Input mirrors thermal lensing effect
Frequency modulation
PRCL length
in Virgo

Some results from a Finesse simulation

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Overview

o The stakes

o Thermal lensing model with Finesse - PRCL length tuning

o The 2 “states” in Virgo

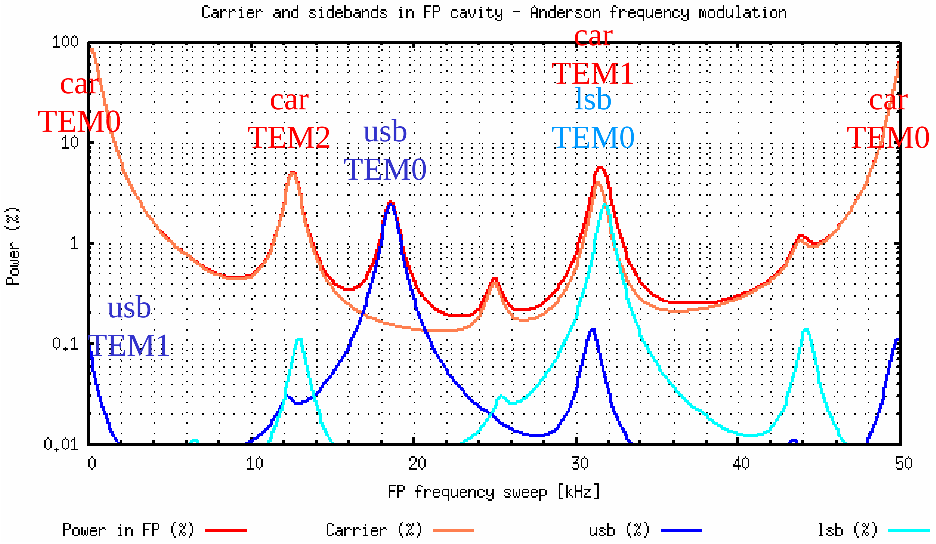
o Transient and demodulation phase change

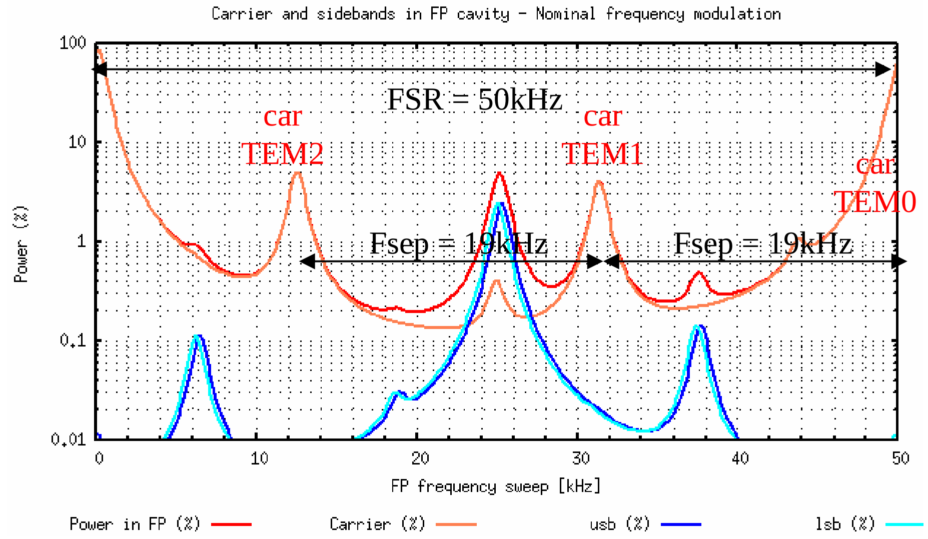
o The double cavity model – Frequency modulation dependence

The stakes

Already, many people had discussions about the advantages and drawbacks of the Anderson modulation frequency choice. This talk intends to bring some arguments on the question…

Change the modulation frequency from the “Anderson” one (6.264MHz) to the “nominal” one (6.271MHz)?





Use Ward or Anderson technique for alignment controls?

Thermal lensing effects affect longitudinal controls in a different way depending on the modulation frequency choice?

Optimal PRCL macroscopic length is tricky in the case of the Anderson modulation frequency?

Thermal lensing model with Finesse & PRCL length tuning

The Finesse simulation

Thermal lensing model:

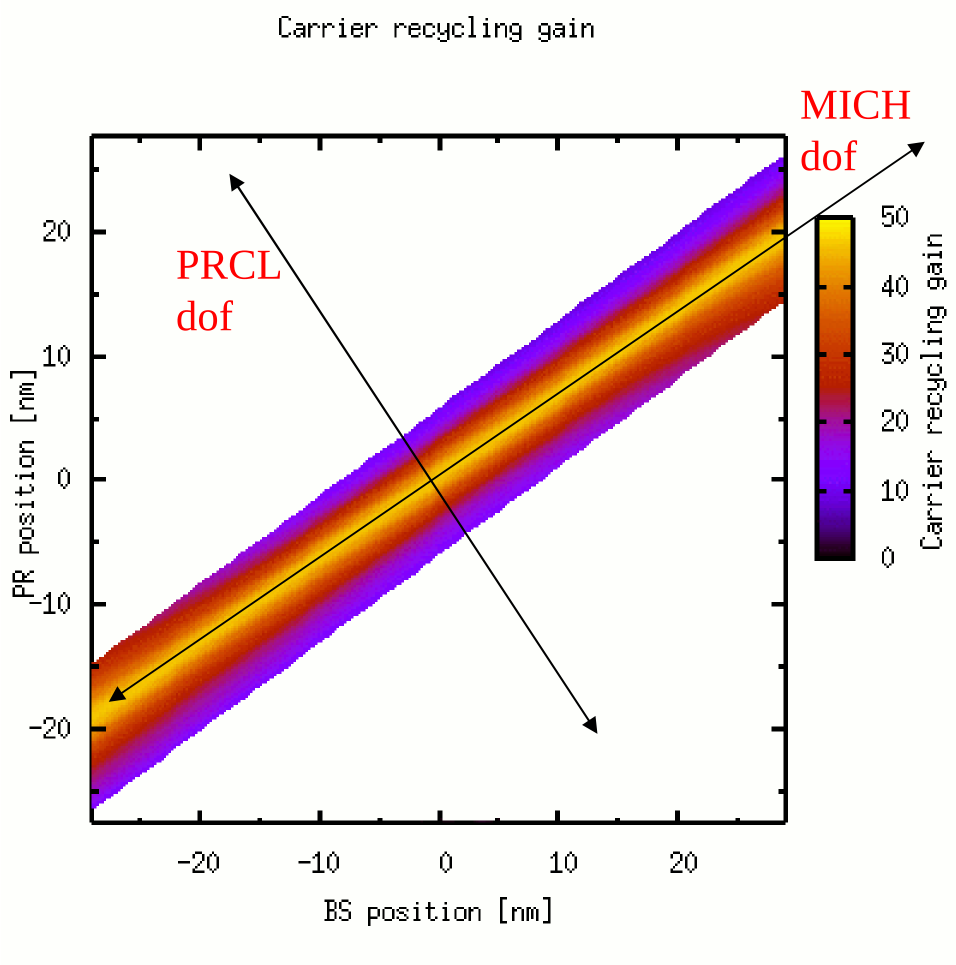
Based on the simple idea of inserting a thin lens in the substrates of the input mirrors of the Fabry-Perot cavities. Focal length is directly proportional to the inverse of the power absorbed by the mirror.

The model takes also into account the asymmetry of absorption between the 2 Fabry-Perot cavities (deduced from Michele Punturo mirror temperature measurement) and the slight expansion of the mirrors due to the temperature increase.

Next results assume that:

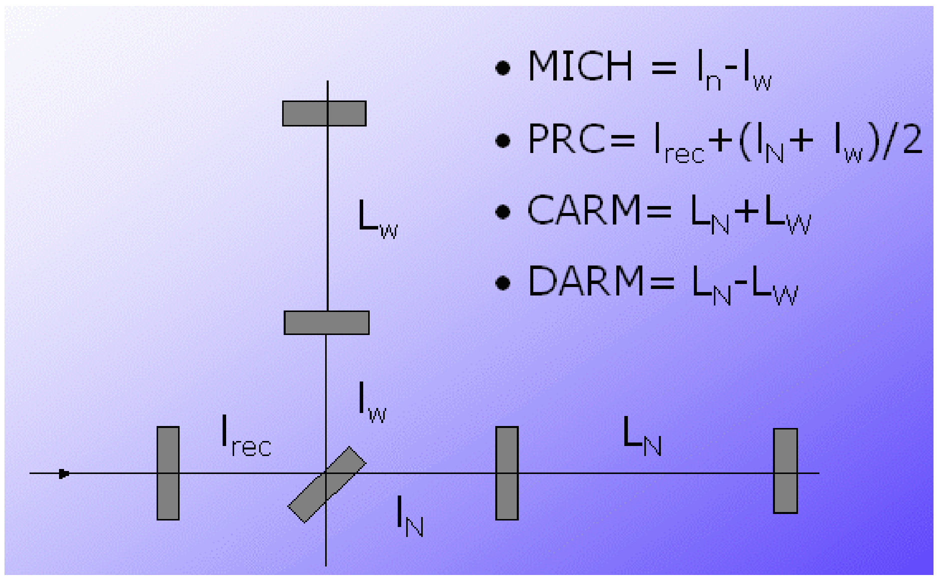
o Computation is done by projecting optical fields on a Hermite-Gauss basis (maximum order for higher order TEM modes = 6)
o CARM and DARM dof are locked with usual error signals B5_ACp and B1_ACp.
o MICH and PRCL dof are not locked.
o BS and PR are moved around the operating point by a few nm.
o Demodulation phases are tuned as in real conditions.

Carrier recycling gain



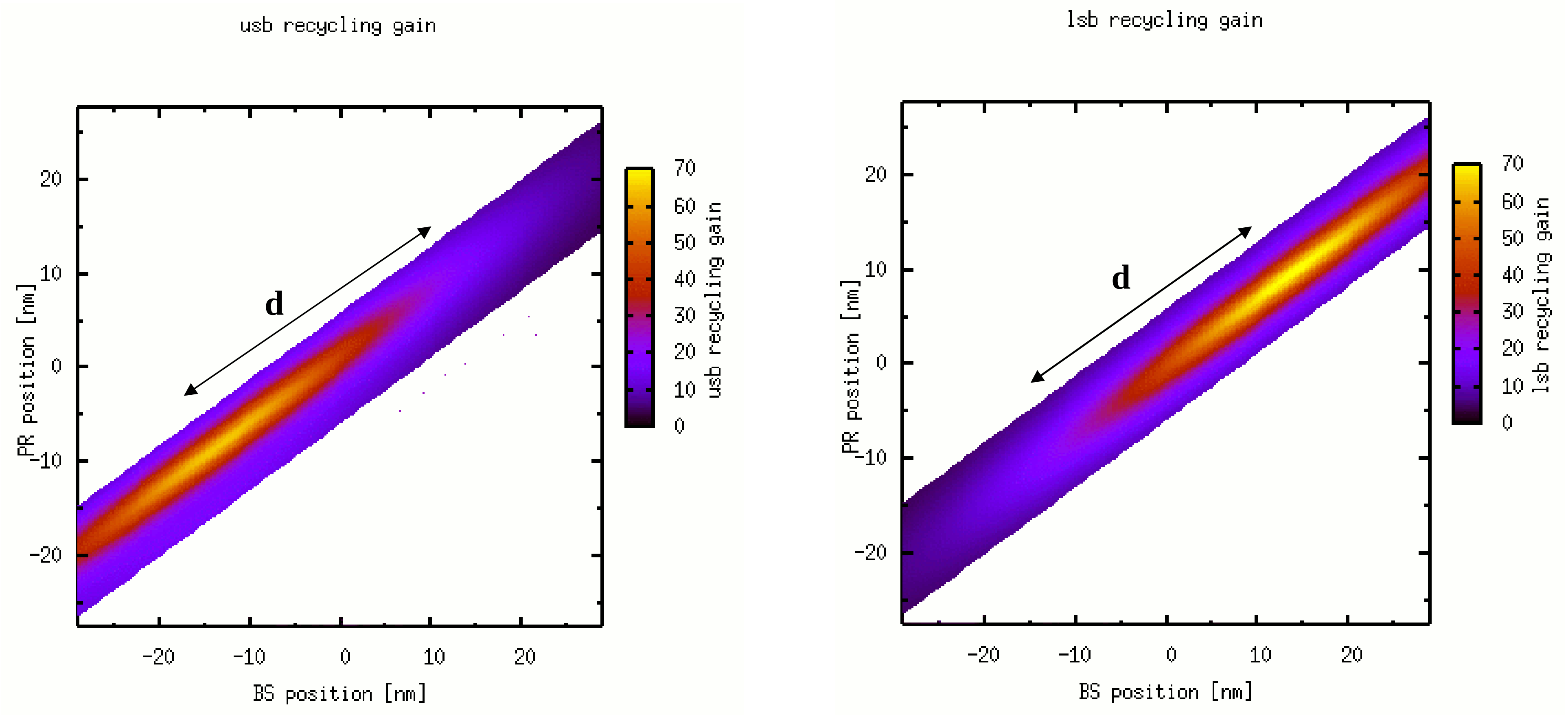
There are 3 dof in the Central ITF: lrec, ln and lw.

We are sensitive and we want to control 2 dof: MICH and PRCL.

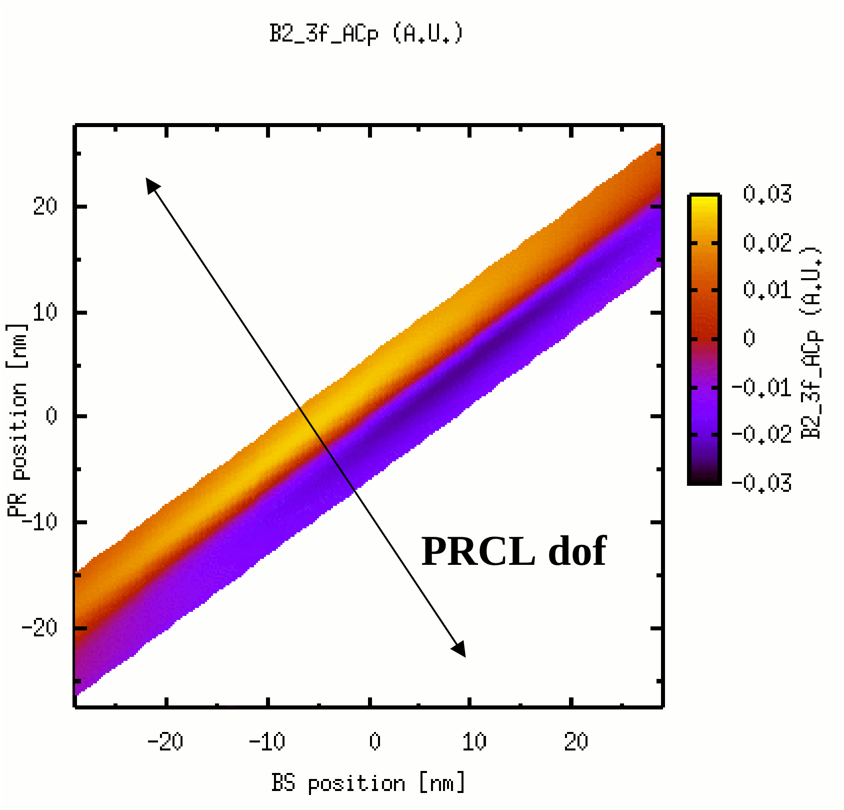


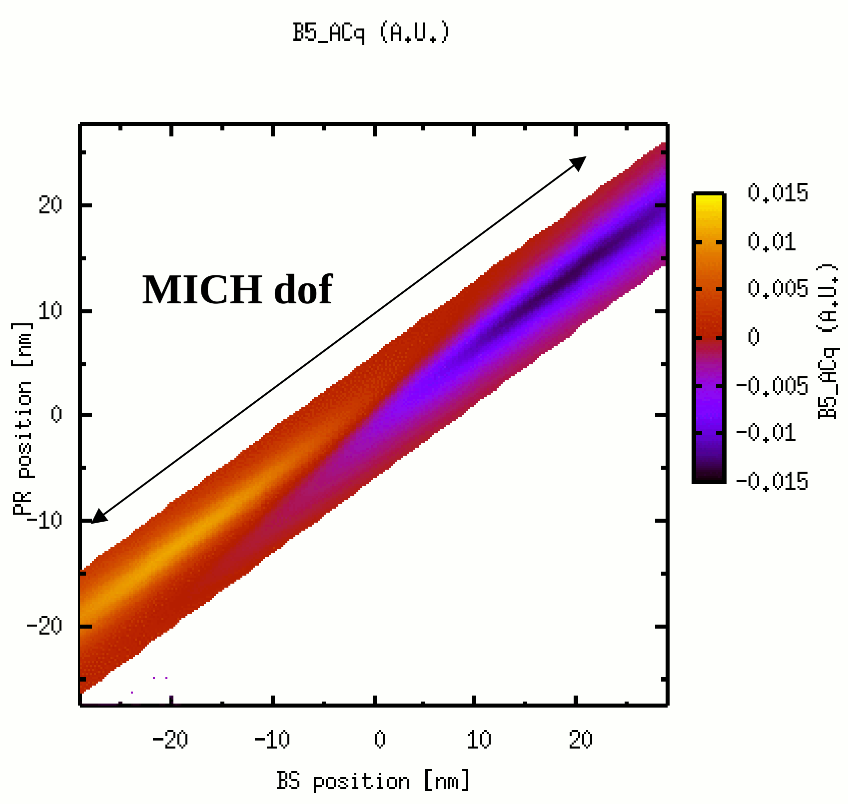
Sidebands recycling gain

Distance between the 2 maxima recycling gain of the sidebands =
d = lambda/2 * (Schnupp asymmetry / PRCL length) = 39nm (in Virgo)



