Per aspera
ad astra

CEB for CMB

Chalmers University, MC2

Chalmers University of Technology

Cold-Electron Bolometers: Current Status and Perspectives

Leonid S. Kuzmin

Chalmers University of Technology, Gothenburg, Sweden

In collaboration with:

Paolo de Bernardis, Silvia Masi & Maria Salatino (Rome University), Sumedh Mahashabde and Michail Tarasov (Chalmers), Bruno Maffey (Manchester Un), Neil Trappe (Maynooth Un), Alexander Sobolev (IREE), Phillip Mauskopf (Cardiff University), Peter Day (Caltech), Nikolay Kardashev (ASC), Ghassan Yassin (Oxford University), Andrey Pankratov(NSTU), Andrej Zaikin, Dmitry Golubev (Karlsruhe University), Victor Dubrovich (Pulkovo), Eugeni Il'ichev (IPHT), Grigory Goltsman (MSPU, Mikhail Kupriyanov (MSU)

ESA consortium on Multichroic Systems,

Outline

- **Cold-Electron Bolometer (CEB)**
- **Main features for COrE**
- **Multichroic systems for COrE**
- **Seashell Antenna**

Leading technologies:

Single technology?

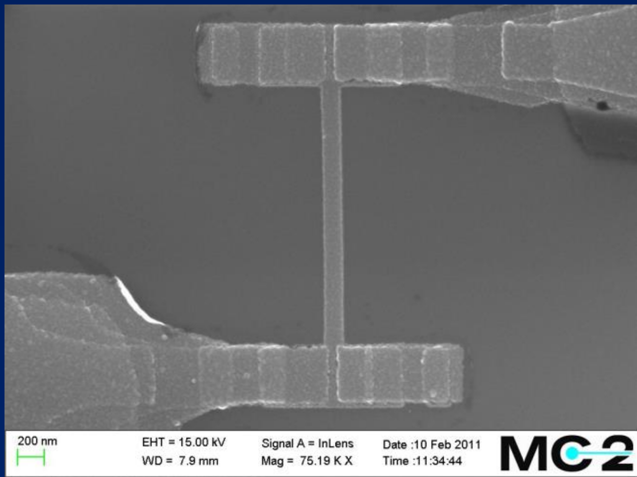
- Are we ready to select a baseline technology?

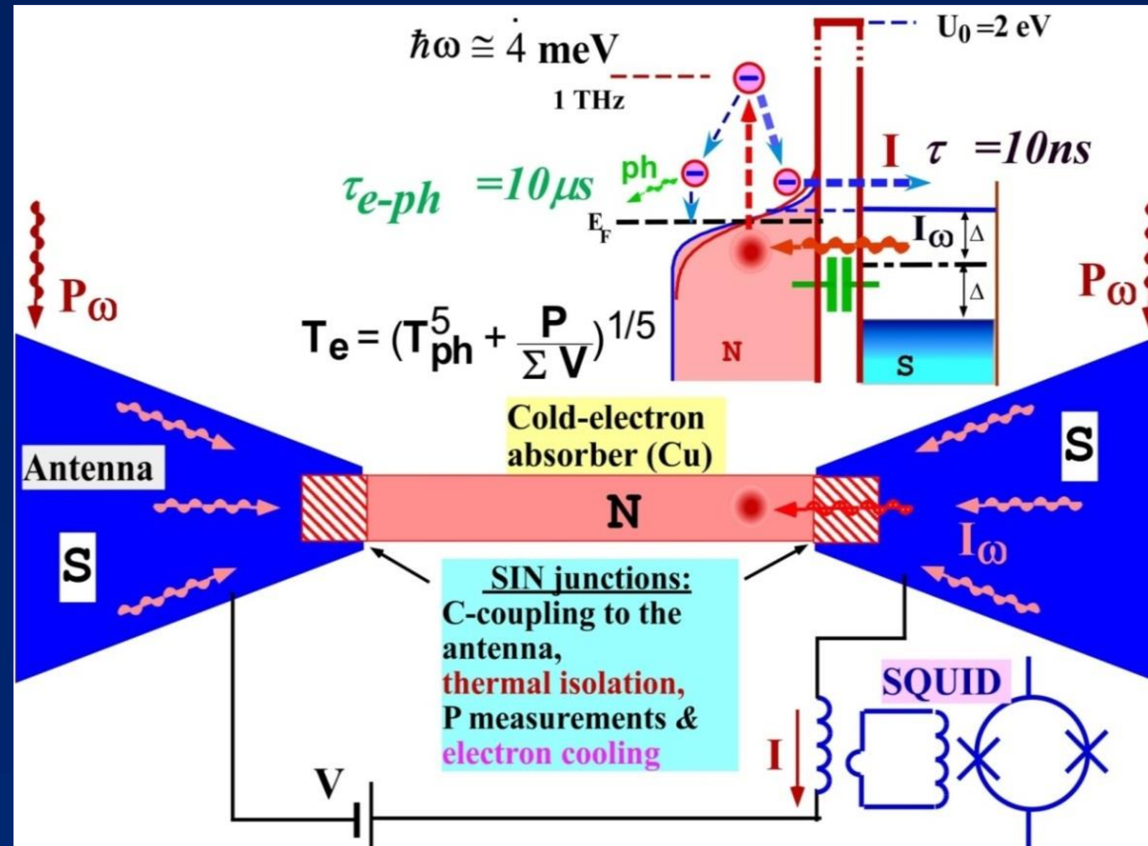
	TESs	KIDs	CEBs
Sensitivity		ν > 100GHz	On paper
Time constant	τ ~ 1ms	τ ~ 0.1ms	τ ~ 0.1ms
Dynamic range	Medium	High	Medium?
CR sensitivity	High	High	Low
Space qualif. readout		P. dissipation	Mux?
Fabrication	Complex	Less complex	
Sensitivity to T fluctuations	Sensitive	Low	Low
EMC			
TRL	5	4	3

TRL- Technology Rediness level (1 – 10)

Michel Piat, Paris

Cold-Electron Bolometer (CEB) with Capacitive Coupling to the Antenna



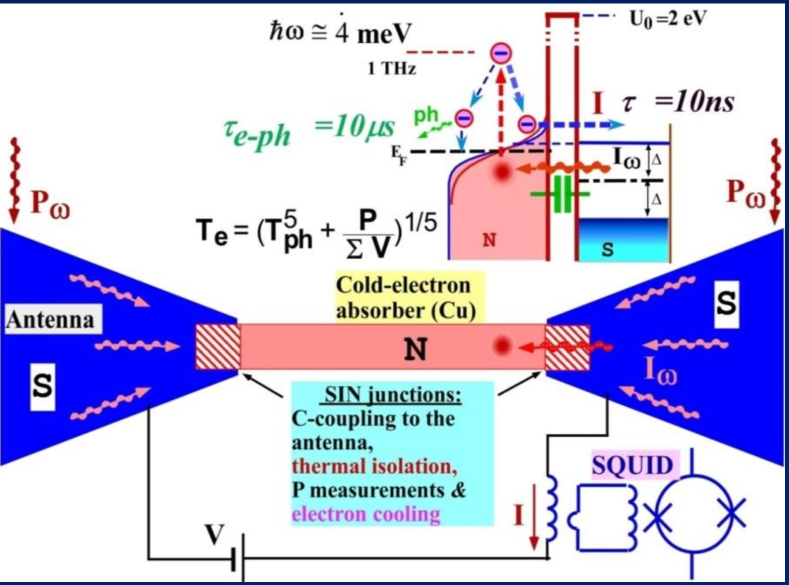


Main features of the CEB:

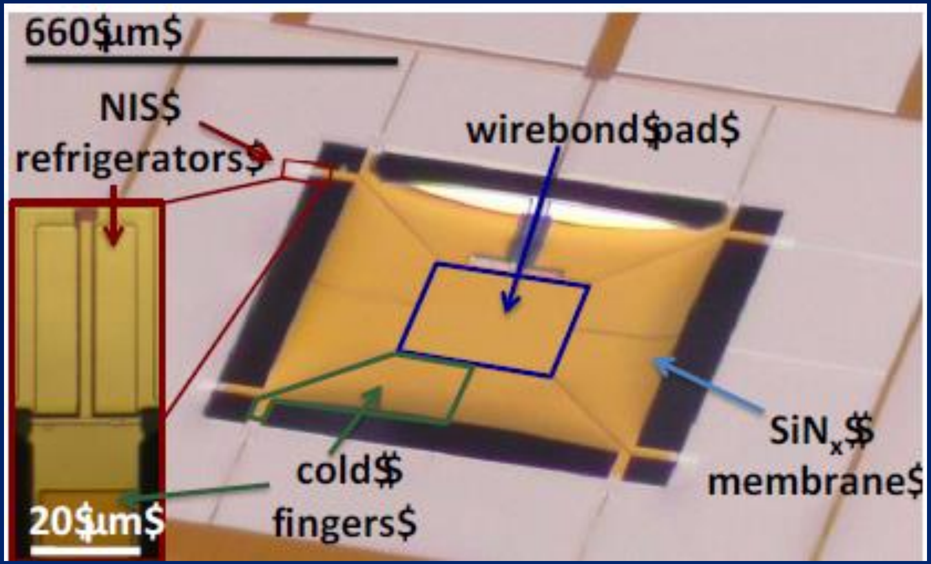
1. High sensitivity due to electron cooling effect:
2. High dynamic range due to direct electron cooling
3. Very easy to fabricate CEBs in array
4. Insensitivity to Cosmic Rays (1 glitch / 40 days!)

Cold-Electron Bolometer (CEB)

