Laser Spectroscopy Experiments Service Level Description

FRIB-S30206-RC-009104-R001

Issued 28 August 2024

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9/3/2024

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Revision History

Revision	Issued	Changes
R001	3 September 2024	Original Issue

Authorizing Document

None.

Authorized Documents

None.

Authorized Committees and Boards

None.

Named Program Roles

None.

Awareness Training

None.

Enabling Training

None.

1 Objective

This documents describes the level of service FRIB will be able to provide for the operation of the BECOLA laser spectroscopy system and for user support for experiments with this scientific instrument.

2 Abbreviations

BECOLA	BEam COoling and LAser Spectroscopy
BMIS	Batch Mode Ion Source
BOB	Beam Observation Box
CEC	Charge Exchange Cell
CLS	Collinear Laser Spectroscopy
DAC	Digital to Analogue Converter
DAQ	Data Acquisition
ERR	Experiment Readiness Review
FHG	Fourth harmonic generation
HV	High Voltage
PMT	Photo Multiplier Tube
ppm	per per million
RFQ	Radio Frequency Quadrupole
RISE	Resonant Ionization Spectroscopy Experiment
SHG	Second Harmonic Generation
SSD	Solid State Detector (Si detector)
THG	Third Harmonic Generation
Ti:S	Titanium Sapphire

3 BECOLA Facility Overview

The Beam Cooling and Laser Spectroscopy (BECOLA) facility [1, 2] performs laser resonant fluorescence spectroscopy and laser resonant ionization spectroscopy using the Resonant Ionization Spectroscopy Experiment (RISE) instrument.

The gas stopping system [3], Batch Mode Ion Source (BMIS) [4], and the local offline ion source [5] can be produce beams at an energy of approximately 30 keV. These beams are used to measure hyperfine structures and isotope shifts, allowing for the determination of ground/isomeric state spins, differential mean-square charge radii, magnetic-dipole moments and electric-quadrupole moments. Spectroscopic measurements can be conducted on ions, neutrals, DC or bunched beams.

4 Standard Configuration

4.1 Physical Configuration

4.1.1 Overall Configuration

The layout of the BECOLA facility in Room 1361B is shown in Figure 1.

