Design of a spherical array of microphones for room acoustics applications.

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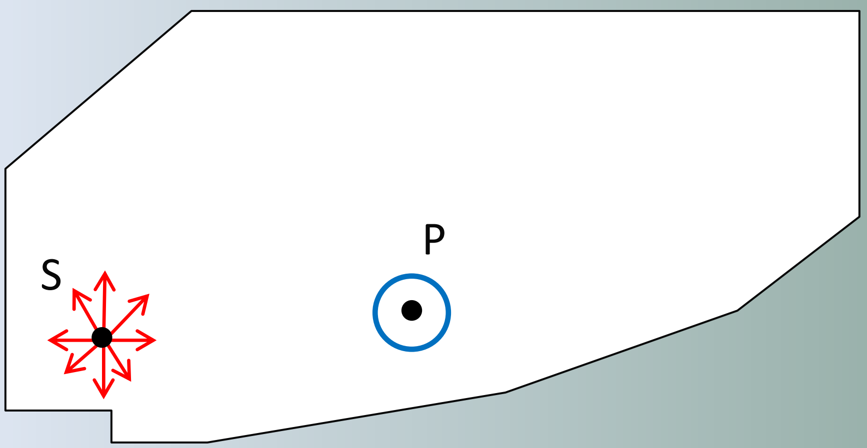
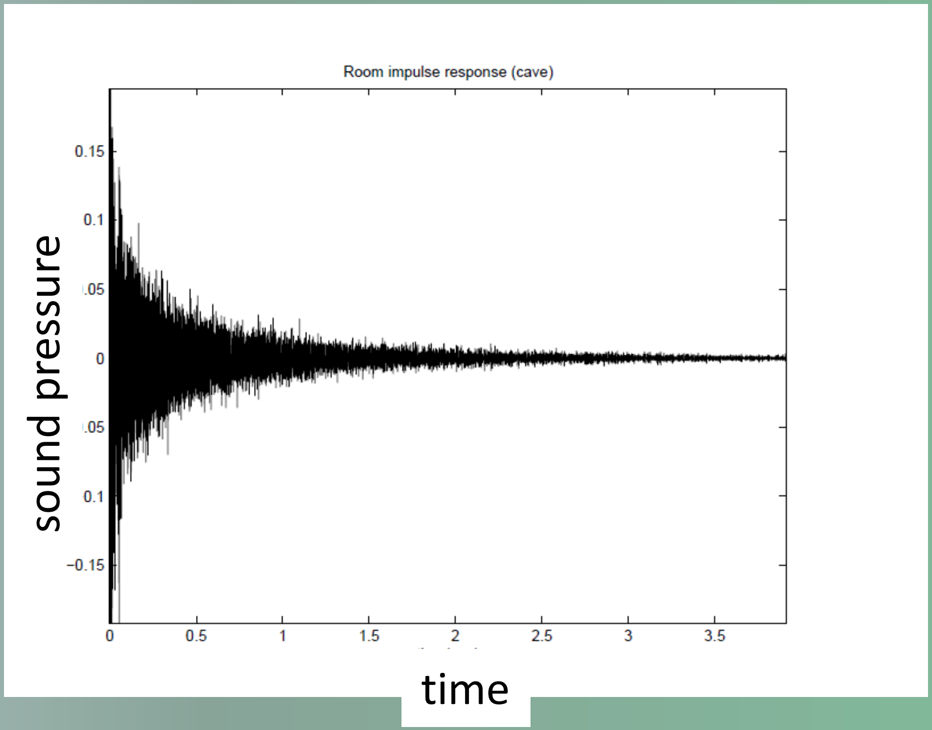
(*) Now at Deltatec s.a. (Ans-Liège)

The room impulse response RIR

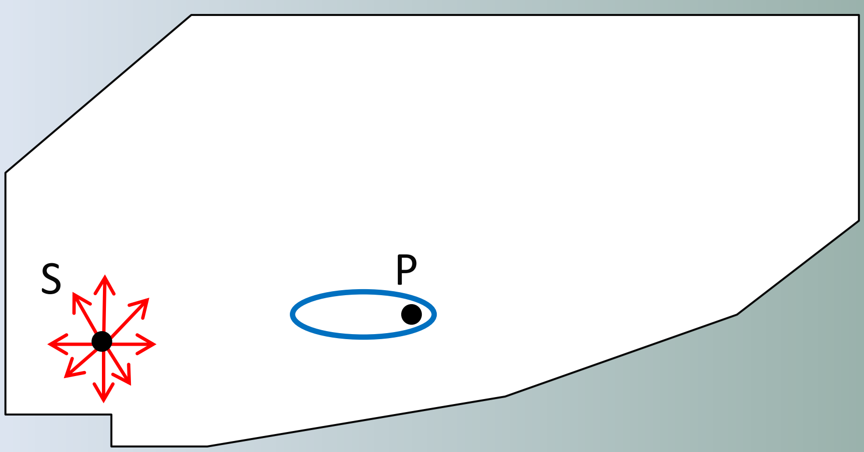
(between an *omnidirectional* source and an *omnidirectional* receptor)

