Recycling cavities design update

M.Barsuglia, R.Bonnand, Q.Benoit, R.Flaminio, M.Galimberti, M.Granata, J.Marque, M.Pichot, G.Vajente , J.-Y.Vinet, H.Yamamoto

Virgo Collaboration meeting, February 9th 2010

Overview

- Introduction
- Simulation developments
- Stable recycling cavities design
- Thermal effects
- Pick-off extraction
- Conclusions

AdVirgo baseline design

Recycling cavities:

Configuration (two mirror telescope *à la LIGO*)

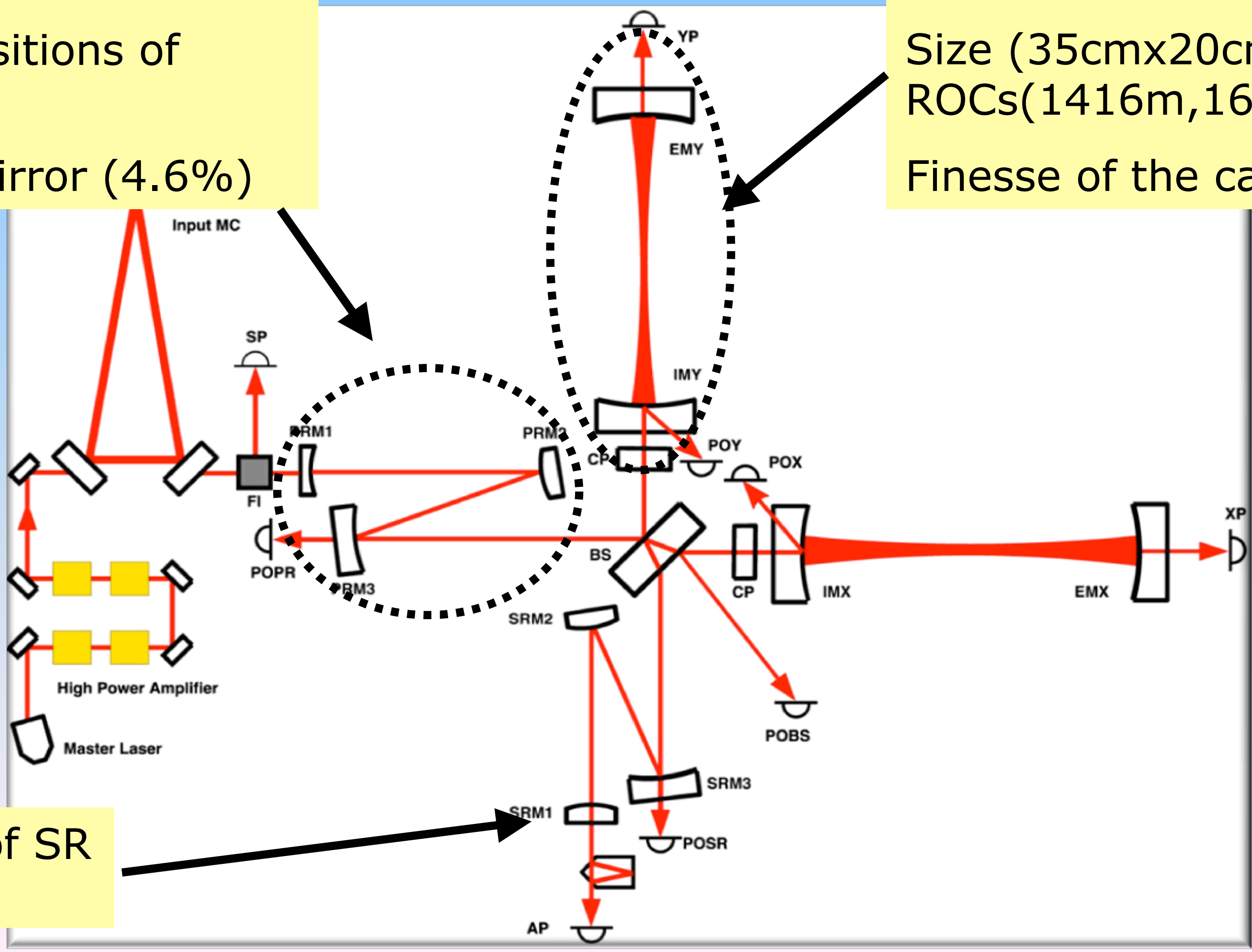
ROCs, preliminary positions of mirrors

Transmission of PR mirror (4.6%)

geometry of 3km cavities (bi-concave)

Size (35cmx20cm), ROCs(1416m,1646m)

Finesse of the cavities (900)



Transmission of SR mirror (11%)

Stable recycling cavities?

Advantages:

- Better RF sidbands
- Better audio GW sidebands
- Easier extraction of pick-off from recycling cavity
- Small PRC/SRC mirrors (easy changeable, if needed)
- Smaller beam at INJ and DET
- Common LIGO/Virgo design - possibilities to joint work

Disavantages:

- Astigmatism (folded arms)
- Multi-mirror suspensions
- Alignment signals reduced
- More length noise (3 mirrors instead of 1)

Simulation developments

FFT codes

- DarkF (M.Pichot, J.-Y. Vinet)
  - Stable recycling cavities implemented - under test
  - Virgo configuration available - AdVirgo to be tested
- SIESTA (M.Galimberti, R.Flaminio)
  - Graphics under root are back (thanks to Damir)
  - Fabry-Perot cavity ready - under test
  - Now stable recycling cavities under implementation
- SIS (H.Yamamoto)
  - Acceleration algorithm for stable cavities implemented - tested
  - Double cavity configuration ready
  - Dual recycling configuration (AdVirgo/AdLIGO) planned

ABCD matrix models

- @APC (M.Granata, M.Barsuglia)
  - Stable recycling cavity design - astigmatism losses evaluation
  - Note: VIR-007A-09
- @LMA (R.Bonnand, R.Flaminio)
  - Study of thermal effects in different configuration
  - Note: VIR-0769B-09

Modal codes

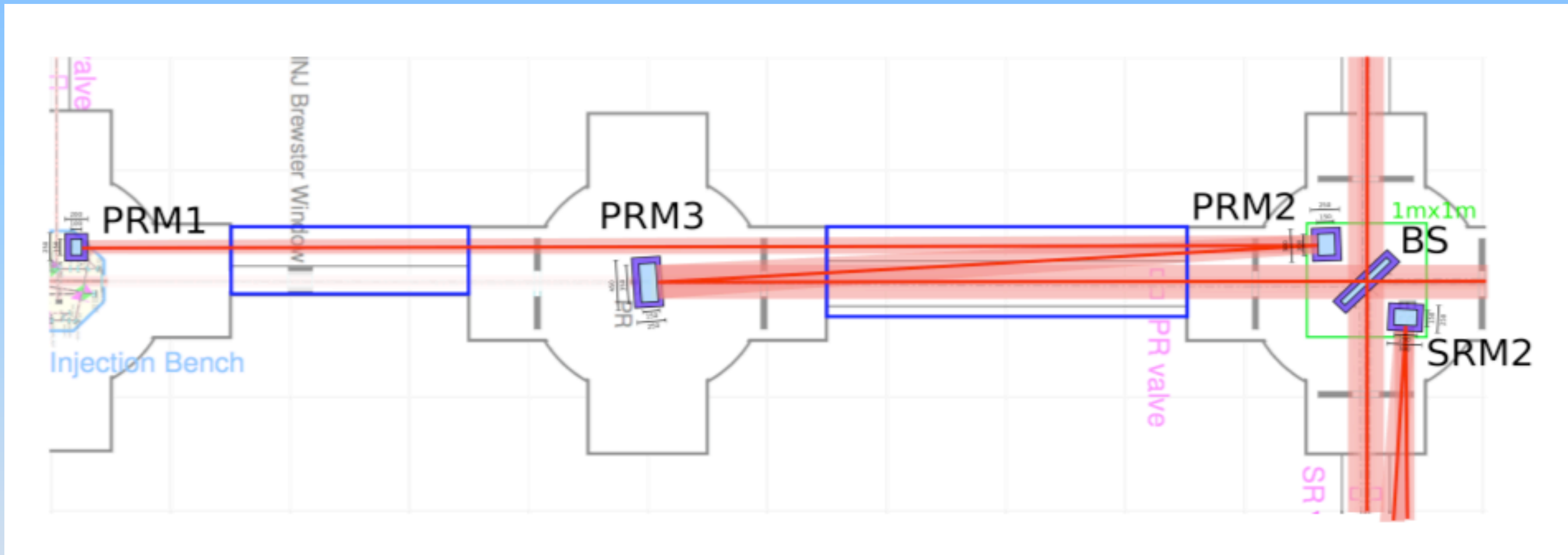
- Finesse (developed by A.Freise, used by J.Marque)
  - Double cavity configuration used for long time
  - Simulation of the complete AdVirgo interferometer in various recycling cavity configuration (with m+n < 8)
  - Study of thermal effects including a thermal lens in the recycling cavity
  - Recently a new version of Finesse has the possibility to include maps

