TRIUMF - EEC SUBMISSION EEC meeting: 200807S *Original Proposal*	TRIUMF	**Exp. No.** S1191 - *Pending (Stage 1)* **Date Submitted:** 2008-06-09 10:07:11

Title of Experiment:

Precision Mass Measurements of Proton-Rich Aluminum Isotopes

Name of group:

TITAN

Spokesperson(s) for Group

V. Ryjkov, J. Dilling

Current Members of Group:
(name, institution, status, % of research time devoted to experiment)

V. Ryjkov	TRIUMF	Research Associate	50%
J. Dilling	TRIUMF	Research Scientist	50%
M. Brodeur	University of British Columbia	Student (Graduate)	20%
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A. Lapierre	TRIUMF	Research Associate	20%
D. Lunney	TRIUMF/IN2P3	Senior Research	20%
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Beam Shift Requests:

Basic Information:

Date submitted: 2008-06-09 10:07:11

Date experiment ready:

Summary:

The proton rich ^{23}Al and ^{22}Al, are believed to have very small proton separation energies. They are therefore considered candidates for proton halos. We propose precision mass measurements of these nuclides to determine the unknown proton-separation energy of ^{22}Al and improve that of ^{23}Al by an order of magnitude. We are also planning to improve the knowledge of other proton rich Aluminum isotope masses with direct mass measurements, in particular ^{24}Al.

Plain Text Summary:

Summary of Experiment Results:

Primary Beamline: isac2a

ISAC Facilities

ISAC Facility: TITAN Yield

ISAC-I Facility:

ISAC-II Facility:

Secondary Beam

Isotope: Al22, Al23, Al24, Al25 (RIB) Al27, Mg24, Mg2

Energy: 30

Intensity Requested: >10^2

Minimum Intensity: >10^2

Maximum Intensity: 10^7

Energy Units:

Energy spread-maximum:

Time spread-maximum:

Angular Divergence:

Spot Size: 1

Charge Constraints:

Beam Purity: 5

Special Characteristics:

Experiment Support

Beam Diagnostics Required:

Signals for Beam Tuning:

DAQ Support:

TRIUMF Support: All equipment is in place and running. Only normal operating support from TRIUMF is required.

NSERC:

NSERC:

Other Funding:

Muon Justification:

Safety Issues: Safety issues for the TITAN experiment have been already addressed in the required documents and have met approval. A safety request for the specific beams of this proposal will be made after the decision of the EEC.

TRIUMF EEC NEW RESEARCH PROPOSAL

Detailed Statement of Proposed Research for Experiment # S1191

PRECISION MASS MEASUREMENTS OF PROTON-RICH ALUMINUM ISOTOPES.

Spokespersons: V.L. Ryjkov and J. Dilling for the TITAN collaboration.

Abstract: The proton rich ^{23}Al and ^{22}Al, are believed to have very small proton separation energies. They are therefore considered candidates for proton halos. We propose precision mass measurements of these nuclides to determine the unknown proton-separation energy of ^{22}Al and improve that of ^{23}Al by an order of magnitude. We are also planning to improve the knowledge of other proton rich Aluminum isotope masses with direct mass measurements, in particular ^{24}Al.

Please use text in 12 point font and add extra pages. Note, however, that the EEC Committees strongly recommend that you limit your submissions, including figures and tables, to no more than 4 pages for the MMSEEC and 10 pages for the SAPEEC. The following information should be included:

(a) **Scientific value of the experiment**: Describe the importance of the experiment and its relation to previous work and to theory. All competitive measurements at other laboratories should be mentioned. Include examples of the best available theoretical calculations with which the data will be compared.

