Comparative analysis of the 3D impulse directivity of a batch of six violins

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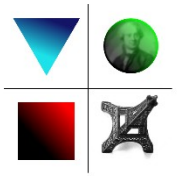
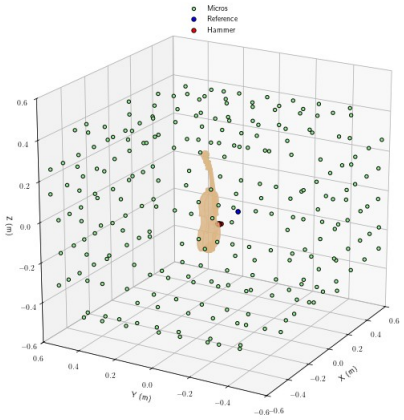
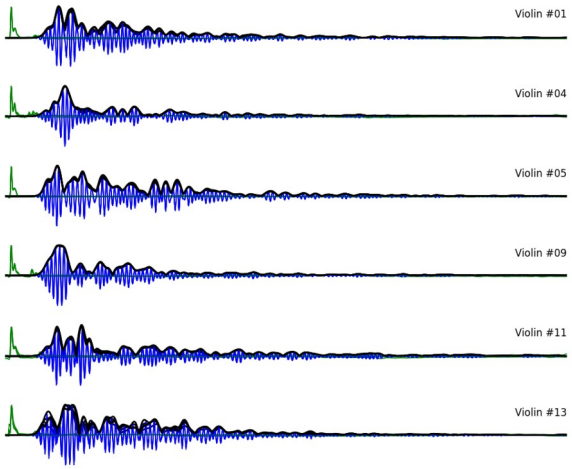
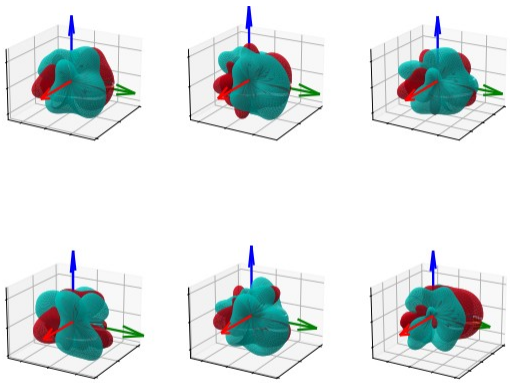






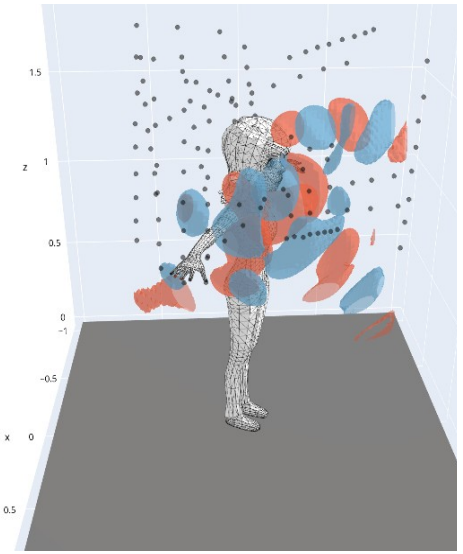


The Bilbao project

- **Objective** : Demonstrate the relationship between mechanical behaviour and tonal quality of the violin.

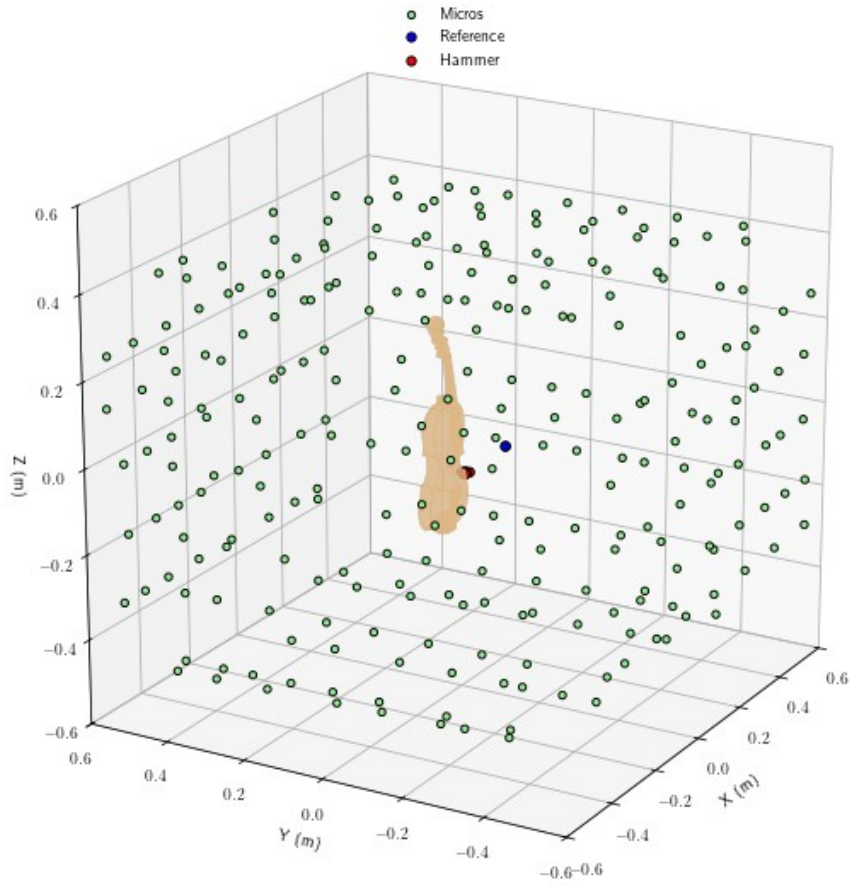
The RayoVox project (ANR)

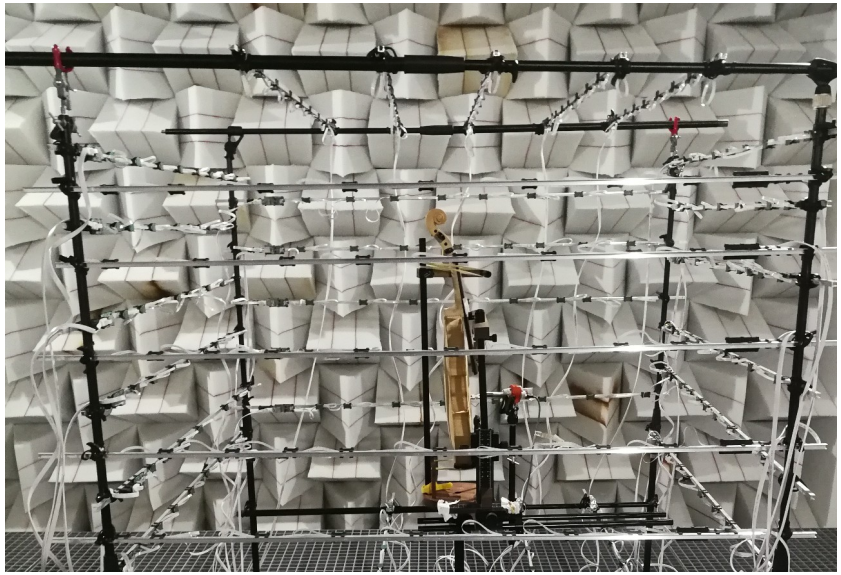
- **Objective** : Develop an instrumentation to measure
  - with high resolution
  - in the near and far field
  - The 3D directivity of the voice

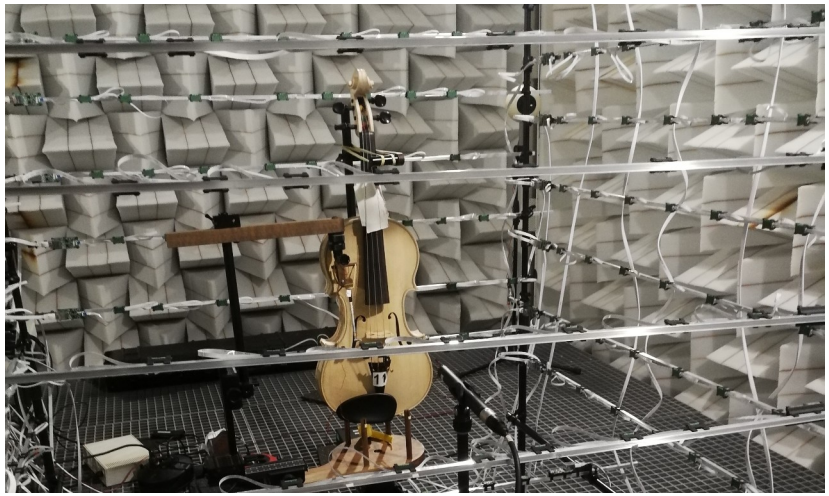


Measurement Setup

- A 1m^3 Mems microphone array
- 256 elements arbitrary set on the faces
- 2 reference microphones
- 1 impact hammer







