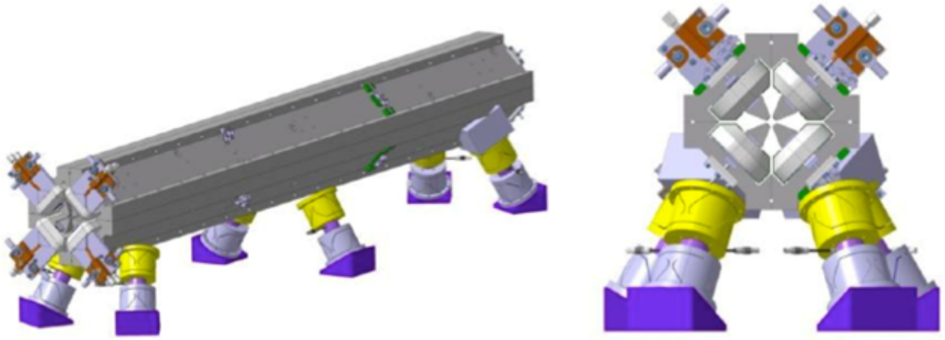
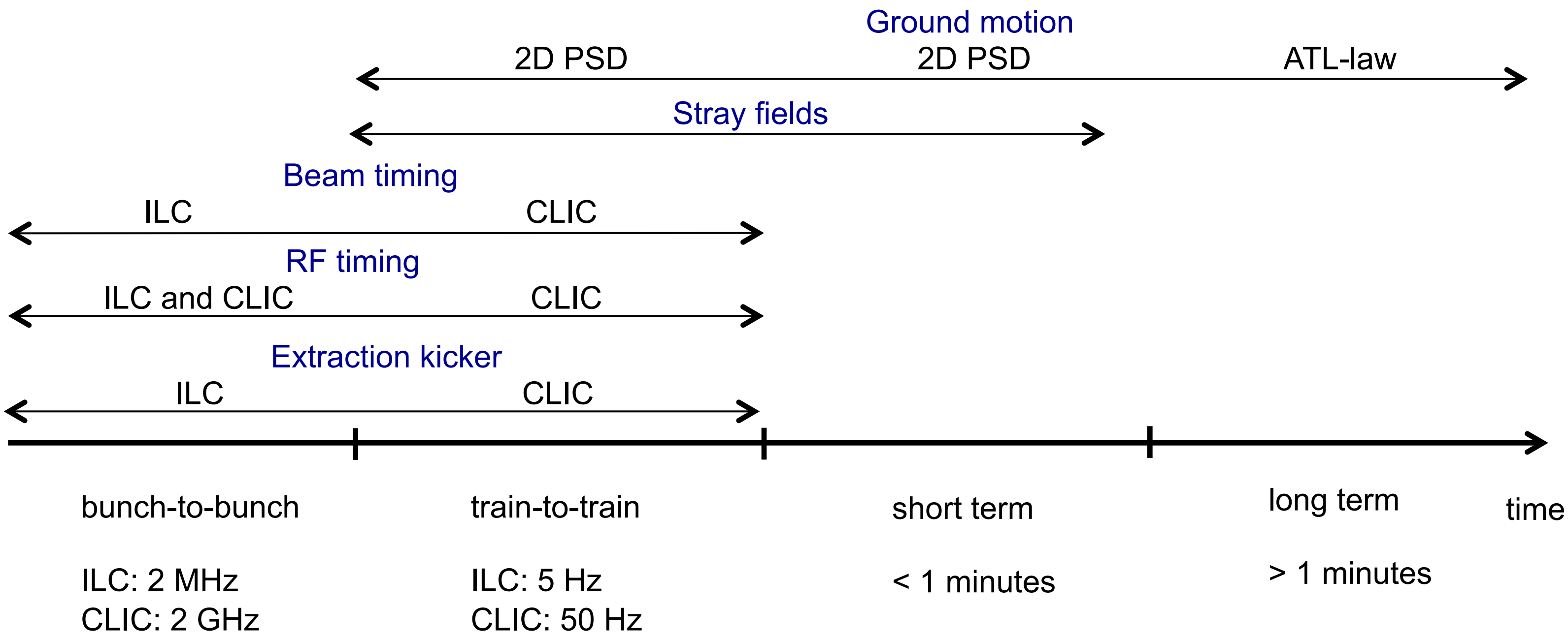


Key luminosity issues due to dynamic effects

Jürgen Pfingstner

Most critical dynamic effects in ILC and CLIC



Fundamental difference of mitigation methods for ILC and CLIC due to the different beam structure:

ILC can mitigate bunch-to-bunch due to “large” Bunch separation: (FONT system see later)

Big advantage compared to CLIC.

