# Localization in Wave Field Synthesis and Higher Order Ambisonics at different positions within the listening area

Hagen Wierstorf[1], Alexander Raake[1], Sascha Spors[2]

[1] Assessment of IP-based Applications, Technische Universität Berlin
[2] Institute of Communications Engineering, Universität Rostock

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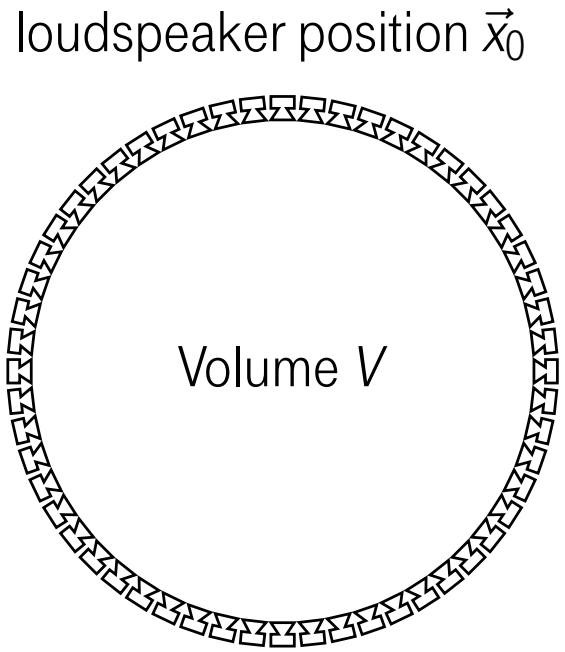
Deutsche Telekom Laboratories

# Sound Field Synthesis

## single layer potential

$$P(\vec{x}, \omega) = \int_{\partial V} D(\vec{x}_0, \omega) G(\vec{x}, \omega) dA$$

- driving signal $D(\vec{x}_0, \omega)$
- Green's function $G(\vec{x}, \omega)$
- **Wave Field Synthesis** and **Near-Field Compensated Higher Order Ambisonics** solutions to this problem



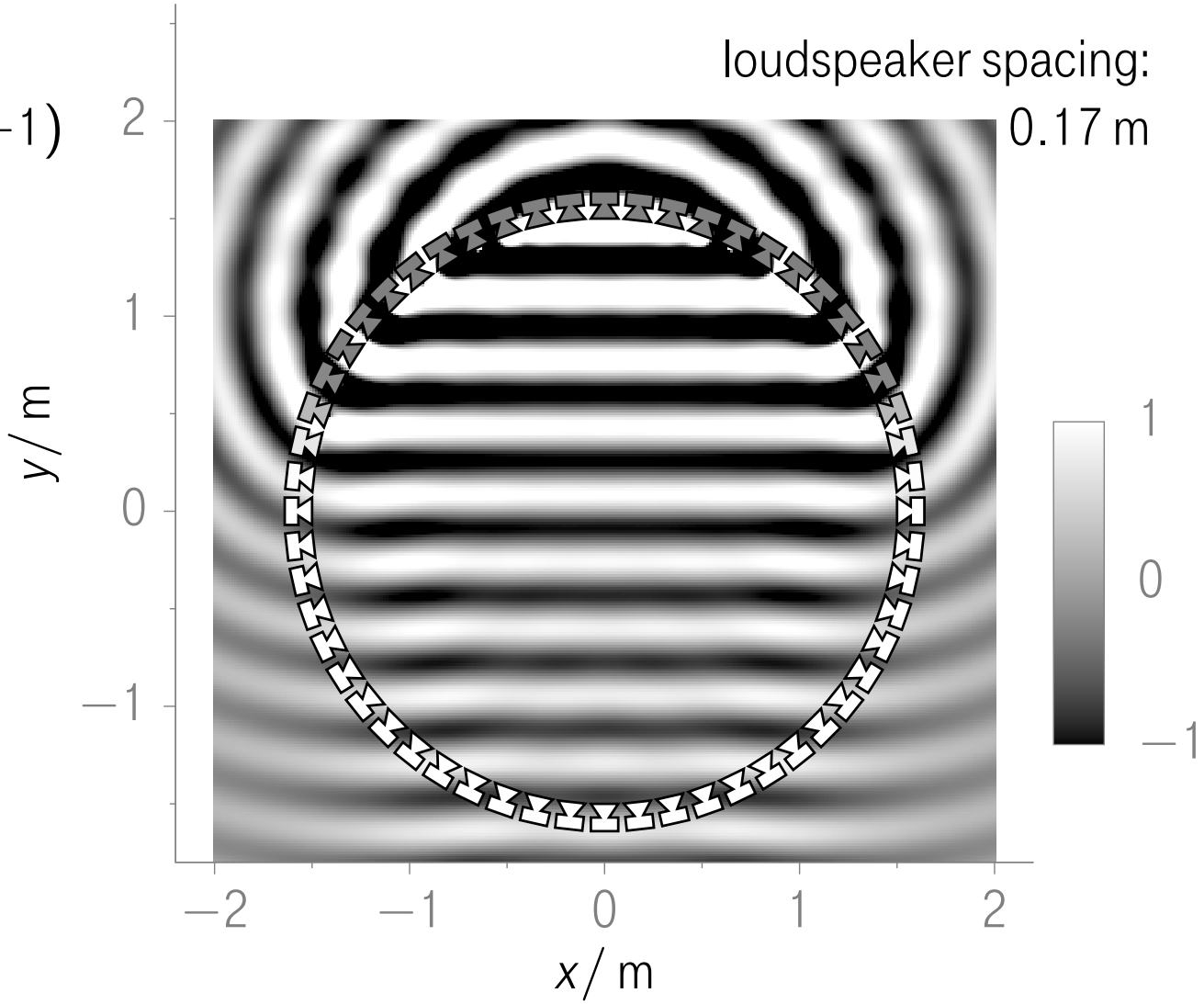
# Wave Field Synthesis

snapshot of the sound field $P(\vec{x}, \omega)$

plane wave
going to $(0, -1)$

$f = 1000\,\mathrm{Hz}$

loudspeaker spacing:
0.17 m



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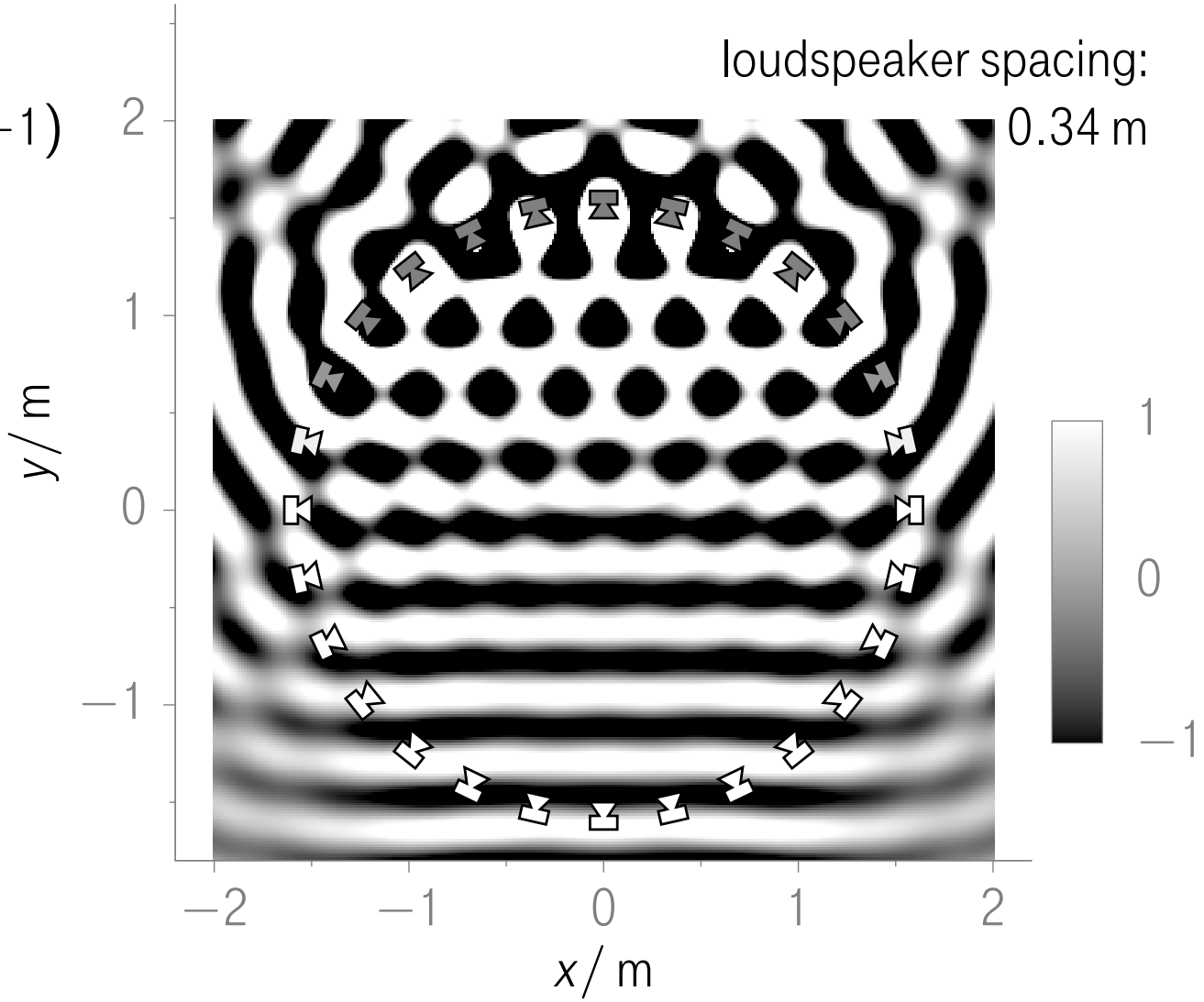

# Higher Order Ambisonics

snapshot of the sound field $P(\vec{x}, \omega)$

plane wave
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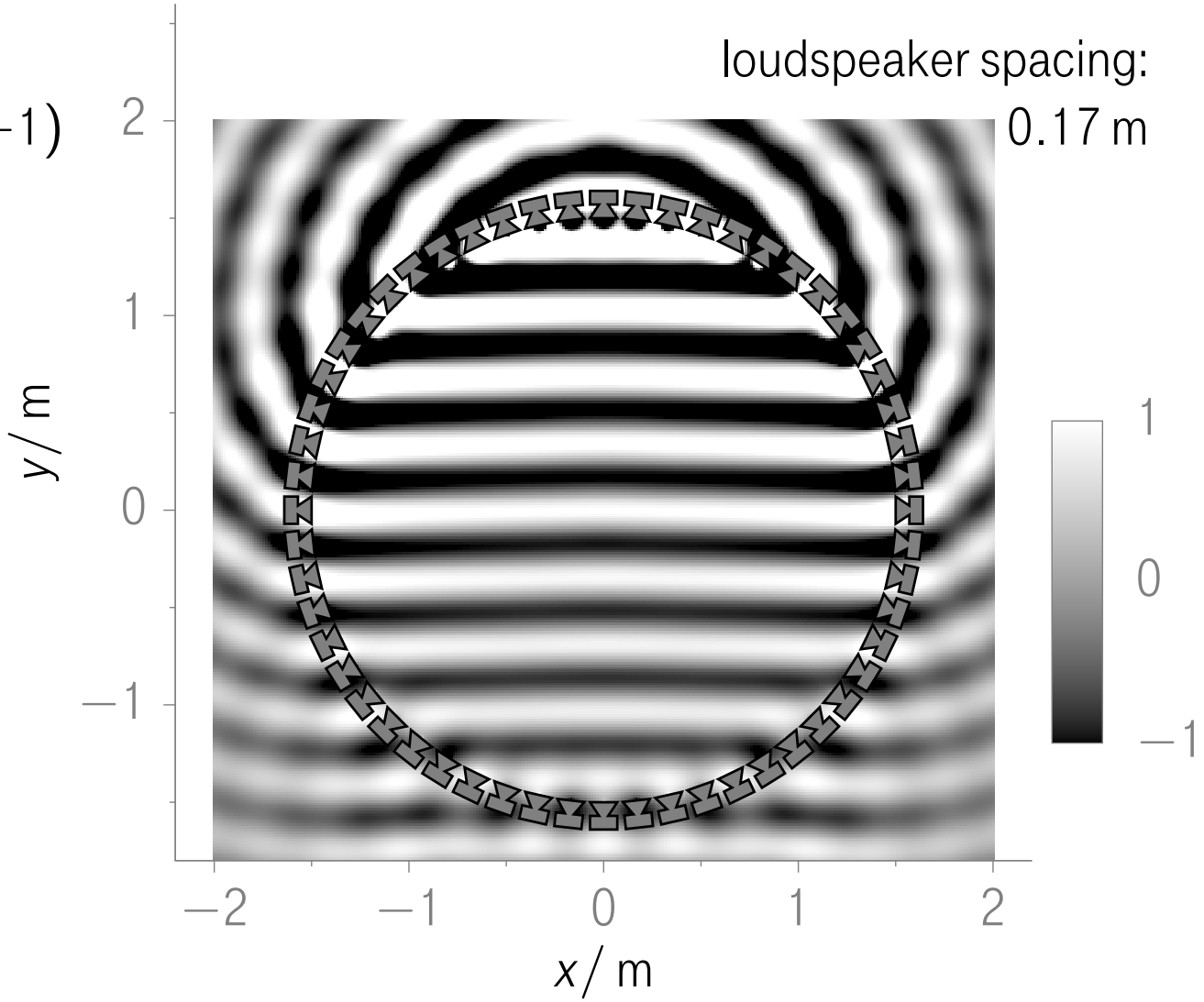

