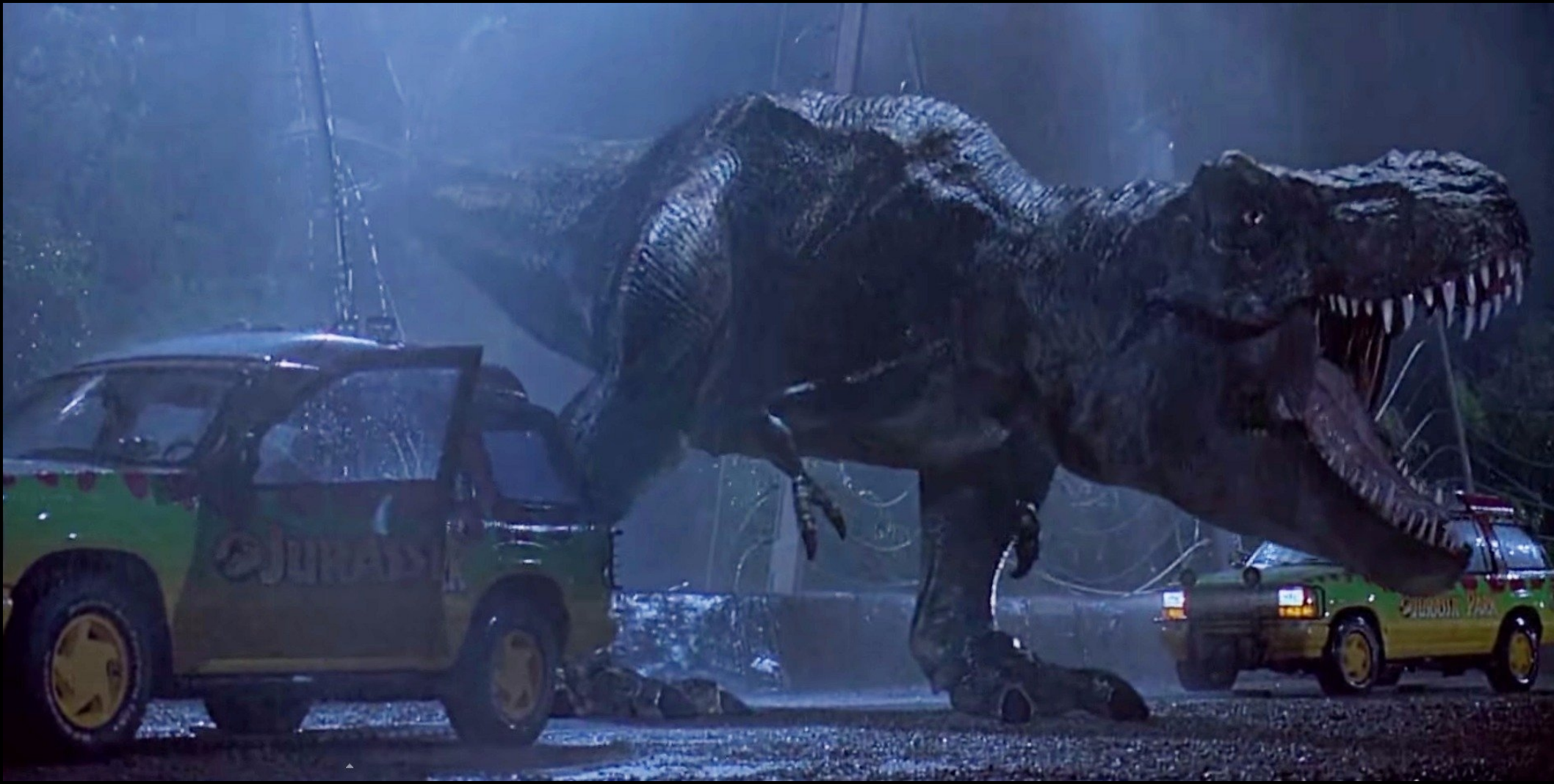
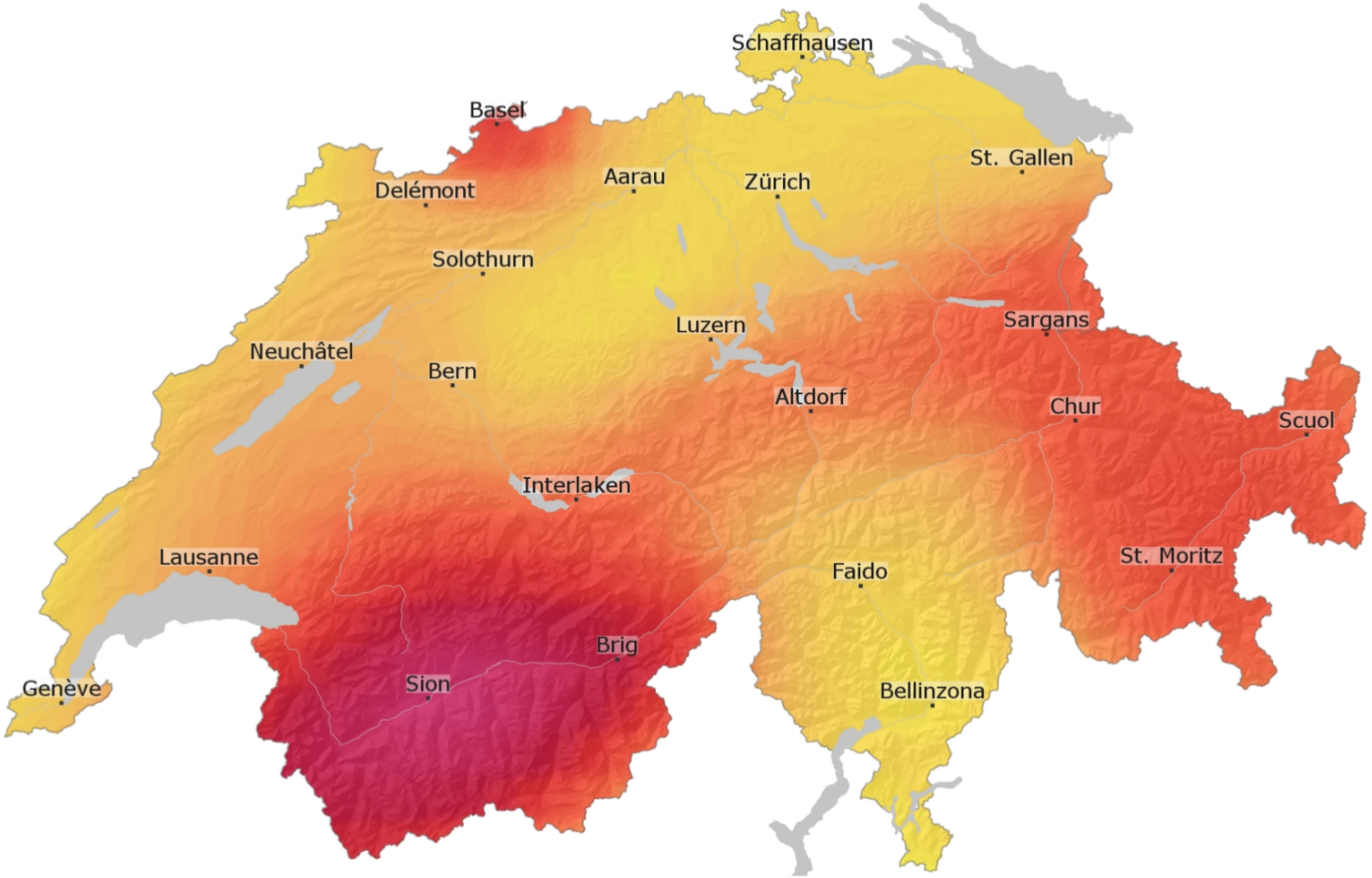
Ground Motion Effects in the LHC

