European Organization for Nuclear Research

MECHANICAL STABILIZATION AND POSITIONING OF CLIC (MAIN BEAM) QUADRUPOLES WITH SUB-NANOMETRE RESOLUTION

K. Artoos, C. Collette[**], M. Esposito, P. Fernandez Carmona,

M. Guinchard, S. Janssens*, R. Leuxe, R. Morón Ballester

* PhD student ULB-CERN

** Associate ULB

The research leading to these results has received funding from the European Commission under the FP7 Research Infrastructures project EuCARD

Outline

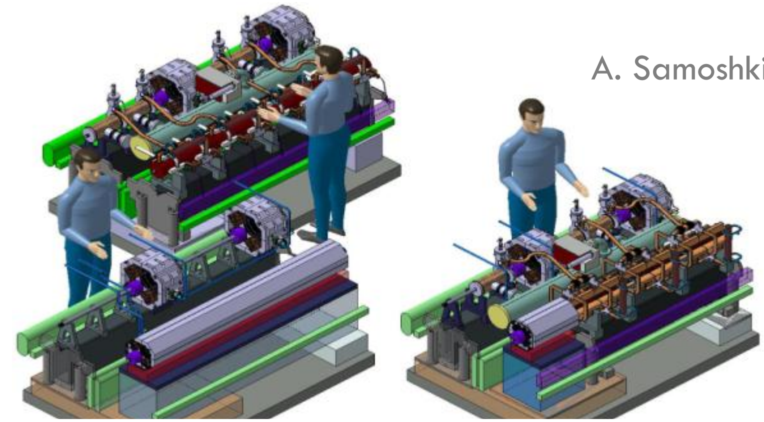
- Introduction/reminder
- CDR chapter anno October 2010
- New Years resolutions for 2011
  - **Commercial break**
- New Years resolutions for 2012

Initial requirements

3992 CLIC Main Beam Quadrupoles:

Four types :

~ 100 to 400 kg, 500 to 2000 mm



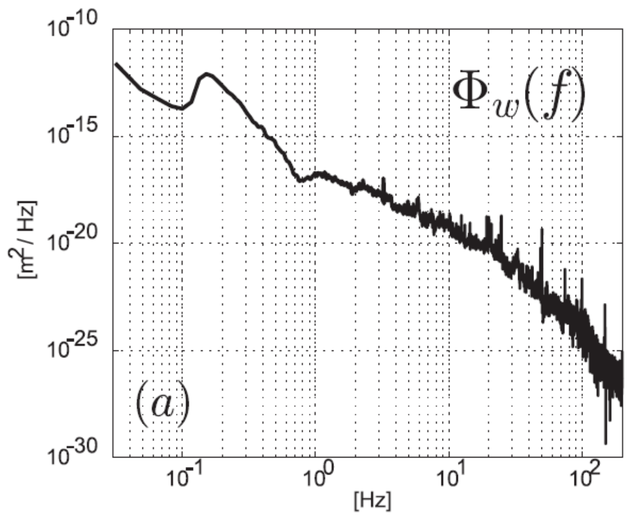
A. Samoshkin

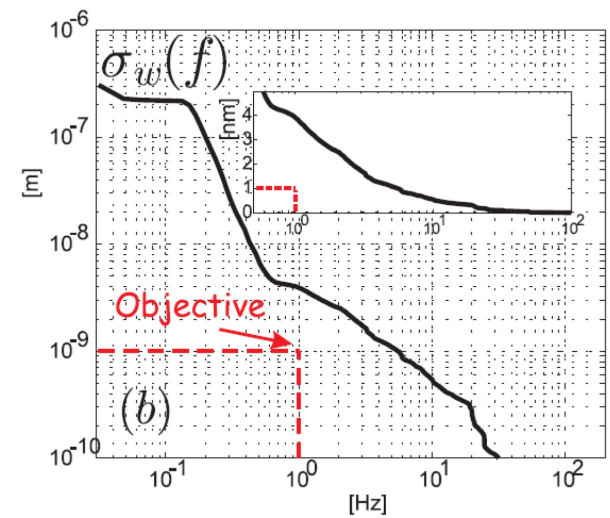
Type 4: 2m, 400 kg Type 1: 0.5 m, 100 kg

Stability (magnetic axis):

$$\sigma_x(f) = \sqrt{\int_f^\infty \Phi_x(\nu) d\nu}$$

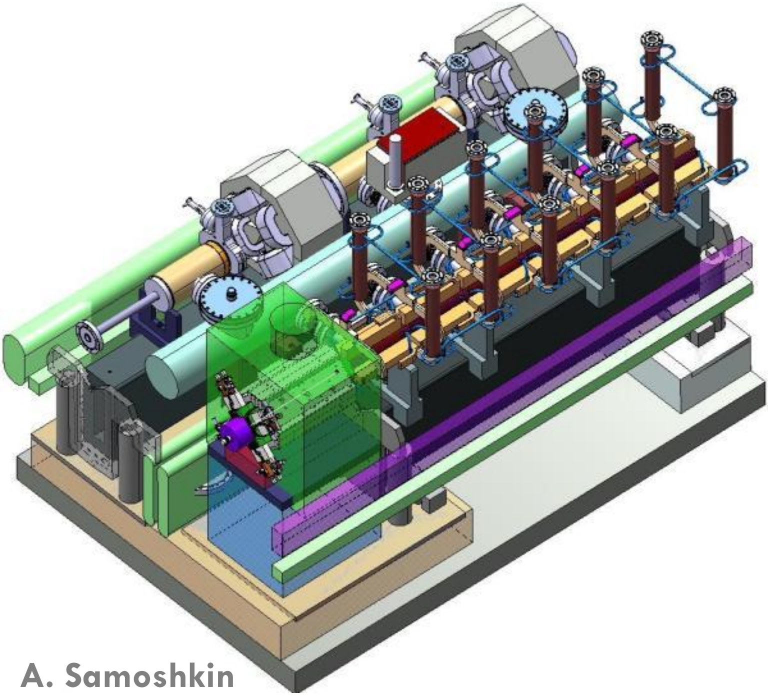
Vertical MBQ	**1.5 nm > 1 Hz**
Vertical Final Focus	**0.2 nm > 4 Hz**
Lateral MBQ, FF	**5 nm > 1 Hz** **5 nm > 4 Hz**





Introduction/Reminder:

Other requirements



A. Samoshkin

<u>Stiffness-Robustness</u>

- Applied forces
- Compatibility alignment
- Uncertainty
-Transportability

Strategy STIFF support

<u>Available space</u>

Integration in two beam module

620 mm beam height

<u>Accelerator environment</u>

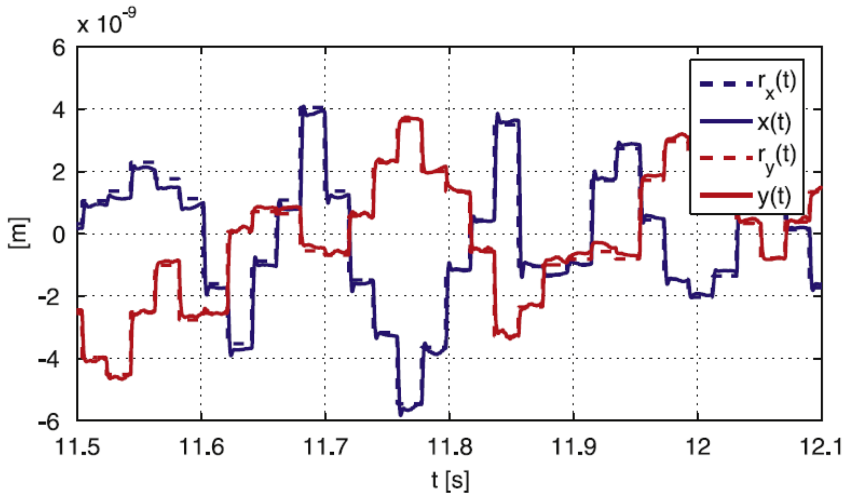
- High radiation
- Stray magnetic field

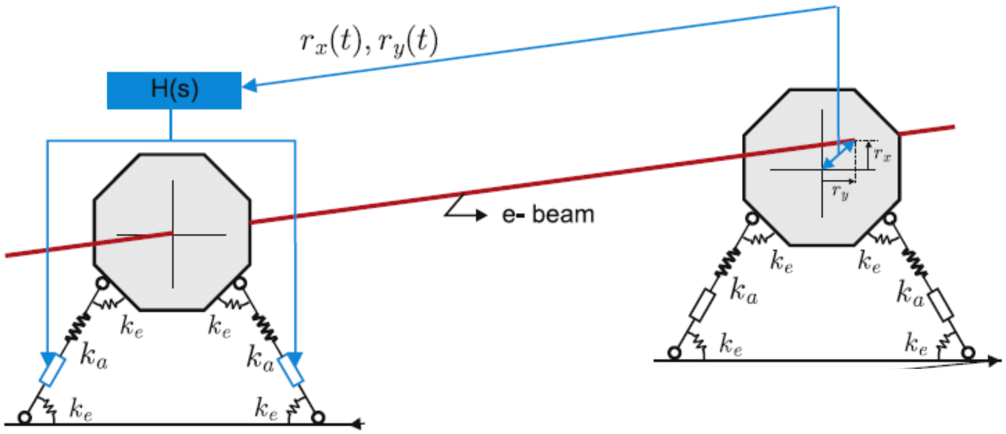
Additional study

« Nano-positioning» feasibility study

Modify position quadrupole in between pulses (~ 5 ms)

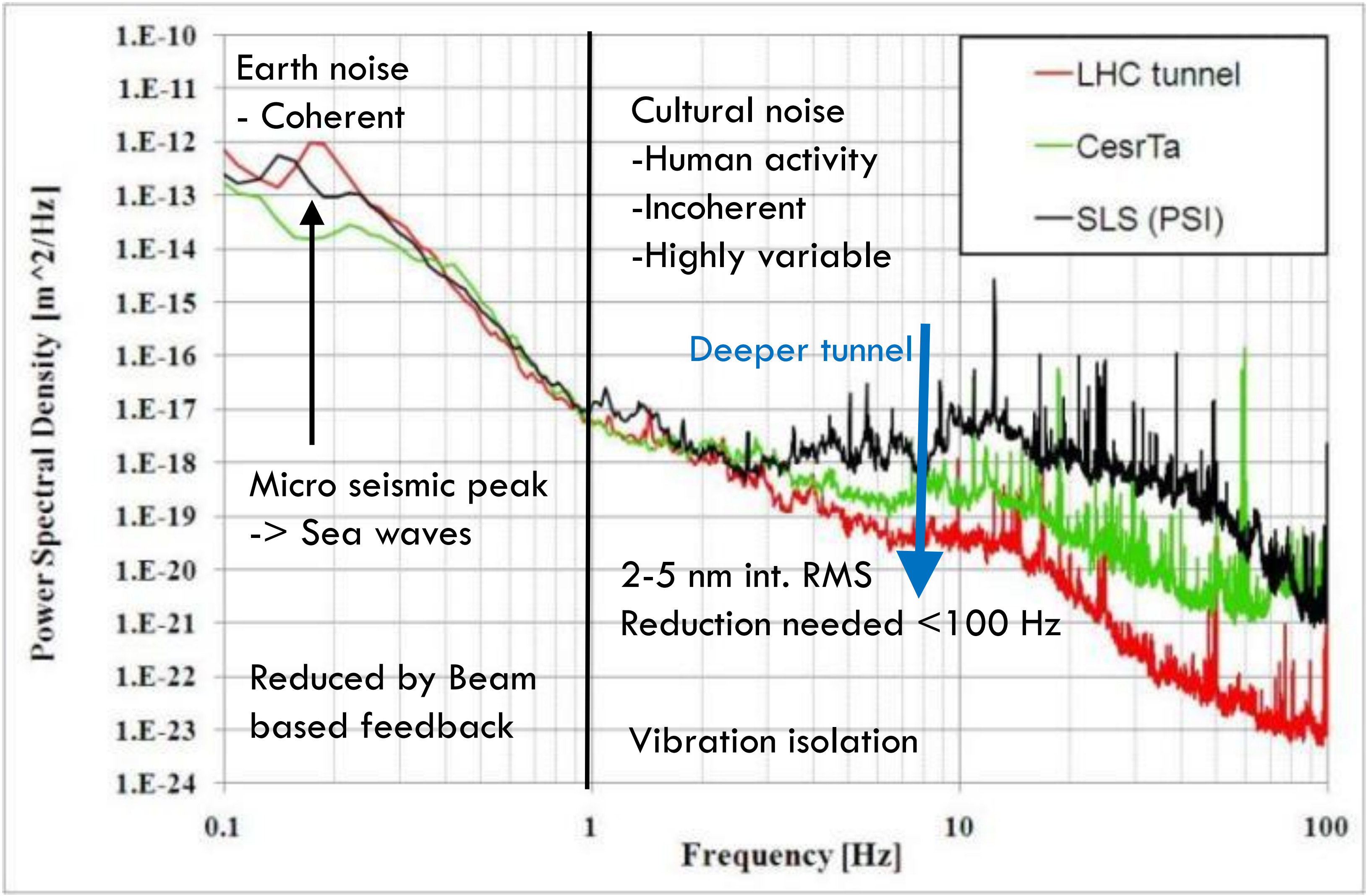
Range ± 5 µm, increments 10 to 50 nm, precision ± 1nm





