Computer Code Requirements for ILC Design

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Characteristics of ILC, from beam dynamics point of view

- High final energy (250~500 GeV beam energy)
- Long Main Linacs (~10 km/linac for 500 GeV ECM)
- Large charge/beam pusle (3000 bunches/pulse, 2E10e/bunch)
- Long Damping Rings (6~17 km/ring)
- Very low Emittance in Damping Ring and Downstream. ($\gamma\varepsilon_y$ = 2~4E-8 m)
- Very small beam size at Interaction Point (600 nm x 6 nm for 500 GeV ECM)

ILC schematic Layout
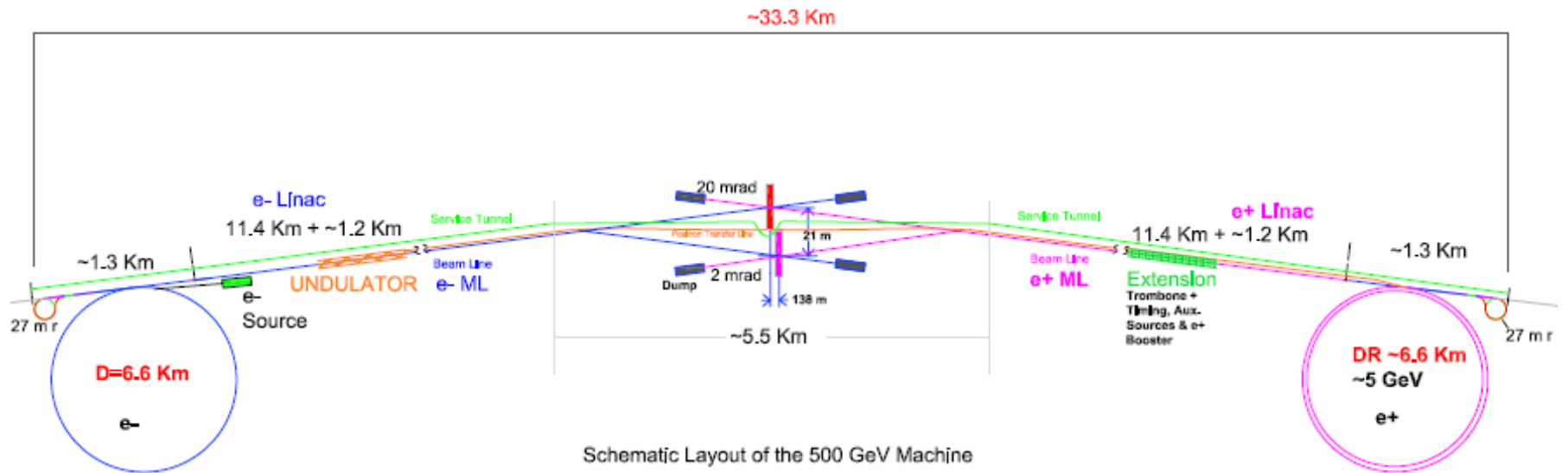
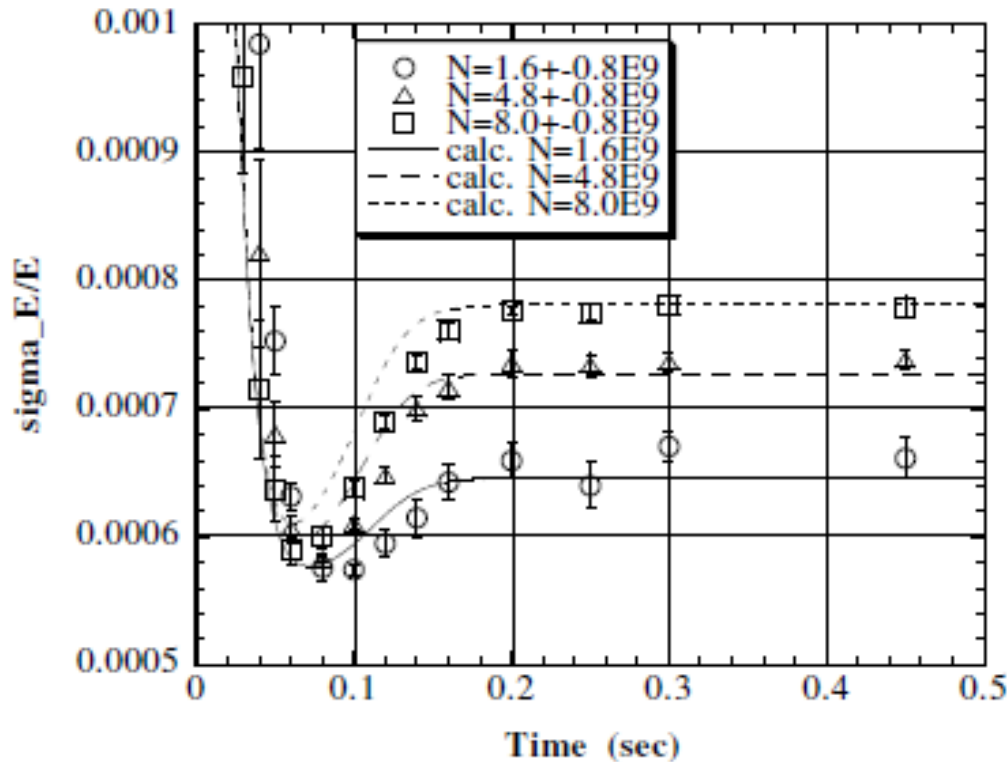Schematic Layout of the 500 GeV Machine
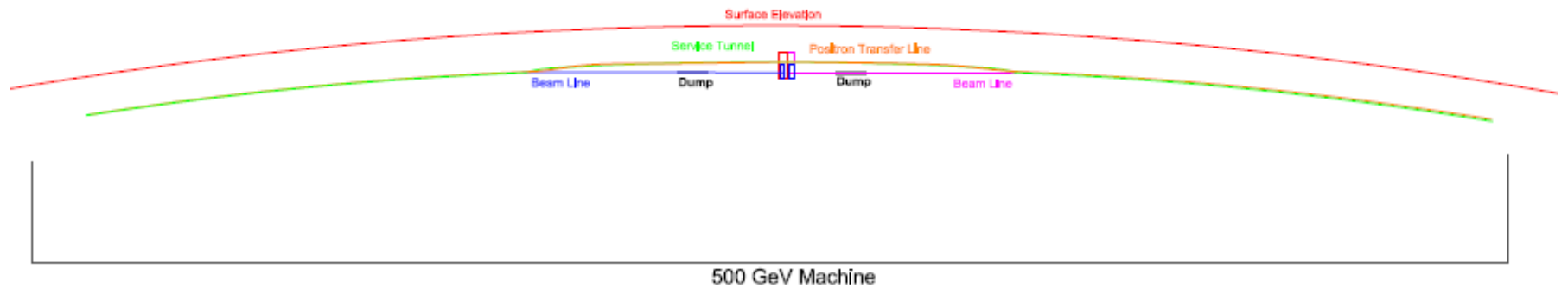
500 GeV Machine