A presentation
65 Million Hours In The Making

hector garcia morales
CERN/University of Oxford


JURASSIC PARK

SEISMIC ACTIVITY IN SWITZERLAND



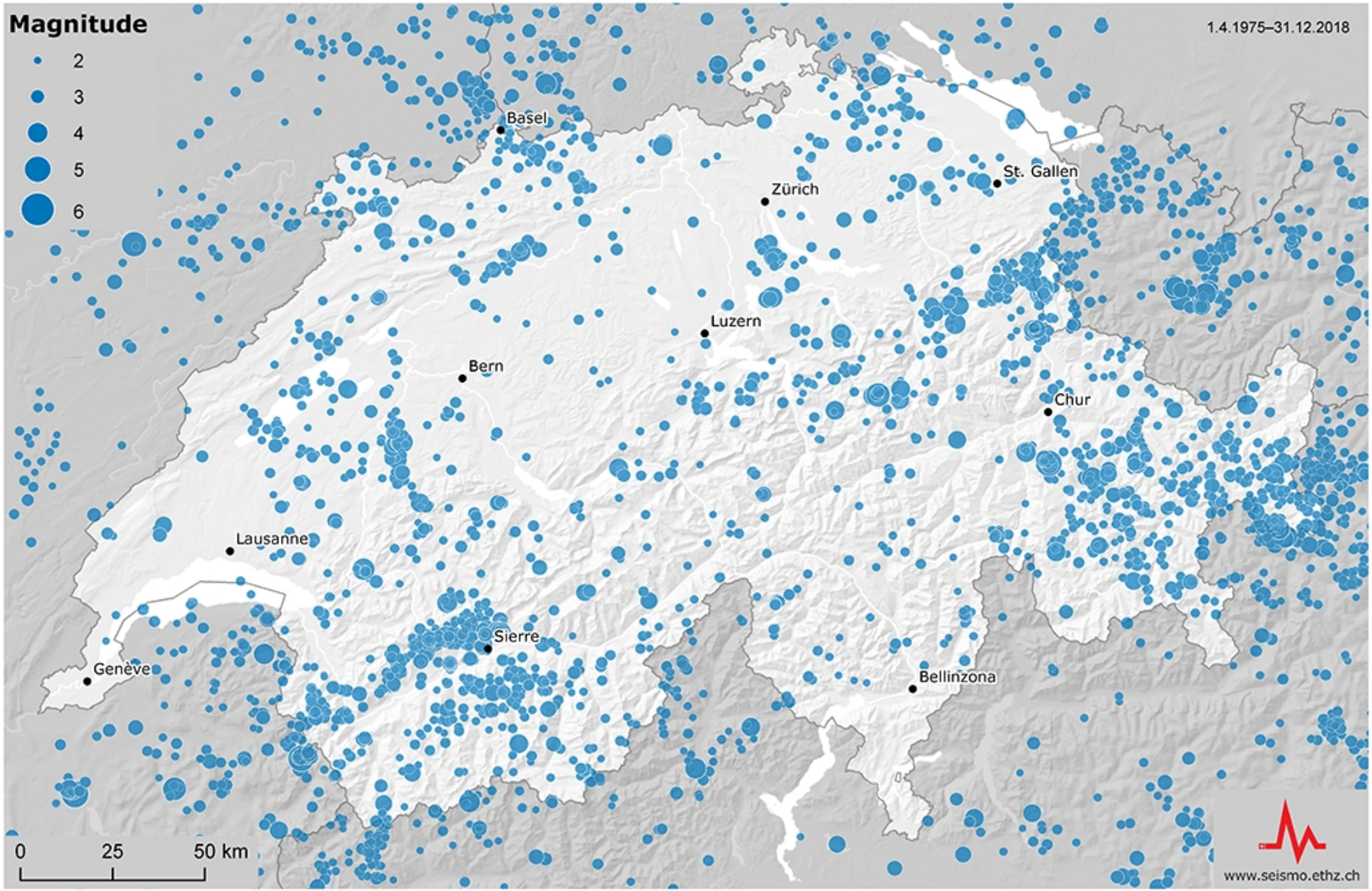
Aléa sismique
accélération horizontale à 5 hertz
10 % en cinquante ans

