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# Impact of the Suuperconducting Linac on the HEBT and Ring


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# IMPACT OF THE SUPERCONDUCTING LINAC ON HEBT AND RING

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## INTRODUCTION

The superconducting linac, now the choice for the SNS, has the potential to accelerate up 1.3 GeV by improving the accelerating gradient over the first few years of operations. It will be desirable that the transfer lines and the accumulator ring are compatible with 1.3 GeV operation. This means that the transfer lines and accumulator ring should work at 1 GeV on day one, and as the linac energy increases, these should also work at 1.3 GeV with some changes. These changes in the energy cannot be continuous because two of the injection chicane dipoles have to change for every energy step, as discussed below. The superconducting linac and desire for upgrade to 1.3 GeV will have several impacts on the transfer lines and accumulator ring.

## $H^-$ Stripping in HEBT

The Lorentz stripping of $H^-$ per meter is given by

$$fractional\_loss\_per\_meter \cup \frac{B}{A_1} e^{-\frac{A_2}{\beta\gamma c B}}$$

Where B is the magnetic field in Tesla, $\beta$,$\gamma$ are relativistic parameters, and $A_1$ and $A_2$ are constant and given by $A_1 \approx 8\text{x}10^{-6}$ Vs/m, $A_2 \approx 4.3 \text{ x } 10^9$ V/m .

For the 1 GeV design the magnetic filed of 0.3 Tesla was chosen to keep the stripping losses down to 1.2 x $10^{-7}$ per meter. To keep the same losses per meter at 1.3 GeV the magnetic field should be 0. 25 Tesla. Figure 1 shows the stripping losses per meter as a function of magnetic field for 1 and 1.3 GeV.

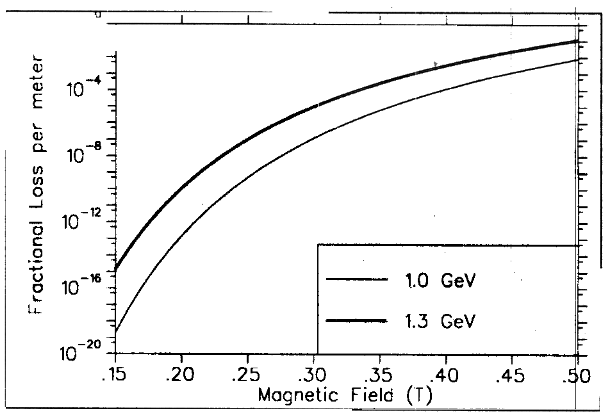


Figure 1: Fractional $H^-$ stripping loss per meter as a function of magnetic field.

For 1.3 GeV, the magnetic rigidity will increase by ~ 20% and the magnetic field has to decrease by about 20% to keep the stripping losses the same. Therefore, to obtain the same bending angle, the magnetic length will increase by about 40%. Table 1 shows the required magnetic fields and magnetic lengths for 1 and 1.3 GeV.

Table 1: Required magnetic field for 1 and 1.3 GeV to maintain same loss rate.

| **Parameters** | **1.0 GeV** | **1.3 GeV** |
|---|---|---|
| $\beta\gamma$ | 1.81 | 2.17 |
| Magnetic field for loss rate of 1.3 x $10^{-7}$ per meter | 0.3 T | 0.25 T |
| Magnetic length to bend 3 degrees | 1 meter | 1.42 meters |

**Transverse Matching**

Since the proposed superconducting linac transverse lattice consists of doublet focusing and the HEBT lattice is FODO, one will need an extra cell in the Linac to Achromat Matching Section (LAMS) in the HEBT to match the doublet lattice to the FODO lattice. An extra cell will increase the length of HEBT by 8 meters. Due to this extra matching cell and longer dipoles, the new 1.3 GeV compatible HEBT will be about 25 meters longer.

## Acceptable Energy Jitter and Spread

The SNS accumulator ring requires ± 4MeV energy spread at the injection foil for beam stability. Figure 2 shows the energy spread at the end of the normal conducting linac, before the buncher cavity, and at the foil when the buncher cavity is off.

