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The Collinear Fast Beam laser Spectroscopy (CFBS) experiment at TRIUMF

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ABSTRACT

Laser spectroscopy experiments at radioactive ion beam facilities around the world investigate properties of exotic nuclei for scientific endeavours such as, but not limited to, the investigation of nuclear structure. Advancements in experimental sensitivity and performance are continuously needed in order to extend the reach of nuclei that can be measured. The collinear fast beam laser spectroscopy (CFBS) setup at TRIUMF, coupled to an out-of-plane radio-frequency quadrupole Paul trap, enables measurements of some of the most fundamental nuclear properties for long-lived ground and isomeric states. The first comprehensive overview of the CFBS experiment is provided along with descriptions of key developments that extend the reach of laser spectroscopy experiments. A novel data acquisition technique structured around three-dimensional spectra is presented, where the integration of a custom multi-channel-scalar provides photon counts correlated with arrival time and acceleration voltage for post-experiment analysis. In addition, new rapid light manipulation techniques are discussed that suppress undesirable hyperfine pumping effects and regain losses in experimental efficiency.

1. Introduction

Laser spectroscopy is an experimental technique developed for the investigation of exotic nuclei that has been in use for several decades at many facilities around the world [1–5]. Measuring the isotope shifts and (where possible) hyperfine splittings of atomic transitions can yield nuclear model-independent quantities such as nuclear spin, magnetic dipole and electric quadrupole moments, and changes in mean-squared charge radii. These measurements provide an insight into the behaviour and properties of long-lived nuclear ground and isomeric states.

The collinear fast-beam laser spectroscopy (CFBS) experiment at TRIUMF, Canada, is a collinear laser spectroscopy experiment, developed to probe nuclear properties of exotic isotopes. For high resolution laser spectroscopy experiments, the radioactive ions are accelerated away from the target to reduce the inherent effects of Doppler broadening within hot targets. As the energy spread of the ion beam from the target remains constant during acceleration a larger total velocity decreases the relative velocity distribution of the ions. The observed linewidths of measurements can therefore be decreased down to the order of a few MHz (approaching the natural line widths of atomic transitions), improving the resolution. The experimental beam line is shared with the polarising group at TRIUMF, which utilises the polarising effect of optical pumping to provide nuclear spin-polarised ion beams for various experiments [6,7].

Recent experiments by the CFBS group have included high-precision quadrupole moment ratio measurements of ^{11}Li and ^{9}Li using zero-field β-NQR [8]; the neutron-deficient ^{74}Rb isotope for testing the unitarity of the CKM matrix [9]; the neutron-rich rubidium isotopes for shape behaviour effects [10]; and the single particle behaviour of the neutron-deficient francium isotopes [11,12].

This manuscript aims at providing an overview of the CFBS collinear laser spectroscopy setup at TRIUMF. In addition to describing key components of the system, special emphasis is given to reporting a multi-dimensional data acquisition system and recently developed techniques based on high-frequency intensity modulation and rapid frequency switching of laser light.

2. Overview of the experimental setup

Radioactive atoms are produced at TRIUMF through the impact of protons from a 500-MeV cyclotron on various thick targets [13].

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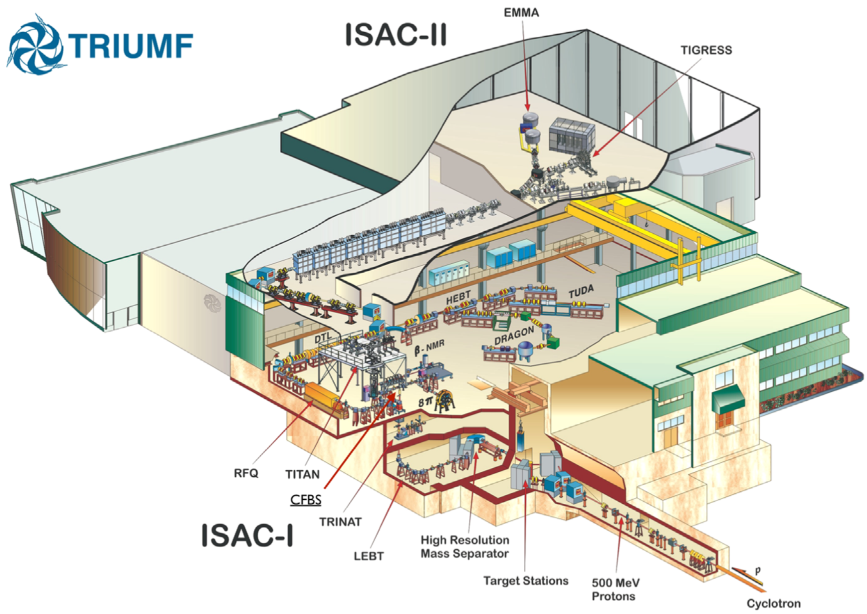

Fig. 1. The CFBS beam line is situated in the low-energy area of the ISAC-1 hall, downstream of the two ISAC target stations and high-resolution mass separator.

