PARAMETRIC INSTABILITY OBSERVATION IN ADVANCED VIRGO

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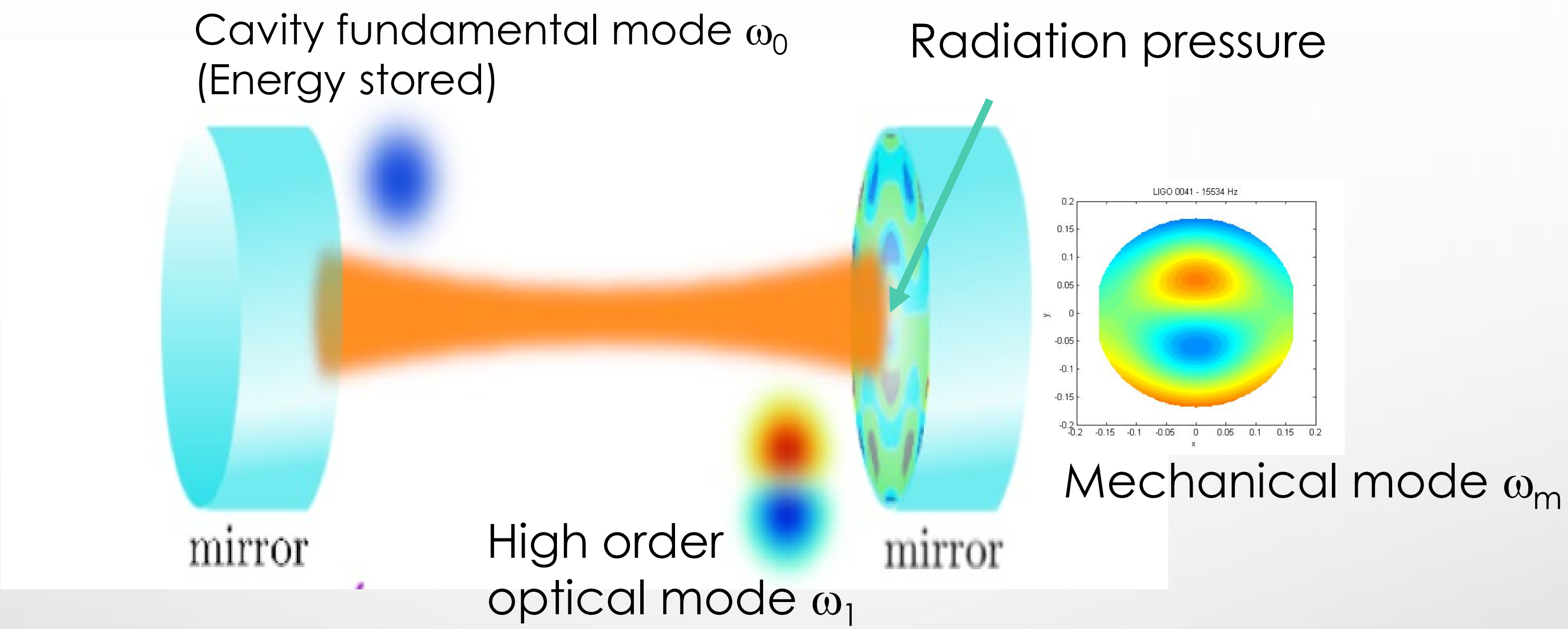
ON BEHALF OF THE VIRGO COLLABORATION

SECOND EPS CONFERENCE ON GRAVITATION

JULY 5TH- 7RD 2021 – ONLINE EVENT

Parametric Instability : 3 modes interaction



Thermally excited acoustic mode scatters TEM_{00} mode

$\rightarrow$ sidebands $\omega_o \pm \omega_m$

Resonance with high order TEM_1 if $\omega_o \pm \omega_m = \omega_1$ due to radiation pressure

Resonance condition:

$\omega_o - \omega_1 = \omega_m$, high spatial overlap

PARAMETRIC GAIN R_M

$$\Delta\omega_{om} = |\omega_0 - \omega_1| - \omega_m$$

Beat Note

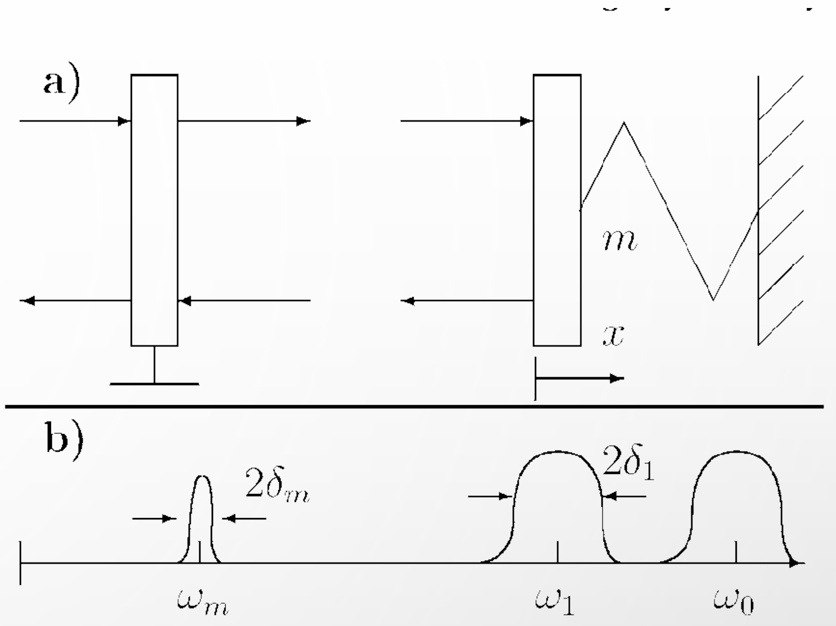


Fig. 1. Scheme of FP resonator with movable mirror (a) and frequency diagram (b).

Mechanical Quality factor

Optical quality factor

Power in arm

Spatial Overlapping Parameter

$$R_m = \frac{4Q_1Q_mP}{LMc\omega_m^2}\frac{\Lambda}{(1+(\Delta\omega_{om}/\delta_1)^2)}$$

Arm length

Mass of the mirror

Mechanical mode

Optical Gain

Optical mode linewidth

Λ and the **Optical Gain** are estimated with the simulations.

Braginsky et al, PLA 287 (2001) 331-338

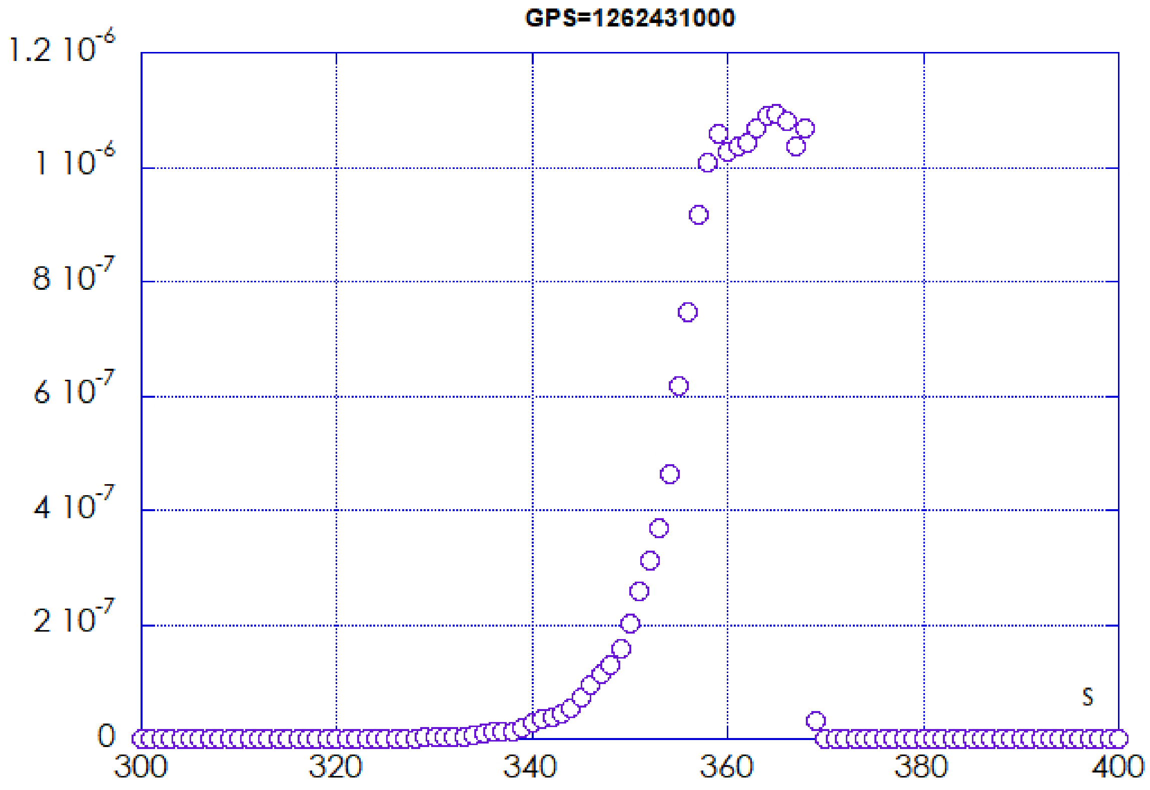
INSTABILITY CONDITION

- INSTABILITY WHEN $R_M > 1$
  - P, Q_M AND L ARE IMPORTANT
  - LINEWIDTH Δ_1 (OPTICAL LOSSES)
  - THE MECHANICAL MODE IS PUMPED