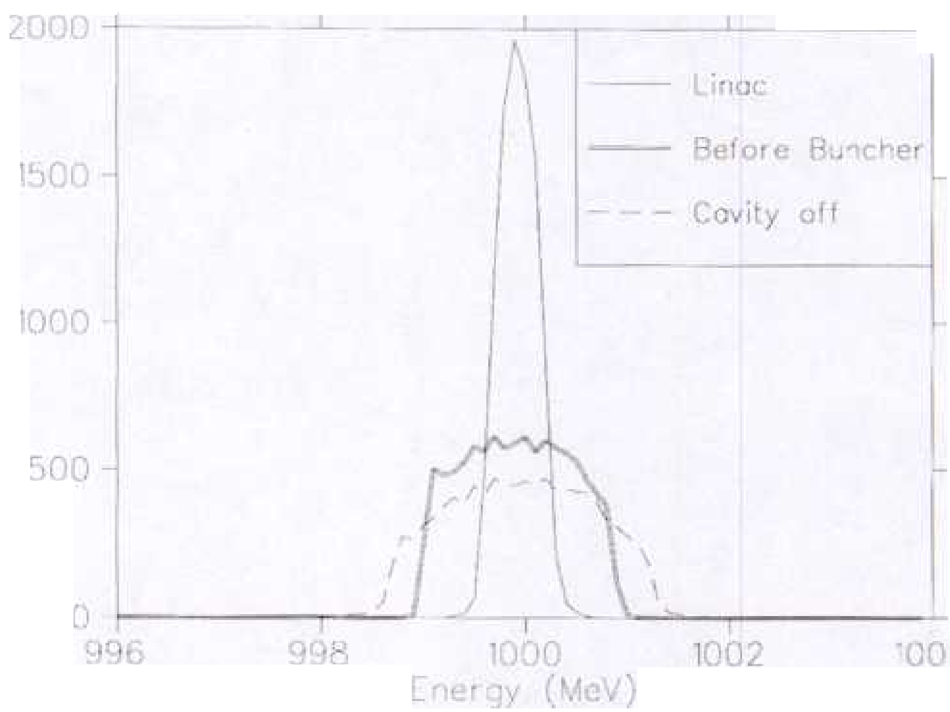


Figure 2: Energy spread at end of linac, at the buncher cavity, and at the injection foil when the cavity is off for normal conducting linac.

The energy spread is about ± 1.8 MeV for 99.99% of the beam. This means the maximum allowable energy jitter is about ± 2.2 MeV.

The proposed scheme to provide controlled energy spread is to use an RF cavity (energy spreader) at 805 MHz ±100 kHz to provide a random phase scan. The resulting beam energy distribution is shown in figure 3.

Figure 3 also shows the energy distribution one would obtain by a conventional debuncher. The long energy tails are reduced significantly with the phase scan.

