# Safety Report
## Experiment 1057
## Investigation on ground state structure in the mirror pair $^{9}$C-$^{9}$Li

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# 1 Introduction

In the nuclear shell model, the nominal energy ordering of orbitals in the first three excitation levels is $1s_{1/2}$, $1p_{3/2}$, $1p_{1/2}$, $1d_{5/2}$, $2s_{1/2}$, and $1d_{3/2}$. This ordering can determine the properties of stable nuclei up through to $^{40}$Ca. However the relative energy levels of these orbitals can shift. Studies of neutron-rich and proton-rich mirror nuclei have clearly showed that the energy level of the $2s_{1/2}$ orbital can shift dramatically due to the Coulomb energy difference between the two nuclei. Extreme cases indicate the possibility that the energy level of the $2s_{1/2}$ orbital can slip down below that of the $1p_{1/2}$ state.

The neutron-rich and proton-rich T=3/2 pair, $^{9}$C and $^{9}$Li, represent a excellent laboratory to test the possibility of a low lying $2s_{1/2}$ orbital. Both $^{9}$C and $^{9}$Li have filled their $1p_{3/2}$ level respectively with protons and neutrons. However if the $2s_{1/2}$ orbital is low lying for the $^{9}$C case, there is the possibility it could form a significant fraction of the $^{9}$C ground state. This could explain, for example, the anomalous quenching of the $^{9}$C magnetic moment.

If one proton could be removed from $^{9}$C and similarily one neutron from $^{9}$Li, the resulting T=1 pair, $^{8}$B and $^{8}$Li, could reveal the ground state makeup of $^{9}$C and $^{9}$Li from noting which excited states of $^{8}$B and $^{8}$Li are present. If the $2s_{1/2}$ orbital does play a significant role in the $^{9}$C ground state, the removal of a proton from a $2s_{1/2}$ orbital will leave the resultant $^{8}$B in a negative parity excited state. Removal from a $1p_{3/2}$ or a $1p_{1/2}$ orbital would leave behind a positive parity state. There is a hint that the $2s_{1/2}$ orbital is low lying for the $^{9}$C configuration as evidence has been reported for a $2^{-}$ state at 3.5 MeV in $^{8}$B. There does not seem to be a mirror state in the analog nucleus $^{8}$Li. They are all positive parity. The lack of a mirror $2^{-}$ level would be an indication of broken isospin symmetry.

The experiment proposes to remove one nucleon from $^{9}$C and $^{9}$Li through the isospin equivalent reactions $^{2}$H($^{9}$C,$^{3}$He)$^{8}$B and $^{2}$H($^{9}$Li,$^{3}$H)$^{8}$Li. The $^{3}$He and $^{3}$H will carry the spectroscopic information of which $^{8}$B or $^{8}$Li states are excited. Isospin symmetry requires that the same T = 1 states be present in both $^{8}$B and $^{8}$Li. The degree of difference between the energy level spectra is indicative of the amount of isospin breaking. The presence of a $2^-$ state in $^8$B, which has no analog $^8$Li state, would indicate direct isospin breaking and the degree to which the $2s_{1/2}$ orbital plays a role in the $^9$C ground state.

# 2 Description of the Experiment

The experiment will take place in two phases, one with radioactive $^9$Li and $^8$Li beams, and one with a radioactive $^9$C beam. This report focuses exclusively on the first phase of the experiment, which will take place between 17 and 28 August 2006 and employ only Li beams. The location of the experiment will be the TUDA facility in the ISAC-I hall. The experiment will use S2 and LEDA silicon strip detectors. The configuration of these detectors has been used before in the E1031 $^{12}$C-$^{12}$C fusion run of April 2006. The E1057 configuration is shown in the figure. The beams required for this experiment are 2+ $^9$Li, 2+ $^8$Li, 4+ $^{18}$O, and 4+ $^{16}$O. The latter two are stable beams used to establish tunes for the radioactive species. The energy required for the $^9$Li run is 1.68 MeV/u or 15.12 MeV. In order to have some guidance on the exit channel parameters, there will be an elastic scattering run using a $^8$Li beam at two different energies, 1.6 MeV/u (14.4 MeV) and 1 MeV/u (9 MeV).

The target ladder was used in the previous TUDA experiment, E1056. The target will be a self supported foil of 100 $\mu$g/cm$^2$ of $(CD_2)_n$. The layout for the target ladder is shown in the figure.

The dominant backgrounds in this experiment will come from elastic scattering of Li on carbon. The ion energies for these events are different from those from deuterium and can be separated from the desired signal. There will also be background from the radioactive beam decays. The decay chain for $^9$Li is $^9\mathrm{Li}(\beta^-)^9\mathrm{Be(n)}^8\mathrm{Be}\rightarrow 2\alpha$. The $\beta$ particles will have a rather low pulse height signal in the detectors and no timing correlation with the RF. These should be easily distinguishable from good events. The two $\alpha$ decays will be quite inconvenient. However TDC-RF correlation and background subtraction should reduce this background to a manageable level.