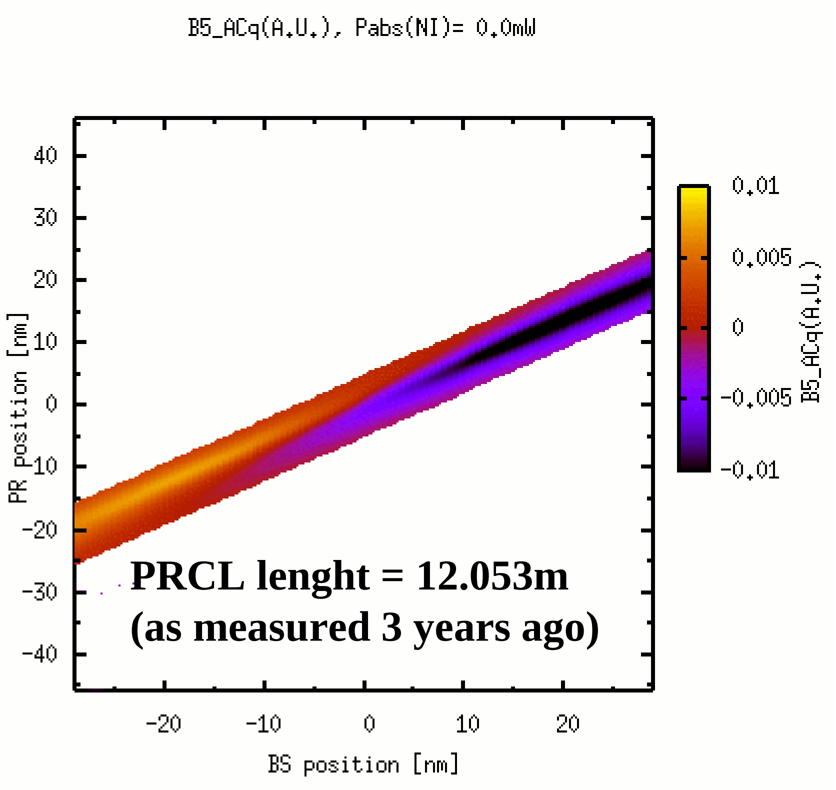
The central ITF locking error signals

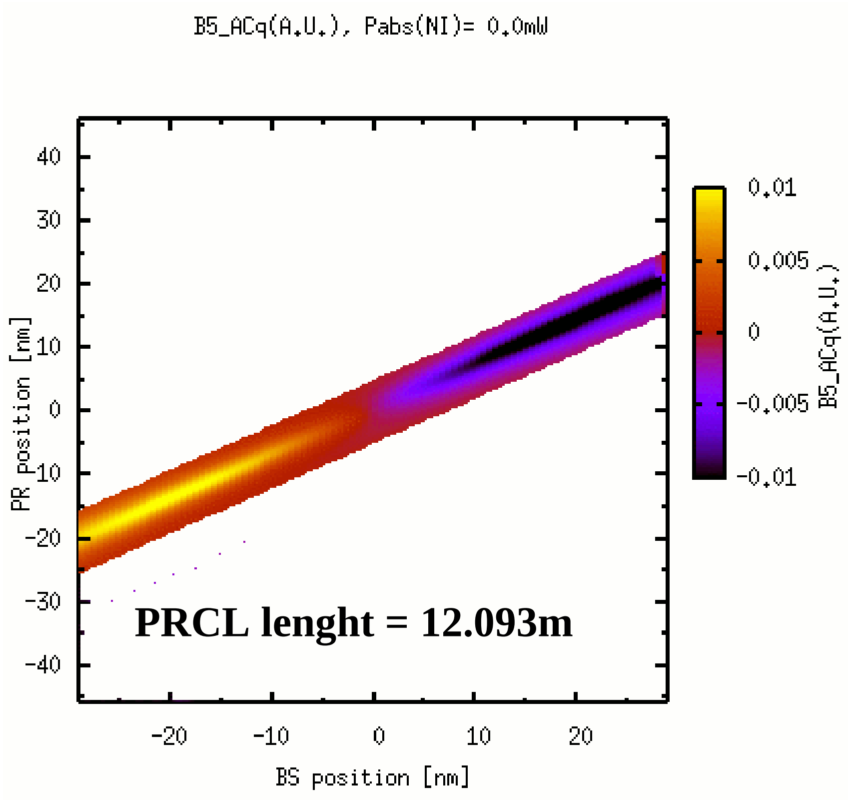




B2_3f_ACp (diode in reflection of ITF) = PRCL error signal
B5_ACq (diode on a pick up beam of the BS) = MICH error signal

MICH error signal respect to PRCL lenght





Macroscopic PRCL lenght in Virgo may be mistuned by 4cm. This could lead to couplings between MICH and PRCL dof difficult to handle…

PRCL length general discussion

These 4cm discrepancy can be explained by 2 reasons:

1) When the PR mirror was changed 2 years ago, the change of payload shifted the mirror by 2cm towards the BS.

2) 12.06-12.07m is the optimal length when one makes the analytical computation (depending a bit on the length of the FP and on the modution of frequency) and that is verified by the simulation when using perfect gaussian beams. But using more higher order modes (6) in the simulation lead to 12.093m …

One has to emphasize that the optimal PRCL length depends also on the phase in reflection of the FP cavities particularly in Virgo! This is true because of the "Anderson" frequency choice.

In the case we would have chosen the "nominal" frequency of modulation, the phase in reflection of the FP cavities would not depend on the modulation frequency itself, on the macroscopic length of the FP cavities, on the finesse of the FP cavities, mode matching, …

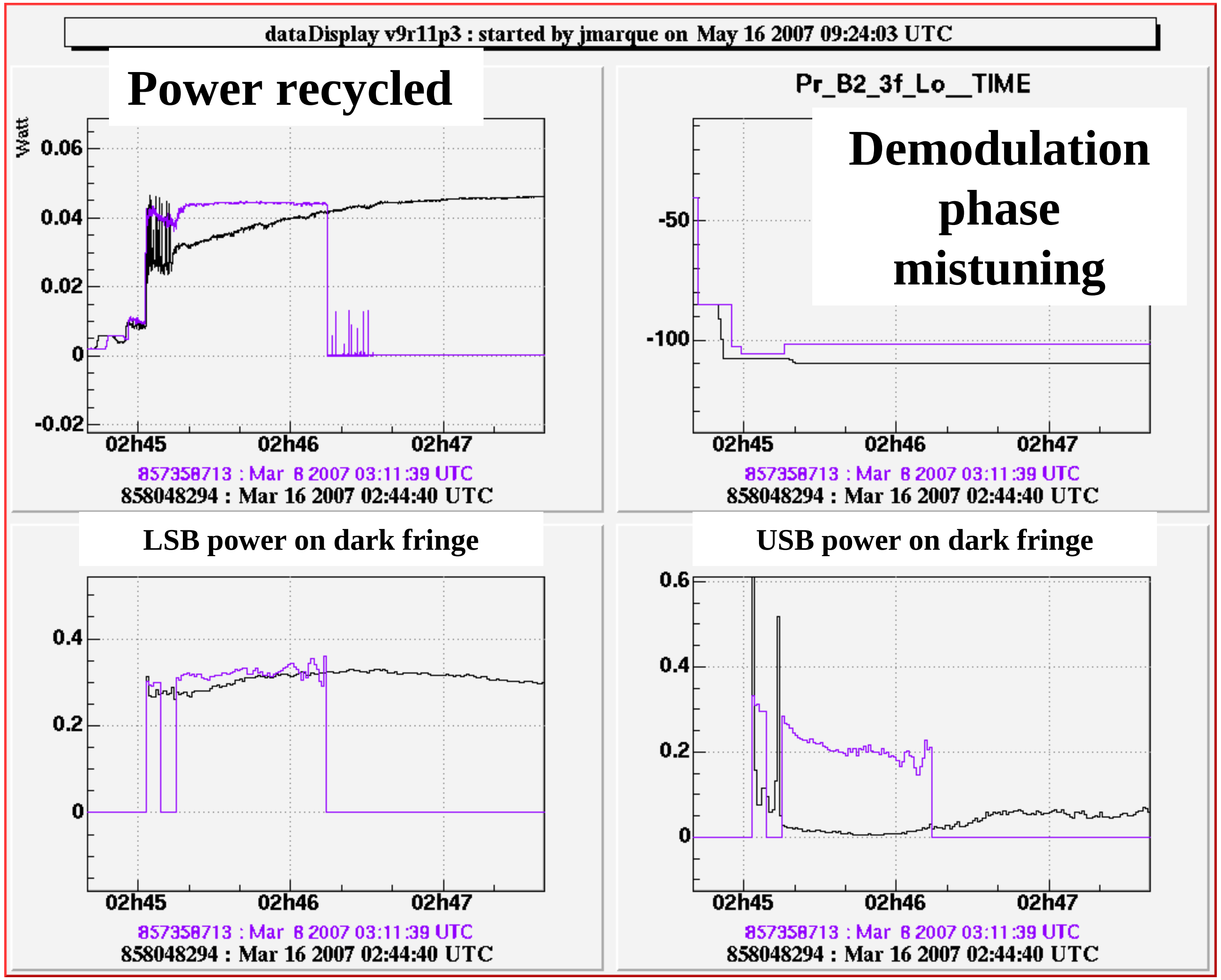
Examples:

1) If we decide to change the FP Finesse from 50 to 150, optimal PRCL length is then 12.00-12.01m (analytical computation).

2) If we change the frequency modulation by 600Hz, optimal PRCL length is lower by 1cm…

The 2 “states” of Virgo

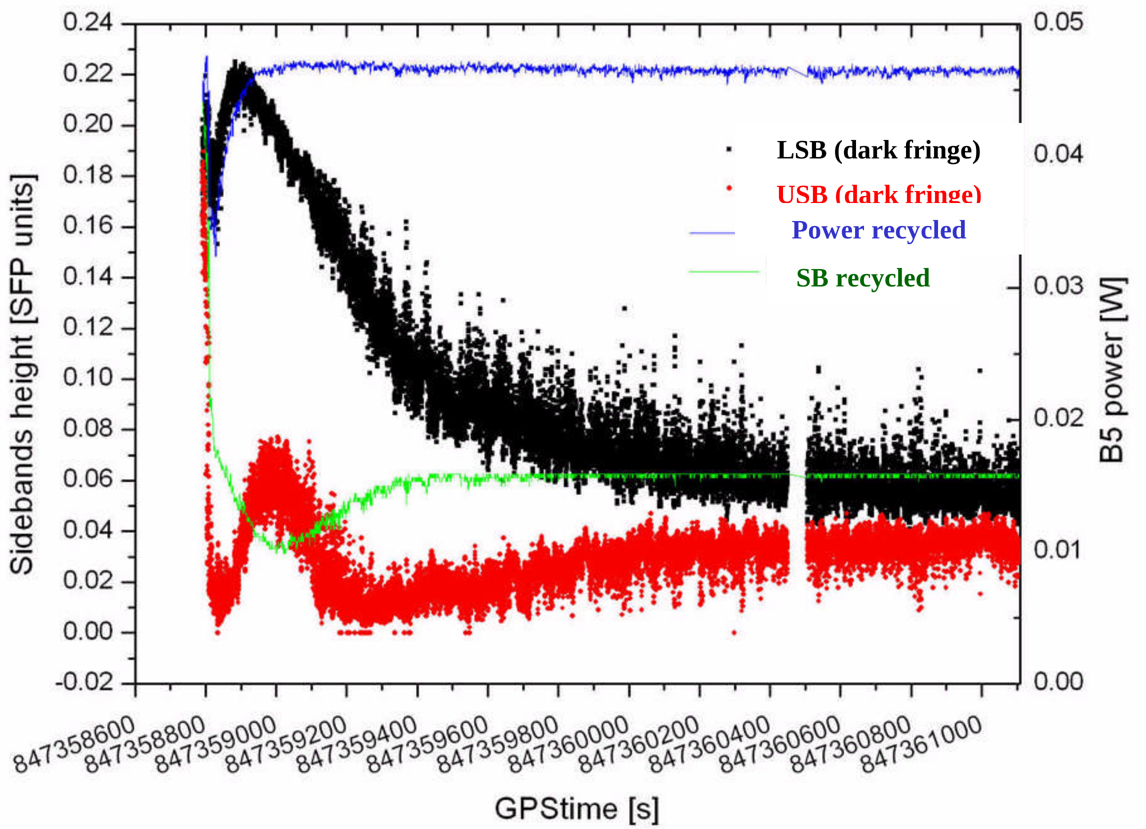
The 2 “states” & how to jump from one to another



The ITF can jump between 2 states during the lock acquisition.

Only one allows us to keep the lock…

Carrier & Sidebands evolution during thermal transient



One hour of thermal transient can be seen in the signals

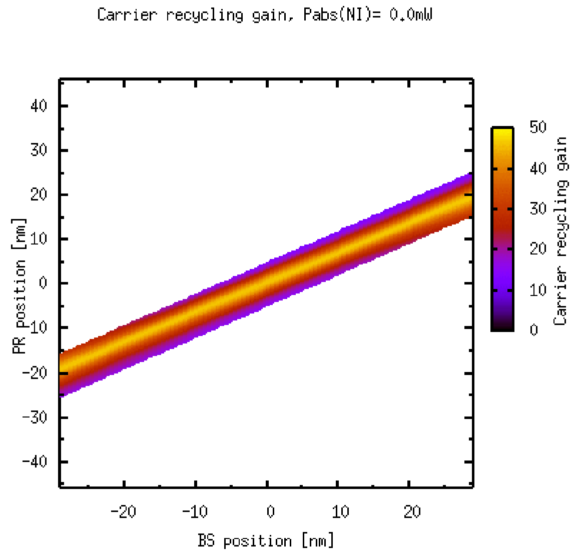
Some numbers about thermal lensing in Virgo:

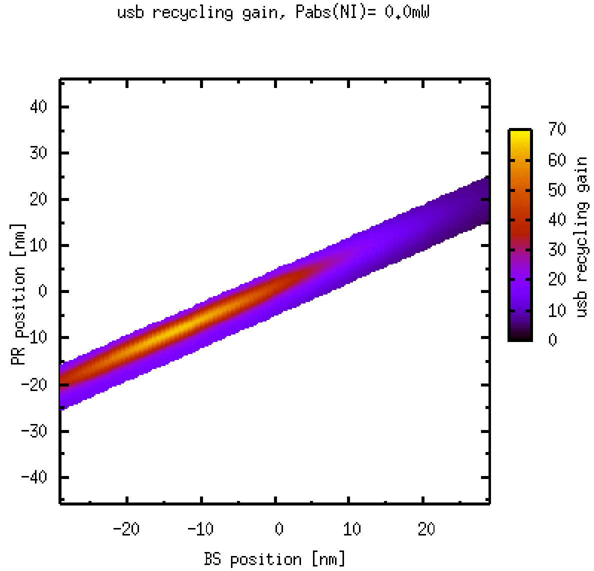
300W in recycling cavity, input mirror substrate 10cm long, 5kW in FP cavities

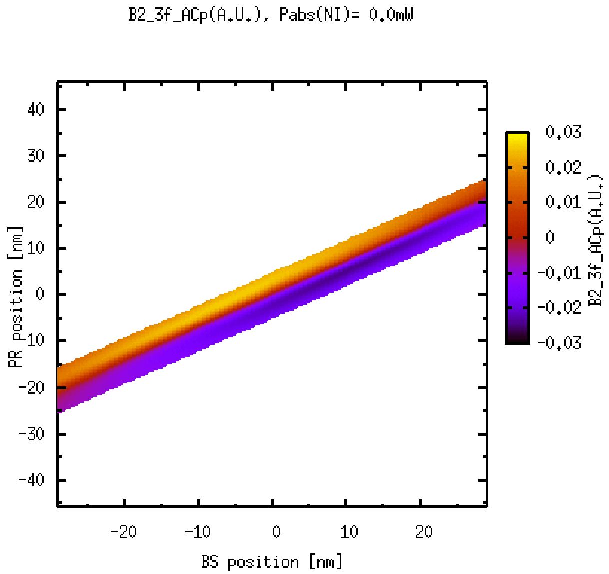
LMA absorption characterisation: 0.7ppm/cm + 1.2 ppm => 8mW absorbed

Mirror temperature measurement (drum mode frequency shift) => 4 to 6 times more

EVOLUTION with thermal lensing

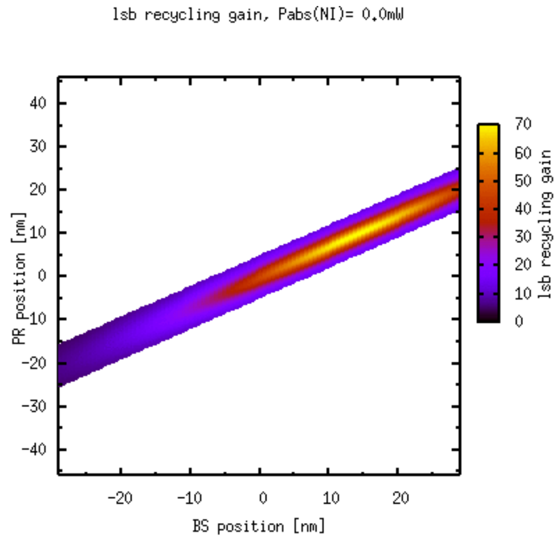


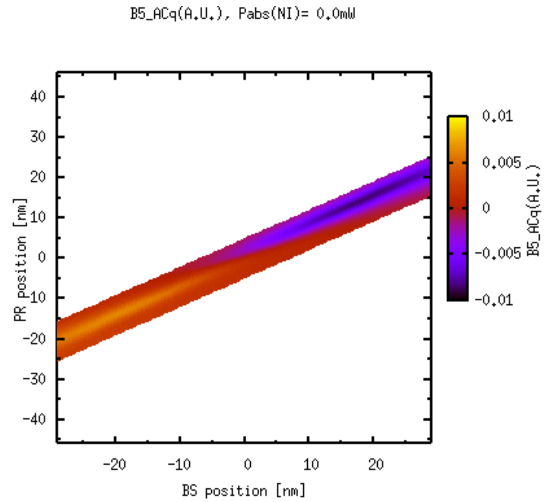




Around 10mW absorption, transition from one to two zones of resonances => 2 operating points for the ITF.

