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The APS Beam Transfer Line from Linac to Booster Synchrotron

In this note, we describe the recently designed APS beam transport system to the booster synchrotron. Another transfer system which guides the beam from the booster to the storage ring is described in ref. 1, and therefore it will not be treated here.

The system of interest consists of two parts; the transfer line LTOA from the injector linac to the positron accumulator ring (PAR) and the transfer line ATOB from the accumulator ring to booster synchrotron. For the design, we assumed that the *rms* transverse emittance of the linac output beam is about 1.1 mm mrad at 450 MeV and the energy spread is ±1%. The plan view of the designed beam transfer line is shown in Fig. 1. In this figure, B1 bends the beam to PAR by 0.2 radian and B2 is the PAR septum (which bends the beam by 0.2 radian). B3 restores the beam from PAR to the linac to booster line (by 0.2 radian bends). B4 then bends the beam toward the booster (by 0.18 radian bends) and B5 is the booster septum (0.27 radian bends). This figure further shows the magnets inside the booster (QB1, B6, QB2), where one can see the usual F0D0 structure. The total horizontal distance from the booster injection septum to the end of the linac is about 43 meters. The output parameters for the linac reference particle were assumed to be β_x=2 m and β_y=8 m which can be easily obtained by adjusting the quadrupoles in the linac. With these values, the matched system between the linac and PAR is depicted in Fig. 2. This figure indicates that the maximum β_x is approximately 20 meters, which translates

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into $\sigma_x=\sqrt{\beta_x\epsilon_n}$ = 4.7 mm in *rms* horizontal beam size (assuming 1.1 mm mrad *rms* emittance from the linac). Between bending magnet B1 and the end of the linac, we show the debuncher system (see Fig. 1). Each sector magnet in the debuncher system bends the beam by 30 degrees. A four-meter long drift space after a series of magnets (i.e. DB1,DQ1,DB2,DQ2,DB3,DQ3,DB4) is reserved for the rf cavity, which will suppress the energy spread down to ±0.5%. The rf frequency of this cavity is the same as that of the linac (i.e., 2.8 GHz) and will be operated with the fundamental harmonic mode.

The first synchrotron integral through the bending magnets of the debuncher system is found to be:

$$I_1 = \int \frac{\eta_x}{\rho} ds = -0.7696 \quad .$$

For the particle with $\Delta E/E = \pm 1\%$, the above relation yields the time difference of $\mp$25.65 *psec* with respect to the arrival time of the reference particle. The required rf voltage on the debuncher cavity would then be approximately 10 MV.

The placement of the two doublets (i.e., Q1,Q2,Q3,Q4) on each side of the debuncher system allows the flexibility for matching αs and βs, where α and β denote the usual Twiss parameters. These four doublets can be retuned to produce α and β matching in case the debuncher system is turned off. This is shown in Fig. 3, where we remove the debuncher system and subsequently retune Q1, Q2, Q3, Q4 to restore the same βs and αs as those when the debuncher system is in place.

Between B1 and B2 (which is the PAR septum), we place five equally spaced quadrupoles. These quadrupoles are needed in order to suppress η_x and ${\eta'}_x$ to zero at the end of B2 (i.e., inside the PAR) while retaining βs reasonably small. The Twiss parameters after the PAR septum (B2) are fixed by the PAR lattice structure and given by:

$$\beta_x = 2.0938\ m, \quad \beta_y = 8.2204\ m, \quad \alpha_x = -0.0964, \quad \alpha_y = -0.0243$$

and

$$\eta = \eta' = 0 \qquad .$$

The 2.9 meter distance between QE and B2 is necessary because of the geometrical constraints in PAR. The horizontal phase advance between B1 and B2 is $\Delta\phi = 2\pi$ as it has to be.

The ATOB transfer system is depicted in Fig. 4. In this figure, the PAR septum is located on the right (B2). Therefore, the beam progresses from the right hand side in this figure. B5 is the booster septum, and QB1, B6, and QB2 are the magnets inside the booster. See Fig. 1.

The ATOB system between B2 and B3 has the same configuration as the corresponding B1 to B2 in LTOA (see Fig. 2). The maximum β throughout the ATOB system is shown to be about 30 meters. Since the natural emittance of a beam from the PAR is 0.37 mm mrad, the *rms* beam size corresponding to β_x=30 m is σ_x=3.34 mm, which is small. The two doublets (Q5,Q6,Q7,Q8) between B4 and B5 are the usual matching for αs and βs.

