EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH
CERN - SL Division

SL-Note-2000-002 MS

ENGINEERING CONSIDERATIONS FOR THE PROPOSED BEAM EXTRACTION SYSTEM AT TESLA

B.Balhan, B.Goddard and M.Sassowsky

Abstract

For the TESLA project, the electron and positron beams must be separated after the interaction point. In order to maintain a straight orbit for the incoming beam in the separator, a weak magnetic field is superimposed to exactly cancel the electrostatic force acting on the incoming beam while doubling its effect on the outgoing one. After extraction, the positron beam is guided to its dump, and the electron beam is used for positron production. This paper contains some engineering considerations for the proposed $E \wedge B$ system, in particular with reference to experience gained from the existing LEP electrostatic separator system. The possibility of reusing LEP equipment is also briefly examined.

Geneva, Switzerland
4 January, 2000

Table of content

ENGINEERING CONSIDERATIONS FOR THE PROPOSED BEAM EXTRACTION SYSTEM AT TESLA

Abstract
For the TESLA project, the electron and positron beams must be separated after the interaction point. In order to maintain a straight orbit for the incoming beam in the separator, a weak magnetic field is superimposed to exactly cancel the electrostatic force acting on the incoming beam while doubling its effect on the outgoing one. After extraction, the positron beam is guided to its dump, and the electron beam is used for positron production. This paper contains some engineering considerations for the proposed $E \wedge B$ system, in particular with reference to experience gained from the existing LEP electrostatic separator system. The possibility of reusing LEP equipment is also briefly examined.

1. Introduction

The parameter list for TESLA (500 and 800 GeV centre of mass energy) are shown in table 1 [1-3]. The proposed beam separation at the TESLA interaction region uses orthogonal E and B fields to leave the incoming particle trajectory unaffected and to enable extraction of the outgoing particle. With a 700 ns (200 m) bunch separation, the beams can collide head-on and be separated outside of the detector in the long drift spaces. This is done by a long electrostatic separator with a field of about 4.7 MV/m, starting about 10 m after the IP. To prevent synchrotron radiation from hitting the detector, a weak 0.016 T magnetic field is superimposed so that the incoming trajectory is not bent. With an overall angular deflection of 0.77 mrad, the outgoing beams are offset by 3 cm from the main beam axis at 60 m from the IP. This separation is large enough for septum magnets to further extract the electron beam towards the positron production system and the positron beam towards its dump. The schematic layout is shown in figure 1 [2].

The 250 GeV per beam configuration would require a electric/magnetic field length of about 20 m, with fields of 47 kV/cm and 0.016 T respectively. At the final energy of 400 GeV per beam, either the field levels would need to increase to 75 kV/cm and .026 T respectively, or the lengths would need to increase to about 32 m keeping the original field levels. Considerations concerning feasibility and engineering aspects of this proposed system, and on the possible reuse of the LEP separator system, are noted in the following sections.

Table 1: TESLA design parameters

		500GeV	*800GeV*
Energy per beam	GeV	250	400
Repetition rate	Hz	5	3
Bunch spacing	ns	337	189
Bunches / pulse		2820	4500
leptons / bunch		2.0E+10	1.4E+10
Extracted beam angle	mrad	0.768	0.768
gamma		5E+05	8E+05
Pulse length	ms	0.95	0.85
Duty factor		0.0048	0.0026
Pulse beam current	mA	9.5	11.9
Average beam current	uA	45.1	30.2
Pulse beam power	GW	2.4	4.7
Average beam power	MW	11.3	12.1
Bunch energy	J	800	896
Pulse energy	MJ	2.26	4.03
Separator field length	m	20.4	32.6
Electrostatic kick	mrad	0.384	0.384
Separator field	kV/cm	47.1	47.1
Magnetic field	T	0.016	0.016

