FCCIS workshop, Roma, Nov 13-15, 2023
https://indico.cern.ch/event/1326738/timetable/

Laboratoire d'Annecy de Physique des Particules

LAPP activities: ground motion, vibration models, simulations, SuperKEKB

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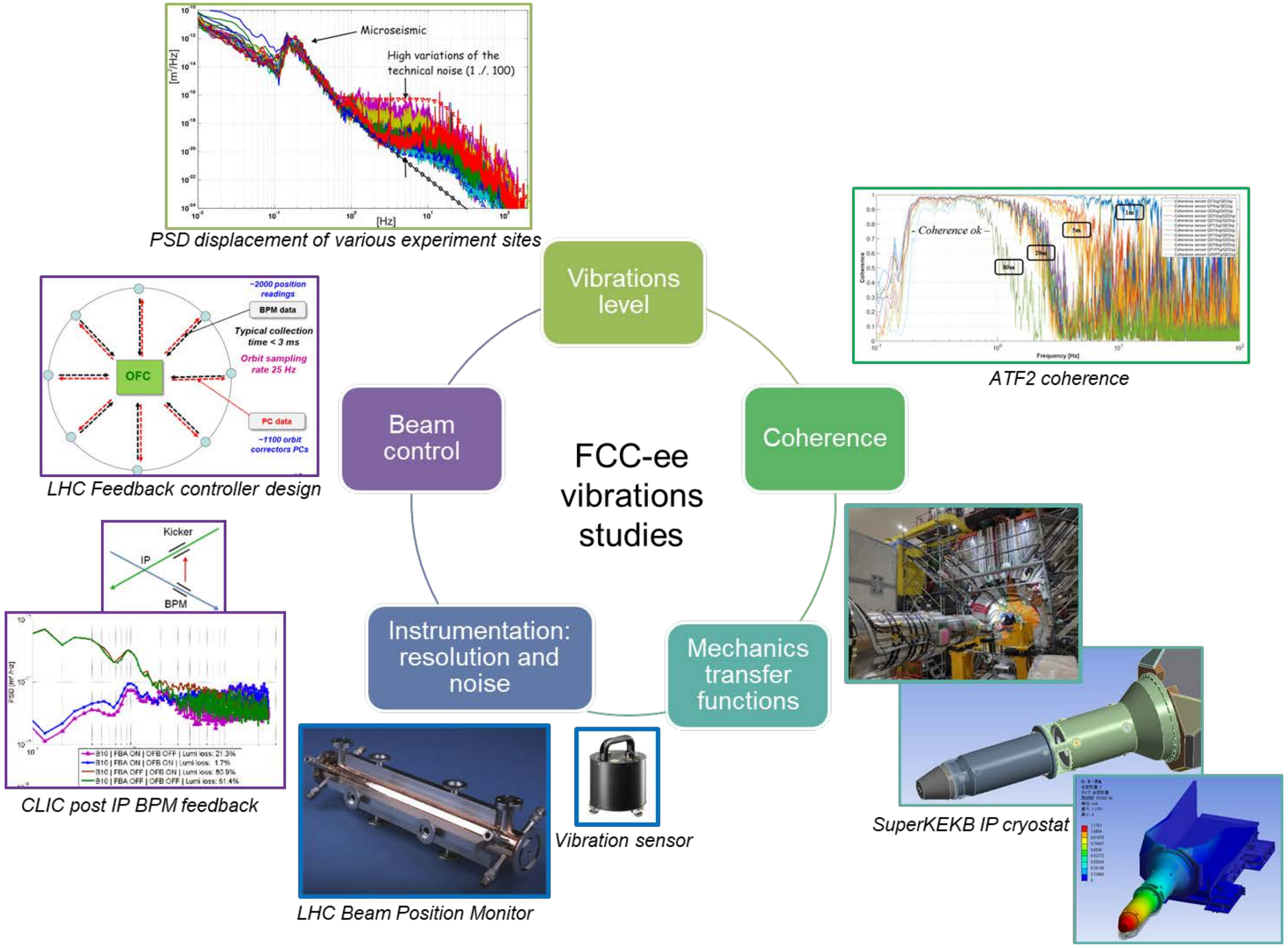
LAPP

LAPP activities on FCC-ee

- **Global scheme of the vibrations effects on the beam and the related controls:**



- ❖ Vibrations (ground motion and mechanics)
- ❖ Instrumentation
- ❖ Control
- ❖ Beam parameters (position, emittance, luminosity…)

- **Global view of the team works:**

Vibrations models & global effects

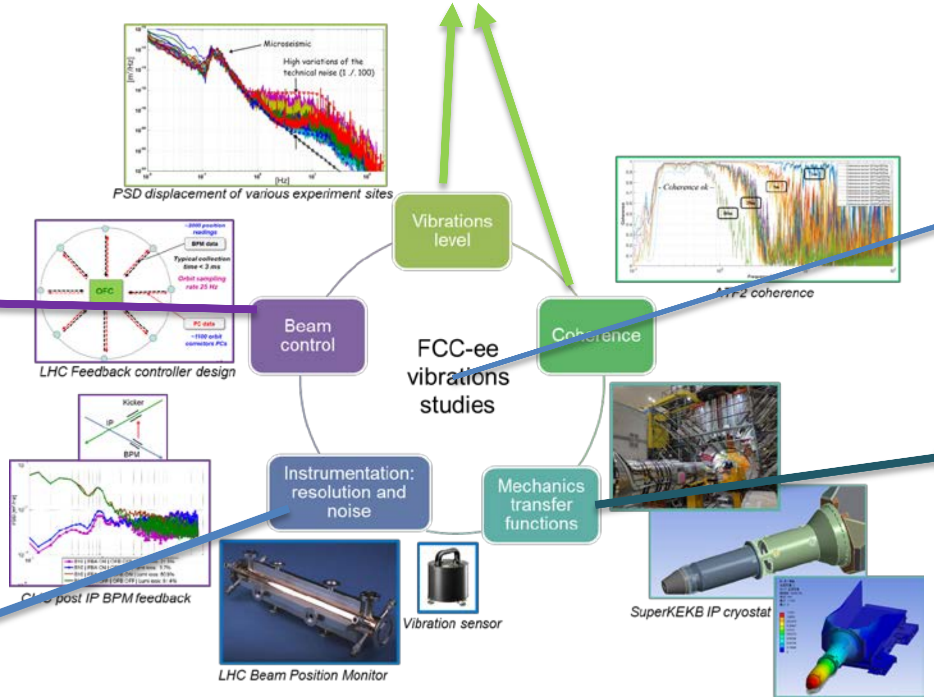
*- **3: Uniform waves** (static deformation) – optics studies*
- Dynamic aspects: prospect of a GND generator (GND motion and coherence studies at SuperKEKB)

Optics simulation – beam parameters

*- **2: FCC-ee MDI** simulation (MAD-X)*
- SuperKEKB: Capability to estimate the observed vibrations effects (SAD)

Beam control

- IP feedback simulations (CLIC) – done in the past
- Trajectory control (ATF2) – done in the past



Mechanics and positioning

*- **1: FCC-ee MDI** mechanical modelling*
*- **4: SuperKEKB**: Effects of cantilever cryostats and of various sources*
- FCC-ee Arc-cell prototype : mechanical studies will start ASAP
- Transverse R&D with a new positioning system
- Active system for vibrations controls (ATF2, CLIC) – done in the past

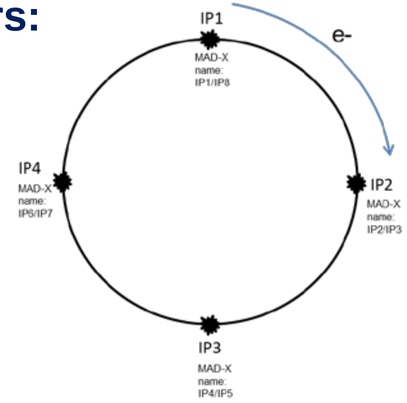
Instrumentation

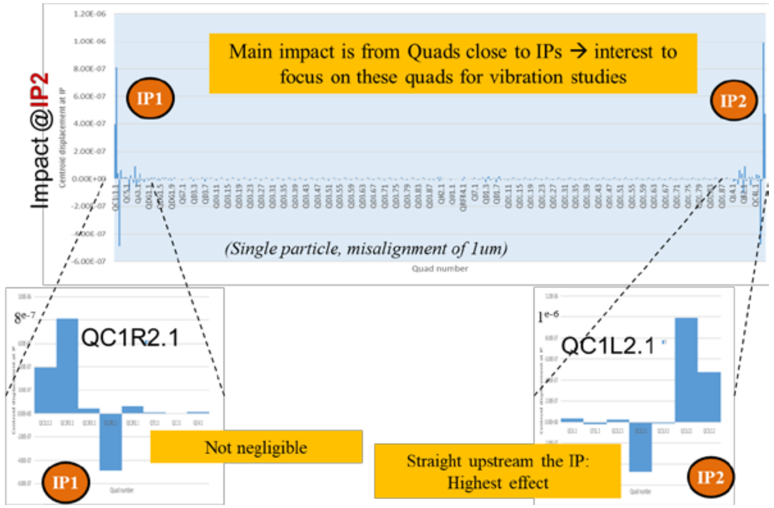
- Vibrations sensors (R&D and sensors in operation on site)

MDI strategy

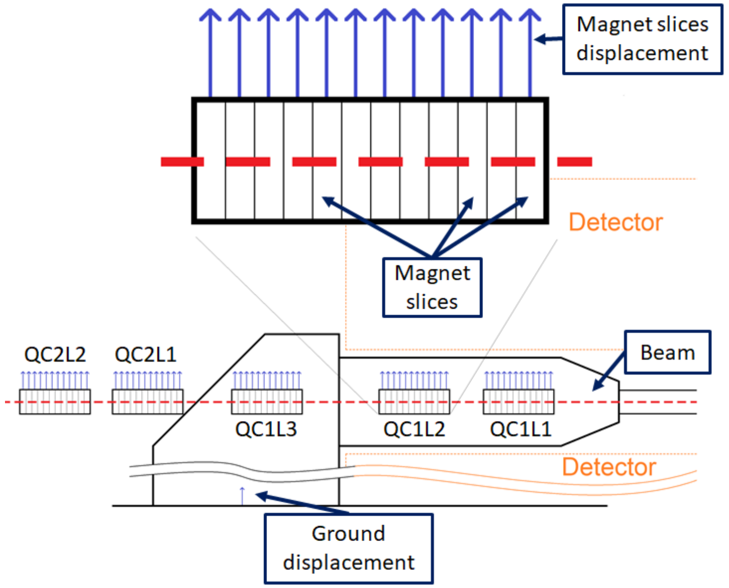
▪ Study parameters:

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

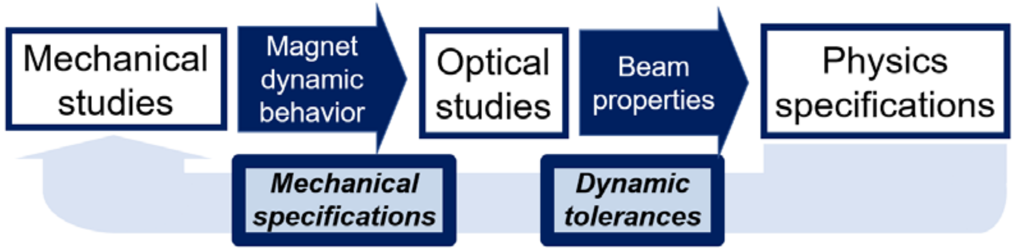




➢ *For the next studies, focus on these 10 quadrupoles placed around the IP*



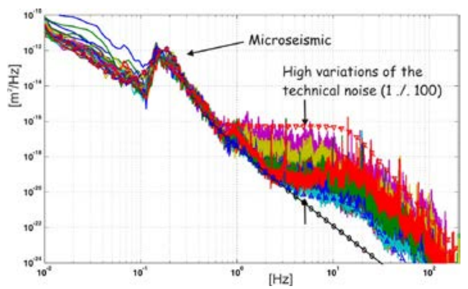
▪ A global and innovative approach to set the tolerances of the magnet dynamic behavior:



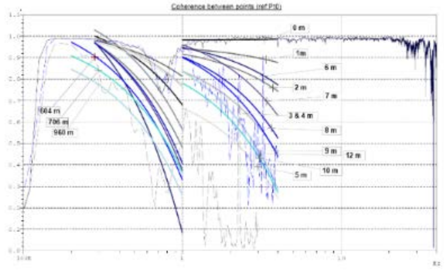
Coupling of the mechanical and the optics studies

➢ *The tolerances of the mechanics are adjusted by the evaluated beam parameters of the optics simulation*

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



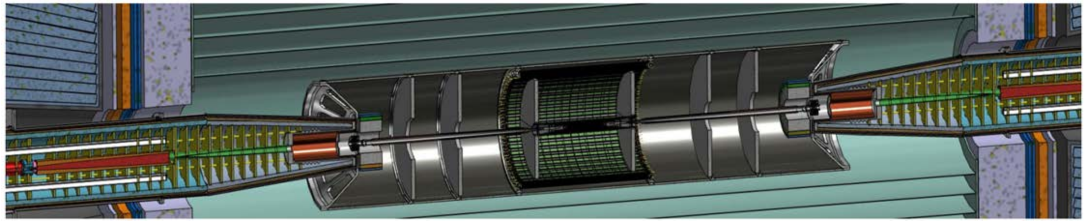
PSD displacement of various sites



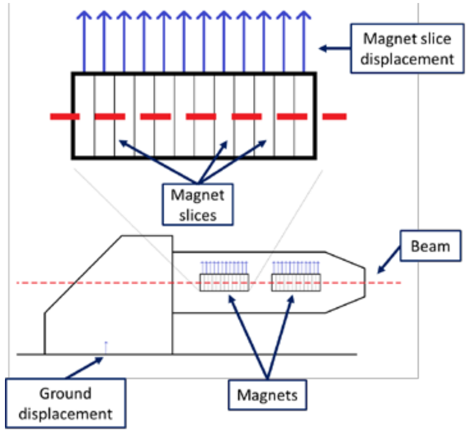
Coherence measurements at LHC

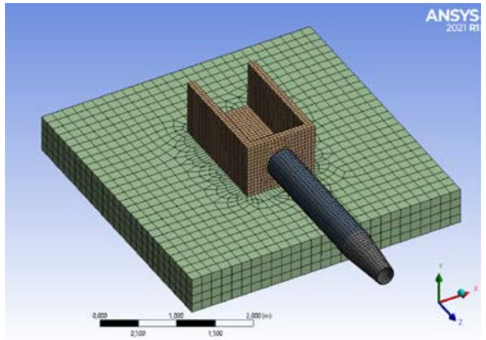
Mechanics : methodology of the dynamic behavior evaluation

The final assembly is complex and not enough achieved to be evaluated

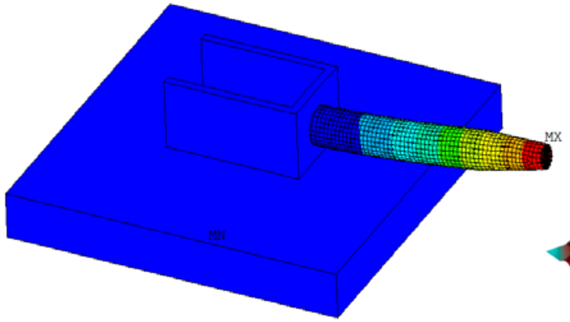


- **Development of a methodology on a simple geometry inspired by a known case: SuperKEKB**

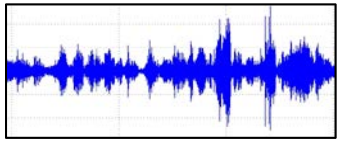




Finite elements model under ANSYS of a simple structure



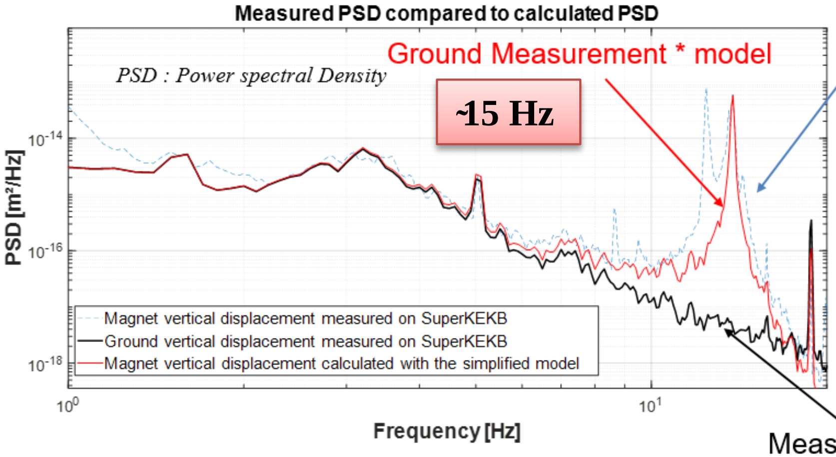
Modal analysis and state-space matrices calculation



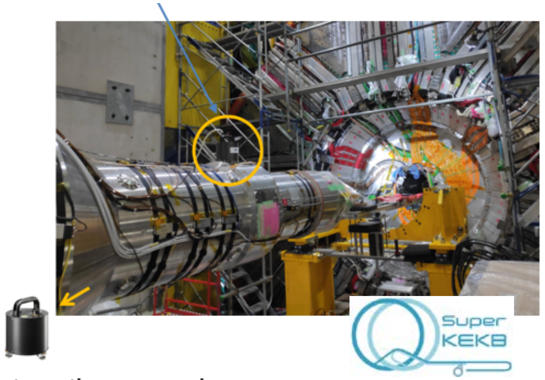
MATLAB

n output temporal displacements files: calculated at the optics magnet slices and at the ***MAD-X sample time***

Exploitation of the state system under Matlab



Measurement on the cryostat

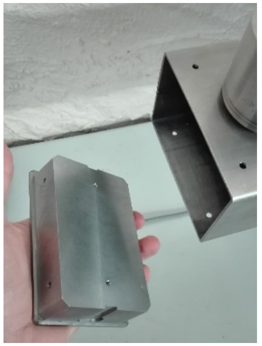


Measurement on the ground

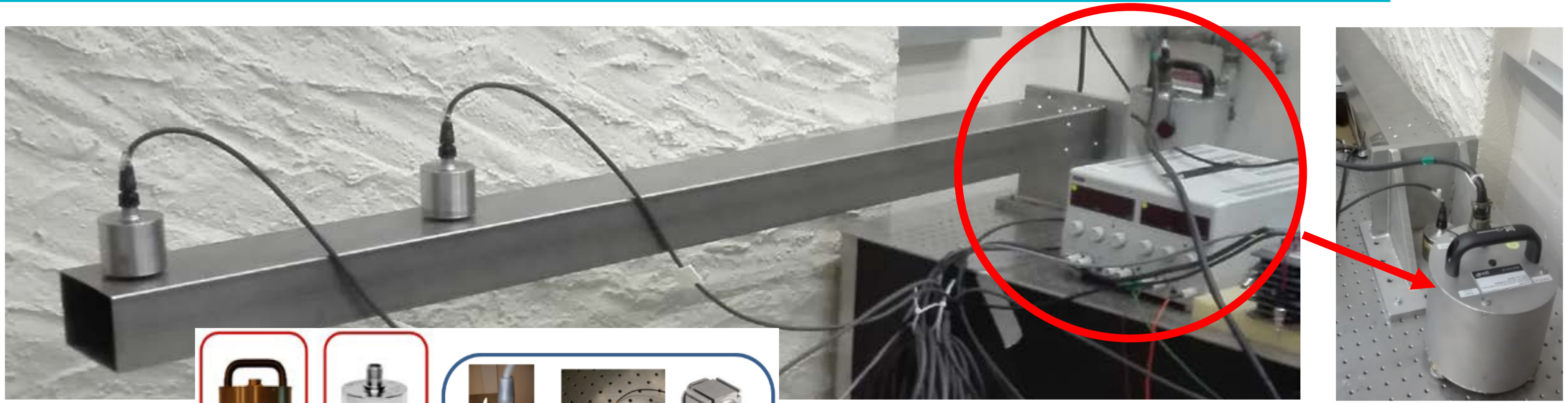
Test of the method on a prorotype

For more details, S. Grabon's presentation: [*https://indico.cern.ch/event/1064327/timetable/*](https://indico.cern.ch/event/1064327/timetable/)

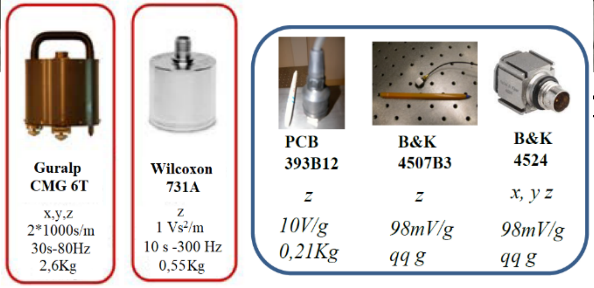
Mechanics : validation of the method on a cantilever beam prototype



