CERN-PBC-Notes-2023-005

24 July 2023
rebecca.louise.ramjiawan@cern.ch

TT20 unsplit beam optics for dedicated ECN3 operation

R. Ramjiawan, M.A. Fraser, F.M. Velotti
CERN, CH-1211 Geneva, Switzerland

Keywords: North Area, TT20, ECN3, P42, beam optics

Summary

The Transfer Tunnel 20 (TT20) in the CERN North Area (NA) contains transfer lines TT21-25 to transport beam extracted from the Super Proton Synchrotron (SPS). The beam is shared between three primary production targets simultaneously using two sets of Lamberston septa magnets. Proposals for a future facility in the ECN3 underground cavern might require new optics in the TT20 transfer lines to provide high-intensity, 'unsplit' beam directly to future NA experiment(s). Here, we present an optics to transmit an unsplit beam through the splitter magnets without collimation and through the transfer lines without losses. The T4 target is unsuitable for high beam intensity and a closed magnetic orbit bump is proposed to bypass the target.

Contents

1 TT20 transfer lines

To serve experiments in the CERN NA, a continuous beam of 400 GeV protons is slow extracted from the SPS and deflected into the TT20 transfer lines. Two 'splitters', each composed from three radiation-hard Lambertson septum magnets (MSSB) and one collimator (TCSC), are used to share the beam between three primary production targets, T2, T4 and T6, simultaneously. A schematic of the TT20 transfer lines in the CERN NA is shown in Fig. 1. The beamlines following these targets deliver various secondary and tertiary beams to experiments across a range of energies.

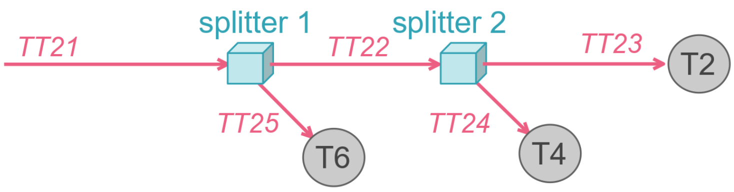


Figure 1: Configuration of the TT20 transfer lines (TT21-25) showing how the beam is shared via two splitter magnets to provide beam to three targets (T2, T4, T6) simultaneously.

1.1 Transfer lines to ECN3

In this note we consider the requirement from a future high intensity experiment housed in the ECN3 cavern for a dedicated and unsplit beam. Such a beam would propagate through TT21, TT22, TT24 and P42 to the T10 target. Beam which has not interacted with the T4 target enters the P42 beamline and is transported to the T10 target. Kaons produced in the T10 target are then selected by the K12 secondary beamline and delivered to an experiment in ECN3, currently the NA62 experiment. Whether the subsequent K12 secondary beamline will be removed or rebuilt will depend on the experiment located in ECN3.

2 Unsplit optics

The optics in the TT21, TT22 and TT24 transfer lines were rematched to provide a dedicated beam to ECN3 by transporting it unsplit through the two TT20 splitters [1]. This beam will be deflected into the field-free region at the top of first splitter allowing the beam to pass into the TT22 transfer line. At the end of the TT22 line, the beam will be deflected into the lower gap of the second splitter so that it will be diverted into the TT24 line. To avoid exceeding the T4 target intensity limitations during dedicated cycles, the unsplit beam could bypass the T4 target via a vertical, closed orbit bump.

The magnet strengths in the P42 primary line were left unchanged from SFTPRO operation as they will not have pulse-to-pulse modulation (PPM) functionality before the CERN Long Shutdown 4, in addition to a single quadrupole magnet downstream of T4 that is non-laminated (QSL.043033). Similarly, the strength of the magnet QSLD.2201 in the TT22 transfer line was left unchanged as it is not laminated and therefore cannot support pulsed operation. In Table 1 the quadrupole gradients for the unsplit optics, where they differ from the operational SFTPRO Q-split optics, are reported.

