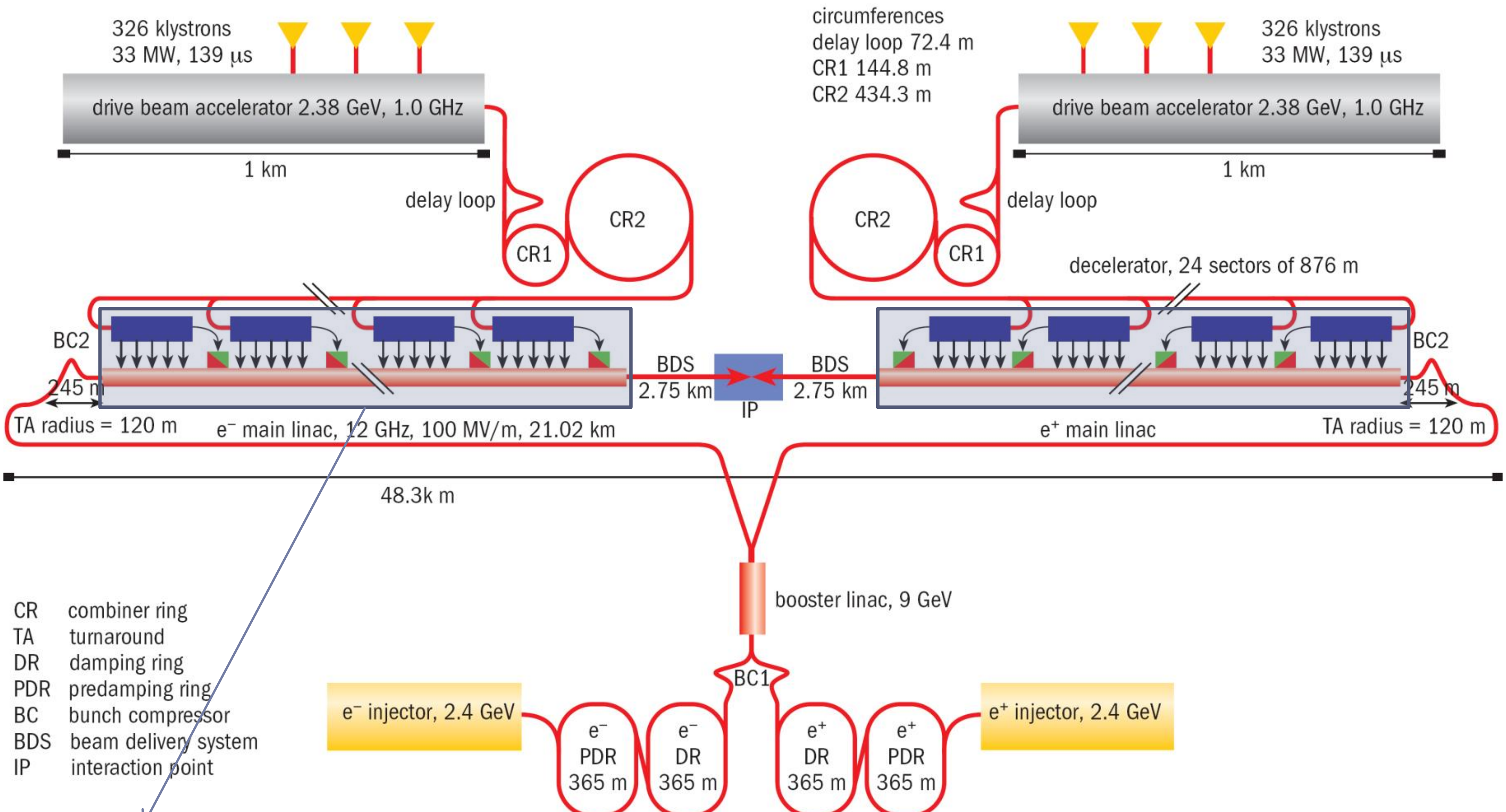
Outline

- Short overview of the CLIC project
- Timelines
- CLIC "feasibility demonstration"
- Stabilization of Main Beam Quadrupoles
- Experimental verification of Quadrupole stability
- Outlook for JLAB collaboration

CLIC Layout @ 3TeV



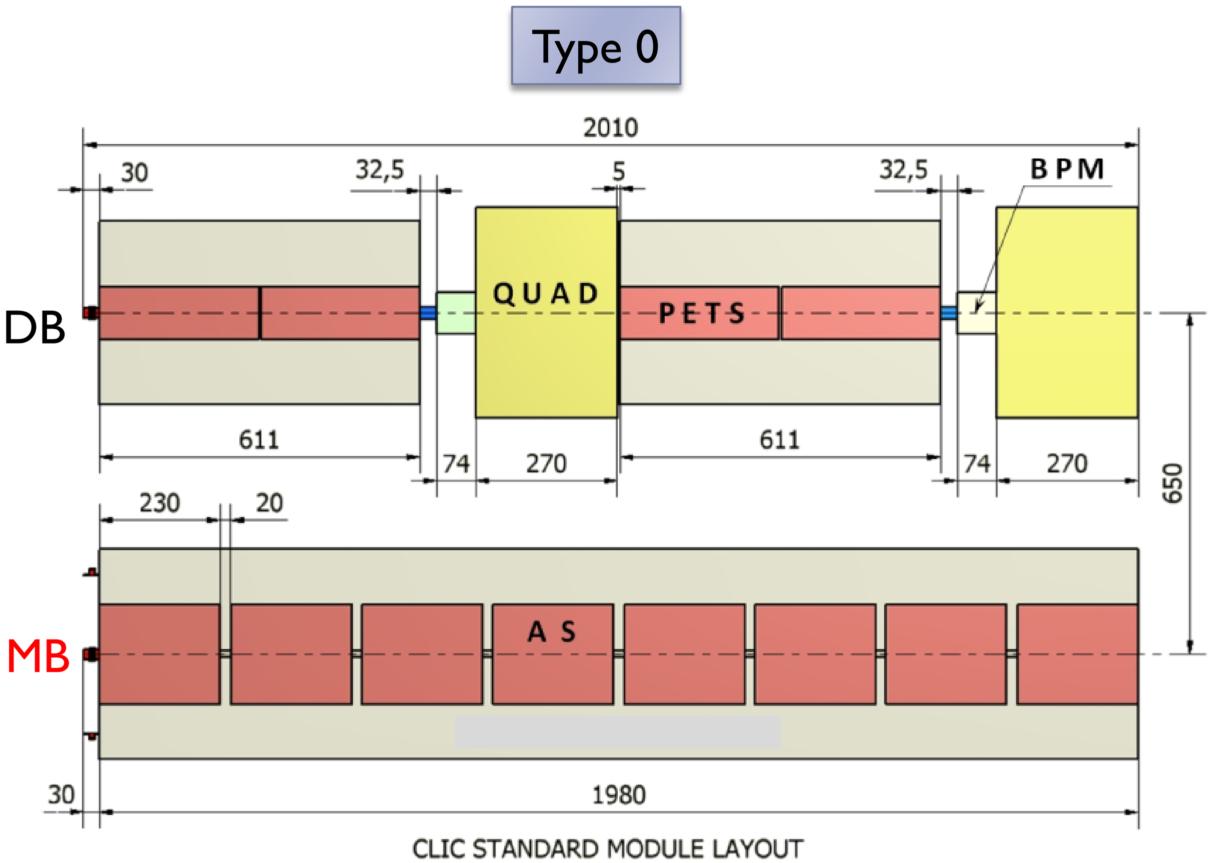
Per linac:
Module: 10460
Accelerating structures: 71406 PETS: 35703
MB quadrupoles: 1996 DB quadrupoles: 20920

CLIC main parameters

http://cdsweb.cern.ch/record/1132079?ln=fr http://clic-meeting.web.cern.ch/clic-meeting/clictable2007.html

Center-of-mass energy	CLIC 500 GeV		CLIC 3 TeV	
Beam parameters	Relaxed	Nominal	Relaxed	Nominal
Accelerating structure	502		G	
Total (Peak 1%) luminosity	$8.8(5.8)\cdot10^{33}$	$2.3(1.4)\cdot10^{34}$	$7.3(3.5)\cdot10^{33}$	$5.9(2.0)\cdot10^{34}$
Repetition rate (Hz)	50			
Loaded accel. gradient MV/m	80		100	
Main linac RF frequency GHz	12			
Bunch charge 10^9	6.8		3.72	
Bunch separation (ns)	0.5			
Beam pulse duration (ns)	177		156	
Beam power/beam MWatts	4.9		14	
Hor./vert. norm. emitt($10^{-6}/10^{-9}$)	7.5/40	4.8/25	7.5/40	0.66/20
Hor/Vert FF focusing (mm)	4/0.4	4 / 0.1	4/0.4	4 / 0.1
Hor./vert. IP beam size (nm)	248 / 5.7	202 / 2.3	101/3.3	40 / 1
Hadronic events/crossing at IP	0.07	0.19	0.28	2.7
Coherent pairs at IP	10	100	$2.5\ 10^7$	$3.8\ 10^8$
BDS length (km)	1.87		2.75	
Total site length km	13.0		48.3	
Wall plug to beam transfert eff	7.5%		6.8%	
Total power consumption MW	129.4		415	

Module types and numbers



<u>Total per module</u>

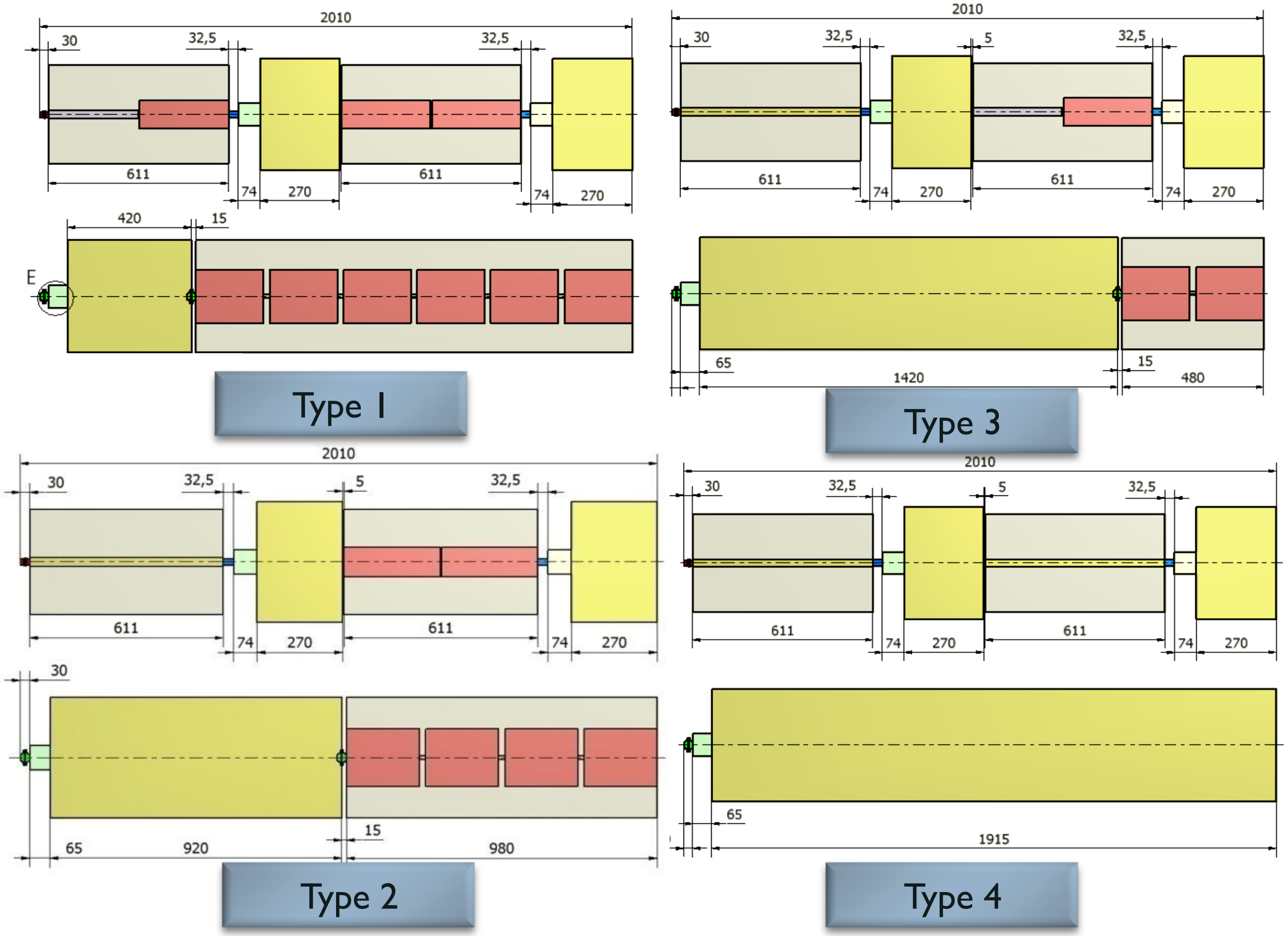
8 accelerating structures
8 wakefield monitors

4 PETS
2 DB quadrupoles
2 DB BPM

<u>Total per linac</u>

8374 standard modules

Module types and numbers



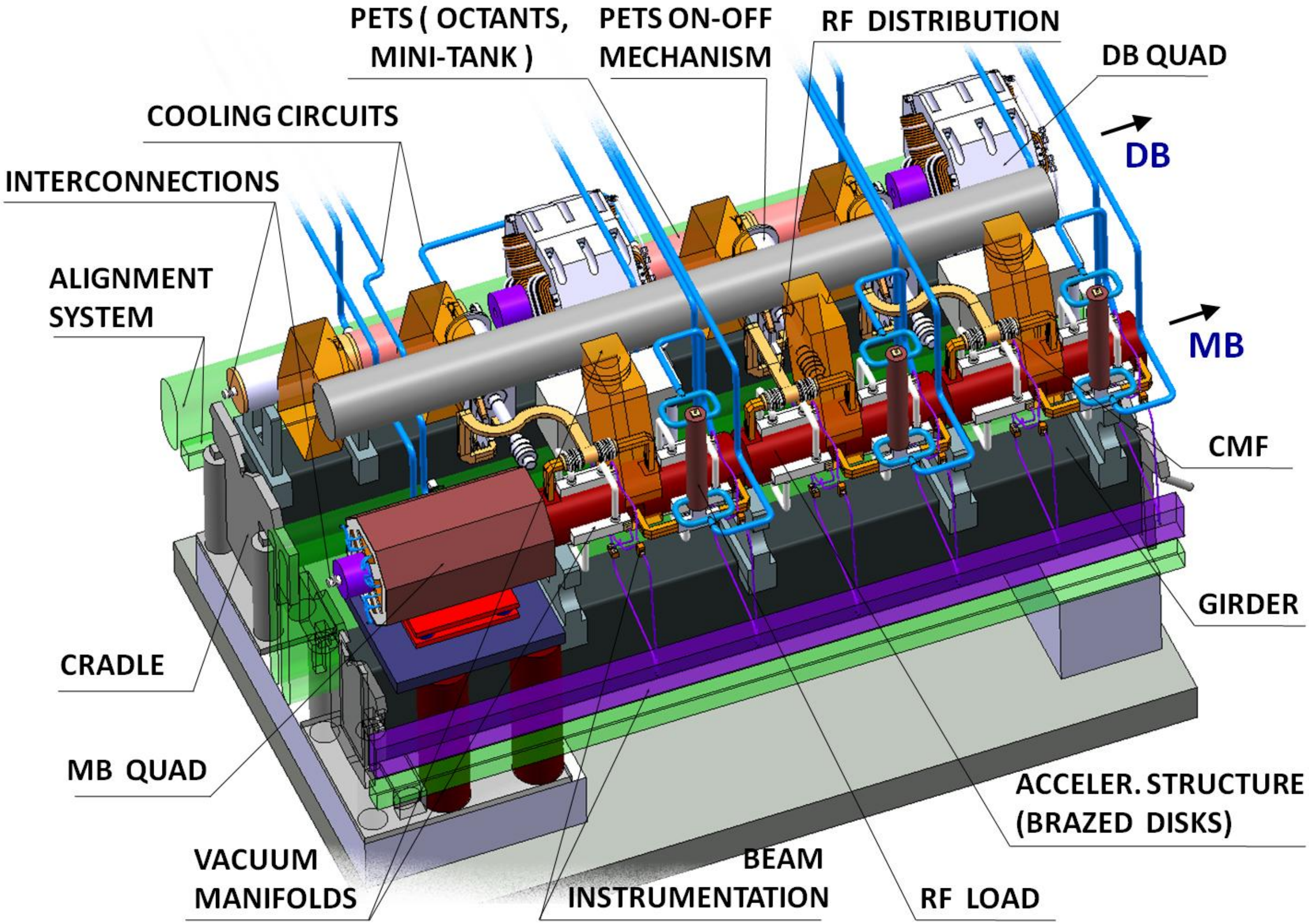
Total per linac

Quadrupole type 1: 154
Quadrupole type 2: 634
Quadrupole type 3: 477
Quadrupole type 4: 731

Other modules

- modules in the damping region (no structures)
- modules with dedicated instrumentation
- modules with dedicated vacuum equipment
- …

Module type 1



All 3D models made by A. Samoshkin

Linear Colliders tentative schedule endorsed by ILC GDE/EC and CERN Directorate

CLIC

Physics requests based on LHC results?
Linear Collider assessment based on technology maturity, performance, cost and risks?

