Workshop LiteBIRD-Italia 2023 @ INFN-LNF

Beam systematics

C. Franceschet, D. Maino & M. Bersanelli

MHFT beam systematic effects – context

- **Beam systematics and LiteBIRD**
  - Control of beams is a critical aspect for the mission
  - Very stringent requirements on beam knowledge
  - Both main beam and sidelobes
  - Very large number of detectors

- **Beam characterization involves several steps**
  - Beam computation (e.g. GRASP)
  - H/W measurements
  - Straylight simulations through the mission
  - Impact on science (mainly on *r*)

- **Different expertises are required**
  - Clarify languages and definitions
  - Requirements are «difficult to specify» (especially for far sidelobes)
  - Coordination / joint work is crucial

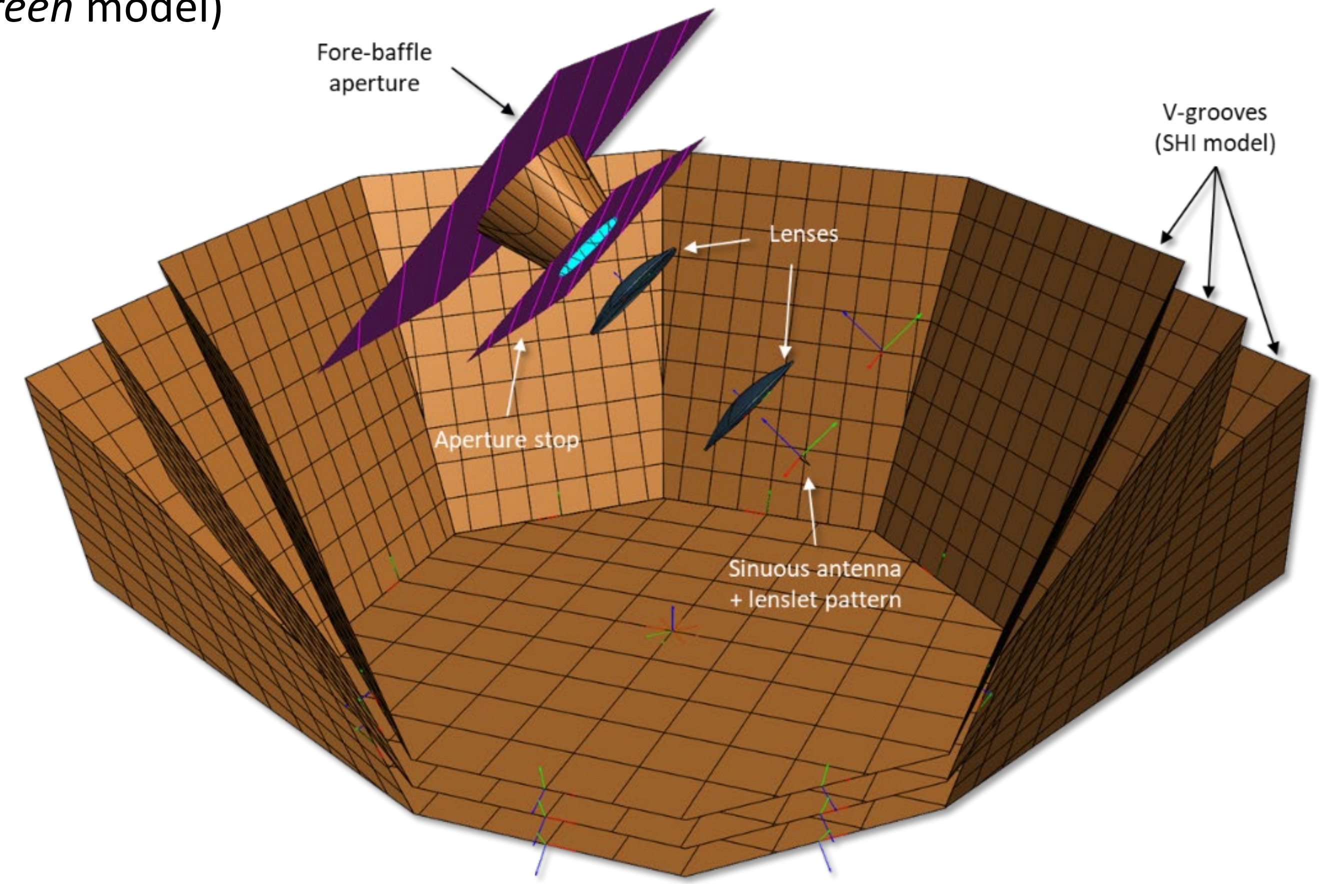
MHFT beam systematic effects – summary

- **Optical model (C. Franceschet)**
  - MFT realistic model implementation with GRASP
  - MFT focal plane configuration IMo v 1.3
  - Main beam & sidelobes simulation

- **Assessment of the impact of beam systematics on observations (D. Maino)**
  - From sidelobes to instrument requirements (from L3 to L4 reqs)
  - Different convolution approaches
  - Preliminary results

The MHFT optical model

- **MFT optical model**
  - *PH-PE-2lens-MFT-300x22-frozen-april2019* by Pete Hargrave (Apr. 2019)
  - Aperture stop ∅ = 300 mm (*aperture in screen* model)
  - HDPE lenses ($n = 1.52$)
  - No tube, filters and HWP
  - No FPU & internal baffles



