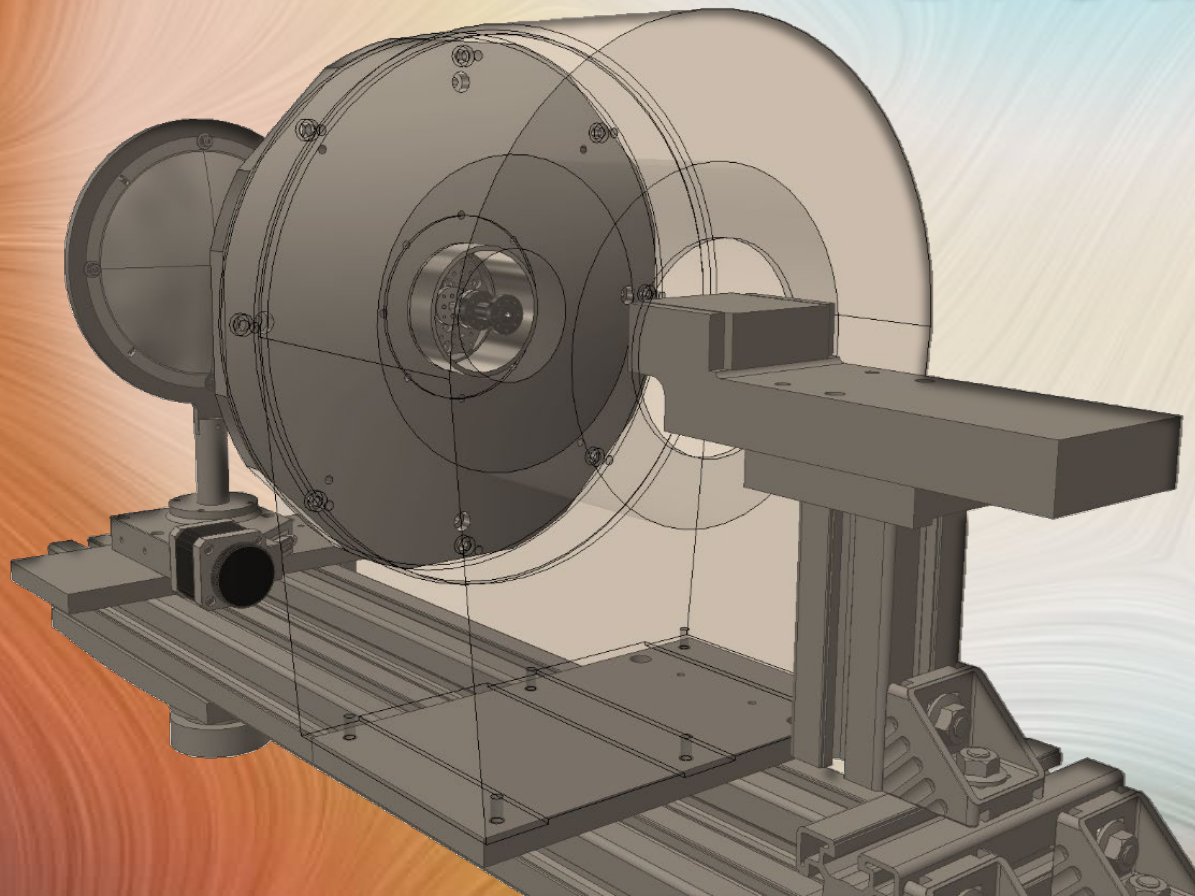
LiteBIRD MHFT Bread-Board testing



CMB Systematics & Calibration Focus Workshop

30 Nov 2020 – 3 Dec 2020
Kavli IPMU, Kashiwa, Japan

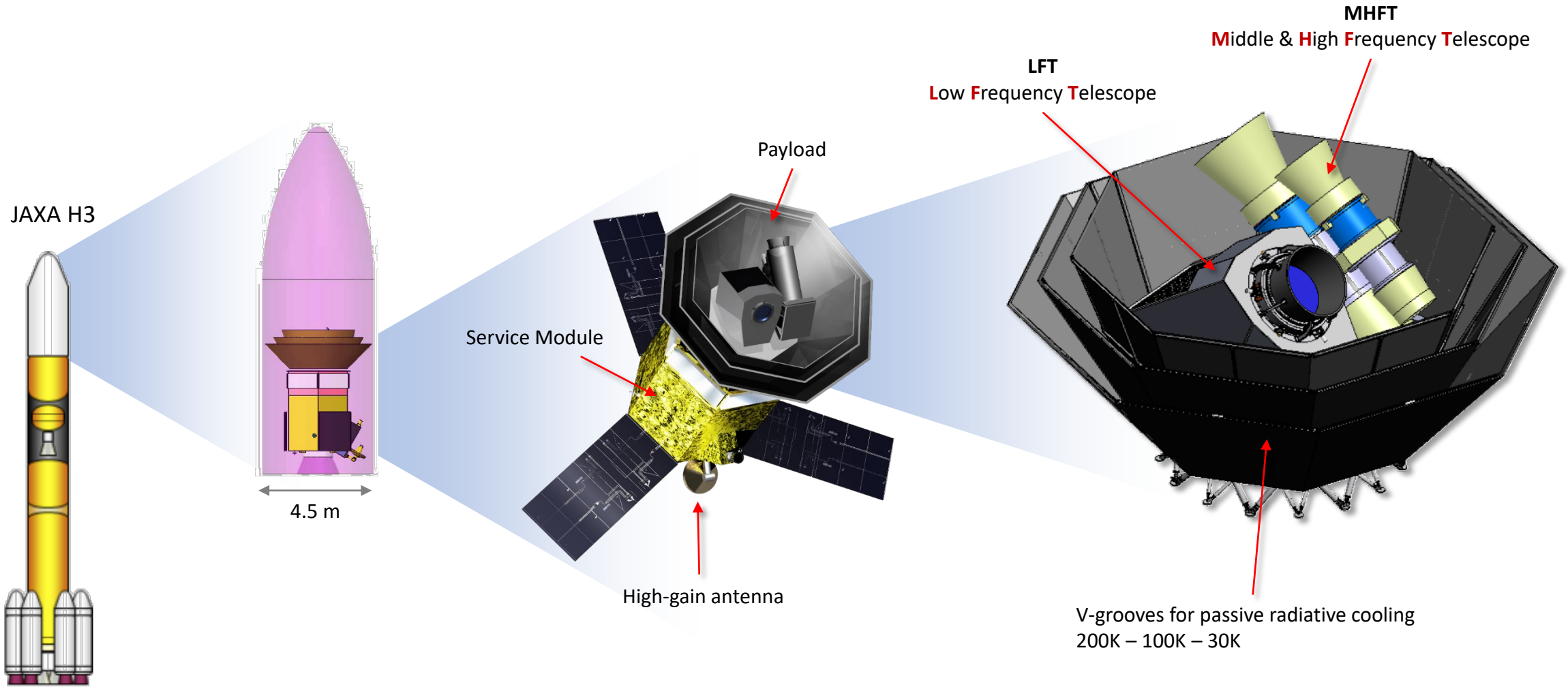
Cristian Franceschet
M. Bersanelli
S. Bounissou
M. De Petris
J. Gudmundsson
H. Imada
L. Lamagna
B. Maffei
S. Realini
A. Ritacco
and the LiteBIRD RF & Optics teams

Mission overview

- LiteBIRD is a satellite for studies of B-modes of the CMB polarization
- **May 2019**: selected for JAXA's strategic L-class mission*
- Expected launch in **2029** with JAXA's H3 rocket
- 3 years observations around *Sun-Earth Lagrangian point* **L2**
- All-sky surveys
- **15 frequency bands**: 34 – 448 GHz
- **Angular resolution**: 70 – 20 arcmin

* http://www.isas.jaxa.jp/home/rikou/godo/2019/0602/gbi7uzhxfxmz/misison_selection_announcement_may2019.pdf

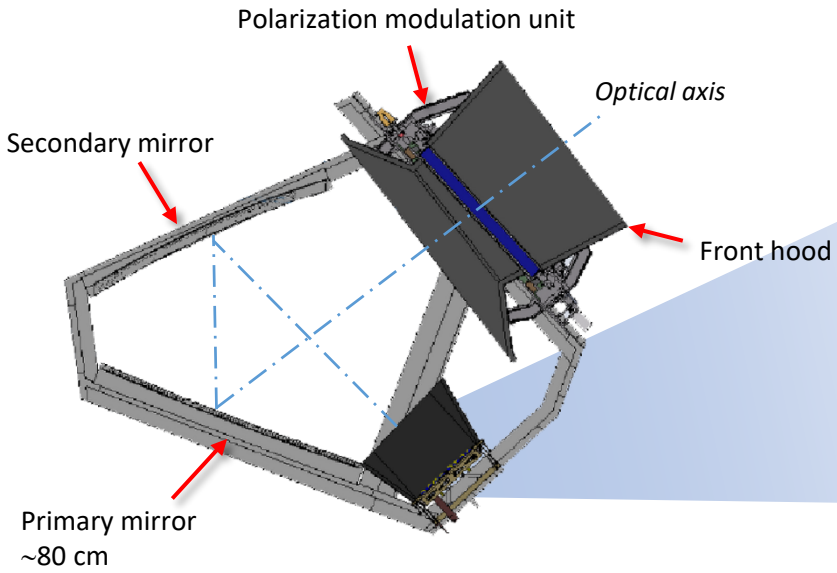
Satellite & payload overview



Reference: The LiteBIRD collaboration, "Probing Cosmic Inflation with the LiteBIRD Cosmic Microwave Background Polarization Survey", Progress of Theoretical and Experimental Physics (2020, in preparation)

The telescopes

The Low Frequency Telescope

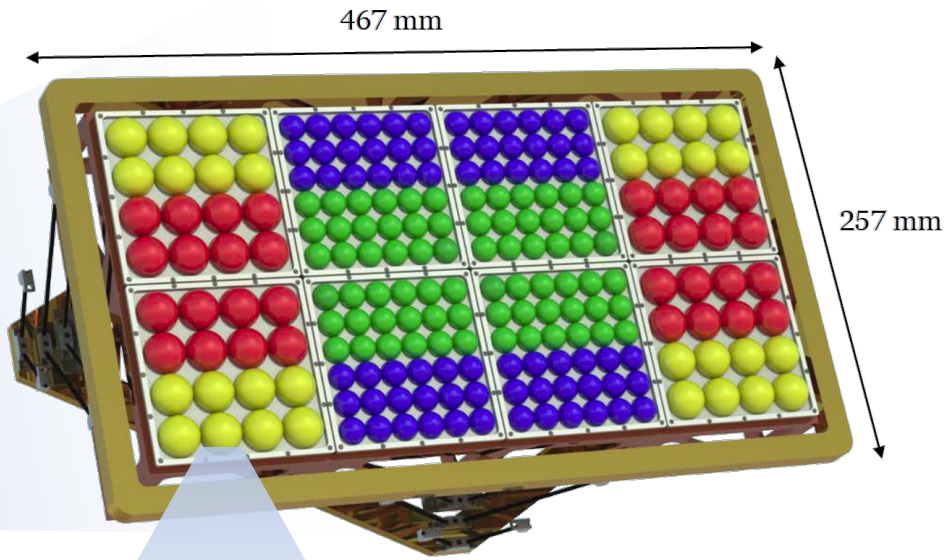


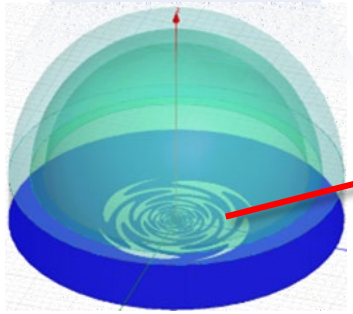
Dual reflectors telescope
f/3.0 Crossed-Dragone

Main requirements

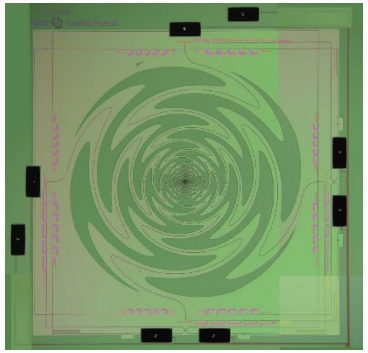
- 9 channels between 34 and 161 GHz
- Field of view > 18° × 9°
- Beam size < ~1°
- Far sidelobe knowledge < -56 dB
- Temperature of HWP < 20 K

