



ATIAM

acoustique des salles

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Modes entretenus et libres

corde frotée
prise

THARPE

4K

25Hz

8S

corde
touche

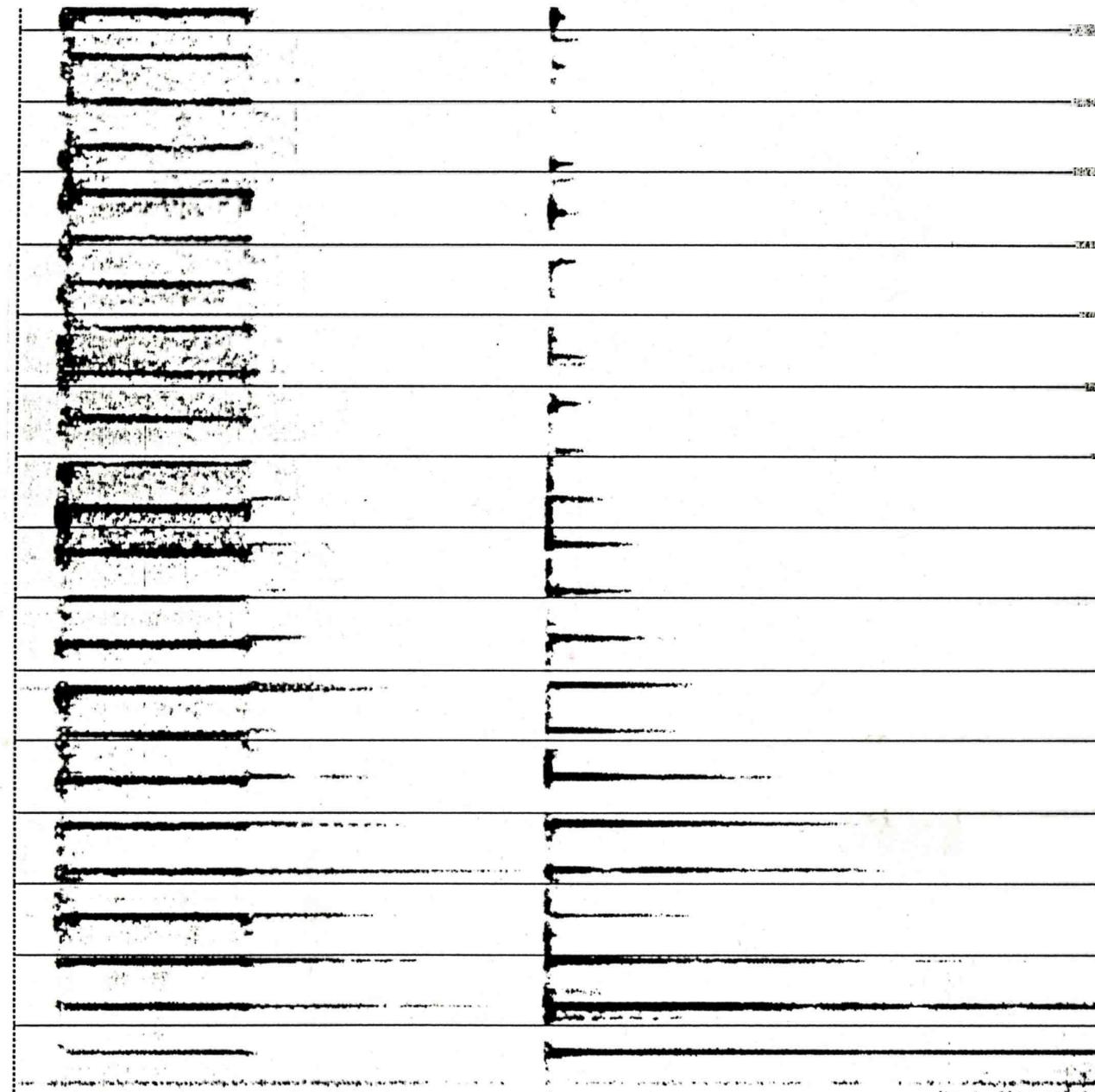
of bande

entretenu

(1) 5 X 94

M. Castellengo

libre



Nombre des modes

- salle parallélépipédique rectangle :

$$\nu_n^2 = \left(\frac{k_n c}{2\pi} \right)^2 = \left(\frac{n_x c}{2l_x} \right)^2 + \left(\frac{n_y c}{2l_y} \right)^2 + \left(\frac{n_z c}{2l_z} \right)^2$$

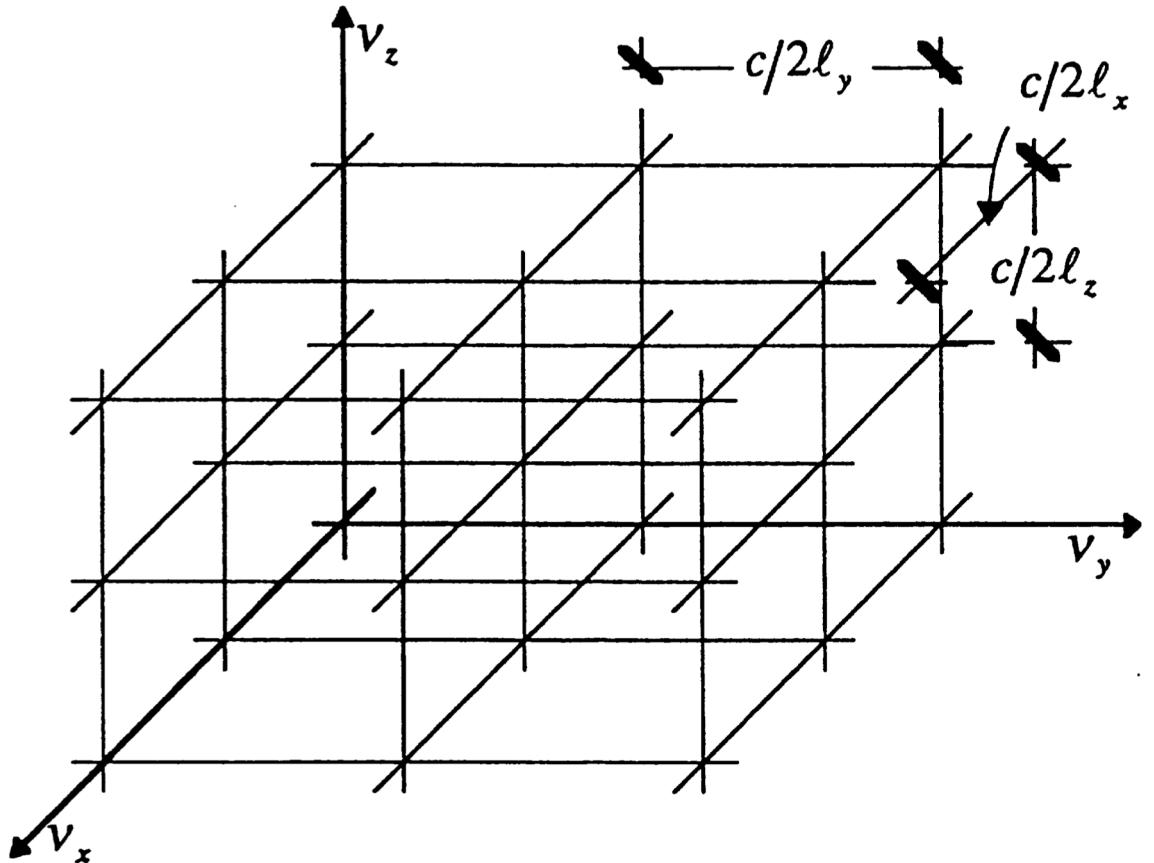
- cellule élémentaire :

$$v_e = \frac{c}{2l_x} \cdot \frac{c}{2l_y} \cdot \frac{c}{2l_z} = \frac{c^3}{8V}$$

- volume $V = l_x \cdot l_y \cdot l_z$

- un seul octant :

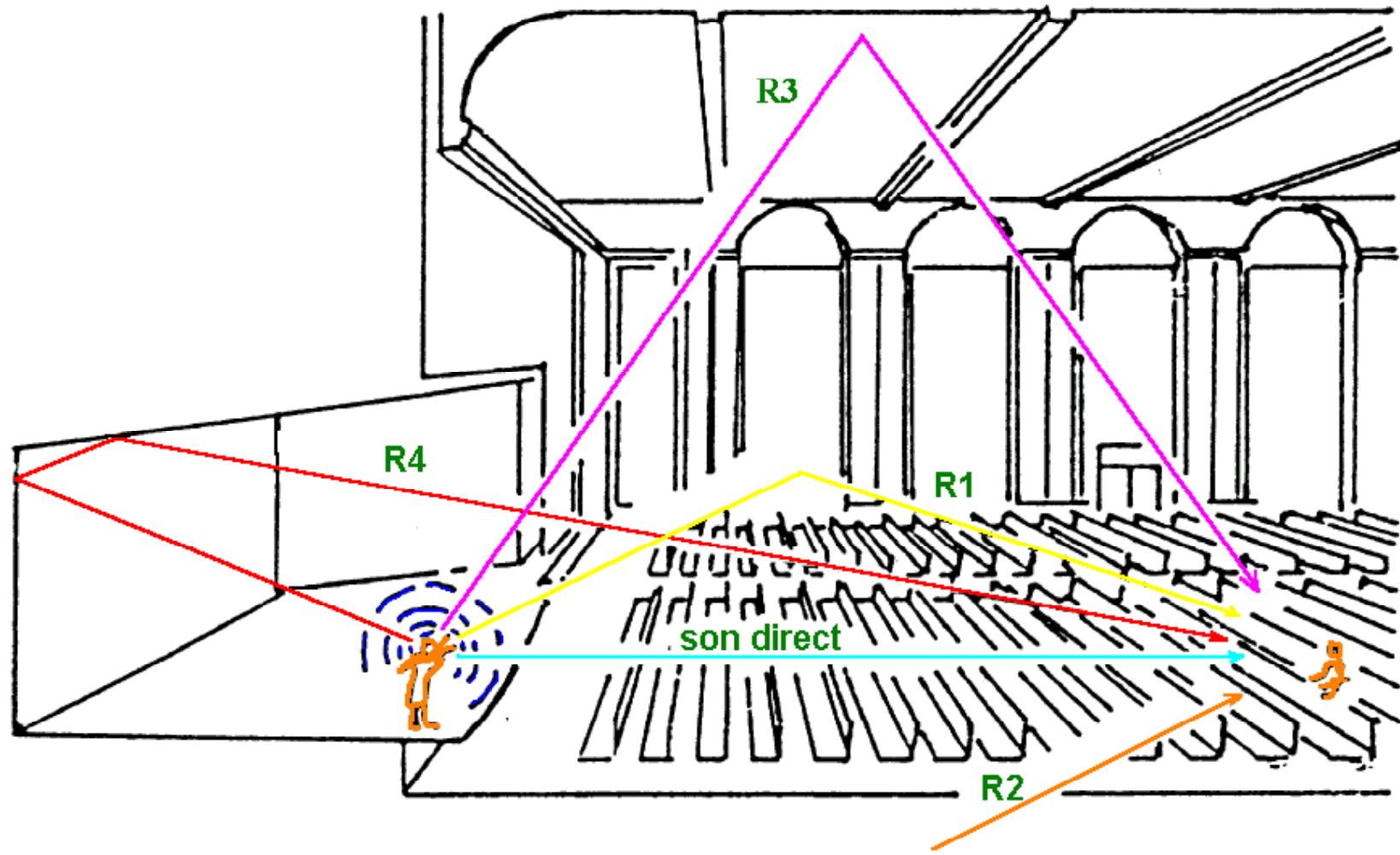
$$v_v = \frac{4\pi\nu^2}{8} d\nu$$



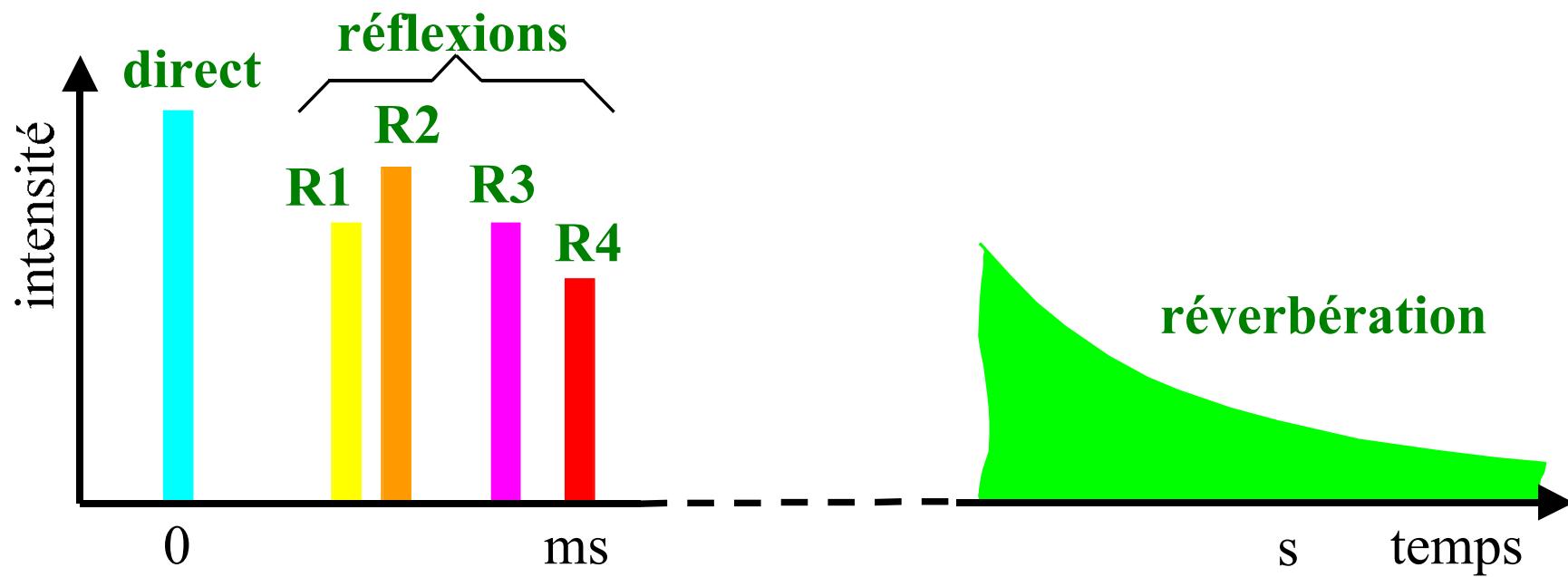
Densité de modes

- densité moyenne : $dN = \frac{\nu_v}{\nu_e} = \frac{4\pi V\nu^2}{c^3} d\nu$
- basses fréquences :
 - modes isolés
- hautes fréquences :
 - modes superposés
- limite :
 - fréquence de Schroeder : $f_s = 2000\sqrt{\frac{T}{V}}$

La notion de réponse (d'après Beranek 1962)

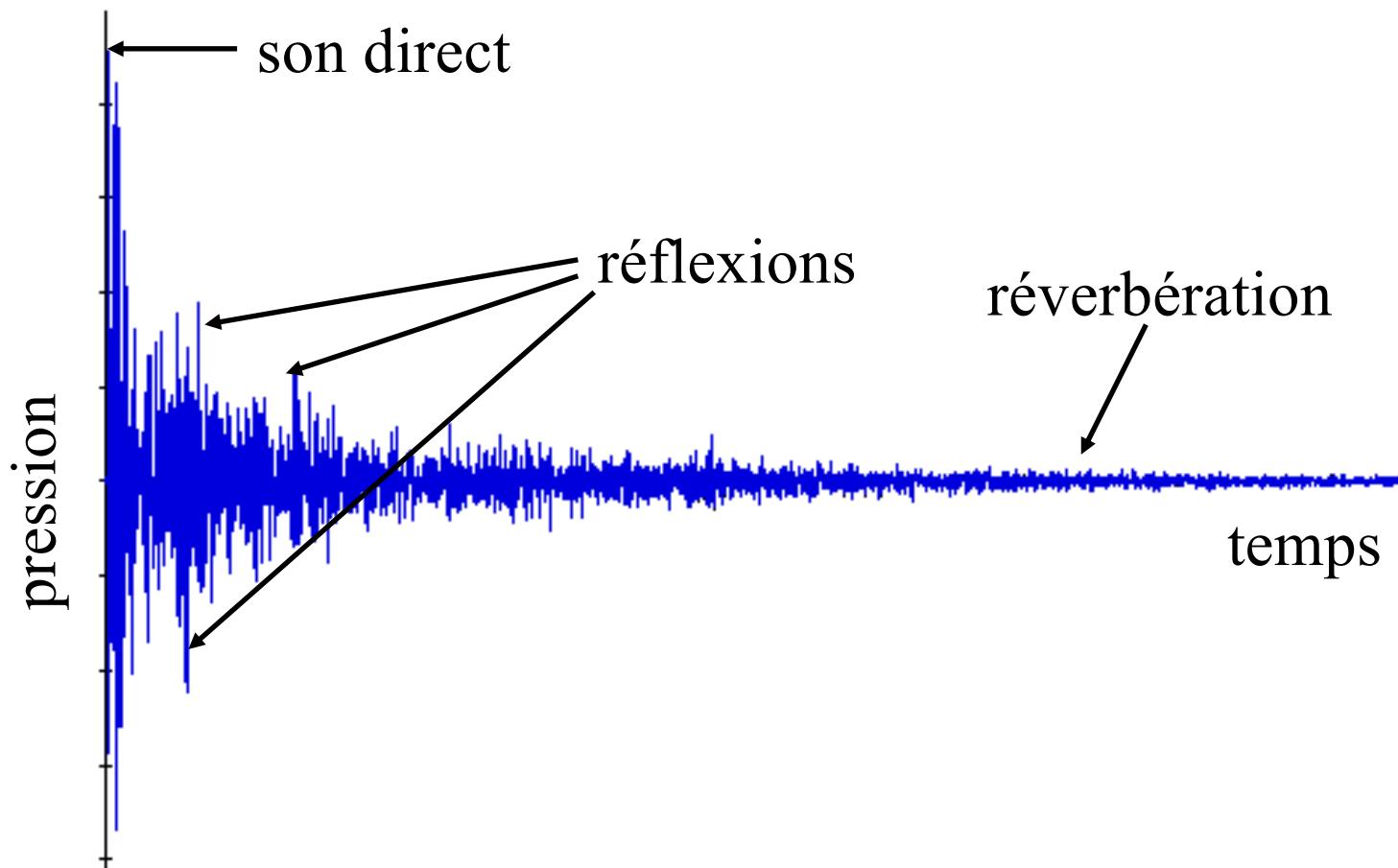


Rélectogramme



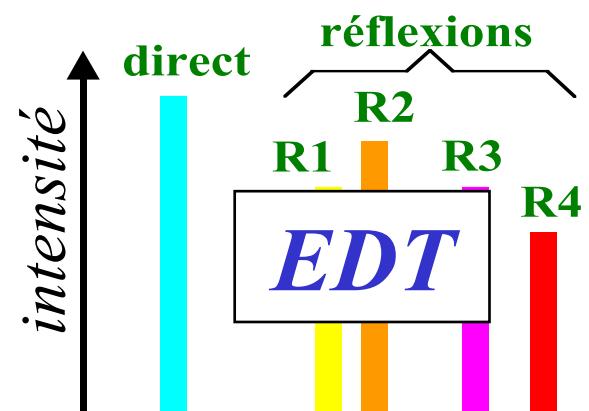
Qualité des salles de concert (2)

- Les éléments de la réponse



Qualité des salles de concert (3)

- Schématiquement :