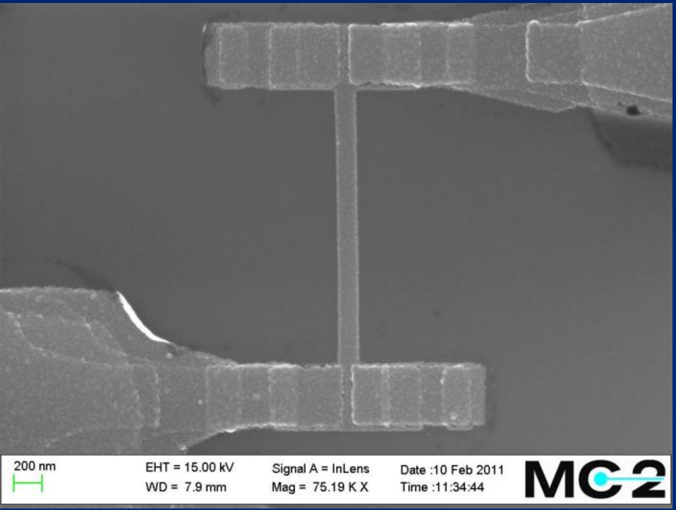
Direct electron cooling



Jeol Ullom. Cooling platform



V=10^5 µm^3

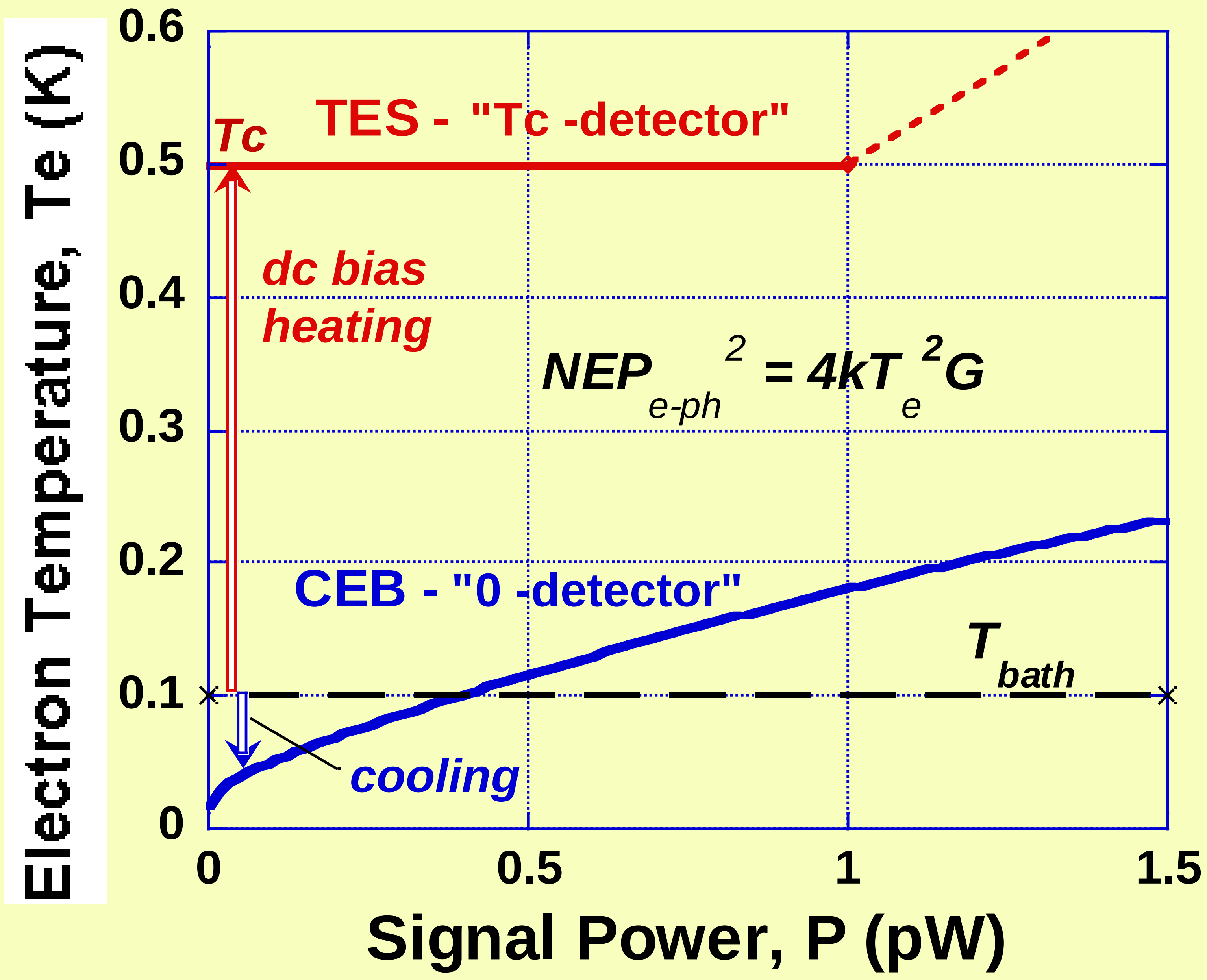


V=0.02 µm^3

Main features of the CEB:

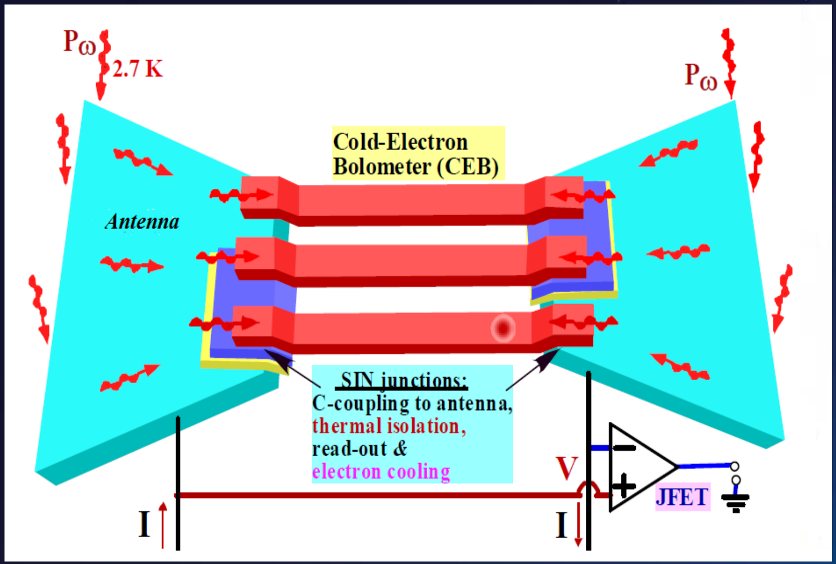
1. High sensitivity due to electron cooling effect:
2. High dynamic range due to direct electron cooling

TES and CEB. Operating Temperature

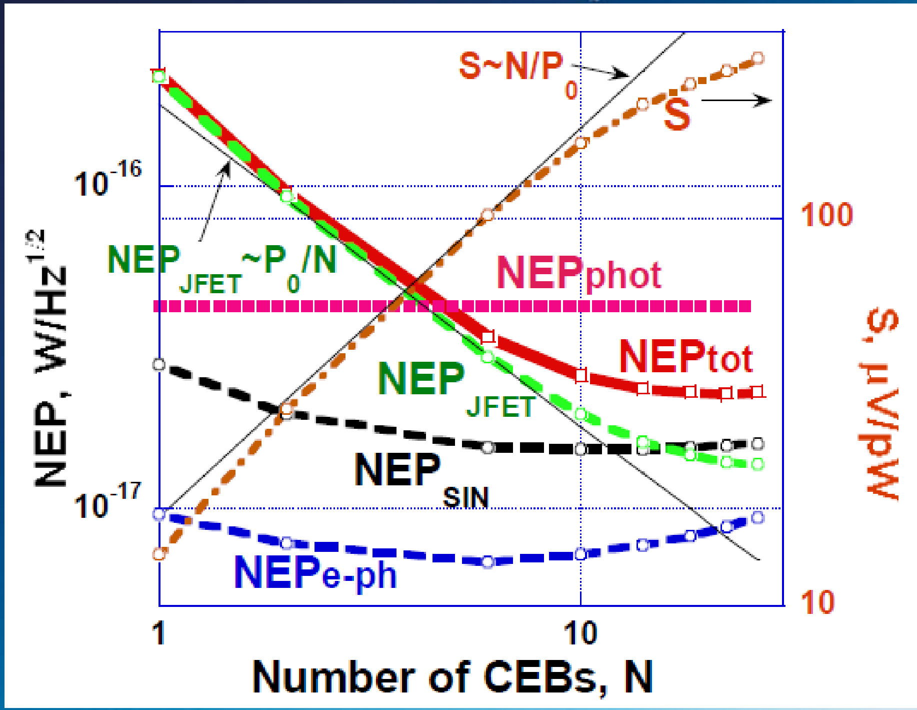


OBSERVATION OF PHOTON NOISE BY COLD-ELECTRON BOLOMETERS

A. Gordeeva[1,2], A. Pankratov[1,2,3], L. Revin[1,2,3], V. Zbrozhek[1], V. Shamporov[1,2], A. Gunbina[1], L. Kuzmin[1,4]



Parallel/series array of CEBs for work under high optical power load and matching with the JFET readout.



NEP components and photon NEP in dependence on the number of CEBs

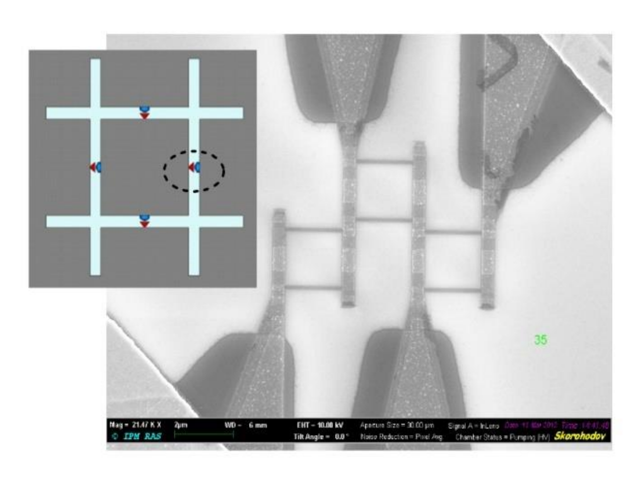
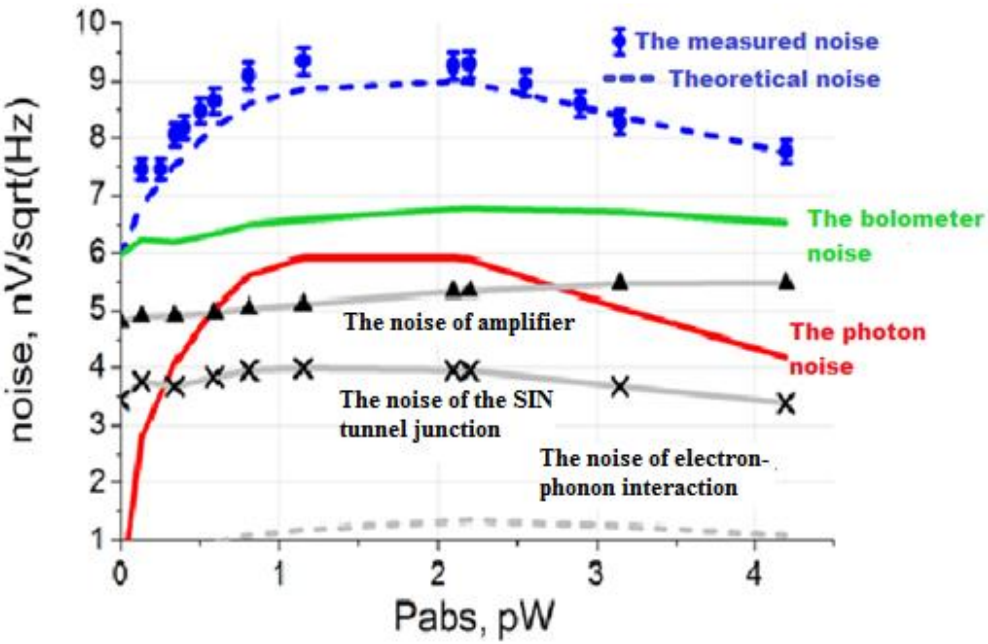


Figure 3 - cross-slot antenna with central frequency 350 GHz with integrated cold-electron bolometer detectors

Results



Noise Equivalent Power

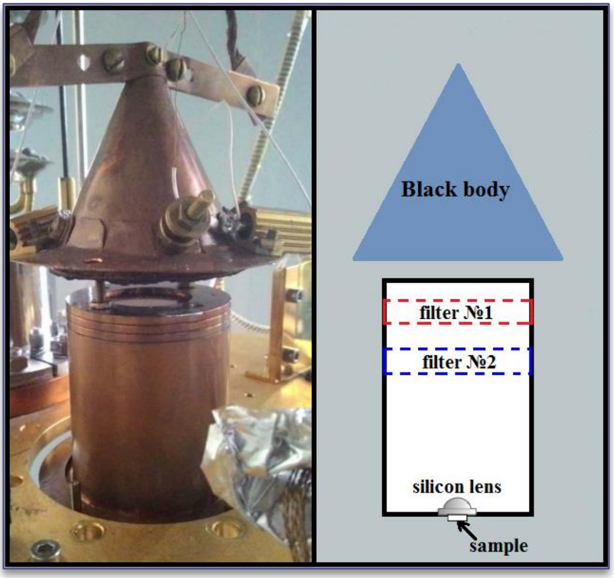
$$NEP^2 = NEP^2_{e-ph} + NEP^2_{amp} + NEP^2_{SIN} + NEP^2_{ph}$$

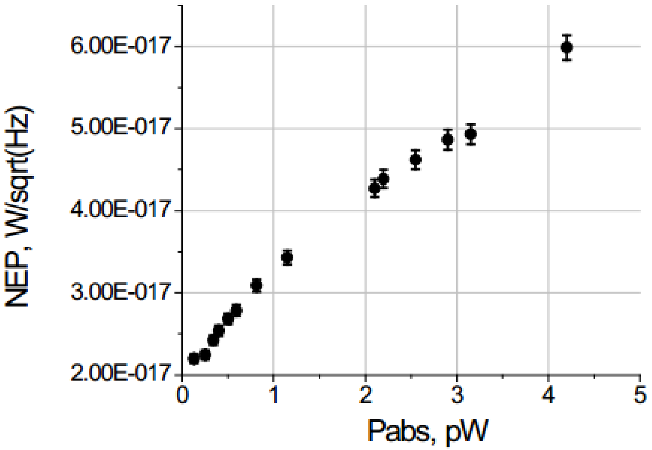
NEP_{e-ph} - The NEP of e-ph interaction

NEP_{amp} - The NEP of amplifier

NEP_{SIN} - The NEP of the SIN tunnel junctions

NEP_{ph} - The photon noise NEP





NEP as a function of the absorbed power

Responsivity of this bolometer is $3.8 \cdot 10^8$ V/W, NEP=$2.2 \cdot 10^{-17}$ W/√Hz at power load of 0.1 pW and responsivity is $2.5 \cdot 10^8$ V/W, NEP=$4.2 \cdot 10^{-17}$ W/√Hz at power load of 2 pW.

