Vibration Stabilization Experimental Results

CLIC Main Beam and Final Focus Magnet Stabilization

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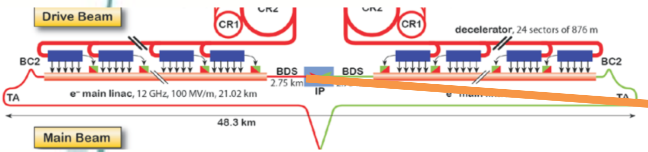
Outline

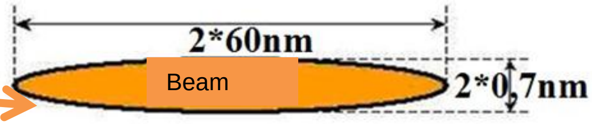
- Introduction
- Final Focus quadrupole stabilization
- Main Beam Linac quadrupole stabilization
- Global performance
- Conclusion and identification of limiting factors

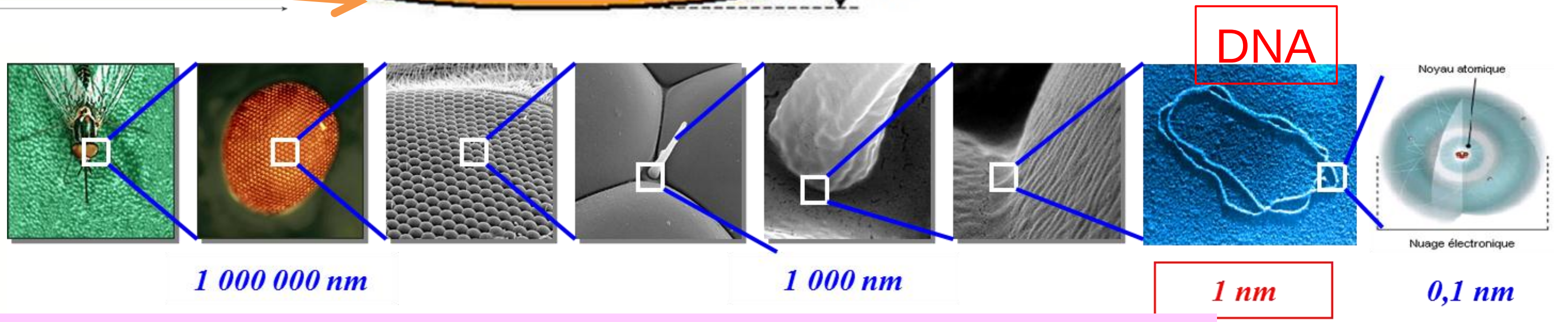
Introduction

- Although the two systems shown have different demonstration objectives, the final MDI stabilisation system will probably take the best of both…
- Or something completely different…

Why do we need stabilization?







But Vibration Sources can amount to 100s of nm:
Ground motion, Traffic, Lifts, cooling water, ventilation, pumps, machinery, acoustic pressure

Transmitted:

- from the ground through the magnet support,
- directly to the magnet via beam pipe, cooling pipes, cables...

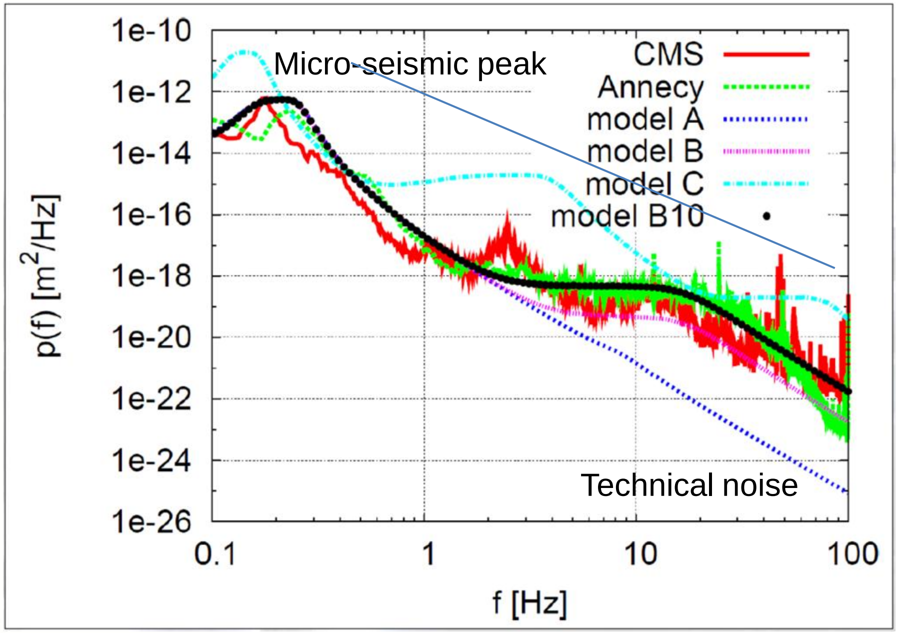
We cannot rely only on the quietness of the site

Stabilization techniques have to be developed

What we are aiming at

- Ground motion has an impact on luminosity

=> especially when beam guiding quadrupole magnets vibrate



	FF	MBQ
Vert.	**0.2 nm > 4Hz**	**1.5 nm > 1 Hz**
Lat.	**5 nm > 4 Hz**	**5 nm >1 Hz**

<1Hz	1Hz<f<100Hz	100Hz<f
Beam-based feedback	Mechanical stabilisation	Low Ground motion

- At the IP (mechanical + beam feedback), we aim at 0,1nm at 0,1Hz

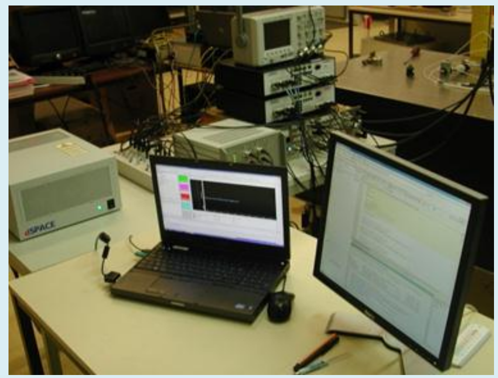
Active Stabilization techniques have been chosen

What is needed?

Active Stabilisation means :

measure => decide action => act

sensor | *feedback/-forward* | *actuator*



-measure sub-nanometre
-low frequency
-Large band width (0.5-100Hz)
-Low noise
-Smalest delay for real-time
-Small and light
=> Seismic sensors

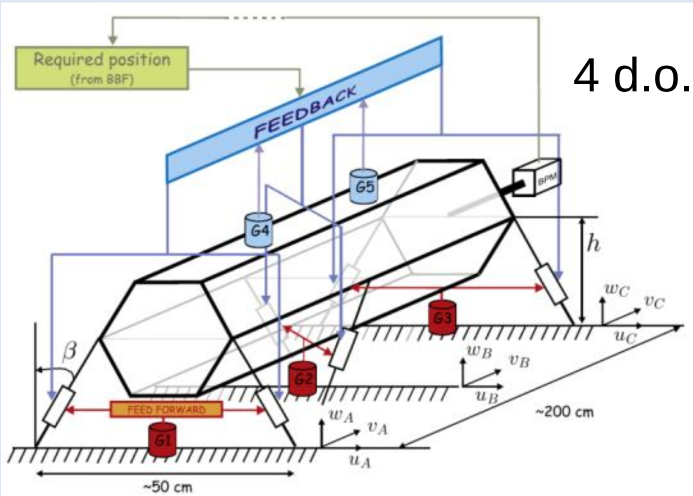
-real-time feedback
-Mutli-channel
-simulation possibilities
-Fast electronics
-Large dynamics(>16bits)

-Nanometre displacement
-Displace heavy weight
-Compact
-Real-time response
=> Piezoelectric actuator

