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Alternative Options for the LINAC4 Transfer Line

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Abstract

LINAC4 [1] is a 62mA, 160 MeV H^- linac under study at CERN. LINAC4 should replace LINAC2, a 50 MeV proton linac, as injector to the PS booster. LINAC4 reference layout [2] foresees a transfer line, 193m long [3], which pass through the PS tunnel to join the present LT line at BHZ30. As an alternative layout we looked at the possibility of placing LINAC4 in place of LINAC2 and reusing the existing transfer lines. In addition we studied another line with new optics. The results of these investigations are reported in this paper.

Geneva, Switzerland
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1. Introduction

LT-LTB-BI is being used to transfer the 150 mA beam of 50 MeV protons from LINAC2 to PS booster. This line is made of three straight sections which are connected with two bending magnets, BHZ20, and BHZ30 which bend the beam by -16 degrees (280 mrad) and 22 degrees (384 mrad) respectively. It has the total of 26 quadruples which are of four different types. The third straight section which ends to PS booster comprises a septum and a distributor which are responsible of splitting the incoming bunch amongst the four booster rings.

Since it is possible for LINAC2 to be replaced with the new 160 MeV linac of H^- ions, we studied the possibility of transferring the more energetic beam of LINAC4 through the LT-LTB-BI line. Three are some advantages in using this line, shorter and having less bending dipoles with respect to the line which passes through the PS tunnel, which together result to lower emittance increase. Using the same quadruples and necessity of less voltage in the buncher cavities are some of advantages.

The objections and limitations for the beam transport are: minimum emittance increase, minimum losses, beam pipe to rms beam size ratio of at least 5, energy spread, dispersion, and matching the Twiss parameters to the PS booster. The dispersion at the PS booster must be less than 1.4m. The energy spread of 1MeV in bunches at the SCL output must be lowered to less than 100keV at the PS booster. Finally, as the matched beam parameters at the PS booster at 160MeV are as yet unknown, we made a parallel beam at the point of injection.

We studied two different type of optics, in the first one we kept in place all the quadruples as in the present LT-LTB-BI line and in the second optics we made the line with a new set of quadruples.

For adjusting the optics and linear matching we used the program TRACE3D, and then we evaluate the quality of the beam with PATH MANAGER. To start the simulation of the beam dynamics in PATH MANAGER we exploited two sorts of sources; the beam out of simulated LINAC4, End to End, and a generated beam with the same parameters as output of simulated LINAC4, Generated Beam. The results of TRACE3D are included in the Appendix.

2. Transfer lines optics

In common for both the new optics is upgrade of both the bending magnets to bend the 160MeV beam of H^- ions. For this reason the gradients of the bending magnets must be increased by a factor of 1.86.

a. Keeping the same quadruples: 160MeV Transfer Line (LT-LTB-BI+)

In addition of two bending magnets, the last quadruple of SCL is supplemented to the LT-LTB-BI line. To decrease the emittance growth in the bending magnets, we added a de-buncher cavity just before BHZ20 with the total voltage of 850kV at 352.2 MHz, and another with 360kV at the same frequency before septum and distributor to decrease the energy spread to 100kV to be accepted in PS booster. Finally we made the same optics in Path Manager to see the multi particle effects, and consequently we had to make changes in the optics to lower the emittance growth in the line and also avoid losses. The quadruple changes, their maximum gradient and their values in LT-LTB-BI are listed in table 1. The initial and final beam parameters are listed in table 2.

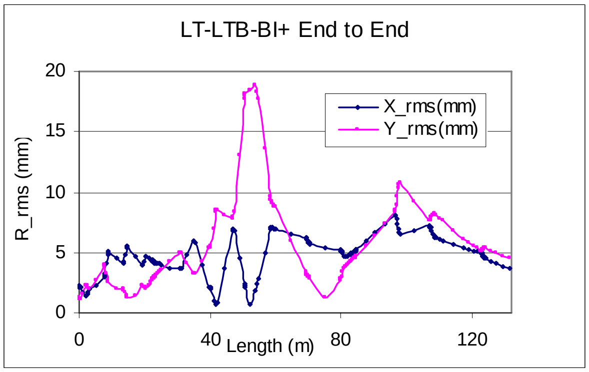
Name	Type	Name in File	LT-LTB 50MeV [T/m]	Max Gradient [T/m]	Value for 160MeV [T/m]
--	--	SCL Q 20	--	--	-13.0
lt.qdn10	VII	Quadruple 01	3.93	4.19	**4.50**
lt.qfn12	VII	Quadruple 02	-3.06	4.19	-3.10
lt.qdn20	VII	Quadruple 03	2.38	4.19	4.0
lt.qfn22	VII	Quadruple 04	-1.95	4.19	-3.50

