SLAC-PUB-10306
January 2004

START TO END SIMULATIONS FOR THE SPARX PROPOSAL

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Abstract

We report in this paper the results of start to end simulations concerning the SPARX option based on an S-band normal conducting linac. One of the most critical systems is the bunch compressor. The effects on beam dynamics of a magnetic chicane system and a rectilinear RF compressor integrated in a high brightness photoinjector, are analyzed and compared in this paper.

INTRODUCTION

The SPARX proposal is devoted to the realization in Italy of a large scale ultra-brilliant and coherent X-ray source [1]. Two spectral complementary regions around 13.5 nm and 1.5 nm, are considered for the radiation source. A preliminary set of the required beam parameters are reported in table 1. Two basic schemes have been considered for the Linac, as shown in figure 1: the first one, the Hybrid Scheme, consists in an advanced high brightness photoinjector, with a RF compression stage [2], followed by a first linac (Linac 1) that drives the beam up to 0.5 GeV with the correlated energy spread required to compress the beam in the next magnetic chicane. The second linac (Linac 2) drives the beam up to 2.5 GeV while damping the correlated energy spread, taking profit of the effective contribution of the longitudinal wake fields provided by the S-band accelerating structures.

Table 1 – Beam Parameters

Beam Energy	2.5	GeV
Peak current	2	KA
Emittance (projected)	2	μm
Emittance (slice)	1	μm
Energy spread	0.1	%

In the Fully Magnetic Scheme the first compression stage is provided by a magnetic chicane after the Linac 1 at 350 MeV. An intermediate linac section, Linac 2, drives the beam up to 1 GeV. The next magnetic chicane compresses the beam up to the project requirements. The final Linac 3 brings the beam up to 2.5 GeV, while compensating the final energy spread of the beam.

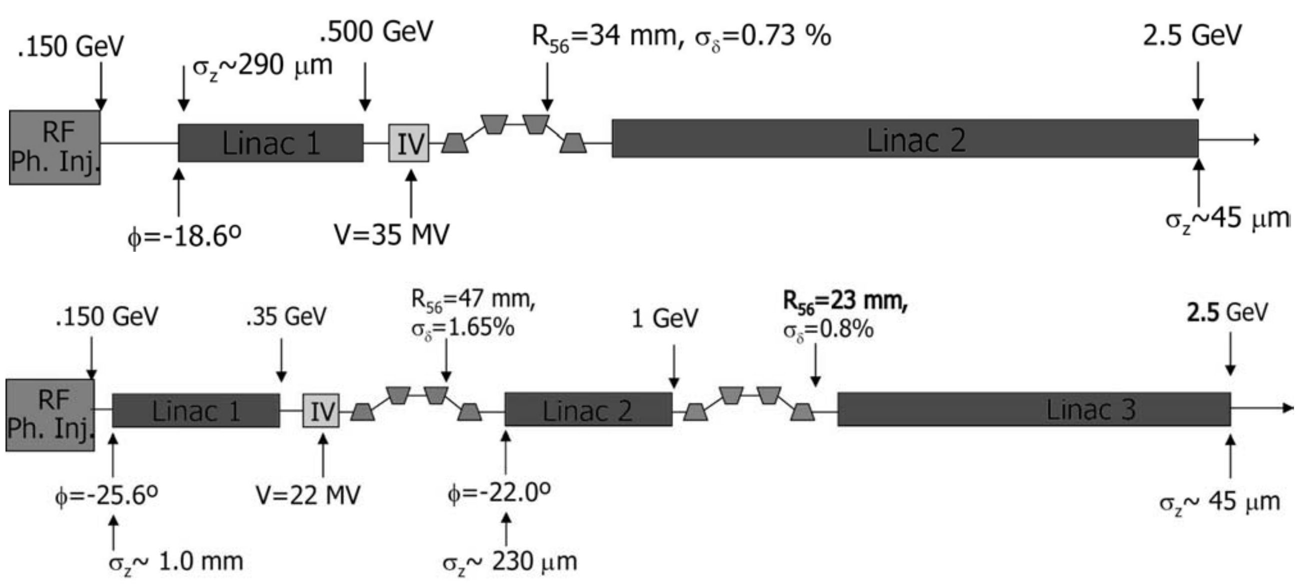

Figure 1: Schematic layout of the two SPARX linac designs: upper plot the Hybrid scheme, lower plot the Fully Magnetic scheme

Work supported in part by the Department of Energy contract DE-AC03-76SF00515.
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309
Presented at the Particle Accelerator Conference (PAC 03), 5/12/2003 - 5/16/2003, Portland, OR, USA

