ITER ECH Transmission Lines

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GA: R. Callis, J. Doane, J. Lohr, C. Moeller, R. Olstad

VLT Conference Call January 21, 2009

Topics

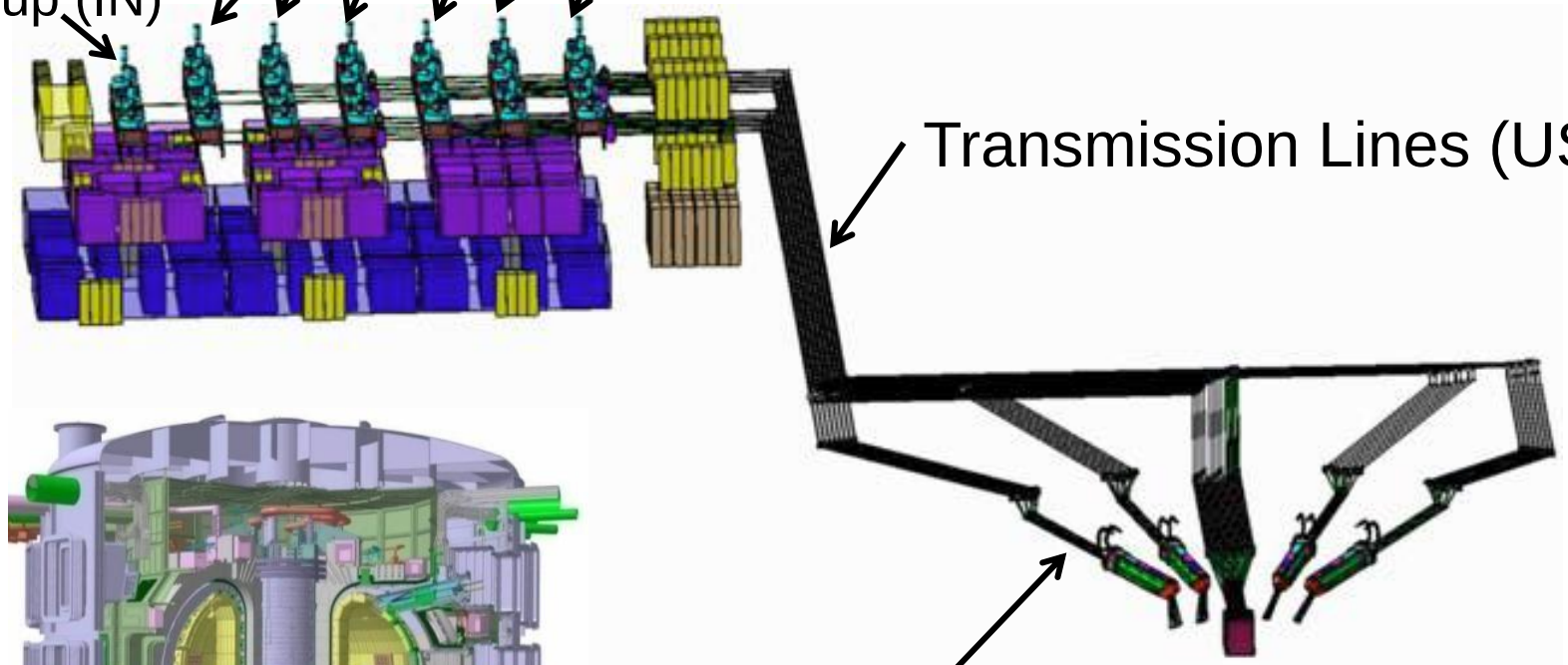
- Introduction and Overview of US Program for ITER ECH Transmission Lines

- Measurement of Losses:
  - Theory
  - Experiment

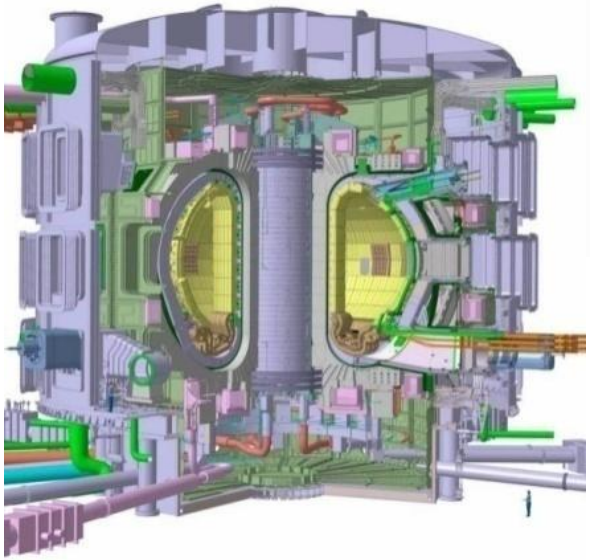
ECH/ECCD System for ITER

3 start-up (IN)

24 MW, 170 GHz Gyrotrons (EU, JA, RF)



Transmission Lines (US)