lt.qdn30	VII	Quadruple 05	0.7	4.19	2.75
lt.qfn32	VII	Quadruple 06	-1.19	4.19	-2.50
lt.qdn40	VII	Quadruple 07	1.573	4.19	2.25
lt.qfn42	VII	Quadruple 08	-1.731	4.19	-1.80
lt.qdn50	VII	Quadruple 09	1	4.19	1.052
lt.qfn55	VII	Quadruple 10	-1	4.19	-1.798
lt.qdn60	VII	Quadruple 11	0.55	4.19	-1.60
lt.qdn65	VII	Quadruple 12	-0.55	4.19	1.60
lt.qfw70		Quadruple 13	0.5	1.6	**-1.65**
lt.qdn75	VII	Quadruple 14	-0.65	4.19	1.193
ltb.qdn10	VII	Quadruple 15	1	4.19	-1.40
ltb.qfn20	VII	Quadruple 16	-0.6	4.19	0.10
ltb.qdw30		Quadruple 17	0.78	1.6	-0.30
ltb.qfw40		Quadruple 18	-0.83	1.6	0.30
ltb.qfw50		Quadruple 19	0.81	1.6	-0.35
ltb.qdw60		Quadruple 20	-0.76	1.6	0.57
BI.Q10		Quadruple 21		1.7	-1.0
BI.Q20		Quadruple 22		1.7	1.08
BI.Q30		Quadruple 23		1.7	-0.445
BI.Q40		Quadruple 24		1.7	0.365
BI.Q50		Quadruple 25		7.5	-0.40
BI.Q60		Quadruple 26		7.5	0.35

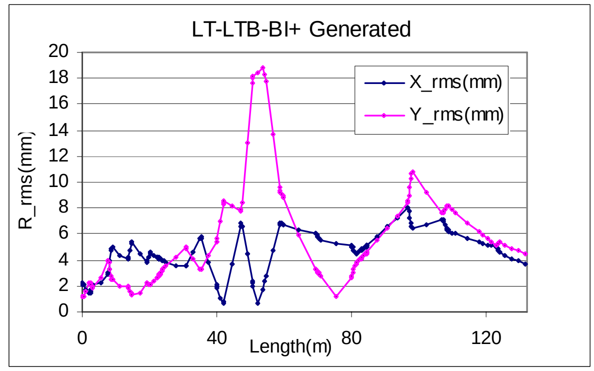
Table 1. Quadruple values.

LT-LTB-BI+	Generated beam	End to End	
		2D Space charge	3D Space charge
ε_x increase	4.9%	6.1%	4.6%
ε_y increase	13.7%	24.2%	25.3%
α_x	0.52	0.51	0.76
β_x (m/rad)	22.8	21.6	27
α_y	0.62	0.51	0.54
β_y (m/rad)	31.7	29.5	32.5
Transmission	100%	100%	98.69%

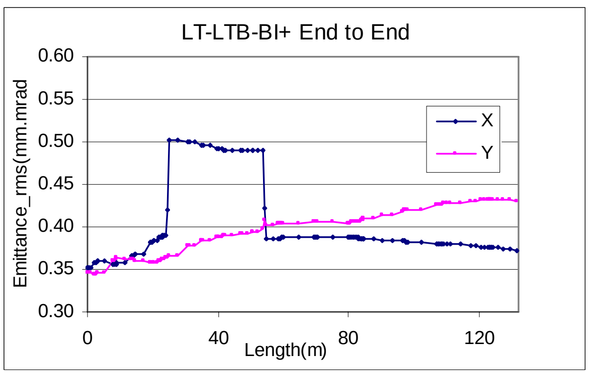
Table 2. Beam parameters and emittance growth in LT-LTB-BI



