PROCEEDINGS OF SCIENCE

Towards a measurement of charm production induced by 400 GeV/c protons on a thick target at CERN SPS

Nikolaus Owtscharenko[a,*]

[a] *Center for Particle Physics Siegen (CPPS), Experimentelle Teilchenphysik, Universität Siegen Walter-Flex-Str. 3, 57068 Siegen, Germany*

E-mail: owtscharenko@hep.physik.uni-siegen.de

The SHiP collaboration proposes a general purpose fixed-target experiment to search for hidden particles at the new beam-dump facility at CERN SPS. For the interpretation of these searches a precise knowledge of the differential charm production cross-section in a thick target, including the cascade production, is essential. For this purpose, a dedicated measurement at CERN SPS has been proposed. An optimization run has been performed with 400 GeV/c protons interacting with a thick target of up to 1.6 nuclear interaction lengths. The production and decay of charmed hadrons in the target is detected by emulsion films arranged in a moving brick containing emulsion cloud chambers. A magnetic spectrometer using silicon pixel, scintillating fiber and drift-tube detectors is built to measure charge and momentum of the decay daughters and is followed by an RPC muon tagger. We report on the experiment design, track matching and first results of the optimization run.

PoS(CHARM2020)061

**** 10th International Workshop on Charm Physics (CHARM2020), ****
**** 31 May - 4 June, 2021 ****
**** Mexico City, Mexico - Online ****

*Speaker

1. Introduction

Knowledge of the charm production cross-section in a thick target is essential for the sensitivity of the proposed SHiP [1, 2] experiment. Especially the enhancement through cascade production in a target, which is expected to be large, has so far never been measured. The SHiP-charm project [3] aims at measuring the double-differential cross-section, $\mathrm{d}^2\sigma/(\mathrm{d}E\,\mathrm{d}\theta)$ for charm production, using the 400 GeV/c primary proton beam, extracted from SPS at CERN. The target is a mockup of the SHiP target and consists of passive material interleaved with emulsion cloud chambers (ECC), with the purpose to study the properties of the particle shower as it is created and evolves in the target. A varying amount of absorber bricks is placed upstream of the active target to emulate different target thicknesses. The setup is completed by a magnetized tracking spectrometer and by a muon tagger. In July 2018, an optimization run took place at the H4 beam line. Here we address the challenge of reconstructing common tracks and events from the information recorded by the fundamentally different ECC and pixel detectors. Also the identification of interaction vertices in a high-density environment is discussed. This is complicated by the fact that the ECC detector carries no timing information and was moving relative to the beam and pixel detector in order to prevent overexposure during a given spill.

2. The SHiP-charm experiment

The experiment setup is optimized towards a full topological and kinematic reconstruction of charmed hadrons emerging from the interaction of 400 GeV/c CERN SPS protons in the target. Vertex and track reconstruction can be provided by the ECC, while the spectrometer provides kinematic reconstruction, starting with the pixel detector directly downstream of the ECC. With the high timing resolution of 25 ns and a high spatial resolution it offers the crucial association of tracks from the target to timestamped events recorded by the electronic detectors.

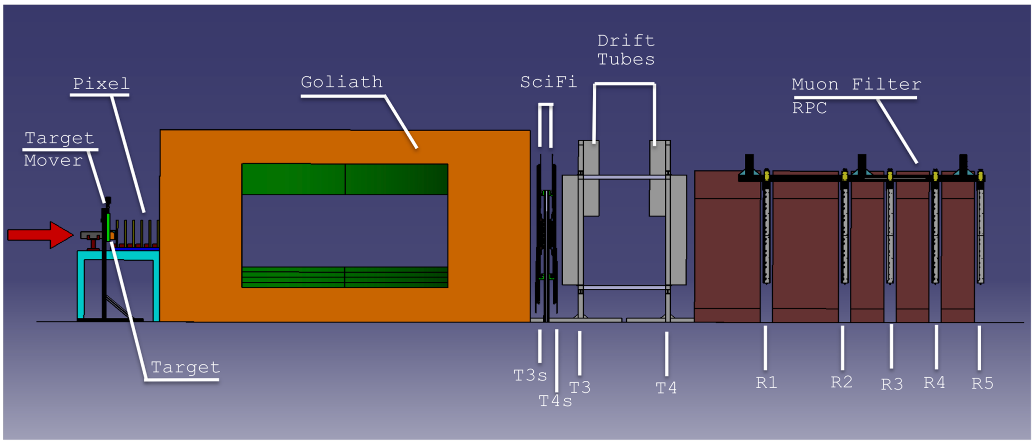

Figure 1: Setup of the SHiP-charm experiment as implemented for the optimization run. The red arrow indicates the proton beam. The whole apparatus extends approximately 10 m along the beam axis.