RDR

TDP1

TDP2

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
ILC								?	?	?	?
CLIC											?

R&D,Conceptual Design&Cost Estimation

Technical design & industrialisation

Project approval & final cost

CDR

Intermediate TD

TDR

CLIC cost peer review

CERN Council decision
CLIC Technical Design

CLIC

CLIC critical issues
R&D strategy and schedule

Overall list of critical issues (Risk Register) under:

https://edms.cern.ch/nav/CERN-0000060014/AB-003093

Issues classified in three categories:

- **CLIC design and technology feasibility**

  Fully addressed by 2010 by specific R&D with results in Conceptual Design Report (CDR) with Preliminary Performance & Cost

- **Performance and/or Cost**

  Both being addressed now by specific R&D to be completed before 2016 with results in Technical Design Report (TDR) with Consolidated Performance & Cost

For each feasibility issue, R&D program and objectives defined:

Discussed @ Advisory CommitteE (ACE) on June 2009

http://indico.cern.ch/conferenceDisplay.py?confId=58072

10 CLIC Feasibility Issues

- **Two Beam Acceleration:**
  - Drive beam generation
  - Beam Driven RF power generation
  - Two Beam Module
- **RF Structures:**
  - Accelerating Structures (CAS)
  - Power Production Structures (PETS)
- **Ultra low beam emittance and beam sizes**
  - Emittance preservation during generation, acceleration and focusing
  - Alignment and stabilisation
- **Detector**
  - Adaptation to short interval between bunches
  - Adaptation to large background at high beam collision energy
- **Operation and Machine Protection System (MPS)**

CLIC specific

CLIC+ILC Common Issues
CLIC more challenging requirements

ACE4 on Feasibility Issues

SYSTEMS		Critical parameters
Structures	**Main Beam Acceleration Structures:** Demonstrate nominal CLIC structures with damping features at the design gradient, with design pulse length and breakdown rate .	100 MV/m 240 ns < 3·10-7 BR/(pulse*m) RF to Beam efficiency > 30%?
	RF Power production structures: Demonstrate nominal PETS with damping features at the design power, with design pulse length, breakdown rate and on/off capability	136 MW, 240 ns < 10-7 BR/(pulse*m)? Beam to RF efficiency >? On/Off < 20 ms
Two Beam	**Two Beam Acceleration (TBA):** Demonstrate RF power production and Beam acceleration with both beams in at least one Two Beam Module equipped with all equipments	Two Beam Acceleration with simultaneous & nominal parameters as quoted above for individual components
Drive Beam	**Drive Beam Production** - Beam generation and combination - phase and energy matching - Potential feedbacks	100 Amp peak current 12GHz bunch repetition frequency 0.2 degrees phase stability at 12 GHz $7.5\ 10^{-4}$ intensity stability
	RF power generation by Drive Beam - Rf power extration - Beam stability	90% extraction efficiency Large momentum spread
Beam Physics	**Generation and Preservation of Low Emittances** Damping Rings, RTML and Main Linacs	Emittances(nm): H= 600, V=5 Absolute blow-up(nm): H=160, V=15
Stabili zation	**Main Linac and BDS Stabilization**	Main Linac : 1 nm vert. above 1 Hz; BDS: 0.15 to 1 nm above 4 Hz depending on final doublet girder implementation
Operation and reliability	**Operation and Machine Protection** Staging of commissioning and construction MTBF, MTTR Machine protection with high beam power	drive beam power of 72 MW @ 2.4 GeV main beam power of 13 MW @ 1.5 TeV
Detector	**Beam-Beam Background** Detector design and shielding compatible with breakdown generated by beam beam effects during collisions at high energy	$3.8\ 10^{8}$ coherent pairs

CLIC Feasibility Issues

System	Item	Feasibility Issue	Unit	Nominal
Two Beam Acceleration	Drive beam generation	Fully loaded accel effic	%	96
		Freq&Current multipl	-	2*3*4
		12 GHz beam current	A	4.5*24=100
		12 GHz pulse length	nsec	170
		Intensity stability	1.E-03	0.75
		Timing stability	psec	0.1
	Beam Driven RF power generation	PETS RF Power	MW	130
		PETS Pulse length	ns	170
		PETS Breakdown rate	/m	< 1·10-7
		PETS ON/OFF	-	@ 50Hz
		Drive beam to RF efficiency	%	90%
		RF pulse shape control	%	< 0.1%
	Accelerating Structures (CAS)	Structure Acc field	MV/m	100
		Structure Pulse length	ns	240
		Structure Breakdown rate	/m MV/m.ns	< 3·10-7
	Two Beam Acc module	Power producton and probe beam acceleration in Two beam module	MV/m - ns	100 - 240
Ultra low beam emittance & sizes	Ultra low Emittances	Emitttance generation H/V	nm	550/5
		Emittance preservation: Blow-up H/V	nm	160/15
	Alignment	Main Linac components	microns	15
		Final-Doublet	microns	2 to 8
	Vertical stabilisation	Quad Main Linac	nm>1 Hz	1.5
		Final Doublet (assuming feedbacks)	nm>4 Hz	0.2
Operation and Machine Protection System (MPS)		drive beam power of 72MW@2.4GeV		
		main beam power of 13MW@1.5TeV		

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Dynamic imperfections

- Important is the multi-pulse emittance
- Counteract dynamic effects by

- fast component stabilization (between pulses)
- beam based trajectory feedback
- longitudinal feedbacks
- slow component stabilization (…drifts)
- beam tuning
- beam based alignment
- occasional repetition of (motorized) mechanical pre-alignment

- Presently we do not have a full model of the imperfections (some models of ground motion, technical noise estimate not yet available…)
- Derive some specifications for subsystems:

MB emittance preservation

Limit luminosity fluctuations to less than10%
Many small contributions add up; define individual budgets

Source	budget	tolerance
Damping ring extraction jitter	0.5%	kick reproducibility $0.1\sigma_x$
Transfer line stray fields	?%	data needed
Bunch compressor jitter	1%	
Quadrupole jitter in main linac	1%	$\sigma_{jitter} \approx 1.8\,\mathrm{nm}$
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%	
...	?%	

Stabilization of the quadrupoles of the main linac

One of the CLIC feasibility issues

C. Hauviller/ EN

CLIC Meeting April 9, 2010

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

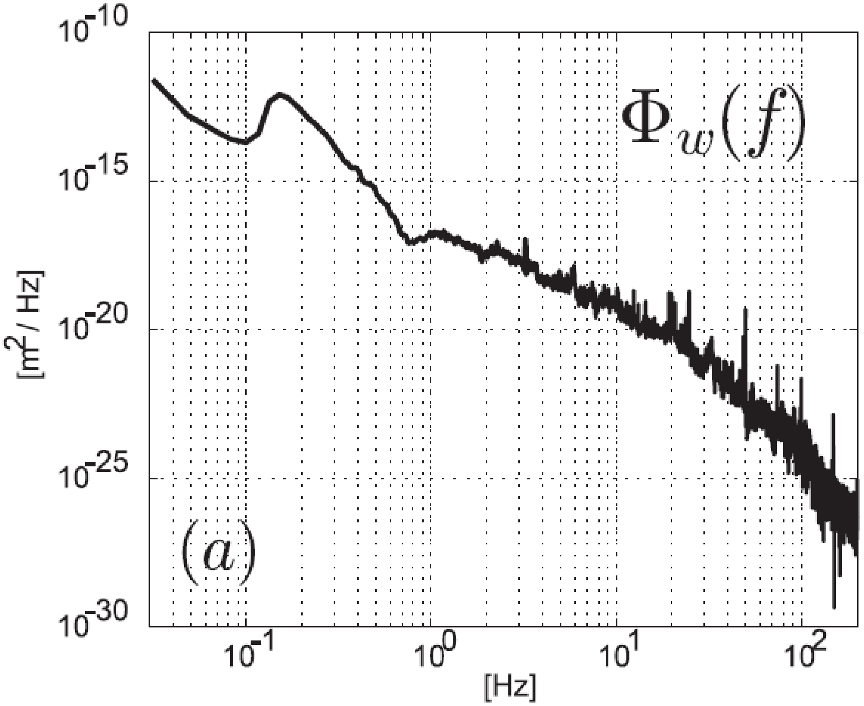
- Main beam quadrupoles to be mechanically stabilized:
  - A total of about 4000 main beam quadrupoles
  - 4 types: Type 1 (~ 100 kg), 2, 3 and 4 (~400 kg)
  - Magnetic length from 350 mm to 1850 mm

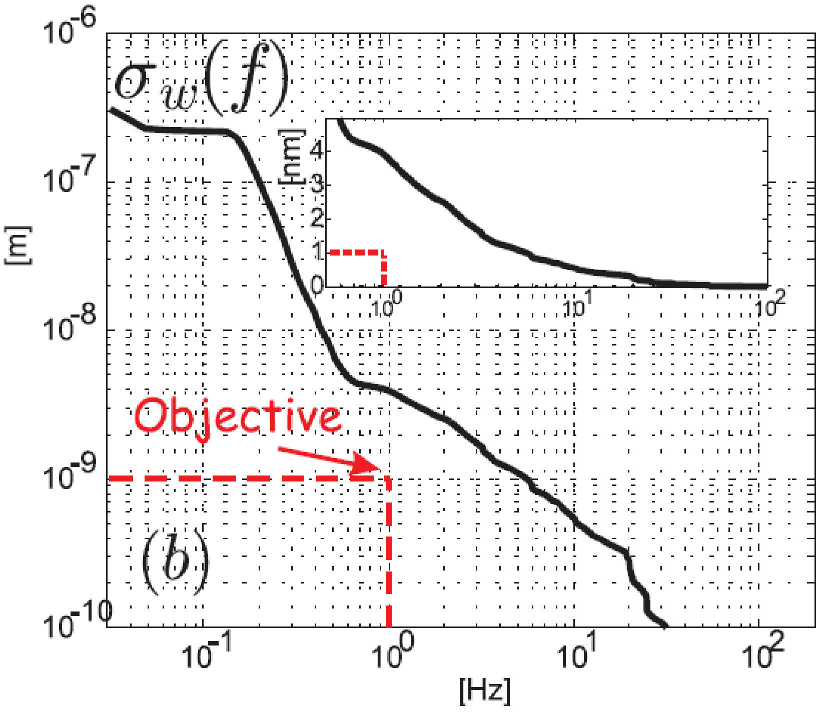
- Mechanical stabilization might be On at some quads and Off of some others

How to measure the performances?

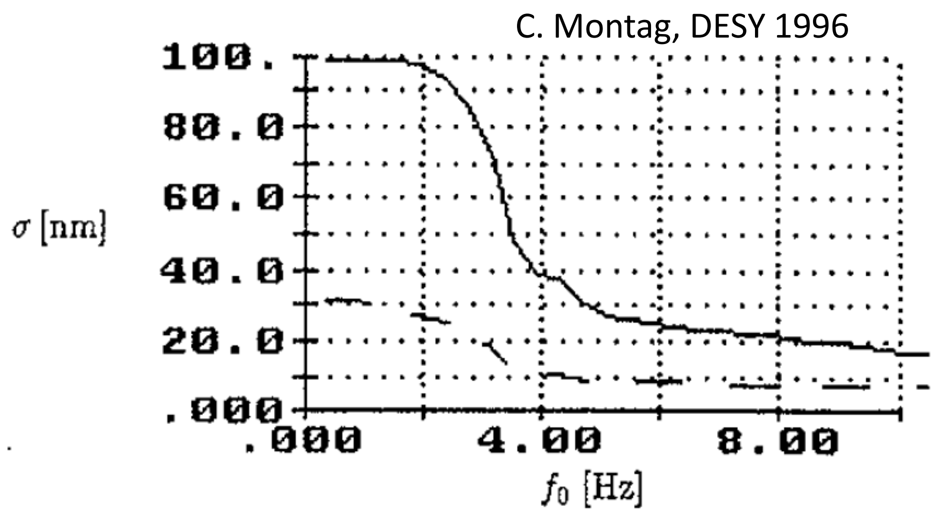
Compute the integrated r.m.s. displacement at n Herz from the measured PSD (Power Spectral Density)

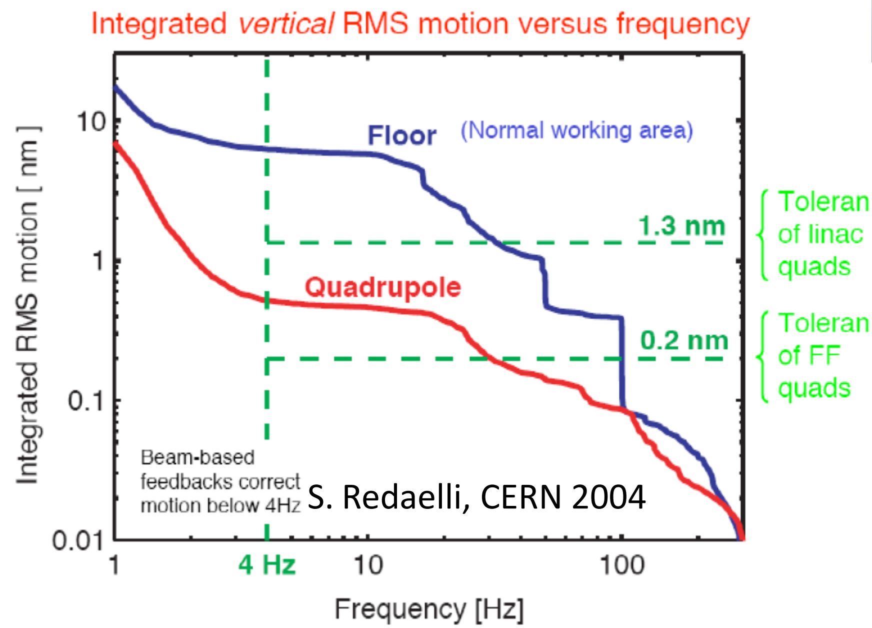
$$\sigma_x(1) = \sqrt{\int_1^\infty \Phi_x(f)\,df}$$

