ILC and CLIC Luminosity Performance with Intra-train FB

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Thanks to Andrea Latina and Daniel Schulte,
CERN, Geneva

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Introduction

- Luminosity goal for the future linear colliders very demanding: very small transverse spot size and nanometre level beam stability at the IP
- Static and dynamic imperfections can significantly degrade the luminosity/emittance
- To combat the emittance dilution the beam based alignment and tuning techniques are required
- To keep the beams in collision feedback (FB) systems are required in different parts of the machine:
  - Slow FB systems:
    - Beam orbit steering
    - Slow ground motion compensation
  - Inter-pulse FB
  - Intra-pulse FB:
    - Operates at high frequency (~ 1 MHz) and acts within a bunch train
    - Removes the relative offset jitter at the IP steering the beams back into collision

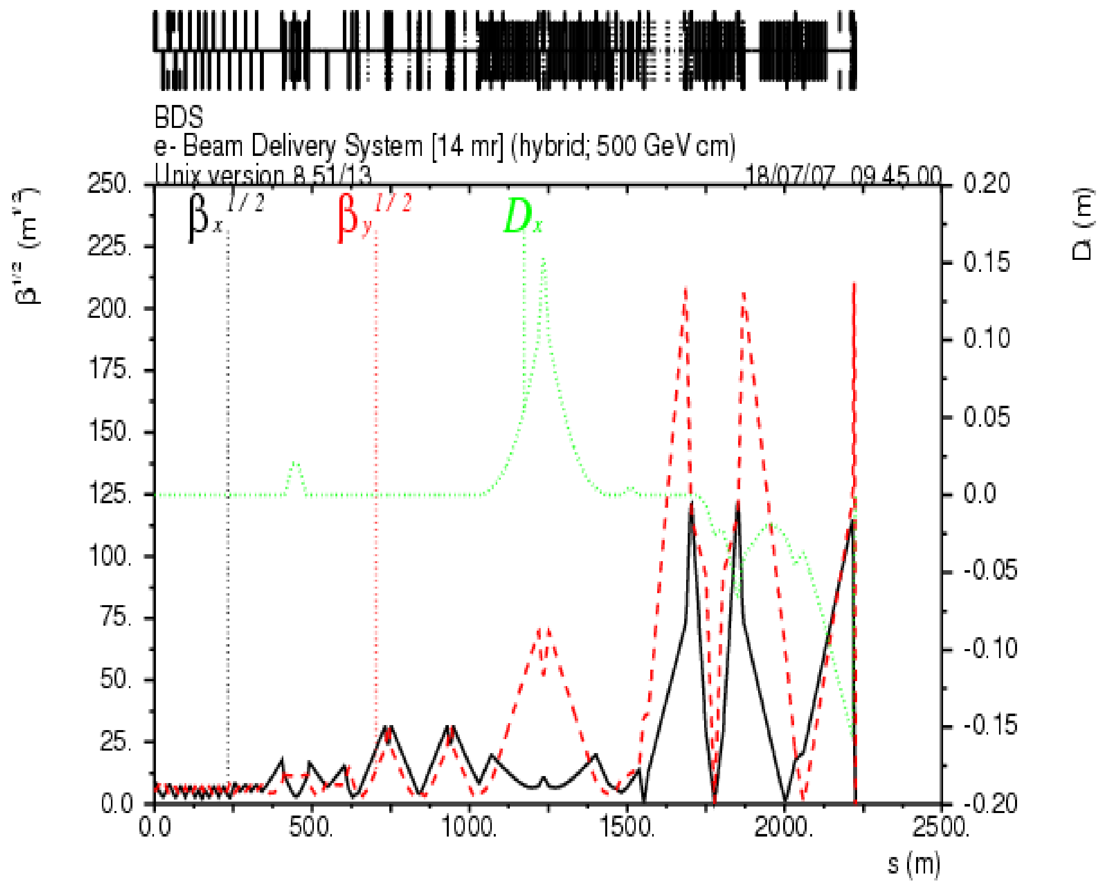
Simulation parameters: ILC (500 GeV cms)

(RDR 2007):

Design luminosity (10^{34} cm^{-2} s^{-1}): 2
Emittances $\gamma\varepsilon_x / \gamma\varepsilon_y$ (nm rad): 10^4/40
IP Beta functions β^*_x / β^*_y (mm): 20/0.4
IP beam sizes σ^*_x / σ^*_y (nm): 639/5.7
Bunch length σ_z (μm): 300
Particles/bunch at IP (10^9): 20
Bunches/pulse: 2625

<u>Beam time structure:</u>
Linac repetition rate (Hz): 5
Bunch separation (ns): 369.2
Bunch train length (μs): 1000

Beam delivery system:



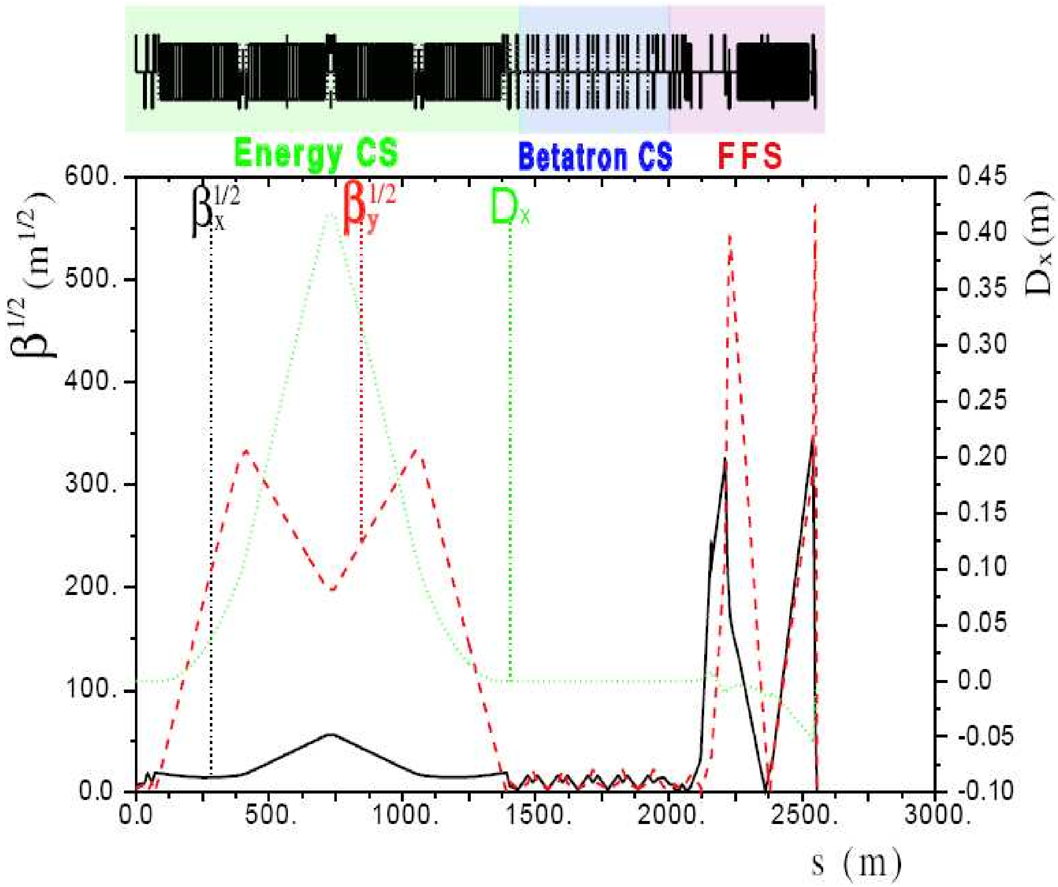
Simulation parameters: CLIC (3 TeV cms)

(updated 2008):

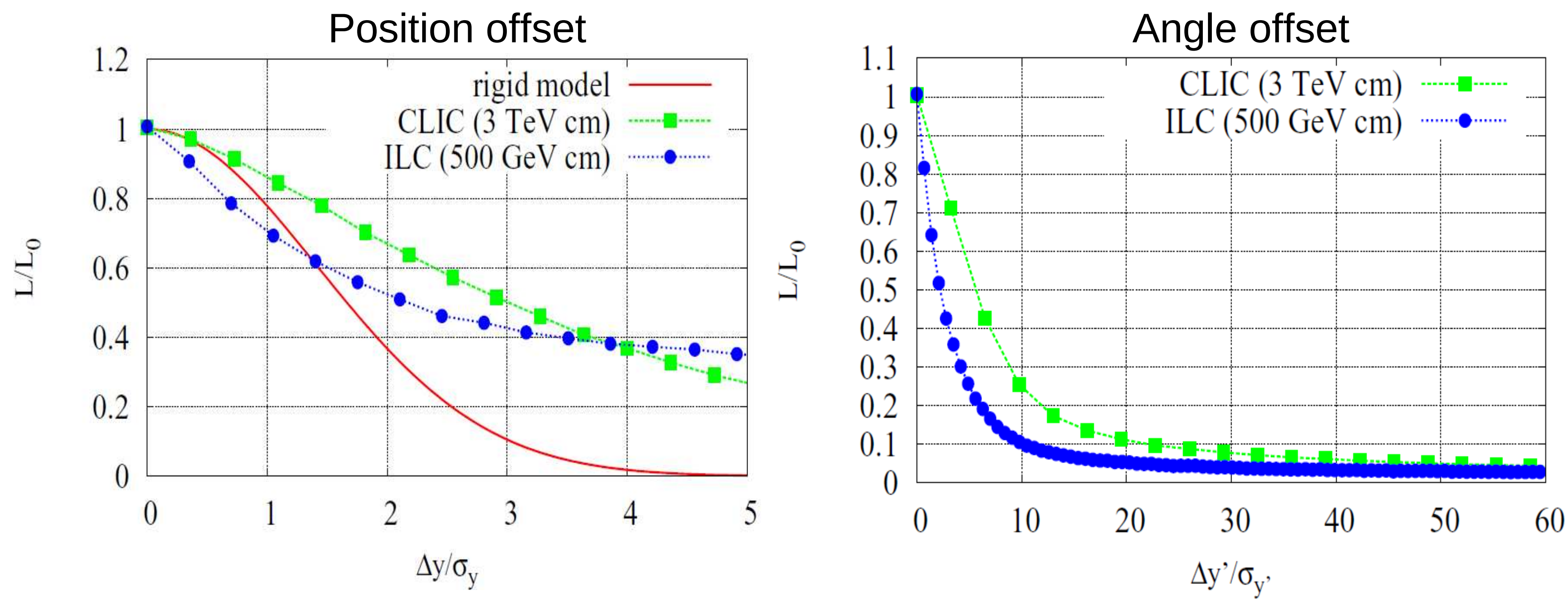
Design luminosity (10^{34} cm^{-2} s^{-1}): 5.9
Emittances $\gamma\epsilon_x$/ $\gamma\epsilon_y$ (nm rad): 680/20
IP Beta functions β^*_x/ β^*_y (mm): 6.9/0.068
IP beam sizes σ^*_x/ σ^*_y (nm): 45/0.9
Bunch length σ_z (μm): 44
Particles/bunch at IP (10^9): 4
Bunches/pulse: 312

<u>Beam time structure:</u>
Linac repetition rate (Hz): 50
Bunch separation (ns): 0.5
(740 times smaller than for ILC !)
Bunch train length (μs): 0.156
(6400 times smaller than for ILC !)

