

PROBING FUNDAMENTAL INTERACTIONS BY AN ELECTROSTATIC ION BEAM TRAP*

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(Received January 4, 2013)

Our work focuses on precision measurements of β - ν correlation from the β -decay of ${}^6\text{He}$ by the use of an innovative ion trapping device, the Electrostatic Ion Beam Trap, which incorporates the radioactive ion beam, ion trapping, ion bunching, and a radiation detection system. Production of ${}^6\text{He}$ radioisotopes would be carried out by the use of neutron-induced reactions and for the ionization an Electron Beam Ion Trap would be used.

DOI:10.5506/APhysPolB.44.647

PACS numbers: 23.20.En, 23.40.Bw, 27.20.+n, 37.10.Ty

1. Introduction

One of the possibilities to study fundamental interactions and the underlying symmetries is via precision measurements of the parameters of β -decay of trapped radioactive atoms and ions. For example, determining the β - ν angular correlation coefficient in a trap can probe the minute experimental signal that originates from possible tensor or scalar terms in the weak interaction, thus probing possible new physics of beyond-the-standard-model nature [1]. For precision measurements of this correlation traps are mandatory since the recoiling nuclei, subsequent to the β -decay, are at sub-keV energies. The advantage in using radioactive isotopes is that once the isotopes are produced, a more or less table top experiment can be performed to study aspects of fundamental interaction physics, in a complementary manner to studies at the high-energy frontier, like at large colliders as the LHC.

* Presented at the Zakopane Conference on Nuclear Physics “Extremes of the Nuclear Landscape”, Zakopane, Poland, August 27–September 2, 2012.

In recent years there have been numerous experiments [1, 2] with trapped radioisotopes for β - ν correlation measurements. Here we describe a novel technique for β -decay studies using an Electrostatic Ion Beam Trap (EIBT) [3]. The advantage of an EIBT in the current context is the ability to have the ions as a beam which enhance the accuracy of the ion kinematics as well as a large free field region that simplified the detection configuration. Another major advantage of the EIBT is that it can be used to study practically any radioactive isotope, unlike other existing setups (*e.g.* magneto-optical trap). Moreover, the long storage times (few seconds) simplifies for studying ${}^6\text{He}$ having a half-life of $\tau = 807$ ms. ${}^6\text{He}$ decays via β^- to ${}^6\text{Li}$ and to an anti-neutrino. The β -decay transition rate W (inverse lifetime) in case of a non-oriented nucleus is given by [4]

$$dW \propto \xi \left\{ 1 + a_{\beta\nu} \frac{\vec{P}_e \cdot \vec{P}_\nu}{E_e E_\nu} + b \frac{m_e}{E_e} + \dots \right\} \propto \xi \left\{ 1 + \frac{P_e}{E_e} a_{\beta\nu} \cos \theta_{e\nu} + \dots \right\}, \quad (1)$$

where $a_{\beta\nu}$ (β - ν correlation coefficient), b and others are the β -decay coefficients. E_e , \vec{P}_e , E_ν , \vec{P}_ν are the energies and momenta of the electron and neutrino. For a pure Gamow-Teller decay as in the case of ${}^6\text{He}$ ($J^\pi = 0^+ \rightarrow J^\pi = 1^+$), the expected angular correlation coefficient is $a_{\beta\nu} = -1/3$. Any deviation from the prediction of $-1/3$ may indicate physics beyond the Standard Model [1].

2. Experimental details

The initial and necessary step for the ${}^6\text{He}$ production scheme [5], Weizmann Institute Radioactive Electrostatic Device (WIRED), consists of a D + T neutron generator, producing 14 MeV neutrons that impinge on a hot (1500 K) porous BeO target. As a result ${}^6\text{He}$ is produced via the ${}^9\text{Be}(n, \alpha){}^6\text{He}$ reaction. The ${}^6\text{He}$ atom diffuse into an EBIT where they are ionized, accumulated and bunched [6, 7]. The ion bunch is then accelerated (~ 4 keV), steered, focused and injected into the trap chamber where β -decay studies are performed. The beam-line is maintained at a pressure of 10^{-7} – 10^{-8} mbar, and the trap chamber is pumped from below by a cryogenic pump to $\sim 10^{-10}$ mbar. The set-up termed as WIRED and various components of the set-up are depicted in Fig. 1.

