Luminosity Stability and Stabilisation Hardware

D. Schulte for the CLIC team

Special thanks to J. Pfingstner and J. Snuverink

Strategy

- Show that luminosity is stable with the baseline solution
  - Developing a model of the imperfections
    - Ground motion, element jitter, mechanical stabilisation, …
  - Develop mitigation methods
    - Feedback, system design, …
  - Integrate into code and perform fully integrated simulations with PLACET and GUINEA-PIG
  - This proves that a given solution is valid
- Understand the luminosity performance
  - Find simplified models to understand the effects
  - Ensure that full simulation results are understood
  - Point toward improvements for performance or cost

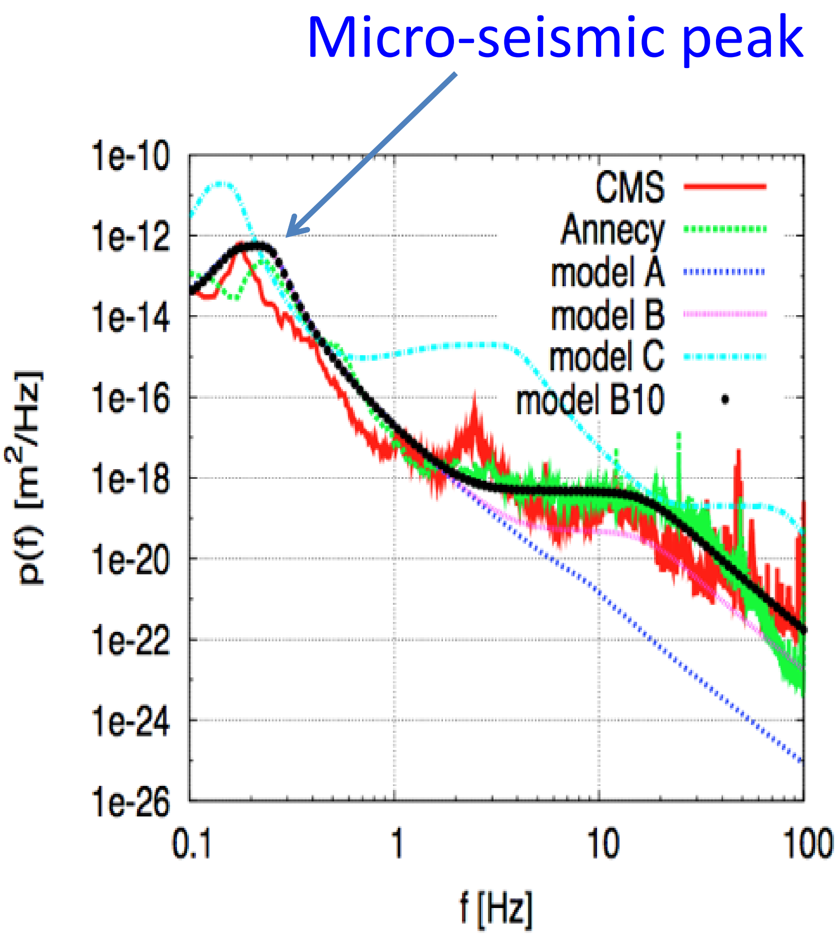
Model

Ground Motion

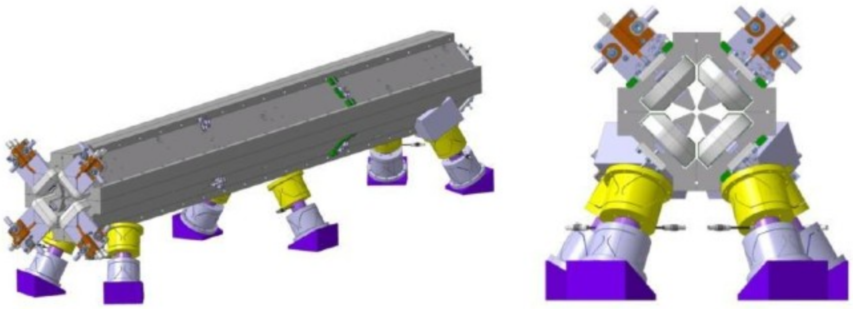
- Important source of luminosity loss
  - Level of ground motion at final site is not known
  - Technical noise transmitted via the ground is not known

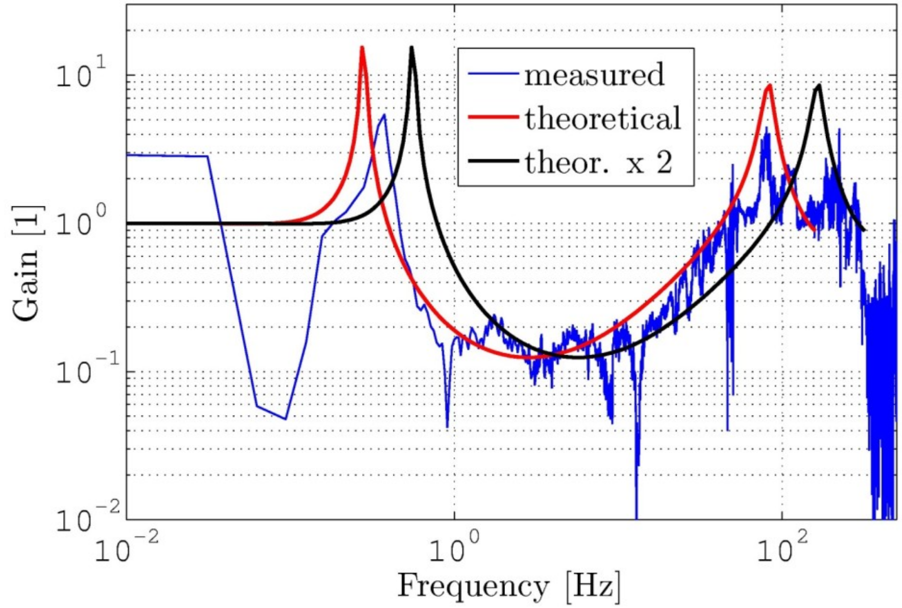
- Use two models
  - Short time scales (< 100 s)
    - A. Seryi models: P(ω,k)
  - Long time scales
    - ATL law: $\langle(\Delta y)^2\rangle = A*t*L$

- Model A corresponds to LEP tunnel with no technical noise
- Model B10 is made to fit measurements at Annecy and the CMS hall
  - Ad hoc correlation based on model B
- For ATL model we use A= 0.5 $nm^2/(ms)$



Main Linac Quadrupole Stabilisation





- System reduces quad movements above 1 Hz (int. RMS 1 nm)
- Reduces emittance growth and beam jitter for high frequencies
- Implemented transfer function into beam dynamics code
  - For the moment all elements are moved with transfer function
  - But magnets completely dominate the luminosity loss

