A New Beam Delivery System (BDS) for the TESLA Linear Collider

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Abstract

An overview of the proposed new BDS for the TESLA linear collider is presented. Several major changes have been incorporated since the publication of the TESLA Conceptual Design Report (CDR) [1]. The most notable of these modifications are: incorporation of the photon-based positron source upstream of the interaction point (IP), *i.e.* at the exit of the electron linac; a new concept for the collimation system, including integration of the emittance measurement section; an increase in the length of the final telescope, which, together with a new spent beam extraction line, allows for cleaner extraction of both the spent electron (positron) beam and the beamstrahlung photons.

1 INTRODUCTION

The current version of the beam delivery system (BDS) for the TESLA linear collider reflects several major modifications with respect to the reference design given in [1]. The BDS system is required to perform the following functions:

- strong demagnification of the beam by the final focus ($\sigma^*_{x,y}$ = 550, 5nm, CCS and FT in figure 1);
- collimation of beam halo for detector backgrounds in both energy and betatron space (E-COLL and β-COLL in figure 1 respectively);
- emittance measurement station, which is now included in the collimation section (β-COLL);
- collimation protection against fast energy errors, using a magnetic energy spoiler system (MES);
- and finally the incorporation of the e^+ source at the e^- exit of the linac (upstream of the BDS, e^+ wiggler and arc in figure 1).

The complete lattice functions (β_x, β_y and D_x) are show in figure 1. The original CDR lattice was approximatley 1200 m long as compared to current 1700 m, the increase in length being predominantly driven by (i) the stretching of the final telescope to allow for a single dump hall (section 4) and (ii) the inclusion of the e^+ source and second IP switchyard (section 2). Section 3 will briefly cover the philosophy of the new collimation system, which is also represents a significant change in philosophy and design from the original CDR reference lattice.

2 BEAM SWITCHYARD

A beam switchyard has been included to permit the operation of two detectors on a time sharing basis. Its design is constrained by the required horizontal separation of the two electron beamlines which over a distance of ~300 m must allow enough room for the positron target (see fig. 2). In addition the arc emittance growth should be kept small for a 400 GeV beam. An arc optics has been adapted from the double bend achromat lattice used in small equilibrium emittance rings. It is composed of two periodic sections of about 110 m length. Their net bending angles of about 8 mrad and ±7.4 mrad are set (together with the remaining BDS dipoles) to achieve the desired crossing angles at the two IPs (0 and ~34 mrad, respectively). The dipole magnets are split into 7.5 m lengths (B≈0.1T), the first 5 of which are common to both beam lines. Separate beam chambers and magnets are used as soon as the beam axis is at least 5 cm away from the 2 cm radius photon beam tube. The magnets need not be septa since their field may leak over the photon beam line. Beam switching will be controlled by the polarity reversal of the first five dipoles. The first quadrupoles in the arcs can be separated assuming a 15

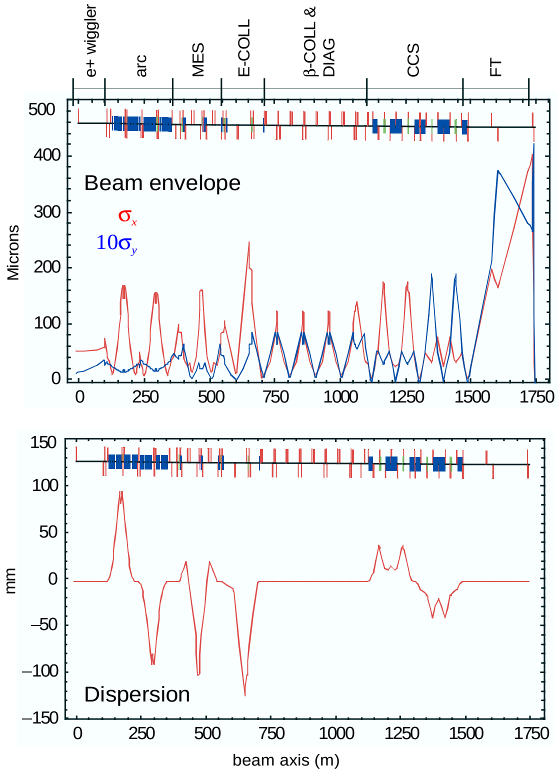

Fig. 1: TESLA Beam Delivery System (BDS) lattice functions.

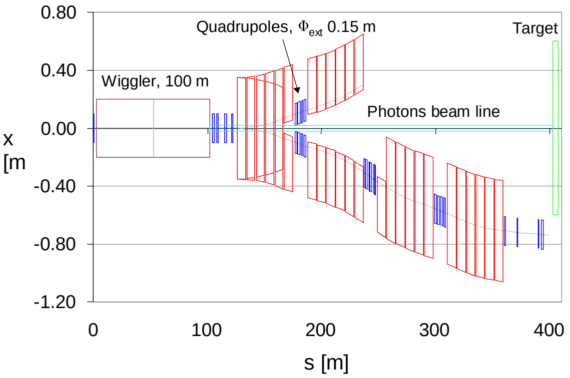

Fig. 2: Magnet layout of the beam switchyard, showing the e^+ source wiggler (undulator) and target.