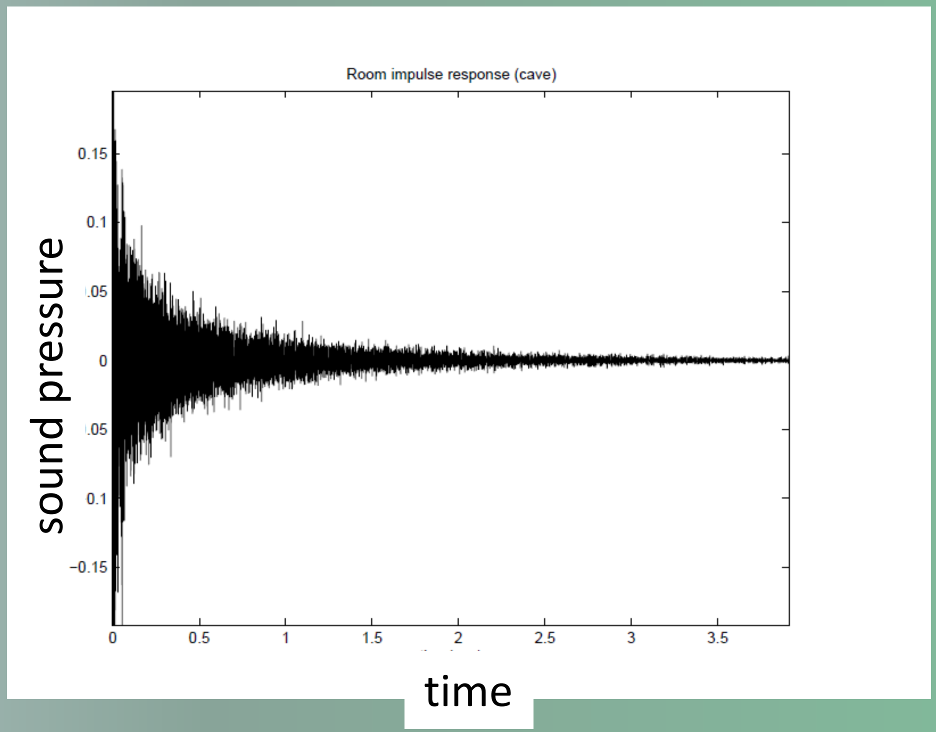




The directional (or spatial) room impulse response DRIR

(between an *omnidirectional* source and a *directional* receptor)





Directional room impulse responses DRIR can help to:

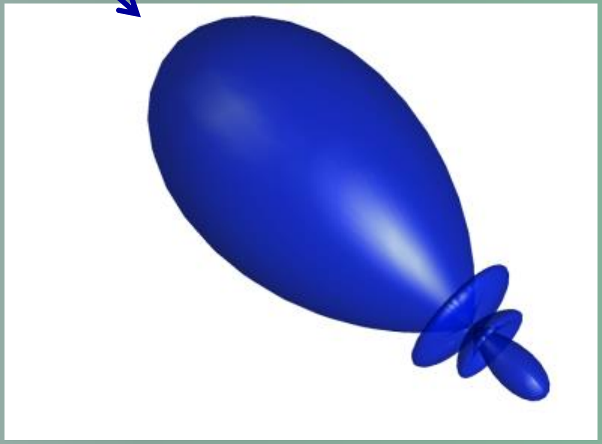
- Evaluate « spatial » room acoustics parameters, such as the lateral energy fraction LEF, the left/right ratio LRR or the reverberation time in a particular direction,

- Detect possible (flutter) echoes in a particular direction,

- Create 3D auralization of acoustic spaces.

How to measure Directional room impulse responses DRIR ?

- With a microphone antenna (microphone array), which can provide ***beamforming*** and ***beamsteering***.



Beam pattern of array output

Which kind of antenna for that application ?

(form, size, number of microphones,…)

- **Master project** of Hermine Feron (2013),
- Spherical array, 10cm radius,
- Rigid sphere,
- 16 microphones,
- *Nearly uniform* distribution on the sphere,
- Two souncards (8 inputs each),
- Recordings in *wav format,
- DSP in *Matlab*.

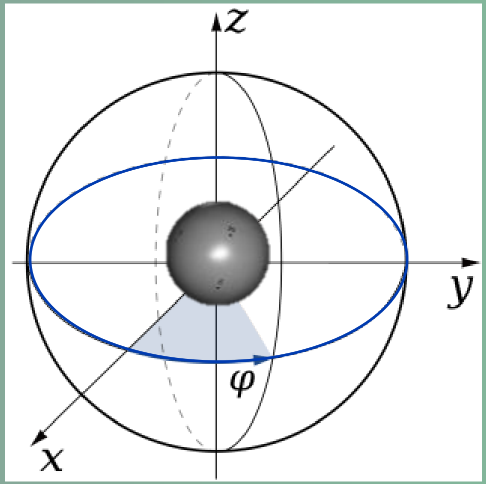
How does it work ?

(some *hopefully few* mathematics)

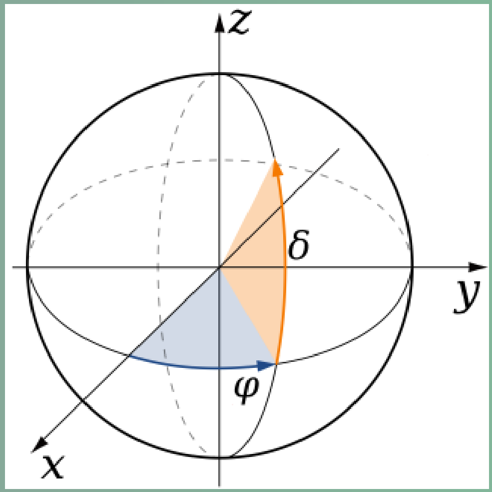
- The sound field *P(k,r,Ω)* existing around the antenna can be described by a series of spherical harmonics functions.
- $\Omega = (\phi,\delta)$.
- $k=2\pi f/c$ (the wave number).

$$P_{nm}(k,r) = \int_{\Omega\in S^2} P(k,r,\Omega)\mathcal{Y}_n^{m^*}(\Omega)d\Omega = \mathcal{S}\left\{P(k,r,\Omega)\right\},$$

$$P(k,r,\Omega) = \sum_{n=0}^{\infty}\sum_{m=-n}^{n} P_{nm}(k,r)\mathcal{Y}_n^m(\Omega) = \mathcal{S}^{-1}\left\{P_{nm}(k,r)\right\},$$



Spherical coordinates



How does it work ? (some *hopefully few* mathematics)

$$P_{nm}(k,r) = \int_{\Omega \in S^2} P(k,r,\Omega)\mathcal{Y}_n^{m^*}(\Omega)d\Omega = \mathcal{S}\left\{P(k,r,\Omega)\right\},$$

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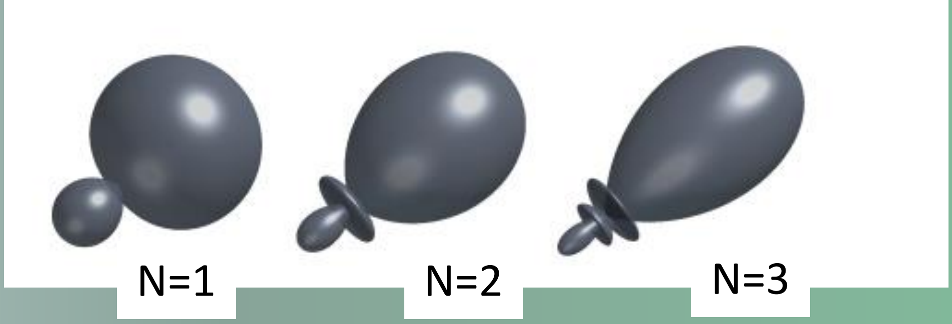
- If you know the *spherical* coefficients $P_{nm}(k,r)$, then you obtain the sound field in any direction Ω.
- « n » is limited to the order « N » of the array => the directional lobe of sensitivity has a *non-zero* extent.