- Analytical modal code (developed by G.Vajente)
  - Simulation of the complete AdVirgo interferometer with m+n < 8
  - Study of thermal effects including a thermal lens in the recycling cavity

Advanced Virgo

Stable recycling cavities design

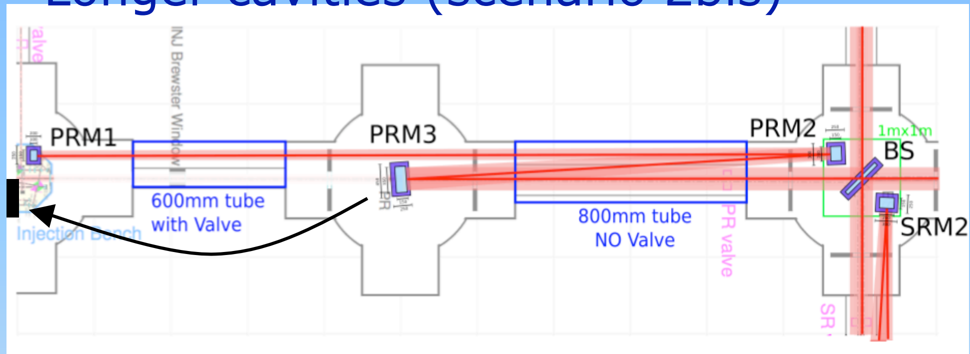
NDRC-baseline



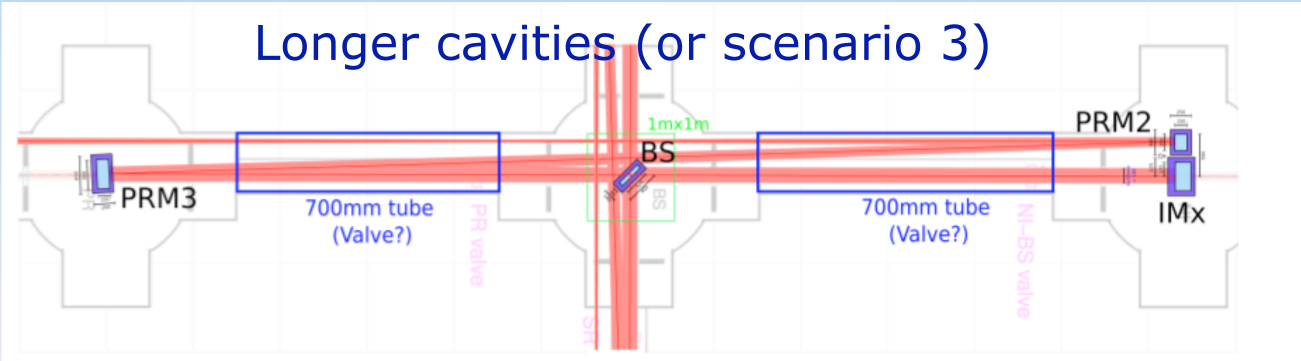
RoC (m)	Lengths (m)	Angle of incidence (deg)
PRM3 = 12.80	ITM to PRM3 = 11.5	1.7
PRM2 = -2.04	PRM3 to PRM2 = 5.5	1.7
PRM1 = -2.04	PRM2 to PRM1 = 10.5	-

Different scenarios: telescopes in the common part

Longer cavities (scenario 2bis)

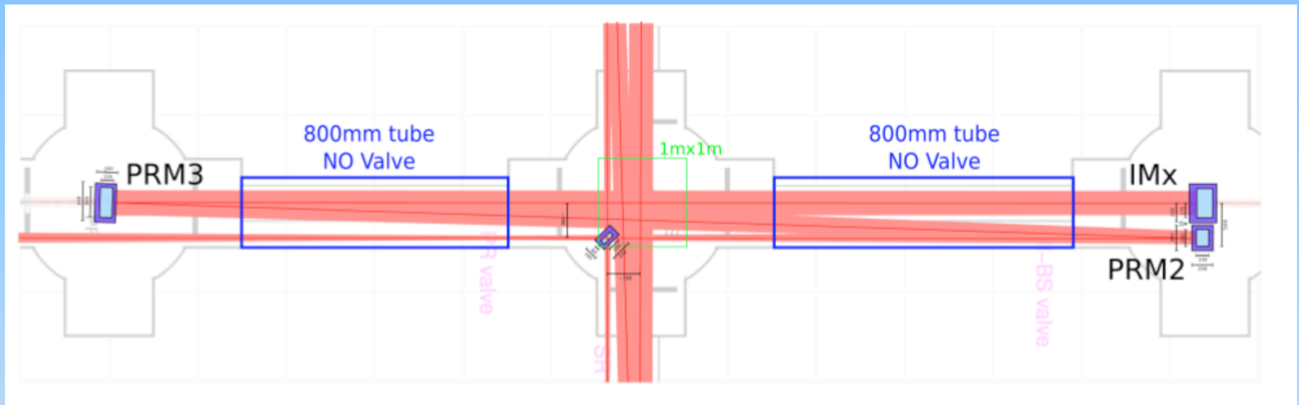


Longer cavities (or scenario 3)

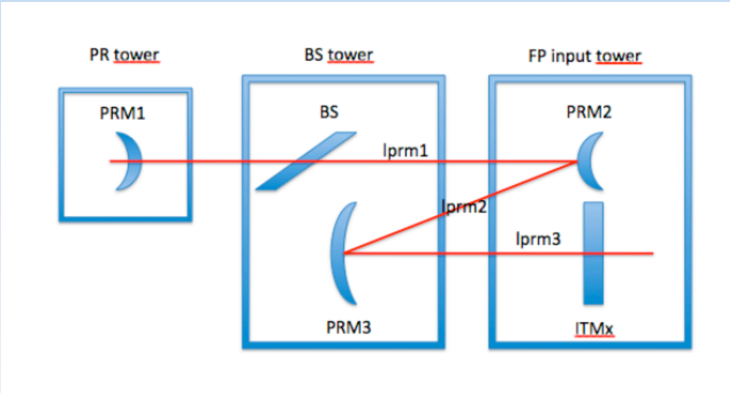


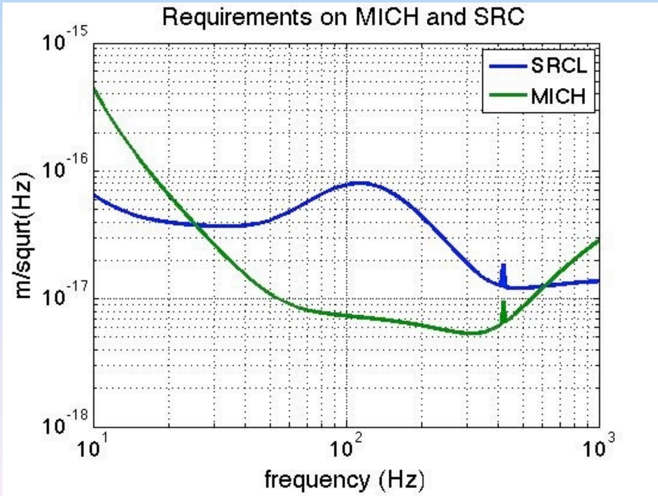
Different scenarios: telescopes in the differential part

Longer cavities and telescopes in the small Michelson cavities (or scenario 4)

