CERN-PBC-NOTE 2023-008

9 October 2023
nikolaos.charitonidis@cern.ch

Possible operational scenarios for a quasi-simultaneous operation of proton and ion beams in the North Area Experimental Areas

N. Charitonidis, D. Banerjee, J. Bernhard, M. van Dijk, L. Nevay and L. Gatignon[†]

CERN, 1 Esplanade de Particules, Meyrin, Switzerland
[†] also with Univ. of Lancaster, Physics Department, LA14YW, Lancaster, UK

Keywords: `SPS, operational scenarios, north area, secondary ion beams`

Summary

The implications of the experimental proposals for ion operation in the North Area (NA) post-LS3 are being studied within the Physics Beyond Colliders framework [1] in collaboration with the ATS Future Ions Working Group, which has been established with the mandate to study possibilities and limitations of the CERN injector complex for delivering ions to the SPS experimental areas and the LHC after LS3 [2]. This document describes three conceptual scenarios for quasi-simultaneous operation of protons and ions slowly extracted towards the North Area beam lines as a possible mean to optimize the overall beam delivery to the NA experiments. All these scenarios need to be checked against all accident scenarios in a dedicated risk assessment and the overall gain of such an investment weighted versus simple time-sharing of the two different modes.

Contents

1 Introduction **2**

2 Possible scenarios for quasi-simultaneous proton and ion operation **4**
2.1 Scenario 1: Ions in H2/H4, ions to H8, and protons to P42 and M2 lines . . 4
2.2 Scenario 2: Ions in H2/H4, protons serving the H6/H8/P42 and M2 lines . . 5
2.3 Scenario 3: Ions in all lines in one supercycle, protons to all lines in the next, alternating. 5

3 Conclusions **5**

1 Introduction

The CERN North Experimental Area was designed in the 1970s in order to provide proton beams to a variety of experiments. It is serving this purpose since over 40 years [3]. Since 1986, also ion beams were extracted to the North Area, initially Oxygen ions. These were followed by Sulfur from 1990 and Lead as well as several other ion species later on. The slowly extracted proton beam from the Super Proton Synchrotron (SPS) is transported via the TT20 line and is split, using two chains of three Lambertson septum magnets, towards the three North Area Targets, designated T2, T4, and T6, located in the underground cavern TCC2. Later, for compatibility with heavy ion operation, the second set of horizontal dipoles of the T2 wobbling station (type MTR) were modified to allow splitting of the beam into the H2 and H4 beam lines. The aforementioned Lambertson septa are not laminated. The unavoidable beam losses require a radiation hard construction of the excitation coils, which are wound from hollow, water-cooled, mineral-insulated cables. If the splitter magnets were to be exchanged by laminated ones, particular attention would need to be given to minimization of beam losses, which can be demanding for laminated material, as found in the past [4]. For the transport and focusing of the 400 GeV/c slowly-extracted proton beam, specially constructed quadrupoles have been installed, some of them non-laminated. The TDC2 region where the primary proton beam is split as well as schematics of the NA beam lines in today's ion configuration are shown in Figure 1.

Today, the North Area proton and ion operation are completely separated in time, i.e. scheduled during different periods of the year. Usually, the ions are scheduled towards the end of each operational year given the long setting-up effort throughout the injector complex for their production, transport, and extraction, as well as profiting from the ion run to cool-down the complex before the (E)YETS. The *modus operandi* for protons is using both splitter magnets simultaneously, as shown schematically in Figure 1. This allows adjustable sharing of the beam intensity between the T2, T4, and T6 targets. Nowadays, during the ion operation, the T6 target is not used since there is no ion experiment in ECN3 anymore. For this, the beam was split towards T6 in the past to still allow using the H8 beam line via the T4 target for ion beams. During ion operation, splitter 1 is switched off by default, meaning that the beam passes through the field free region, while the beam is only split between T2 and T4 using Splitter 2. Out of the beamlines served from the T4 target, both

