TRIUMF - EEC SUBMISSION EEC meeting: 201107S *Original Proposal*	**Exp. No.** S1333 - *Pending (Stage 1)* **Date Submitted:** 2011-05-27 10:01:07

Title of Experiment:

Direct mass measurement of beta-delayed two-proton emitter 31Ar

Name of group:

TITAN

Spokesperson(s) for Group

A. Chaudhuri, J. Dilling

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

A. Chaudhuri	TRIUMF	PDF	40%
J. Dilling	TRIUMF	Research Scientist	20%
B. Schultz	TRIUMF	PDF	20%
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S. Ettenauer	University of British Columbia	Student (PhD)	20%
V. Simon	MPI-K Heidelberg	Student (PhD)	20%
M. Simon	TRIUMF	PDF	20%
E. Mané	TRIUMF	PDF	20%
C. Jesch	University of Giessen	Student (PhD)	20%
C. Scheidenberger	University of Giessen	Professor	15%
W. Plass	University of Giessen	Assistant Professor	15%
C. Andreoiu	Simon Fraser University	Assistant Professor	15%
M.J.G. Borge	CSIC, Madrid	Professor	15%

G. Gwinner	University of Manitoba	Associate Professor	15%

Beam Shift Requests:

8 shifts on: TITAN

Basic Information:

Date submitted: 2011-05-27 10:01:07

Date experiment ready:

Summary:

The proton drip-line nucleus ^{31}Ar is a known beta-delayed two-proton emitter and also a candidate for direct two-proton radioactivity. To determine whether ^{31}Ar is a possible ground state 2p-emitter, precise mass and Q-value is required. Mass of ^{31}Ar has never been measured directly. The ground state mass excess was calculated with the Coulomb displacement energy systematics. We propose a direct precision mass measurement of ^{31}Ar using TITAN facility at TRIUMF. This measurement will also allow a test of the Coulomb displacement-energy systematic and the isobaric multiplet mass equation (IMME).

Plain Text Summary: The proton drip-line nucleus 31Ar is a known beta-delayed two-proton emitter and also a candidate for direct two-proton radioactivity. To determine whether 31Ar is a possible ground state 2p-emitter, precise mass and Q-value is required. Mass of 31Ar has never been measured directly. The ground state mass excess was calculated with the Coulomb displacement energy systematics. We propose a direct precision mass measurement of 31Ar using TITAN facility at TRIUMF. This measurement will also allow a test of the Coulomb displacement-energy systematic and the isobaric multiplet mass equation (IMME).

Summary of Experiment Results:

Primary Beamline: isac

ISAC Facilities

ISAC Facility: TITAN Yield

ISAC-I Facility:

ISAC-II Facility:

Secondary Beam

Isotope: 31Ar

Energy: 20

Intensity Requested: 100

Minimum Intensity: 30

Maximum Intensity: 10^7

Energy Units: keV

Energy spread-maximum:

Time spread-maximum:

Angular Divergence:

Spot Size: 5

Charge Constraints:

Beam Purity:

Special Characteristics:

Experiment Support

Beam Diagnostics Required:

Signals for Beam Tuning:

DAQ Support:

TRIUMF Support:

NSERC:

NSERC:

Other Funding:

Muon Justification:

Safety Issues:

TRIUMF EEC NEW RESEARCH PROPOSAL

Detailed Statement of Proposed Research for Experiment # S1333

Direct mass measurement of β-delayed two-proton emitter ^{31}Ar

Abstract

The proton drip-line nucleus ^{31}Ar is a known β-delayed two-proton emitter and also a candidate for direct two-proton radioactivity. To determine whether ^{31}Ar is a possible ground state 2p-emitter, precise mass and Q-value is required. Mass of ^{31}Ar has never been measured directly. The ground state mass excess was calculated with the Coulomb displacement energy systematics. We propose a direct precision mass measurement of ^{31}Ar using TITAN facility at TRIUMF. This measurement will also allow a test of the Coulomb displacement-energy systematic and the isobaric multiplet mass equation (IMME).

(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.

