

ONLINE DATA ANALYSIS SYSTEM FOR ISOCHRONOUS SCHOTTKY MASS SPECTROMETRY EXPERIMENT

Facility for Antiproton and Ion Research in Europe and
GSI Helmholtzzentrum für Schwerionenforschung

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Internship and Training Project Report
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Abstract

This report presents a comprehensive summary of works with the NTCAP system and online data analysis system, including detailing its relocation to the ESR Messhutte laboratory and operational guide.

Chapter 1 introduces the research background. Chapter 2 addresses the development and implementation of an online data analysis system, motivation for building the system, explaining its functionality, and elaborating on memory requirements and capabilities. Practical aspects such as installation procedures and code execution on different platforms (lxir131 and lxbk0496) are also discussed in detail. Chapter 3 presents a short summary. The appendixes introduce the process of shifting the NTCAP system to the ESR Messhutte, a map of signal cables for the NTCAP system, and a detailed overview of the scaler signals at Messhütte and details of the operation process of the NTCAP system, covering the procedures for starting and shutting down the NTCAP system.

This report aims to offer assistance to users engaging in future experiments involving the NTCAP system and online data analysis.

Declaration

I hereby declare that the project entitled “**ONLINE DATA ANALYSIS SYSTEM FOR ISOCHRONOUS SCHOTTKY MASS SPECTROMETRY EXPERIMENT**” is my own work and that I have correctly acknowledged the work of others.

Acknowledgements

I would like to express my heartfelt gratitude to my mentor, Dr. Yuri Litvinov, whose unwavering support has been instrumental in the successful completion of this research endeavor. Professor Litvinov's generous provision of funding not only facilitated the financial aspects of the study but also exemplified his commitment to providing a conducive research environment. His guidance and unwavering support have granted me significant research freedom, allowing exploration of various methodologies and approaches, and enriching the depth and breadth of this work.

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Contents

1	Introduction	13
1.1	Background	13
1.2	Motivation	14
2	Online Data Analysis System	16
2.1	How does the system work	16
2.2	Memory Requirements and Server Capability	20
2.3	How to install online data analysis system	21
3	How to run the online data analysis system.	24
3.1	Mount NTCAP hard disk on lxir131 server	24
3.2	Run “queqiao” on lxir131	25
3.3	Run “analysis_iq_sc” on lxbk0496	26
3.4	Simplified Operational Procedure for Online Data Analysis System	28
3.4.1	System Initialization	28
3.4.2	Usages	29
	Usage-1: identify the $^{229}\text{Th}^{89+}$ ions in the ^{229}Th experiment	29
4	Conclusion	35
A	Scaler Signals Map at Messhütte	37
B	How to operate NTCAP	43
B.1	Start the NTCAP system	43
B.2	Turn off the NTCAP system	46
C	Adjustment of the NTCAP Reference Level	48

List of Figures

2.1	Current layout of NTCAP system	16
2.2	Flowchart of the Queqiao program.	17
2.3	User interface of the queqiao program.	18
2.4	User interface of the “analysis_iq_sc” program.	18
2.5	User interface of the “ROODY” program and one of a projected histogram	19
2.6	The used time for copying data from NTCAP computer to Astrum server and analyzing data is shown in the figure. The blue and yellow points represent the used time for copying and analyzing, respectively. The left and right side represent the “iq” and “sc” data, respectively.	20
2.7	The folder of the online data analysis system.	21
3.1	Mounting the NTCAP hard disk	24
3.2	The “Online data analysis system for IMS experiment” interface.	29
3.3	The ”queqiao” interface and the ”browser” interface.	30
3.4	The “ analyse_iq_sc ” interface.	31
3.5	The “ rionidgui ” interface.	32
3.6	The experimental spectrum and simulated spectrum.	33
3.7	The combine_injection interface in combine_tdms mode.	34
3.8	The generated 3D spectrum.	34
A.1	the ESR Messhütte.	38
A.2	Distribution diagram of signal sources from various devices.	39
A.3	Photos of signal of electron cooler. This image correspond to section A in the figure A.2	40
A.4	Photos of signal of gas jet Target (S1,S2,S3,S4,Inhibit) and ESR DCCT current (DCCT tarfo). This image correspond to section B and C in the figure A.2	40
A.5	Injection or kicker signal of the ESR. This image correspond to section C in the figure A.5	41

A.6	Fan in/Fan out modul. This image correspond to section D in the figure A.2	42
B.1	Photo of NAT hard drive box of NTCAP system	43
B.2	Turn on the NI crate.	44
B.3	Turn on the NIM crate.	44
B.4	Turn on the NTCAP main computer.	44
B.5	Turn on the Synology Assistant of NTCAP system.	45
B.6	Load hard disk on NTCAP computer.	45
B.7	E121 folder.	46
B.8	NTCAP user interface.	46
C.1	User interface of NLRFSAs Soft Front Panel	49

List of Tables

2.1 Meanings of scaler signal.	19
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Chapter 1

Introduction

1.1 Background

Mass and lifetime are fundamental properties of atomic nuclei, providing insights into the nuclear structure and decay characteristics [1, 2, 3, 4]. These parameters are key input quantities in nuclear astrophysical models, contributing significantly to our understanding of the origin of heavy elements in the universe. The precise measurement of the mass and lifetime of short-lived atomic nuclei is a formidable challenge faced by scientists worldwide. One effective experimental solution to this challenge is the installation of heavy-ion storage ring mass spectrometers behind radioactive beamlines.

Currently, Isochronous mass spectrometry (IMS) has emerged as crucial experimental tools for measuring the mass of short-lived atomic nuclei using storage rings [3, 5]. In time-of-flight experiments, the flight period of ions is typically measured using a time-of-flight detector. The core component of this detector includes a 100-nanoseconds thick carbon foil. Each time ions pass through the carbon foil, secondary electrons are generated on its surface. Guided by the internal electromagnetic field of the detector, these secondary electrons hit a microchannel plate and undergo further multiplication. The resulting secondary electrons are collected by subsequent RC circuits, forming the signal. However, the energy loss incurred by ions passing through the carbon foil limits the storage time of ions in the storage ring to approximately 1 millisecond, equivalent to around 1500 revolutions. This limitation makes it challenging to use time-of-flight detectors for experiments requiring the measurement of ion decay lifetimes.

In recent years, researchers at the GSI Helmholtz Centre for Heavy Ion Research in Germany have developed a novel experimental approach [6]. They utilize longitudinally sensitive Schottky detectors [7, 8] in IMS exper-

iments, enabling non-destructive measurement of ions' revolution frequency. The Schottky detector collects signals induced by ions on its surface, allowing precise measurements of the ions' revolution frequency and the number of ions. This innovative technique facilitates the simultaneous and accurate measurement of both the mass and lifetime of atomic nuclei.

1.2 Motivation

One of the centerpieces of the experiment is the data acquisition system NTCAP [9, 10]. The NTCAP data acquisition system is a very powerful data acquisition system. This system can record IQ data at a very high sampling rate and record scalar data simultaneously. NTCAP operates stably and is an essential tool for conducting experiments. The NTCAP system has successfully gathered extensive data for various experiments, including the bound state beta decay of $^{205}\text{Tl}^{81+}$ [11, 12] experiment, the search for a double gamma decay channel with $^{72}\text{Ge}^{32+}$ nuclei experiment. Its recent outstanding performance in the Isochronous Schottky Mass Spectroscopy experiment stands out, reaffirming its robust utility and effectiveness.

However, some issues currently remain unresolved. The problem is that the data recorded by NTCAP cannot be processed quickly. Due to the particularly large volume of data recorded by the system, there is simply no way to process it rapidly during the experiment. Currently employed methods involve spending a significant amount of time after the experiment concludes to analyze the data and understand the experimental situation.

As a result, any issues that arise during experiments cannot be promptly identified. For example,

1) During the ^{205}Tl experiment conducted in 2020, there was saturation happened in the Schottky spectrum. During the experiment, the HKR control system was upgraded. The Schottky's amplifier was turned on by default in the new control system. This causes the RF signal coming out of Schottky to exceed the reference level of the DAQ, eventually causing the signal to saturate. This results in a lot of time being wasted in post-data processing to correct the impact of this error.

2) In the ^{72}Ge experiment carried out in 2021, the γ_t was not properly set up. At the beginning of the experiment, it was thought that a commercial spectrum analyzer was sufficient. Later, it was found that the sampling frequency width of the commercial spectrum analyzer was too narrow, making it impossible to record a broad spectrum which is critical to identify the spectrum corresponding to the ions-of-interest and determine the γ_t parameter of the isochronous setting. To identify the peak corresponding to the

target nucleus, the sampled spectrum of NTCAP must be used. In addition, through subsequent data analysis, it was found that to determine the γ_t parameters set in the experiment, a wide spectrum must be collected. This is all inseparable from the NTCAP data acquisition system. However, because the data collected by NTCAP is too large, it cannot be analyzed in real-time during the experiment. This results in the inability to quickly find the peak corresponding to the ion of interest during the experiment and the γ_t parameters set by the experiment cannot be quickly known.

3) In a laser experiment carried out in 2022, there were problems with the scalar data. The NIM crate was not turned on and the clock signal for the NTCAP scaler was not generated during the second half of the experiment. Throughout the second half experimental period, there were errors in recording scalar data, and the personnel remained unaware of these issues.

These errors have caused valuable beam time been wasted and add significant complexity to subsequent data processing. Therefore, we have developed this system to analyze the data collected by the NTCAP system in real-time.

