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THE "PHYSICS BEYOND COLLIDERS" PROJECT FOR THE CERN M2 BEAM

D. Banerjee†, Univ. of Illinois, Urbana Champaign, US / CERN EN-EA, Geneva, Switzerland,
J. Bernhard, M. Brugger, N. Charitonidis, V. de Jesus, L. Gatignon, A. Gerbershagen, E. Montbarbon, B. Rae, M. Rosenthal, M.W.U. Van Dijk, CERN EN-EA, Geneva, Switzerland,
B.M. Veit, Johannes Gutenberg Universitat, Mainz, Germany,
G.L. D'Alessandro, University of London, London, UK,
S. Cholak, Taras Shevchenko National University of Kyiv, Kyiv, Ukraine

Abstract

Physics Beyond Colliders is an exploratory study aimed at exploiting the full scientific potential of CERN's accelerator complex up to 2040 and its scientific infrastructure through projects complementary to the existing and possible future colliders. Within the Conventional Beam Working Group (CBWG), several projects for the M2 beam line in the CERN North Area were proposed, such as a successor for the COMPASS experiment, a muon programme for NA64 dark sector physics, and the MuonE proposal aiming at investigating the hadronic contribution to the vacuum polarisation. We present integration and beam optics studies for 100 – 160 GeV/c muon beams as well as an outlook for improvements on hadron beams, which include RF-separated options and low-energy antiproton beams and radiation studies for high intensity beams. In addition, necessary beam instrumentation upgrades for beam particle identification and momentum measurements are discussed.

INTRODUCTION

The emphasis of the CBWG studies lies on the large number of fixed target proposals for the North Area which comprises two surface halls, EHN1 and EHN2, and an underground cavern, ECN3. A schematic of the North Area is presented in Fig. 1. This paper will present the proposals made at the M2 beam line [1], which delivers high-energy

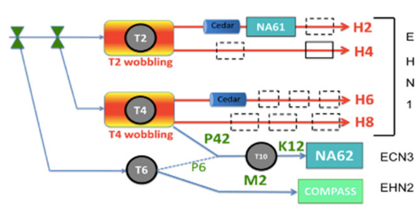

Figure 1: Layout of CERN North Area.

and high-intensity muon and hadron beams towards the experimental hall, EHN2, as well as low-intensity electron beams for detector calibrations.

THE EHN2 PROJECTS

The muon beam proposals made for the M2 beam line include:

- A future QCD facility [2] at M2 which is the successor of COMPASS [3] with proposals for a proton radius measurement and Deep Virtual Compton Scattering (DVCS)/Deep Virtual Meson Production (DVMP) measurements.
- The MuonE experiment [4] which intends to measure the hadronic vacuum polarisation as the main contributor to the uncertainty of the gμ-2 measurement. It requires a parallel 150 GeV/c muon beam with maximal intensity of 5x107/s. The longitudinal size of the experiment is expected to be 40 m - 60 m.
- The NA64 experiment [5] which proposes to search for dark matter coupling specifically to muons in two experimental phases - Phase 1 and 2. Phase 1 requires a parallel muon beam of 100-160 GeV/c with intensity in the order of 105-106 μ/s and a space of 20 m. For Phase 2 an installation inside the SM2 magnet of COMPASS is requested to be able to utilise the COMPASS spectrometer. The requested intensity for this phase is 107 μ/s.

CBWG STUDIES FOR THE M2 PROJECTS

Compatibility and Integration

For the muon program of all experiments the case of simultaneous installation and even operation of at least two experiments was studied, for the latter under the assumption that the beam momentum and intensity required will be the same for all experiments under consideration. Two possibilities were identified - downstream of the present COMPASS setup with an available space of 14.5 m and upstream of the COMPASS setup, where the present CEDAR detectors are housed, with an available space up to 40 m. The downstream option was deemed more suitable as a test beam setup and the upstream option was identified suitable for NA64μ Phase 1 or MuonE with minor modifications to the beam. Optics were studied with TRANSPORT [6] and the beam distribution was checked with HALO [7] software to have a parallel, small beam in that location together with a focussed beam downstream for COMPASS/NA64 Phase 2. The tentative optics for such a case is shown in Fig. 2 with the beam parameters in Figs. 3,4. The 3 m iron

† dipanwita.banerjee@cern.ch

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block for muon identification, to be used for MuonE, was taken into account to check the beam distributions.

