

**Feasibility item 6: Main Linac
active alignment/beam based
feedback/stabilization**

Possible technical implementation,
R&D program until 2010

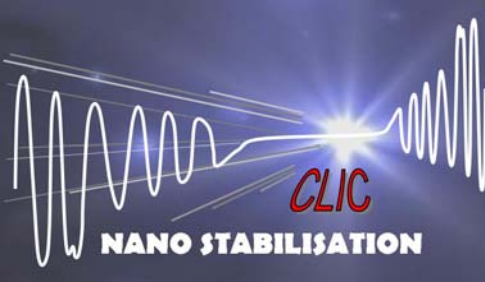
C. Hauviller
CERN

CLIC stabilization requirements

- Mechanical stabilization requirements:
Quadrupole magnetic axis vibration tolerances:

	Final Focus quadrupoles	Main beam quadrupoles
Vertical	0.1 nm > 4 Hz	1 nm > 1 Hz
Horizontal	5 nm > 4 Hz	5 nm > 1 Hz

- Main beam quadrupoles to be mechanically stabilized:
 - A total of about 4000 main beam quadrupoles
 - 4 types
 - Magnetic length from 350 mm to 1850 mm
- Mechanical stabilization might be On at some quads and Off of some others



Contents

- Organization
- Actions
 - Sensors
 - Characterize vibrations/environmental noise
 - Actuators
 - Feedback
 - Overall design + analysis
 - Integrate and apply to Linac
 - Final Focus
- Conclusion

The Stabilization Working Group

- Stabilization work for CLIC started beginning of the century, then stopped at CERN due to LHC priority.
Kept alive at LAPP.
- Stabilization considered as a critical item with associated resources 18 months ago.
- Working group established beginning 2008 in the framework of the CLIC Technical Committee
 - Collaboration between institutes
 - Face-to-face meetings every 3 months
 - Chairman: Claude Hauviller

Organization

- Collaboration: Laboratories participating (to-date):
 - LaViSta (LAPP, Universite de Savoie-SYMME)
 - CERN (EN, TE, BE)
 - JAI- Oxford University
 - CEA-DSM-IRFU-SIS
 - PSI
 - Information from DESY, SLAC,...
 - Contacts with universities
- Extra financing through FP7



ACE090527



MONALISA
C. Haujviller



IRFU/SIS



Tasks defined in the mandate

- Demonstrate 1nm quadrupoles stability above 1Hz (*Linac*) (*going below 1Hz would be appreciated*)
- Demonstrate or provide evidence of 0.1nm stability above 4Hz (*Final Focus*)
 - *Differences compared to previous studies*
 - *0.1 nm is beyond what we have shown*
 - *apply stabilization in an accelerator environment (e.g. 2BTS)*
 - *achieve 1nm with realistic equipment (a complete system), not simple elements on a special table*
 - *verify performance with (two) different methods*
- Characterize vibrations/noise sources in an accelerator
- Compatibility with pre-alignment
- Sensitivity to relaxed specifications

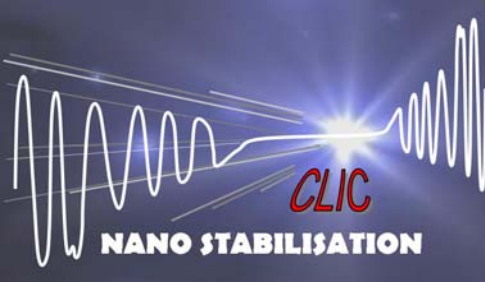
Remarks

- Active vibration control is not yet a mature technology.
- Activity should be defined as R&D but with CLIC engineering as objective.
- It will take time to achieve the final objective but a work plan has been agreed in March 2008 with CDR as an important milestone
- Most of the collaborators have background on vibrations but not on the specific field of stabilization.

Approach

- Competency center: understand the subject in depth
- Build a knowledgeable team
- Use the existing know-how spread in many places:
 - Previous theses (in particular Montag, Redaelli, Bolzon,...)
 - Work done in the labs: Low emittance Light sources, FEL, ILC,...
 - Work (mainly) in the universities on satellites and radiotelescopes
- Apply to realistic mock-up(s)
- Create a reference web site:

http://clic-study.web.cern.ch/CLIC-Study/CLIC_Stabilisation/Index.htm



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- Organization
- **Actions**
 - Sensors
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Actions list (keywords)

- Sensors
- Characterize vibrations/environmental noise sources in an accelerator
- Actuators
- Feedback
- Overall design + analysis
- Integrate and apply to Linac

Sensors

Program of work

- Develop and test sensors
- Qualification with respect to EMC and radiation
- Calibrate by comparison.
 - Interferometer to calibrate other sensors
 - Create a reference test set-up (at CERN)
- State of the art of sensor development and performances (to be updated on a yearly basis)

Ground motion sensor review

Table of Contents

1. Characteristics
 1. Sensor noise
 - Noise sources
 - Noise detection
 2. Sensitivity
 3. Resolution
2. Sensor types
 1. Geophone
 2. Accelerometer
 3. Feedback seismometer
 4. Capacitive distancemeter
 5. Stretched wire system
 6. Other sensor
3. Comparison

Sensors

How to measure vibrations/ dynamic displacements with amplitudes of 0.1 nm?

- **Seismometers** (geophones) Velocity
- **Accelerometers** (seismic - piezo) Acceleration



Streckeisen
STS2
x,y,z

2*750Vs/m
120 s -50 Hz
13 kg



Guralp
CMG 3T
x,y,z

2*750Vs/m
360s -50 Hz
13.5 kg



Guralp
CMG 40T
x,y,z

2*800Vs/m
30 s -50 Hz
7.5 kg

Guralp
CMG 6T
x,y,z

2*1000Vs/m
30s-80Hz



Eentec
SP500
z

electrochemical

2000Vs/m
60 s -70 Hz
0.750 kg



PCB
393B31
z

1.02Vs²/m
10 s -300 Hz
0.635 kg

↑
Improved performances
Lab environment

Sensors

- **Optical sensors**

- Vibrometer

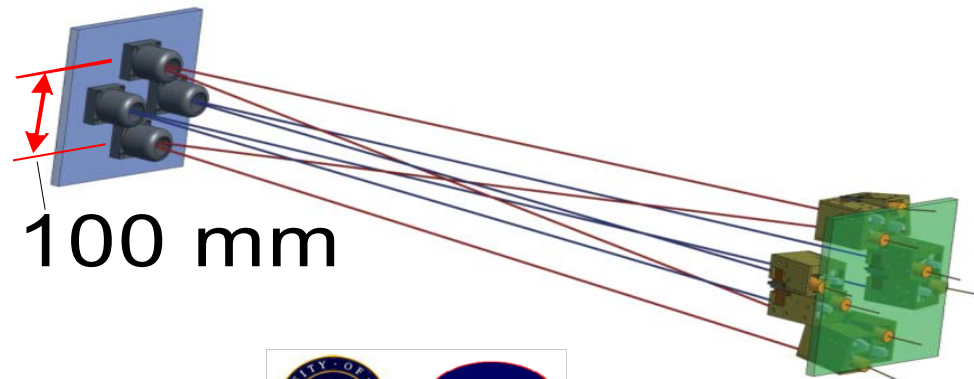
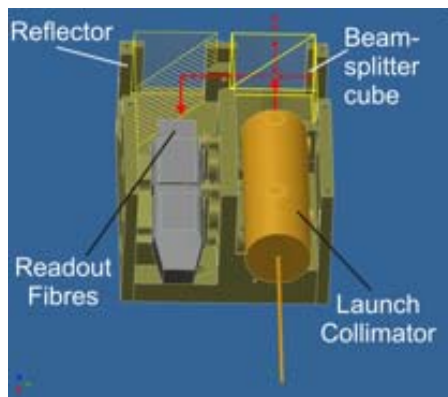
- Supplier Polytec; at CERN

- Under performances qualification but lab is too noisy!

- Interferometer (measures displacement)

- Industrial products under study at CEA-IRFU (Renishaw, Attocube)

- Low cost “Optical transducer” under development with precision of 1nm at 1Hz Compact Straightness Monitor MONALISA at Oxford



Sensors

Characterization for low intensity signals:

Which sensor?

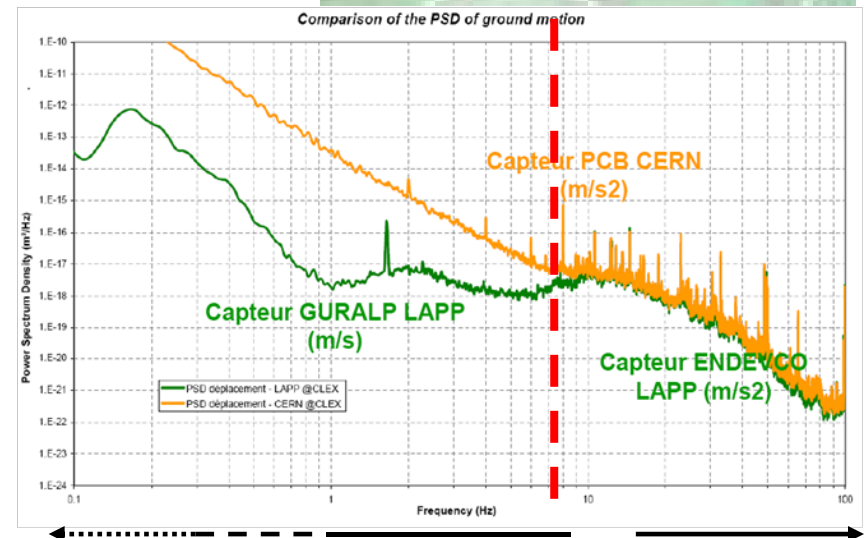
Quality of its measurement?

Sensitivity + resolution

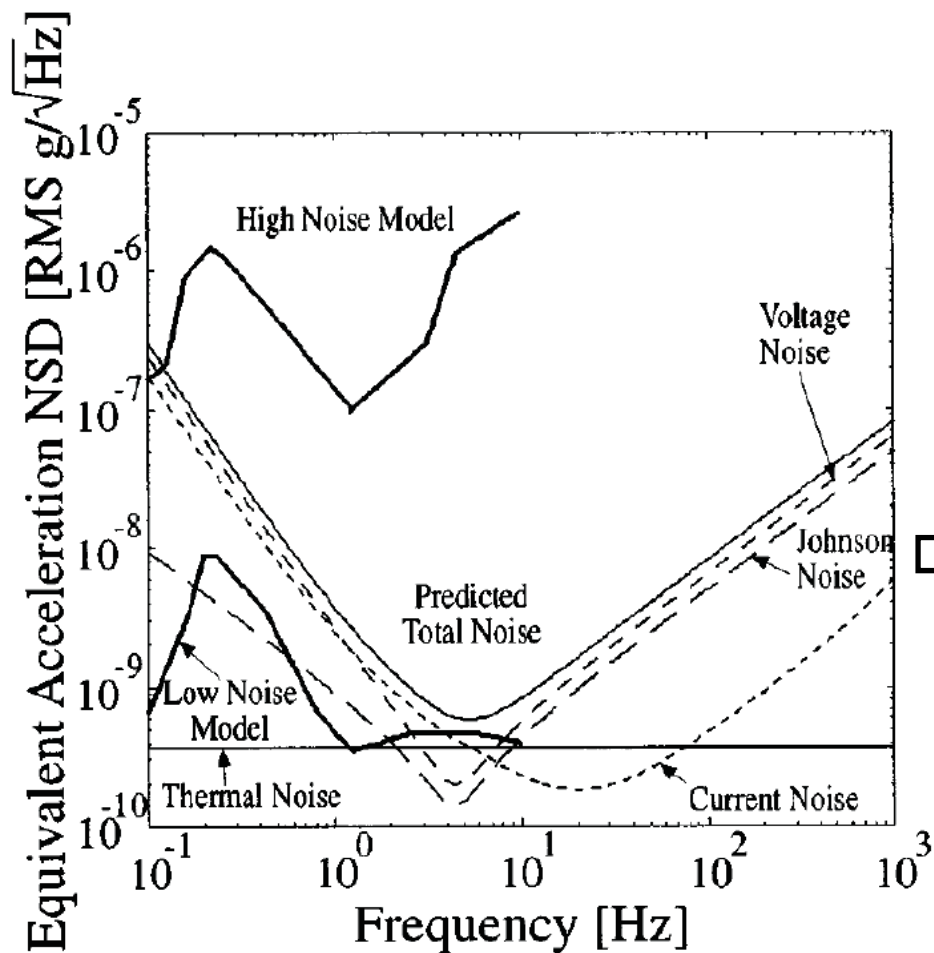
Cross axis sensitivity

Noise level, « self noise »
measurement (ex. blocking the
seismic mass or by coherence)