UP WITH A TIME CONSTANT:

$$\tau_{PI} = |\tau_m/(1 - R_m)|$$

τ_m : natural time costant of the mechanical mode



$$A = A_o\, e^{t/\tau_{PI}}$$

PI OBSERVED IN VIRGO

On January 7-8th

- A sequence (a few tenths) of unlocks occurred after the Christmas break when the Power was increased from 18W to 27W and the TCS used to optimize the ITF contrast.

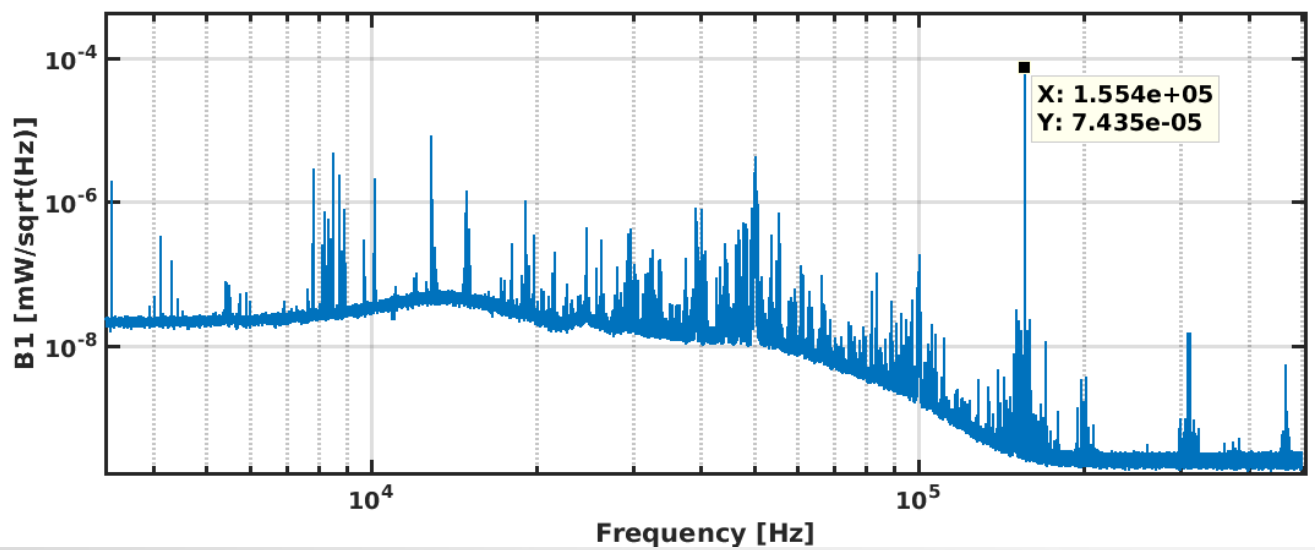
Description:

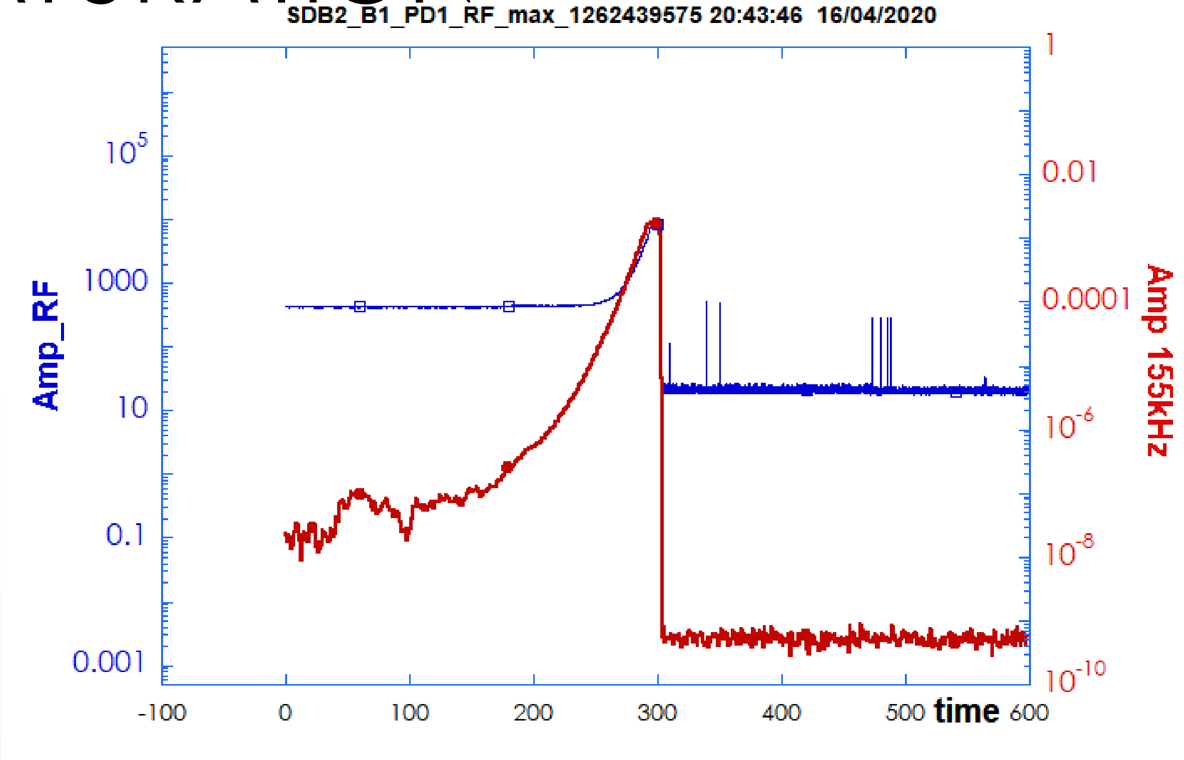
- The PI occurred on the North Arm;
- A high frequency mode (155 kHz) of the NI mirror is coupled with TEM1
- Instability triggered by the NE mirror change of T due to TCS adjustment
- Signal present both on N and W arms signals
- The optical signal is visible on the dark port camera and a strong RF signal is visible on all the PD and QPD.