The base temperature is 200 mK and the current is 2 nA. The relation of photon noise to the others is 0.9

Olimpo

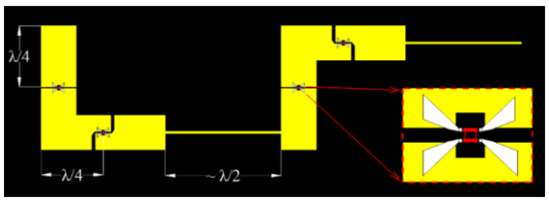
- The OLIMPO balloon payload (Masi et al. 2008), with solar panels, ground shield and sun shield removed.
- Note the tiltable 2.6m primary mirror and the lightweigth secondary.
- Measurement of the spectral deformation of the CMB in rich clusters of galaxies (the effect Sunyaev-Zeldovich).

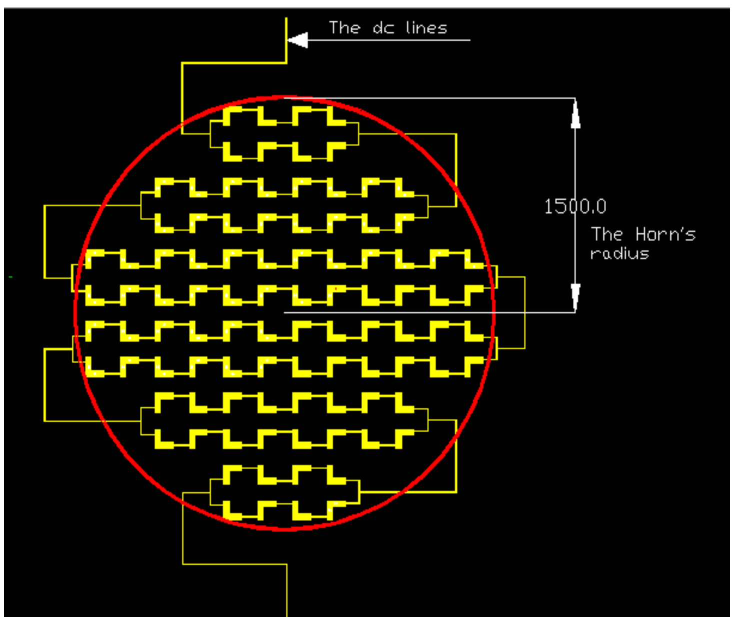
Olimpo

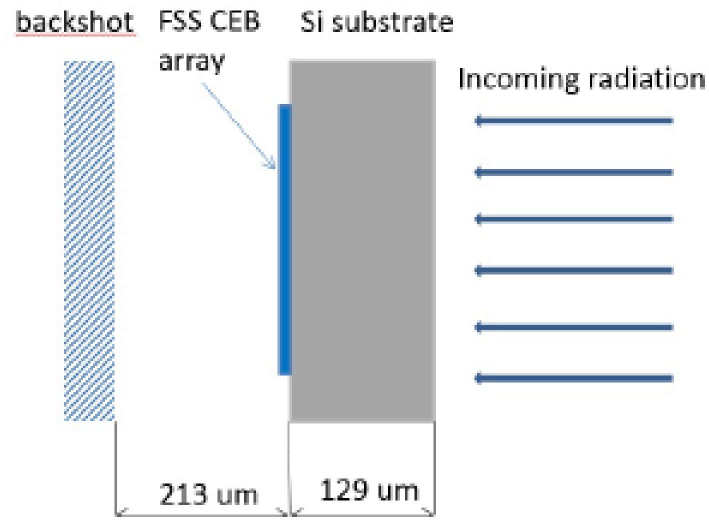
Initial requirements

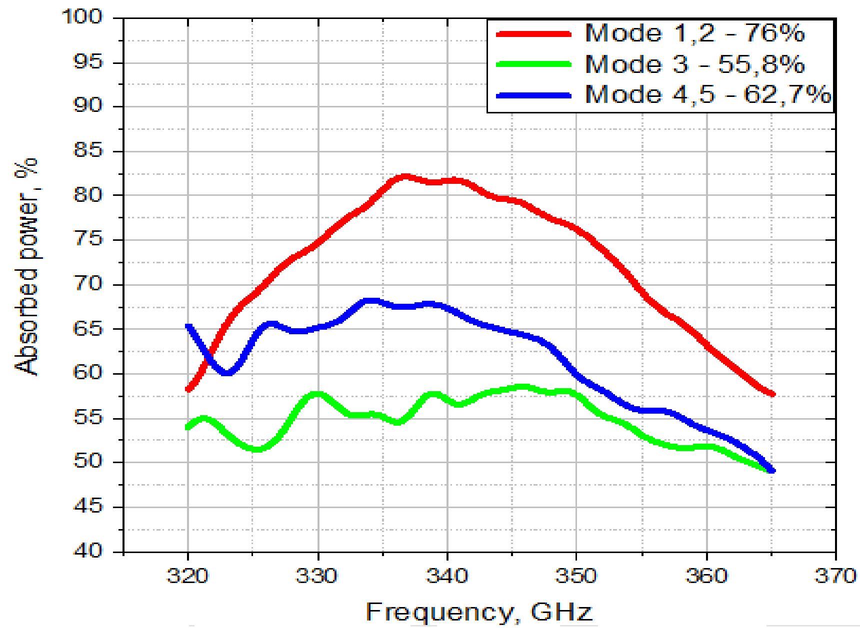
Central frequency – 345 GHz
Bandwidth – 10 %

Initial structure (one cell)



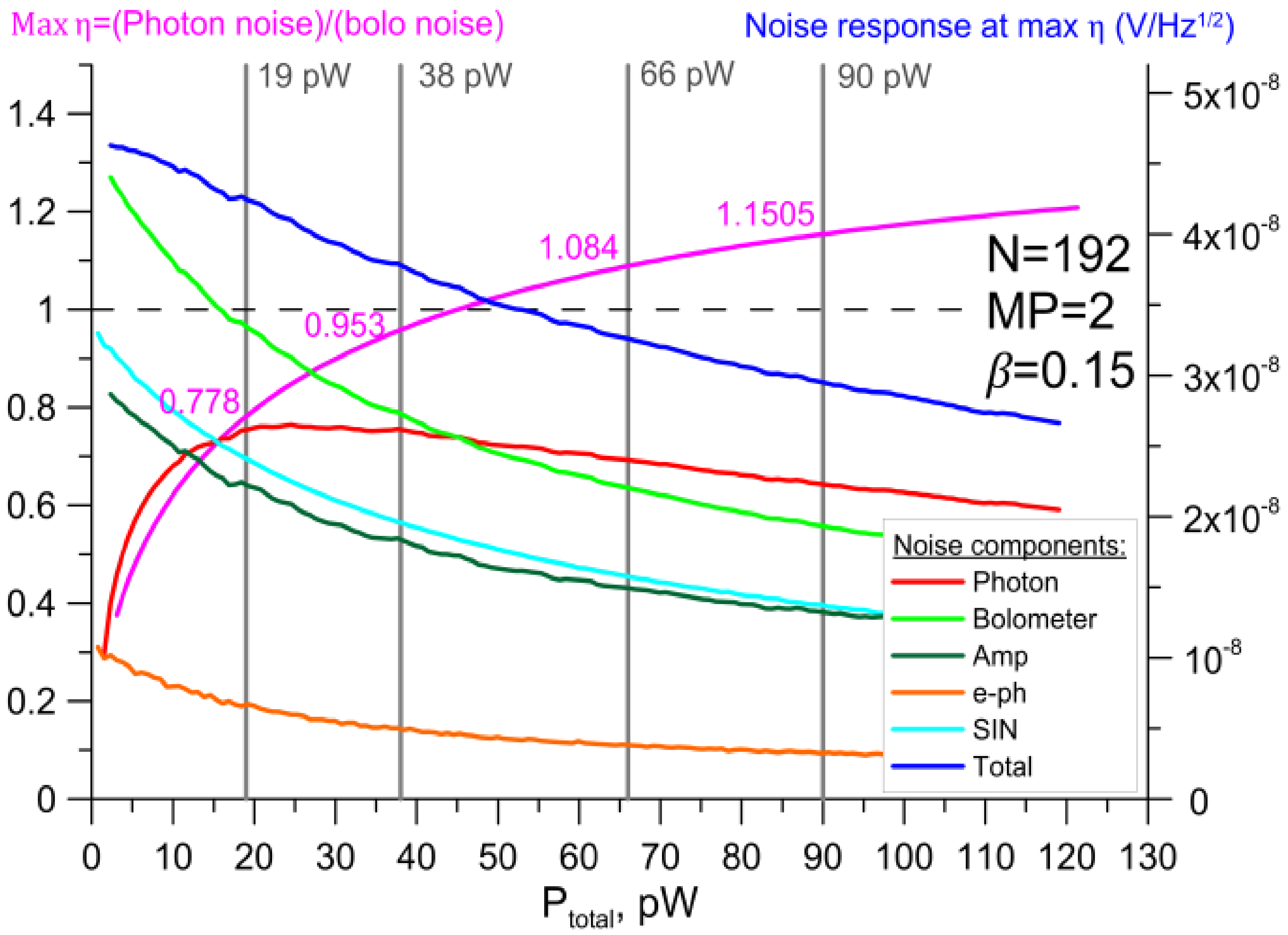






The array of 96 cold-electron bolometer.

Photon noise-limited CEB array for OLIMPO



The noise components and the ratio of photon noise to the bolometer noise.

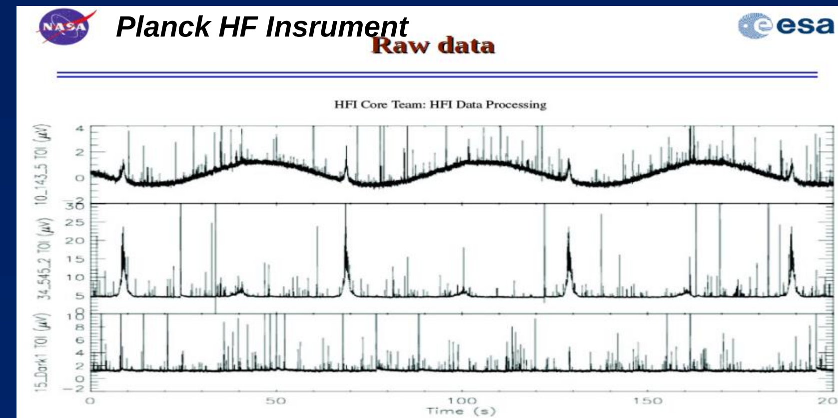
Cosmic Rays- dramatic problem!

Cosmic Ray tests of CEB in Rome:

- 137Cs source (660 keV photons) in front of the window.

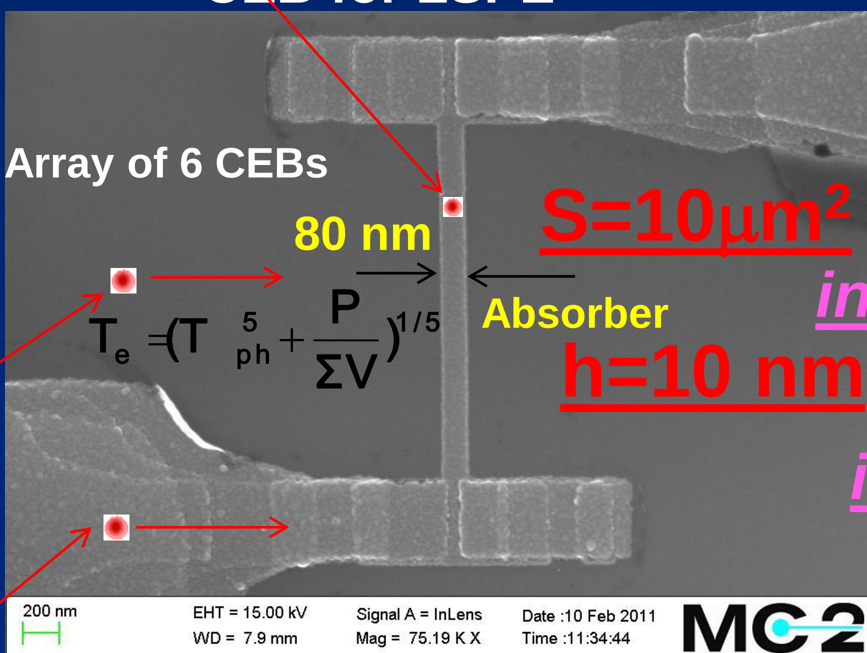
- No single glitch was detected!

