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Summary Design of an upgraded booster-to-ring transfer line (BRTL) for SLS 2.0 with improved diagnostic capabilities. Related documents OPA lattice files: <code>br1opt2cc</code>, <code>sls_f6cwo_bxs_xbeam</code>, <code>booster</code>, <code>b068_000</code>, <code>btr068b</code> Documents are available on <code>afs/psi.ch/project/SLS2</code> → Docs/Notes for tech notes and → BD/Lattices/Reference for the lattice files.	

Modification History

Version 5 – 11.3.2021

- Based on injection meetings in March 2020 updated parameters for injection elements.
Upgrade **btr068b**

Version 4 – 1.12.2020

- Based on injection meetings in Nov.2020, realistic parameters for new in-air thick septum and in-vacuum thin septum are assumed. Upgrade **btr066b**.

Version 3 – 5.11.2020

- The previous version had an error, final angle of BRTL was factor 2 too large
- Re-use of left over SITF screen/BPM units, correctors inserted
- Upgrade `btr062m`, minimum modification `btr062b` removed.

Version 2 – 13.8.2020

- Re-use of left-over SwissFEL injector test facility (SITF) quads, upgrade `btr062h`

Version 1 – 11.8.2020

- Minimum modification `btr062b` and upgrade `btr062g`

Introduction

Storage Ring Lattice B068 is base for the Technical Design Report [1]. The lattice defines the point of injection, which is the end point of the booster-to-ring transfer line (BRTL). Position and angle of this point have changed in comparison to the existing SLS, which requires a modification of the BRTL.

Since injection into the SLS 2.0 storage ring is a crucial issue and depends on thorough control of the injected beam parameters, the value of extended diagnostics capabilities in the BRTL cannot be overestimated. Therefore an upgrade of the BRTL is proposed. Due to re-use of several components available in-house, the investment will be moderate and pay off by efficient commissioning.

The existing SLS-BTRL (**br1opt2cc**)

Layout and optics

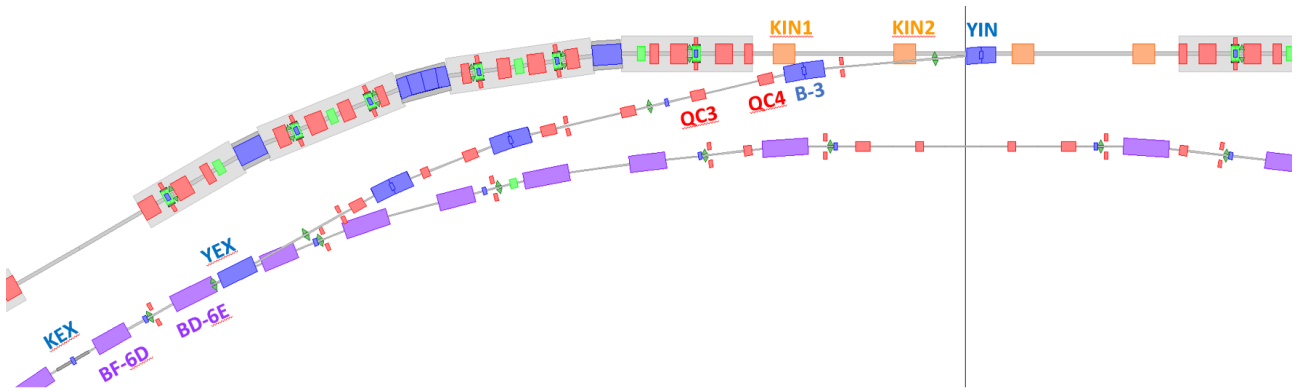


Fig.1 Layout of the existing BRTL, also see Fig. f34_a in [2].

The existing BRTL as shown in Fig. 1 is described in chapter 3.4 of [2]. The design was considered as uncritical, claiming that just 6 quadrupoles are required to provide matching of six beam parameters (β_x , α_x , β_y , α_y , D_x , D_x') between booster and ring. A 7th quad was added to increase flexibility. In the first version, an achromatic section was foreseen for emittance measurements [3], but later was given up for simplicity and compactness. The initial optics was matched to the periodic solution of the storage ring, until it turned out that focusing to the septum reduces the storage ring acceptance required to capture the injected beam [4]. Since then the optics as shown in Fig.2 has not been changed. 2 of the 7 quads are switched off.

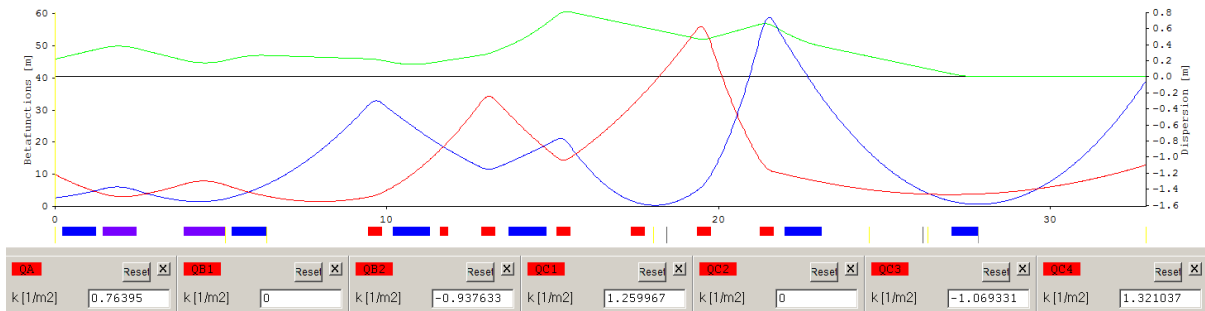


Fig. 2: Optics of the existing BRTL as it is used today.

The quads are of type QS (1 $\times$) / QL (6 $\times$) as also installed in the booster, they have magnetic lengths of 220 / 400 mm and reach a maximum gradient of 13.7 T/m at 120 A current.