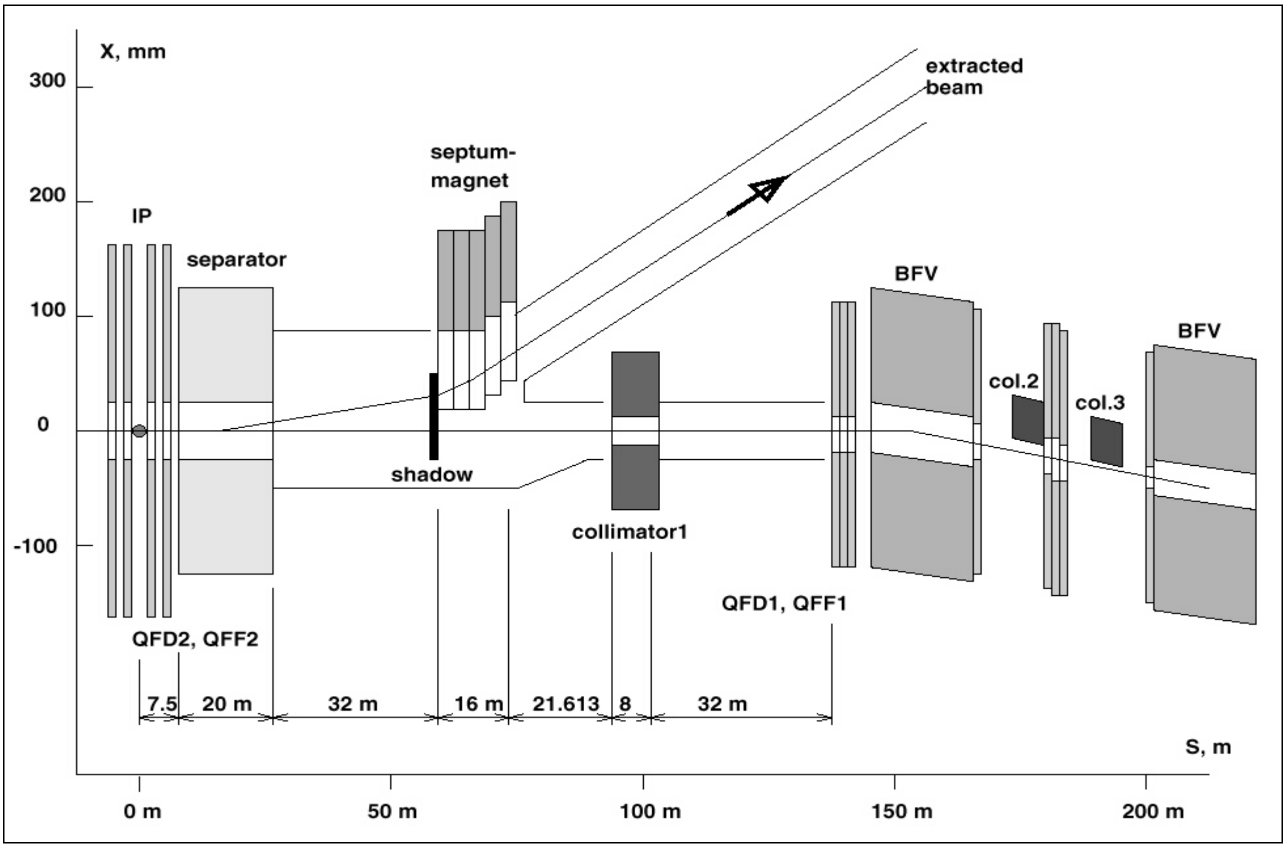

Figure 1. Schematic layout of the interaction region [2], showing the proposed separator.

2. Electrostatic System

Reference will be made frequently to the existing LEP ZL separators. Longitudinal and transverse sections of are shown figures 2 and 3 [4, 5].

For TESLA, fields of 50 kV/cm for several tens of metres would be required. This could be feasible with hardware similar to that used in LEP, powered by two (or more) high voltage generators, with an operational inter-electrode gap of 5 cm and applied electrode voltages of ±125 kV.

2.1 Field quality

The field quality obtainable with the LEP type electrodes is very good, with a region about 10 cm wide over the whole gap height (5 cm) with a relative field homogeneity of +/-10^{-3}, figure 4. Between adjacent units the end effects can be minimised by keeping the longitudinal distances smaller than the gap height, figure 5, such that the system is as compact as possible.

2.2 Operational aspects

For the LEP system, the main operational 'observables' for a particular separator are the high voltage breakdown rate and the current drawn.

At the field levels given above, high voltage breakdown is not expected to be a problem, if adequate precautions are taken to prevent direct Synchrotron Radiation or scattered beam particles from striking the electrodes or the surrounding vacuum chamber [6,7]. With no beam present, a LEP separator operating under similar conditions will have a breakdown rate of the order of 0.2 / hour.

The highest operational fields used in LEP are around 30 kV/cm, at which breakdown rates are negligible (<0.01 / hour) for stable beam conditions (2 x 3 mA beam current at 100 GeV per beam).

For the current drawn, in the LEP case this is not a problem *per se* for levels up to a large fraction of a milli-Ampere, as long as the generator is functioning correctly. Electrode heating through dissipation of this power or, for example, higher-order mode power is also suppressed in LEP separators by use of a closed cooling circuit using an inert dielectric liquid

2.3 Synchrotron radiation

Assuming that direct SR can be shielded against, the flux of scattered SR is likely to provide the most serious performance challenge at these electric fields. More information will be required about the detailed operating conditions before the likely performance can be evaluated. However, in LEP, separators have been operated successfully in zones with high fluxes of scattered SR, as evidenced by the high currents drawn of several hundreds of μA with beam present [8]. The design seems robust enough to work under these conditions.

2.4 Gap adjustment

For high voltage conditioning it is essential that the electrode positions can be adjusted in both directions compared to the nominal position.