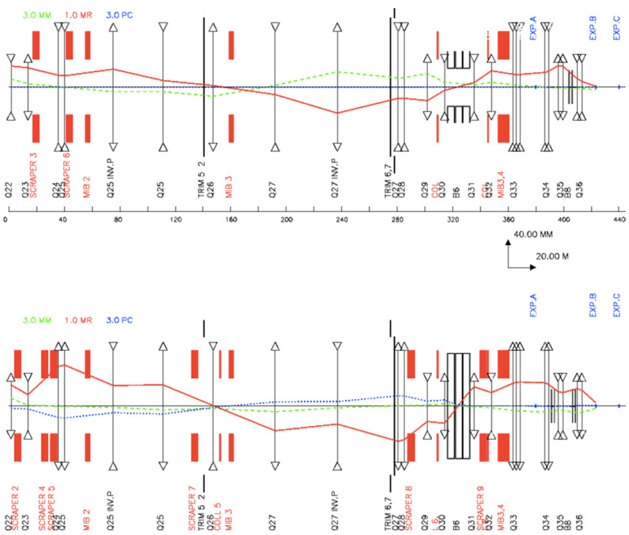

Figure 2: Tentative optics for a parallel beam for the upstream located experiment with a focused beam downstream.

As both COMPASS and NA64μ are reliant on a pure muon beam in terms of momentum definition and particle contamination, the background from particle interactions upstream, in the MuonE setup, was also checked for the downstream experiments with FLUKA and Geant4. Fig. 5 shows the spectrum of particles downstream which includes a low energy muon tail.

Due to this, parallel running can be excluded, however, simultaneous installation, removing the heavy materials from upstream can still be an option to reduce the change over time.

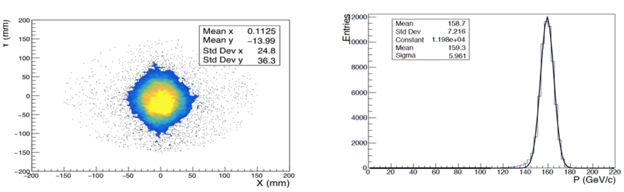

Figure 3: Beam size for the upstream experiment – σx = 17 mm, σy = 28 mm, σx' = 0.2 mrad and σy' = 0.3 mrad. The momentum distribution is also shown with σ_P = 6 GeV/c for an incoming beam of 160 GeV/c.

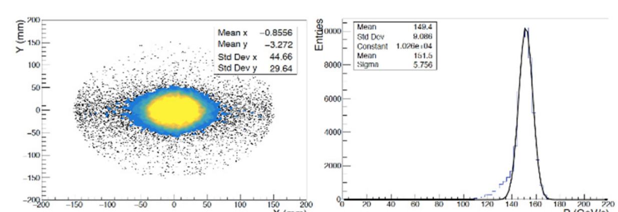

Figure 4: Beam size for the COMPASS target/NA64μ Phase 2 location – σx = 22 mm, σy = 21 mm, σx' = 1.2 mrad and σy' = 1.4 mrad. The momentum distribution is also shown with σ_P = 5.8 GeV/c and a degraded mean energy of 151 GeV/c due to the material of the MuonE installation upstream.

RF Separated Beam

The proposal for a new QCD facility requires a higher content of kaons and positive pions in the beam. This motivated a study for an RF-separated beam [8], which would be used to enrich the content of a wanted particle species in the beam by suppression of unwanted particles.