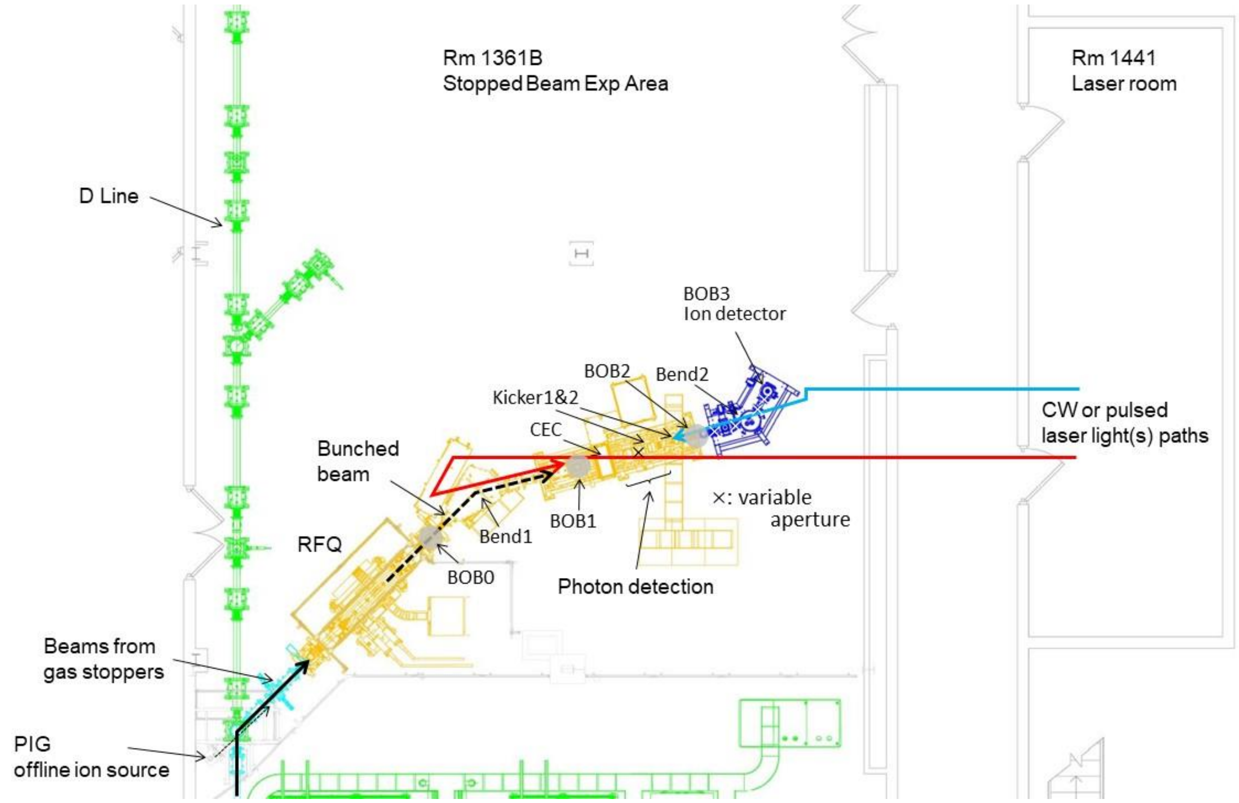

Figure 1: Layout of the BECOLA facility. The BECOLA facility is in room 1361B receiving beams from gas stoppers via D-line. The laser room (room 1441) is across the hallway, and laser light is transported to the beam line by optical fibers or using mirrors.

Ion beams from one of the gas stoppers or BMIS are delivered through the D line into the RFQ [6] after the 45-degree bend, which can be retracted when the offline ion source is used. The offline ions source, a discharge plasma sputtering source [5], is located at the 0-degree port behind the bend. The ion beam energy from the gas stopper is typically 30 kV. The Radio Frequency Quadrupole (RFQ) cools and bunches the ion beam, extracting it at approximately 29,850 eV. A feedback loop [7] stabilizes this energy to within few tens of part per million (ppm). The RFQ can also extract a DC beam in transmission mode. The ion beam can be neutralized through charge exchange reactions with sodium vapor in the Charge Exchange Cell (CEC) [8]. Laser light(s) are overlapped with the ion/neutral bunches for laser spectroscopy. Three photon detection systems [1, 9] with light collection mirrors are installed after the CEC. The low-vacuum beam line (5×10^{-9} torr) serves as the laser-atom beam interaction region for the resonant ionization spectroscopy. The resulting ions are deflected by the Bend2 towards the ion detector (MagneTOF) in the Beam Observation Box (BOB) number 3 (BOB3) at the end of the beam line. The Doppler tuning can be achieved by scanning the voltage applied to the photon detection system for ions or to the CEC for neutrals.

Three BOBs are located along the beam line, each equipped with a Faraday cup and solid-state detector (SSD). BOB1 and 2 also contain apertures (3, 5, 7 mm in diameter and open) for aligning laser light and the ion beam. Five additional continuously variable apertures (0 to 30 mm in diameter) are distributed along the beam line. The laser room (Room 1441) is located across the hallway, and laser light(s) is (are) transported via optical fibers or a mirror transport system. Laser light can be injected into the beam line in either the collinear or anti-collinear direction relative to the beam momentum, typically for fluorescence and ionization spectroscopy, respectively.

4.1.2 Laser System Configuration

The standard configuration is summarized in Table 1. Contact the BECOLA Instrument Scientist for the latest operation status of the laser systems.