Characterization of the PI

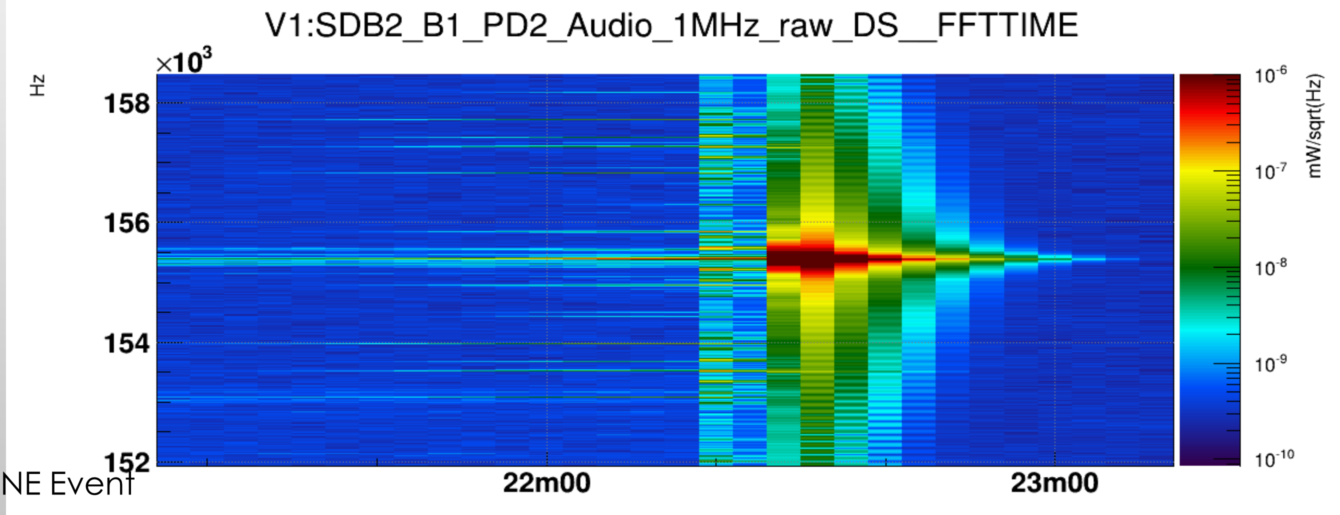
- Parametric gains spans from 2 up to 10
- Depend on the TCS WP
- During a single PI event R change because of the NE mirror RC due to its heating by the TEM1 power increase

THE ORIGIN OF THE SATURATION



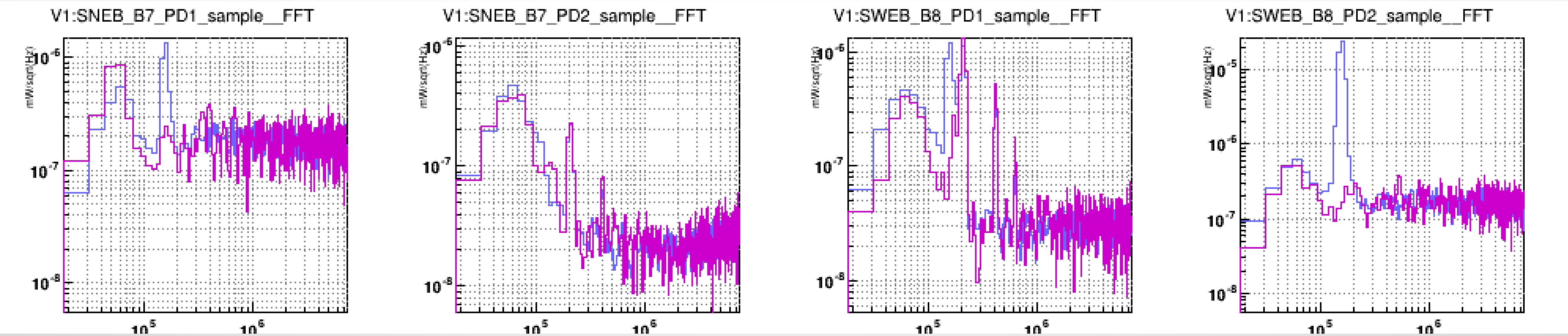


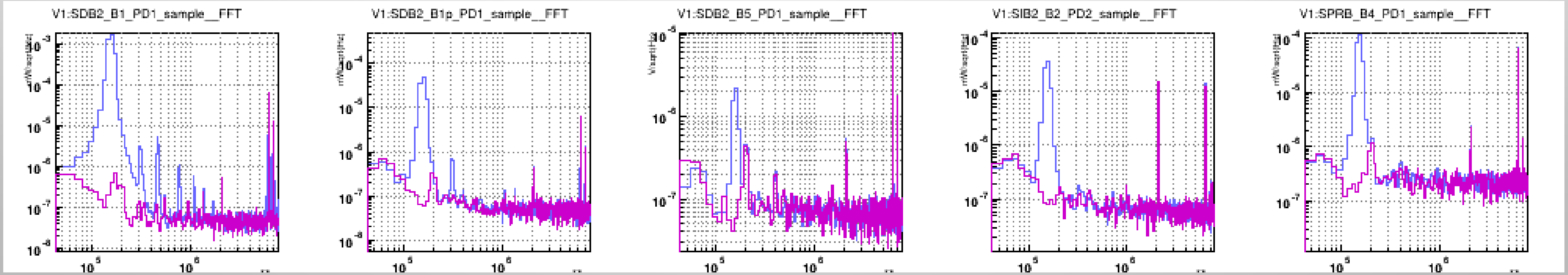
The saturation is due to a ~155kHz oscillation exponentially growing up until it saturates **B1 RF** and causes the unlock, **following the peak at 155kHz we can estimate with more accuracy the time evolution of the instability.**



155KHZ LINE SEEN BY ALMOST ALL THE PDS AND QPDS

In the ideal case, the beat between TEM00 and TEM01 cannot be detected by a photodiode perfectly centered on the beam axis and orthogonal to the wavefront.
However, even a small clipping or tilt of the beam can give a non-zero result of the intergral between these two modes.
We can see it almost everywhere in the interferometer

