Integrated Simulations

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Motivation

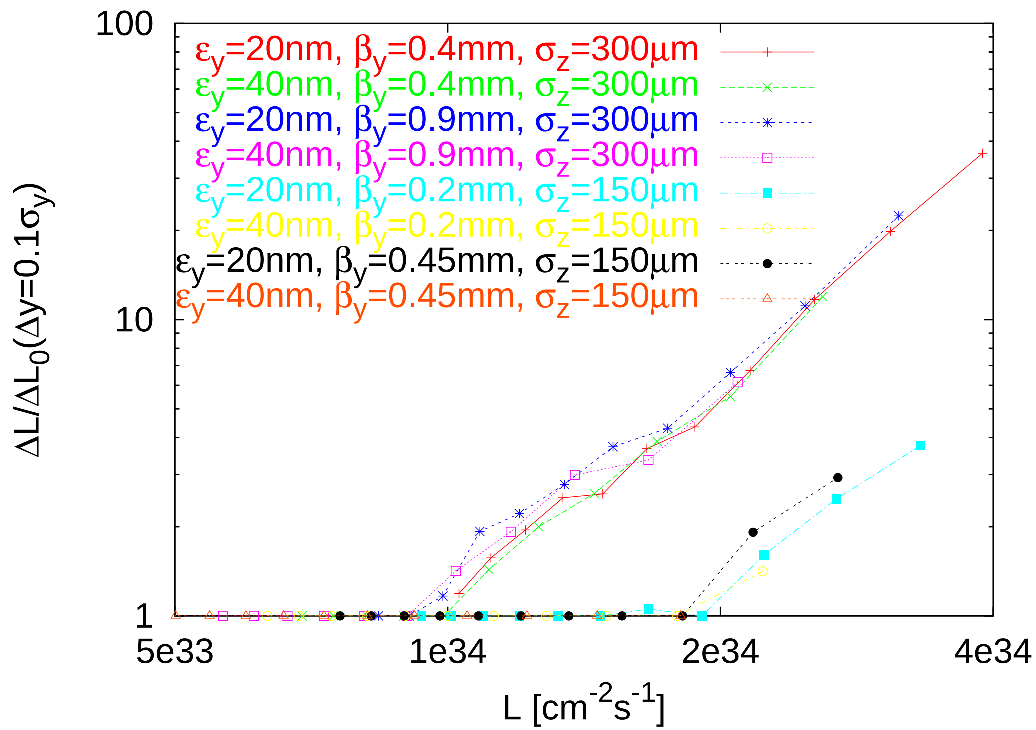
- Understanding of the performance of tuning, correction and feedback assuming realistic condictions remains one of the important R&D topics
- Integrated simulations are essential to understand matching of different time scales
  - e.g.: If one optimises a tuning knob, how long does it take to get a realiable luminosity measurement given the beam delivery system feedbacks?
  - How do the different feedback systems interact?
  - Which bandwidth is available for each feedback system/correction and tuning procedure
- The correlations of the particle distribution introduced in one sub-system can be important for other sub-systems (e.g. banana effect)

- Different diagnostics can be used to asses beam parameters

  - this can be affected by correlations/need to understand the time scales

Example: Banana Effect

- Due to high disruption D_y emittance growth is not a good measure for luminosity any more
- The correlation within the beam matters
- High disruption unavoidable since $\mathcal{L} \propto D_y/\sigma_z P_{beam}$
- Effective disruption parameter can be even higher since each slice of the beam may be smaller than the beam projection

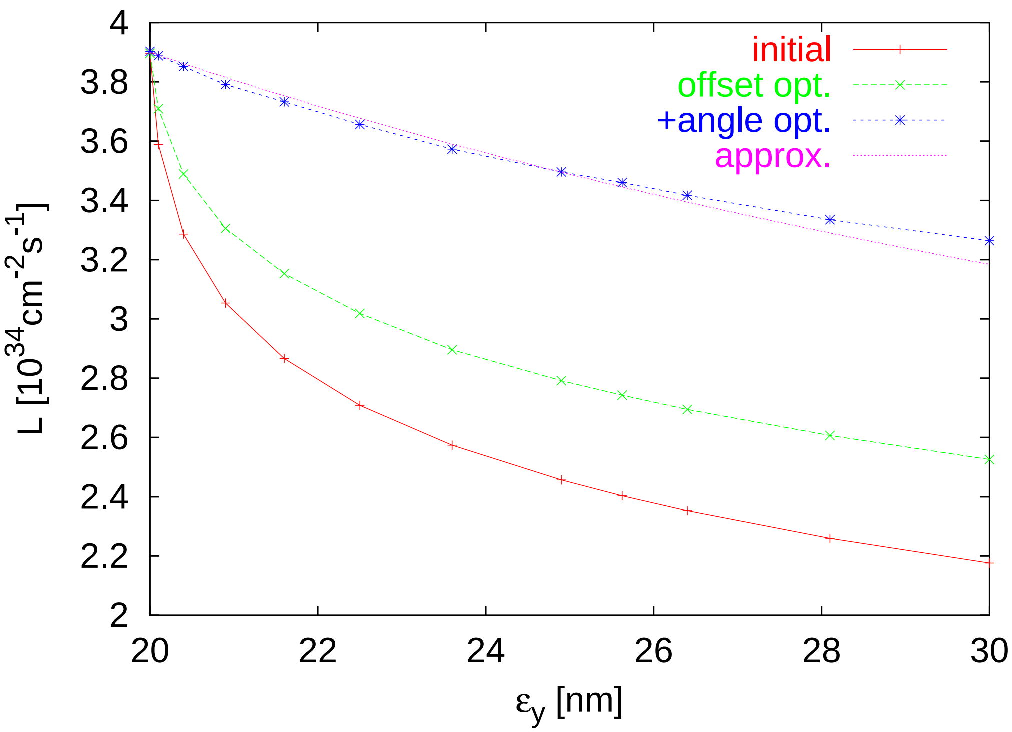


Solution for Static Case

- Simulations were performed for TESLA, for ILC disruption is lower
- Luminosity can be optimised by scanning offset and angle
- Should be even possible within a single pulse

⇒ Certainly more complicated than feedback with BPM

⇒ For dynamic case full simulation is required



Ground Motion

- Studies are based on TRC ground motion models (from A. Seryi)
  - B: medium stable stable
  - C: noisy site
- Model takes into account the correlation of the ground motion
- For the study, the motion during the pulse duration is neglected

Simulation Procedure

- All simulations were performed with PLACET (beam transport) and GUINEA-PIG (beam-beam effects)
- Only beam delivery systems are included (thanks to M. Woodley)
- Consistent ground motion is taken for electrons and positrons
- Simple feedback algorithm used
- Beam-beam feedback based on BPM after collision point
- Orbit feedback based on BPMs and dipole correctors in beam delivery system
- Simulations performed using seperated tracking/correction modules