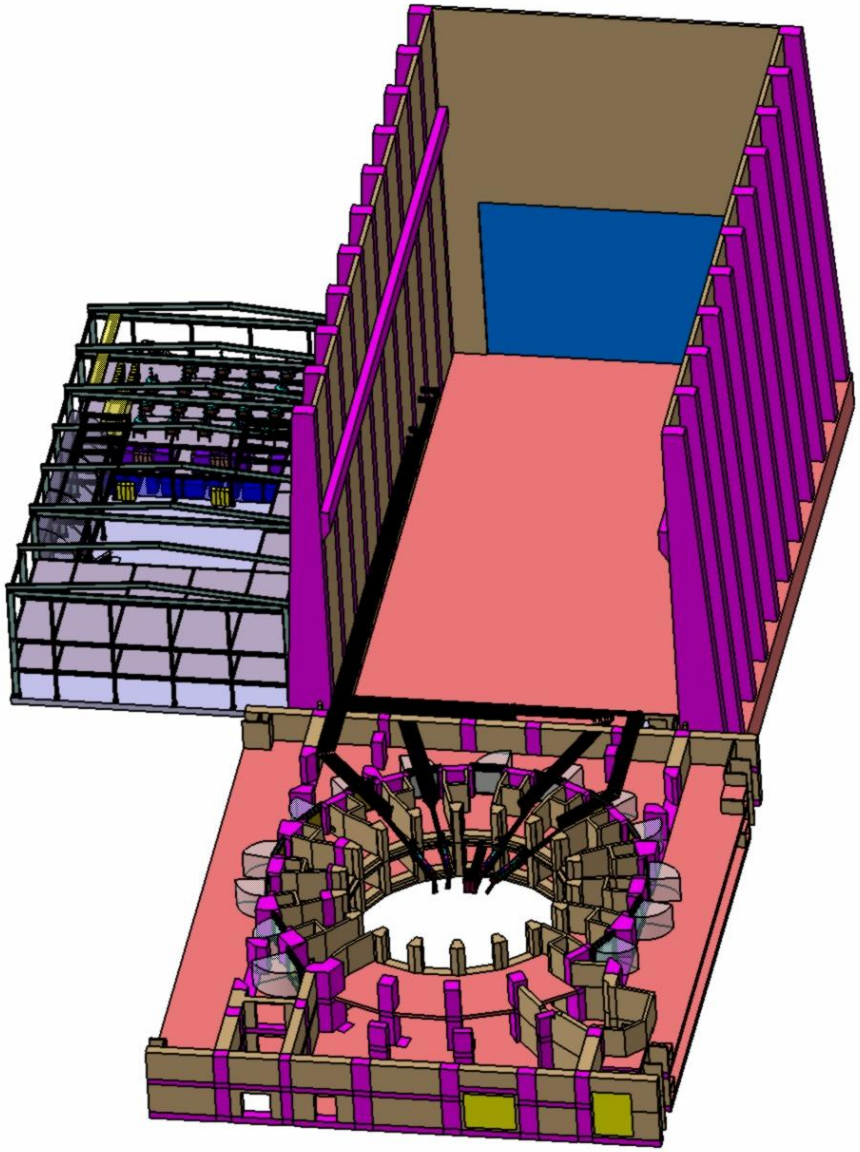
New, improved ITER

Launchers (EU, JA) at the tokamak ports

20 MW at plasma

Courtesy M. Henderson, ITER

ECH Transmission Lines



- 170 GHz, 1 MW per line
  - 2 MW per line if 2 MW gyrotrons are built
- 24 – 48 MW, total
- > 4000 m precision waveguide
- > 300 miter bends
- Required Efficiency
  - 20/24 = 83%!

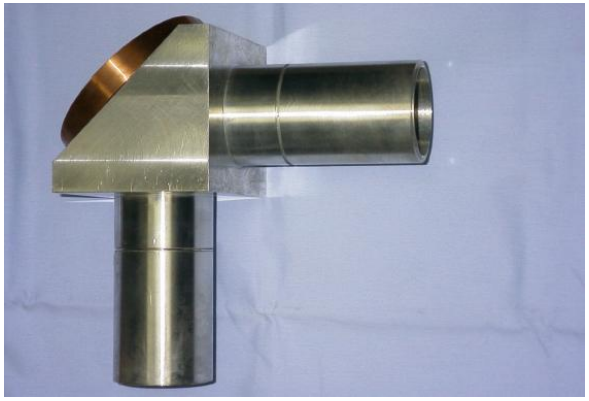
Courtesy T. Bigelow, D. Rasmussen

ECH Test Facility at ORNL

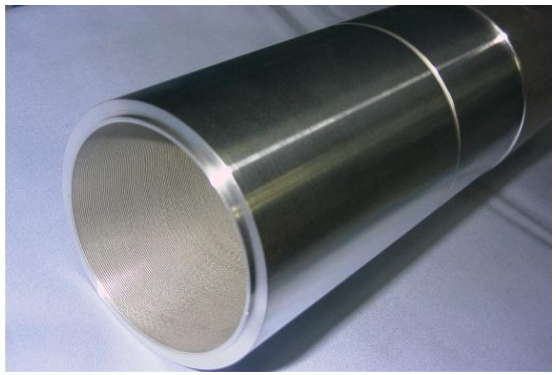
- US ITER ECH headed by IPO / ORNL
  - D. Rasmussen, T. Bigelow, J. Caughman
- Layout, specifications, etc.
- Will build a 170 GHz CW gyrotron test facility for testing prototype components
- Initial test results will be obtained with available 140 GHz gyrotron

General Atomics Components

- General Atomics has extensive experience in transmission lines for 1 MW power level



