Feedback Simulation Studies

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- Different levels of feedback
  - no feedback
  - intra-pulse position feedback
  - + pulse-to-pulse orbit feedback
  - intra-pulse luminosity optimisation
  - + pulse-to-pulse orbit feedback

Simulation Procedure

- All simulations were performed with PLACET (beam transport) and GUINEA-PIG (beam-beam effects)
- Only beam delivery systems are included
- 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 separated tracking/correction modules

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

Feedbacks Schema for ILC

- 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

Feedback Algorithms Used

- Orbit feedback:

  - Response matrix: $x = R \cdot u$
    ('u' knobs = strength of the dipoles, 'x' state = BPM readings)

  - Kalman gain matrix: $\hat{x} = Ax + Bu$, ...
    (control theory formalism, more details later)

- Beam-Beam feedback:

  - Response matrix

  - Scan method (changing only the last dipole)

  - Bracketing method (changing only the last dipole)

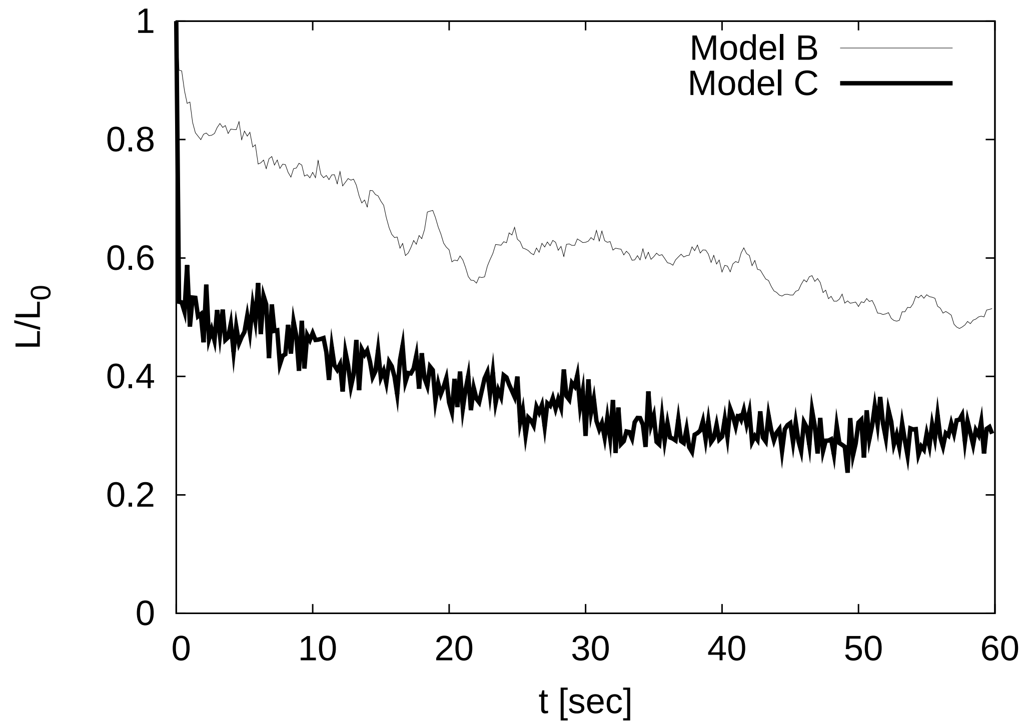
ILC Results

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^2s^{-1}
- After 60 seconds:

  ⇒ B: $L \simeq 50\%$ L_0

  ⇒ C: $L \simeq 30\%$ L_0

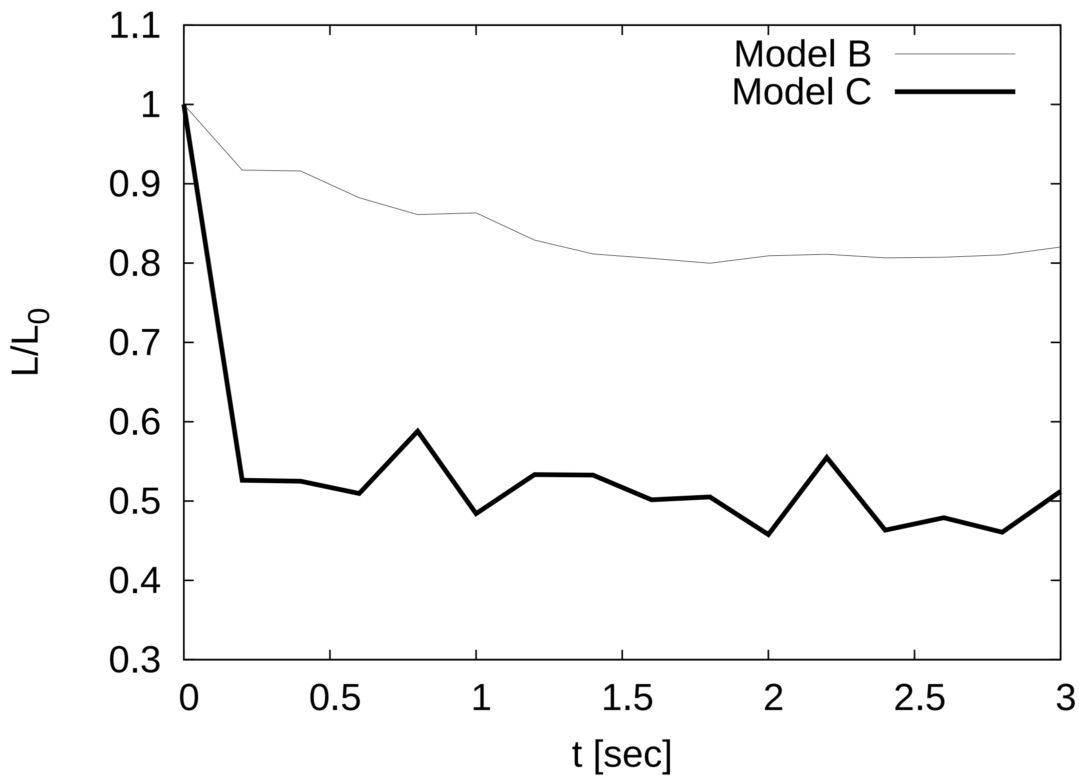


ILC Simulation with no Feedbacks

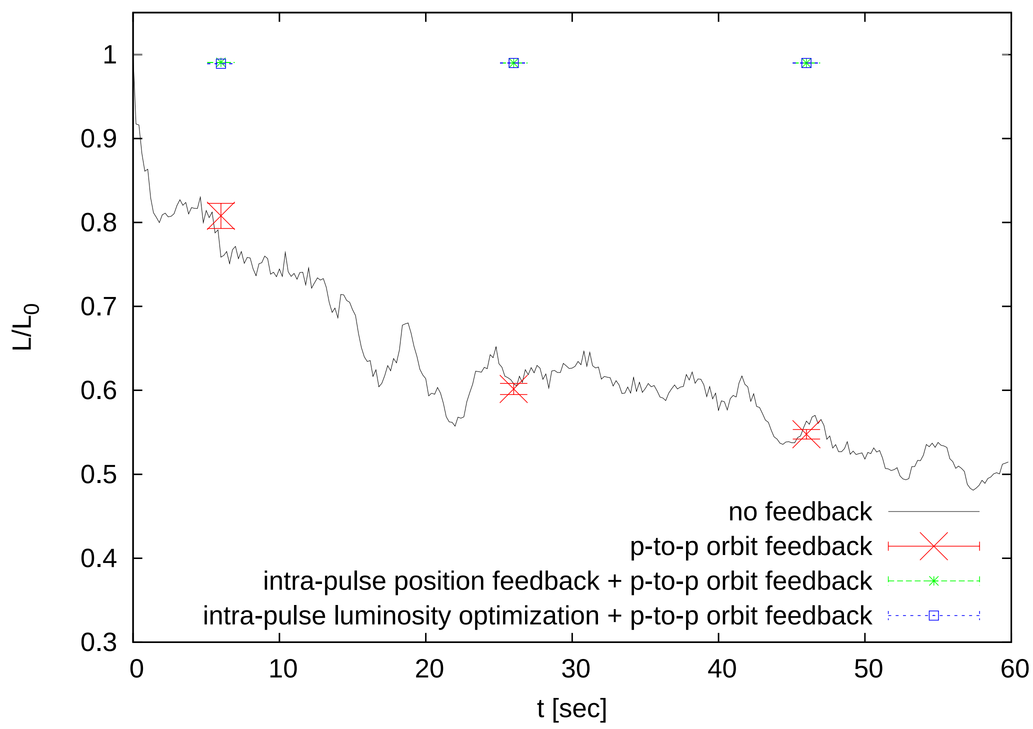
- Perfect alignment at t=0
- 3 seconds after:

  $\Rightarrow$ B: L $\simeq$ 80% L_0

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



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



$\Rightarrow$ Orbit Feedback:
Response Matrix

$\Rightarrow$ Intra-pulse optimization
helps significantly

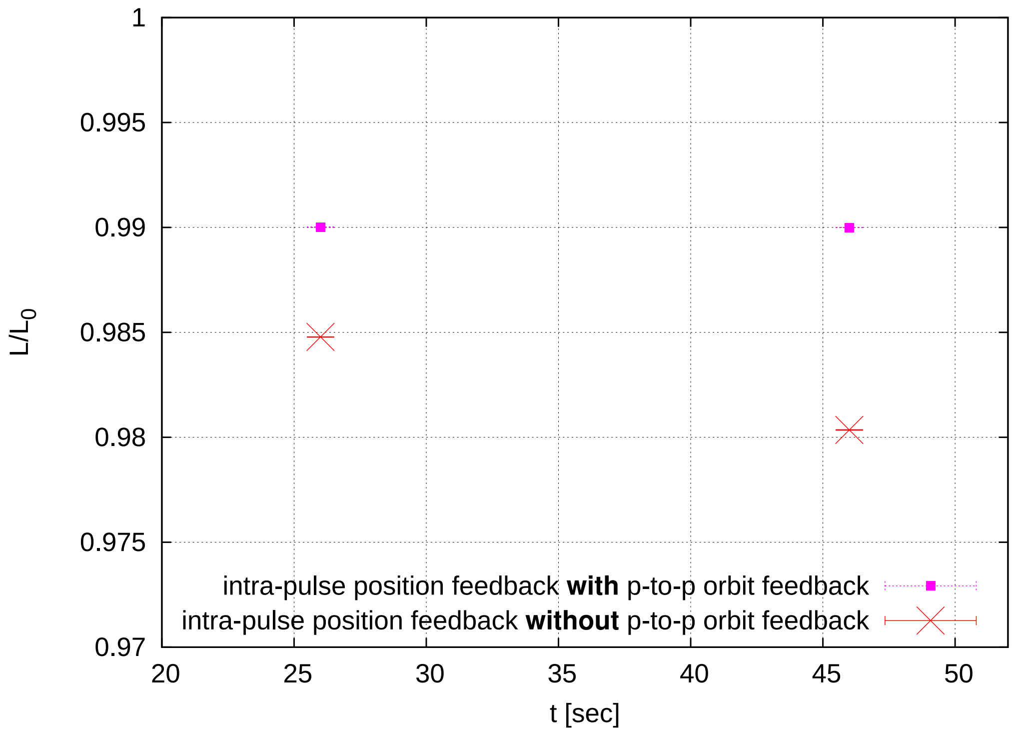
$\Rightarrow$ The efficiency of the pulse-to-pulse
orbit feedback has to be studied