Previous Results for TESLA

- Luminosity loss in percent for noise ground (model C)
- Simplified feedback model
  - all elements creep back to their initial position

⇒ significant luminosity loss with no luminosity optimisation

⇒ pulse-to-pulse feedback can help significantly

correction applied	slow feedback gain			
	0.01	0.02	0.04	0.1
No feedb.	73	71	67	56
offset correction	36	33	29	26
+angle correction.	22	19	16	15
offset optimisation	15.1	11.7	9.3	7.8
+angle optimisation	10.4	7.3	5.7	4.6

ILC Results with no Feedback (A. Latina)

Simulation when no feedbacks are active for the models B and C

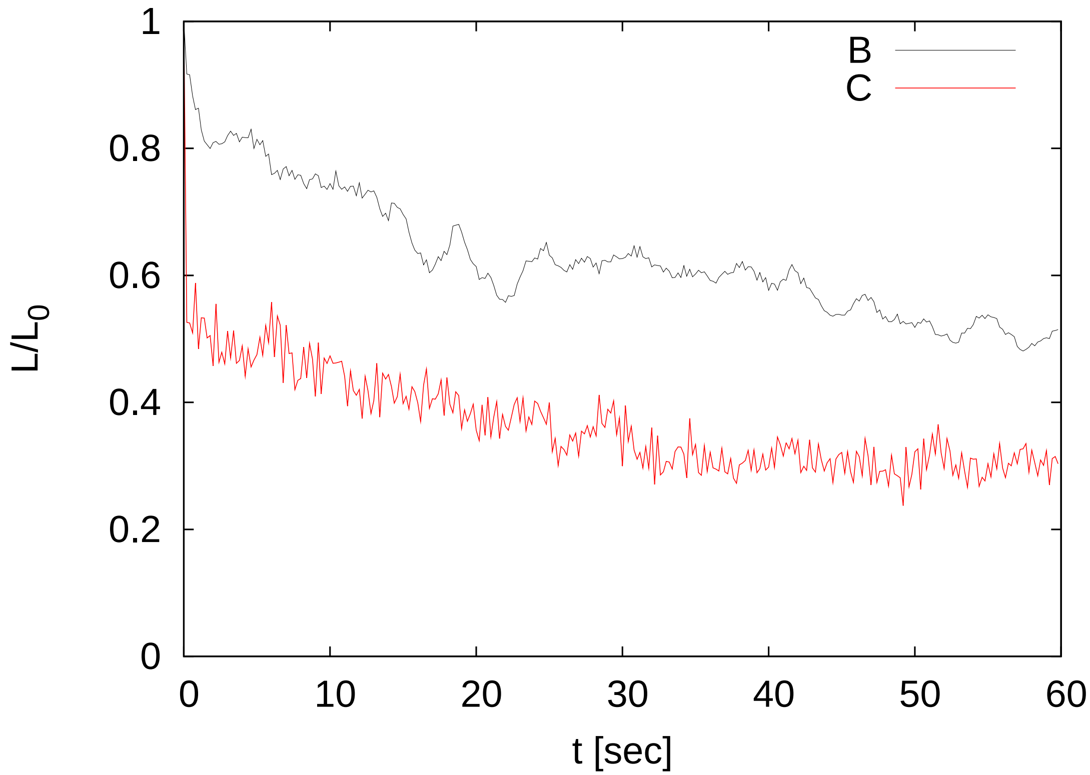
- Perfect alignment at t=0

  - $L_0 \simeq 1.40 \cdot 10^{34}$ $cm^2 s^{-1}$

- After 60 seconds:

  $\Rightarrow$ B: $L \simeq 50\%\ L_0$

  $\Rightarrow$ C: $L \simeq 30\%\ L_0$

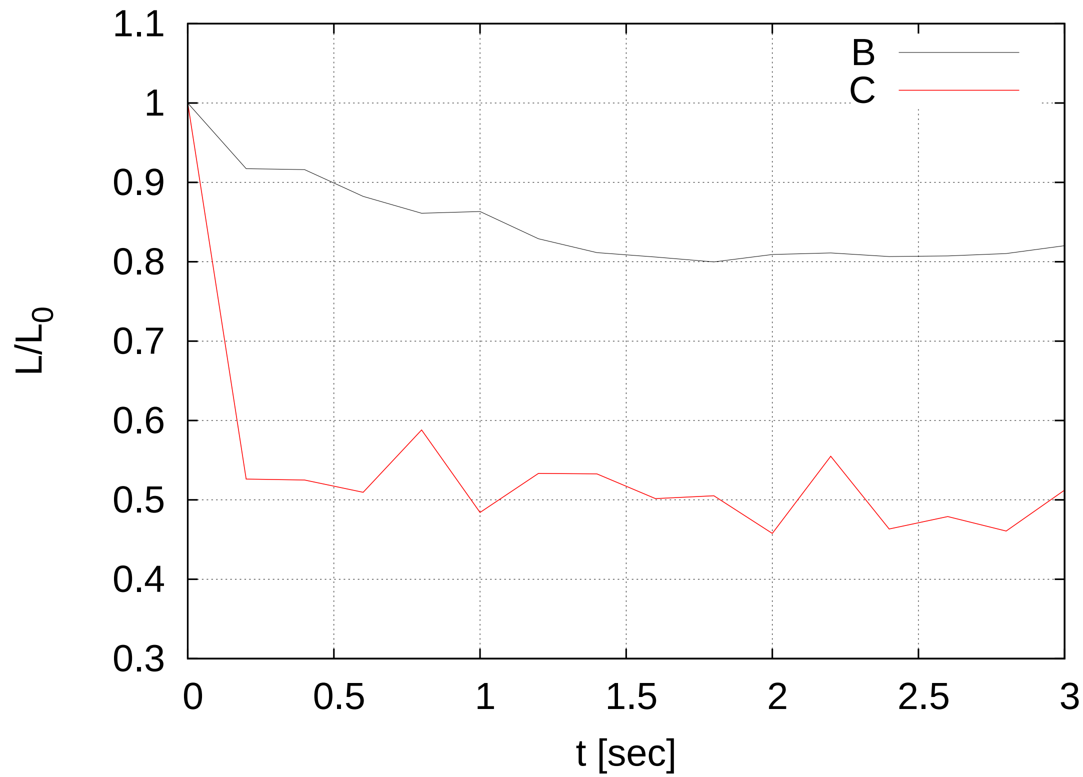


Short Time Scale

- Perfect alignment at t=0
- 3 seconds after:

$\Rightarrow$ B: $L(t=3) \simeq 80\%\ L_0$

$\Rightarrow$ C: $L(t=3) \simeq 50\%\ L_0$

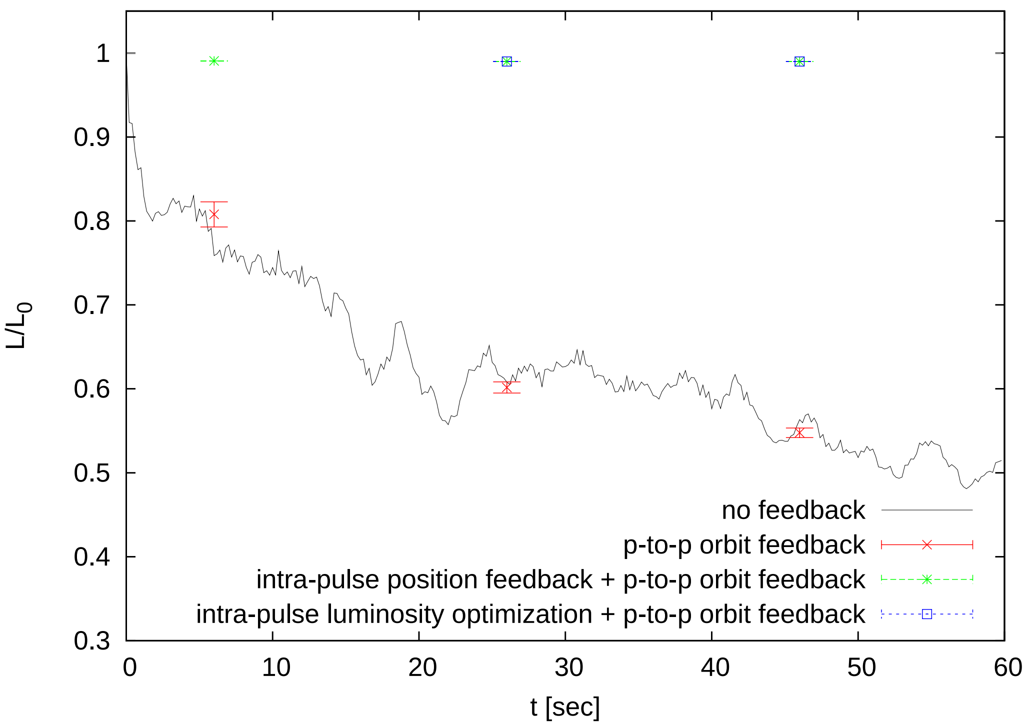


Feedbacks Schema

- pulse-to-pulse orbit feedback:
  - orbit correction based on BPM readings and dipole correctors
    - 14 correcting dipoles
    - 136 BPMs

- intra-pulse feedback:
  - Beam-Beam correction based on BPM after collision point
  - Luminosity optimization based on offset scan or direct maximization (bracketing method)

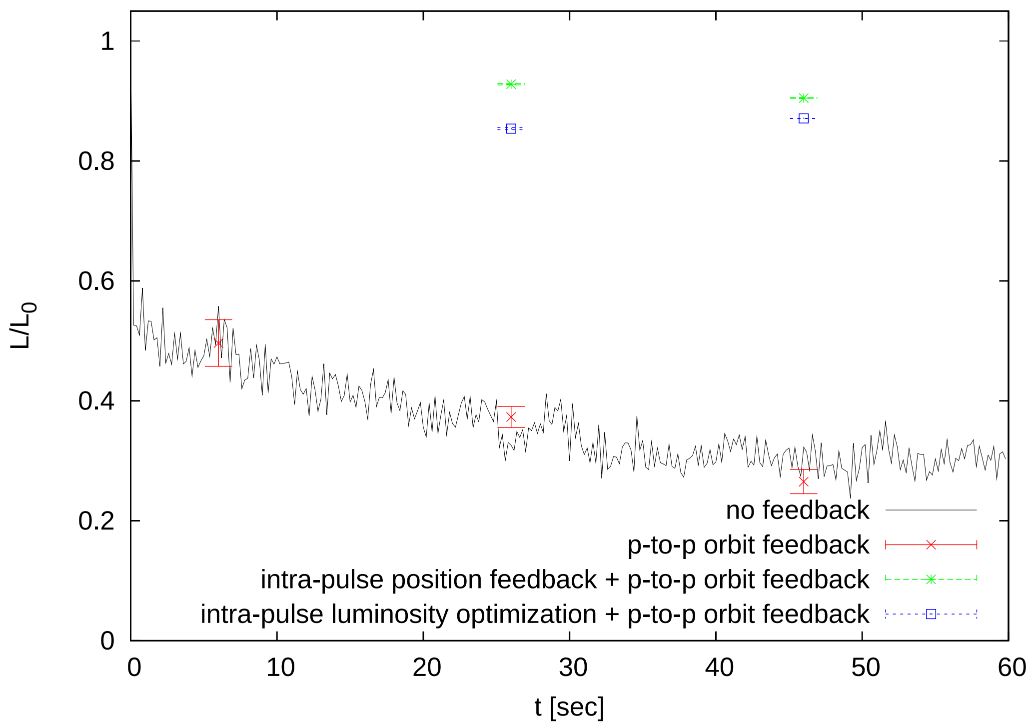
Intra-Pulse Optimization with Pulse-to-Pulse Orbit FB (B)



$\Rightarrow$ Intra-pulse optimization helps significantly

$\Rightarrow$ The efficiency of the pulse-to-pulse orbit feedback has to be studied

Intra-Pulse Optimization with Pulse-to-Pulse Orbit FB (C)



$\Rightarrow$ Intra-pulse feedback helps significantly

- Intra-pulse BB works fine
- Intra-pulse optimization has to be analyzed

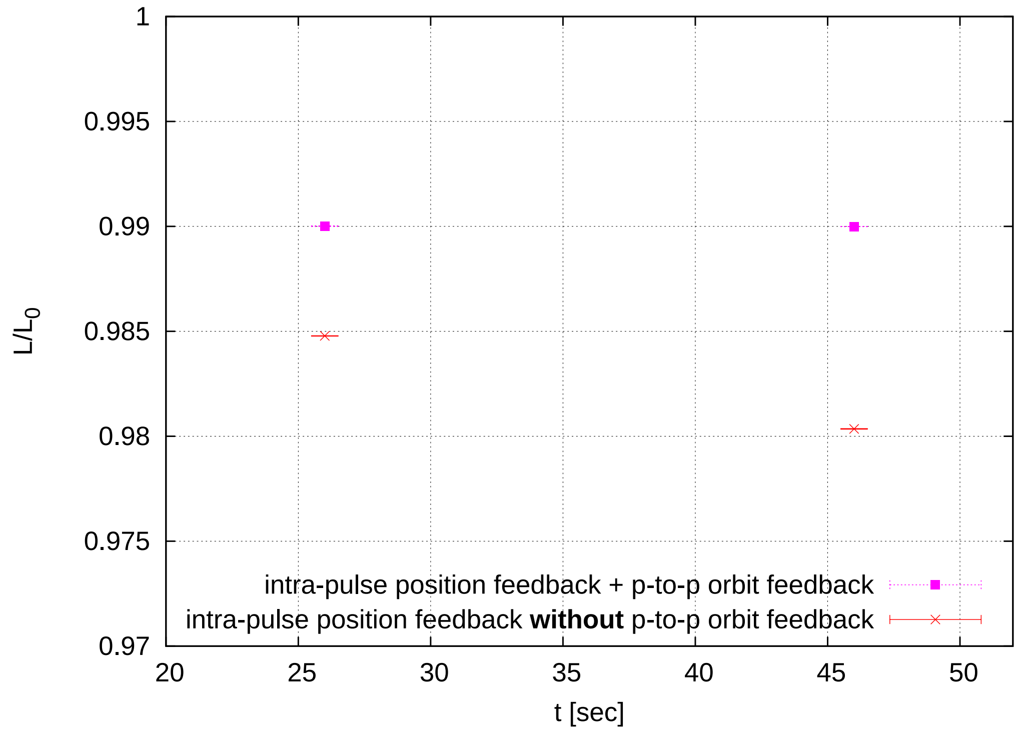
$\Rightarrow$ Like in the model B, p-to-p orbit feedback alone seems not to produce good results

