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MUON BACKGROUND MINIMISATION USING THE SECOND ACHROMAT OF THE NA62-BD EXPERIMENT

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Abstract

The NA62 experiment [1] in the North Area at CERN exploits the K12 beamline for secondary beams as well as in beam dump mode, the later exploiting interactions of 400 GeV protons with a movable dump-collimator, the TAX. Such interactions are theorised to generate potential light dark matter candidates such as the axion. Any such rare process search requires precise knowledge and experimental reduction of the predominant background. A previous examination has been performed successfully, involving tuning the magnetic fields of the first achromat down stream of the beam dump in K12 to reduce the flux of muons significantly. This contribution aims to explore further improvements using similar methods on the second achromat in the same K12 beamline, using BDSIM simulation software.

INTRODUCTION

The North Area [2] at the CERN Super Proton Synchrotron (SPS) has a history of fixed target experiments dating back to the 1980s. The SPS accelerator provides protons of up to 400 GeV/c within slow extractions in periods of about 4.8 seconds. The North Area complex is shown in figure 1. Currently, approximately 6×10^{12} protons are extracted towards the T4 beryllium target. The non-interacting protons continue to the P42 beamline [2] that transports the beam to the T10 target, producing a mixed hadron beam, which then is transported along the K12 beamline to the NA62 experiment when in kaon physics mode.

In secondary beam mode, the K12 beamline uses a Beryllium target upstream of the beam dump TAX, as depicted in Fig. 2. The secondary hadron beam consists of about 6% kaons, which are used to investigate ultra-rare decays and Charge-Parity (CP) violation [1]. In beam dump mode, the motorised target is moved out of the beam and the proton beam is dumped in the TAX dump-collimator. The TAX is split into two parts. The first is composed of copper and iron, the second of iron only. Due to interactions of the proton beam in upstream material and in the TAX, hadrons are produced that subsequently decay into muons, which form the major particle background of this experiment and must therefore be minimised.

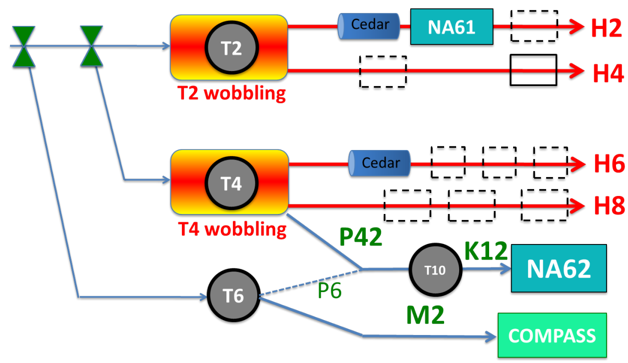

Figure 1: North Area complex

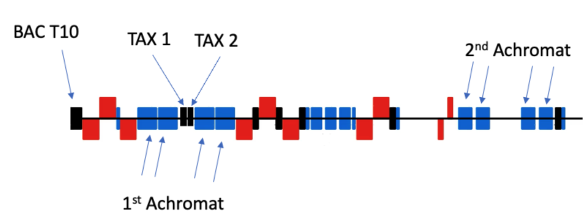

Figure 2: Schematic diagram of the K12 beamline from T10 TAX (left) up to and including the 2nd achromat (right), showing Quadrupoles (red) and Dipoles (blue).

In total, the K12 beamline including the NA62 detector is 270 m. The points of interest, the muon veto detector MUV3 and the end of the second achromat, are 248 m and 100 m respectively. The beam aperture at MUV3 is 3.2 m by 3.2 m. In beam dump mode, i.e. with the closed dump-collimator, NA62 searches for light dark-matter candidates, such as axions and dark photons. Searches for such particles

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complement searches taking place at the LHC. The beamline configurations, possible improvements, and physics sensitivity in beam dump mode have been studied within the Physics Beyond Colliders (PBC) initiative at CERN [3].

MUON BACKGROUND ANALYSIS

In the standard hadron beam mode, a set of four strong dipole magnets form an achromat that selects the momentum of the K12 beam to 75 GeV/c along with gigatracker detectors (GTK) [4] within an about 1 % momentum band. A second achromat in the beamline, again a set of four dipoles, is used to measure precisely the momentum of each single passing beam particle, and has been left unchanged with respect to the set magnetic fields so far during beam dump running. This study focuses on tuning the fields of those four magnets, aiming to reduce the muon background by sweeping them away from the experiment. The process involved changing these fields to those of different configurations, denoted by 1 (normal), 0 (off) and -1 (polarity inverted).