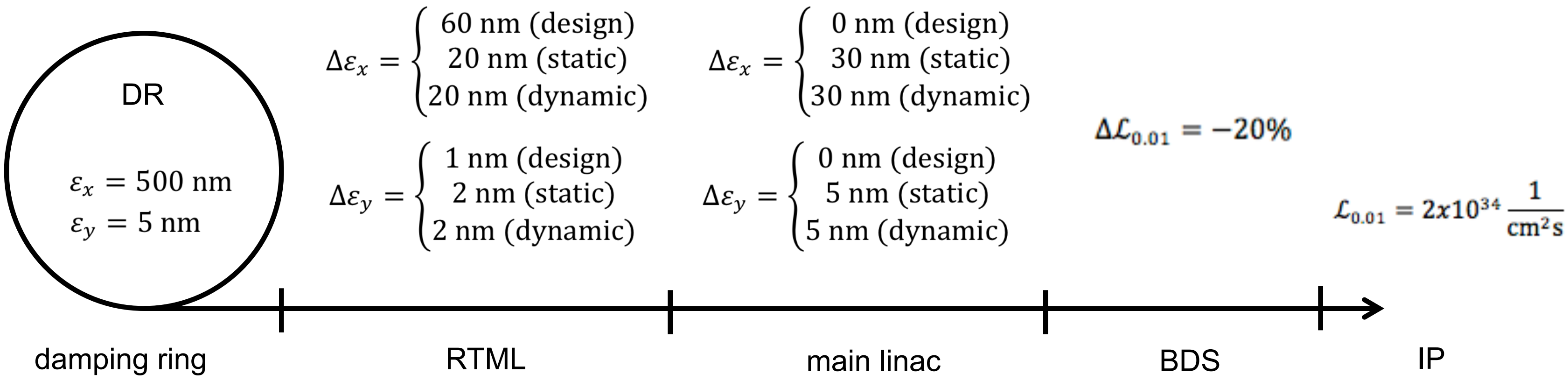
CLIC can mainly only work on train-to-train basis and hence more effort is necessary. Bunch-to-bunch operation is kept as a reserve only for the IP-FB.

Luckily the repetition rate of CLIC is higher (50Hz).

Imperfection budgets

Loss due to dynamic imperfections is integral part of the design: Budgets for losses are assigned.

Example of CLIC: Luminosity without static and dynamic imperfections is 2.5 x $L_{0.01}$



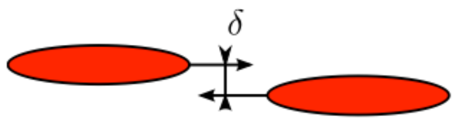
Comment: Talk focuses on dynamic imperfections; not all dynamic effects are covert:

- Dynamic vacuum
- Wake fields
- Other instabilities

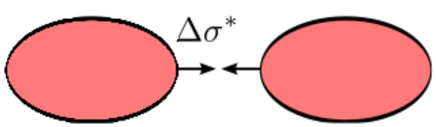
Ground motion

Ground motion in ILC: problem aspects

Two problems due to ground motion

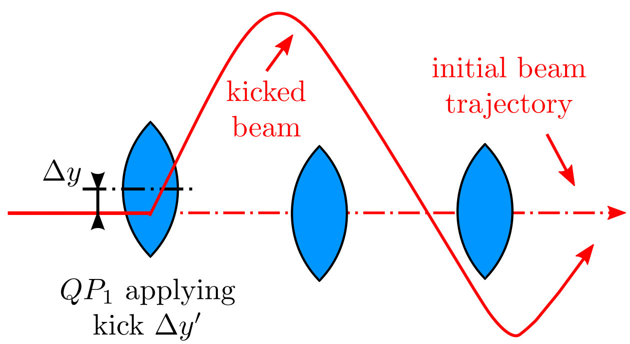


beam-beam offset at IP



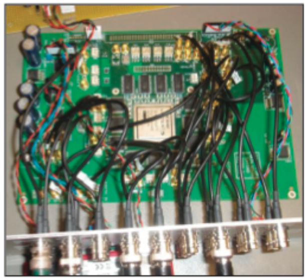
beam size growth at IP

Reason and effect of beam oscillations



Two-folded mitigation approach of ILC

1. Bunch-to-bunch feedback:
   - Oscillations of first bunches in long train are measured (BPM) and the following bunches are re-steered
   - Method is very effective and used several times in ILC
   - Fast electronics is essential (FONT)



- Well advanced design
- Tested and improved at ATF2
- P. N. Burrows et al

2. Train-to-train feedback:
   - Coupled local corrections
   - Necessary but less important then for CLIC

Ground motion in ILC: mitigation strategy in the main linac

Train-to-train

Beam oscillations from ML cause only small Δε in ML (big advantage), but some Δε in BDS (collimator wakefields).

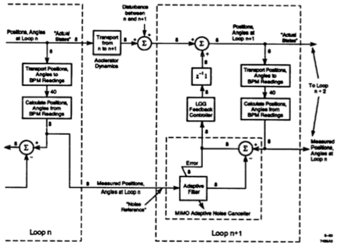
Tolerances (Sery, Hendrickson, White) without additional correction in ML:

> Ground motion C or K acceptable
> Additional component jitter should be <30nm

Component jitter <30nm has been and will be investigated at XFELs. At the moment is seems to be challenging and therefore: bunch-to-bunch orbit correction after main linac (baseline).