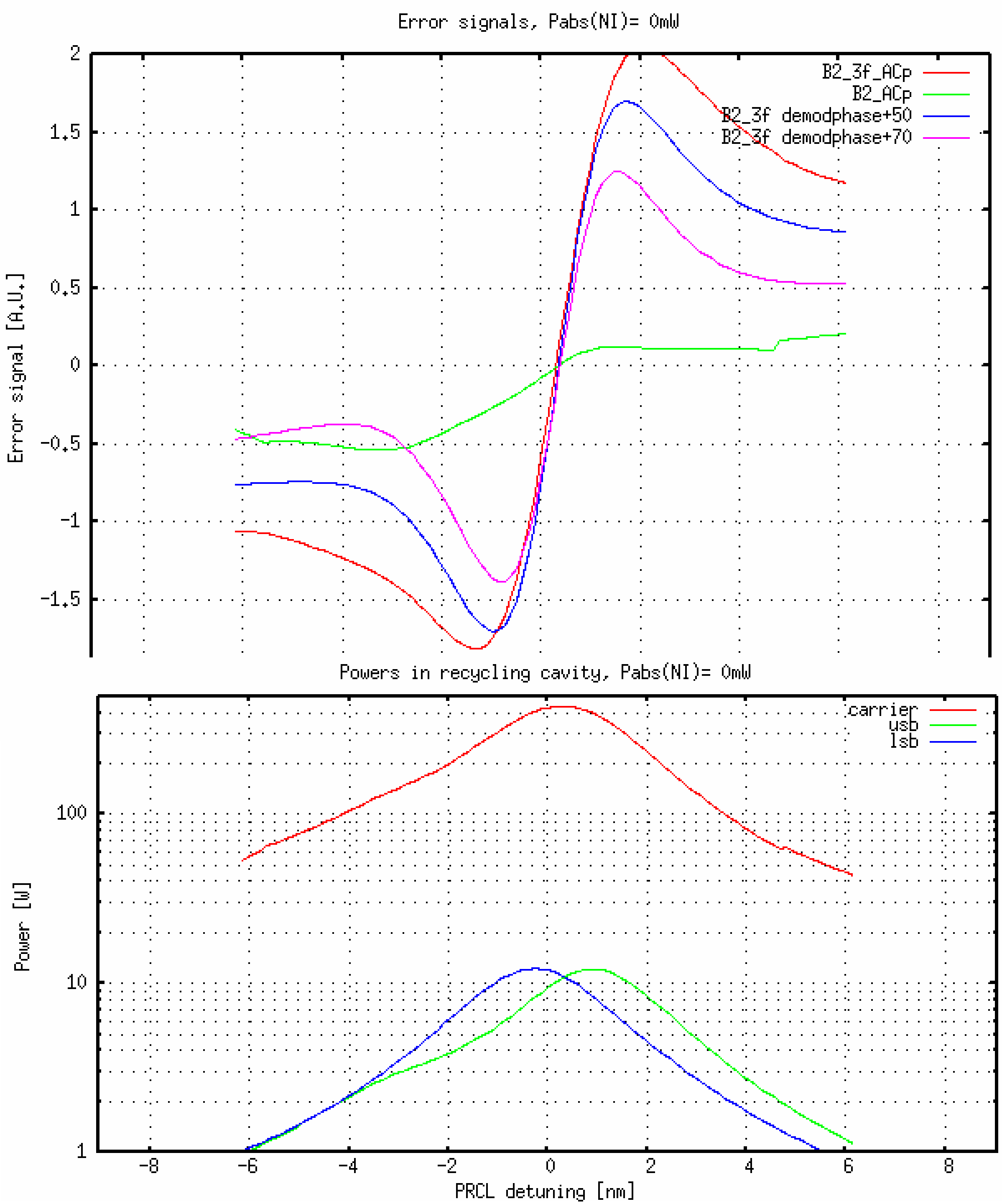
Error signals look good for both operating points.





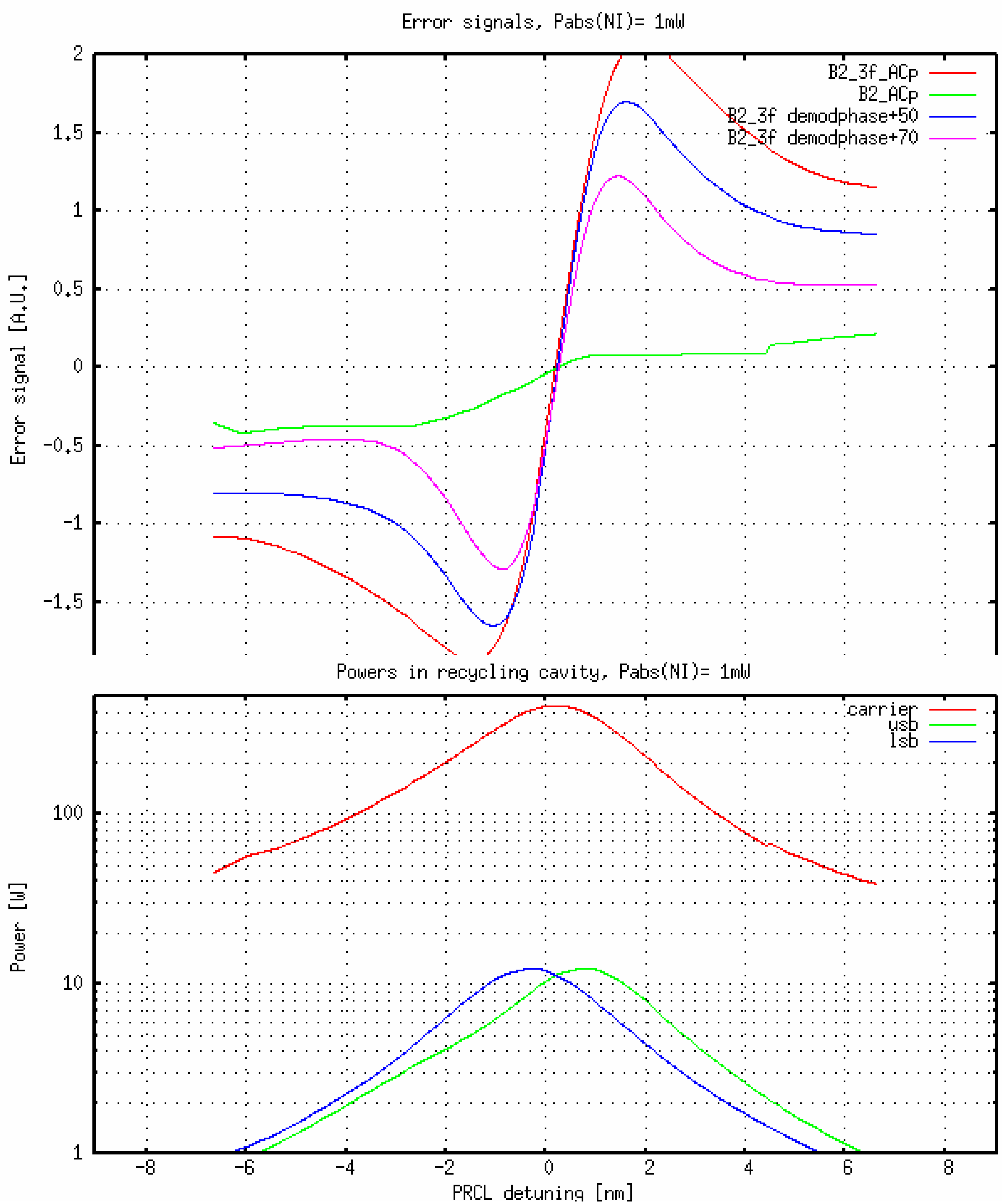
Transient and demodulation phase change

0

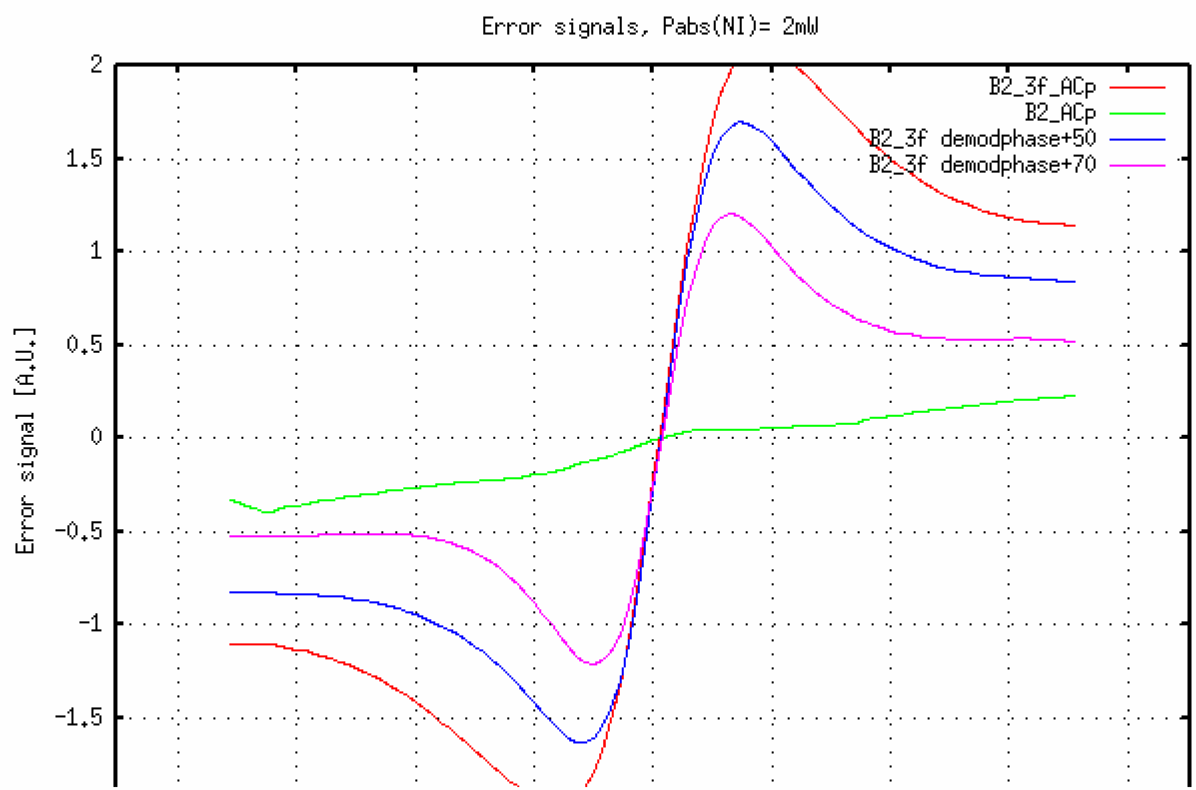


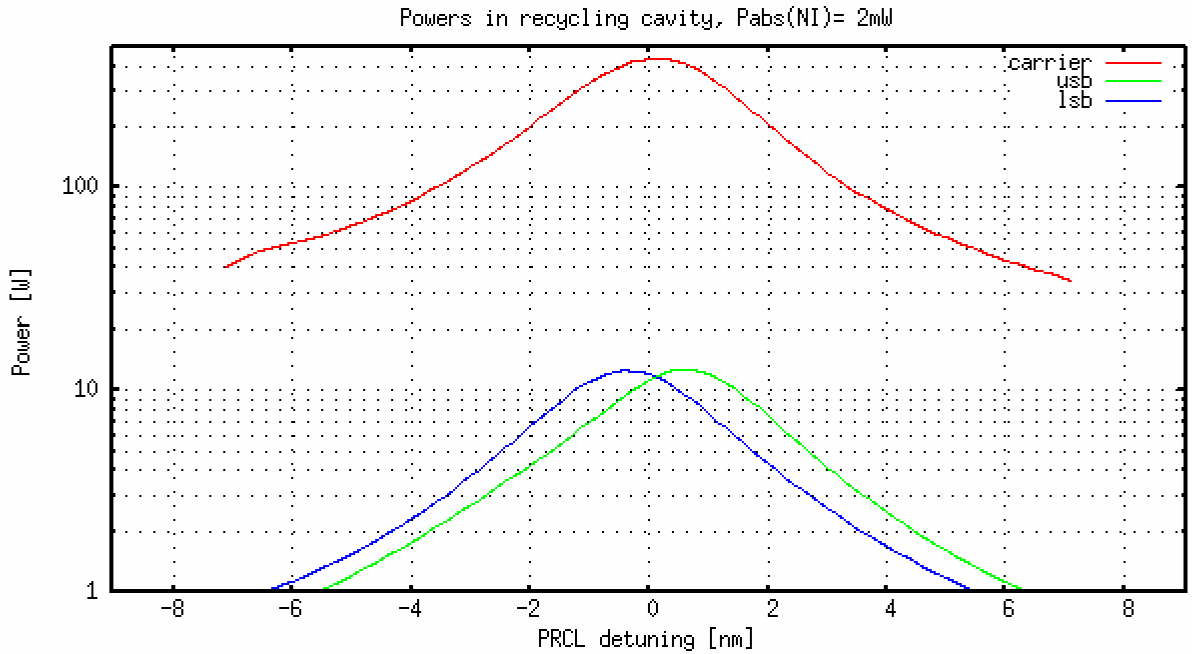
No thermal lensing.
PRCL error signal is unsensitive to a mistuning of the demodulation phase.

CARM, DARM and MICH are always controlled in this simulation.