How does it work ? (some *hopefully few* mathematics)

$$P_{nm}(k,r) = \sum_j \alpha_j P(k,r,\Omega_j) \mathcal{Y}_n^{m*}(\Omega_j)$$

- The *spherical* coefficients $P_{nm}(k,r)$ are determined by combining the 16 pressure signals measured in the directions Ω_j (j=1,16).

$P(\omega,\Omega_j)$ → $P_{nm}(\omega)$ →

16 microphones signals

$(N+1)^2$ Spherical coefficients

Array output:

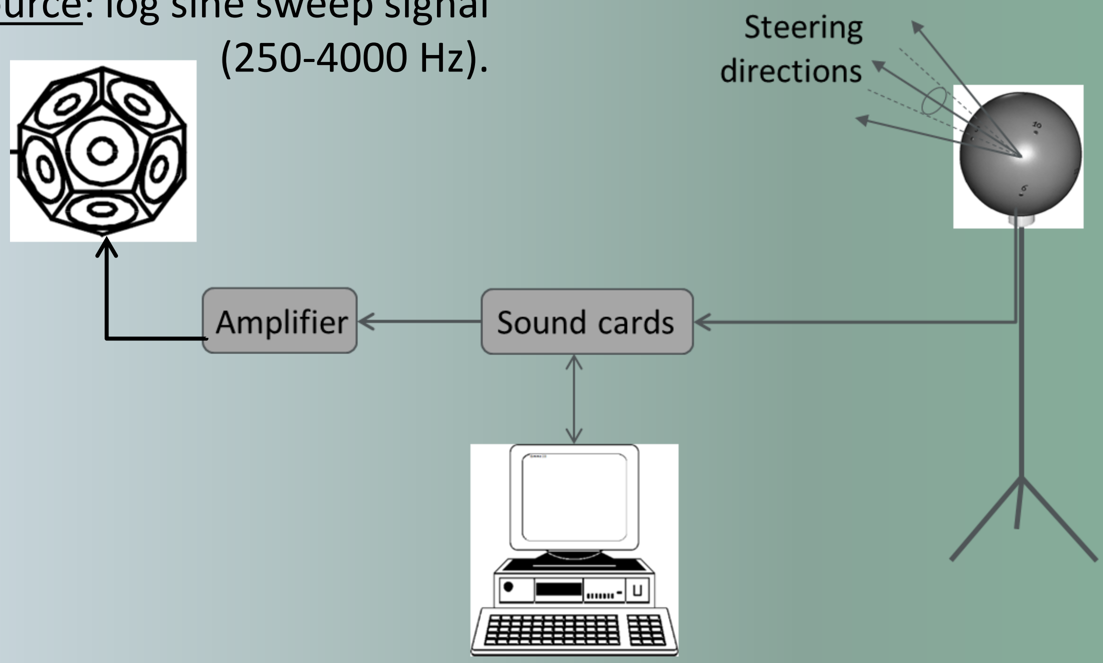
$$Y(\omega,\Omega_l) = \sum_{n=0}^{N} \sum_{m=-n}^{n} W_{nm}^{*}(\omega,\Omega_l) P_{nm}(\omega)$$

Weights: they depend on the steering (*look-up*) direction Ω_l.

Several algorithms…

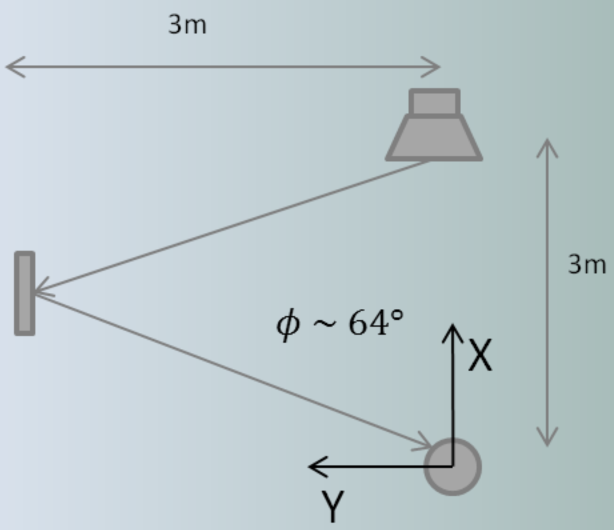
Measurement of Directional room impulse responses DRIR.

Sound source: log sine sweep signal (250-4000 Hz).



Deconvolution of the 16 recorded sweeps leads to 16 RIRs (not yet DRIRs !)

Example 1: One reflecting panel in the anechoic room.



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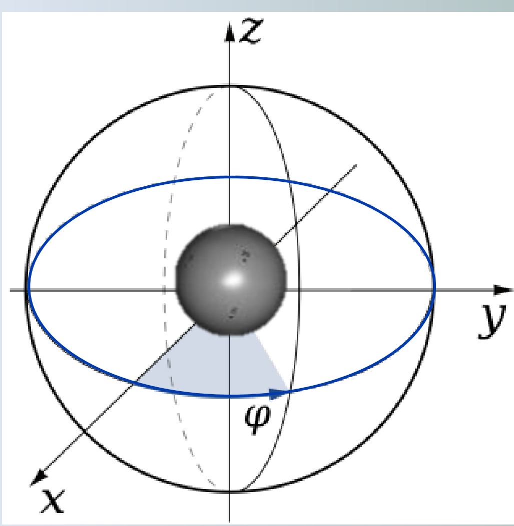
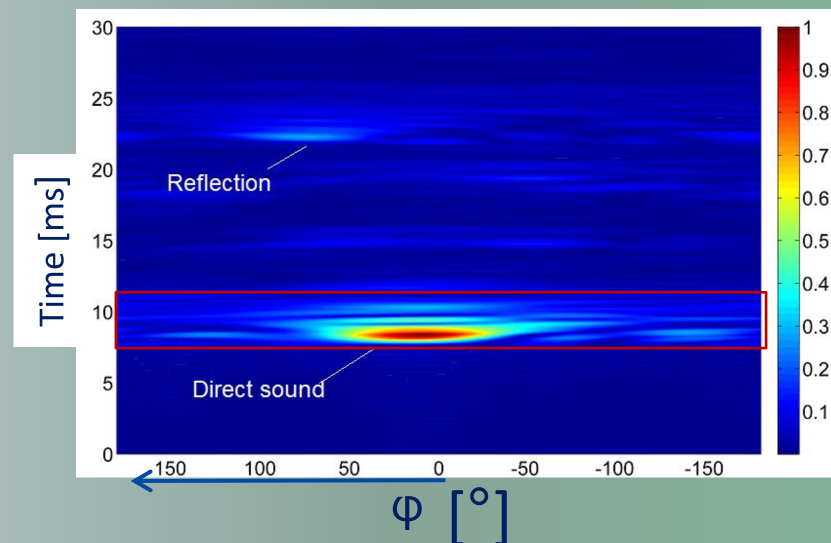