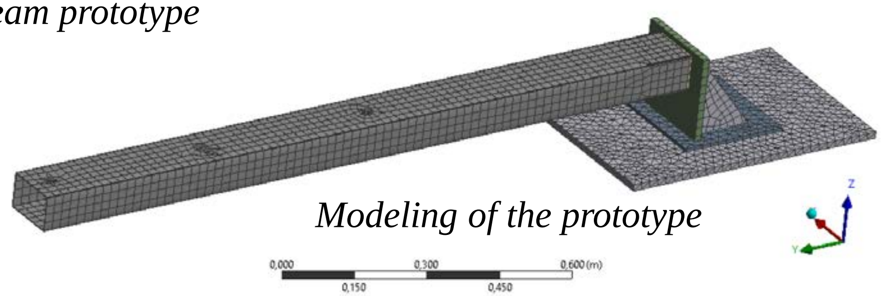
Possibility to add masses



Cantilever beam prototype



Instrumentation

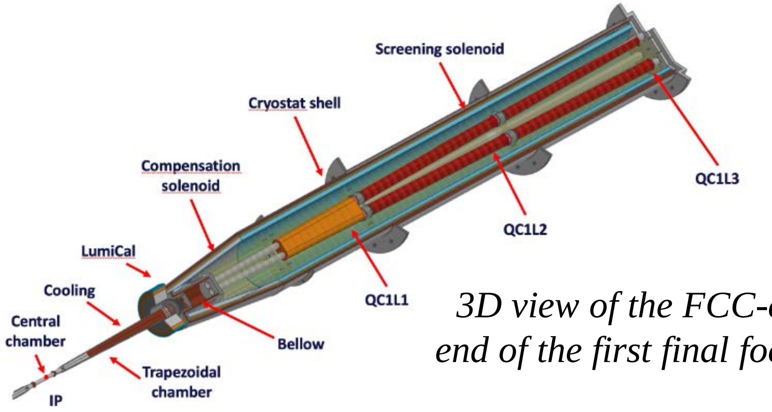


Modeling of the prototype

- Study of 3 configurations and of cantilever coupling complexity -

Conclusion of the mechanics aspects

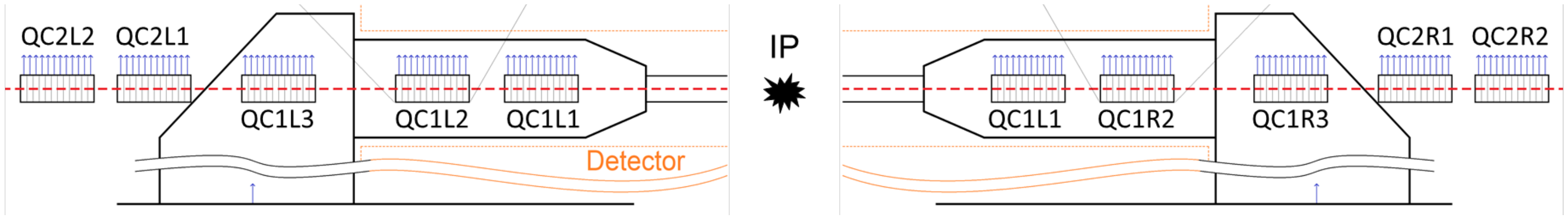
- The method to study the dynamic behavior of the mechanical assembly and its coupling with the optics to evaluate the effects is developed and will allow to define and to verify the tolerances
- Validation of the method on a elementary prototype which could be adapted with various operation configurations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



3D view of the FCC-ee IR until the end of the first final focus quadrupole

Optics : beam tracking studies

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

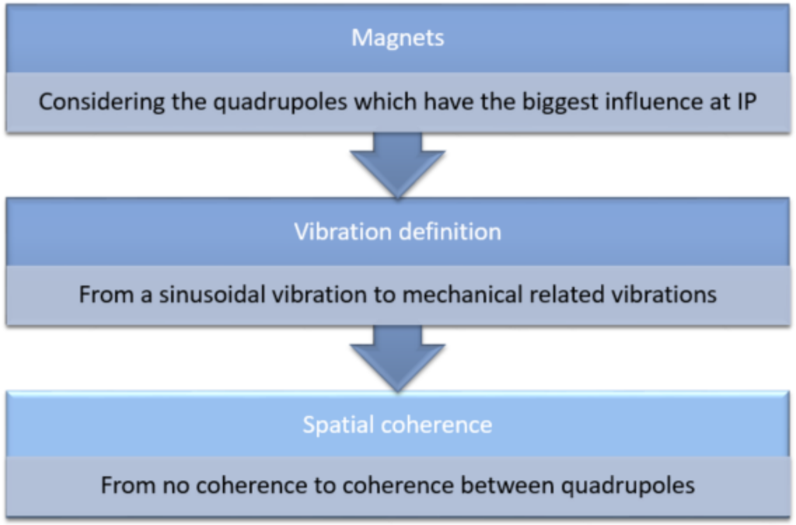


- *Tools:*
  - V22.2 layout used:~91 km long
  - Z lattice considered, as smallest beam spot sizes at IP
  - Optics simulation with MAD-X:

    Dynamical study -> Tracking module used, number of accelerator turn dependent
  - **No optics correction** considered, to highlight vibrations impact on beam characteristics

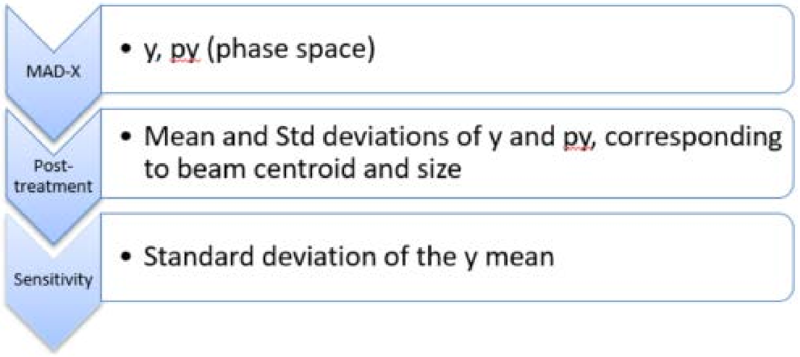
For more details, E. Montbarbon's presentation: *https://indico.cern.ch/event/1064327/timetable/*

- *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

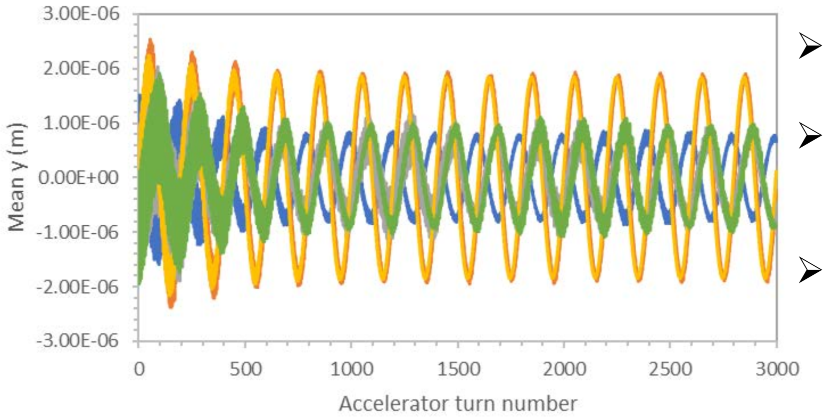
- *Observables:*



- **First studies:**

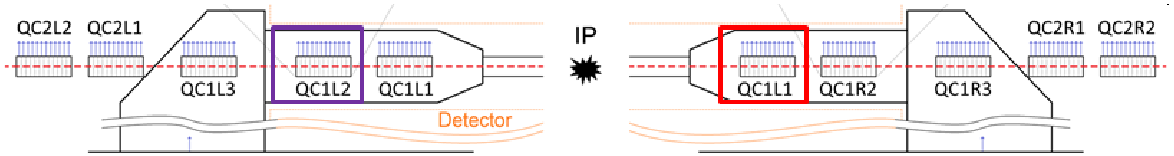
All FFS Quadrupoles

- Bunch of **200 electrons**, gaussian beam
- Tracking study over **3000 turns** (⇔ 1s beam time)
- Vibration of all FFS quadrupoles: sine 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

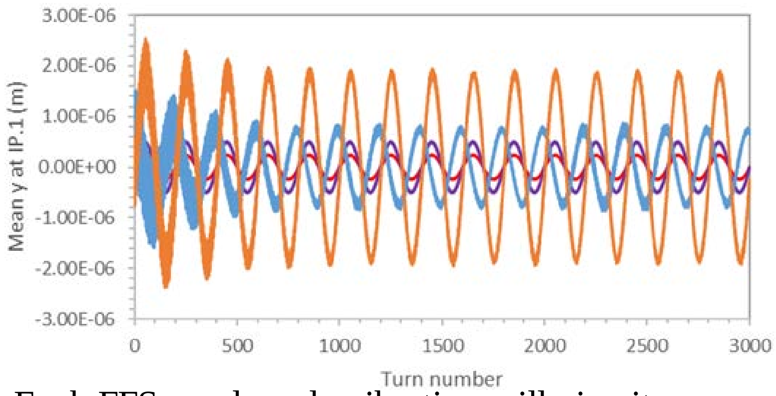


- ➢ 15 Hz pattern noticed in each seed
- ➢ Amplitude of y mean and phasing between the seeds very different
- ➢ Need to focus the studies on the impact of individually vibrating quadrupole

Each FFS Quadrupole



Comparison with individual vibrations of the most impacting quad. at IPs



- o 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

- ➢ Each FFS quadrupole vibration will give its own contribution to the mean vertical offset @ IP.