Intra-Pulse Optimization without Pulse-to-Pulse FB (B)

Optimization with / without p-to-p orbit feedback.

- P-to-p orbit feedback recovers ≈1% of the luminosity

⇒ Pulse-to-pulse feedback helps

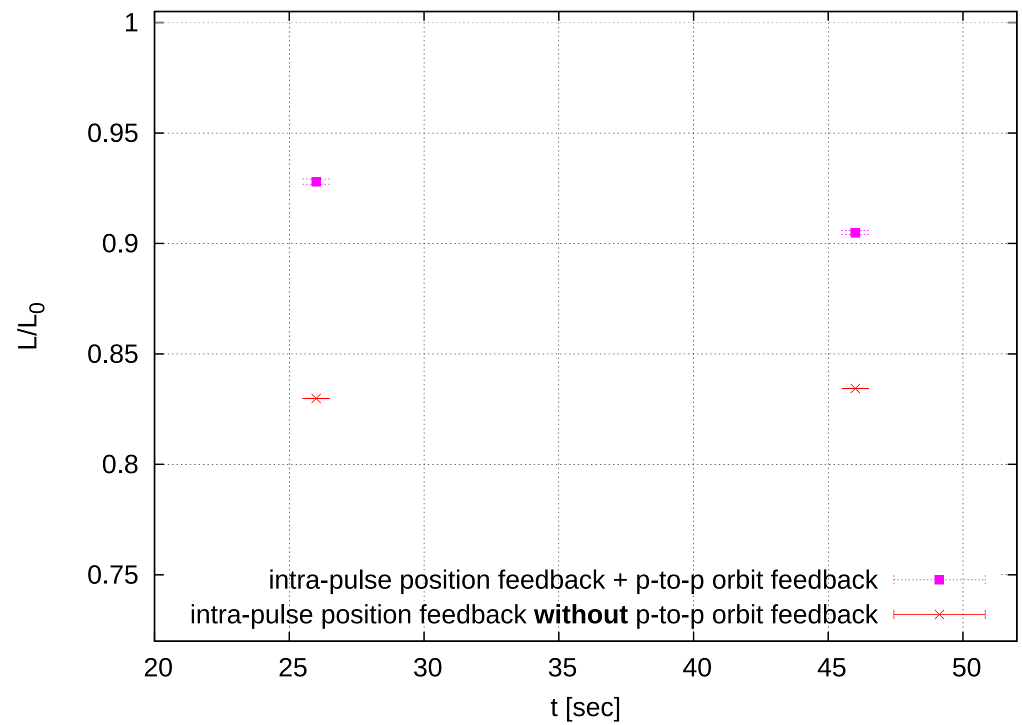


Intra-Pulse Optimization without Pulse-to-Pulse FB (C)

Optimization with / without p-to-p orbit feedback

- P-to-p orbit feedback helps to recover ≈5-8% of luminosity

⇒ Pulse-to-pulse feedback helps

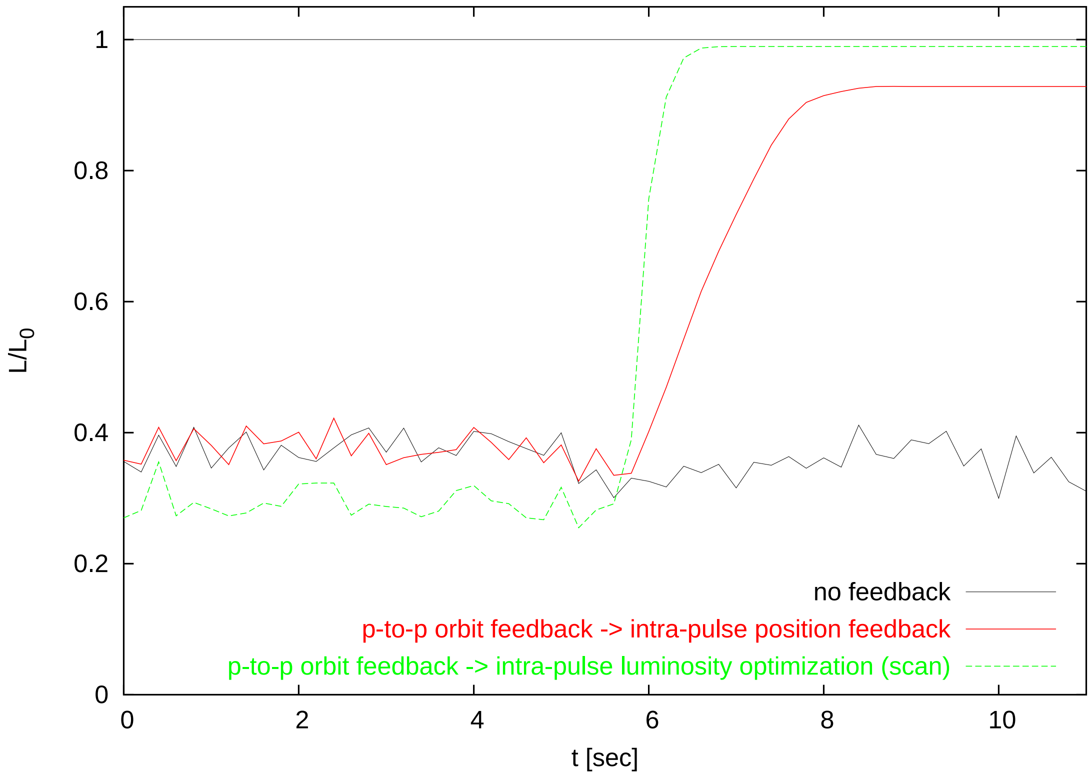


Comparison between P-to-P and IP feedbacks, for model C

- First 6 seconds, p-to-p orbit feedback alone

- Intrapulse feedback is switched on at the 6th second.