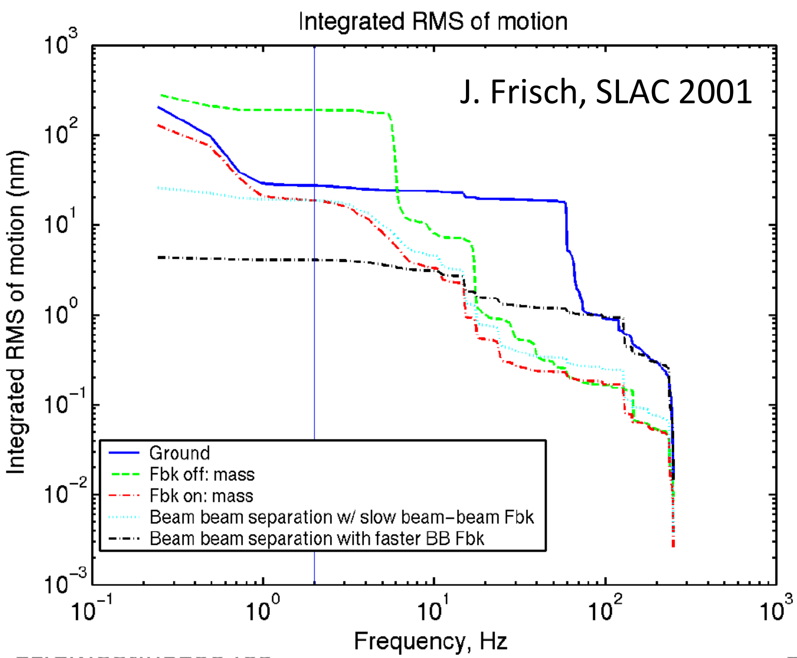


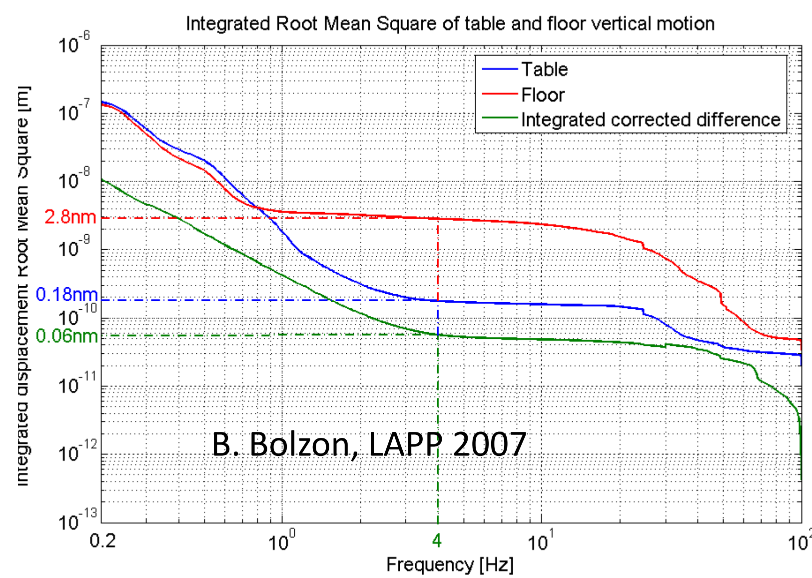


Previous performance on stabilization

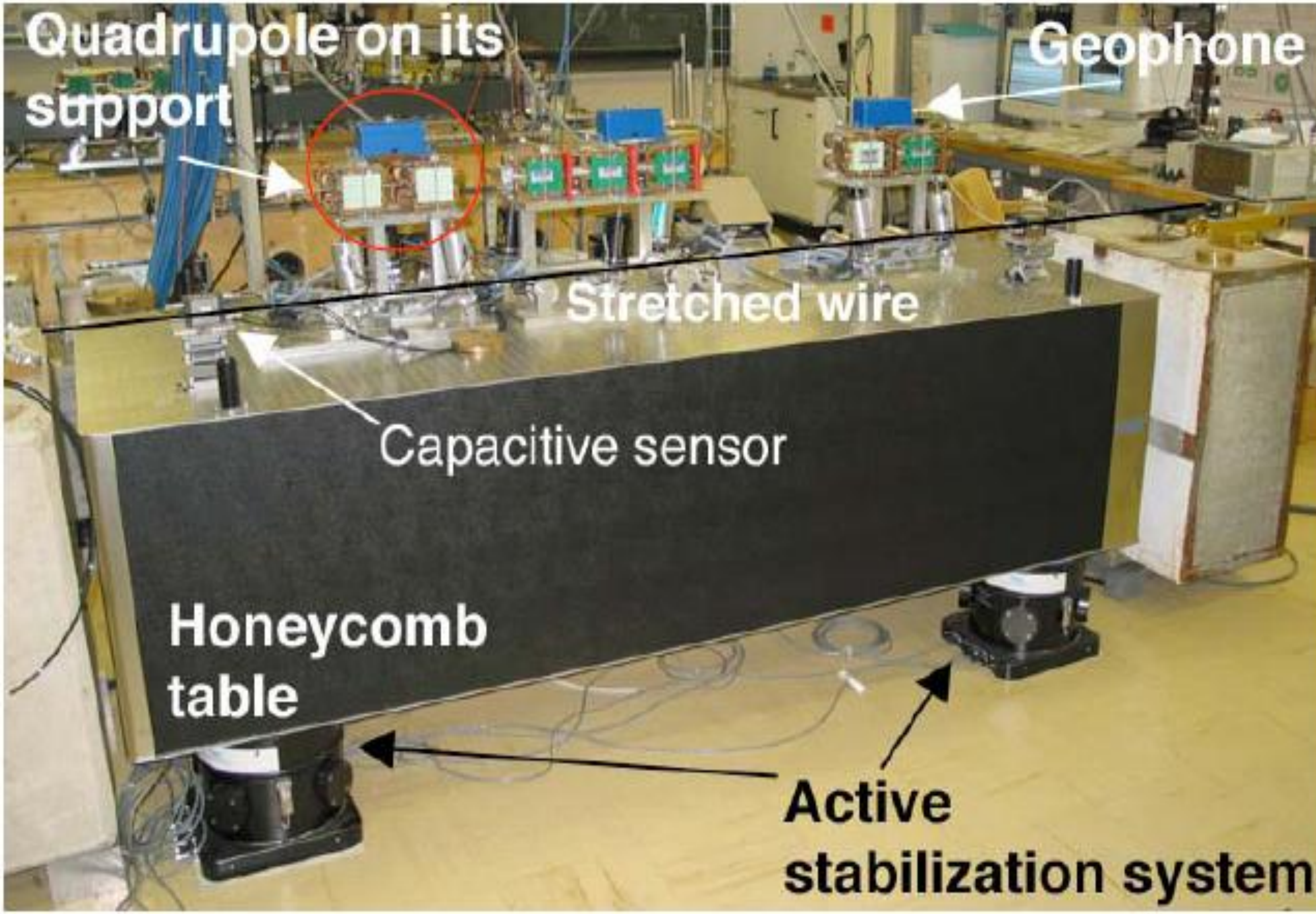






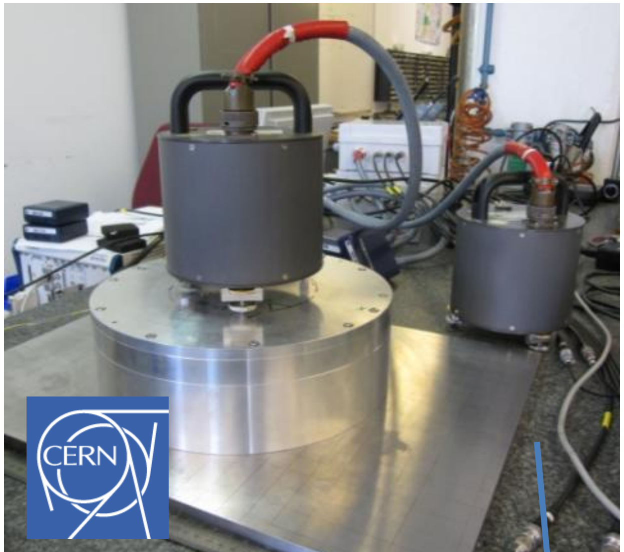


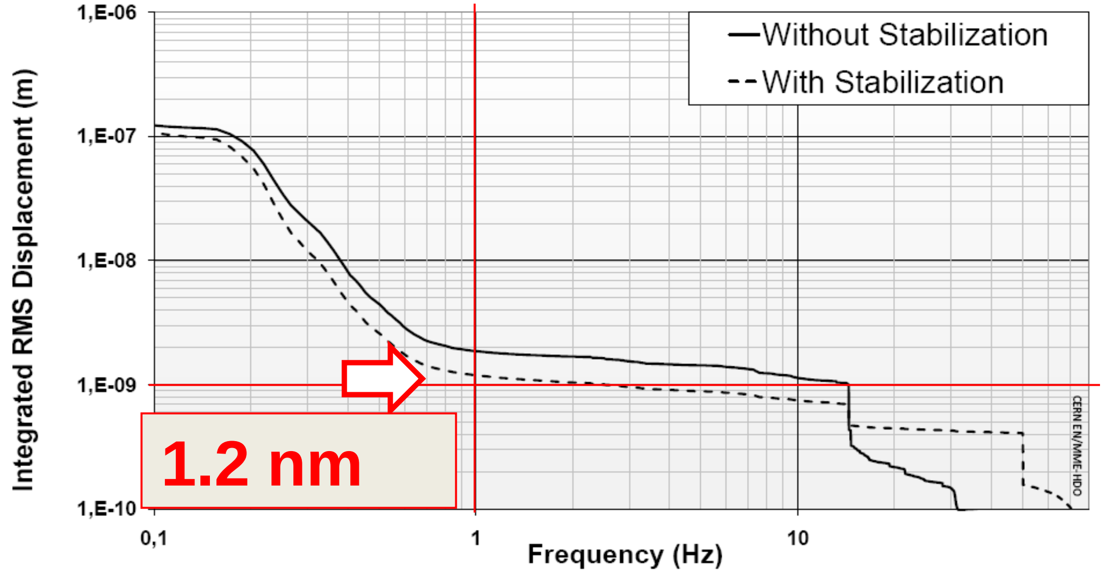
Mock-up built in 2004 (S. Redaelli)



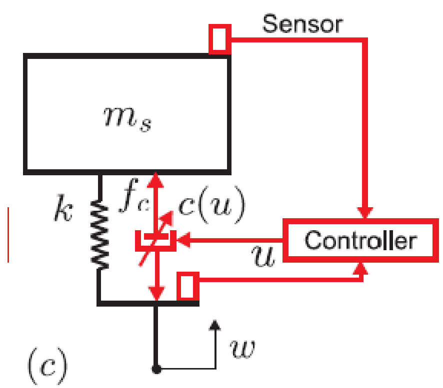
Performance at CERN

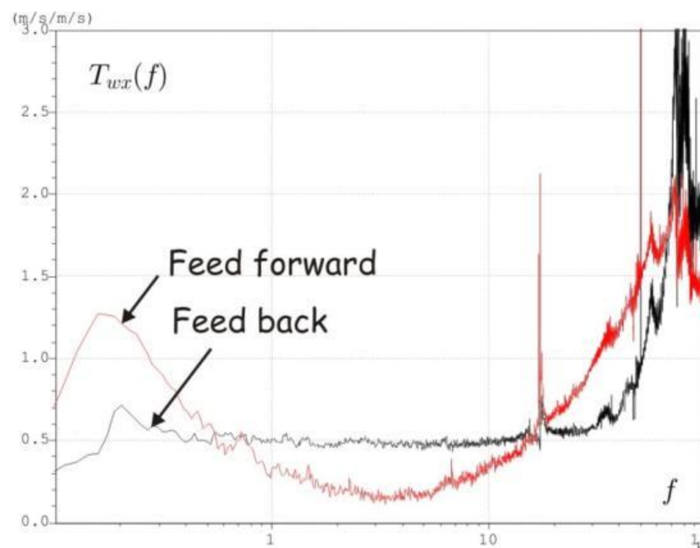
Stabilisation single d.o.f. with small weight ("membrane")



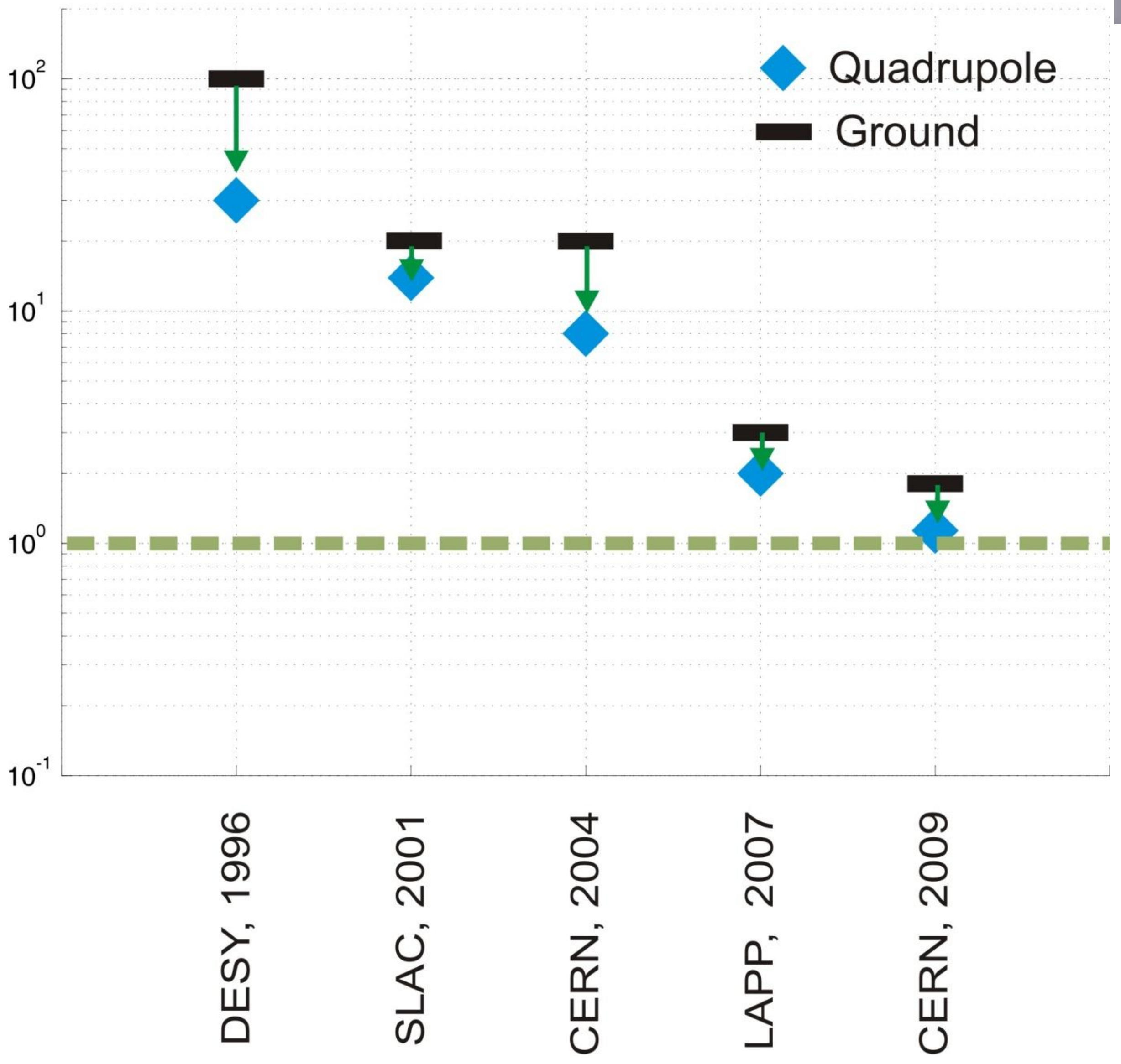


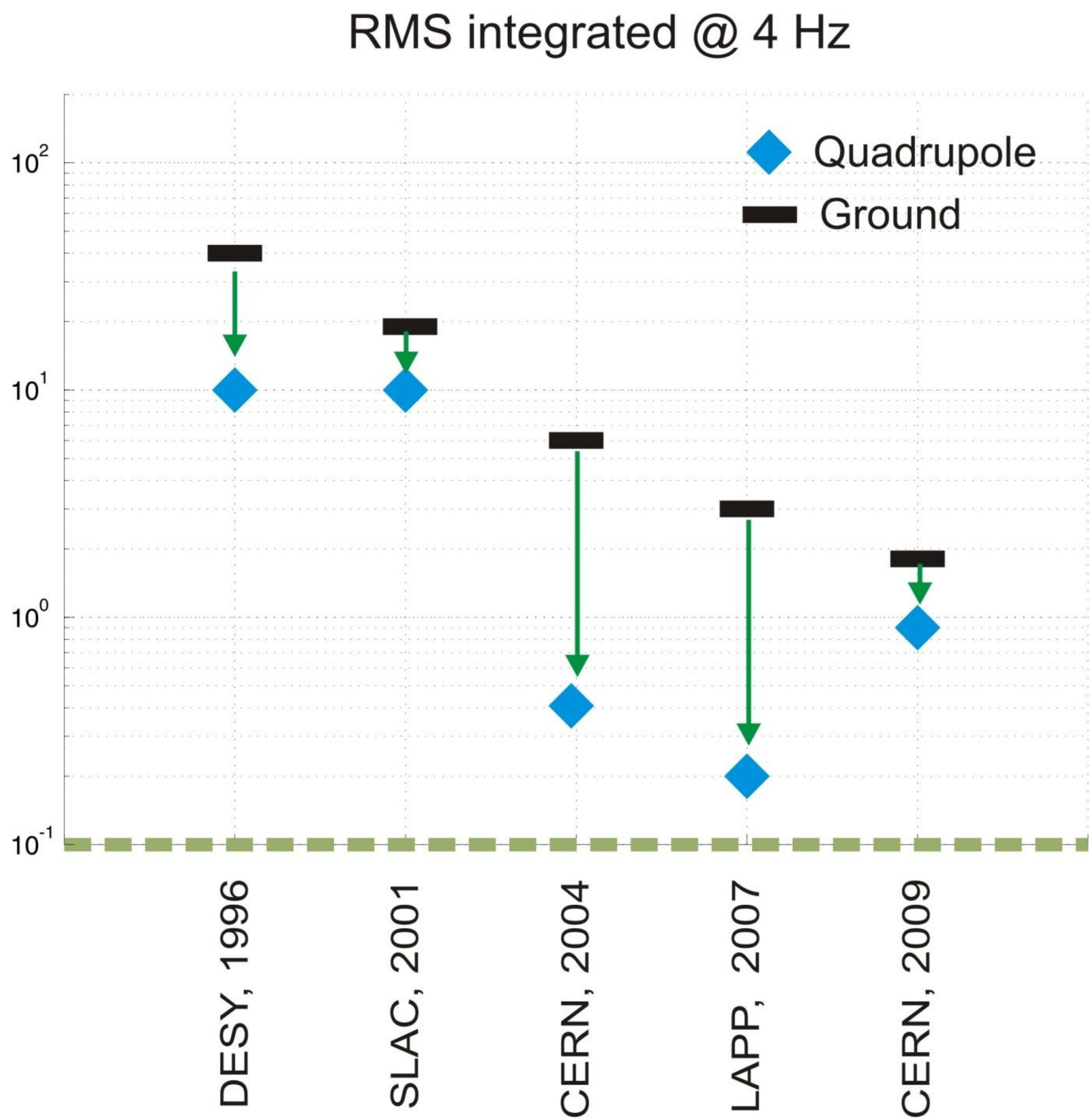
This is a marble, not a TMC table...





RMS integrated @ 1 Hz





RMS integrated @ 4 Hz
Quadrupole
Ground
10^2
10^1
10^0
10^{-1}
DESY, 1996
SLAC, 2001
CERN, 2004
LAPP, 2007
CERN, 2009

Contents

- R & D Actions
  - Sensors
  - Characterize vibrations/environmental noise
  - Actuators
  - Feedback
  - Test mock-ups
- Integrate and apply to CLIC
  - CDR and TDR
- The team

State of the art of ground motion sensors

Table of Contents

Sensors

How to measure nanometers and picometers ?