The BRTL contains 3 identical dipoles of type BG with 1100 mm magnetic (arc) length, which reach a max. field of 1.225 T at 120 A, resp. the design deflection angle of 8.2° at 2.7 GeV with 113.7 A.

Further there are 3 vertical and 1 horizontal corrector (the three bends are also used as horizontal correctors), 4 optical screens and 3 BPMs.

Geometry

The coordinate system is the machine coordinate system, centered at WSLA hall with the Y-axis pointing to the middle of storage ring straight 1L. A rotation by -12° (clockwise) transforms it to the building coordinate system, where the $-X$ axis points to the entrance ("Achse 0").

Pulsed magnets parameters are given in sec. 2.9 and 3.2.7 of [2] with *net* length and deflection:

- ABOMA-KEX 1000 mm -4.9 mrad $= -0.28^\circ$
- ABOMA-YEX 1040 mm -6.47° [assume] length = arc length
- ARIMA-YIN 800 mm $+5.0^\circ$ length = straight length; arc length = 801.016 mm

The BRTL starts at the exit edge of BD-6E (see Fig.1). Since BF-6D and BD-6E are combined function magnets with quadrupole and sextupole moments, the orbit (in the travelling beam coordinate system) has an offset at BD-6E exit of $x = 14.7816$ mm $x' = 7.2932$ mrad $= 0.417870^\circ$

The position of BD-6E exit is $X = -20699.143$ mm $Y = 37715.856$ mm $W = 22.711800^\circ$

The orbit offset adds $dX = -x \sin(W)$ $dY = x \cos(W)$ $dW = x'$

Thus **BRTL startpoint is** $X = -20704.850$ mm $Y = 37729.4914$ mm $W = 23.129670^\circ$

The BRTL ends at the exit of the injection septum [ARIMA-]YIN.

Position in ring $X = 830.000$ mm $Y = 44049.237$ mm $W = 0^\circ$

Calculated from BRTL $X = 829.667$ mm $Y = 44023.029$ mm $W = -0.000330^\circ$

Difference $dX = 0.333$ mm ≈ 0 $dY = 26.208$ mm $dW \approx 0$

The difference dY is just the design offset of the injected beam of 26.000 mm, see figure f295_a in [2].

The discrepancies in dX , dW are negligibly small. The arc length of YIN was used, since YIN is installed parallel to the 1L straight and the injected beam comes from the side.

The yoke width of magnets are relevant for the lateral minum distances:

Quads QS/QL full yoke width = 280 mm + 90 mm on one side for connectors
width including adjustment support = 380 mm
iron length 200/380 mm, total length $\sim 280/460$ mm

Dipoles BG full yoke width = 450 mm + 210 mm on one side for connectors
yoke length 1085 mm, total length 1282 mm [11]

Injection kickers KIN full width = 220 mm
width including linear drive for adjustment = 420 mm

Underpass minimum width = 800 mm (for trolley)

Lattice files

Storage ring `sls_f6cwo_bxs_xbeam.opa`

Transferline `br1opt2cc.opa` (septum YEX length had to be corrected from 1020 to 1040 mm!)

Booster `booster.opa`, derived from Tracy file `booster.lat`, which once was generated from the database using the Lattice Builder application; geometry agrees to the micron with `b39_th.opa` (BD angle had to be corrected from 6.440° to 6.441° , is wrong in database and Tracy file!)

Injection elements [19]

Elements are tunable, we here anticipate the nominal data for the reference injected orbit ending at $x = -7.0$ mm, $x' = 0$ mrad at the exit of the thin septum.

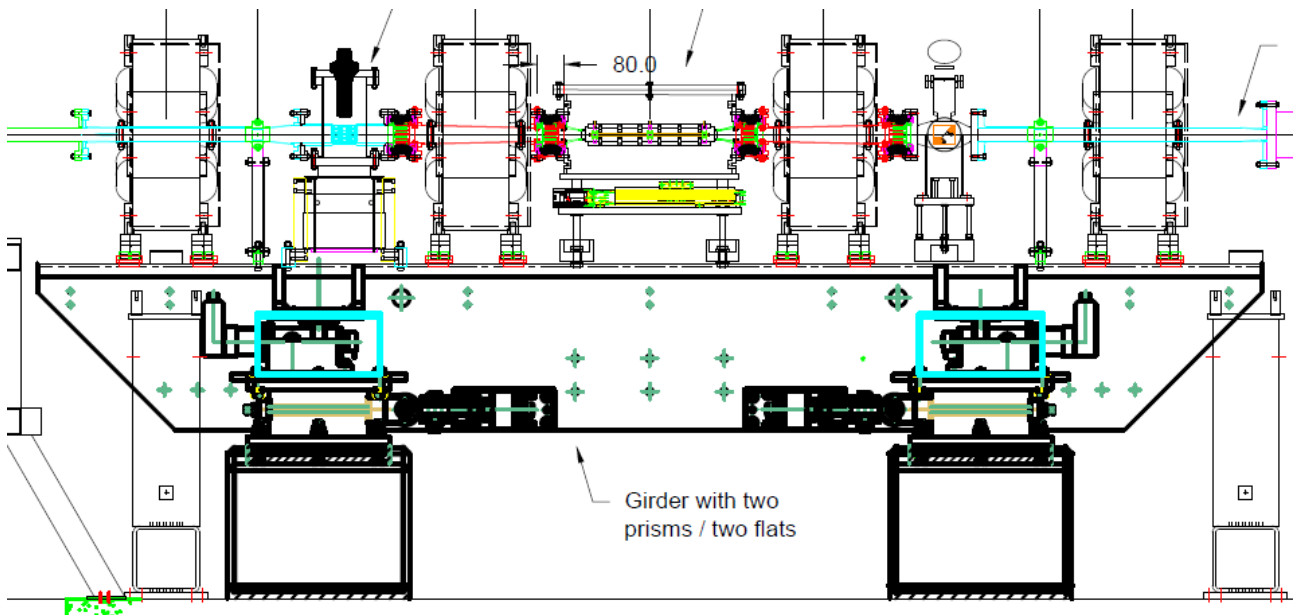


Figure 3. Central part of injection area with thin septum Y3 centered between two pairs of large aperture quadrupoles of type QA, to be re-used from SLS, mounted on a SLS-girder. Two large aperture BPM/Corrector stations are located near the outer quads. Courtesy C.H. Gough.