HYBRID SCHEME

The PhotoInjector design considers a 1 nC bunch, 10 ps long (flat top) with a 1.2 mm radius, generated inside a 1.6-cell S-band RF gun of the same type of the BNL-SLAC-UCLA one, operating at 140 MV/m peak field equipped with an emittance compensating solenoid (B=3090 G). Three standard SLAC 3-m TW structures each one embedded in a solenoid boost the beam up to 150 MeV. Applying the RF compression method, together with the proper setting of the accelerating phase and solenoid strength it is possible to increase the peak current while preserving the beam transverse emittance [2]. We have obtained, (Parmela [3] simulation), a bunch average current of 300 A with a normalised rms emittance below 1 μm, as shown in figure 2, using the parameter setting listed in table 2.

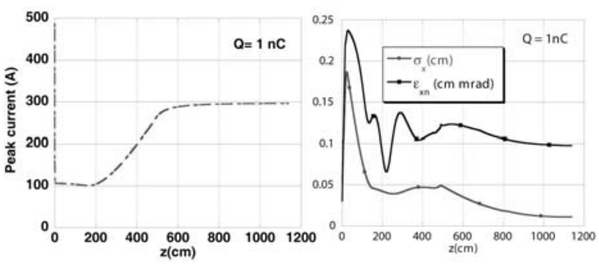

Figure 2: Parmela simulations of the peak current (left), rms norm.emittance and rms beam envelope (right), along the PhotoInjector structure.

Table 2

TW section	I	II	III
Gradient [MV/m]	15	25	25
Phase [Deg]	-86	-37	0
Solenoid field [G]	1120	1280	0

The Linac consists in a first accelerating section, Linac I, where 7 standard SLAC 3-m structures bring the beam up to an energy of .5 GeV. The accelerating phase is -18.6°, and the resulting energy spread is about 0.7%. A fourth harmonic cavity (11.424 GHz), follows, 60 cm long, in order to linearise the beam energy correlation. A magnetic chicane with R_{56} = 34 mm, about 15 m long, compresses the beam from 290 μm to 45 μm. A second accelerating section, Linac II , with 34 SLAC structures, in which the beam travels on crest, brings the beam energy up to 2.5 GeV and remove the energy spread .

FULLY MAGNETIC SCHEME

The PhotoInjector system consists of a 1.6 cell RF gun operated at S-band and high peak field on the cathode, (120 MV/m), generating a 6 MeV beam. The gun solenoid field is B=2730 G, and the injection phase is 33°. The beam is then focused and matched into 2 accelerating sections of the SLAC type, as described in [4]. Our simulations using PARMELA indicate that we can generate in this way a beam at 155 MeV with a rms correlated energy spread of 0.2%, and a rms norm. emittance of 0.6 μm (at 1.0 nC bunch charge and I = 90 A peak current). The slice energy spread and the slice norm. emittance, calculated over a 130 μm slice length, are well below 0.04% and 0.5 μm respectively, all over the bunch.

In the first accelerating section, Linac I, four standard SLAC 3-m structures bring the beam energy up to .35 GeV. The accelerating phase is -25.6°, and the resulting energy spread is about 0.17%. A fourth harmonic cavity follows in order to linearise the beam energy correlation. A magnetic chicane, about 3m long, with R_{56} = 47 mm compresses the beam from 1 mm to 230 μm. A second accelerating section, Linac II , with ten SLAC structures, operating at 22° off crest, accelerates the beam up to 1 GeV with energy spread 0.8%. The second chicane, R_{56} = 23 mm, 15 m long, compresses the beam up to 45 μm. In the third linac section, Linac III, twenty seven structures, accelerating the beam on crest, bring the beam energy up to 2.5 GeV and compensate the energy spread

TIMING JITTER ANALYSIS

One of the relevant aspects in the SPARX project is the sensitivity of the compression system to the laser pulse temporal jitter [5]. The performances of the two proposed schemes have been analysed and compared adding a 1° phase error at the RF gun injection stage.

The two channels have been optimized, with the code Litrack [6], to obtain the minimum sensitivity of the compressed beam properties to the phase error. For the hybrid scheme the optimized on has been performed on the channel downstream the RF compression stage, looking for the best combination of the relative phase of the first linac section, the X-band cavity voltage and the R_{56} value of the magnetic chicane. The same has been done for the purely magnetic channel regarding the parameters of the first two linac sections, the X-band and the two magnetic chicanes. The results are reported in table 3 and in figures 3 and 4. It's worth to notice that with the optimized Hybrid scheme in all of the three cases the final peak current is higher than 2 kA, and with the Purely Magnetic scheme, we have two cases with 2 kA and one with the peak current 10% lower.

