Study of Vibrations Impact on FCC-ee Performance and Stabilisation Needs in the MDI Area

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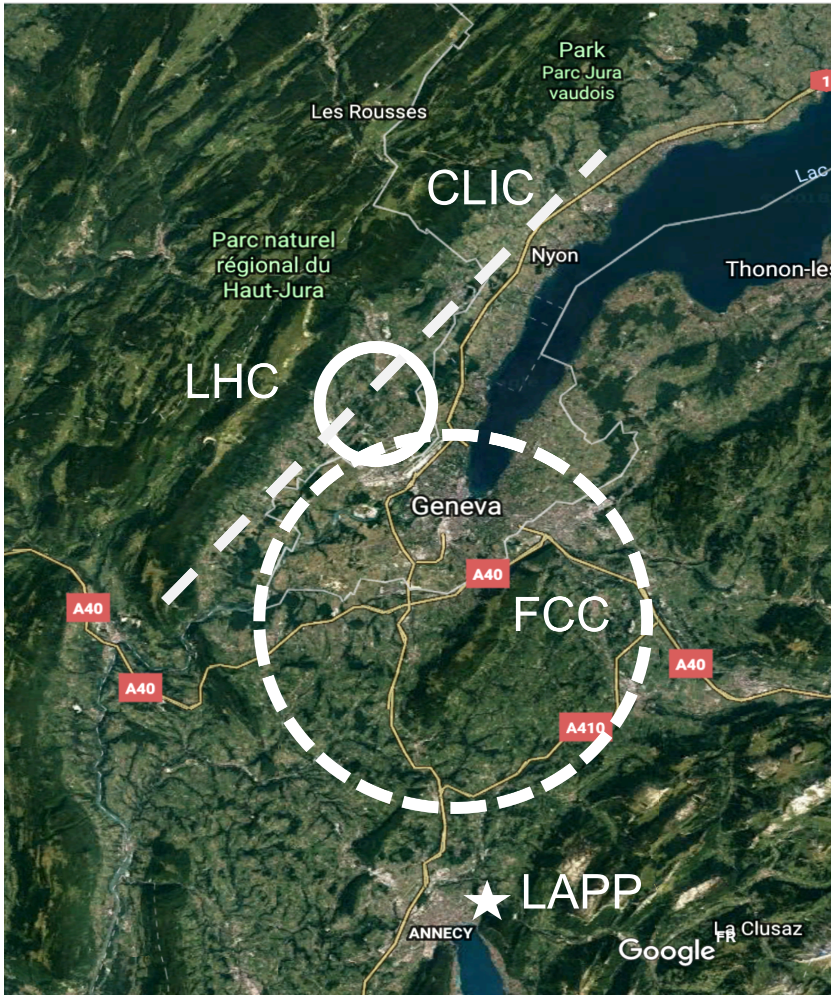
FCC France, LPNHE Paris, 14-15 November 2019

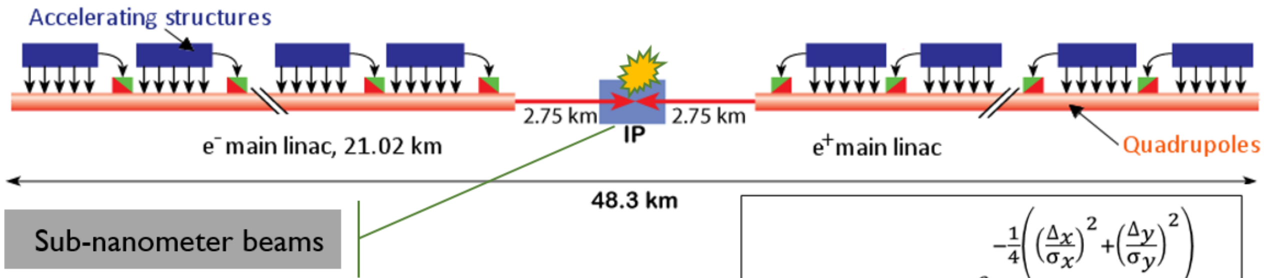
Successful operation of future colliders requires advanced vibration analysis and control.

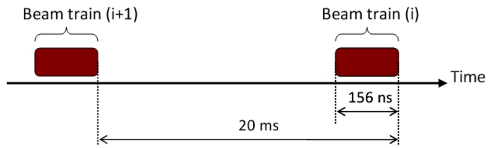
- **Linear Collider**
  - Need to preserve very low emittance along beamline and collide nanometer beams
- **Circular Collider**
  - Need to minimize emittance dilution and stabilize interaction point
- **Vibration effects**
  - Misaligned quadrupoles induce orbit distortion via feed-down effect
  - Orbit distortion generates beam offset at IP and emittance blow-up due to nonlinearities
- **Vibration countermeasures**
  - Feedback and feedforward
  - Active and passive stabilizations



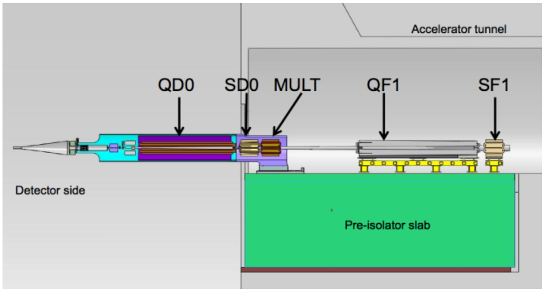
CLIC Project

- *CLIC Final focus R&D:*

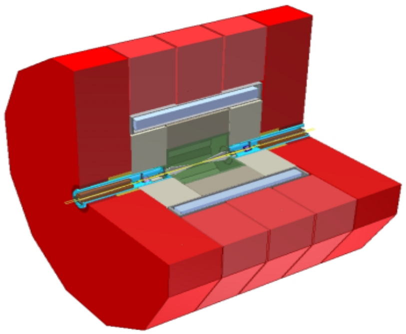




Beam repetition: 50 Hz



$$L(\sigma_{x,y}, \Delta_{x,y}) \sim \frac{e^{-\frac{1}{4}\left(\left(\frac{\Delta x}{\sigma_x}\right)^2 + \left(\frac{\Delta y}{\sigma_y}\right)^2\right)}}{\sigma_x \sigma_y}$$



- **Many controls will be performed all along the collider whose these two critical challenges:**

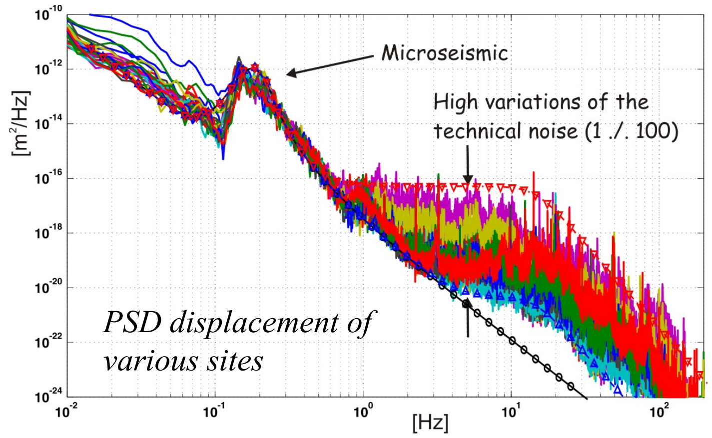
  Main Linac – active control
  - Keep ultra low emittance by minimizing beam size all along the collider

  Interaction point – active control
  - Maximize the cross section by minimizing the beam-beam offset

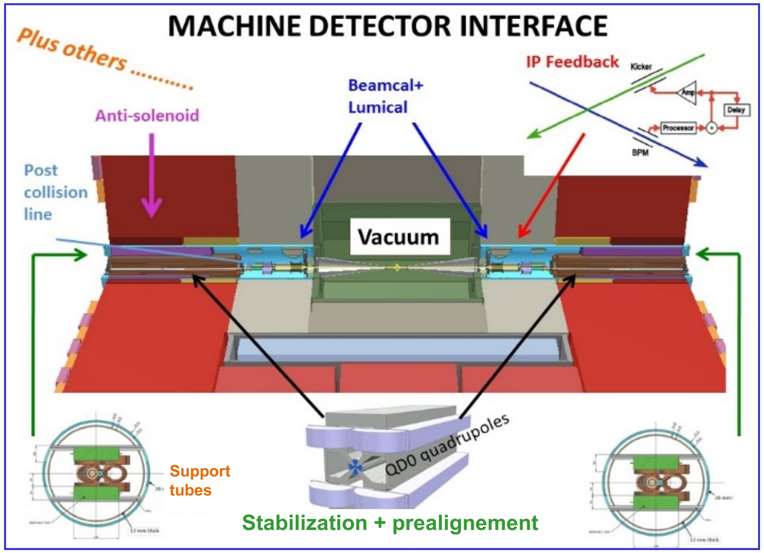
Spec. : Beam offset <= 0,2 nm RMS @ 0,1Hz ⟹ **Ground motion mitigation is needed**