Table 1: Quadrupole gradients for the unsplit optics.

Quadrupole	Gradient [T/m]	Strength [m^{-2}]
qtld.2101	-13.206	-0.006543
qtlf.2102	17.590	-0.009898
qtld.2103	-13.049	0.013184
qnlf.2104	18.607	-0.009780
qnld.2105	-14.104	0.013946
qnl.2112	10.564	-0.010571
qnl.2113	-7.605	0.007918
qtl.2114	6.444	-0.005700
qnl.2115	-4.558	0.004830
qtl.2116	9.265	-0.003416
qnl.2117	-8.534	0.006943
qtaf.2202	13.134	-0.007961
qtad.2204	-8.730	0.009844
qnlf.2410	16.306	0.012221
qtld.2402	-18.465	-0.013839
qtlf.2403	18.416	0.0138031
qnlf.2405	20.832	0.015614
qtad.2407	-14.310	-0.010725

During SPS resonant slow extraction, the momentum of the extracted beam varies. For these studies, we assume that the TT21 and TT22 magnet field strengths ramp linearly with the energy of the extracted beam thus minimising dispersive contributions to the beam size. The splitter magnets cannot be ramped as they are not laminated and the TT24 and P42 magnets are not ramped, meaning that for the subsequent TT24 and P42 lines we must take into account this dispersive contribution. To model this effect, the beam momentum in the TT21 and TT22 lines was taken to be the the instantaneous extracted momentum spread, $\delta_p = 1 \times 10^{-4}$, whereas, for the TT24 and P42 lines, the full momentum spread of the SPS beam is used, $\frac{\Delta p}{p} = [-1.5 \times 10^{-3}, 1.5 \times 10^{-3}]$.

The Twiss functions $\beta_{x,y}(s)$ and the horizontal and vertical dispersions for these optics are shown in Fig. 2. The vertical dispersion is large inside of the vertical dogleg in TT21 due to the change in depth between extraction from the SPS and the NA beamlines. In the P42 beamline, the horizontal dispersion is very large and exceeds 10 m.

To avoid losses, the largest T4 XTAX (Target Attenuator eXperimental areas) setting of 40 mm x 20 mm is suggested to accommodate the larger beam divergence at the T4 target. The beam size at the T4 target is $\sigma = 0.41 \times 0.20$ mm, as determined with particle tracking. A round beam was achieved on the T10 target with a beam size of $\sigma = 0.21$ mm both horizontally and vertically, which is compatible with the dimensions of the T10 target. Beam sizes at other key locations throughout the TT20 and P42 transfer lines are given in [1].

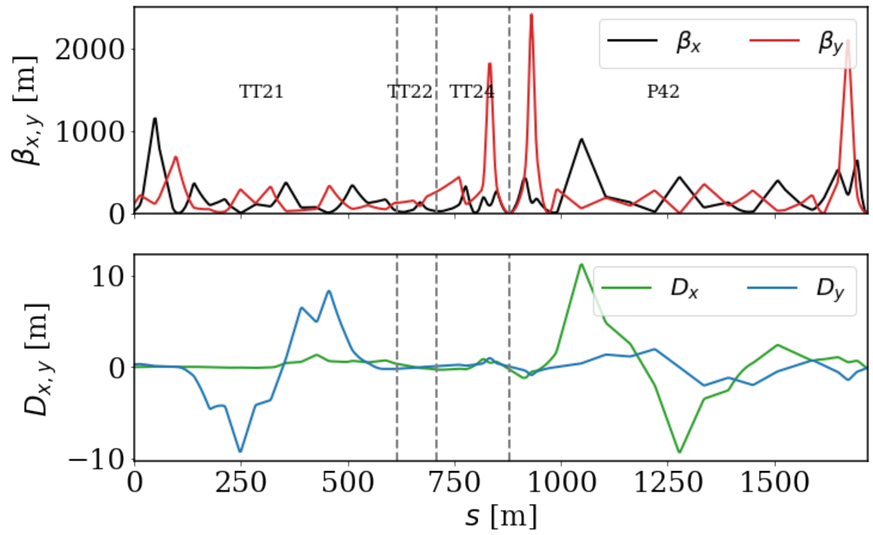


Figure 2: Twiss $\beta_{x,y}$ and dispersion functions for the unsplit beam from the start of TT21 to the T10 target. The TT21, TT22, TT24 and P42 regions are indicated.

