Luminosity Performance Studies of Linear Colliders with Intra-train Feedback Systems:

Simulations and Experimental Plans

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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

Beam structure of linear colliders

Property	ILC 500 GeV ('cold'-RF design)	CLIC 3 TeV ('warm'-RF design)	units
Electrons/bunch	2.0	0.37	10^{10}
Bunches/train	2820	312	
Train Repetition Rate	5	50	Hz
Bunch Separation	308	0.5	ns
Train Length	867.7	0.156	μs
Horizontal IP Beam Size (σ_x)	655	45	nm
Vertical IP Beam Size (σ_y)	5.7	0.9	nm
Longitudinal IP Beam Size	300	45	μm
Luminosity	2.03	6.0	$10^{34}\text{cm}^{-2}\text{s}^{-1}$

Beam time structure:

CLIC Linac repetition rate (Hz): 50 (10 times higher than for ILC !)

CLIC Bunch separation (ns): 0.5 (616 times smaller than for ILC !)

CLIC Bunch train length (μs): 0.156 (5562 times smaller than for ILC !)

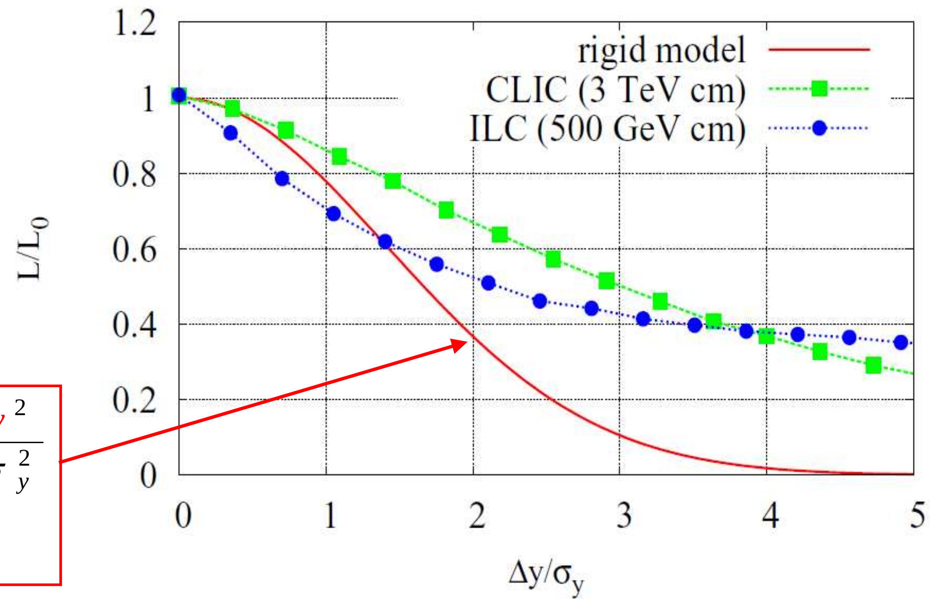
Luminosity degradation

Relative beam-beam position offset at the IP

(mainly from vibrations of last focusing quadrupoles)

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

$$\frac{L}{L_0} = e^{-\frac{\Delta y^2}{4\sigma_y^2}}$$

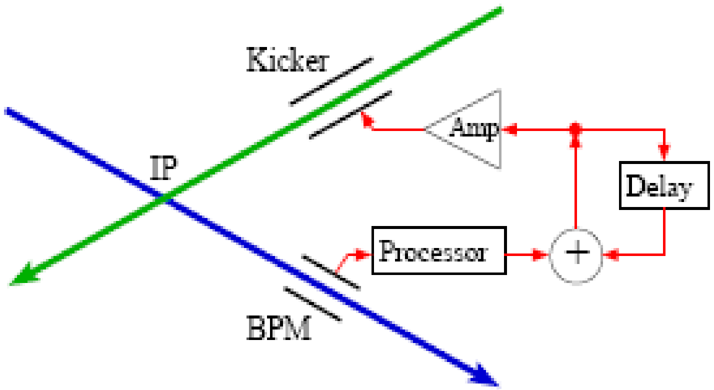


For instance, in order to maintain the luminosity 10% of nominal the electron and positron beam vertical position overlap needs to be stabilised to within 0.5 σ_y for ILC and 1 σ_y for CLIC

Beam-based FB system necessary to steer the beams back into collision !

