NLC Beam Delivery System Developments

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Outline

• Final Focus upgrades
  - Weaker quadrupoles and sextupoles
  - Looser magnet tolerances
  - Reduced non-linearities and “halo-amplification”

• Collimation upgrades
  - Halo reduction by means of non-linear optical elements
  - Integrated Collimation System and Final Focus designs

• Conclusions
Chromaticity locally compensated at the Final Doublet with sextupoles
Additional sextupoles upstream cancel the geometric aberrations.

Disadvantages:
Strong X-focusing quads in the Beta-matching section in order to cancel chromaticity (T126) and second order dispersion (T166)
3 X-sextupoles and 2 Y-sextupoles needed to cancel all the significant 2\textsuperscript{nd} and 3\textsuperscript{rd} order aberrations.

X and Y sextupoles are interleaved and they could generate higher order aberrations.
**Chromatic correction in 2000 FF**

- Straightforward in the Y plane
- Trickier in X plane:

\[ \Delta x' = \frac{K_F}{(1 + d)} (x + ?d) \Rightarrow K_F(-dx - ?d^2) \]

\[ \Delta x' = \frac{K_S}{2}(x + ?d)^2 \Rightarrow K_S(\frac{d x + ?d^2}{2}) \]

\[ \Delta x' = \frac{K_F}{(1 + d)} (x + ?d) + \frac{K_{\beta\text{-match}}}{(1 + d)} x \Rightarrow 2K_F(-dx - \frac{?d^2}{2}) \]

- If we require \( K_S h = K_F \) to cancel FD chromaticity, then half of the second order dispersion remains.

**Solution:**

The \( \beta \)-matching section produces as much X chromaticity as the FD, so the X sextupoles run twice stronger and cancel the second order dispersion as well.

\[ K_{\beta\text{-match}} = K_F \quad K_S = \frac{2K_F}{?} \]
New:

A bend and a triplet have been added between the X and Y sextupoles in the “Geometric Correction Section” (GCS)

The dispersion in the GCS is set so the Y-sextupole and the X-quads together cancel the T166 generated in the FD, so strong X-quads are no longer needed.

The triplet ensures the optimal phase advance between the X-sextupoles, so only 4 sextupoles are needed to cancel the 2\textsuperscript{nd} and 3\textsuperscript{rd} order aberrations.
More advantages:

Quads and Sexts are weaker, tolerances on field errors and vibrations are relaxed.

Almost no “Halo amplification” from high order aberrations because:

All the quads needed to build the -I between the sextupoles are in low-β points, so the FD-phase chromaticity is negligible.

The chromaticity through the system and the geometric non-linearities in the FD-phase are reduced to a minimum.

All residual significative 4th order aberrations can be canceled with decapoles, leaving space for luminosity upgrades in the due years.
**Final Focus performance**

- **BDS energy reach**
- **Chromaticity through the BDS**

![Graph showing luminosity versus energy with different geometries and ideal luminosity curves.](image)
NLC - The Next Linear Collider Project

**Final Focus performance**

Luminosity and IP beam spot sizes vs beam energy-offset

Beam size across the FD for off-energy particles
BDS luminosity reach at design emittances

BDS luminosity vs emittances
Final Focus performance

BDS vertical quadrupole position tolerances for 2% luminosity loss

BDS luminosity degradation vs time. The value of the ATL coefficient is assumed to be $A=5 \times 10^{-7} \text{m}^2/\text{m/s}$.
**Final Focus performance**

BDS quadrupole and bend field errors tolerances for a 2% luminosity loss

BDS luminosity degradation due to random quad field errors as a function of the error magnitude (scaled from errors tolerances).
Nonlinear handling of beam halo

- One wants to **focus beam tails** leaving the core of the beam unchanged
  - Use **nonlinear** elements (e.g. octupoles)

- **Several** nonlinear elements needed to provide **focusing in all directions**
  - Similar to **FODO** strong focusing

- A very simple and elegant solution is to use **Octupole Doublets (OD)** in series
**Background and collimation**

- **Major source of detector background in the new FF:**
  Large offset particles which hit the FD and/or emit photons that hit the vertex detector.
  Such particles can originate in the linac (wakefields, gas-scattering, multipole-fields aberrations) or...
  can originate in the Collimation Section or in the Final Focus, because of high order aberrations.