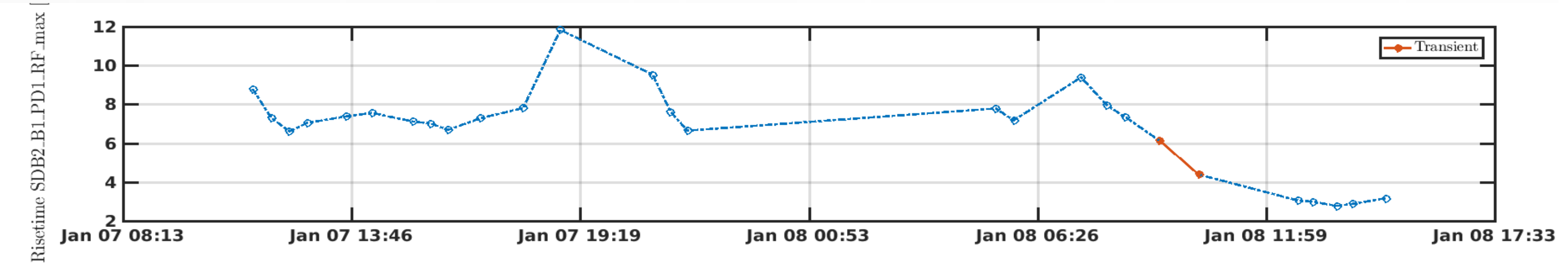




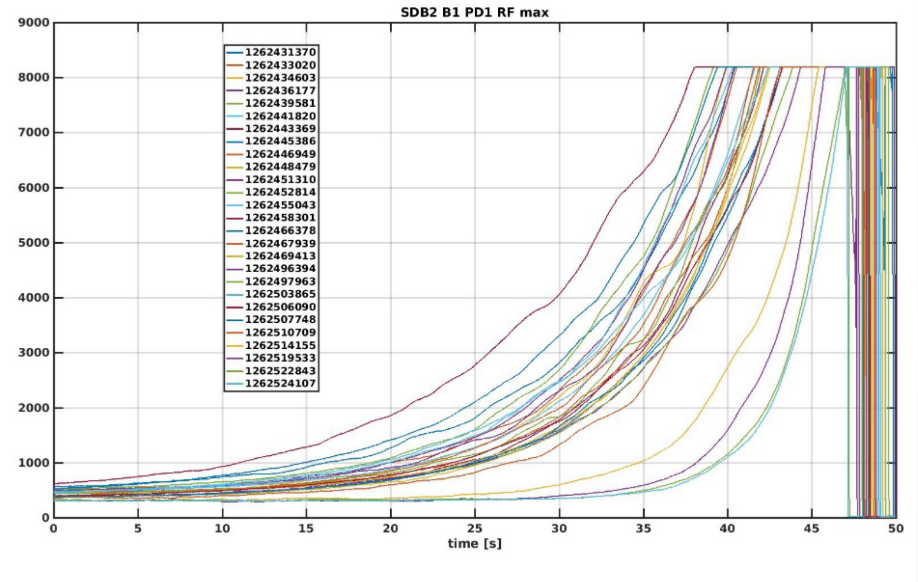
Credits: A. Allocca

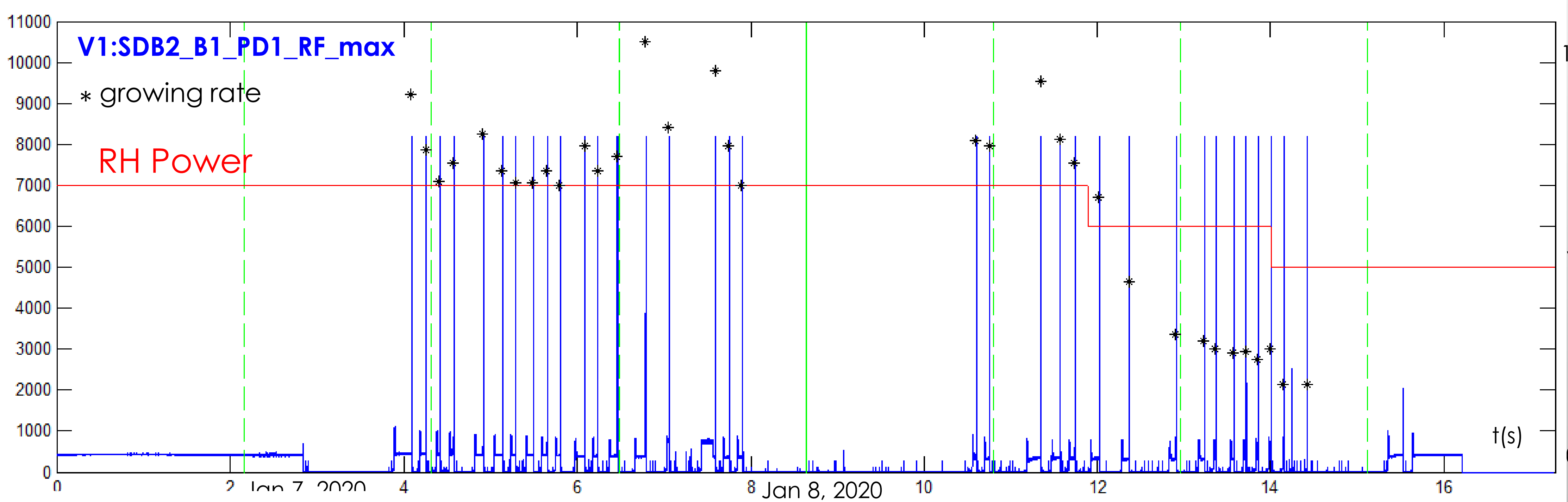
PI RISETIME

The risetime of the exponential growth depends on the TCS working point



Credits: M.Mantovani, J. Brooks, P. Ruggi

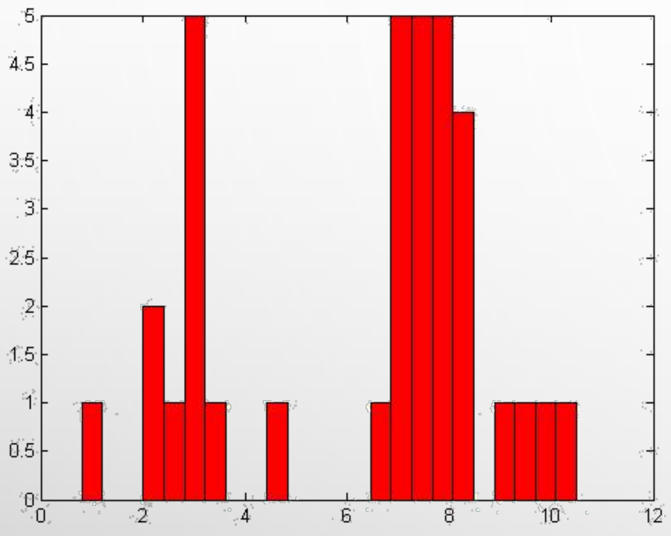




Credits: G. Bogaert

Rmax change during all the events

From the risetime τ_{PI} we can compute the corresponding parametric gains



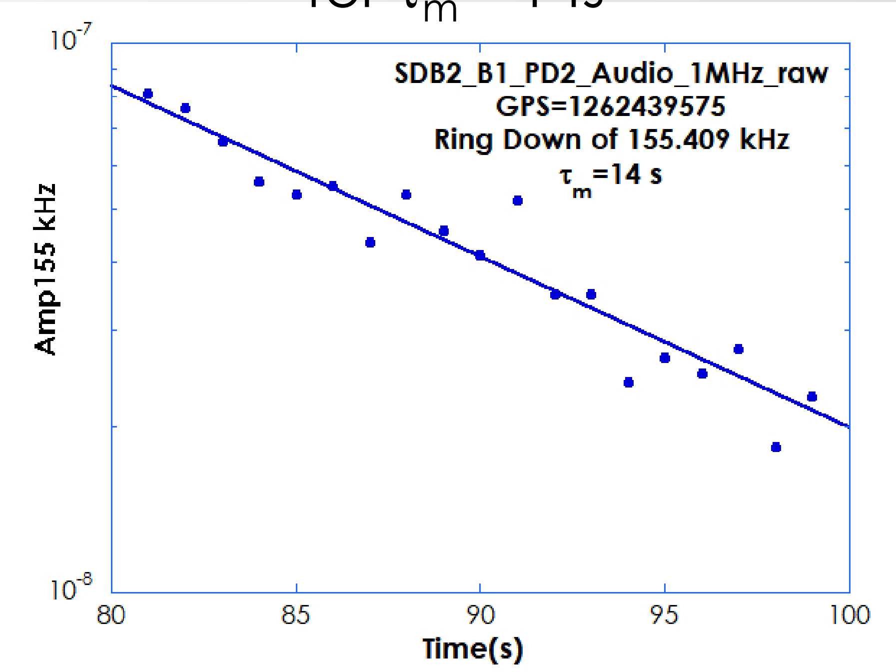
$$\tau_{PI} = \tau_m/(1 - R_m)$$

