The COSmic Monopole Observer

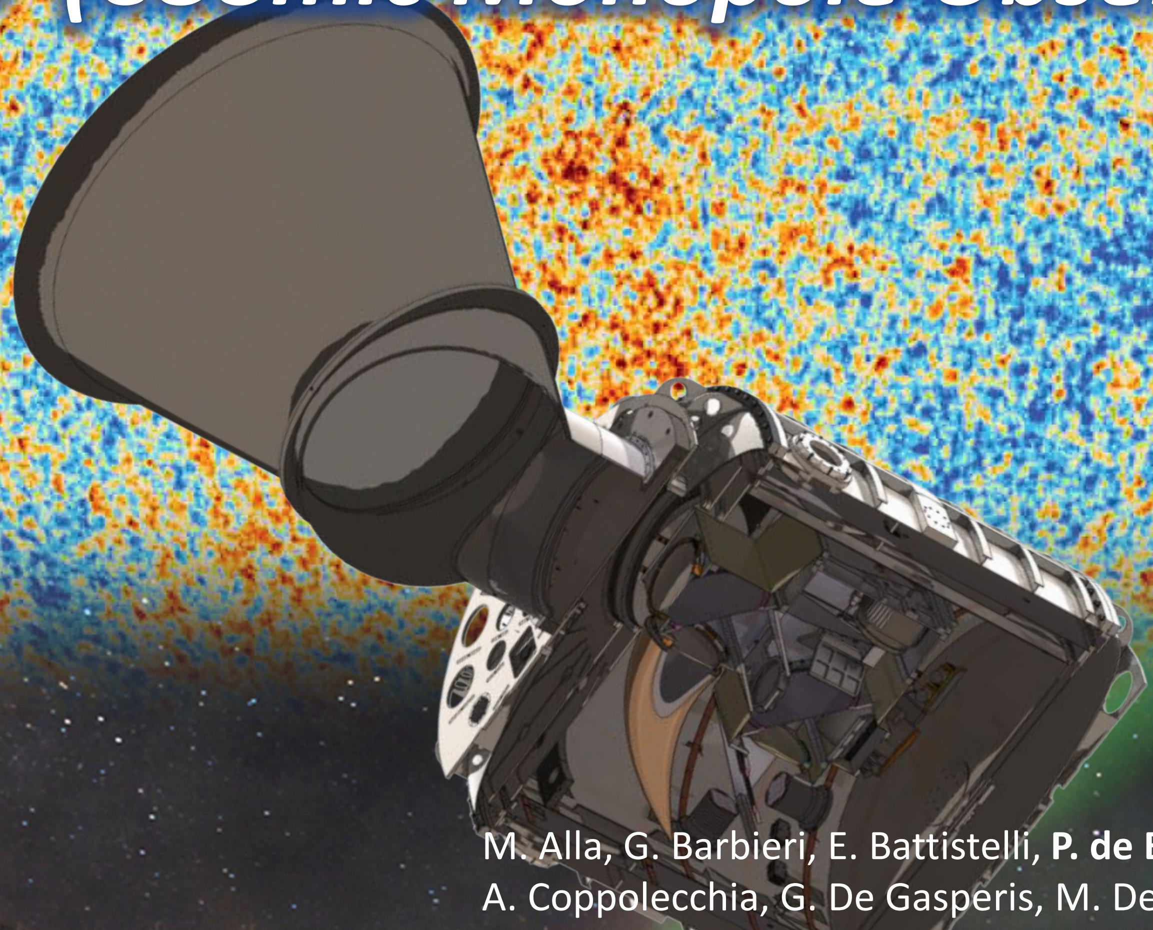
Luca Lamagna
Physics Dept., Sapienza University of Rome

On behalf of the COSMO collaboration

Challenges at the CMB Frontier,

Chino Cultural Complex - June 29, 2026

COSMO (COSmic Monopole Observer)



M. Alla, G. Barbieri, E. Battistelli, **P. de Bernardis**, M. Bersanelli, F. Capponi, F. Columbro, A. Coppolecchia, G. De Gasperis, M. De Petris, I. di Nitto, M. Dolci, C. Franceschet, M. Gervasi, G. Isopi, G. Kyryakou, A. Limonta, L. Lamagna, E. Manzan, E. Marchitelli, S. Masi, A. Mennella, A. Occhiuzzi, M. Oddone, A. Paiella, G. Pettinari, F. Piacentini, L. Piccirillo, G. Pisano, S. Realini, C. Tucker, M. Zannoni

Sapienza Università di Roma
CNR IFN Istituto di Fotonica e Nanotecnologie
Università degli Studi di Milano Bicocca
Universitas Studiorum Mediolanensis
Cardiff University / Prifysgol Caerdydd
Manchester 1824 The University of Manchester
INAF - Osservatorio Astronomico d'Abruzzo

Ministero dell'Università e della Ricerca
FIS
PRIN Programmi di Ricerca Scientifica di Rilevante Interesse Nazionale
Programma Nazionale di Ricerche in Antartide

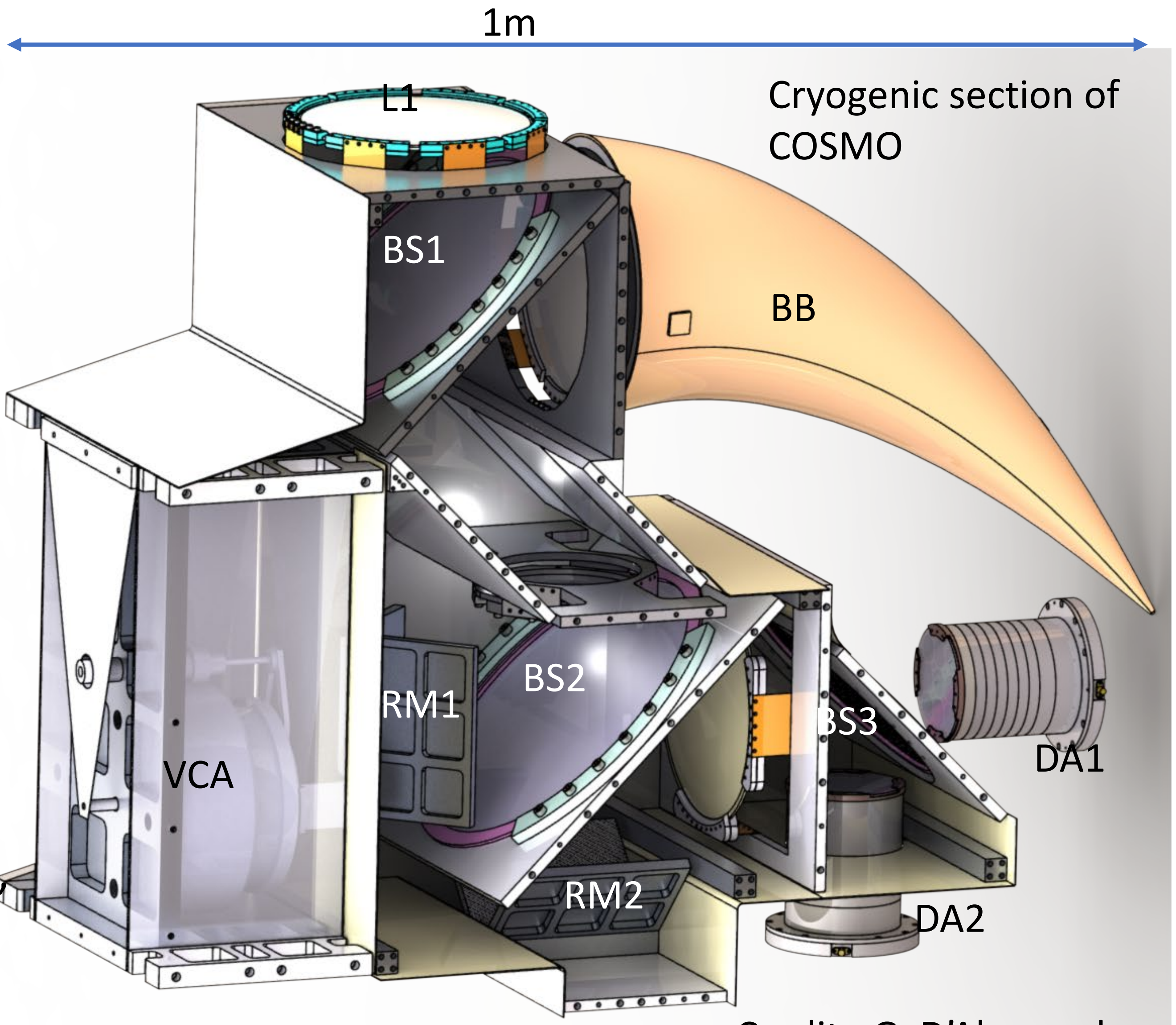
https://cosmo.roma1.infn.it

Ground-based spectral distortion measurements?!?

- Spectral distortions are tiny signals on top of much brighter backgrounds.
- From the ground, the main limitations are atmosphere, sidelobes, window emission, and EMI.
- Space is the final route to high-precision measurements.
- BUT: ground-based experiments remain crucial as affordable, fast, iterative testbeds — and may detect the largest distortions first.

COSMO in a nutshell

- **COSMO** is a *pathfinder* experiment, ground-based in the first implementation, balloon-borne in its second step.
- High transmission bands: **125-175 GHz** ($y_{SD} < 0$) and **200-285 GHz** ($y_{SD} > 0$) ~**5 GHz** resolution.
- FTS is cryogenically cooled @3K;
- Tunable (2.5-4 K) reference internal calibrator;
- A continuous and **fast** (few seconds) **interferogram scan** is achieved via a voice-coil actuator.
- Fast detectors (multi-mode KIDs, τ=60 μs) so that **fast sky-dips** are continuously performed to measure and reject atmospheric emission and its slow fluctuations.
- Operation from the Concordia French-Italian base in **Dome-C, Antarctica**. Average PVW of 210μm, T < -60C, stable weather in the winter season (*Tremblin et al. A&A, 2011*). Atmospheric emission strongly reduced wrt mid latitude sites.



Credit : G. D'Alessandro

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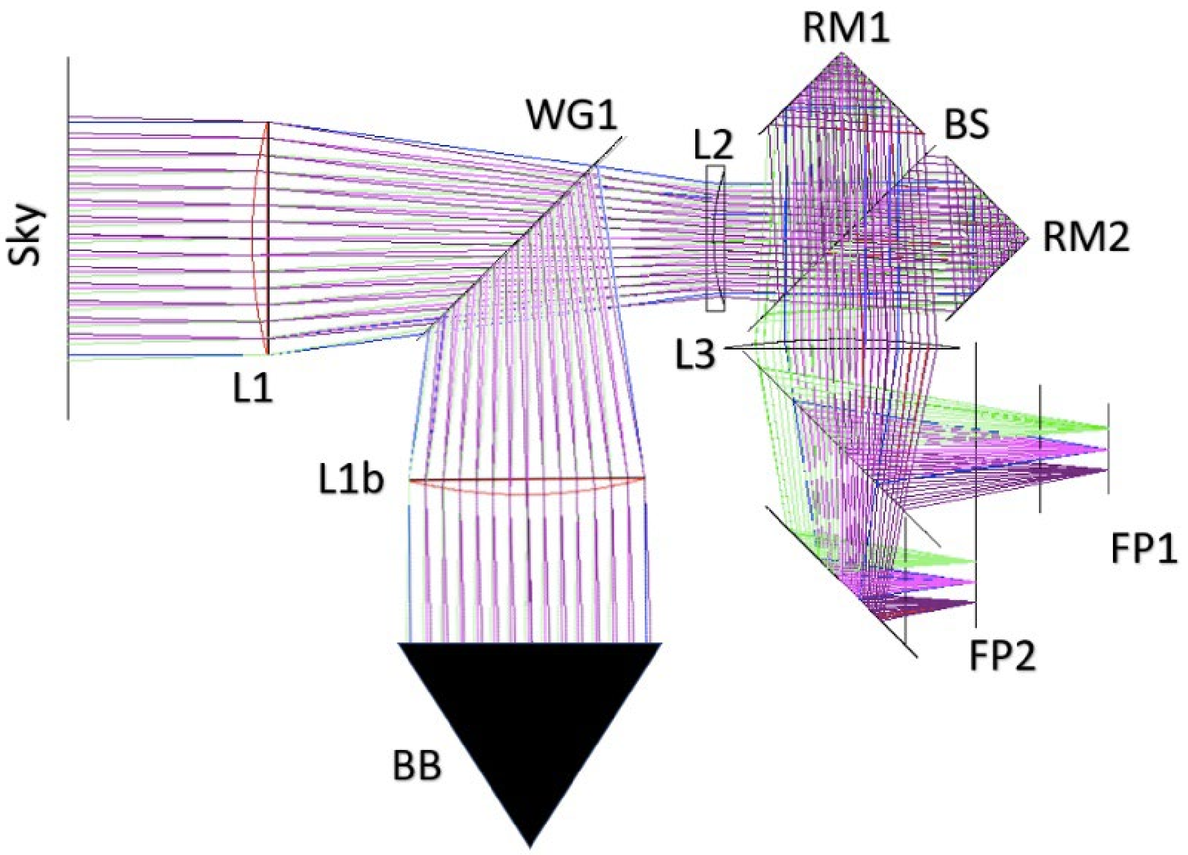


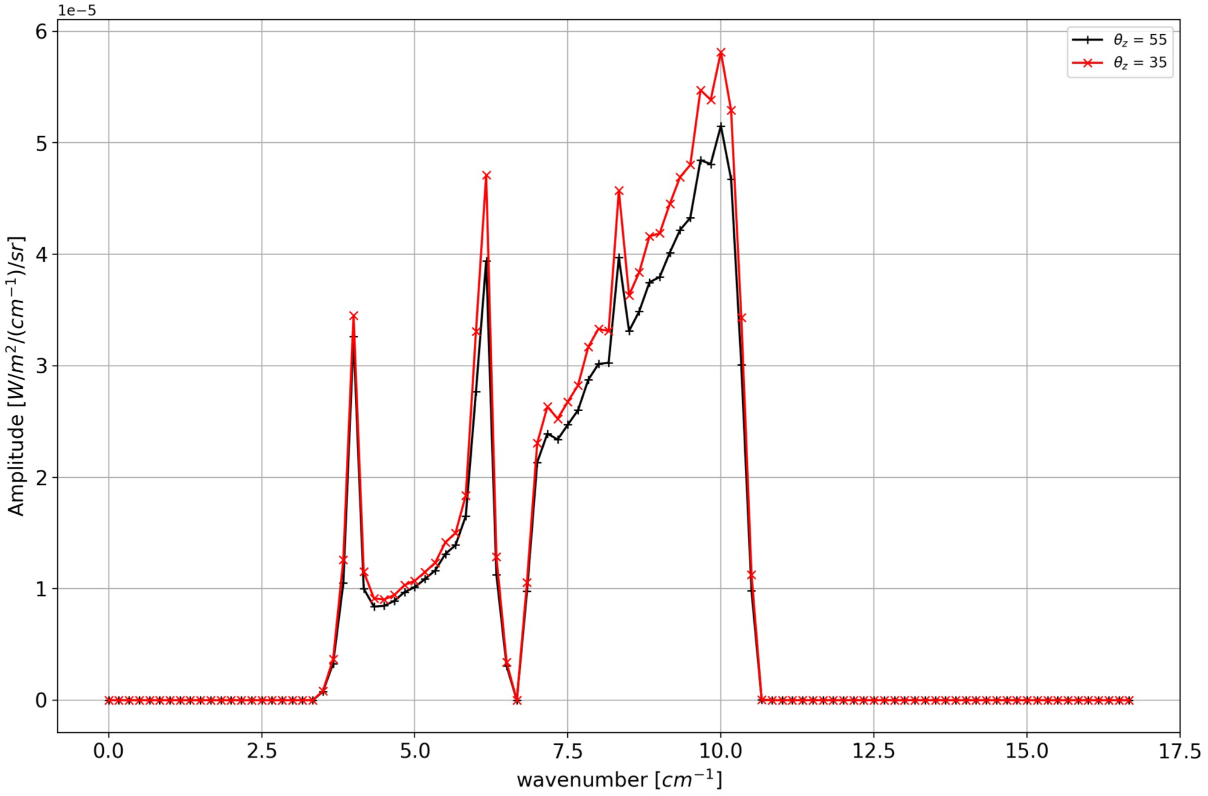
Scanning strategy - rationale

A basic breakdown of the dominant contributions to the differential signal:

$$S_{in} = \left[\left(B_{CMB}(\tilde{\nu}) - B_a(\tilde{\nu}) \right) e^{-\frac{\tau(\tilde{\nu})}{\cos(\mathrm{el}(t))}} + \left(B_a(\tilde{\nu}) - B_{ref}(\tilde{\nu}) \right) + B_w(\tilde{\nu}) \right] F(\tilde{\nu})$$

The signal is doubly-modulated by the scanning mirror (FTS) and by periodically changing the air mass through a boresight modulation.