Signal processing: Resolution,
filtering, window, FFT, DSP,
integration, coherence



Sensor noise Sources



A. Bertolini et al. *Review of scientific instruments*, 69:2767-2772, 1998.



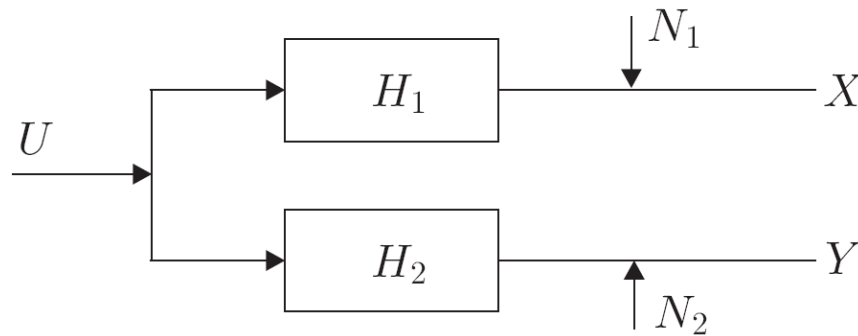
We need a technique to evaluate the overall measurement noise

Sensor noise Detection

Prepared by C. Collette

C. Montag. *PhD thesis,*
Hamburg University, 1996.

Two geophones side by side:



$$\begin{cases} X(\omega) = H_1(\omega)U(\omega) + N_1(\omega) \\ Y(\omega) = H_2(\omega)U(\omega) + N_2(\omega) \end{cases}$$

$$\begin{cases} \Phi_{ss} = H^2 \Phi_{xx} \\ \Phi_{nn} = \Phi_{yy} - H^2 \Phi_{xx} \end{cases}$$

where $H(\omega) = \frac{\Phi_{xy}}{\Phi_{xx}}$

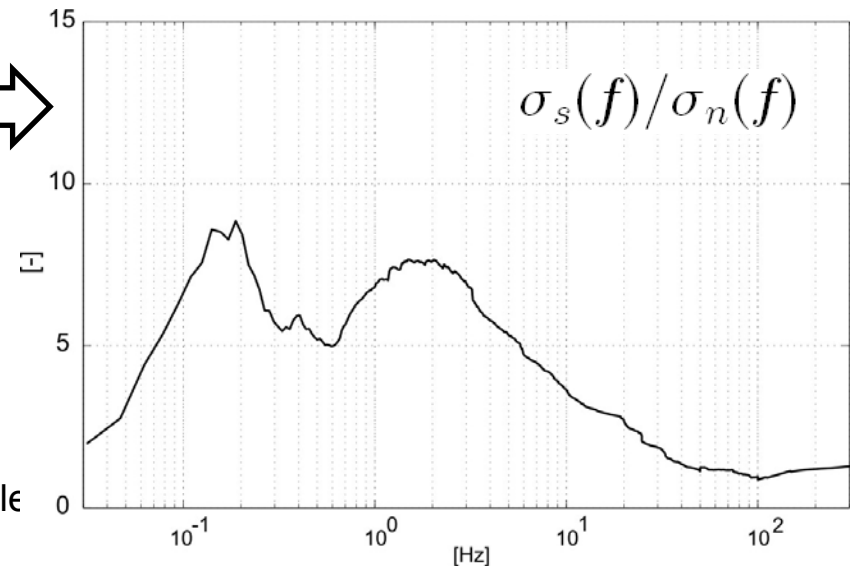
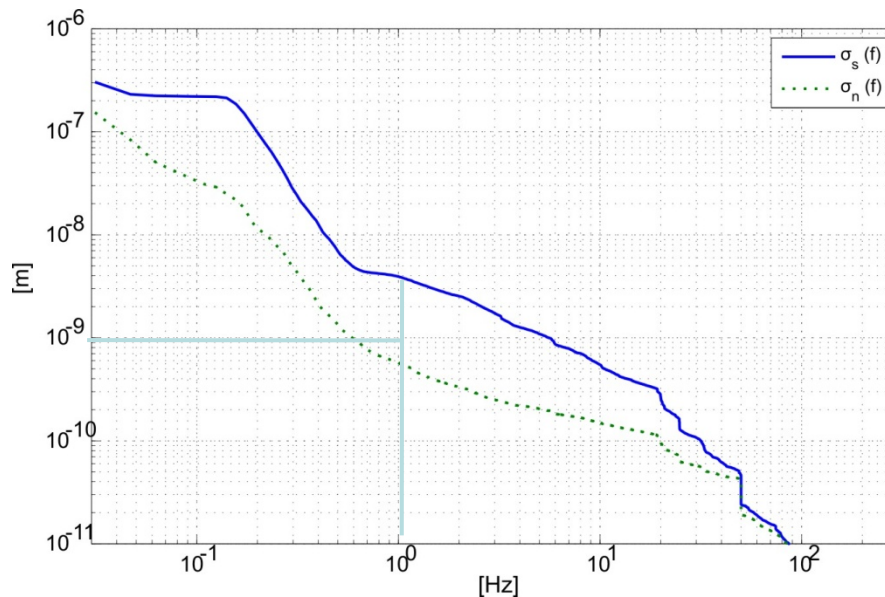
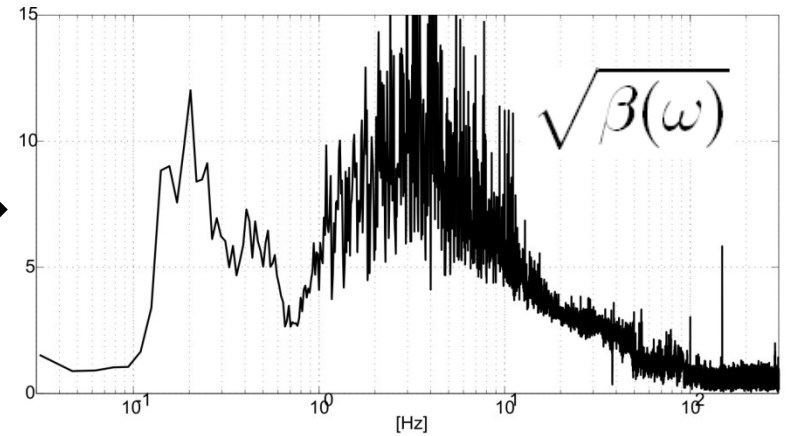
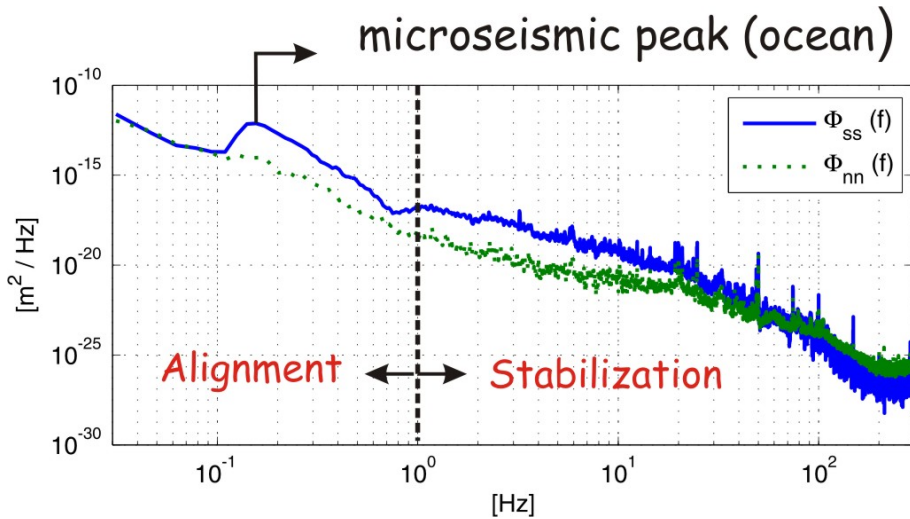
$$\Rightarrow \begin{cases} \sigma_s(\omega) = \left[\int_{\omega}^{\infty} \Phi_{ss}(\nu) d\nu \right]^{1/2} \\ \tau_n(\omega) = \left[\int_{\omega}^{\infty} \Phi_{nn}(\nu) d\nu \right]^{1/2} \end{cases}$$

Signal to noise
spectrum ratio:

$$\beta(\omega) = \frac{\Phi_{ss}}{\Phi_{nn}}$$

Sensor noise detection

Guralp CMG 40T, LHC tunnel
(summer 2008)

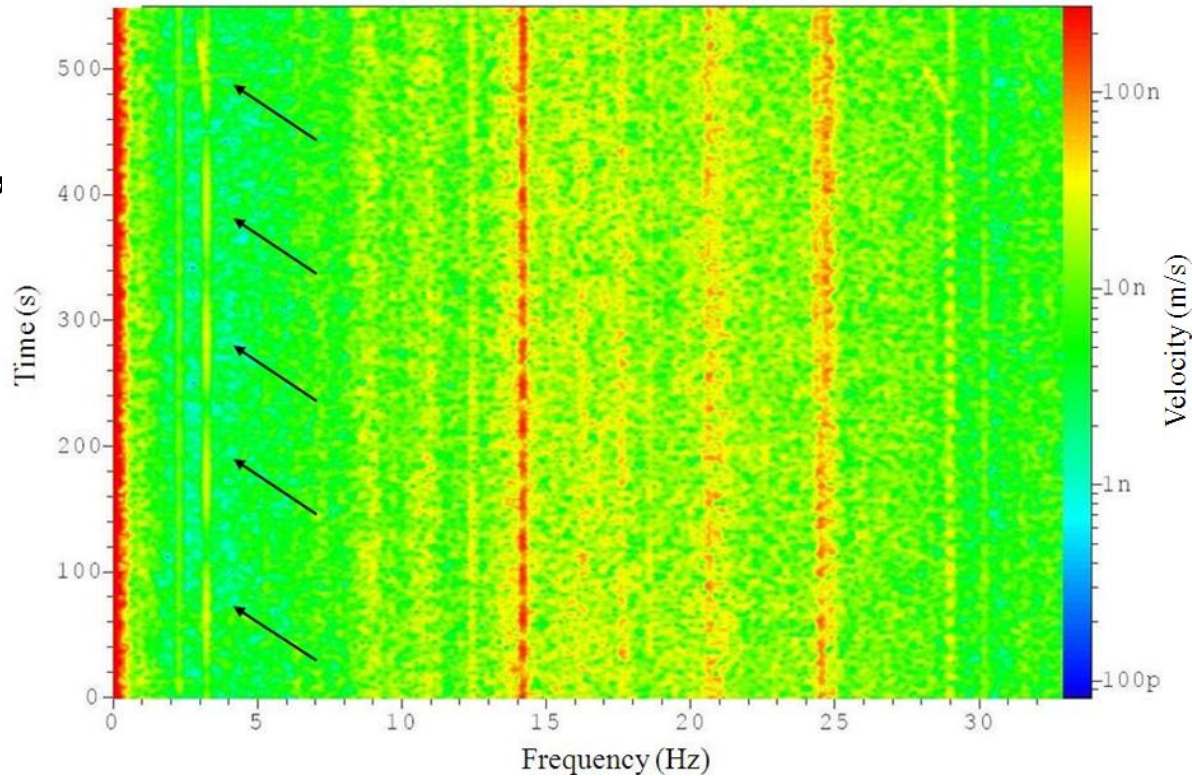


ville

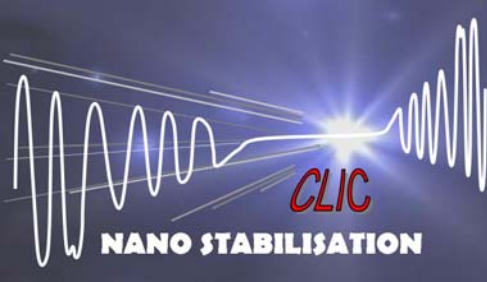
Sensor Signal processing

- Resolution, filtering window, FFT, DSP, ...