Beam delivery system:



Luminosity versus beam-beam offset



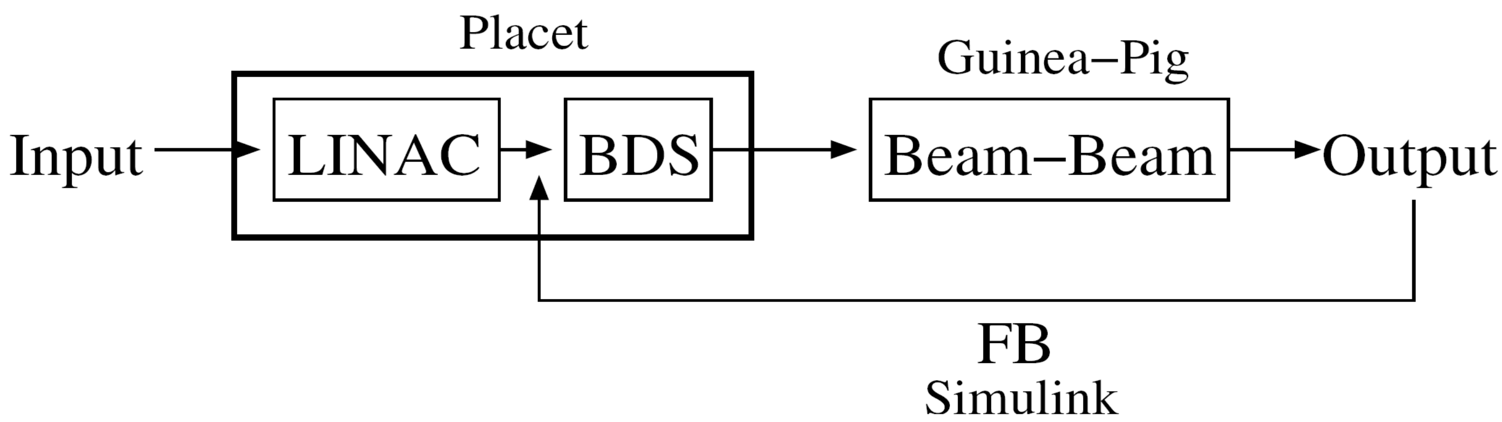
Simulations with Guinea-Pig: beam-beam effects (beamstrahlung, hourglass effect, pair creation, …). Disruption parameters: D_y=19.4 (ILC); D_y=3.5 (CLIC)

Vertical separation between beams mainly from fast magnet vibrations

Beam based FB system necessary to keep the beams in collision

PLACET based start-to-end simulations

Simulation set up:



For the ILC we use a proportional and integral (PI) controller algorithm embedded in Simulink (MATLAB)

Alternatively, we can also use a similar PI controller algorithm implemented with Octave (a free clone of MATLAB), which is easily callable from PLACET

Benchmarking with earlier start-to-end simulations [based on the code MERLIN, by Glen White, & D. Kruecker et al., EUROTeV-Report-2007-019] may be useful to achieve reliable predictions

ILC start-to-end simulations
LINAC

- PLACET scripts for tracking along LINAC + BDS, linked with Simulink (Matlab)
- LINAC:
  - Sliced bunches tracked along the LINAC
  - Initial vertical norm. emittance (exit from DR and RTML) = 24 nm
  - Initial injection jitter (from DR and RTML) = 0.1σ
  - Including long- and short-range transverse and longitudinal wakefield functions
  - Structure misalignment. Survey alignment errors:

Table 1: Assumed initial static errors with respect the module axis in the main linac.

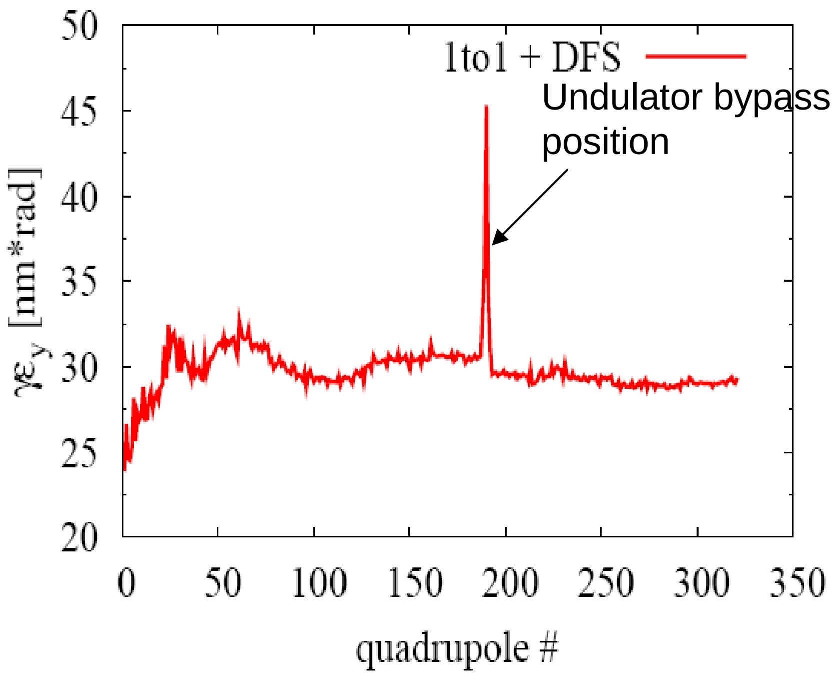
Error	value
Cavity offset	300 μm
Cavity tilt	300 μrad
Quadrupole offset	300 μm
Quadrupole roll	300 μrad
BPM offset	200 μm

  - Static beam based alignment algorithms: 1to1, DFS
  - Ground motion (different models tested): A, B, C and K [Andrei Seryi's models]

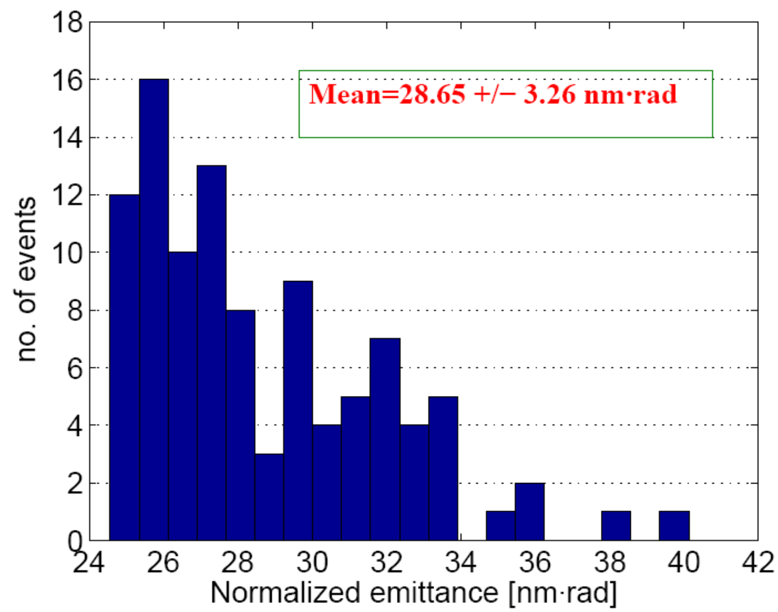
ILC start-to-end simulations

Beam based alignment of the main linac

LET simulation example (100 random seeds averaged) for the ILC:



Emittance growth in the main linac of 20 %

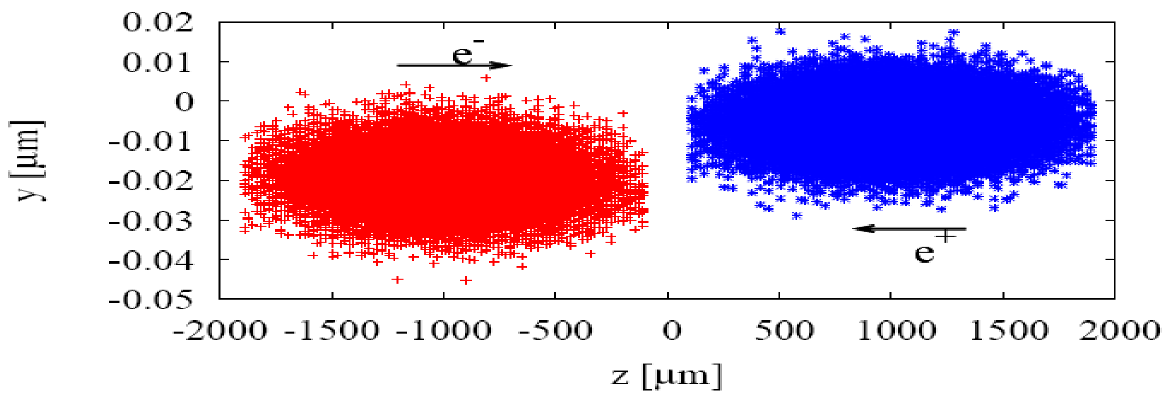


Vertical emittance dilution for 100 seeds of applying misalignments (static and GM), 1-to-1 and DFS correction

Undulator alignment being studied by Duncan Scott et al. (Daresbury). In this simulation we have replaced the undulator by a matching transport matrix !

