Follow up on vibration studies: estimation of the impact at the collimators

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Many inputs from previous works of M. Guinchard, M. Schaumann, M. Fitterer, J. Wenninger, P. Fessia, D. Valuch, et al.

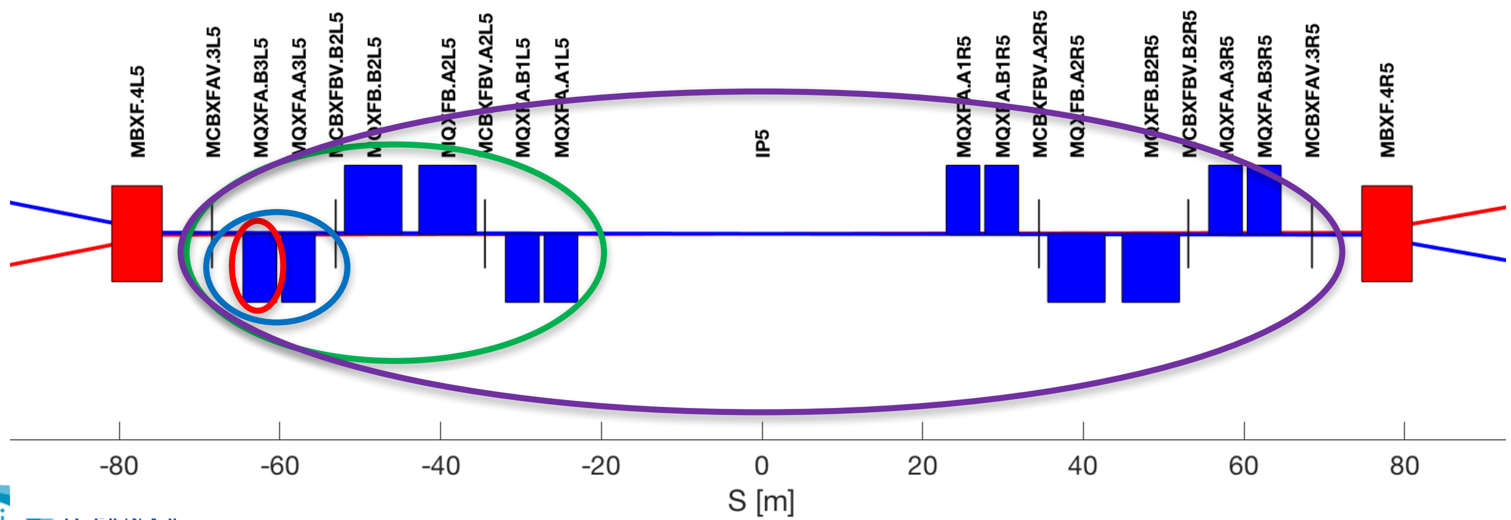
99th HiLumi WP2 Meeting – 25/07/2017

Outiline

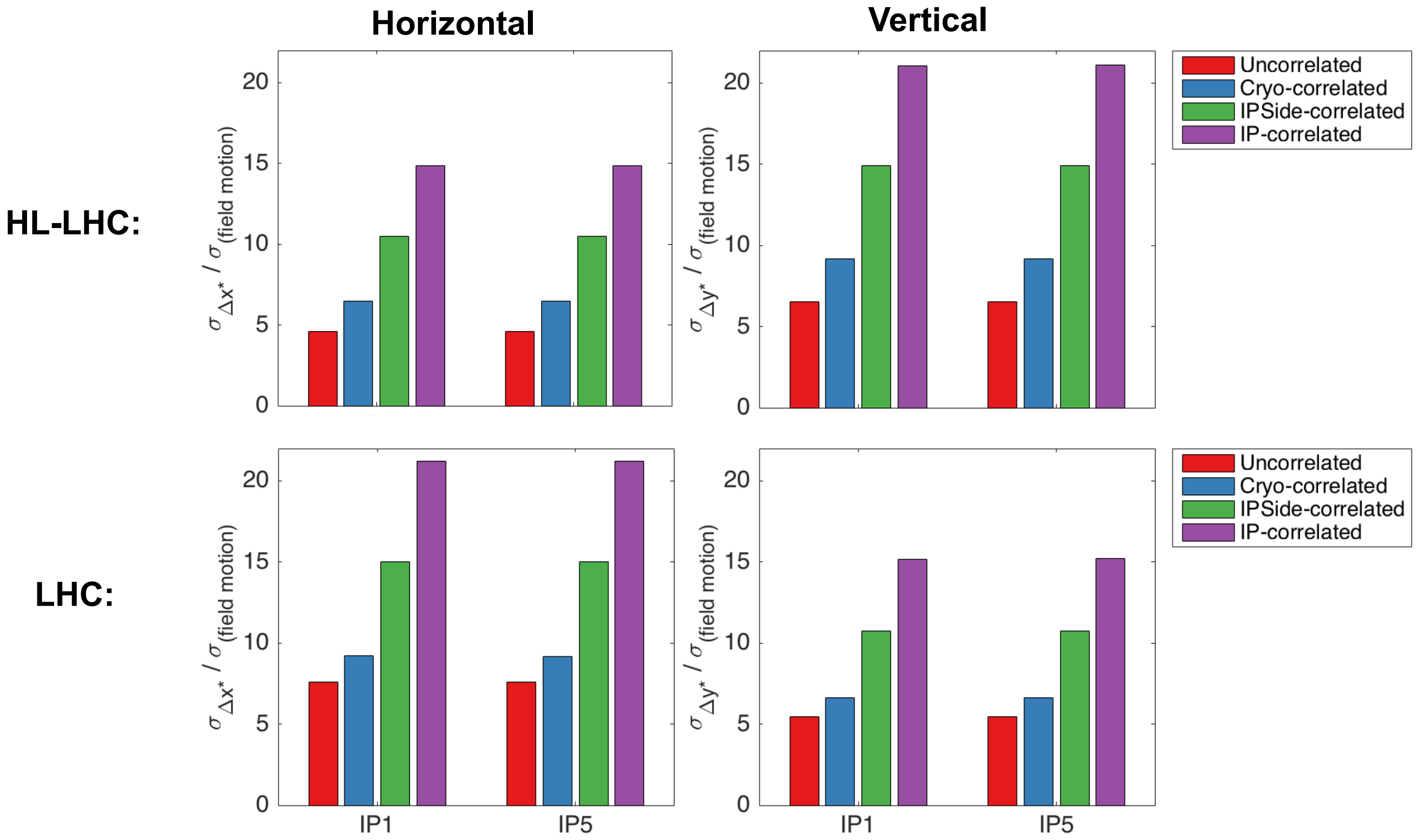
- Recap from my previous presentation.
  - Initial picture slightly changed.
- New calculations:
  - Normalisation with respect to beam sigma.
  - Luminosity reduction estimation.
  - Amplification effects at collimators.
- Recap on actual ground motion estimation.
  - Amplification of cold mass.
  - Old measurements/estimations.
- TODO list

From previous meeting

- Computing closed-orbit **separation** at the IPs under the effect of triplet **transverse** misalignments.
- "**Best case**" scenario:
  - Each element moves independently from the others.
  - **Sum in quadrature of each single element effect**
- "**Worst case**" scenario:
  - The whole IR moves coherently according to the worst mode.
  - **Sum of the absolute effects within each IR, then in quadrature over the 4 IRs**



Conclusions from previous meeting:



- The main concern is the factor 2 smaller (nominal) beam size at IP1/5 with respect to LHC.

