# Integrated luminosity performance studies of linear colliders with intra-train IP-FB system: ILC and CLIC

Javier Resta Lopez
JAI, Oxford University

In collaboration with P. N. Burrows, A. Latina and D. Schulte

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# Introduction

- Luminosity goal for the future linear colliders very demanding: very small transverse beam size and subnanometer level beam stability
- Static and dynamic imperfections can significantly degrade the luminosity/emittance
- To combat beam jitter feedback (FB) systems will be required in different parts of the machine
- Here we focus our study on luminosity performance with intra train IP-FB system (for ILC and CLIC)
- We present a model for start-to-end simulations based on the tracking code PLACET
- Different sources of beam jitter have been studied (Here we show examples of collimator wakefield effects in ILC and CLIC)
- We compare simulation results of luminosity performance with intra-train IP-FB (for ILC and CLIC) in terms of correcting the IP beam jitter due to different scenarios of GM
- Plan for the improvement of the simulation model

# Introduction

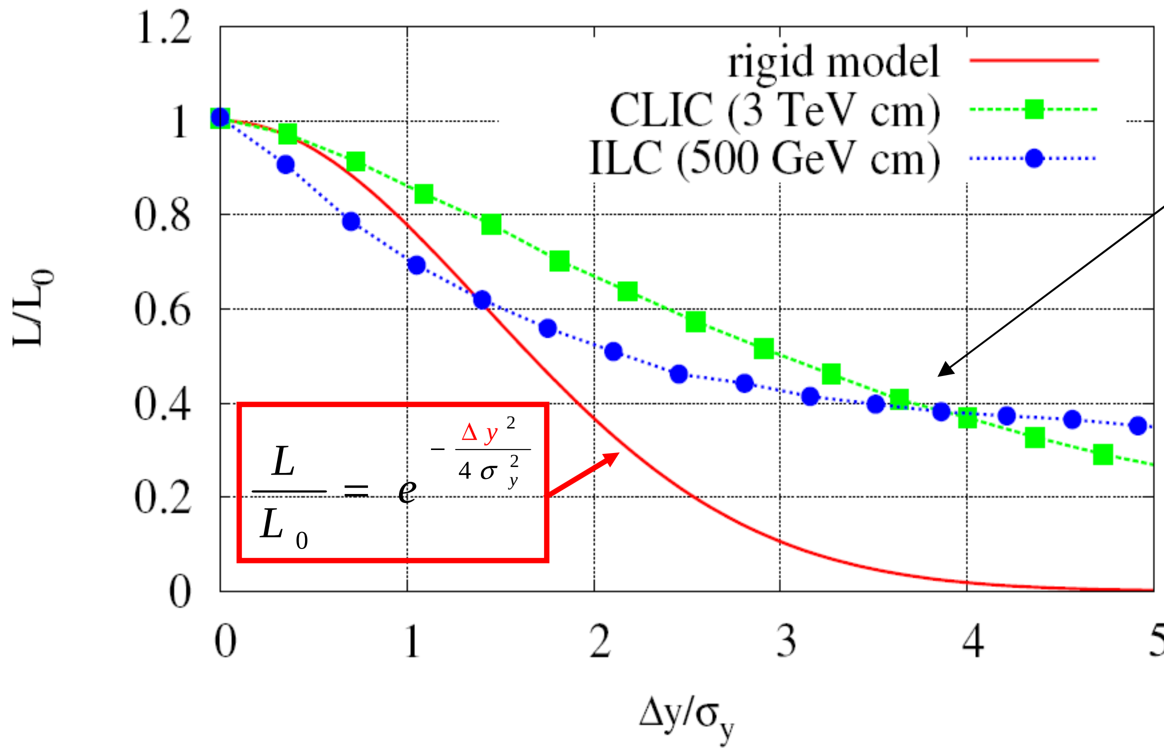
## Train structure

| **Property** | **ILC 500 GeV** | **CLIC 3 TeV** | 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 | $\mu$s |
| Horizontal IP Beam Size ($\sigma_x$) | 655 | 45 | nm |
| Vertical IP Beam Size ($\sigma_y$) | 5.7 | 0.9 | nm |
| Longitudinal IP Beam Size | 300 | 45 | $\mu$m |
| Luminosity | 2.03 | 6.0 | $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ |

For CLIC 616 times smaller bunch separation and 5562 times smaller bunch train length than for ILC !
IP intra-pulse FB is more challenging.

# Introduction

## Luminosity degradation versus relative offset of the colliding beams




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

GUINEA-PIG simulations

Disruption factor:
$D_y$=19 (ILC)
$D_y$=7.6 (CLIC)

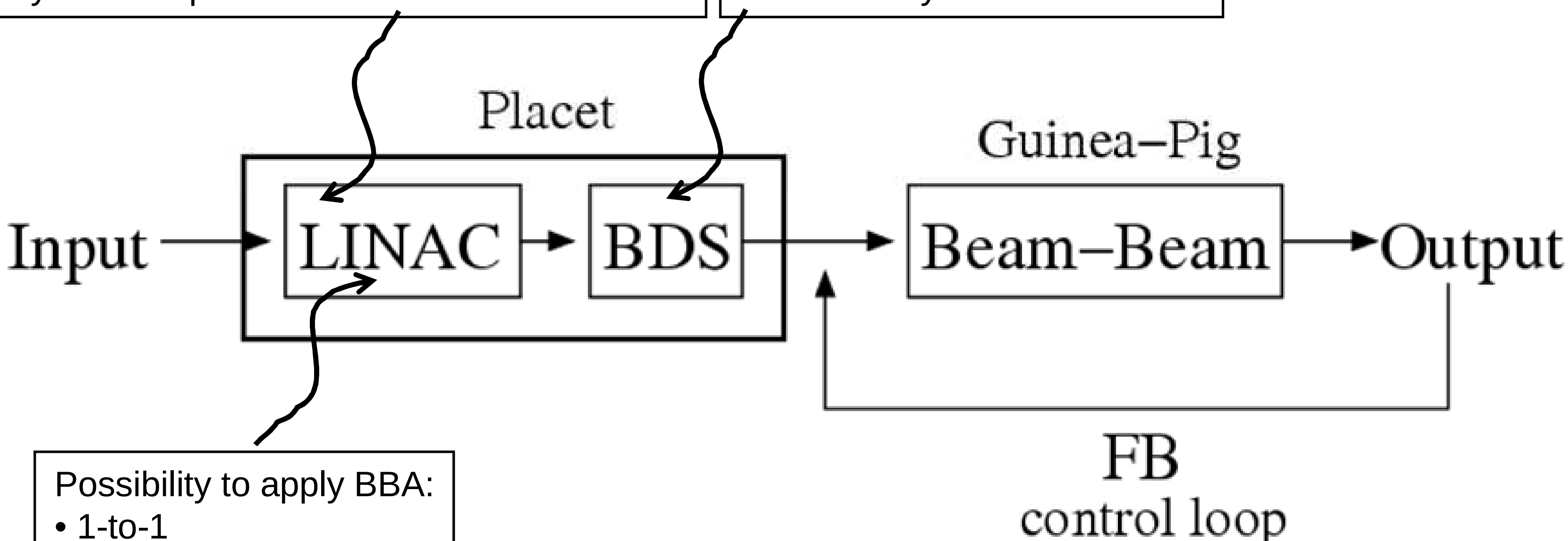
For larger $D_y$ the luminosity becomes increasingly sensitive to small offsets

