FCC Week 2023
Indico: https://indico.cern.ch/event/1202105/
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Laboratoire d'Annecy de Physique des Particules

Towards mechanics and optics evaluation of the vibrations effects for the FCC-ee MDI

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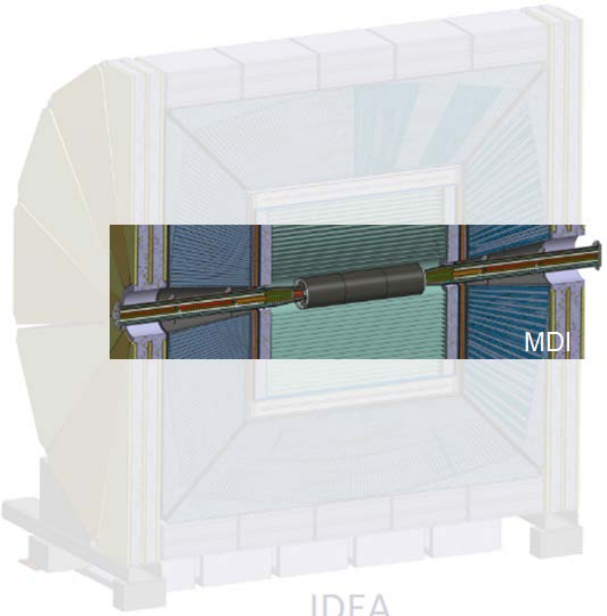
FUTURE CIRCULAR COLLIDER

Presentation overview

- ❖ Context
- ❖ Optical studies
- ❖ Mechanical studies
- ❖ Complementary studies
- ❖ Summary



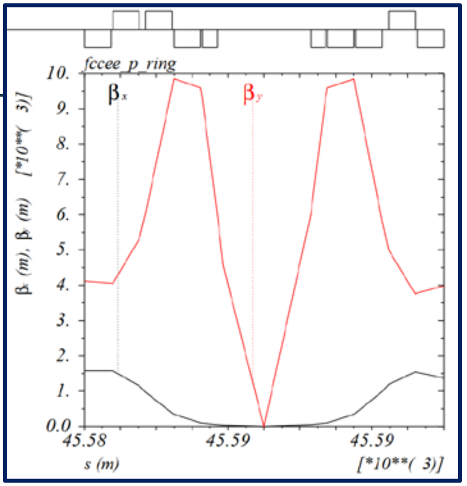
Strategic location of LAPP
(CERN – LAPP : 50 kms)

- **Task 4 "alignment tolerances & vibration control" (CERN, LAPP, INFN & Oxford) with 2 sub-tasks:**
  - ❑ **Vibrations study and its associated control strategy**
  - ❑ **Beam optics simulations of vibrations, and impact on beam emittance/luminosity**

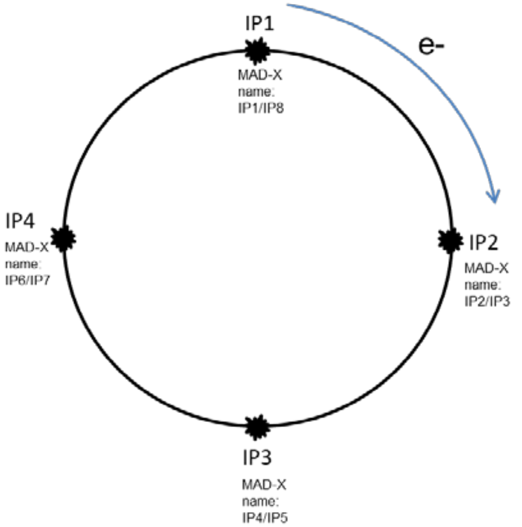
Laboratoire d'**A**nnecy de **P**hysique des **P**articules

Vibrations (& misalignment) are a strategic issue of MDI

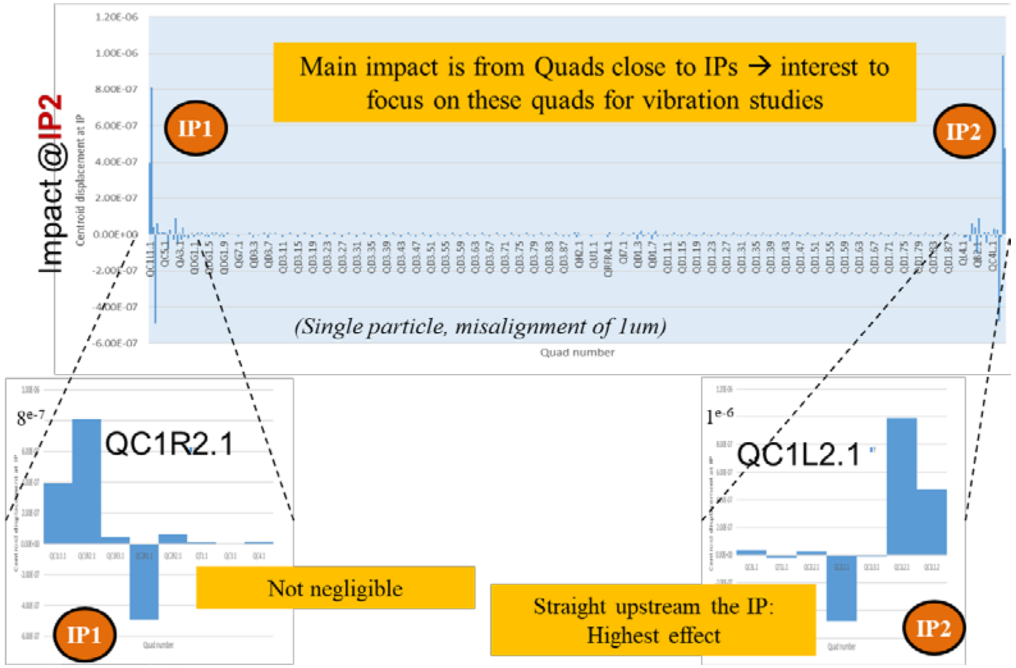
- **Study parameters:**
  - All quadrupoles individually misaligned by 1 µm in the vertical plane
  - Twiss parameters evaluation thanks to MAD-X
  - Observable: y offset at IPs