- **Status and prospects:**

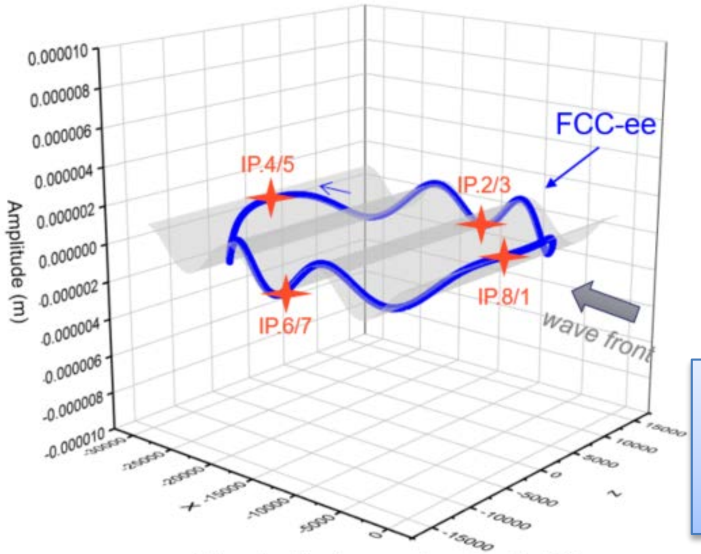
- The method to evaluate the impact of time-dependent vertical vibrations applied in the Final Focusing System (FFS) on beam phase space is developed and the tracking studies will be gradually complexified
- Use of the MUST computing facility (IN2P3/USMB) to deal with all simulations scenarios
  - ➢ This study will require dedicated investigation to provide more realistic results and is a long term work (vibrations relative to mechanics design, local and global corrections…)

❖ **This study is integrated into a more global one: Effect of plane ground waves**

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

  Aims of the study:

  - Compute the response of a potential spatial coherence on the performances of FCC-ee
  - Compare simulation results obtained to the ones of other machines (e.g. LEP, LHC)



Schematics of the plane ground wave impacting FCC-ee

Characteristics of the wave:

- Incident angle: 0 rad
- Phasing advance: $\pi/2$ rad
- *n*: harmonic number

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

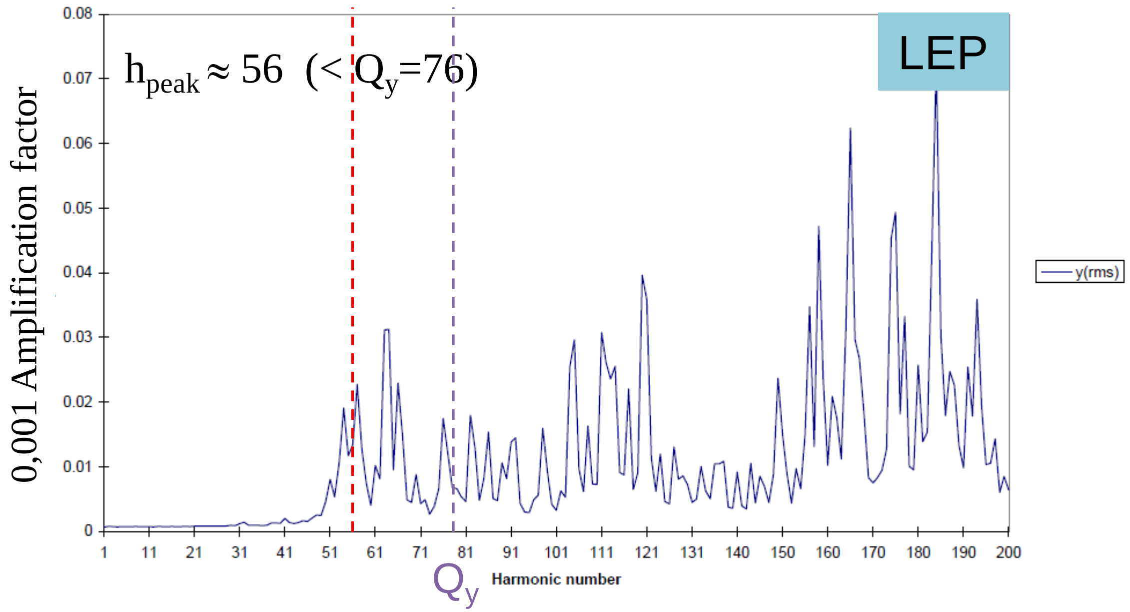
- **Assumptions:**
  - Only one beam considered: no beam-beam effect introduced in the simulations
  - Beam made out of only one particle, placed on the ideal closed orbit
  - **No multi-turn tracking**
  - No local nor global correction
  - Work performed on the Z lattice (V22)
  - Sinusoidal plane ground wave

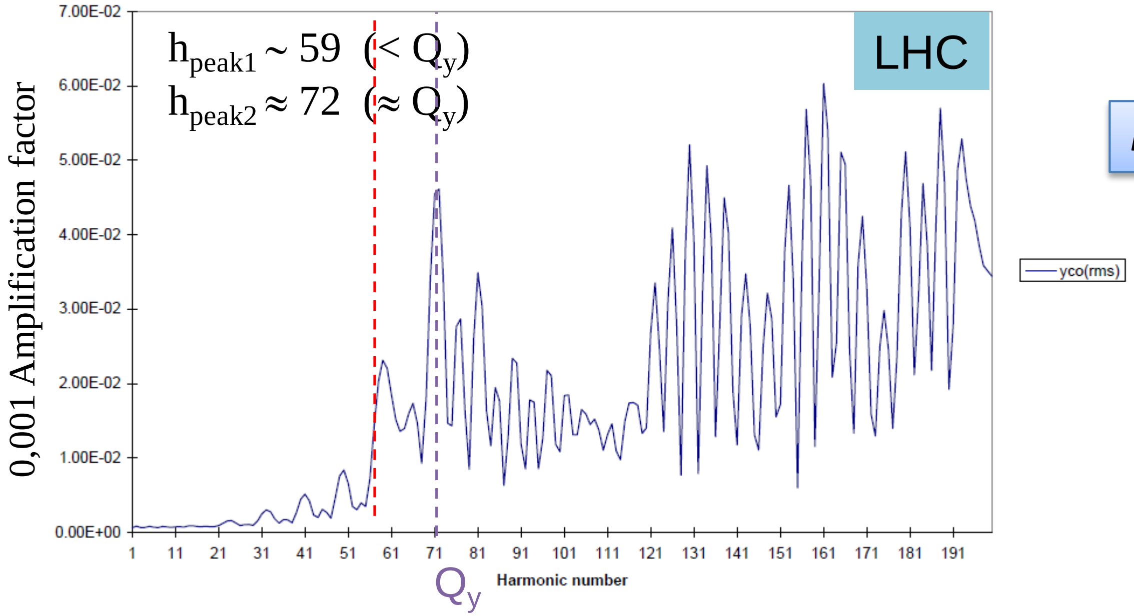
- Vertical misalignment attributed to each quadrupole j along the accelerator ring, regarding the corrugated model:

$$\varepsilon(j) = A * \sin\left(\frac{2\pi f}{v_{wave}}(X(j) * \cos(\alpha) - Z(j) * \sin(\alpha)) + \varphi\right)$$

(With α : wave front tilt angle and φ : phasing advance)

- **Estimated amplification factor for LEP & LHC in function of the harmonics numbers:**
  - ***yco***: difference of vertical offsets between the closed orbit and the ideal closed orbit at the four Interaction Points (IPs), given by the TWISS table
  - ***yco(rms)*** : vertical RMS value of the vertical closed orbit offset over the whole ring, written in the SUMM table
  - ***amplification factor*** : to normalize from the maximum amplitude : $\frac{yco(rms)}{maximum\ amplitude\ of\ the\ wave} \times C$





