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SECONDARY BEAM LINE EFFICIENCY STUDIES AT THE CERN PS EAST EXPERIMENTAL AREA

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Abstract

The East Area of the Proton Synchrotron has undergone extensive renovation, marking a significant milestone in its more than 55-year history as one of CERN's enduring facilities for experiments, beam tests, and irradiation. This facility, which serves over 20 user teams for about 200 days annually, now boasts an enhanced infrastructure to cater to future beam test and physics requirements. It also features new beam optics that ensure a better transmission and purity of the secondary beams, with the addition of pure electron, hadron, and muon beams. With this contribution, we present the ongoing performance studies underway following the implementation of the East Area secondary beamlines in the BDSIM (Beam Delivery Simulation) Monte Carlo simulation software. Using BDSIM, the impact on the transmission, purity, and overall efficiency of the secondary beams is assessed to the measured performance, paving the way for possible additional modifications and further upgrades.

INTRODUCTION

The East Experimental Area at CERN, utilizing protons at 24 GeV from the Proton Synchrotron (PS) for over 50 years[1][2], complements the CERN North Experimental Area, which utilizes 400 GeV protons from the Super Proton Synchrotron (SPS), facilitating various experiments and test beams. After undergoing a detailed study phase from 2009 to 2015, a renovation project was approved by the CERN Council in 2016 and was implemented during a long shutdown from 2019-2020, beginning operation in 2021. This contribution introduces a general overview of the new beamline designs and infrastructure upgrades, and reports on the performance evaluation of the East Area secondary beamlines.

THE EAST AREA BEAMLINES

The East Area beam cycle in the PS is 2.4 seconds long, including a 0.4-second plateau at top energy for slow extraction of the beam, delivering 3×10^{11} protons to the East Area. Secondary beams are generated when these protons collide with target heads arranged in a multi-target configuration. Three secondary beamlines (T09, T10, and T11) operate in the East Area, as shown in Fig. 1, with each destination typically receiving 1-2 cycles per minute. T10 and T11 share the same multi-target, while T09 has its own. The average intensity limit for radiation protection is 3×10^{10} protons/second per destination. The characteristics of the secondary beams delivered to the EA experimental areas are summarized in Table 1.

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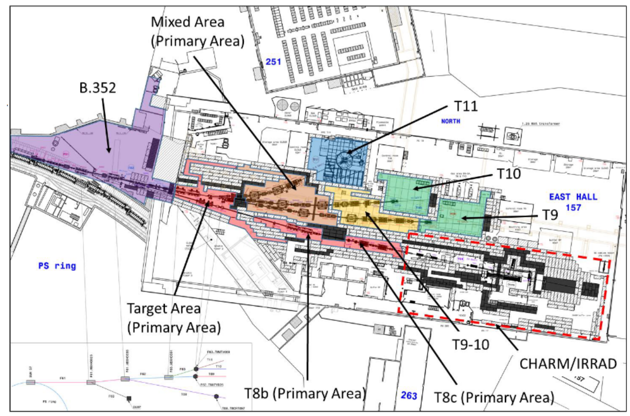

Figure 1: Layout drawing of the East Area after the renovation[3].

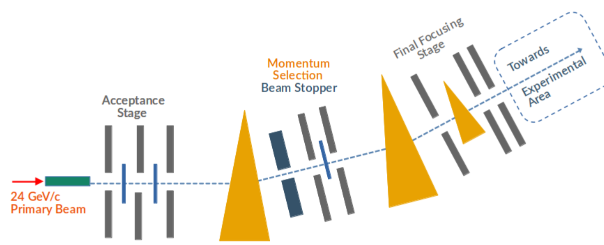

Figure 2: Schematic of the T10 beamline layout.

Table 1: Beam parameters of the East Area

Parameter	T09	T10	T11
Max length	50.2 m	44.7 m	31.5 m
Max GeV/c	16 GeV/c	12 GeV/c	3.5 GeV/c
$\Delta p/p$ (%)	± 0.7 to ± 15	± 0.7 to ± 15	± 0.7 to ± 15
Max int/spill	10^6	10^6	10^6
particle types	$e^-/h/\mu^+$	h/μ^+	h/μ^+

General Description of the Beamlines

A vertical production angle of 30 mrad for T09 and 35 mrad for T10 and T11 is imposed to prevent primary protons from entering the experimental areas and to avoid crossing among the lines. A cast iron primary dump acts as a shield for all three lines, specifically placed to prevent the non-interacting primary protons from contaminating the lines. A schematic of a typical beamline layout is shown