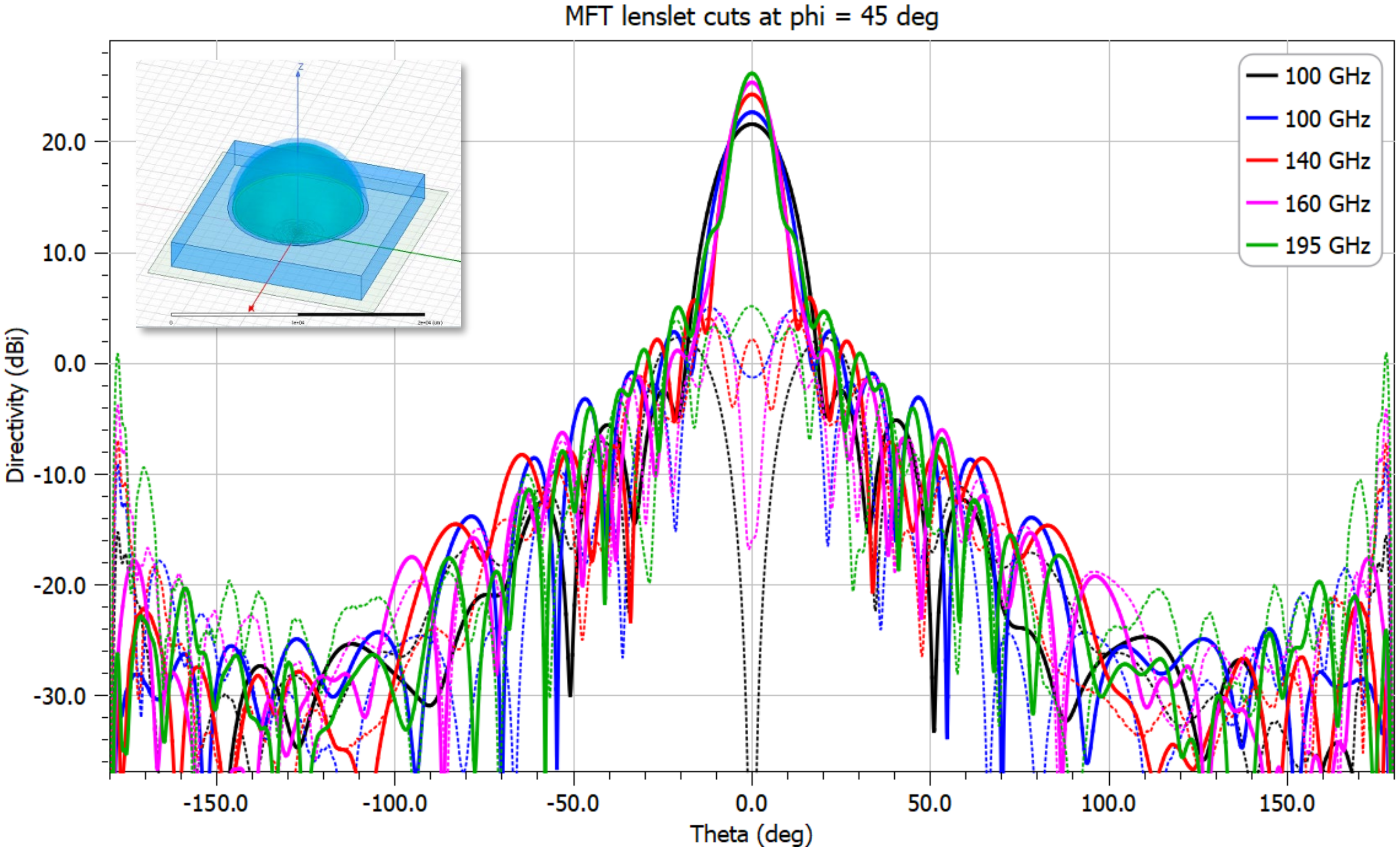
- **FPU & beam former**
  - FPU configuration IMO v 1.3(*)
  - 49 MFT pixels implemented
  - Lenslet pattern by Greg Jaehnig (Apr. 2022)

- **V-grooves**
  - Model based on SHI drawings
  - Perfectly reflective panels
  - Only three panels of the first layer included
  - No other payload/satellite structures (e.g. telescopes envelope, etc.)

(*) FPU configuration described here: https://docs.google.com/presentation/d/1RstZ7ahXCZ5q0qni4B-paJjjexNn8Xj--qKQPj5J6No/edit#slide=id.g1433b67e216_0_0

Sinuous antenna + lenslet response

- **Sinuous antenna coupled to Si-lenslet**
  - HFSS model "*SinuousAntenna LBMF_A_HFSS_20210420 p17_dL10mm_v1_ant4um*" by G. Jaehnig
  - Converted into GRASP ".cut" format
  - Verification after spherical waves expansion by GRASP (*constant phi cuts*)