For instance, for $\Delta\sigma_y \approx 0.5\sigma_y$ (ILC) and $\approx 1\sigma_y$ (CLIC) → 10% luminosity loss

# Simulation procedure

- Sliced bunches tracked along the LINAC
- Including long- and short-range transverse and longitudinal wakefield functions
- Alignment survey errors
- Dynamic imperfections: GM

- Macroparticle tracking
- Alignment survey errors
- Dynamic imperfections : GM
- Collimator wakefields
- Crab cavity wakefields



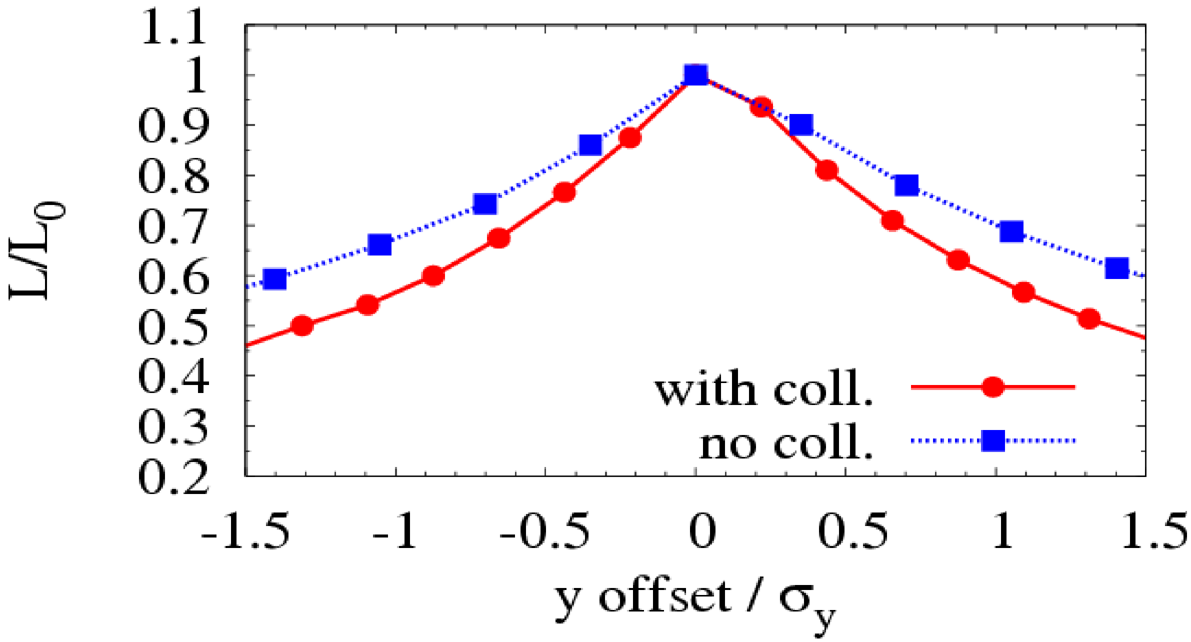

Possibility to apply BBA:
- 1-to-1
- DFS

- PI controller algorithm embedded in Simulink (MATLAB)
- Alternatively, we have also implemented a similar PI algorithm using Octave (a free clone of MATLAB)

# Collimator wakefield effects

## ILC luminosity

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




y offset at the entrance of the BDS ≈ $0.2\ \sigma_y = 0.4\ \mu m$ ( ~ 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 postlinac orbit steering feedback systems using cavity BPMs (resolution ~ 100 nm) and stripline kickers