Spherical coordinates



Time evolution of array output in the horizontal plane:
Algorithm 'Delay and Sum' (DAS)

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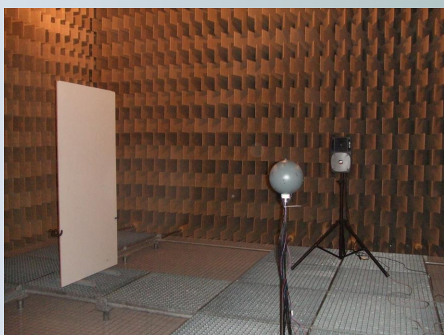
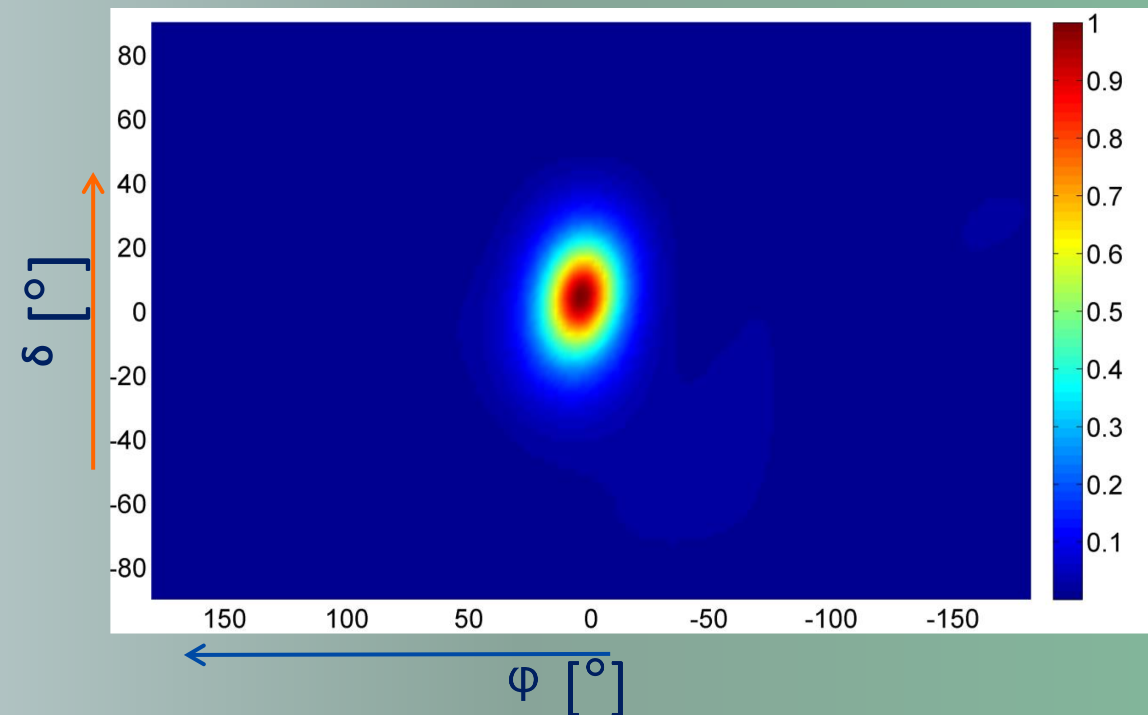
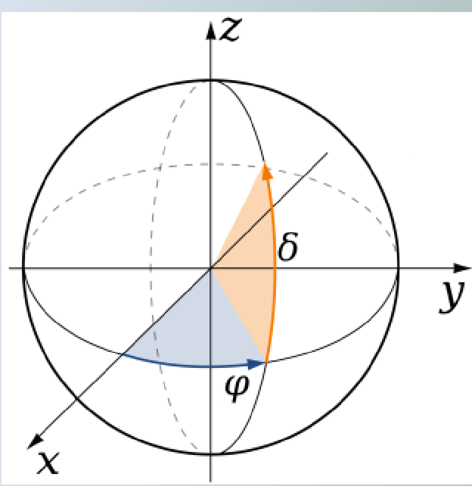


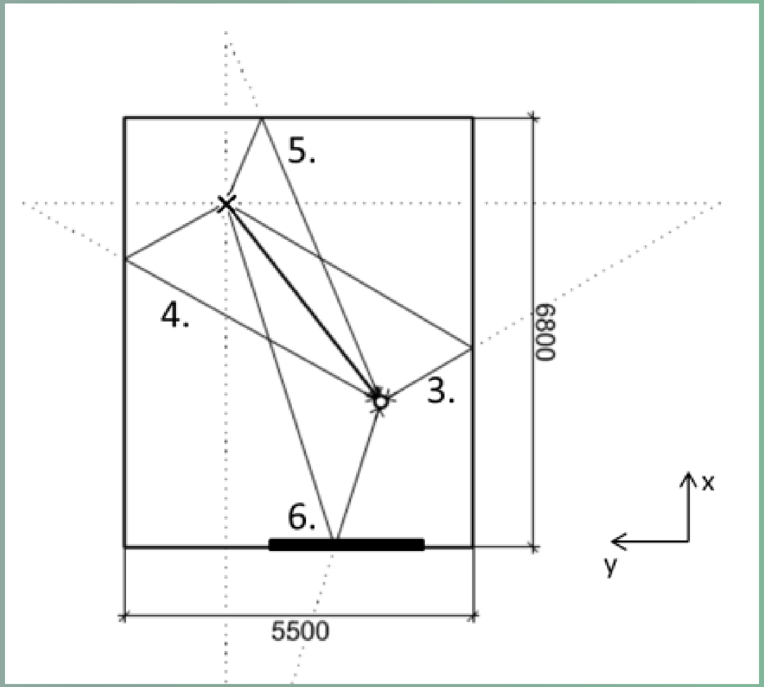




Spherical coordinates

Space distribution of array output in a specified time window (direct contribution):
Algorithm ‘Minimum-variance distortionless response’ (mvdr)

Example 2: DRIRs in a shoebox reverberant room.



