Some Comments on Feedback and Feedforward at the IP

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Useful and inspiring discussions with Christophe Collette, Juergen Pfingstner and Andrea Jeremie

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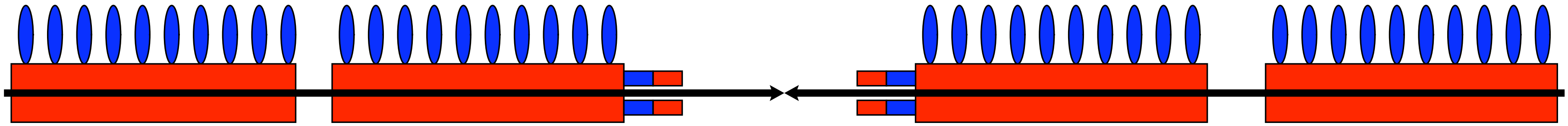
System Design

- The IP feedback/feedforward system controls the beam-beam offset
- Available beam signals are for each beam pulse
  - the beam-beam deflection from the post-collision BPMs
  - the incoming beam jitter from the pre-collision BPMs
  - the incoming beam offset from the pre-collision BPMs
  - other beam-beam signals (energy loss, coherent and incoherent pairs, ...)
- Other available signals are
  - the mechanical motion of the ground from ground motion sensors
  - the mechanical motion of the quadrupole support from ground motion sensors
  - the mechanical motion of the final quadrupoles from the ground motion sensors

Feedback Design

- Currently three feedback systems are foreseen
  - a mechanical feedback for the quadrupoles (ground motion sensors on quadrupoles+actuators)
  - an intra-pulse beam-based feedback (BPMs+kickers)
  - a pulse-to-pulse beam-based feedback system (BPMs+kickers)
- Note
  - the mechanical feedback could be replaced with a feedforward
- Suggested addition is a feedforward system
  - based on ground motion sensors
  - using the kickers

Proposed Layout



- Sensors are used for mechanical feedback
- Feedforward kicker does not need to be identical with intra-pulse feedback kicker
- Expected beam-beam offset due to quadrupole slice offsets δ_i and kicker strength k can be calculated via

$$\Delta y = a k_{ff} + \sum_i b_i \delta_i$$

- Choose k_{ff} such that $\Delta y = 0$ is expected

  $\Rightarrow$ final beam motion is determined by sensor noise

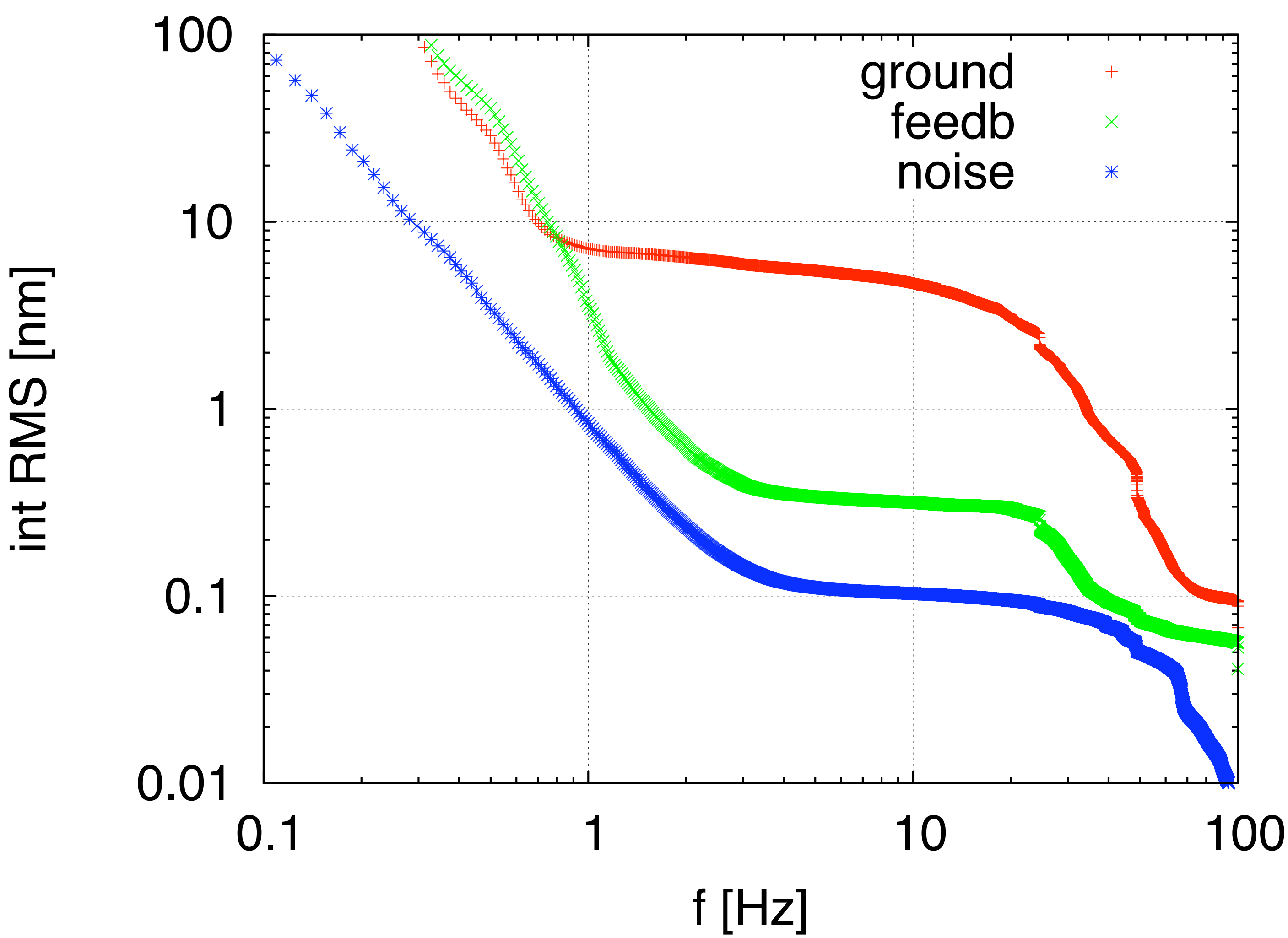
  - and imperfections in system knowledge