The understanding of the exotic decay modes revealed by the proton-rich nuclei in the vicinity of proton-drip line is important for nuclear structure studies. Recent technological advances in production of radioactive ion beam have contributed to the investigation of the nuclear decay modes in most proton-rich nuclei. One of the particularly interesting decay modes is β-delayed two-proton emission which was first predicted by Goldanskii [GOL80] and was first experimentally observed for ^{22}Al [CAB83]. The β2p decay channel has been observed in nine more nuclei so far; they are ^{23}Si, ^{26}P, ^{27}S, ^{31}Ar, ^{35}Ca, ^{39}Ti, ^{43}Cr, ^{45}Fe, and ^{50}Ni (see review article [BLA08] for detailed discussion). ^{31}Ar is the most-studied nucleus with respect to the β2p decay. A series of experiments to study the β2p-decay branch of ^{31}Ar have been performed in ISOLDE [AXE98, BOR02, FYN00]. Several β2p branches were observed in the decay of ^{31}Ar, the most intense ones proceeding through the isobaric analog state in ^{31}Cl [AXE98]. However the decay mechanism is not yet established with certainty. A proposed decay scheme of ^{31}Ar is shown in figure 1.

Direct two-proton (2p) decay is another exotic decay mode. The direct 2p-decay process was first proposed theoretically by Goldansky [GOL60]. More than 40 years later, the first 2p-radioactivity was discovered in case of ^{45}Fe [GIO02, PFU02]. ^{31}Ar has been also predicted to be a direct two-proton emitter [GOL61]. The nuclei with $S_p>0$ while $S_{2p}<0$ are the possible candidates for the two-proton radioactivity. The 2p-decay rate is extremely sensitive to the two-proton separation energy S_{2p} and hence an accurate determination of this quantity is required [BRO91]. Aysto and Cerny [AYS89] used Kelson-Garvey approach [KEL66] to find that ^{31}Ar (S_{2p}= -191 keV) is an interesting candidate to study with respect to the 2p-emission. However, no experimental evidence was found for direct two-proton decay of ^{31}Ar [BOR87]. Another search was made for two-proton emission from the ground state of ^{31}Ar. No events were observed and

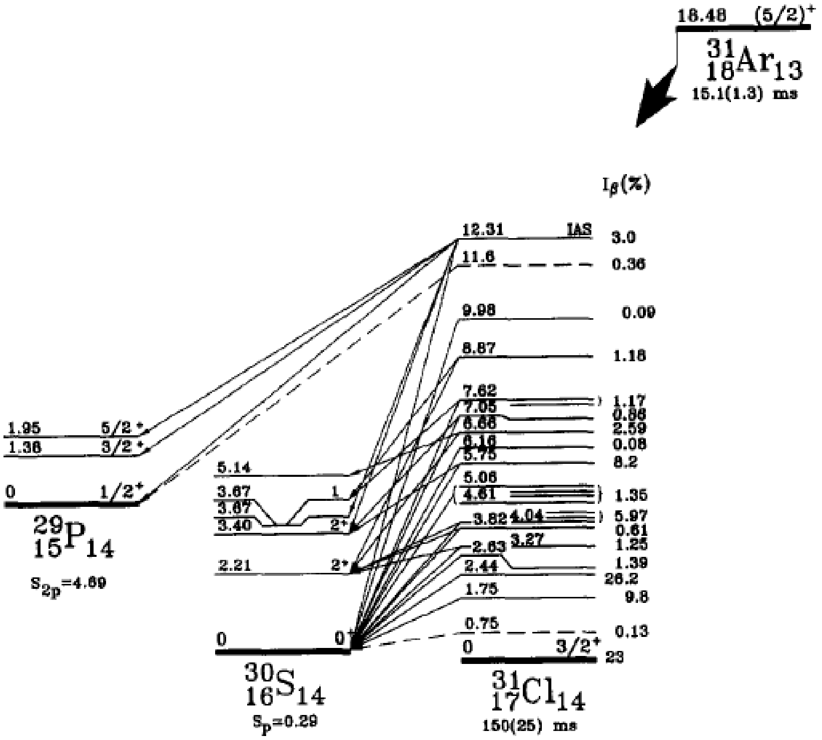

Figure 1: Proposed decay scheme of ^{31}Ar [AXE98a].

the upper limit for the branching ratio was reported 5% [BOR90]. Later the upper limit on the absolute branching ratio for 2p-radioactivity is reported as 6.0 x 10^{-4} [AXE98]. However, the lack of precise mass value of ^{31}Ar prevents from unambiguous determination of the sign of the S_{2p} [see table I].

