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The LPCTrap for the measurement of the β-ν correlation in ^{6}He

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Abstract. The application of traps to precision measurements of the β-ν angular correlation coefficient a in nuclear β-decay is pursued by several laboratories world wide. Various nuclear transitions are addressed and different trap devices are used. At GANIL, a novel transparent Paul trap (LPCTrap) has been built downstream from the SPIRAL source to determine a in the pure Gamow-Teller decay of ^{6}He. This transition is driven by the axial-vector interaction. The forbidden tensor interaction may be observed through a precise measurement of a. The LPCTrap consists of an RFQ-Buncher, a transparent Paul trap, and the detection system. It is currently the only facility that uses a Paul trap with a novel geometry to perform high-precision nuclear physics experiments. All the elements have been tested and meet the requirements. In this contribution we give a short status report of the project underlining the highlights achieved so far.

PACS. 23.40.Bw Weak-interaction and lepton (including neutrino) aspects – 24.80.+y Nuclear tests of fundamental interactions and symmetries – 29.27.Eg Beam handling; beam transport

1 The RFQ-Buncher

An RFQ-Buncher is a powerfull tool to improve the quality of radioactive beams required for high-precision experiments [1]. It serves to reduce the emittance and time structure of the radioactive ion beam.

At GANIL, the $^{6}He^{+}$ ions will be delivered in continuous mode, with an emittance of about 80 π mm · mrad. The ions are cooled by collisions with buffer-gas atoms or molecules inside the RFQ-Buncher. After an accumulation time varying from one to a few tens of milliseconds depending on the production rate, the ions are extracted as a short ion bunch ($\Delta t_{\mathrm{FWHM}} \sim 100$ ns, $\Delta E_{\mathrm{FWHM}} \sim 3$ eV) with improved emittance ($\epsilon \approx 10\ \pi$ mm · mrad). The device was tested on-line at LIMBE/GANIL using different combinations of ion species and buffer gases [2]. The highlight from these experiments was the cooling and bunching of $^{4}He^{+}$ ions in H_2 with an efficiency of 5–10%. This is the lighest ion ever investigated in such a device. Figure 1 shows the accumulation time for a production yield of 4 to 5×10^{8} ions/s. This value is close to the expected rate of 3.2×10^{8} ions/s of $^{6}He^{+}$ ions from SPIRAL [3].

The coupling between the LPCTrap and SPIRAL was recently tested using $^{16}O^{+}$ ions transferred at 12.7 keV

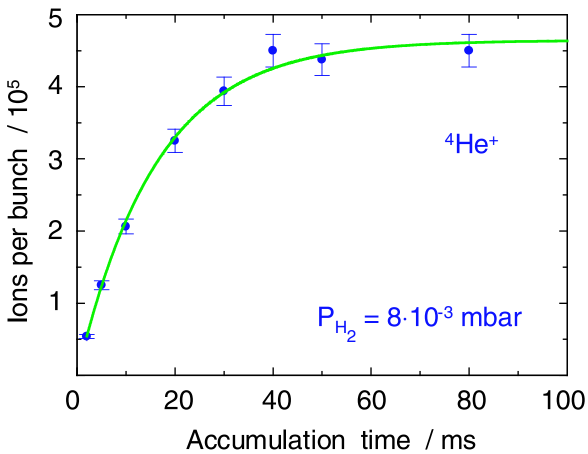

Fig. 1. Accumulation of $^{4}He^{+}$ in the RFQ-Buncher.

through a low-energy beam line (LIRAT). The experimental setup is sketched in fig. 2. The buffer gas was helium since the ionization potential for H_2 (15.4 eV) is close to the ionization potential for O (13.6 eV). Micro-Channel-Plates (MCPs) located at the end of the beam line were used for time-of-flight identification of the extracted ion bunch. The width of the time-of-flight distribution for $^{16}O^{+}$ was $\sim$ 700 ns after slowing down the beam to about 1 keV. This value is high due to the large number of ions stored in the RFQ. The incident $^{16}O^{+}$

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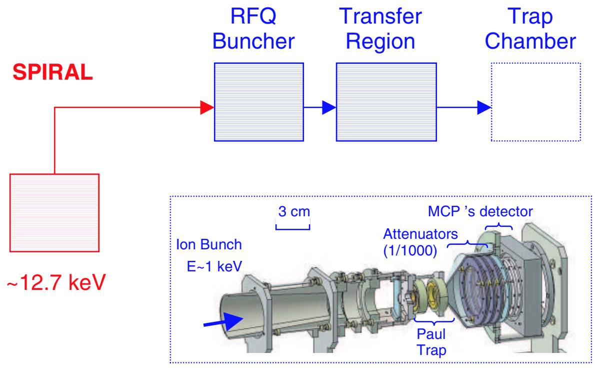

Fig. 2. Sketch of the LPCTrap setup downstream from SPIRAL. Only the components inside the trap chamber (white square) are shown to scale. The ion optics in front of the trap is used to reduce further the energy of the ion bunch before trapping.

