NLC - The Next Linear Collider Project

"Now Bliss is Everywhere…"

DR→IP←DR Simulations

Collaboration + MAC Meeting
May 2002

P. Tenenbaum

Linear Collider Simulations "Taskforce"

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With additional helpful input from:

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Motivations

- Interest in performing beam tuning simulations on all of LC design
  - historically concentrated on main linac
  - some activity in BDS, BC regions
  - Helpful to have a single "tuning" code for the job
- Seek to study interaction between tuning algorithm and other effects
  - "Does a tuned-up beamline respond to ground motion the same way as a nominally perfect one?"
  - Small beam distortions have big lumi impact – "Banana Instability"

Motivations (2)

- Some problems can *only* be studied properly with an integrated beamline
  - example: ground motion – actually need 2 beamlines pointing at each other!
- Technical Review Committee (TRC)
  - Luminosity WG, Low-Emittance Transport (LET) sub-WG: considering BC-to-IP performance in unified manner
  - "…members of this group…should set common standards and use common computer codes to predict emittances…" (from the charge)

The Codes Issue

- Codes typically used for LC work @ SLAC:
  - LIAR
    - Designed for simulation of tuning & errors
    - Can't handle bunch compression, sextupoles, or higher multipoles
  - DIMAD
    - Good at high-order optics, includes bunch compression
    - Poor linear accelerator code (no transverse wakes), poor for tuning simulations
  - GUINEAPIG
    - Commonly-used beam-beam code
    - doesn't do any other beam dynamics!

The Grand Synthesis

- Assimilate DIMAD tracking engine into LIAR
  - use DIMAD for bunch compressor bends, beam delivery
  - use LIAR for BC RF, linacs
  - “seamless integration”
- Use GUINEAPIG to compute luminosity from LIAR/DIMAD runs
- Run everything under MATLAB
  - take advantage of MATLAB graphics, scripting, etc.
  - “LIAR is the accelerator and MATLAB is the control system”

The Grand Synthesis -- Example

- NLC run – DR exit to IP
- Uses LIAR with DIMAD tracking options
  - Bunch is compressed
    - R_{56} properly represented
  - Energy spread is right
    - wakefields properly handled
  - Beam sizes are right
    - chromatic correction works

nlc.basic - Notepad

File Edit Search Help

```
    ... Tracking routine called ...

     Tracking routine   T R A C K
     ~~~~~~~~~~~~~~~~~~~~~~~~~~~~

     Order of calculation           : 2
     Coupled calculation            :  T
     Transverse short-range WFs     :  T T T T F F F F F F
     Transverse long-range WFs      :  F F F F F F F F F F
     Transverse error LR WFs        :  F F F F F F F F F F
     Longitudinal short-range WFs   :  T T T T F F F F F F
     Longitudinal long-range WFs    :  F F F F F F F F F F
     Emittance reference            : CENTROID
     Emittance definition           : NORMALIZED
     Emittance selection            : BUNCH
     Reinitialization of beam       :  T
     Bunch selection for markers    : 1
     Bunch selection for RF-BPMs    :  0
     Bunch for slice measurement    :  0
     Update of logbook              :  F


     End of DIMAD tracking   A N A L Y S I S :
     ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

     LONGITUDINAL
        - acceleration:    E_0    =    1.980 GeV   -->   E_f    =  249.983 GeV
        - spread:          E_sig  =    0.000 GeV   -->   E_sig  =    0.616 GeV
        - rel. spread     SIGE/E  =    0.000 %     -->  SIGE/E  =    0.247 %
        - bunch centroid Z pos    =                                  0.001 mm
        - bunch length    SIGZ    =    5.000 mm    --> SIGZ     =    0.110 mm
     BEAM BLOW-UP
      - Train Emittance:  g_x    =   30.826 %             g_y    =   13.550 %
        - BMAG mismatch:   BMAGX  =    1.034                BMAGY  =    1.019
     FINAL BEAM SIZE:
        - Horizontal:      S_x    =    0.222 um             S_x'   =   36.020 urad
        - Vertical:        S_y    =    2.481 NANOMETER      S_y'   =   18.689 urad
     FINAL BETA FUNCTIONS
        - from beam:       B_x    =     6.17 MILLIMETER     B_y    =   132.98 MICROMETER
        - from TWISS:      B_x    =     8.00 MILLIMETER     B_y    =   110.00 MICROMETER
     FINAL ALPHA FUNCTIONS
        - from beam:       A_x    =  -0.0050                A_y    =    0.056
        - from TWISS:      A_x    =  -0.0009                A_y    =    0.001
     FINAL GEOM. EMITTANCE
        - initial value:   E_x    = 7.74E-10 rad*m          E_y    = 5.16E-12 rad*m
        - wrt centroid:    E_x    = 8.00E-12 rad*m          E_y    = 4.63E-14 rad*m
     FINAL NORM. EMITTANCE
        - initial value:   E_x    = 3.00E-06 rad*m          E_y    = 2.00E-08 rad*m
        - wrt centroid:    E_x    = 3.92E-06 rad*m          E_y    = 2.27E-08 rad*m

 INFO>  End of command file! STOP!
```