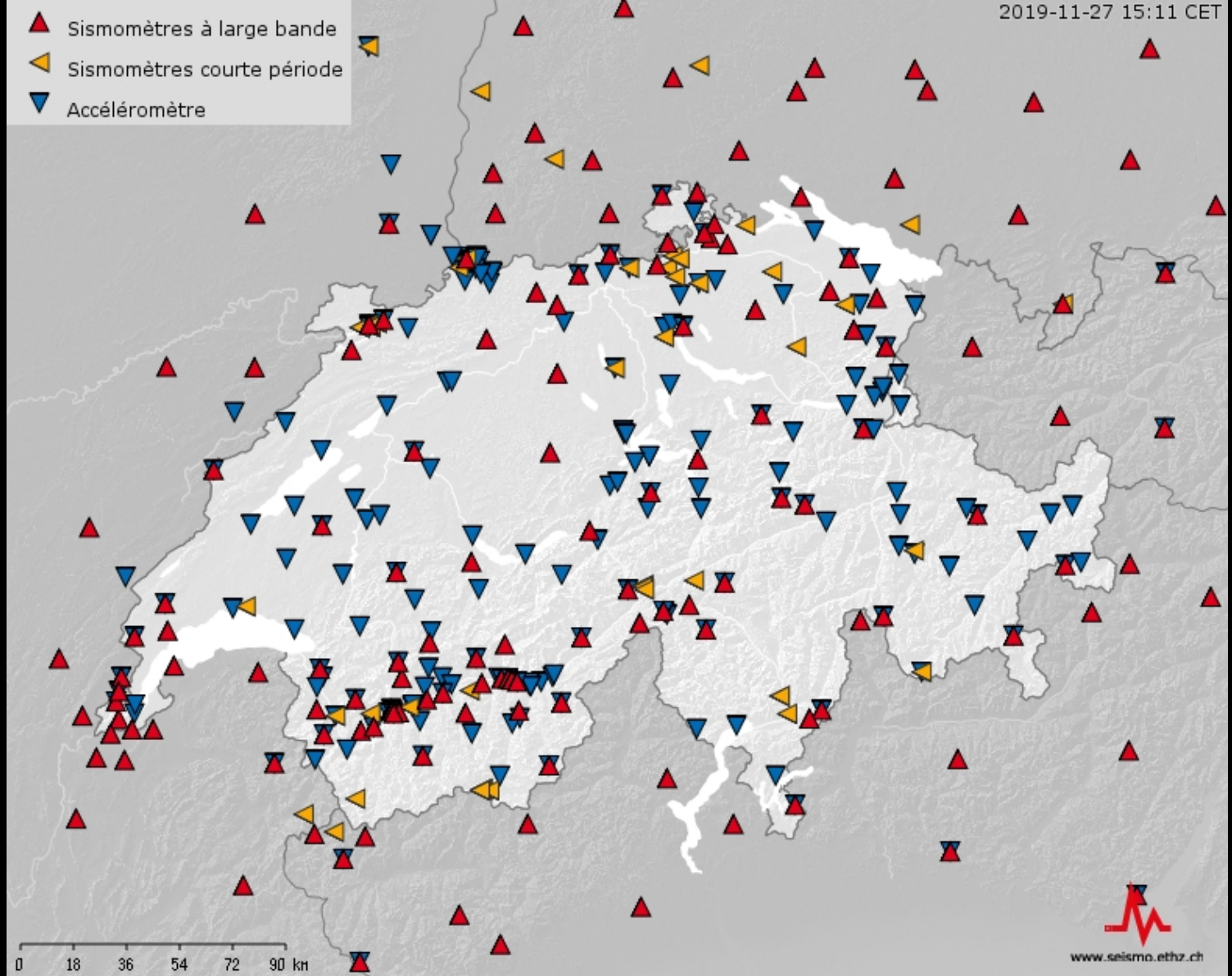
forte

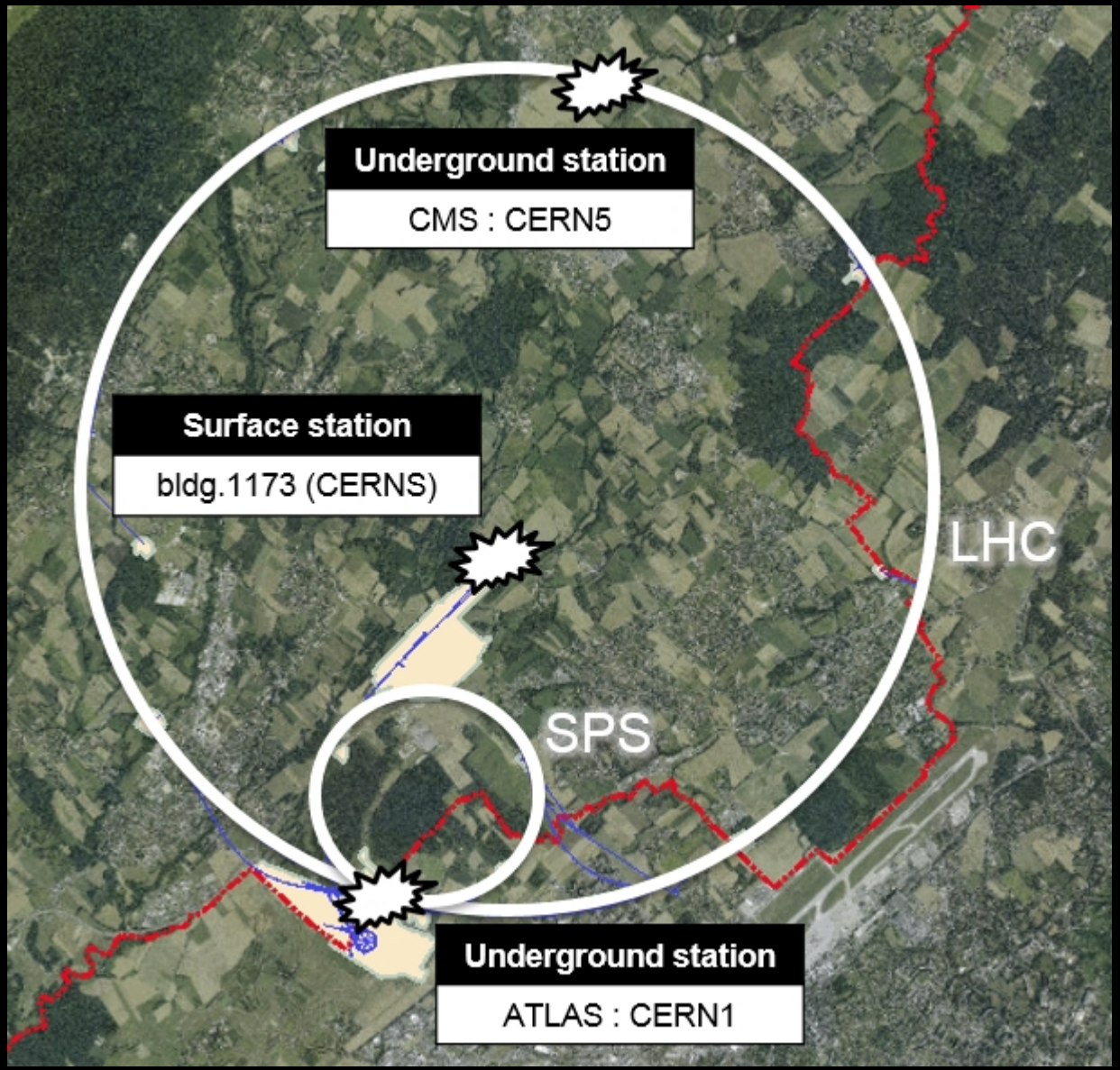
0 0.25 0.5 0.75
accélération [g]

0 20 40 60 80 km

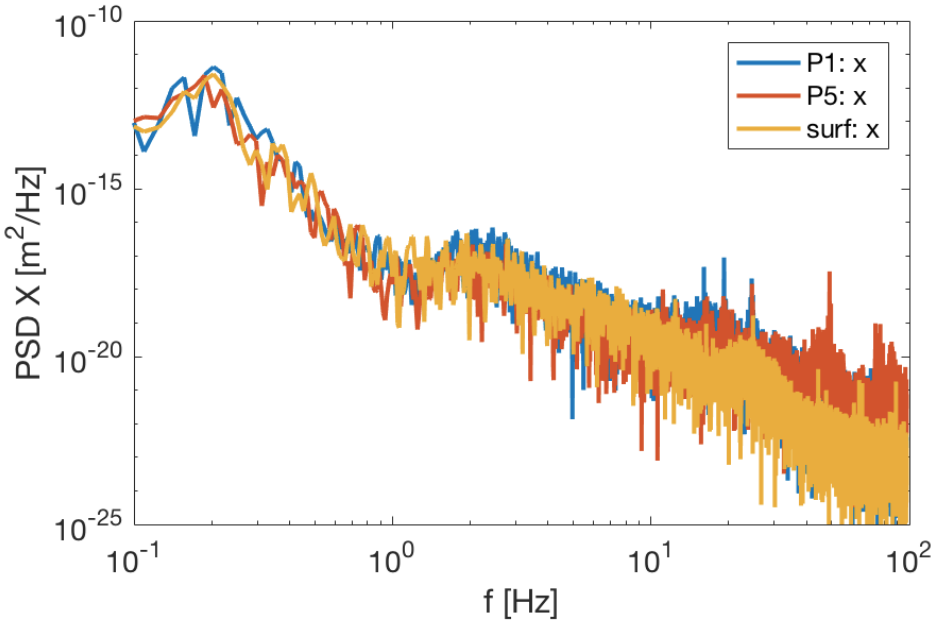
www.seismo.ethz.ch


Magnitude
2
3
4
5
6
1.4.1975–31.12.2018
Basel
Zürich
St. Gallen
Luzern
Bern
Chur
Lausanne
Sierre
Genève
Bellinzona
0
25
50 km
www.seismo.ethz.ch