Chapter 2

Online Data Analysis System

2.1 How does the system work

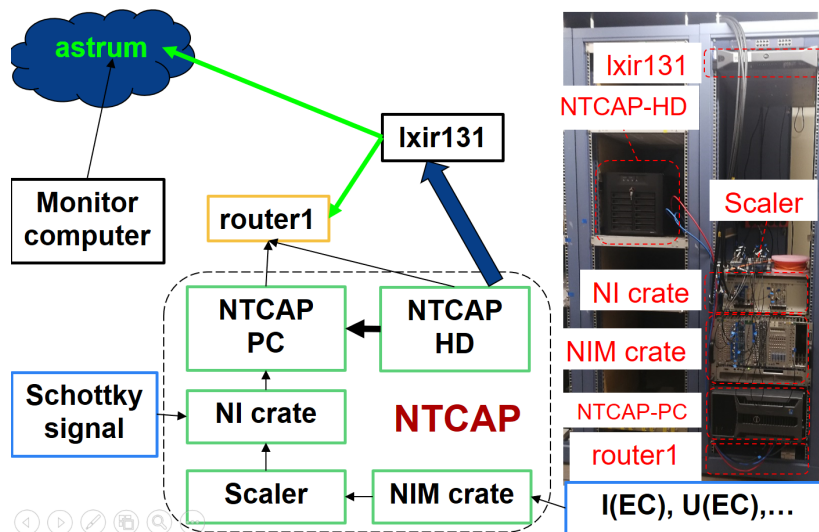


Figure 2.1: Current layout of NTCAP system

Above is the current architecture of online data analysis system. Due to the utilization of NI module in the NTCAP system, these NI module components operate with outdated library software. In order to avoid compatibility issues arising from software updates, which could render certain plugins inoperable, NTCAP is constrained to function within a local area network (LAN) environment. To facilitate data transmission to a remote server, we have established a dedicated server named Ixir131. This server is equipped with two network interface cards (NICs), enabling simultaneous connections to both

the local network and the internet. The hard drive of the NTCAP system is mounted onto the lxir131 server. Data is then transferred from the hard disk of the NTCAP to the luster server using the lxir131.

Currently, this system consists of three code components. The first com-

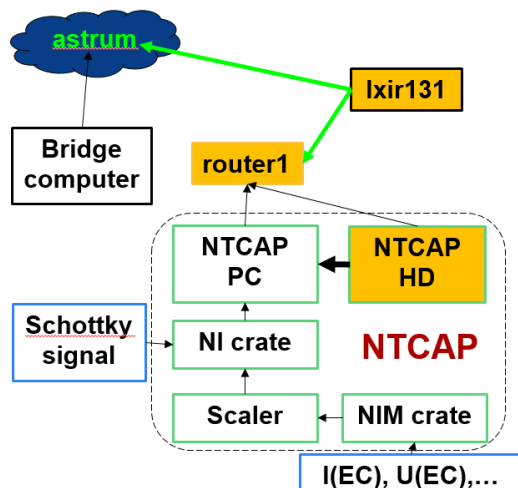


Figure 2.2: Flowchart of the Queqiao program.

ponent “queqiao” runs on the lxir131 server. This part of the code monitors whether there is new data on the NTCAP hard drive. If new data is detected, it is automatically transferred to the luster server.

Figure 2.3 shows the user interface of the queqiao program. Users can set “hostname”, “username”, “keyfilename”, the data path on the NTCAP storage hard disk and designate the storage path for data on the cluster directly through this user interface. Once the parameters are configured, clicking the “Start” button initiates the process of transferring the data.

IQ and SC data are presented in separate lists, with the left list representing data files on the NTCAP harddisk and the right list representing data files on the cluster server. Files currently undergoing transmission are marked in yellow, while those that have completed the transfer are highlighted in green.

The second component “analyze_iq_sc” runs on the cluster server. The user interface is shown in figure 2.4. This code component handles the data transferred to the server automatically. It can concurrently utilize multiple CPU resources to do fft for multiple files. On average, processing one file takes 5 minutes. The system is capable of concurrently processing multiple files, with an overall data processing latency of 5 minutes.

The third code component “Online server” is responsible for generating visualizations and graphs. After executing this section of the code, the program retrieves preprocessed data from the hard drive, generates various

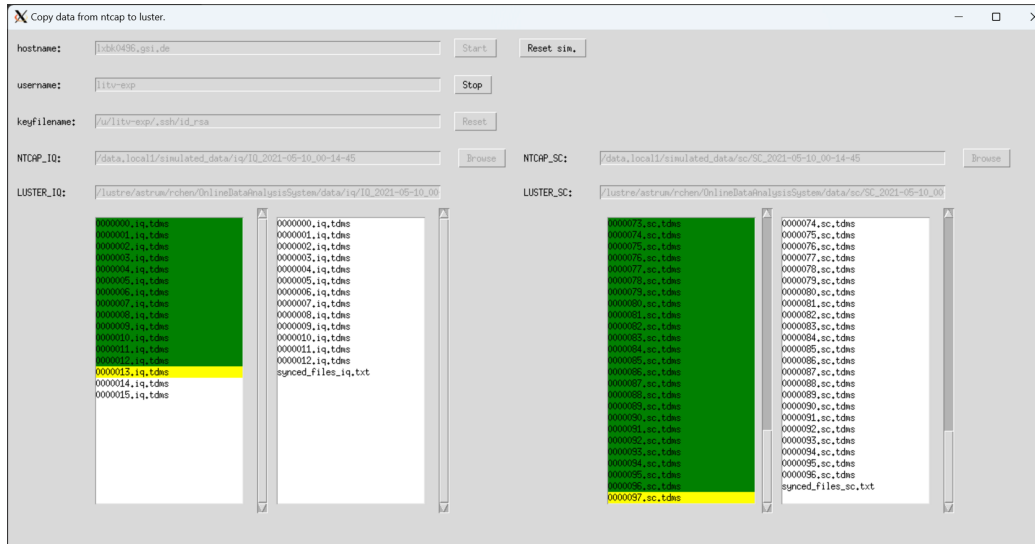


Figure 2.3: User interface of the queqiao program.

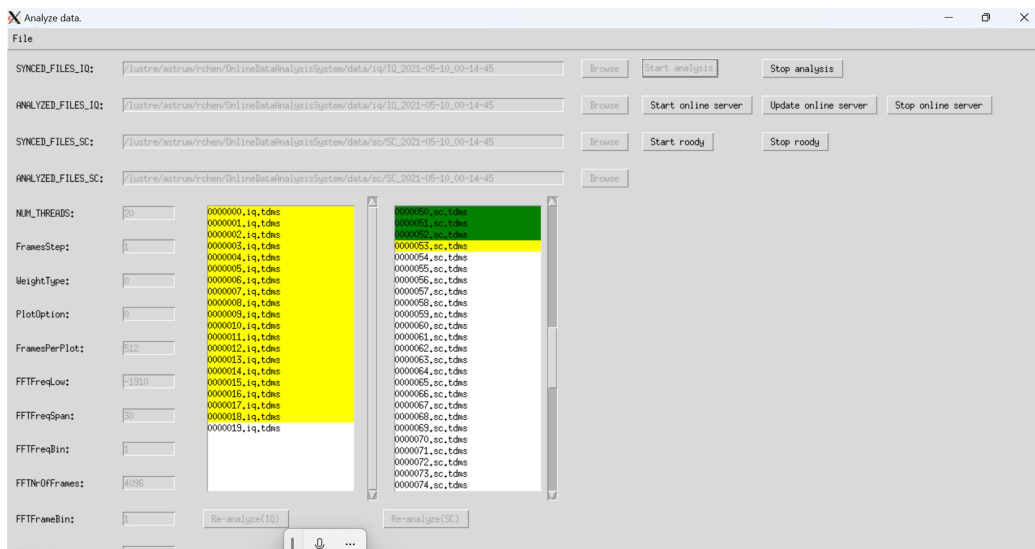


Figure 2.4: User interface of the “analysis_iq_sc” program.

graphics, and stores them on the server. Currently, we utilize the ROODY software to establish a connection with the server, retrieve graphics stored there, and display them on the terminal. The experimental results displayed using ROODY are presented in figure 2.5.

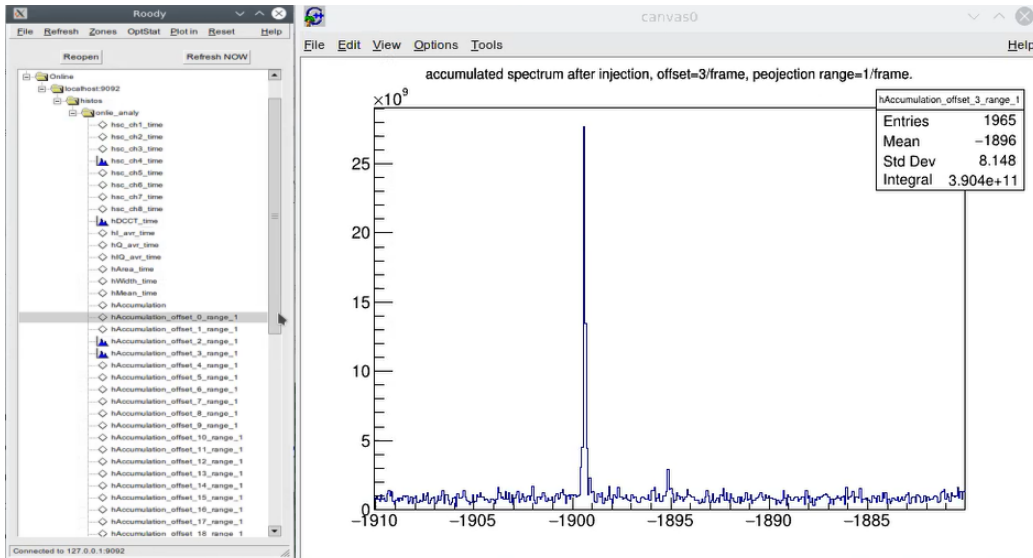


Figure 2.5: User interface of the “ROODY” program and one of a projected histogram

Up to now, there are 66 graphs defined in the Roody interface. You can add your own graph based on your requirements. The meanings of these 66 graphs are as follows:

1) “hsc_ch1_time/hsc_ch2_time/...hsc.ch8_time”: The rate of each scaler channel versus time. The meanings of these scaler channels are shown in Table 2.1:

Scaler No.	Content
Sc1	Cooler voltage
Sc2	Cooler current
Sc3	Pressure of gas target
Sc4	SIS kicker signal (From ESR Musshutte)
Sc5	ESR DCCT current
Sc8	Status of gas target
Sc9	Raw kicker signal (SIS kicker 49)

Table 2.1: Meanings of scaler signal.