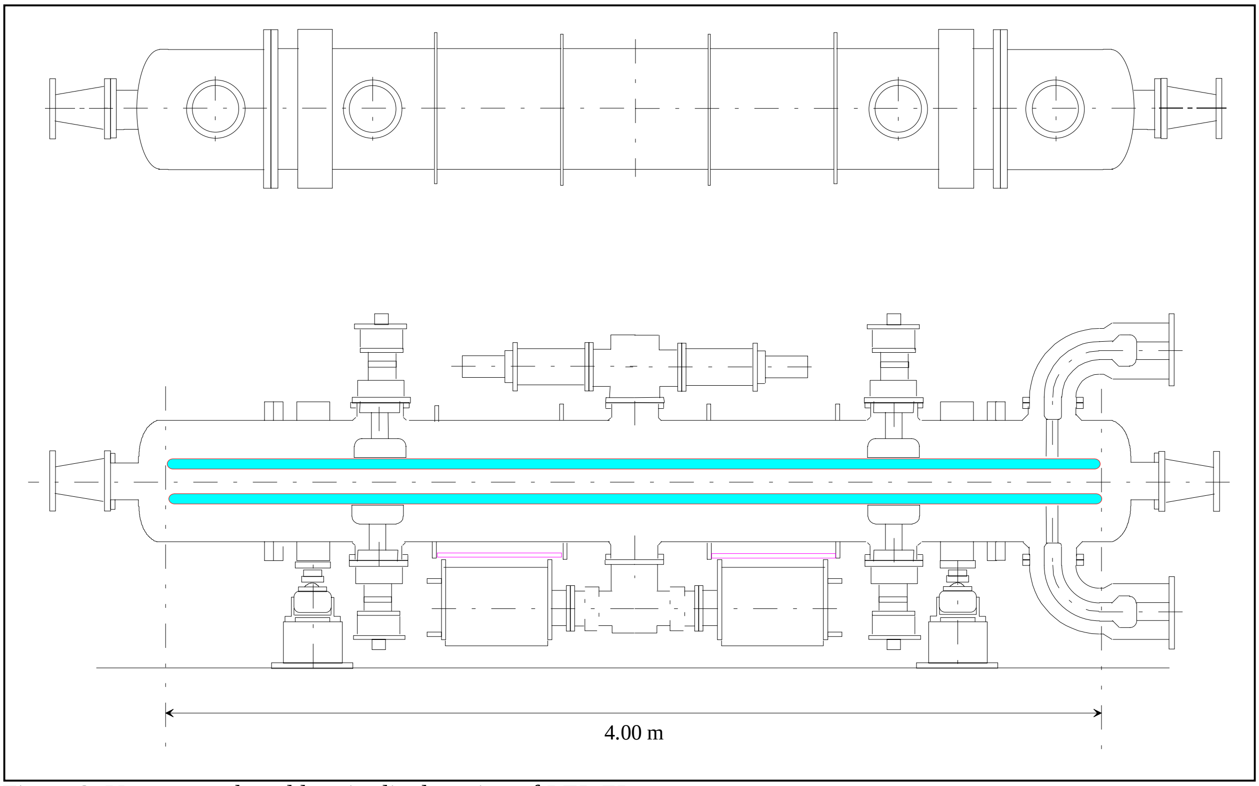

Figure 2. Vacuum tank and longitudinal section of LEP ZL separator.

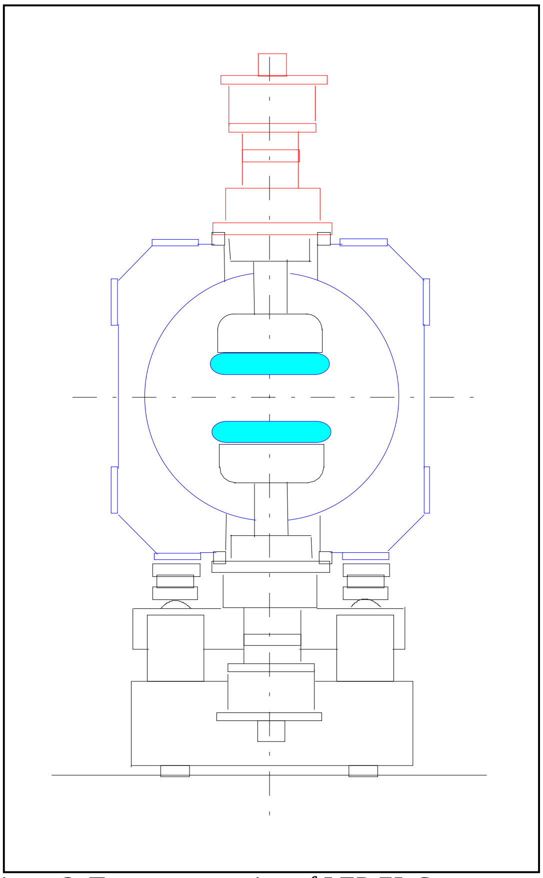

Figure 3. Transverse section of LEP ZL Separator.