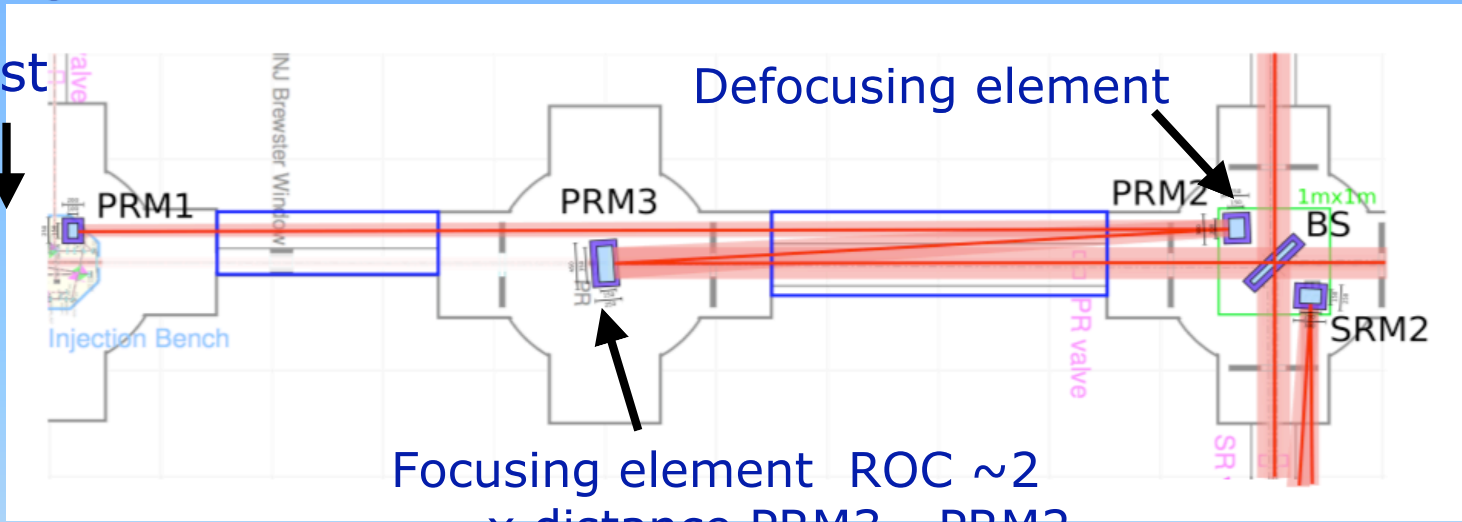


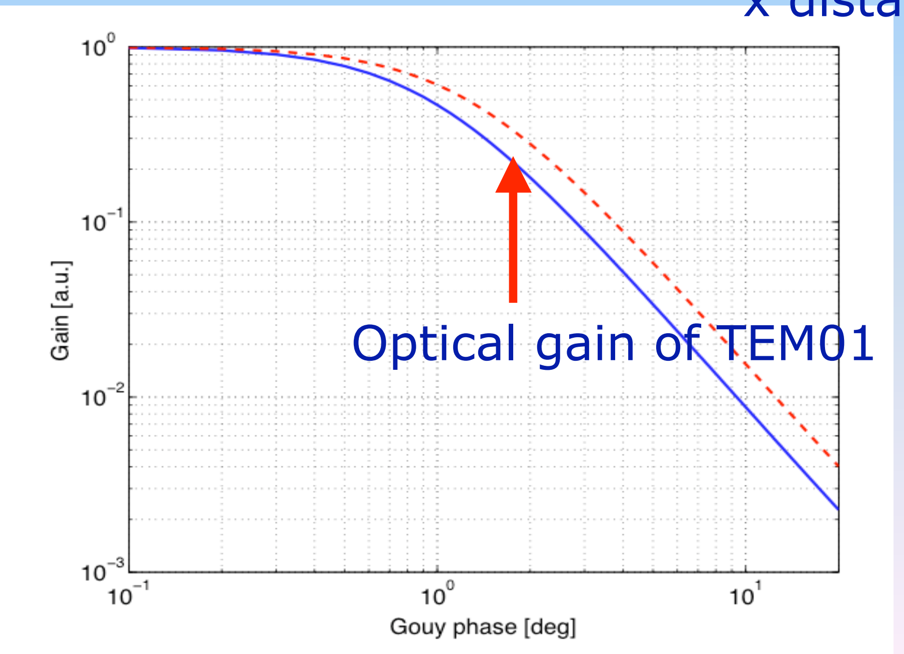
Scenario 4bis





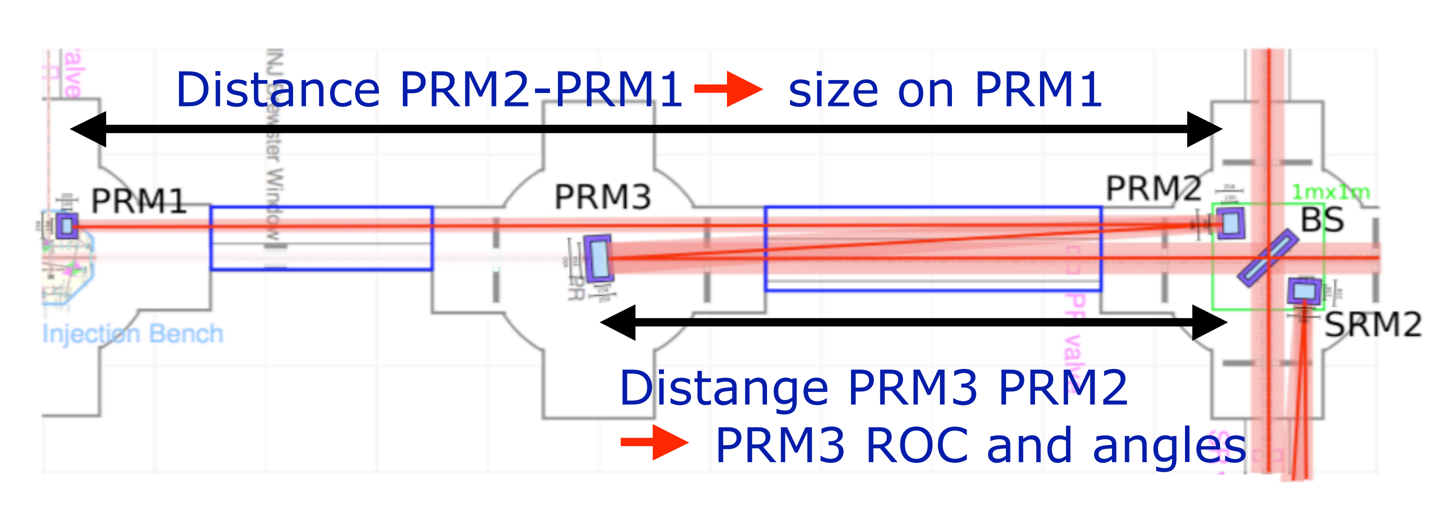
Design details/1

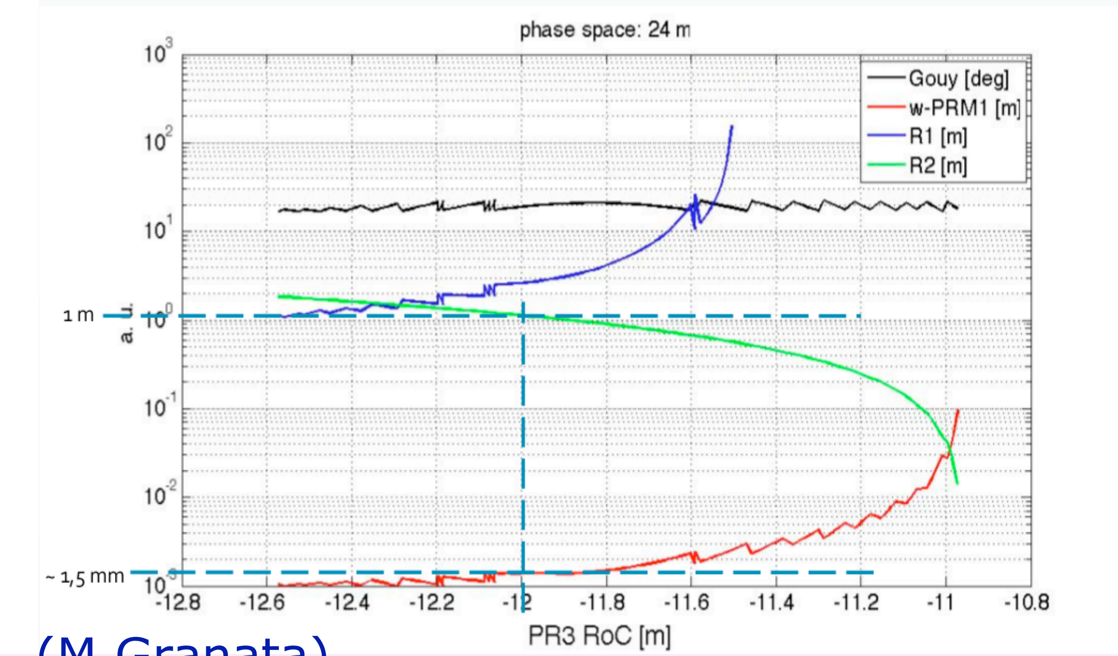




- Concept from adLIGO
- 20 degrees Gouy phase, compromise between:
  - Stability
  - Alignment signal amplitude (see Barsotti at Amaldi 2009 and also LIGO-T0900043-00)