4.2 Operational Modes and Features

4.2.1 Ion beam DC and Bunch Mode

The RFQ cooler/buncher can operate in either a DC ion beam (transmission) mode or bunched ion beam mode. In DC mode, a high intensity ion beam (10s of nA) can be transported from the offline ion source to the CLS beam line for laser spectroscopy. However, the maximum number of ions per bunch in bunch mode is limited to 10^6-10^7. Exceeding this limit distorts the hyperfine spectrum due to the space charge in the trap in the RFQ.

4.2.2 Ion Beam and Neutral Beam Mode

In ion beam mode, the Doppler tuning scanning voltage is applied to the photon detection systems. For neutral beam mode, the ion beam from the RFQ cooler/buncher is neutralized in the CEC with a sodium vapor. In this case, the scanning voltage is applied to the CEC. The neutralization efficiency typically reaches 50%, with additional population distribution over low-lying electronic states that depend strongly on the beam element.

4.2.3 Fluorescence Mode

The photon detection system is used to detect laser resonant fluorescence. Up to three photon detection systems can be used in this mode, positioned at distances 40, 60 and 70 cm from the CEC. Each system is equipped with an ellipsoidal reflector for light collection, and a photomultiplier tube (PMT). These systems are isolated from the ground potential, and the scanning voltage can be applied for Doppler tuning in ion beam mode.

4.2.4 Resonant Ionization Mode

Ions created using resonant laser ionization technique are deflected in the Bend2 and detected by the ion detector (MagneTOF) installed in the BOB3 at the end of the beam line. The remaining ions that do not interact with the laser are removed using the kicker1 and/or kicker2. This mode is typically applied to bunched neutral beams.

4.2.5 Collinear and Anti-collinear Mode

Laser light can be injected into the CLS beam line in either collinear (same direction as the ion beam momentum) or anti-collinear (opposite direction as the ion beam momentum) direction. The collinear mode is used for the fluorescence measurement mode with an optical fiber for the laser light transport from the laser room. The anti-collinear mode is used for the resonant ionization spectroscopy with laser light transported using mirrors.

4.3 Electronics, DAQ and Analysis Software

All electronics, controls, and data acquisition software necessary to perform laser spectroscopy measurements will be provided and are the sole responsibility of the BECOLA Instrument Scientist. A dedicated DAQ system [2], comprising both hardware and software based on CS Studio, is available. The DAQ software is used for online monitoring and preliminary analysis. Comprehensive analysis packages based on Python, Mathematica or Root can be provided upon request.

4.4 Ancillary Systems

Additional detector systems can be installed after BOB3, subject to space constraints.

5 Support by Instrument Scientist

Every experiment will go through FRIB's multi-step ERR process [10]. FRIB personnel will meet with the users prior to the first ERR to prepare for it. Required resources other than those already stated in the approved proposal need to be identified by the user at this time.

5.1 Support by Instrument Scientist

FRIB provides dedicated instrument scientist support for BECOLA. The instrument scientist will coordinate the setup of the experiment and offer on-site assistance from 9:00 AM to 5:00 PM on weekdays. For critical technical support during experiments, users can contact the operator in charge (OIC), who will decide whether to call the instrument scientist.

The BECOLA Instrument Scientists will provide the following support:

- Answer technical questions for users preparing experiment proposals.
- Provide necessary software packages for the BECOLA data acquisition system.
- Ensure device operates as specified in the standard configuration.
- Modify device running modes during the experiment as needed.
- Provide support during the experiment to ensure proper functioning of the device.
- Assist users in inspecting and understanding the on-line data from BECOLA detectors.
- Assist users during the off-line analysis phase.