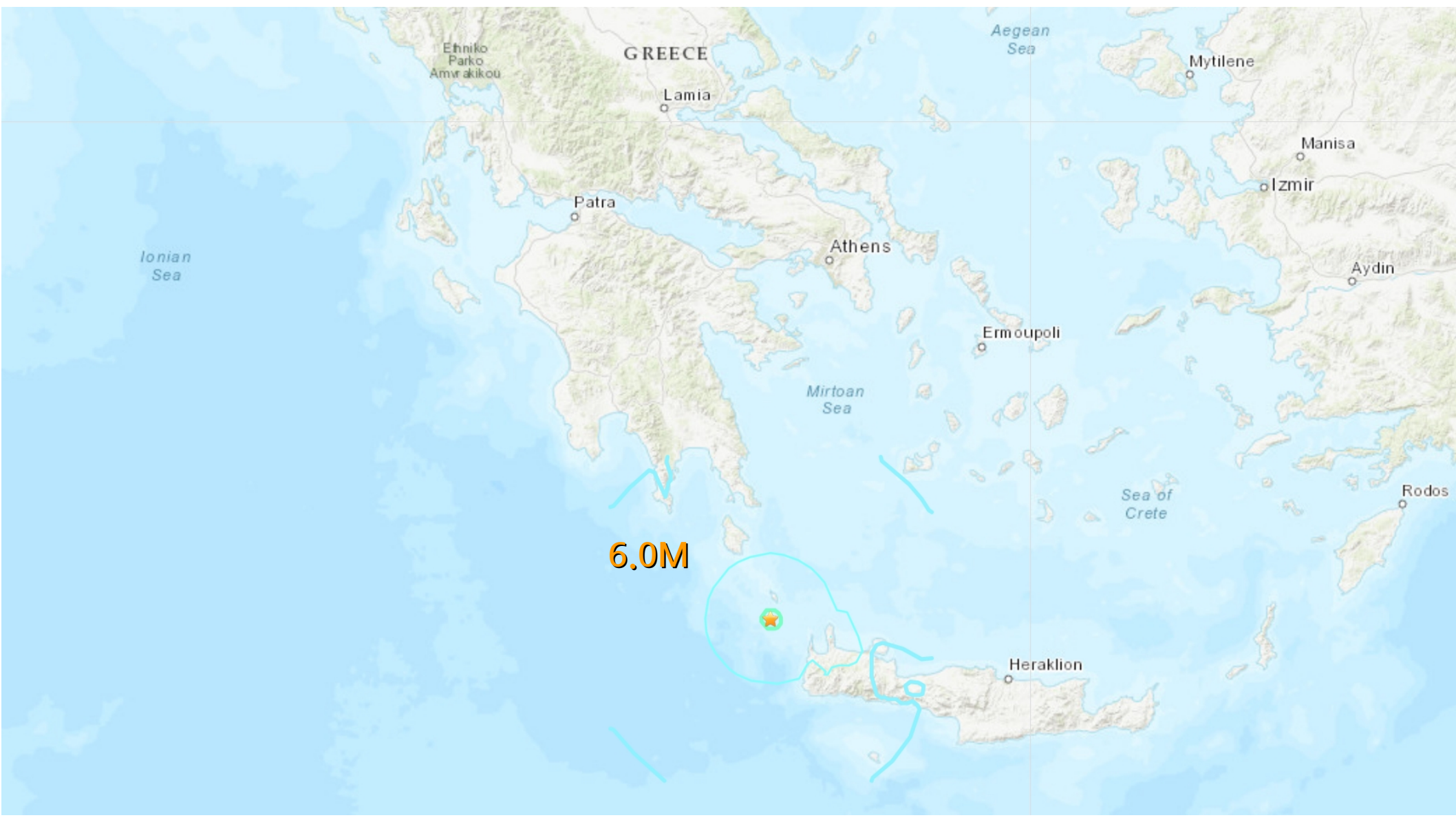

Sismomètres à large bande
Sismomètres courte période
Accéléromètre
2019-11-27 15:11 CET
0 18 36 54 72 90 km
www.seismo.ethz.ch

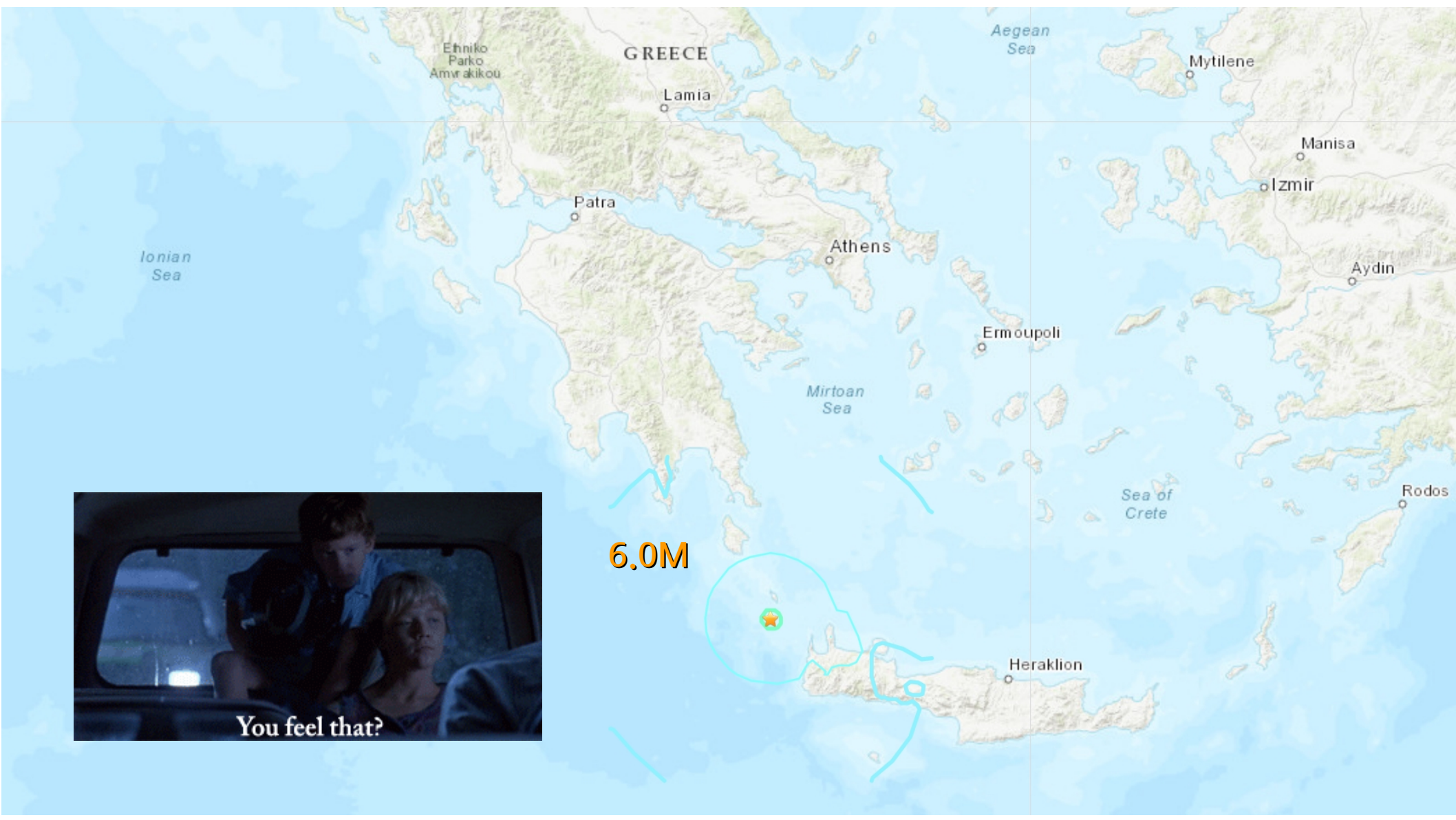

Underground station
CMS : CERN5
Surface station
bldg.1173 (CERNS)
LHC
SPS
Underground station
ATLAS : CERN1

Ground Motion Power Spectral Density



Courtesy of D.Gamba


Ethniko Parko Amvrakikou
GREECE
Lamia
Aegean Sea
Mytilene
Manisa
Izmir
Patra
Athens
Ionian Sea
Aydin
Ermoupoli
Mirtoan Sea
Sea of Crete
Rodos
6.0M
Heraklion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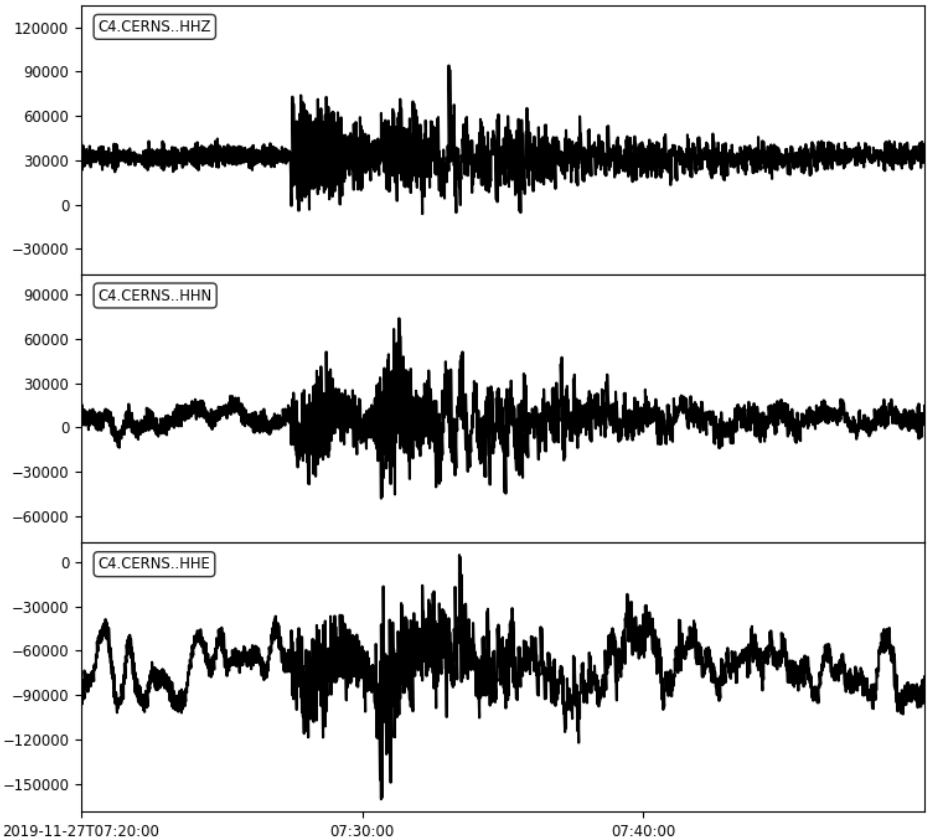
Mytilene
Manisa
Izmir
Patra
Athens
Ionian Sea
Aydin
Ermoupoli
Mirtoan Sea
Sea of Crete
Rodos
6.0M
Heraklion
You feel that?