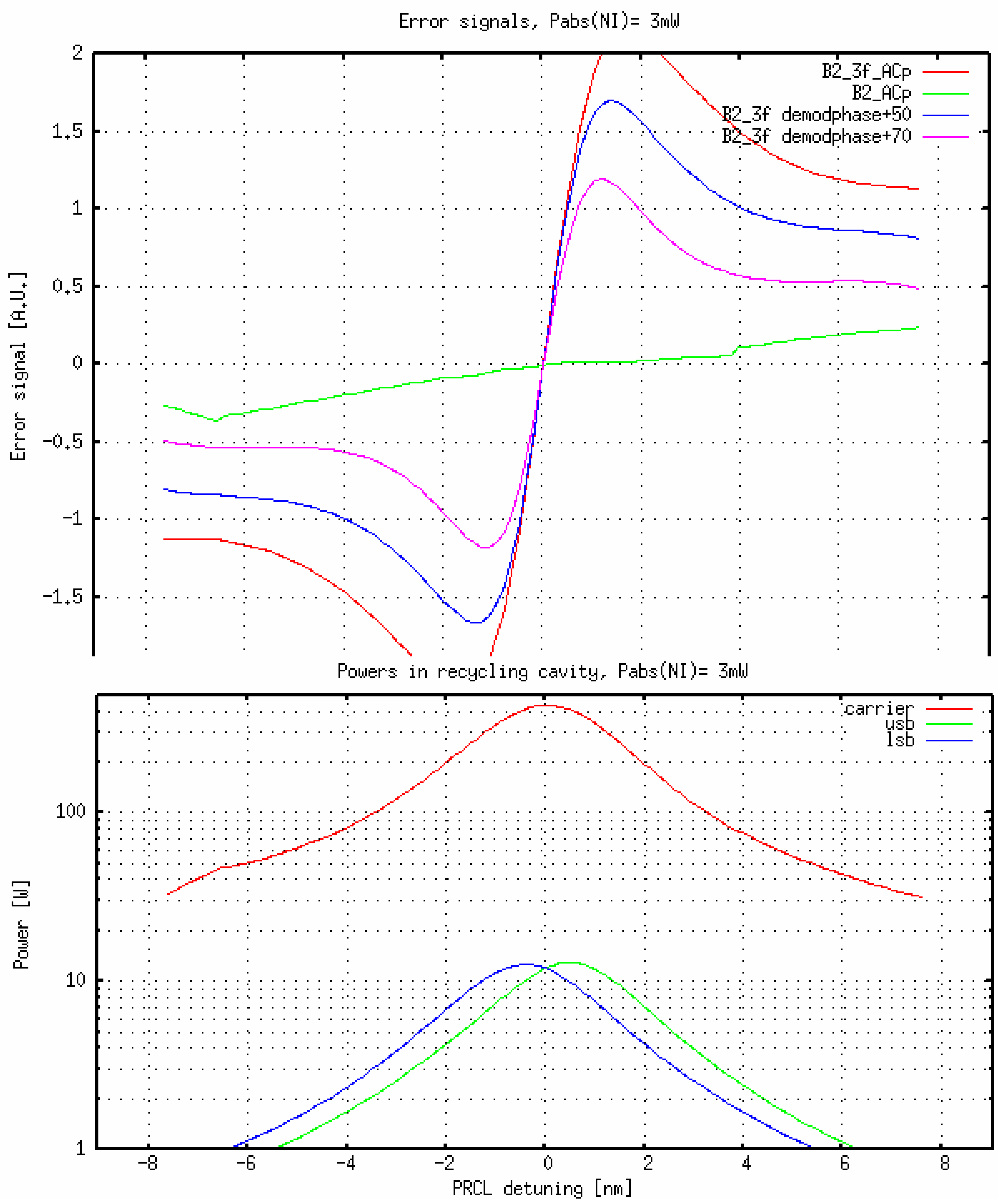


Error signals, Pabs(NI)= 1mW
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
Error signal [A.U.]
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)= 1mW
carrier
usb
lsb
Power [W]
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]


Error signals, Pabs(NI)= 2mW
Error signal [A.U.]
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
2
1.5
1
0.5
0
-0.5
-1
-1.5

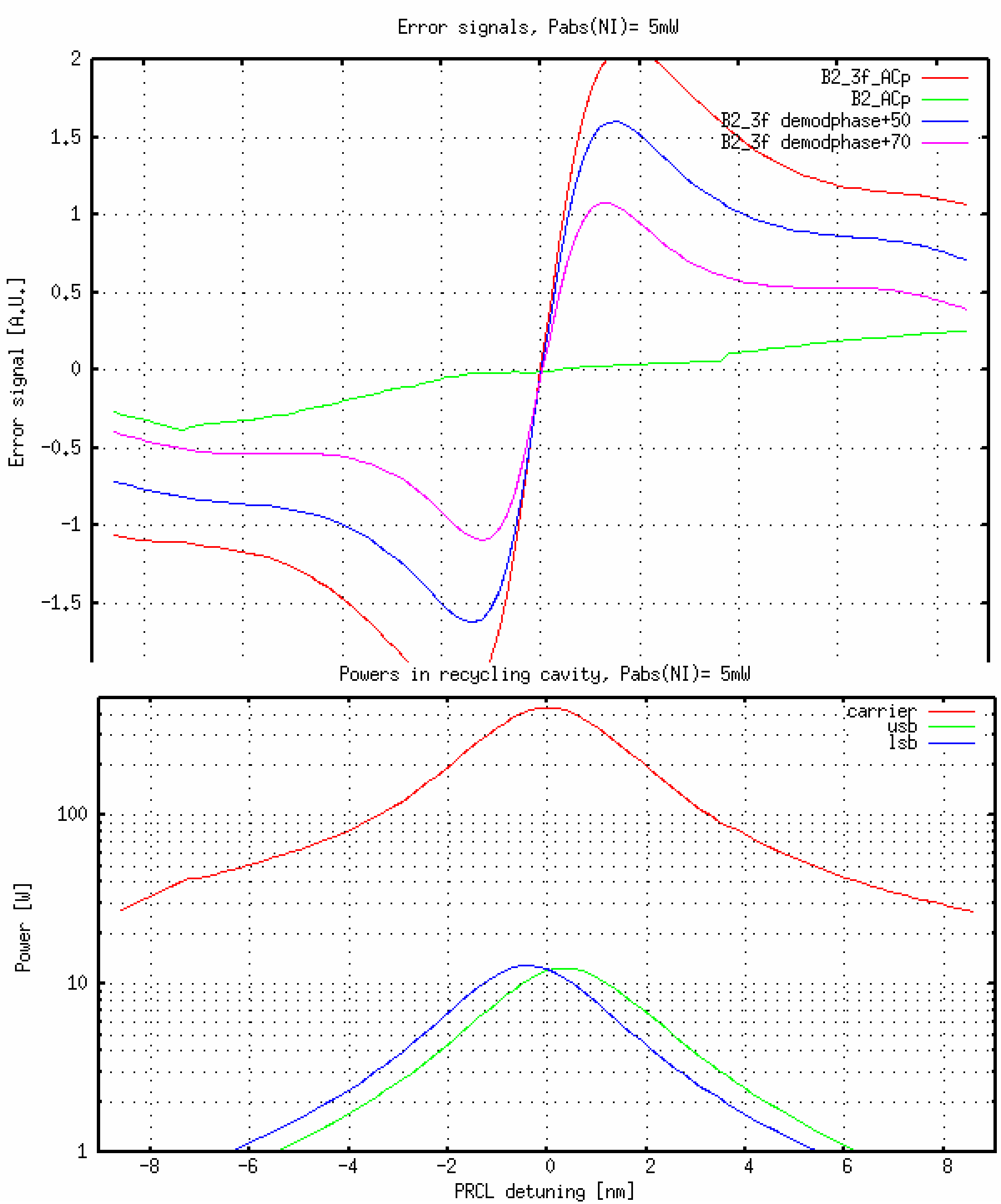

Powers in recycling cavity, Pabs(NI)= 2mW
Power [W]
PRCL detuning [nm]
carrier
usb
lsb
100
10
1
-8
-6
-4
-2
0
2
4
6
8

3

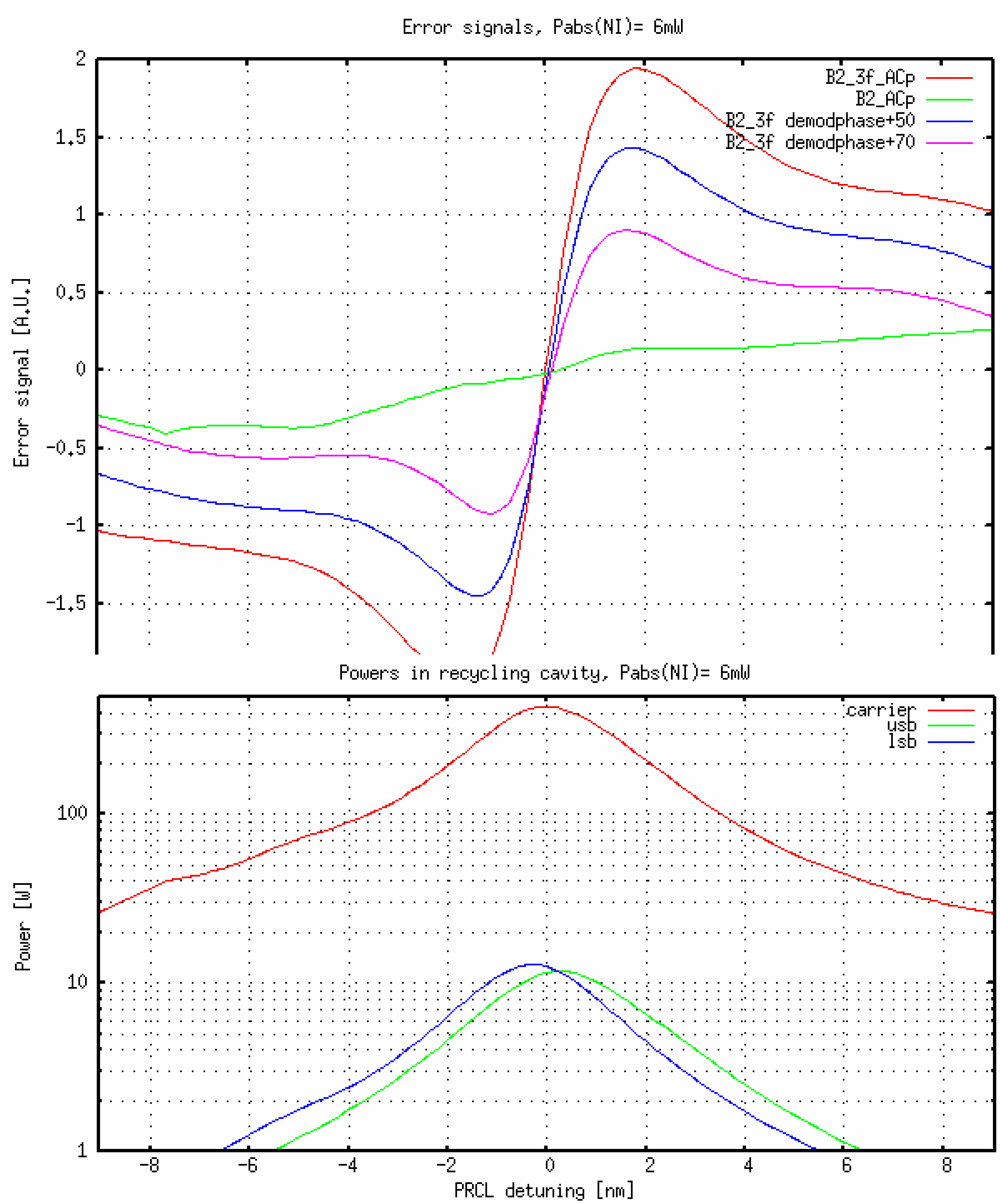


Error signals, Pabs(NI)= 3mW
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
Error signal [A.U.]
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)= 3mW
carrier
usb
lsb
Power [W]
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]

5

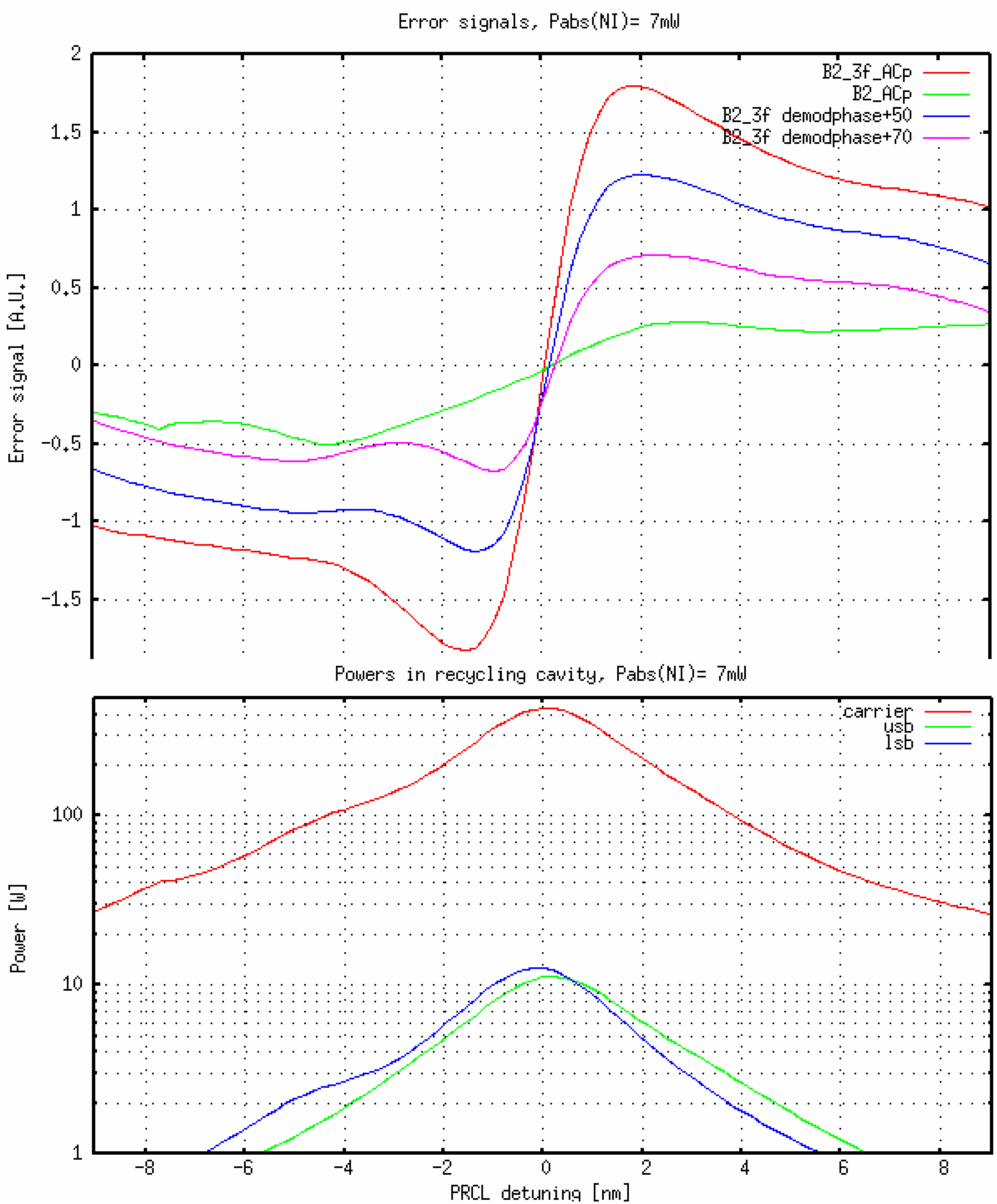

Error signals, Pabs(NI)= 5mW
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
Error signal [A.U.]
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)= 5mW
carrier
usb
lsb
Power [W]
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]

6



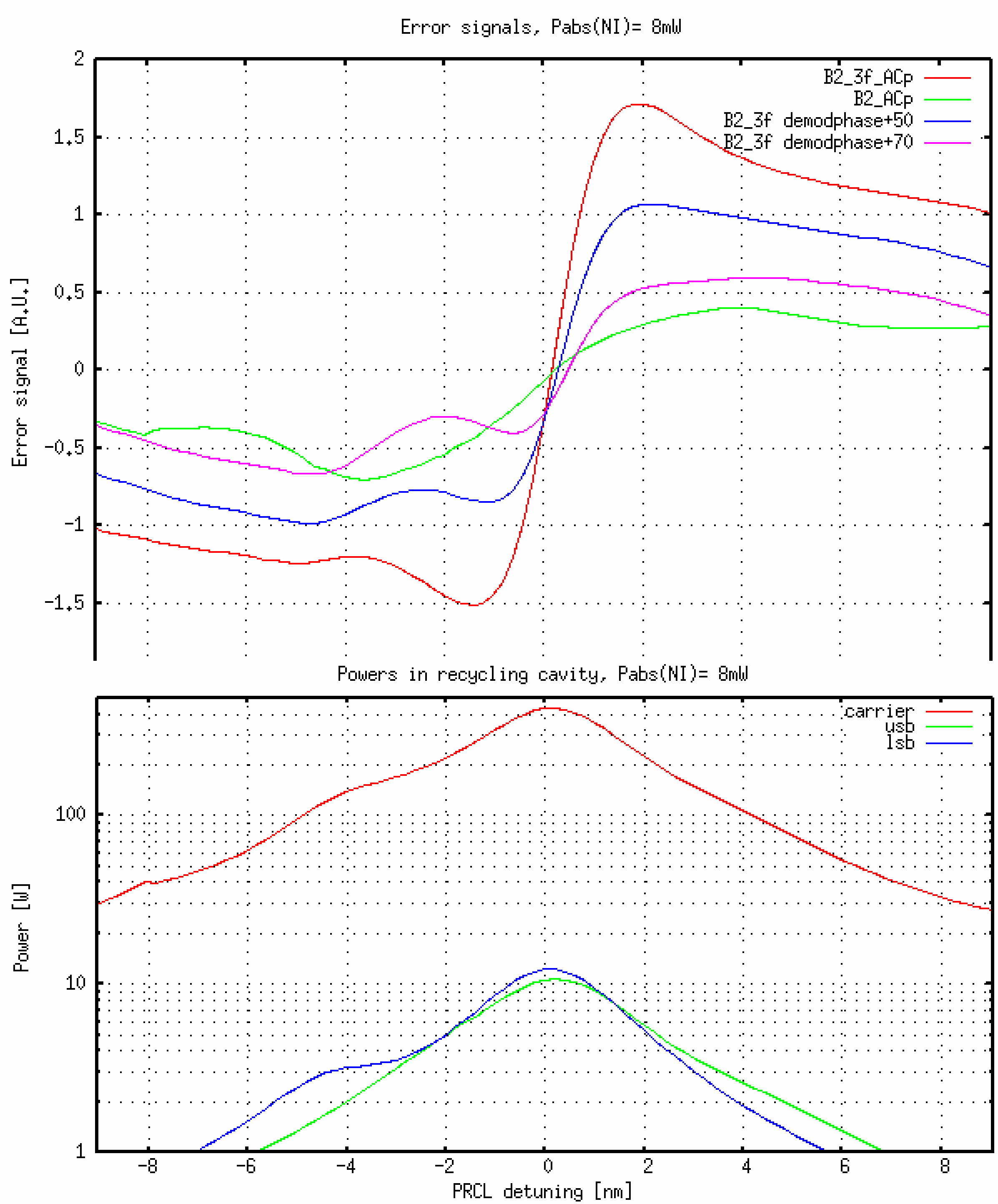
Error signals, Pabs(NI)= 6mW
Error signal [A.U.]
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)= 6mW
Power [W]
carrier
usb
lsb
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]

