An ion trap for β-delayed neutron spectrum measurement

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Abstract

A Beta decay Paul Trap (BPT) has been constructed at Argonne National Laboratory for the precise beta decay measurement. We have demonstrated the capability of producing and transferring a low-energy, bunched, and isotopically pure ions beam. In the trap, ions are cooled to sub-eV energies, and confined in a volume of less than 1 mm^3.

The trap has an open geometry which allows four sets of radiation detectors covering a substantial potion of solid angle. In combination with Microchannel Plate (MCP) detector and plastic scintillator detector, BPT is able to measure the beta delayed neutron spectrum to 1% level.

1. Introduction

Beta delayed neutron is emitted by an excited state of a nucleus immediately following beta decay. This is likely to happen when the decay leaves the daughter nucleus in an excited state that is above the neutron separation energy. The neutron emission is delayed by the beta-decay half-life of the precursor, which is on a time scale of slow enough to be controlled by human reaction. The yield of the delayed neutrons is only about 1 percent of the prompt neutrons, but they are very important for the design and operation of nuclear reactor control systems [1]. Therefore, reliable and accurate data of beta delayed neutron processes are needed.

The neutron's lack of total electric charge makes it difficult to measure. The common method of detecting a charged particle by looking for a track of ionization does not work for neutrons directly.

BPT bypasses measuring neutron directly, by detecting the recoiling nucleus. From the Time-Of-Flight (TOF) of recoiling daughter ions, neutron spectrum can be reconstructed. ^{137}I has been trapped in BPT and data taking is still undergoing.

2. Ion Trap System

The ^{137}I is produced at Argonne National Laboratory from a 2mCi ^{252}Cf source. The deceleration, cooling and bunching of the ^{137}I ions are performed at Canadian Penning Trap injection system (Fig. 1) [2,3]. $^{137}I^{+}$ ions are efficiently loaded (> 90%) to BPT (Fig. 2.1, 2.2), where the measurement is taken.

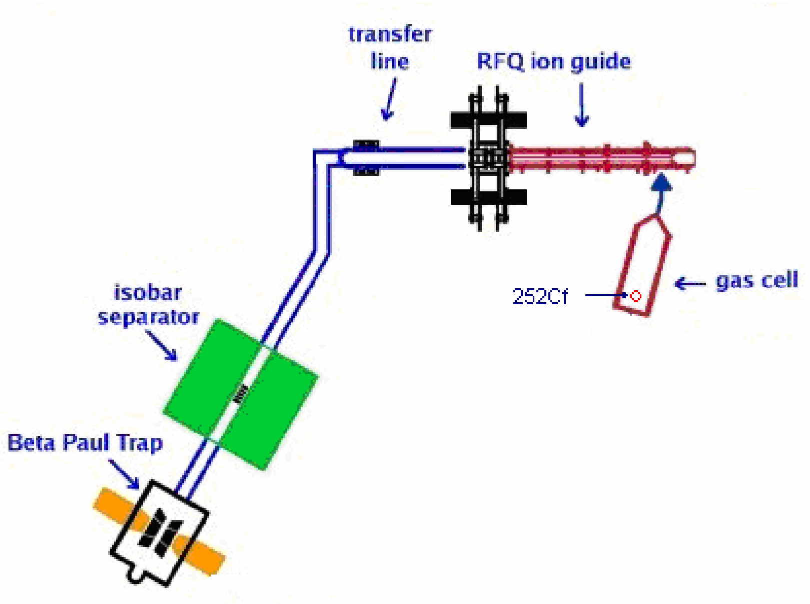
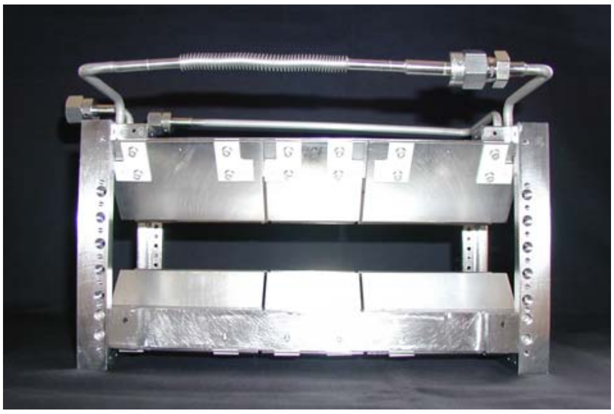