Reference

1. 7 GeV Advanced Photon Source Conceptual Design Report, ANL-87-15, April 1987.

Table 1

LTOA Parameters
(450 MeV Bρ=1.502741971 T-meter)

Output Twiss parameters from linac
$\beta_x = 2.0,\ \alpha_x = -2.6471,\ \beta_y = 8.0,\ \alpha_y = 1.2761, \eta_x = \eta'_x = 0.$

Element	Length (m)	Magnet Strength $k_1 = B'/B\rho[m^{-2}], \rho[m]$
DRIFT	1.0	
Q1	0.3	−2.43858136
DRIFT	0.5	
Q2	0.3	2.34234022
DRIFT	1.0	
DB4	0.7853981634	−1.5
DRIFT	0.175	
DQ3	0.3	−2.29368658
DRIFT	0.175	
DB3	0.7853981634	1.5
DRIFT	0.175	
DQ2	0.3	−0.346325068
DRIFT	0.175	
DB2	0.7853981634	1.5
DRIFT	0.175	
DQ1	0.3	−2.29368658
DRIFT	0.175	
DB1	0.7853981634	−1.5
DRIFT	4.0	
Q3	0.3	2.34234022
DRIFT	0.5	
Q4	0.3	−2.43858136
DRIFT	0.5	
B1	0.4	2.0
DRIFT	2.9	
QA	0.3	−0.570326594
DRIFT	0.5	
QB	0.3	5.94266496
DRIFT	0.5	
QC	0.3	−5.11232683
DRIFT	0.5	
QD	0.3	5.98093389
DRIFT	0.5	
QE	0.3	−1.08220044
DRIFT	2.9	
B2	0.4	−2.0

Output Twiss parameters from LTOA
$\beta_x = 2.0938,\ \alpha_x = -0.0964,\ \beta_y = 8.2204,\ \alpha_y = -0.0243, \eta_x = \eta'_x = 0.$

- Sign convention follows the PAR convention.
- Positive k1 means the horizontal focusing.

Table 2

ATOB Parameters
(450 MeV Bρ=1.502741971 T-meter)

Output Twiss parameters from PAR
$\beta_x = 2.0938,\ \alpha_x = 0.0964,\ \beta_y = 8.2204,\ \alpha_y = 0.0243, \eta_x = \eta_x' = 0.$

Element	Length (m)	Magnet Strength $k_1 = B'/B\rho[m^{-2}], \rho[m]$
B2	0.4	2.0
DRIFT	2.9	
QE	0.3	−1.08220044
DRIFT	0.5	
QD	0.3	5.98093389
DRIFT	0.5	
QC	0.3	−5.11232683
DRIFT	0.5	
QB	0.3	5.94266496
DRIFT	0.5	
QA	0.3	−0.570326594
DRIFT	2.9	
B3	0.4	−2.0
DRIFT	0.5	
Q5	0.3	−2.6829611
DRIFT	0.5	
Q6	0.3	2.21367797
DRIFT	2.0	
Q7	0.3	1.51751309
DRIFT	0.5	
Q8	0.3	−2.97160186
DRIFT	0.5	
B4	0.4	2.22222
DRIFT	2.0	
Q9	0.3	2.45101084
DRIFT	0.3	
Q10	0.3	−2.11597359
DRIFT	1.3	
B5	0.8	−2.936859784
	(Inside the Booster)	
DRIFT	1.4	
QB1	0.6	−0.536298
DRIFT	0.44327	
B6	3.1	33.55
DRIFT	0.44327	
QB2	0.6	0.596851
DRIFT	3.98654	

Output Twiss parameters from ATOB after B5
$\beta_x = 4.6951,\ \alpha_x = 1.2742,\ \beta_y = 9.2317,\ \alpha_y = -1.8473, \eta_x = 0.4912, \eta_x' = -0.164$

- Sign convention follows the booster convention.

Figure Captions

Fig. 1 Layout of linac-to-PAR-to-booster transfer line.

Fig. 2 β and dispersion function from linac to PAR transfer line.

