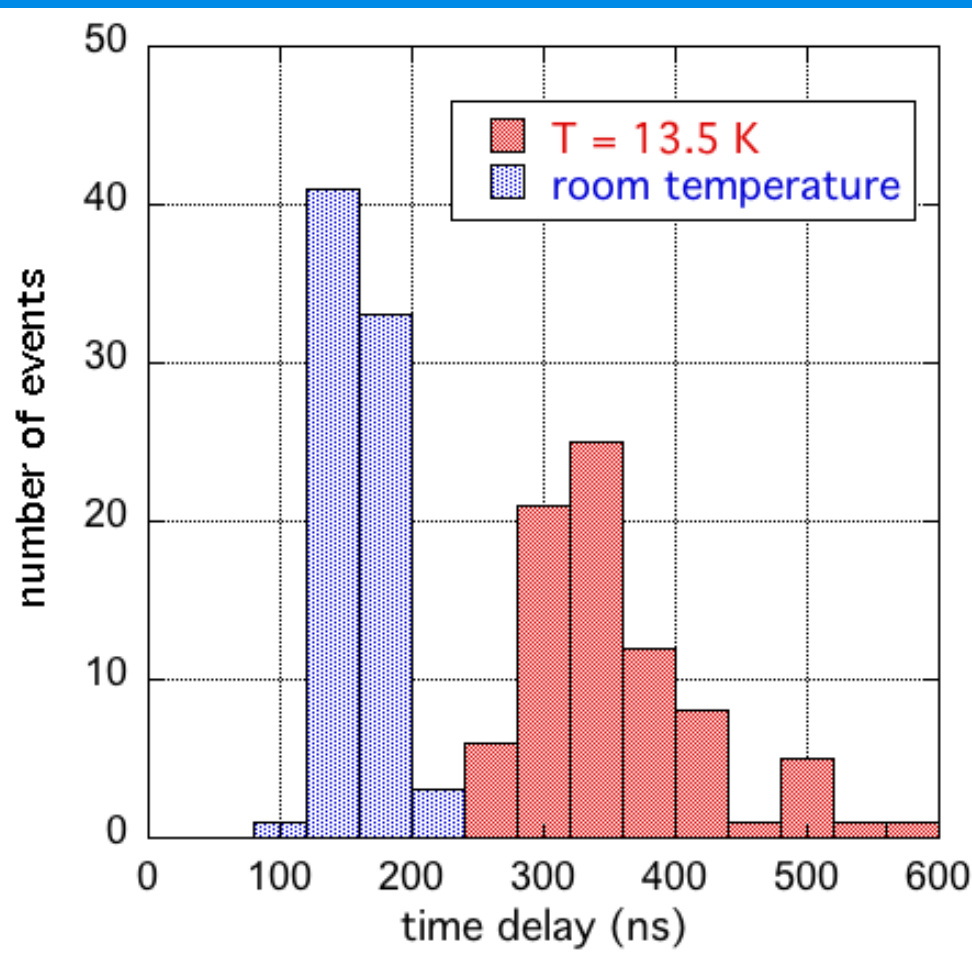
Scintillation light was read out either through a PMT shielded against magnetic field (or APD directly coupled to the GSO crystal)

Light yield



- 1) No difference B-field On/Off
- 2) Decrease by a factor of ~ 2 comparing $T=13.5\text{K}$ and $T = 300\text{K}$ (effect seen in the past using X rays)

