An electron front end for the Fermilab multi-species 8 GeV SCRF linac

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Overview

- Fermilab is considering a 8 GeV superconducting linac whose primary mission is to serve as an intense H- injector for the main injector (MI). This accelerator is also planned to be used for accelerating other species (protons, electrons, muons,...). In the present study we investigate the possibility to use the linac for accelerating electrons up to ~7 GeV. We propose a design for the electron front end and the needed modifications of the β=1 section of the linac to generate electron bunch with parameters similar to those anticipated in foreseen drivers for FEL-based light sources and linear collider (round beam) injectors

The SCRF linac

Overview:

- The propose SCRF linac will consist of six sections (see talk by Shekar Mishra):
  - Conventional RFQ,
  - Single spoke resonator,
  - Double spoke resonator,
  - Triple spoke resonator,
  - Squeezed TESLA cavity (for β=0.81)
  - Standard TESLA cavity (i.e. β=1) ← Part of the linac used for electron transport

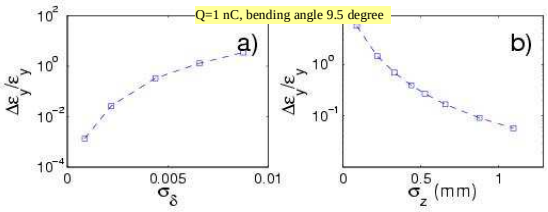
Sub-system associated to electrons

General considerations:

- The sub-systems associated to the generation, transport and manipulation of the electron bunch should be designed to have a minor impact on the linac primary design pertaining to H- transport,
- Only the β=1 section of the SCRF linac will be used for acceleration of the electron bunches (β<1 section would complicate the beam dynamics) [β=1 section is refer to as "main linac" hereafter]
- The electron injector must therefore be an off-axis injector (w.r.t. the main linac) and the use of a dispersion-less dog leg is required for injection in the main linac.
- We foreseen to fit the electron injector in the service building located above the β<1 sections of the SCRF linac

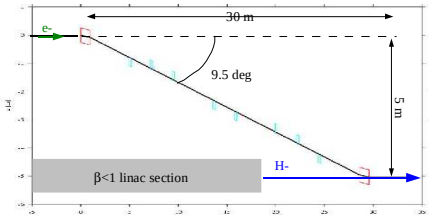
Off-axis injection of e- beam:

- The dog leg bending angle is a compromise between real estate, chromatic effect (due to non closure of high order dispersion) and coherent synchrotron radiation (CSR) induced emittance dilution

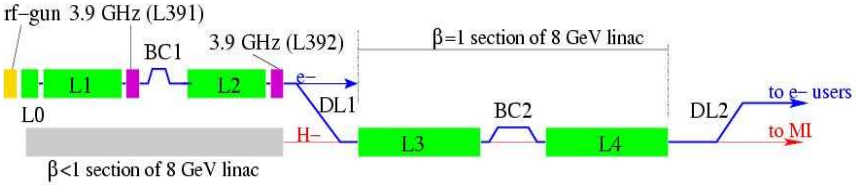


Vertical emittance dilution versus incoming beam fractional momentum spread (a) and incoming bunch length. The incoming energy spread should be < 0.2 %, the bunch length > 0.5 mm

Based on numerical simulation a dogleg was devised: the nominal bending angle is 9.5 deg, the incoming beam fractional energy spread should be kept below 0.2% while the rms bunch length (chromatic emittance dilution) should not be shorter than 0.5 mm (CSR induced emittance dilution).



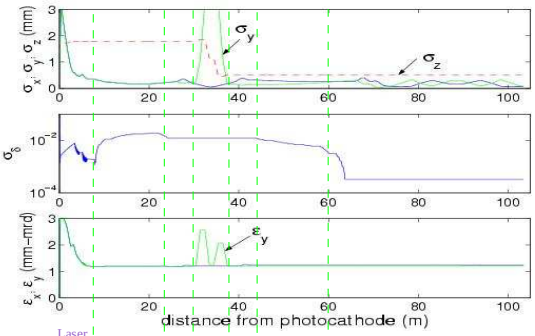
Floor view of the dogleg begin system



Overview of the SCRF LINAC along with e- sub-system. L0...L4 are 1.3 Ghz TESLA-type linacs, DL1, DL2 are dogleg, BC1, BC2 are magnetic bunch compressors, and L391, L392 are 3.9 Ghz accelerating section