Normalization for the experiment will be done in two ways, one of which requires a new device which is presently being installed behind the TUDA chamber as is shown in the attached figure. The device is a channeltron supplied by the beam diagnostics group. It will be mounted in a standard ISAC diagnostics box clamped to the TUDA stand. It works by inserting a metal target in the beam line to intercept and stop the beam. Secondary emission electrons will be knocked out of the surface and pulled toward the channeltron by an electric field created by the application of the appropriate bias. The channeltron is essentially one element of a micro-channel plate which acts like a dynode chain in a photo-multiplier. The electron current emerging from the channeltron can be amplified, discriminated, and counted. It should operate in the flux range of this experiment, $10^6$ pps. Although we don't plan to use high-intensity beams for tuning, the diagnostic box will be equipped with a faraday cup for current integration, which can be used if the metal foil used for a channeltron target is removed. The other normalization method is simply counting the elastically scattered Li ions using the forward Si detectors.

The TUDA acquisition system is VME based and capable of acquiring data from up to 512 electronic channels, which is more than enough for the proposed setup (max.

Table 1: Radiation fields observed around TUDA in $\mu$Sv/hr for a $^{8}$Li beam flux of $2{\times}10^{7}$ s$^{-1}$

| Collimator | FCUP | distance(m) |
|---|---|---|
| 1700 | >2000 | contact |
| 50 | 100 | 0.5 |
| 10 | 30 | 1.0 |

320). The VME DAQ is also capable of handling up to 20 kHz event rate and again this should be more than sufficient for this experiment. The data will be acquired online event by event allowing cuts and coincidence requirements to be applied offline as necessary. The data being acquired will be monitored online using a Sun workstation to verify beam and target status and detector/electronics stability. The electronics and the data aquisition system that will be used is the fairly standard TUDA setup, and except for some minor modifications and upgrades, has been used for all the previous TUDA experiments. The present electronics setup and DAQ was used as recently as July 2006 for the E1056 $^{7}$Li($^{8}$Li,$^{7}$Li)$^{8}$Li experiment.

# 3 Safety Concerns

The present experiment is almost a standard TUDA setup except for the channeltron box, and should have no real safety issues other than RIB. The HV bias supplied to the current integrators comes via a interlocked current-limited power supply that runs with or without beam. Running ethanol in the preamp chiller was approved for previous experiments. The instrumentation for the channeltron is still in a state of evolution, and cannot be commented on at this point. It involves HV, but hookup is viewed to be similar to that of the bias shields for E1031 which was run in April 2006. The channeltron is a low current device and the HV P/S will be current limited. Thus the probability of even a mild electric shock, the sort that would cause only discomfort and present no serious risk of injury, should be low. There are no substantive safety concerns for this experiment apart from the radiation fields produced by the decay of the beam.

The upcoming experimental run will utilize fluxes of $10^{6}$ s$^{-1}$ of $^{9}$Li and up to $5{\times}10^{6}$ s$^{-1}$ of $^{8}$Li. The recent Loveland experiment, E1023, has shown that such high fluxes of $^{9}$Li are readily available. Except for the neutron decay, the decay chain of $^{9}$Li, $^{9}$Li($\beta^{-}$)$^{9}$Be(n)$^{8}$Be$\rightarrow 2\alpha$, is similar to that of $^{8}$Li in that for each case a high energy electron can be emitted (13.59 MeV endpoint for $^{9}$Li and 12.96 MeV for $^{8}$Li). Hence the expected beta and gamma fields of $^{9}$Li can be predicted from the July 2006 E1056 $^{8}$Li run at TUDA. The table gives the results of radiation surveys conducted during E1056.

The requested $^{9}$Li beam flux will be down a factor of 20 from the E1056 beam flux. Hence the expected radiation fields due to $\beta$ decays and the associated bremsstrahlung will be a factor of 20 lower than what is stated in the table. At 1m from the chamber, the expected fields will be well below the 10 $\mu$Sv/hr limit for casual occupancy.

In 50% of the decays, where the $^9$Li does not beta decay into the $^9$Be ground state, the excited $^9$Be state will distintegate into a neutron and two alpha particles via an intermediate $^8$B state. The alphas are no problem as they cannot exit the chamber. However the neutrons emitted can have some radiological consequences. In 44% of the decays neutrons of about 0.7 MeV will be emitted and in 4.5% of the decays the neutron energy will be about 7.7 MeV.

Fortunately there are measurements of the radiological effects of these neutron decays. Surveys conducted during experiment E1023 reported 65 $\mu$Sv/hr at two meters and zero degrees from the beam stop for a beam of 1.5 ppA of $^9$Li. The requested beam flux for E1057 is 0.15 ppA, down by a factor of 10 from experiment E1023. Hence the neutron radiation fields are expected to be 1/10 as large as those in E1023, and will therefore be more easily manageable.