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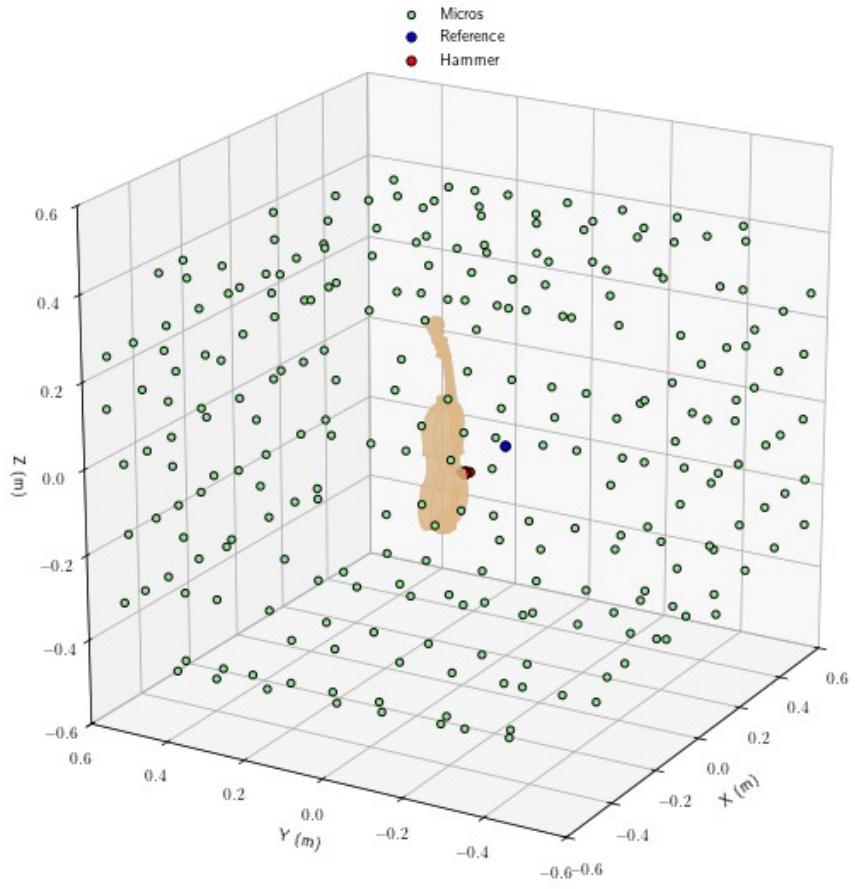
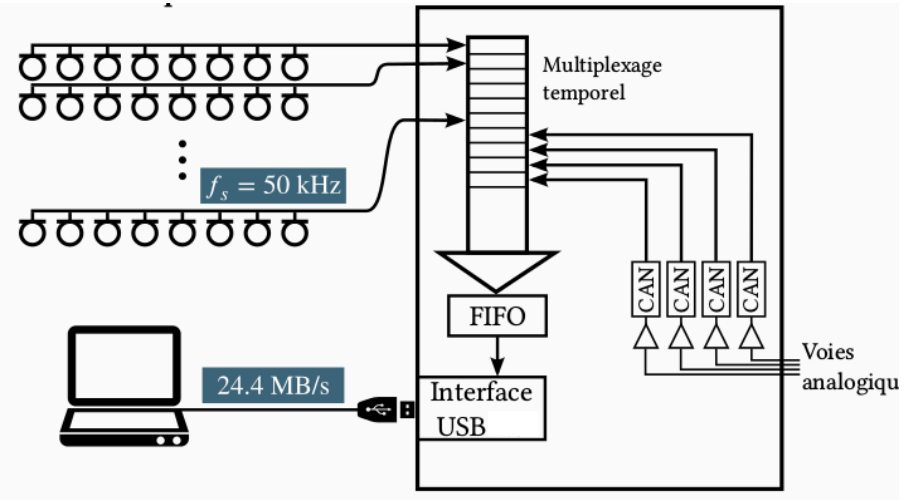
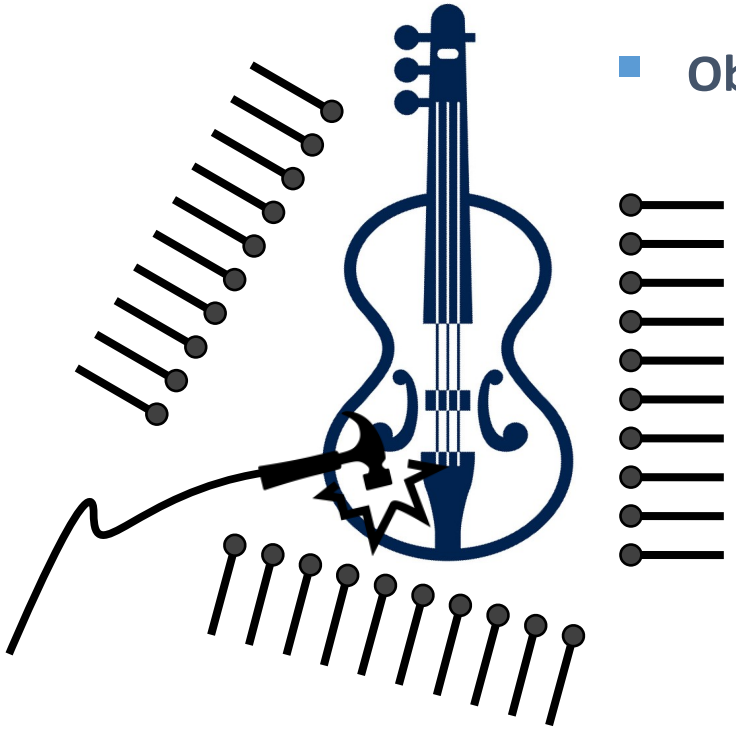


- Digital recorder Mµ256
- I2S digital Mems
- Sampling frequency : 50 kHz
- Digitization : 24 bits
- Control and data transfer : USB3
- Data Stream : 51.2 MO/s
- Dedicated python library