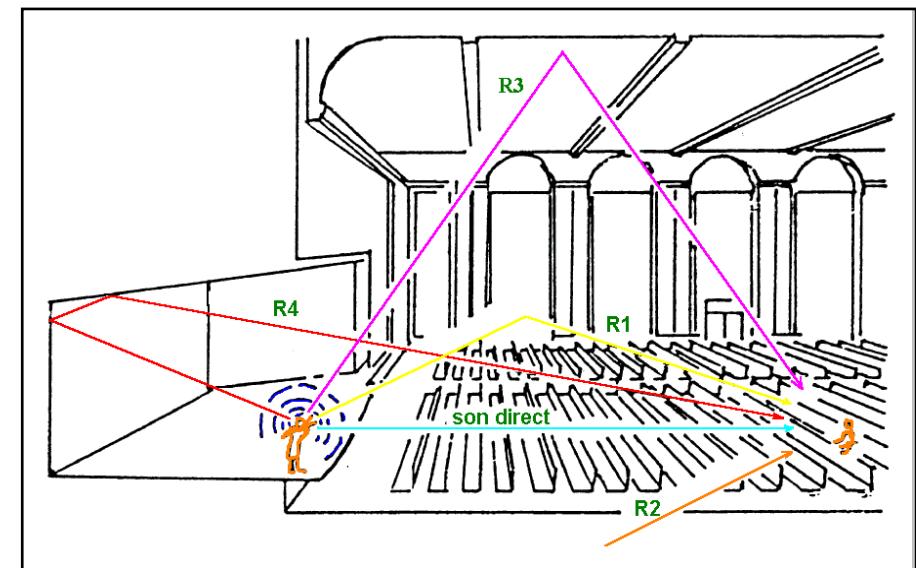


EDT : temps de réverbération

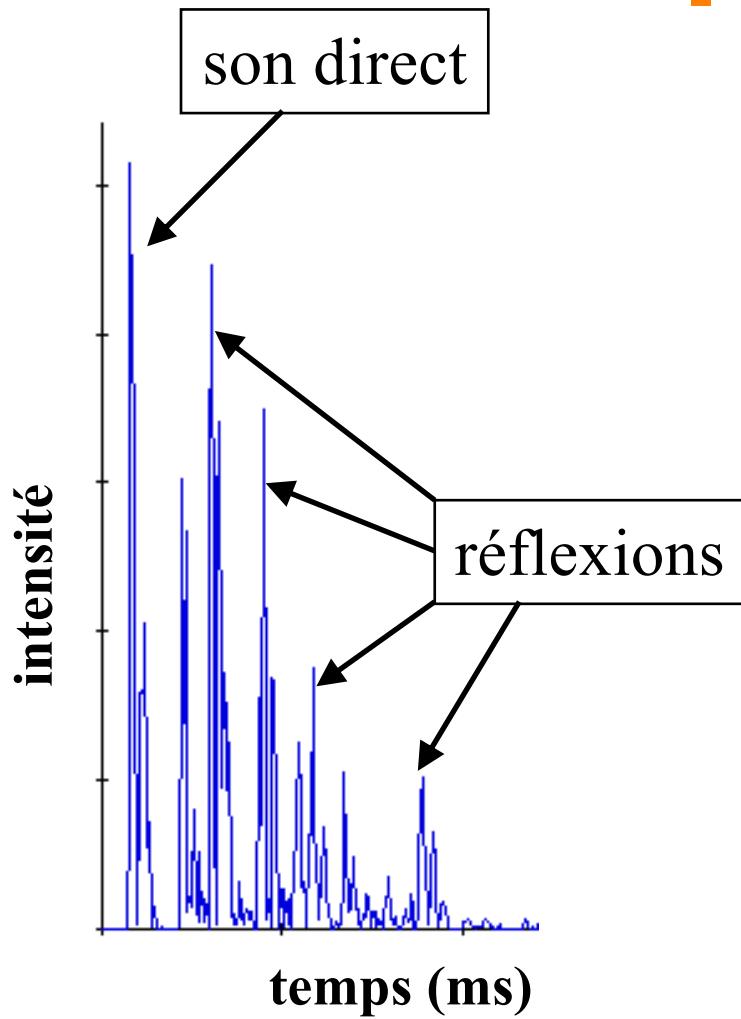
C80

TR : temps de réverbération

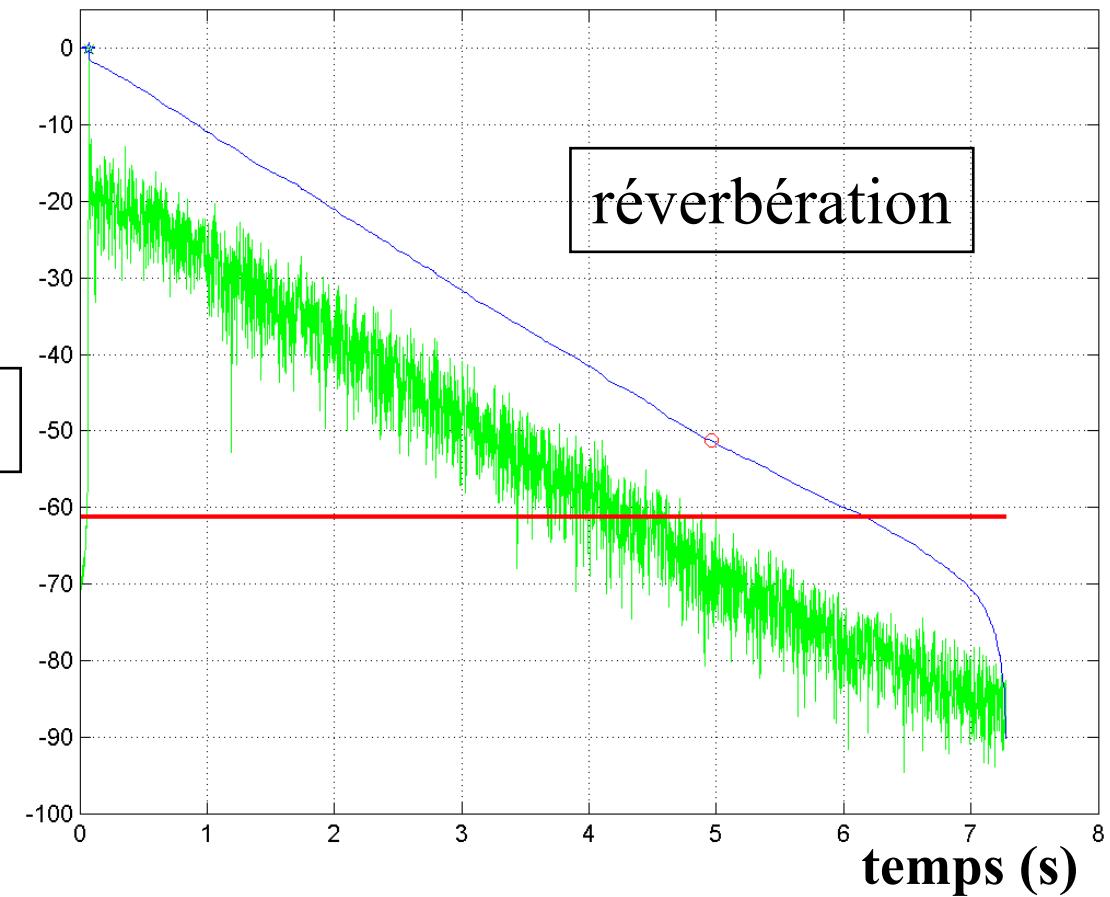
C80 : rapport d'énergie



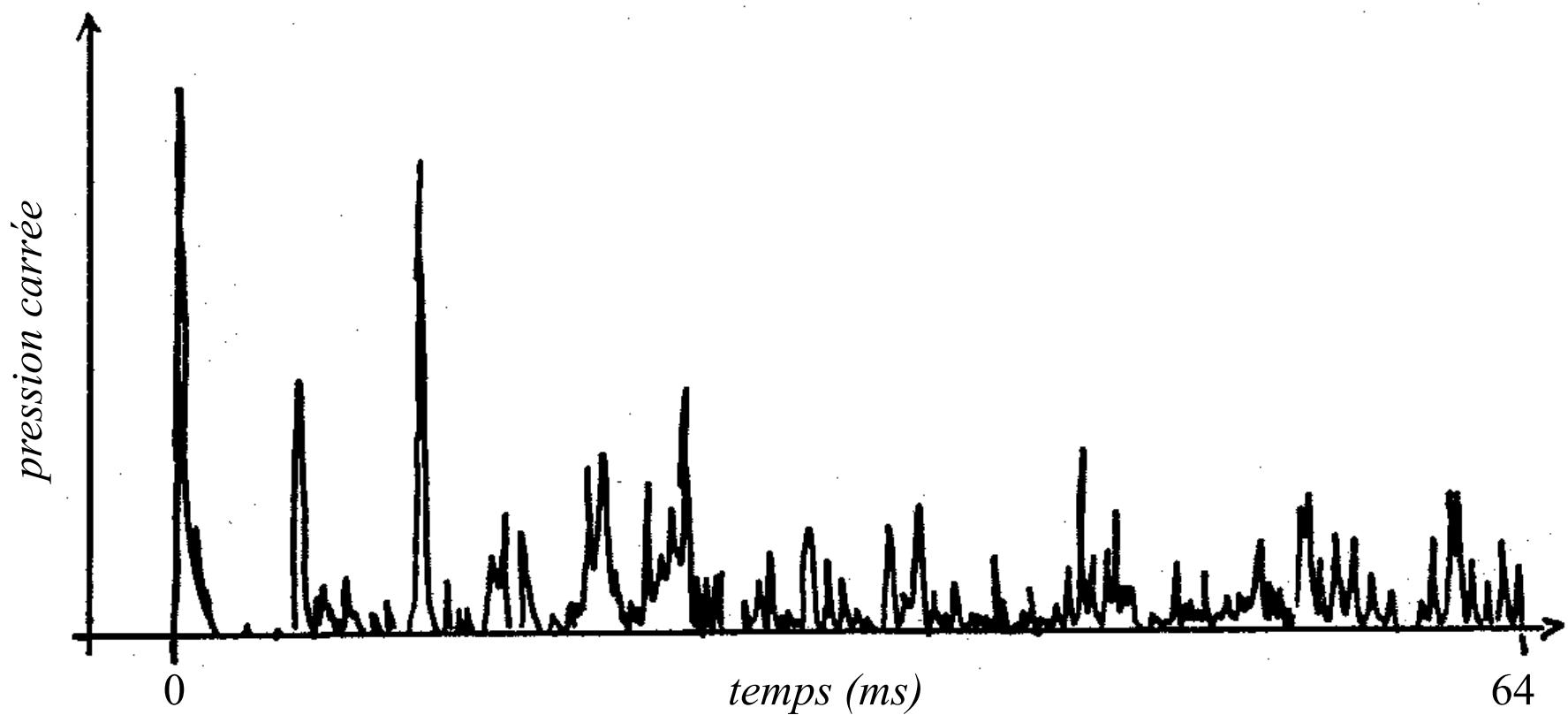
Qualité des salles de concert (4)



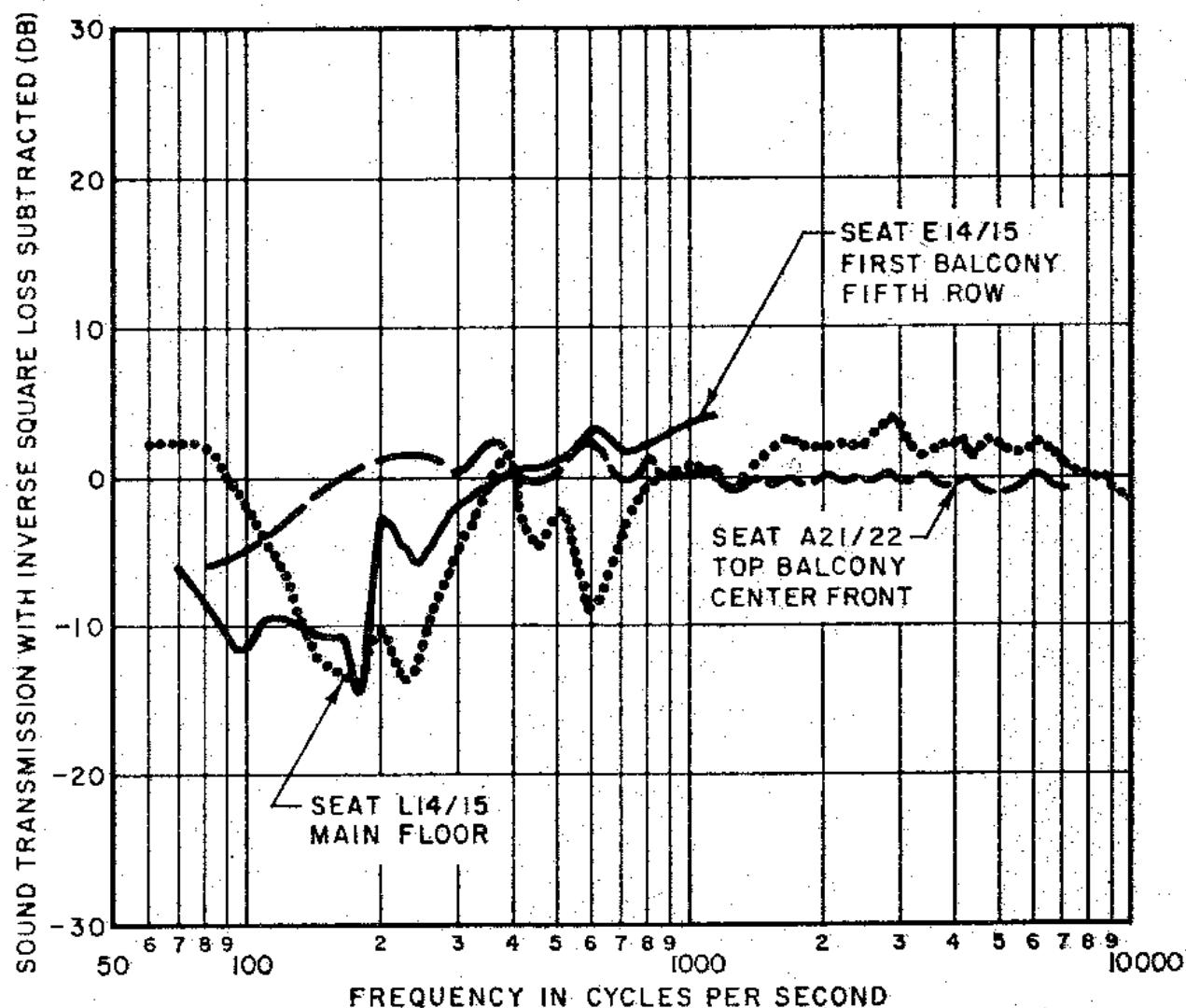
- Le résultat d'une mesure



Réflectogramme mesuré



Absorption du son direct (effet de sol, Schultz & Watters 1964)



Principaux indices

Amplitude sonore	$G = 10 \log \left[\int_0^{\infty} p^2(t) dt \middle/ p_{ref}^2 \right]$ $\Delta L_r = 10 \log \left[\int_0^{\infty} p^2(t) dt \middle/ (r/5)^2 \left(\int_0^{5ms} p^2(t) dt \right) \right]$	+2dB $\sigma < 1,5$ dB
Effet d'espace	$L_f = \sum_{i=5}^{80ms} r_i \cos \alpha_i \middle/ \sum_{i=0}^{80ms} r_i$ $K = \left(\int_0^{80ms} p_d(t) p_g(t) dt \right) \middle/ \left(\int_0^{80ms} p_d^2(t) dt \cdot \int_0^{80ms} p_g^2(t) dt \right)^{1/2}$ $LE = \left(\int_{25ms}^{80ms} p_\infty^2(t) dt \right) \middle/ \left(\int_0^{80ms} p_o^2(t) dt \right)$	$> 0,12$ $< 0,23$ $> 0,18$
Précision	$D = \left(\int_0^{50ms} p^2(t) dt \right) \middle/ \left(\int_0^{\infty} p^2(t) dt \right)$ $C = 10 \log \left[\left(\int_0^{80ms} p^2(t) dt \right) \middle/ \left(\int_{80ms}^{\infty} p^2(t) dt \right) \right]$ $t_c = \left(\int_0^{\infty} t p^2(t) dt \right) \middle/ \left(\int_0^{\infty} p^2(t) dt \right)$ $1/t_i : \int_0^{t_i} p^2(t) dt = 0,3 \int_0^{\infty} p^2(t) dt$ $1/t_s : \int_{t_s}^{\infty} p^2(t) dt = 0,3 \int_0^{\infty} p^2(t) dt$ $EDT : \text{régression de } 0 \text{ à } -10\text{dB}$ $MTF(\Omega) = \int_0^{\infty} p^2(t) \exp\{-j\Omega t\} dt$	$> 0,12$ -4,5 à -1,5 musique romantique -2,5 à +1,5 musique baroque < 140 ms $\approx 1,8$ s
Réverbération	T_R : régression de -5 à -35dB	dépend du volume
Timbre (équilibre tonal)	$S = 10 \log \left[\left(\int_{500Hz}^{5000Hz} P(f) df \middle/ 4500 \right) \middle/ \left(\int_{50Hz}^{500Hz} P(f) df \middle/ 450 \right) \right]$ $EDT \text{ mesuré par bande d'octave}$ $T_R \text{ mesuré par bande d'octave}$	

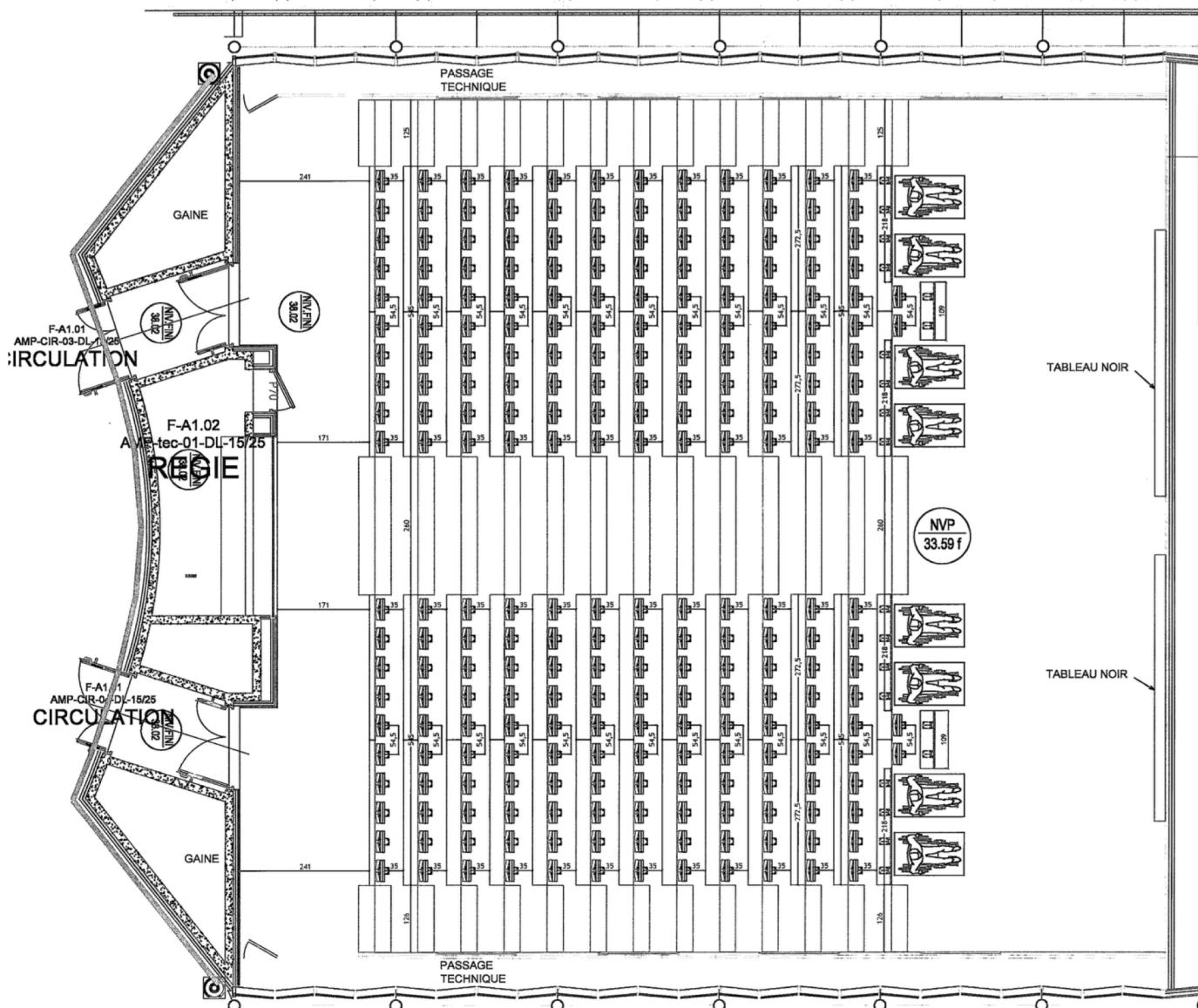
Bruit de fond (Reynolds 1981)

Type of Space (and Communication Requirements)	NC Rating	Approx. dBA
Voice or music studio (very quiet for recording)	15 - 25	25 - 34
Radio or TV studio (quiet for broadcasting)	20 - 30	30 - 38
Concert and recital halls, opera houses (for critical hearing and listening)	15 - 25	25 - 34
Large auditoriums, drama theaters and churches (for good listening conditions)	< 25	< 34
Small auditoriums, theaters and churches (for good listening conditions)	< 35	< 44
Bedrooms, sleeping quarters, hospitals, hotels, motels, residences and apartments (for sleeping, resting and relaxing)	25 - 40	34 - 47
Lecture and assembly halls (for good listening conditions)	< 30	< 38
Classrooms, seminar rooms, study rooms and laboratories (no amplification and normal listening conditions)	30 - 40	38 - 47
Private or semiprivate offices, small conference rooms, etc. (for good listening conditions)	30 - 40	38 - 47
Large offices, reception areas, retail stores, restaurants, etc. (for moderately good listening conditions, telephone use satisfactory)	35 - 45	42 - 52
Lobbies, corridors, laboratory work spaces, drafting and engineering rooms, general secretarial areas (for moderately fair listening conditions, telephone use occasionally slightly difficult)	40 - 50	47 - 56
Light maintenance shops, office and computer rooms, etc. (for moderately fair listening conditions, telephone use slightly difficult)	45 - 55	52 - 61
Shops, garages, power-plant control rooms, arenas, stadiums, airports, railroad stations (for just acceptable speech and telephone communication)	50 - 60	56 - 66
Factory and shop areas (for work spaces where speech or telephone communication is not required, but where there must be no risk of hearing damage)	60 - 75	66 - 80

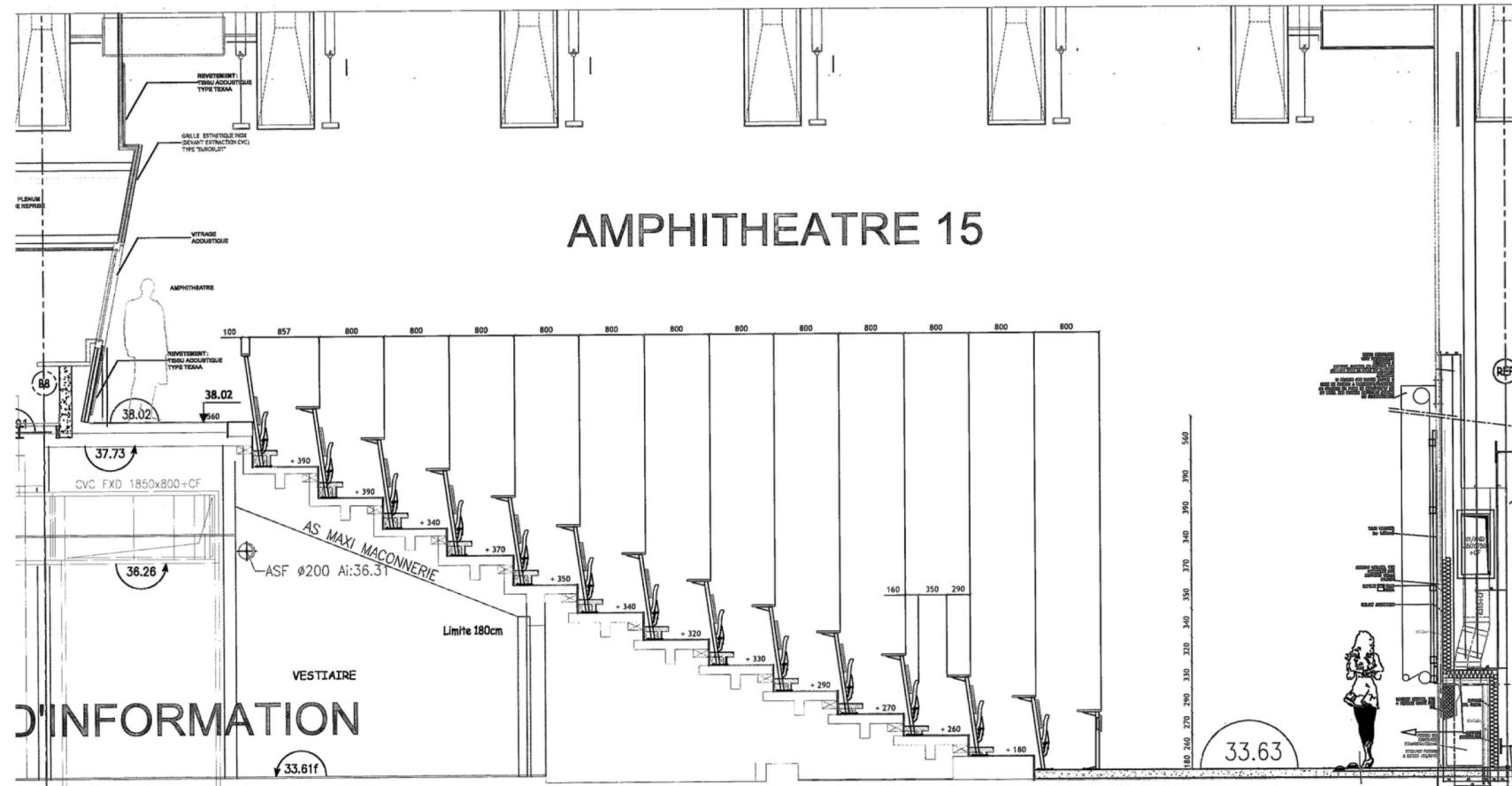
Qualité des salles de concert (5)