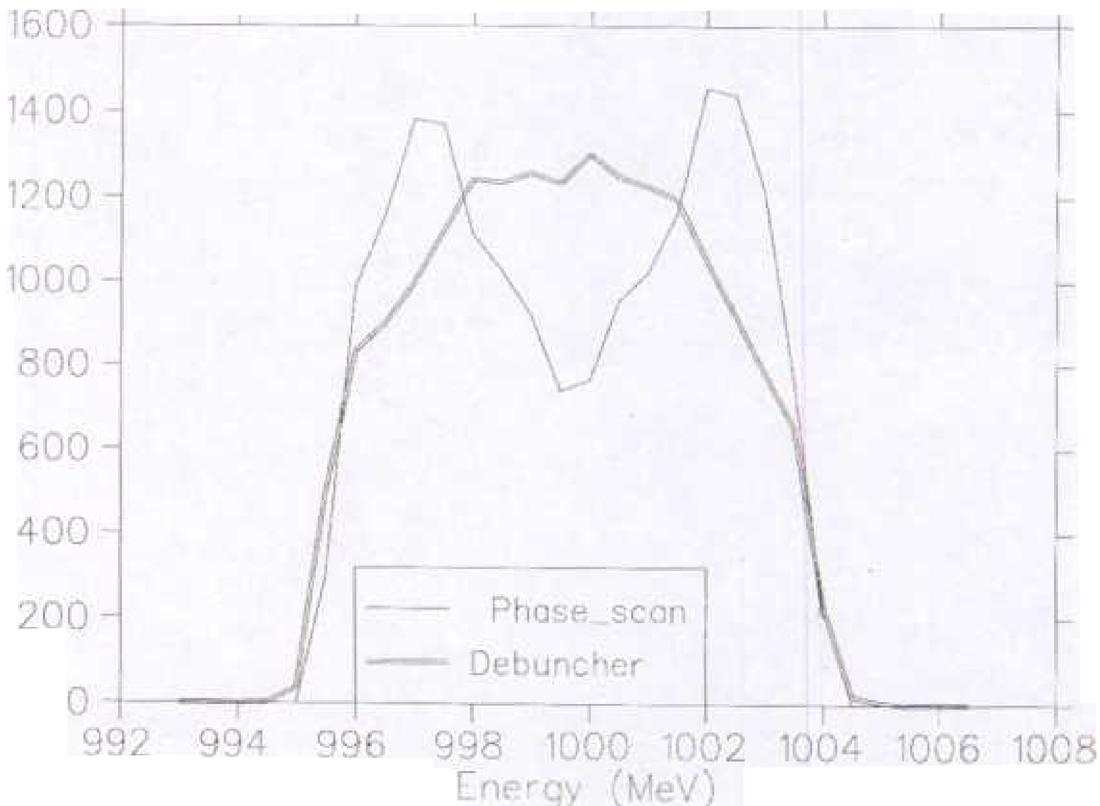


Figure 3: Energy distribution at injection foil using an RF cavity at 805 MHz ±100 kHz (phase scan) and for a conventional debuncher.

There will be another RF cavity (energy corrector) before the energy spreader cavity to correct the energy jitter from the linac. This RF cavity will operate at same frequency as the linac (805 MHz) and will be phase locked with linac. Figure 4 shows the plot of linac phase jitter and the energy jitter below which all the energy can be corrected for all the available places for the corrector cavity in the present HEBT and 1.3 compatible HEBT. At present, for the normal conducting linac, the energy and phase errors are about ±2.2 MeV and ±6 degrees due to phase and amplitude errors of 0.5 deg and 0.5%. To correct this energy error, there is a corrector cavity located 77 meter downstream of the linac, which can have the maximum voltage of ±2.7 MV. At the cavity, the phase slip due to energy error is about 17 degrees/MeV.

For the new HEBT compatible with 1.3 GeV, the energy corrector cavity will be located about 85 meters downstream of the linac. At this location, phase slip due to energy error is about 20 degrees/MeV for a 1.0 GeV beam and about 11 degrees/MeV for 1.3 GeV. The predicted phase and energy jitter for the superconducting linac are lower than the limits in shown figure 4[1]. The required voltage for 1 GeV will be about 3.0 MV and for 1.3 GeV will be about 4.8 MV.

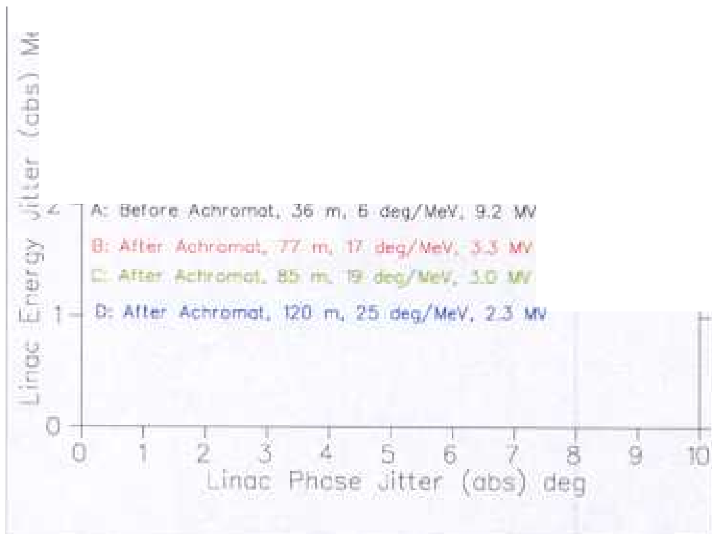


Figure 4: Correctable phase and energy jitter out of the linac with the corrector at different locations in the HEBT. Points below the line are correctable.

Table II shows the predicted phase and energy jitter for normal conducting and superconducting linac if the phase and amplitude errors are 0.5 degrees and 0.5%. The energy corrector cavity can correct energy jitter in the both cases. In case of 1.3 GeV beams it needs 4.8 MV. There is enough space in the 1.3 GeV compatible HEBT for a longer rf cavity.