# Collimator wakefield effects

## CLIC luminosity

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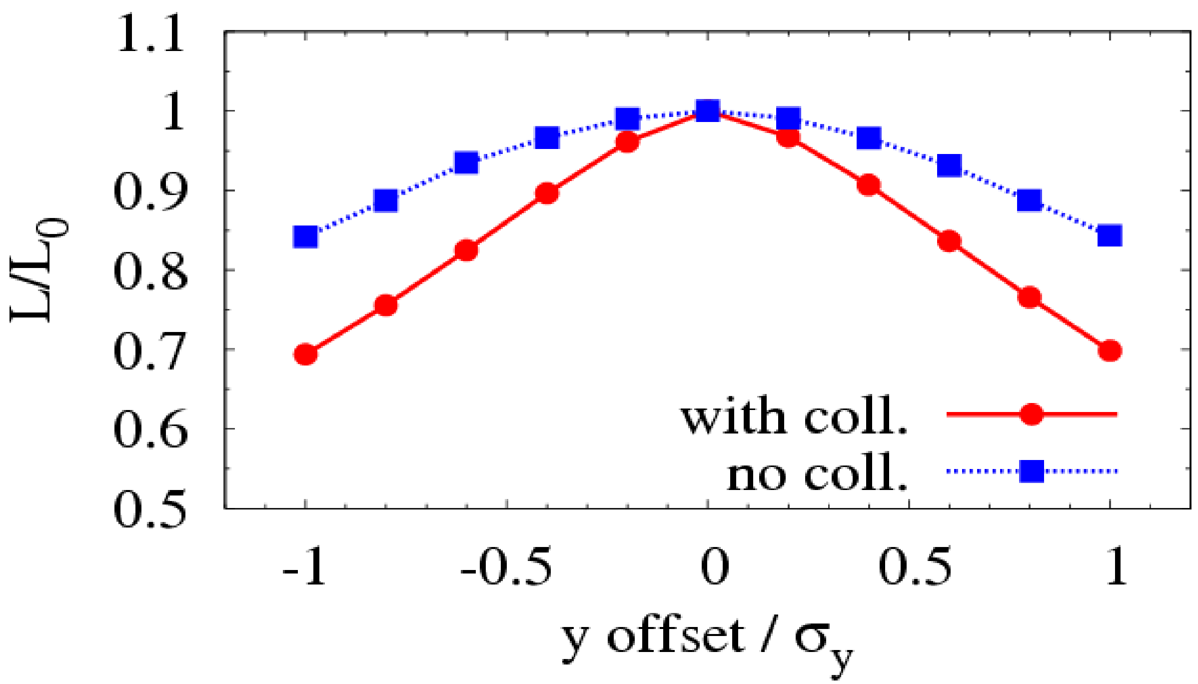
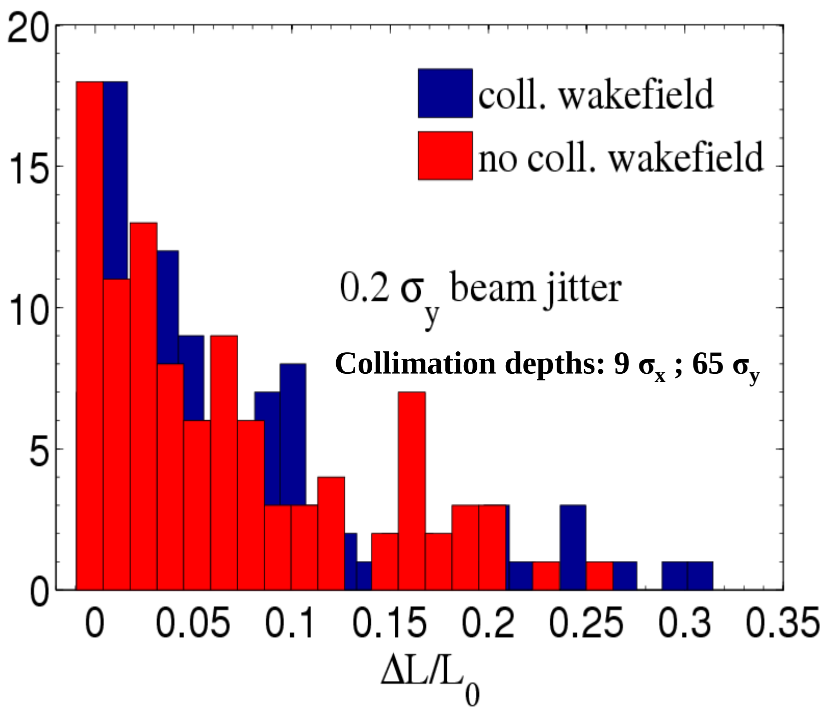



y offset at the entrance of the BDS ≈ $0.2\ \sigma_y = 0.1\ \mu m$ ( ~ 10% luminosity loss)

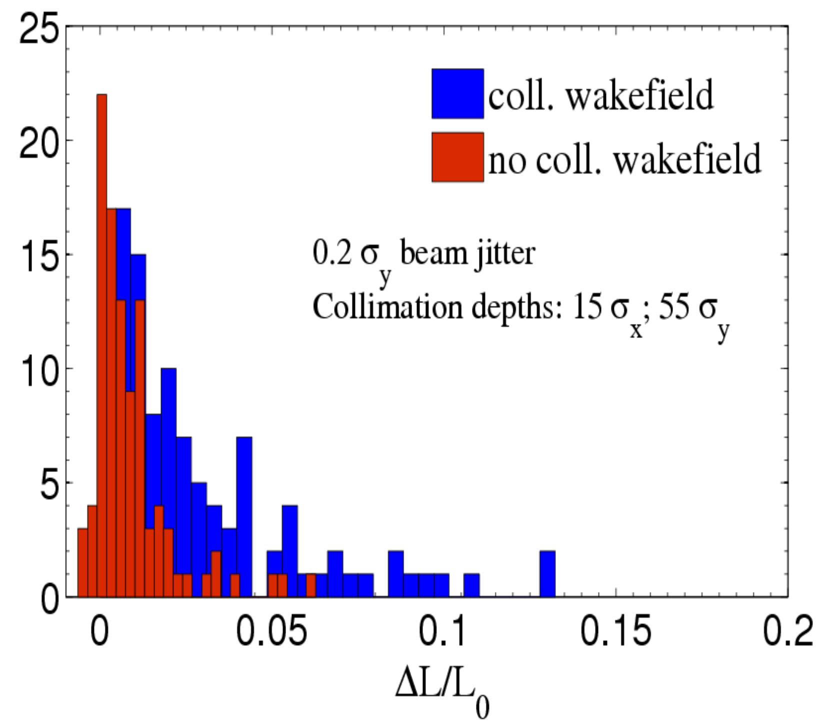
# Collimator wakefield effects
## Beam position jitter + collimator wakefields

Luminosity loss distribution (100 machines simulation):