ILC integrated simulations
BDS, beam-beam

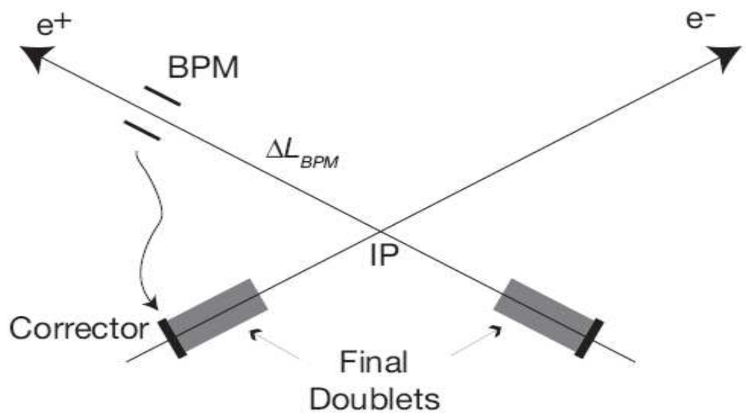
- BDS & IP:
  - BDS optics 14 mrad (version 2007)
  - Each bunch binned in 50000 macroparticles
  - 0.2 s of GM (different models tested)
  - Collimator wakefield effects
  - Beam-beam interaction at the IP (Guinea-Pig):
    - Luminosity and beam-beam deflection
    - Output for studies on EM background



ILC integrated simulations
Fast intra-train FB system

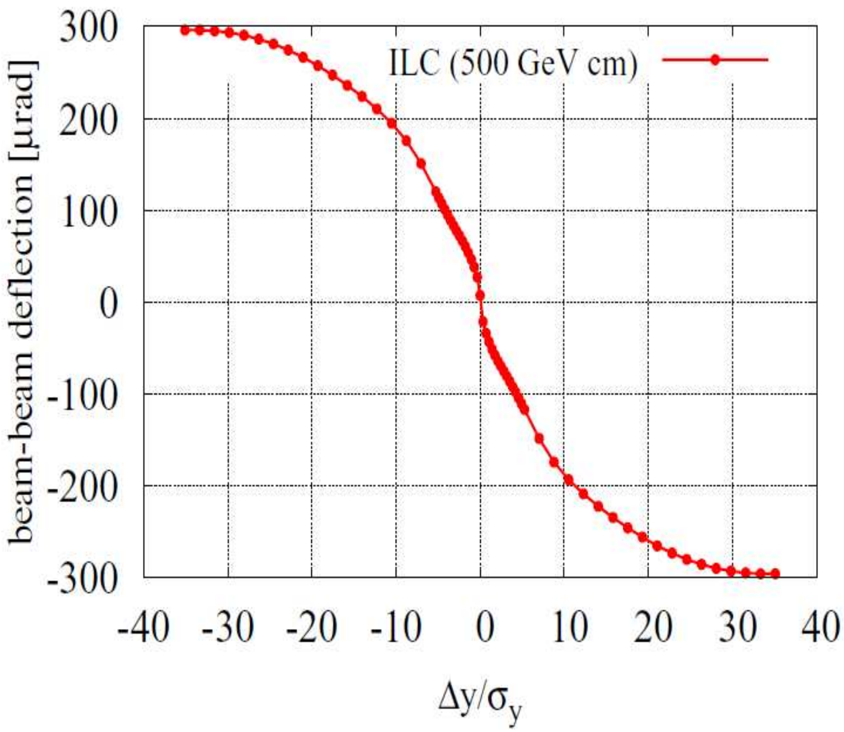
IP intra-train position FB:

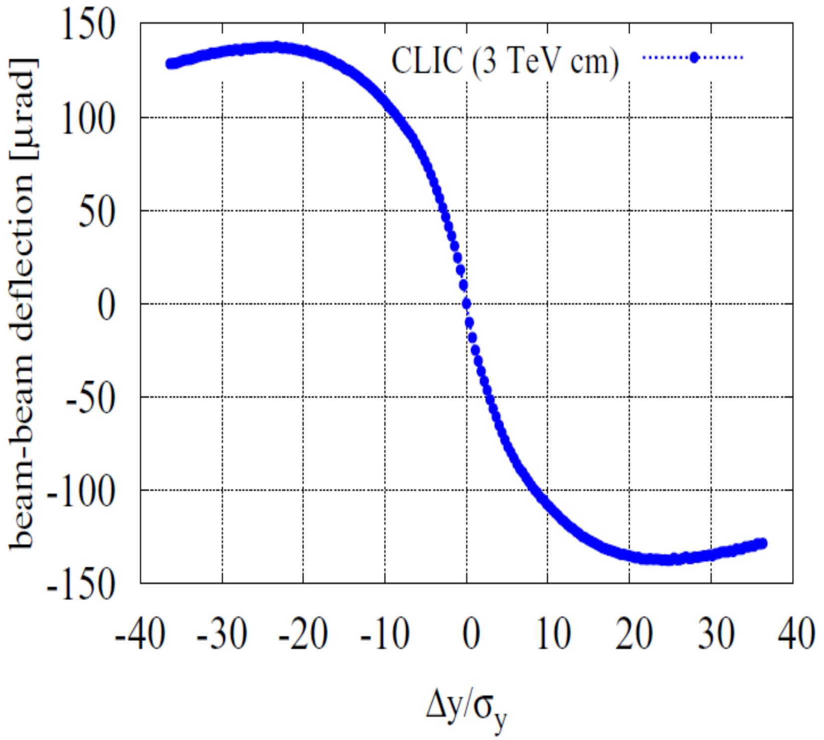
- Stripline kicker located at 3.5 m upstream of the IP between the sextupole SD0 and the final quadrupole QF1
- BPM at $\pi/2$ phase advance downstream of IP to measure the beam positions to determine the b-b deflection angle
- BPM resolution $\sim 1\ \mu m$
- Kicker magnetic field error (dB/B) 0.1 %



Beam-beam deflection angle

The beam-beam deflection curve is the signal measured by the BPM of the IP position FB system to determine the response of the corrector

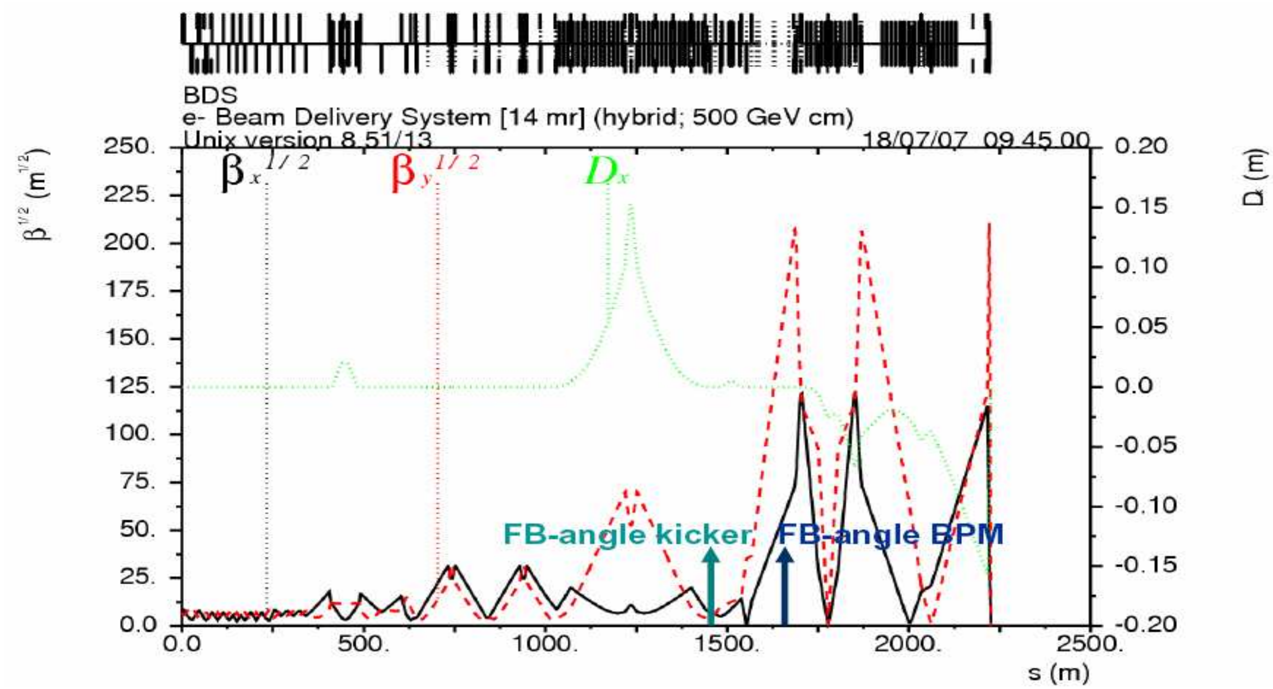




ILC integrated simulations
Fast intra-train FB system

IP intra-train angle FB:

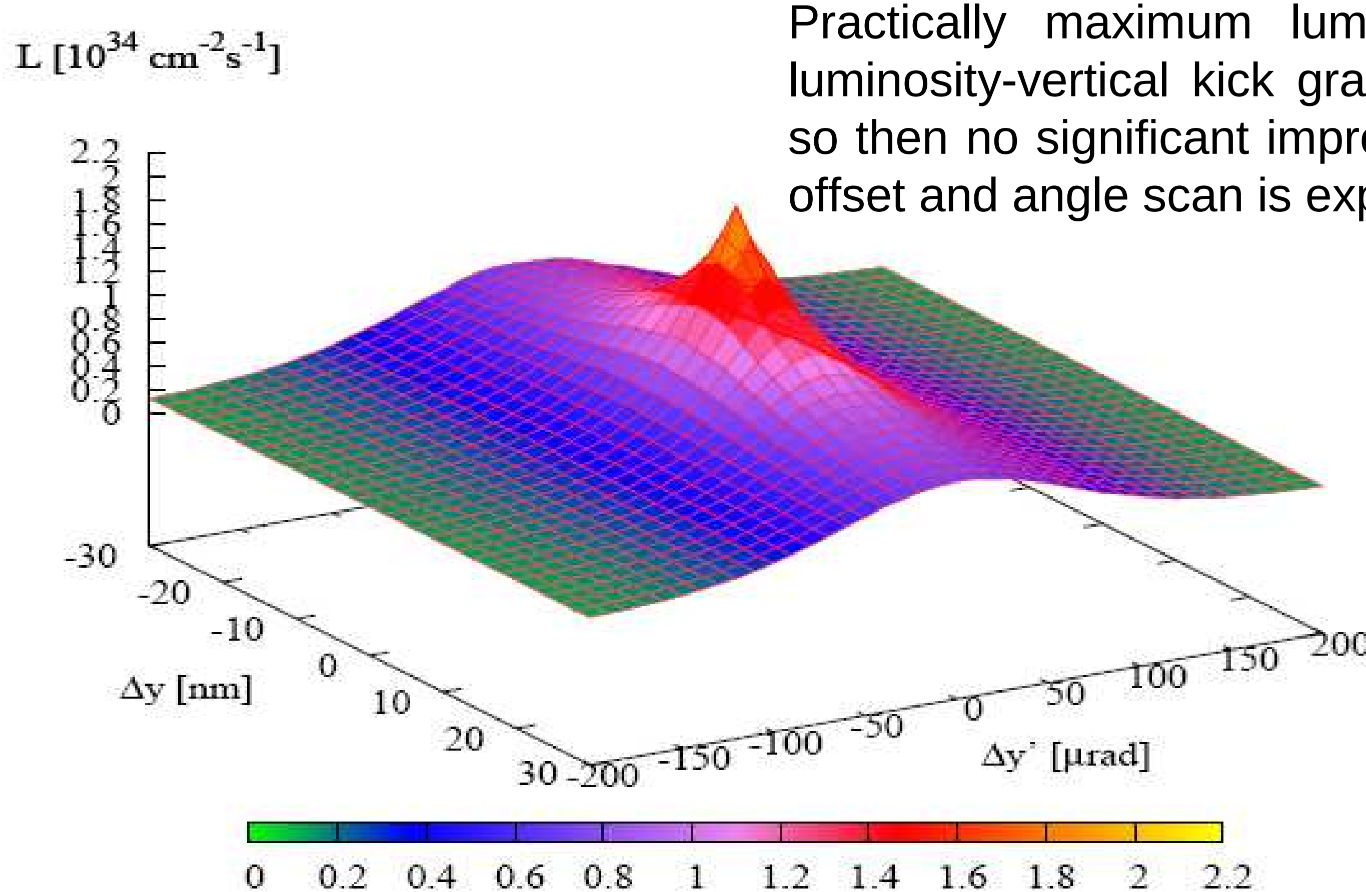
- Stripline at the entrance of the final focus with a downstream BPM at $\pi/2$ phase advance