**Need to establish
a standard of
measurement !**



Vertical vibrations in the LHC tunnel
Intermittent excitation at 3Hz partly hidden
by the averaging



Contents

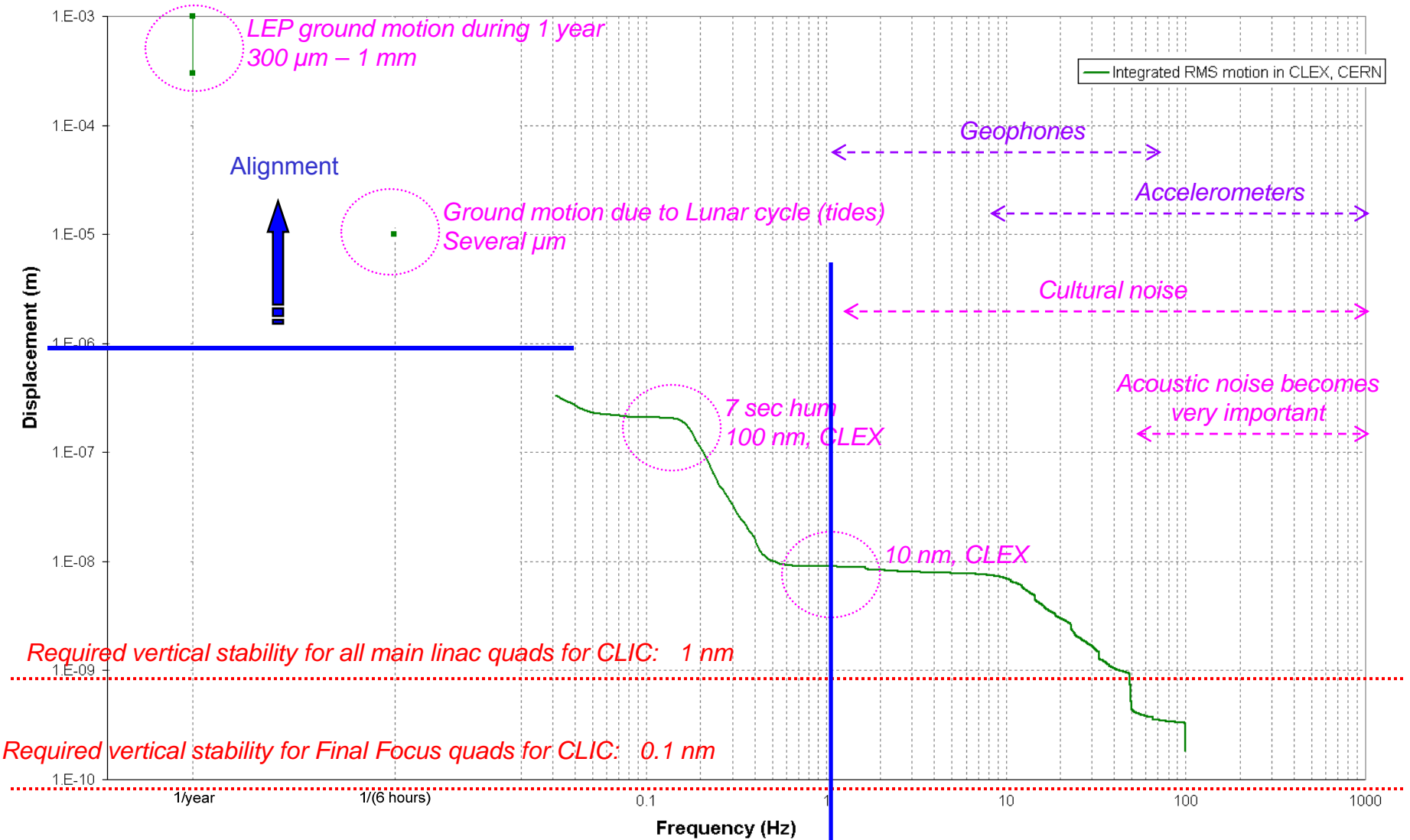
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Characterize vibrations/noise sources in an accelerator and detectors

- Program of work

- Summary of what has been done up to now (several studies done by DESY, SLAC, LAViSta, CERN)
 - Large number of measurements done for years in many places including third generation light sources. Critical analysis of the results based on sensors and methodologies. Pertinence for CLIC ? Qualification of labs (quiet enough?)*
- Additional correlation measurements to be done at LHC over distances of $\sim 1000\text{m}$ and in a long building on the surface
 - Done and analysed.*
- Continue measurements in CLEX environment at different installation phases, at “quiet lab”, at PSI, at CsrTA,...

Environmental vibration levels – orders of magnitude, CERN site



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Correction with beam-based feedback

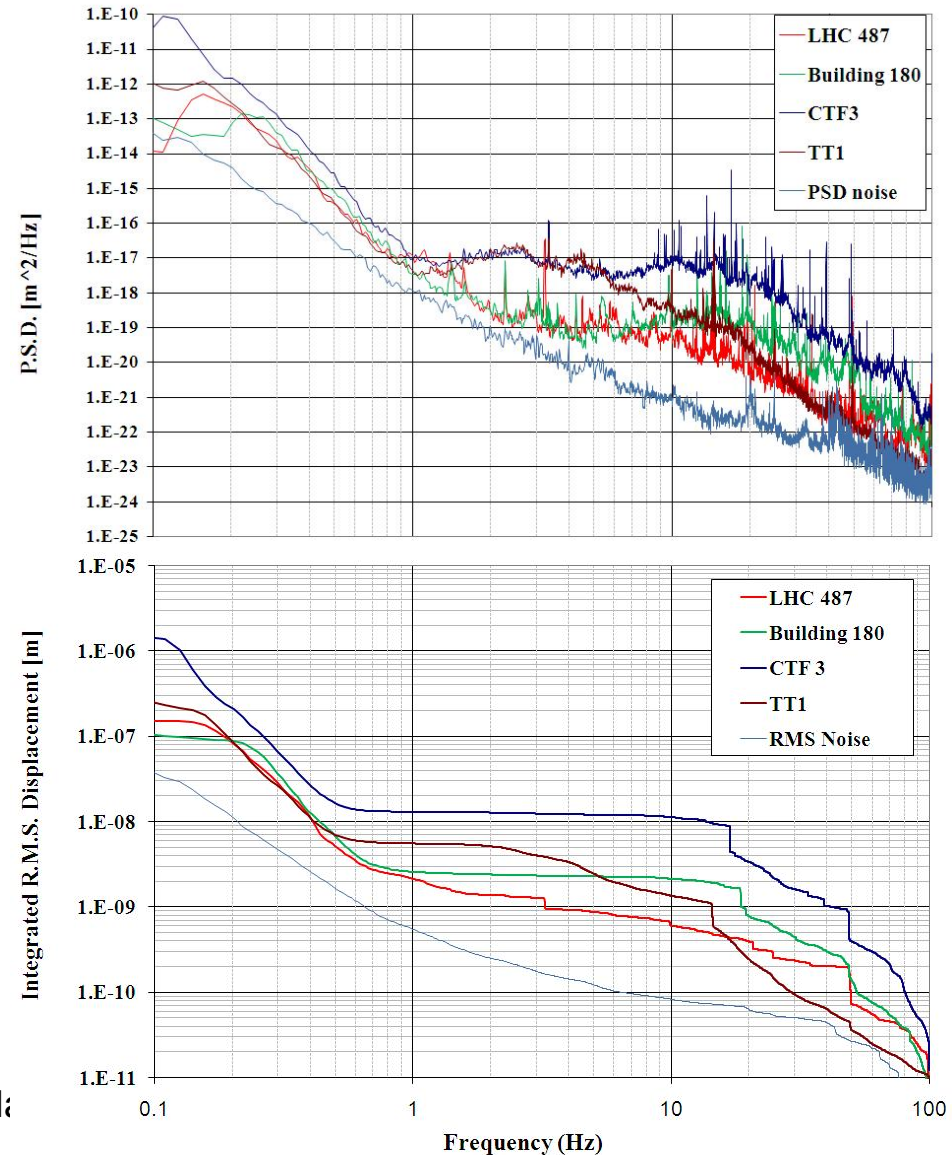
“Slow” motion

“Fast” motion

Mechanical stability of main beam quadrupoles

Vibrations on CERN site

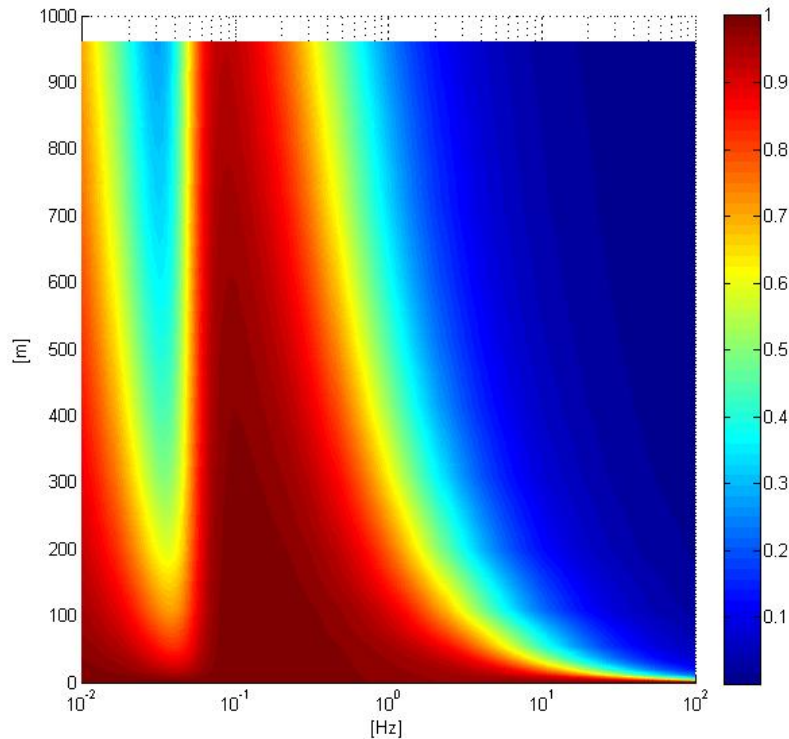
- LHC tunnel
- Surface building
- CTF3
- “Quiet lab”
(under installation in TT1)