LFT focal plane unit





Silicon lenslet

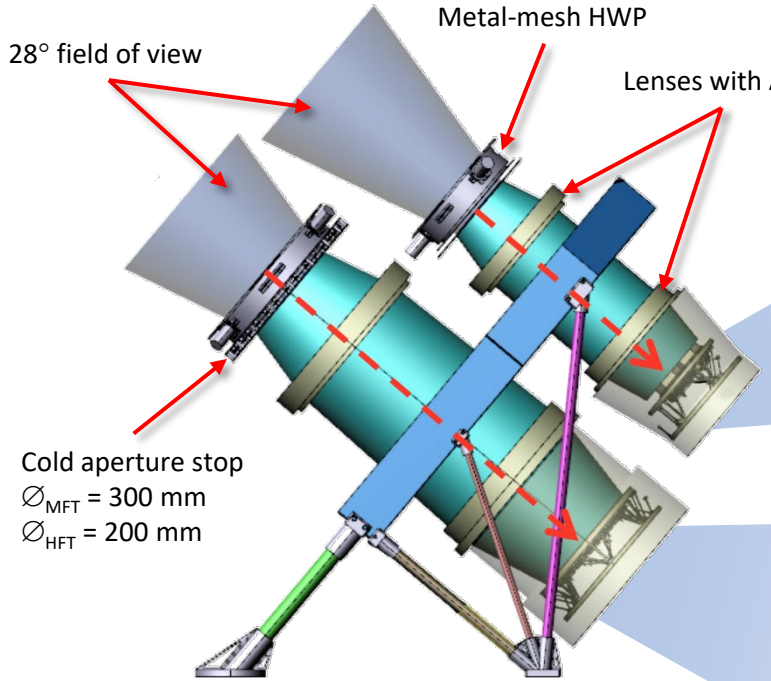


Sinuous antenna
broadband trichroic pixels

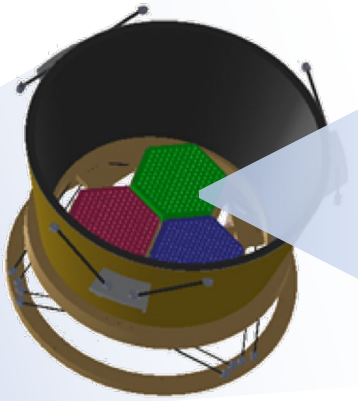
Reference: Sekimoto, Y., et al., 2020 SPIE 11453-37

The telescopes

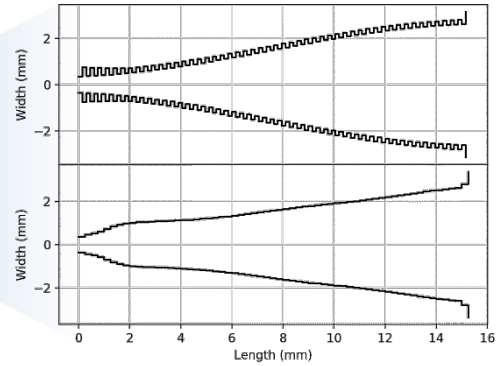
The **M**iddle-**H**igh **F**requency **T**elescope



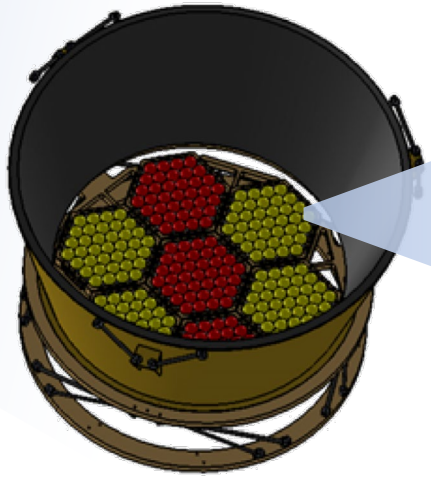
HFT focal plane unit



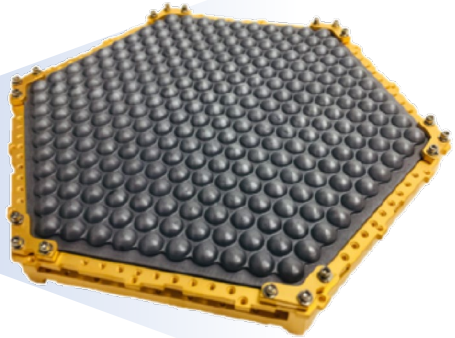
Corrugated/spline feed-horns



MFT focal plane unit



Silicon lenslets coupled to sinuous antennas

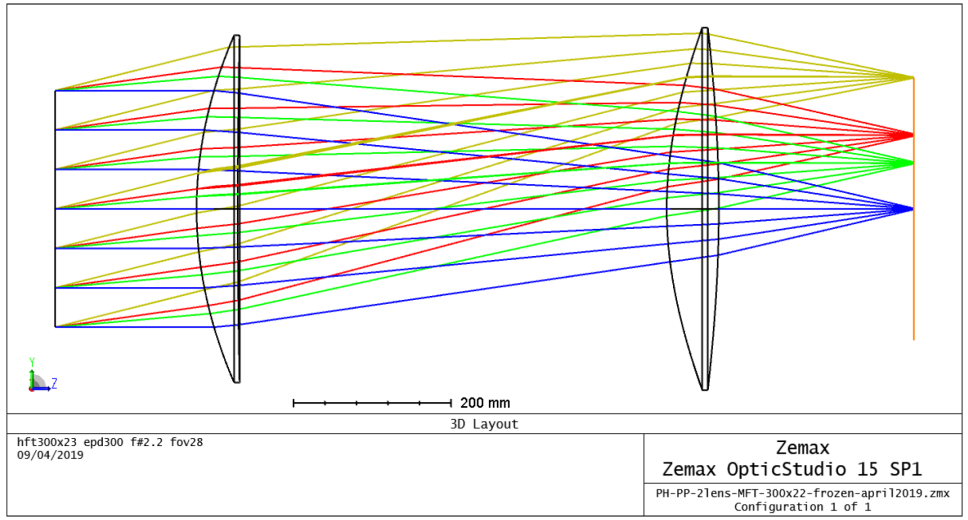


Main requirements

- 9 channels between 89 and 448 GHz
- Field of view ~28°
- Beam size 0.6° to 0.3°
- Far sidelobe knowledge < -56 dB
- Temperature of HWP < 20 K
- f/2.2 telescopes with AR-coated PP lenses (n = 1.52)

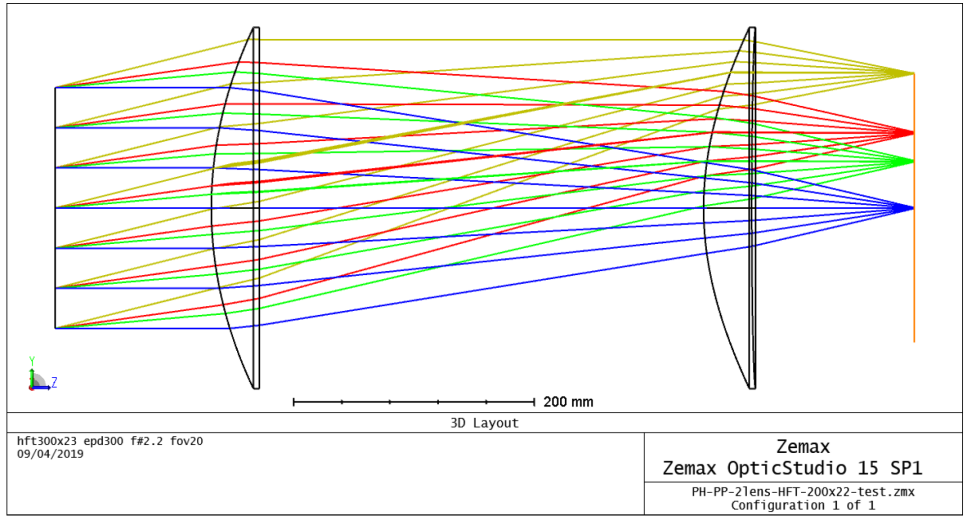
Reference: The LiteBIRD collaboration, Progress of Theoretical and Experimental Physics (2020, in preparation) // Lamagna, L., e al., "The optical design of the LiteBIRD Middle and High Frequency Telescope", Proc. of SPIE 11443-283 (2020)

The MHFT optical design



Middle Frequency Telescope (89 – 270 GHz)

- f/# = 2.2
- Entrance Pupil Diameter ∅ = 300 mm
- Field of view: 28°
- Focal plane radius = 167.5 mm
- Effective focal length = 658.8 mm
- Total tube length = 1091.9 mm



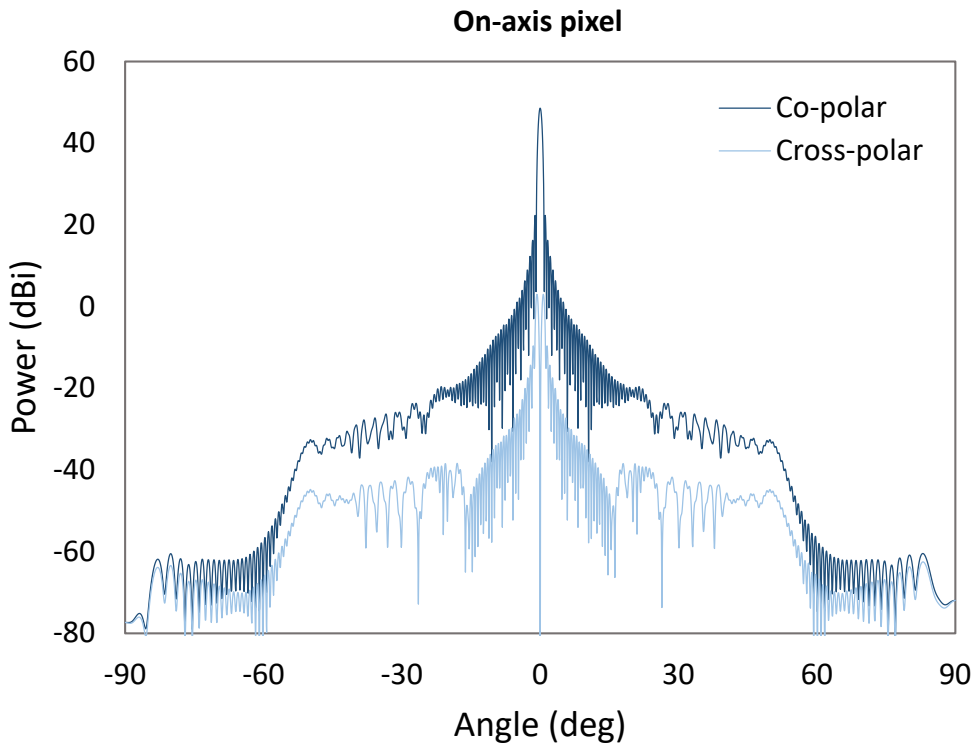
High Frequency Telescope (238 – 448 GHz)