The linear SIMO system under study

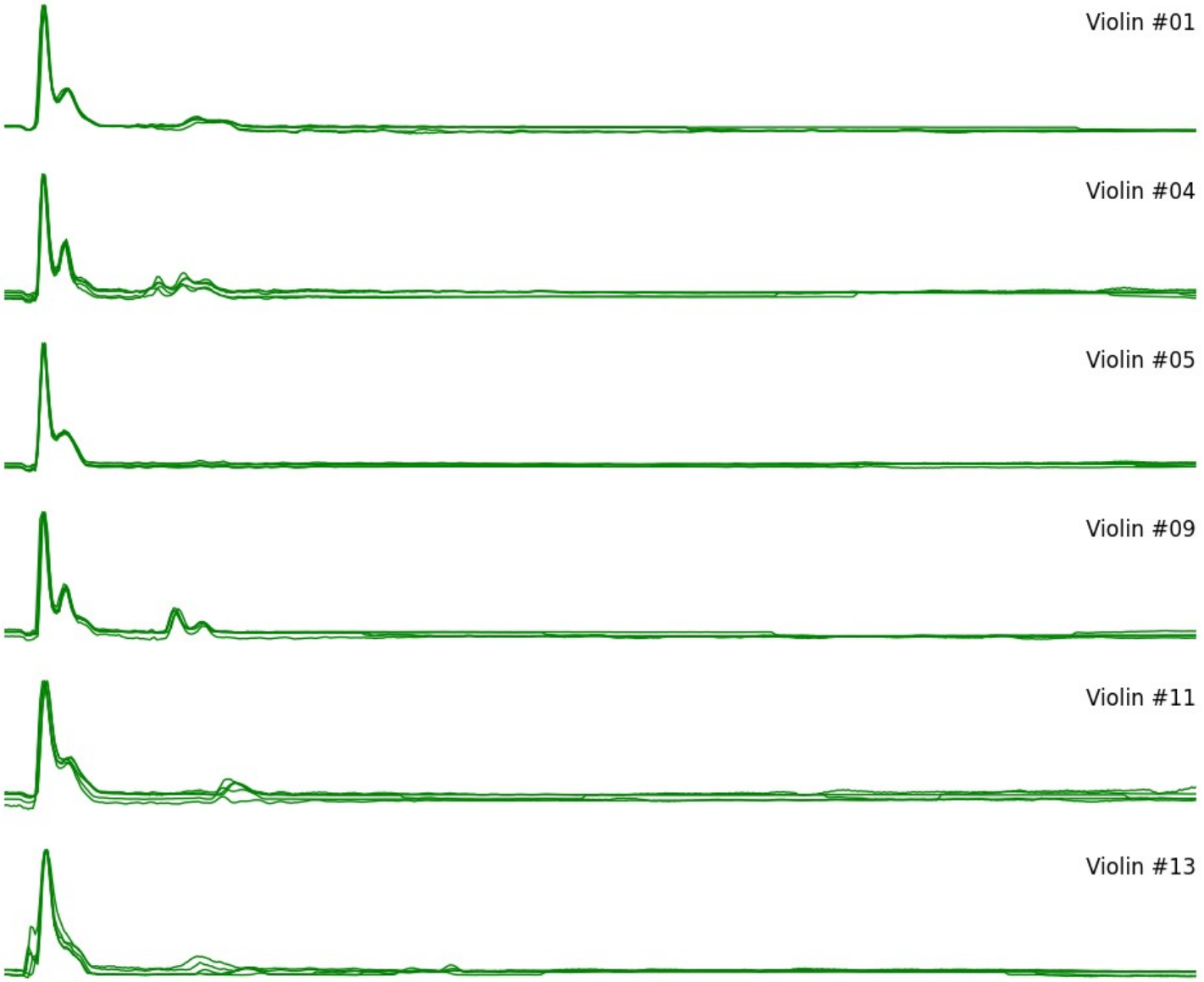


- **Objective** : Measure with high resolution $D_\infty(\Omega)$ the 3D directivity of the violins
  - *Measured data* :
    - The hammer impact f(t)
    - 256 acoustic responses $m_i(t)$ (i = 1,…,256)
      - $i = (r_i, \Omega_i) = \mathbf{r_i}$
      - A set of arbitrary points
      - around the violin

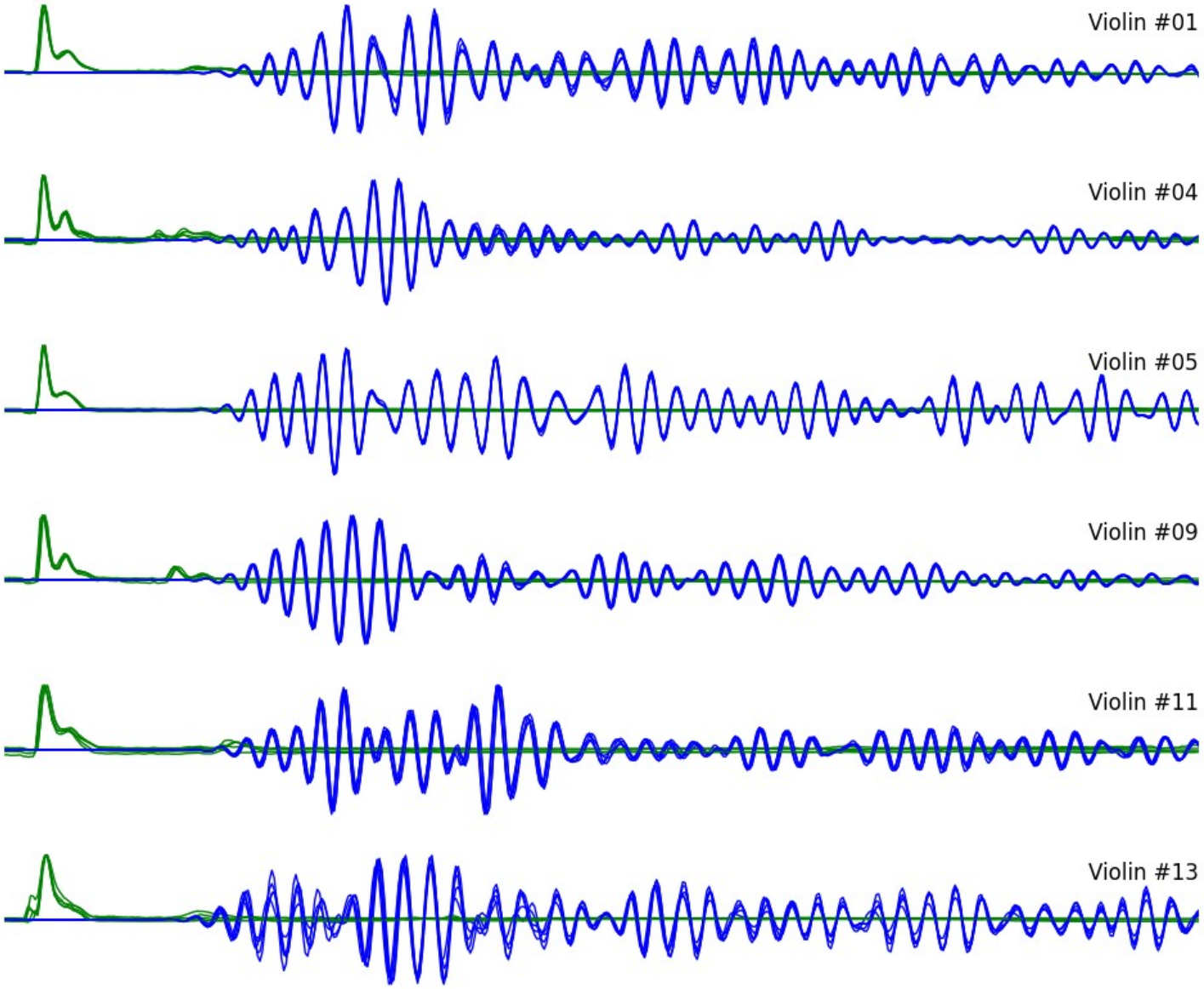
- *Unknowns of the violin*
  - The vibration FRF
    - $\mathbf{H_{fv}}(\mathbf{r_s}, \omega)$
  - The vibroacoustic FRF
    - $\mathbf{H_{vp}}(\mathbf{r_s}, \mathbf{r_i}, \omega)$

- *What we need is what we get*
  - The acoustic response to a unitary force at the base of the bridge :
    - $\mathbf{H_{fp}}(\mathbf{r_s}, \mathbf{r_i}, \omega) = \mathbf{H_{fv}}(\mathbf{r_s}, \omega)\mathbf{H_{vp}}(\mathbf{r_s}, \mathbf{r_i}, \omega)$