- In addition/ alternative dipole correctors
- Use to increase time to next realignment with cams

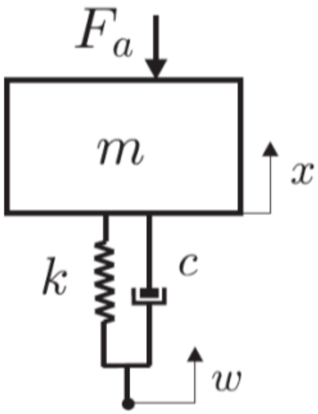
Characterisation ground vibration

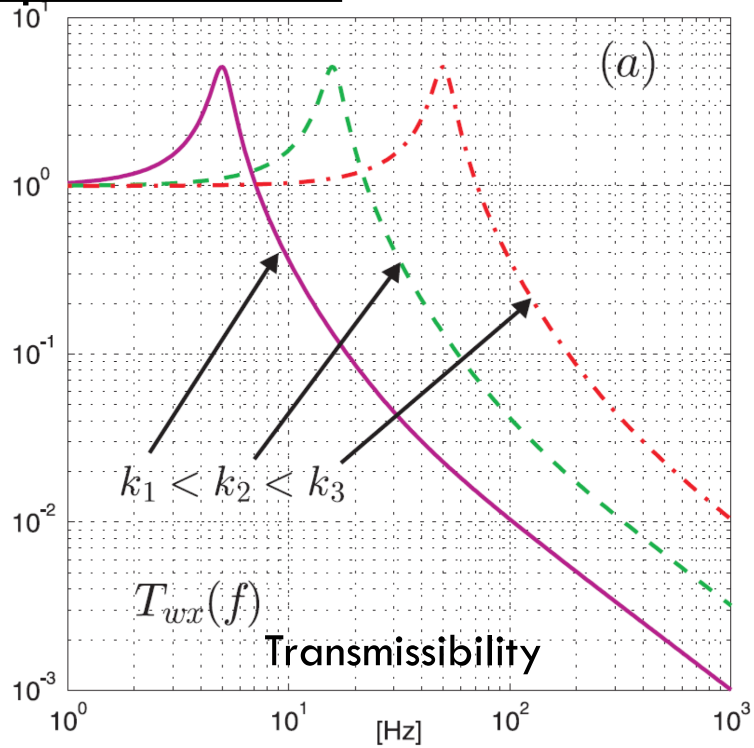


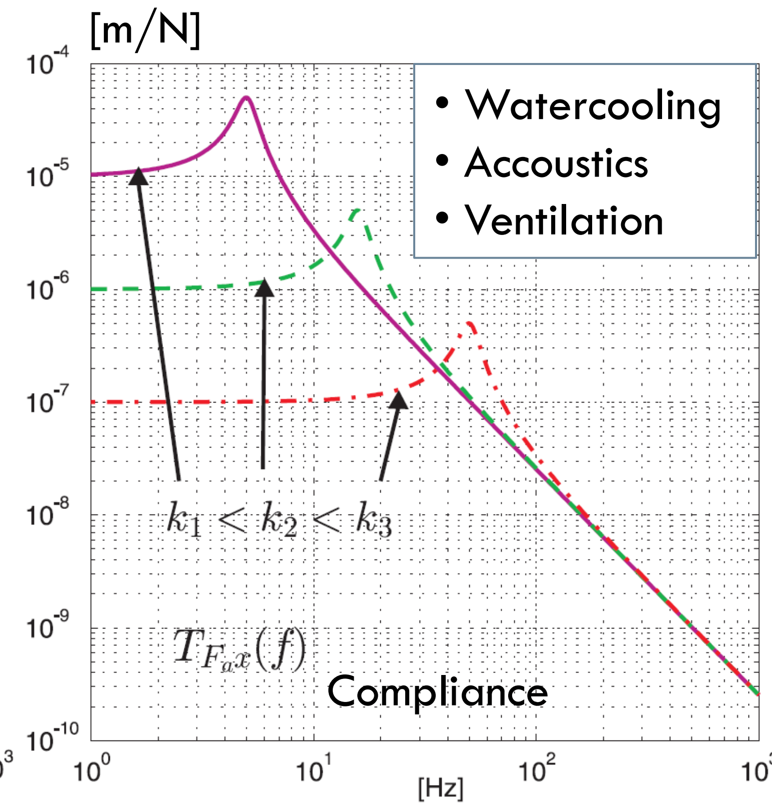
Introduction/Reminder:

Passive Isolation Strategies

Effect of support stiffness







Soft support :

- Improves the isolation
- Make the payload more sensitive to external forces Fa

Practical application

Very Soft (1 Hz)

- Pneumatic actuator
- Hydraulic actuator

k~0.01 N/μm

Soft (20 Hz)

- Electromagnetic in parallel with a spring
- Piezo actuator in series with soft element (rubber)

k~1 N/μm

Stiff (200 Hz)

- Piezoelectric actuator in series with stiff element (flexible joint)

Piezo k~100-500 N/μm

COMPARISON

Very Soft (1 Hz)

\+ Broadband isolation
\- Stiffness too low
\- Noisy

Soft (20 Hz)

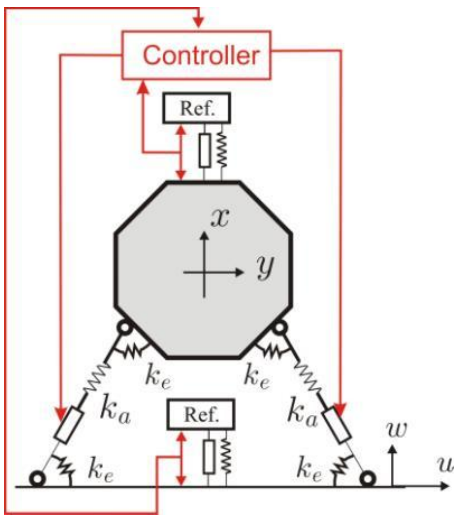
\+ Passive isolation at high freq.
\+ Stable
\- Low dynamic stiffness
\- Low compatibility with alignment and AE

Stiff (200 Hz)

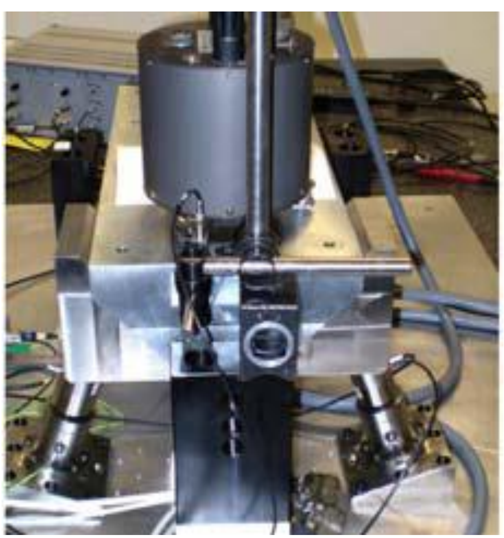
\+ Extremely robust to forces
\+ Fully compatible with AE
\+ Comply with requirements
\- Noise transmission
\- Strong coupling (stability)

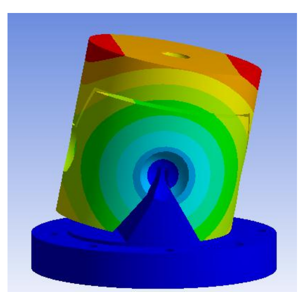
C. Collette

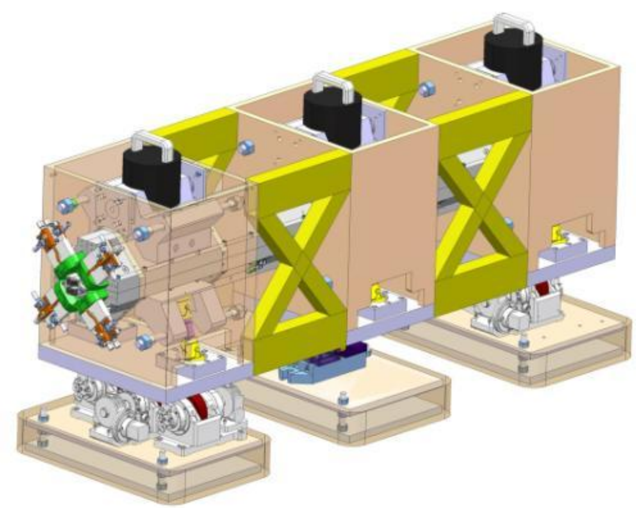
Concept



- Inclined stiff piezo actuator pairs with flexural hinges (vertical + lateral motion)
  (four linked bars system)
- X-y flexural guide to block roll + longitudinal d.o.f.+ increased lateral stiffness.
- (Seismometers)/ inertial reference masses for sensors

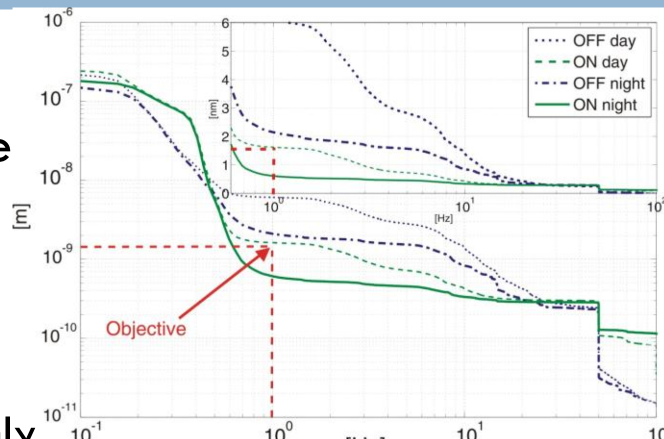






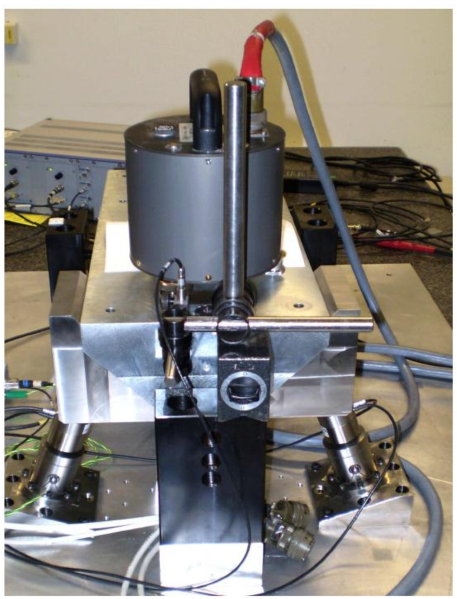
CDR Chapter Anno October 2010 (OBSOLETE)

1 d.o.f. (membrane

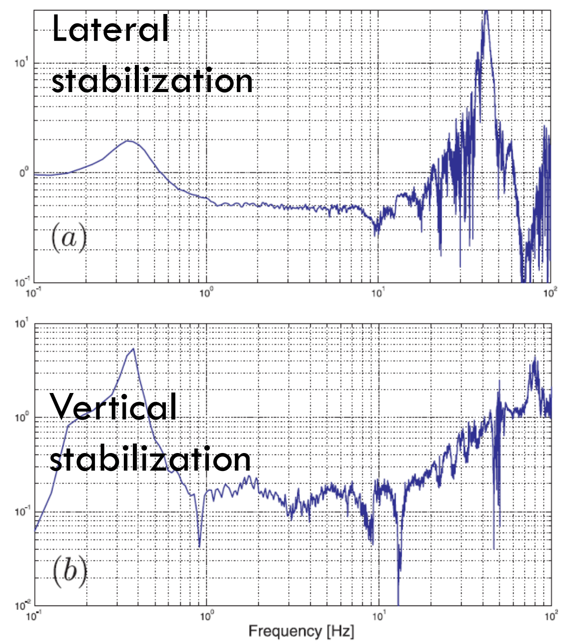


0.6 nm from 2.2 nm
1.6 nm from 6.4 nm
0.44 nm at 4 Hz

Feedback only



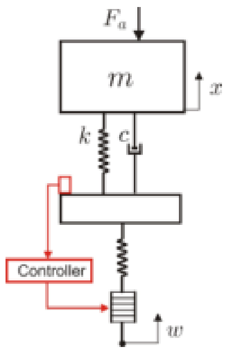
2 d.o.f. (tripod)