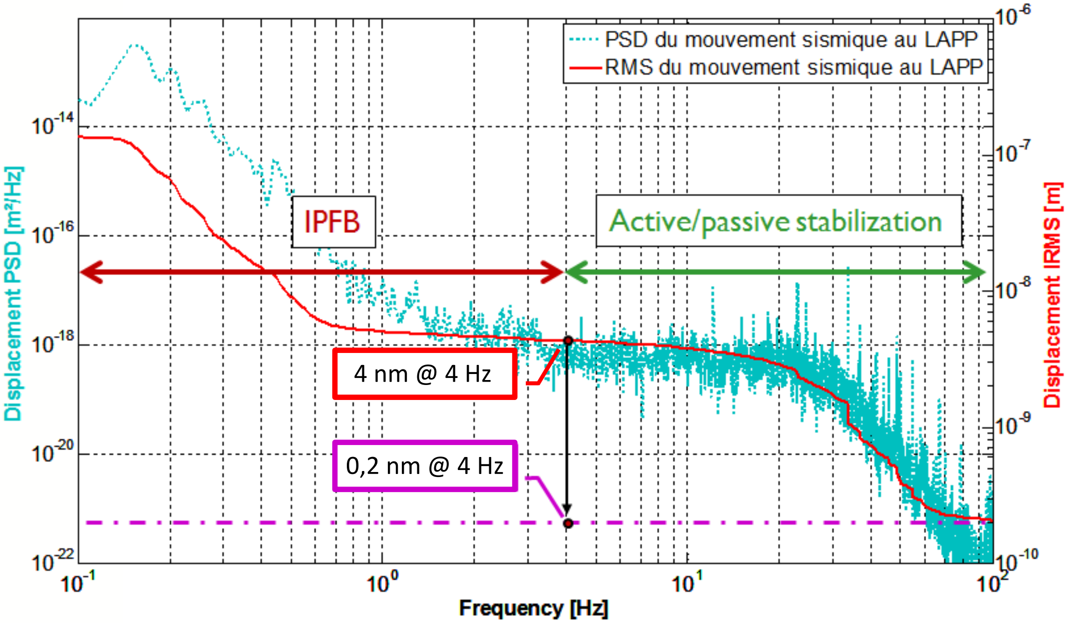
Strategy of Control

- ***Seismic motion:***
  - *Described by Power Spectral Density (PSD)*
  - *Seismic activities (starting in low frequencies)*
  - *Technical noise (human activities, cooling…)*



- ***Beam trajectory control & mechanical stabilization:***

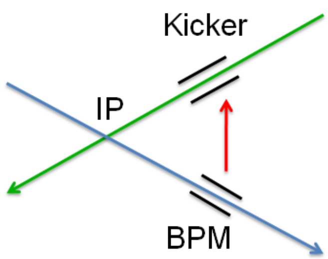


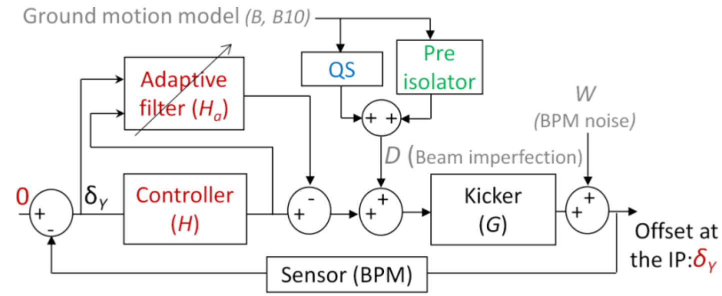


- At the Interaction Point (beam feedback: IPFB + mechanical stabilization),
- We aim at **0,2 nm RMS at 0,1 Hz**

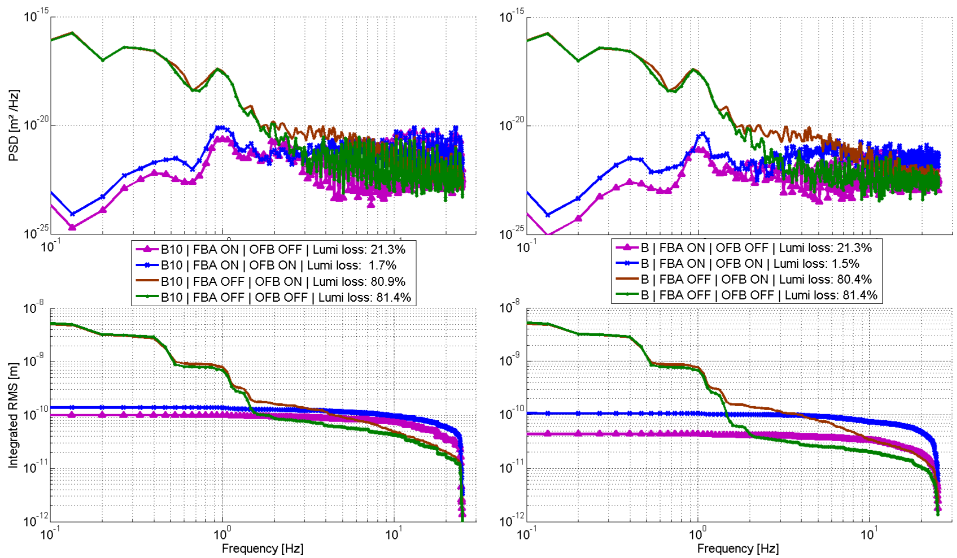
IP Feedback

- ***Beam trajectory control : simulation under Placet***





Feedback and adaptive control scheme



Luminosity vs control ON or OFF and vs model of seismic motion (deal under Placet)

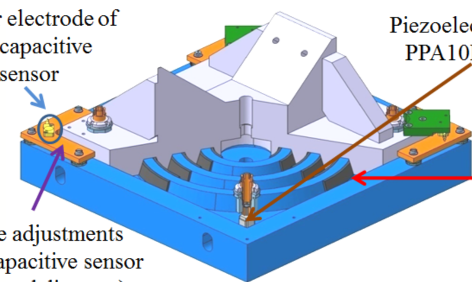
➢ ***Has to be tested on a realistic environment…***

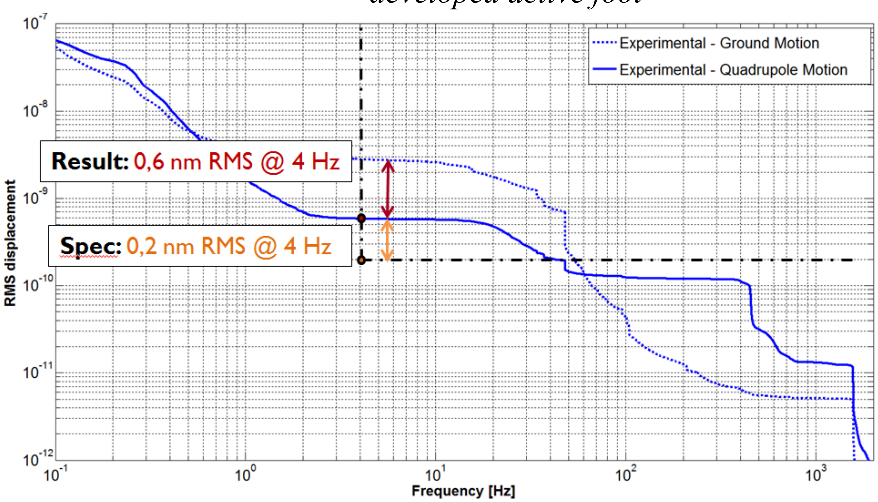
- *Caron B et al, 2012, "Vibration control of the beam of the future linear collider", Control Engineering Practice.*
- *G. Balik et al, 2012, " Integrated simulation of ground motion mitigation, techniques for the future compact linear collider (CLIC) ", Nuclear Instruments and Methods in Physics Research*

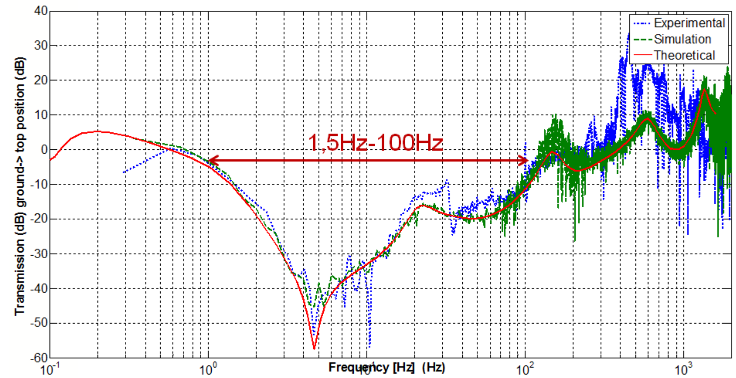
Active Control : Demonstration

- ***Prototype of active control system :***

Commercial sensors and a developed active foot







- **Results with commercial sensors : 0,6 nm RMS@4Hz.**

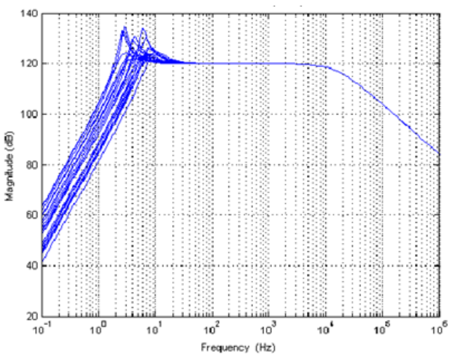
- Balik et al, "Active control of a subnanometer isolator", JIMMSS, 2013.
- R. Le Breton et al, Nanometer scale active ground motion isolator, Sensors and Actuators A: Physical, 2013.