Fig. 3 β and dispersion function from linac to PAR transfer line with debuncher system turned-off (Q1,Q2,Q3,Q4 are retuned)
$K_{Q1} = 3.54889478$,
$K_{Q2} = -2.26869615$,
$K_{Q3} = 2.26749141$,
$K_{Q4} = -1.86517773$

Fig. 4 β and dispersion function from PAR to booster transferline.

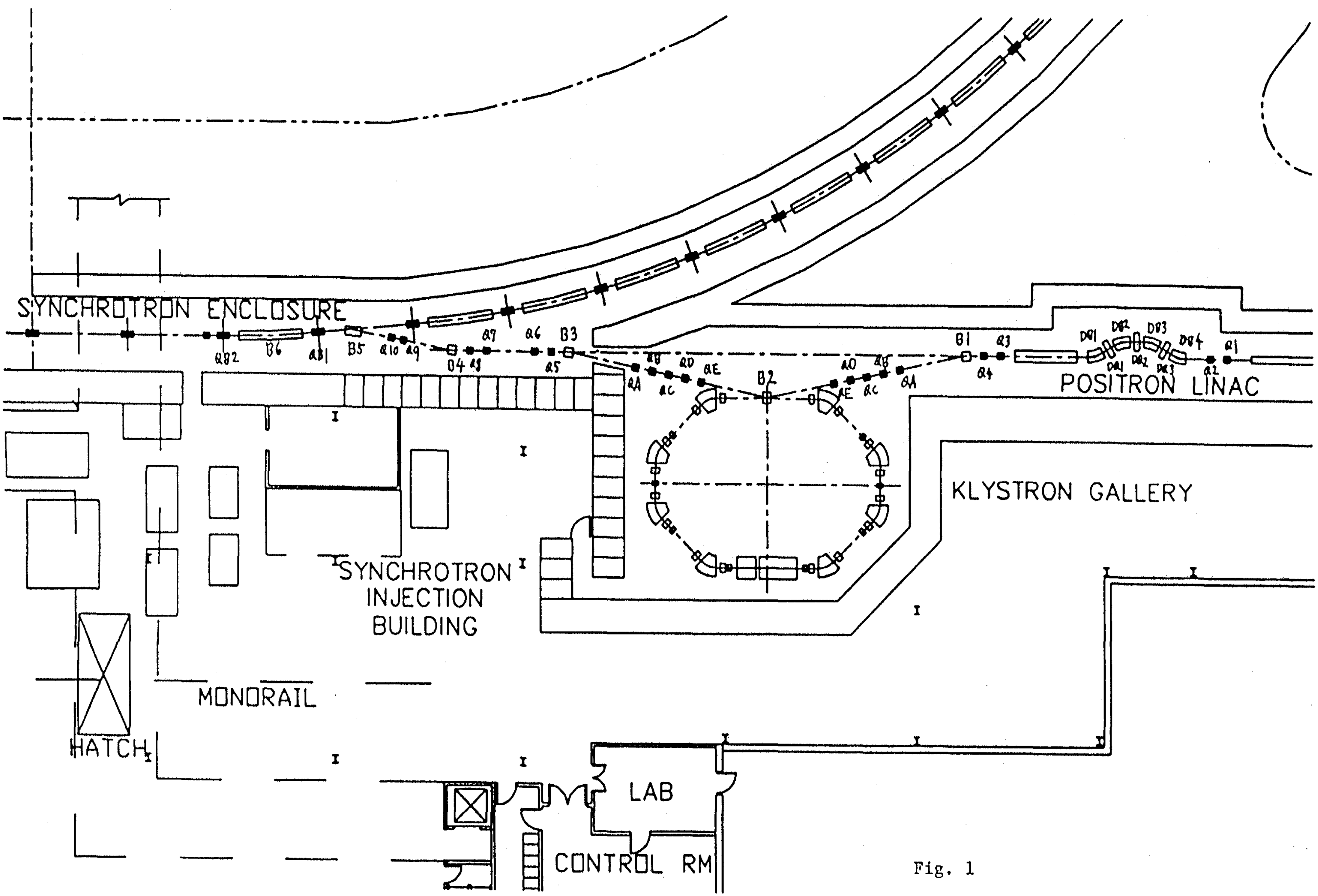
SYNCHROTRON ENCLOSURE
POSITRON LINAC
KLYSTRON GALLERY
SYNCHROTRON INJECTION BUILDING
MONORAIL
HATCH
LAB
CONTROL RM
B1
B2
B3
B4
B5
B6
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q9
Q10
QB1
QB2