Design details/2

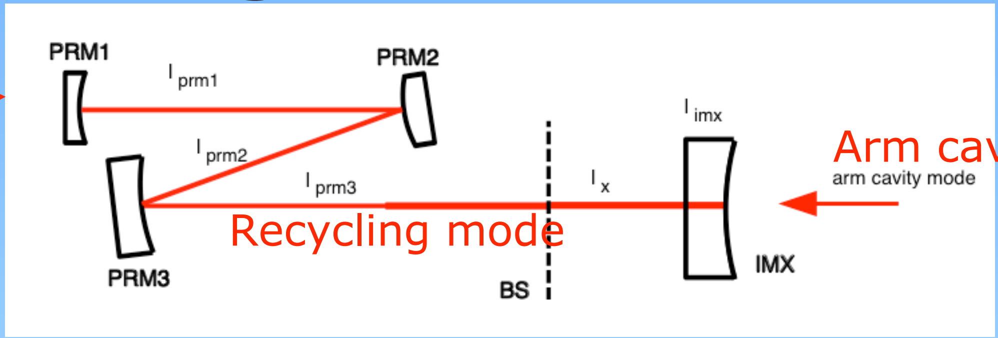




(M.Granata)

- Constraints on
  - Size on PRM1 (power density)
  - ROC of PRM2 (not too small)

Astigmatism losses



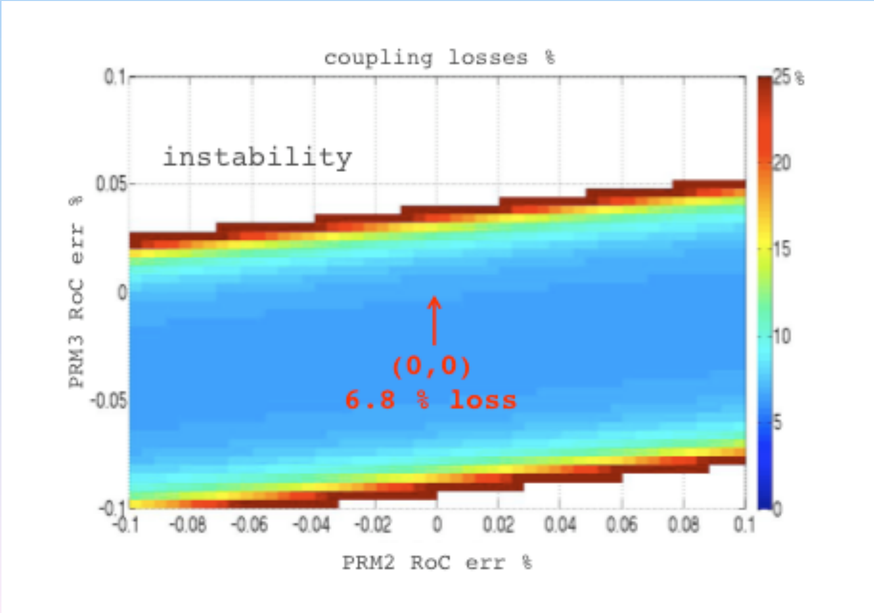
- Simple method: gaussian propagation (ABCD matrix with astigmatism) and overlap integral (alrerady used for adLIGO)
- It supposes recycling cavity and arm cavity decoupled

$$\gamma(q_1, q_2) = \langle U(q_2) | U(q_1) \rangle$$

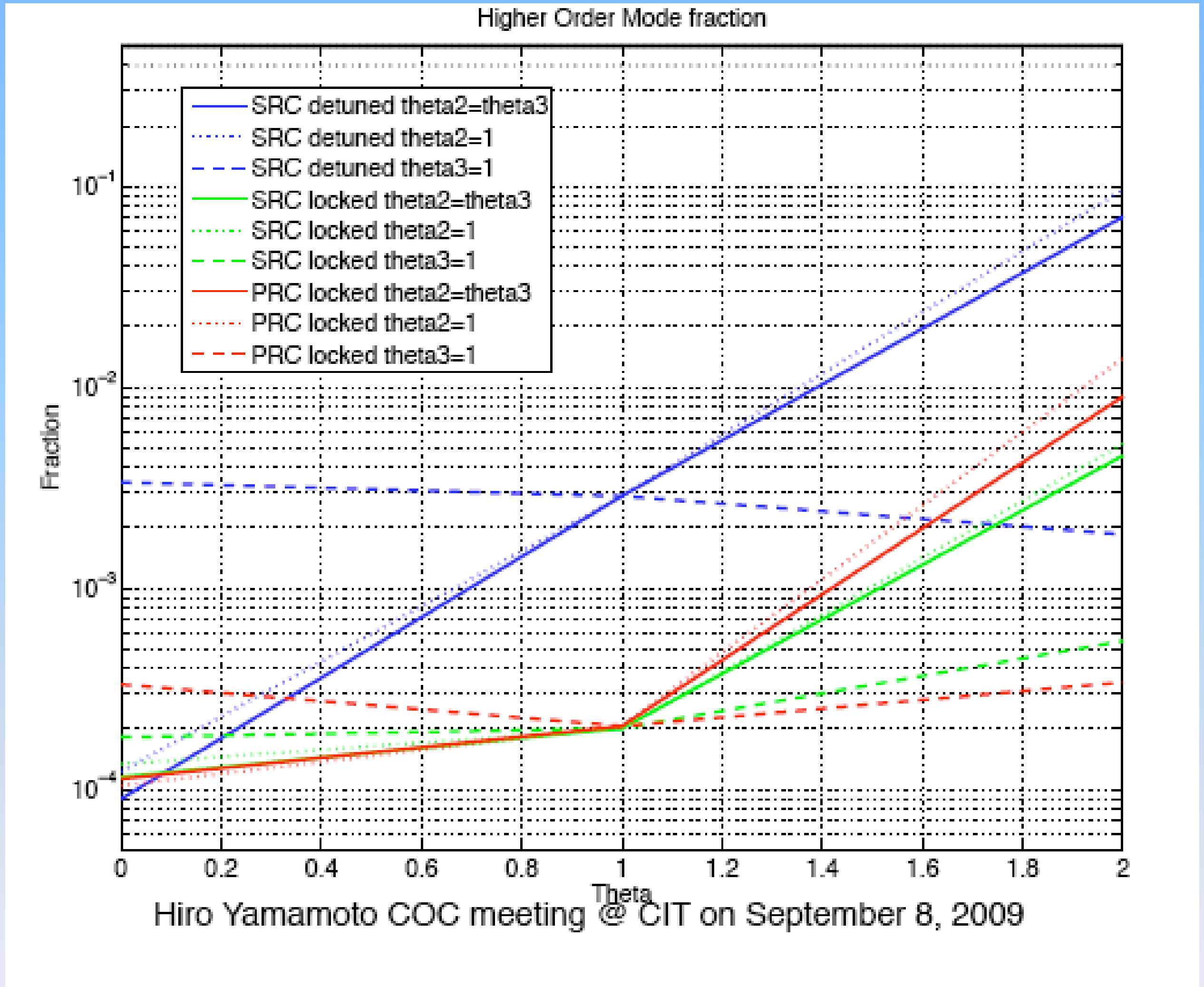
$$L = 1 - \gamma^2_{NDRC} \cdot \gamma^2_{FP}$$

Result with overlap integral

Losses(power) = 6.8 % (for comparison adLIGO about 1%)



Astigmatism losses:FFT simulation



H.Yamamoto - LIGO parameters

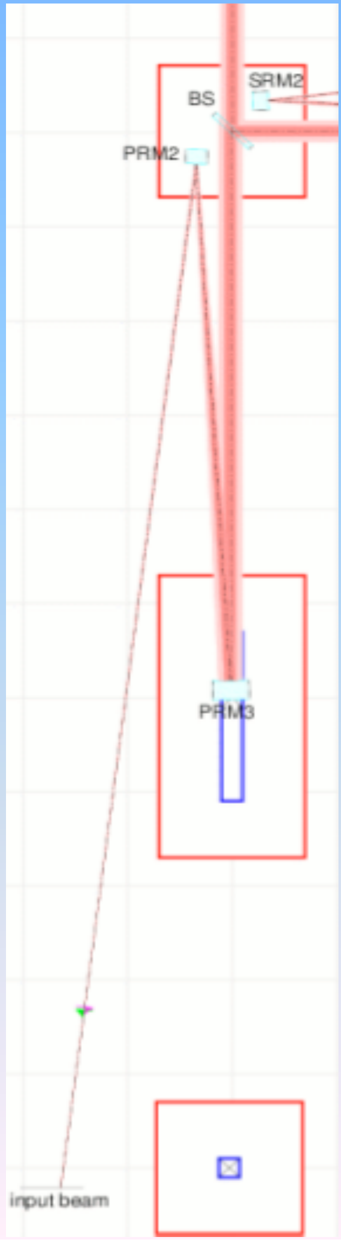
Reduction of astigmatism

- Compensate the astigmatism of PRM3 (concave) with PRM2 (convexe) → proper choice of angles

i.e. With the baseline, the design ratio of angles to cancel astigmatism = 3, difficult to realize

- Maybe a partial compensation?