Optics now analyzed

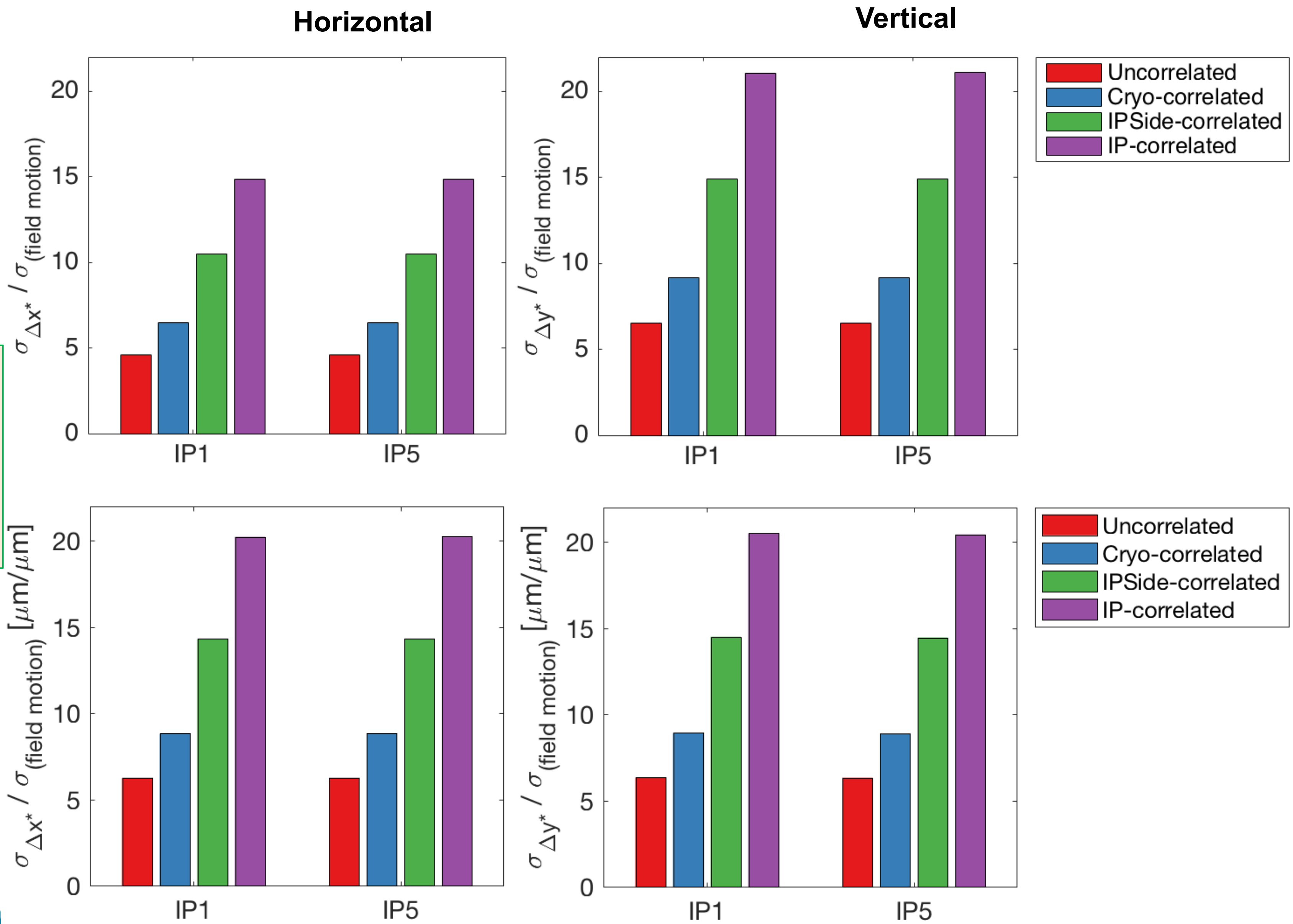
- HL-LHC 1.3 **July 2017** (**≠ January 2017**):
  - **β* = 15cm (as in January, even if present baseline is 20 cm)**
  - on_x1=255; phi_ir1 = 90; on_x5=255;
  - on_x2=170; phi_ir2 = 90; on_x8=-250;
  - on_lhcb=-1; on_alice=1;
  - E = 7 TeV; σ_E = 1.08e-04; ε_N = 2.5 μm
- LHC (runII/2016/opt_400_10000_400_3000_totem5.madx)
  - β* = 40cm
  - on_x1 =-185; on_x5 =185; on_x2 = 200; on_x8 = -250;
  - on_sep(1258)=0; on_o(1258) = 0;
  - E = 6.5 TeV; σ_E = 1.13e-04; ε_N = 3.75 μm

Repeated simulations.

HL-LHC 1.3 January

Probably different phase advance. **To be re-checked**

HL-LHC 1.3 July



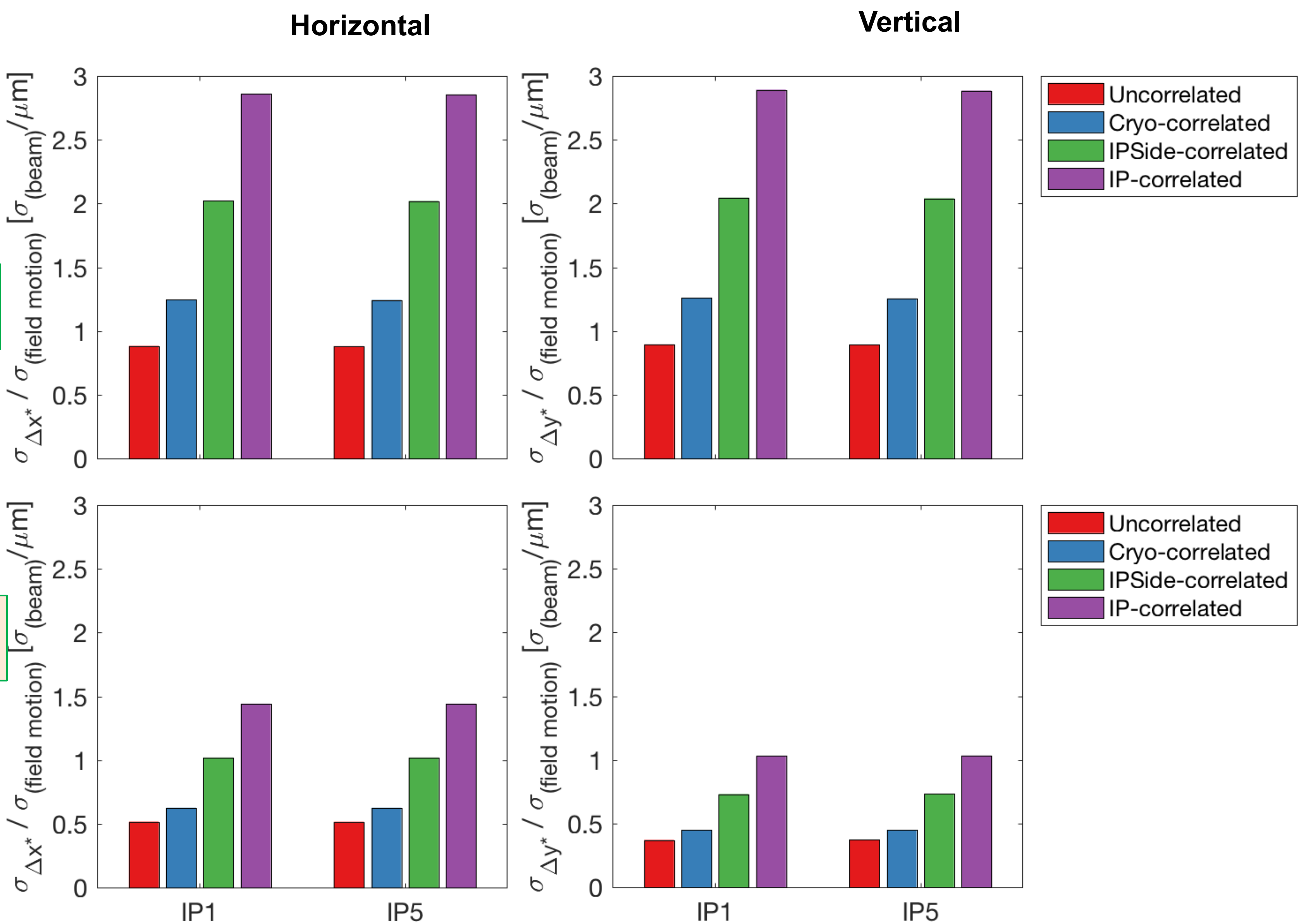
Normalisation to beam size

HL-LHC:

Beam
σ ≈ 7 μm

LHC:

Beam
σ ≈ 15 μm



Luminosity [1]

$$\mathcal{L} = \frac{N_1 N_2 f N_b}{2\pi\sqrt{\sigma_{1x}^2+\sigma_{2x}^2}\sqrt{\sigma_{1y}^2+\sigma_{2y}^2}} W e^{\frac{B^2}{A}} S$$

$$W = e^{-\frac{1}{4\sigma_x^2}(d_2-d_1)^2}$$

Reduction due to horizontal offset

$$A = \frac{\sin^2(\frac{\phi}{2})}{\sigma_x^2} + \frac{\cos^2(\frac{\phi}{2})}{\sigma_s^2}$$

$$B = \frac{(d_2-d_1)\sin(\frac{\phi}{2})}{2\sigma_x^2}$$

Reduction due to offset AND angle

$$S = \frac{1}{\sqrt{1+\left(\frac{\sigma_s}{\sigma_x}\tan(\frac{\phi}{2})\right)^2}}$$

Reduction due to angle

[1] Concept of Luminosity, W. Herr and B. Muratori, (CERN-2006-002)