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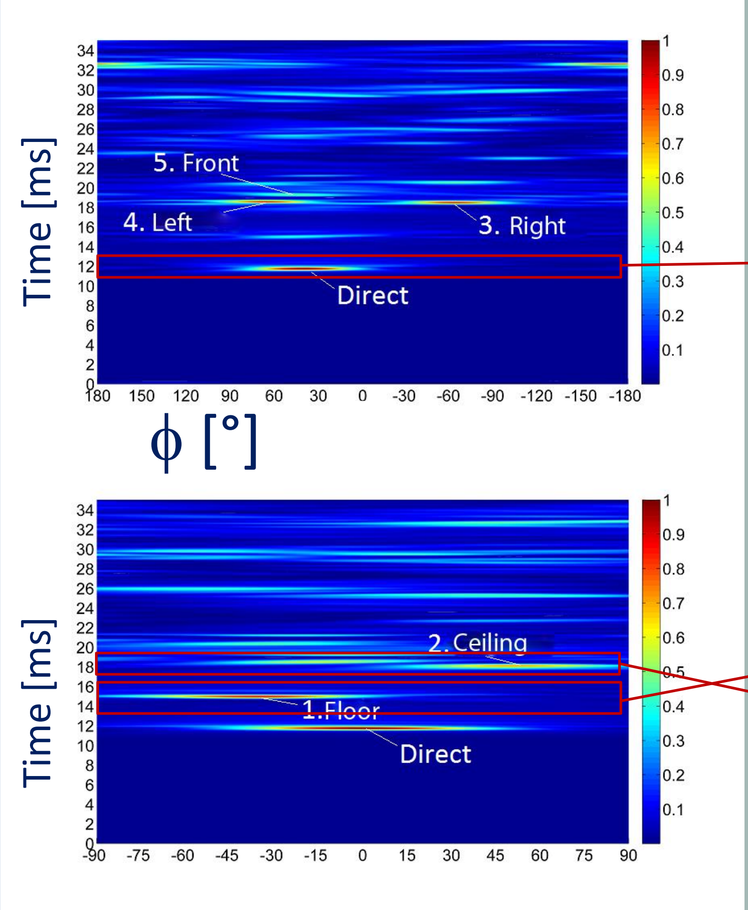
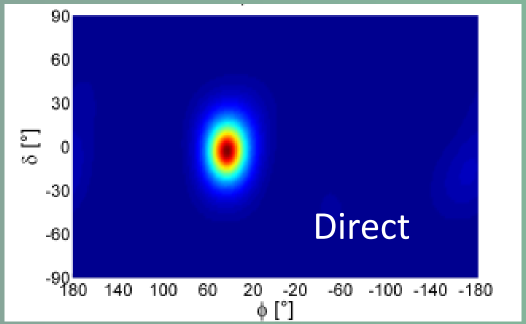


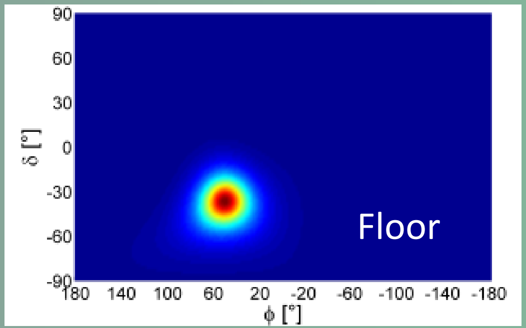
δ [°]