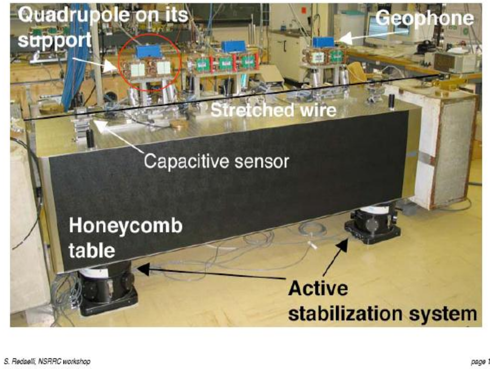


0.9 from 2 nm

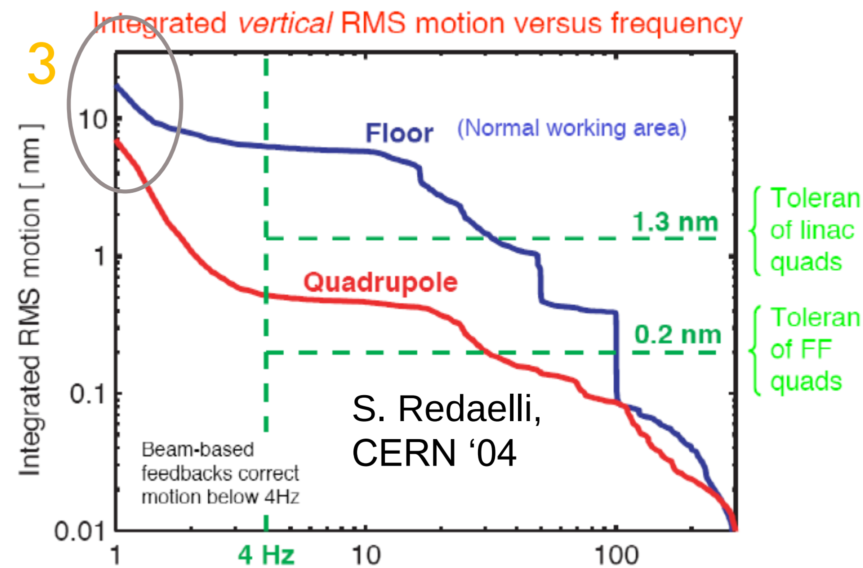
Transfer function not very good for luminosity

Previous performances on stabilization of accelerator components



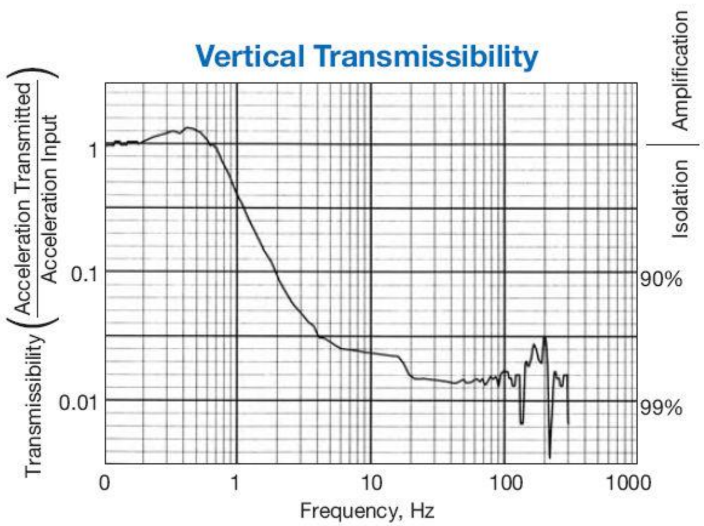


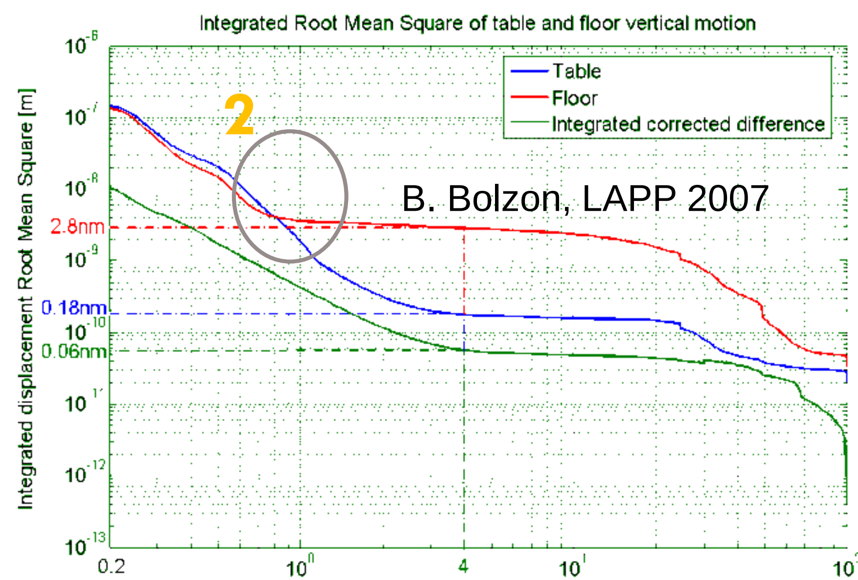
TMC STACIS™



TMC table:

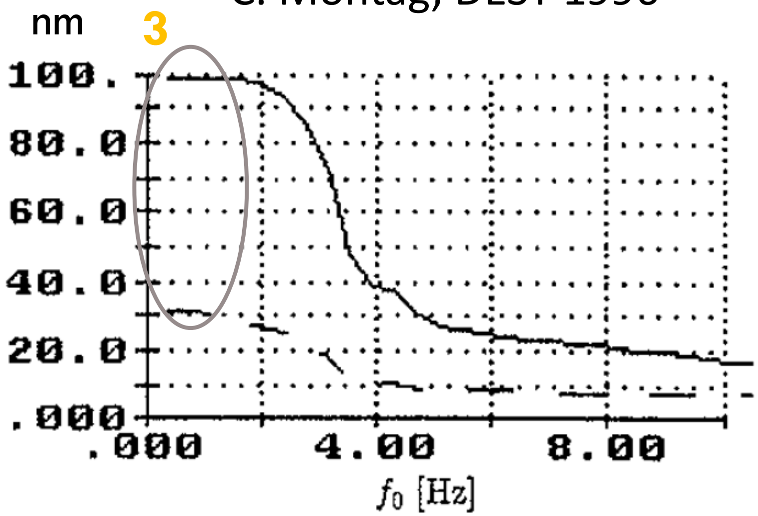
Stiffness: 7 N/µm (value catalogue)

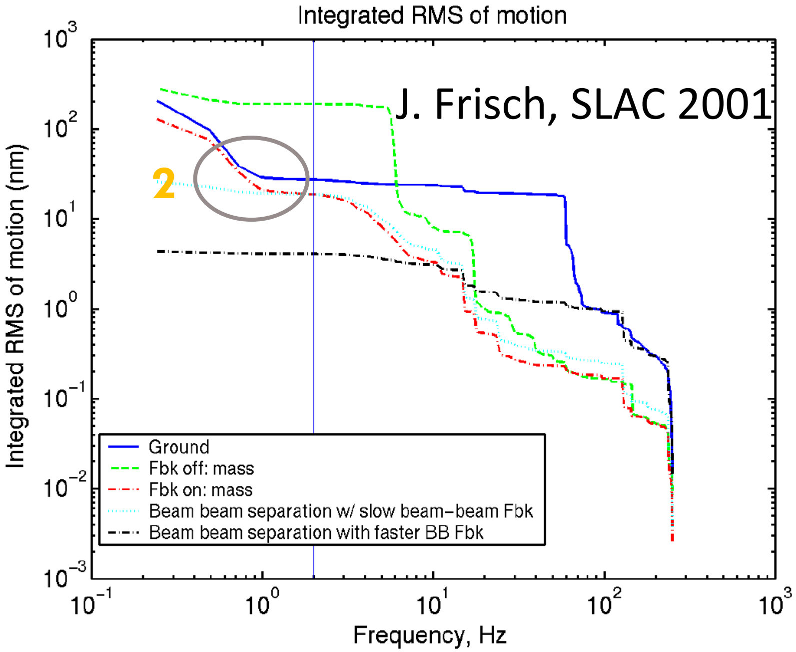




Previous performances on stabilization of accelerator components

C. Montag, DESY 1996





Resolutions for 2011

Five R&D themes in 2011:

1. Performance increase
   →Reach requirements from higher background vibrations + include direct forces
   → Increase resolution (Final focus)
2. Compatibility with environment
   → Radiation, magnetic field, Operation, Temperature
3. Cost optimization
   → Standardize and optimize components, decrease number of components, simplify mounting procedures,…
4. Overall system analysis
   → Interaction with the beam-based orbit and IP feedback to optimise luminosity Integration with other CLIC components
   → Adapt to changing requirements
5. Pre-industrialization
   → Ability to build for large quantities

Gain limited by Stability

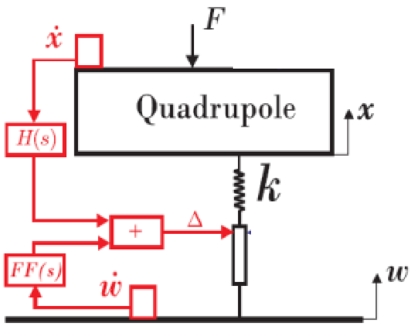
Sources of instability:

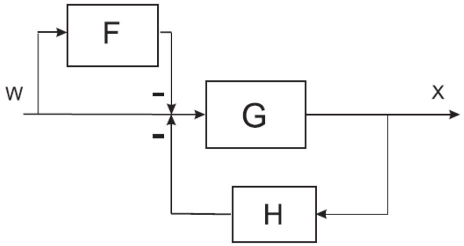
- Type of filters
- Sensor/Actuator
- Delay
- Mechanical « spurious » resonances
- Clipping

Performed work:

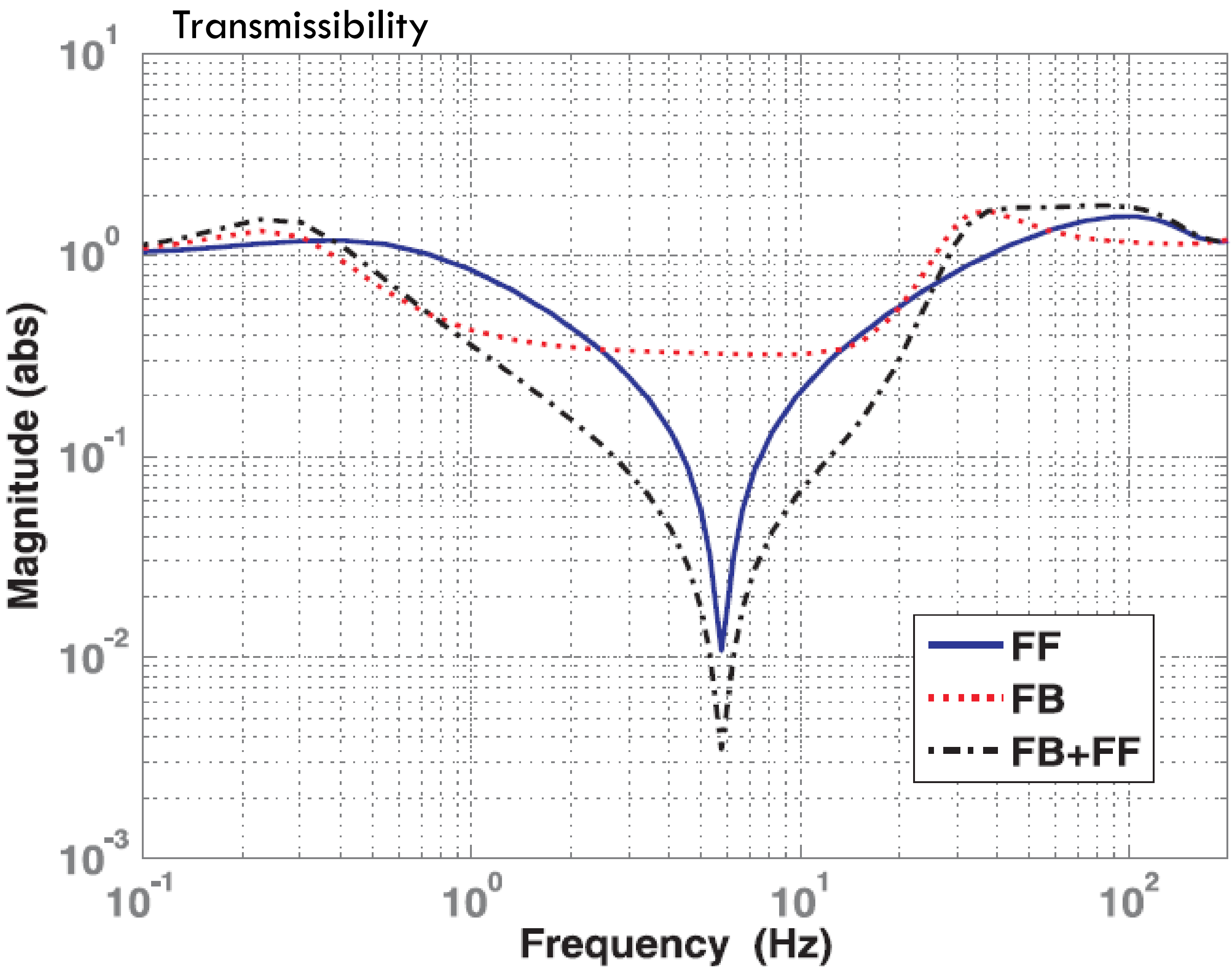
- Improvement model + controller
- Improvement type of filters
- Feedback + Feed Forward
- Study other sensors
- Change to analogue Hardware + Hybrid
- LOCAL controller
- Modal analysis , small improvements on test benches Type 1
- Optimisation of electronics

