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Authors GM Stinson		*Page* 1 *of* 12
Subject Updated calculation for beam line 4A		

1. Introduction

It is proposed that the new proton beam line, BL4N, to ISAC be extracted from extraction port 4—that from which beam lines 4A and 4B were extracted for beam delivery to the proton experimental hall. Because the proton hall was decommissioned as far as experiments are concerned, neither of these lines has been operated for some years.

In order to redetermine the properties of beam extracted from this port, beam development time has been allocated to study extraction along beam line 4A. This report presents a study of this line using the newly generated extraction parameters and the program INTRAN[1)] which incorporates the program TRANSPORT[2)].

Note: A recent E-mail Yi-Nong Rao indicates that he and R. Baartman use the program OPTR[3)], of which the author does not have a copy. In that program quadrupole fringe fields are included, a feature not not available in TRANSPORT. Rao notes "INTRAN calculated beam envelopes differ from the OPTR results, notably in the vertical plane".
That being the case, it is suggested that the files used for the results given in this report be rerun using the program OPTR.

2. Input parameters

For these calculations revised extraction parameters determined by Y-N Rao have been used. Table 1a lists the extraction parameters used at 450.5 MeV and 475 MeV. The 450.5 MeV parameters are those used by M. Schippers in his exploration of BL4N[4)]; the 475 MeV parameters were calculated at the request of the author[5)]. Note that the R_{5i} matrix elements at 450.5 MeV were either not calculated or, more probable, were not listed by Schippers in his note.

The phase-space parameters that were used are listed in table 1b. These appear to be canonical and were used at both energies.

3. Tune calculations

For each of the two energies two calculations of beam envelopes were made. The two calculations differ in the optical conditions imposed upstream of the 4AB2 35.5° dipole. In all cases the beam is doubly achromatic ($R_{16} = R_{26} = 0$) between the exit of dipole 4VB1 and the entrance of dipole 4AB2. All tunes are labeled according to the beam line (4A), the energy and either an 'x' or a 'y'. Thus the four tunes are labeled 4a450x, 4a450y, 4a475x and 4a475y.

In addition to being doubly achromatic at the exit of the vault dipole 4VB1, the 'x-tunes' 4a450x and 4a475x have been designed such that the four quadrupoles 4AQ4/5/6/7 produce simultaneous point-to-point and waist-to-waist imaging in the horizontal plane ($R_{12} = R_{21} = 0$) and simultaneous parallel-to-point and waist-to-waist imaging in the vertical plane ($R_{33} = R_{34} = 0$) at monitor 4AM5. Quadrupoles 4AQ8/9/10 are designed to produce a (dispersed) double waist at monitor 4AM7 upstream of the (old) TISOL target at the position labeled 4AT3. The merit of these tunes is that a beam of known characteristics is produced at the 4AM5 and 4AM7 monitors.

The 'y-tunes' 4a450y and 4a475y have been designed such that quadrupoles 4AQ4/5 produce point-to-point imaging ($R_{12} = 0$)in the horizontal plane and parallel-to-point imaging ($R_{33} = 0$) in the vertical plane at the SFU location. As with the x-tunes, a (dispersed) double waist at monitor 4AM7 upstream of the (old) TISOL target at the position labeled 4AT3. Because (to my knowledge) there is no monitor at the SFU location, these y-tunes are inferior to x-tunes—although there are dispersed double-waists at the 4AM7 monitor in all cases.

Table 2 lists the transport input for the 4a450x tune.

Figure 1 shows the beam envelopes computed by TRANSPORT for the 4a450x and 4a450y tunes. Those for the 4a475x and 4a475y tunes are shown in figure 2.

4. Quadrupole settings for the x- and y-tunes

R. Baartman[6] gives an expression for the B–I relationship of the standard 4-inch quadrupole type 4Q14/8 as

$$B_{calc}(\mathrm{kG}) = a_1 \times x + a_3 \times x^3 + a_5 \times x^5 \pm B_r \ , \tag{1}$$

in which $a_1 = 8.767\,\mathrm{kG}$, $a_3 = 0.666\,\mathrm{kG}$, $a_5 = -2.164\,\mathrm{kG}$, $B_r = 0.050\,\mathrm{kG}$ and the parameter x is defined as

$$x \ = \ \frac{I}{I_{max}} \ ,$$

with I and I_{max} respectively being the quadrupole current and the maximum design current of this quadrupole, which is 500 A.