Beam-based IP fast FB system

A fast IP-FB system for linear colliders is based on the measurement of the incoming trajectories of the early bunches in the electron or positron trains. This information is then used as the input to the feedback system for steering the later bunches into collisions at the IP



Key elements:

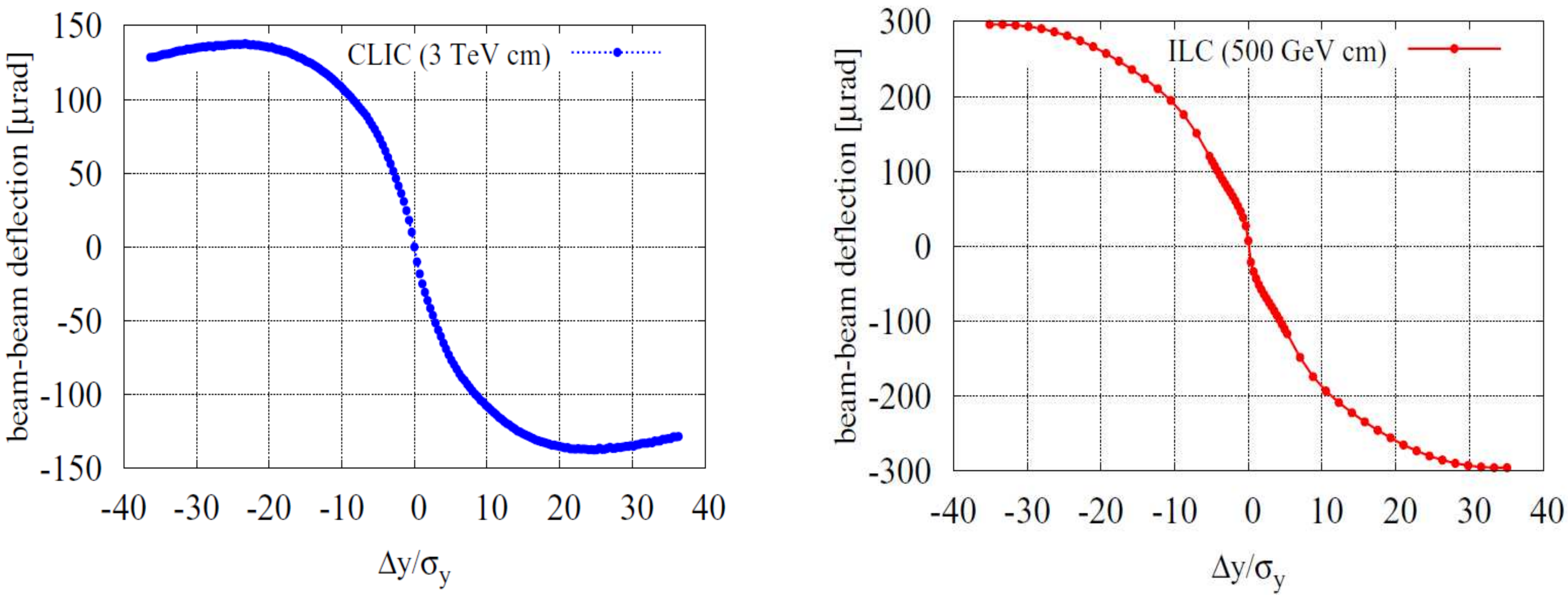
- BPMs: to register the beam orbit
- Fast signal processor: to translate the raw BPM pick off signals into a normalised position output
- FB circuits: delay loops, applying gain, …
- Amplifiers: to provide the required output drive signals

The latency time of the system is dominated by the time-of-flight of the beams between the IP and the FB components

Beam-beam deflection

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

From Guinea-Pig simulations:

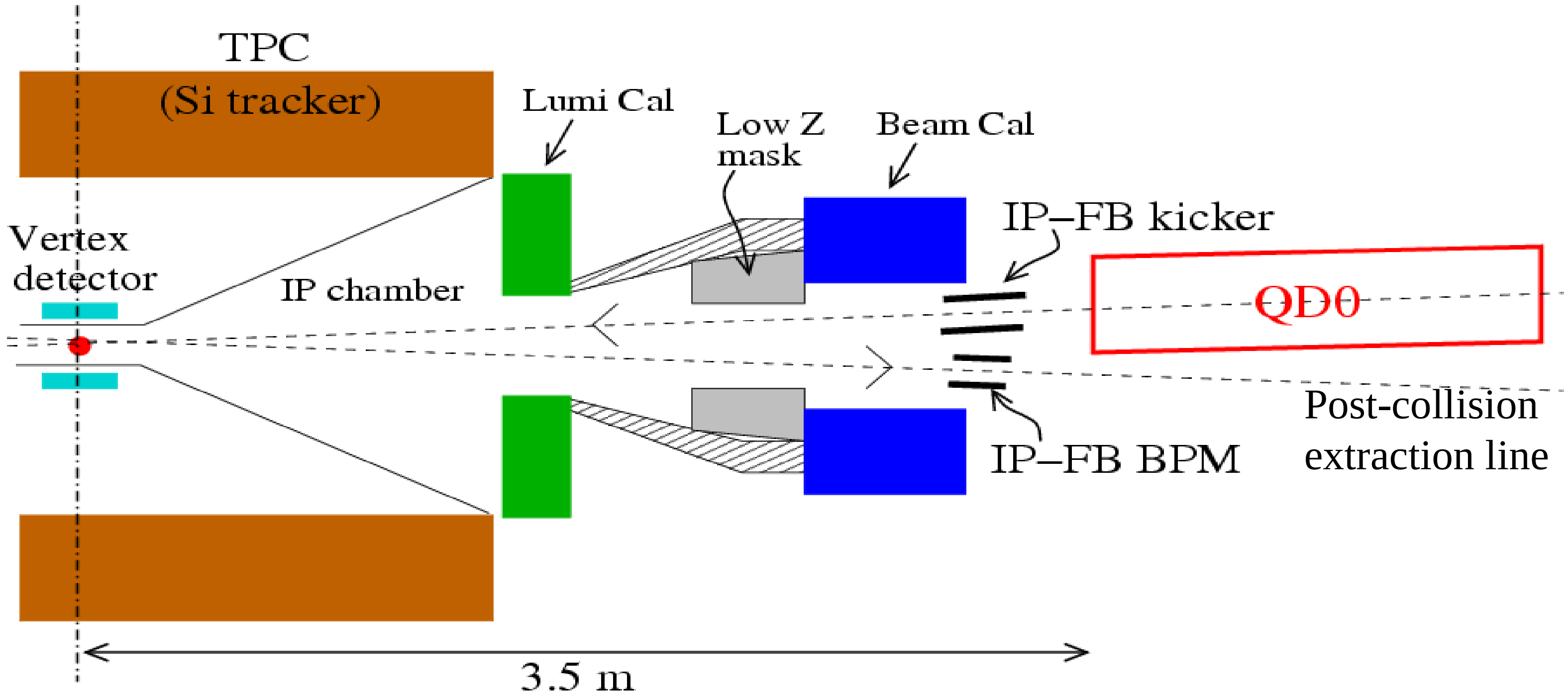


For instance, for CLIC (3 TeV c.m.) with 10 σ_y the b-b deflection angle is 2 times smaller than for the ILC (0.5 TeV c.m.)

MDI:

IP FB system position

Tentative CLIC interaction region design



Possible IP-FB system position:
IP-BPM between the calorimeter mask and the extraction magnets
(at ~ 3 m from the IP)

The IP-FB system has to operate in an environment of background particles!