The pixel detector consists of six layers of ATLAS IBL double-chip modules with hybrid pixels [4]. Each plane offers an active area of about 6.9 cm^2 with a material budget of 350 µm of silicon.

The following GOLIATH magnet [5] and the scintillating fiber (SciFi) detector further downstream complete the spectrometer. The SciFi detector consists of 8 layers with an active area of $40 \times 40\,\text{cm}^2$ per layer. Figure 1 shows the full setup.
To study the charmed hadron production in different depths, target configurations of different material budget are available. Short targets of 29 active emulsion sheets and 28 passive lead (tungsten) layers and thick targets of 57 emulsion films and 58 lead sheets are combined with different numbers of passive absorber bricks. A detailed description of the target can be found in Ref. [6]. In all targets the thickness of a single passive sheets is 1 mm, while active emulsions films are 315 µm thin. An overview of the different configurations can be seen in Figure 2. Target thicknesses between 0.16 and 1.6 interaction lengths can be simulated. With the ECC technique, targets can only be irradiated once and are disassembled and digitized afterwards. Tracks and vertices can be reconstructed within the `FEDRA` framework with a precision as high as 3 µm [7]. Ionization in the emulsion is permanent and an unambiguous reconstruction is ensured up to a track density of at least $1000/\text{mm}^2$. To prevent overexposure and to record as many events on a single brick as possible, a moving pattern was established. During one SPS spill of 5.2 s the target is moved through the beam with a velocity of approximately 2.6 cm/s. In between spills the target is moved vertically by either 1 or 2 cm. This allows for irradiation of 10, respectively 5, SPS spills on a single target with proton rates between 7700 and 13 800 per spill.

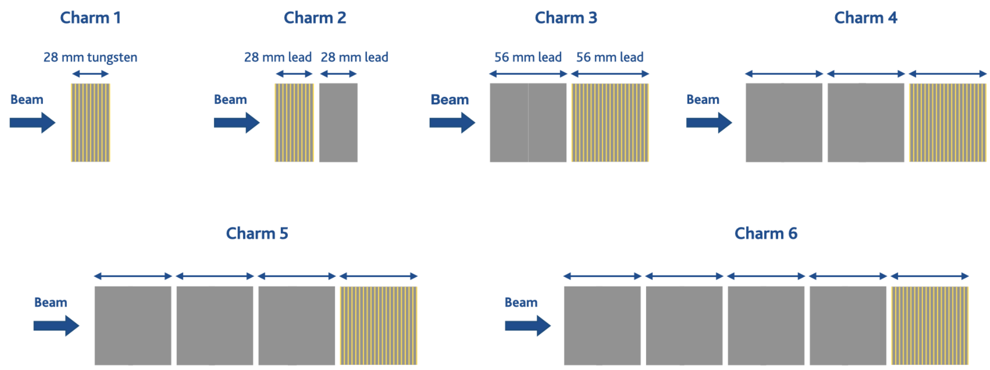

Figure 2: Different target configurations including passive absorber bricks in front of the ECC. Passive sheets in the Charm 1 ECC are made of tungsten.

3. Optimization run at SPS

The optimization run was performed with the goal of integrating the different sub-detectors and to develop the necessary tools for event reconstruction and data analysis. Special focus was put on the reconstruction of common tracks and events from the fundamentally different ECC and pixel detectors. The connection of vertices to timing information is critical for kinematic event reconstruction and for a successful measurement. Figure 3 shows the tracks reconstructed independently in the ECC and pixel detectors for an example run.

Track reconstruction in different detectors is essentially a problem of alignment. The alignment is complicated by the moving pattern of the ECC and by the high occupancy in both detectors. We

PoS(CHARM2020)061

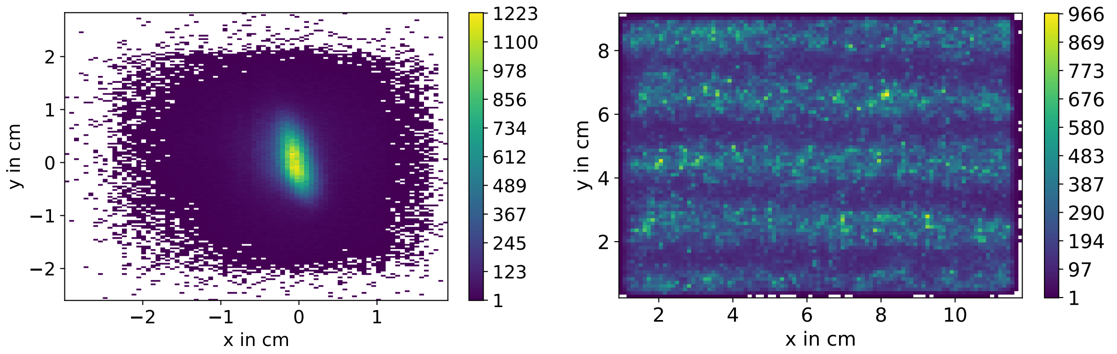

Figure 3: X-Y position of tracks reconstructed in the most upstream pixel detector plane (left) and in the most downstream ECC segment (right) for the same run in their respective rest frames. The non-uniform distribution of horizontal lines in the ECC resembles the five spills of one run.