Short-term

- Beam orbit should not be too far off.
- Orbit is fixes at a few points with slow orbit feedback systems.
- Individual feedbacks are coupled (exchange of information):



2. Adaptive MIMO noise canceller added to the typical feedback loop.

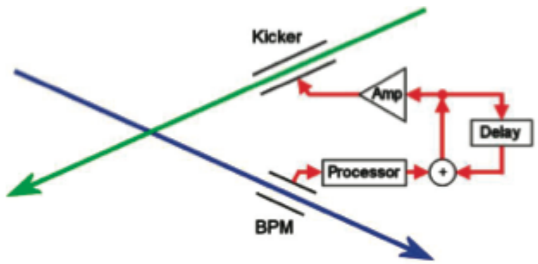
- adaptive, cascaded feedback system
- successfully applied at the SLC (SLAC)
- T. Himel et al.

Long-term

Studies (D. Schulte) showed that a after 20/100 days (models C/B) short-term FB is not sufficient. A re-application of the beam-based alignment will be performed.

Ground motion in ILC: mitigation strategy in the BDS

Bunch-to-bunch: IP-FB



J. Resta-Lopez

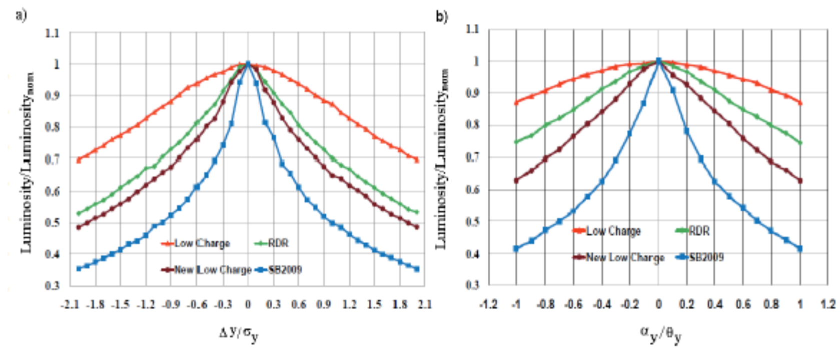
- Beam-beam deflection force is dependent on beam offset.
- Beam deflection can be used for feedback: BPM, FONT, kicker (ultra-fast)
- Many simulations performed (White, Walker)

Tolerances with only offset IP-FB:

- Ground motion should be between model B and C (very similar to CLIC)
- Additional component jitter should be <10nm
- QD0 jitter should be <50 nm

I

But …



L.I. Malysheva

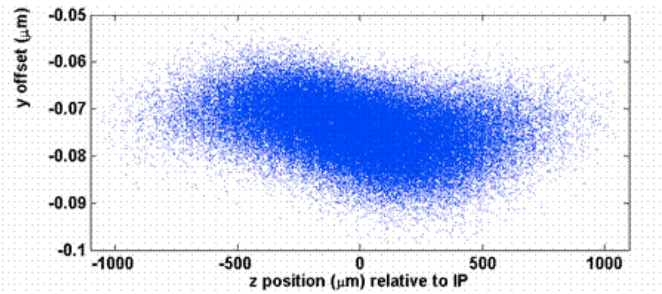
- IP beam parameter have changed to a higher disruption factor, which makes offsets more problematic.
- If the luminosity loss is too high, additional methods can be applied: beam angle feedback and luminosity scans.

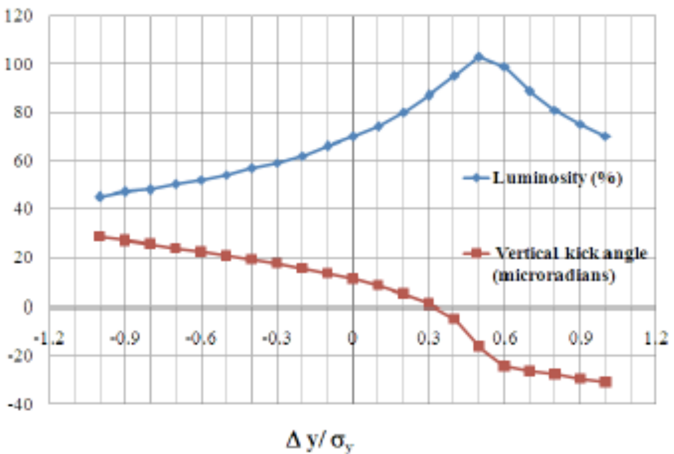
Ground motion in ILC: additional techniques and resume

Problems of the IP-FB:

A. Also angle of beam causes Δ*L*. Angle also fakes offset for IP-FB. Beam angle feedback can resolve this problem.

B. Beam distortion due to short-range wake fields cause beam-beam deflection of 0 not to produce the highest *L* (banana effect). This can be resolved by *L*-scans with fast *Lumi*-monitors (D. Schulte, O. Napoly)





L.I. Malysheva

Short- and long-term: same as in ML

Resume:

- Ground motion is under control
- But an update of integrated simulations with GM model of ILC site and new beam parameters would be valuable
- These simulations would clarify which methods are necessary and how high the luminosity loss is.

