# High-precision mass measurements and in-trap branching ratio measurements at TITAN, TRIUMF

C. Andreiou,[1] J.C. Bale,[2,3] B.R. Barquest,[2] M. Brodeur,[4] T. Brunner,[5] U. Chowdhury,[2,6] S. Ettenauer-Malbrunot,[7] J. Even,[2] A. Finlay,[2,3] D. Frekers,[8] A.T. Gallant,[2,3] G. Gwinner,[5] J. Kelly,[4] R. Klawitter,[2,9] B.A. Kootte,[2,5] A.A. Kwiatkowski,[10] D. Lascar,[2] K.G. Leach,[11] E. Leistenschneider,[2,3] A. Lennarz,[2,8] H. Savajols,[12] B.E. Schultz,[4] R. Schupp,[2,6] D.A. Short,[1,2] and J. Dilling[2,3]

[1]*Simon Fraser University, Burnaby, British Columbia, Canada*

[2]*TRIUMF, Vancouver, British Columbia, Canada*

[3]*University of British Columbia, Vancouver, British Columbia, Canada*

[4]*University of Notre Dame, Notre Dame, Indiana*

[5]*McGill University, Montreal, Quebec, Canada*

[6] *University of Manitoba, Winnipeg, Manitoba, Canada*

[7]*CERN, Geneva, Switzerland*

[8]*Westfälische Wilhems-Universität Münster, Münster, Germany*

[9]*University of Heidelberg, Heidelberg, Germany*

[10]*Cyclotron Institute, Texas A&M University, College Station, Texas*

[11]*Colorado School of Mines, Golden, Colorado*

[12]*GANIL, Caen, France*

Four experiments for TRIUMF's Ion Trap for Nuclear and Atomic Science (TITAN) [1] were scheduled at ISAC-TRIUMF. TITAN comprises three on-line ion traps for high-precision measurements. The Measurement PEnning Trap (MPET) combines electrostatic and magnetic fields to trap ions in a small volume. We measure the cyclotron frequency and thus determine the mass using the Time-Of-Flight Ion-Cyclotron-Resonance (TOF-ICR) technique on radioactive ions with lifetimes as short as 9 ms. The masses are then used to probe nuclear structure, investigate nucleosynthesis, improve the nuclear-physics foundation of neutrino physics, or test fundamental symmetries. To prepare the beam, a linear RadioFrequency Quadrupole (RFQ) ion trap is used to accumulate, cool, and bunch the hot radioactive ion beam (RIB). An Electron Beam Ion Trap (EBIT) can be used to charge breed the beam, thereby improving the achievable precision or reducing beam time requirements. The Helmholtz configuration of the magnet and seven radially placed ports and windows also allow optical access to the trapping volume; seven SiLi detectors are used to measure x-rays from the highly charged ions (HCI). The detectors are part of the TITAN Electron Capture (TITAN-EC) sub-program, wherein the branching ratio of odd-odd intermediate nuclides are measured to benchmark the nuclear matrix elements of two-neutrino double-β decay. Normalization can be done with an in-line PIPS detector or with a germanium detector; the latter is used when the electron beam is used to increase the radial confinement of the radioactive ions.

Decay spectroscopy experiments are encompassed under the approval proposal S1066. In November, the desired species was $^{110}$Ag, which was delivered with overwhelming amounts of $^{110}$In to make it impossible to achieve the science objectives, which were to verify and to improve the precision of the 1965 value [2]. The data taken is under analysis by D.A. Short for his Master's thesis at Simon Fraser University.

The two radioactive mass-measuring experiments focused on nuclides near the neutron dripline to investigate the rapid-neutron-capture or *r*-process which is believed to occur in supernovae and neutron-star mergers and to be the source of elements heavier than iron. S1466 and S1373, “Shell quenching of N=82 shell gap studied through mass measurements of the r-process waiting point $^{130}$Cd nucleus” and “Precise mass measurements of Sr and Rb isotopes in the vicinity of the r-process path,” were thus scheduled sequentially.

Immediately preceding the experiments, a storm caused a site-wide power outage lasting several hours. As a result, several cryogenic systems for the accelerators had to be warmed up and then re-cooled; the ISAC target received substantial thermal shock (decreasing yields); and, the TITAN efficiencies reduced by worsened vacuum and smaller transport efficiencies. These consequences and the loss of beam time reduced the achievable scope of the experiments. The cadmium yields had fallen an order of magnitudes from before and after the power outage; they were insufficient to tune through the RFQ and tune the TITAN system. Based on yield measurements of rubidium and strontium isotopes, we could only be able to re-confirm previous measurements [3,4] and perform none of heavier isotopes. We focused on measuring an isomer in $^{98}$Rb; however, the maximum charge state which could be used with the experimental system under these circumstances led to insufficient precision to resolve the isomer from the ground state.

S1445, “High precision mass measurements for the determination of $^{74}$Rb's *Q*-value,” focused on preparations for the high-precision mentioned in the title ($\delta Q/Q \sim 10^{-9}$) and could not be performed due to a conflict in the beam schedule. The nuclide $^{74}$Rb is the heaviest superallowed $0^+ \rightarrow 0^+$ β emitter, and its short half-life and low production yield pose substantial challenges. This preparatory experiment was envisaged to investigate the charge breeding with krypton from the OfflLine Ion Source (OLIS) under beam-time conditions and ensure the expected gains due to the high charge states could be realized.

[1] J. Dilling, P. Bricault, M. Smith, and H.-J. Kluge, The proposed TITAN facility at ISAC for very precise mass measurements on highly charged short-lived isotopes, Nucl. Instrum. Methods Phys. Res. **B204**, 492 (2003).

[2] L. Frevert, R. Schneberg *et al.*, Zeit. f. Phys. **182**, 439 (1965).

[3] V.V. Simon, T. Brunner, U. Chowdhury, B. Eberhardt, S. Ettenauer, A.T. Gallant, E. Mané, M.C. Simon, P. Delheij, M.R. Pearson, *et al.*, Penning-trap mass spectrometry of highly-charged, neutron-rich Rb and Sr isotopes in the vicinity of A = 100, Phys. Rev. C **85**, 064308 (2012).

[4] R. Klawitter, A. Bader, M. Brodeur, U. Chosdhury, A. Chaudhuri, J. Fallis, A.T. Gallant, A. Grossheim, A.A. Kwiatkowski, D. Lascar, K.G. Leach, A. Lennarz, T.D. Macdonald, J. Pearkes, S. Seeraji, M.C. Simon, V.V. Simon, B.E. Schultz, and J. Dilling, Mass measurements of neutron-rich Rb and Sr isotopes, Phys. Rev. C **93**, 045807 (2016).