Miter Bend



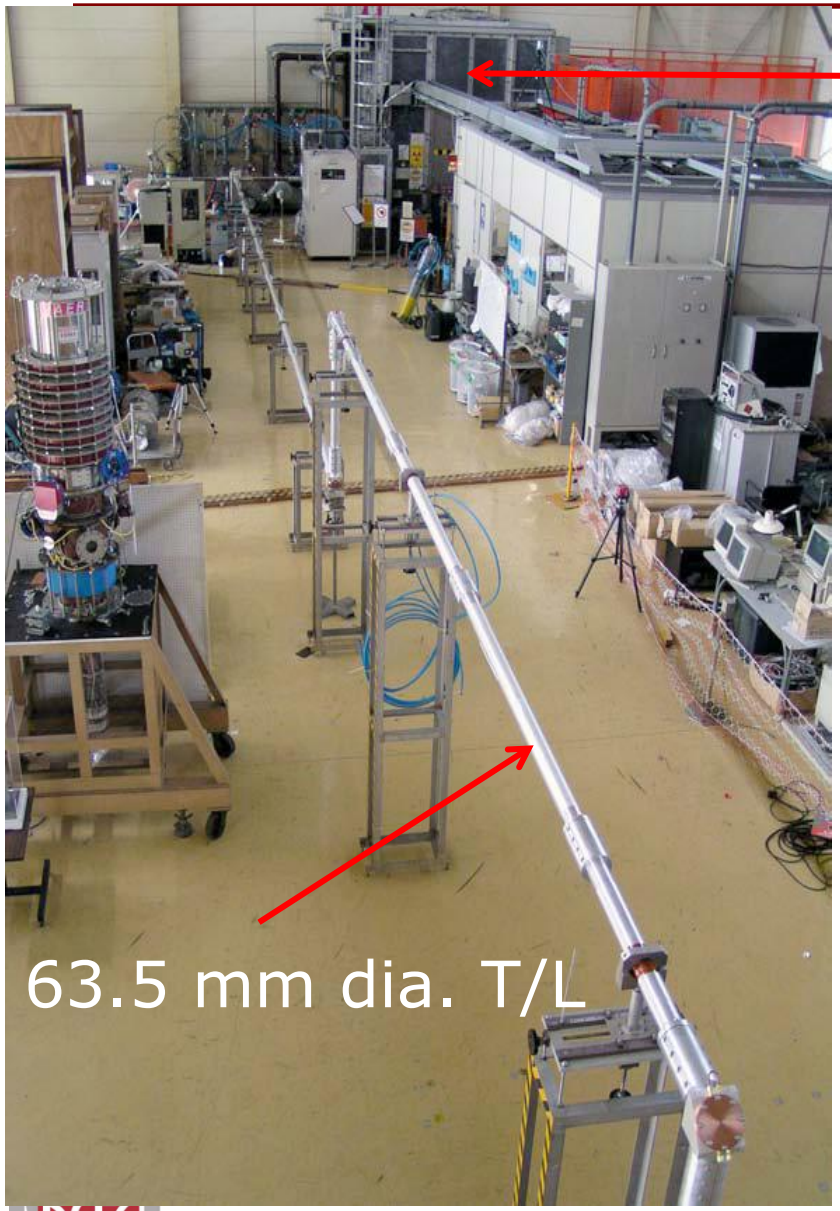
63.5 mm Corrugated waveguide
$\lambda/4$ = 0.44 mm corrugations

Switch

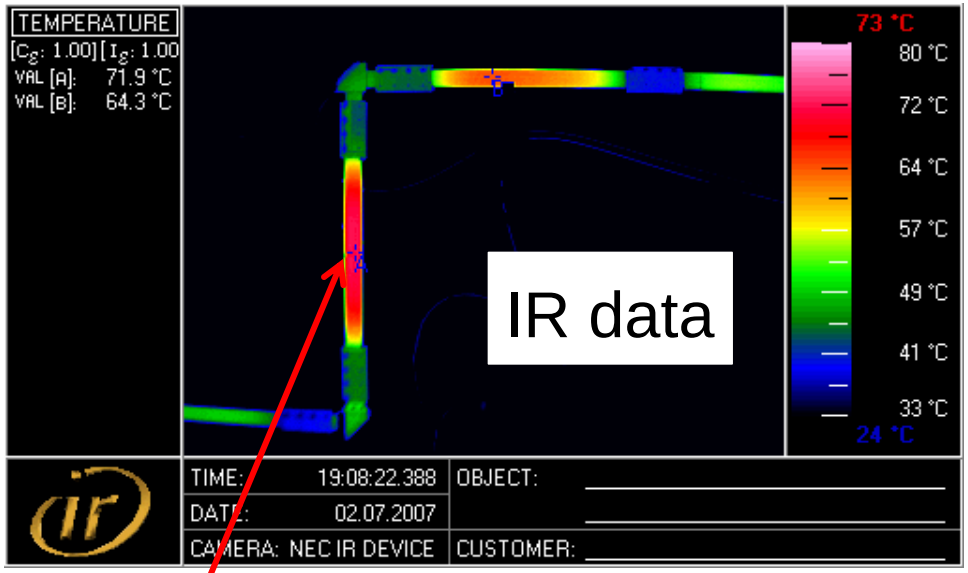
- **HE_{11} mode in 63.5 mm diameter waveguide**
- **Ongoing tests of advanced GA components at JAEA**

J. L. Doane and R. A. Olstad, "Transmission Line Technology for ECH," Fusion Sci. Technol., Vol. 53, 39-53 (2008).

JAEA T/L Test



1 MW, 170 GHz Gyrotron



Trapped Mode, $\Delta T \approx 50\,℃$

- **Complete test set up at JAEA: Gyrotron, Trans. Line, Launcher**
- **Collaboration with US on T-Line Testing; GA Components**

VLT Virtual Laboratory for Technology For Fusion Energy Science

Losses in ITER ECH T/L

Losses	ITER DDD 5.2 Estimate	MIT Estimate (2007)*
Injection Loss		
Coupling Loss, Tilt, Offset	0.035 dB	0.116 dB
Intrinsic Loss		
Miter Bends	0.248 dB	0.190 dB
Polarizers	0.044 dB	0.066 dB
Extrinsic Loss		
WG Sag, Tilt, Offset	0.078 dB	0.075 dB
Other Loss (incl. straight guide)	0.025 dB	0.043 dB
Total Loss	**0.43 dB (10%)**	**0.49 dB (11%)**