Catalogue products

<u>Absolute velocity/acceleration measurements</u>

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



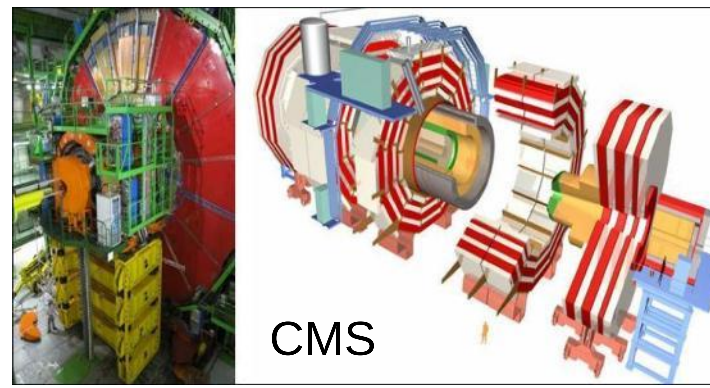


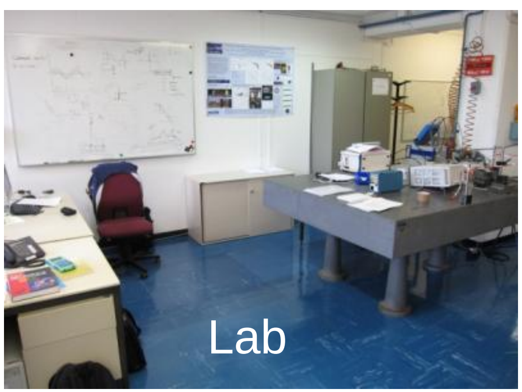
Streckeisen STS2	Guralp CMG 3T	Guralp CMG 40T	Guralp CMG 6T	Eentec SP500	PCB 393B31
x,y,z	x,y,z	x,y,z	x,y,z	z	z
				electrochemical	
2*750Vs/m	2*750Vs/m	2*800Vs/m	2*1000Vs/m	2000Vs/m	1.02Vs^2/m
120 s -50 Hz	360s -50 Hz	30 s -50 Hz	30s-80Hz	60 s -70 Hz	10 s -300 Hz
13 kg	13.5 kg	7.5 kg		0.750 kg	0.635 kg

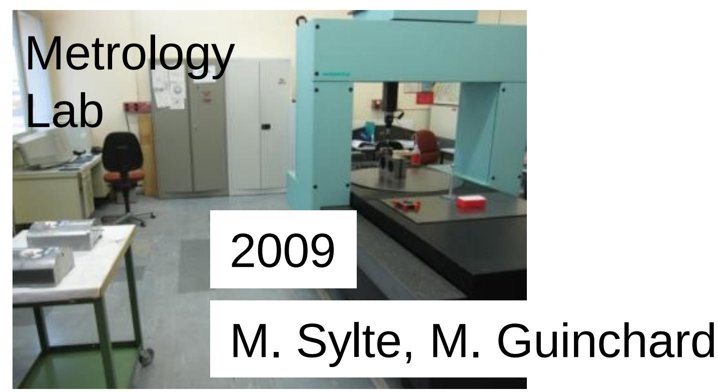
Improved performances
Lab environment

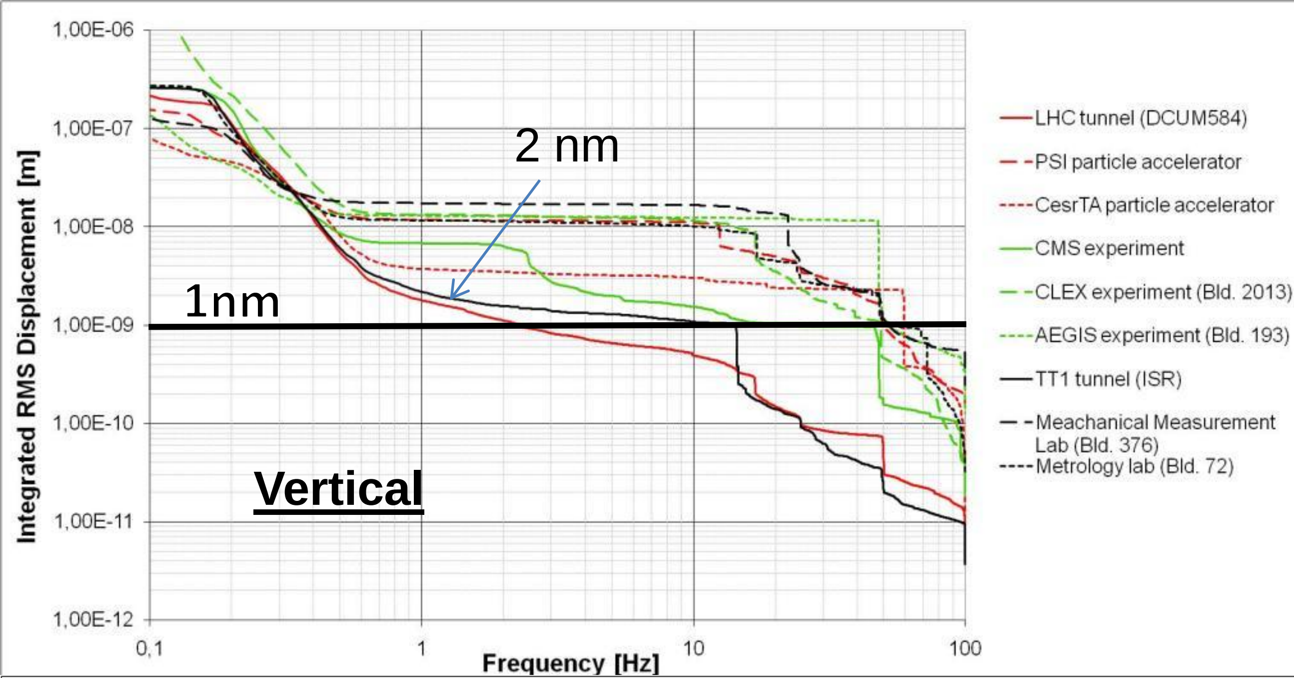
Characterize vibrations/environmental noise

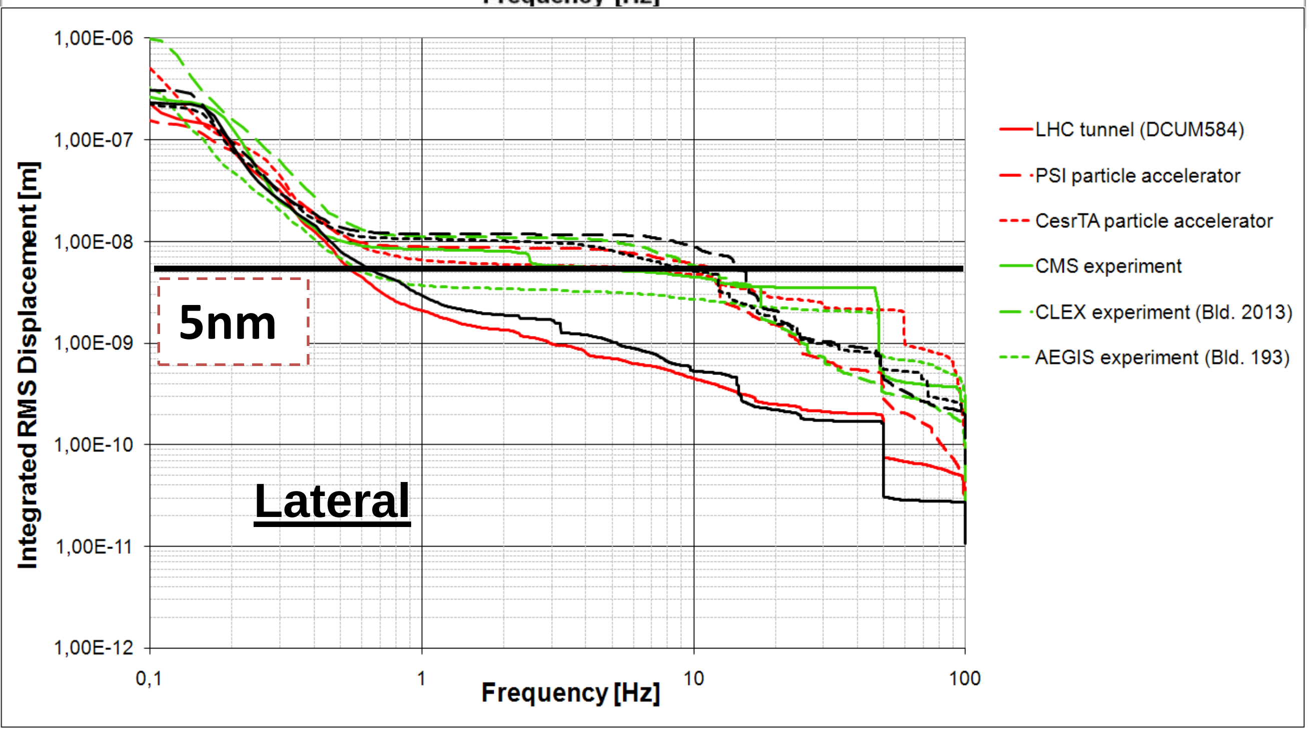
What level of vibrations can be expected on the ground?









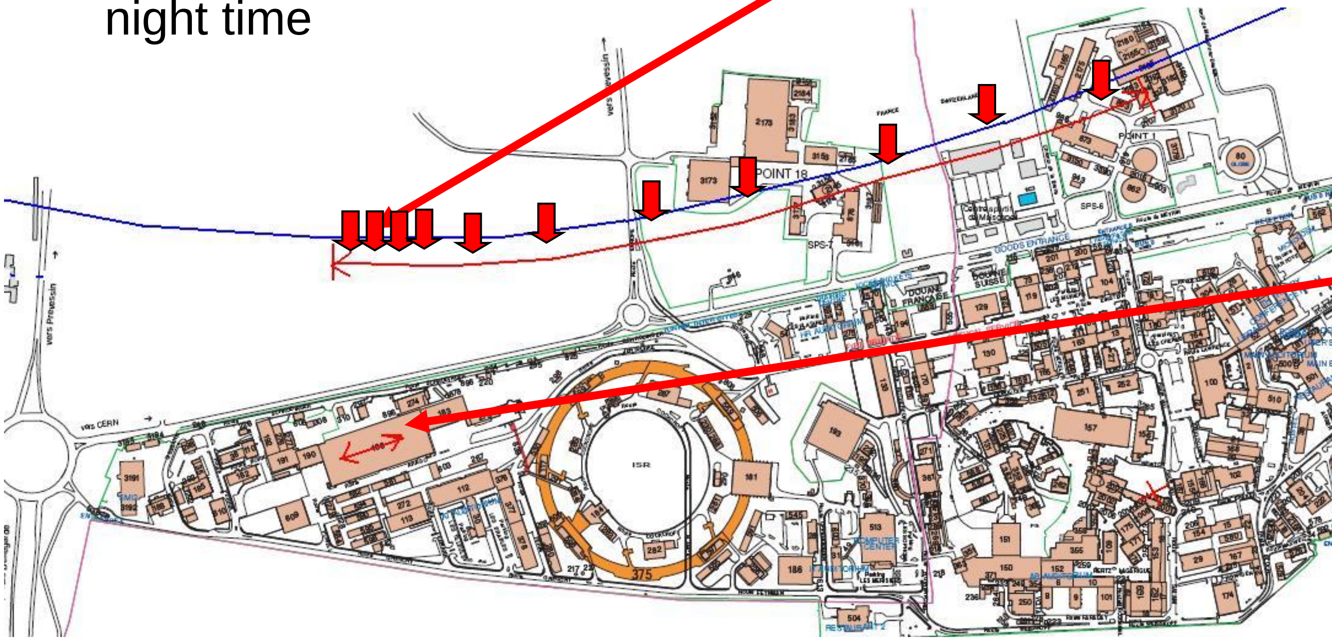


Measured on the floor

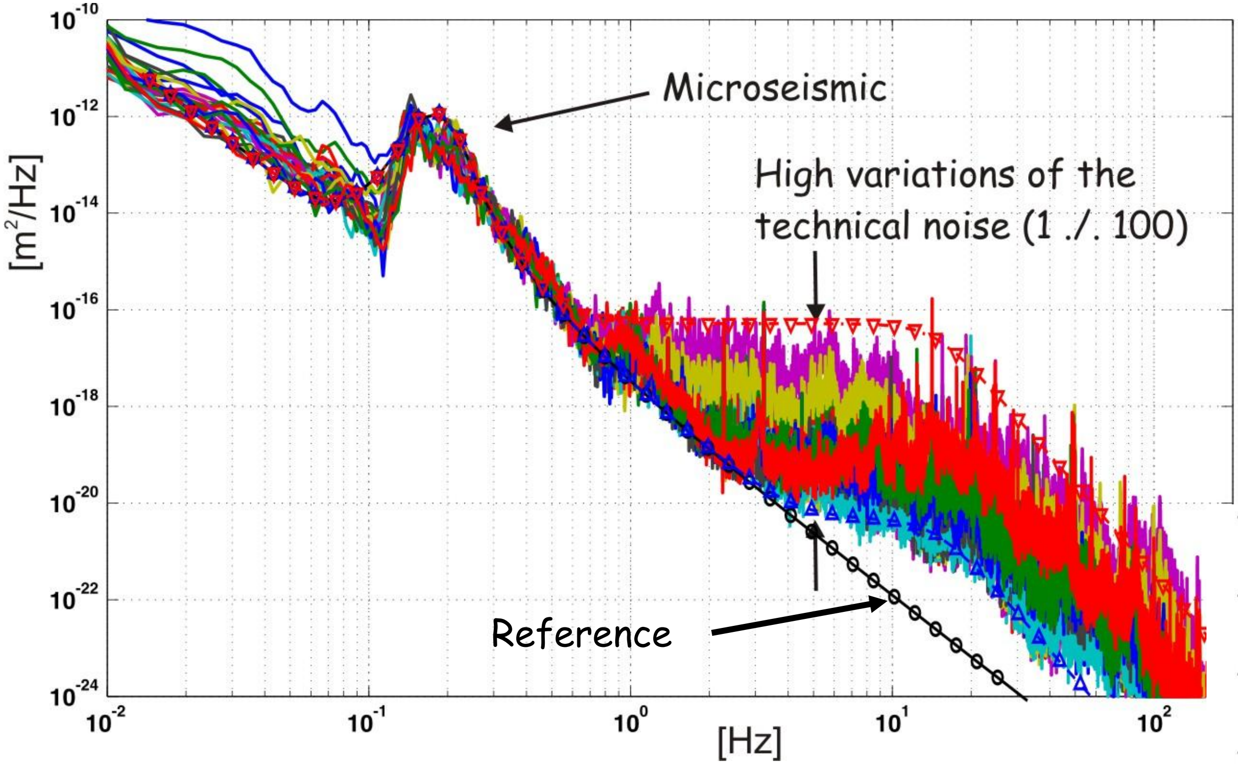
M. Sylte, M. Guinchard

Measurements in the LHC tunnel

LHC DCUM 1000
~ 80 m under ground
LHC systems in operation,
night time



Characterize vibrations/environmental noise



Vertical ground motion

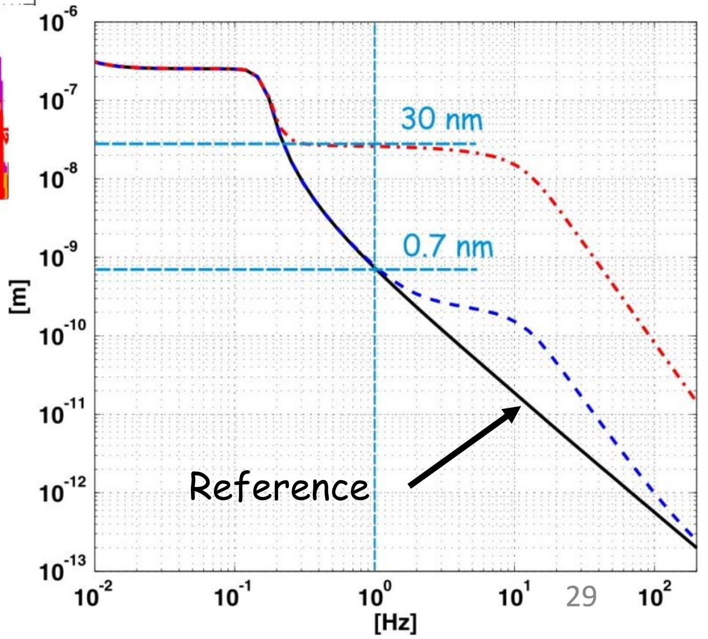
Additional technical noise:

$$N(\omega) = \frac{N_0}{1 + (\frac{\omega}{\omega_0})^6}$$

$$f_0 = 2\pi (Hz)$$

Low technical noise: $N_0 = 5 * 10^{-3} (nm^2/Hz)$

High technical noise: $N_0 = 50 (nm^2/Hz)$



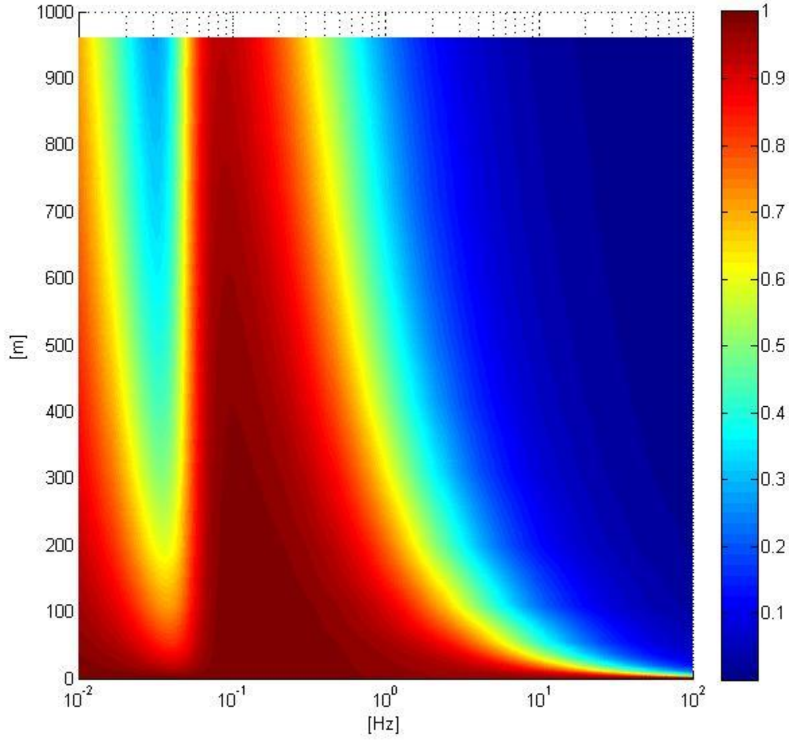
Ref. : $A = 10^{-4}\ (\mu m^2 s^{-1} m^{-1}); B = 10^{-4}\ (\mu m^2 s^{-3});$

