Linear Collider Module Control and Stabilization

A.Jeremie

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Outline

- Introduction
- Module control
- Stabilization
- Conclusion

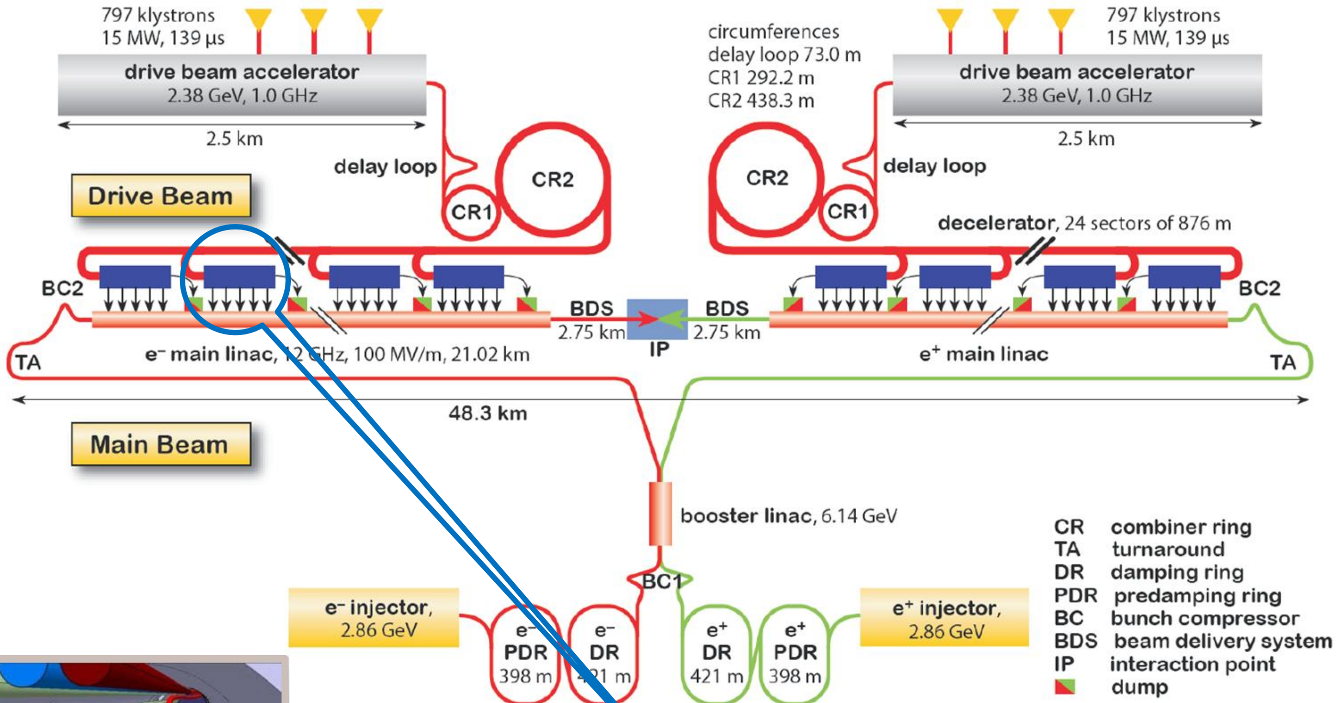
CLIC case study although applicable to other systems

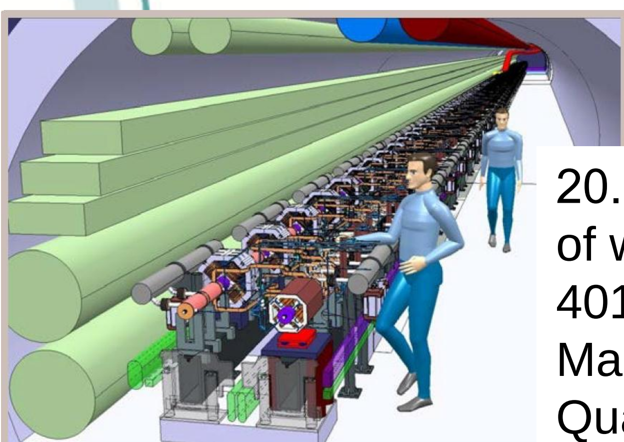
Slides from (and others)

- K.Artoos, M.Draper, A.Samoshkin (CERN)
- S.Vilalte, G.Balik (LAPP)
- S.Jansens (Nikhef)
- CDR

