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PRESENTS

Diffusion in concert halls analyzed as a function of time during the decay process

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This paper was presented at Auditorium Acoustics, IOA, Dublin 2011 (full paper)

ABSTRACT

Diffusion and scattering continue to be hot topics in room acoustics and in particular in auditorium acoustics. It is being heavily debated how scattering due to surface roughness and room geometry relates to the level of diffusivity in a room. We suggest the Dynamic Diffusion Curve (DDC) as a tool for evaluation of the level of diffusion in an impulse response. The idea is that a high degree of diffusion is connected with a low directional trend; theoretically an ideal diffuse sound field has equal probability of any direction of propagation and thus the intensity should be low, whereas a one-dimensional propagating sound wave has a high intensity level (equal to the sound pressure level).

DDC is derived from the difference between the decay curve derived from the backwards integrated squared impulse response measured or simulated with an omni-directional microphone and the decay curve of the backwards integrated intensity impulse response, which can be measured or simulated by a combination of three intensity probes or three figure-of-eight microphones (x, y and z directions). So, DDC is a measure of the amount of non-directional energy as a function of the time during the decay process.

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Diffusion in Concert halls analyzed as a function of time during the decay process

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Agenda

- Why investigate diffusivity?
- Directional Diffusion and Steady State Diffusivity
- Defining the Dynamic Diffusion Curve (DDC)
- Normalising the DDC
- Typical features of the DDC
- DDC in (models of) 12 concert halls
- DDC as a function of distance in 2 halls
- DDC and flutter echo
- Conclusions

Motivation, why investigate diffusivity?

- Diffusivity is assumed to be important for the quality of concert halls
- Efforts are put into promoting diffuse reflections;
  - making surfaces scatter sound
  - shape of geometry
  - distribution of materials

Therefore we should understand better how given designs affect diffusivity in rooms.

Steady State Diffusivity

Thiele (1953) defined Directional Diffusion (d in %) as

$$d = (1 - \frac{\mu}{\mu_0}) \times 100\% = \frac{E - I}{E} \times 100\%$$

where E is sound energy and I is sound intensity

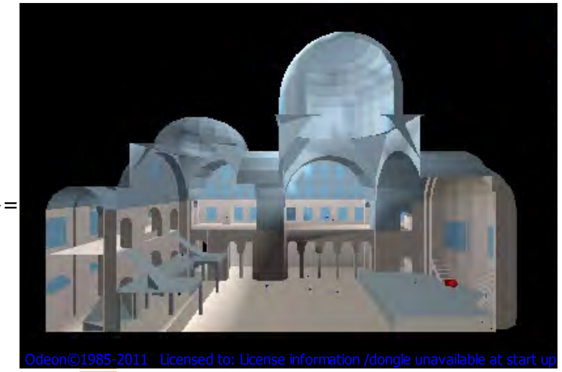
*D*irectional *D*iffusion is usually close to 100%, so instead we may prefer to define *S*teady *S*tate *D*iffusivity in dB as:

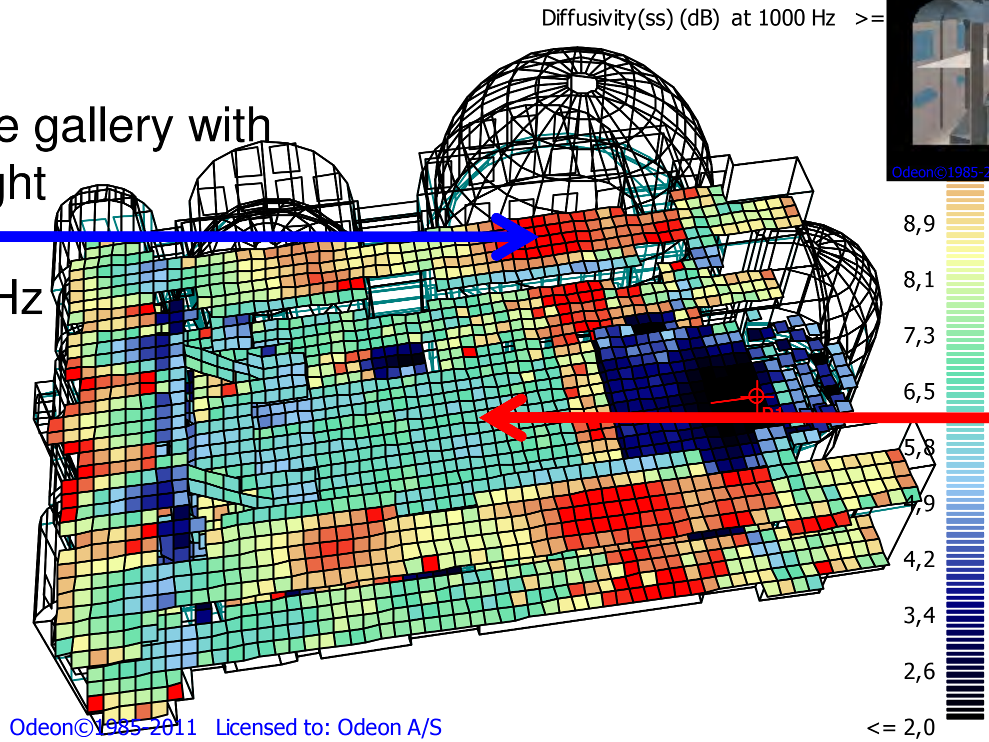
$$D(ss) = 10 \times \log_{10}(E) - 10 \times \log_{10}(I) \qquad [\mathrm{dB}]$$

Note! $I = \sqrt{I_{8x}^2 + I_{8x}^2 + I_{8z}^2}$

Steady State Diffusivity

Example on D(ss) at different locations





Receiver in side gallery with no visible no sight

19.2 dB@1000Hz

Receiver at floor 6.4 dB@1000Hz

Dynamic Diffusivity Curve – DDC energy and intensity curves

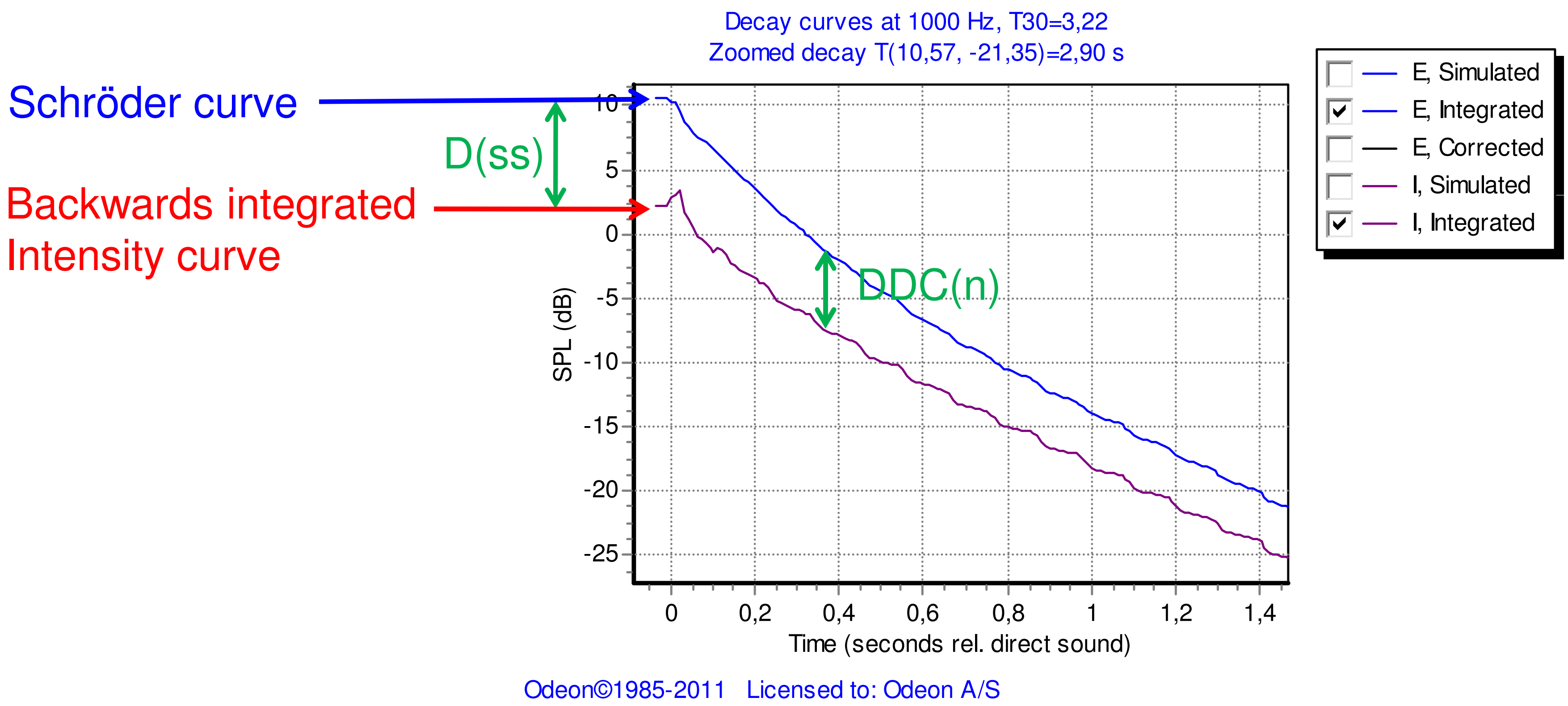
Backwards integrated squared impulse response curve