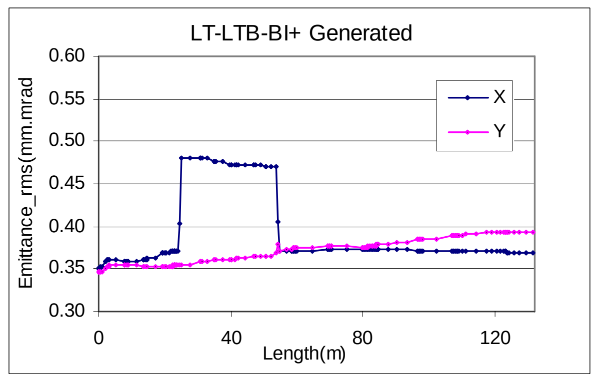
RMS envelope: End to End



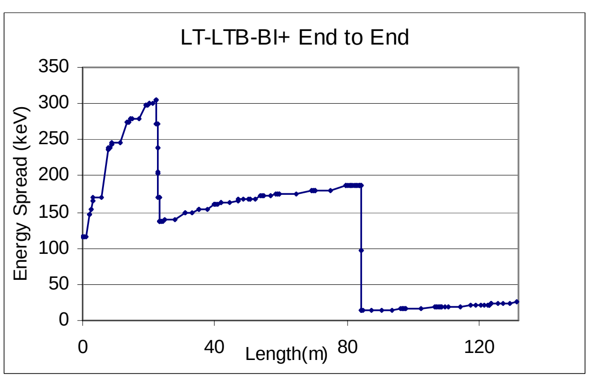
Generated beam



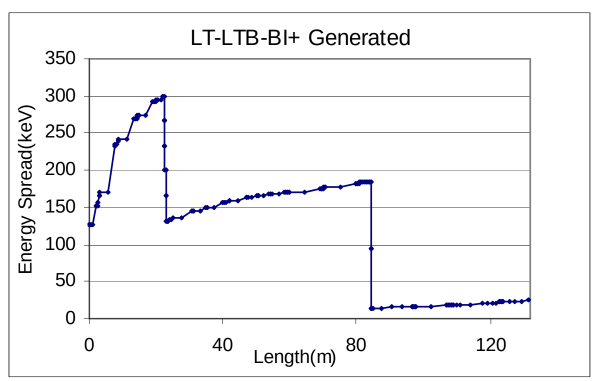
RMS emittance: End to End



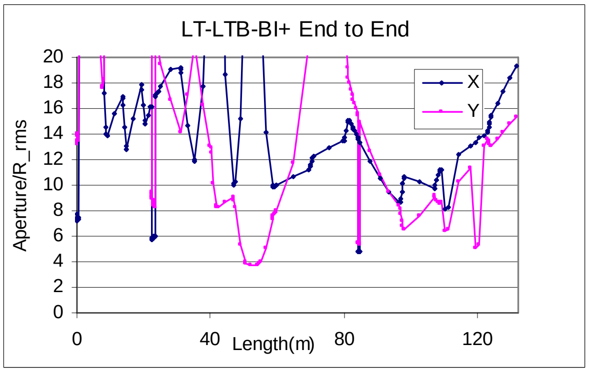
Generated beam

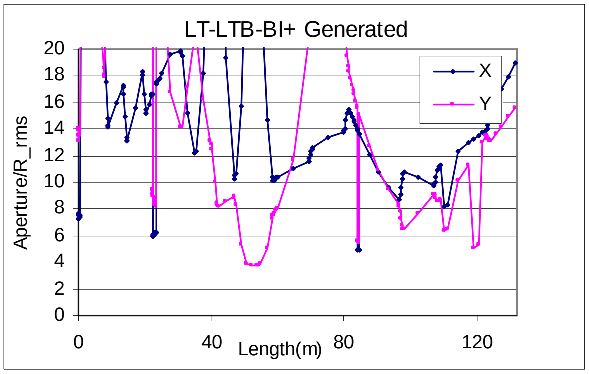


Energy spread: End to End



Generated beam

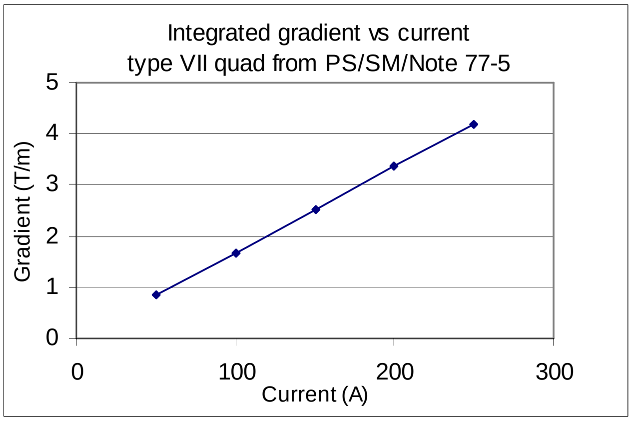




Aperture/RMS : End to End

Generated beam

The diagram of the measured gradients of lt-qdn / lt-qfn quadruples, type VII quadruples, shows that type VII magnets are far from their saturation point and can be used, one needs new measurements, for the new transfer line.



Gradient vs. current in type vii magnets

b. Using New quadruples, "GreenField".

In the second approach we studied the case where LINAC4 is pushed downstream in the LINAC2 tunnel leaving just 6 meters to BHZ20. Besides 18 new quadruples that are listed we used one de-buncher with the total voltage of 855kV rather than two de-bunchers 850kV and 360kV which were used in LT-LTB-BI+. To pass the beam through the same path, we just kept the bending magnets in their places and increased their strengths.