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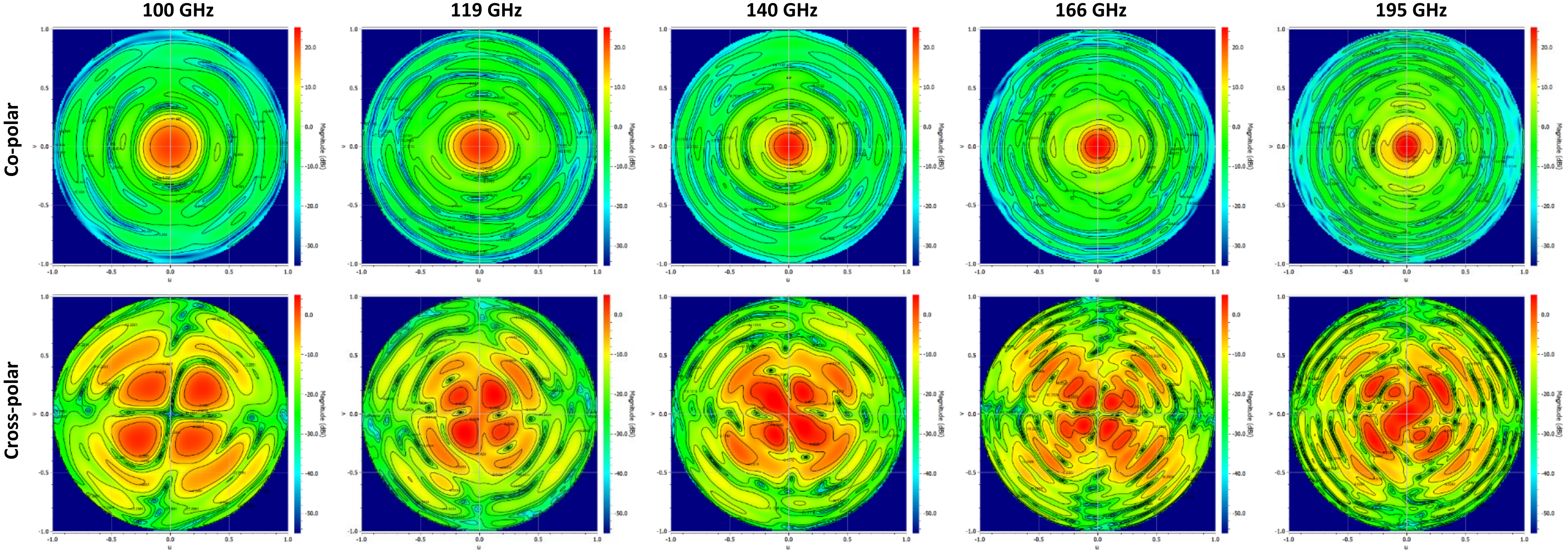
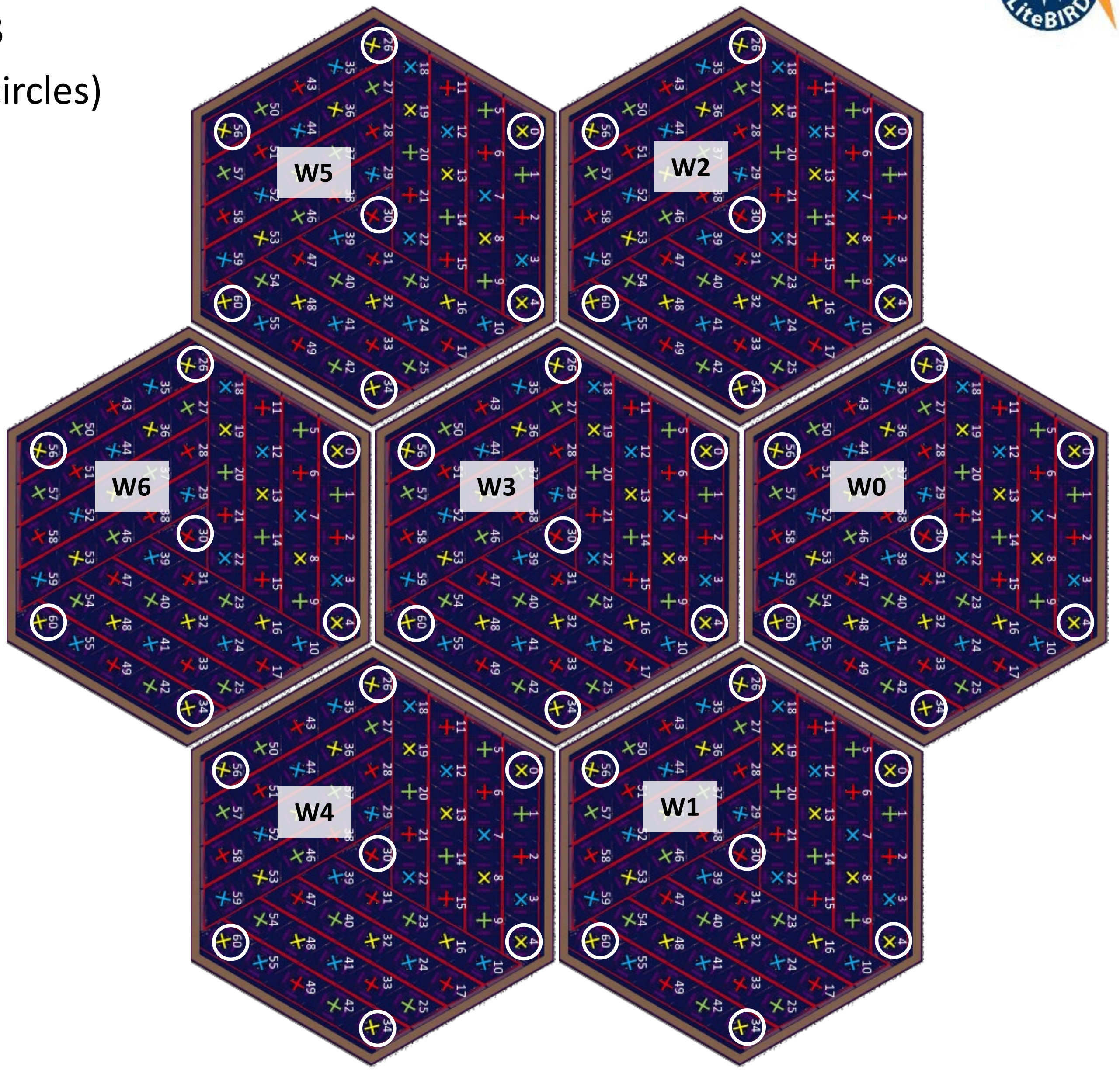


MFT focal plane configuration

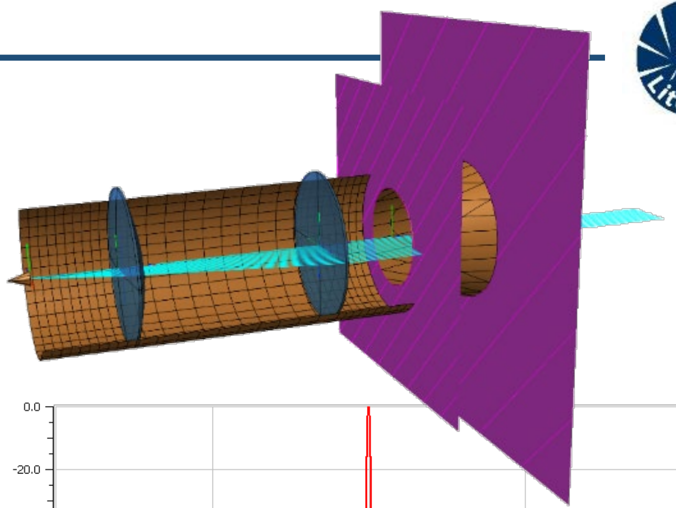
- **FPU configuration reported in IMo version 1.3**
  - 7×7 pixels sampled on the focal plane (white circles)
    - 001_00X_**000**_YYY
    - 001_00X_**004**_YYY
    - 001_00X_**026**_YYY
    - 001_00X_**030**_YYY (center pixel of the wafer)
    - 001_00X_**034**_YYY
    - 001_00X_**056**_YYY
    - 001_00X_**060**_YYY
  - X = wafer number, YYY = frequency

- **Di-chroic and tri-chroic channels**
  - **W0** : 119 – 166 GHz
  - **W1** : 119 – 166 GHz
  - **W2** : 100 – 140 – 195 GHz
  - **W3** : 100 – 140 – 195 GHz
  - **W4** : 100 – 140 – 195 GHz
  - **W5** : 119 – 166 GHz
  - **W6** : 119 – 166 GHz



