Vibrations Impact on FCC-ee's Luminosity

Estimations Based on a Simple Girder Mock-Up

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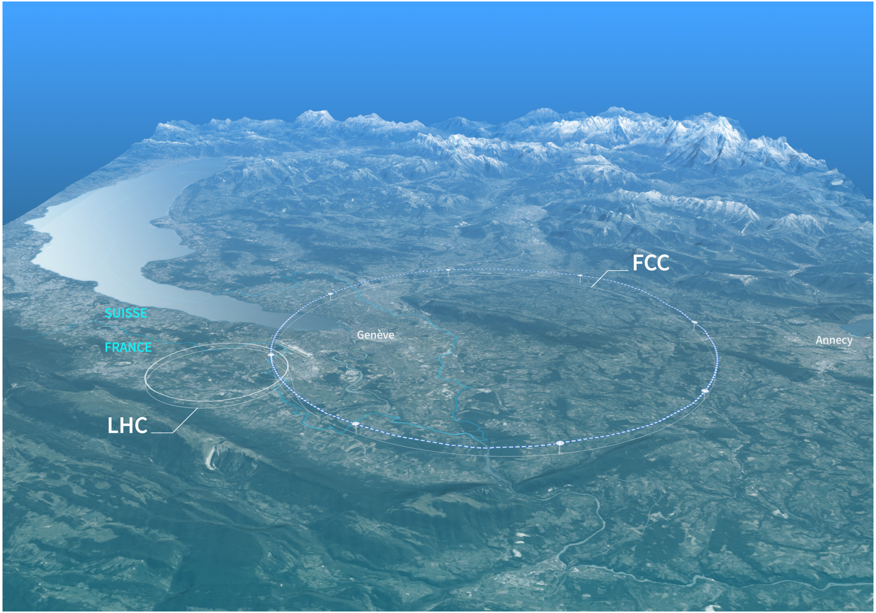
FCC Context

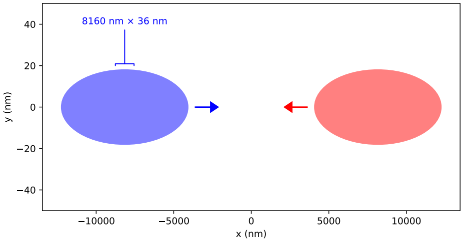


FCC Context

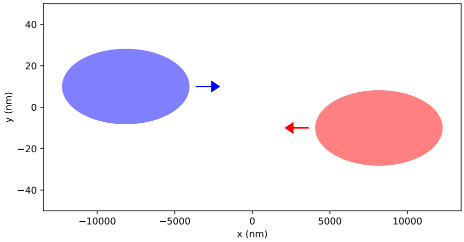
Operation Mode	**Z**	**WW**	**ZH**	**$t\bar{t}$**
Beam energy [GeV]	45.6	80	120	182.5
Circumference [km]	90.66			
SR power / beam [MW]	50			
RF frequency [MHz]	400.8			
$\beta^*_{x/y}$ [mm]	110 / 0.7	220 / 1	240 / 1	900 / 1.4
Energy loss / turn [GeV]	0.0387	0.369	1.86	9.93
Colliding bunches / beam	11200	1856	300	60
Colliding bunch population [10^{11}]	1.8	1.38	1.69	1.58
ε_x at collision [nm]	0.71	2.16	0.66	1.65
ε_y at collision [pm]	2.1	2.0	1.0	1.32
Luminosity / IP [10^{34} cm^{-2}s^{-1}]	144	20	7.5	1.45

- Same-ish lattice for all modes
- Currently two lattices under consideration: LCC and GHC
- *pencil* beam: nanometer level, wide and short