Through a proper (and feasible) combination of the two scanning frequencies, a (sparse) sampling of the IGs associated to different air masses is performed, allowing to reconstruct the part of the spectrum that is sensistive to air mass.



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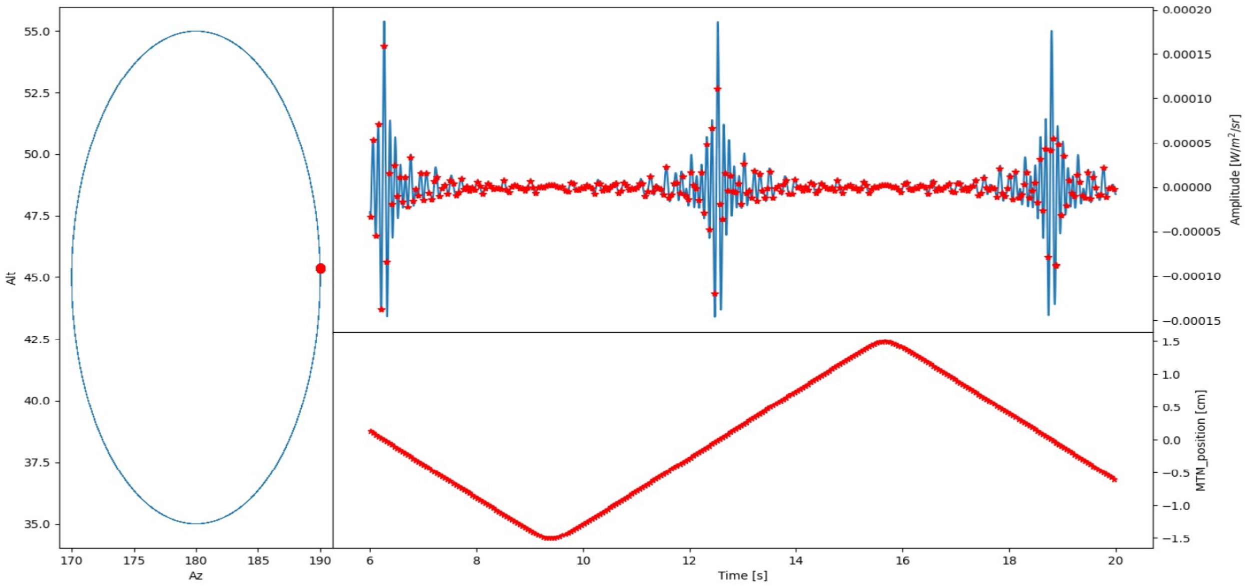

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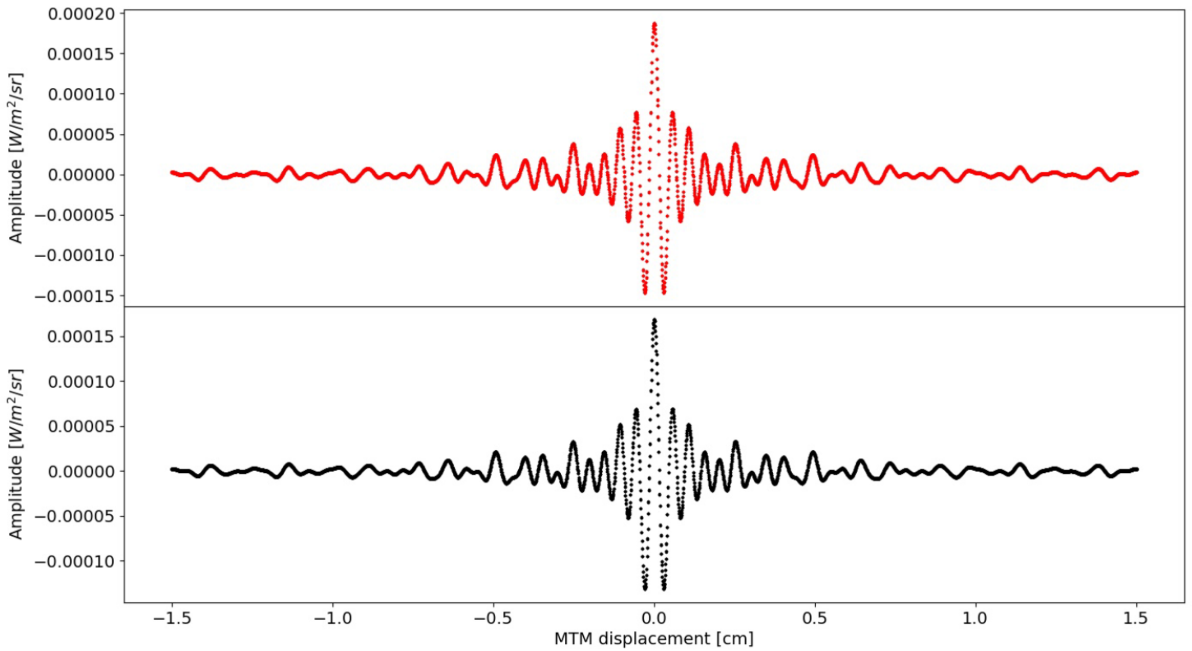
Spinning: 1200 rpm, Integrated for 3 minutes



(max and min elevation shown)

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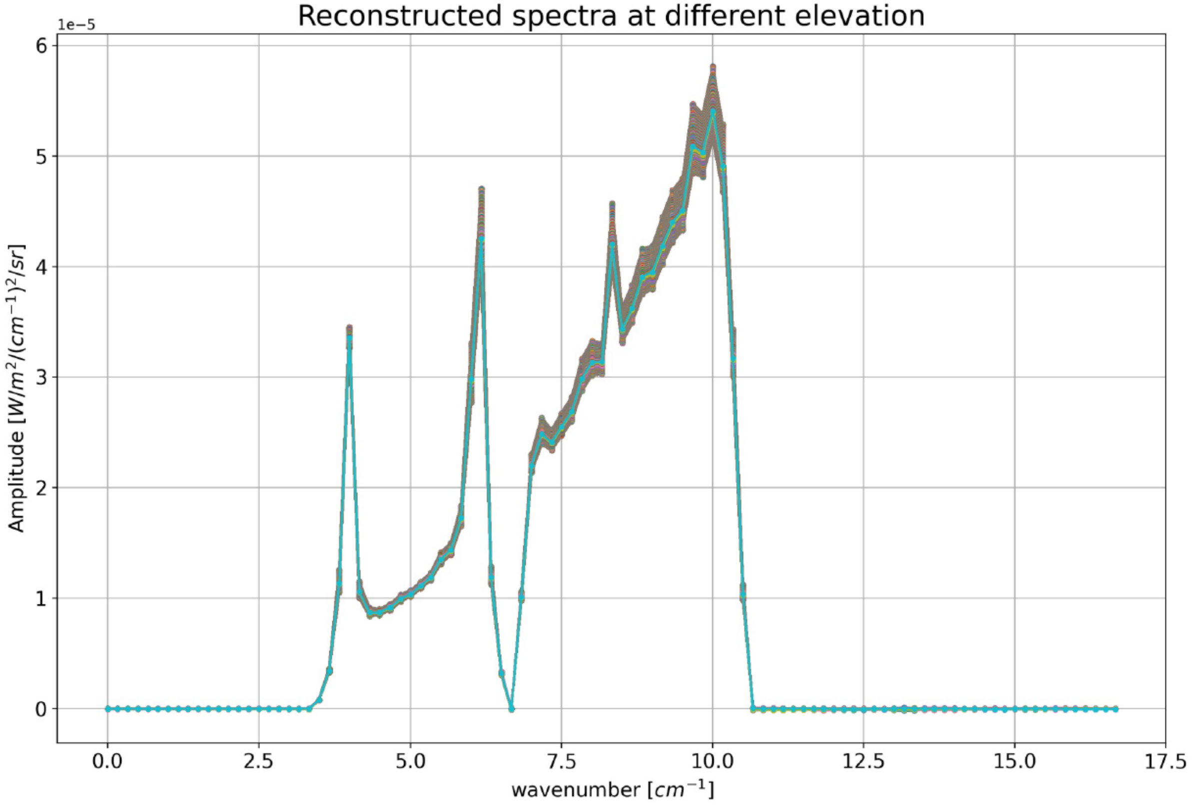

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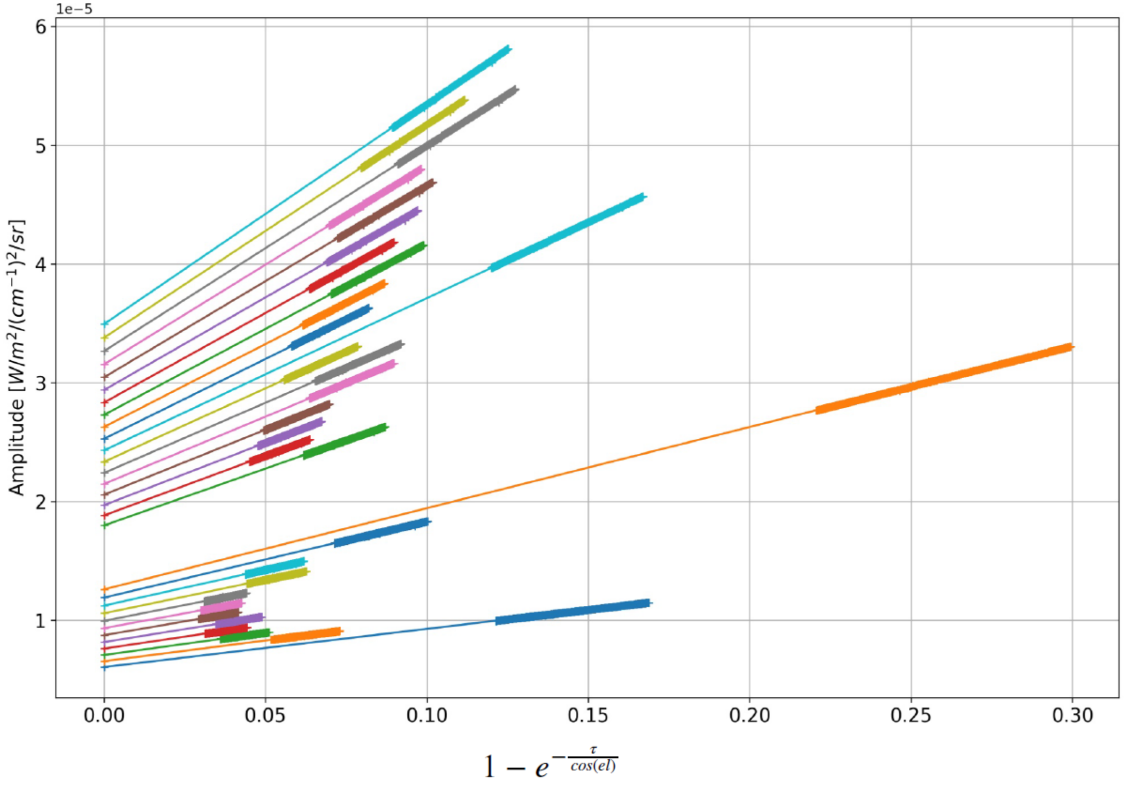
Through a proper (and feasible) combination of the two scanning frequencies, a (sparse) sampling of the IGs associated to different air masses is performed, allowing to reconstruct the part of the spectrum that is sensitive to air mass.

Extrapolation to 0 air mass for all the freq.



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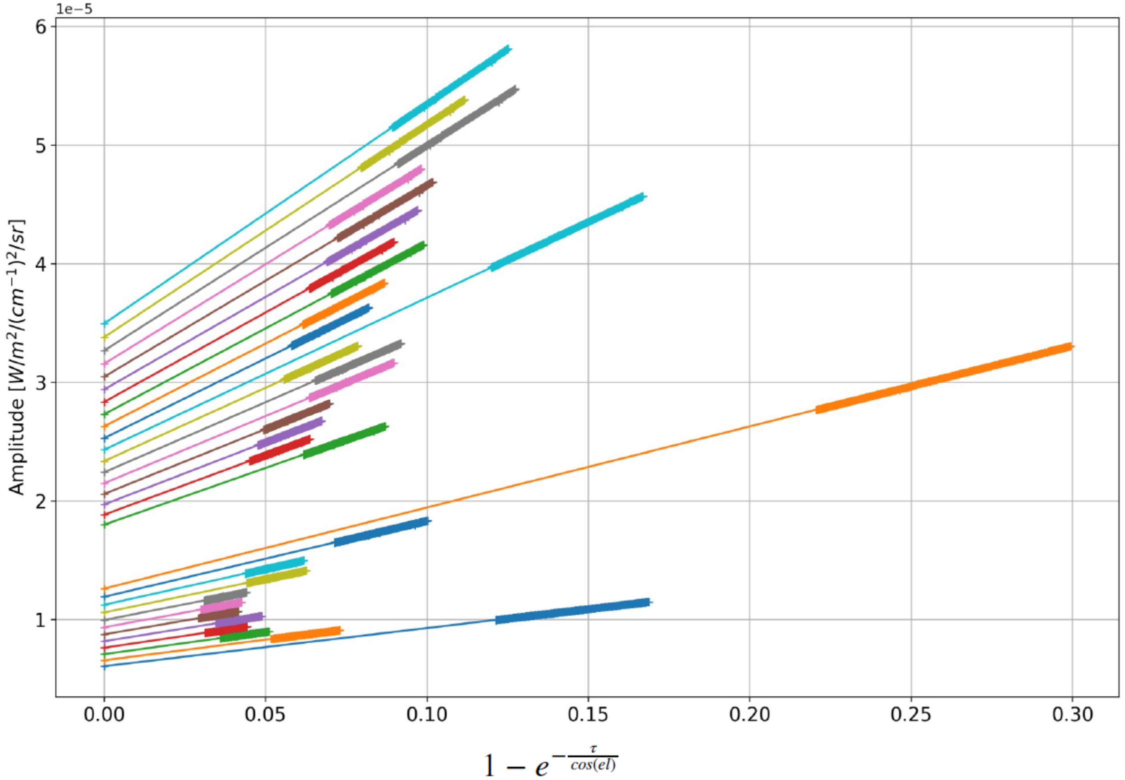
Criticalities:

- Frequency choice for optimal sampling and IG rebinning
- Fast modulation implies need for fast detectors (KIDS)
- Careful ground pickup mitigation to avoid large modulated signals requires accurate modeling of external baffling
- Pointing reconstruction data reduction must comply with the robustness needed to discriminate at least the largest y distortion.