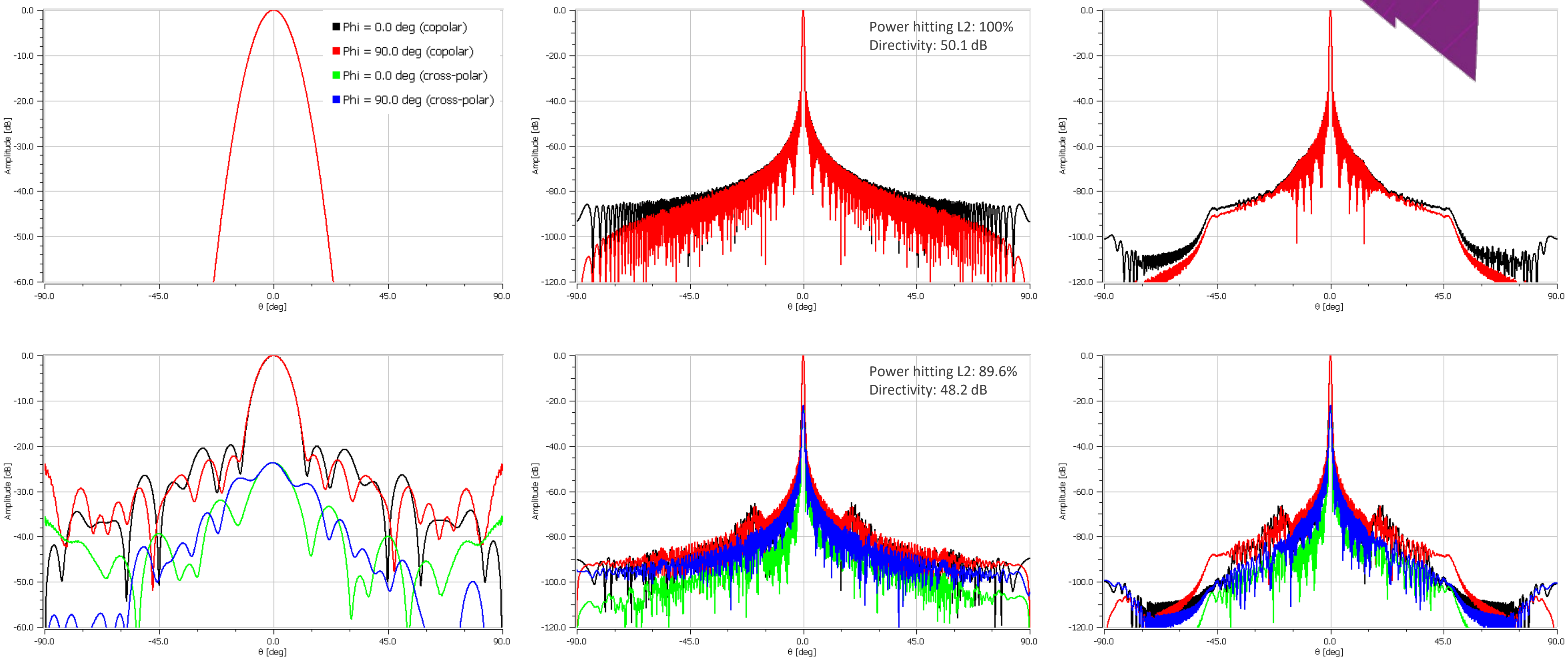
MFT beams with Physical Optics (PO)

- **GRASP® PO simulations of MFT on-axis pixel @140 GHz**
  - *Gaussian pattern* vs *Sinuous antenna plus lenslet*
  - Phi = 0 and phi = 90 planes at LOS direction
  - Beam former → aperture stop → baffle aperture