- 2). “hDCCT_time”: This parameter is equivalent to “hsc_ch5_time.”
3. “hI_avr_time/hQ_avr_time/hIQ_avr_time”: These 3 graphs represent the average I/Q/IQ values over time for each frame of the spectrum. I/Q/IQ represent the real part, imaginary part, and magnitude of IQ signal. The time duration of each frame is approximately equivalent to 13.1 milliseconds which consists of $2^{18} = 262144IQsamples$.
4. “hArea_time/hWidth_time/hMean_time”: These parameters denote the area/width/mean value of the frequency spectrum over time for each frame of the spectrum.
5. “hAccumulation”: Currently empty, intended for storing the cumulative spectrum of all frames from multiple injections.
6. “hAccumulation_offset_0_range_1/hAccumulation_offset_1...49_range_1”: These graphs present the cumulative spectrum for the 1st, 2nd, ...49th frame of multiple injections, each with a specified offset and range.

2.2 Memory Requirements and Server Capability

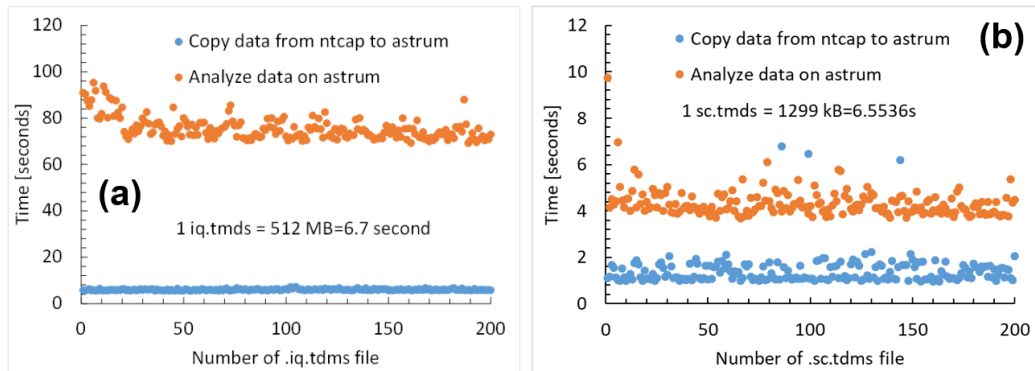


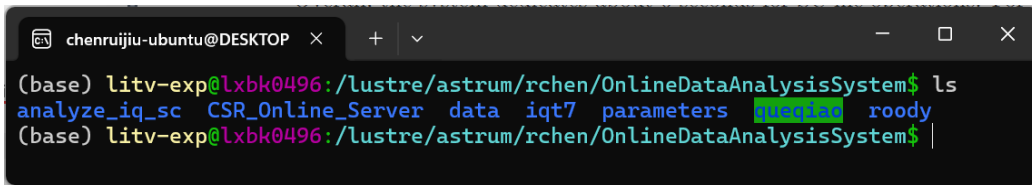
Figure 2.6: The used time for copying data from NTCAP computer to Astrum server and analyzing data is shown in the figure. The blue and yellow points represent the used time for copying and analyzing, respectively. The left and right side represent the “iq” and “sc” data, respectively.

When analyzing a single file (.iq.tdms, size=512 MB) on a single CPU (single thread), the operation demands approximately 2.8 GB of memory. Scaling up with 20 threads significantly increases the memory requirement to 56 GB. Fortunately, there are 32 CPUs and 128 GB of memory on the

Astrum server, rendering it well-equipped to handle real-time online data analysis efficiently.

Figure 2.6 depicts the time spent on data transfer and processing. Currently, the system takes approximately 6 seconds for the transfer and around 80 seconds for the processing of a single IQ file (512MB, contains about 6.7s spectrum with a sampling rate 20 MSamples/s). The transfer and processing of one SC file (16.7 MB, contains approximately 262.144s scaler data with a clock rate of 1kHz) typically require 1 second and 5 seconds, respectively. Overall, the system dedicates about 6 seconds for SC file operations. For IQ data, employing parallel processing across multiple CPUs enables the system to ensure a time expenditure of approximately 90 seconds from data generation to completion of processing for each IQ data.

2.3 How to install online data analysis system

A terminal window with a dark background and light text. The window title is "chenruijiu-ubuntu@DESKTOP". The terminal shows a shell prompt "(base) litv-exp@lxbk0496:/lustre/astrum/rchen/OnlineDataAnalysisSystem\$ ls" followed by the output: "analyze_iq_sc CSR_Online_Server data iqt7 parameters quoniam roody". The second line shows the prompt "(base) litv-exp@lxbk0496:/lustre/astrum/rchen/OnlineDataAnalysisSystem\$ |".

```
chenruijiu-ubuntu@DESKTOP x + v - □ x
(base) litv-exp@lxbk0496:/lustre/astrum/rchen/OnlineDataAnalysisSystem$ ls
analyze_iq_sc CSR_Online_Server data iqt7 parameters quoniam roody
(base) litv-exp@lxbk0496:/lustre/astrum/rchen/OnlineDataAnalysisSystem$ |
```

Figure 2.7: The folder of the online data analysis system.

Figure 2.7 shows the folder of the online data analysis system. The folder `/lustre/astrum/experiment_data/2024-05_E018/OnlineDataAnalysisSystem` includes 7 sub-folders. Here is a more detailed set of instructions for installing the online data analysis system:

1. Create a folder named “OnlineDataAnalysisSystem” on the astrum server:

```
mkdir OnlineDataAnalysisSystem
cd OnlineDataAnalysisSystem
```

2. Enter the folder “OnlineDataAnalysisSystem” and download/install programs:

(a) Install queqiao:

```
git clone https://github.com/ruijiuchen/queqiao.git
cd queqiao/
pip install -r requirements.txt
pip install .
```

(b) Install analyze_iq_sc:

```
cd ..
git clone https://github.com/ruijiuchen/analyze_iq_sc.git
cd analyze_iq_sc
pip install -r requirements.txt
pip install .
```

(c) Install CSR_Online_Server:

```
cd ..
git clone git@github.com:ruijiuchen/CSR_Online_Server.git
cd CSR_Online_Server/
make clean
make
```

(d) Install iqt7:

The iqt7 code is not open source. If you need this code, please contact Brandau, Carsten (C.Brandau@gsi.de) or Ruijiu Chen for it.

```
cd iqt7
make
make clean
```

(e) Install roody:

The roody code is not open source. If you need this code, please contact Ruijiu Chen for it.

```
cd roody
make clean
make
```

3. Create a data folder:

```
mkdir data
```

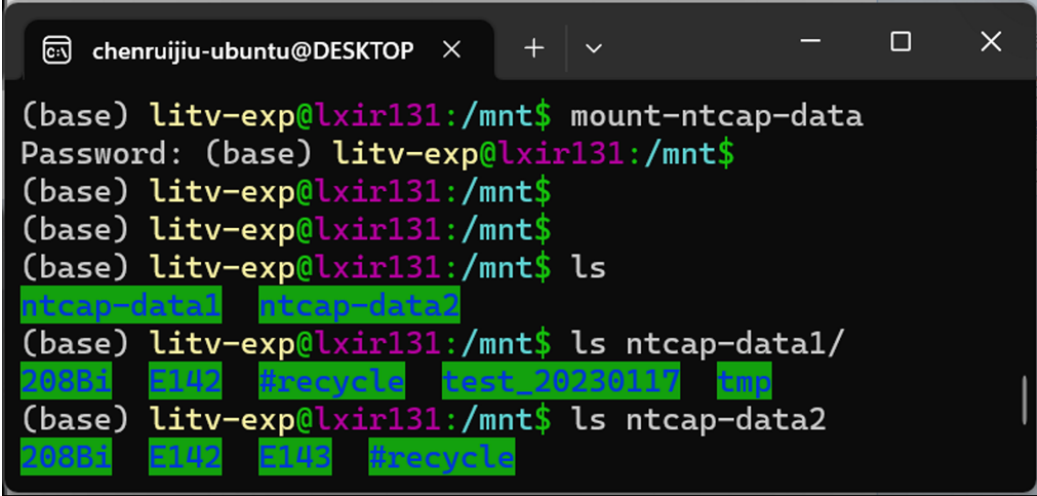
By following these steps, you should be able to successfully install and configure your online data analysis system. If you encounter any errors during the execution of these steps, please check the terminal output for more detailed information and ensure that your system meets the necessary dependencies.

Chapter 3

How to run the online data analysis system.

3.1 Mount NTCAP hard disk on lxir131 server

Mount the NTCAP hard disk on the lxir131 server by running the 'mount-ntcap-data' command on the lxir131 computer.



```
chenruijiu-ubuntu@DESKTOP x + v - □ ×  
(base) litv-exp@lxir131:/mnt$ mount-ntcap-data  
Password: (base) litv-exp@lxir131:/mnt$  
(base) litv-exp@lxir131:/mnt$  
(base) litv-exp@lxir131:/mnt$  
(base) litv-exp@lxir131:/mnt$ ls  
ntcap-data1 ntcap-data2  
(base) litv-exp@lxir131:/mnt$ ls ntcap-data1/  
2088i E142 #recycle test_20230117 tmp  
(base) litv-exp@lxir131:/mnt$ ls ntcap-data2  
2088i E142 E143 #recycle
```

Figure 3.1: Mounting the NTCAP hard disk

3.2 Run “queqiao” on lxir131

1. Login to lxir131 and initiate queqiao to copy data from NTCAP hard disk to the “astrum” server.

- Open a terminal and use SSH to connect to the lx-pool.gsi.de server. Enter the following command in the terminal and press Enter:

```
ssh -X litv-exp@lx-pool.gsi.de
```

Enter your password to complete the login.

- Once successfully logged into lx-pool.gsi.de, use the following command to connect to the lxir131 server:

```
ssh -X lxir131
```

Enter your password to complete the connection.

- Navigate to the Software Directory: Use the following command to navigate to the installation directory of the software :

```
cd /lustre/astrum/experiment_data/  
2024-05_E018/OnlineDataAnalysisSystem/
```

- Create a New Screen Session: For better management of software operations, you can create a new screen session using the following command:

```
screen -S OnlineDataAnalysisSystem
```

This will create a screen session named “OnlineDataAnalysisSystem.”

- Enter the “queqiao” Directory: Inside the screen session, use the following command to enter the “queqiao” directory:

```
cd queqiao
```

- Activate Conda Environment: Activate the Conda environment named “iqt7_env_ruijiu” by entering the following command:

```
conda activate iqt7_env_ruijiu
```

- Run the “queqiao”: Finally, run your Python script:

```
queqiao ../parameters/queqiaosettings_E143Exp_simulation.toml
```

Important: If you are logging in from a Windows operating system, please ensure that you have started the X server on your Windows system. Otherwise, you will see the mistakes.