ILC




CLIC

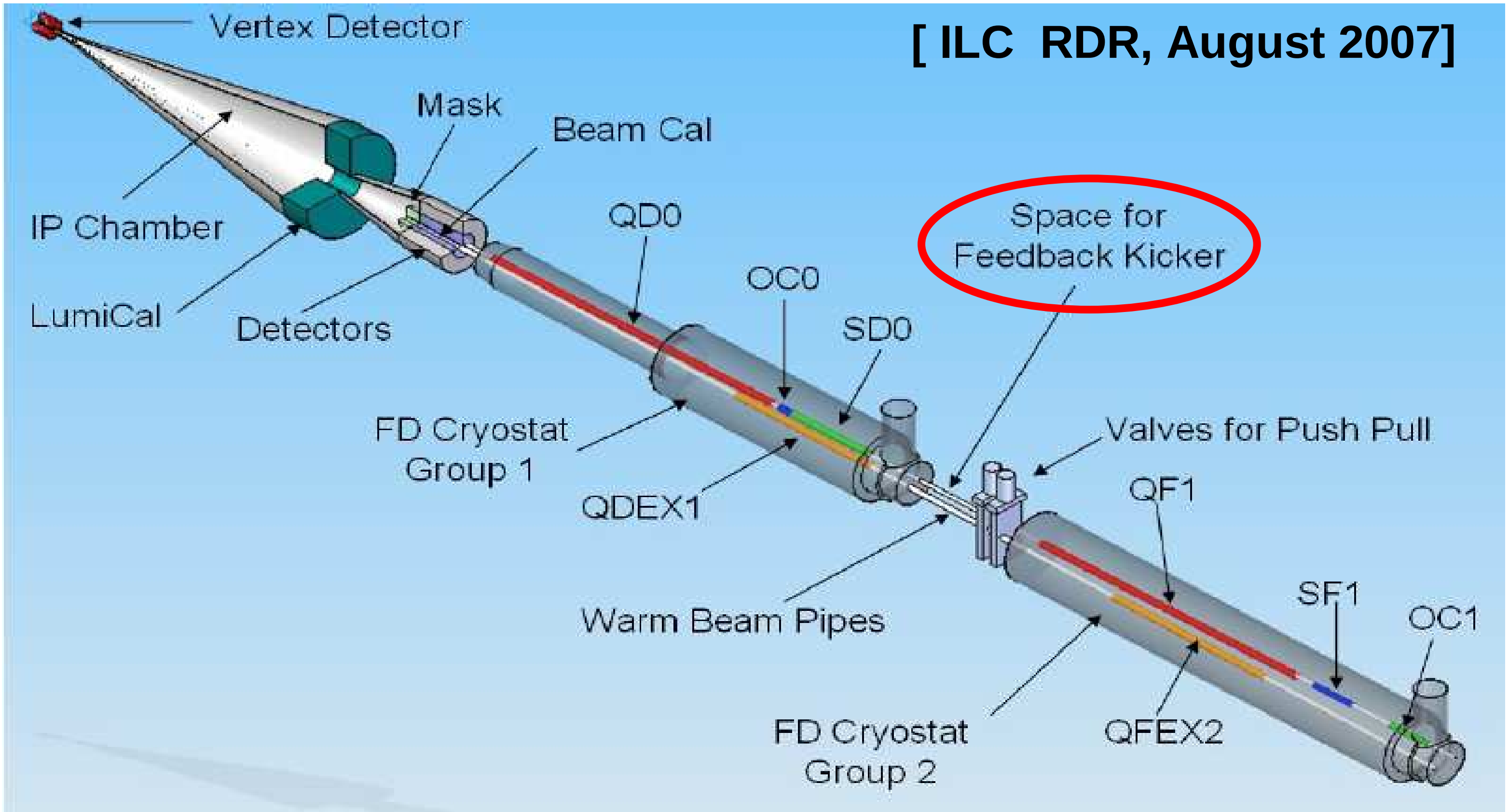


# IP intra-train beam-based FB for ILC

- The ILC train timescale structure allows bunch-to-bunch feedback corrections using digital FB processors (demonstrated by FONT4 at ATF)
- For beam-beam relative position correction at the IP:
  - Stripline kicker near the IP in the incoming beamline between the sextupole SD0 and the final quadrupole QF1
  - BPM (1$\mu$m resolution) at $\pi/2$ phase advance downstream of the IP
- For angle correction a stripline kicker at the entrance of the FFS with a downstream BPM at $\pi/2$
- For the simulations we use a FB loop based in a classical proportional and integral (PI) control algorithm

# ILC IR

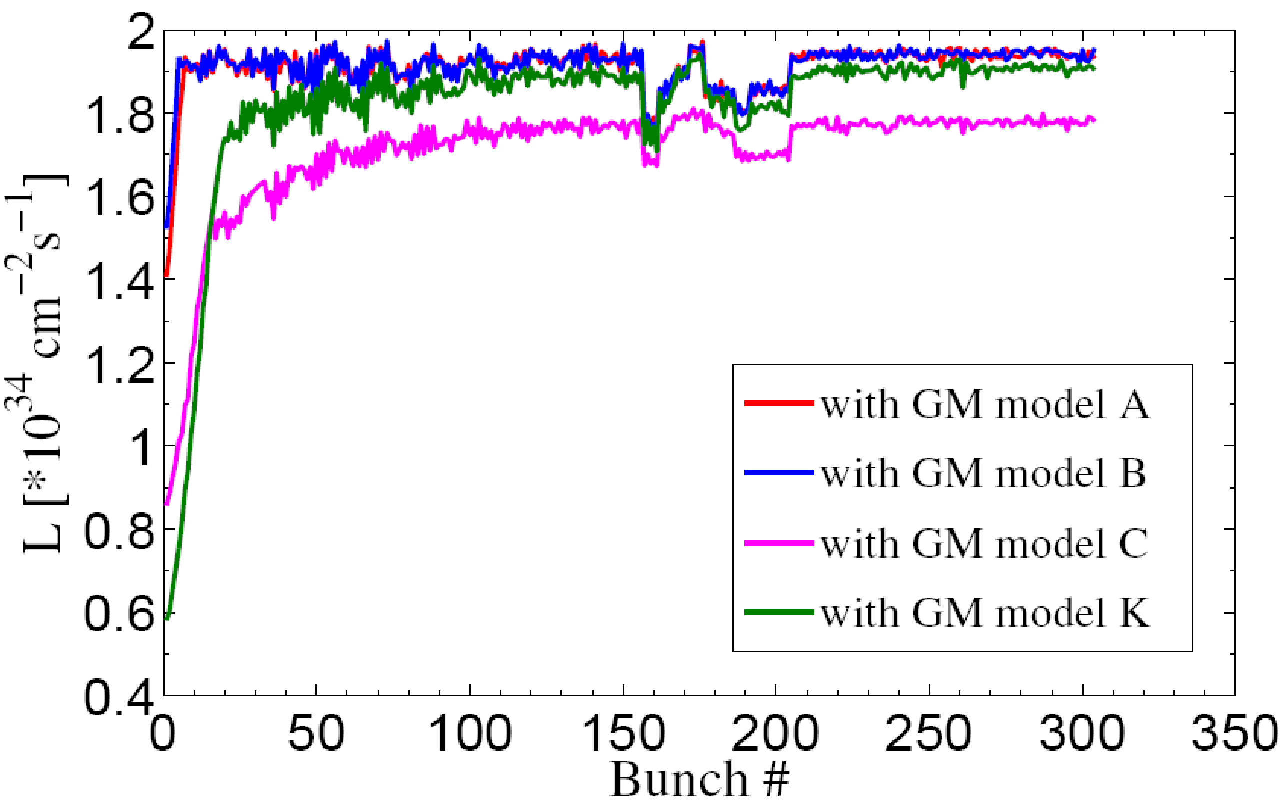
## Position of IP-FB elements




Kicker about 7 m upstream of the IP

# ILC luminosity result with IP-FB
## Different scenarios of ground motion

- Example for 1 single random seed of GM (0.2 s of GM applied to both main linac and BDS)
- Considering 40 % emittance growth in the main linac