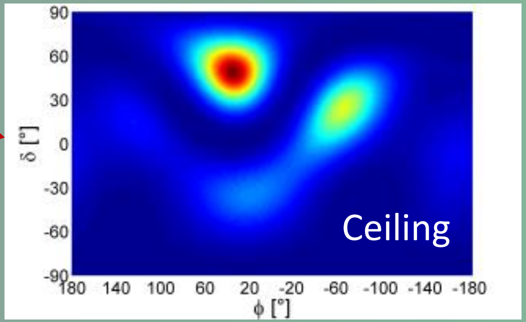
10,7 to 12,7 ms

14 to 16 ms

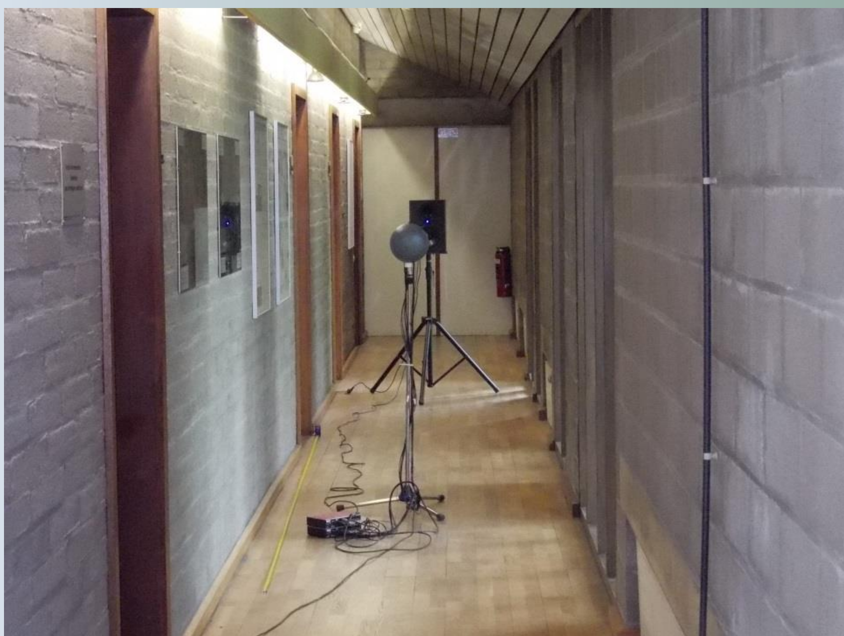
17 to 18,2 ms



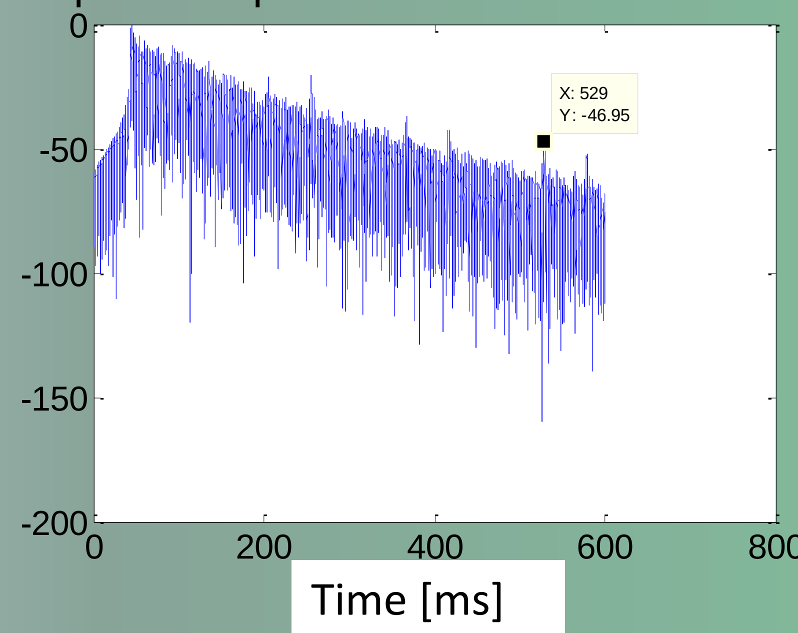




Example 3: DRIRs in a long corridor, closed by reflecting doors.



Omnidirectional RIR



Flutter echoes

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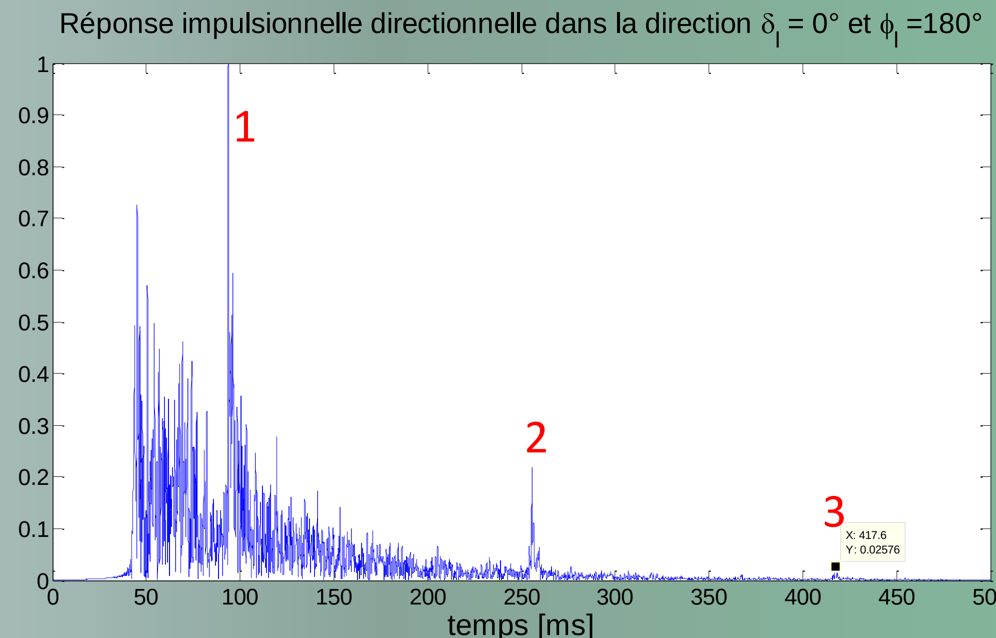
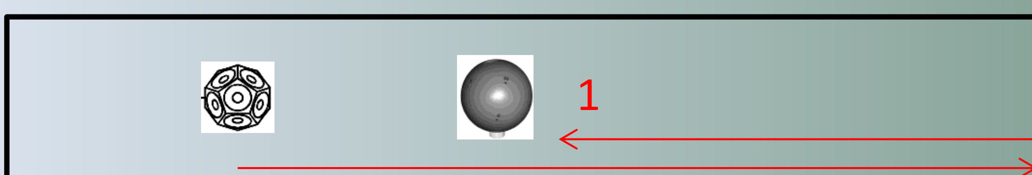


0° ⟷ 180°



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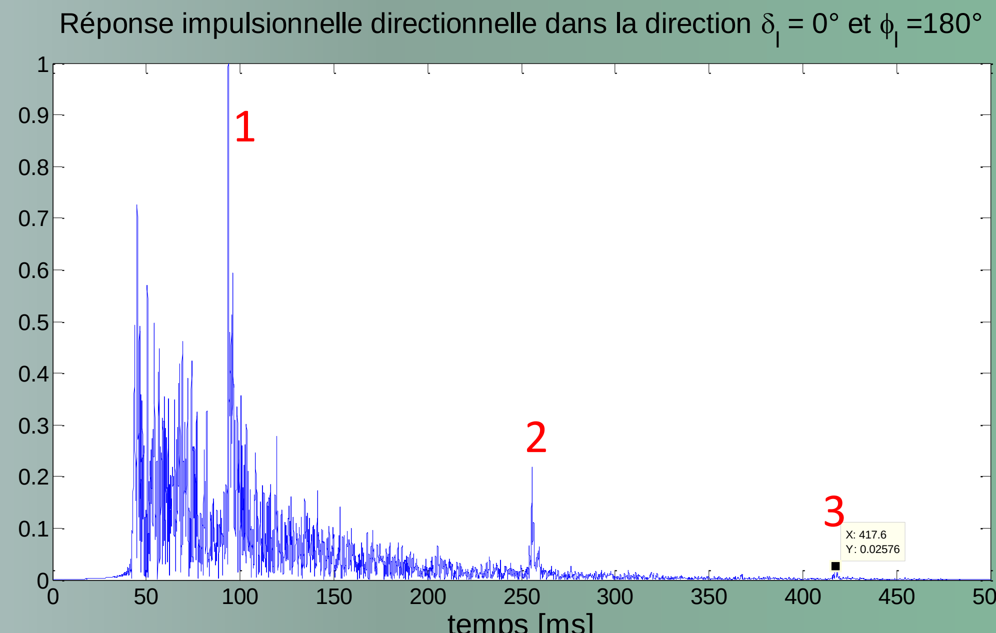