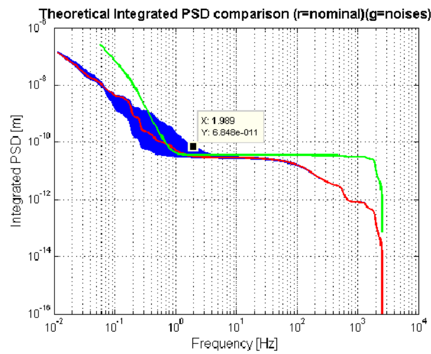
- *Sensors dedicated to measurement but not to control*
- *Two needed technologies for the selected bandwidth (geophones for low frequencies and accelerometers for high frequencies)*
  - ➢ *complexity of the control*

➢ ***Main limitation : SENSORS (Experimental and theoretical demonstration).***

Sensors : Measurements on Site

- ***Development of a new vibrations sensor dedicated to control:***

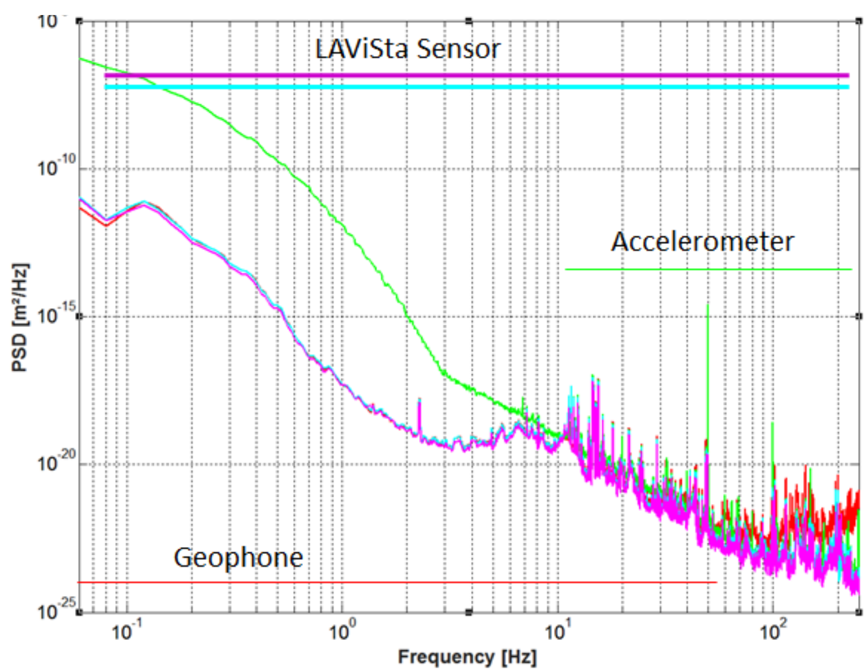




Prototypes developed since 2011

➢ Approach validated → Patent n° FR 13 59336.

- ***Comparison with Güralp and Wilcoxon sensors at CERN (ISR):***



Geophone (Güralp 3-ESP)
Low frequencies

Accelerometer (Wilcoxon 731A)
Mid-High frequencies

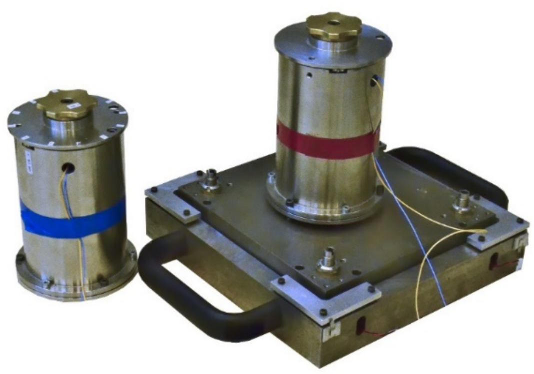
LAViSta sensor (x2)
Large bandwidth

Active Control with the Developed Sensors

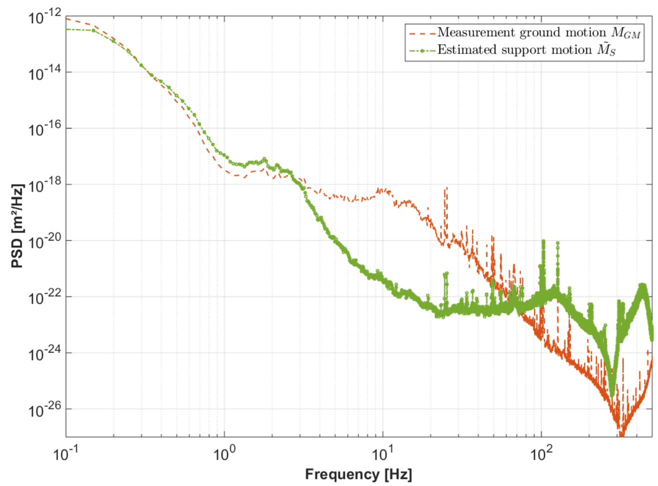
- ***CLIC Demonstration of faisability at reduced scale***
  - CLIC specification (displacement of the QD0 final focus) : 0,20 nm RMS@4Hz
  - Previous results with LAPP active foot + 4 commercial sensors : 0,60 nm RMS@4Hz

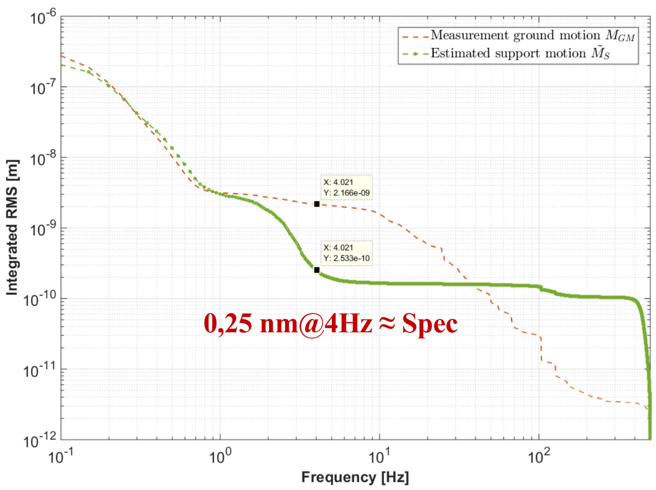
➢ **Results of control (autumn 2016) with LAPP active foot + 1 LAPP vibrations sensor : 0,25 nm RMS@4Hz**

- *Only 1 sensor in feedback -> control less complex and more efficient*



- LAPP active foot + LAPP sensors (one on ground used to monitor ground motion and 1 on top used in feedback) -