- Click the “Start” button to initiate data synchronization from the NTCAP hard disk to the “astrum” server.
- Initiate system testing using E143 data. Press ‘reset’ to clear the uploaded file list. Click on the ‘Reset sim’ button to reimport the E143 data from

```
/luster/ap/litv-exp/2021-05-00_E143_TwoPhotonDecay_ssanjari/  
NTCAP/iq/IQ_2021-05-10_00-14-45
```

to

```
/data.local1/simulated_data/iq/IQ_2021-05-10_00-14-45.
```

Click “start” to copy data from

```
/data.local1/simulated_data/iq/IQ_2021-05-10_00-14-45
```

on lxir131 to

```
/luster/astrum/rchen/OnlineDataAnalysisSystem/data/iq/IQ_  
2021-05-10_00-14-45
```

on lxbk0496 server.

3.3 Run “analysis_iq_sc” on lxbk0496

1. Log in lxbk0496 and initiate the “analysis_iq_sc” to analyze the IQ and SC data on the “astrum” server.

- SSH Login to lx-pool.gsi.de: Open a terminal window. Enter the following command and press Enter:

```
ssh -X litv-exp@lx-pool.gsi.de
```

Enter your password when prompted to log in.

- SSH to lxbk0496: After successfully logging in to lx-pool.gsi.de, enter the following command and press Enter:

```
ssh -X lxbk0496
```

Enter your password when prompted to establish a connection.

- **Navigate to the Software Directory:** Use the following command to change the directory to the location of the software (assuming it's at `/lustre/astrum/rchen/OnlineDataAnalysisSystem/`):

```
cd /lustre/astrum/experiment_data/2024-05_E018/  
OnlineDataAnalysisSystem/
```

- **Create a Screen Session:** To manage software operations effectively, create a new screen session with the following command:

```
screen -S OnlineDataAnalysisSystem
```

This will create a screen session named “OnlineDataAnalysisSystem.”

- **Enter the `analyze_iq_sc` Directory:** Inside the screen session, navigate to the “`analyze_iq_sc`” directory with the following command:

```
cd analyze_iq_sc/
```

- **Activate Conda Environment:** Activate the Conda environment named “`iq7_env_ruijiu`” by entering the following command:

```
conda activate iq7_env_ruijiu
```

- **Run the Analysis Script:** Execute the Python script (assuming it's named `analyze_iq_sc.py`) with the following command:

```
analyze_iq_sc ../parameters/parameters_E143Exp_simulation.toml
```

- **Start Data Conversion:** Click the “Start analysis” button in the user interface of “`analysis_iq_sc`” program (see figure 2.4) to begin the conversion of TDMS files to frequency spectra.
- **Click “Start online server.”** button in the user interface of “`analysis_iq_sc`” program (see figure 2.4). After the background color of the “Start online server” and “Update online server” buttons turns grey, initiate “Start Roody” button.

- Plot results in Roody. Double-click on the graph object within the Roody interface as shown in figure 2.5, for example, “hD-CCT.time.” This action will display the graph illustrating the DCCT value versus time. To convert the time axis to a time format, right-click on the time axis and select the “SetTimeDisplay” option. Additionally, you can refresh the graph every 10 seconds by clicking on “Refreshing” and choosing the “10 seconds” option.

3.4 Simplified Operational Procedure for Online Data Analysis System

3.4.1 System Initialization

Below are the relevant paths to the code and data used in the system:

- Code:

```
(base) litv-exp@lxbk0497:/lustre/astrum/experiment_data/
2024-05_E018/OnlineDataAnalysisSystem$
```

- Raw tdms data:

```
litv-exp@lxbk0497:/lustre/ap/litv-exp
```

- Binary data:

```
litv-exp@lxbk0497:/lustre/astrum/experiment_data/2024-05_E018/
OnlineDataAnalysisSystem/data/$
```

To initiate the system, users must log in to the GSI computer, where they can execute commands to start the system management protocols. Open a terminal on any GSI Linux computer, such as the one in the Measurement Room. Start the “Online Data Analysis System” (see Fig. 3.2) by entering the following command in the terminal:

```
(base) litv-exp@lxbk0497:~$ start_OnlineDataAnalysisSystem
```

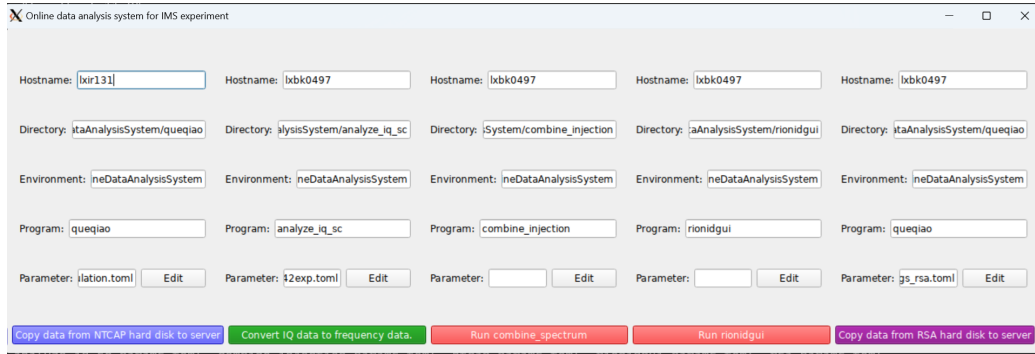


Figure 3.2: The “Online data analysis system for IMS experiment” interface.

The interface of the “Online Data Analysis System” (see Fig. 3.2) currently includes five functions, each corresponding to a button. By clicking each button, the program will automatically complete the following four steps: 1) Open a xterm terminal; 2) Log in to the server with the parameters “hostname”; 3) Activate the conda environment; 4) Run the program. The details of the five main functions are followings:

1. Run the “**queqiao**” program to copy TDMS data file on NAS harddisk to the server.
2. Run the “**analyze_iq_sc**” program to convert TDMS files into frequency files (“*****.bin_time/***.bin_fre/***.bin_amp**”).
3. Run the “**combine_injection**” program in the “**combine_tdms**” mode to merge multiple TDMS files into one spectrum.
4. Run the “**rionidgui**” program for ion identification.
5. Run the “**queqiao**” program to copy RSA data to the server at `\lustre\ap`.

3.4.2 Usages

Usage-1: identify the $^{229}\text{Th}^{89+}$ ions in the ^{229}Th experiment

The system has been used in the ^{229}Th experiment conducted in June 2026 for ion identification. To quickly identify the spectrum, we need to perform the following four steps: 1) transfer NTCAP recorded data to the server; 2) run the analysis program to convert TDMS data into frequency data; 3) run the “**rionidgui**” program for ion identification to confirm the beam

is $^{229}\text{Th}^{89+}$ ions; 4) run the “**combine_injection**” program to concatenate multiple files into one spectrum, calculating the lifetime of $^{229}\text{Th}^{89+}$ ions.

1. Copy tdms data from NTCAP hardisk to server.

Fig. 3.3 shows the user interface of “**queqiao**”. The program can be started through following steps:

- Click the button “**Copy data from NTCAP computer to the lustre server**” via the “**Online data analysis system for IMS experiment**” interface (see fig. 3.2).
- Set the directories for IQ (NTCAP_IQ) and SC raw data (“NTCAP_SC”) using the “Browse” button (see the right side of Fig. 3.3).
- Starting the data transfer by clicking the “start” button (see the left side of Fig. 3.3).

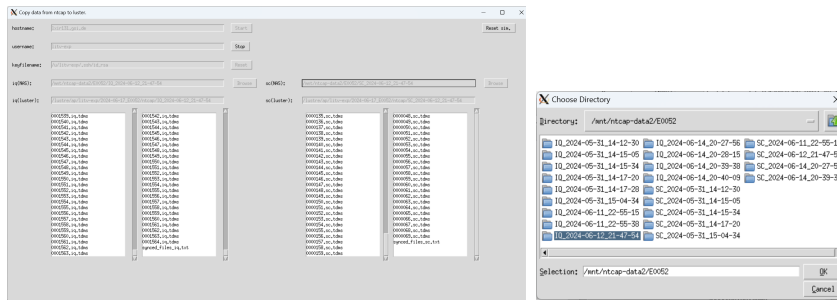


Figure 3.3: The “queqiao” interface and the “browser” interface.

2. Convert each TDMS file to a frequency spectrum file

Fig. 3.4 shows the user interface of “**analyze_iq_sc**”. The data analysis is conducted through the “**analyze_iq_sc**” program, which performs Fast Fourier Transforms (FFT) and generates spectra for each TDMS file. The specific steps include:

- Run the “**analyze_iq_sc**” program by clicking the “**Convert IQ data to frequency data**” button via the “**Online data analysis system for IMS experiment**” interface (see fig. 3.2).
- Initiate FFT conversion of IQ data to a frequency spectrum for all TDMS files using the “**start FFT**” button in the “**analyze_iq_sc**” interface (see fig. 3.4).. When you click the “**start**”

FFT” button, the program runs the “**iq7**” program to convert each TDMS data into 3D spectral data, covering the full frequency range. The time axis of this 3D spectral data is stored in the “*****.iq.tdms.bin_time” file, the frequency is stored in the “*****.iq.tdms.bin_fre” file, and the amplitude information is stored in the “*****.iq.tdms.bin_amp” file. A small range spectrum **FFT** is stored as a **TH2D** object in the “*****.iq.tdms.root” file. The program will convert each TDMS file into four files. For example, the “*****.iq.tdms” file is converted into the following four files: “*****.iq.tdms.bin_time”, “*****.iq.tdms.bin_fre”, “*****.iq.tdms.bin_amp”, and “*****.iq.tdms.root”.