ILC integrated simulations

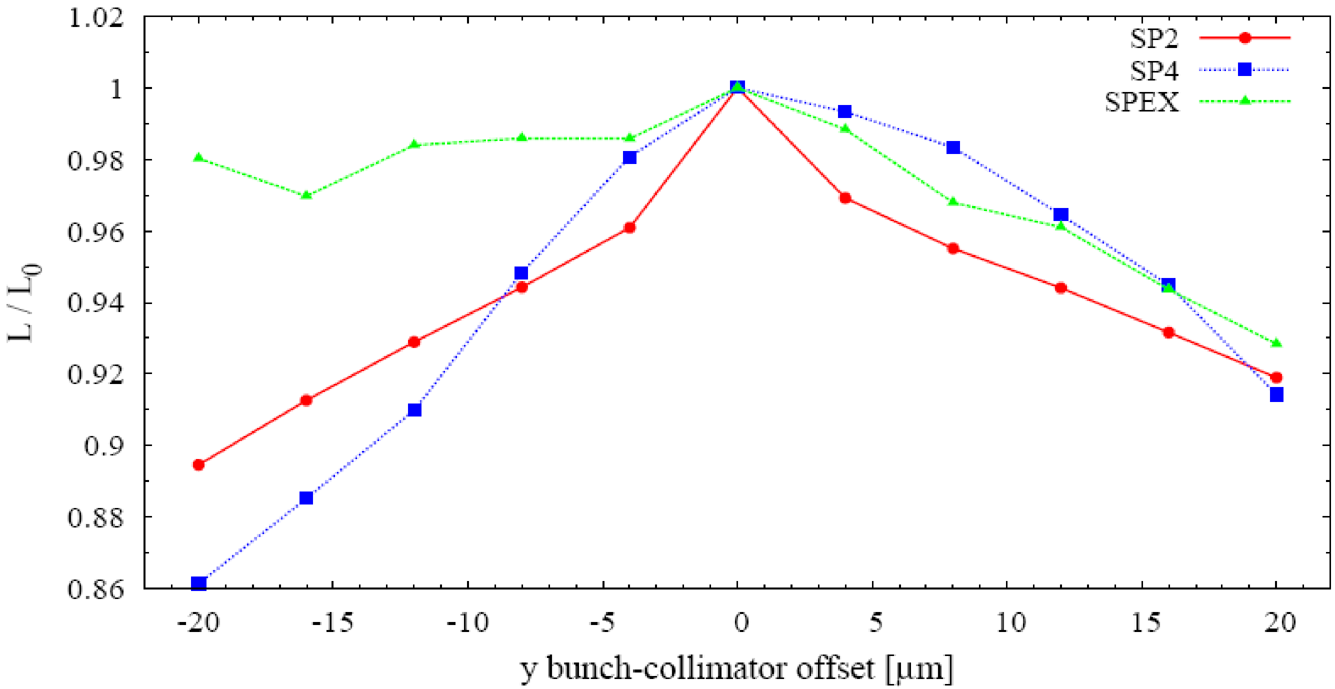
Luminosity optimisation: position and angle offset scan

Practically maximum luminosity when luminosity-vertical kick gradient is zero, so then no significant improvement from offset and angle scan is expected



ILC integrated simulations
Collimator wakefield effect on the luminosity

- Luminosity loss due to vertical misalignment of each spoiler:

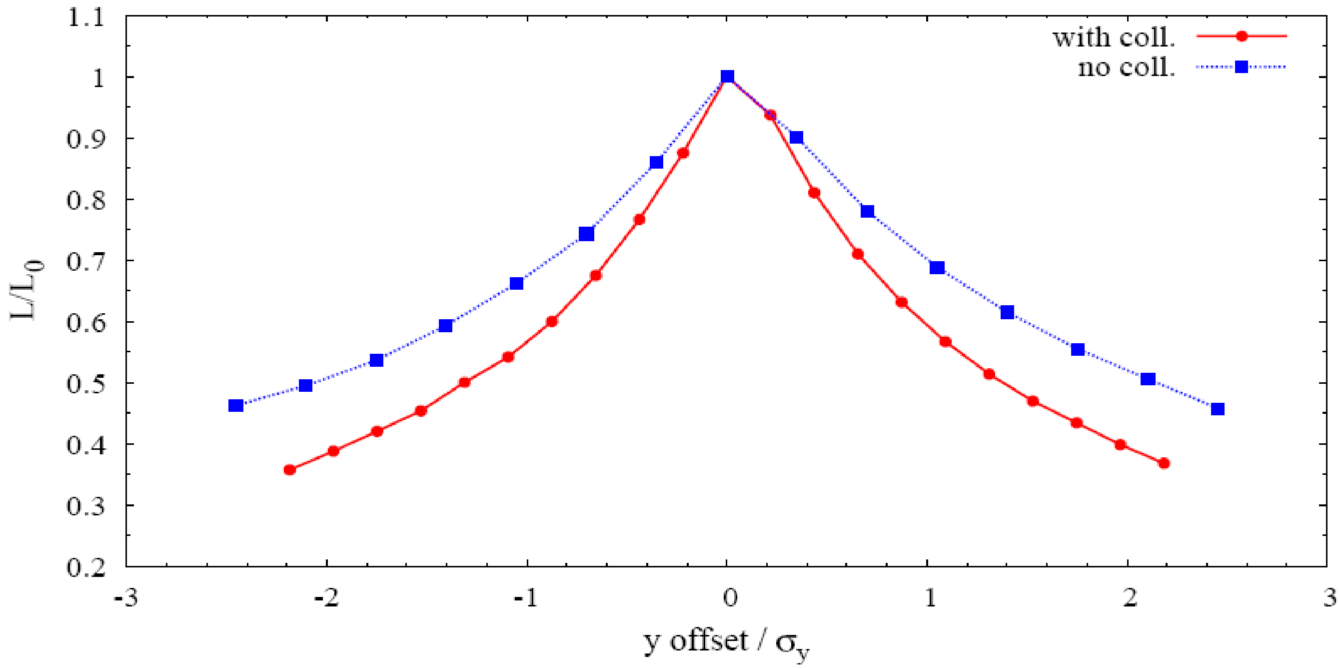


Collimator misalignment tolerance ≈ 20 μm (~ 10% luminosity loss)
It can be achieved with optical survey alignment techniques!

ILC integrated simulations

Collimator wakefield effect on the luminosity

- Luminosity loss versus initial vertical position jitter at the entrance of the BDS
- The join effect of all the BDS collimators is considered



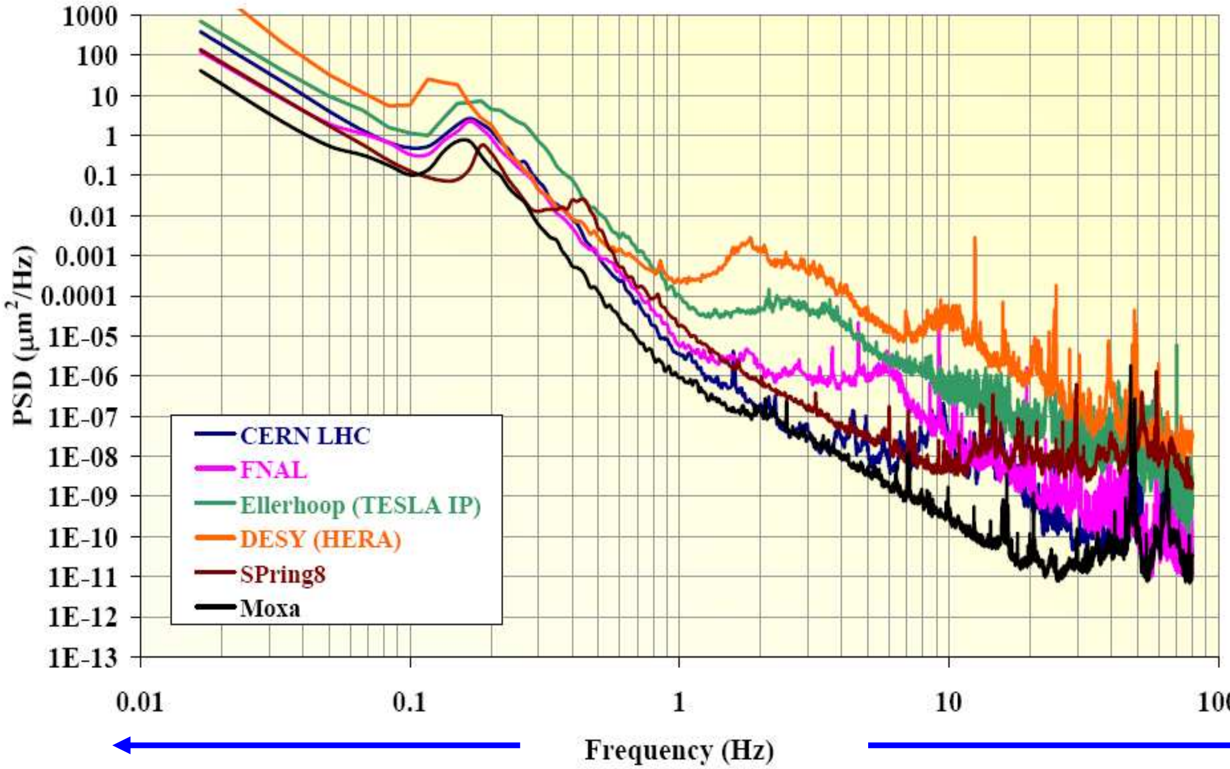
Jitter tolerance $\approx 0.2\ \sigma_y = 0.4\ \mu m$ (~ 10% luminosity loss)

The jitter position of the incoming beam at the entrance of the BDS should be corrected at the submicrom level, for example by mean of precise orbit steering feedback systems using cavity BPMs and stripline kickers

Ground motion

Power spectral density

For ground motion measurement information see for example:
http//vibration.desy.de (DESY database)



Sources of vibration:
- Natural seismic motion
- Man-made (cultural noise)

Andrei Seryi's models:

Model A=CERN
Model B=Fermilab
Model C=DESY
Model K=KEK

Slow motion: emittance growths
Beam size effects

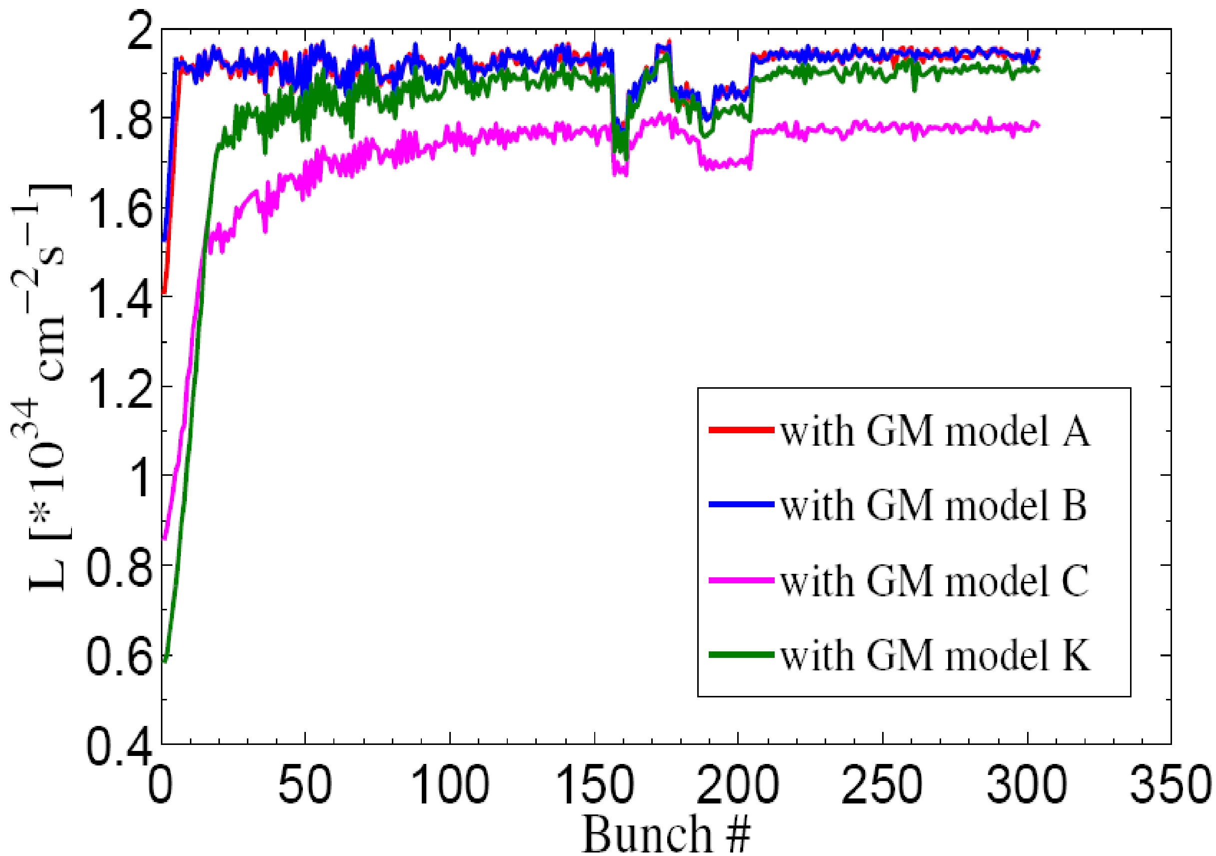
> 5 Hz

Fast motion: beam jitters
Beam-beam offsets

ILC Luminosity results

Different scenarios of ground motion

Example for 1 single random seed



Nominal: $L=2x10^{34}\ cm^{-2}s^{-1}$

- For the noisiest site (model C), applying fast position and angle FB stabilization, a recovery of 85 % of the nominal value is obtained.

- For quiet sites (model A and B) practically the 100 % of the nominal luminosity would be achievable

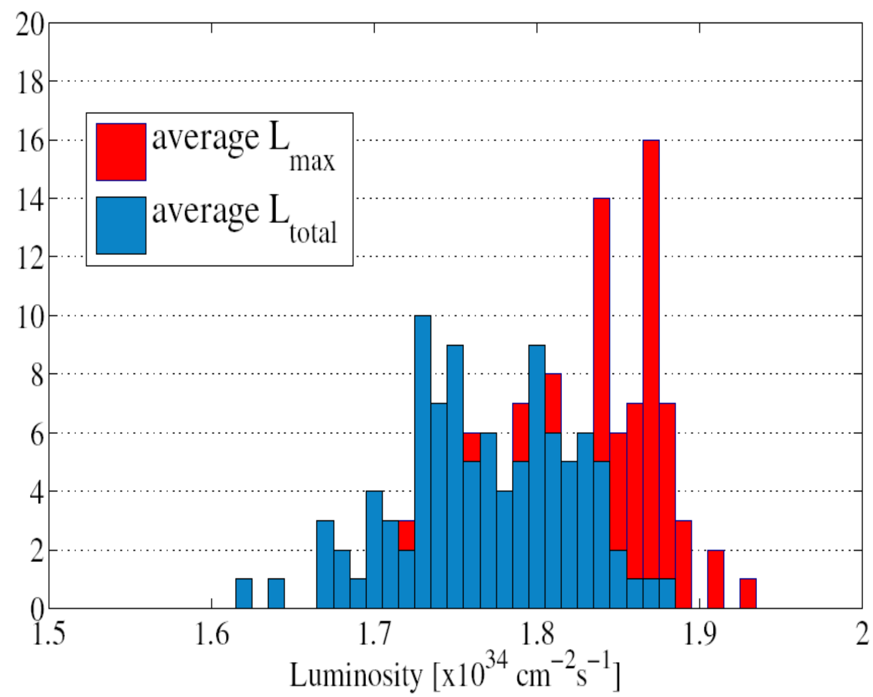
ILC Luminosity results

Statistical fluctuation of the luminosity

Example for 100 random seeds with ground motion model C

$\mathbf{L_{total}}$ corresponds to the average over the first 300 bunches of the train, giving a mean value μ=1.768 x 10^{34} cm^{-2} s^{-1} (88 % of the nominal luminosity)

$\mathbf{L_{max}}$ represents the maximum achieved luminosity with a mean value μ=1.831 x 10^{34} cm^{-2} s^{-1} (92 % of the nominal luminosity)



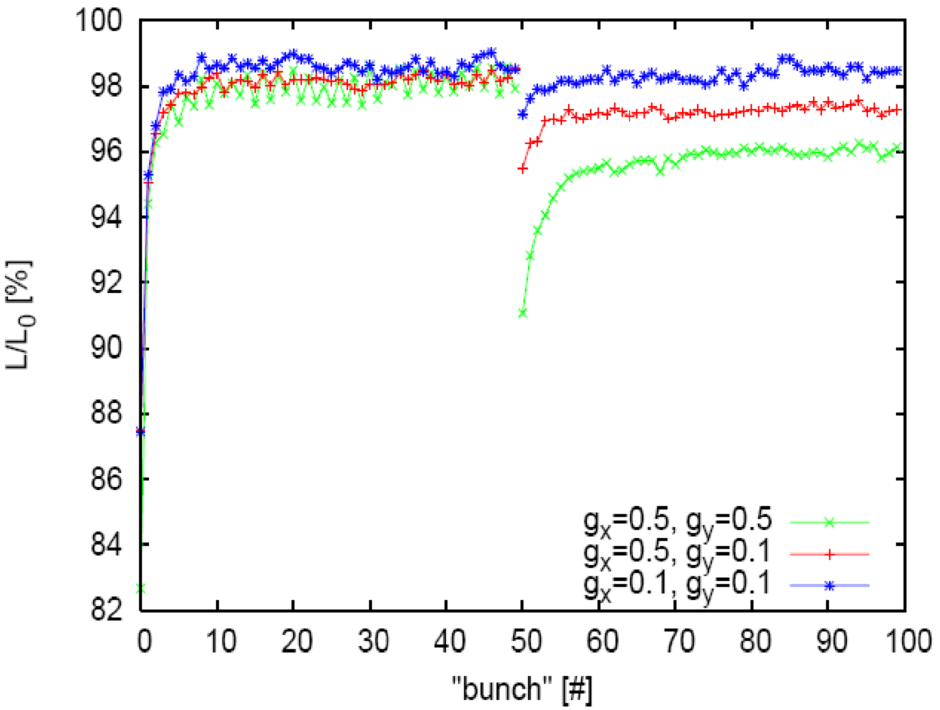
IP-intra-train position FB for CLIC

For CLIC, much smaller train length and shorter bunch spacing. IP intra-pulse FB is more challenging.

FONT3 has demonstrated latency times ≈20 ns (using FB analogue processor)

If bunch separation 0.5 ns, then possible FB correction each 40 bunches (≈8 iterations per pulse)

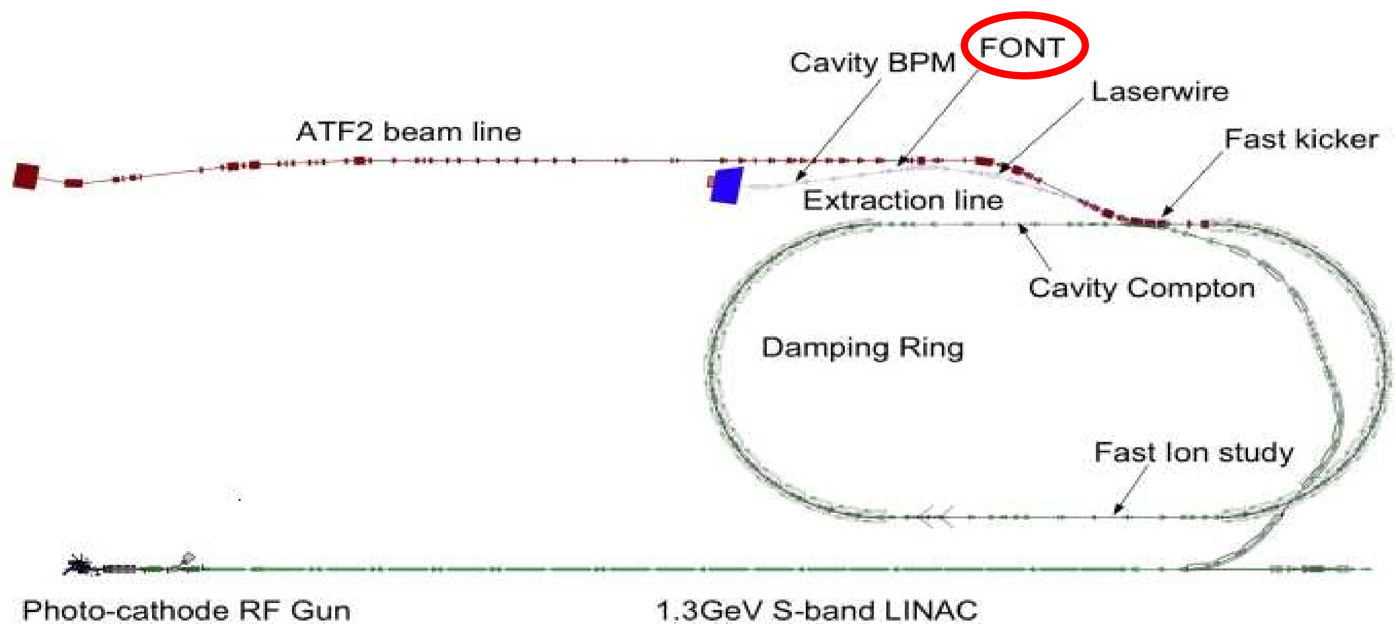
[A. Latina et al., EUROTeV-Report-2007-065]