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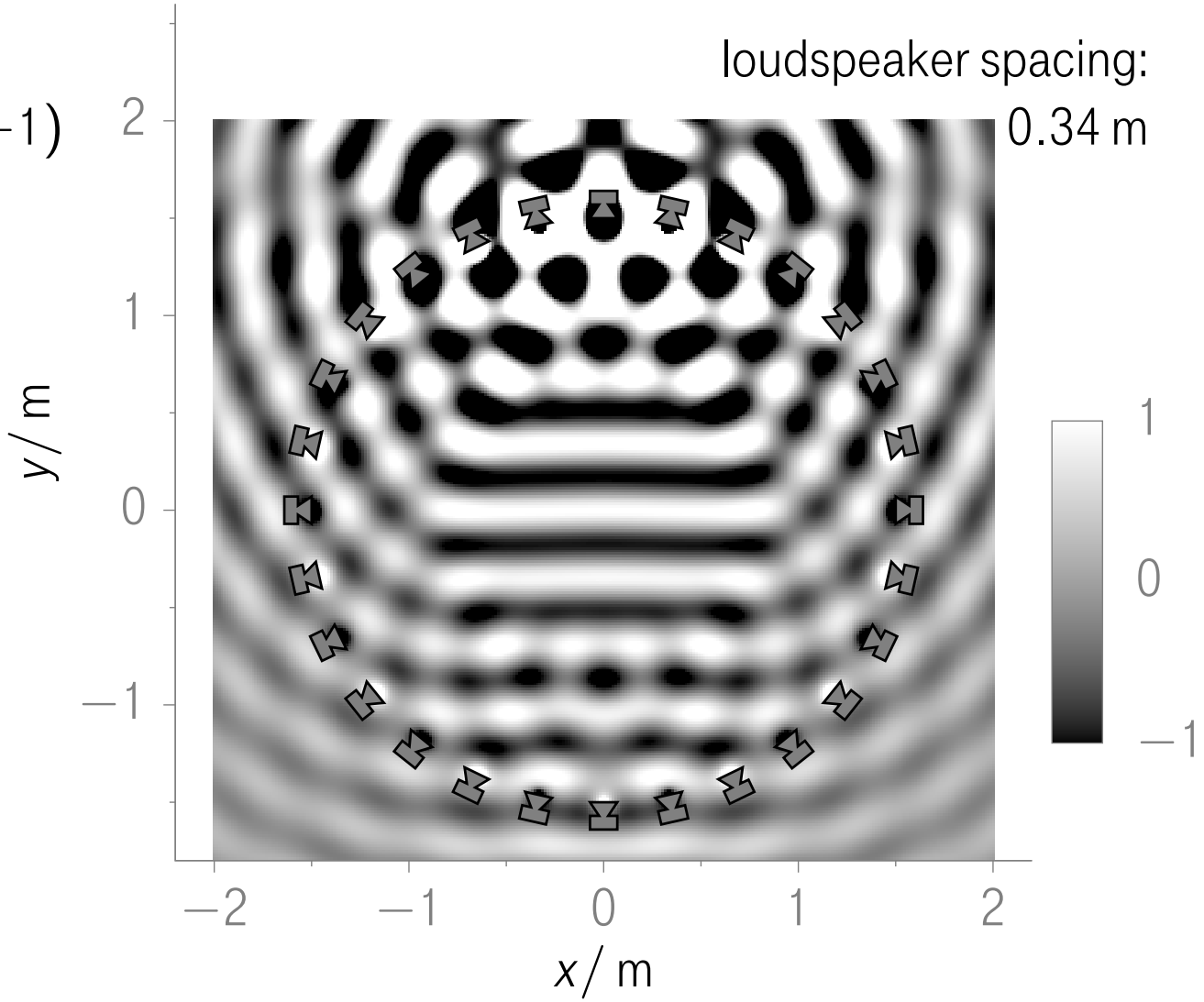


# Localization results for Wave Field Synthesis

- Localization is the same for real and virtual sources for loudspeaker spacings around 0.12 cm
- Localization is slightly worse for virtual sources for loudspeaker spacings around 0.24 cm

But: results only for a central listening position

Vogel (1993), *Application of Wave Field Synthesis in Room Acoustics*, Delft
Start (1997), *Direct Sound Enhancement by Wave Field Synthesis*, Delft
Verheijen (1997), *Sound Reproduction by Wave Field Synthesis*, Delft
Wittek (2007), *Perceptual differences between Wave Field Synthesis and stereophony*, Surrey

# Localization test

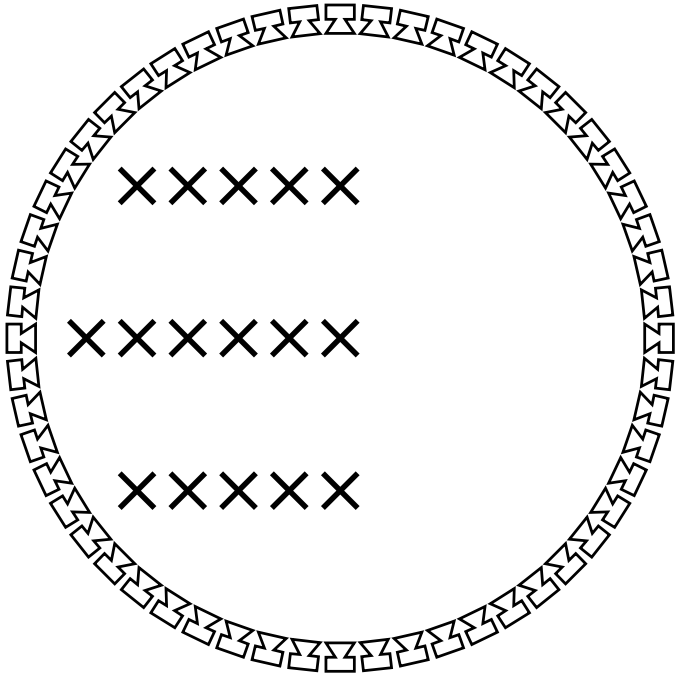
## method

- head-pointing method with laser pointer mounted on the head (Makous 1990)
  ⇒ listener has to face the source, smallest human localization error (Mills 1958)
  ⇒ laser pointer gives visual feedback and enhances the cooperation with the motor system (Lewald 2000)
- white noise pulses 700 ms long, 300 ms pause
- 12 subjects, 16 different positions
- 3 circular loudspeaker arrays with a radius of 1.5 m consisting of 56, 28, or 14 loudspeakers
- simulated by dynamic binaural synthesis (Wierstorf 2012)
- all randomized, 5 repetitions for each condition and position

Makous and Middlebrooks (1990), *Two-dimensional sound localization by human listeners*, JASA
Mills (1958), *On the minimum audible angle*, JASA
Lewald et al. (2000), *Sound localization with eccentric head position*, Behav Brain Res
Wierstorf et al. (2012), *Perception and evaluation of sound fields*, Open Seminar Acoust

# Localization test

## setup



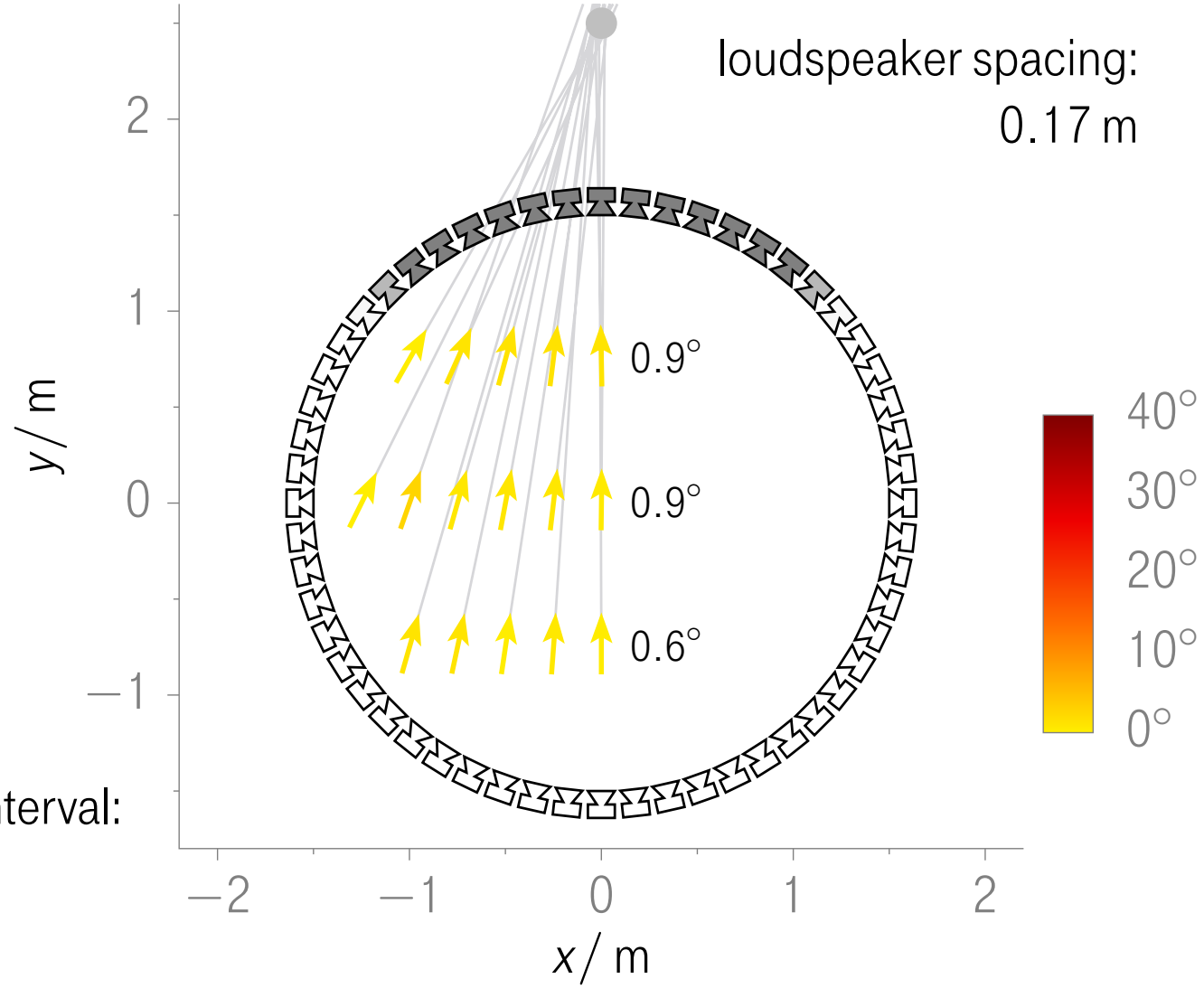
# Localization test with Wave Field Synthesis

results for a point source at (0, 2.5) m

mean error:
0.8°

max error:
2.6°

confidence interval:
1.4°



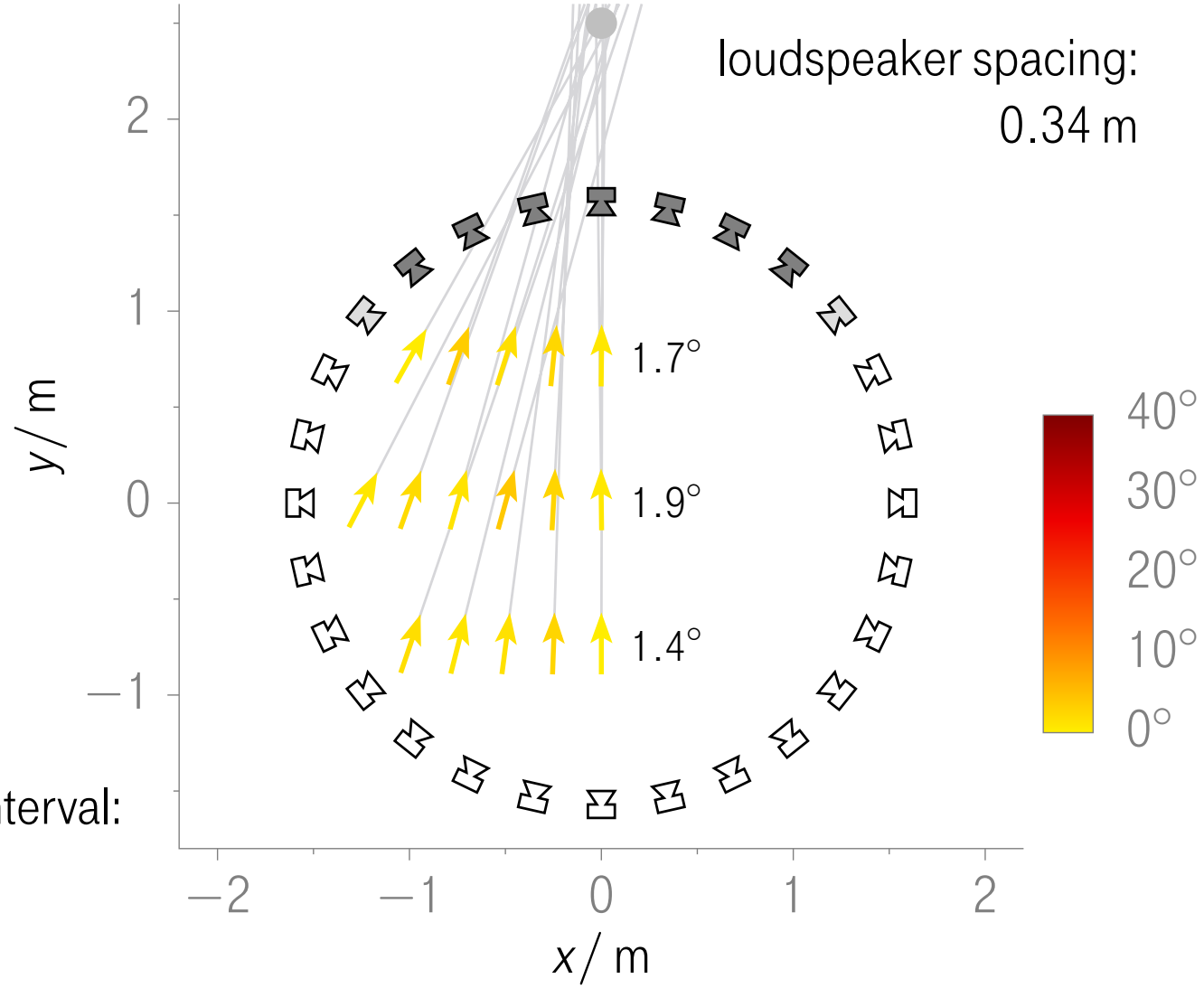
# Localization test with Wave Field Synthesis