employ a Newton-Raphson algorithm to determine the best set of alignment parameters based on a minimization of the total χ^2 of tracks computed from matched tracklets [8]. With this approach eight alignment parameters $\boldsymbol{\alpha} = (x_0, y_0, z_0, \theta_{xz}, \theta_{yz}, \theta_{xy}, v_x, v_y)$ are determined simultaneously, where x_0, y_0, z_0 are the offset of the pixel detector with respect to the emulsion reference frame, the two velocities v_x and v_y characterize the target mover, and the rotations of the pixel detector about the x, y, and z axes are denoted by θ_{yz}, θ_{xz} and θ_{xy}, respectively. A more detailed description of the sub-detectors and the reconstruction algorithm can be found in Ref. [9].
Two criteria are chosen for track selection: The track must have an angle $\theta < 64$ mrad in order to be within detector acceptance; and it has to originate from a vertex with at least six associated tracks. After alignment of an example run (82.6 ± 0.4) % of selected emulsion tracks can be matched and attributed to a timestamp. Table 1 shows the matching resolutions.

parameter	value
σ_x	36 µm
σ_y	63 µm
σ_{tx}	3.4 mrad
σ_{ty}	2.8 mrad

Table 1: Mean uncertainties for origin (x, y) and angles (tx, ty) of matched tracks for an example run, extracted from the residual distributions.

4. Summary and outlook

The SHiP-charm experiment was developed to measure the enhancement of charm production due to cascade production in a thick target. An optimization run was performed at CERN SPS in order to integrate the sub-detectors. We developed an alignment and event-building procedure for a moving emulsion target without timing information and a pixel tracking detector as first instance of a spectrometer in a high occupancy environment. Two aspects were crucial for the successful alignment: The introduction of an (unwanted) velocity in y direction, and a set of adequate input parameters for the algorithm. With this procedure, more than 82 % of the selected emulsion tracks were assigned a timestamp. Software and detector setup will be further optimized for a dedicated charm cross-section measurement at the CERN SPS after the LHC Long Shutdown 2.

Acknowledgments

Emulsion data: Antonio Iuliano, Antonia Di Crescenzo, INFN Napoli; Pixel modules and R/O software: Fabian Hügging, David-Leon Pohl, SiLab, Universität Bonn; Alignment and matching: Christopher Betancourt, Universität Zürich; Pixel tracking: Vadim Kostyukhin, CPPS, Universität Siegen; Project: Markus Cristinziani, CPPS, Universität Siegen.
This work is supported by the German Science Foundation (DFG) through a research grant and a Heisenberg professorship under contracts CR-312/4-1 and CR-312/5-1.

References

[1] SHiP Collaboration, *The experimental facility for the Search for Hidden Particles at the CERN SPS*, JINST **14** (2019) P03025.

[2] SHiP Collaboration, *A facility to Search for Hidden Particles (SHiP) at the CERN SPS*, CERN-SPSC-2015-016, arXiv:1504.04956 [physics.ins-det].

[3] SHiP Collaboration, *Measurement of associated charm production induced by 400 GeV/c protons*, 2017, CERN-SPSC-2017-033.

[4] ATLAS IBL Collaboration. *Production and Integration of the ATLAS Insertable B-Layer*, JINST **13** (2018) T05008.

[5] Y. Gaillard, *Specification technique concernant la refection de l'electro-aimant Goliath*, 1969, EDMS 1326984.

[6] SHiP Collaboration, *Reconstruction of 400 GeV/c proton interactions with the SHiP-charm project*, 2020, CERN-SHiP-NOTE-2020-002.

[7] V. Tyukov, I. Kreslo, Y. Petukhov and G. Sirri *The FEDRA Framework for emulsion data reconstruction and analysis in the OPERA experiment*, Nucl. Instrum. Meth. **A559** (2006) 103.

[8] A. Bocci and W. Hulsbergen *TRT Alignment For SR1 Cosmics and Beyond*, 2007, ATL-INDET-PUB-2007-009.

[9] SHiP Collaboration, *Track reconstruction and matching for SHiP-charm*, CERN-SHiP-NOTE-2020-003.