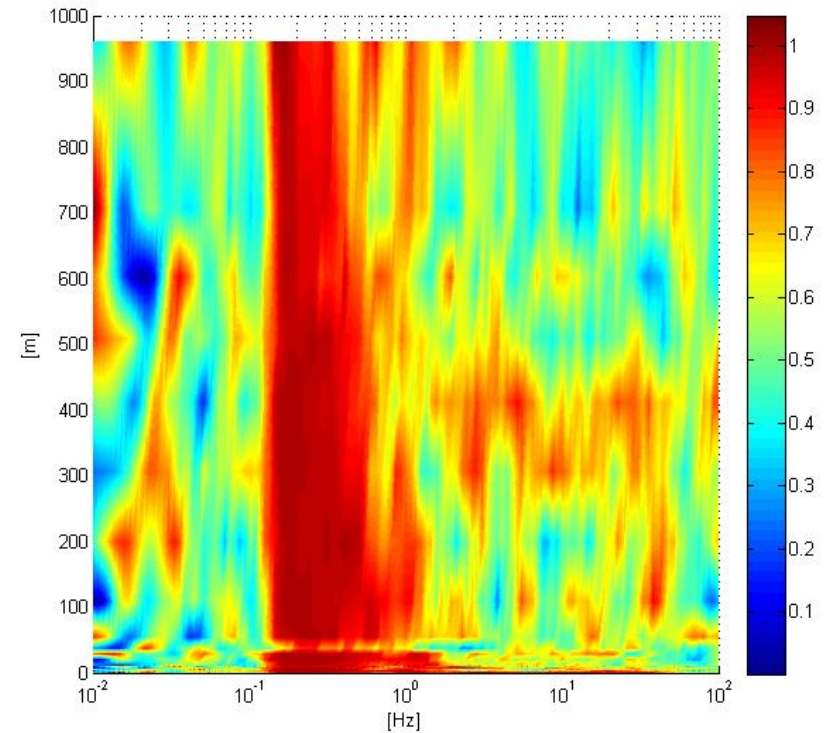
Correlation over long distances in LHC tunnel

Prepared by C. Collette

Coherence using a theoretical model
(ATL law)



Calculated from measurement
(2008)



→ 3D ground motion model to be considered for the alignment

Actuators

Program of work

- State of art of actuators development and performances (to be updated on a yearly basis)
- Develop and test various damping techniques (passive and active)

State of art of actuators development

Table of Contents

- Introduction and requirements
- Comparison of actuator principles
 - Different actuators
 - Piezo electric actuators
 - Electro-magnetic actuators
 - Magneto striction
 - Electro-static plates
 - Shape memory alloys
 - Scaling laws
- Design of actuators for sub nanometer positioning
 - Hysteresis free guidance
 - Non contact direct metrology
 - X-Y kinematics
 - Trajectory control and dynamic accuracy + resolution considerations
 - Limitations
- Different configurations of piezo based actuators
- Providers of nano actuators and vibration isolation
- Nano positioning applications
- Bench mark projects
- References

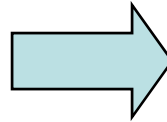
Actuators

Usable actuators with 0.1 nm resolution?

Resolution but also movement reproducibility?

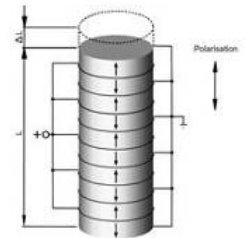
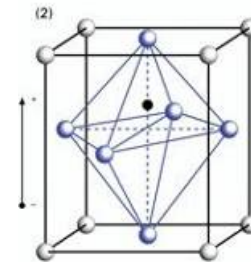
Friction

Guiding systems with **friction**



Real resolution limited to 1 μm (0.1 μm)

Solution under development:
Piezo actuators PZT
(sensitive to shear)



Actuators

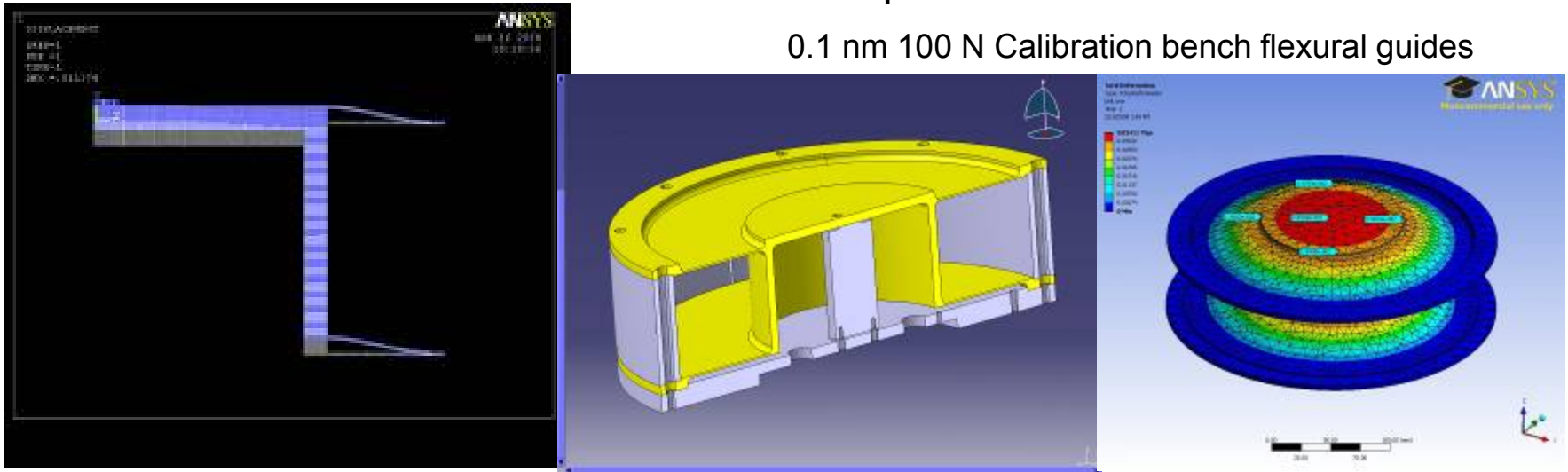
Usable actuators with 0.1 nm resolution?

Solution under development: Piezo actuators PZT

+ flexural guides

+ feedback capacitive sensor

0.1 nm 100 N Calibration bench flexural guides



But only for few kg and rigid objects....

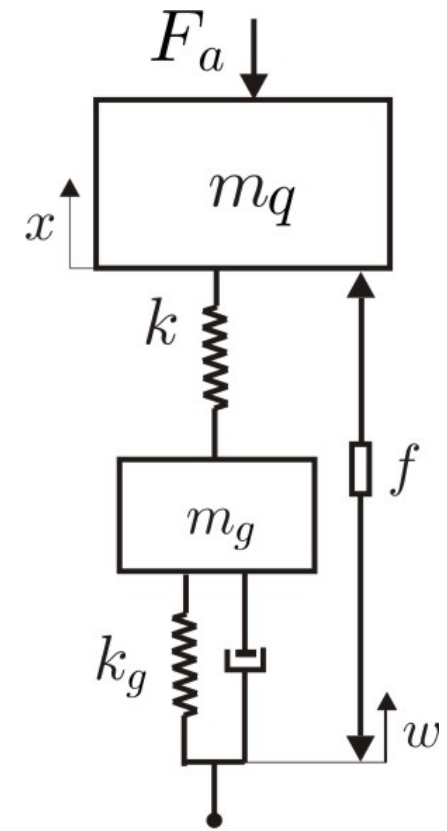
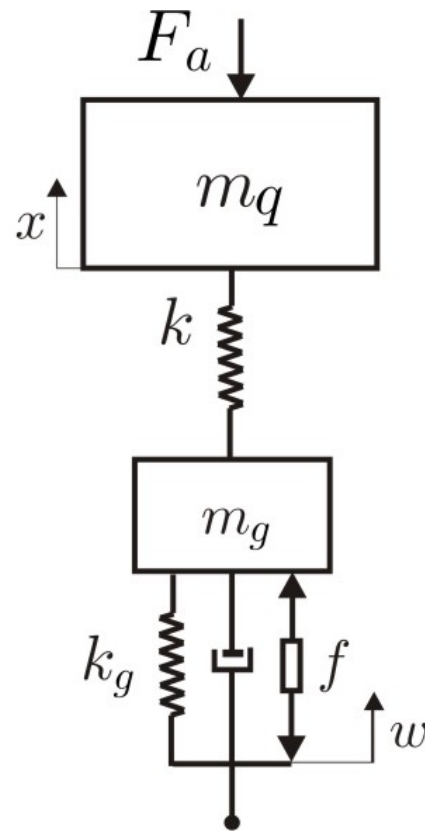
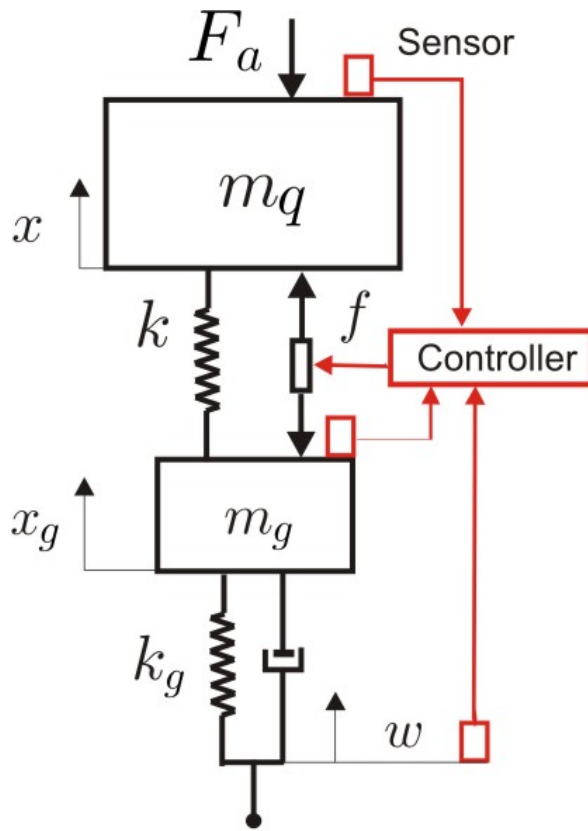
***Techniques to be developed for heavier (up to 400Kg)
and larger structures (up to 2 meter long)
Moreover, possible range up to many microns.***

Feedback

Program of work

- Develop methodology to tackle with multi degrees of freedom (large frequency range, multi-elements)
LAViSTa demonstrated feasibility on models
Similar problems elsewhere like the adaptative optics of the European ELT
- Apply software to various combinations of sensors/actuators and improve resolution (noise level)
High quality acquisition systems at LAViSTa and CERN

Stabilization strategies



Similar in size ELT project

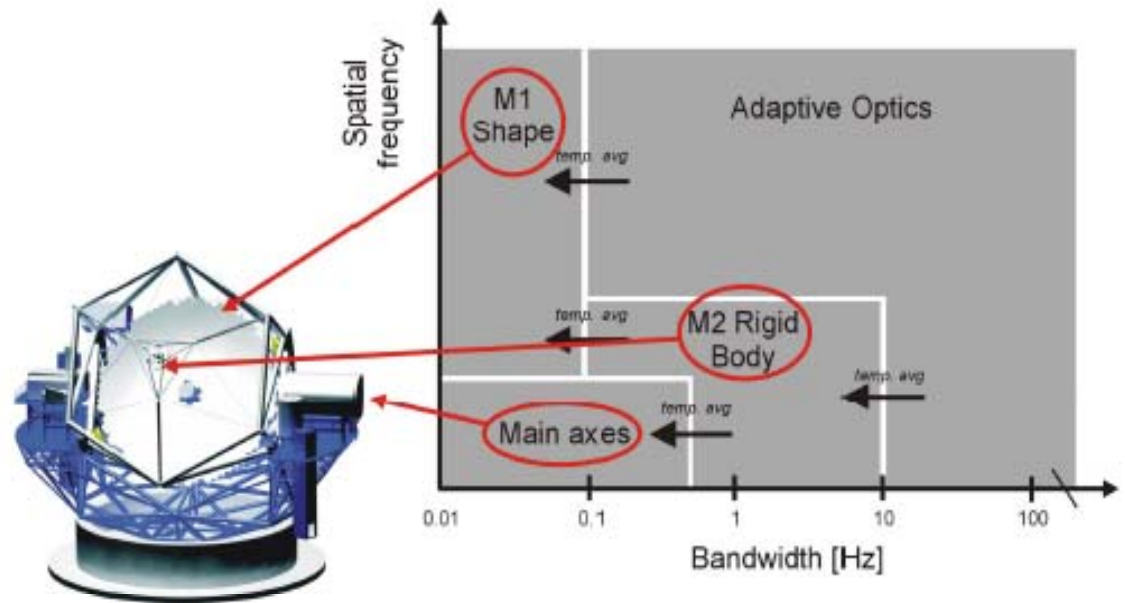


Figure 3: Temporal and spatial frequency distribution of the various control layers of a large telescope (adapted from [8]).