This relationship was generated using the program PHYSICA[7] and is shown in figure 3.

Again using PHYSICA this relationship was inverted to yield an I–B equation:

$$\frac{I}{I_{max}} = p_0 + p_1 \times y + p_3 \times y^3 + p_5 \times y^5 \tag{2}$$

in which $p_0 = -7.5797\,\mathrm{A}$, $p_1 = 0.90077\,\mathrm{A}$, $p_3 = -0.35102\,\mathrm{A}$, $p_5 = 0.41821\,\mathrm{A}$ and the parameter y is defined by

$$y \ = \ \frac{B}{B_{max}} \ ,$$

with B the field calculated from equation 1 and $B_{max} = 7.289\,\mathrm{kG}$ the maximum value of B_{calc} obtained from equation 1 for $I = I_{max}$. This relationship is shown in figure 4.

Table 3 lists the calculated quadrupole settings for the four tunes together with their fields as calculated from equation 2.

4. Discussion

This report has presented two possible tunes for beam line 4A at energies of 450.5 and 475 MeV. Estimates for the quadrupole settings were also given.

However, no estimate of the dipole currents have been given. These can be obtained from logs available in the control room. Should these energies not been run in the past dipole settings may be inferred by momentum scaling other tunes at other energies.

The caution given in the introduction should be repeated. If it is felt that inclusion of quadrupole fringe fields is necessary, then these tunes should be rerun in a program that incorporates such fields.

References

1. *INTRAN,* A USER FRIENDLY INTERFACE TO TRANSPORT, TRIUMF computing document TRI-CD-96-xx, TRIUMF, October, 1996.
2. K. L. Brown, F. Rothacker, D. C. Carey and Ch. Iselin, *TRANSPORT A COMPUTER PROGRAM FOR DESIGNING CHARGED PARTICLE BEAM TRANSPORT SYSTEMS*, CERN Report 80-04, March 1980.
3. Reference to OPTR
4. M. Schippers, *Proposal for beam line 4N to new ISAC production targets*, TRIUMF, November, 2007.
5. Yi-Nong Rao, *Private communication*, TRIUMF, September, 2008.
6. R. Baartman, *B–I Curve fits for TRIUMF Quads*, TRIUMF note TRI-DN-07-04, TRIUMF, February, 2007.
7. J. L. Chuma, *PHYSICA USER'S GUIDE*, TRIUMF Report TRI-CD-98-01, TRIUMF, February, 1998.

Table 1a. Extraction parameters at 450.5 MeV and 475 MeV

Parameter	450.5 MeV	475 MeV
R_{11} (cm/cm)	−0.07600	−0.08100
R_{12} (cm/mr)	0.32800	0.32800
R_{16} (cm/%δp/p)	1.44300	1.32300
R_{21} (mr/cm)	−3.06700	−3.07400
R_{22} (mr/mr)	0.08400	0.11800
R_{26} (mr/%δp/p)	0.86800	1.02400
R_{33} (cm/cm)	1.93300	2.00100
R_{34} (cm/mr)	0.86800	0.88200
R_{43} (mr/cm)	2.92600	3.18800
R_{44} (mr/mr)	1.84700	1.90400
R_{51} (cm/cm)	—	−0.39900
R_{52} (cm/mr)	—	−0.01800
R_{56} (cm/%δp/p)	—	2.72100

Table 1b. Phase space parameters at 450.5 MeV and 475 MeV

Parameter	Value
±x (cm)	0.127
$\pm\theta$ (mr)	1.604
±y (cm)	0.561
$\pm\phi$ (mr)	0.575
$\pm\delta$p/p (%)	0.100

Table 2 – TRANSPORT input for the 4a450x tune

'2008/09/18 - 4A at 450.509 MEV - TO TISOL - PS & FF OF YI-NONG 2007/08/23'