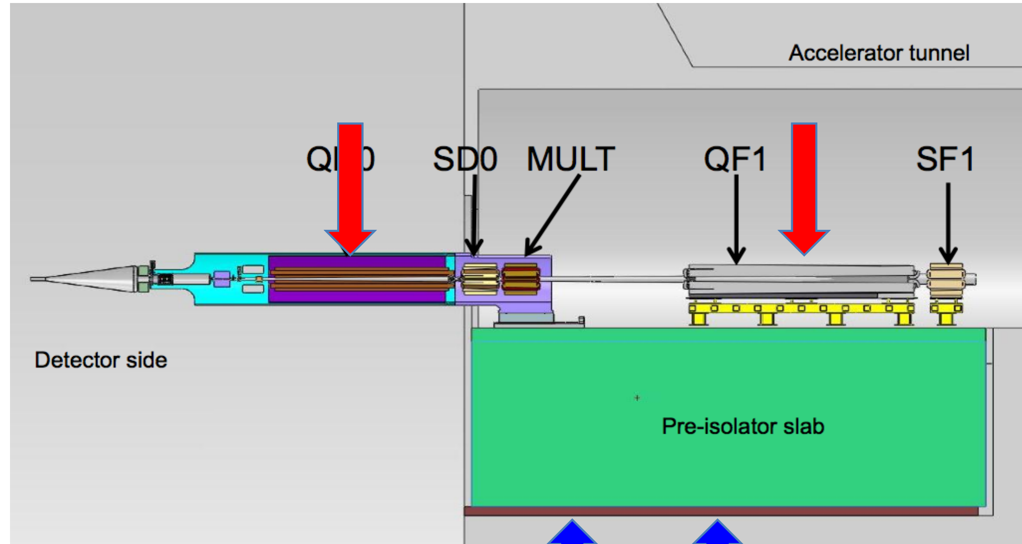
Taken from CERN stabilisation group

Pre-Isolator Transfer Function

Transfer function is complex

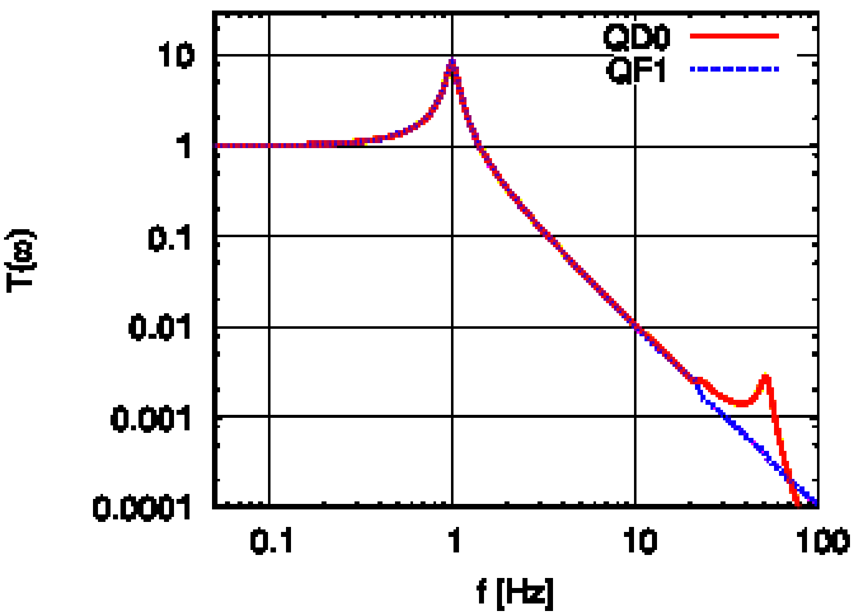
Modified ground motion generator to correctly model this

In reality will have also active stabilisation

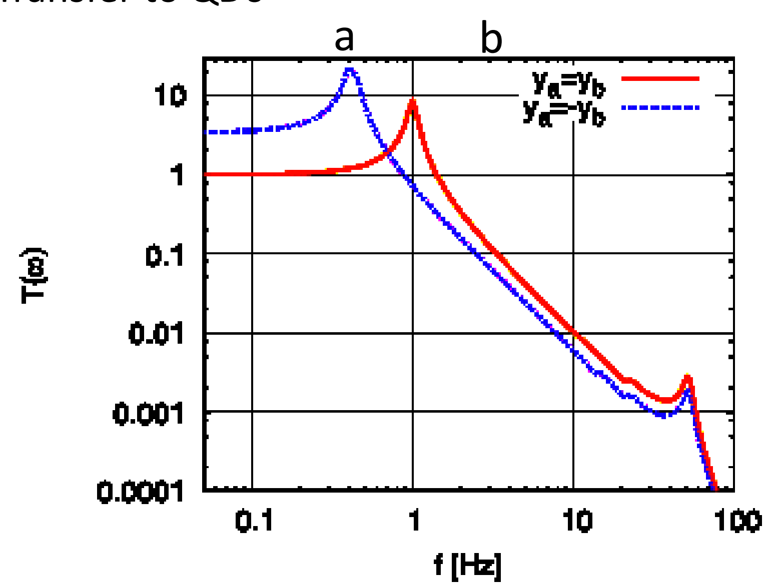


A. Gaddi et al.

Transfer for coherent motion



Transfer to QD0



Hardware Noise

Active stabilisation will induce noise

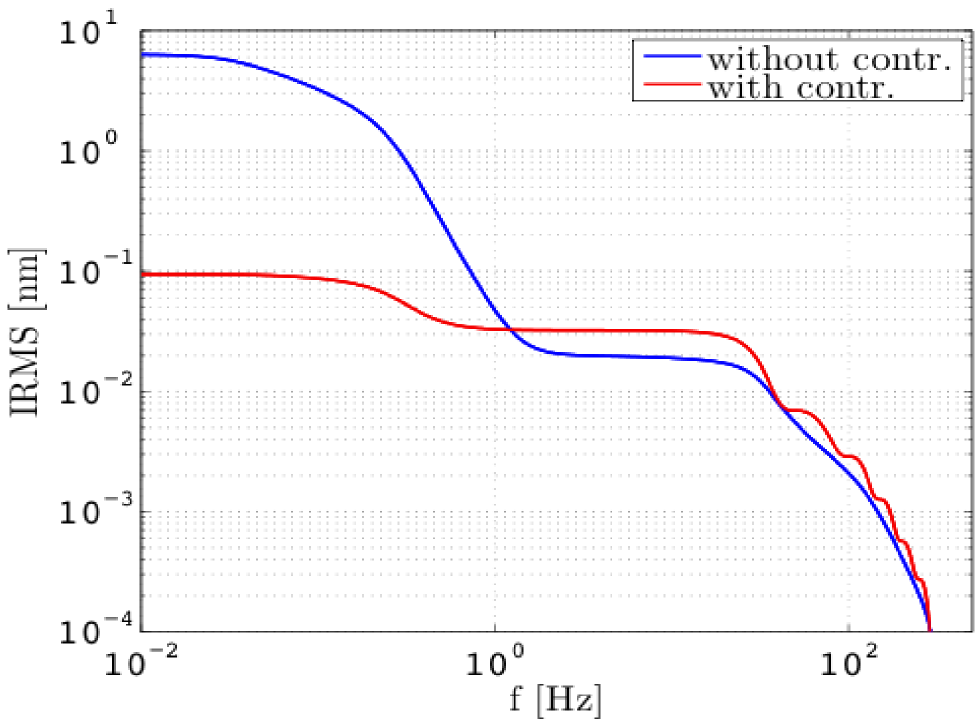
Received a spectrum last Friday

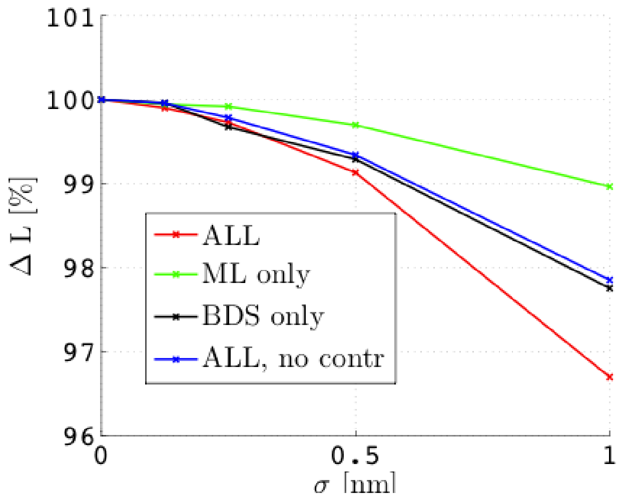
Simple model weights noise with feedback transfer function