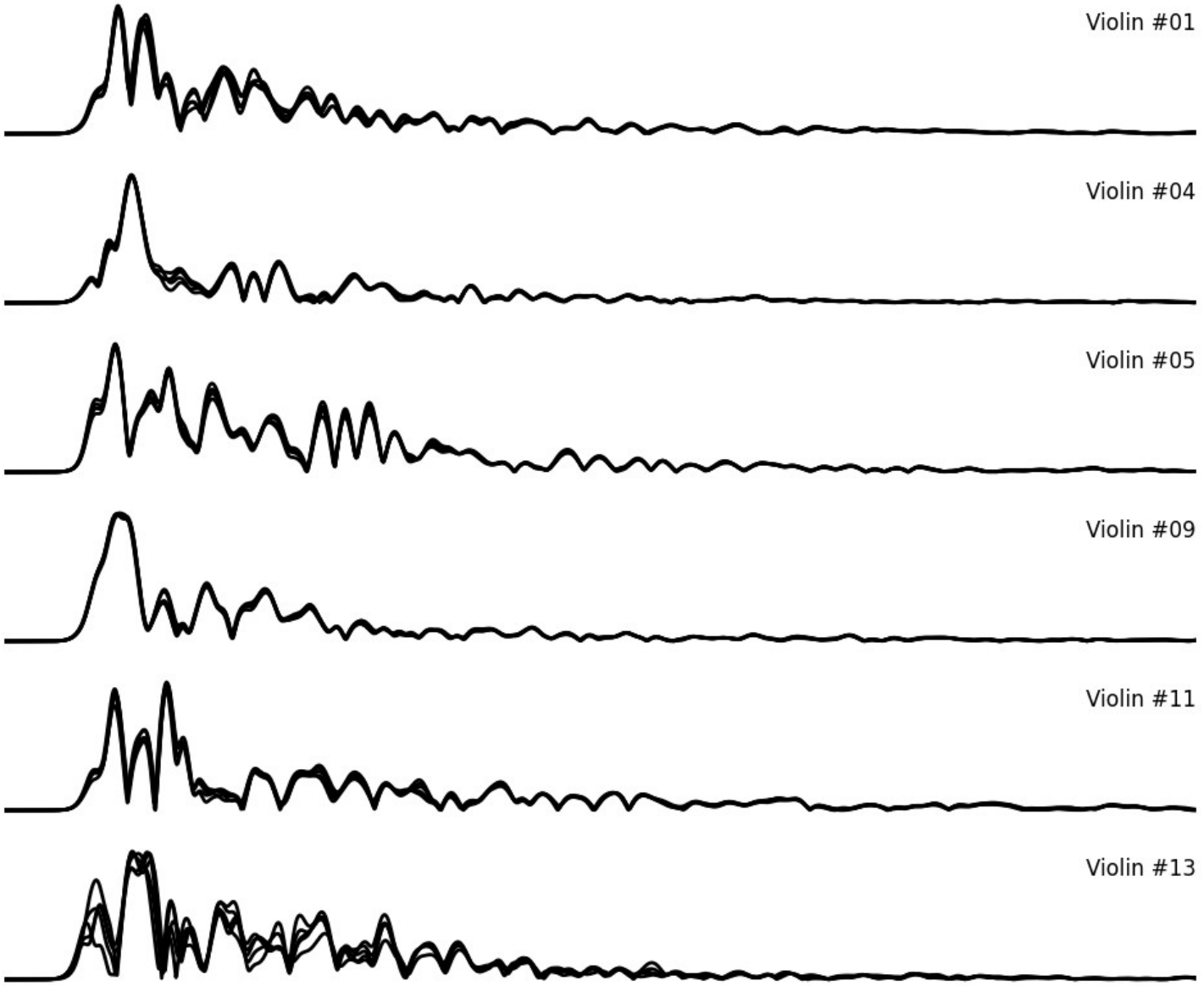
Bouncing Hammer impacts



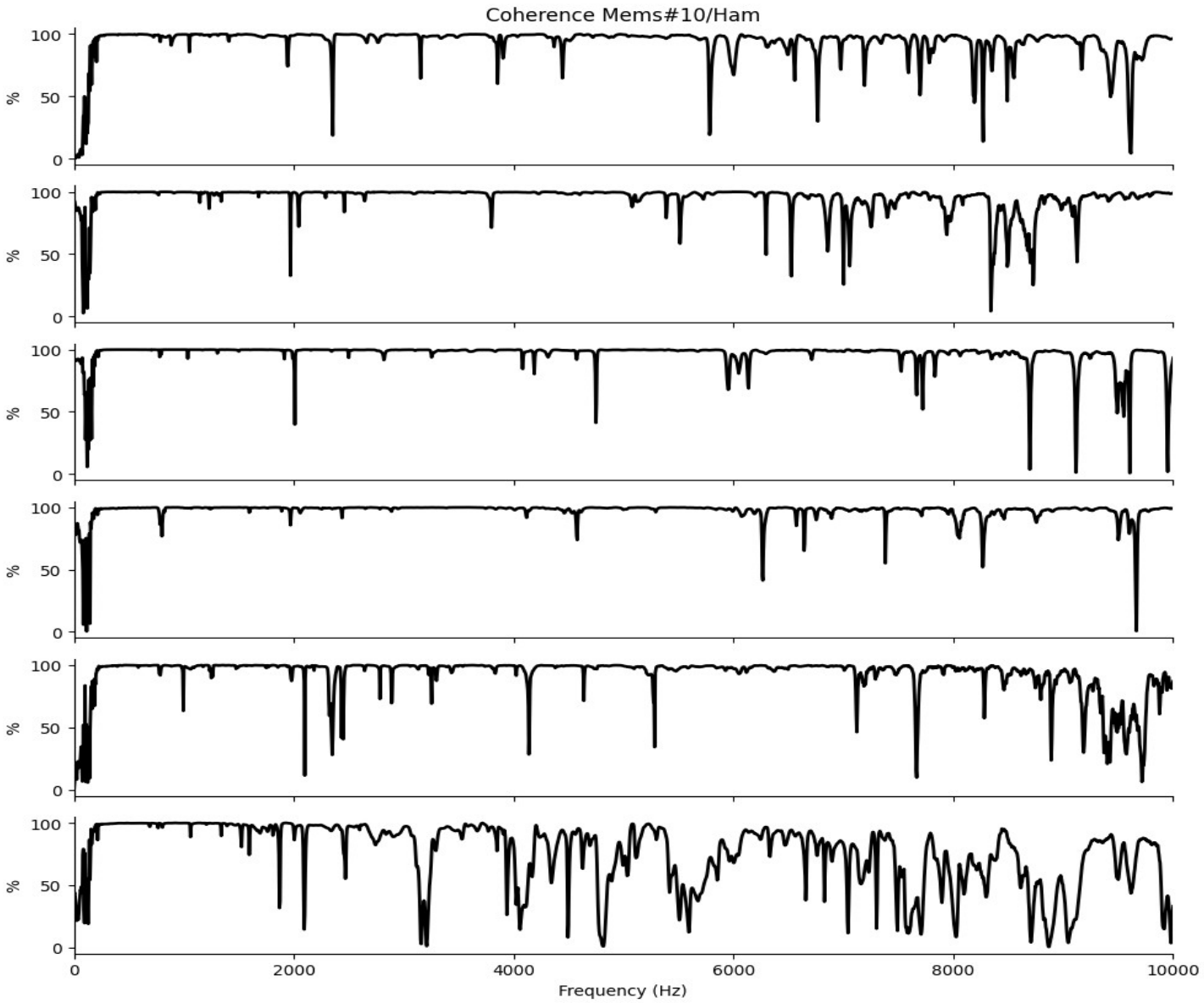
Reference Responses to bouncing Hammer impacts