Table II: The predicted phase and energy jitter for normal conducting and superconducting linac if the phase and amplitude error are 0.5 degrees and 0.5%.

| | Phase Jitter (degrees) | Energy Jitter (MeV) | References |
|---|---|---|---|
| NC linac | ±6 | ± 2.2 | 2 |
| SC linac | ±1.5 | ± 1.5 | 1 |

**Acceptable Transverse Emittance**

For the present hybrid ring lattice the average number of foil hits during accumulation is shown in Figure 5 as a function of linac emittance. This average number of foil hits was calculated for a given beam distribution on target [3]. For the correlated option beam is painted in the 120 π mm mrad and for the anti-correlated option beam painted in the 160 π mm mrad phase space area. Figure 6 shows the fractional nuclear scattering losses as a function of the linac emittance. Assuming these losses will occur in the injection area (~ 10 meter), Figure 7 shows the estimated radiation level for a 100-day run at 1 foot from the beam line, 4 hours after shutdown, in the injection area as a function of linac emittance.

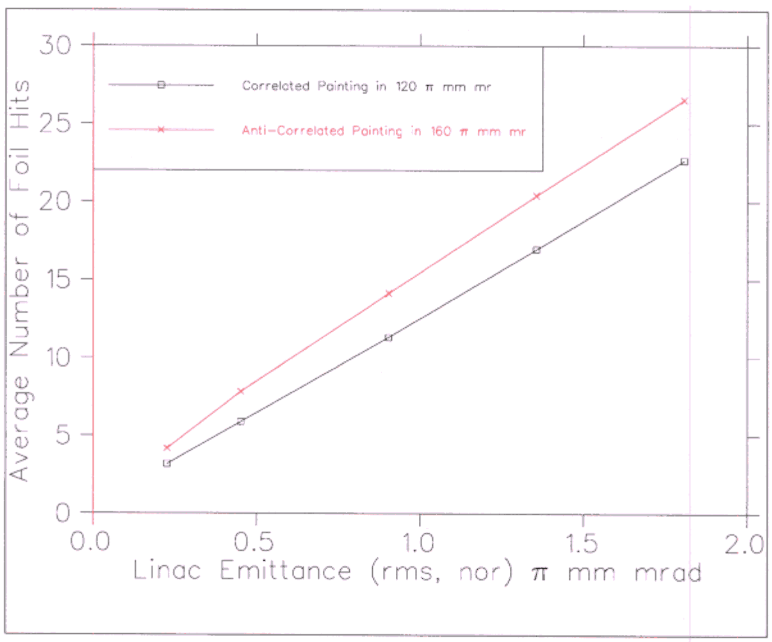


Figure 5: Average number of foil hits during the accumulation (1225 turns) as a function of linac emittance. For the correlated option the painted phase space area is 120 π mm mrad and for anti-correlated painting, the phase space area is 160 π mm mrad.

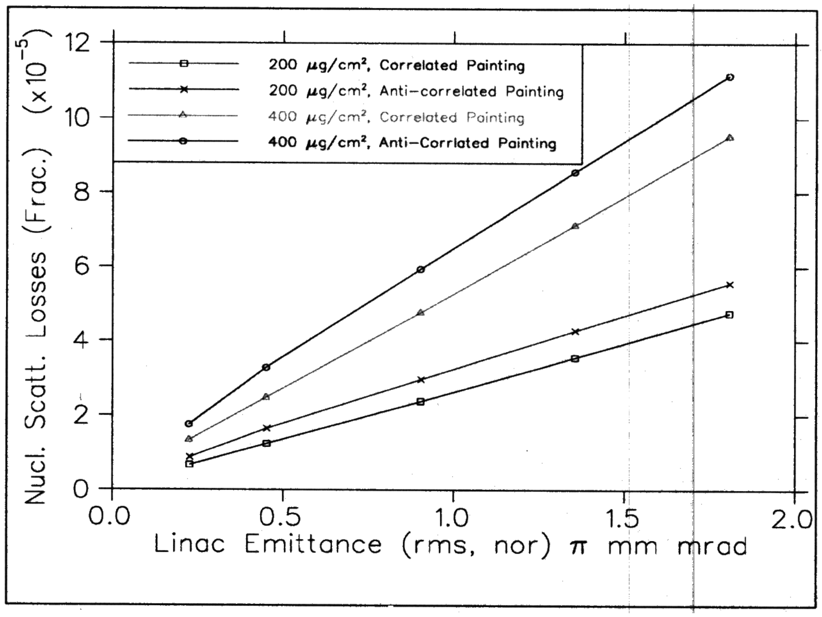


Figure 6: Nuclear scattering losses due to foil traversal during the injection (1225 turns) as a function of linac emittance.