results for a point source at (0, 2.5) m

mean error:
1.7°

max error:
4.0°

confidence interval:
1.5°



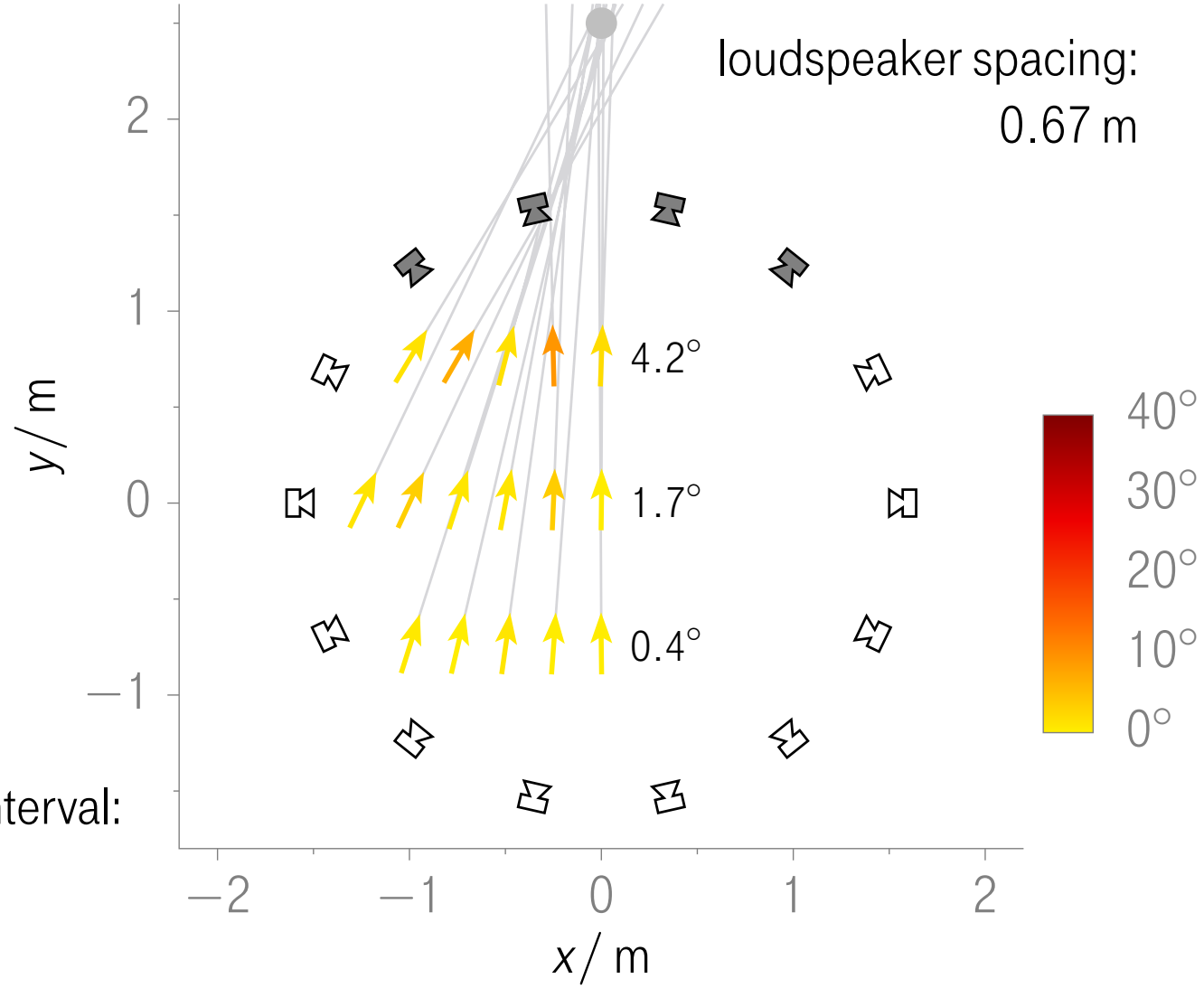
# Localization test with Wave Field Synthesis

results for a point source at (0, 2.5) m

mean error:
2.1°

max error:
9.3°

confidence interval:
1.8°



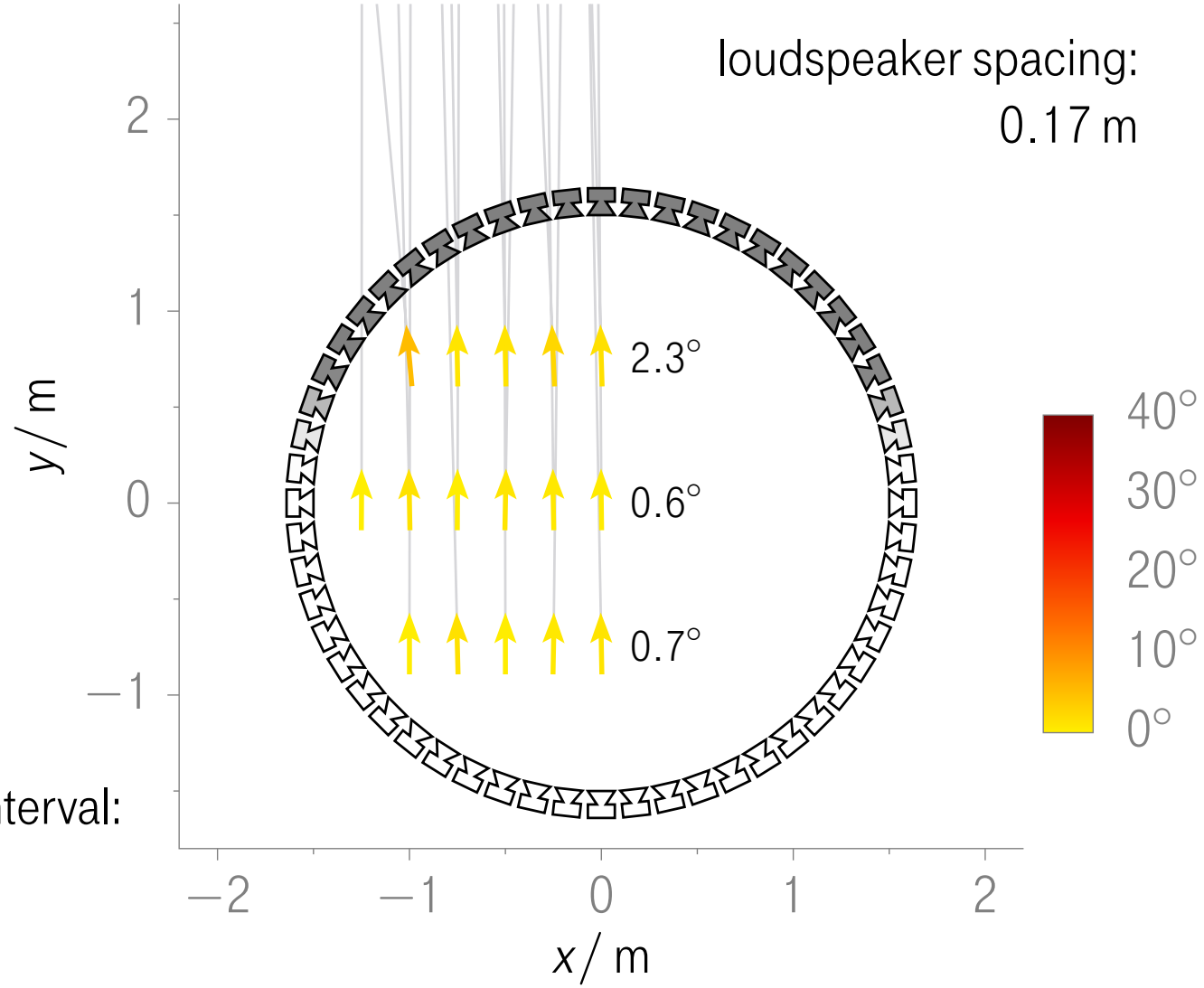
# Localization test with Wave Field Synthesis

results for a plane wave going to $(0, -1)$ m

mean error:
1.2°

max error:
5.3°

confidence interval:
1.4°



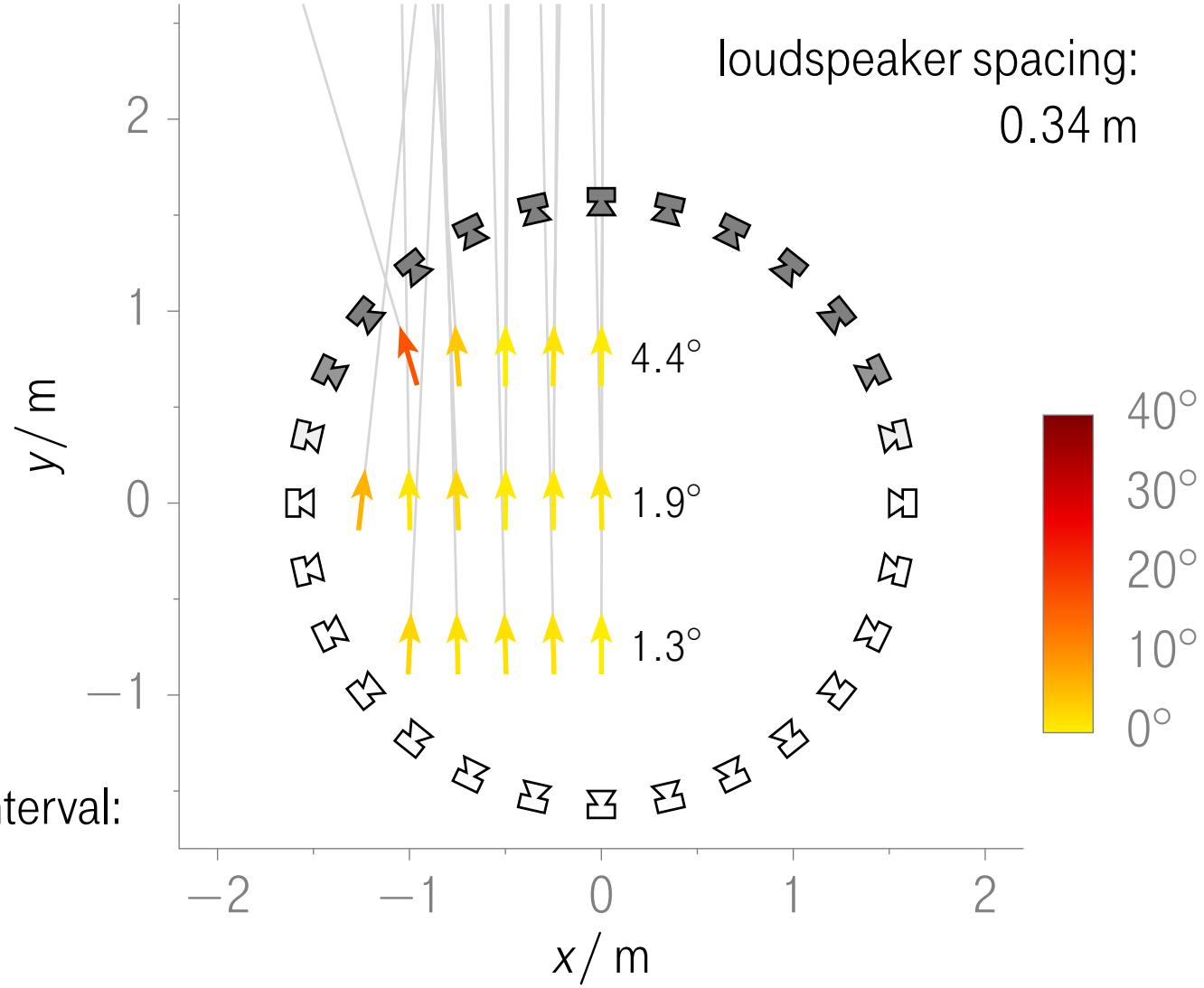
# Localization test with Wave Field Synthesis

results for a plane wave going to $(0, -1)$ m

mean error:
2.5°

max error:
16.7°

loudspeaker spacing:
0.34 m




confidence interval:
1.5°

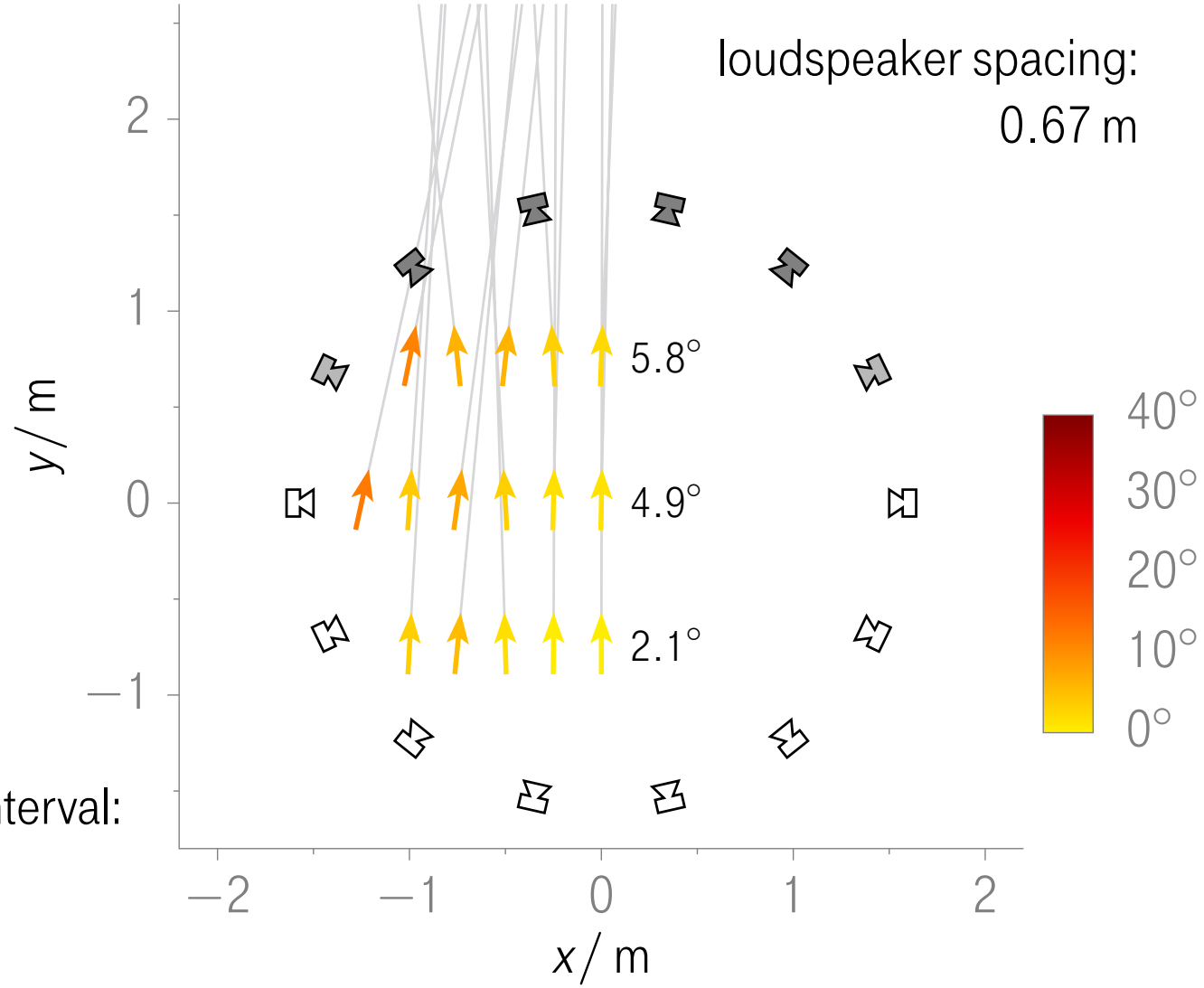
# Localization test with Wave Field Synthesis