3 Bypassing the T4 target

The T4 target plates are 2 mm thick and vertically separated by 40 mm. If the beam is bumped ≥ 3 mm vertically, it can pass between these plates without interception. A suitable closed orbit bump could be created using two existing bumper magnets (MDLV.240209 in TT24 and MDX.X0430048 in P42) in combination with a new magnet upstream of the T4 target, approximately 153 m after the start of the TT24 line. All three bumper magnets require a laminated yoke for PPM operation. A preliminary non-PPM bumper magnet has been installed so that this option can be tested during 2023.

The deflection angles of the three bumper magnets are given in Table 2 together with relevant beam parameters. The beam envelopes and magnet apertures for the vertical orbit bump are shown in Fig. 3. The bumper power converters are bipolar and the trajectory bump can be made above or below the target.

Bumper	mdlv.240209	MNPA30 (new)	mdx.x0430048
Horizontal beam envelope (99.5%)	7.3 mm	5.4 mm	7.1 mm
Vertical beam envelope (99.5%)	4.6 mm	3.0 mm	11.9 mm
Vertical beam offset	0 mm	−4.4 mm	0 mm
Deflection angle	62.3 µrad	60.4 µrad	39.1 µrad

Table 2: Design parameters for the bumper magnets used to produce the vertical closed orbit bump of 3 mm at the T4 target.

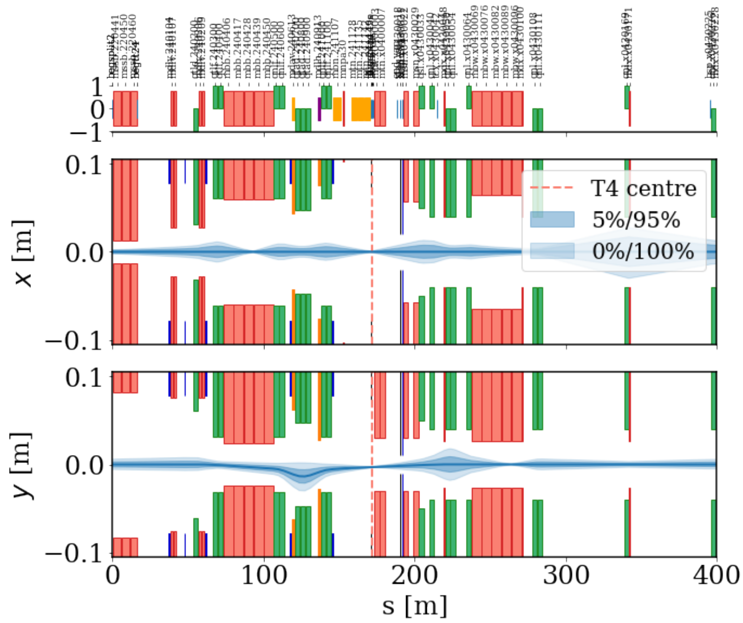


Figure 3: The vertical magnetic 3 mm orbit bump used to bypass the T4 target plate. The beam envelope (blue) is shown together with the magnet apertures for comparison. Longitudinal positions are given relative to the start of TT24.