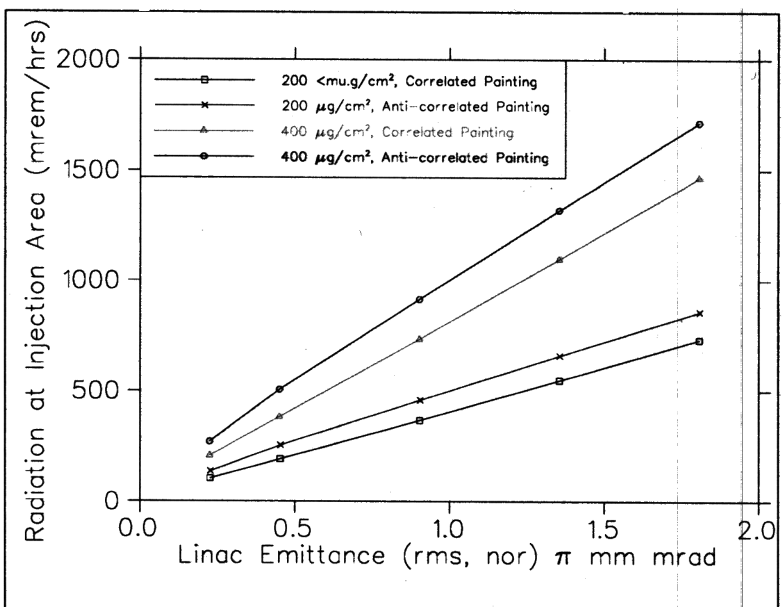


Figure 7: Radiation level, for a 100-day run, at 1 foot from the beam line, 4 hours after shutdown, in the injection straight section as a function of linac emittance. This assumes all nuclear scattering losses are located in the injection straight section.

The present injection septum design can accommodate a maximum linac emittance of 0.5 pi mm mrad (rms, normalized). If the linac emittance becomes larger, the septum design will have to be changed.

For the 1.3 GeV compatible design the average number of foil hits will be reduced by 10% at 1.0 GeV. At 1.3 GeV the number of hits will be increased by about 50%.

## $H^-$ and $H^0$ Stripping at Injection

The length of the injection straight section has to longer to accommodate 40% longer injection chicane magnets to avoid $H^-$ Lorentz stripping. To prevent foil stripping to $H^0$ in n=4 and lower excited states, the injection stripping foil is located downstream of the injection dipole at a field of 2.4 kG. Figure 8 shows the lifetime of excited states of $H^0$ as a function of the magnetic field.

The desirable field to put the stripping foil in is about 2.1 -2.5 kG, therefore one has to change two injection dipoles when going from 1 to 1.3 GeV. Figures 9 and 10 show the schematic layout of the injection straight section for 1.0 and 1.3 GeV.