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Cross-Checking

- Does LIAR/DIMAD really “do the right thing?”
  - combining 2 codes is tricky
  - Opportunities for bugs are substantial
- Cross-check with other “Grand Master” LC codes
  - MERLIN (N. Walker, DESY)
  - PLACET (D. Schulte, CERN)
  - Both written with no input from LIAR or its authors
- April 13—15, 2002

What was compared

- Bunch compressors
  - correct final energy
  - correct σ_E
  - correct σ_z
- Single NLC RF Structure
  - ⊥ Wake y' vs z within bunch, offset structure
- Single TESLA Cavity
  - y' vs z within bunch, pitched cavity
- Main Linac
  - correct final energy
  - correct σ_E
  - Emittance growth for 1 σ_y oscillation
- Main Linac + BDS
  - RMS beam size
  - Centroid position at IP
  - Emittance growth for 1 σ_y oscillation
- BDS Alone
  - Beam size, position vs. centroid energy

What was Compared (2)

- **Used both TESLA and NLC beamlines**
  - **Problem with CLIC deck**
    - **will be "benchmarked" when deck ready**

- **All codes agree to few % level, all tests**
  - **Bandwidth studies not complete yet**
  - **Documentation in progress**

Tests of 3 Linear Collider Beam Dynamics Simulation Programs

D. Schulte, P. Tenenbaum, N. Walker, A. Wolski, M. Woodley

LCC-Note-zzzz
TESLA-Note-zzzz
CLIC-Note-zzzz
DRAFT 22-Apr-2002

Abstract

We report on tests of 3 linear collider beam dynamics simulation programs: PLACET, MERLIN, and LIAR. The programs are used to simulate the performance of the TESLA, NLC, and CLIC beamlines from the main linac to the IP. In each case the beamlines have no errors or misalignments.

1 Introduction

In the context of the International Linear Collider Technical Review Committee (ILC-TRC), it is necessary to review the performance of tuning algorithms and diagnostic devices for TESLA, NLC, and CLIC in order to evaluate the reliability of their published luminosity estimates. The most straightforward means of reviewing such algorithms is to implement each one in simulation and observe the results.

Three simulation programs are available to the TRC which are deemed adequate in principle for use in this context: PLACET [1]; MERLIN [2]; and LIAR with DIMAD tracking options [3, 4]. One pre-requisite for establishing confidence in the results of the tuning simulations is to ensure that each program is reliably simulating the basic beam dynamics of the linear colliders.

To this end, we simulated CLIC, NLC, and TESLA main linac and beam delivery regions using all 3 of the aforementioned programs. The simultations were for "perfect" machines: no misalignments or errors were present. In addition, the TESLA and NLC bunch compressor systems were simulated using MERLIN, LIAR, and MAD [5].

2 Basic Physics and Parameters of Interest

The tests concentrated on a limited group of studies that were expected to reveal any deviations between the programs which would be significant during the tuning studies. These tests are described below.

2.1 Bunch Compressors

The fundamental quantities of interest in the bunch compressor studies are:

- Final RMS bunch length
- Final RMS energy spread
- Final centroid energy

Note that the NLC bunch compressor was simulated with longitudinal and transverse wakefields, while the TESLA bunch compressor was simulated without wakefields. Because of the details of the TESLA bunch compressor design, the wake-free case is believed to be a reasonable simulation of the system for perfect machine studies.

NLC Tuning Studies for TRC I: Single-Bunch, Static

- **Defining precise tuning algorithm for each NLC region**
  - **still doing "piecewise tuning studies"**
  - **Goal: "Tuning Book" that ardent reviewer can use to reproduce all NLC LIAR results with other code**
  - **Work in progress, draft available**

Next Linear Collider Low Emittance Transport Tuning Book:
Part 1: Static, Single Bunch Errors and Correction

P. Tenenbaum for the NLC Collaboration
Version 2, Date: 27-Mar-2002

Abstract

We describe the procedure for the initial tuning of the Next Linear Collider (NLC) low-emittance transport region to eliminate static errors which influence the single-bunch performance of the system. The description includes: the expected distribution of *ab initio* errors and misalignments (and a description of some "shortcuts" in the tuning procedure required to reach same); the expected (or in some cases specified) performance of diagnostic instrumentation used in the tuning; a detailed description of the tuning algorithms to be employed.