Extrapolation to 0 air mass for all the freq.



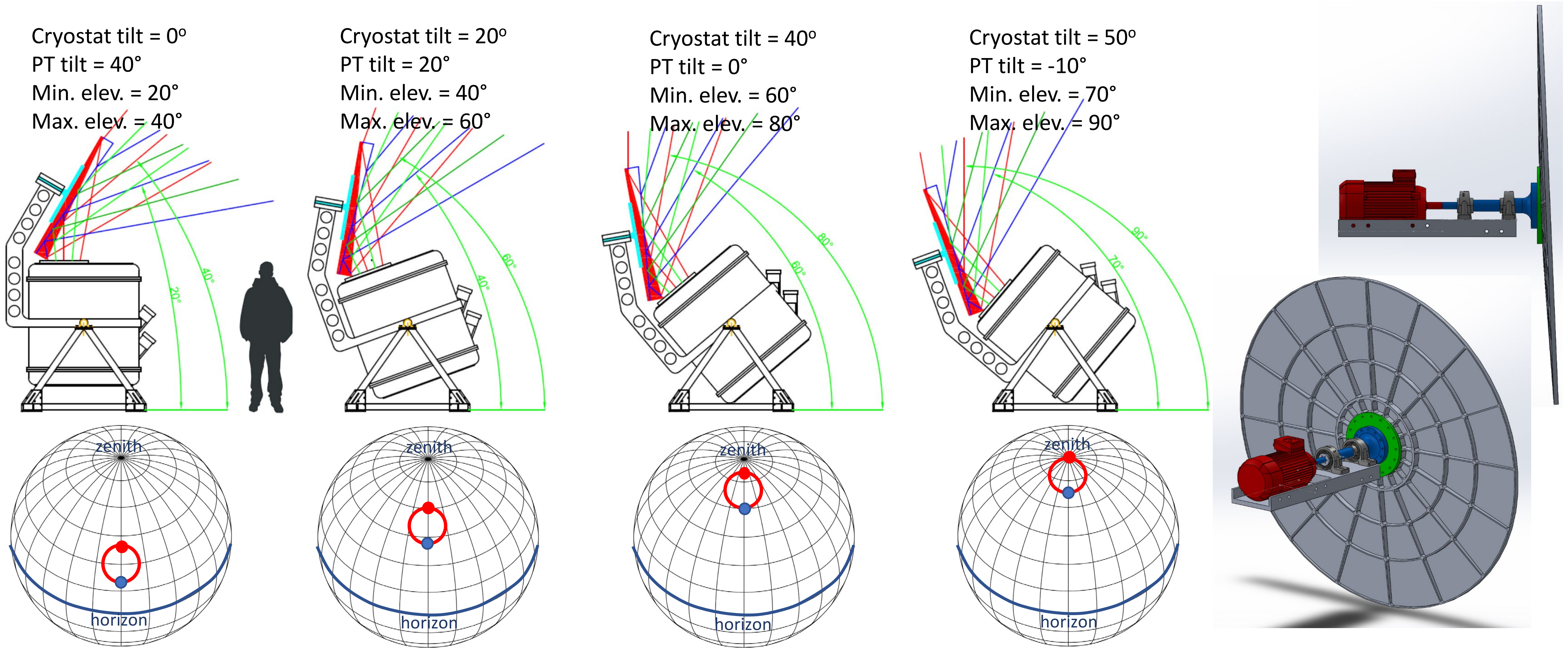
Scanning strategy - implementation

Cryostat tilt = 0°
PT tilt = 40°
Min. elev. = 20°
Max. elev. = 40°

Cryostat tilt = 20°
PT tilt = 20°
Min. elev. = 40°
Max. elev. = 60°

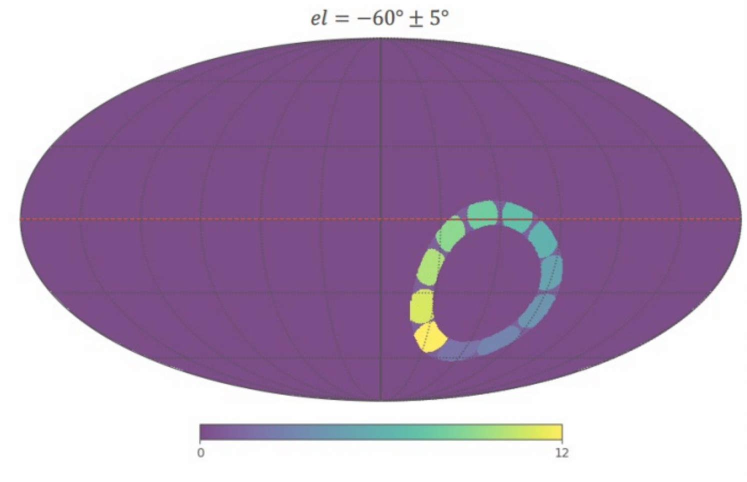
Cryostat tilt = 40°
PT tilt = 0°
Min. elev. = 60°
Max. elev. = 80°

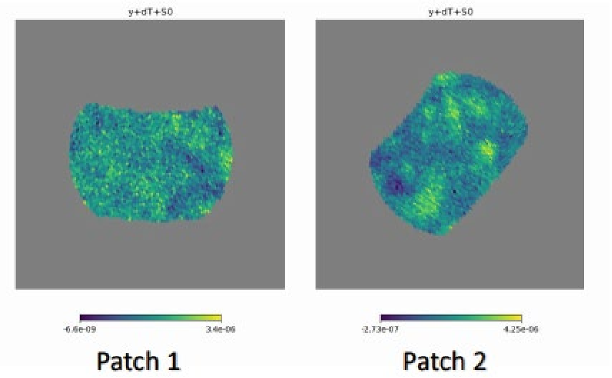
Cryostat tilt = 50°
PT tilt = -10°
Min. elev. = 70°
Max. elev. = 90°

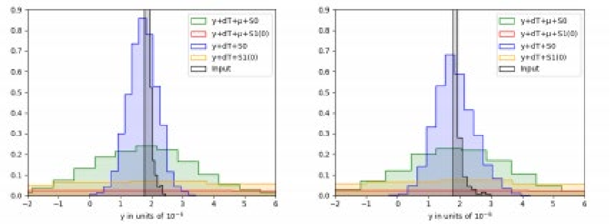


COSMO Simulation Framework

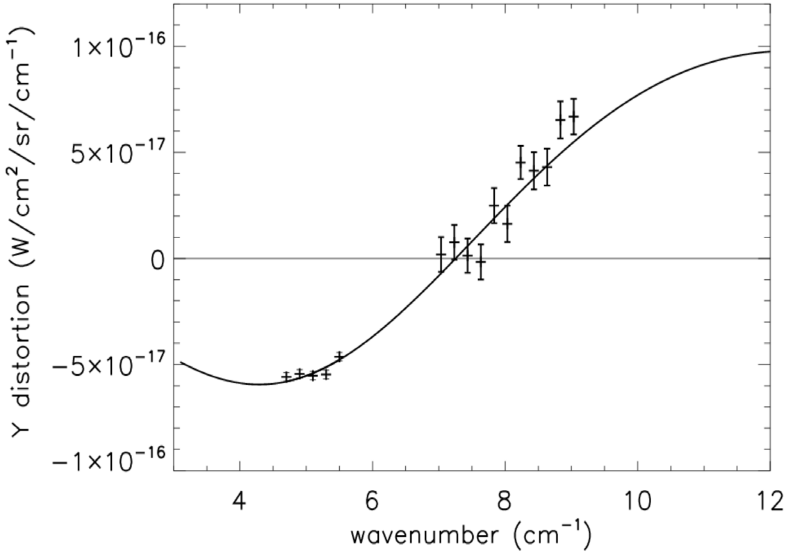
- Pixel-space







- 11x **10°x10°** sky patches are observed with **1° resolution**, in the southern sky and with varying levels of galactic signals.
- Assuming photon noise limited performance, dominated by the atmospheric emission (AM model) and cryostat window (with $\varepsilon = 1\%$)
- ILC-based simulations: COSMO can extract the isotropic comptonization parameter (assumed to be $y = 1.77 \cdot 10^{-6}$) as $y = (1.76 \pm 0.26) \cdot 10^{-6}$ in the presence of the main Galactic foreground (thermal dust) and of CMB anisotropy, and assuming perfect atmospheric emission removal (L. Mele)

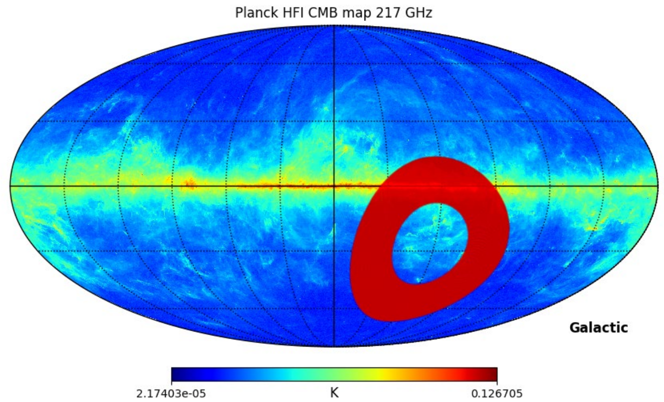


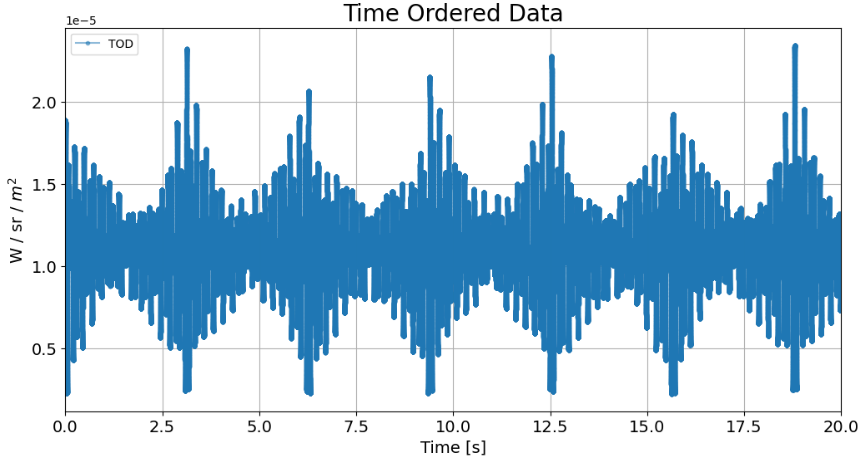
$\lvert y \rvert \cdot 10^{-6}$ (20% priors on CIB and Dust)
1.99 ± 0.88
1.59 ± 0.83
1.95 ± 0.87
2.62 ± 1.87
2.94 ± 2.26
2.66 ± 2.45
3.29 ± 2.28
1.76 ± 1.28
1.90 ± 0.88
1.93 ± 0.97
1.87 ± 0.90

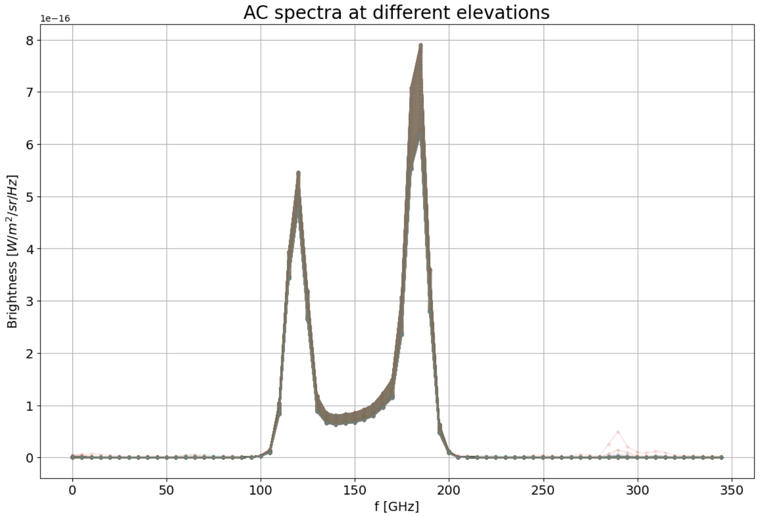
(PdB, SM, L. Mele)

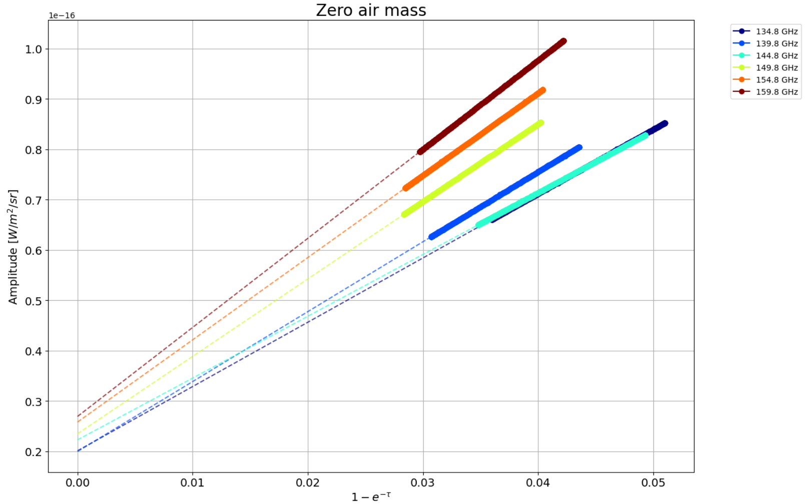
COSMO Simulation Framework

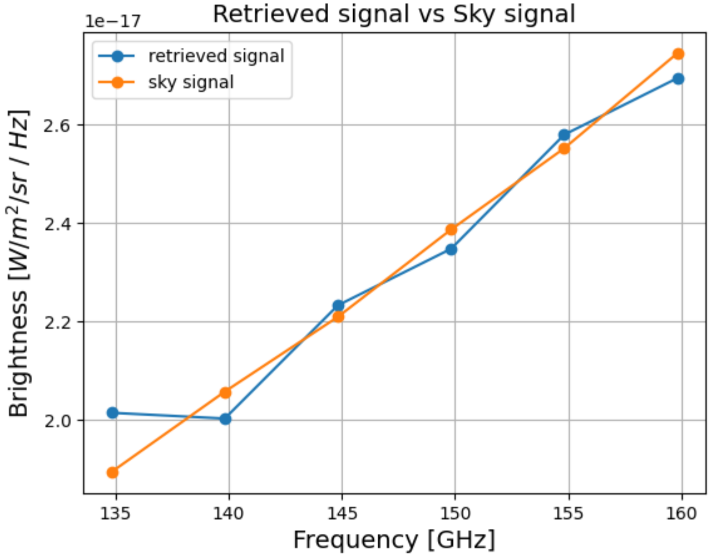
- Time domain
  - Drifts in PWV content and choice of data chunks
  - Impact of scanning frequencies
  - Effectiveness of sparse sampling and of zero air-mass extrapolation