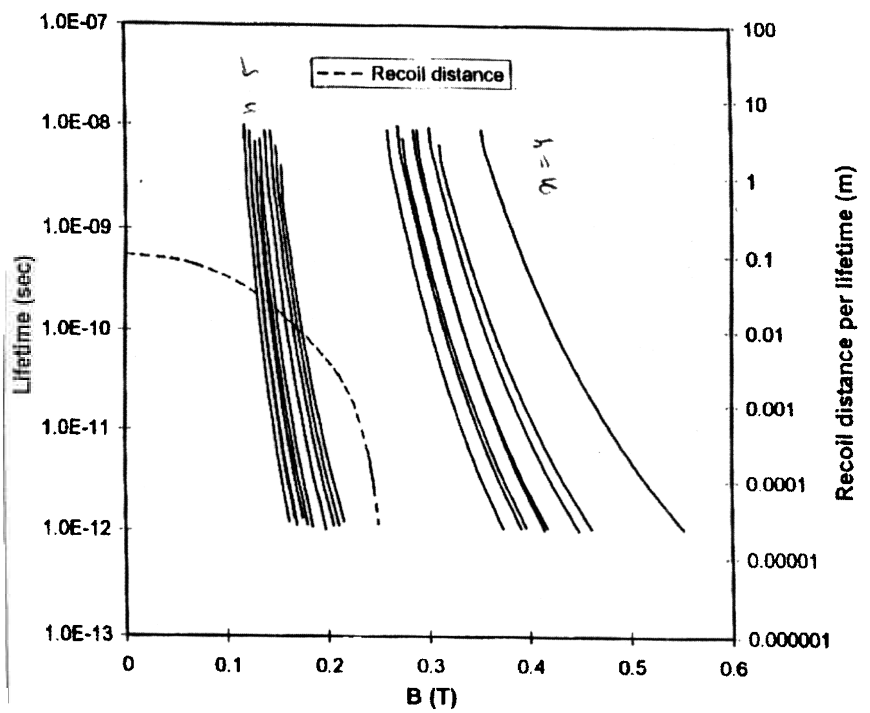


Figure 8: The lifetime of excited states of $H^0$ as function of the magnetic field.

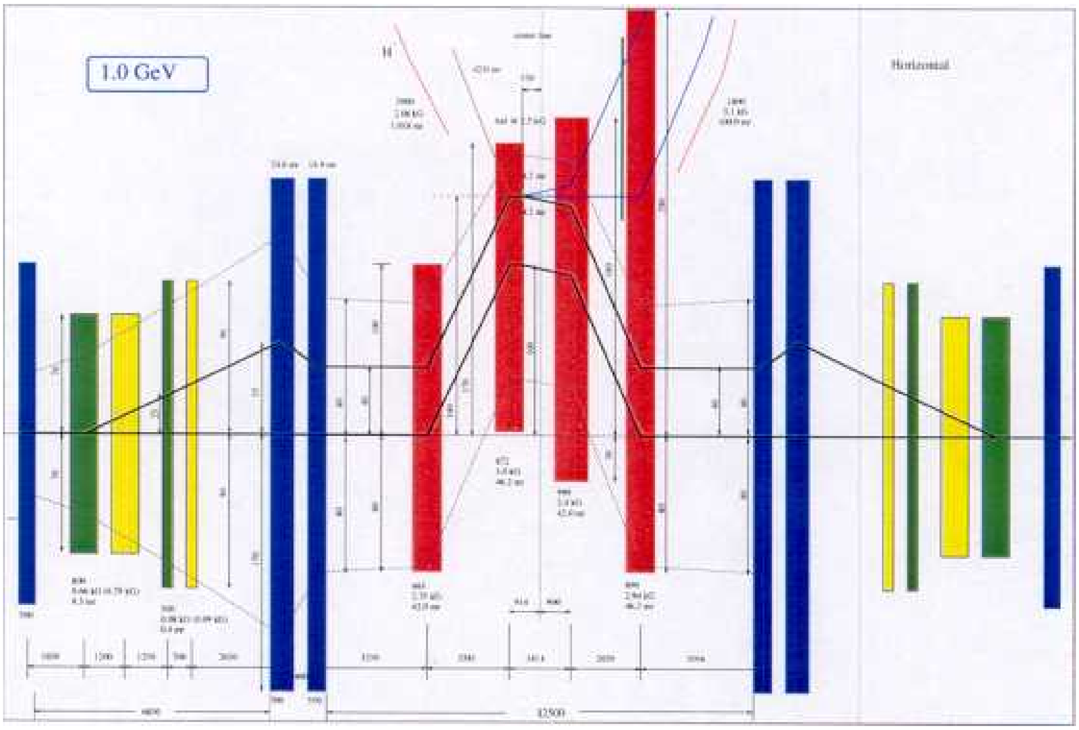


Figure 9. Schematic layout of the injection straight section for 1.0 GeV. The red elements are the fixed injection chicane, the blue are ring lattice quadrupoles, and the yellow and green elements are vertical and horizontal dynamic kickers, respectively.

