SOURCE LOCALIZATION AND FAR-FIELD EXTRAPOLATION FOR WIND-TUNNEL MEASUREMENTS OF JET INSTALLATION NOISE

Alessandro Bassetti, Sebastian Oertwig and Henri Siller

Institute of Propulsion Technology – Engine Acoustics

THE DJINN - ENODISE CONFERENCE

Aeroacoustic Installation Effects
In Conventional and New Propulsion Systems
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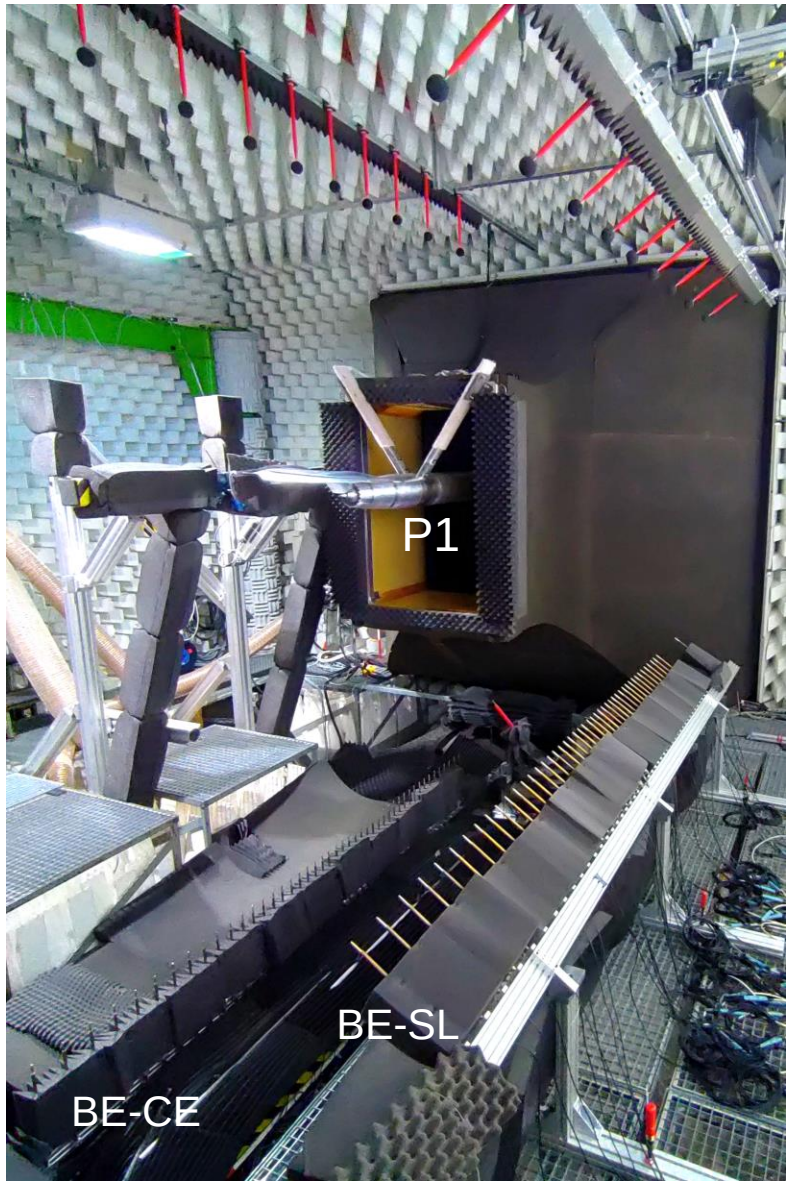
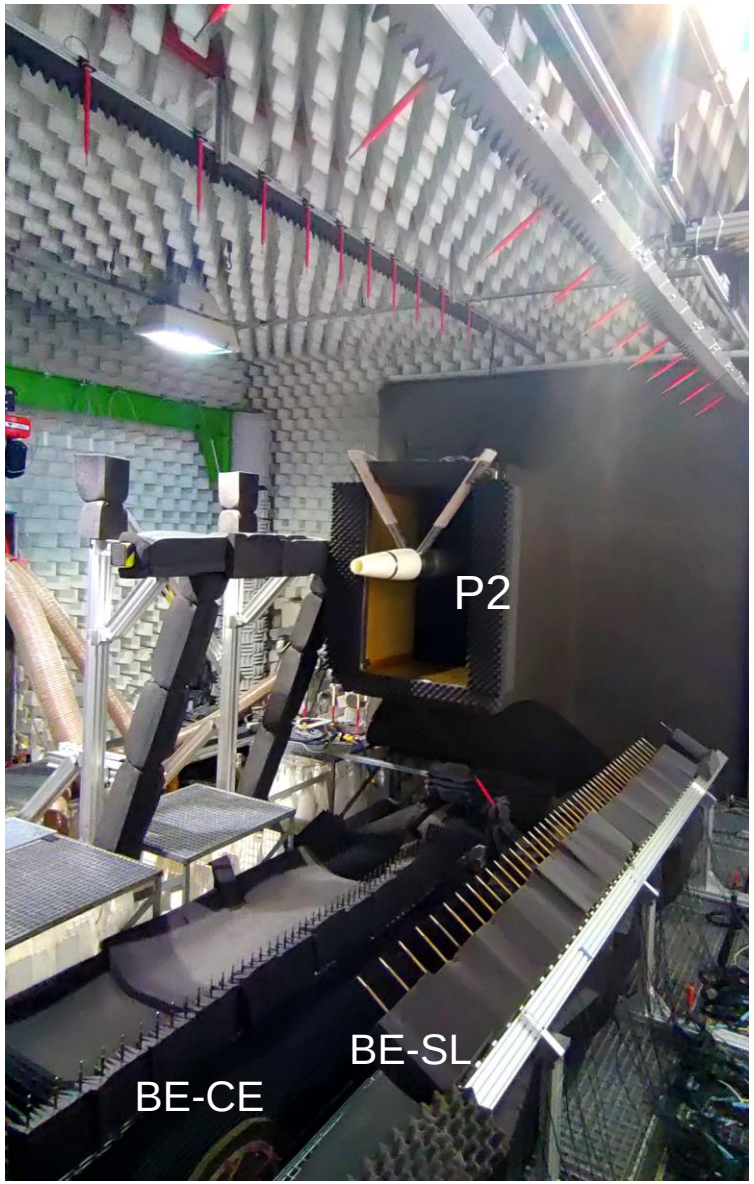
Berlin Germany

DLR

Acoustic array measurements in AWB





Tested configurations:

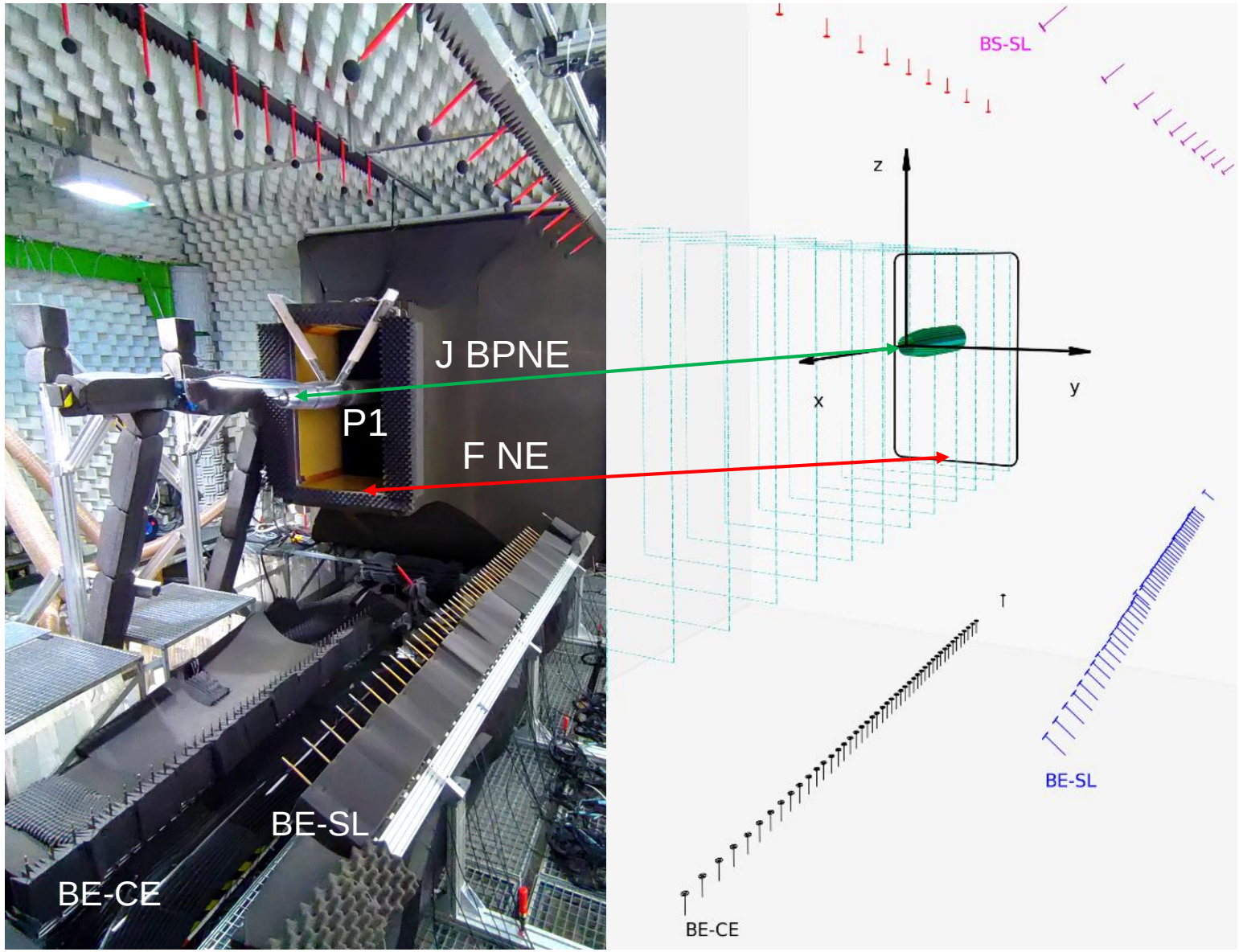
P1, engine under the wing
- Short cowl nozzle
- Pylon and wing

P2, engine rear-side fuselage
- Long cowl nozzle
- No Pylon
- Fuselage and tail planes (not shown in the picture)

Linear arrays of microphones:

BE-CE, BE-SL
- 47-sensors
- Parallel to nozzle axis
- Fly-over, sideline azimuth

Simplified physics of wind tunnel measurement



Aeroacoustic Wind Tunnel Braunschweig

https://www.dlr.de/en/research-and-transfer/research-infrastructure/aeroacoustic-wind-tunnel-braunschweig