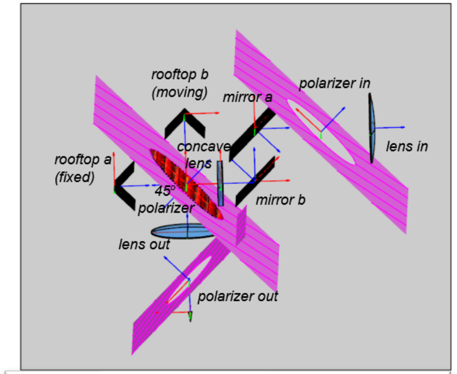
(M. Contini, E. Marchitelli, G. De Gasperis)

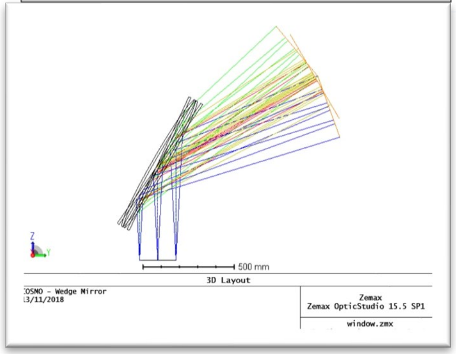
COSMO Simulation Framework

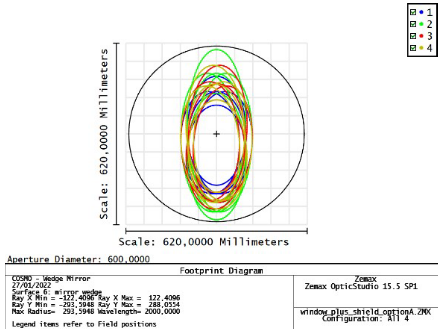
- Hardware non-idealities and systematics breakdown

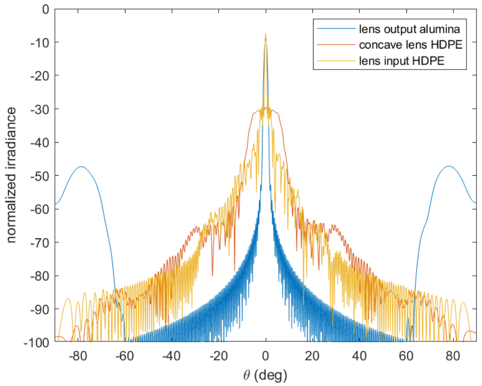
- Informed by optical (Zemax+GRASP) simulations and radiometric models and by real-life subsystem-level tests
- Spillovers and baffling (warm and cold)
- Multi-mode feeds
- Beam systematics vs modulation
- Differential chromaticity
- Constraints on reference calibrator characterization
- Understanding of the overall thermal/radiative environment to monitor and correct for imbalance and contamination.

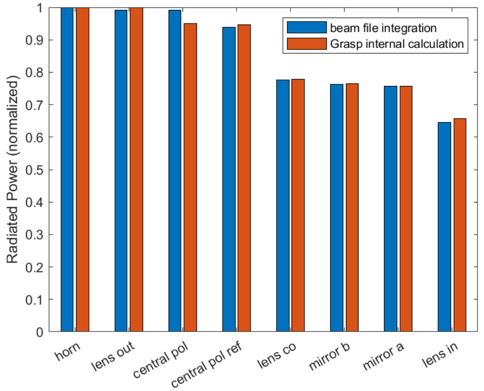
(C. Quintiliani, Y. Kyriakou, M. De Petris, LL)