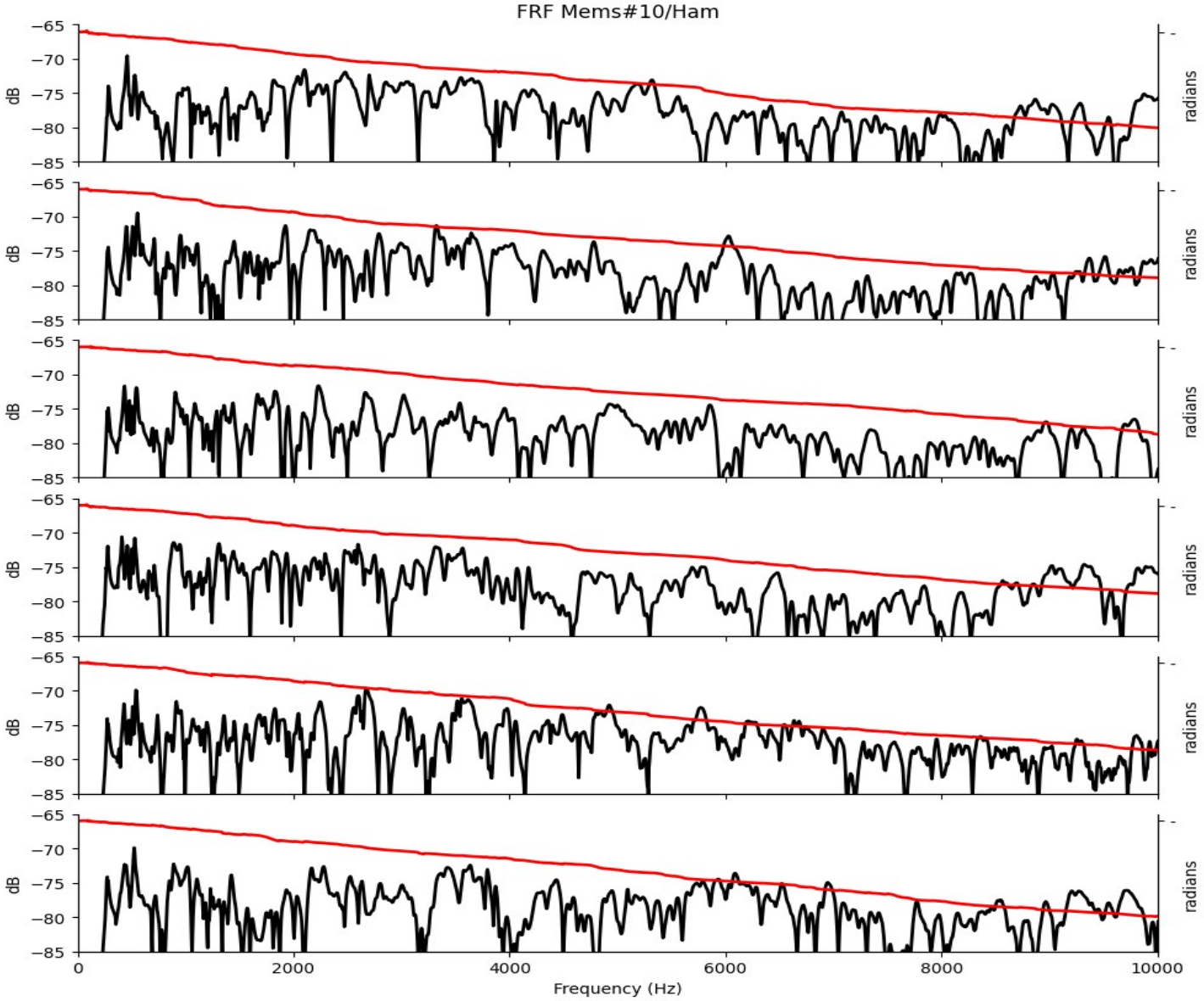
Reference Responses envelopes



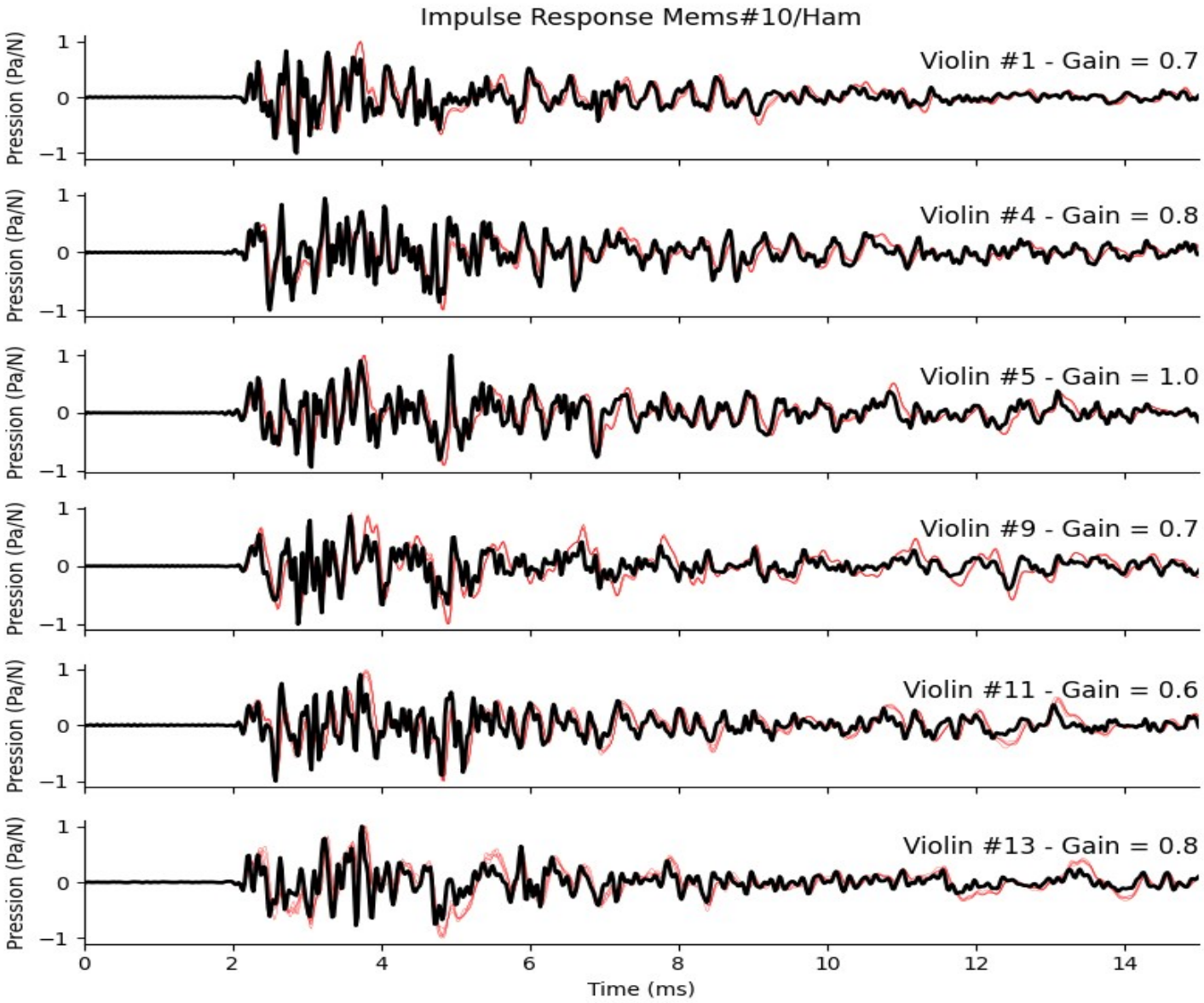
Coherence of 5 impacts for each violin



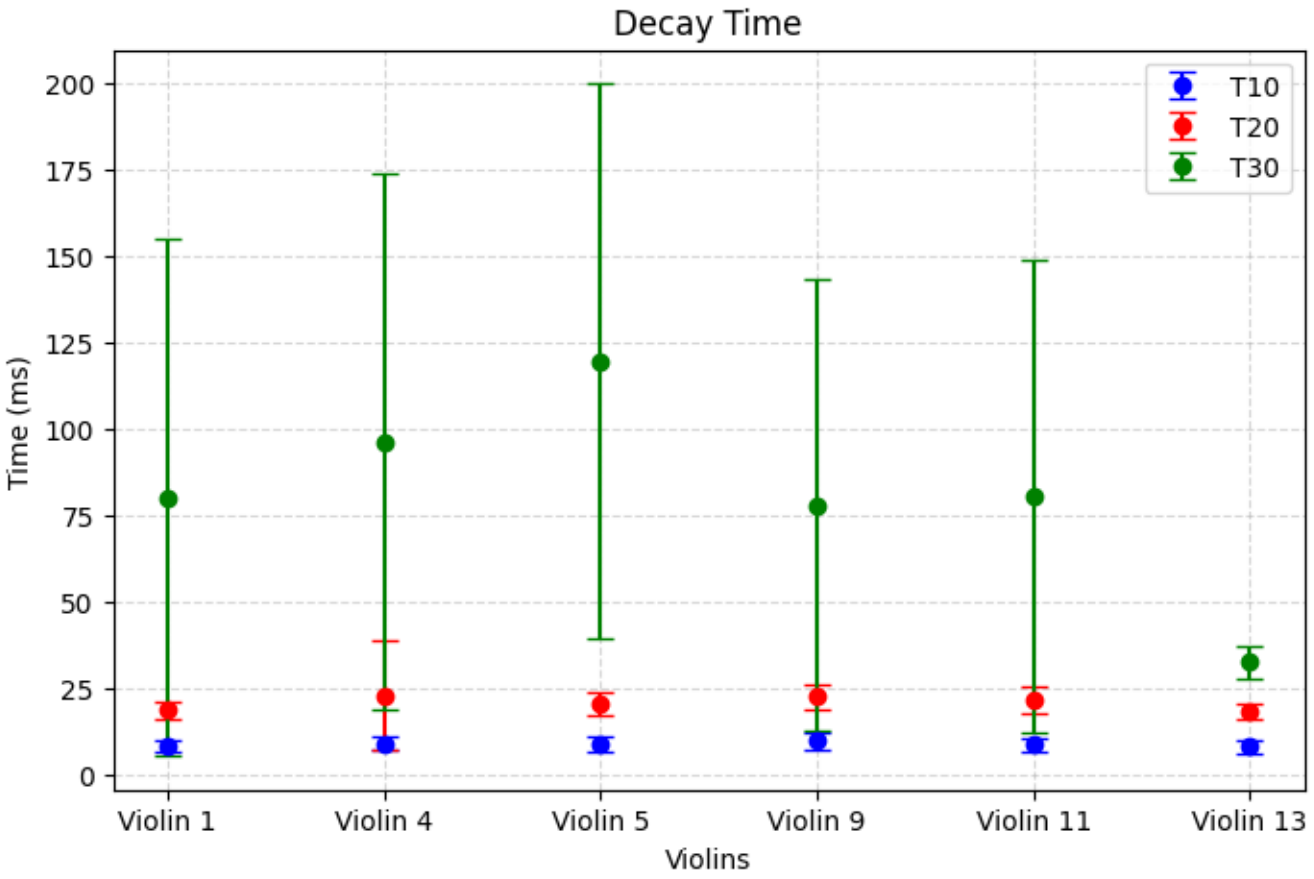
Frequency response functions



Impulse Response functions



Analyzing the RI enveloppes



Processing the directivity : The HELS method

$$P(r_q, \theta_q, \phi_q, k) = \sum_{n=0}^{N} \sum_{m=-n}^{n} c_{mn}(k) h_n^{(2)}(kr_q) Y_n^m(\theta_q, \phi_q).$$