The distributor and Septum which have been kept in the same position were two other devices that imposed other constraints to the line. New magnets' gradients, as well as their length and aperture are listed.

In this option, we made the first straight part of the transfer line shorter by 16 meters. In this case the longitudinal spread after BHZ30 was less than 55 degrees which resulted to a completely flat beam in longitudinal phase space at the end of the transfer line. Beam parameters are also tabled to make the differences completely clear. The values in the aperture column refer to the radius if not mentioned clearly.

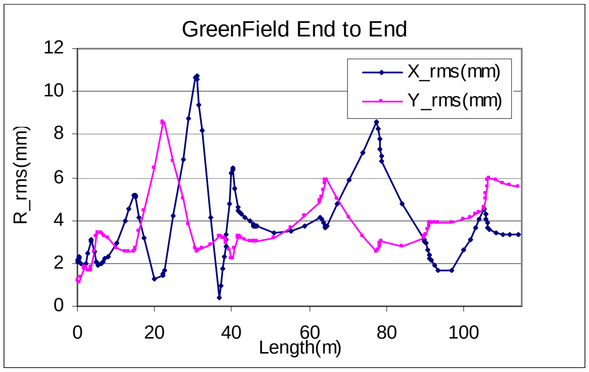
GreenField	Length [m]	Strength	Radius [cm]
Drift 1	0.119		1.6
Quadruple 1	0.3	-3.85 [T/m]	7
Drift 2	1.3175		7
Quadruple 2	0.3	2.95 [T/m]	7
Drift 3	1.3715		7
Quadruple 3	0.3	-3.5 [T/m]	7
Drift 4	1.3715		7
Quadruple 4	0.3	2.3 [T/m]	7
Drift 5	1.3715		7
BHZ20	1.002	-5.378 [T]	10 Ver
Drift 6	4.493		7
Drift 7	2.445		7
Quadruple 9	0.3	-1.7379 [T/m]	7
Drift 8	2.255		7
Drift 9	4.9		10
Quadruple 10	0.3	1.2 [T/m]	10
Drift 10	4.8		10
Drift 11	3.395		10
Quadruple 11	0.3	-1.7696 [T/m]	10
Drift 12	1.305		10
Drift 13	4.493		7
BHZ30	1.006	7.347 [T]	10 Ver
Drift 14	0.555		7
Quadruple 15	0.3	0.71 [T/m]	7
Drift 15	1.3175		7
Quadruple 16	0.3	-3.5 [T/m]	7
Drift 16	1.3175		7