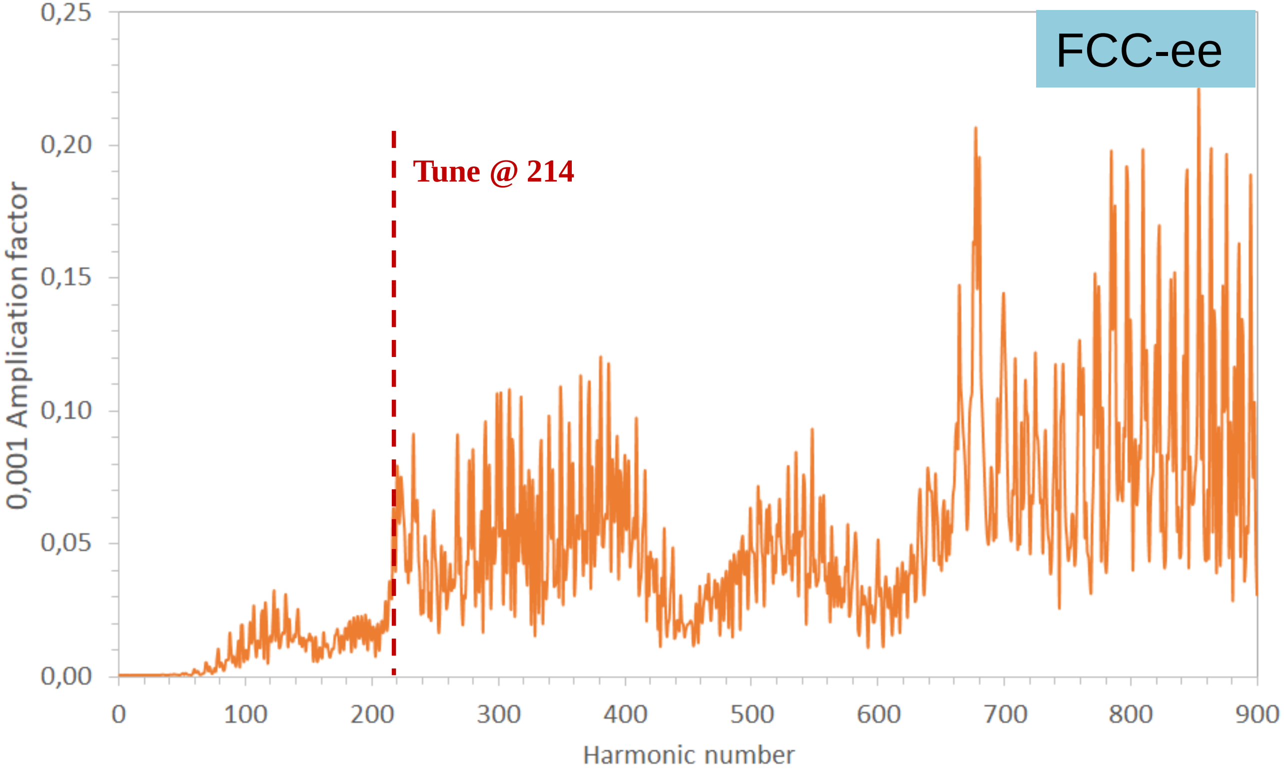
Keil, 1997

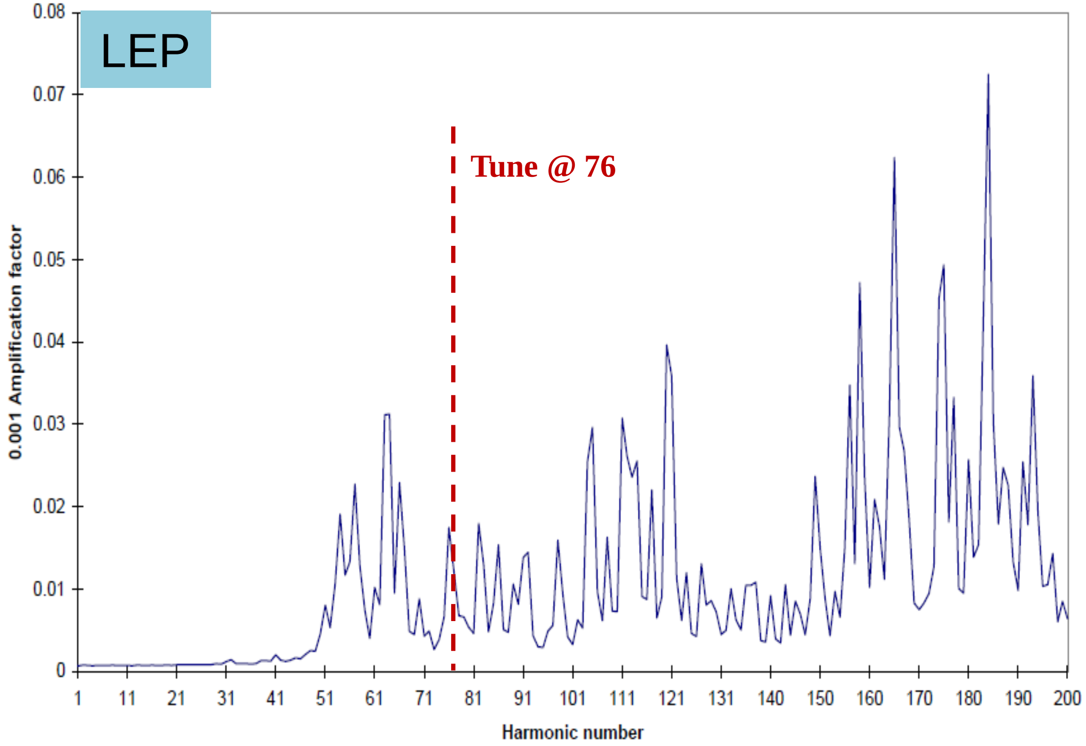
- **Biblio:**

E. Keil, Effect of Plane Ground Waves on the Closed Orbit in Circular Colliders, CERN SL/97-61 (AP), 1997
RJ Steinhagen, "LHC Beam Stability and Feedback Control", 2007
M.Schaumann, "The effect of ground motion on the LHC and HL-LHC beam orbit", 2023

Results: amplification factor comparison

- **FCC-ee MAD-X result and comparison with the LEP results :**

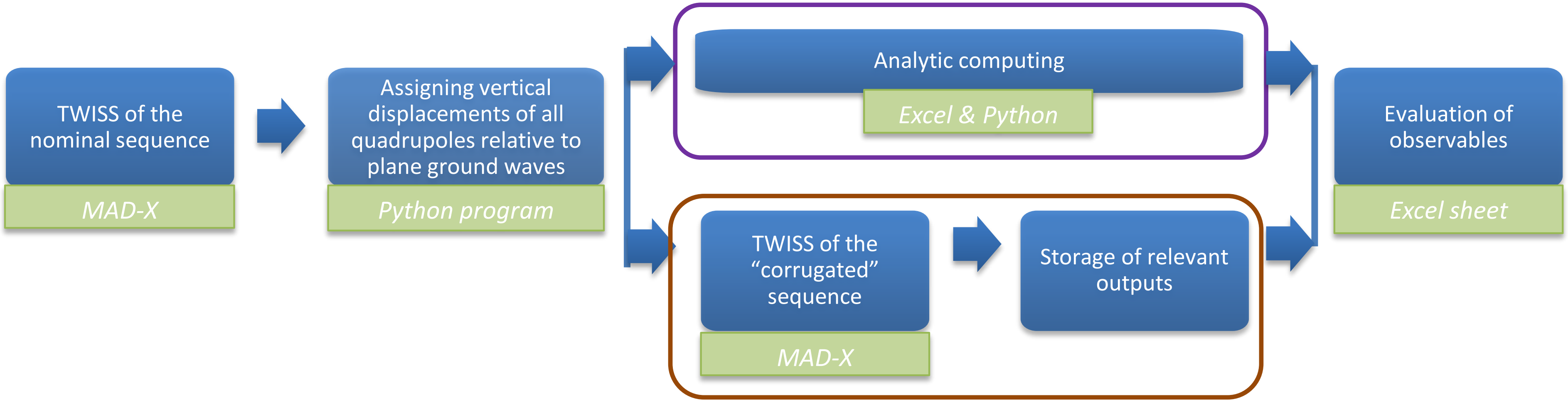




- **FCC-ee is more sensitive**.
- Now it has to be investigated the meaning and the induced effects on the machine with further analysis

Uniform waves: context

- **2 methods are carried out (simulation and analytic approaches):**



- **Analytic: sequence made out with quadrupoles only**
- **Optics simulation: full sequence of FCC-ee**

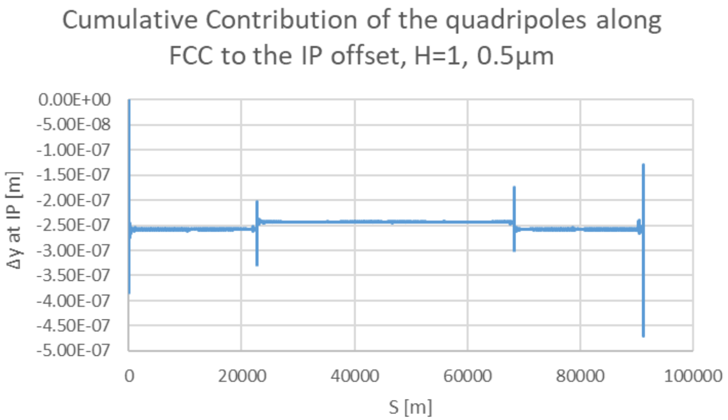
Both approaches are complementary and strengthen the obtained results

- **Definition of the analytic approach:**

Each misalignment of quadrupole ε generates a dipole kick δ: as $\delta = kl\varepsilon$

The i^th dipole kick creates a perturbation yco_j of the closed orbit:

$$yco_j = \sum_{j=0}^{n} \frac{\sqrt{\beta_i \beta_j}}{2\sin(\pi Q)} . \cos(\pi Q - 2\pi\, \Delta\mu_{ij}). k_j l_j \varepsilon_j$$

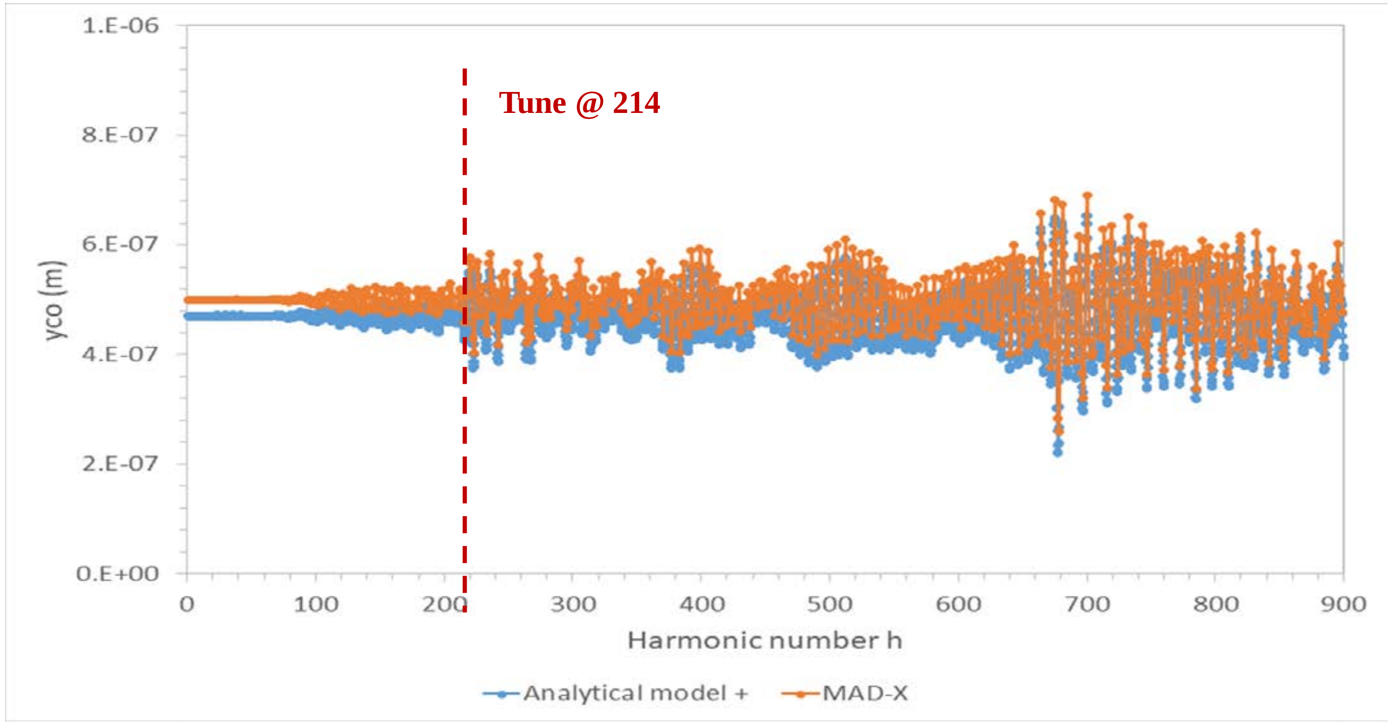


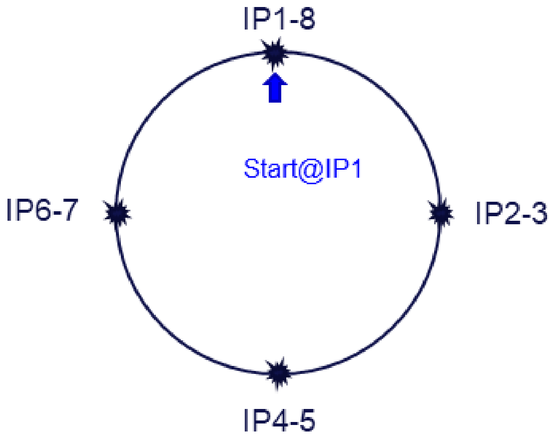
Large portion of the contribution comes from the quadrupoles close to the IPs