Machine imperfections

- Imperfections in the different sub-systems of a linear collider can significantly degrade luminosity

- Static imperfections:
  - For example: errors of reference line, elements to reference line
  - To combat them in Linac and BDS: excellent prealignment, improvement of lattice design, beam-based alignment (1-to-1, dispersion free steering), beam-based tuning

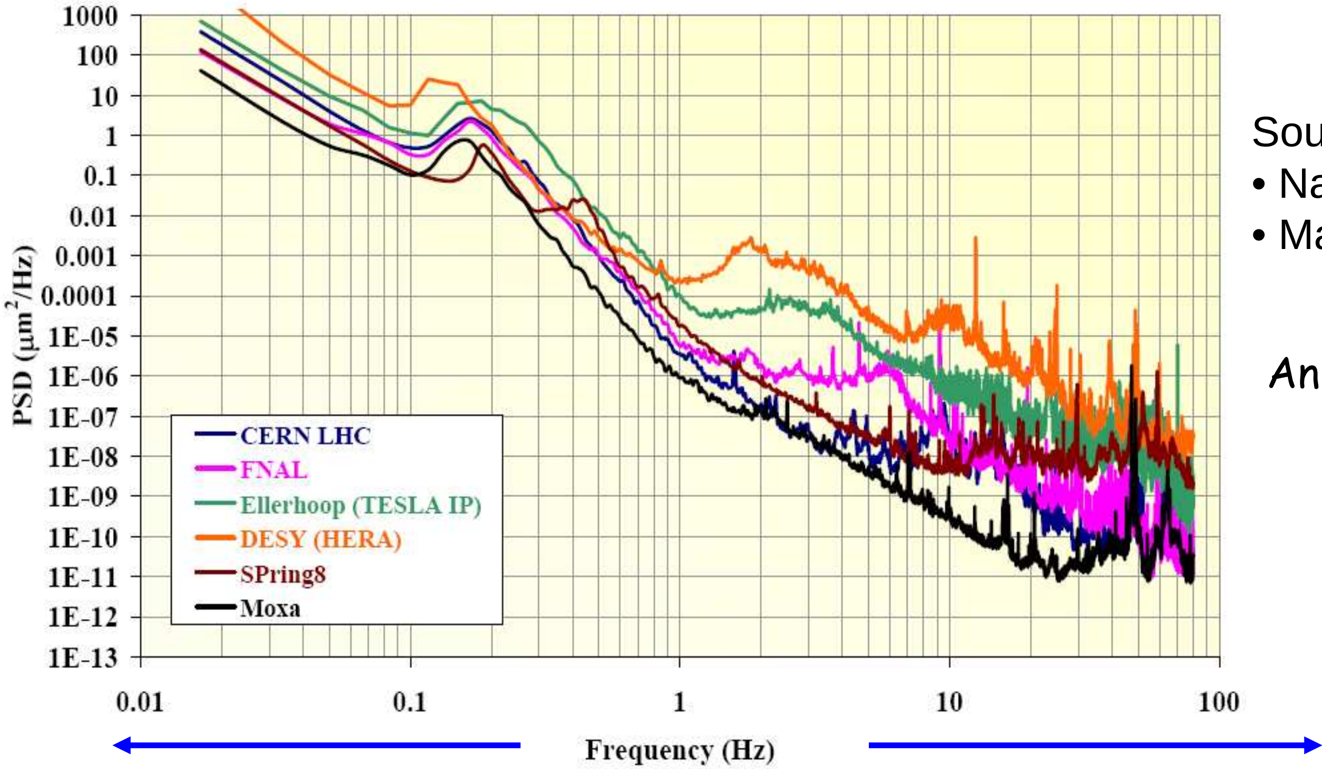
- Dynamic imperfections:
  - For example: element position jitter, RF jitter (linac cavities), electronic noise, beam jitter, GROUND MOTION (seismic motion, cultural noise).
  - To combat them in Linac and BDS: component stabilisation, improvement of lattice design, feedback systems (acting at different timescales), re-tuning, realignment

The IP-FB systems could be considered as the last 'weapon' of defence against, for example, transverse jitters of the final focus magnets !