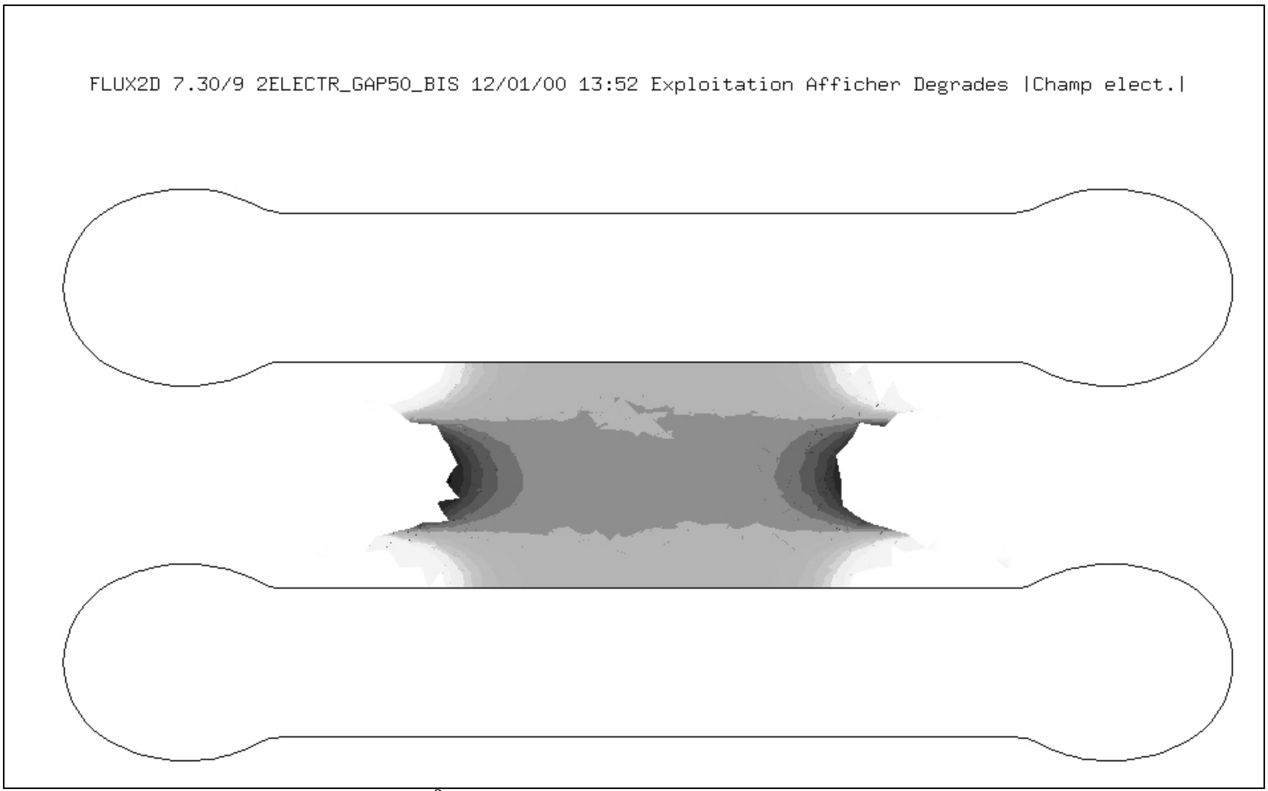

Figure 4. The good field region (+/-10^{-3}) is shown shaded for LEP electrodes at 5 cm vertical gap. Note the over-dimensioned shims for the gap height. Darkest regions correspond to 50.05 kV/cm, lightest shaded regions to 49.9 kV/cm. Asymmetric and non-smooth contours are artefacts of the finite element mesh.