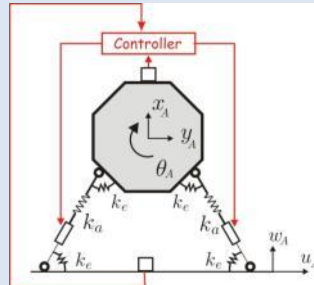
Accelerator environment
=> Magnetic field resistant and radiation hard

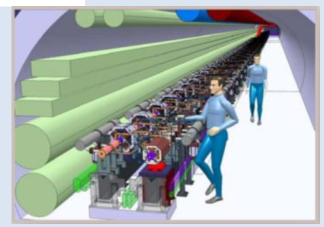
2 « similar » active solutions

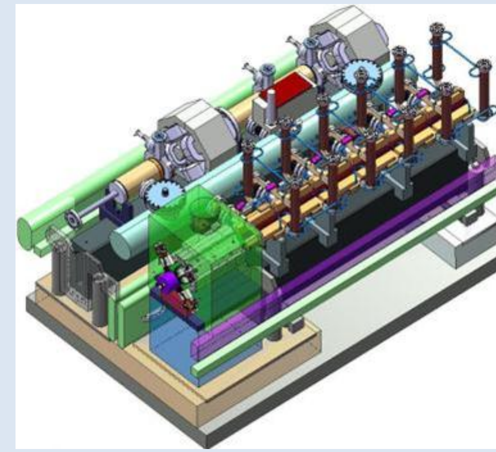
Main Beam Linac quadrupole demonstration (« CERN »)



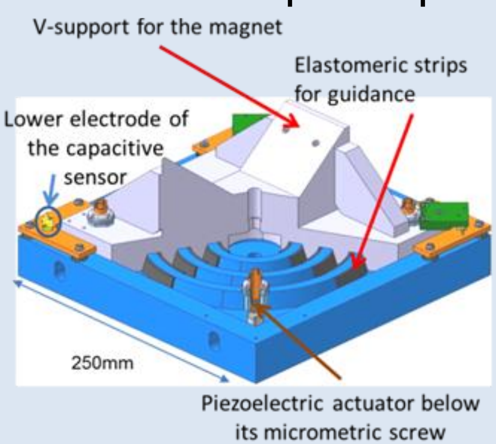
4 d.o.f.

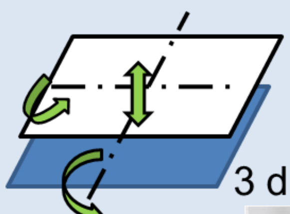




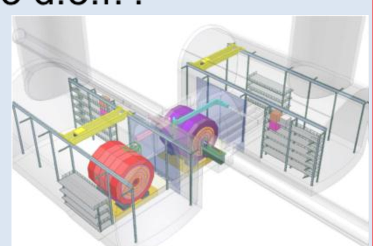


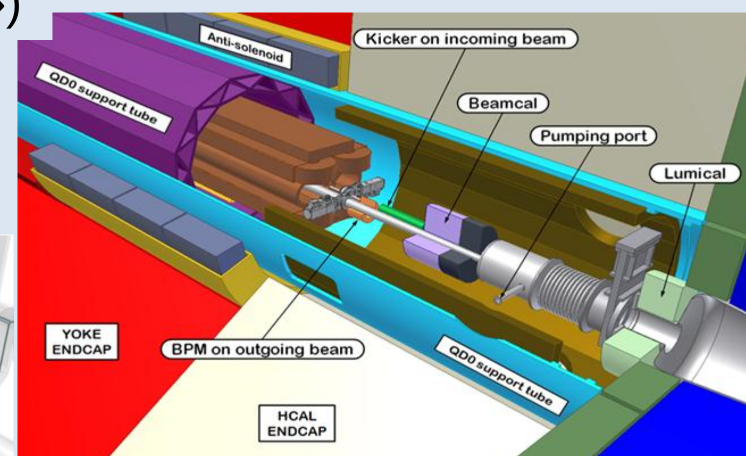
Final Focus quadrupole demonstration (« Annecy »)





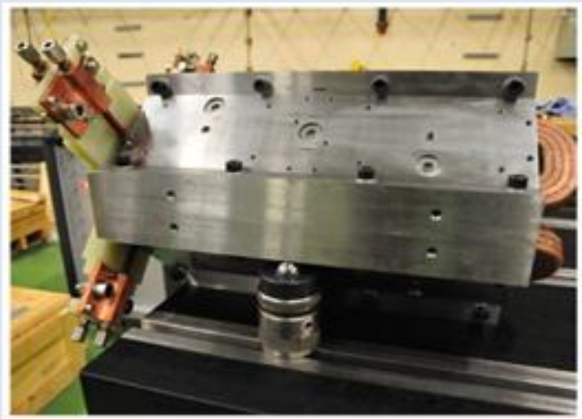
3 d.o.f. :





