

Introduction to the Data Analysis of NA62 Experiment

Eliot Genton under the supervision of Dario Soldi

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1 Introduction

This report covers the work done aswell as a global view of my experience working on the Level 0 Trigger process of the NA62 experiment under the supervision of Dario Soldi. This work took place under the organisation of the Summer Student Programm offered by CERN. This programm offers the possibility of undergraduate and graduate students to take part in a research experiment as well as follow lectures given by CERN lecturers.

The motivation for this research internship was to analyze the L0TP data collected by the NA62 experiment in 2021 and compare it to previously analyzed data from 2018 and before. This was to be done by further developing analyzers coded in C++. However, due to multiple issues, the data gathering of the NA62 experiment was badly delayed and within the short 9 week frame of my internship this made it such that I got very little access to new sets of data. However, I was still able to learn many new tools and have an insight into the world of a great institution with an incredibly determined team. In this report I will first give a succinct summary of the NA62 experiment, of its goals and components. Secondly, I will give a summary of the goal of the internship and lastly I will present the results I obtained for the analysis I did.

2 NA62 Experiment Summary

One of the most complex aspect of this project was to understand the global perspective of the experiment and how each component of the experiment collaborated towards this goal. This was a key step to understand the research I was to conduct as well as where the research fitted in the general project of NA62.

The North Area (NA) 62 experiment, was approved in 2005 and started to gather

data in 2015. This experiment aims to study extremely rare kaon decays through the interaction of high energy (400 GeV/c) protons from the Super Proton Synchrotron (SPS) into a beryllium target. Indeed the collision between these two leads to a 1 GHz beam of particles from which about 6 % are kaons [1]. The physics motivation that arises behind the study of kaons is due to their possible decays. Indeed, the process $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ are very attractive to study for the progress of flavour physics. These decays are dominated by short-distance dynamics which activate the Glashow–Iliopoulos–Maiani mechanism and the branching ratio can be computed with great accuracy however is also extremely sensitive to new physics (e.g Supersymmetry)[2]. The branching ratios of these decays are of the order of 10^{-11} making NA62 the experiment to measure one of the rarest events measured in experimental physics. Knowing the interesting subtleties in these process, the experiment aims to extract a 10 % measurement of the Cabibbo–Kobayashi–Maskawa matrix parameter V_{td} used to measure the probability of a top quark to decay into a down quark [3].

To do so the experiment aims to collect about 100 $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events at the Standard Model prediction with a signal to background ratio of 10:1 within about 2 years of data taking. It is important to note that the signature track of these decays are single pion charged track since the detection of neutrinos is nearly impossible. With the decay being so rare the biggest challenge of this experiment is to reject most of the background noise up to the factor of sensitivity needed along with adequate veto systems and particle identifications. 3 Macro regions can be distinguished in the experiment: the upstream region in which the beam is tracked, the fiducial volume in which the particle decays and lastly the downstream region where the decayed particles properties are analyzed. To understand this in further detail, it is important to look at the structure of the NA62 experiment and give a succinct summary of each component.

3 Experimental Set Up

The NA62 experiment consists of roughly 10 sub parts, which are mostly detectors and each play a fundamental role in the measurement of the rare events. A figure summarising the apparatus of the experiment can be found in figure PUT FIGURE NUMBER.

1) The beam: The incoming beam contains 75 GeV/c positively charged particles derived from the primary source which is the CERN SPS accelerator and is directed towards a fixed beryllium target. This beam momentum is chosen to maximize the kaon production and the number of decays within the fiducial volume.