$\omega_1 = 2\pi * 0.14\ (rad/s); d_1 = 5; a_1 = 0.1\ (\mu m^2/Hz); v_1 = 1000\ (m/s)$

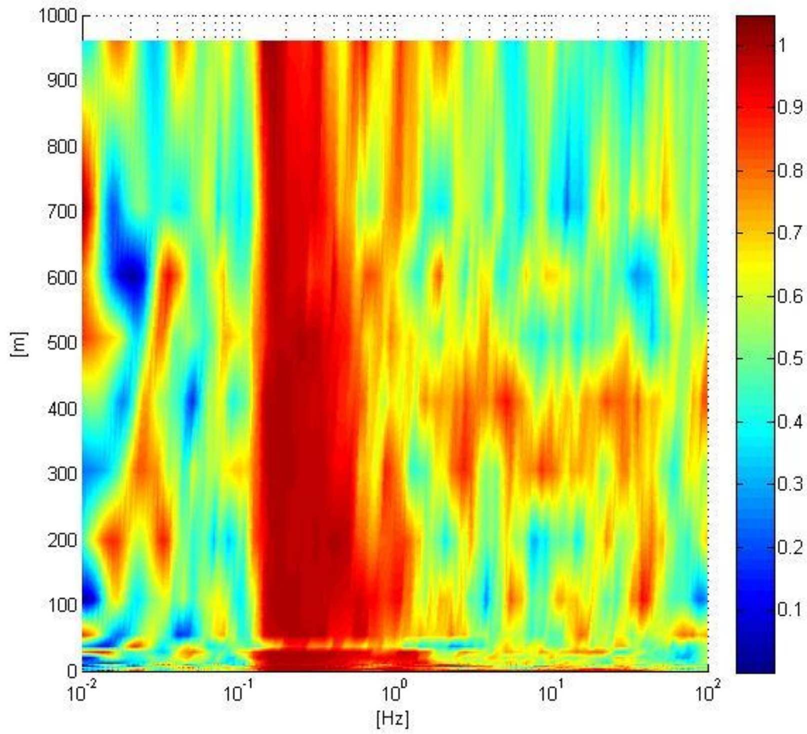
Characterize vibrations/environmental noise

Correlation over long distances in LHC tunnel

Coherence using a theoretical model (ATL law)



Calculated from measurements (2008)



Actuators

Program of work

- State of art of actuators development and performances (updated on a yearly basis)

- Develop and test various damping techniques (passive and active)

State of art of actuators

Table of Contents

Actuators

First selection parameter: Sub nanometre resolution and precision

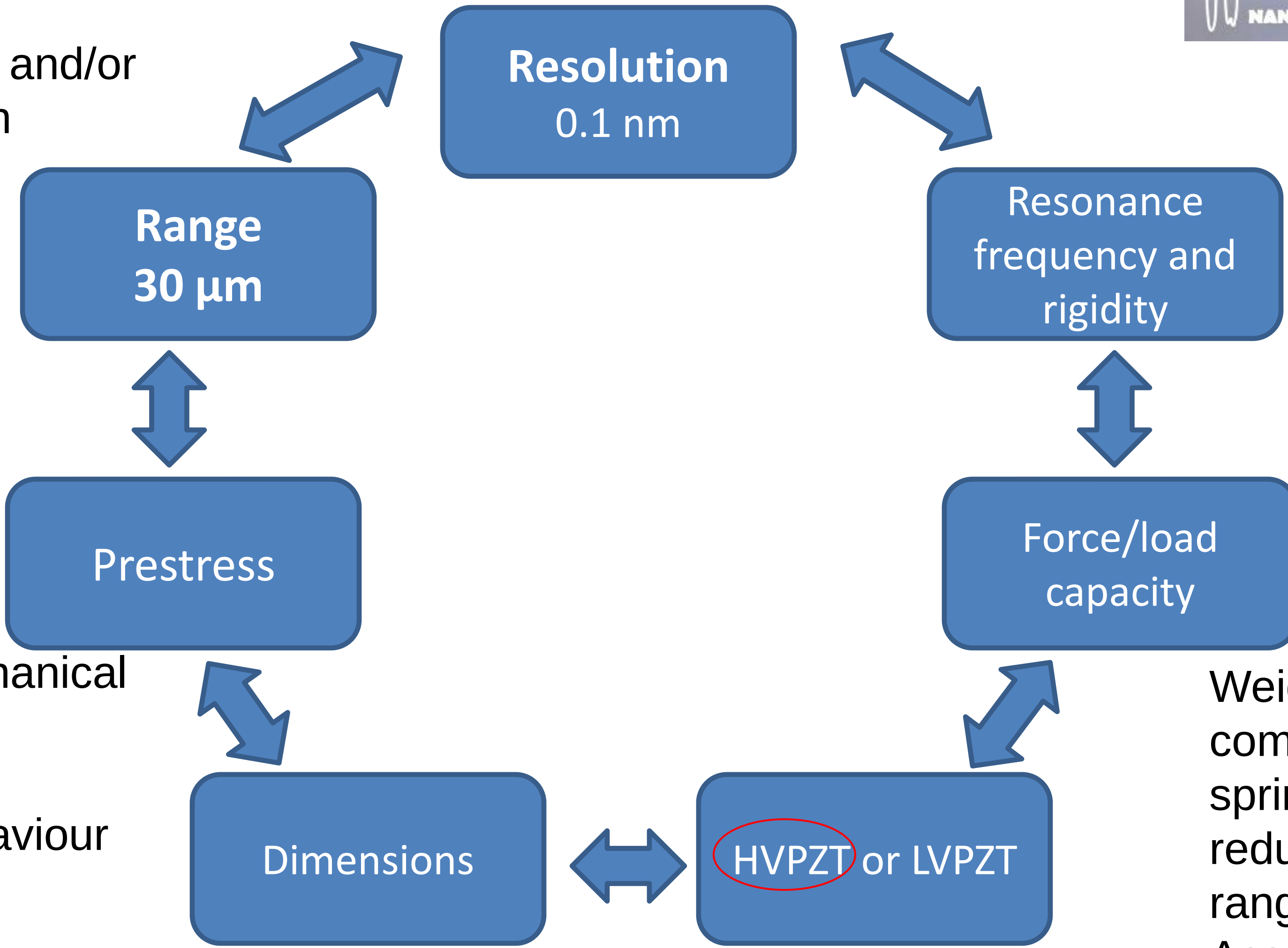
Actuator mechanisms with moving parts and friction excluded (not better than 0.1 µm, hysteresis)

Solid state mechanics

Piezo electric materials	High rigidity	+ Well established - Fragile (no tensile or shear forces), depolarisation
Magneto Strictive materials	High rigidity	-Rare product, magnetic field, stiffness < piezo, - force density < piezo+ No depolarisation, symmetric push-pull
Electrostatic plates	No rigidity, ideal for soft supports	Risk of break through, best results with µm gaps, small force density, complicated for multi d.o.f. not commercial
Electro magnetic (voice coils)	No rigidity, ideal for soft supports	Heat generation, influence from stray magnetic fields for nm resolution
~~Shape Memory alloys~~		Slow, very non linear and high hysteresis, low rigidity, only traction
~~Electro active polymers~~		Slow, not commercial

Selection of piezo actuators

Positioning and/or stabilisation



As high as possible

Up to 100Kg

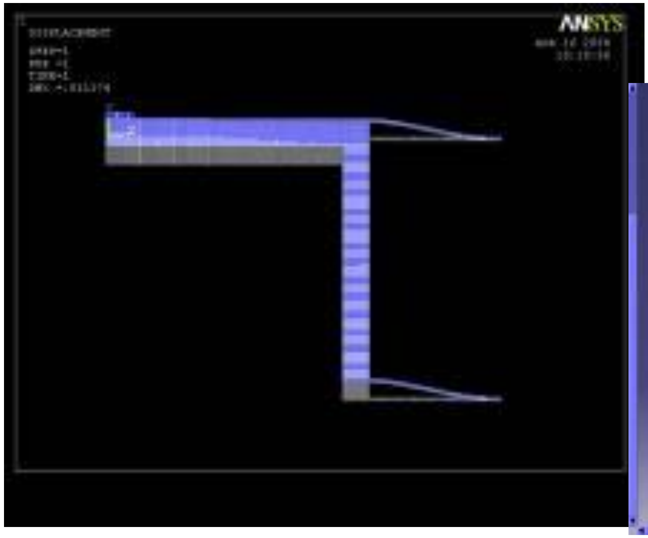
(< 20 % mechanical limit)
20 MPa for dynamic behaviour

Weight compensating spring, reduces range
Assembly

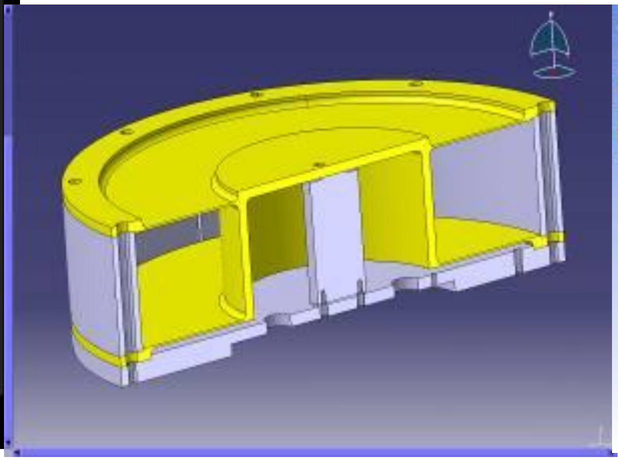
Required power, frequency range controller

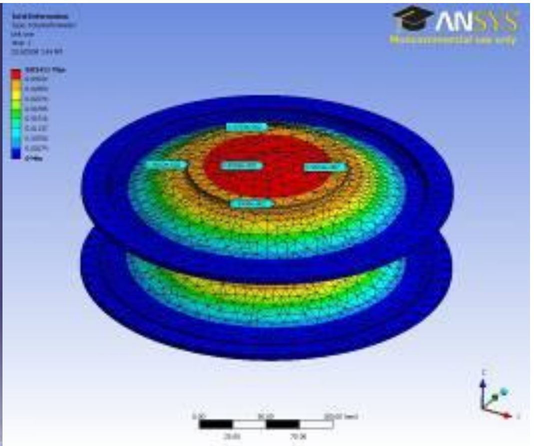
Actuators

An example of the integration of piezo actuators PZT in an actual support
- Use of flexural guides against shear forces
- Use of a feedback capacitive sensor



0.1 nm 100 N Calibration bench flexural guides





Techniques to be applied for heavier (up to 400Kg) and larger structures (up to 2 meter long)

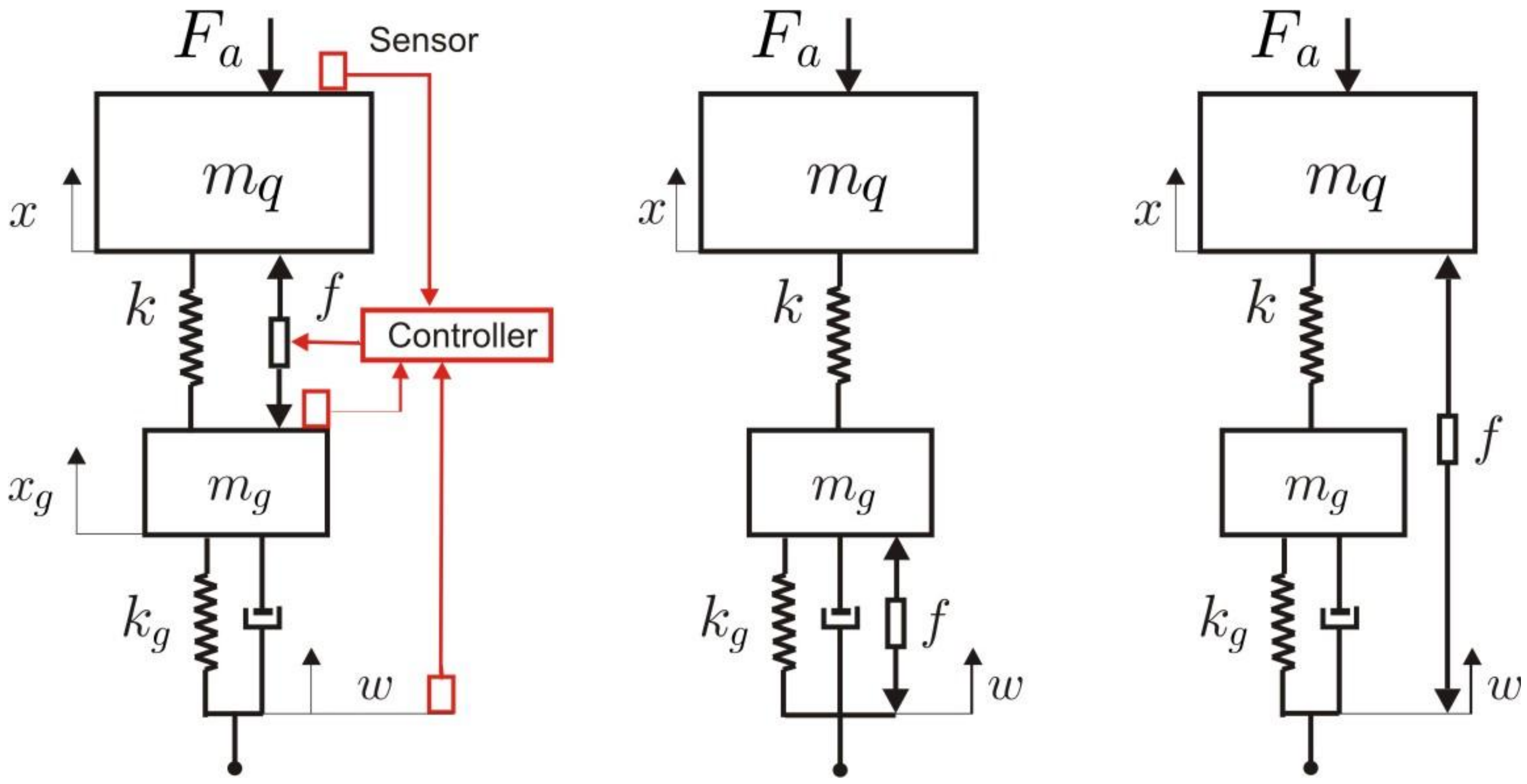
Feedback

Program of work

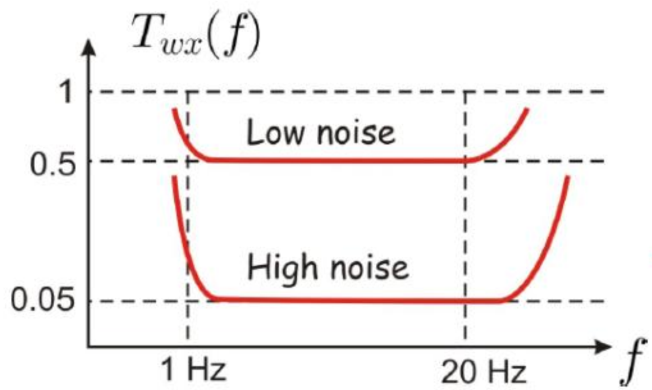
- Develop methodology to tackle with multi degrees of freedom (large frequency range, multi-elements)
  - *LAViSTa demonstrated feasibility on models*
  - *Similar problems elsewhere like the adaptative optics of the European ELT*

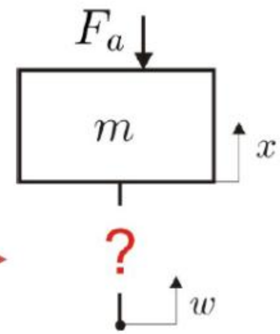
- Apply software to various combinations of sensors/actuators and improve resolution (noise level)
  - *High quality acquisition systems at LAViSTa and CERN*

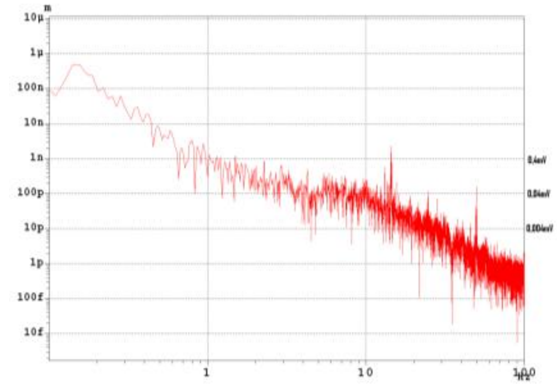
Stabilization strategies



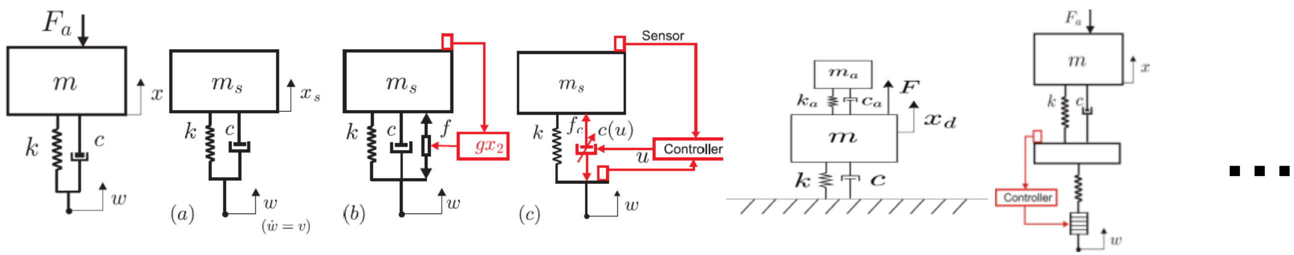
How to support the quadrupoles?