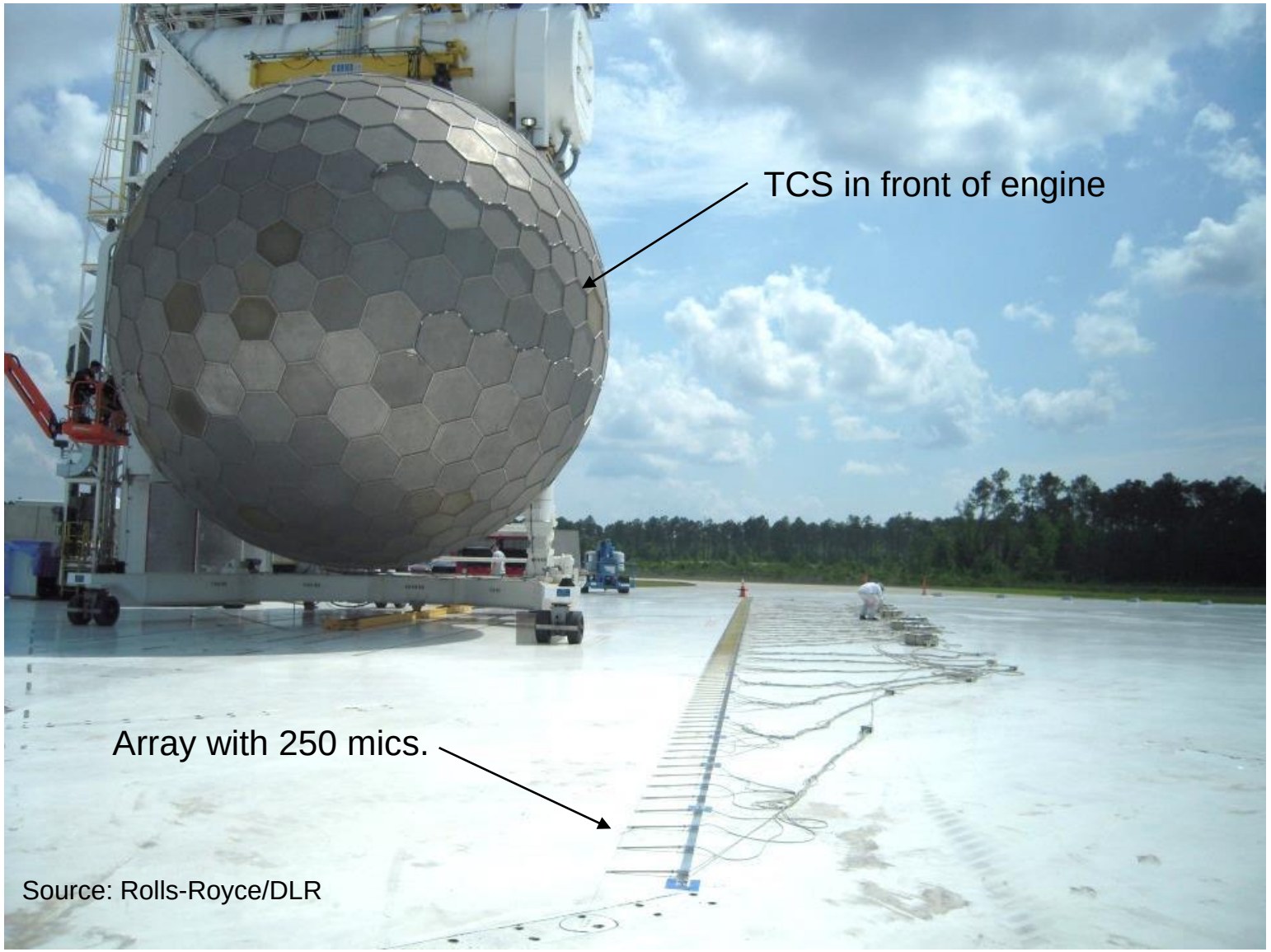
Sketch:

- Flight-stream nozzle exit (F NE)
- Bypass nozzle exit (J BPNE) of engine simulator
  - Origin of reference system
  - X=downstream nozzle axis
- Microphone arrays
- Modelled interface between flight-stream column and medium at rest

Flight simulation stream simplified as rectangular-flow column with infinitely thin shear layer

Source in the flow column;
Microphone in resting ambience

Linear array measurements



Source: Rolls-Royce/DLR

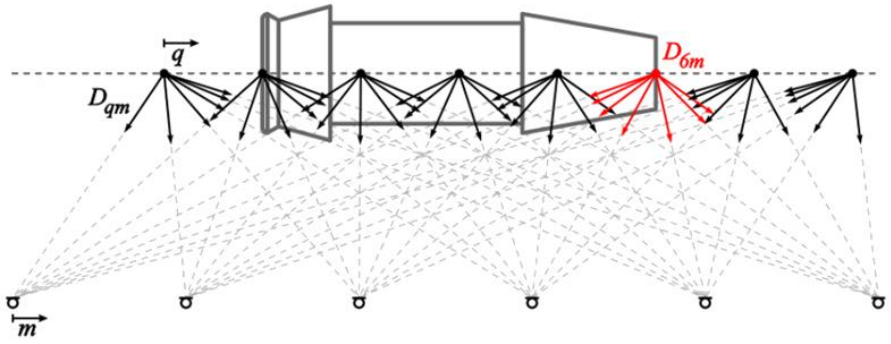
Test-bed experiments of engines

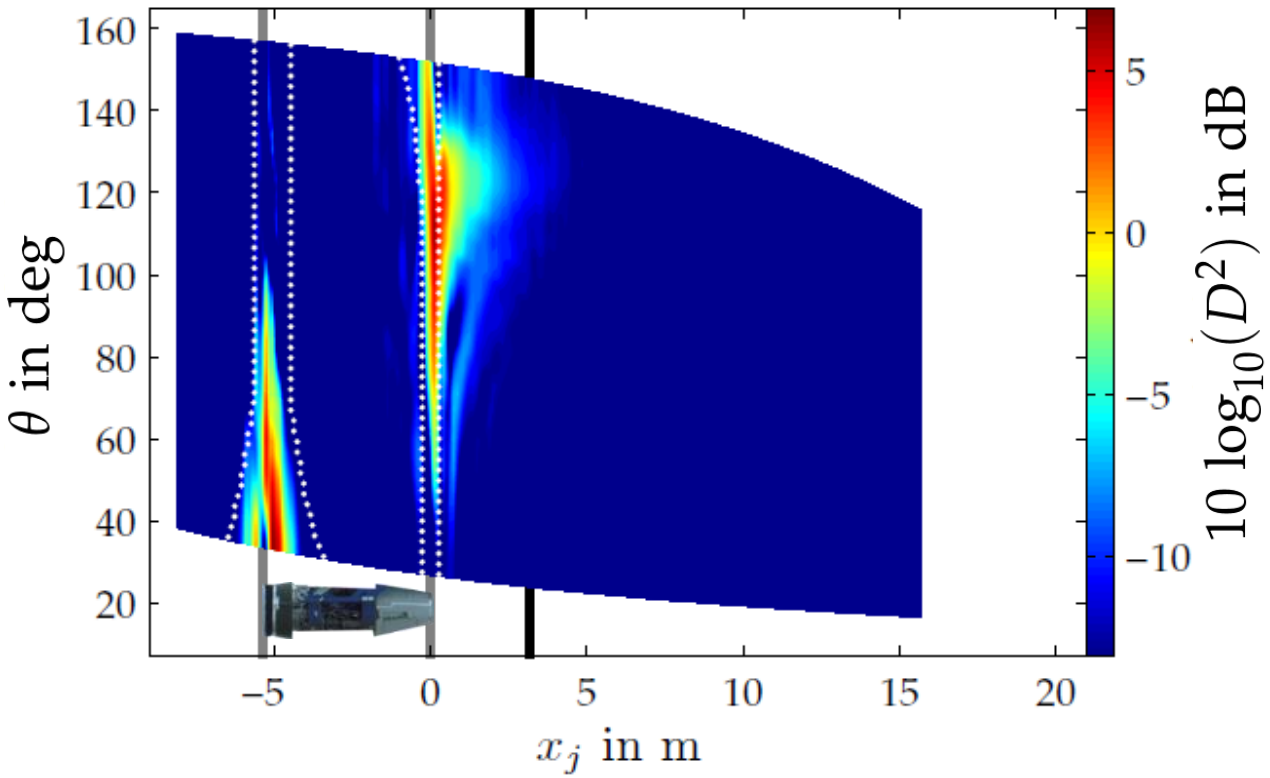
- Engine suspended over a very large concrete basement
  - Engine behind the very large golf ball (turbulence control screen)
  - Polar array of microphones at about 50 m from the engine
- Engine axis parallel to the array

Reliable method to define the position of different sources along the axis of a turbo-fan engine

- Frequency dependence
- Directivity

SODIX





1. Model of cross-spectral matrix at microphone positions, assuming incoherent directive point sources and a free-space Green's function

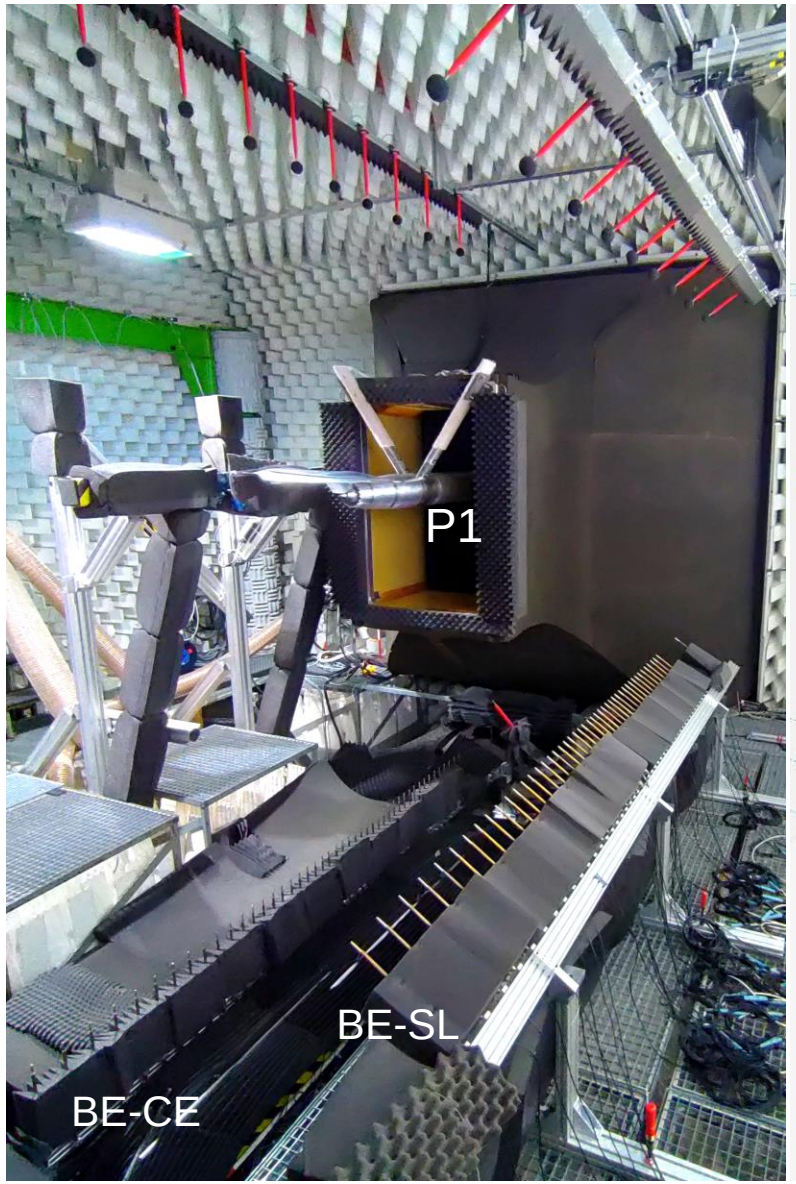
$$C_{mn}^{\mathrm{mod}} = \sum_{j=1}^{J} g_{jm} D_{jm} D_{jn} g_{jn}^{*} \qquad D_{jm} \geq 0$$

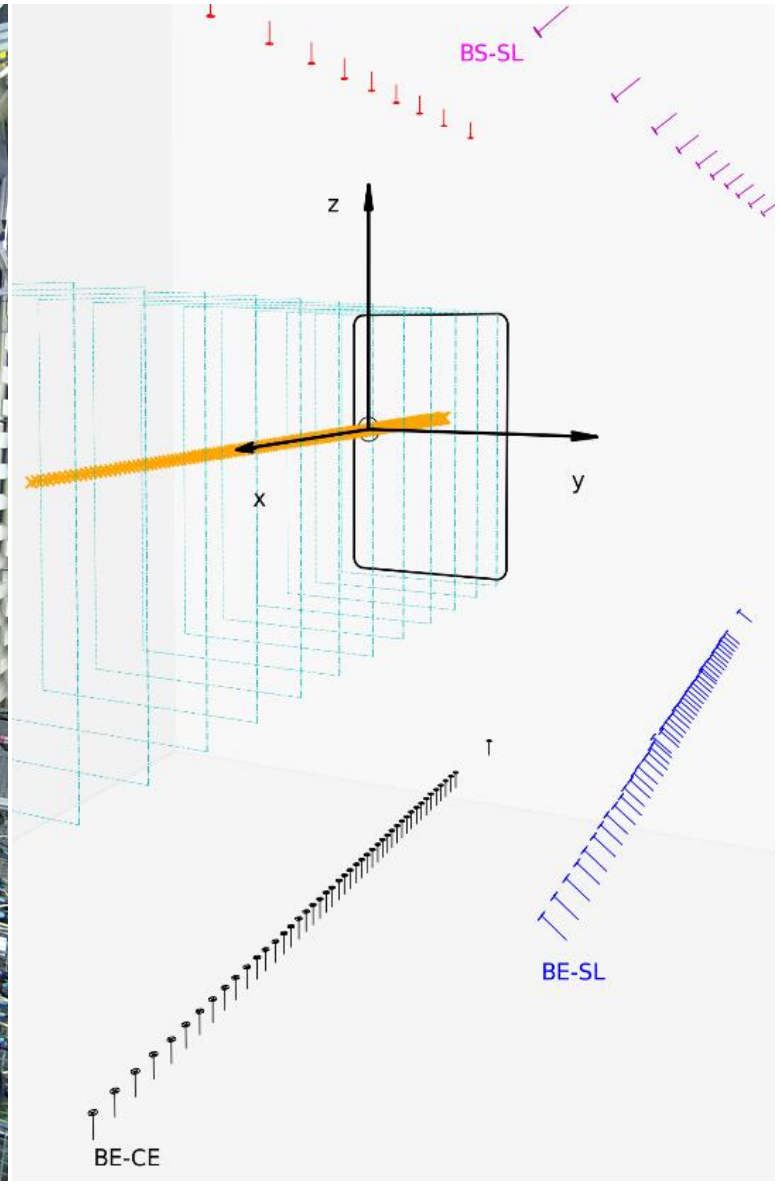
2. Best fit of the modeled cross-spectral matrix to the measured one

$$F(D) = \sum_{m,n=1}^{M} \left| C_{mn} - C_{mn}^{\mathrm{mod}} \right|^2 = \min$$

