Summary

The compact linear collider study aims to establish the feasibility of constructing a linear electron positron collider with multi-TeV centre-of-mass energy. At this collider beam dynamics issues are of great importance. One of the critical issues is the phase and amplitude stability of the RF in the main linac. The required stability is specified and the underlying physics is detailed. This leads to very stringent performance specifications for the beam instrumentation.

RF Timing Jitter in CLIC

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- Origin of the main linac RF phase and amplitude jitter tolerance
- Sources of main linac RF jitter
- Remarks on Mitigation strategies
- Conclusion

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RF Jitter

- An RF phase or amplitude jitter leads to
  - beam energy errors
  - multi-pulse emittance growth
- Both can lead to luminosity loss
  - the energy spread smears the luminosity spectrum
- Relevant is the RF phase with respect to the beam
- The beam loading can also lead to amplitude errors
- All drive beam bunches are generated in one place

  $\Rightarrow$ may have coherent errors
- In the following will consider jitter effects and assume that static imperfections can be tuned out

Jitter Tolerance

- For the physics an energy spread is bad
  - the intrinsic energy spread is $\sigma_{E,int} \approx 0.0035E$

  $\Rightarrow$ Previous CLIC Physics Study Group had already asked for configurations with less energy spread for some measurements

  - $\sigma_{E,jitter} \leq 0.001E$ seems acceptable
  - $\sigma_{E,jitter} \leq 0.002E$ seems significant

  $\Rightarrow$ aim for 10^{-3}
- Energy errors lead to transverse emittance growth

  $\Rightarrow$ limit luminosity loss
- The beam delivery system bandwidth is limited

  $\Rightarrow$ the resulting luminosity reduction needs to be limited

Simulation Results

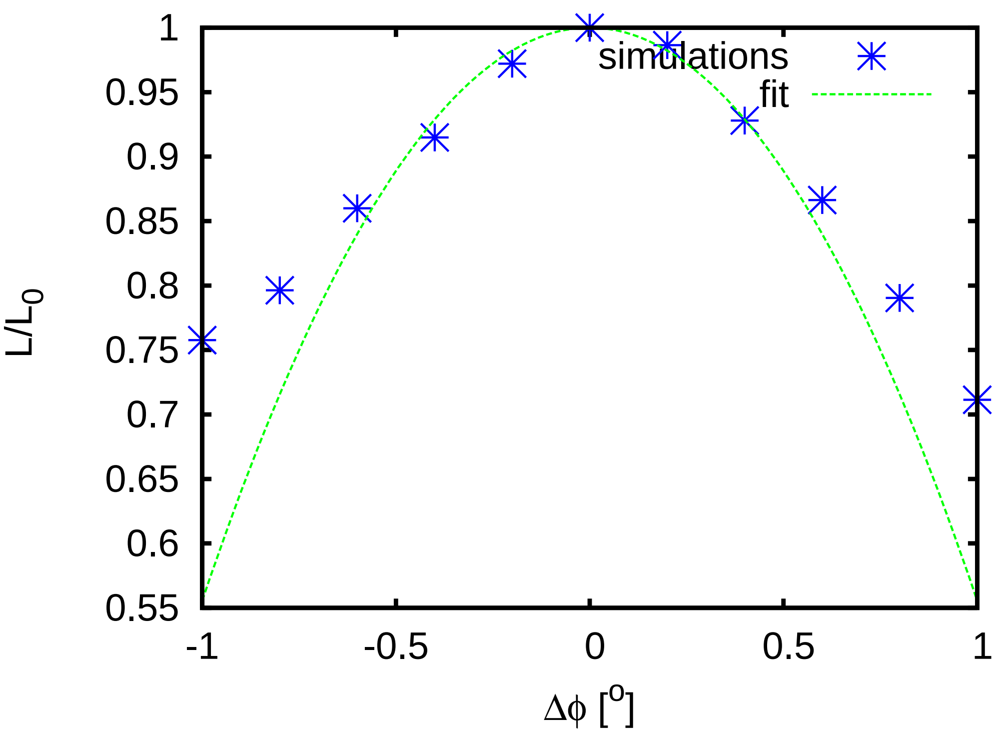
- Integrated simulations have been performed of main linac, BDS and beam-beam for perfectly aligned system (to determine BDS bandwidth)
  - for old BDS lattice and beam parameters

