ILC Main Linac Design Simulation

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OBJECTIVES

- Single-bunch emittance preservation in curved ILC Main Linac using Dispersion Free Steering (DFS)
- ILC main Linac lattice design : from ILC BCD-like to Realistic Realization
- New Codes : CHEF and Lucretia - DFS Implementation
- Dynamic Alignment: Ground Motion and Adaptive Alignment

Emittance preservation

- ILC Main linac will accelerate e⁻/e⁺ from ~15 GeV→ 250 GeV
  - ⇨ Upgradeable to 500 GeV
- Two MAJOR design issues include (a) efficient acceleration of the beams (Energy frontier) and (b) emittance preservation (Luminosity frontier)

Luminosity Scaling

$$L \propto \frac{\eta_{RF} P_{RF}}{E_{CM}} \sqrt{\frac{\delta_{BS}}{\varepsilon_y}}\, H_D$$

Small Normalized vertical emittance

- *Vertical plane* - more challenging:
  - ⇨ Large aspect ratio (x:y) in both spot size & emittance (400:1)
  - ⇨ ~ 2-3 orders of magnitude more difficult

Sources of Emittance Dilution

Single Bunch

- Transverse Wakefields:
  - ⇨ Short Range : Misaligned cavities or cryomodules
- Dispersion from Misaligned Quads or Pitched cavities
- XY-coupling from rotated Quads
- Transverse Jitter

Tolerance	Vertical (y) plane
BPM Offset w.r.t. Cryostat	300 μm
Quad offset w.r.t. Cryostat	300 μm
Quad Rotation w.r.t. Cryostat	300 μrad
Cavity Offset w.r.t. Cryostat	300 μm
Cryostat Offset w.r.t. Survey Line	200 μm
Cavity Pitch w.r.t. Cryostat	300 μrad
Cryostat Pitch w.r.t. Survey Line	20 μrad
BPM Resolution	1.0 μm

Design Parameters

- ⇨ 10.5 km length
- ⇨ 9 Cell structures at 1.3 GHz
- ⇨ Injection energy = 15.0 GeV
- ⇨ Extraction energy = 250 GeV
- ⇨ Initial Energy spread= 150 MeV

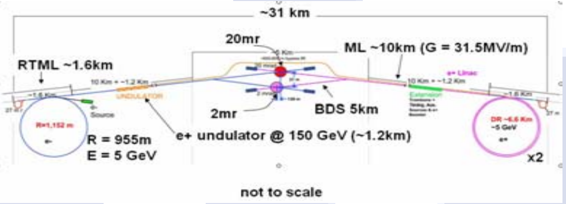
Beam condition

- ⇨ Bunch Charge: 2.0 x 10^{10} particles/bunch
- ⇨ Bunch length = 300 μm
- ⇨ Normalized injection y-emit. = 20 nm-rad

BCD

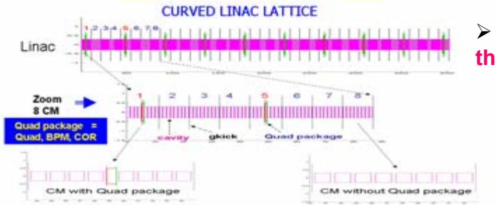
- Curved tunnel;
- Cavity - *31.5 MV/m gradient* and *Q of 1×10^{10}* with *eight-cavity per Cryomodule*; 1 Quad / 32 cavities;
- Optics - FODO lattice, with β phase advance of 75⁰ / 60⁰ in x /y plane; Each quad has a Cavity style BPM & Vertical Corrector magnet.

Beam Based Alignment

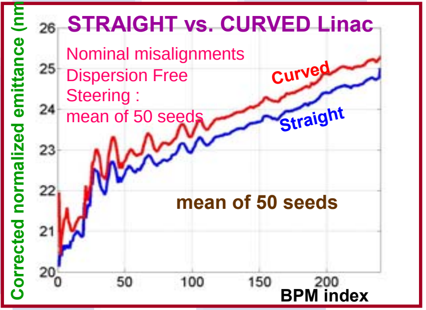


- ➢ *One-to-One (1:1) Steering*
  - Find a set of BPM Readings for which beam should pass through the exact center of every quad and Use the correctors to Steer the beam
  - One-to-One alignment generates dispersion which contributes to emittance dilution and is sensitive to the BPM-to-Quad offsets
- ➢ *DISPERSION FREE STEERING (DFS):* DFS is a technique that aims to directly measure and correct dispersion in beamline:
  - Measure dispersion (via mismatching the beam energy to the lattice). Calculate correction (via steering magnets) needed to zero dispersion apply the correction
  - Successful in rings (LEP, PEP) but less successful at SLC (Two-beam DFS achieved better results) (Note: SLC varied magnet strengths (center motion?))