- La mesure acoustique d'une salle tient compte de la fréquence
- Pour chaque fréquence, elle donne :
 - le *temps de réverbération* TR
 - le *temps de réverbération initial* EDT
 - le rapport *énergie initiale/énergie réverbérée* C80
 - le niveau sonore normalisé, ou *force sonore* G

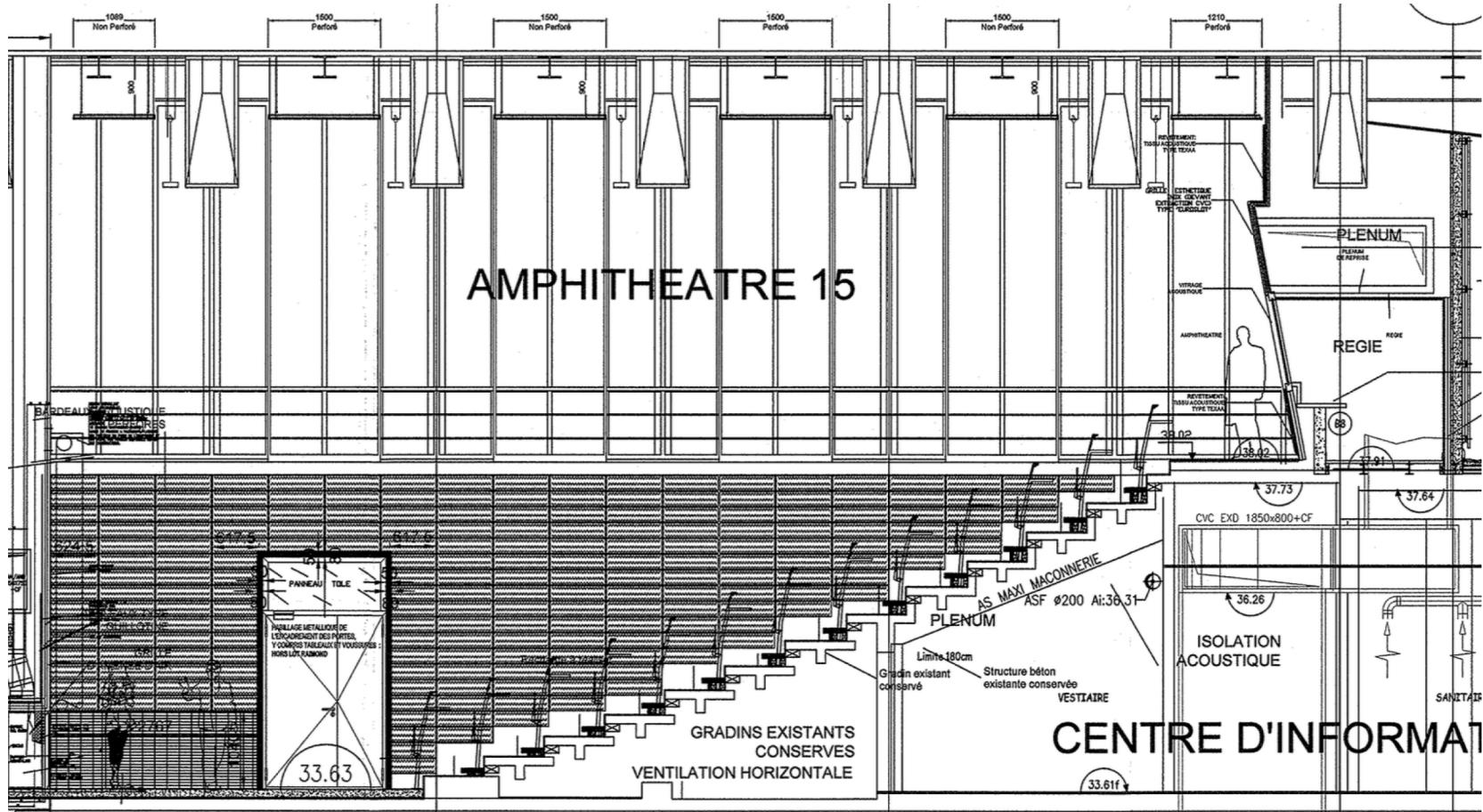
L'Amphi 15 de l'UPMC



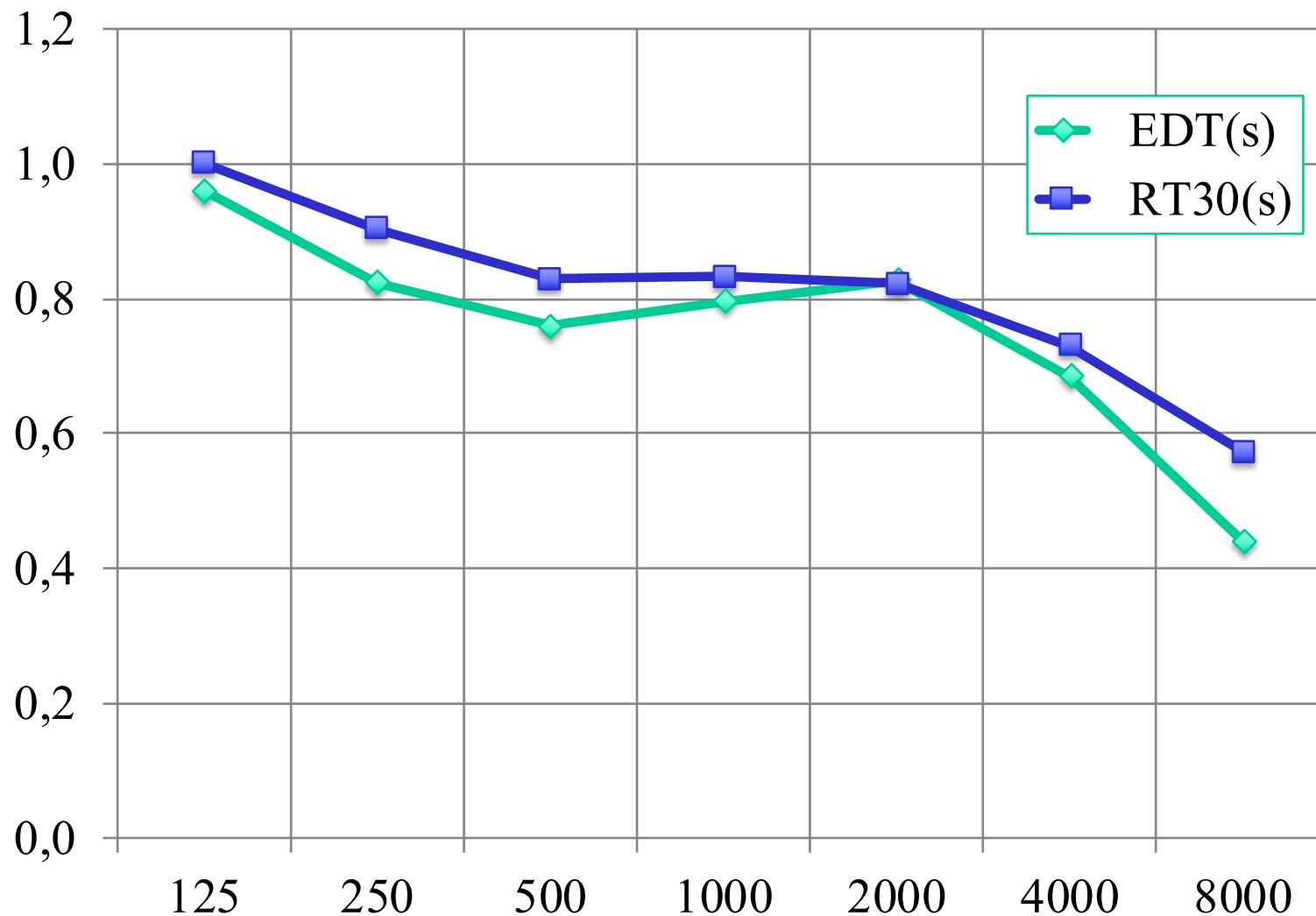
L'Amphi 15 de l'UPMC



L'Amphi 15 de l'UPMC



L'Amphi 15 de l'UPMC

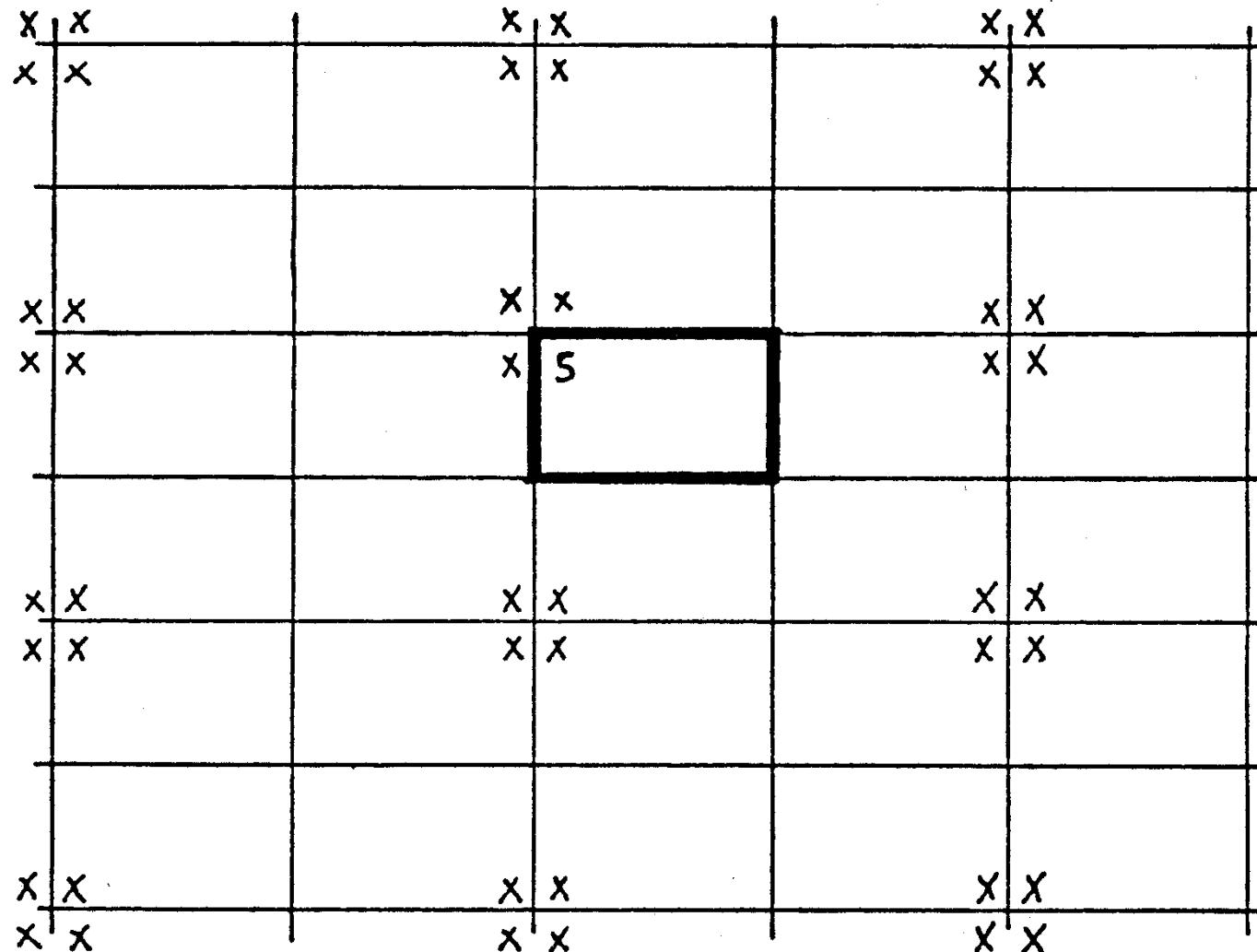


L'Amphi 15 de l'UPMC

Moyennes	Dyn(dB) #	EDT(s)	RT30(s)	C_80(dB)	D_50(%)	Tc(ms)	Ampli(dB) #	Level(dB) #
Full	-57,4	0,7	0,8	6,2	80,6	43,9	7,4	53,5
125	-36,5	1,0	1,0	3,1	65,9	71,8	7,5	28,1
250	-56,1	0,8	0,9	6,4	80,9	43,5	15,9	43,7
500	-57,1	0,8	0,8	6,3	80,5	43,0	9,9	44,5
1000	-60,7	0,8	0,8	5,2	76,6	52,5	7,9	46,7
2000	-63,8	0,8	0,8	4,7	74,4	54,6	9,8	47,0
4000	-64,0	0,7	0,7	6,5	81,6	42,8	7,2	45,2
8000	-65,2	0,4	0,6	10,8	92,2	21,9	3,5	45,8

STD	Dyn(dB) #	EDT(s)	RT30(s)	C_80(dB)	D_50(%)	Tc(ms)	Ampli(dB) #	Level(dB) #
Full	1,8	0,1	0,0	0,8	2,7	6,1	0,9	1,0
125	4,1	0,2	0,2	3,0	15,0	15,2	2,4	2,3
250	2,0	0,1	0,0	1,1	3,8	10,4	0,7	1,0
500	3,6	0,1	0,0	1,3	4,3	7,4	1,2	1,1
1000	2,4	0,1	0,0	0,8	3,4	5,8	1,1	1,2
2000	1,3	0,1	0,0	0,8	3,7	6,9	1,1	1,3
4000	1,1	0,0	0,0	0,6	2,2	4,4	1,3	1,3
8000	0,8	0,1	0,0	1,1	1,9	4,2	0,8	0,7

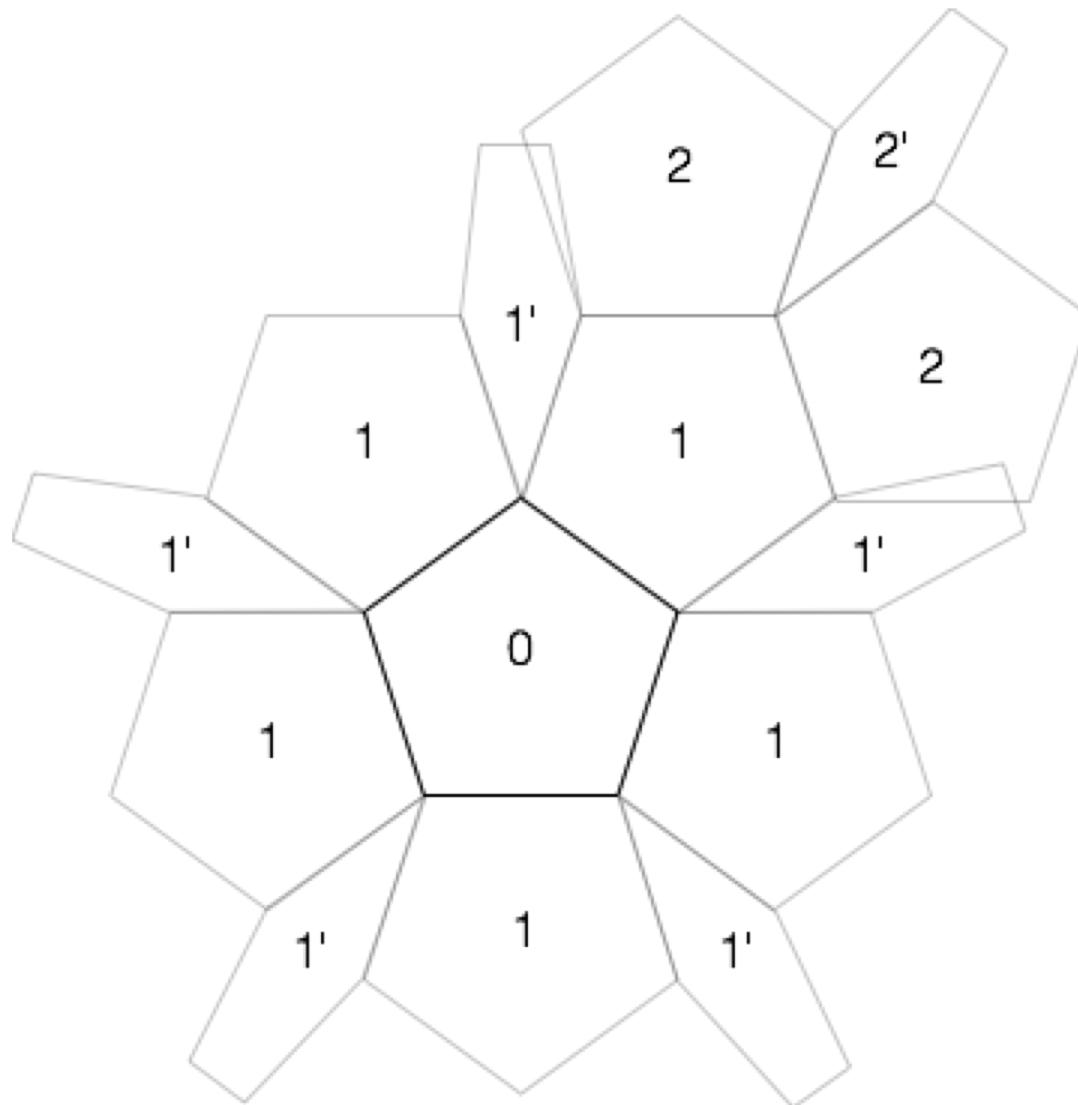
Densité des retours



Densité des retours

- salle rectangulaire : $dN(t) = \frac{4\pi c^3 t^2}{V} dt$
- se généralise au début de la réponse
- en fin de la réponse : densité constante

Images d'un pentagone



Nombre de source images dans la couche i

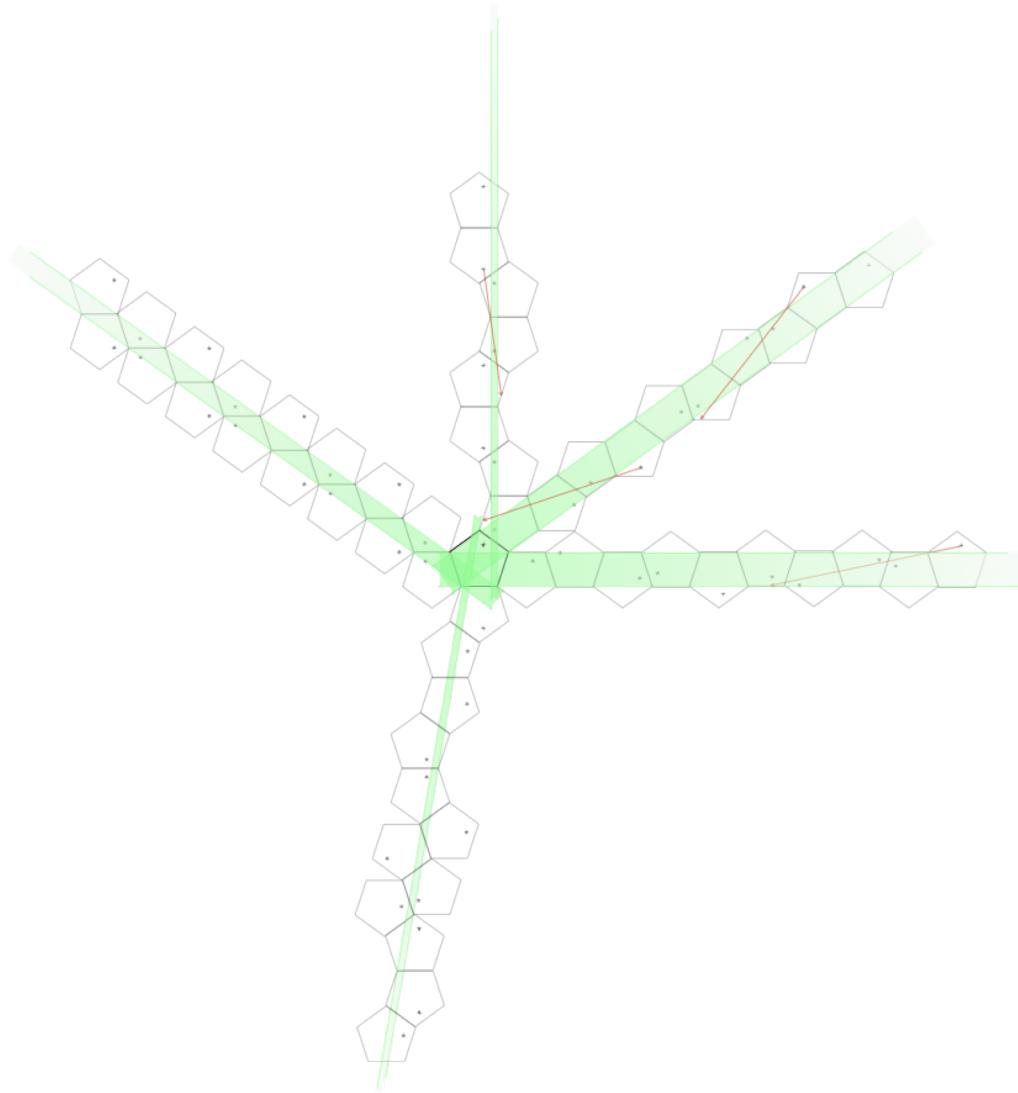
- Ce nombre croît exponentiellement
 - Salles pentagonales :

$$N_i \approx \frac{5 (\sqrt{3} + 1)^{2(i+1)}}{2^{i+1} \sqrt{3}}$$

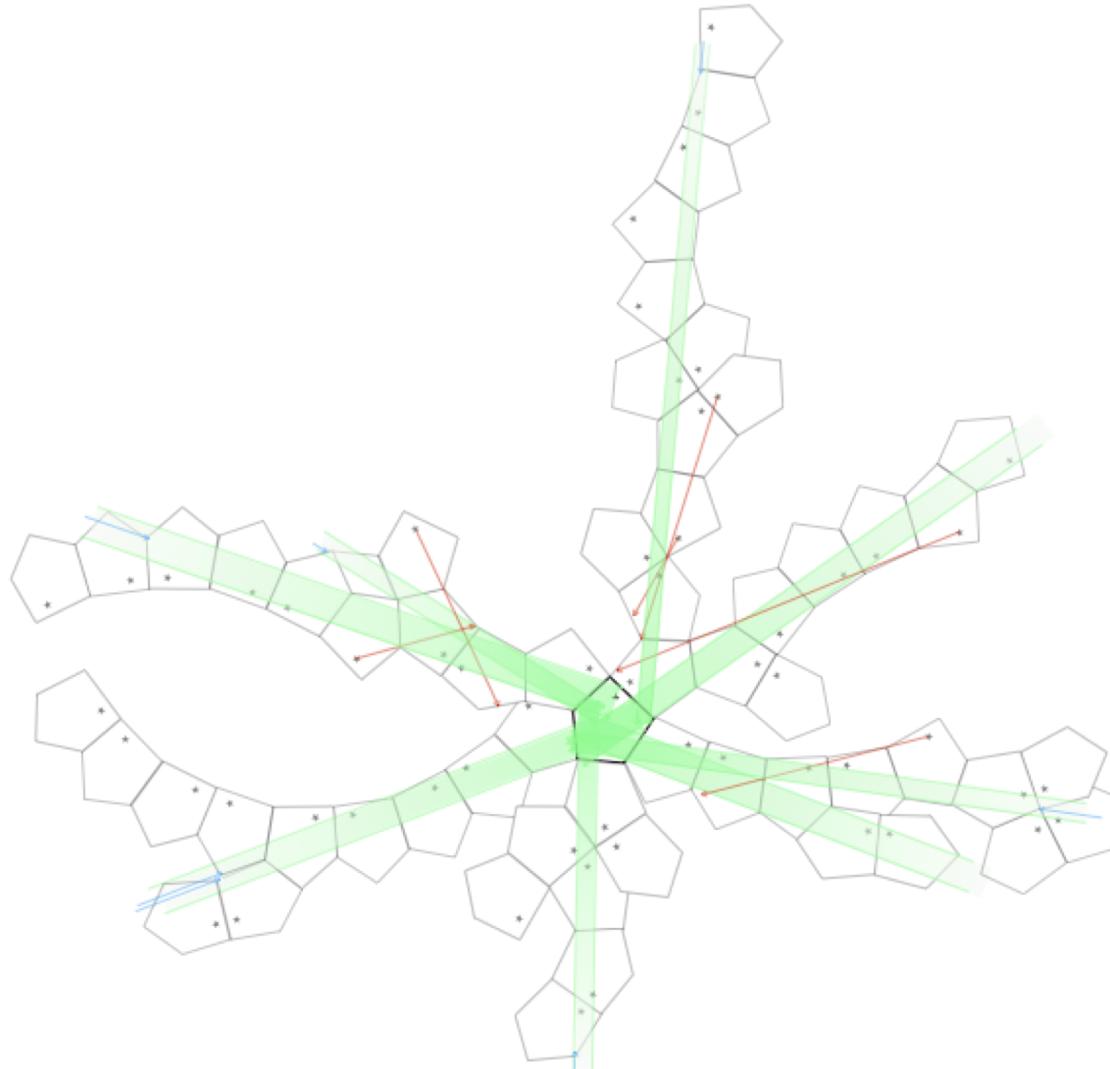
- Salles dodécaédriques :