$$1.5\ s < \tau_{PI} < 10.5\ s$$

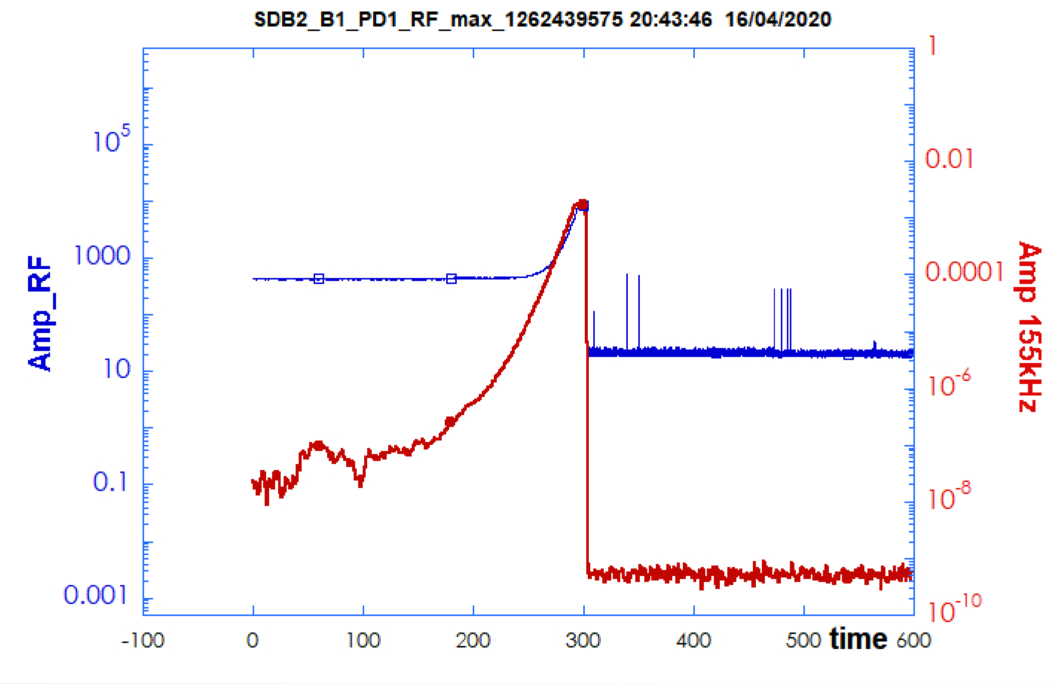
$$\boxed{2.3 < R_m < 10}$$

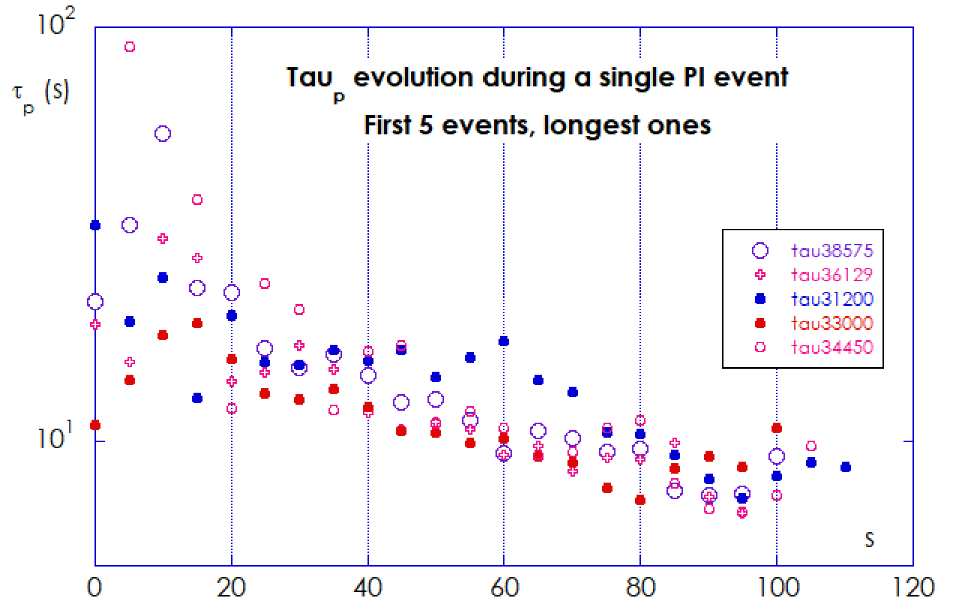
τ_m : natural time constant of the mechanical mode

for $\tau_m \approx 14$s



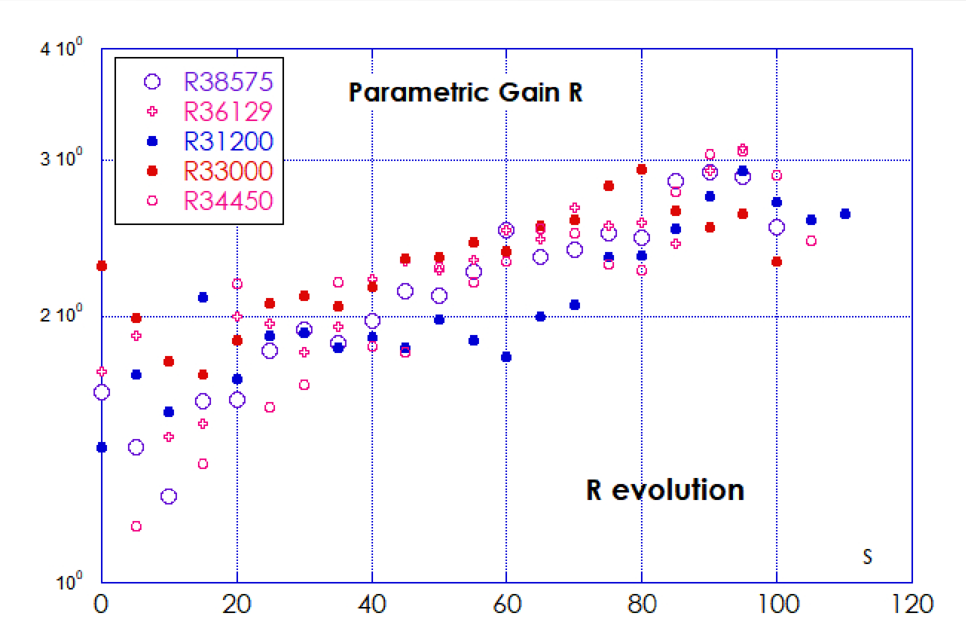
The PI ring up are more quick, and τ_{PI} lower as soon as the WP of the ITF is closer to the instability point.





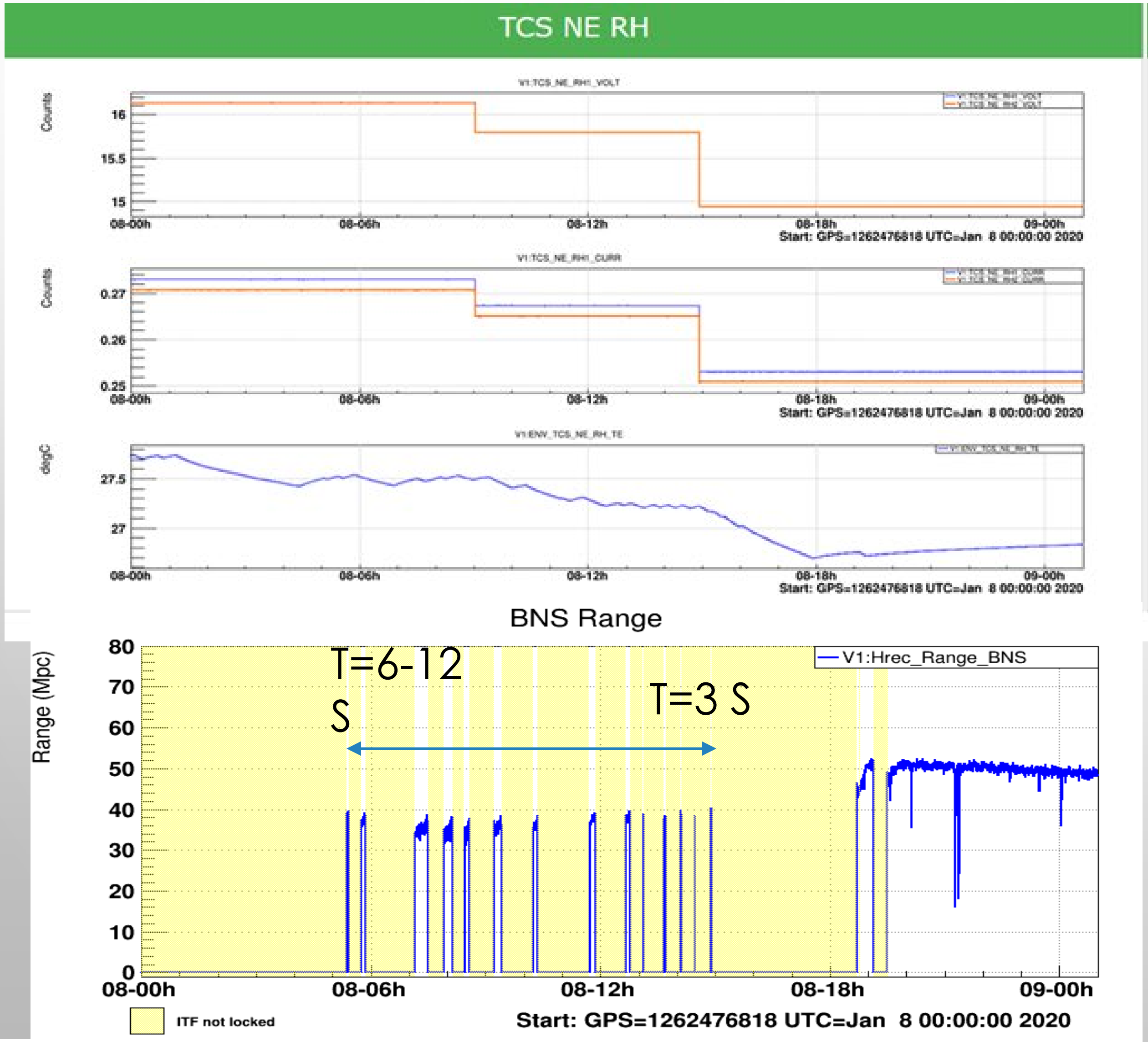
Following the excited peak at 155kHz we can estimate with more accuracy the time evolution of the instability.