Introduction



Cool

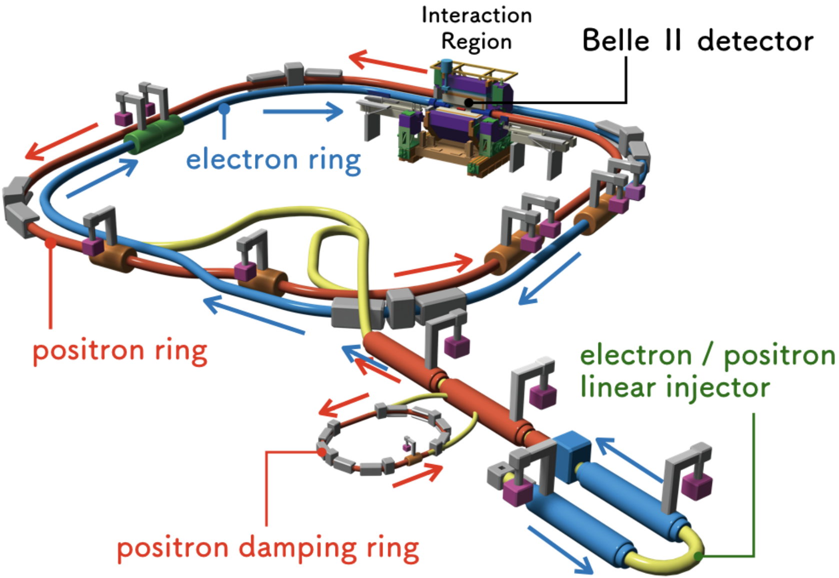


Not cool

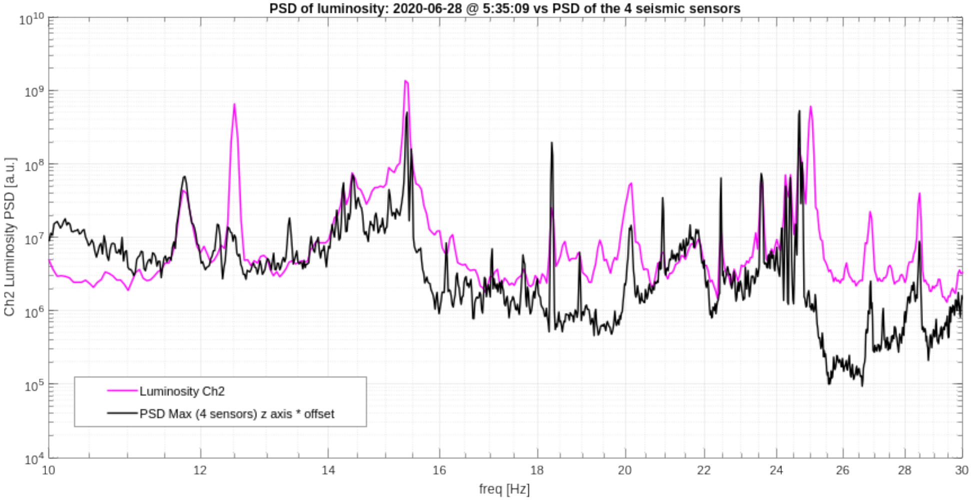
- **First estimate** of vibration effects on beam position and luminosity
- **Check approach**, trying to see if the approach makes sense

$\rightarrow$ Establish baseline on Z mode for more detailed studies

SuperKEKB


Interaction
Region
Belle II detector
electron ring
positron ring
electron / positron
linear injector
positron damping ring

Luminosity and Vibrations

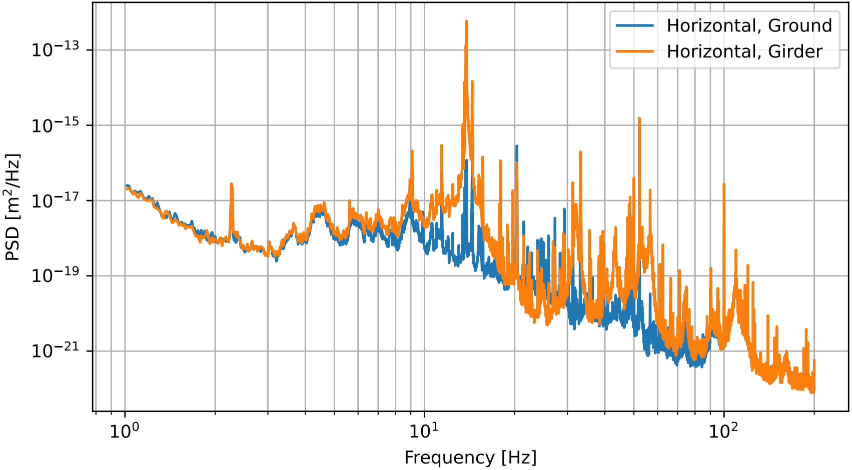


Correlation between vibrations and luminosity shown at SuperKEKB

Background & Girder Measurements

Vibration measurements done on vertical/horizontal planes by engineering teams[1]:

- On the ground
- On a granite girder

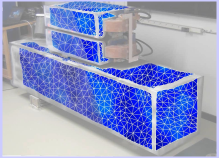
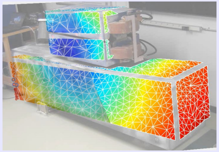


[1] https://edms.cern.ch/document/2919485/1

Girder Modes

Resonant frequencies and damping:

- 2 main modes considered, one per plane, only translations for now[2]

Mode number	Mode shape		EXP frequency	SIMU frequency	Damping* found via SIMU
Mode#01		Tilting around X	14.0 Hz	13.6 Hz	0.0045
Mode#04		Up and Down + Tilting Y	73.1 Hz	76.7 Hz	0.01

[2] Given by Audrey Piccini (EN-MME)

Transfer Function Analysis

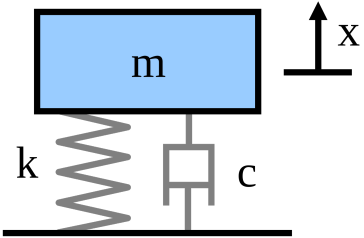
Ground-to-girder amplification can be modeled with transfer functions

$$H(f) = \frac{1}{1 - \left(\frac{f}{f_n}\right)^2 + \left(i \cdot 2 \cdot \zeta \frac{f}{f_n}\right)}$$

Where:

- f: frequency [Hz]
- f_n: resonant frequency [Hz]
- ζ: damping ratio

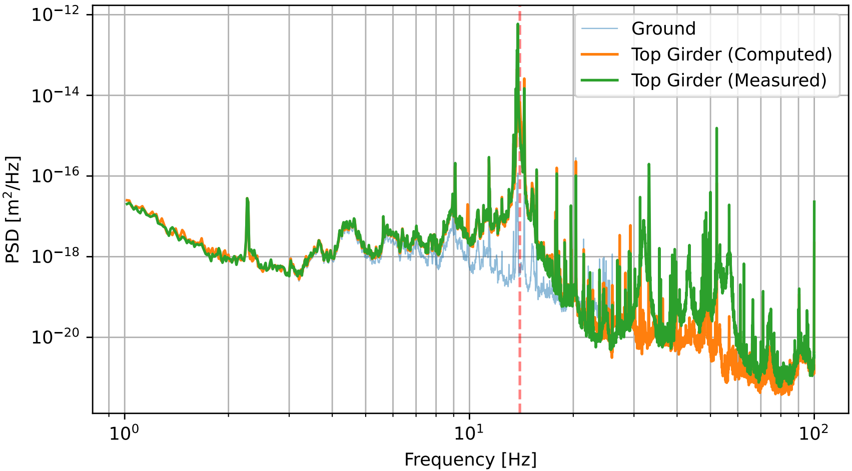
Mass-Spring-Damper model



Transfer Function Validation

Ground + transfer function should equal the measurement on top of the girder

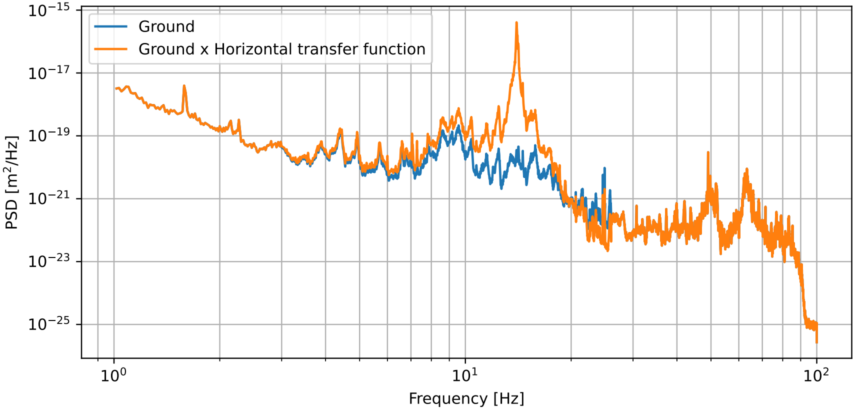
- Horizontal PSDs (~14Hz):