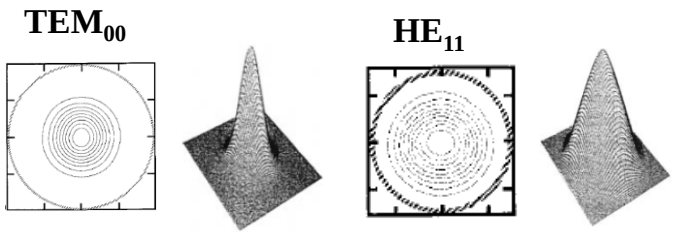
Main loss

- **Estimated Transmission line Losses appear consistent with requirement of < 17% Loss**
- **But, these calculations assume a pure HE_{11} mode is excited on the transmission line.**

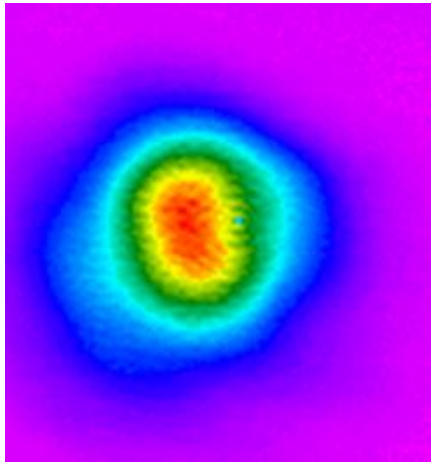
*From: S.-T. Han et al., Proc. IRMMW-THz, 2007

Problems with Higher Order Modes (HOMs)

- **HOM Effect on Insertion Loss:**
- The output beam of the gyrotron, a Gaussian (TEM_{00}) mode, is not a perfect match to the waveguide HE_{11} mode
  - Loss of ~2%



- The output beam of the gyrotron is not a perfect TEM_{00} mode.
  - Loss may be 5 to 10%

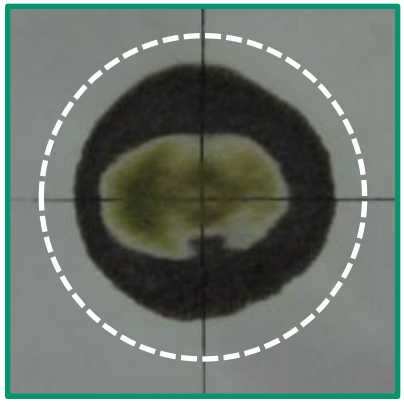


Typical beam, 1 MW, 110 GHz gyrotron (J Lohr, GA)

- **HOM Effect on Transmission Loss**:
  - Need to evaluate T/L loss with a multimode microwave beam; additional loss.

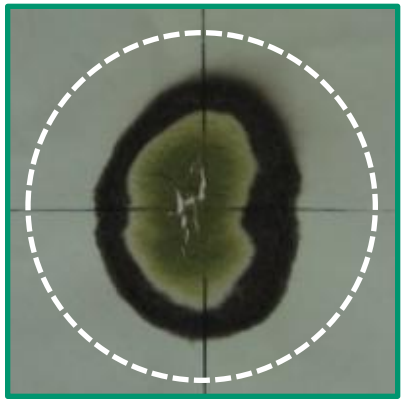
Higher Order Modes on a Transmission Line

Burn Paper measurements of 500 kW, 84 GHz CPI Gyrotron at KSTAR

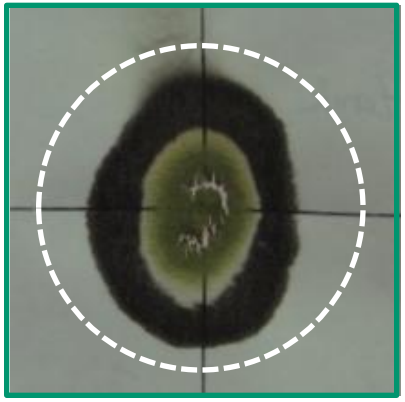


1. 0 mm

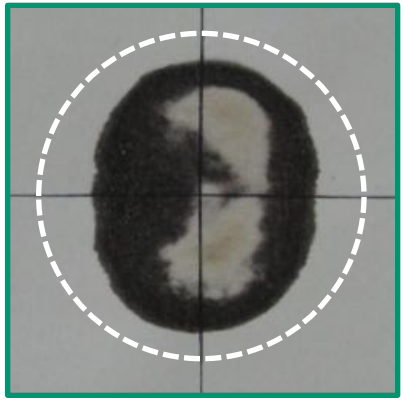
2. 748 mm



3. 958 mm (w/ M/B)



4. 1706 mm
(w/ M/B)

