EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

August 16, 2019

Upgrading the NA61/SHINE Local TPC Data Acquisition System

Anna Coerver

Barnard College, Columbia University, New York, NY

Supervisor: Wojciech Bryliński

Abstract

This document summarizes my work as a Summer Student in the NA61/SHINE experiment. I discuss the SHINE 2020 upgrades, specifically those to the TPC data acquisition system. I present the process for creating a flow of simulated data from the TPC readout electronics to online event reconstruction software currently being developed. This involved taking "real" data with cosmic rays, reading out that data, and decoding it to be read by the event reconstruction software. Additionally, I discuss the creation of a simulated trigger system for both hardware and software purposes. This work helps to ensure that, once SHINE is back in operation, the real-time event reconstruction software will work smoothly with the new readout electronics.

Contents

1 Introduction **3**
1.1 The NA61/SHINE Experiment 3
1.2 SHINE 2020 Upgrade 3

2 Upgrading the Local TPC Data Acquisition System **4**
2.1 TPC DAQ 4
2.2 Setting up the LMPD as a Cosmic Ray Detector 4
2.3 Online Event Display 5
2.4 Simulating the TPC Data Flow 5
2.5 Simulating Trigger Signals 6

3 Conclusion **7**

4 Acknowledgements **7**

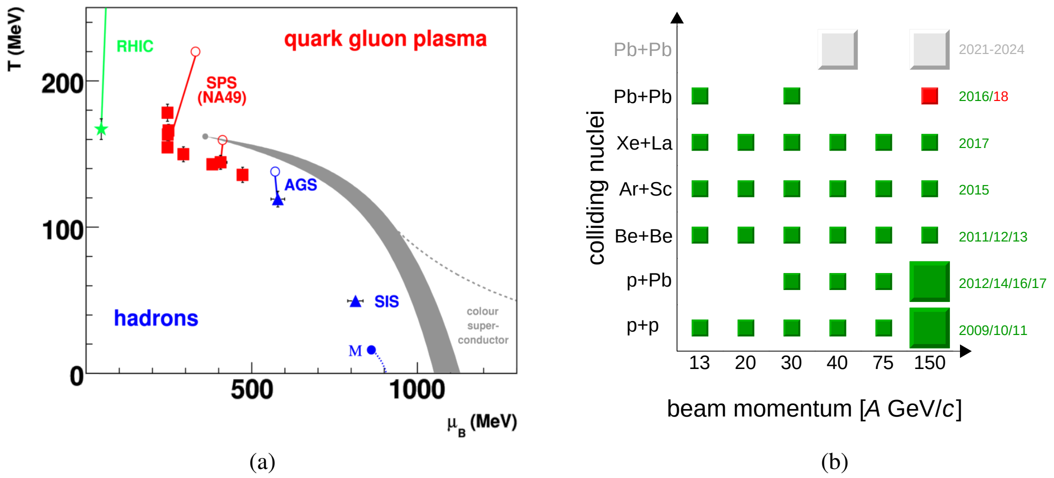

Figure 1: (a) Phase diagram of strongly-interacting matter. (b) Collisions conducted at NA61/SHINE. (NA61 and NA49 Library of Images)

1 Introduction

1.1 The NA61/SHINE Experiment

SHINE (SPS Heavy Ion and Neutrino Experiment) was created to explore the phase transition between confined matter and the quark-gluon plasma (QGP) (Fig. 1a). It uses a variety of beam momenta (13A-158AGeV/c) and collisions of different systems (p+p, Be+Be, Ar+Sc, Xe+La, Pb+Pb) to cover the area of the strongly-interacting matter phase diagram where the critical point is expected (Fig. 1b) [1]. In addition to investigating this phase transition, SHINE is shifting to a new focus in open charm production at SPS energies, a previously unexplored topic. SHINE hopes to answer the questions:

1. What is the mechanism of open charm production?
2. How does the onset of deconfinement impact open charm production?
3. How does the formation of quark-gluon plasma impact J/Ψ production?

These open charm hadron measurements are made possible by the addition of a micro vertex detector, which provides the spatial resolution necessary to reconstruct primary and secondary vertices from the collisions. Pilot data taken in 2016 using Pb+Pb collisions at a beam momentum of 150AGeV/c confirmed the success of the measurement technique and resulted in direct detection of open charm hadrons (specifically D^0s) at SPS energies. Beyond 2020, the newly-upgraded SHINE will use Pb+Pb collisions to further measure open charm hadron production.

