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PROPOSAL TO THE ISOLDE COMMITTEE

# A SEARCH FOR AXIONS AND MASSIVE NEUTRINOS.

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## SUMMARY

Experimental efforts to prove the existence of the axion - a light neutral pseudoscalar boson predicted theoretically from a solution of the strong CP conservation problem - have failed so far. The most stringent laboratory limit on the axion mass $m_a < 20$ keV makes a search by the axion analog to the Mossbauer effect an attractive possibility. A sensitivity gain of several orders of magnitude is possible.

The existence of a heavy neutrino emitted in ß decay with a branching ratio of .8 % has been recently suggested. Previously obtained results from measurement of the internal bremsstrahlung in electron capture decay lead us to believe that an accuracy of .1 % on the branching ratio of a possible neutrino with a mass of 5 - 50 keV can be obtained.

We propose to serve both purposes by conducting two experiments on one strong, high-purity $^{125}I$ source, which can only be produced at ISOLDE.

For the periode 1992-93 we request 40 shifts of beam time.

I.INTRODUCTION.

It is often assumed that general relativity and the minimal standard model suffice to describe all known natural phenomena. A positive result from either of the two experiments we propose here will prove this assumption wrong.

The standard model Lagrangian must contain a strong CP violating term, which, however, is at variance with experimental observation. The only known way out of this problem [1] has as a necessary and observable consequence the prediction of the existence of a light, neutral pseudoscalar boson - the axion [2]. Axion dynamics might operate on its own intermediate scale, $f_a$, which neither coincides with the weak interaction scale ( which is also excluded by terrestrial experiments [3]) nor on grand unification scale ( which seems excluded by cosmological arguments [4] ). The mass, $m_a$, and the coupling, $g_a$, to quarks or nucleons of mass m is roughly related to the axion scale by:

$$m_a \sim m_\pi^2/f_a \qquad g \sim m/f_a$$

We propose here a search based on the axion-mediated analogue to the Mossbauer effect [5], which requires the axion mass to be less than the energy of the Mossbauer transition ( typically < 100 keV ).

Although we discuss in the following explicitly axions, one might, of course, stumble over other hitherto unknown or unseen weakly interacting particles.

The recent claims of evidence [6,7] for the emission in ß decay of a heavy neutrino ( ~ 17 keV ) with a branching ratio of .8 % arise considerable interest due to their impact on the standard model [8]. However, one class of experiments claim a positive effect [6,7], whereas others produce a null result [9]. A sensitive test with a method distinctly different from those used in these experiments is highly desirable in order to settle this dispute.

The bremsstrahlung spectrum from an electron capture ß decay contains the same principal shape dependence ( from phase space factors ) of the neutrino mass as does ß decay. The shape of the spectrum, however, is more complex and the intensity of the interesting part of the spectrum is very low, unless the nuclear Q-value happens to be close to the atomic energy scale. In the latter case a resonant enhancement occurs and makes the method directly competitive with β decay measurements. But since the low energy part of the photon spectrum can be absorbed, it is still possible - through the use of a very strong source - to obtain a high statistical accuracy, and thus a competitive experiment. Previous measurements of the bremsstrahlung from EC decay [10] have demonstrated the ability to reach an accuracy of the order of 1% on a possible heavy neutrino branch. We propose here to improve on this type of experiment to reach an accuracy of the order of .1 % .

By a coincidence of nature both proposed experiments can be conducted using a strong, ultra-clean $^{125}I$ source, which can only be produced at ISOLDE, since it needs in both cases to be free of contaminating radioisotopes at the $10^{-12}$ level or better.

## II. THE AXION EXPERIMENT.

Consider the setup scetched in Fig.1 of an axion resonance scattering experiment. In a conventional Mossbauer experiment the gamma radiation from the 35 keV transition to the ground state of $^{125}Te$ is resonantly absorbed, and the lack of transmitted gammas or the enhancement of the reemission of X rays is recorded. The resonance condition is tuned by a doppler shift of the resonance energy of the absorber atoms. An analogue axion resonance effect is singled out by inserting a suitable absorber, which shields the conventional radiation, but is transparent to axions.