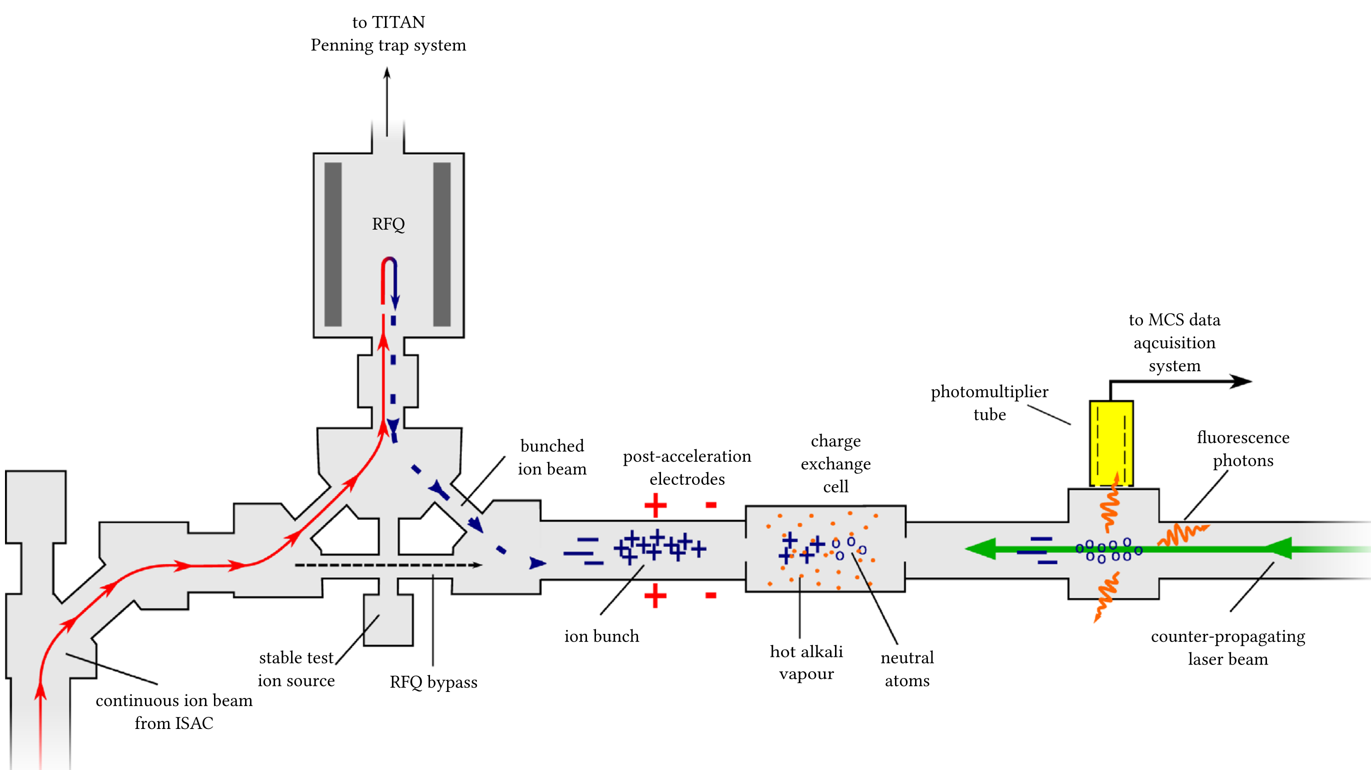

Fig. 2. The beam line is designed to collinearly overlap an ion/atom beam with laser light. Radioactive ions produced in the ISAC target area are accelerated to the experiment where they are steered on to the path of a counter-propagating laser beam. Ions may travel via an RFQ Paul trap for ion bunching and a charge-exchange cell is utilised for experiments involving electronic transitions in the atom.

The atoms are ionised within the target module and then accelerated to typically 20 or 28 keV, determined by the electric potential applied to the target. The isotopes of interest are mass-selected using a two-stage, high-resolution separator ($m/\Delta m \approx 5000$), delivered vertically to the experimental ISAC-1 (Isotope Separator and ACcelerator) hall and then directed towards the CFBS experiment located in the low energy area using electrostatic ion optics (Fig. 1).

The ion beam can be brought to the laser spectroscopy beam line as a continuous beam or sent via a radio-frequency quadrupole (RFQ) Paul trap (Fig. 2), held at a potential slightly below that of the energy of the ion beam. The ions are bunched within the Paul trap, reverse-extracted and re-accelerated to the potential of the RFQ into the collinear laser spectroscopy setup for investigation.