Thin septum Y3

The thin septum in Fig.3 is an in-vacuum eddy current septum. The tapered beampipes extend through the adjacent quadrupoles and continue to bellows for up to ± 5 mm lateral movement.

- Maximum deflection 15 mrad, nominal deflection 13.4400 mrad ($= 0.770^\circ 055'$)
- Magnetic length 300 mm
- Septum thickness 1 mm
- Inner edge nominal position at $x = -5.0$ mm

Thick septum Y12

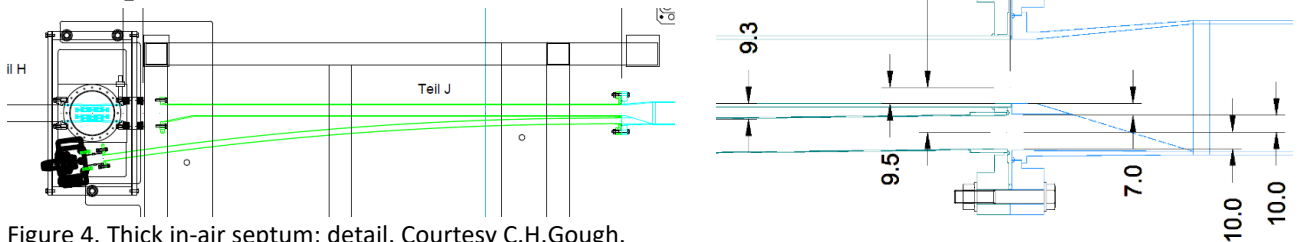


Figure 4. Thick in-air septum; detail. Courtesy C.H.Gough.

The thick septum of Fig. 4 is an in-air septum. Parameters refer to the injected (curved) beam:

- Total length 1900 mm, with 1500 mm active (magnetic) length and 200 mm on both ends.
- On the upstream side another 162 mm are required for electrical insulator and valve.
- Length of straight path for stored beam orbit is 1690 mm.
- Nominal deflection angle $6.790^\circ 418'$ ($= 118.515$ mrad)
- Nominal beam position and angle at exit: $x = -26.5$ mm, $x' = 18.3740$ mrad $= 1.052^\circ 753'$
- Septum thickness is 7.0 mm at entry, inner edge position at $x = -9.5$ mm.
- Injection channel aperture at entry is ± 10 mm $\times$ ± 3 mm.

Injection into SLS 2.0 storage ring

Thick septum exit in 1L straight (i.e. for stored beam) is at $X = 480.000$, $Y = 44116.746$ mm. [5]

Fig. 5 below shows the 3-sigma booster beam without emittance exchange (i.e. $\varepsilon_x = 12.5$ nm at 2.7 GeV) at an offset of $x = -7.0$ mm, $x' = 0$, with $\beta_x = 8$ m, since a smaller beta than that of the stored beam provides best injection efficiency [4] (the optimum value depends on the injection scheme, if it is off-axis, aperture sharing or on-axis, but in any case it is smaller than the beta function of the periodic solution):

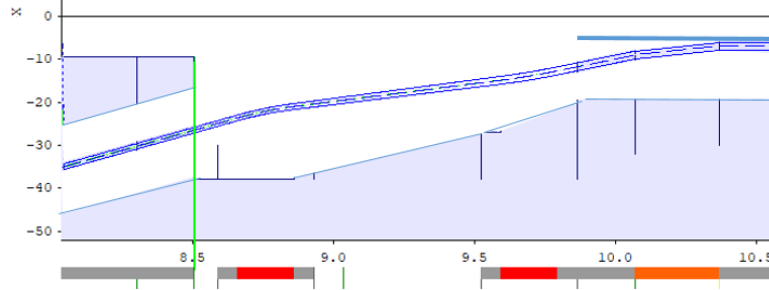


Figure 5. Sketch of incoming beam from BTRL. The thin septum is indicated by the orange bar, the exit from the thick septum by the green line. Re-used SLS quads of type QA are shown as red bars. Apertures are only sketched by hand. Bending of the injected beam and curvature of injection channel inside the thick septum are not shown.

The thin septum has a nominal deflection angle of 13.4400 mrad. Tracking backwards, the focusing from the quadrupoles has to be taken into account, and gives the coordinates at the exit of the thick septum (green line in Fig.5) as new BRTL end point: $X = 480$ mm $Y = 44116.745 - 26.500$ mm $W = 1.052'753^\circ$

The orbit offset of 26.5 mm at Y12 exit leaves ± 10 mm clearance to the incoming beam for the nominal case where the beam has an offset of $x = -7.0$ mm at the thin septum exit as shown in Fig.5. For positions between $x = -4.7 \dots -9.3$ mm, the position at thick septum exit varies between $-25 \dots -28$ mm (i.e. within ± 1.5 mm of the available ± 10 mm), while the angle varies very little, between $18.52 \dots 18.23$ mrad (which gives only ± 0.3 mm variation at the entry the thick septum). Of course, further optimization can be done by adjusting thick and thin septa deflection angles.

Geometry

The endpoint of the existing BRTL (septum exit using **active** length, c.f. page 4) is at

$$X = 830.000 \text{ mm} \quad Y = 44049.237 - 26.000 \text{ mm} = 44023.237 \text{ mm} \quad W = 0^\circ$$

The endpoint of the new BRTL, as mentioned above, is at

$$X = 480.000 \text{ mm} \quad Y = 44116.746 - 26.500 \text{ mm} = 44090.246 \text{ mm} \quad W = 1.052'753^\circ$$

So the changes (new - old) are

$$dX = -350 \text{ mm} \quad dY = 67.009 \text{ mm} \quad dW = 1.052'753^\circ$$

Note that centering new and old storage rings in the WSLA hall results in a radial shift new vs. old of +67.509 mm for the long straight midpoints. i.e. in Y direction for straight 1L.