Time response



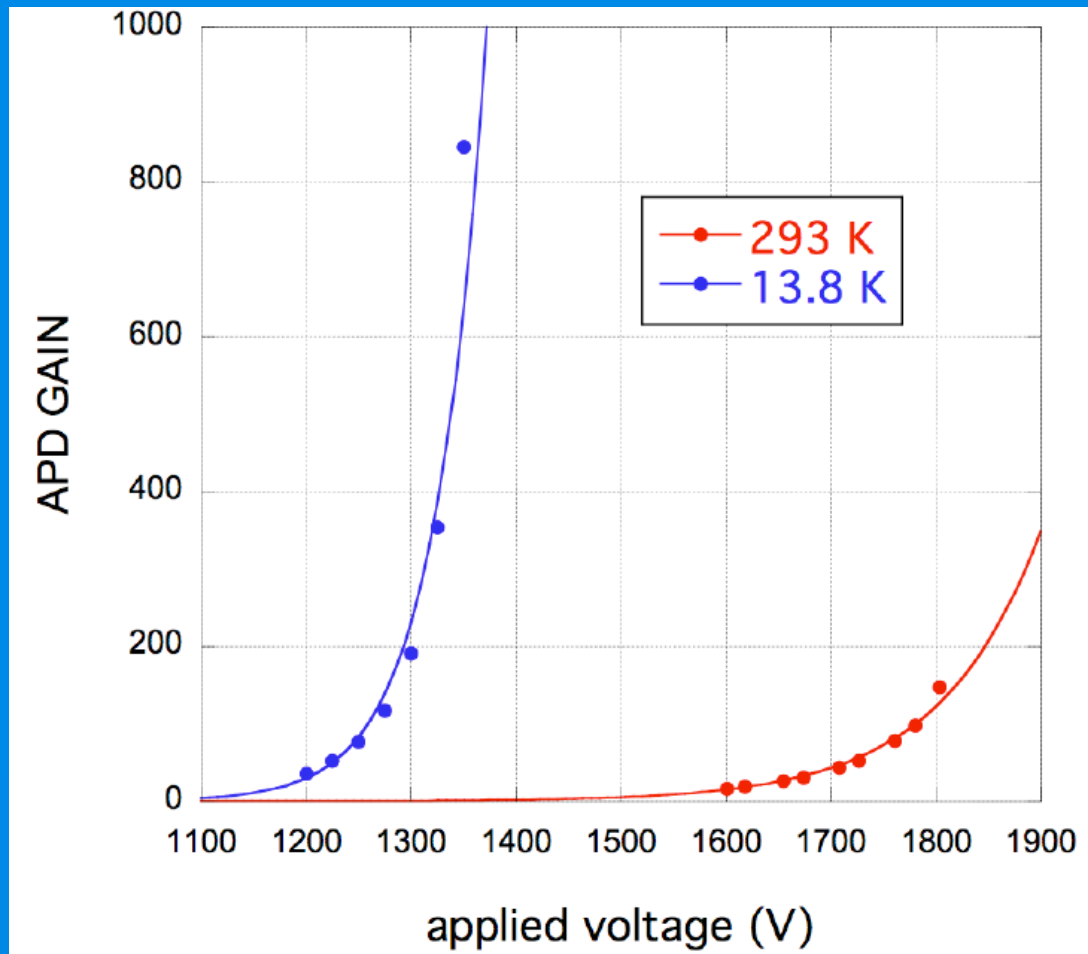
Waveforms (typically > 100) from the GSO signal recorded on a 1GHz bandwidth oscilloscope in coincidence with signals in a layer of plastic scintillator

The decay time is temperature dependent (the observed value is related both to the response time of the apparatus and the scintillation time of the GSO)

Small effect (~10%) B-field On/Off

If response time of apparatus T independent then at $T=13.5\text{K}$ $\tau = 293 \pm 20 \text{ ns}$ (to be investigated....)