CRETE RECENT EARTHQUAKE

2019-11-27T07:19:59.9991 - 2019-11-27T07:49:59.9991



How ground motion affects in the LHC

Effects of Ground Motion

Low frequency

- Slow orbit drifts $f <\approx 1$ Hz
- Realignments

Intermediate frequency

- Closed orbit jitter $1 < f < 100$ Hz
- Intensity and luminosity loss

High frequency

- Emittance growth $f > 100$ Hz
- Lifetime reduction

Effects of Ground Motion

From the ground to the beam

What is the response of the beam to an excitation?

$$R(\omega) = |H(\omega)|^2 \cdot f(\omega)$$

$$R_{\mathrm{rms}} = \left(\int_0^\infty R(\omega) d\omega \right)^{1/2}$$

Orbit distortion

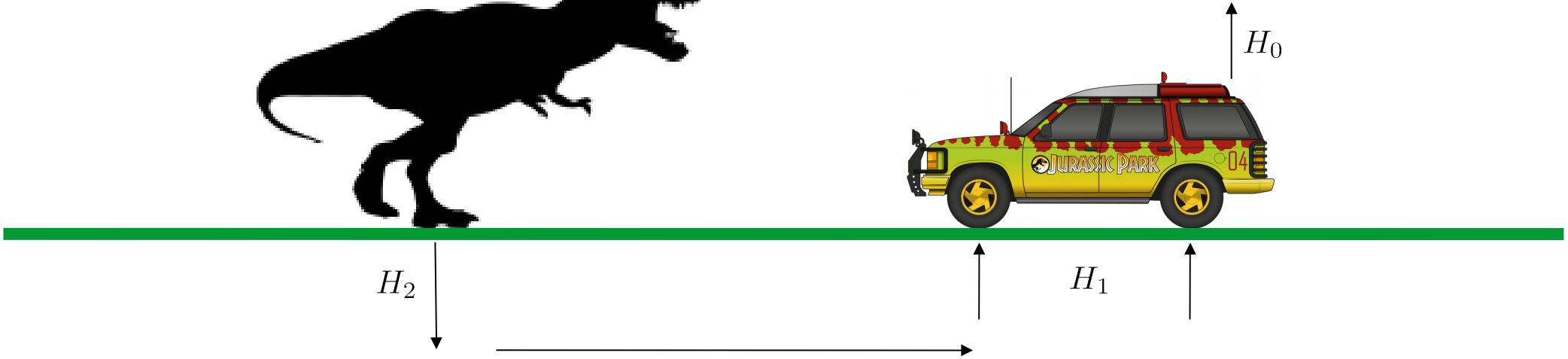
A quadrupole displacement is translated into an orbit shift

$$\frac{\Delta x_s}{\sqrt{\beta_s \epsilon_N / \gamma} \Delta x_q} = \frac{\sqrt{\beta_q} (K1L)_q}{\sqrt{\epsilon_N / \gamma}} \frac{\cos(2\pi\phi_{qs} - \pi Q_x)}{2\sin(\pi Q_x)}$$

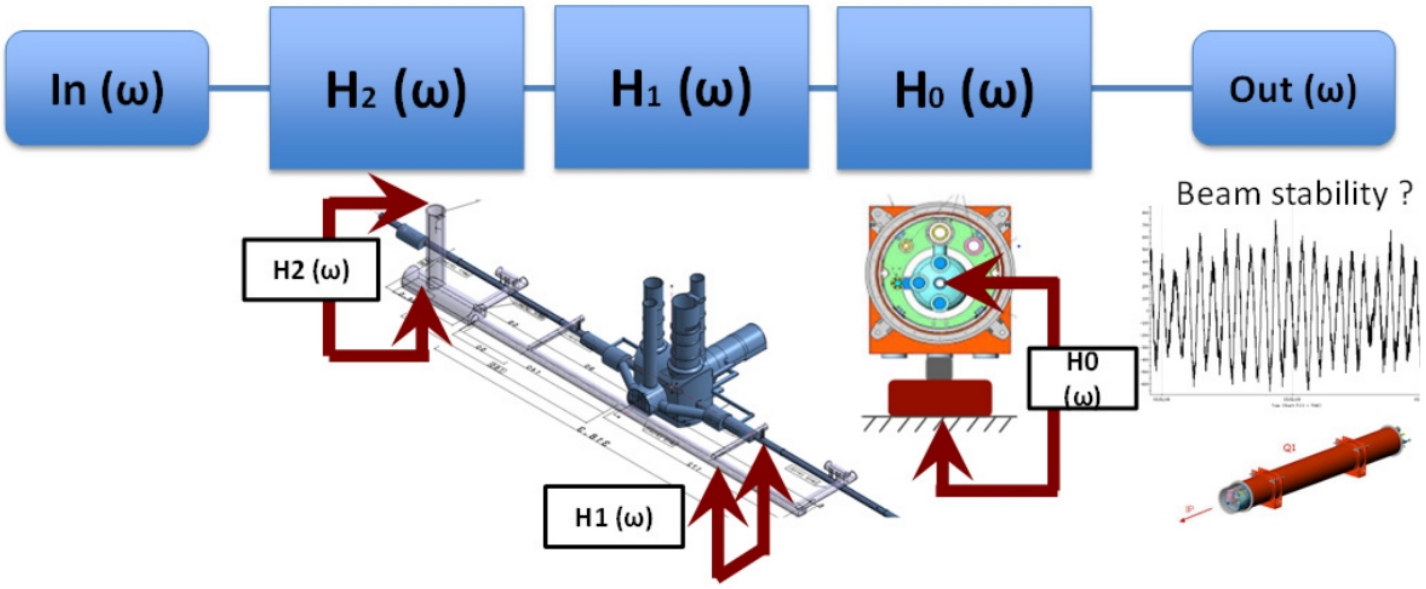
which translates into an orbit separation and luminosity decrease

$$\mathcal{L} = \frac{N^2 f_{rev} N_b}{4\pi\sigma_{beam}^2} W \qquad W = e^{-\frac{1}{4\sigma_{beam}^2}(\delta_s)^2}$$