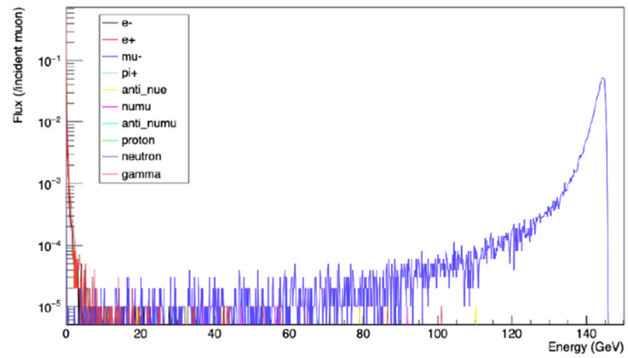

Figure 5: Produced particles after passing MuonE (FLUKA / Geant4).

The RF-separation scheme is shown in Fig. 6. The first optics study has been done as shown in Fig. 7 for the location of the first RF cavity which takes into account momentum selection and smooth focus of the beam towards RF1.

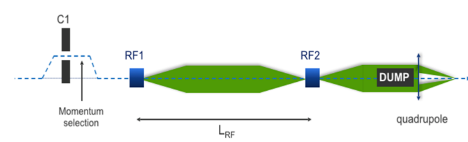

Figure 6: Scheme of RF separated beams.

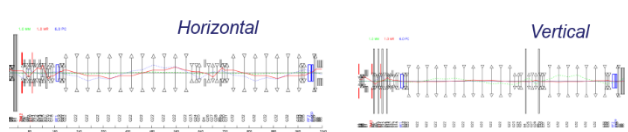

Figure 7: First optics measurements for placement of the first RF cavity.

Radiation Studies for High Intensity Beam

The currently used high-intensity pion beam for Drell-Yan measurements at COMPASS is limited in intensity by radiation protection considerations to about 4 x 108 hadrons/4.8 sec spill. A FLUKA study has been launched in collaboration with the RP group at CERN to understand better the origins of radiation stemming from the beam tunnel taking into account the material of the two installed CEDAR detectors. As a preliminary result, the current radiation levels at the entrance to EHN2 could already be confirmed by the simulation, which shows the main origin of radiation is the COMPASS target and absorber. In the beamline the main contribution comes from the hadrons

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lost in the dipole magnet bending the beam down, and the considerable interaction in the CEDAR vessels, which are filled with Helium gas at 10.5 bar. The simulated radiation map is shown in Fig 8. A study for the optimisation of the surrounding shielding at the CEDAR location is planned as well as a study to understand how the so-called "sky-shine" radiation in EHN2 could be reduced.

Beam Instrumentation Upgrades

Studies have also been performed to upgrade the beam instrumentation for the M2 beam line including the CEDAR upgrade, which has been implemented, and a proposal for beam momentum station (BMS) upgrades.

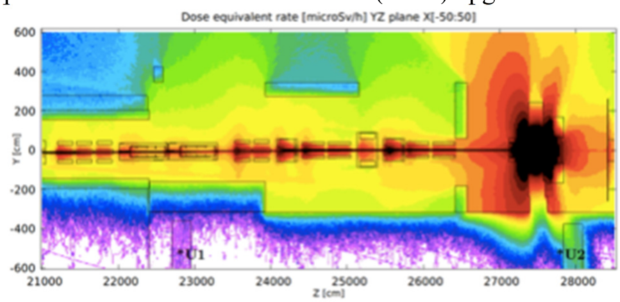

Figure 8: Preliminary simulation results for the radiation map of the 2018 high intensity hadron beam (3.8 x 10^8/spill) at the entrance to EHN2, where the beam is entering from the left side.

In order to improve the high temperature gradient which leads to a dynamic change of temperature over the gas volume of the detectors as shown in Fig. 9 (left) an upgrade of the thermal shielding has been proposed and implemented at the beginning of 2018. The new system consists of a better insulating layer around the gas vessel that allows for air circulation. Fig. 9 (right) shows the improved temperature stability.