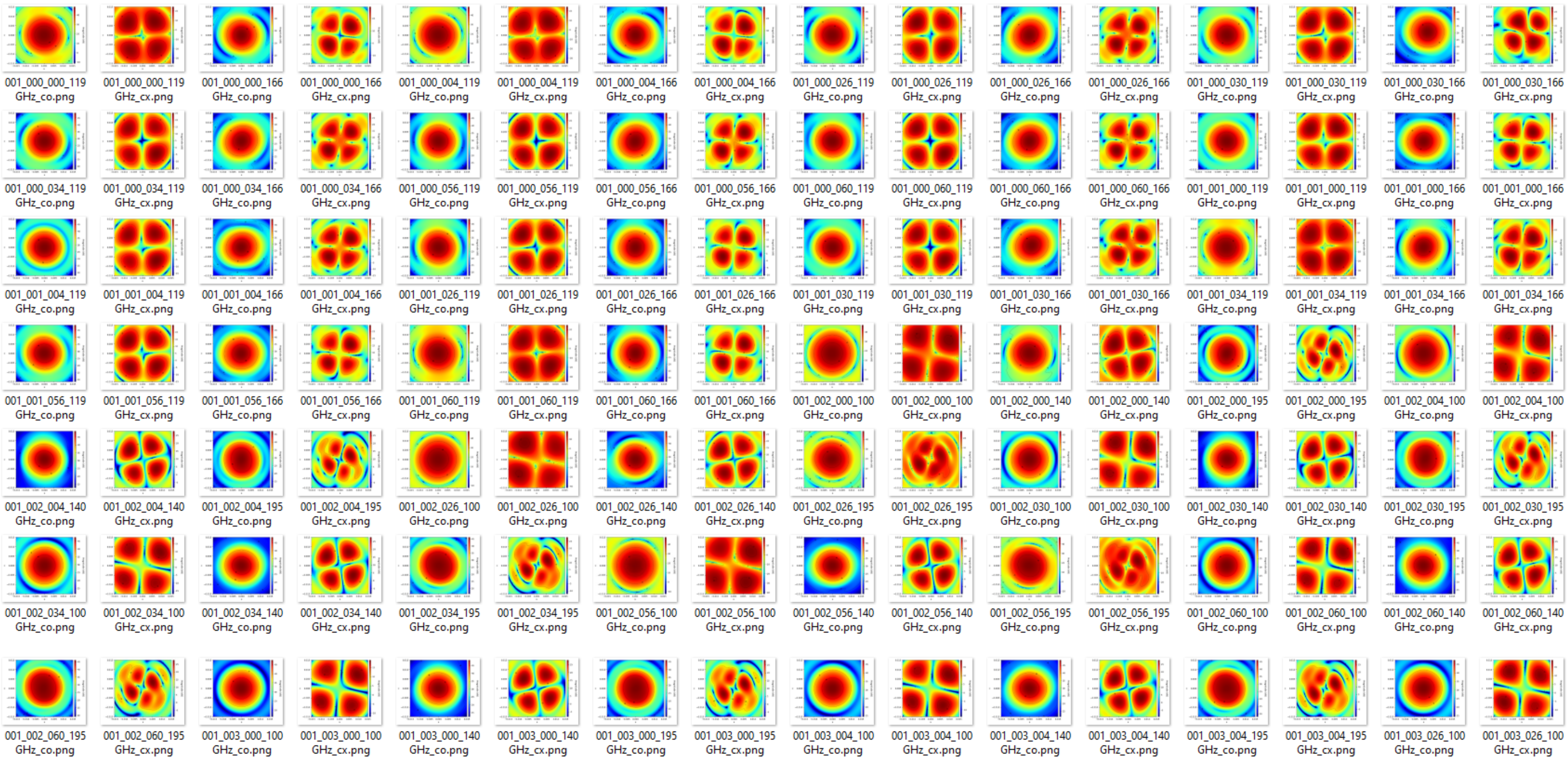
Gaussian beam former

Sinuous antenna & lenslet



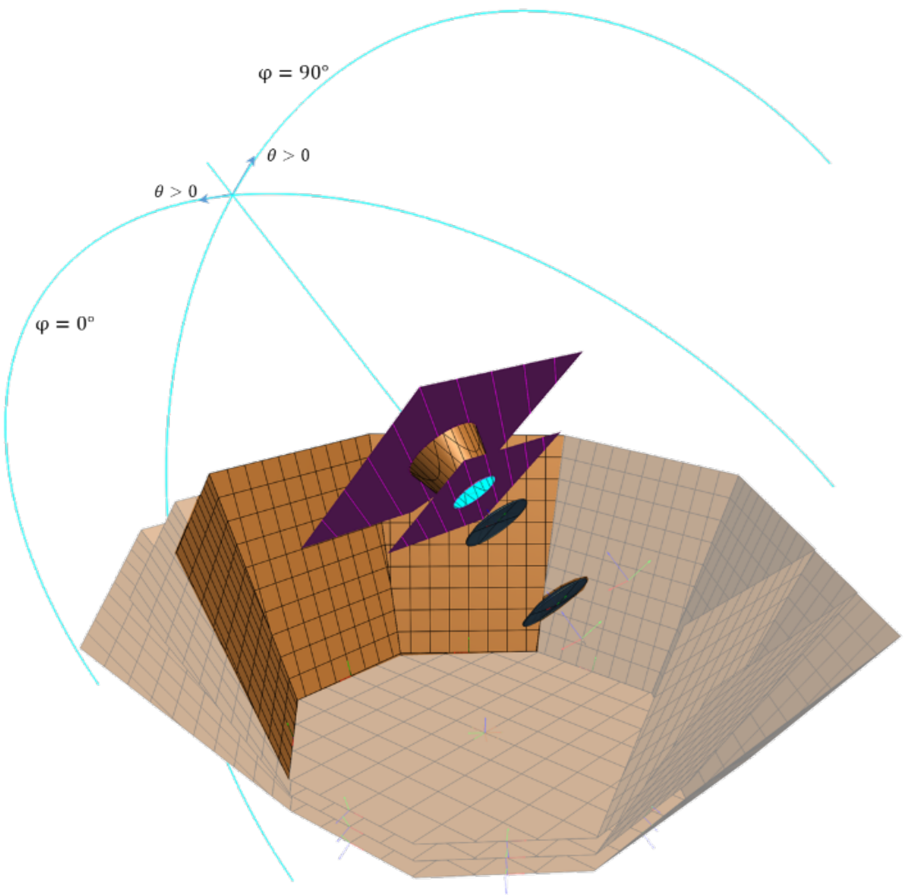
MFT beams with Physical Optics (PO)

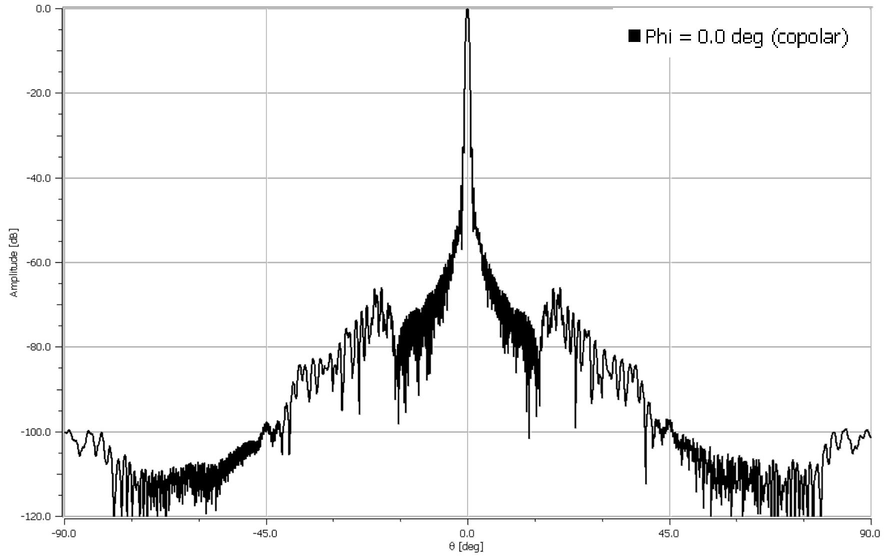
- **Co-polar and cross-polar MFT beams at 100, 119, 140, 166 and 195 GHz**

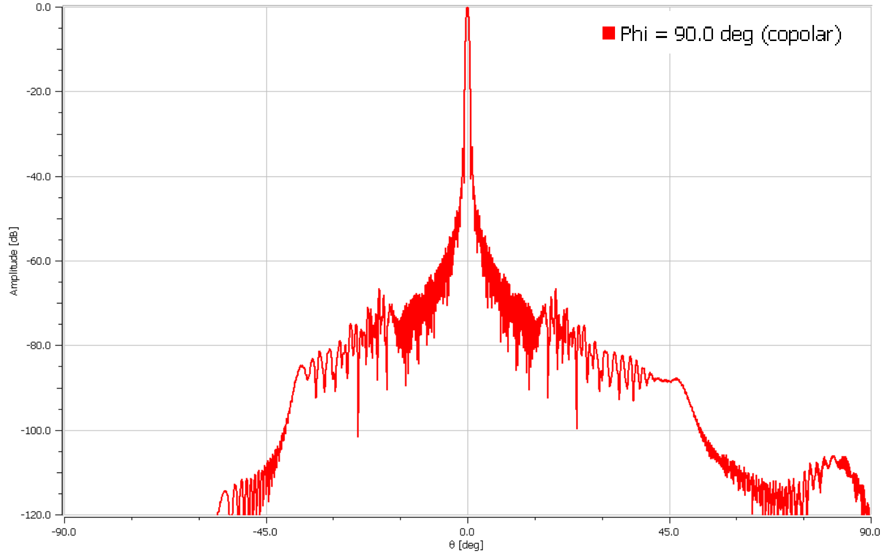


MFT side-lobes with Physical Optics (PO)

- **GRASP® PO simulations of MFT on-axis pixel @140 GHz**
  - 3 front panels of 1st V-groove
  - Phi = 0 and phi = 90 planes at LOS direction
  - Beam former → aperture stop → baffle aperture → VG1