Transfer function for dummies

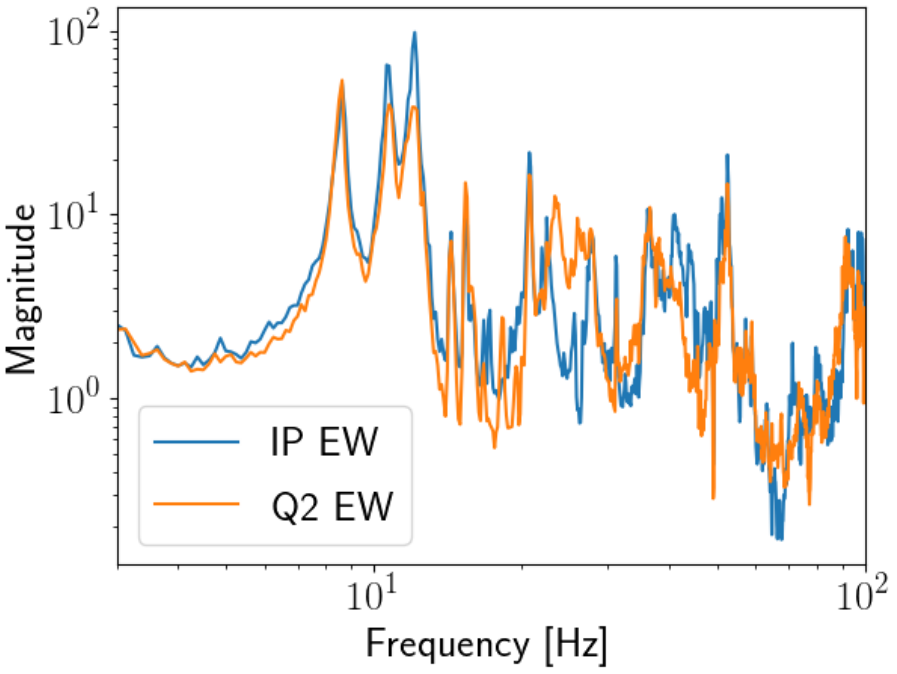


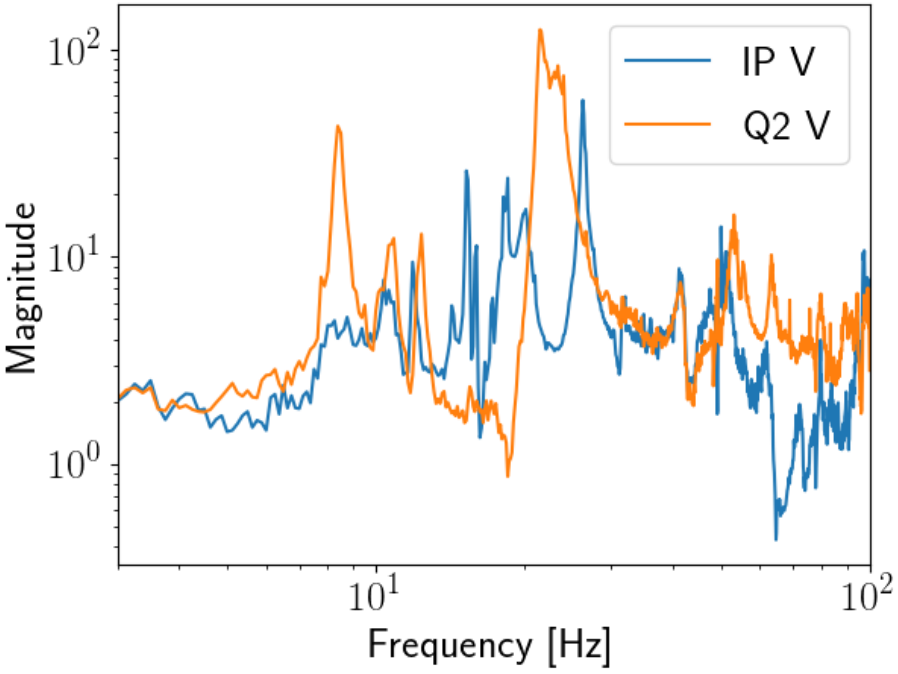
$$H(\omega) = H_0(\omega) \cdot H_1(\omega) \cdot H_2(\omega)$$



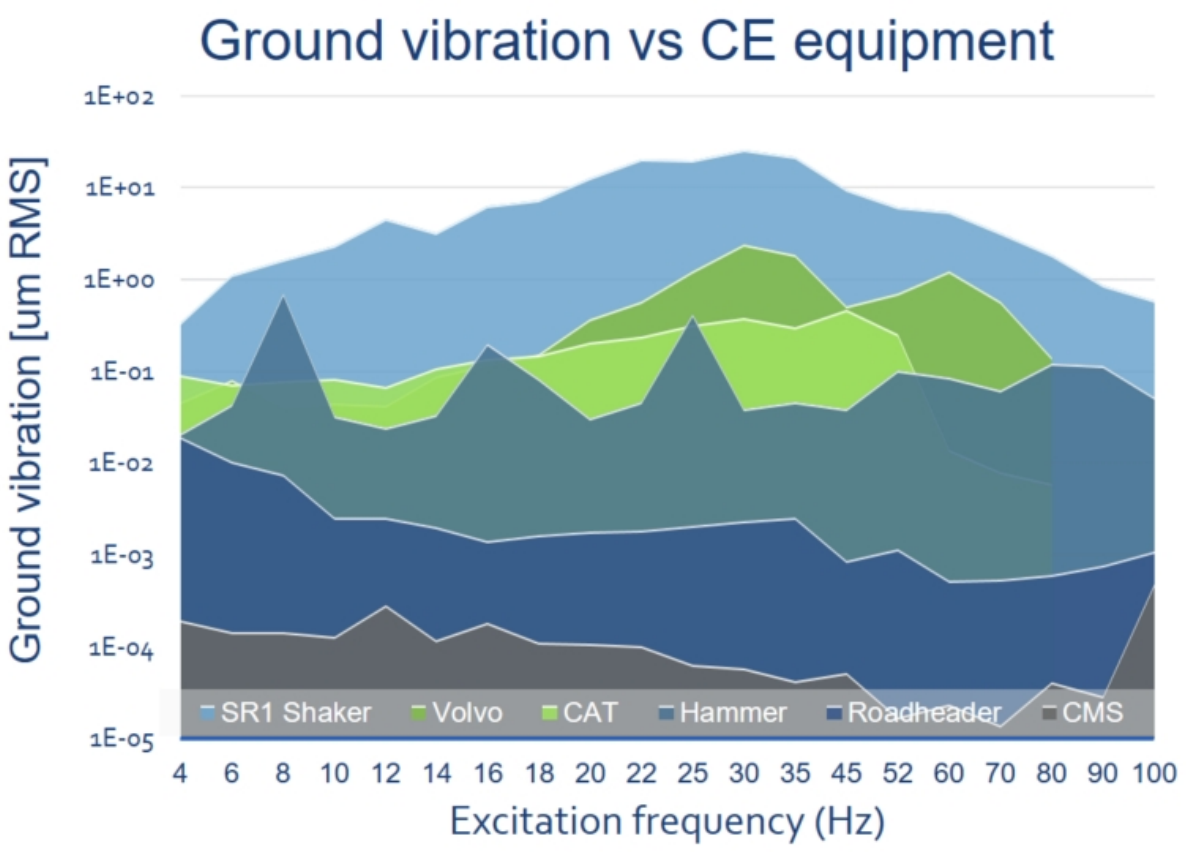
$$H(\omega) = H_0(\omega) \cdot H_1(\omega) \cdot H_2(\omega)$$