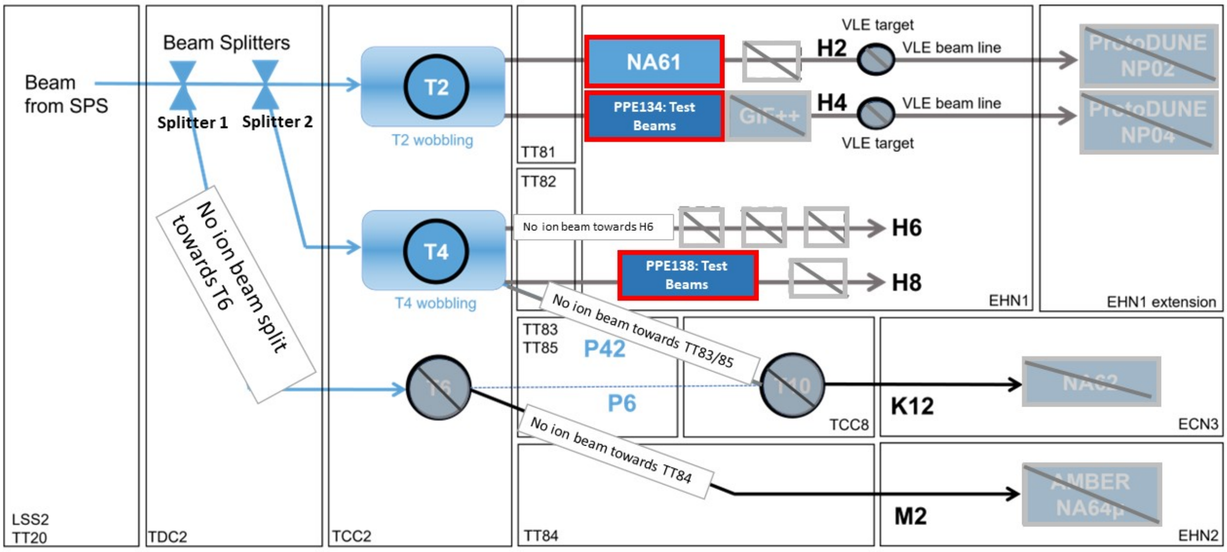

Figure 1: Schematics of the North Area transfer lines, the splitting and target regions (TDC2 / TCC2) and the three experimental areas (EHN1, EHN2 and ECN3) are shown. In today's ion configuration, no ion beam is split towards the TT83, TT84 and TT85 lines. The ion beams are currently serving the T2 beamlines (H2/H4) and the H8 beamlline of T4. The M2, P42 and K12 beams are not operating during the ion period of the year.

P42 and H6 are switched off during the ion period and ions are only available to H8 as there is no dedicated splitter magnet downstream of T4 (see Figure 1). The splitting between the H2 and H4 lines of T2 is done using the custom-made splitter, which is essentially a vertically movable MTR magnet that has been adapted for this purpose with a steel plate comprising a cylindrical, 10 mm diameter field-free hole in the center. This allows the ion beam to be split horizontally between the H2 and H4 lines. Note that these MTR magnets are not laminated. A special hardware interlock is present in order to avoid any accidental extraction of the full proton beam into the surface areas [5]. The interlock is complemented by software (SIS) as well as hardware and RP monitoring tools. Today, the only approved fixed target ion physics experiment is NA61/SHINE, comprising a proposed long-term ion physics program [6, 7]. The experiment is located in the PPE152 experimental area of the H2 line of EHN1. Another idea for an intended experiment has been brought forward recently by the NA60+ collaboration [8] that aims for a possible installation in the H8 line after LS3. In addition, many R2E and R&D test-beams are regularly being scheduled in both the H4 and H8 lines.

2 Possible scenarios for quasi-simultaneous proton and ion operation

Currently, the way the North Area ion interlock has been designed and implemented forbids sending protons and ions as primary beams to the North Area within the same super-cycle. This is important in terms of safety in order to avoid a severe accident, namely the primary proton or ion beam being extracted at its full intensity into the surface buildings of EHN1 and EHN2. In this document, we summarize three possible scenarios in which protons and ions might share the same SPS super-cycle from the experimental areas perspective, with the purpose to operate protons in the P42/K12 and M2 lines and at the same time as operating with ions in the aforementioned EHN1 lines. All these scenarios will need to be checked against all accident scenarios in a dedicated risk assessment. In all cases, interlocks need to be implemented that essentially will ensure that

1. no proton beam is extracted by accident at full intensity in any surface area and
2. no primary ion beam will be extracted at full intensity in any surface area and namely the surface experimental halls EHN1 and EHN2.

2.1 Scenario 1: Ions in H2/H4, ions to H8, and protons to P42 and M2 lines

This operational scenario would allow ions with a rigidity up to 380 GeV/c/Z towards the H2 beam line (serving currently NA61/SHINE) and primary beam of the same rigidity or fragmented beams of any rigidity lower than 380 GeV/c/Z towards the H4 line within the same super-cycle as proton operation of P42 and M2. In case that the H8 line is also scheduled for ions, then the Splitter 2 current would need to be adjusted on a cycle-by-cycle basis for splitting the proton and ion beams having different rigidities. During the proton cycle, primary protons would continue towards P42, with the T4 target being in OUT position. The T6 line (M2) will be served only with protons (from Splitter 1). In this case, in terms of transverse optics, during the ion cycle, the ion beam would need to be focused through the field-free region of Splitter 1, while for proton cycle the beam would need be vertically large on Splitter 1 and be focused on the deflecting region of Splitter 2. This essentially means spill-by-spill steering on the splitter magnets and spill-by-spill optics for the different species, hence requiring to replace QSLD2201, i.e. a TT20 quadrupole, and the splitter magnets with corresponding laminated magnets in case beams with different rigidities are transferred. In terms of interlocks, the existing LOKN protection system already now prevents primary beams with a wrong rigidity to be transported to the experimental areas. Limiting the rigidity of M2 (in case of lower primary momenta) as well as dedicated, fast interlocks are the minimum safety measures that should be considered.