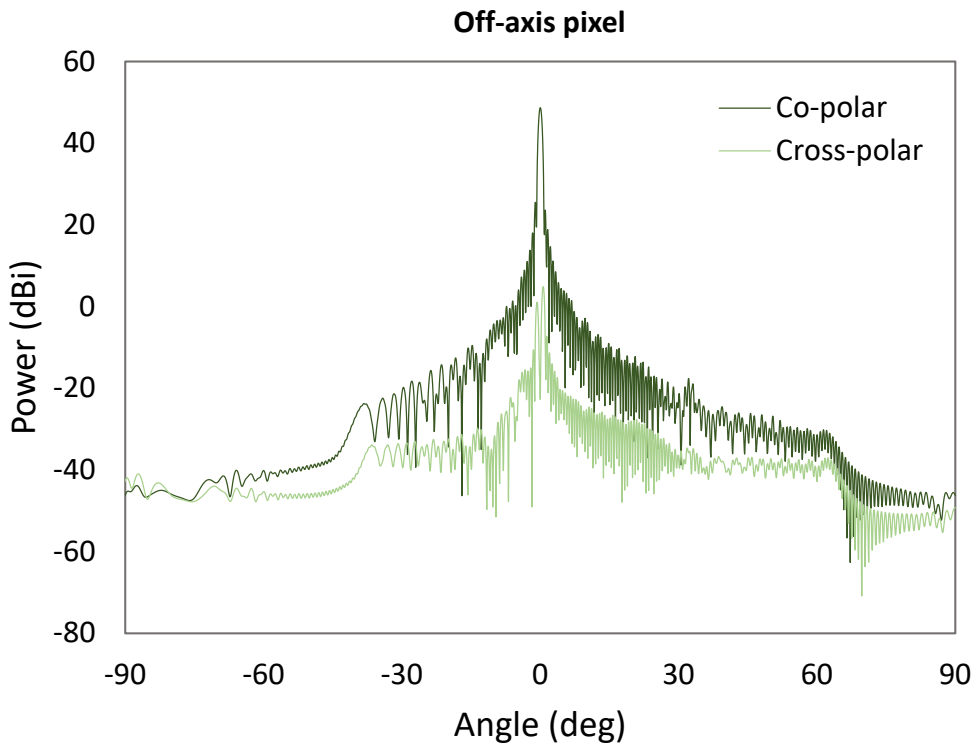
- f/# = 2.2
- Entrance Pupil Diameter ∅ = 200 mm
- Field of view: 28°
- Focal plane radius = 112.4 mm
- Effective focal length = 438.5 mm
- Total tube length = 714.7 mm

Credits: P. Hargrave, 2019

The MHFT optical modeling

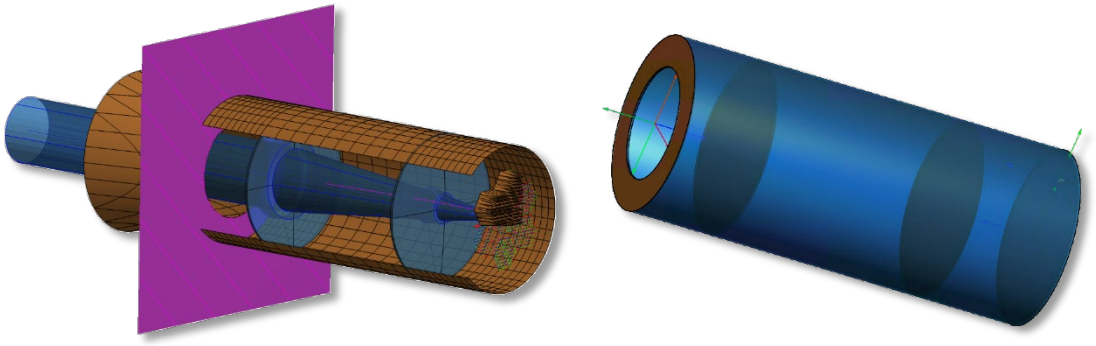
- Simulation of the MFT at 100 GHz ($\varphi = 45°$) with PO



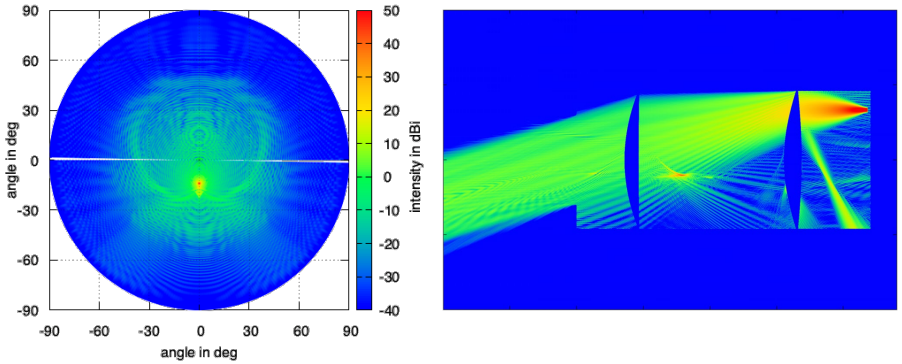


The MHFT optical modeling

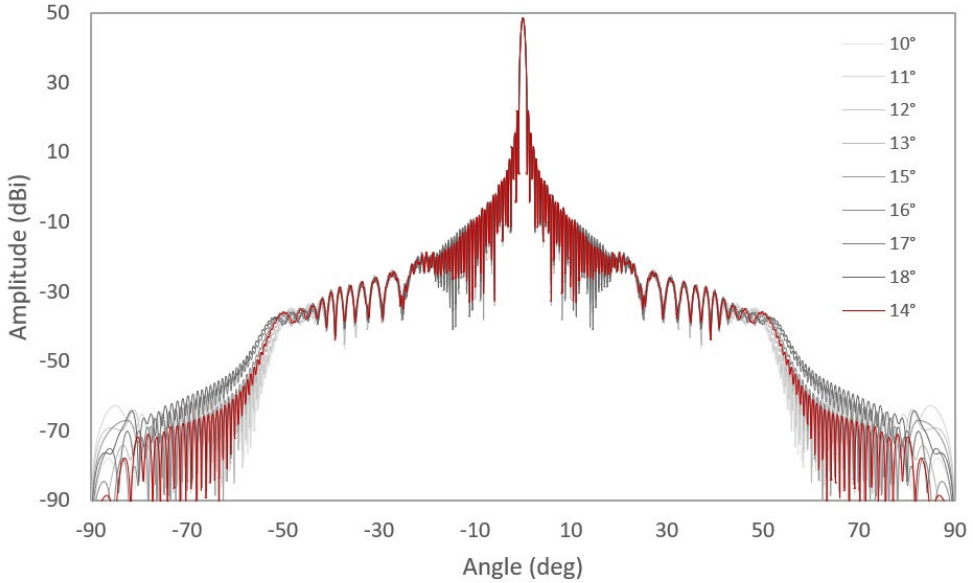
PO and MoM GRASP models of the MFT optics



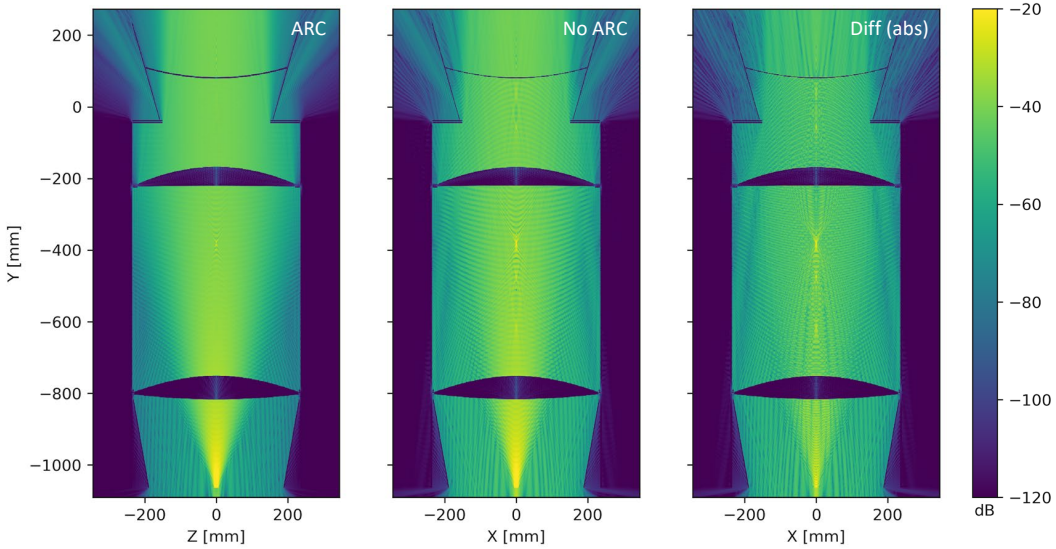
Study of the ghosting inside the MFT tube at 100 GHz



Study of the MFT fore-baffle flare angle at 100 GHz



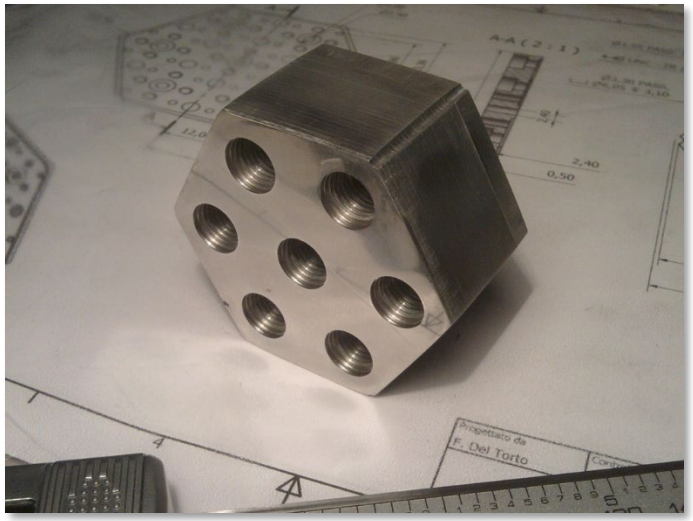
Study of the Anti-Reflection Coating on the MFT lenses at 100 GHz



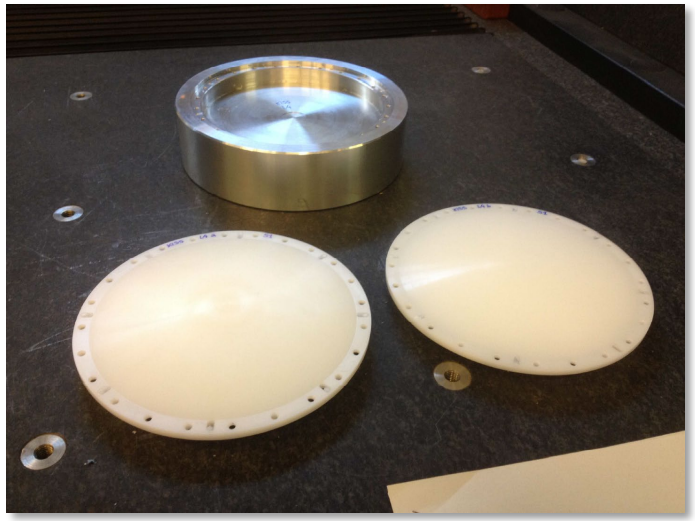
The Bread-Board Model

- A **simple refractive optics** to validate modeling w.r.t. measurements
- Using **already available** hardware

Feed-horns array



Dielectric lens prototype



- No focal plane TES detectors ⇨ **well-known horn** coupled to VNA
- Room temperature measurements

The Bread-Board Model objectives

- Verify the **accuracy & limitations of measurement methods**
  - Far-field

    Simplest and most accurate, but for «small» antennas only
  - Compact Antenna Test Range

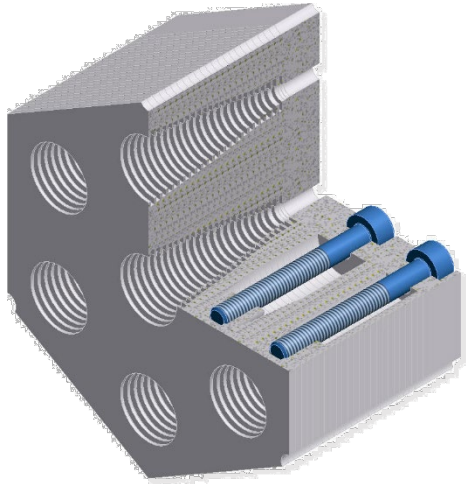
    Direct measurement, but difficult to set-up
  - Near-field

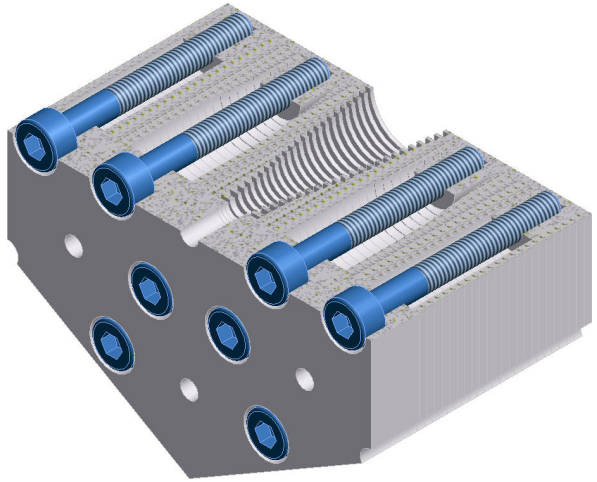
    Reliable, but requires near-to-far transformations