$$\mathbf{p} = \left[P(r_q, \theta_q, \phi_q, k)\right]_{q \in [0,\ldots,Q-1]},$$

$$[\mathbf{H}]_{q,\psi(n,m)} = h_n(kr_q) Y_n^m(r_q, \theta_q, \phi_q)$$

$$[\mathbf{c}]_{\psi(n,m)} = c_{mn}.$$

$$\mathbf{p} = \mathbf{H}\mathbf{c}$$

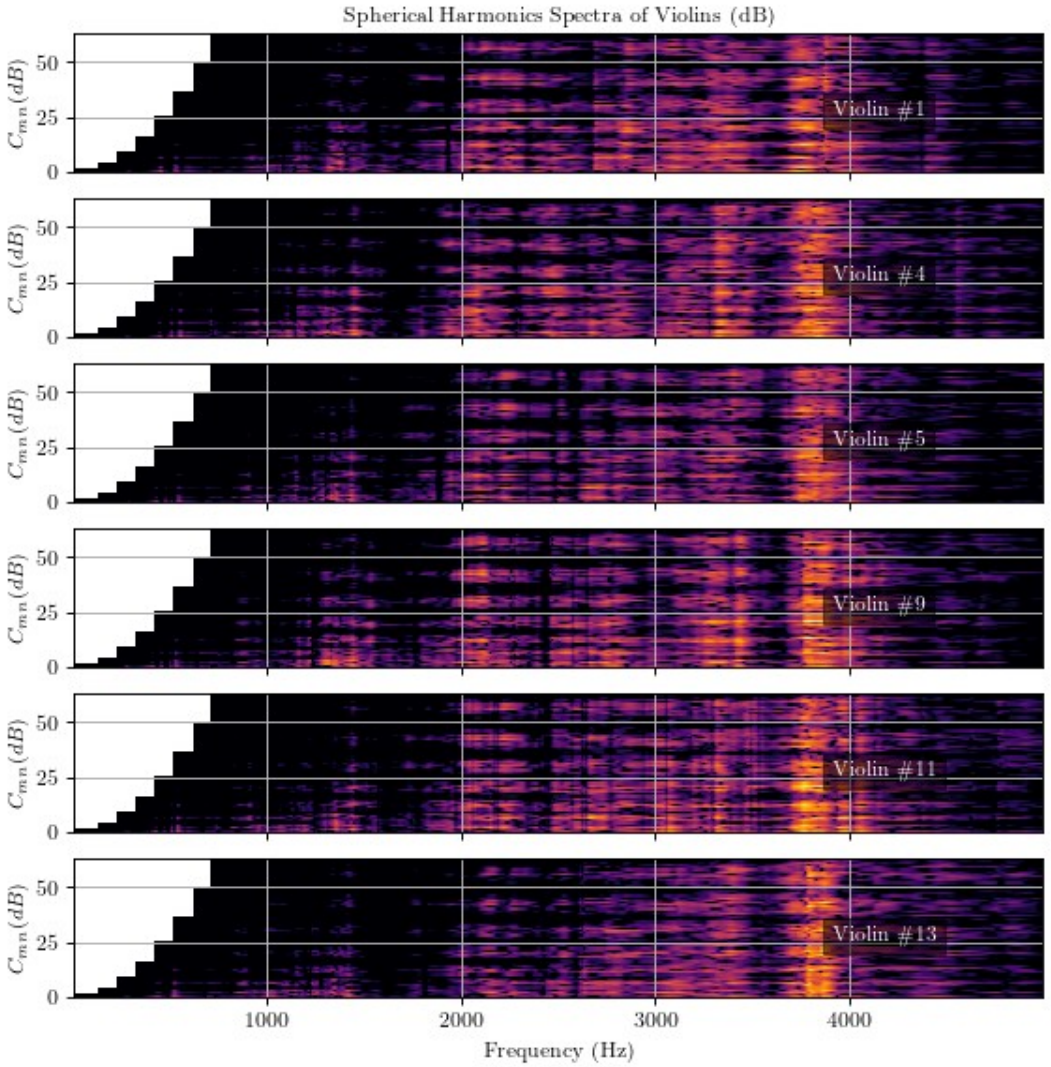
Processing the directivity : The HELS method

$$\mathbf{p} = \mathbf{H}\mathbf{c}$$

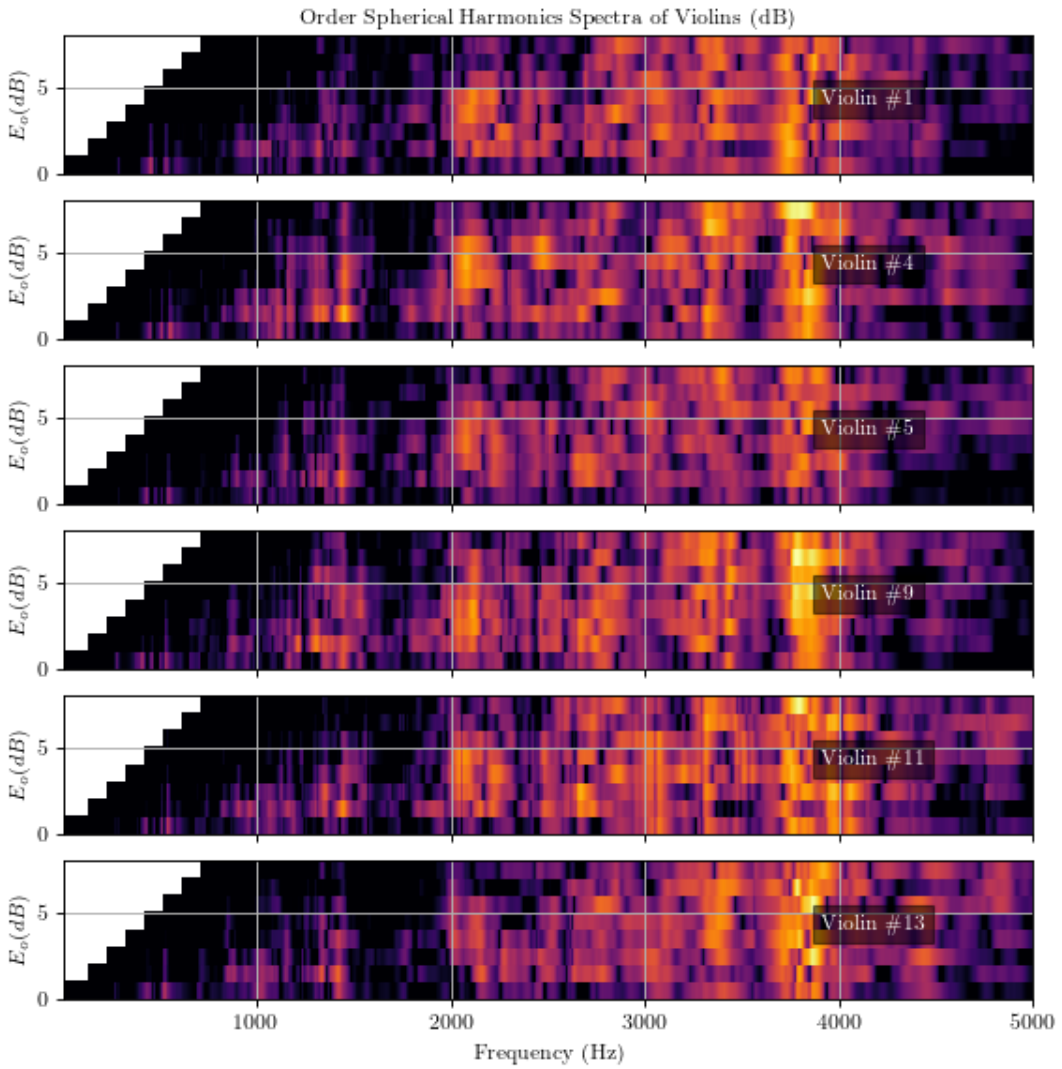
$$\hat{\mathbf{c}} = \left(\mathbf{H}^{\mathrm{H}}\mathbf{H} + \lambda\mathbf{I}\right)^{-1}\mathbf{H}^{\mathrm{H}}\mathbf{p},$$

$$\hat{D}_{\infty}(\theta,\phi) = \sum_{n=0}^{N}\sum_{m=-n}^{n}\hat{c}_{mn}(k)j^{n+1}Y_n^m(\theta,\phi).$$