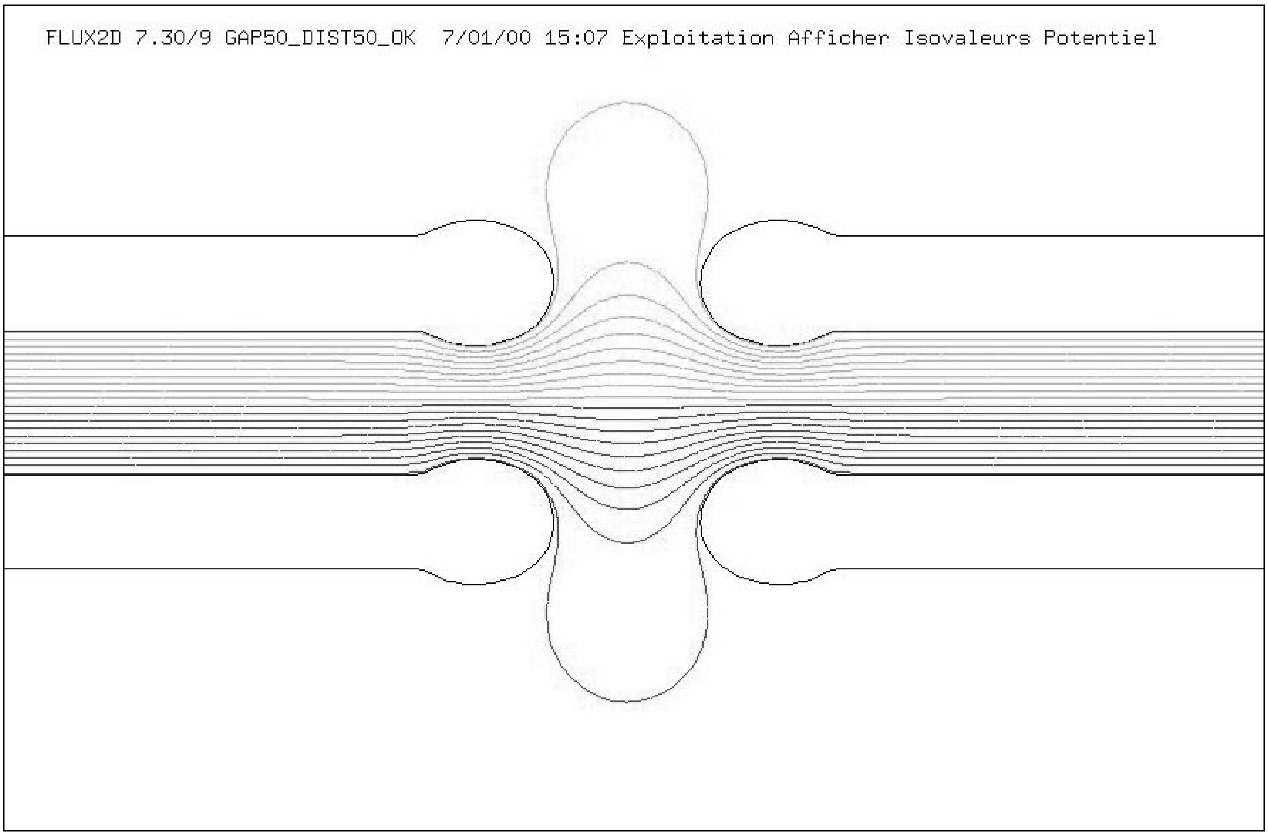

Figure 5. Equipotential lines showing end effects between adjacent separator electrodes at 5cm vertical and longitudinal gap.

2.5 Effects of high voltage breakdown

In case of a high voltage breakdown, a capacitive pickup or current transformer can be used to produce an interlock signal within about 10 μs.

With the compact configuration shown in figure 5 it is very likely that a high voltage breakdown on one electrode will trigger breakdown of adjacent electrodes within a few nanoseconds. Consequently, during the 10 μs before the interlock is activated, and until the beam is cut, the kick from the separator will be anywhere between zero and the nominal value in an uncontrolled manner.

To decouple the individual electrode pairs such that a high voltage breakdown on one pair does not produce a breakdown elsewhere may be possible. This would require a larger longitudinal inter-electrode spacing, probably of the order of two metres. The obvious disadvantage of such a layout is that the effective field strength per metre of separator is lower by about 30 - 50 % - i.e. 30 m would be required to install the system for 500 GeV rather than the 20 m planned. In any case, the beam will couple the units, such that breakdown of several or even all electrodes may happen simultaneously.

The recovery time after a high voltage breakdown is determined by the characteristics of the external circuit. A time between a few hundred ms and a few seconds is realistic.

2.6 Dimensions

The electrode transverse dimensions will depend on the allowed inter-electrode gap, which in turn depends on the good-field region required *and* on the aperture necessary for the beam and for scattered particles, SR etc. Assuming a 5 cm vertical gap, the existing LEP electrodes are already largely over-dimensioned (too wide with over-pronounced shims for this gap).

If a smaller vertical gap is possible, the surrounding vacuum tanks, electrodes and high voltage feedthroughs can be dimensioned accordingly. A reduction on the present LEP vacuum tank diameter would then appear possible, by between 20 and 40 %.

2.7 Upgrade to TESLA 800

The TESLA 800 upgrade would require operation at fields of around 75 kV/cm, if the 20 m system length were conserved. This corresponds to applied voltages of about ±200 kV at gap of 5 cm, or ±150 kV at 4 cm, which would almost certainly not be possible with separators based on the LEP design. At these field levels, it is likely that field emission and high voltage breakdown for LEP-type electrodes would make operation impossible.

The other solution for TESLA 800 is to extend the separation system to 32 m of field length at 50 kV/cm, to give the same angular deflection to the 400 GeV leptons. This will obviously need to be taken account of in the initial geometry for TESLA 500; otherwise, major modifications to the proposed extraction septum and dump lines will be necessary for the upgrade.

