NLC - The Next Linear Collider Project

NLC Final Focus Developments

Pantaleo Raimondi, Andrei Seryi
SLAC

NLC Collaboration Meeting
Fermilab
February-March 2001
Plan of the talk

• **Main features of new Final Focus vs “traditional”**
  – Concepts and problems of “traditional” Final Focus
  – Principles of new FF
  – Bandwidth, energy range, background

• **Recent developments for NLC FF**
  – Background control and collimation

• **Conclusions**
Final Focus task

**FF should focus the beams to small sizes at IP**

- Chromaticity of FF is determined by the final doublet
- FD chromaticity scales as $L^*/\beta^*$, and thus the chromatic dilution of the beam size $\Delta \sigma/\sigma \sim \sigma_E L^*/\beta^*$ is very large
- Design of a FF is driven by the necessity of compensating the FD chromaticity
Concepts and problems of traditional FF

- Chromaticity is compensated by sextupoles in dedicated sections
- Geometrical aberrations are canceled by using sextupoles in pairs with \( M = -1 \)

**Problems:**

- Chromaticity not locally compensated
  - Bandwidth limited since \( M \neq -1 \) for off energy particles
  - Sensitivity to \( \delta E \) in between the sources of chromaticity
  - Bends have to be long and weak
  - Large aberrations for beam tails
  - Long, scaling to high \( E \) difficult

SLC FF, FFTB and extrapolated NLC-FF design are conceptually identical
FFTB ~150m long! NLCFF ~1750m long!
Principles of new FF

- Final Doublet is required to provide the necessary demagnification.

- Chromaticity is cancelled **locally** by two sextupoles interleaved with FD, a bend upstream generates dispersion across FD.

- Geometric aberrations of the FD sextupoles are cancelled by two more sextupoles placed in phase with them and upstream of the bend.
A new FF with the same performance as NLC FF can be ~300m long, i.e. 6 times shorter.
Further extensions of new FF: longer L*

New FF with twice L* and with an additional bend and with soft bend.

Larger L* allows the use of large bore quadrupoles which decreases collimation requirements.

Larger L* also simplifies the design of the detector, and allows to make more rigid support of the FD.

<table>
<thead>
<tr>
<th>Table 1: Beam parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy (GeV)</td>
</tr>
<tr>
<td>Normalized emittances $\gamma\epsilon_x / \gamma\epsilon_y$ ($\mu$m)</td>
</tr>
<tr>
<td>Beta-functions $\beta_x / \beta_y$ at IP (mm)</td>
</tr>
<tr>
<td>Beam sizes $\sigma_x / \sigma_y$ at IP (nm)</td>
</tr>
<tr>
<td>Beam divergence $\theta_x / \theta_y$ at IP ($\mu$rad)</td>
</tr>
<tr>
<td>Energy spread $\sigma_E$ ($10^{-3}$)</td>
</tr>
<tr>
<td>Angular dispersion $\eta_x^I$ at IP ($10^{-3}$)</td>
</tr>
</tbody>
</table>

Optics of the new NLC FF. (ver ff01) L* = 4.3m

$L*$ should be optimized considering both detector and accelerator issues.
NLC - The Next Linear Collider Project

IP bandwidth

- The IP bandwidth for new FF with $L^*=4.3m$ is similar or better than for the traditional FF with $L^*=2m$. 

IP bandwidth of the traditional and new NLC FF.

- $(\beta/\beta_0)^{1/2}$ -- the beam size defined from beta function vs $\Delta E/E$
- $\sigma/\sigma_0$ -- luminosity equivalent beam size vs $\Delta E/E$
- $L/L_0$ -- luminosity versus rms $\sigma_E$
FD bandwidth

- The FD bandwidth is rarely discussed but very important.
- Large FD bandwidth is necessary to minimize background due to off energy particles.
- New FF has much larger FD bandwidth.

FD bandwidth of the Traditional and New NLC FF. Normalized betatron functions at the final doublet versus energy offset $\Delta E/E$. 
Multi TeV energy range of new FF

- New FF with fixed geometry can go up to ~1TeV CM
- From 1TeV and higher one need to adjust geometry. Possibly, that the IP position may be kept fixed by adjusting upstream of FF optics

Geometrical Luminosity vs CM energy for the new FF for different parameter sets

[3 TeV parameters: CLIC report 2000-008]
[5 TeV parameters: PAC97 Delahaye et al.]
Collimation and background …

- Traditional FF generate beam tails due to aberrations and it does not preserve betatron phase of halo particles.
- New FF is virtually aberration free and it does not mix IP and FD phase particles.

Both IP and FD phase collimation required for traditional FF.

Collimation design may benefit from smaller amount of aberrations of the new FF.

Halo beam at the FD entrance. Incoming beam has 100 times larger coordinates in IP phase than in FD phase.