Fig. 1

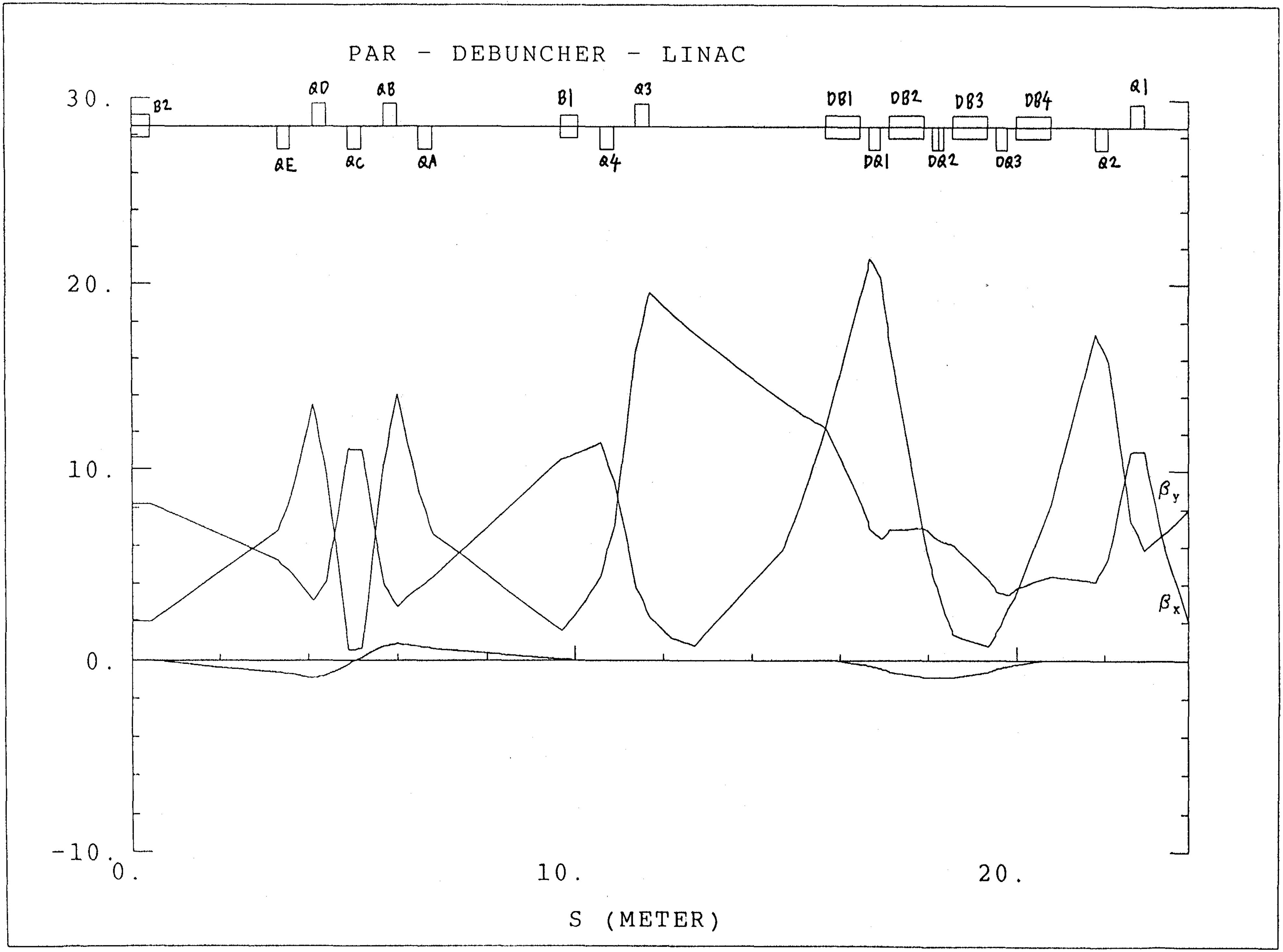
PAR - DEBUNCHER - LINAC
B2
QD
QB
B1
Q3
DB1
DB2
DB3
DB4
Q1
QE
QC
QA
Q4
DQ1
DQ2
DQ3
Q2
30.
20.
10.
0.
-10.
0.
10.
20.
S (METER)
β_y
β_x