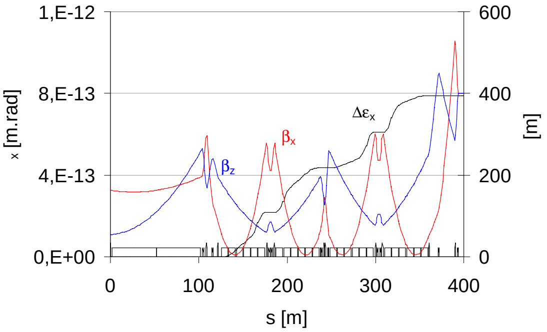

Fig. 3: Optics functions and emittance growth (at 400GeV) for the BDS ARC.

cm outer diameter. The emittance growth induced by synchrotron radiation for a 400 GeV beam sections is about 8% of the nominal horizontal emittance (see fig. 3). Finally, the quadrupole in front of the wiggler is tuned to produce a 150×14 μm^2 linear optics spot size of the photon beam on the target, a value which is a small addition to the ~1 mm^2 spot set by the opening cone of the radiation, and can thus accommodate the helical undulator required for polarised e^+ production [2].

3 COLLIMATION SECTION

In the original CDR reference design [1], the collimation system and the diagnostics section (emittance measurement station) were two separate systems. In order to save tunnel length, these systems have been merged into one collimation and diagnostics section. This has been made possible in part by a change in design philosophy for the collimation system, which now comprises of:

1 a pure betatron collimation system with four collimators (spoilers) separated by 45° in both *x* and *y* phase;

2 an upstream collimator in a dispersive system, used for (predominantly) momentum collimation;

3 A non-linear magnetic system upstream of the momentum collimator, which is used to "blow-up" the beam size on that collimator in the event of a large (>2%) $\Delta P/P$ error.

At each spoiler $\beta_x = \beta_y = 800m$, which translates into a design beam size of 128×7 µm at 250GeV. The beam size allows Carbon (Graphite) spoilers to survive ~3 design bunch at full charge (2×10^{10}). In addition, the 45° lattice and relatively large beam sizes affords an excellent emittance measurement system, using flying carbon wire scanners[3]. Given a required collimation depth of $12\sigma_x$ by $80\sigma_y$ [4], the collimator gaps in the betatron collimation section are set to ±1.5 mm and ±0.5 mm for *x* and *y* respectively; this includes a factor of cos(45º/2) ≈ 0.92, which allows for the "corner clipping" in phase space of a system based on 45º degree phase separation. The energy collimator is set to the nominal ΔP/P = 2% value (±2 mm).

The spoiler protection philosophy has also been revised. In the CDR [1], the collimation system was so designed that all spoilers could withstand a direct hit from several nominal bunches. The philosophy is now that a fast momentum error is the likeliest failure scenario, and so we protect only the momentum spoiler. This is achieved by the upstream magnetic energy spoiler (MES, figure 4), which is a non-linear system containing two skew-sextupoles separated by an *I* transform, at the centre of which is placed an octupole magnet at a point of high dispersion (≈100 mm). The resulting non-linear dispersion generated by the octupole ($\propto \delta^3$) translates to an offset at the second downstream skew-sextupole, resulting in an energy dependent skew-quadrupole. Using simple thin-lens analysis, it can be shown that the relative increase in vertical beam size at the spoiler can be estimated as

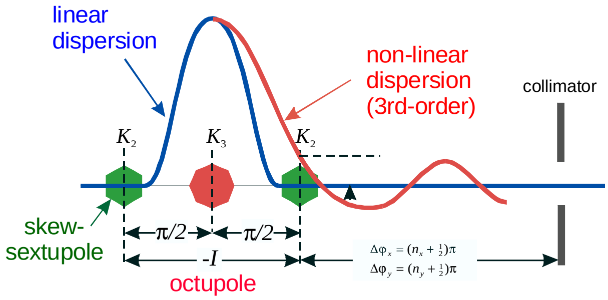

Fig. 4: Magnetic Energy Spoiler (MES) concept

$$\frac{\sigma_y(\delta)}{\sigma_y(0)} \approx \frac{1}{6} R_{12} K_2 K_3 D_x^3 \sqrt{\frac{\varepsilon_x \beta_x \beta_y}{\varepsilon_y}}\,\delta^3$$

where R_{12} is the linear Greens function from the octupole to the skew-sextupole, K_2 is the skew-sextupole strength, K_3 the octupole strength, D_x the dispersion at the octupole, $\beta_{x,y}$ the beam parameters at the skew-sextupole, and δ the relative momentum error ($=\Delta P/P$). Taking $R_{12} = 200$ m, $K_2 = 5\ \mathrm{m}^{-2}$, $K_3 = 1000\ \mathrm{m}^{-3}$, $D_x = 100$ mm, and $\beta_x = \beta_y = 400$ m, we obtain $\sigma_y(\delta)/\sigma_y(0) \approx 10$ for $\delta = 2\%$;