Introduction

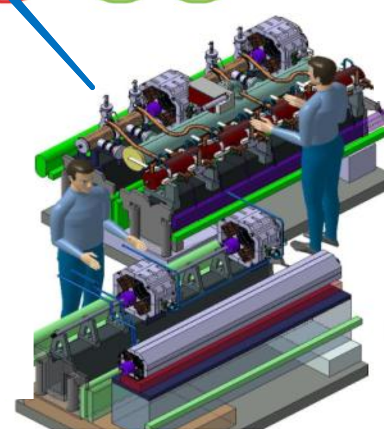
CLIC and CLIC modules



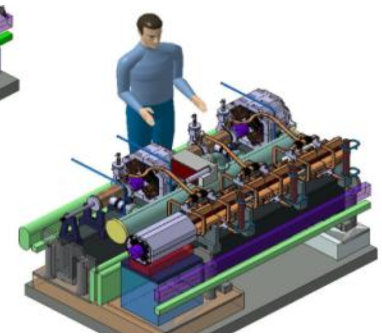


20.920 “Modules” of which there are 4010 with CLIC Main Beam Quadrupoles

Type 0: No Main Beam Quad



Type 4: 2m, 400 kg

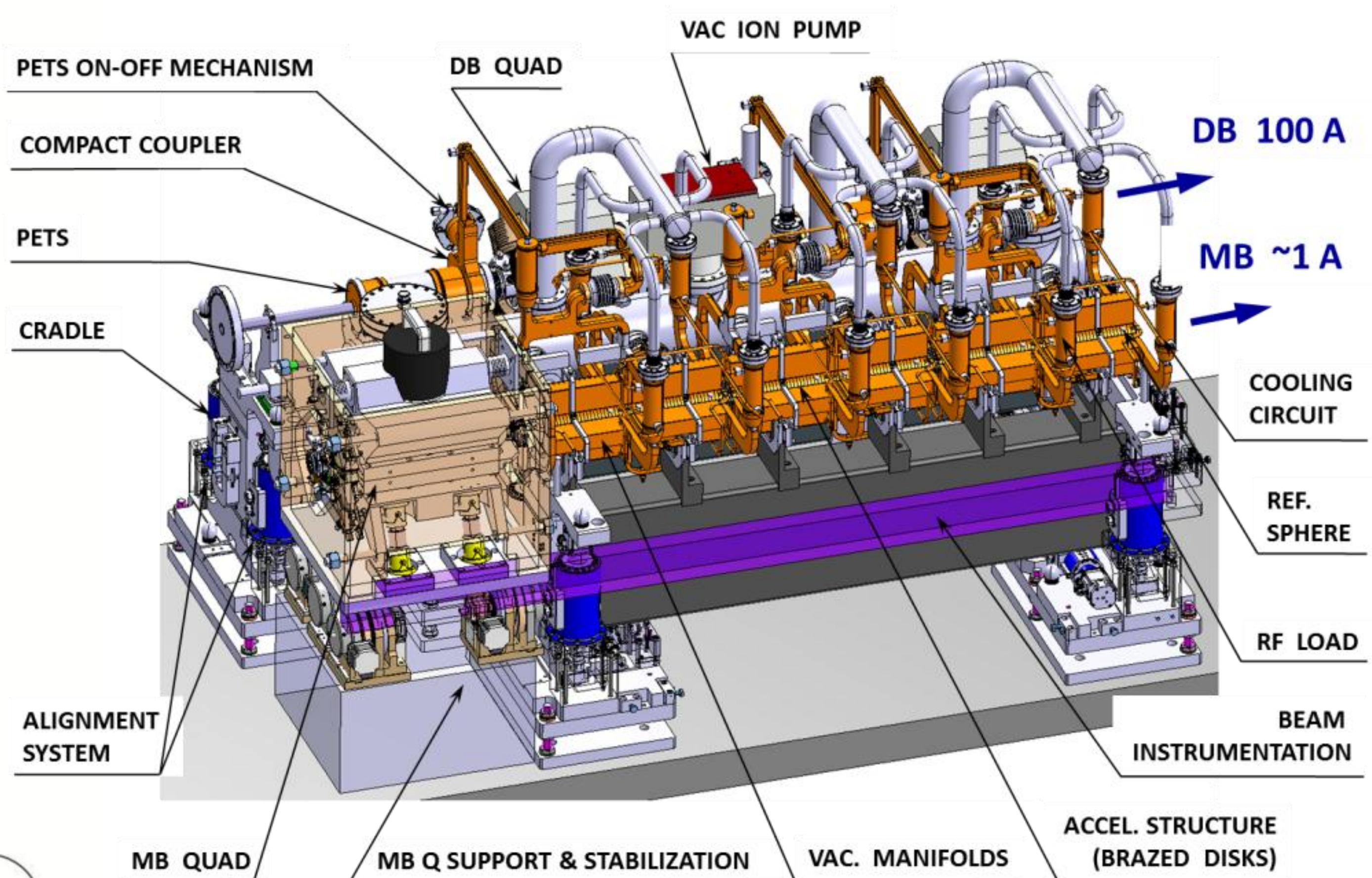


Type 1: 0.5 m, 100 kg

Module control

What is being controlled?

There are a lot of components on each CLIC Module!



Channels

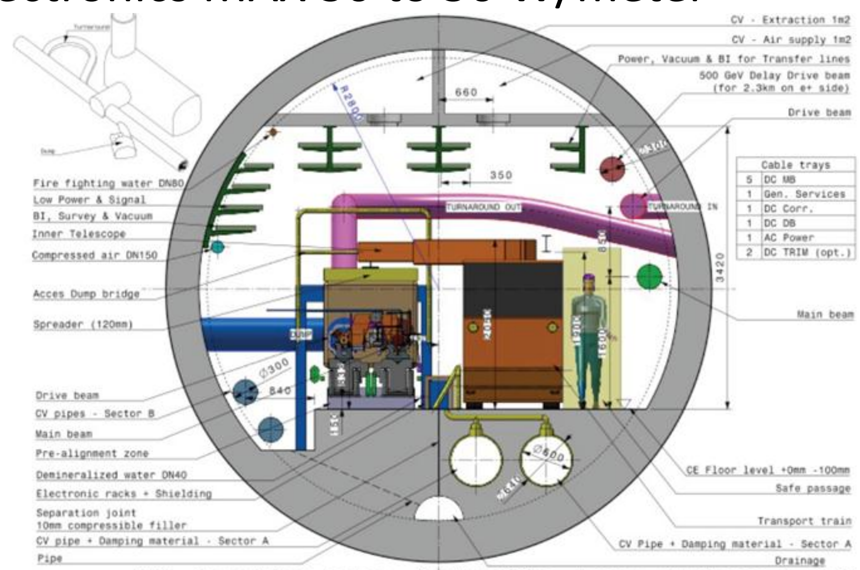
Module acquisition signals ~200	Number of signals	Signal frequency	Sampling frequency [Samples/s]	Resolution [bits]	Readout frequency [Hz]	Total data rate [kbits/sec]
Beam instr.	39	100 MHz	200×10^6	16	50	1060
RF instr.	23	50 MHz–1 GHz	$200\times10^6–2\times10^9$	10–12	50	1980
Cooling	72	DC	1	12	1	0.03
Alignment	34	DC	100	16–24	1	78
Stabilization	21	1 kHz	2×10^3	20	100	840
Vacuum	12	10-100 Hz	1×10^3	16	1	0.02
Power	2	DC	DC	12	150	6

Module control signals ~175	Number of signals	Signal frequency	Resolution [bits]	Transmission frequency [Hz]	Total data rate [kbits/sec]
Beam instrumentation	26	–	16	50	2.0
RF instrumentation	4	DC	1	50	0.2
Cooling	88	<1 kHz	–	1	–
Alignment	28	DC	16	50	1210
Stabilisation	6	DC	18	100	12
Vacuum	20	10-100 Hz	–	1	–
Power	2	DC	12	100	20

Key requirements

- Tunnel space
  - Access only every 900m, Front-End electronics close to Hardware (cabling issues)
- Limited power dissipation
  - Total power dissipation to air = 150 W/meter
  - Power budget for all Front-End electronics MAX 30 to 50 W/meter
- Radiation Hardness
  - Electronics lifetime 10–15 years
  - withstand 15 kGy or be shielded
  - neutron flux => single-event

