

Bunch Length Collimation in the NLC

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In order to achieve high luminosity, the NLC requires very short bunches. The three primary considerations that determine the bunch length are: the bunch length is not larger than β_y^* , the emittance growth due to the transverse wakefields increases with the bunch length, and the energy spread due to the longitudinal wakefield increases as the bunch length is decreased. For the NLC parameters, the optimal bunch length is between 100 and 200 μm .

When generating these bunches in the bunch compressors, one typically populates long bunch length tails. These tails will be deflected to large transverse amplitudes by the transverse wakefields. In addition, the long longitudinal tails will be converted into energy spread as it goes through the main linac. In the final focus, the energy tails will generate a transverse halo due to chromatic effects. Both sources of transverse tails will create unacceptable background in the detector. Therefore, the longitudinal tails have to be collimated before entering the final focus. It is better to do it at the beginning of the main linac.

Collimation

To avoid those problems, we decided to design a bunch length collimation system for the NLC. The system should be located before or at the beginning of the NLC main linac, and remove the particles beyond $3\sigma_z$ in longitudinal direction.

The only way to cut longitudinal tails is to convert it to transverse direction and remove it by collimator. The ideal case is the bunch length has monotonic energy distribution, i.e. the bunch length tails are energy tails. The energy spread can be transferred into horizontal displacement with dispersion. Collimators are set there to cut the tails, so that the bunch length tails are removed.

Collimator location

Figure 1 is the layout of the damping ring to the final focus of the NLC. The damping ring, two steps bunch compression and the X-band main linac.

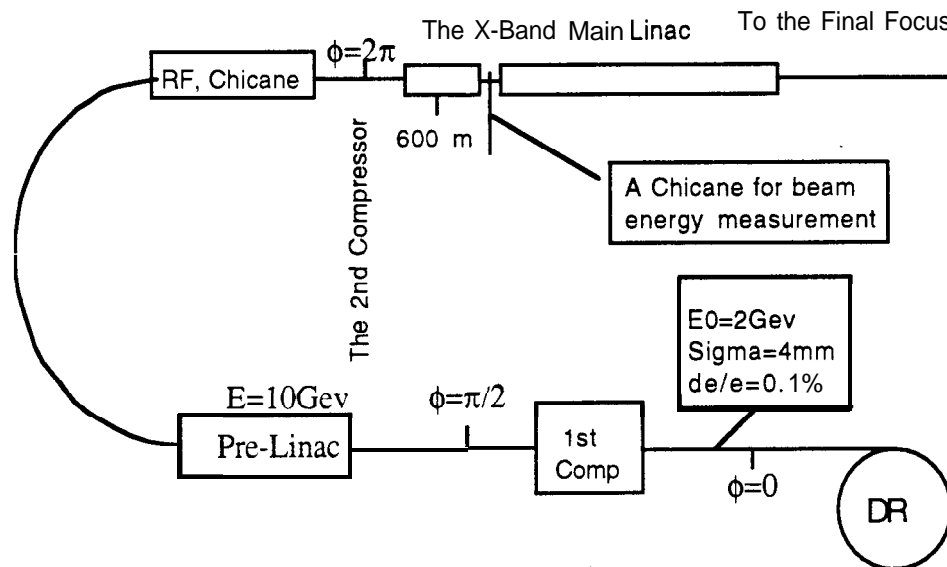


Figure-1 The layout of NLC (not on scale)

The longitudinal phase $\Phi = n\pi$ is right phase to have collimator. So, we choose the first collimation at the exit of the damping ring. Here, the energy spread is small (0.1 %), for $3\sigma_z$ bunch length collimation, it needs to cut beyond $\pm 0.3\%$ energy spread particles, assuming the collimator $1/2$ gap = $1500 \mu\text{m}$, $\sigma_e/E = 0.1\%$ and the dispersion $\eta = 0.5 \text{ m}$ is needed. There is a spin rotation system has been designed at this location. It is achievable to have 0.5 m dispersion in the system.

The second bunch length collimation is good to put at right after the second compressor. Due to the space limitation, we choose to put collimator at the first 600 meters of acceleration in the X-band main linac, since there is a chicane to be made for beam energy measurement.

Particles Loss Due to the Bunch Length Collimation in the Present NLC Design^[1,2]

We put the two bunch length collimation systems into the present two-step compression system and the main linac lattice design. When

considering to cut beyond $2\sigma_e$ energy spread particles, we can check how many particles loss at the collimators.