Tunnel Measurements

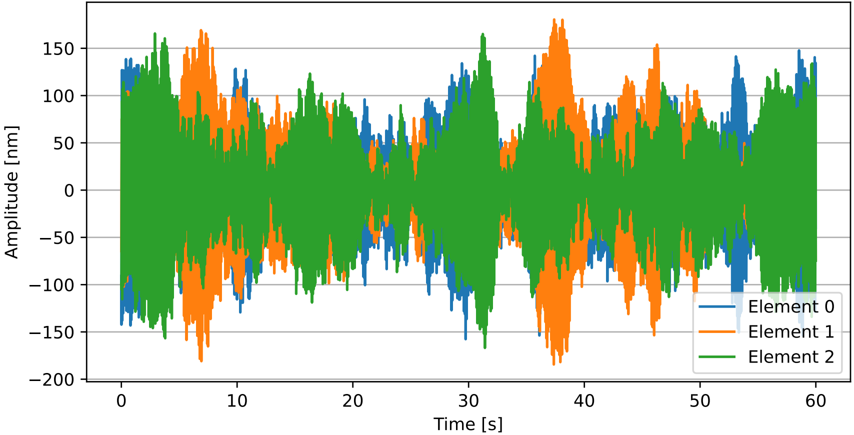
Vertical ground measurements were performed, horizontal is assumed similar

- Horizontal PSD with transfer function applied:



Time Series Generation

- Random phases are assigned to frequency components
- Different seeds create uncorrelated element motions
- 1800+ individual elements simulated, to be paired with each quadrupole