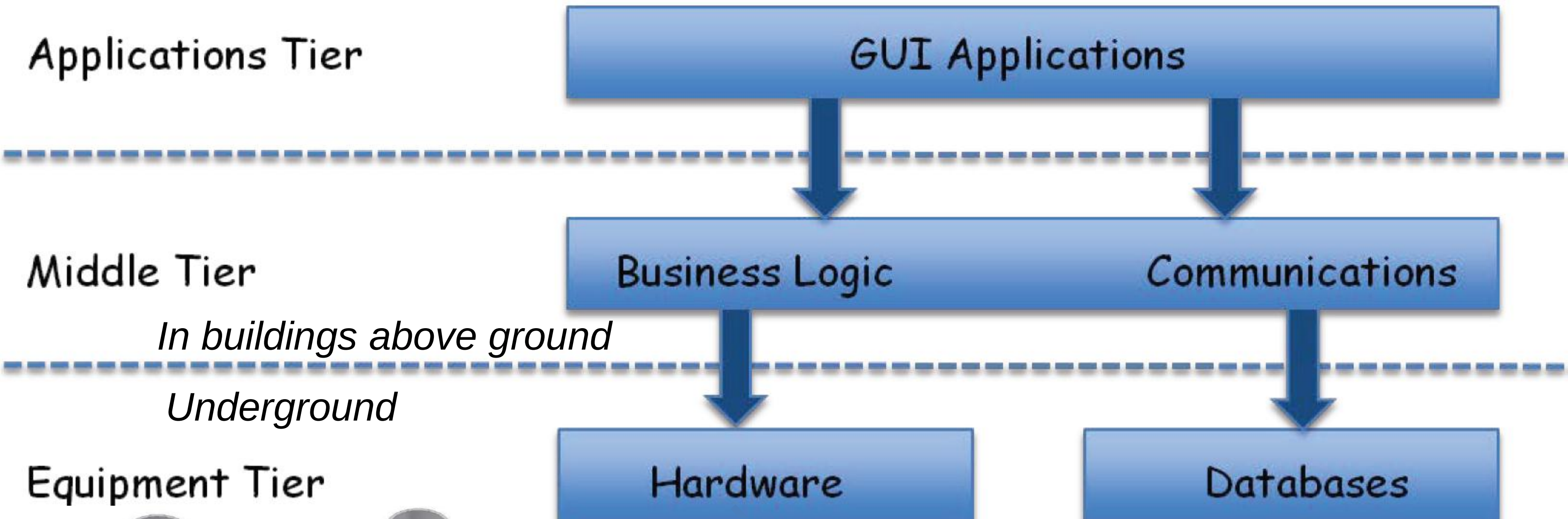
  upsets or single-event latch-ups

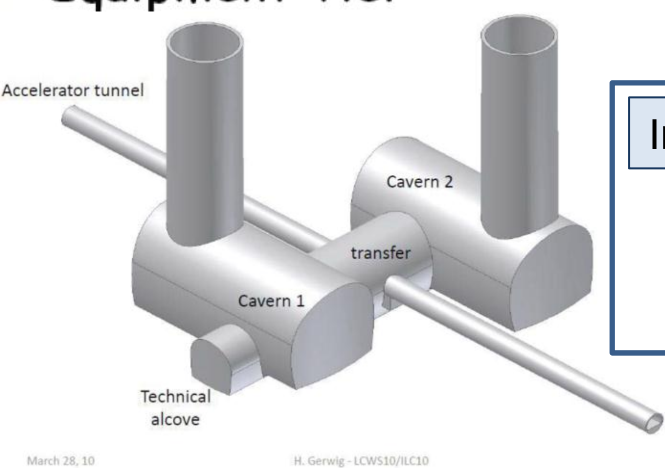


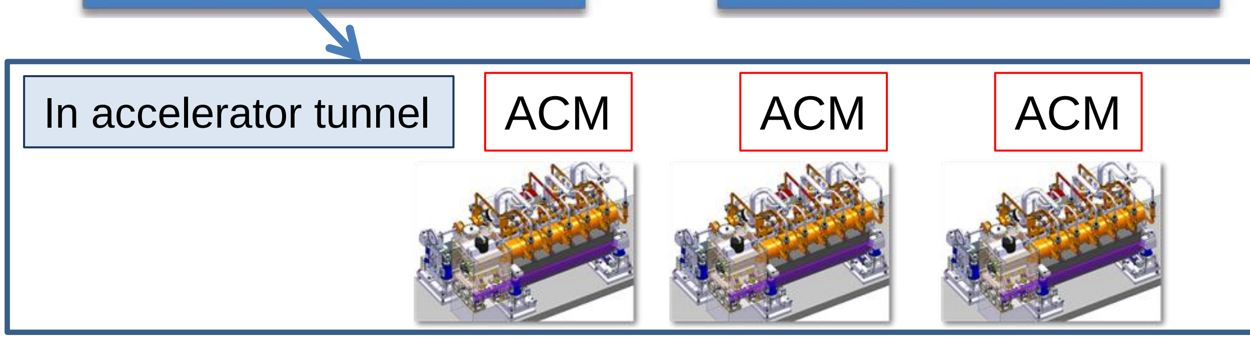
CLIC - Typical Cross Section - Diameter 5600mm - Junction with Turnaround - 1:25
Draft - J.Osborne / A.Kosmicki - August 9th 2010

CLIC Control software architecture

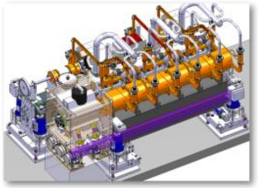
Still under development!







ACM



Acquisition and Control Module

Here « Module » is the electronic card!
Module (itallic) is still the CLIC module…

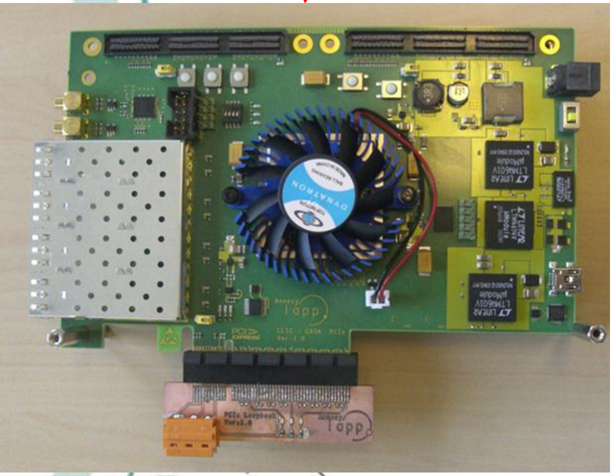
- Characteristics
  - Synchronized with Machine Timing System; CLIC will be pulsed @ 50 Hz
  - Bi-directional and synchronous data transfer via optical links (ACM ⇔ CLIC control); Configuration and diagnostic commands; White Rabbit network
  - Time stamping of acquisitions
  - Need for Real-Time feedback loops (Beam trajectory, …)
- Hardware choices
  - Long distance (~878 m) between the underground alcoves => one local ACM per *CLIC module* (every 2.01 m) as close as possible to each *module*.
  - Modular architecture with similar hardware modules for each CLIC sub-system. Acquisition crate with standard form factor, one crate per *module*.
  - Hardware module /standardized connectivity & backplane protocol
    - *common* hardware part (carrier concept) dealing with powering (standard set of voltage sources), data communication and diagnostics
    - *specific* part (one or multiple mezzanines) implementing the sub-system-specific acquisition and controls actions (DACs, ADCs, etc)