FB + FF





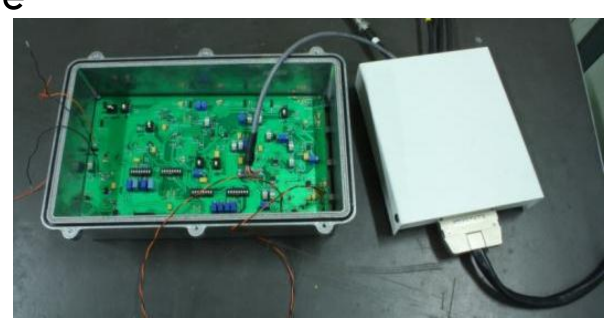
Stef Janssens



Controller electronics

PXI

Analogue



P. Fernandez-Carmona

Power ≈80W
Cost ≈15000CHF
Volume ≈13 l

Power ≈2 W
Cost ≈100CHF
Volume ≈0.15 l

From Digital to Analogue

+ **Lower latency**
Low enough noise
+ **Low cost**
+ Small volume
+ Less sensitive to single events
+ Low power consumption
-Limited flexibility, no external communication

Hybrid circuit

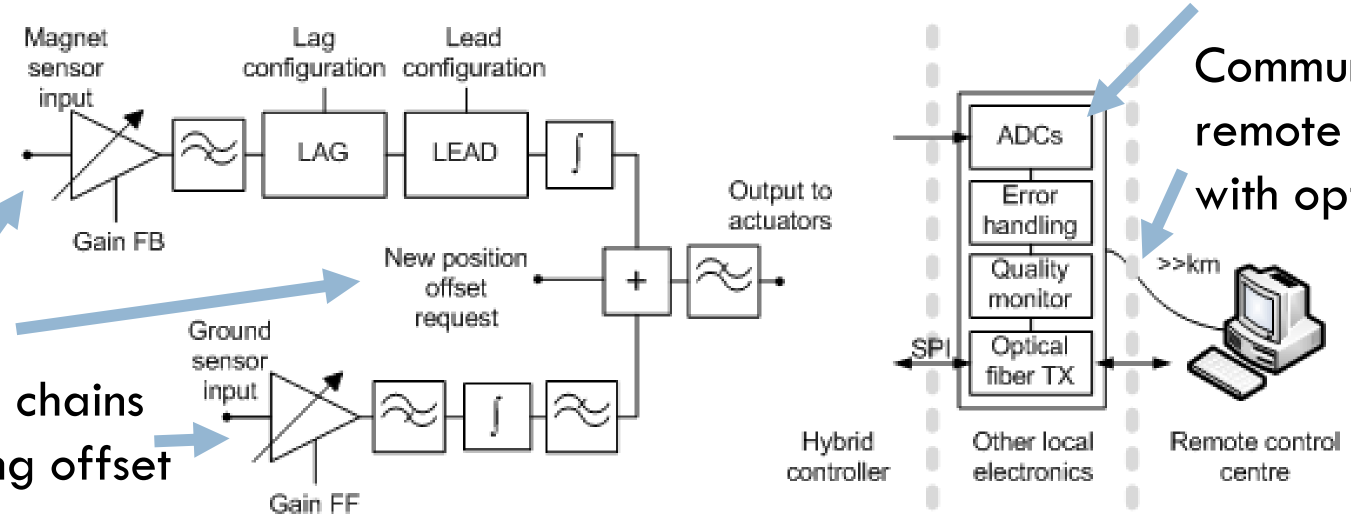
Controller electronics: Hybrid

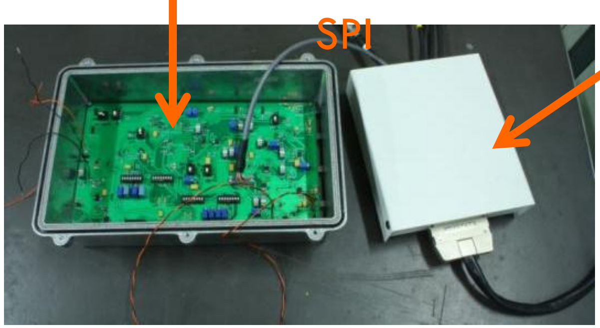
Local electronics

ADCs digitize signals
For remote monitoring

Communication to remote control center with optical fiber

2 analogue chains
+ positioning offset

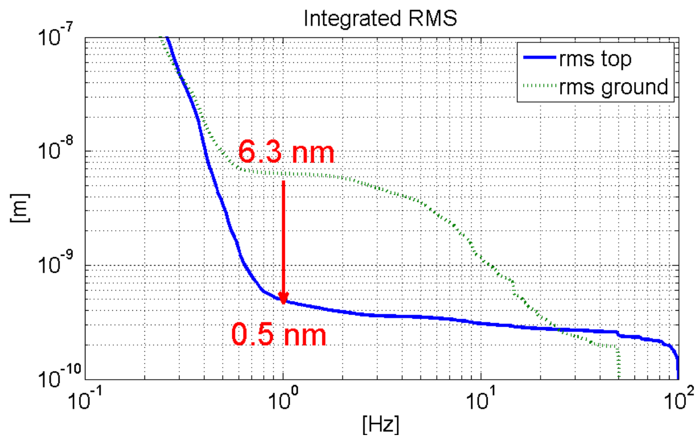




Control loop delay	Stabilization performance
43µs	100%
80 µs	90%
90 µs	80%
100 µs	60%
130 µs	30%

Stabilization on Type 1 magnet

- Water cooling 4 l/min
- With magnetic field on
- With hybrid circuit



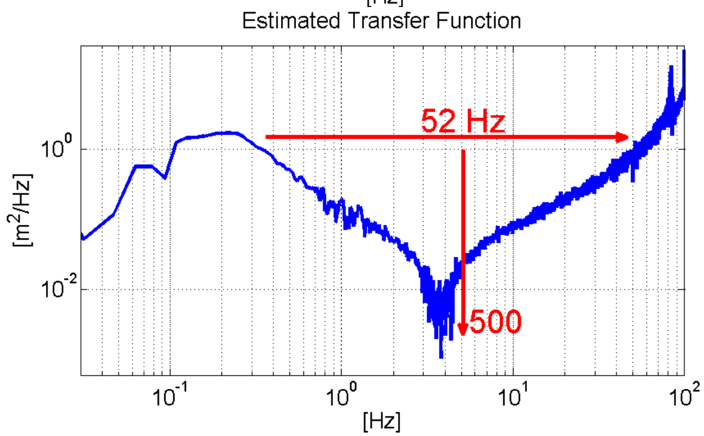
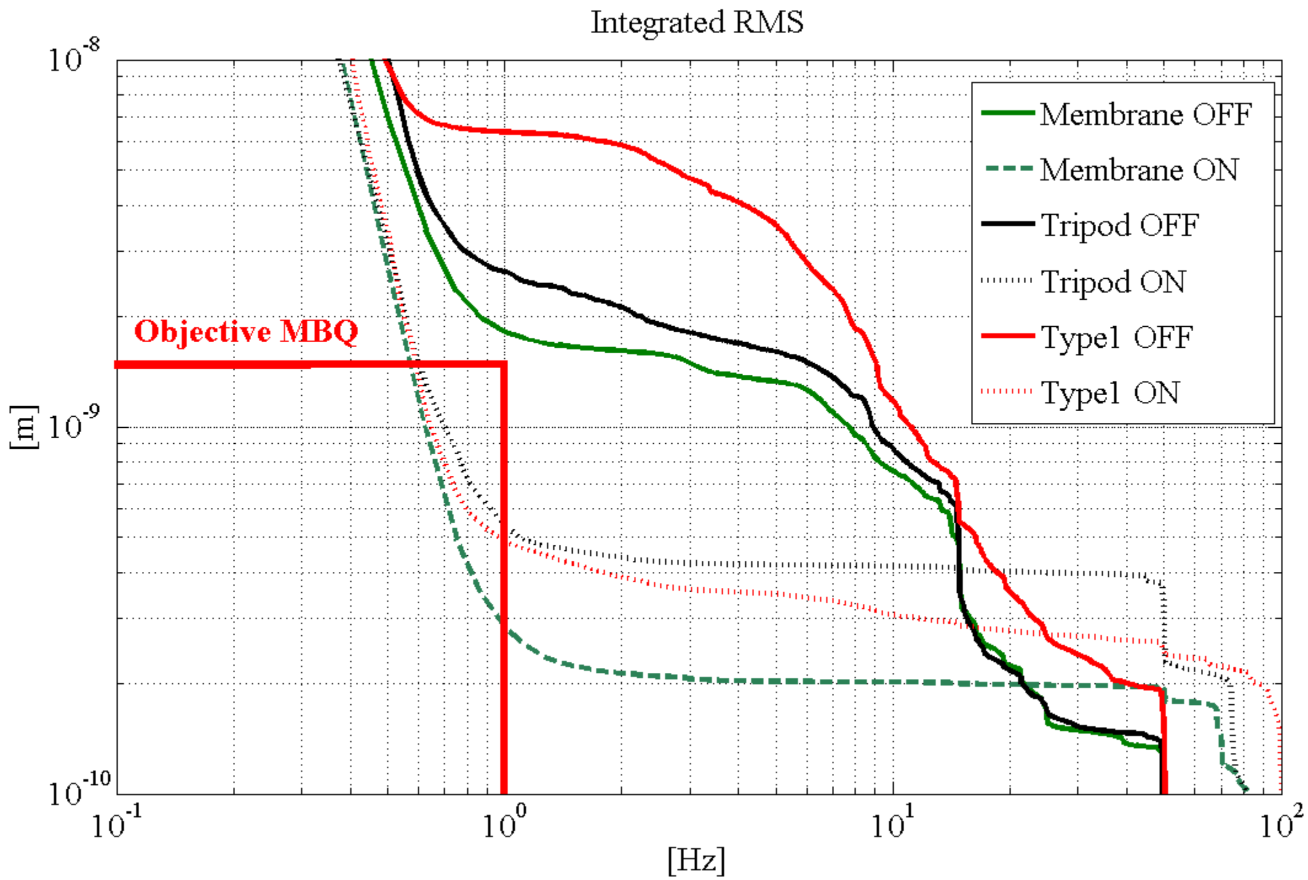


Figure	Value
R.m.s @ 1Hz magnet	**0.5 nm** (during the day)
R.m.s @ 1Hz ground	6.3 nm
R.m.s. attenuation ratio	~13
R.m.s @ 1Hz objective	**1.5 nm**

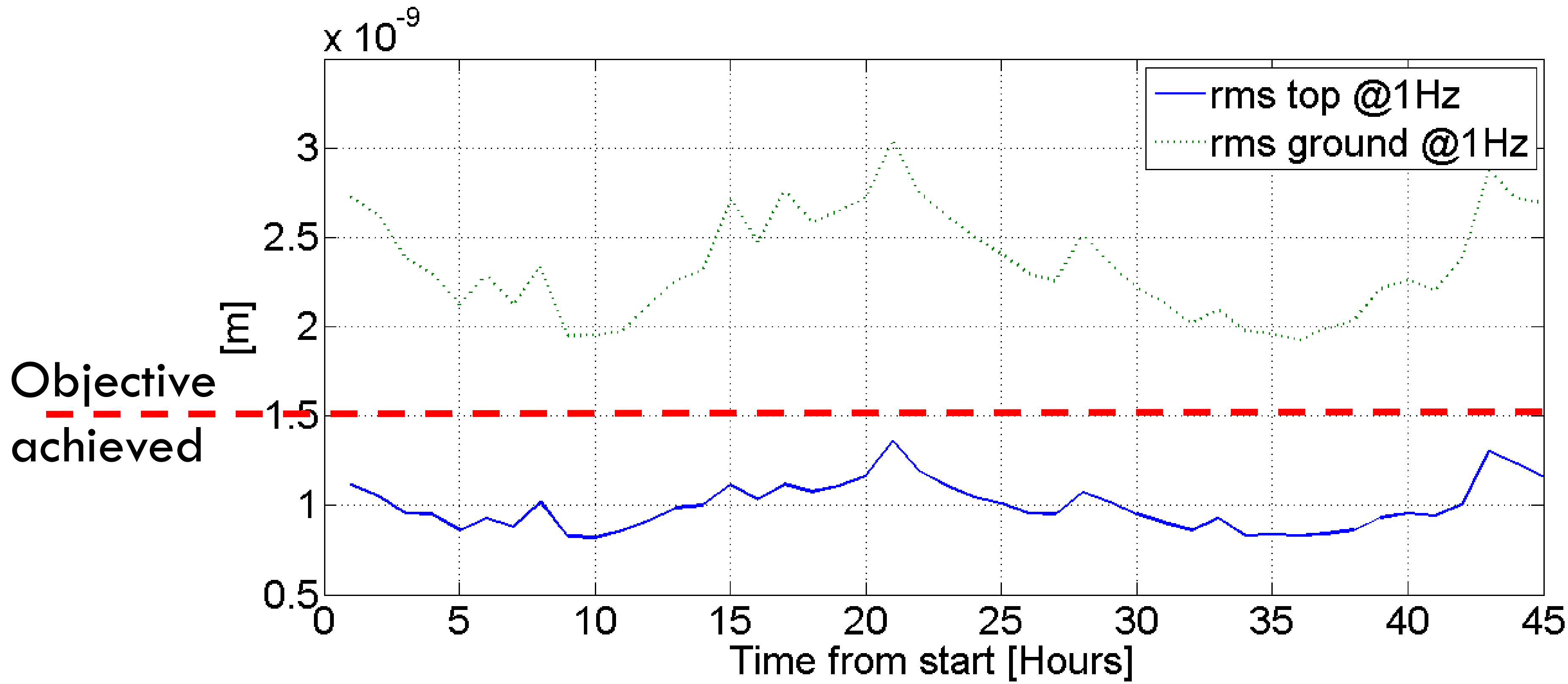
Stabilization results



- Objective reached on all testbenches
- **0.3 nm** on Membrane, **0.5 nm** on Tripod, **0.5 nm** on Type 1 (day)