Magnets to be stabilised

Main Beam quadrupoles

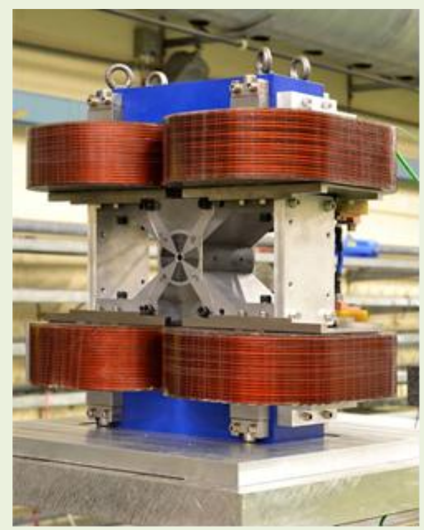


Type 1
500mm
100kg

Type 4
2000mm
450kg

Final focus quadrupole prototype

Permanent magnet ($Nd_2Fe_{14}B$) + coils

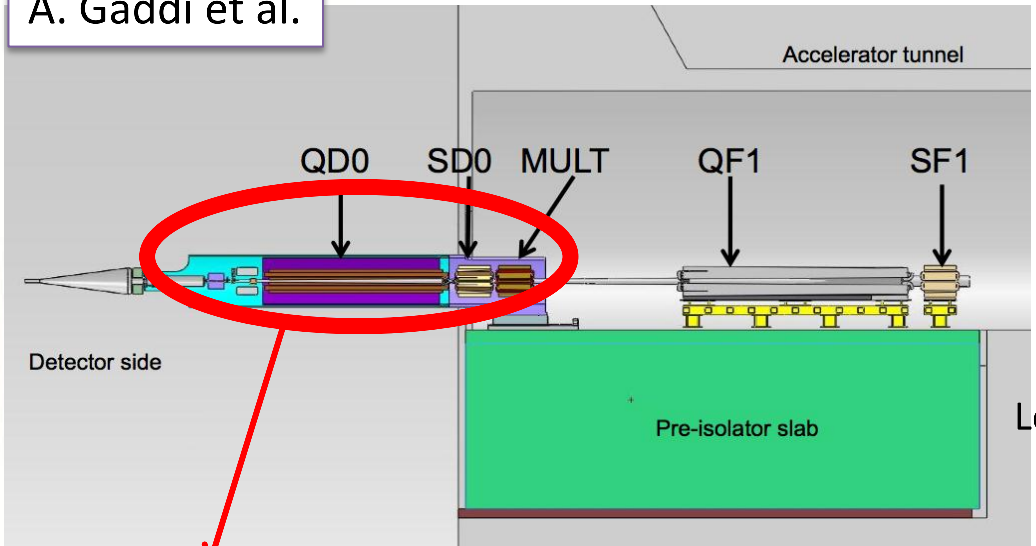


Final Focus Stabilization

- Mechanics
- Instrumentation
- Electronics and acquisition
- Results

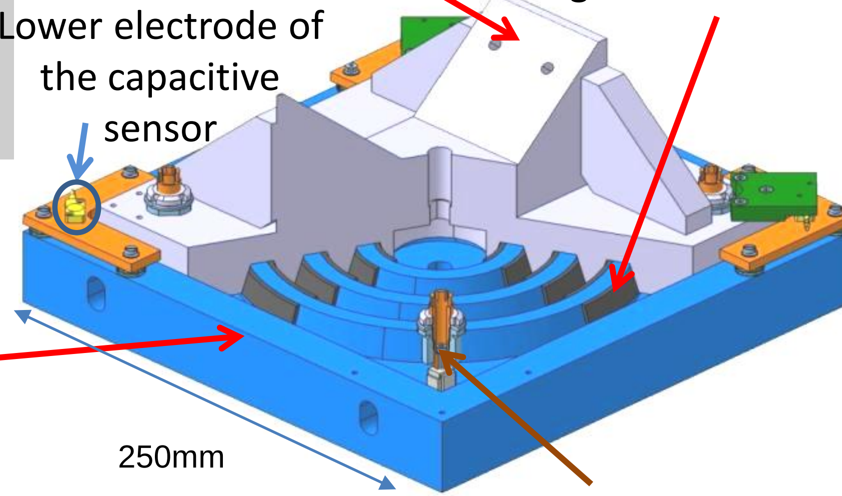
Final Focus quadrupole: Passive and active solution

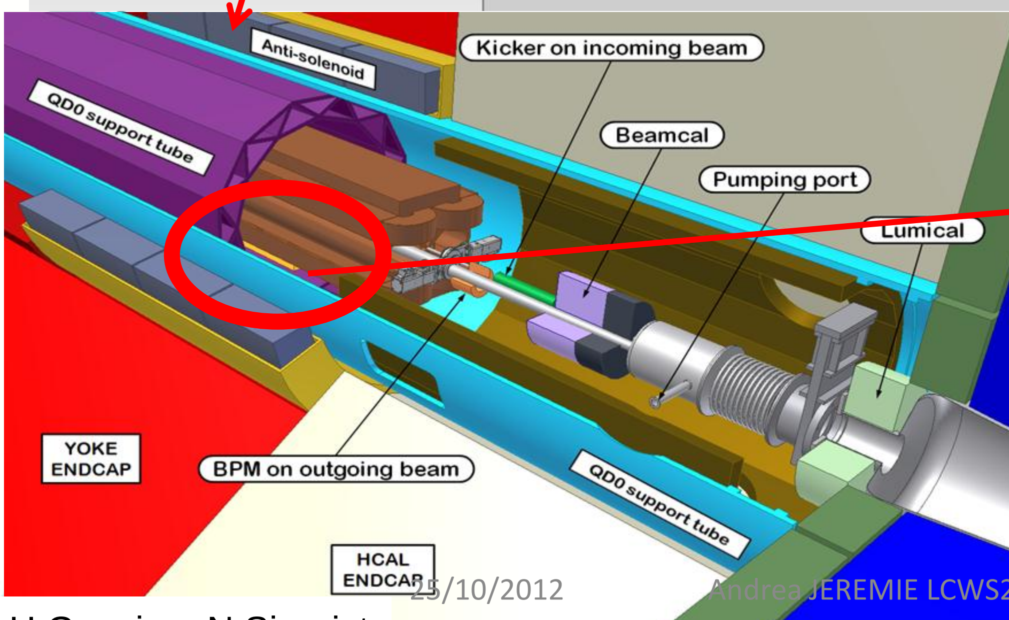
A. Gaddi et al.



Add coherence between QD0 and QF1 and reduce band-width on which active stabilisation has to act

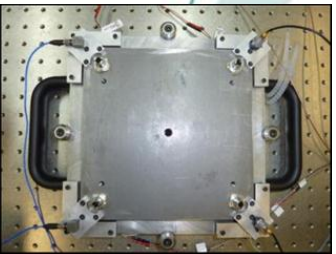
V-support for the magnet



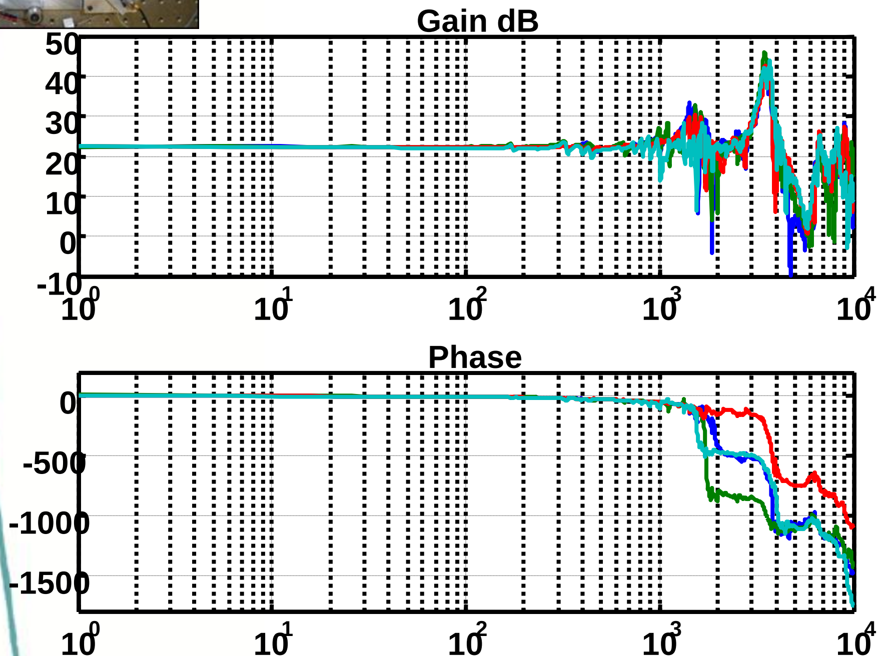


Additional passive stage directly under active system is also envisaged

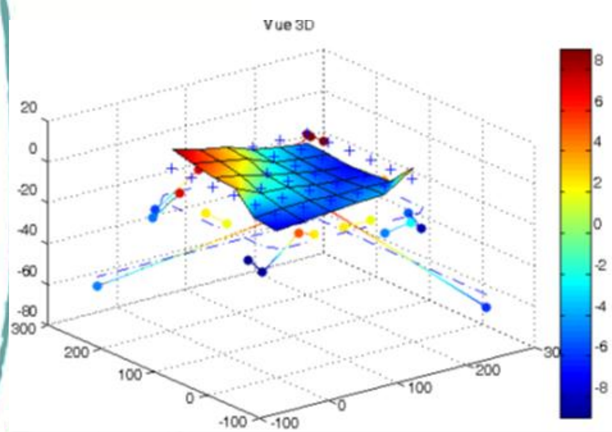
H.Gerwig + N.Siegrist

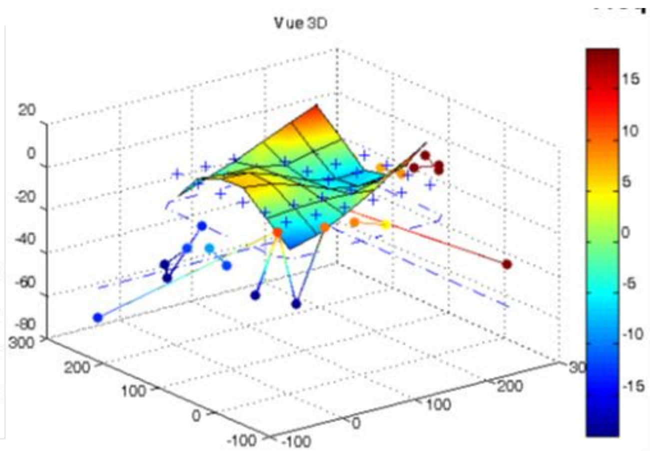


Mechanical characteristics



Intrinsic resonances if change of phase by 90°: other peaks just from boundary conditions
=> 2 resonance peaks just below 2kHz and near 4kHz.