- If no other solution, use off-axis parabola?



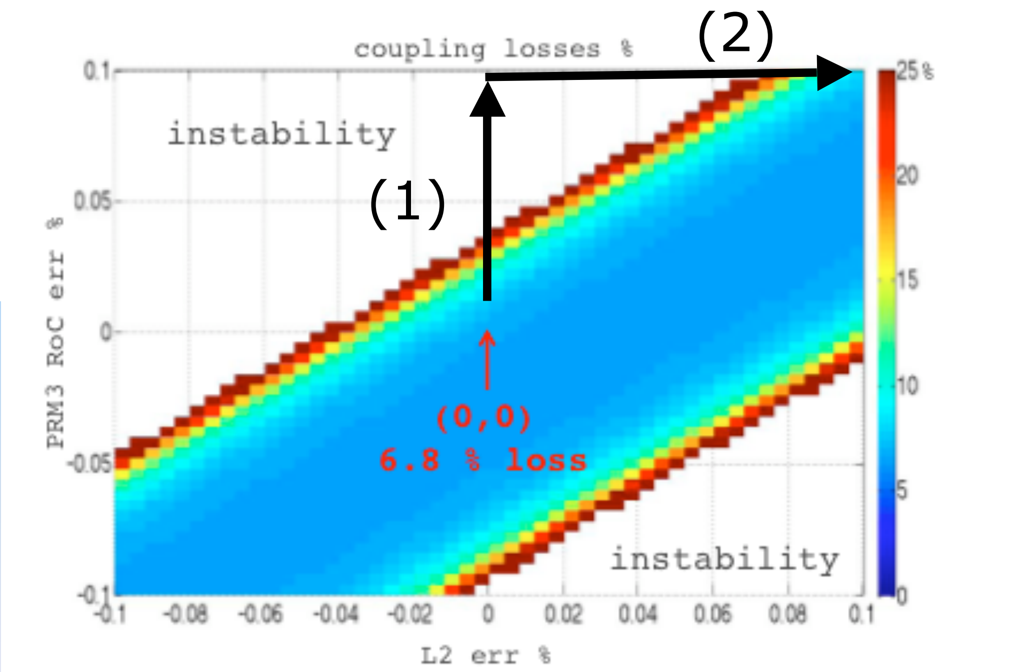
(J.Marque)

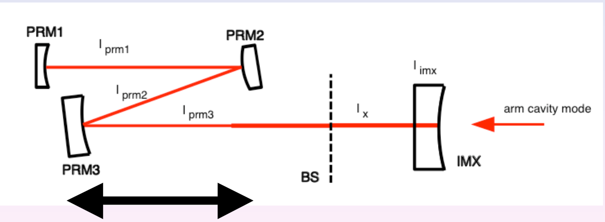
Tolerances

	Stability tol.	Gouy phase tol.
RM3	$\pm$ 0.03 %	$\pm$ 0.02 %
RM2	$\pm$ 0.3 %	$\pm$ 0.1 %
RM1	$\pm$ 20 %	$\pm$ 11 %
L3	$\pm$ 100 %	$\pm$ 100 %
L2	$\pm$ 0.04 %	$\pm$ 0.02 %
L1	$\pm$ 4.0 %	$\pm$ 1.0 %

polisher precision about 0.1% (from L.Pinard)

(M.granata et al.)





- ❑ Errors in ROCs can be compensate by changing the distance PRM2 PRM3

aLIGO design

Table 1: Optical Parameters and Distances in Advanced LIGO Cavities

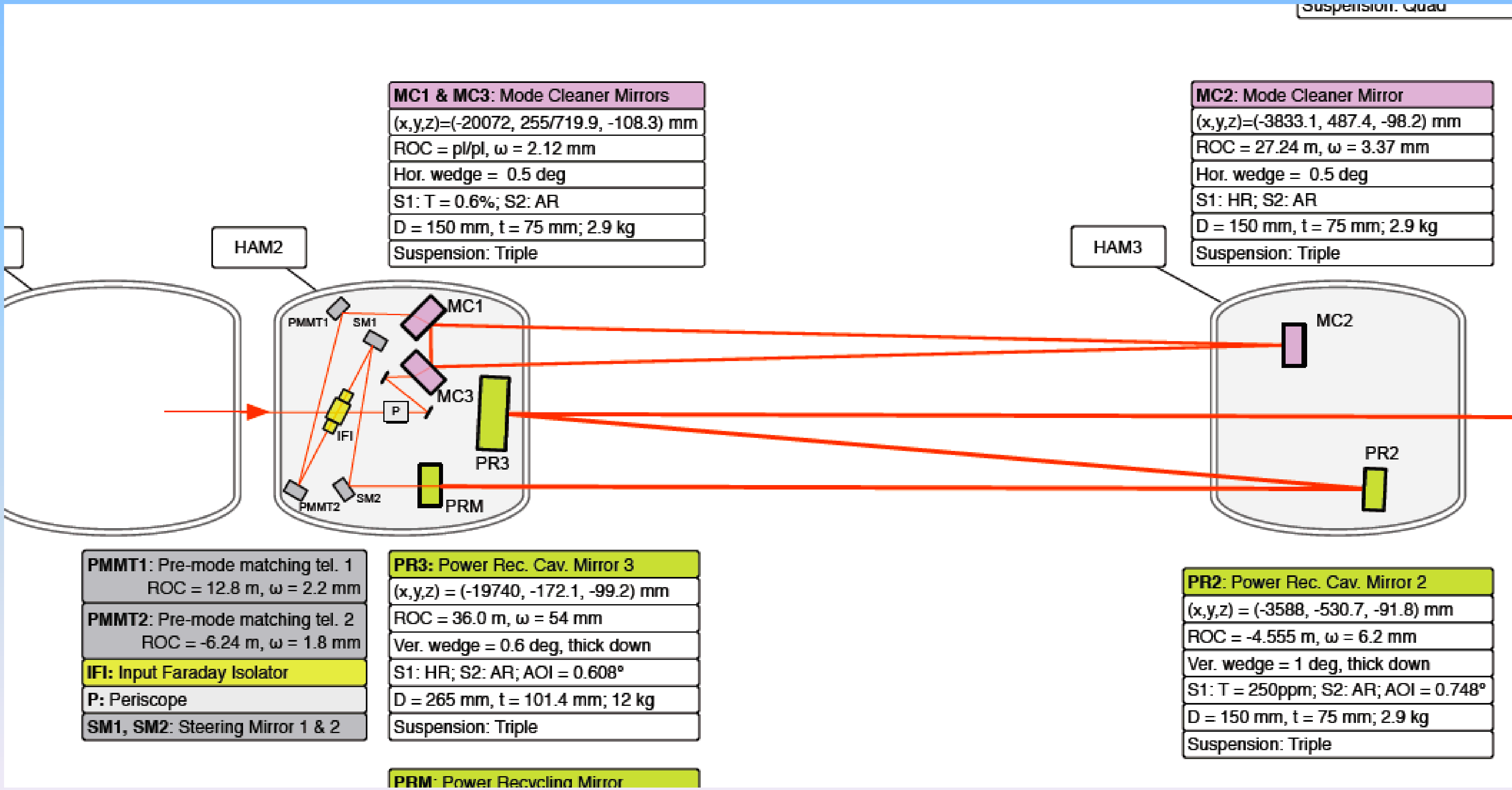
Recycling Cavity Parameters 25° PRC and 19° SRC Gouy Phase and 0 W Power Level

Definition	*Unit*	*PRC*		*SRC*	
		Straight	Folded	Straight	Folded
P(S)RM radius of curvature	m	-10.997	-8.8691	-5.6938	-11.3984
Distance b/w P(S)RM and P(S)R_2	m	16.6037	15.7971	15.726	15.941
P(S)R_2 ROC	m	-4.555	-4.41	-6.427	-4.894
Distance b/w P(S)R_2 and P(S)R_3	m	16.1558	15.2065	15.4607	16.0079
P(S)R_3 ROC	m	36	34	36	36
Distance b/w P(S)R_3 and BS	m	19.5384	19.4221	19.368	20.1072
BS Effective thickness	mm	0	0	131.5	132
Distance b/w BS and CP	m	$4.8497^{\#}$	$9.4767^{\#}$	4.8046^{Ψ}	9.4314^{Ψ}
Distance b/w CP and ITM	mm	5	5	5	5
ITM ROC	m	1934	1934	1934	1934
Reqd. beam waist size in arm	mm	12.0	12.01	12.0	12.01
Beam Size at ITM*	mm	53.0	53.1	53.0	53.1
Beam waist location from ITM	m	1834.2	1835	1834.2	1835
Arm Cavity Length	m	3994.5	3996.0	3994.5	3996.0
ETM ROC	m	2245	2245	2245	2245
Beam Size at ETM*	mm	62.0	62.1	62.0	62.1
Schnupp Asymmetry (X_{SML}-Y_{SML})	mm	50.4	-50	50.4	-50
Angle of Incidence at P(S)R_2	degree	0.79	0.963	0.87	0.878
Angle of incidence at P(S)R_3	degree	0.615	1.144	0.785	0.916