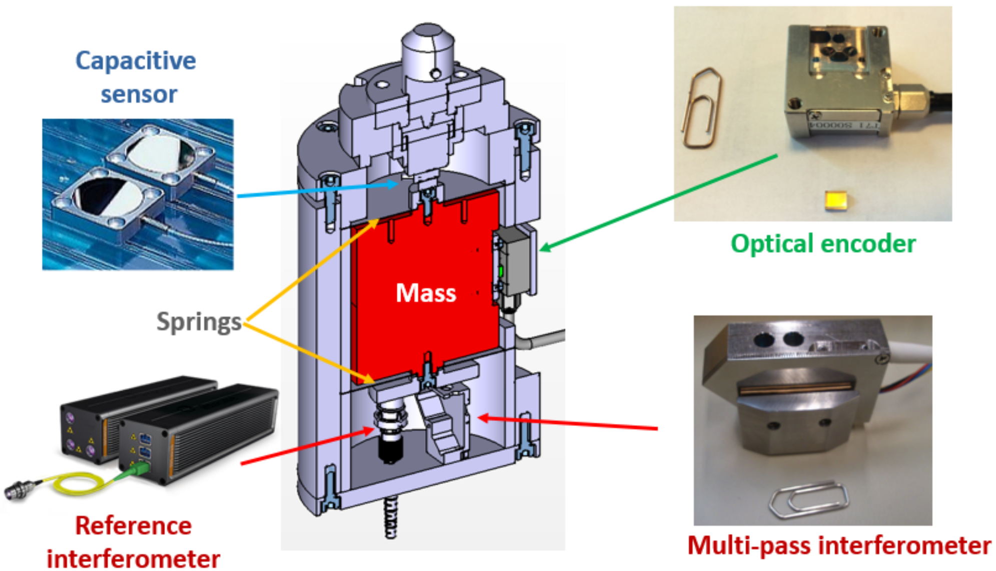
*- Displacement **without control** / **with control** **at LAPP** -*

➢ *Collider environment*
➢ *Large scale*

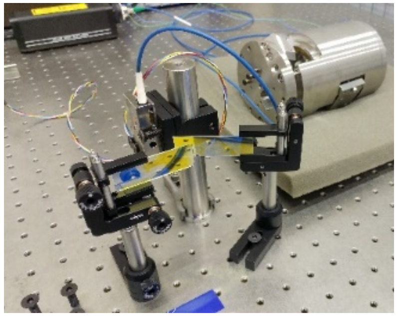
G. Balik, B. Caron, B. Aimard, L. Brunetti, G. Deleglise, « Vibration Control Using a Dedicated Inertial Sensor », IEEE Sensor Journal (Volume : 18, Issue: 1), 2018

Current Sensor Vibration Improvements

- ***Comparison of different technologies for the embedded sensitive part***
  - PACMAN (-> 2017) : Particle Accelerator Components' Metrology and Alignment to the Nanometre scale (Marie Curie program at CERN)
  - Use of the LAPP sensor with dedicated instrumentations



- Capacitive sensors : PI & Lion Precision
- Optical encoder : Magnescale
- Interferometer : Attocube & a developed one (INRiM (It) and ISI Brno (Cz))

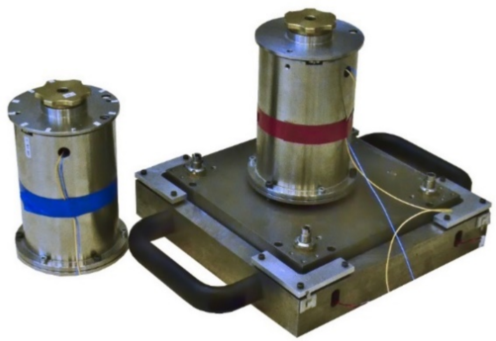


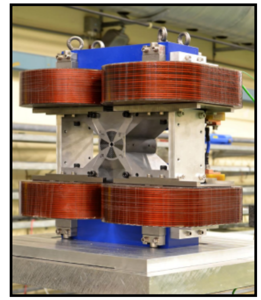
Multi-pass interferometer

Optical encoder

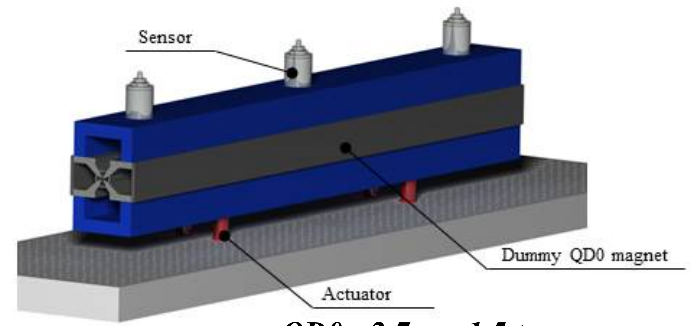
- *P. Novotny et al, "What is the best displacement transducer for a seismic sensor?", IEEE Inertial Sensors and Systems 2017, Hawaï, USA.*

From the Demonstration to a Large Scale Experiment



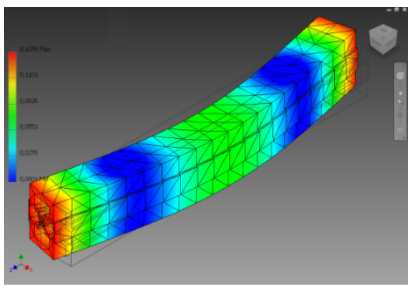


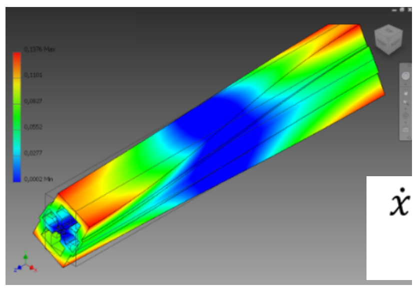
Slide of QD0

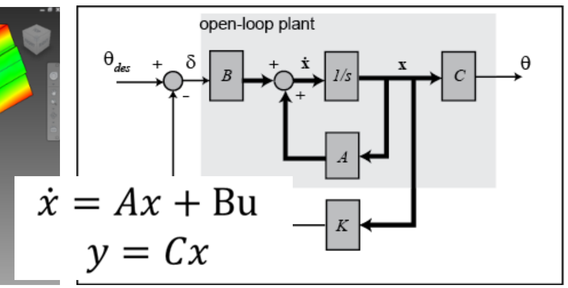


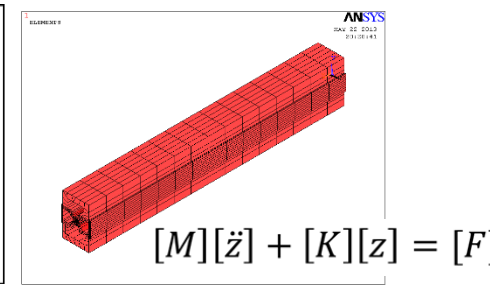
QD0 : 2,7m – 1,5 tons

- ***Simulation***









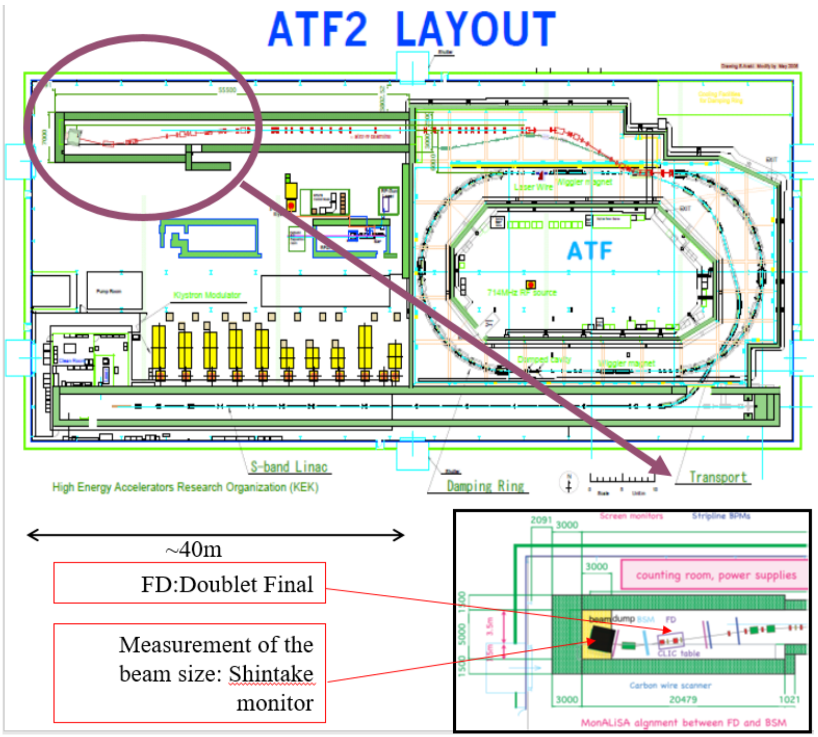
- FEM : Modal analysis using finite elements - Determination of the most significant modes (frequency response characteristics)
- Expression in the form of a state space model and study of the control strategy
- Integration in a control loop (using Simulink for example) with the full simulation (sensor, actuators, ADC, DAC, Data processing…. And seismic motion model and its coherence)
- Control in simulation (location and number of active feet, type of active feet, degrees of freedom, type of control (SISO, MIMO))

Simulation of active control with all the elements (electronics, mechanics, instrumentation, feedback, disturbances…) could be adapted to FCC