0 Changes in this Version

0.1 Changes from Version 1, Date 08-Mar-2002

- *EBC1* EM quads are on independent power supplies.
- *EBC1* structures are powered by separate klystrons.
- 8 quads in PPS line downstream of *EBC1* SBD are EM quads.
- *EPCOL* BPMs and WS are added.
- *EBC1* and *EPLIN* quad alignment and steering are added.
- Sketches of tuning for regions from *EPCOL* through *EFFH* added.
- *QD0* BPM-to-quad RMS error estimate (30 μm) added.
- Laser wire response formula changed.

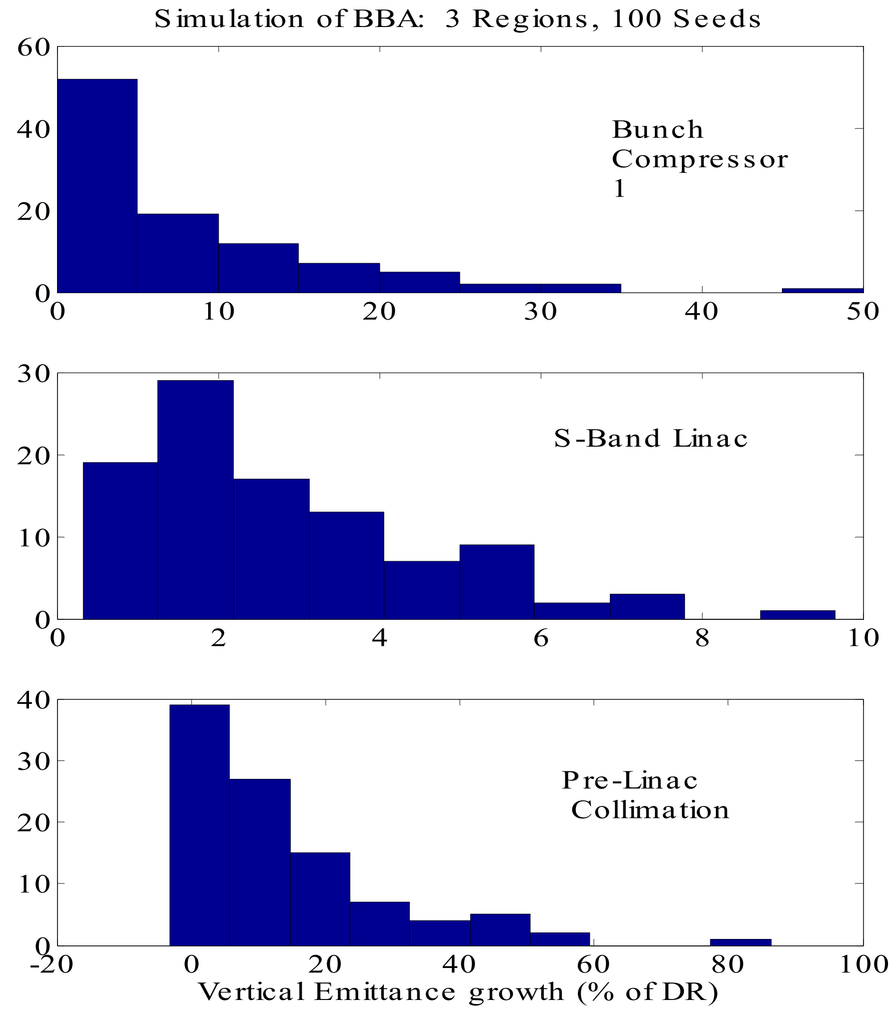
1 Introduction and Terms

The Next Linear Collider (NLC) Low-Emittance Transport (LET) region extends from the extraction of the main damping ring to the interaction point. The LET is conceptually subdivided into the injector, the main linac, and the beam delivery system. Each main system is further subivided into subsystems (which are assembled in individual decks) and sub-subsystems (within a given deck). The injector decks are *nlc010.ebc1.xsif, nlc020.eplin.xsif, nlc030.epcol.xsif, nlc040.ebc2.xsif*. The main linac decks are *nlc050.elin1.xsif, nlc060.elin2.xsif, nlc070.elin3.xsif, nlc080.eltb3.xsif, nlc090.ebyp3.xsif, nlc100.ebtl250.xsif*. The beam delivery system decks are *nlc110.ebsy.xsif, nlc120.eirth.xsif, nlc130.effh.xsif*.