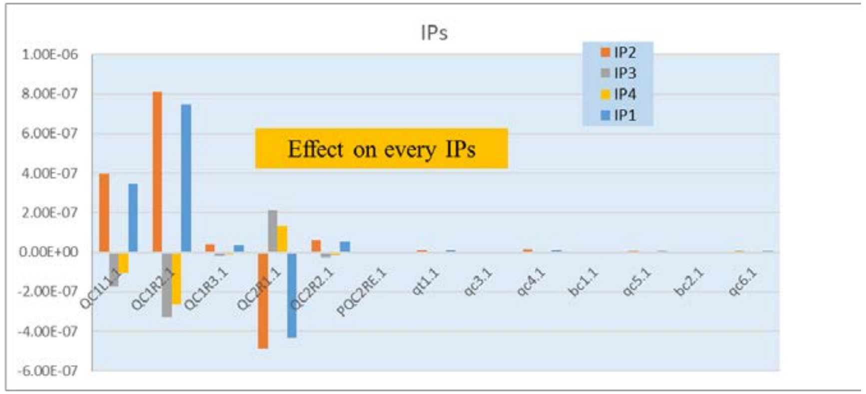
Beta function at IP



At IP2:



At the other IPs:

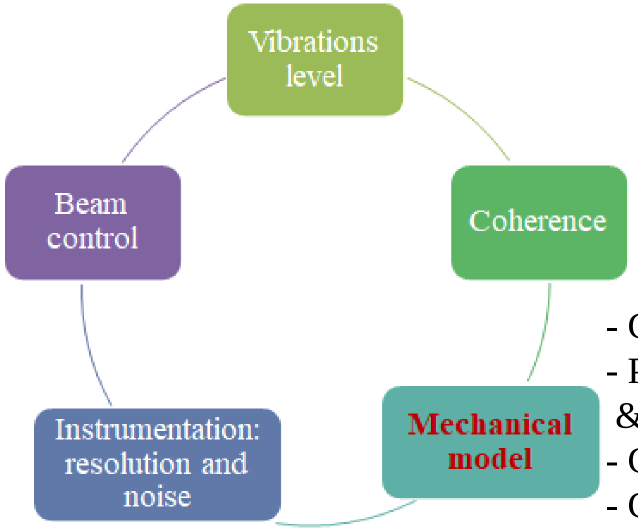


- The largest vertical offset at IP2 and next IPs comes from the vertical misalignment of the FFS quadrupoles

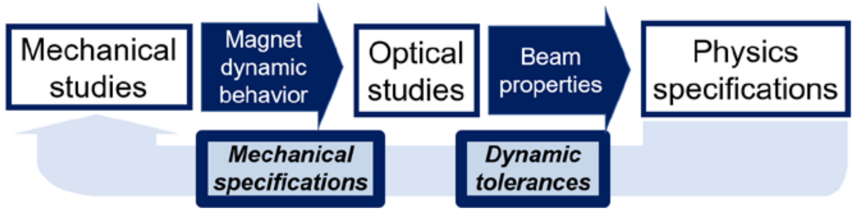
  ➡ For the next studies, focus on these 10 quadrupoles placed around the IP

Goal : set tolerances to the magnet dynamic behaviour

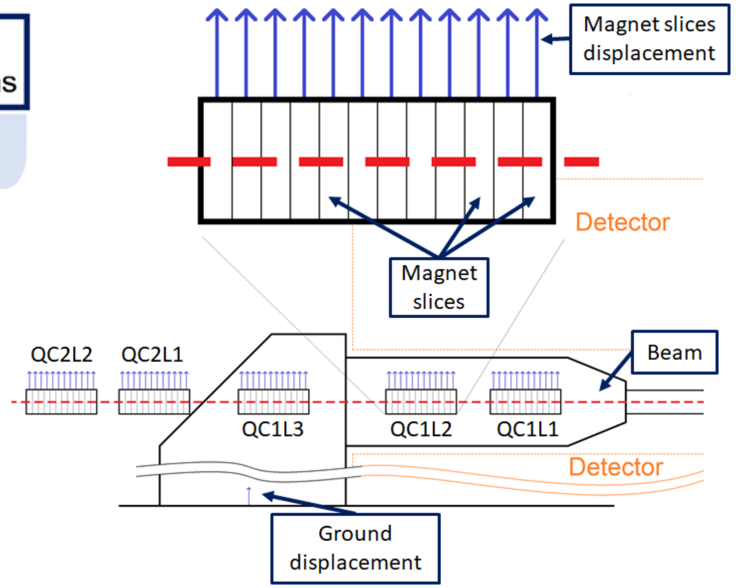
- **A global approach:**



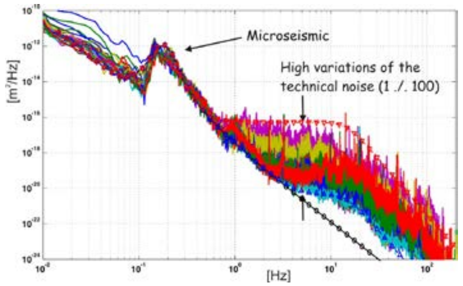
- Concrete
- Positioning system & alignment
- Girder
- Cryostat support
- Coupling Cryostat - magnet
- Magnet



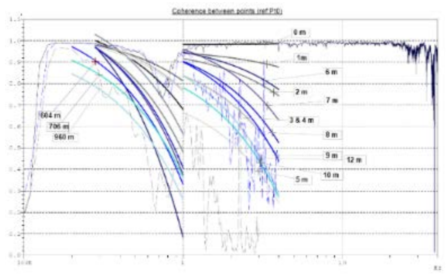
Step 1 : coupling of the mechanical and the optics studies



- **The MDI assembling transfer functions have to be integrated in the whole simulation (finite elements modelling)**
- **An optics simulation is needed to validate the MDI assembling (Track particles under MAD-X)**



PSD displacement of various sites

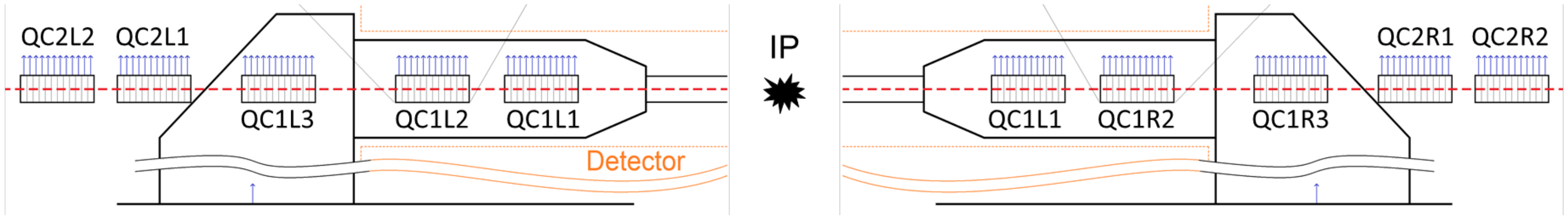


Coherence measurements at LHC

➢ Complementary study to the current ones (T. Charles, K. Oide et al)