- ✓ About 0.1nm effective jitter
- ✓ <0.1% luminosity loss

Consider not to implement this for final CDR results

- Will be considered later

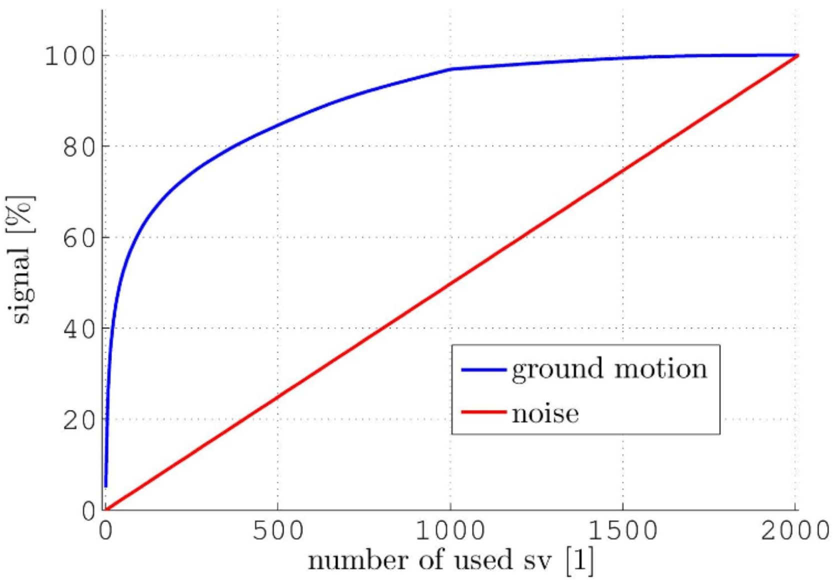




Feedback Design

Feedback Design

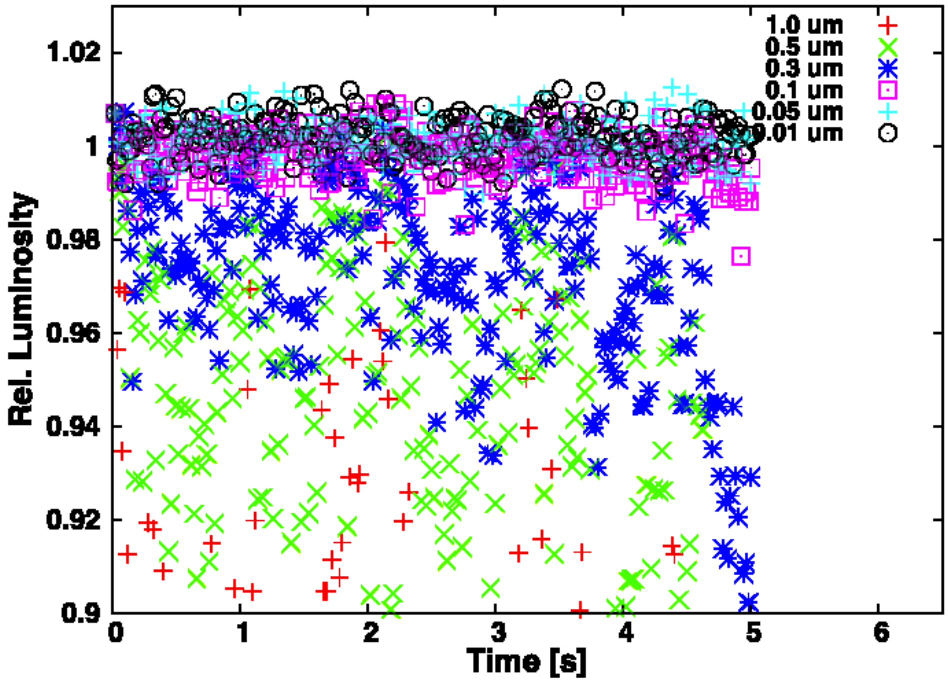
- Every magnet is equipped with a BPM
  - We use information from all BPMs
- Each quadrupole is equipped with a corrector
  - Dipole magnet and mover from stabilisation system
- Correct the orbit globally
  - In matrix inversion only the most important singular values are used
  - Currently 16 singular values are used at full gain
  - 300 singular values are used at gain of 0.05
- Some singular values are important for luminosity but not yet well measured
  - Room for improvement

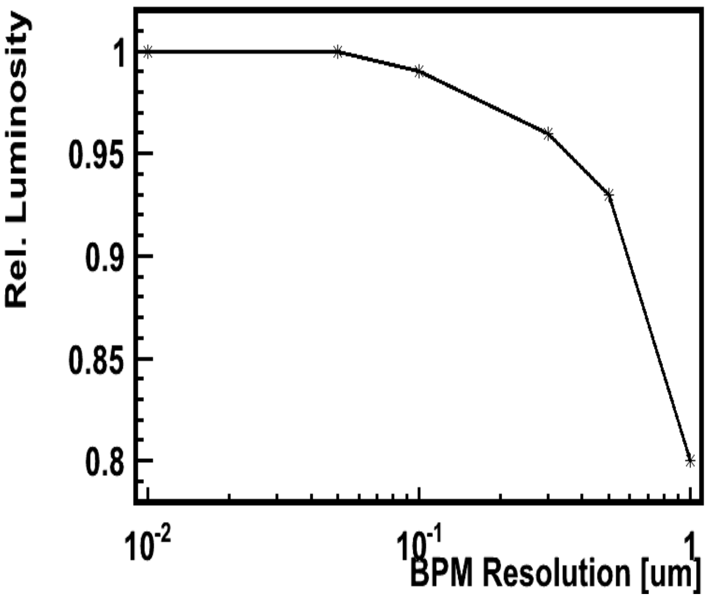


Orbit feedback and IP feedback are independent

Required BPM Resolution

- Let the feedback run at full speed
  - No ground motion, only BPM errors
- Baseline BPM resolution of 50 nm leads to less than ΔL/L<<1%
  - Value chosen to resolve 0.1σ beam jitter in the main linac
  - Significantly improved result due to noise-robust beam based feedback
    - Previous requirement had been 20nm for ΔL/L=1%