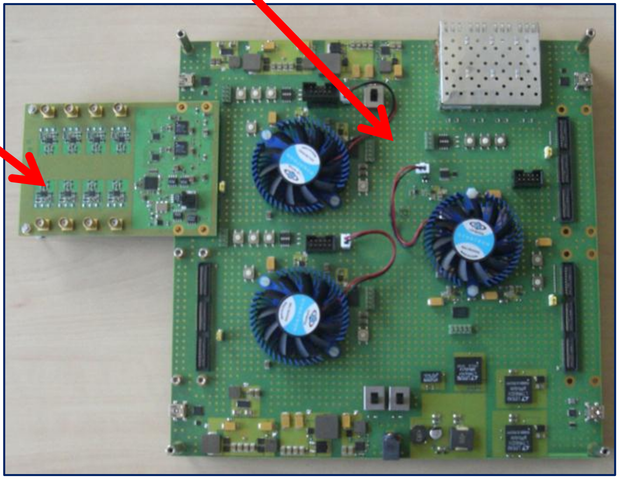
ACM Development for a BPM

(for the Instrumentation part see T.Lefevre's talk)

Parts that are needed to fit in a standard electronics crate:

- Service Board (currently a PCI board only for network): autonomous 12VDC power supplies from 230VAC line, network access and distribution on back-plane.
- Instrument Boards:
  - Standard Mother Board (based on FPGA)
  - Sub-system specific Board (Mezzanine)

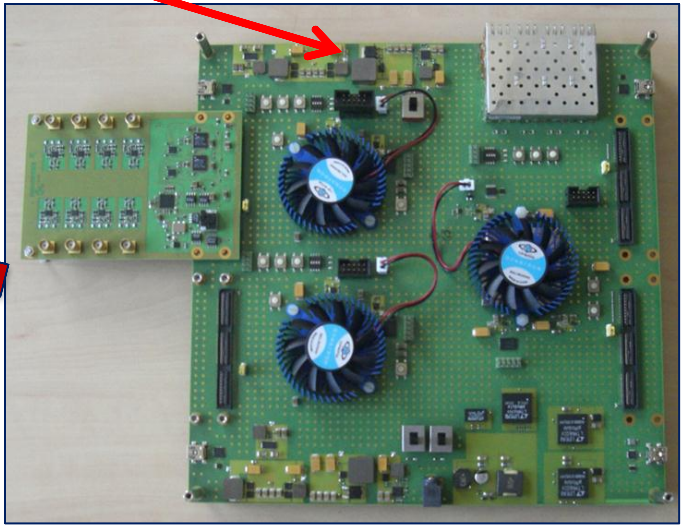


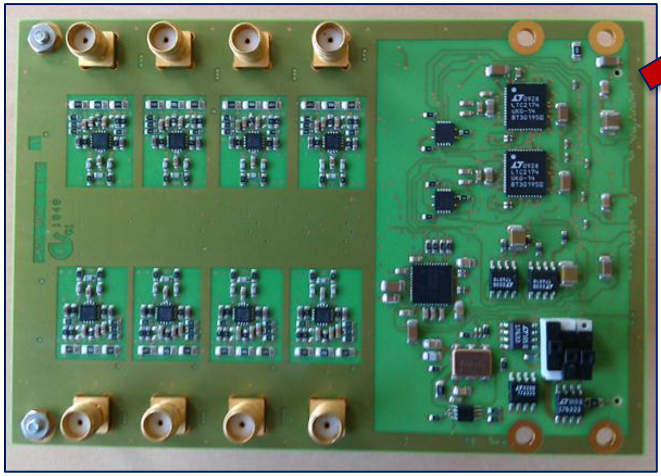


Test with an evaluation board

Possible architecture: standard motherboards with mezzanines dedicated to the subsystems.
In 2011, development of an evaluation board allowing the module emulation and generic acquisition mezzanine.

→ 8 channels, Fs=96Msps (CTF3 clock).
→ tests of the LTC2175 ADC: 11,7bits.
→ tests of the LTC6406 OPA (ADC driver).





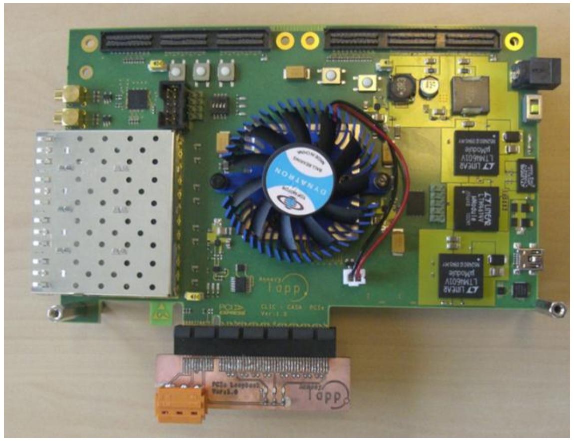
Allows to test input shaping for BPM and will allow acquisition with beam.

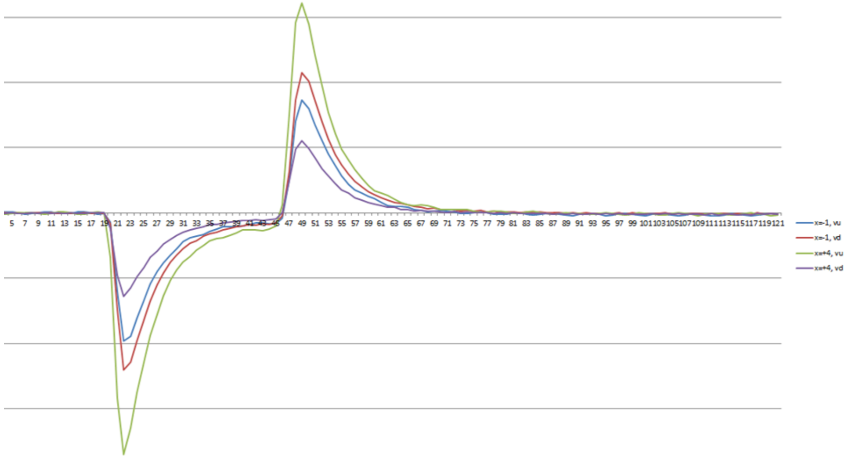
=> test lots of different configurations for future CLIC developments

BPM shaping and acquisition

First tests performed with a PCIe board instead of mother board. Developed for the module crate network, can host a mezzanine in a stand alone configuration.

Filter characterization with network analyzer & characterization of the full chain: OK.