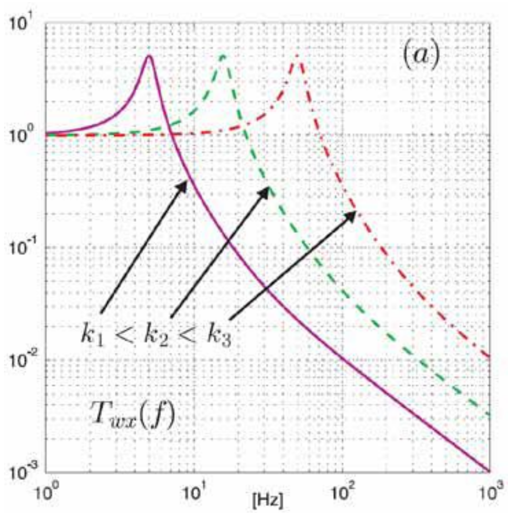


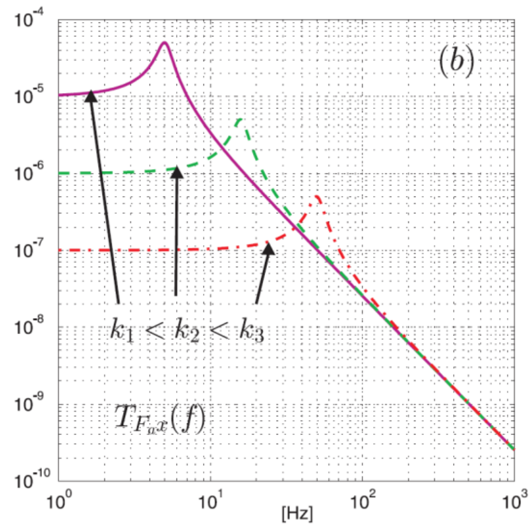
Comparison control laws and former stabilisation experiments

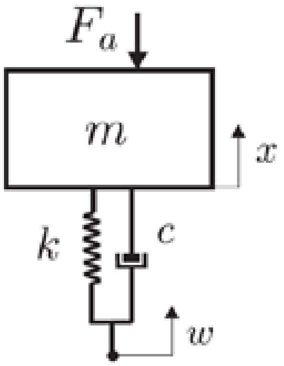


	DESY, 1996	CERN, 2004	LAPP, 2007	SLAC, 2002
Experiment description	1 d.o.f	1 d.o.f	1 d.o.f	6 d.o.f, 42 kg
Actuator	Piezo	Piezo	Piezo	Electrostatic
Control strategy	FB	TMC	TMC	FB
Positioning	NO	NO	NO	NO
Rigidity	Stiff	Soft	Soft	Soft
(RMSw/RMSx)@1Hz	~3	~3	~2	~50
Stages	1	2	2	1

How to support the quadrupoles? Soft versus rigid ?







Soft: + Isolation in large bandwidth

- But more sensitive to external forces

- Elastomers and radiation

Rigid: - High resolution required actuators

But available in piezo catalogues

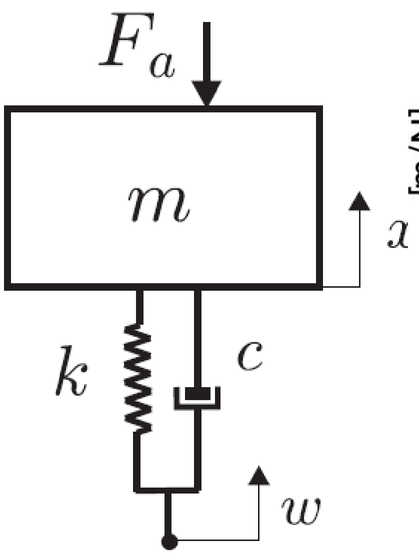
+ Robust against external forces

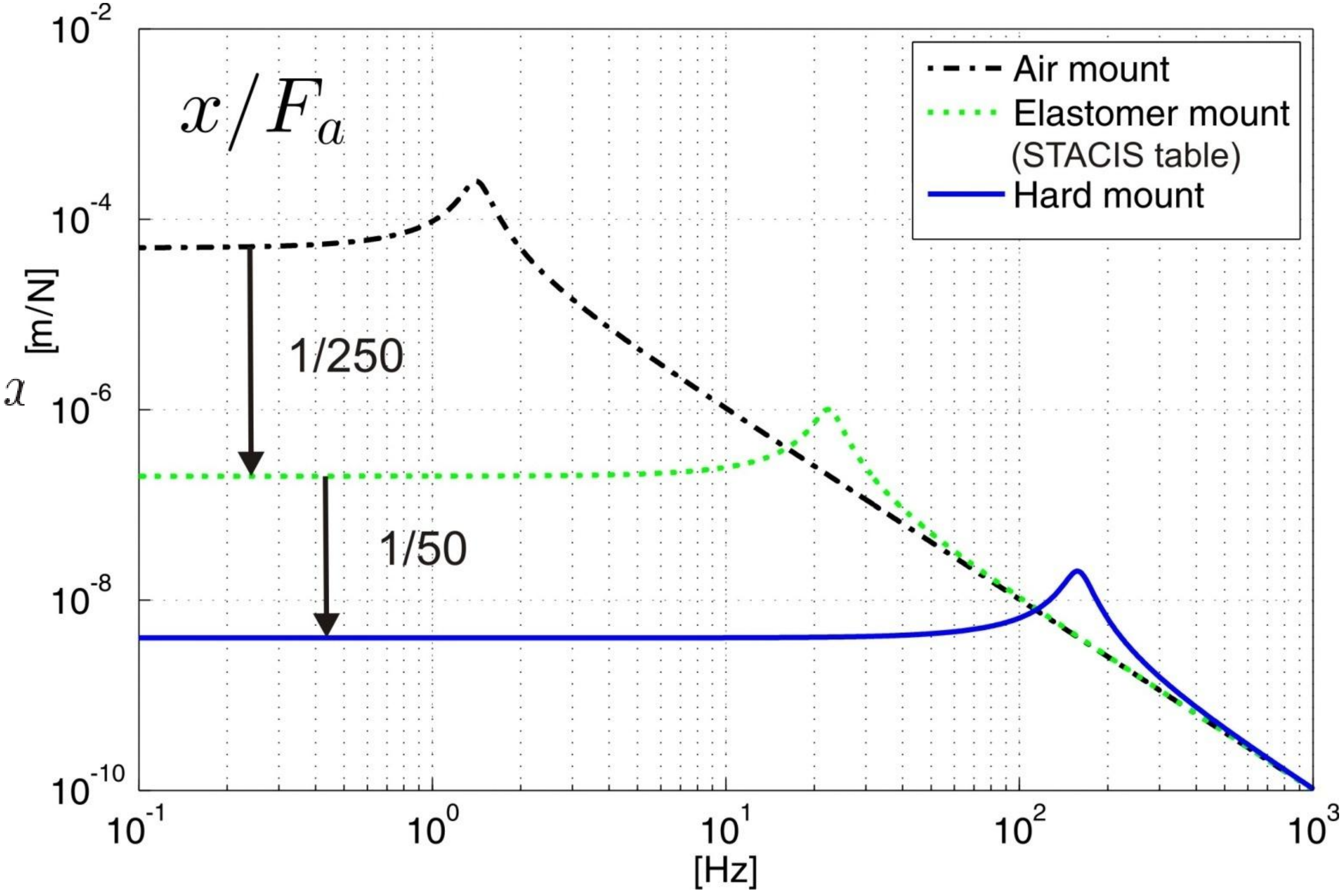
+ Nano positioning

External forces: vacuum, power leads, cabling, water cooling, interconnects, acoustic pressure,….

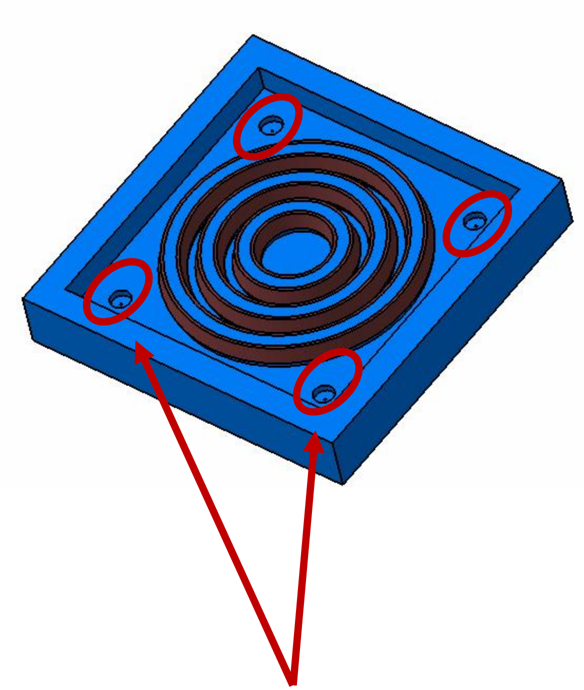
How to support the quadrupoles?

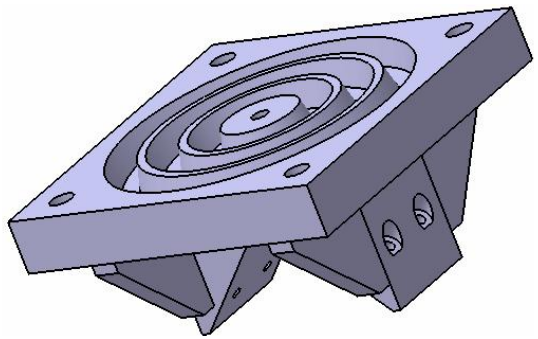
Robustness to external force (compliance)

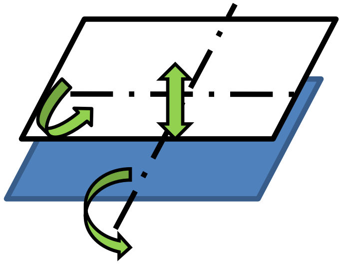


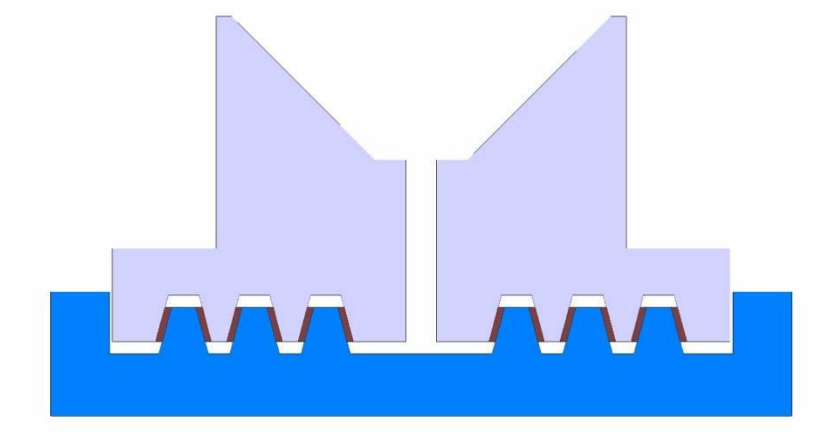


Option LAPP:
Soft support and active vibration control

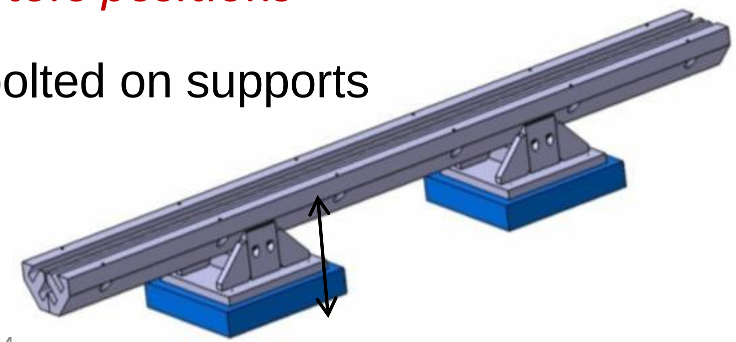






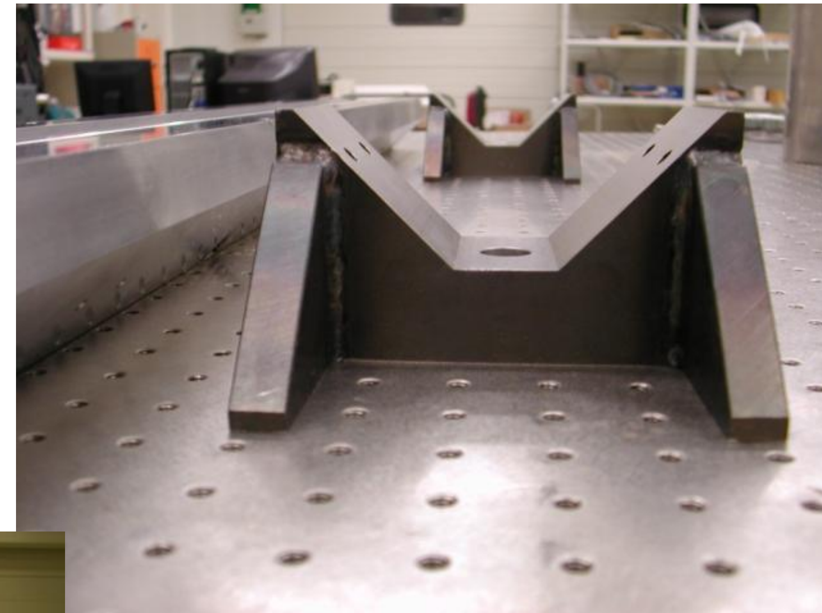


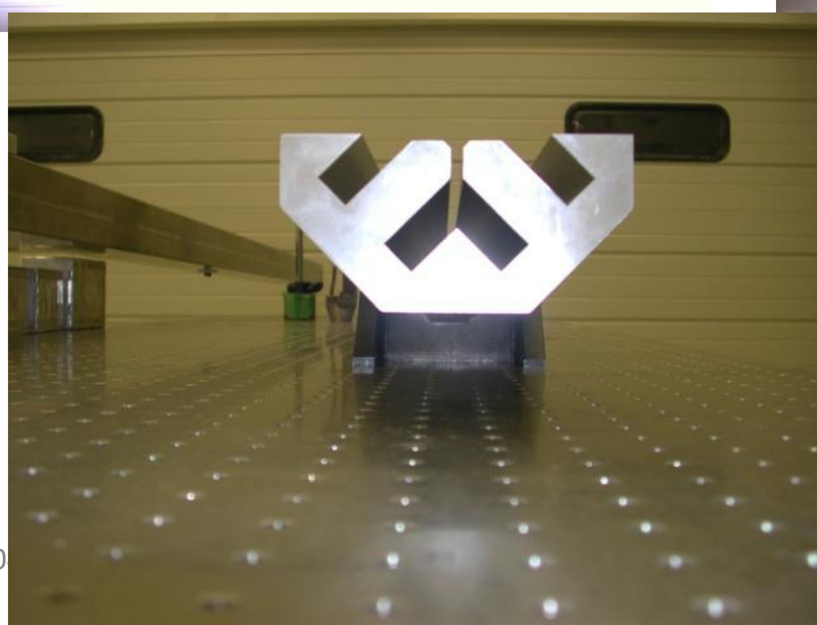
•Poles are bolted on supports



Option LAPP:

Status: Construction + tests on elastomer





Test Mock-ups (CERN)

Rigid support and active vibration control

(up to 6 dof)

