SOLENOID RETARDING SPECTROMETER AND A FROZEN TRITIUM SOURCE FOR USE IN A NEUTRINO MASS EXPERIMENT

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Invited talk given
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Abstract

A solenoid retarding spectrometer in combination with a source of frozen tritium will be used to study the vicinity of the tritium beta spectrum endpoint. The high resolution and high luminosity of the system suggest an increased sensitivity to finite neutrino masses.

1. INTRODUCTION

Some discussion has come up with the ITEP finite neutrino mass result ($m\nu_e = 26^{+6}$ eV)[1] which seems incompatible with the results of other tritium decay experiments. The lowest upper limit from this type of experiment for $m\nu_e$ is claimed by the Zürich group ($m\nu_e < 18$ eV)[2]. Additional evidence for inconsistency can be obtained from the supernova data for electron type neutrino mass of $m\nu_e < 15$ eV[3]. The experimental precision of current tritium decay experiments has reached a limit at which systematic effects play an important role. Moreover, they suggest the importance of confirming $m\nu_e$ in independent experiments and if possible by different spectrometers.

One crucial point is the distortion of the high energy end of the tritium β-spectrum due to energy loss processes in the source. For the solid state sources used until now, e.g. tritium labelled valine[1] or tritium implanted into carbon[2], one has to correct for final state effects. The size of these modeldependent corrections is of the order of the quantity to be determined. An improvement of this situation is to use a source containing pure tritium, for which reliable final state corrections have been calculated[4].

A second major problem in tritium experiments is the precise determination of the resolution function (RF) of the spectrometer in use. In order to get a reasonable transmission the resolution widths of toroidal spectrometers are usually broader than the interesting interval at the endpoint of the T-betaspectrum. Integral electrostatic spectrometers can achieve a higher resolution and a simple shaped resolution function. But they generally suffer from a higher background or a small solid angle. Two independent proposals[5,6] suggest solenoid retarding spectrometers, (SRS), a combination of a magnetic field gradient and a retarding electrostatic potential[7].

2. PRINCIPLE OF SRS OPERATION

The experimental approach uses a combination of superconducting solenoids ($B_0 \simeq 8.6, 8.6, 2.0$ T,) arranged along a common horizontal axis as shown in Fig.1. The tritium source is placed in the field maximum of solenoid I. The energy E of a decay electron is divided into cyclotron energy $E_\perp$ and kinetic energy $E_\parallel$ parallel to the local B-field. The angle α between the trajectory and the B-field is given by

$tg^2\alpha = E_{\perp}/E_{\parallel}$. The electrons follow the stray magnetic field lines via cyclotron motion to an area of low magnetic field midway between the 8.6 T solenoids ($B_1 \approx 0.0018$T). If the motion is adiabatic $E_{\perp}$ is converted into $E_{\parallel}$ according to the adiabatic invariant $P_{\perp}^2 / B = \text{const.}$ so that

$$E_{\perp 1} = (B_1/B_o)\, E_{\perp o} \approx 2.1 \times 10^{-4}\, E_{\perp o}$$

with the numbers as given above. In the center plane region, where the magnetic field reaches its minimum value B_1, the electron moments would thus be highly parallel to the field lines. Along their way the electrons see an electrostatic potential distribution which is created by an arrangement of ring electrodes.

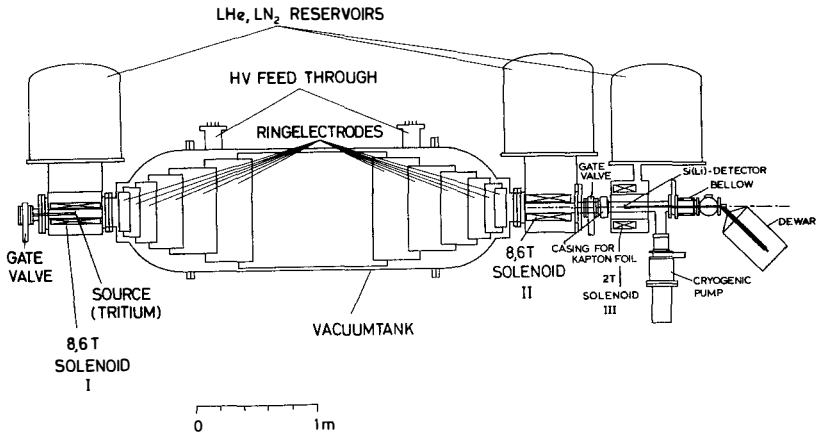

Fig. 1: The SRS consists of a high B field source region ($B_o \approx 8.6$ T). The B field minimum in the center plane ($B_1 \approx 0.0018$ T), and the high field detector area. The retarding electrostatic potential is created by a set of ring electrodes.

The potential distribution ϕ is nummerically optimized to serve two purposes:

a) It provides the retarding potential summit ϕ_{max} with a radial homogeneity of $5 * 10^{-5}$ in the center plane.

b) The electrons are continuously decelerated so that the cyclotron step length $\Delta z = (2v_{\parallel}\pi)/\omega$, where ω is the cyclotron frequency, is small everywhere. Hence $\Delta B/B$, the change of B-field per cyclotron step length over

the mean field, is sufficiently small to approximate adiabatic conditions.