# ILC Luminosity result

## cpu time

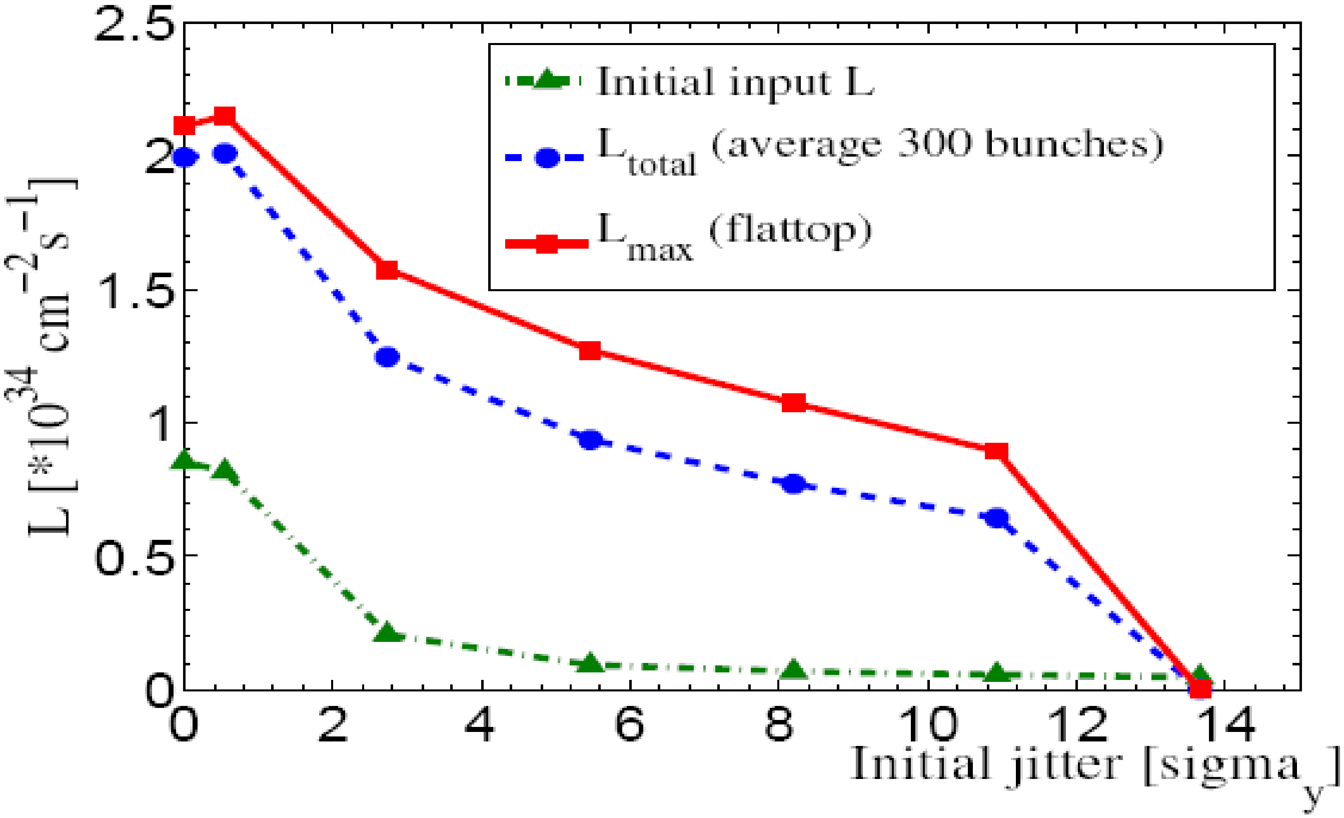
Remark:

- Start-to-end simulation (of the first 300 bunches) Linac+BDS+Beam-beam with IP- FB system for 1 single seed of GM: cput=02:04:18 in the Oxford Particle Physics Cluster with 2.0, 2.4 and 2.8 GHz Xeon processor running Linux

- If collimator wakefield calculation included (bipolar and quadrupolar modes implemented in Placet), the cput is much longer (addition of 10 minutes per bunch)

# ILC luminosity result

## with additional beam position offset at the entrance of the BDS

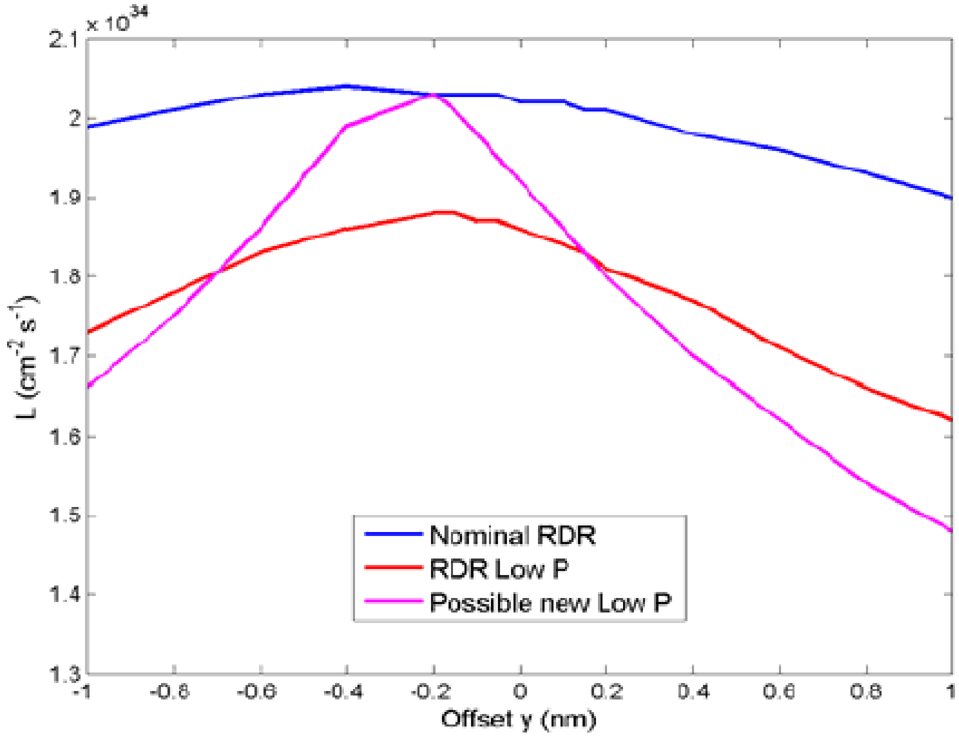



GM model C has been applied

Capture range of the IP-FB system <~10 $\sigma_y$ initial position offset at the entrance of the BDS

