Overall Simulation of Luminosity Preservation

D. Schulte for the beam physics team and friends

IWLC2010, October 2010

Overview

- Focus is on the need for the CDR
- Need to document impact of system design
- Need to document impact and mitigation of static imperfections
  - strategy is to treat systems independently (e.g. RTML, main linac, BDS)
- Need to document impact and mitigation of dynamic imperfections
  - start with independent systems
  - but need to look at interaction

Low Emittance Preservation Chapter

- System design
  - performance of lattice design (Andrea et al.)
  - FBII and vacuum (Giovanni et al.)
  - resistive wall wakefields (Giovanni et al.)
- Static imperfections
  - RTML (Frank et al.)
  - main linac (Andrea, Daniel et al.)
  - BDS (Rogelio et al.)
- Transverse dynamic imperfections
  - transverse model assumptions
  - fast feedback in ML and BDS (Jochem, Javier, Bernard C., Andrea, Daniel et al.)
  - long term stability (Juergen et al.))
- RF dynamic imperfections (Daniel et al.)

Related Talks

- System Design: F. Stulle, R. Tomas, H. Garcia, B. Dalena
- Simulations: J. Reste Lopez, J, Snuverink, B. Dalena, A. Latina
- FBII: A. Oeftinger
- Stabilisation with hardware: K. Artoos, Ch. Collette, A. Jeremie, A. Gaddi
- Alignment: H. Meinaud-Durand, T. Touze
- Feedback controler design/system identification: J. Pfingstner, G. Baelik
- IP feedback: Ph. Burrows
- RF stability: G. Sterbini, A. Dubrowskyi, G. Morpurgo, Ph. Burrows, D.S.

Beam Emittance Budgets

- For the main beam emittances a budget has been established
  - $\epsilon_y \leq 5\,\mathrm{nm}$ and $\epsilon_x = 500\,\mathrm{nm}$ after damping ring extraction
  - $\epsilon_y \leq 10\,\mathrm{nm}$ and $\epsilon_x = 600\,\mathrm{nm}$ after ring to main linac transport
  - i.e. $\Delta\epsilon_y \leq 5\,\mathrm{nm}$ during transport to main linac
  - $\epsilon_x \leq 660\,\mathrm{nm}$, $\epsilon_y \leq 20\,\mathrm{nm}$ before the beam delivery system with the growth mainly in the RTML
  - i.e. $\Delta\epsilon_y \leq 10\,\mathrm{nm}$ in main linac
  - for the BDS the budget is a 20% spot size increase in the vertical plane compared to perfect system
- The budgets include design, static and dynamic effects
  - 50% of the growth for static imperfections
    - requires 90% of the machines to perform better than the target
  - 50% of the growth for dynamic imperfections
    - averages out with time
- Dynamic studies need to be done across more than one system

Dynamic Imperfections

- Luminosity loss is part of the emittance budget

Source	budget	tolerance
Damping ring extraction jitter	0.5%	kick reproducibility $0.1\sigma_x$
Dynamic magnetic stray fields	2%	data needed
Bunch compressor jitter	1%	
Quadrupole jitter in main linac	1%	$\sigma_{jitter} \leq 1.3\,\mathrm{nm}$, +FB
RF amplitude jitter in main linac	1%	0.075% coherent, 0.22% incoherent
RF phase jitter in main linac	1%	0.2° coherent, 0.8° incoherent
RF break down in main linac	1%	rate$< 3 \cdot 10^{-7}\,\mathrm{m}^{-1}\mathrm{pulse}^{-1}$
Structure pos. jitter in main linac	0.1%	$\sigma_{jitter} \approx 880\,\mathrm{nm}$
Structure angle jitter in main linac	0.1%	$\sigma_{jitter} \approx 440\,\mathrm{nradian}$
Crab cavity phase jitter	2%	$\sigma_\phi \approx 0.017^\circ$
Final doublet quadrupole jitter	2%	$\sigma_{jitter} \approx 0.17(0.34)\,\mathrm{nm}$–$0.85(1.7)\,\mathrm{nm}$
Other quadrupole jitter in BDS	1%	
...	?%	

$\Rightarrow$ Long list of small sources adds up

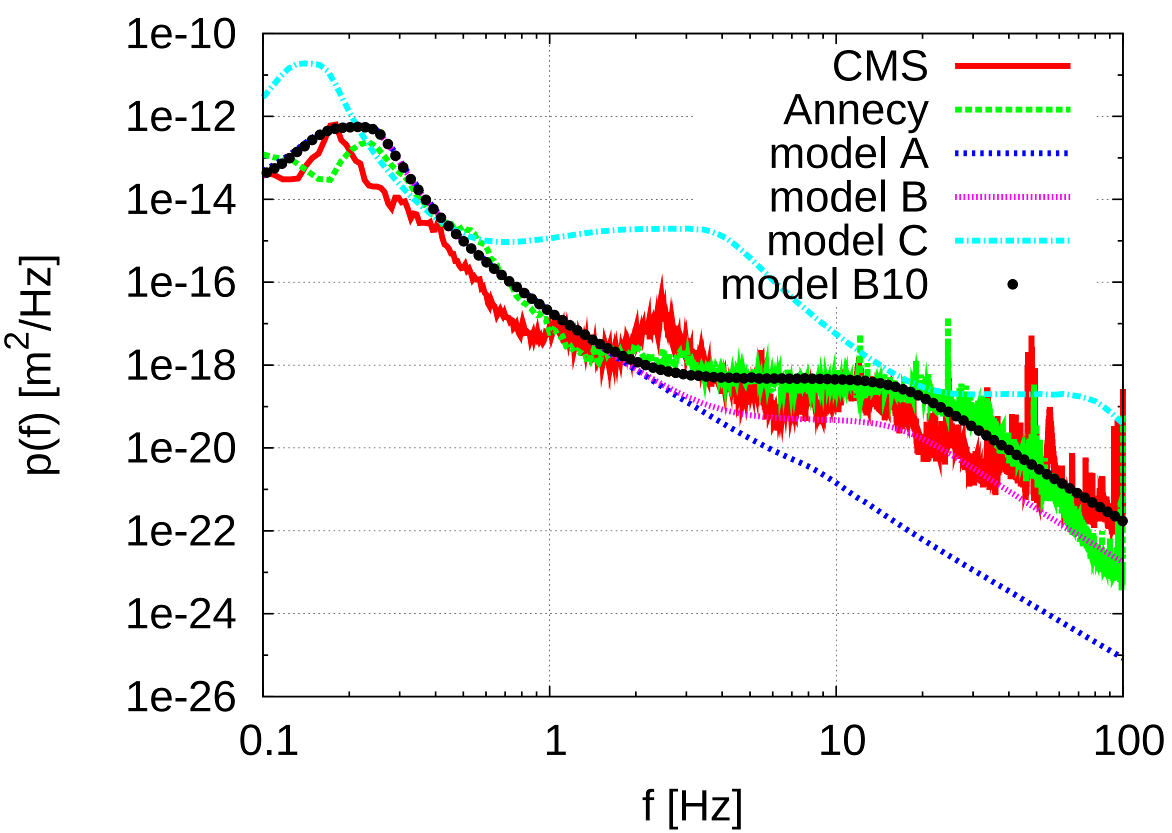
$\Rightarrow$ Impact of feedback system is important