Table I: Summary of the ground state mass excess and S_{2p} value of ^{31}Ar

Reference	Mass Excess (keV)	S_{2p} (keV)
[BOR91]	11455 (90)	-37 (103)
[BAZ92]	11488 (86)	-70 (100)
[AUD03]	11290 (210)	130 (210)
[AME13]	11294 (206)	127 (212)

The mass of ^{31}Ar has never been measured directly [AUD03]. The mass of ^{31}Ar was indirectly determined by measuring the two-proton energy in the transition ^{31}Cl* [IAS] $\rightarrow$ ^{29}P + 2p [BOR91, BAZ92]. The ground state mass-excess of ^{31}Ar was calculated using the systematics of Coulomb displacement energy given by [ANT86]. The determined mass excess of ^{31}Ar ground state is 11488 (86) keV [BAZ92] and 11455 (90) keV [BOR91] respectively. However, the extrapolated mass excess of ground state ^{31}Ar as reported in AME2003 [AUD03] is 11290 (210) keV. The preliminary value of the mass excess of ^{31}Ar is quoted as 11294 (206) keV in AME2013 [AME13]. A summary of the indirectly determined and extrapolated mass excess and two-proton separation energy of ^{31}Ar are given in table I.

A direct precise mass measurement of ^{31}Ar will pin down the sign of S_{2p} and help to confirm experimentally the possibility of 2p-radioactivity of ^{31}Ar. Also, this measurement will allow a test of the Coulomb displacement energy systematics. Moreover, this measurement also helps to address the questions concerning the validity of the isobaric mulitplet mass equation (IMME) for the most exotic nuclei. An additional cubic term is needed for the A=32, T=2 quintet in IMME [SIG11]. Measuring ^{31}Ar mass, one can check whether the A=31, T=5/2 is consistent with the generally accepted quadratic form in IMME or it needs the additional cubic term [BOR11].

(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.

Penning trap is the instrument of choice for the direct high-precision mass measurement of ^{31}Ar. A charged particle is confined inside a Penning trap by the combination of a strong homogeneous magnetic field and a super-imposed quadrupolar electric field. The magnetic field provides the radial and the electric field provides the axial confinement of the charged particle. The ability to trap the charged particle in a small volume in a well-defined field is the key feature of the Penning trap which makes it most useful for a precision experiment like mass measurements. Penning traps have been widely used as a very accurate tool for high-precision mass measurement of short-lived nuclei in recent years. However, the mass measurement capability of the Penning trap facilities is limited by the half-life of the nuclei to be measured. TITAN [DIL06] at TRIUMF's ISAC facility is the only Penning trap facility capable of the precision mass measurement of ^{31}Ar ($T_{1/2}$=14.4 ms). The unique capability of TITAN facility for the precision mass measurement of short-lived nuclei is already demonstrated by the measurement of ^{11}Li ($T_{1/2}$=8.8 ms), which is the Penning trap mass measurement of shortest-lived nuclei so far [SMI08].

Presently, the TITAN facility (figure 2) consists of three ion traps: (1) a buffer gas-filled radio-frequency quadrupole ion trap (RFQ) for cooling and bunching of ions [SMI06], (2) an electron beam ion trap (EBIT) for charge breeding of the ion to boost the precision of mass measurement [LAP10] and (3) a precision measurement Penning trap (MPET). In addition, an off-line ion source (OIS) for the testing and calibration of the traps and a Bradbury-Nielsen gate for selecting a specific mass-to-charge ratio are in use. A cooler Penning trap (CPET) and a multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS) will be included in the TITAN facility in near future (figure 3).