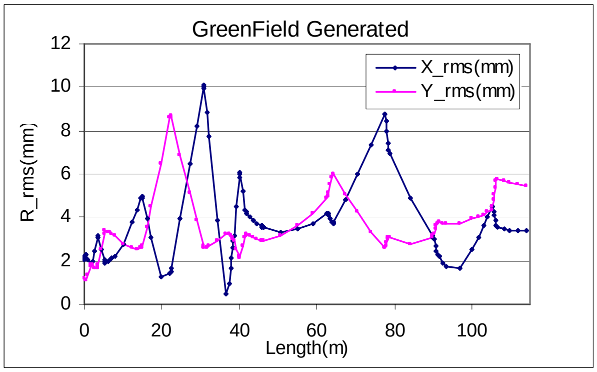
Quadruple 17	0.3	1.5 [T/m]	7
Drift 17	1.6175		7
Drift 19	2.1734		7
Drift HalfCell	0.11135		2.5
Buncher C1		0.285 [MV]	2.5
Drift Gap	0.2227		2.5
Buncher C1		0.285 [MV]	2.5
Drift Gap	0.2227		2.5
Buncher C1		0.285 [MV]	2.5
Drift HalfCell	0.11135		2.5
Drift 20	9		7
Drift 21	7.331		7
Quadruple 19	0.461	-0.53 [T/m]	7
Drift 22	0.839		7
Quadruple 20	0.461	0.8 [T/m]	7
Drift 23	6		7
Drift 24	6.98		7
Quadruple 21	0.462	-1.08 [T/m]	7
Drift 25	0.538		7
Quadruple 22	0.462	0.85 [T/m]	7
Drift 26	10.854		7
Quadruple 23	0.462	-0.51 [T/m]	7
Drift 27	0.838		7
Quadruple 24	0.462	0.6 [T/m]	7
Drift DS1	0.382		7
Distributer	2.002		5 Ver x 5 Hor
Drift DS2	6.701		7
Septum	2.882		3 Ver x 7 Hor
Drift DS3	2.212		7
Quadruple 25	0.466	-1.65	7
Drift 28	0.284		7
Quadruple 26	0.466	1.45	7
Drift 29	3.463		7
Drift 30	4.165		7

Table 3. Line elements values.

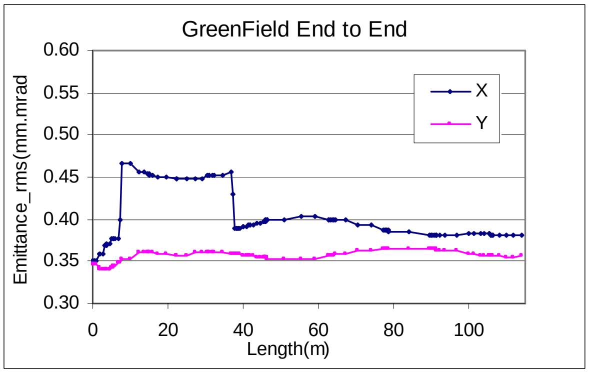
GreenField	Generated beam	End to End	
		2D Space charge	3D Space charge
ε_x increase	8.0%	8.4%	12.4%
ε_y increase	1.1%	2.7%	4.7%
α_x	-0.18	-0.13	-0.14
β_x (m/rad)	18.8	18.1	24.7
α_y	0.26	0.37	0.26
β_y (m/rad)	51.7	53.1	58.7
Transmission	100%	100%	99.1%

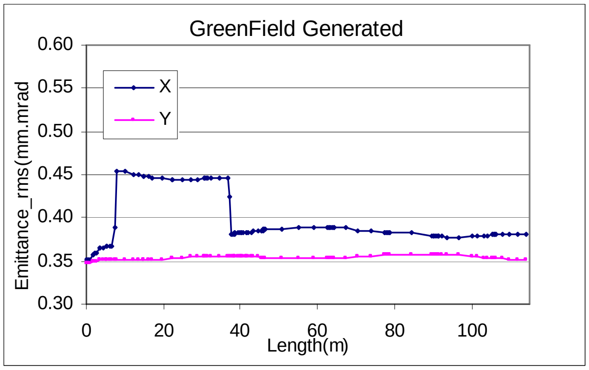
Table 4. Beam parameters and emittance growth in GreenField.