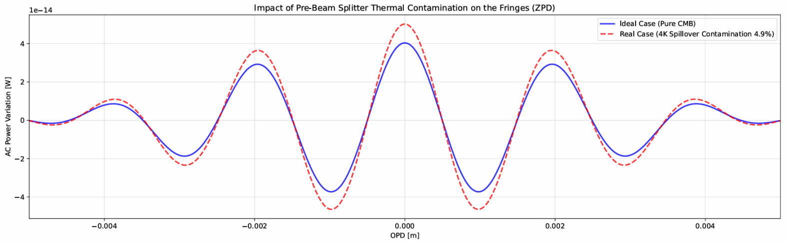


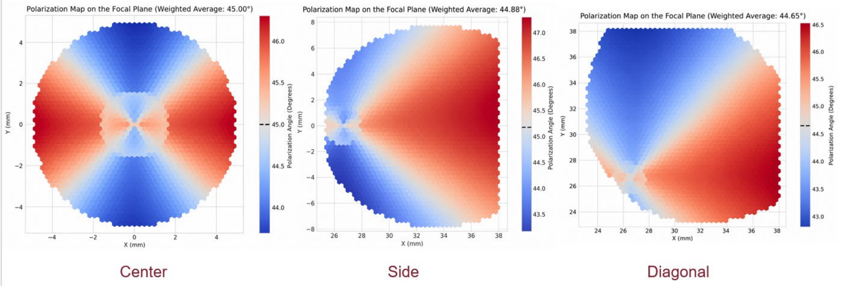




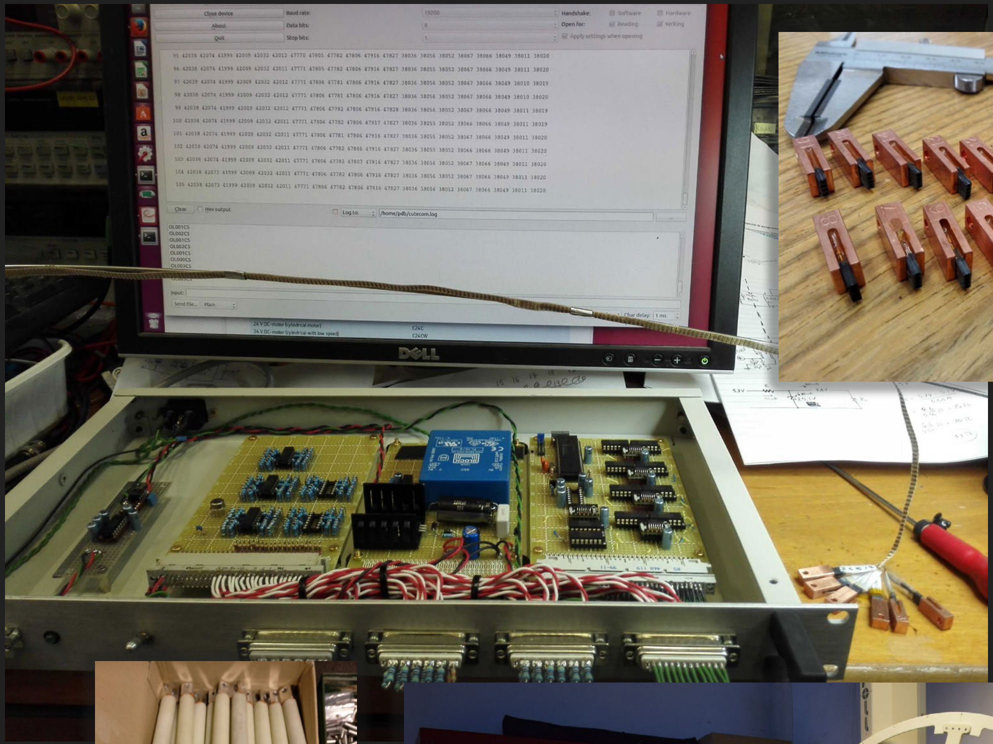


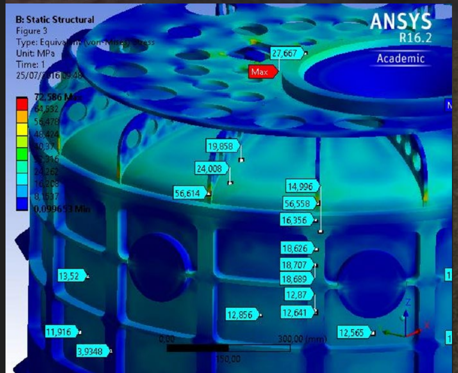


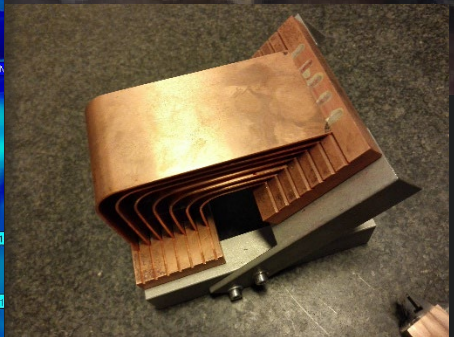




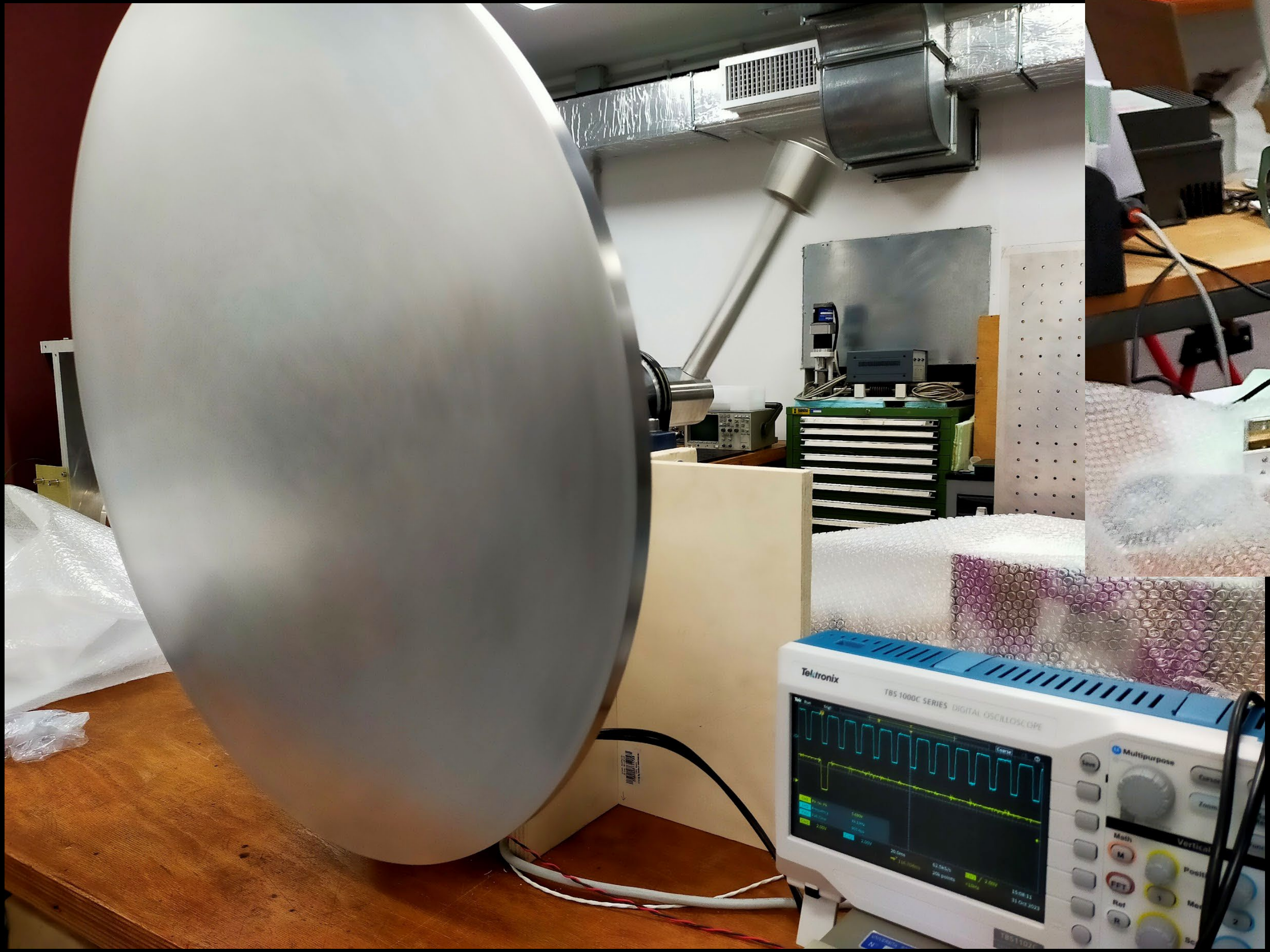
COSMO hardware

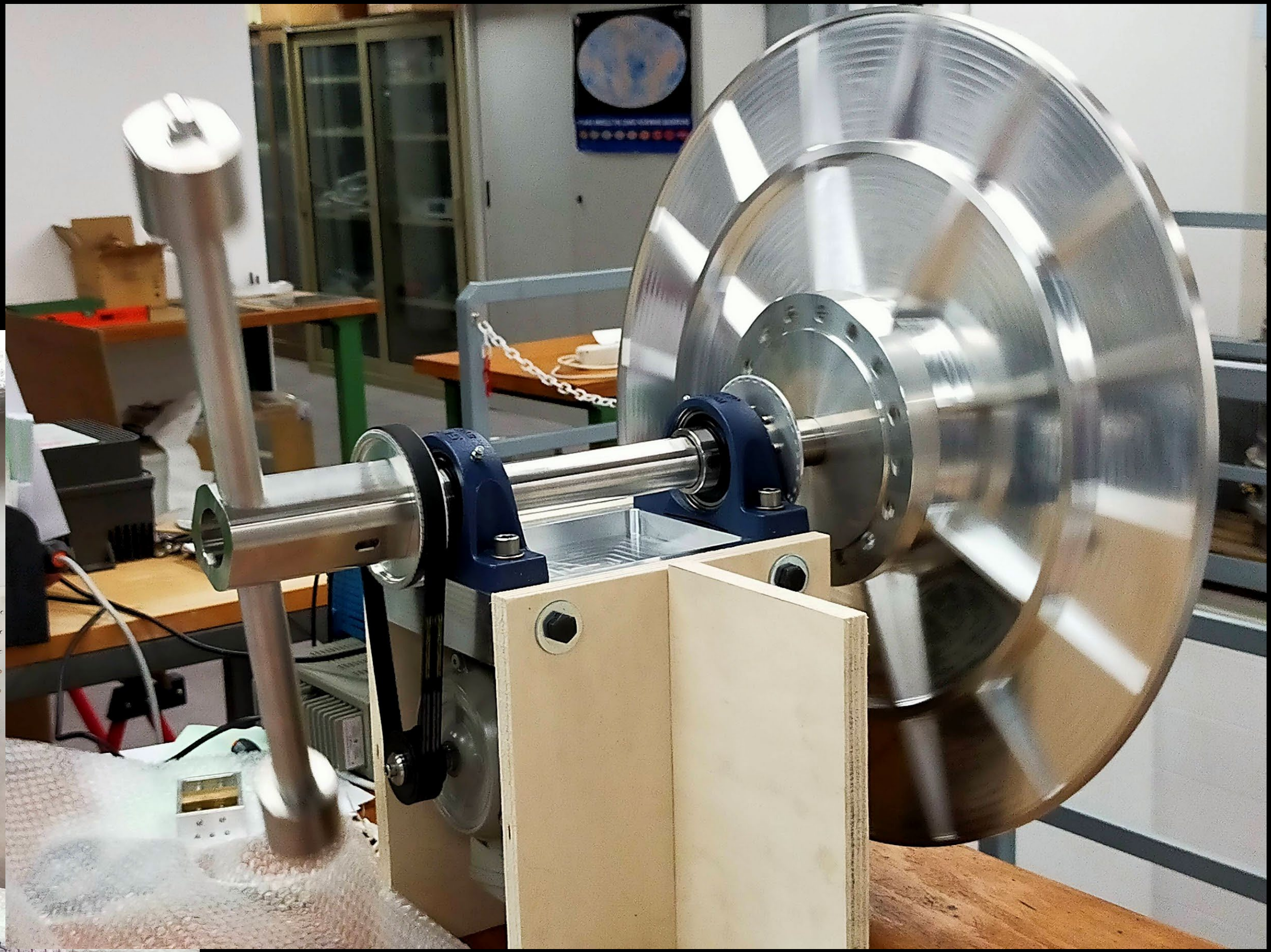






COSMO sky scanner

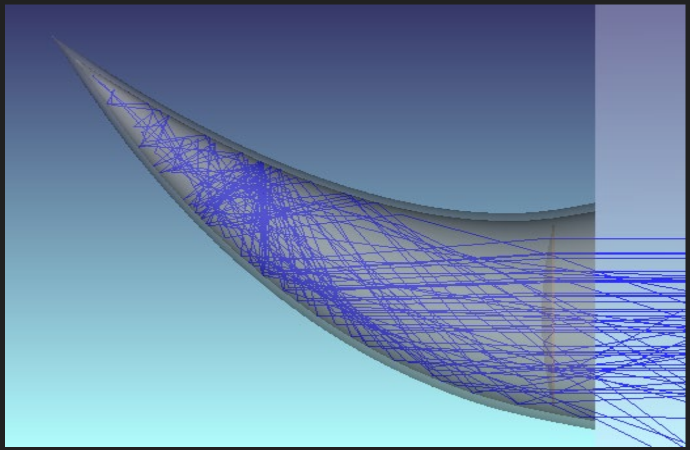


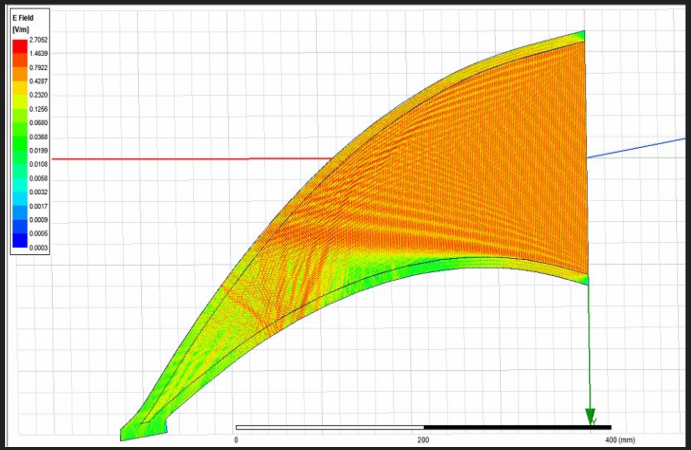


Tested up to 180 rpm
(then we got afraid)

Reference Blackbody

- A parabolic cavity providing an emissivity very close to unity
- Thermal gradients <1mK (FEM simulation in Comsol Multiphysics, assuming a single compact element)
- Ray-Tracing simulations have been performed to maximize of the # of reflections with the absorbing coating (Emerson & Cuming CR-110)
- HFSS simulations provide a residual total reflectance of 1×10^{-6} @ 120 GHz
- A prototype of the calibrator has been assembled and tested.



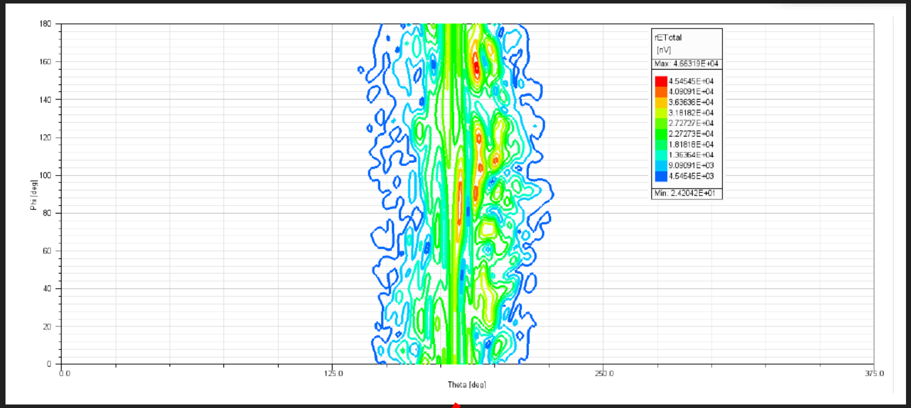


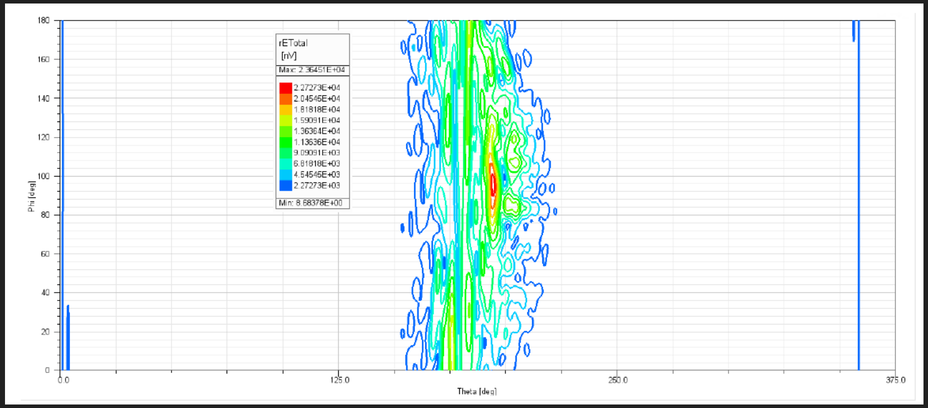
External Al mold

Teflon master mould to shape the absorbing coating

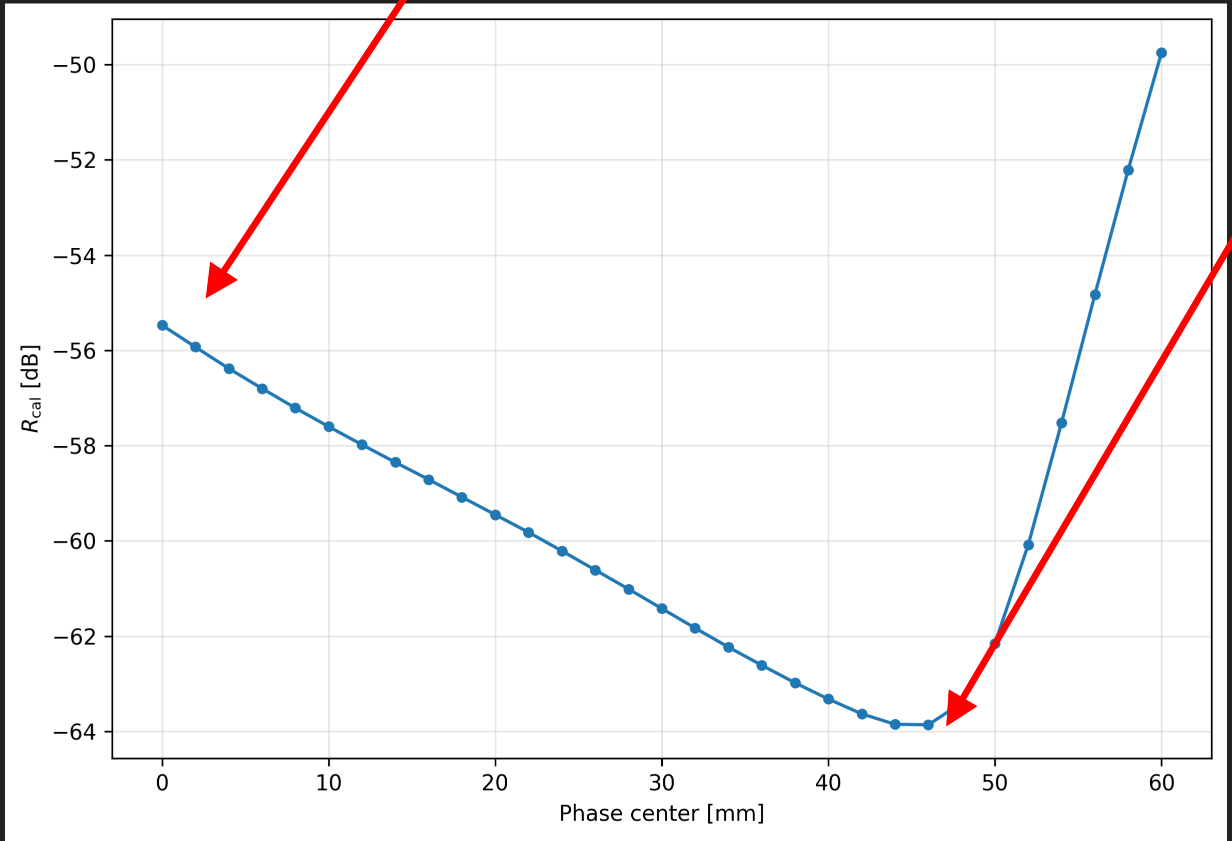
Credits: L.Mele, A. Capponi

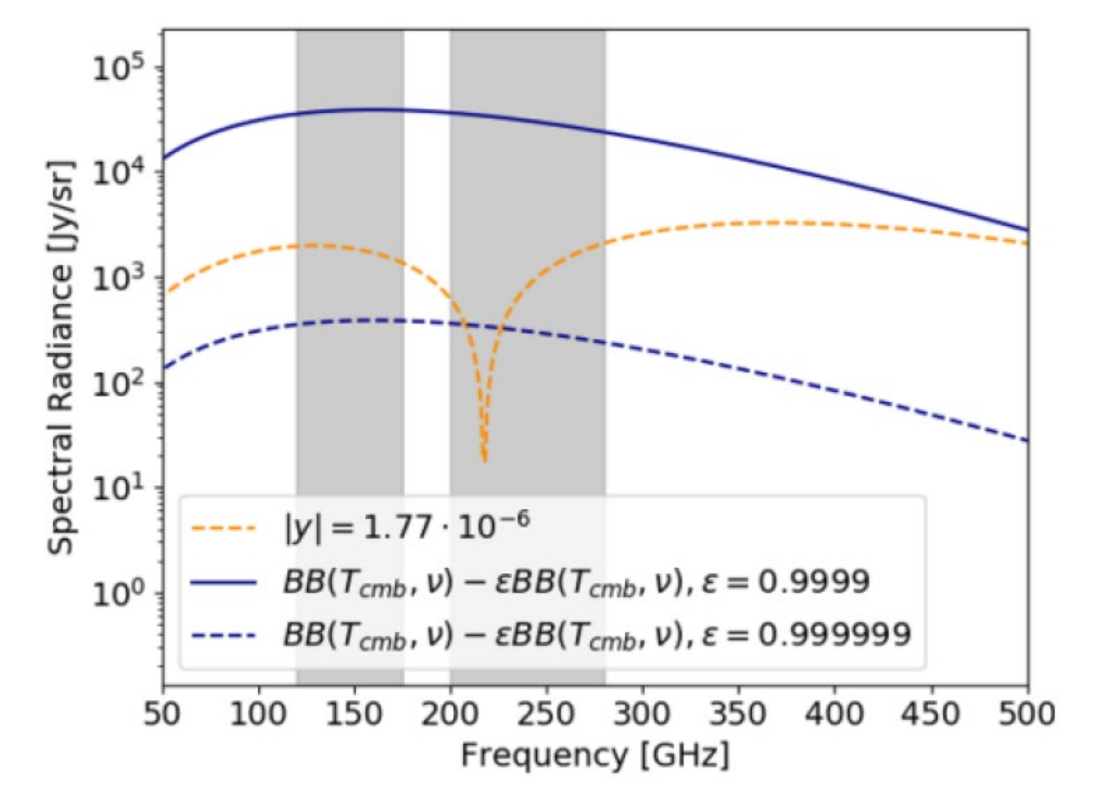
Reference Blackbody – coupling (aka «where is the blackest region?»)