In the standard configuration, 1111, the fields of this achromat are deflecting positive particles downwards, upwards, upwards and again downwards, respectively. While in theory, there are 81 (3^4) possible configurations, the first two magnets are connected via a single power supply, removing one degree of freedom, and leaving 27 possible combinations. Each one of these configurations was tested to search for the most suitable candidate.

The Beam Delivery Simulation (BDSIM) [5] software has been used in this investigation. It is based on Geant4 [6] that is a toolkit for the simulation of the passage of particles through matter and fields. The version of Geant4 used in this investigation is 10.7.2 along with the FTFP_BERT physics list that includes a full set of high energy physics processes. This has been used to simulate generation and transport of muons up to 248 m along the beamline, where the last detector of the NA62 muon veto system is located (MUV3). Muon distributions transverse to the beam axis were plotted for this location in order to compare to experimental data that is going to be taken during the next NA62 beam dump run. In this analysis, muon biasing methods [7] were used to increase statistics and minimise computation time. This form of biasing works by scaling up the number of muons by a pre-determined factor chosen before the simulation is run. Using programming scripts, the biasing is applied to a particular point in the line, in this case the 1st TAX (see figure 2). The simulation is then stopped and rerun from the next point in the line using this biased flux of muons. To optimise the computation time, an energy cut-off of 1 GeV has been used in addition. A sample was generated with 10^7 protons on target which were simulated on the CERN htcondor farm.

RESULTS

The best configuration is chosen to be the one with the lowest integrated muon flux per event when compared to the standard 1111 configuration. Figures 3 and 4 show the positive and negative muon backgrounds at MUV3 (248 m) for the standard 1111 configuration. Figures 5 and 6 show the ratio of the best found configuration over the standard configuration. These are 1100 (-+00) for $\mu+$ minimisation and 00-10 (00-0) for $\mu-$ minimisation. The intensity axes on each of the 2D distribution plots represent the normalised muon flux per event. Figures 7 and 8 show the complete list of configurations used in this study. The shown errors are the square root of the events. The best reduction in muon background reaching MUV3 is about 2-3% when compared to the standard configuration 1111.

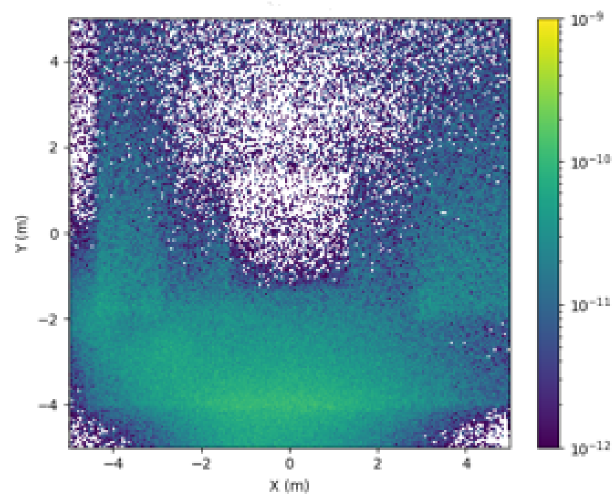

Figure 3: μ^+ distribution of the 1111 configuration at 248m along the K12 beamline.

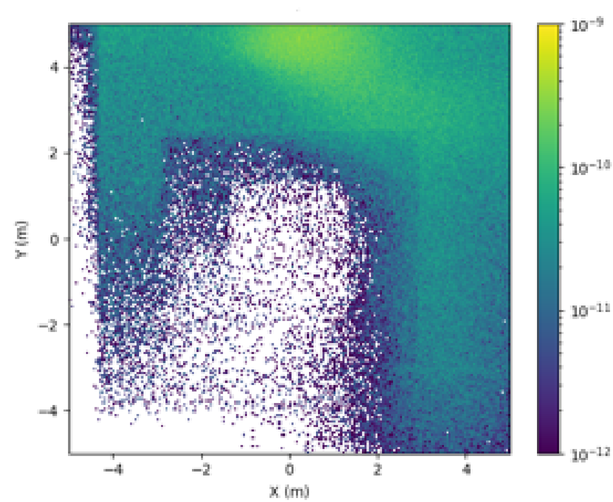

Figure 4: μ^- distribution of the 1111 configuration at 248m along the K12 beamline.