# Issues to be studied

- New Low P parameter option, travelling focus (A. Seryi)




Higher sensitivity to any beam offset
ACTION: study of the operation of the intra-train IP-FB system for the new Low P parameters

# IP intra-train beam-based FB for CLIC

- 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 beam-beam relative position correction at the IP:
  - Stripline kicker located the incoming beamline downstream of the final quadrupole QD0
  - BPM (1$\mu$m resolution) at $\pi/2$ phase advance downstream of the IP
- Due to latency constraints no angle intra-train FB system designed for CLIC
- Latency times of about 20 ns have experimentally been demonstrated by the FONT3 system at ATF using a FB analogue processor.
- For the simulations we have considered a correction iteration every 20 ns. The systems performs approximately a correction every 40 bunches (8 iterations per train)
- In this case we have employed a FB control loop based in a single proportional control algorithm (and we have also investigated a PI algorithm)

# Latency of the intra-train IP-FB for CLIC

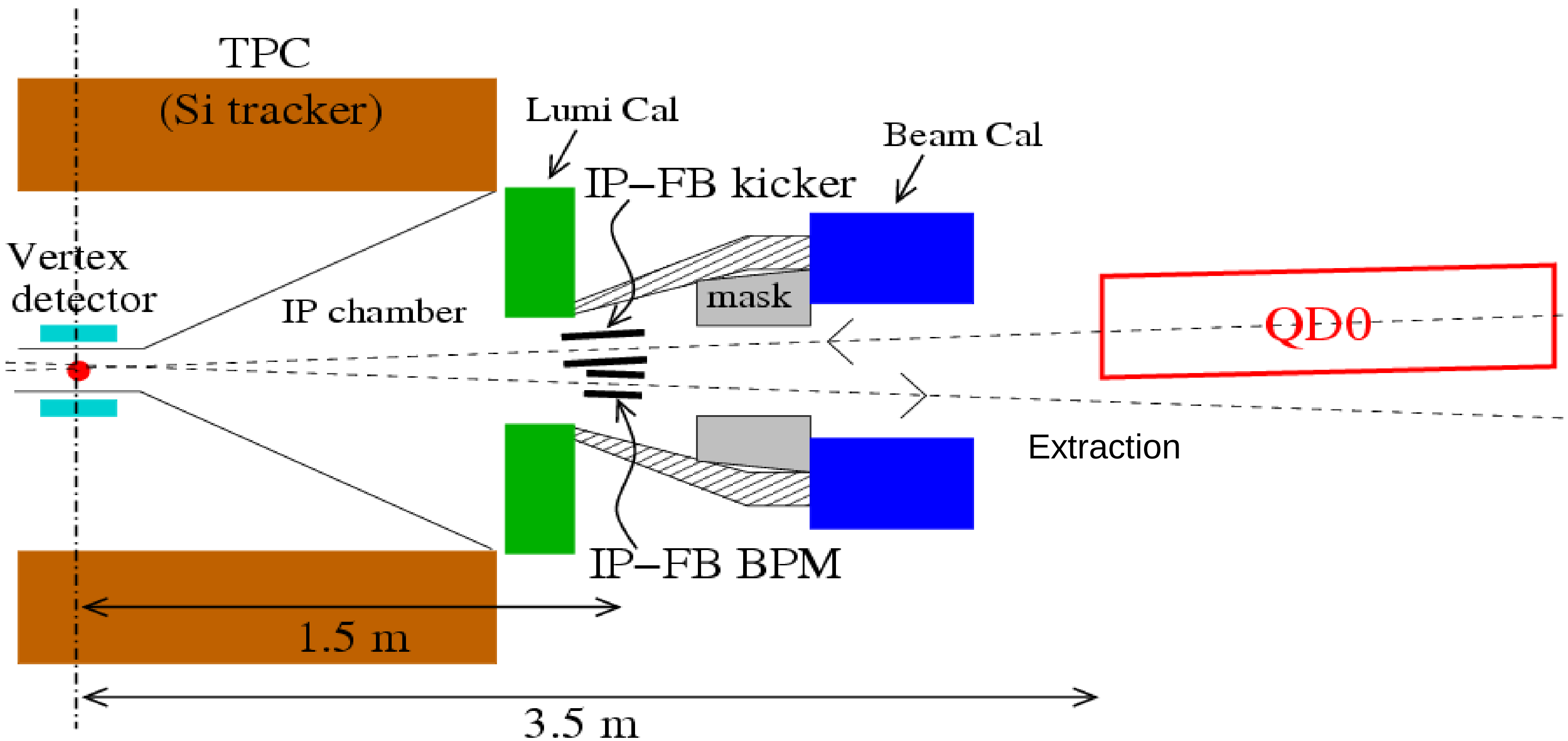
- From FONT3:

| Source of delay | Latency [ns] |
|---|---|
| Beam time-of-flight * | 4 |
| Signal return time | 6 |
| BPM processor | 5 |
| Amplifier risetime | 5 |
| **Total** | **20** |