Credits: E. Catena





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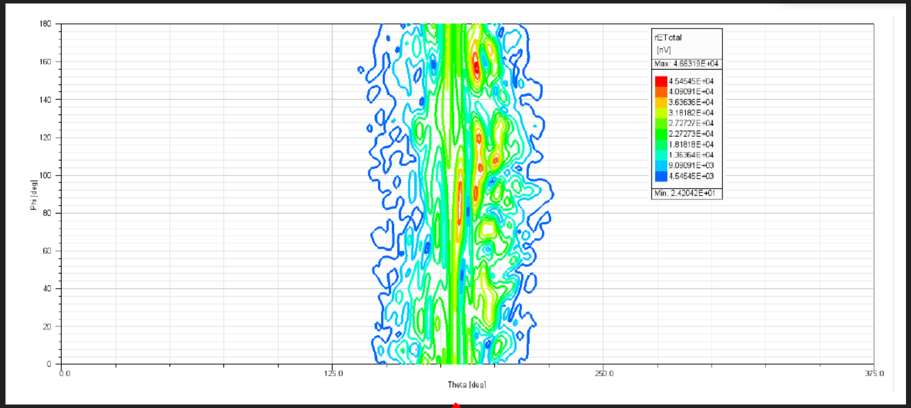

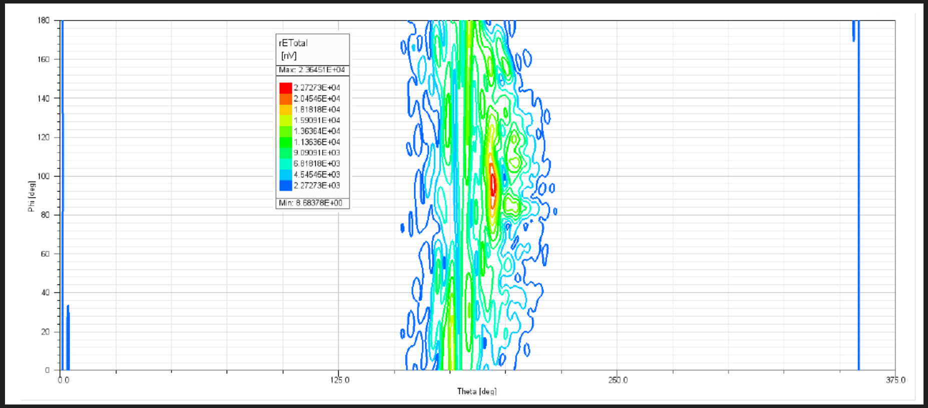

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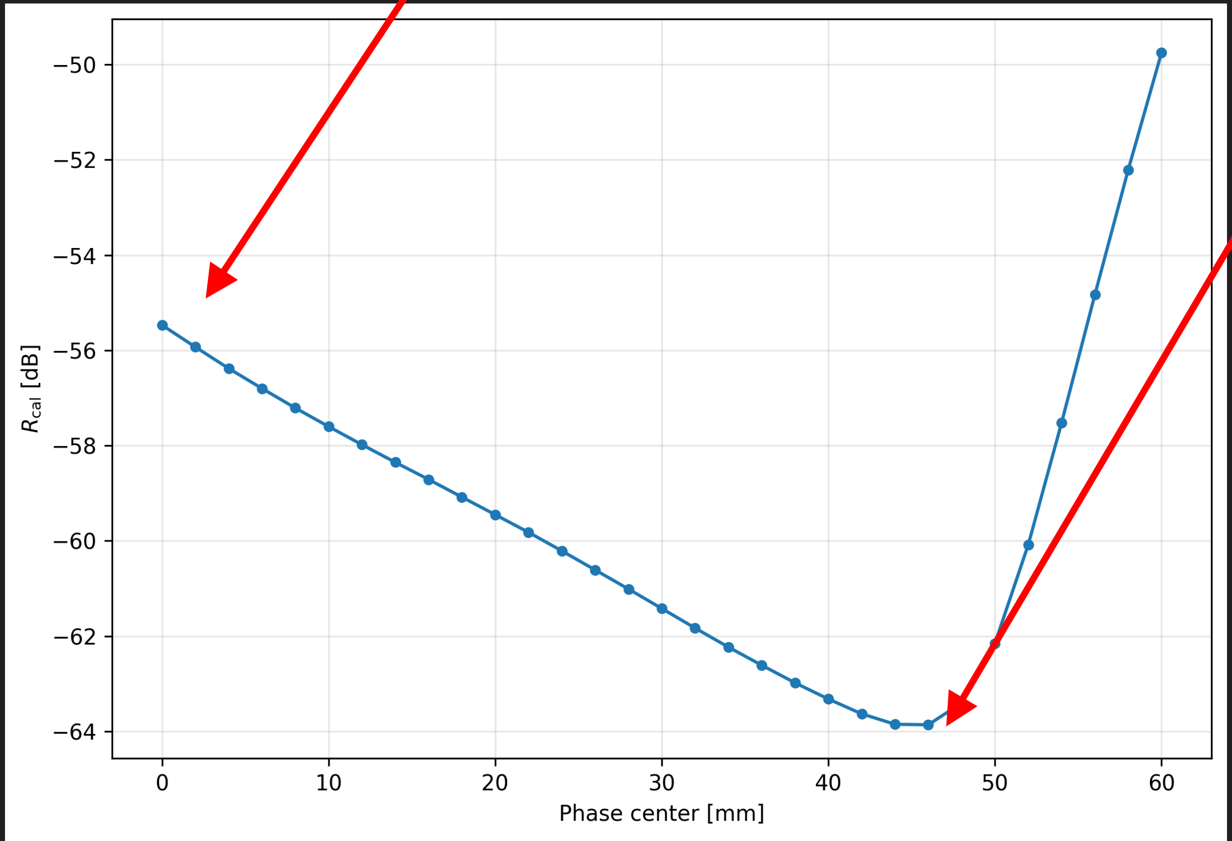
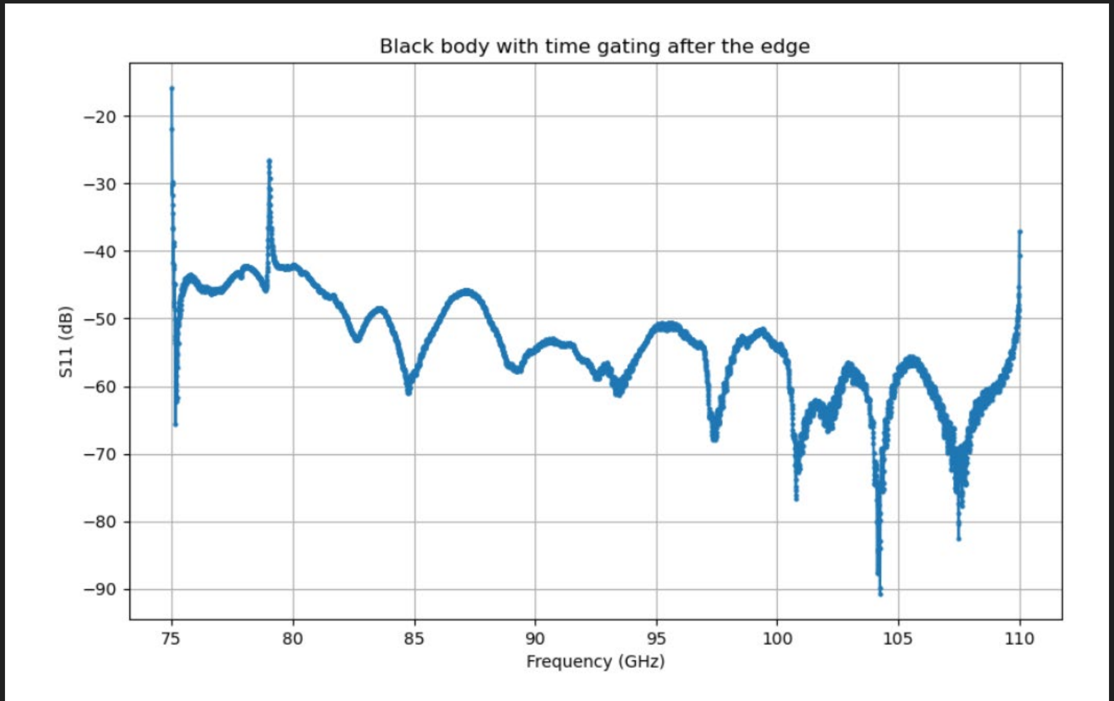
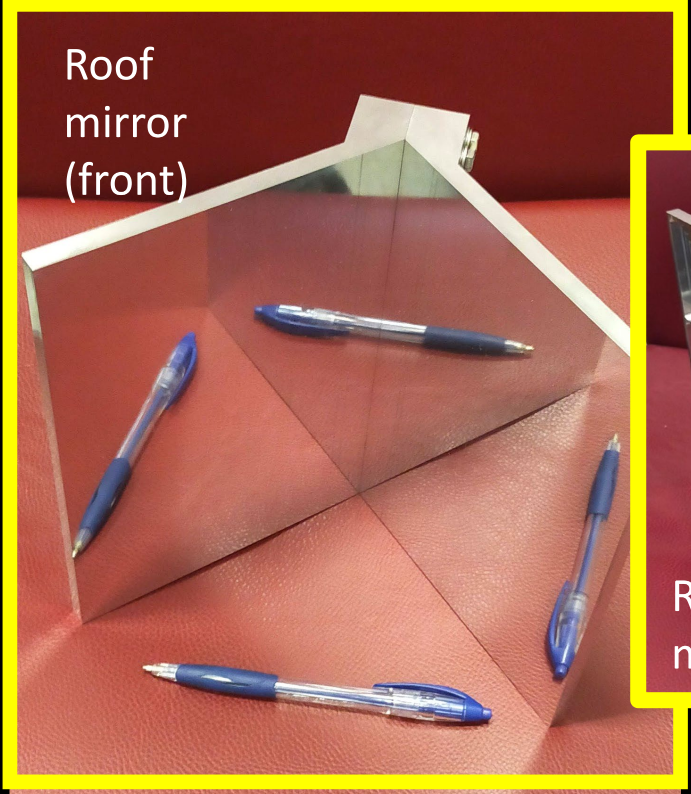
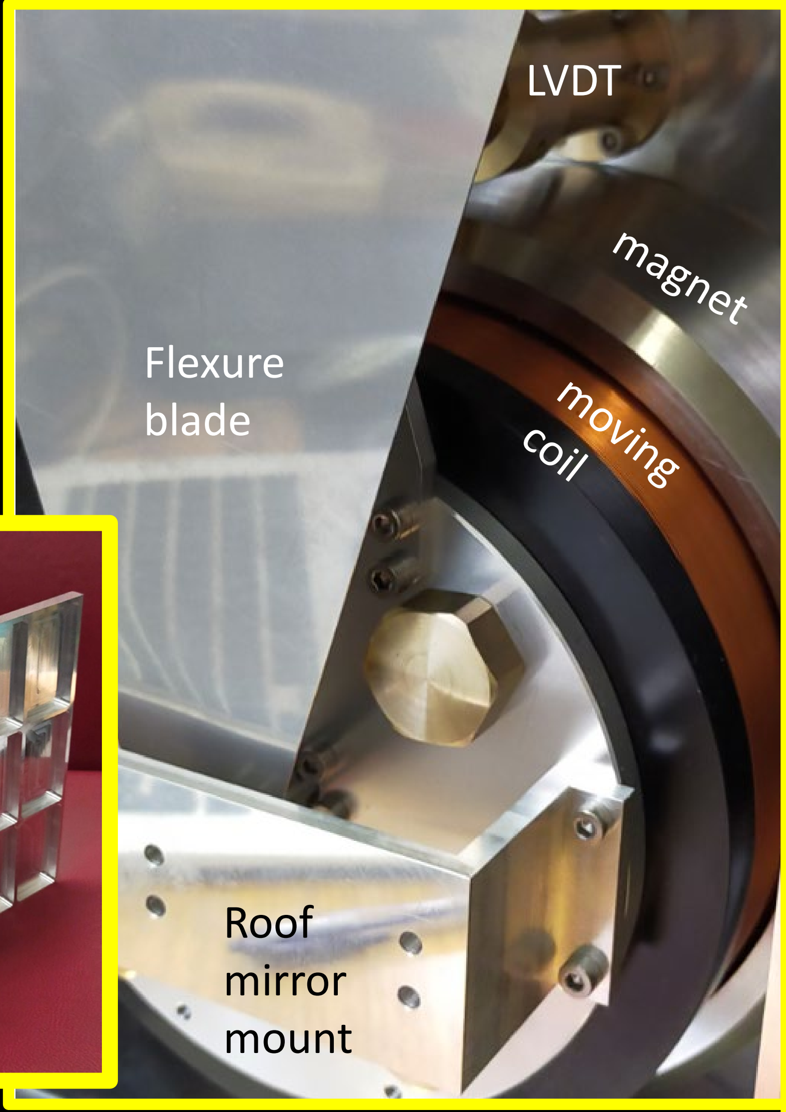


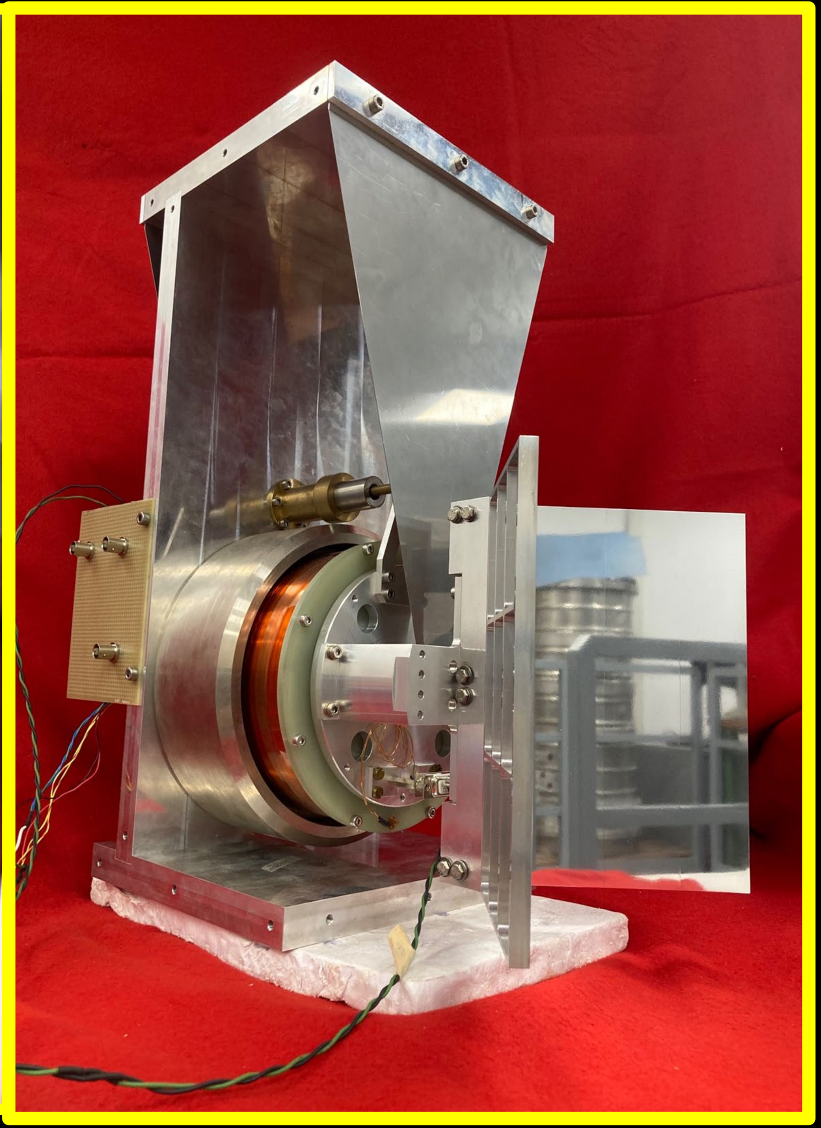


Mirror Transport System

- Cryogenic operation – frictionless design to minimize heat load
- Based on a powerful voice coil with steel flexure blades support, to move one roof mirror. up to 0.2 cm/s.
- Eddy currents in moving coil support minimized by means of a dielectric coil support.