Dynamic effect

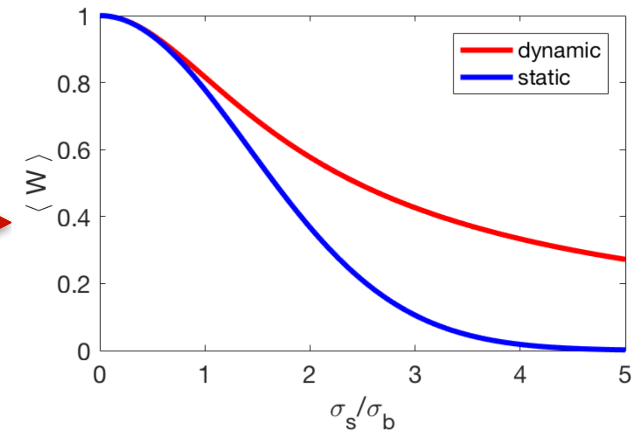
Assuming all Gaussian:

$$\langle W \rangle = \int_{-\infty}^{\infty} e^{-\frac{1}{4\sigma_b^2}(s)^2} \frac{1}{\sqrt{2\pi}\sigma_s} e^{-\frac{s^2}{2\sigma_s^2}} \mathrm{d}s$$

$$= \frac{1}{\sqrt{2\pi}\sigma_s} \int_{-\infty}^{\infty} e^{-\frac{s^2}{2}\left(\frac{1}{2\sigma_b^2}+\frac{1}{\sigma_s^2}\right)}$$

$$= \frac{\sqrt{2}\sigma_b}{\sqrt{\sigma_s^2 + 2\sigma_b^2}}$$

$$= \frac{\sqrt{2}}{\sqrt{\sigma_s^2/\sigma_b^2 + 2}}$$



Where:

$$\sigma_b = \sigma_{\text{beam}}$$

$$s = d_2 - d_1$$

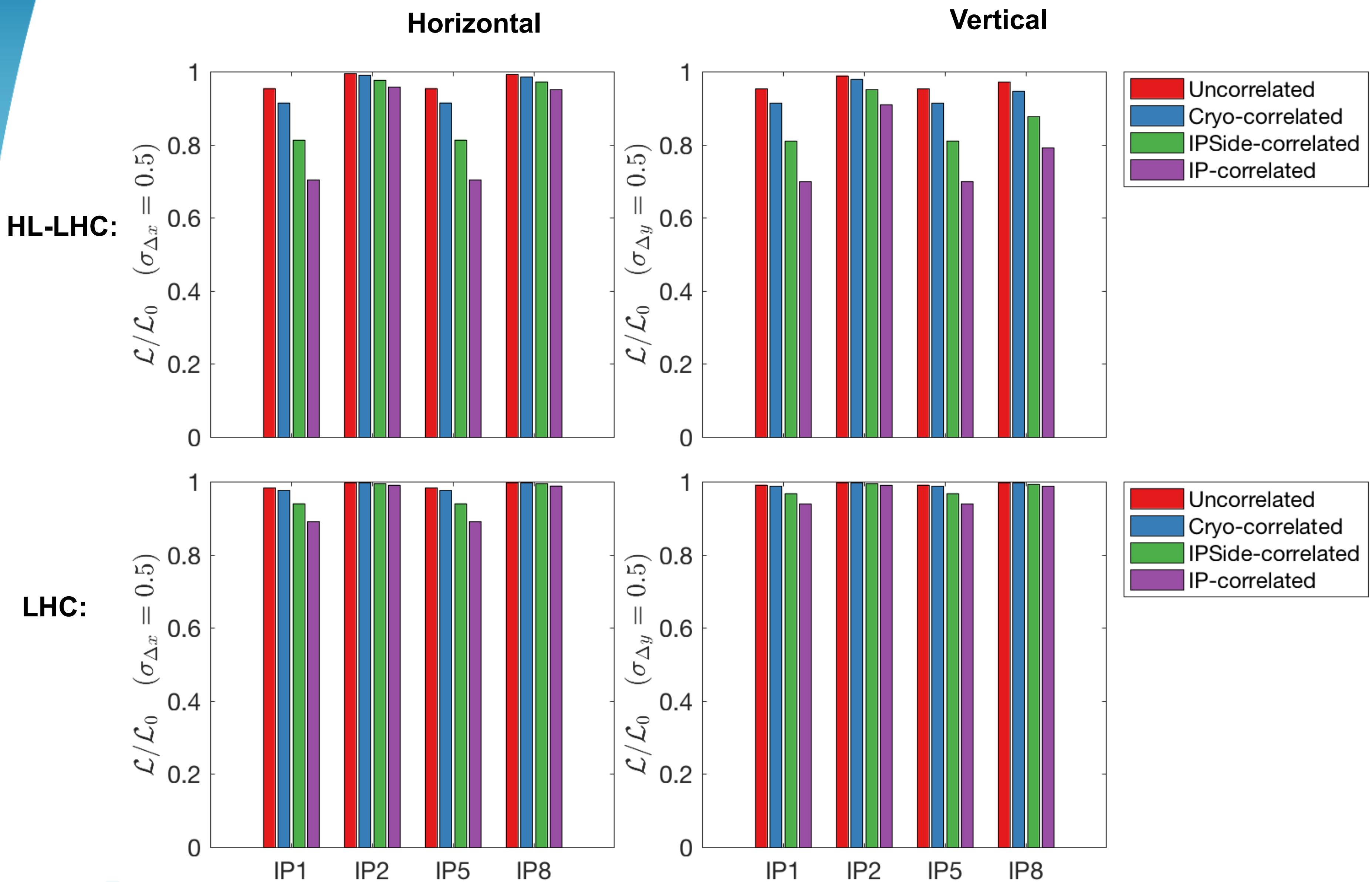
$$\sigma_s = \text{r.m.s. separation jitter}$$

For uncorrelated planes:

$$\langle W \rangle = \frac{2}{\sqrt{\sigma_{sx}^2/\sigma_x^2 + 2}\sqrt{\sigma_{sy}^2/\sigma_y^2 + 2}}$$

Luminosity loss (dynamic)

σ_{field} = 0.5 μm



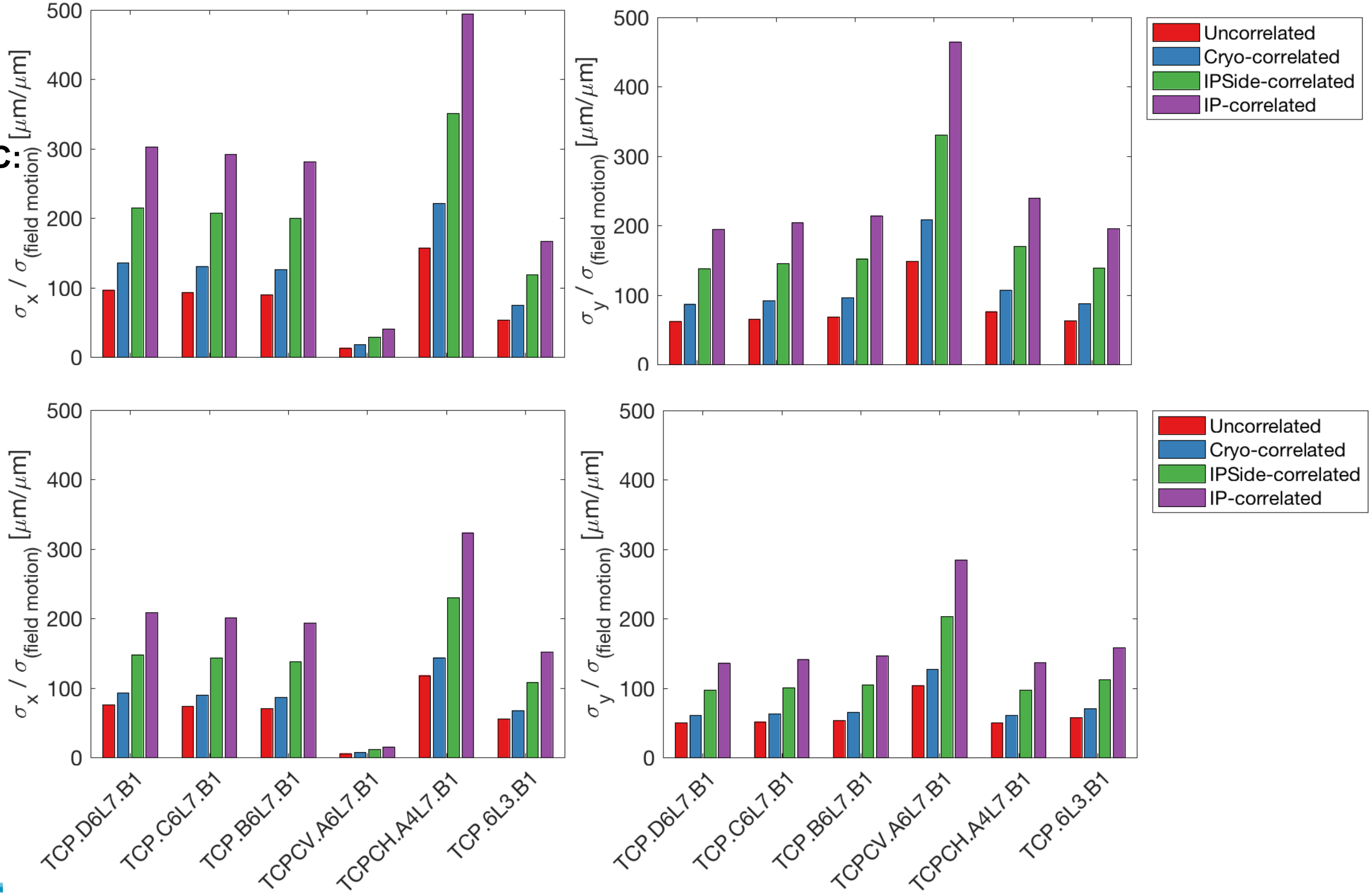
Effect at collimators (B1)