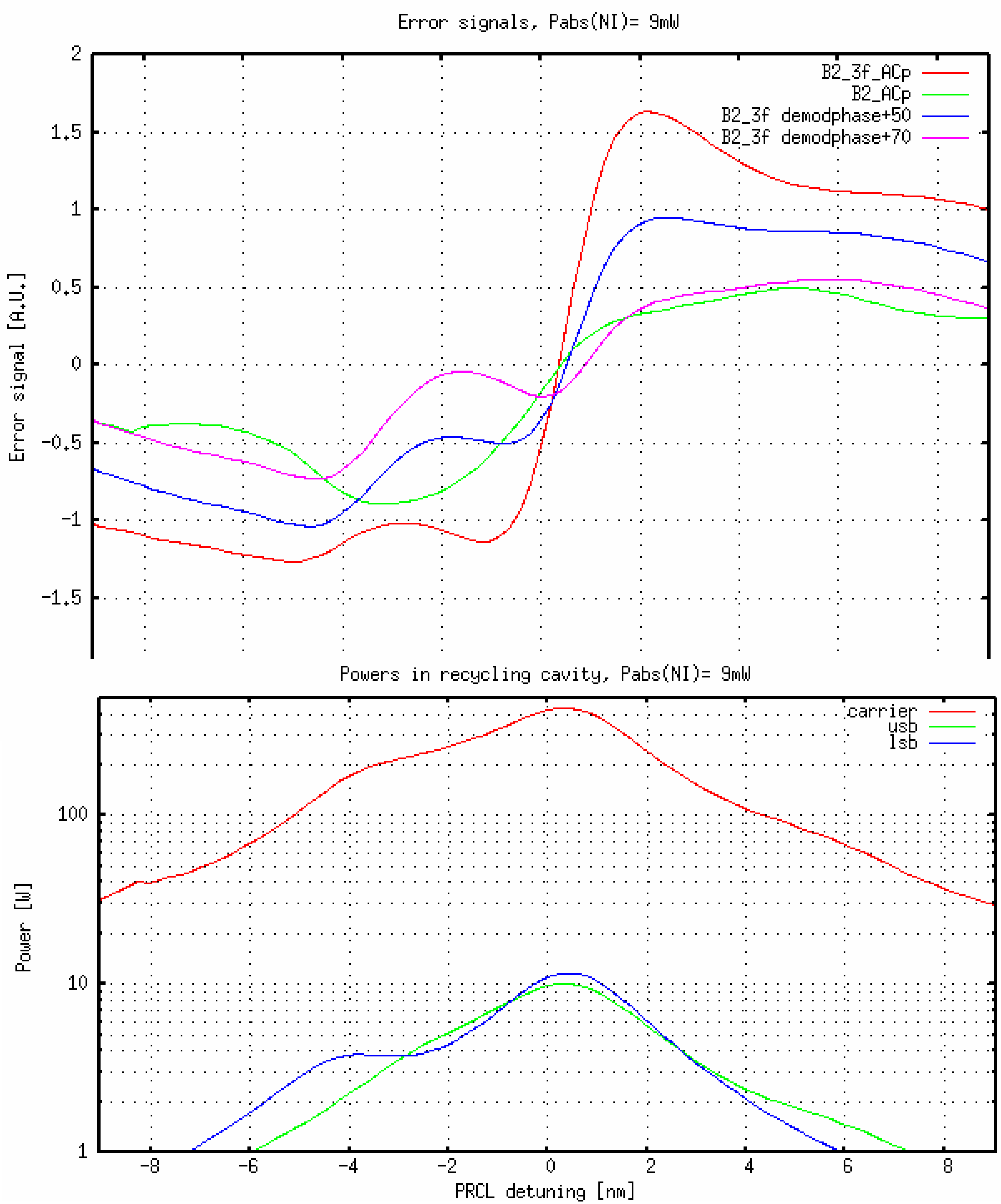
7

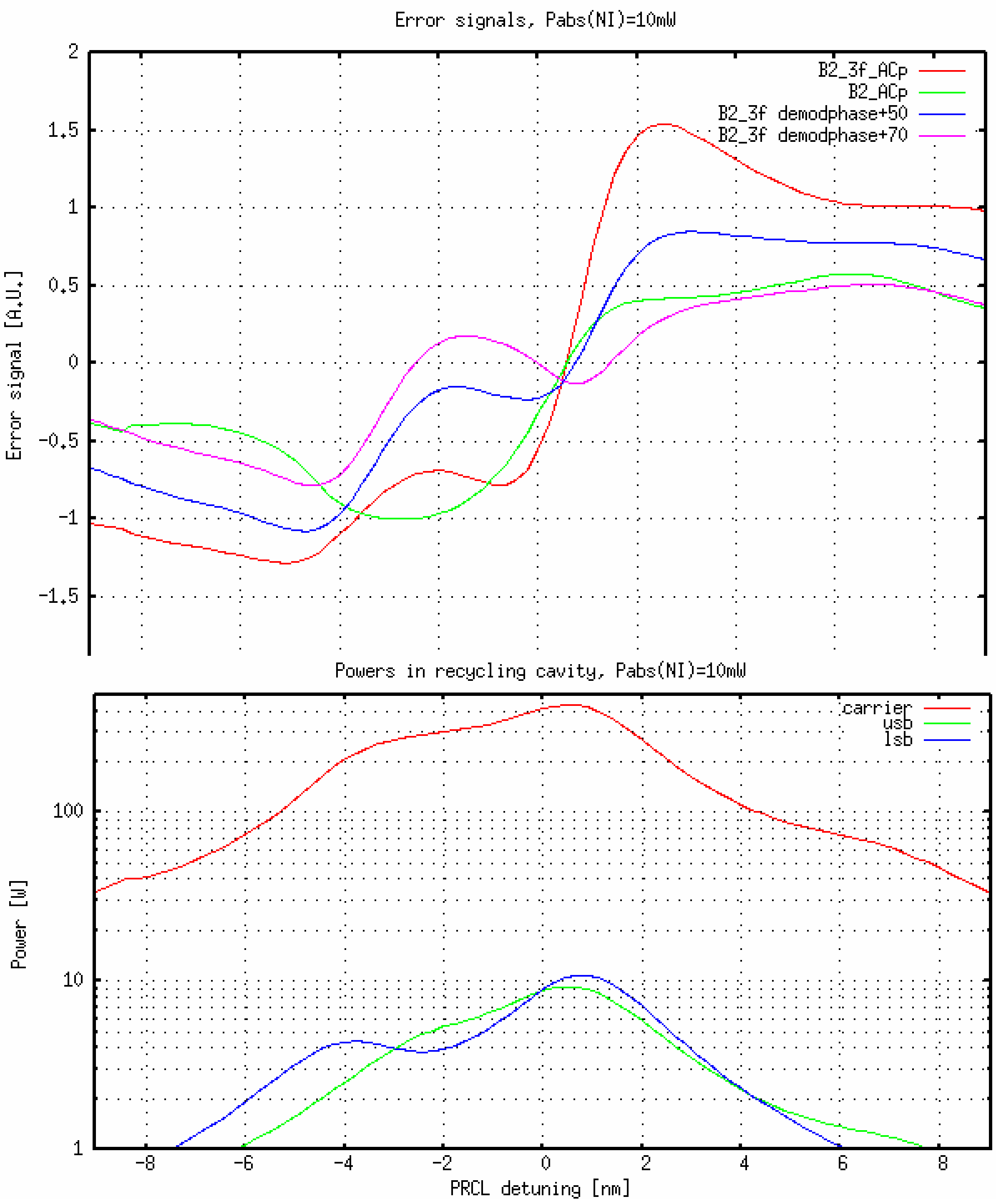


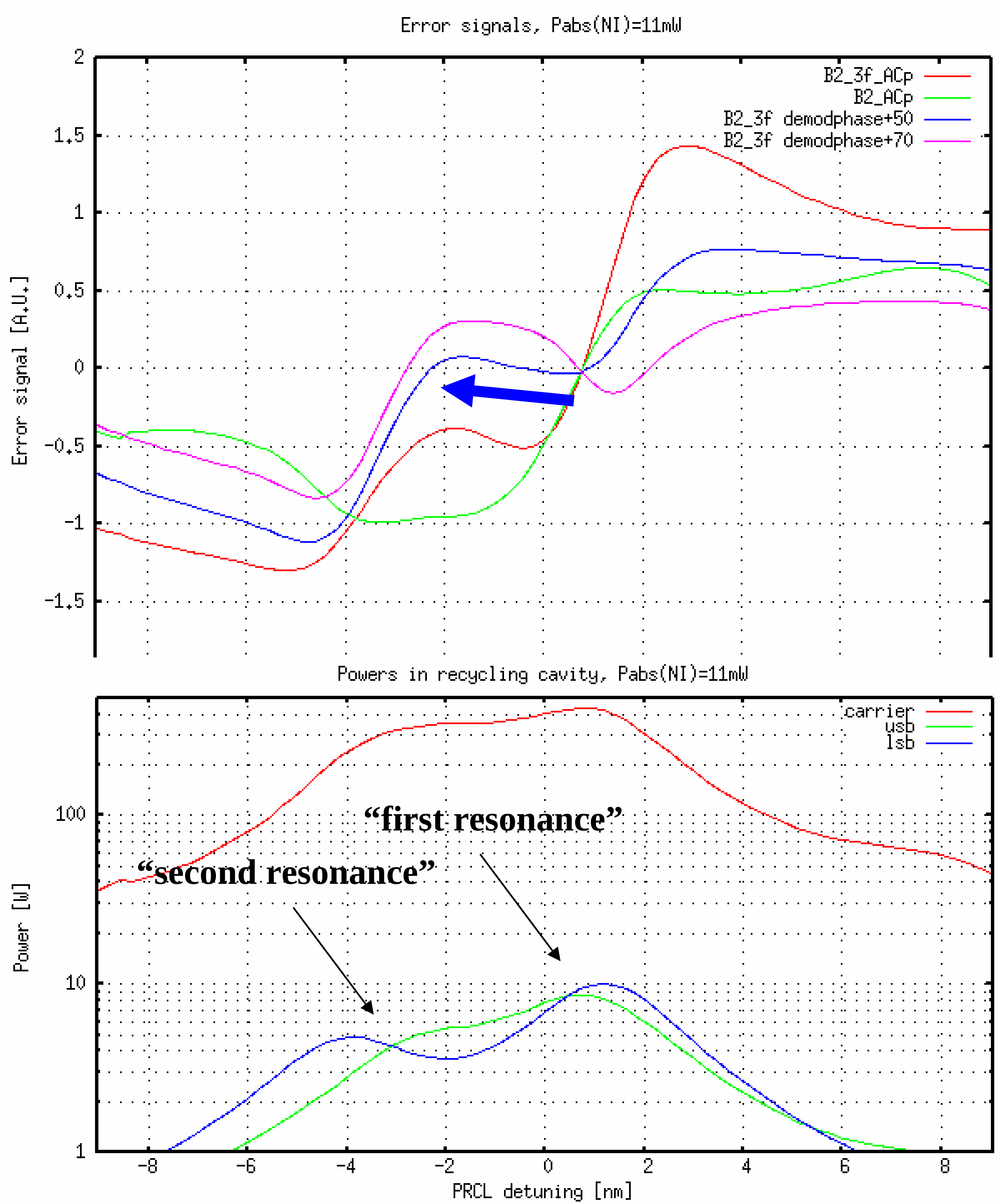
Error signals, Pabs(NI)= 7mW
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
Error signal [A.U.]
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)= 7mW
carrier
usb
lsb
Power [W]
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]

8


Error signals, Pabs(NI)= 8mW
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
Error signal [A.U.]
Powers in recycling cavity, Pabs(NI)= 8mW
carrier
usb
lsb
Power [W]
PRCL detuning [nm]


Error signals, Pabs(NI)= 9mW
Error signal [A.U.]
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)= 9mW
Power [W]
carrier
usb
lsb
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]

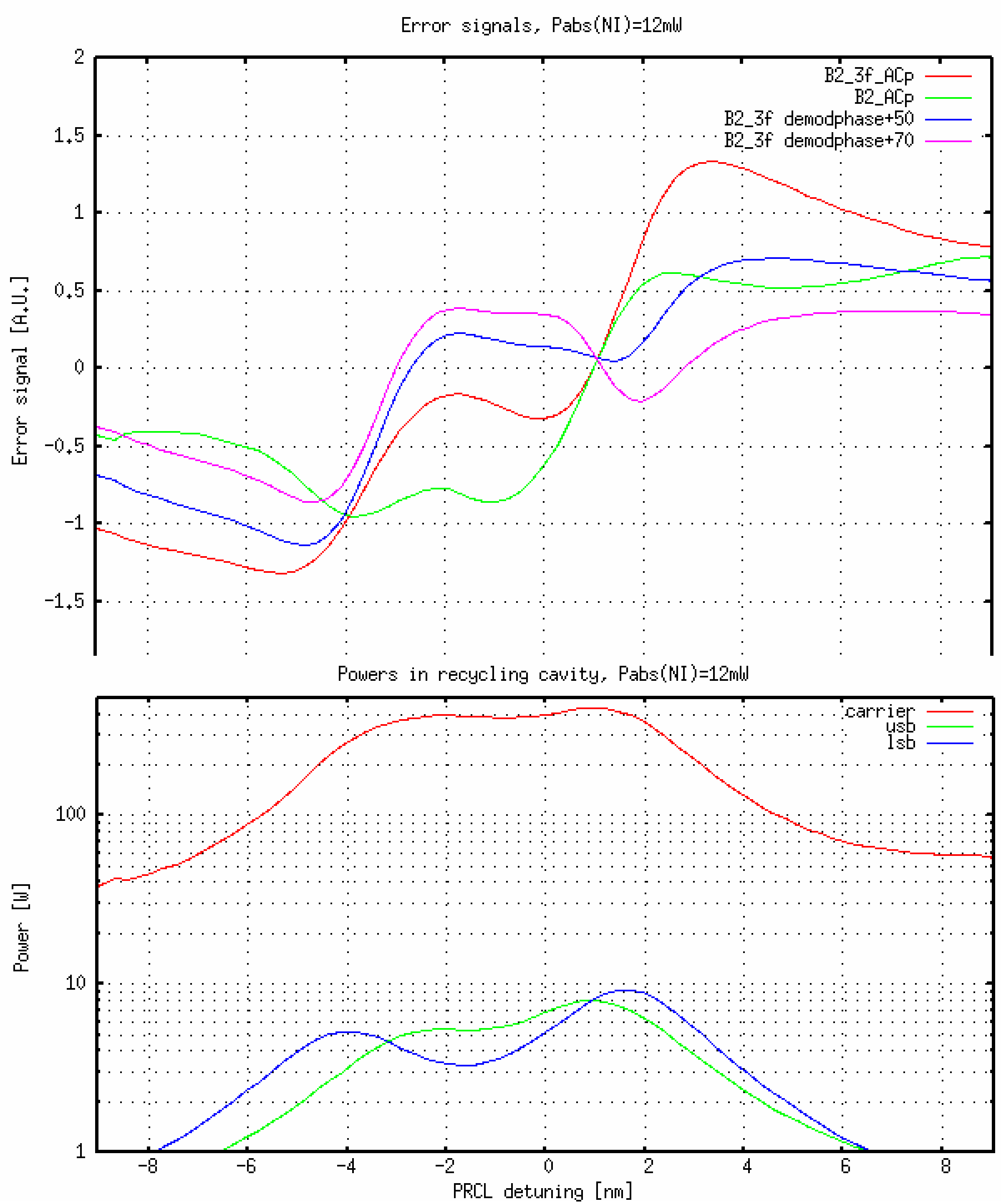

Error signals, Pabs(NI)=10mW
Error signal [A.U.]
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)=10mW
Power [W]
carrier
usb
lsb
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]



Second zone of resonance appeared.