[1] U. Michel and S. Funke: „Inverse method for the acoustic source analysis of an aeroengine.“ In: 2nd Berlin Beamforming Conference, 2008, Berlin.
[2] S. Funke, A. Skorpel and U. Michel: „An extended formulation of the SODIX method with application to aeroengine broadband noise.“ In: 18th AIAA/CEAS Aeroacoustics Conference, 4-6 June 2012, Colorado Springs, USA. AIAA 2012- 2276.
[3] S. Funke, R. P. Dougherty und U. Michel: „SODIX in comparison with various deconvolution methods.“ In: 5th Berlin Beamforming Conference, 2014, Berlin.
[4] S. Oertwig, H. Siller and S. Funke: „Advancements in the source localization method SODIX and application to short cowl engine data.“ In: 25th AIAA/CEAS Aeroacoustics 2019 Conference, 20-23 May 2019, Delft, The Netherlands.
[5] S. Oertwig, Schumacher, H. Siller and S. Funke: „Extension of the source localization method SODIX for coherent sound sources.“ In AIAA AVIATION 2021 FORUM, 2-6 August 2021, VIRTUAL EVENT.

Source representation with SODIX



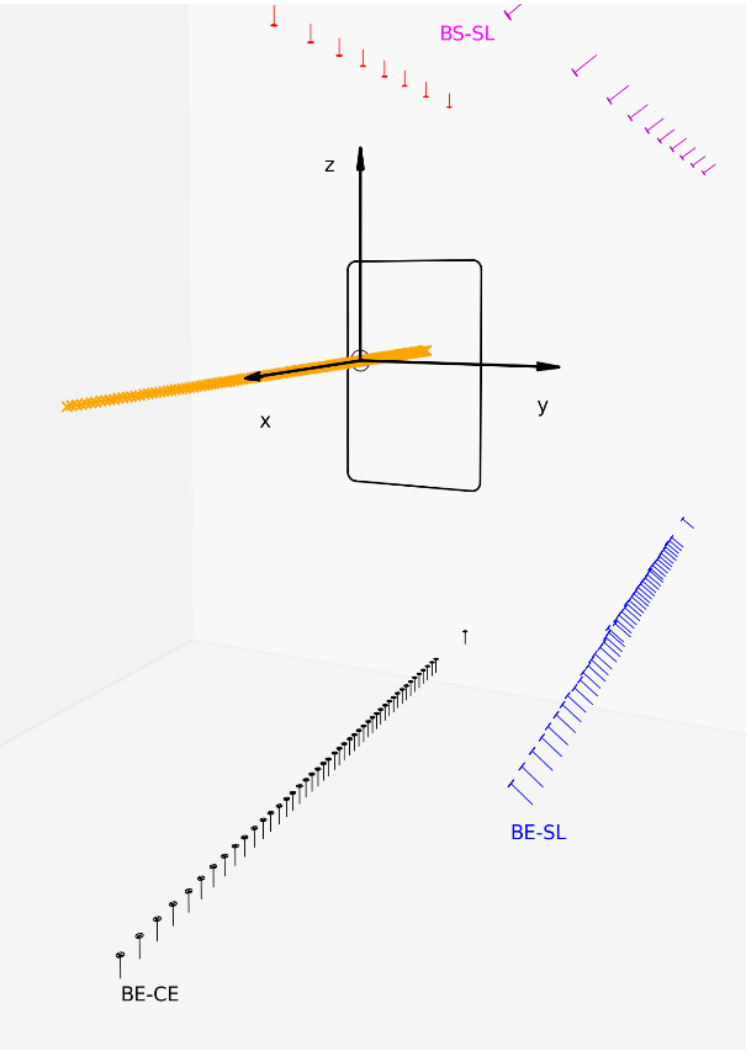


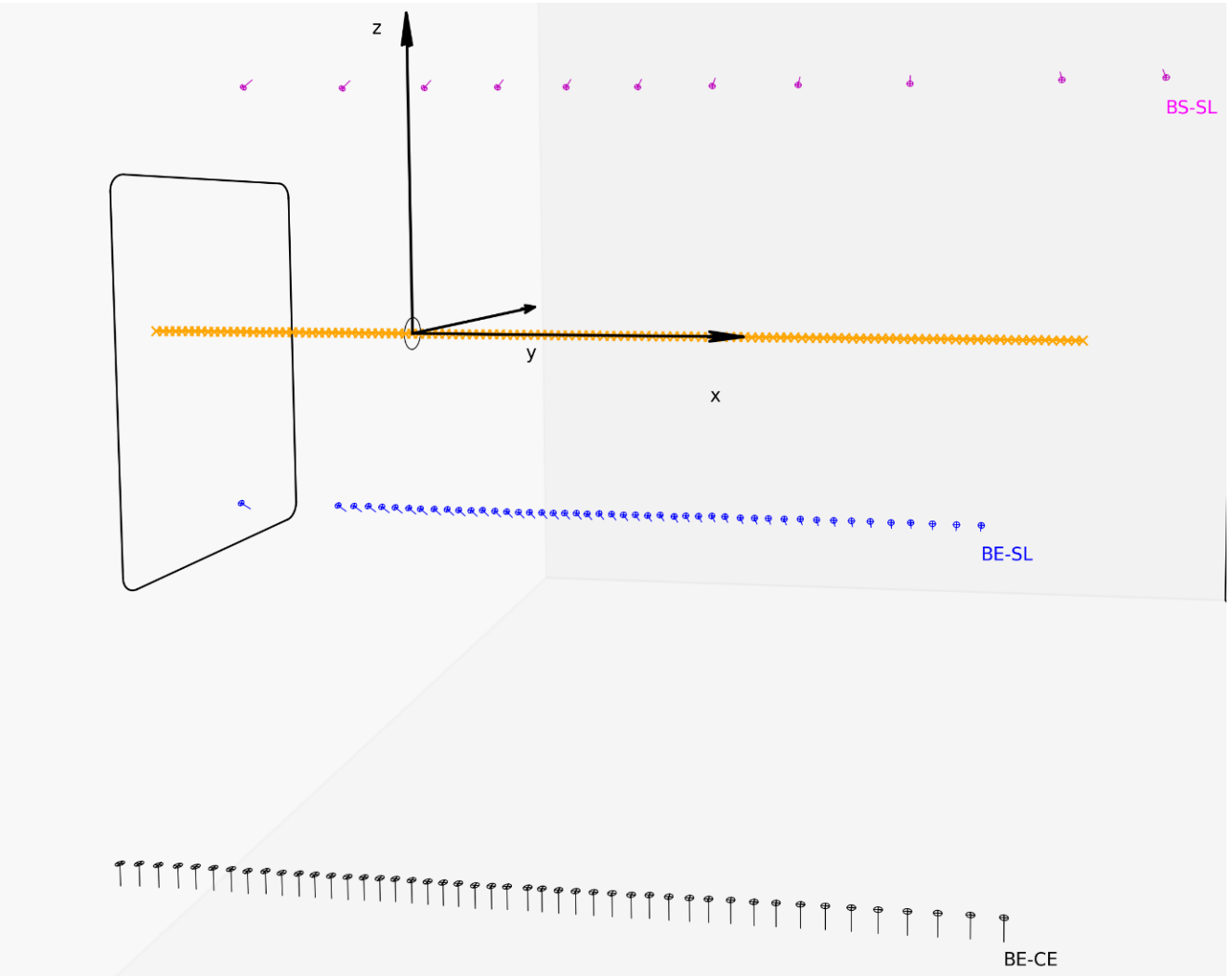
Set of point sources

- On the nozzle centreline
  - Source domain varies with frequency
  - Length comparable to microphone distance

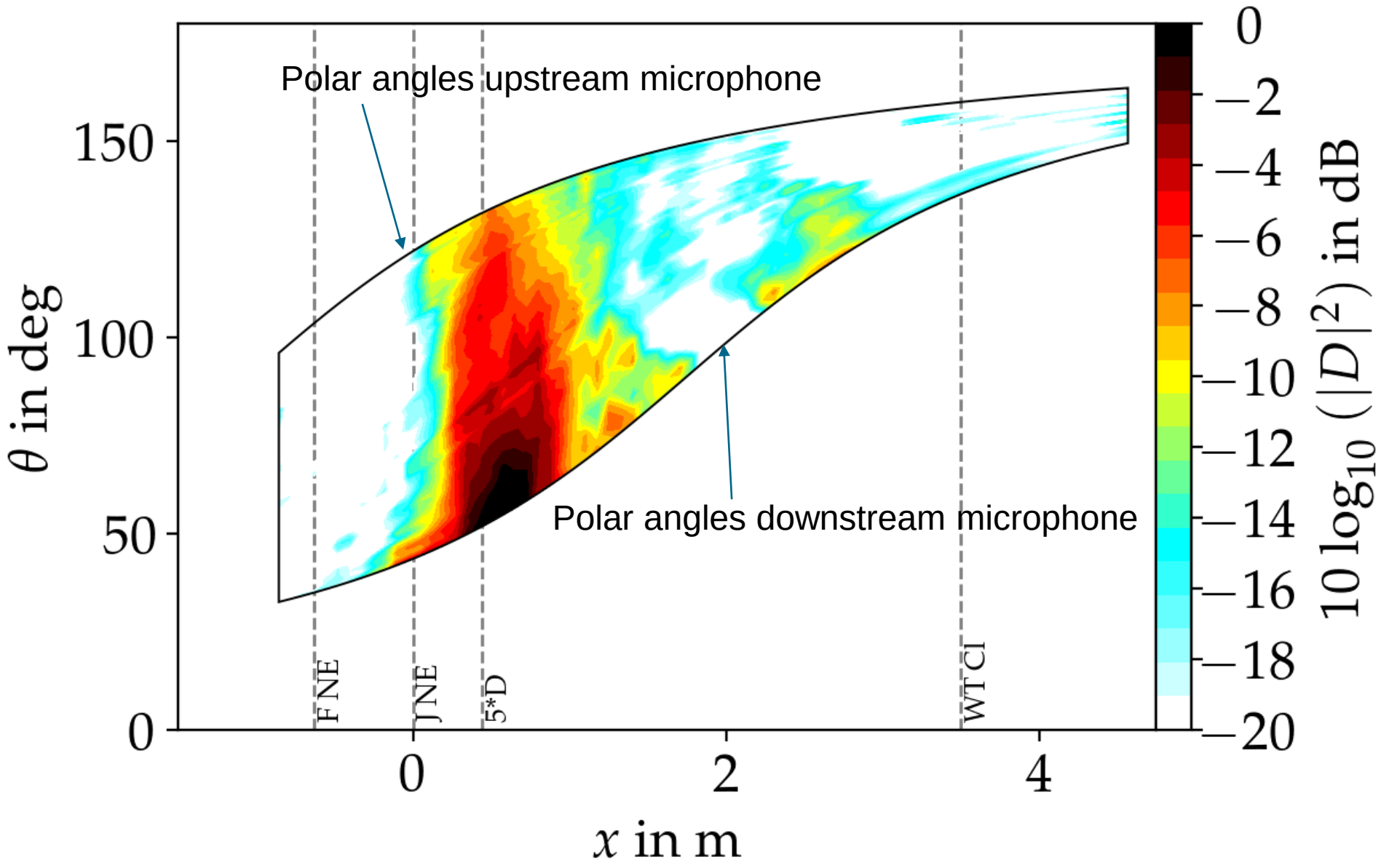
- Non-uniform directivity
  - SODIX output defined within source to microphone view-angle limits