Simulation using MatLIAR



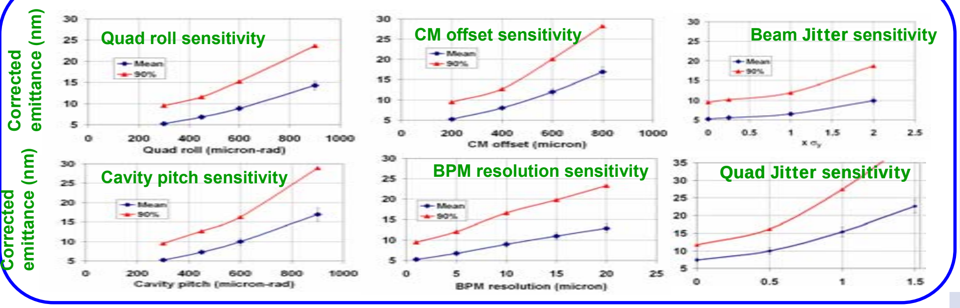
- ➢ Modifications in LIAR @FNAL to simulate the curvature:
  - The curvature is simulated by adding kinks between the CM
  - The matched dispersion condition at the beginning of the linac is artificially introduced into the initial beam



SUMMARY

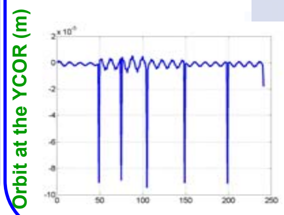
- Emittance growth in curved linac is not significantly different from that of the straight Linac
- Using DFS, mean emittance dilution can be limited to < 10 nm growth (Effect of Quad, beam jitter and ground motion can degrade it further)
- Almost insensitive to Quad offset, BPM offset, Cavity offset and CM pitch

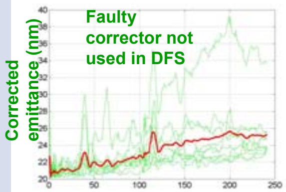
DFS Sensitivity Studies



BPM / Corrector Failure

5 randomly chosen vertical correctors not working. Adjusted the adjacent two correctors to guide the beam on to the design orbit



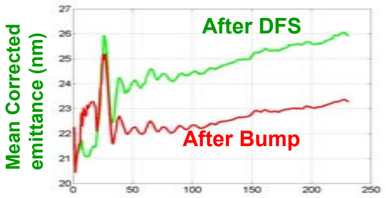


Exclude faulty correctors from the DFS and the results are fine

Dispersion Bumps

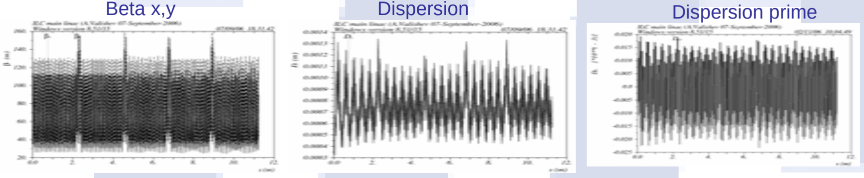
Bumps in ILC main linac are incorporated by having two sets of correctors 90^0 apart in betatron phase, each set consisting of two correctors 180^0 apart. The corrector fields are then varied and the beam size near the end of the main linac is measured with two wire scanners placed 90^0 apart (2% resolution assumed for the beam size measurement).

1 Bump (starting at energy = 16.16 GeV)

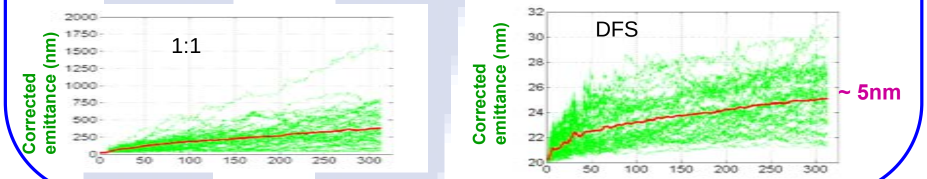


Linac Lattice Design

- **Initially, curvature in ILC BCD lattice is introduced using GKICK element (in MatLIAR) or using multipole approach (MAD). A new version of the Latttice using SBEND was worked out, which can be used in both MAD and MatLIAR.**
- **All realistic cold and warm space drifts have been used in the new lattice**