1. Stabilisation single d.o.f. with small weight (membrane)

   Program going on with further improvements

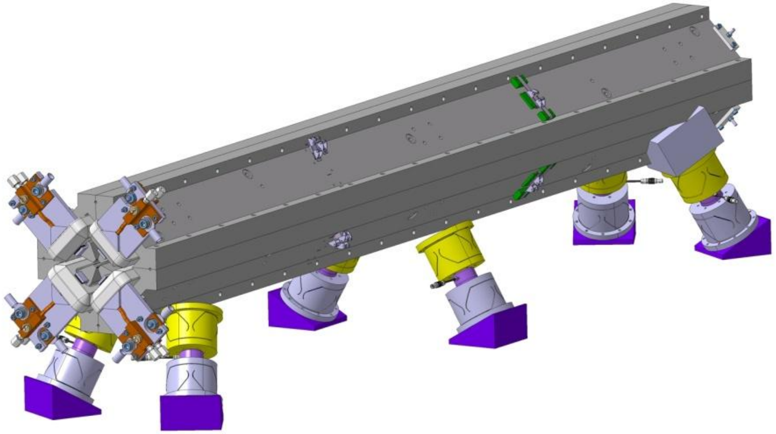
2. Tripod with weight type 1 MBQ with 1 active leg

   Presently under tests

3. Tripod type 1 MBQ with 3 active legs

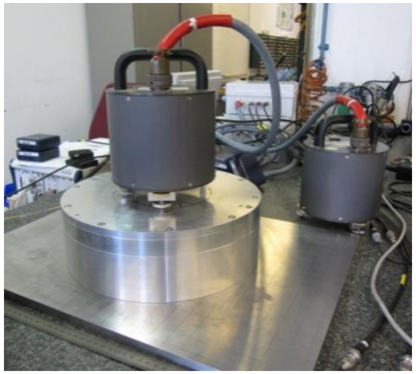
   Inclined leg with flexural joints
   Two inclined legs with flexural joints
   Add spring guidance
   Test equivalent load per leg

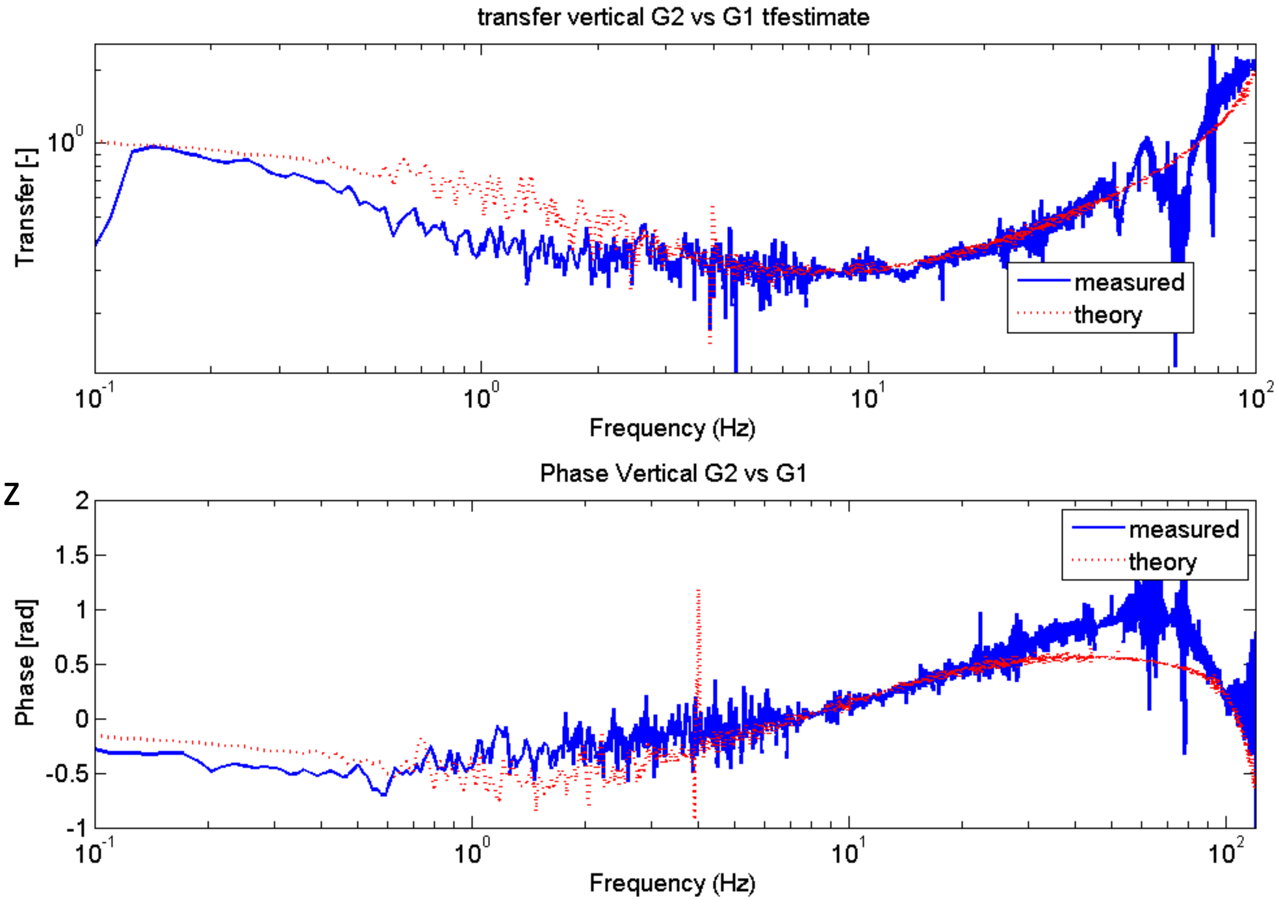
4. MOCK-UP Type 4 MBQ on hexapod



Test Mock-ups (CERN)

1. Stabilisation **single d.o.f. with small weight** ("membrane")





Theory vs measurement:
Transfer function
Measurement better< 2 Hz

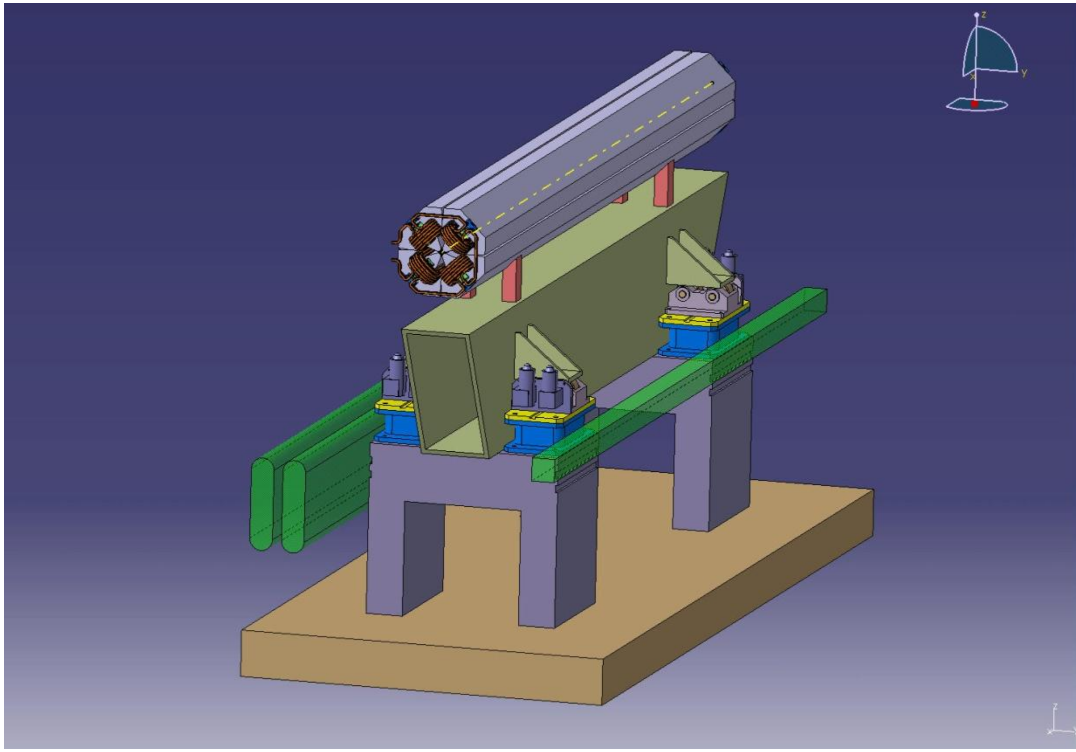
Phase
Diff. > 40 Hz

Model is good representation 2-40 Hz
Differences between theory and Measurements are under investigation

Main Beam Mock-up

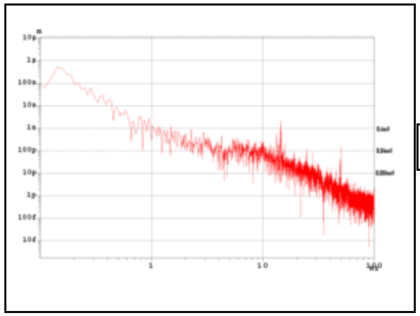
- **Functionalities**
  - Demonstrate stabilization in operation:
    - Magnet powered, Cooling operating
    - Configurations
      - 1- Stand-alone
      - 2- Integrated in Module
      - 3- Interconnected
    - Accelerator environment

- **Parts / Measuring devices**
  - Floor (damping material)
  - Support
  - Pre-alignment
  - Stabilization
  - Magnet
  - Vacuum chamber and BPM
  - Independent measurement



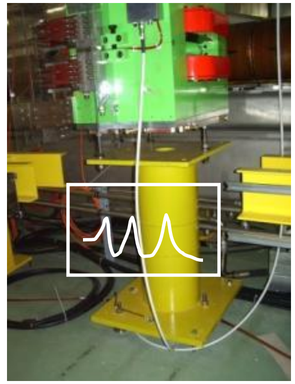
Dynamic analysis

Vibrations on the ground

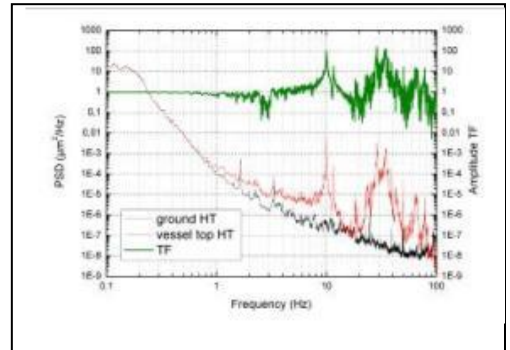


Broadband excitation with decreasing amplitude with increasing frequency.

Transmissibilty



Result on magnet



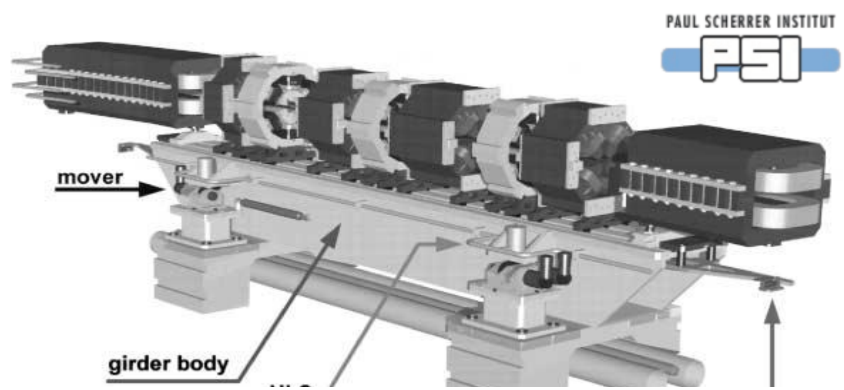
Amplification at resonances

Lessons learnt from light sources:

Increase natural frequencies **ALL** components

- **Maximise rigidity**
- **Minimise weight (opposed to thermal stability)**
- **Minimise beam height (frequency and Abbé error)**
- **Optimise support positions**
- **Increase damping**

- **Alignment system as rigid as possible**
- **+ optionally locking of alignment**



MB quad alignment with excentric cams

Outline

- Short overview of the CLIC project
- Timelines
- CLIC “feasibility demonstration”
- Stabilization of Main Beam Quadrupoles
- Experimental verification of Quadrupole stability
- Outlook for JLAB collaboration

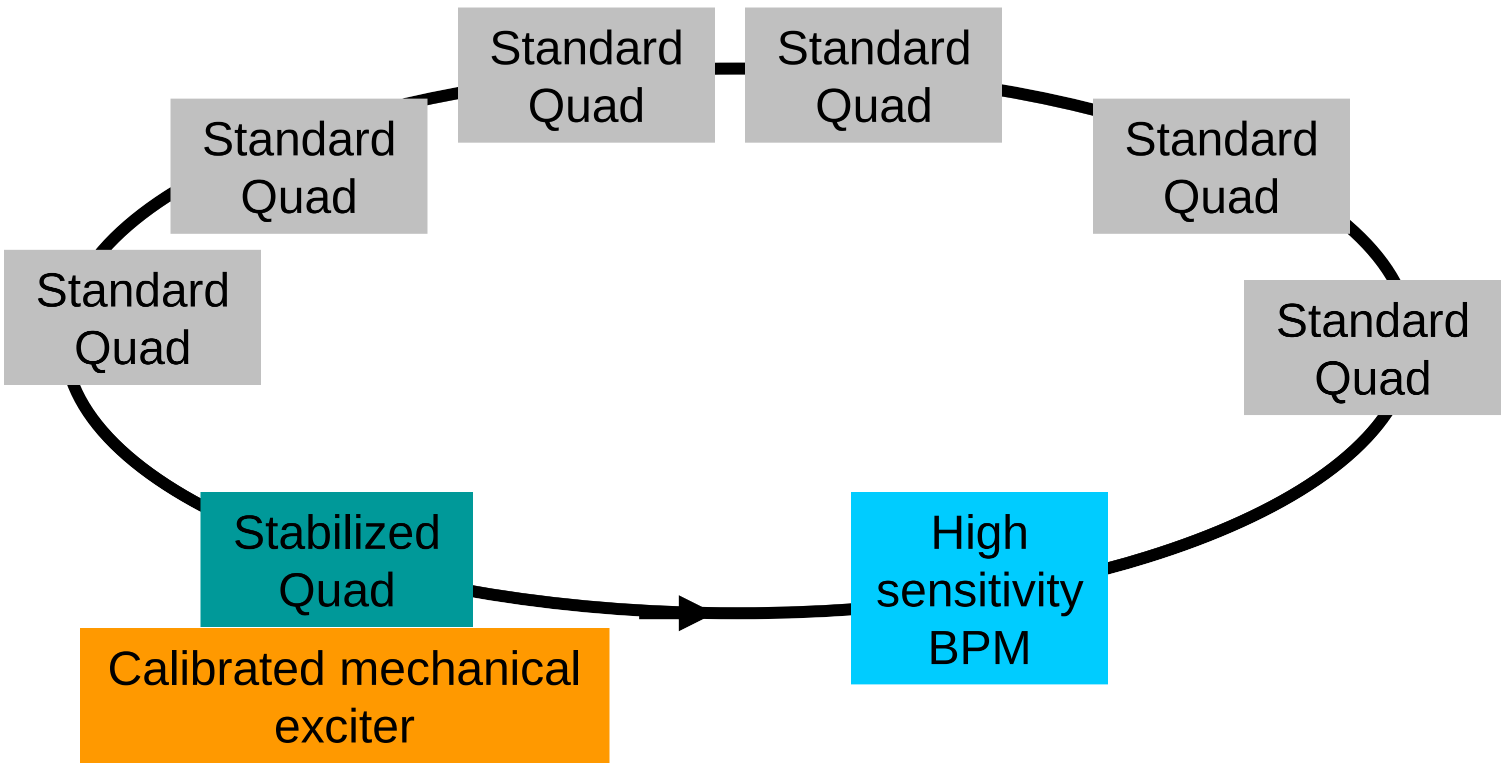
Necessary complementary verification ?

- The demonstration of the stabilization of the magnet (=Magnetic field?) is based on “zero” signals of electromechanical sensors on the outer shell of the magnet.
- The physical size of the sensors do not allow to mount them close to the pole tips or inside the magnet.
- Pole tip vibrations, coil vibrations might exist without the outer monitors measuring them.
- The limited number of monitors might not catch all vibrations.