- Luminosity optimisation is best

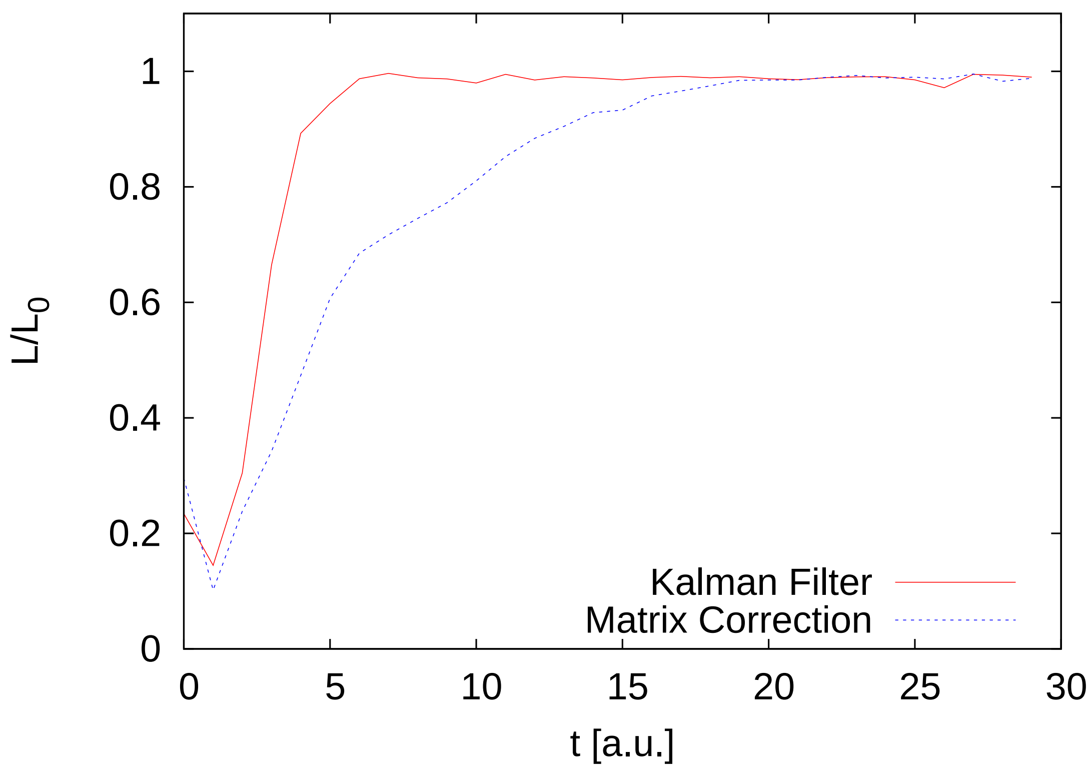


In progress: Feedback System Based on the Kalman Filter

- Use of the digital control theory formalism for feedback systems

- Kalman Filter:
  - estimates the state of the system from a vector of measurements
  - applies a gain matrix to determine the corrections for the predicted state vector
  - keeps into account the noise in the measurements and in the state vector
  - minimizes the rms of the state vector (e.g. position of the beam)

Kalman Filter vs. Matrix Optimization



In progress: Extended Kalman Filter + Neural Networks

- Limit of the KF: estimates the state of processes governed by a <u>linear</u> difference equation

  $\Rightarrow$ The response function for ILC is not linear

- Possible solution: Extended Kalman Filter + Neural Networks:
  - EKF:
    - like the KF, but linearizes, around the current state, any non-linear function that models the system
  - NN:
    - provides to EKF the non-linear response function of the system,
    - dynamically improves its model of the system itself, as the network learns about it during its functioning.

Emittance and Luminosity Tuning

- Use of main linac emittance tuning bumps predicts very good performance for CLIC
  - in CLIC wakefields dominate, in ILC dispersion
- New bumps with measurement point at the end of the linac or the IP give even better performance
- Luminosity tuning bumps optimise the value that is really relevant
- Emittance tuning allows to separate the two linacs
- Luminosity simulating laser wires can be considered
- General trade-off will be between using most relevant value against being able to identify position a the problem
- Need different procedures during commisioning

Laser Wire Based Bumps

- Consider using luminosity emulating bumps
  - fixed laser spot
  - matched to target beam size
  - no need to scan but just optimise luminosity
- Just maximise the number of scttered photons
- Beam needs to be aligned to laser spot by a scan, but does not need to be repeated for each measurement
- For each degree of freedom, number of converted photons measured at five settings
- The optimum is determined by a fit
- The procedure cycles through the degrees of freedom

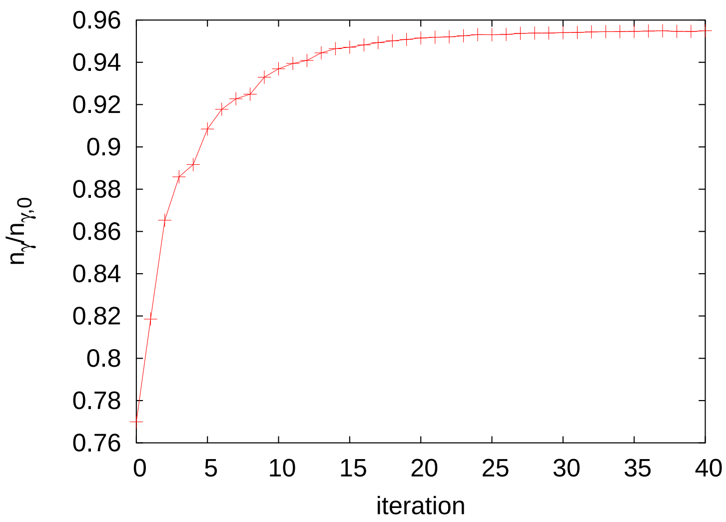
Results

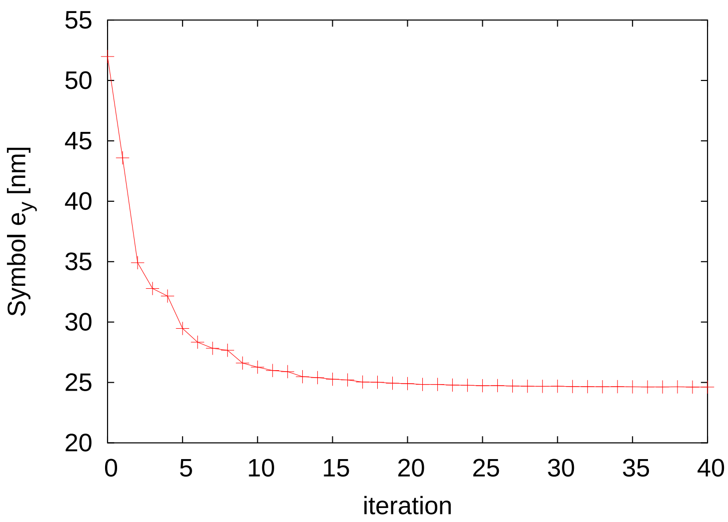
- Main linac (from TRC) is simulated using all misalignments and full beam-based alignment procedures