Strategy to Evidence Beam Stability for CDR

- Perform integrated simulation of main linac, beam delivery system and collision including
  - RF phase and amplitude jitter
  - a realistic model of the ground motion and technical noise
  - realistic transfer through supports, including mechanical feedback
  - realistic sensitivity curves and noise for ground motion sensors for beam-based feedforward
  - a realistic concept of the beam-based feedback
- Have an integrated simulation of main linac, BDS and beam-beam interaction
  - PLACET, benchmarked with LIAR, MAD, Merlin, Lucretia, SLEPT etc., tested at CTF3
  - GUINEA-PIG, benchmarked with CAIN

Ground Motion Models

- Some examples are shown
  - Annecy and CMS hall floor
  - models based on Andrei Seryi's measurements
- LEP/LHC tunnel is relatively quiet
- Model B has similar shape as Annecy or CMS hall floor
  - B10 if we amplify one peak by factor 10 agrees even better
  - other models exist



A. Seryi, CLIC stabilisation team

Stability and Feedback

- Stability is required to avoid luminosity degradation of a tuned machine
  - beam-based feedback will be used for low-frequency motion
  - typical luminosity with feedback is loss

$$\Delta\mathcal{L}_{total} = \Delta\mathcal{L}_{uncorr}(g) + \Delta\mathcal{L}_{noise}(g) + \Delta\mathcal{L}_{residual}(t)$$

$\Delta\mathcal{L}_{uncorr}$ actual dynamic effect that is not yet corrected/amplified
How fast does the feedback need to be?

$\Delta\mathcal{L}_{noise}$ feedback tries to correct dynamic effect that is faked by diagnostics noise
How good does the feedback need to be?

$\Delta\mathcal{L}_{residual}$ local feedback cannot correct all global effects
For how long is the feedback sufficient?

Feedback Design

- The sensitivity to noise has been looked at for the main linac and the BDS (J. Snuverink, J. Resta Lopez, J. Pfingstner, D.S.)

  $\Rightarrow$ some $10\,\mathrm{nm}$ resolution are required in BDS, $50\,\mathrm{nm}$ in main linac

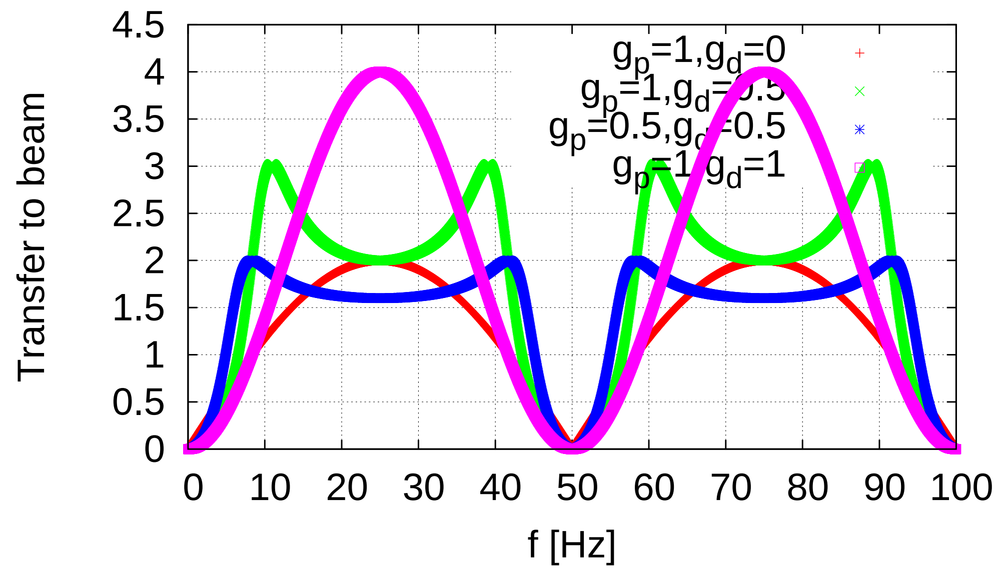
- The ability to keep the luminosity for some time has been studied by J. Snuverink

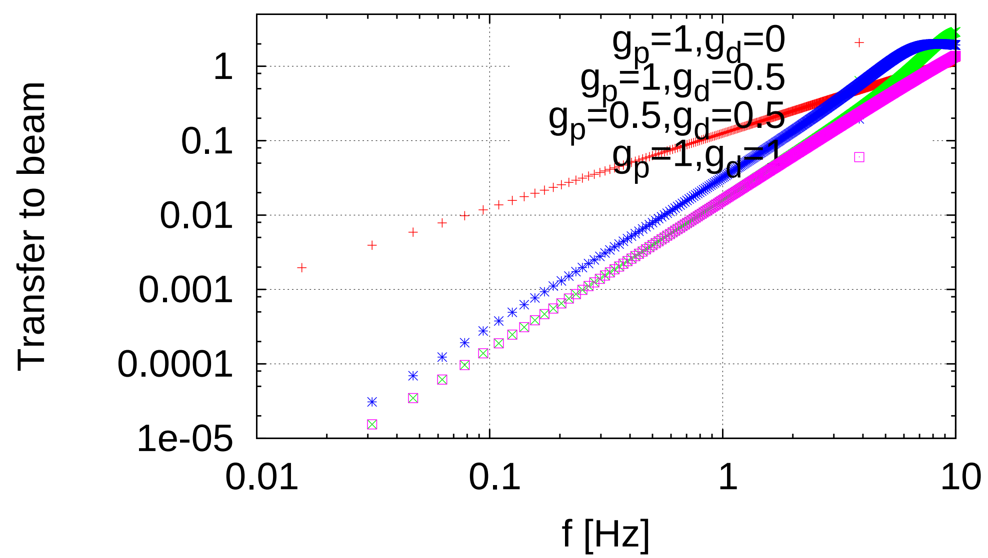
  $\Rightarrow \approx 10\,\%$ reduction of luminosity after $1000\,\mathrm{s}$