ATF2 : Opposite Vibration Control Approach with respect to CLIC

- *Optimization of the coherence*

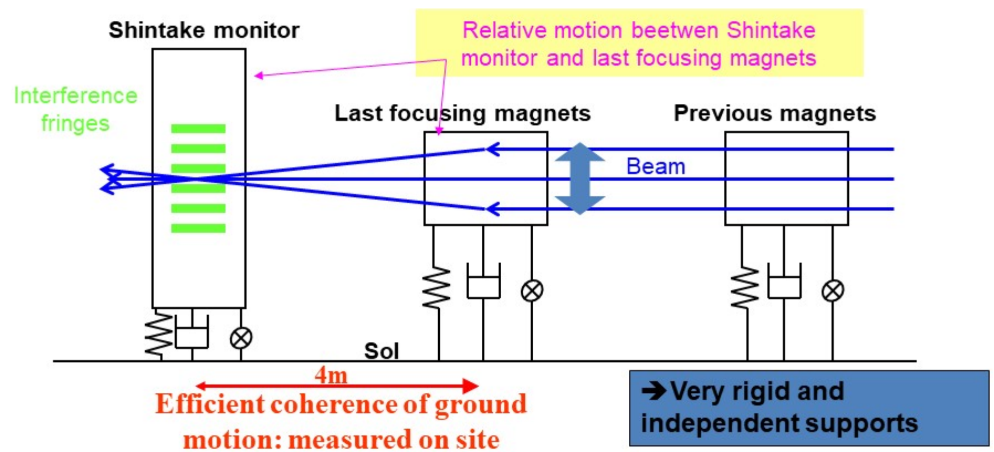
  ➢ ***ATF2 Objectives :*** *Steady and repetitive beam with a radius of 37 nm at the focus point.*

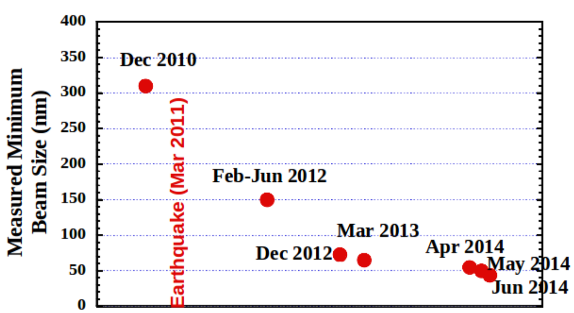


❑ It requires to have a relative motion between the Shintake Monitor and the final focus magnets: **10 nm above 0.1Hz** in the vertical direction

➢ Solution 1 : Active isolation of the elements (i.e. CLIC)

➢ **Solution 2 : optimization of the motion coherence between the elements**



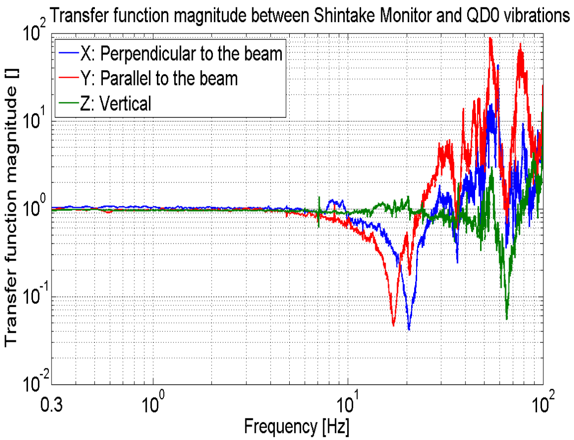


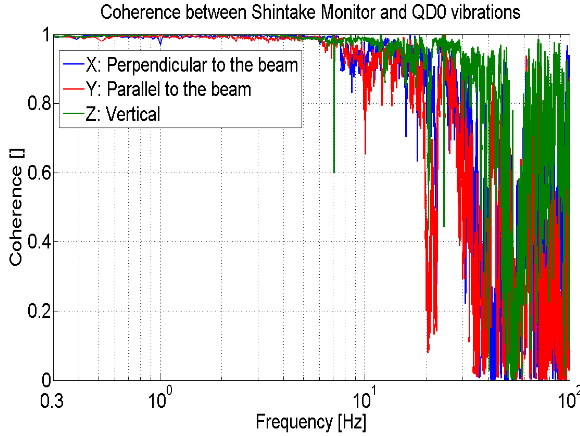
➢ Transfer function between ground and final focus and Shintake monitor has to be as close as possible to 1

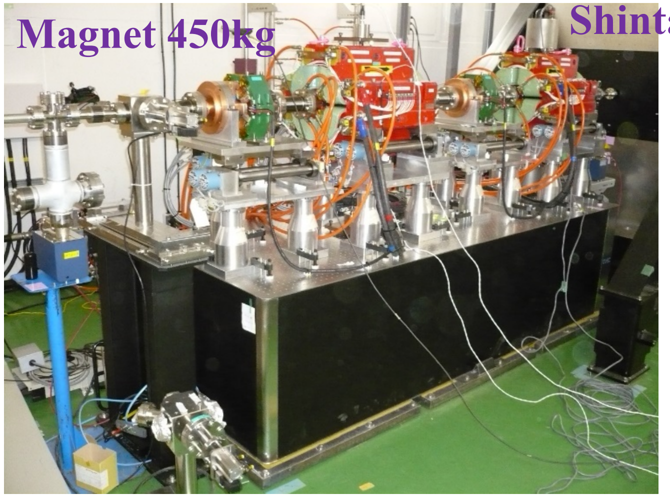
Demonstration of linear colliders - ILC

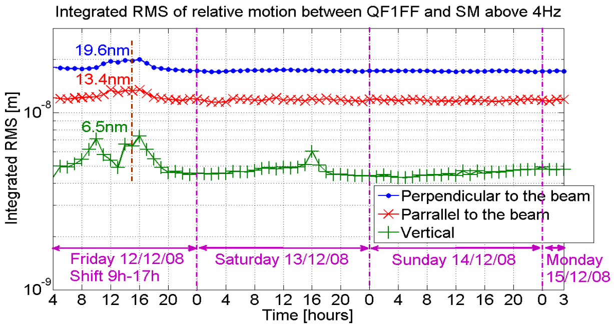
ATF2: Optimization of the Relative Motion

- ***Final setup of the final focus:***









- Very stiff in z direction (first eigenfrequency at 70Hz induced by the final doublet supports) - beeswax

- ***Relative motion between shintake monitor and final doublets of [4 – 6] nm RMS @ 0,1 Hz (vertical axis):***

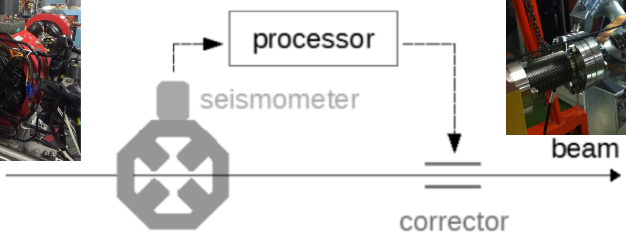
	Tolerance	Measurement [SM-QD0]	Measurement [SM-QF1]
Vertical	7 nm (for QD0) 20 nm (for QF1)	4.8 nm	6.3 nm
Perpendicular to the beam	~ 500 nm	30.7 nm	30.6 nm
Parallel to the beam	~ 10,000 nm	36.5 nm	27.1 nm

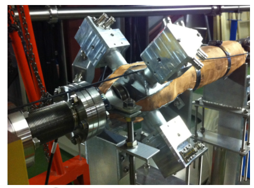
For FCC: strategy of control (CLIC vs ATF2)

ATF2: Feedforward Activities

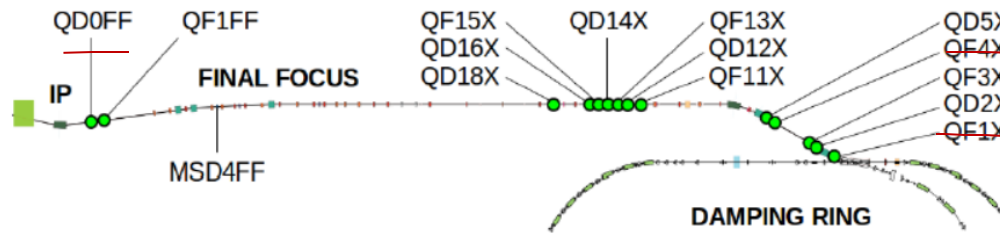
- History : satisfy vibratory specifications of final focus system (support, characterization, measurements….) and installation of vibration sensors along the accelerator
- In progress : development of group competences on beam control, collaboration on feedforward with CERN, Oxford and KEK