Table 3

	Hybrid	**F. Magnetic**
$\Delta\phi$ (ps)	I_{peak}(kA)	I_{peak}(kA)
0	2.0	2.0
+1	1.9	1.8
-1	2.4	2.3

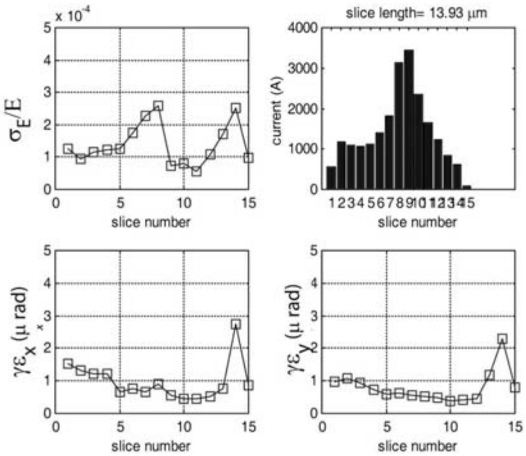

Figure 3: Slice analysis of the beam properties at the exit of the linac, for the hybrid reference case.

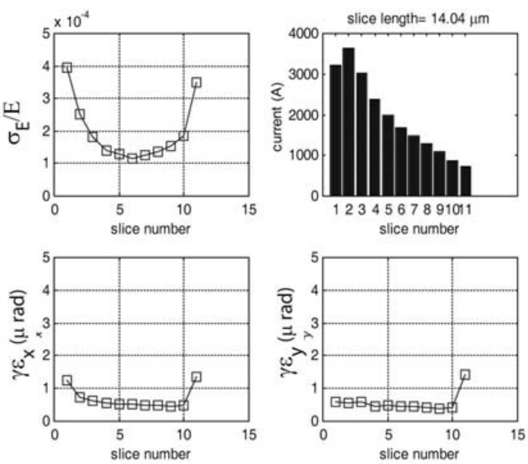

Figure 4: Slice analysis of the beam properties at the exit of the linac, for the fully magnetic reference case.

THE FEL SASE SOURCE

The beam quality has been tested by simulating the FEL process at the wavelength of 1.5 nm with the beam parameters obtained at the end of the last compression stage. The simulations have been done with the time dependent version of PERSEO [7]. The beam has been longitudinally "sliced" in five regions where the average parameters (emittance, energy, energy spread, current) have been calculated. The parameters of the slice with the higher current have been selected for the simulation. In table 4 a list of the "best slice" beam parameters for each case are shown. In table 5 the saturation length in presence of ±1° of phase jitter are reported for both schemes. The hybrid scheme with a phase jitter of +1° shows overcompression effects, resulting in more than 2 µm x-emittance. The magnetic saturation length is in this case of about 36 m.

Table 4

Case	I_{peak} (A)	ε_{nx}(m-rad)	ε_{ny}(m-rad)	γ	σ_E/E
Hybrid Reference	2790	0.83E-06	0.49E-06	4977	1.82E-04
Hybrid +1 °	2230	0.95E-06	0.51E-06	4982	5.53E-04
Hybrid -1 °	3330	2.13E-06	0.66E-06	4977	5.64E-04
Magnetic Reference	3237	0.84E-06	0.56E-06	5038	3.49E-04
Magnetic -1 °	2748	0.84E-06	0.62E-06	5038	2.80E-04
Magnetic +1 °	3744	1.10E-06	0.56E-06	5038	4.60E-04

Table 5

Case	Sat. L (m) (Steady State)	Sat. L (m) (Time Dependent)
Hybrid Reference	18.7	19.5
Hybrid +1 °	23.3	23.6
Hybrid -1 °	36.5	36.7
Magnetic Reference	18.5	19.0
Magnetic -1 °	19.6	20.5
Magnetic +1 °	19.9	20.2

CONCLUSIONS

We have analysed the effects of a phase jitter (±1°) on the SPARX beam quality considering two different concept for compression schemes,. The parameters have been set to obtain an equivalent compression factor between the two schemes. The slice parameters in terms of emittances, energy spread are comparable. The purely magnetic compression provides a more linearised longitudinal phase space which could in principle allow a further compression. We expect to obtain similar results also in the hybrid scheme with the IV harmonic cavity located upstream the RF compressor. The beam quality have been tested with time dependent PERSEO simulations showing a slightly lower sensitivity to phase jitter for pure magnetic compression. The low number of macroparticles considered in the ELEGANT simulations doesn't allow a correct representation of collective effects arising from the CSR coupling. A further effort in this direction is required to complete the analysis.

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