Laboratoire d'Annecy de Physique des Particules

Vibrations mitigation: from SuperKEKB to FCC-ee

L. Brunetti for the LAPP-FCC team

FCC IS kickoff meeting, 10 November 2020

in collaboration with IJClab, KEK & CERN

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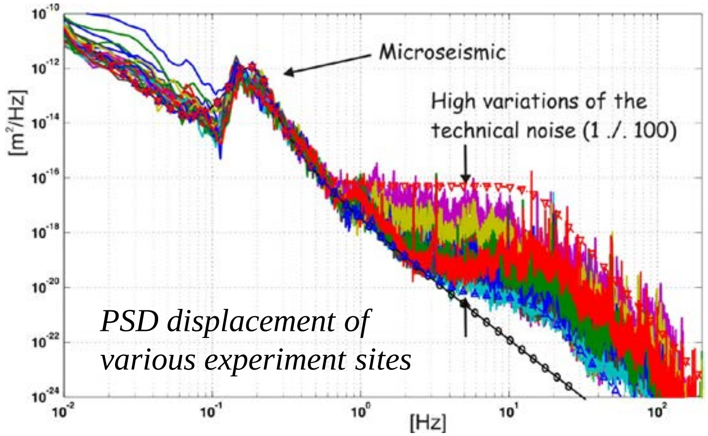
FCC-ee vibrations mitigation

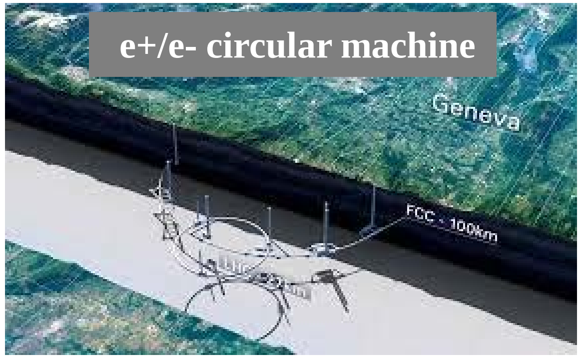
- **Vibrations mitigation tolerances**

Energy	45.6	80	120	175
σx(IP) (μm)	6.4	13	13	36
σy(IP) (nm)	**28**	**41**	**36**	**66**

FCC-ee beam size in function of the energy



➢ What are the vibrations tolerances of the elements, especially at the IP, given the vertical beam size?



Criticality of the vibration issues

LHC — *FCC-ee or SuperKEKB* — *CLIC*

- Vibrations mitigation are less critical than for the linear colliders (single pass, nano beam…) but in which limits…
- Strategy of the vibrations mitigation for FCC-ee?

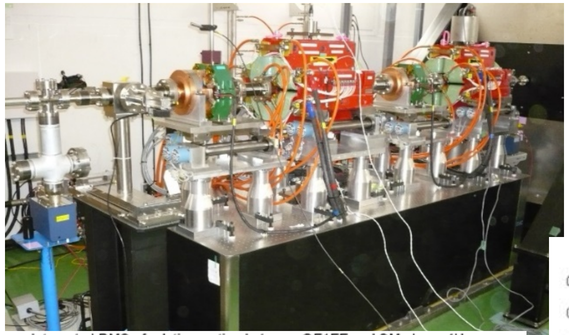
FCC ee mitigation

- **Vibrations mitigation strategy – illustrations with LAPP developments**

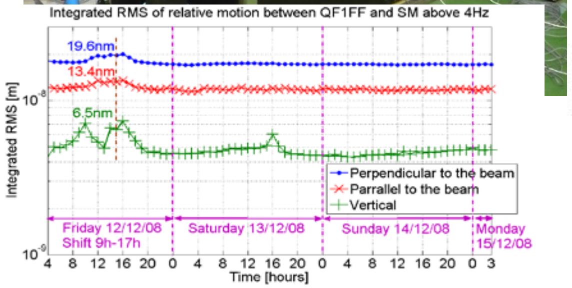
Option "low cost"

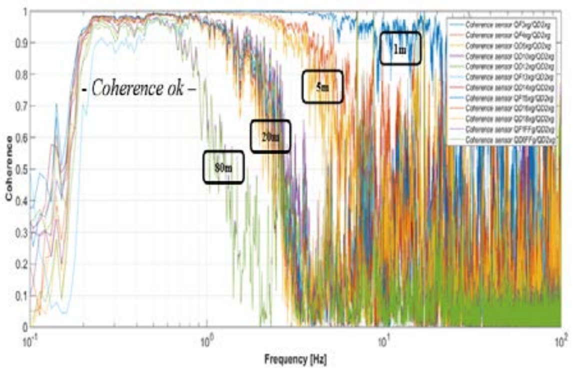
- **Based on the coherence motion, reducing the relative motions between the elements : strategy of the main experiments**

Example of ATF2 (jp) : relative motion between shintake monitor and final doublets of [4 – 6] nm RMS @ 0,1 Hz (vertical axis):



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

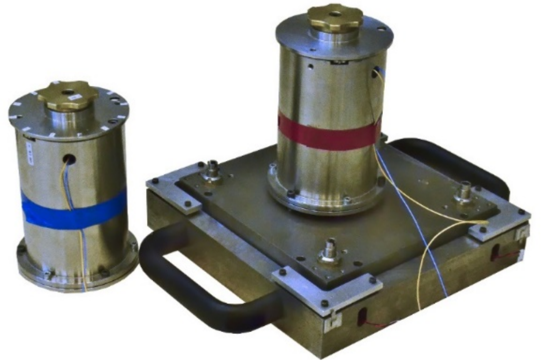




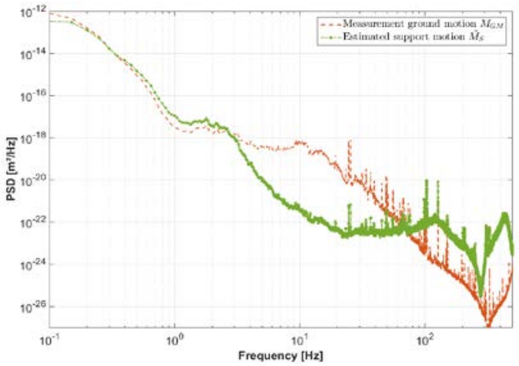
Option "high cost"

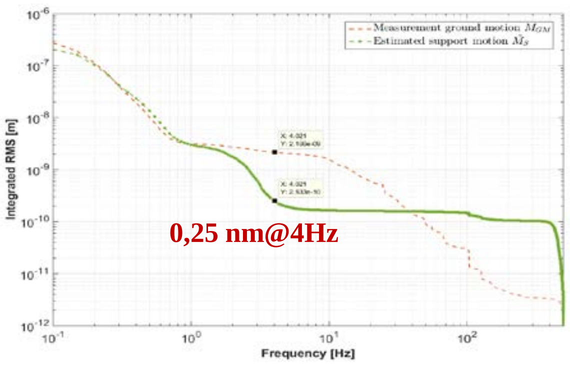
- **Active control: reducing the absolute motion**

Example of CLIC : feasibility demonstration of an absolute displacement of 0,25nm RMS@4H with specific actuators and developed sensors



- 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 -

Coherence

Strategy for FCC-ee?

Active control

Criticality of the vibration issues

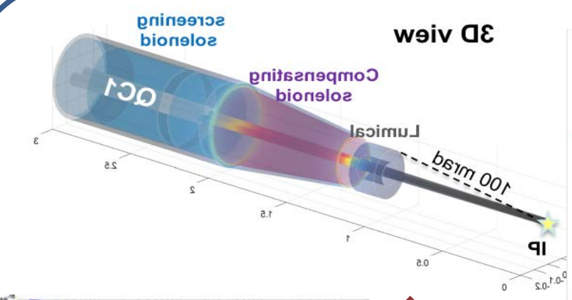
Not very critical | **Has to be defined** | **Extremely critical**

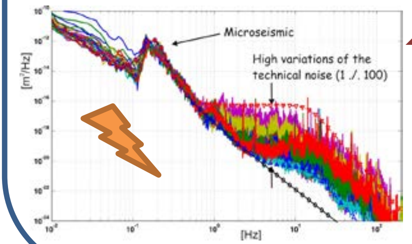
FCC ee mitigation at the IP

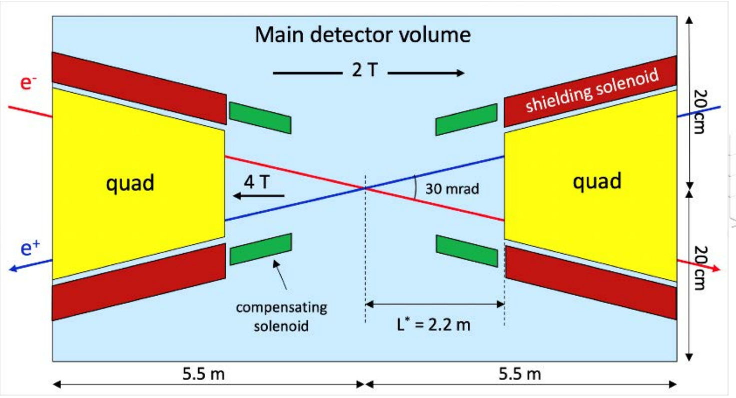
- **First approach: MDI strategy**

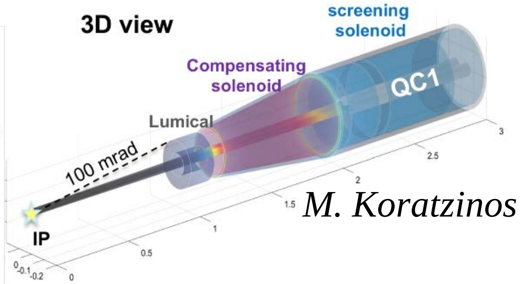
The FF quads for the e+ and e- beams are closed (axes distance of about 100 mm) and the revolution frequency of the machine is about 3 KHz, then we could consider that:

• In principle, any coherent motions of the e+ and e- FF quads per side creates the same orbit deviation for both beams *(except for the main arc quadrupoles where beta functions are different, need to be investigated also in relation to positioning concept)*
• Only the incoherent motions needs to be investigated.