And first Instrument readout tests
- Good shape, expected levels

Conclusion for Module Control

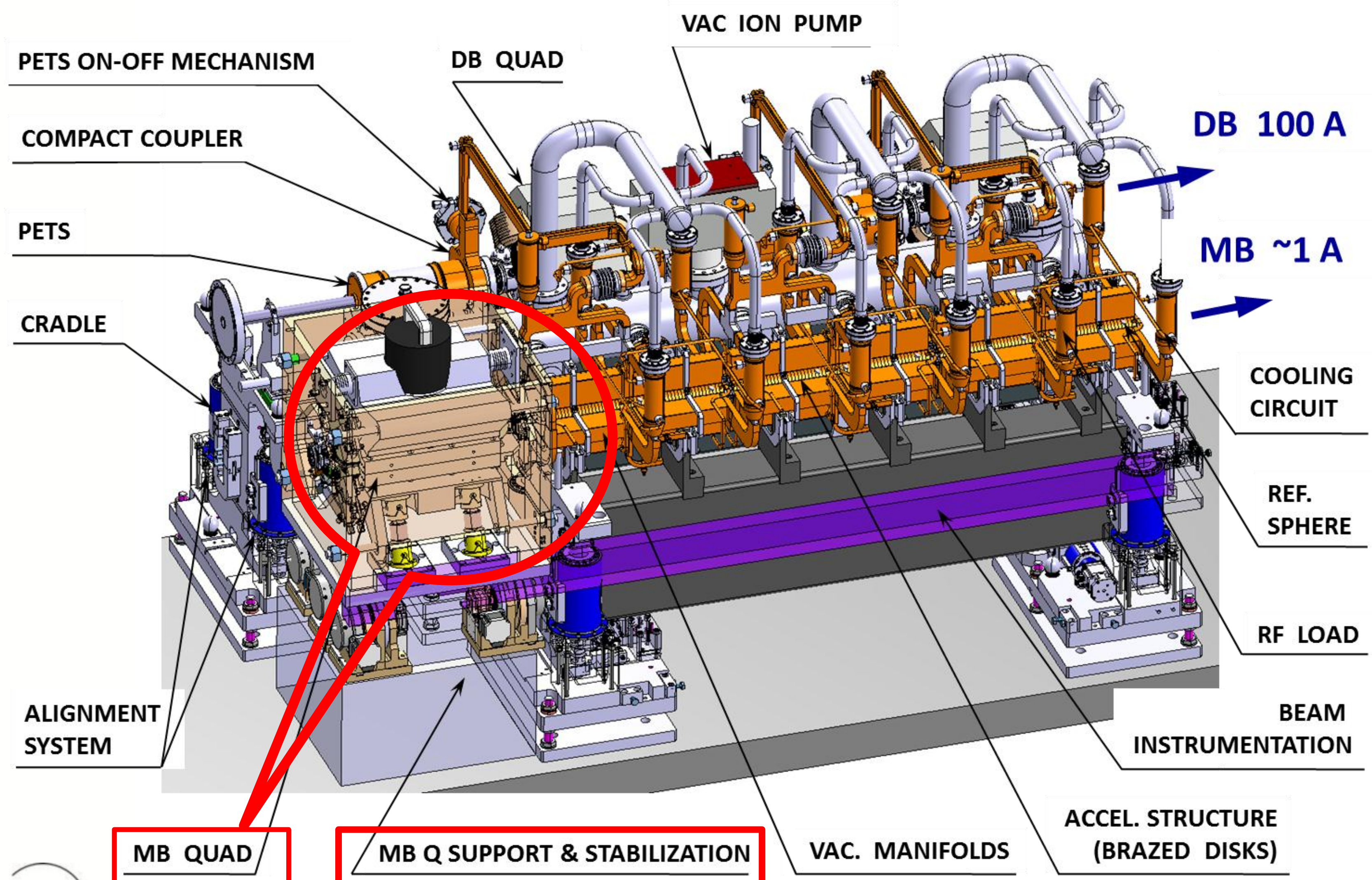
- Lots of channels (~375) for acquisition and control
- Need for a distributed and standardized system
- Evaluation boards very helpful
- First results of instrument readout
- Next step:
  - test in accelerator environment
  - Start by shielding components
  - Power consumption will be evaluated also

Stabilization

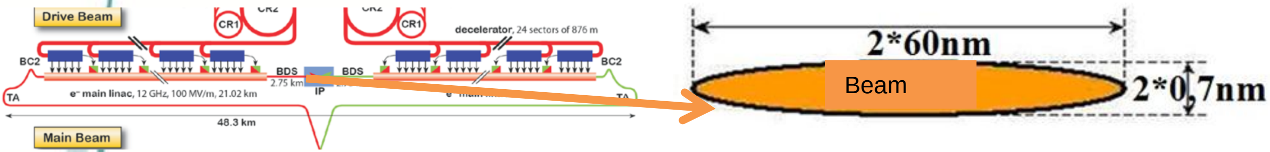
- Another sub-system with channels to be read-out and controlled

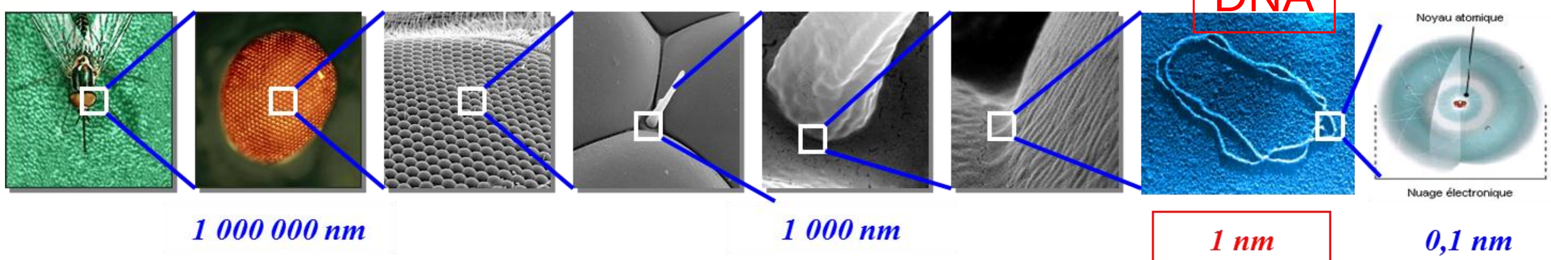
Let's go back to CLIC Module

Main Linac Module with Type 1 quadrupole



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

	Last magnet	Main Beam Quad
Vert.	**0.2 nm > 4Hz**	**1.5 nm > 1 Hz**

Active Stabilization techniques have been chosen

What is needed?

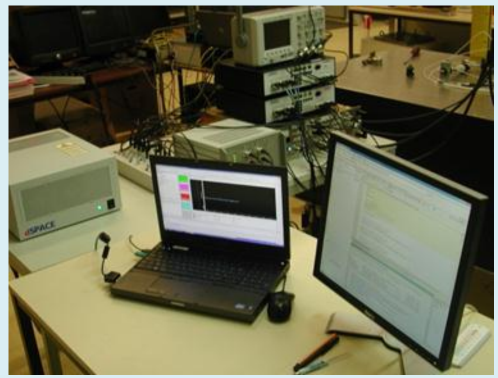
Active Stabilisation means :