One of the new exciting phenomena appearing in the nuclear systems far away from the beta stability region is the occurrence of nuclear halos. In these exotic *halo* systems the valence nucleon(s) is mostly outside of the core nucleus. The first nuclear halo, in ^{11}Li halo, was identified on the neutron-rich side of the nuclear chart by its unexpectedly large reaction crossection[1]. Since then the halo occurrence in nuclear and other quantum systems has been extensively studied[2,3]. It was determined that for the halo structure to occur, two conditions have to be fulfilled: a) the binding energy of the valence nucleon(s) has to be small; b) the wavefunctions of the valence nucleons need to have low angular momentum[3]. The latter condition arises from the fact that the repulsive centrifugal potential was found to suppress the halo formation. Similarly, the repulsive Coulomb interaction also has a negative effect. The predicted theoretical trends have been so far confirmed: studies of many neutron rich halo candidates have supported halo occurrence in many of them. However, on the proton rich side the results have not been quite so clear. The most studied case has been ^{17}Ne, for which theoretical and experimental evidence is somewhat contradictory[4] .

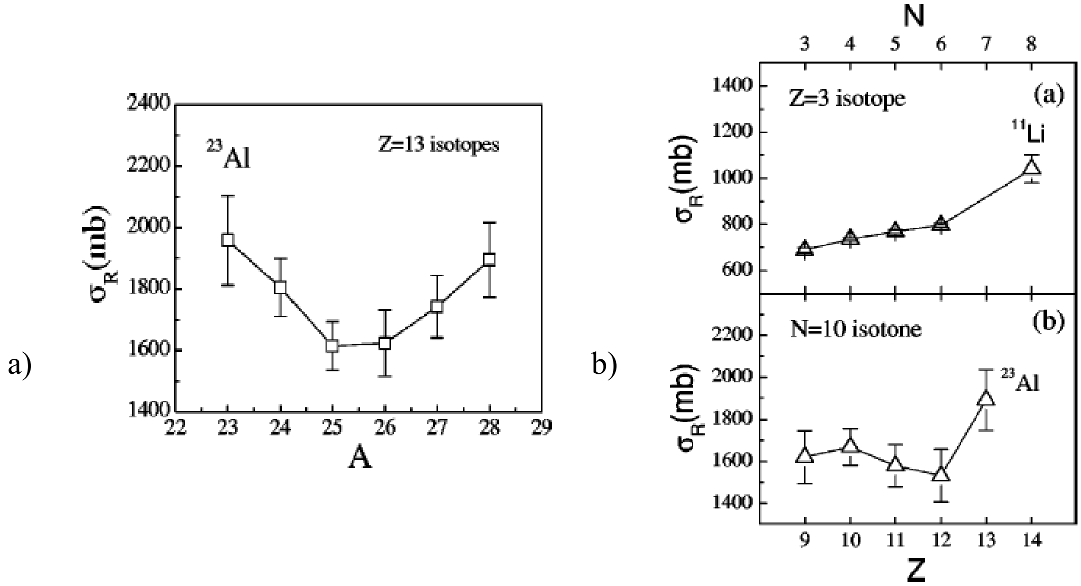

Figure 1. Reaction cross-section measurements of nuclei neighboring ^{23}Al. a) Reaction cross-sections of different Aluminum isotopes. b) Cross-section increase along the N=10 isotone chain. Cross-section measurements along Z=3 isotope chain that includes ^{11}Li halo nucleus is shown for comparison. Data from Ref.6.

Halo structure in ^{23}Al. Recently, reaction cross-section measurements were performed in the region adjacent to the proton rich Aluminum isotopes[6,5,7] (see Figure 1). A significant increase was observed for the ^{23}Al nucleus when compared to its isotonic and isotopic neighbors. This increase was interpreted as the presence of a one-proton halo in ^{23}Al. The simple shell model expectation for the nuclear structure of ^{23}Al is that the valence proton occupies the $d_{5/2}$ shell, and therefore no halo is present due to the large angular momentum (l=2). At the same time halo formation could still be possible if there is a $s_{1/2} - d_{5/2}$ level inversion due to large nuclear deformation[8]. Glauber model calculations have also shown that a large admixture of $s_{1/2}$ wavefunction is required to reproduce reaction cross-section data[5]. At the same time, β-decay[9] and β-NMR[10] studies of the ^{23}Al nucleus have determined the ground state of ^{23}Al to have 5/2+ angular momentum and parity. This implies a $d_{5/2}$ state for the valence proton and therefore, no halo, due to large angular momentum. No measurements have been made so far that would investigate halo structure in ^{22}Al.

