Start-to-End Simulations of Low-Emittance Tuning and Stabilization

P. Tenenbaum, SLAC

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Linear Collider "Laptops at Dawn" Team

D. Schulte, A. Seryi, N. Walker, G. White, M. Woodley

CERN, DESY, SLAC, Queen Mary University London

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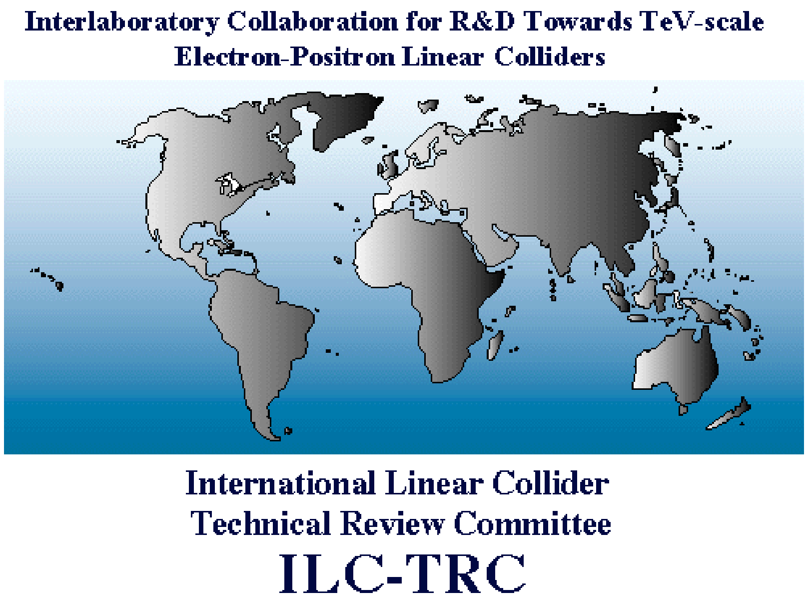
Getting to Luminosity

- Goal for LC: Make luminosity @ 500 GeV CM
  - Seek > 10^{34} /cm^2/s
  - Accelerate trains of bunches on every linac pulse
  - Compress (in z), demagnify (in x,y)

Parameter	TESLA	GLC/ NLC	CLIC
DR Energy	5 GeV	2 GeV	2.4 GeV
$\gamma\varepsilon_y$ @ DR	20 nm	20 nm	5 nm
$\gamma\varepsilon_y$ @ IP	30 nm	40 nm	10 nm
σ_z @ DR	6 mm	5.5 mm	1.3 mm
σ_z @ IP	300 µm	110 µm	35 µm
β_y^*	400 µm	110 µm	50 µm
σ_y^*	5 nm	3 nm	1.5 nm
Lumi	3×10^{34}	2×10^{34}	2×10^{34}

Introducing the Low Emittance Transport (LET)

- Everything from DR exit to IP
  - Bunch compressors,
  - Linac,
  - Beam Delivery



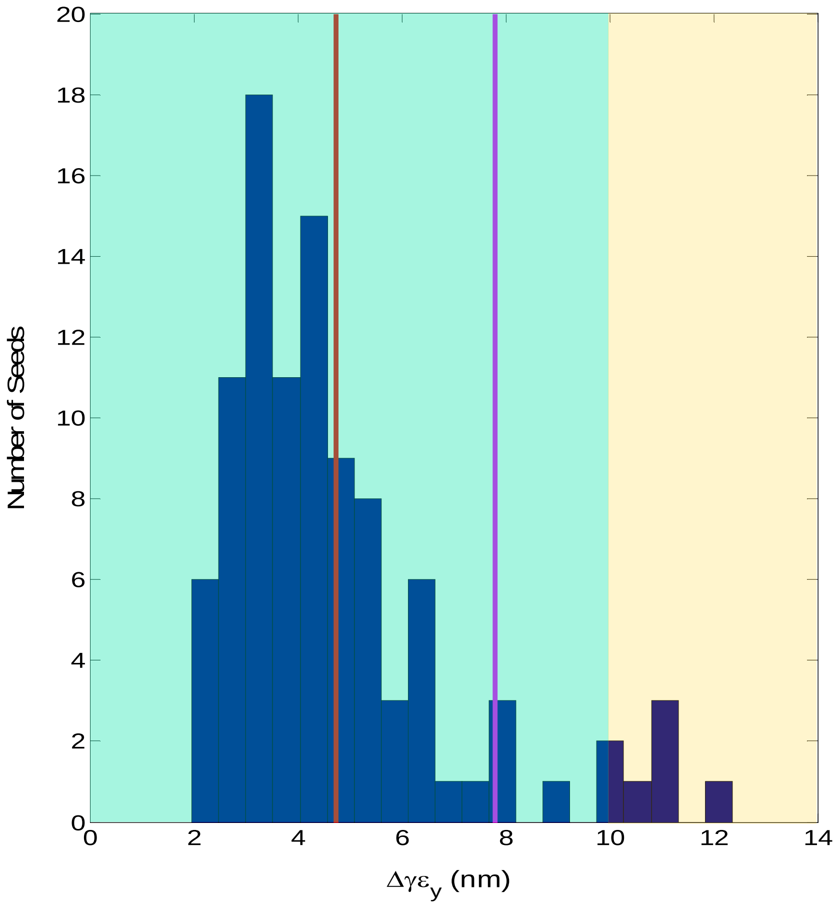
- From the 2003 TRC Report:
  - "...the feasibility of each LET design has been established."