Note: Limit is 200 μm, but in 2012 smaller movements caused dumps [Rogelio]

Horizontal **Vertical**

HL-LHC:

LHC:



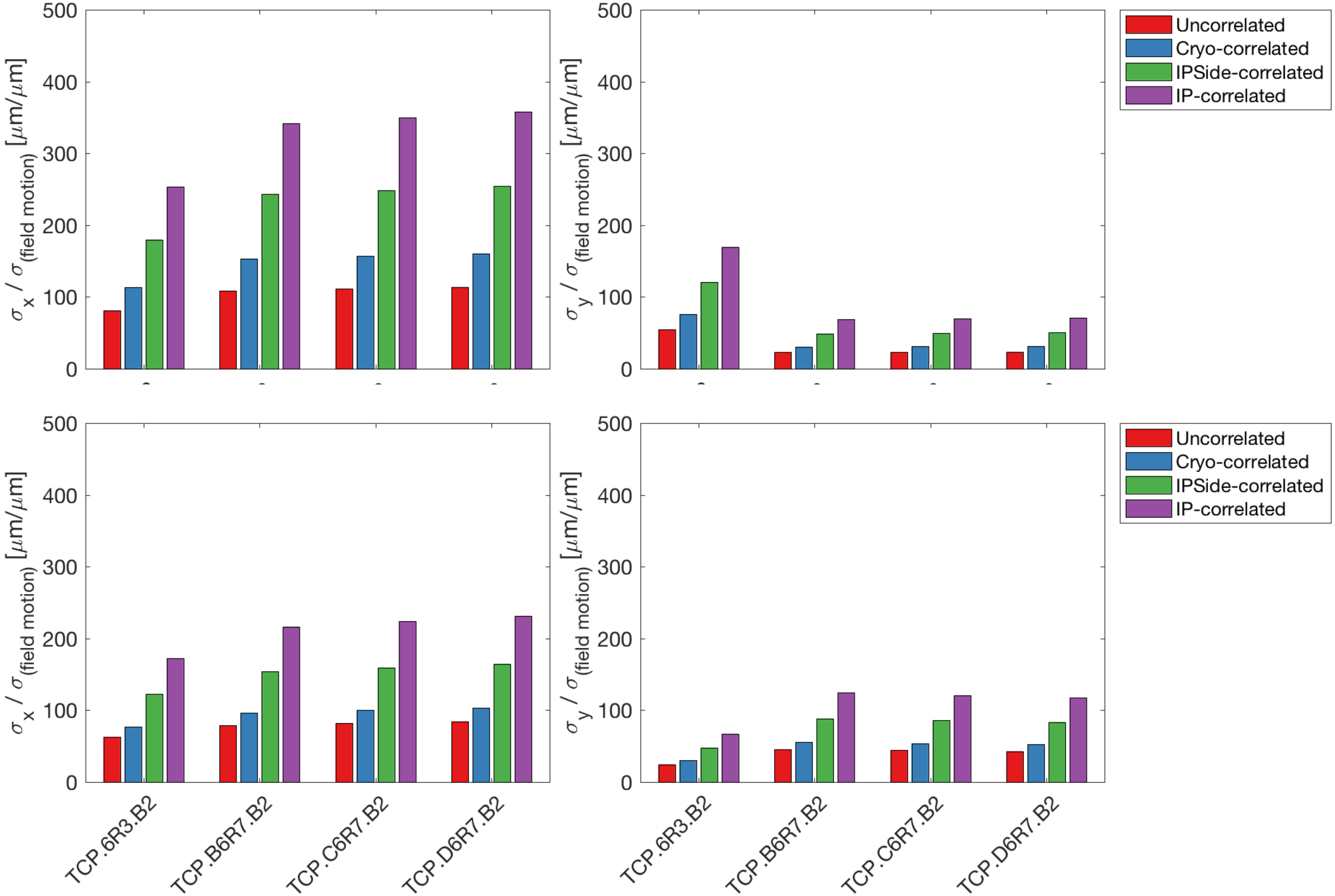
Effect at collimators (B2)

Note: Limit is 200 µm, but in 2012 smaller movements caused dumps [Rogelio]

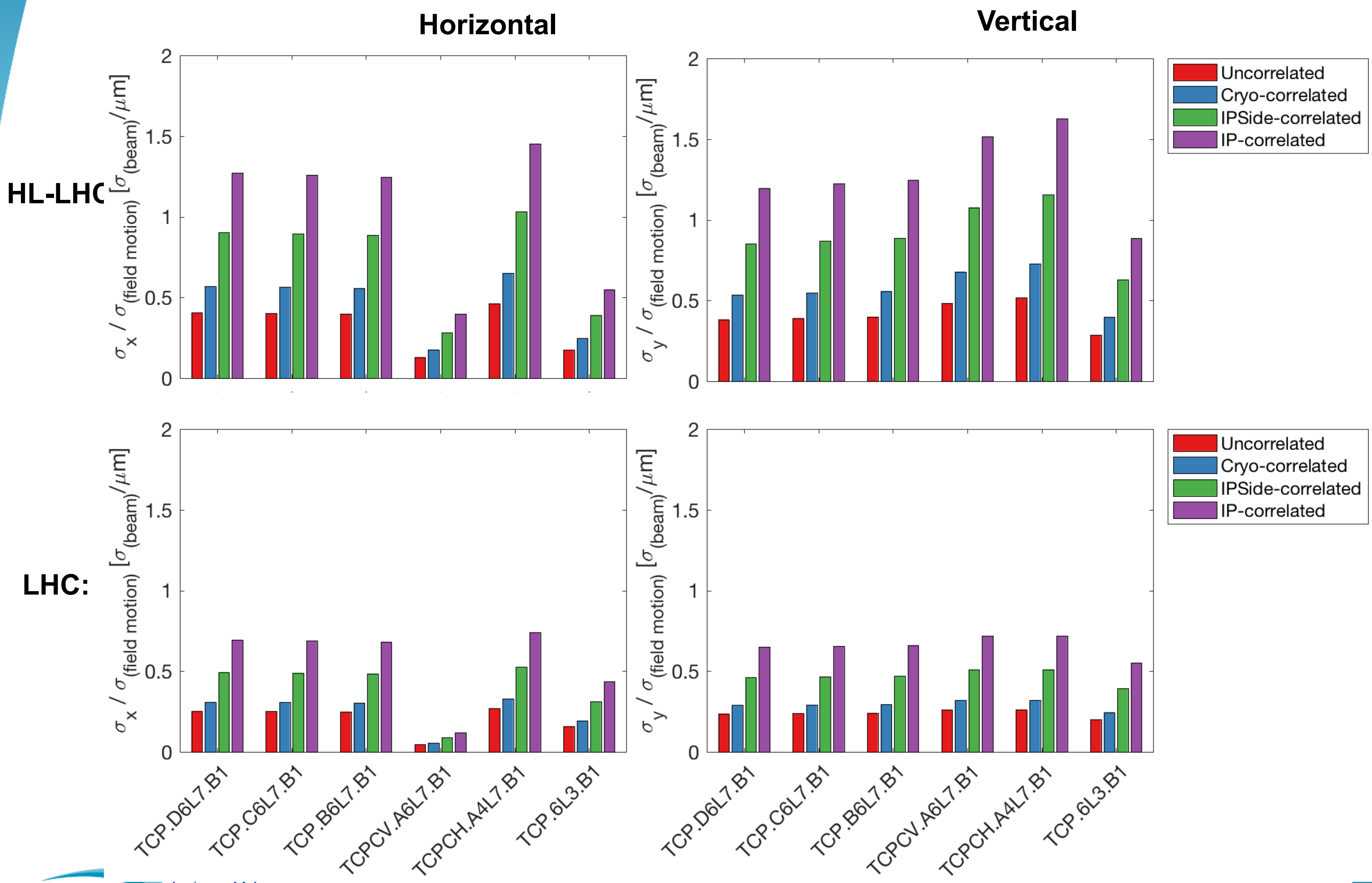
Horizontal | **Vertical**

HL-LHC

LHC:

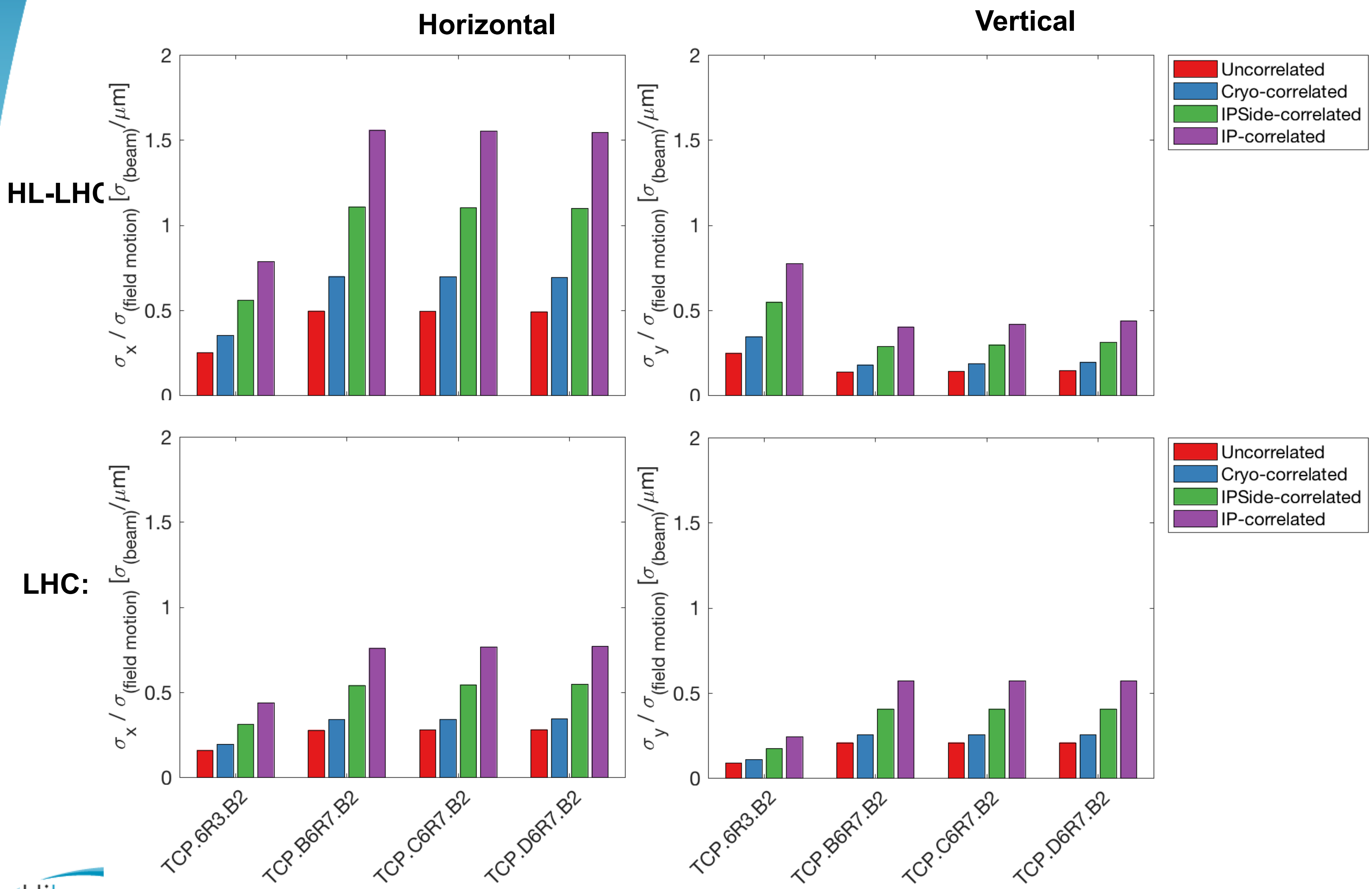


Effect at collimators (B1) – norm beam sigma

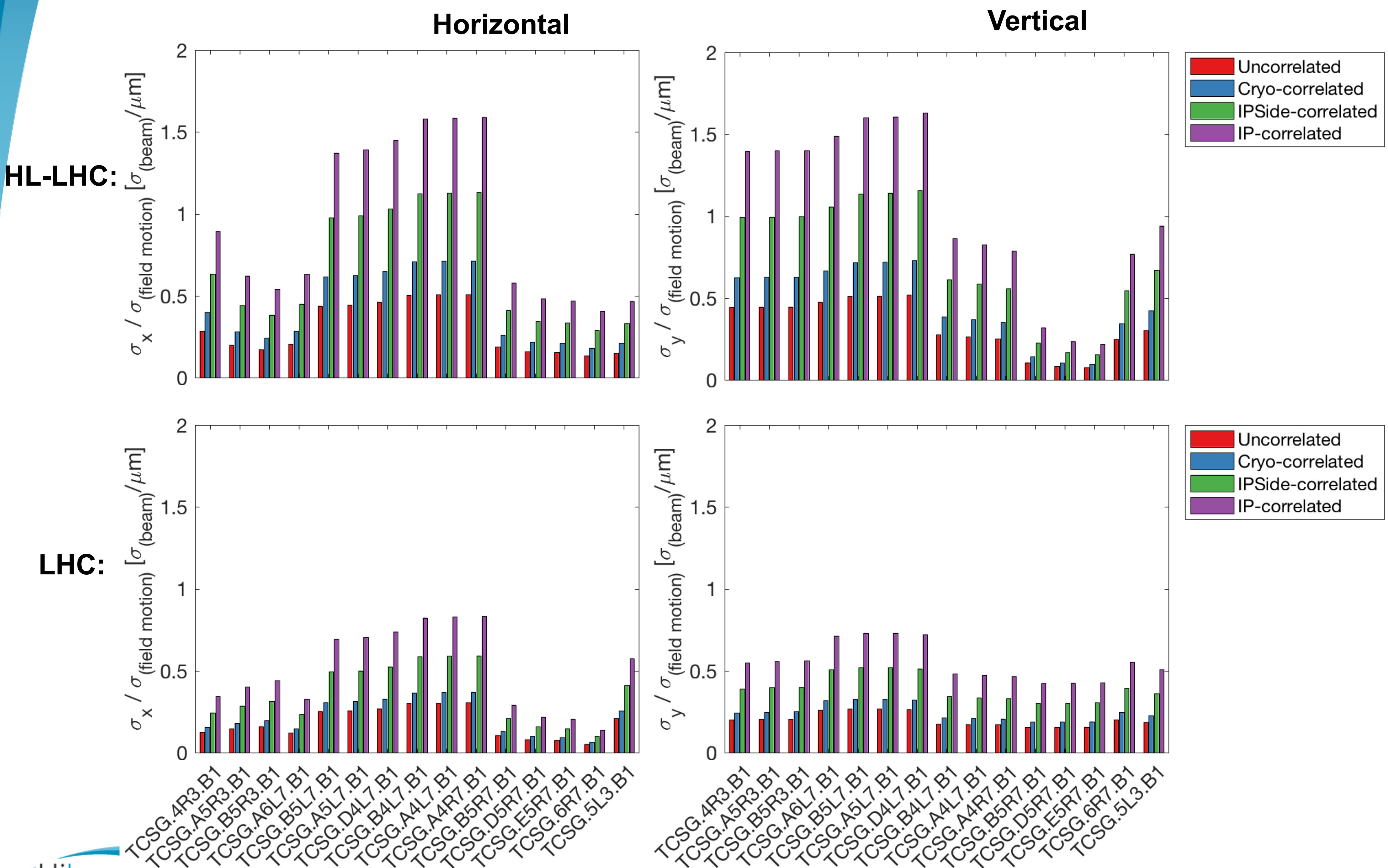


HiLumi HL-LHC PROJECT
CERN

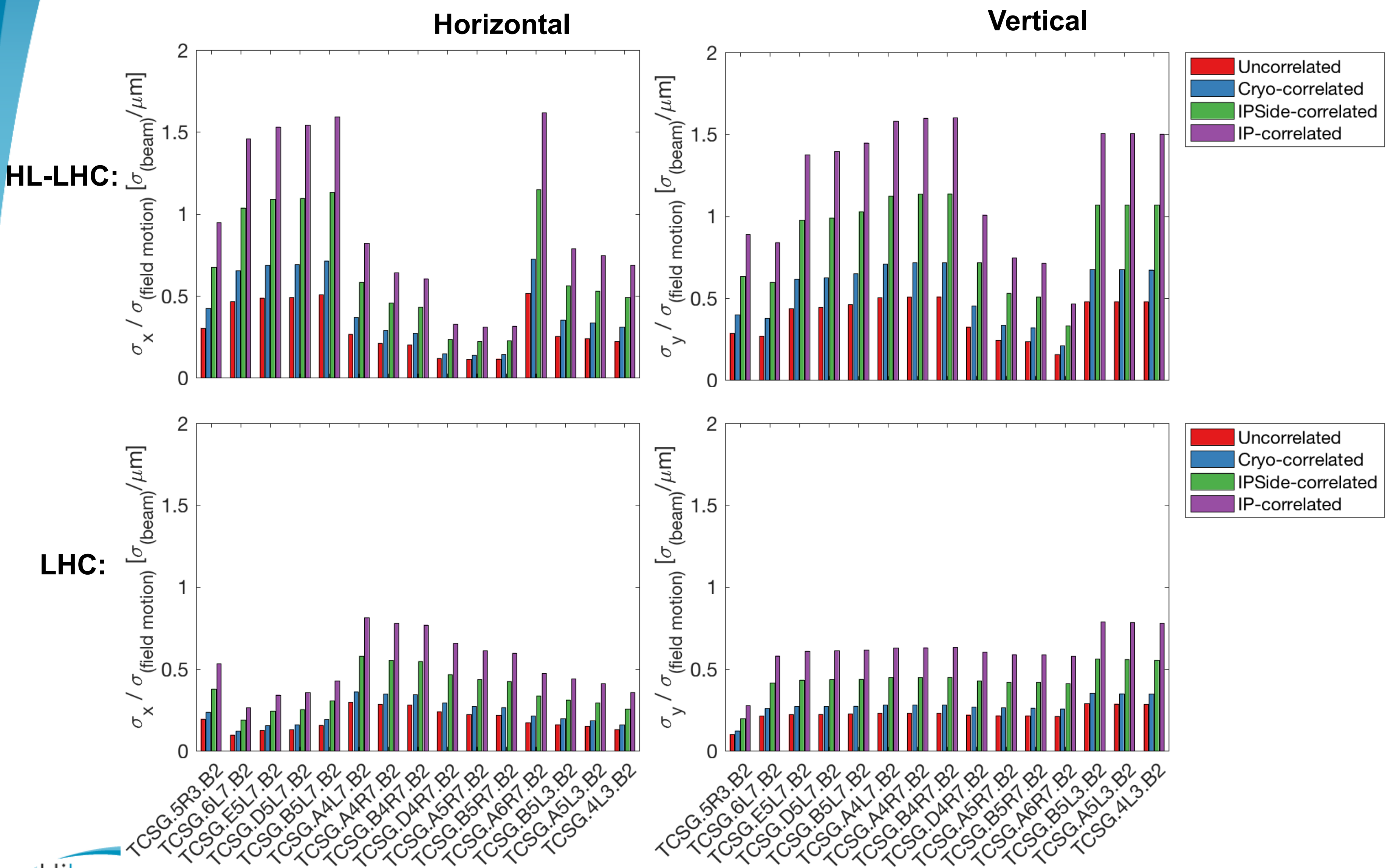
Effect at collimators (B2) – norm beam sigma