results for a plane wave going to $(0, -1)$ m

mean error:
4.3°

max error:
12.3°

confidence interval:
2.3°



# Localization test with Higher Order Ambisonics

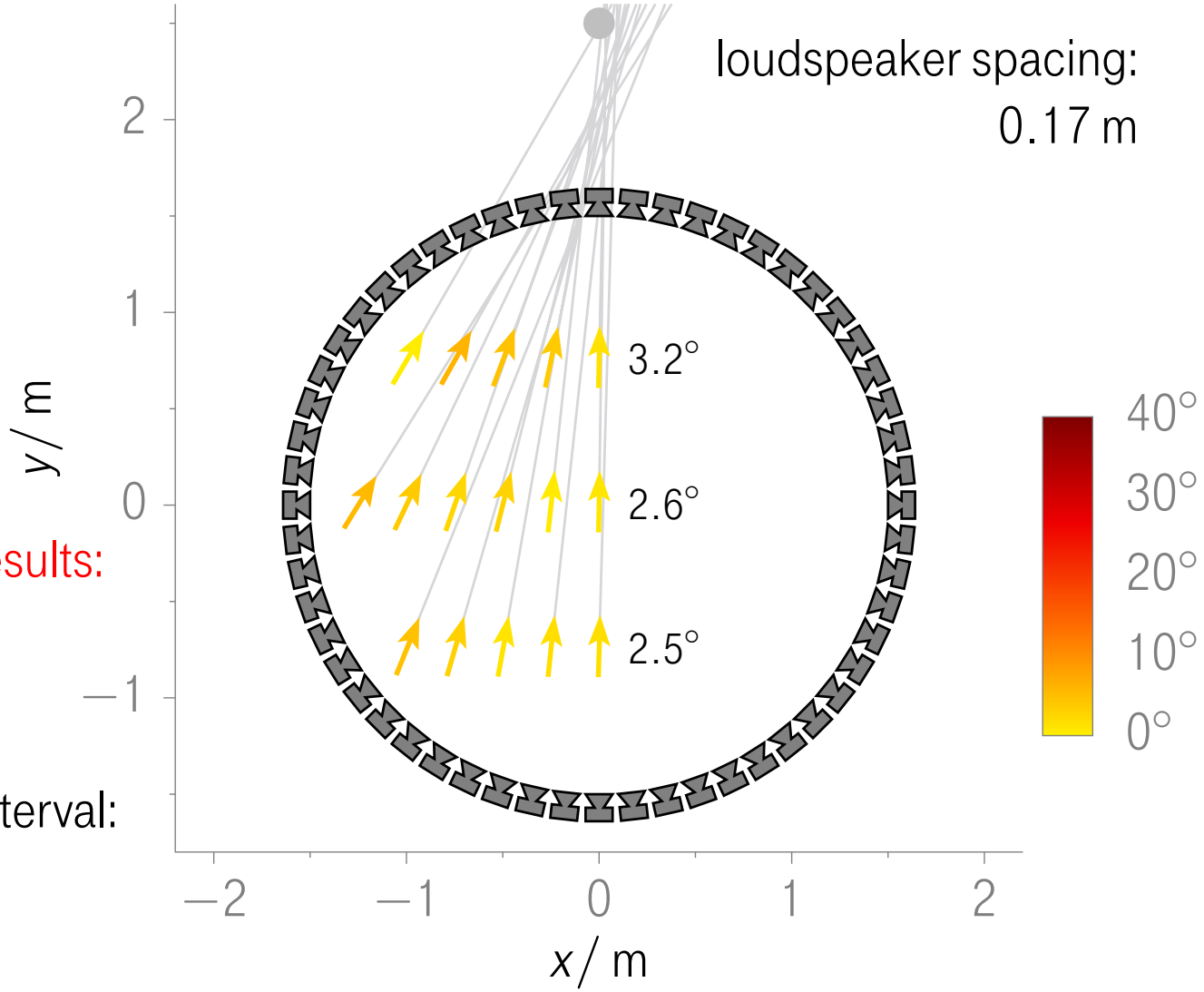
results for a point source at (0, 2.5) m

mean error:
2.8°

max error:
6.2°

preliminary results:
3 listeners

confidence interval:
3.0°



# Localization test with Higher Order Ambisonics

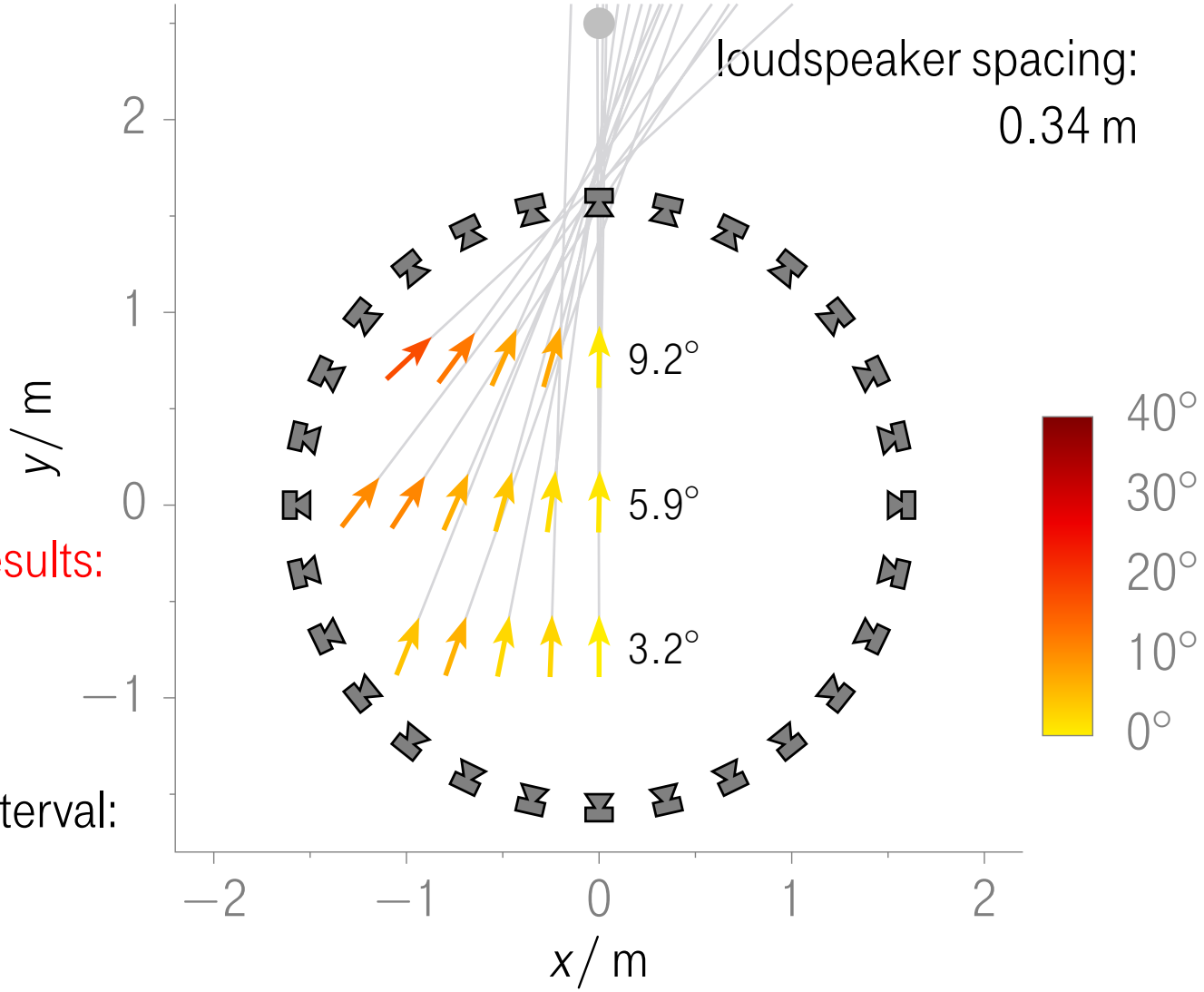
results for a point source at (0, 2.5) m

mean error:
6.1°

max error:
17.6°

preliminary results:
3 listeners

confidence interval:
2.7°



# Localization test with Higher Order Ambisonics

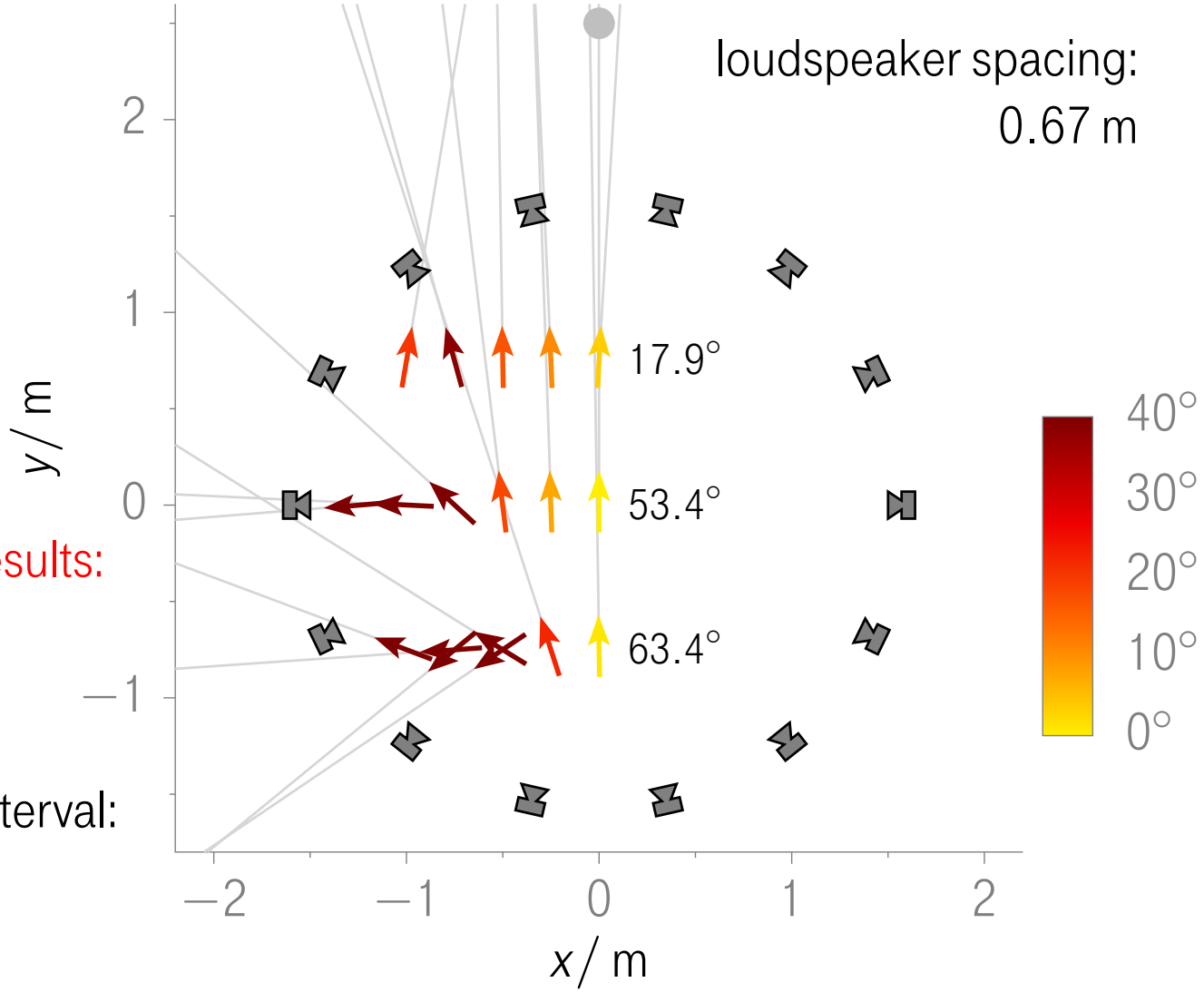
results for a point source at (0, 2.5) m