Electrons with an energy $E_{\parallel}$ between the $e\phi_{max}$ and the beta spectrum endpoint E_{max} can pass the retarding potential. For reasons of noise and background, they are refocussed on a $7cm^2$ Si detector in a second high magnetic field behind solenoid II. The advantages of the SRS:

a) All electrons emmitted from the source in the foreward 2π solid angle pass the energy filter. With a source size $S = 1.33\ cm^2$ the luminosity is $L = S\Delta\Omega/4\pi$ is $0.66\ cm^2$

b) Small total resolution width given by the amount of energy $E_{\perp 1}$ that is left in the cyclotron motion

$$E_{\perp 1max} = B_1/B_0\ E_{\perp 0} \approx 4eV \quad (E_{\perp 0} = 18.6\ keV)$$

c) There is no material in the active volume of the SRS

3. PRELIMINARY SYSTEMATIC CHECKS

The resolution function (RF) of the SRS can be monitored with field emission electrons from a metal tip at the source site, and a faraday detector. Fig.2 shows the experimental RF: an increase from 0 to 1 of the transmission as a function of potential difference U between tip and center electrode (CE). In comparison the theoretical RF for an isotropically emitting point-like source and the influence of the Fermi-distribution of the field emission electrons to the ideal RF is shown.

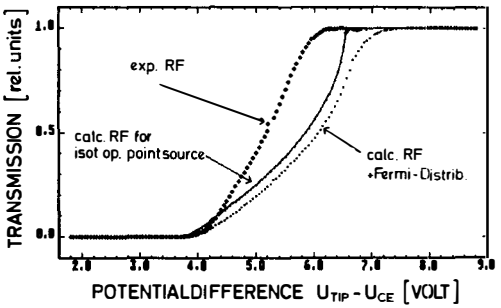

Fig.2) Experimental RF : an increase of transmission as a function of potential difference between tip and center electrode. The absolute tip potential is at 13 kV. Also shown is the calculated ideal RF and its deformation by the Fermi-distribution of the field emission electrons

The RF does not occur at an $\Delta U = 0$ V but at 4V due to the work function of the center electrode material. As the tip is not perfect isotropically emitting source, the obtained exp. width ΔE is smaller than the theoretical. Changes of the tip surface during operation, lead to different emission angles and shifts in the RF, but we never obtained resolution widths exceeding the theoretical limits.
The RF can additionally be shifted by the penetrating voltage U_p created by the small electrodes affecting the radial homogeneity of the analysing potential peak at the center electrode. This influence can be demonstrated by the shift in the RF with the relative potential difference between the CE and 8 electrodes neighboring the CE symmetrically (Fig.3).

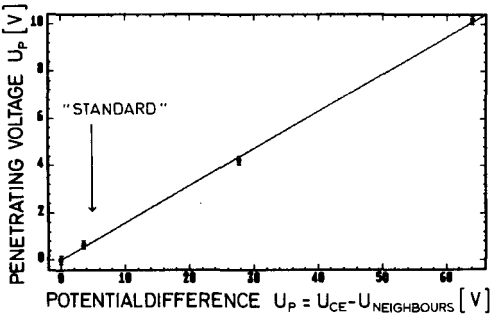

Fig.3)
The penetrating voltage U_p as a function of potential difference between center electrode and the 8 symmetric neighbour electrodes. The Up ≈ 1V for the numerically optimized potential distribution ("Standard ") is in good agreement with the calacutions.

3. THE SOURCE

The ideal source for the SRS would be atomic spin polarised T stored in a high magnetic field at low temperature, but until now its realisation seems failed.
We therefore use a thin film of frozen T_2 gas at 3-4 K. Due to the van-der-Waals nature of the T_2 crystal typical solid state excitations (eg. plasmons) do not occur. We estimated energy loss processes for a 20 keV electron passing a 50 Å T film and and found that 95% traverse the film without being scattered. Furthermore backscattering from the Al-substrate has also been calculated and affects at maximum 0.2% of the decay electrons in the interesting 100 eV energy bin below the endpoint E_{max}. In a preliminary test chamber we were able to stabilize T films

of 10 -1000 monolayers at 2.8 K. They are monitored with laser ellipsometry and are stable within the resolution (3-4 Å) over periods of at least 20 h.
The final source setup incorporates a separated vacuum chamber for film preparation and diagnoses. During operation the source is placed in a 4 K tube (120 mm) that effectivley prevents room temperature radiation from reaching the film. The tube also works as a baffle to freeze out residual gas atoms that might contaminate the source film. A detailed calculation of this effect taking a residual gas pressure of $< 10^{-10}$ mbar into account yields a contaminant film deposition rate of 10^{-3} monolayers in 24 h.
Because of the very low vapor pressure (10^{-16} mbar at 4 K) the contamination of the SRS with T atoms from the source is negligible.

4. THE DETECTOR

A Si(Li)- detector with an intrinsic energy resolution of 1.5 keV at 20 keV will be placed in the 1-2 T field of solenoid III. It is shielded against 18.5 keV background electrons from the tank by the steep magnetic gradient of solenoid II by a factor of $8*10^{-3}$. Furthermore a thin capton foil between tank and detector will prevent T_2 gas diffusion to the detector.

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