3. Magnetic System

The necessary dipole magnetic field must be produced in the centre of the separator tank. This would best be done using an external yoke and coils, since the addition of laminations and coils in the ultra-high separator vacuum will introduce severe complications for the high voltage performance.

A parameter list for the dipole magnetic system is shown in table 2. The iron length of a single unit is assumed to be 4 m.

3.1 Coils

The magnetic field levels are low, so despite the large gap the required value for the Ampere-turns is moderate. The coils can thus be built compact, the coil cross-section being about 4 cm x 10 cm with a current of about 500 A.

3.2 Mechanical construction

The gap size is determined by the outer dimensions of the separator tank. Due to the large size of the magnet, the mechanical construction would have to be studied in some detail. It would probably not be built from single punched laminations (because of steel wastage, closing of the poles during punching and welding). Spacers on the open side would probably be necessary for mechanical stability.

3.3 Yoke

A rough 2D model shows that the small distance of the pole face to the return yoke and the large pole gap creates a partial "magnetic short circuit". Most of the field lines from the left shim do not pass the mid-plane of the magnet, but directly enter the return yoke. This effect is shown in figure 7.

The return yoke thickness is not determined by magnetic requirements because of the low field levels. It can be thus much thinner than the pole width.

3.4 Field homogeneity

The partial magnetic short circuit mentioned above means that the field homogeneity is difficult to modify with shims on the pole face. However, a region of about 6 cm x 6 cm with a relative field homogeneity of $+/-10^{-3}$ can be found, figure 8.

Table 2. Design parameters for a dipole magnet built around a LEP separator.

COIL		
Conductor height	mm	14
Conductor width	mm	14
Cooling hole diameter	mm	6
Edge rounding	mm	1
Conductor length	m	123.6
Conductor area	mm^2	167
Resistance of coil (hot)	mΩ	13.3
Current	A	500
Current density	A/mm^2	3
Dissipated power per coil	kW	3.32
Weight of coil	kg	184
Coil window height	mm	34
Coil window width	mm	94
Ampereturns per coil	A	6000
Ampereturns whole magnet	A	12000
COOLING		
Number of cooling circuits per coil		1
Number of coils per magnet		2
Pressure drop	bar	6
Coolant velocity	m/s	1.3
Flow per cooling circuit	l/min	2.2
Total cooling flow	l/min	4.5
Temperature increase	deg	21.2
MAGNET		
B at 500 A	T	0.026
Iron length	mm	4000
Gap height	mm	600
Resistance (full load)	mΩ	26.6
Maximum static Voltage	V	13.3
Dissipated power	kW	6.6