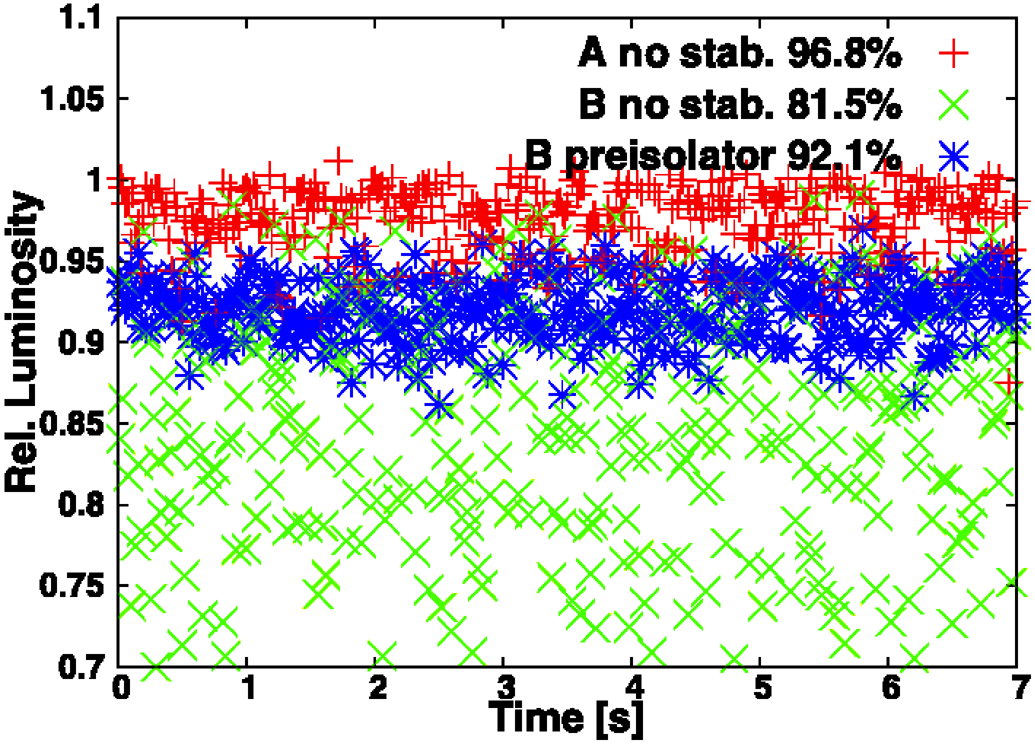
Results

Luminosity with Beam-based Feedback

No stabilisation used, vertical plane only

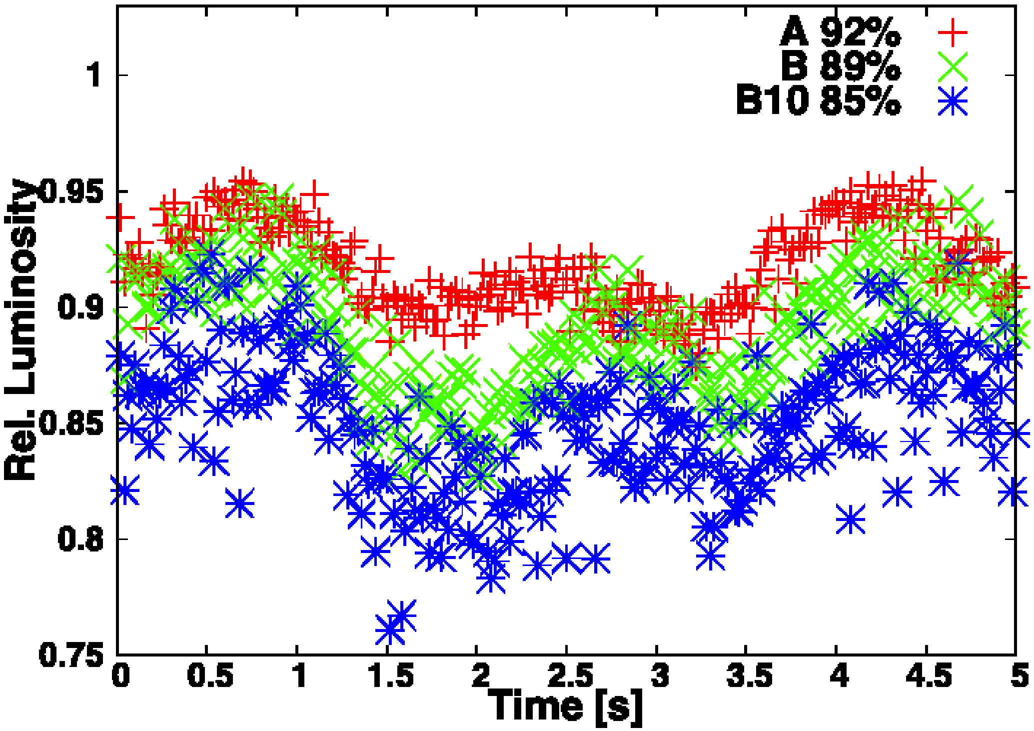
Results:

- Model A
  - ΔL/L=3.2%
  - does not need any stabilisation hardware
- For model B
  - ΔL/L=18.5%
- With final doublet stabilisation
  - ΔL/L=7.9%
- B10 and C are not acceptable



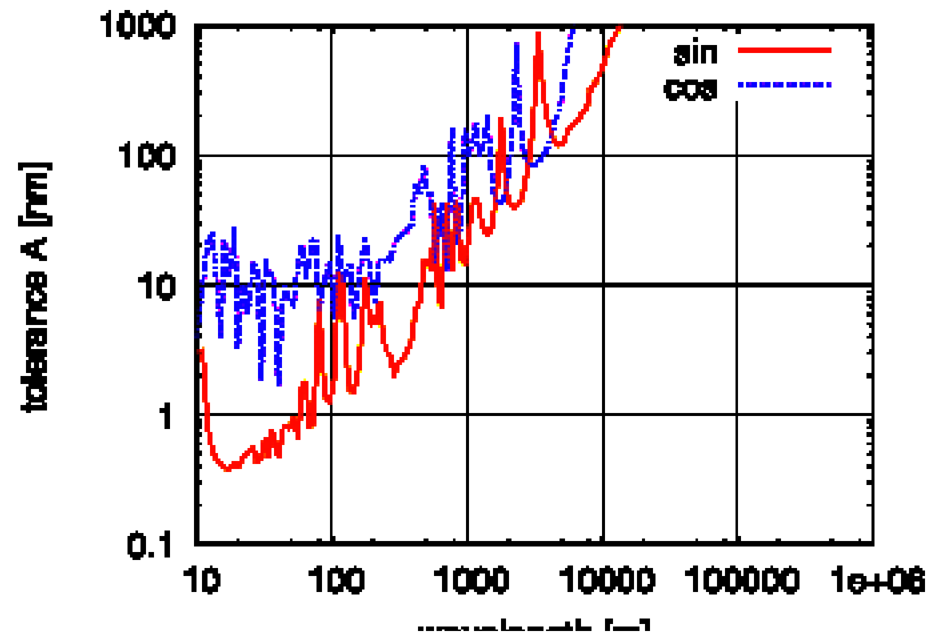
Adding Magnet Stabilisation

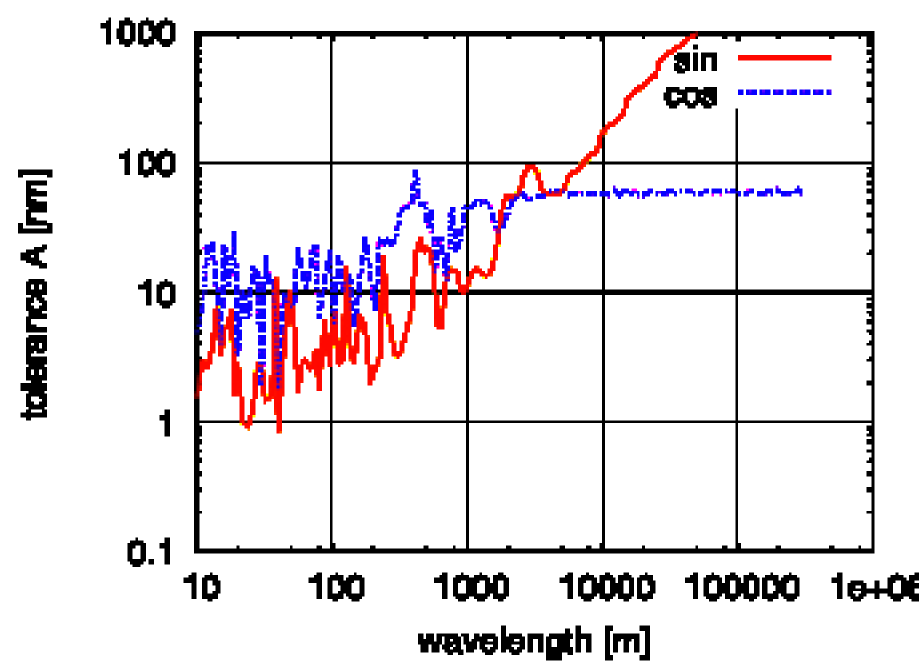
- Use the main linac transfer function for all magnets, except final doublet
  - Conservative approach, might be able to do better in BDS
- Model A is worse
  - ΔL/L=8%
- Model B is slightly worse than with pre-isolator alone
  - ΔL/L=11%
- Model B10 now about acceptable
  - ΔL/L=15%
  - Are still optimising controller



Note: Simplified Calculation

- Simplified calculation allows to determine impact of each ground motion mode as function of
  - Wavelength
  - Frequency
- Tolerance shown
  - ΔL/L=10%
  - sinus/cosinus with respect to IP
- Upper plot has no stabilisation
- Lower plot has air hook final doublet stabilisation





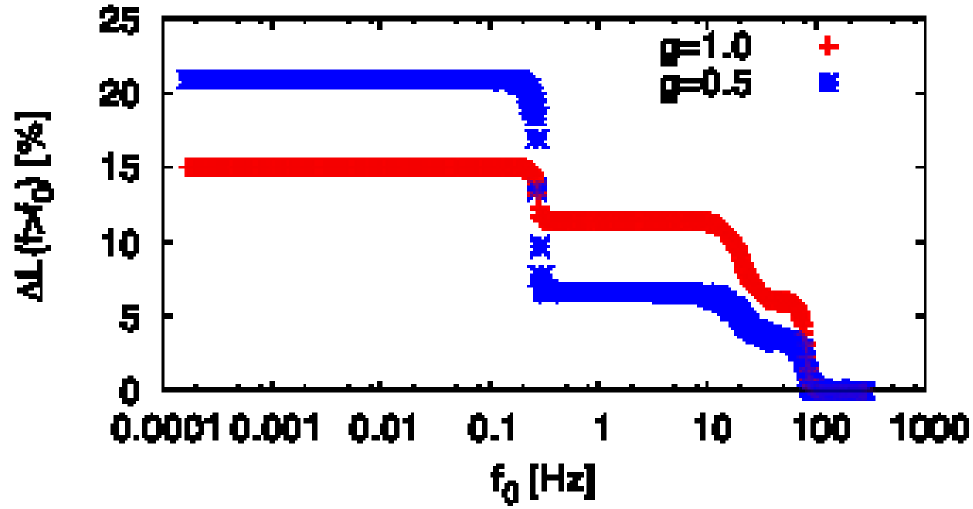
Consequences for Stabilisation Equipment