$$E(t_n) = 10 \times \log_{10} \int_{t=\infty}^{t=t_n} E(t)\, dt \qquad [dB]$$

Backwards integrated intensity curve

$$I(t_n) = 10 \times \log_{10} \sqrt{(\int_{t=\infty}^{t=t_n} I(t)_{8x}\, dt)^2 + (\int_{t=\infty}^{t=t_n} I(t)_{8y}\, dt)^2 + (\int_{t=\infty}^{t=t_n} I(t)_{8z}\, dt)^2}$$

Dynamic Diffusivity Curve – DDC example; energy and intensity curves



Dynamic Diffusivity Curve – DDC

DDC is the difference between energy and intensity curves

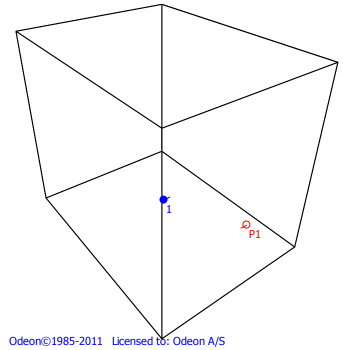
$$DDC(n) = E(n) - I(n)$$

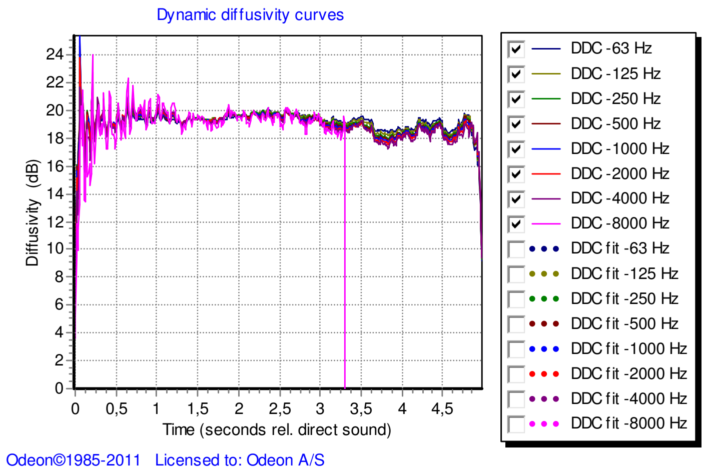
$$= 10 \times \log_{10} \int_{t=\infty}^{t=t_n} E(t)\, dt$$

$$- 10 \times \log_{10} \sqrt{\left(\int_{t=\infty}^{t=t_n} I(t)_{8x}\, dt\right)^2 + \left(\int_{t=\infty}^{t=t_n} I(t)_{8y}\, dt\right)^2 + \left(\int_{t=\infty}^{t=t_n} I(t)_{8z}\, dt\right)^2} \quad [\mathrm{dB}]$$

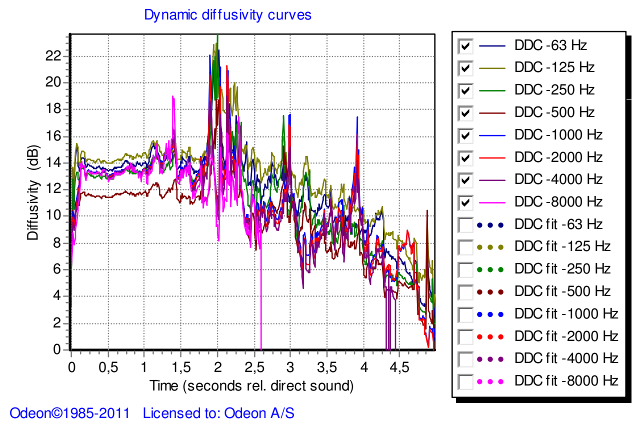
Comparing DDC for rooms with different T30

Box shaped room 12 x 14 x 16





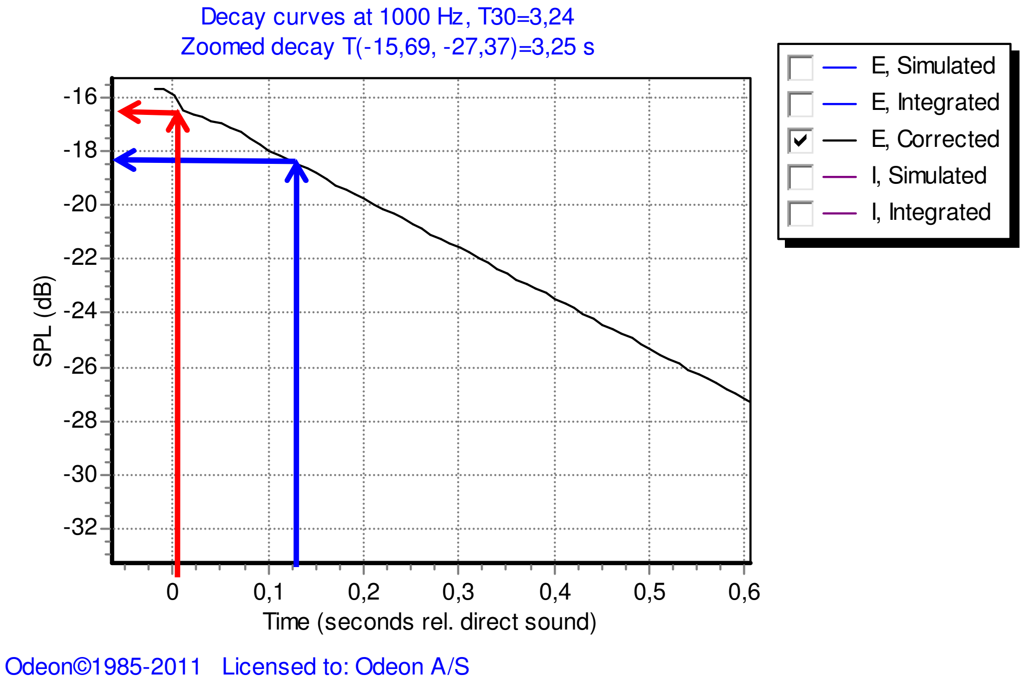
T30=3.24s@1000 Hz
All hard surfaces
Low scattering



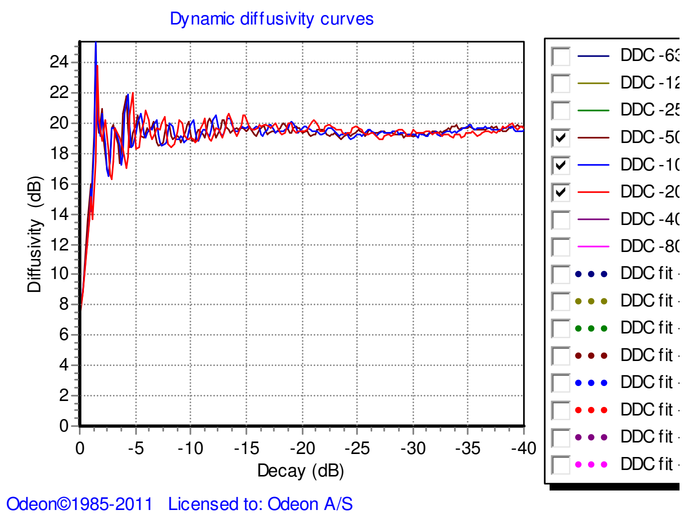
T30=1.65s@1000 Hz
hard surfaces+absorbing ceiling
High scattering