4 SFTPRO beam during dedicated operation

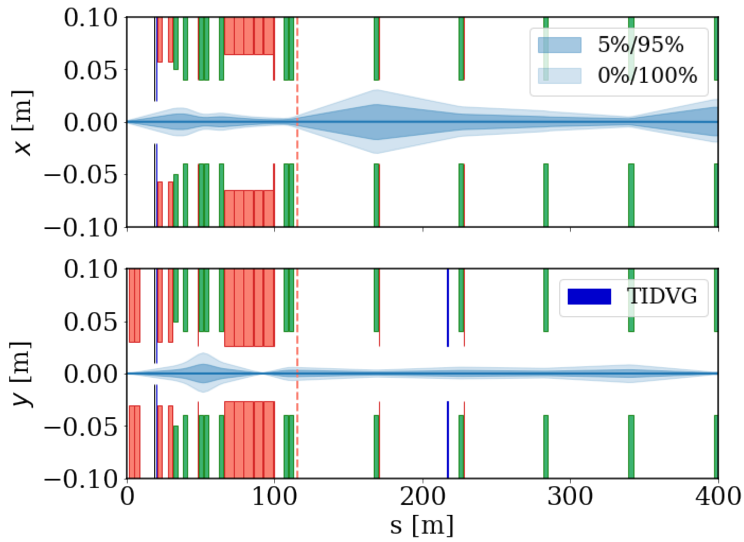
A system of three magnets surrounding the T4 target and associated XTAX, referred to as the 'wobbling station' [2], are used to select different energies for the three beamlines following the T4 target: P42, H6 and H8. The MTN magnets in this wobbling system are not laminated and therefore must have the same settings between SFTPRO and dedicated ECN3 cycles. This means that during SFTPRO cycles when shared beam is provided to H6 and H8, any beam which does not interact with the T4 target will be transported into P42.

Before LS4, the P42 magnets will not have PPM functionality and it could potentially cause problems to transport this fraction of the SFTPRO beam through P42 during dedicated operation. If this is the case, a vertical corrector magnet installed after QNL.430111 could be used to deflect the beam onto an internal dump. We propose to use the spare TIDVG#4 [3] as an internal dump with a configuration as shown in Fig. 4.

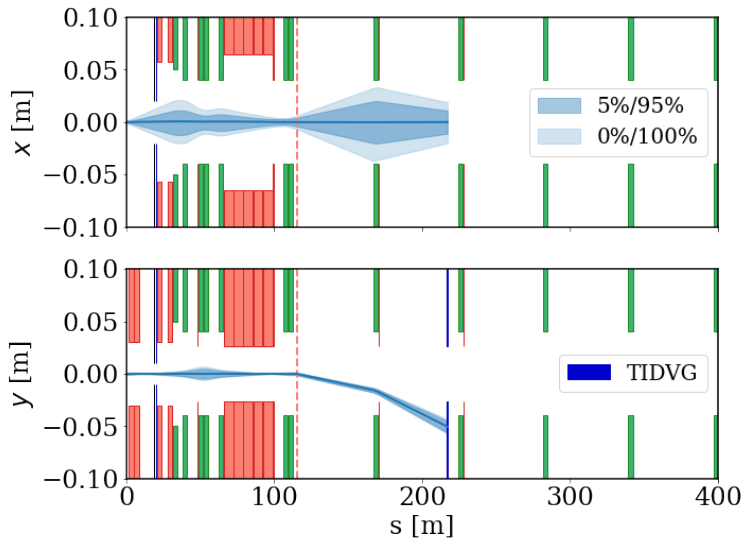
5 P42 instrumentation installation

5.1 Beam loss monitors

With a view to higher intensity beams in ECN3 and the associated risks, 13 Beam Loss Monitors (BLMs) were installed in the P42 primary line [4] to measure prompt beam loss, which was not previously possible. Regions of elevated dose rates along the beamline have been observed and the BLMs will be helpful towards diagnosing transmission issues and for continuous monitoring of regions where the tunnel shielding is limited, such as at the EHN1



(a) Unsplit optics.



(b) Operational Q-split optics (SFTPRO operation).