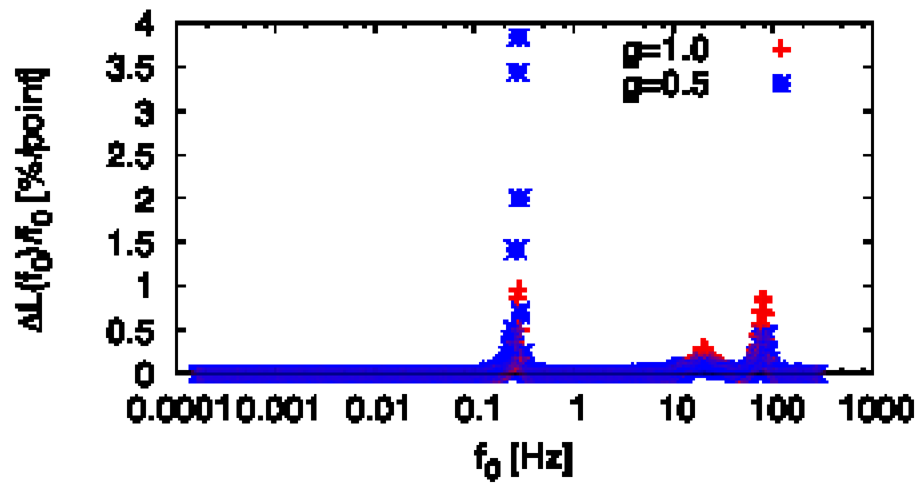
Estiamate luminosity loss for each ground motion mode (B10)

Estimated luminosity loss is 15%
- final doublet is assumed perfectly stable
- reasonable agreement with simulations

Luminosity loss is due to
- amplification close to micro-seismic peak
- amplification below 100Hz
- residual effects between 10 and 50Hz