BRTL upgrade (btr068b)

In the existing BRTL it is not possible to suppress dispersion, so quadrupole scans for measurement of beam parameters in the horizontal dimension have to employ a 6-dimensional fit procedure ($\beta_x, \alpha_x, \varepsilon_x, D_x, D_x', \sigma_p$) which tends to an ill-conditioned linear system and thus is much less robust to measurement errors than a 3-dimensional fit ($\beta_x, \alpha_x, \varepsilon_x$) in an achromatic region [6]. The latter is routinely applied in the linac to booster transfer line (LBTL), which has an independent energy spread (σ_p) measurement in the BY side-branch.

A mere adaption of the existing BRTL would perpetuate the shortcomings. However, a good knowledge and control of the injected beam parameters will be essential for successful commissioning of the SLS 2.0 storage ring, in particular since advanced beam manipulations like emittance exchange in the booster are foreseen [7].

Therefore, an upgrade of the BRTL will be appropriate in the scope of the SLS 2.0 project.

Quadrupoles

The new beam line will need more (and preferably) stronger quads in order to provide an intermediate achromatic section. The existing quads of type QS/QL are rather limited in strength. Calibrations:

```
type ql leng 0.40 bmax 2 rad 18.0 {b 2 bres 0.00054 tlin 0.1144}
type qs leng 0.22 bmax 2 rad 18.0 {b 2 bres 0.00058 tlin 0.1192}
```

$$B' = (B_{res} + T_{lin} \times I) \quad k = B'/(B\rho)$$

With 120 A power supply the maximum gradient of QL/QS is 13.7 / 14.3 T/m and the maximum strength at 2.7 GeV is $k = 1.52 / 1.59 \text{ m}^{-2}$.

There is no sufficient number of spares available; these quads were made in 1999. However 10 quads of type QFA are left over from SITF, and they have suitable parameters [13]:

Gradient 25 T/m, bore diameter 45 mm $\rightarrow$ 5036 Amp-turns per coil (from Maxwell) but 6750 actually because they are rather short. Coils have 5 layers of 9 turns, $5 \times 5 \text{ mm}$ $\varnothing 3 \text{ mm}$ hollow Cu conductor.

Iron length 150 mm (assumed as magnetic length here), total length 269 mm, yoke width 350 mm, total width 403 mm including connectors, see Fig.4. The maximum gradient is reached at 150 A and 16.8 V.

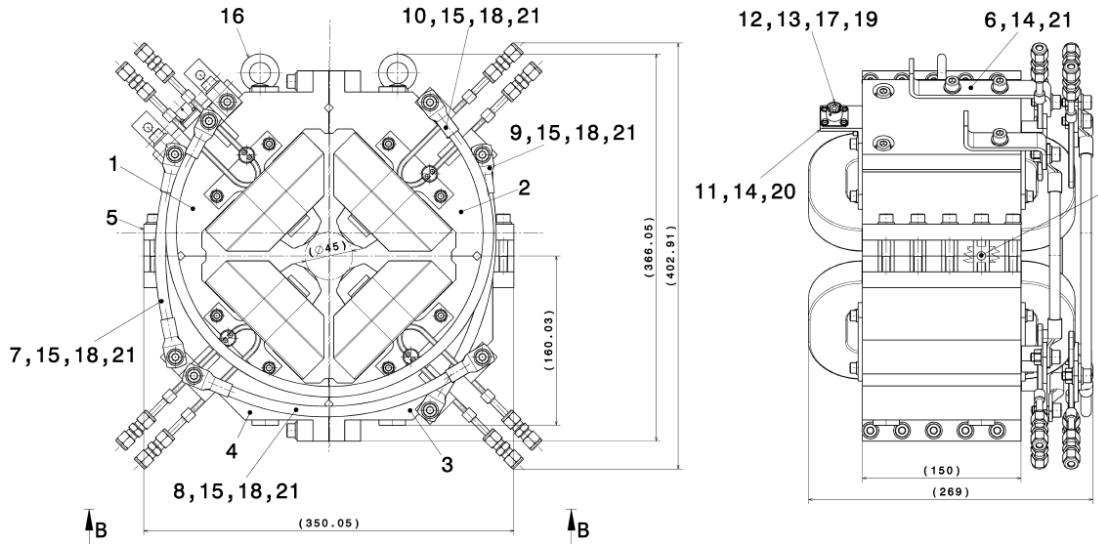


Fig. 6 QFA type quadrupole [14]. Courtesy A. Gabard.

Today booster quads (18) and BRTL quads (7) as well as the storage ring quads (177) are operated with unipolar 120 A PS. Booster and BRTL PS will be replaced later, after SLS 2.0 installation, whereas the storage ring PS will be left over and could be used as spares in case of failures.

The electromagnetic undulator in straight 9L of the SLS will not be used at SLS 2.0 anymore. It is powered by six 150 A 4-quadrant (i.e. bipolar) power supplies with 65 V maximum voltage [15], which would become available then [16]. Two QFA connected in series require a voltage of 33.6 V and provide a max. integrated gradient of 7.5 T ($= 2 \times 150 \text{ mm} \times 25 \text{ T/m}$), which is much larger than the integrated gradient of QL, which is

5.4 T ($= 0.4 \times 13.7$ T/m). Pair gross length is 540 mm and thus slightly larger than QL (~ 460 mm). The max. strength at 2.7 GeV is about $k = 2.77 \text{ m}^{-2}$.

