TRIUMF - RESEARCH PROPOSAL	**Experiment no.** E1074	**Sheet** 1 **of** 13

Title of proposed experiment

Ground state mass determination of the halo nucleus ^{11}Li

Name of group

TITAN

Spokesperson for group

Jens Dilling and Fred Sarazin

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F. Buchinger	McGill	Lecturer	30%
B. Moore	McGill	Professor	30%
G. Gwinner	U. of Manitoba	Professor	40%
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L. Bromley	McGill University	M.Sc. Student	80%
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J. Vaz	TRIUMF	Post-doc	100%
V. Ryjkov	TRIUMF	Post-doc	100%

Date for start of preparations: Summer 2006

Date ready: Aug. 2006

Completion date: date

Beam time requested:

12-hr shifts	**Beam line/channel**	**Polarized primary beam?**

6 12h shifts of stable ^{7}Li at 30 keV from OLIS

4 12h shifts of ^{11}Li at 30 keV from ISAC

SUMMARY

The halo occurrence observed in light neutron-rich nuclei, such as ^{11}Li, is among the most exciting phenomena observed far away from stability. It is a remarkable behavior from the nuclear physics point-of-view, but more generally it is an example of quantum behavior in a microscopic few-body system, where some of its weakly bound components are venturing (tunneling) beyond the binding potential of the core. Since the first experiment pointing out the extended nature of the ^{11}Li nucleus [TAN85], much work both experimentally and theoretically (see [JEN04] for a recent review on halo physics) have been performed to study and to understand the halo nature of ^{11}Li (and other nuclei). The halo phenomenon was first suggested by Hansen and Jonson [HAN87]. In their simple model, they link the extended matter radius of ^{11}Li to the weak binding energy of its last two neutrons (S_{2n}). The matter radius decays as an exponential with a length equal to $\hbar/(2\mu S_{2n})^{1/2}$. Although more advanced models now exist, the binding energy of ^{11}Li remains a key ingredient of those models and the calculated matter radius is still (very) sensitive to the two-neutron separation energy. With models of increasing complexity, it is highly desirable to measure the mass of ^{11}Li within a few hundred eV.

BEAM and SUPPORT REQUIREMENTS	**Sheet** 3 **of** 13

Experimental area

TITAN
ISAC I

Primary beam and target (energy, energy spread, intensity, pulse characteristics, emittance)

Secondary channel

Stable ^{7}Li from OLIS at 30 keV of at least $1 \cdot 10^{5}$ ions/s
^{11}Li from ISAC at 30 keV of at least $1 \cdot 10^{4}$ ions/s

Secondary beam (particle type, momentum range, momentum bite, solid angle, spot size, emittance, intensity, beam purity, target, special characteristics)

TRIUMF SUPPORT:
Summarize all equipment and technical support to be provided by TRIUMF. If new equipment is required, provide cost estimates.

NOTE: Technical Review Forms must also be provided before allocation of beam time.

NON-TRIUMF SUPPORT:
Summarize the expected sources of funding for the experiment.
Identify major capital items and their costs that will be provided from these funds.

SAFETY	**Sheet** 4 **of** 13

Summarize possible hazards associated with the experimental apparatus, precautions to be taken, and other matters that should be brought to the notice of the Safety Officer. Details must be provided separately in a safety report to be prepared by the spokesperson under the guidance of the Safety Report Guide available from the Science Division Office.

Taking the ISAC ^{11}Li beam in continuous mode gives a neutron field around the beam dump (be this the RFQ or Penning trap) of 10μSv/Hr at 0.5m. This requires general flagging and ideally borated paraffin shielding, as used at E996 (GSI experiment).

General TITAN safety (HV).

(A) Scientific Motivation:

The halo occurrence observed in light neutron-rich nuclei, such as ^{11}Li, is among the most exciting phenomena observed far away from stability. It is a remarkable behavior from the nuclear physics point-of-view, but more generally it is an example of quantum behavior in a microscopic few-body system, where some of its weakly bound components are venturing (tunneling) beyond the binding potential of the core. Since the first experiment pointing out the extended nature of the ^{11}Li nucleus [TAN85], much work both experimentally and theoretically (see [JEN04] for a recent review on halo physics) have been performed to study and to understand the halo nature of ^{11}Li (and other nuclei). The halo phenomenon was first suggested by Hansen and Jonson [HAN87]. In their simple model, they link the extended matter radius of ^{11}Li to the weak binding energy of its last two neutrons (S_{2n}). The matter radius decays as an exponential with a length equal to $\hbar/(2\mu S_{2n})^{1/2}$. Although more advanced models now exist, the binding energy of ^{11}Li remains a key ingredient of those models and the calculated matter radius is still (very) sensitive to the two-neutron separation energy. With models of increasing complexity, it is highly desirable to measure the mass of ^{11}Li within a few hundred eV.