Table-1 particles loss percentage at the collimation systems

collimation location	beam loss %
the 1st collimation only	4%
the 2nd collimation only	2%
both collimations together	5%

The following figures show the bunch shape at the end of the -main linac. As calculated by a modification of K. Bane's LITRACK program.

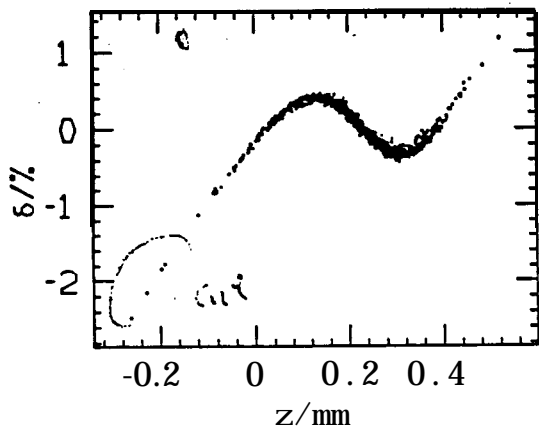


Figure 2 the bunch shane without the bunch length collimation

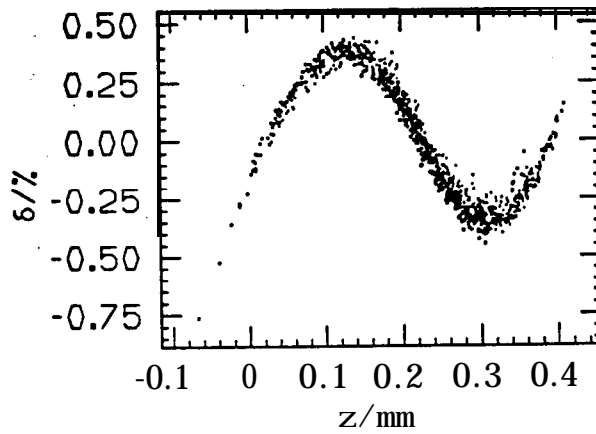


Figure 3 the bunch shane with the 1st bunch length collimation only.

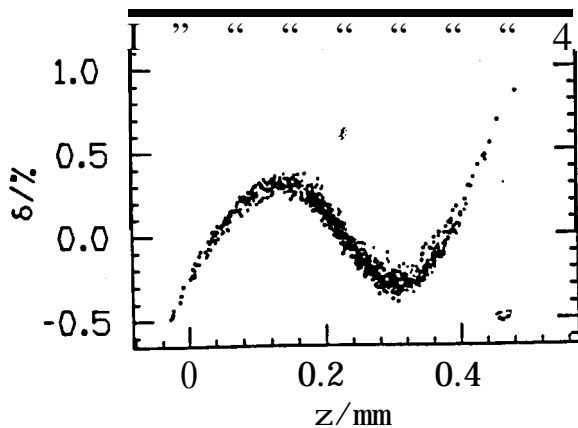


Figure 4 the bunch shane with the 2nd bunch length collimation only

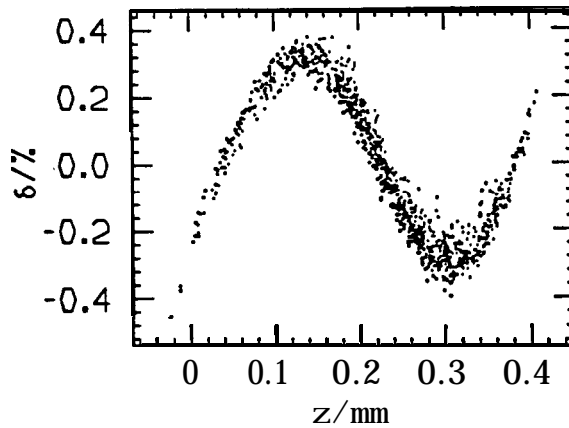


Figure 5 the bunch shane with both bunch length collimations.

NLC Bunch with monotonic energy distribution required

It is significant to make the beam energy has longitudinal monotonic distributions. Therefore, the bunch length collimation is made by energy tails cut. To meet above requirement, we can choose the main linac RF phase and put the beam behind the RF crest, so that there are only 10% of particles beyond $4\sigma_z$ have energy spread greater than $4\sigma_e$. So if a collimator 1/2 gap = 750 μm , $\sigma_e/E = 1\%$ and dispersion $\eta = 2.5 \text{ cm}$, it implements $\pm 3 \sigma_e$ energy tails cut.