Normalising DDC

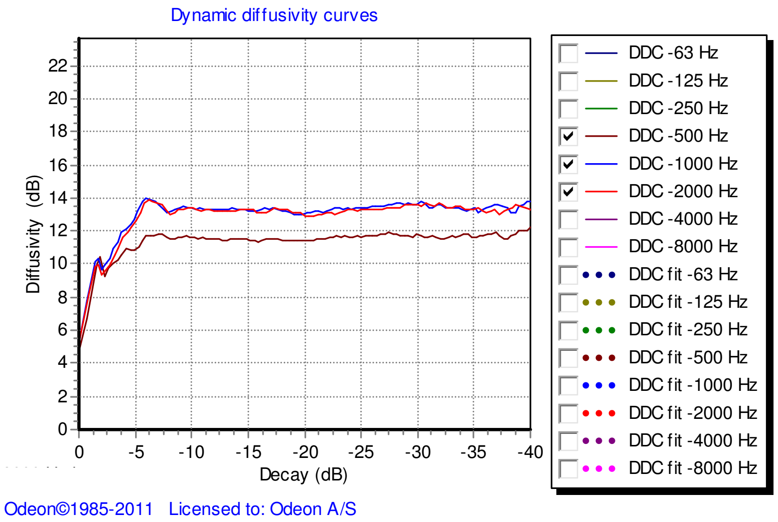
- Use Schröder curve for normalization
- Substitute time axis with decay [dB]



Normalising DDC



T30=3.24s@1000 Hz
All hard surfaces
Low scattering

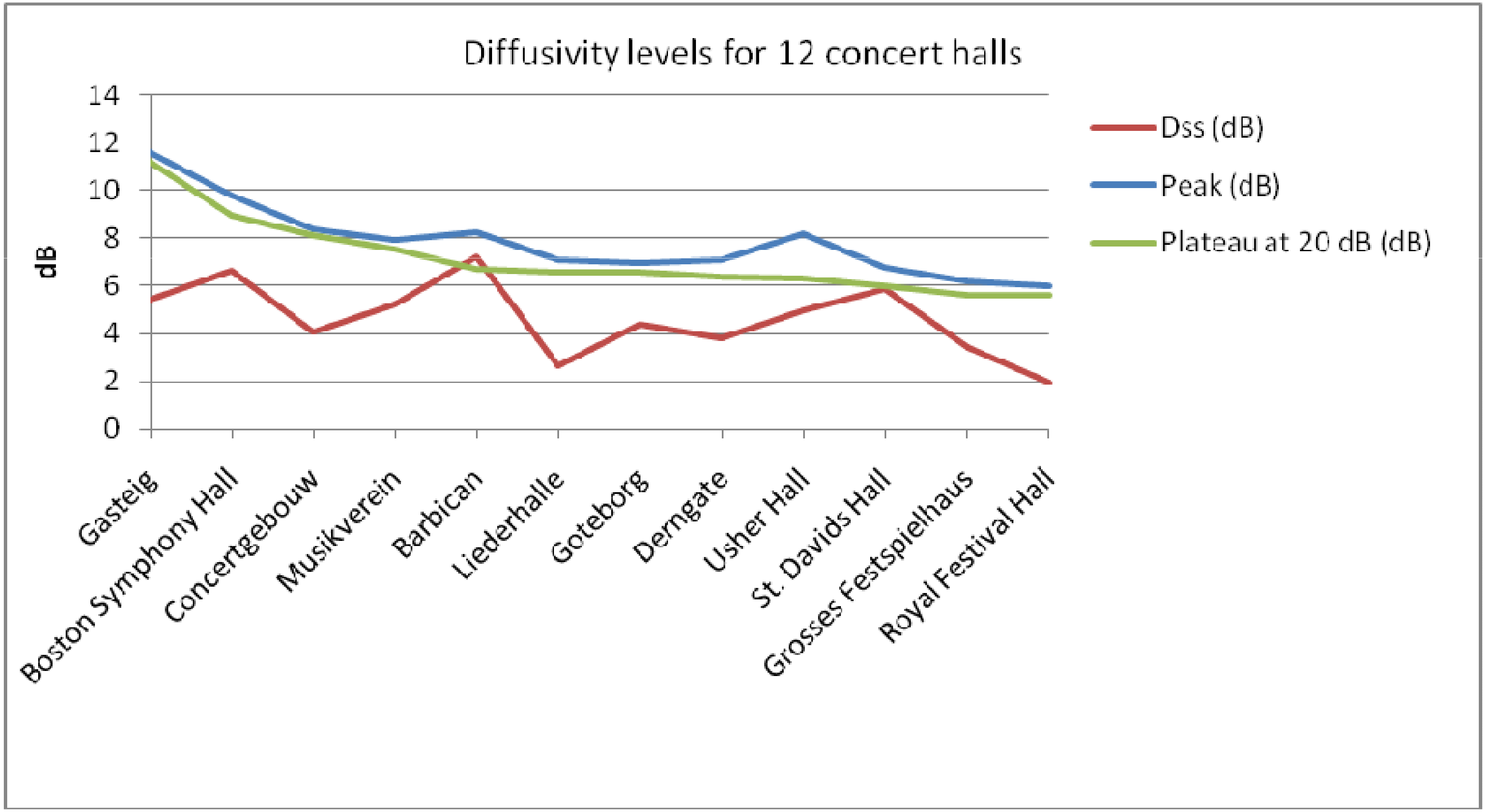


T30=1.65s@1000 Hz
hard surfaces+absorbing ceiling
High scattering

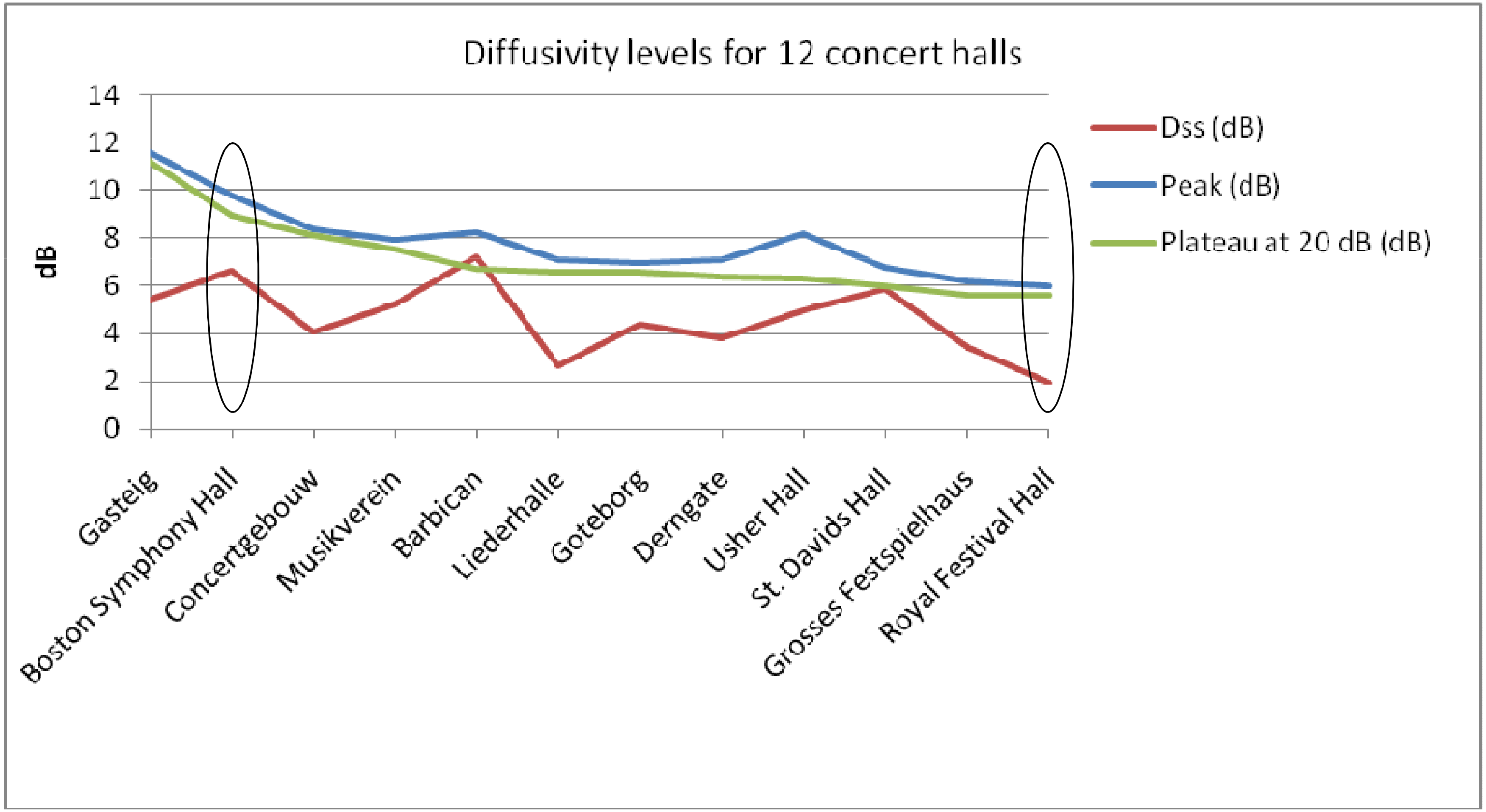
Typical features of DDC

- Initial value Dss is lower that later values
- A peak appears within the first 5 (to 10) dB
- DDC reaches its plateau level after some 5 to 10 dB decay
- The plateau can have ripples e.g. in case of a flutter echo