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

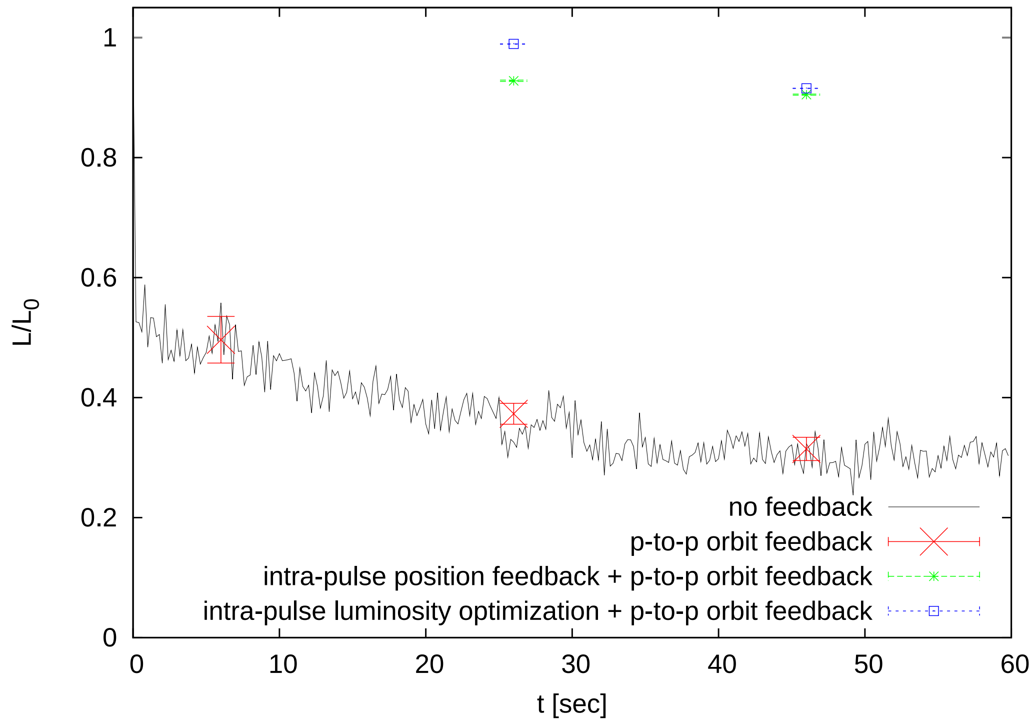
Optimization with / without P-to-P orbit feedback.

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

⇒ Pulse-to-pulse feedback helps



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



⇒ Intra-pulse feedback helps significantly

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

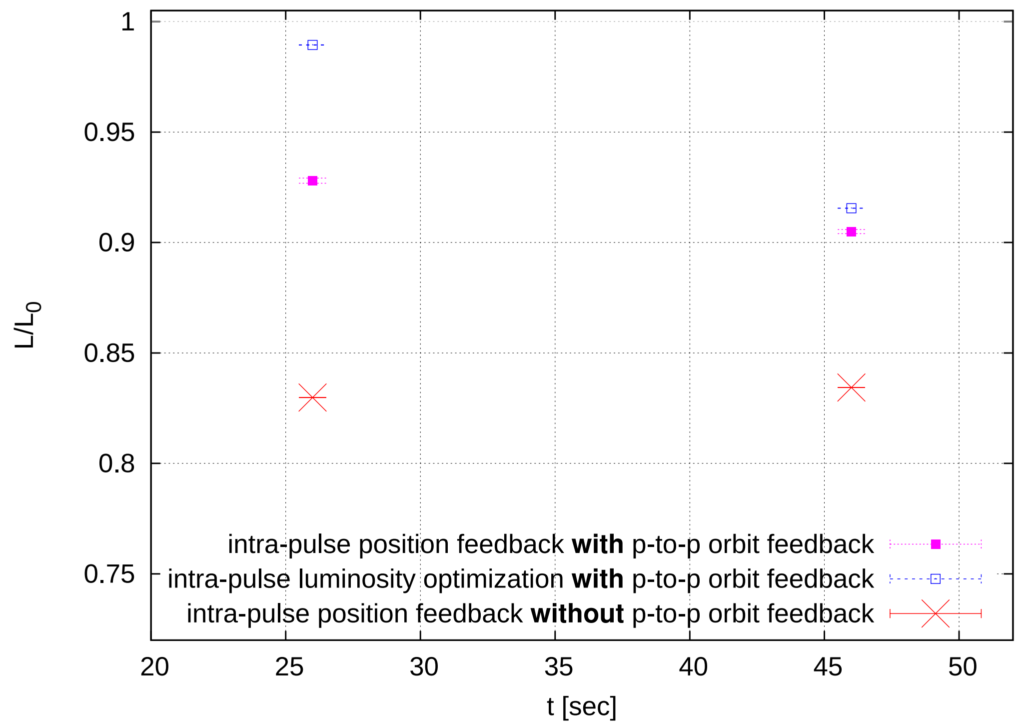
⇒ Like in the model B, P-to-P orbit feedback alone seems not to produce good results