Mass measurements of ^{22}Al and ^{23}Al. In addition to the angular momentum of the valence proton, its separation energy is a very strong indicator of the halo formation. The available proton-separation energy data of ^{22}Al[11,12] and ^{23}Al[13-15] is listed in Table 1. In the case of ^{23}Al, the two reaction data are in good agreement with each other, as well as the IMME prediction for the ground state mass excess. However, there are no mass measurements of ^{22}Al. The combination of the two extrapolation methods produces a rather wide range of values for the possible proton-separation energy. It is also quite remarkable that this range does not exclude the possibility of the more neutron-deficient isotope having same or even a more strongly-bound valence proton. This goes against single nucleon separation energy systematics seen everywhere on the nuclear chart. This striking feature also supports very exotic structure in ^{23}Al. Since removing a neutron from ^{23}Al has very little, if any, effect on the valence proton separation energy, it suggests that they belong to different parts of the nucleus. The possibilities include a halo structure or proton skin if the removed neutron belongs to the core, or a well-separated cluster structure, i.e. a "nuclear molecule".

Table 1. Proton-separation energy data of the halo candidates of this proposal. Note that there is no experimental data for ^{22}Al.

Isotope	Method	Ref.	Value, keV
^{23}Al	IMME evaluation	14	147 ± 6
	^{24}Mg(^{7}Li,^{8}He)^{23}Al	13	119 ± 28
	^{28}Si(^{3}He,^{8}Li)^{23}Al	15	125 ± 25
^{22}Al	IMME evaluation	11	248 ± 99
	AME 2003 extrapolation based on systematic trends	12	20 ± 90

Additional considerations. ^{23}Al structure is also important in astrophysics for explaining lack of ^{22}Na production in novae, since it could be part of an escape channel from Ne-Na proton capture cycle via ^{22}Mg(p,γ)^{23}Al channel. Also, preparation work is underway to conduct collinear spectroscopy and ground state moment measurements on the aluminum isotopes. Such experiments will provide information on the proton distribution (size and deformation) in these nuclei. Knowing the mass of the isotopes is crucial for properly extracting the charge size information from the isotope shift data. The mass of ^{25}Al is fairly well known from several different (indirect) reaction measurements. Nevertheless, it is beneficial to compliment the reaction measurements with a direct mass measurement. Moreover, the mass of ^{24}Al is deduced from a single ^{24}Mg(p,n)^{24}Al reaction measurement conducted in 1969. For the isotope shift measurements it is imperative to have a precise value of ^{24}Al mass, particularly since the reaction cross-section data of the aluminum isotopes shows an increase for this isotope (see Figure 1). This increase suggests that significant structure changes along this isotopic chain.

(b) **Description of the experiment**: Techniques to be used, scale drawing of the apparatus, measurements to be made, data rates and background expected, sources of systematic error, results and precision anticipated. Compare this precision with that obtained in previous work and discuss its significance in regard to constraining theory. Give a precise list of targets to be used in order of their priority.

The TITAN facility is operational and has conducted its first mass measurements of short-lived isotopes[16]. So far, we have established the overall systematic uncertainty of 5×10^{-8} when operating under wide range of conditions, and in some cases down to few ppb. For the isotopes in this proposal, their masses need to be established with precision of at least 5 keV. This corresponds to the relative uncertainty of 2×10^{-7}, well within the capability of TITAN. In terms of production yields, measurements with as little as a few thousand per second were already conducted, and with half-lives as short as 8.8 ms (^{11}Li).