In this section we document the parameters of beamline elements in each section of the NLC LET which are relevant to the procedure for initial tuneup. Note that at this time the use of adjustable permanent magnets is being considered. Such magnets would be tunable in a range from 80% of full strength to 100% of full strength. It is crucial to treat separately the magnets which can potentially be made PMs, and which ones can be only EMs. For example, the PMs clearly cannot be turned completely off, and therefore cannot accept a tuning procedure which relies on

Static Single-Bunch Tuning: Some Examples

- 3 regions
  - Bunch Compressor 1
  - Pre-linac
  - Pre-linac energy coll
- Errors
  - BPM offsets
  - magnet misalignments
  - magnet strength errors
- Algorithms
  - steer BPMs flat
  - Dispersion Free Steer
  - Sext alignment
  - RF structure align
- Caveats
  - Results are preliminary
  - Need to include global emittance knobs



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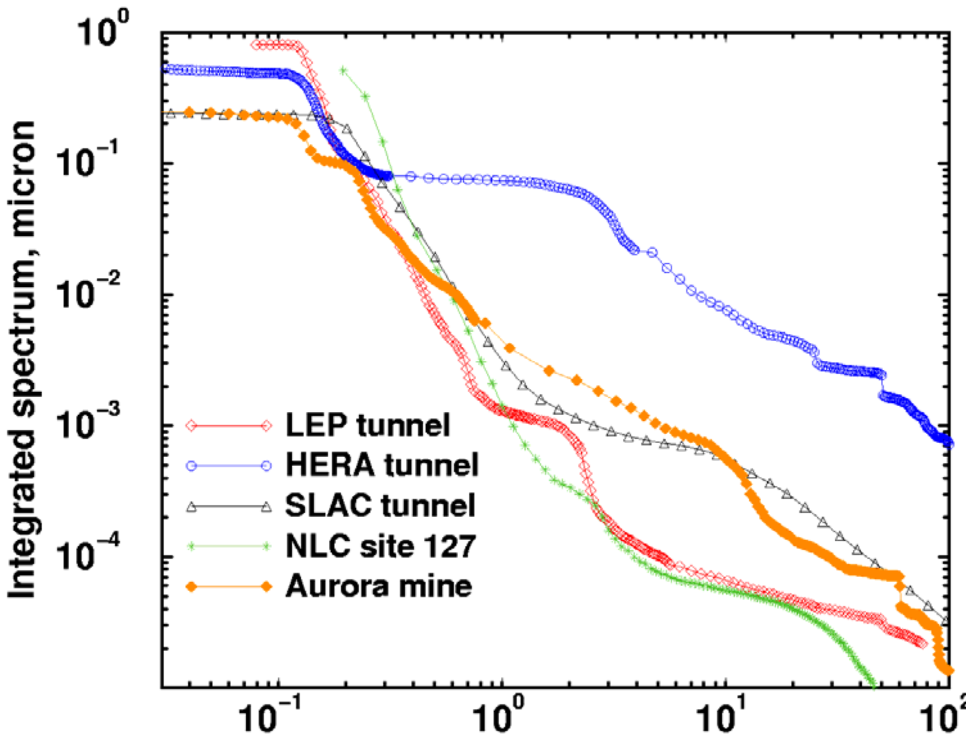
Single-Bunch Static Tuning: Plans

- Complete first iteration of region-by-region algorithm tests
  - compare results to NLC Emittance Budget
  - Iterate as needed
- Assemble “end to end” tuning simulation
  - concatenate regional tuning sims, with appropriate adjustments
- Test-drive the TESLA tuning algorithms
- Compare NLC and TESLA tuning sims with same by other TRC Members / Codes