Damping Ring

Most things are similar to other e+e- rings, photon sources or e+e- ring colliders.

But, some differences:

- High quality Beam should be Extracted.
- Total storage time < 200 ms, 10000 turns
  - Equilibrium state cannot be reached.
  - Transient phenomena are important.
- Extraction and Injection (for next beam pulse) will be simultaneous.
  - Complicated bunch to bunch interaction. Bad quality injected bunches can affect good quality bunches.

Transient phenomena should be considered.

Transient phenomena - Example from ATF DR

FIG. 4. Energy spread vs store time in the damping ring at different intensities. The lines are from a calculation assuming an emittance ratio of 0.006.

Intrabeam scattering

$$\tau_z < \tau_y,$$

$$\varepsilon_{y,inject} >> \varepsilon_{y,equilibrium}$$

Calculation used SAD, with some 'cheating' in the transient region.

Cheating

Calculate equilibrium emittances, $\varepsilon_{x,e}, \varepsilon_{z,e}$ without intrbeam scattering.

For calculation of intrqabeam scattering effect, $\Delta\varepsilon_{x,y,z}$, at time *t*,

$$\varepsilon_{x,e}, \quad \varepsilon_{y,e} + \left(\varepsilon_{y,i} - \varepsilon_{y,e}\right)e^{-2t/\tau_y}, \quad \varepsilon_{z,e}$$

are put as equilibrium emittqances without intrabeam scattering.
Then, emittances at *t* are evaluated as

$$\varepsilon_x = \varepsilon_{x,e} + \left(\varepsilon_{x,i} - \varepsilon_{x,e}\right)e^{-2t/\tau_x} + \Delta\varepsilon_x,$$

$$\varepsilon_y = \varepsilon_{y,e} + \left(\varepsilon_{y,i} - \varepsilon_{y,e}\right)e^{-2t/\tau_y} + \Delta\varepsilon_y,$$

$$\varepsilon_z = \varepsilon_{z,e} + \left(\varepsilon_{z,i} - \varepsilon_{z,e}\right)e^{-2t/\tau_z} + \Delta\varepsilon_z$$
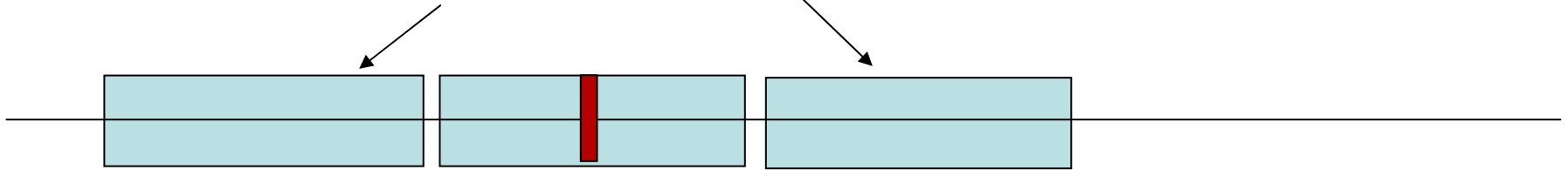
Looks OK, qualitatively.
But really good approximation?

Main Linac

- Very long but basically simple
  - Many iteration of simple unit
    - Unit: Accelerating cavities + BPM + Quad magnet + steering magnet
- Number of components/linac (250 GeV)
  - 7700 Cavities
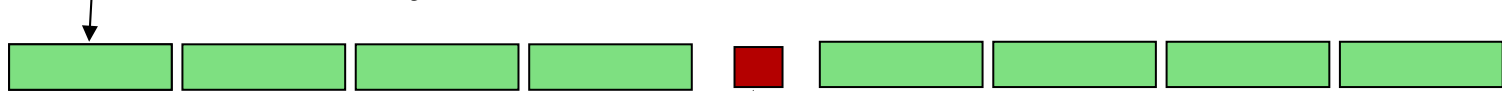 - 320 BPMs, Quads, Steerings

Unit of main linac
about 320 units/linac

Cryomodules without magnet package

Cryomodule with magnet package

9-cell SC cavity

Magnet package

BPM

Dipole SC magnet

Quadrupole SC magnet

Example of Main Linac tuning simulation - DFS

One-to-one orbit correction (BPM reading zeroed)
Divide linac into sections, and in each section:
(1) Measure orbit with nominal beam energy. (y0,i at i-th BPM)
(2) Reduce initial beam energy and accelerating gradient from the linac entrance to the end of previous section by a common factor δ (e.g. 10% or δ= -0.1).
(3) Measure orbit. (yδ,i at i-th BPM)
(4) Set dipole correctors in the section to minimize

$$w\sum_i \left[\left(y_{\delta,i} - y_{0,i}\right) - \left(y_{\delta,i,des} - y_{0,i,des}\right)\right]^2 + \sum_i \left[y_{0,i} - y_{0,i,des}\right]^2$$

$y_{0,i}$: BPMread with nominal energy, $y_{\delta,i}$: BPMread with changed energy,

$y_{0,i,des}, y_{\delta,i,des}$: Designed beam position (nonzero in curved linac)
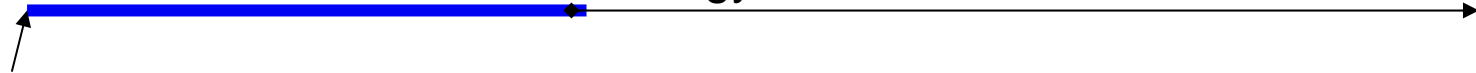
(5) Iterate from (1) to (4).
(6) Go to next section.

There are many variations of DFS in many simulations codes.