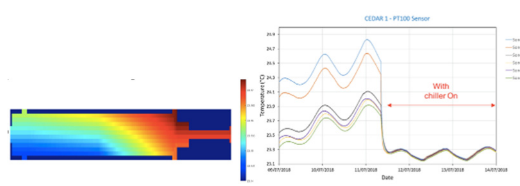

Figure 9: Measured temperature gradient along the CEDAR1 gas vessel. The min-max variation is below 0.1°C (left). Temperature stability of CEDAR1 during a test phase in the summer of 2018. In addition, the day/night variation of temperature is clearly observed (right).

In context of the NA64μ phase 1 studies, simulations were performed with HALO and Geant4 [9] to check the performance of the BMS to define the incoming beam momentum. The BMS consists of beam defining hodoscopes labelled BM01- 06 as shown in Fig. 10. Figure 11 (left) shows the current momentum resolution of 1% and Fig. 11 (right) shows the expected improvement in the momentum resolution for different detector resolutions. Therefore, a BMS upgrade could be envisaged by replacing the existing hodoscopes with detectors of much better spatial resolution.

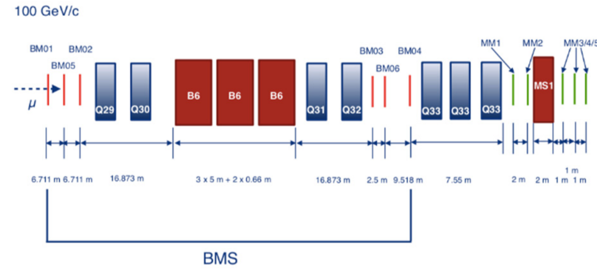

Figure 10: Schematic of the beamline showing the BMS.

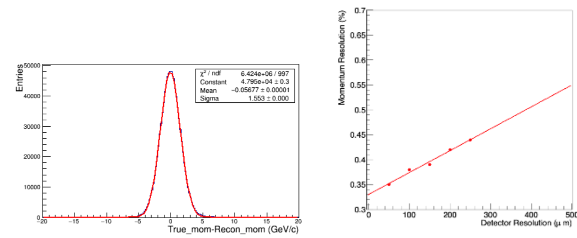

Figure 11: Left: Momentum resolution of 1 % estimated for the current BMS setup with simulation. Right: Estimated momentum resolution dp/p [%] as a function of detector resolution.

CONCLUSION

The EHN2 working group of the CBWG has initiated and completed various studies focusing on the proposals for the M2 line and in almost all cases given good indications of the feasibility and implications of the beams and infrastructure modifications associated with the proposed experiments. All studies are included and discussed in detail in the PBC report [10]. The studies will continue to further finalise the experiment installations and feasibility.

REFERENCES

[1] N. Doble *et al.*, NIM A 343 (1994) 351-362.

[2] O. Denisov *et al.*, Letter of Intent: A New QCD facility at the M2 beamline of the CERN SPS, preprint for discussion, arXiv:1808.00848 [hep-ex] (2018).

[3] COMPASS collaboration, Addendum to the COMPASS-II Proposal, CERN-SPSC-2017-034, SPSC-P-340-ADD-1 (2017).

[4] C. Matteuzzi, Talk at the 1st meeting of the Conventional-Beams WG, Geneva, 2017.

[5] S. Gninenko *et al.*, Addendum to the NA64 Proposal: Search for the A'!invisible and X!e+e decays in 2021, CERNSPSC- 2018-004, SPSC-P-348-ADD-2.

[6] TRANSPORT – A Computer program for designing charged particle beam transport systems. CERN 80-04 Super Proton Synchrotron Division (1980).

[7] HALO – A Computer program to compute muon halo CERN 74-17 Laboratory II Experimental Areas Group (1974).

[8] P. Bernard, P. Lazeyras, H. Lengeler, V. Vaghin, Particle separation with two-and threecavity RF separators at

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPGW063

CERN, CERN Yellow Reports: Monographs, CERN (1968).

[9] Geant4—a simulation toolkit. NIMPA.506.250A. (2003).

[10] L. Gatignon *et al*., Report from the Conventional Beams Working Group to the Physics beyond Colliider Study and to the European Strategy for Particle Physics – CERN-PBC-Report-2018-002.