Beam Collimation

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Outline

- Zeroth-Order Design Report (ZDR) study
- Current concept
- Required R&D
Present Status

• Collimation is essential to lower backgrounds and provide machine protection (MPS) against very large trajectories
• Location set by number of generated muons
• Zeroth-Order Design Report (ZDR) collimation provided passive MPS but had tight tolerances (like final focus)
• CD-1 design has looser requirements on collimation depth
• Alternate concepts investigated—ideas but no completely satisfactory solution yet!
• Still outstanding issues regarding collimation requirements, wakefields, and damage limits
Beam Collimation

- Collimation system must remove large amplitude particles that will generate backgrounds in the detector
  - Transverse tails from wakefields
  - Tails from beam-gas/beam-photon/intra-beam scattering
  - Energy tails

- Backgrounds from particles hitting final doublet and synchrotron radiation

- Muons from collimators are problem at detector
NLC ZDR Collimation Design

• NLC ZDR collimation system is >2km long with strong optics to survive single train impact—40 km beta functions
• Strong sextupoles are needed to correct chromaticity with tight alignment and jitter tolerances
• Tight apertures for focusing
• Collimates Final Doublet (FD) and IP phases asymmetrically (40 \( \sigma_y \) vs. 150 \( \sigma_y \))
• Thus need very accurate control of phase advance with additional multipole magnets
Collimation and Machine Protection

- Collimation system also an integral part of the Machine Protection System (MPS)
- Collimation system must protect downstream components from frequent large amplitude trajectories

- Problem: nominal beams will destroy all materials in a single pulse!
  - High energy linac beam of 10 x 1 µm will cause ΔT > 8x10^5 °C
  - Thermal shock is thought to damage Cu when ΔT > 180 °C and Ti when ΔT > 800 °C ⇒ beam sizes in excess of 120 x 120 µm
  - Less difficult at low energy (10 GeV) because of larger emittances
Collimation and Machine Protection (2)

• Use pre-linac collimation at 10 GeV to remove tails due to damping ring (DR) and 1st bunch compressor (BC1) and to protect against pre-linac energy faults
  – This low energy system can be designed for passive survival in about 100 meters—CD-1 version is based on the ZDR design with spoilers and absorbers

• Believe that main linac collimation system only needs to protect against frequent energy errors—pure betatron errors can be made infrequent by limiting magnet mover speeds and feedback corrector strengths

• Looking at $dBy/dt$ due to shorted quadrupole magnet pole

• Need full simulation to verify above
Post-Linac Collimation Design

- Alternates to ZDR design considered:
  - laser systems
  - resonant nonlinear collimation generated with octupoles
  - nonlinear system using octupoles to reshape distribution
  - self-healing collimators (i.e. liquid metal or solidifying liquid metals)

- Choose to pursue quasi-conventional ‘consumable’ collimators which can be used for ~1000 ‘hits’
- Self-healing ‘renewable’ systems also sound promising
Post-Linac Collimation Design (2)

- Separate energy collimation with passive survival from downstream betatron collimation
- Continuum in betatron collimation choices:
  - ZDR-style with strong optics and passive survival of ‘conventional’ collimators but tight tolerances
  - FODO-lattice system with very small gaps which require self-healing design but have loose tolerances
- Length in all these systems does not vary too much: 1~2 km for both energy and betatron phase space
- Questions regarding collimator damage and wakefields
Post-Linac Collimation System

• 4-D parameter space:
  – tolerances
  – collimator survival
  also
  – muon backgrounds
  – tail populations

• ZDR design pushed tolerances

• Redistribute the pain—ease tolerances with engineering design!

Single Pulse Collimator Damage

Conventional collimators
not damaged

‘Consumable’ collimators
damaged \( \sim 1000x \) per year

‘Renewable’ collimators
damaged each pulse

Never
Seldom
Always

Tighter
Looser

Optics Tolerances
Population of Beam Tails

- NLC ZDR had minimum apertures of $7\sigma_x \times 36\sigma_y$
- Assuming $10^{-8}$ Torr in linac $\Rightarrow \Delta N \sim 10^4$ particles
- Assuming gaussian beam with injected $20\sigma_y$ oscillation $\Rightarrow \Delta N \sim 10^7$ particles to collimate but $L/L_0 \sim 20\%$

- ZDR assumed 1% average beam loss per collimator, i.e. 1000x safety factor
- Apertures are larger in CD-1 final focus: $12\sigma_x \times 45\sigma_y$ (see previous figure illustrating the synchrotron radiation fan)
- Reduce average beam loss requirement to $< 10^{-3}$
Collimation Damage

- Metallic collimators could be damaged by direct energy deposition and ohmic heating from image currents.
- Present limits based on old damage experiments at SLAC and theoretical values based on full constrained system.
- Need better understanding of materials limitations.
- Plans for tests using Final Focus Test Beam, laser heating, and PEP-II.
Collimator Wakefields

- With large $\beta$-functions and small gaps transverse wakefields can be significant in collimator sections
- Resistive wall wakefields in SLC collimators measured to be 4x higher than theory??
- Theoretical geometric wakefield in smooth planar collimators has unphysical divergence ($W_\perp \propto \text{width}$)??
- Roughness wakefields uncertain??

- Measure wakefields in special test facility this fall
Summary

• ZDR system had desirable features but tight tolerances and was over-designed with full passive protection and large tail populations

• Present concept based on separate energy and $\beta$ collimation with passive protection only for energy errors

• To proceed:
  – Further understanding of linac fault rate
  – Model for tail populations
  – Need limit on muon rates in the detector
  – Require materials and wakefield R&D!