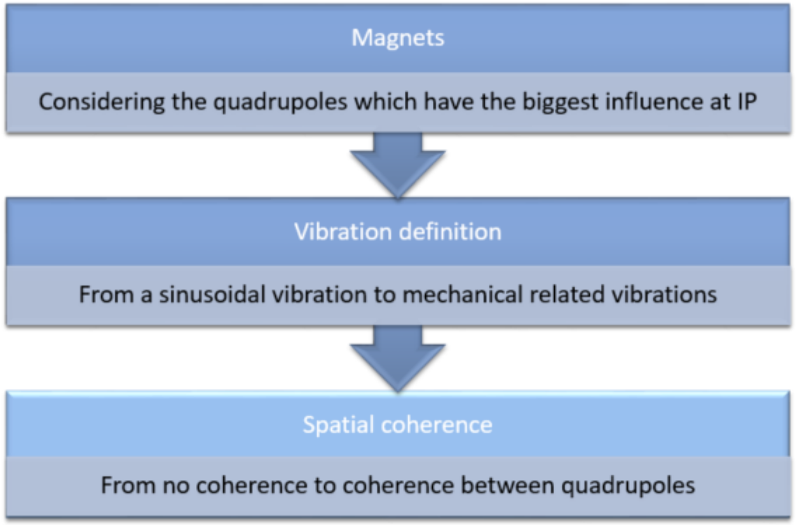
Optics : beam tracking studies

- **Methodology:**
  - *consideration of one-block quadrupoles (no slicing yet)*



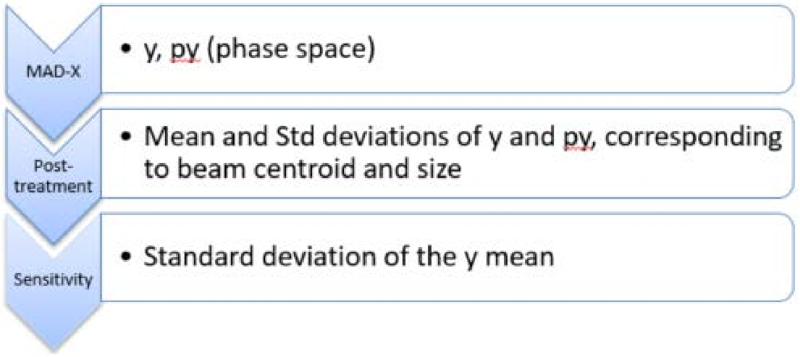
- *Tools:*
  - ❑ V22.2 layout used:~91 km long
  - ❑ Z lattice considered, as smallest beam spot sizes at IP
  - ❑ Optics simulation with MAD-X:
    Dynamical study -> Tracking module used, number of accelerator turn dependent
  - ❑ **No optics correction** considered, to highlight vibrations impact on beam characteristics

- *Setup:*



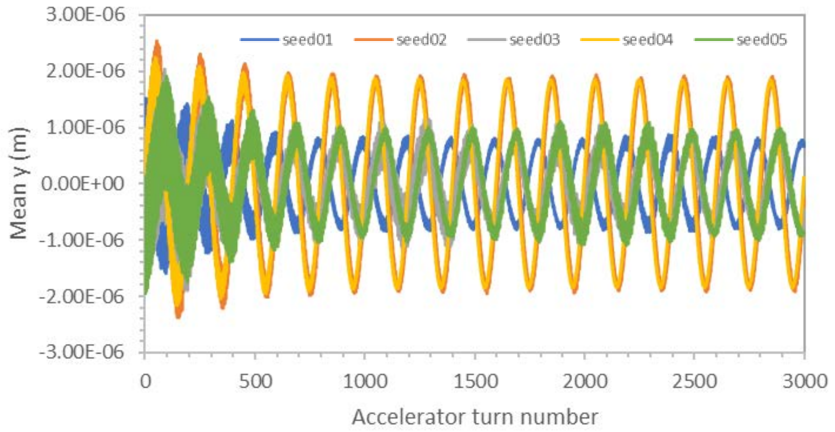
- **40 FFS quadrupoles** considered
  → 5 per IP side, with 4 IPs
- Based on the previous study evaluating the impact of individually misaligned quadrupoles
- After studying a static case, vibrations are defined by a **sine** wave function.
- 15 Hz Frequency chosen to correspond to the **first mode frequency** of the **SuperKEKB** cryostat
- **Correlation** between magnetic elements and/or girders along the ring

- *Observables:*



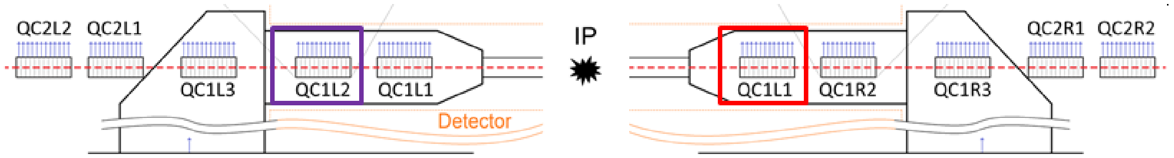
Optics : beam tracking studies – preliminary results

- **First studies:**
  - Bunch of 200 electrons, gaussian beam
  - Tracking study over 3000 turns (⇔ 1s beam time)
  - Sinusoidal vibration of all FFS quadrupoles at 15 Hz with 1 μm of amplitude
  - Random phase advance between all quadrupoles, fixed at the first turn -> simulation of 5 seeds to efficiently compare results

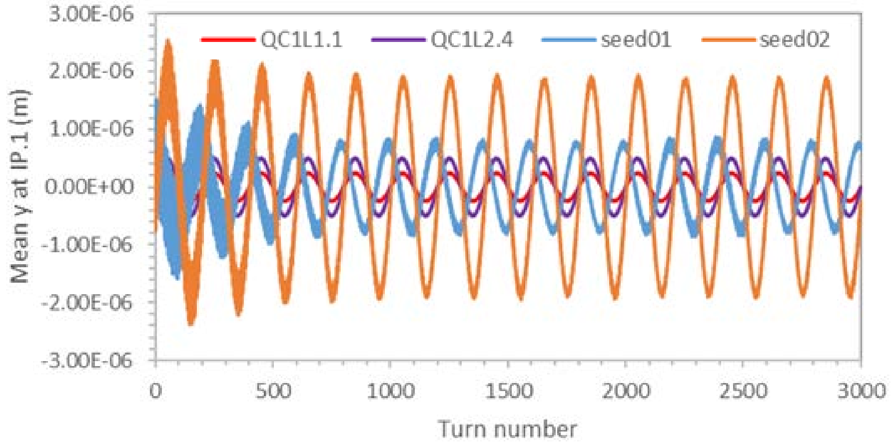


- **Observations:**
  - 15 Hz pattern noticed in each seed
  - Amplitude of y mean and phasing between the seeds very different

➢ Question: what are the contributions of each FFS quadrupole?