Orientation: flow from left to right





SODIX Solution



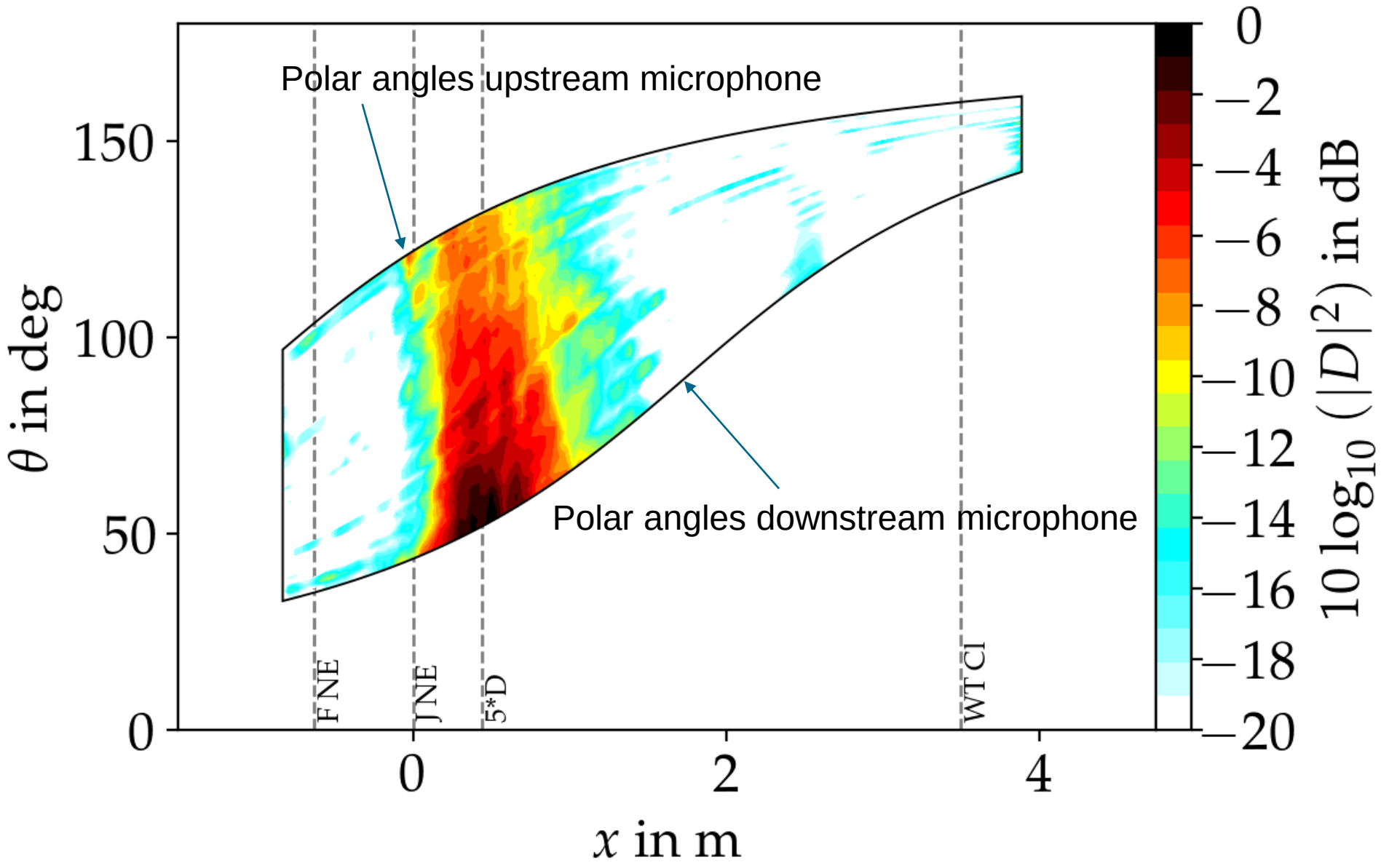
Static jet

- P2
- Velocity ratio 1
- M=0.75
- Equivalent to single stream

SODIX interrogation region includes the whole extension of the wind tunnel

- BE-SL array
- Geometrical near field

SODIX Solution at double frequency



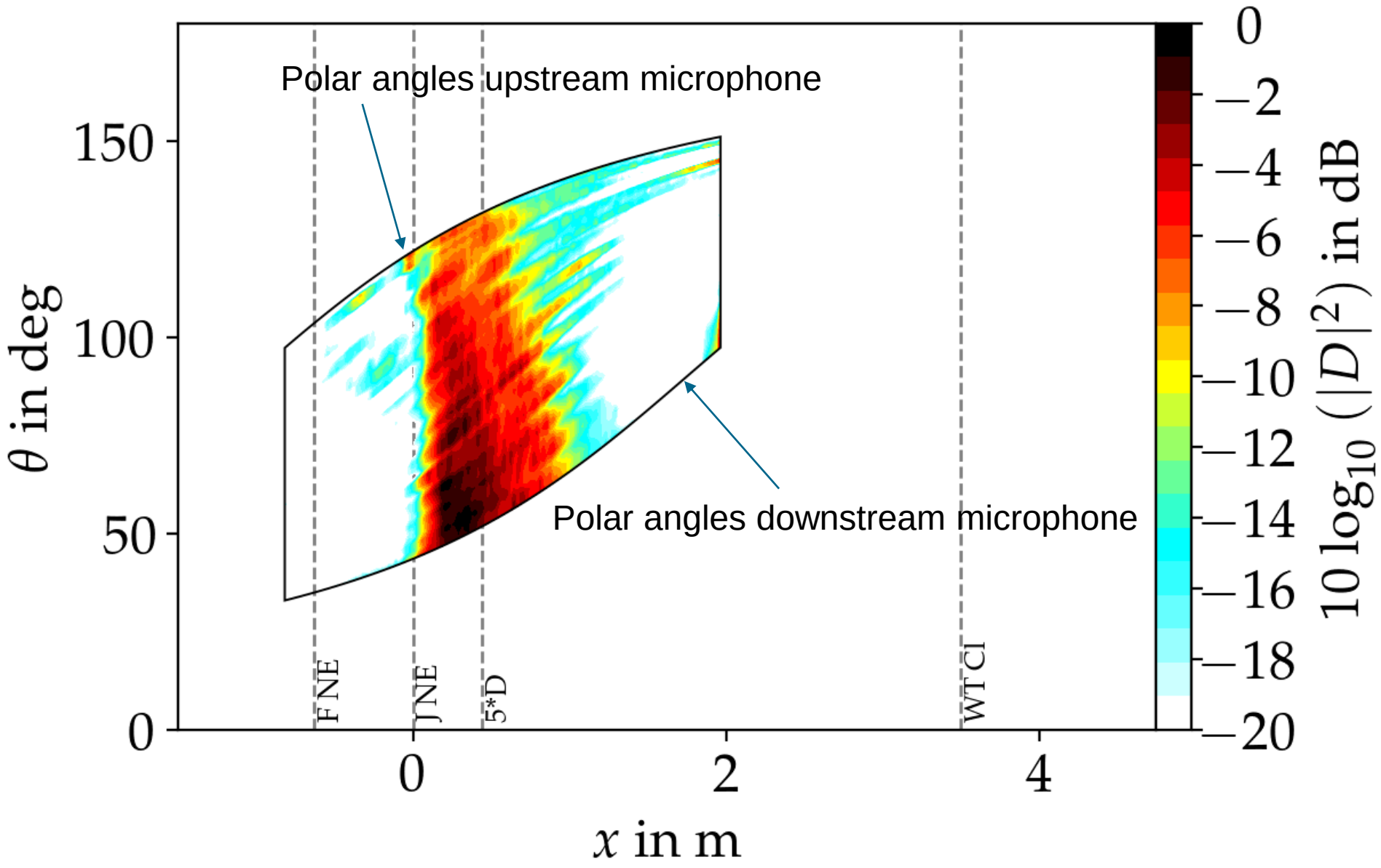
Static jet

- P2
- Velocity ratio 1
- M=0.75
- Equivalent to single stream

SODIX interrogation region includes the whole extension of the wind tunnel

- BE-SL array
- Geometrical near field
- Reduced length at increased frequency

SODIX Solution at 4*frequency



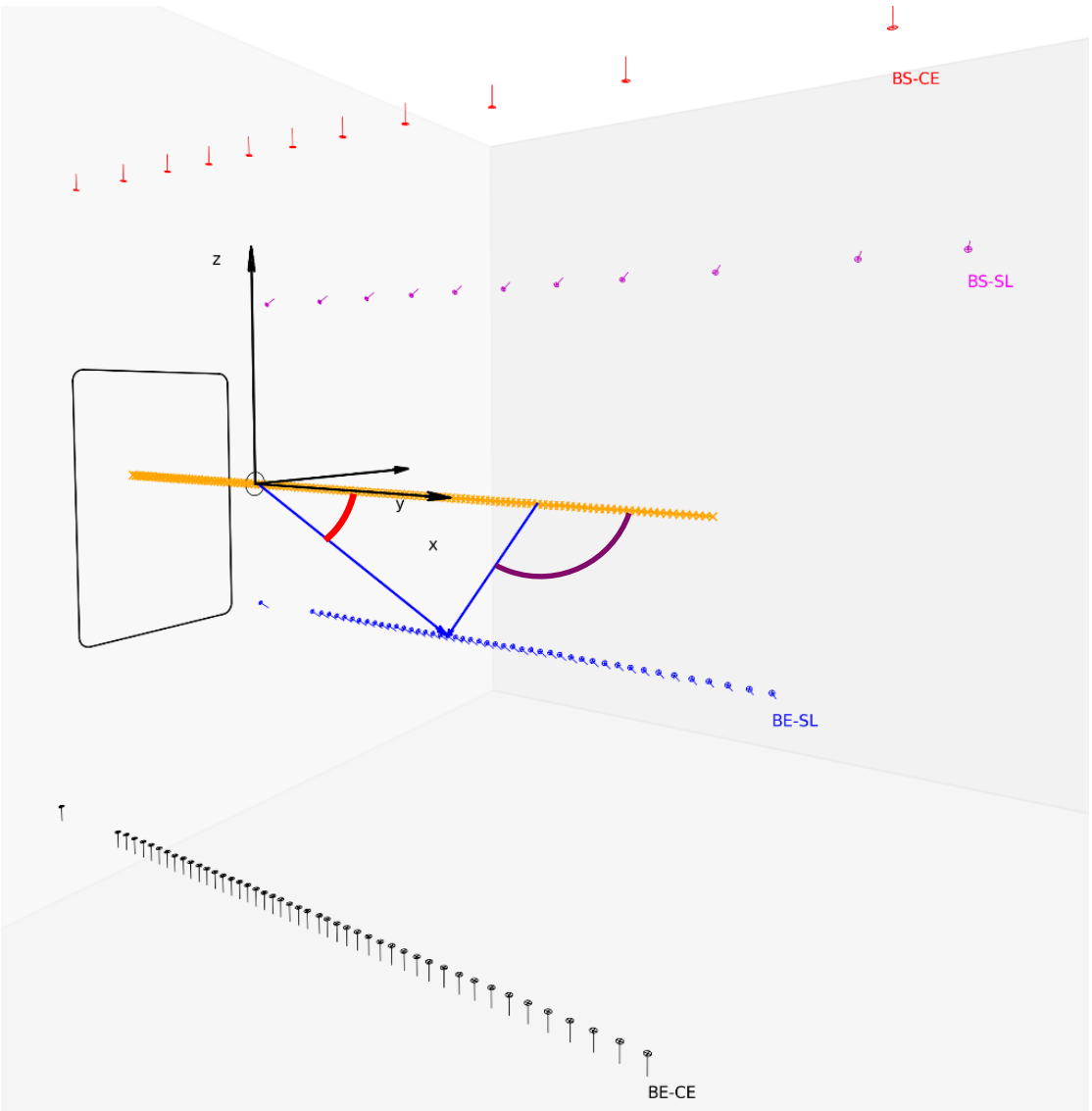
Static jet

- P2
- Velocity ratio 1
- M=0.75
- Equivalent to single stream

SODIX interrogation region includes half extension of the wind tunnel

- BE-SL array
- Geometrical near field
- Reduced length at higher frequency

Geometrical near field

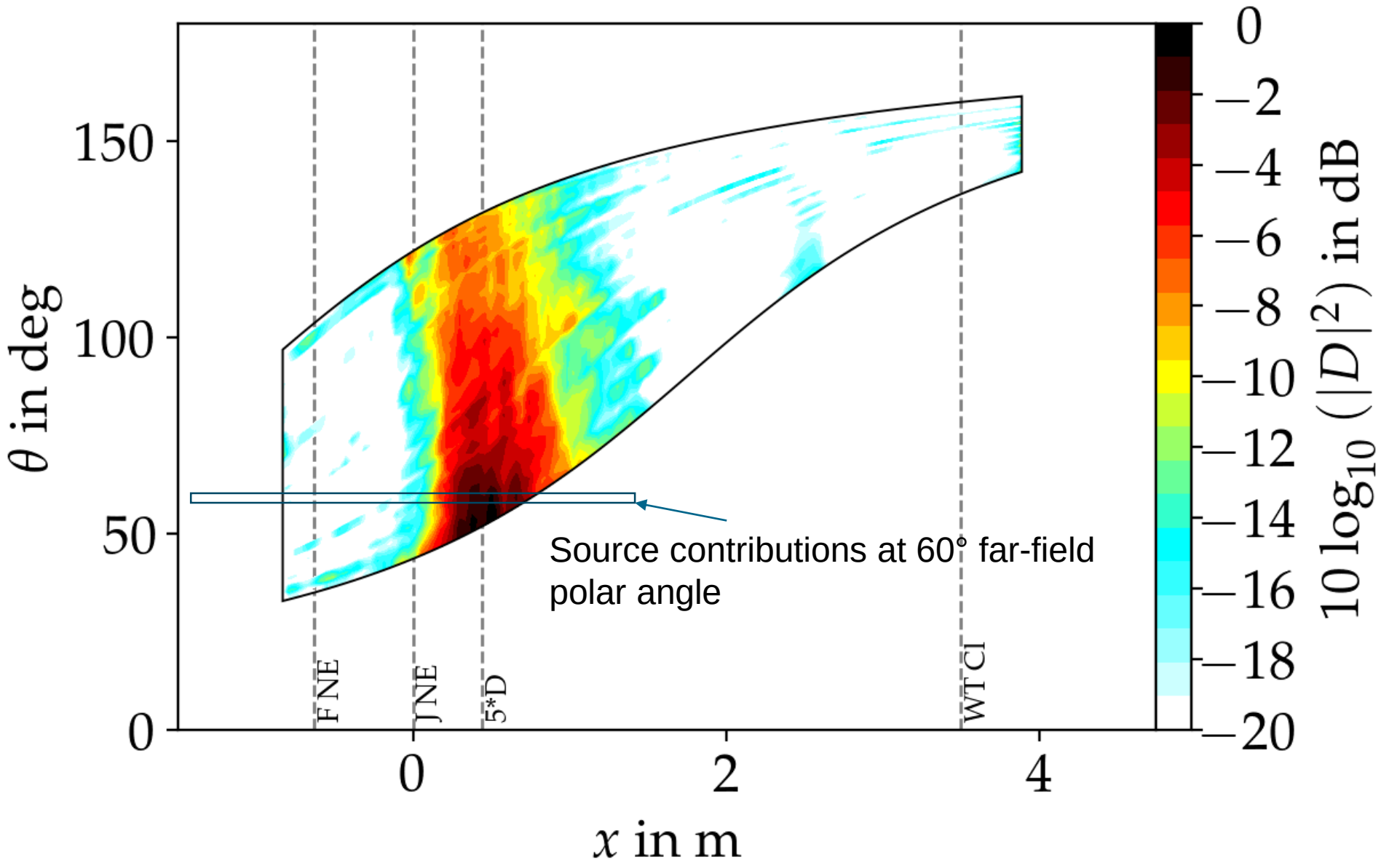


Microfones are placed few diameters away from jet axis:

- Different sources see a single microphone at different polar angles