Figure 4: Beam envelopes through the first section of P42, showing the possibility of using a dipole to deflect the SFTPRO beam entering P42 into an internal dump. The aperture of the proposed TIDVG#4 is shown in dark blue and the location of the suggested dipole position as a dashed line. (a) The unsplit beam is undisturbed, while (b) the SFTPRO beam is deflected and dumped onto the TIDVG#4.

ramp and ECN3 bridge.

The suggested locations for the BLMs are shown in Fig. 5, where the second BLM at 52 m was not installed because of difficulties with cabling.

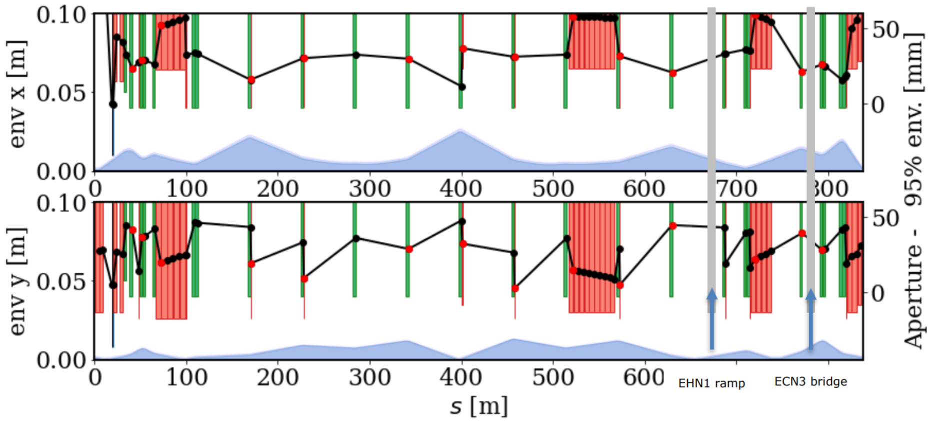


Figure 5: Beam envelope (95%) (Q-split optics) is shown (blue) with the magnet apertures for comparison. The black markers give the difference between the aperture and the 95% beam envelope, the red markers highlight proposed locations for the BLMs. Longitudinal positions are all given relative to the centre of the T4 target. Two regions close to RP limits are indicated with grey bands.

5.2 Beam profile monitors

Three additional beam profile monitors (BSGs) [5] were installed in P42 during the Year End Technical Stop (YETS) 22/23, bringing the total to four. The four BSG locations are highlighted in Fig. 6. The BSG locations were chosen so as to map out a range of phase advances, while including a BSG in a high dispersion region and one near the T10 target. These BSGs could be used to empirically rematch the optics in the case that the observed discrepancies between the TT20 optics model and beamline are not resolved [6].