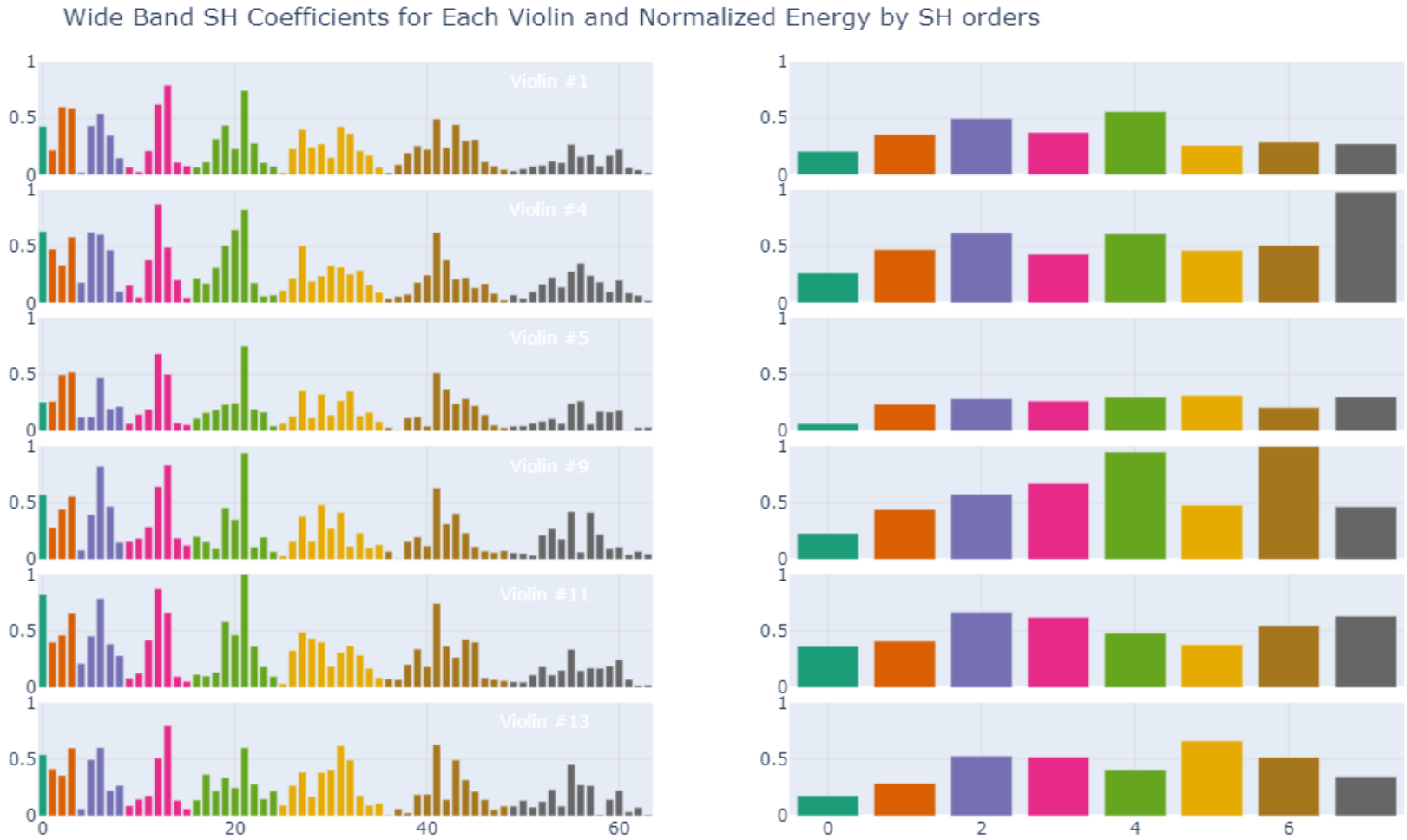
Spherical Harmonics Spectra



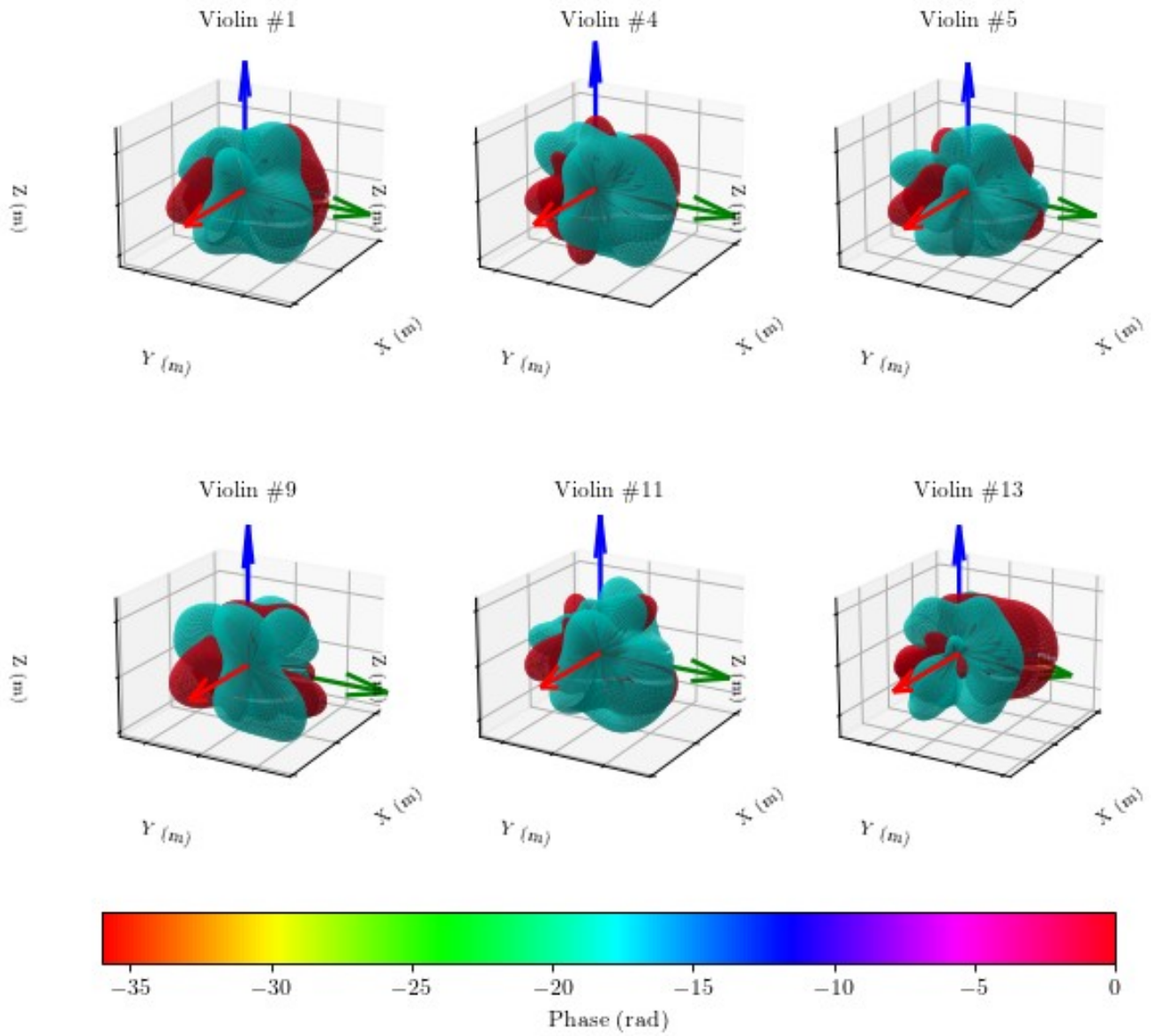
Spherical Harmonics Spectra



Wide Band Spherical Harmonics Spectra



Wide Band 3D far field directivity (3D-FFD)