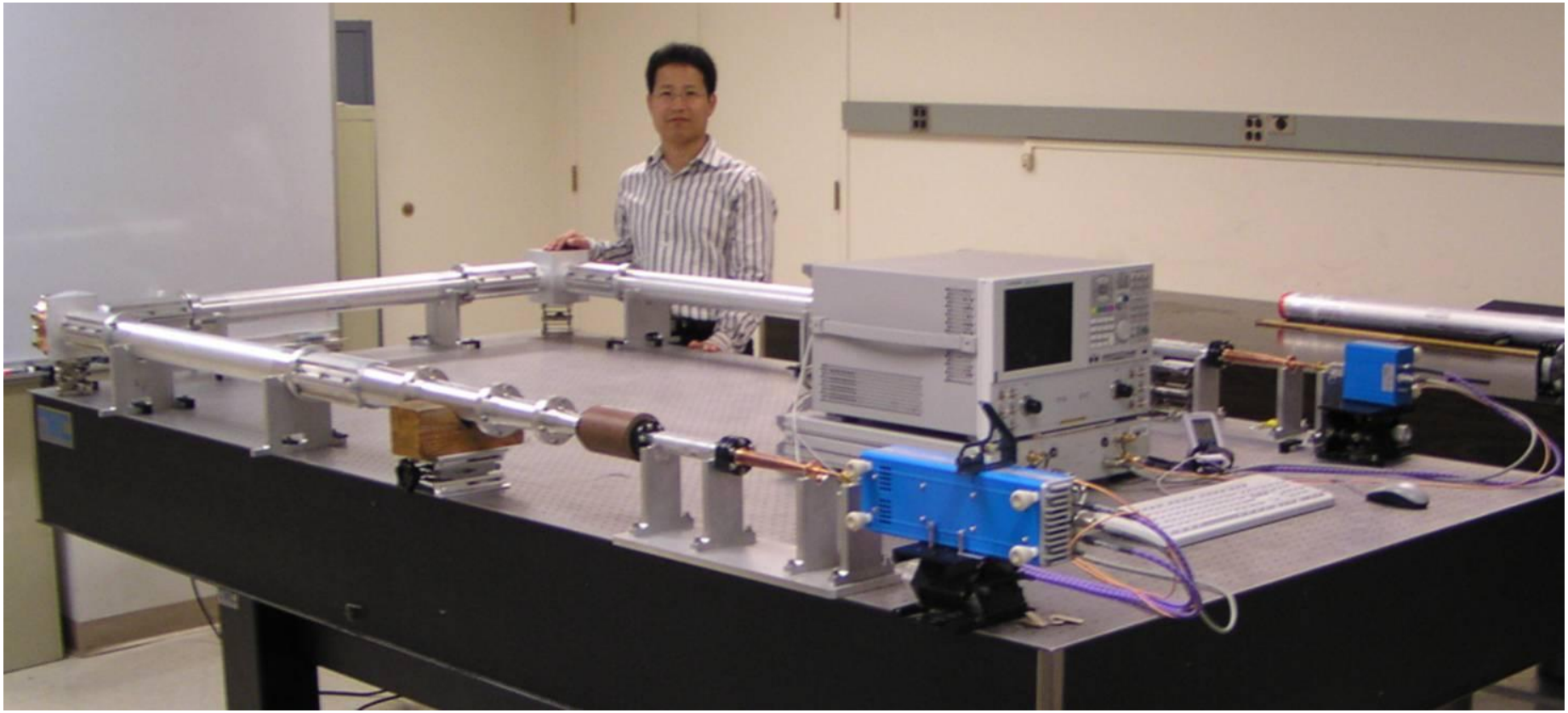


5. 3368 mm
(w/ M/B & WG S/W)

6. 3368 mm
(w/ M/B & WG S/W divert)