- SODIX enables an extrapolation to far observer positions
  - Sum of effect of the axially distributed sources
    - Radial spreading
    - Possible atmospheric attenuation

- Identification of reference aeroacoustic data measured at large distance
  - QinetiQ data issued for EU project JEAN
  - NTF (Noise test facility) Farnborough UK
  - Measured at over 100 D

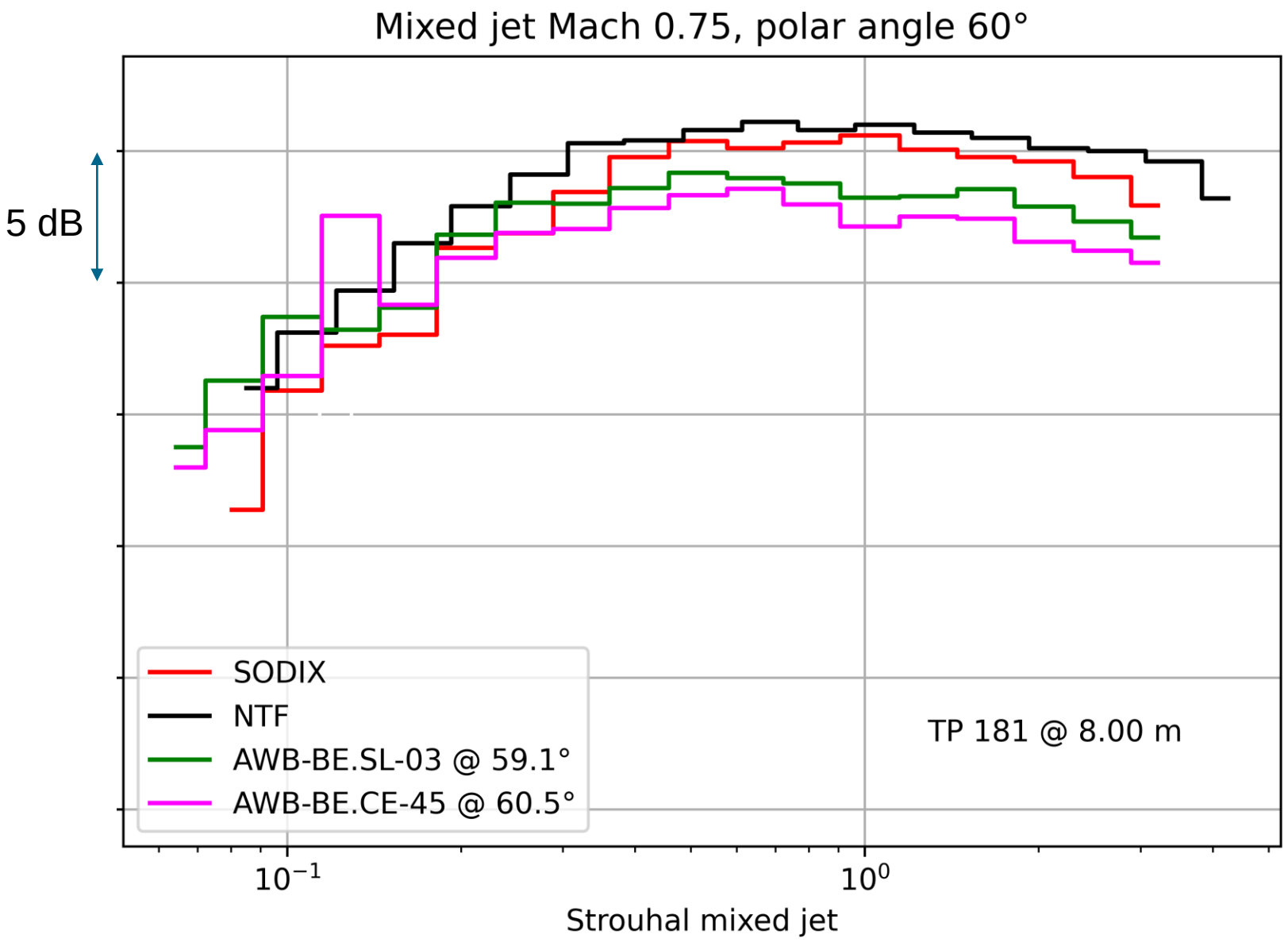
SODIX extrapolation



SODIX interrogation region is integrated, for each frequency band, across the line describing the polar angle dependence at varying source.

1. For a far observer the polar angle dependence is defined for each point source.
2. The strength is interpolated within the directivity limits of the sources.
3. All contributions within the array limits are added up for all frequency bands

Extrapolation to large distance SODIX vs Reference



Static jet

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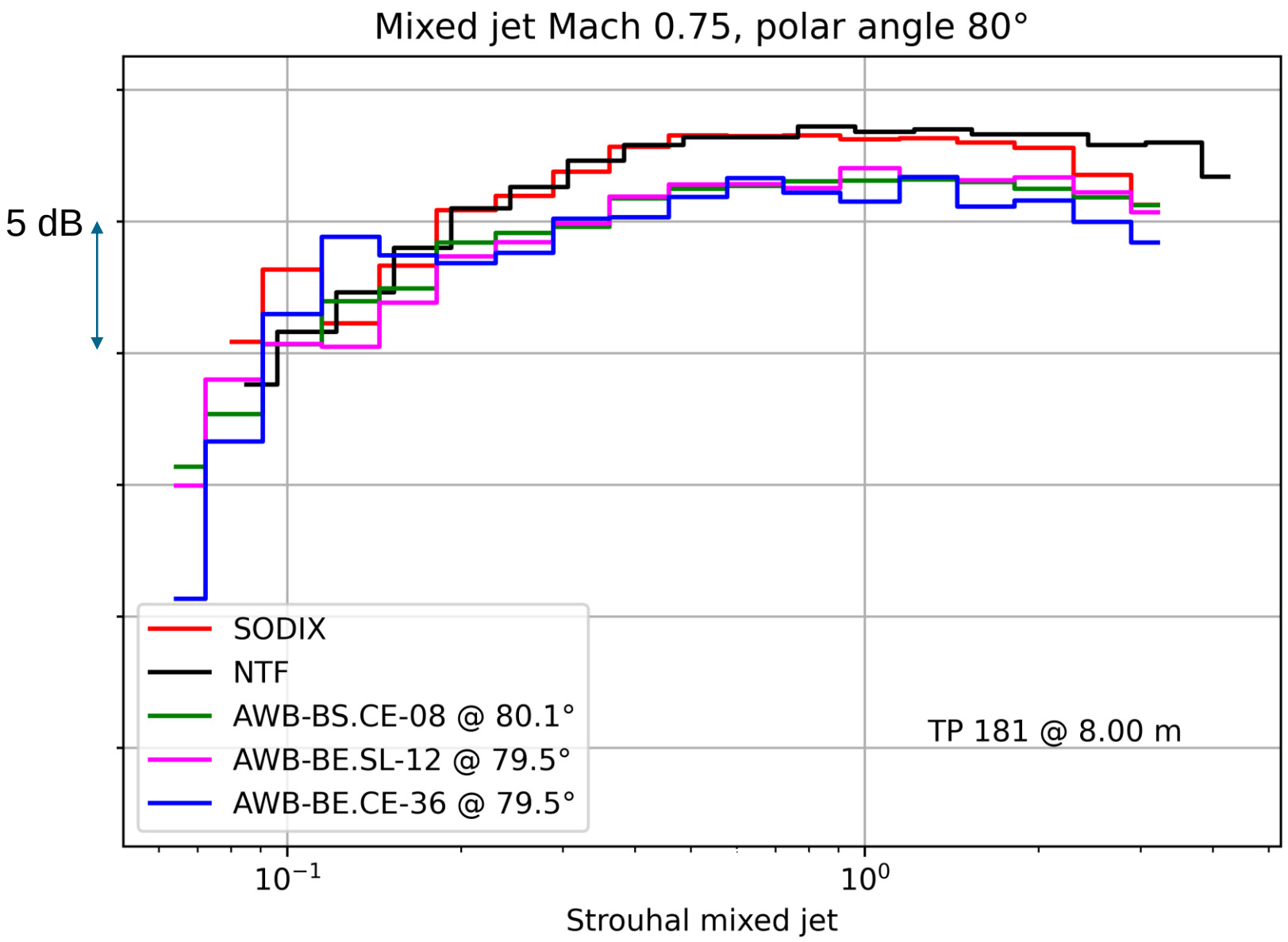
- Velocity ratio 1
- M=0.75, D=80 mm
- Equivalent to single stream