Layout and Concept

Fig. 7 shows the layout of the BRTL upgrade:

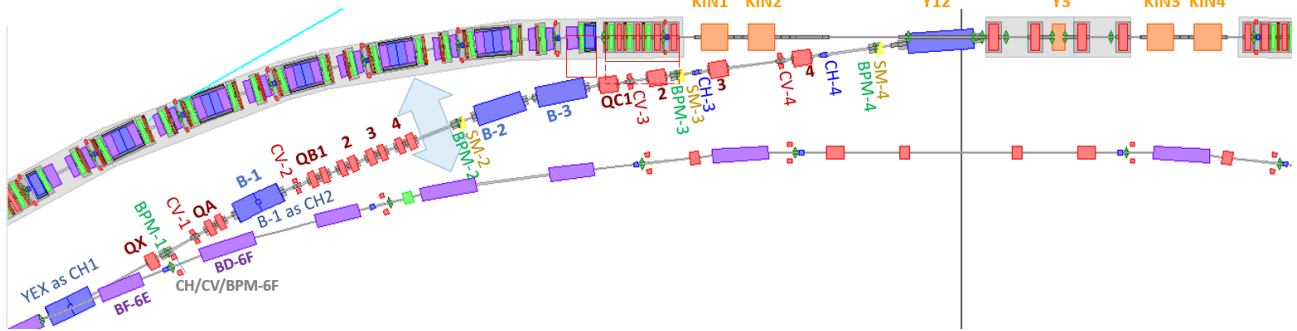


Figure 7. Schematic layout of the upgrade BRTL version btr068b.

The red frames in Fig. 7 indicate space required for the “drawer” to move in/out the end bend (910 mm from orbit) [8], and the width of the QP/QPH quads to ring inside (568 mm) [9]. The dotted red frame indicates another 500 mm for cable and water pipe connectors: these may be flexible to bent them away from the transfer line, or they could be crumped to use less space, so solutions can be found *without* considering the inconvenient option to connect the quads from the ring outside [12].

The present BRTL contains 6 QL-type and 1 QS-type. The QS type is moved to become QX, 4 QL-types are continued to be used as QC*, and 5 QFA-pairs become QA and QB*.

QX is added to suppress (together with QA) the dispersion after the first bend B-1. Presently screen ABRDI-SM-1 takes this place, however it is never used because it is blinded by synchrotron light from the booster and thus can be abandoned. The available space between ABOMA-BF-6E and the booster BPM/corrector 6F has a length of ~ 480 mm and a space from ~ 240 to ~ 320 mm between orbits, so a QS type easily fits in (even a QL would fit).

QB-3 and QB-4 are added to provide sufficient focusing to do an emittance measurement on screen SM-2 in front of the 2nd dipole, B-2.

The locations of the four QC* quads have been chosen to avoid conflicts with the ARS12 ring quads and the kickers KIN-1, KIN-2 and the pingers (not shown in figure).

B-2 and B-3 basically act like one large magnet, the deflection angles of both are reduced from the present 8.200000° to $6.778^\circ 249'$. This changes the sagitta from 19.7 to 16.2 mm, which may still fit into the existing vacuum chamber. The dipoles are straight rectangular magnets.

For diagnostics, four left over SITF-units will be used, which combine a stripline BPM and an optical screen in a common housing as shown in Fig. 8. The apertures are matched to the QFA quads. In the first unit, no screen will be installed, since it is not useful at this location (blinded by booster synchrotron light). The first used screen however is named SM-2 to avoid confusion, it is together with BPM-2 and will be used for emittance measurement, the next one, SM-3 (with BPM-3) is for energy spread measurements (see below), while the last screen, SM-4 (with BPM-4) is reserve.

Another screen is located in the ring after the thin septum. Due to the large size of the Y3-tank, the screen will be located after the adjacent quad QP8YO, which demagnifies the injected beam position by about 20%. Perhaps in early commissioning it would be switched off.

All positions and distances after B-1 have been changed. This will require a number of new beam pipes and new supports.

An underpass, 0.84 m wide, would be available in the measurement section (blue double arrow in Fig.7).

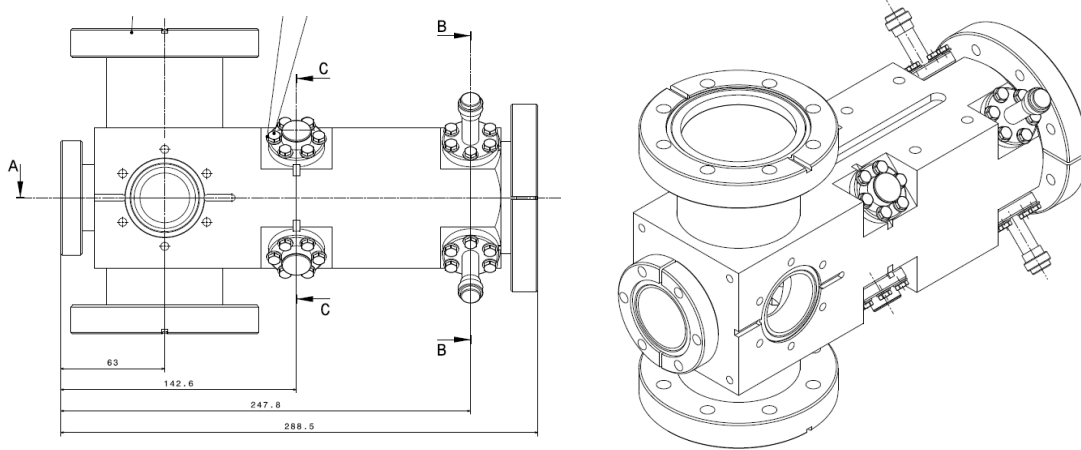


Figure 8: SITF screen monitor and stripline BPM units [17]. Ccourtesy Boris Keil.

Injection optics

Fig. 9 shows two different optics for injection: the first one contains an achromatic straight, and the second is a relaxed optics without achromatic region, where 4 of the quads are switched off and the others are at moderate currents. In both cases matching is performed to $\beta_x = 3.74$ m, $\alpha_x \approx 0$, $\beta_y = 14.5$ m, $\alpha_y = -1.57$, $D = 0.0204$ m, $D' = -0.0229$ at thick septum exit (= right end of Fig. 9), which corresponds to the periodic for the storage ring in nominal optics except a reduced $\beta_x = 8$ m at thin septum exit.