Courtesy M. Joung, KSTAR

ITER T/L Cold Test – VNA Measurement at MIT

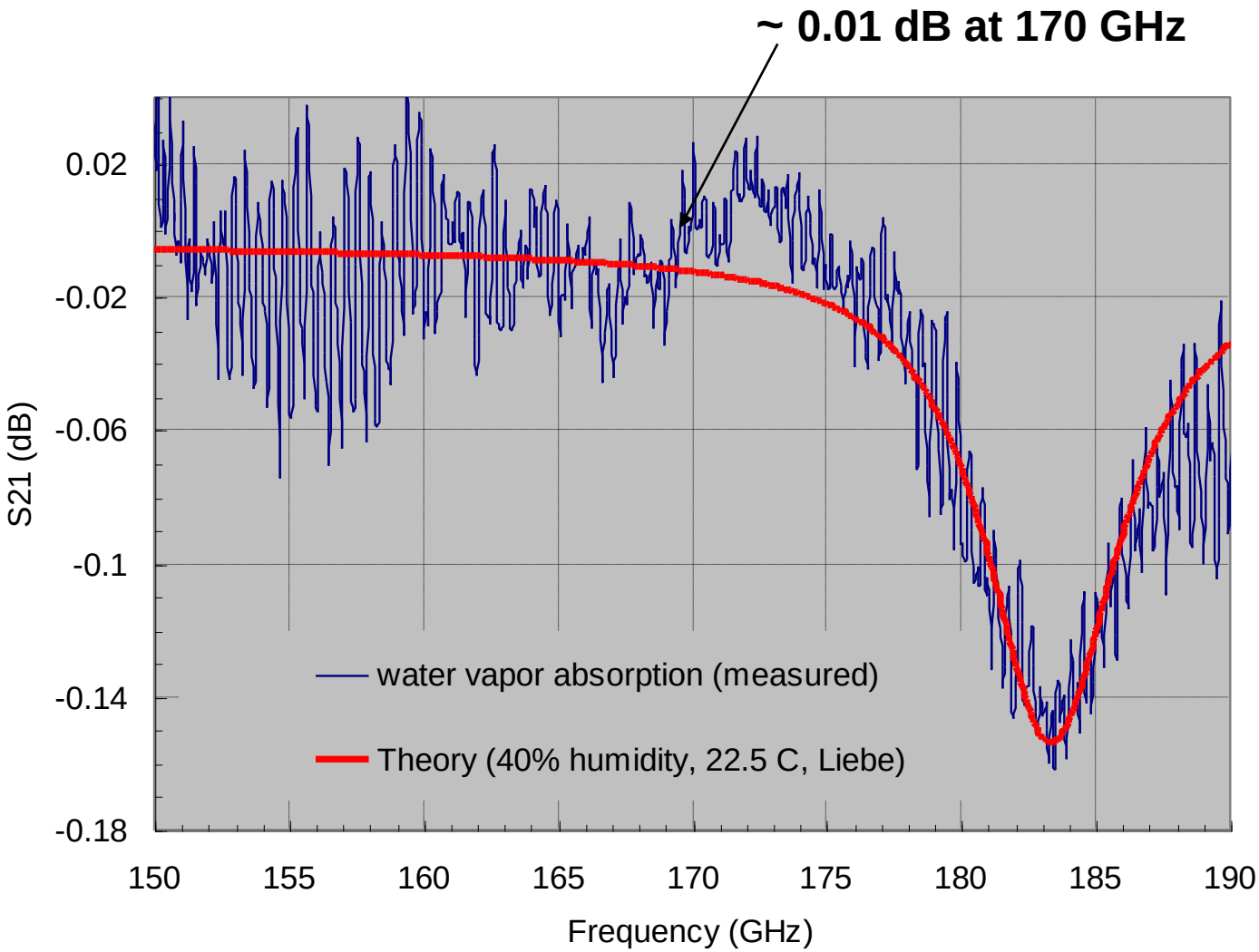


Device under test:

- 2 miter bends + 3 m straight w/g + 2 corr. tapers

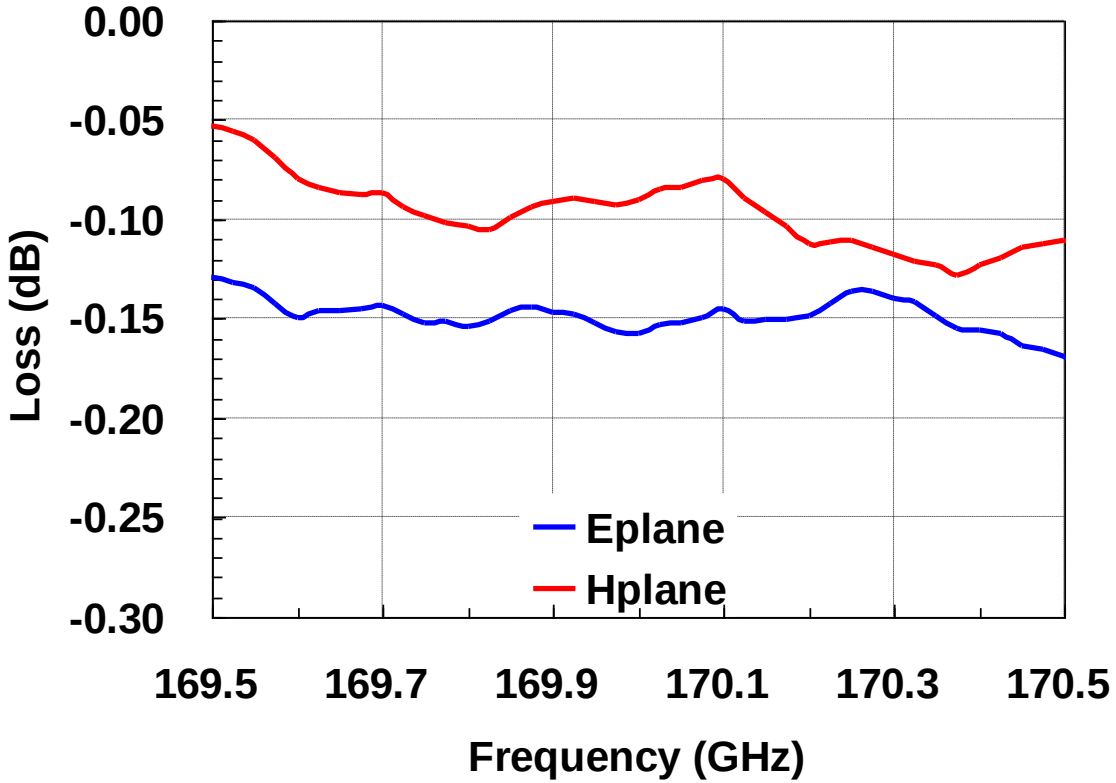
S. T. Han et al., Low-Power Testing of Losses in Millimeter-Wave Transmission Lines for High-Power Applications, Intl. J. IRMMW, v 29, n 11, p 1011-1018 (Nov., 2008).

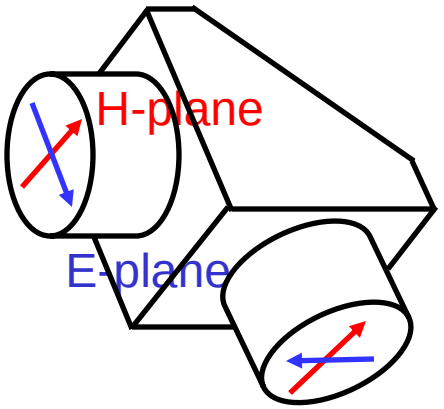
WATER VAPOR ABSORPTION



- Benchmark procedure by measuring water vapor absorption at 183.3 GHz
- The additional loss at 170 GHz is about 0.01 dB