- **Two possible solutions:**
  Reduce halo size by means of non-linear optical elements (Halo Folding)
  Stop halo on physical scrapers (Collimation)
Strong focusing by ODs

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

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

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

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

  5\textsuperscript{th} order Focusing in all directions  
  Next nonlinear term focusing - defocusing depends on \( \varphi \)

- Works best if the phase advance in the doublet is small
NLC FF with two ODs

Two ODs are placed in NLC FF for active folding of beam tails

$\beta_x/\beta_y$ chosen to have the optimal folding across QF1/QD0

Halo size across the FD decreases by $\sim 4$ times in both planes

This leads to relaxation of the collimator depth by about a factor of 4

NLC FF with two octupole doublets placed between the $\beta$-matching section and the GCS
Halo folding in the NLC FF

Flat Distributed Input beam (in IP units):

\((\sigma_x, \sigma'_x, \sigma_y, \sigma'_y, \sigma_e) = (24\mu m, 1.1\text{mrad}, 5.4\mu m, 4.5\text{mrad}, 3\%)\)

roughly corresponding to \(N_\sigma = (120, 60, 2000, 200, 15)\)

greater size than the nominal NLC beam
Collimation System requirements

2000-Collimation System still designed for CD1-FF
NOW much less demanding requirements in terms of scraping, BUT:
Much more demanding requirements in terms of OPTICAL PROPERTIES

Chromo-geometric non-linearities have to be smaller than in the FF, otherwise Collimation depth defined by the Collimation System itself(!)

FD halo vs energy for 2001-FF and CD1-FF
(in CD1-FF plots, 40% of the beam lies outside the limits of the vertical scale)
2001 Collimation System design
(in progress)

High order aberrations smaller then in the FF
Clear, understandable, phase relation between collimator jaws and FD and IP

Linear system easy to understand, model and TUNE
FD-collimators need high $\beta$'s, IP-collimators low $\beta$'s

Residual Chromaticity (only at the IP phase) easily compensated in the FF with no loss in Bandwidth.

Wakefield dilution only from FD-jaws

Energy Collimators at the FD phase $\Rightarrow$ the residual T166 helps(!) to cancel the T166 from the FD...
New scheme of the Collimation Section and Final Focus with ODs
All the tracking results shown in the previous slides include the CS
Efficiency of the 2001-CS

Up to $10^9$ particles/pulse can be collimated in the CS, leaving about $10^4$ residual particles easily collimated in the FF with less then 10 residual muons hitting the detector.

L.P.Keller
CS additional properties

Collimator depth relaxed by at least a factor of 6
Wakefields reduced ~ 6-36 times
All half-gaps > 1mm, spoiler gaps ~ absorber gaps =>
spoilers just to protect absorbers
Much less likely to hit the jaws with spurious beam
Beam fraction to be collimated reduced ~ 10-1000 times

Energy acceptance much larger than 2%
no need to collimate when a klystron 8-pack trips

BDS total deviation from a straight line ~ 3.5m
tunnel can be aligned with the linac

If the FF bends have to be rescaled at higher energies, the
upstream bends can be readjusted, so the IP will not move

BDS about 1 mile long
Conclusions

- Final Focus properties improved, better tolerances, less non-linearities, better understanding and handling of the background sources
- Non-linear collimation relaxes the Collimation System, simpler optics, less particles to collimate, less stress on the hardware, less wakefields, better tolerances and tunability
- Preliminary studies on the new BDS show promising results