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

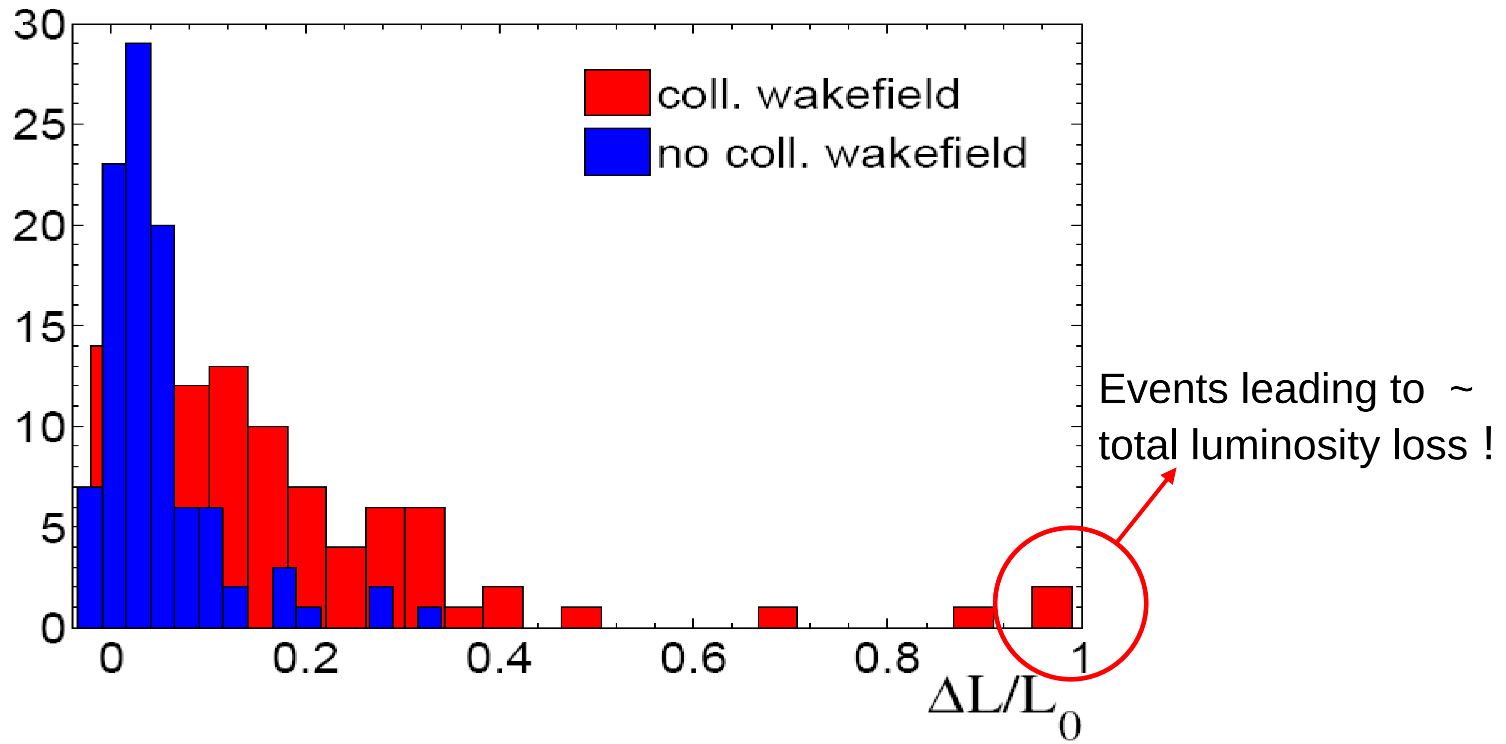
Fast motion: beam jitters
Beam-beam offsets

Other important source of luminosity loss:

Collimator wakefield effects

CLIC example:

Simulation of 100 machines, assuming $0.2\sigma_y$ jitter at the BDS entrance (using a normal offset distribution)