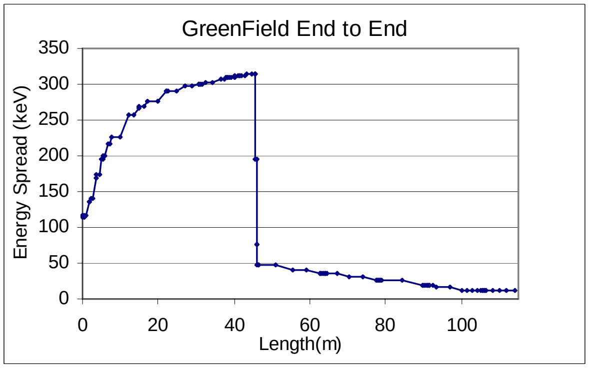


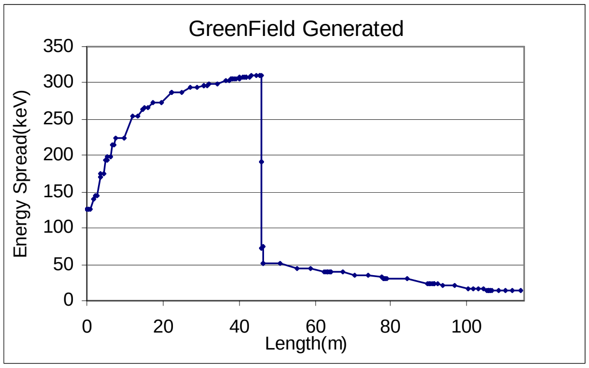
RMS envelope: End to End | Generated beam



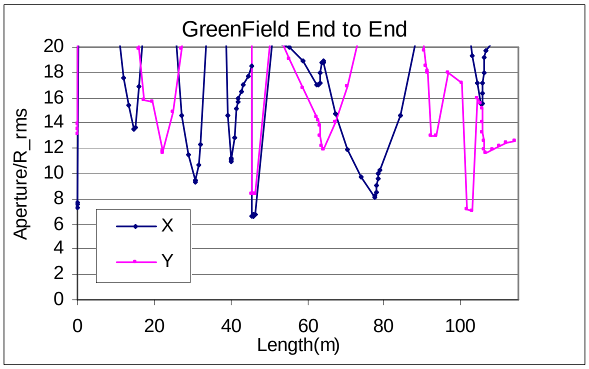


RMS emittance: End to End | Generated beam

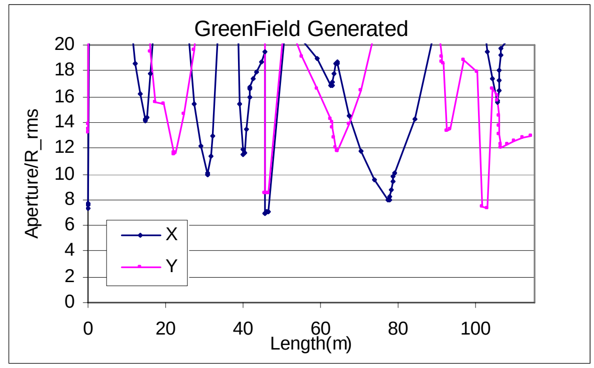




Energy spread: End to End | Generated beam



Aperture/RMS: End to End



Generated beam

3. Conclusion

From the beam dynamics point of view LT-LTB-BI line can be used to transfer the 160MeV beam of LINAC4 to the PS booster without any need of new quadruples. It needs two de-buncher cavities at 750kV and 360kV respectively. The strength of the dipoles should be increased by a factor of 1.86 to pass the beam through the same layout.

In the GreenField option, we used 18 new quadruples, one buncher cavity in 855kV and two bending dipoles. This solution improved drastically the emittance growth in the y plane.