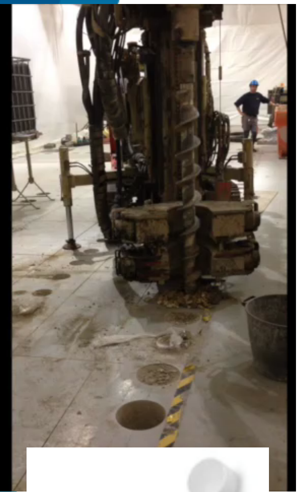
Effect at secondary collimators (B1) norm beam sigma

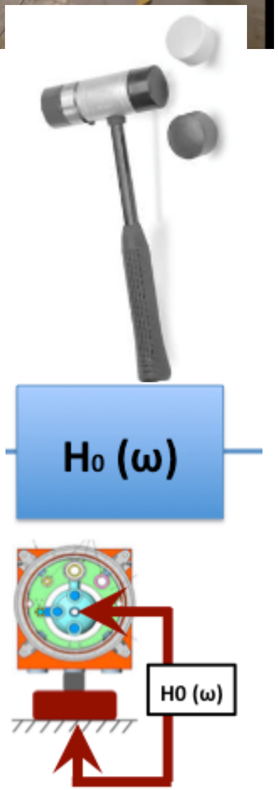


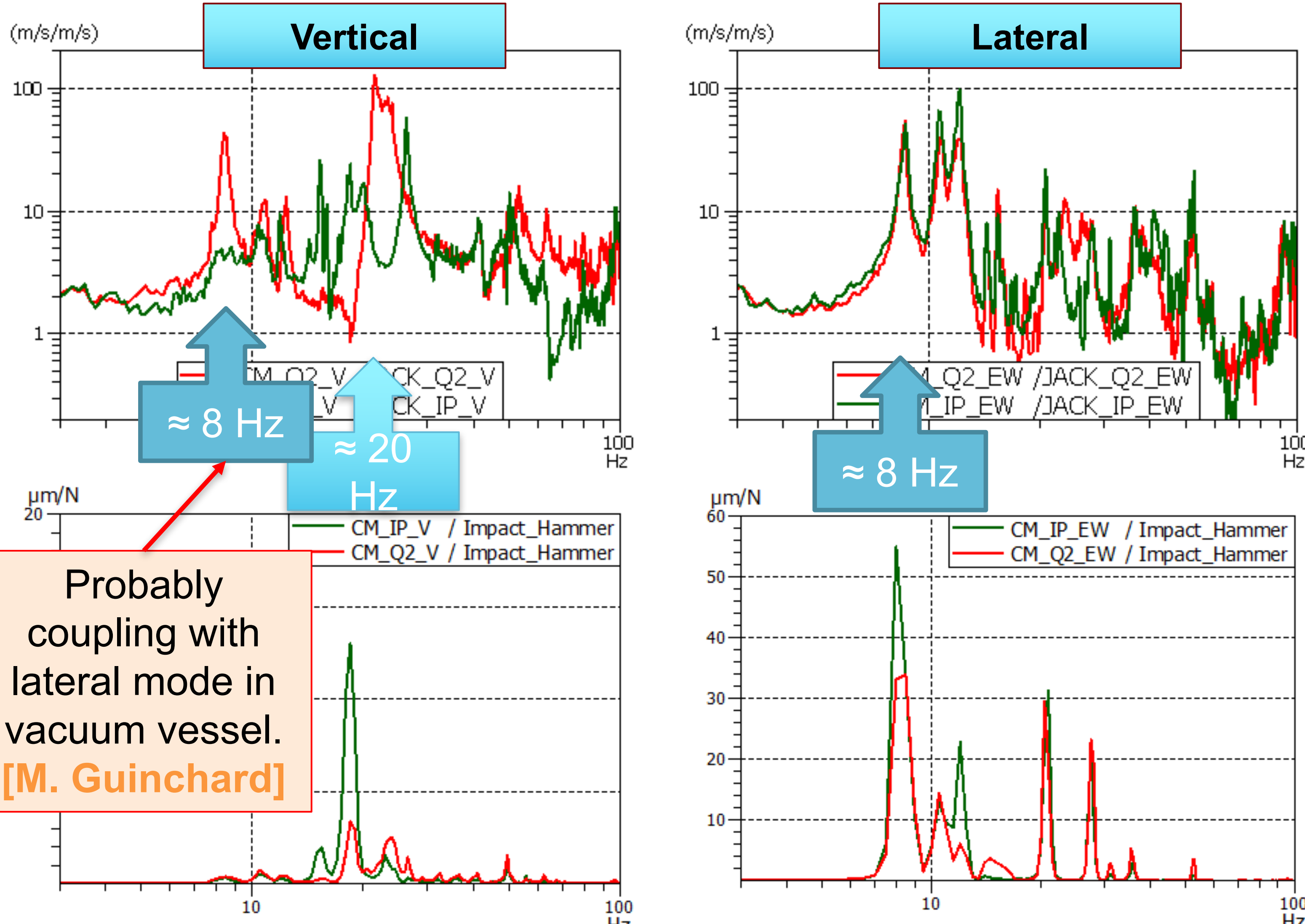
Effect at secondary collimators (B2) norm beam sigma