mean error:
44.9°

max error:
121.2°

preliminary results:
3 listeners

confidence interval:
3.0°



# Localization test with Higher Order Ambisonics

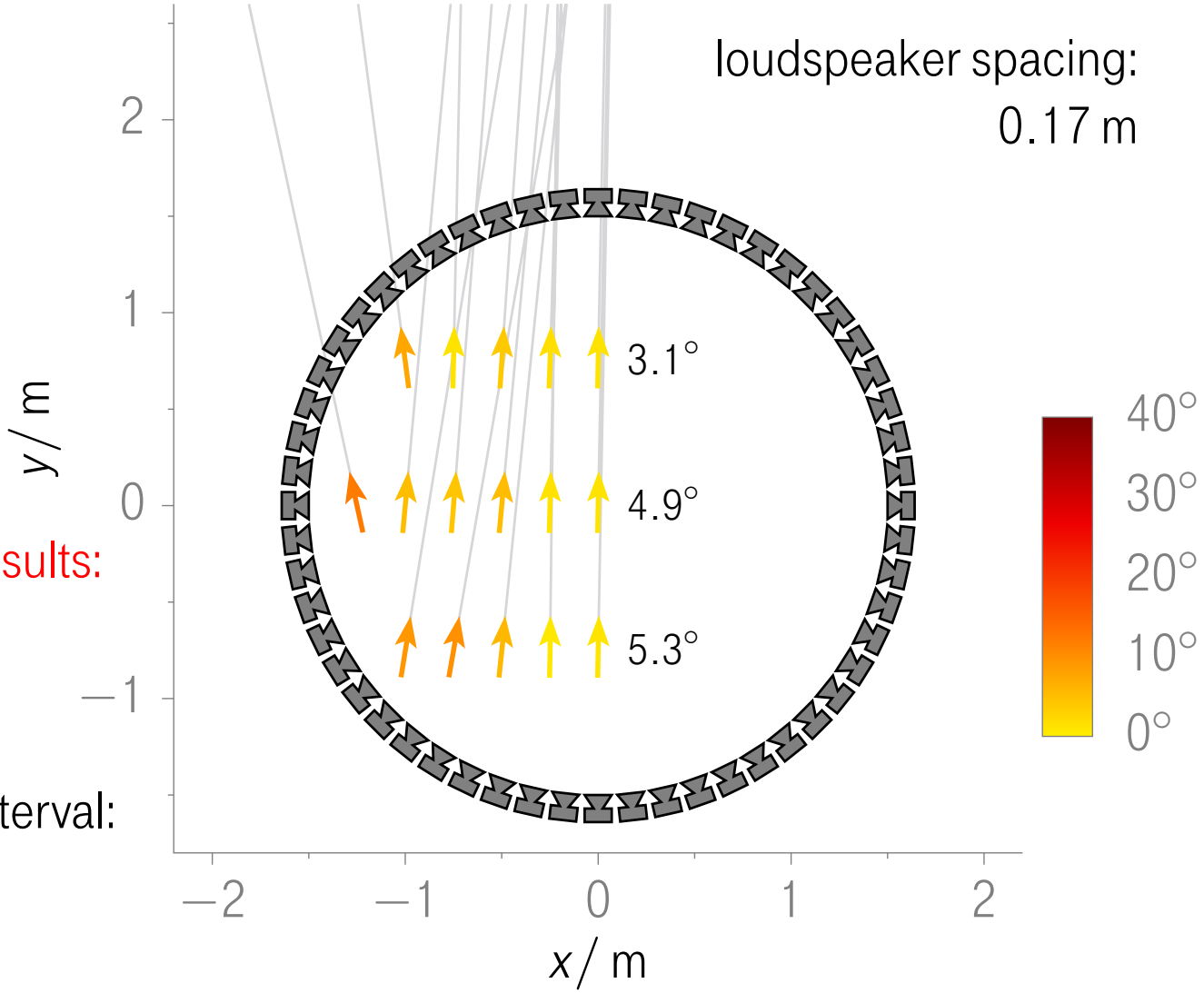
results for a plane wave going to at $(0, -1)$ m

mean error:
4.4°

max error:
12.2°

preliminary results:
3 listeners

confidence interval:
4.6°



# Localization test with Higher Order Ambisonics

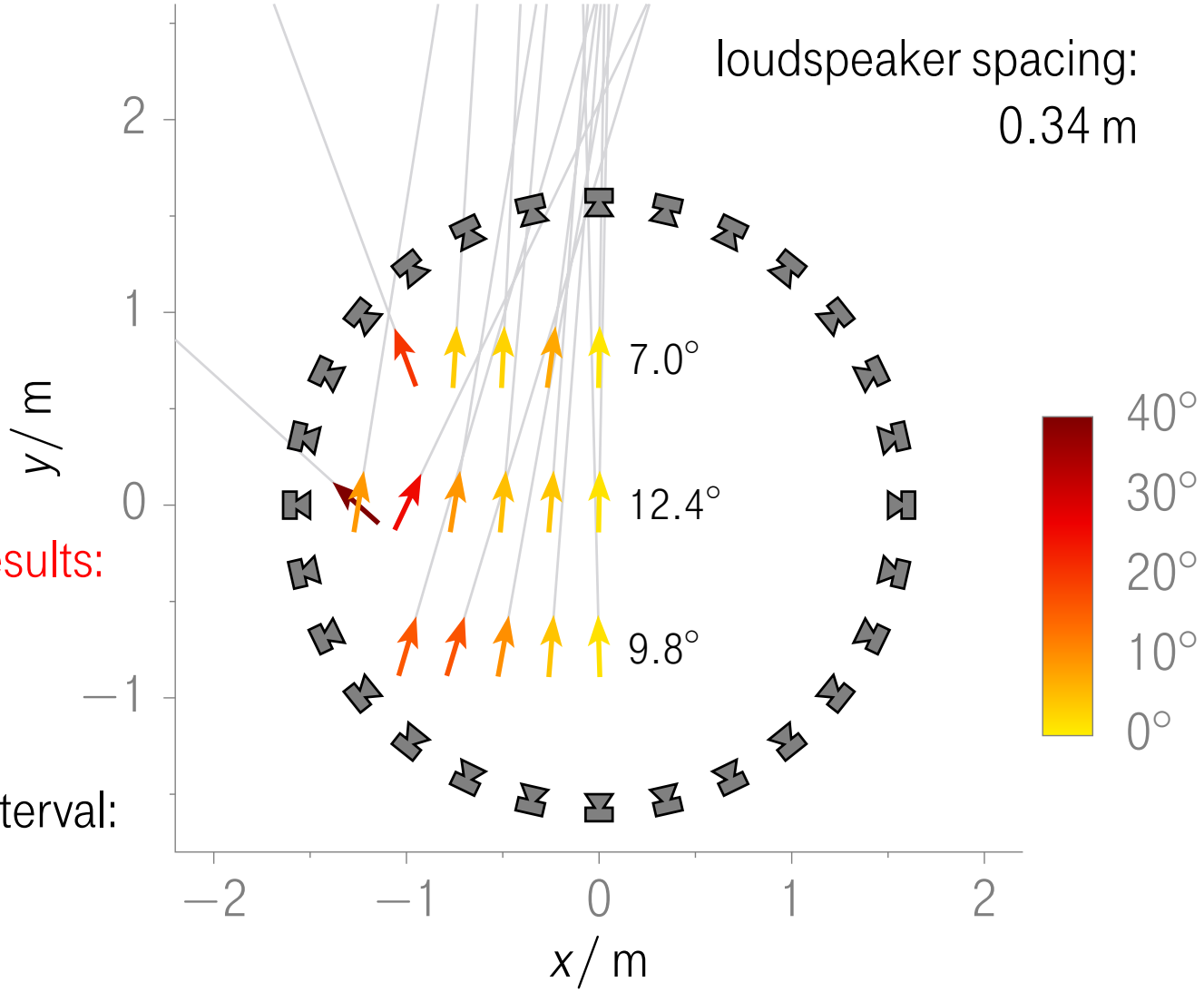
results for a plane wave going to at $(0, -1)$ m

mean error:
9.7°

max error:
28.9°

preliminary results:
3 listeners

confidence interval:
3.7°



# Localization test with Higher Order Ambisonics

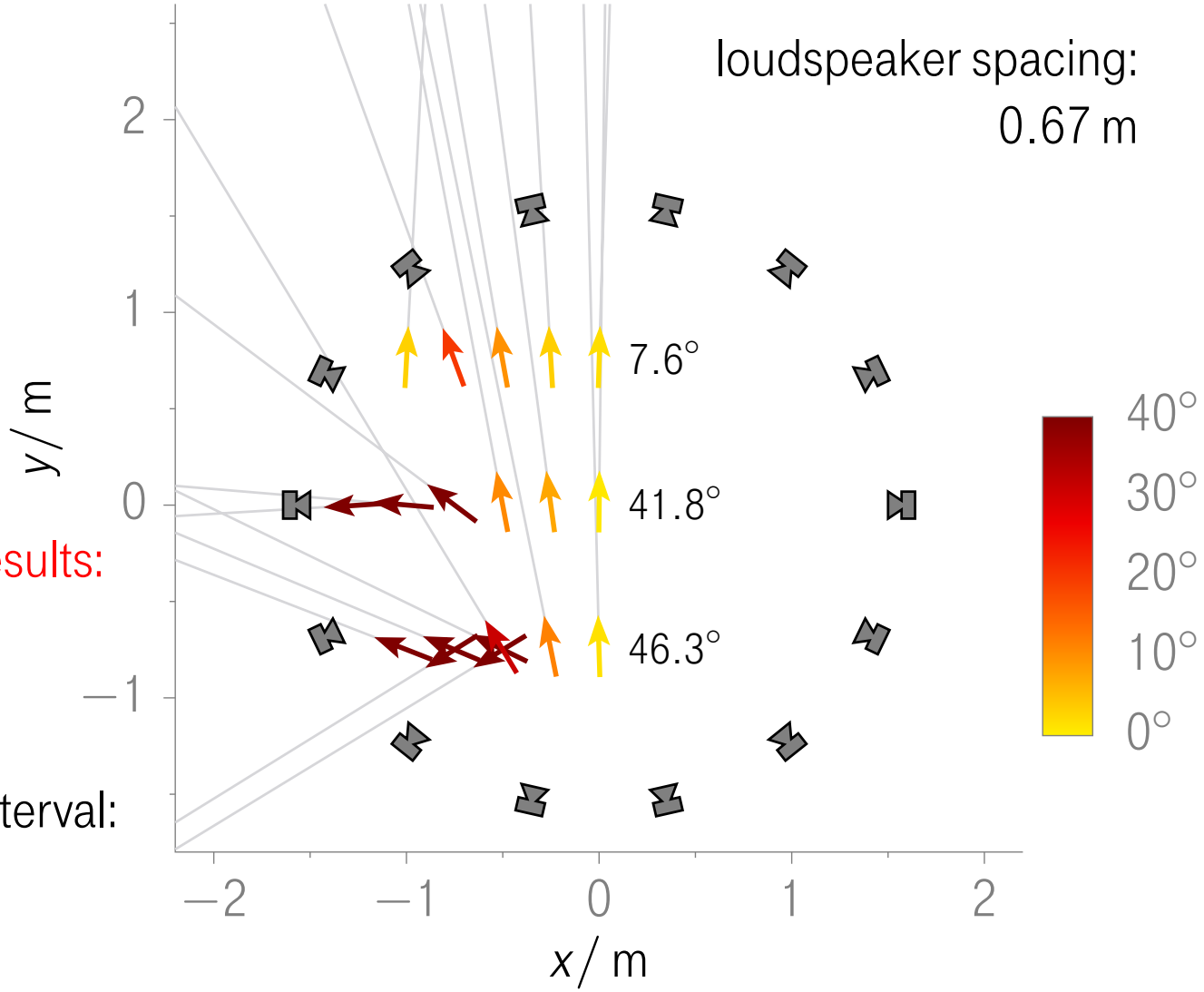
results for a plane wave going to at $(0, -1)$ m

mean error:
31.9°

max error:
103.6°

preliminary results:
3 listeners

confidence interval:
3.5°



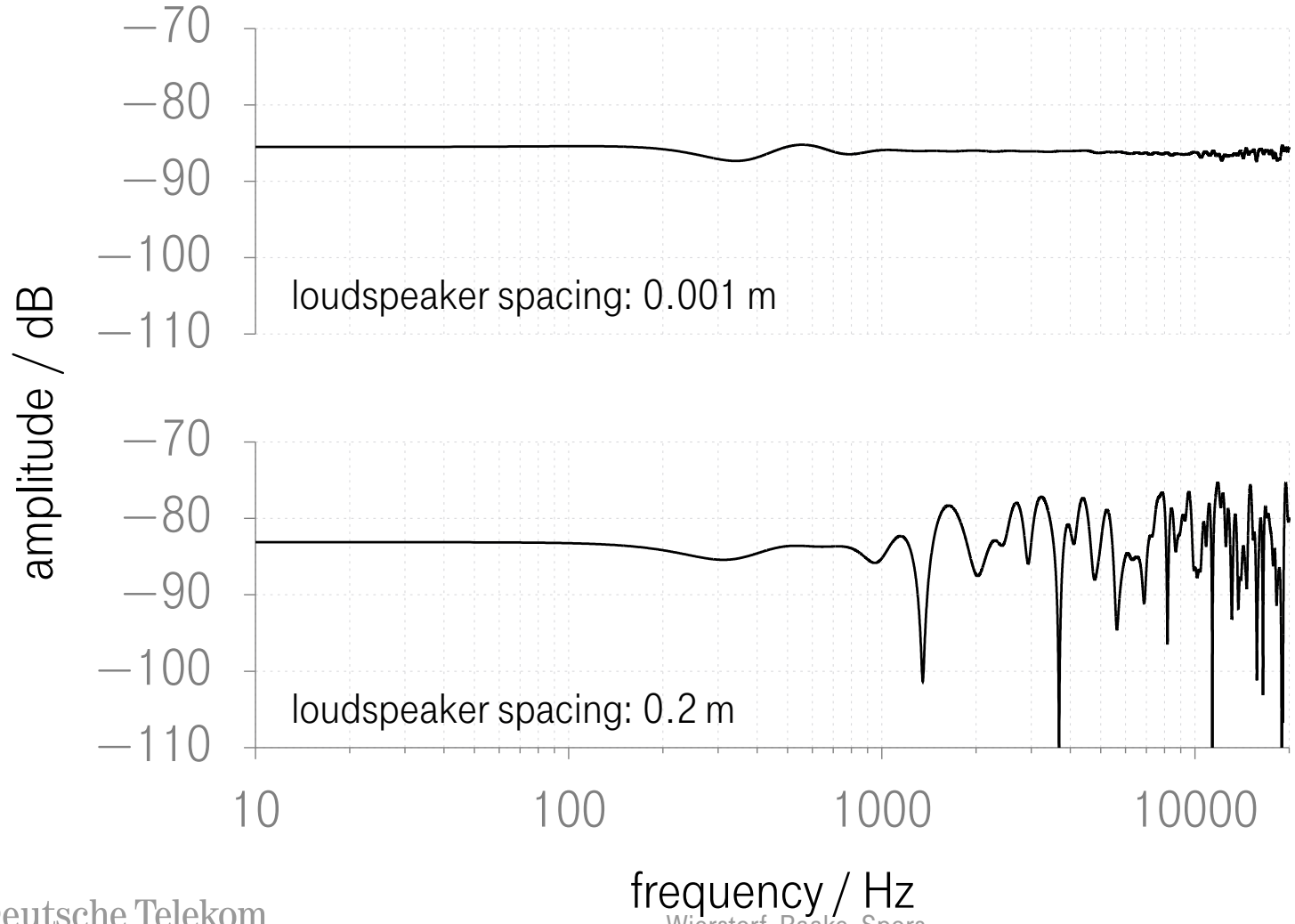
# Conclusion

- Wave Field Synthesis and Higher Order Ambisonics are different solutions to the same problem
- **WFS**: localization is not impaired for a loudspeaker spacing of around 20 cm, the same holds for a linear array (Wierstorf, 2012)
- **WFS**: localization is only slightly impaired for larger loudspeaker spacings
- **NFC-HOA**: preliminary results confirm a pronounced sweet spot in which the localization is not impaired
- **NFC-HOA**: outside of that sweet spot large deviations and more than one source can occur