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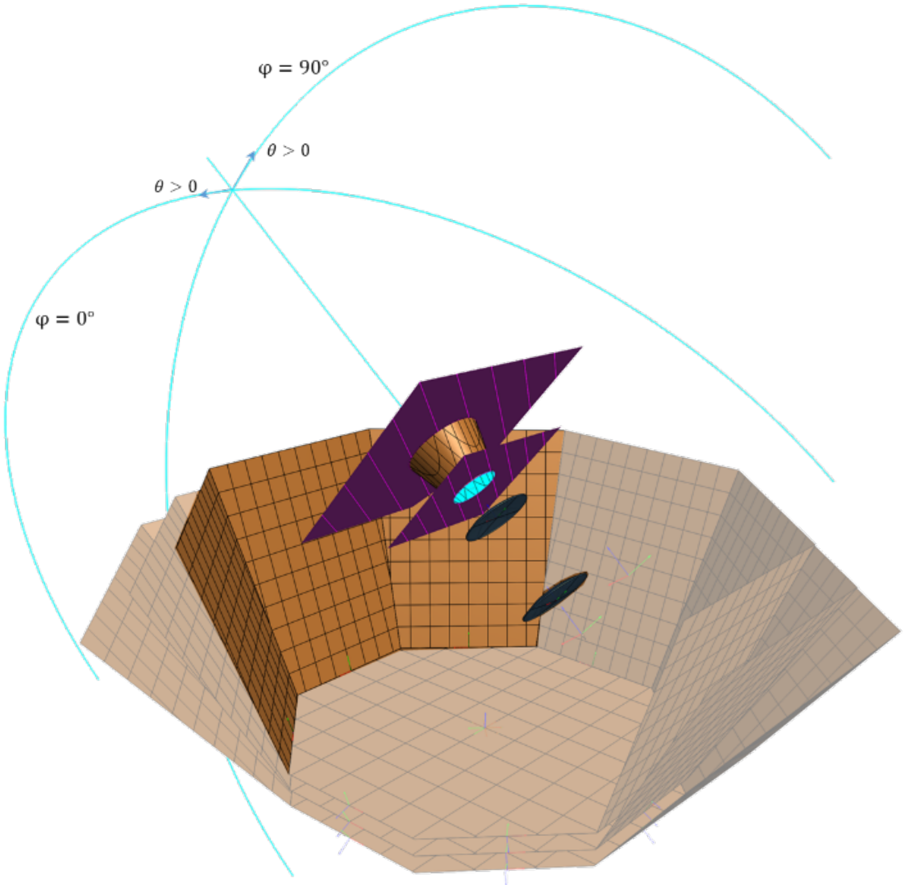
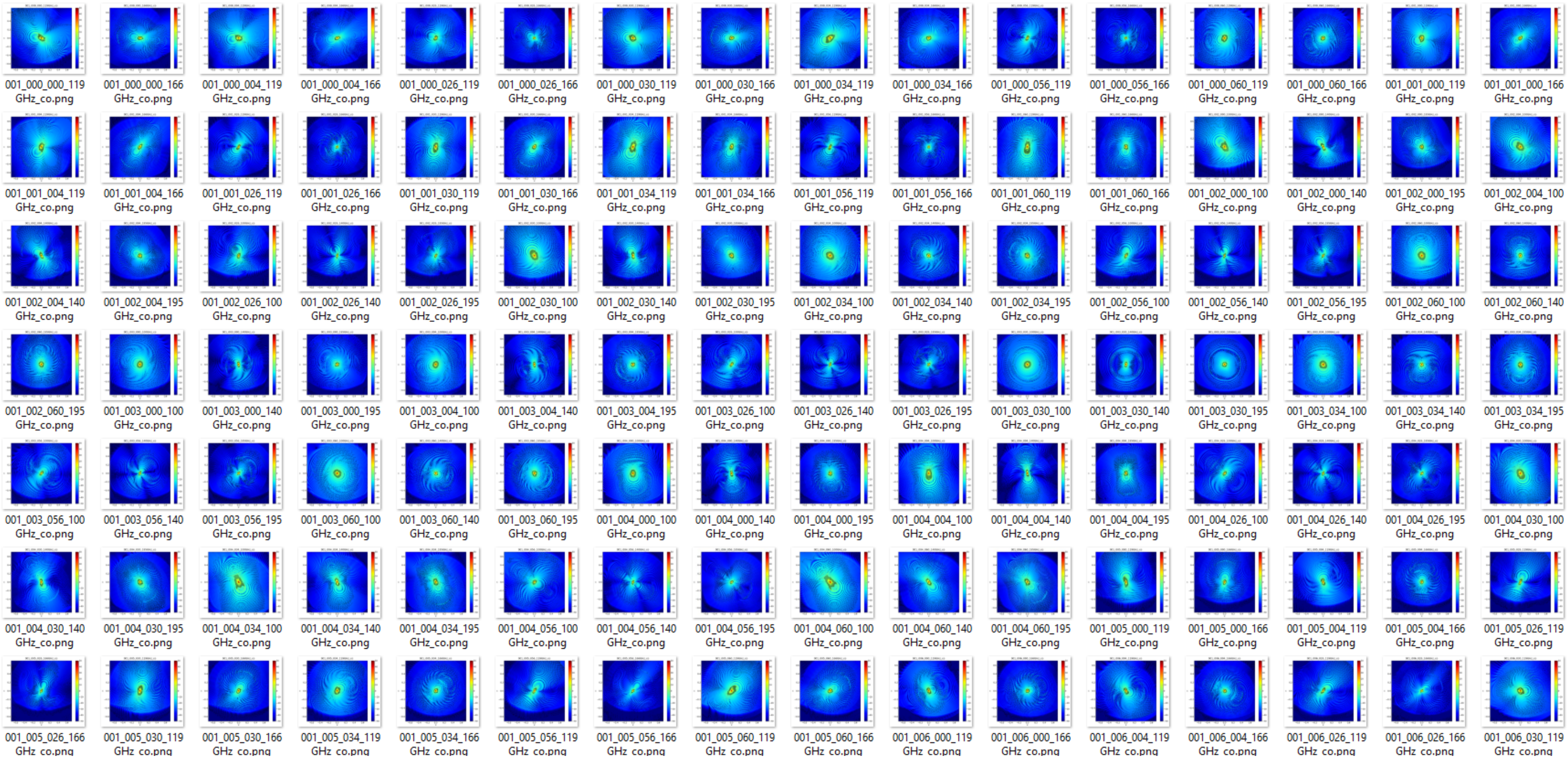


- **Some notes on the PO approach**
  - Not feasible for the whole model
  - 1st order interactions only at the VG1 front panels
    - *Reflections*
    - *Diffraction*
      - At the top and side edges
      - Panels bottom is not illuminated
  - 2nd order interaction does not converge
  - “Back lobes” difficult (impossible?) to be evaluated

MFT side-lobes with Physical Optics (PO)