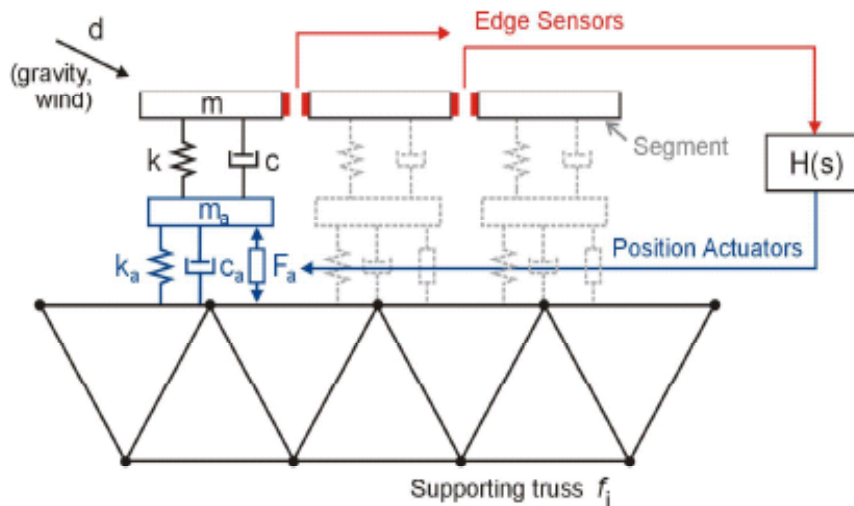


Figure 4: Co-phasing strategy of segmented mirrors. Every segment is equipped with 3 position actuators.

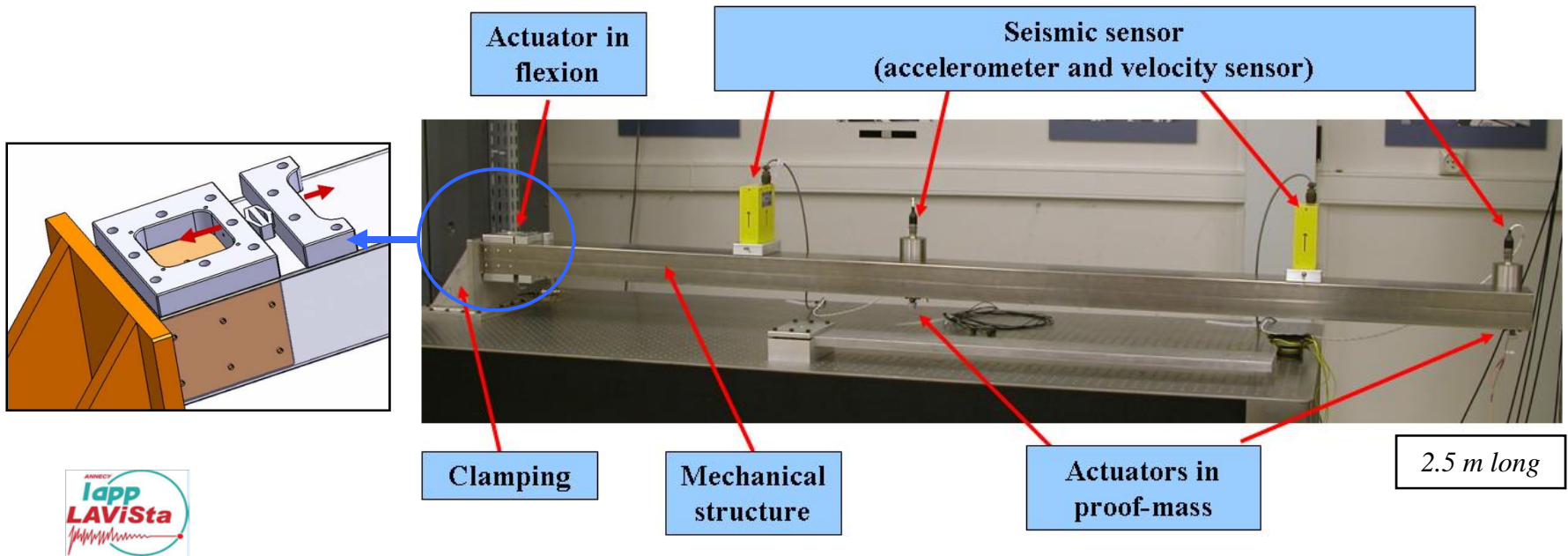
2952 actuators
5604 sensors

A. PREUMONT et al.
(To be presented to the
Smart09 - July 2009)

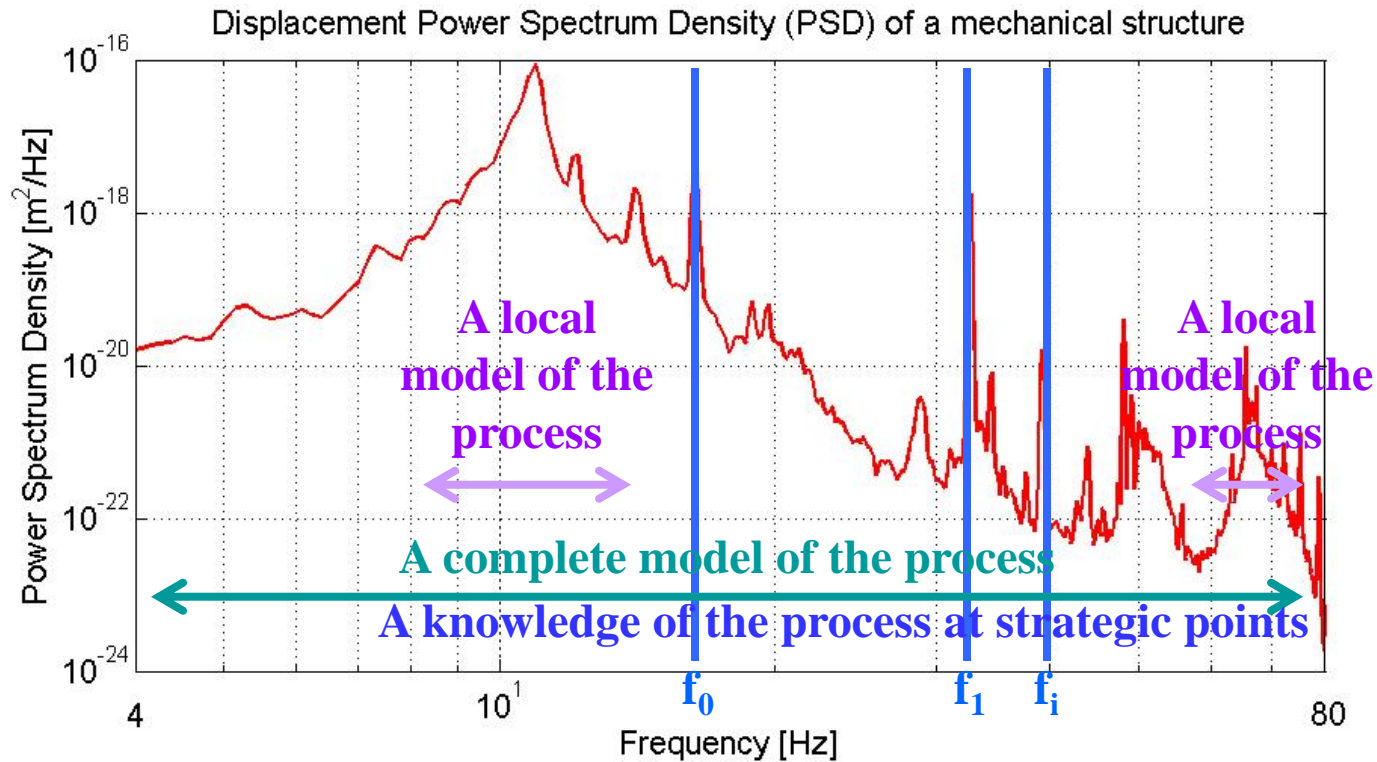
Feedback

Active rejection of canteliver beam resonances: home-made

Mechanical structure and its instrumentation



Feedback



- 1 - A knowledge of the structure at strategic points : *for lumped disturbances*
- 2 - A local model of the structure : *for the disturbances amplified by eigenfrequencies.*
- 3 - A complete model of the structure : *for the entire structure*



Contents

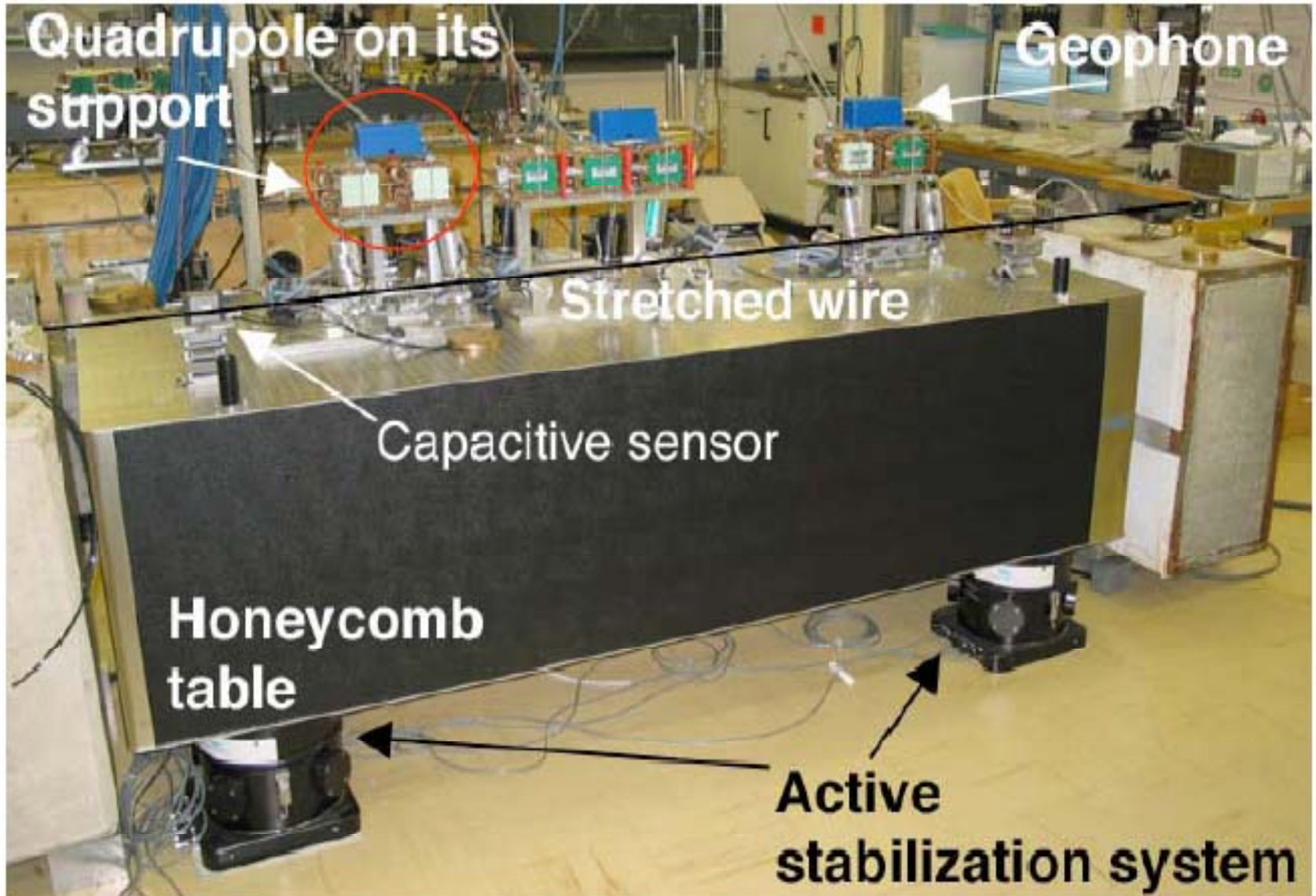
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Overall design