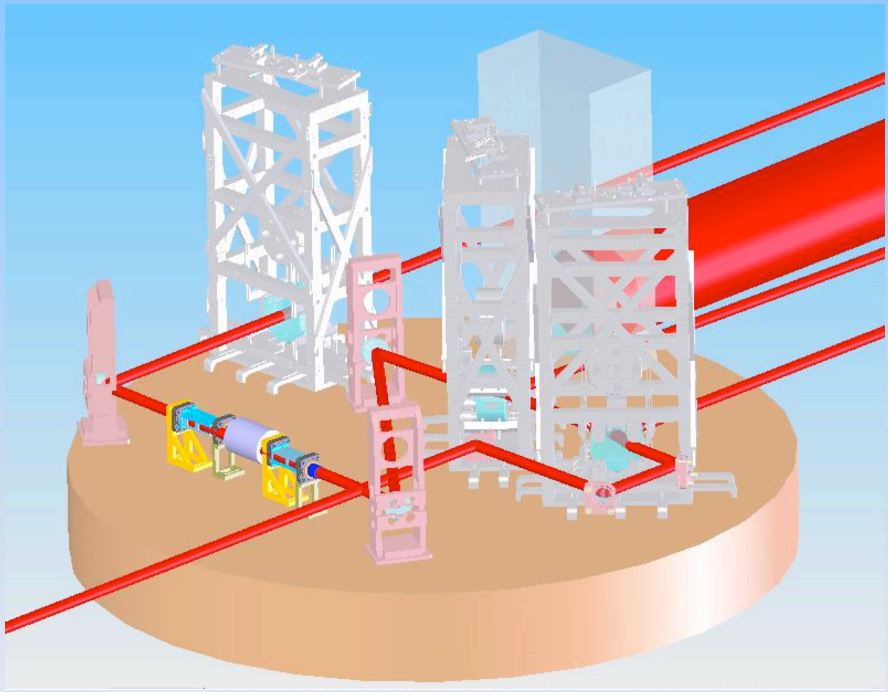
SML = Short Michelson Length, * Beam Size mentioned are 1/e^2 (Intensity) beam radius, # Y arm, Ψ X arm