Experimental test planning of Fast FB for LC

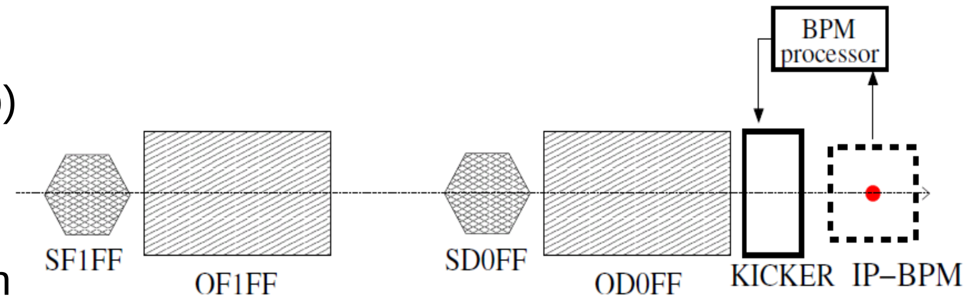
- In the context of the Feedback On Nano-second Timescales (FONT) project (see talk by Philip Burrows)
- Fast intra-train FB to be located in the ATF2 EXT line
- Goal:

  Control of beam position down to 5 % of the rms vertical beam size at the IP, which will require a stability control better than 1μm at the ATF2 final focus entrance

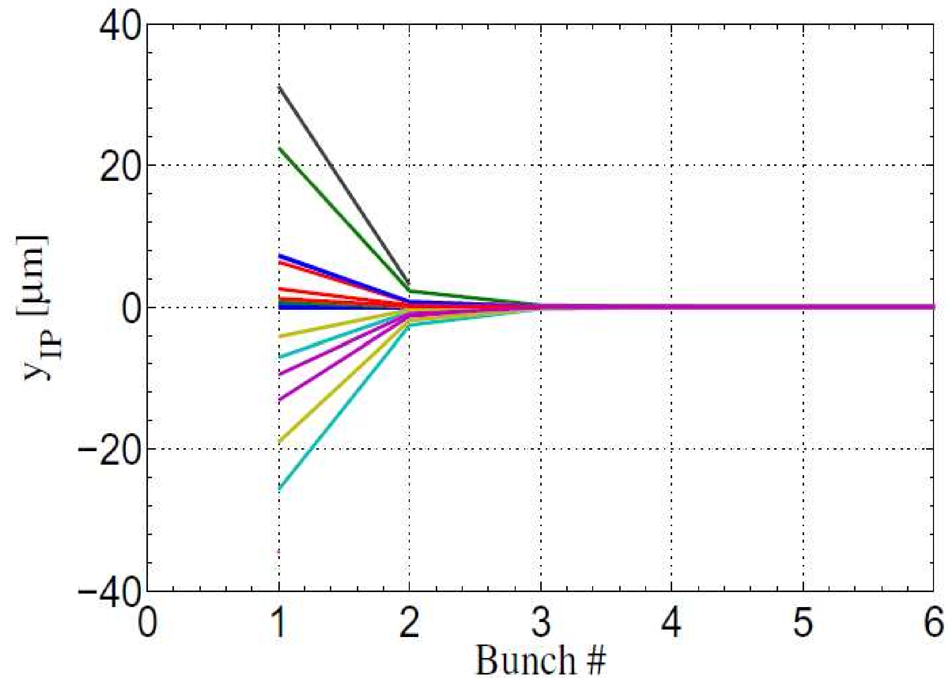


Experimental test planning of Fast FB for LC

- We are also designing an intra-train FB system at the ATF2 IP (before dump)
- Goal:
  Correct residual bunch-bunch jitter due for example to the fast vibration of the FD quadrupoles. Stability control better than ~ 5 nm
- Using a Cavity BPM with nm level resolution



Simulation example correcting several position offsets at the ATF2 IP:



Summary and outlook

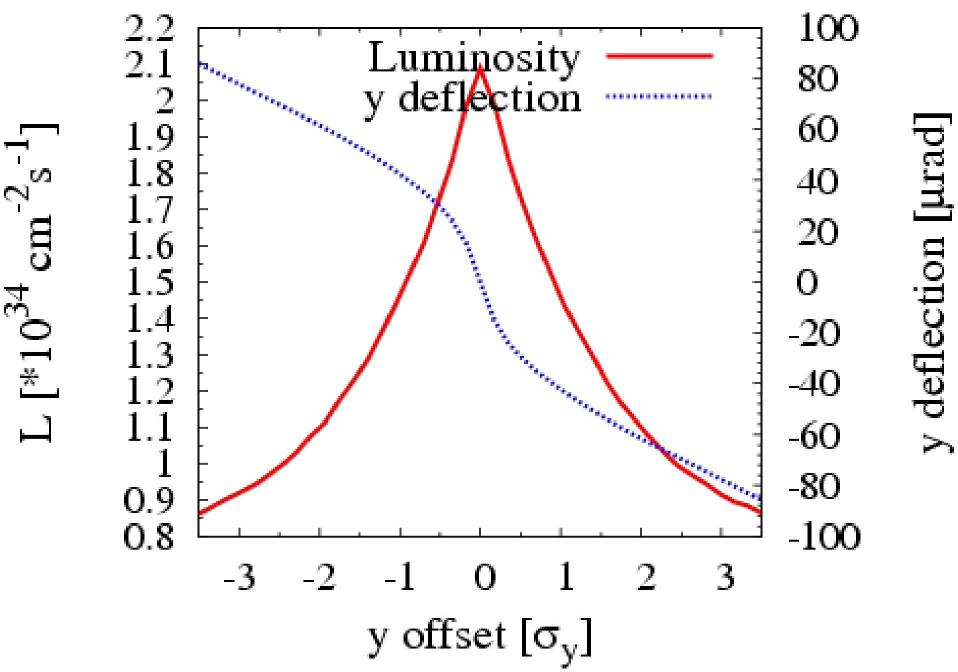
- The different sources of beam jitter and contribution to the luminosity loss of the future LC should be carefully studied
- The aim is to make realistic tracking simulations including different static and dynamic errors
- To achieve the required luminosity of the future LC necessary FB systems operating on different time scales
- We have studied intra-train FB at IP to keep the beams in collision. Simulation results of the luminosity performance for the ILC have been presented
- For ILC possible bunch-to-bunch correction. For CLIC more challenging (intra-train IP position correction each 40 bunches ?)
- The exact positions of the BPMs and kickers for the CLIC IP-FB have to be defined. Further study is needed
- We plan to improve the simulation model adding the missing error sources, e.g. crab cavity effects
- Suggestions are welcome

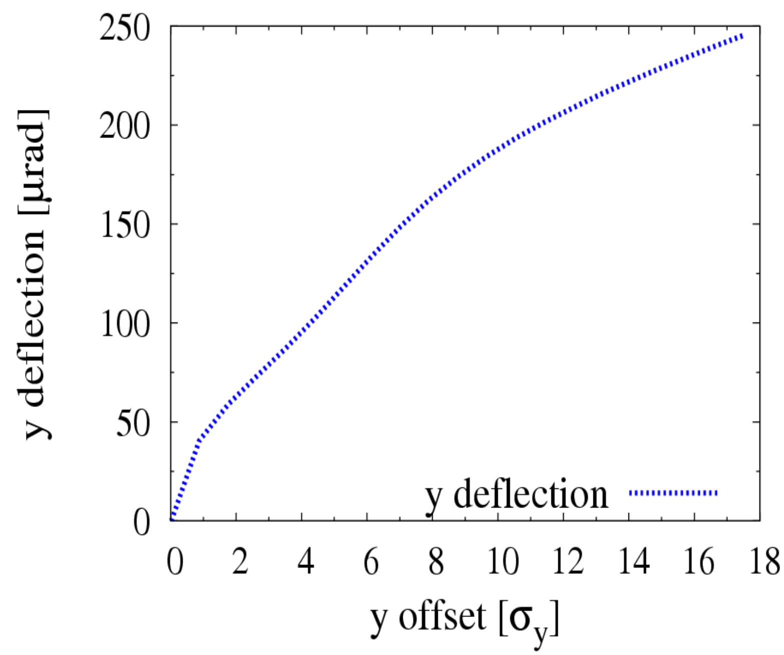
Extra …

Luminosity and beam-beam deflection at the IP

- Luminosity is max when lumi-vertical kick gradient is zero → Not expected a relevant improvement from offset and and angle scan

- The beam-beam deflection is linear in beam offset only for small vertical displacements





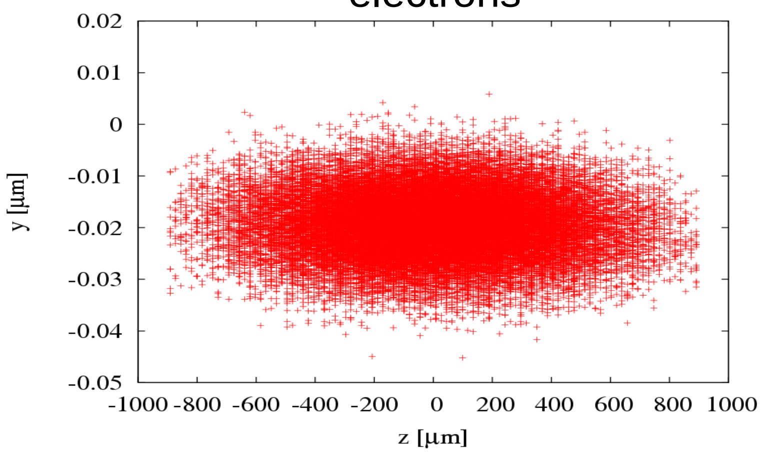
~ nm vertical offset → ~ tens of urad deflection angle

Longitudinal profile of a sample bunch at the IP

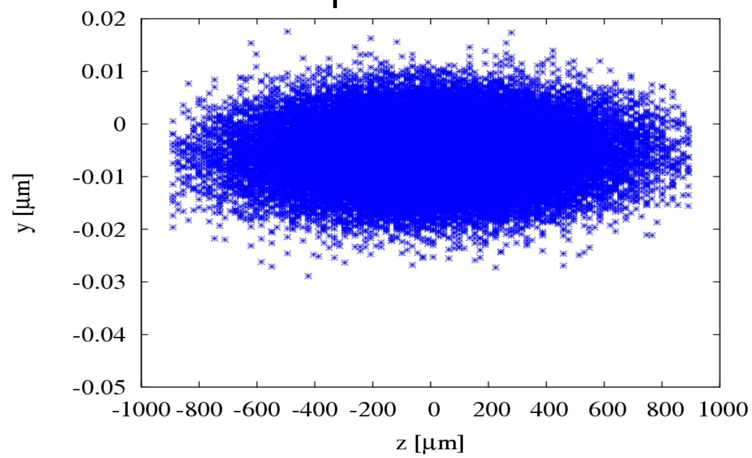
y vs z

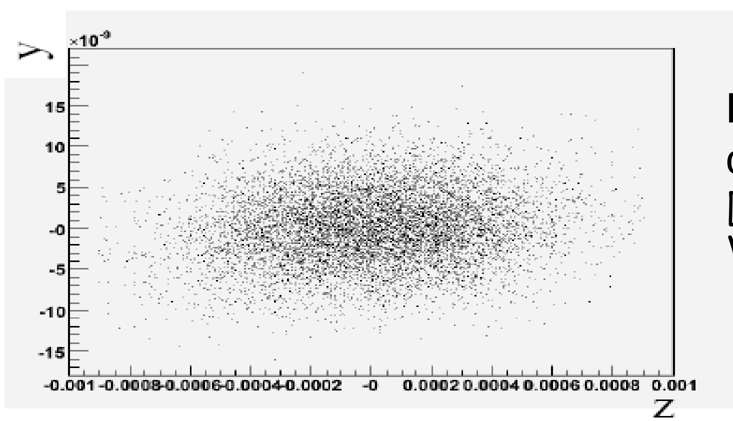
For the present ILC linac simulations the short-range wakefield effects are much smaller than for previous TESLA linac simulations.
Practically no banana effect!