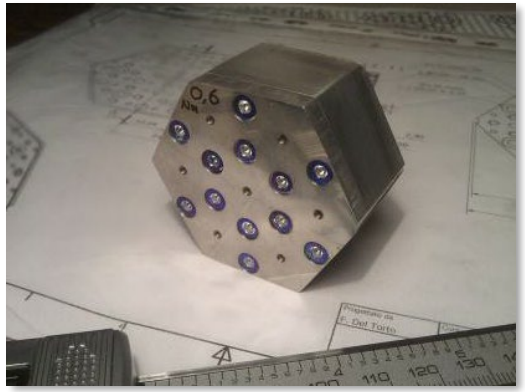
- Reliability of **refractive optics simulations** vs **precision required by LiteBIRD**
  - GRASP®, CST®, HFSS®, SRSR-D®, Zemax®
- Verify to **what extent** measurements and simulations agree
- Provide a **test bed for the RF calibration plan** at following levels of integration

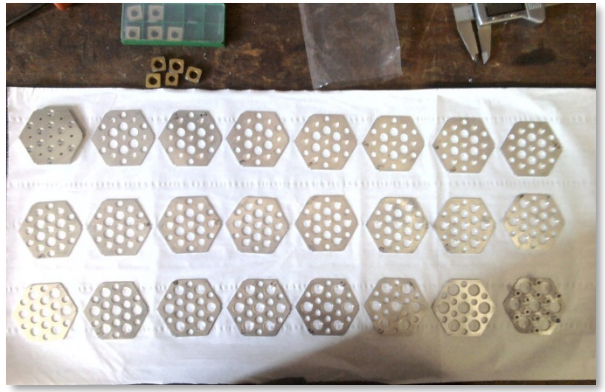
The Bread-Board Model BB1

- W-band feedhorns array (ASI technological development)
  - Array design and manufacturing
    - 7-elements array
    - Dual profiled corrugations
    - Waveguide ∅ = 2.40 mm
    - Aperture ∅ = 9.74 mm
    - Horns apertures spacing 17.85 mm
    - Manufacturing w/ platelet technique



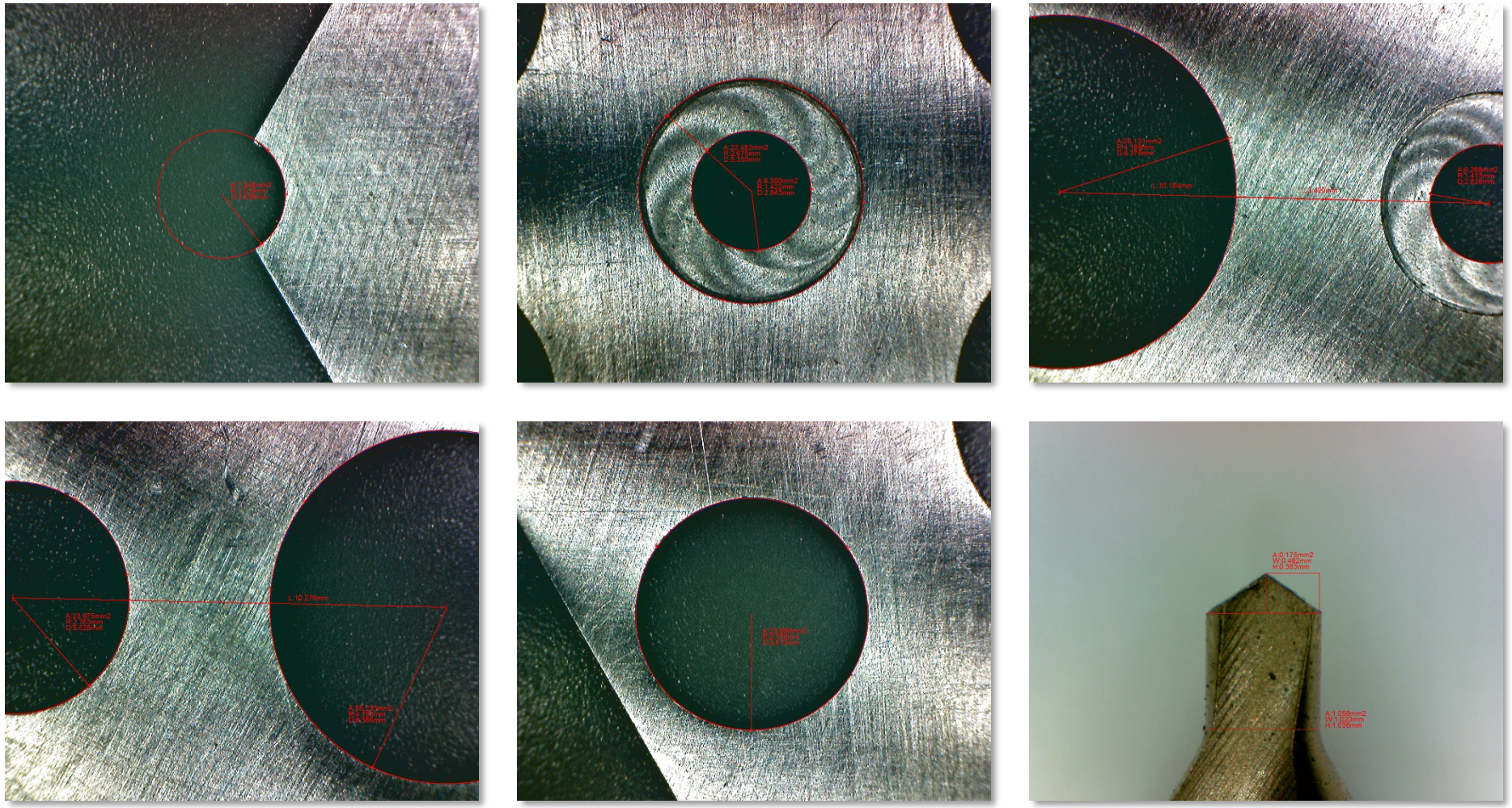






The Bread-Board Model BB1

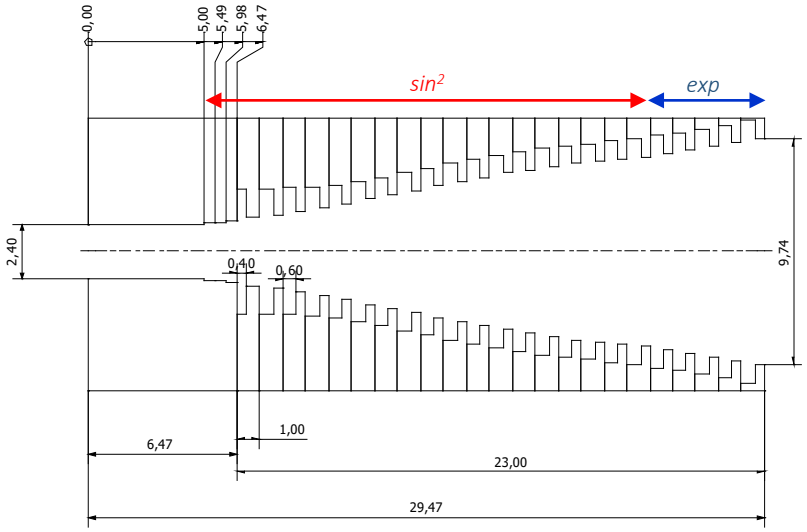
- W-band feedhorns array (ASI technological development)
  - Mechanical tolerance verification ~0.02 mm

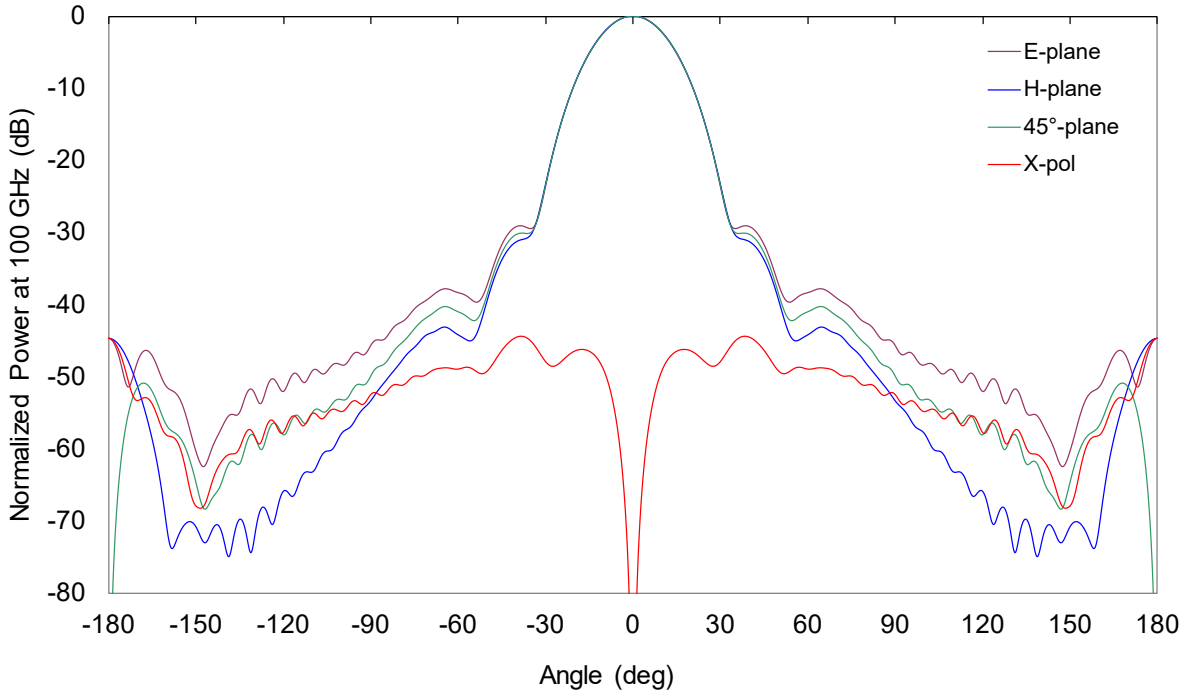


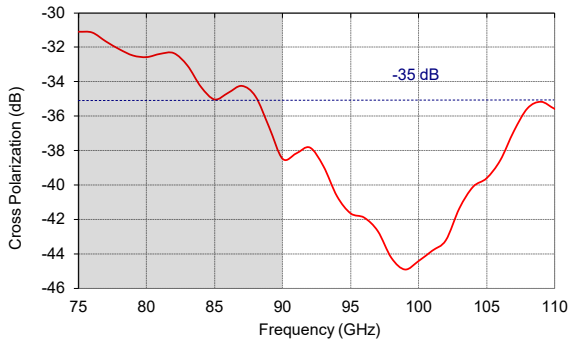
Credits: F. Del Torto, 2011

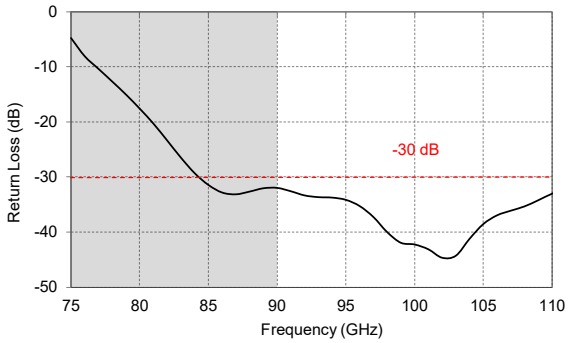
The Bread-Board Model BB1

- W-band feedhorns array (ASI technological development)
  - Electromagnetic performance
    - f_0 = 100 GHz
    - FWHM at f_0 = 18.5°
    - 20% bandwidth (90 – 110 GHz)
    - Side lobes < -30 dB
    - Cross-pol < -35 dB
    - Return loss < -30 dB