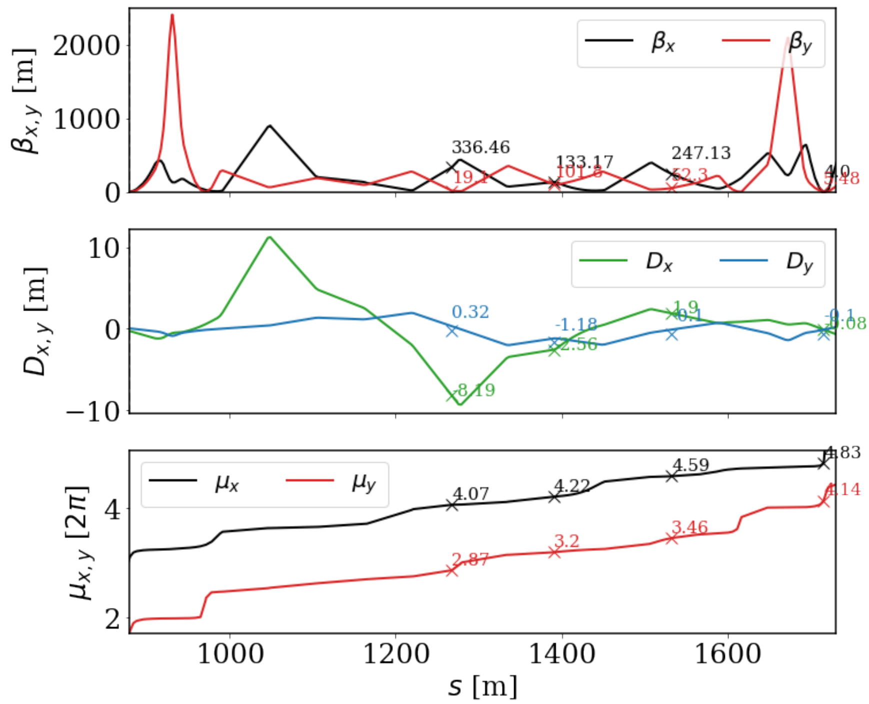


Figure 6: Twiss $\beta_{x,y}$ function, dispersion and phase advance in the P42 beamline with the four BSG locations highlighted.

6 Conclusions

We presented a new optics designed to provide an unsplit beam for a future high intensity facility in ECN3. Any magnets without PPM functionality were left unchanged from their current operational values. Tracking studies suggest that with the largest T4 XTAX setting the beam can be propagated to the T10 target without losses.

A high intensity beam would exceed the limitations of the T4 target and therefore a vertical magnetic orbit bump is proposed, to bump the dedicated beam between the T4 target plates. This orbit bump would comprise two existing bumper magnets with an additional magnet installed upstream of the T4 target. This orbit bump will be tested during Run 3.

During dedicated ECN3 operation, beam will still propagate into the P42 line on SFTPRO cycles because the MTN magnets cannot be pulsed. This could potentially cause problems as the P42 magnets will not be PPM and cannot be changed between the dedicated and SFTPRO operation. One proposed solution is to use a vertical dipole to deflect the SFTPRO beam into an internal beam dump. The TIDVG#4 was shown to be a suitable candidate.

To cope with higher intensity in the P42 beamline, 13 BLMs and 3 additional BSGs were installed. The BLMs will be useful to mitigate and continuously monitor the beam loss which was previously observed in the P42 beamline. The BSGs will be valuable during studies towards identifying the sources of the TT20 optics discrepancy. In case this discrepancy is not resolved, the BSGs would be useful for empirically rematching the optics.

References

[1] F. Velotti *et al.*, "Beam size specification for TT20," CERN, Geneva, Tech. Rep. EDMS #2787943, 2022. [Online]. Available: https://edms.cern.ch/document/2761319/1

[2] I. Efthymiopoulos, "*Target Station T4 Wobbling - Explained*," 2003. [Online]. Available: https://sba.web.cern.ch/sba/Documentations/Target/T4/T4Wobbling3.pdf

[3] B. Goddard and F. Velotti, "Functional requirements for the TIDVG beam dump block," CERN, Geneva, Tech. Rep. EDMS #1684859, 2016. [Online]. Available: https://edms.cern.ch/document/1684859/1

[4] J. Bernhard *et al.*, "Installation of Beam Loss Monitors in the North Area P42 Primary Line," CERN, Geneva, Tech. Rep. EDMS #2777729, 2023. [Online]. Available: https://edms.cern.ch/document/2777729/0.2

[5] M. Fraser *et al.*, "Installation of additional Beam Profile Monitors in the North Area P42 Primary Line," CERN, Geneva, Tech. Rep. SPSX-B-EC-0002, EDMS #2777725, 2022. [Online]. Available: https://edms.cern.ch/document/2777725

[6] F.M. Velotti, "TT20 optics measurements," 18 May 2022, presented at SPS MPC #20 - NA spill quality, part I. [Online]. Available: https://indico.cern.ch/event/1159207