measure => decide action => act

sensor

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

feedback/-forward



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

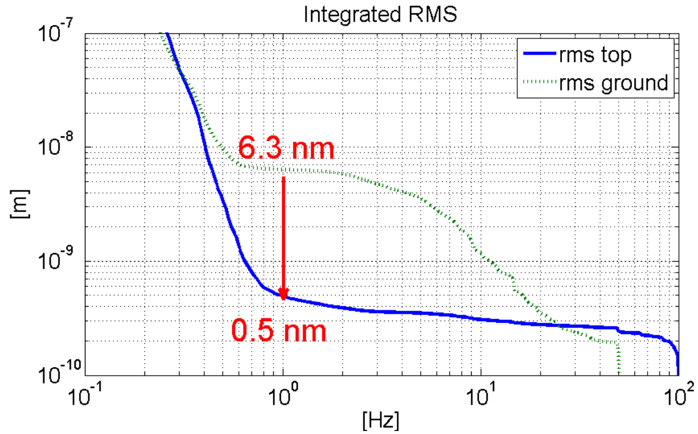
actuator

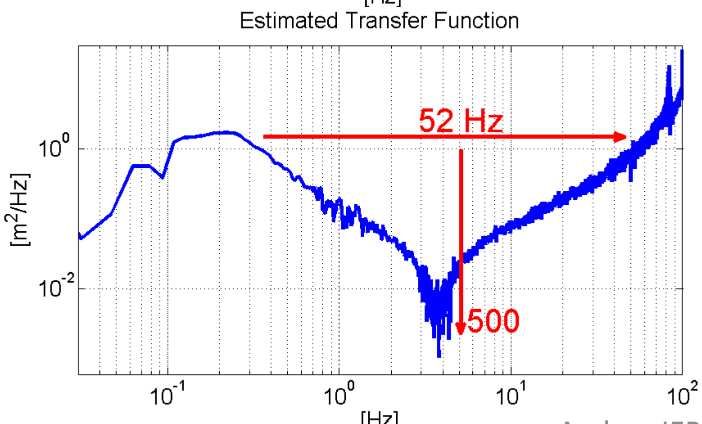
-Nanometre displacement
-Displace heavy weight
-Compact
-Real-time response
=> Piezoelectric actuator

Accelerator environment
=> Magnetic field resistant and radiation hard

Stabilization on Type 1 MBQ

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





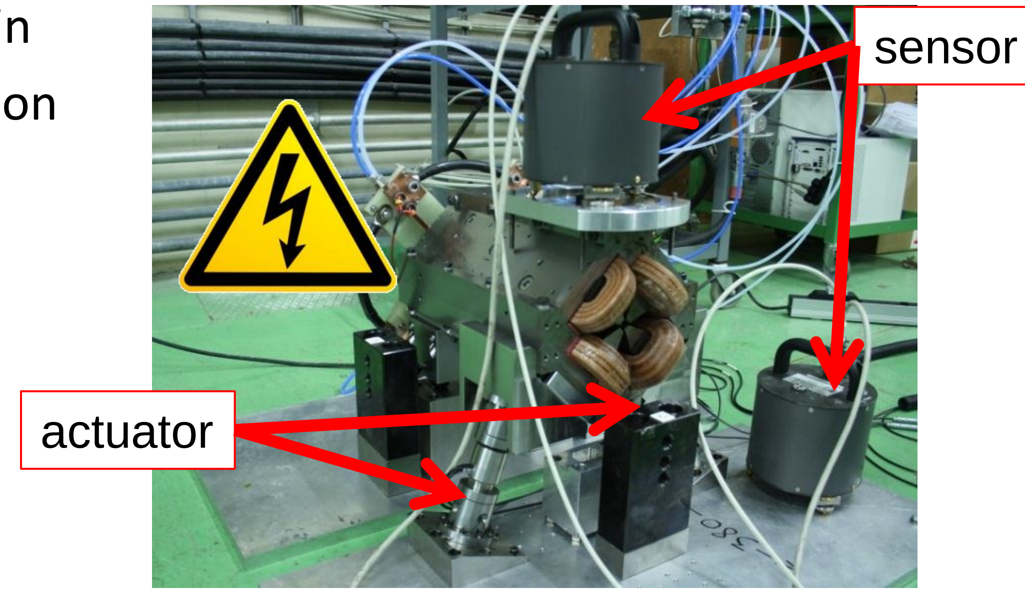
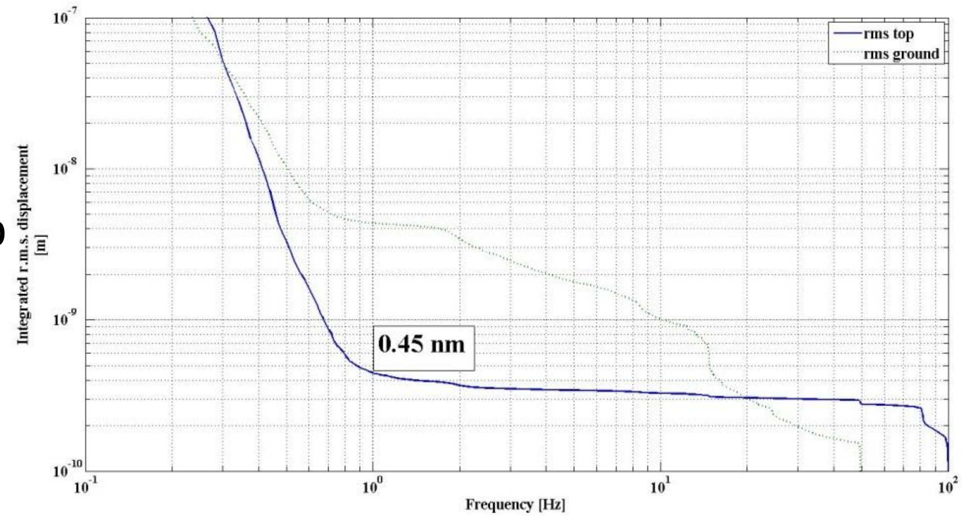
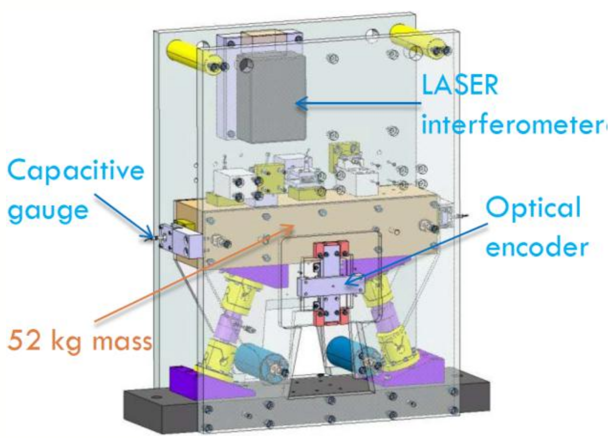