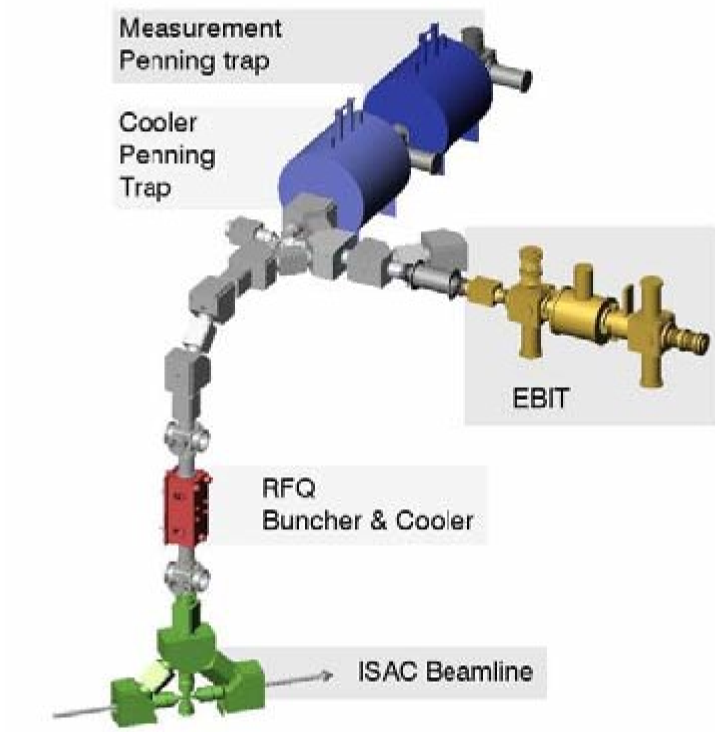

Figure 2. TITAN experimental setup. The radioactive/stable beam is delivered from ISAC beamline into the RFQ gas filled cooler/buncher. So far only the Penning trap has been connected to the TITAN RFQ and received both stable and radioactive ions from it. The EBIT charge breeder is to be commissioned in August 2008. The Cooler Penning trap is under construction and the University of Manitoba.

The system is constantly being improved, and we believe that we can measure isotopes with even lower yields than we previously demonstrated (a few hundred pps are within reach of the system).

Yields for proton rich aluminum isotopes are largely unknown, as Table 2 indicates. Of available ISAC targets, SiC target is expected to have the highest in-target production yield. So far, on the proton rich side the yields of the ground and metastable states of ^{26}Al were measured, and an attempt to determine the yield of ^{25}Al was made. However large ^{25}Na isobaric contamination made the latter yield measurement impossible. Also, yields of several short-lived Aluminum isotopes were measured on the neutron-rich side. Based on the yield measurements[17,18] and in-target production expectations it was determined that release properties of the SiC target are not optimal for the production of short lived Aluminum isotopes. However, given the ability of TITAN to conduct mass measurements using very low rate beams, it is possible that even release-suppressed yields would be sufficient for a mass measurement. Other ISAC targets that could be suitable for this measurement include Ta HP target, TiC HP target and the actinide target currently under development. Yield and isobar suppression measurements should be conducted to determine the best target for this measurement.

Table 2. Expected yields for isotopes to be measured, as well as other proton-rich aluminum isotopes, including the isobaric contaminants expected to be present. The Aluminum isotope in-target production yield includes surface ionization efficiency factor of 13% demonstrated with TRILIS laser ionization source.