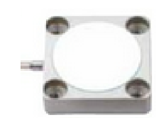
First intrinsic resonance frequency near 2kHz : experimental and theoretical values agree.

Sensors and actuators

Sensor type	Electromagnetic Geophone		Piezoelectric Accelerometer		Electrochemical Geophone	Capacitive
Model	GURALP CMG-40T	GURALP CMG-6T	ENDEVCO 86	WILCOXON 731A	SP500	D-015.00
Company	Geosig	Geosig	Brüel & Kjaer	Meggitt	EENTEC	Physik Instrumente
Output signal	Velocity (X,Y,Z)		Z acceleration		Velocity	Distance
Sensitivity	1600 V/m/s	2400 V/m/s	10 V/g	10 V/g	2000 V/m/s	0.67 V/µm
Bandwidth [Hz]	[0.033-50]	[0.033-100]	[0.01-100]	[0.05-500]	[0.0167-75]	[0-3000]
Mass [g]	7500	2600	771	555	750	<10
Zeros	[999, 0, 0, 0]	[0, 0, 0]		Real part < 0		



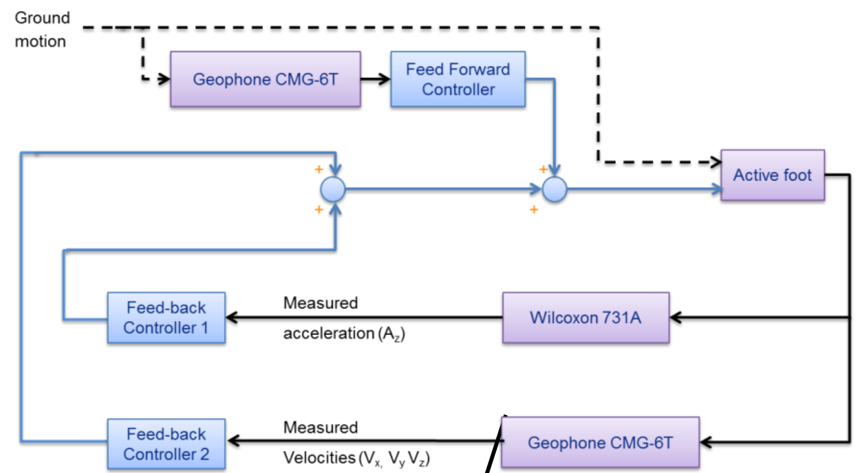


PPA10M piezoelectric actuators

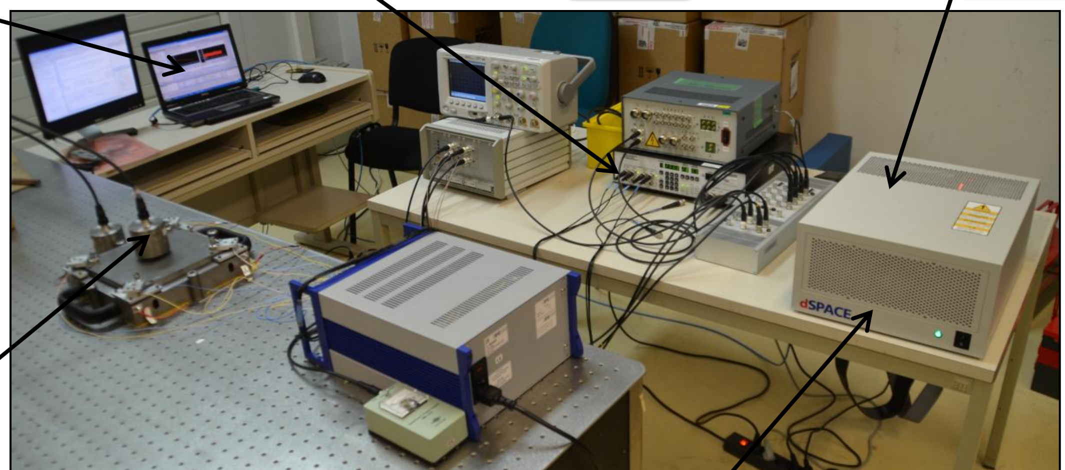
Resolution	Resonnance	Response time	Max Force	Max displacement
0.08nm	65kHZ	0.01ms	400N	8µm

Experimental set-up



Amplifiers, filtres, inputs/outputs, signal conditionning

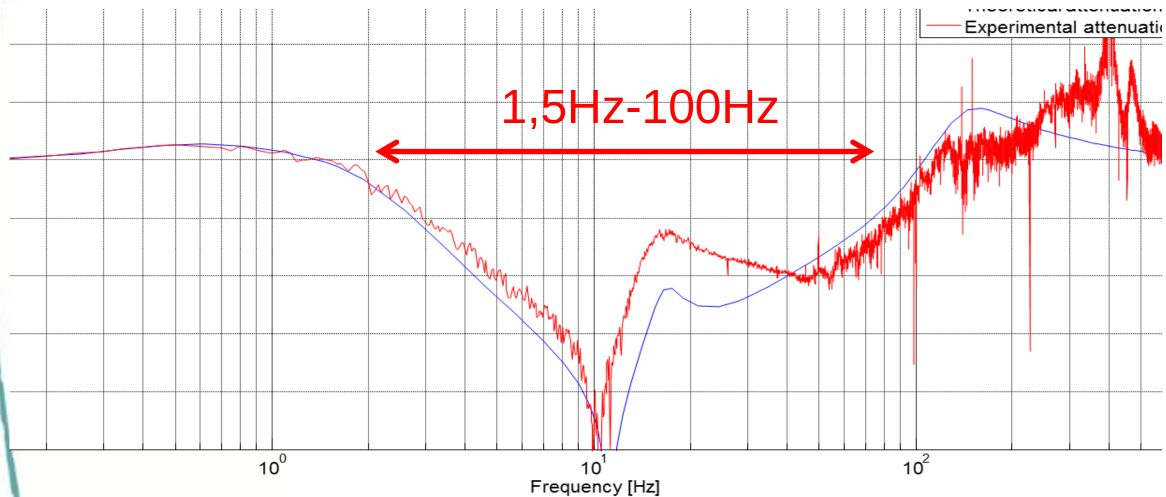
Matlab and dSPACE ControlDesk



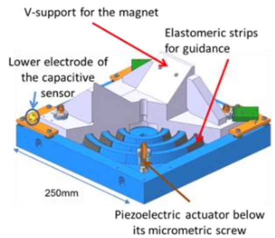
Active system with sensors

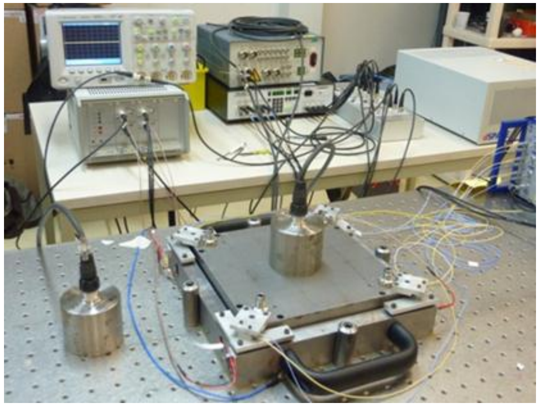
dSPACE real-time system dedicated to rapid prototyping and simulation with 16bits ADC