In both cases there was a loss of ~1% which was due to the halo.

To make a comparison beam parameters at the end of the line, transmission and emittance increase for both optics are listed again in table 5.

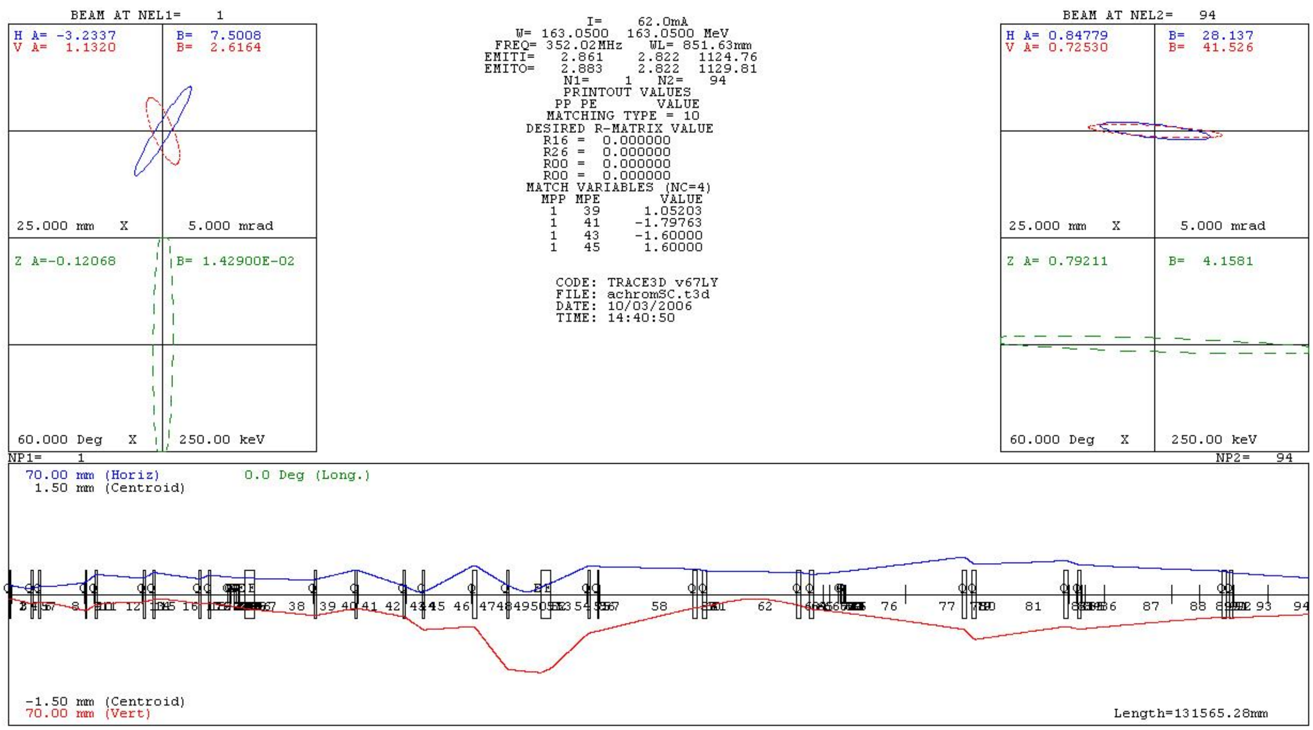
END to END	LT-LTB-BI+		GreenField	
	2D Space charge	3D Space charge	2D Space charge	3D Space charge
ε_x increase	6.1%	4.6%	8.4%	12.4%
ε_y increase	24.2%	25.3%	2.7%	4.7%
α_x	0.51	0.76	-0.13	-0.14
β_x (m/rad)	21.6	27	18.1	24.7
α_y	0.51	0.54	0.37	0.26
β_y (m/rad)	29.5	32.5	53.1	58.7
Transmission	100%	98.69%	100%	99.1%