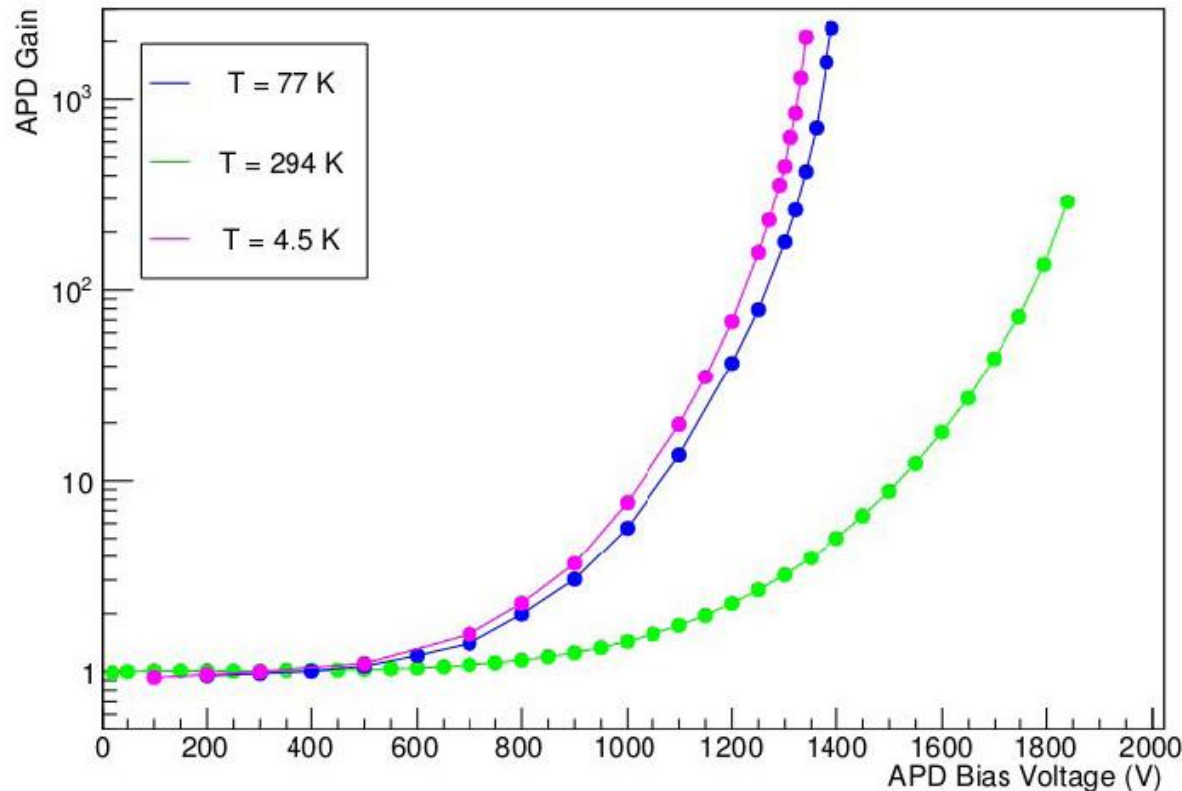
Not obvious that APDs work at cryogenic temperatures.....



Bare beveled silicon APD from Advance Photonics, 16mm diameter, UV sensitive

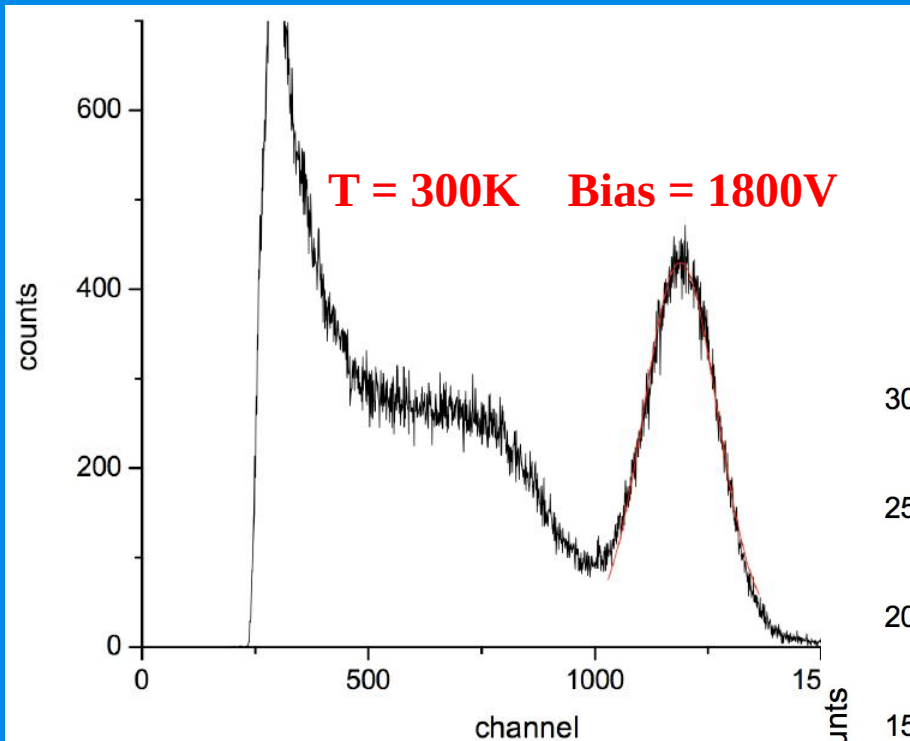
Gain measured using a 5.9 keV X-ray (Fe) source