Ground Motion in CLIC: mitigation strategy

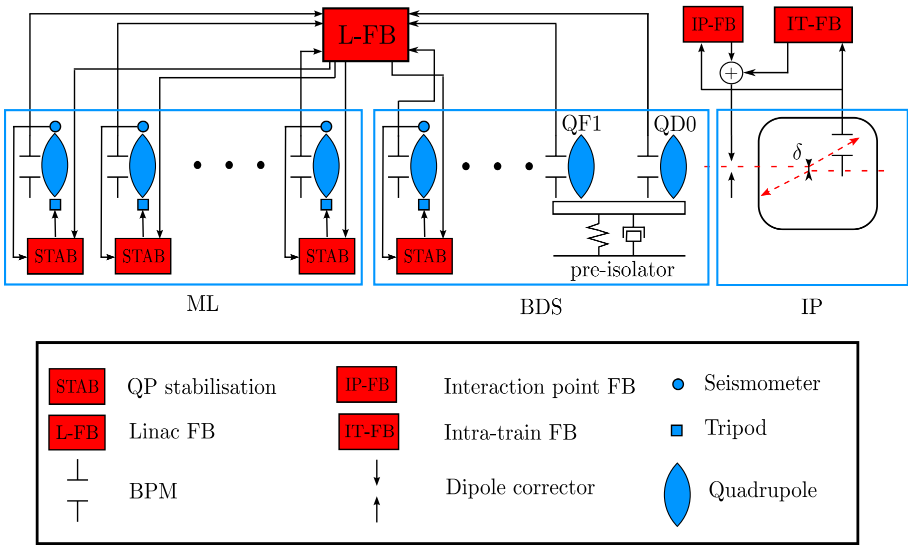
Differences to the ILC

- Bunch-to-bunch feedback is hardly possible
- Only at IP FONT system is kept as a reserve

- Train-to-train feedback can correct slow ground motion (not sufficient).
- Faster motion is corrected with additional magnet stabilisation

- Also the main linac is more sensitive due to filamentation

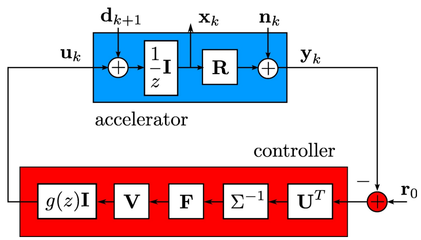
Mitigation methods



- Slow motion (<4Hz):
  - orbit feedback (L-FB)
  - IP-feedback
- Faster motion (>4Hz):
  - quadrupole stabilisation system
  - pre-isolator

Ground motion in CLIC: status of studies

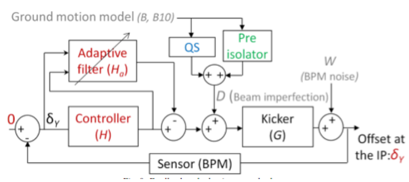
Orbit-FB



J. Pfingstner et al.

- Fully coupled feedback system (difference to ILC)
- SVD-base orbit controller.
- Decoupled channels optimised automatically to balance ground motion and BPM noise.

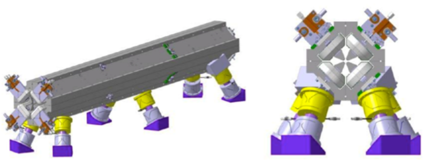
IP-FB



G. Balik et al.

- Different designs proposed and tested in simulations
- Most advanced algorithm from LAPP/SYMME in Annecy
- Adaptive FF-FB control scheme

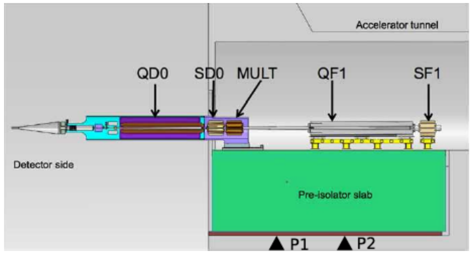
QP stabilisation



K. Artoos et al.

- Significant R&D efforts at CERN, but also in Annecy
- Seismometer measures QP motion, which is damped by piezo-actuated tripod.
- Full-mockup build and functionality verified!
- New sensors are being developed to even improve results.

Pre-Isolator

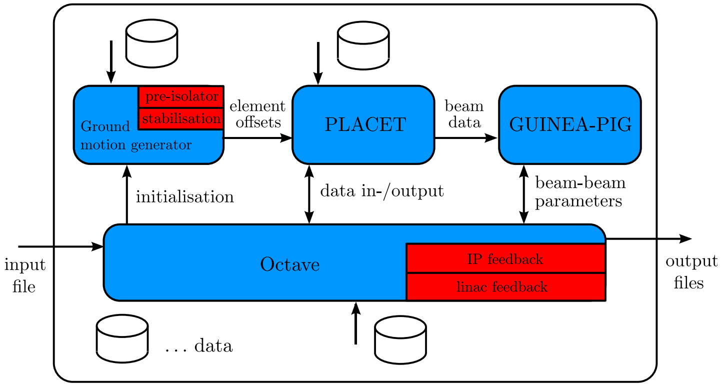


A. Gaddi et al.

- For QD0 and QF1, QP stabil. is not sufficient
- Dedicated passive mass-spring system
  - 100 tons concrete bloc
  - 10 air springs
- Full-scale mockup build and tested at CERN!