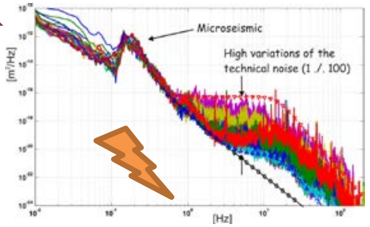




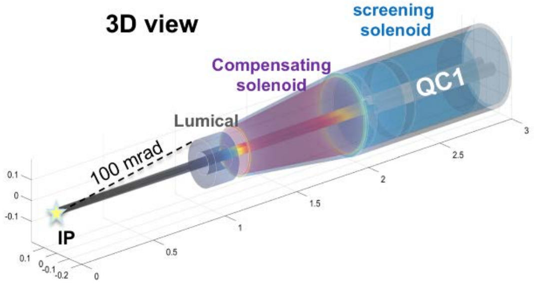




M. Koratzinos



Strategy based on the coherence at the both side?

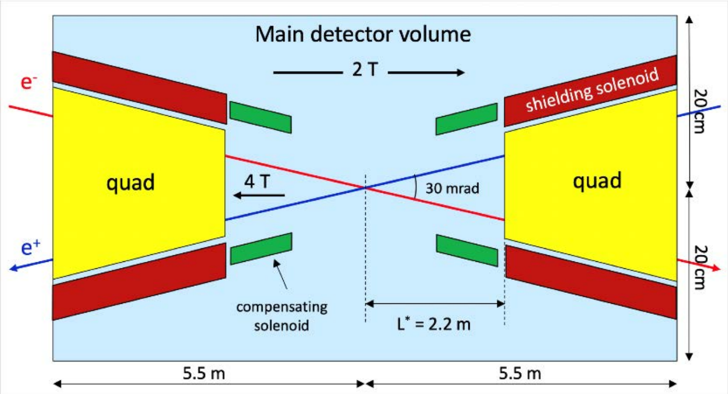


Active (and / or passive) control

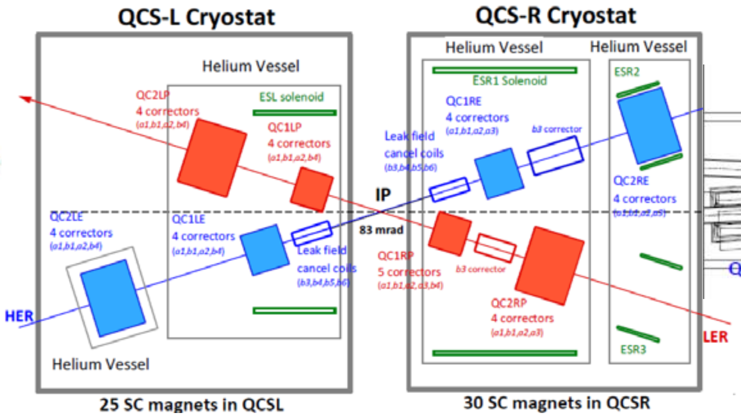
- **Validation of this approach? Within which limits?** *Multiturns vs length & nanobeam*

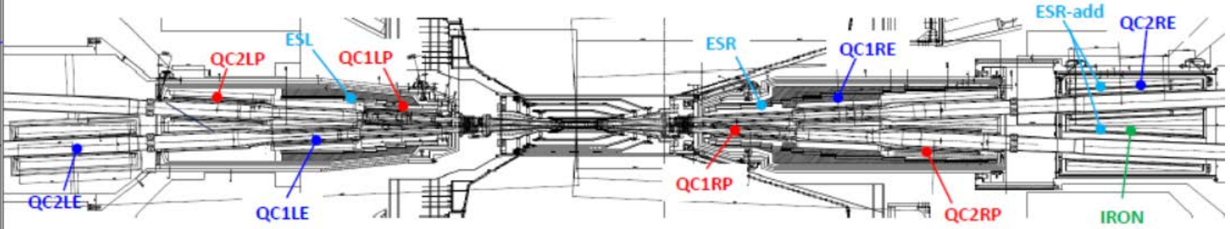
o Note that the orbit feedback (beam-beam deflection) based on IP BPM and kicker will have an action on an estimated bandwidth about [0 to 20-40 Hz] (depending the IP BPM resolution) with an efficiency which will decrease in function of the frequency

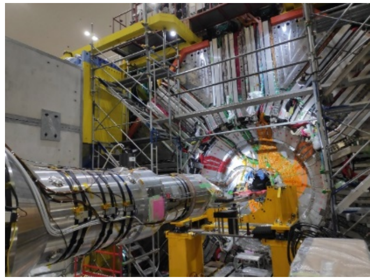
Vibration mitigation : SuperKEKB vs FCC-ee



	SuperKEKB	FCC-ee
Energy(GeV)	7 (e^-) | 4(e^+)	45.6,80,120,175
σx(IP) (μm)	11 | 10	6.4,13,13,36
σy(IP) (nm)	56 | 48	28,41,36,66
Cryostat in cantilever	yes	yes







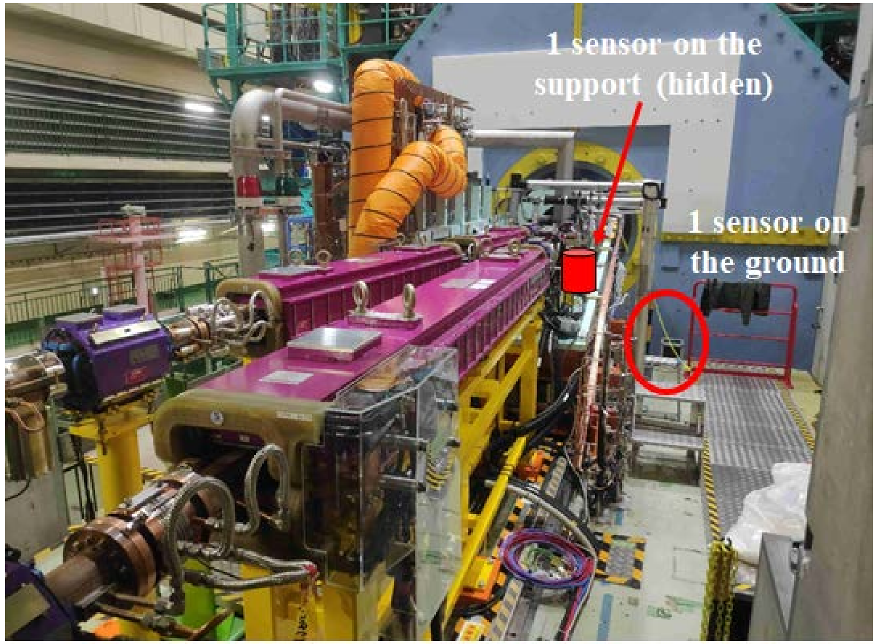
- **Similarities, advantages and opportunities:**

  Collider in operation, similar beam, cryostat in cantilever
  Various common issues : BPM resolution, IP feedback…

- **Difference:**

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

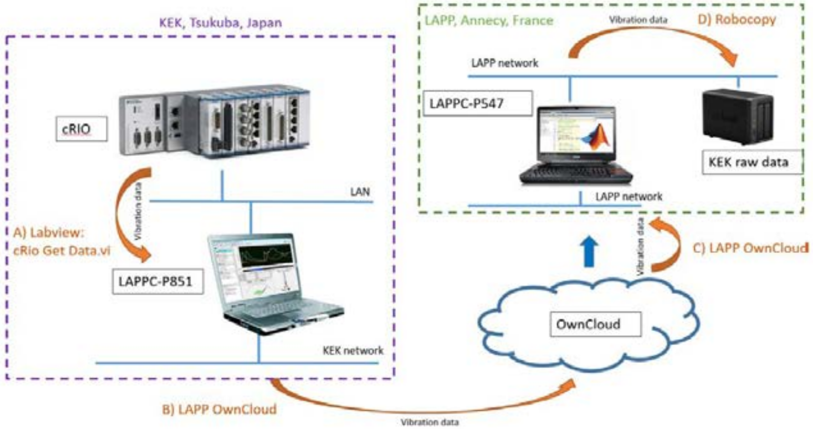
SuperKEKB – vibration measurements



Global view of the final installation (back side)