⇒ Limited BDS bandwidth leads to 2% luminosity loss for

  - $\sigma_\Phi \leq 0.15^\circ$
  - $\sigma_G \leq 6 \times 10^{-4} G$

- Final energy error due to uncorrelated jitter σ_{incoh} is about

$$\sigma_{coh} \approx \frac{\sigma_{incoh}}{\sqrt{10}}$$



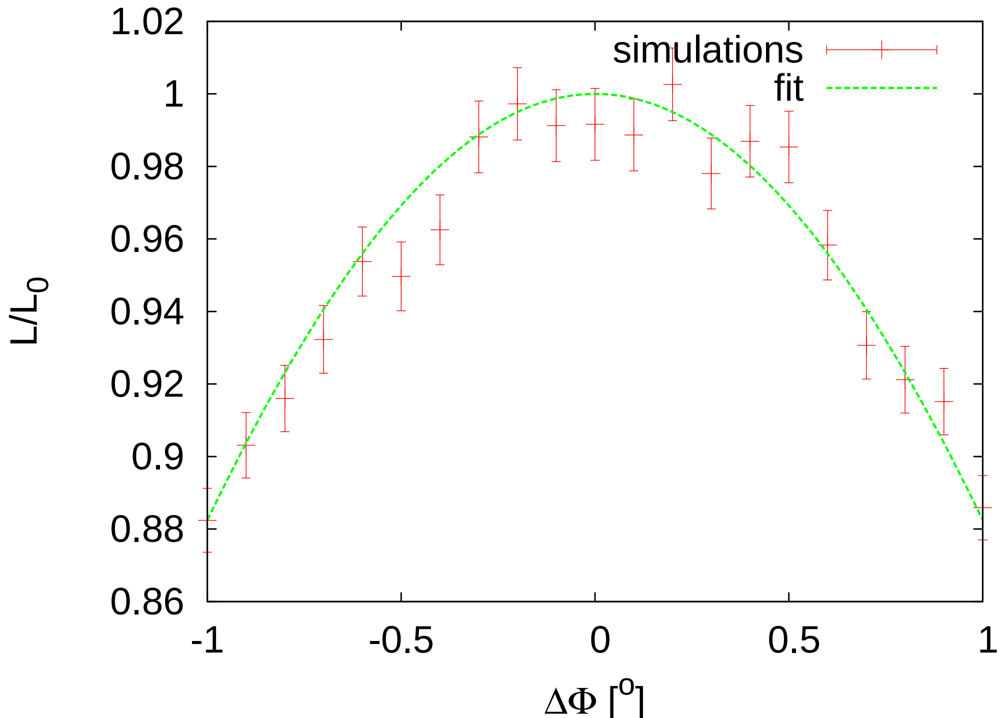
Simulation Results

- Simulation has been repeated for new parameters and BDS lattice
  - integrated simulations of main linac, BDS and beam-beam for perfectly aligned system
  - multi-pulse emittance growth in the main linac with realistic mis-alignments

$\Rightarrow$ Most tight is BDS bandwidth leads to 2% luminosity loss for

  - $\sigma_\Phi \leq 0.25°$
  - $\sigma_G \leq 10 \times 10^{-4} G$

- Bandwidth appears significantly better
  - need to be confirmed with higher statistics



imperfection	size	$\Delta L/L\,\%$
$\sigma_{\phi,coh}$	$0.5°$	0.55
$\sigma_{a,coh}$	0.1%	0.4
$\sigma_{\phi,incoh}$	$1.0°$	0.65
$\sigma_{a,incoh}$	0.3%	0.5

Luminosity Loss

- Main beam current errors lead to different beam loading hence to energy errors
- Main beam phase errors lead to dephasing between main and drive beam and wrong timing at the collision point

  - luminosity loss from energy error is dominating

- For small perturbations one can express the luminosity loss as

$$\frac{\Delta L}{L} \approx 1.0\% \left[\left(\frac{\sigma_{\Phi,coh}}{0.1^\circ}\right)^2 + \left(\frac{\sigma_{G,coh}}{4\cdot 10^{-4}G}\right)^2 + \left(\frac{\sigma_{\Phi,incoh}}{0.3^\circ}\right)^2 + \left(\frac{\sigma_{G,incoh}}{12\cdot 10^{-4}G}\right)^2 + \left(\frac{\sigma_{\Phi,beam}}{0.1^\circ}\right)^2 + \left(\frac{\sigma_{I,beam}}{24\cdot 10^{-4}I}\right)^2\right]$$