The maximum $^8$Li beam flux will be 1/4 of that delivered to experiment E1056. Therefore we expect that the radiation fields will not exceed 1/4 of those measured during E1056. Of course, the $^8$Li beam does not decay by neutron emission, so the neutron radiation field will not be hazardous during this part of the experiment.

The safety procedure for this experiment follows. The area surrounding the TUDA chamber will be barricaded to prevent access within 2 m of the TUDA beam dump and the beamline FCUP (FC4) during the initial beam tuning. Once the $^9$Li tune of $10^6$ pps is established, field measurements will be done for:

1. The beamline faraday cup, FC4, intercepting the beam.
2. The TUDA beam dump intercepting the beam. This situation has 2 cases:
   (a) Empty target ladder location in the beam, channeltron foil intercepting.
   (b) $(CD_2)_n$ target in the beam, channeltron foil intercepting.

Gamma, beta and neutron monitors will be used in the measurements. Case 2(b), with the $(CD_2)_n$ and channeltron foil targets in place, will be the normal running condition. A detailed survey will be done for this case and barricades and notices will be setup accordingly.

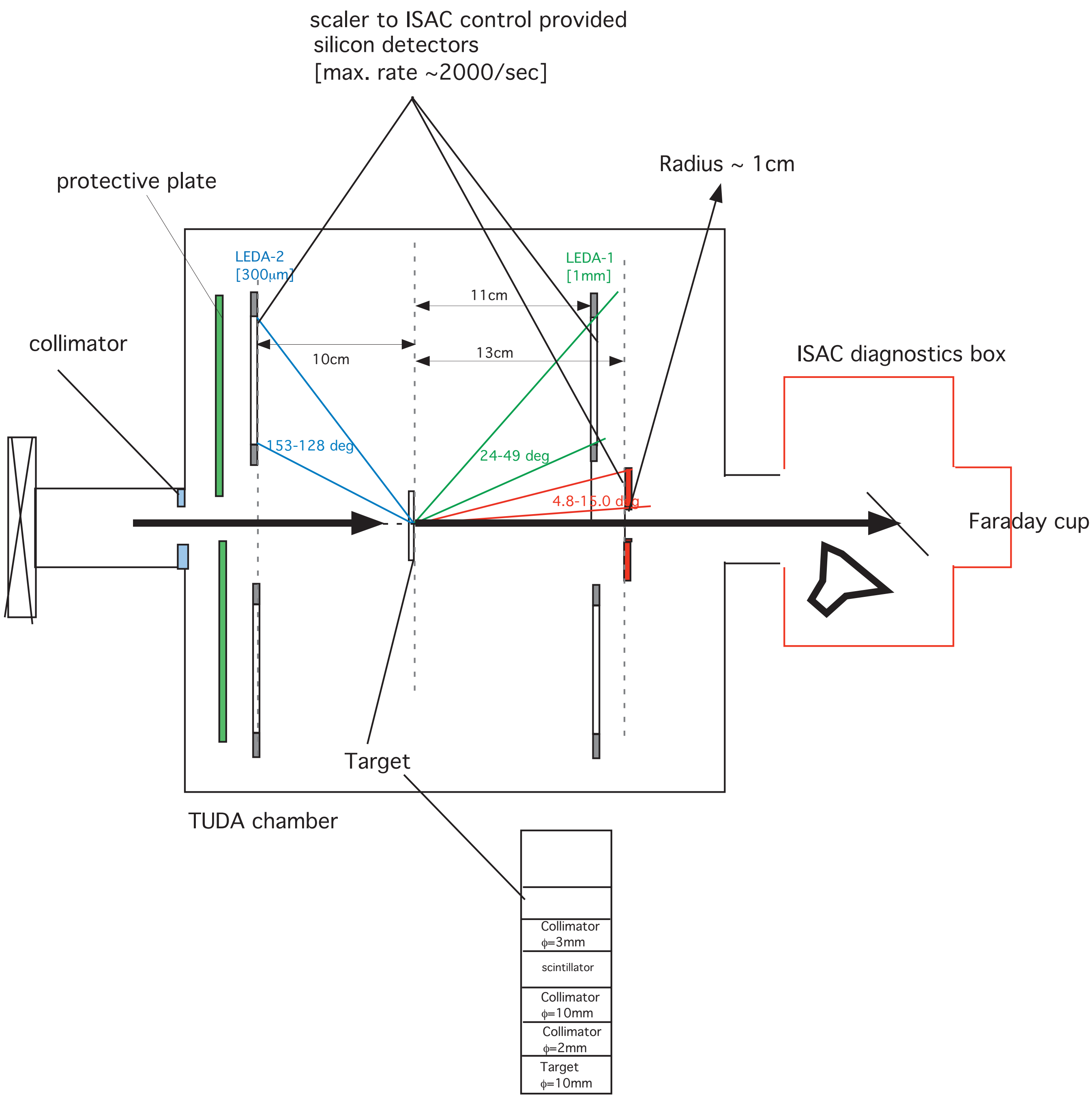


Figure 1: Schematic depiction of the E1057 setup.