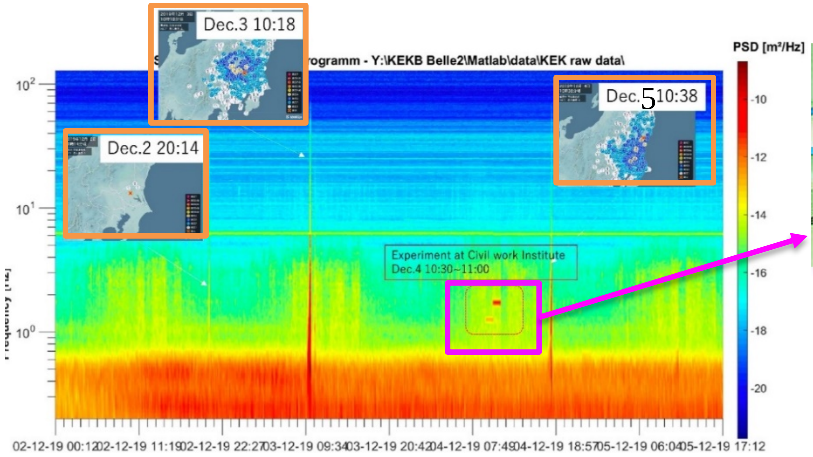
Monitoring 10'/our to limit the data

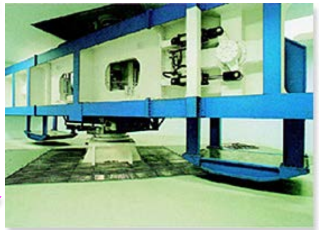
Guralp 6T



Architecture of the acquisition

4 seismic sensors - 2 at each side of the BELLE II detector





Experiment of accelerate centrifugal force close to KEK

Vibration analysis: earthquake and external perturbations

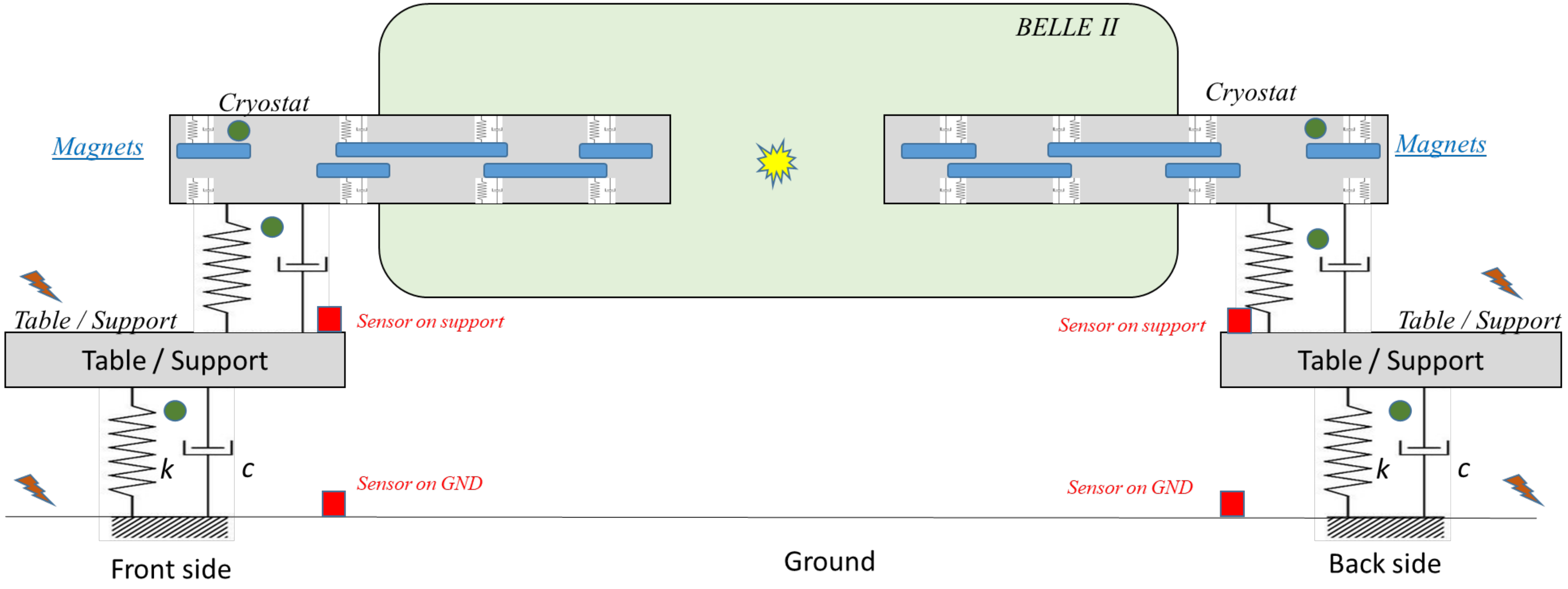
Long-term monitoring with continuous available data for the collaboration

- Monitoring of the seismic motion and the collider cultural noise
- Identification of disturbances or specific event (not the topic)
- Weekly reports are available at : https://lappweb.in2p3.fr/SuperKEKB/

SuperKEKB: current vibration measurements

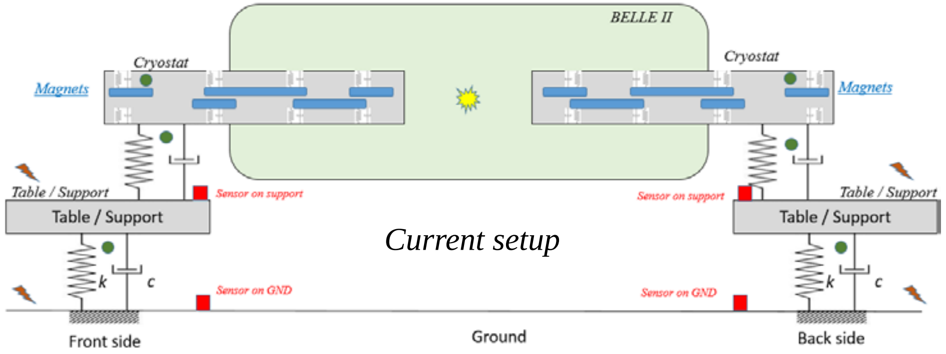
- **Setup:**

  - Disturbances on the ground
  - Disturbances on the support (table) and eigenfrequencies of the support (table)
  - Eigenfrequencies of the cryostat
  - Eigenfrequencies of the magnets

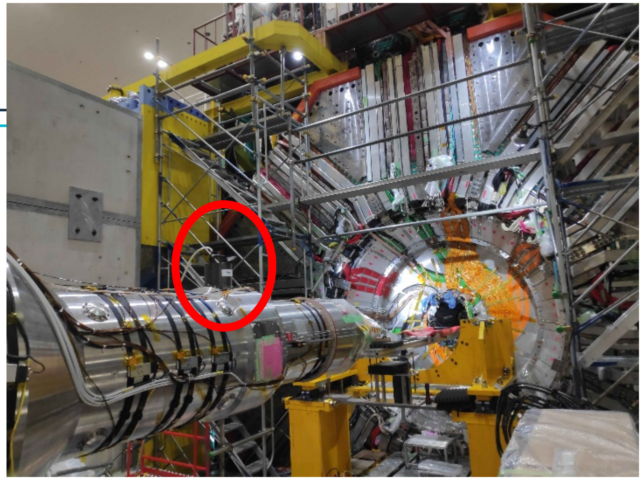


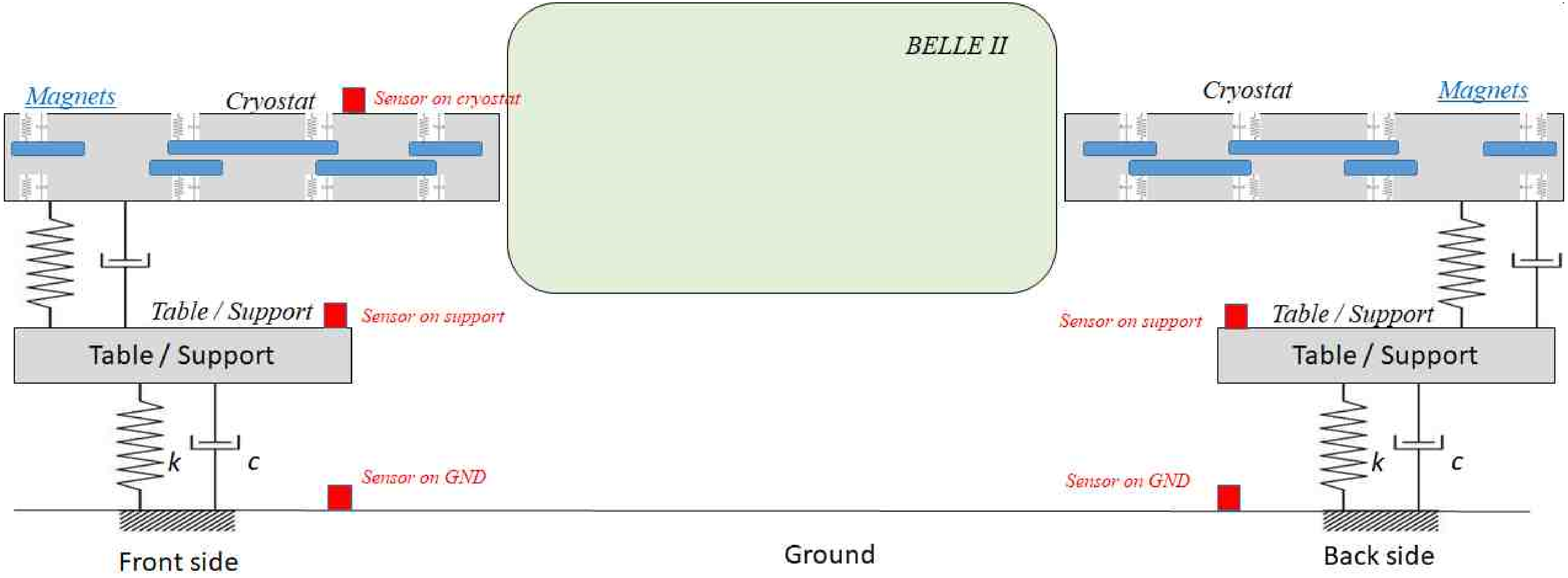
- 2 direct measurements of the ground motion
- 2 indirect measurements of the final focus magnets (support of the cryostats)

- **Setup:**
  - 2 cryostats outside the BELLE II detector
  - 1 available position on the front side cryostat (plate) at about the half length



Current setup

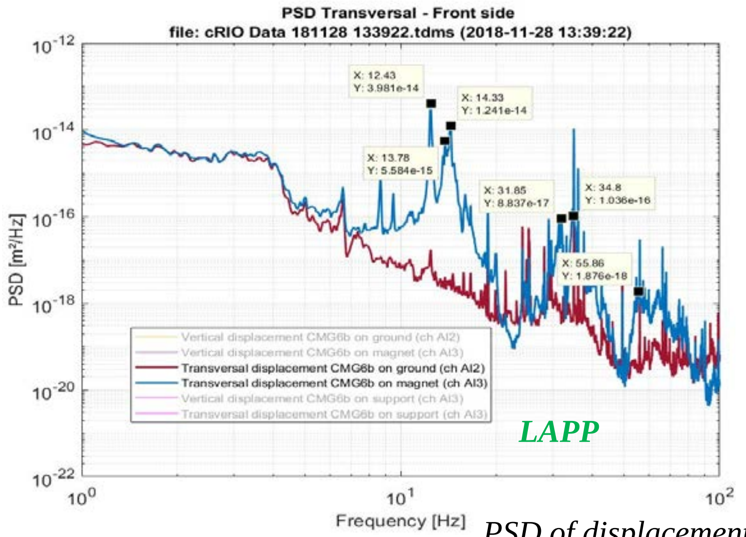

Dynamics measurements on the cryostat (LAPP)

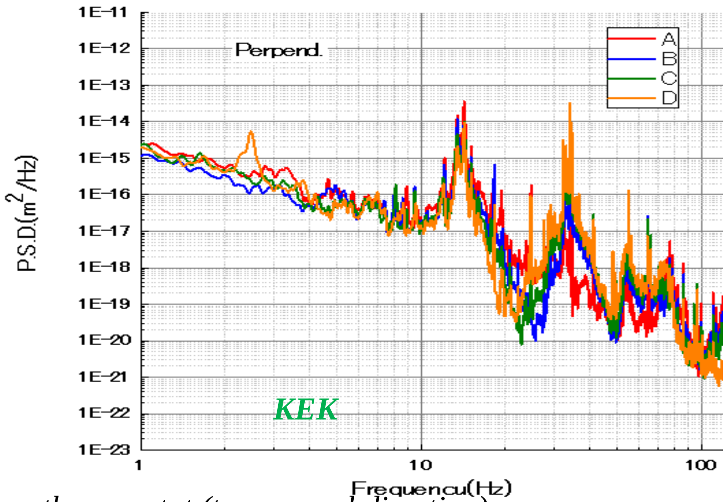


Setup during the dynamics measurements

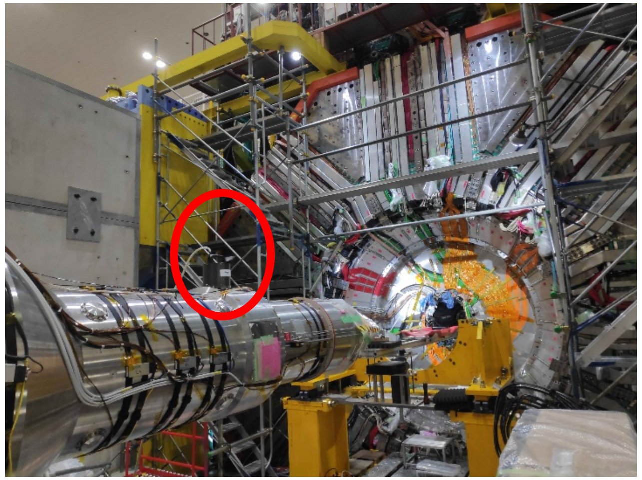
SuperKEKB : preliminary measurements (2018)