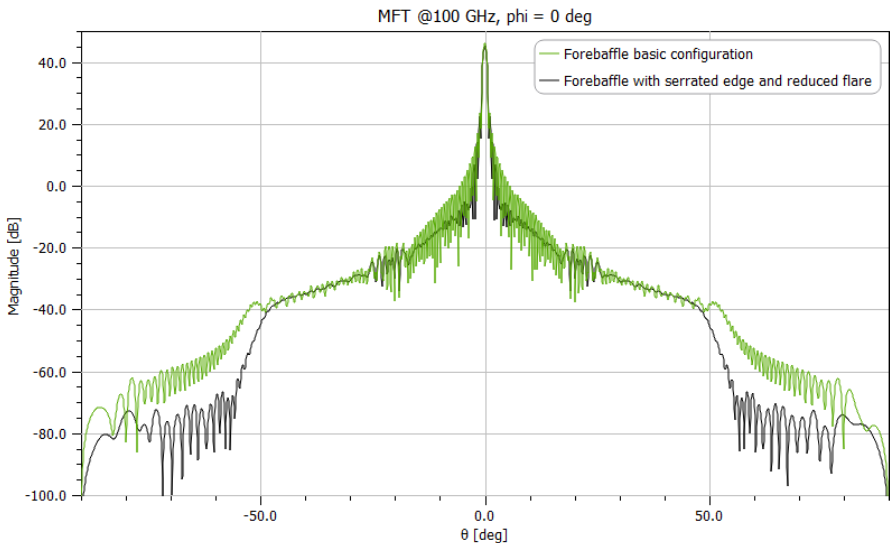
- **Co-polar and cross-polar MFT beams at 100, 119, 140, 166 and 195 GHz**



Next steps

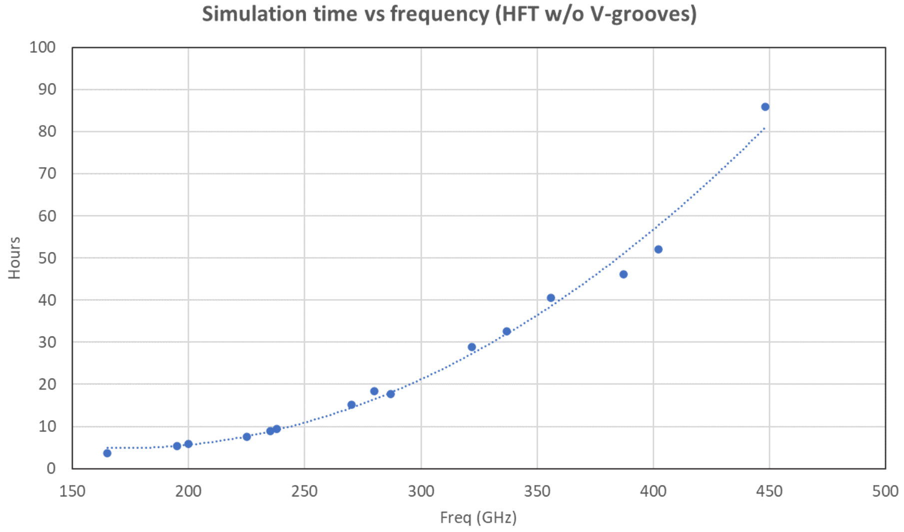
- **Improve the MFT realistic model**
  - Include the forebaffle with “trumpet-shaped” aperture edge
  - Include tube, baffles, etc.
  - Include small and large structures
  - Repeat MFT optics simulations with MoM and GTD

  !!! Simulation time strongly limits this activity !!!



- **Implementation of HFT model & optical simulations**
  - Far sidelobes simulations for a subset of pixels (in progress)

  !!! Simulation time strongly limits this activity !!!



From beam profiles to instrument requirements

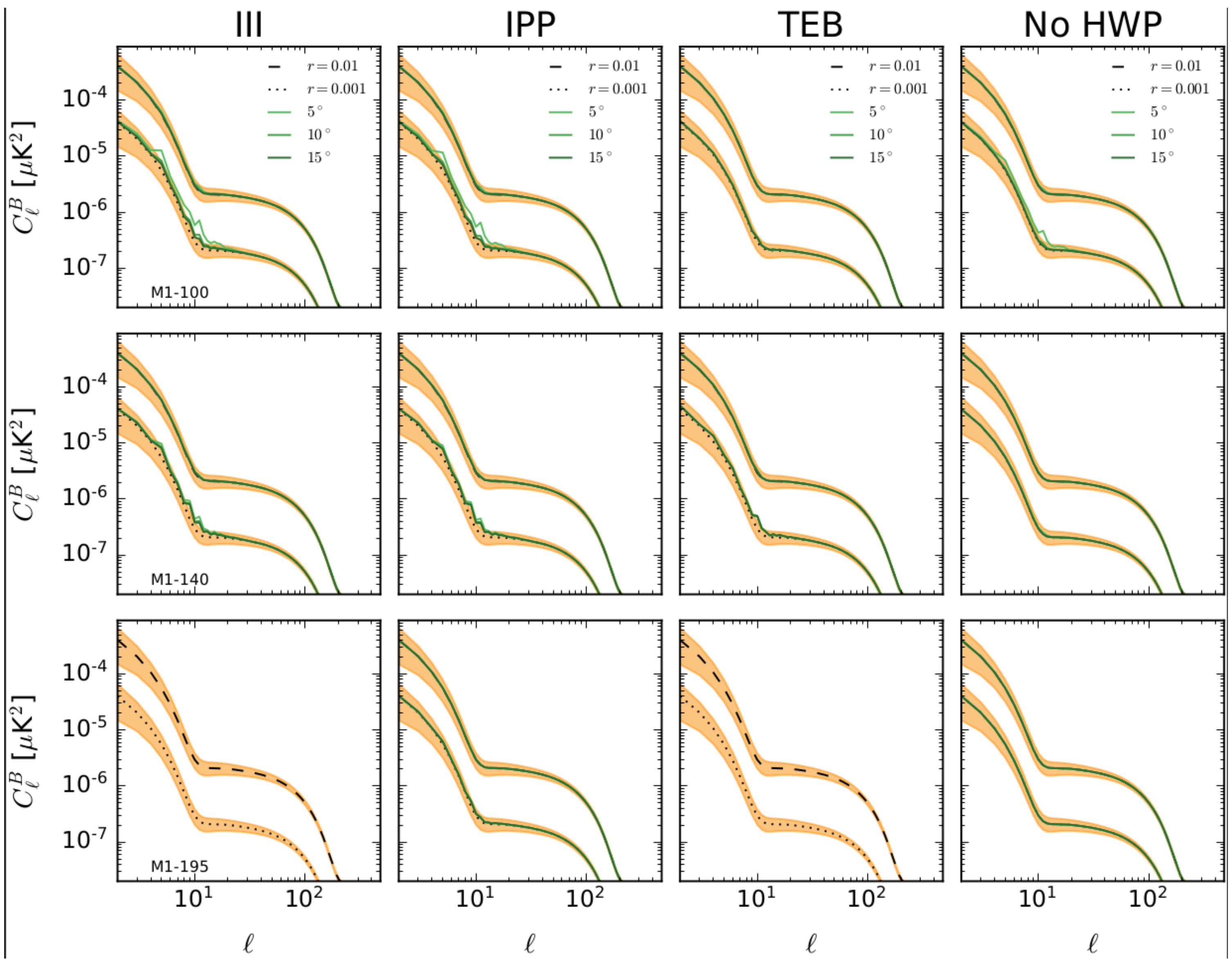
Motivation

- find a simple and direct way to derive beam requirements:
  - closer to actual beam measurement procedure
  - directly related to actual beam properties specified by, e.g., power dB level
  - avoid complications due to full data processing: clearly isolate the actual impact of beam shape only