Expectation time for a single glitch – 40 days!



Double protection against Cosmic Rays by extremly smalll volume of absorber!

CEB for LSPE



Gain

in Area

:1000

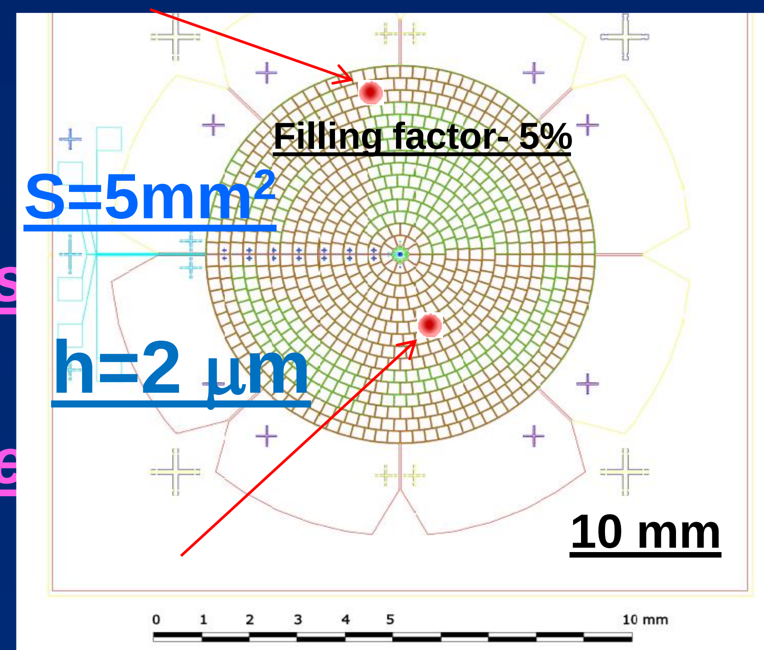
in thicknes

:100

in volume

:10⁵

Spider-web with TES for LSPE

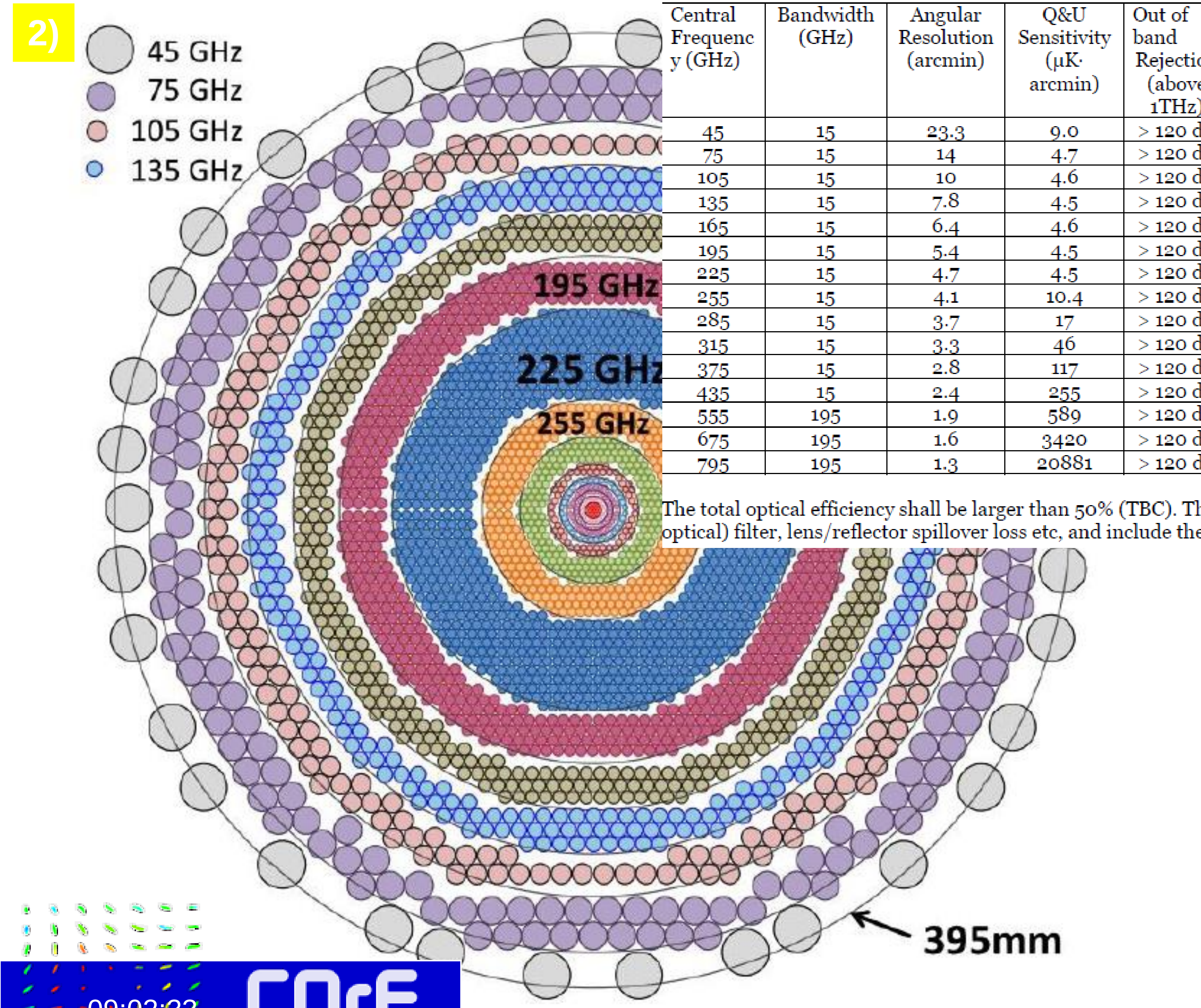


ESA/ ESTEC - ITT AO/1-7393/12

Next Generation Sub-millimetre Wave Focal Plane Array Coupling Concepts.

Multifrequency Systems for COrE

APC Paris Laboratoire de Astroparticule et Cosmology
Cardiff University, UK
Chalmers Technical University, Göteborg
La Sapienza, Rome
Manchester University, UK
NUI Maynooth, Ireland

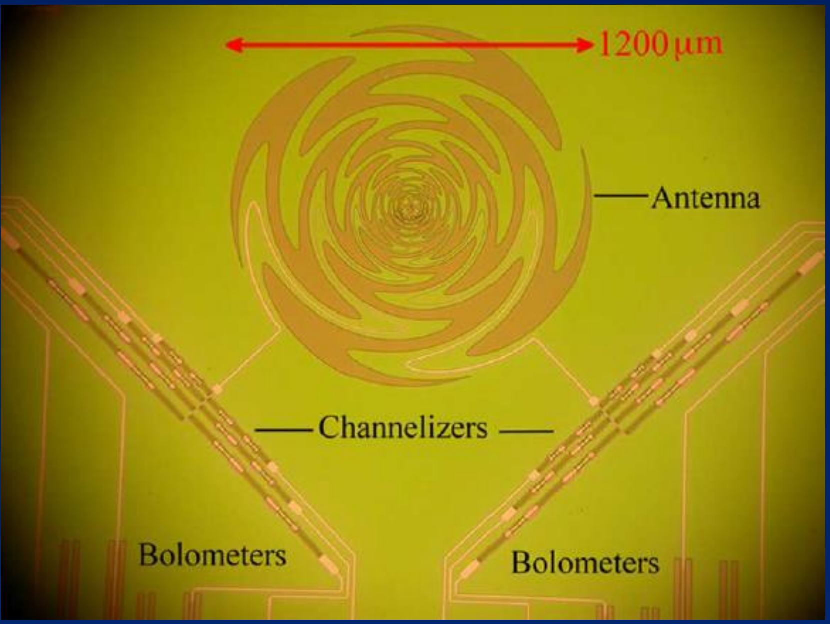


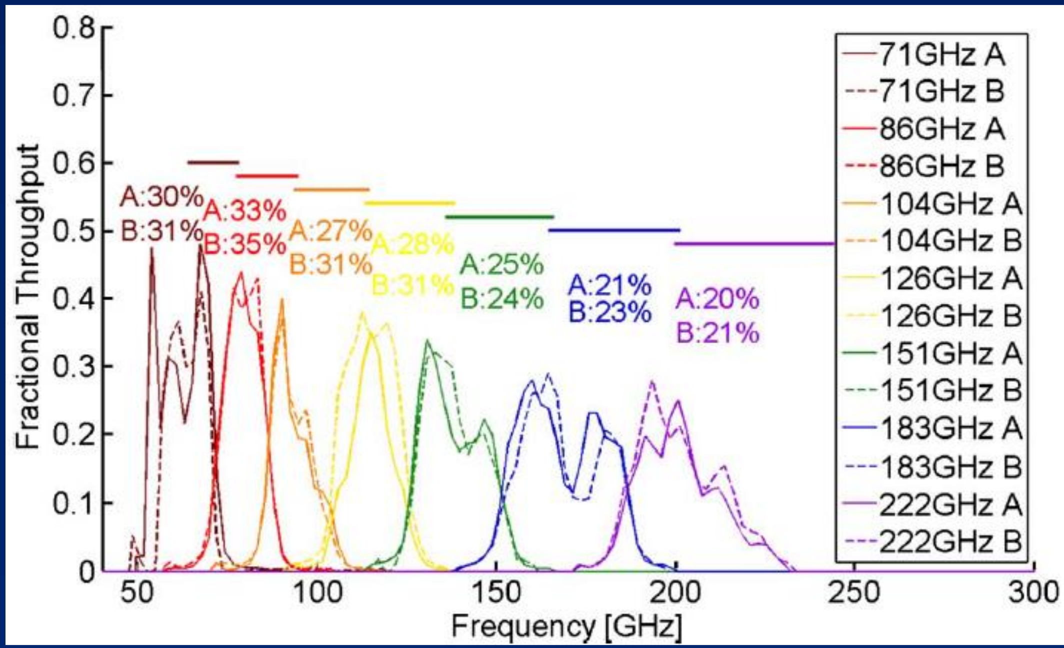
Central Frequency (GHz)	Bandwidth (GHz)	Angular Resolution (arcmin)	Q&U Sensitivity (μK·arcmin)	Out of band Rejection (above 1THz)	Beam Ellipticity (% @-3dB)	Cross – polarisatio (dB)
45	15	23.3	9.0	> 120 dB	< 1%	< -30 dB
75	15	14	4.7	> 120 dB	< 1%	< -30 dB
105	15	10	4.6	> 120 dB	< 1%	< -30 dB
135	15	7.8	4.5	> 120 dB	< 1%	< -30 dB
165	15	6.4	4.6	> 120 dB	< 1%	< -30 dB
195	15	5.4	4.5	> 120 dB	< 1%	< -30 dB
225	15	4.7	4.5	> 120 dB	< 1%	< -30 dB
255	15	4.1	10.4	> 120 dB	< 1%	< -30 dB
285	15	3.7	17	> 120 dB	< 1%	< -30 dB
315	15	3.3	46	> 120 dB	< 1%	< -30 dB
375	15	2.8	117	> 120 dB	< 1%	< -30 dB
435	15	2.4	255	> 120 dB	< 1%	< -30 dB
555	195	1.9	589	> 120 dB	< 1%	< -30 dB
675	195	1.6	3420	> 120 dB	< 1%	< -30 dB
795	195	1.3	20881	> 120 dB	< 1%	< -30 dB

The total optical efficiency shall be larger than 50% (TBC). This includes any (quasi-optical) filter, lens/reflector spillover loss etc, and include the (bolometer) coupling.