Simplyfied Model

- Four independent point-like quadrupoles
  - correlations will help
  - assume that measured stability is stability of whole quadrupole
- Quadrupole stabilisation feedback and beam feedforward modelled by using sensor noise
- Beam-based feedback adds kicker strength k_b
- PID controller used:

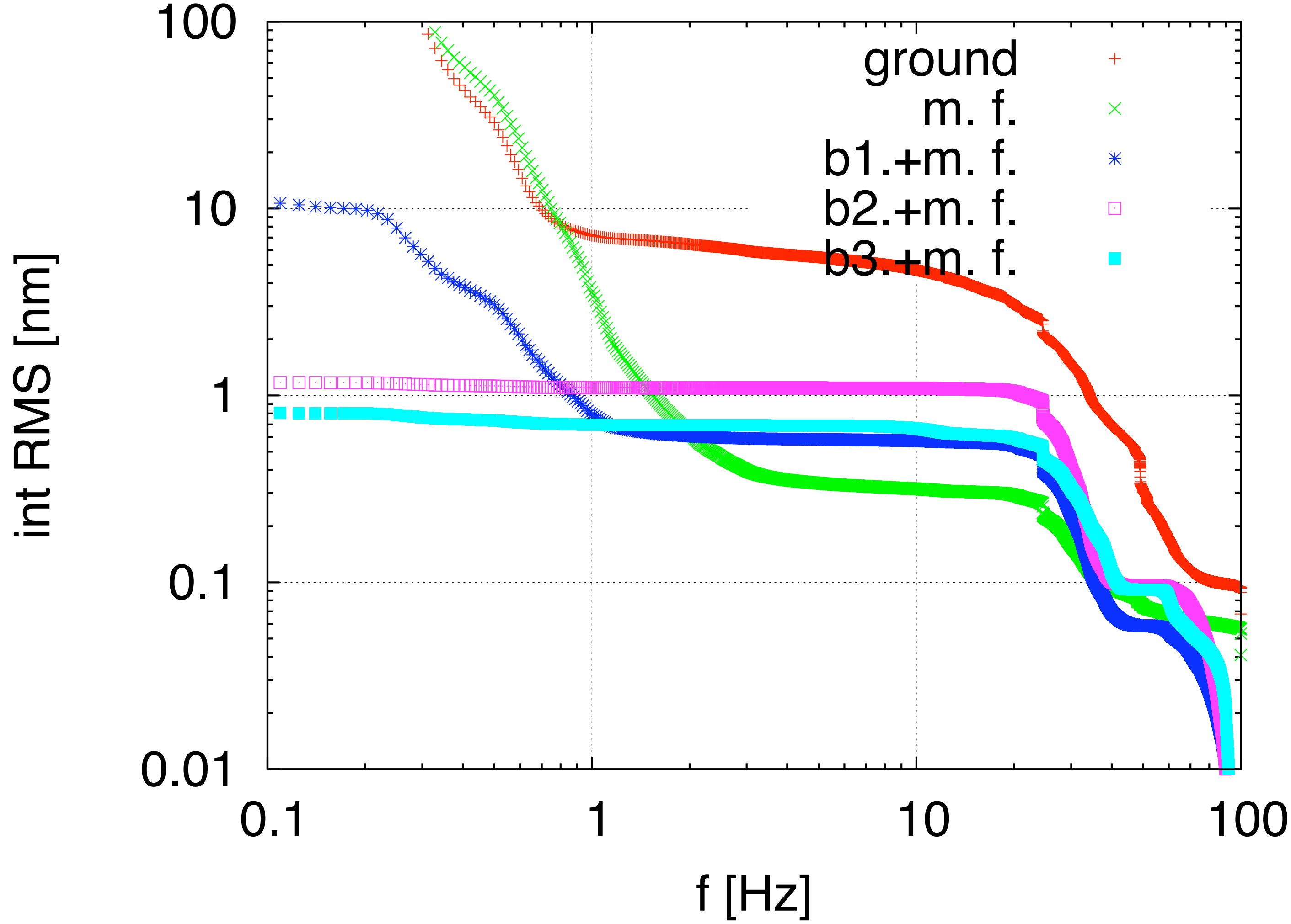
$$\begin{aligned} k_b(n) &= g_i k_b(n-1) \\ &+g_p \frac{\Delta y(n-1)}{a} \\ &+g_d \left(\frac{\Delta_y(n-1)}{a} - \frac{\Delta y(n-2)}{a} + k_b(n-1) - k_b(n-2) \right) \end{aligned}$$