Example of DFS (Dispersion Free Steering) in Main Linac

1-to-1 correction in whale linac.
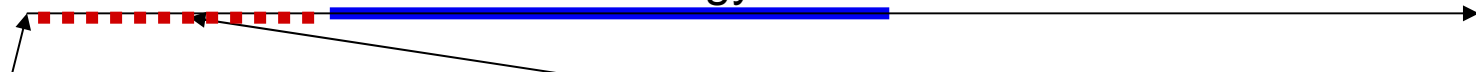
1st section
  Measure orbit with nominal energy

Change injection energy and measure orbit
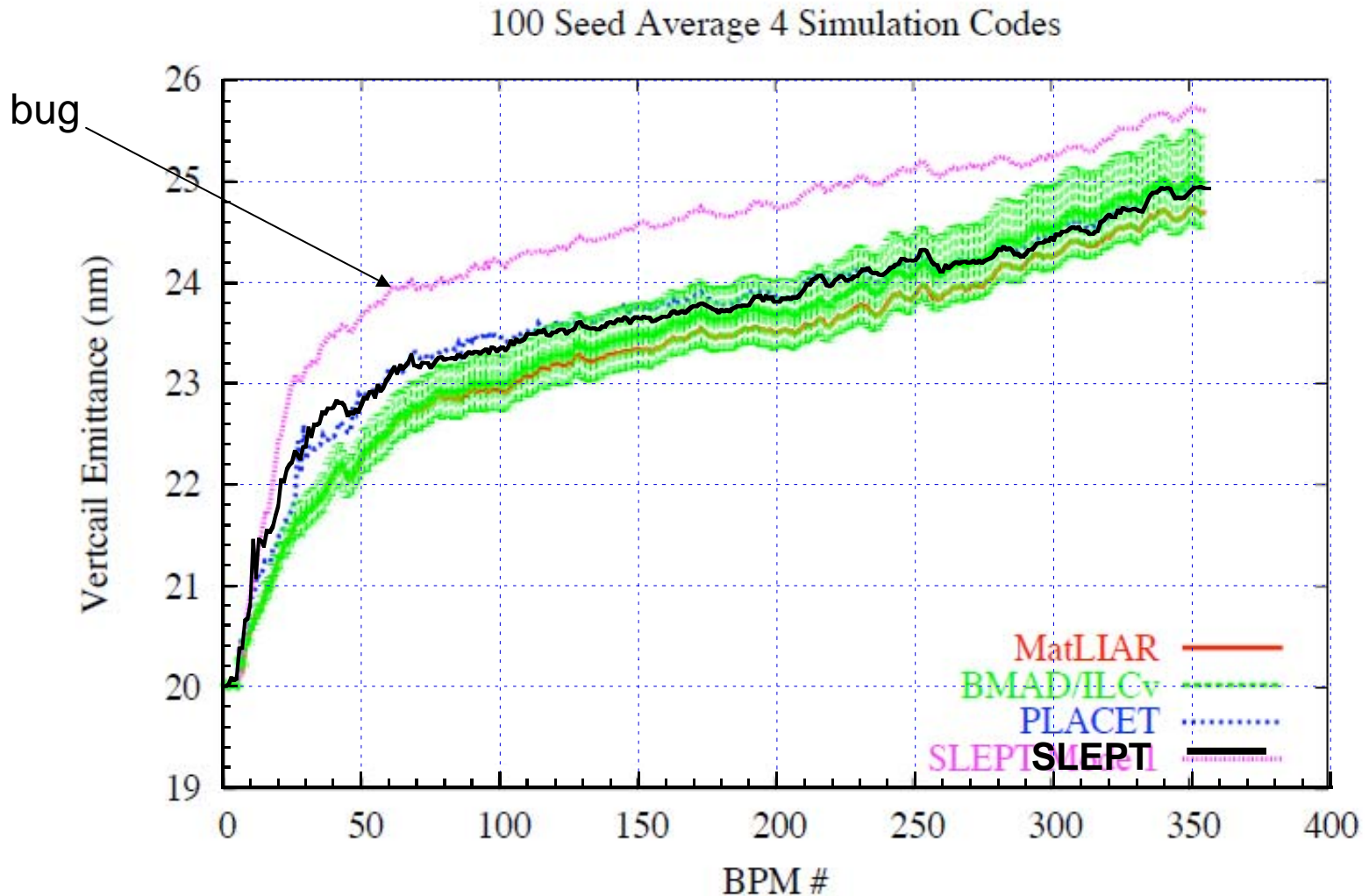Set correction, then, iterate several times.