So What’s the Problem?

- “Feasibility” tests ruled out fundamental design errors (excessive SR, etc)
- Obstacles to delivering luminosity come from
  - Misalignments
  - Mistuning
  - Dynamic effects (vibration/ripple/drift…)
- Tolerances far tighter than what can be achieved “ab initio” with survey, etc
  - Beam-based tuning and stabilization methods are absolutely essential!

What's the Problem? (2)

- Need to estimate performance of tuning systems
  - Algorithms, instrumentation, etc.
- Analytic expressions almost never possible
- Resort to simulation of the tuning process



Isolated versus Integrated

- Traditional LET study approach:
  - Design BC, linac, BDS separately
  - Specify parameters at system boundaries
  - Check to make sure the pieces fit together!

This works IFF errors are easily combined across system boundaries, simple (RMS) quantities suffice to describe system performance, and the residual errors in upstream systems do not interact with tuning algorithms in downstream ones.

In the LET, none of these conditions are true!

Isolated versus Integrated (2) – painful examples

- Errors that are not simple to combine
  - BDS has chromo-geometric errors
    - $\Delta\gamma\varepsilon \propto \gamma\varepsilon$ incoming
  - Ground motion effects
    - Can have long wavelengths – offsets in 1 system can be cancelled by offsets in the next!
- When RMS isn't enough
  - Non-Gaussian beams
    - Particles far from core @ IP do not reduce luminosity of core!
  - "Banana" effect
    - Small $\Delta\gamma\varepsilon$ ➔ large lumi reduction
- Error interaction
  - Mistuned BC changes E, σ_E into main linac

Isolated versus Integrated (3) -- Summation

The only way you will ever believe the result is if you simulate the complete tuning of 2 LETs and simulate the collision of the resulting beams @ the IP!

Lattice Representation

- Full instantiation is demanded
  - Every element has its own problems...
  - Large lattice data structure (>100 MB for 1 LET, and 2 LETs are needed)
  - Some care is required for efficiency when you wrestle with 200 MB worth of LET!
- More important: preserving relationships between elements
  - Several elements on a girder or powered in series
  - "The IR is always exceptional!"

Beam Representation

- Most of the LET is linac structures
  - Longitudinal representation crucial
  - Typical: represent beam with “slices”
- Slices not adequate in some areas
  - BC bends: migration in z
  - BDS: details of transverse distribution important
- Obligated to use slices in some areas, pointlike rays in others
  - Compromise: use rays everywhere but bin them for linac simulations!

Codes We Have Used

- Quite a few...
- Both ray-type and slice-type
  - Single- and multi-bunch
- None were initially written for full LET studies
  - All adapted, reasonably successfully, but...