$$N_i = \frac{10(29.97)^i (316 + 157\sqrt{14})}{23}$$

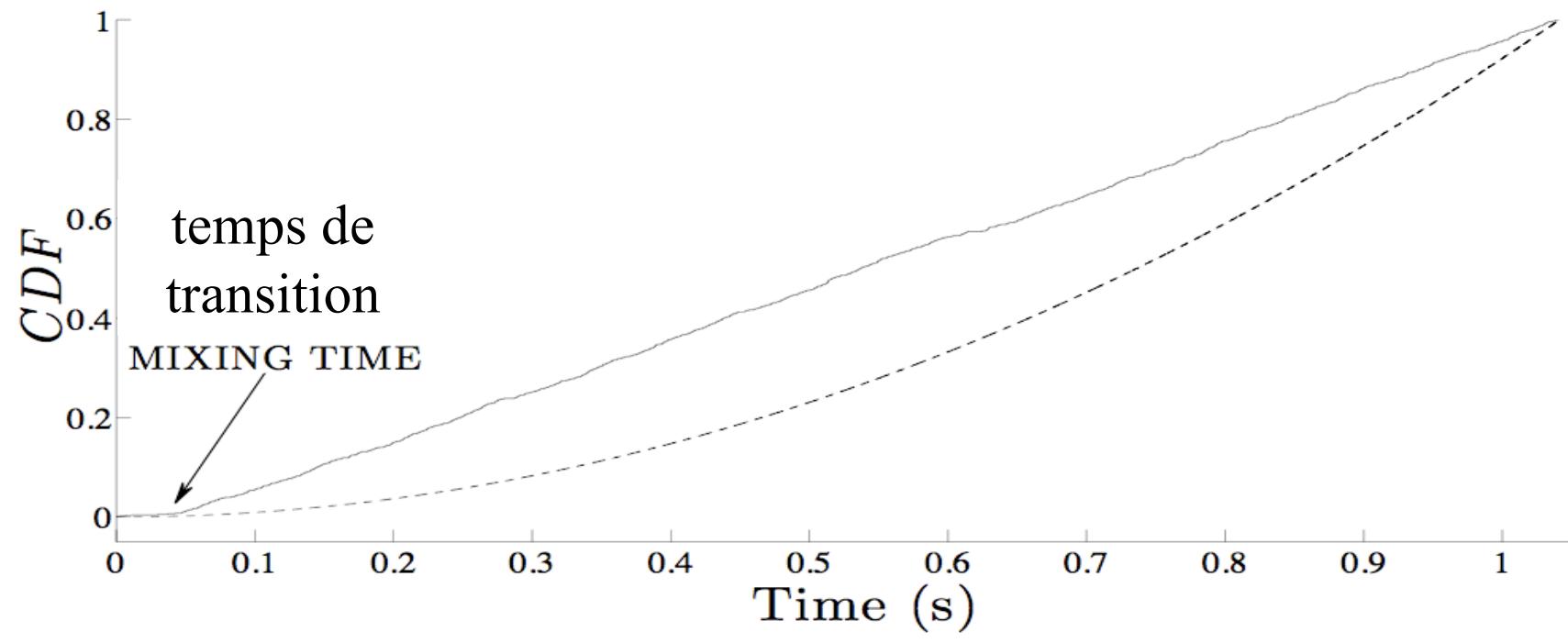
Sources images visibles et invisibles (pentagone régulier)



Sources images visibles et invisibles (pentagone irrégulier)

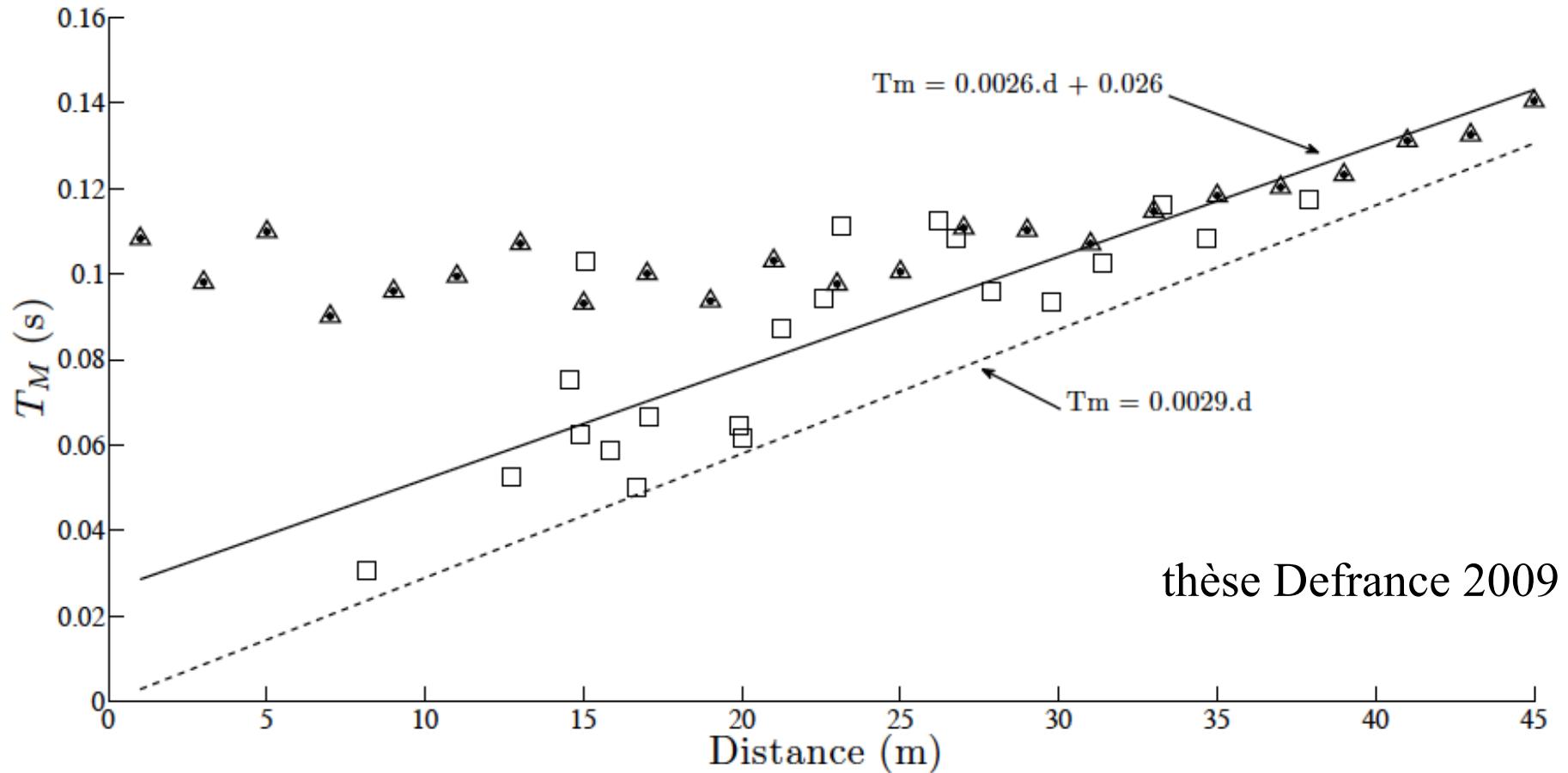


RI mesurée à Pleyel



Thèse Defrance 2009

Temps de mélange

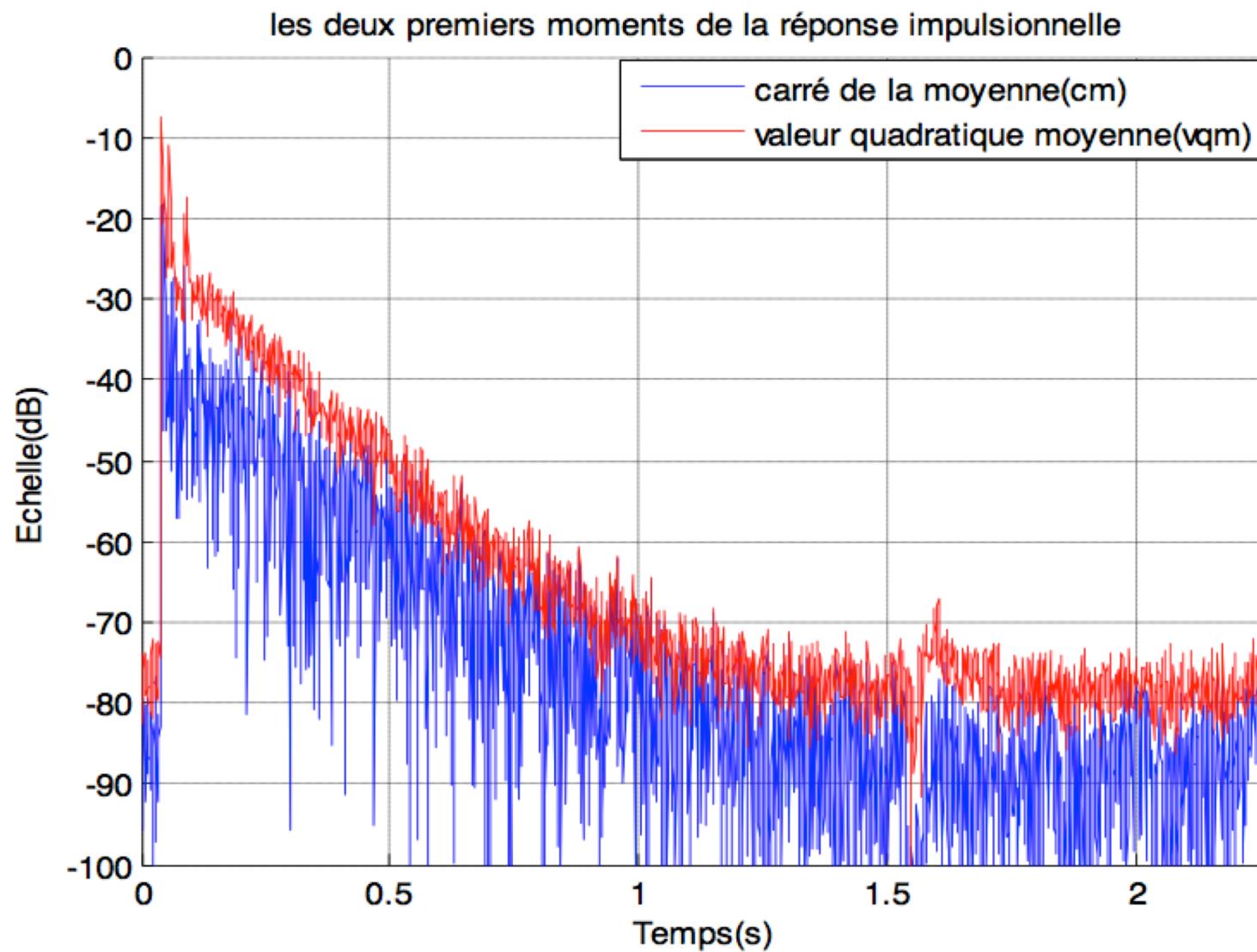


triangles = modèle ; carrés = expériences.

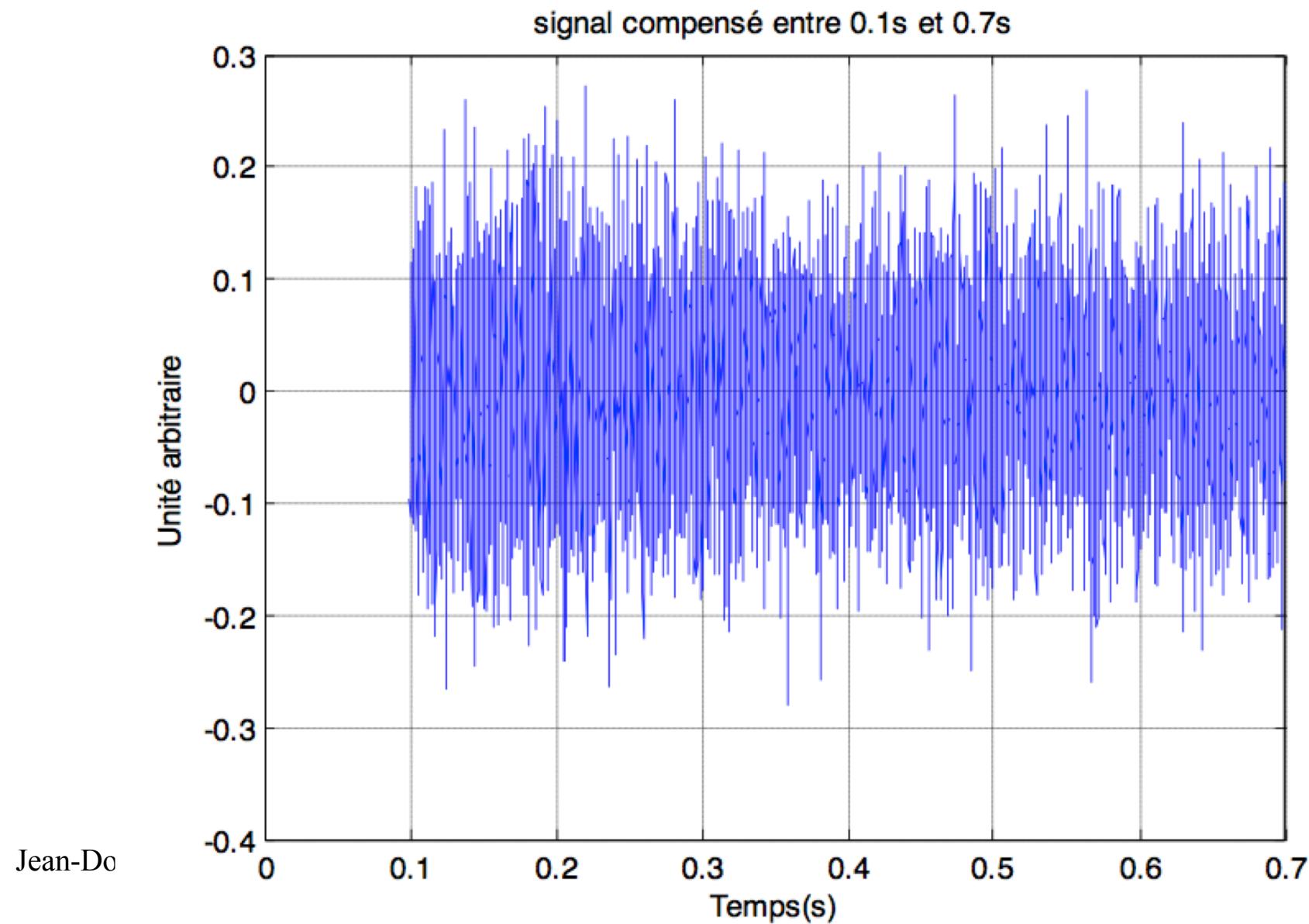
ligne tireté : minima du modèle (régression linéaire)

ligne continue : valeurs moyennes expérimentales (régression linéaire)

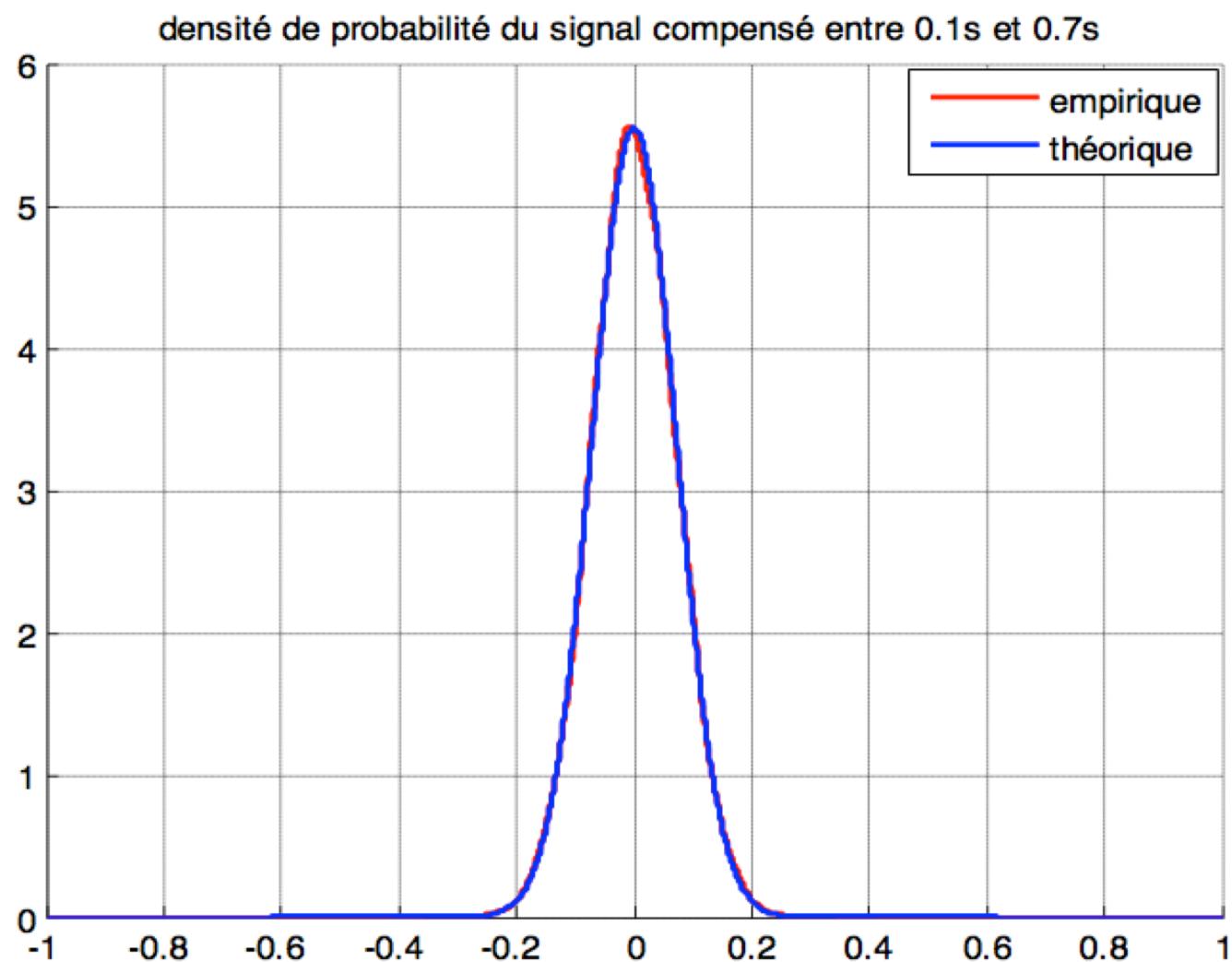
Aspects statistiques



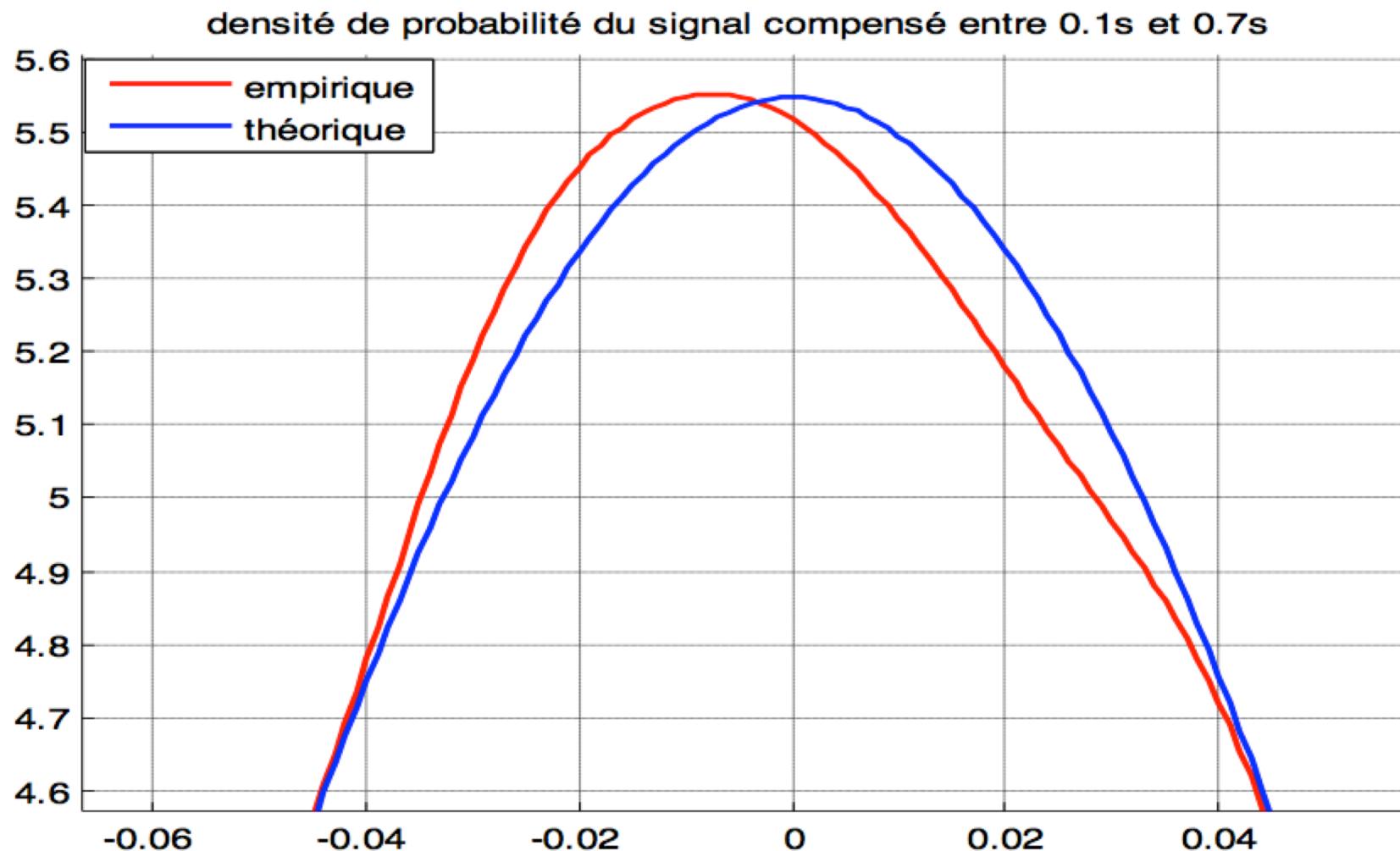
Aspects statistiques (2)