- **Dynamics measurements:**

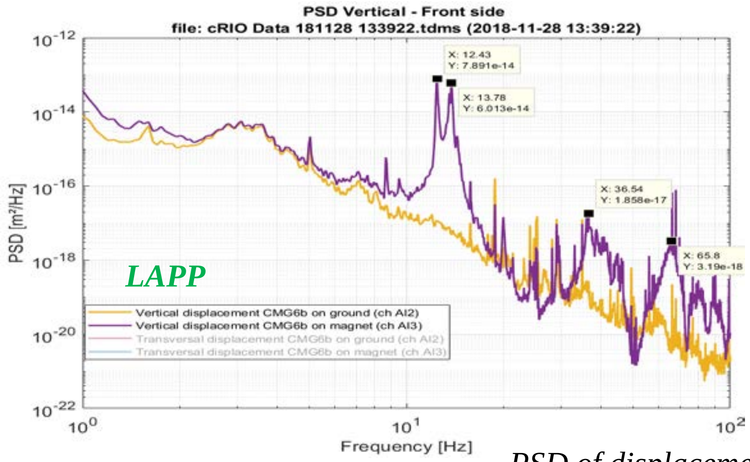


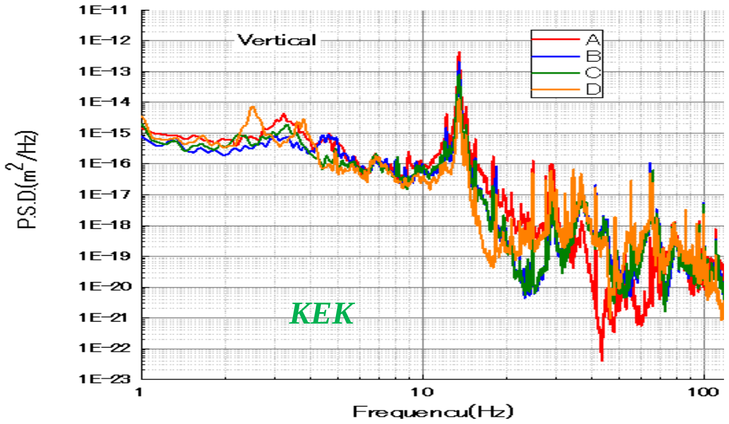


PSD of displacements on the cryostat (transversal direction)

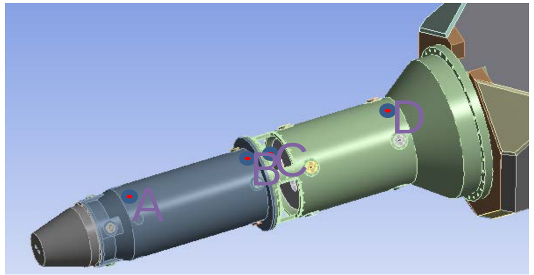


Dynamics measurements on the cryostat (LAPP)

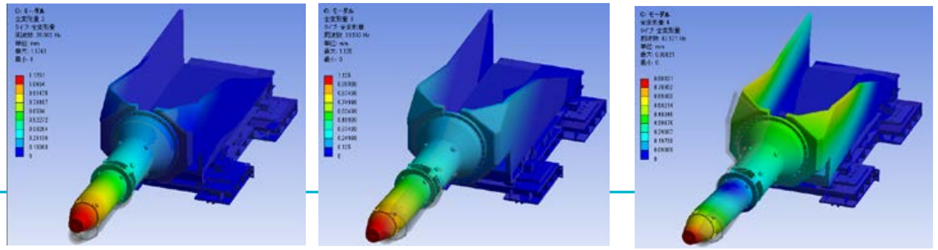




PSD of displacements on the cryostat (vertical direction)



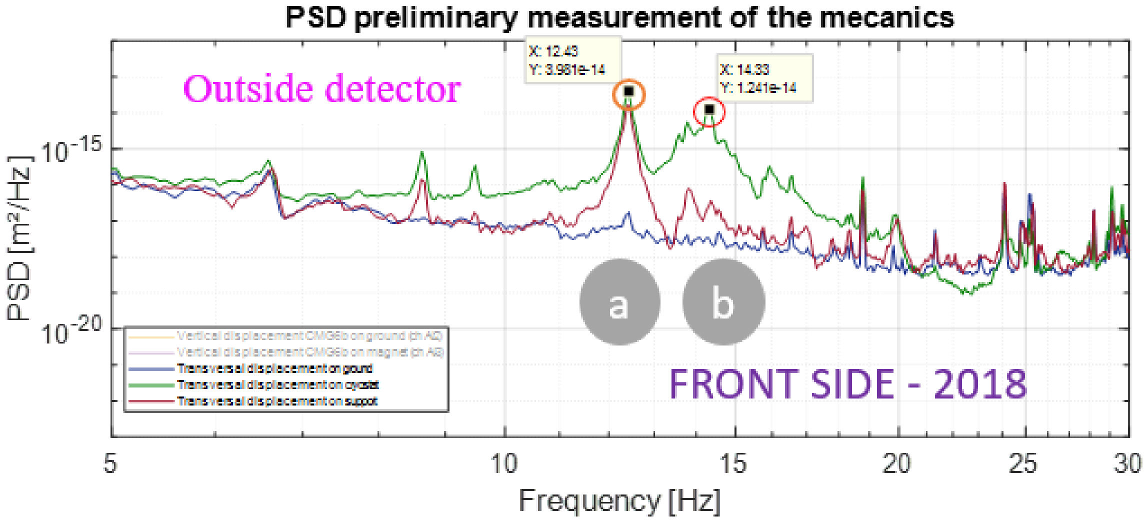
Design of the cryostat (KEK)

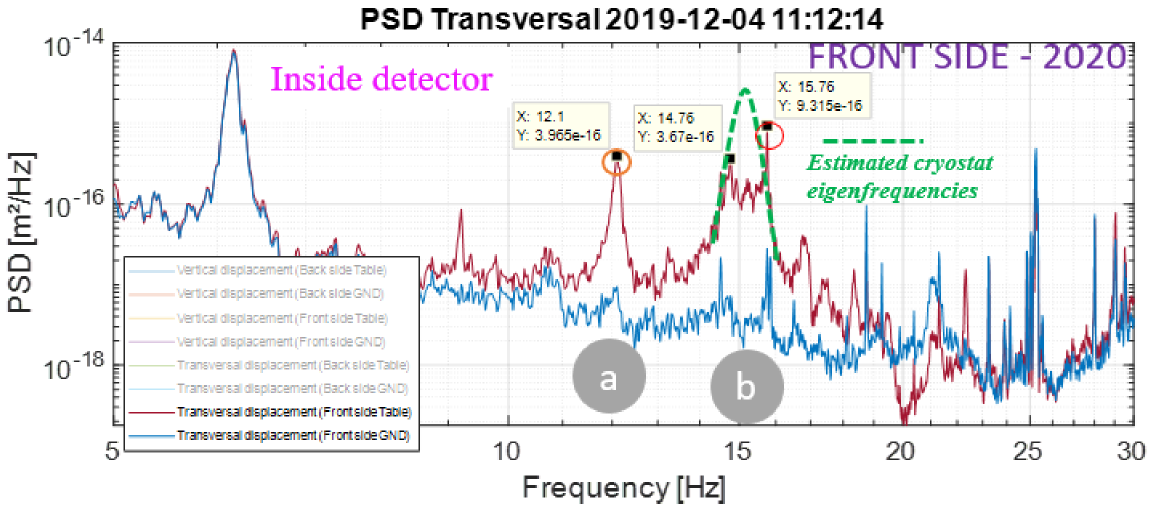


- **1st mode at about 15Hz**

Cantilever cryostat similarities

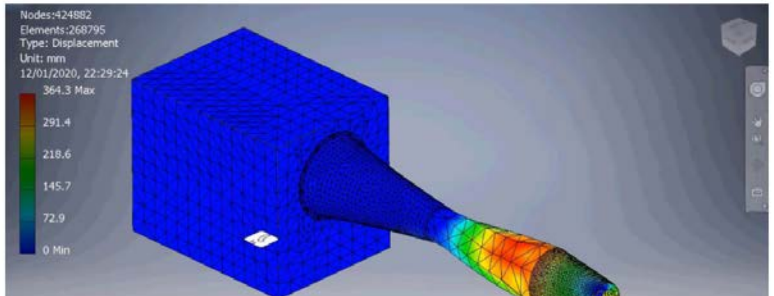
- **SuperKEKB cryostat:**





- o The eigenfrequencies have changed: Support (a) [12,4 -> 12,1] / Cryostat (b) [14,3 -> 15,7] and the amplitudes have changed
- o In the both cases, no information about the magnets themselves

- **FCC-ee cryostat:**
  - o SuperKEKB: first modes : 15 Hz (frontside) & 25 Hz (backside)
  - o A ratio of about at least 10 between the first flexion mode and the 1st twist mode seems reasonable
  - o FCC-ee : The first simulated twist mode (modelled by M. Koratzinos) is at about 300 Hz



M. Koratzinos

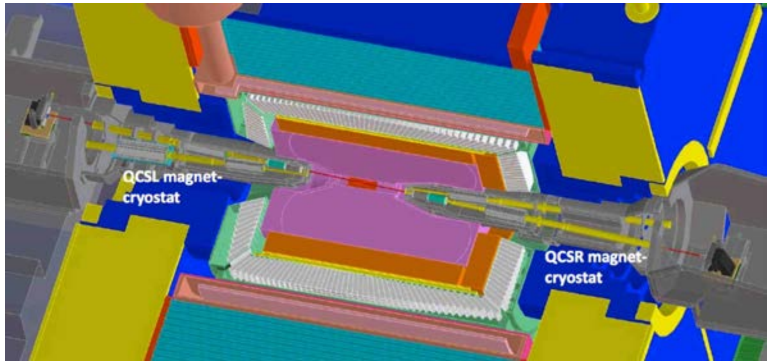
In my "version zero" toy mechanical simulation the twist mode (F9) had a main frequency of 306 Hz.