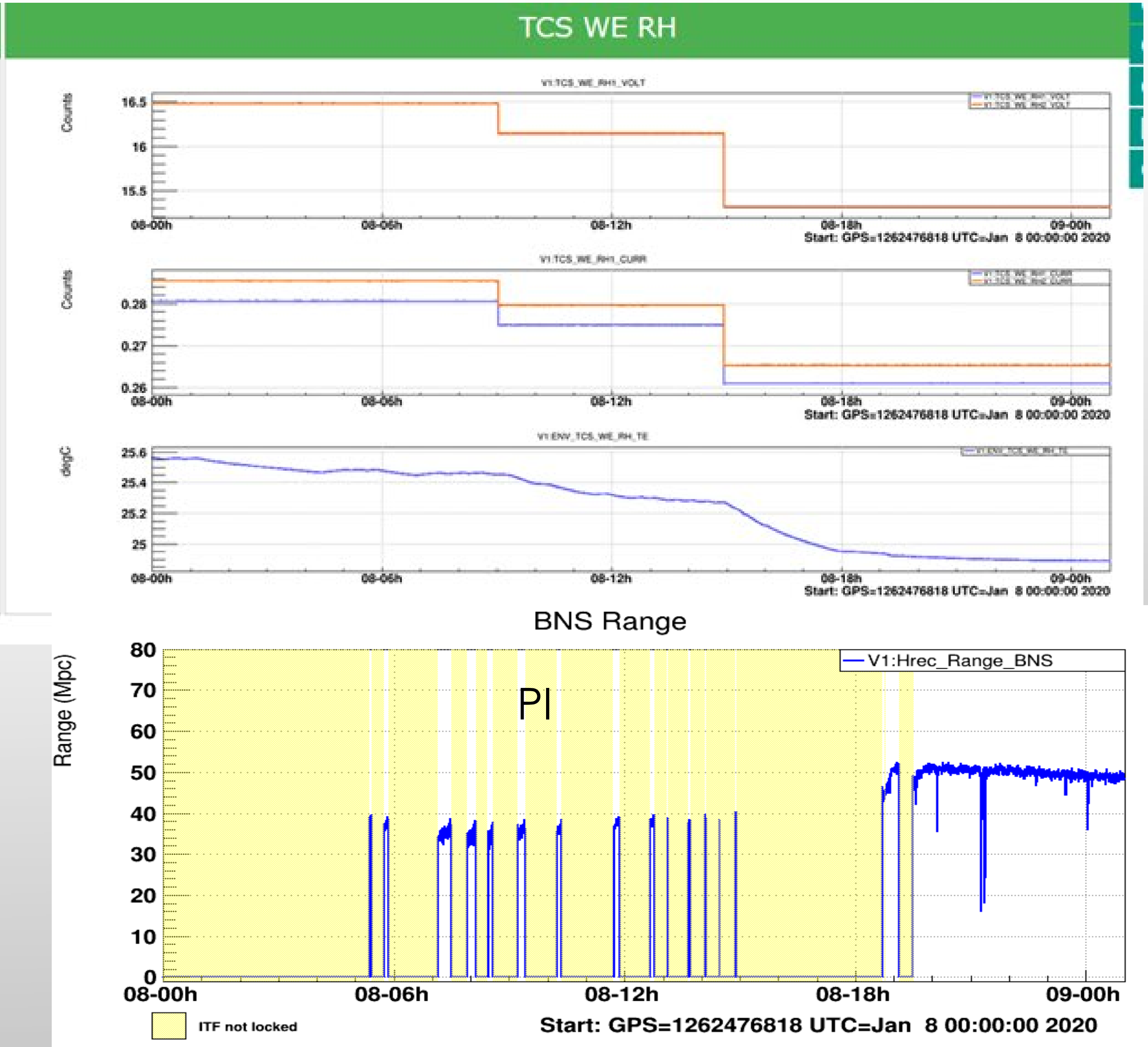
Tau changes and spans from 20 to 7-8 s,
R spans from 1.5 up to 3. (it is due to the heating of the TEM1 power)



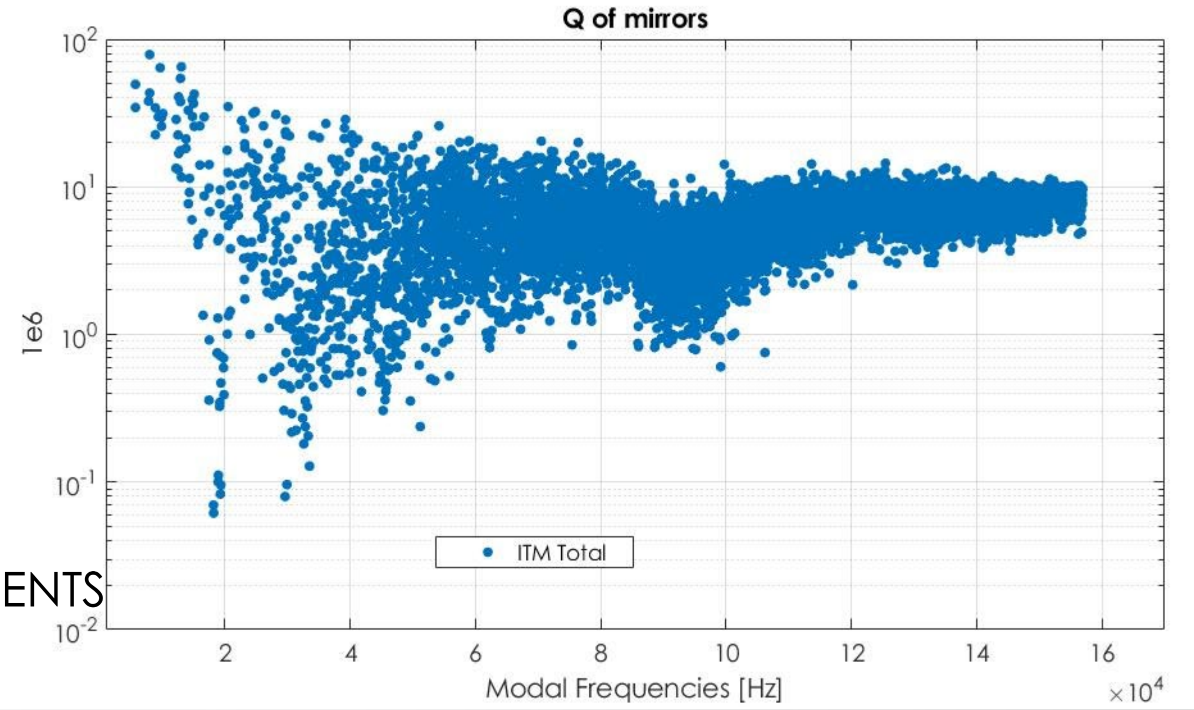
R evolution during a single PI

- THE PI EVENTS WERE CURED BY SLIGHTLY TUNING THE CAVITY GOUY PHASE BY CHANGING THE ETMS RING HEATER WORKING POINT;