Proposed approach

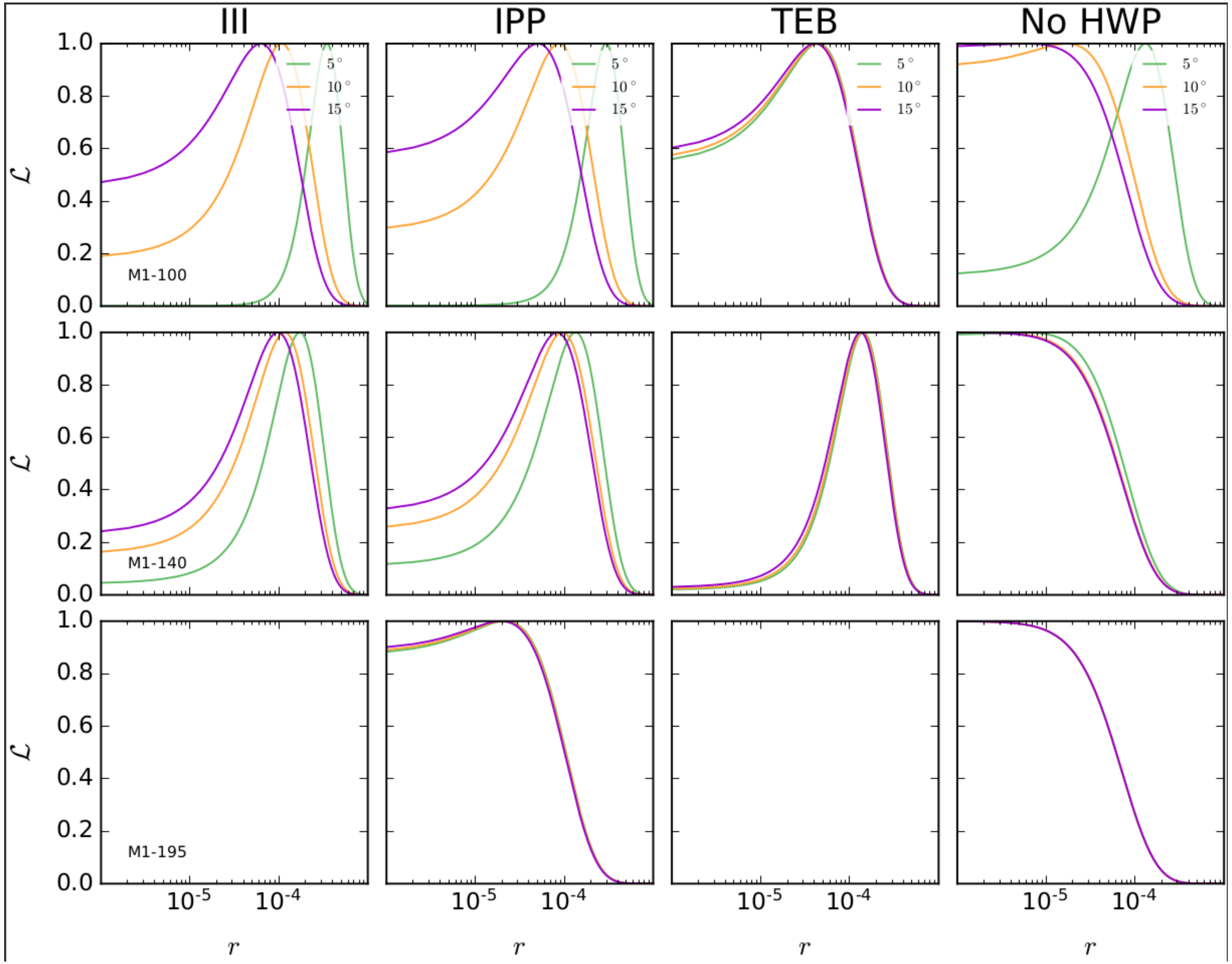
- Assume that we recover the input CMB B spectrum but for cosmic variance (CV)
- No component separations, no instrumental noise
- Use sidelobe convolved galactic signal as residual contamination
- Compare CMB B spectrum + galactic signal w.r.t. CV (we cannot beat cosmic variance!)
  - visual inspection of contaminating signal
  - construct likelihood for *r* to evaluate its impact in terms of Δr
- Useful to evaluate the goodness of polarised beam approximation in convolution with/without HWP
  - ***III:***used in PTEP (the same **I** beam used also for **Q** and **U** components)
  - ***IPP***: combine Q and U beam to create a "polarised" beam ($P^2 = Q^2+U^2$)
  - ***TEB:*** from beam alm: use alm^T for total intensity and create alm^P as linear combination of alm^E and alm^B for convolution of the polarised signal
  - ***NO-HWP:*** use Planck *totalconvolver* with beam as produced by GRASP (this is the actual beam shape)

Preliminary results (PTEP) @ MFT 100/140/195



- No ***III/TEB*** convolution @195
- ***III*** and ***IPP*** very similar: both 5 and 10 degs cuts are larger than CV
- ***TEB*** and ***No-HWP*** very similar with only 5deg cuts showing smaller excess over CV

Preliminary results: *r* likelihood



- Impliment a simple *r* likelihood (no noise, CV and residual galactic sidelobes signal as contaminant)
- ***III*** and ***IPP*** cannot go lower than 5 10-5very similar: both 5 and 10 degs cuts are larger than CV
- ***TEB***: near sidelobes are more important than far sidelobes
- ***No-HWP*** (actual beam shape):
  - 140 & 195: beam knowledge down to 5 degs is enough to reach r error budget and …
  - … this is true @100 with knowledge between 5 and 10 degs

Next steps

- Use latests beams from Cristian: on-going already produce beam alm
- Consider 3 cases:
  - central beams in the central Wafer (for trichroic 100/140/195)
  - use larger off-axis beams
  - use all beams combined
- Cut the beam not in angle but according to its own power level (should be closer to actual beam measurements)
- We are in touch with Clement and provide him with our No-HWP beam convolver maps to derive his own beam requirements and compare with our simple approach. This should be the basis for moving from L3 to L4 requirements.