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Final Report on the
SUMMER STUDENT PROGRAM

Development of the Event Display of the COMPASS Experiment

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Abstract

A brief review of the COMPASS experiment is given. An introduction of the PHAST software as a tool for physical data analysis is given. A function for the "event display" of the COMPASS experiment using PHAST is developed and described. Some sample events reconstructed by the function are displayed.

1   Introduction

The COMPASS (COmmon Muon Proton Apparatus for Structure and Spectroscopy) experiment is a high-energy physics experiment at the Super Proton Synchrotron (SPS) at CERN. It has been approved in 1997, and started taking data in 2002[1]. It uses the CERN SPS high-intensity muon and hadron beams to investigate the nucleon spin structure and hadron spectroscopy[2]. After data acquisition is performed, a reconstruction software called CORAL (COmpass Reconstruction and AnaLysis) is used to reconstruct events and detectors details from raw data[3]. CORAL outputs mDST ("mini Data Summary Trees") files, which contain physics data that can then be analyized using another software. PHAST (PHysics Analysis Software Tool) software, used along with ROOT data analysis framework, allows further data processing and filtering[3].

In the early days of particle physics, data acquisition and "event display" were practically the same. However, in modern experiments, they are not anymore. While events in high-energy experiments can be very complex, event displays can reflect this complexity. In the meantime, they can also provide visual summaries of the events. Some can argue that "you can describe geography and a route with words, but sometimes nothing beats a map with a line marking the way"[4]. In general, physicists use event displays to view geometries and monitor detectors. But, nevertheless, event displays are also important for communicating science to the public.

In this work, we construct a function for the event display of the COMPASS experiment. We use ROOT data analysis framework, and PHAST software. The function features top and side views of the event, displaying experiment setup, tracks, vertexes, and clusters. General information about the event is also provided. In §2, we briefly review the COMPASS experiment. In §3, an introduction about the PHAST software is given. We describe the event display function in §4, and show some samples of reconstructed events. Finally, a conclusion is made in §5.

2   The COMPASS Experiment

The initial setup of the COMPASS experiment is described in Ref.[2]. The setup was upgraded after 2005. In this section, we give a short overview of the apparatus. For more details, see Ref.[3].

The COMPASS experiment has been proposed with the goal of better understanding the structure and dynamics of hadrons. COMPASS uses deep inelastic scattering of a muon beam off a polarized ^6LiD or NH_3 target to study the nucleon spin structure[2]. The aims of experiments with hadron beams at COMPASS include:

- precision spectroscopy of light mesons and baryons,

- systematic study and identification of potential exotic configurations,

- study of chiral dynamics processes, and

- testing predictions of chiral perturbation theory.

To achieve these goals, only state-of-the-art components have to be used for the experiment setup. We can divide the COMPASS setup into four parts: the beam line section, the target region, the Large Angle Spectrometer (LAS), and the Small Angle Spectrometer (SAS). Figure 1 shows a three-dimensional view of the COMPASS setup.

The beam line section also includes the detectors that identify the particles of the incoming beam. Different beams are used depending on the physics program in process. Beams of different particles include hadron beams, muon beams, and electron beams. Hadron and muon beams can have either positive or negative charge. It usually takes about thirty minutes to switch between beams. For measurements with muon beams, a Beam Momentum Station (BMS) is used to determine the momentum of the incident beam. Downstream of it, two Cherenkov counters are placed for identification of different hadrons (pions, kaons, or protons) existent in the hadron beam.