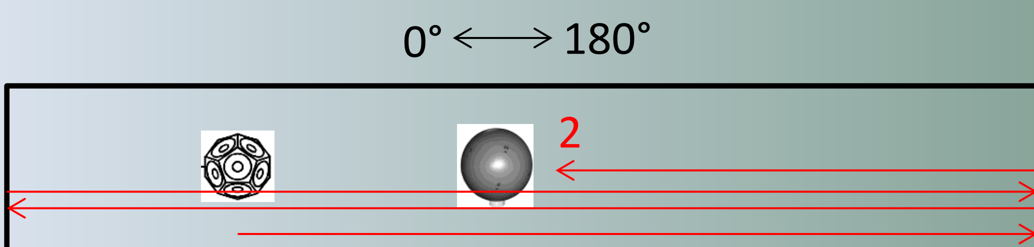

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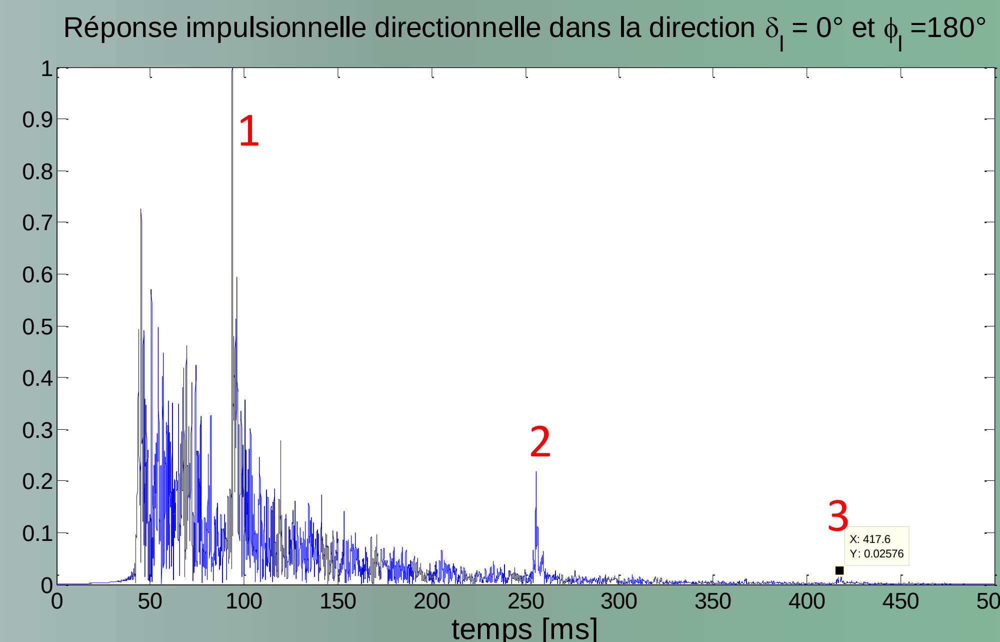
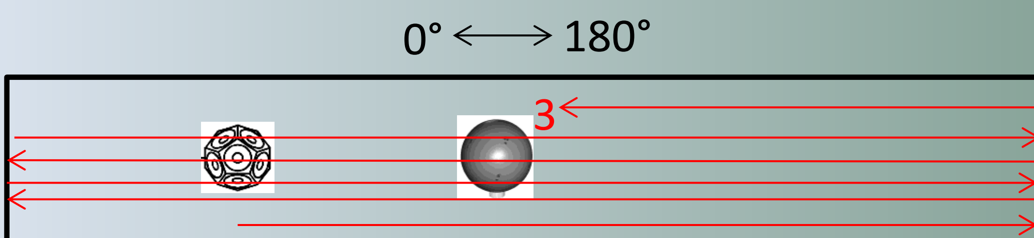
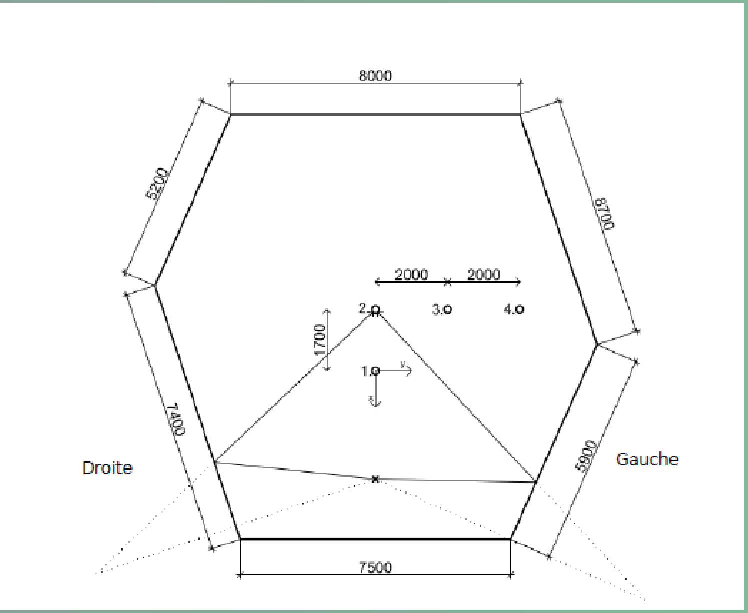
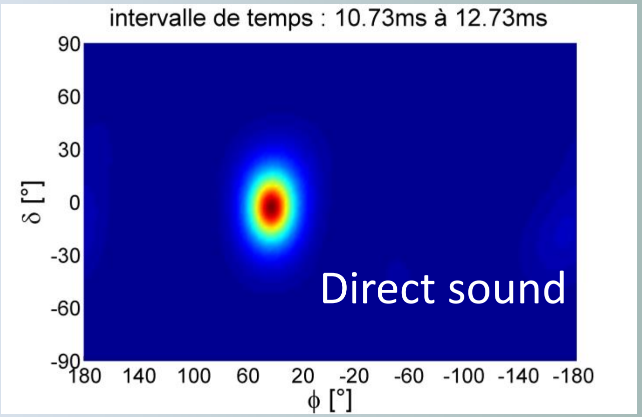


