LCLS-II Technical Note

LCLS-II Injector Couplers Options Performance

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1 Introduction

LCLS-II Injector is a critical part of the accelerator complex due to the small emittance of the low energy beam to be preserved to match the downstream sections requirements. In this note we investigate the emittance dilution caused by the RF couplers asymmetric field for the 1.3 GHz 9-cell TESLA cavities of the injector. We compare 2 different layouts for the injector and 4 different couplers configurations for the 1st cold TESLA cavity that is responsible for most of the emittance dilution due to the couplers field. All the cases studied have a bunch charge of 300 pC, being the more problematic case in term of emittance. Beam dynamics simulations are carried out using tracking code ASTRA [1].

2 Layouts studied

The first layout studied is composed of the 187 MHz RF gun, a first solenoid, the 1.3 GHz APEX buncher, a second solenoid and a cryomodule including 8 TESLA cavities, as shown in Fig. 1. The gun, buncher and solenoid are room temperature elements, while the cryomodule is superconductive.

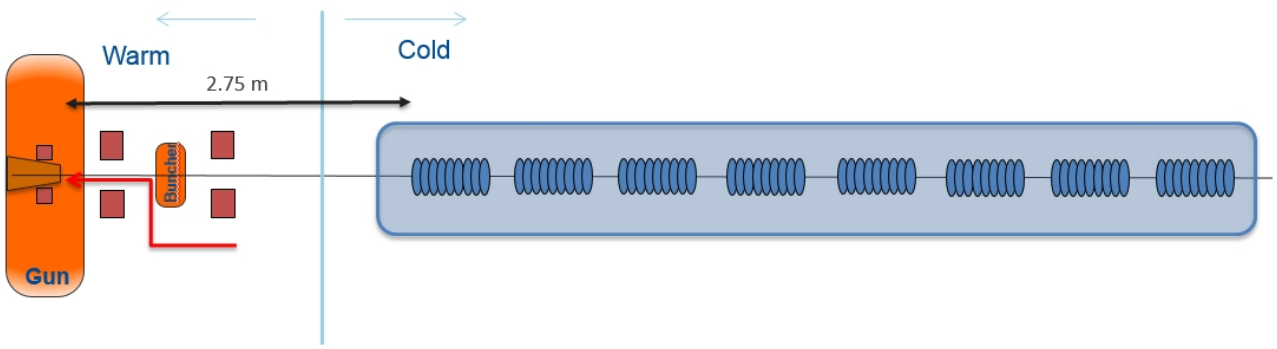

Figure 1 Schematic of Layout 1

Table 1 shows the elements of the lattice with the distance of their center from the cathode, their length, the peak field as used in the simulations and their phase.

Table 1: Elements of the lattice simulated for layout 1.

Element	Position (m)	Length (mm)	Peak Field (MV/m , T)	Phase (mm)
RF Gun	0.00	199	20	2.76393
1st solenoid	0.306	800	0.0394246	--
Buncher	0.895	200	3.99856	-70.54
2nd solenoid	1.701	800	0.0246965	--
1st cavity	3.4	1318.8	18.4154	-20.5726
2nd cavity	4.7848	1318.8	0.0	0.0

3rd cavity	6.16959	1318.8	0.0	0.0
4th cavity	7.55438	1318.8	30.5	0.0
5th cavity	8.93917	1318.8	30.5	0.0
6th cavity	10.324	1318.8	30.5	0.0
7th cavity	11.7088	1318.8	30.5	0.0
8th cavity	13.0935	1318.8	30.5	0.0

The second layout studied has the warm section identical to the first one. In the cold section it is introduced a cold TESLA cavity, installed in a single cavity cryomodule, before the standard cryomodule used in layout 1. This layout should provide more flexibility in case of a cavity failure or operability in non-optimal condition. It also would make the replacement of a malfunctioning part less problematic. A scheme of the layout 2 is presented in Fig. 2 and the data of the elements of the lattice are reported in Table 2.