The detection rate of axions is proportional to the source strength, $A_s$, and to the square of the axion branching ratio, $B_{ax}^2$:

$$R = K \cdot A_s \cdot B_{ax}^2$$

where the prefactor, K, depends on the geometry of the setup and on some nuclear parameters ( including the probability of recoilless emission and absorption ). In a real experiment, of course, this rate has to be measured relative to some background rate, $R_0$, which turns out to be in a reasonably low-background setup determined by the radiochemical purity of the source. The $K \cdot A_s$ product turns out to be superior for the 35 keV transition in $^{125}Te$. In this case the final sensitivity after a measuring time, t, to $B_{ax}$ turns out to be:

$$B_{ax} \; \alpha \; (R_0 \cdot t)^{1/4} \cdot (A_s \cdot t)^{1/2}$$

For a 40 shifts collection time at ISOLDE and measured background rates, the final sensitivity turns out to be ~ $10^{-7}$.

Although the sensitivity deteriorates with the background rate only as the 1/4 th power, the high detection efficiency of the setup demands a radiochemical purity of the source of the order of $10^{-12}$ or better. By another auspicious coincidence of nature, the two neighbouring isotopes, $^{124}I$ and $^{126}I$, which are the most likely sources of contamination, are not produced ( due to the stability of $^{124}Xe$ and $^{126}Xe$ ( see Fig.2 ), when the $^{125}I$ source is obtained from a collection of $^{125}Cs$, which is produced at ISOLDE at a near record rate of 2 x $10^{11}$ nuclei per second. Test sources collected at ISOLDE and post-chemically cleaned have achieved the required level of purity.

## III. THE NEUTRINO EXPERIMENT.

The search of a heavy ( 5 to 50 keV ) component of the electron neutrino in the bremsstrahlung experiment is conceptually clear and has been described in detail earlier [10]. We argue here, that the decay of $^{125}I$ is a superior case. The setup consists of a source, an absorber to remove the low energy photons (X rays and 35 keV gamma rays), and a low-background Ge detector. Fig.3 shows a spectrum from a measurement on a test source.

The decay has an effective Q-value of 151 keV, and the spectrum is dominated by the 2P and 3P branches, which are 3.6 keV apart and have an intensity ratio of about 5 to 1.

With reference to previous experiments [10] the improvements we suggest are the following:

1. The count rate in the interesting region (100 - 150 keV) will be increased by at least a factor of ten, as a consequence of a stronger source and a higher detection efficiency. The absorber

thickness will be optimized to keep the total count rate of the detector at such a level, that pile-up is not a problem.

2. The intrinsic background will be reduced significantly due to technological progress made in terms of using low-level materials only in the detector construction.

3. The background contribution from the source will be reduced due to the extreme purity of the source, as described in the previous section.

## IV. CONCLUSION.

We propose to do two experiments on one and the same source:

1. An axion search with a sensitivity ( $B_{ax} \sim 10^{-7}$ ), which is at least an order of magnitude better than present terrestrial limits for axion masses below 35 keV. In case a signal is observed, the mass of the axion can be determined from the "axion isomer shift".

2. A search with a sensitivity of roughly .1 % for the branching ratio of a heavy neutrino with a mass of roughly 5 - 50 keV. This experiment should give conclusive evidence for or against the proposed 17 keV neutrino.

## V. BEAM TIME REQUEST

We request a total of 40 shifts for the periode 1992-93.

## VI. REFERENCES

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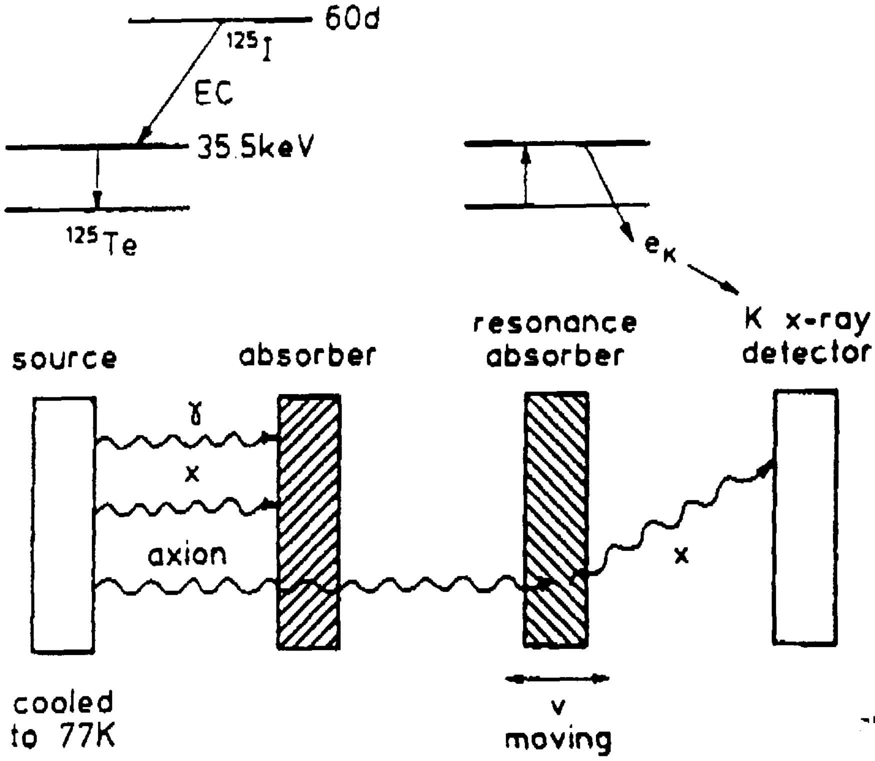