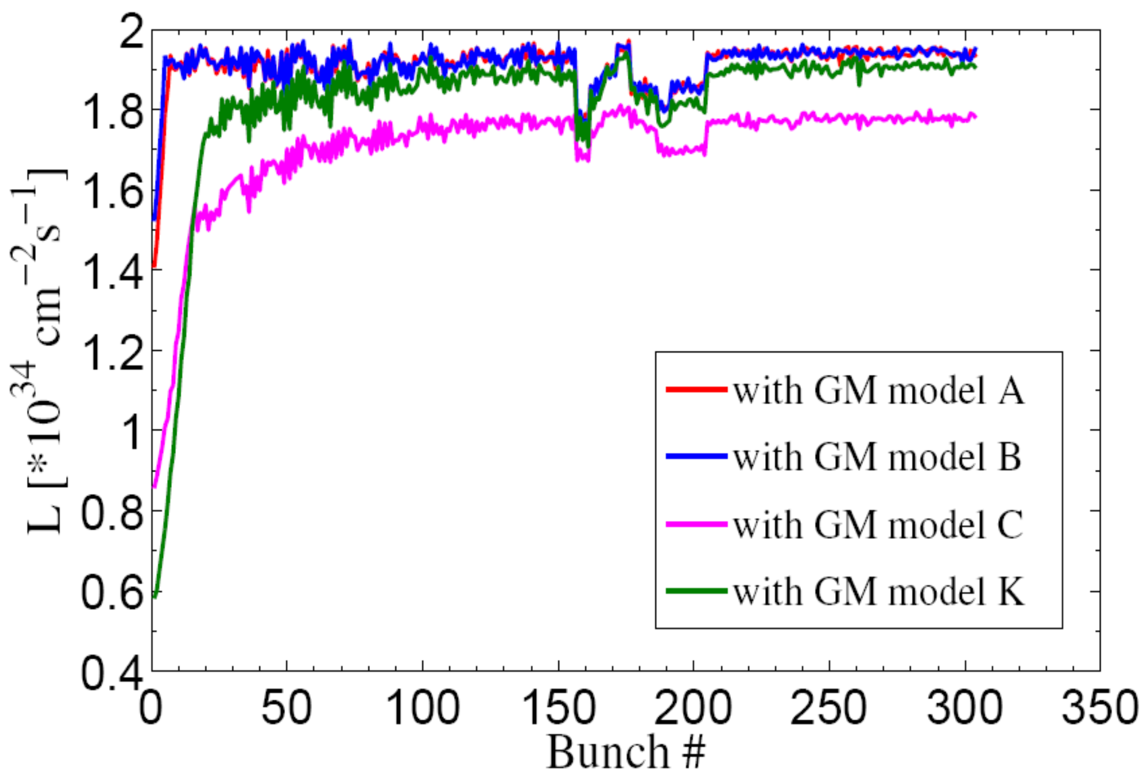


Wakefields in the BDS can cause severe single or multibunch effects leading to luminosity loss !

ILC Luminosity simulation results

Luminosity performance with fast IP-FB, applying different models of ground motion

Considering 8 nm normalised vertical emittance growth in the main linac (20% emittance growth)



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

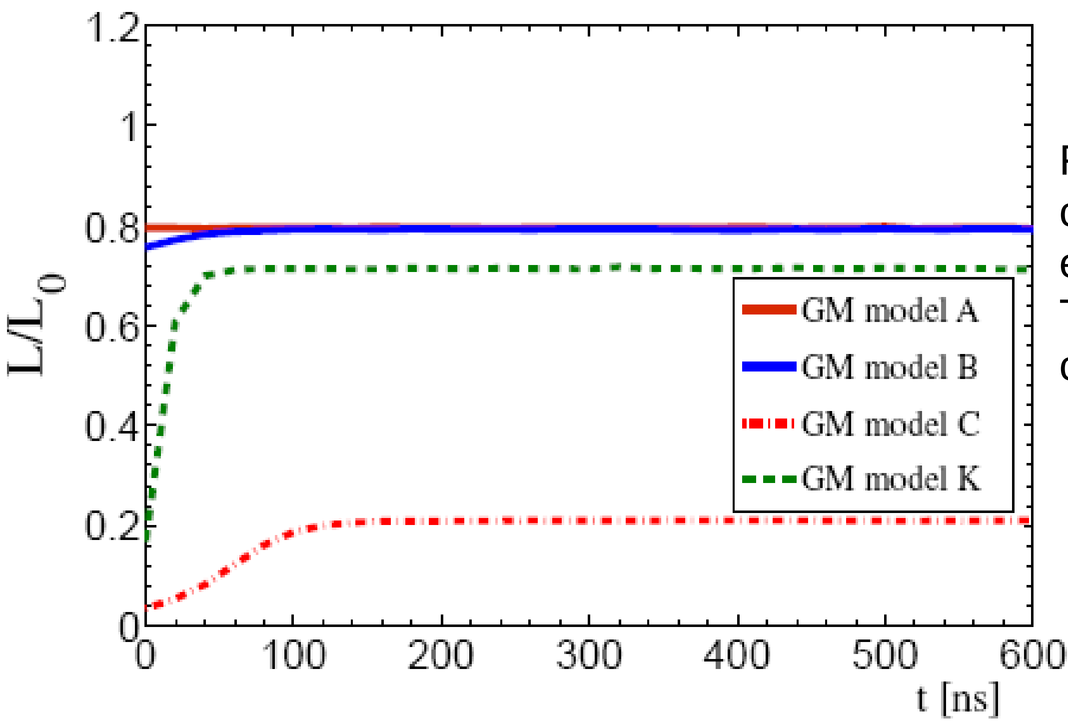
- For quiet sites (model A and B) practically ~ 90% - 100% of the nominal luminosity would be achievable