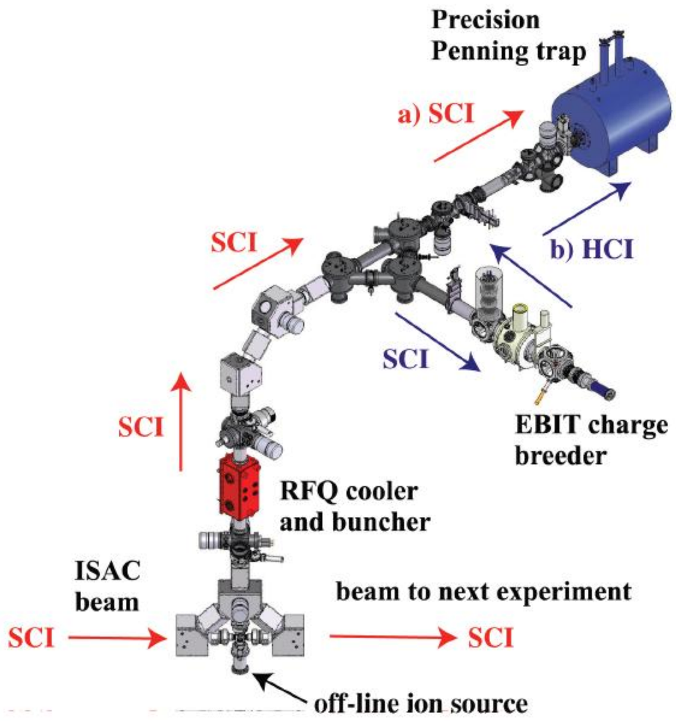

Figure 2: Schematic drawing of TITAN facility [RYJ08].

Radioactive ion beams delivered by ISAC at energy of ~ 20 keV will be cooled and bunched by RFQ during the proposed measurement. The extracted ions will be transferred to a multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS). The MR-TOF-MS will be used during the proposed measurement to clean the isobaric contaminants due to its capability of isobaric separation even within 1 ms. This device is presently being designed and built at the University of Giessen and will be commissioned in TITAN in spring 2012. A mass resolving power of 10^5 has been achieved and isobaric separation has been demonstrated using MR-TOF-MS, ion cooling and mass analysis can be performed in about 1 ms [PLA08].

Next the ions will be transferred to the measurement Penning trap (MPET) where the high-precision mass measurement will take place using the time-of-flight ion cyclotron detection technique [KOE95]. A high-precision mass determination using the Penning trap is carried out by measuring the ion cyclotron frequency $\omega_c = qB/m$, where q/m is the charge-to-mass ratio of the ion and B is the strength of the magnetic field. The mass of the ion of interest is obtained from the comparison of its cyclotron frequency ω_c with that of a well-known reference ion. Due to the short half-life of ^{31}Ar ($T_{1/2}$=14.4 ms) and modest desired relative mass precision of the order of $\delta m/m \sim 10^{-7}$, ions will not be sent to the EBIT for charge-breeding. For short-lived nuclide ^{31}Ar a measurement cycle of 100 Hz repetition rate will be suitable. The feasibility of such measurement cycle has been already tested in TITAN using ^{12}C ion delivered by OLIS. A time-of-flight resonance of that measurement is shown in figure 4. TITAN system is capable of performing measurement at very low yield. A relative mass uncertainty goal in the order of 10^{-7} is possible given statistics.

Contaminants pose great challenge to the high-precision mass measurement in a Penning trap. Non-isobaric contaminants will be taken care by the Bradbury-Nielsen gate. However, we are expecting isobaric contaminants produced by the FEBIAD source. The possible isobaric contaminants and the estimated resolving power needed to separate them from ^{31}Ar beam are listed in the table II.