Last year, the MISTRAL collaboration (based at ISOLDE – CERN) reported at the ENAM'04 conference [BAC04] the first precise mass measurement of ^{11}Li from which they extracted the S_{2n} of the two halo neutrons.

While the MISTRAL measurement does not appear particularly anomalous, it is about 76 keV away from the 2003 Atomic Mass Evaluation (AME) [AUD03], which corresponds to a change of about 20% of the binding energy of the two halo neutrons. As the MISTRAL measurement is so much more precise than the other existing measurements, it is expected to pin down the mass and the S_{2n} for ^{11}Li in the next mass compilation. A possible issue here is that the next generation of halo models may be based on a single precise experimental determination of the ^{11}Li binding energy. And, in this context, it is worth noting that a preliminary and unpublished ^{11}Li mass measurement at MISTRAL made in 2002 placed the mass of ^{11}Li within the limits of AME'03 with a precision of ±25keV [LUN03].

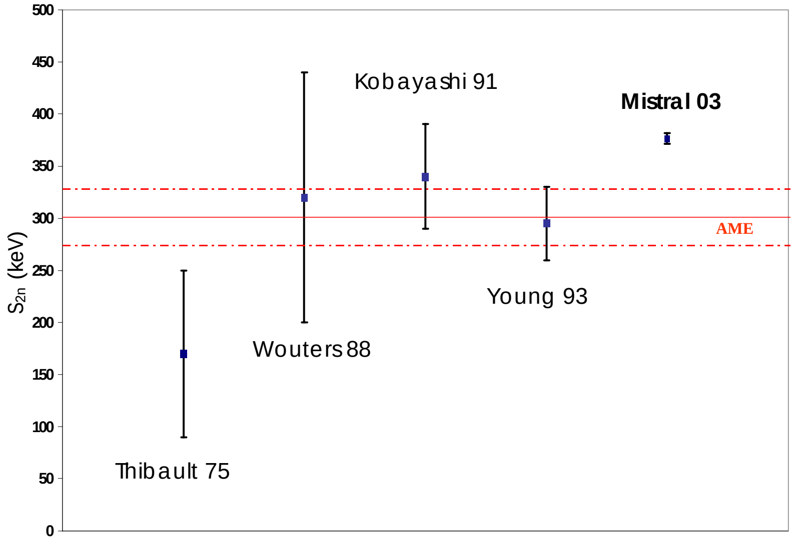

Figure 1: Comparison of the various S_{2n} (mass) measurements for ^{11}Li (from [BAC04])

This 2002 measurement is about 3σ away from the present MISTRAL estimate. It therefore makes sense that a measurement with a similar precision using a different experimental setup should be undertaken to confirm the MISTRAL measurement. It is also important that this new measurement could be performed in a timely manner, as the binding energy of ^{11}Li is a key ingredient in so many models, some of them based on new experimental results. For example, the charge radius of ^{11}Li can be deduced from the total isotope shift for ^{11}Li, which was recently measured at TRIUMF-ISAC [NOR05a]. The ^{11}Li binding energy is here needed to calculate the mass dependent isotope shift, which is subtracted to the measured total isotope shift to give the ^{11}Li charge radius. The effect of the new mass measurement by MISTRAL is quite dramatic (35% change) [NOR05b]. We propose to use the TITAN facility at ISAC/TRIUMF to measure the mass of ^{11}Li by using the superior ^{11}Li yield available at ISAC.

References:

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(B,C) Description of the measurement technique and the experimental procedure

A detailed description of the TITAN facility and the experimental procedure is given in the EEC proposal "High accuracy mass measurements for superallowed nuclear β-decay emitters".
A schematic of the TITAN facility is shown in figure 2 below.