electrons



positrons





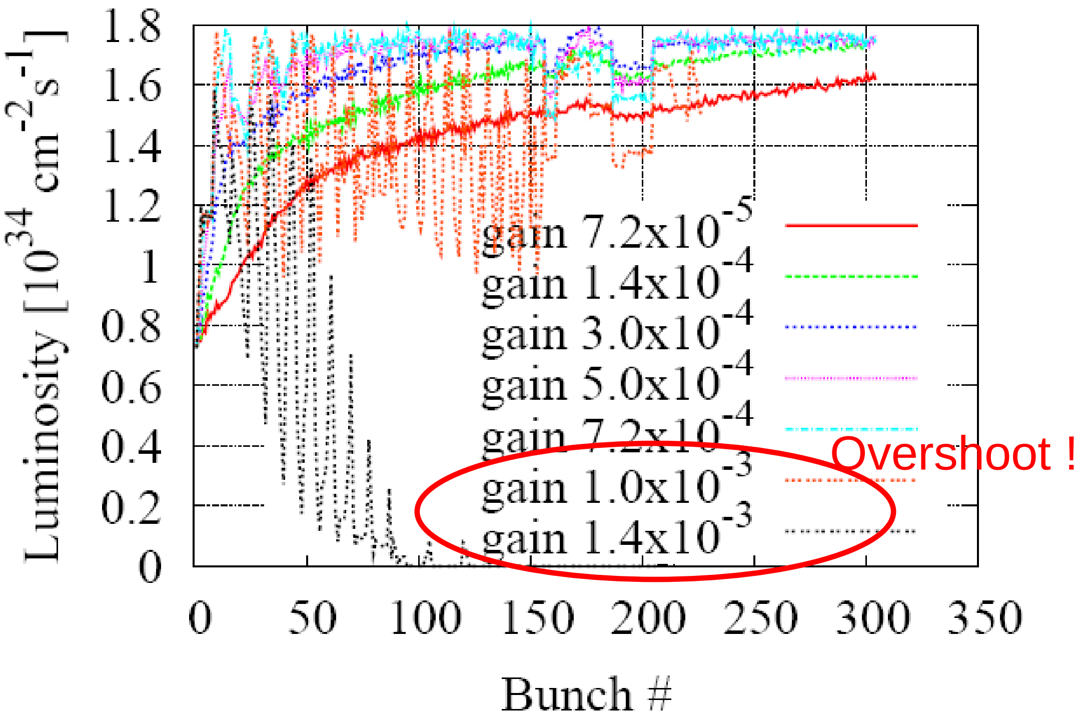
Benchmarking: A similar result have been obtained using the tracking code Merlin
[I. Melzer-Pellmann, LET Beam Dynamics Workshop, December 11-13, 2007, SLAC]

ILC integrated simulations

Fast intra-train FB system

- Gain factor optimisation:

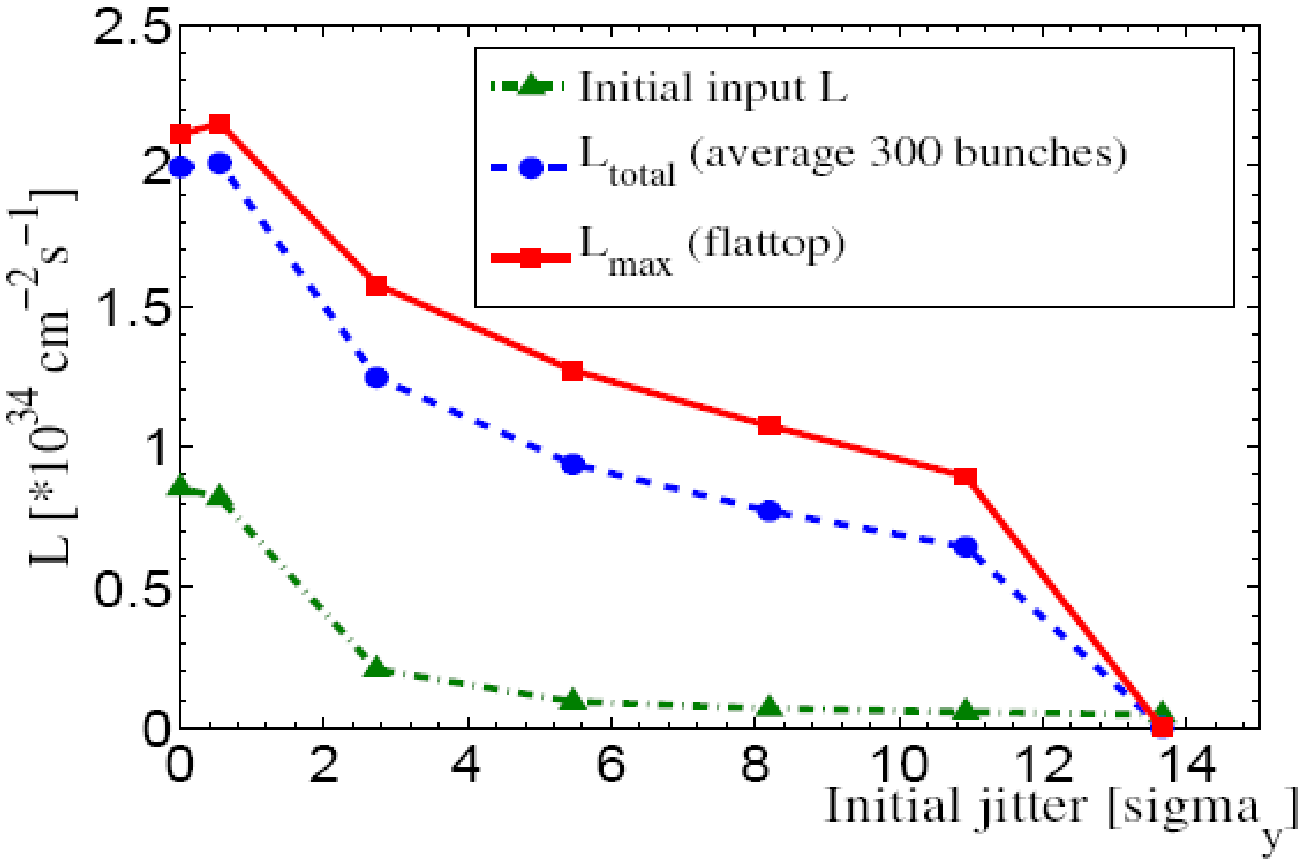
A large gain is desirable to decrease the convergence time. However a too strong gain factor produces an overshoot of the beam. As a compromise we have chosen **g=3.0 x 10^{-4},** achieving FB convergence with the first 50 bunches



ILC Luminosity results

Sensitivity to an additional position jitter generated at the entrance of the BDS

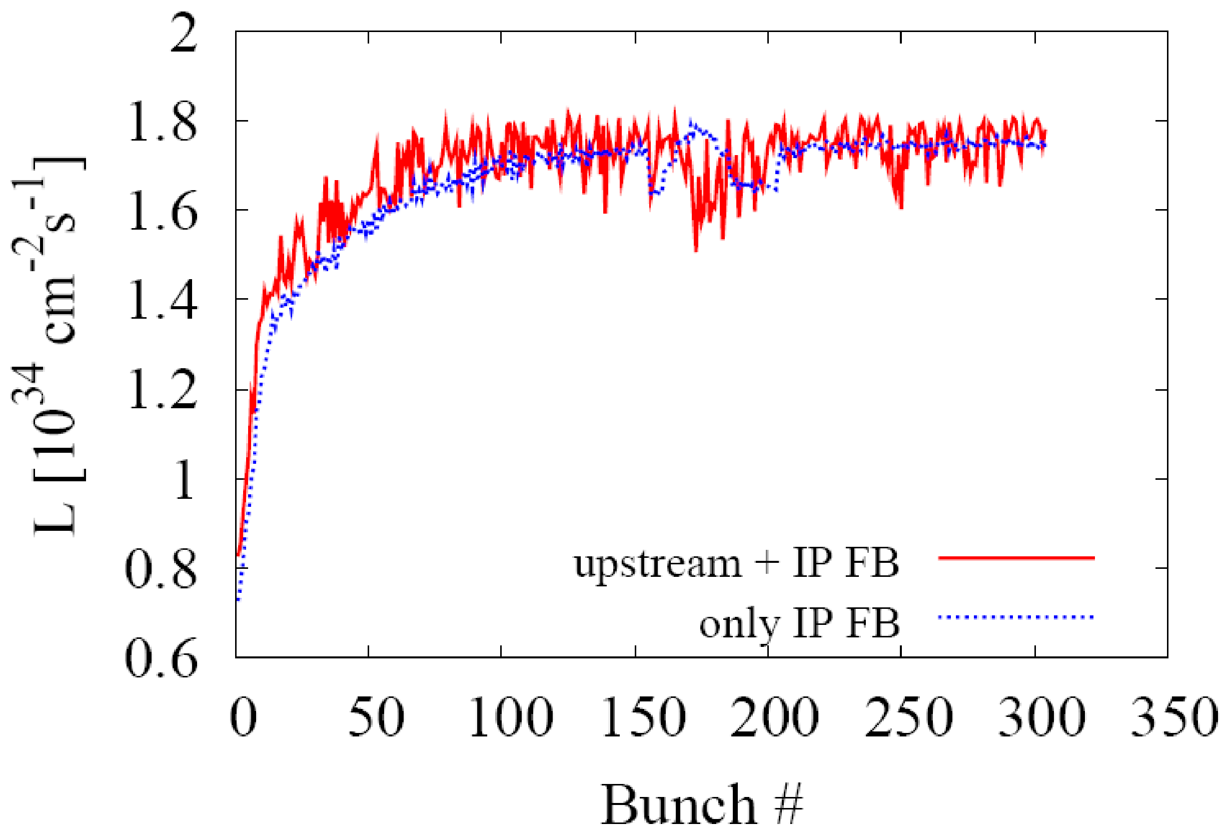
Example with 1 single random seed



ILC Luminosity results

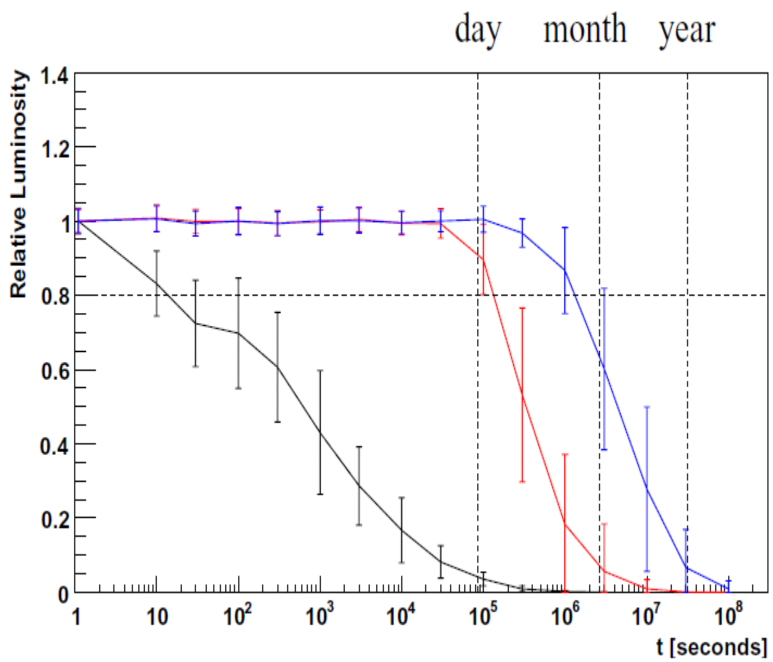
Joint operation upstream intra-train FB + IP intra-train FB