  - makes us confident that full integration works

  $\Rightarrow$ leaves several $100\,\mathrm{s}$ for tuning for tuning

Simplified Feedback Model



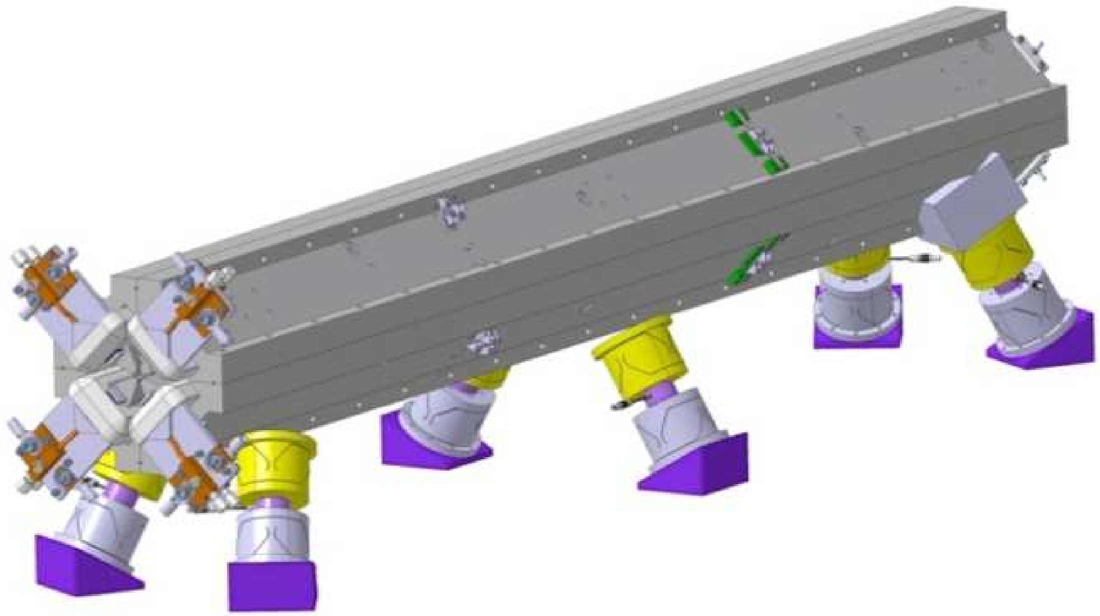


- Ignore incoming beam jitter
- Assume linear system response
- Home-made controller
  - serious study of controler design started in Annecy (B. Caron et al.)

    ⇒ integration needed

Main Linac Quadrupole Support

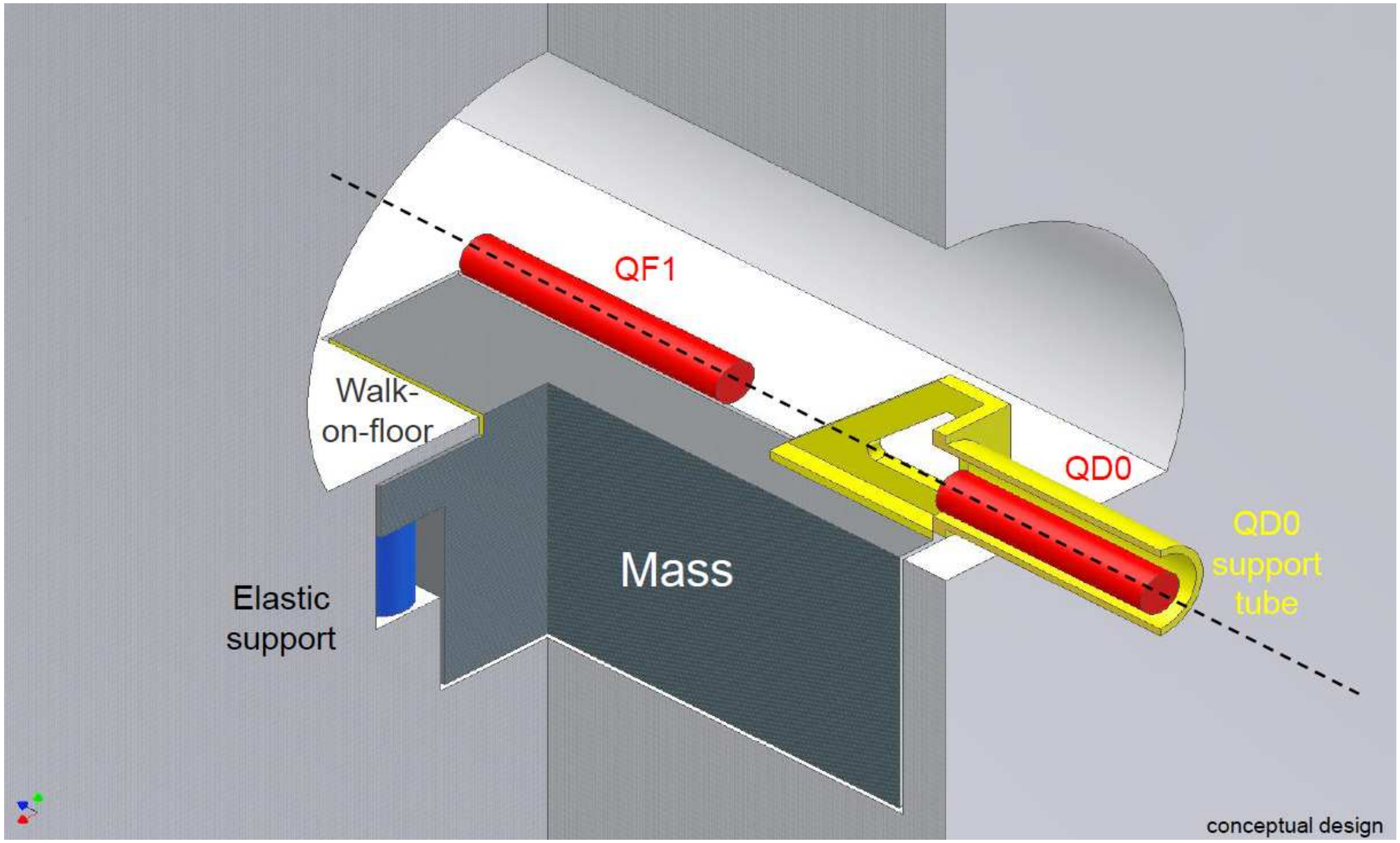
- Mechanical stabilisation is essential
- Two concepts have been developed
  - soft support (Annecy)
  - rigid support (CERN)