0					
13.	'COOR'	12.00000;			
16.00	'XO '	16.00000	9.29640;		
16.00	'ZO '	18.00000	−5.31156;		
16.00	'TO '	19.00000	155.18703;		
16.00	'G/2 '	5.00000	3.80000;		
16.00	'K1 '	7.00000	0.50000;		
16.00	'K2 '	8.00000	2.80000;		
1.00	'BEAM'	0.12700	1.60400	0.56100	0.57500
		0.00000	0.10000	1.02389;	
-17.	'2ND ' ;				
12.	' '	0.00000	0.00000	0.00000	0.00000
		0.00000	−0.94900	0.00000	0.00000
		0.00000	0.00000	0.00000	0.00000
		0.00000	0.00000	0.00000;	
1.00	'FOIL'	0.00000	0.27300	0.00000	0.27300
		0.00000	0.00000	0.00000	0.00000;
14.00	'4CM1'	−0.07600	0.32800	0.00000	0.00000
		0.00000	1.44300	1.00000;	
14.00	'4CM2'	−3.06700	0.08400	0.00000	0.00000
		0.00000	0.86800	2.00000;	
14.00	'4CM3'	0.00000	0.00000	1.93300	0.86800
		0.00000	0.00000	3.00000;	
14.00	'4CM4'	0.00000	0.00000	2.92600	1.84700
		0.00000	0.00000	4.00000;	
3.0	' '	0.48500;			
5.00	'4VQ1'	0.41110	4.96248	5.08000;	
3.0	'Q1EX'	0.00001;			
3.0	'4VM1'	0.30004;			
3.0	' '	0.32751;			
5.00	'4VQ2'	0.40700	−4.56382	5.08000;	
3.0	'Q2EX'	0.00001;			
3.0	' '	0.49970;			
3.0	' '	0.50460;			
5.00	'4VQ3'	0.39720	4.60690	5.08000;	
3.0	'Q3EX'	0.00001;			
3.0	' '	0.91090;			
3.0	' '	−0.04528;			
3.0	' '	0.04546;			
19.00	'SOL1'	0.49962	0.00000;		
3.0	' '	0.04547;			
3.0	'4VM2'	0.58473;			
3.0	' '	0.40988;			
3.0	' '	−0.04528;			
3.0	'B1IN'	0.00001;			

Table 2 – TRANSPORT input for the 4a450x tune (continued)

20.0	' '	180.00000;			
2.0	' '	20.00000;			
4.00	'4VB1'	1.56290	15.25574	0.00000;	
2.0	' '	20.00000;			
20.0	' '	−180.00000;			
3.0	'B1EX'	0.00001;			
−10.0	' '	−1.00000	6.00000	0.00000	0.00100;
−10.0	' '	−2.00000	6.00000	0.00000	0.00100;
−10.0	' '	3.00000	3.00000	0.70000	0.10000;
3.0	' '	0.27130;			
3.0	' '	0.20177;			
3.0	' '	0.04546;			
19.00	'SOL2'	0.49962	0.00000;		
3.0	' '	0.04547;			
3.0	'VWAL'	2.29552;			
3.0	'PWAL'	0.95205;			
3.0	'4AM3'	0.39400;			
3.0	'VSM2'	0.53300;			
3.0	'HSM3'	0.31800;			
3.0	' '	0.37480;			
5.00	'4AQ4'	0.40640	3.79528	5.08000;	
3.0	'Q4EX'	0.00001;			
3.0	' '	0.34460;			
5.00	'4AQ5'	0.40640	−5.06663	5.08000;	
3.0	'Q5EX'	0.00001;			
3.0	'POL '	0.77980;			
3.0	'POLA'	0.00001;			
3.0	'SFU '	1.31800;			
−10.	' '	−1.00000	2.00000	0.00000	0.00100;
−10.	' '	−3.00000	3.00000	0.00000	0.00100;
3.0	'4AM4'	1.19800;			
3.0	'ABB2'	0.32500;			
3.0	' '	0.49380;			
5.00	'4AQ6'	0.40640	−5.94079	5.08000;	
3.0	'Q6EX'	0.00001;			
3.0	' '	0.24460;			
5.00	'4AQ7'	0.40640	4.62273	5.08000;	
3.0	'Q7EX'	0.00001;			
3.0	'M4.4'	0.52580;			
3.0	'SM6 '	0.68600;			
3.0	'SM65'	0.31200;			
3.0	'M4.7'	0.38300;			
3.0	'4AM5'	0.32500;			
−10.0	' '	−1.00000	2.00000	0.00000	0.00100;
−10.0	' '	−2.00000	1.00000	0.00000	0.00100;
−10.0	' '	−3.00000	3.00000	0.00000	0.00100;

Table 2 – TRANSPORT input for the 4a450x tune (continued)