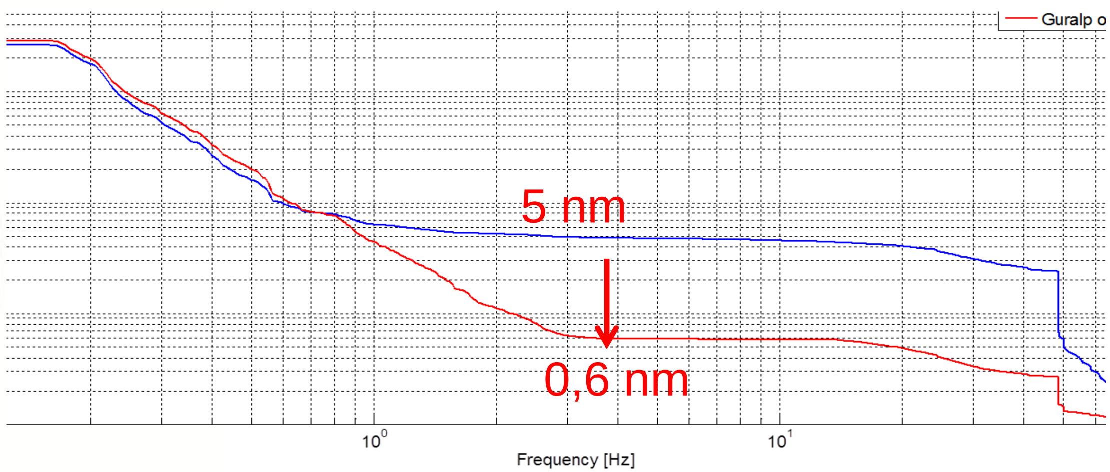
FF stabilization results



Attenuation up to 50dB between 1,5-100Hz





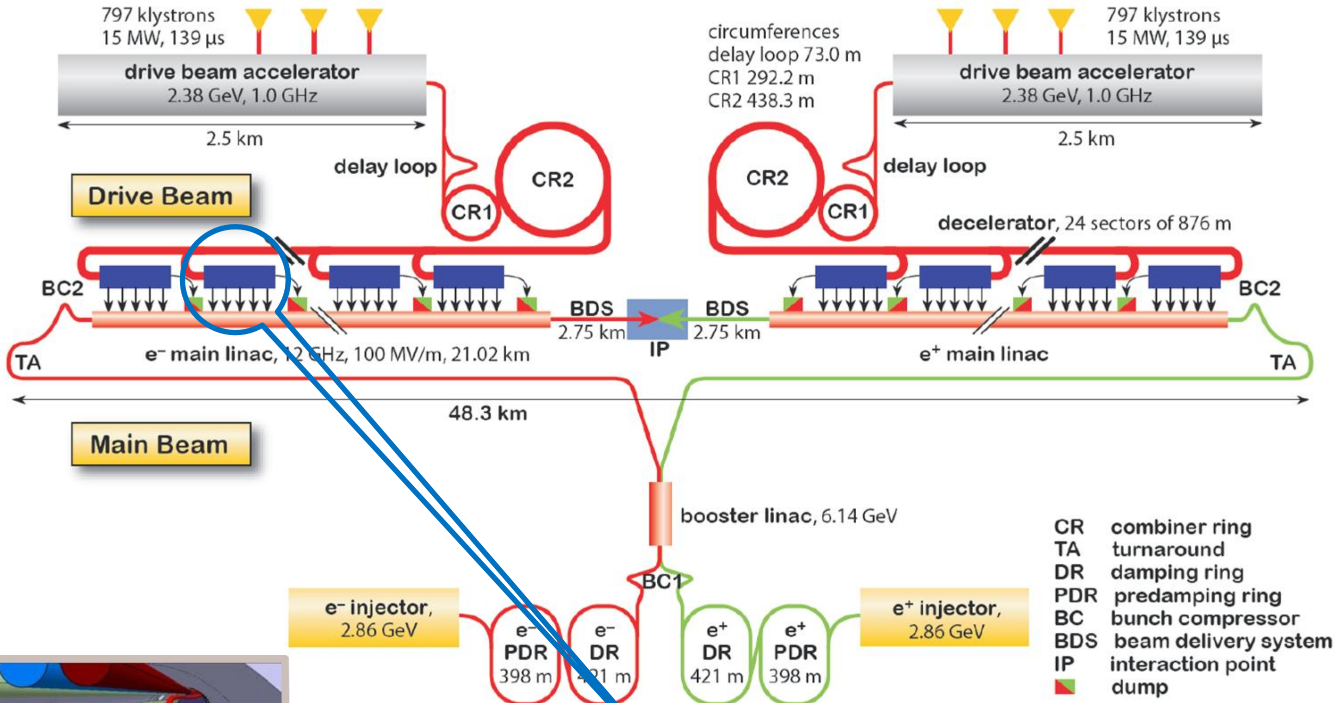


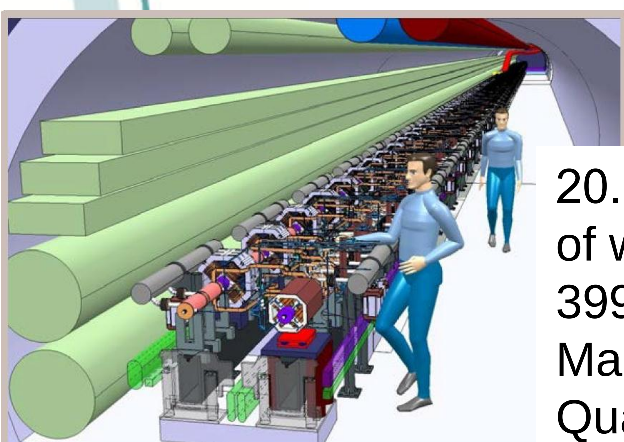
RMS ground at 4 Hz: 5 nm
RMS on foot at 4Hz: 0,6nm
RMS ratio: 8,3