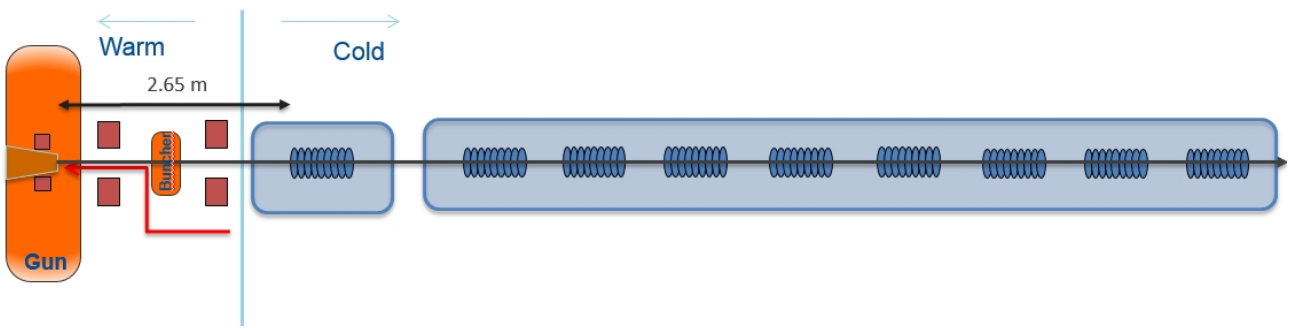

Figure 2 Schematic of Layout 2

Table 2: Elements of the lattice simulated for layout 2.

Element	Position (m)	Length (mm)	Peak Field (MV/m , T)	Phase (mm)
RF Gun	0.00	199	20	8.71227
1st solenoid	0.306	800	0.0395903	--
Buncher	0.895	200	3.41908	-84.676
2nd solenoid	1.701	800	0.022815	--
1st cavity	3.3	1318.8	19.297	-26.924
2nd cavity	8.73965	1318.8	24.7517	16.8985
3rd cavity	10.1244	1318.8	6.2049	-11.805
4th cavity	11.5092	1318.8	30.5	0.0
5th cavity	12.894	1318.8	30.5	0.0
6th cavity	14.2788	1318.8	30.5	0.0
7th cavity	15.6636	1318.8	30.5	0.0

8th cavity	17.0484	1318.8	0.0	0.0
9th cavity	18.4332	1318.8	13.4365	-6.05196

3 Couplers configurations

As simulations have showed [2], the couplers of the cold cavities are responsible for a significant emittance dilution in the injector. This effect is taking place mostly in the first TESLA cavity, where the energy of the beam is small (~800 KeV). To reduce this emittance growth different couplers configurations for the first cold cavity have been considered and compared to find the best one.

The first option is to use a TESLA cavity with standard HOM couplers, shown in Fig. 3. The standard configuration include one High Order Mode (HOM) coupler upstream of the cavity and one HOM coupler downstream, rotated compared to the first one, in order to balance the rf kicks. The power coupler of the cavity is also downstream on the opposite side of the HOM coupler.

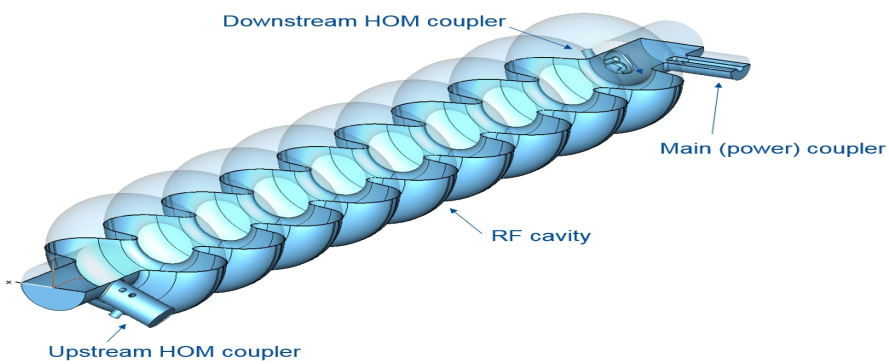

Figure 3 Design of the TESLA cavity with Standard couplers configuration

A second option studied is a design proposed by Fermilab, where the upstream HOM coupler is moved downstream, forming a downstream group of 2 HOM couplers and 1 power coupler, as seen in Fig. 4

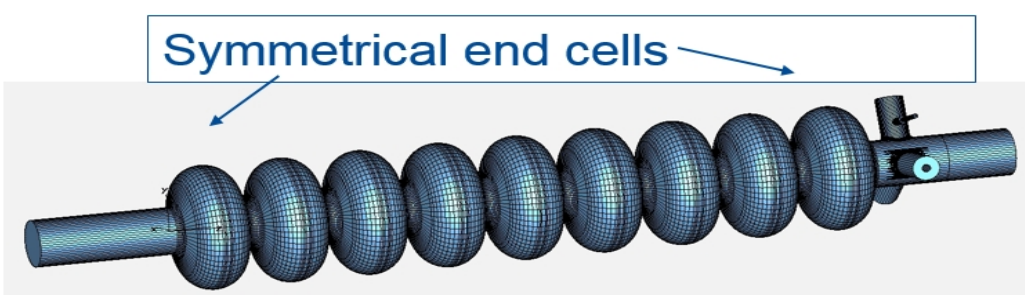

Figure 4 Design of the TESLA cavity with downstream HOM couplers configuration

A third option was proposed by SLAC and consist of a cavity with 2 HOM couplers upstream, one in front of the other, in order to compensate the dipole kick. This upstream group is moved 20 mm away from the cavity. Downstream the configuration is with one HOM coupler and the power coupler (see Fig. 5).