- For new parameters and lattice

$$\frac{\Delta L}{L} \approx 1.0\% \left[\left(\frac{\sigma_{\Phi,coh}}{0.18^\circ}\right)^2 + \left(\frac{\sigma_{G,coh}}{7\cdot 10^{-4}G}\right)^2 + \left(\frac{\sigma_{\Phi,incoh}}{0.6^\circ}\right)^2 + \left(\frac{\sigma_{G,incoh}}{22\cdot 10^{-4}G}\right)^2 + \left(\frac{\sigma_{\Phi,beam}}{0.18^\circ}\right)^2 + \left(\frac{\sigma_{I,beam}}{42\cdot 10^{-4}I}\right)^2\right]$$

- Could propose following budgets

Drive beam current jitter	$7\cdot 10^{-4}$
Drive beam phase jitter	0.2°
Main beam current jitter	10^{-3}
Main beam phase jitter	0.1°

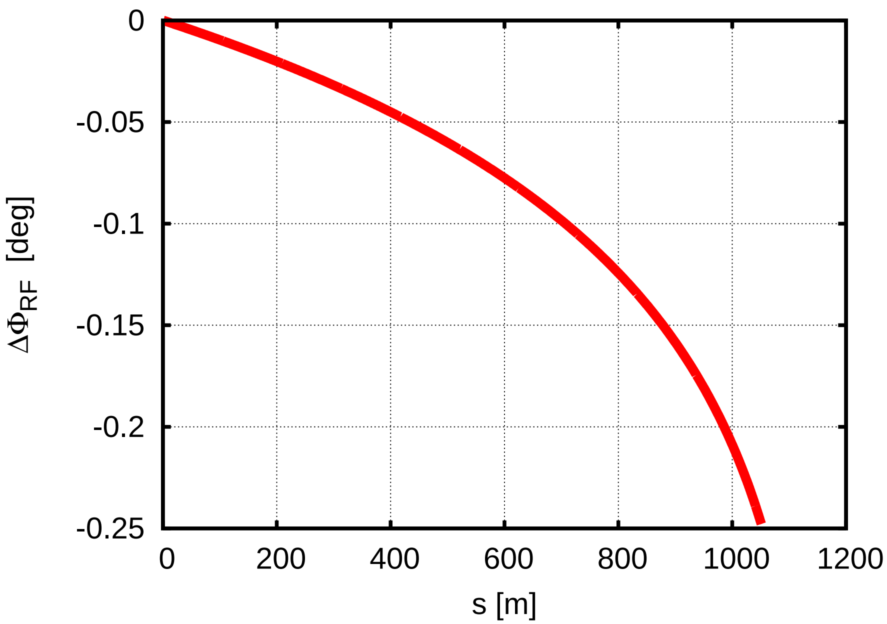
- Need to be able to measure these imperfections

Drive Beam Jitter Sources

- RF gradient error is given by drive beam current error $\Delta G/G = \Delta I/I$
- RF phase error is given by drive beam timing error $\Delta\Phi = 2\pi c\Delta t/\lambda$
- The whole drive beam is generated in one complex

  $\Rightarrow$ discuss coherent errors first
- Drive beam phase jitter sources
  - transverse jitter
  - energy errors in bunch compressors
  - timing errors in injector
  - path length changes
- Drive beam intensity errors
  - injector current variations
  - collimation
  - other losses

Transverse Drive Beam Jitter



Caluclation by E. Adli

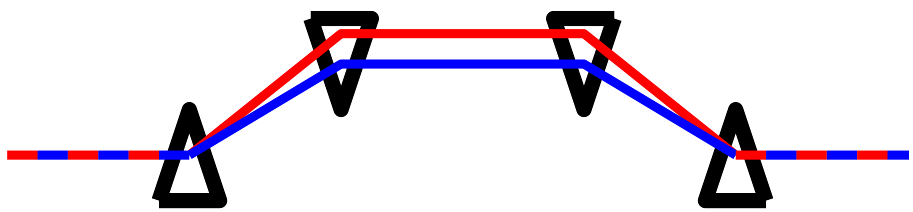
- Longitidinal motion due to transverse angles
- Assumed that systematic effect is tuned out