Main Beam Linac Stabilization

- Mechanics
- Electronics and acquisition
- Results

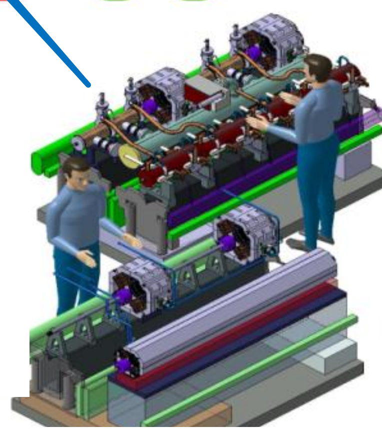
CLIC and CLIC modules

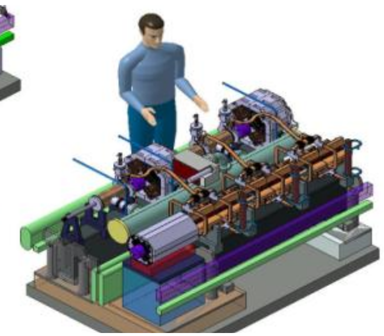




20.926 “Modules” of which there are 3992 with CLIC Main Beam Quadrupoles

Type 0: No Main Beam Quad

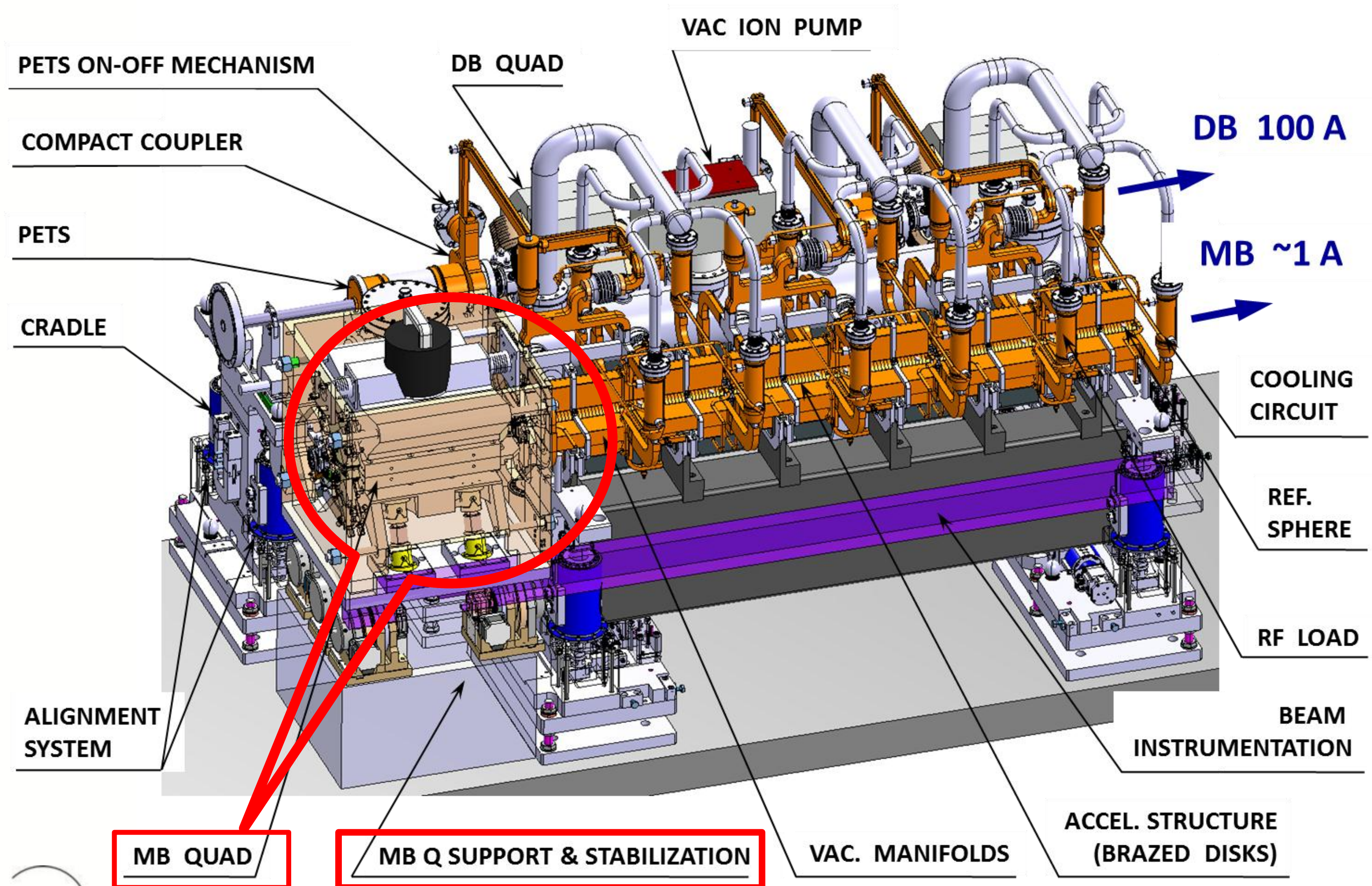




Type 4: 2m, 400 kg

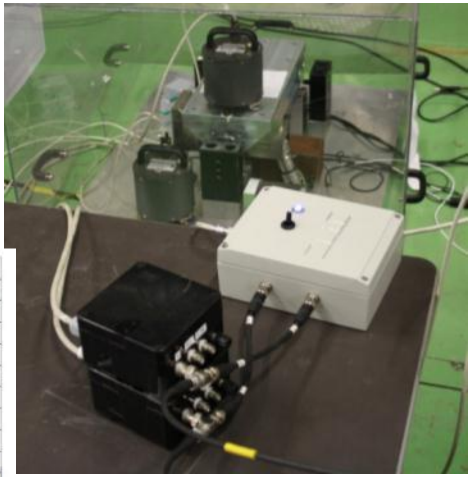
Type 1: 0.5 m, 100 kg

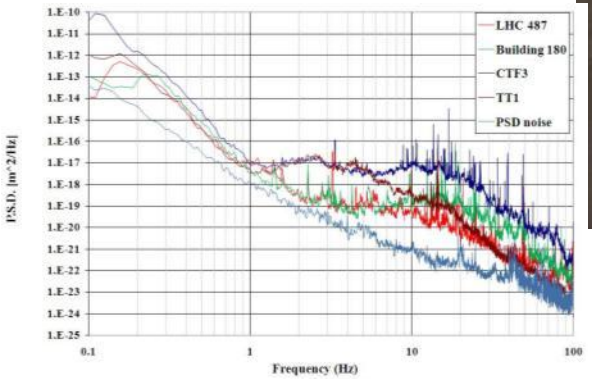
Main Linac Module with Type 1 quadrupole

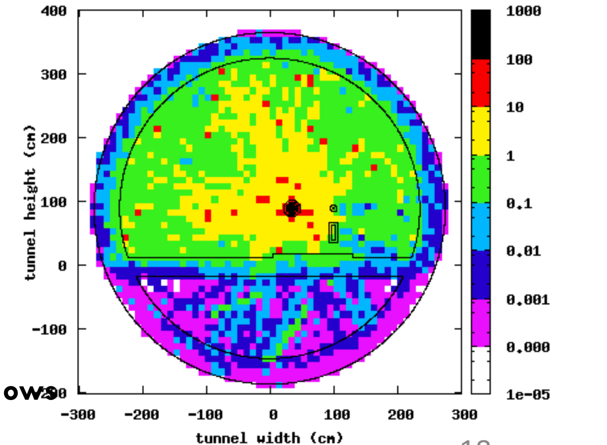


Design constraints

- Inputs:
  - Resolution 2 µV
  - Dynamic range 60 dB
  - Bandwidth 0.1-100 Hz
- Output:
  - Dynamic range 140 dB
- Resistance to radiation
  - Shielding, location, design
- Cost (~4000 magnets to be stabilized)
- Power restrictions (cooling)







MB 9 GeV

Courtesy S. Mallows

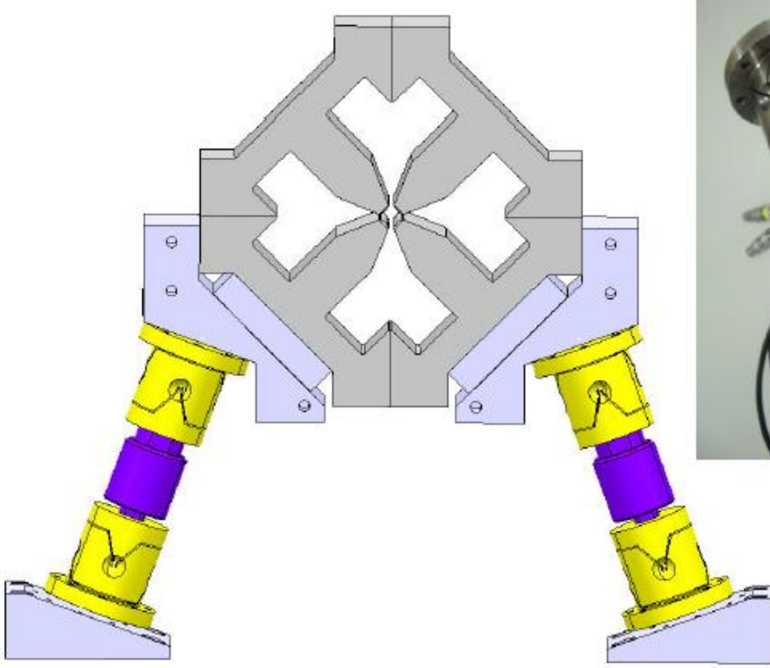
Actuator support

stabilisation support section made of

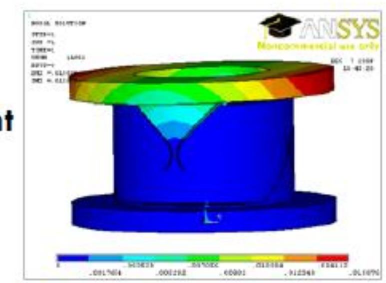
Inclined stiff piezo actuator pairs with flexural hinges (vertical + lateral motion)