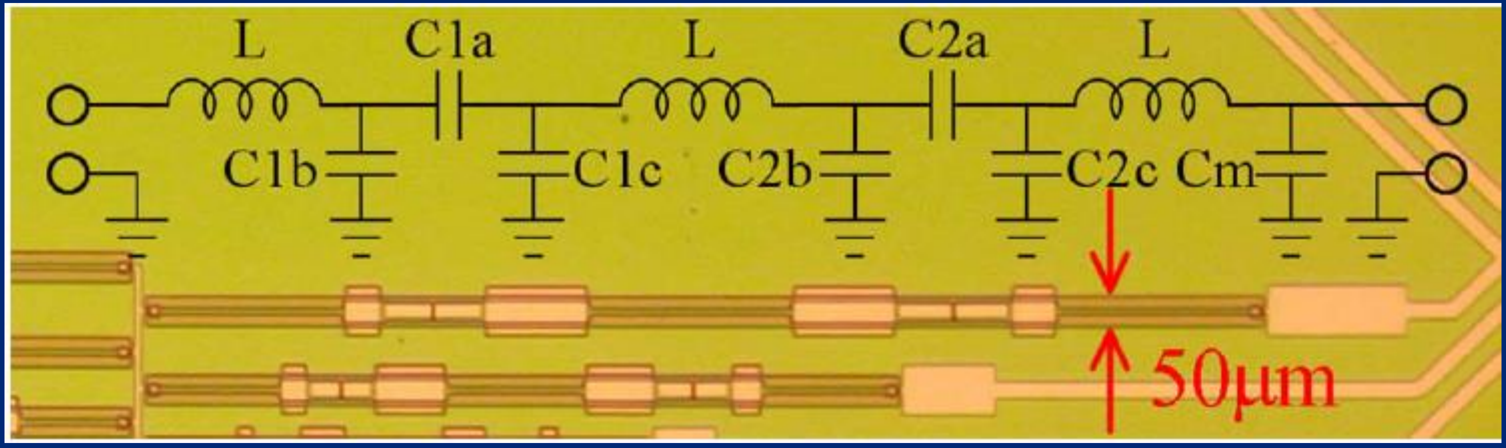
Sinuous Antenna

R. O'Brian et al., IEEE Appl. Sc. (2011)



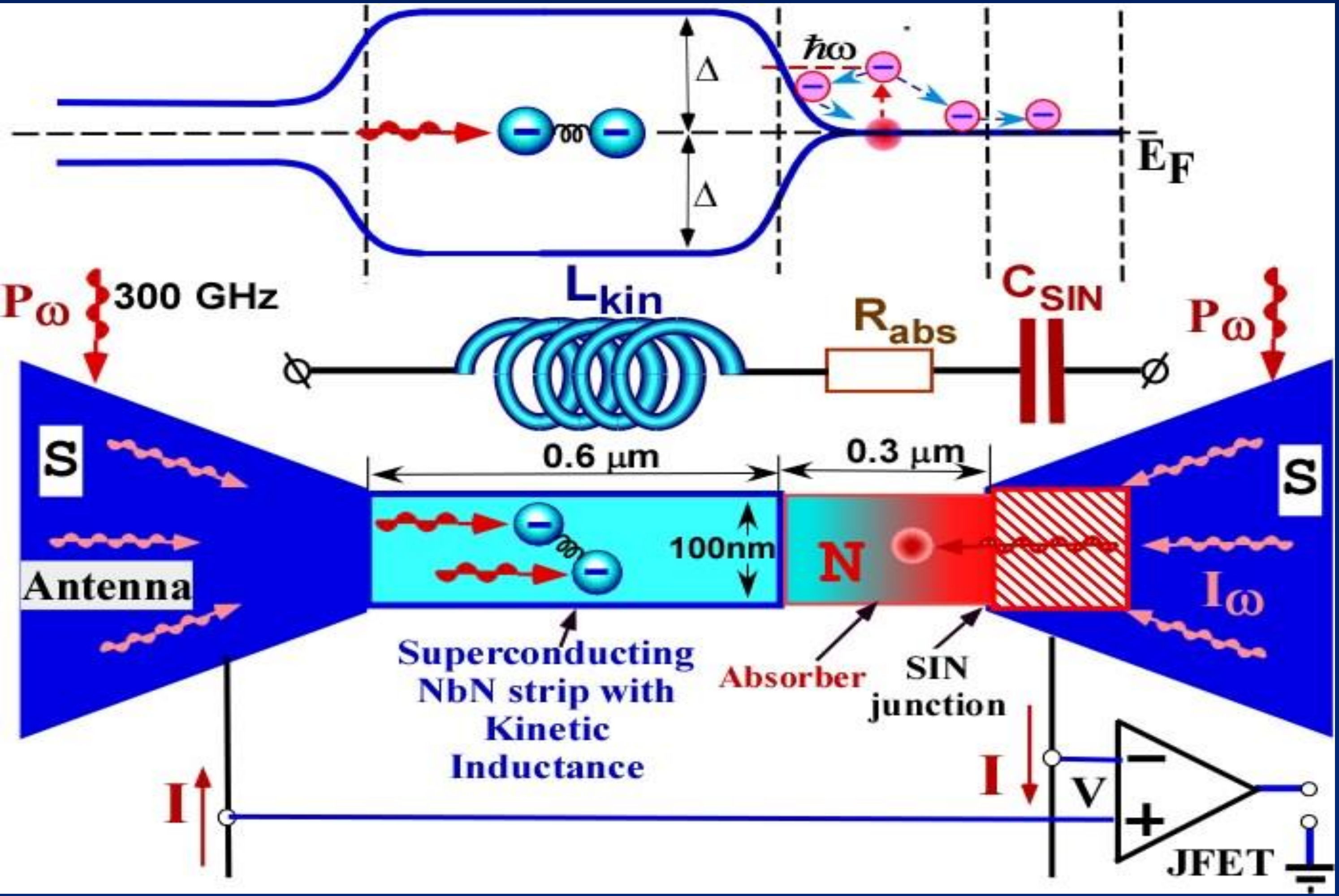


Length of Microstrip lines is 7 mm!



Resonance Cold-Electron Bolometer (RCEB) with Nanofilter by a Kinetic Inductance of the NbN strip and a Capacitance of the SIN Tunnel Junctions

L. Kuzmin, ISSTT, 2013; IEEE TST, 2014



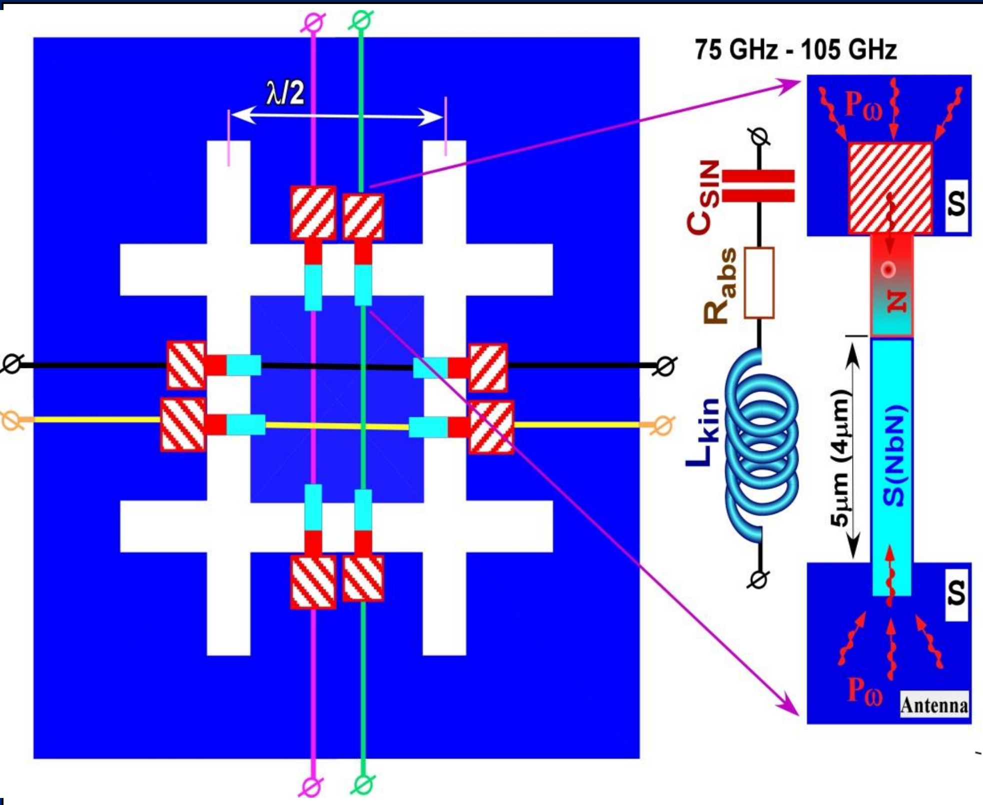
$$L_k = \frac{\mu_0 l}{w}\left[\frac{\lambda^2}{b}\right]$$

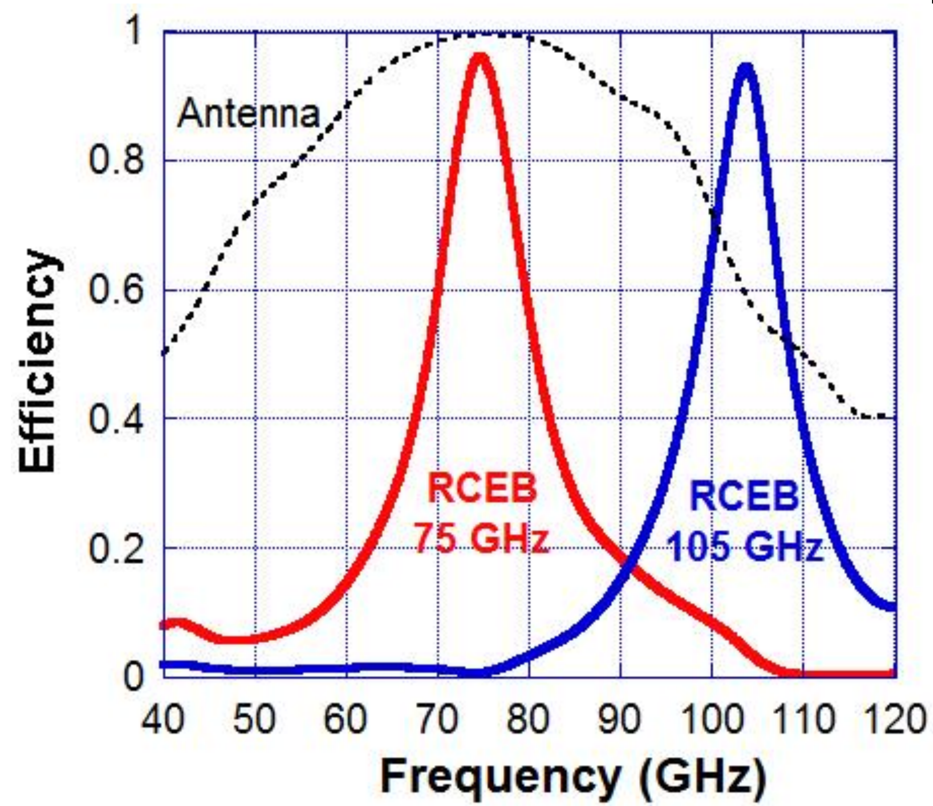
NbN: λ=400 nm, b=10 nm, Lkin =140 pH for *l*=0.6 μm