2) CEDAR (Kaon Tag): This is used to identify kaons from all the other beam

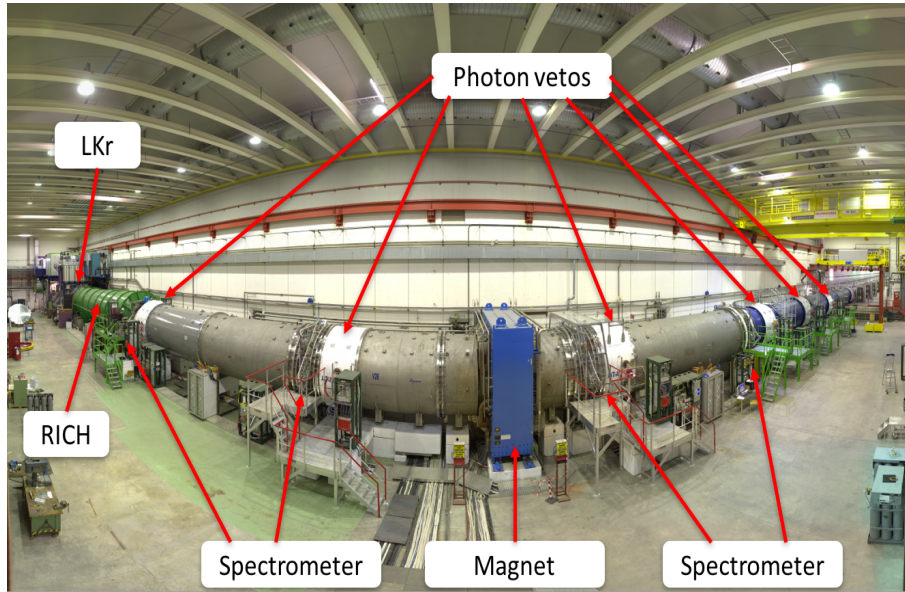


Figure 1: Annotated photograph of the NA62 experiment apparatus and its components

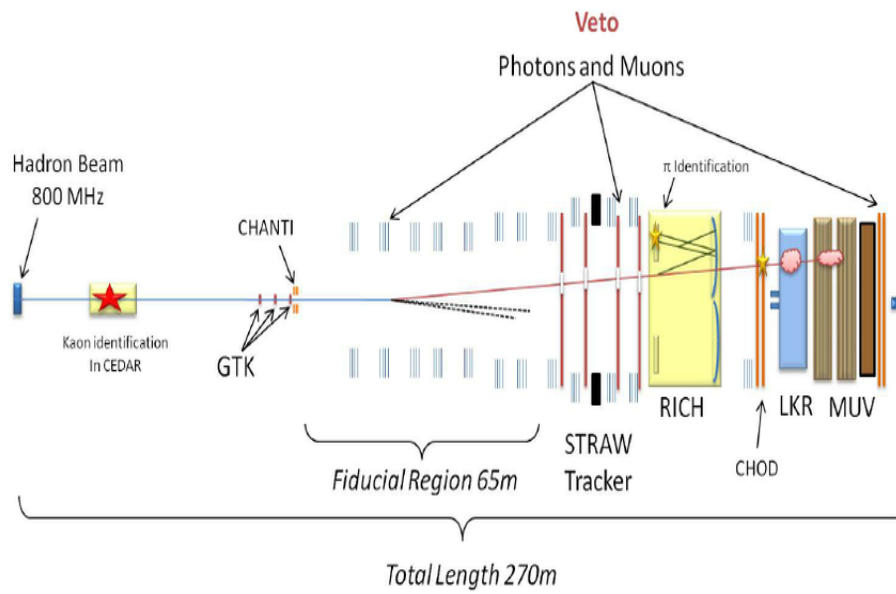


Figure 2: Simplistic graphical representation of the NA62 apparatus described in this section.

components. This is done by using a Cherenkov counter detector called CEDAR/KTAG which detects the photons emitted by 75 GeV/c kaons.

3) Giga Tracker (GTK): This is a beam spectrometer that is placed right before the decay regions of the Kaons. It provides precise evaluation of the time, direction, and momentum of all incoming particles. These measurements can then be used for decay selection and for background reduction which is of extreme importance for an experiment looking for such rare decays.

4) CHANTI: This is short for the Charged Anti-counter Detector. The role of this detector is to veto events caused by the interaction between the beam and the third station of the GTK. This is a scintillator detector.