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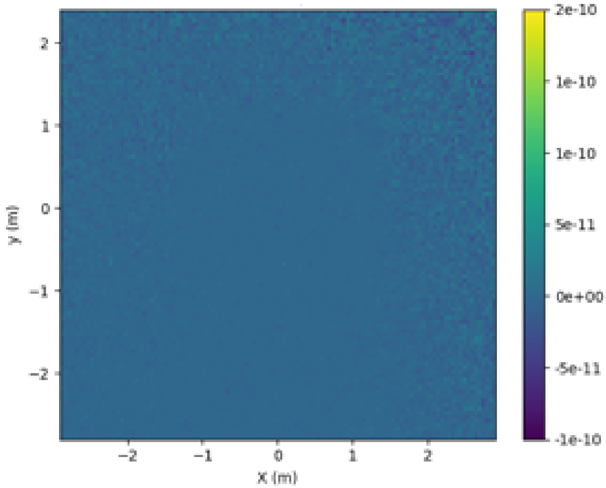

Figure 5: μ^- background difference of 1111 and 00-10 configurations at 248m along the K12 beamline.

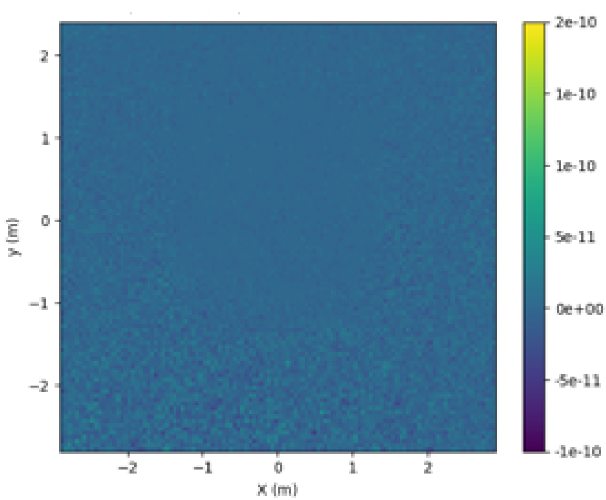

Figure 6: μ^+ background difference of 1111 and 1100 configurations at 248m along the K12 beamline.

CONCLUSION

After applying a similar technique used for the original optimisation of the first achromat, it has been found that the best combinations available for background minimisation are 1100 for μ+ and 00-10 for $\mu-$. These both result in a background minimisation of only approximately 2-3%, meaning the magnets of the second achromat have no important effect on background reduction. Further improvements on the background are not expected without adding additional beamline elements upstream of the second achromat, subject to further study.

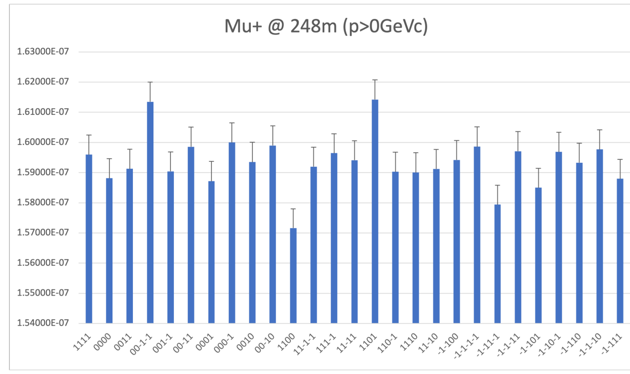

Figure 7: Graph showing μ^+ output at 248m using all possible field configurations. The vertical axis is the integrated muon flux per event and the horizontal axis is the total number of possible configurations.

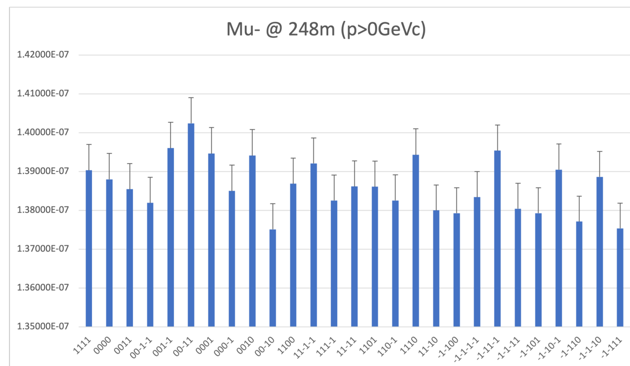

Figure 8: Graph showing μ^- output at 248m using all possible field configurations. The vertical axis is the integrated muon flux per event and the horizontal axis is the total number of possible configurations.

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