Q=10, Rabs=15 Ohm, ωLkin=300 Ohm @ 350 GHz, SIN: S=0.04 μm^2

09:02:33

Cross-Slot Antenna with RCEB for 75 and 105 GHz





Cross-Slot Antenna - J. Zmuidzinas et al,

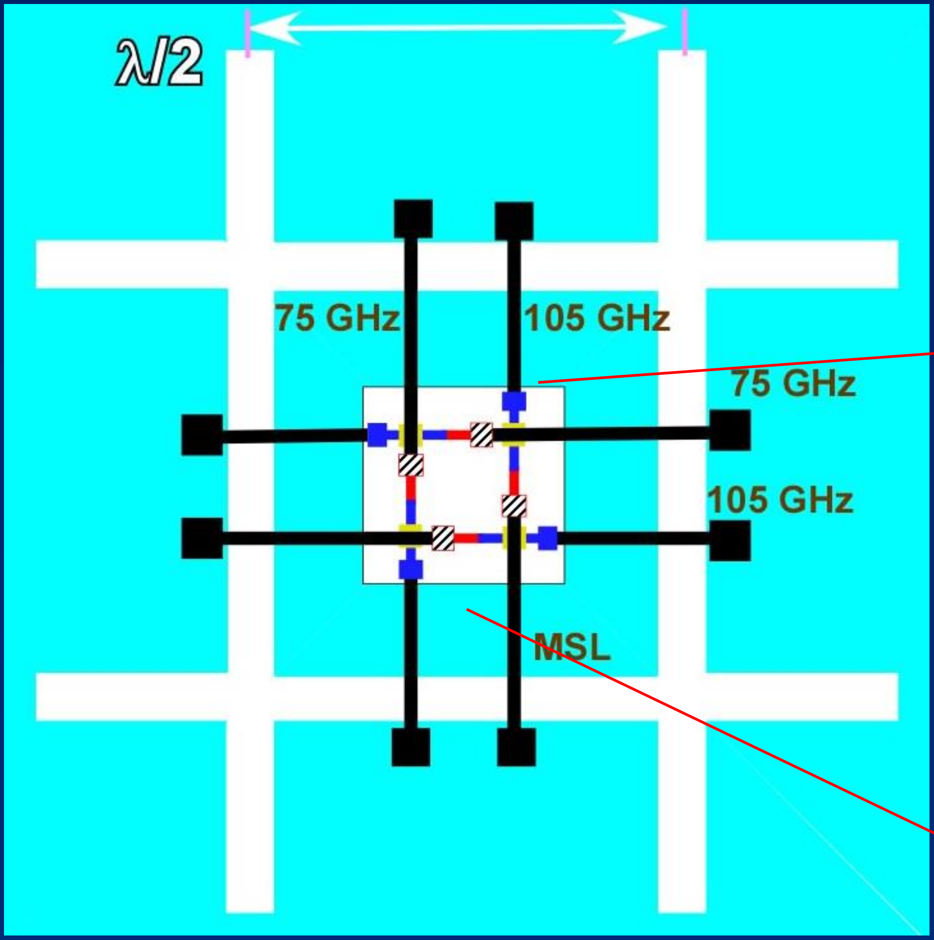
Preliminary frequency selection in each pixel is done by the antenna and the final selection is done by RCEB.

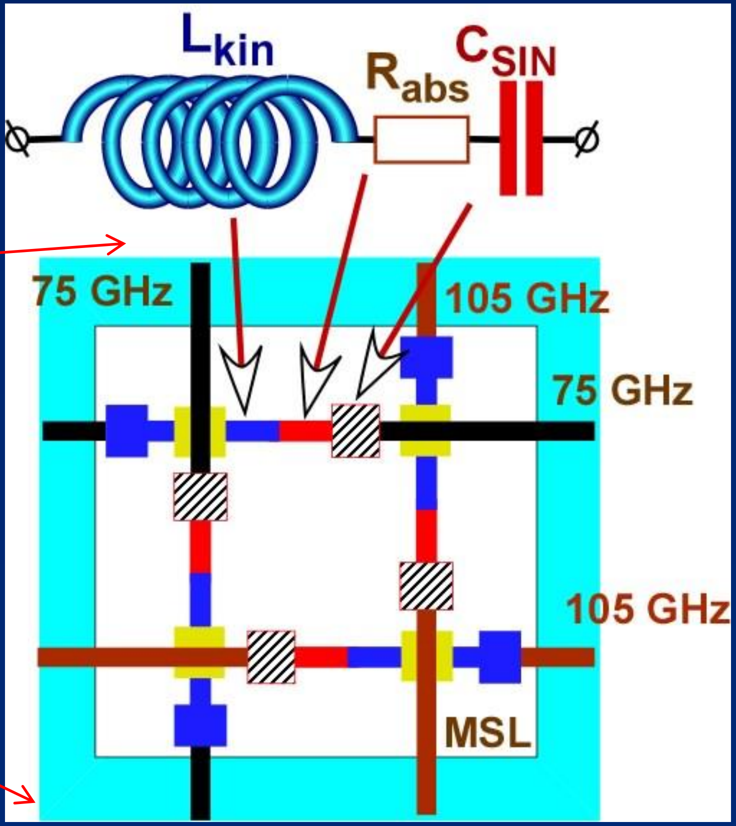
Lkin/sq=4$\pi\lambda^2$/b /H NbN: λ=300 nm,b=10 nm, Lkin/sq=20 pH/sq, Lkin =400 pH, l=2 μm, Q=10, ρ=20 Ohm, Rabs=20 Ohm, SIN: S=0.2 μm^2, C1=11fF,

Cross-Slot Antenna with RCEB for 75 and 105 GHz

Length of MSLs is 300 μm ! (in contrast to 7 mm for the sinuous antenna)

Overcross of the kinetic inductance and the microstrip line. Complicated interection of MSLs





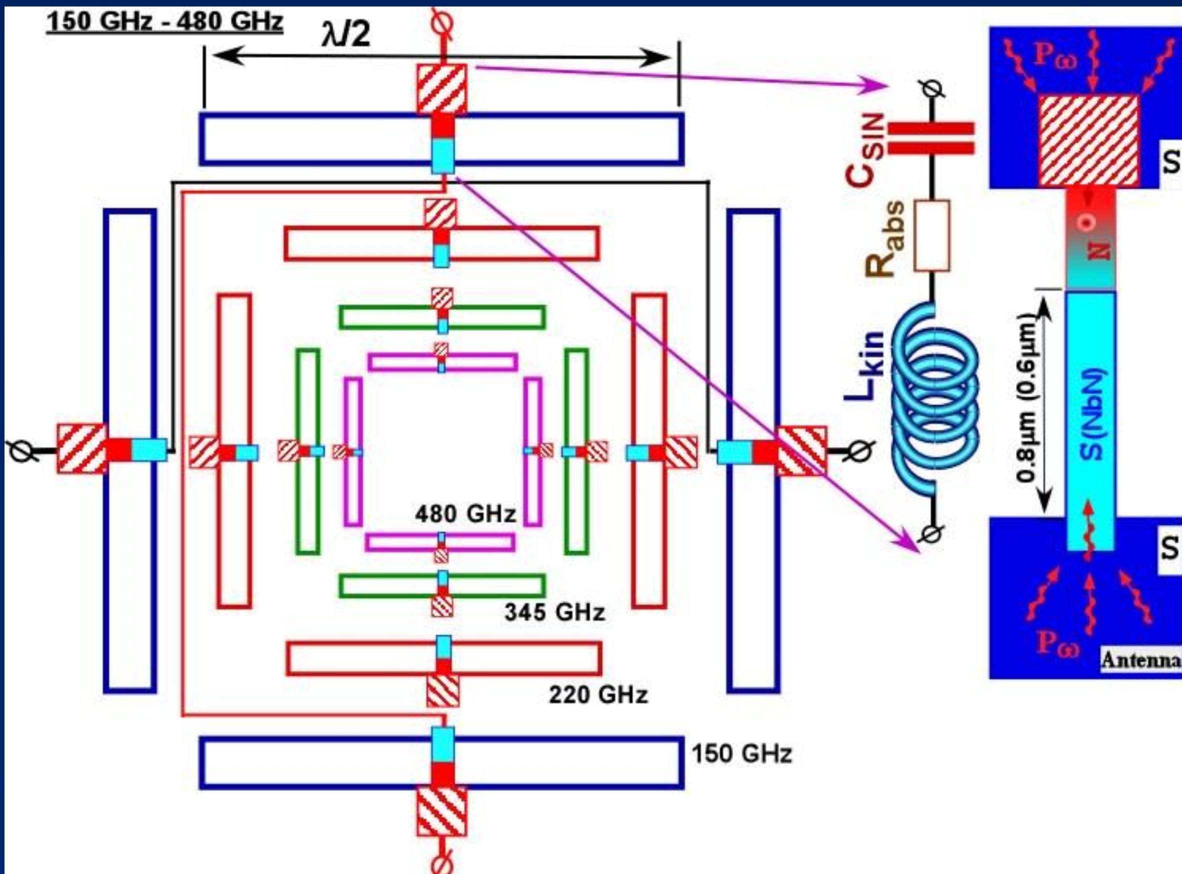
“Seashell” Slot Antenna with RCEBs

Leonid Kuzmin , Rome, 21 Sept 2013

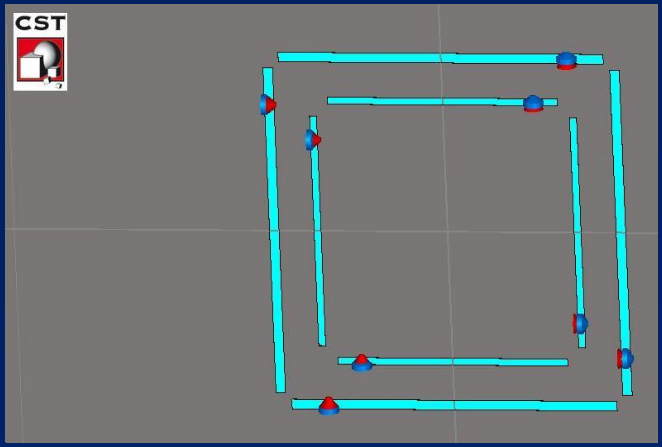
Stimulative discussions with Paolo de Bernardis are acknowledged

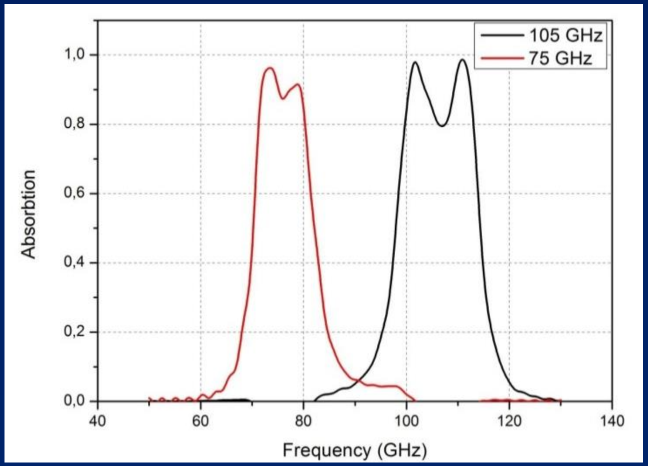
For OLIMPO

R. O’Brian et al.,

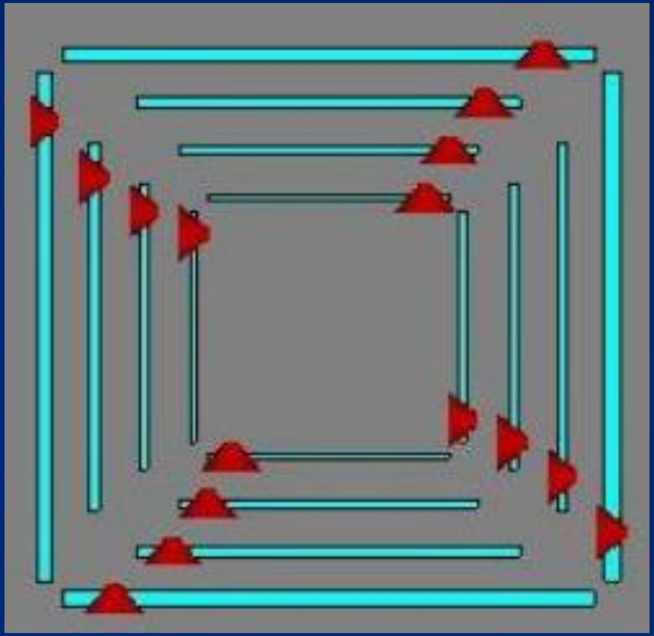


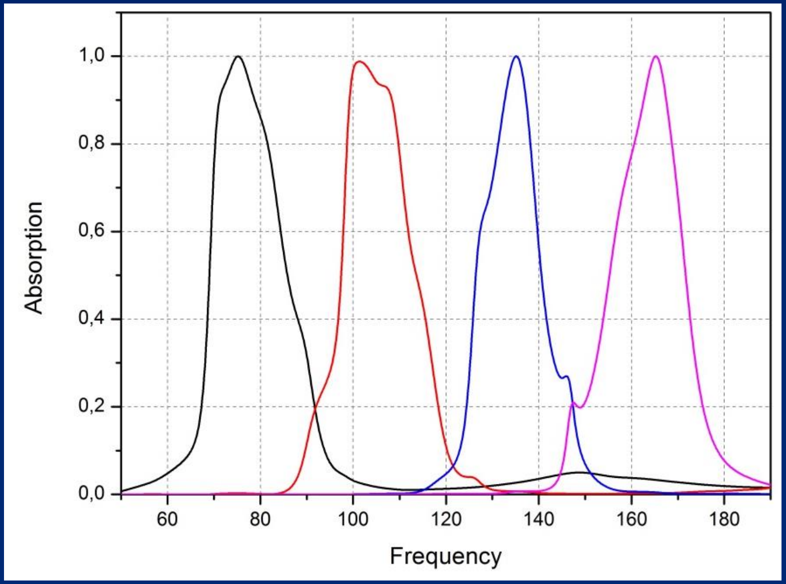
"Seashell" Antenna with λ/2 Slots and RCEBs