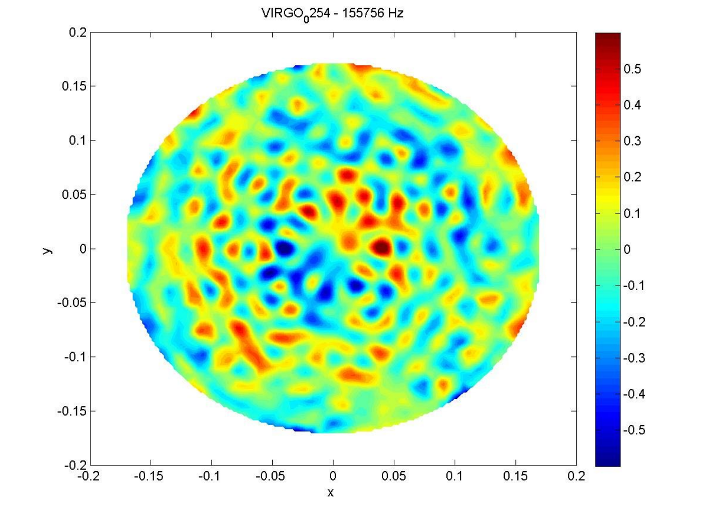
SIMULATION PERFORMED

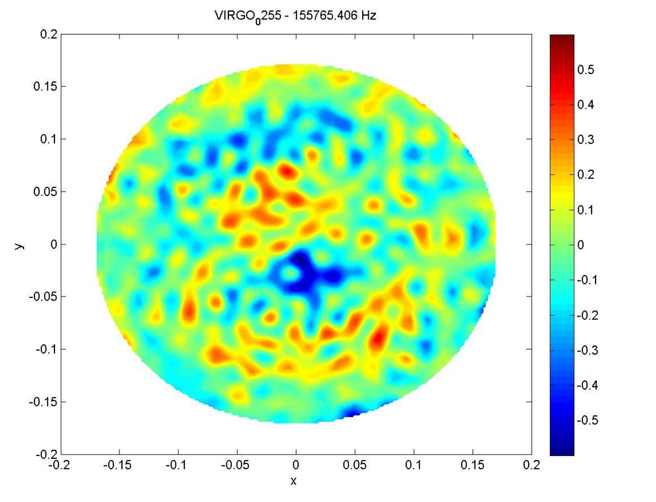


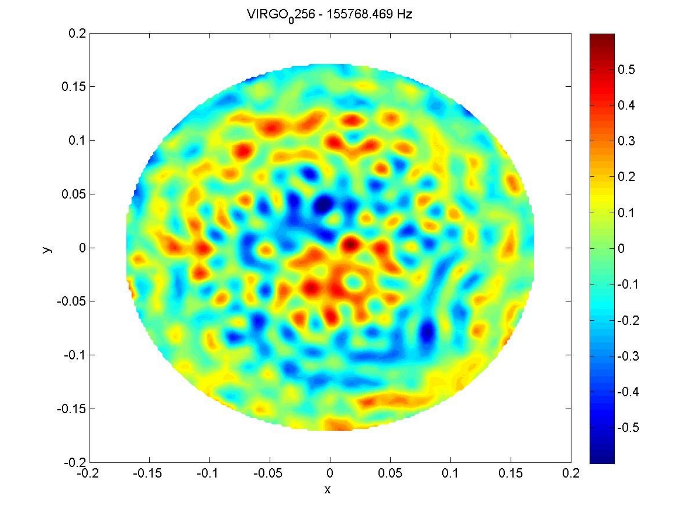
- **MECHANICAL FEM DEVELOPED.**
  - 8500 MODE MAPS (0-157 KHZ).
  - FREQUENCY AGREEMENT WITHIN 1%,
  - Q INFLUENCED BY THE EARS LAYERS
  - PREDICTION HELPS TO INTERPRET THE Q MEASUREMENTS (INFLUENCED ALSO BY THE VIOLINS)
  - MAPS USEFUL TO IDENTIFY THE CRITICAL MODES.

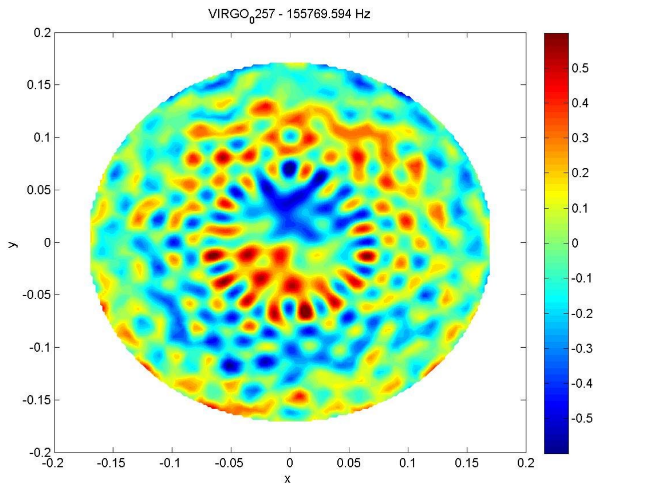
- **OPTICAL SIMULATION**
  - AGREEMENT BETWEEN THE DIFFERENT SIMULATION MODELS (ANALYTICAL, FINESSE).
  - TWO WAYS OF COMPUTING THE OPTICAL MODES WITH THE INFINITE AND FINITE SIZE MIRROR → THE GAIN COMPUTATION IS MORE AFFECTED IF THE HIGH ORDER MODES MUST BE INVOLVED

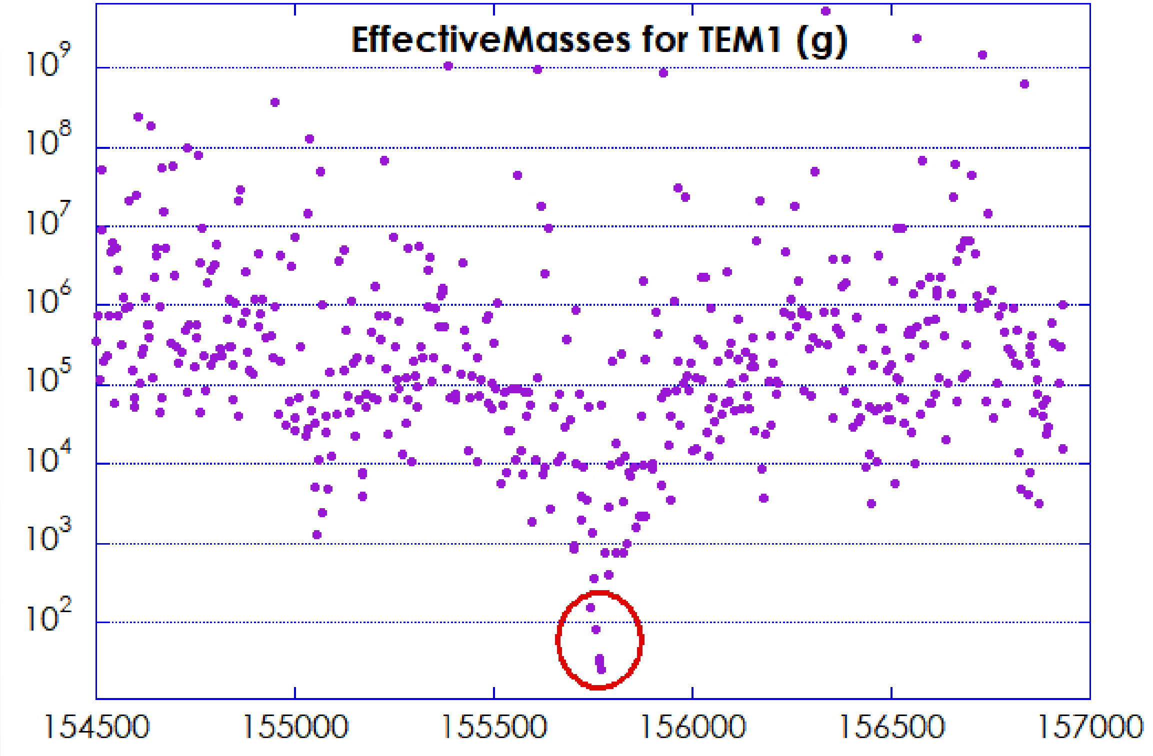
SELECTION OF THE MODES











ANSYS mechanical simulations have been performed to compute all the mechanical modes around 155 kHz, and optical simulations were run again using these mechanical maps