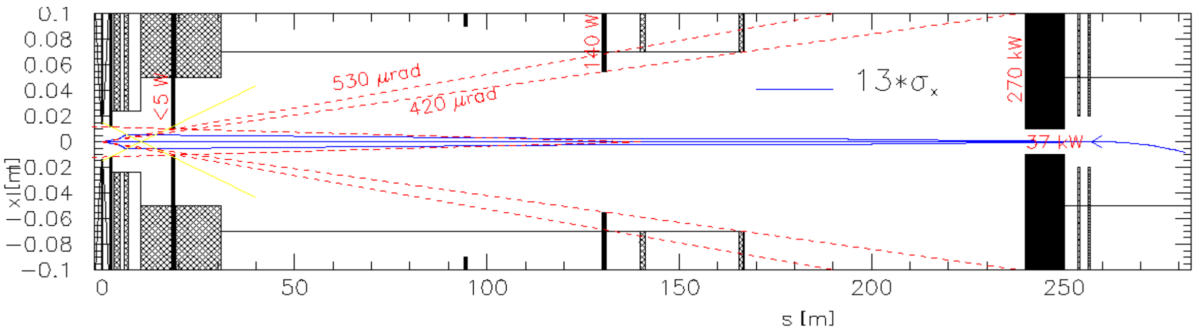

Fig. 5: Final transformer horizontal layout, with beamstrahlung average deposited power on collimators.

such an increase is more than sufficient to allow the momentum spoiler to accept up to ~30 bunches without damage.

4 FINAL FOCUS SYSTEM

The final focus optics has been modified with respect to the previous design [1] to account for the new positioning of a dump hall about 250 m from the IP. This hall will house both the beam dump and the main collimator for beamstrahlung photons. At the IP, e$^+$ and e$^-$ collide head-on and the photon flux travels up the incoming beam line all the way to the dipoles of the chromatic corrections section. The final transformer has been re-designed (see fig. 5) in order to encompass the dump hall and to offer an angular clearance of about 400 µrad half-angle for the beamstrahlung photons Such a 260 m long final telescope is far from optimum from the point of view of the chromatic aberrations. A 1% momentum bandwidth is recovered by introducing a weak intermediate doublet at about 150 m from the IP between the superconducting final doublet and the first doublet at about 260 m.

For a last drift of length l^*=3 m, the superconducting doublet quadrupoles are 1.7 m and 1.0 m long with a gradient of 250 T/m. Given the new desire for a 9.2 m long 4 T detector solenoid, it is foreseen to use Nb$_3$Sn quadrupole cables at 1.8 K to stay away from the critical line (see fig. 6). An R&D program has started to build such a magnet prototype[6]. These magnets could be powered up to about 20% higher energies but they would have to be replaced for the 800 GeV energy upgrade which requires 2.5 m and 1.4 m long quadrupoles at the same gradient.

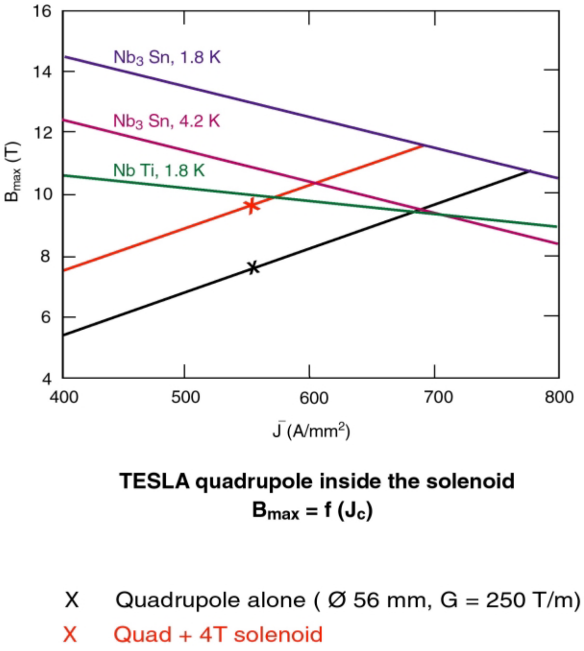

Fig.6: Superconduting quadrupole lines of charges compared to critical limits [5].

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