1.2 SHINE 2020 Upgrade

SHINE is undergoing upgrades during the Long Shutdown 2 (LS2) (Fig. 2), and will begin operating again in 2020. One relevant upgrade taking place is the exchange of the current Time Projection Chamber (TPC) readout electronics with much faster readout electronics, increasing the data taking rate from 80 Hz to 1 kHz. This upgrade in turn requires an upgrade of the Data Acquisition (DAQ) system, which must adapt to read out this new data at new rates. The readout electronics upgrade goes hand in hand with the installation of a new vertex detector with a wider acceptance and larger data rate capabilities than the one commissioned in 2016. The combination

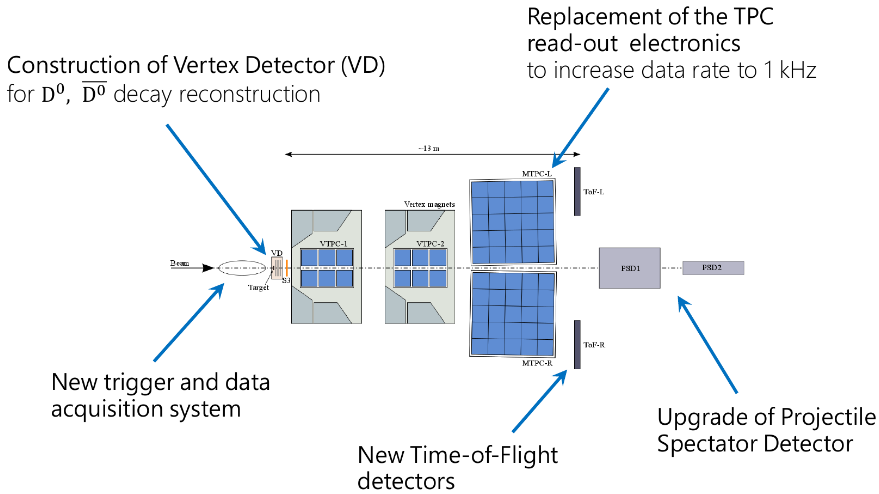

Figure 2: NA61 upgrades taking place during LS2

of this new vertex detector and the faster data taking rate will provide the data and statistics needed to conduct a detailed study of open charm production at SPS energies [2]. SHINE is also developing new software for online event reconstruction, a tool the experiment does not yet have. This software will recreate the collisions as the data is being taken, rather than after the fact. My role in SHINE is to, using data from the new readout electronics, create a simulated flow of realistic data to this online event reconstruction software so that it can be tested before the experiment begins to take data again.

2 Upgrading the Local TPC Data Acquisition System

2.1 TPC DAQ

The SHINE TPCs give information on the position of particles as they move through the detector. The TPCs are filled with a neutral gas mixture, which is then ionized by particles from the collisions. The knocked-off electrons are dragged upwards to sensors by an applied electric field, giving a shadow of the tracks the particles took through the detector. The data is read out from the TPCs using front-end electronics (FEEs), which consist of 32 channels each. For our set-up we used four cards and thus had 128 channels of data. The data from the FEEs is read out into binary files, and then decoded in the DAQ system.

2.2 Setting up the LMPD as a Cosmic Ray Detector

In order to correctly simulate the data SHINE will be producing after the upgrade, we set up a tabletop cosmic ray detector using a Low Momentum Particle Detector (LMPD) prototype, which functions as a miniature TPC, and the readout electronics from the upgraded SHINE TPC. This set-up (Fig. 3) included the LMPD sandwiched between two boards of scintillators and photomultiplier tubes (PMTs), and had to be connected to a gas supply in the experimental area. I set up the trigger system for this experiment by activating the data taking trigger whenever a signal above a certain threshold (tuned to produce a reasonable data rate) was received from both the top and bottom board of scintillators and PMTs. Each board had 8 channels, so OR operators between the 8 channels were used to check whether there was a signal from each board, then an AND operator

Figure 3: LMPD set-up: scintillators and PMTs on top and bottom, LMPD and front-end cards in middle.

was introduced between the two boards to check if both received a quasi-simultaneous signal. An analog-to-digital converter (ADC) read out the analog signals from the set-up.

2.3 Online Event Display

In order to check whether the LMPD set-up was working, I prepared software that would display the events we were receiving in real time in the form of the tracks the particles left in the detector. We displayed the signals from the particles in both the spatial and time domains (Fig. 4). These histograms were created by running the event files through a decoder, then taking the maximum ADC values (and corresponding time stamps) from each channel each time an event was recorded. The top figures in Fig. 4 show the ADC values without pedestals taken into account, and the bottom figures show the values with pedestal subtraction.

2.4 Simulating the TPC Data Flow

In order to simulate the flow of data from the readout electronics to the event reconstruction software, software had to be developed to read and decode the events as they arrived. An overview of the code goes as follows:

1. Events are received in their original data form.
2. The Reader module opens these events, reads the event size, and separates the data from the header.
3. The reader loads the data, grouped into 32-bit words, into a buffer.
4. The buffer of data, as well as the event ID and event length, are used to instantiate a "raw event" object. This object is pushed to a queue of raw events.