C. Hauviller, K. Artoos, Ch. Collette et al.

Quadrupole Support

- Heavy mass on a spring
- Mechanical low pass filter

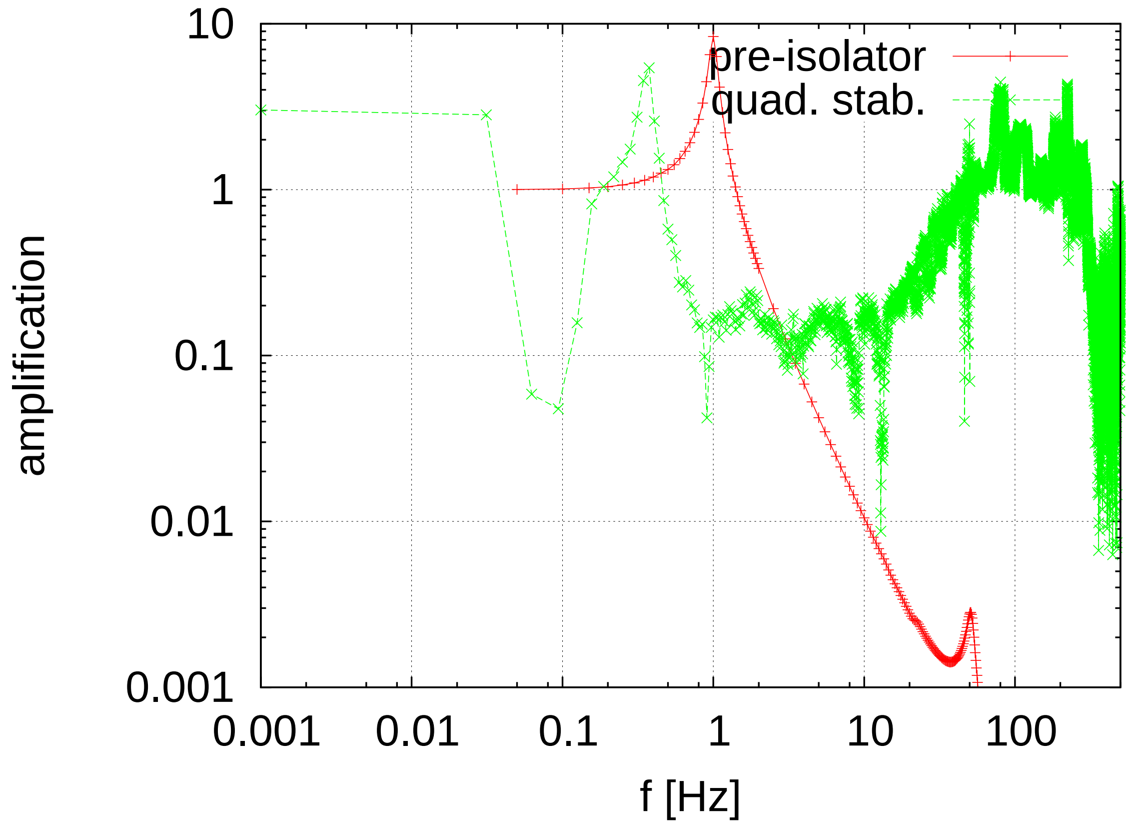


Alain Herve, Andrea Gaddi, Huber Gerwig

Example: Pre-Isolator and ML Quadrupole

- Transfer functions are known
  - for the final doublet support (pre-isolator)
  - for the main linac quadrupoles
- Need to check, if model is good enough

Transfer functions from F. Ramos and Chr. Collette



Pre-Isolator Result

- Consider only final doublet with $5\,\mathrm{nm}$ RMS jitter

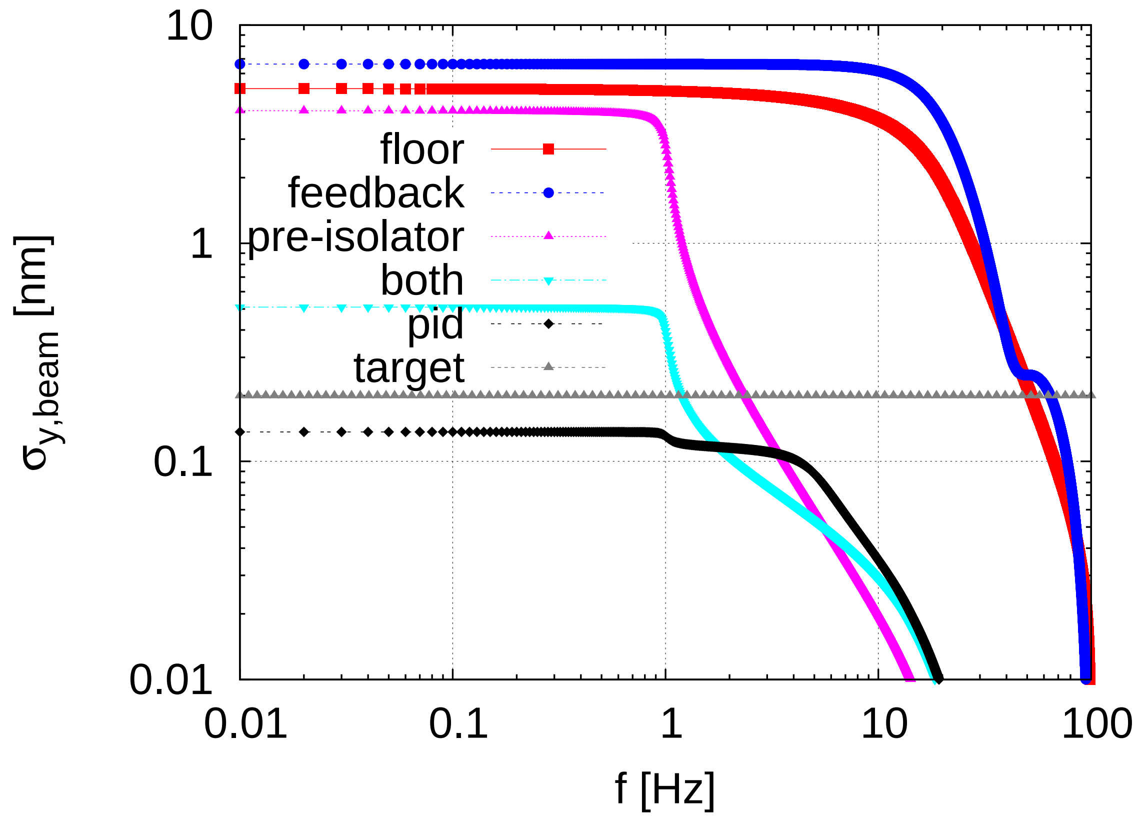
$$P(\omega) = P_0 \frac{1}{1+\left(\frac{\omega}{\omega_0}\right)^6}$$

$\omega_0 = 40\pi$ (Ch. Collette)

- Beam-based feedback and pre-isolator
  - two different controllers used

⇒ So far OK

⇒ B. Caron et al. have better controler



$$\langle y^2 \rangle = \int_0^\infty T_B(\omega)^2 p_Q(\omega) + p_N(\omega) d\omega$$