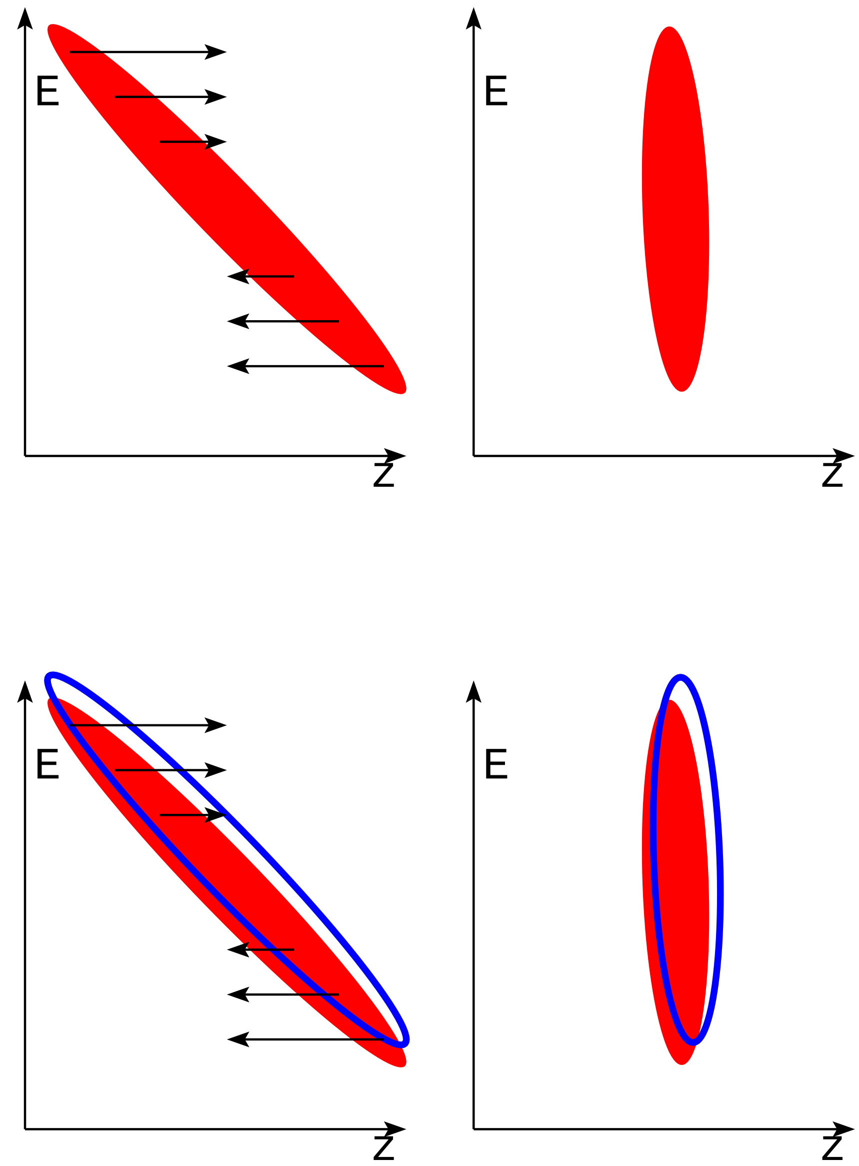
$\Rightarrow$ Only jitter component left

- Decelerator is most important (largest phase advance)
- Need to average over local phase error to obtain effective phase error

$$\left(\frac{\Delta x}{\sigma_x}\right)^2+\left(\frac{\Delta x'}{\sigma_{x'}}\right)^2+\left(\frac{\Delta y}{\sigma_y}\right)^2+\left(\frac{\Delta y'}{\sigma_{y'}}\right)^2\leq 1^2$$

Drive Beam Bunch Compressor





- The drive beam needs to be compressed longitudinally

  $\Rightarrow$ energy errors will translate into phase errors

$$\delta z = R_{56} \Delta E / E$$

$\Rightarrow$ Can attempt to avoid compression

Example: Tolerances for Single Stage Compressor

- Looking at compression stage just before drive beam decelerator
- Compression is $R_{56} \approx 0.36\,\mathrm{m}$