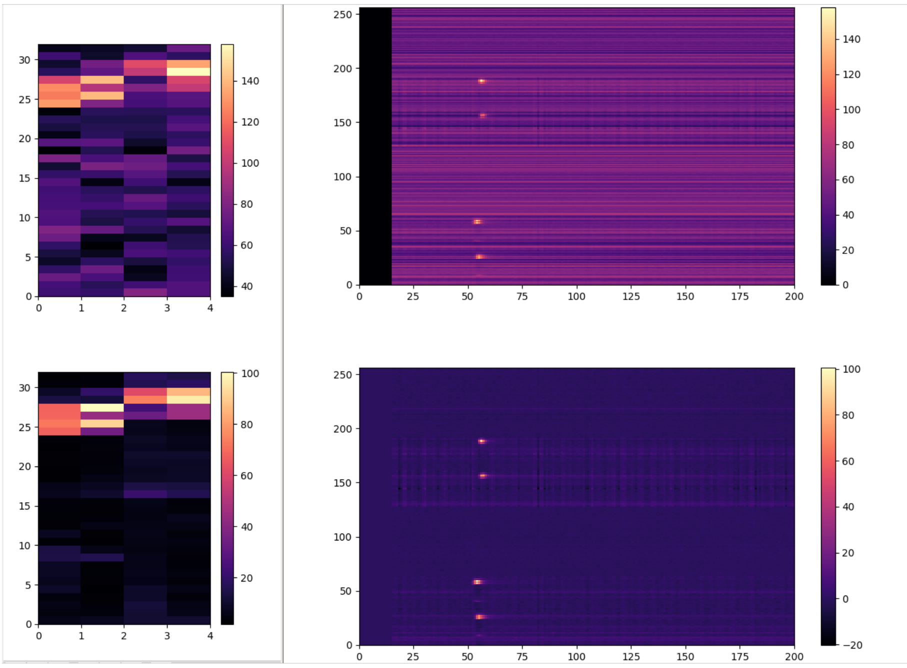

Figure 4: An example of a cosmic ray particle traveling through the LMPD set-up. The spatial display is on the left, with channel numbers of pad 1 on the y-axis and pad number on the x-axis. The waveform plot is on the right, which has channels of all four pads on the y-axis and arrival time on the x-axis.

5. The Decoder module pulls from this queue of raw events and decodes the data, returning ADC and timestamp values for each channel and creating a queue of decoded events.

The data in its decoded state is then ready to be sent to the online event reconstruction software.

2.5 Simulating Trigger Signals

A major part of correctly simulating the data flow is simulating the trigger that decides the data rate the event reconstruction software is receiving. The simulated triggers themselves will be pulses created by an Arduino, with somewhat "random" time delays between pulses. To create these time delays, I wrote a Python script that generates one million random floats between 0 and 10 seconds, ordered the list, and then found the difference (the time delay) between each float. Plotting and fitting these values gives a roughly exponential distribution following $f(x) = N \times e^{-x}$, where $N = 22,000$, $x = 10,000$ and the normalization constant is 0.22. Normalizing the fitted function and finding the expectation value gives an expected time delay of ~10 μs. This information can be used to generate a large array of "random" time delays that can be run through on a loop to generate fake trigger signals.

This method of producing fake trigger signals will have both a hardware and a software application. The time delays generated will be used both to set the flow of events to the simulated data acquisition system, and to generate fake triggers with an Arduino using voltage pulses. The Arduino pulses will be used to check that the hardware of the experiment responds correctly to trigger signals.

3 Conclusion

During my time with SHINE, I participated in arranging a miniature data-taking set-up, as well as prepared online event display software and a trigger system for this process. I then developed software that simulates reading and decoding a data stream taken with SHINE's new readout electronics. This software still needs to be integrated with the online event reconstruction software, and then tests of the event reconstruction software with a simulated data flow and simulated trigger signals can be run.

4 Acknowledgements

I am sincerely grateful to Wojciech Bryliński for his mentorship during this project and for his guidance of how to have a great summer at CERN! Thanks to Dariusz Tefelski, Lucasz Mik, and Piotr Podlaski for their assistance with my projects, and for welcoming me into the SHINE team. I would also like to thank the University of Michigan team for their support and for putting so much work into making this amazing summer possible. This work was supported in part by the U.S. National Science Foundation.

References

[1] N. Abgrall et al. NA61/SHINE facility at the CERN SPS: beams and detector system. *Journal of Instrumentation*, 9(6):P06005, Jun 2014.

[2] Dag Larsen. Upgrade of the NA61/SHINE Facility beyond 2020 for an Expanded Physics Programme. *Universe*, 5(1):24. 18 p, 2019.