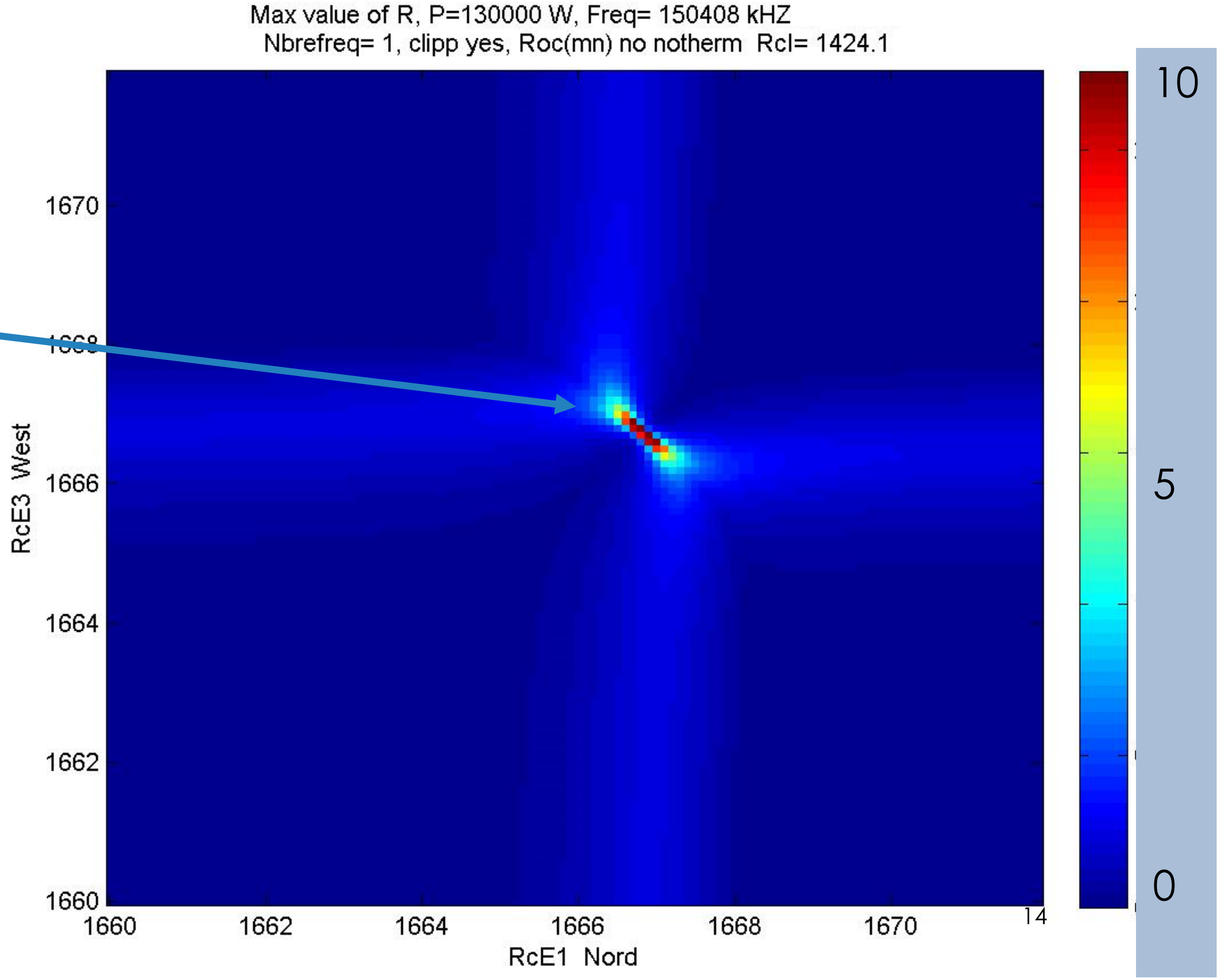
Analytical and Finesse PI give a pretty good overlap.

SIMULATIONS

FOR EACH MECHANICAL MODE WE CAN BUILD A MAP OF RCE WEST VS RCE NORTH AND FIND A POSSIBLE INSTABILITY AROUND THE GOUY PHASE VALUE OF OUR CAVITIES.

AT THIS POINT THE THE GAIN VALUE R DEPENDS ALSO ON THE SPATIAL OVERLAP BETWEEN THE OPTICAL TMS AND THE MECHANICAL MODES.

HERE THE CASE OF OUR PI, SUPPOSING AN OVERLAP OF 2 AS A STARTING CONDITION.

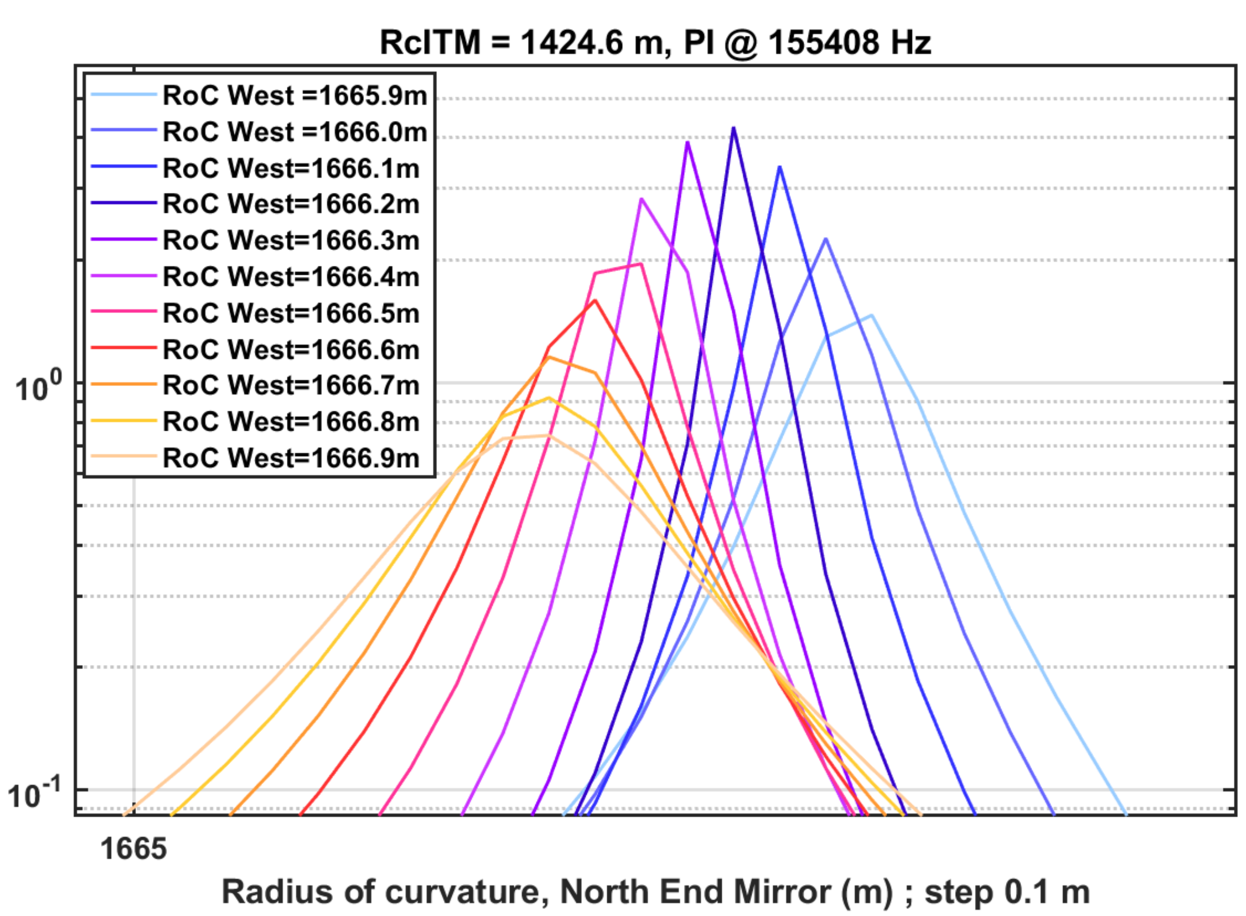


Credits: G. Bogaert

SIMULATIONS: HOW THE GAIN CHANGES WITH THE RCE VALUE

- THE PARAMETRIC GAIN CHANGES VERY FAST WITH THE ROC: A ROC VARIATION OF 1M CAN GIVE RISE/DAMP AN INSTABILITY

→ THIS CAN BE USEFUL ALSO FOR A FUTURE PERSPECTIVE, AS DAMPING HIGH FREQUENCY INSTABILITY CAN BE PERFORMED BY SLIGHTLY CHANGING THE TEMPERATURE OF THE TEST MASS.



Credits: G. Bogaert

CONCLUSIONS AND FUTURE PERSPECTIVES

- IN ADVANCED VIRGO WE OBSERVED THE FIRST PARAMETRIC INSTABILITY AT 155KHZ
- IT WAS CURED BY SLIGHTLY TUNING THE CAVITY GOUY PHASE BY CHANGING THE ETMS RING HEATER WORKING POINT
- THE SIMULATIONS PERFOMED CONFIRM THAT A PI CAN ARISE AROUND THAT FREQUENCY.

FUTURE PERSPECTIVE

- ➢ WORK IS ONGOING TO IDENTIFY POSSIBLE INSTABILITIES UP TO 200 KHZ FOR O4 AND O5
- ➢ HIGH FREQUENCY INSTABILITIES CAN BE DAMPED BY SLIGHTLY TUNING THE RING HEATER WORKING POINT OR, NOT TO SPOIL THE CONTRAST DEFECT, BY CHANGING THE TEST MASS TEMPERATURE WITH SUITABLE HEATING SYSTEMS (HEATING BELTS AROUND THE TOWERS).
- ➢ USING DAMPERS FOR THE LOW FREQUENCY RANGE: PROBABLY NOT NEEDED BECAUSE OF THE LOW Q DUE TO THE PARTICULAR SHAPE OF THE EARS IN ADV.
- ➢ USING DAMPERS FOR THE HIGH FREQUENCY RANGE WILL TAKEN INTO ACCOUNT ESPECIALLY IN O4 AND O5 WHERE HIGH POWER IN THE ARMS ARE FORESEEN