* Assuming IP-BPM distance ≈1.2 m

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

# CLIC IR
## Tentative IP-FB BPM and kicker positions

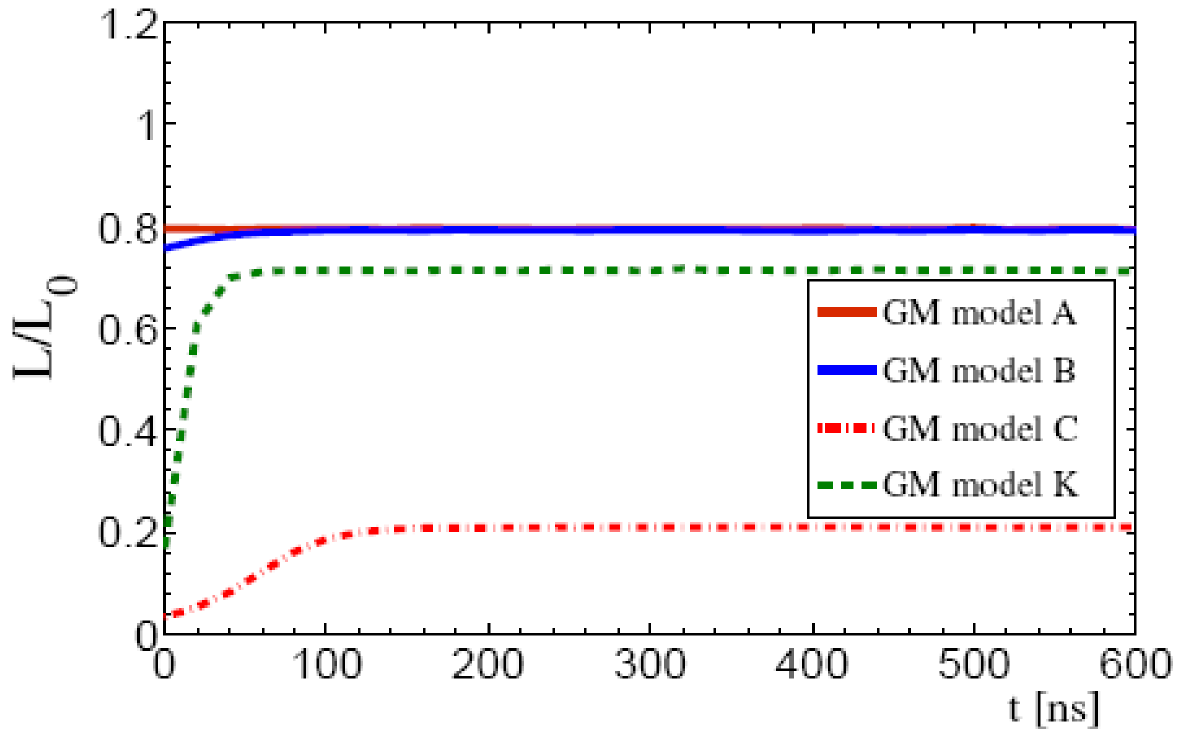



Possible IP-FB system positions:
IP-FB elements at ~1.5 m from the IP: time-of-flight= 5 ns; total latency = 21 ns

If IP-FB elements closer to IP, possibly more extra radiation for the vertex tracker (to be evaluated)

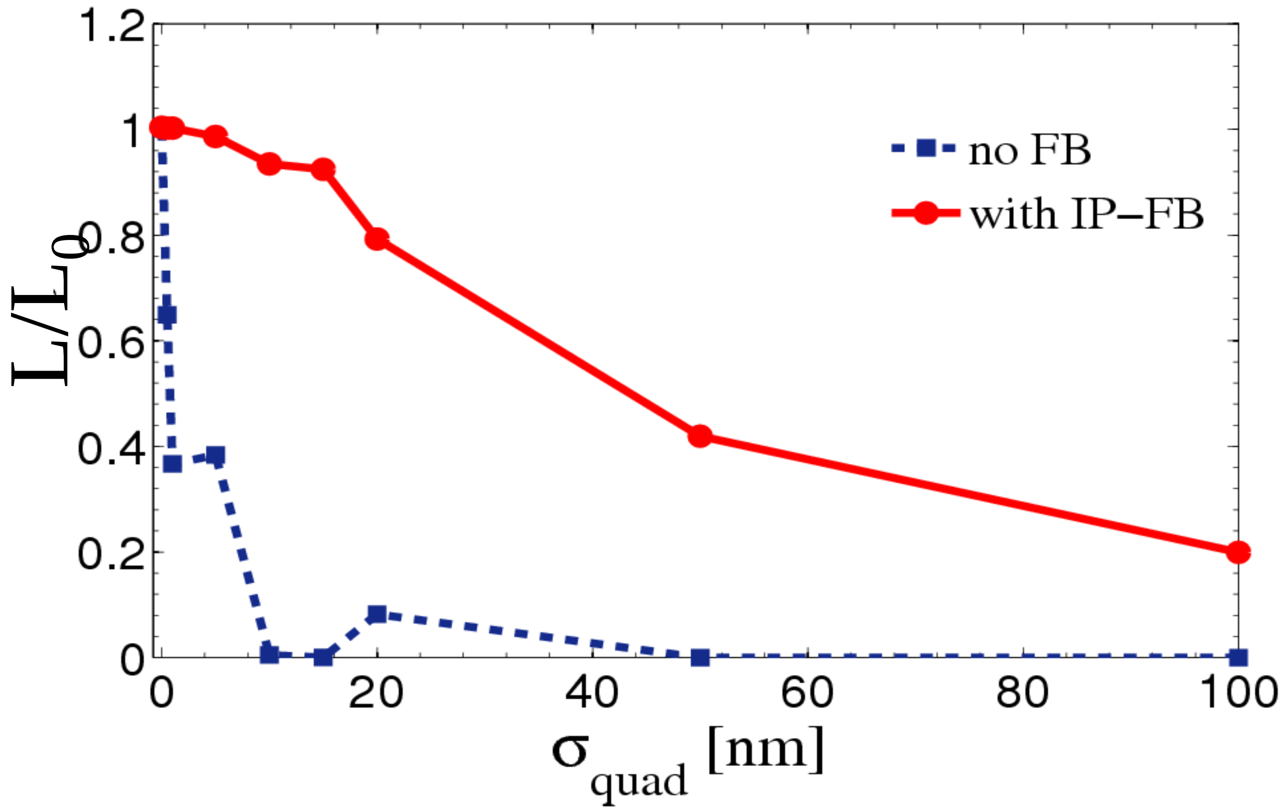
# CLIC luminosity result with IP-FB
## Different scenarios of ground motion

- Considering 10% vertical emittance growth in the main linac
- Using a classical proportional control loop (with one single gain factor or proportional coefficient)