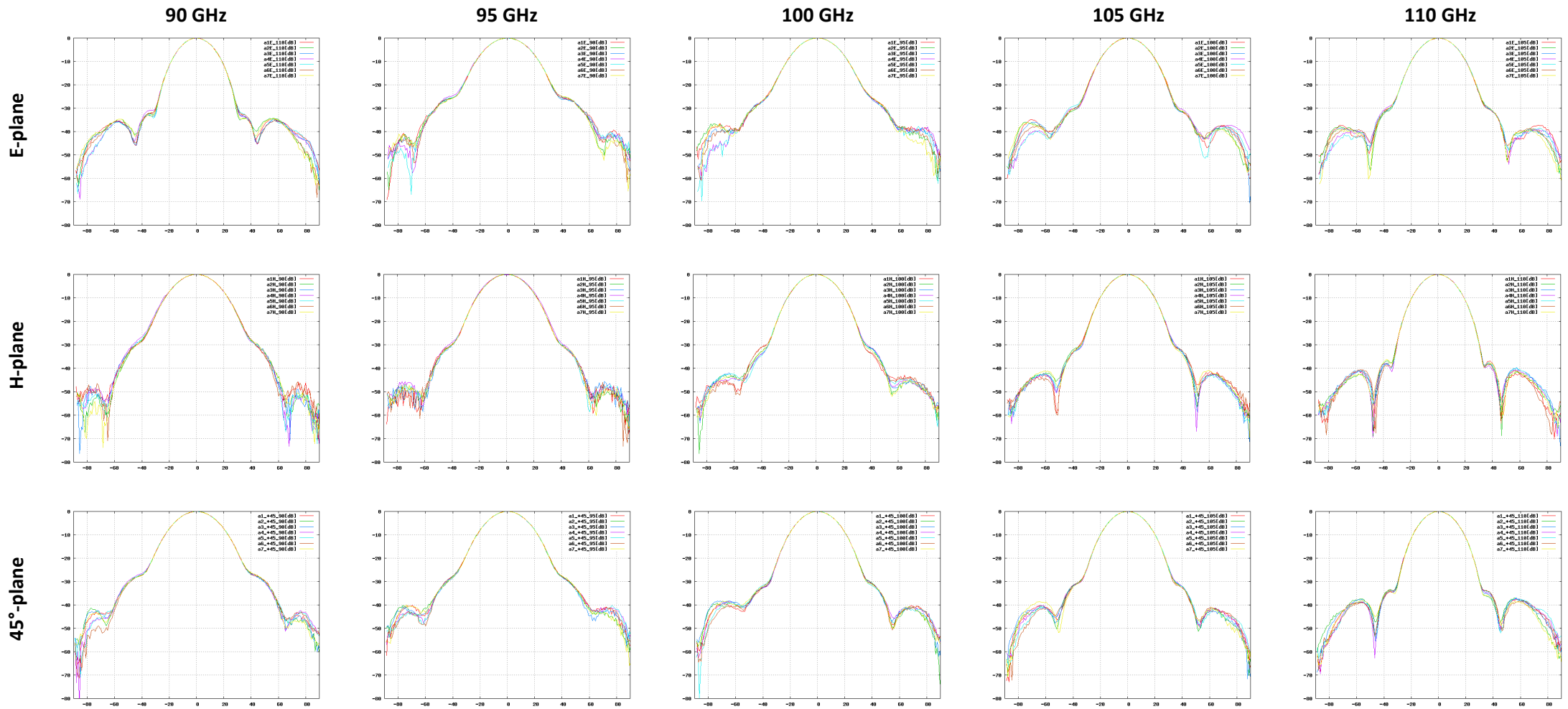






The Bread-Board Model BB1

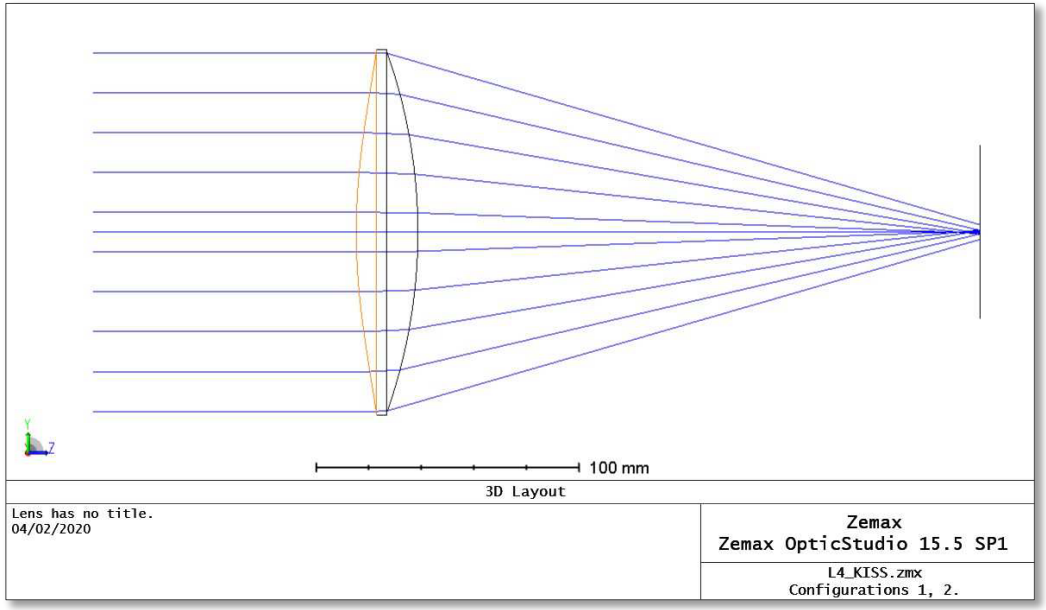
- W-band feedhorns array (ASI technological development)
  - Co-polar radiation pattern characterization

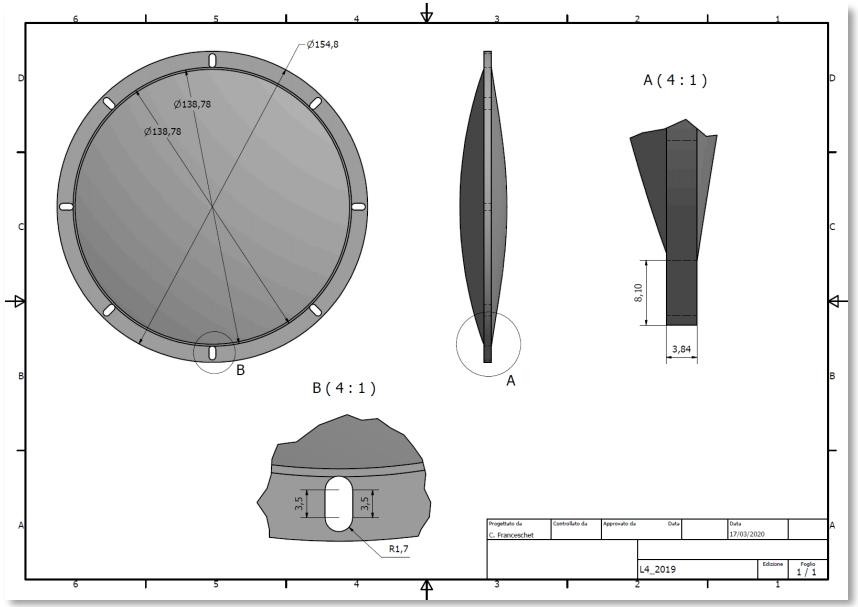


Credits: A. Simonetto, 2011

The Bread-Board Model BB1

- HDPE lens prototype L4 (KISS experiment spare)
  - Entrance pupil ∅ = 136 mm
  - lens aperture ∅ = 138.7 mm
  - Effective Focal Length = 210,4 mm
  - HDPE index of refraction @300K = 1.52
  - No anti-reflection coating

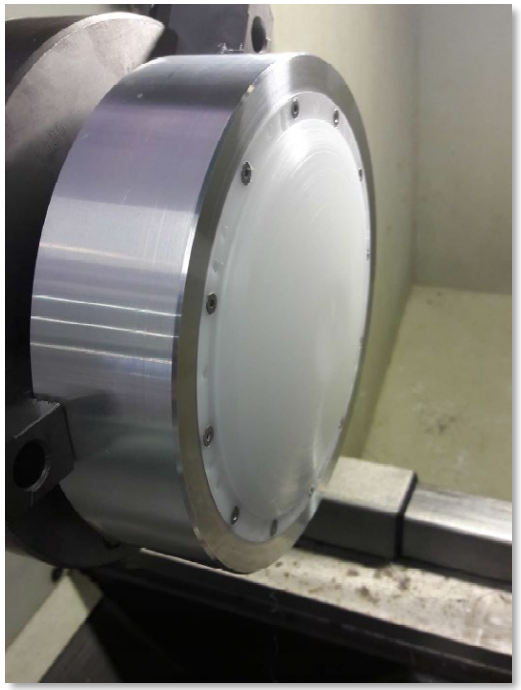


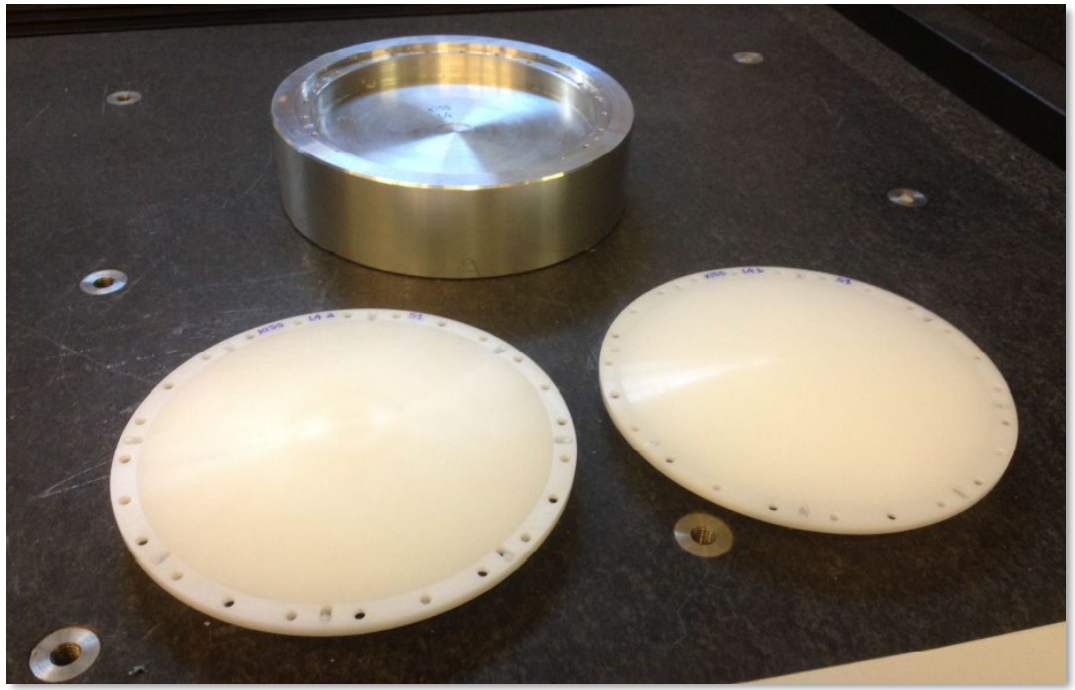


Credits: design by M. De Petris for the KISS experiment // Mechanical design by LPSC – Grenoble

The Bread-Board Model BB1

- HDPE lens prototype L4 (KISS experiment spare)
  - Manufacturing with HDPE w/o ARC