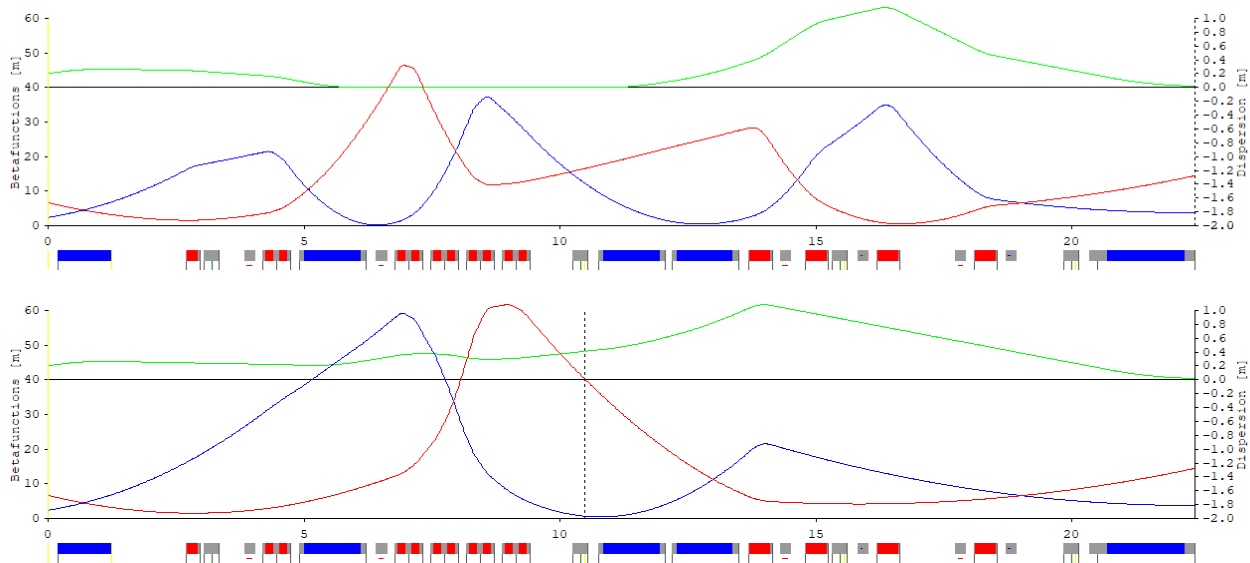


Fig. 9 different optics for injection: top achromatic, bottom relaxed. The dotted line shows the position of the emittance measurement screen SM-2. In relaxed mode, quads QX, QC-2,3,4 are off, but some QBs and QC-1 change polarities.

Measurement optics

Figure 10 shows various optics settings in emittance measurement mode, where a wide range of betatron phases has to be covered, and Table 1 gives quadrupole strengths, beta functions at the measurement screen and the tune advance from the start to this point.

Mode (a) produces a double waist at screen SM-2 and defines a kind of middle point from where the two extreme modes (b) and (c) are realized: mode (b) is maximum horizontal focusing; although the vertical beta function is large, 3-sigma of a beam with 12.5 nm emittance (assuming full emittance exchange) correspond to a ± 7.5 mm high beam spot on the screen. Mode (c) is for maximum vertical focusing. As to be seen from

Table 1 the tune range corresponds to a horizontal/vertical betatron phase range of $>170^\circ$ in both planes and thus would enable a robust tomographic phase space measurement.

Mode (d) is for measurement of energy spread at SM-4. Like in the other measurement modes, the QC*-quads are switched off, so dispersion is determined only by the (well known) dipole angles (provided that dispersion suppression at the first screen has been proven). The betatronic contribution to the beam size at the last screen corresponds to an energy spread of $0.81 \cdot 10^{-4}$, a factor >10 smaller than the energy spread of the extracted beam ($8.5 \cdot 10^{-4}$ at 2.7 GeV) which thus can be measured at good resolution of $< 1\%$.