- ➢ **The limit conditions of the both cryostats are similar**
- ➢ **The indirect cryostat measurements allow to have an interpolation of the resonance modes**

SuperKEKB: luminosity measurements

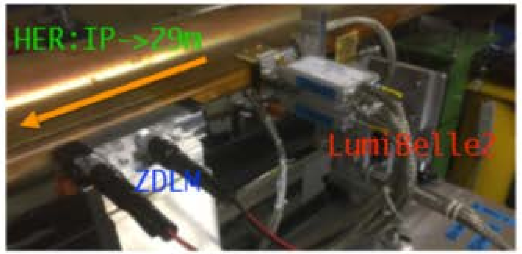
➢ Correlation between vibrations measurements and luminosity measurements

- 4 luminosity measurements (**IJClab**) 2 on the HER(e+) beam, 2 on the LER(e-) beam at 1 KHz
- About the same measurements (ZDLM) are done by **KEK**



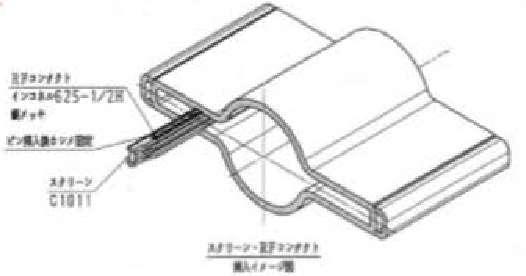
✦ Goal: fast relative luminosity monitoring based on radiative Bhabha scattering as input to SuperKEKB IP dithering orbit feedback system (and for machine tuning and backgrounds studies)

- **Train Integrated Luminosity (TIL)**: ΔL/L ~ 1% @ 1 kHz
- **Bunch Integrated Luminosity (BIL)**, 2500 bunches/train, 4 ns, ~ 1% @ few Hz



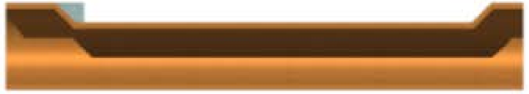
✦ Radiative Bhabha process at vanishing photon scattering angle

- Rate proportional to Luminosity
- Large cross section ~ 0.2 barn



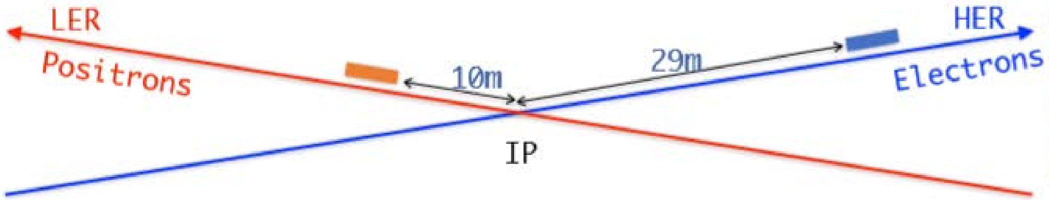
✦ Two complementary techniques from LAL and KEK:

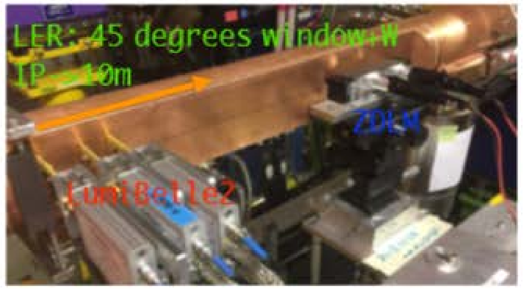
- ➢ **LumiBelle2 (LAL): sCVD diamond detector ~ 4.5x4.5x0.5/0.14 mm³**
- ➢ **ZDLM (KEK) Cherenkov detector + scintillator + PMT**



✦ Two commonly optimised locations:

- 10m downstream of IP in LER ⟶ Bhabha positrons
- 29m downstream of IP in HER ⟶ Bhabha photons





C. G. PANG (LAL) Fast luminosity monitoring @ SuperKEKB 6

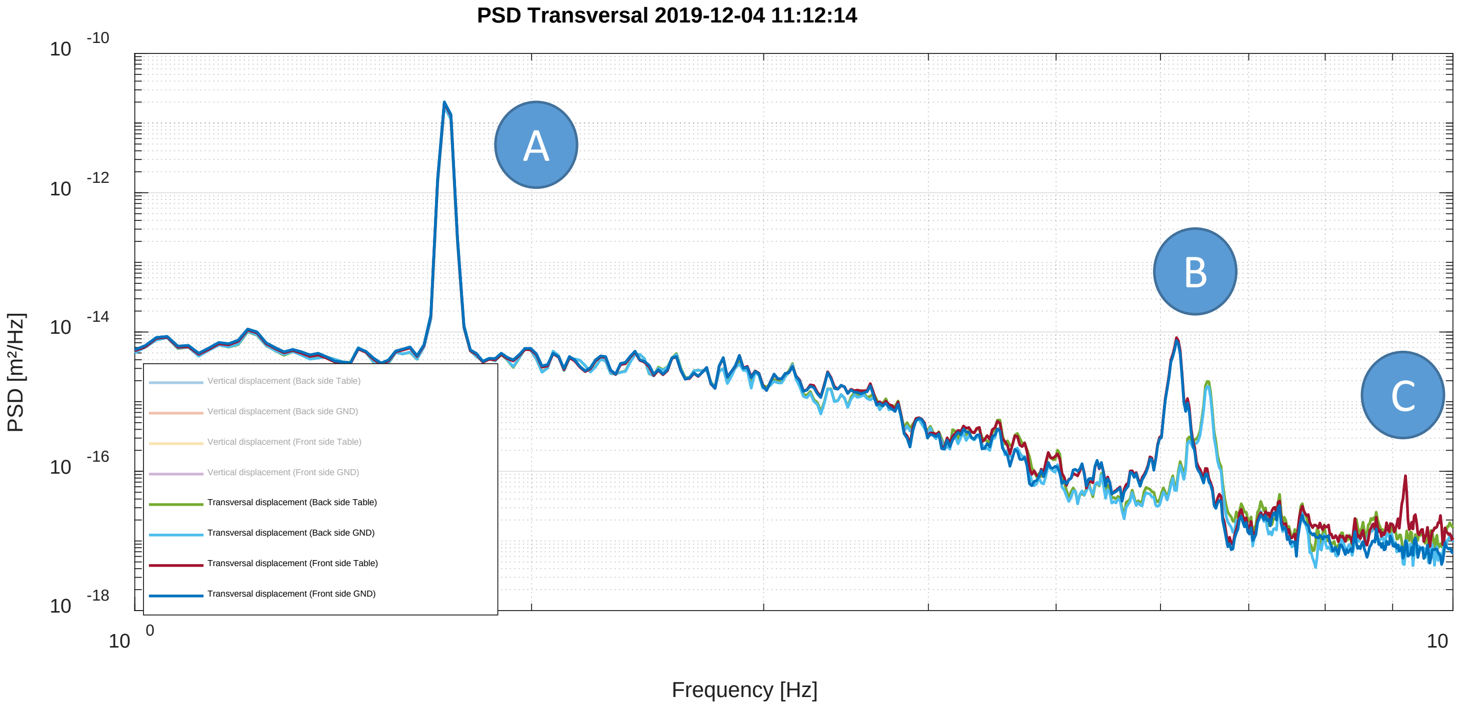
SuperKEKB : target of the correlation study (vibrations vs luminosity)

- The luminosity dynamics part is not present without disturbance: steady luminosity
- The luminosity disturbances come from various sources

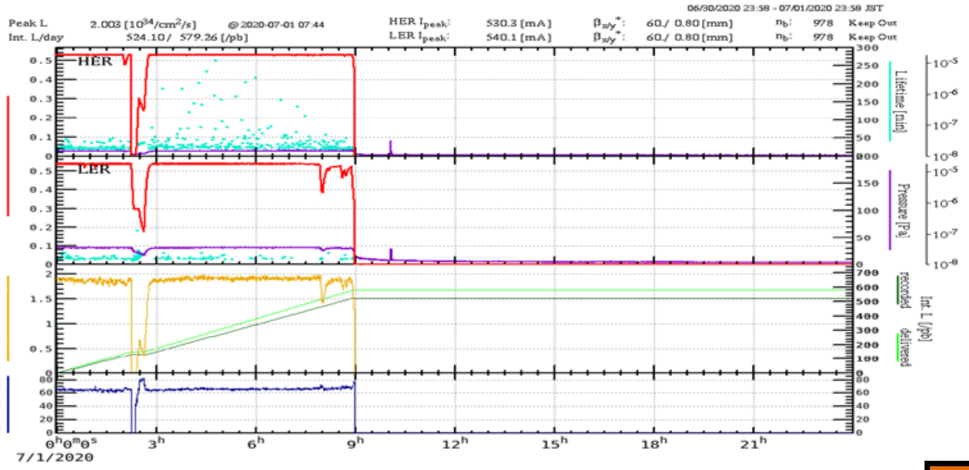
Variation of the luminosity in function of the disturbances in term of type, frequency, direction, amplitude…

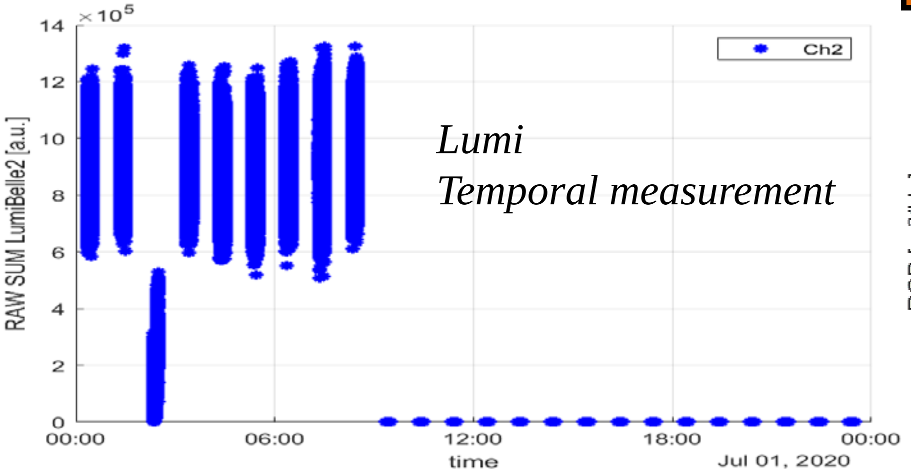
Types of disturbances:

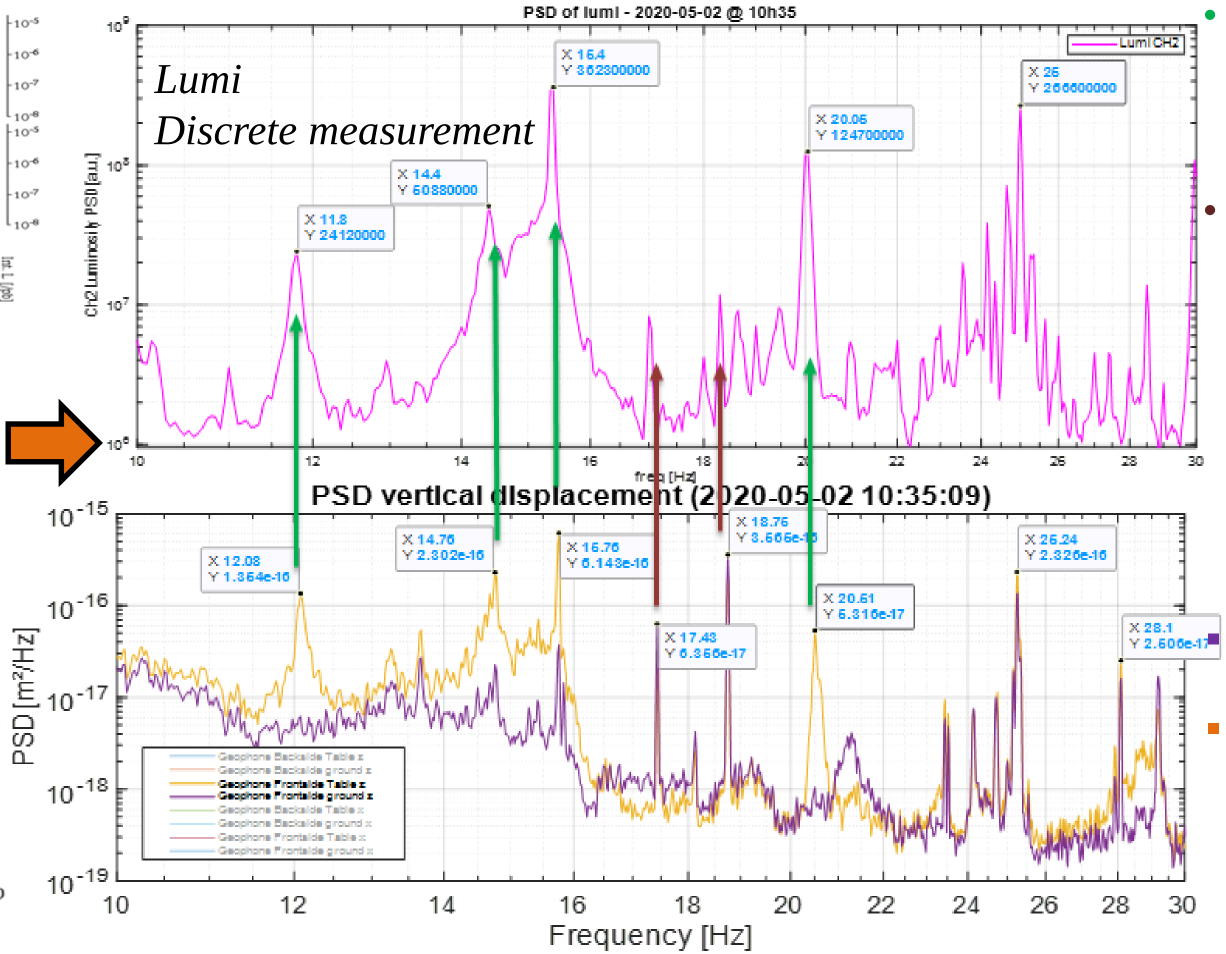
- A: perturbations (external?) **coherent at the both sides** of the detector and **not amplified by the mechanics** (low frequency) – distant source?
- B: perturbations (external?) **not coherent at the both side and not amplified by the mechanics** – local source?
- C: eigenfrequency – **mechanics or a source on the cryostat support** (not measure on the ground)



- **Method:**
  - *To understand the impact of vibrations on the beam with a disturbance that is either coherent on the whole accelerator (ex: seismic motion), or localized (ex: pump) or amplified by mechanics (ex: cryostat resonance mode of the asymmetric final focus)*

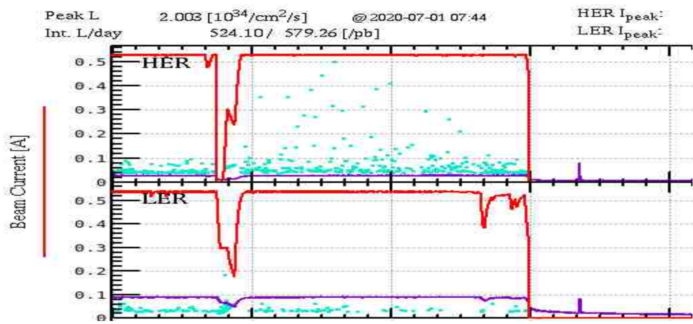




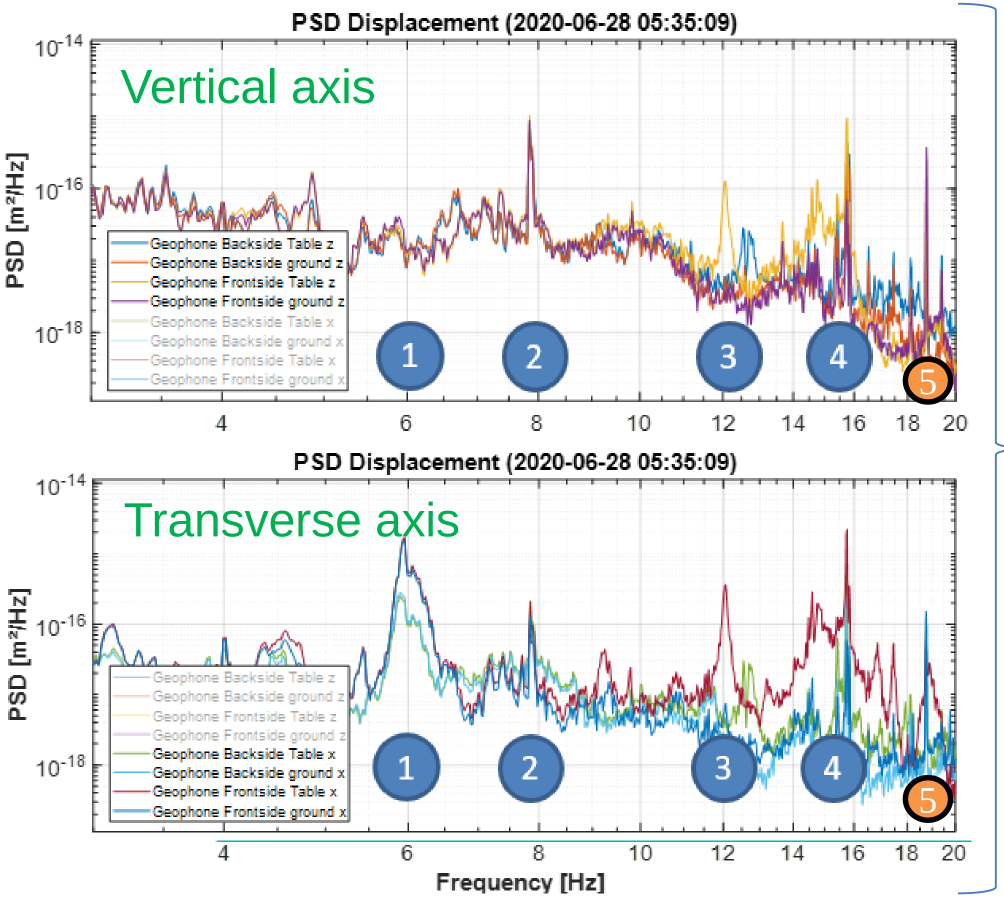


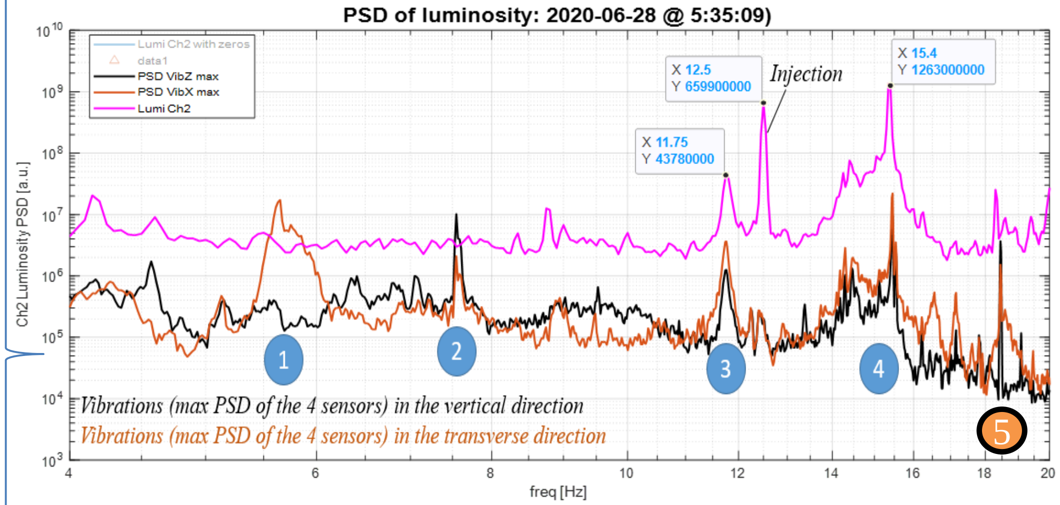
- Front side cryostat resonance modes -> relevant influence on the luminosity
- Coherent disturbance at both sides of the BelleII detector : few or no influence on the luminosity
- *Vibrations on the ground*
- *Vibrations on the cryostat support*