Wierstorf et al. (2012), *Localization of a virtual point source within the listening area for Wave Field Synthesis*, 133rd AES

# Open questions

- influence of the room
- coloration



# Reproducible Research

- Sound Field Synthesis Toolbox
  `http://github.com/sfstoolbox/sfs/`
- SoundScape Renderer
  `http://spatialaudio.net/ssr/`
- Head-Related Transfer Function
  `http://dev.qu.tu-berlin.de/projects/measurements/`

Wierstorf and Spors (2012), *Sound field synthesis toolbox*, 132nd AES
Geier and Spors (2012), *Spatial Audio Reproduction with the SoundScape Renderer*, VDT International Convention
Wierstorf et al. (2011), *A free database of head-related impulse response measurements in the horizontal plane with multiple distances*, 130th AES


Questions?

http://spatialaudio.net

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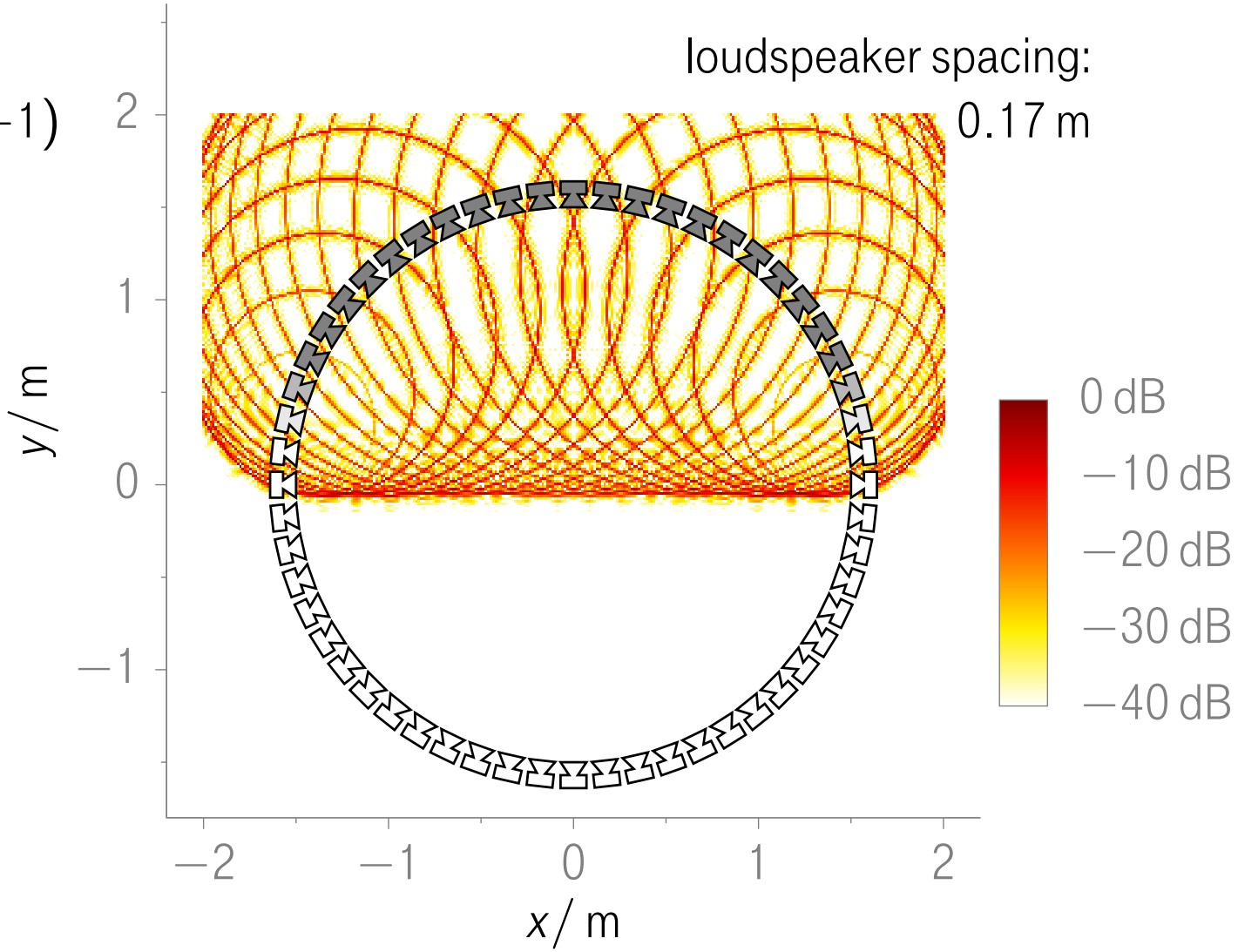

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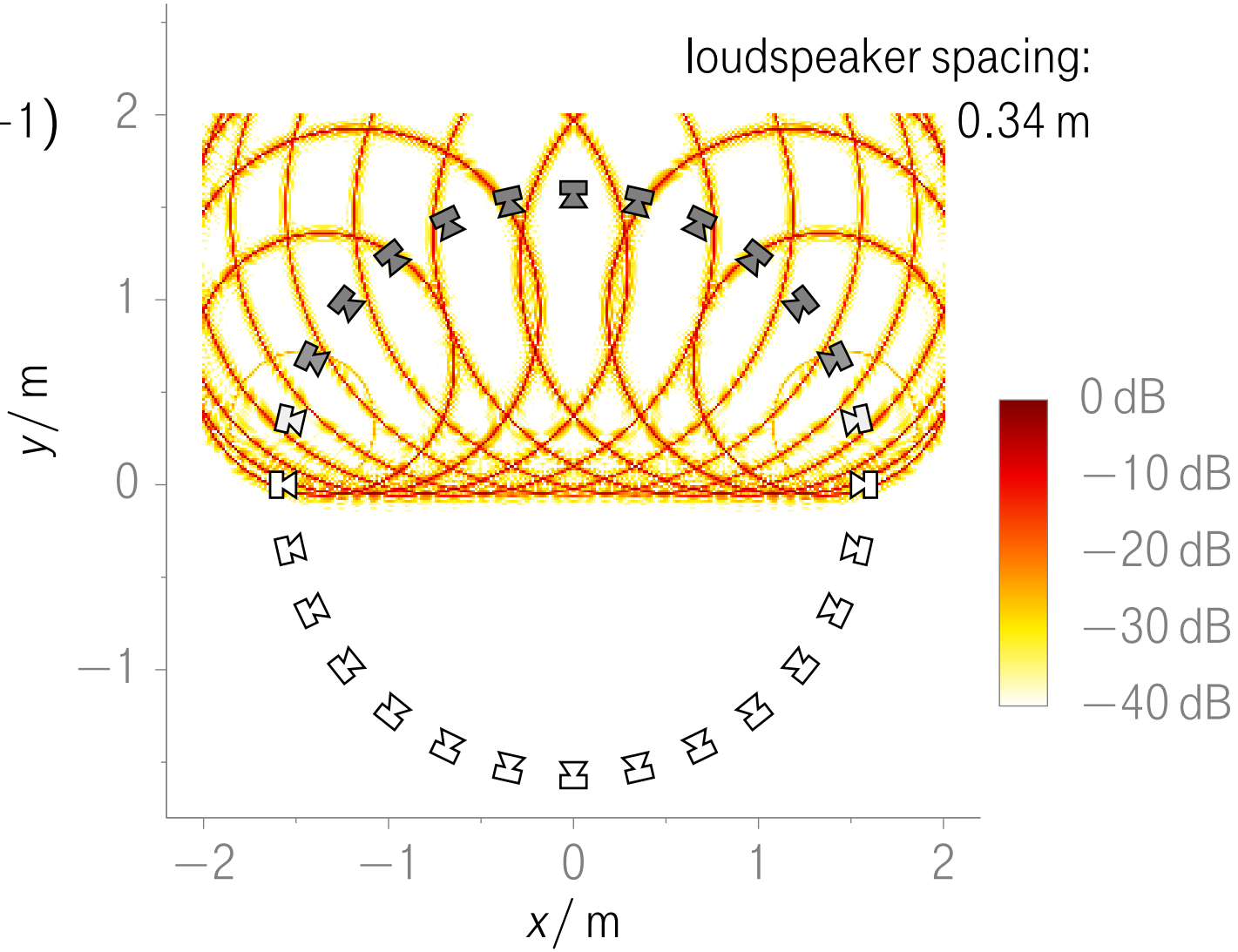