5) Photon Veto Detectors: The experiment has a photon veto system. This once again helps reducing the background coming from the $k \rightarrow \pi\pi_0$ signal up to an inefficiency of around 10^8 . This photon veto system provides a hermetic coverage performed by three subsystems (Large Angle Vetos, Liquid Krypton Calorimeter and the Small Angle Vetos) which all together cover angles in a range of 0-50 mrad.

6) Straw Tracker: This is a downstream spectrometer that aims to detect the decayed particles after the 60m long path in vacuum they just took. These systems therefore measure the momentum, direction of secondary charged particles.

7) RICH: This stands for the Ring Imaging Cherenkov detector, which is placed in between the Straw chamber and the LKr calorimeter. This detector helps distinguish between pions and muons within the range of 15-35 GeV/c. As the particles pass through the Cherenkov detector, they emit photons at angles that depend on the momentum and mass of the particle and the pressure of the nitrogen gas.

8) CHOD and NewCHOD: CHOD stands for Charged Hodoscopes. This is a scintillation detector that measures the time and position of charged particles to provide trigger signals to select events with one or more charged particles as well as to associate tracks in time with kaon tracks in the GTK detector. The NA62 experiment was also equipped with a new Charged Hodoscope to work together with the new one (NewCHOD).

9) Muon Veto System : The Muon Veto System similarly to the Photon Detector is divided in three different detectors (MUV1, MUV2 and MUV3) all placed just after the LKr detector. The first two detectors are hadronic calorimeters created using layers of both iron and scintillators. However, the MUV1 detector has an added transverse segmentation to separate between hadronic and electromagnetic parts of showers. The MUV2 was previously present within the NA-48 experiment

10) The last element of the system which will be presented is the NA62 Trigger and Data Acquisition System. There will be a special focus on the Level Zero Trigger (L0) as this is what my project mainly focused on and therefore I will give more information than for the other parts of the system.

The NA62 Experiment must measure an extremely rare decay of order 10^{12} within a flux of incoming particles of about 750MHz and a total event rate of 10 MHz. The rate at which information is delivered in the experiment makes it that collecting information of every single particle would be completely impossible. This therefore requires the presence of high performance Trigger and Data Acquisition System that can filter the information at different levels to collect a reasonable amount of data. The Trigger System I had to focus on during this project is named the Level Zero Trigger (L0). This trigger systems compares the primitives of one or more pre-defined and coded series of masks then sending the results of the computation to all subsystems. Primitives are 64 bit words that contain basic information on an event such as the time of the event as well as the encoded characteristics. It is important to note that not all detectors from NA62 are present within the L0TP computational process. Only hits (events) in the LKr, CHOD, New CHOD, RICH, CHOD LAV and MUV3. The data generated by each detector is then sent via Ethernet to the L0TP. The primitives within the experiment are categorised depending the conditions satisfied by the event, such as their time and position. This essential information combined with other important factors are essential for the data analysis that is done using Analyzers.

4 Tools used for the project

During this project I had to learn the usage of new tools of data analysis aswell as generic clustering tools for accessing the data.

4.1 SSH

To access any information regarding the NA62 Data I had to become familiar with SSH login. I personally used the program MobaXterm to access this data.

4.2 Analyzers

Once connected to the CERN servers it is important to understand how to manipulate any of the data generated by the experiment. To do so during this project we used analyzers. Analyzers are codes written in C++ Object Orientated Programming style. An analyzer takes the information from the L0TP and its specific detectors and uses this to make a statistical analysis of the data by looking at different interesting parameters. It is a very powerful and intuitive tool to create plots of

interesting parameters that can then be visualise through the ROOT file. A short list of parameters analyzed during this project can be found in section 5. As a first step into this project, I was taught to run old analyzers on a single set of data. Multiple data sets are generated from a run of the experiment. A single set of data consists of a list of around 6-10 bursts and each burst represents a short amount of data gathering from the experiment (5 seconds). One must compile the analyzer and run a specific data file through the analyzer. It is important to note that it is possible to run multiple analyzers on a same single data file, this is simply done by listing multiple analyzers within the configuration file. After processing the data through the CERN servers, the output file generated from this manipulation is a ROOT file located in the personal folder of the user within the CERN servers with all the generated data analysis from the multiple analyzers.