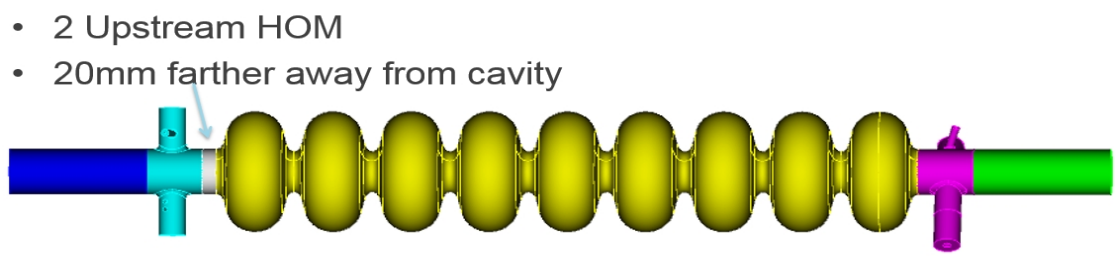

Figure 5 Design of the TESLA cavity with 3 HOM couplers configuration

The last option considered is the one with only the power coupler (downstream) and no HOM couplers. RF high order modes are dumped by cylindrically symmetric HOM absorbers, placed along the beam line outside of the cavity, like at Cornell's ERL. Fig. 6 shows a drawing of the HOM absorbers used at Cornell.

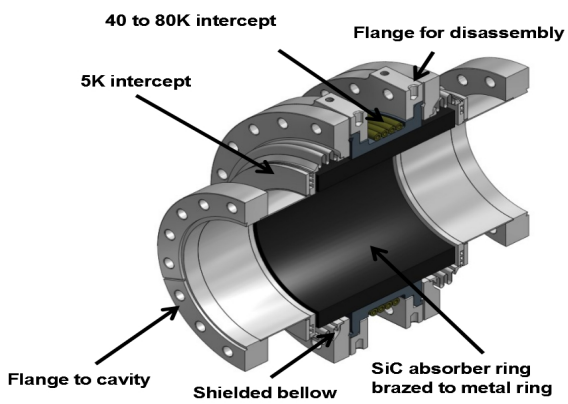

Figure 6 Technical drawing of a HOM absorber

For all the options illustrated 3D field maps of the cavities with their coupler configuration and nominal coupling values have been produced with the code CST Microwave Studio [3].

4 Simulations results

Simulations of layout 1 and 2 have been carried out. For the rf gun, buncher and solenoids the field maps used are 1D. For the cold cavities 3D field maps were used. All the TESLA cavities

have standard configuration of their couplers except the first one, for which we have tried the different options presented above. The results of the simulations for layout 1 are reported in Table 3.

Table 3: Simulations results for layout 1 with different couplers configurations of the first TESLA cavity.

Simulation	E (MeV)	σ_x (mm)	σ_y (mm)	σ_z (mm)	σ_E (MeV)	$\gamma\varepsilon_x$ (mm mrad)	$\gamma\varepsilon_x$ (mm mrad)	Δx (mm)	Δy (mm)
ASTRA 1D (symmetrical)	93.06	0.3319	0.3324	1.2986	0.0977	0.4665	0.4685	-	-
Astra 3D standard HOM	92.37	0.3876	0.4483	1.2818	0.0898	0.5612	0.9122	-1.6	-0.16
Astra 3D downstream HOMs	92.34	0.3725	0.4443	1.3063	0.0768	0.4243	0.5454	-1.7	-0.23
Astra 3D 3 HOMs	92.40	0.3262	0.3197	1.2723	0.0719	0.4048	0.5857	-1.7	-0.27
Astra 3D no HOMs	92.36	0.4128	0.4463	1.2998	0.0761	0.4512	0.5152	-1.8	-0.24

In Fig. 7 it is also showed the evolution of the emittance along the injector for layout 1.