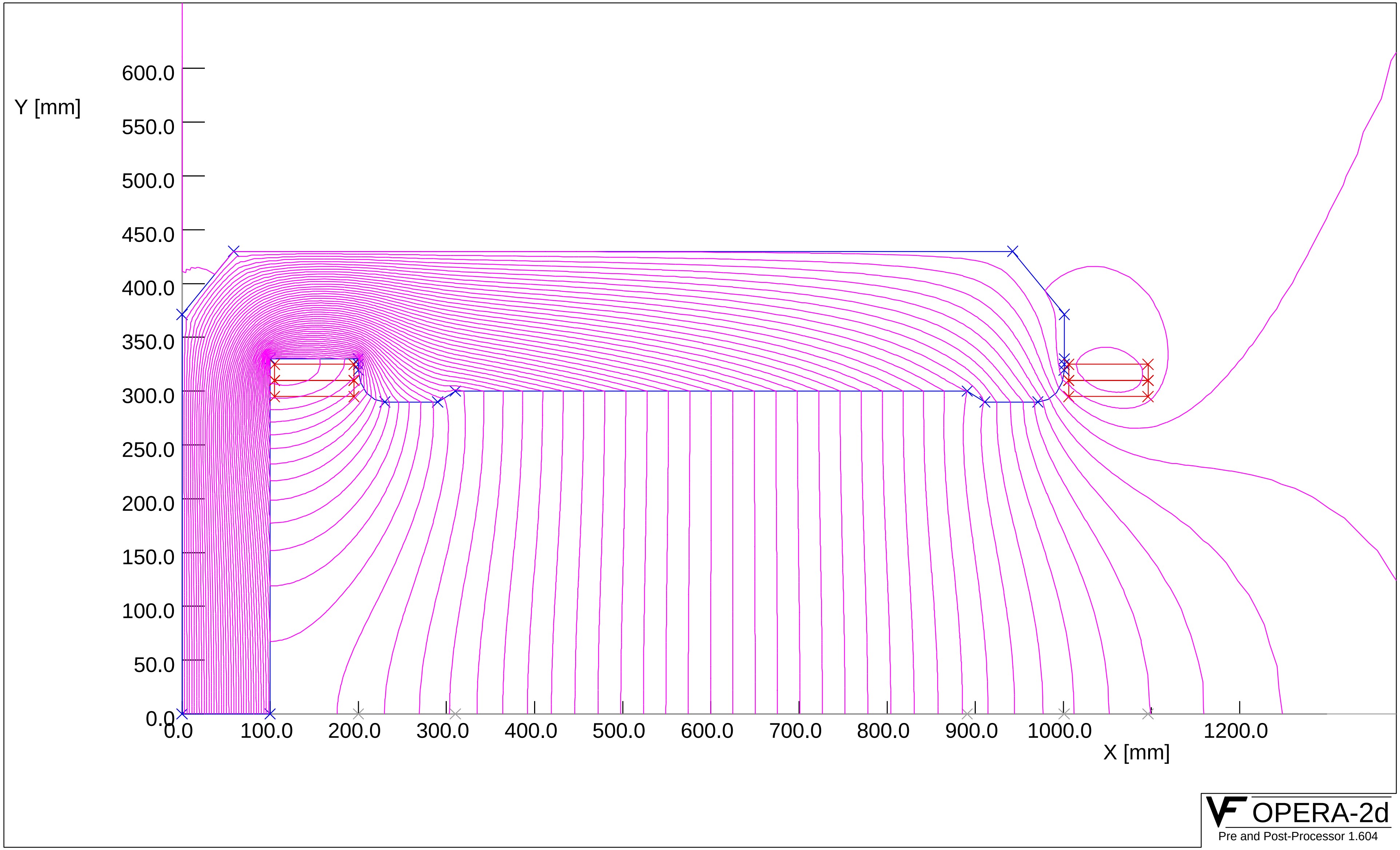

Figure 6. Magnetic flux lines for a dipole built around an existing LEP separator.