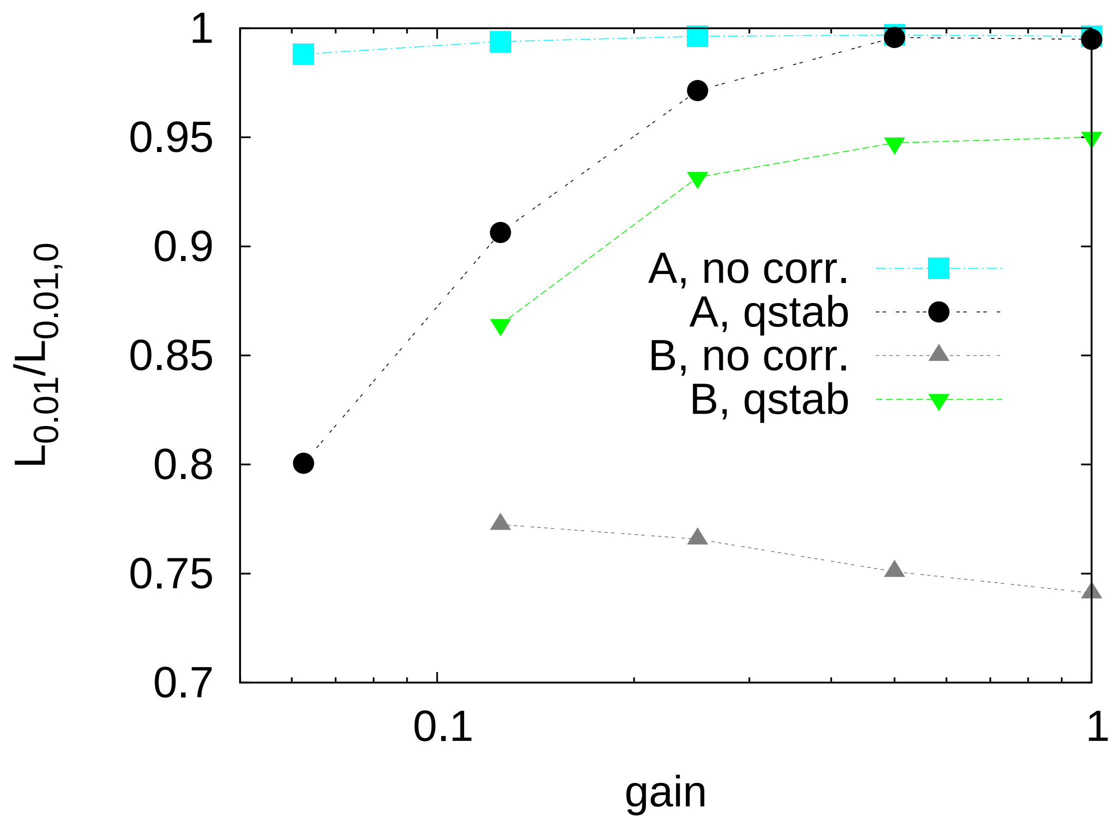
Impact of Ground Motion

- Assumed a direct one-to-one transfer to beam line elements and simplified feedback
- Stabilisation is air hook

⇒ A is good enough

⇒ B is marginal

⇒ B10 is bad



⇒ A medium noisy site (B) is almost OK, if we stabilise the final doublets

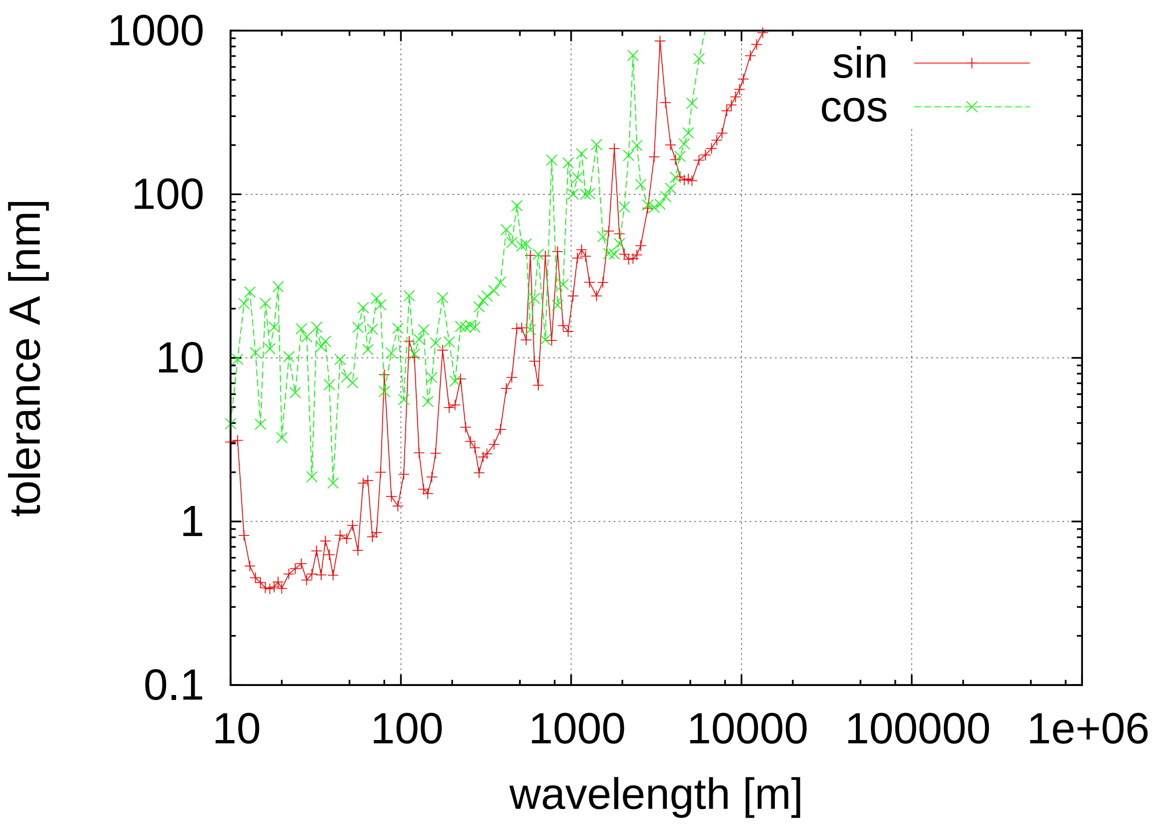
Tolerance for Ground Motion

- Full simulation of the machine from start of linacs
- Determine amplitude for 10% luminosity loss
- No correction applied