- Comparison of the obtained results with individual vibrations of the quadrupoles which have the largest impact at IPs:
  - In this case, QC1L1.1 or QC1L2.4, placed around IP.1/8, exited with a sine at 15Hz and a amplitude of 1 μm



- **First conclusions:**
  - Each FFS quadrupole vibration will give its own contribution to the mean vertical offset at the IP.
  - Need to focus the studies on the impact of individually vibrating quadrupoles

Optics : beam tracking studies - conclusions and perspectives

- **Conclusions for optics part:**
  - Impact of time-dependent vertical vibrations applied in the Final Focusing System (FFS) on beam phase space
    - Cumulative perturbation of FFS quadrupoles located along time
    - Tracking studies gradually complexified
    - Use of the MUST computing facility (IN2P3/USMB) to deal with all simulations scenarios

  - This study will require dedicated investigation to provide more realistic results and is a long term work.

  At a longer term:

  - Define vibrations relative to mechanics design
  - Add local and global corrections

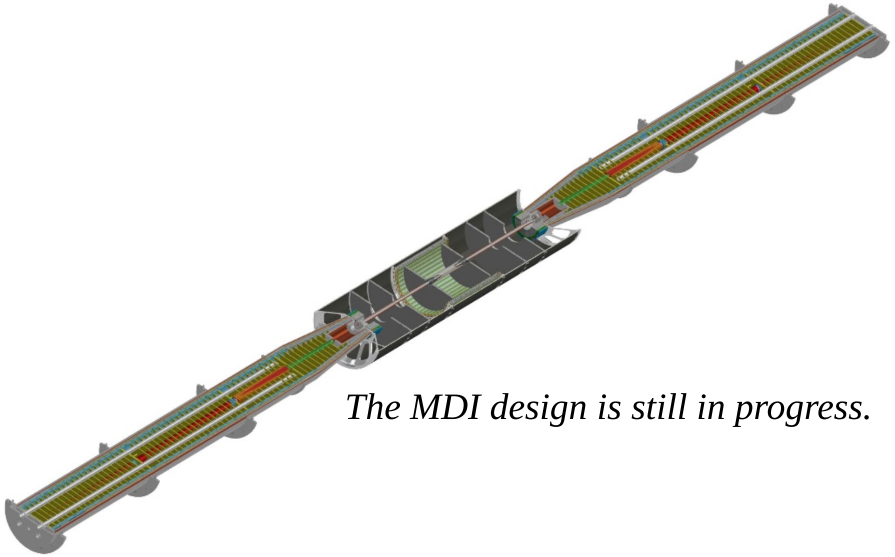
For more details, E. Montbarbon's presentation: *https://indico.cern.ch/event/1064327/timetable/*

- **Situation:**

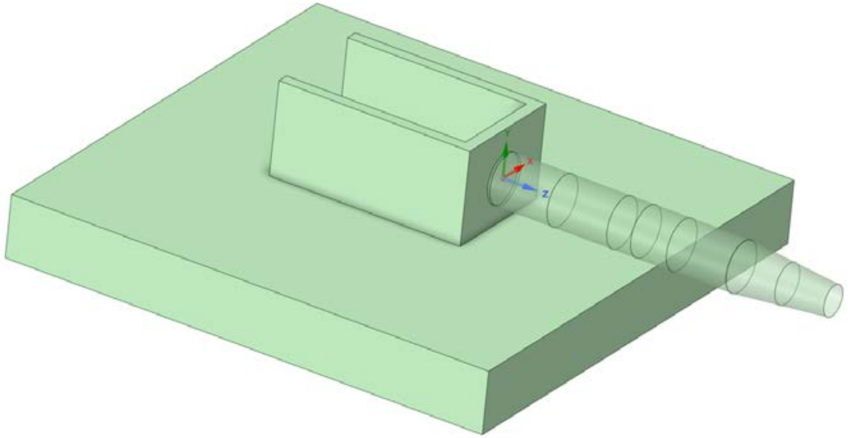
  This study is integrated into a more global study:

  - Effect of plane ground waves (coherent static misalignment) on the closed orbit of FCC-ee, to evaluate global coherence (slide 11):
    - No cumulative perturbation
    - Vertical misalignments allocated to all quadrupoles along the ring

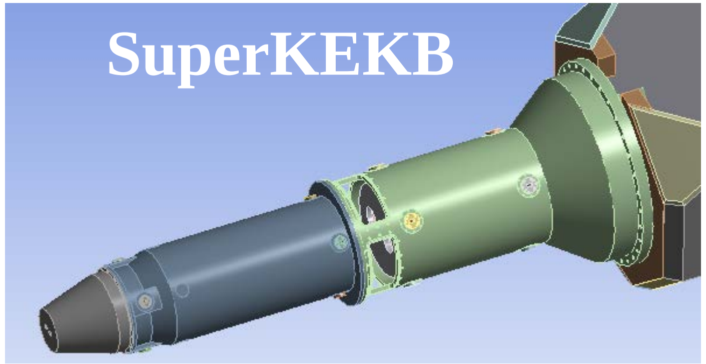
Mechanics : current situation and assumptions

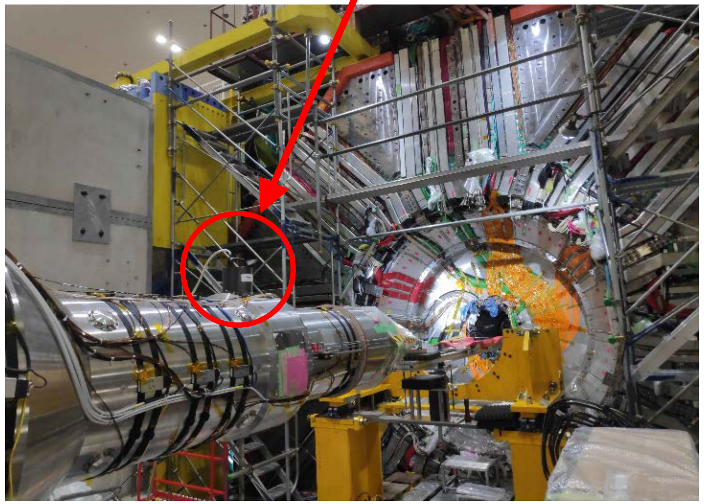


The MDI design is still in progress.