Results: yco(m)

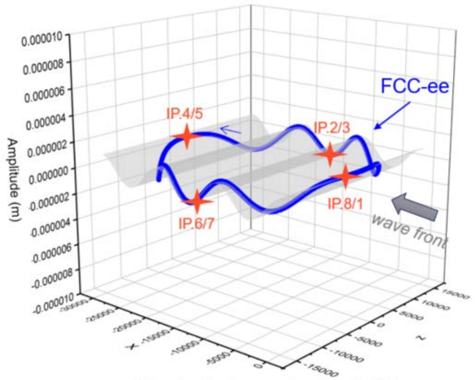
- **Comparison analytical model vs MAD-X**

Difference of vertical offsets between the closed orbit and the ideal closed orbit @ IP.8





Fcc-ee IPs locations

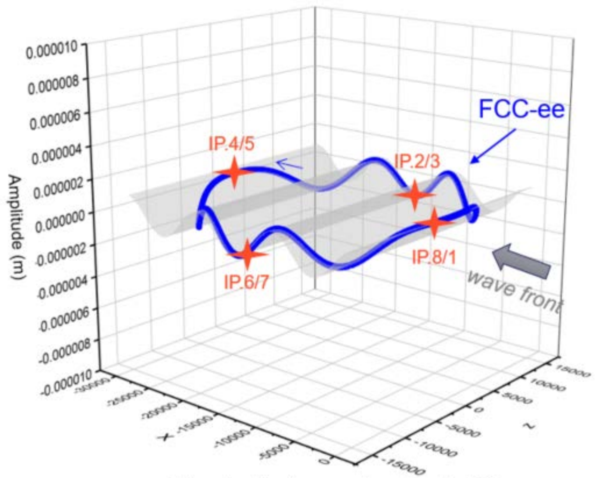


Schematics of the plane ground wave impacting FCC-ee

- Except an initial offset which has to be fixed**, the correlation of the two approaches is very consistent**
- First main peak @ 214 is coherent with the vertical tune machine
- More investigation is ongoing to comfort the complementary of the 2 methods
  - **Analytic**: fast knowledge of each quadrupole effect on the trajectory
  - **Optics simulation**: accurate evaluation of the effects of all the magnetics elements on the beam parameters

Prospects

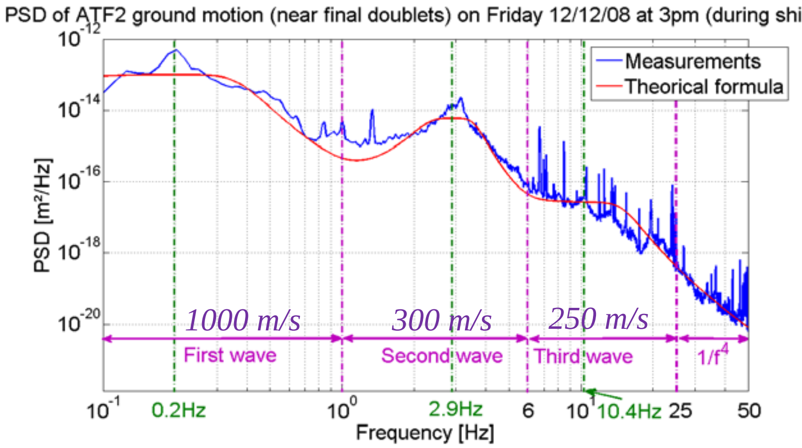
- **Short term:**
  - Investigation of the offset (vs lattice and magnetic elements)
  - Parametric study to test the influence of the phase and the direction of the waves
    - *Presentation during a next optics meeting soon*



Schematics of the plane ground wave impacting FCC-ee

- **Mid-term:**
  - Evaluate a more realistic setups with known waves speeds and directions (collaboration is initiated with a French seismology lab) to convert harmonic to frequency

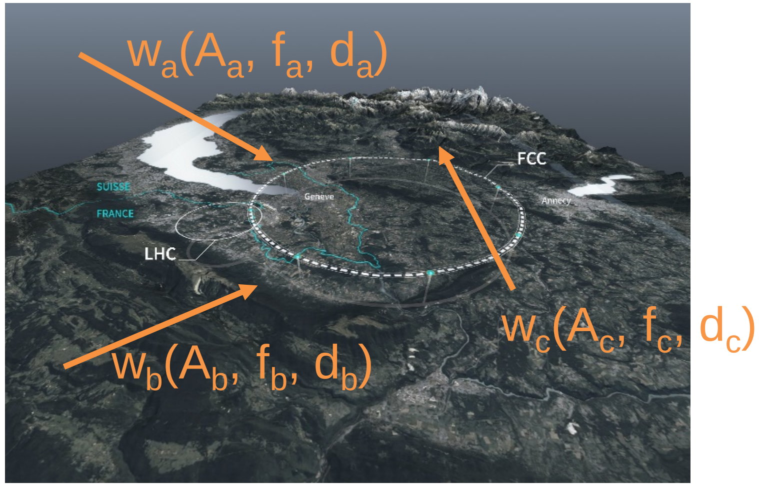
Study on plane waves done @ ATF2 – comparison model vs measurements



- **Theoretical formula of the DSP of the absolute ground motion:**

$$p(w)=\sum_{i=1}^{3}\frac{a_i}{1+\left[d_i(w-w_i)/w_i^2\right]^4}$$

- a_n, w_n, d_n: amplitude, freq and width of the 3 main waves



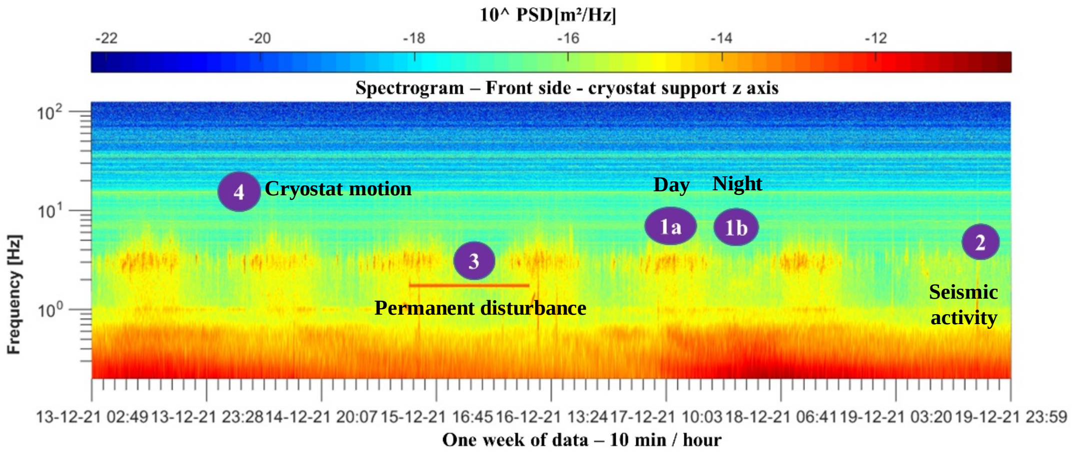
  - 1st study will be done at SuperKEKB

- **Long term: roadmap in progress….**

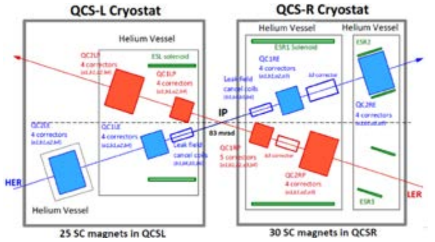
Complementary studies : SuperKEKB

- **Useful demonstrator at SuperKEKB:**

4 vibrations measurements H24 at both sides of BELLE II

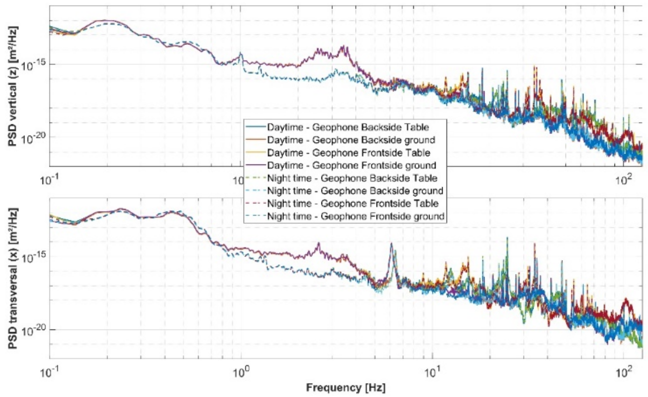


Spectrogram of one week data from a sensor placed at one side of the Belle-II detector

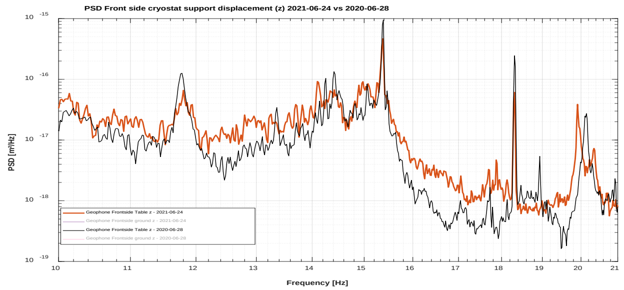


- ❑ Comparison day – night
- ❑ Seismic events
- ❑ External disturbances
- ❑ Drift in time
- ❑ Coherence…

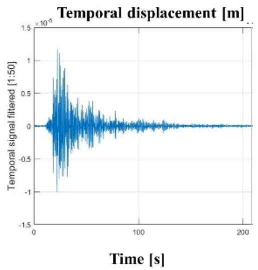
- **Some examples of vibratory analysis at the MDI:**