2nd section
  Measure orbit with nominal energy

Change injection energy and Acc voltage before the section.
Orbit adjust at the beginning of the section and measure orbit in the section.
Set correction, then, iterate several times.

Next section. (About 15 sections/linac)

Code Benchmarking, DFS results of 4 codes, with same sets of misalignment

100 Seed Average 4 Simulation Codes

bug

Vertcail Emittance (nm)

BPM #

MatLIAR
BMAD/ILCv
PLACET
SLEPT**SLEPT**

Added by K.K. to Jeff Smith, 200607, Vancouver WS
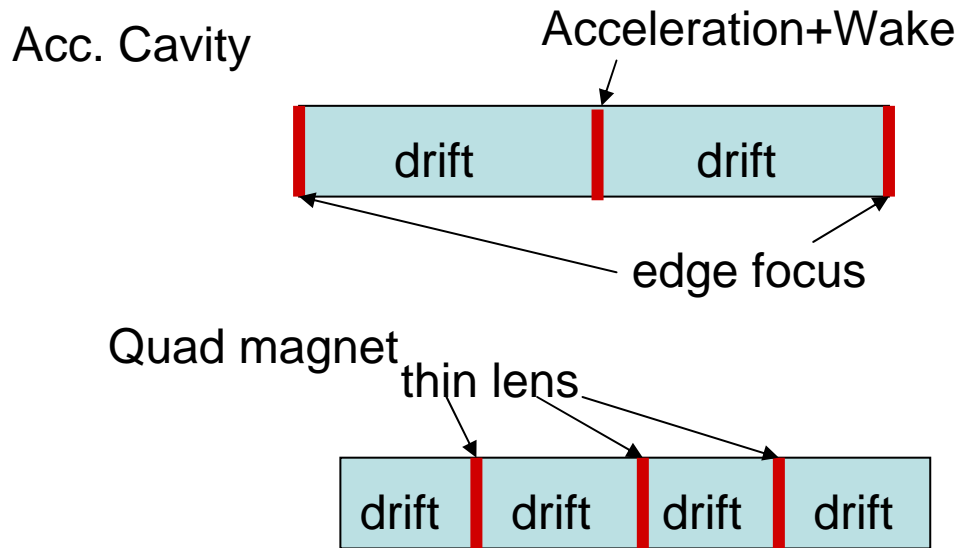
Simulation of Main Linac

- Complex error setting and change
  - e.g. Alignment simulation, Ground motion
- Complex corrections
  - e.g. Dispersion Free Steering
- Need many trials with different errors and different correction algorithms.

It is desirable details of algorithms can be set as input parameters, or algorithms can be changed easily (? like SAD script ?)

Each process (e.g. tracking through each component) should be very fast

Code for Main Linac - Fast

- Very simple process at each component is good enough.
- Approximation is necessary for saving CPU time.

Acc. Cavity

Acceleration+Wake

drift	drift

edge focus

Quad magnet

thin lens

drift	drift	drift	drift

Transverse motion is linear.

Code for Main Linac
- example of approximation

Non linear transverse motion is ignored

- Tracking up to 2nd order moment of particle distribution,

  $<x>$, $<y>$, $<px>$, $<py>$, $<xx>$, $<xy>$, $<xpx>$, $<xpy>$, , ,

  ('slices' instead of macro particle)

  – Reduce calculation of wakefield (~ square of number of particles)

z of each 'slice' is fixed

  – Longitudinal wakefield felt by each 'slice' is the same for all cavities.

  – Transverse wake calculatino can be simple.

Final Comment on Code for Main Linac

Main Purpose of present stage of Main Linac Simulation is:

- To check (demonstrate) the machine of present design can achieve designed performance. Or,
- To estimate tolerances of various errors

Requirement is different from a code

- To improve performance of existing machines.

Put every known effect may not be a good idea.

Problems (?) of SAD for ILC Simulation

- Bunch Compressors
  - Wakefield: Time consuming?
  - CSR
- Spin Rotator
  - Spin dynamics
- Main Linac
  - Wakefield: Time consuming
- Helical Undulator (e+ source)
- ? ? ?
- Translation from/to other codes (International work.)

END