−10.0	' '	−4.00000	4.00000	0.00000	0.00100;
3.0	'B2IN'	0.29099;			
3.0	'B2CL'	0.27500;			
3.0	'B2 '	0.27500;			
3.0	'B2EX'	0.00001;			
3.0	'2IN '	0.48172;			
2.0	' '	17.75000;			
4.00	'4AB2'	1.56420	13.52822	0.00000;	
2.0	' '	17.75000;			
3.0	'B2EX'	0.00001;			
−10.	' '	−1.00000	6.00000	0.00000	0.00100;
−10.	' '	−2.00000	6.00000	0.00000	0.00100;
3.0	' '	1.96835;			
5.00	'4AQ8'	0.40640	2.12843	5.08000;	
3.0	' '	0.30480;			
5.00	'4AQ9'	0.40640	−3.76553	5.08000;	
3.0	' '	0.30480;			
5.00	'AQ10'	0.40640	2.32280	5.08000;	
3.0	'4AM6'	0.48260;			
3.0	'VSM4'	0.53340;			
3.0	'HSM5'	0.31430;			
3.0	'FERF'	4.52000;			
3.0	'4AM7'	2.73320;			
−10.0	'XWT3'	2.00000	1.00000	0.00000	0.00010;
−10.0	'YWT3'	4.00000	3.00000	0.00000	0.00010;
−10.0	'XST3'	1.00000	1.00000	0.30000	0.05010;
−10.0	'YST3'	3.00000	3.00000	0.30000	0.05010;
3.0	'4AT3'	1.41650;			
3.0	'4AM8'	1.29855;			
3.0	'WALL'	1.35255;			
3.0	'DUMP'	3.04800;			
SENTINEL					
SENTINEL					

Table 3 – Quadrupole fields and currents

Currents required for the 450.5 MeV tunes

Quadrupole	Tune 4a450x		Tune 4a450y	
	B (kG)	I (A)	B (kG)	I (A)
4VQ1	4.96248	278.039	4.96278	278.057
4VQ2	−4.56382	255.247	−4.55098	254.535
4VQ3	4.60690	257.645	4.60669	257.633
4AQ4	3.79528	213.945	4.16160	233.374
4AQ5	−5.06663	284.261	−5.40387	305.427
4AQ6	−5.94079	343.469	−5.78396	331.691
4AQ7	4.62273	258.530	5.53868	314.410
4AQ8	2.12843	123.799	2.83849	163.107
4AQ9	−3.76553	212.376	−4.32957	242.411
4AQ10	2.32280	134.742	2.16119	125.653

Currents required for the 475 MeV tunes

Quadrupole	Tune 4a475x		Tune 4a475y	
	B (kG)	I (A)	B (kG)	I (A)
4VQ1	5.35459	302.224	5.35459	302.224
4VQ2	−4.77403	267.085	−4.77403	267.085
4VQ3	4.69683	262.696	4.69683	262.696
4AQ4	3.81272	214.865	4.25042	238.139
4AQ5	−4.87981	273.189	−5.40387	305.427
4AQ6	−6.61165	402.156	−5.99086	347.363
4AQ7	4.87089	272.670	5.53868	314.410
4AQ8	2.72387	156.881	3.02251	173.019
4AQ9	−4.27334	239.373	−4.36050	244.089
4AQ10	2.15261	125.168	2.16119	125.653