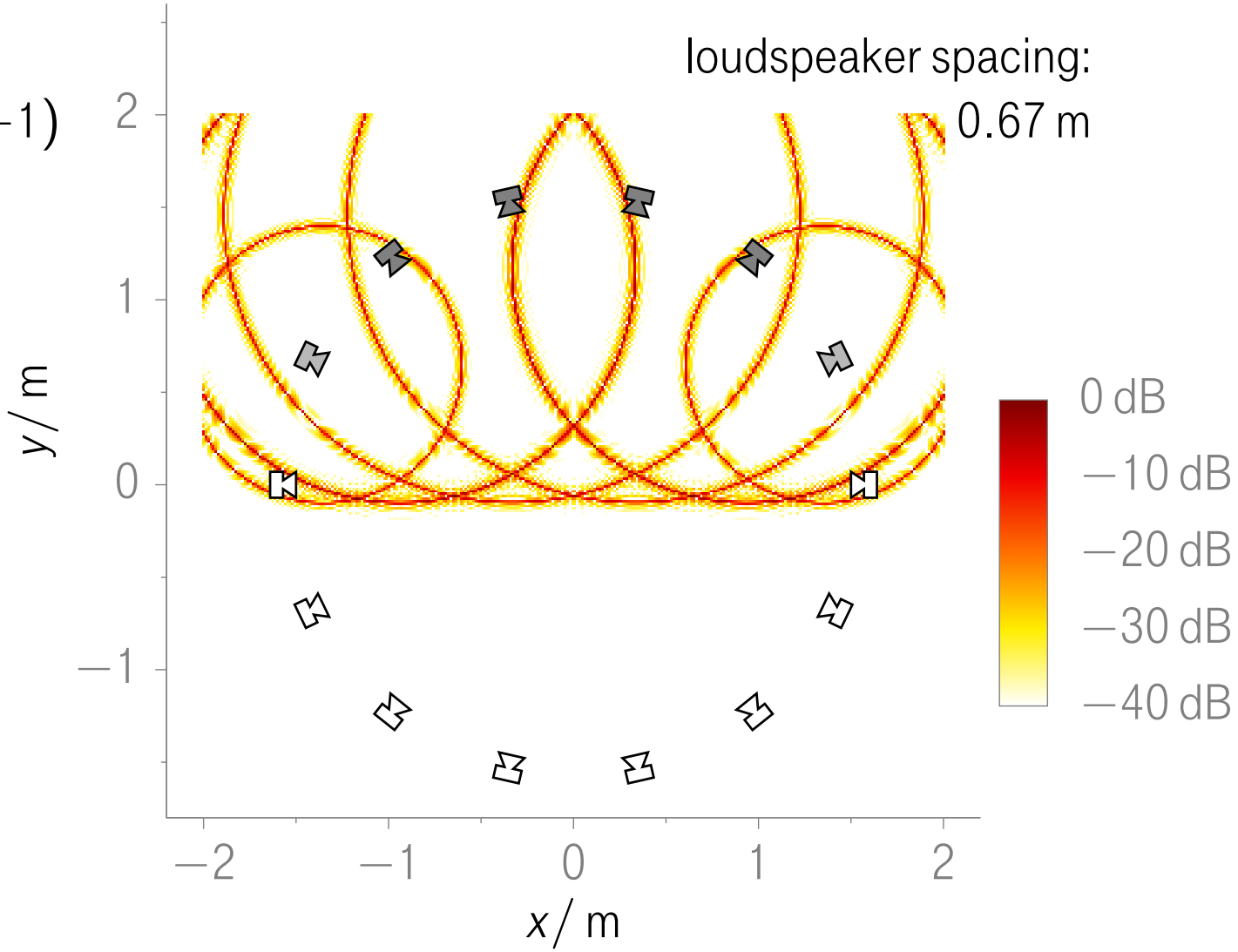
# Wave Field Synthesis

snapshot of the sound field $p(\vec{x}, t)$

plane wave
going to $(0, -1)$

$t = 4$ ms

loudspeaker spacing:
0.67 m



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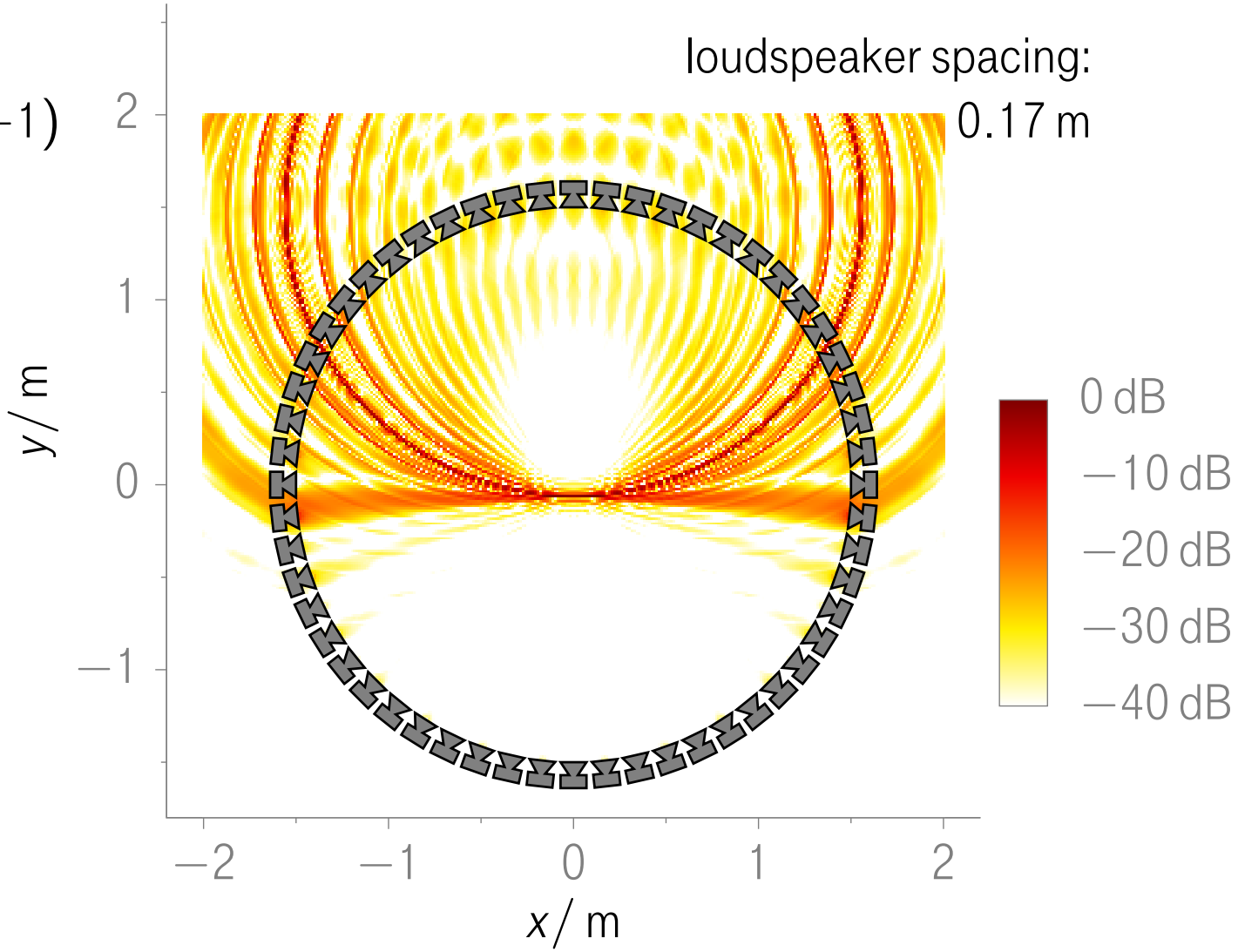

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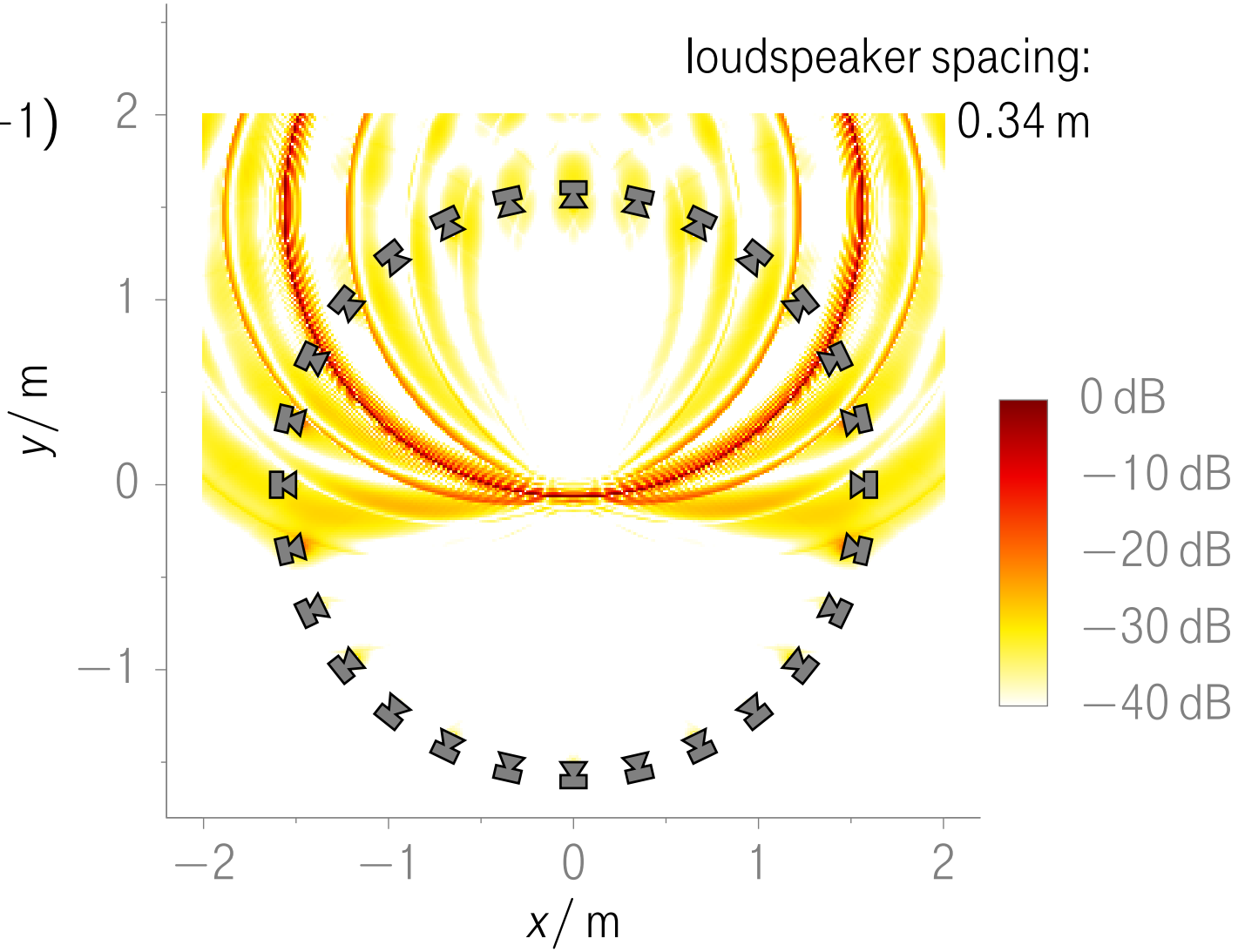

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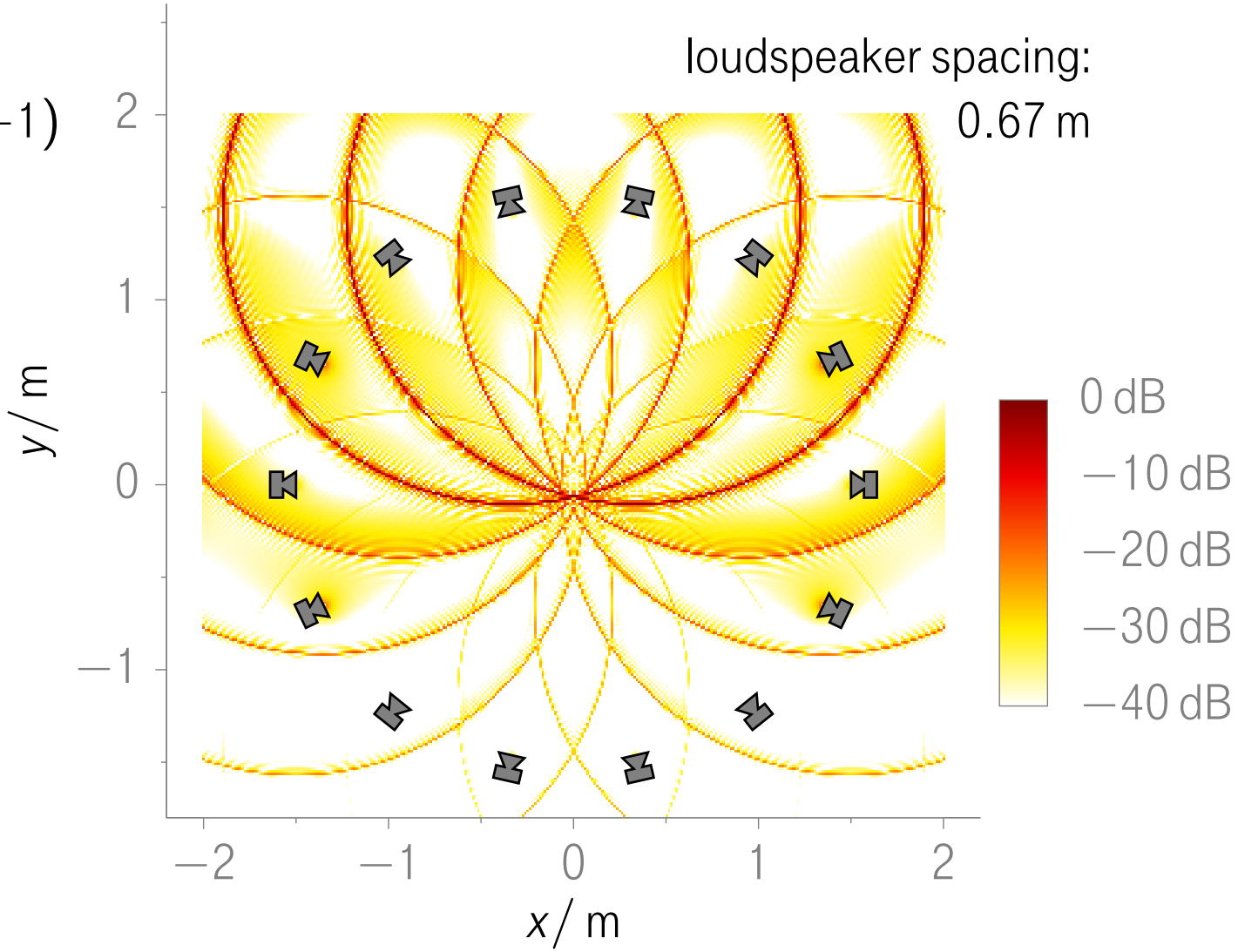

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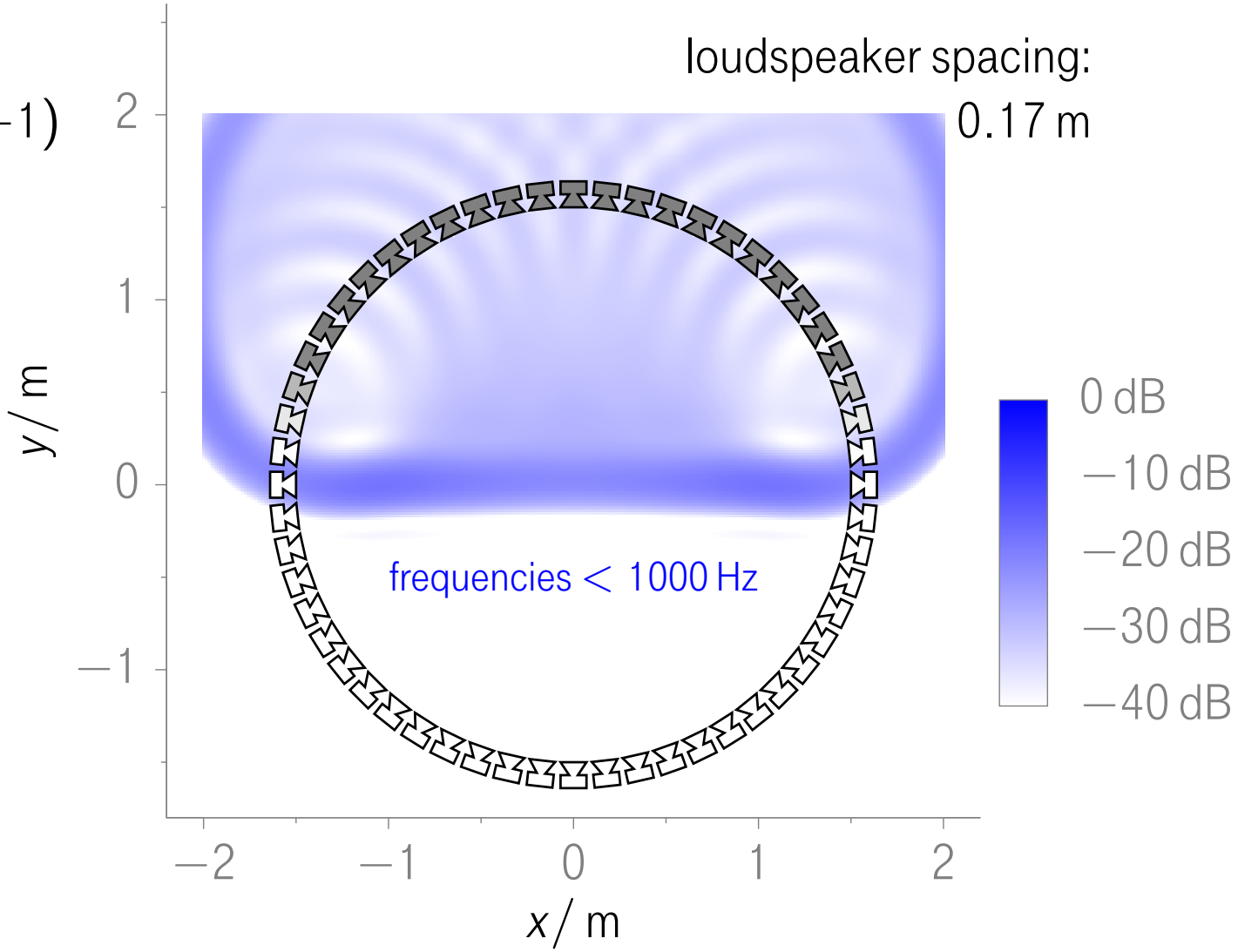