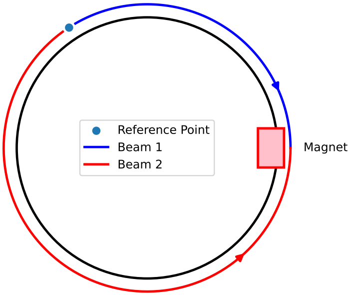


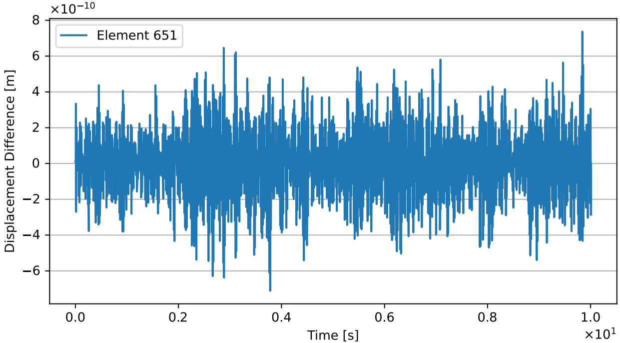
Beam-Dependent Displacements

Beam 1 and Beam 2 will experience a different displacement at the same element

- Due to inverse direction and "slow" speed

=> Higher frequencies, despite low amplitudes, will create larger differences

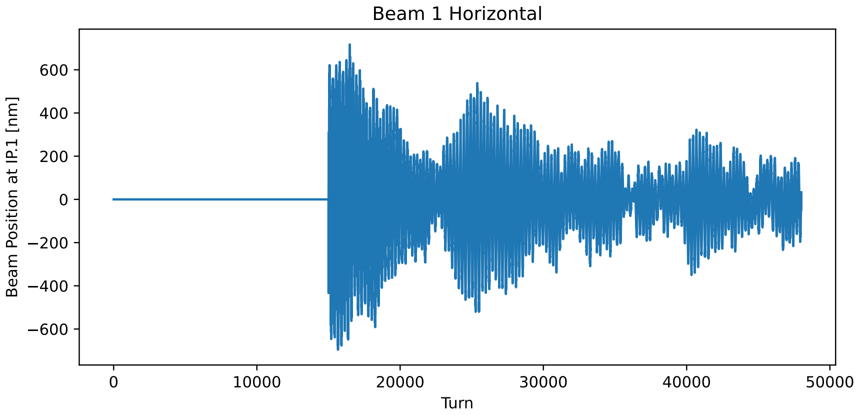




Tracking Simulation

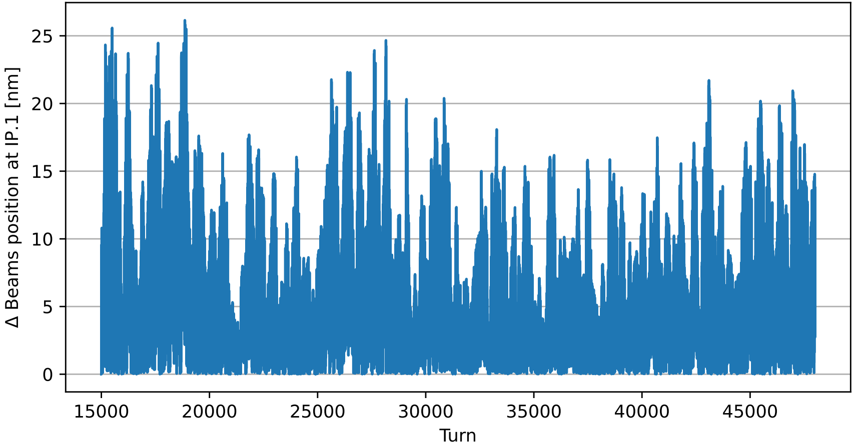
- 15,000 "empty" turns for baseline check
- 33,000 turns with vibrations (10 seconds), on both planes
- ~1800 quadrupoles with independent motion

=> Record position at IP.1

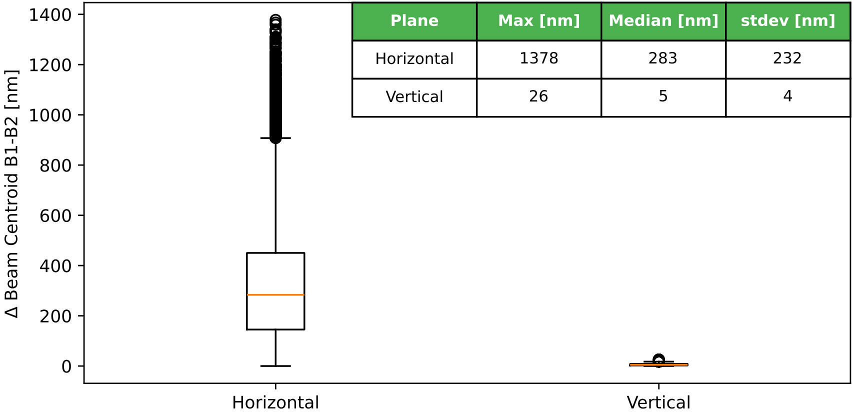


Beam Separation Results

Vertical beam separation at IP1:



Statistical Analysis

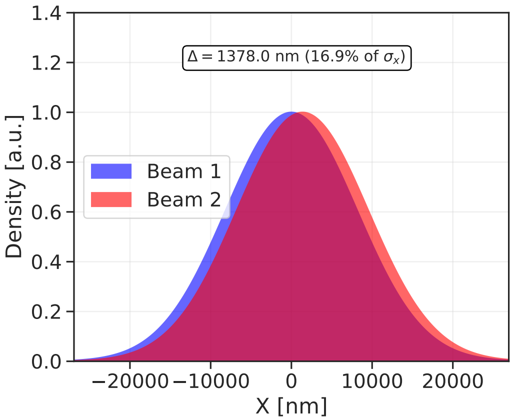


Plane	Max [nm]	Median [nm]	stdev [nm]
Horizontal	1378	283	232
Vertical	26	5	4

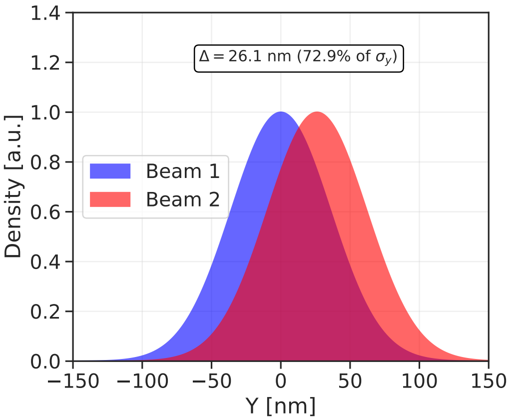
- 90% percentile offsets:
  - Horizontal 655×10^{-9} m
  - Vertical 12×10^{-9} m

Displacement vs Beam Size

At the maximum displacements, the beam distributions would look as below



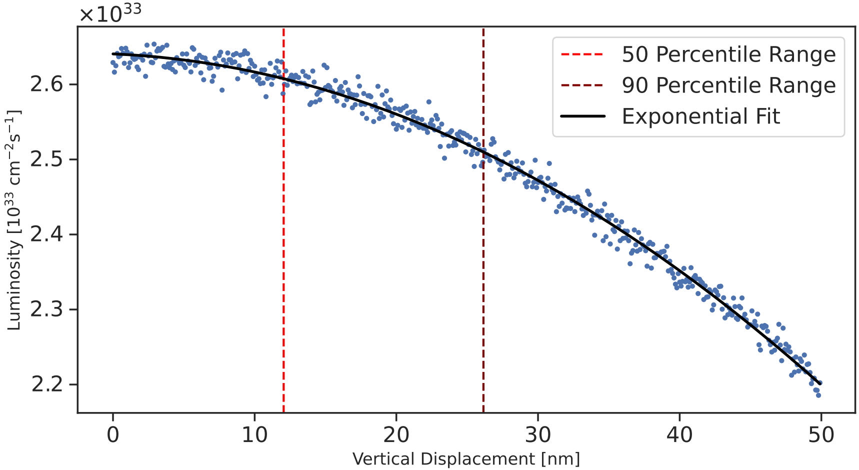
Horizontal displacements are small



Vertical displacements are large

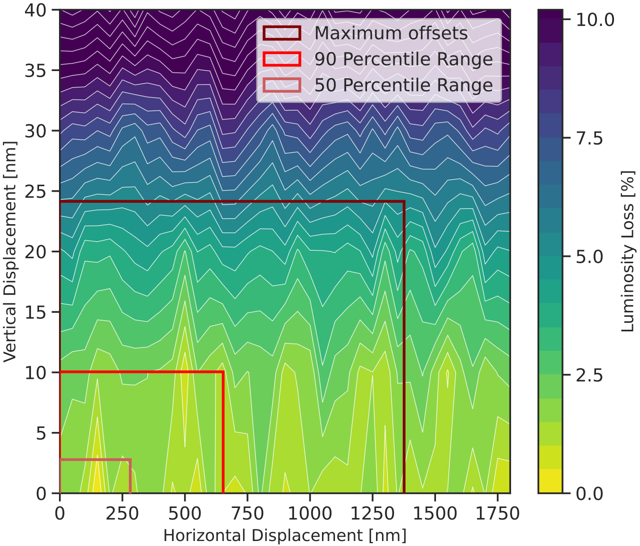
Luminosity Impact

- Luminosity is computed via a line with one beam-beam element
- Fixed emittance
- Only variable is the offset



Simulated range shows minimal luminosity loss for these vibration levels

Luminosity Impact



Only the vertical offsets have an impact, as expected $\Rightarrow$ remains small

Conclusions

Current Results:

- Calculations, simulations and methodology implemented
- Horizontal and vertical displacements on quadrupoles
- Vibrations give nanometer level beam offset at IP.1 in **first estimate**

Current limitations:

- Angular displacements of quadrupoles not included
  - Measurements not performed
  - No asymmetry between beams
- Vibration modes are *simplified*
- Emittance change not accounted for
- Crossing angles not accounted for
- No field errors or misalignments
- Beam 2 is a mirror of Beam 1