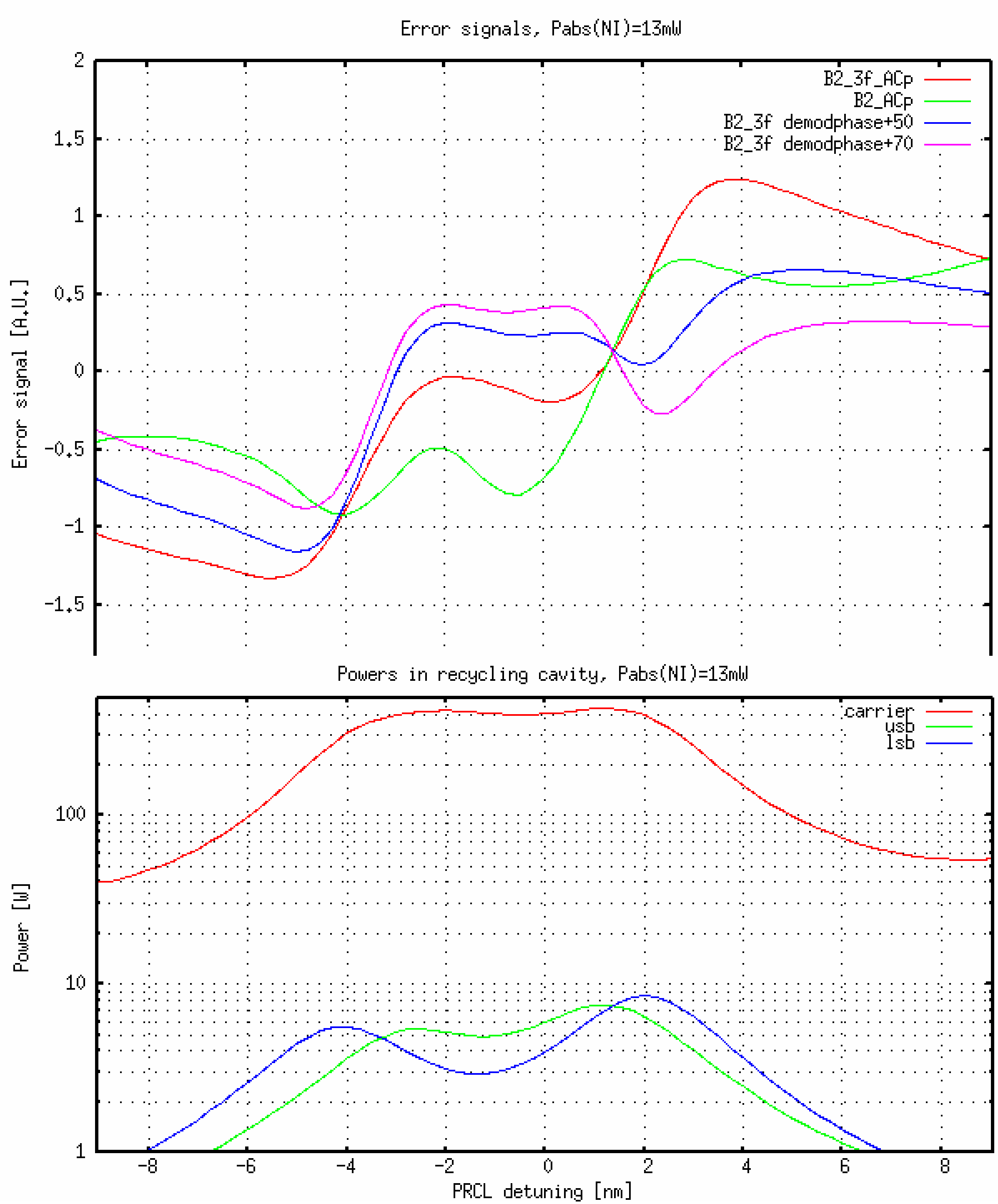
A change by 50 degrees of the demodulation phase of B2_3f allows to jump to the "second resonance".

Critical: time window to operate this change is not well defined…

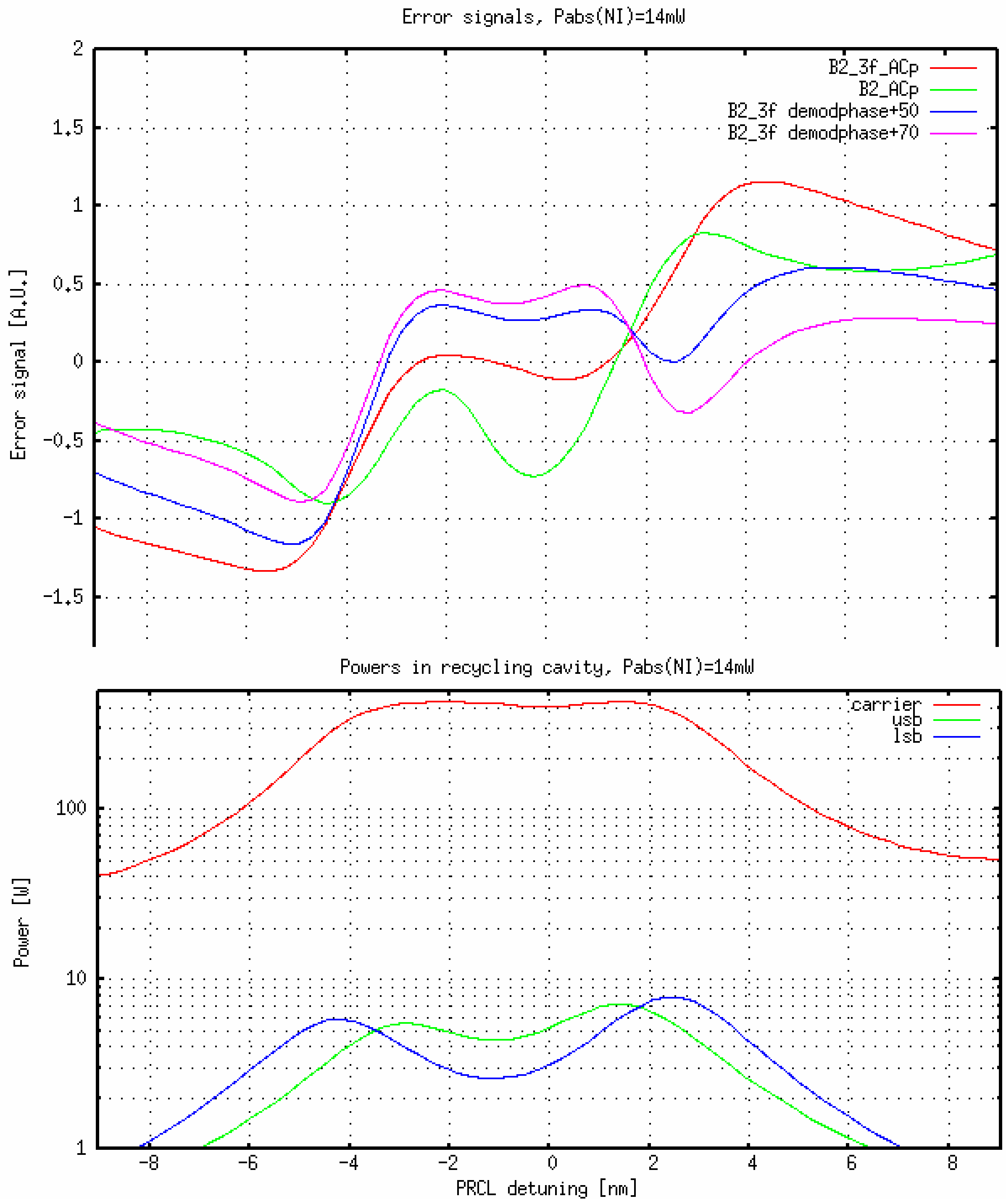


Error signals, Pabs(NI)=12mW
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
Error signal [A.U.]
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)=12mW
carrier
usb
lsb
Power [W]
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]

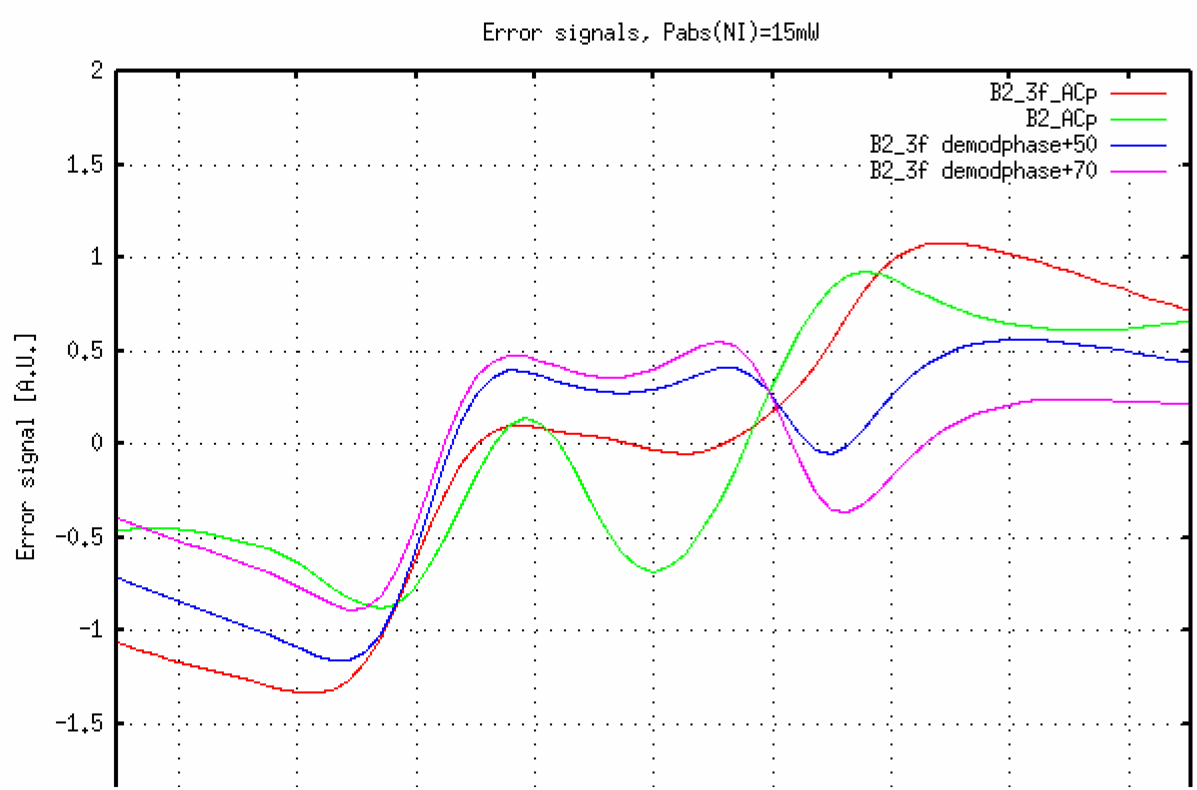
13

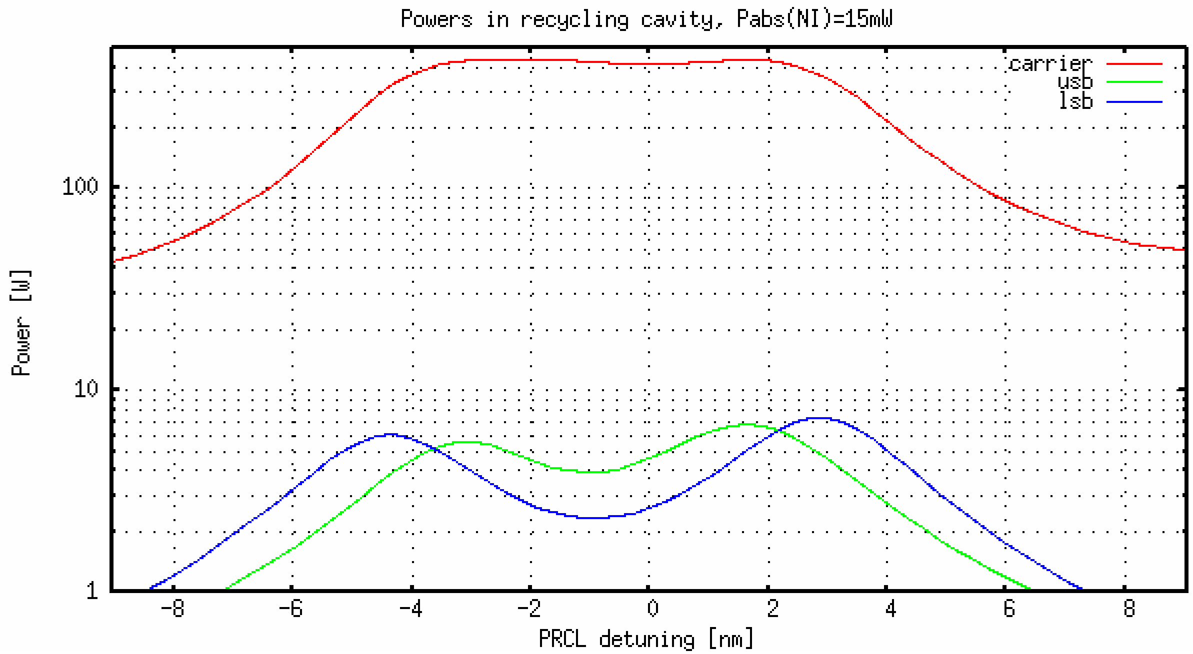

Error signals, Pabs(NI)=13mW
Error signal [A.U.]
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)=13mW
Power [W]
carrier
usb
lsb
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]

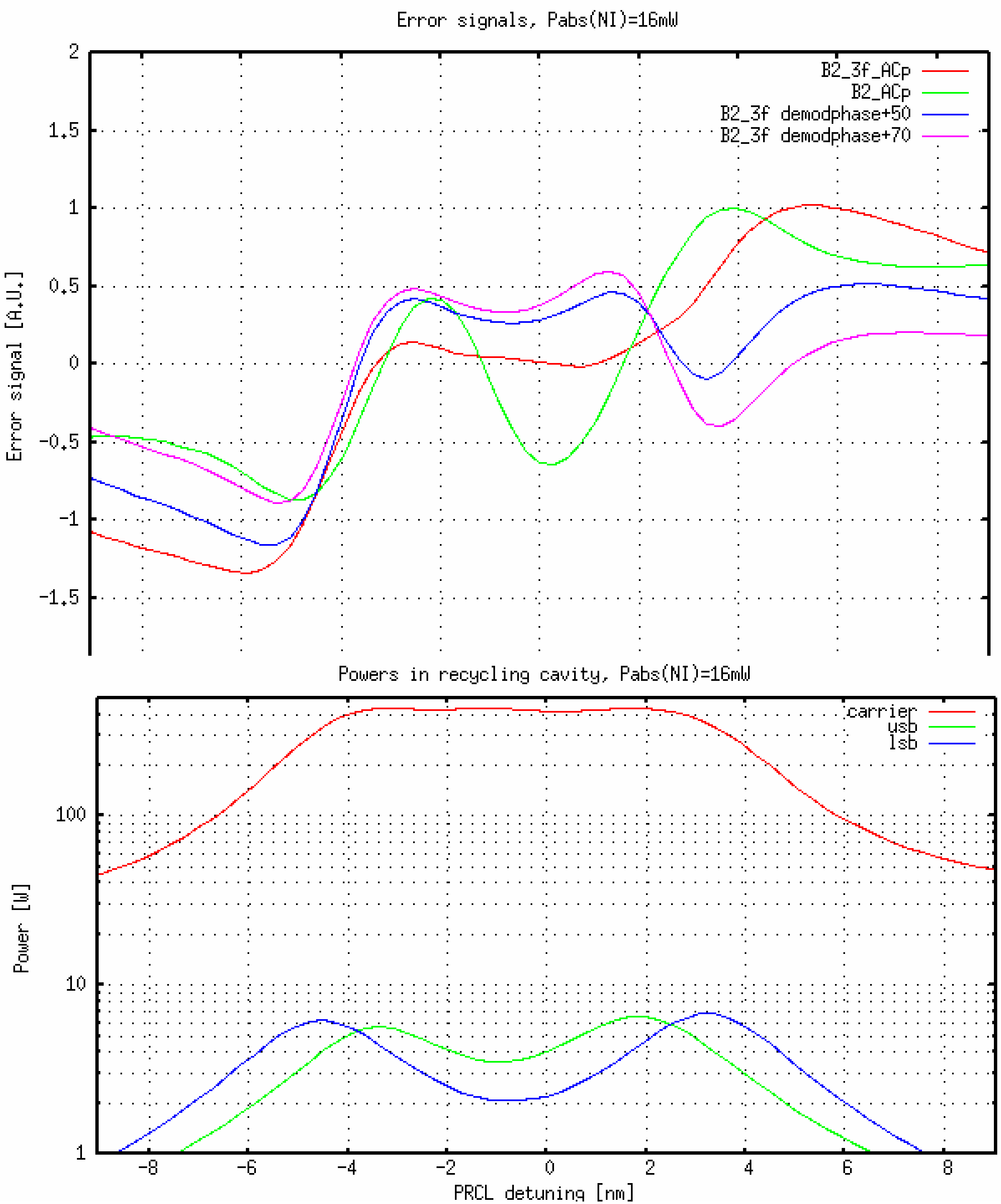
14



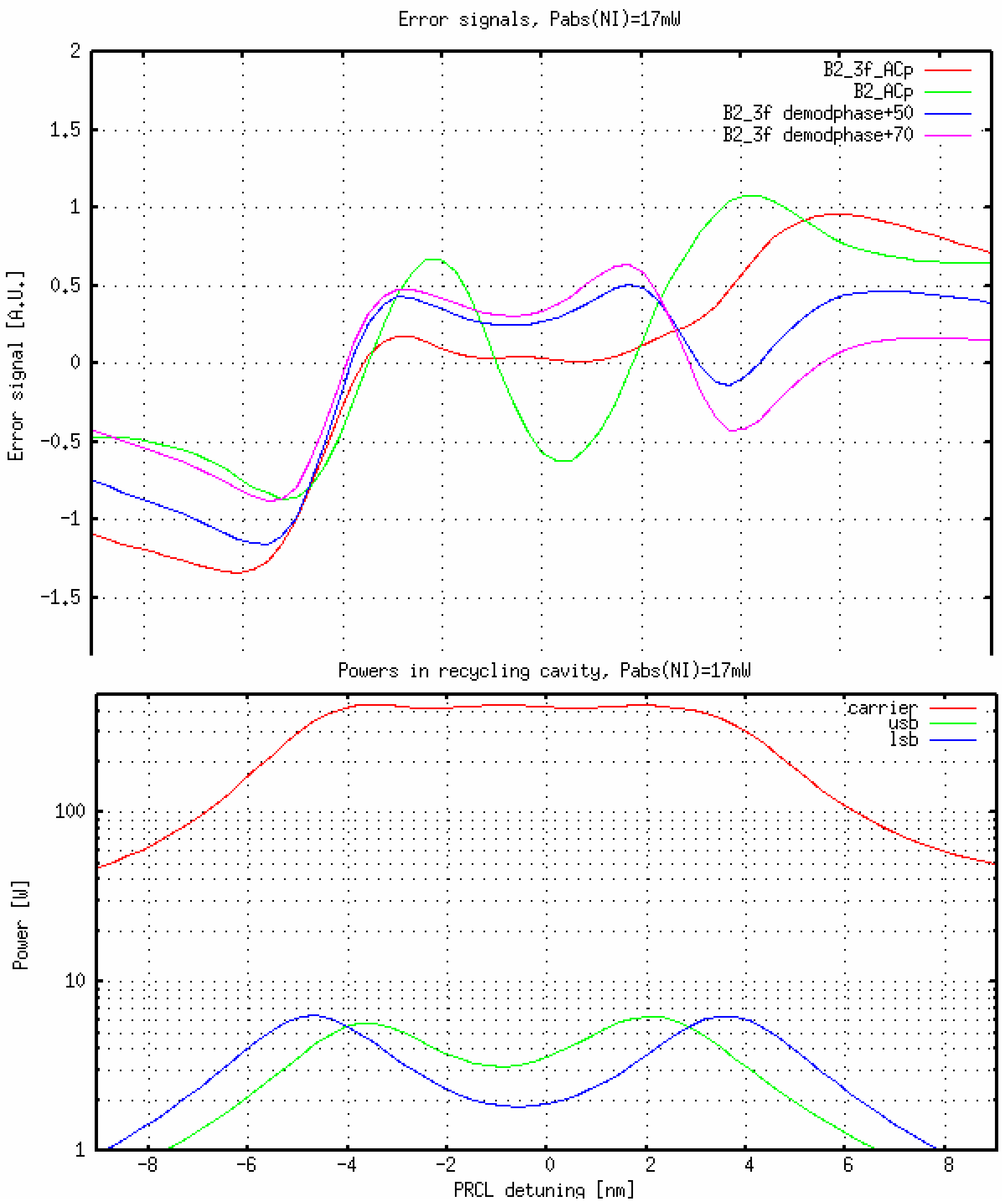
Error signals, Pabs(NI)=14mW
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
Error signal [A.U.]
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)=14mW
carrier
usb
lsb
Power [W]
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]