Table 5. Beam parameters and emittance growth comparison

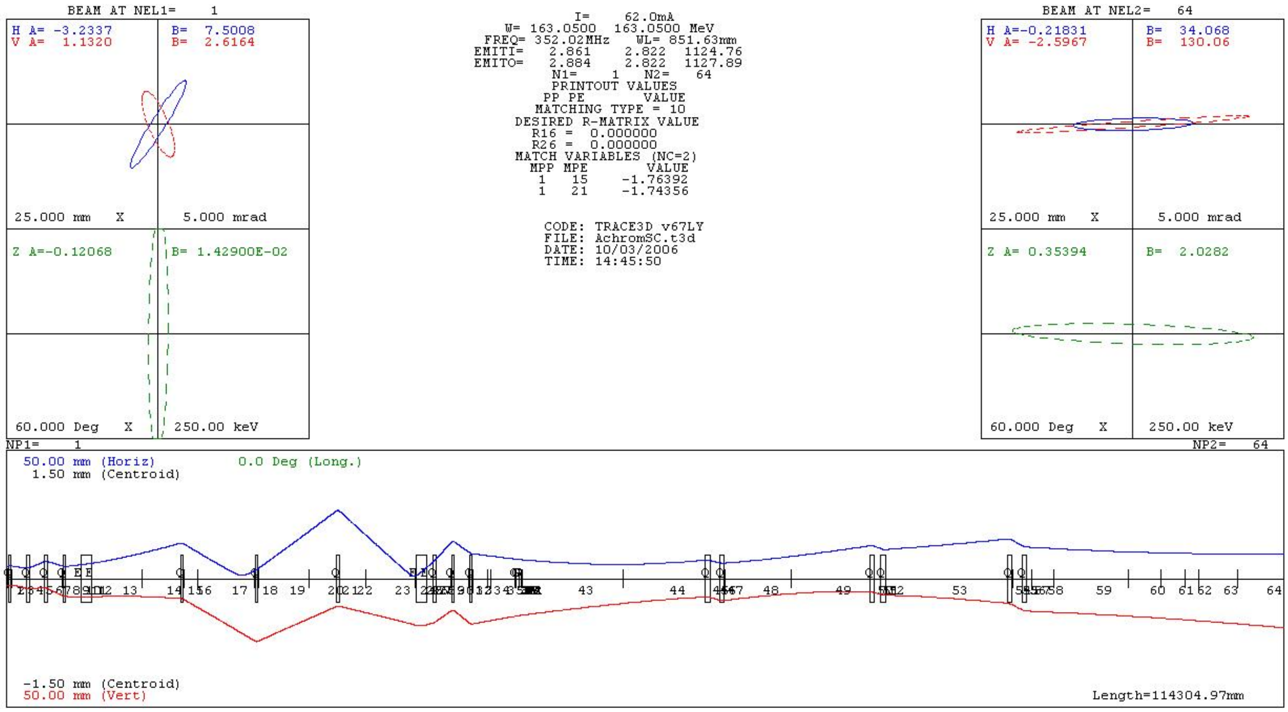
We studied another option with all new quadruples and the exactly same layout as LT-LTB-BI, the emittance increase with 2D space charge was 1% less than LT-LTB-BI+, but when we simulated with the 3D space charge there was 15.1% more emittance increase.

4. Appendix

The graphs of the beam at the entrance and exit of the transfer line, together with the envelope in vertical and horizontal planes.



TRACE3D plots for the LT-LTB-BI+ line (x,y beam envelope)



TRACE3D plots for the GreenField line (x,y envelope)

5. References

[1] Linac4, a new injector for the CERN PS booster, CERN-AB-2006-027, R. Garoby, F. Gerigk, K. Hanke, A.M. Lombardi, M. Pasini, C. Rossi, E. Sargsyan, M. Vretenar, Proc. of the EPAC06 Conf. Edinburgh, UK, 26-30 June 2006 ,

[2] STRUCTURE OF LINAC4 TECHNICAL DESIGN REPORT, M. Vretenar 03.04.2006 rev. 20.6.2006

[3] Giulia Bellodi, private communication

[4] Klaus Steffen, High Energy Beam Optics, NY Interscience publication, 1965

[5] PS/SM/Note 77-5