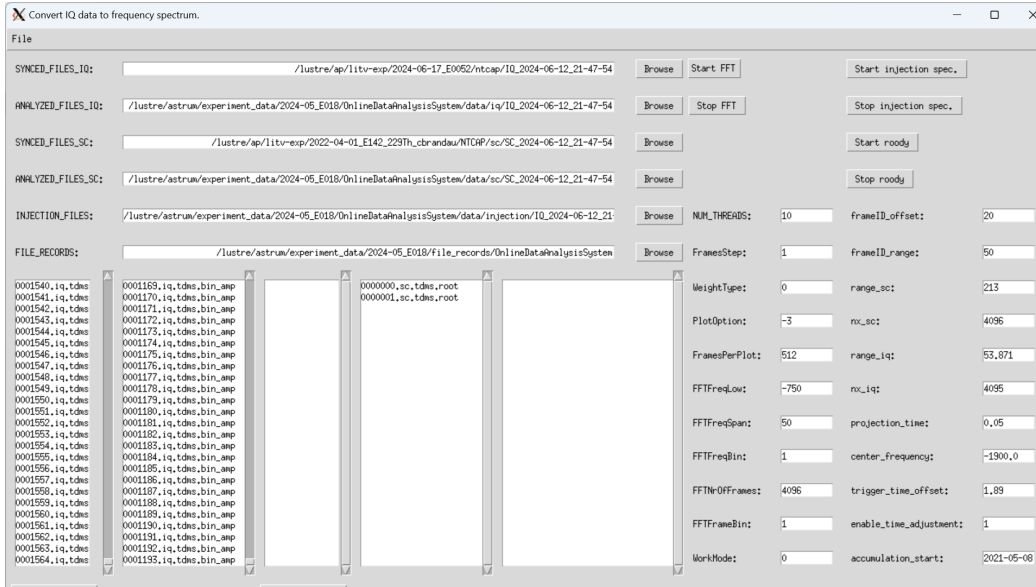


Figure 3.4: The “**analyse_iq_sc**” interface.

3. Ion identification

Fig. 3.5 and 3.6 show the user interface of “**ronidgui**”. The principle of calculating the simulated spectrum is explained in the appendix. During the use of the program, the frequency of the $^{229}\text{Th}^{89+}$ ions needs to be manually specified, and then the simulated spectrum is calculated. When the input frequency of the $^{229}\text{Th}^{89+}$ ions is correct, the simulated frequency spectrum will completely match the experimental frequency spectrum. The operation procedures are as follows:

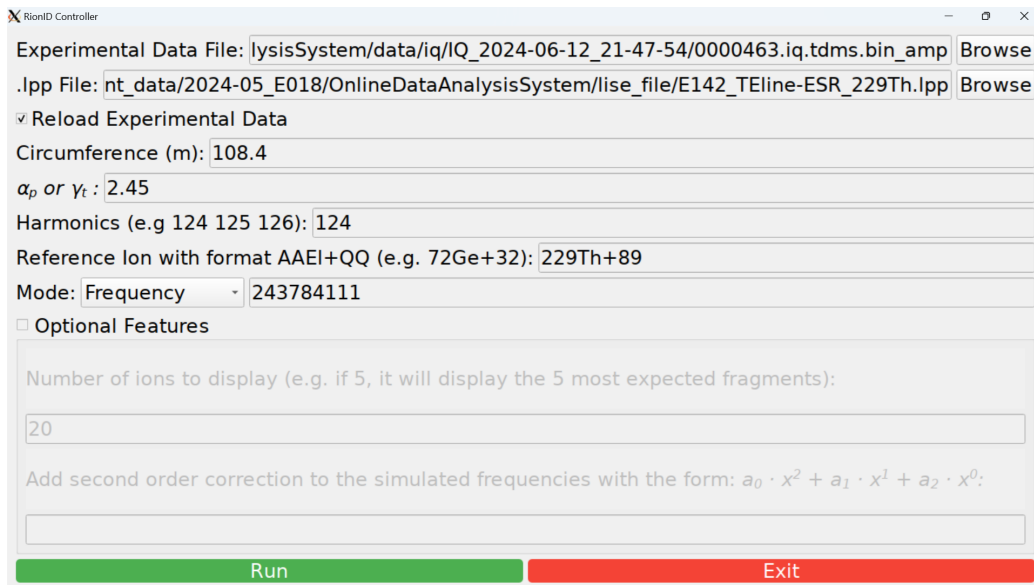


Figure 3.5: The “**rionidgui**” interface.

- (a) Run the “**rionidgui**” program by clicking the “**Run rionidgui**” button in the interface (see Fig. 3.2).
- (b) In the “**rionid**” interface (see Fig. 3.5), set the data file, LISE file, and other parameters. Then, click the “**Run**” button in the “**rionid**” interface to generate the experimental frequency spectrum and simulated data (see Fig. 3.6).

4. Calculating the lifetime of $^{229}\text{Th}^{89+}$ ions.

Fig. 3.7 and 3.8 show the user interface of “**combine_injection**”.

- (a) Run the “**combine_injection**” program by clicking the “**Run combine_spectrum**” button in the interface (see Fig. 3.7).
- (b) In the “**combine_injection**” interface (fig. 3.7), select the “**combine_tdms**” mode and set the parameters such as file directory, file start and stop indices, average number, frequency range, and start date. Then, click the “**Start**” button to generate the 3D spectrum 3.8. The bottom panel of Fig. 3.7 shows the projection of the 3D spectrum onto the x-axis. Right-click on the bottom histogram in the Fig. 3.7 to open a dropdown menu. In the dropdown menu, select “FitPanel” to perform the fitting. For detailed fitting methods, refer to the link <https://root.cern/manual/fitting/>.

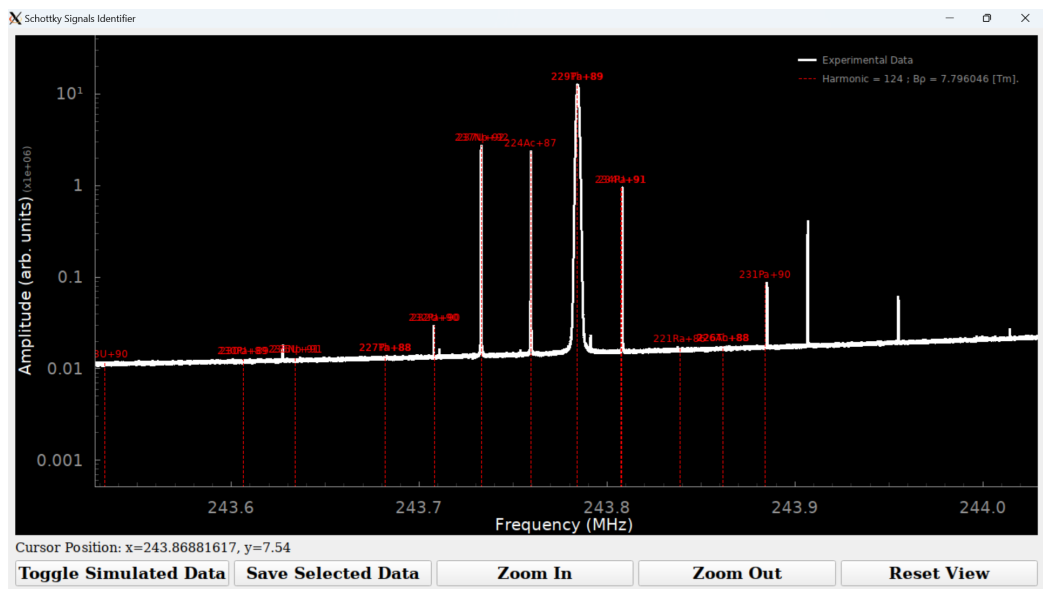


Figure 3.6: The experimental spectrum and simulated spectrum.

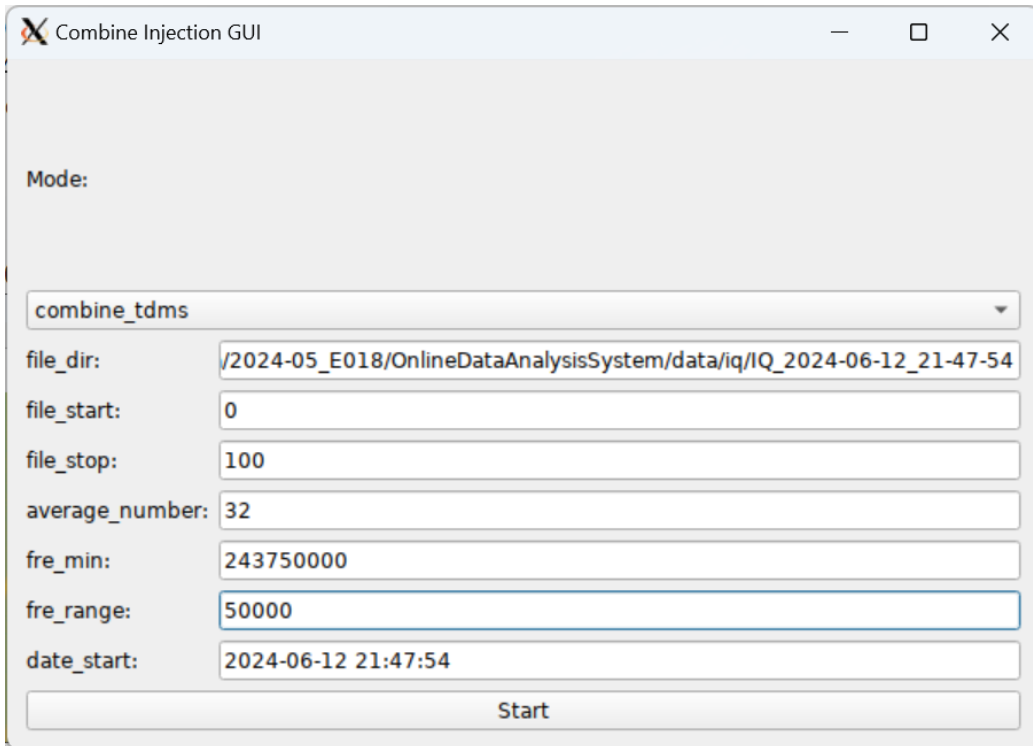


Figure 3.7: The combine_injection interface in combine_tdms mode.