Ground motion in CLIC: results and outlook

Integrated simulations



(J. Snuverink et al)

Result 1: (Harmonisation of methods)

- ground motion sensors with different transfer function works better
- sensors are cheaper as before and
- performance is significantly better

Result 2: feasibility issue solved

	A	B	B10	C
V1	8.7 %/4.0 %	9.3 %/5.1 %	15.8 %/11.7 %	120.3 %/100.8 %
V2	1.4 %/0.0 %	1.6 %/0.5 %	2.0 %/0.8 %	67.6 %/71.5 %

Current activities

Optimisation of operation and cost:

- Try to omit QP stabilisation in ML with direct ground motion measurement. Experiment at ATF2 is ongoing (Y. Renier)
- Custom Sensor design (K. Artoos et al, A. Jeremie et al (Annecy)), unfortunately in hold now
- Long-term techniques: On-line DSF (J. Pfingstner)

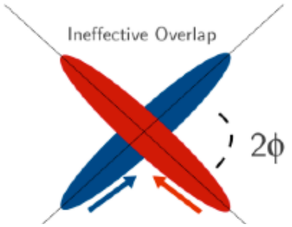
Luminosity loss (from 120%) due to

- Ground motion models A, B, B10 an C
- Quadrupole stabilisation V1 and V2
- Hand-tuned and automated orbit feedback design

Timing issues

Crab cavity in ILC

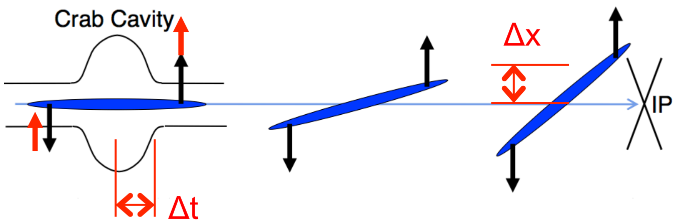
- Due to bunch collision with crossing angle, luminosity is lost



R. Calaga

- Crab cavity can recover this loss by compensating tilt

G. Burt



- If beam passes not at the zero crossing of the cavity magnetic field, beam is deflected coherently which creates offset at the IP.

- Therefore, there are tight tolerances for the synchronisation of the two cavities (G. Burt et al):

> 61 fs cavity-to-cavity synchronisation (uncorrelated) for 2% luminosity loss

- Proof-of-principle has been performed at the JLab ERL facility with the Cornell LLRF system (M. Liepe).

> - Cavity (different type and frequency) could be controlled to 37fs.
> - For two cavities this corresponds to 37fs*√2=52fs (uncorrelated), which leaves an error of 30fs for the timing reference to reach 61fs.

- Two crab cavities have been synchronised (Cockcroft Institute) to 60fs by a coaxial connection (15m length instead of 50m in reality).

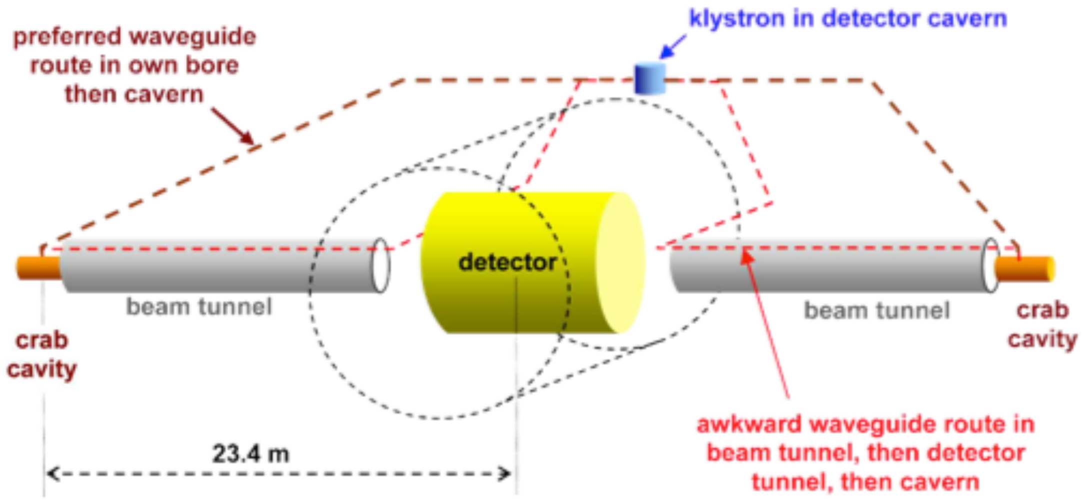
Crab cavity in CLIC

- Cavity synchronisation tolerances more tight for CLIC than for ILC

CLIC: 4.4 fs (uncorrelated, for ΔL=2%)
ILC: 61 fs

- Tightest timing tolerance for CLIC
- Synchronising two individual klystrons that power the cavities seems to be out of reach for CLIC (in contrast to the ILC)
- Solution: One common klystron (12GHz) will power both cavities

- Biggest challenge is to maintain identical RF path length of 40m to better than 1μm.
- Plan is to use an additional optical interferometer that could provide reference phases synchronised to 1fs.
- More work is needed!