⇒ Sine-like pertubations (with respect to IP) are more important

  - beam-beam offset

⇒ Long wavelength are less harmfull



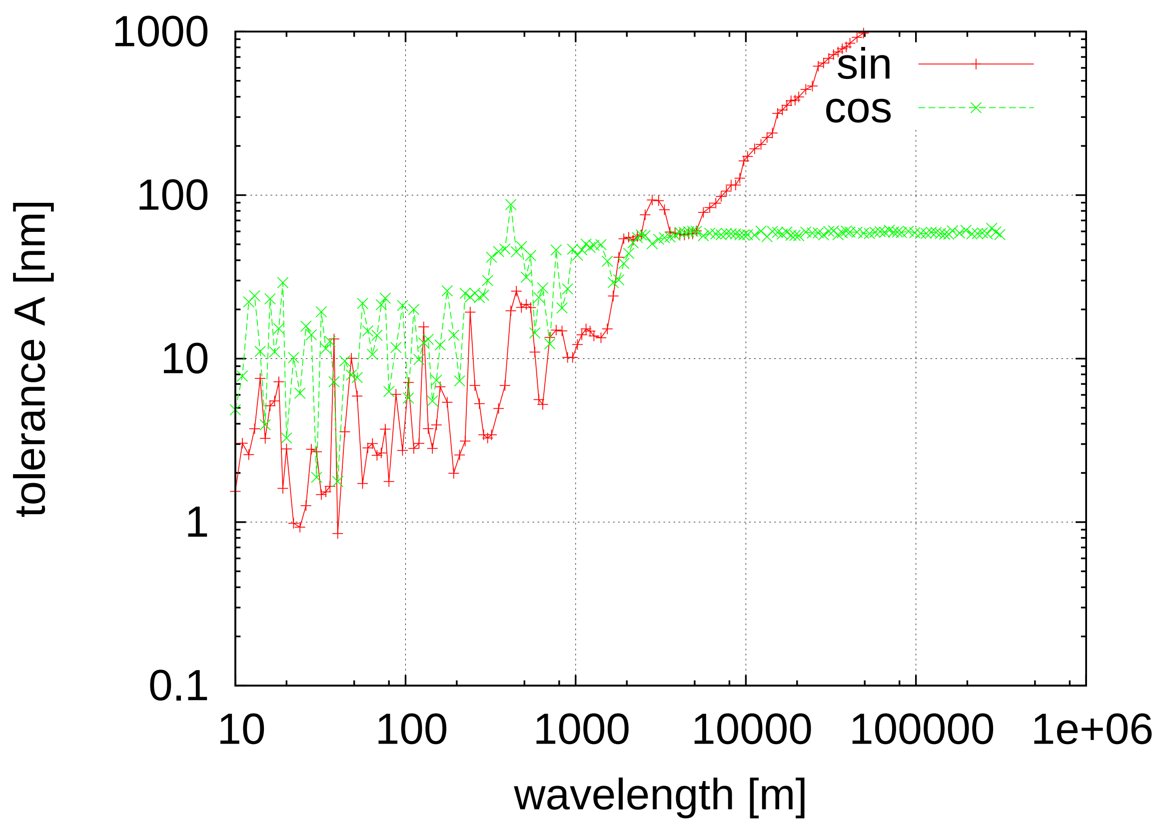
Fixed Final Doublet

- Full simulation of the machine from start of linacs as before
- Final doublet plus multipoles are stabilised perfectly

⇒ For short wavelengths, sine-like perturbations are more important

⇒ For long wavelengths, cosine-like perturbations are more important

  - machine moves away from final doublets



Results

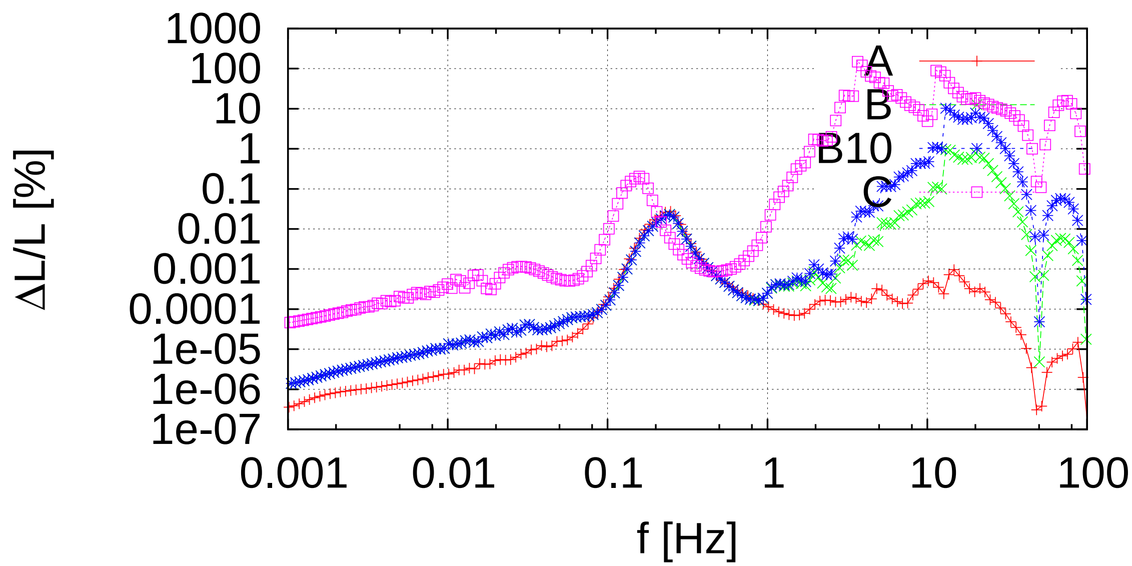
- Final doublet is perfectly stabilised
- Beam-based dead-beat feedback

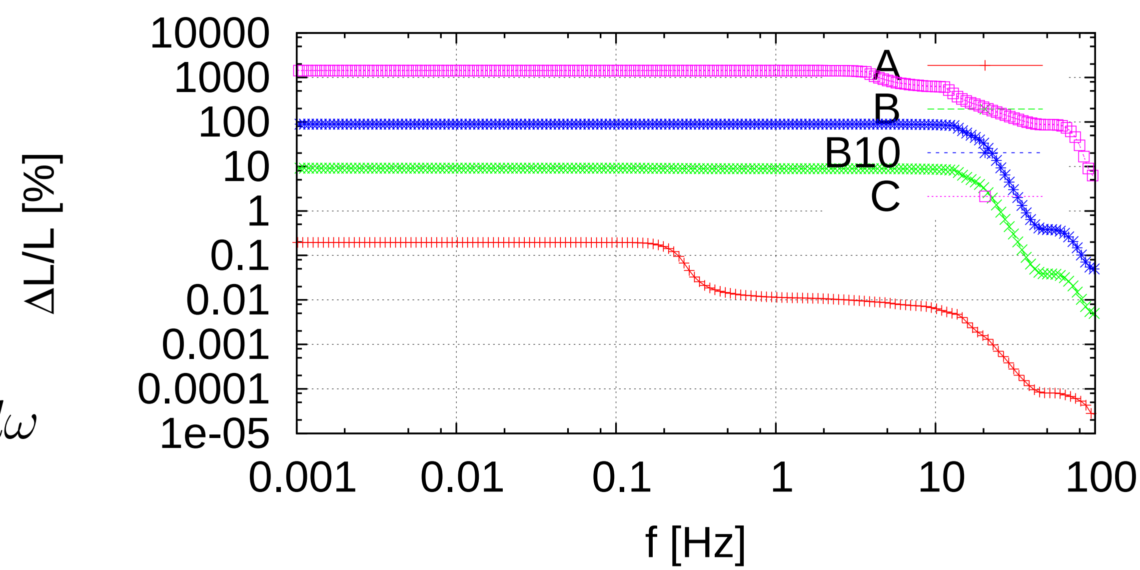
⇒ Ground motion model A is worse than with beam feedback only