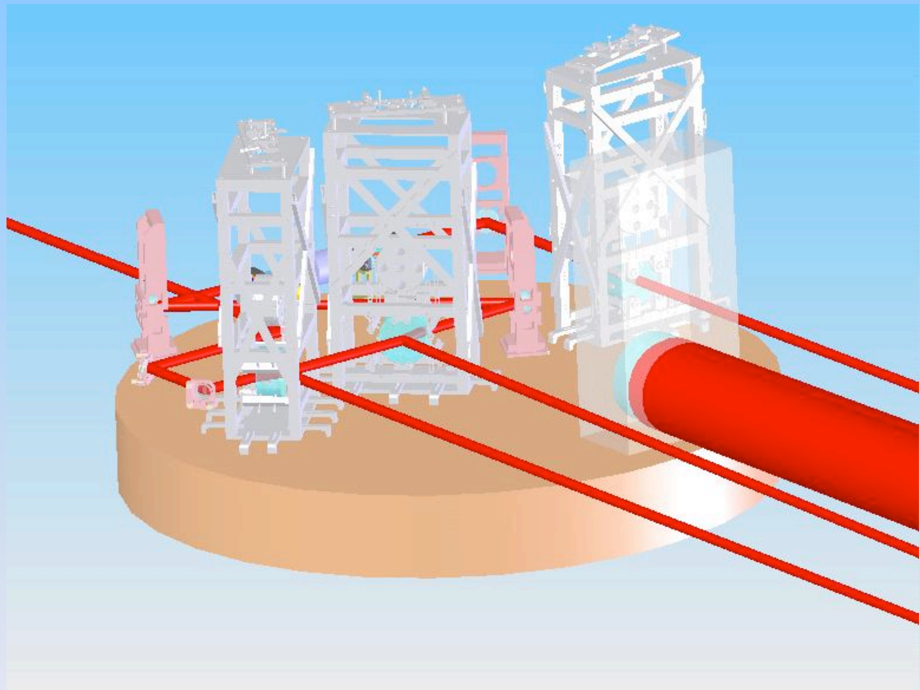
Guido Mueller - T0900043 - Oct 2009

aLIGO design/PRC



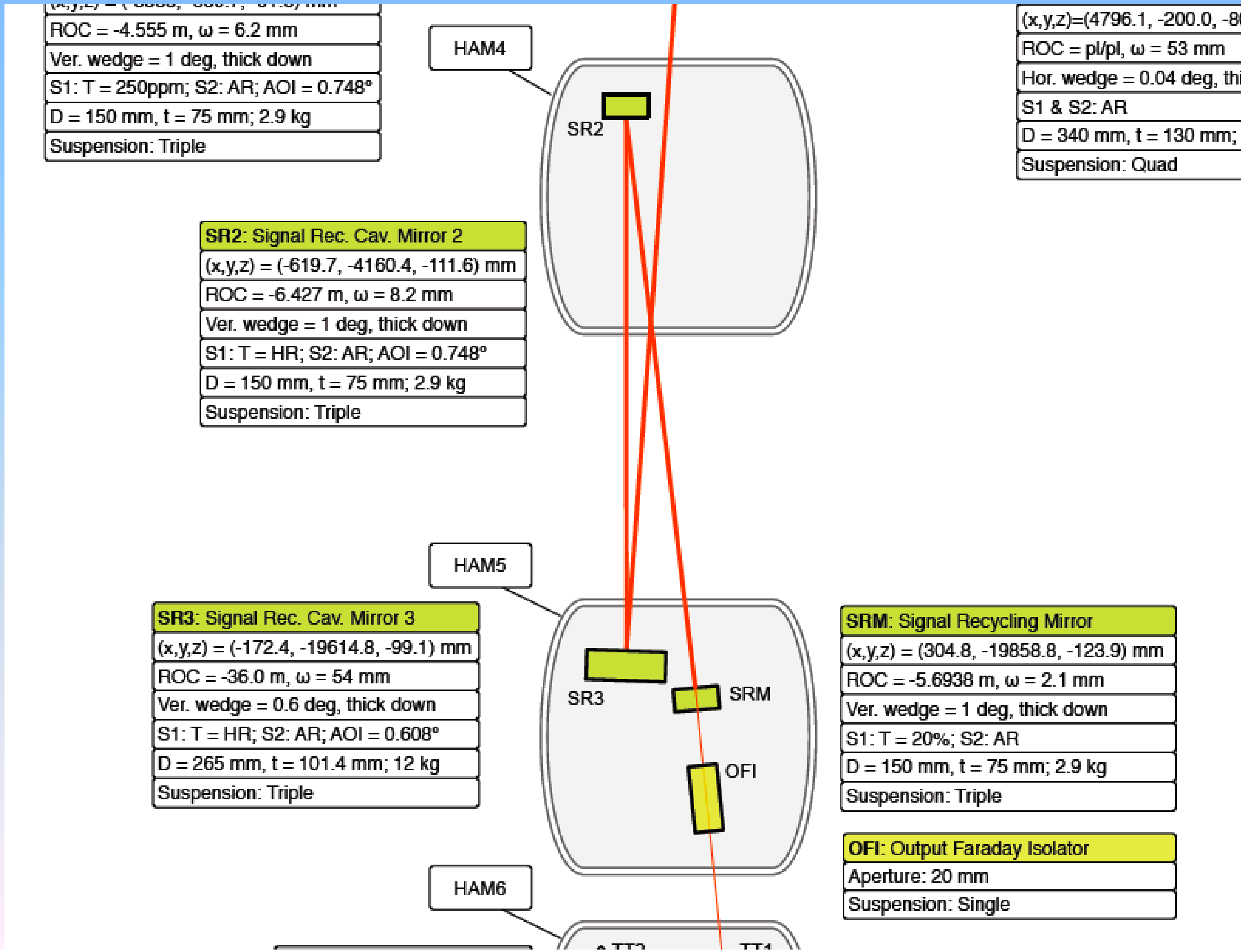
aLIGO PRC design/details





Guido Mueller - G050526-00 - May 2005

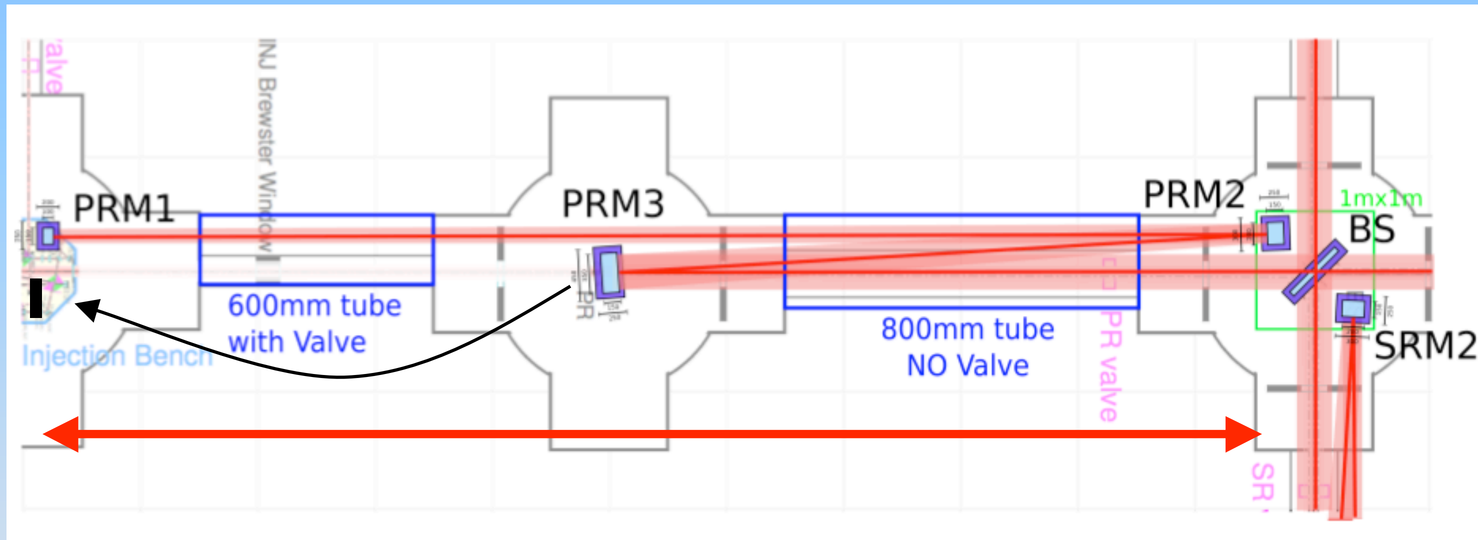
aLIGO design/SRC



Scenario *2bis*

0.50 m

(aLIGO 0.48 m)



~10.5 m (aLIGO 16m)

Angles ~1.3 deg

Thermal effects

Inputs from TCS: expected performances for AdVirgo

- With P=125 W and 0.5 ppm absorption : 4.5 km focal length expected
- Higher absorptions measured in Virgo - which is the realistic value for absorption?

- Thermal effects + TCS simulated maps available (made with ANSYS+ Zemax / profile obtained with axicon)
- Compensation profile can be improved wrt Virgo - how much?

- Sensing will be improved wrt Virgo - how much?

How to include TCS in OSD simulation?

- Two inputs:

  1/ Residual deformation of the HR surfaces (ITM and ETM)

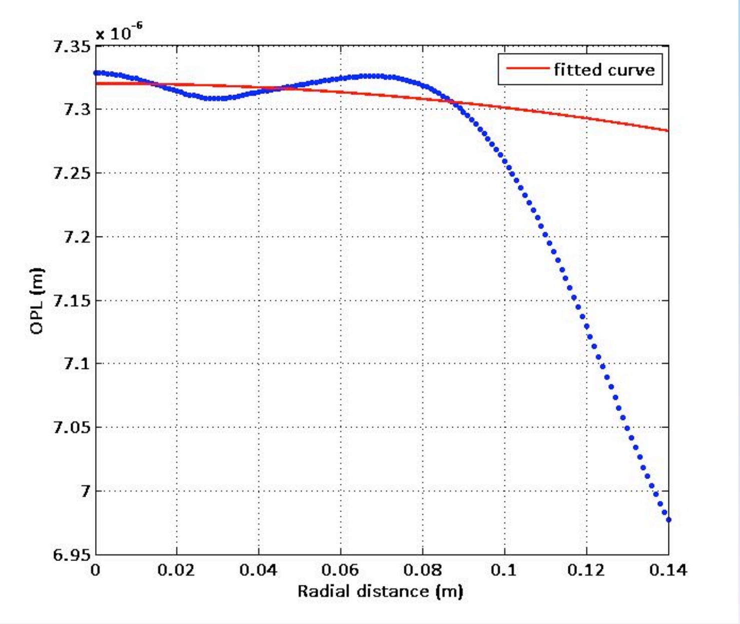
  2/ Residual optical path length OPL (ITM substrate)

- Quadratic fit of the OPL gives 256 km thermal lens

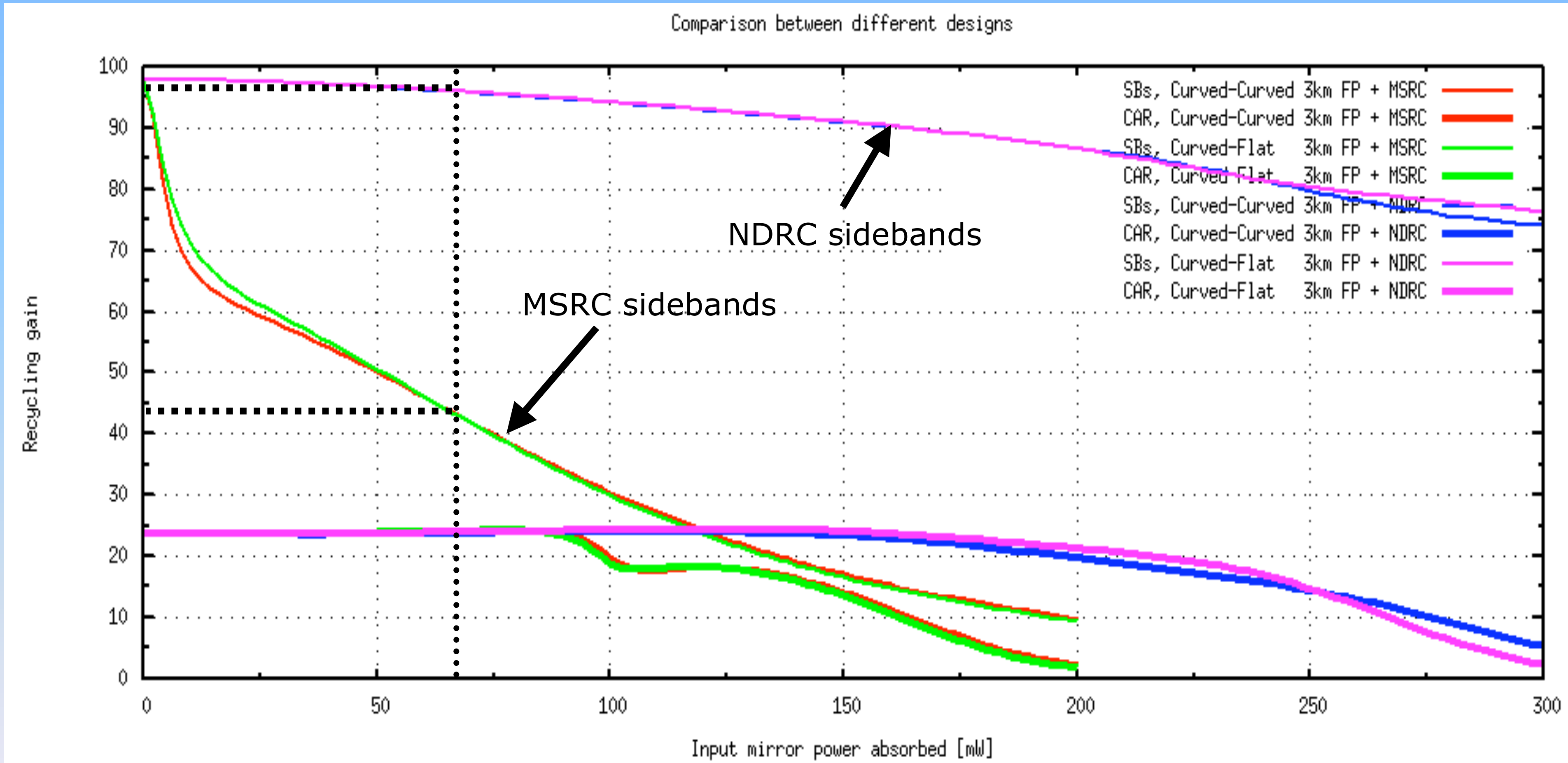
  Really a good approximation?