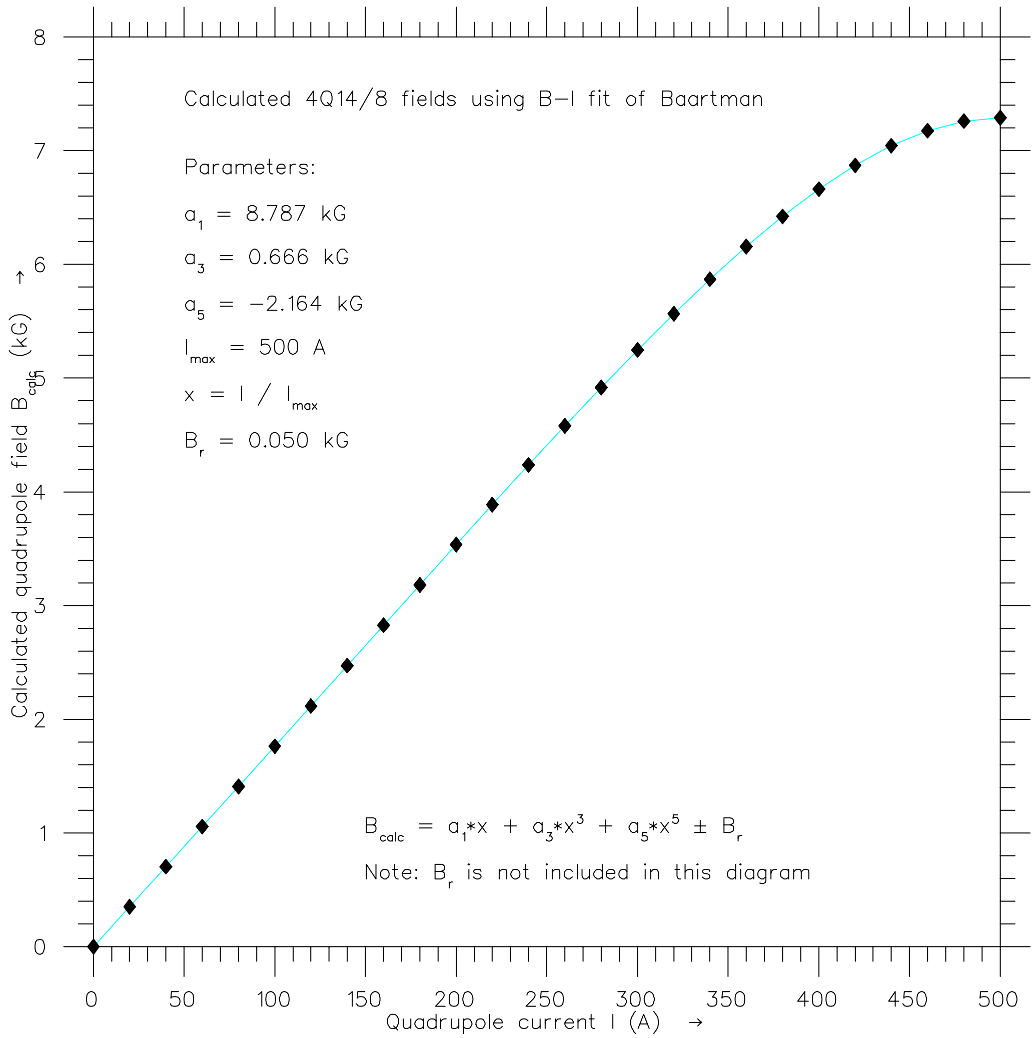

Fig. 1. The B–I fit of Baartman for 4Q14/8 quadrupoles.