Should tailor hardware transfer function to these findings



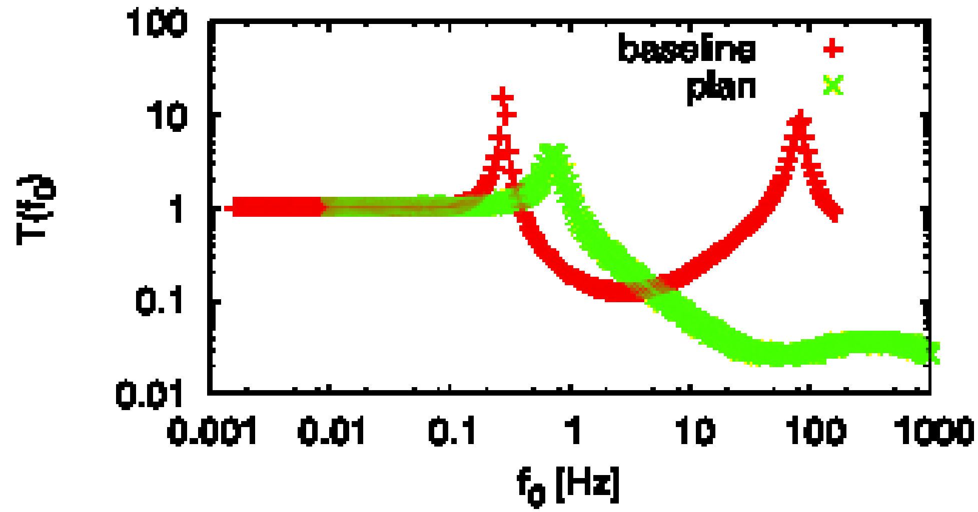


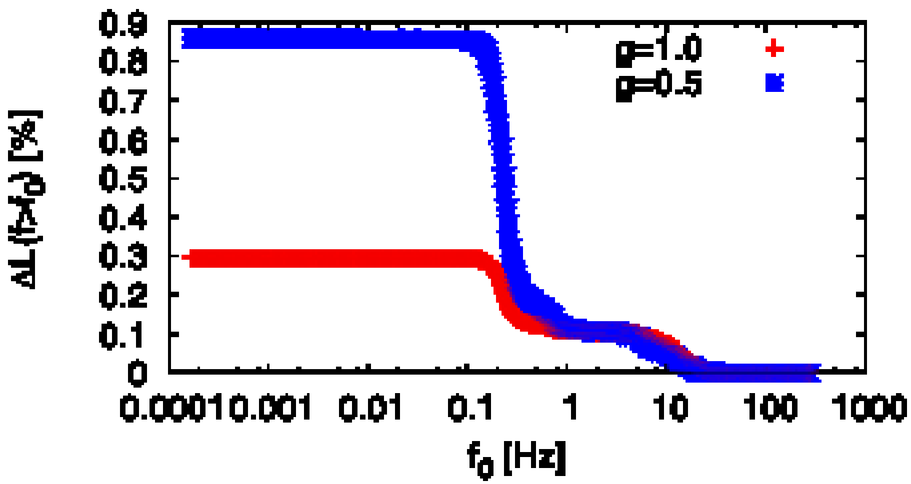
Improved Transfer Function

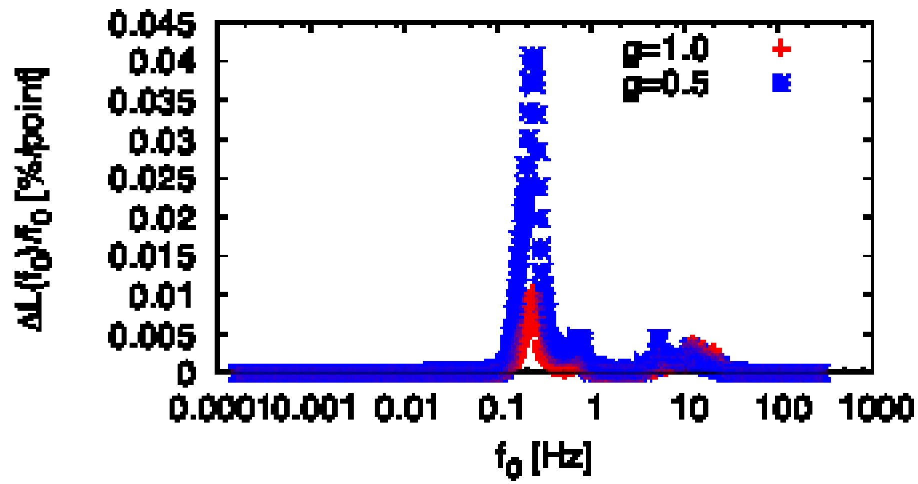
Modify baseline transfer function

1. to shift resonance away from micro-seismic peak
2. avoid second resonance

Significant improvement in the two resonances expected







Result for Optimised System

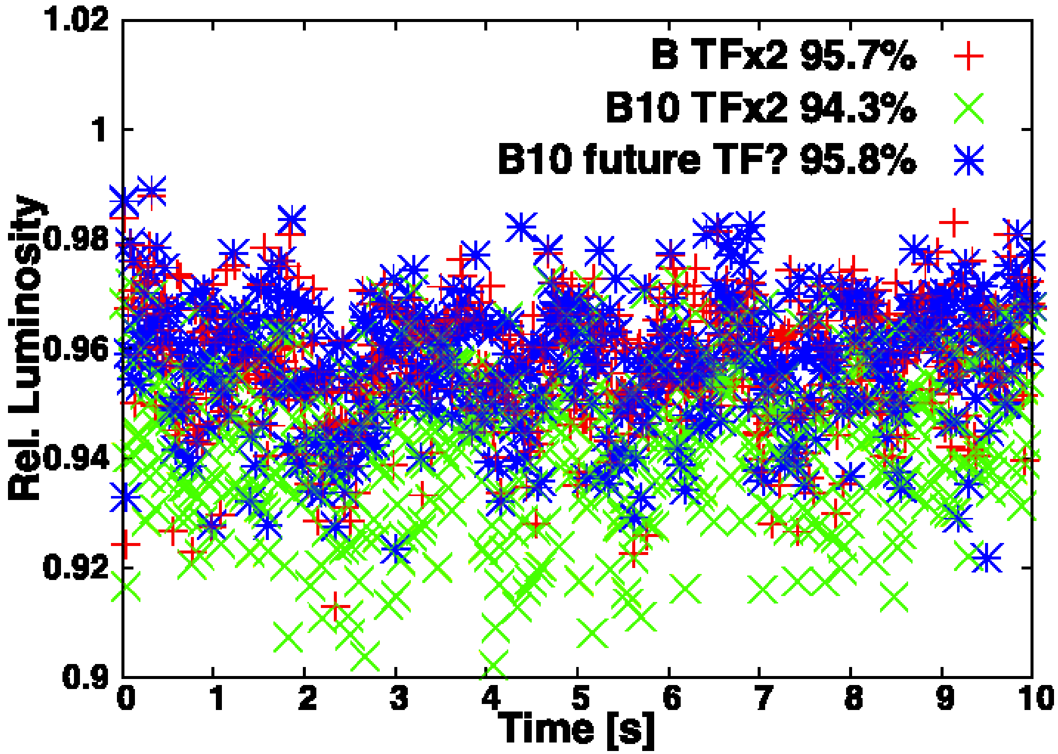
- Full simulation of vertical only

✓ Performance would be satisfactory
  - ΔL/L=4.2%

- Residual loss should be largely due to final doublet
  - currently simulations with PID are running

- Concept for hardware exists

- But hardware needs to be developed



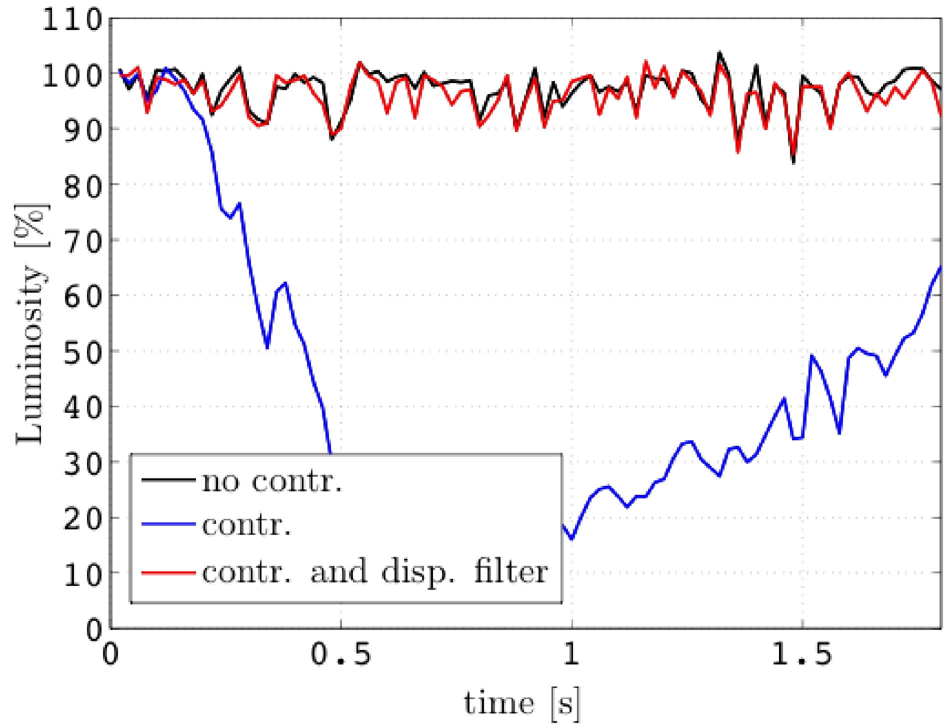
Impact of RF Jitter

- RF jitter leads to luminosity loss
  - Limited BDS bandwidth
  - Residual dispersion
- Can interact with orbit feedback
  - Non-zero horizontal target dispersion in BDS fakes orbit jitter
- Performed simulation of baseline machine with RF jitter and running feedback

✓ Not a problem in the vertical plane

✓ Filtering the dispersion signal and reducing horizontal gain reduces additional effect
  - RF jitter 2.6% loss
  - RF jitter and feedback 3.8%
  - Impact on orbit feedback is negligible $\Delta(\Delta L/L)=O(0.1\%)$

- Further optimisation should be possible

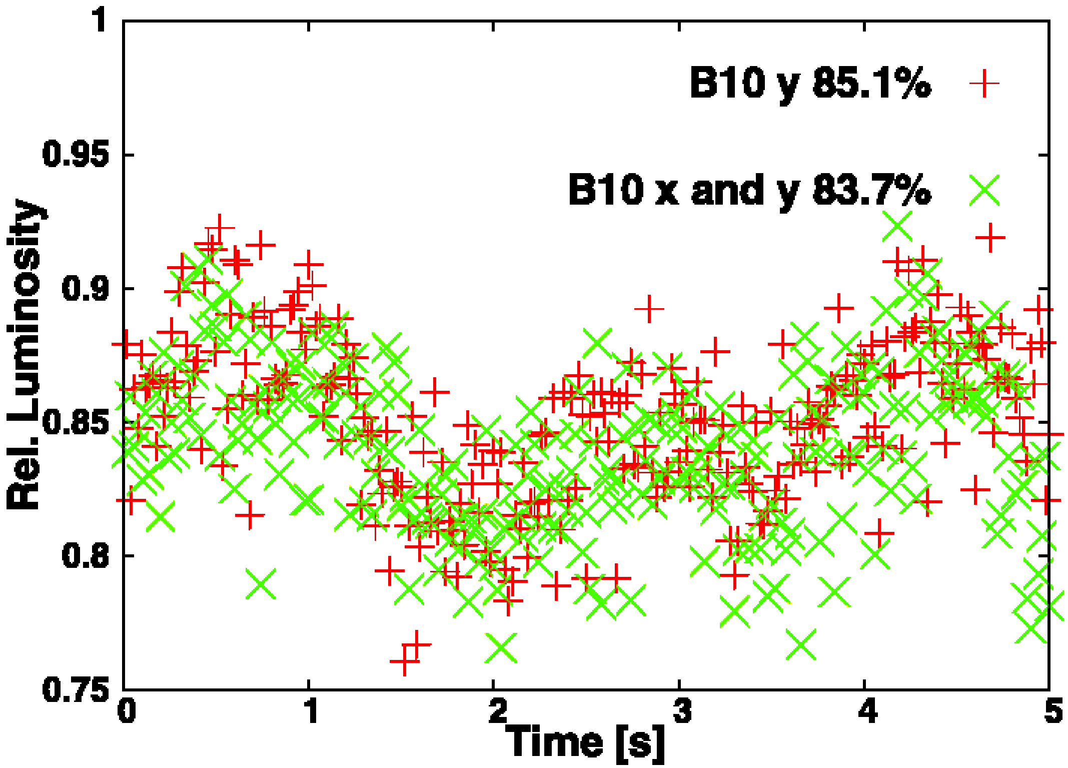


Need to re-run final simulations with dispersion filter

Horizontal Motion

- Would expect more margin in horizontal plane
  - Larger emittance
- But some additional complications
  - Transfer function is different in x
  - Have to use lower gain because of horizontal dispersion