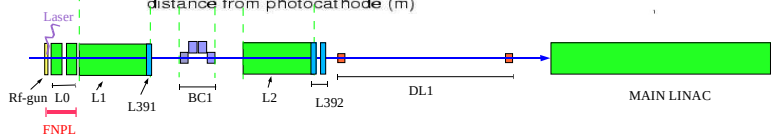
Fermilab/NICADD facility as a photoinjector

We propose to use the Fermilab/NICADD photoinjector larboratory (FNPL) to generate, prepare and inject the electron bunch in the main linac. FNPL is an L-band photoinjector under operation in the A0 Hall at Fermilab, and will soon be upgraded to finally consists of an RF-gun followed by two TESLA SRF cavities. This injector would produce an emittance compensated beam with ~40-50 MeV energy ready to be injected in a TESLA accelerating module for further acceleration



parameter	value	units
laser injection phase	44	rf-deg
laser radius on cathode	0.75	mm
laser flat top length	20	ps
laser rise time	2	ps
E-peak on cathode	66	MV/m
L0 accelerating voltage	12.5–25	MV
L0 phase	0 (on-crest)	rf-deg
L1 accelerating voltage	200	MV
L1 phase	-25 off-crest	rf-deg
L391 accelerating voltage	28.4	MV
L391 phase	+155 off-crest	rf-deg
L2 accelerating voltage	200	MV/m
L2 phase	0 (on-crest)	rf-deg
L392 accelerating voltage	28.0	MV
L392 phase	90 (0-crossing)	rf-deg
reduced energy γ	182.5	-
charge Q	1	nC
bunch length σ_z	516	μm
frac. energy spread σ_δ	3.3×10^{-4}	-
norm. emit. ε_x	1.24	mm-mrd
norm. emit. ε_y	1.20	mm-mrd

Table 1: Nominal settings for the rf-stations and photocathode of the laser, and beam parameters downstream of DL1 (section part of table)

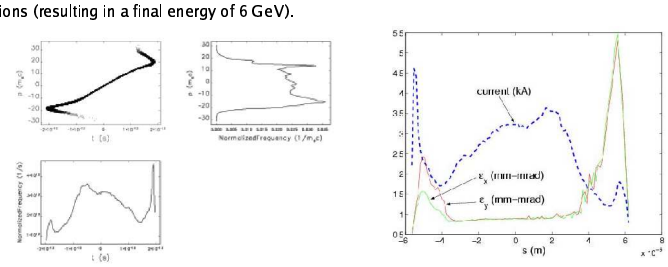


Beam dynamics in the photoinjector (see above table and figures):

- The beam is generated in an L-Band rf-gun using CsTe photo-cathode
- Downstream of the rf-gun, a ¼ TESLA accelerating module consisting of two cavities (12 MV.m and 25-35 MV/m) will accelerate the beam up to 40-50 MV (cavities are operate on-crest),
- The beam is then injected in a TESLA module (8 cavities operated at 25 MV/m) operated off-crest to impart the proper time-energy correlation for subsequent compression in a bunch compressor (BC1)
- Upstream of BC1, 3rd order accelerating section provide a knob for correcting longitudinal phase space distortions,
- Downstream of BC1, the beam is accelerated up to 400 MeV and then passed through a second 3rd order section (operated at zero-crossing) for removal of correlated energy spread before injection in the (narrow energy band width) dog leg DL1.

Impact on the main linac design

- Because of the off-axis injection requirement, it is not possible in our present injector design to compress the bunch down to 50 microns (to reach multi-kA peak current) without significant vertical emittance dilution due to CSR in DL1.
- Instead we propose to incorporate in the main linac a pulsed dipole chicane that can be used to compress the bunch by a factor of ~10.
- Presently the chicane is located at 840 MeV (the linac L3 is operated approximately 56 deg off-crest and the linac L4 on crest). Both linac have an accelerating gradient of 20 MV/m in the present simulations (resulting in a final energy of 6 GeV).



Longitudinal phase spaces and slice beam parameters at 6 GeV (before extraction with DL2)

Conclusion

Preliminary studies support the use of the proposed Fermilab SCRF linac to accelerate electron beam up to 7 GeV,
Using in-house expertise (work on photo-injector, development of 3.9 Ghz superconducting cavities), it is possible to built a photoinjector (based on the FNPL facility) to produce and prepare electron before injection in the b=1 section of the SCRF linac
More detailed studies (performance simulations, optimization) are on-going, along with R&D on possible application of such an electron beam (linear collider test facility, free-electron lasers,...)