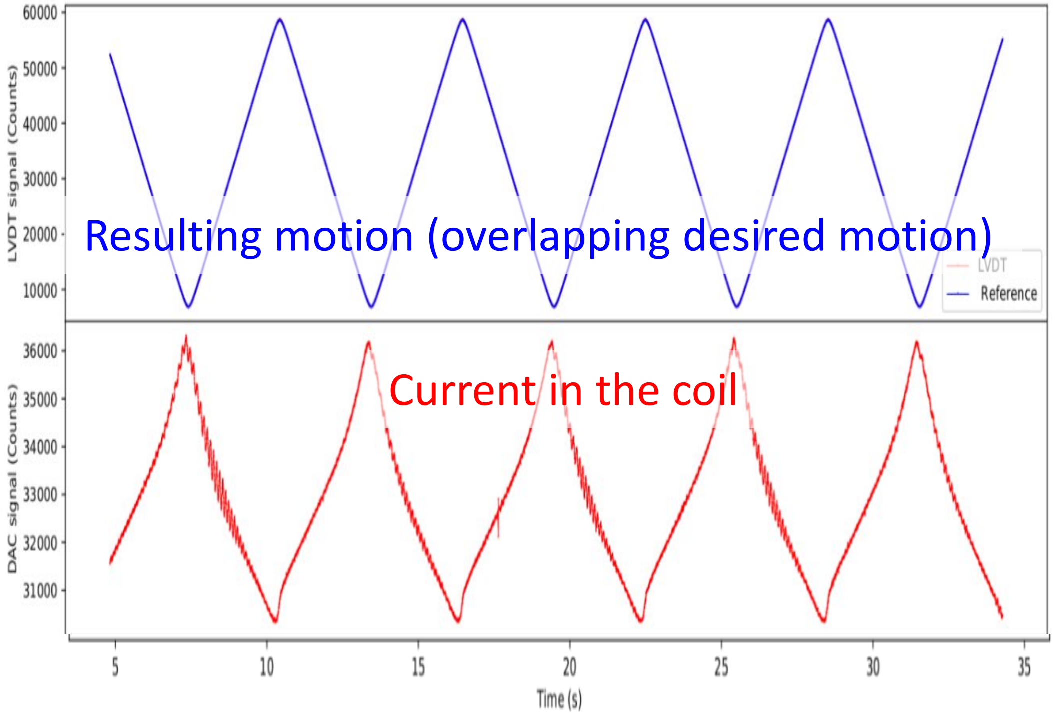




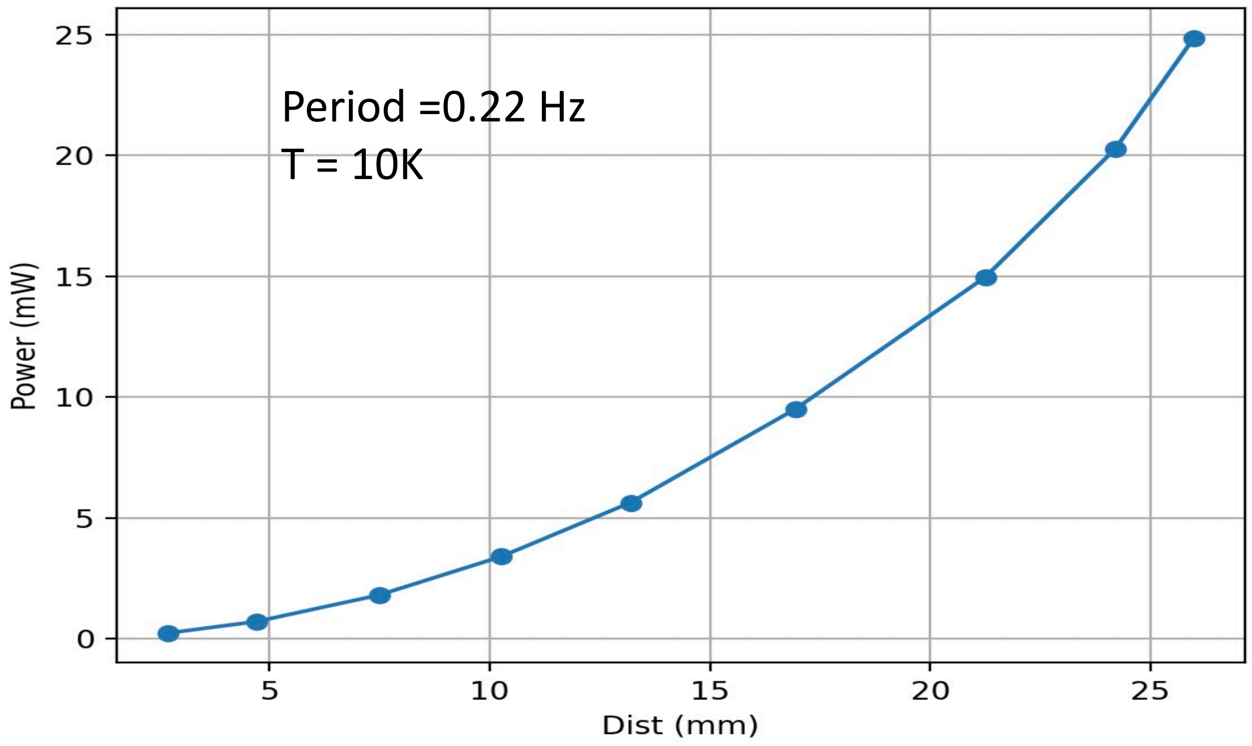


Cryogenic Roof Mirror Transport Mechanism

- Based on harmonic steel flexure blades supporting a large voice coil
- Drive electronics based on digital generator, DAC, current pump, coil, LVDT sensor, ADC, digital PID feedback loop.
- Auxiliary NIR FP interferometer for precision position readout (< 1 μm) procured.
- Good measured performance (@room temperature **and at cryogenic temperature**)



Credits: E. Marchitelli



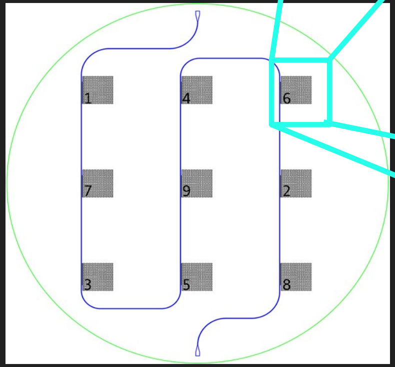
Credits: G. Barbieri Ripamonti, F. Columbro

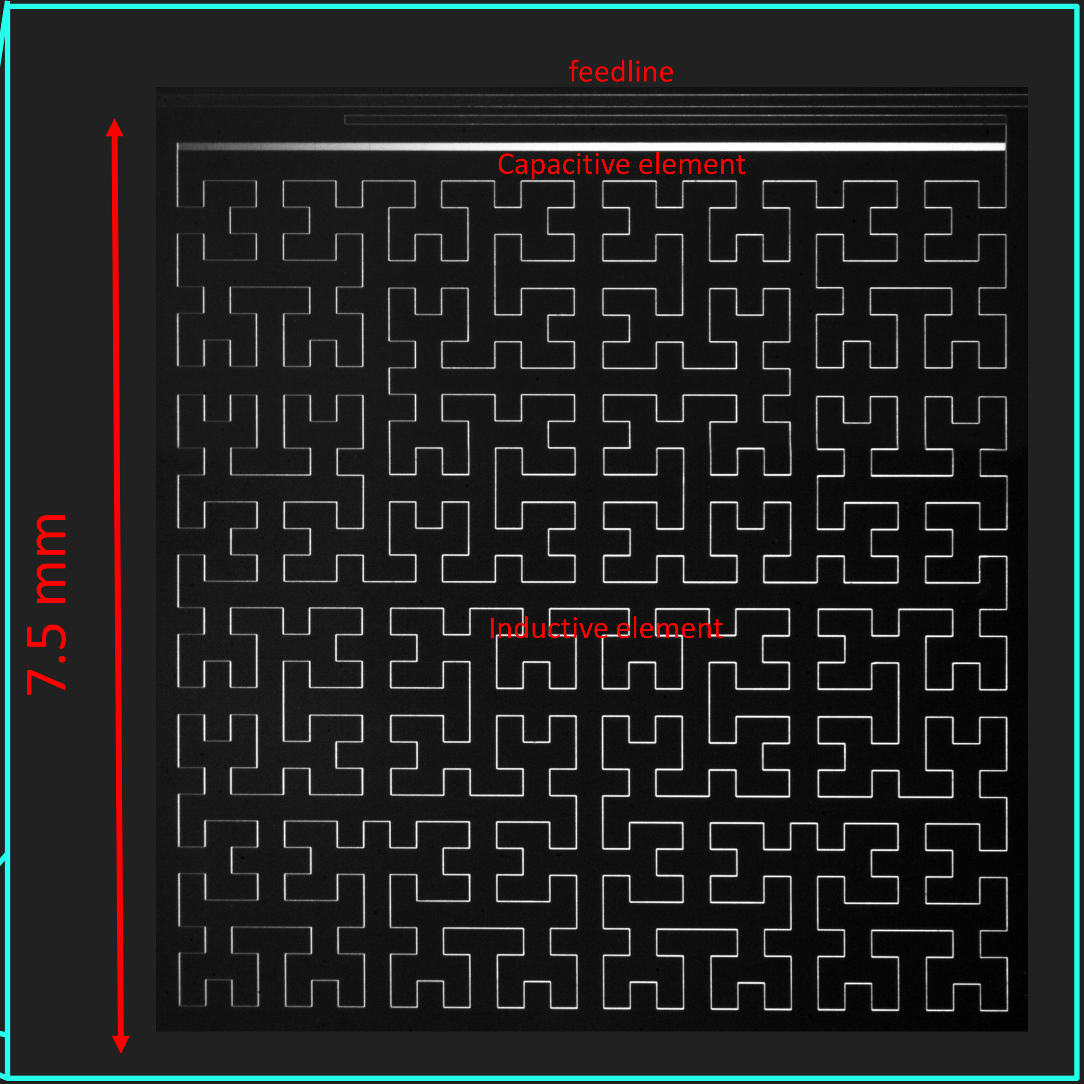
Kinetic Inductance Detector Arrays

- The throughput of the system, which includes the cryogenic differential MPI, is limited by the available room in the cryostat, and the angular resolution required by the measurement is modest (~1°)
- For these reasons the two focal planes, sensitive in the 150GHz and 250GHz bands, are filled with just 9 multimode feed-horns, each feeding one large Kinetic Inductance Detector (KID) fabricated with the same process developed for the OLIMPO ones (Paiella et al. 2019, Masi et al. 2019).
- Nine 7.5mm x 7.5mm pixels accommodated on a 4" Si wafer
- Photon noise limited performance, (scales as $N_{modes}^{1/2}$)
- 150GHz prototype currently under test

Index	n_c	C [pF]	ν_r [MHz]	Q_c
1	16	6.80	85.1	13 700
2	15	6.35	88.1	12 400
3	14	5.89	91.4	11 100
4	13	5.44	95.1	9800
5	12	4.99	99.4	8600
6	11	4.53	104.2	7500
7	10	4.08	109.9	6400
8	9	3.63	116.5	5300
9	8	3.17	124.6	4400

Low resonance frequencies to cope with lumped condition





Credits: A. Paiella, F. Cacciotti, G. Isopi, E. Marchitelli (Sapienza) G. Pettinari (IFN-CNR)

Kinetic Inductance Detector Arrays

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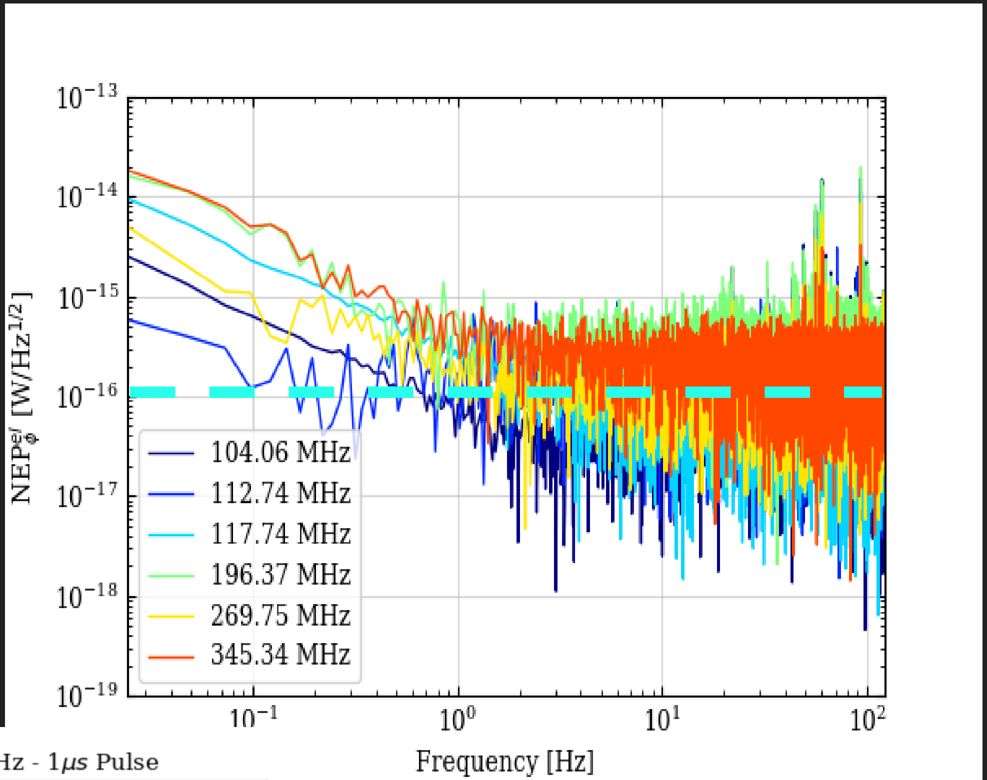
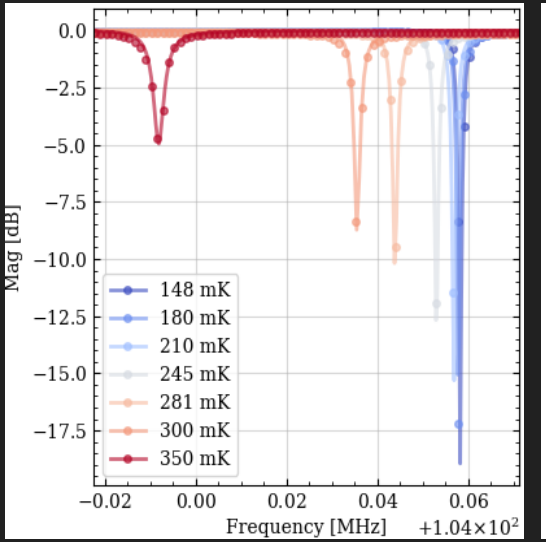
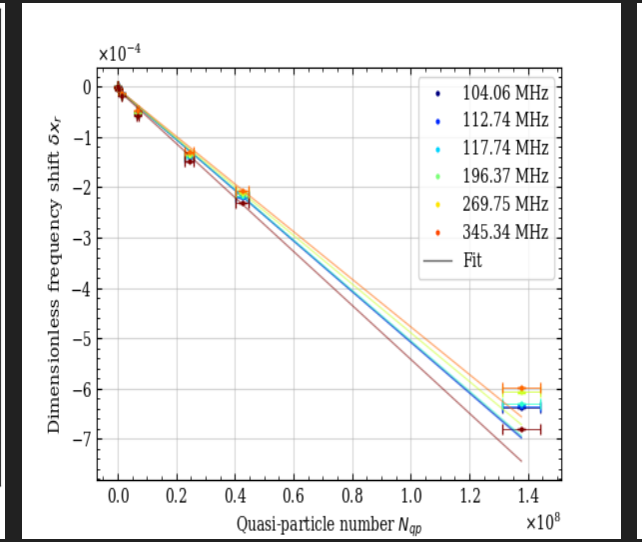
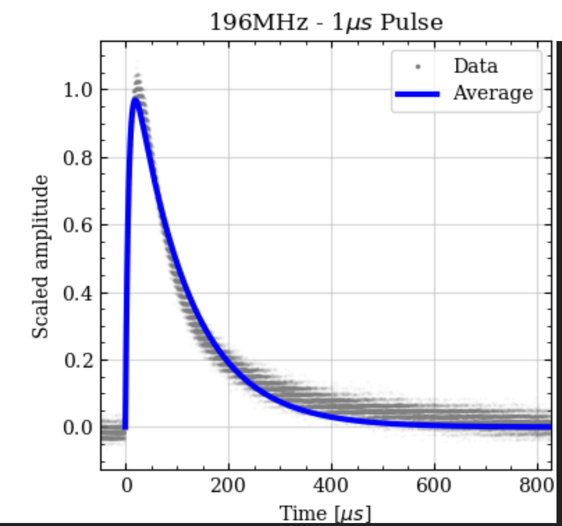
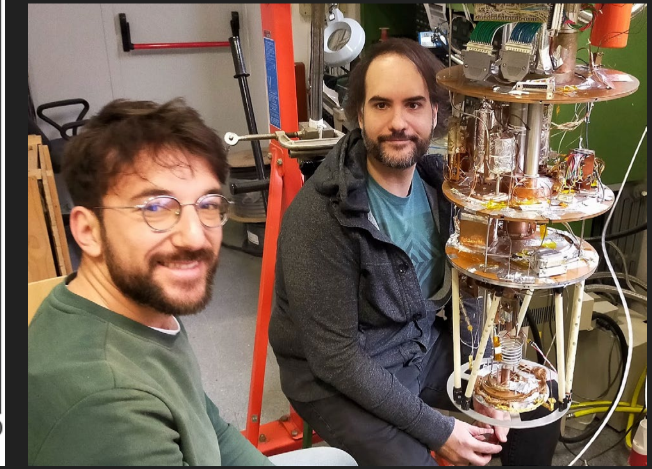