4.3 ROOT

To understand how to manipulate the ROOT file required me to learn basic coding skills in this language as I had never worked with it in the past. By downloading the ROOT program aswell as using the graphical interface provided by the TBrowser function it was then possible to observe the plots generated by the analyzer. A screenshot of this graphical interface is given in the following figure.

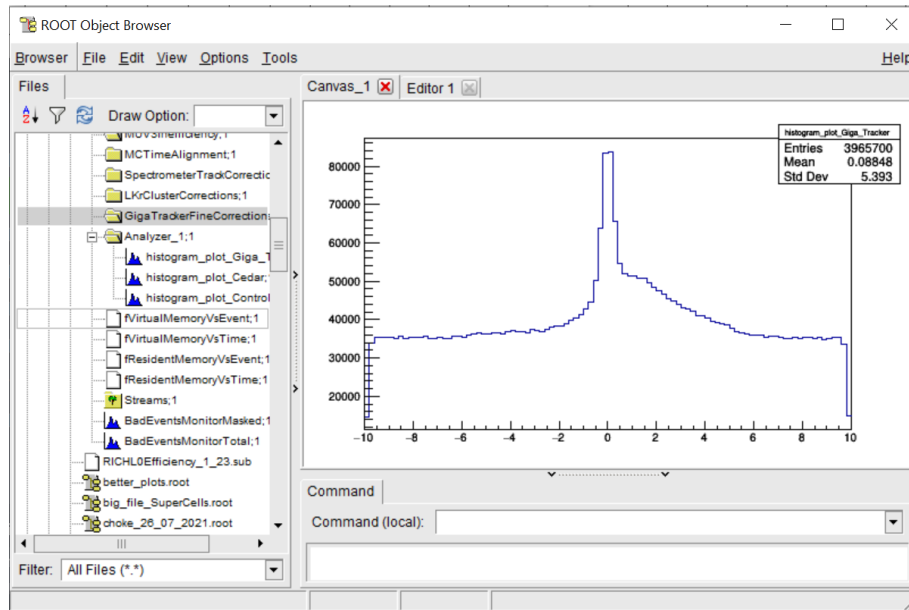


Figure 3: Using the TBrowser function on ROOT enabled access to the graphics plotted within the analyzers.

I was then taught by my supervisor how to not only run an analyzer or set of analyzers on a single set of data but to automatise this process on multiple data

sets. This is essential to analyze much more efficiently data and therefore reduce the statistical uncertainty on the analysis. To do this required to use a script written by my supervisor Dario. With this it was then possible to analyze many data files at once and perform interesting data analysis.

5 Data Analysis

5.1 Results

A first interesting parameter to analyse and to introduce the manipulation of analyzers was the efficiency of the photon detection within a detector. To do this it was essential to calculate the ratio of primitives detected in the system versus the number of photon measured in the experiment. This value is highly dependant on the energy of the particle as the number of emitted particles vary with the energy intensity reaching a maximum of 75 Gev. This kind of measurement was then re-

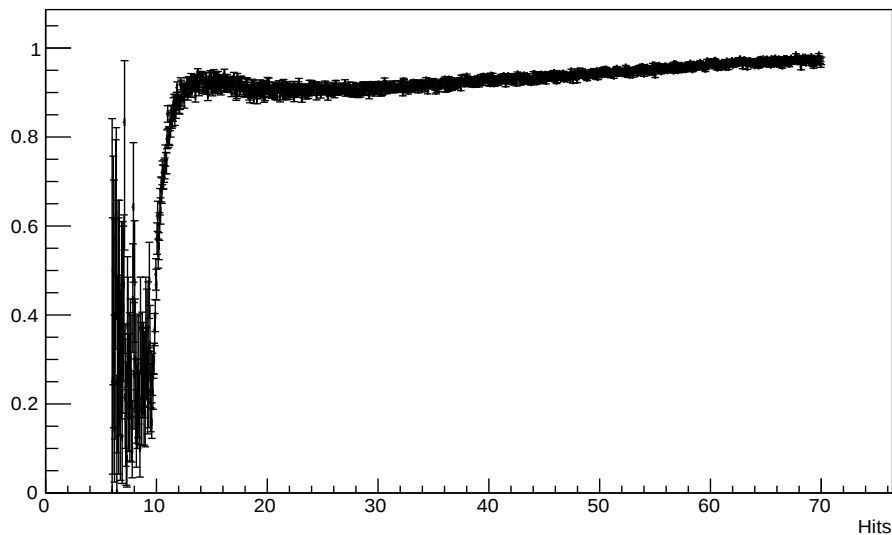


Figure 4: Efficiency of photon measurement from supercells vs the energy of measured muons