Program of work *(as defined in March 2008)*

- Linac (a demonstrator mock-up will be built)
 - Compatibility of linac supporting system with stabilization (including mechanical design): eigenfrequencies, coupling between girders, coupling of mechanical feedback with beam dynamics feedback,...
 - Design of quadrupole (we have to stabilize the magnetic axis) mock-up will have “real” physical dimensions and all mechanical characteristics but not the field quality required by CLIC

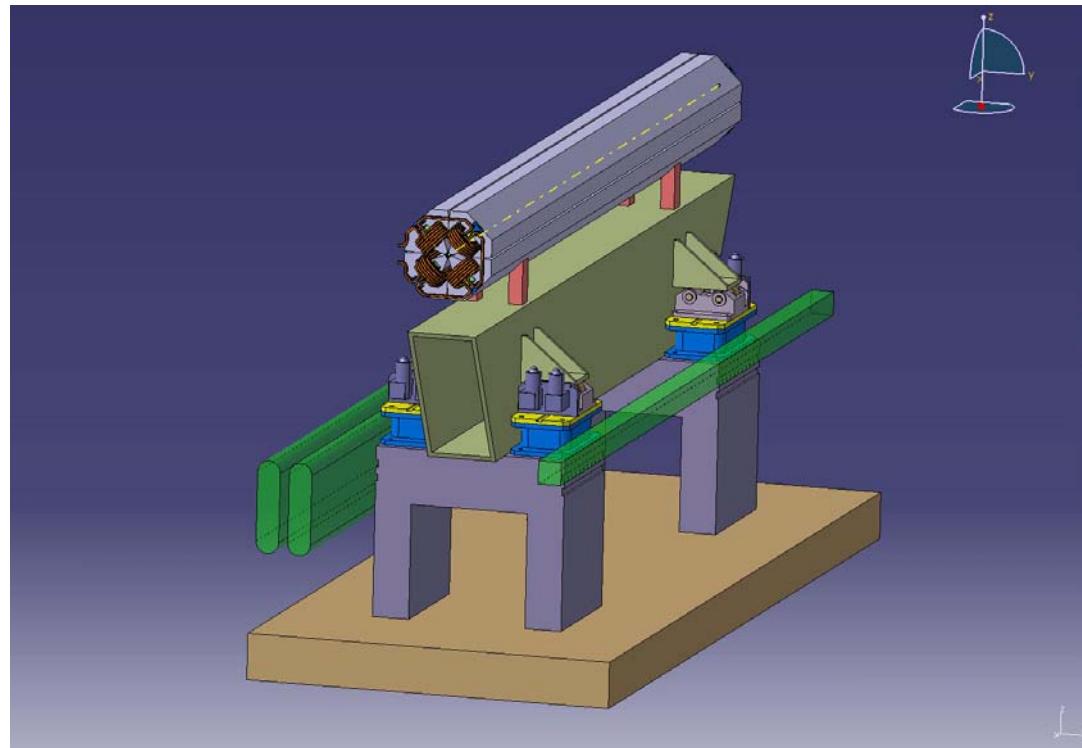
Mock-up built in 2004 (S. Redaelli)



Main Beam Mock-up

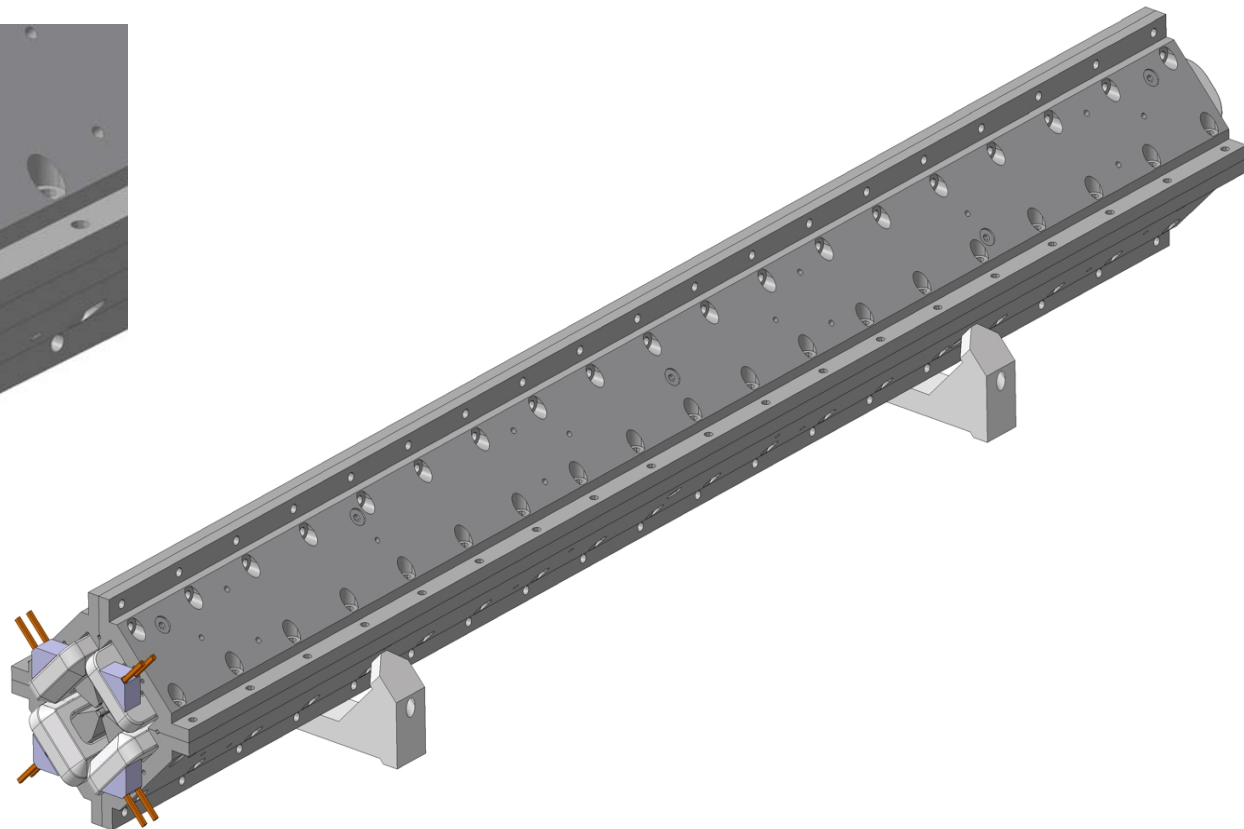
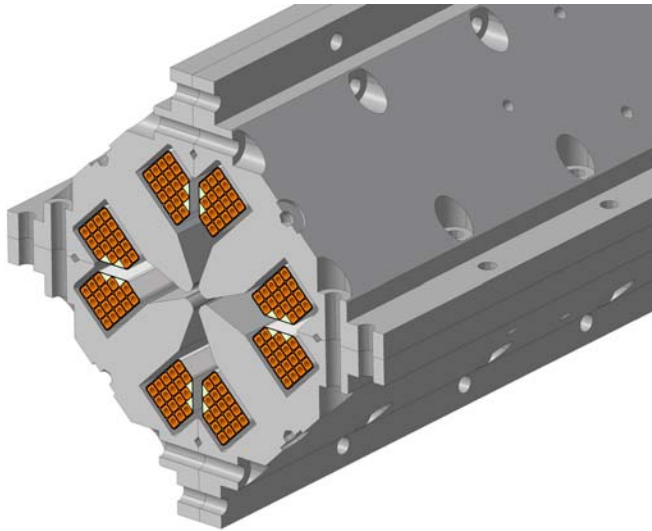
Work launched within the collaboration

- **Functionalities**
 - Demonstrate stabilization in operation:
 - Magnet powered, Cooling operating
 - Configurations
 - 1- Stand-alone
 - 2- Integrated in Module
 - 3- Interconnected
 - Accelerator environment
- **Parts / Measuring devices**
 - Floor (damping material)
 - Support
 - Pre-alignment
 - Stabilization
 - Magnet
 - Vacuum chamber and BPM
 - Independent measurement



Main beam quadrupole

- Under final design.
- Plain material (incompatible with corrector magnet)
- Assembly methods to be tested (accuracy of some microns!)



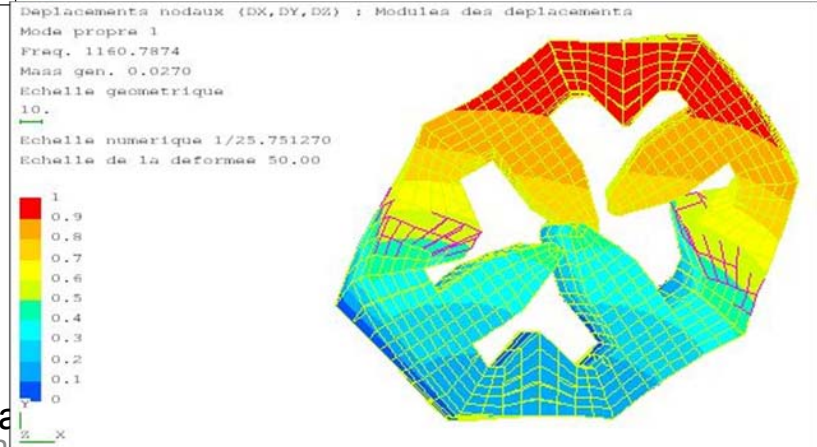
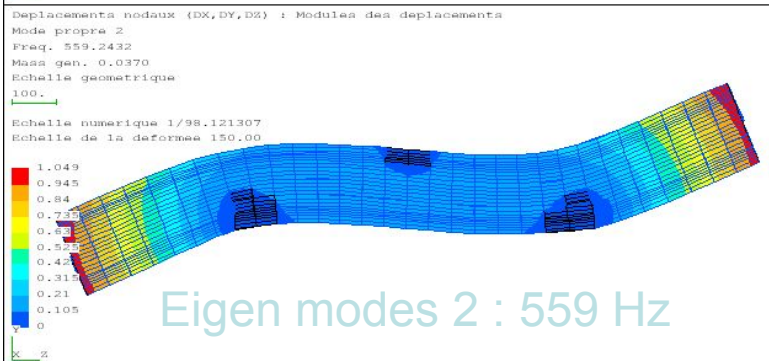
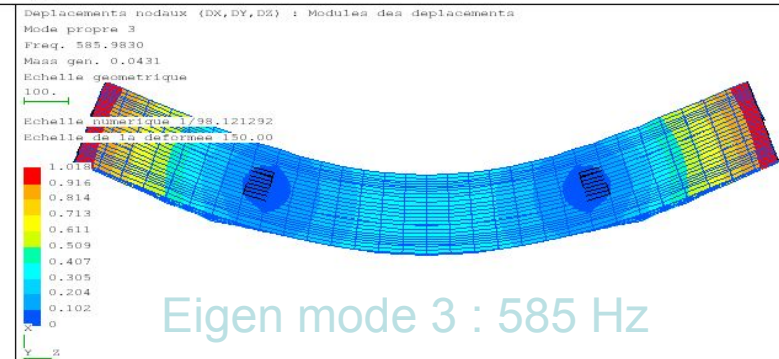
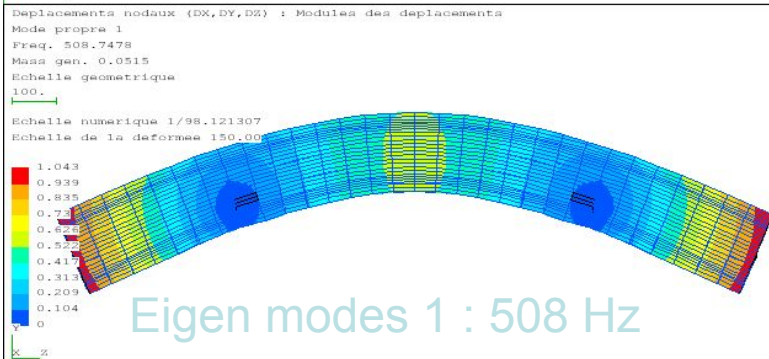
Main beam quadrupole