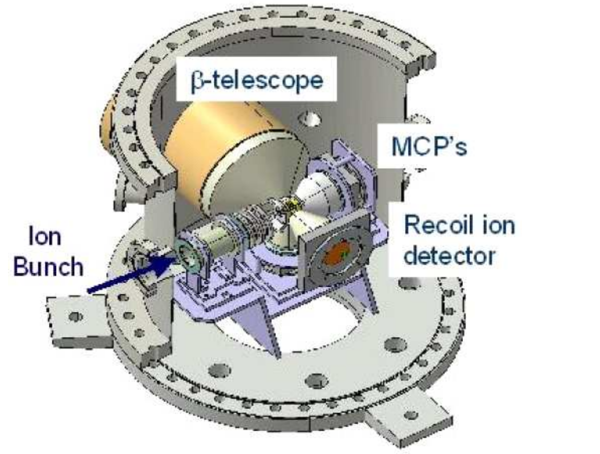

Fig. 3. Trap chamber with the detectors required for the correlation measurement.

current (I_i) was 500 pA. The accumulation time in the RFQ-Buncher was about 2 ms. Thus, the number of injected ions per cycle exceeded the space charge limit of the RFQ-Buncher. In addition, other ion species observed in the time-of-flight spectrum were created inside the RFQ by collisions between the $^{16}O^+$ ions and the background molecules. The extracted ion bunches were collected in a 90%-attenuator plate located in the transfer region between the RFQ-Buncher and the Paul trap. The plate was attached to a pA-meter to read out the current (I_e). The ratio I_e/I_i was 0.09. However, we deduced from the time-of-flight spectrum that the extracted oxygen current was approximately $I_e/2$. Thus, we can conclude that the injection and bunching efficiency measured was about 4.5% in the first test. The next test run with stable ions downstream SPIRAL will be in December 2004. Among other tests aimed at optimizing the efficiency, we also intend to confine the ions in the Paul trap.

2 The transparent Paul trap

The transparent Paul trap is a storage device for the confinement of the decaying $^6He^+$ ions. It is made out of two sets of concentric rings centered on the beam axis (fig. 2). Each set is composed of two rings, inner and outer. The RF voltage ($V_{RF} \approx 120 V_{pp}$ and $\nu_{RF} \approx 1.1$ MHz for $A = 6$) is only applied to the inner rings. The outer rings are grounded except during injection and ejection of the ions. In the trapping configuration the RF voltage generates nearly the same potential as that provided by a hyperbolic Paul trap. However, in the present geometry, an electrode-free region allows the detection of the decay products. Figure 3 shows the trap chamber with the detectors placed around the trap. The use of this trap to confine the decaying source has advantages over other techniques. A sample of about 2×10^4 ions (measured value) can be held almost at rest, at energies below 100 meV, in a small volume (1–2 mm^3) without interaction with matter ($P_{\rm chamber} = 2 \times 10^{-6}$ mbar).

The Paul trap is currently tested off-line using $^6Li^+$ ions produced in a contamination-free ion source located in front of the RFQ-Buncher. After cooling and bunching, the $^6Li^+$ ions are slowed down by means of the ion optics located in front of the trap to about 130 eV ($\Delta E_{\rm FWHM} \approx 3$ eV) and captured in-flight in the trap. The trapping efficiency achieved is 25% (extraction after 500 μs of trapping time). The survival time of the $^6Li^+$ ions in the trap (time constant) is a bit above 200 ms. The trapping of $^6He^+$ will be similar to the trapping of $^6Li^+$ ions.

3 The detection system

The coefficient a will be determined by measuring the time of flight of the recoiling ions in coincidence with the β particles. The detection system consists of MCPs with a delay-line anode for position sensitivity (recoil ion detector) and a β-telescope. The detectors will be placed around the trap in a back-to-back geometry as shown in fig. 3. This geometry gives the maximum sensitivity for the detection of tensor-like interaction through the decay of $^6He^+ (\rightarrow {}^6Li^{++} + \beta^- + \bar{\nu})$.

Systematic investigations have been carried out to charaterize the recoil ion detector [4]. A detection efficiency above 50% has been achieved even for ions in the sub-keV energy range. Furthermore, the value does not depend on the angle of incidence of the ion on the detector. The detector has a temporal and spatial resolution (FWHM) of $\approx$ 400 ps and $\approx$ 120 μm, respectively. The β-telescope comprises a Double-Sided-Silicon-Strip Detector (DSSSD) and a plastic scintillator. The DSSSD has a position resolution of about 1 mm and is currently tested. The plastic scintillator together with a light guide and a photomultiplier has been tested using a ^{22}Na source. The energy resolution is about 10% at 1 MeV.

The efficiency of the system shows that, from the statistical point of view, the proposed experiment is feasible. An experiment is planned for March 2005.

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