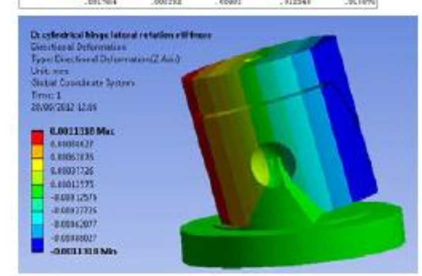
(each magnet will have 2 or 3 sections depending on its length)

PI Piezoelectric Actuator
High stiffness (480N/μm)
Sufficient travel (15 μm)
Good resolution (0.15 nm)

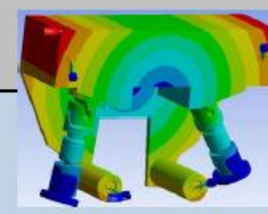
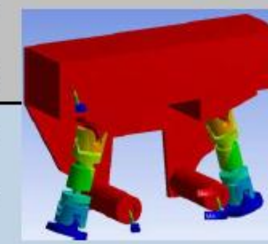
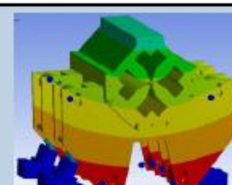
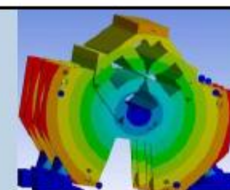
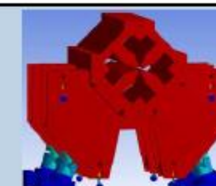


Universal Flexural Joint
2 rotation axes in the same plane
rotational stiffness (k_e=220Nm/rad)
Axial stiffness (k_{aj}=300N/μm)





Analytical & FE results

		Hz k_h [N/µm]	Vt k_v [N/µm]	4-bar mode f [Hz]	4-bar mode shape	θ mode f [Hz]	θ mode shape	Vertical mode f [Hz]	Vertical mode shape
Without xy guide	Analytical	0.21	203	9.2		255		319	
	Ansys classic	0.21	204	9.2		255		319	
	Ansys WB	0.21	203	8.3		245		312	
With xy guide	Analytical	35	229	153		310		339	
	Ansys classic	44	225	125		275		327	
	Ansys WB	38	220	145		303		336	
Type 1 MBQ with xy guide		k_h=69 [N/µm]	k_v=227 [N/µm]	119 [Hz]		303 [Hz]		319 [Hz]	

Longitudinal stiffness

Without xy guide	With xy guide (pins totally fixed on 1 end)	With xy guide (pins fixed to steel plates)
0.03 N/µm	278N/µm	48 N/µm

Longitudinal mode

Without xy guide	With xy guide (pins totally fixed on 1 end)	With xy guide (pins fixed to steel plates)
3.4 Hz	280 Hz	65 Hz

Control

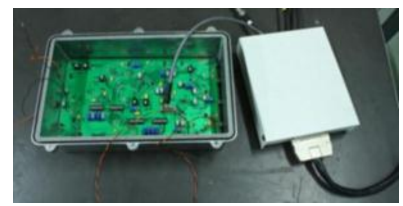
Component	Delay
ADC	8 µs
Electro-optic transducer	100 ns
Optic fiber transmission	**5 µs/Km**
Opto-electric transducer	120 ns
DAC	3 µs
Actuator (20nm single step)	1 µs
Typical catalog delay values for the components	

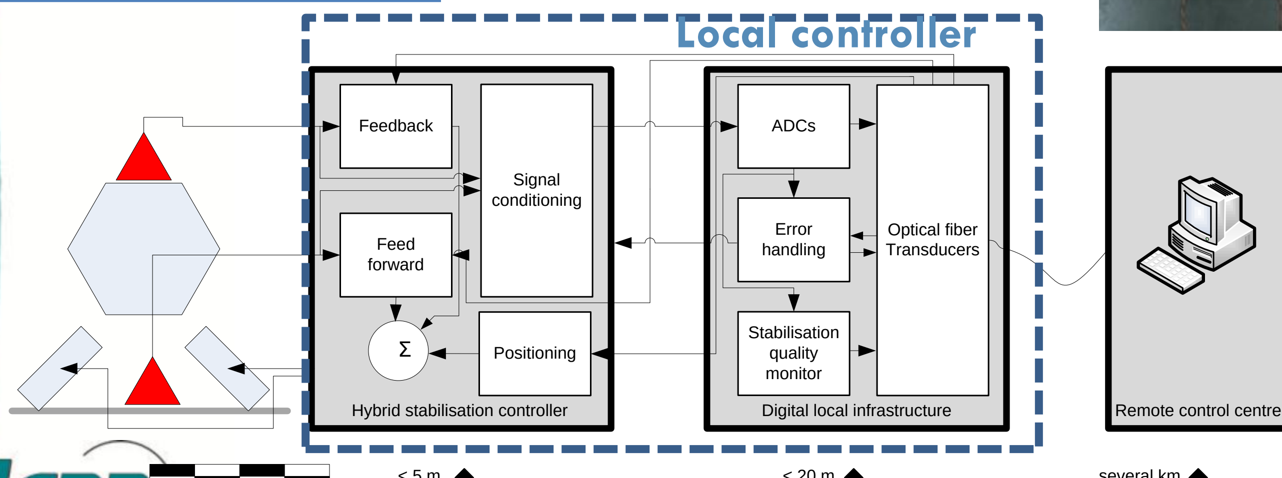
↔

The farther away the control hardware, the less effective the stabilisation system => Need for a local controller

↔

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



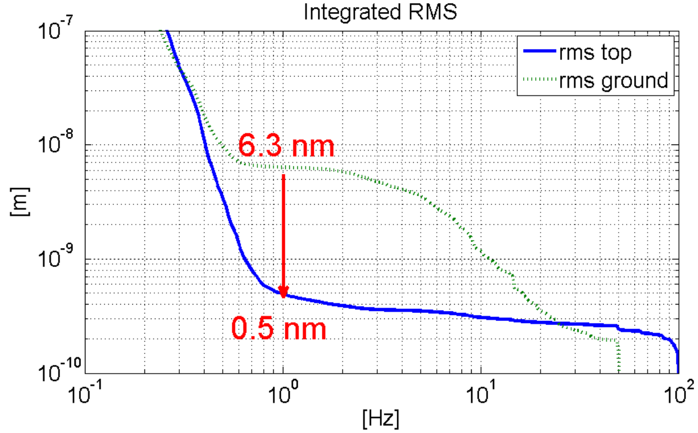


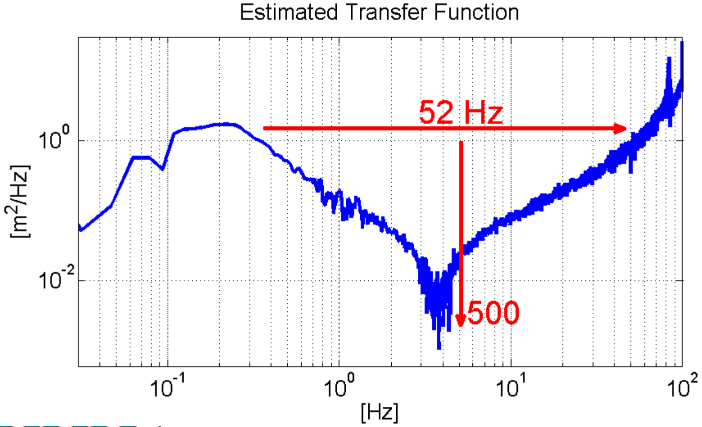
Digital and analog hybrid controller :