5.2 Additional Support

The BECOLA Instrument Scientists can provide training to users on specific components of the BECOLA equipment. Training sessions are offered once per experiment at a mutually agreed-upon time with the experimenters. These trainings are introductory in nature and aim to equip users with basic knowledge needed to operate the instrument. It is the user's responsibility to assemble the collaboration team capable of fully executing the experiment and achieving the desired science goals. The following training segments are available, with approximate durations:

- Overview and operation of the BECOLA ion transport system (2 hours)
- Overview and operation of the BECOLA laser system (2 hours)
- Overview and operation of the BECOLA local ion sources (2 hours)
- Overview and operation of the BECOLA DAQ system (2 hours)

6 Instrument Specific User Responsibilities

BECOLA users must adhere to the *FRIB Roles and Responsibilities of Scientific Users* document [11]. In more detail, FRIB expects BECOLA users to:

- Take the lead role during the preparation and running phase of the experiment.
- Possess sufficient training and a capable team to operate BECOLA for their experiment.
- Be responsible for the integrity and safety of their experimental system, if applicable.
- Inform the BECOLA Instrument Scientist about required beam properties and experimental setup prior to the first Experiment Readiness Review (ERR).
- Timely identify necessary utilities and services for their experiment.
- Communicate the duration pre- and post-experiment BECOLA space occupation.
- Submit an execution plan to the BECOLA Instrument Scientist before the final ERR.
- Report any incidents to the Operator-in-Charge (OIC) and the BECOLA Instrument Scientist.
- Communicate any changes to the experiment in a timely manner. Some requests may require consultation with system experts who may only be available during weekdays and regular business hours.
- Keep the allocated vault space to the experiments tidy and leave it in the same condition or better than found.
- Maintain a pressure of $<1\times10^{-8}$ Torr or better in their setup, if necessary for running experiments in resonant ionization mode.

6.1 Prior to Start of experiment and During Setup

Every experiment will go through FRIB's multi-step ERR process [10]. The BECOLA Instrument Scientist will meet with users prior to the first ERR to prepare for it. Any required resources beyond those listed in the approved proposal must be identified by the user at this time. Resources available for experiment preparation and setup include:

- Mechanical design support
- Installation and alignment support
- Vacuum support, including leak checking
- Electric and plumbing work
- Data Acquisition Support for user-owned instrumentation (if applicable) [12]
- Control system support for archiving of process variables (e.g. Faraday cup readings)

Before the experiment begins, the BECOLA Instrument Scientist will meet with the user to develop an operations plan encompassing vault access, expected tuning time, and any beam changes planned. The spokesperson is responsible for developing a shift schedule with at least two people on shift at all times. Experimenters on shift must be capable of executing the experiment.

6.2 During Experiment

A pilot beam will be tuned to BECOLA through the RFQ in DC mode and placed on the Faraday cup in the BOB0. At this point, the user will take control of the beam. The users are responsible for the transport of laser light required for the experiment, and aligning it with the ion beam. Any questions specifically related to BECOLA during the experiment should be directed to the BECOLA Instrument Scientist.

6.3 After Experiment

After the conclusion of an experiment, users must remove any ancillary equipment from 1361B within the previously agreed-upon timeframe. Data will be transferred to the spokesperson and archived at FRIB [13].

7 Additional Instrument Support not Covered in this Service Level Description

Any request for support not covered in this service level description must be submitted to the FRIB Manager for User Relations prior to the submission of an experiment proposal for pre-approval.

8 References

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[3] C.S. Sumithrarachchi et al., Beam thermalization in a large gas catcher, Nucl. Instrum. Methods Phys. Res. B 463, 305 (2020).

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[7] K. König et al., High voltage determination and stabilization for collinear laser spectroscopy applications, Rev. Sci. Instrum. 95, 083370 (2024).

[8] A. Klose et al., Tests of atomic charge-exchange cells for collinear laser spectroscopy, Nucl. Instrum. Methods Phys. Res. A 678, 114 (2012).

[9] B. Maaβ et al., A 4π Fluorescence Detection Region for Collinear Laser Spectroscopy, https://doi.org/10.48550/arXiv.2007.02658.

[10] FRIB Experiment Readiness Review Program, FRIB-S30206-PG-000033.

[11] Roles and Responsibilities of the Scientific Users, FRIB-S30206-PG-000028.

[12] Scientific Data Acquisition Service Level Description, FRIB-S30206-RC-008646.

[13] FRIB Data Management Plan FRIB-S00000-PL-000467.