Feasibility of a new polarized active detector for low-energy $\nu$

Biagio Saitta

Department of Physics University of Cagliari
and INFN Sezione di Cagliari

• 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 $\nu$ oscillations)
  - Test for new physics beyond the Standard Model (exotic right handed weak interactions)
  - To improve the sensitivity to magnetic moment of $\nu$’s

- Polarized nucleon structure functions
- Applications in physics not involving $\nu$
**ν - e Scattering**

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

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

Kinetic energy of the scattered electron

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

\[C_0 = \eta_e \cdot q\]

For \(\nu_\mu\) and \(\nu_\tau\) (NC only)

For \(\nu_e\) (NC and CC)

Radiative corrections not included but they have been computed
Example: $\nu$- electron cross sections

$E_\nu = 1$ MeV

Unpolarized electrons

Fully polarized electrons

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

Biagio Saitta - NOW 2012
\( \overline{\nu} \)- electron

\[ E_\nu = 1 \text{ MeV} \]

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

The difference in cross sections between \( \overline{\nu}_\mu \) and \( \overline{\nu}_e \) 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 $\sim 9000$ photons/MeV (at $T = 300K$)

- Relatively fast scintillator ($\tau_1 = 30-60 \text{ ns}$, $\tau_2 \sim 300-400 \text{ ns}$)

- GSO is $\text{Gd}_2\text{SiO}_5$. The “G” stands for Gd and $\text{Gd}$ 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)

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
No differences detected when H is applied along the different edges of the cube
The theoretical curve is the Brillouin function describing the behavior of a collection of independent $^{7}$-ions. The saturation magnetization induced at $T = 4$ K and fields of 4-5 Tesla is 80-85%. 6.7% of electrons are polarized. Small but sizeable!
On a 1m$^3$ detector - 20m from a 1 GW reactor - the yield would be about 650 events/day with a ~10% variation between the two orientations of the field ($\nu$ – electron elastic scattering only, no efficiencies yet nor backgrounds)
Optical properties
(small crystal of 2x2x250 mm$^3$ size, B = 0.9 T)

Response at room temperature

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

Spectral

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

(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)

Signal lifetime

Spectral response
Irradiation with 511 keV $\gamma$’s

A 1 cm$^3$ crystal placed in a cryocooler (T ~ 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)
1) No difference  B-field On/Off
2) Decrease  by a factor of  ~2  comparing T=13.5K and T = 300K
   (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=13.5K $\tau = 293 \pm 20$ ns (to be investigated...)

Biagio Saitta - NOW 2012
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
Observe again a factor $\sim 2$ decrease in number of photons and more noise at lower $T$. 

$\textbf{Spectra using Cs}^{137}$

- $T = 300K$  Bias = 1800V
- $T = 13.5K$  Bias = 1325V
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 (25x25x150 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 $\gamma$ irradiation, a reduction of a factor $\sim$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….)

Biagio Saitta - NOW 2012