The target region changes according to the COMPASS physics program. Most of the runs with hadron beams use a liquid hydrogen target. The target region includes the target and the detectors located in its neighbourhood. Different detectors are installed upstream and downstream of the target in order to determine the trajectory of beam particles before entering the target, and measure the number of charged particles in the final state. The liquid hydrogen target is easily
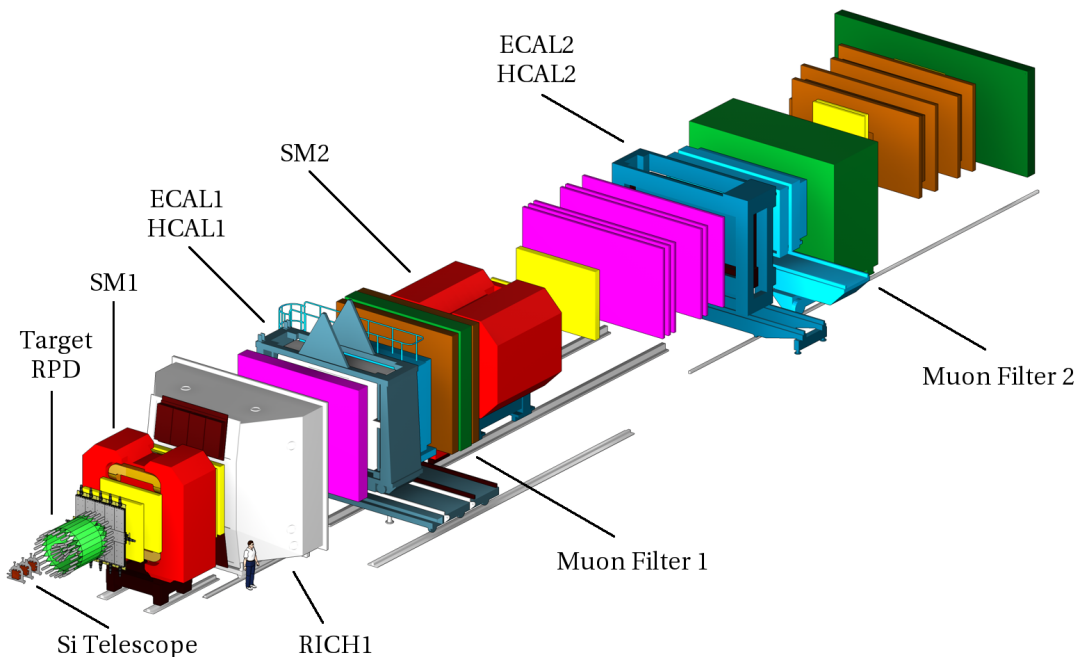
Figure 1: Three-dimensional view of the COMPASS setup for a hadron run in 2009. The beam comes from the left side. Only the downstream part of the setup is shown here. Different colors are indicative of different types of detectors[3].

replaced with a solid-target holder when needed.

Both the LAS and SAS include an electromagnetic calorimeter and a hadron calorimeter, along with a muon filter. The LAS includes the first dipole magnet (SM1), and the tracking detectors surrounding it, in addition to the RICH-1 counter. Also, the new electromagnetic calorimeter (ECAL1) has been installed during the upgrade, for the detection of photons and electrons at larger angles. The role of the LAS tracking detectors is to measure scattered particles with polar angles less than 180 mrad. The SAS constitutes the downstream part of the setup. It includes the second dipole magnet (SM2), and the tracking detectors surrounding it.

The trigger system is designed to select the processes that are of interest to the running physics program. Accordingly, different trigger counters are combined for different programs. The COMPASS data acquisition (DAQ) system has to meet the conditions of the trigger rate and the corresponding data flow.

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3 PHAST Software

PHAST is a framework for data analysis of the COMPASS experiment. It can process mini Data Summary Trees (mDST). It is used for the following purposes[5]:

- accessing reconstructed event information,

- developing code for physical analysis,

- processing mDST and filtering events' sub-samples.

To use PHAST, one needs to have at least a C++ compiler and ROOT. Analysis is done simply by reading existing mDST and filling histograms with physics values of interest to the user. This can be done inside "user function(s)". Some examples of user functions are provided in the directory of the software.

PHAST can also be used to produce microDST of events of interest that can be selected by iterating an algorithm on mDST. One can call a certain user function by the option `-uN`, where `N` is the number of the user function. To produce a microDST, one uses the option `-o` followed by the output file. Some examples of starting PHAST are:

- (with `UserEventN`)
  `$./phast -uN path-to-mDST-directory/mDST*.root`

- (producing a microDST)
  `$./phast -uN -o microDST*.root path-to-mDST-directory/mDST*.root`

Description of classes and functions for data access can be found in HTML documentation or in the PDF version.

4 Event Display

In this section we describe the function we have developed for the event display of the COMPASS experiment using reconstructed event data from mDST. The function can produce one `.gif` file per event. The output canvas is divided into four parts. The upper and lower left parts provide top and side views of the event, respectively. The upper right part displays specific event information, while the lower right part is a general scale of the calorimeter clusters based on their energies.