✓ The additional luminosity loss is 1.4%

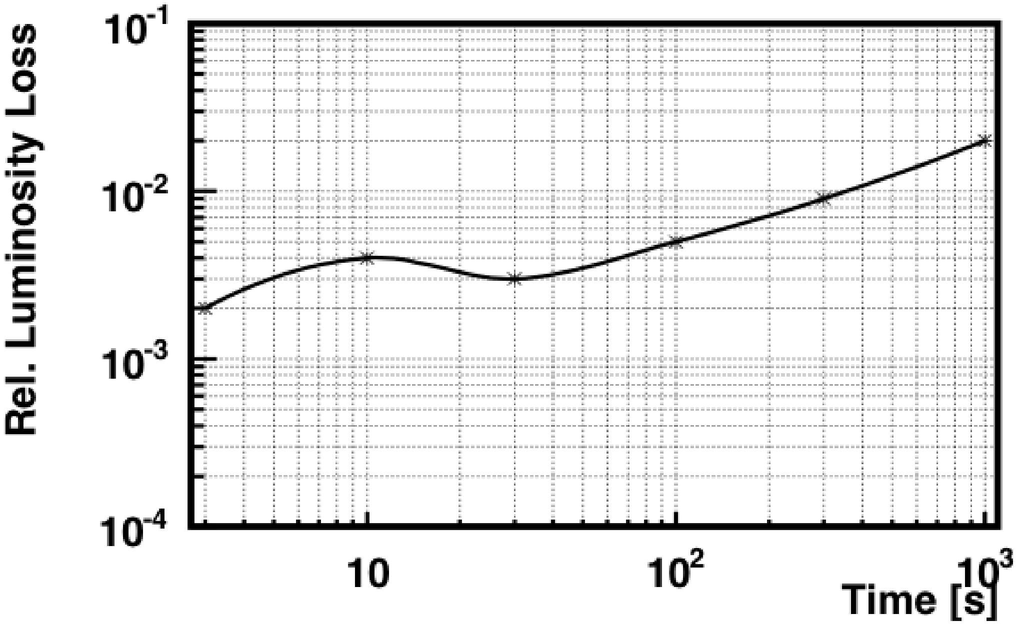


Need to repeat some simulations with horizontal feedback

Long Term Luminosity Stability

- Beam-based orbit feedback can only maintain luminosity for limited time
- Simulation of long term ground motion
  - Apply long term motion using model B/B10
    - Feedback is not active during this period
  - Run the feedback until it converges
    - Running during the ground motion could yield better results

- Can probably be improved by optimizing beam-based feedback
- Can use tuning knobs to further improve



Future

- Finish studies for CDR

- Improve the controller
  - Better algorithms
  - Better layout

- Guide improvement of hardware
  - Interaction with beam-based feedback
  - Cross talk between different systems
  - Ground motion sensor based feed-forward on the beam

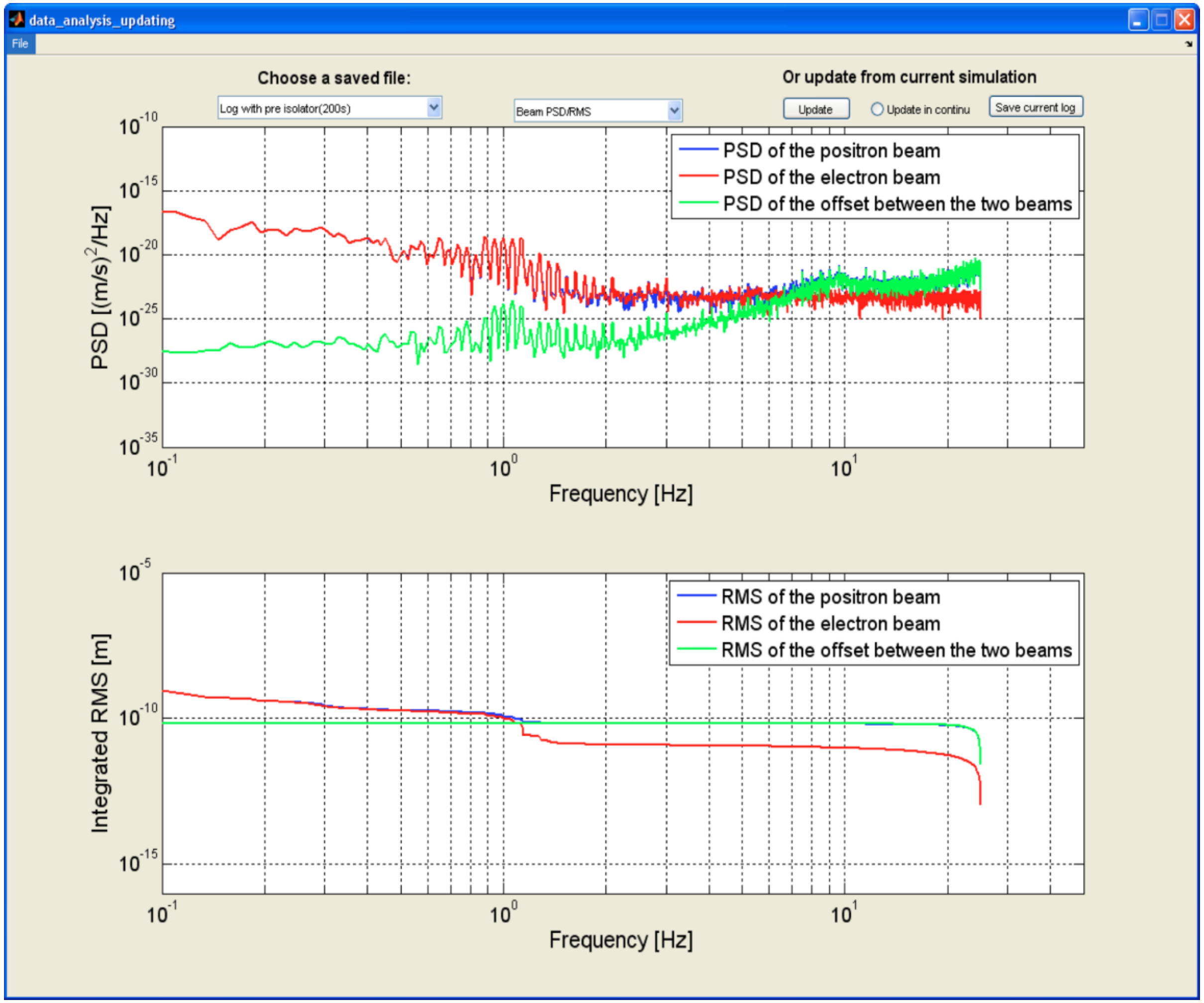
- Further improvement of modelling
  - Technical noise, ground motion, RF jitter, stray fields

- Cost reduction

- Integrated tests
  - E.g. pulse-to-pulse beam vs. ground motion in ATF2/ATF3

Improved Controller

- Non-linear controller at IP is being tested in Annecy (B. Caron)
  - Will be integrated when tests are successful

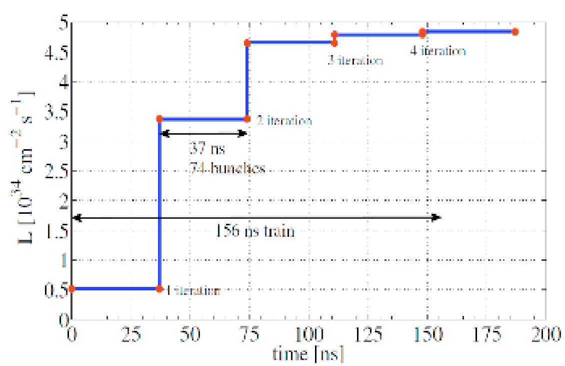


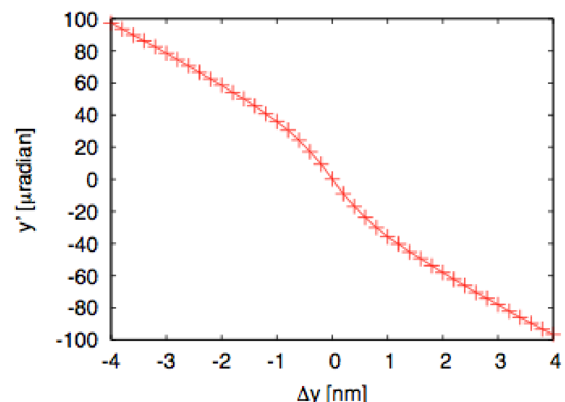
Intra-pulse Interaction-point Feedback

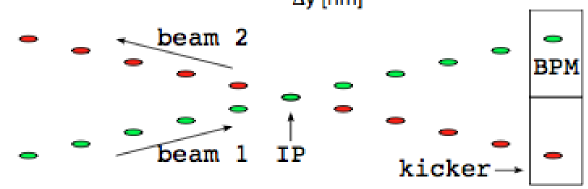
Intra-pulse feedback is being developed at Oxford

- Is currently kept as a reserve
- Can yield up to factor 4 reduction of luminosity loss
- i.e. factor 2 in tolerances
- Can have secondary beneficial effects