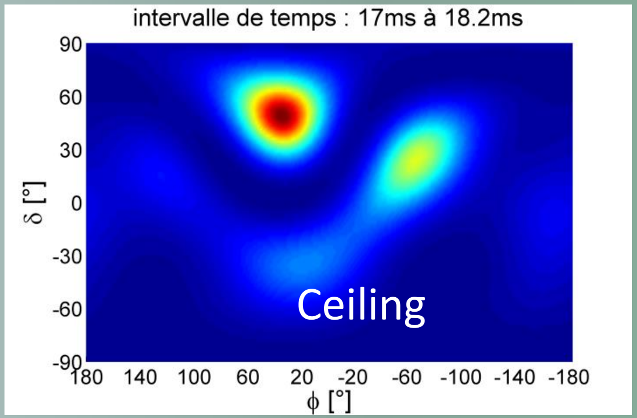


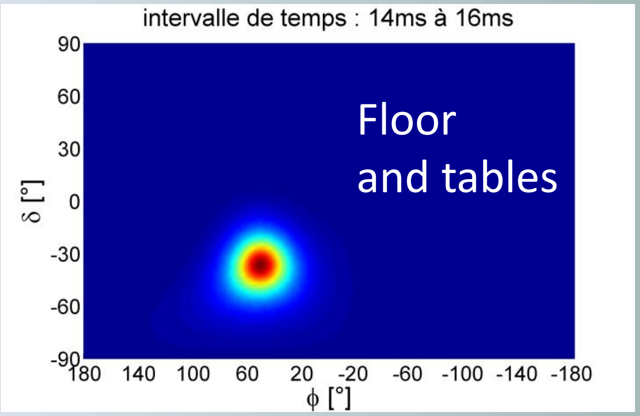
Example 4: DRIRs in an auditorium.

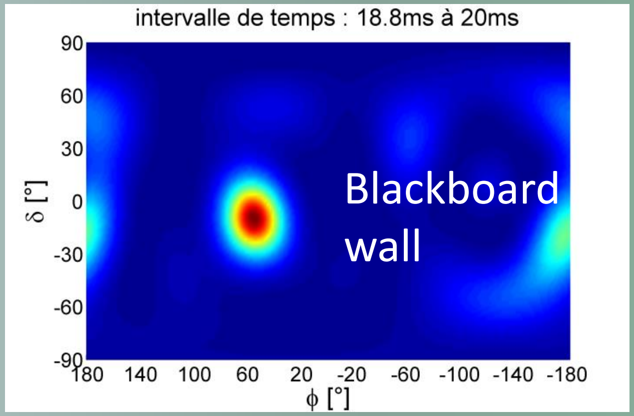


Example 4: DRIRs in an auditorium.



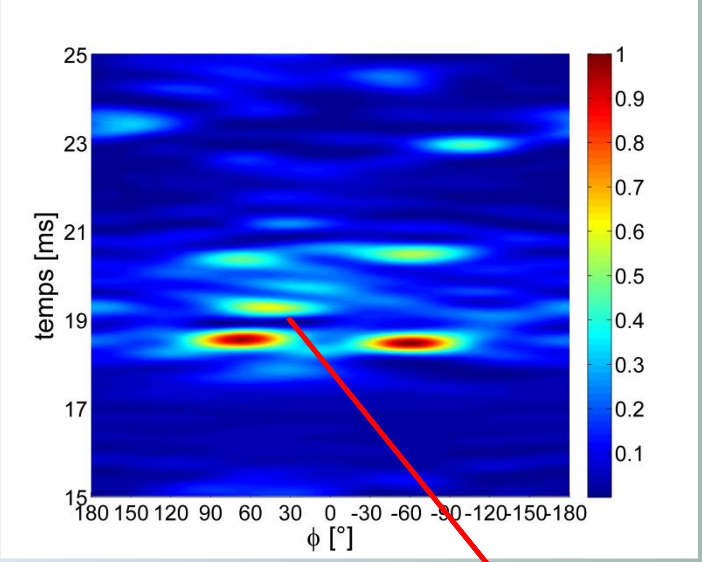


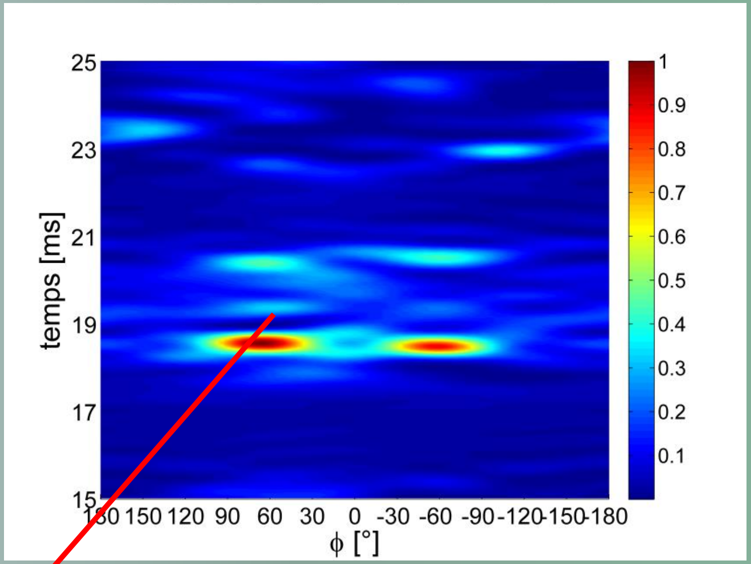




Example 4: DRIRs in an auditorium.

DRIR between 15 and 25ms

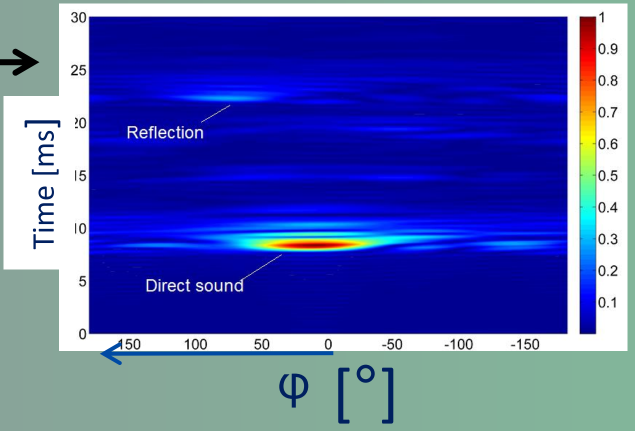




Effect of absorbing material on the blackboard wall.

Future works …

- Improving the selectivity of the antenna:



- Illustration of the dynamic evolution of the reflections (at least the first-order ones).
- Automatic computation of the room acoustics' spatial parameters.
- Tests in great volumes (theatres, industrial halls).