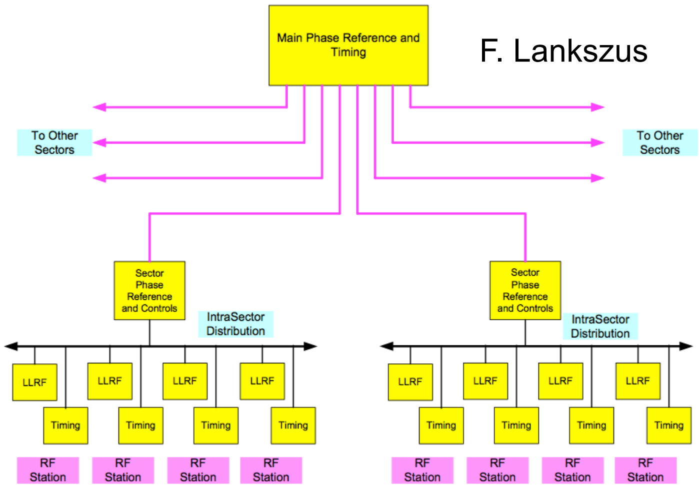
RF to beam synchronisation in ILC

Tightest Tolerances:

- Main RF (correlated): 0.35° (≈750 fs)
- Bunch compressor (corr.): 0.24° (≈500 fs)

Solution:

- Global optical timing system
- Central time reference distributes signal to sectors, where signal is further distributed.



Achievements:

- For shorter distances (300m) a stabilisation to <10 fs has been shown at DESY (F. Loehl)
- For the required length (15km) two experiments (J. Frisch et al, and K. Czuba) have been performed, where one stabilised fiber optics link was used.
- Both experiments could reach a phase stability of 250-300 fs.

Resume:

- The error of two links have to be taken into account and also the sector phase distribution system has to be taken into account.
- Specifications seem to be reachable.

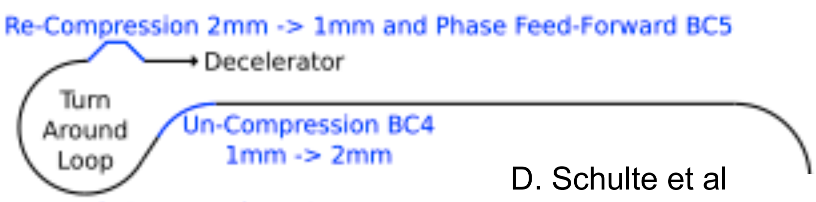
RF to beam synchronisation in CLIC

Tightest Tolerances (constant offset):

- Order of magnitude tighter than ILC
- Main RF (correlated): 0.2° (46 fs)
- Correlated offset is equivalent to the main and drive beam offset error.
- Very challenging tolerance

Solution part 1: path length FF correction

- Measure drive beam and timing error with respect to time reference (2 options, see later) and correct with FF by changing path length after turn around.
- This relaxes tolerances at end of drive beam accelerator to 2.5°
- But timing reference has to be accurate to 10 fs.



D. Schulte et al

Solution part 2: DB accel. tolerances

- The tolerance of 2.5° impose tight tolerances for drive beam accelerator
  - Charge stability: 0.75×10^{-3}
  - Klystron power and phase stability: 0.2% and 0.05°

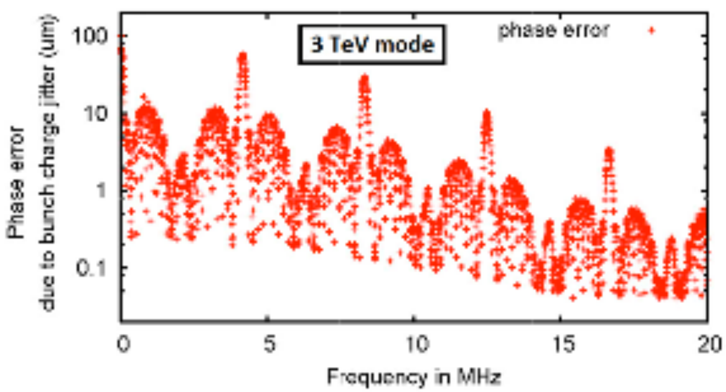
Achievements:

- Timing reference system has been designed to achieve 10fs stability (see later).
- In CTF3 the charge stab. could be improved from 2x10-3 to 0.6×10^{-3}.
- Also klystron power stability is 0.21%.
- Also klystron phase is very close to requirements and further improvements are planned.

RF to beam synchronisation in CLIC

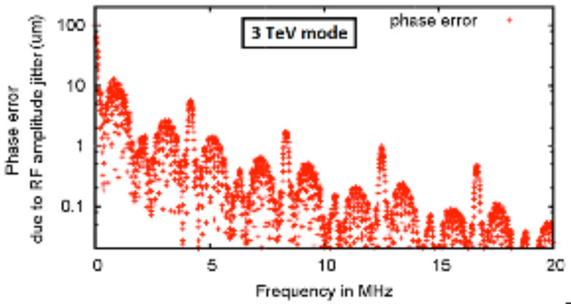
More complex offset errors:

- Work has to been done (A. Gerbershagen) do analyse the effect of drive been phase errors of certain frequencies.
- Drive beam recombination tends moves lower frequency components to to higher frequencies.
- PETs and ML accelerating structures have a filtering behavior for higher frequency errors.
- Also FF-correction is taken into account.