Amplification by cold mass



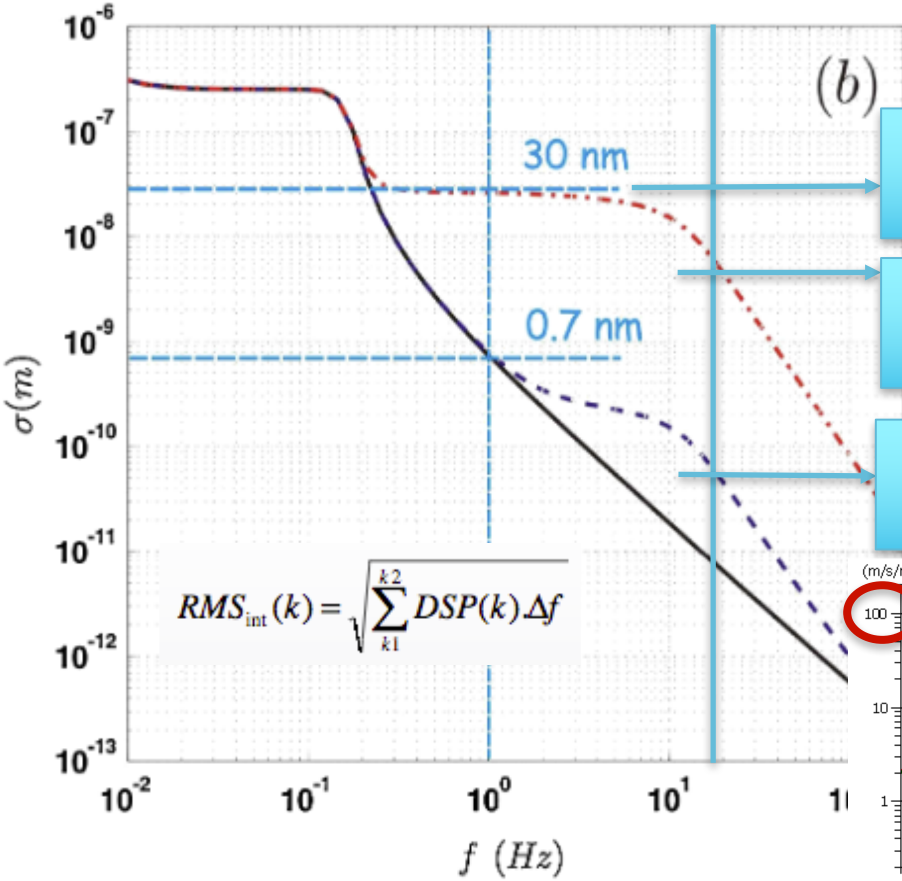




Probably coupling with lateral mode in vacuum vessel. [M. Guinchard]

Measurements confirmed by modal analysis [5].

Expected triplet motion



x 100

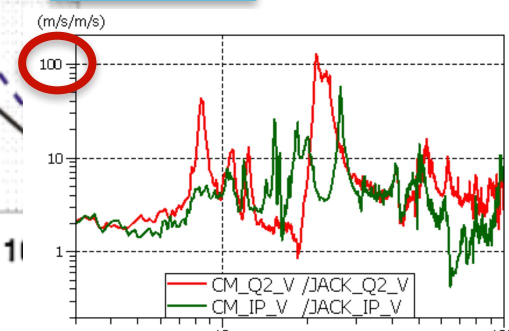
30 nm → 3 µm

4 nm → 0.4 µm

0.04 nm → 0.004 µm

Pessimistic approach

Proper computation by M. Guinchard:



« According to the transfert function measured at SM18 on Q1, the expected motion of the coldmass during **LHC operation** is around **0,1 µm** integrated from 100 Hz » [**M. Guinchard, 16/07/2015**]

« For standard civil engineering tools at the surface, the expected **magnetic center motion should stay below 0.5 µm** between 4 and 100 Hz; » [**M. Guinchard, 29/05/2017**]

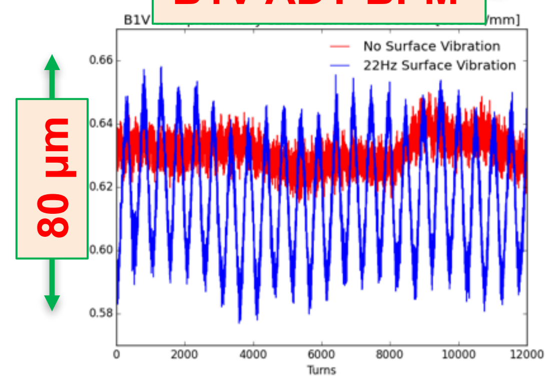
Measurements done in the past

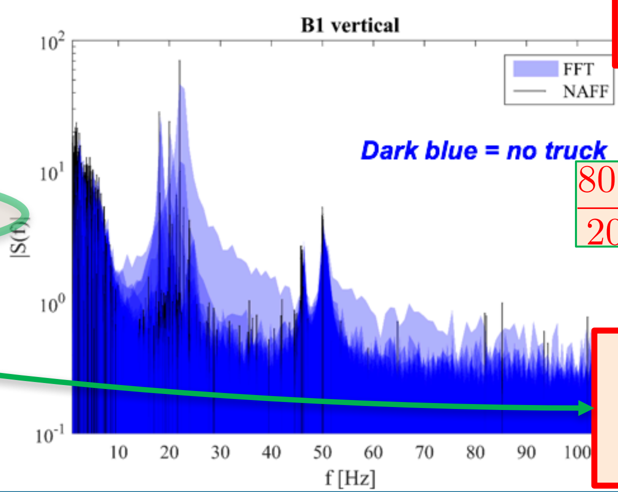
Vibrating truck impact

- Beam measurements with the vibrating truck were performed for the squeezed optics (80 cm) at 6.5 TeV and at injection.
  - *Multi-turn data (all BPMs) & ADT data.*
- Measurements results:
  - *Beam oscillations were only observed in the vertical plane ⇔ truck location.*
  - *Beam oscillations were only observed for **vibration frequencies of 18-22 Hz** – consistent with the triplet resonances.*
  - *Observed B1/B2 amplitude ratio of ~2.5 implies that the different triplet quads oscillated with different amplitudes.*
  - *The oscillation amplitudes of the triplet CMs were in the **few μm range for a ground motion amplitudes of ~50 nm** in the tunnel.*

The observations are consistent with the triplet resonances that enhance the vibrations by a factor >> 10

B1V ADT BPM





Rough calculation:

$$\sqrt{\frac{\beta_{ADT}}{\beta^*}} \approx 20$$

Amplification **x5 (?!)** by LHC optics

$$\frac{80\ [\mu m]}{20 \times 5} = 0.8\ [\mu m]$$

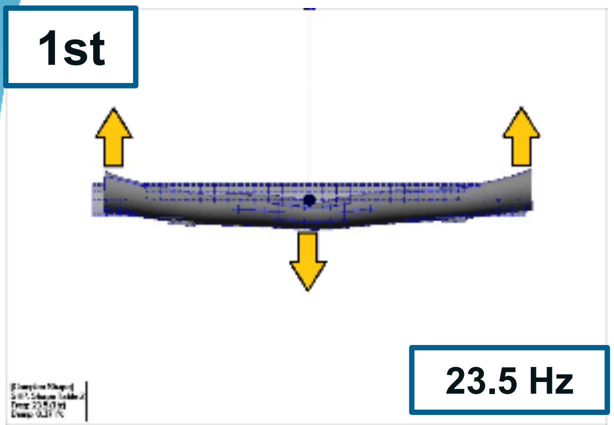
Amplification **x16?! (x100)** by cold mass

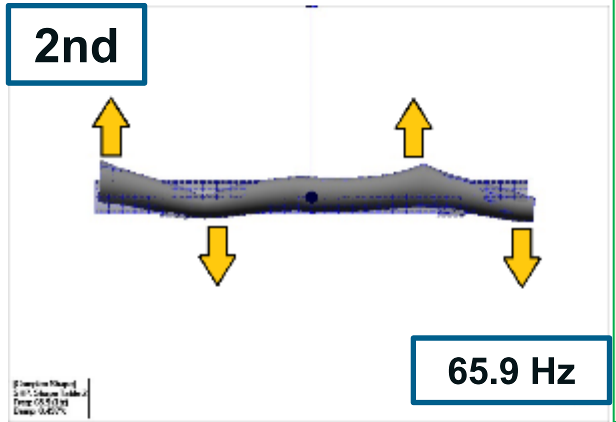
Chamonix 16 - Civil Engineering & Eathquakes

From: Jorg Wenninger, 28 Jan 2016 link

MQXA Cold Mass – EMA Results (modal shapes)