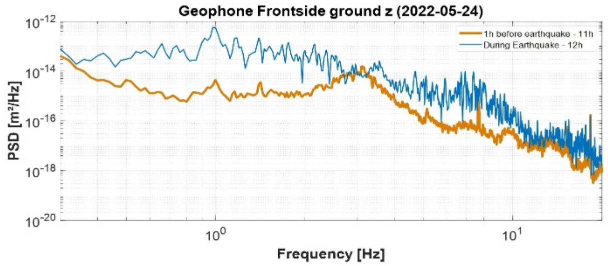


Day-night vertical and horizontal PSD on both sides of Belle II detector



Drift of the mechanical assemblies behavior in time

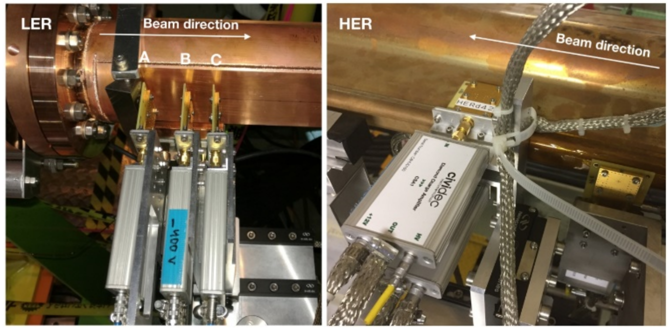




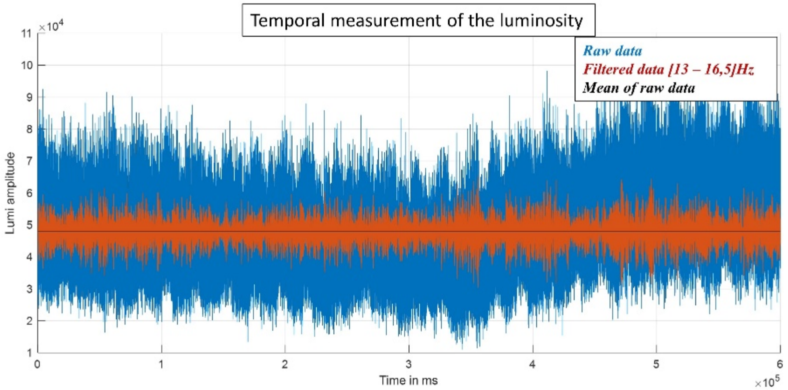
Detection of the earthquakes

- *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*

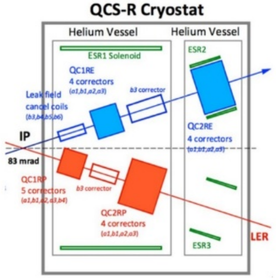
- **Coupled analysis with luminosity measurements:**
  - Influence of the mechanics

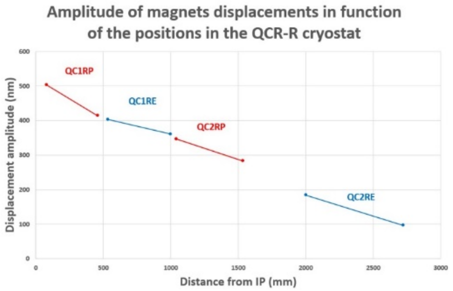


*Experimental layout in both ring (left: LER, right: HER) of the luminosity measurements - **IJClab***

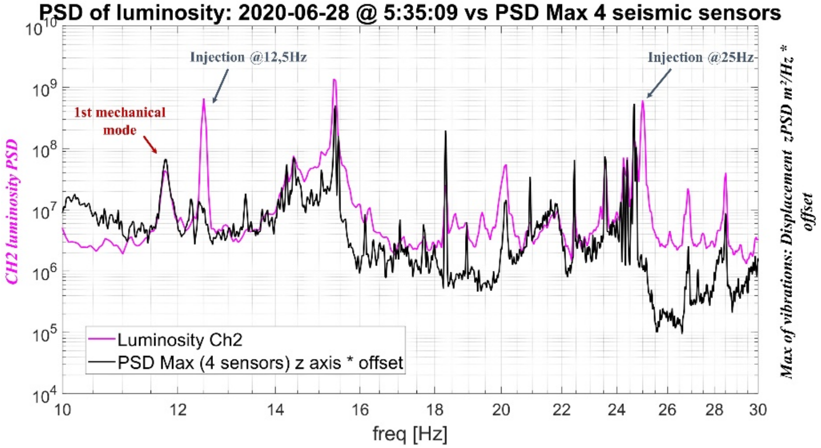


Example of time measurement of a luminometer



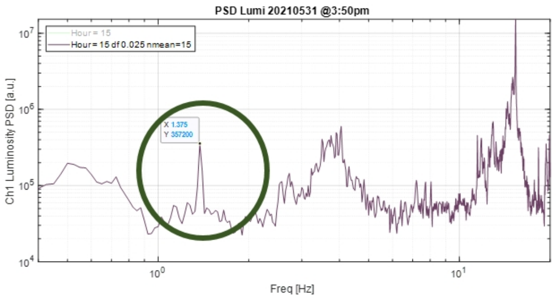


Positions of focusing magnets in the QCR-R cryostat (left) - Maximum amplitudes of the deformation (right)

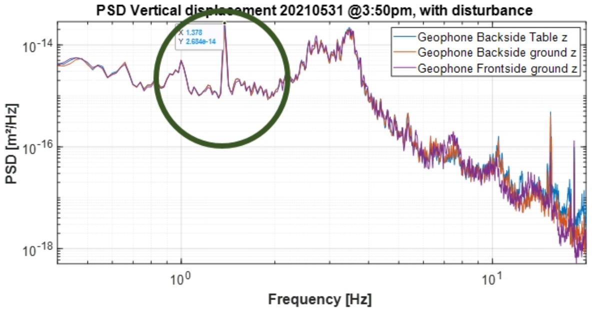


Comparison between the PSD of luminosity and the PSD max (z-axis) of the four sensors located around the BELLE II detector in [10-30] Hz bandwidth.

  - Influence of coherent vibrations



PSD of the luminosity measurement (CH1)

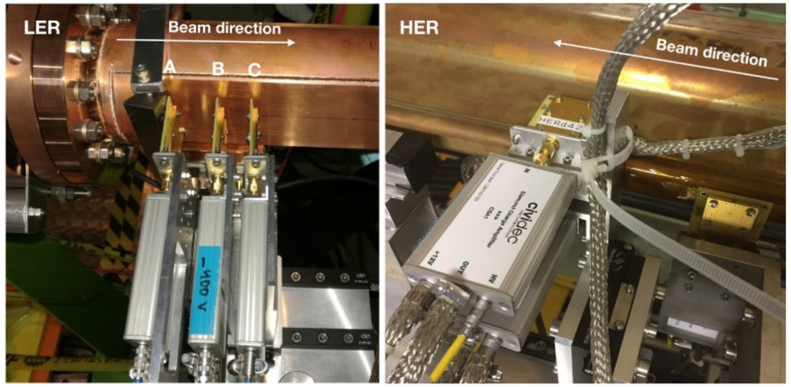


PSD of the vertical displacement

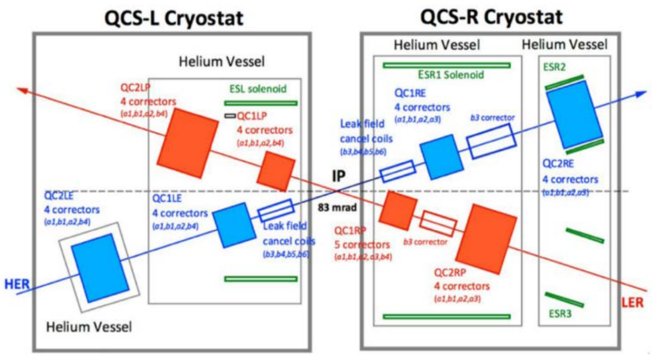
PSD of the luminosity (left) and vibrations (right) with a peak at the same frequency due to the external disturbance

- Study in progress: to do the correlation between real measurements and the optics simulation under SAD

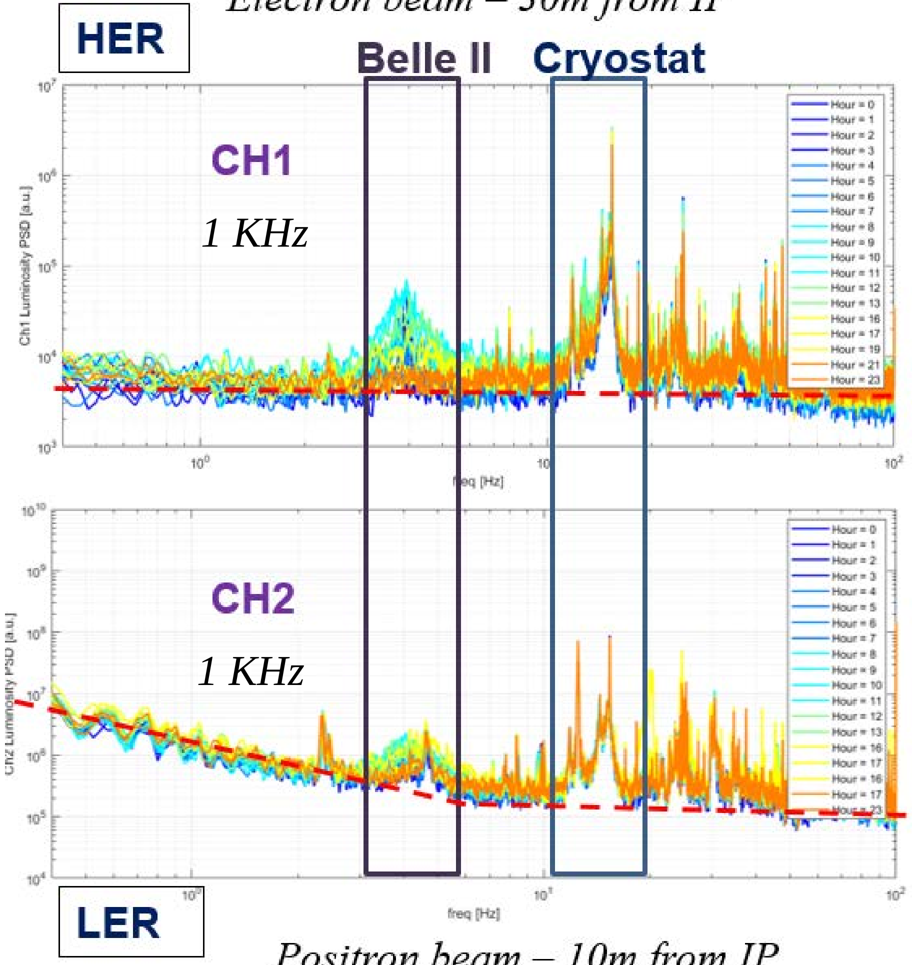
- **Analysis of the luminosity measurements:**