Feedforward setup



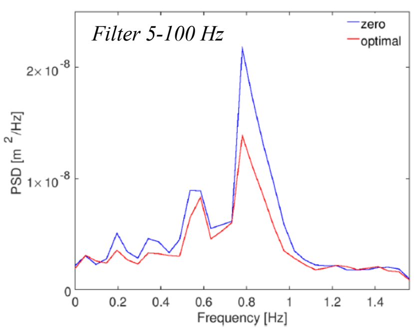


- Setup of the Feedforward -

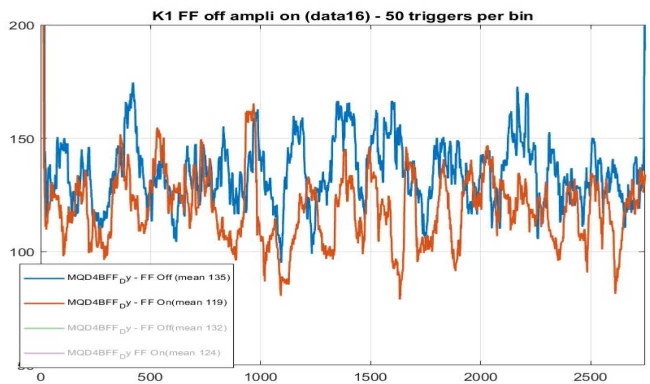


- Layout of the GM sensors along the collider-

Perturbations control in the extraction line



- The obtained experimental results with 1 geophone and 1 kicker -

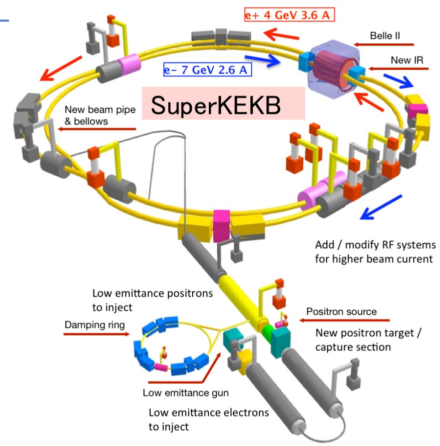


Comparison Feedforward ON / OFF

- ❑ *Jitter reduction around 10-20% due to very unstable run conditions and strong jitter at the injection of the extraction line*

D.R. Bett *et al*, « Compensation of orbit distortion due to quadrupole motion using feed-forward control at KEK ATF », NIM A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 895, 2018

SuperKEKB Project



- Collaboration with LAL and KEK groups
- Seismic sensor systems installed on both sides of BELLE II

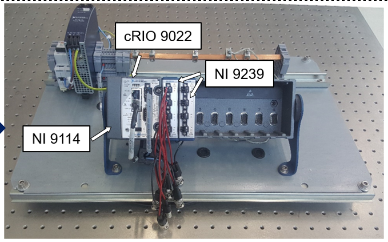
Setup

➢ ***Direct application from CLIC***

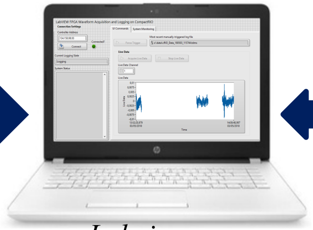
① *Seismic sensor Guralp 6T*

Protection box (chocs, lead, mu-metal)

Sensors power supply and signal conditioning



② *Real time measurement National Instrument setup*



Labview: Monitoring & logging

Remote acces

2 Targets :

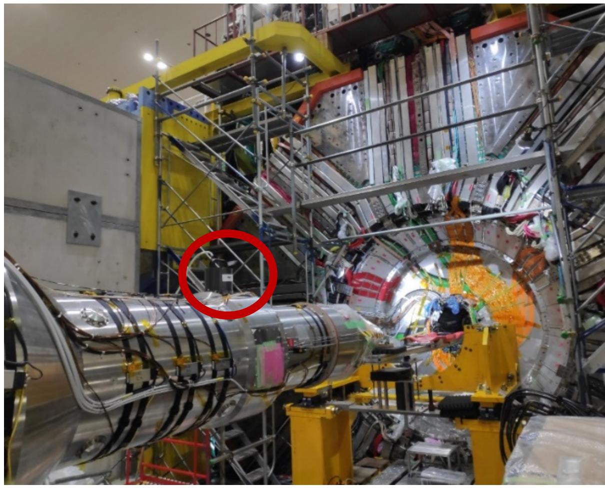
A- **Real-time vibration measurements (seismic motion and cultural noise) close to the detector in transversal directions**

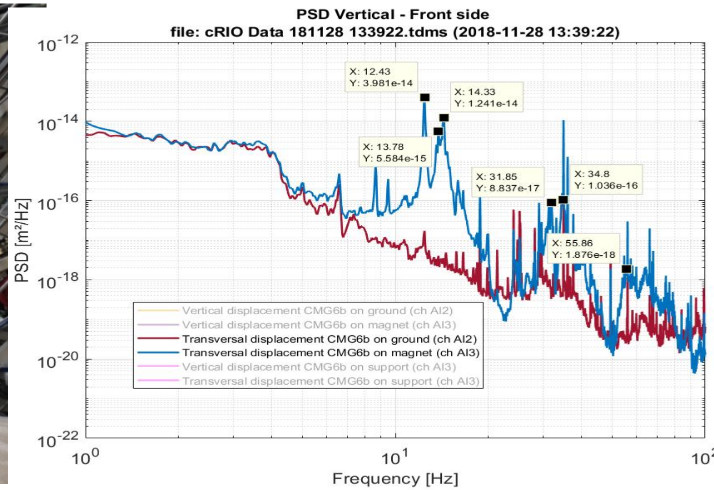
B- Study the correlation between measured luminosity and vibrations

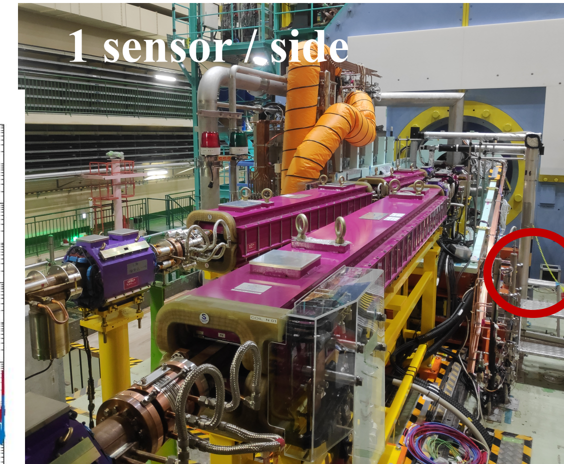
SuperKEKB: Experimental Activities on Site

- **Preliminary measurements June 2018**

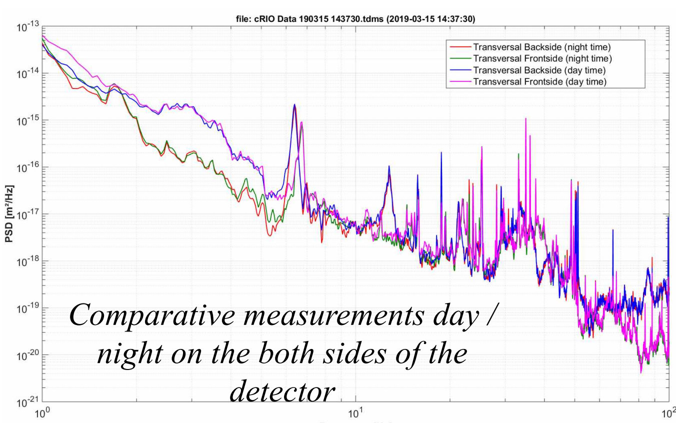
- Preliminary measurements of the cryostat dynamics-



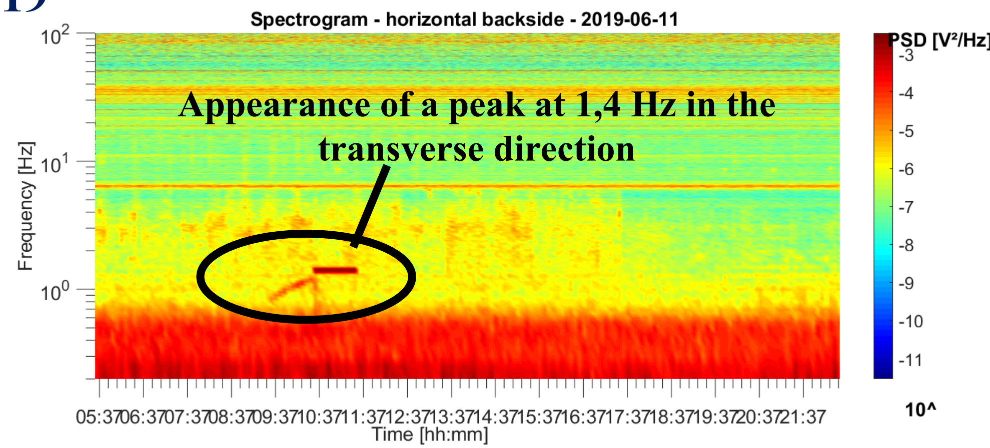




- **H24 monitoring operational since Feb19**



Comparative measurements day / night on the both sides of the detector



Continuous monitoring in time

<u>For FCC: strategy of SuperKEKB control (closer to ATF2) no active control + beam feedback</u>