Error signals, Pabs(NI)=15mW
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
Error signal [A.U.]
2
1.5
1
0.5
0
-0.5
-1
-1.5


Powers in recycling cavity, Pabs(NI)=15mW
carrier
usb
lsb
Power [W]
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]

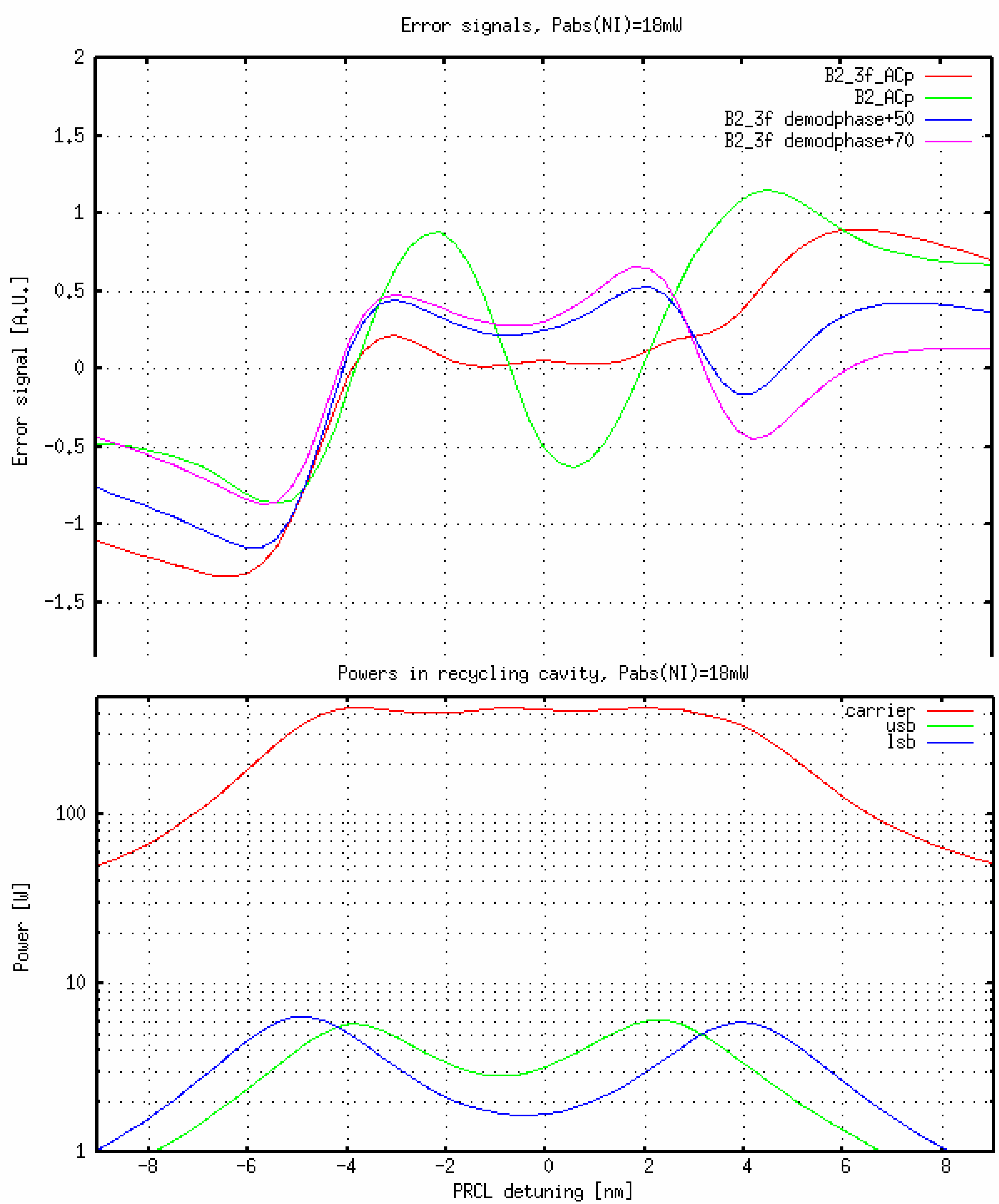

Error signals, Pabs(NI)=16mW
Error signal [A.U.]
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)=16mW
Power [W]
carrier
usb
lsb
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]

17

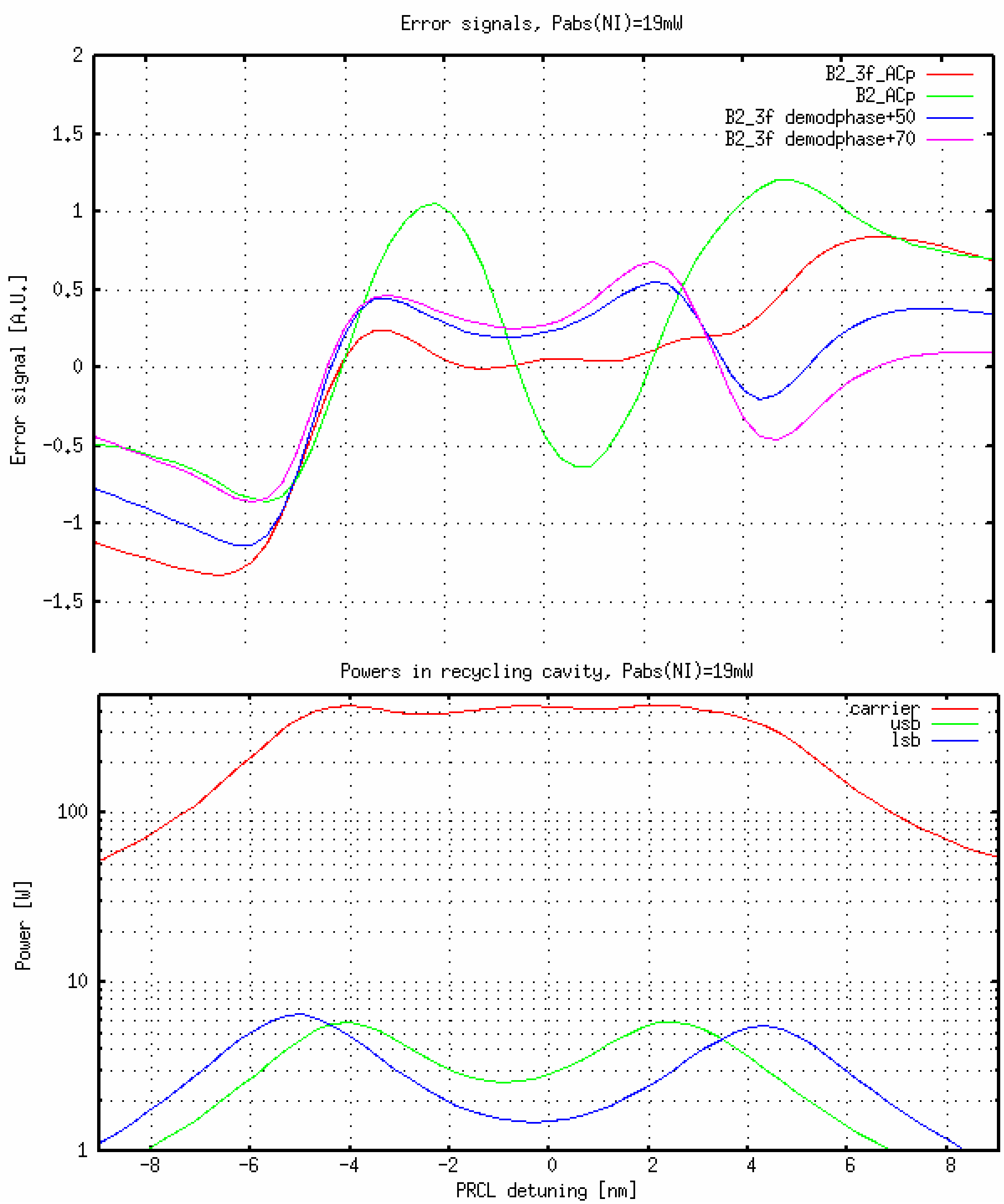


Error signals, Pabs(NI)=17mW
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
Error signal [A.U.]
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)=17mW
carrier
usb
lsb
Power [W]
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]

18

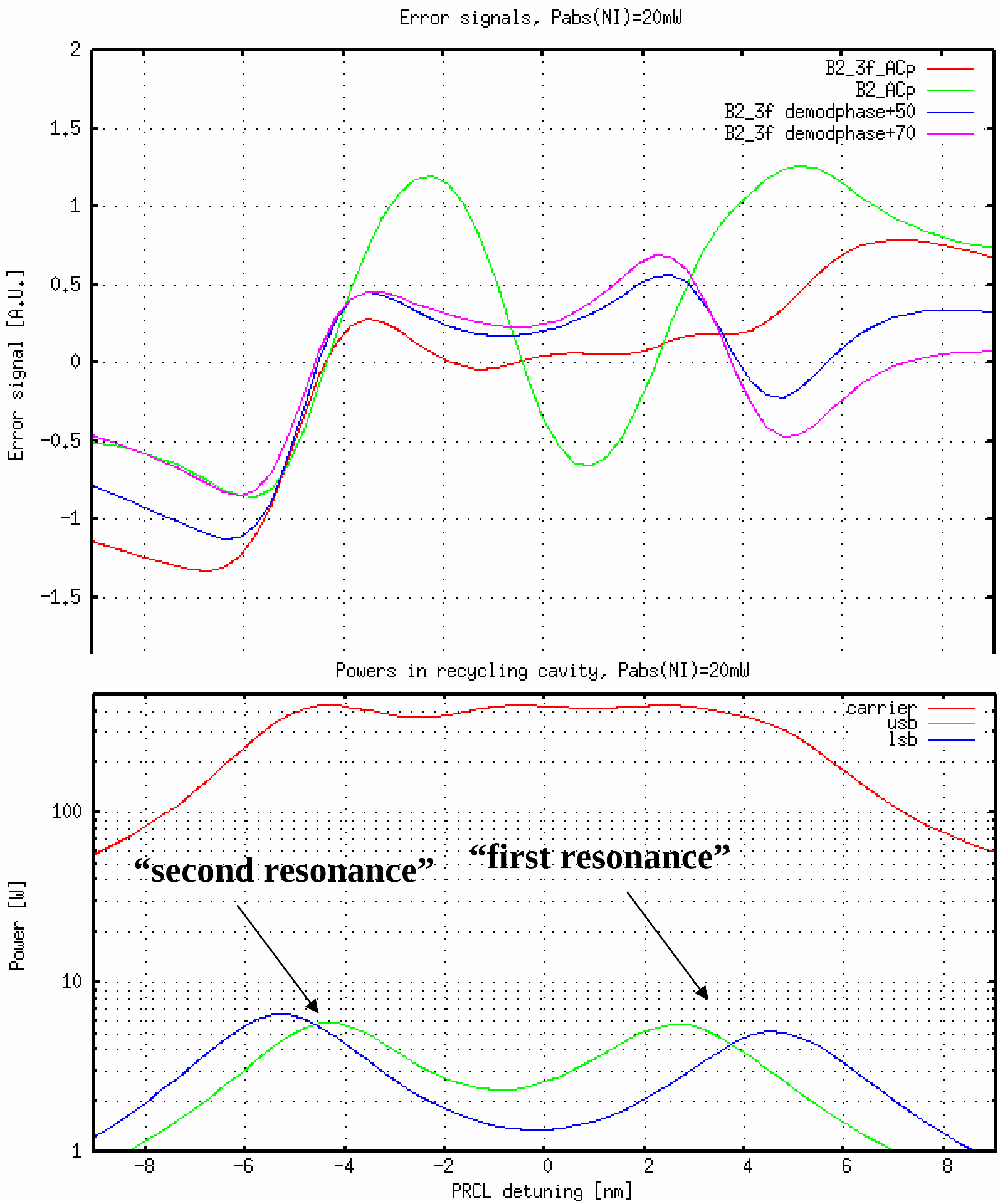


Error signals, Pabs(NI)=18mW
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
Error signal [A.U.]
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)=18mW
carrier
usb
lsb
Power [W]
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]


Error signals, Pabs(NI)=19mW
Error signal [A.U.]
B2_3f_ACp
B2_ACp
B2_3f demodphase+50
B2_3f demodphase+70
2
1.5
1
0.5
0
-0.5
-1
-1.5
Powers in recycling cavity, Pabs(NI)=19mW
Power [W]
carrier
usb
lsb
100
10
1
-8
-6
-4
-2
0
2
4
6
8
PRCL detuning [nm]

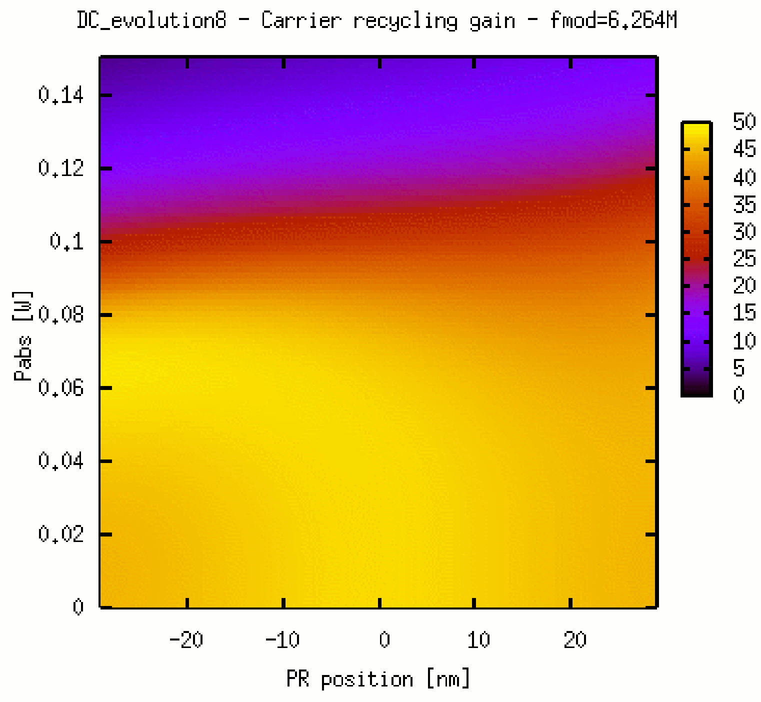
“second resonance”: operating point depends slightly on demodulation phase tuning => problem of offset between various error signals

“first resonance”:
error signal sign has flipped! Looks very difficult to keep the lock on this operating point…



The double cavity model
& how the resonance of the sidebands depend on the frequency modulation