  $\Rightarrow$ Emittance grwoth is too large

- Use one dispersion bump before, one after linac

  $\Rightarrow$ four degrees of freedom





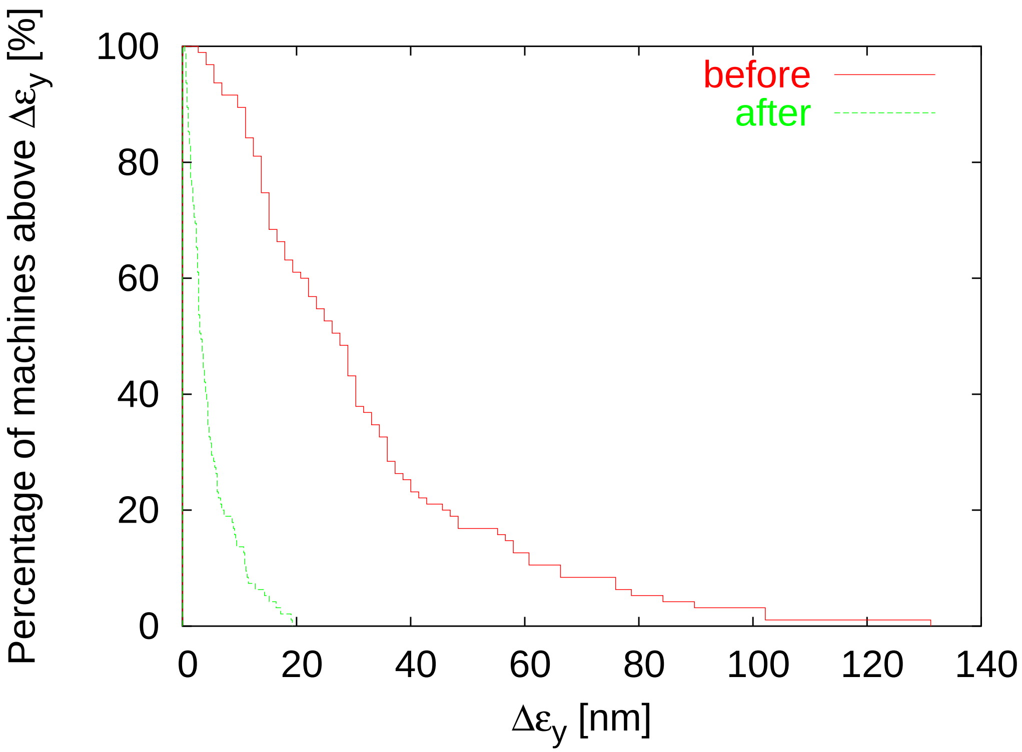
Probability Distribution

- For different random number generator seeds results vary

  $\Rightarrow$ are interested in probability distribution

- After application of bumps no machine has more than $\Delta\epsilon_y \geq 20\,\mathrm{nm}$

- But more realistic bumps should be tried



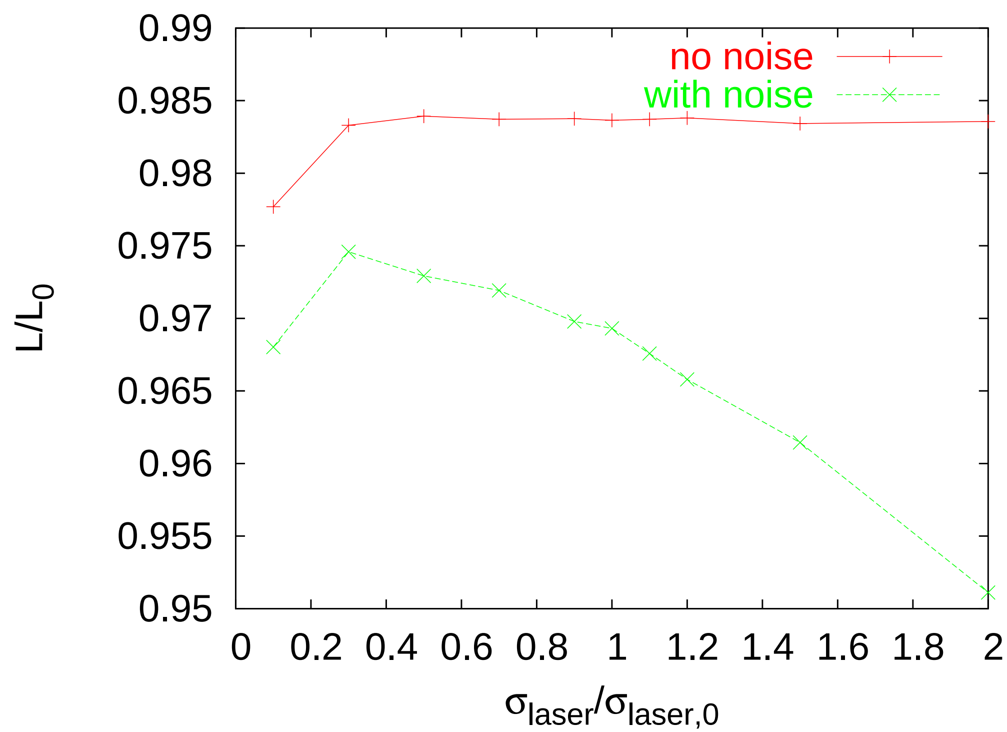
Further Results on Bumps

- Relative positions of laser and a feedback BPM needs to be determined

⇒ Simulations for CLIC showed that the position measurement needs to be updated only after optimisation of a few knobs

- Error in laser spot size might be a problem

  ⇒ still the optimum beam-laser luminosity corresponds to optimum conditions



Beam Parameter Tuning at IP

- Determination of beam parameters from IP measurements seems quite difficult if more than one parameter needs to be determined

  $\Rightarrow$ use tuning knobs which only affect one parameter at a time

- Many different signals exist
- Best is luminosity (e.g. low angle Bhabhas), but needs some time
- Good signal are incoherent pairs
- Potentially good are radiative Bhabhas (depends on geometry)
- Beamstrahlung is also available