Figure 1 System overview

2.1 The Beta-decay Paul Trap

2.1.1 Ions confinement

The cooled, bunched, and purified $^{137}I^{+}$ ions are loaded to BPT efficiently. Ions are confined with the combination of DC and RF field. In the axial direction, a DC potential well of -90 V are applied on the segmented electrode plates (Fig. 3.1). The depth of the potential well is 2V at the central 1cm region according to the simulation by Simion 7. In the radial direction, the ions are confined by an RF field with peak-to-peak amplitude of 600V at frequency of 264 kHz (Fig. 3.2). A PseudoPotential [4] Well of several volts over 1cm at the center is achieved under such RF condition.



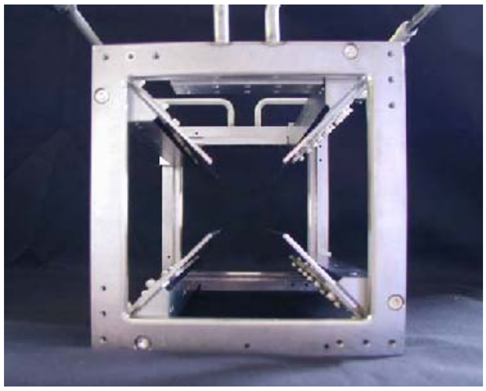
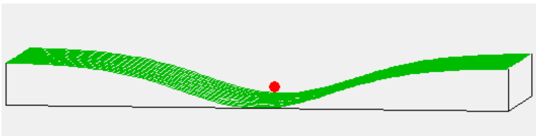


Figure 2.1 electrodes, view of axial direction

2.2 electrodes, view of radial direction



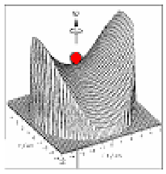


Figure 3.1 Simion simulation: 2V over 1cm

3.2 PseudoPotential : ~5V over 1cm

2.1.2 Cooling

High purity ^{4}He buffer gas is injected to the trap maintaining a pressure ~ 10^{-5} torr in the vacuum chamber to cool the $^{137}I^{+}$ ions. Liquid nitrogen could circulates in the trap frame to further reduce the thermal energy of ^{4}He and $^{137}I^{+}$ below 0.1 eV, which is low enough to let ions be confined within $1mm^{3}$ by electrical potential well. According to the simulation, ions cloud shrinks to $1mm^{3}$ within 40 ms after capture.

2.1.3 Storage

By adjusting the time interval between capture and ejection of ion bunches, and measuring the decay rate of ejected ^{137}I by Si detector, the storage time of the trap is determined to be >30 sec, which is comparable to the ^{137}I decay life time.

2.2 Detection

The detector system consists of two MCP detectors, for ion detection, and two plastic scintillator detectors, for β detection. (Fig. 4). The MCP detectors are in the vacuum. Due to vacuum properties, plastic scintillator detectors sit in the air, and isolated from the vacuum by a thin berillium layer to let low energy electron pass through. An event is triggered by a β signal on any plastic scintillator detector, and the timing difference between the β signal and the MCP signal is recorded. The neutron spectrum can be extracted from the TOF of recoiled ^{136}Xe ion.