Miter Bend Loss Measurement

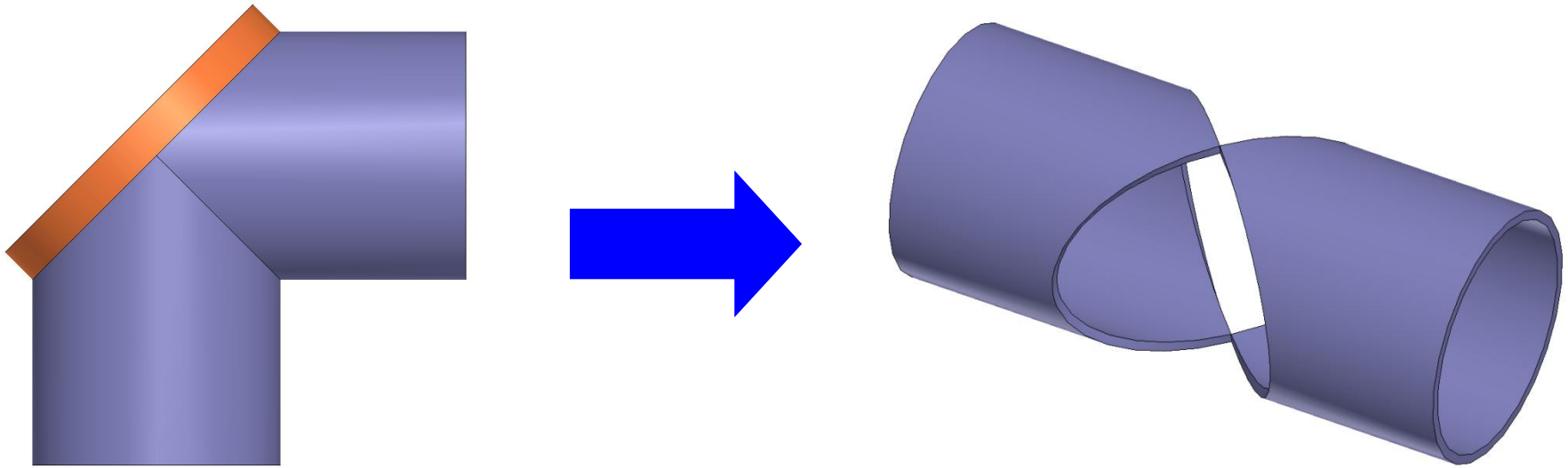




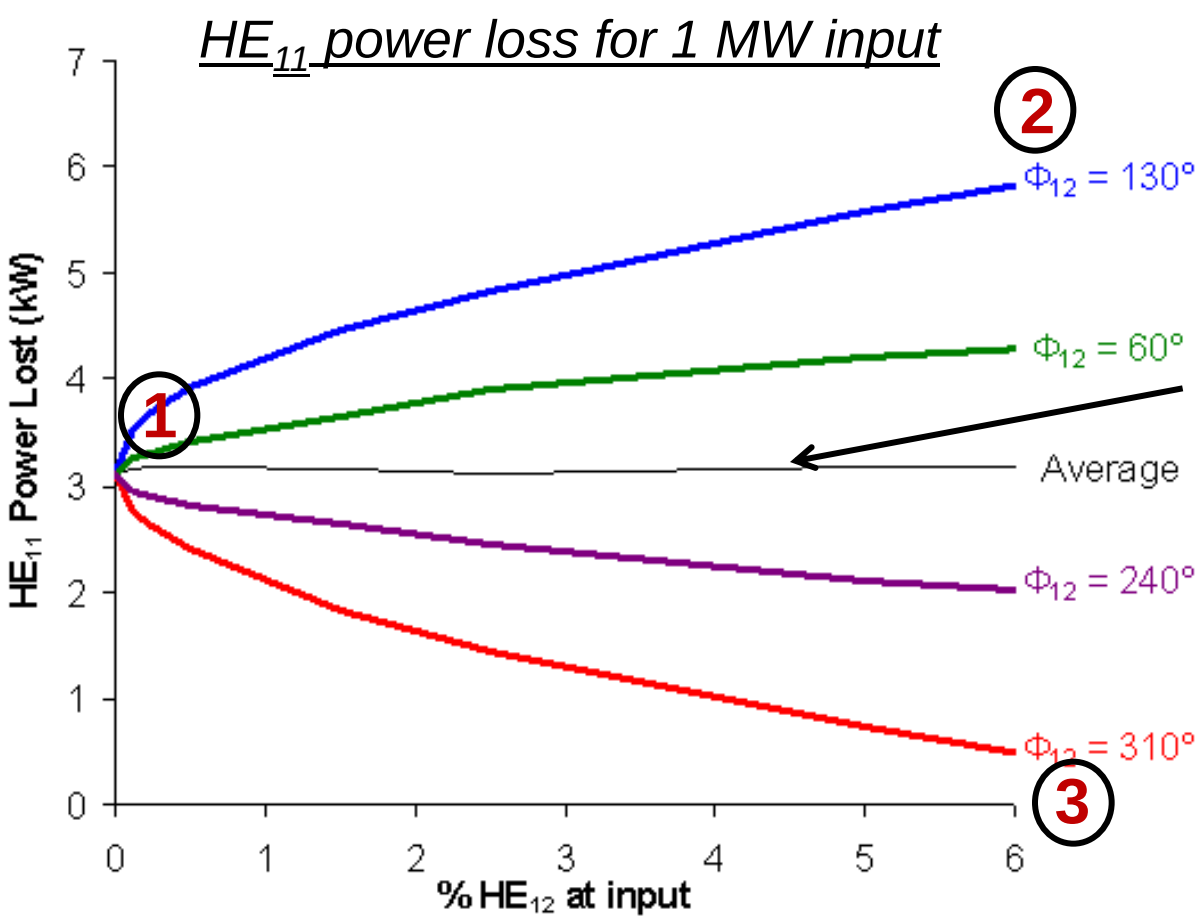
DUT (1 Miter bend)	Theory (dB)	Measured (dB)
E-Plane Bend	0.029	0.06 ± 0.02 dB
H-Plane Bend	0.025	0.05 ± 0.02 dB

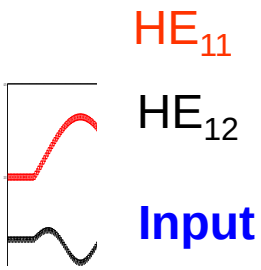
Loss Theory including HOMs

- Problem analyzed using new numerical code at MIT (Shapiro et al.)
  - Propagates fields represented as plane waves through a gap-like geometry (shown below) using an FFT-based algorithm

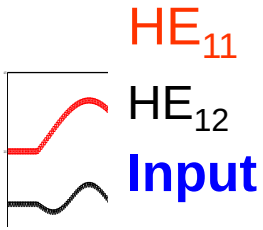


Miter Bend Losses with HOMs





Miter Bend loss when HOMs are ignored



- Small fraction of HOMs have a major impact on Miter Bend mode conversion losses!