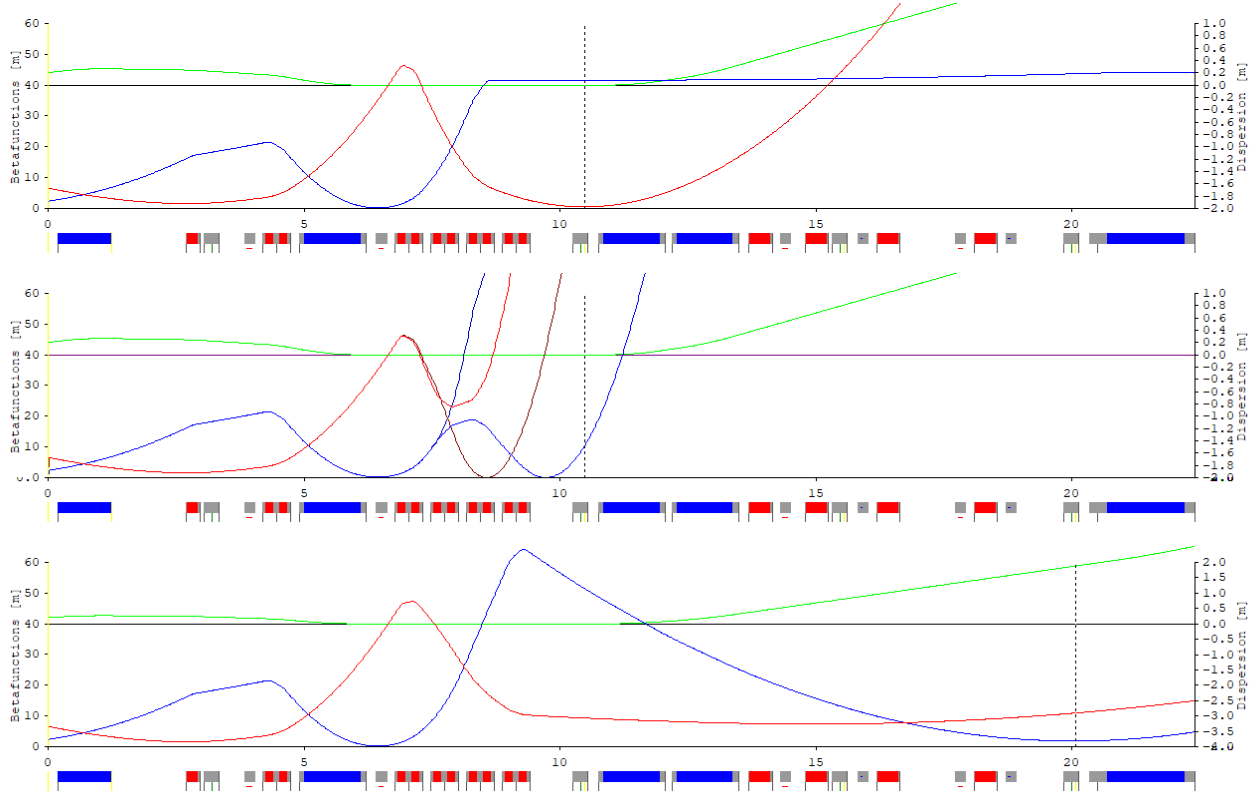


Fig. 10: measurement modes: top (a), middle (b) in brighter and (c) in darker colors, bottom (d); see text for explanations.

Table 1: quad strengths, tune advances (from start to screen SM-2) and beta functions for achromatic and relaxed injection modes, and for various measurement modes

	QX	QA	QB1	QB2	QB3	QB4	QC1	QC2	QC3	QC4	ΔQ_x	ΔQ_y	β_x	β_y
	[m ²]										[m]			
achrom. inj.	+0.73	+2.03	-2.28	0	+2.57	+0.23	-1.33	+0.82	+1.17	-1.13	0.565	0.344	12.3	16.5
relaxed inj.	0	+0.12	+1.16	+1.03	-1.59	-0.57	+1.06	0	0	0	0.222	0.378	0.66	40
(a)	+0.73	+2.03	-2.49	0	+1.92	0	0	0	0	0	0.558	0.530	42	0.55
(b)	+0.73	+2.03	-2.70	+2.70	+2.70	+2.0	0	0	0	0	1.035	0.322	10.3	500
(c)	+0.73	+2.03	-2.49	-2.20	+2.66	0	0	0	0	0	0.554	0.802	71	114
(d)	+0.73	+2.03	-1.71	-0.45	+0.54	+1.44	0	0	0	0	at screen SM-4		β_x	D_x
													1.84	1.88

Beam steering

The existing BRTL has three vertical correctors CV-1,2,3 and only one horizontal corrector, CH, since the three bending magnets can be used as horizontal correctors too. However, this is inconvenient due to hysteresis. In order to construct superknobs for position and angle at the septum exit, which will be needed in commissioning, two pairs of discrete correctors will be employed: CH-3,4 and CV-3,4, see Fig. 11, bottom. The same layout would be desirable for centering the beam in the emittance measurement section, however space is insufficient, so like in the existing BRTL, current increments of the extraction septum YEX and B-1 have to be used as horizontal correctors “CH-1,2”, but a pair of vertical correctors CV-1,2 is inserted, see Fig. 11.

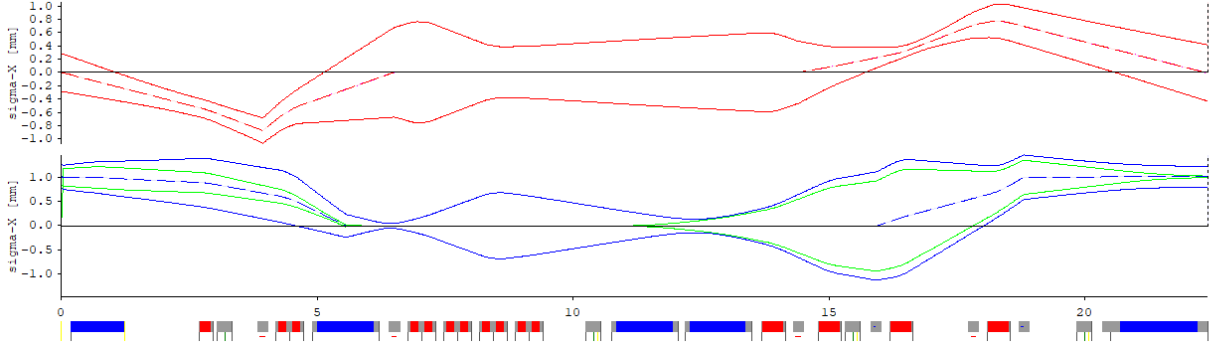


Figure 11: Beam steering.

Just as an exercise, the plot shows how an incoming beam with offset and angle is centered in the measurement section using extraction septum YEX and dipole B-1 as horizontal correctors, and discrete vertical correctors CV-1, CV-2, and how the same offset and angle is set for injection steering at the exit from the thick septum using CH-3,4 and CV-3,4. Envelopes correspond to 1-sigma of booster beam assuming 12.5 nm emittance in both planes and 0.085% energy spread. Incoming resp. outgoing beam: $x = 1.0$ mm, $x' = 0$, $y = 0$, $y' = -0.2$ mrad.

Diagnostics [18]

As demonstrated in Fig. 10 and Table 10, the betatron phase variation of almost 180° in both planes will enable a tomographic beam parameter measurement in the achromatic section. The most extreme possible focusing at screen SM-2 may result in an rms beam size of about 10 μm , assuming that the horizontal emittance is reduced to 2 nm by emittance exchange, so a screen resolution of better than < 20 μm , as available from SwissFEL screens, may be acceptable, considering that the most extreme case may not be fully covered.