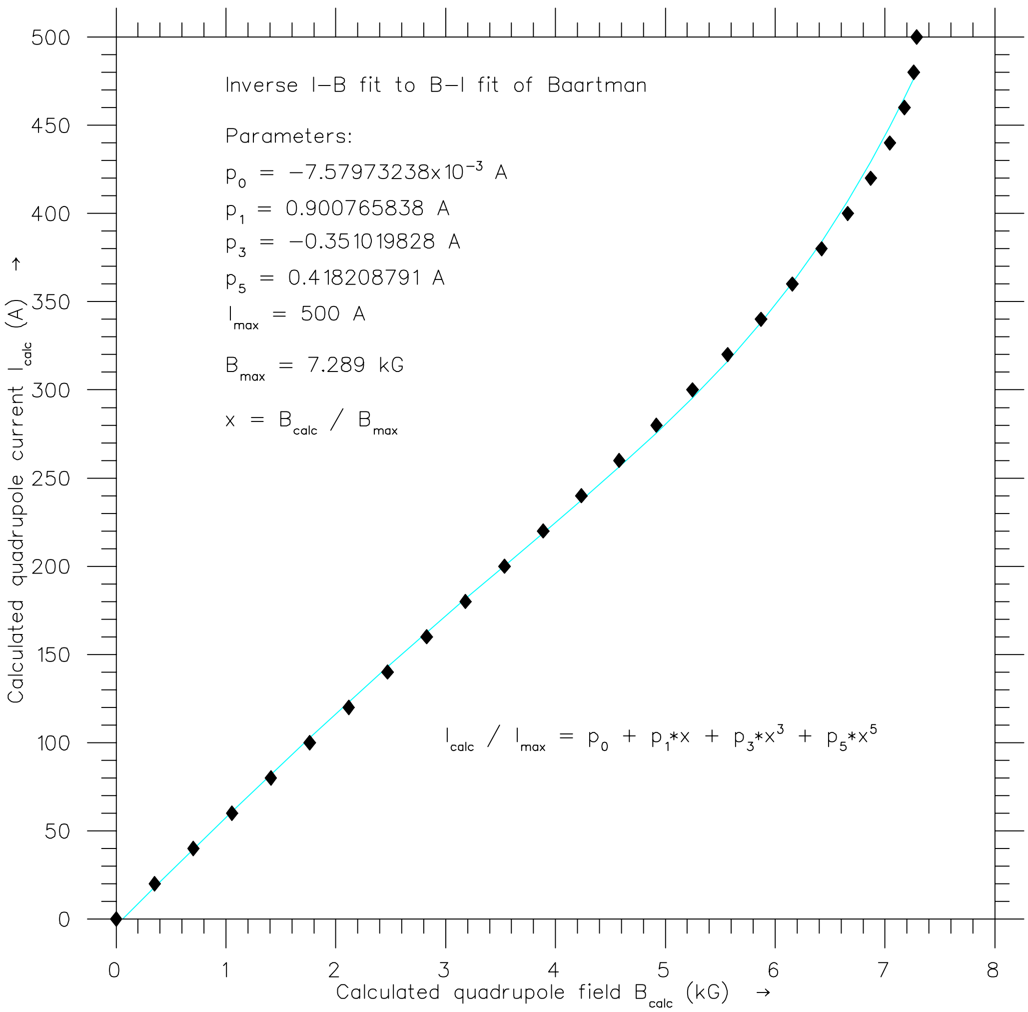

Fig. 2. The inverse I–B curve for the B–I fit of Baartman.