Transfer function for LHC quad





Effects of HL Civil Engineering works



T-Rex

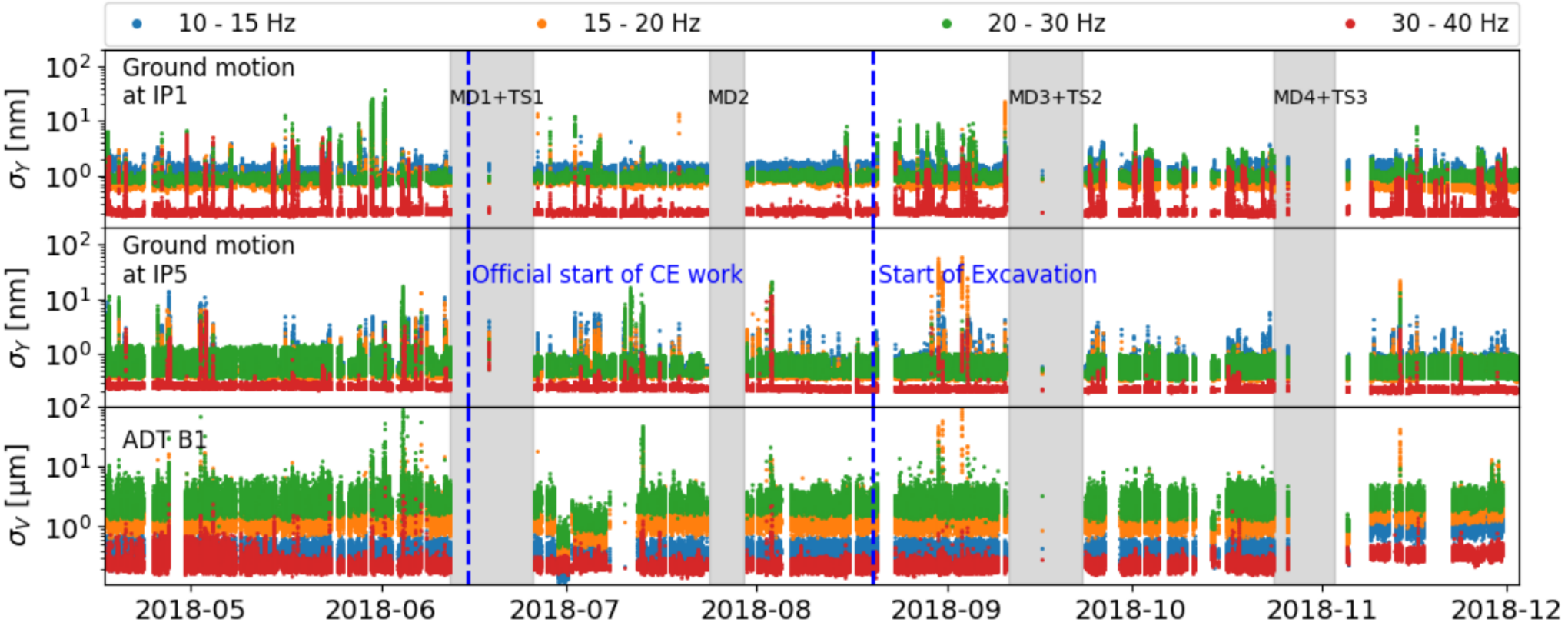
Diplodocus

Triceratops

Stegosaurus

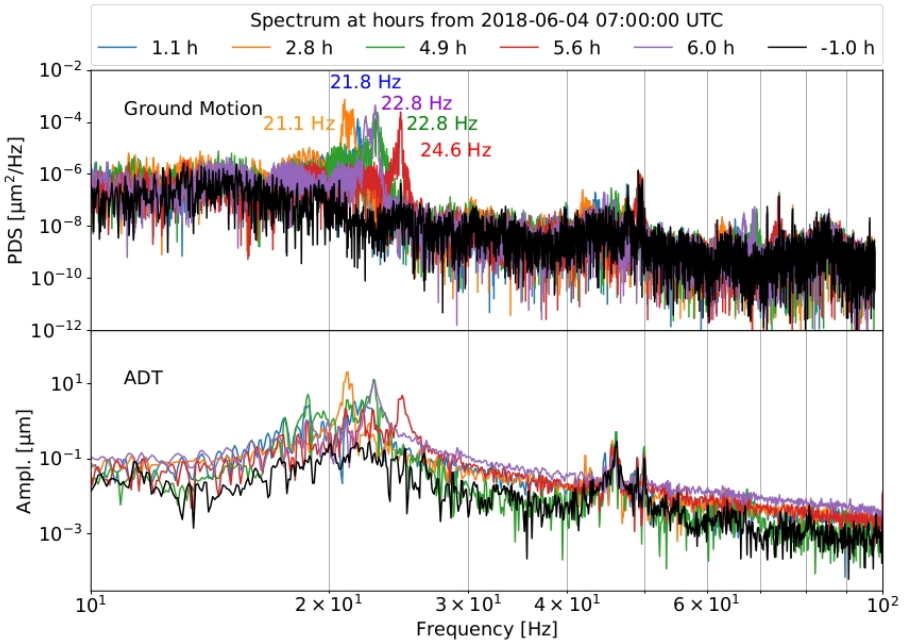
Courtesy of M.Schaumann

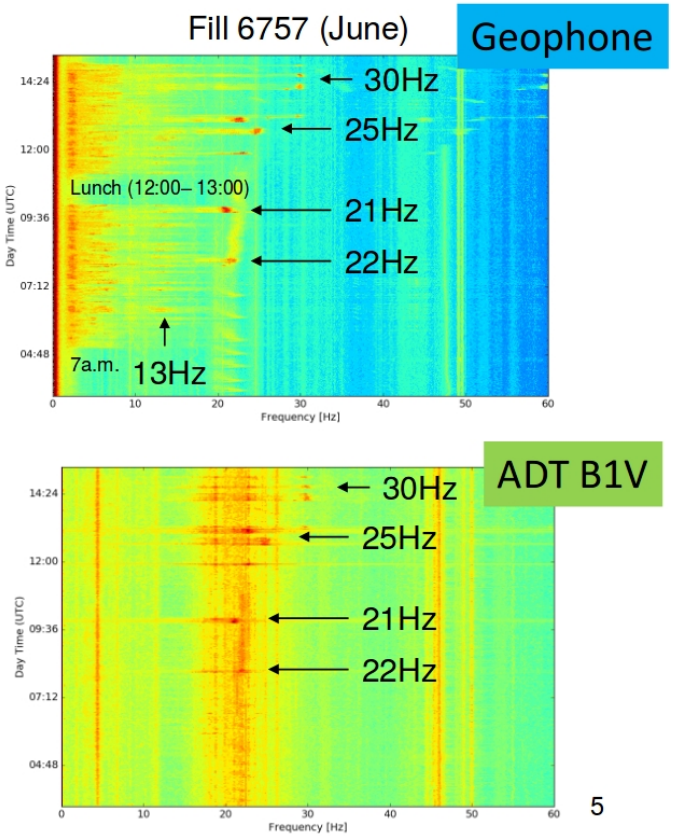
Effects of HL Civil Engineering works



Courtesy of M.Schaumann

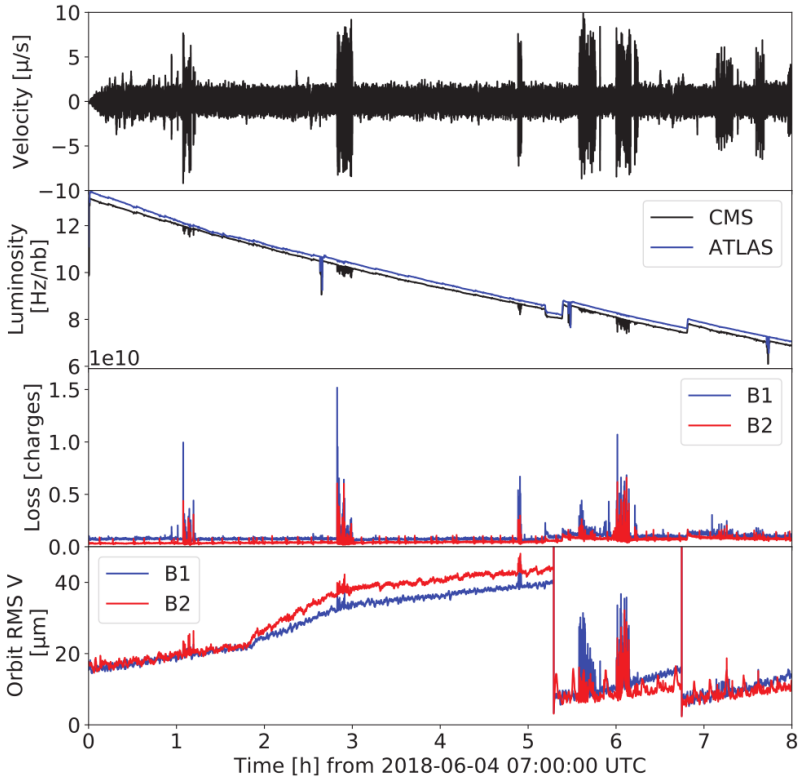
Effects of HL Civil Engineering works





Courtesy of M.Schaumann

OPERATIONAL IMPACT



- Orbit jitter
- Luminosity loss
- Particle losses

Courtesy of
M.Schaumann

About HL

Energy stored in the beam tails

Beam transverse distribution is not purely Gaussian:

- Overpopulated tails
- More accurate models:
  - Double Gaussian distribution.
  - Levy-Student distribution.

In case of orbit jitter at the primary collimator:

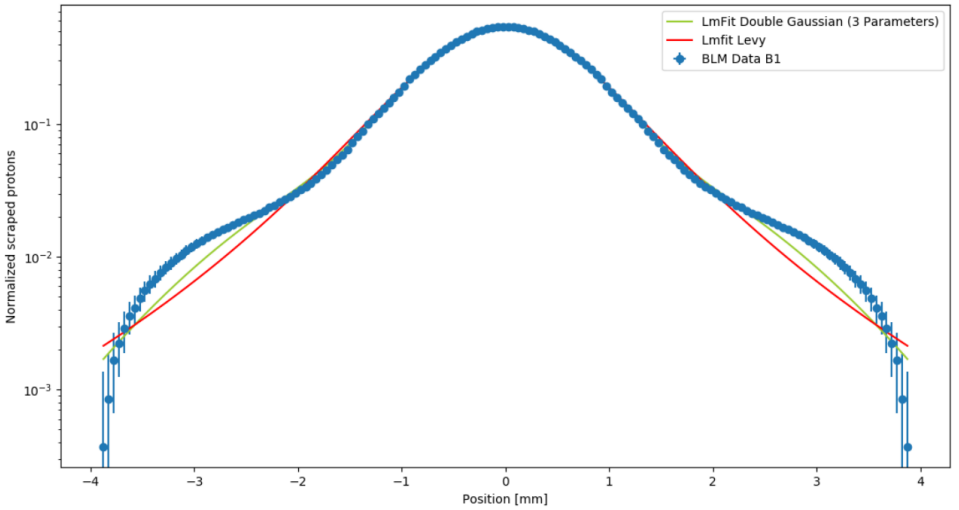
- Is there a risk of beam dump?
- Is there a risk of collimator damage?