peated for many other background decays including double pion decays etc. This was a reproduction of the results presented in [4] p.13 in which a similar calculation is made and the same pattern is found. A similar exercise was to look at the momentum distribution of different particles and this was for example done for the momentum of the pion as seen below This was mostly an basic exercise to get familiar with the programs as well as the data manipulation.

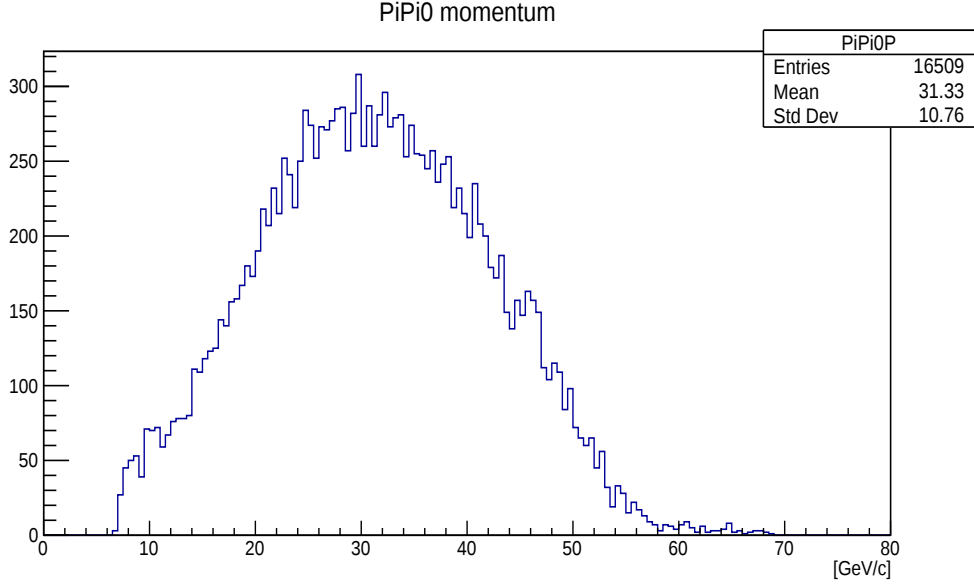


Figure 5: Distribution of pion momentum from the decay of a Kaon into a pair of pions.

However another interesting feature to look at was the possibility for the detectors to enter CHOKE mode. The "CHOKE" indicates that a sub-detector is overloaded with data and is close to a situation where it will soon not be able to accept any further triggers without potentially losing data. The L0 Trigger Processor will in this case respond to choke signals and suspend L0 triggers dispatching as soon as possible[REFERENCE]. It is easily possible to distinguish what detectors enter choke mode and therefore it is possible to see what detector suffers more from it. Looking at this on 2018 data gave the following result. This shows a predominant choking effect in the HSC part of the experiment. However I did not get the chance to compare this with data from 2021.

The most interesting data analyzed and the only proper comparison I was able to perform during this internship was by looking at the counts performed by different detectors at different intensity. This was an important parameter to look out. Indeed, during my internship there were many problems involving the beam. It was then important to start the runs at a low intensity. By doing this analysis and seeing that an extrapolation of the intensity would lead to a similar level of data taking as in 2018, this was a strong argument to decide to increase the intensity of the beam. I was allowed to present this at one of the weekly run meetings in front of the panel of experts of the experiment.