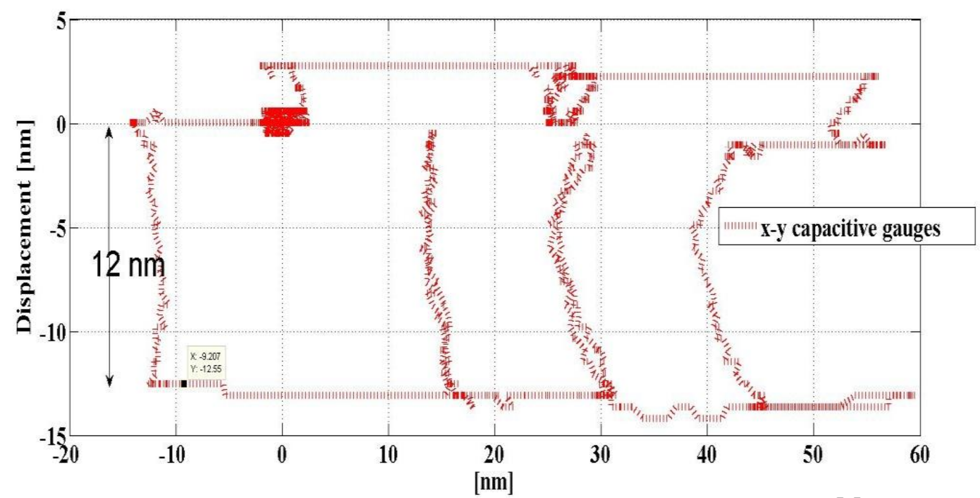
Figure	Value
R.m.s @ 1Hz magnet	**0.5 nm**
R.m.s @ 1Hz ground	6.3 nm
R.m.s. attenuation ratio	**~13**
R.m.s @ 1Hz objective	**1.5 nm**

2012: Positioning + Stab. test bench X-y guide prototype operational

Improves the mechanics: no resonance before 100Hz







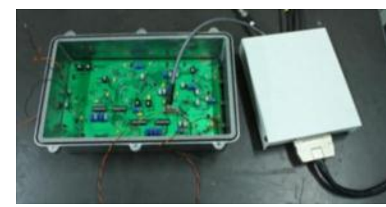
Control and module

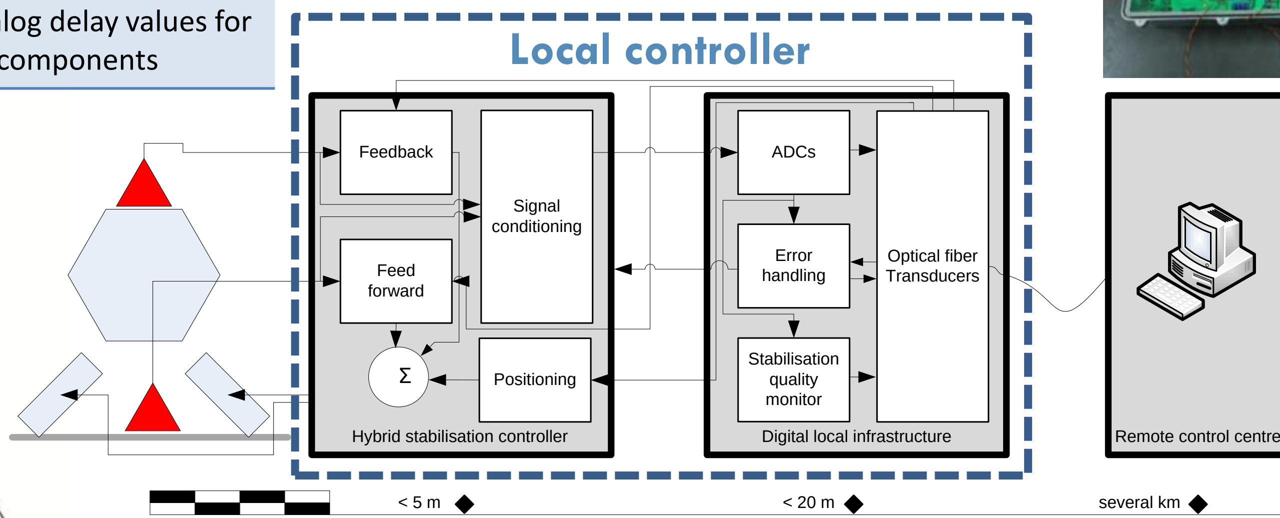
Component	Delay
ADC	8 µs
Electro-optic transducer	100 ns
Optic fiber transmission	**5 µs/Km**
Opto-electric transducer	120 ns
DAC	3 µs
Actuator (20nm single step)	1 µs
Typical catalog delay values for the components	

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

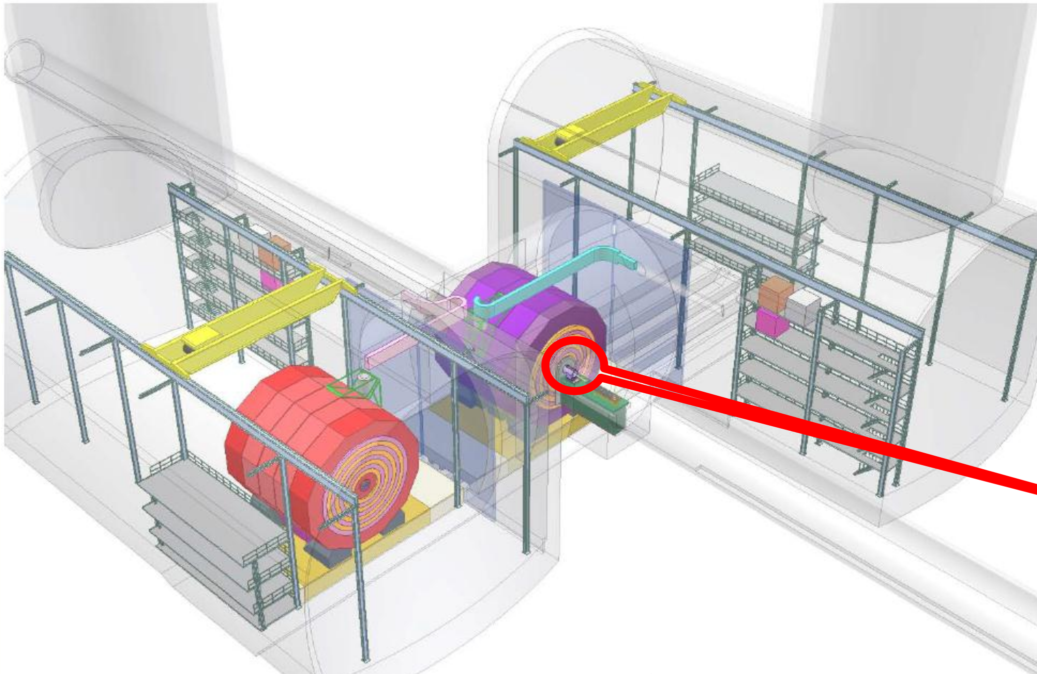
Control loop delay	Stabilization performance
43µs	100%
80 µs	90%
90 µs	80%
100 µs	60%
130 µs	30%