Luminosity Tuning

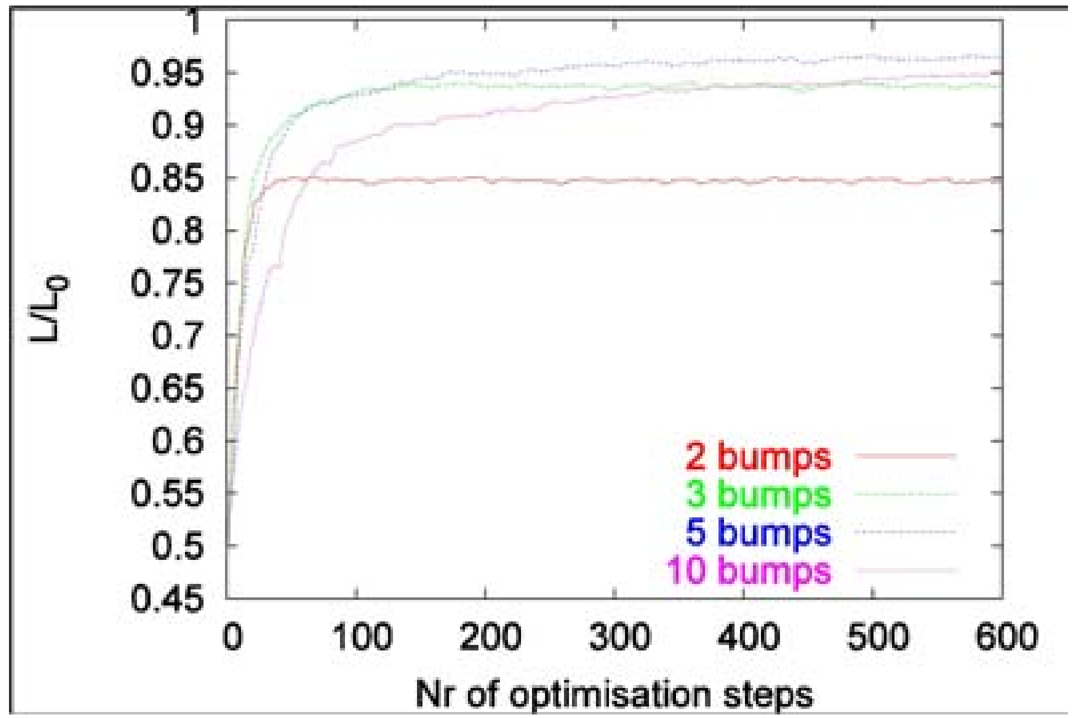
- Simulation for CLIC with wakefield bumps