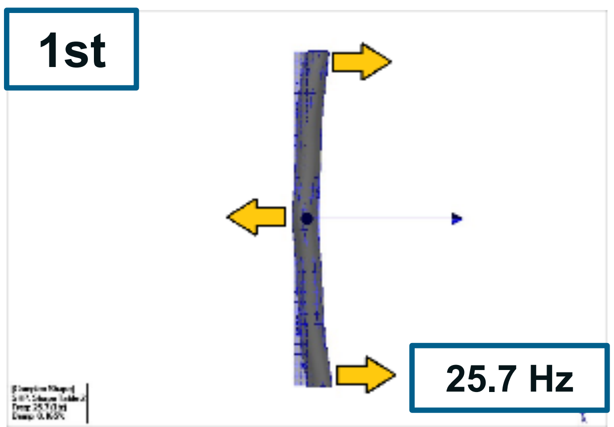
Vertical Modes

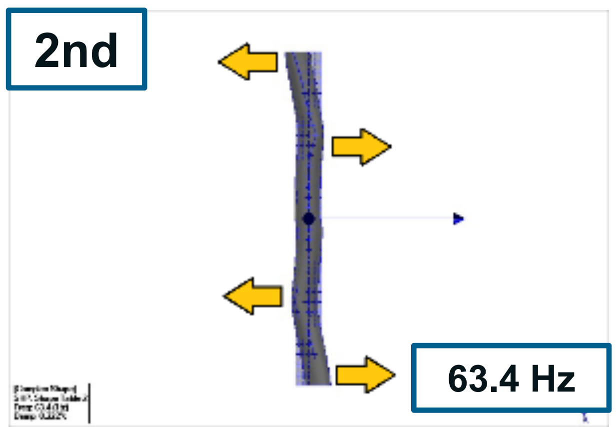


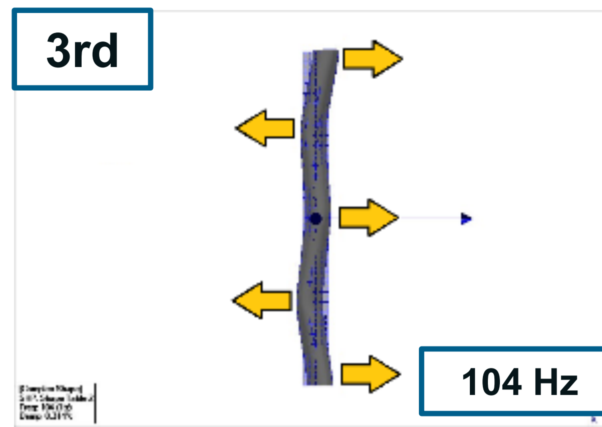


- In the previous simulations I assume that the whole magnet is rigidly displaced.
- The **actual effect on the beam might be smaller**.
  - **TODO: simulate it.**
  - **Repeat for HL-LHC.**

Lateral Modes







Still TO DO…

- Perform new **measurements**:
  - 3 **geophones** sensors (IP1, IP5 and surface) are now logged on Timber.
    - Contact person is Michael Guinchard.
  - Look at correlations with beam orbit (**DOROS, ADT**) and losses at collimators.
    - More ADT data will be available/logged during summer.
      - (see also [7] for online data retrieval)
  - **Spectra** of the **beam oscillation** have been computed only occasionally in the past
    - need to perform systematic analysis.
- Follow up on the response of the **new cold masses**.
  - **Simulations** taking into account actual **vibration modes**.
  - Contact person is Delio Duarte Ramos.

Still TO DO…

- Idea of having back the “vibrator truck” back to CERN for further studies.
  - When tests done in 2015 only looked at multi-turn data (good enough for a few Hz expected oscillations)
  - Presently this idea is dropped, but it could be re-considered [P.Fessia].

- Contribute to OP effort:
  - Jorg and Michaela aim is to observe and quantify the noise now and next year when excavation works will start.
  - Also interested in single-source events (earthquakes).

- Follow Geothermie 2020 evolution. [9]

GEothermie2020

- The program might be stopped in Geneva.
  - It could induce small earthquakes (several per week)
  - **Expected cold mass movements up to 10 µm!** [10]
- Recent developments close to Vernier:

> Le 27 mars dernier, SIG a entrepris un forage géothermique dans le quartier Concorde/Châtelaine. Un puits qui permettra de produire de la chaleur grâce à la présence d'une nappe d'eau souterraine, découverte dans le cadre du programme GEothermie 2020.

- But much less deep drilling (only about 60 m) and not of a few thousand metres as foreseen by GEothermie2020 plan.

… to be followed up!

Conclusions

- HL-LHC optics is very similar to LHC in terms of sensitivity to ground motion, but:
  - x2 smaller beam size -> x2 more sensitive to possible luminosity degradation.
  - x2 more sensitive at collimators.
- Confidence on the model of ground motion
  - Geophones will give additional information.
- It is important to follow up on the new cold mass design (and its resonances)
  - We might gain what we loose from optics.

--- Thanks for your comments ---

Some references

1. **Vibration analysis of TT41 TAG41,** M. Guinchard, 16 Jul 2015 link
2. **Observation of ground motion in the LHC**, M. Fitterer, 27 Aug 2015 link
3. **Lessons Learned from the Civil Engineering Test Drilling and Earthquakes on LHC Vibration Tolerances**, J. Wenninger, 28 Jan 2016 link
4. **Vibration: is still an issue?,** P. Fessia, 26 Jan 2017 link
5. **Overview of the vibration issues for the HL-LHC project,** M.Guinchard, 29 May 2017 (link)
6. **ADT Operation**, D. Valuch, 16 Dec 2015 (link)
7. **ObsBox status and plans in the transverse plane**, D. Valuch, 30 Mar 2016 (link)
8. **Vibration monitoring of LHC accelerators. SIG Collaboration for seismic measurements.** (link)
9. **Déplacements attendus au CERN lors de séismes induits** (link)
10. **Geophones UP53 & UL16**, Morgane Cabon, 16 Jul 2016 (link)

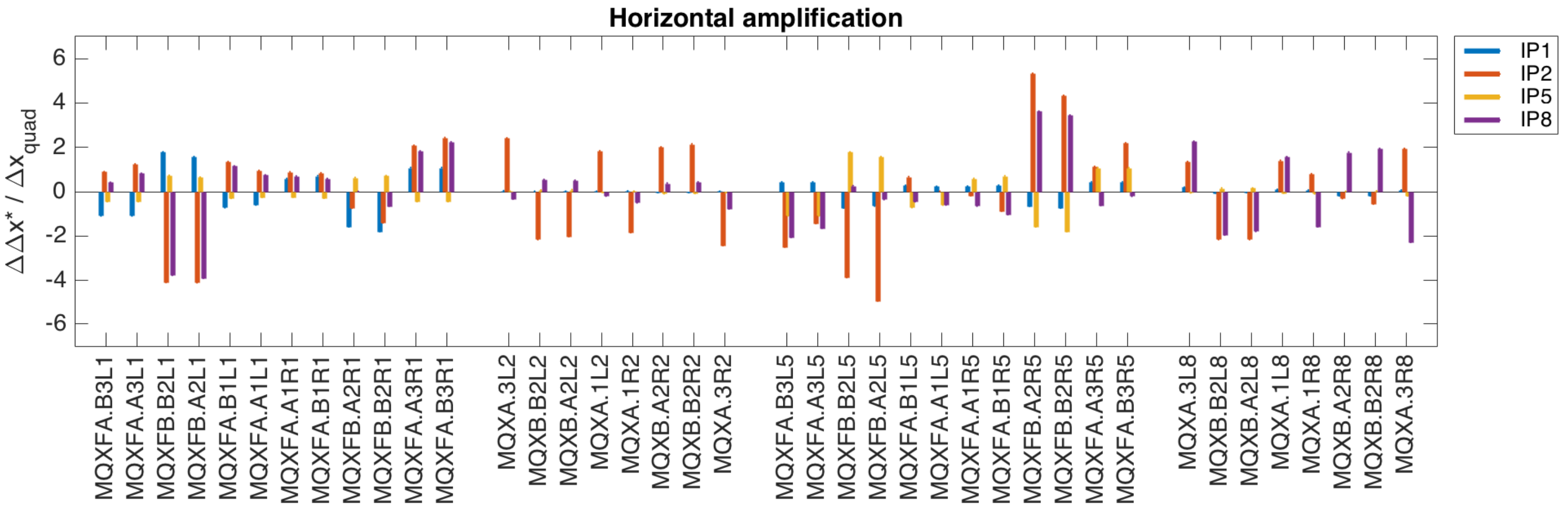
11. **Swiss Seismic Network data** available here: http://arclink.ethz.ch/webinterface/ (See also http://www.seismo.ethz.ch)

From last meeting

- Rogelio clarifies that one **cannot rely on the orbit feedback to maintain collision**. ...
- Gianluigi suggests **marking the frequencies** of the two modes on the spectrum plot. ✓
- Gianluigi suggests **normalising** the plot to **beam sigma** and to show the **corresponding luminosity reduction**. ✓
- Gianluigi suggests trying to use **measurements** with the DOROS and the measurements of the ground motion at the triplets in order to **infer the amplification factors and/or typical patterns in the movement of the triplets.** ...
- Gianluigi suggests checking the induced movements of the beam also at the **positions of collimators** as a large movement there can lead to loss spikes and beam dump. Rogelio: limit is 200 μm, but smaller movements led to beam dumps in 2012 ✓

Repeated simulations.

HL-LHC 1.3 January



Probably different phase advance. **To be re-checked**

HL-LHC 1.3 July