  - machiene drifts away from final doublets

⇒ Other are also not good enough

$$\langle \Delta L \rangle = \int \int P(\omega, k) T^2(\omega) G(k) dk d\omega$$

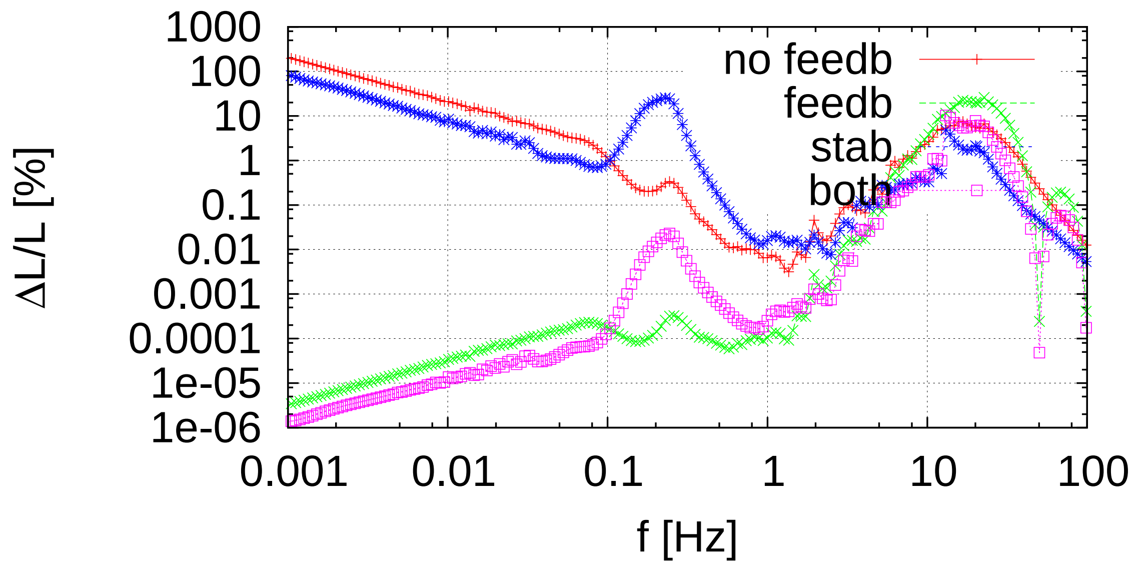


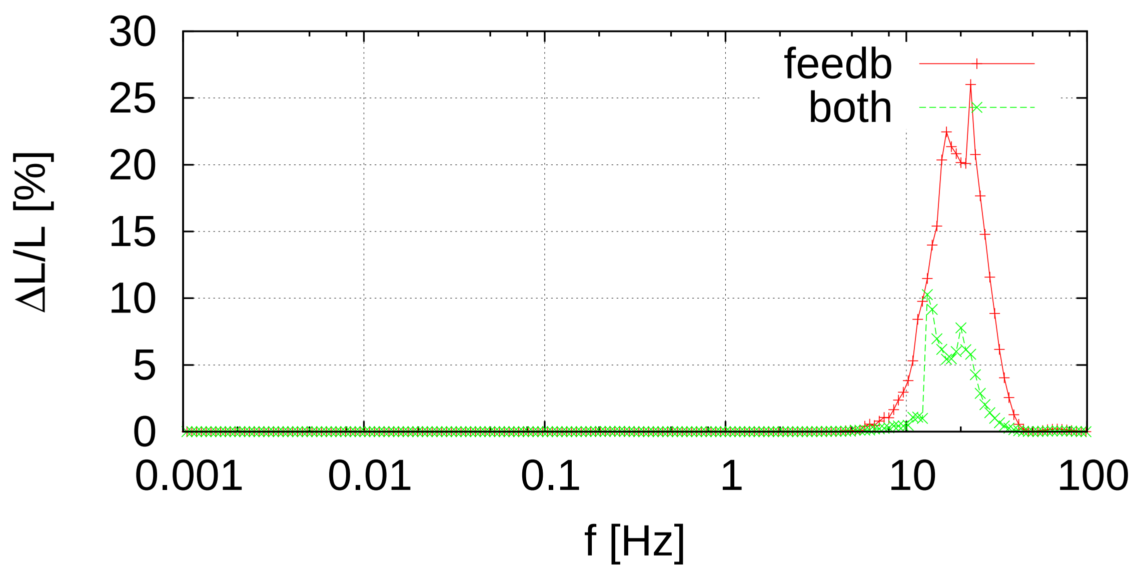


Reason for Luminosity Loss

- Ground motion B10 is used
- The residual loss is still dominated by frequencies above about $10\,\mathrm{Hz}$

$\Rightarrow$ The residual problem are at frequencies above $\approx 10\,\mathrm{Hz}$





Simplified Simulation Results

- Feedback directly applied to ground motion
  - dead-beat controler used
- Mechnical stabilisation applied to everything
  - only final doublet treated separately
- Ground motion model B10 used
- Results:
  - only beam-based feedback: $\Delta\mathcal{L}/\mathcal{L} \approx 60\%$
  - stabilised final doublet: $\Delta\mathcal{L}/\mathcal{L} \approx 30\%$
  - also stabilised magnets: $\Delta\mathcal{L}/\mathcal{L} \approx 3\%$
- Intra-pulse feedback will improve this (J. Resta Lopez)

Main Linac and BDS Mechanical Feedback/Feed-Forward

- In the main linac and BDS ground motion sensor based beam feed-forward can be used
- Aim is to make the system cheaper
  - no mechanical feedback on quadrupoles
  - measurement of quadrupoles motion
  - correction by orbit correctors
- Requires is good system knowledge

  $\Rightarrow$ Juergen's thesis
- More challenging than the local mechanical stabilisation but could be less costly