  ⇒ will perform them for ILC

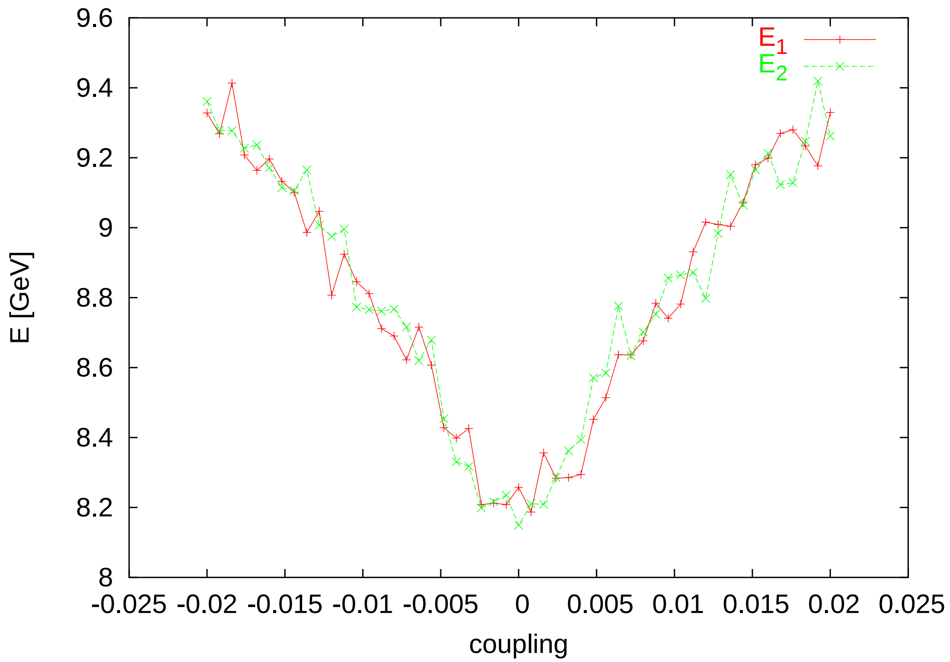
- Tuning yields excellent performance

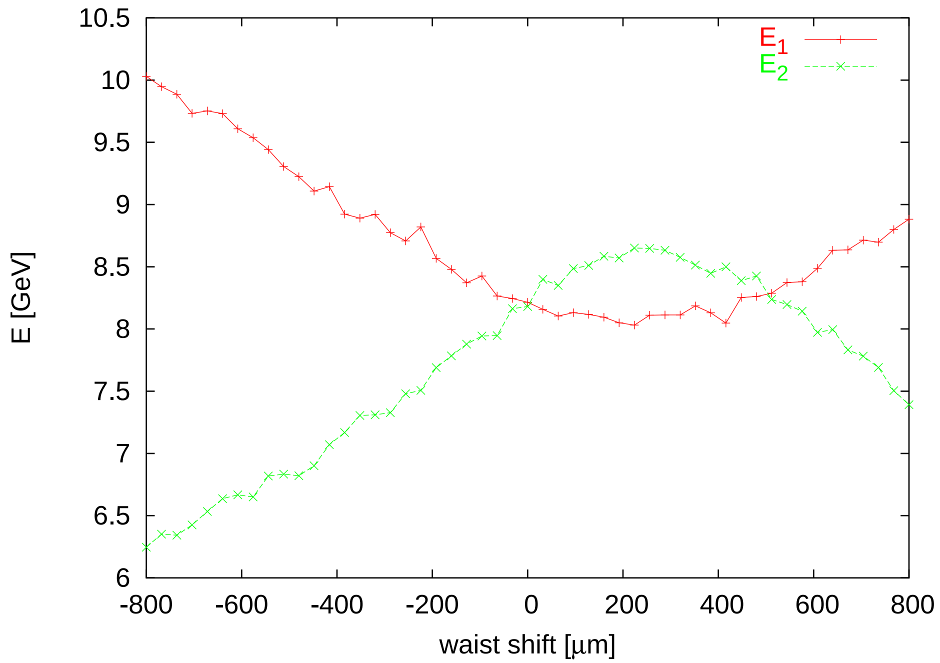
- Luminosity used

  ⇒ will need to use realistic signal



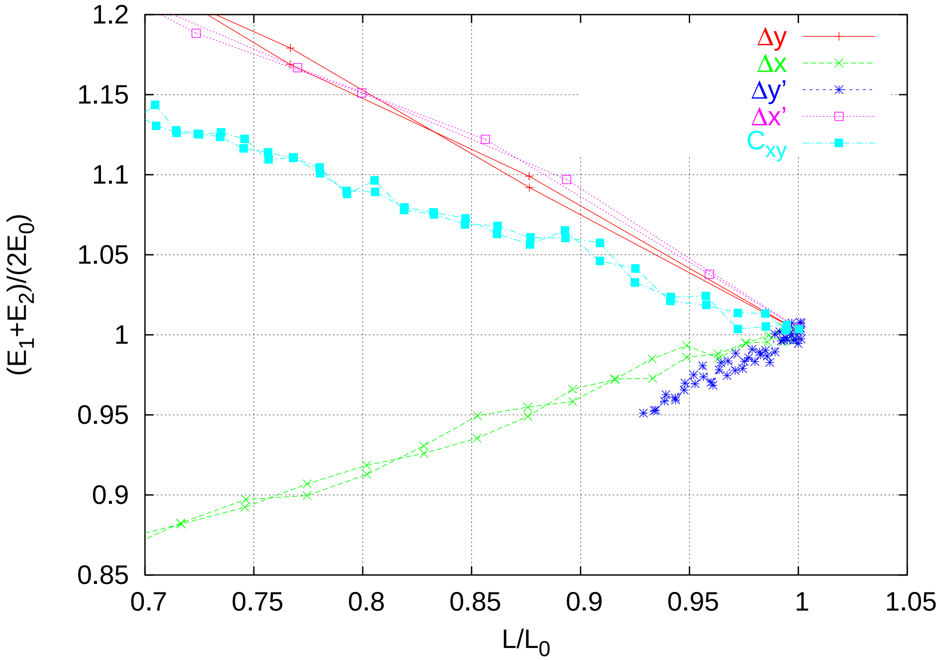
Use of Beamstrahlung

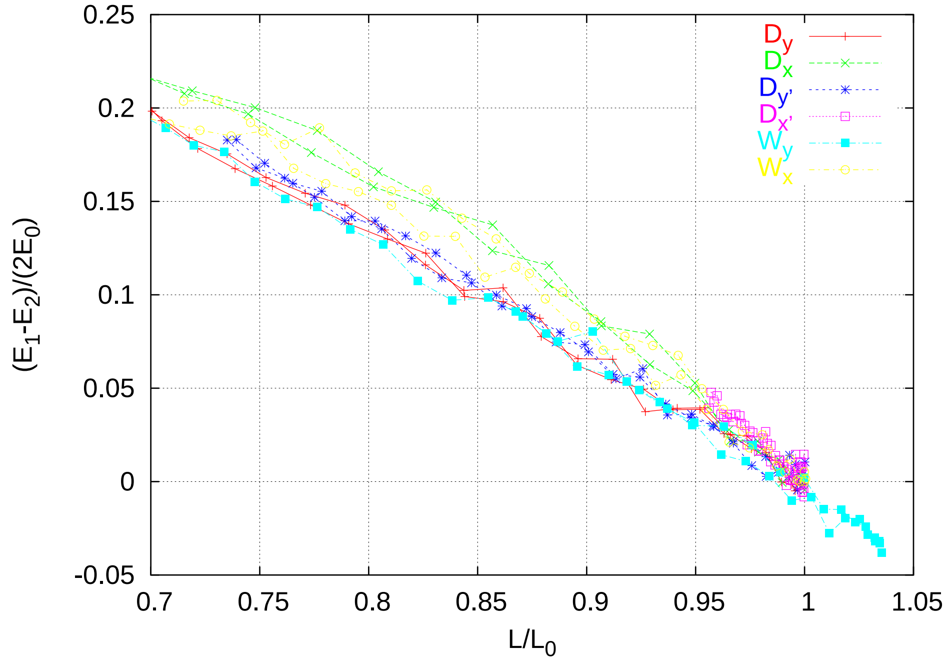




- Depending onknob maxmise/minimise sum/difference of beamstrahlung from both beams

Resolution

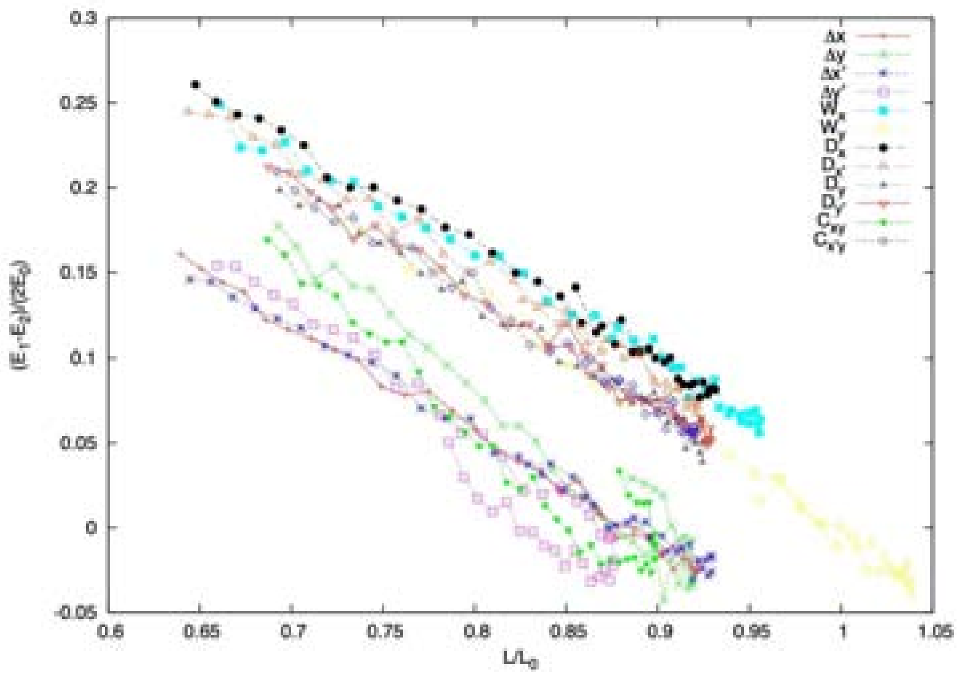




- Luminosity resolution is about as good as beamstrahlung energy resolution
  $\Rightarrow$ but beware of systematics

Parameter Dependence

- In most cases an error in one parameter does not affect the optimisation of another one
- Problems with ($\Delta x'$, W_x) (W_y, $\Delta x'$) (R_{23}, $\Delta x'$) (R_{23}, Dy') (R_{23})
- Needs to be completely studied
- Full optimisation is being tested right now



Plans

- Implementation of full lattice when available
- Implementation of fast tracking between bunch compressor and beam delivery system
  - particle tracking is available
- Improved feedback models
- Full study of IP parameter tuning procedure
- Realistic noise during tuning/correction
- Realistic multi-bunch studies

Conclusion

- Still important integrated studies need to be carried out
- Luminosity and emittance bumps seem to be very efficient
- Intra-pulse feedback is vital

  $\Rightarrow$ need to understand bunch-to-bunch variations
- Multi-bunch studies
- We are geared up to participate in these studies
- Main areas seem to be currently:
  - feedback simulations
  - beam tuning studies
  - aligment studies