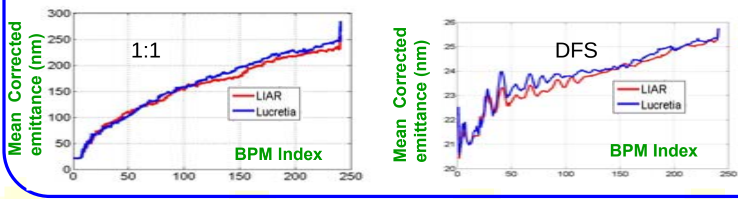


- **Applying Initial Misalignments; 50 seeds of DFS; Mean corrected emittance growth**



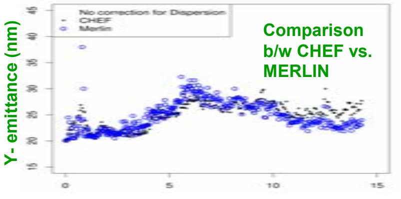
LUCRETIA - DFS

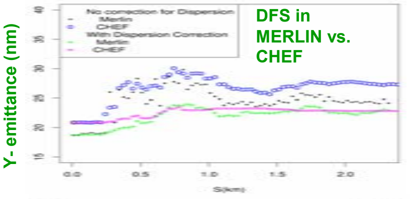
- **Liar vs. Lucretia: Curved Lattice; Nominal Misalignments; 50 seeds**

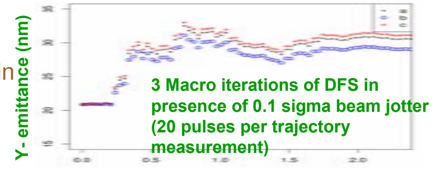


CHEF -DFS

- **CHEF** *(by Leo Michelotti & Francois Ostiguy, FNAL)*
  - –Interactive program for accelerator Optics
  - –Uses high level graphical user interfaces to facilitate the exploitation of lower level tools incorporated into a hierarchy of C++ class libraries.
  - –GUI integrated, Linux, Windows
  - –Used for circular machines and transfer lines, **being upgraded for ILC**
  - – Stability of DFS is studied in the presence of beam jitter and also Ground Motion







3 Macro iterations of DFS in presence of 0.1 sigma beam jotter (20 pulses per trajectory measurement)

Adaptive Alignment (AA) and Ground Motion

- ✓ Proposed by V.Balakin in 1991 for VLEPP project
- ✓ **“local” method**: *BPM readings (A_i)* of only 3 (or 5 or so on) neighboring quads are used to determine the necessary shifting of the central quad (Δy_i).

$$\Delta y_i = \mathrm{conv} * [A_{i+1} + A_{i-1} - A_i * \{2 + K_i.L.(1 - \frac{\Delta E}{2E})\}]$$

conv : Speed of convergence of algorithm
A_i : BPM reading of the central quad and so on
K_i : Inverse of quad focusing length
L : Distance between successive quads
ΔE : Energy gain between successive quads
E : Beam Energy at central quad

- ➢ **ILC BCD Like Lattice – Straight – Only one quad at 10th position is misaligned by. 300µm (BPMs are perfectly aligned with Quads, and have perfect resolution)**

- Straight lattice: DF steered
- 10 GMseeds;GM of 15 hrs. in step of 1 hr
- When AA incorporated: AA of 100 iterations after every one hr. (conv.= 0.2)

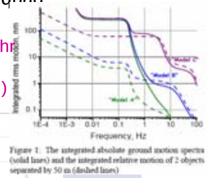
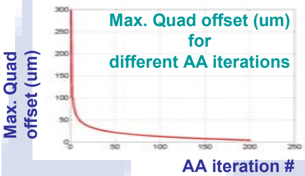
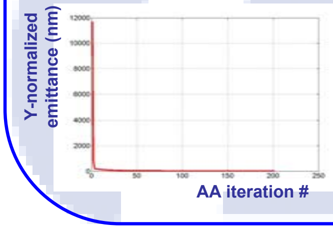
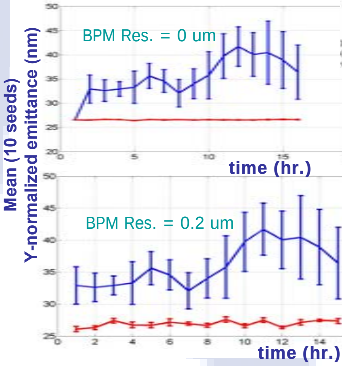


Figure 1: The integrated absolute ground motion spectra (solid lines) and the integrated relative motion of 2 objects separated by 50 m (dashed lines)







After GM only (no AA)

AA every 1 hr. after GM