An upstream fast FB system downstream of the linac in the BDS diagnostic section
The aim is to eliminate offsets caused fast vibrations of quadrupoles and cavities of the main linac, which can not be controlled by a slow FB system

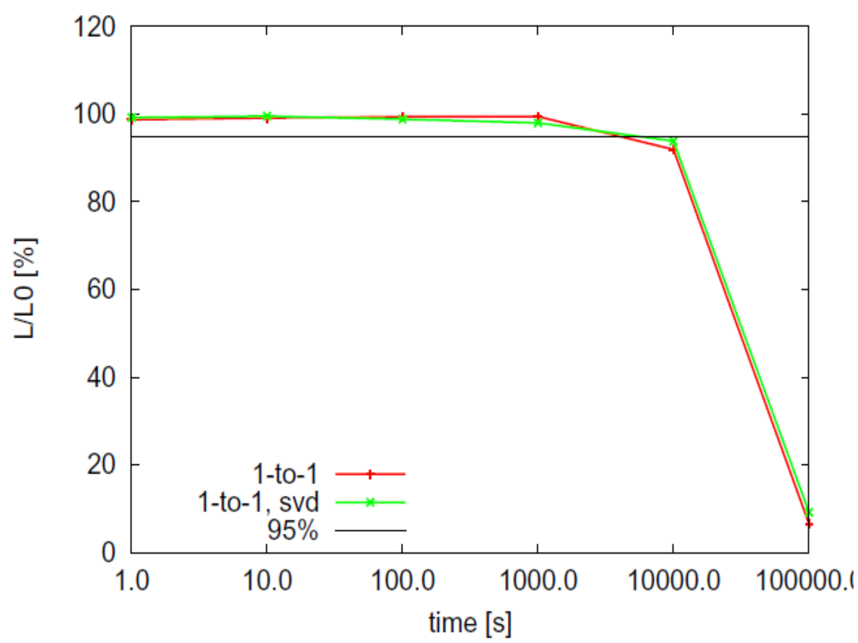


Luminosity preservation over long time scales

ILC: MERLIN based simulations
[D. Kruecker et al., EUROTeV-Report-2007-019]



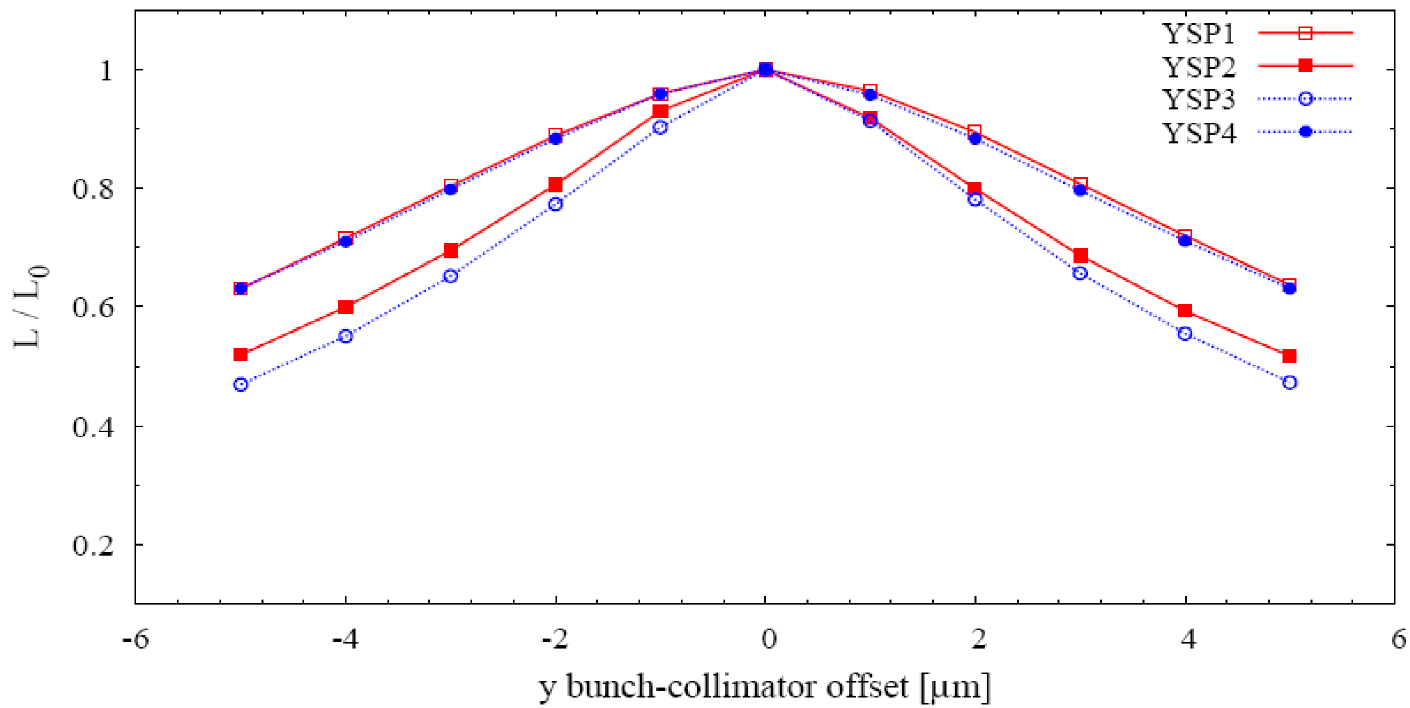
CLIC: PLACET based simulations
[A. Latina et al., EUROTeV-Report-2007-065]



- Applying ATL ground motion
- To keep the luminosity over long time scales will require the application of further luminosity tuning knobs methods.

CLIC luminosity simulations
Collimator wakefield effect on the luminosity

- Luminosity loss due to vertical misalignment of each spoiler:

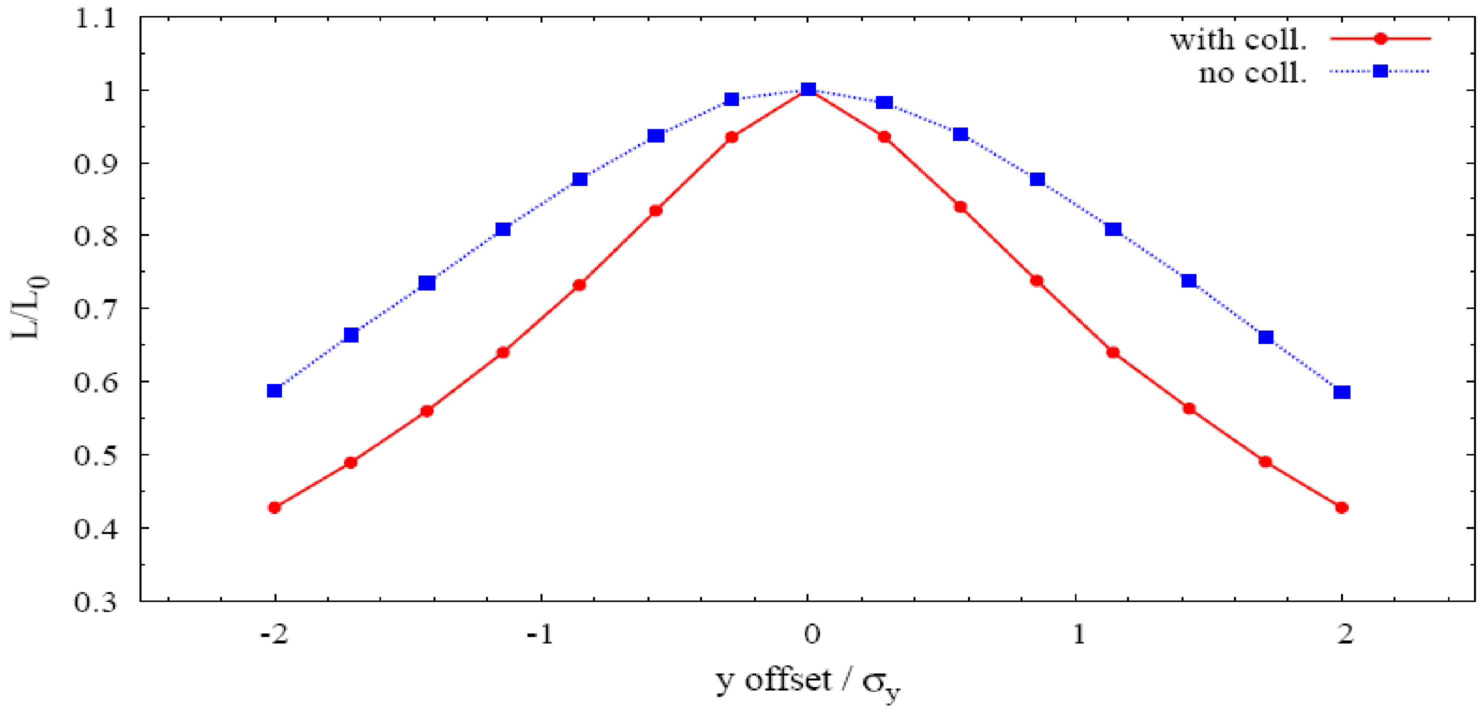


Collimator misalignment tolerance $1/2\ \sigma_y \approx 1\ \mu m$ (~ 10% luminosity loss)
(one order of magnitude smaller than ILC tolerance)
Challenging!

CLIC luminosity simulations

Collimator wakefield effect on the luminosity

- Luminosity loss versus initial vertical position jitter at the entrance of the BDS
- The join effect of all the BDS collimators is considered



Jitter tolerance $0.2\ \sigma_y$ (~ 10% luminosity loss)
(Similar to ILC initial jitter tolerance)