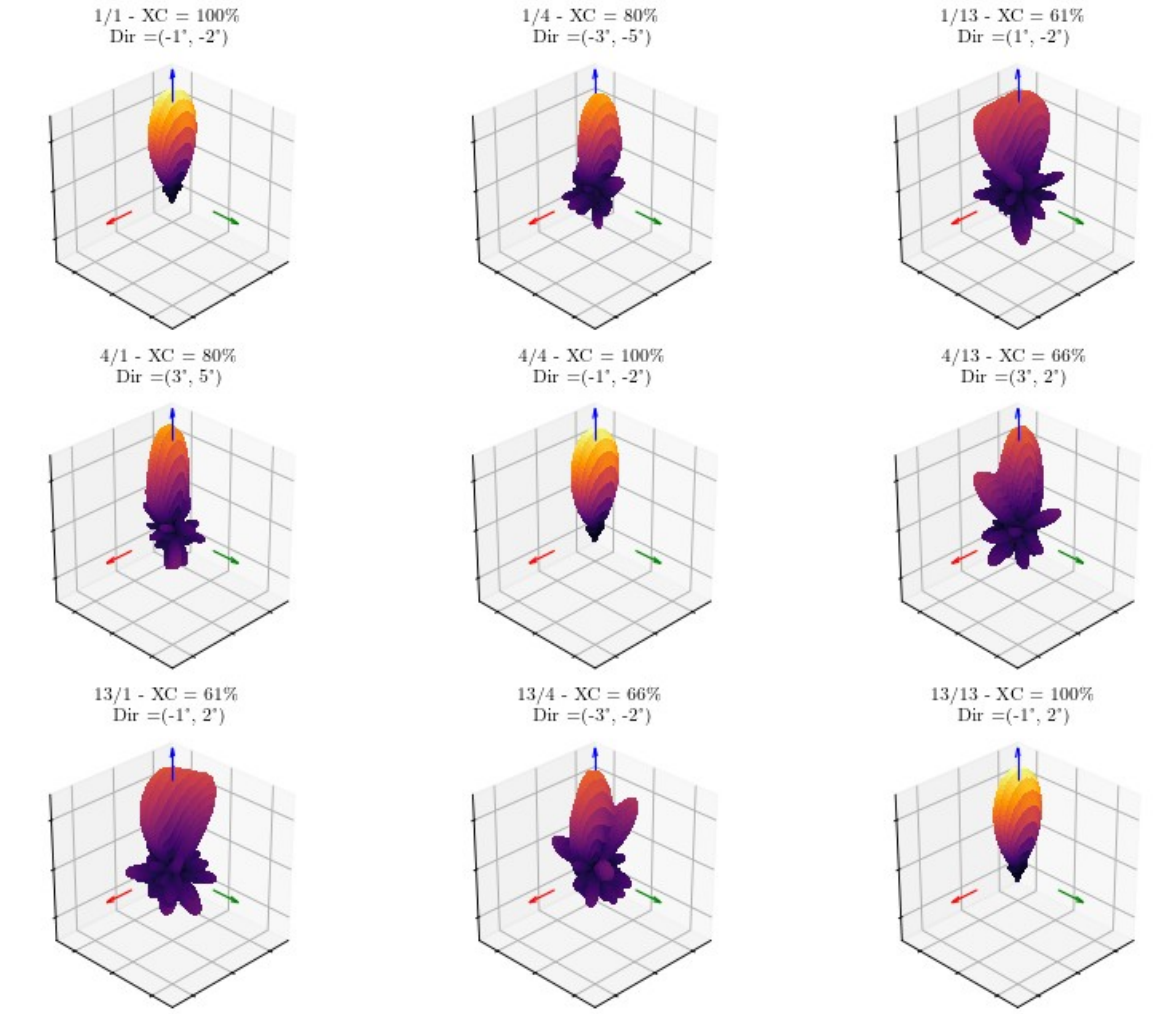
Track the similarities of the FFDs :

The spherical cross-correlation

$$XC(\Omega) = \sum_{n=0}^{N} \sum_{m=-n}^{n} \hat{c}_{mn}^{(1)*} \hat{c}_{mn}^{(2)} j^{n+1} Y_n^m(\Omega)$$

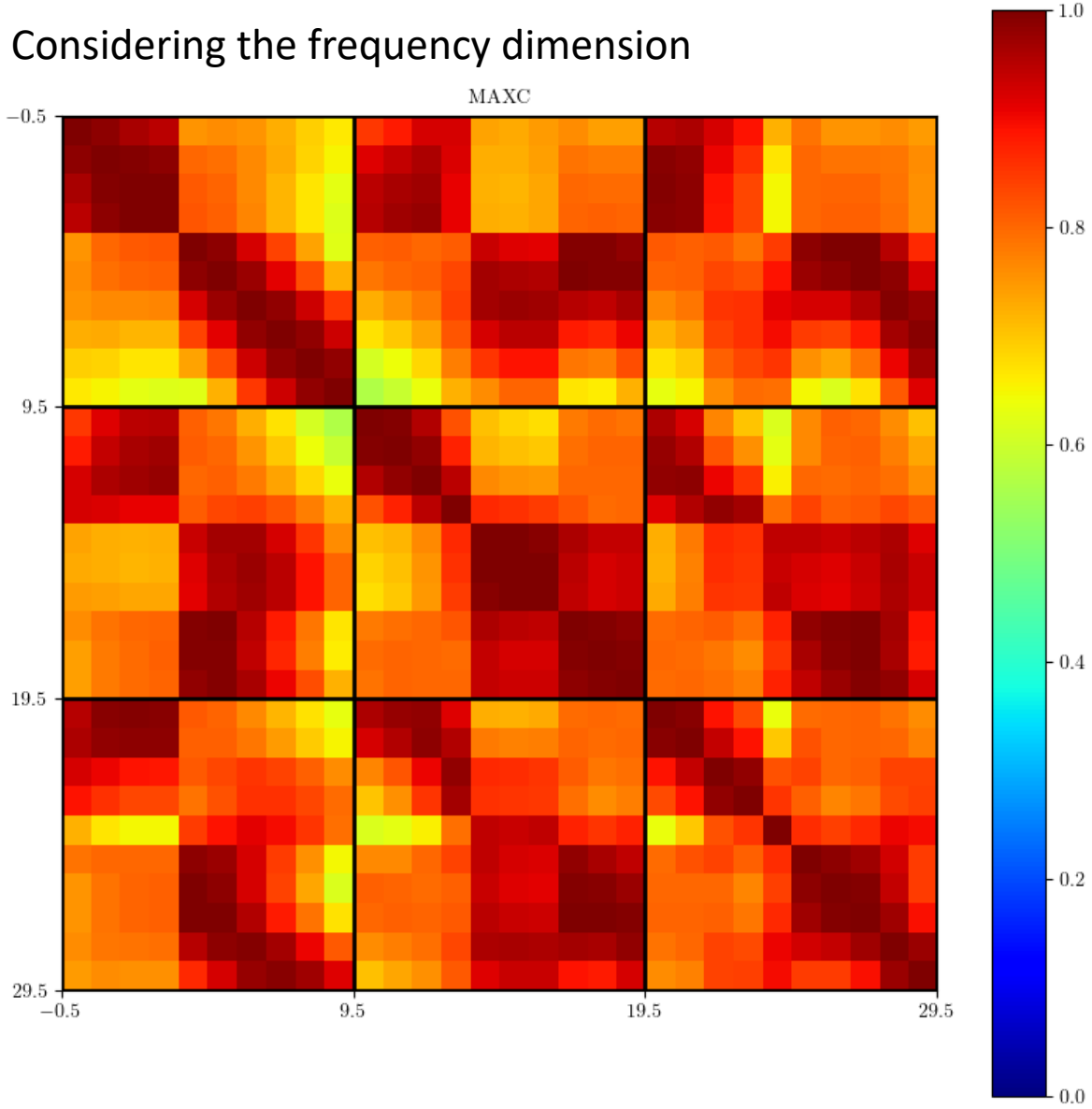
- Leverage the spherical correlation to estimate :
  - The level of similarities between 2 FFDs
  - The directions of the similarities

Track the similarities of the FFDs :



Track the similarities of the FFDs :

Considering the frequency dimension



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