FCC-ee: Machine Detector Interface (MDI)

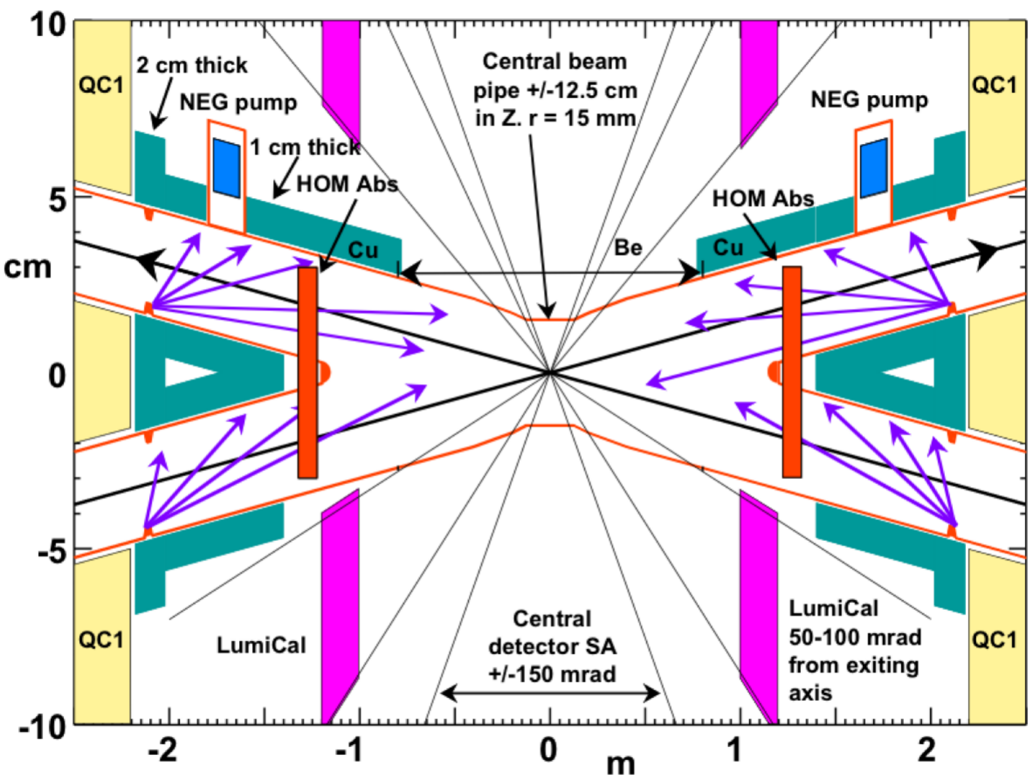
Collaboration: BINP, BNL, CERN, CNRS, EPFL, INFN, NBI, SLAC

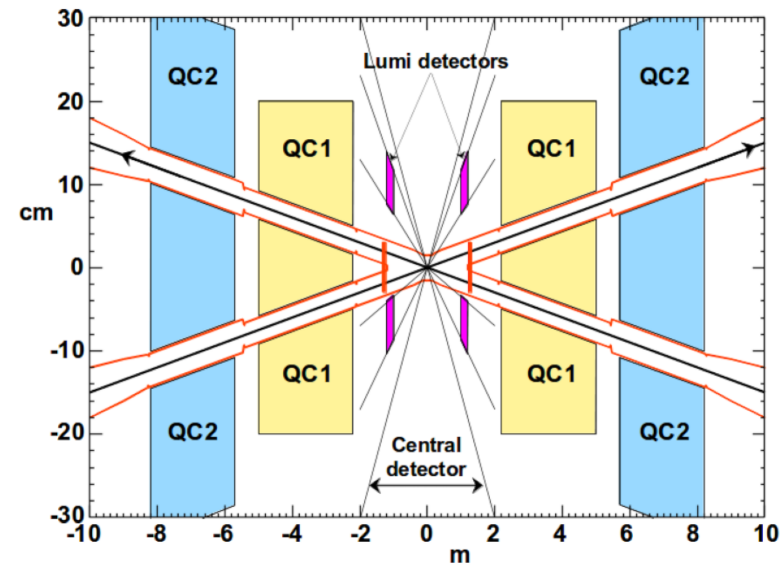
Main topics investigated by the MDI collaboration:

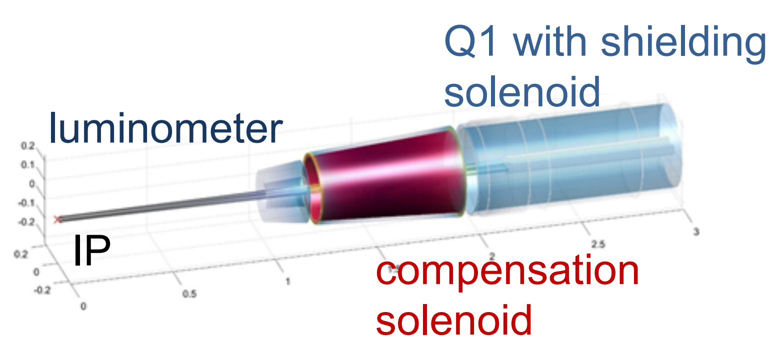
- Mechanical integration of the baseline design
- Mechanical stabilization and alignment
- Assembly concept: magnets, cryogenics, vacuum system, luminometer
- Heat load evaluation with HOM analysis in the MDI area
- Final Focus quadrupole design
- IR optics with 2 or 4 IPs
- IR layout
- SR in the MDI area: characterization, impact on detectors and mitigation
- Beam dynamics studies, including beam backgrounds
- Luminosity measurement

	superKEKB	FCC-ee	CLIC
Energy(GeV)	7 (e^-) | 4(e^+)	45.6,80,120,175	190,750,1500
σx(IP) (µm)	11 | 10	6.4,13,13,36	149,60,40 nm
σy(IP) (nm)	56 | 48	28,41,36,66	2.9,1.5,1
Cantilever	yes	yes	yes-> No