Aspects statistiques (3)



Aspects statistiques (4)



"mélange" (Vivié et Cassan p.86, d'après Cremer)

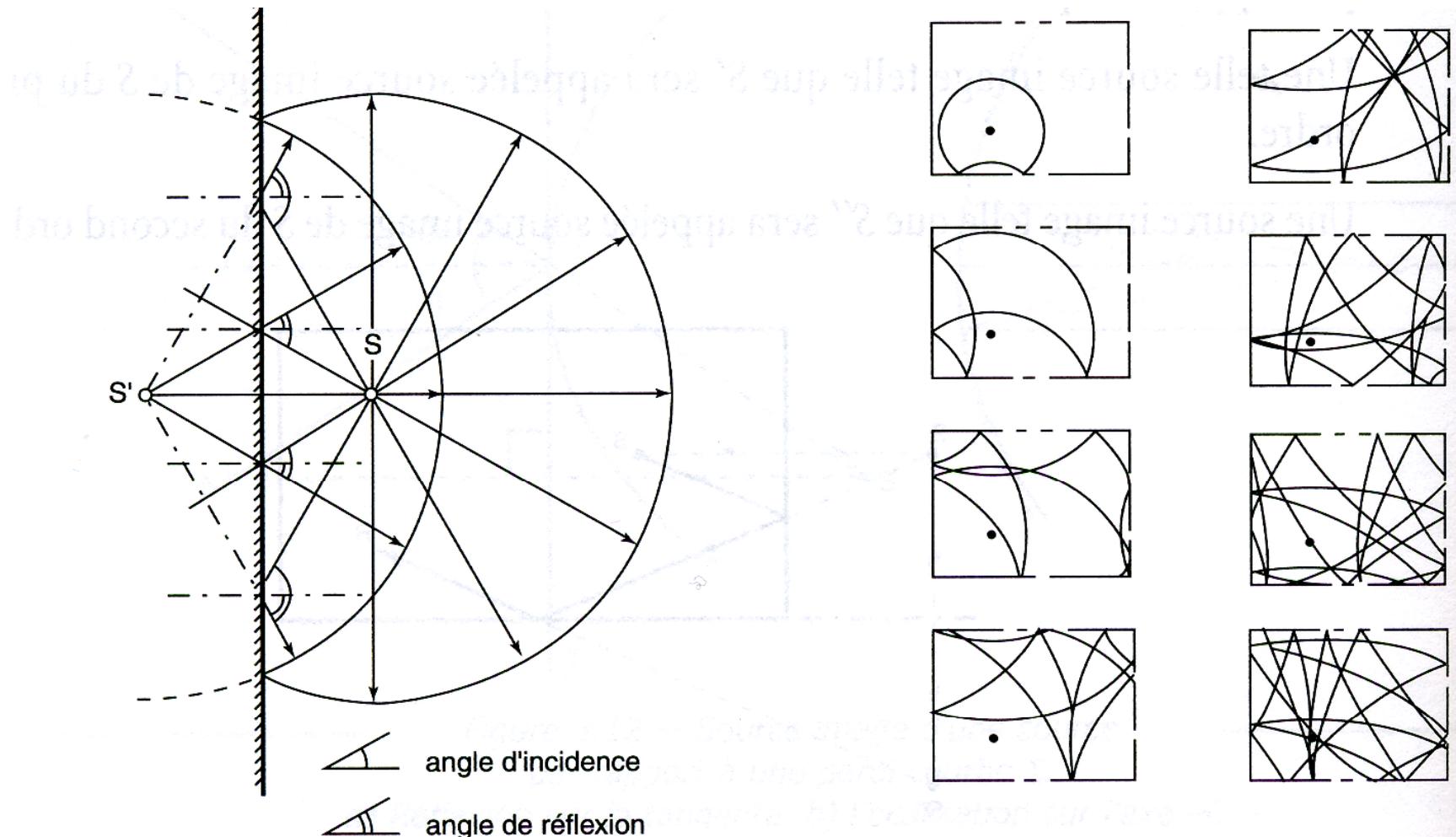


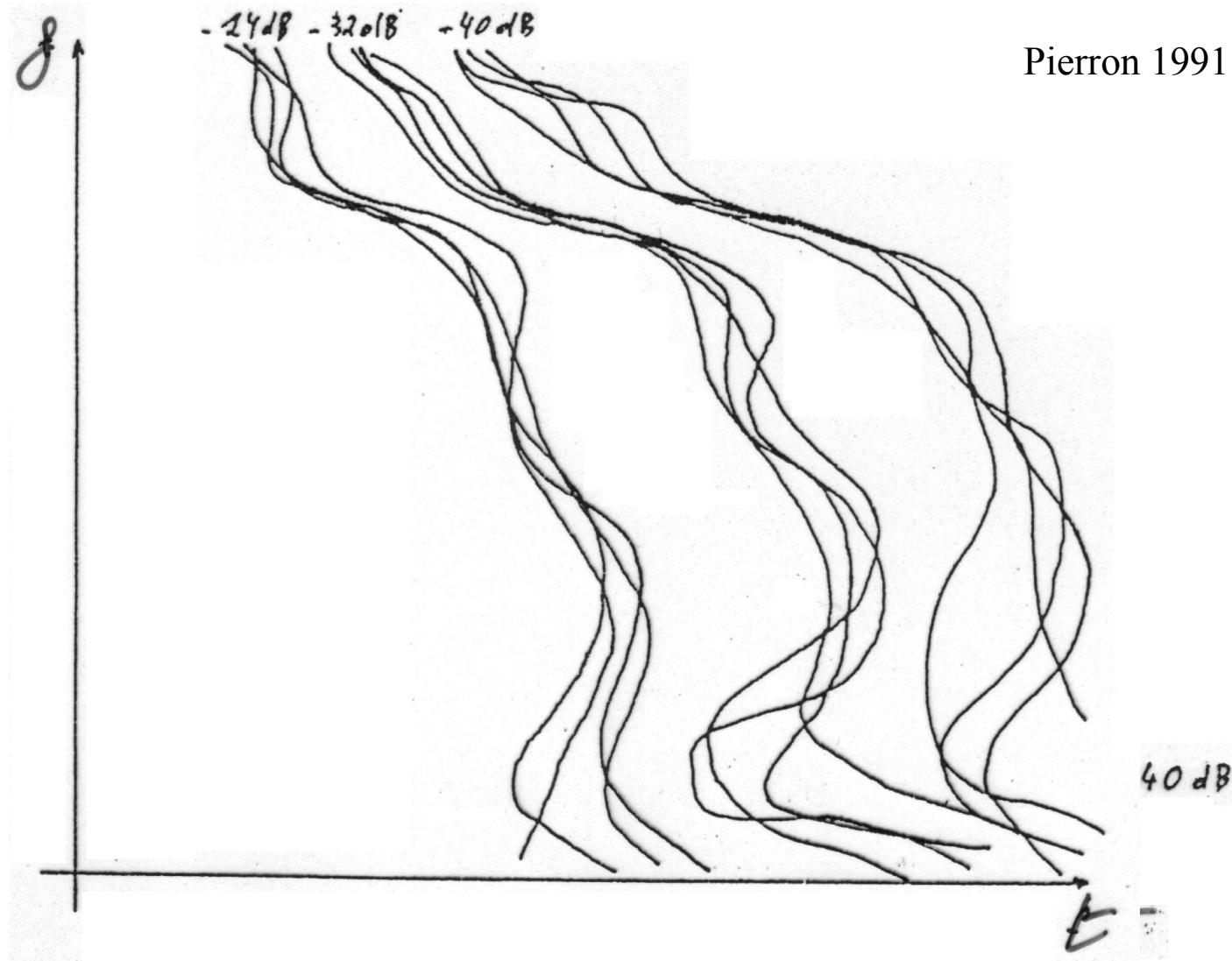
Figure 3.14 – a) Construction d'un front d'onde.

b) Propagation des fronts d'onde à divers instants dans une salle parallélépipédique.

La réverbération est statistique !

I Messiaen :

- 1 source
- 4 micros



Are Concert Halls random number generators?

Assessing concert halls
with reference to a stochastic model

Anders Christian Gade provided
the measurement results.

1. The stochastic model

- The impulse response is a superposition of pulses, originating from image sources
 - Mean number of image sources: $\Delta N = \frac{4\pi c^3 t^2}{V} \Delta t = \lambda(t) \Delta t$
(rectangular room hypothesis)
- Number of arrivals at time t :
 - Poisson distribution: $p(N, t) = \frac{\lambda^N(t)}{N!} \exp(-\lambda(t))$
 - possibly more than 1 ray!

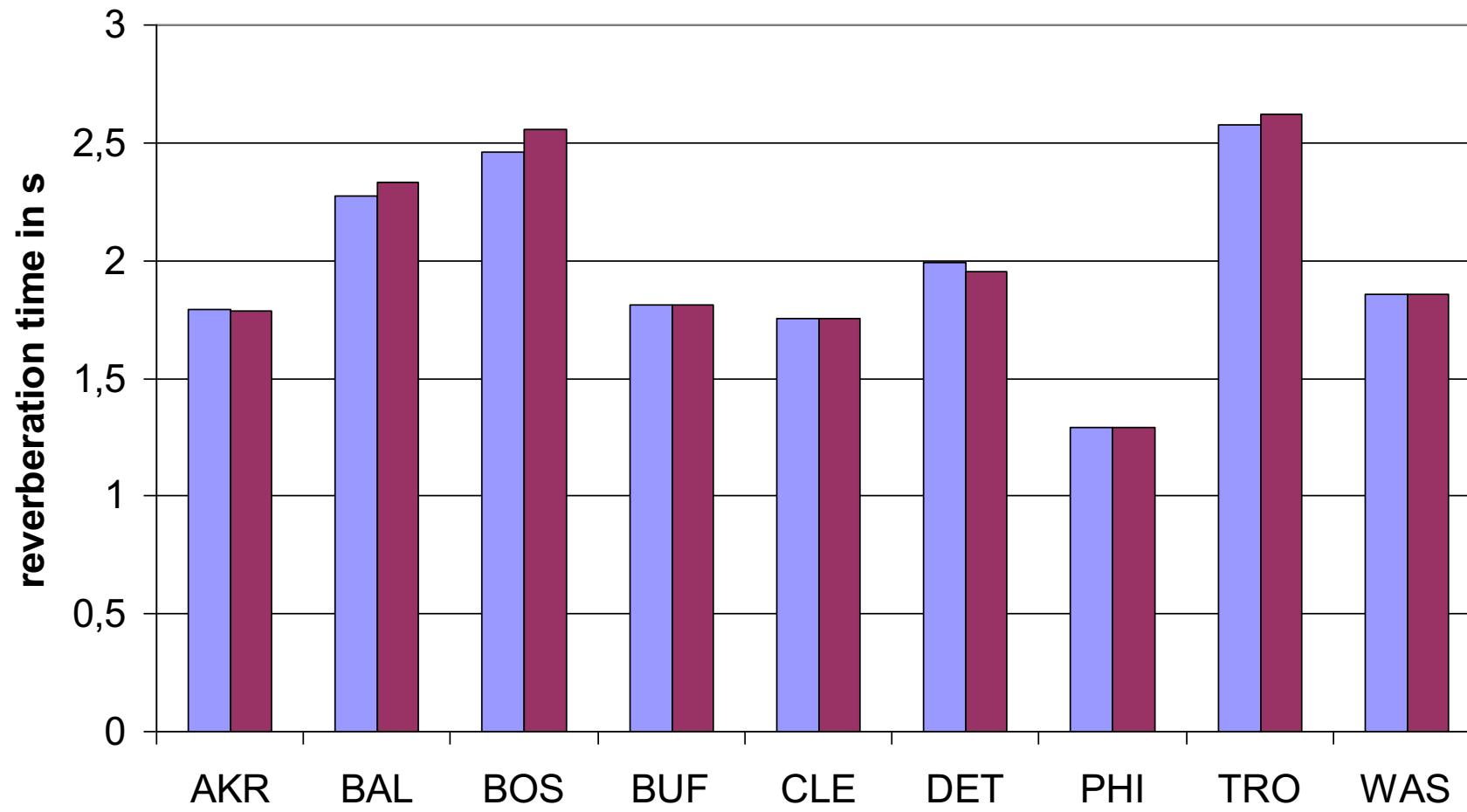
The stochastic model

- Each ray hits the walls of the room
 - Mean number of reflections: $\overline{n(t)} = \frac{ct}{\ell} = \bar{n}$
where ℓ is the mean free path $\ell = \frac{4V}{S}$
- Number of reflections per ray:
 - Poisson distribution: $p(n) = \frac{\bar{n}^n}{n!} \exp(-\bar{n})$
- Level of each ray:
 - $I = (1 - \alpha)^n$
- Several rays possible + geometrical attenuation

2. The nine US concert halls

City	Shape features
Akron	Wide fan, 2 balconies
Baltimore	Oval, 2 balconies
Boston	Rectangular, 2 balconies
Buffalo	Wide fan, 1 balcony
Cleveland	Horse shoe, box + large rear balcony
Detroit	Horse shoe, box + large rear balcony
Philadelphia	Horse shoe, 3 balconies
Troy	Rectangular, 2 balconies
Washington	Rectangular, 2 balconies

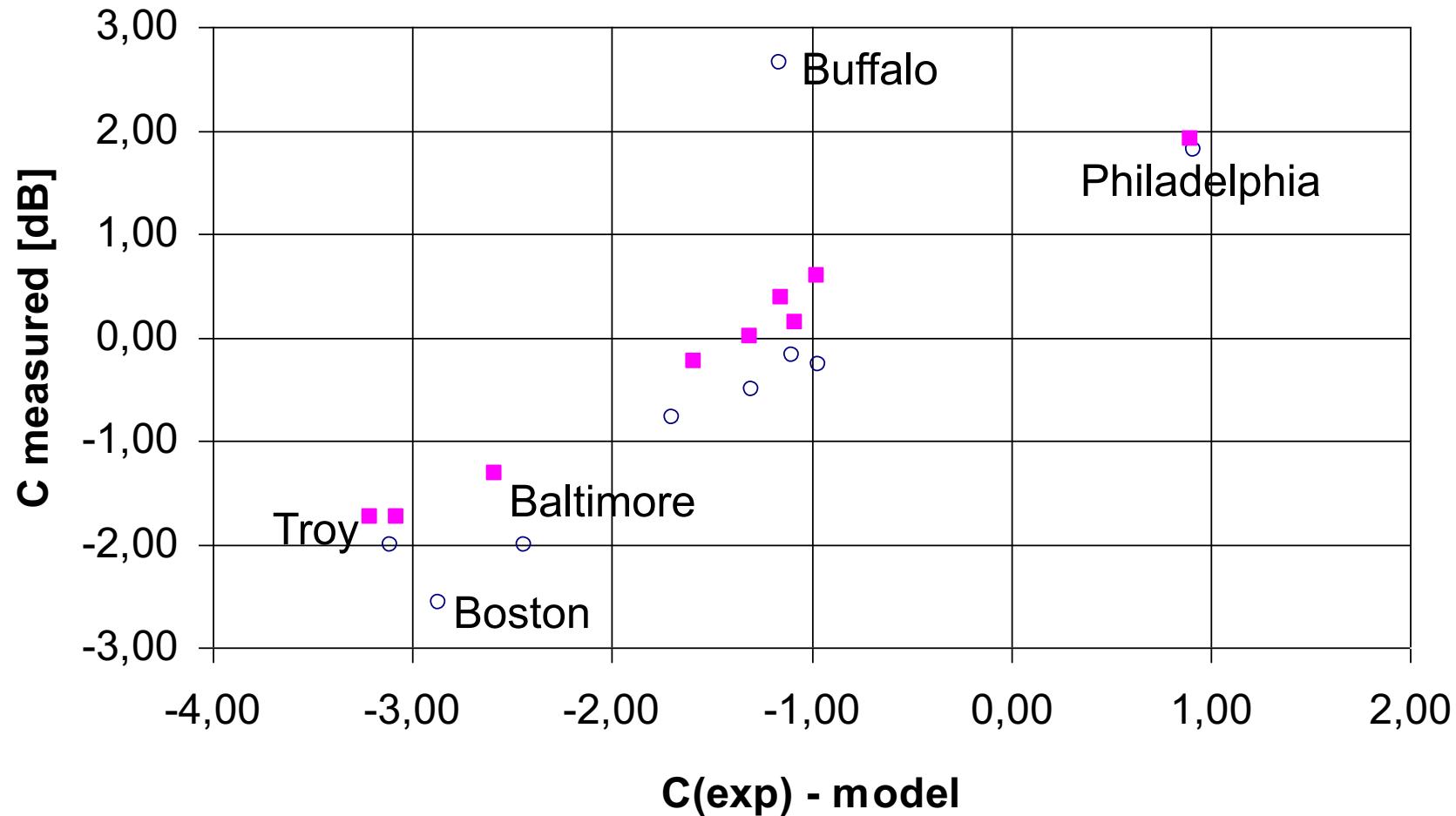
Reverberation times



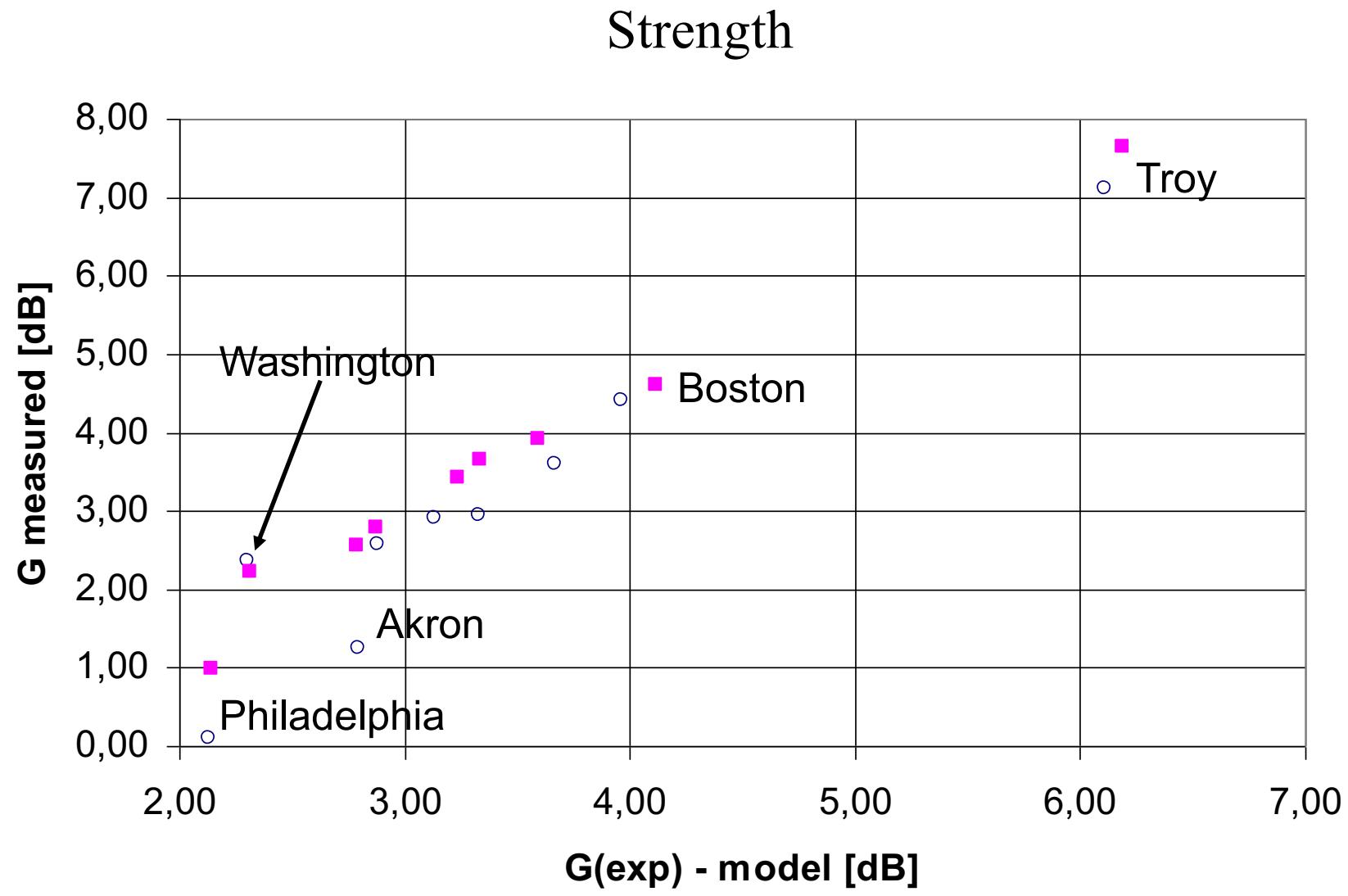
left: simulated values;

right: measured values

Clarity



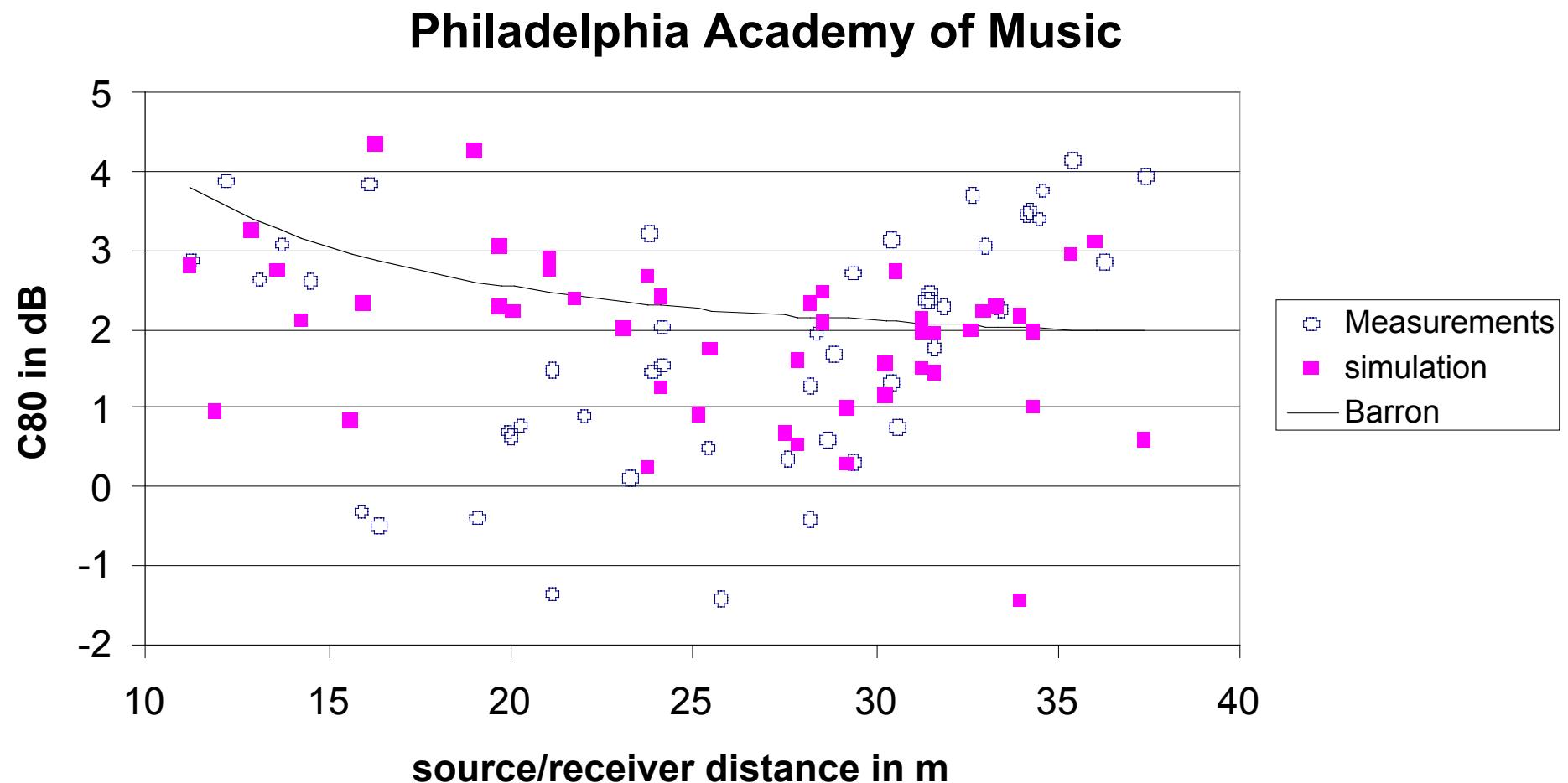
Gade's model: $C = -0.4 + C_{\text{exp}}$ with $C_{\text{exp}} = 10 * \log(\exp(1.04/RT) - 1)$ dB