The EIBT was developed at the Weizmann Institute of Science in 1996 for storing ions at typical energy of few keV. The principle of operation of an EIBT is based on the analogy to classical optical resonator: here ions bounce back and forth between electrostatic mirrors. Each mirror consists of a set of eight electrodes and produces a retarding field which reflects the beam along its path and focuses it on the lateral direction. Ions with kinetic energy of ~ 4 keV are injected through the grounded entrance mirror, when the ions

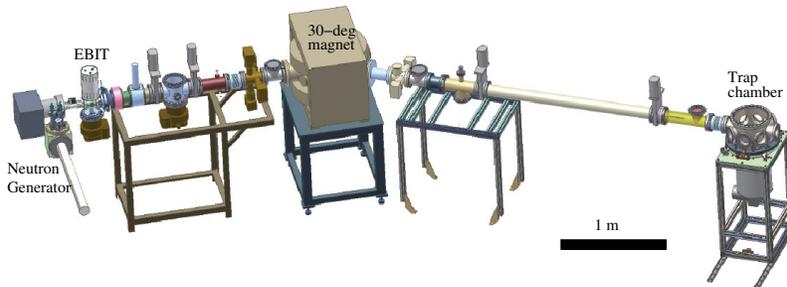


Fig. 1. Computerized drawing of Weizmann Institute Radioactive Electrostatic Device.

fill the trap; potentials on the entrance mirror are quickly raised (< 50 ns) so that the ions oscillate back and forth between the mirrors. For ${}^6\text{He}^+$, the revolution time is $\sim 2 \mu\text{s}$. A pick-up electrode is used to continuously monitor the bunch location. The details of the detection techniques of the recoils are described elsewhere [8, 9].

2.1. Simulation results

Extensive simulations of the relativistic kinematics of the β -decay of ${}^6\text{He}$ in the EIBT, including all realistic parameters of the experimental set-up, have been carried out using the GEANT4 [10] Monte-Carlo code. The simulations provide the energy and angular dependencies of outgoing particles by considerations of the total 3-body energy, momentum conservation and

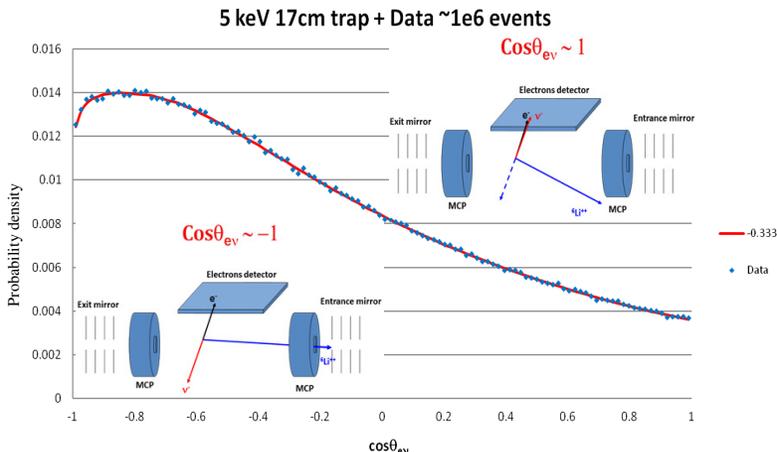


Fig. 2. Results of GEANT4 simulations of a realistic geometry for the β -decay of ${}^6\text{He}$ in the EIBT using a ${}^6\text{He}$ bunch length of 10 mm, at a kinetic energy of 5 keV. The slight distortion of the linearity in $\text{cos}\theta$ dependence around $\text{cos}\theta = 1$ and $\text{cos}\theta = -1$ is due to losses out of the MCP and through the annular hole respectively.

the physics of the β -decay process. The second order corrections introduce additional energy and angular dependencies for the β -decay parameters. However, for an energy average, in the ${}^6\text{He}$ β - ν correlation coefficient $a_{\beta\nu}$ those dependencies are rather weak [11]. Therefore, the β -decay rate for ${}^6\text{He}$ has linear dependence to the β - ν correlation coefficient $a_{\beta\nu}$. Figure 2 presents a realistic simulation of the β - ν correlation for the geometry of the trap and detector dimensions and characteristics. $a_{\beta\nu}$ is deduced from a fit of the experimental spectrum to a linear combination of the two probability density functions considering pure axial ($a_{\beta\nu} = -1/3$) and pure tensor ($a_{\beta\nu} = +1/3$) couplings.

3. Present status

Presently, the entire beam line has been assembled and have started test measurements of trapping and bunching stable ${}^4\text{He}^+$ and ${}^4\text{He}^{++}$. The 14-MeV neutron generator, furnace and the EBIT are expected to arrive by the first quarter of 2013. Preliminary measurements with stored ${}^6\text{He}$ are expected by mid 2013. The details of the set-up and its various progressive phases are reported earlier in Refs. [8, 9].

This work has been supported by the Israel Science Foundation and by the Bi-national US–Israel Foundations (BSF).

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