Development of the process using a simplified 3D model





sensor

Similarities:

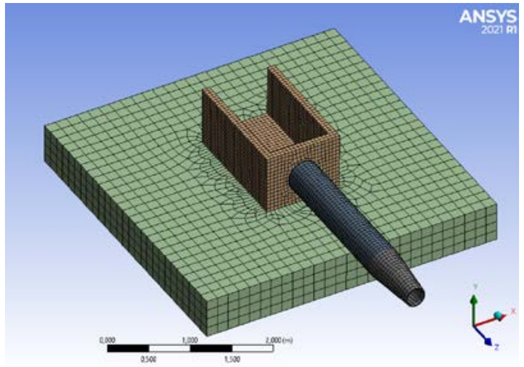
Similar beams, cryostats in cantilever…

Difference:

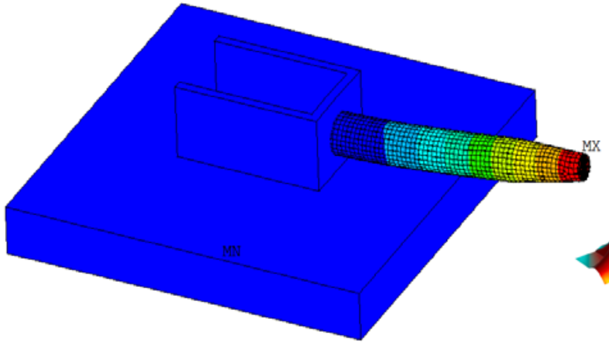
The HER and LER final focus magnets are not symmetrical inside the cryostat

Mechanics : methodology of the dynamic behavior evaluation

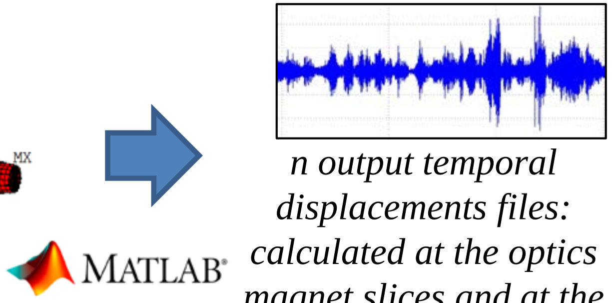
- **Development of a methodology on a simple geometry inspired by a known case: SuperKEKB**



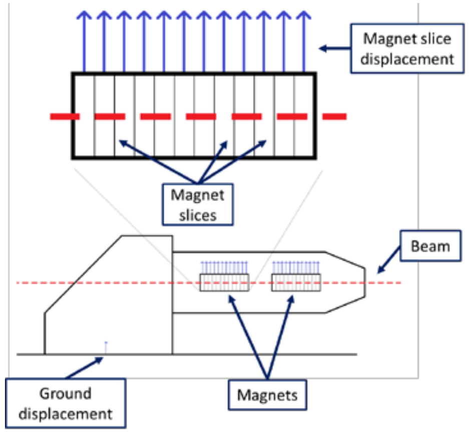
Finite elements model under ANSYS of a simple structure



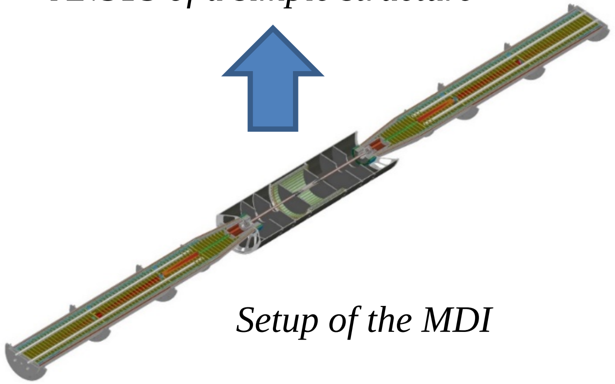
Modal analysis and state-space matrices calculation



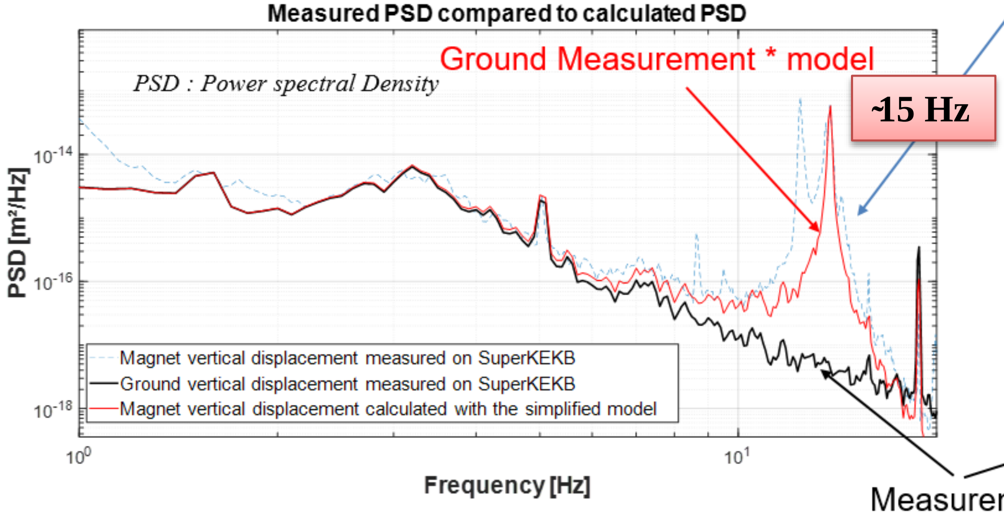
n output temporal displacements files: calculated at the optics magnet slices and at the MADs sample time