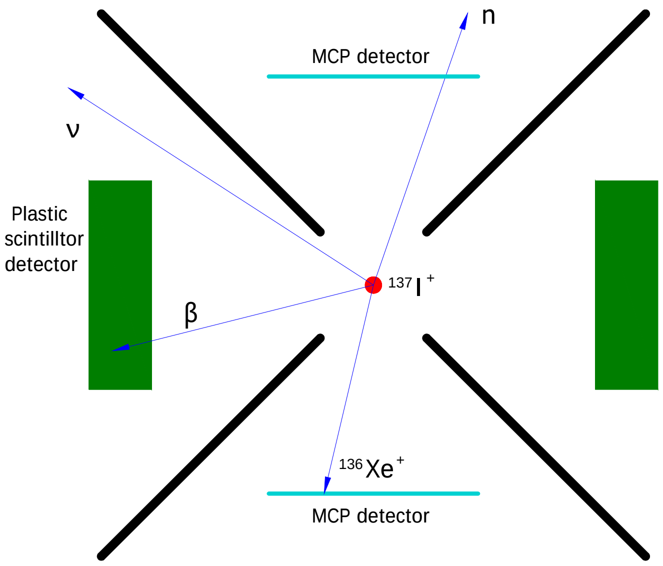


Figure 4 Detector system

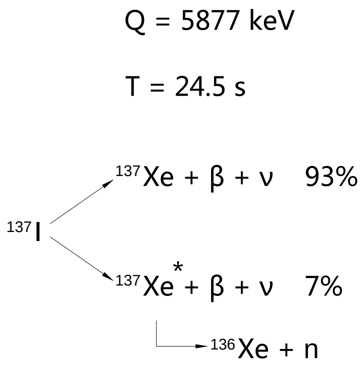


Figure 5 Decay Mode

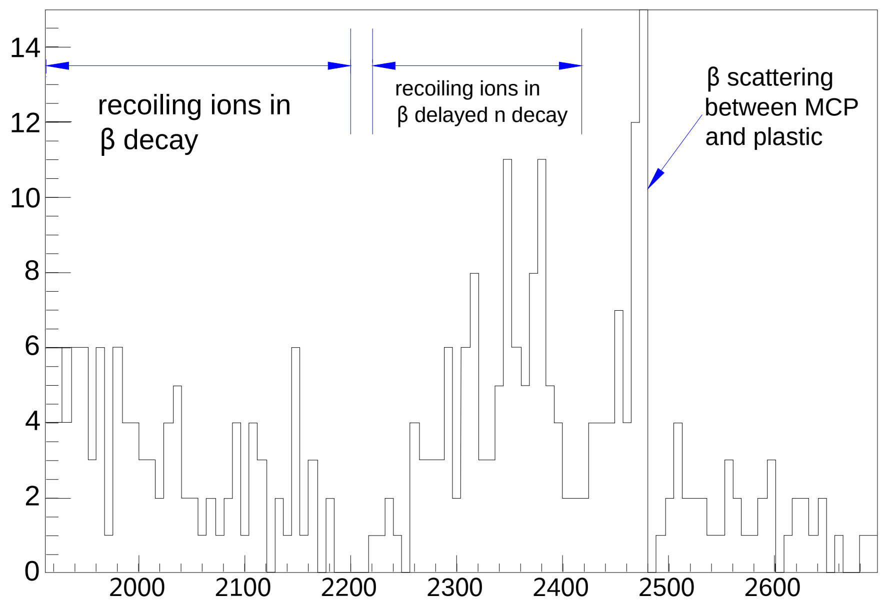


Figure 6 data

Up to now, 100 hours data has been taken with the event rate of about 1 per hour. The β scattering between MCP detector and plastic scintillator indicates the zero TOF position. The recoiling ions spectrum in β delayed neutron decay is clearly showing up.

3. Conclusion and outlook

BPT has demonstrated it's feasibility to measure β delayed neutron spectrum with the TOF technique. The detector timing resolution, ions cloud property and high statistics are the key facts to get a high precision measurement.

The Californium Rare Isotope Breeder Upgrade (CARIBU) [5] at Argonne National Laboratory will provide much higher yields of neutron-rich isotopes. With a 1Ci ^{252}Cf source and a larger gas catcher, CARIBU is able to give 100 times more ^{137}I than the current facility we are using.

In a few months, BPT will be moved to CARIBU, to measure the neutron spectrum with much higher statistics, of ^{137}I, and other isotopes. CARIBU also provides research opportunities in decay data measurement of relevance to AFC applications with emphasis on reactor decay heat.

This work is supported by the U.S. Department of Energy, Lawrence Livermore National Laboratory (Contract DE-AC52-07NA27344), Argonne National Laboratory (contract DE-AC02-06CH11357) and Natural Sciences and Engineering Research Council of Canada.

References

[1] D'Angelo, Progress in Nuclear Energy, Vol. 41, 1, 2002.
[2] J.C. Wang et al., Nuclear Physics A 746 (2004) 651c.
[3] G. Savard et al., International Journal of Mass Spectrometry 251 (2006) 252
[4] H. Dehmelt, Advances in Atomic, Molecular, and Optical Physics 3 (1967) 53.
[5] G. Savard et al., Nuclear Instruments and Methods in Physics Research B 266 (2008), pp. 4086-4091