FCC-ee: MDI Design Status





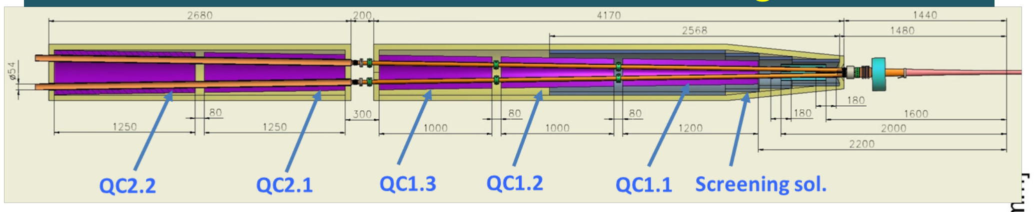


3D sketch of key IR systems over first 3 m from IP

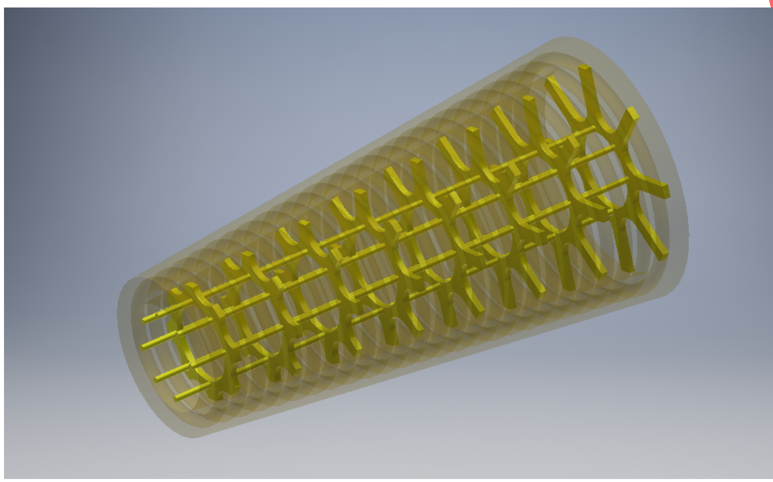
MDI collaboration

Status of mechanical design

advanced SC final-focus magnets

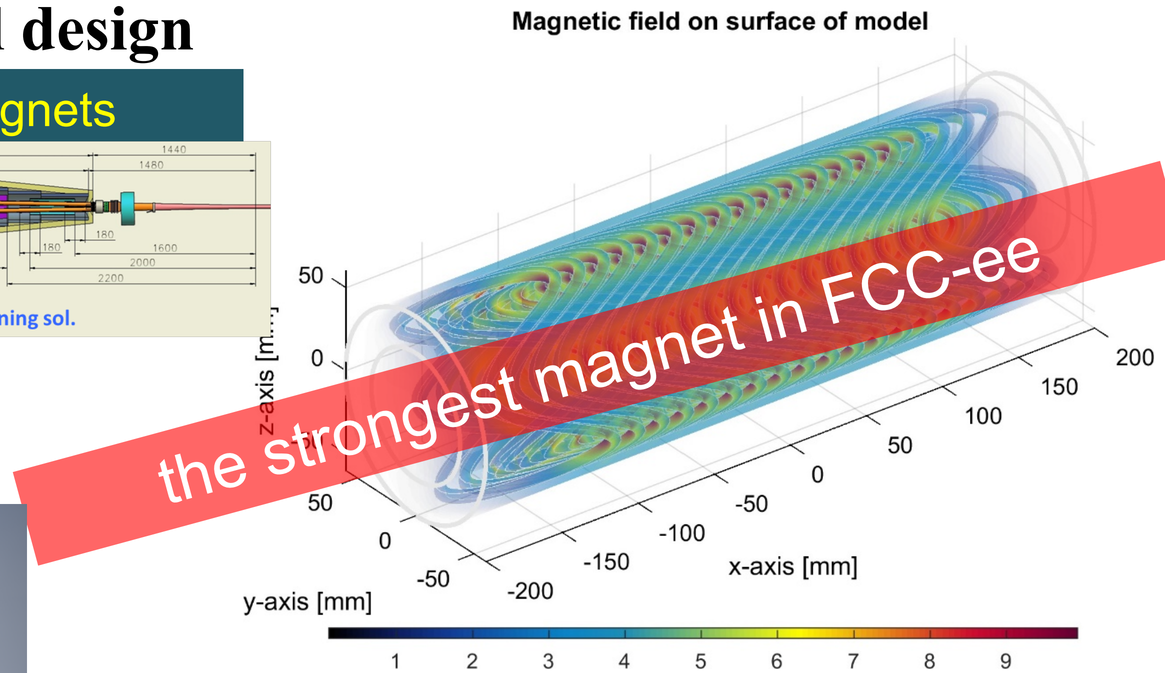


First design of quadrupoles supports inside the cryostat

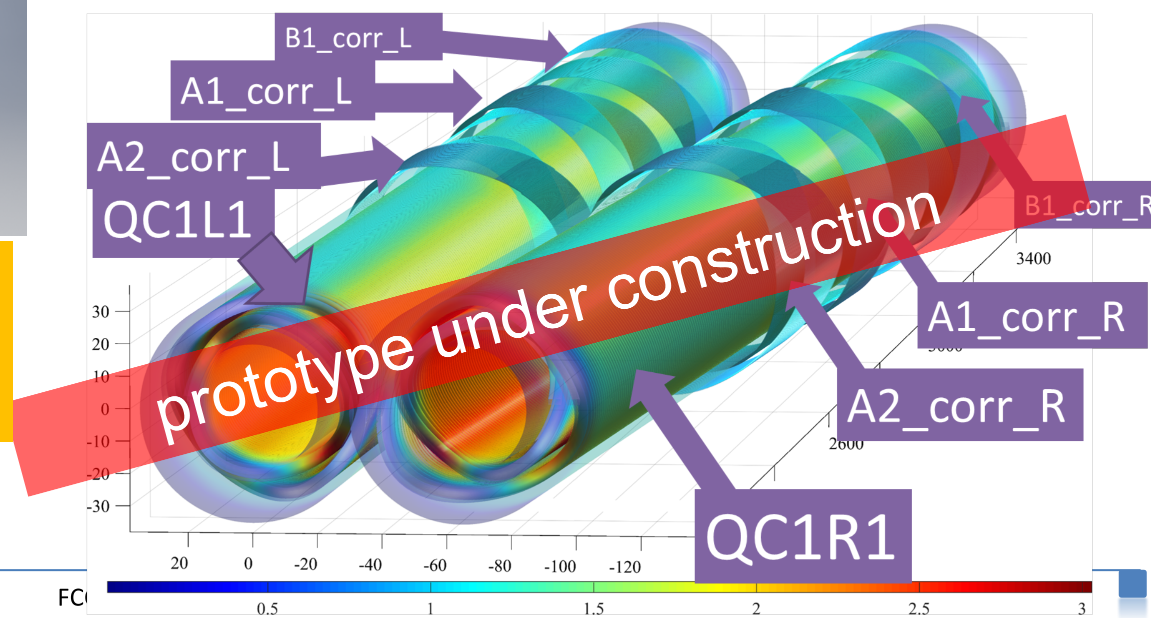


The idea is to use a stiff skeleton which will replace the very heavy cryostat.
All load bearing capability will rely on this skeleton

M. Koratzinos



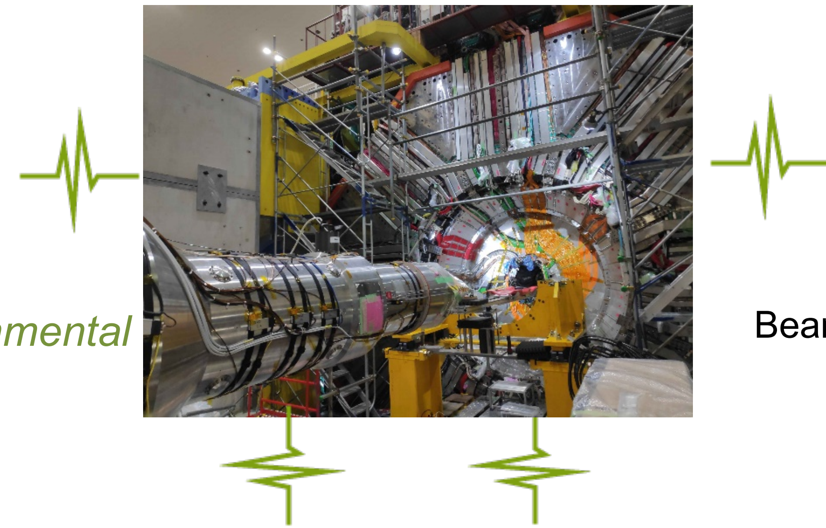
final quadrupole pair near IP

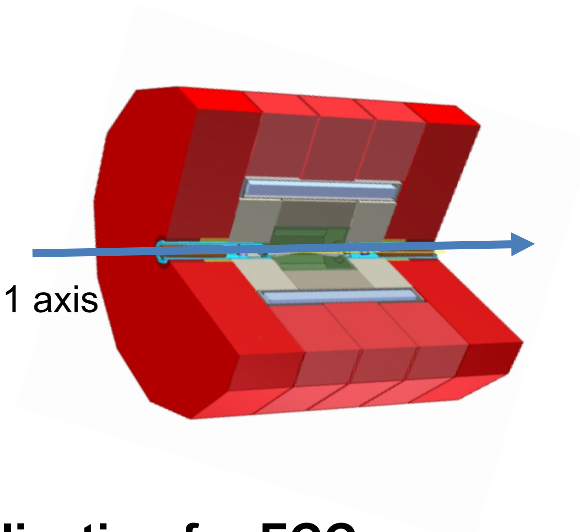


Vibrations impact on FCC-ee performance

Example of system in cantilever mode (superKEKB)

Seismic and environmental perturbations





Main steps towards the study of vibrations and stabilisation for FCC-ee

- Define the **vibration specifications** of beams at the interaction points: optics simulations.
- Dynamics studies of mechanical elements: magnets, supports, cryostat, …
- **Stabilisation strategies**: active and/or passive control, IP feedback with frequency range of interest, development of needed controls.
- Full simulations taking into account vibration sources, stabilisation strategies, dynamic modelling and beam controls to check if specifications are respected.
- Iterate the previous points following the evolution of the layout (2 vs 4 IPs) and MDI design.
- R&D on vibration sensors, actuators and associated technologies (if needed).
- Experimental tests on the **SuperKEKB** project and other interesting experiments.
- Prototyping of key components.

Conclusions and future plans

- *Further developments of LAPP sensor (Comparison of different technologies for the embedded sensitive part, radiations…)*
- Continue monitoring of vibrations of superKEKB with correlation studies of luminosity and get more involved on beam dynamics and control (IP feedbacks)
- Optics study -> Specifications… -> mitigation strategy (concrete, mechanics, control, instrumentation…)
- Continue collaboration on mechanical design of final focus system

Thank you for your attention!