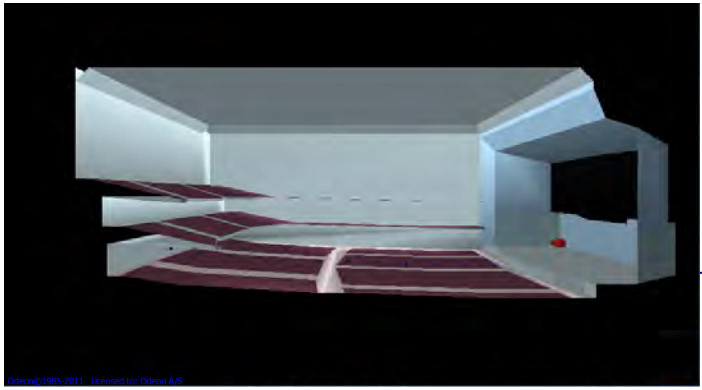
12 Concert halls (models)
Source mid stage – receiver mid-parterre
Dss, Peak and Plateau levels



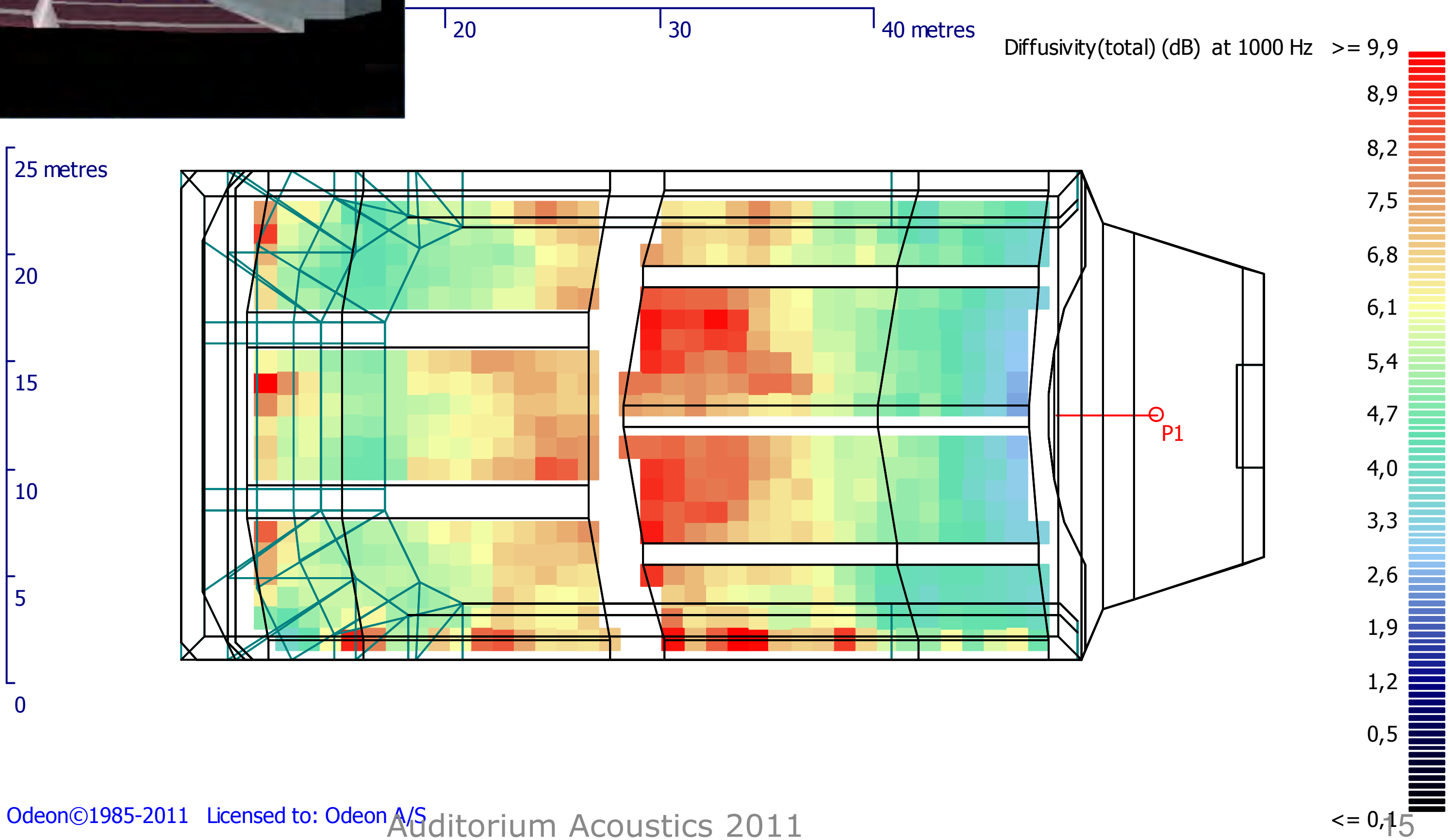
Two examples for comparison