The function has three parameters (all variables of type `double`) with default values that can be changed by the user when calling the function. The parameters are:

- the time window within which the tracks and clusters are included in the display, and its default value is 10 ns, and

- the minimum and maximum values of the Z coordinate, which is plotted on the X axis in both top and side views, and they have default values of -6 m and 53 m, respectively.

The Y axis corresponds to the X coordinate in the top view and the Y coordinate in the side view, and in both views it ranges from -2.25 m to 2.25 m.

The function can be called inside a PHAST `UserEvent`, simply by including the function file, and then drawing, as shown in Figure 2, where `NN` is the number of the `UserEvent`. The three parameters can be omitted if the user wants to apply the function with the default values of the parameters. Finally, PHAST can be started as shown in §3, using the `UserEvent` option.

```
3   #include "<function_filename>.cc"
4
5 ▾ void UserEventNN(PaEvent& e)     {
6       Draw(e,<timewindow>,<minz>,<maxz>);
7   }
```

Figure 2: How to call the "event display" function inside a `UserEvent`.

The function displays several features of the event, including the experiment setup, the event tracks, vertices, calorimeter clusters, and some information specific to each event. First of all, the setup is drawn by use of the material maps included in the mDST, which can be accessed using PHAST predefined functions. The setup is displayed in green, where the shade of the green depends on the radiation length of the material at each point of the setup. The darker the shade, the shorter the radiation length. However, materials with radiation lengths equal to or greater than that of the air are drawn in white.

Particle tracks with meantime within the specified time window are the only ones displayed. They are drawn as black lines, unless their momentum has been defined. In this case, tracks with negative charge are drawn as blue lines, while those with positive charge are drawn as red lines. Finally, the total number of tracks, and the number of tracks within the time window are both displayed in the upper right part of the canvas. Then vertices are drawn as stars. Primary

vertices are drawn as magenta stars, except for the best primary vertex which is drawn as cyan star in a bigger size. Secondary vertices are drawn as yellow stars. The total number of vertices is also displayed in the upper right part of the canvas.

Finally, calorimeter clusters within the specified time window are displayed. They are drawn as red circles, except for clusters associated with charged tracks which are drawn as orange circles. The radii of the circles are scaled as a logarithmic function of the energy of the cluster. Their scale is displayed in the lower right part of the canvas. The total number of clusters, and the number of clusters within the time window are both displayed in the upper right part of the canvas.

In addition to the information referred to before, some other information about the event is displayed in the upper right part of the canvas. These include the unique event number, the run number, the event number in spill, the spill number, the event time, the beam flux and momentum, the trigger, and the specified time window. However, the beam momentum is only displayed if the primary vertex has been identified. If the user chose to apply the function to a Monte Carlo event, the unique event number, the run number, the spill number, and the event time will be omitted. Figures 3, 4, and 5 show some sample events displayed by the function from different experiment setups from different physics programs.
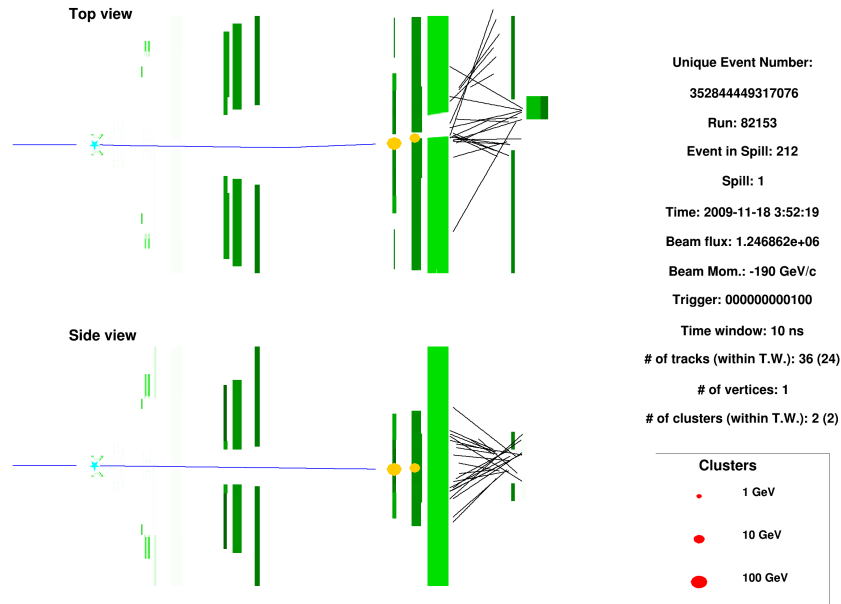