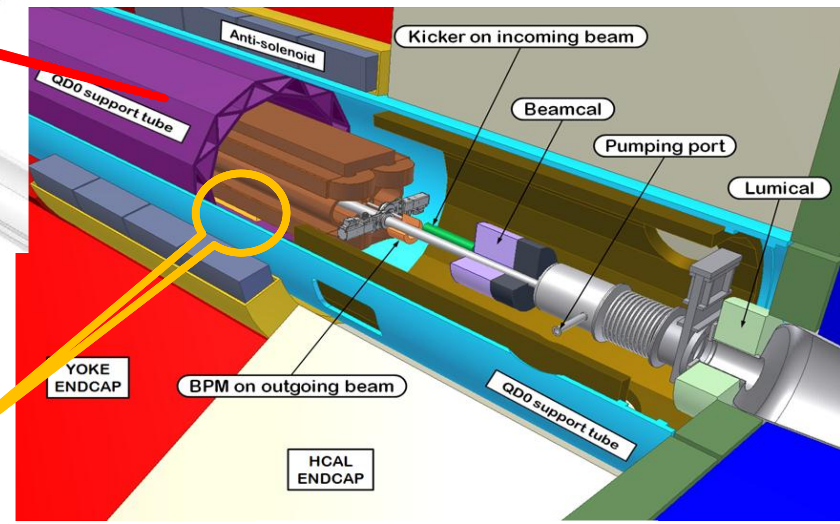
Digital and analog hybrid controller

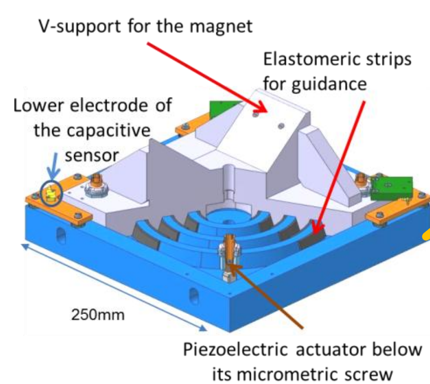




Special case for the last magnet inside detector : Final Focus magnet

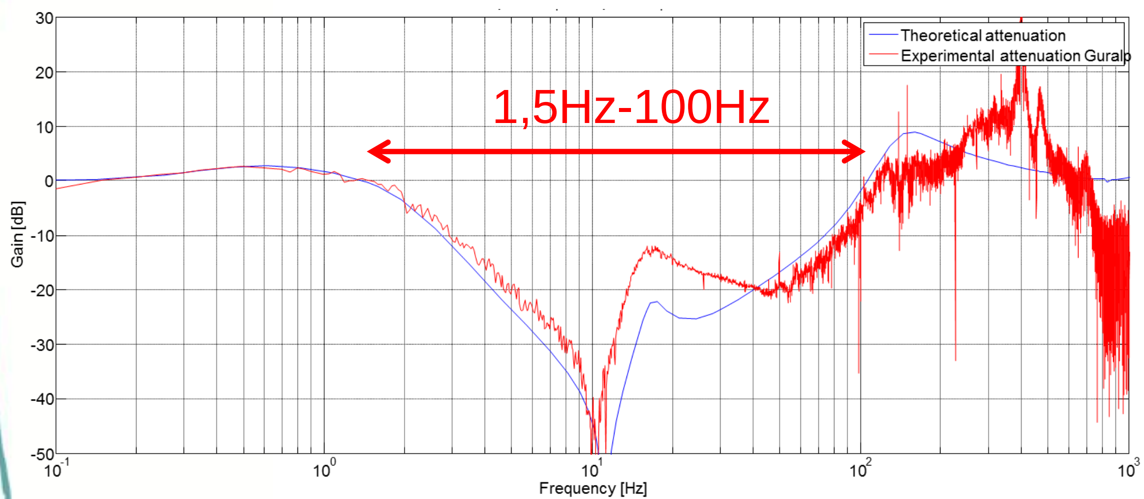




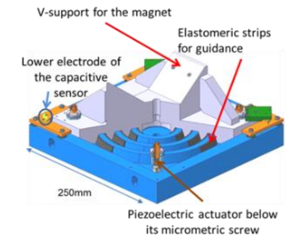


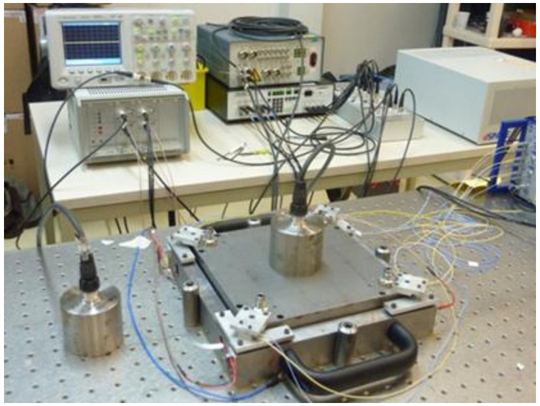
H.Gerwig + N.Siegrist

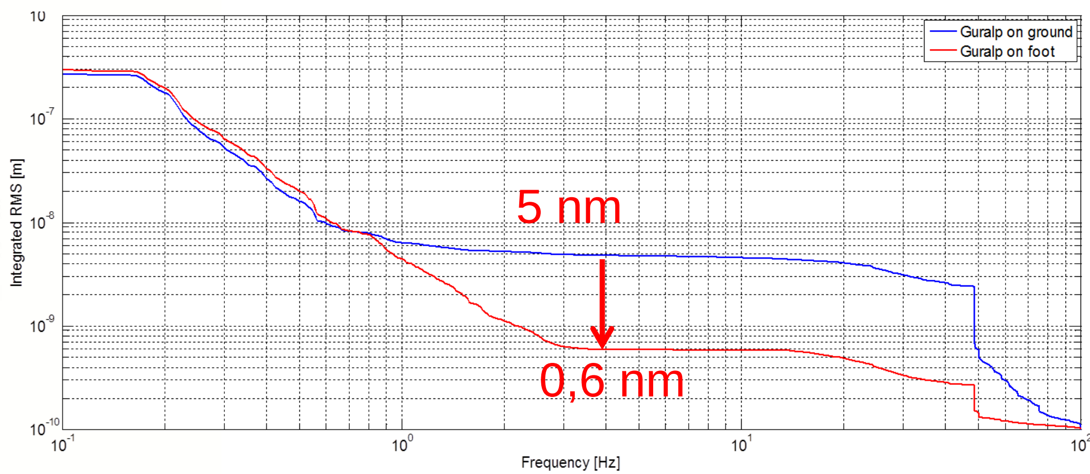
FF stabilisation results



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

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 and electronics
- Next step: tests in accelerator environment

Conclusion and impact for Industry

- Linear Colliders: very creative, yet complex projects
  - Many development needs on different topics
- Large scale strategies needed
  - Increasing number of components to check
- CLIC divided into semi-standartized modules
  - Industrialization eased
- Hundreds of signals to readout and control => standard components, with modularity
  - Electronics development
- Unprecedented stabilization needs bringing together state-of-the art sensors, actuators and precision automatics
  - Sensors development needed to enhance performance