At the beginning of the main linac, the beam bunch length is 100 μm . The energy distributions are calculated by the following formula:

$$E(z) = E_0(z) + V_{\text{rf}} \cdot \cos(\Phi_0 + kz) - \int W_L(z'-z) \cdot \rho(z') \cdot dz'$$

Where $E_0(z)$, is the initial energy distribution at the beginning of the main linac. Here $E_0(z) = 10 \text{ GeV}$. V_{rf} is the main linac rf peak voltage. ' Φ_0 ' is the center particles' accelerating phase. k is the number of the rf wave form. $W_L(z'-z)$ is the main x-band linac longitudinal wake field, it was calculated by K. Bane. $\rho(z')$ is particles' distributions, here gaussian distributions are considered. Minus sign is for the wake field causing beam energy loss.

Table-2 Some narameters for the three NLC design phases

	NLC-I	NLC-II	NLC-III
RF phase	16"	16"	16"
energy gain in 600 m	33 mv/m 20Gev	55 mv/m 33Gev	70 mv/m 42Gev
# of particles	$7 \cdot 10^9$	$11 \cdot 10^9$	$14 \cdot 10^9$
energy spread	1.0%	1.2%	1.28%
# of particles to be cut (%)	$1.54 \cdot 10^8$ (2.2%)	$3.30 \cdot 10^8$ (3.0%)	$7.84 \cdot 10^8$ (5.6%)

We assume the particle energy has gaussian distribution at the first 600 meters of acceleration in the main linac. For the three NLC design phases, when 16" of the RF phase is chose, behind the RF crest, the beam energy spreads are about 1%. It is we expected. If we put collimator to cut

$\pm 2 \sigma_e$ (i.e. $\pm 2\%$) the energy tails, where there are less than 10% particles to be cut. Table-2 lists some parameters and the percentages of particles are lost at the collimators. Figure 6 shows the energy distribution along the bunch.

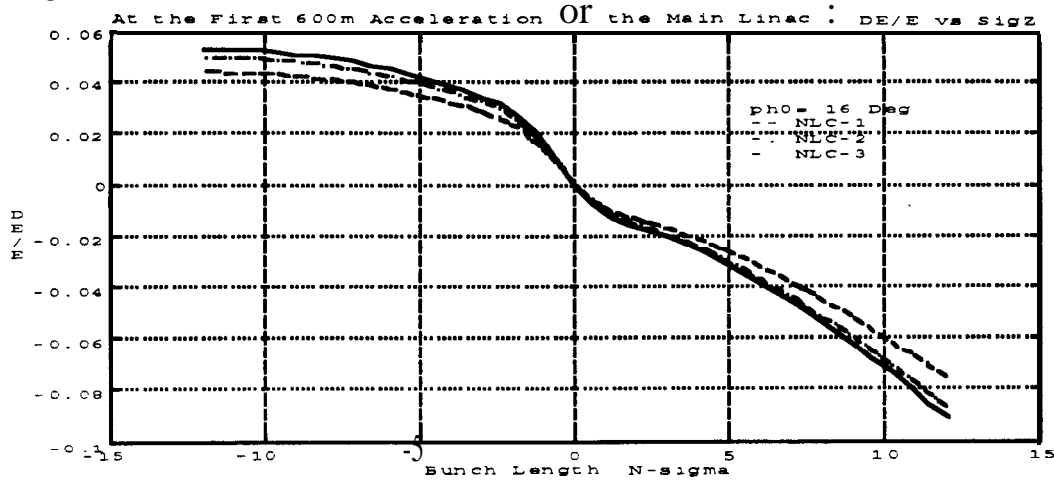


Figure-6 Energy distributions for the three NLC design phases

Conclusion and discussion

As we see, the bunch length collimation is important to the final luminosity achievement. It is possible to have two bunch length collimations in the NLC design lattice. The bunch has nearly monotonic energy distributions, when we choose the RF phase is 16° behind the RF crest for all three NLC design phases. The energy spreads are about 1%. If we decide to collimate $\pm 2\%$ energy tails, there will be less than 10% of particles cut at the collimation systems. Before determining the utility of the collimators, a number of additional questions remain to be answered. In particular, we need to study the longitudinal and transverse wake fields induced by the collimations and the related tolerances.

Our results show that the collimator at the exit of the damping ring is relatively straight forward and is effective. Because of the non-linear δ -z, and therefore x-z dependence, the second collimation in the linac may be more difficult.

References

- [1] T. O. Raubenheimer, NLC-Note 2
- [2] F. Zimmermann, NLC-Note 3