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COMMISSIONING RESULTS OF THE TERTIARY BEAM LINES FOR THE CERN NEUTRINO PLATFORM PROJECT

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Abstract

For many decades the CERN North Area facility at the Super Proton Synchrotron (SPS) has delivered secondary beams to various fixed target experiments and test beams. In 2018, two new tertiary extensions of the existing beam lines, designated "H2-VLE" and "H4-VLE", have been constructed and successfully commissioned. These beam lines have been designed to provide charged particles of both polarities in the momentum range from 0.3 GeV/c to 12 GeV/c. During the design phase, multiple simulation tools and techniques have been employed to optimize the tertiary beam line layout in terms of particle production, transverse beam dynamics and particle identification on an event-by-event basis. In this paper, a comparison of the simulated performance and the first measurement results obtained during the commissioning phase are presented.

INTRODUCTION

The CERN North Area facilities provides mixed secondary charged particle beams in the momentum range of 10 GeV/c up to 400 GeV/c. In 2018, this spectrum has been enlarged by two tertiary very low energy (VLE) beam lines, denoted H2- and H4-VLE, extending the existing H2 and H4 beam lines (see Fig. 1). These new lines are designed for providing charged particle beams of both polarities in the range of 0.3 GeV/c to 12 GeV/c. Their conceptual design principles are described in [1] together with an illustration of the area is presented. Presently, these tertiary branches are serving two large-size prototype time projection chambers based on Liquid Argon technology, for the future Deep Underground Neutrino Experiment (DUNE) [2]. In 2018, both new beam lines have been successfully commissioned. In the present work, measurements performed during the commissioning phases in both beam lines are presented and compared with the lines' simulated performance, optimized both using beam optics codes [3] and fully detailed Monte-Carlo simulations. Furthermore, the particle identification potential of these beam lines is discussed using the instrumentation recently developed for this purpose.

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DESIGN AND INSTRUMENTATION

The generation of the tertiary particles requires the transport of a secondary mixed beam, over about 600 m, via the existing H2 and H4 beam lines to two secondary targets, located at the beginning of the VLE beam lines. The intrinsic coupling between the available momenta of H2 and H4 secondary beams imposed the choice of opposite charges for the two beam lines: for H2 (H4) a negatively (positively) charged beam of 80 GeV/c was setup. To optimize the flux and composition of the VLE beams, tungsten was chosen as target material for generating the tertiary particles for beam momenta up to 3 GeV/c, while copper was used above 3 GeV/c. The required momentum selection is performed by bending dipoles combined with a momentum-defining collimator present in each beam line. The beam optics of both lines have been extensively studied in various beam optics codes, e.g. MAD-X/PTC, to match in detail the experimental conditions. Additionally, fully detailed Monte-Carlo models in GEANT4 (by using G4beamline [4], see Fig. 1) and FLUKA [5, 6] have been developed to include the particle production and the in-flight decays of particles in the simulations. This enables the estimation of the expected beam rate and composition, as well as the backgrounds.

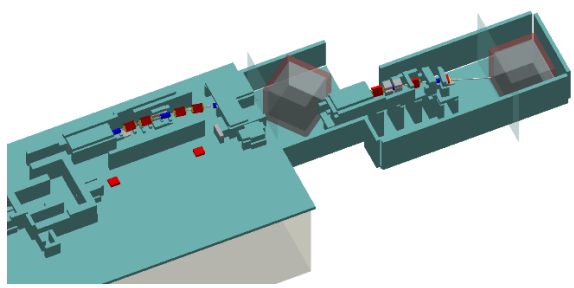

Figure 1: The G4beamline model of the downstream region of the H2 and H4 beam lines including the VLE extensions.

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For the measurement of the beam intensity, quality and composition various instruments are used, which also allow for an event-by-event particle identification: newly developed scintillating fibre profile monitors [7] measure the beam profiles at several locations along the beam lines. Surrounding a bending dipole they are operated in a spectrometer configuration providing additional information about the momentum of each individual particle. The experimental trigger is provided by a similar type of fibre monitors (but this time read-out by two conventional PMTs instead of SiPMs), of which three are placed in each beam line. The signals measured by two of these monitors that are separated by the maximum available distance, are connected to a time-to-digital converter and allow for a time-of-flight (TOF) measurement for each particle. The particle identification scheme is completed by two threshold Cherenkov counters, commonly used in the experimental areas [8], operated with CO_2 gas with maximum pressures equal to 5 and 15 bar, respectively. The two Cherenkov counters, combined with the time-of-flight measurements, allow effective particle identification throughout the requested momentum spectrum of the VLE beam lines.