$\Rightarrow \delta E/E = 3 \cdot 10^{-5}$ leads to $\delta z = 10.8\,\mu\mathrm{m}$

- corresponds to phase tolerance

- for fully loaded operation one finds

$$\frac{\delta E}{E_0} = \frac{2\delta G}{G_0} - \frac{\delta N}{N_0}$$

$\Rightarrow$ tolerance

$|\delta G/G_0| \leq O(1.5 \cdot 10^{-5})$

$|\delta N/N_0| \leq O(3 \cdot 10^{-5})$

$|\delta \Phi| \leq O(0.01^\circ)$ for compressor RF

- Compression at an earlier stage with larger energy spread can increase tolerance for $\delta G/G_0$ and $\delta N/N_0$

$\Rightarrow$ compress in DBA, uncompress for combiner rings, recompress afterwards

- phase tolerance is not affected much

Mitigation Strategy

- Increase beam delivery system acceptance

    but new limit from physics

- Stabilise drive beam

    - stable injector
    - stable RF
    - longitudinal feedback/feedforward
    - bunch compressor design

- Tie main beam to drive beam phase

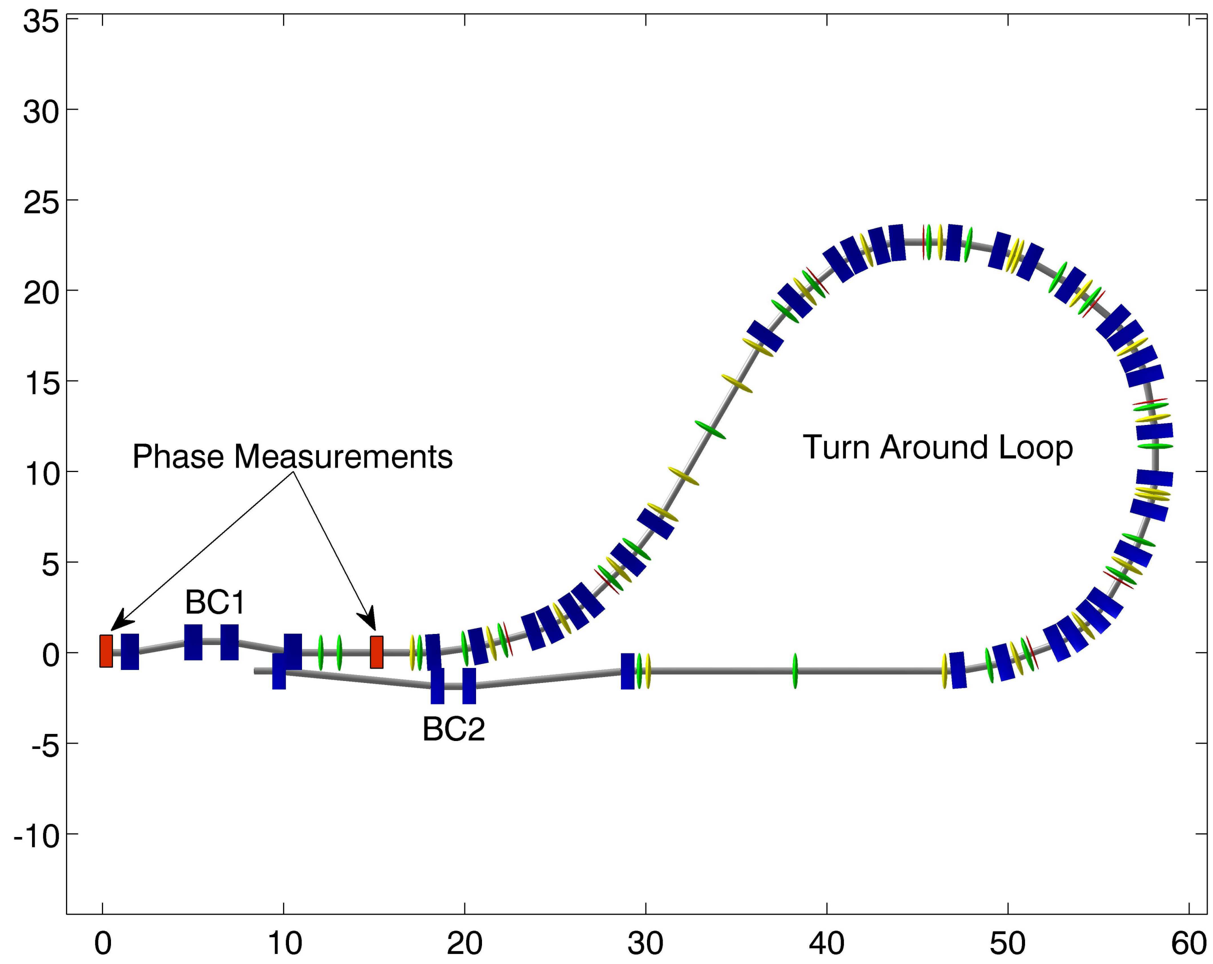
    - one to the other or both to a common reference
    - via feedback/feedforward
    - via RF (e.g. bunch compressor)