Improvement:

- By choosing length of DB accelerating structure correctly, additional damping for weakly damped frequencies is achieved.



Conclusions:

- With the measured error set at CTF3, the phase tolerances can be met for the 3TeV machine
- For energy scaled machines, the tolerances cannot be fully met. But results are very close.

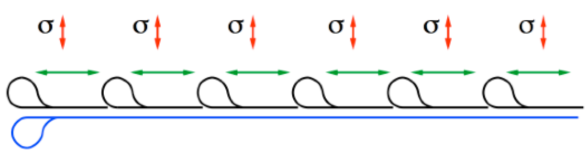
Timing reference systems in CLIC

A. Global synchronisation

Tolerances:

- Necessary accuracy <10 fs over 50km.
- XFEL at DESY reaches this value, but only over 300m
- ILC/NLC results over 15km are 250fs

Proposed idea: D. Schulte



- Chaining of reference lines
- Each line needs an accuracy of 2.3 fs

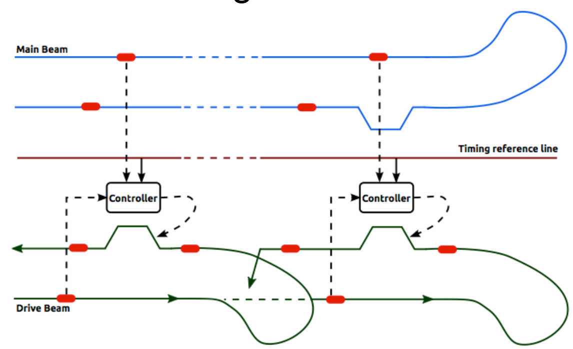
Status:

- Far from realisation
- Activities have to be launched

B. Synchronisation to main beam

Solution:

- Highly stable local oscillator picks up the phase of the outgoing main beam
- Drive beam is aligned to main beam 160μs later



Status:

- Local oscillators have been developed and tested successfully (A. Andersson et al)
- At the moment a system test of a full phase correction FF-system is ongoing
- This solution is feasible, but has a disadvantage for the MB-MB synchronisation (see next slide).

Beam-beam synchronisation in ILC and CLIC

ILC

- Did not find sufficient information to comment.
- There was a comment in the TDR on a feedback system for the beam arrival time.
- But this cannot cure jitter-like train-to-train timing errors

CLIC

Tolerance:

66fs for 1% luminosity loss

Global synchronisation system:

- System needs anyway a accuracy of 10fs along the complex for RF synchronisation.
- Problem solved with a longitudinal FF system in MB turn around.

MB synchronisation system:

- This does not help: tolerance for relative phasing after RTML is tight.
- Tolerance could be relaxed by measuring relative phasing in central complex and correcting in final focus
- Actor: energy change or focusing change of QP in final focus
- No detailed information either

Stray fields

Stray fields in ILC

Problem

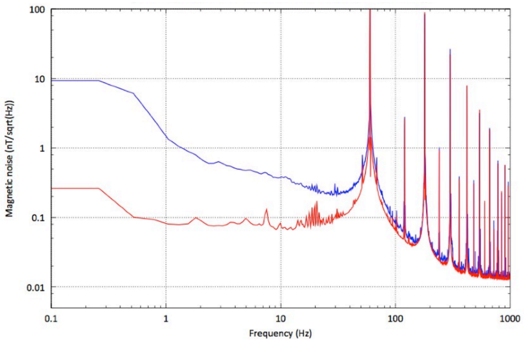
- Magnetic fields from external sources as
  - RF system / drive beam
  - Nearby equipment (motors, …)
  - External sources (power lines, …)
  - Earth magnetic field
- Mag. fields kick beam and create oscillations and further Δε.

RTML

- Estimate (Kubo) predicts 20% beam oscillation for uncorrelated stray fields of 2nT.
- This offset is foreseen to be corrected with a orbit FF-system, where offset information overtakes beam in the turn around loop.
- For larger oscillations: Δε in turn around

Measurements

- Two known measurements (J. Frisch et al and D. Sergatskov)
- Spectra show fields up to 100nT IRMS. But multiples of beam repetition rate will be seen as DC by beam (e.g. lines frequency).
- Remaining components in the order of 2nT



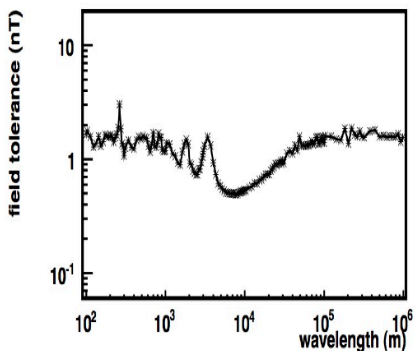
D. Sergatskov

Resume

- J. Frisch et al mention that knowledge about 2D-PSD is necessary to make more precise statements, e.g. for BDS.
- Hence, stray fields are most like no problem for the ILC, but studies are not very detailed.