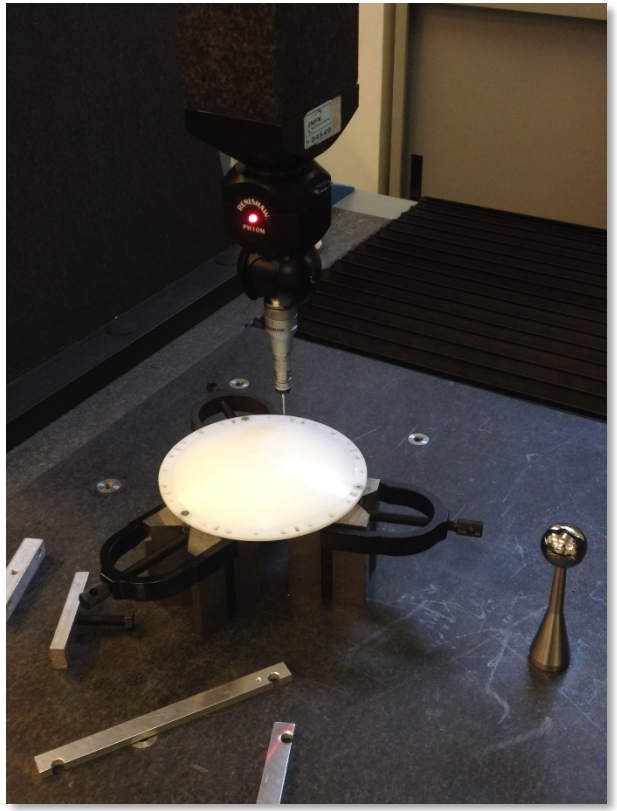




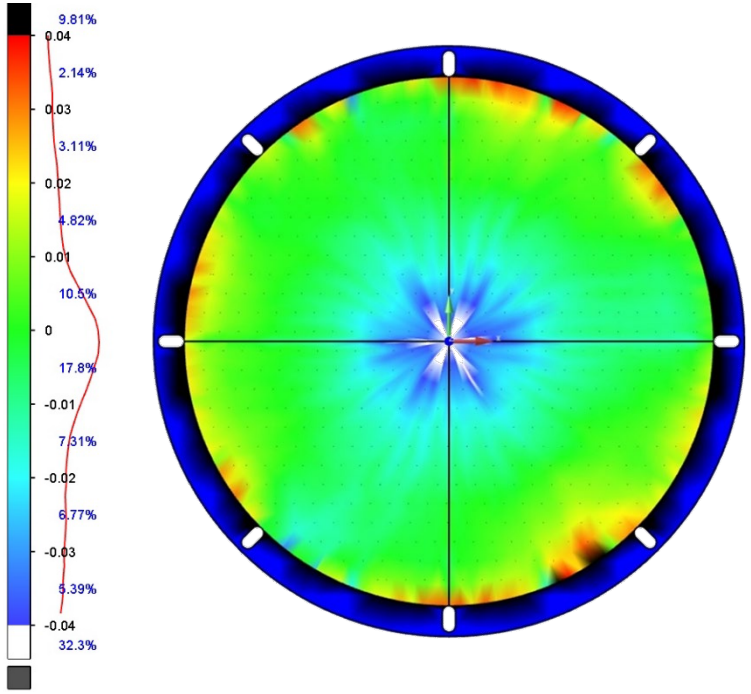
Credits: lens manufacturing by A. Mattei, INFN Sezione di Roma

The Bread-Board Model BB1

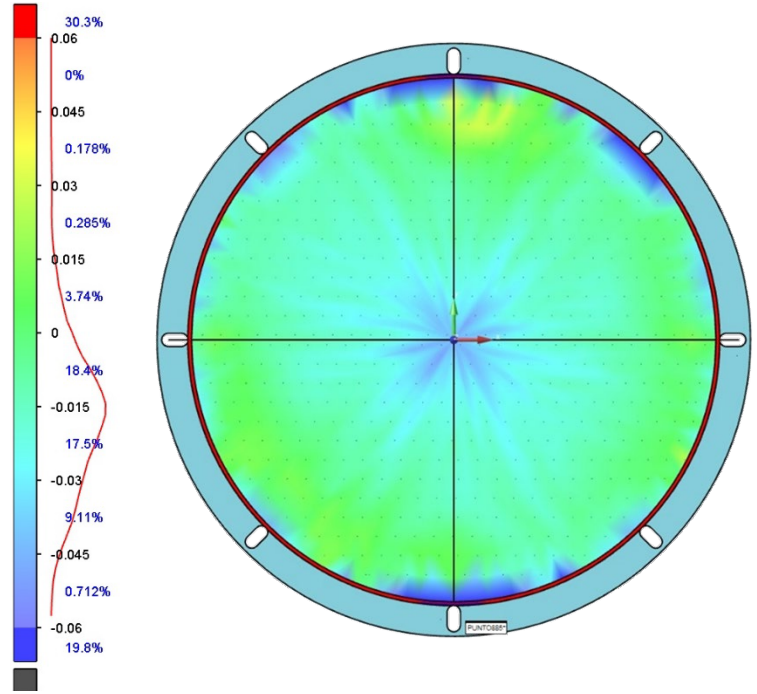
- HDPE lens prototype L4 (KISS experiment spare)
  - Mechanical tolerance verification with 3D metrology



Map of deviations from nominal surface (5 mm grid sampling)



First surface r.m.s. ~15 μm

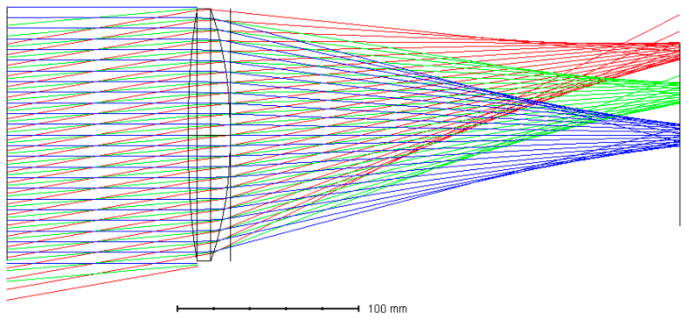


Second surface r.m.s. ~20 μm

The Bread-Board Model BB1

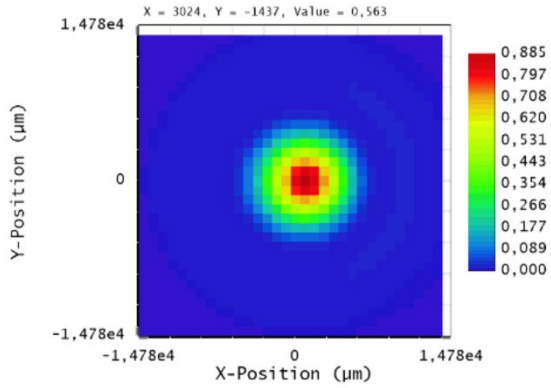
- Modeling of the BB1 with Zemax and GRASP PO

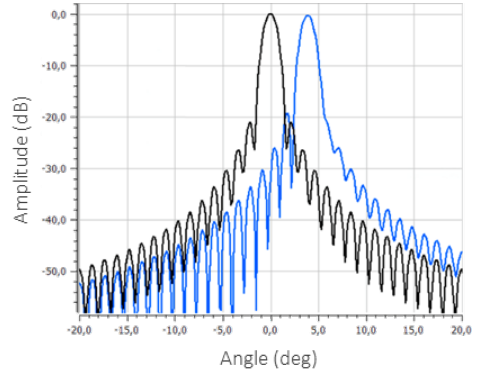
BB1 model with Zemax



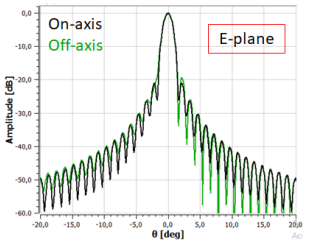
BB1 model with GRASP

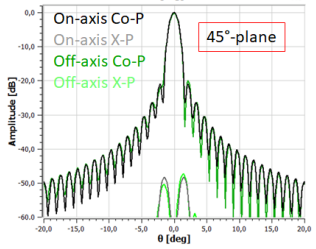
Verification of off-axis beam pointing

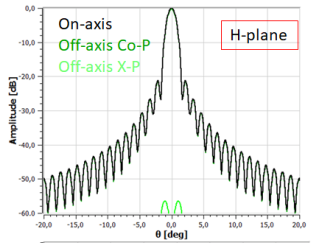


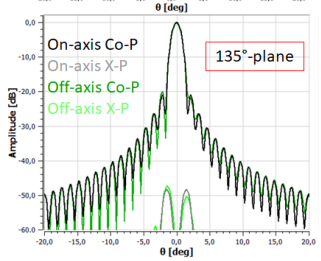


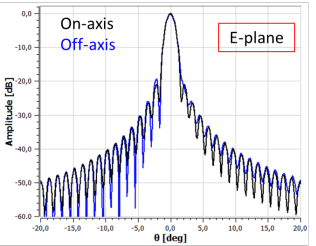
Radiation pattern at 100 GHz (on-axis & off-axis pixels)