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

Optimization with / without P-to-P orbit feedback

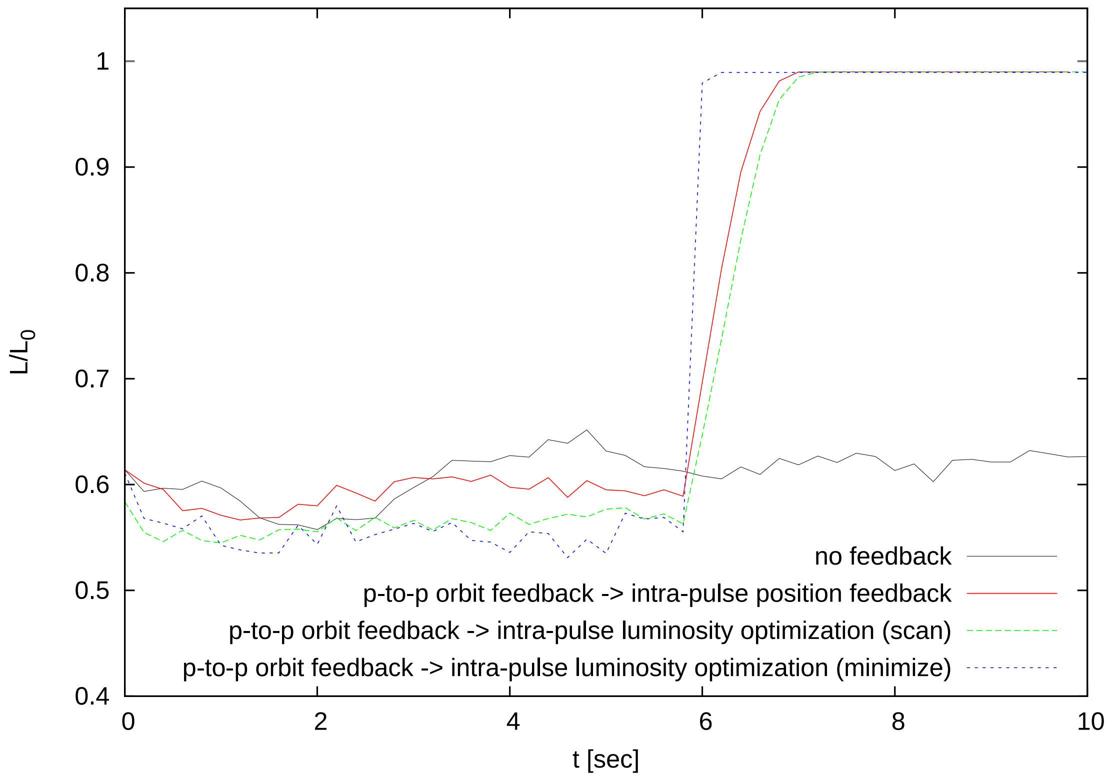
- P-to-P orbit feedback helps to recover ≈5-8% of luminosity
- Notice that luminosity optimization overcomes the Beam-Beam FB