Gade's model: $G = -1.6 + G_{exp}$ with $G_{exp} = 10 \cdot \log(RT/V) + 45 \text{ dB}$

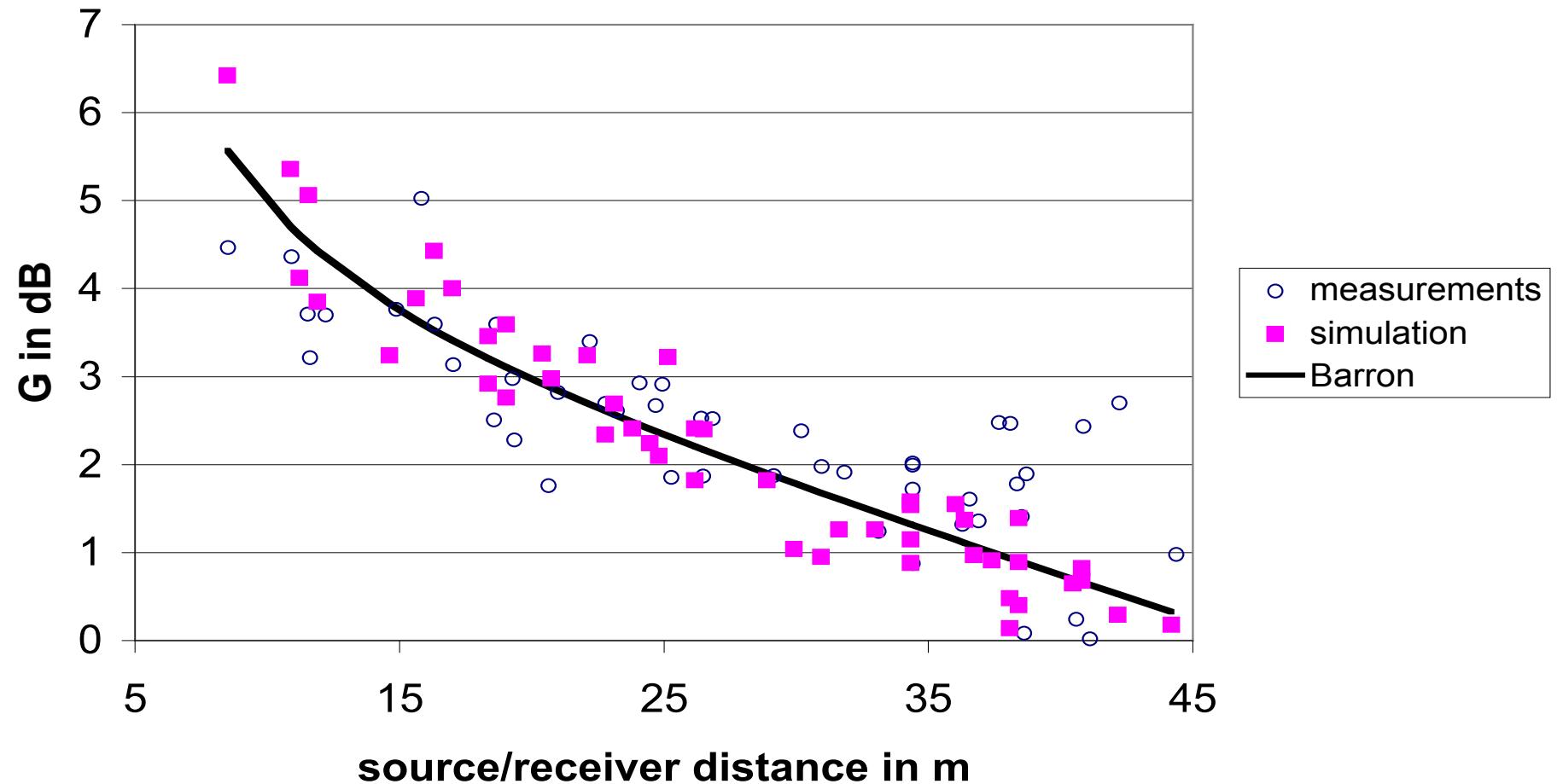
3. Within hall differences

A case of agreement for Clarity

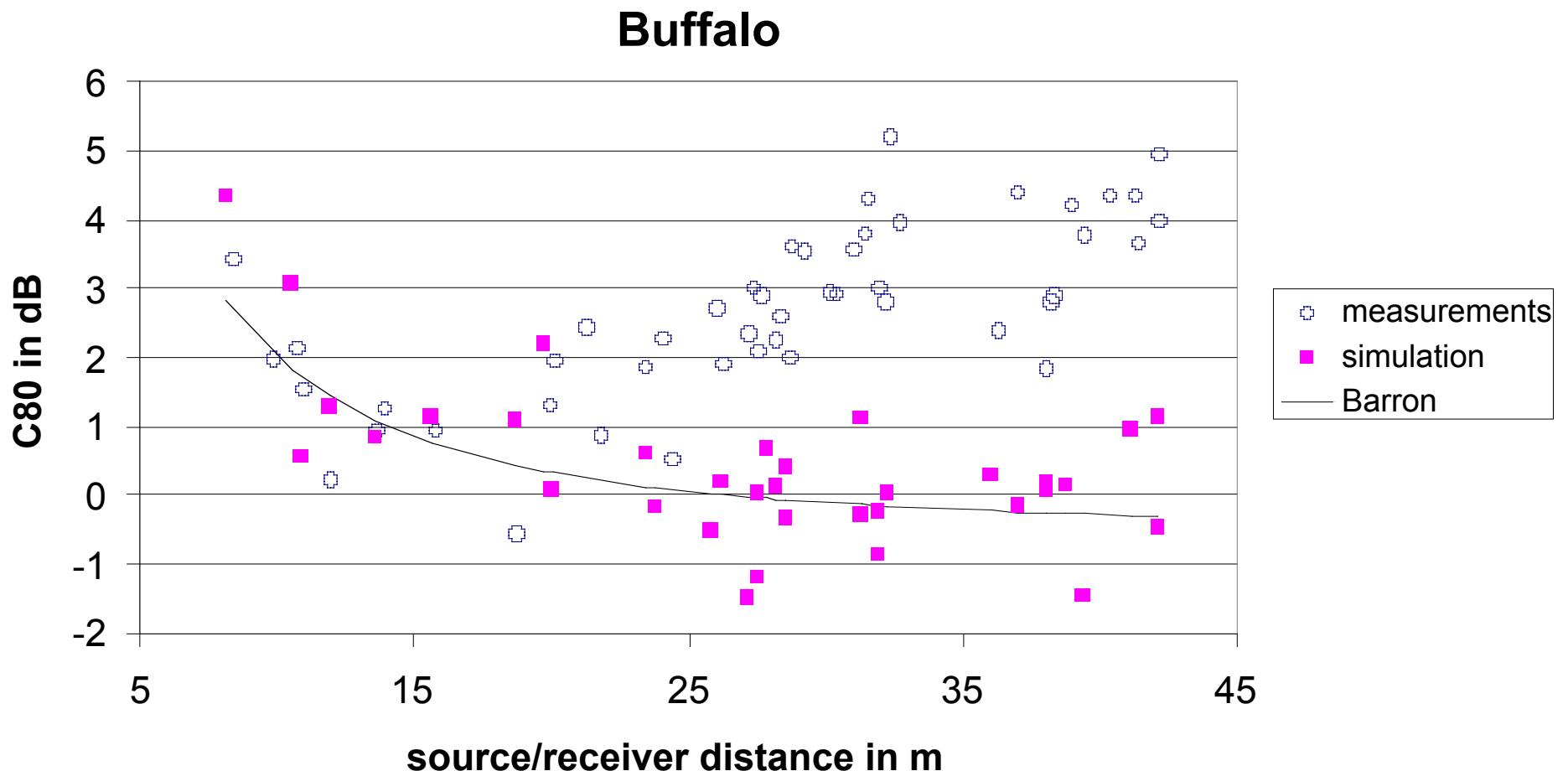


A case of agreement for Strength

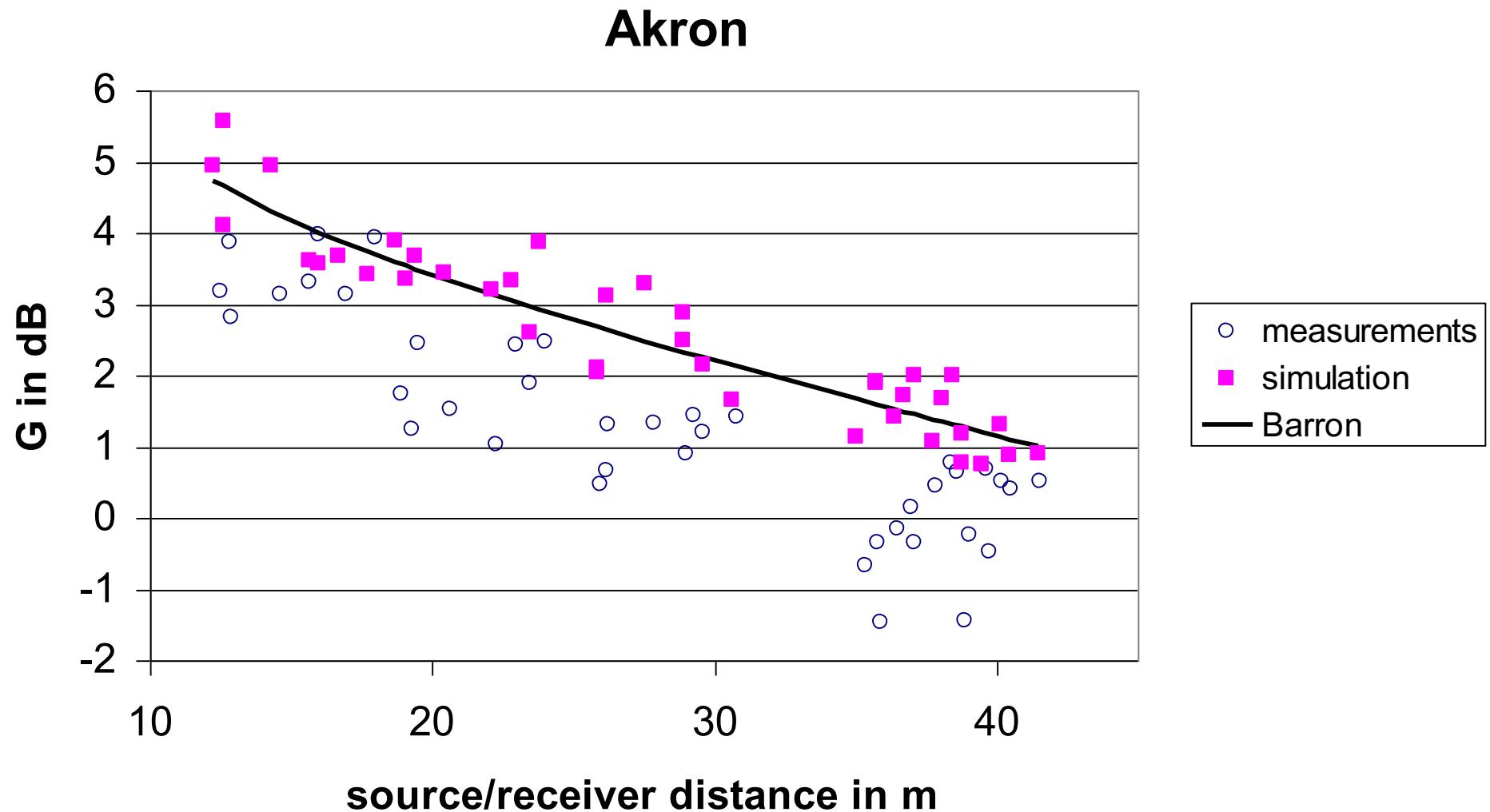
Washington



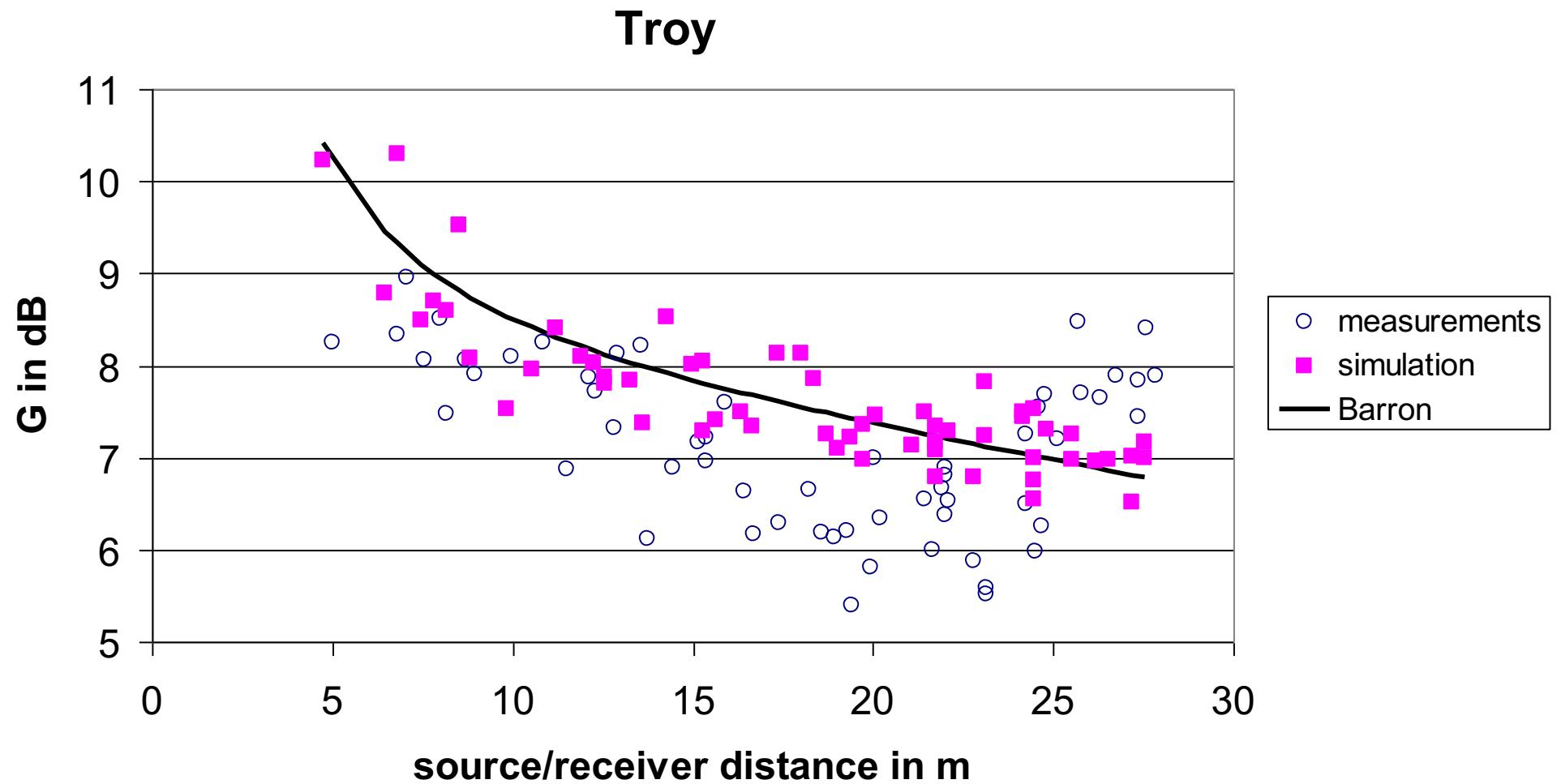
Abnormal Clarity



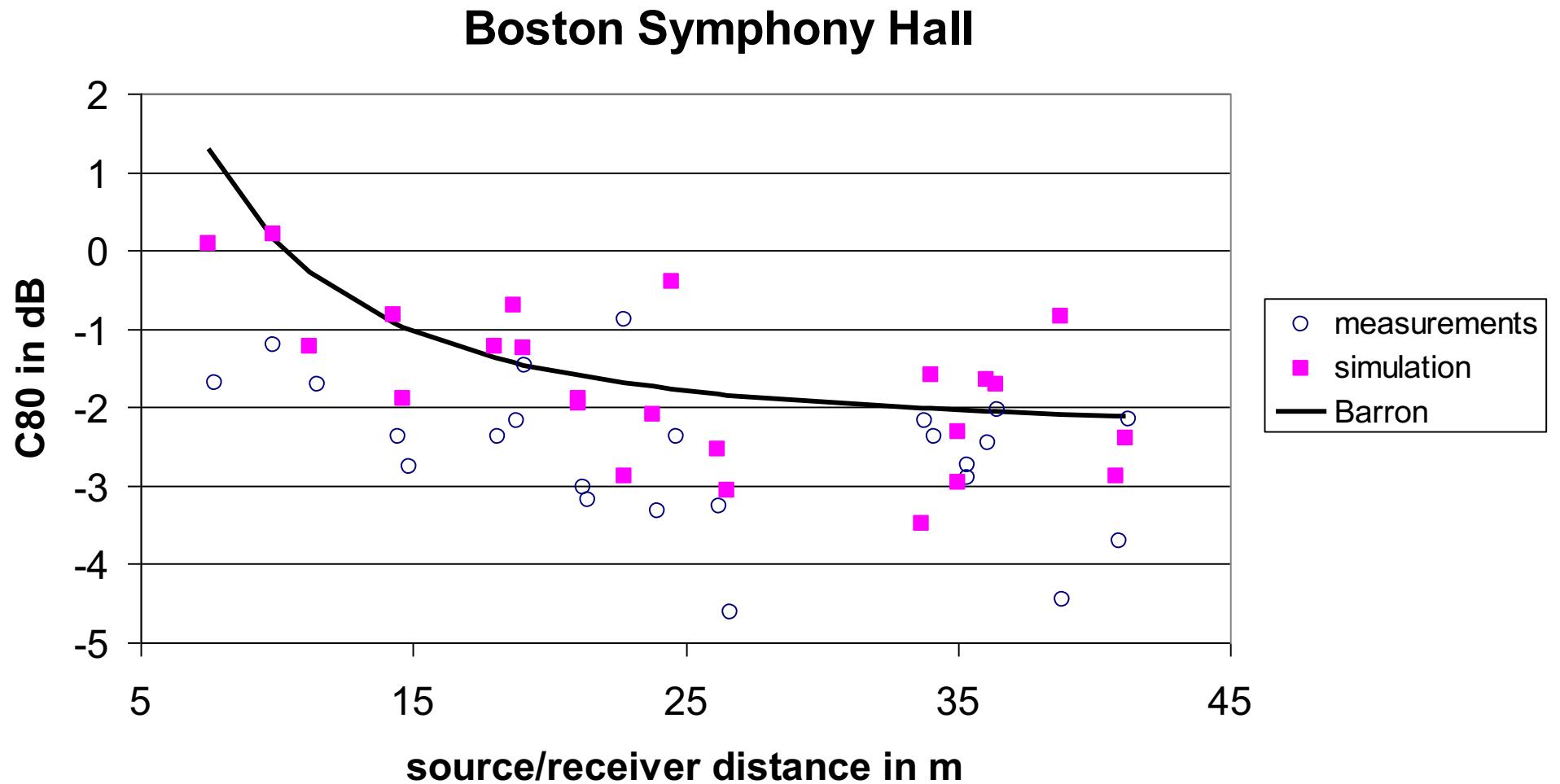
Abnormal Strength (1)



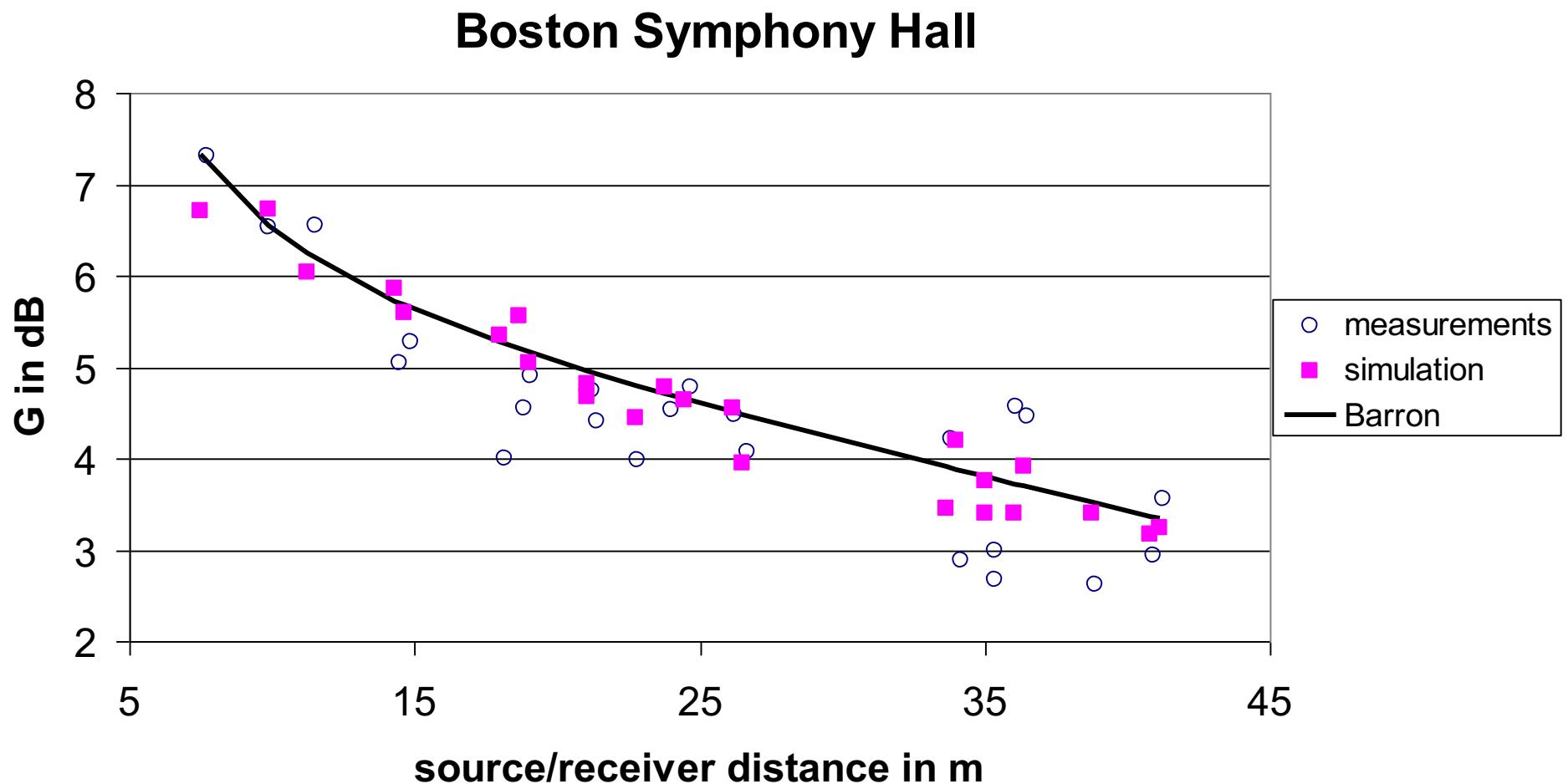
Abnormal Strength (2)



A regular hall: Clarity



A regular hall: Strength



4. Mean absorption

City	α
Akron	0.31
Baltimore	0.28
Boston	0.29
Buffalo	0.32
Cleveland	0.36
Detroit	0.33
Philadelphia	0.44
Troy	0.26
Washington	0.38

- Piano practice rooms:
 $\alpha_m = 0.3 \pm 20\%$
- IEC Rec. 268-13:
 $\alpha_m = 0.27 \pm 10\%$

Target value:

$$\alpha_m = 0.3$$

Conclusion

Concert Halls are not
random number generators!