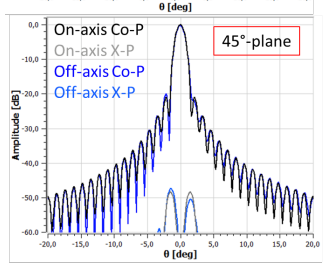


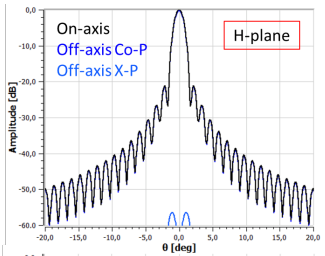


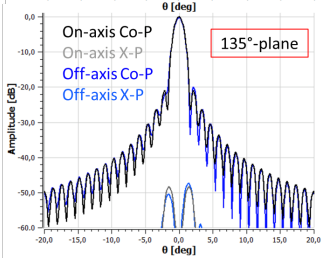






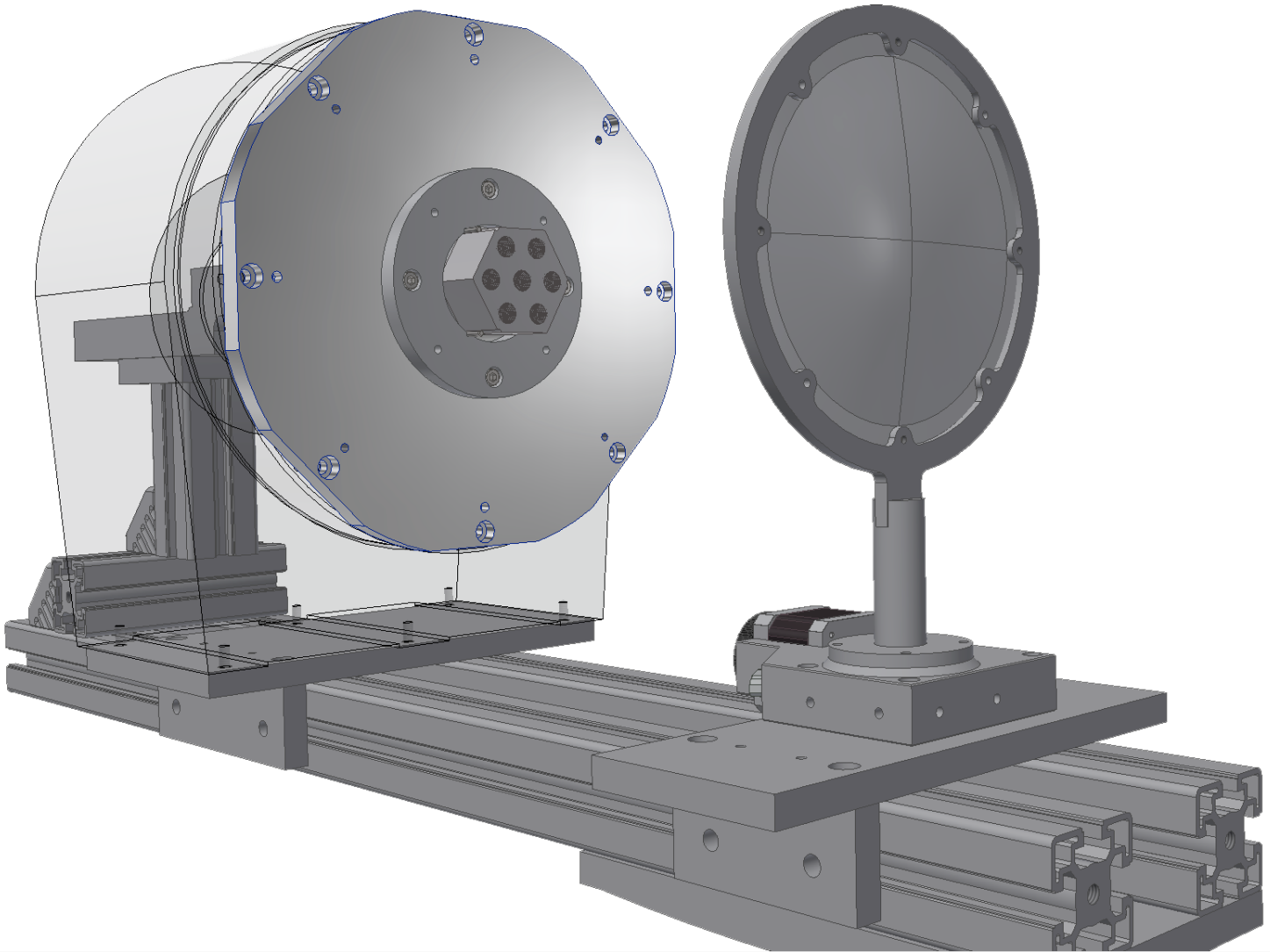


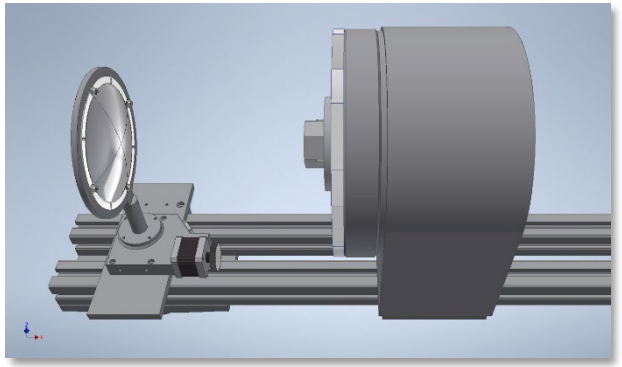


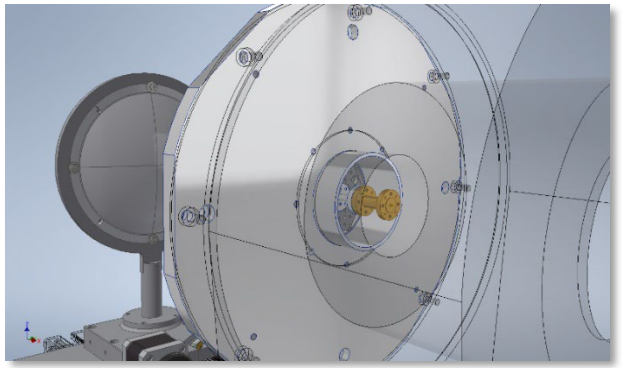


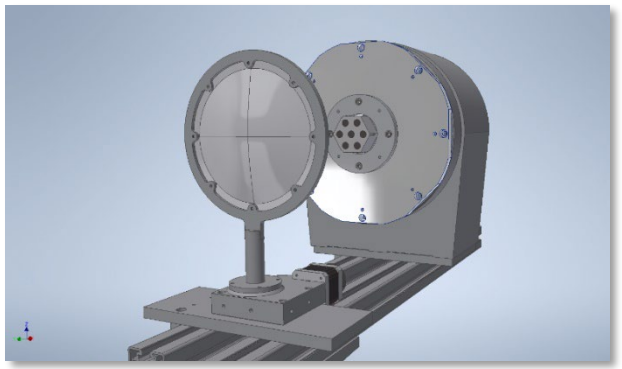
The Bread-Board Model BB1

- Mechanical configuration of the BB1



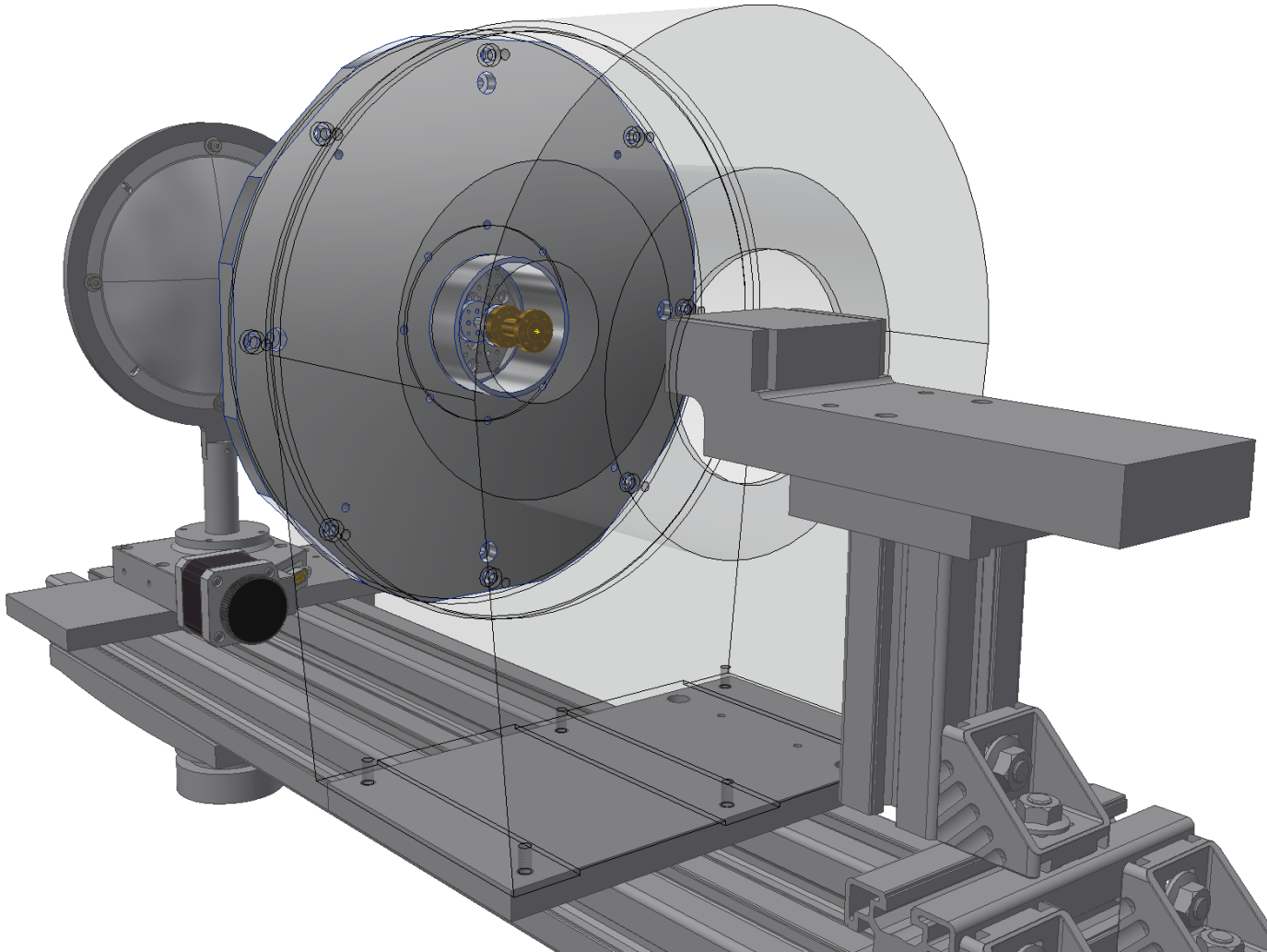


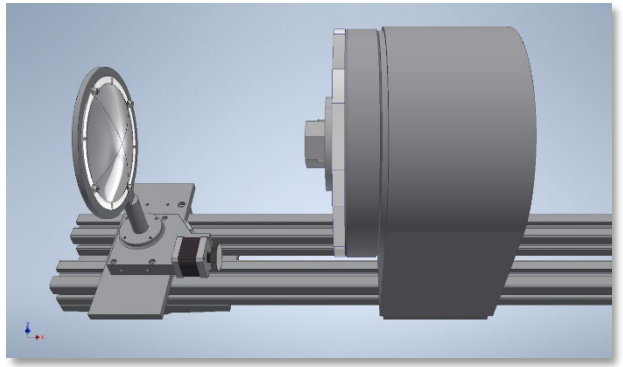


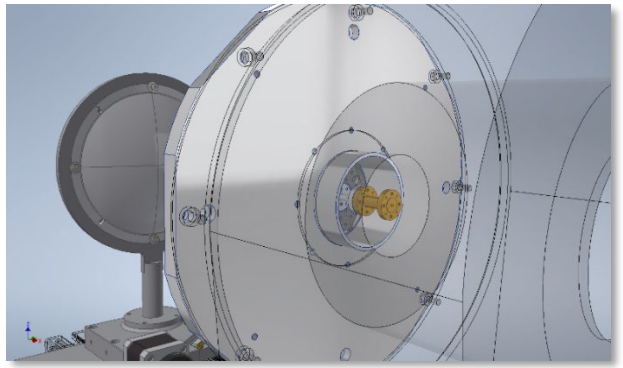


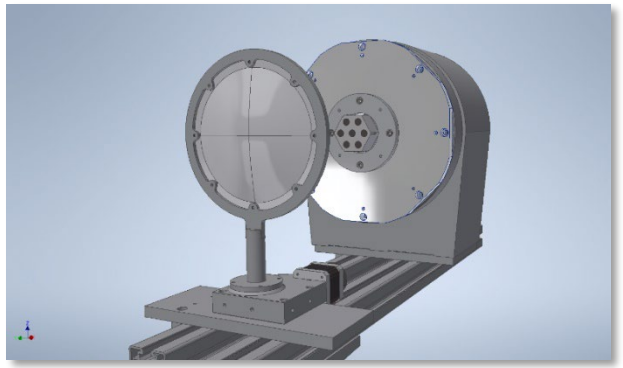
The Bread-Board Model BB1

- Mechanical configuration of the BB1



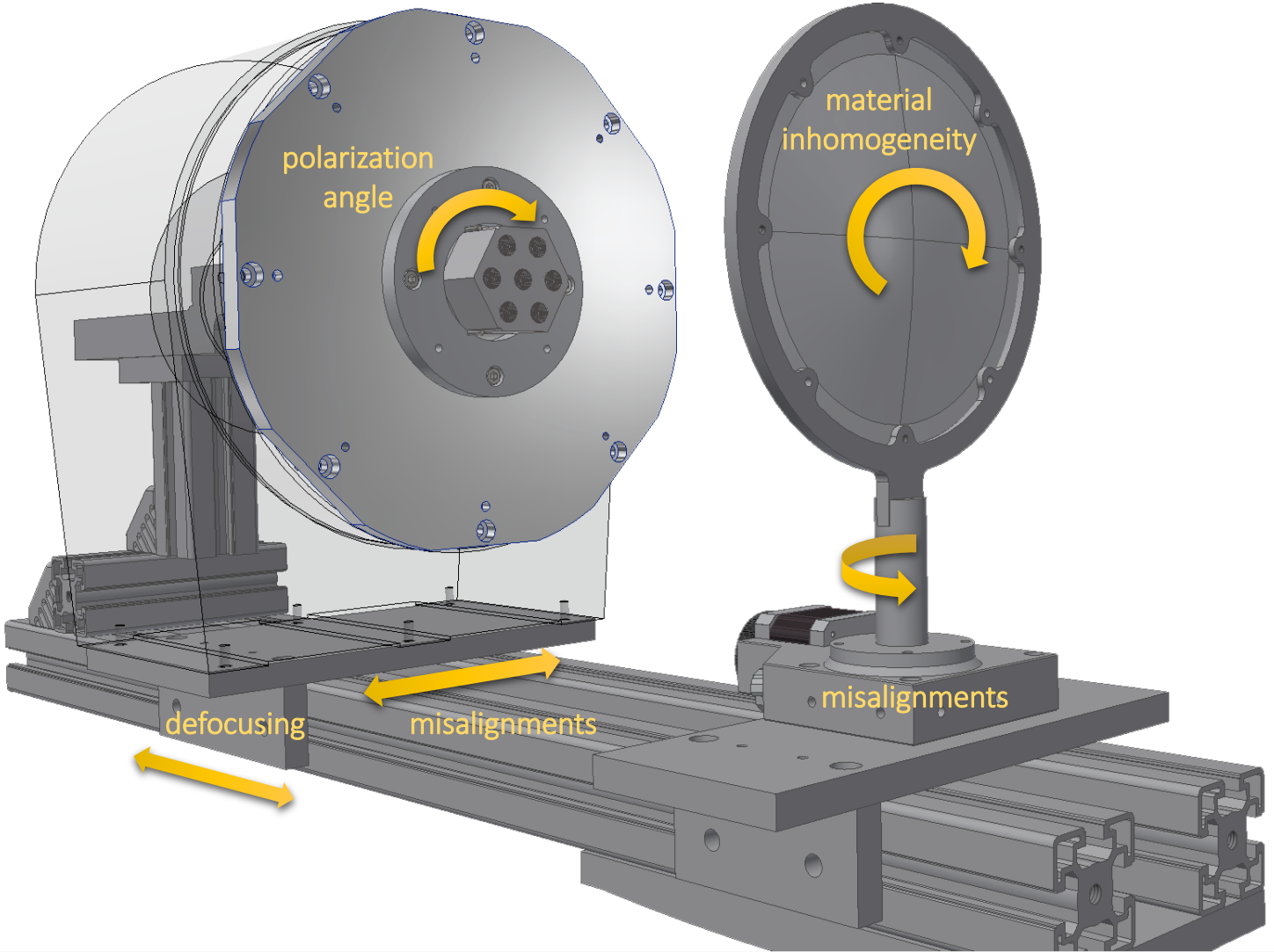


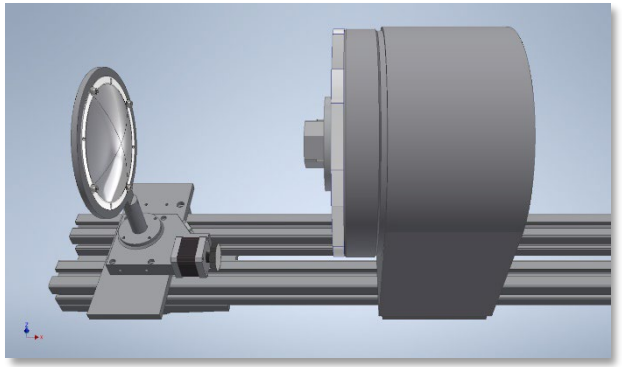


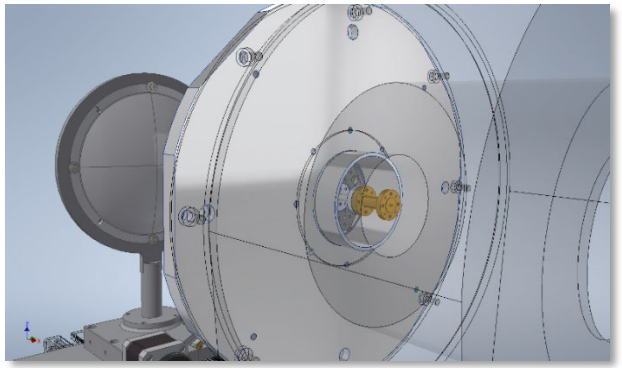


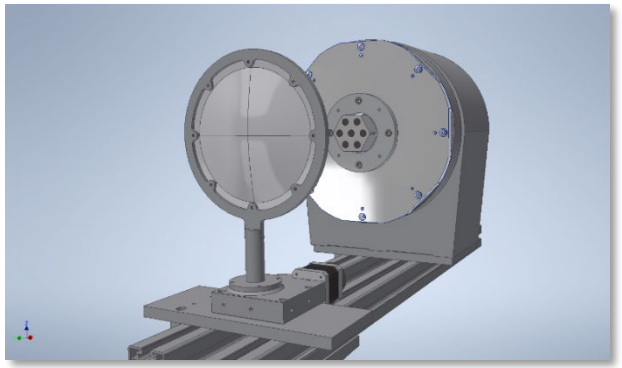
The Bread-Board Model BB1

- The BB1 test plan in a screenshot





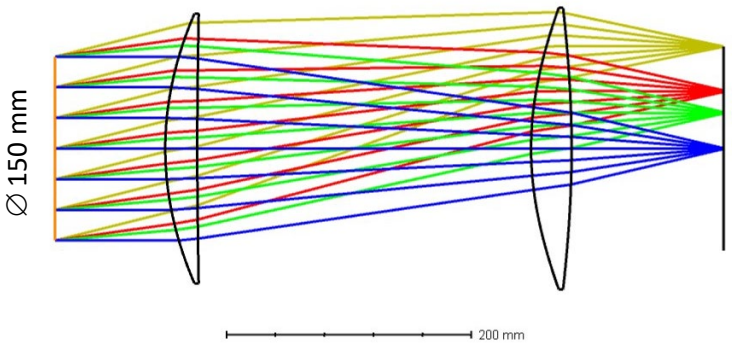




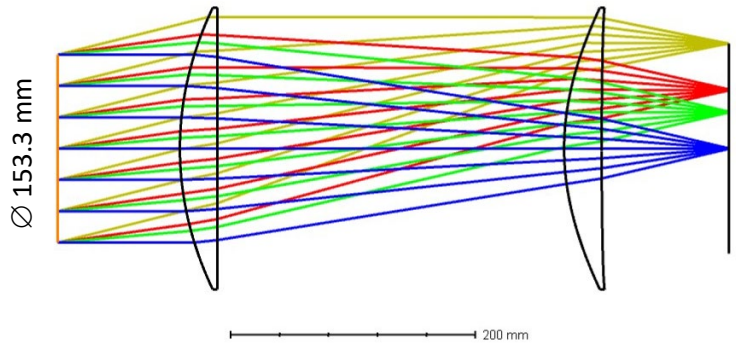
Towards the Bread-Board Model BB2

- Scaled version of MHFT
- Two lenses (polypropylene or HDPE)
- Corrugated feedhorn with MHFT illumination

Scaled MFT by a factor 0.5



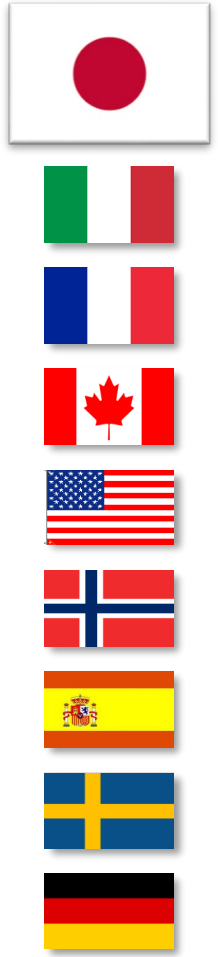
Scaled HFT by a factor 0.76



- Focal number f/2.2
- Compatible with ~300 GHz operation

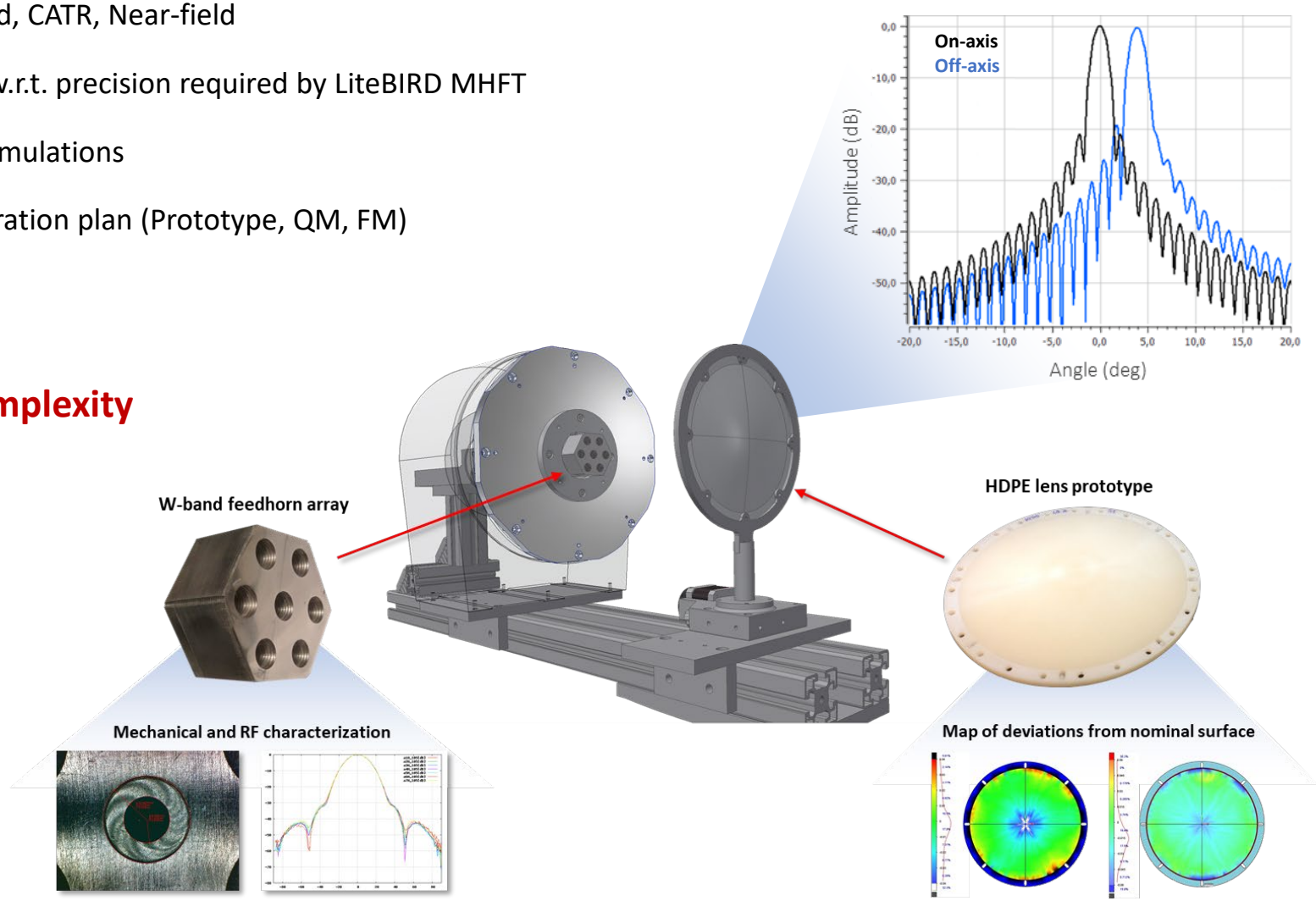
Acknowledgements

- This work is supported in **Japan** by ISAS/JAXA for Pre-Phase A2 studies, by the acceleration program of JAXA research and development directorate, by the World Premier International Research Center Initiative (WPI) of MEXT, by the JSPS Core-to-Core Program of A. Advanced Research Networks, and by JSPS KAKENHI Grant Numbers JP15H05891, JP17H01115, and JP17H01125.
- The **Italian** LiteBIRD phase A contribution is supported by the Italian Space Agency (ASI Grants No. 2020-9-HH.0 and 2016-24-H.1-2018), the National Institute for Nuclear Physics (INFN) and the National Institute for Astrophysics (INAF).
- The **French** LiteBIRD phase A contribution is supported by the Centre National d'Etudes Spatiale (CNES), by the Centre National de la Recherche Scientifique (CNRS), and by the Commissariat à l'Energie Atomique (CEA).