SODIX extrapolation includes sources from nozzle to 25 D downstream

AWB-*** single-channel extrapolations, made with frequency-fixed source center

NTF reference data, measured at over 100 D

Extrapolation to large distance SODIX vs Reference



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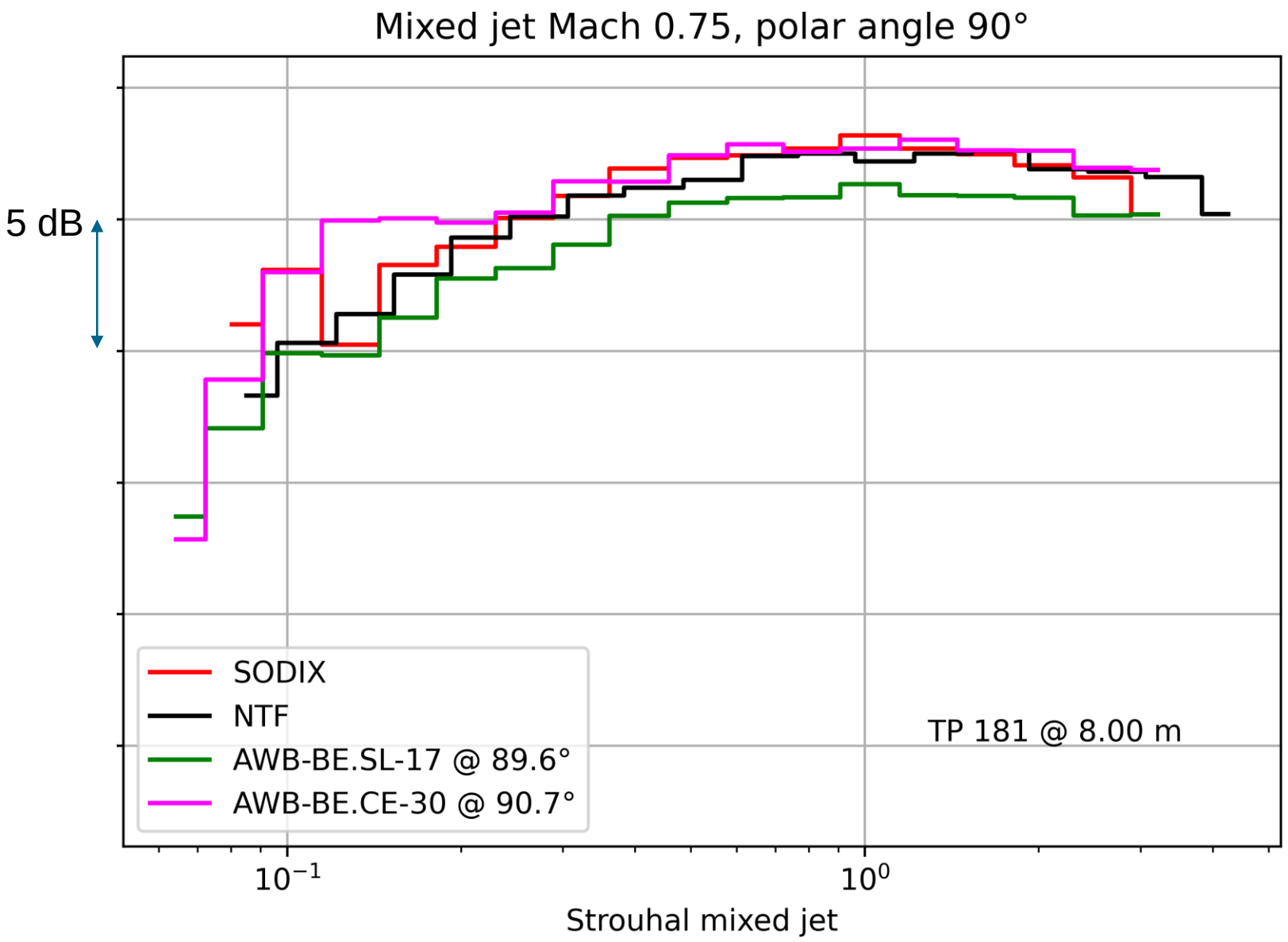

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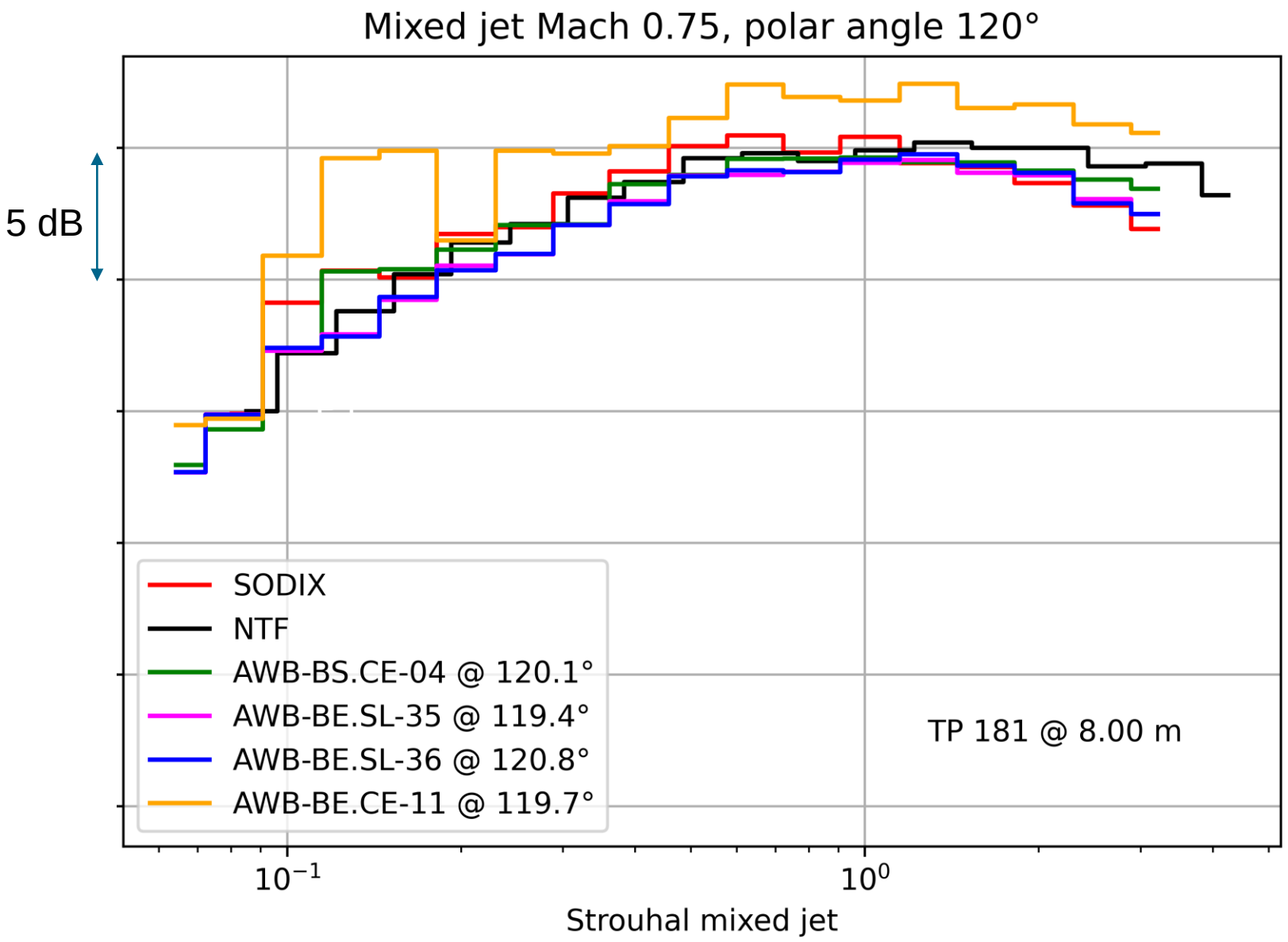

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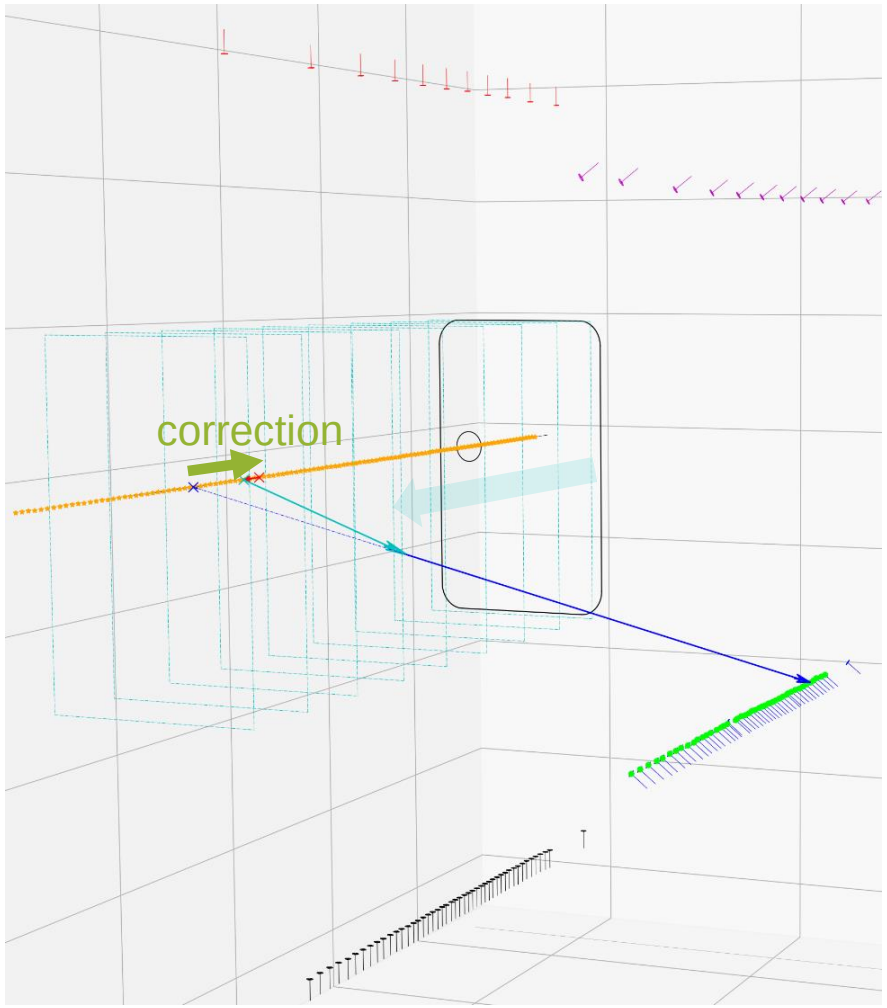
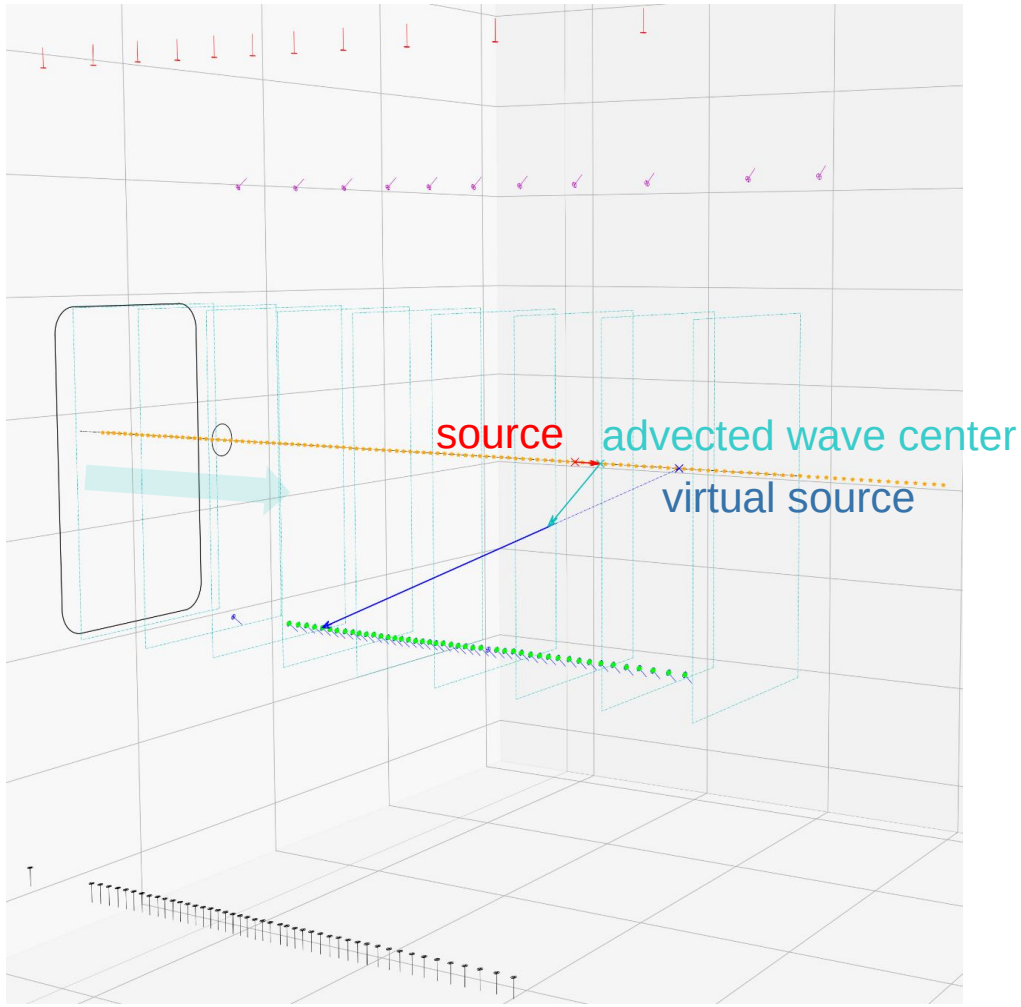
NTF reference data, measured at over 100 D