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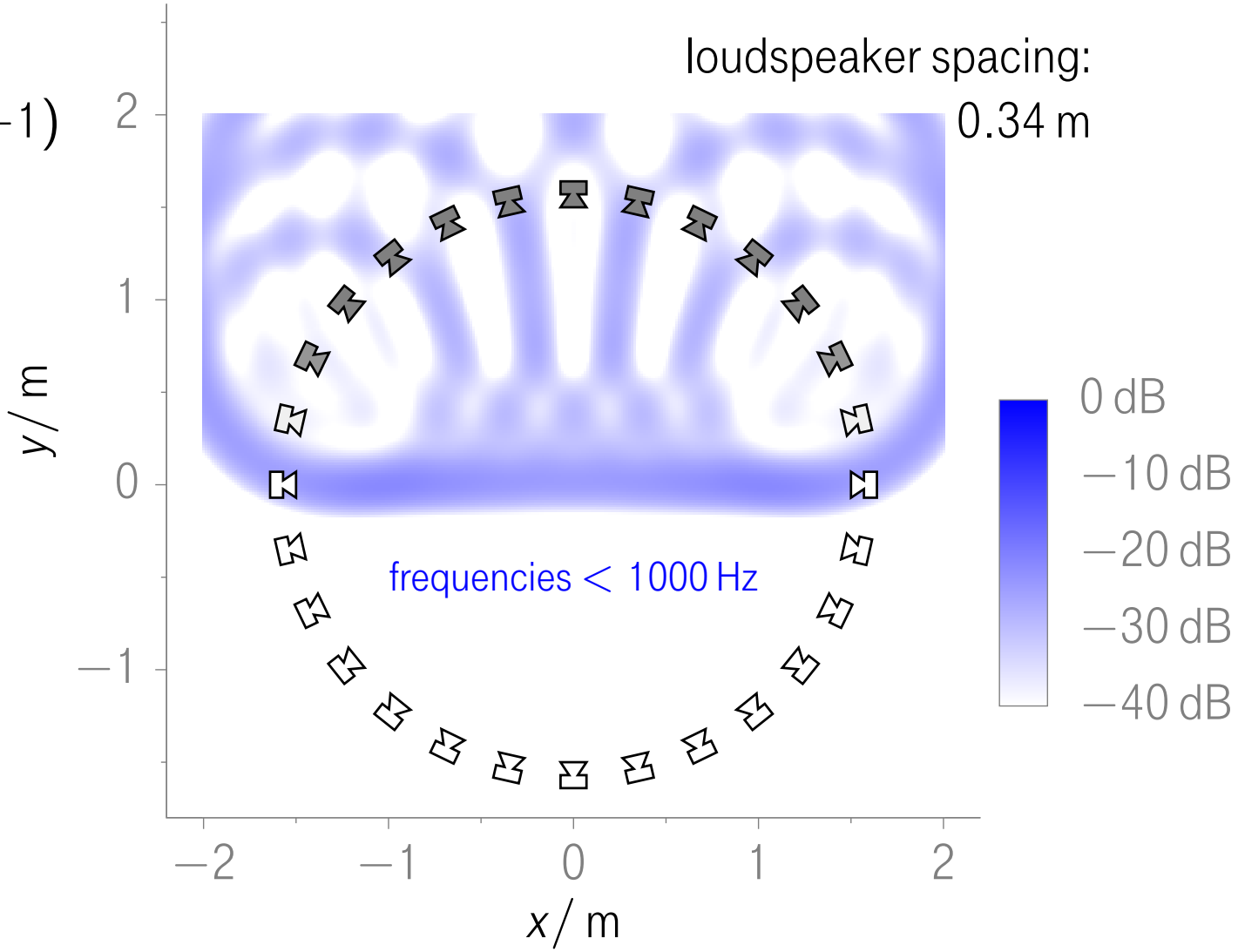

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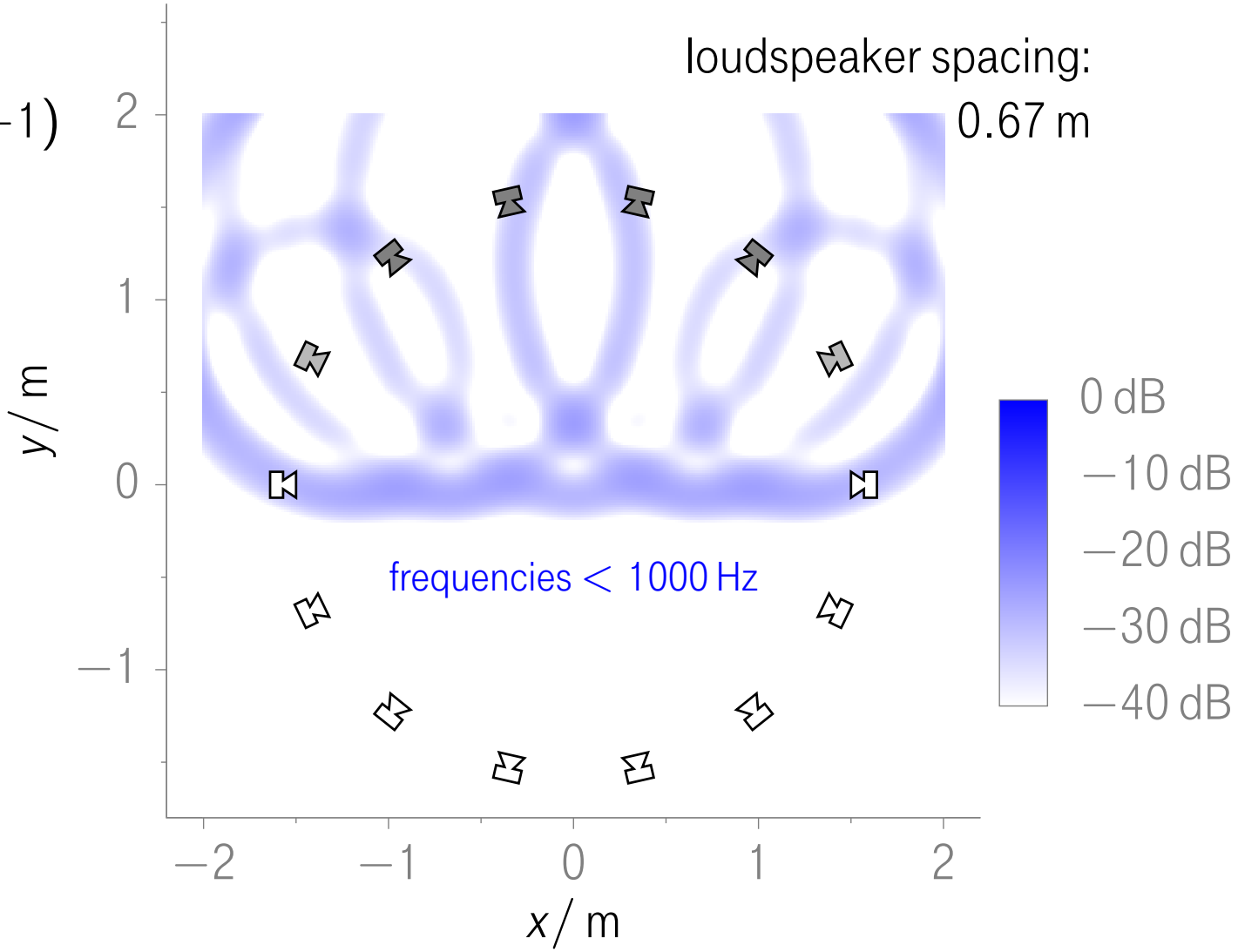

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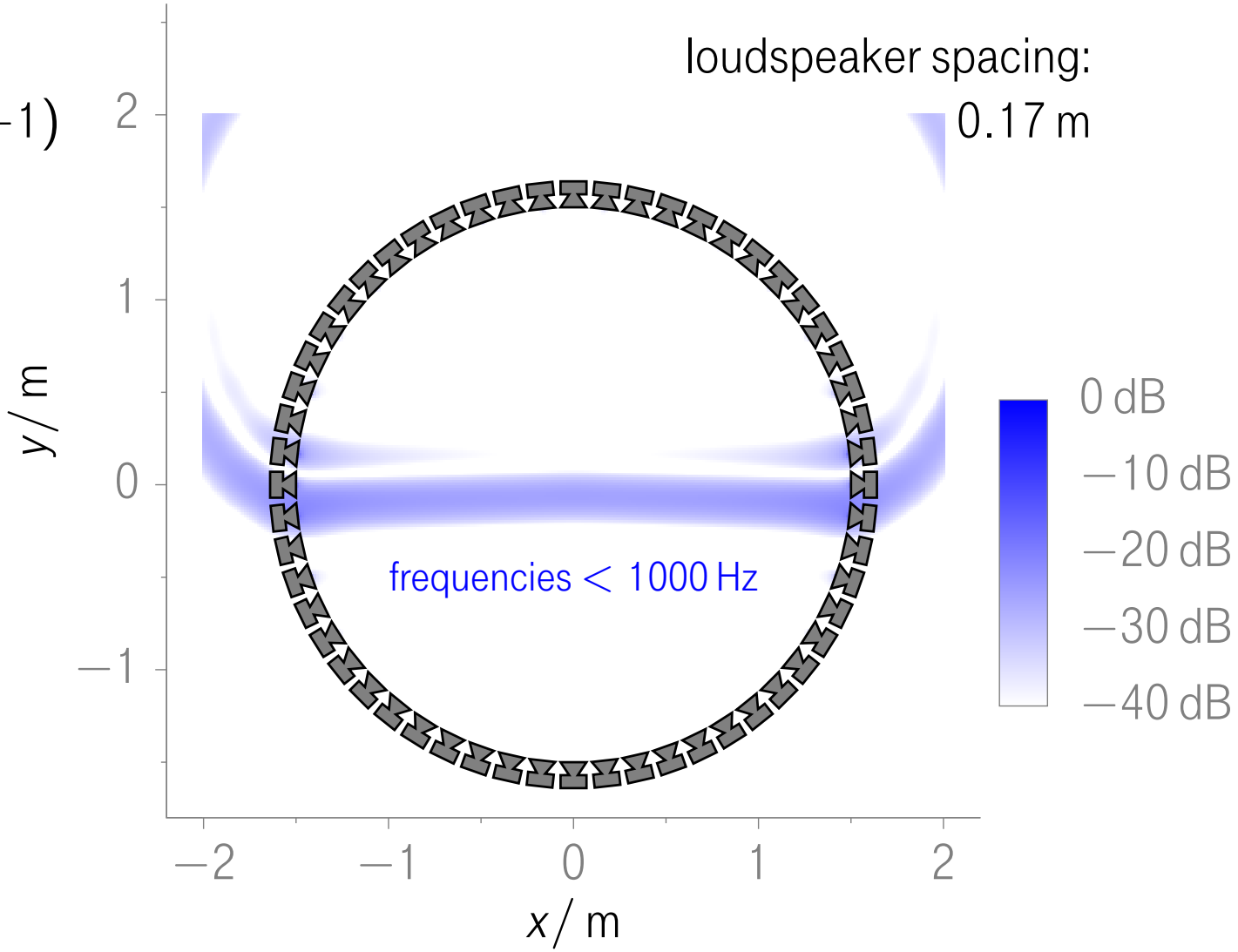

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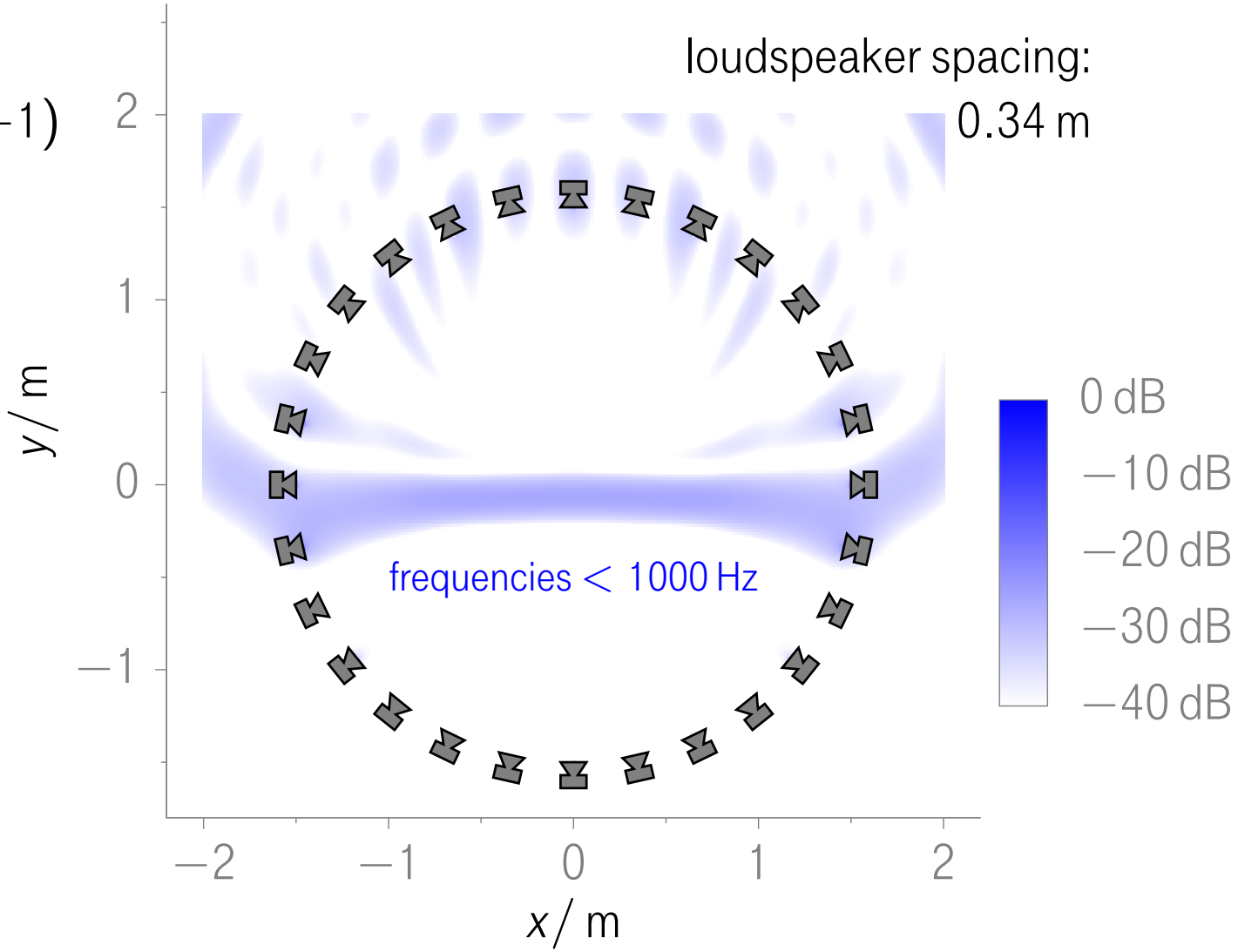

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