A different APD... same result

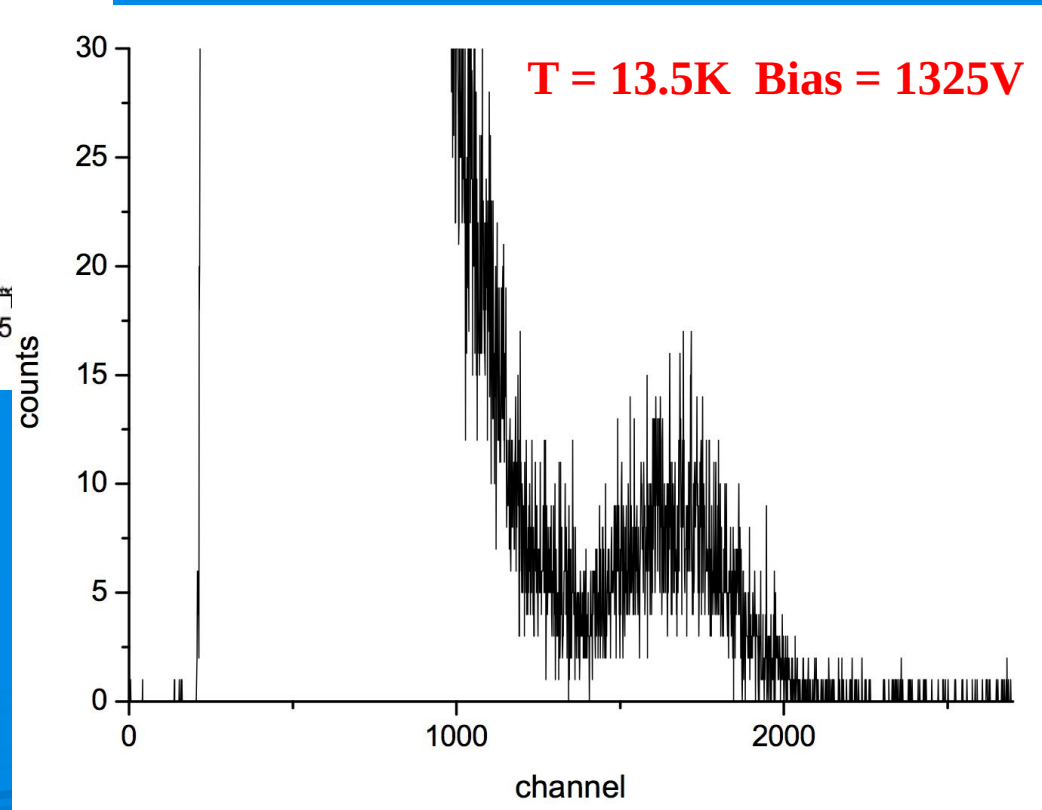


A limit on the gain is set by discharges appearing at bias voltages exceeding ~ 1400 V

Spectra using Cs^{137}



Observe again a factor ~ 2
decrease in number of photons
and more noise at lower T



Plans for the near future

- Determine the degree of polarization of the nucleus (nucleons)
- A SQUID readout is being implemented (i.e. detecting the change in magnetic flux when energy is deposited) and appears very promising.
 - Important consequence: lower energy threshold
 - Will be tested using a radioactive source: observe time coincidences between magnetic and scintillation signals.
- Test asymmetry induced by polarization using photons (if possible)
- Hope to use large ($25 \times 25 \times 150 \text{ mm}^3$) crystals already in hand (a 1/5400 fraction of a real detector).
- Getting together of “interested parties”

Conclusions

- The feasibility of a polarized GSO target has been demonstrated, albeit on a small scale.
- The degree of polarization amounts to 6.7% of the total number of electrons (80-85% of maximum achievable)
- (APDs seem to work at cryogenic temperatures)
- In the presence of a B-field and as a function of temperature:
 - No significant differences in the spectral and time response of GSO were observed when excited with a laser pulse.
 - With γ irradiation, a reduction of a factor ~ 2 in the number of photons and a longer response time are observed.
- A new readout using SQUID is being implemented and several tests on larger crystal will be carried out

Fishing in a neutrino sea might prove to be a miraculous fishing.....



(Apologies to Konrad Witz for the liberty taken with his painting and please do not ask who....)