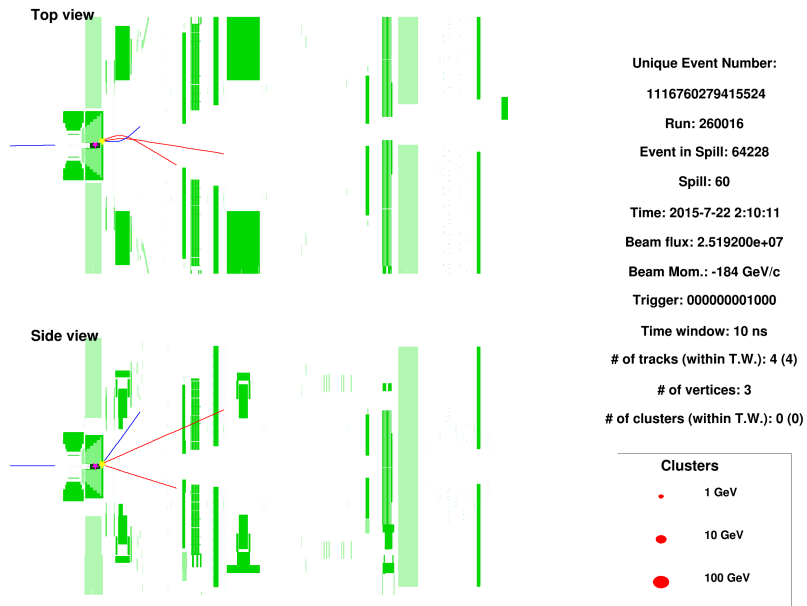Figure 3: A sample event from the Primakoff run in 2009.

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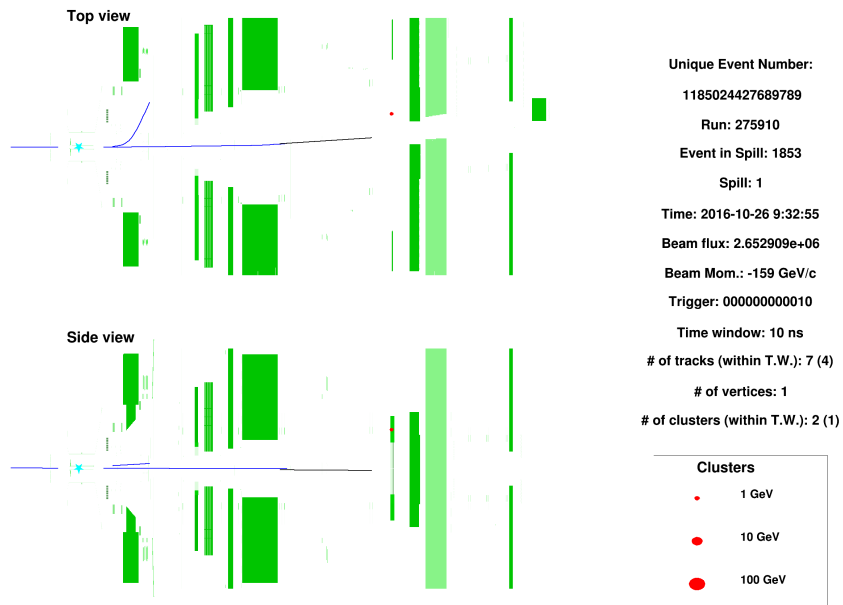Figure 4: A sample event from the Drell-Yan run in 2015.

Figure 5: A sample event from the Deeply Virtual Compton Scattering run in 2016.

5 Conclusion

An algorithm for the event display of the COMPASS experiment has been developed and tested on events of different setups from different physics programs. The preliminary result of this work has been reported at the COMPASS software weekly meeting. There is still a room for developing the algorithm further to widen the range of its intended users.

References

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[3] Abbon, P. *et. al.* (2015). The COMPASS setup for physics with hadron beams. *Nuclear Instruments and Methods in Physics Research A,* **779,** 69-115. doi: 10.1016/j.nima.2015.01.035

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[5] *PHysics Analysis Software Tools.* (2017, March 1). Retrieved August 13, 2017 from `http://ges.home.cern.ch/ges/phast/index.html`

Acknowledgements