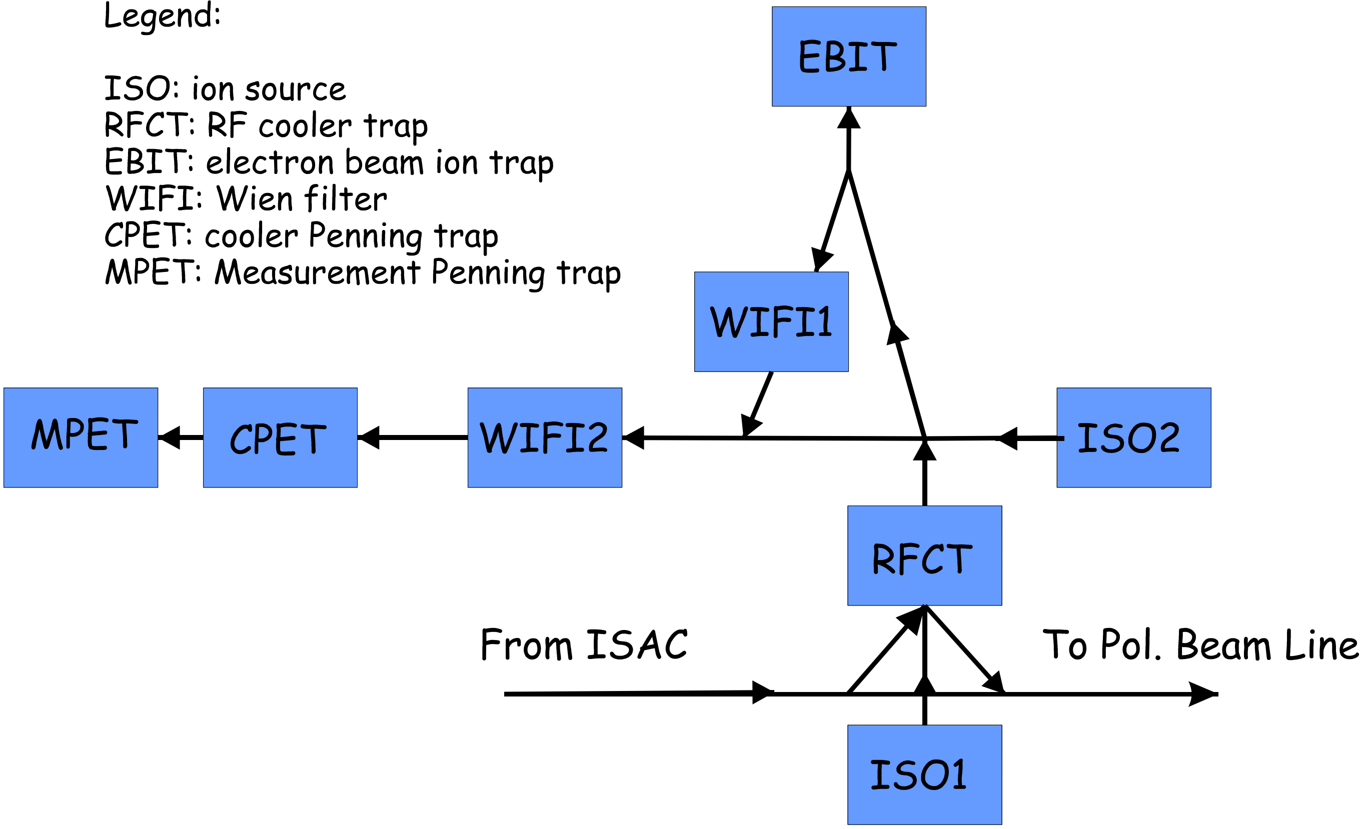

Fig. 2 Schematic of the TITAN setup.

The presently available production rate of ^{11}Li available at ISAC-TRIUMF (about 44,000 ^{11}Li per second measured at the yield station) makes it possible to measure its binding energy, despite its 8.6ms half-life. For a mass determination in a single charge state, a relative accuracy of $\delta m/m \approx 5 \bullet 10^{-8}$ at an exitation time of 20 ms and with a total cycle number of N= 10 000, could be reached. In this case, a single charge state would be sufficient, since only a factor of 3 is gained, and losses due to the breeding process can be avoided. Also additional filtering is not needed, since the Li beam is extremely clean. The absolute mass uncertainty would be 550 eV.

The procedure would include the bunching and cooling of Li in the TITAN RFQ, which is filled with helium gas. Since the He und Li masses are rather close, higher losses due to hard-sphere collisions are anticipated. These collisions scatter the charged Li ions either out of the RF-phase and lead to unstable trajectories, or the scattering leads to collisions with the RFQ rod structure directly.

Instead of the regular 50 % transmission for the RFCT, a conservative number of 1% is assumed. The remaining ions bypass the EBIT and go through WIFI2, where a moderate suppression of contamination can be achieved. Production of contamination could arise from charge exchange processes in the RFCT.

Moreover, since no charge-breeding is foreseen, the Li ions could be directly transferred into the measurement trap (MPET), hence the experiment could be done, even without the cooler Penning trap (The cooler trap will be brought to TRIUMF spring 2007. It is presently being designed, built and tested at the University of Manitoba).

(D) Readiness

The TITAN facility is presently under construction and first on-line measurements are planned for the second half of the year 2006. At that time the system will be without the Cooler Penning Trap (CPET). However, measurements of isotopes such as Li are possible and could be carried out at that stage.
The system and procedure could be tested in an ideal way, by providing Li beam from the off-line OLIS ion source and establish the transfer efficiency, including the cooling in the RFCT. Moreover the mass of ^{7}Li is known to 80 eV or $\delta m/m = 2 \cdot 10^{-10}$ and therefore can be used to calibrate the magnetic field of the measurement Penning trap.

(E) Beam request

We request six 12h-shifts of stable ^{7}Li at 30 keV from the off-line ion source.
Once the procedure is established and sufficient accuracy and transfer efficiency is achieved the request for ^{11}Li would be 4 shifts. During the ^{11}Li run, beam-time would be required from the off-line source for field calibrations. The ^{7}Li beam would be needed for approximately 20 min each every 4 h.

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