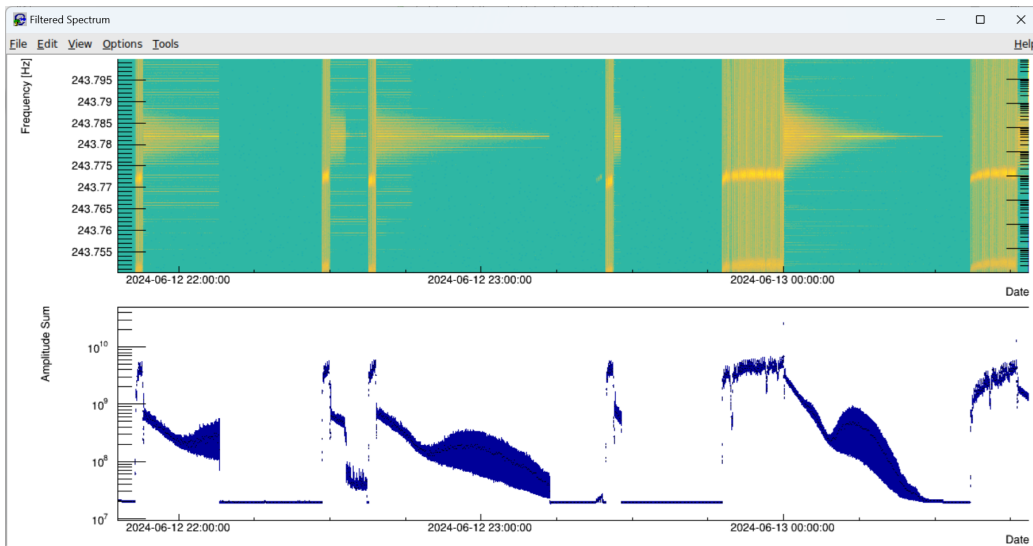


Figure 3.8: The generated 3D spectrum.

Chapter 4

Conclusion

The mass and lifetime of atomic nuclei are fundamental property that enhance our comprehension of their structure and decay properties. These characteristics significantly influence the nuclear astrophysical models, which elucidate the formation of heavy elements in the universe. Accurately measuring the mass and lifetime of short-lived atomic nuclei represents a significant challenge in current nuclear physics research. Utilizing heavy-ion storage ring mass spectrometers after radioactive beamlines offers an innovative approach to overcoming the difficulties associated with measuring these properties of short-lived nuclei.

Isochronous Mass Spectrometry (IMS), utilizing storage rings, has become an indispensable tool for mass and lifetime measurements. The typical method involves a time-of-flight detector, which measures ions' flight time. Despite its effectiveness, the physical interaction of ions with the detector's carbon foil shortens their storage time, limiting the method's utility for lifetime measurements.

In response to this limitation, the GSI Helmholtz Centre for Heavy Ion Research has pioneered the use of longitudinally sensitive Schottky detectors within IMS experiments. This approach avoids destructive measurement and allows for the simultaneous and precise determination of the mass and lifetime of atomic nuclei.

Central to these experiments is the NTCAP data acquisition system, a robust and effective instrument that has proven its value across various experiments, notably in the Isochronous Schottky Mass Spectroscopy experiment. Based on NTCAP system, we further develop the online data analysis system that processes experimental data swiftly, yielding real-time insights into experimental conditions.

The online data analysis system described in this report is a testament to the successful marriage of data acquisition and processing. Developed to

address the delays in data handling, it ensures that experimental anomalies are promptly detected and rectified, preserving the integrity of the research and minimizing the loss of valuable beam time.

The system's architecture is well-conceived, consisting of multiple code components operating in concert. Queqiao, the first component, ensures efficient data transfer from the NTCAP hard drive to the cluster server. The second component, `analyze_iq_sc`, utilizes cluster server resources to perform fast Fourier transforms (FFT) on the data, maintaining a processing latency of only five minutes. The third component, an online server, generates visualizations for analysis and interpretation.

The memory requirements for this system are substantial, with a single-file analysis demanding approximately 2.8GB of memory. However, the Astrum server, equipped with 32 CPUs and 128GB of memory, is more than capable of meeting these demands, facilitating efficient real-time online data analysis.

For those looking to implement this system, the report provides detailed instructions for installation, encompassing software setup and configuration steps. It also offers guidance on system operation, from initiating data synchronization to analyzing data and visualizing results.

In conclusion, the integration of the NTCAP system with the online data analysis system represents a leap forward in experimental nuclear physics. It embodies the collaborative spirit of researchers and engineers, whose efforts have yielded an innovative experimental approach and a powerful toolset for advancing our understanding of atomic nuclei. This report not only captures the essence of these developments but also serves as an invaluable guide for future endeavors in the field.

Appendix A

Scaler Signals Map at Messhütte

In the Messhütte laboratory, a comprehensive set of 11 signals is collected from various components, including the electron cooler, gas jet target, and ESR. Figure A.1 shows the photo of the ESR Messhütte.

All 11 signals have been converted into frequency signals, and specifically, six signals highlighted in red are designated for recording by the NTCap scaler. The breakdown of these signals is as follows:

A. Electron Cooler (4 channels):

1. **V-Ecool: Voltage of Electron Cooling.**
2. **I-Ecool: Electron current of Electron Cooling.**
3. **P-Gun: Pressure of the electron gun of Electron Cooling.**
4. P-Coll: Pressure of the collector of Electron Cooling.

B. Gas Jet Target (5 channels):

- S1, S2, S3, S4.
- **Inhibit: Status of the gas jet target.**

C. ESR (2 channels):

1. **Injection: Kicker signal of ESR.**
2. **DC-Trafo: Beam current of ESR measured by DCCT.**

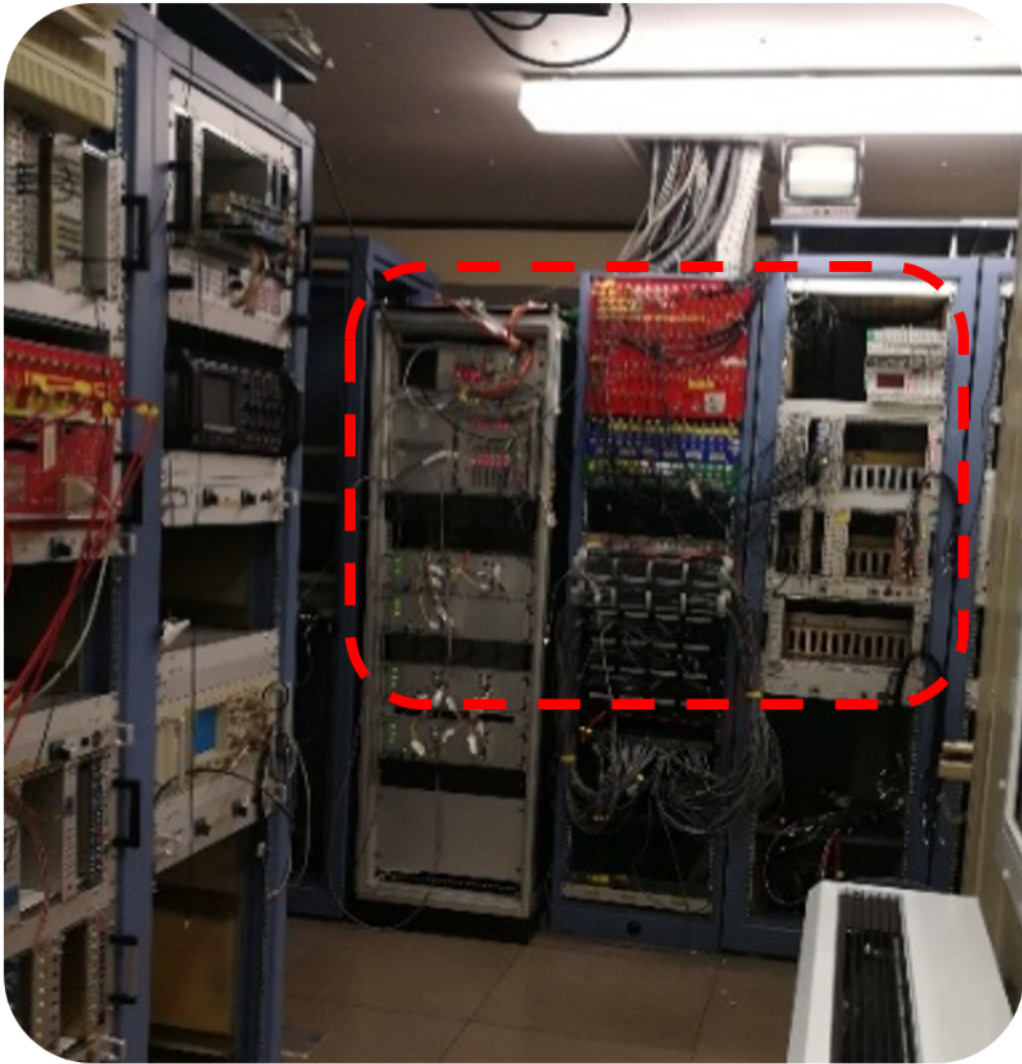


Figure A.1: the ESR Messhütte.