Isotope (half-life)	Yield estimates and SiC in-target production estimates.	Isobaric contaminant (half-life).	Isobar mass separation, estimated yield at peak.
^{22}Al (100ms)	>10^2 (2×10^7)	^{22}Na(2.6 years)	880, 1.2×10^{12} ##
		^{22}Mg(3.9 s)	1100, ~10^7
^{23}Al (470ms)	~10^3 (4×10^8)	^{23}Na(stable)	1300, ~10^{12}
		^{23}Mg(11.3 s)	1750, 4.8×10^8 ##
^{24g}Al (2.1s)	~10^4 (1×10^{10})	^{24}Na(15 hrs)	2700, 6.5×10^{10} ##
		^{24}Mg(stable)	1600, ~10^{10}
^{25}Al (7.2s)	~10^5 (1×10^{11})	^{25}Na(59 s)	53000, 2.2×10^9 ##
		^{25}Mg(stable)	5400, ~10^{10}
^{26g}Al (~10^6 y)	6×10^{10} ## (1×10^{11})	^{26}Na(1.1 s)	4500, 3.9×10^7 ##
		^{26}Mg(stable)	6000, ~10^{10}

- measured yield

(c) **Experimental equipment**: Describe the purpose of all major equipment to be used.
Details of all equipment and services to be supplied by TRIUMF must be provided separately on the Technical Review Form available from the Science Division Office.

In addition to the TITAN facility, the ISAC yield station will be needed to determine the yields, isobaric contaminants and their suppression by the mass separator. In addition, a quadrupole ion guide under development at ISAC could be involved at the later stage of the proposed experiment to help reduce isobaric contamination.

(d) **Readiness**: Provide a schedule for assembly, construction and testing of equipment. Include equipment to be provided by TRIUMF.

The TITAN setup is operational and ready to perform the measurements outlined above. Preliminary tests of the cleaning of isobaric contamination have demonstrated that contamination in excess of 20:1 can be handled without significant effect on the precision of the measurement.

For the measurements of ^{22}Al and ^{23}Al, sodium and magnesium isobaric contaminants are expected to be present. We fully expect to be able to handle such a cocktail beam in the mass measurement.

To measure the mass of ^{24}Al, it is doubtful that the mass separator can reduce the isobaric contamination to the benchmark 20:1 ratio acceptable for the TITAN mass measurements at this time. For this second phase measurement to proceed, further technical developments are therefore needed. One of such developments is the quadrupole RF guide combined with the laser ionization source currently being constructed by the ion source group. Another way to reduce isobaric contamination is to use other components of TITAN facility as they come online. Two possibilities exist. First, we can use EBIT charge breeder as a Penning trap isobar separator by filling it with low pressure Helium buffer gas. A second option is to conduct the mass measurements on the highly-charged ions and adjust the charge breeding parameters so as to discriminate between the isobars. EBIT is scheduled to be commissioned at the end of Summer 2008. First tests of the ISAC rf quadrupole ion guide are also expected by the end of 2008.

While some of the measurements proposed here require additional technical developments, they are expected to be in place shortly. There is a strong possibility that a significant portion of the proposed measurements can be done immediately. We therefore **request that stage 2 approval is granted for this proposal.**

(e) **Beam time required**: State in terms of number of 12-hour shifts. Show details of the beam time estimates, indicate whether prime-user or parasitic time is involved, and distinguish time required for test and adjustment of apparatus.

Knowing yields and the ability to reduce Sodium contamination to acceptable levels using ISAC mass separator is crucial in determining the readiness of the experiment. We therefore request that beam development time is allocated to this experiment as soon as possible. Below we list the beamtime requested to conduct precision mass measurements of the isotopes in question. Estimated yields from Table 2 were used to determine the beamtime necessary to conduct the measurements.

Purpose	Shifts	Notes
^{22}Al – ^{22}Na, ^{23}Al – ^{23}Na yields and mass separation	4	Determine yields and mass separation for SiC, Ta, TiC and UO2 targets
Startup (beam tuning, TRILIS)	2	
^{23}Al mass measurement	4	
^{22}Al mass measurement	6	
Startup (beam tuning, TRILIS)	2	2nd phase, with improved Sodium suppression
^{25}Al mass measurement	1	
^{24}Al mass measurement	3	
TOTAL	22	

(f) **Data analysis**: Give details and state what data processing facilities are to be provided by TRIUMF.

The data evaluation methods are well developed for the TITAN mass spectrometer system, and all the necessary software tools are available.

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