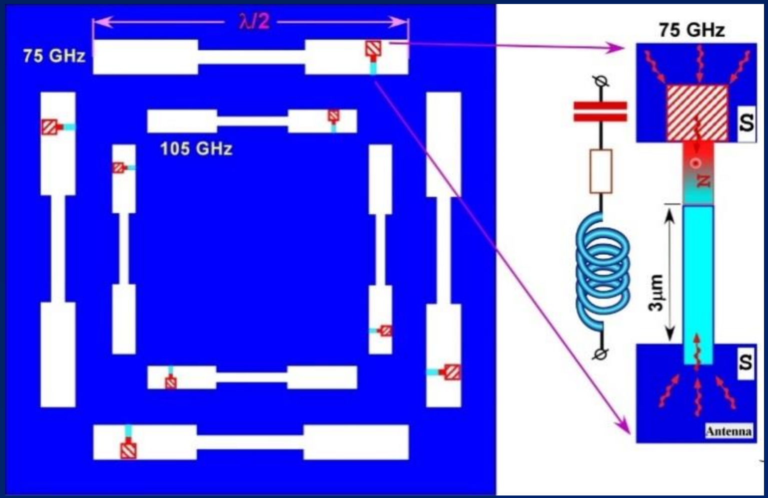
Beam ellipticity 4.9% at 75 GHz
8% at 105 GHz

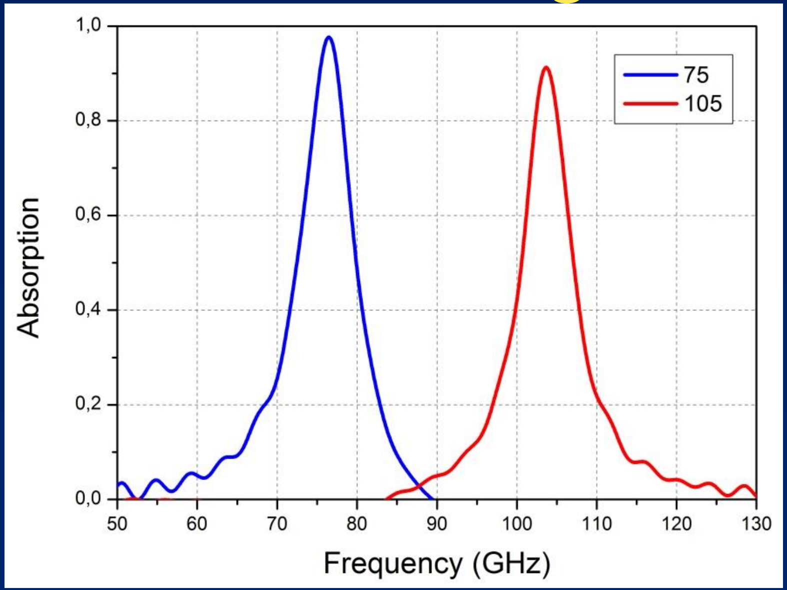




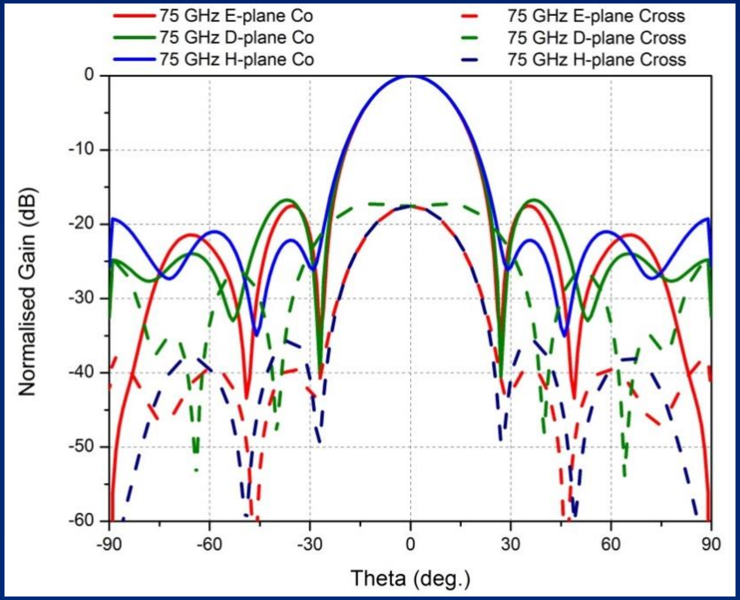
Absorption in 4-Frequency Seashell Slot Antenna with RCEBs designed for 75, 105, 135, and 165 GHz

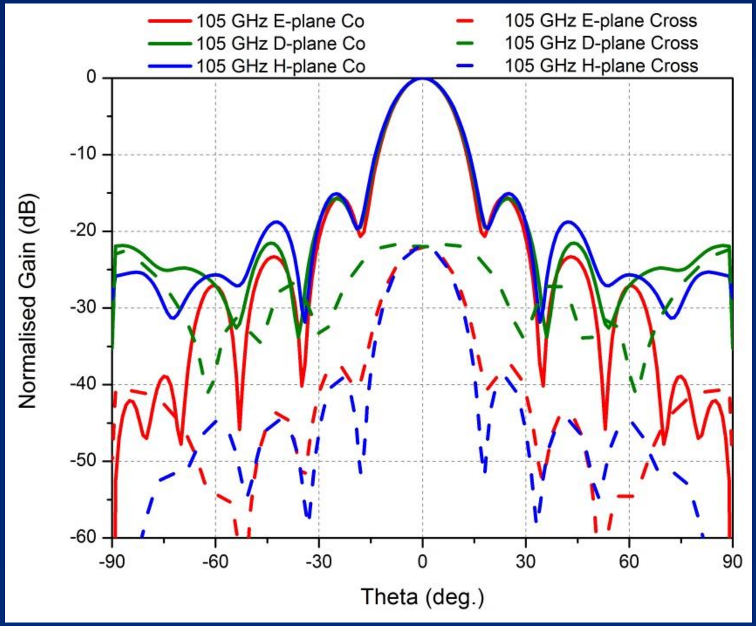
Seashell antenna with $\lambda/2$ H-slots (lumped capacitances) and RCEB filtering



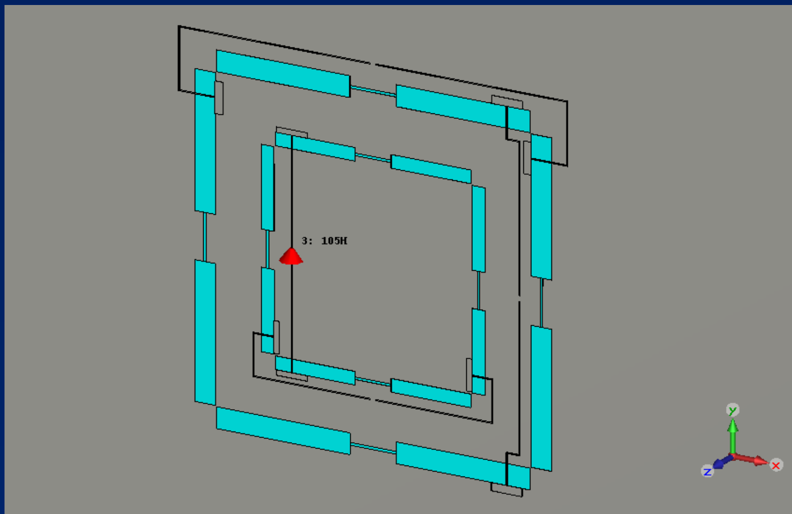


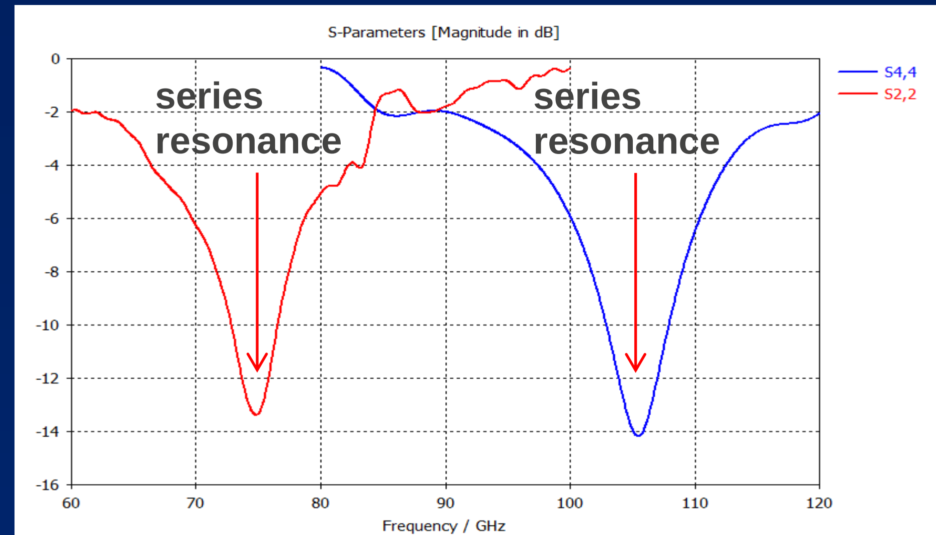
Beam ellipticity 2% at 75 GHz
0.3% at 105 GHz





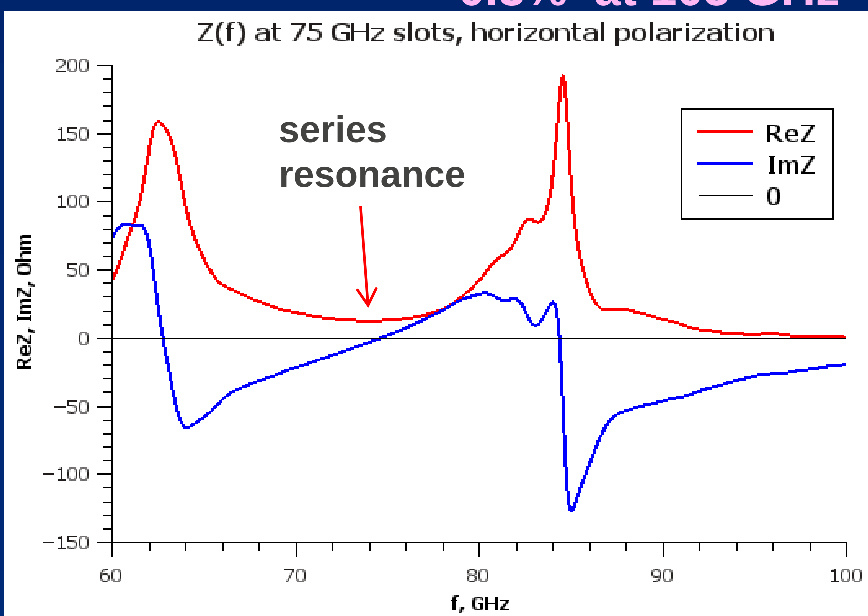
Seashell Antenna with λ/2 H-slots and MSLs with CEB

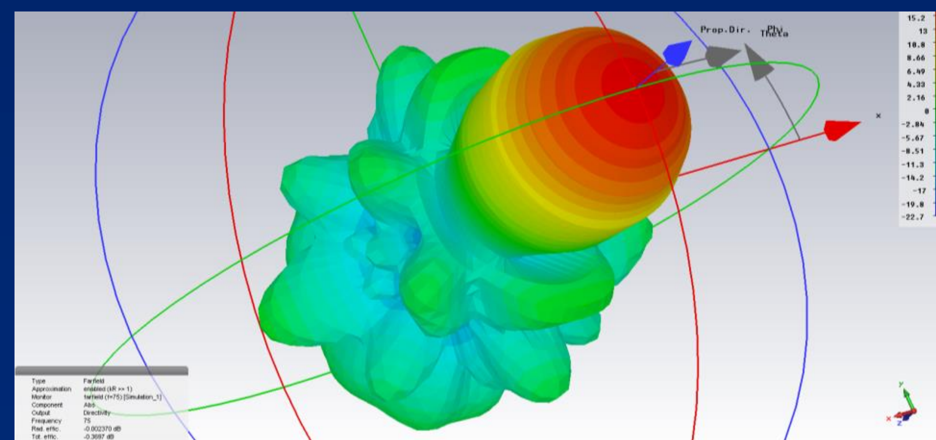




Beam ellipticity 2% at 75 GHz

0.3% at 105 GHz





Ellipticity: 2% – 4% !