2.2 Scenario 2: Ions in H2/H4, protons serving the H6/H8/P42 and M2 lines

This scenario would allow ions with a rigidity up to 380 GeV/c/Z towards the H2 beam line and NA61/SHINE and the same primary or fragmented beam of any lower rigidity towards the H4 line within the same super-cycle as protons to the T4 and T6 targets. In this case, the ion beam will only be present in the beam lines derived from the T2 target. In this case, the ions would pass through the field-free regions of both splitter magnets that both would be set for protons. In terms of transverse optics, the ion beam should be focused on the field free regions for both splitter magnets, while the protons should be large vertically in Splitter 1 and vertically focused on the deflecting region of Splitter 2.

2.3 Scenario 3: Ions in all lines in one supercycle, protons to all lines in the next, alternating.

In this scenario, all beam lines would receive the ions and all lines also the protons, in alternating super-cycles. In this case, the splitter magnet currents would need to be adjusted on a super-cycle by super-cycle basis for the different momenta of protons and ions, and at the same time allowing different sharing between proton and ion beams for both Splitter 1 and Splitter 2. This scenario is not possible without laminated splitter magnets and fully laminated magnets all along TT20. Also the interlock logic will be quite complicated in order to avoid possible accidents, and for the moment there is no physics-driven request for ions in the P42/K12 and M2 lines.

3 Conclusions

We have detailed three possible operational scenarios for a quasi-simultaneous proton and ion operation serving the North Area experiments that could allow the proton operation to be extended for a few weeks more while at the same time providing ions to NA61/SHINE. All scenarios are far from trivial to implement, especially given the significant changes that need to be done in the interlock logic, including also clean timing signals between the two different species, and more precise estimation of the various accident scenarios in all cases. Also, it is clear that the extraction chain, including the splitter magnets and the TT20 magnets, needs to be checked and proven compatible with such possibilities. Also, the duty cycle of ions (maximum today 35%, average with LHC fillings 20%) would be severely impacted if a proton cycle is to be included in the super-cycle. Pulse-to-pulse modulation (PPM) operation would be necessary for some magnets, also including the splitter magnets in some of the scenarios. The second scenario therefore would be an option to consider since it does not require lamination of the splitters. In general, the cost vs. benefit of such a project needs to be carefully evaluated in detail, taking into account input from accelerator operation and transfer lines (i.e. BE-OP and SY-ABT). Especially, a time-wise sharing might achieve similar or better overall performance for the physics program. A further risk assessment is also mandatory.

References

[1] *Mandate of the Physics Beyond Colliders Study Group (Revised January 2021)*. 2021. URL: https://pbc.web.cern.ch/mandate-physics-beyond-colliders-study-group-revised-january-2021.

[2] *Working Group on Future Ions in the CERN Accelerator Complex*. https://www.overleaf.com/read/ghgkrxqtzpms.

[3] D. Banerjee et al. *The North Experimental Area at the CERN Super Proton Synchrotron*. CERN-ACC-NOTE-2021-0015.

[4] J. Kurdez. *MSSB septum splitter magnet for the North Experimental Area at CERN in the context of the planned BDF/SHiP extraction line*. https://indico.cern.ch/event/977630/.

[5] T. Hakulinen et al. *Personnel Protection of the CERN SPS North Hall in Fixed Target Primary Ion Mode*. https://accelconf.web.cern.ch/ICALEPCS2013/papers/momib06.pdf.

[6] A. Aduszkiewicz et al. *Measurements of $\pi\pm$, $K\pm$, $\bar{p}$ and p spectra in proton-proton interactions at 20, 31, 40, 80 and 158 GeV/c with the NA61/SHINE spectrometer at the CERN SPS*. Eur. Phys. J. C, vol. 77, no. 10, p. 671, 2017.

[7] A. Acharya et al. *Measurements of $\pi\pm$, $K\pm$, $\bar{p}$ and p spectra in $^{7}Be + ^{9}Be$ collisions at beam momenta from 19AGeV/c to 150 AGeV/c with the NA61/SHINE spectrometer at the CERN SPS*. Eur. Phys. J. C, vol. 81, no. 1, p. 73, 2021.

[8] T. Dahms et al. *Expression of Interest for a new experiment at the CERN SPS: NA60+, CERN-SPSC-2019-017, SPSC-EOI-019, May 2019.*