CLIC Luminosity simulation results

Luminosity performance with fast IP-FB, applying different models of ground motion

Considering 10 nm mormalised vertical emittance growth in the main linac (50% emittance growth)

For CLIC with nominal inter-bunch separation of 0.5 ns and a nominal train length of 156 ns the design of an IP intra-train FB is very challenging !!

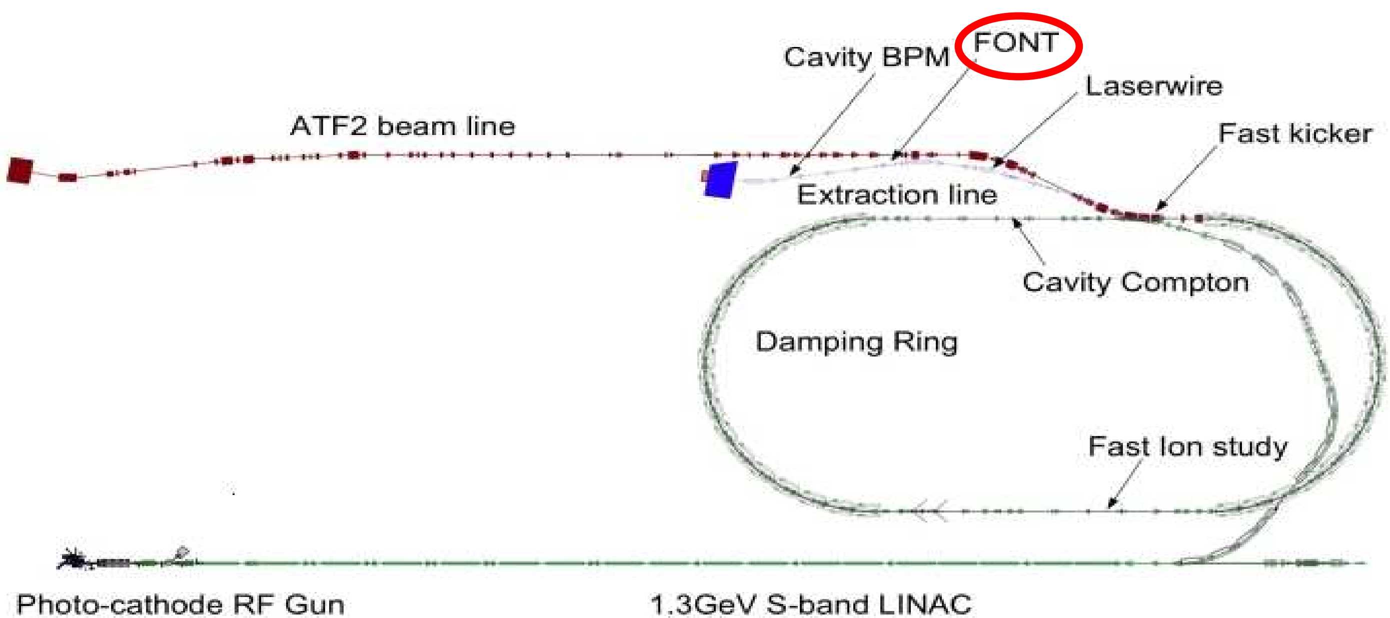


For the simulations we have considered a correction iteration every 20 ns.
The system performs approximately a correction every 40 bunches