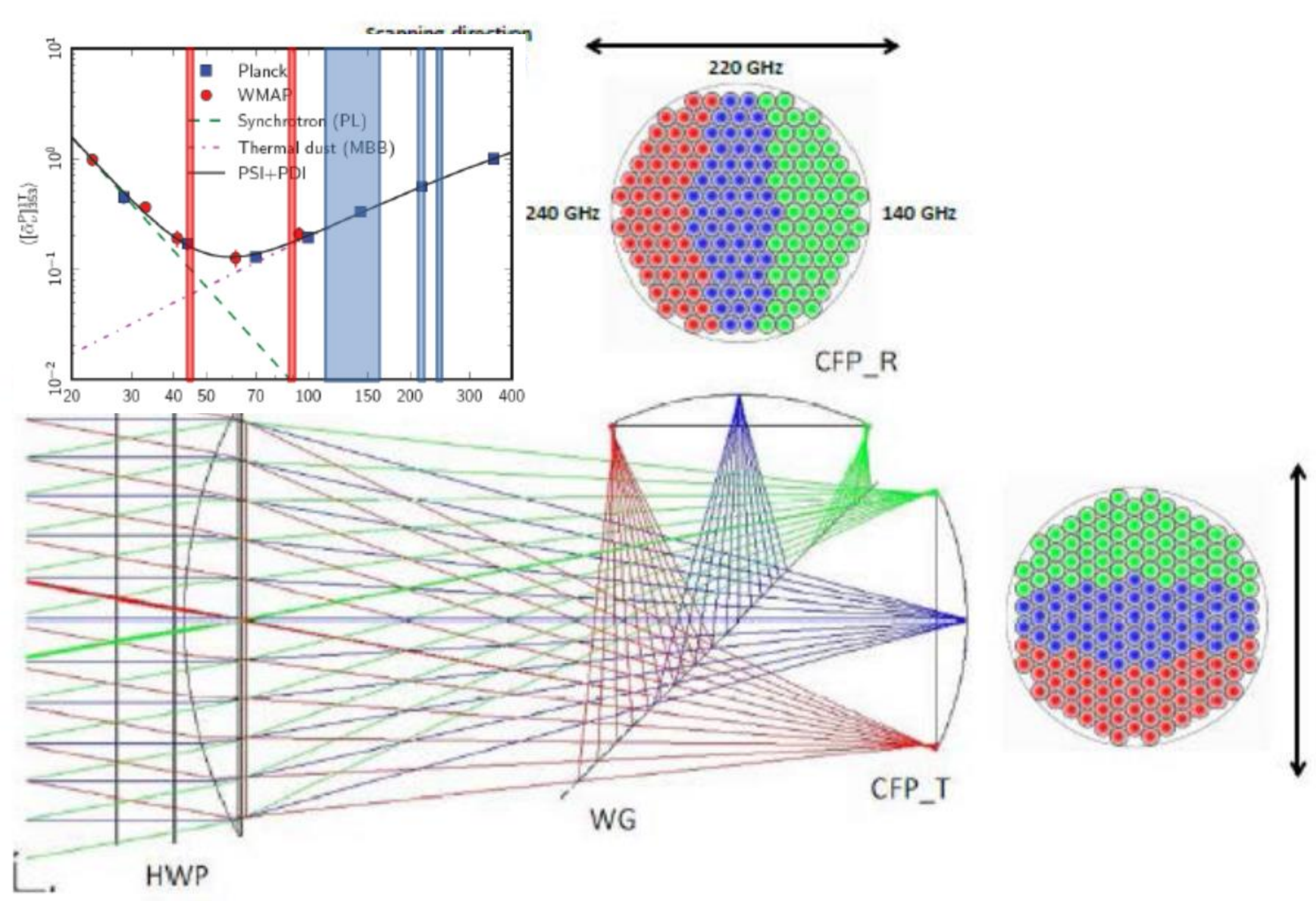
ReZ = 13 Ohm

Bandwidth: 20%

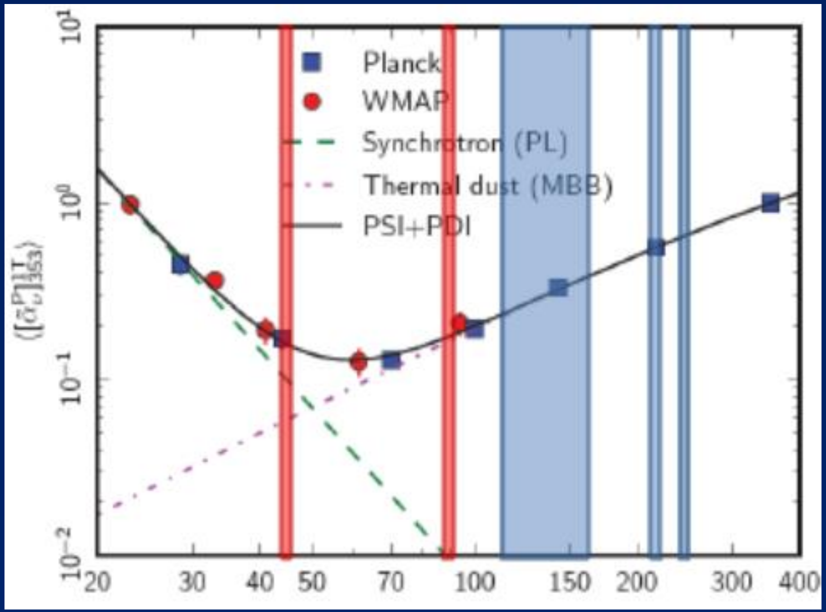
Crosspol: 12-20 %

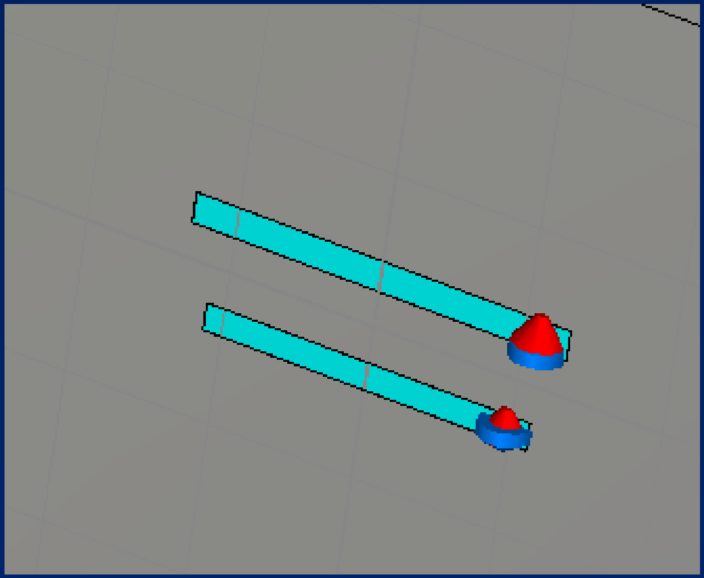
LSPE. 220 & 240 GHz for Dust.

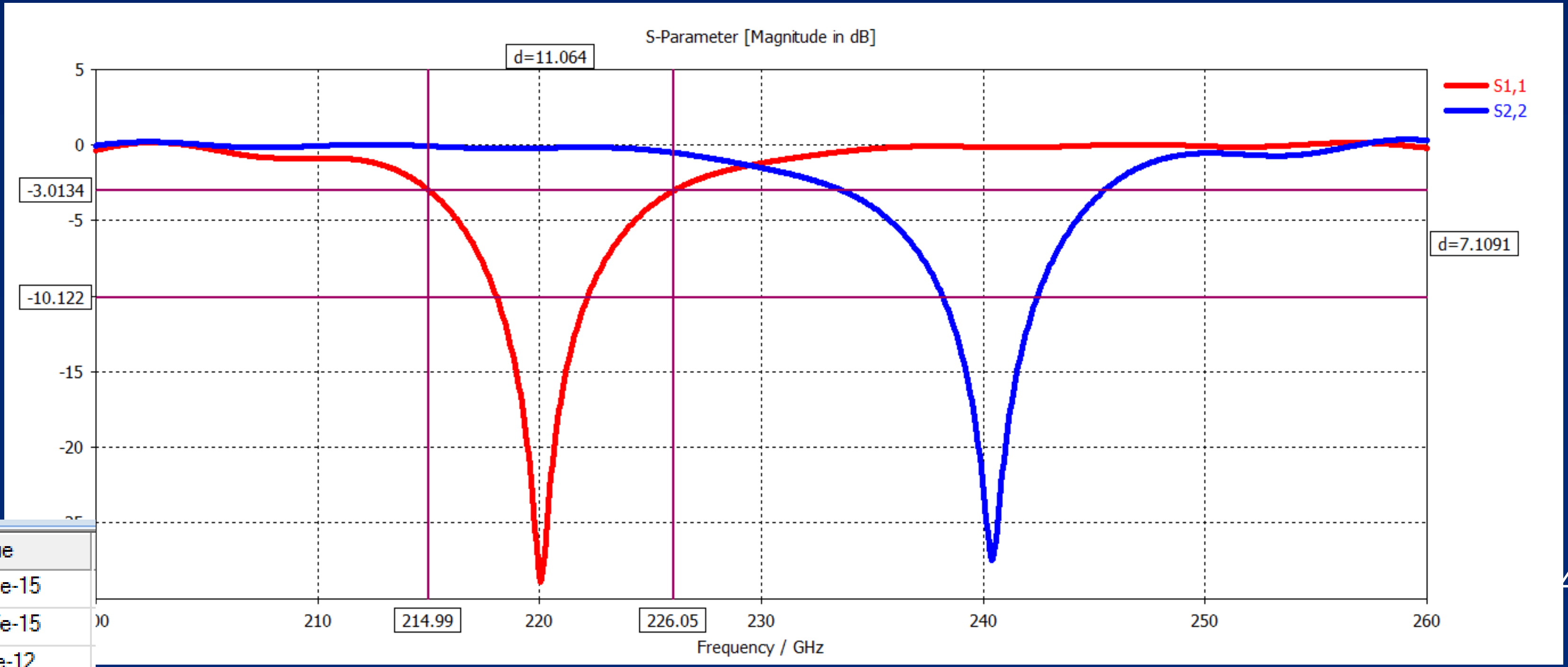
Bandwidth – 5%



LSPE. 220 & 240 GHz. Multichroic System with RCEB







Nar /	Value
C1	1.01e-15
C2	0.95e-15
L1	500e-12

Cold-Electron Bolometer for COrE:

- **Photon noise-limited bolometer**
- **High immunity to CR: 1 glitch/40 days (instead of 1glitch/sec for Planck).**
- **High saturation power due to electron cooling of absorber.**
- **Insensitive to T fluctuations due to decoupling of electron and phonon system.**
- **SQUID readout with multiplexing can be used.**
- **Technology of SIN tunnel junctions – similar to SQUIDs**

Next Generation of Multichroic Systems for COrE

- **Resonant Cold-Electron Bolometer (RCEB) with nanofilter**
- **Cross-Slot Antenna with resonance selection by RCEBs**
- **Seashell Antenna: - independent tuning of slots with resonance selection !**