- The **Canadian** contribution is supported by the Canadian Space Agency.
- The **US** contribution is supported by NASA grant no. 80NSSC18K0132.
- **Norwegian** participation in LiteBIRD is supported by the Research Council of Norway (Grant No. 263011).
- The **Spanish** LiteBIRD phase A contribution is supported by the Spanish Agencia Estatal de Investigación (AEI), project refs. PID2019-110610RB-C21 and AYA2017-84185-P.
- Funds that support the **Swedish** contributions come from the Swedish National Space Agency (SNSA/Rymdstyrelsen) and the Swedish Research Council (Reg. no. 2019-03959).
- The **German** participation in LiteBIRD is supported in part by the Excellence Cluster ORIGINS, which is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy (Grant No. EXC-2094 - 390783311).
- This research used resources of the Central Computing System owned and operated by the Computing Research Center at KEK, as well as resources of the National Energy Research Scientific Computing Center, a DOE Office of Science User Facility supported by the Office of Science of the U.S. Department of Energy.
- In addition, the authors would like to acknowledge the Ile de France region through its DIM-ACAV programme, the university Paris-Saclay through a chaire d'excellence and the OSUPS that have supported the work presented here.



LiteBIRD MHFT Bread-Board testing – Summary

- A **simple refractive optics to validate** modeling w.r.t. measurements
  - Verify measurement methods → Far-field, CATR, Near-field
  - Reliability of refractive optics modeling w.r.t. precision required by LiteBIRD MHFT
  - Agreement between measurements & simulations
  - Provide a test bed for the MHFT RF calibration plan (Prototype, QM, FM)
- Using **already available** hardware
- Add optical elements to **increase complexity**
  - Second lens (AR coating)
  - Stop aperture
  - Fore-baffle, tube, HWP prototype, etc.
- Towards a **scaled MHFT optics**



CMB Systematics & Calibration Focus Workshop

30 Nov 2020 – 3 Dec 2020
Kavli IPMU, Kashiwa, Japan