⇒ Pulse-to-pulse feedback helps



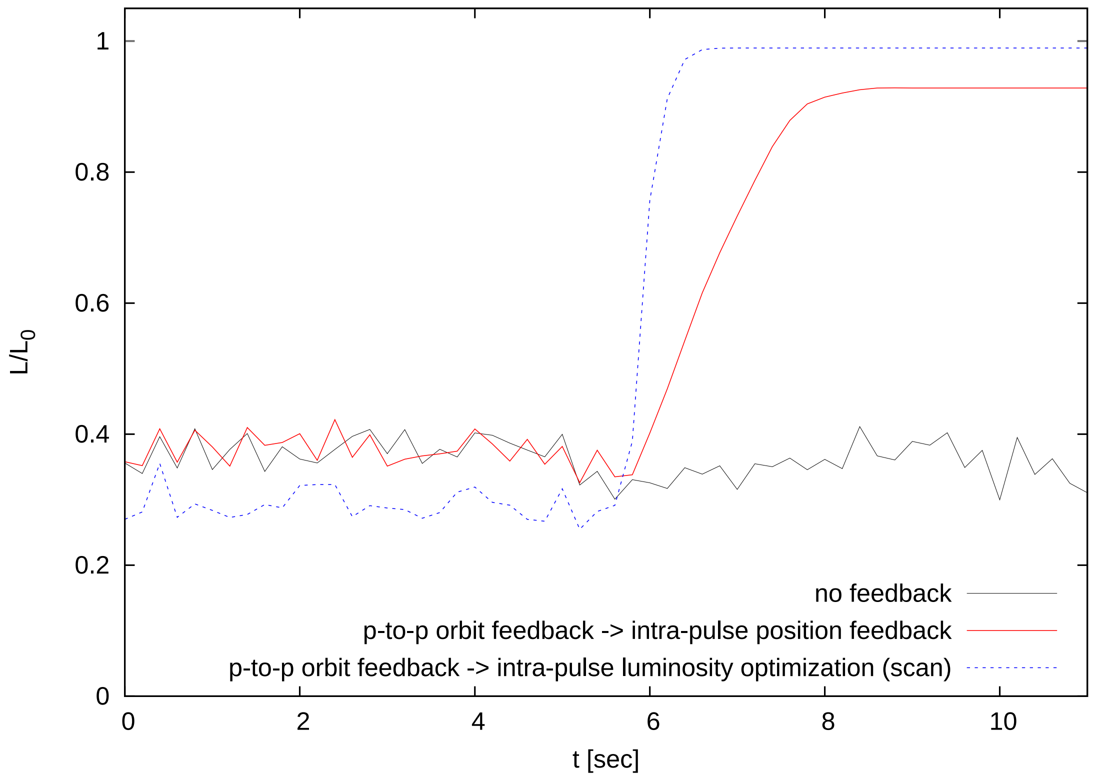
Comparison between P-to-P and IP feedbacks, for model B

- First 6 seconds, P-to-P orbit feedback alone
- Intrapulse feedback is switched on at the 6th second.



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.

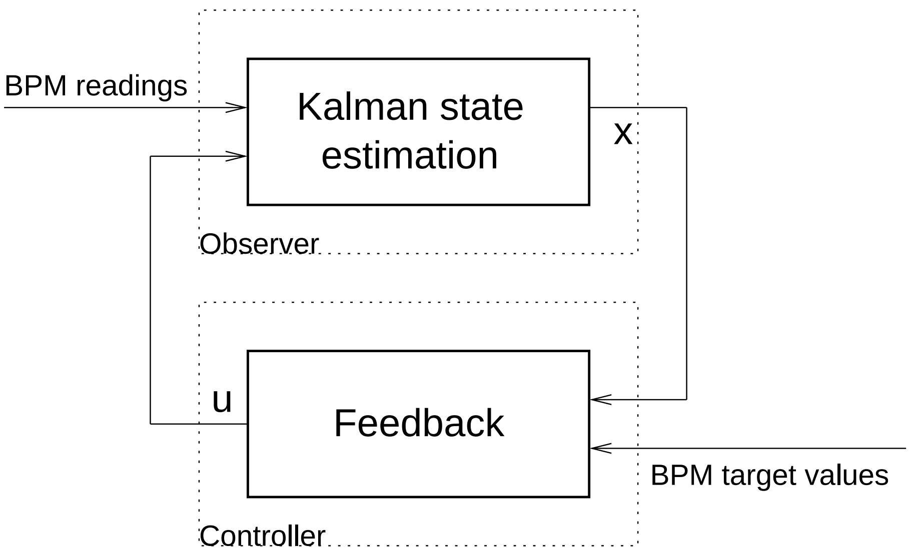


Improvement: Feedback System Based on Kalman Filter

- Use of the digital control theory formalism

- 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)

