ISTITUTO NAZIONALE DI FISICA NUCLEARE

Laboratori Nazionali del Gran Sasso

INFN/BE-91/05
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The Study of $\nu_e e^-$ Scattering with a Neutrino Source

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ABSTRACT

We discuss the possibility of using a radioactive source to study the $\nu_e e^-$ scattering. In order to have a strong signal in a 100 gr/cm^2 thick liquid scintillator surrounding the source and in order to be sensitive to a low magnetic moment of the neutrino the threshold on the electron recoil energy has to be set very low, around 200 keV. This has two consequences: a huge experimental setup and a big active volume, where the expected signal due to ^8Be solar neutrinos is as high as the one produced by a large magnetic moment of the neutrinos from the source.

1 The Neutrino Source

The $\nu_e e^-$ cross section can be measured using the neutrinos produced by an electron-capture radioactive source. A good candidate is ^{51}Cr ($T_{1/2} = 27.7$ days):

$$^{51}Cr + e^- \rightarrow ^{51}V + \nu_e (B.R.90\%) \quad (1)$$

$$^{51}Cr + e^- \rightarrow ^{51}V + \nu_e + \gamma (B.R.10\%) \quad (2)$$

yielding neutrinos with energies of 746 keV (81%) and 751 keV (9%) for the first channel, 426 keV (9%) and 431 keV (1%) for the second channel (5 keV are taken by x-rays and Auger electrons).

In the second reaction a 320 keV γ is also emitted and it can be used to measure the source activity.

A 25.4 kCi ^{51}Cr source has already been produced [1] and a much stronger one ($\sim$ 1 MCi) is foreseen for the calibration of the Gallex detector [2]. It is possible to obtain such a source by activating with neutrons a sample of enriched chromium grains (enriched in ^{51}Cr and depleted in ^{53}Cr, which has a very large neutron cross section).

A $\sim$ 1 MCi source can be obtained using a 45 kg chromium target (17% ^{50}Cr) in a 21 day irradiation at a 35 MW reactor [1].

2 The Experimental setup

The measurement of the $\nu_e e^-$ cross section with a neutrino source allows the use of a 4π detector and it can be made in an underground laboratory, to minimize the background. The disadvantages are the γ activity of the chromium source and its short half life (each day the activity decreases by 2.5 %).

The cromium source, a sphere with a 15 cm radius , is surrounded by a thick shielding, to suppres the γs produced by the source itself, and it is the core of a concentric sphere detector similar to Borexino [3]. The active part of the detector is a liquid scintillator layer where the recoiling electron with energy above 200 keV are seen by photomultipliers.

2.1 The Source Shielding

We can extrapolate the result of [1] to obtain a γ activity of the source of: 0.1 MCi at 320 keV, 0.92 Ci between 1 and 1.5 MeV, 2.08 Ci between 1.5 and 2.1 MeV and negligible above 2.1 MeV. All this can be dumped down to $\sim$ a few γs/day with a 1600 gr/cm^2 thick passive shielding surrounding the source.

The γ activity of the source above 1 MeV is mainly due to the presence of Sb and Ag contained as impurities in the chromium grains (7.4 ± 1.1 and 18.0 ± 2.7 ppm respectively). Their reduction would weaken the shielding requirement. Furthermore, the events due to the ^{124}Sb and ^{110m}Ag decay ($T_{1/2}$ = 60.2 and 249.8 days respectively) have a time dependence which is different from the signal due to the neutrino interaction.

A material which can be used for the shielding is tungsten. Because of its high density (19.3 gr/cm^3) a tungsten shielding can be only 72 cm thick (this corresponds to $\sim$ 1400 gr/cm^2, the remaining part of the shielding will be made with water and liquid scintillator). Its radioactive cleaness has been checked to be at least as good as the one of OFHC copper [4].

We can therefore use the background measured in a double beta decay experiment with a germanium detector surrounded by a thick copper shielding [5] to estimate the following activity due to the tungsten sphere: 32600 γs/day with energy between 1 and 2 MeV and 4330 γs/day above 2 MeV.