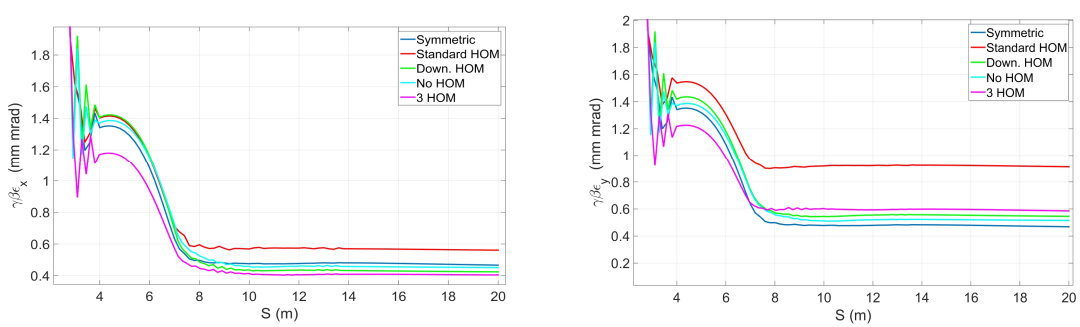

Figure 7 Horizontal (left) and vertical (right) emittance along the Injector (layout 1).

Table 4: Simulations results for layout 2 with different couplers configurations of the first TESLA cavity.

Simulation	E (MeV)	σ_x (mm)	σ_y (mm)	σ_z (mm)	σ_E (MeV)	$\gamma\varepsilon_x$ (mm mrad)	$\gamma\varepsilon_x$ (mm mrad)	Δx (mm)	Δy (mm)
ASTRA 1D (symmetrical)	100.00	0.1760	0.1762	1.2003	0.1044	0.6652	0.6664	-	-
Astra 3D standard HOM	99.34	0.1513	0.2229	1.1749	0.0600	0.7049	1.0920	-1.2	-0.17
Astra 3D downstream HOM	99.29	0.1698	0.1731	1.2137	0.0587	0.6507	0.7535	-1.3	-0.20

Astra 3D 3 HOMs	99.36	0.1383	0.2065	1.1803	0.0548	0.5301	0.8490	-1.3	-0.22
Astra 3D no HOMs	99.32	0.1407	0.1510	1.2078	0.0581	0.5922	0.6968	-1.3	-0.20

In Fig. 8 it is also showed the evolution of the emittance along the injector for layout 2.

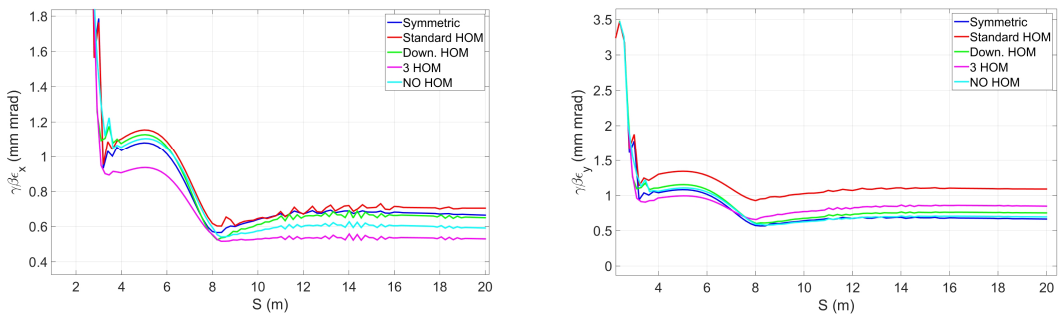

Figure 8 Horizontal (left) and vertical (right) emittance along the Injector (layout 2).

As can be seen results for layout 1 are slightly better than for layout 2. This is probably due to a better optimization of the parameters for layout 1, since layout 2 provides more flexibility and then potentially better performances. Nevertheless the results are close for both layouts and significant difference between the two should not appear. Between the options for the couplers, the alternatives to the standard configuration all perform similarly and sensibly better than the standard, which may give too large vertical emittance dilution for the 300pC scenario. To make a decision on which option to choose other information needs to be studied, like cost, engineering work, etc.

References

[1] K. Floettmann, "Astra," DESY, October 2011; http://www.desy.de/~mpyflo/.
[2] A. Vivoli et al., "Effect of Cavity Couplers Field on the Beam Dynamics of the LCLS-II Injector", LINAC'14, THPP060, Geneva, Switzerland (2014).
[3] Computer Simulation Technology, "CST Microwave Studio", http://www.cst.com/Content/Products/MWS/Overview.aspx, (2006).