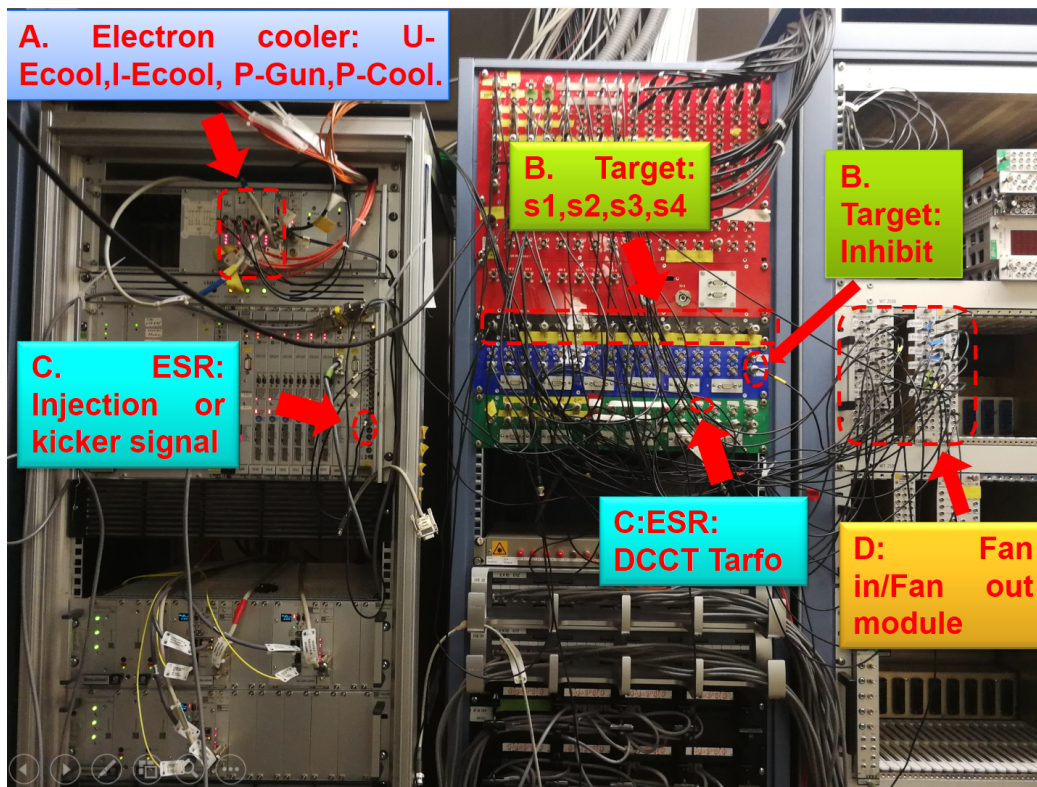


Figure A.2: Distribution diagram of signal sources from various devices.

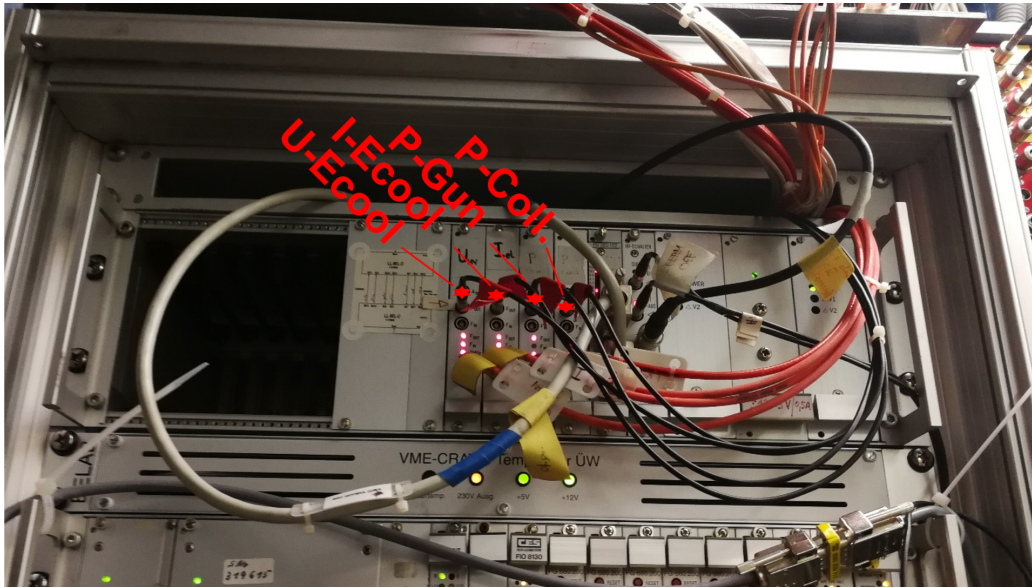


Figure A.3: Photos of signal of electron cooler. This image correspond to section A in the figure A.2

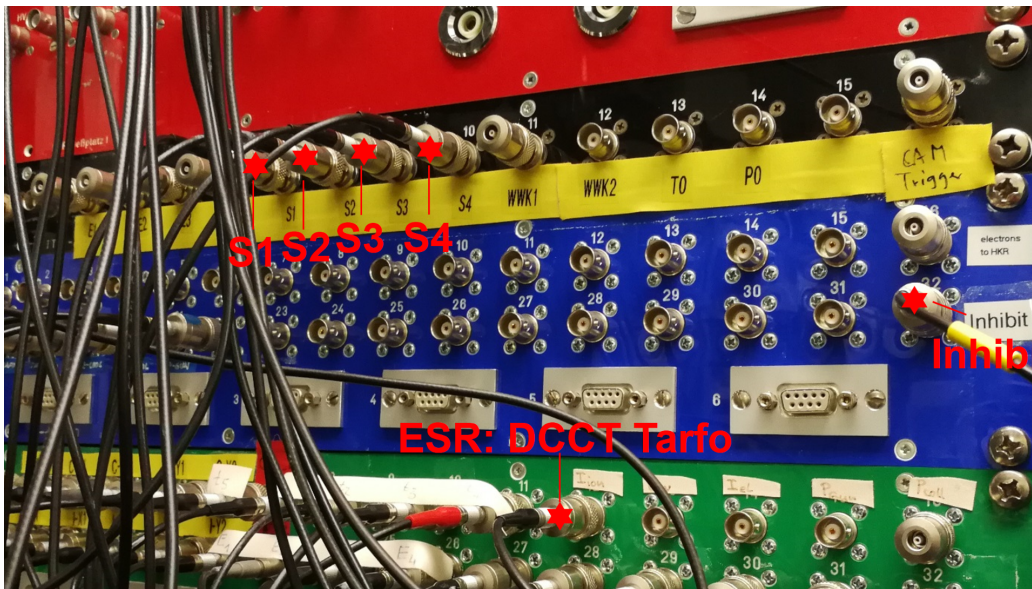


Figure A.4: Photos of signal of gas jet Target (S1,S2,S3,S4,Inhibit) and ESR DCCT current (DCCT tarfo). This image correspond to section B and C in the figure A.2



Figure A.5: Injection or kicker signal of the ESR. This image correspond to section C in the figure [A.5](#)

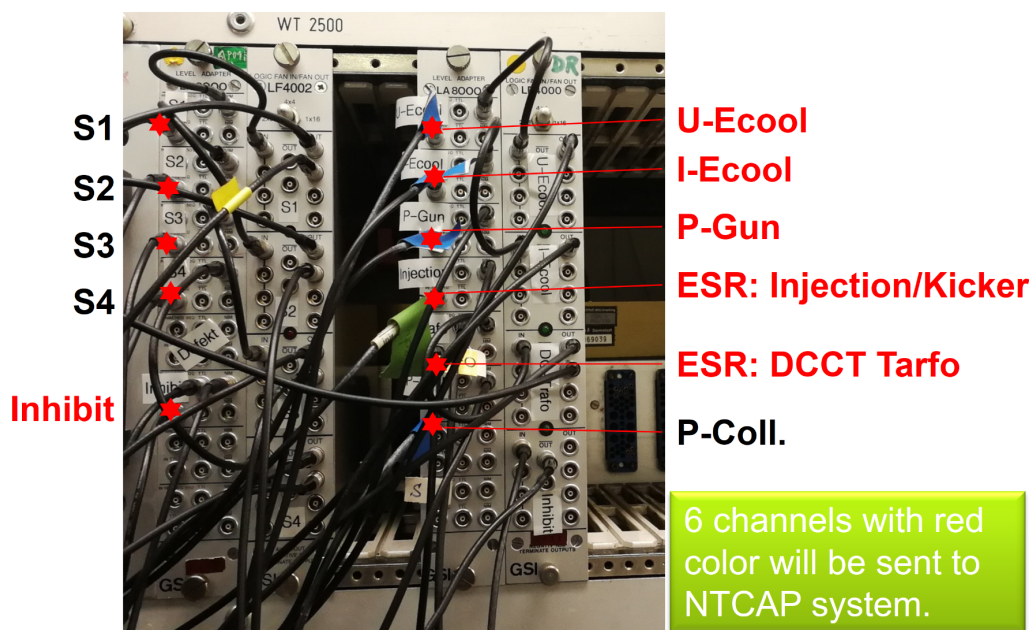


Figure A.6: Fan in/Fan out modul. This image correspond to section D in the figure A.2

Figure A.6 shows a central hub for consolidating signals from different devices. Utilizing the Fan in/Fan out module, each signal is divided into two channels, directed toward distinct experimental terminals. The signals from the red-highlighted ports in figure A.6 are specifically sent to the Scaler plugin of the NTCAP system. Notably, the signals emerging from the Fan in/Fan out module are in NIM format, whereas the Scaler plugin of the NTCAP system requires TTL signals. To facilitate this conversion, the signals from the Fan in/Fan out module must traverse through dedicated conversion modules, as illustrated in figure ??, with corresponding inputs labeled ch.26-41. Additionally, the Schottky RF signal lines have already been installed within the ESR Messshutte laboratory, and their connection to the RF input port of the NTCAP system will be done in the near future.

Appendix B

How to operate NTCAP

Kindly adhere strictly to the instructions, particularly during duty shifts in the midnight. Failure to do so may result in potential damage to the system or its improper functionality. In 2023, a critical incident occurred when the NIM crate was inadvertently left switched off during an experiment, leading to the absence of trigger generation. As a consequence, the recorded scaler data for that period was empty.

B.1 Start the NTCAP system

1. Start NAT hard drive box as shown in figure [B.1](#)



Figure B.1: Photo of NAT hard drive box of NTCAP system

2. Start NTCAP crate as shown in figure [B.2](#)



Figure B.2: Turn on the NI crate.

3. Switch on the NIM crate

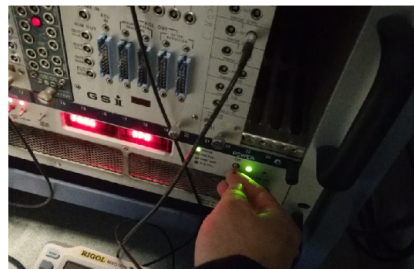


Figure B.3: Turn on the NIM crate.

4. Start NTCAP main computer



Figure B.4: Turn on the NTCAP main computer.

The password is: ntcap1805.