Performance of Mechanical Feedback



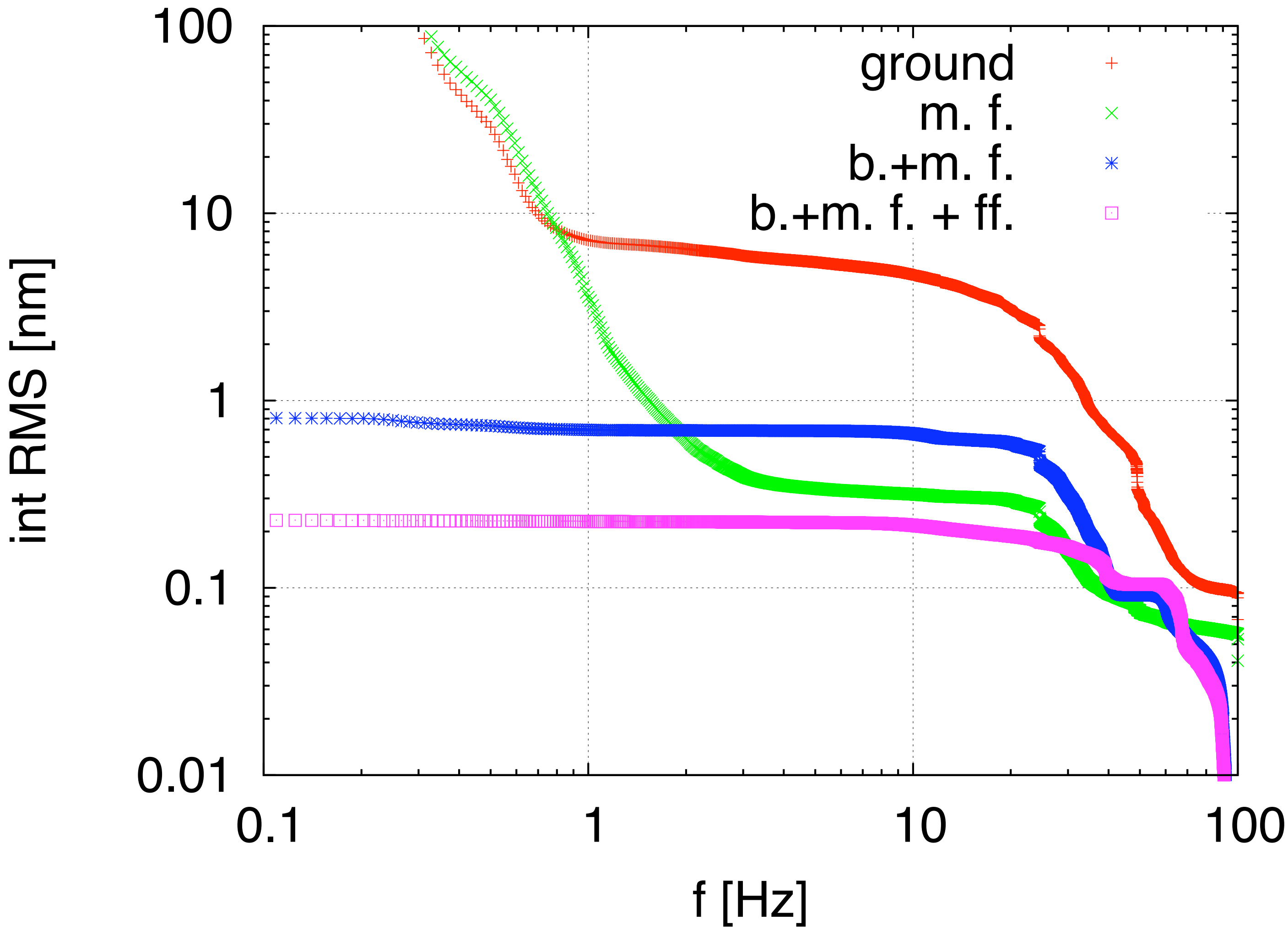
Data from B. Bolzon et al., noise assumed to be real-time measurement noise (A. Jeremie)