# CLIC luminosity result with IP-FB

## Introducing additional quadrupole position jitter (to all quadrupoles in the BDS)

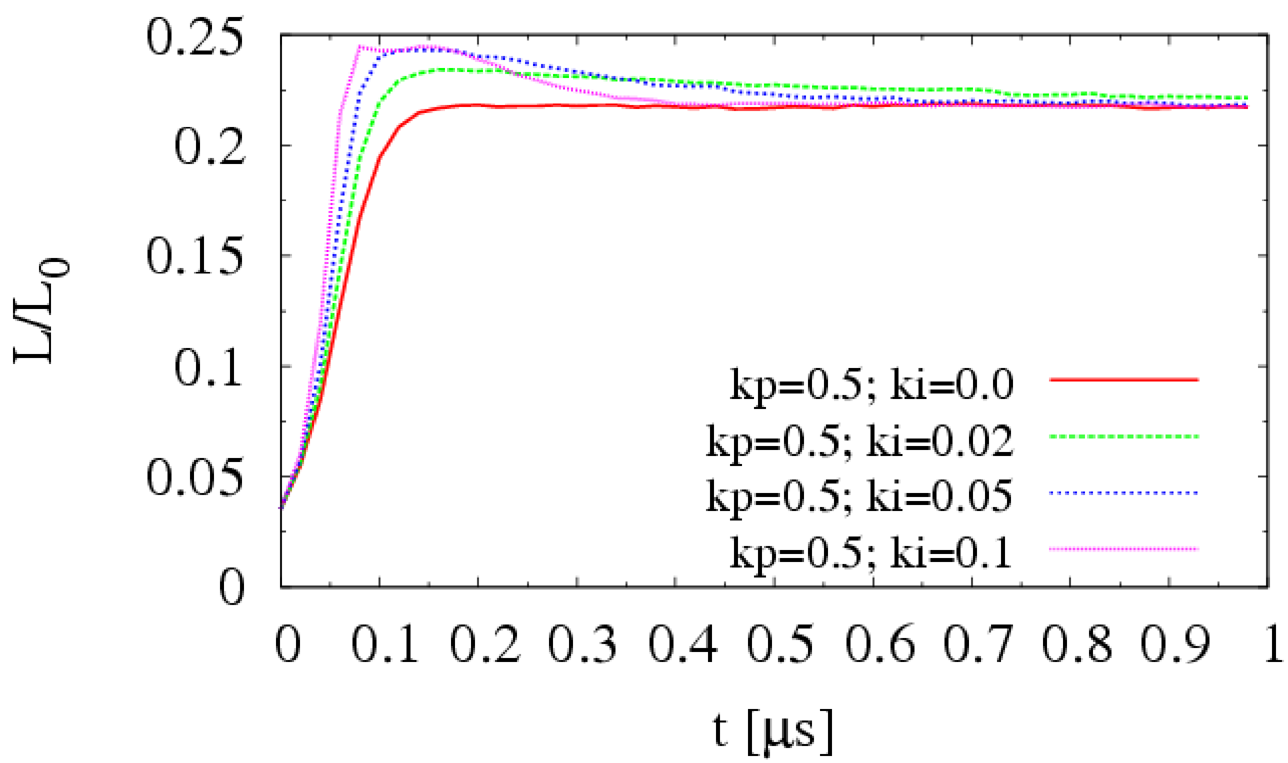



In this case
no GM applied

The main contribution to the IP beam jitter coming from QD0
For quadrupole position jitter < 20 nm, the IP-FB system manages to recover more than 80% of the nominal luminosity

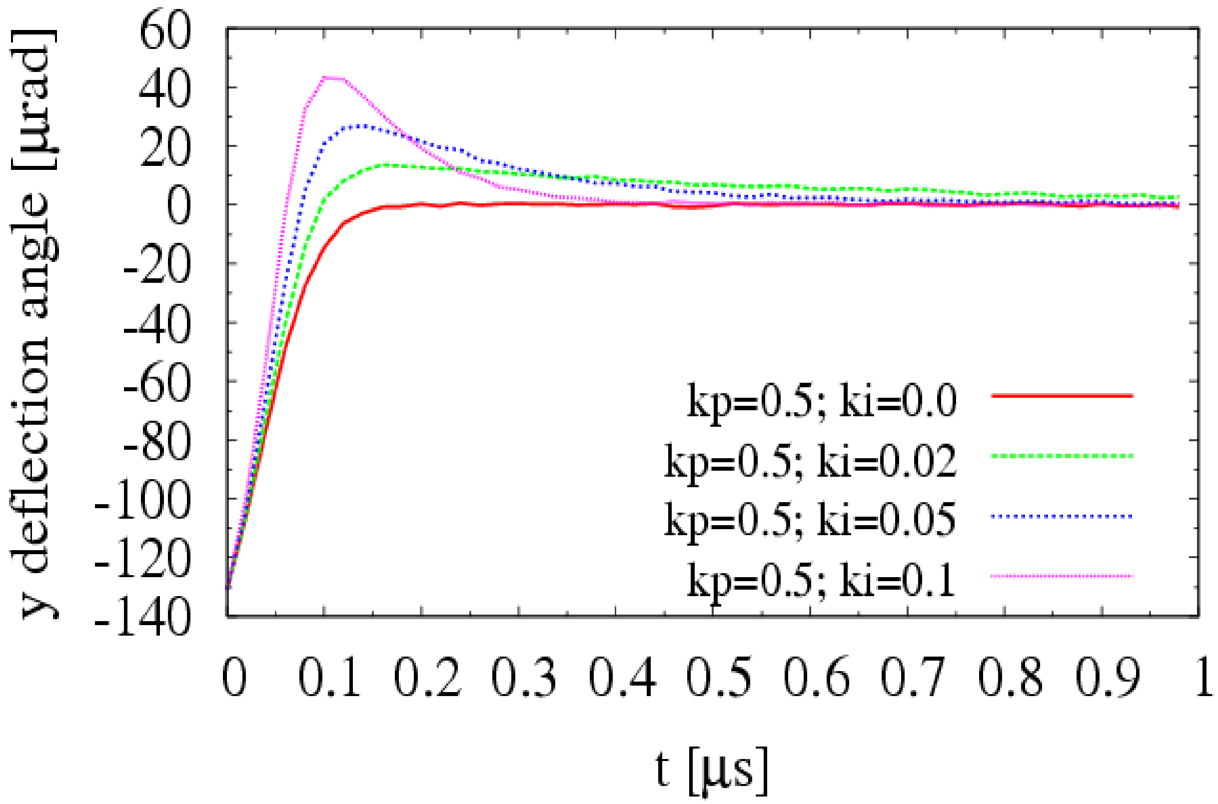
# CLIC luminosity with IP-FB
## PI control loop

- Using a classical PI (proportional term + integral term) algorithm
- 0.05 s of GM model C (1 seed)
- 10 nm emittance growth in the main linac



# CLIC luminosity with IP-FB

## PI control loop




Correction of vertical deflection angles ~ 100 μrad

# Summary and plans

- 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
- Here we have shown simulation results using intra-train FB systems for both ILC and CLIC
- Action plan:
  - Addition of the missing subsystem in the model, e.g. RTML
  - Addition of crab cavity wakefield effects (in progress)
  - Study of the IP-FB operation for the new Low P parameter (travelling focus) option of the ILC
  - Upgrade of these simulations with more sophisticate FB algorithm (for example adaptive algorithms)
- Suggestions are welcome