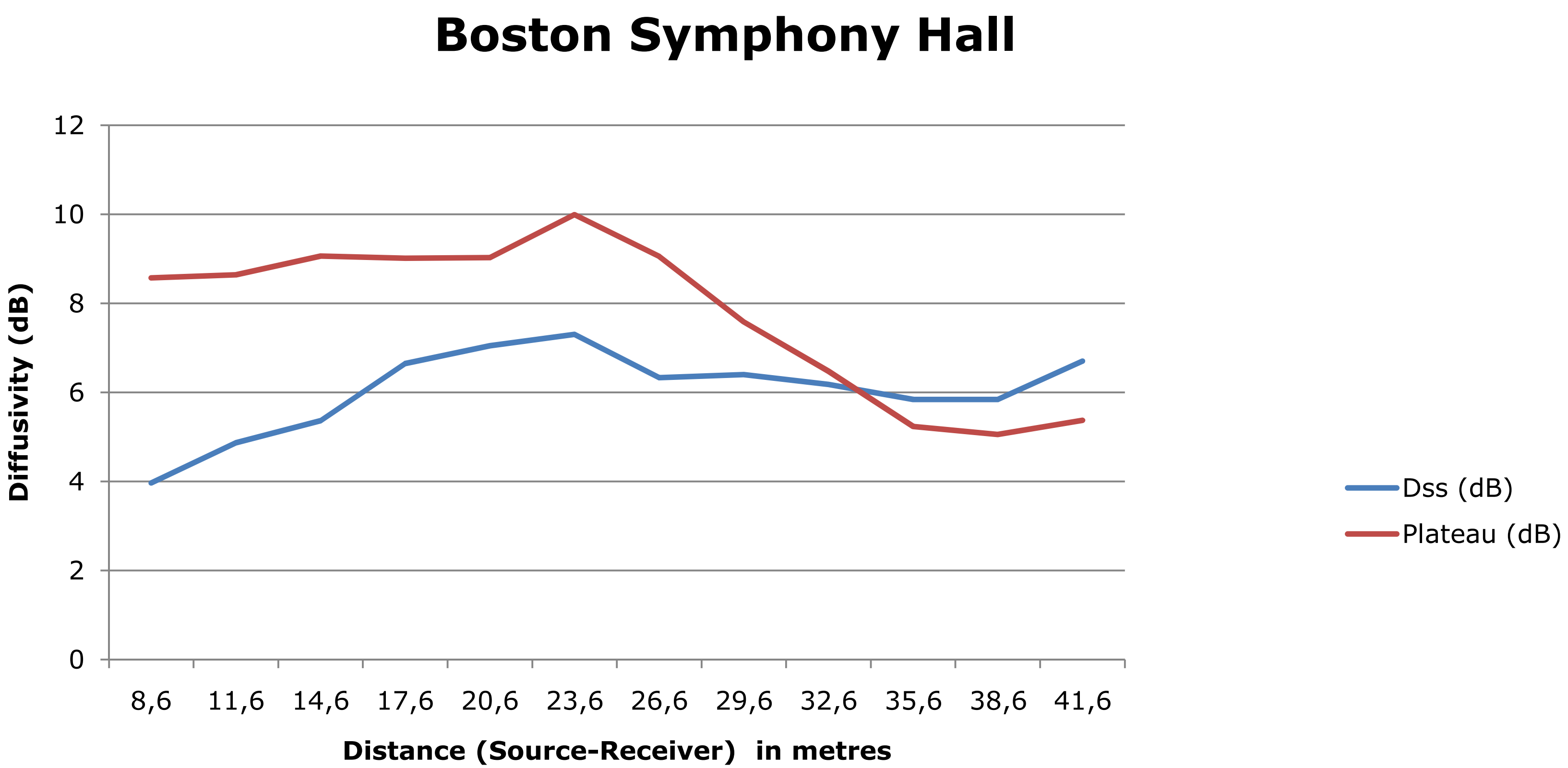
Diffusivity(Dss) – Boston Symphony Hall



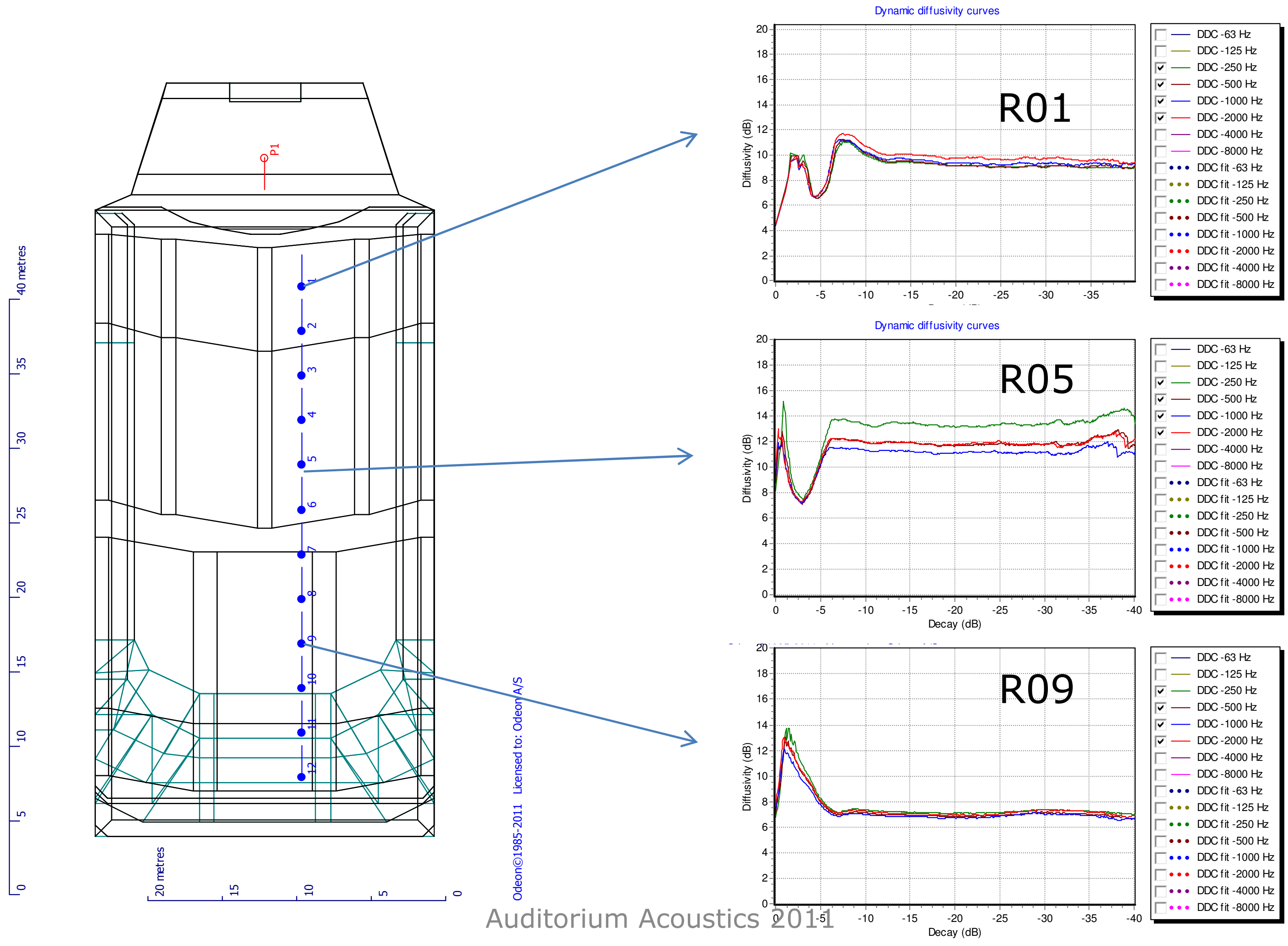
Floor level, only



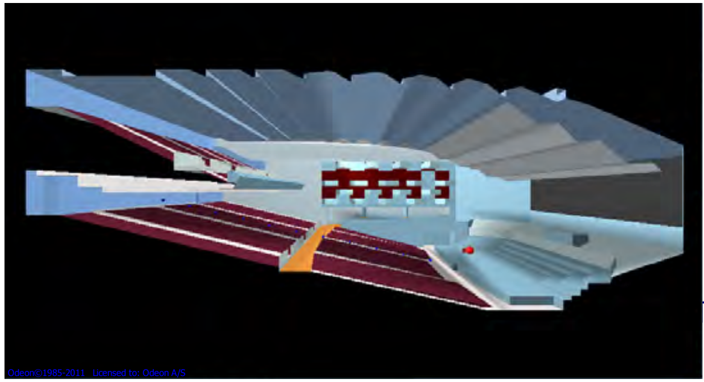
Dss and Plateau levels as a function of distance