SuperKEKB: correlation vibrations - luminosity



- **Analysis method:**





PSD of displacements on the cryostat (transversal direction)

1
- Only transverse direction
- No transfer function GND Support
- Partially coherent at the both sides of the detector
  - ➢ *0 correlation*

2
- Transverse and vertical direction
- No transfer function GND Support
- Coherent at the both sides of the detector
  - ➢ *0 correlation*

3
- Transverse and vertical direction
- Mecanics mode (transfer function GND – support)
- Only at one side of the detector
  - ➢ *correlation*

4
- Transverse and vertical direction
- Mecanics mode (transfer function GND – support)
- Only at one side of the detector
  - ➢ *correlation*

5 More complex case…

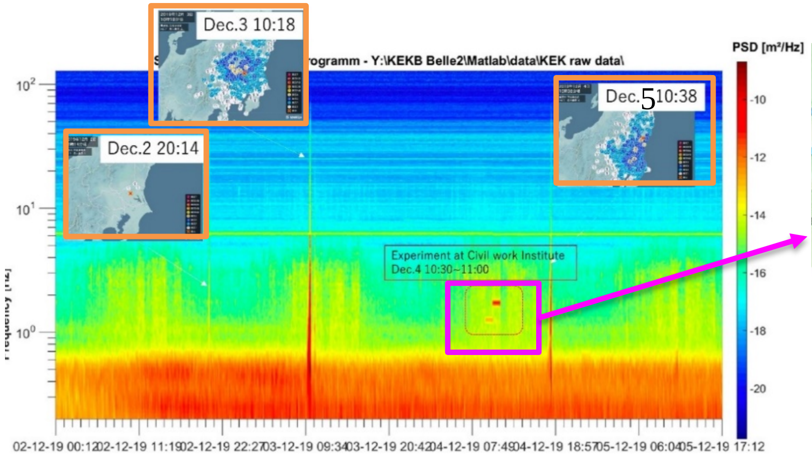
- Carry out a systematic analysis (under Matlab) according to the vibrations measurements (direction, max, diff, coherence…), the beam intensity, the measured luminosity, the beam control… in progress!
- Correlation method, criteria ...

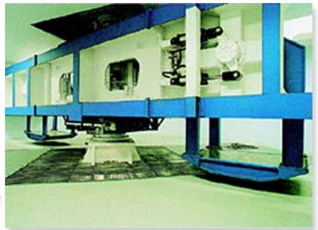
➢ **Objectives :**

- To evaluate the vibrations effects on the beam
- **To identify the common issues with FCC-ee, in particular with the increasing of the beam intensity**

SuperKEKB: correlation vibrations - luminosity

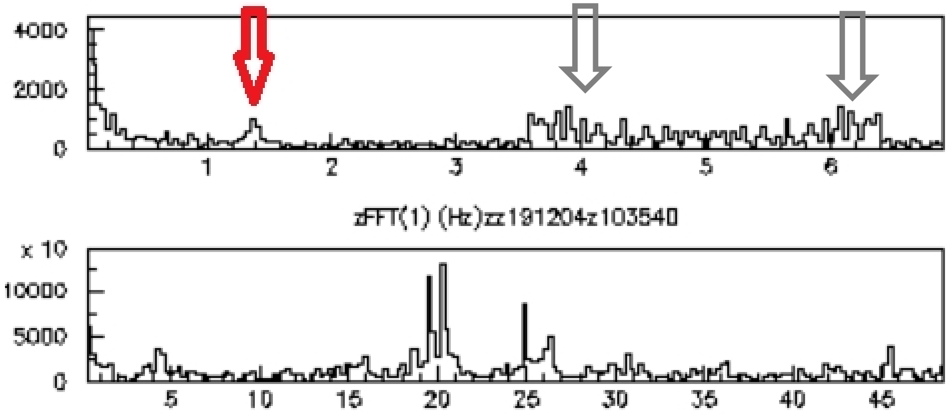
- **The limits (the tolerances…):**



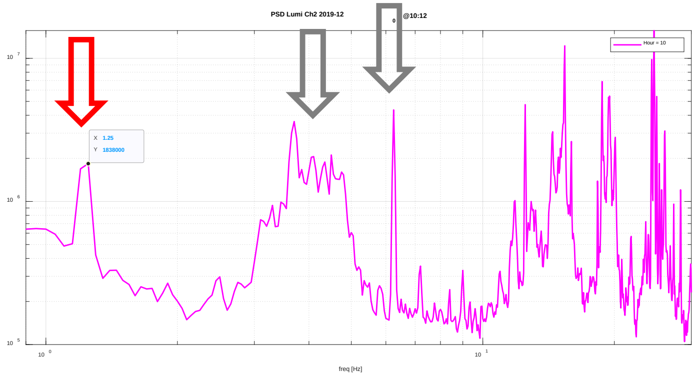


Experiment of accelerate centrifugal force close to KEK

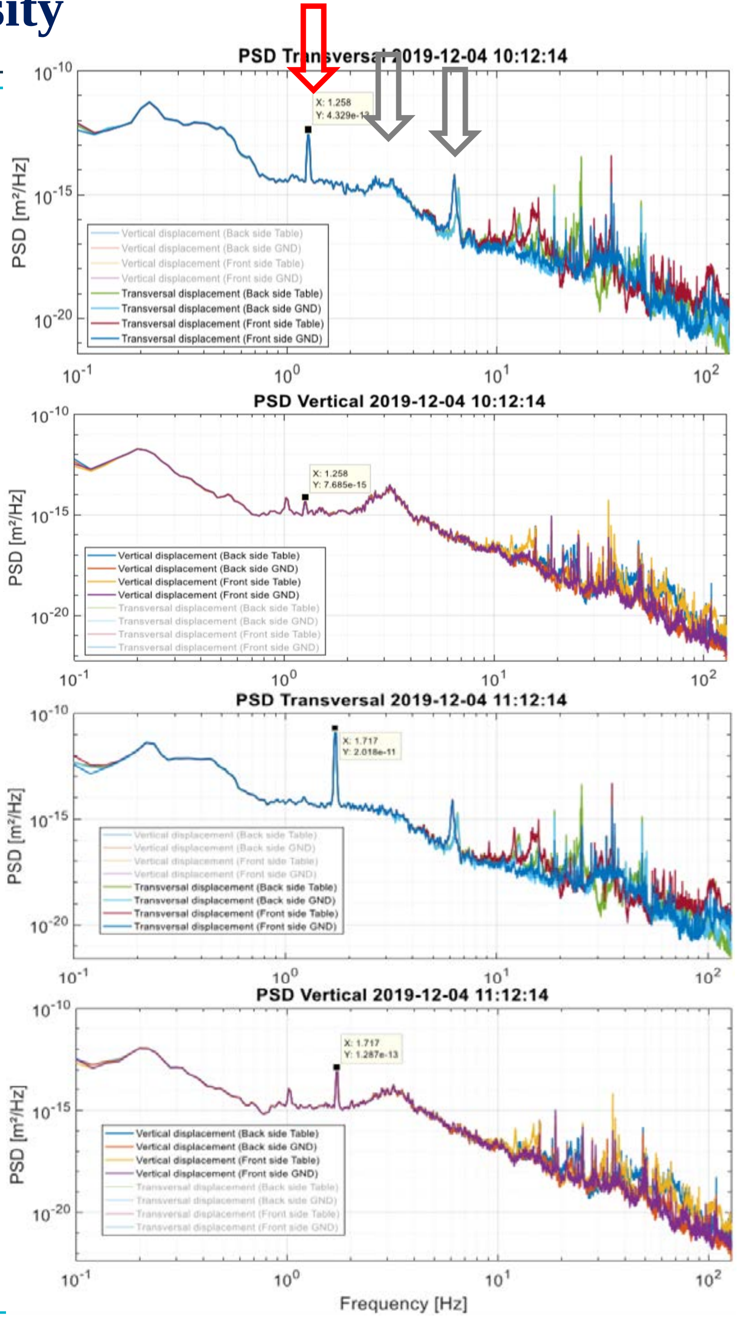
Vibration analysis: earthquake and external perturbations



FFT of the ZDLM luminosity (KEK)

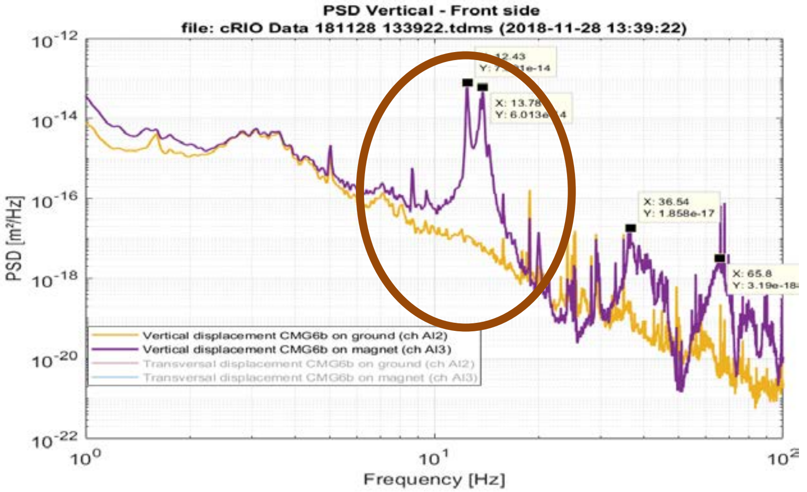


PSD of the luminosity (IJClab) at the beginning of the acceleration phase

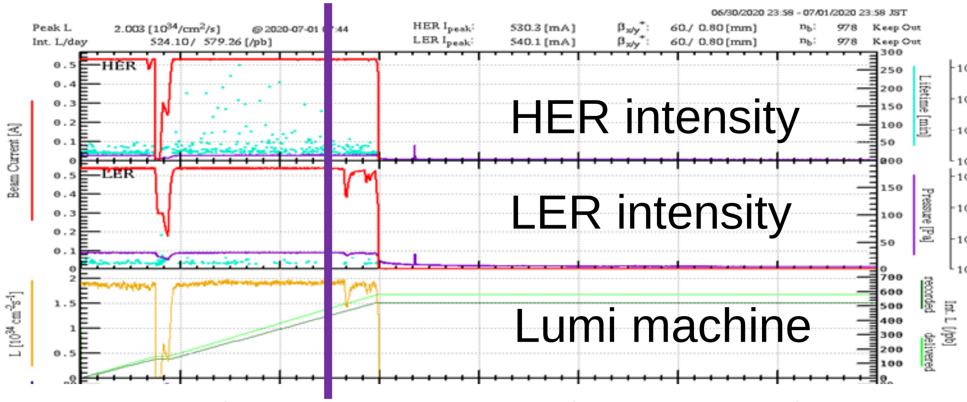


- The peak [1,2 – 1,7] Hz is measured (during the acceleration phase) by the luminometers and by the seismic sensors even if the disturbance effects are coherent for the four sensors…