Dynamic behaviour (analysis+test)

(Guillaume Deleglise LAPP)

- Length 1500 mm, 4 lateral supporting lines (d=350 mm)

Projet CLIC : Etude de l'influence de l'ecartement des appuis



Girder Design – Geometry and Supports

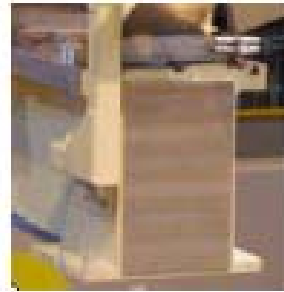
- A box-type cross section is preferable for high stiffness in flexure (both directions) and torsion.
- Full-length welds, gussets and plate stiffeners can significantly increase the overall stiffness.



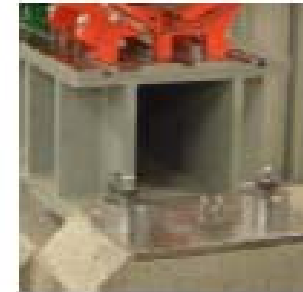
SPring-8



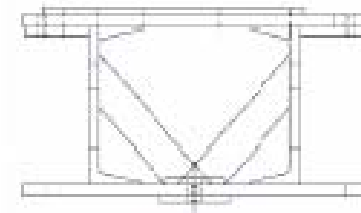
Boomerang



Diamond



CLS



APS

- Unsupported length of the girder should be kept as small as possible (SPring-8 girders are supported at six points).

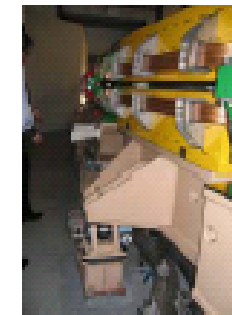
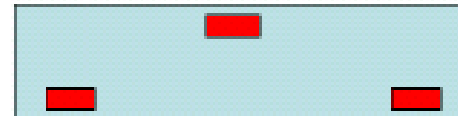
CLS



Supports at Airy Points



3-Point Support



Boomerang

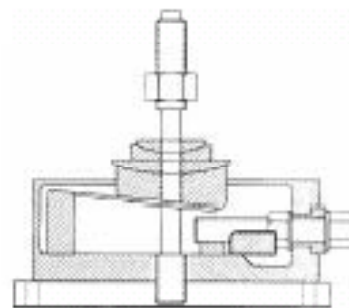
Girder Design - Alignment Mechanisms



Threaded Rod

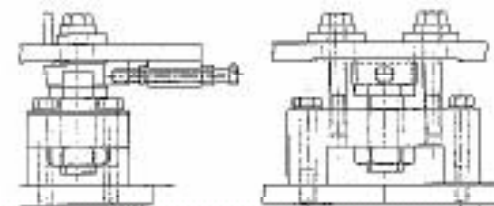


Threaded Rod with Lateral Adjustments (APS)



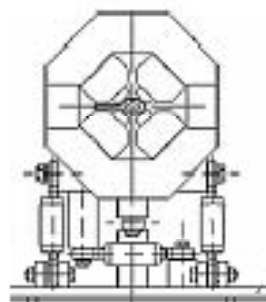
Wedge Jack (APS)

http://www-group.slac.stanford.edu/met/IWAA/TOC_S/PAPERS/KTsum02.pdf

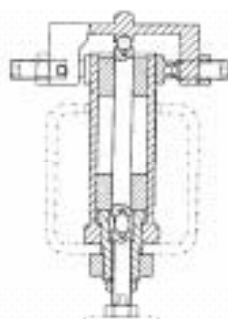


SPring-8 Alignment

<http://accelconf.web.cern.ch/AccelConf/e00/PAPERS/WEP4A17.pdf>



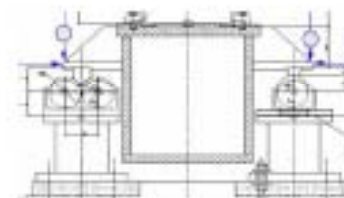
Six-Strut System



Cartridge Adjuster (CEBAF)*



Motorized Jack (ESRF)



Cam Mover (SLS)



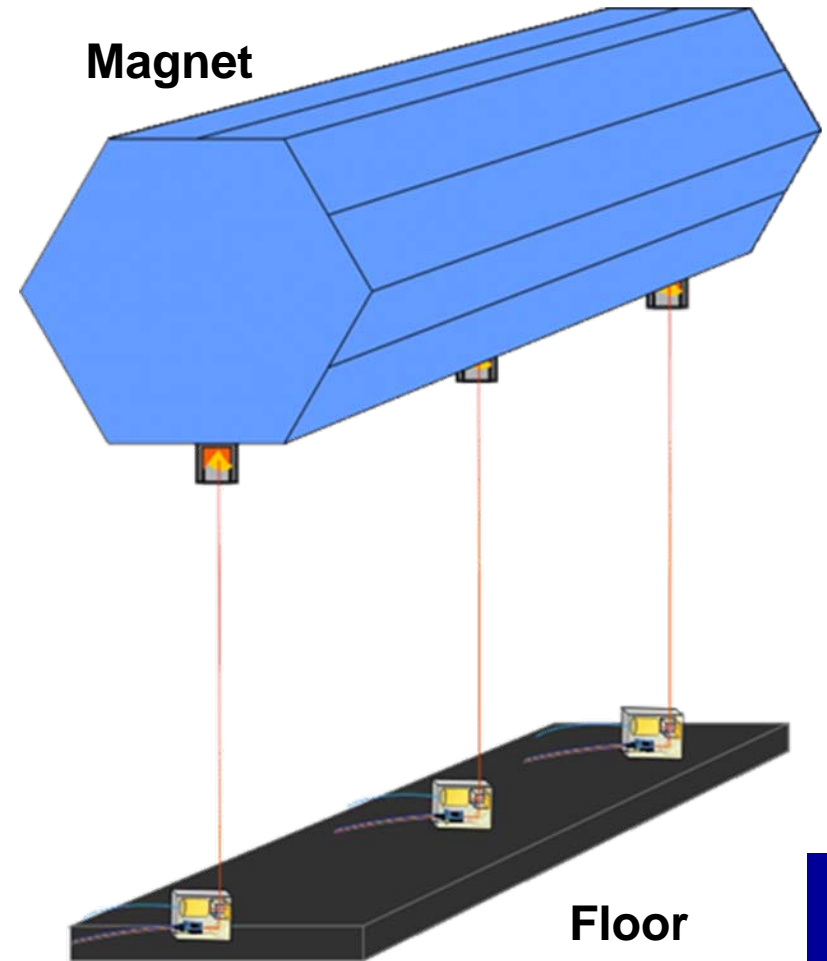
*Upgraded in NSRRC
32 Hz for 10 tons*

* Other Concepts [1994] http://www-group.slac.stanford.edu/met/IWAA/TOC_S/Papers/RRula95a.pdf

Monitoring CLIC magnet 2010

- Test several points along the magnet
 - at first independent DMs
- Compare readings with accelerometers
 - on the magnet
 - and on the floor

Paul Coe / Oxford (TILC'08)



Integrate and apply to Linac

Program of work *(as defined in March 2008)*

- A mock-up should be ready to provide results by June 2010 with several types of sensors including interferometers (intermediate milestones to be defined accordingly). The mock-up should perform better than required for main linac in order to “provide evidence” for final focus requirements.
- Mock-up to be integrated in CLEX (important to have the stabilization together with the alignment) or in other accelerators
- Beam experiment in CESRTA (storage ring)
 - 1st step (June 2009): excite a quad with narrow band and measure the beam blow-up (BPM equipped with BBQ)
 - 2nd step: install a full mock-up

Global alignment / stabilization strategy for main linac magnets



- Once / year
Mechanical pre-alignment => 0.1 mm
- Once / few weeks
Active pre-alignment using HLS, WPS, RASNIK => $\pm 10\ \mu\text{m}$ on a sliding window of 200 m
- Once / couple of hours
Beam based active alignment with movers – complex procedure => $1\ \mu\text{m}$
Beam based alignment with magnet correctors or actuators
and mechanical stabilization on=> *few nm*
- “Steady state”

Beam position
measurement with
BPM

Beam based feedback correction with correctors



Main Beam Mock-up

Compatibility between functionalities?

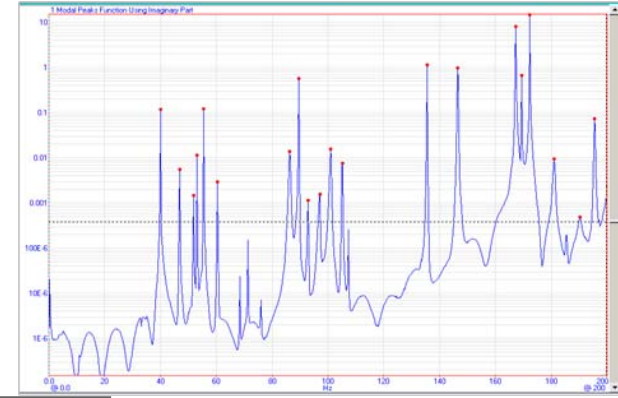
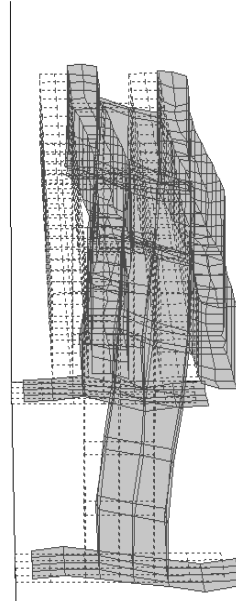
- Stabilization is better achieved with a rigid support
- Adjustable re-alignment needs a flexible support
- *To minimize the incompatibility, fix on a rigid ground, minimize the beam height, design movers, girder, magnet with “high” first eigenfrequency: a challenge!*

Support design

Multi degrees of freedom and several deformation modes with different structural damping