Particles of incoming beam are placed on a surface of an ellipsoid with dimensions $N_\sigma(x,x',y,y',E) = (800,8,4000,40,20)$ times larger than nominal beam parameters.
Summary of new FF benefits

- New FF is much shorter => significant cost reduction
- New FF has similar bandwidth and several orders of magnitudes larger dynamic aperture than the traditional FF
- New FF is compatible with $L^* = 4.3m$ that simplifies engineering of the IP area, and probably helps the stabilization of the final doublet
- Scaling to multi-TeV region is extremely attractive for the new FF

- New FF is much more aberration free, both for the beam core and for beam tails =>
  - Background is less of an issue in the new design. Collimation requirements and procedure may be relaxed with the new FF

Recent developments are being devoted to this issue see next pages…
Final Focus and background

- Experience of SLC Final Focus shows that:
  - X & Y spot sizes were limited by background and aberrations

- Background is also a concern for future machine...

SLC FF, FFTB and traditional NLC-FF were conceptually identical: non-local chromaticity correction
SLC Background

Tracking identified large contribution to the background from high order aberrations in the “FD phase” generated in the CCS of the SLC FF

Example:
sextupoles were added to minimize

$$T_{226} = \frac{d^2x^i}{dx'dE/E}$$

Luminosity greatly improved, since smaller IP $\beta^*$ were allowed and detector Up-Time increased
Background and collimation

- Major source of detector background:
  - particles in the beam tail which hit FD and/or emit photons that hit vertex

- Tails can come
  - From FF, due to aberrations
    (New FF designed to have much less aberrations)
  - From linac, etc.

- Tails must be collimated, amount of collimation usually determined by
  - Ratio: FD bore / beam size at FD

- Most tough in x-plane, where collimation at just several sigmas envisioned
Background in new FF

- **New FF already has nice properties in terms of background:** it does not create tails
  - It has much less aberrations, it does not generate tails, does not mix FD and IP phase particles
  - Has large FD bandwidth, moreover, off energy particles have smaller size in FD
  - Dispersion across FD does not increase beam size in FD

- **Is it possible then to require even more?**
  Can FF ameliorate incoming beam tails so that they do not generate background in FD?

*Would this be possible, the requirements to collimation could be relaxed*
Nonlinear handling of beam tail

- One wants to focus beam tails but not to change the core of the beam
  - use nonlinear elements

- Several nonlinear elements needs to be combined to provide focusing in all directions
  - (analogy with strong focusing by FODO)

- Solution has been found that uses octupole doublets for nonlinear tail folding in NLC FF
Strong focusing by octupoles

- **Two octupoles** of different sign separated by drift provide **focusing in all directions** for parallel beam:

\[
\Delta \theta = \alpha r^3 e^{-i3\varphi} - \left(\alpha r^3 e^{i3\varphi}(1 + \alpha r^2 L e^{-i4\varphi})^3\right)^* 
\]

\[
x + iy = re^{i\varphi}
\]

\[
\Delta \theta \approx -3\alpha^2 r^5 e^{i\varphi} - 3\alpha^3 r^7 L^2 e^{i5\varphi}
\]

Focusing in all directions

Next nonlinear term focusing – defocusing depends on \( \varphi \)

- For this to work, the beam should have **small angles**, i.e. it should be parallel or **diverging**
NLC FF with two octupole doublets

- Two octupole doublets are placed in NLC FF for active folding of beam tails.

- Two octupole doublets give tail folding by ~ 4 times in terms of beam size in FD.

- This can lead to relaxing collimation requirements by ~ a factor of 4.

NLC FF, v.54, with two octupole doublets placed in the region where beam is diverging.
Tail folding in new NLC FF

- Two octupole doublets give tail folding by ~ 4 times in terms of beam size in FD
- This can lead to relaxing collimation requirements by ~ a factor of 4

Tail folding by means of two octupole doublets in the new NLC final focus
Input beam has \((x,x',y,y') = (14\mu m, 1.2\text{mrad}, 0.63\mu m, 5.2\text{mrad})\) in IP units (flat distribution, half width) and \(\pm 2\%\) energy spread, that corresponds approximately to \(N\sigma = (65, 65, 230, 230)\) sigmas with respect to the nominal NLC beam
Tail folding reduce beam size in FD. And it does not produce problems in other elements.
Further developments of NLC FF

- If relaxing the collimation depth is indeed feasible, the collimation design becomes easier and should be reoptimized.

- First design of integrated collimation and final focus.

More studies needed!

FF v.54: collimation section and final focus with two octupole doublets
Conclusion

• **Final Focus System** is a **crucial point** in the linear collider designs

• **Years of experience** on SLC-FF and FFTB revealed what are the main limitations and problems and were melted into a “Next Generation FFS” design
  – More compact
  – Allows for a collider to be “adiabatically” upgraded up to 5TeV/CM
  – Much better control of aberration in new FF
  – Allows for active control of background

• **Next step**: more optimal Beam Delivery System that would use all the features of the new FF design