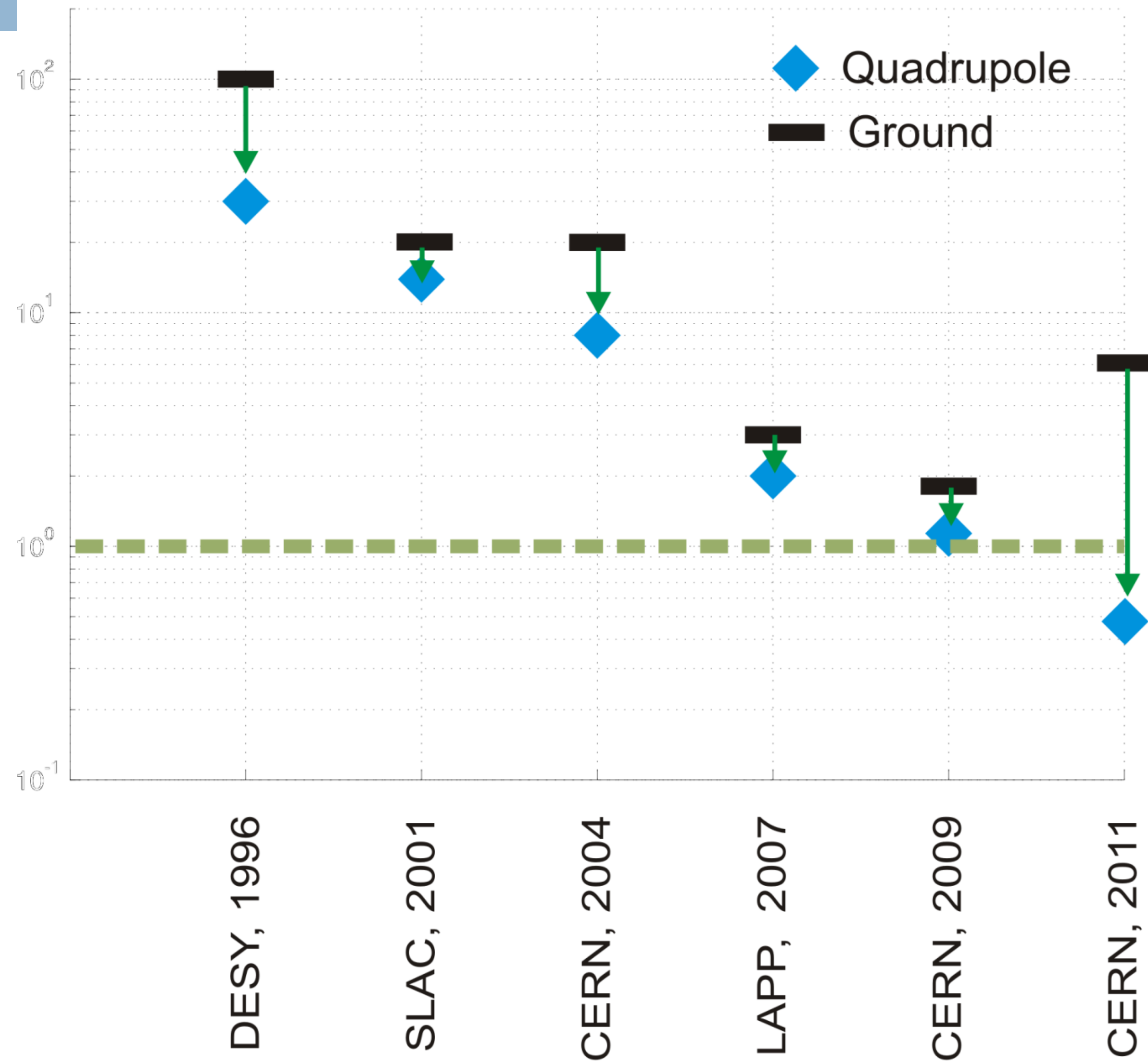
Long Term Stability

- Temperature stable within 0.5 degrees
  - Test with temperature change in preparation

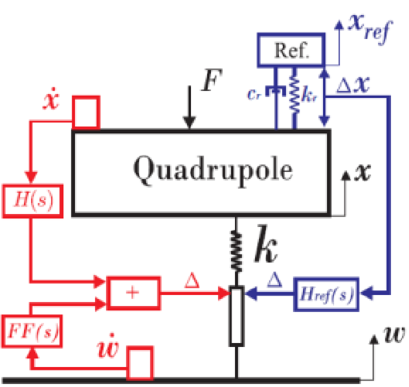


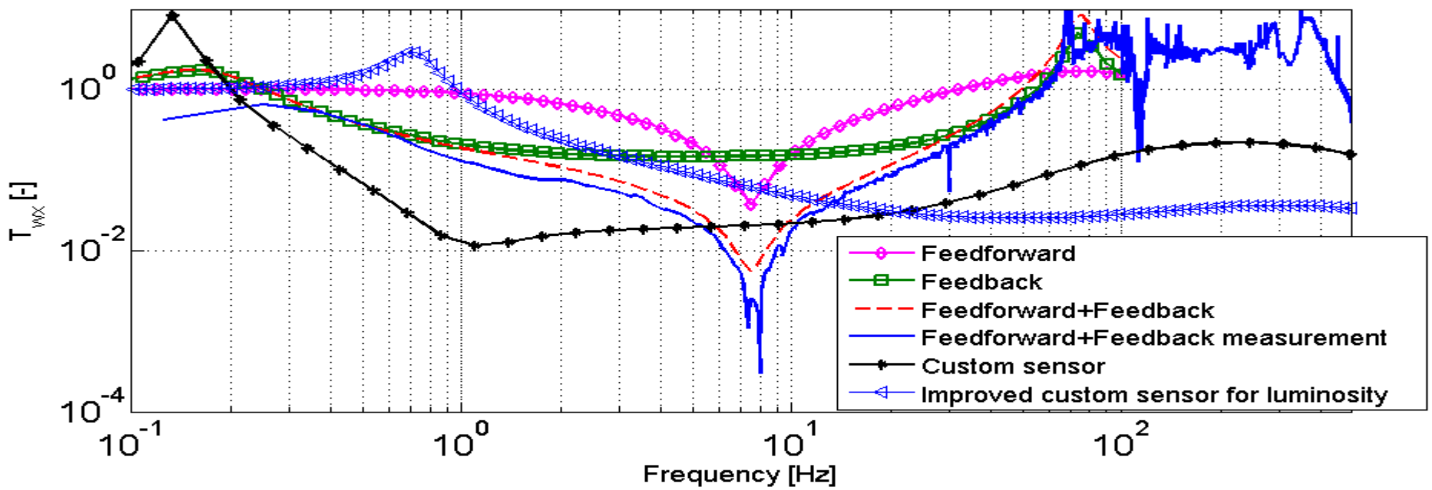
Comparison

RMS integrated @ 1 Hz



Integrated luminosity simulations





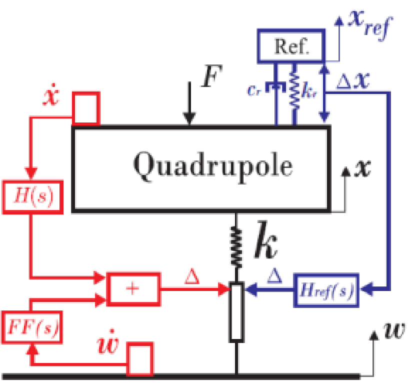
Commercial Seismometer

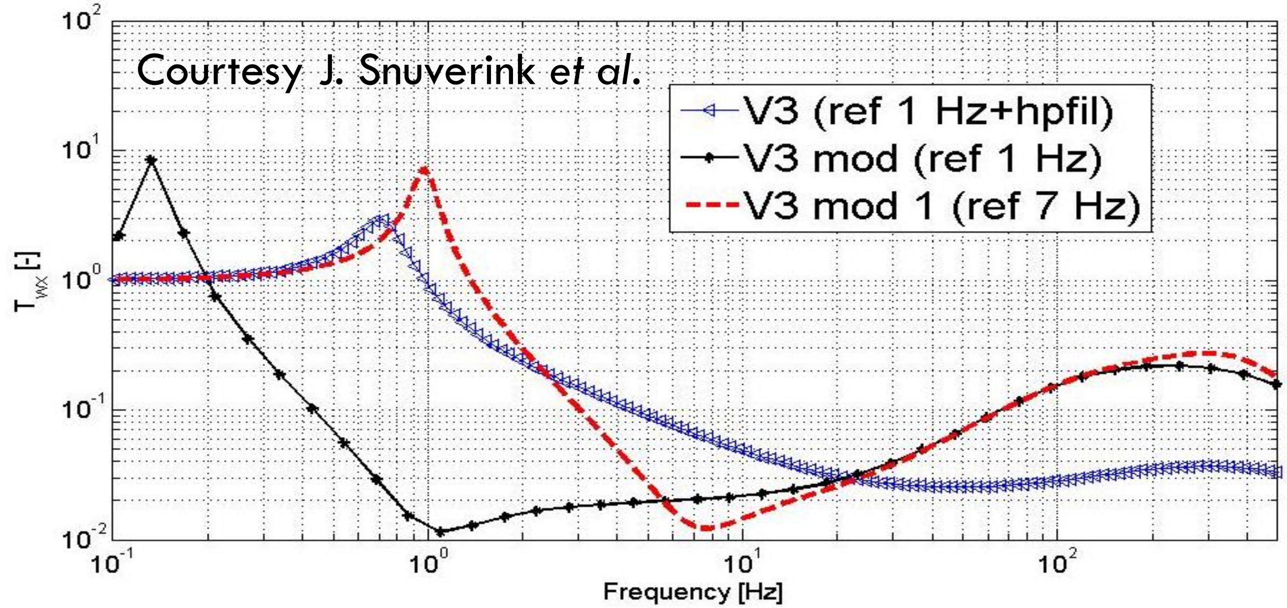
Custom Inertial Reference mass

No stabilization	68% luminosity loss
Seismometer FB maximum gain (V1)	13%
Seismometer FB medium gain (V1mod)	6% (reduced peaks @ 0.1 and 75 Hz)
Seis. FB max. gain +FF (FBFFV1mod)	7%
Inertial ref. mass 1 Hz (V3mod)	11%
Inertial ref. mass 1 Hz + HP filter (V3)	3%

Courtesy J. Snuverink, J. Pfingstner *et al.*

Integrated luminosity simulations





Commercial Seismometer

Custom Inertial Reference mass

No stabilization	68% luminosity loss
Inertial ref. mass 1Hz (V3mod)	11%
Inertial ref. mass 1Hz + HP filter (V3)	3%
Inertial ref. mass 7 Hz (V3 mod 1)	Orbit fb optimised V3: 0.7%

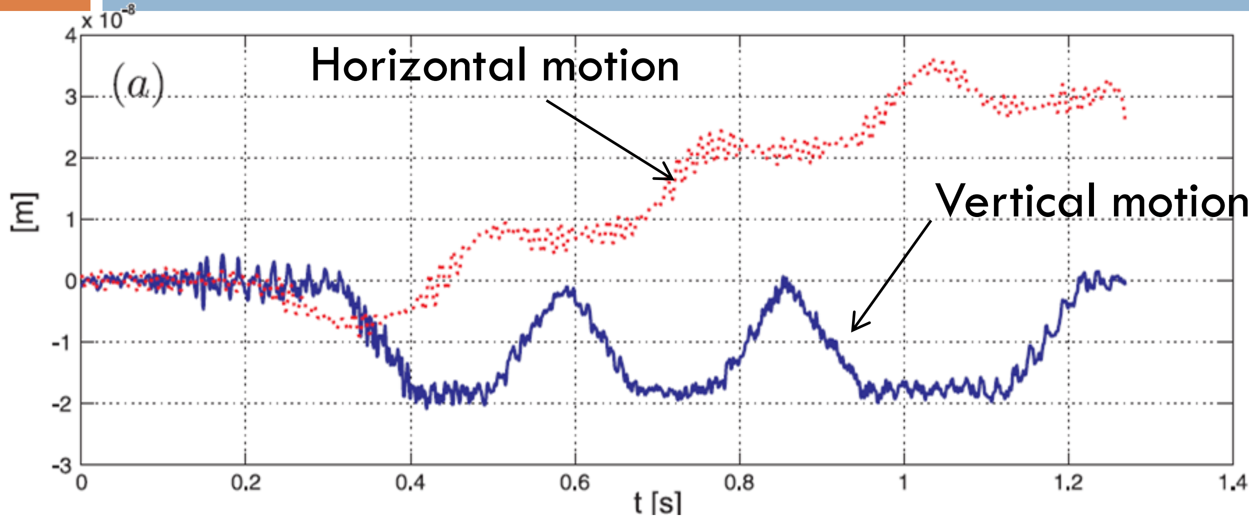
→ref. mass 7 Hz easier to make mechanically!