Along with this panel of counts I also looked at another interesting feature which is the

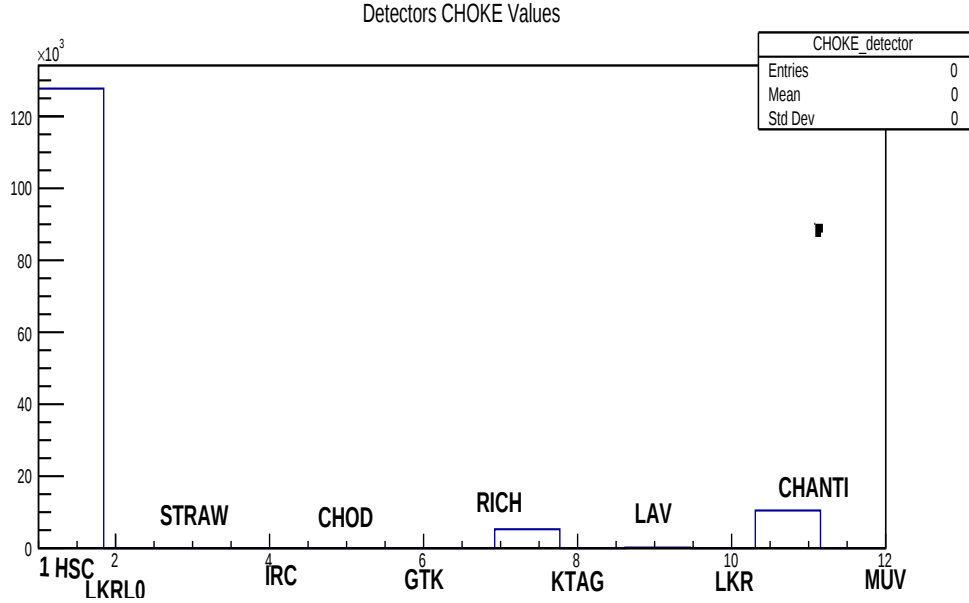


Figure 6: Caption

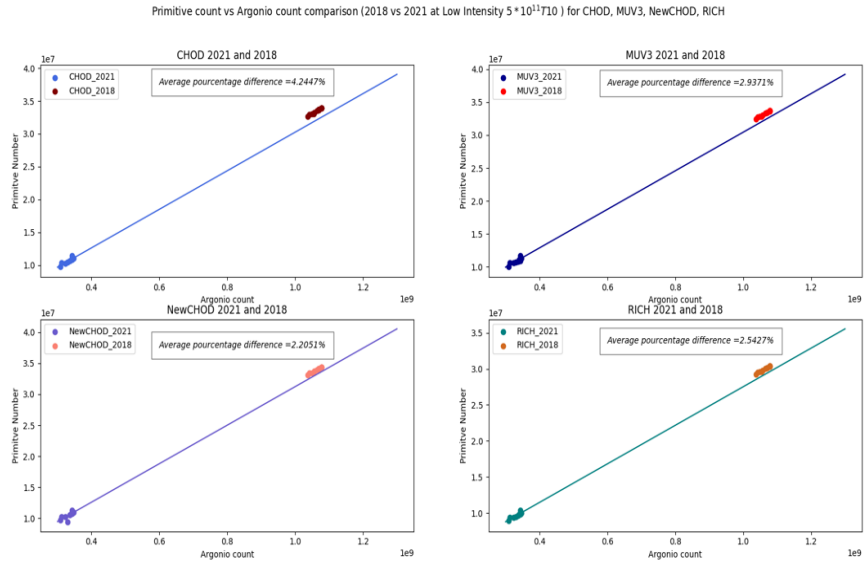


Figure 7: Extrapolation of the Argonio count for 2018 and 2021 data. This helped justify an increase for the intensity of the beam.

6 Conclusion

The NA62 experiment is a complex apparatus that is working on measuring one of the rarest events ever in experimental physics : $K^+ \rightarrow \pi^+ \nu \bar{\nu}$. Among its many

components comes the trigger and data acquisition system on which I did my project this summer. Looking at different parameters such as the detector efficiency or intensity count, it was possible for me to get my first introduction to the world of research.

7 Acknowledgments

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