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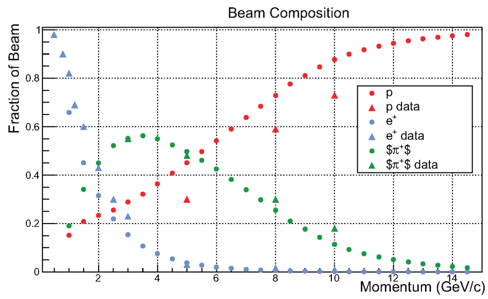

Figure 3: Secondary beam composition as a function of momentum in the East Area as calculated via Monte-Carlo and measured in T09.

in Fig. 2. The initial angular acceptance of the T09 line is defined by a fixed cylindrical collimator of 80 mm diameter. This device also acts as a passive shielding. In T10, no fixed collimator is required due to the absence of upstream equipment and the aperture of the dump. For both T09 and T10, a triplet of quadrupole magnets is used to focus the secondary beam onto a horizontal collimator, where the central momentum of the secondary beam is defined. This momentum is defined by a fixed horizontal angle applied using a dipole, and a horizontal collimator placed between two field lenses. Dispersion is eliminated using a second dipole, guiding the beam to the experimental area. A final quadrupole triplet focuses the beam at the user location, with final horizontal alignment aided by a vertical dipole. The T11 beamline is a shorter line, with fewer components. This compact design is necessitated by the constraints imposed by the position of the CLOUD experiment[4]. Unlike T09 and T10, which require greater flexibility, T11 employs doublets of quadrupoles for both the initial and final focus. Additionally, it utilizes only one field lens quadrupole and collimator with reduced control in both planes. The beam optics are selected to achieve a broad spot for the CLOUD experiment by deliberately over-focusing the beam immediately after the final quadrupole, causing the beam to expand again due to increased divergence. The maximum momentum achievable in T10 and T11 is lower than in T09 due to the reduced length and a larger deflecting angle imposed to avoid interference among the lines. For each line, the beam composition is the same when using the same target head. The expected beam composition from target A, the beryllium-based target, is shown in Fig. 3 as measured during commissioning time in T09 and compared to Monte-Carlo target simulations.

MEASUREMENT DATA AND MONTE CARLO STUDIES

In this section, preliminary results obtained from BDSIM simulations are compared to the measurements obtained during beam operation. Simulations play a crucial role in testing the efficiency of the beamlines and monitoring the anticipated rates of secondary particles accessible to users.

Simulations of the lines are carried out using the “Beam Delivery Simulation” (BDSIM[5]) code, a software tool used for simulating the passage of particles through particle accelerators and beamlines based on the Geant4 simulation toolkit. A BDSIM representation of the T10 line is shown in Fig. 4. The assessment of the line performance facilitates the evaluation of interference from cross signals and backgrounds of the three beamlines during operation.

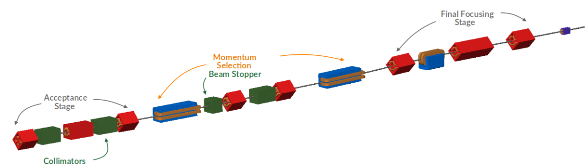

Figure 4: BDSIM visualization of the secondary T10 beamline schematics.

The first simulation campaign analyzed the signal generated at a fixed position in the experimental area. The observables of interest include the beam profile at the focus, the phase space distribution, and the momentum spectrum. The efficiency of the line can be evaluated through the energy distribution of secondary particles as shown in Fig. 5, and by determining the number of secondary particles produced at the target and carried through to the user area for reference aperture of acceptance and momentum collimator settings for different momenta.

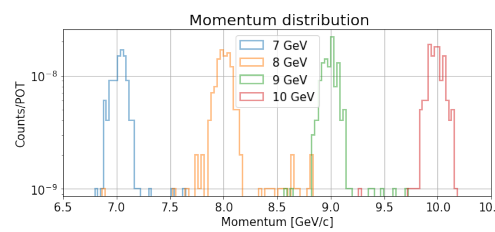

Figure 5: Monte Carlo mixed hadron momentum distribution entering the T10 experimental area.