To cool down this activity to ~ a few γs/day we need a 220 gr/cm^2 thick shielding. This will be made by 1.7 m of water contained in a 2 cm thick plexiglass ball and by the inner part (0.5 m) of the liquid scintillator layer.

The water contributes with only a few events/day to the background if it has a level of ^{238}U, ^{232}Th and ^{40}K of $\sim 10^{-15}$ gr/gr, similar to the one demanded by the Borexino detector (for plexiglass a 10 times worse contamination is acceptable) [6].

2.2 The Active Layer and The External Shielding

The 2.6 m radius sphere which cleans the neutrino flux is surrounded by a 2 m liquid scintillator layer, contained in a 2 cm thick plexiglass ball. The central part only (1 m) of this layer is used as the active detector, whereas the inner and outer part are used as shielding against the radioactivity.

In the following table we give the event rate due to $\nu_e e^-$ weak scattering, with a 200 keV threshold on the electron kinetic energy, in a 1 m thick active volume surrounding the 1 MCi source (we assume that the scintillator has a density of 1 gr/cm^3). The event rate due to the $\nu_e e^-$ electromagnetic scattering is also given for different values of the neutrino magnetic moment (expressed in units of Bohr magnetons).

Weak(events/day)	Electromagnetic		
	$\mu = 10^{-10}$	$6{\cdot}10^{-11}$	$3{\cdot}10^{-11}$
253	117	42	11

Such a signal has to be compared to the background due to the source and its shielding, to the outside, to the scintillator itself and to the solar neutrinos.

The background from the source and its shielding is of the order of a few events/day (with the very good purity we assumed above for the different materials).

The background from outside can also be kept low if, behind the scintillator, there are 3m of water, a 2cm thick steel sphere with the photomultipliers, and 2m of plastic, as in Borexino [6].

The activity of the scintillator is of the order of ~ 0.05 events/day· ton if it has an ultrahigh purity of 10^{-16} gr/gr in the uranium-thorium chain elements (the possibility of reaching this value in a large volume has still to be shown).

Finally the expected contribution of the ^8Be solar neutrinos is of the order 0.6 events/day·ton (weak interaction only): this is going to be the most important background source (if the demanded material purity can be reached and if the calculation of the ^8Be flux is correct).

In order to see a clean neutrino flux, the 1 m thick active scintillator layer starts at the distance r of 3.1 m from the source center, it has a volume of 164 m^3 and it contains $4.9 \cdot 10^{31}$ electrons. If the thickness is kept constant the signal does not change with the distance r, whereas both the scintillator and the solar neutrino background increase as r^2 (the active volume is a spherical shell), and they reach the value of 9 and 100 events/day respectively.

3 Conclusion

We analyze the possibility to use a 1 MCi cromium source in an underground laboratory to measure the $\nu_e e^-$ cross section with a threshold of 200 keV on the electron kinetic energy. The aim is to make an experiment sensitive to a magnetic moment of the neutrino down to a few 10^{-11} Bohr magnetons.

A concentric sphere setup has been discussed, with the cromium source, a 15 cm radius sphere, sitting in the center. Starting from the source surface to the outside we have: 72 cm of tungsten, 170 cm of water, 200 cm of liquid scintillator, 300 cm of water, the sphere with the photomultipliers to read out the fiducial volume of the liquid scintillator layer, and 200 cm of plastic. The whole setup is a huge sphere with the radius of $\sim$ 9.6 m.

If materials with the ultrahigh purity demanded by the Borexino experiment are available, then the background due to the source, to its shielding and to the scintillator itself can probably be kept reasonably low. However, in order to have a clean neutrino flux, the active volume has to be put at the distance of 3.1 m from the source center. Because of this, there is a big active volume where the expected signal due to ^8Be solar neutrinos is as high as the one produced by a large magnetic moment of the neutrinos from the source.

References

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