- Digital: flexibility
- Analog: less latency and higher radiation hardness

Stabilization on Type 1 MBQ

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





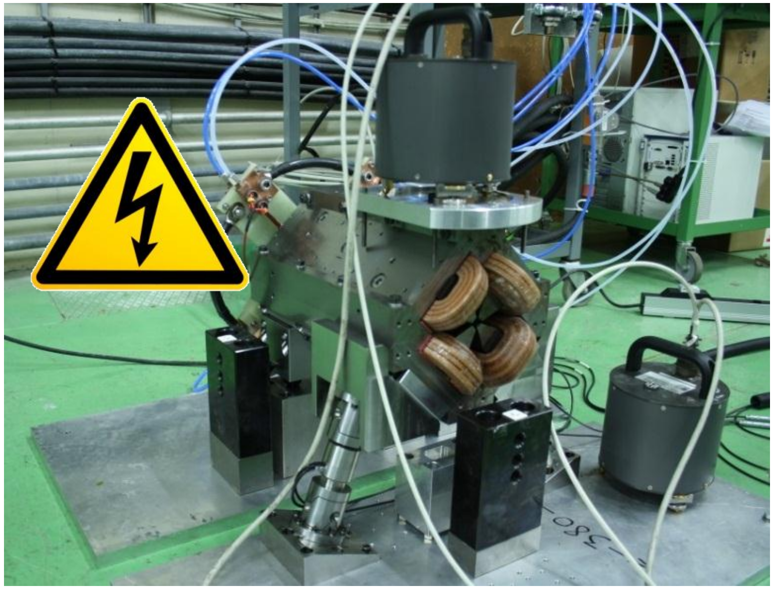
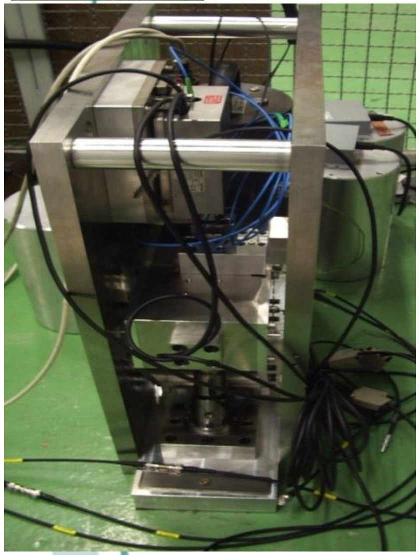
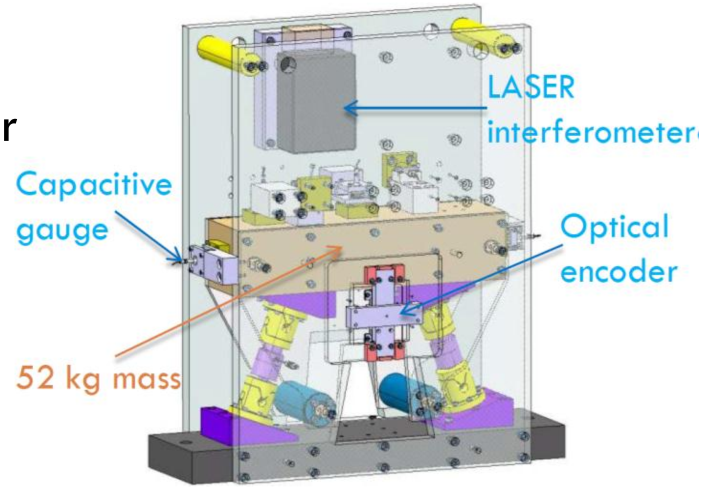


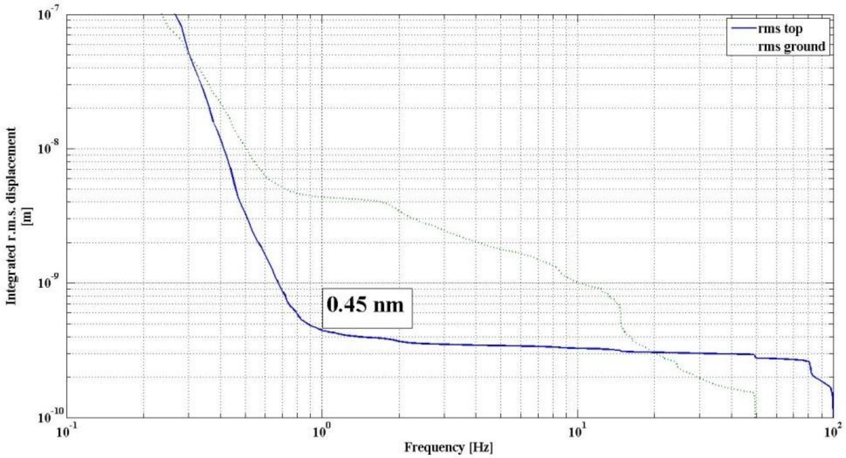
Figure	Value
R.m.s @ 1Hz magnet	**0.5 nm**
R.m.s @ 1Hz ground	6.3 nm
R.m.s. attenuation ratio	**~13**
R.m.s @ 1Hz objective	**1.5 nm**

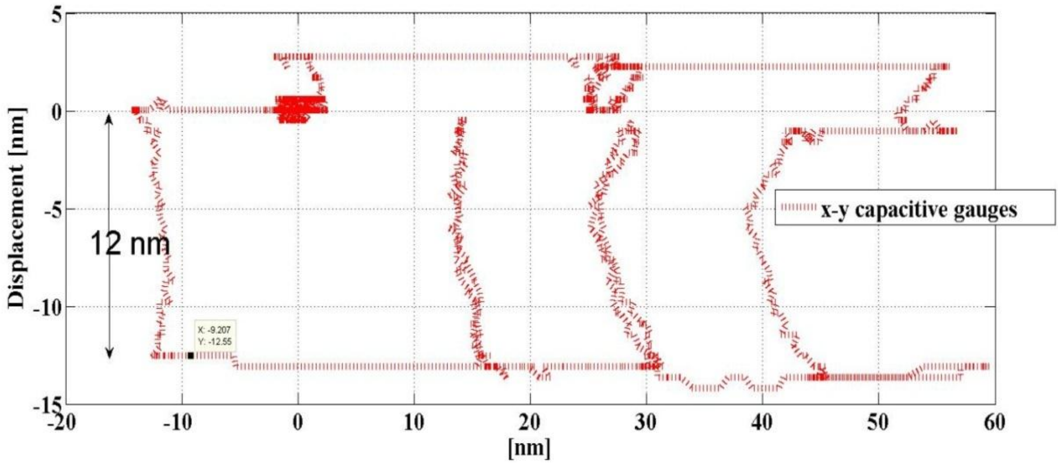
Improved mechanics prototype x-y guide



- X-y guide « blocks » roll + longitudinal direction
- Increases lateral stiffness by factor 500, increases band width without resonances to ~100 Hz
- Introduces a stiff support for nano metrology
- cross check with interferometer







Conclusion for Stabilization

- Different domains needed:
  - Mechanics (supports, guides, mechanical resonators, …)
  - Instrumentation (sensors, compatibility with active control, …)
  - Electronics (acquisition & control, band-width, resolution,…)
  - Automatics (control, real time simulation …)
  - Accelerator physics (beam simulations, luminosity at Interaction Point…).
- Sub-nanometre stabilisation peformed validating CLIC stabilisation feasibility: limiting factor are the « noisy » sensors (especially limiting in the 0.8-6Hz range)
- Integrated luminosity simulations show sub-nanometre beam size at IP and less than 6% luminosity loss (see LCWS 2011 Jeremie and Collette)
- Next step: tests in accelerator environment