3DView: 40.042 Hz

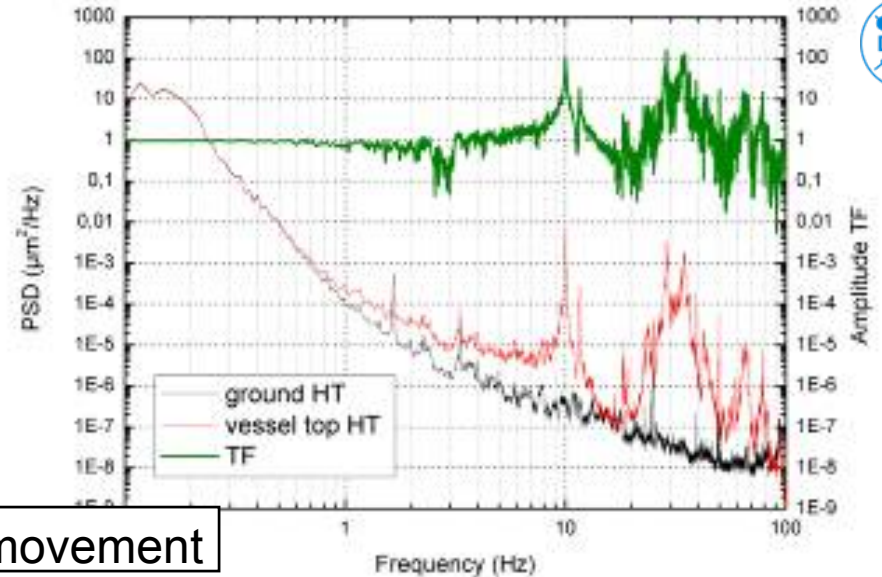


Experimental modal analysis on **CLEX** girder

Amp: 0.5, Dwell: 12
Persp: +10

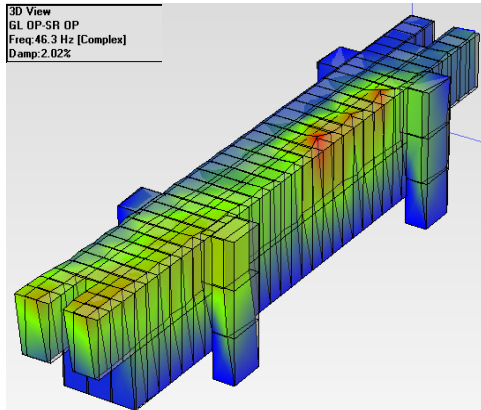


Low Beta LHC

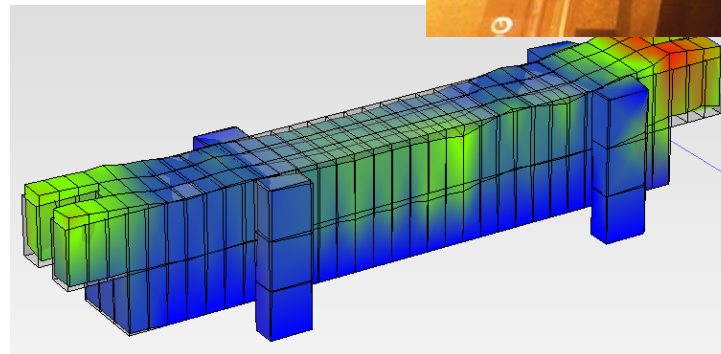
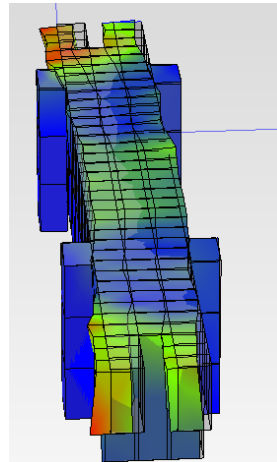


Amplification of floor movement

Mode Shape	Installation on 4 feet		Installation on 3 feet	
	Frequency	Damping	Frequency	Damping
Lateral rigid body mode	46.3 Hz	2.0 %	37.9 Hz	1.6 %
Longitudinal rigid body mode	56.4 Hz	1.2 %	60.3 Hz	1.4 %
Vertical rigid body mode	81.2 Hz	2.4 %	75.8 Hz	2.3 %
First lateral bending mode	129 Hz	0.5 %	108 Hz	0.9 %
First vertical bending mode	147 Hz	1.3 %	153 Hz	0.8 %

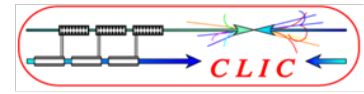


3D View
GL OP-SR OP
Freq: 46.3 Hz [Complex]
Damp: 2.02%



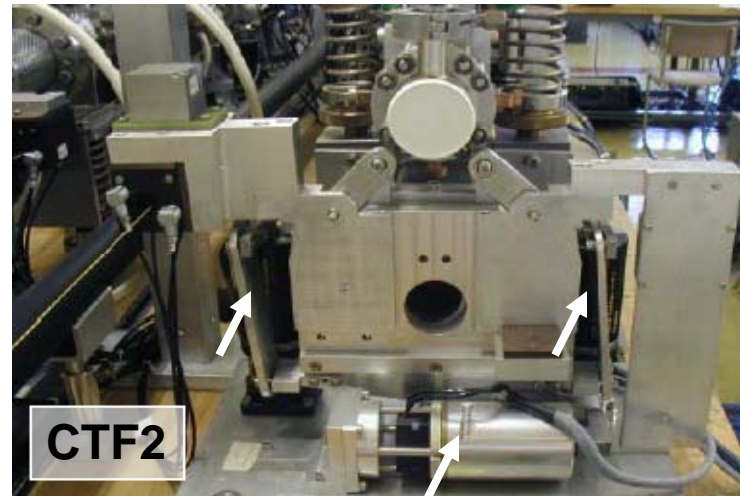
ACE090527
5/21/2009

Overall design



Accelerator environment

- Mechanical coupling via beam pipe, cooling pipe, instrumentation cables,...
- Vibrations inside the structure to be stabilized:
 - Cooling water circuit
 - Inter pulse alignment with stepper motors
- Radiation
 - Radiation level at CLIC not yet estimated
 - Radiation damage effects on electronics:
 - Total dose
 - Displacement
 - Single event error



Beam experiment at CESRTA

- 1st phase: Demonstration of nm-sensitivity for beam motion observation
- 2nd and 3rd phase: demonstration of quad stabilization on a nm-level
- Installation of high sensitivity electronics onto an existing BPM at CESR: BBQ electronics. (M.Gasior et al. (CERN); successfully used for tune diagnostics at CERN, FNAL, BNL
- Using CESR with low emittance beams (order of micrometers)
- Optimization of this electronics for very low frequencies: 10 Hz – 100Hz; observation of beam spectra; selection of narrow frequency window with lowest beam eigen-motion
- Controlled low amplitude beam excitation through current modulation of a corrector dipole.
- Trying to obtain a reasonable signal to noise ratio for beam oscillations of nm-size (expected measurement time: 15 minutes)



Contents

- Organization
- Actions
 - Sensors
 - Characterize vibrations/environmental noise
 - Actuators
 - Feedback
 - Overall design + analysis
 - Integrate and apply to Linac
 - **Final Focus**
- Conclusion

Some words on the Final Focus

- No dedicated full mock-up for FF will be done before CDR, but special features to be integrated in the Linac mock-up
 - Integration of all the final focus features: types of supporting structures, coupling with vertex detector, forward detectors,...
 - Small mock-ups for FF (cantilever) being developed
 - Main features being studied by MDIWG to define inputs to the future program:
 - Type of magnet : permanent or/and superconductors
 - Type of supporting structures: cantilevered beams or connected through the experiment
- A subject for the CLIC/ILC collaboration, presently around ATF2

ATF2 by LaVista

A way to avoid amplification!
Table fixed on one entire face to the floor

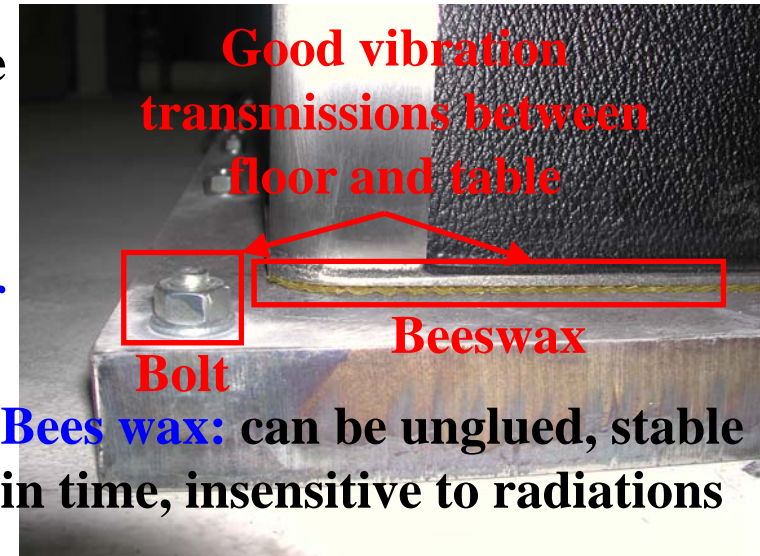


Honeycomb table

Bees wax

3 steel plates
bolted to the floor

Space between
plates to move the
table with slings



Good vibration
transmissions between
floor and table

Beeswax

Bolt

Bees wax: can be unglued, stable
in time, insensitive to radiations

Evolution of resonances with masses simulating FD weight



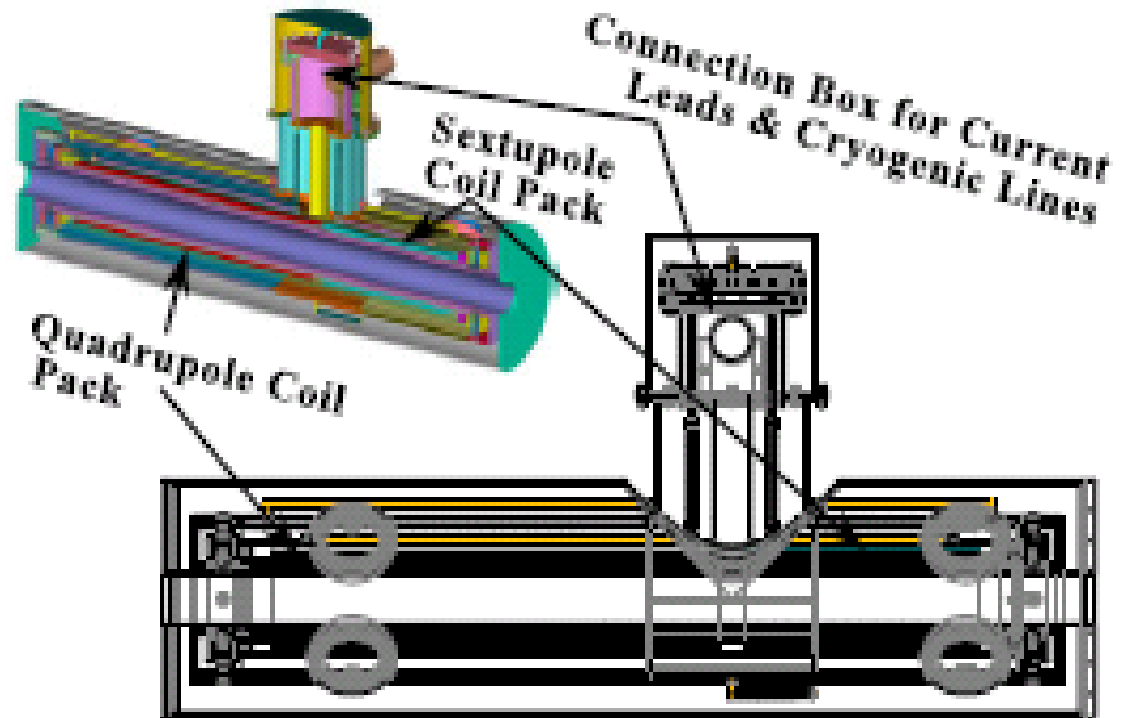
GURALP geophones
(0.033Hz - 13Hz)

ENDEVCO 86 accelerometers
(13Hz - 100Hz)

G. Huviller
Microphone of type 4189



FF mock-up proposal (2011)



Brett Parker
(PAC'08)

Figure 3: ATF2 Magnet Cryostat Overview.

Conclusion



MONALISA IRFU/SIS

The Stabilization Working Group is up and running.

Actions plan is in place.

A pragmatic approach with a deadline in 2010:
a full scale demonstrator with an MB quadrupole built and
qualified.

No prototyping work on the FF before 2010, but involvement of
CLIC study in ATF2 work