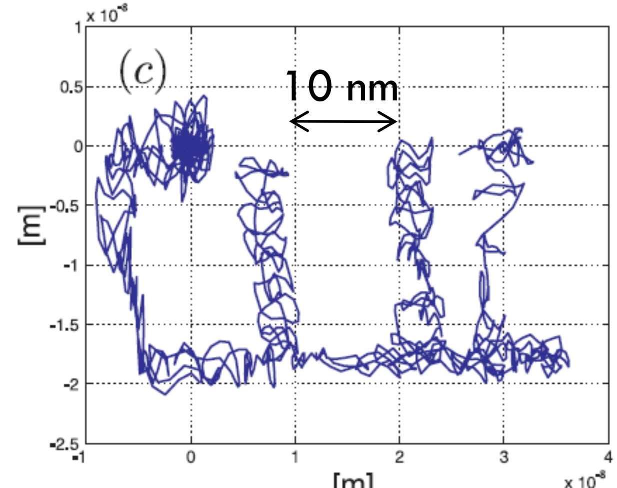
Question: peak at 1 Hz problem?

Other question: Use of measurement files to calculate luminosity?

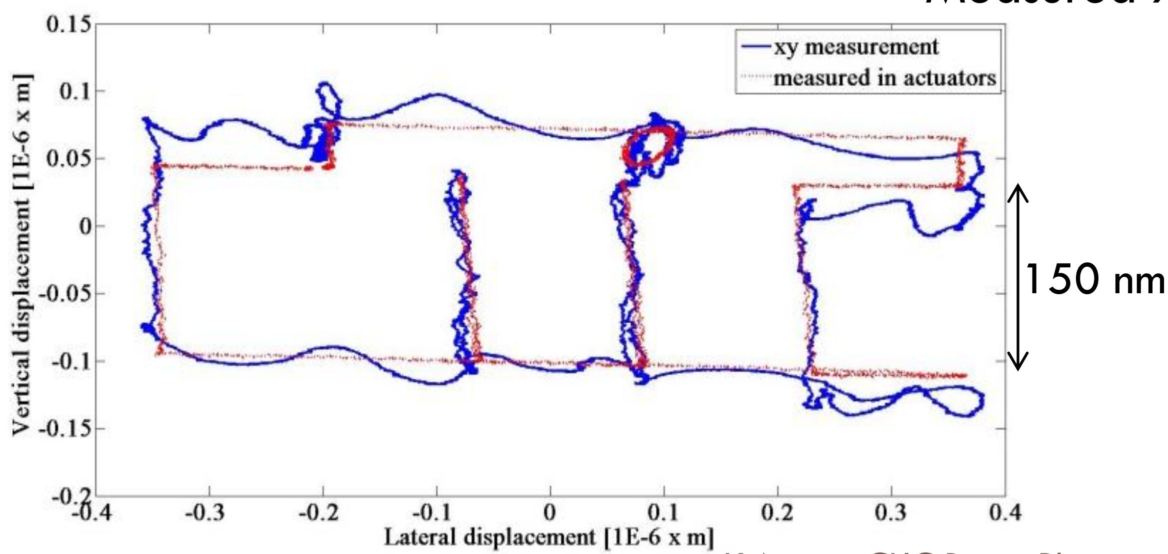
Or inverse: calculate r.m.s from used GM model?

Positioning in 2 d.o.f.



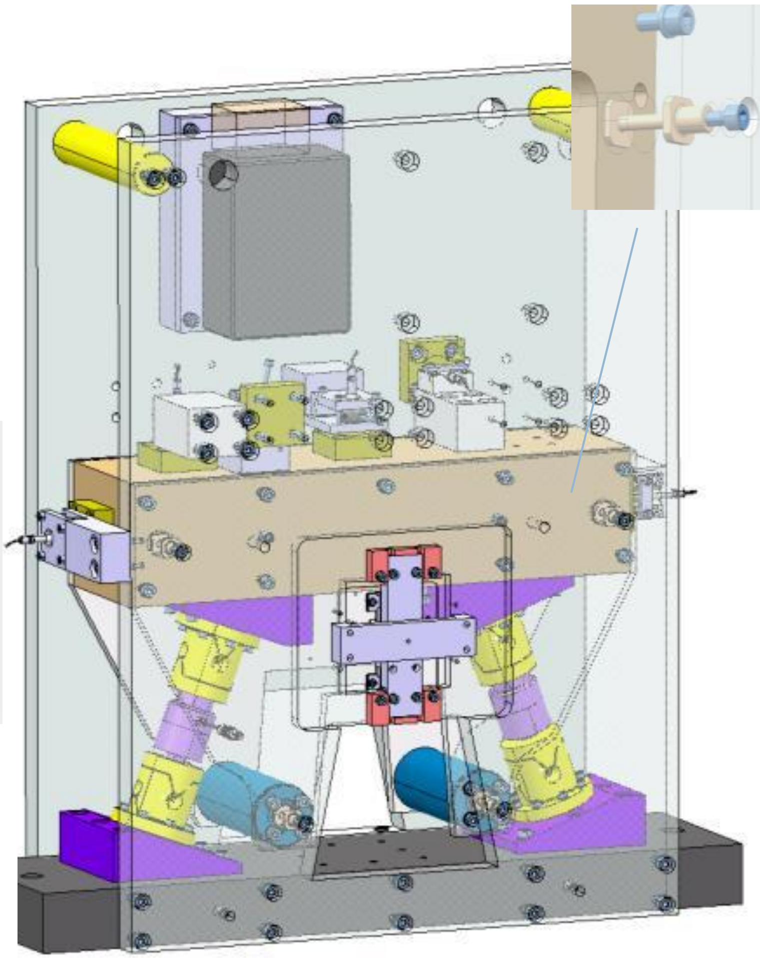


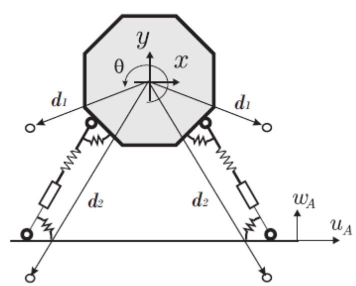
Measured x-y capacitive



Positioning + Stab. test bench
X-y guide prototype

- X-y guide « blocks » roll + longitudinal
- Increases lateral stiffness by factor 500
- Introduces a stiff support for nano metrology





M. Esposito, R. Leuxe

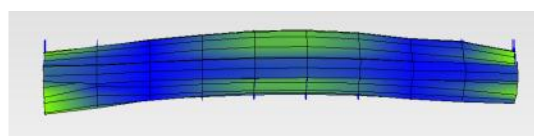
Questions for Beam physics WG for nano positioning

Required resolution (or precision ?)
Size of steps and time available
Evaluate both steering and “alignment”.
Draw back of moving the BPM by some nm to some microns, understand the mechanism and from this the requirements
Should we uncouple the BPM from the nano positioning ?

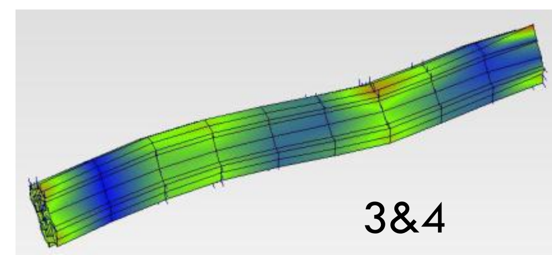
Experimental modal analysis MBQ

MBQ Type 4 in free-free condition

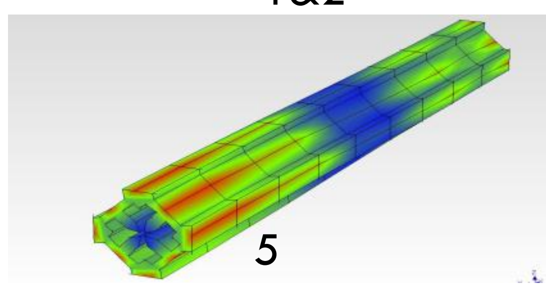
Mode	Freq. (Hz) Measured	Damping (%) Measured
1 & 2	264	1.26
3 & 4	628	3.32
5	656	1.94
6&7	1090	3.54



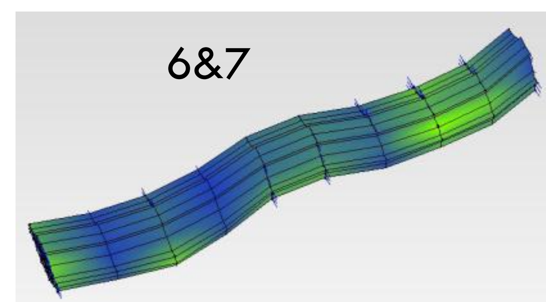
1&2



3&4



5

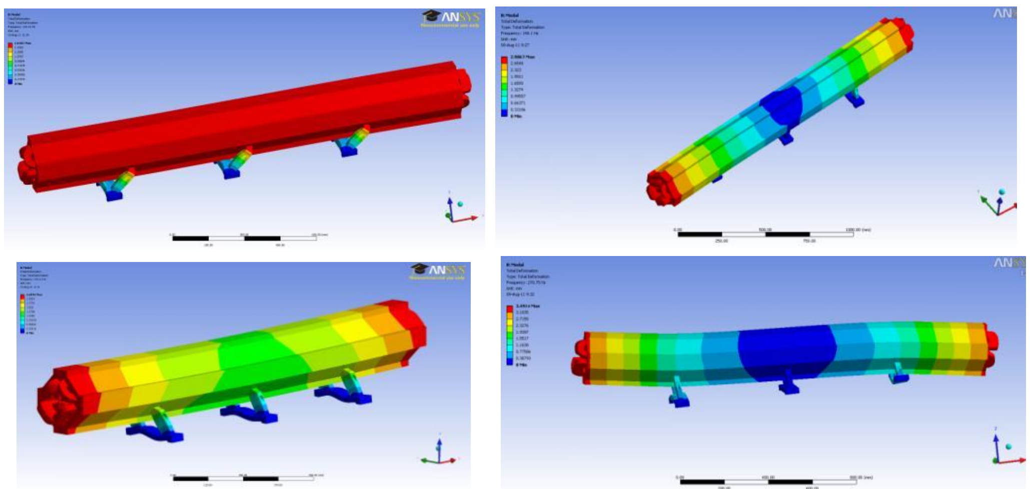


6&7

M. Guinchard, R. Morón Ballester

FE Modal analysis MBQ Type 4 with supports

FE analysis magnet on equivalent “dummy” supports with adaptable stiffness



Magnet suspension modes:

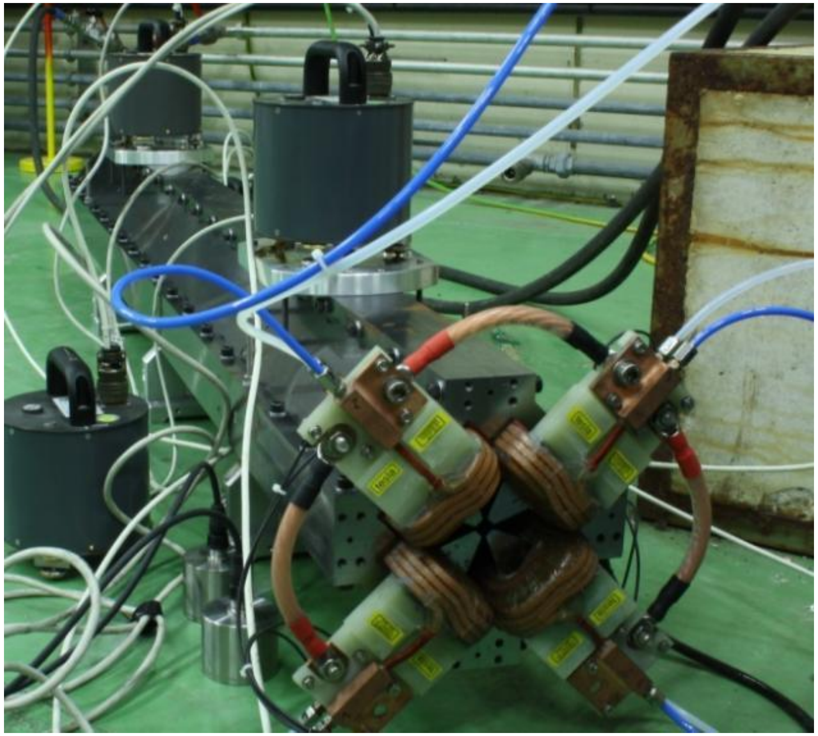
Longitudinal: 124 Hz
Yaw: 134 Hz
Lateral: 164 Hz
Pitch: 257 Hz