T09 Beam Profile and Specifics

Unlike the other lines, T09 has two horizontally deflecting sweeping magnets that allow the creation of a pure neutral beam. By inserting a movable lead foil of 4 mm thickness into this beam a pure positron-electron beam can be produced via conversion of the photons in the neutral beam. A study is ongoing to add this feature to the other East Area lines to expand their capabilities. To compare the rate of particles collected through data and Monte-Carlo, the beam profile simulating the XBPF output, a scintillating fiber monitor placed at the end of the line, obtained using BDSIM is displayed in Fig. 6

The expected rate of particles in standard conditions obtained from the simulation is 8×10^7 mixed hadrons per spill, the same order of magnitude as observed from the data during standard operation. Differences in the rate can arise from how realistic is the model simulated and by the

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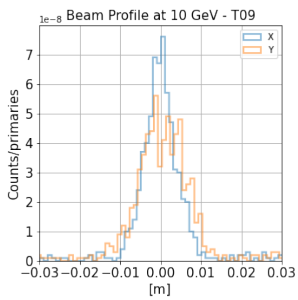

Figure 6: Beam profiles of secondary particles entering XBPF monitors in T09 at 10 GeV/c as simulated in BDSIM.

treatment of the background. The acceptance collimators placed along the line are kept fully open (about 40 mm apertures), while the momentum selection collimator is closed to 10 mm. Future studies will test the beam composition and the pure electron beam performance.

T10 - Beam Parameters and Specifics

T10 has a movable stopper dump made of CuCrZr and Inconel placed in the momentum selection region that serves both as an element for access control and as a filter for high-purity beams. By employing this to filter out hadrons, it is possible to create a pure muon beam.

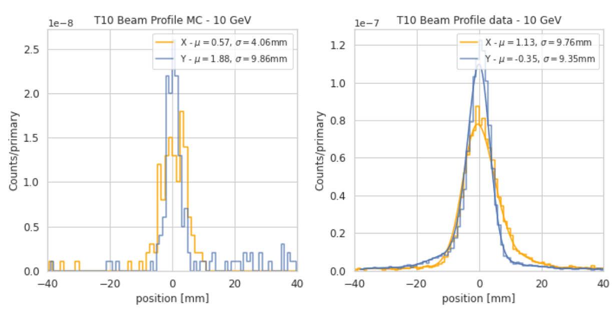

Figure 7: Beam Profile comparison between data (on the right) and Monte-Carlo (on the left) of 10 GeV/c secondary particles entering the T10 XBPF.

Fig. 7 shows a simulated and measured 10 GeV/c focused secondary particle profile, with the acceptance collimators opened to between 20 and 10 mm and the momentum-defining collimator closed to 3 mm. The expected integrated rate of particles obtained with the Monte Carlo is 1.3×10^5 mixed hadrons per spill, while the coincidence events registered during operation give about 3.5×10^5. Ongoing studies are investigating the origin of this difference in the flux, exploring a possible different treatment of the background and the optics layout in the simulation.

Alongside these studies, a series of measurements were conducted on the T10 line wherein each of the three collimators was individually scanned at different aperture sizes for various momenta, while the other collimators were kept fixed. This systematic approach allowed the influence of aperture size on particle flux to be studied for different momenta for each collimator. By repeating the process for all three collimators, a comprehensive insight was gained into how aperture dimensions impact particle flux for varying momentum conditions within the beamline. An example of the scan for 10 GeV particles is shown in Fig. 8. These measurements are crucial for optimizing collimator configurations to enhance particle flux control. From these scans,

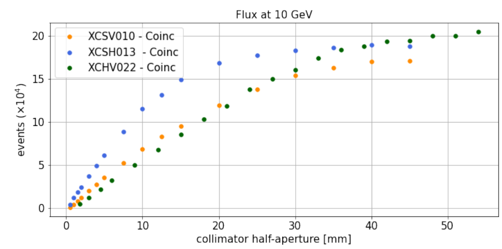

Figure 8: Scan of three collimators in T10 to see the influence on the flux.

it is possible to extrapolate the maximum particle flux for different momenta by opening to the maximum aperture of the three collimators (see Fig. 9). This information gives an insight into how to increase the intensity of the beam at the cost of a beam with broader momentum. Due to the saturation of the monitors, it is not feasible to measure the beam flux at the maximum aperture of all the collimators at the same time. These numbers were then obtained by performing measurements extrapolating a gain factor on the flux per each collimator maximum aperture in turns and then combined.

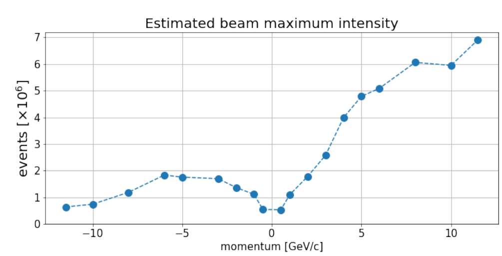

Figure 9: Estimated maximum beam intensity as a function of the beam momentum at maximum collimator aperture.

CONCLUSIONS

Studies comparing Monte-Carlo simulation and measurement data for the CERN East Experimental Area beamlines are ongoing to assess the performance of the lines. The main factors that influence the performance and expected rates are the settings of the collimator apertures and the focusing of the beam. Based on these studies it is possible to predict the flux and beam size according to the requests of test-beam users.

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