An energy spread measurement on screen SM-3 is shown in Fig. 12 (in Fig. 10.d it was shown for SM-4): the betatronic contribution is suppressed, and the beam size is about 650 μm rms, so with 20 μm screen resolution it would be measured at a precision of 3%. A sufficient field of view for all the BRTL screens is 20 mm in diameter, of course larger is always better.

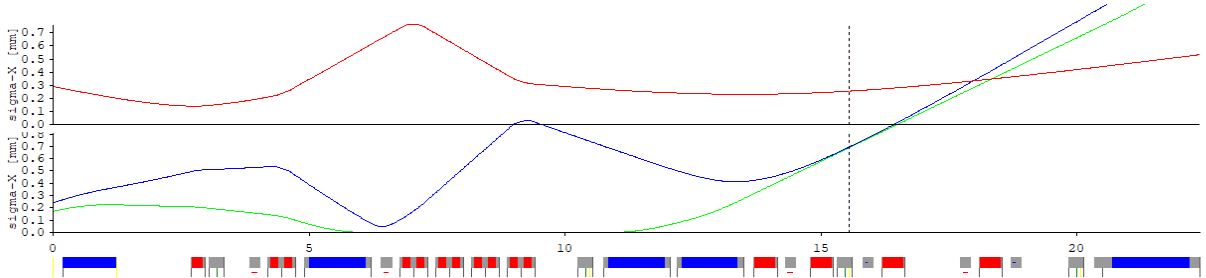


Figure 10: energy spread measurement at SM-3 (assuming 12.5 nm emittance and 0.085% energy spread).

Another screen monitor would be located in the storage ring, after the exit of the thin septum, see Fig.7. This screen would be motorized and frameless, such that it can either show the beam at injection or the recirculated beam after one turn.

The BPMs have to sample well the betatron oscillations along the BTRL. Table 2 lists the normalized betatron phases at the BPMs and the advance from one to the next. Values close to 0.5 (180°) must be avoided. It occurs only once, horizontally in the achromatic optics. Thus, four BPM stations may be sufficient.

Table 2: betatron phases at BPMs and advance between BPMs for achromatic and relaxed optics

	Phase	BPM-1	→	BPM-2	→	BPM-3	→	BPM-4
Achromatic Fig. 9, top	$\phi_x/2\pi$	0.076	0.487	0.563	0.338	1.001	0.065	1.066
	$\phi_y/2\pi$	0.206	0.144	0.350	0.044	0.394	0.401	0.795
Relaxed Fig. 9, bottom	$\phi_x/2\pi$	0.076	0.129	0.205	0.354	0.559	0.085	0.644
	$\phi_y/2\pi$	0.206	0.172	0.378	0.093	0.471	0.140	0.611

Geometry comparison

Table 3 below lists the distances between BRTL and storage ring orbits, compare to Figures 1 and 5. Since distances are given between orbits, the half widths of adjacent elements have to be subtracted. For example in the existing BRTL the space between B3 entry (450 mm wide) and KIN-1 (220 mm wide) is about 244 mm. Numbers in red may require special attention to avoid space conflicts, also see Fig.7, but appear feasible.

Note that the numbers for the existing BRTL refer to the orbit of the existing storage ring, whereas the number for the new BRTL refer to the orbit of the B068 lattice.

Table 3: Distances between transfer line and storage ring orbits [mm].

	Today: br1opt2c		btr068b	
	Entry	Exit	Entry	Exit
B-3			1359	1144
QC-1			1099	1044
QC-2			948.1	893.2
QC-3	1182	1090	764.4	701.6
QC-4	746.0	654.6	503.6	441.7
B-3	579.3	405.5		
SM-3	279.1	279.1		
SM-4/BPM4			264.1	224.7
BPM-3	137.6	137.6		
SM-4P	124.2	124.2		
[thick] septum	61.2	26.3	173.5	26.5

Upgrade summary

Existing BRTL components to be re-used:

- 5 quadrupoles, 4 of QL-type (QC-1,2,3,4), 1 of QS-type (now QB-1 will become QX); all will be moved to new positions.
- 3 bending magnets of BG-type. The first one will stay in place and will not be modified (B-1), the other two will be operated at reduced current / bending angle (B-2 and 3) – to be checked if they need new vacuum chambers.
- 4 corrector magnets of type CH2/CV2 (now as CH and CV-1,2,3), these are double booster correctors connected in pairs, horizontal and vertical are identical, just rotated by 90°.

Additional components for upgrade, which are available in-house

- 10 quadrupoles of QFA type, to be connected in pairs, left-over from SITF.
- 5 (6) power supplies Type “67”, 4-quadrant, 150 A, 65 V, will be left over after SLS shutdown.
- 4 (or more) optical screen / stripline BPM units from SITF.

New components which have to be designed / constructed / purchased:

- Two more correctors of type CH/CV2. To be checked if there are spares, or, since these are double correctors, if two of the existing doubles could be split to get four of half strength.

- Various vacuum chambers, to be specified. Some transition pieces may be needed, since QS/QL quads have 36 mm bore, but QFA have 45 mm. So the measurement section (between B-1 and B-2) could be based on 40 mm pipes, whereas the sections at extraction (before B-1) and injection (after B-3) would be based on the existing 30 mm (?) beam pipes.
- New or modified supports.
- 3 new screens to be inserted into the SITF screen / BPM housings, and cameras.
- 4 new electronics for the stripline BPMs.

Problems and questions

- The underpass is only 84 cm wide. Is the width sufficient for a trolley too? If the monitor station is supported from the side, the width could be increased to about 1.45 m.
- QC-1 changes polarity between achromatic and relaxed mode, but it has only a unipolar power supply. Either get another bipolar one, or drop the relaxed mode, or try to find a better relaxed optics.
- Beam dynamics tasks:
 - Full simulation of tomographic beam parameter measurement. Due to sharp initial focus for dispersion suppression, variation of phase advances while maintaining approximately constant beam size on screen SM-2 (as done in the LBTL) is difficult.
 - Check flexibility for different booster and ring optics mode.
 - Estimate maximum required corrector strengths to know if double correctors could be split into two to get more.

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