- Simple beam-beam feedback based on deflection angle at IP
- Assuming 37 ns latency one can hope for factor 2 gain in tolerance
- Only cures offsets, μm BPM resolution is sufficient, but large aperture
- Collaboration with JAI



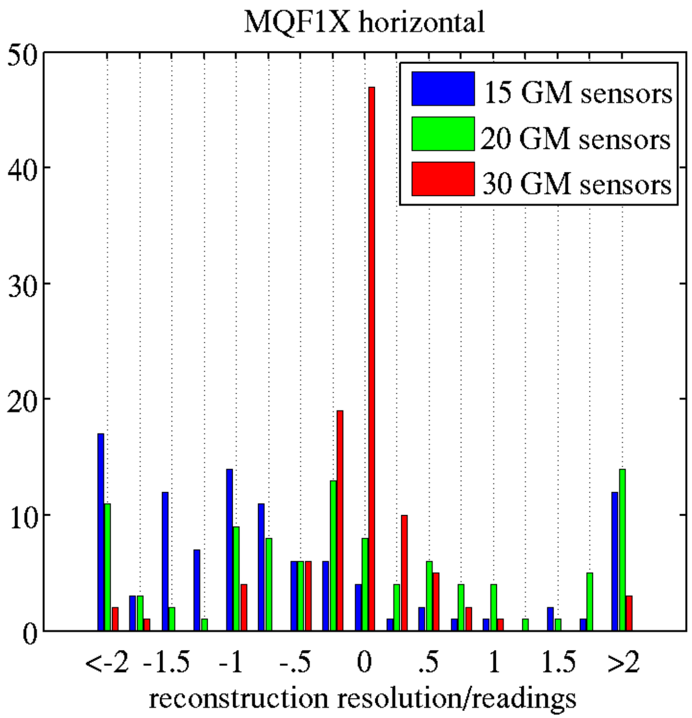


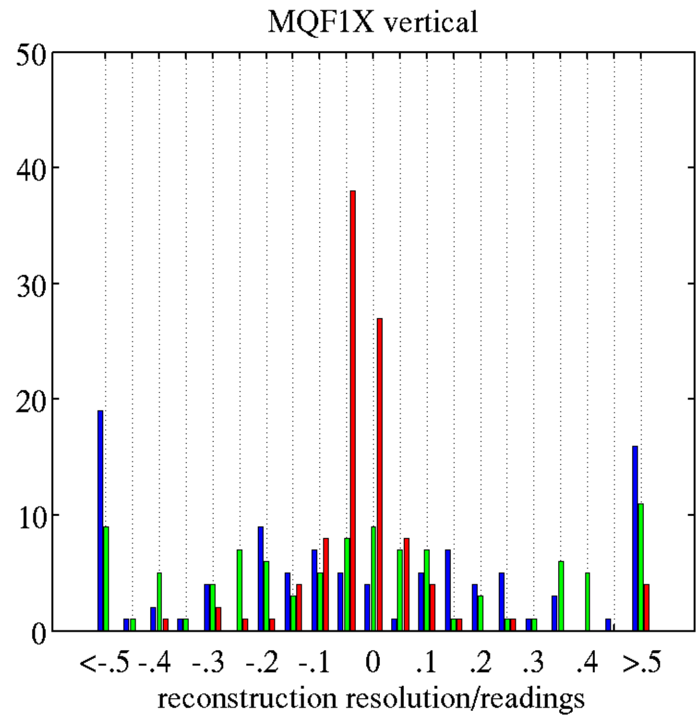


Experiments

- Good opportunity could be ATF2/ATF3
- Ground motion-based feed-forward
  - Measure the motion of quadrupole pulse-to-pulse
  - Predict the beam motion in BPMs for each pulse
  - Compare to measured beam motion pulse to pulse
- Simulation seem promising
  - ATF2 ground motion
  - Sensor sensitivity

Thanks to Y. Renier

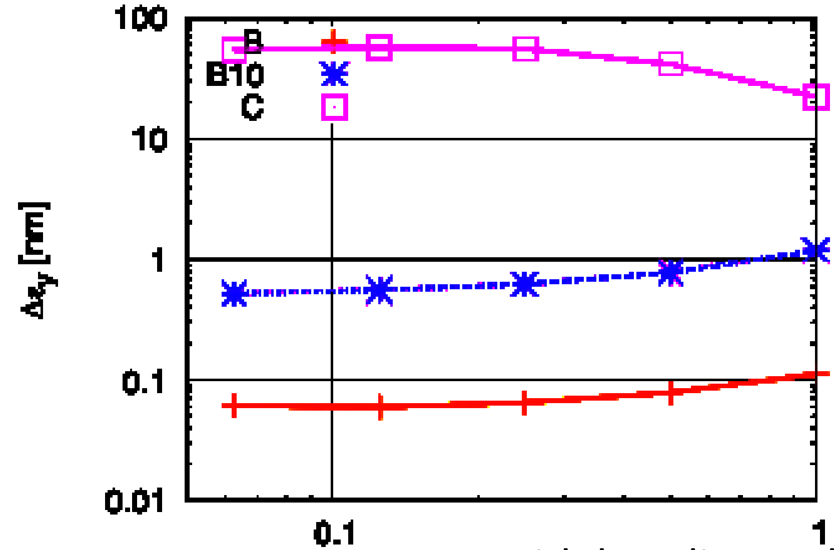




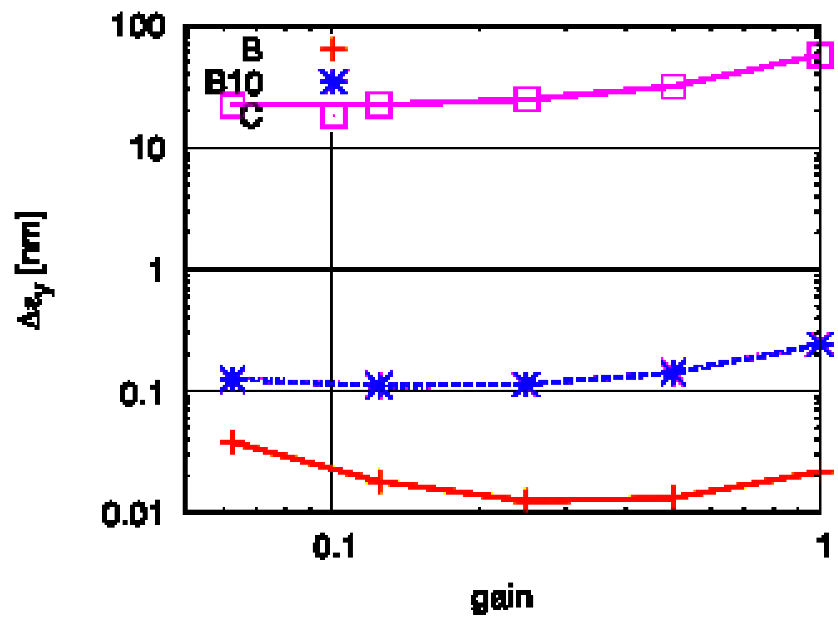
Note: Main Linac Estimate

- Ground motion only
  - Multi-pulse emittance used
  - $\Delta\varepsilon_y$= 0.4nm ≅ ΔL/L=1%
- Model B yields
  - No stab.: ΔL/L=0.15-0.3%
  - Stab.: ΔL/L=0.03-0.06%
  - Stabilisation not required for ground motion only
- Model B10
  - No stab.: ΔL/L=1.5-3%
  - Stab.: ΔL/L=0.3-0.6%
  - Stabilisation marginally required
- Model C does not work
  - Also with stabilisation

No stabilisation



With baseline stabilisation



Conclusion

- The current model for the stabilisation hardware is implemented in our simulations
  - The noise induced by the hardware is not yet included, but appears acceptable
- We have chosen ground motion model B10 as our benchmark point
  - But will adapt to real motion once known
- Horizontal ground motion and interaction with RF jitter seems OK
- Luminosity loss with current baseline hardware would be 16% for B10
  - But further hardware development will improve this; 4.2% (no noise, y only)
- Further optimisation of the beam-based controller and feedback is ongoing
- The use of tuning knobs to reduce the long-term luminosity loss is under investigation
- We plan to gain experience in ATF2/ATF3