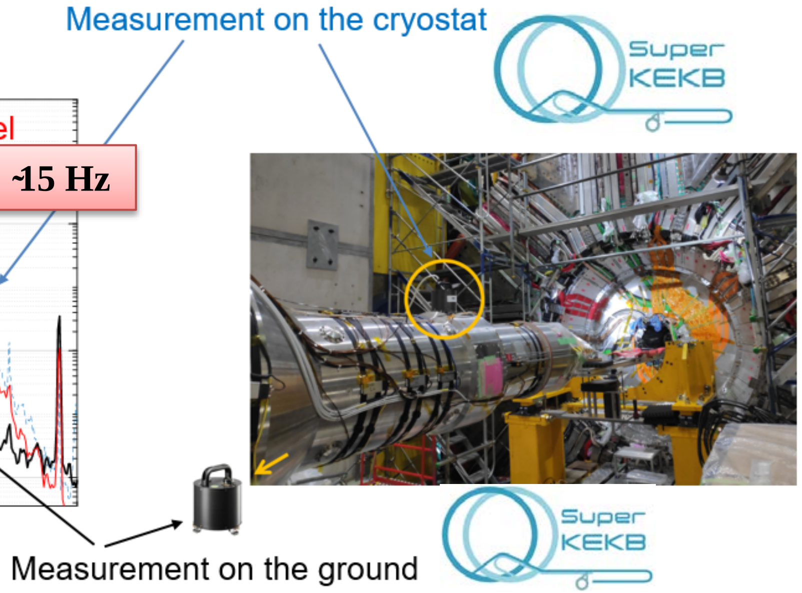


Exploitation of the state system under Matlab



Setup of the MDI



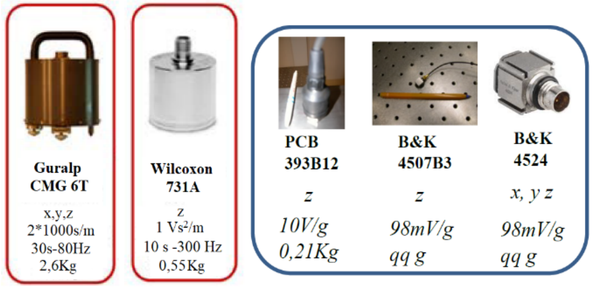


For more details, S. Grabon's presentation:
https://indico.cern.ch/event/1064327/timetable/

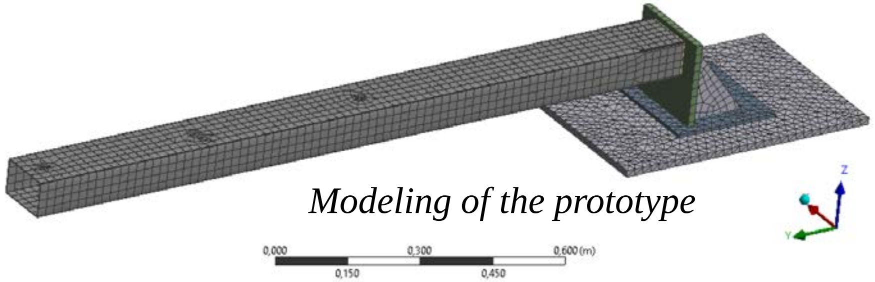
Mechanics : validation of the method on a cantilever beam prototype

Possibility to add masses

Cantilever beam prototype



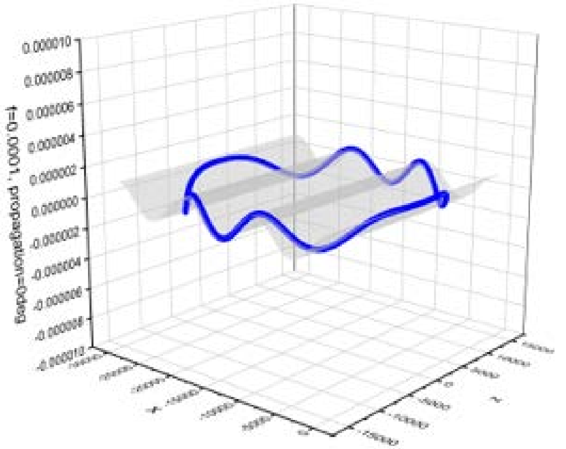
Instrumentation



Modeling of the prototype

- **Conclusion of the mechanics aspects**
  - The method to study the dynamic behavior of the mechanical assembly and its coupling with the optics to evaluate the effects is developed and will allow to define and to verify the tolerances
  - More structure details are waited to be studied and integrated
  - Validation of the method on a elementary prototype which could be adapted with various operation configurations has been processed

Complementary studies : uniform waves



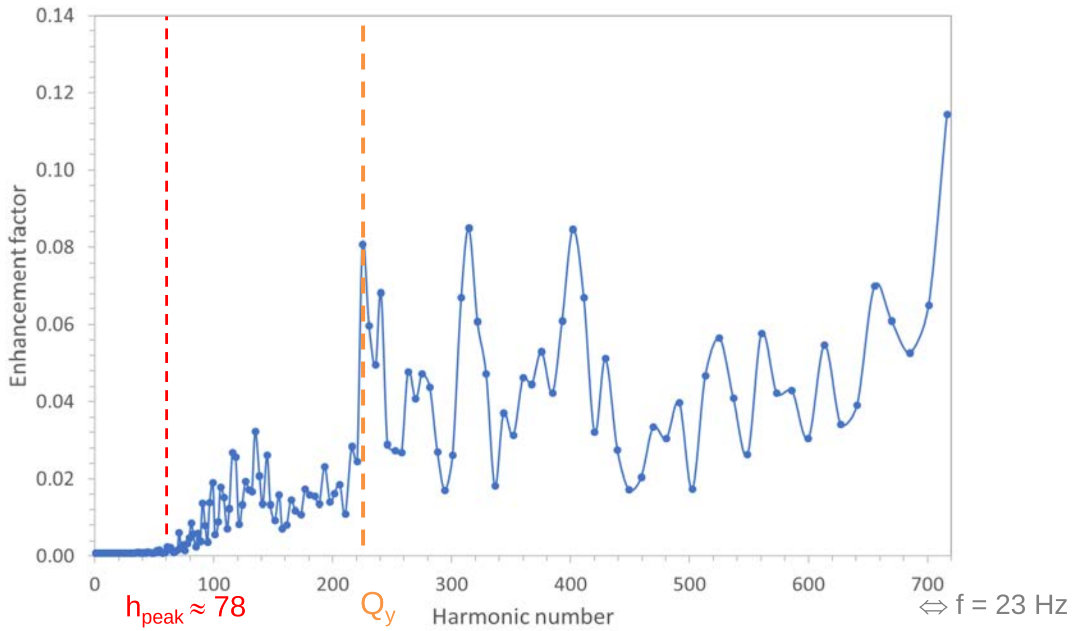
Vertical displacement along the collider (frequency at 1Hz)

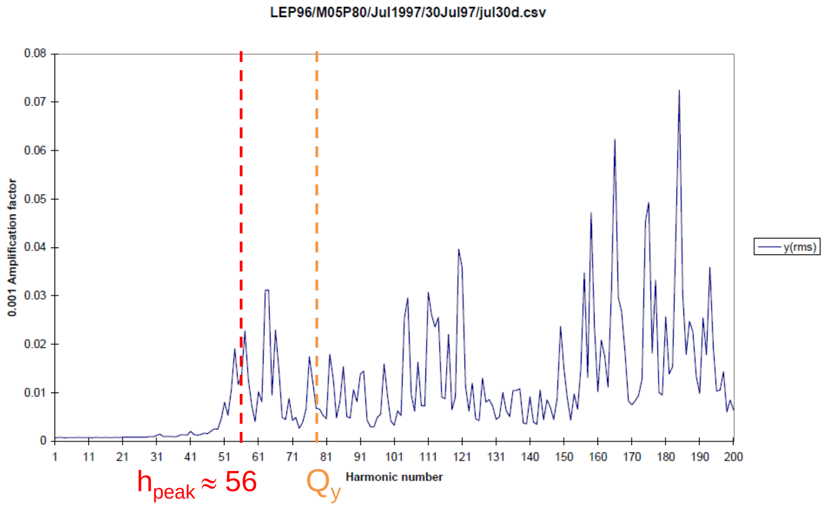
Effect of plane ground waves on the closed orbit of FCC-ee:

Definitions for the corrugated model:

- Study performed with MAD-X, with the TWISS module, which is asked to evaluate the vertical closed orbit offsets at IPs *(y or yco)* and the RMS vertical offset *ycorms*
- Vertical misalignment attributed to each quadrupole j along the accelerator ring, regarding the corrugated model:
- $y(j) = A * \sin\left(\frac{2\pi f}{v_{wave}}\left(X(j) * \cos(\alpha) - Z(j) * \sin(\alpha)\right) + \varphi\right)$

f : frequency of the plane ground wave
C: circumference of the ring = 91,18 km
v_{wave}: velocity of S-waves = 3000 m.s^{-1}
A : amplitude of oscillation = 5.10^{-7} m



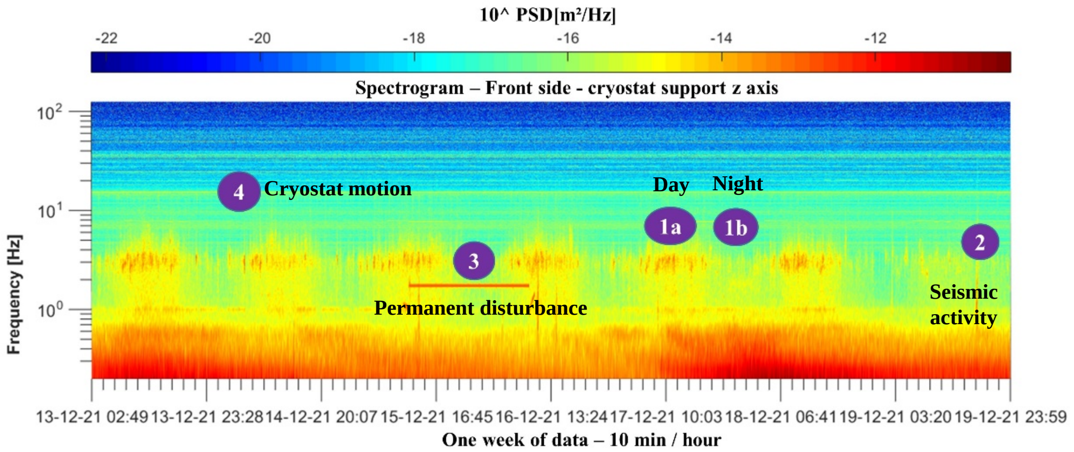


E. Keil, Effect of Plane Ground Waves on the Closed Orbit in Circular Colliders, CERN SL/97-61 (AP), 1997

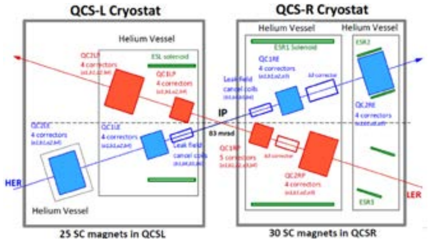
Complementary studies : SuperKEKB MDI

- **Usefull demonstrator at SuperKEKB:**

4 vibrations measurements H24 at both sides of BELLE II

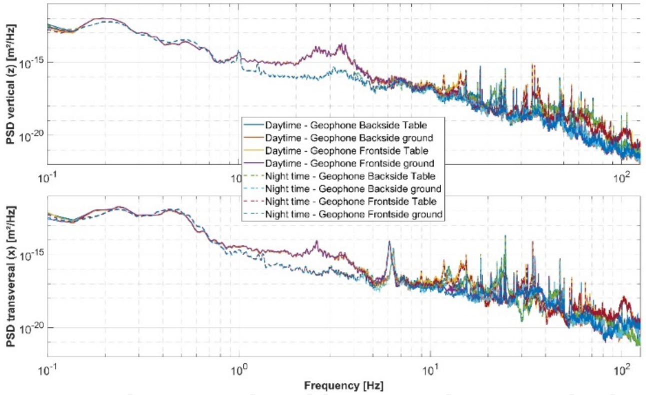


Spectrogram of one week data from a sensor placed at one side of the Belle-II detector

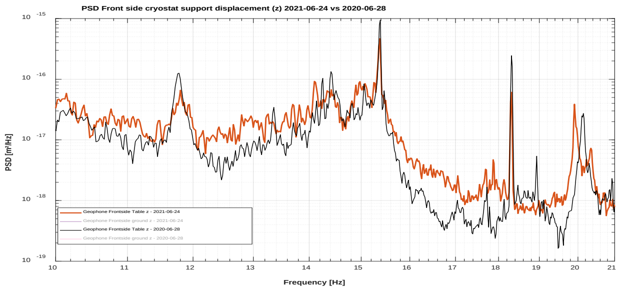


- ❑ Comparison day – night
- ❑ Seismic events
- ❑ External disturbances
- ❑ Drift in time
- ❑ Coherence…

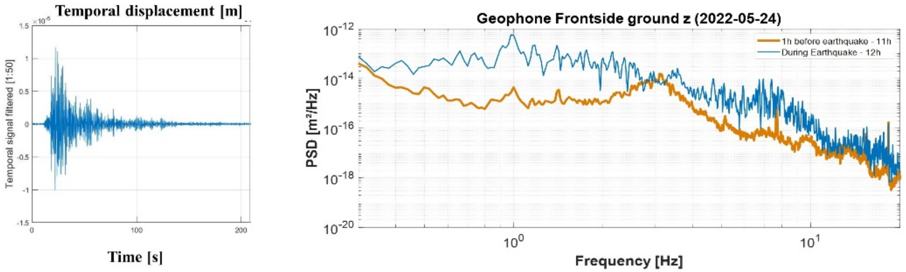
- **Some examples of vibratory analysis at the MDI:**