Stray fields in CLIC

- Wave length dependent studies performed



- Sensitivity for 2% lumi loss
- BDS, anti-symmetric wrt IP
- J. Snuverink

- Tolerances (uncorrected) for 2% lumi loss

[nT]	resonance	random
RTML	0.1/1*	10
ML	10	50
BDS	1	10

*) with turn-around FF orbit correction

- Stray field sources
  - Drive beam has negligible impact due to beam timing (fortunately)
  - Other sources have to be quantified in form of a 2D-PSD P(f,λ).

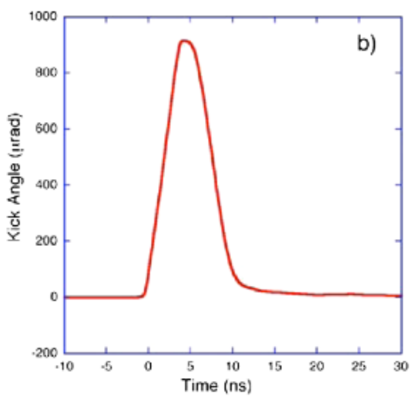
- Resume:
  - Stray fields are considered a problem for CLIC (tolerances similar to ILC)
  - Turn around orbit FF is inevitable (has been put in place)
  - With FF, tolerances are similar for RTML and BDS (bending magnets).
  - Many counter measures possible, but most important are measurements.
  - Work has to be done!

RTML beam oscillations due to extraction kicker stability

Extraction kicker in ILC

Requirements:

- Bunches are extracted one by one (no flat top of kicker voltage)
- Rise and fall time: 6ns (3ns lumi upgrade)

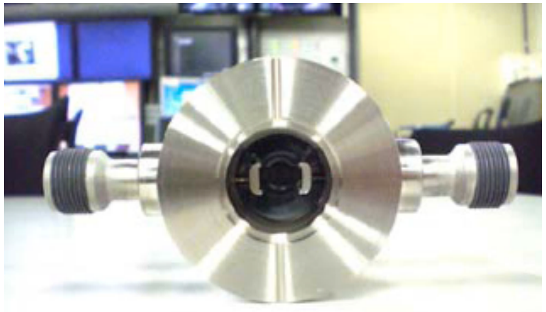


Naito et al

- Induces beam jitter should be <0.1σ
- Rel. kicker amplitude stability: 7×10^{-4}

Achievements:

- Successful results at KEK (Naito et al)
  - Rise/fall time: 3ns
  - Amplitude stability: 3.5×10^{-4} (single bunch)
  - Amplitude stability: 1% bunch train



- Strip-line electrode at ATF (KEK)
- Naito et al

- Recent result (ILC-TDR):
  - Amplitude stability: 10^{-3} for 30 bunches (1320/2625 in ILC)

Resume: Requirements nearly met

Extraction kicker in CLIC

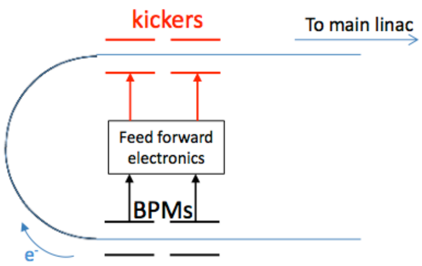
Tolerances:

- Beam jitter: $0.1x\sigma_x$
- Kicker stability: $3x10^{-4}$
- Thin septum stability: $2x10^{-5}$
- Thick septum stability: $2x10^{-6}$

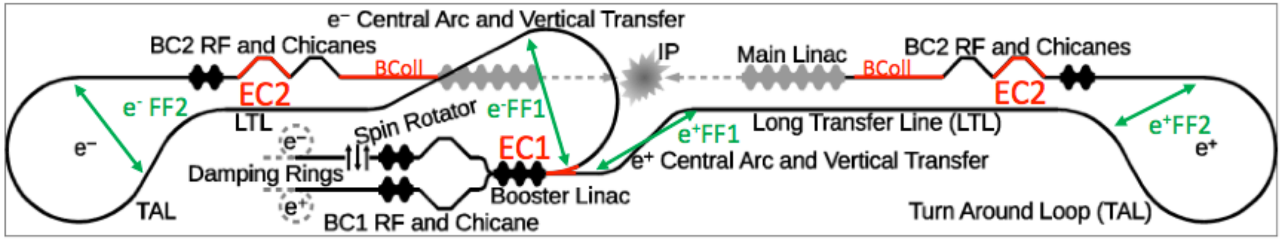
=> Unlikely to be achievable

Double FF system:

- Orbit FF system
- Turn around loop
- Central arc to limit $\Delta\varepsilon$ in turn around



R. Apsimon et al



Tolerances with FF:

- Beam jitter: $0.4x\sigma_x$
- Kicker stability: $5x10^{-3}$
- Thin septum stability: $1x10^{-4}$
- Thick septum stability: $2x10^{-5}$

Ongoing work:

- Tolerances have been relaxed, but are still challenging.
- Results of ILC are achieve stability and rise time, but CLIC need a flat top for bunch train
- Spanish program “Industry for Science” develops strip-line.
- Collaboration with ALBA and ATF
  - Future work is necessary!

Thank you for your attention!