  $\Rightarrow$ could be an alternative described in CDR

Conclusion

- Lots of work has been done

  ⇒ one more step for CDR

  ⇒ focus on documentation

- Plenty of work for the next phase

Reserve

Conclusion

- System design is well advanced for all lines from damping ring to IP
  - some less critical systems require more work
  - fast beam-ion instability and resistive wall wakefield understood
- Static imperfection studies are advanced
  - focus on main linac and BDS
  - main linac reaches targert performance, BDS comes close

  ⇒ finalise studies
- Dynamic imperfections are advanced
  - focus on main linac and BDS
  - transverse and longitudinal jitter treated separately
  - integrated studies give promising results

  ⇒ finalise studies

Issues

- Not all systems designed in RTML

  $\Rightarrow$ but all critical ones

- Not much on RTML static imperfections

  $\Rightarrow$ accepted due to lack of resources, status of BDS shows that this was a wise decision

- BDS static imperfection mitigation does not fully achieve target

  $\Rightarrow$ but comes close, further work also on ATF2

- Integrated dynamic imperfections

  $\Rightarrow$ seems to be working now

- Integration of Annecy feedback

  $\Rightarrow$ need to find a solution

Technical Noise

- Assume that technical noise has litte correlation

  $\Rightarrow$ jitter of each element around its nominal position

- Use previous fit

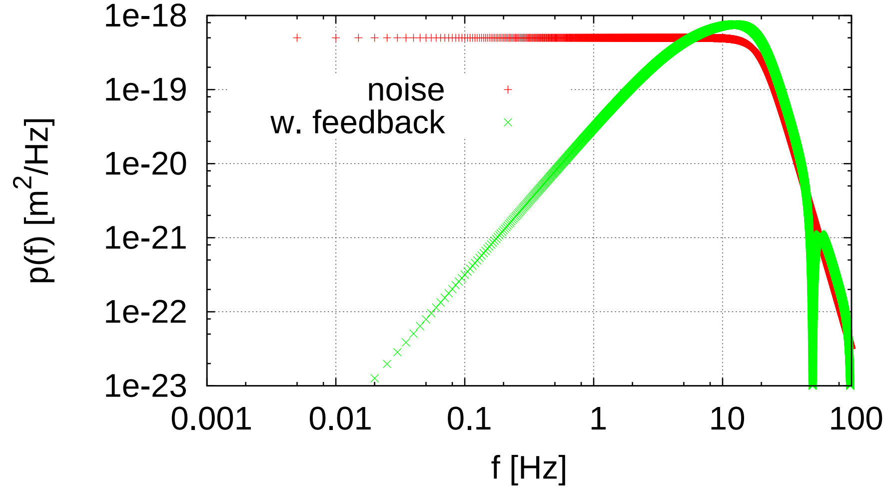
$$P(\omega) = \frac{0.5}{1 + \left(\frac{\omega}{40\pi}\right)^6} \mathrm{nm}^2/\mathrm{Hz}$$

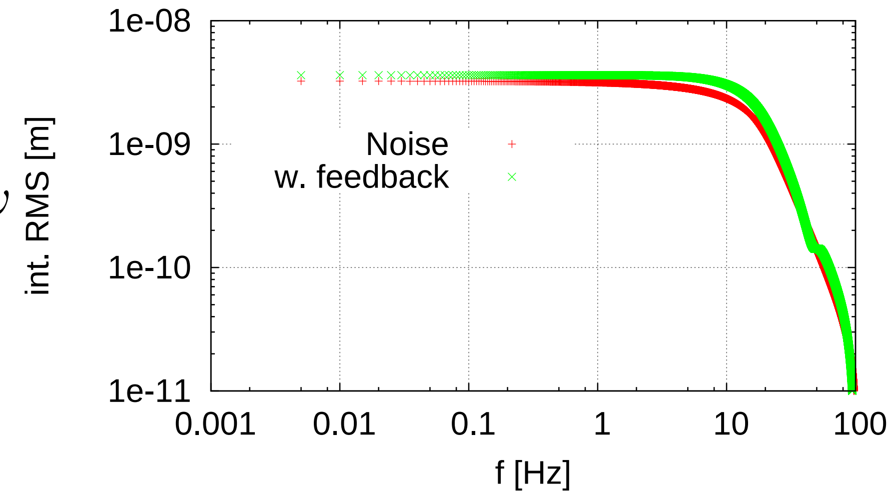
- RMS offset can be calculated as

  $\langle y^2 \rangle = \int_0^\infty \left(P(\omega) T_S^2(\omega) + N_S(\omega)\right) T_B^2(\omega) d\omega$

  used no stabilisation for plots

$\Rightarrow$ Stabilisation needs to provide $T_S(\omega)$ and $N_S(\omega)$ to reduce $\sqrt{\langle y^2 \rangle}$ to specification





Beam Line Design

- We have a design for each critical beamline from the damping ring to the interaction point
  - some system are still missing in the RTML
  - but we expect them not to degrade performance if a proper design is made
- Have studies of the fast beam-ion instability that cover all critical systems
  - very good vacuum in long transport lines needed
  - good vacuum in main linac needed

  $\Rightarrow$ specifications for the vacuum experts exist (G. Rumolo et al.)
- Resistive wall wakefields have been studied for all critical systems
  - the beam pipe radius and material has been defined to avoid any issue (G. Rumolo et al.)

Static Imperfections

- RTML
  - not too advanced
  - should not be too different from ILC

  ⇒ but more work is needed
- Main linac
  - very important design driver
  - studies show emittance preservation better than the target

  ⇒ hardware specifications exist
- BDS
  - very difficult to design and consequently to tune
  - studies are progressing but not yet fully satisfactory

  ⇒ ATF2 is important test bed

  ⇒ in the long run may have to modify system design for better tuning performance

RF Phase and Amplitude Jitter

- We have a model of the impact of RF phase and amplitude errors
  - in the main linac
  - in the drive beam accelerator
  - in the RTML
- We developed a concept of the phase stabilisation system
- We determined the required
  - stablities of klystron phase and power
  - drive beam current stability
  - timing reference errors
  - phase monitor resolution
- The values either have been reached or are not far from existing performances

Sources of Transverse Beam Motion

- A number of sources for transverse beam motion exists
  - ground motion
  - technical noise
  - jitter amplification by mechanical supports
  - RF gradient and phase jitter and dispersion
  - beam jitter from upstream systems
  - dynamic magnetic field variations
  - temperature variations
  - ...
- Not all are due to the technical installation

  $\Rightarrow$ beam stability is site dependent

  $\Rightarrow$ develop beam stabilisation techniques and use what a given site requires

Tools to Reduce Beam Motion

- Choose a quiet site
  - e.g. the LEP/LHC tunnel is relatively quiet
- Avoid technical noise
  - identify sources of noise and modify their design if possible
- Avoid amplification of vibrations through supports etc.
  - careful girder design
- Use mechanical feedback and feedforward
- Use motion sensor based feedforward on the beam
- Use beam-based feedback
  - mainly using BPM signals