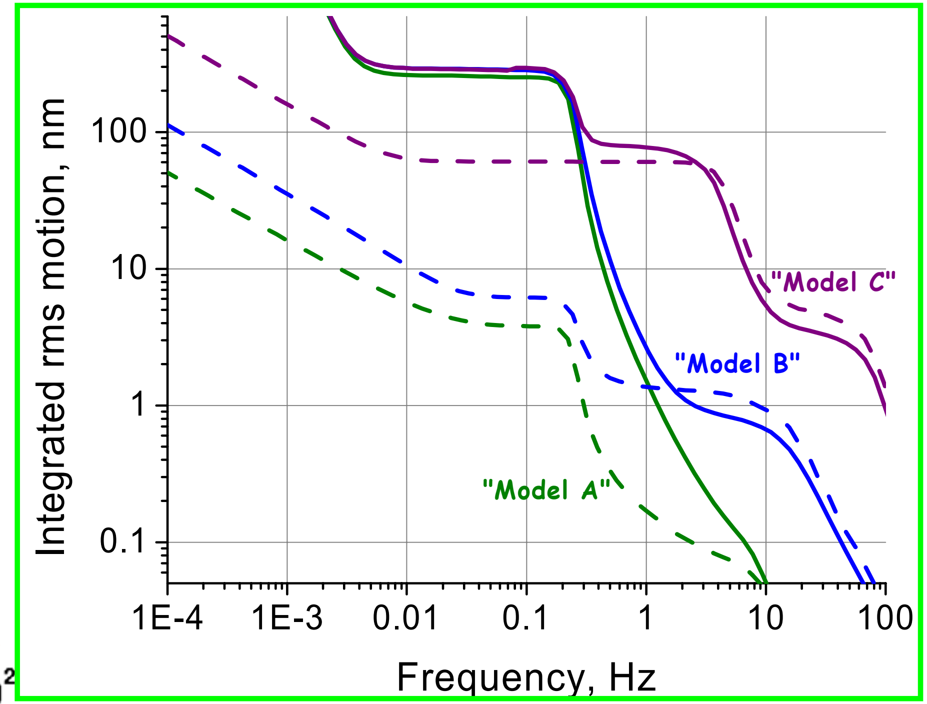
Dynamic Studies: Fast Ground Motion

- Requires 2 beamlines, beam-beam code for luminosity estimate
  - need to include correlations
- Requires complete model of GM
  - frequency dependence, correlations…
  - TRC: use 3 models
    - "A": low amplitudes (NLC 127, LEP tunnel)
    - "B": larger amplitudes (SLC 2AM, Aurora Mine)
    - "C": very large amplitudes (HERA Tunnel)
  - Models implemented in LIAR
    - Good reproduction of measurements
    - Quantitatively good models

Ground Motion Models



Measurements



Models

Solid = absolute, dashed = relative motion for 50 m separation

Note low-frequency rise of ATL motion!

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GM: Details

- Luminosity estimate:
  - GUINEAPIG reports single-bunch luminosity (in m^{-2})
  - Equal to Lum / bunch rate (192 x 120 Hz)
  - NLC-500 design = 8.68×10^{33} m^{-2}
- Getting the right emittance
  - end-to-end tuneup procedure not ready yet
  - don't want to use perfect machine – lumi too high!
  - Compromise:
    - use RF structure offsets to generate "design" levels of emittance dilution
    - 75 µm x 15 µm RMS used
- Results are Preliminary and very small number of seeds used so far (~1)

GM Study: Results

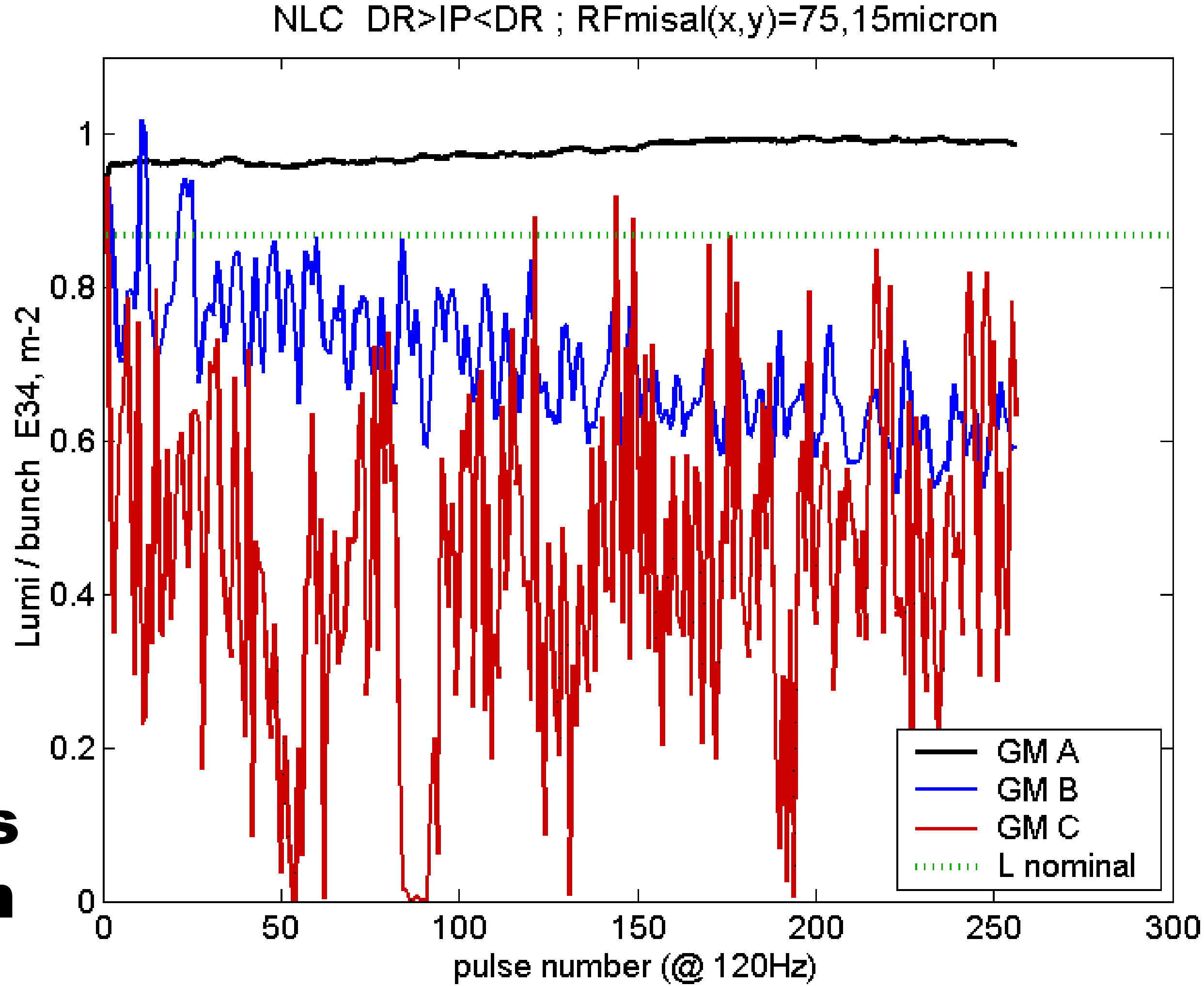
NLC Luminosity:

3 GM Models,

~2 seconds,

1 seed,

no feedback loops or FD stabilization



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GM Study: Results (2)

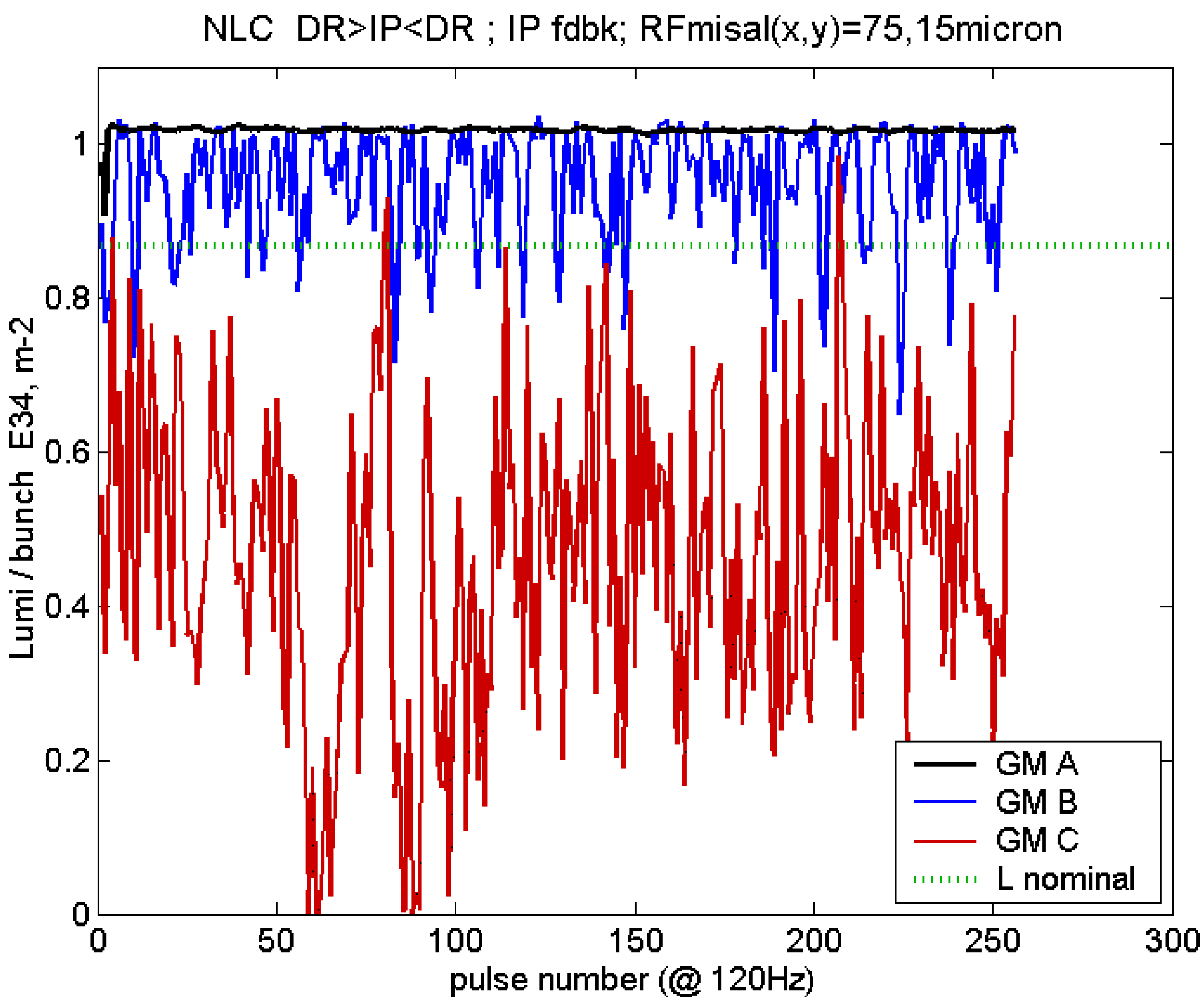
NLC Luminosity:

3 GM Models,

~2 seconds,

1 seed,

1 feedback loop (at IP), no FD stabilization



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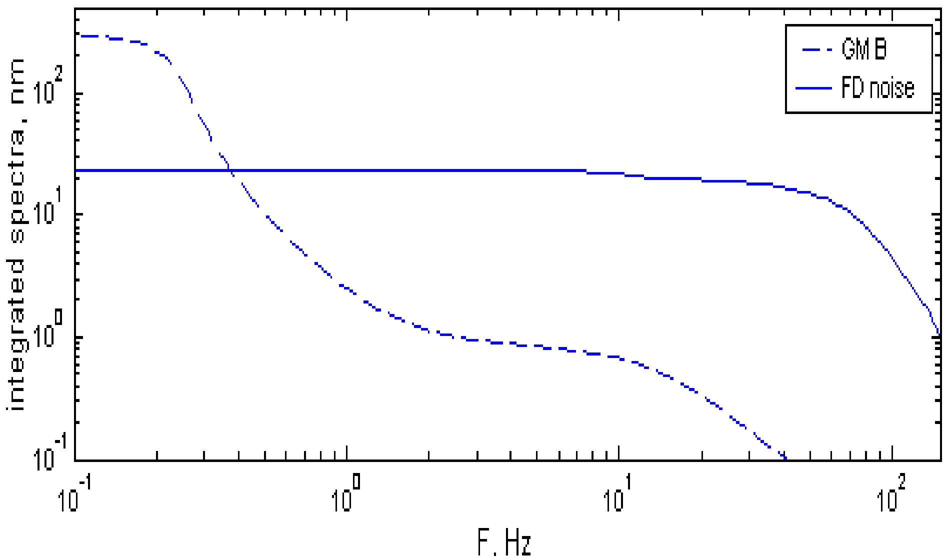
GM: The Message

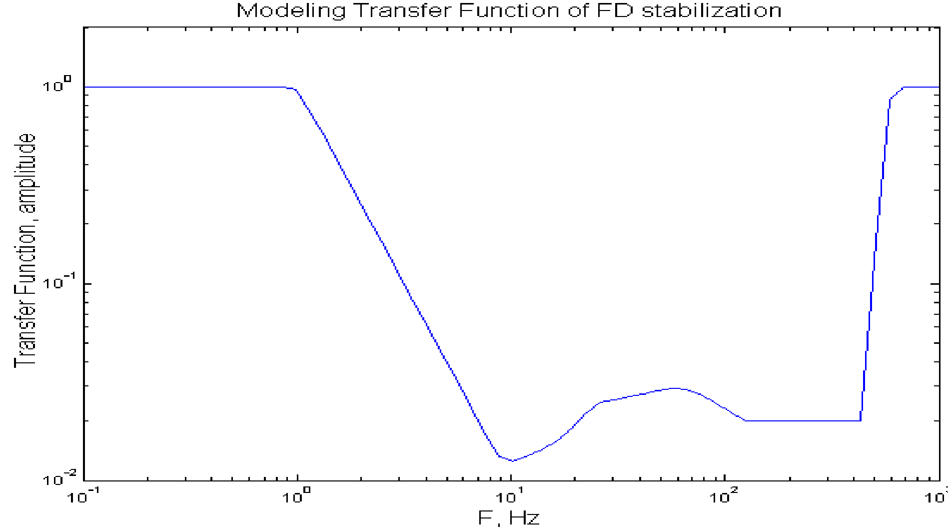
- If fast (wavelike) ground motion were the only source of element motion, then:
  - very quiet “A”-type sites or moderately quiet “B”-type sites would be okay
    - requires train-by-train IP collision feedback
    - FD stabilization *not* required in this case
  - Noisy “C”-type sites would be somewhat too shaky
    - <Lumi> ~ 64% of design

The Detector

- **Detector is not "solid ground"**
  - **lots more motion**
- **How much more?**
  - **no model – no existing detector built to be quiet**
  - **Use SLD measurements as "worst-case"**
  - **Implies ~20 nm motion each FD, *not correlated***
- **Add to GM "B" model, with and w/o FD stabilization**