Fig. 2

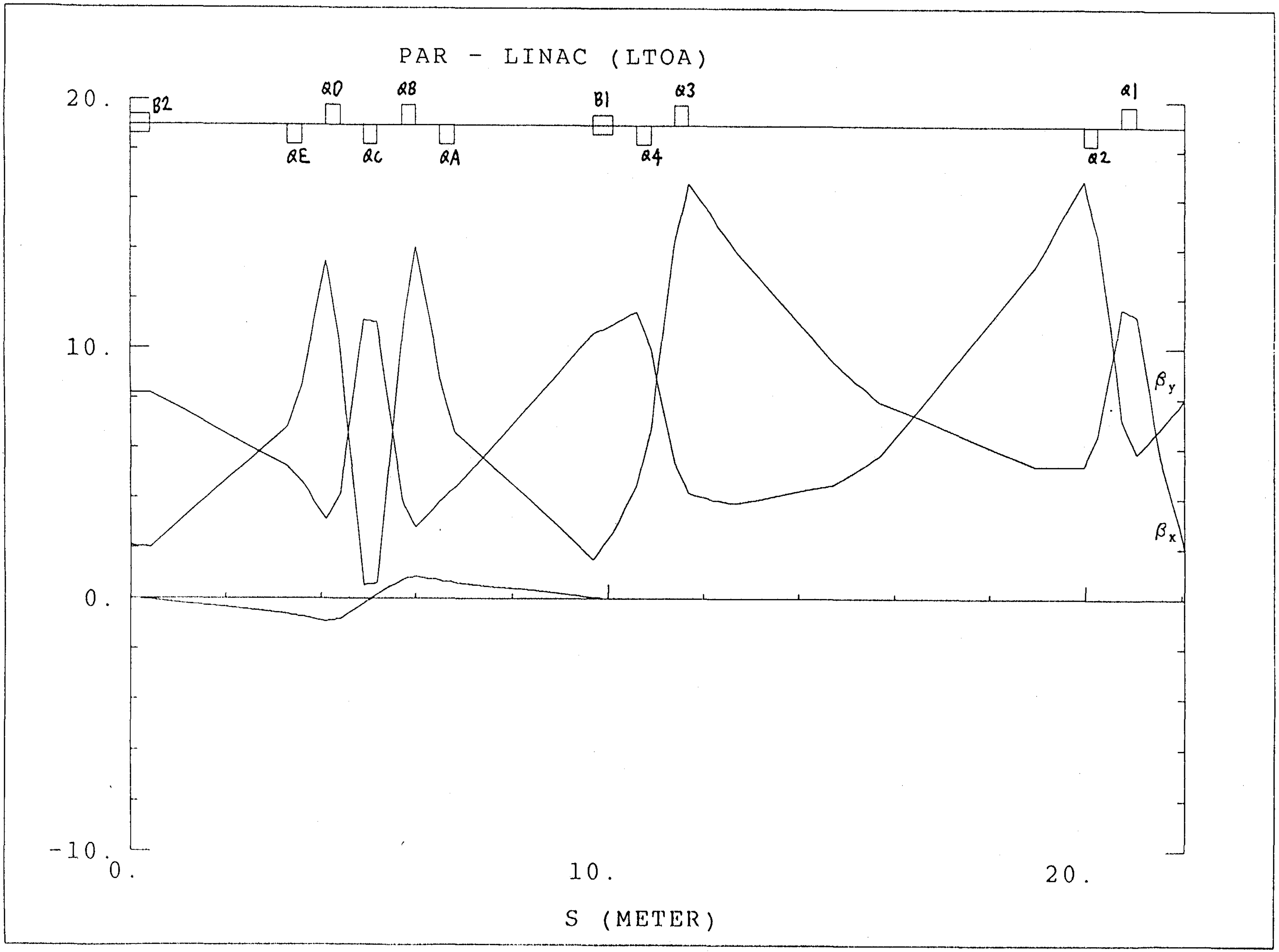
PAR - LINAC (LTOA)
20.
10.
0.
-10.
0.
10.
20.
S (METER)
B2
QD
QB
B1
Q3
Q1
QE
QC
QA
Q4
Q2
β_y
β_x