Question:

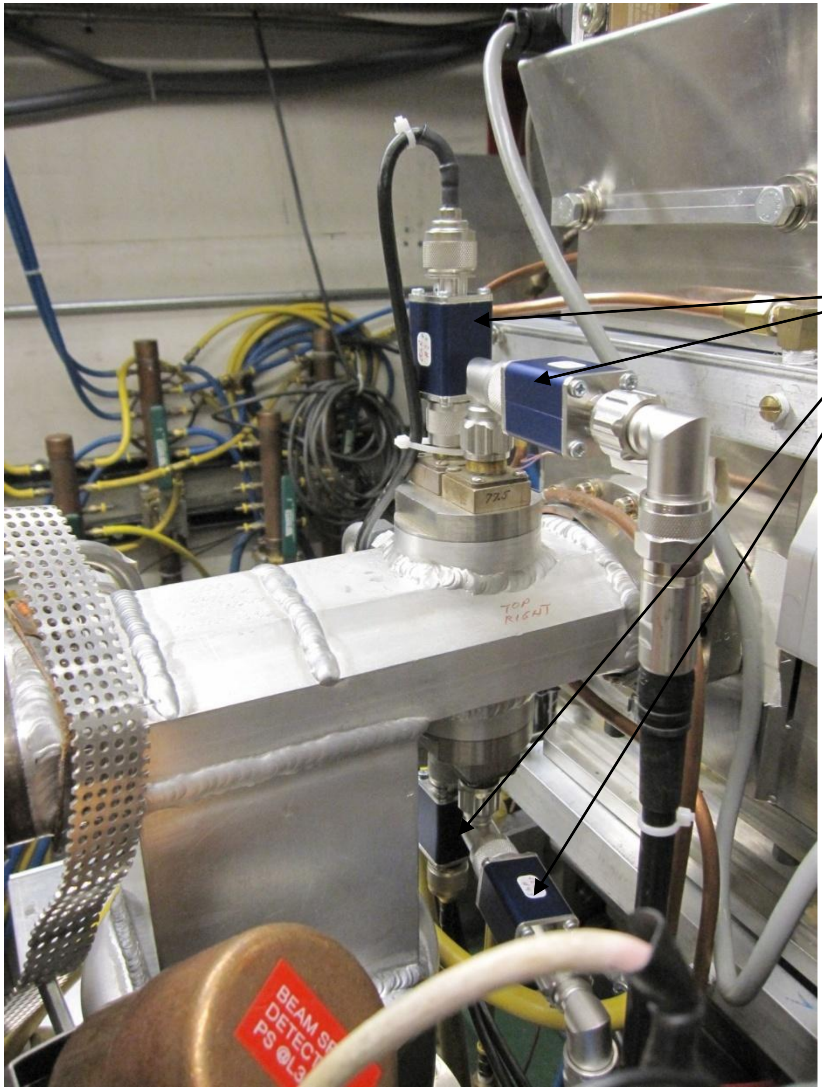
can another physical process be used to verify the stability of the magnetic field? → try a high energetic particle beam

Validation of Quad stabilization principle (1/2)

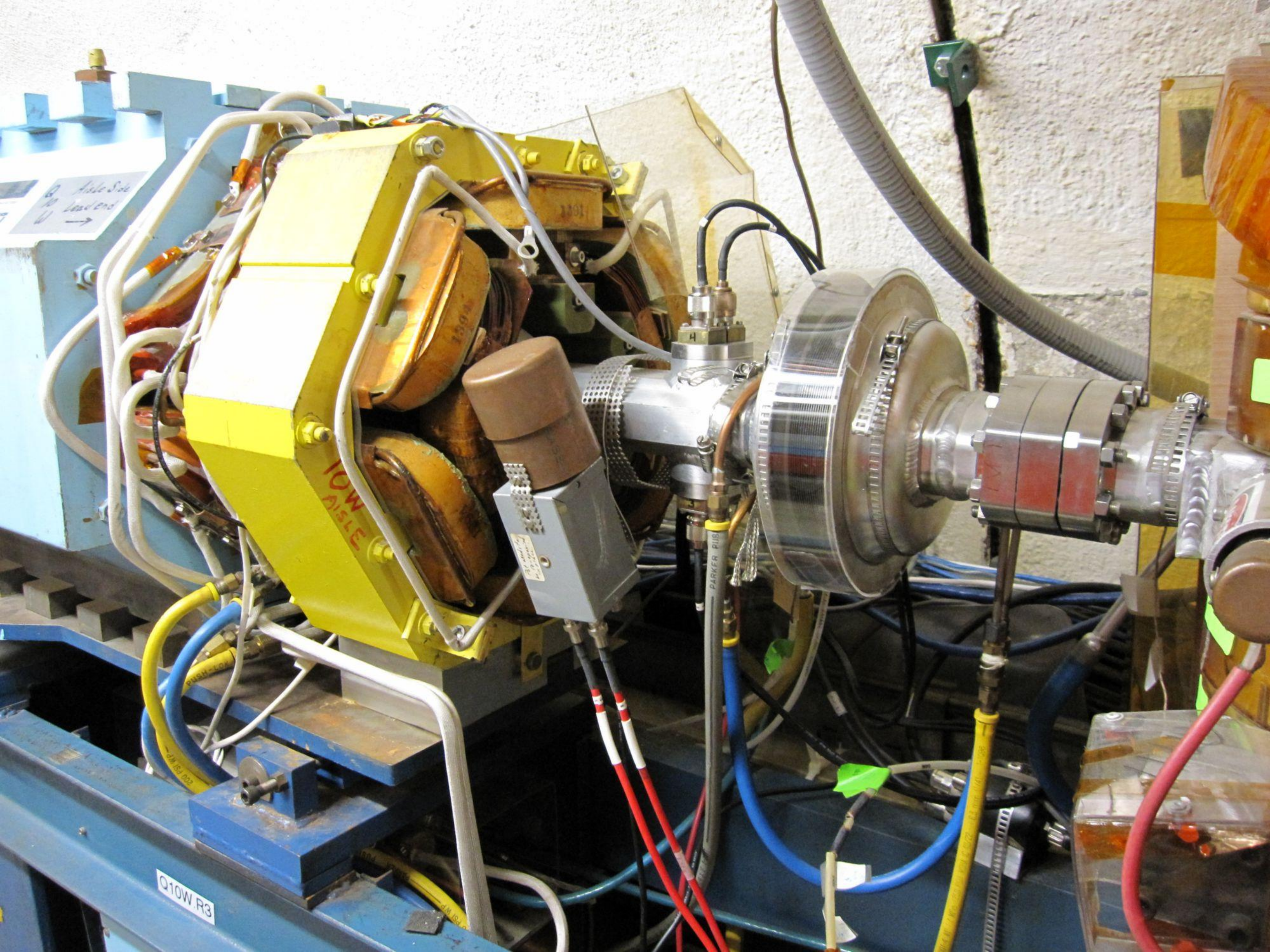


CESR-TA beam stability

- Excitation of beam with a vertical orbit corrector dipole, direct connection to dipole coil (Q10W)
- Observation of beam oscillations on vertical pickups with modified BBQ electronics (Q8W)
  heavy downsampling in special acquisition cards,
  up to 17 minutes measurement time.
- Calibration of the system using a 300 um peak-peak oscillation measured in parallel with BBQ system and local orbit system.
- Various beam conditions, partial shutdown of injector complex etc…
- 4 measurement shifts
- Very friendly and effective support by CESR team



Diode detectors on PU-Q8W

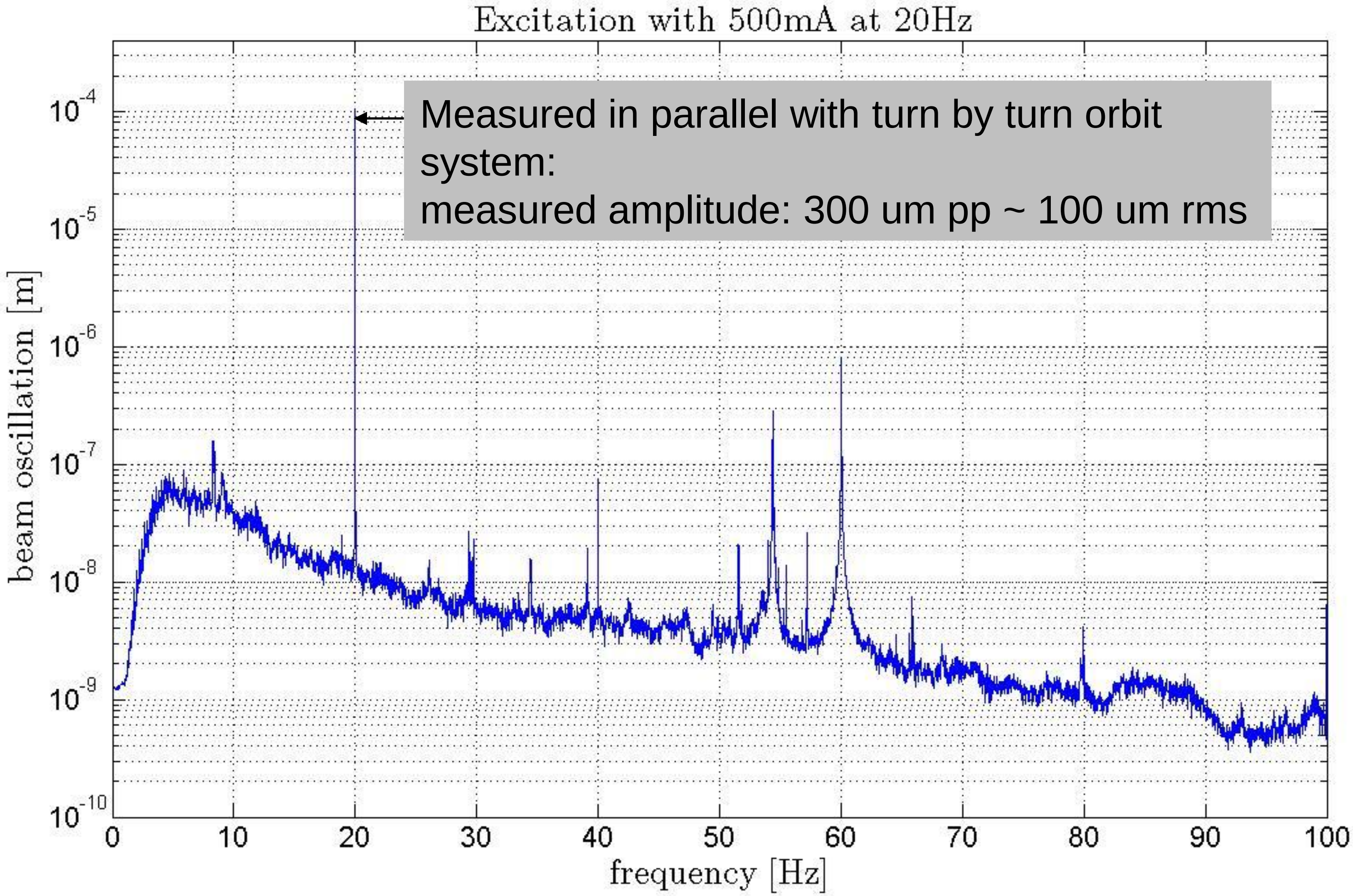

Aisle Side
Lead end
10W
AISLE
Q10W.R3

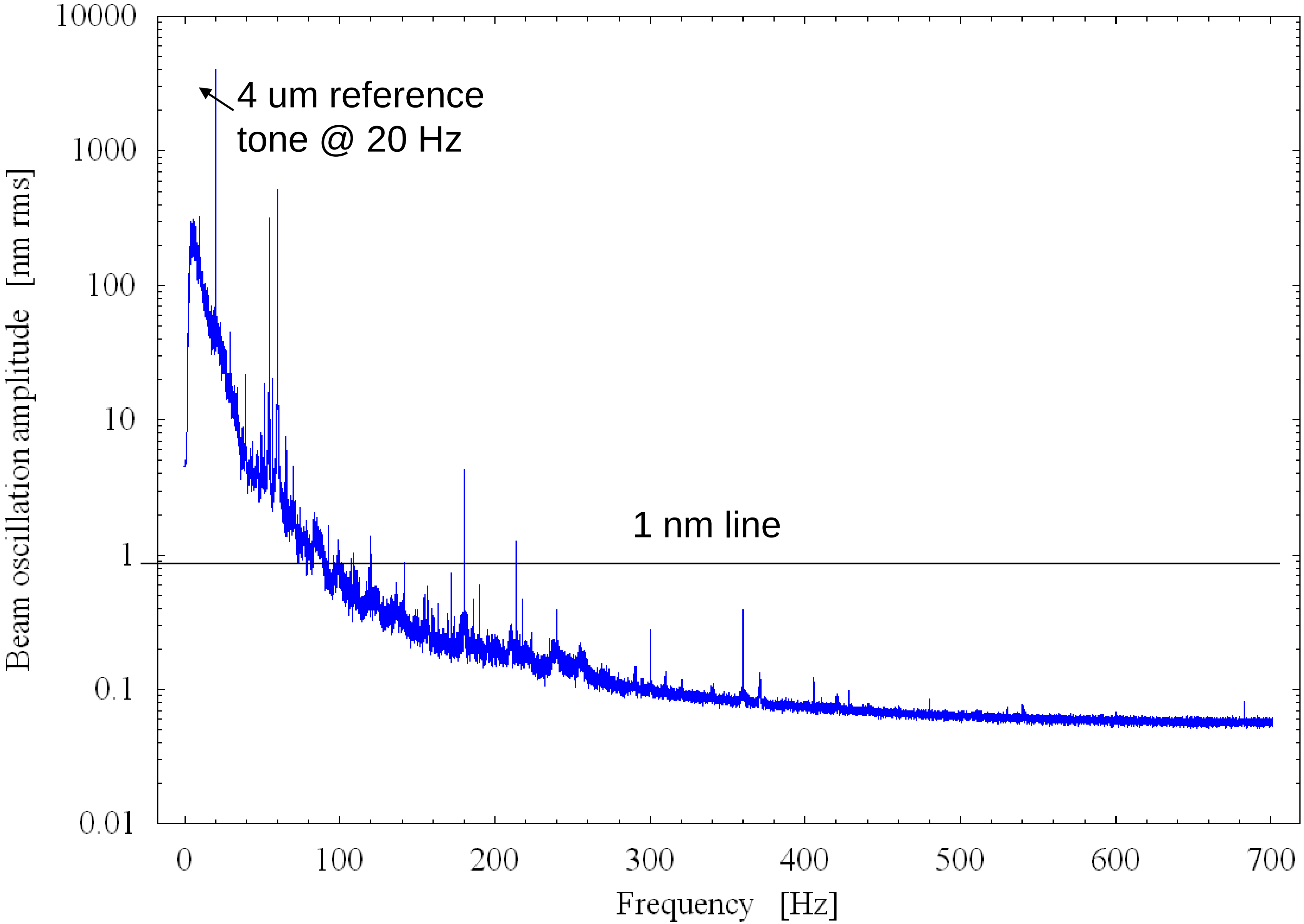
Getting BPM resolutions below the nm

- Aperture of BPM approx. 50 mm or more
- Wide band electronics thermal noise limit: 10^-5 of aperture
- Narrow band front-end gains factor 10…100
- State of the art commercial BPM system (“Libera Brilliance”) reaches 5nm/sqrt(Hz),
  i.e. with 1000 s measurement time 150 pm rms noise.

- Different approach:
  BBQ electronics: “Zoom in” getting high sensitivity for beam oscillations, but loosing absolute information of DC = closed orbit information.

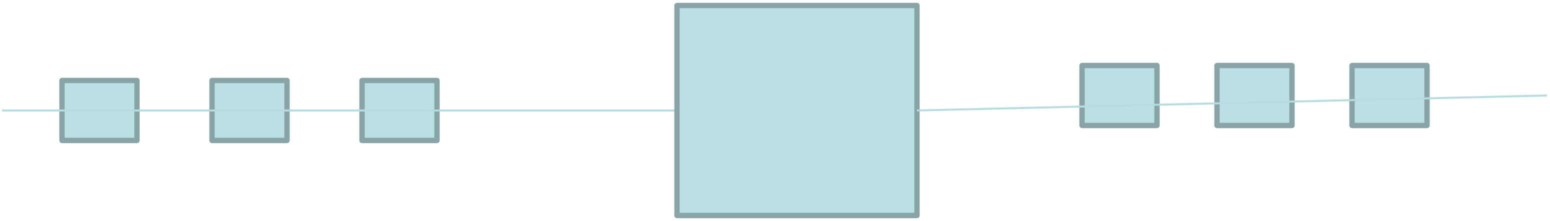
Amplitude Calibration





4 um reference
tone @ 20 Hz
1 nm line
Beam oscillation amplitude [nm rms]
10000
1000
100
10
1
0.1
0.01
0
100
200
300
400
500
600
700
Frequency [Hz]

•The CESR-TA experiment has been repeated at SLS (PSI-Villingen)
• Result: SLS factor 10…50 more stable than CESR-TA,
but still completely excluded to use for direct validation.
• Assume: any circular machine has similar rest eigenmotion of beam,
use extracted beam in spectrometer like configuration.
• No light source has extraction channel for particle beams
• Only a few machines have “constant spill” slow extraction
• JLAB has CW extracted beam



3 + 3 BPMs; define and verify straight line before and after
quad under test (QUT)

World-wide CLIC&CTF3 Collaboration

http://clic-meeting.web.cern.ch/clic-meeting/CTF3_Coordination_Mtg/Table_MoU.htm

34++ Institutes from 19+ countries

Aarhus University (Denmark)
Ankara University (Turkey)
Argonne National Laboratory (USA)
Athens University (Greece)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
Gazi Universities (Turkey)

Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
INFN / LNF (Italy)
Instituto de Fisica Corpuscular (Spain)
IRFU / Saclay (France)
Jefferson Lab (USA)
John Adams Institute (UK)

JINR (Russia)
Karlsruhe University (Germany)
KEK (Japan)
LAL / Orsay (France)
LAPP / ESIA (France)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Patras University (Greece)
Polytech. University of Catalonia (Spain)

PSI (Switzerland)
RAL (UK)
RRCAT / Indore (India)
SLAC (USA)
Thrace University (Greece)
Tsinghua University (China)
University of Oslo (Norway)
Uppsala University (Sweden)