GUINEAPIG

LIAR

MAD8ACC

PLACET

MERLIN

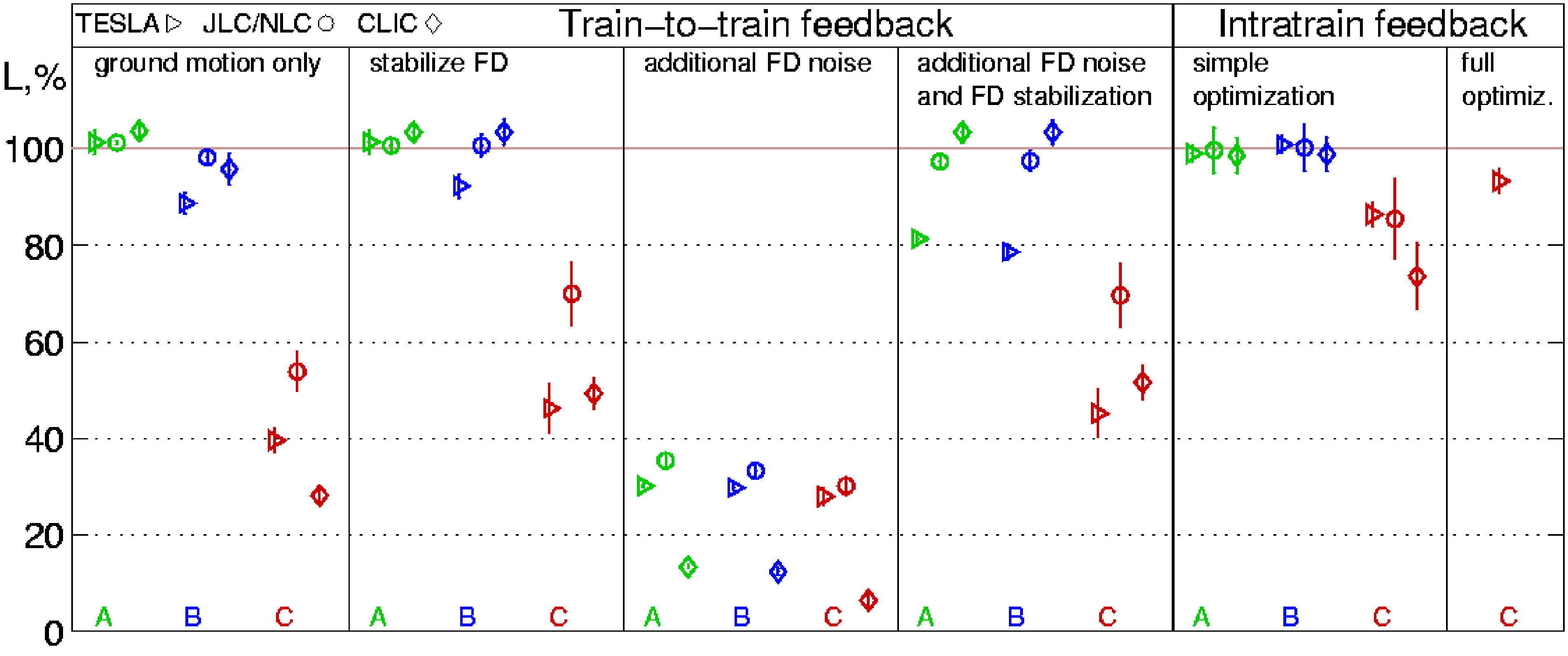
Sample Studies

- Ultimate goal of all-inclusive study of LET tuning/stabilization not yet achieved
- Several studies gone partway
  - Use 2 full LET beamlines (collide beams!)
  - Misalign & steer linac to achieve design $\Delta\gamma\epsilon$ and expected wakefield/dispersion balance
    - BDS and BC assumed perfect
  - Perform study with “tuned” beamline *ansatz*

Sample Study 1 – Ground Motion and Vibration

- Consider TESLA, GLC/NLC, CLIC
- 3 models of ground motion
  - “A”– quiet, to “C” – noisy
- With and without additional detector vibrations at IP
- Several methods of stabilization
- 6 CPU months thrown at the problem!
- See Seryi *et al,* PAC-2003