A-posteriori flight-simulation correction





Ray tracing based on a thin shear layer flow waveguide

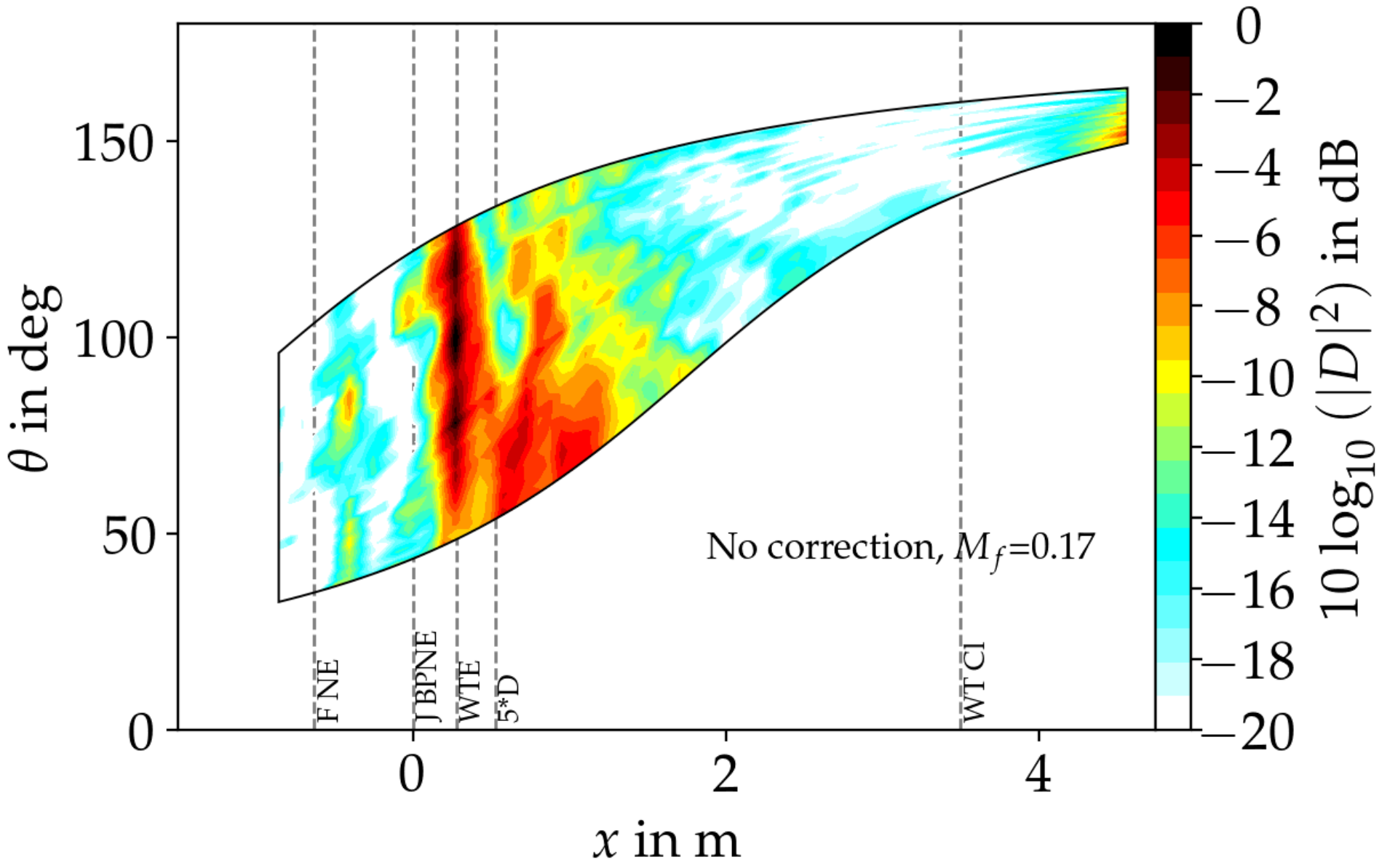
SODIX with free-space & quiescent medium Green´s function:

– x virtual sources

Correction vector →

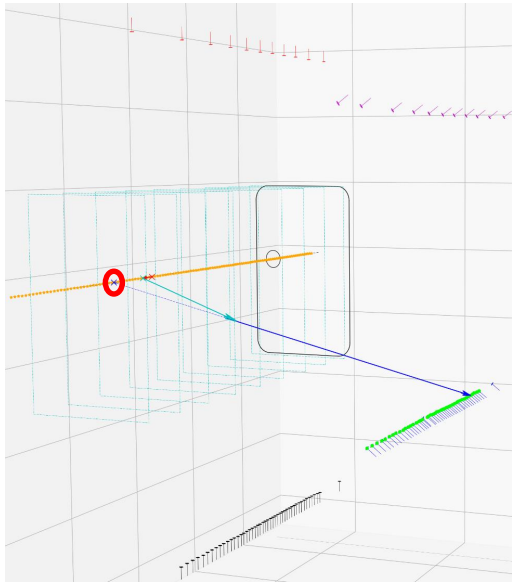
– back to real sources x from virtual sources x