Fig. 3

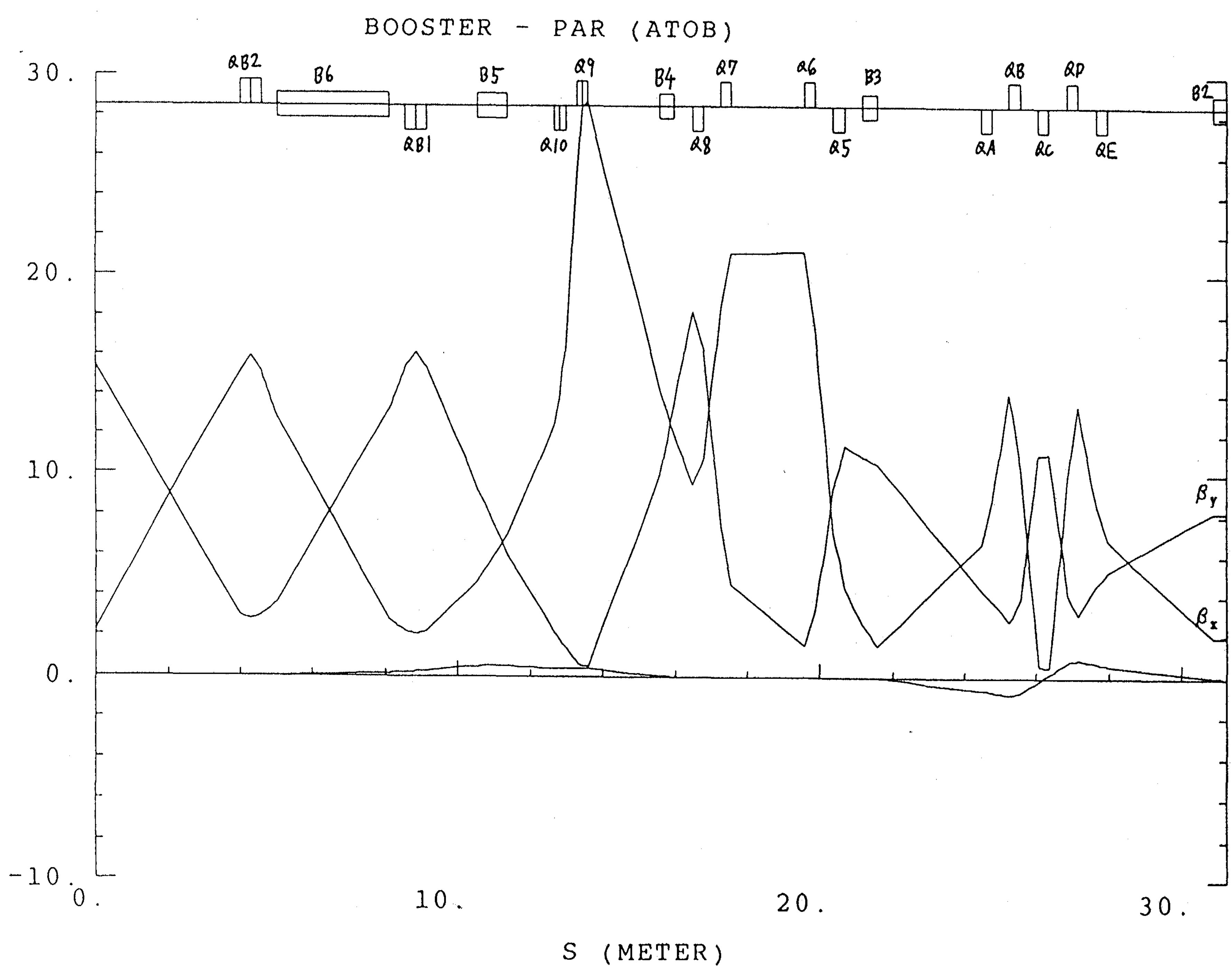
BOOSTER - PAR (ATOB)
QB2
B6
QB1
B5
Q10
Q9
B4
Q8
Q7
Q6
B3
Q5
QA
QB
QC
QD
QE
B2
30.
20.
10.
0.
-10.
0.
10.
20.
30.
β_y
β_x
S (METER)

Fig. 4