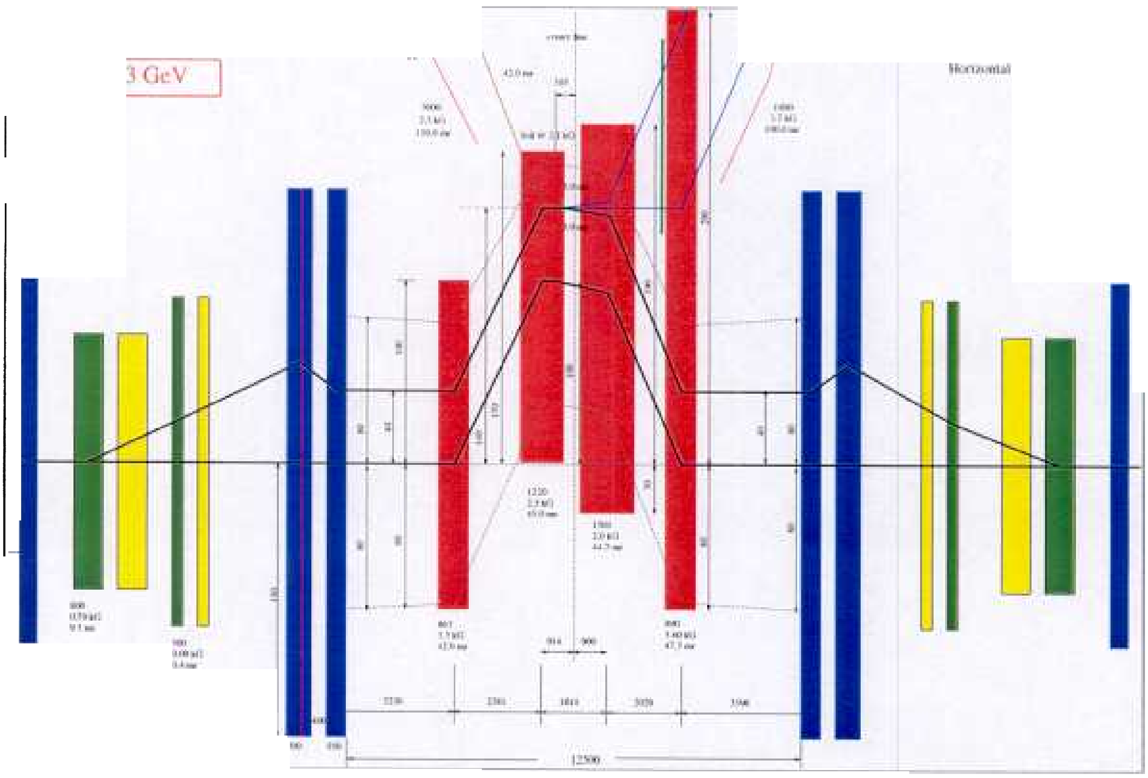

Figure 10. Schematic layout of the injection straight section for 1.3 GeV. The red elements are the fixed injection chicane, the blue are ring lattice quadrupoles, and the yellow and green elements are vertical and horizontal dynamic kickers, respectively.

Table III shows the magnet parameters of the two replaceable fixed chicane dipoles.

Table III : The magnet parameters of the two replaceable fixed chicane dipoles.

| | Length (mm) | Field (T) | Deflection Angle (mr) |
|---|---|---|---|
| | B2 (Before Injection Foil) | | |
| 1.0 GeV | 872 | 0.30 | 46.2 |
| 1.3 GeV | 1220 | 0.25 | 45.0 |
| | B3 (After Injection Foil) | | |
| 1.0 GeV | 990 | 0.24 | 42.0 |
| 1.3 GeV | 1501 | 0.20 | 44.3 |

**Collimators**

Due to the greater range, the collimator length for future .3 GeV operation should increase by about 50%.

**Longitudinal emittance under fault conditions**

Under normal operating conditions, both room temperature and superconducting linacs have an acceptable energy spread. It is generall said that the superconducting linac can continue to provide beam at reduced final energy with more than 2 failed cavities. In this case one has to careful that the longitudinal emittance does not become too large [4]

**References:**


[1] Preliminary Design Report, Superconducting Radio Frequency Linac for the Spallation Neutron Source, page 24, figure 2.1.

[2]T. S. Bhatia, J. H. Billen, A. J. Jason, G. H. Neuschaefer, S. O. Schriber, H. Takeda, K. R. Crandell, SNS Linac: a Physics design for the 805-MHz structures, Los Alamos Report, LA-UR-98-5227.

[3] J. Beebe-Wang, Y. Y. Lee, D. Raparia, J. Wei, Transverse Phase space painting for SNS Accumulator Ring Injection , to be published in the proceedings of the 1999 Particle Accelerator Conference, New York, USA

[4] E. R. Gray, S. Nath and T. P. Wangler, Simulated performance of the superconducting section of the APT linac under various fault and error conditions , Proceeding of the 1997 Particle Accelerator Conference, Vancouver, B.C. , Canada, p 1153