Day-night vertical and horizontal PSD on both sides of Belle II detector



Drift of the mechanical assemblies behavior in time

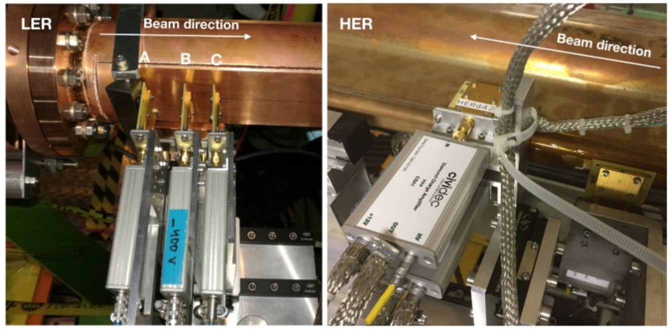


Detection of the earthquakes

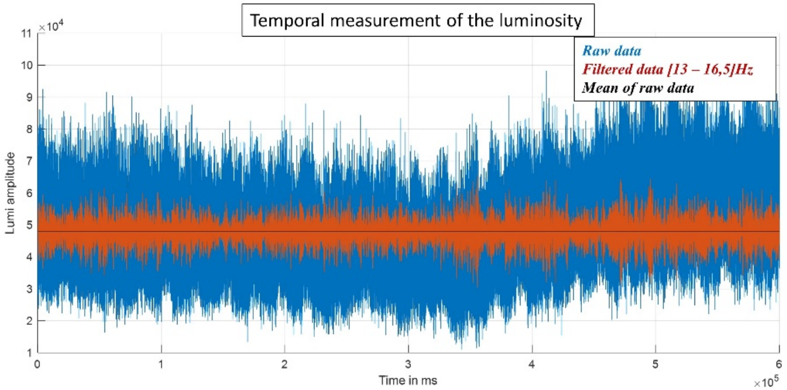
- *SuperKEKB vibration weekly reports: https://lappweb.in2p3.fr/SuperKEKB/*
- *M. Serluca et al, « Vibration and luminosity frequency analysis of the SuperKEKB collider », NIMA (2021).*
- *L. Brunetti et al, "Influence of vibratory effects on the beam parameters of SuperKEKB, IPAC23*

Complementary studies : SuperKEKB MDI

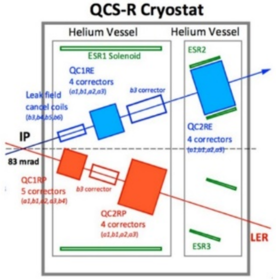
- **Coupled analysis with luminosity measurements:**
  - Influence of the mechanics

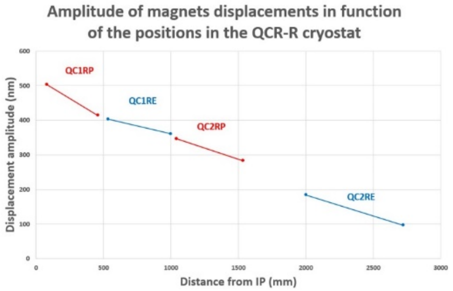


Experimental layout in both ring (left: LER, right: HER) of the luminosity measurements



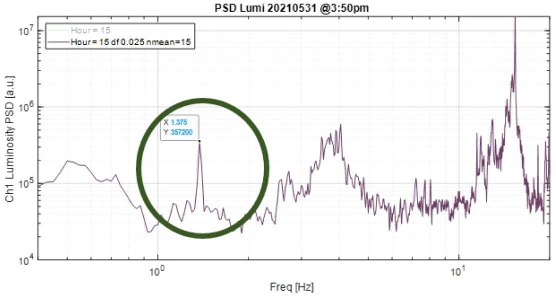
Example of time measurement of a luminometer



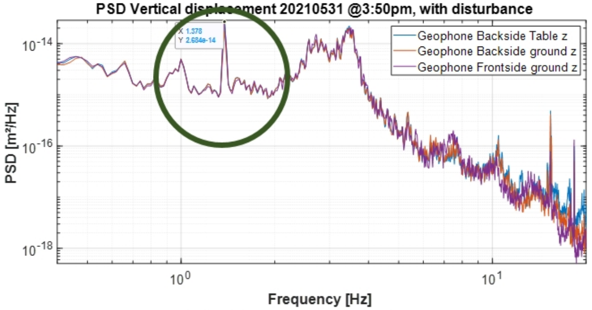


Positions of focusing magnets in the QCR-R cryostat (left) - Maximum amplitudes of the deformation (right)

  - Influence of coherent vibrations

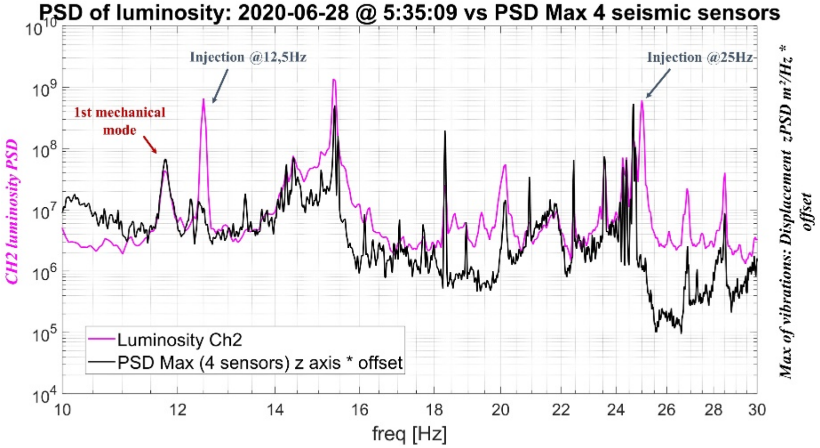


PSD of the luminosity measurement (CH1)



PSD of the vertical displacement

PSD of the luminosity (left) and vibrations (right) with a peak at the same frequency due to the external disturbance



Comparison between the PSD of luminosity and the PSD max (z-axis) of the four sensors located around the BELLE II detector in [10-30] Hz bandwidth.

➢ Study in progress: to do the correlation between real measurements and the optics simulation (M2 internship)

  - Influence of the BELLE II detector motion…

Summary and Outlook

- Complex interplay between mechanical and beam optics studies:
  - Need to run both studies in parallel
  - The output of one study will provide the input parameters of the other one, and vice-versa.
  - Mechanical modelling method is operative to implement new MDI elements
  - Vibrations optics simulations under MAD-X are in progress
  - Possibility to test in the future on a collaborative prototype

- Benefit from the experience of SuperKEKB:
  - Great opportunity to evaluate the effects on a MDI setup and to compare optics simulations and real measurements
  - Demonstrated interest in achieving measurements of global coherence at SuperKEKB and to compare the data to the IP BPM measurements

- *E. Montbarbon, "First studies of final focus quadrupoles vibrations of the Z lattice of FCC-ee", IPAC23*

- *Particular thanks to: M. Boscolo, T. Charles, F. Fransesini, M. Hofer, K. Oide, G. Roy, L. Van Riesen-Haupt, P. Raimondi, T. Raubenheimer, F. Zimmermann and the whole FCC-ee collaboration team*

Annexes