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

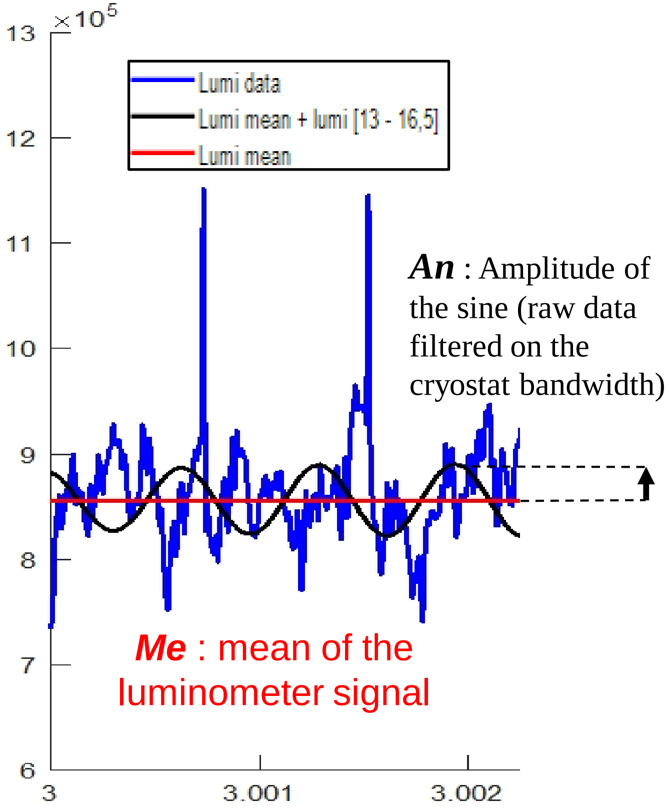


Electron beam – 30m from IP



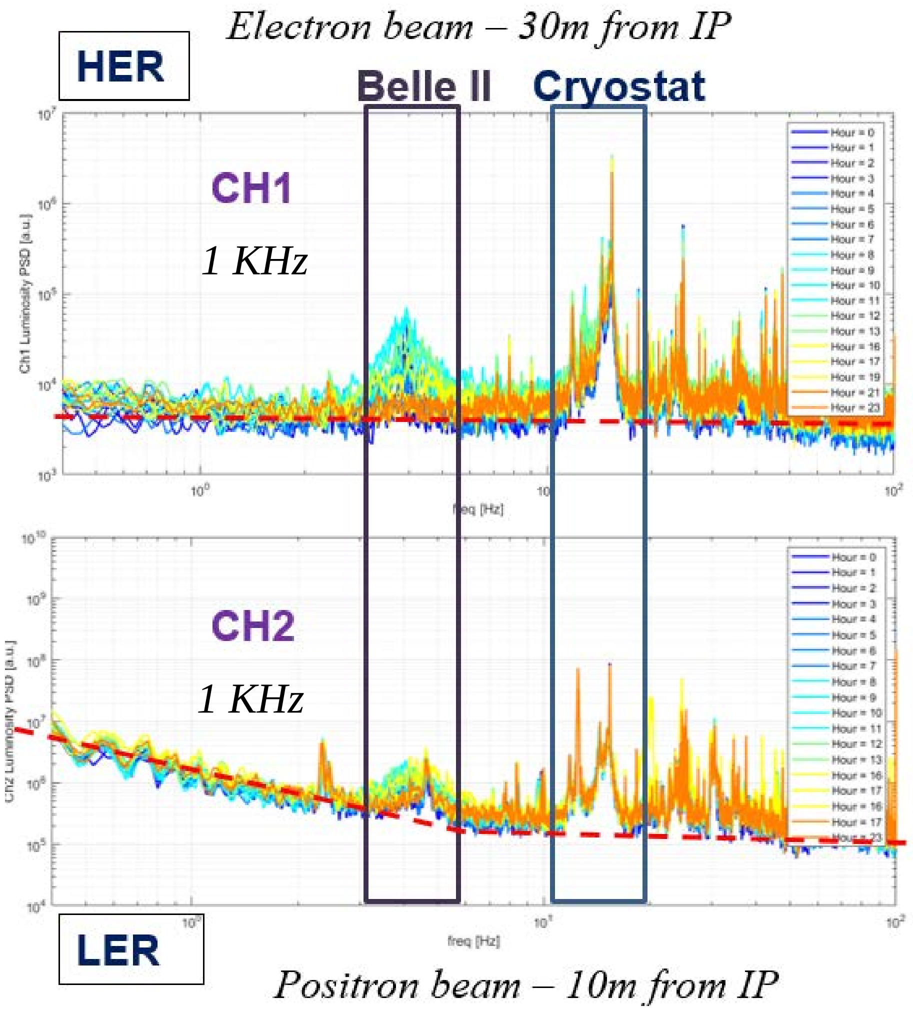
Positron beam – 10m from IP

- The signals contains a lot of information which are very helpful for the beam diagnostic, especially for the vibrations effects…



Temporal measurement of the luminosity (raw data, filtered, average)

- **Quantification:**

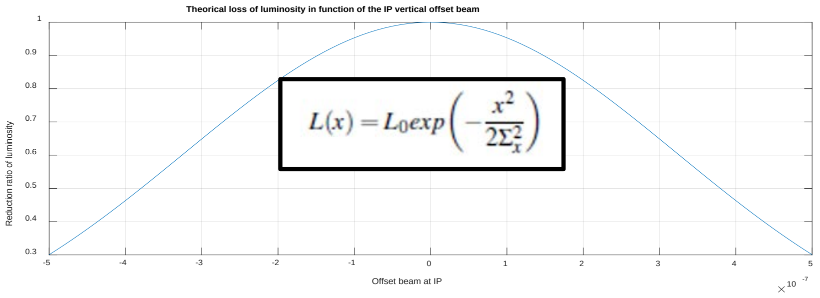


Ratio of the luminometer signal : An / Me

HER	LER
[8-20] %	[1-2] %

- The analysis is in progress but the quantification is complex due to various factors: nature of the beams, positions of the devices, alignment and beam deflection, electronics noise and sensitivity…

- **Simulation under SAD**
  - **Evaluation of the beam deflection in function of the cryostat deformation**
  - **Evaluate the accuracy between the measured and estimated effects**



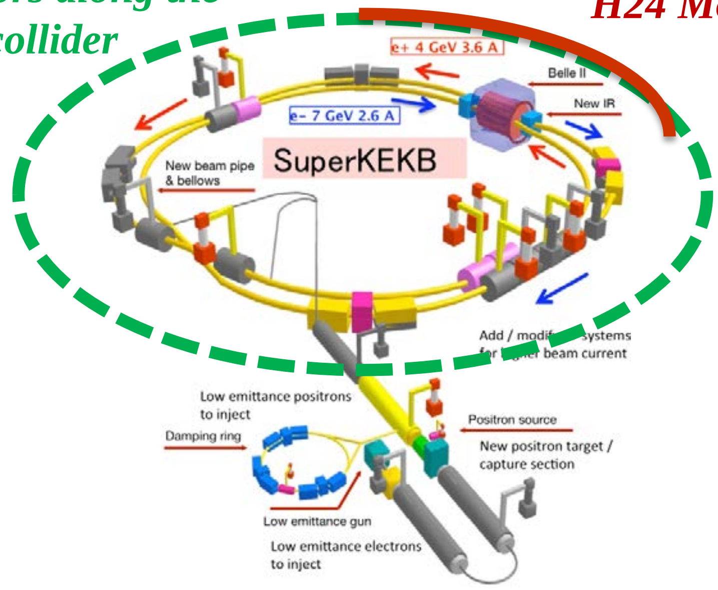
- **The installation of a IP BPMs fast acquisition is in under investigation**
- **To follow the effects vs the increasing of the luminosity will be very relevant**

- **Vibrations effects of coherent vibrations:**

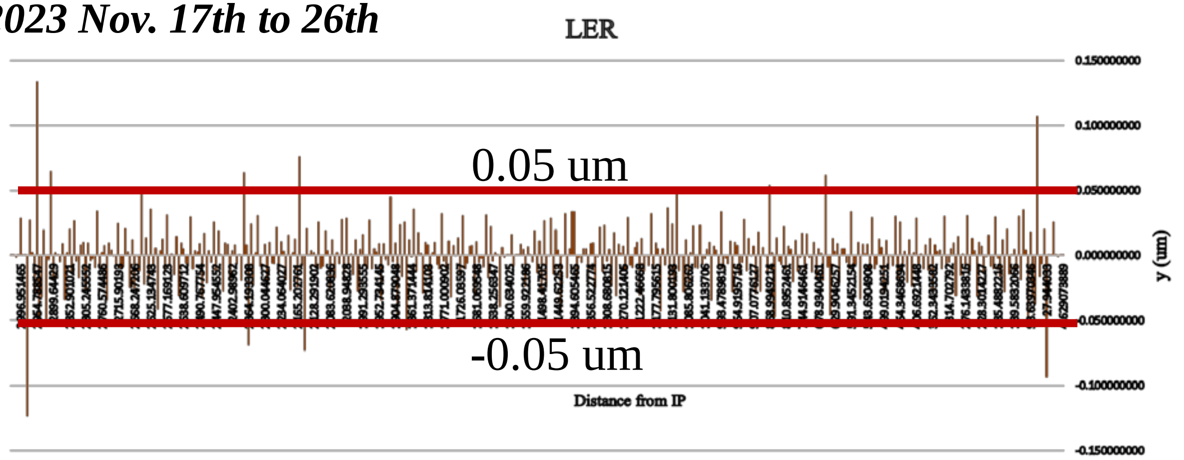
*Planned vibration measurement campaign around the ring – **from 2023 Nov. 17th to 26th***

3 sensors along the collider

H24 Monitoring with 4 sensors



2 synchronized DAQ will be performed



Estimation (using SAD) of the beam vertical offset @IP of each magnet with a misalignment of 1um (threshold of 0,05um)

- Selection of 5 strategic points at about -60m, 25m, 60m, 650m and 1500m from the IP

- **To study the vibrations effects vs spatial coherence**
- **To have relevant inputs from an experiment in operation for the FCC-ee uniform waves study and the FCC-ee GND model**

Summary and Outlook

- **MDI: Complex interplay between mechanical and beam optics studies**
  - Mechanical modelling method is operative to implement new MDI elements
  - Vibrations optics simulations under MAD-X are in progress
- **Uniform waves**
  - Coherent results with LEP and LHC
  - Two consistent, complementary and relevant approaches (MAD-X & Analytic) to have an efficient tool of investigation
  - Large potential of interest (more realistic situation)
- **SuperKEKB: Benefit from an experience in operation**
  - 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
- **Others**
  - Future implication on the arc-cell prototype
  - R&D dedicated to positioning system

o *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*