Integration with Beam-Based Feedback



Three PID controllers shown

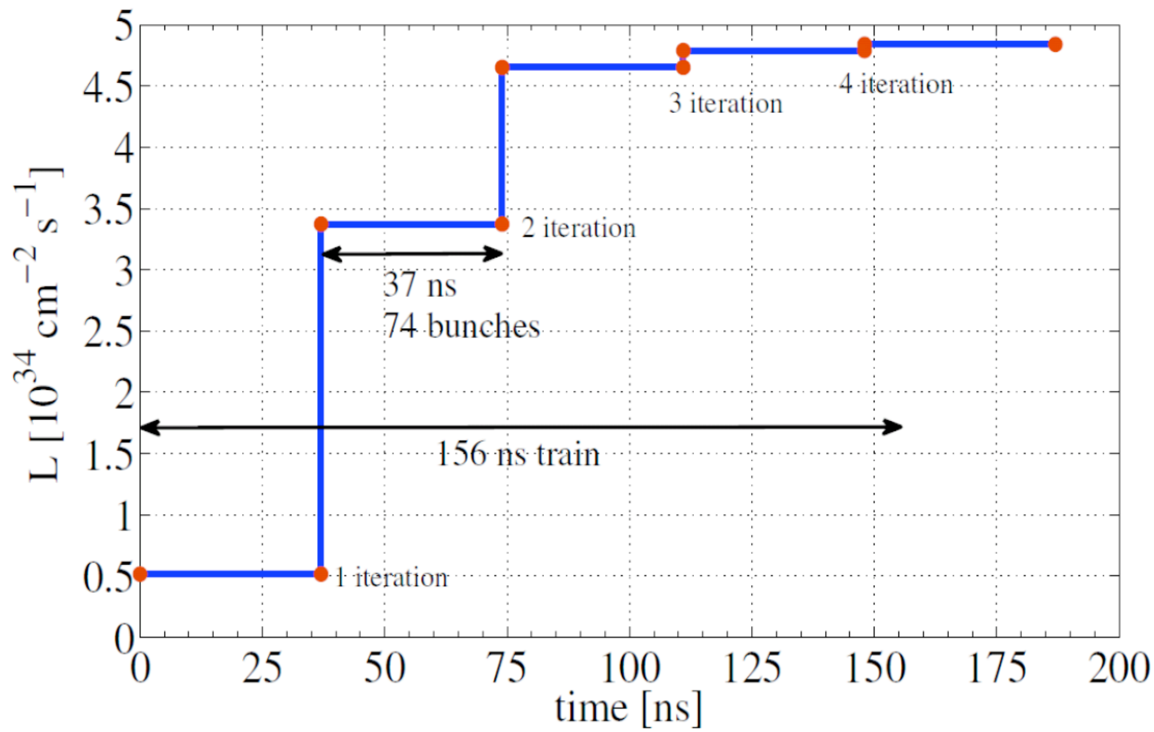
Addition of Feedforward



Best PID controller shown, need to do more detailed analysis

Impact of Intra-Pulse Feedback

- The intra-pulse feedback yields two advantages
  - the luminosity loss for a given beam-beam offset at the beginning of the pulse is reduced by a factor of about 4 (corresponds to tolerance increase by factor 2)
  - the feedback will determine the optimum beam-beam offset more precisely



Thanks to Javier

Conclusion

- We have a proposal for a conceptual feedback/feedforward configuration

  ⇒ need to design and model realistic sub-systems
- Need to address a few points to have necessary input for modelling
  - choose a ground motion spectrum with reasonable assumptions (source)
  - model the mechanical layout (transfer function)
  - design and model the stabilisation system (transfer function)
  - investigate and model sensor noise (source)
- Then put everything into a single simulation
  - optimise controller

  ⇒ preliminary performance prediction

  ⇒ first iteration on design
- Make full simulation
  - e.g. System knowledge, non-linear beam-beam forces, sextupoles, BPMs

  ⇒ predict luminosity performance

  ⇒ iterate