Feedback/Feedforward Design

- Different locations for feedback/feedforward are possible
  - at the drive beam turn around loop
  - in the drive beam accelerator
  - in the beam transport line
- Need a timing reference
  - coupled local oscillators
  - local oscillator triggered by main beam
  - local oscillator triggered by drive beam
- Need to measure
  - beam phase
  - beam energy
  - other quantities

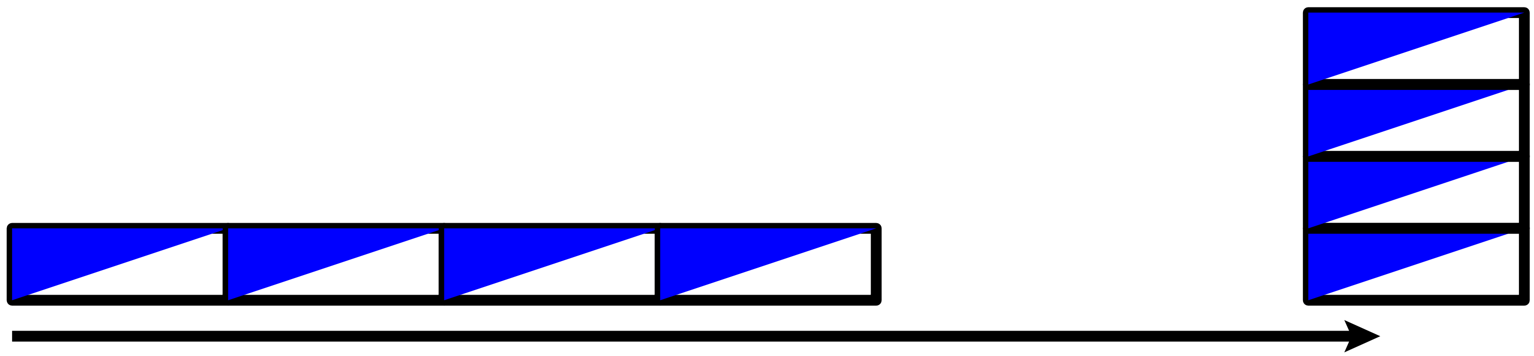
Example Feedforward at Final Turn-Around

- Final feedforward shown
  - requires timing reference (FP6)
  - phase measurement/prediction (FP7)
  - tuning chicane (PSI)
- Measure phase and change of phase at BC1
- Adjust BC2 with kicker to compensate error
- One could also measure phase and energy at BC1



Feedback

- Long drive beam pulse at generation $\approx 140\,\mu\text{s}$
- End of pulse catches up with beginning due to combiner rings



- Also design of sequence of acceleration and bunch compression for drive beam can help to achieve required performance

  - but still need to beam able to measure final jitter

Conclusion

- A very tight tolerance on the drive beam phase jitter exists
- This leads to tight tolerances in the drive beam generation complex
- To meet these tolerances a number of methods could be used
  - using the drive beam RF to compress the main beam
  - feedforward at the final drive beam turn-around
  - beam feedback/feedforward at other locations
  - feedback on the klystron pulses
  - appropriate drive beam bunch compressor design
- Need time reference with sufficient precision
- Need to understand noise sources (e.g. klystons)