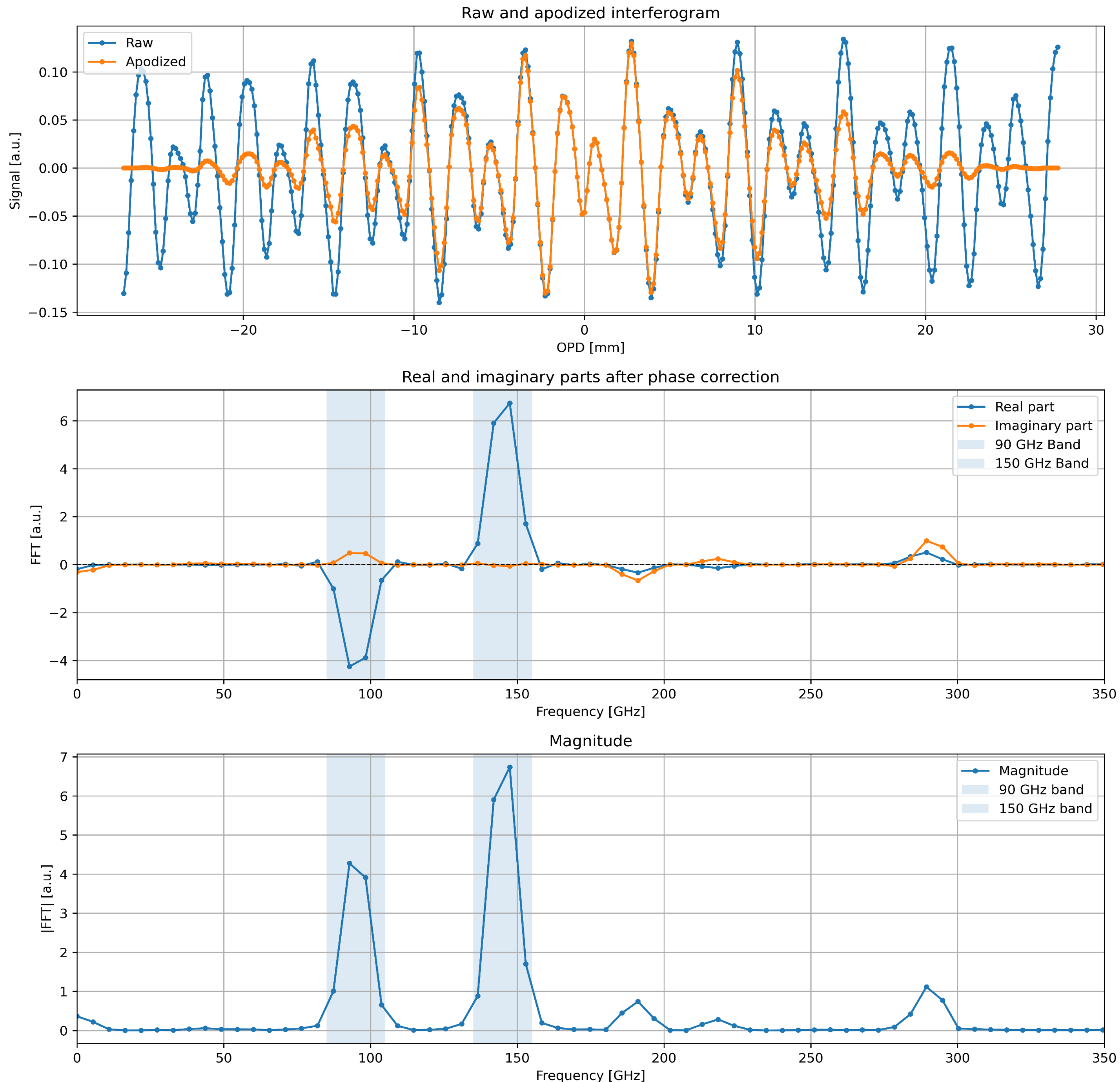


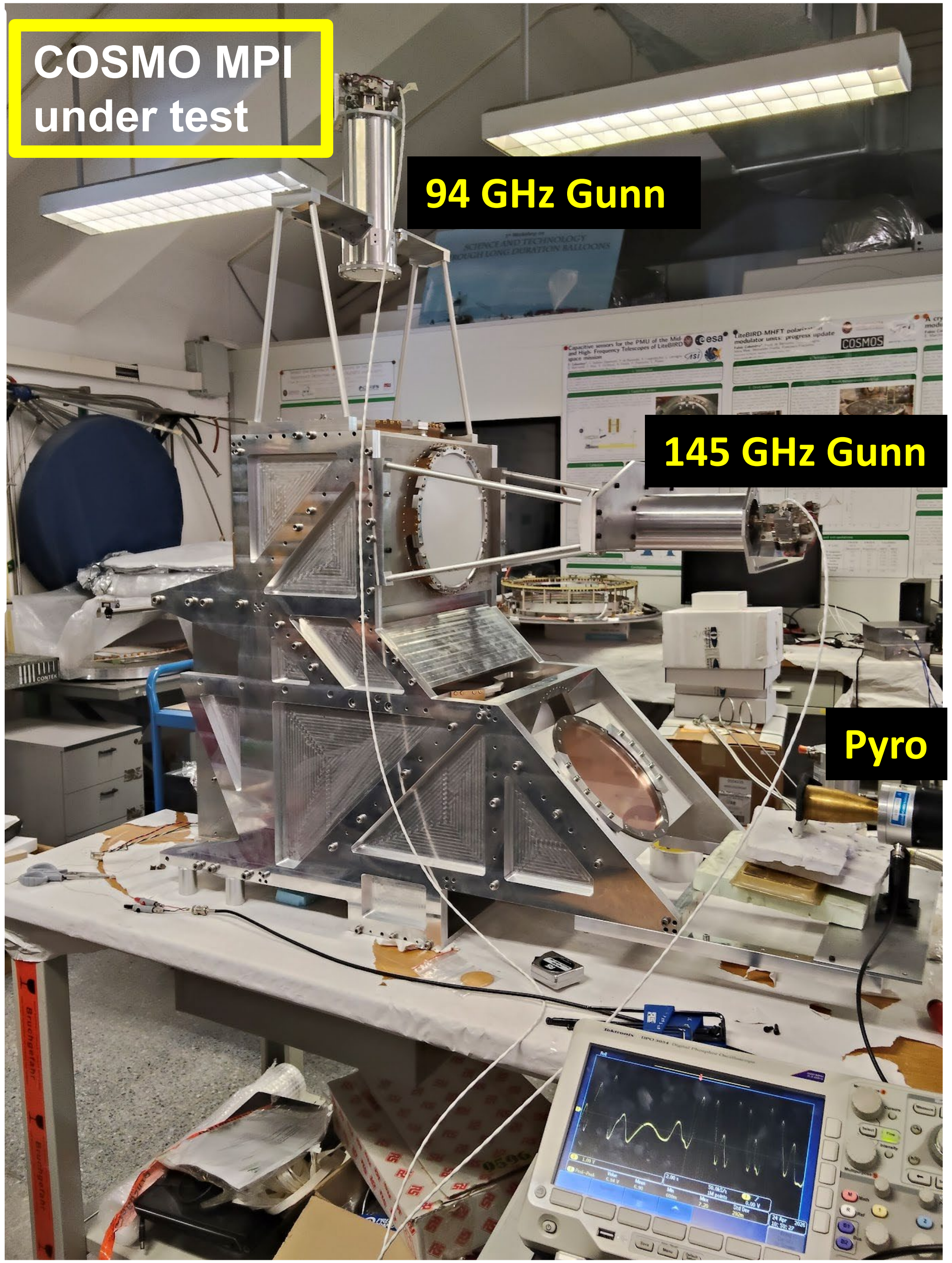







COSMO MPI
under test
94 GHz Gunn
145 GHz Gunn
Pyro


Raw and apodized interferogram
Raw
Apodized
Signal [a.u.]
OPD [mm]
Real and imaginary parts after phase correction
Real part
Imaginary part
90 GHz Band
150 GHz Band
FFT [a.u.]
Frequency [GHz]
Magnitude
Magnitude
90 GHz band
150 GHz band
|FFT| [a.u.]
Frequency [GHz]


COSMO MPI
under test
94 GHz Gunn
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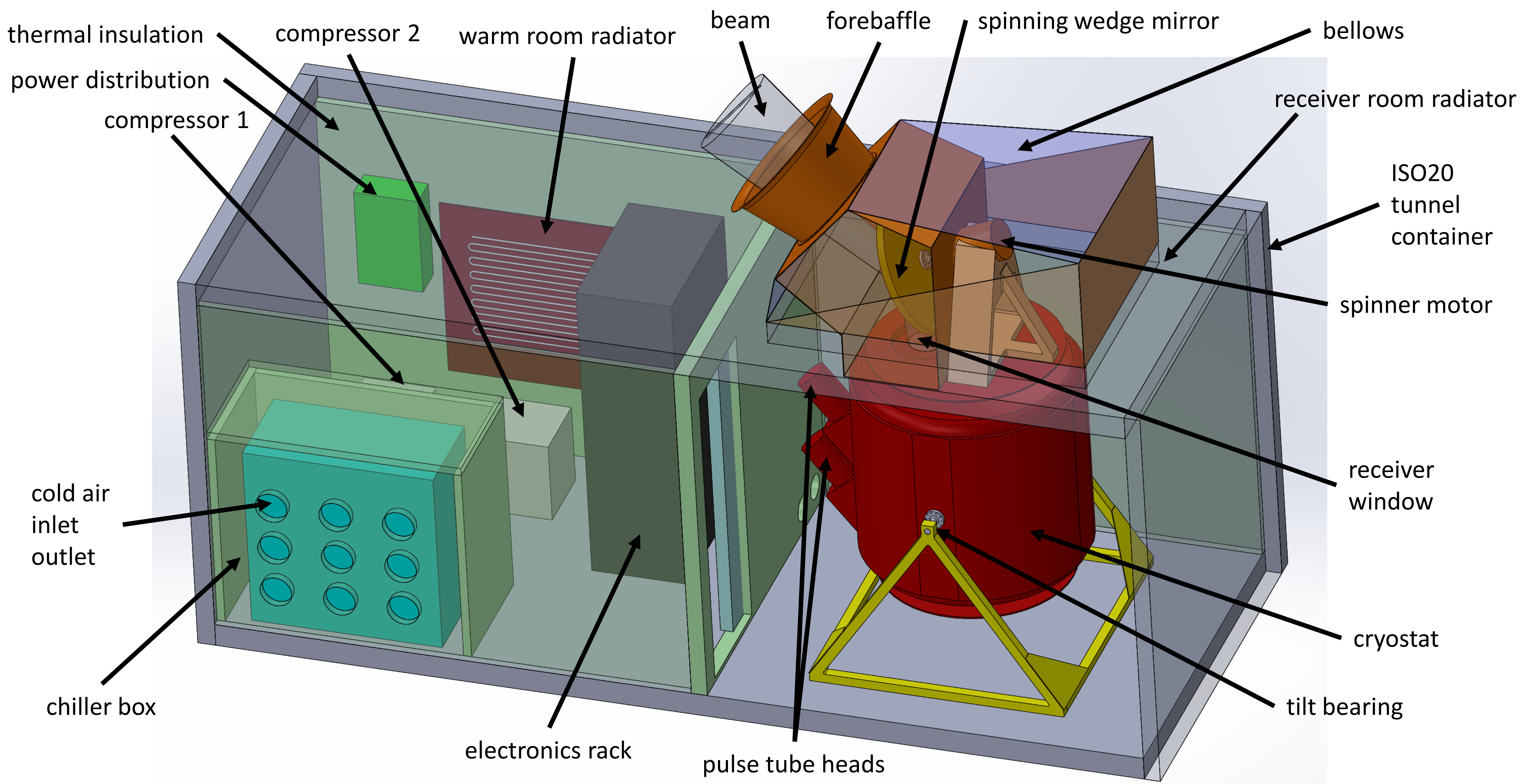
Pyro


COSMO Commissioning:
Campo Imperatore Station
INAF, 2200 m, -20C
2026

COSMO on-site implementation

COSMO on-site implementation – location of main components




COSMO Measurements Campaign
Dome-C - Antarctica
PNRA-IPEV, 3200m, -80C
2029 ?
Picture Credits: Marco Buttu