Decay using Atom and Ion Traps

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Recent advances in the techniques of atom and ion trapping have opened up a new vista in precision $\beta$ decay studies due to the near-textbook source they provide: very cold ($\lesssim 1$ mK) and localized ($\lesssim 1$ cm$^3$), with an open geometry where the daughter particles escape with negligible distortions to their momenta.

**Atom traps:** Magneto-optical traps (MOTs) have demonstrated the ability to measure the angular distribution of short-lived radioactive neutral atoms. Experiments using MOTs have placed stringent direct limits on a possible fundamental scalar current in the charged weak interaction via a precise measurement of the $\beta - \nu$ correlation parameter, $a_{\beta\nu} \ [1, 2]$. These experiments continue to improve, along with others being developed to extend to other cases (for example, see A. Garcia et al.’s contribution to this workshop on searching for tensor interactions using trapped $^6$He). Techniques are also being developed by the TRINAT collaboration at TRIUMF to highly polarize laser-cooled atoms via optical pumping. A proof-of-principle experiment measured the neutrino asymmetry parameter in $^{37}$K [3], with an improved version planned to take beam at TRIUMF in the summer of 2012. The contributions by J.A. Behr, R.J. Holt and L.A. Orozco to this workshop also describe other physics opportunities available using MOTs.

**Ion traps:** Penning traps of ions are best known for the incredible precision with which they can measure masses: relative uncertainties of $\Delta M/M \simeq 10^{-11}$ have been reported on stable species [4], and $\simeq 10^{-8}$ for very short-lived ($\gtrsim 10$ ms) exotic ions [5]. These mass measurements have impacts in many fields of science, including fundamental physics research (CKM unitarity, testing nuclear models, correlation studies, etc.). Penning traps are also used in other applications, including laser spectroscopy, QED effects, electron-capture studies and the astrophysical r-process, to name a few.

**Opportunities at TReX:** Our group at Texas A&M University are in the process of constructing a new double-Penning trap facility, TAMUTRAP, which will take advantage of the radioactive ion beam capabilities of the upgraded Cyclotron Institute facility, TReX [6]. The layout of the Institute’s cyclotrons and experimental equipment is shown in Fig. 1(a), where the components that are currently being built as part of the TReX upgrade are: re-commissioning the K150 cyclotron to deliver high intensity light particle and heavy ion beams; the light and heavy ion guide systems; the charge-breeding ECR ion source and coupling of it to the K500 cyclotron, to provide high quality re-accelerated rare beams of both neutron and proton rich isotopes in the 5 to 50 MeV/u range.

Figure 1(b) shows the plans for the Penning trap facility in relation to the TReX upgrade. Radioactive beams for TAMUTRAP will be produced using the K150 cyclotron which will provide a high-intensity primary beam that will react with a target in front of “BigSol”, a large-acceptance 7-Tesla solenoid which will separate the desired products from deep inelastic reactions. An Argonne National Laboratory type gas-catcher [7] will collect these products and

![a](a) Floorplan of the Cyclotron Institute showing the accelerators and equipment, including the TReX upgrade components.

![b](b) Coupling of the K150 to the TAMUTRAP facility, including a schematic of the double-trap system and principle behind the $a_{\beta\nu}$ measurement.

**FIG. 1:** Facilities layout for the the Cyclotron Institute at Texas A&M University, including the re-commissioned K150 cyclotron and planned Penning trap facility.
transport them via a dedicated low-energy beamline to TAMUTRAP at \( \sim 10 \) keV (or alternatively to the charge-breeding ECR for post-acceleration in the K500 cyclotron). The ions will be cooled and bunched using a segmented gas-filled RFQ and injected at 80 eV into the double-Penning trap with time and energy-spreads of \( 1.2 - 1.6 \) \( \mu \)s and \( 6 - 10 \) eV, respectively.

Both Penning traps will be housed in the 210-mm bore 7-Tesla superconducting magnet which has been purchased from Agilent Technologies and has been demonstrated to have better than 4 ppm homogeneity at full field. The first trap will be a gas-filled (\( \lesssim 10^{-4} \) mbar) cylindrical Penning trap to (optionally) allow for further purification of the rare ion beam following the gas-catcher. The 2nd cylindrical “measurement” trap will be unique in that it will have the largest diameter (180 mm) of any existing Penning trap. The purpose of this large-diameter bore is for the flagship program which will perform \( \beta - \nu \) correlation studies and \( f t \)-value measurements on \( 0^+ \rightarrow 0^+ \) transitions of the short-lived \( \beta \)-delayed proton emitters \(^{20}\text{Mg}, \quad ^{24}\text{Si}, \quad ^{28}\text{S}, \quad ^{32}\text{Ar} \) and \(^{36}\text{Ca} \). We will start with \(^{32}\text{Ar} \) since its decay has already been studied in detail [8, 9], but the others have similar decay schemes and so can be studied in a similar way. The Larmour radii of the \( \beta \)s from these decays (\( \lesssim 5 \) mm) is much less than the protons allowing good spatial separation of the two when detected by position-sensitive Si detectors placed at either end of the measurement trap (see the schematic zoom-in of the magnet in the bottom-right of Fig. 1(b)). The large bore of our magnet allows for complete radial confinement of up to 4.3 MeV protons, which spans the energies of interest produced in these decays. The shape of the proton’s energy spectrum depends on the value of \( a_{\beta \nu} \) and thus the \( \beta - \nu \) correlation can be investigated in a manner similar to that done by Adelberger et al. at ISOLDE [8] where a precision of 0.5% in \( a_{\beta \nu} \) was reached; one advantage we will have over their experiment is the observation of the \( \beta \)’s energy, as well as separation of events where the \( \beta \) and proton were emitted in the same/opposite hemispheres which will help reduce systematics.

In addition to the superallowed program, the system is being designed to be flexible and allow for other fundamental physics studies, including the ability to perform precision mass measurements. Although not a user facility, the Cyclotron Institute has a long history of collaborating with outside users and we expect that with our existing and planned upgrade for extending our RIB capabilities, that collaborative efforts will continue to be formed with groups interested in using our facilities.

The Intensity Frontier: Both atom and ion traps provide extremely clean sources, so experiments can be performed with relatively small sample sizes owing to the very large signal-to-noise ratio. However, high intensities with relatively long access times to radioactive beams would be extremely advantageous to these experiments: most are systematics-limited, where the systematics are themselves statistics limited; i.e. systematic uncertainties could be considerably reduced if their sources could be investigated and minimized by using dedicated beamtime to characterize and quantify them. The TREX facility at Texas A&M University is not a user facility and so can offer better availability of beamtimes than, for example, FRIB or TRIUMF; however, the larger facilities can provide greater intensities. Ideally, one would like to have a facility that can provide both high intensities and long accessibility of beamtimes. Low-energy nuclear physics programs using both MOTs and Penning traps would be able to capitalize on such a facility and meaningfully add to probes of physics beyond the standard model.