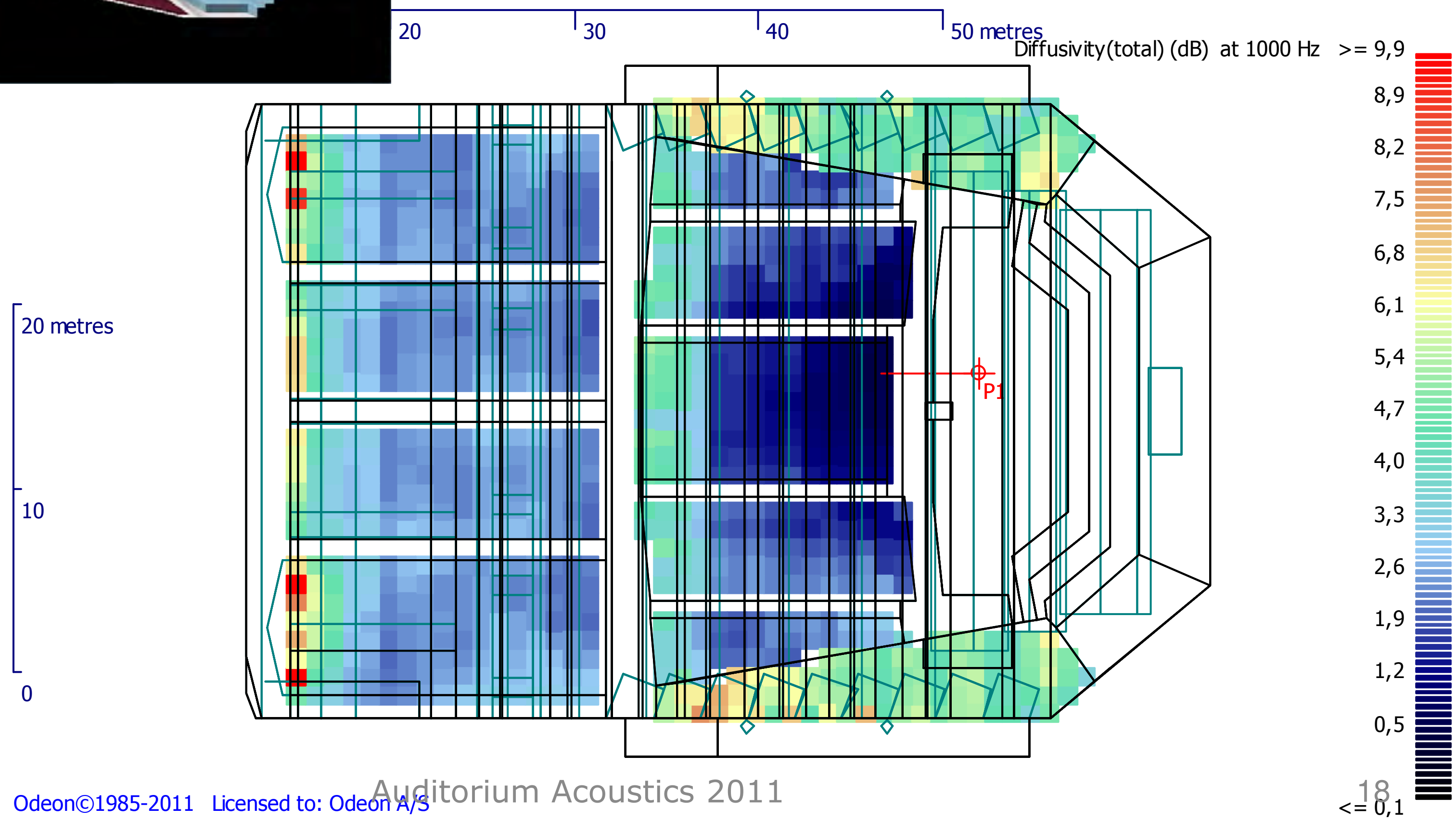
DDC variation with distance in BSH



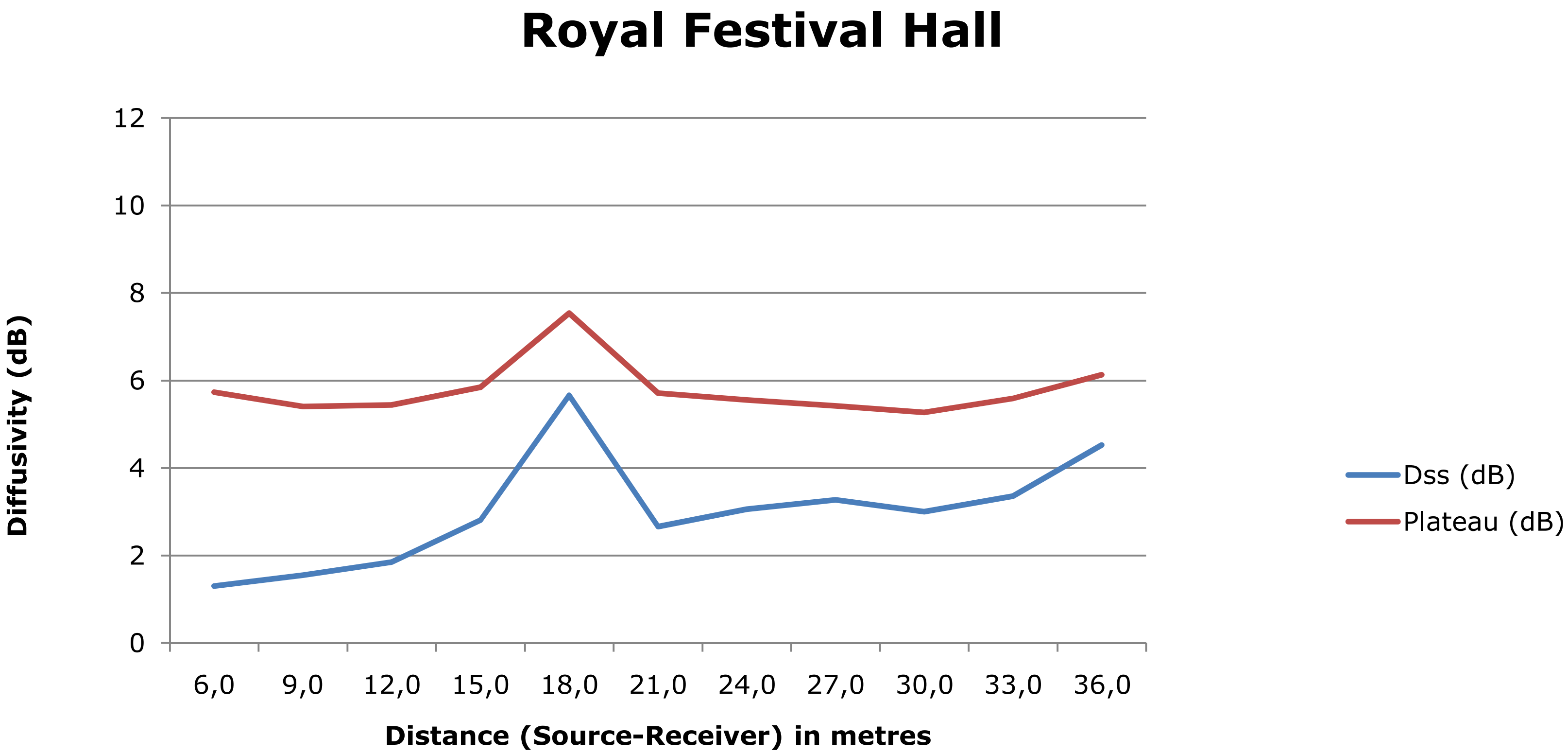
Diffusivity(Dss) – Royal Festival Hall



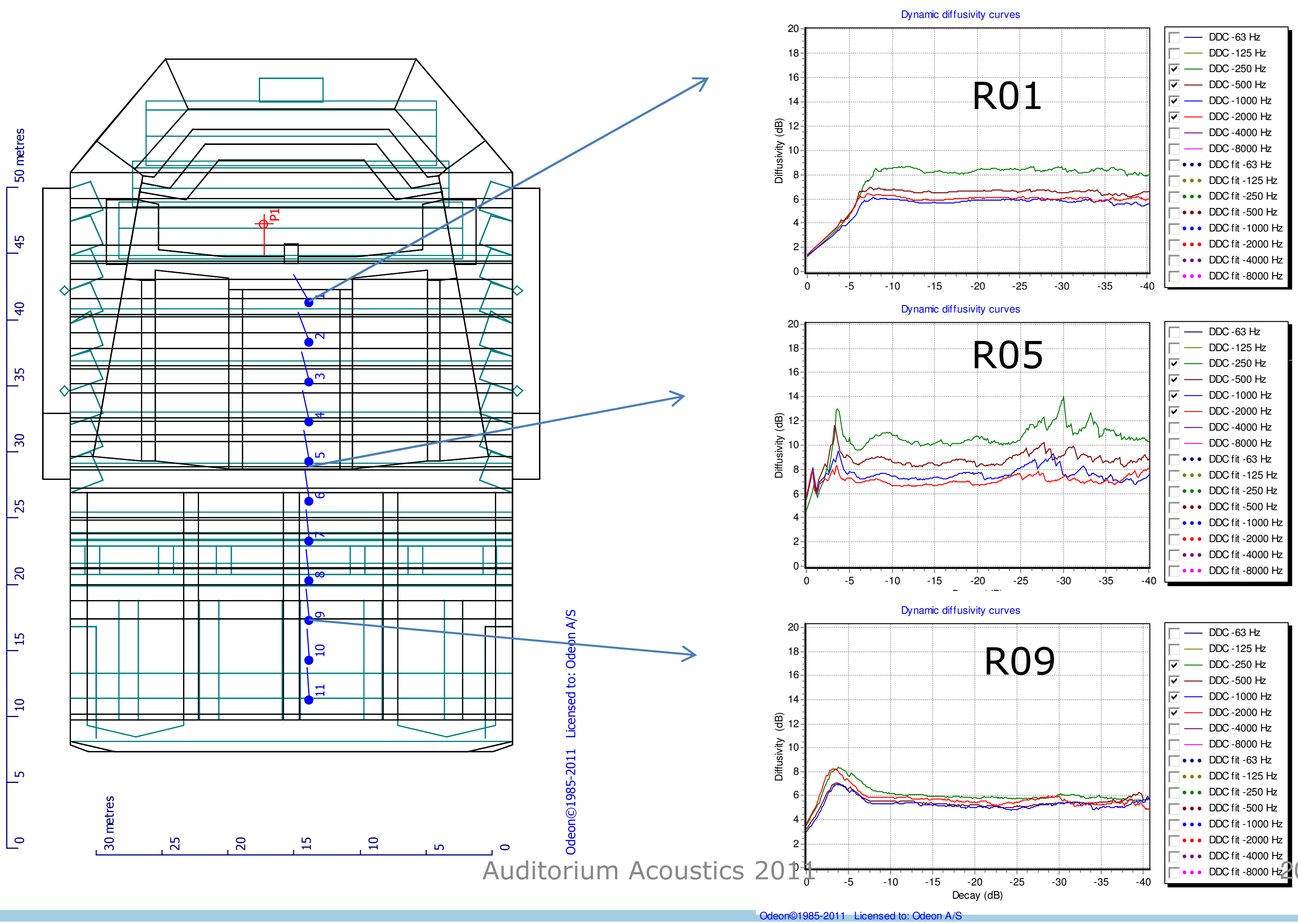
Floor level, only



Dss and Plateau levels as a function of distance

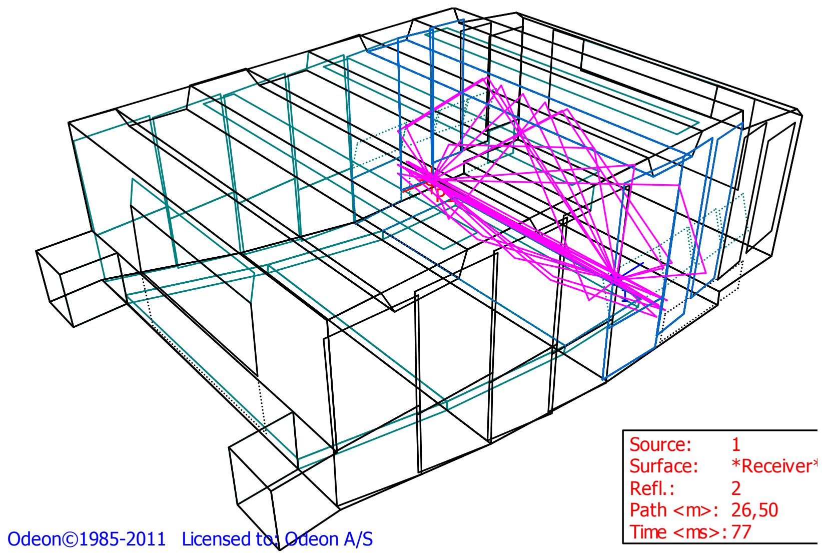


DDC variation with distance in RFH

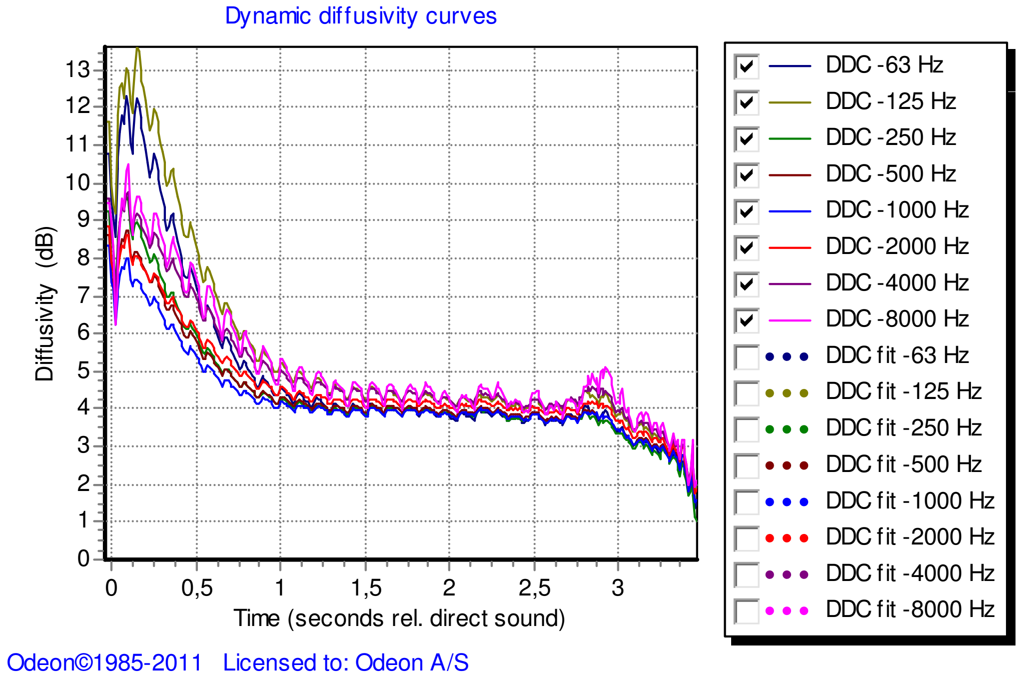


DDC and Flutter Echo

Queen’s Hall, Copenhagen

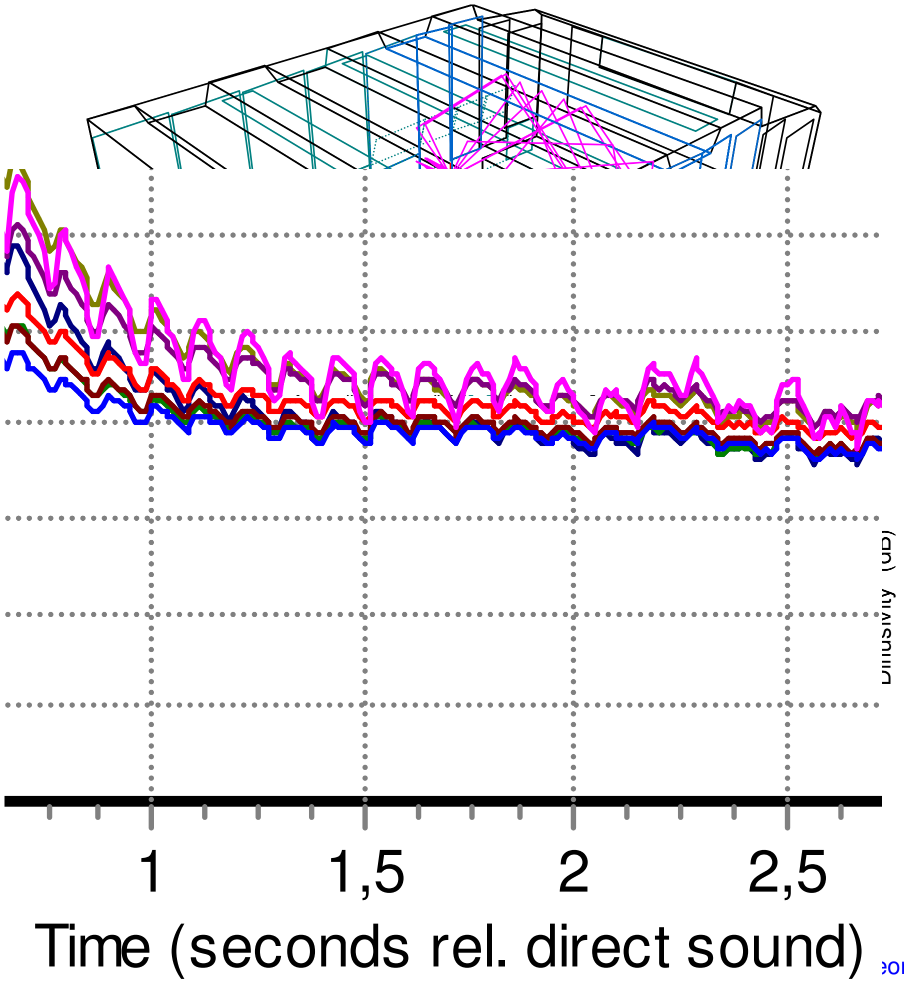


4 reflector panels tilted slightly inwards – creating a flutter echo