Conclusions Modal analysis:

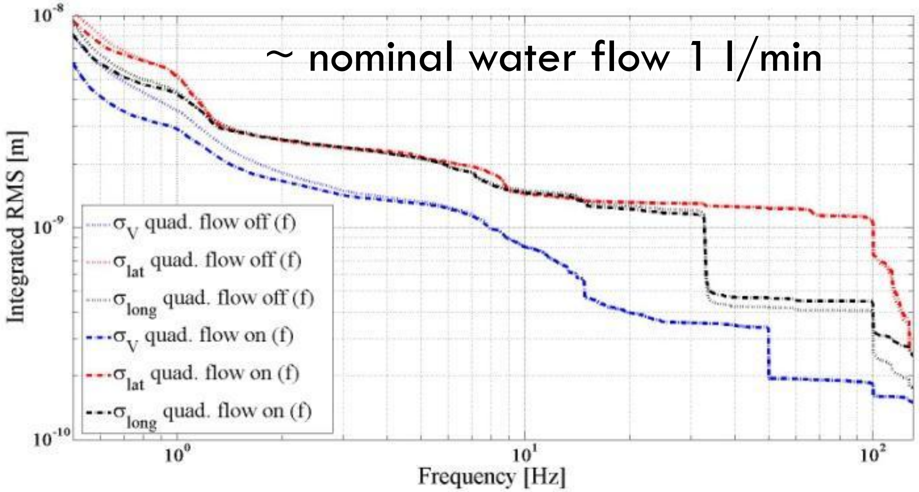
Marco Esposito

- Magnet assembled with bolts is **sufficiently stiff**
- The coil does not participate to the magnet stiffness
- Complete FE model now available that corresponds well to measurements
- There are **no internal modes of the magnet pole tips in the frequency region of interest,** nor in the measurements neither in the model **i.e. The magnet stability can be measured on the outside**
- Most important modes are the **magnet suspension modes** > important input for design

Water cooling tests
T4 MBQ on equivalent supports



S. Janssens

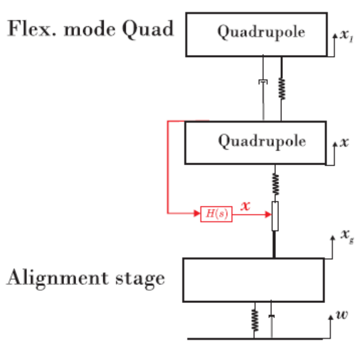


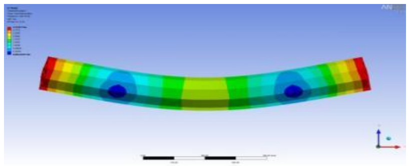
Very small measured increase (< 1 nm)
Very conservative estimate increase of r.m.s. displacement of 2 nm (without stabilisation)

→ Stiff support a good choice

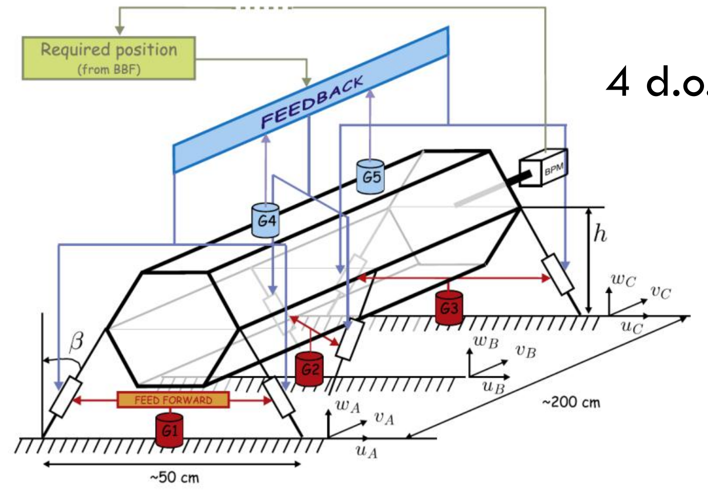
MULTIPLE d.o.f.

<u>Modeling multiple d.o.f. in parts:</u>
get firm understanding of interactions between mechanics and controller

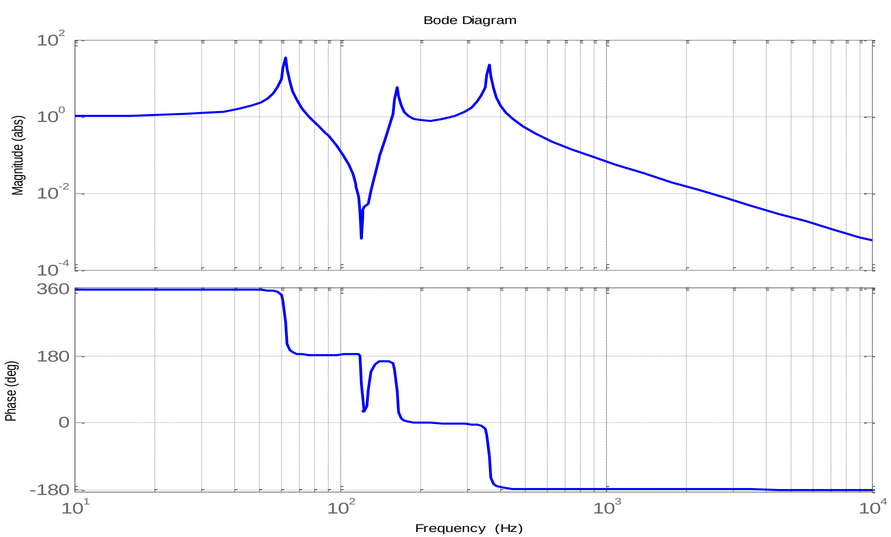


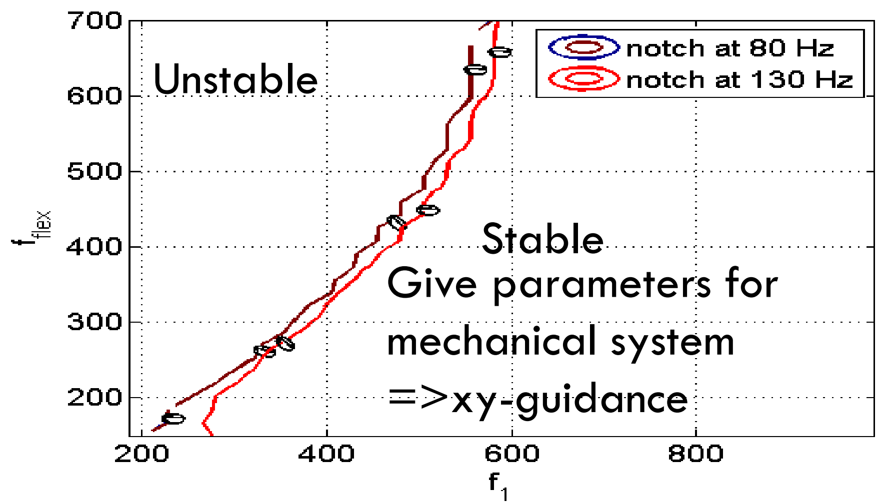


Stef Janssens, Christophe Collette



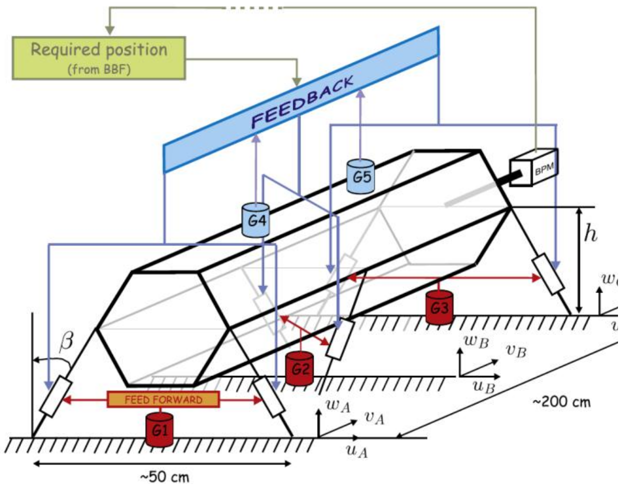
4 d.o.f.





Give parameters for mechanical system =>xy-guidance

MULTIPLE d.o.f.

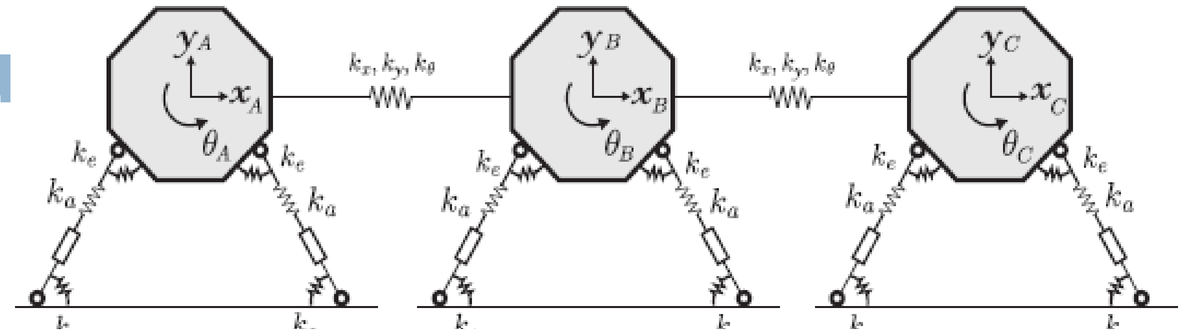


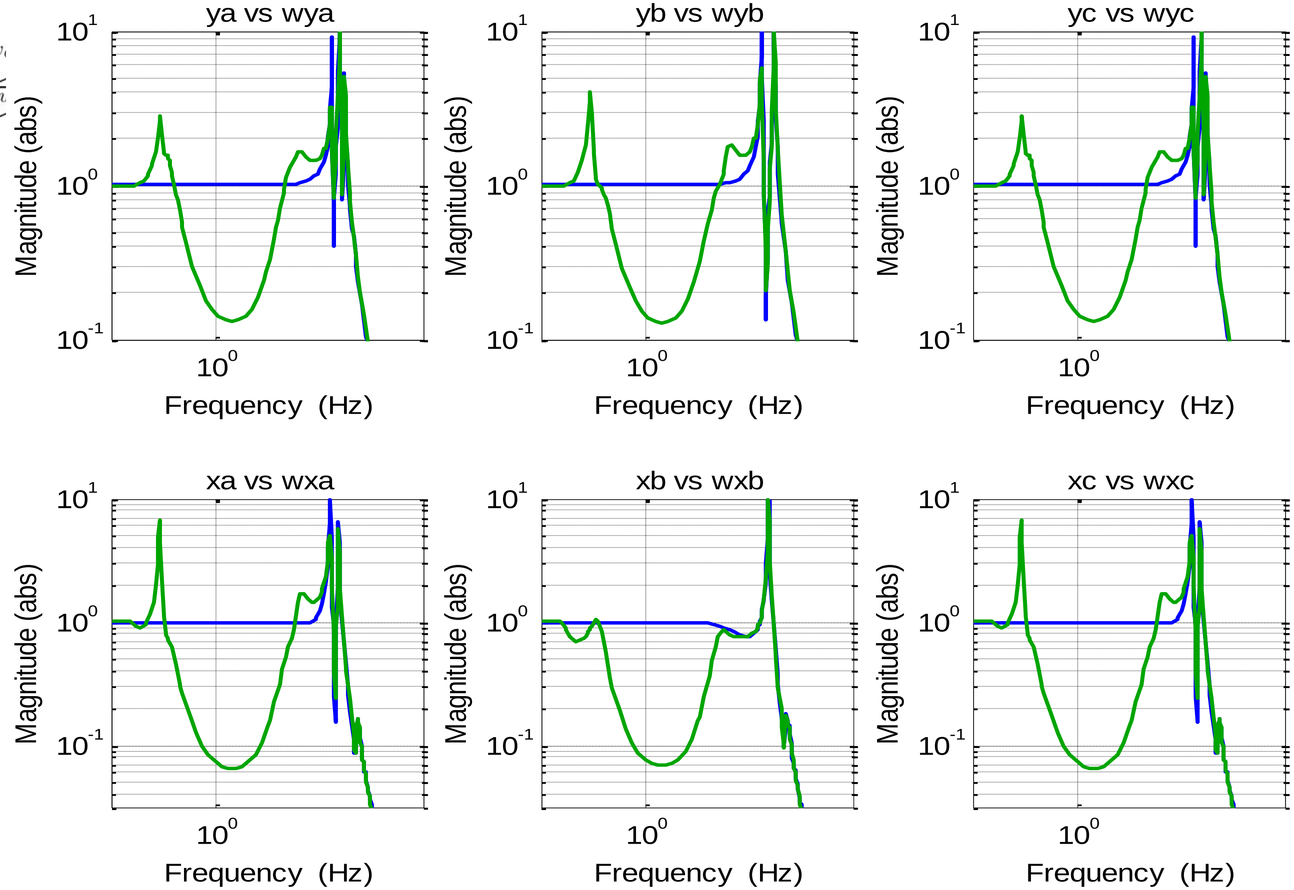
$$\dot{\mathbf{q}} = J\dot{\mathbf{x}}$$

$$M\ddot{\mathbf{x}} + K\mathbf{x} = k_a B\mathbf{\Delta} + k_a BE\mathbf{w}$$

$$K = k_a BB^T$$

$$B = J^T$$





To be done:

- Add alignment

Stef Janssens,
Christophe Collette

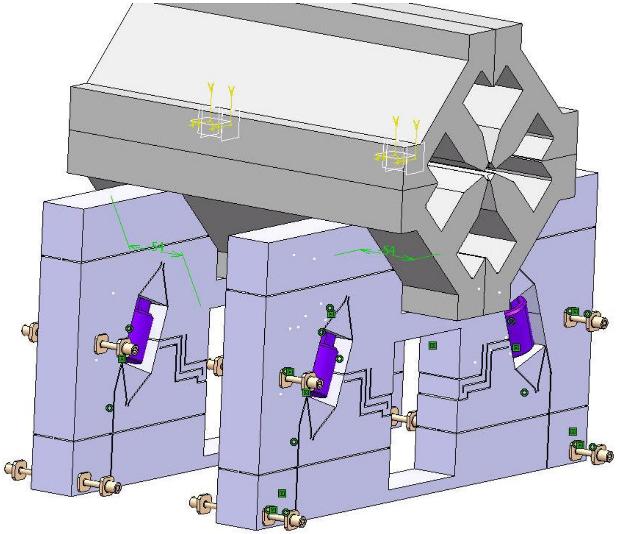
2012

- Continue our 2011 resolutions…

+

- Build and test a stabilised Type 1 and type 4 MBQ placed on the alignment system   At first with Guralp
- Install it (after full testing in ISR) in the test module.
- Design and build a type 1 for CLEX
- Build and test several sensor prototypes
- Remote control part of the electronics
- Radiation testing : SEU + accumulated dose
- Join the work on FF

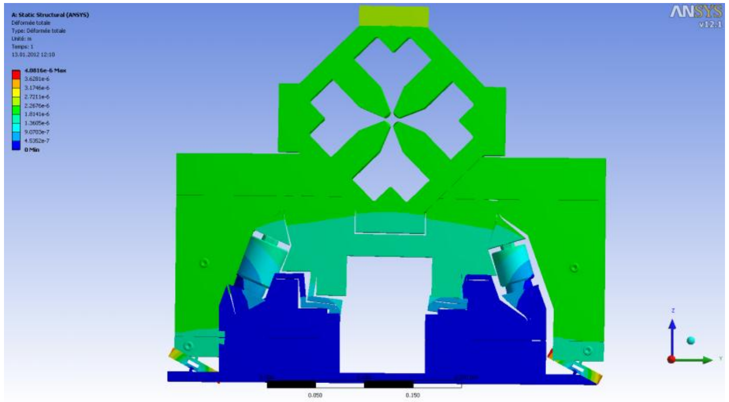
Mechanical design

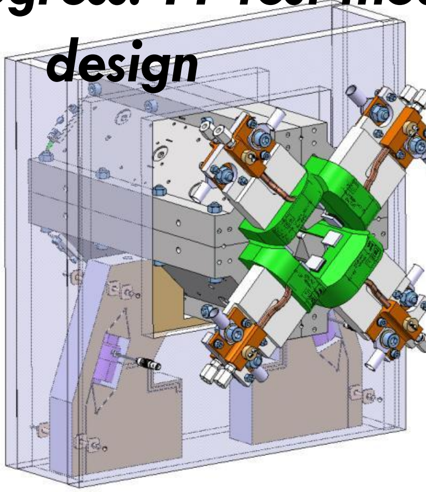


<u>Monolithic approach of the design:</u>

- To simplify the assembly + increase precision
- Reduce assembly stresses on actuator + magnet
- Improve sensor installation: inertial ref. mass and displacement gauges
- Optimise vertical, lateral and longitudinal stiffness
- Solve integration in module
- Mechanical locking for transport
- Improve interface with alignment

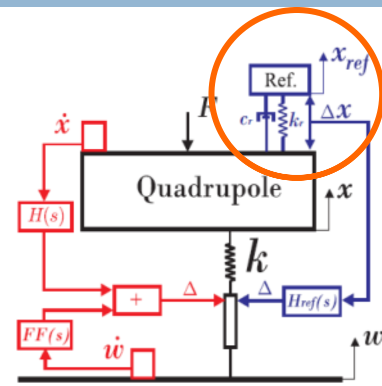
Work in progress: T1 test module design



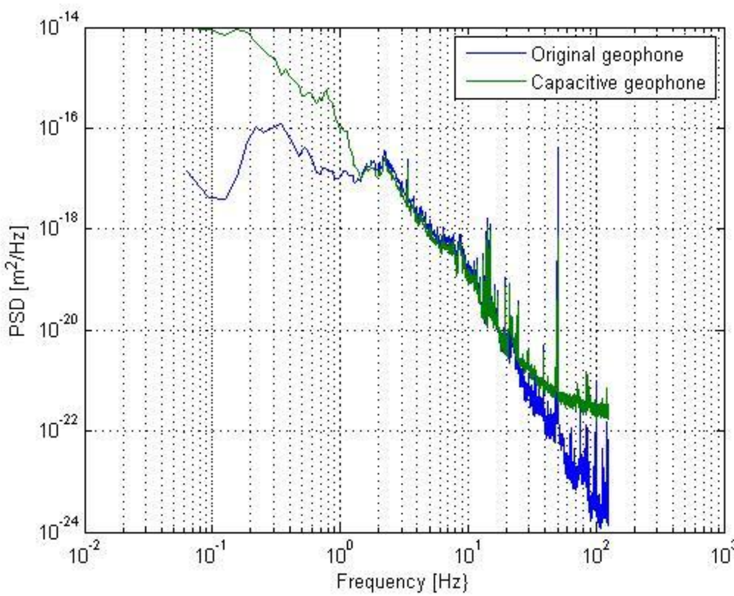


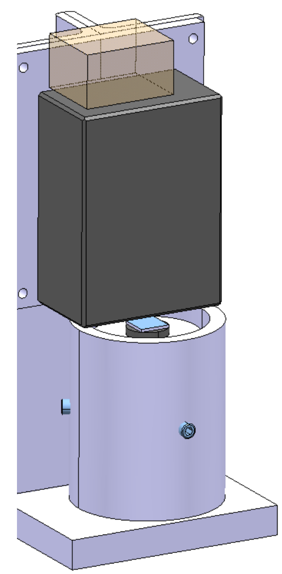
Development Inertial reference

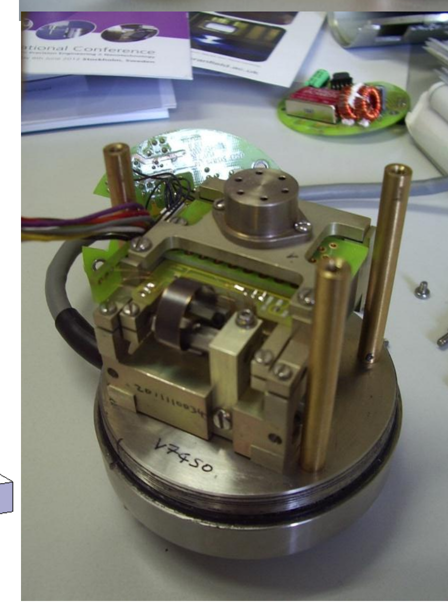
Goal: Improved transfer function
Radiation and magnetic field hard
Lower noise, higher resolution



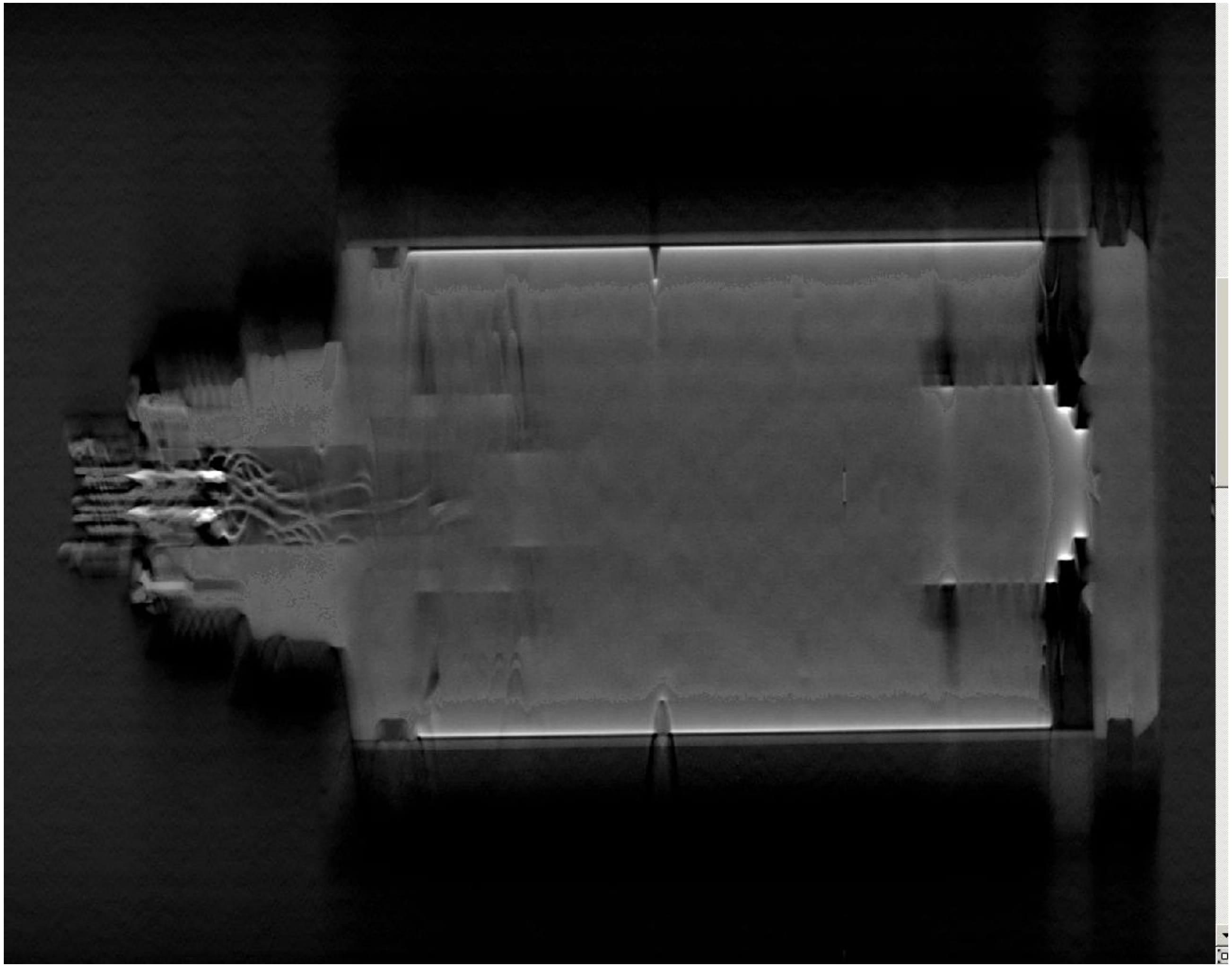
Several Prototypes under preparation + testing
Plan to subcontract 1 development to industry







Before surgery…

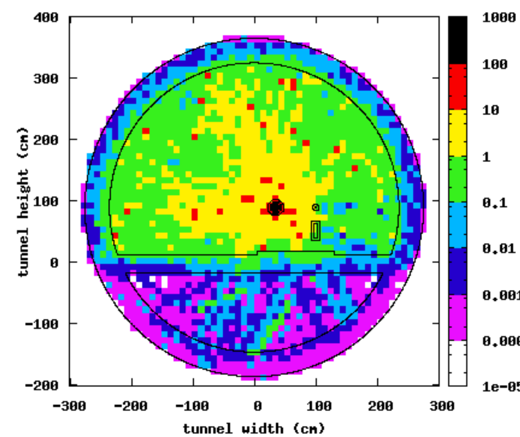


Courtesy J.M. Dalin

Radiation 2012

- Contact with RAD WG
- Option to do SEU tests in the H4IRAD test stand at CERN before summer
- Several components under evaluation. Larger community working on same problems
- Sensitivity simulation of controller to changes in the components
- Essential for CLIC: obtain more complete and sure expected radiation values.
- Available shielding in the CLIC tunnel ????

Pablo Fernandez Carmona



Courtesy S. Mallows

Conclusions

Five R&D themes :

1. Performance increase ✓
2. Compatibility with environment ✓
3. Cost optimization ✓
4. Overall system analysis ✓
5. Pre-industrialization ✓

1. →Reach requirements from higher background vibrations + include direct forces
   → Increase resolution (Final focus)
2. → Radiation, magnetic field, Operation, Temperature
3. → Standardize and optimize components, decrease number of components, simplify mounting procedures,…
4. → Interaction with the beam-based orbit and IP feedback to optimise luminosity Integration with other CLIC components
   → Adapt to changing requirements
5. → Ability to build for large quantities

Publications

http://clic-stability.web.cern.ch/clic-stability/publications.htm