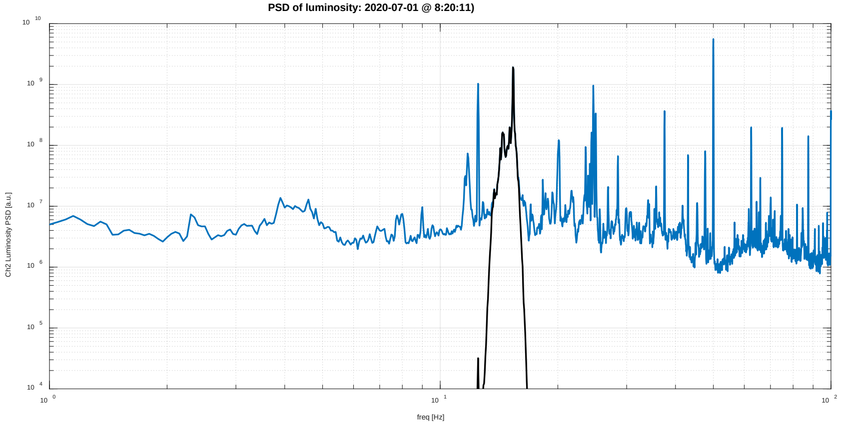
- **A specific aspect: influence of the first flexion mode of the front side cryostat**



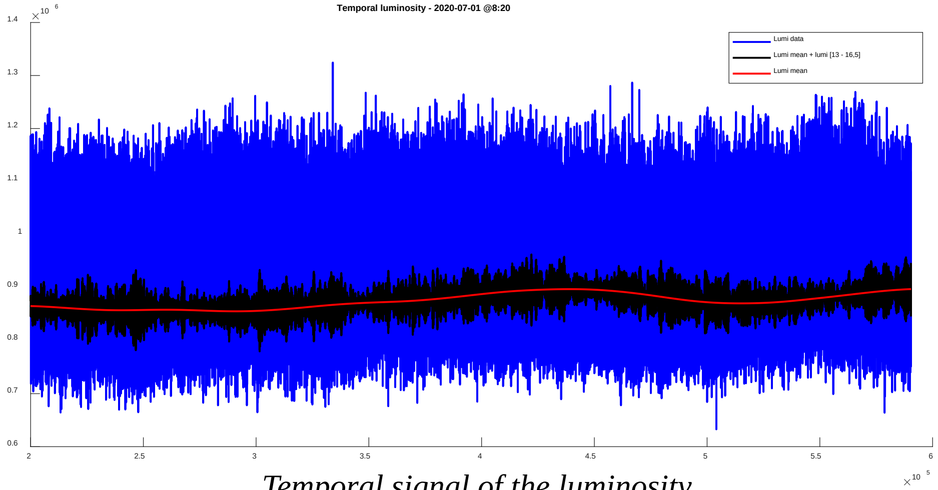
PSD of displacements on the cryostat (vertical direction)



Analysis just before the shunt down (max of intensity) – 1st of July 2020



PSD of luminosity – filtered in black (first flexion mode)



Temporal signal of the luminosity

Luminosity data

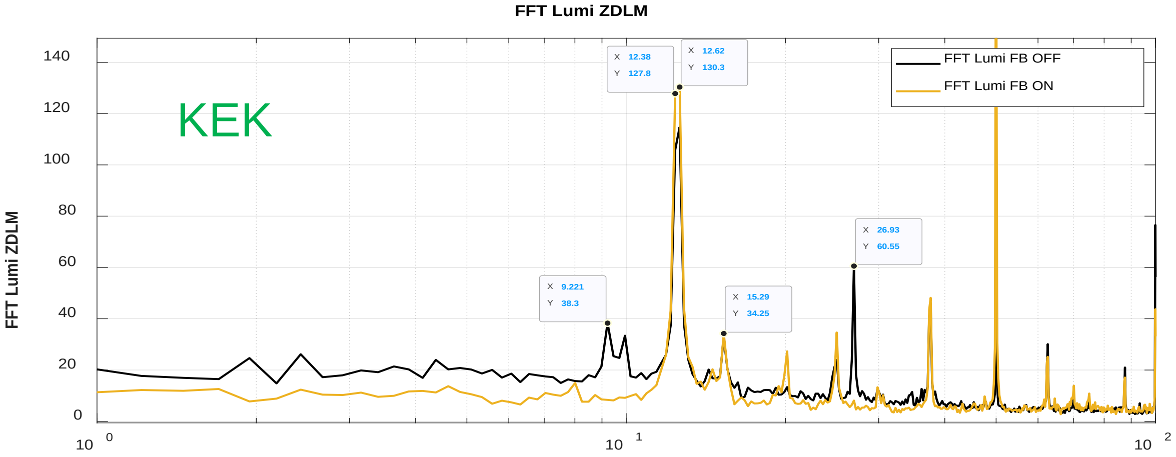
Mean of the luminosity

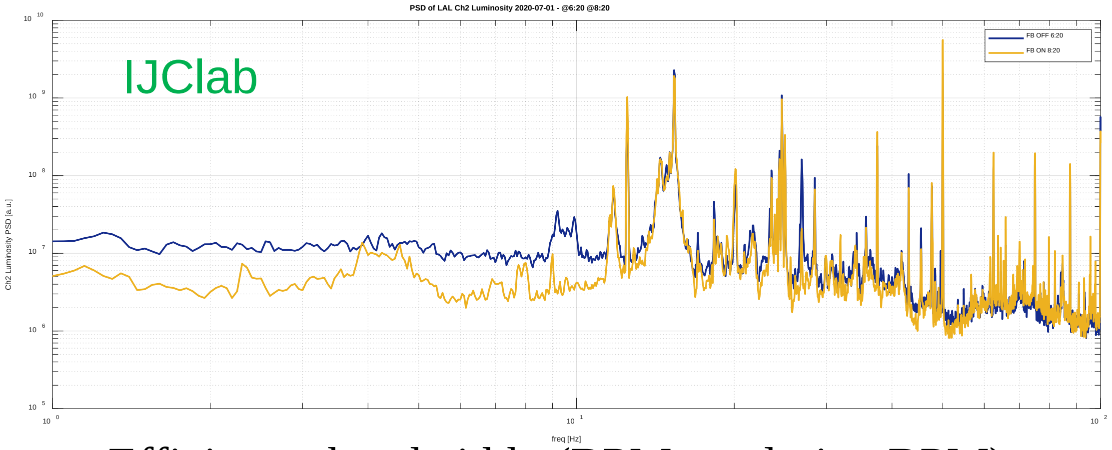
Mean + bandwidth equals to the 1st mode

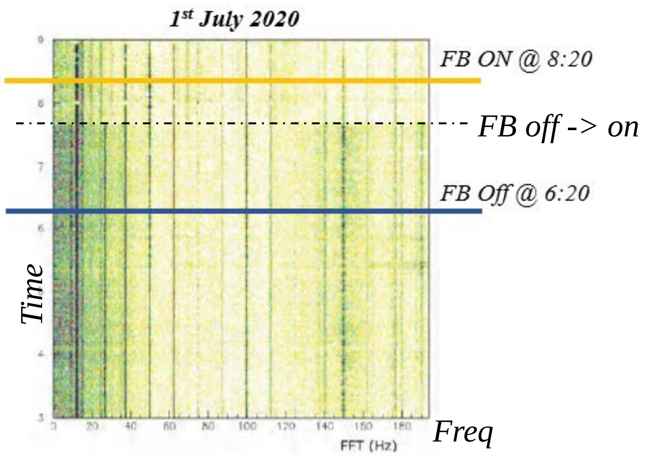
➢ **Each resonance mode reveals a significant disturbance of the luminosity**

SuperKEKB : IP Beam feedback

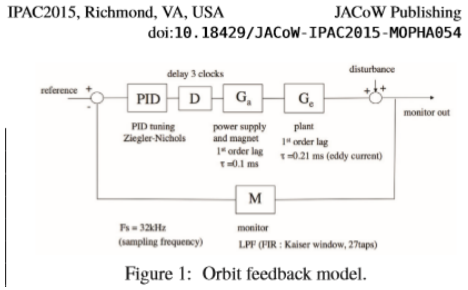
- **Vertical beam feedback with IP BPM & kickers**

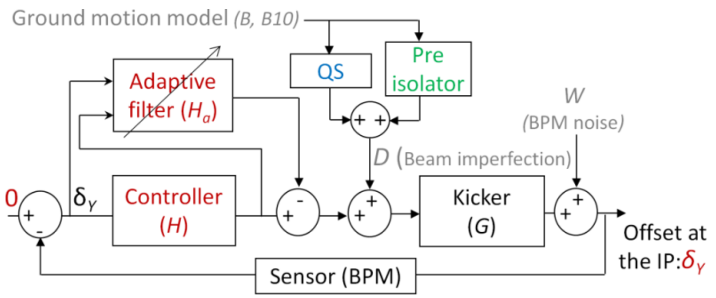




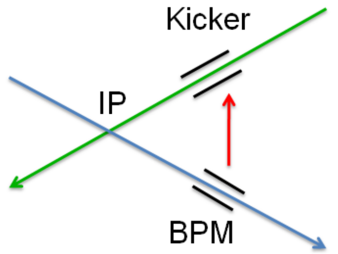


3D spectral measurement of ZDLM lumi (KEK)





Similar feedback developed for CLIC
Feedback and adaptive control scheme



Principle

- o Efficiency, bandwidth, (BPM resolution BPM)
- o Type of control

➢ **SuperKEKB is a great opportunity to test such controls…**

Conclusions & prospects

- **Status:**
  - A lot of similarities SuperKEKB – FCC-ee
  - Vibrations & luminosity data are available in real time
  - Correlation between vibrations and luminosity are identified
  - Some cases are specific to SuperKEKB
  - Some peaks analysis in low frequency seem to confirm the theoretical approach with the coherence and the multi –turns experiments specificities but in certain limits which have to be evaluated…
  - Some other more complex situations have to be more investigated…
  - IP feedback

➢ **SuperKEKB is a great experiment which could be very helpful to study the vibration mitigation aspects of FCC-ee**