Virtual source map

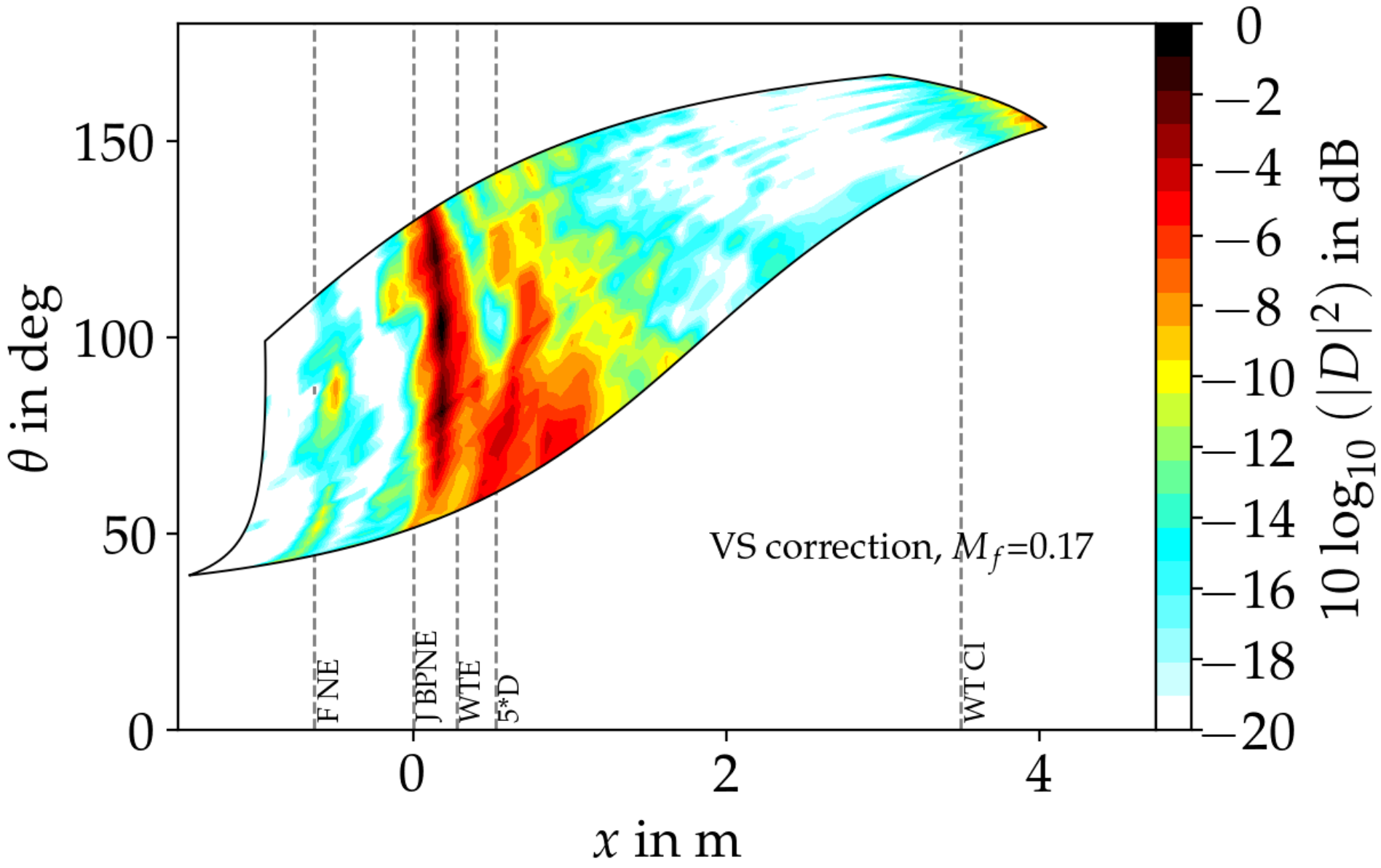


Installed jet

- P1, BL flap
- M_mix=0.76



Corrected source map



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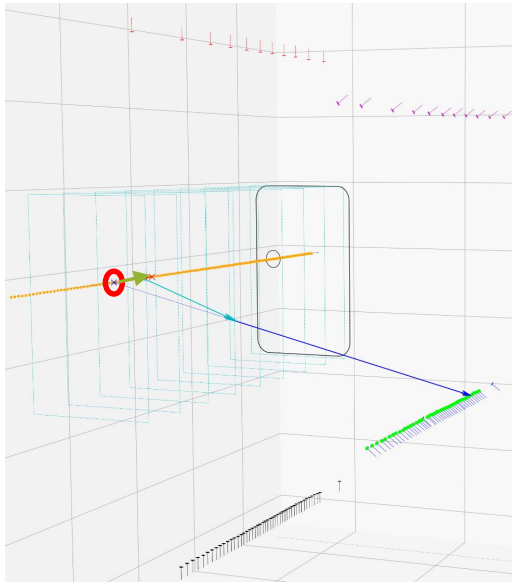
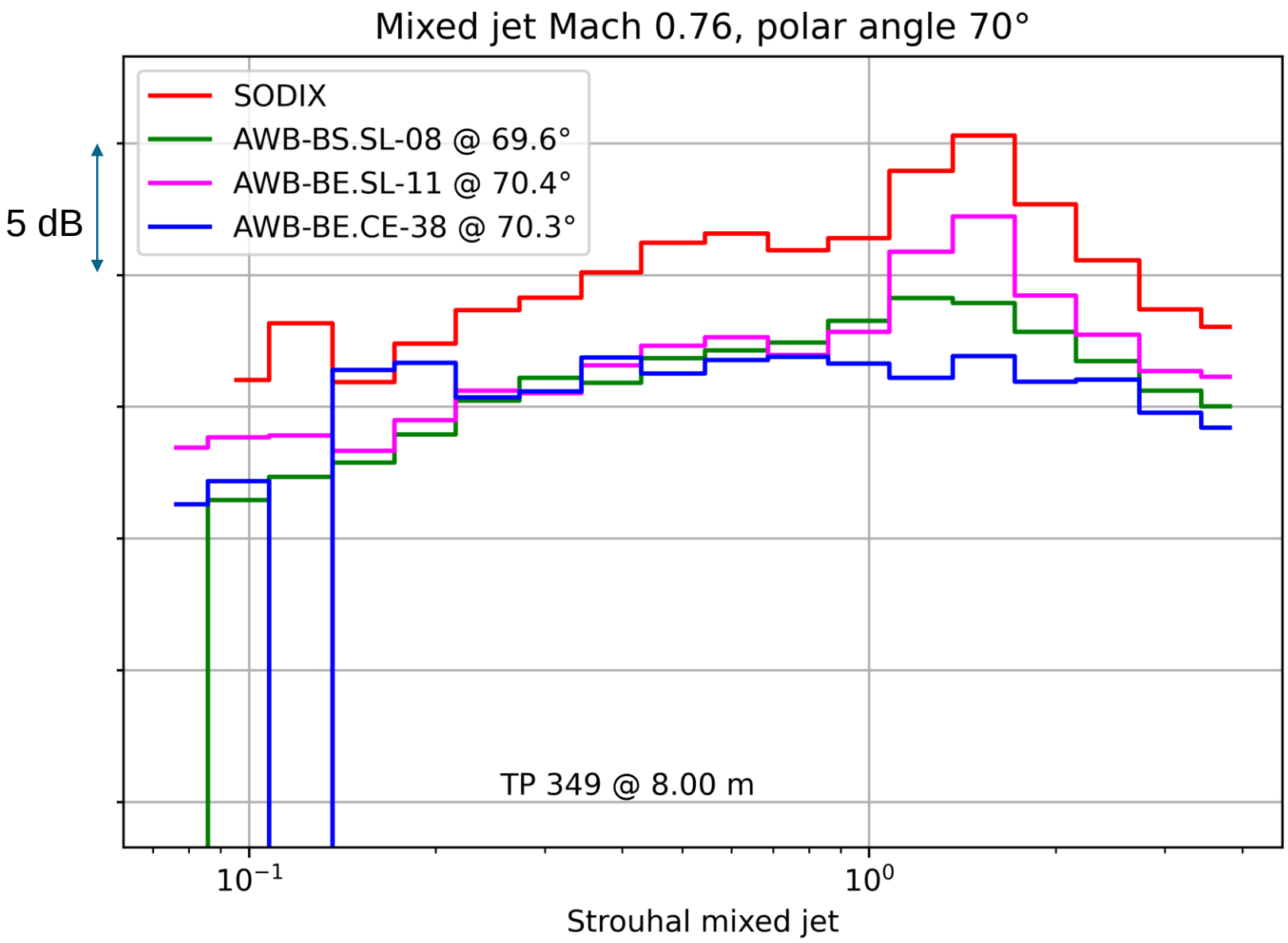


Extrapolation to large distance SODIX vs single-channel



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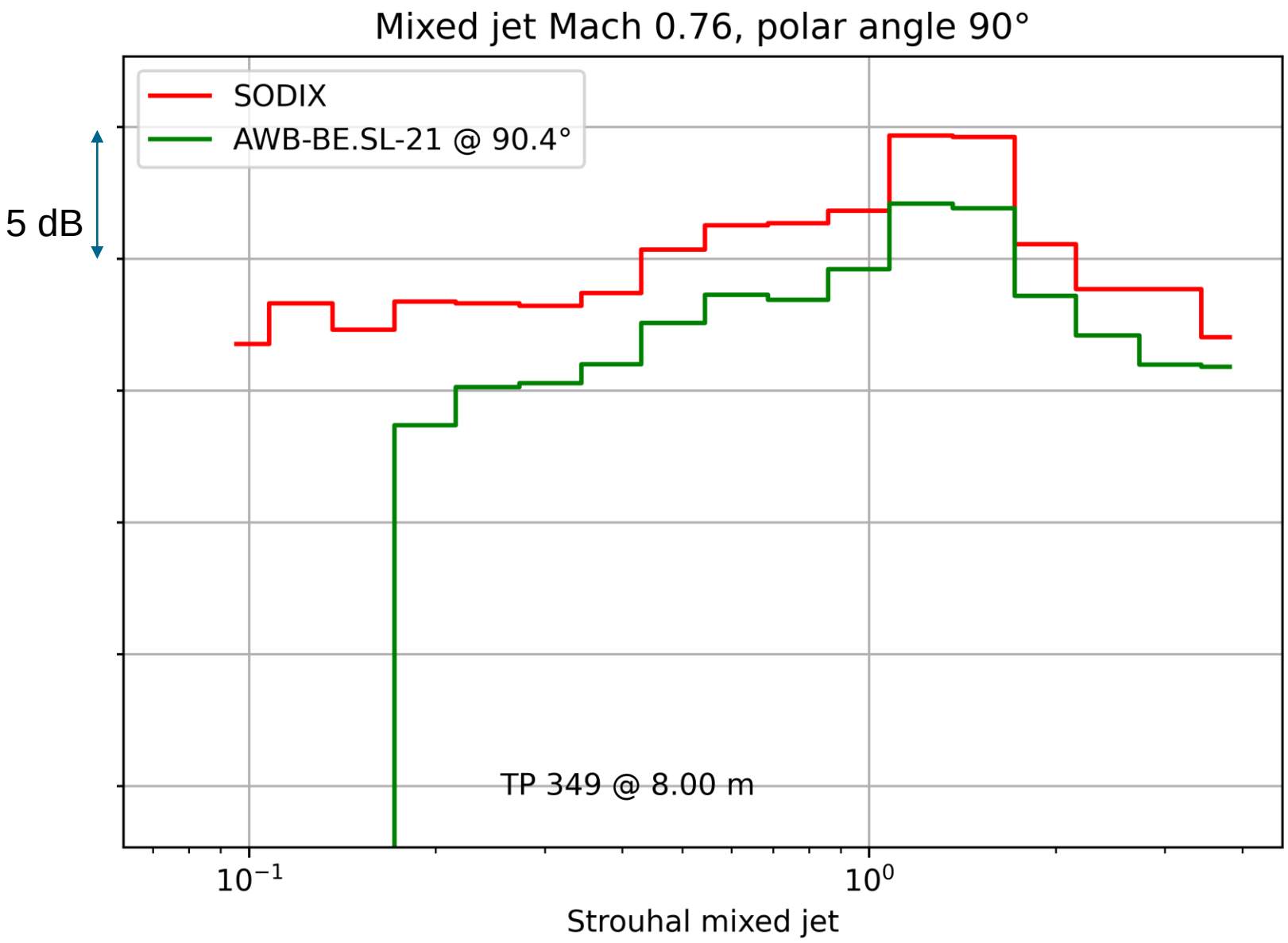

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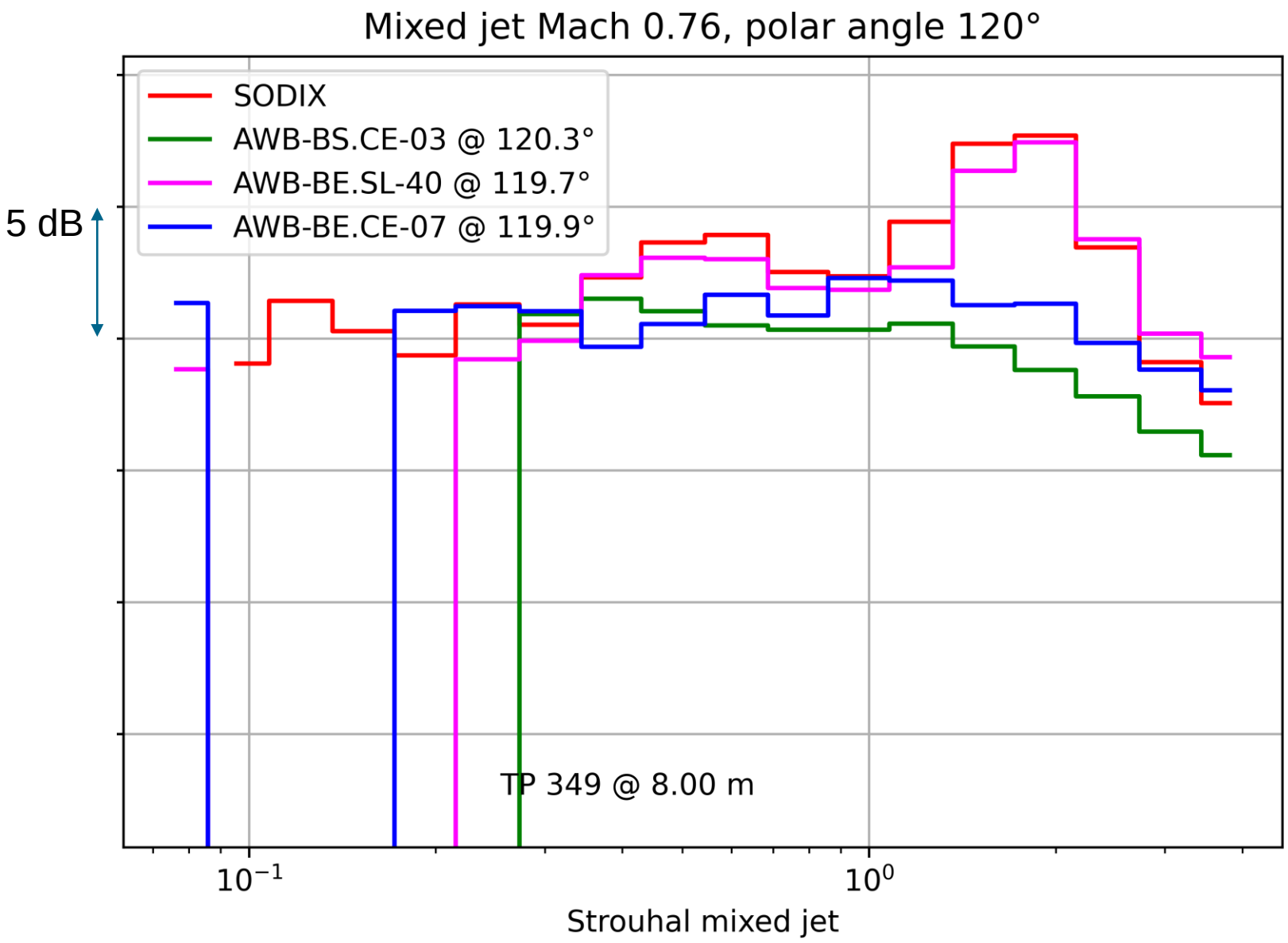

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SODIX extrapolation includes sources from nozzle to 25 D downstream

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Conclusions

Challenges in wind tunnel measurement of jet installation noise

- Size of anechoic chamber limits the acoustic measurement to the source´s geometrical near field
- Shape of the flight simulation nozzle or off-axis sources make difficult the application of Amiet´s theory

Linear-array measurements can be used to extrapolate the noise field to positions beyond the wind tunnel geometrical limits

- SODIX solutions associated with a static jet have been extrapolated to 100 D
  - Compare well to reference data acquired in a very large aeroacoustic facility at polar angles > 60°
    - The current implementation only interpolates within the source-microphone polar angles: lower downstream polar axes are underestimated if the source region is not contained in the source map
  - Solutions are generated directly from the measurement: the definition of a source centroid is not required
  - Improved accuracy at lower polar angles, compared to single-microphone extrapolation
- Sodix solutions for flight-simulation installed jet have similar offset to single-sensor solution as for static case

Ray acoustics approach has been implemented for flight-silmulation corrections

- Numerically efficient alternative to Amiet´s method which handles elliptic or rectangular flow-column sections and allows for arbitrary positioning of the source within the flow column
- Used to correct virtual source maps, can be used to generate SODIX solutions with flow-waveguide Green´s function

Thanks for your attention

Any Questions??? ☺

Acknowledgments

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