However,
stochastic model is valuable reference.

Target absorption: $\alpha_m = 0.3$

Synthèse de RI par modèle stochastique

- Inputs :
 - V : volume en m³
 - RT : RT30 in sec
 - Alpha : coeff. moyen d'absorption (ex: 30%)
 - Dist : distance Source/Recepteur in m
 - Dimension : '1D', or '2D', or '3D' or '3D+'
 - Diffusion
- angles d'incidence calculés pour une salle ellipsoïdale
- Outputs :
 - Surface des parois : formule de Sabine
 - Libre parcours moyen : volume sur surface
 - Intensité des réflexions : atténuation géométrique + nbre réflexions

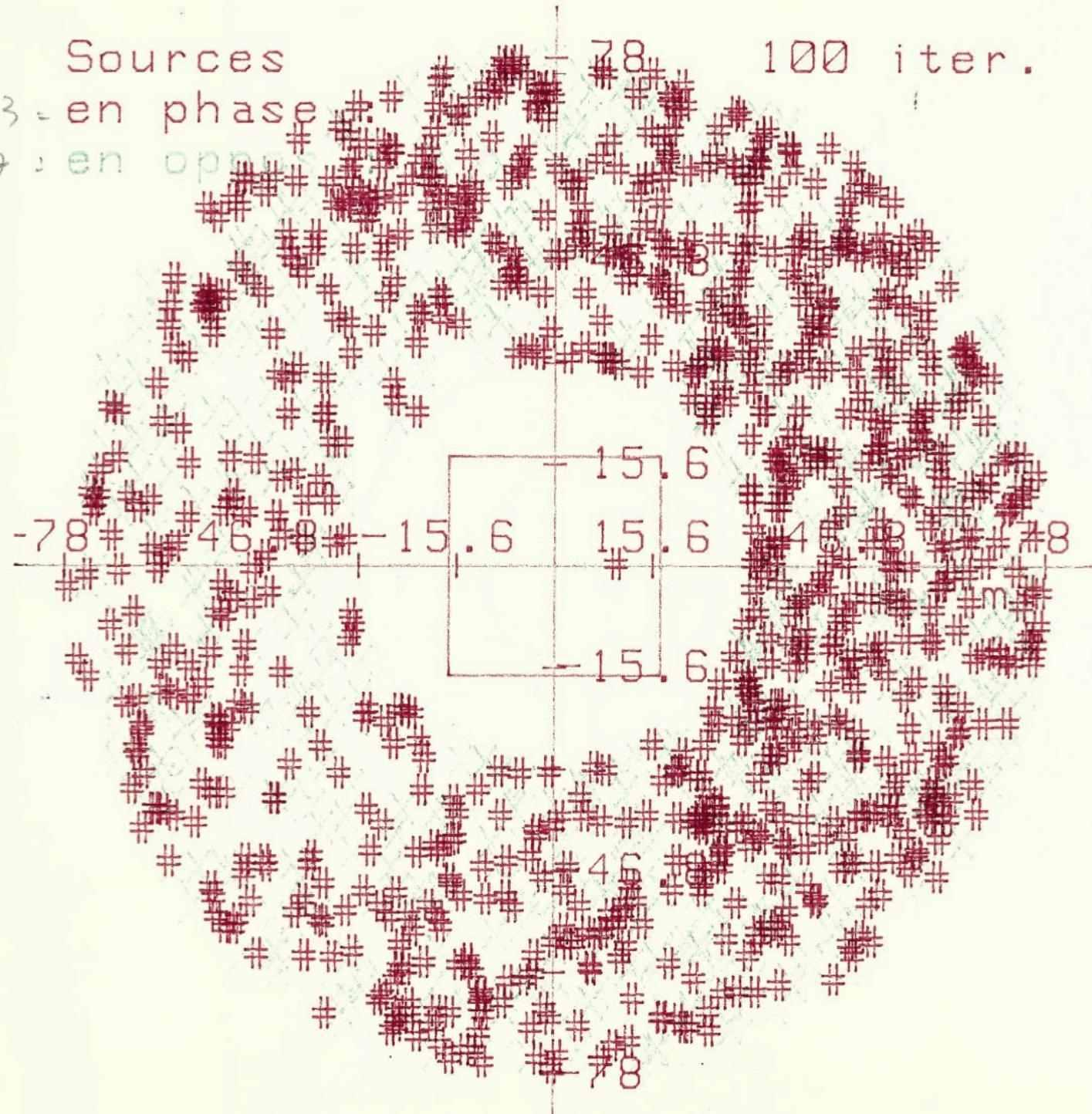
Répartition spatiale des sources images

Sources

893 = en phase

827 : en opp

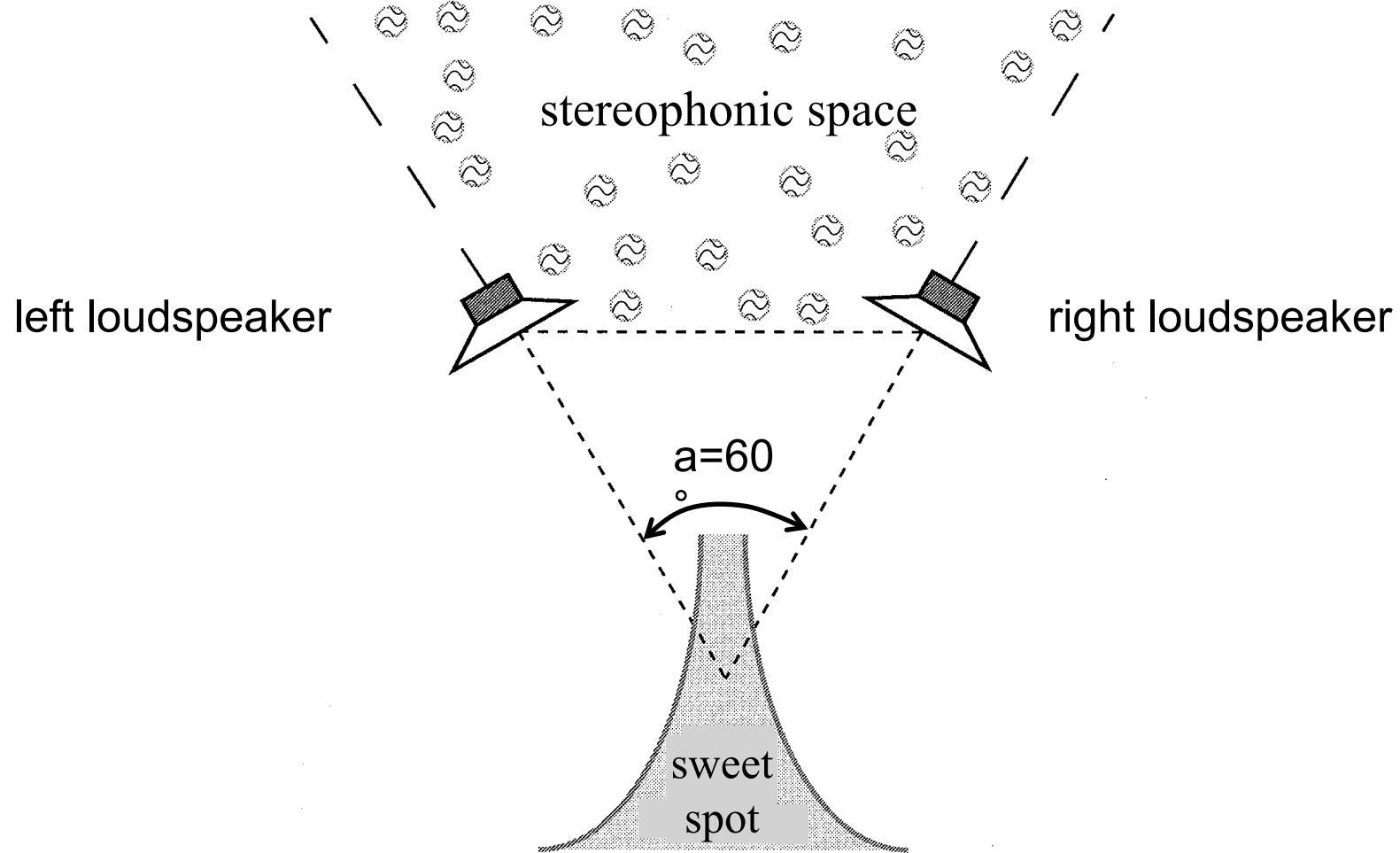
100 iter.



Quelques points spécifiques à traiter

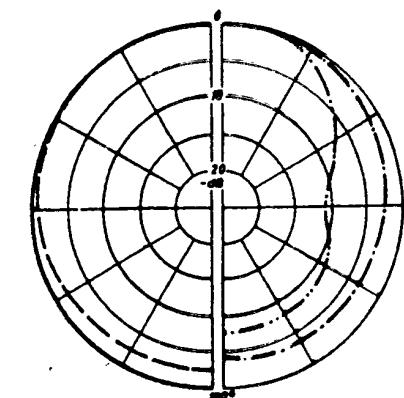
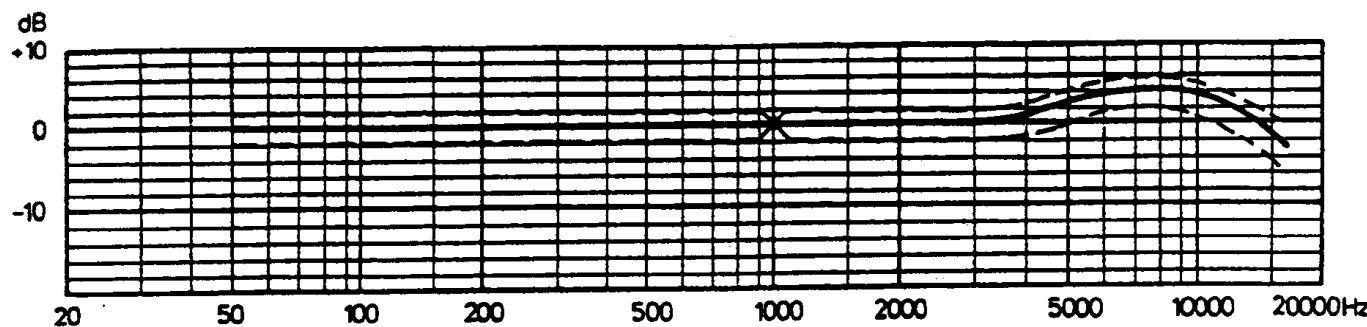
- la source :
 - directivité
- le récepteur :
 - directivité des microphones
 - Couples stéréophoniques
- modèle de calcul :
 - Poisson
 - exponentiel
 - gaussien

stereophonic arangement

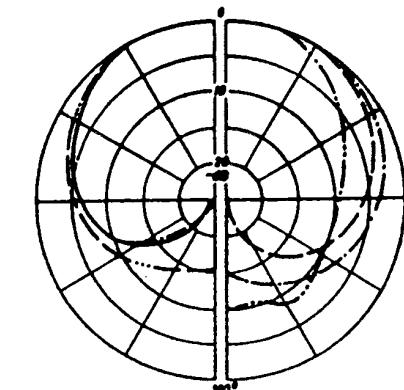
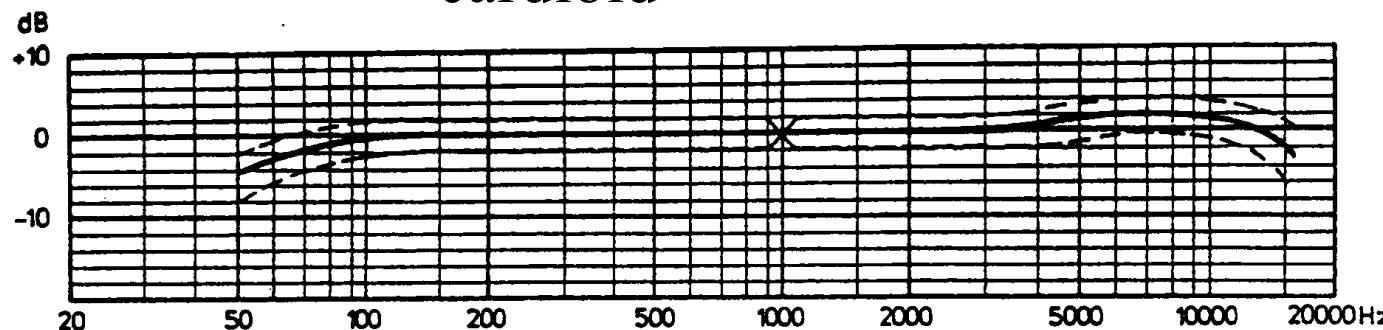


responses and angles

omnidirectional

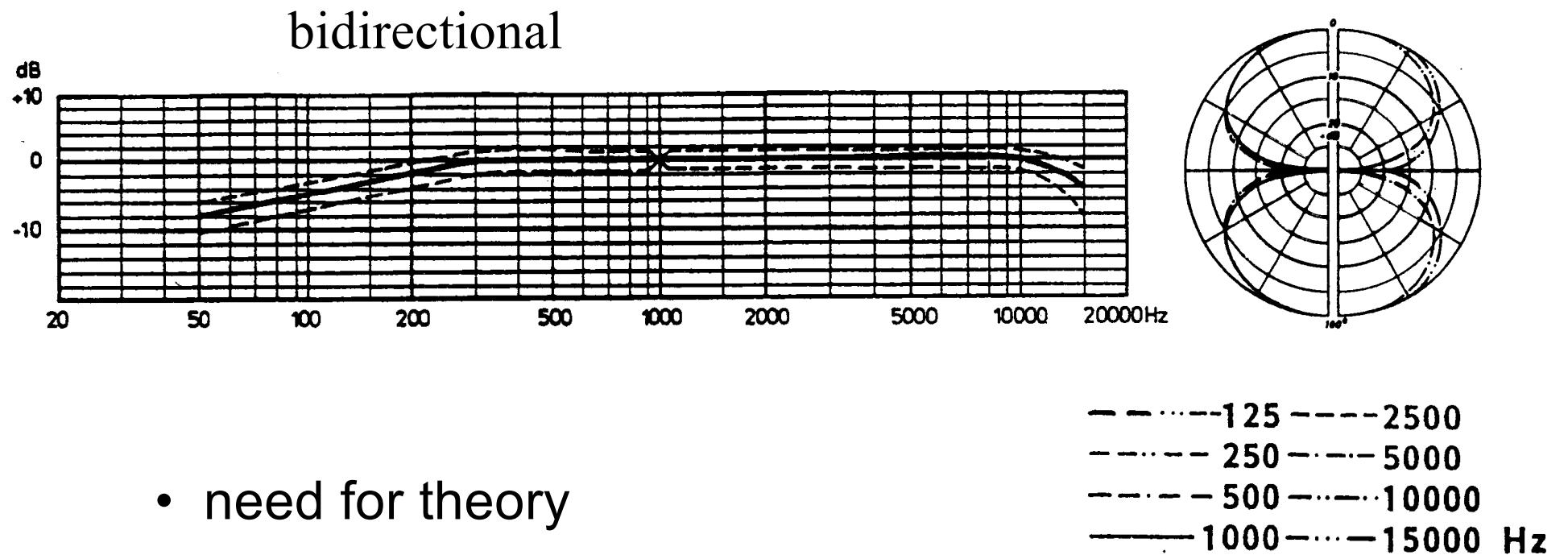


cardioid

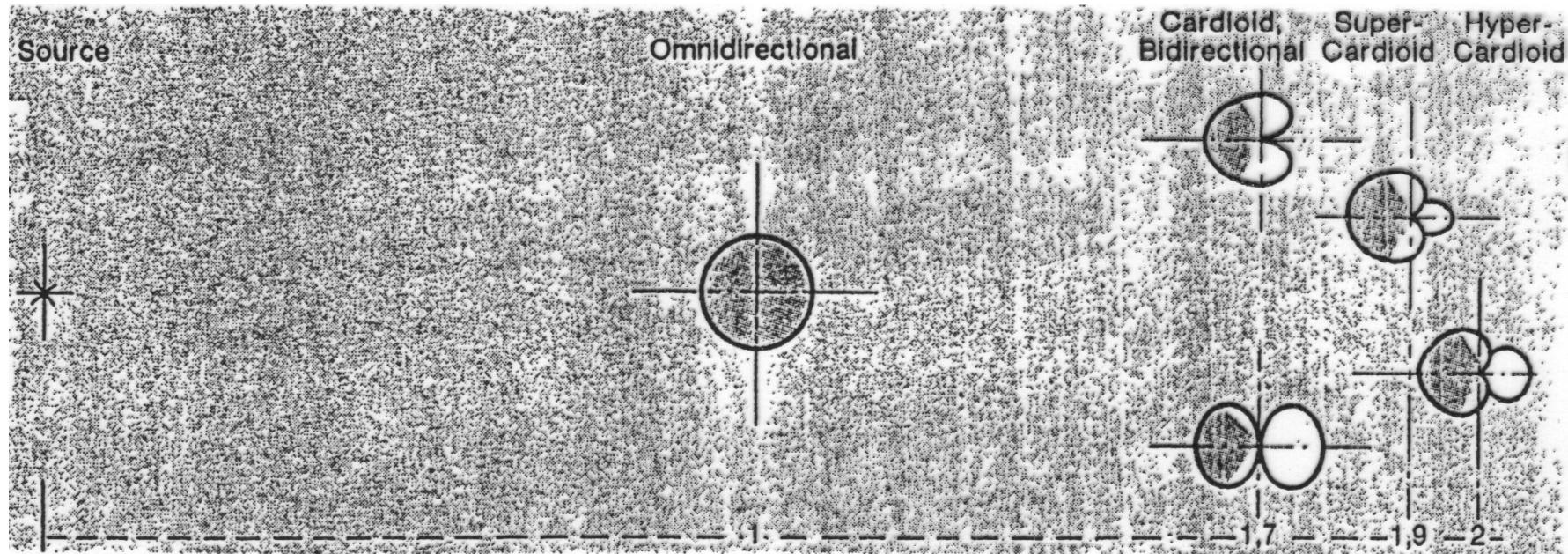


— · · · · 125 — · · · · 2500
— · · · · 250 — · · · · 5000
— · · · · 500 — · · · · 10000
— · · · · 1000 — · · · · 15000 Hz

responses and angles (2)

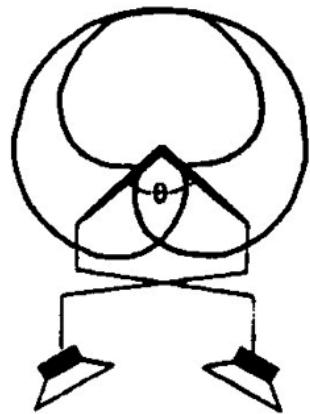


reverberation and distance



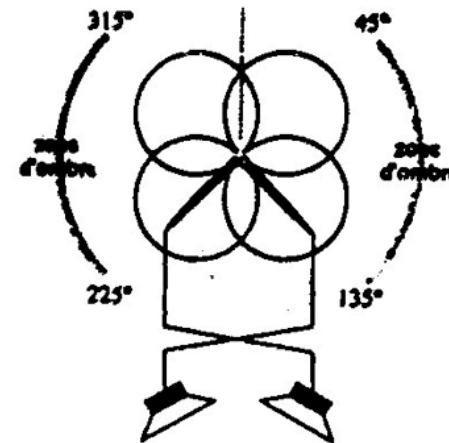
- a question of signal-to noise ratio
- no theory explains all

couples microphoniques (1)



Couple XY

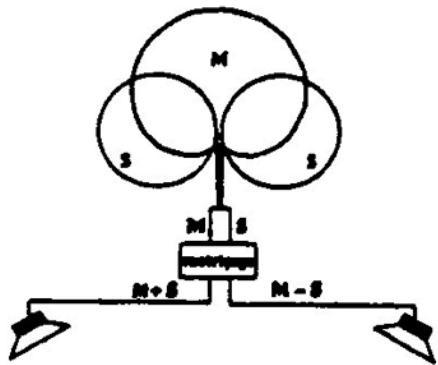
- prise de son en intensité
- bonne localisation
- peu d'espace
- proximité de la source
- $80 < \theta < 130$ et $180 < \theta_{\text{utile}} < 130$