Feedback based on Kalman Filter

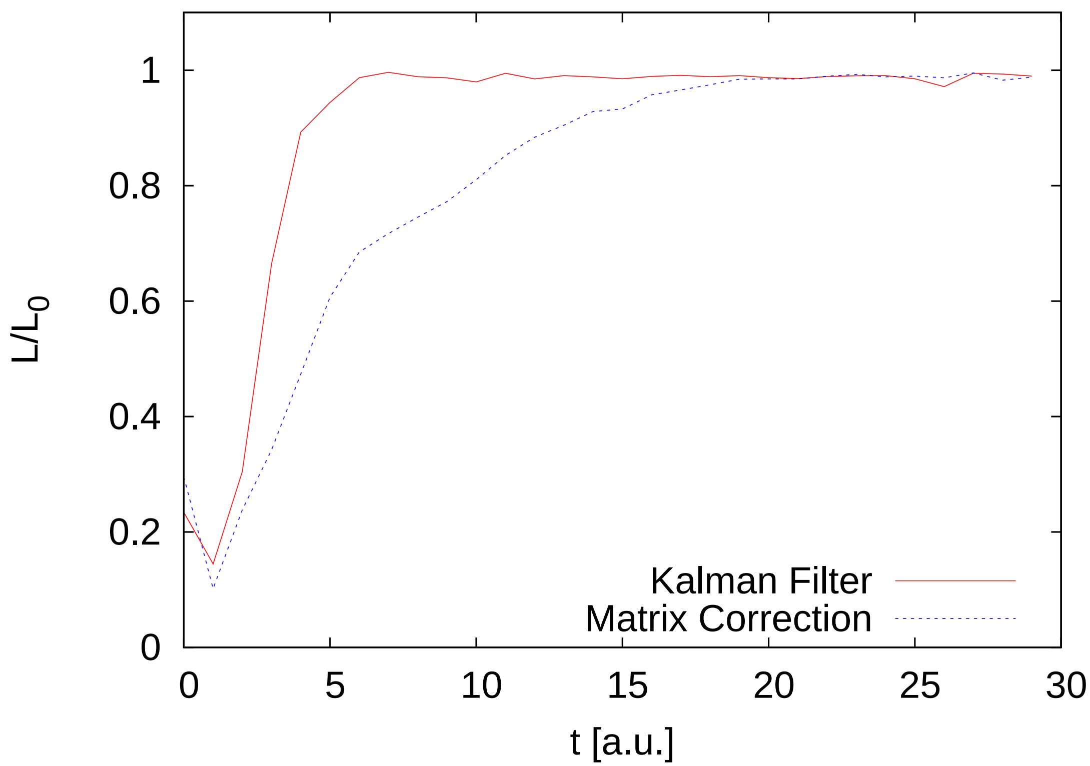


- $\overline{x} = Ax + Bu$ *a priori* state estimation
- $y = Cx$ measurement
- $K = \dfrac{C}{(C\,C^T + R)}$ Kalman gain
- $\hat{x} = \overline{x} + K\,(y - C\overline{x})$ state estimation

- $u = -K\,\hat{x}$ Feedback

- $\vec{x}$ state vector: BPM readings, ...
- $\vec{u}$ knobs: dipoles' strength, ...

Kalman Filter vs. Matrix Optimization for CLIC



Work in Progress: Extended Kalman Filter + Neural Networks

- Limits of the KF:
  - assumes that the state of the process is governed by a <u>linear</u> difference equation
  - assumes that the errors affecting the state and the measurements are Gaussian

$\Rightarrow$ the response function and the errors are not linear!

- Possible solution: Extended Kalman Filter + Neural Networks:
  - EKF:
    - works like the KF, but with a non-linear function as system response
  - NN:
    - provides the non-linear system response function to the EKF,
    - as neural networks can be trained on-line, their response improves dynamically.