Experimental test of intra-train FB at ATF2

- The so-called accelerator test beam facility ATF2 at KEK (Japan) will be the leading international test facility for the production, transport and stabilization of low-emittance beams for any future linear collider, such as ILC or CLIC
- In the context of the Feedback On Nano-second Timescales (FONT) project
- Fast intra-train FB currently under commissioning 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 1 μm at the ATF2 final focus entrance



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 simulations including different static and dynamics 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 steer the beams into collision
- For ILC possible bunch-to-bunch correction. For CLIC more challenging (intra-train IP position correction each 40 bunches ?)
- In the context of the FONT project a fast intra-train FB (FONT5), currently under commissioning in the ATF2 extraction line, will be experimentally tested: latency time (<~ 150 ns)

Appendix

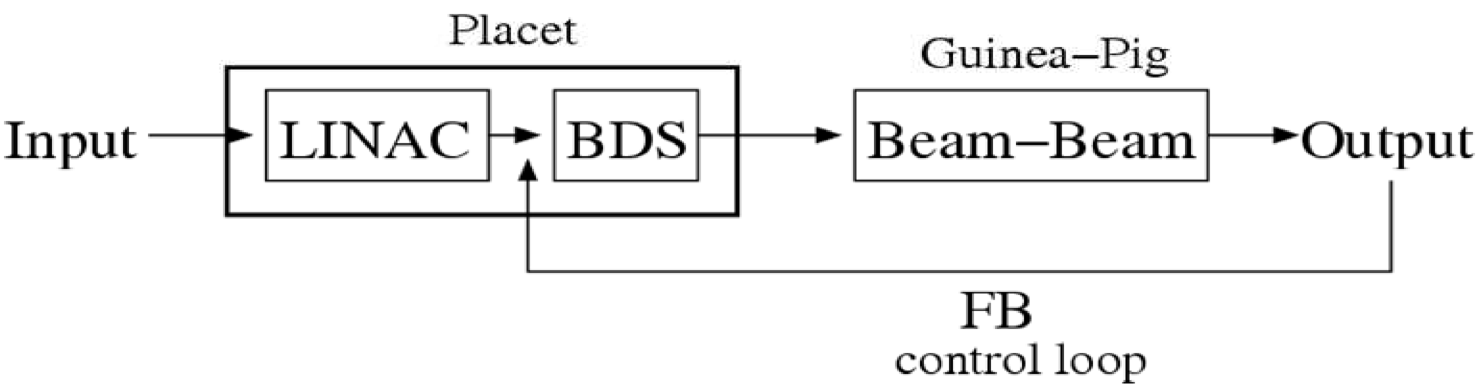
MDI:
Background particles issue

- The IP-FB system has to operate in an environment of background particles.
- Beam background particles might scatter the IP-FB system devices, damaging the FB system elements and distorting the BPM signal. In addition, from this scattering additional background might be generated.
- The ILC & CLIC IP-BPM signal distortion due to secondary emission from beam-beam background has been studied (A. Hartin et al., EUROTeV-Report-2007-041, EUROTeV-Report-2008-030): preliminary simulations has shown that this IP-BPM distortion could be neglected . However, further studies are needed depending on the distance of the FB elements to the IP.

Appendix

Simulation procedure

Tracking studies using the codes Placet + Guinea-Pig
(matlab or octave interface)



- Multibunch tracking along the LINAC
- Bunch by bunch tracking along the BDS to the IP (applying FB at the IP)
- Including:
  - Lattice alignment errors
  - Ground motion (dynamic effects)
  - Cavity wakefield effects
- Output: luminosity, beam-beam deflection, electromagnetic background at the IP