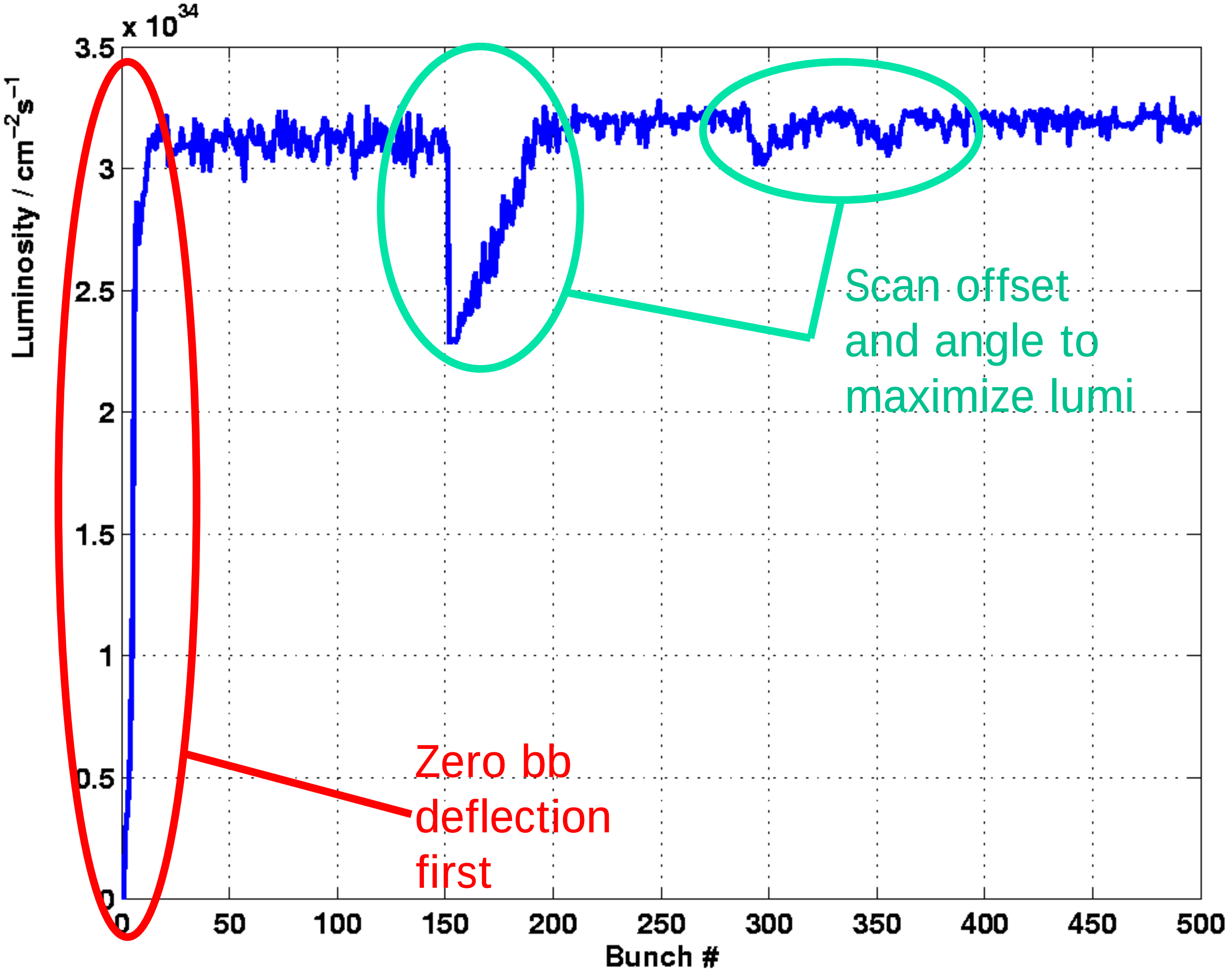
Ground Motion Example (2)



Sample Study 2 – Intra-Train Feedbacks in TESLA

- TESLA with some ground motion
- Feedbacks to tune IP offset and angle during 1 train
- Tune each FB to maximize luminosity signal (don't just zero bb deflection angle)
- See Walker, Schulte, White, PAC-2003.

Intra-Train Example (2)



Path to the Future

- Modifying existing codes to do LET studies was “fastest way from A to B”
  - Generally not optimal – “Frankenstein’s Monster” codes
- Moving towards purpose-built LET codes
  - For linear collider LET
  - For linac-based light sources

Path to the Future (2)

- BC tuning algorithms neglected so far
  - Rectify this!
  - Serious foray into longitudinal tuning
- Once the whole LET is tuned up…
  - Use "tuned LET" model for other studies
    - Collimation
    - Feedback
    - Other operation – limitless vistas of batch jobs!