The double cavity simulation

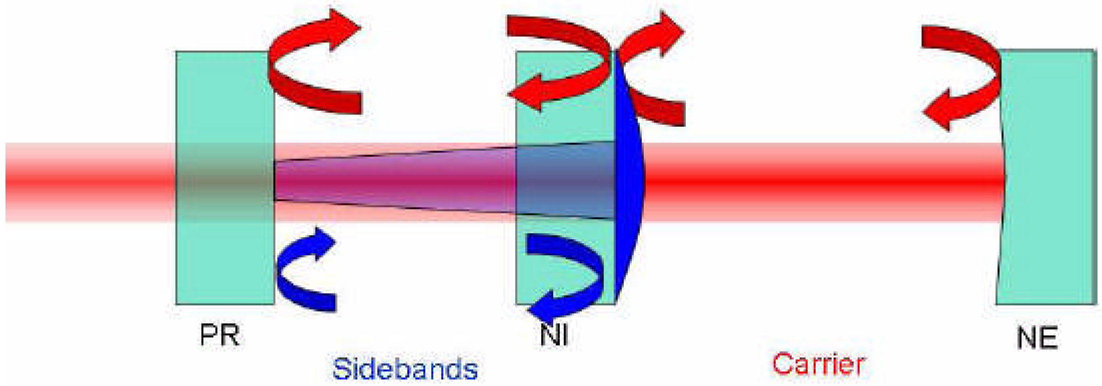


Next results assume that:

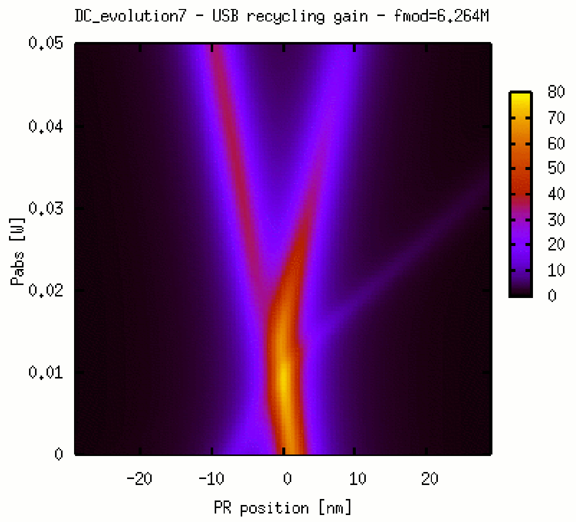
o FP cavity is locked

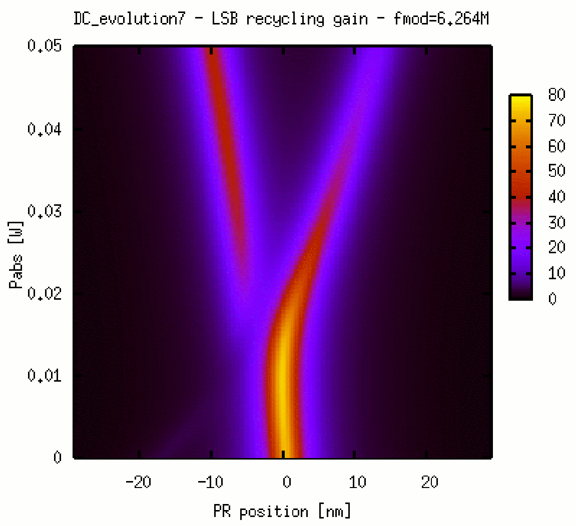
o PR is moved by a few nm.

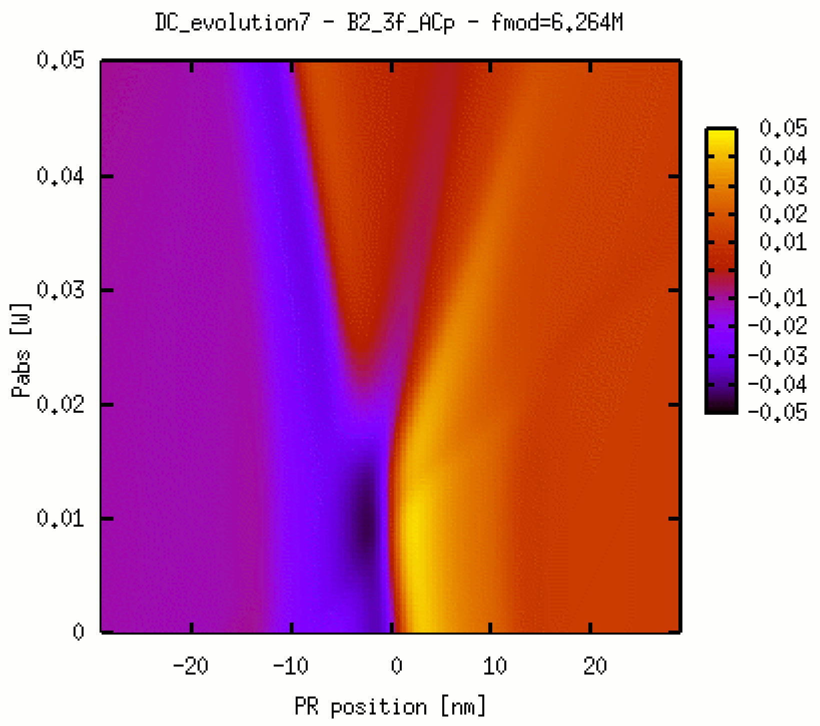
o Macroscopic PRCL length is automatically adjusted to be optimal respect to the Fmod.



Sidebands behaviour with Anderson frequency

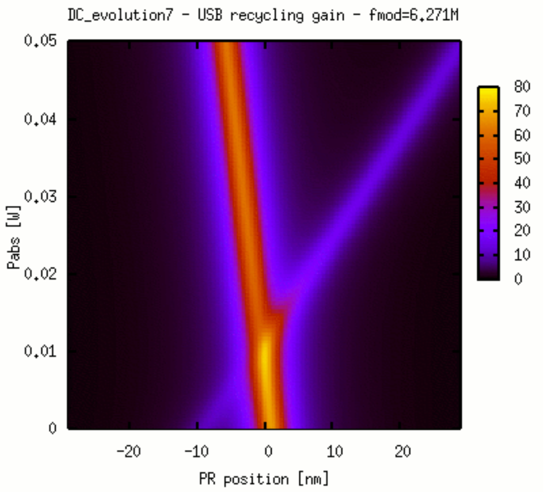


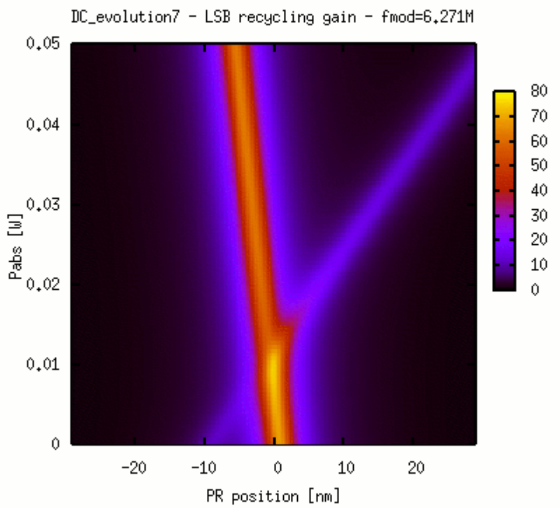


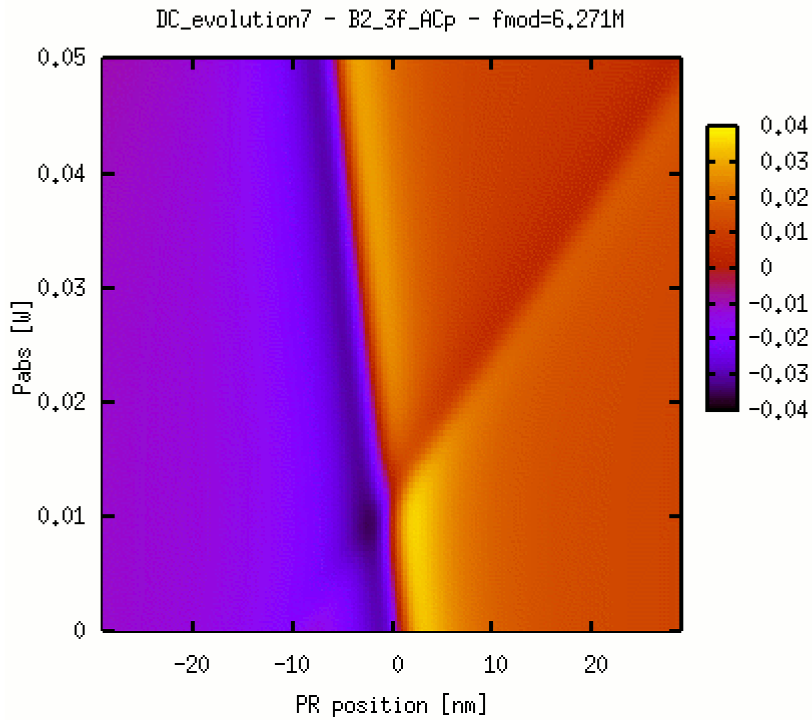


2 error points for the control of PRCL.
From which one is more critical.

Sidebands behaviour with “nominal” frequency

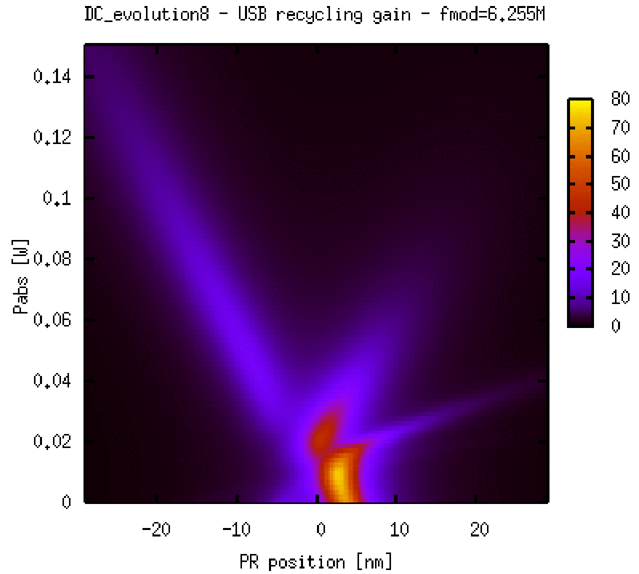


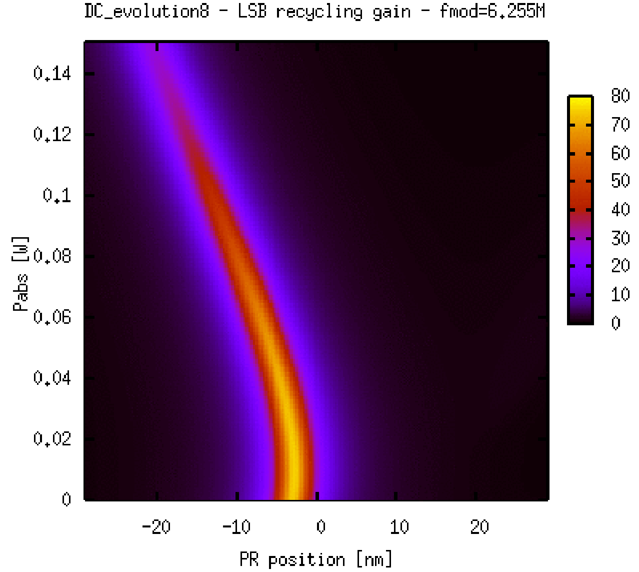


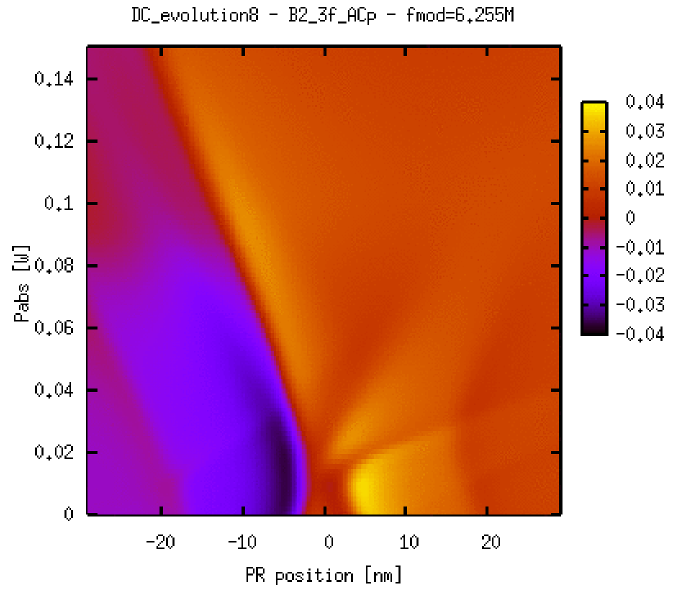


1 error point for the control of PRCL.
Sidebands recycling gain remains good.

Sidebands behaviour with various modulation frequencies



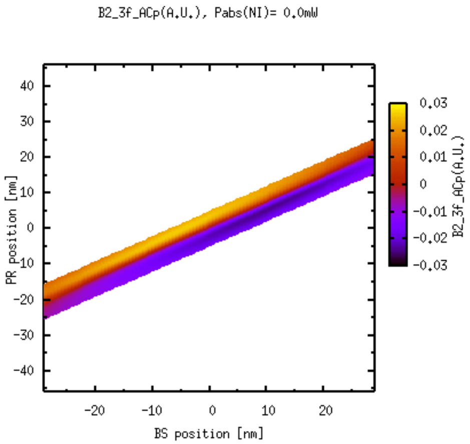


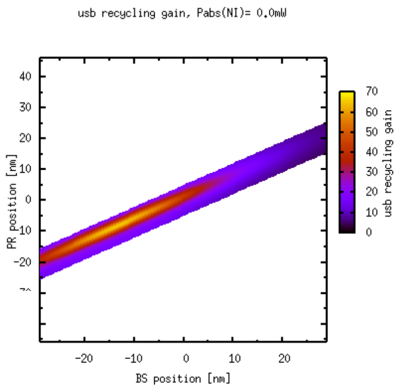


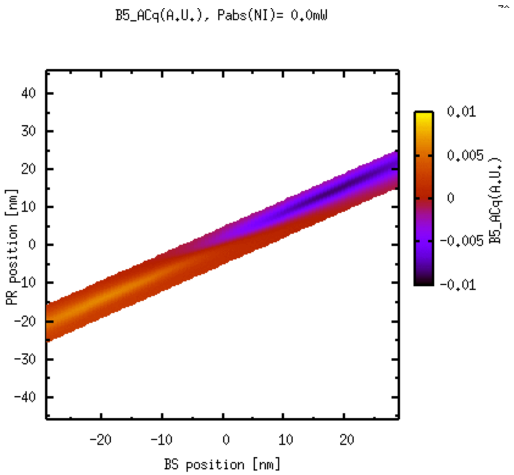
Resonnance of the sidebands in recycling cavity depends highly on the modulation frequency when there is thermal lensing.
Resonance of usb and lsb are always asymmetric except when we choose the "nominal" frequency of modulation.

Back to Virgo: Anderson vs Nominal frequency

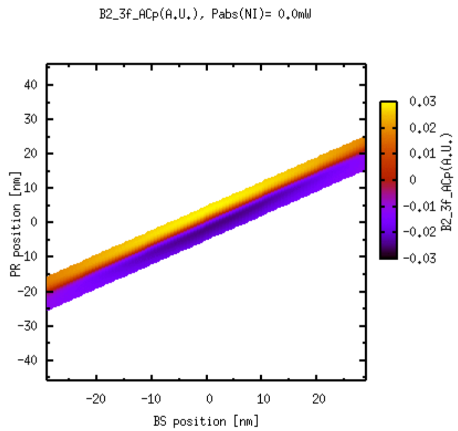
Anderson modulation frequency

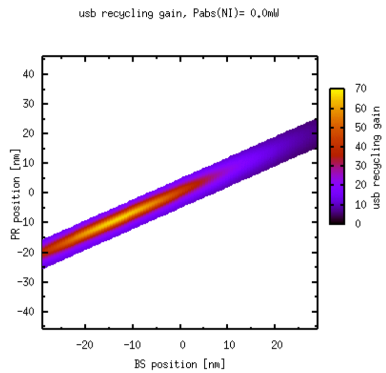


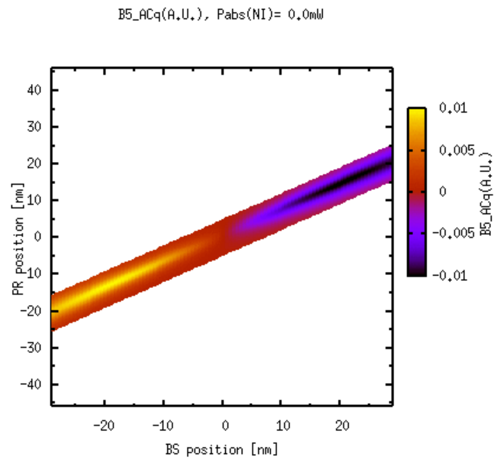




Nominal modulation frequency







Conclusion

The PRCL macroscopic length may be mistuned by 4cm. Is that a problem??

The input mirrors thermal lensing effect leads to 2 operating points in Virgo.
To keep the lock, we jump on the “most stable one” => difficult transition in the locking acquisition, decrease of the recycling gains => demodulation phase change, offsets in the error signals…

Double operating point could be avoided by choosing the “nominal” modulation frequency instead of the “Anderson” one. Would make the lock acquisition easier…
In this case, PR tower would have to be shifted by 6cm and MC tower by 15cm (then FP Finesse could be changed without moving again PR tower).

Anyway, thermal lensing compensation system is mandatory for higher input power…