Modeling Transfer Function of FD stabilization



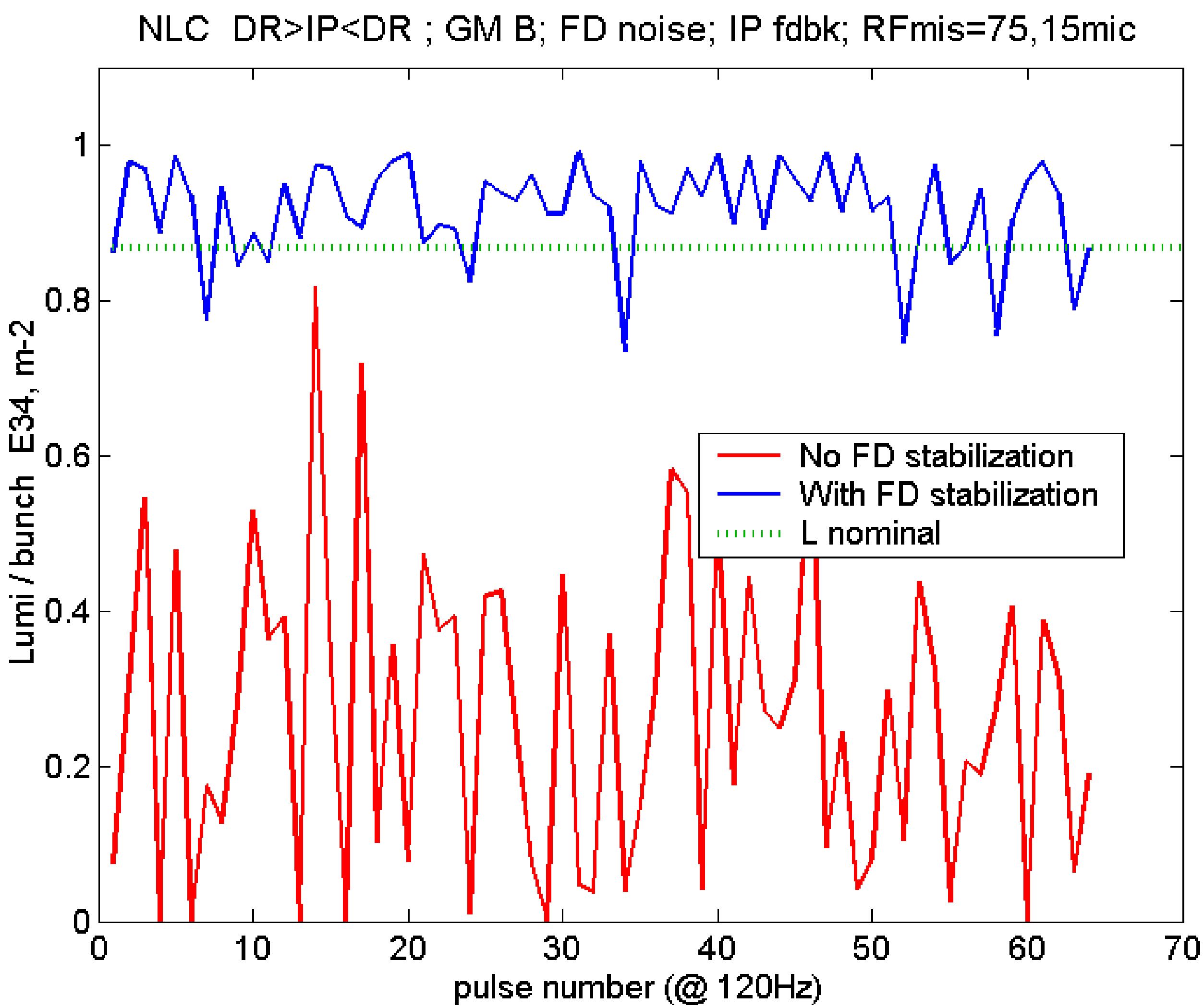
The Detector (2)

Luminosity:

GM “B” + FD noise

IP Feedback ON

With and Without doublet stabilization



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The Detector: The Message

- Doublet Stabilization needed for managing detector noise
- Stabilization adequate if
  - GM is comparable to “B” model
  - Detector noise ~ SLD’s
  - Desired transfer function achievable

Upcoming GM Studies

- Slow Motion (ATL or tunnel settling)
  - Define feedback loops, global tuning knobs, steering algorithms, etc
  - Measure performance as function of long time intervals
    - already done for BDS
- Incorporate static tuning algorithms
- Perform similar studies on TESLA, CLIC

Conclusions

- Integrated LC simulations (DR→IP←DR) a reality
- Permits more "holistic" study of beam dynamics
- Several studies already happening
- Validation of LC luminosity estimates, hopefully on FY2002 time scale