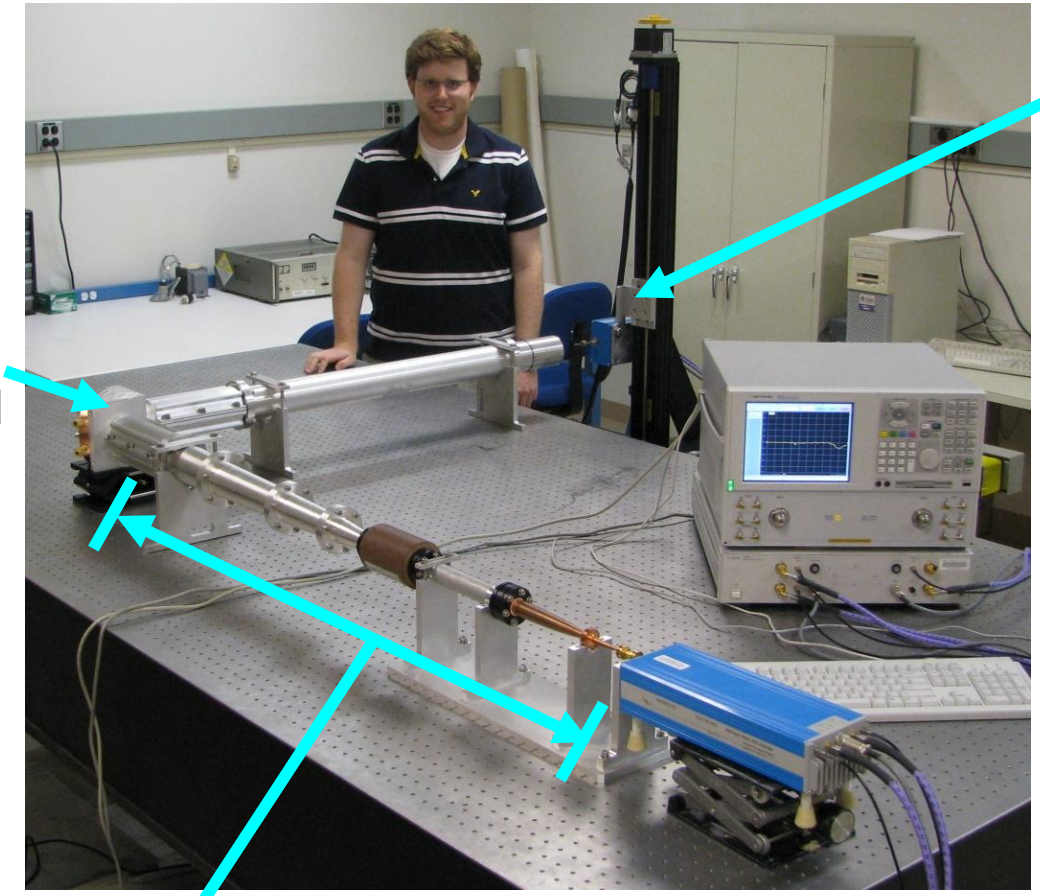
Implications of HOMs

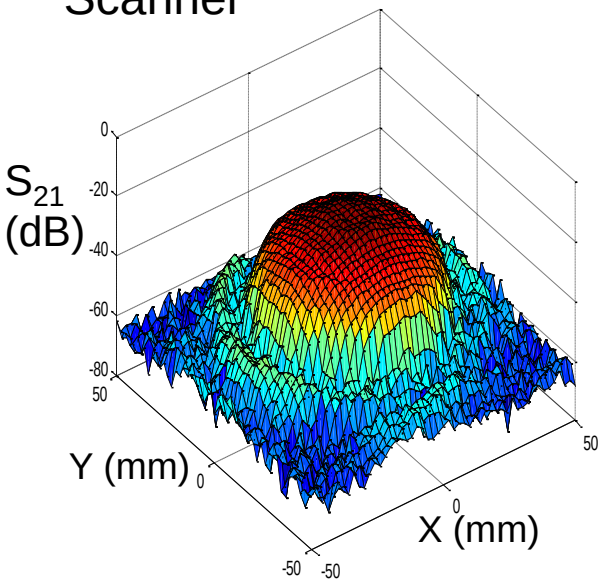
- Theoretical loss on ITER T/L must be evaluated for realistic values of the HOM content
  - Loss depends on HOM's amplitude and phase
  - Change of line length changes the loss

- Components designed for reduced mode conversion loss may not work as expected

→ Important to minimize HOMs injected into line
  → Need specifications agreed to by IO, EU, JA, RF!

Future Plans





Launcher (WR5 TE_{10} rectangular → Ø63.5mm HE_{11} mode converter)

Plans: Scans of mode patterns to measure mode conversion loss, HOM content

Acknowledgments

- Gyrotron Development Program – National Consortium within VLT

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Virtual Laboratory for Tech
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GENERAL ATOMICS

Users

CPI
Communications & Power Industries
CCR

Industry

MIT PSFC
UNIVERSITY of WISCONSIN MADISON
UNIVERSITY OF MARYLAND 18 56

Universities

- US ITER PO

U.S. ITER