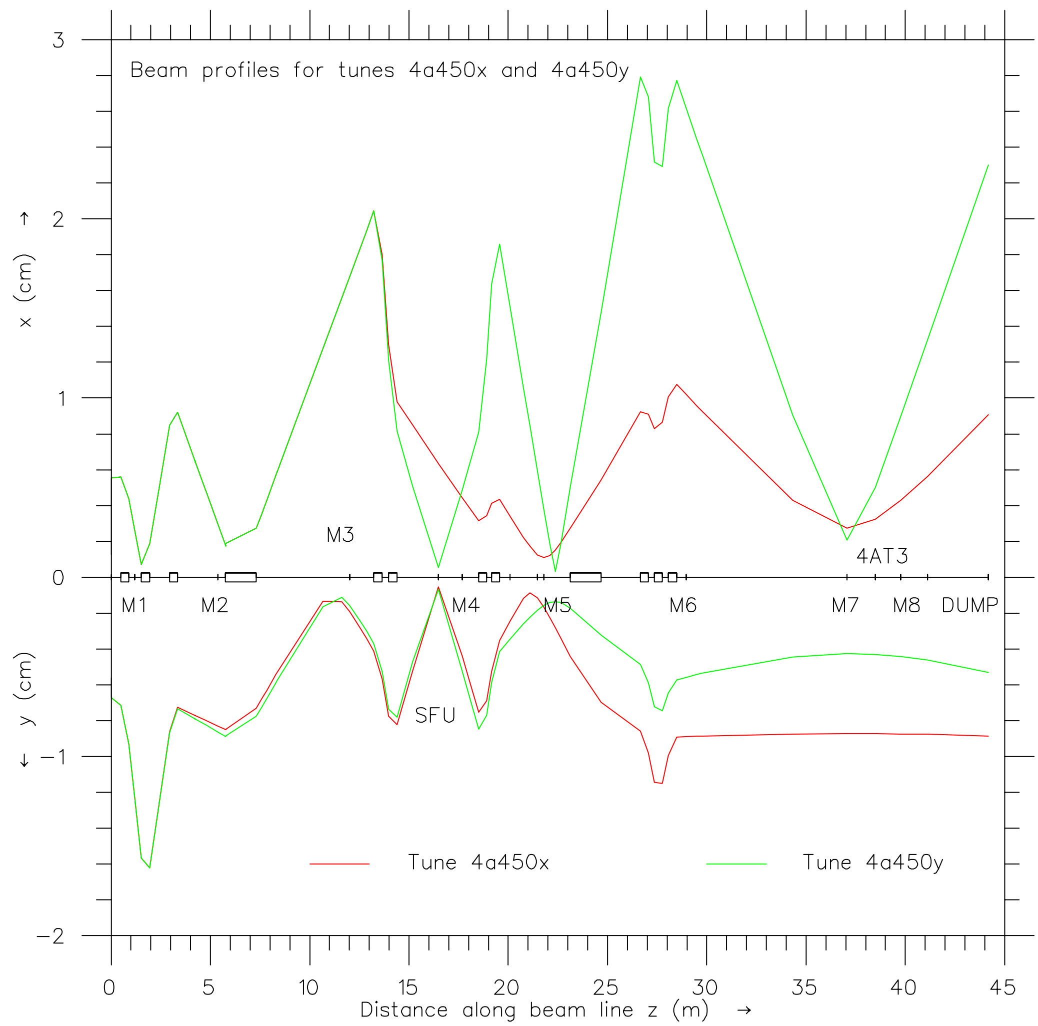

Fig. 3. Beam envelopes computed by TRANSPORT for the 4a450x and 4a450y tunes.

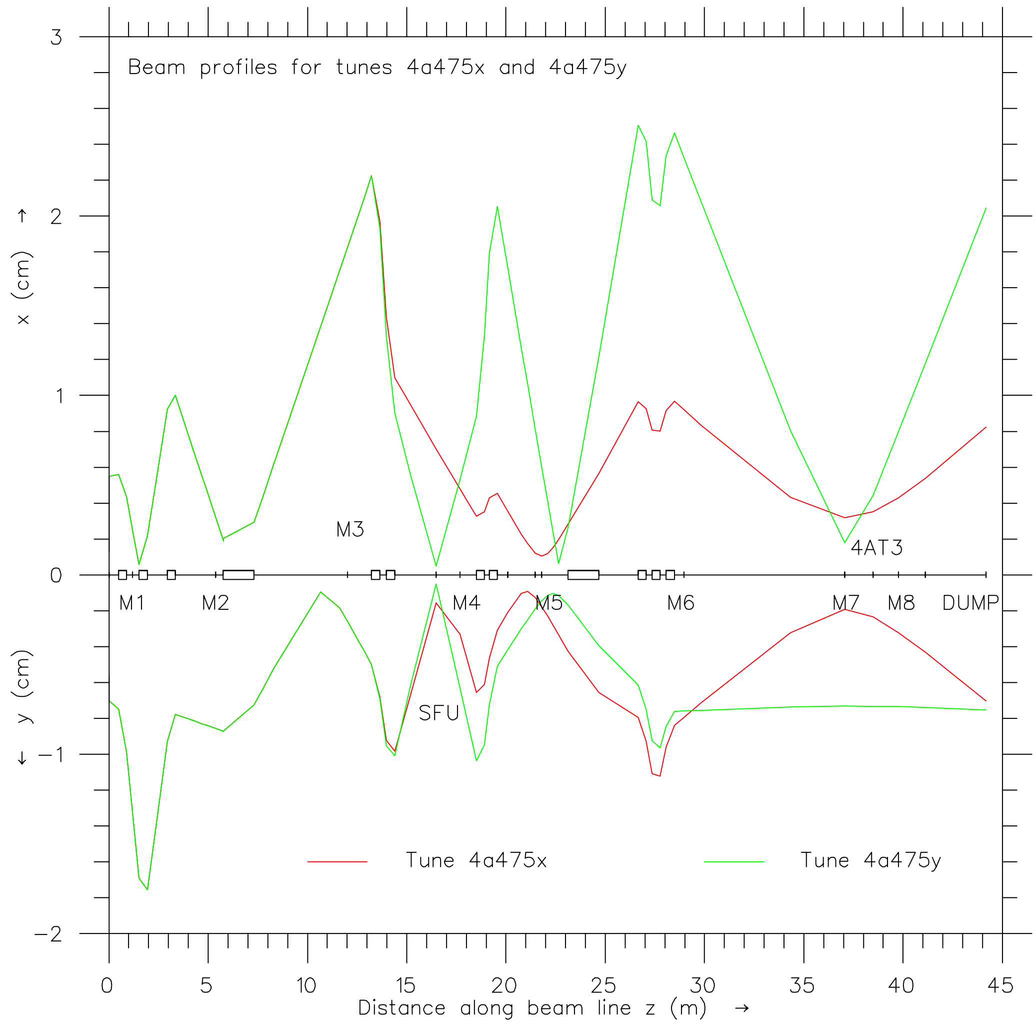

Fig. 4. Beam envelopes computed by TRANSPORT for the 4a475x and 4a475y tunes.