Fig.1 Experimental setup for the axion search.

| | | | | | | |
|---|---|---|---|---|---|---|
| Ba 124 11.9m | Ba 125 3.5m | Ba 126 97m | Ba 127 18m | Ba 128 2.43d | Ba 129 2.2h | |
| Cs 123 5.9m | Cs 124 26.5s | Cs 125 45m | Cs 126 1.6m | Cs 127 6.25h | Cs 128 3.8m | Cs 129 32.06h |
| Xe 122 20.1h | Xe 123 2.08h | | Xe 125 6.8h | | Xe 127 36.4d | |
| J 121 2.12h | J 122 3.6m | J 123 13.2h | J 124 4.15d | J125 60.14d | J126 13.0d | |
| | Te 121 16.8d | | | | | |

Fig.2 The relevant part of the nuclide chart around $^{125}I$

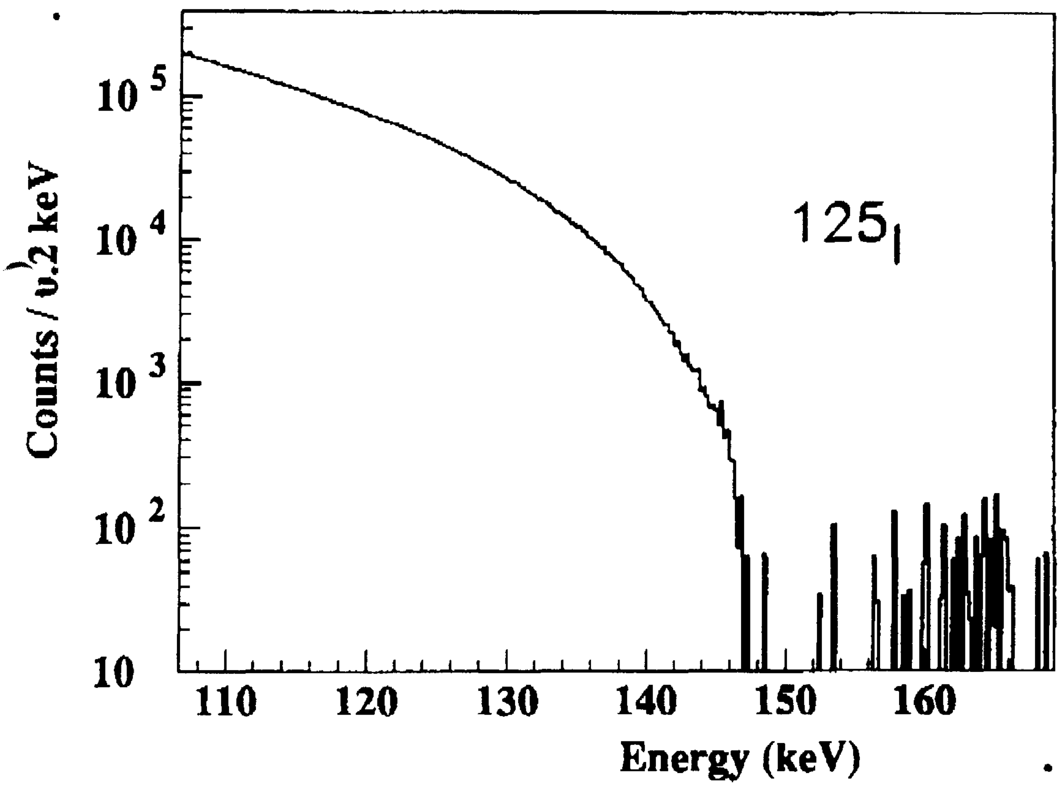


Fig.3 The high energy part of the bremsstrahlung spectrum from the decay of $^{125}I$.