Couple « Stereosonic »

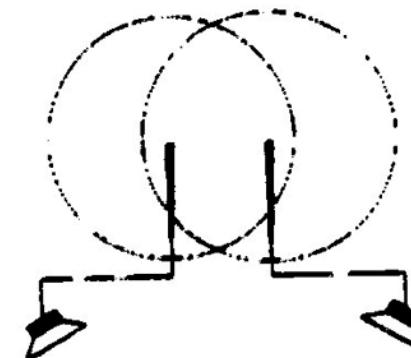
- prise de son en intensité
- bonne répartition angulaire
- à éloigner de la source
- $\theta_{\text{utile}} = 70^\circ$

couples microphoniques (2)



Couple MS

- prise de son en intensité
- θ_{utile} réglable (gain sur le micro bidirectionnel)
- application audiovisuel & cinématographie

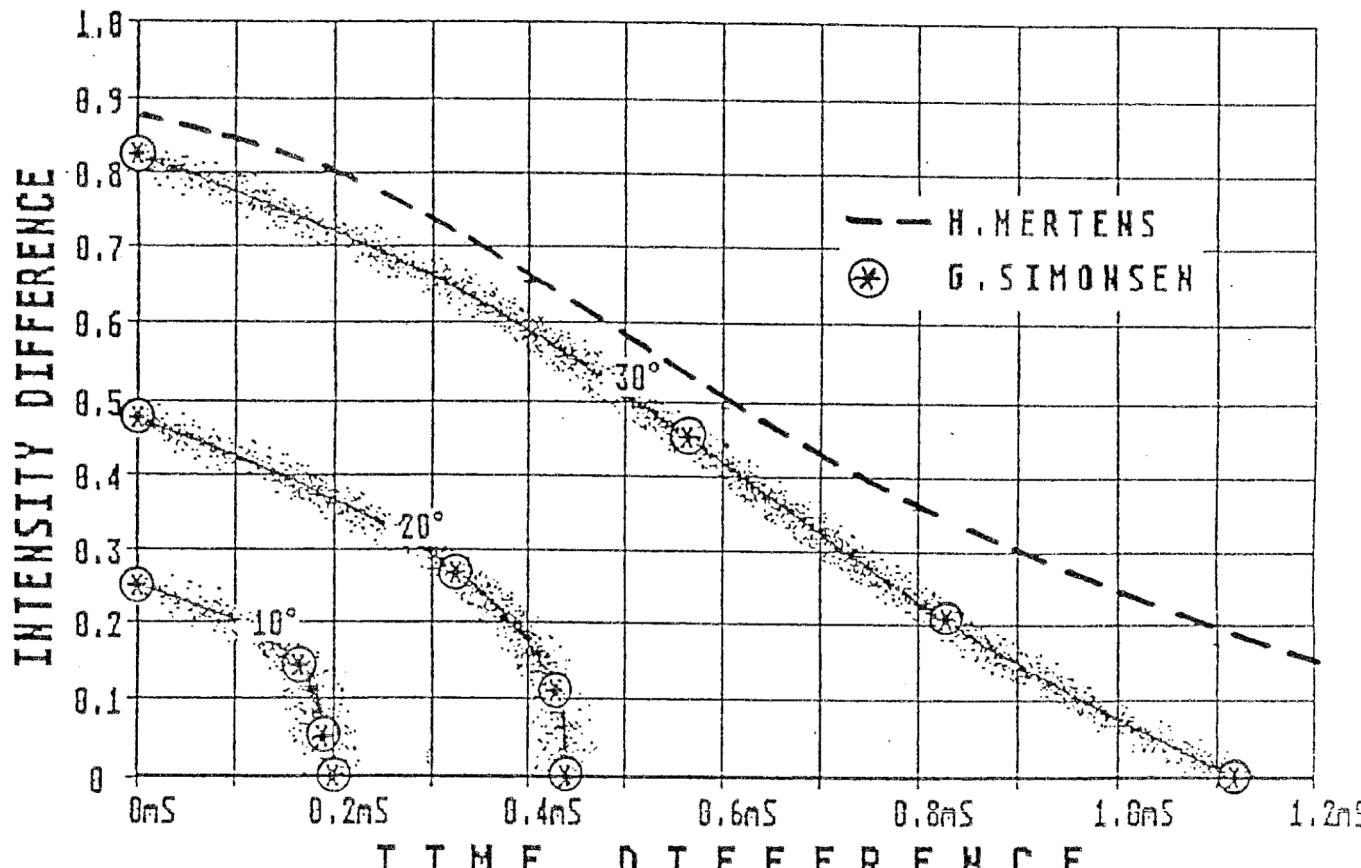


Couple AB

- prise de son en temps
- θ_{utile} réglable (distance entre les microphones)
- $25\text{cm} < e < 50\text{cm}$
- éloigner des sources (distorsion spatiale)

Stereophony

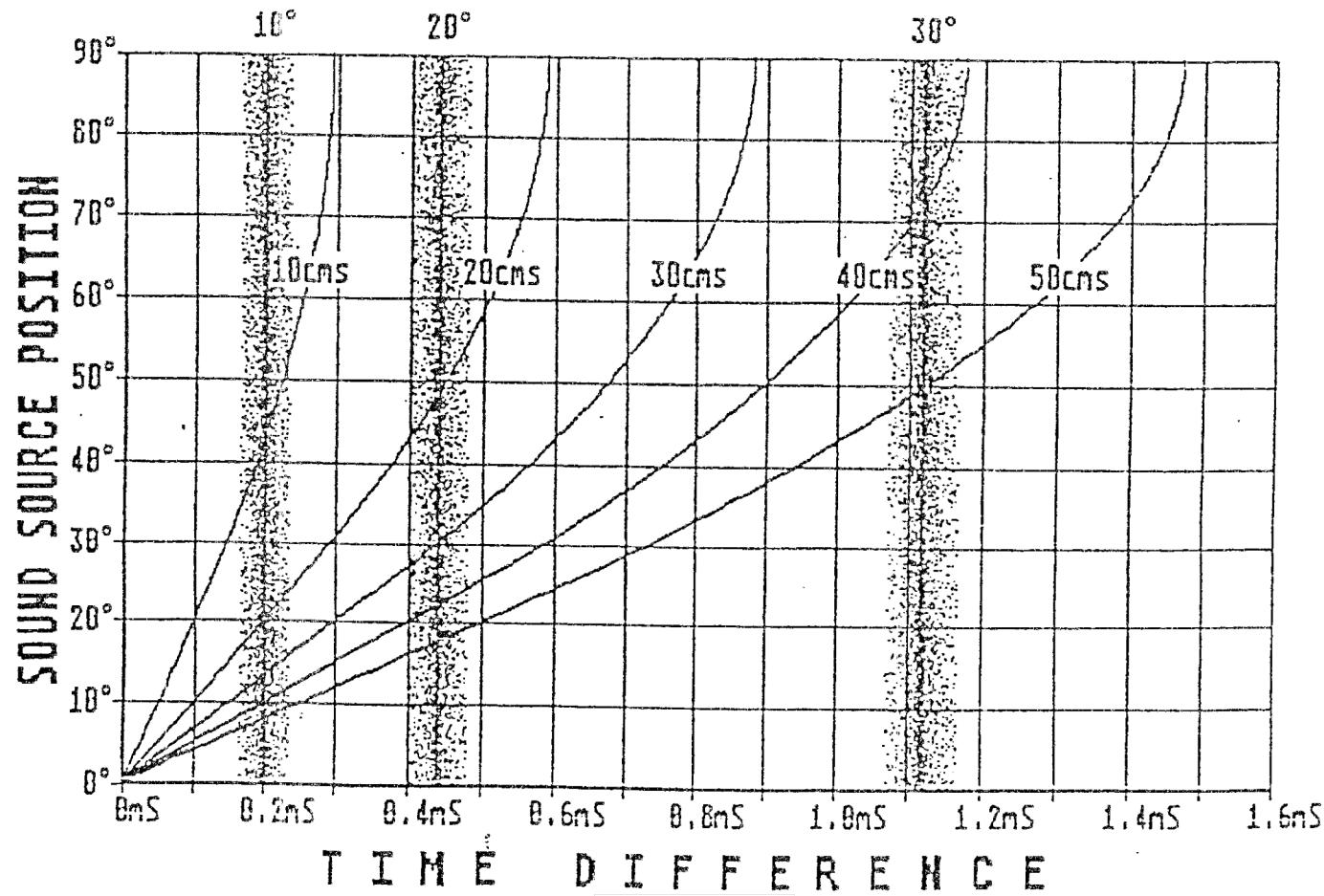
apparent localisation of music instruments



Mike Williams

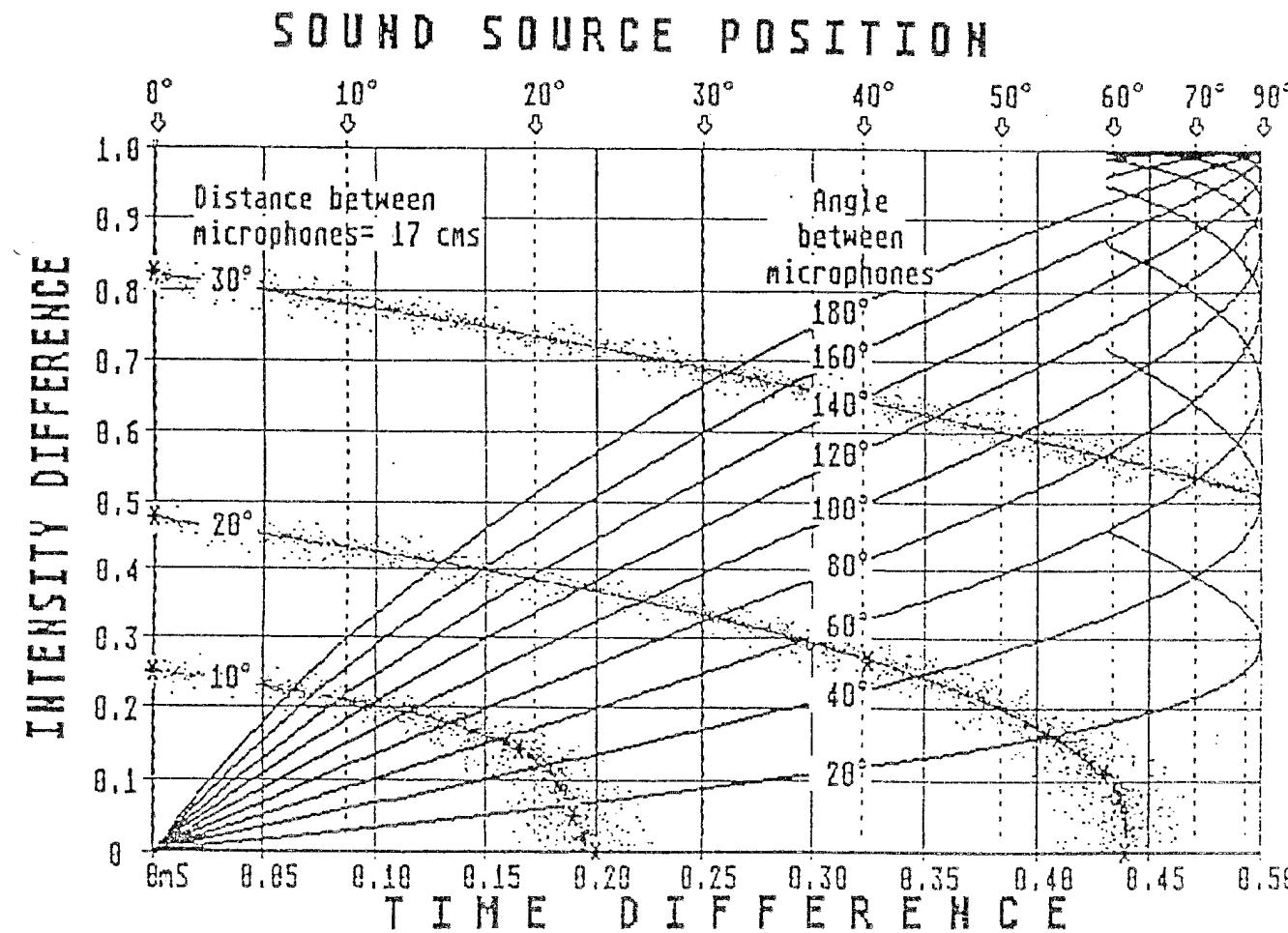
phase stereophony

influence of microphone distance



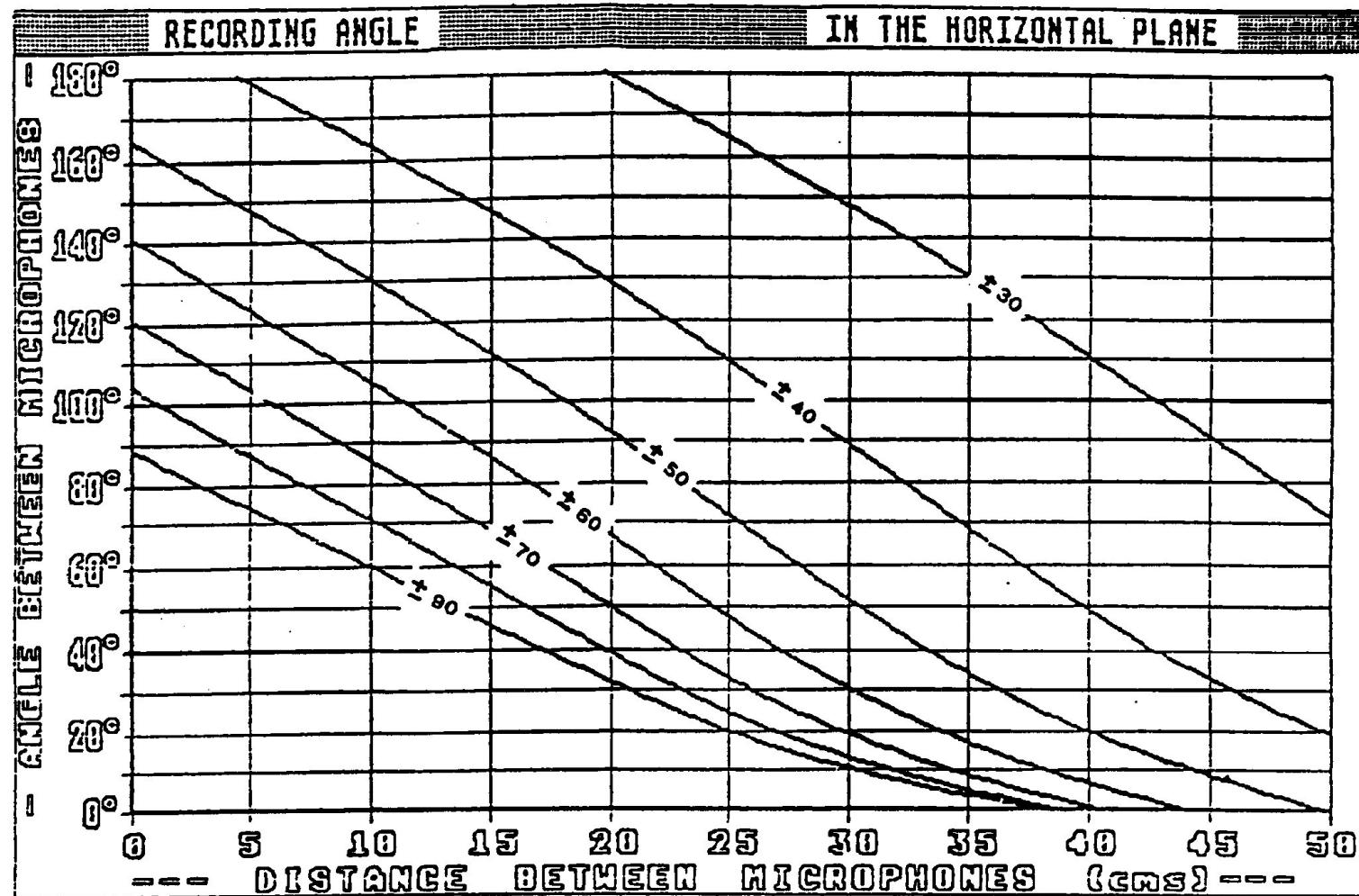
Stereophony

cardioid microphones at angle

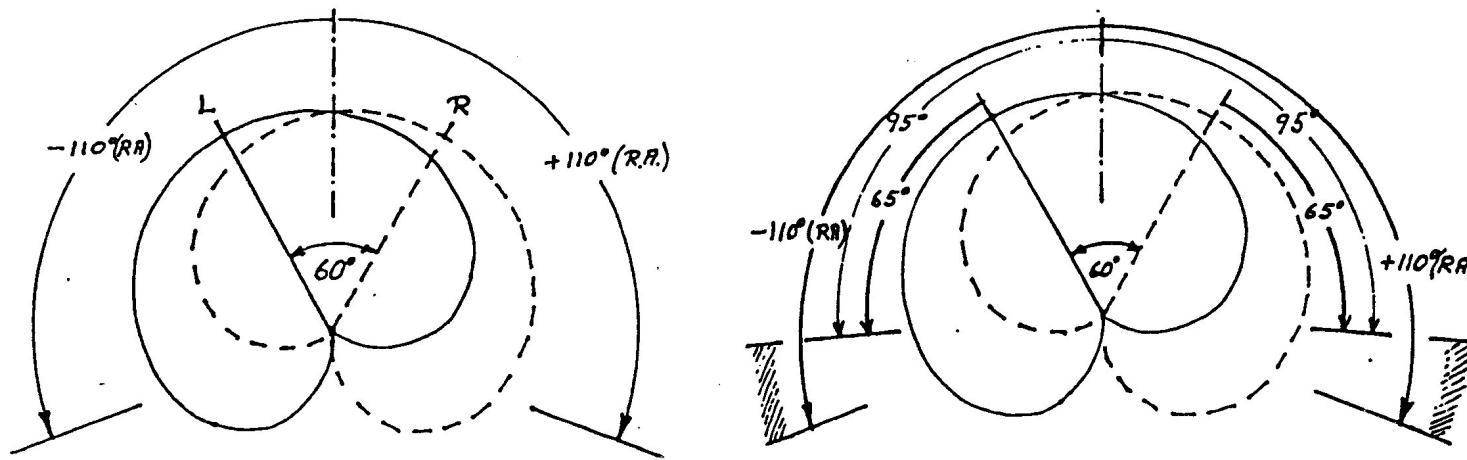
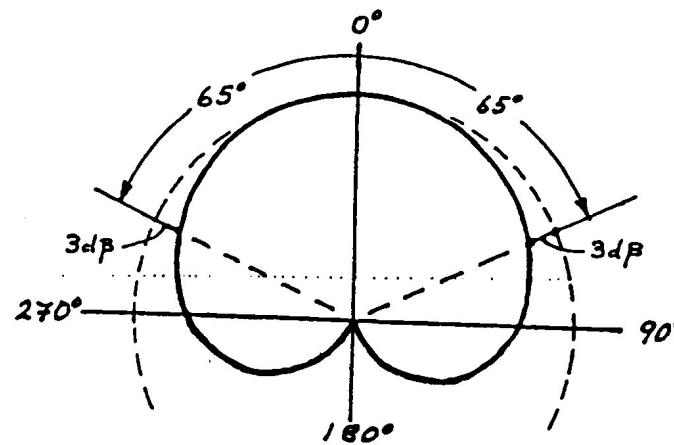


Stereophony

distance between microphones and coverage



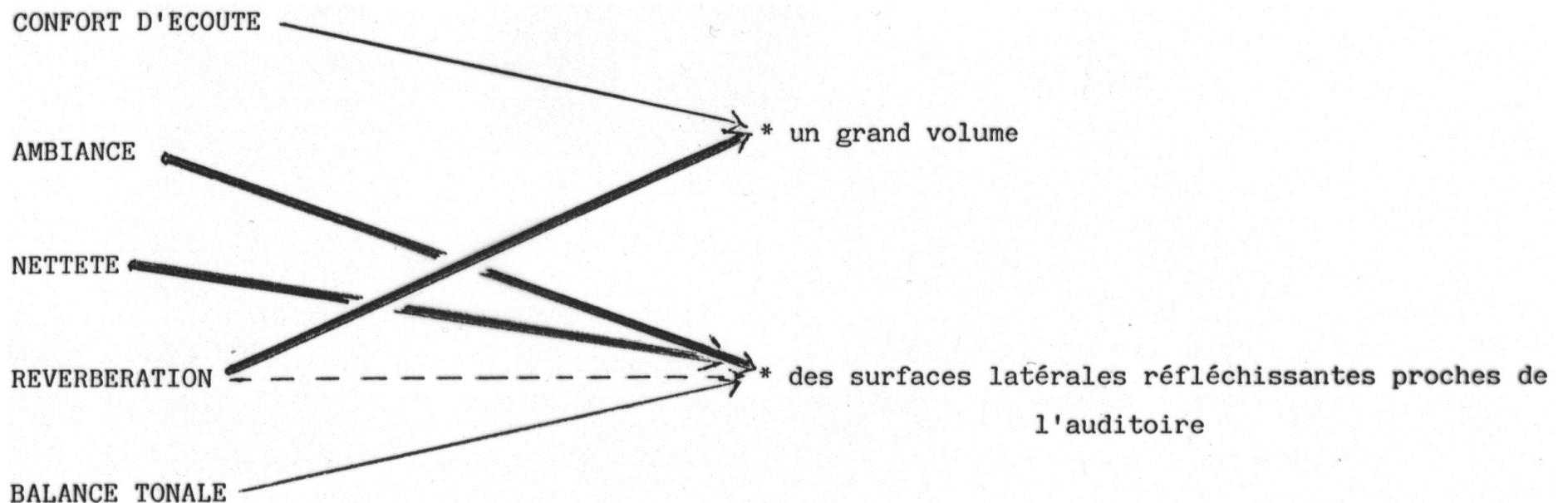
Stereophony coverage angle



stereophony

- maps recording angle
into loudspeaker angle
- no linear proportionality
- but *it works*: widely accepted

Mise en espace



Les "facteurs" (Marshall, ICA 1989)

Four Levels of Activity in Relation to Concert Halls

"Non-linear"

Power

Politics, criticism, public opinion, media, social dynamics, owner aspirations, management.

Art/craft

Composition, performance, perception, design skill, craft.

"Linear"

Engineering

Engineering, psychophysics, contract, construction process, professional

Physical science

Physics and mathematics

Higher members *must not contradict* knowledge collected in the lower but *neither are they explicable in terms of it*.

ARTEC

Etudes de faisabilité et estimation des coûts, et avant-projet afin de déterminer les besoins d'une salle future

S'adressant aussi bien au projet initial d'une salle qu'à la réhabilitation d'une salle existante, ces études établissent les besoins du public et des interprètes, ainsi que la taille et la configuration des salles principales et annexes.

Par ailleurs, Artec peut assister le client pour évaluer l'utilisation de la salle et déterminer le choix de son emplacement, pour estimer le coût global, le budget d'exploitation et l'estimation des recettes et des dépenses, ainsi que l'impact macro-économique, et éventuellement, pour identifier des apports financiers possibles.

Ces études sont indispensables pour assurer le succès du projet, de la construction et de l'exploitation d'un bâtiment destiné aux arts du spectacle.

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