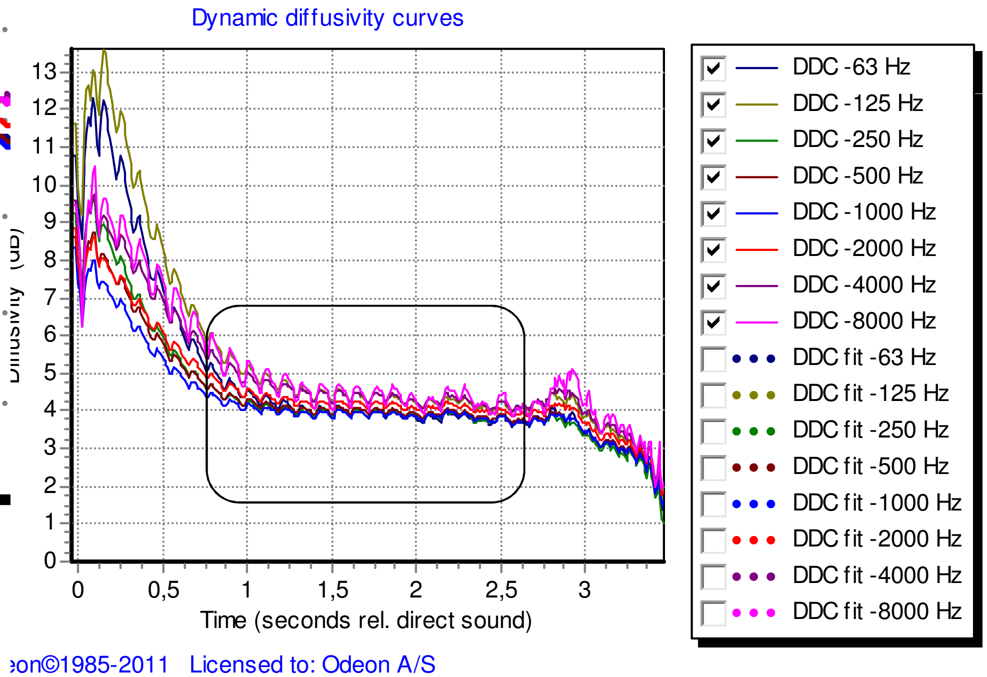


DDC and Flutter Echo

Queen's Hall, Copenhagen

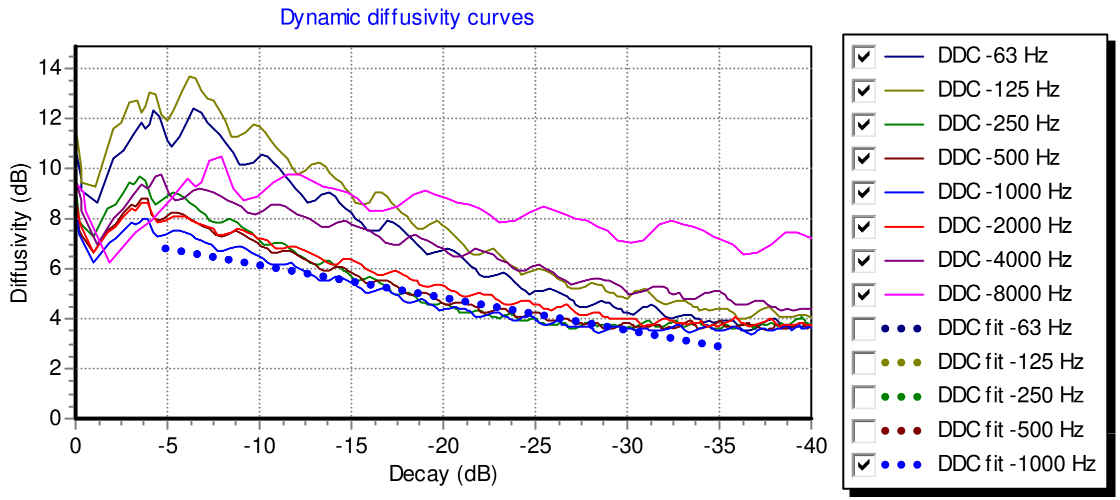


4 reflector panels tilted slightly inwards – creating a flutter echo

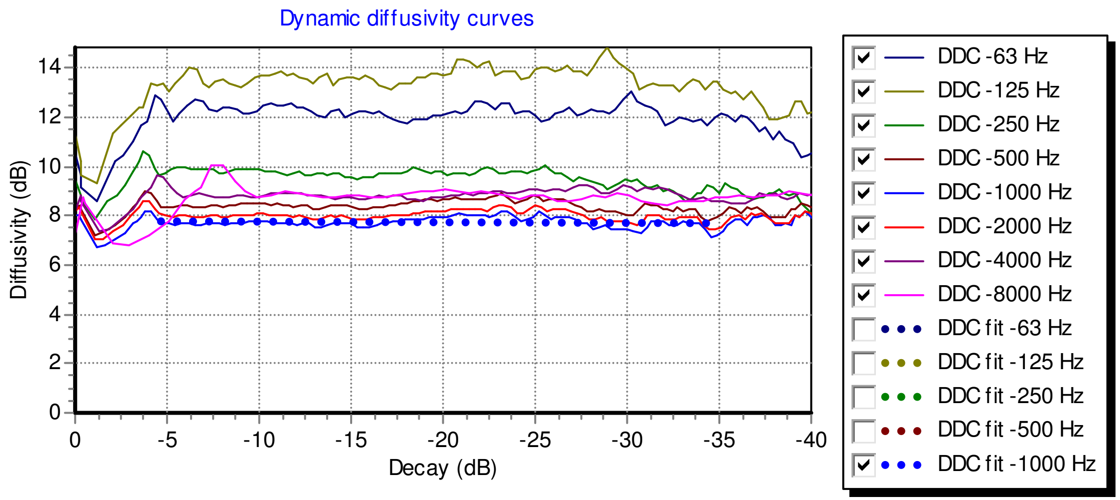


DDC and flutter echo

Before treatment with scattering surfaces



After treatment with scattering surfaces



Conclusions

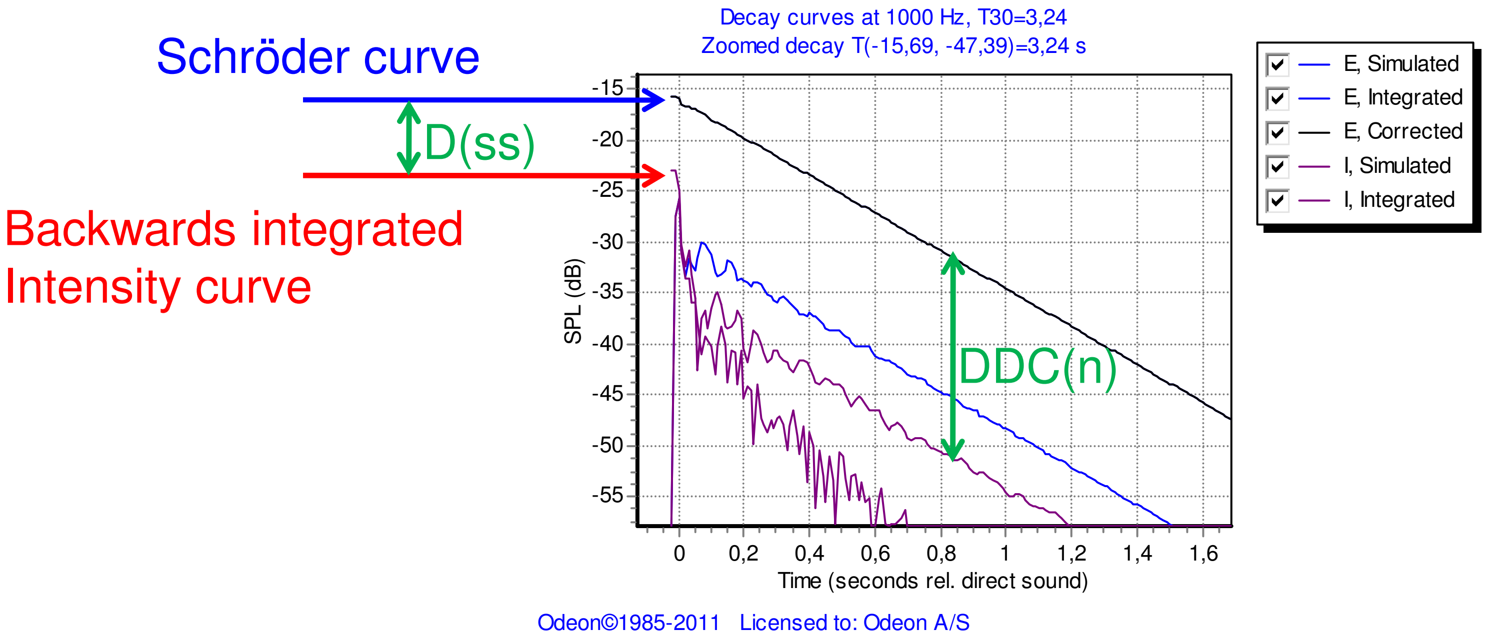
- Dynamic Diffusion Curve DDC is suggested for investigating dynamic behavior of diffusion during decay

- Features for rooms without echoes;
  - Starts with Steady State Diffusion – in auditoria 2-7 dB,
  - Peak value typically within first 5-10 dB of decay
  - Plateau level (rev. diffusion) – in auditoria 5-12 dB

- Features for rooms with echo problems, e.g. flutter echo;
  - Ripples (xx dB?)

- Further research, optimum values, JND's, better tools than DDC?, extract other information from the DDC etc…

Example
Integrated energy and intensity curves



Integrated energy and intensity curves