Need to evaluate the energy stored in the beam tails

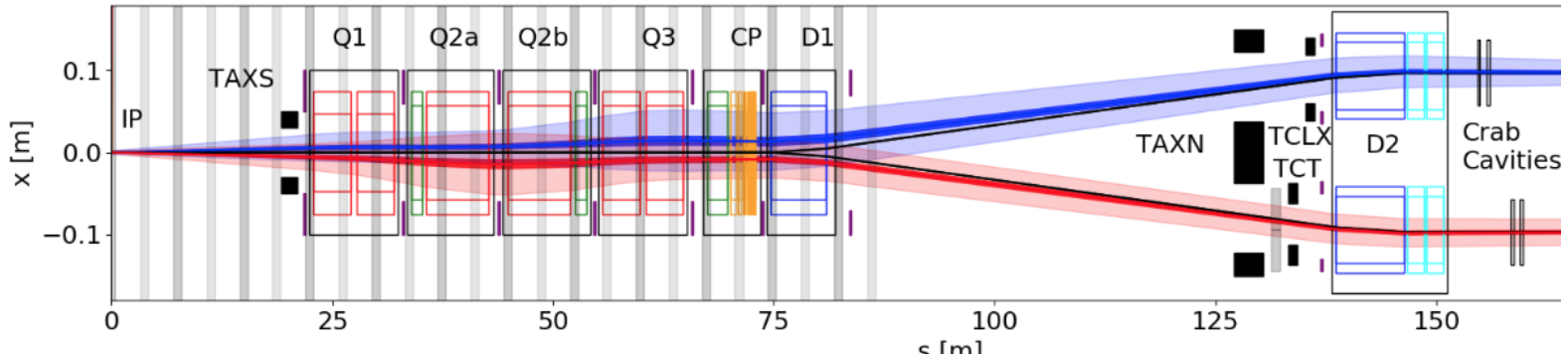
5% of the beam beyond 3 sigma
34 MJ of stored energy

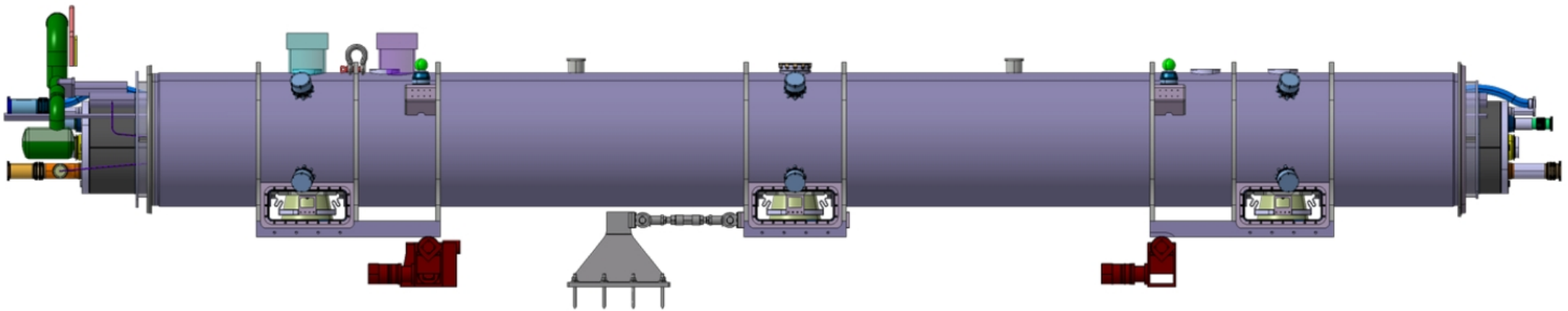
Expected max. rms orbit

	LHC	HL-LHC
Orbit sep. IP1/5 $[\sigma_{beam}]$	0.01	0.03
Luminosity loss [%]	< 0.1	< 0.1
Orbit at TCPs $[\sigma_{beam}]$	0.01	0.02



High Luminosity LHC IR layout

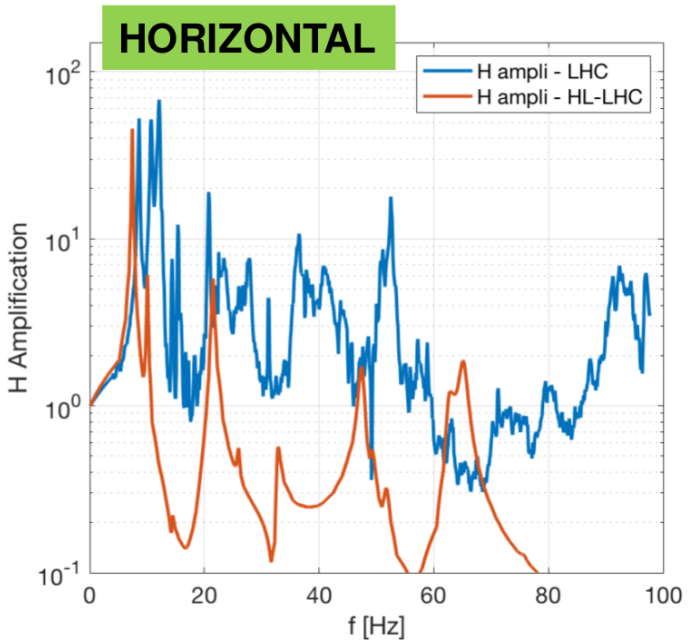


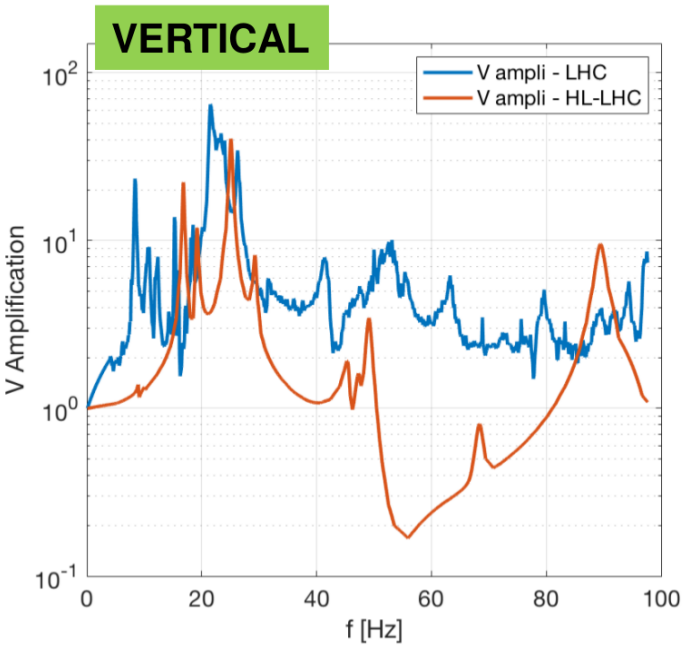


Transfer function for LHC Dipole

Coming soon . . .

But we have some simulations





HL-LHC seems less sensitive to GM than the LHC
(to be benchmarked with measurements)

Open questions

- What is the transfer function of the HL-LHC IT quadrupoles?
- What are these 10Hz oscillations observed in operation?
- Can we avoid future beam dumps due to orbit jitter?
- Is it required a new orbit feedback system for HL-LHC?


I'M SIMPLY SAYING THAT
THE BEAM... UH, FINDS A WAY
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