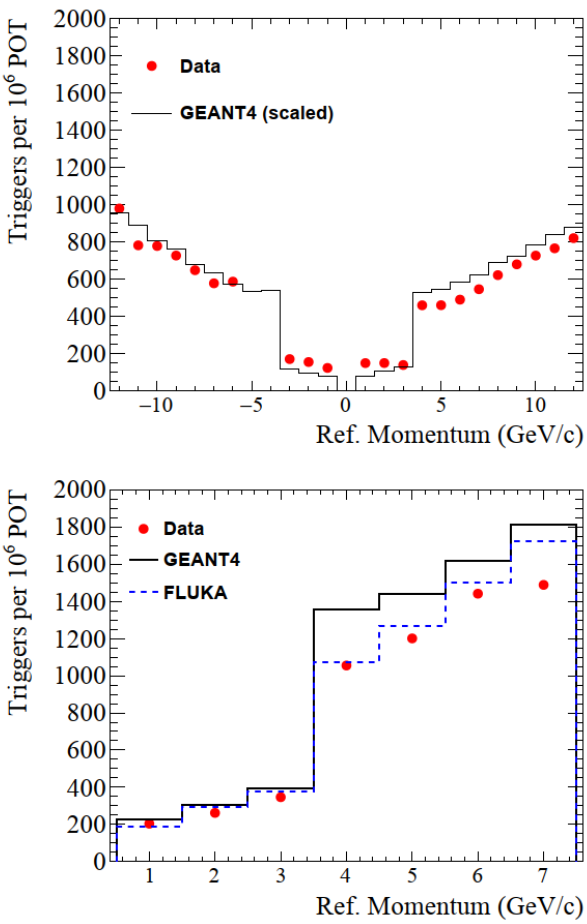

Figure 2: Trigger counts for 10^6 particles impinging on secondary target for different tertiary momenta in H2-VLE (up) and H4-VLE (down). The tungsten target was used for momenta $\leq$ 3 GeV/c, which reduces the particle rate, but simultaneously increases the pion-positron-ratio. Negative momenta correspond to negatively charged tertiary beam.

COMMISSIONING RESULTS

The beam lines were constructed and installed during 2018, followed by a combined commissioning before the "Long Shutdown 2" of CERN. Especially for the H2-VLE beam line, the available beam time was used parasitically with the NA61 experiment in H2 and the NP-04 experiment in H4. The measured performance of the beam lines is summarized in the next subsections.

Trigger Rates and Momentum Spread

Following the tuning of the upstream beam lines and the steering of the secondary beams on the VLE targets, the trigger rate over the full range of momenta and for the two different targets was measured. The results for both lines are shown in Fig. 2. The trigger rate in H4-VLE were found in excellent agreement with the simulations, both using FLUKA and GEANT4, at a level of about 20 %. For H2-VLE, the available data are in excellent qualitative agreement with the simulations, however additional data-taking time is required to ensure a proper calibration of the normalization, which allows for a more quantitative analysis

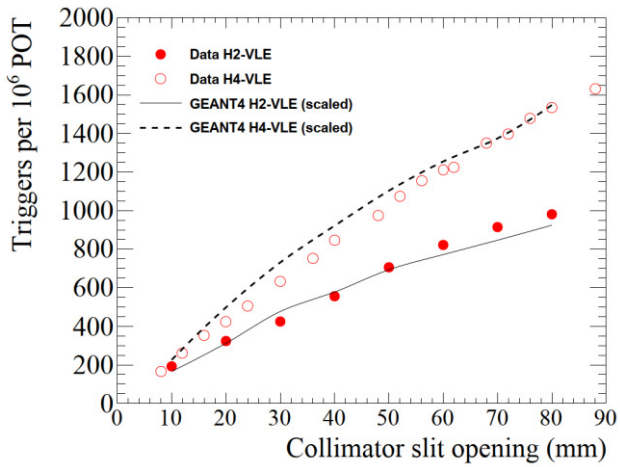

Figure 3: Trigger counts for 10^6 particles impinging on secondary target for different slit openings of the momentum-defining collimator and a reference momentum of 7 GeV/c.

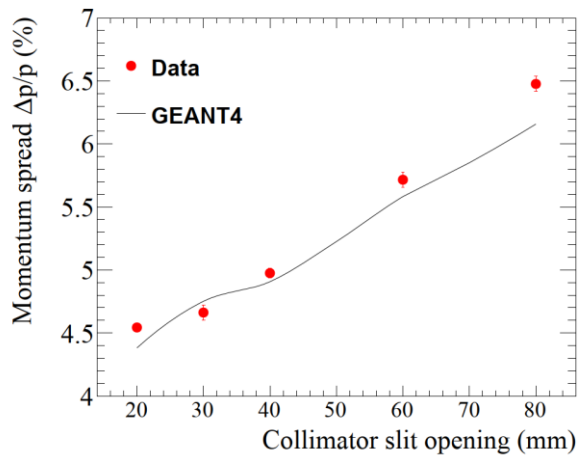

Figure 4: Measured and calculated momentum spread for different slit openings of the momentum-defining collimator and a reference momentum of 7 GeV/c.