5. Run “Synology Assistant” (note that this step is required only for the first time)

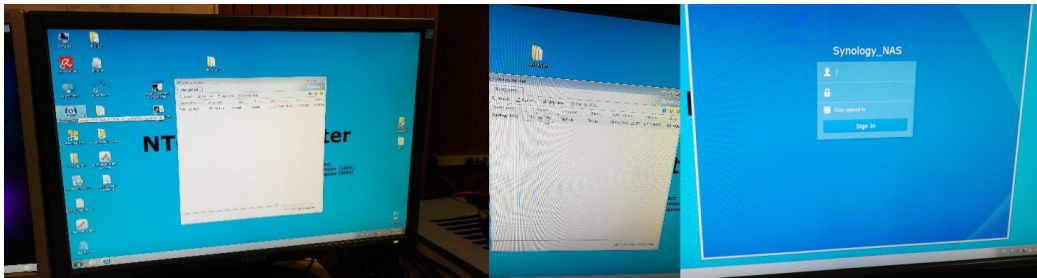


Figure B.5: Turn on the Synology Assistant of NTCAP system.

The username is :admin. The password is :ntcap1805.

6. Load hard disk on NTCAP computer.

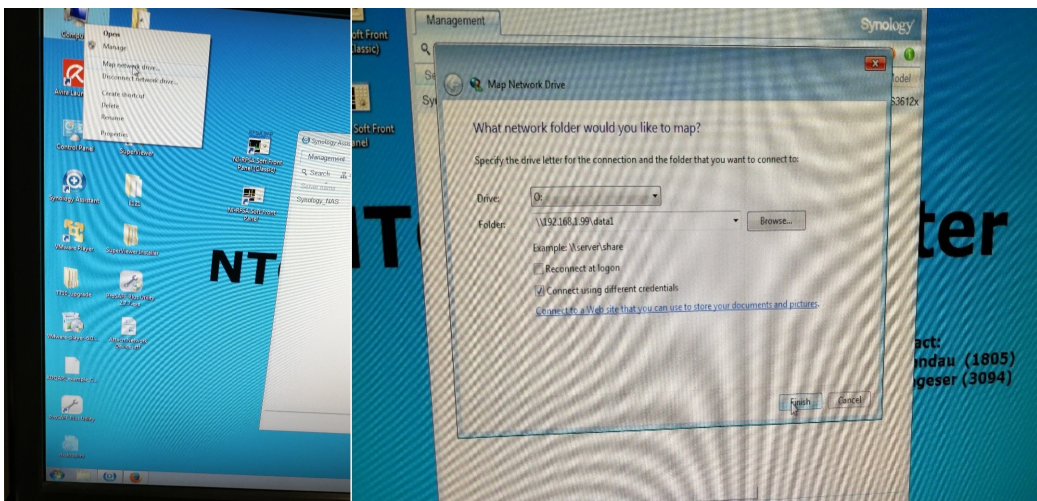


Figure B.6: Load hard disk on NTCAP computer.

The username is : \ntcapuser. The password is :ntcap1805. Select “Drive:O” as “Folder:\\192.168.1.99\data1”, “Drive:P” as “Folder:\\192.168.1.99\data2”.

7. Run NTCAP

- (a) Enter the E121 directory on the desktop and run the labview program

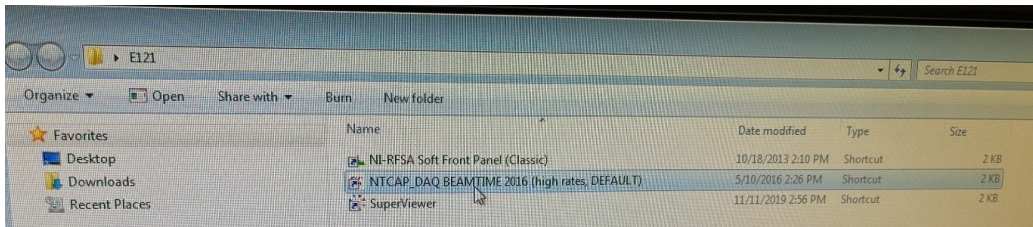


Figure B.7: E121 folder.

- (b) Click “Init”, then click “Start”. The user interface of the NTCAP is as follows.

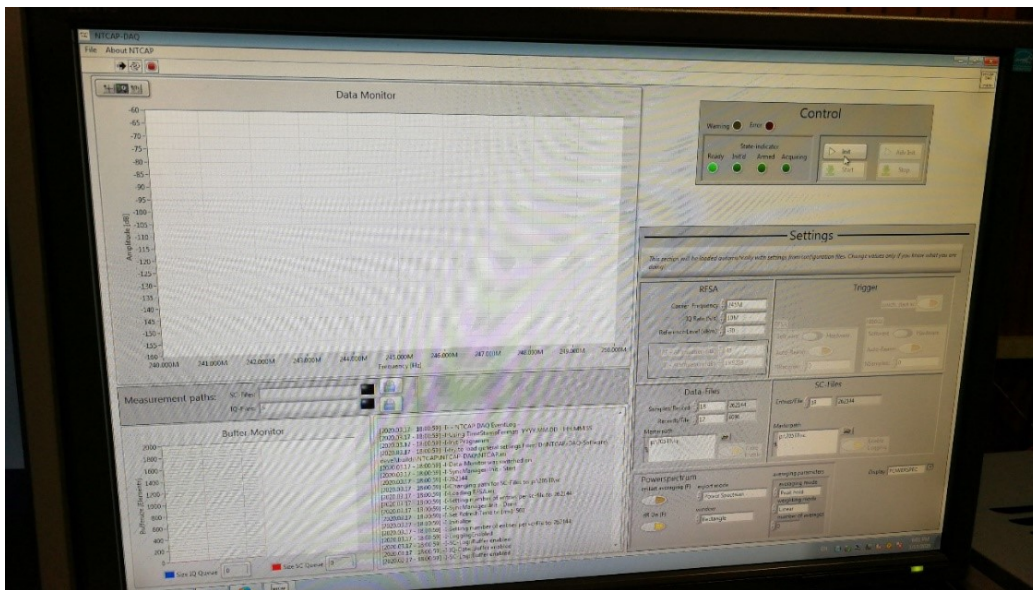


Figure B.8: NTCAP user interface.

B.2 Turn off the NTCAP system

1. Turn off Labview program
2. Disconnect the net hardisk

3. Turn off NAT system in the Synology Assistance.
4. Turn off NTCAP main computer
5. Turn off NTCAP NI crate
6. Turn off NTCAP NIM crate

Appendix C

Adjustment of the NTCAP Reference Level

The accurate calibration of the reference level in NTCAP system is crucial for ensuring reliable measurements and preventing undesirable effects on the frequency spectrum. we introduce the manual adjustment process of the NTCAP reference level, addressing the potential issues associated with improper settings and proposing a step-by-step guide for achieving optimal calibration.

One of the key challenges in NTCAP operation is the need to manually adjust the reference level. If set too low, the frequency spectrum can exhibit a saturation effect, leading to non-proportional relationships between noise power density and ion number. This phenomenon highlights the critical importance of accurate reference level calibration in obtaining meaningful and reliable data from NTCAP experiments.

To address the reference level calibration in NTCAP, a specific set of steps is proposed. These steps aim to guide the user through the adjustment process, ensuring that the reference level is set at an optimal value to avoid saturation effects and maintain the proportional relationship between noise power density and ion number.

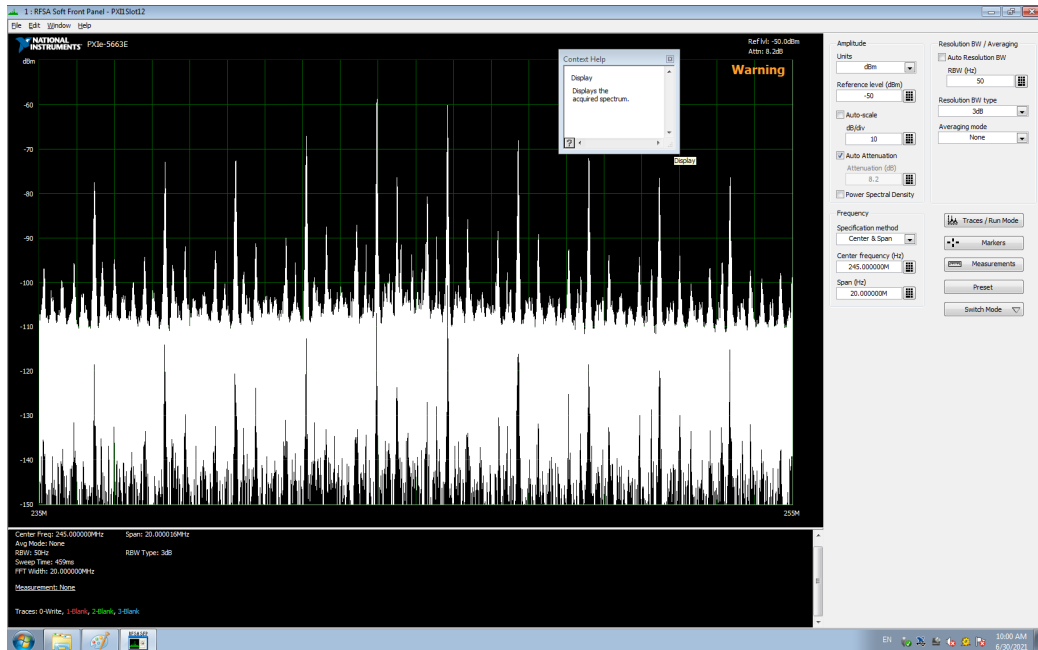


Figure C.1: User interface of NI RFSA Soft Front Panel

Step 1: Software Interface Access

The first step in the calibration process involves accessing the “NI RFSA Soft Front Panel(Classic)” located in the “E143” folder. This software interface provides the necessary tools for adjusting the parameters of the NTCAP system.

Step 2: Setting Resolution/Averaging

Within the software interface, the “Resolution/Averaging” parameter is set to 50 Hz. This step is crucial for achieving a balance between resolution and averaging, contributing to the accuracy of the subsequent steps.

Step 3: Configuring Center Frequency

The center frequency of the NTCAP system is adjusted to 245MHz. This specific frequency setting is chosen to align with the optimal operating con-

ditions for the NTCAP system.

Step 4: Adjusting Reference Level

The reference level is then manually set to an initial value of -50 dBm. If a “Warning” is displayed during this process, the user is instructed to incrementally increase the value, such as to -40dBm, until the warning disappears. The calibration process concludes when the warning disappears, signifying the correct reference level for the NTCAP system.

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