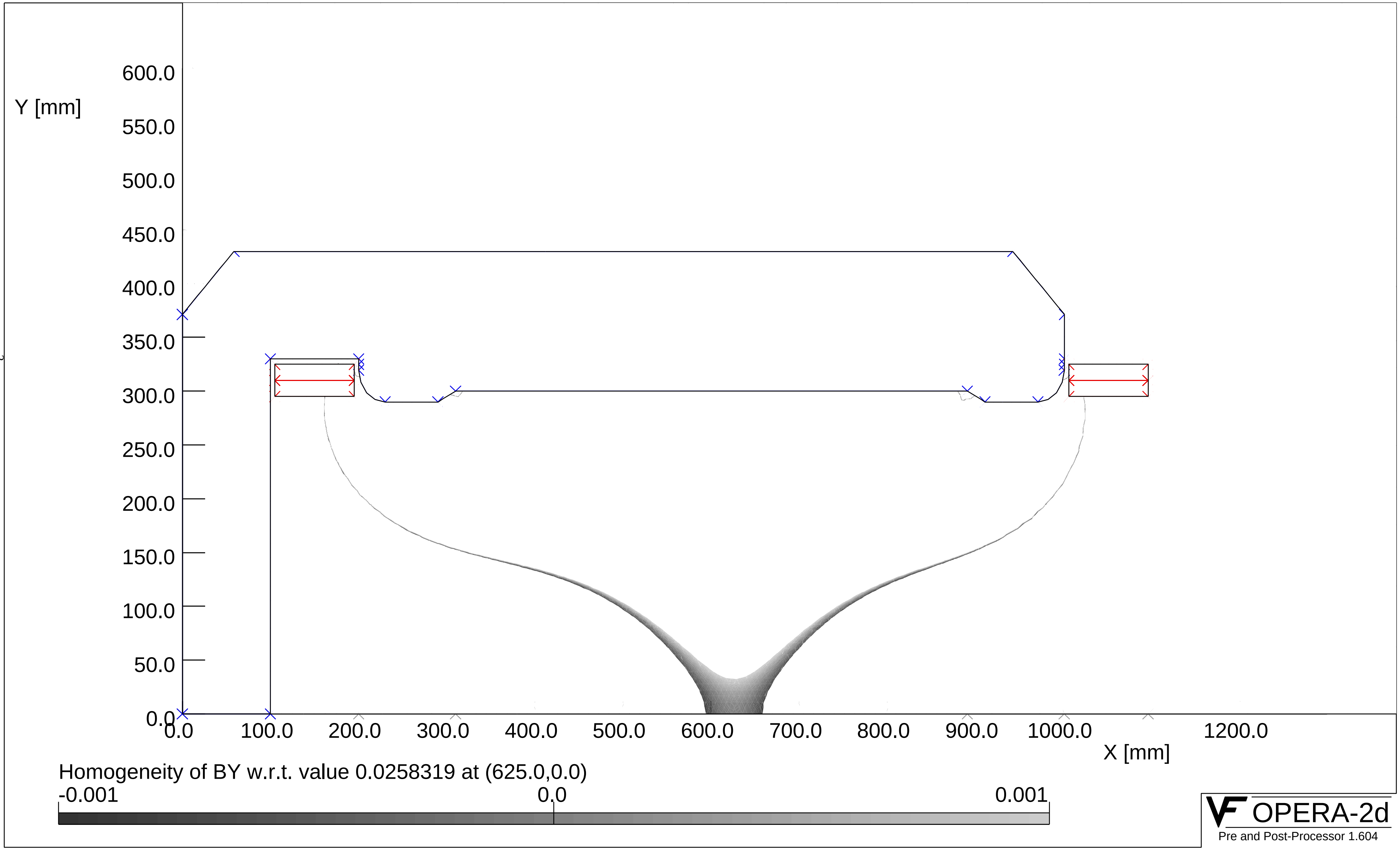

Figure 7. Good field region (+/- 10^{-3}) for a dipole built around an existing LEP separator.

4. Possible reuse of LEP equipment

At the end of LEP operation and dismantling in 2001, a large number of LEP electrostatic separators and associated HT circuitry, generators and control systems will become available for other applications if required. For TESLA at 500 GeV it would in theory be possible to use the LEP system, with the addition of extra units where required for the energy upgrade.

4.1 Advantages

Reuse of the LEP separator system has the following advantages:

- No development is required. The development of a complete new high voltage system (electrodes, vacuum tanks, connectors, cables, resistors, generators, …) is time consuming, expensive and also technically risky.
- The equipment exists, with plenty of spare material available.
- Some documentation exists (specifications, test reports, history, operating instructions, schematics, …).
- The performance of the system, both in the laboratory and in the LEP e+e- collider, is well known and documented.
- The system worked well in LEP due to generous safety margins and over-dimensioning, and as such is likely to work even for more demanding applications.
- The cost of reusing an existing system will be much less than that of developing and building a new one.
- The expertise associated with the system exists.

4.2 Disadvantages

There are some disadvantages to reuse of the LEP system, mentioned below:

- The system is physically over-dimensioned for the TESLA application. Although this means increased safety margins it also means larger volumes and, more importantly, a much larger magnetic system than necessary, with the attendant difficulties (some of which are mentioned in section 3). Reducing the size of the system will mean redesigning most of the components.
- The LEP system was designed to fit into the rather large LEP tunnel, and may not be compatible with the TESLA IR physical layout.
- Reuse of an existing system often means that design and functionality have to be compromised for compatibility.
- Adopting completely an existing system could lead to a lack of in-depth expertise and knowledge, which might be important in case of unforeseen problems.

5. Conclusion

The proposal to use a charge / mass separator for the TESLA interaction region seems, at first sight, technically feasible. The experience gained with the construction and operation of the LEP separator system appears relevant for the design of the system.

The reuse of the LEP separator system 'as-is' could be possible, but would probably not be completely suitable, due to the physical dimensions and other arguments given above. Another, more attractive, solution would be to reuse the design of the most critical components only, with an adaptation to the TESLA requirements in terms of size, electrode length, resistor values, etc. of the rest of the system.

6. References

[1] TESLA Project Team, Particle-Accelerator, vol.46, no.1, p.185-96, 1994.

[2] R.Brinkmann, G.Materlik, J.Rossbach, A.Wagner (eds), DESY 1997-048, http://www.desy.de/~schreibr/cdr/cdr.html

[3] O.Napoly, Private communication.

[4] W.Kalbreier, N.Garrel, M.Laffin, V.Mertens, G.Rogner and G.von Holtey, Proc. 2nd European Particle Accelerator Conf., Nice, Vol. 1, 1990.LEP ZL

[5] B.Balhan, A.Burton, E.Carlier, J-P.Deluen, J.Dieperink, N.Garrel, B.Goddard, R.Guinand, W.Kalbreier, M.Laffin, M.Lamont, V.Mertens, J.Poole, H.Verhagen, Proceedings Particle Accelerator Conference, p.557-9 vol.1, 1995.

[6] N.Garrel, B.Goddard, W.Kalbreier and R.Keizer, Le Vide: Science, technique et applications, Suppl. to 275, 386 (1995).

[7] W.Kalbreier and B.Goddard, IEEE Trans. Electr. Insul. 28 (4), 1993.

[8] B.Balhan, N.Garrel, B.Goddard, T.Spickermann and J.Tan, SL MD Note 216, 1996.

Distribution

Authors

SL/MS section leaders,

SL/MS/ES section

W.Kalbreier	SL/MS
W.Weterings,	SL/MS
H.Burkhardt	SL/AP
O.Napoly	DAPNIA-SEA, CEA Saclay, 91191 Gif/Yvette CEDEX, France
H.Owen	CLRC Daresbury Laboratory, Daresbury, Warrington, Cheshire, WA4 4AD, GB.
M. Tonutti	III. Physikalisches Institut, Physikzentrum, RWTH Aachen, D-52056 Aachen, Germany