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in this beam line. The effect of the momentum-defining collimator on the trigger rate (Fig. 3) and momentum spread (Fig. 4) has been also studied. Specifically, a trigger rate change of a factor eight in H4-VLE, respectively four in H2-VLE, between the extreme settings of the collimator slit opening is observed. A similar curve of the trigger rate change could be reproduced after scaling the GEANT4 simulation to the observed trigger rate with fully-opened collimator. A variation of the beam momentum spread between about 4.5 % and 7 % was possible via the collimator slit opening as expected by the conducted simulations. This offers the flexibility of having either a more confined beam momentum or an increased beam intensity.

Particle Identification and Beam Composition

The successful commissioning and calibration of the beam instrumentation required for particle identification allowed a rigorous measurement of the beam composition during the DUNE NP-04 data-taking phase in H4-VLE. To identify and distinguish the individual particle types composing the VLE beams, a combination of the time-of-flight and Cherenkov measurements was necessary. For the various momenta used, a specific setup of the Cherenkov gas pressures is necessary. The PID schema used is described in [9]. The result of the combination chosen is shown in Fig. 5 for a 1 GeV/c beam. The protons are significantly slower than positrons, pions and muons, due to their higher mass. They can thus be distinguished by their time-of-flight. Positrons, pions and muons are almost fully relativistic at 1 GeV/c and have a similar TOF. For the latter, a threshold Cherenkov counter operated with CO_2 at 1.2 bar releases a signal, which allows the separation of positrons from pions and muons (here: grouped to “pion-like” particles) due to their similar masses. The small second peak for the positron-like particles at about 100 ns relates to a systematic effect leading to a signal delay of about 4-5 ns for some of the events, whose origin is currently under investigation. These events have been classified as positrons due to their observed signal in the Cherenkov counter tuned for that particular purpose.

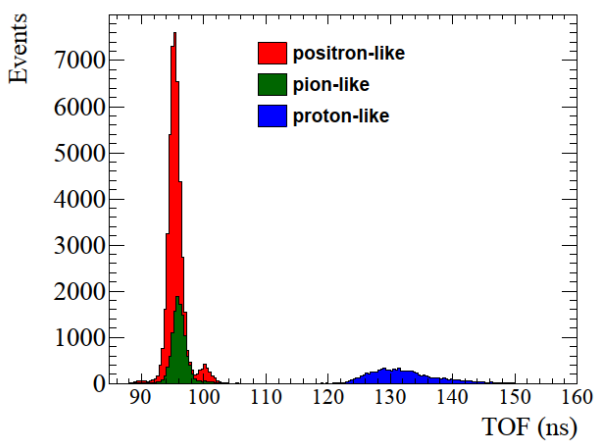

Figure 5: Particle Identification combining time-of-flight measurement and Cherenkov tagging for a 1 GeV/c beam in H4-VLE.

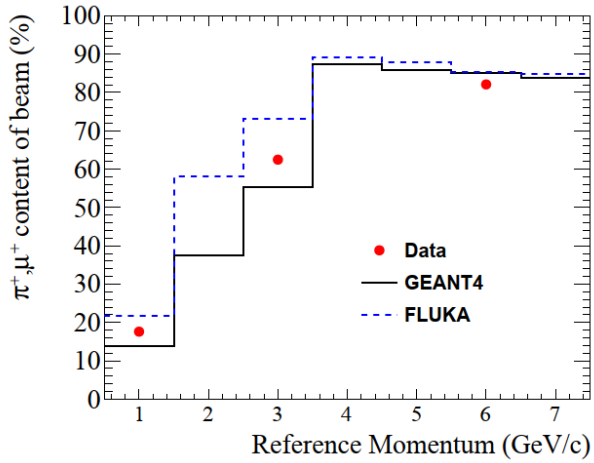

Figure 6: Pion and muon content of the beam in H4-VLE ($\geq$ 4 GeV/c the positron content is not distinguishable in the utilized scheme and therefore added). For momenta $\leq$ 3 GeV/c ($\geq$ 4 GeV/c) the tungsten (copper) target was used.

The beam content measurement is compared to simulations in Fig. 6. For momenta p $\geq$ 4 GeV/c also the positron content was added, since the used identification scheme did not allow a separation of the three particle species. More details on this analysis are presented in [9].

SUMMARY

In late 2018, both the H2-VLE and the H4-VLE beam lines were successfully commissioned. The beam instrumentation, which performed within design specifications, allowed for a successful event-by-event identification of the different particle species composing the VLE beams. A combination of time-of-flight as well as tagging by threshold Cherenkov counters for the various momenta was employed. An excellent agreement of the measured trigger rates and beam composition with the expected performance in H4-VLE could be observed both in FLUKA and in GEANT4, as well as a promising qualitative agreement between data and Monte Carlo was shown in H2-VLE. A full study of the H2-VLE performance, with additional data-taking periods in 2021 after the "Long Shutdown 2" at CERN is being planned.

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