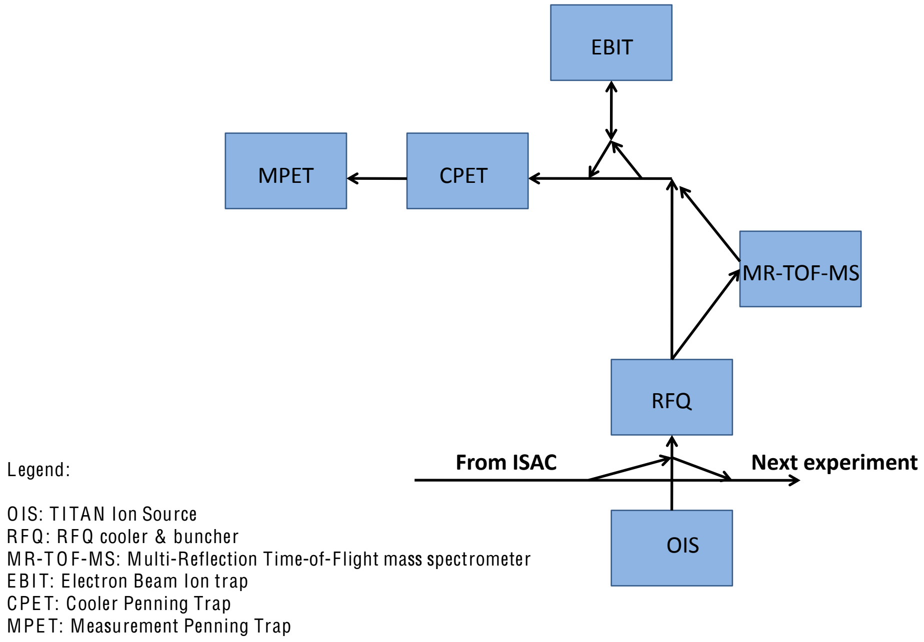

Figure 3: Schematic of TITAN facility in future including CPET and MR-TOF-MS

Due to the shorter half-life of ^{31}Ar, dipole cleaning at the MPET at the cost of additional measurement time will not be done. The isobaric contaminants except ^{31}Na can be cleaned away by the mass separator at the ISAC with a resolving power of about 5000. A multi-reflection time-of-flight mass spectrometer (MR-TOF) will help the isobaric separation of ^{31}Na from ^{31}Ar. Alternatively the target used for the beam production at ISAC can be connected by a cooled transfer line to a plasma discharge ion source. For the production of ^{31}Ar, ISOLDE experiments employed this technique to mainly let gaseous elements through to the ion source and reduce the contamination of Na and K [FYN00, BOR00]. We have discussed with the ISAC beam development group about the possibility of using this method at TRIUMF. We were informed that ISAC beam development group already have a FEBIAD ion source design for a cooled transfer line and they have operated it with a Al_2O_3/Nb target as a test in collaboration with the ISOLDE group [DOM11]. We propose to use this technique for the production of ^{31}Ar beam.

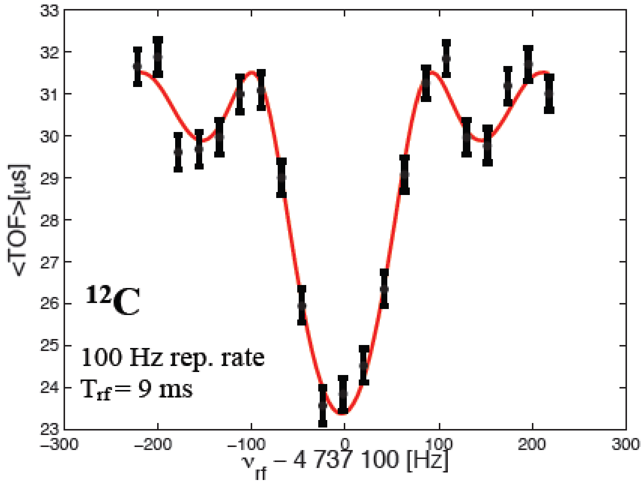

Figure 4: Time-of-flight ion cyclotron resonance of singly-charged ^{12}C for 100 Hz repetition rate measurement cycle [ETE10].

Table II: List of possible isobaric contaminants and estimated resolving power needed to separate them from beam of interest. Mass excess were taken from [AUD03].

Isobaric contaminant	Mass Excess (keV)	Resolving power needed
^{31}Cl	-7070(50)	1600
^{31}S	-19043(1)	1000
^{31}Na	12540(100)	24000
^{31}Al	-14955(20)	1200
^{31}Mg	-3190(17)	2100

(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 set-up, ISAC mass separator to suppress the isobaric contaminants and the ISAC yield station to determine the yields will also be required.

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

The TITAN set-up is fully operational and capable of measurement of short-lived radioactive ions at low yield. However, this measurement will also need MR-TOF which will be commissioned in spring 2012. This experiment could start as early as spring 2012.

(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.

^{31}Ar beam has not been developed at TRIUMF to the date. It is foreseen that ^{31}Ar beam will be developed using TiC target coupled to the FEBIAD source. We request 4 shifts for the measurement and 4 shifts for tuning the set-up including the optimization of isobaric cleaning. We therefore request a total of 8 shifts.

We request stage 1 approval since the requested nuclide needs beam developments.

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

The data analysis methods are well-developed and operational for TITAN mass measurement. All necessary software tools and computers are available.

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