  Coupling losses

  - with 256 km lens = 300 ppm
  - with real OPL = 2200 ppm



RF sidebands in PRC



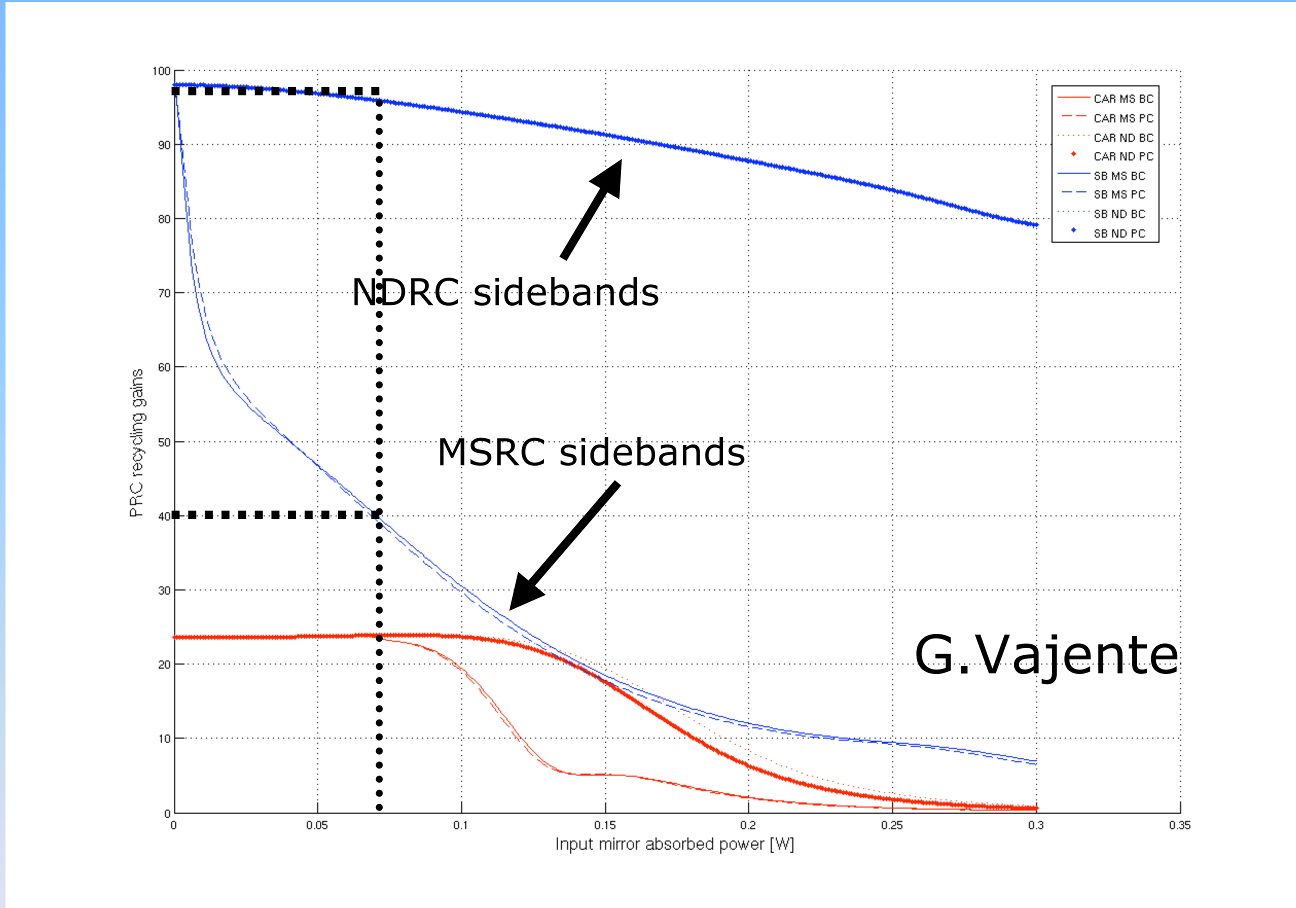
J.Marque

40 km thermal lens G_rec ~50% for MSRC, >90% for NDRC

Recycling gain (total power for all modes)

RF sidebands in PRC

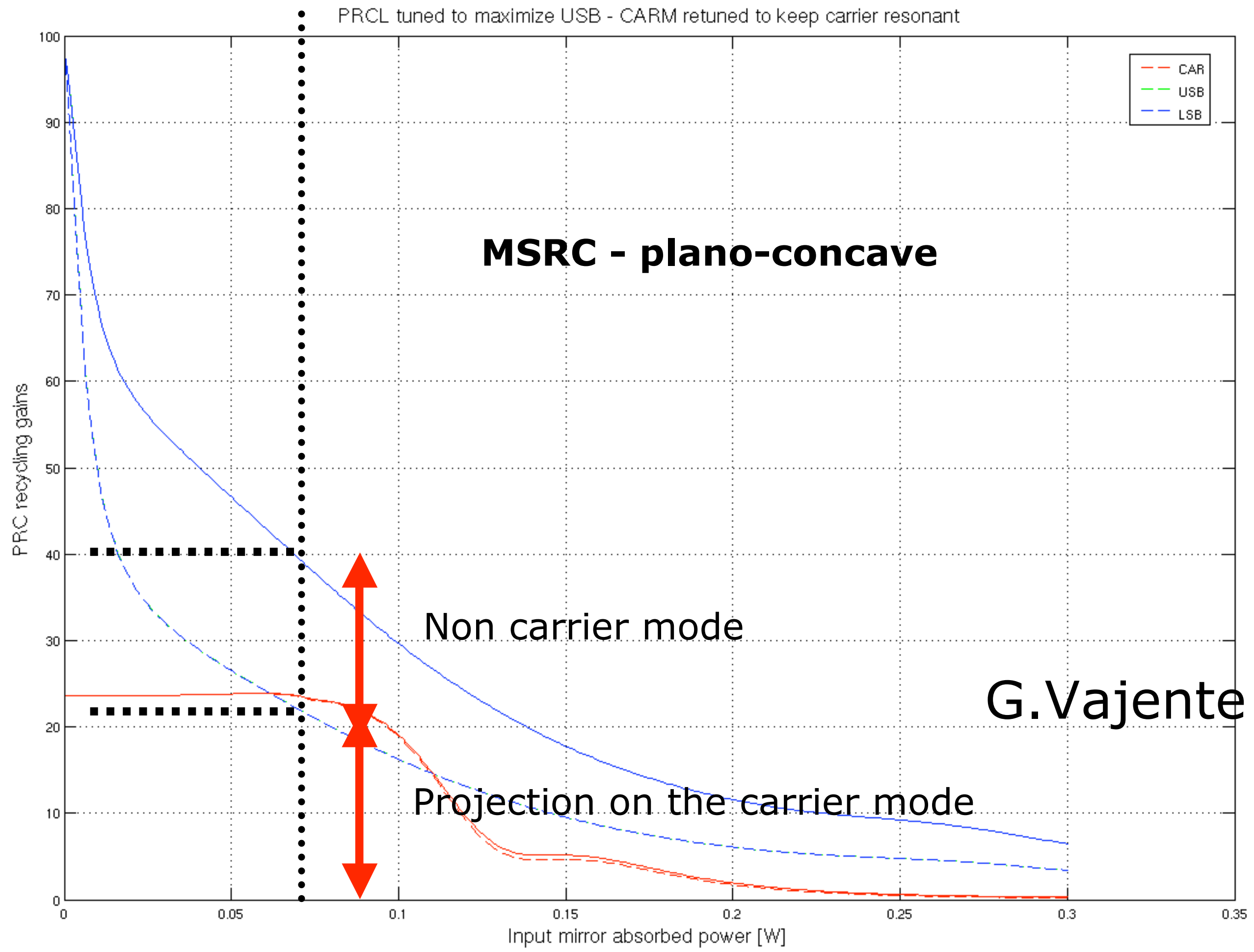
- Recycling gain (total for all modes)
- "Locked" error point (adjust position of PR and NE)



40 km thermal lens G_rec ~50% for MSRC, >90% for NDRC

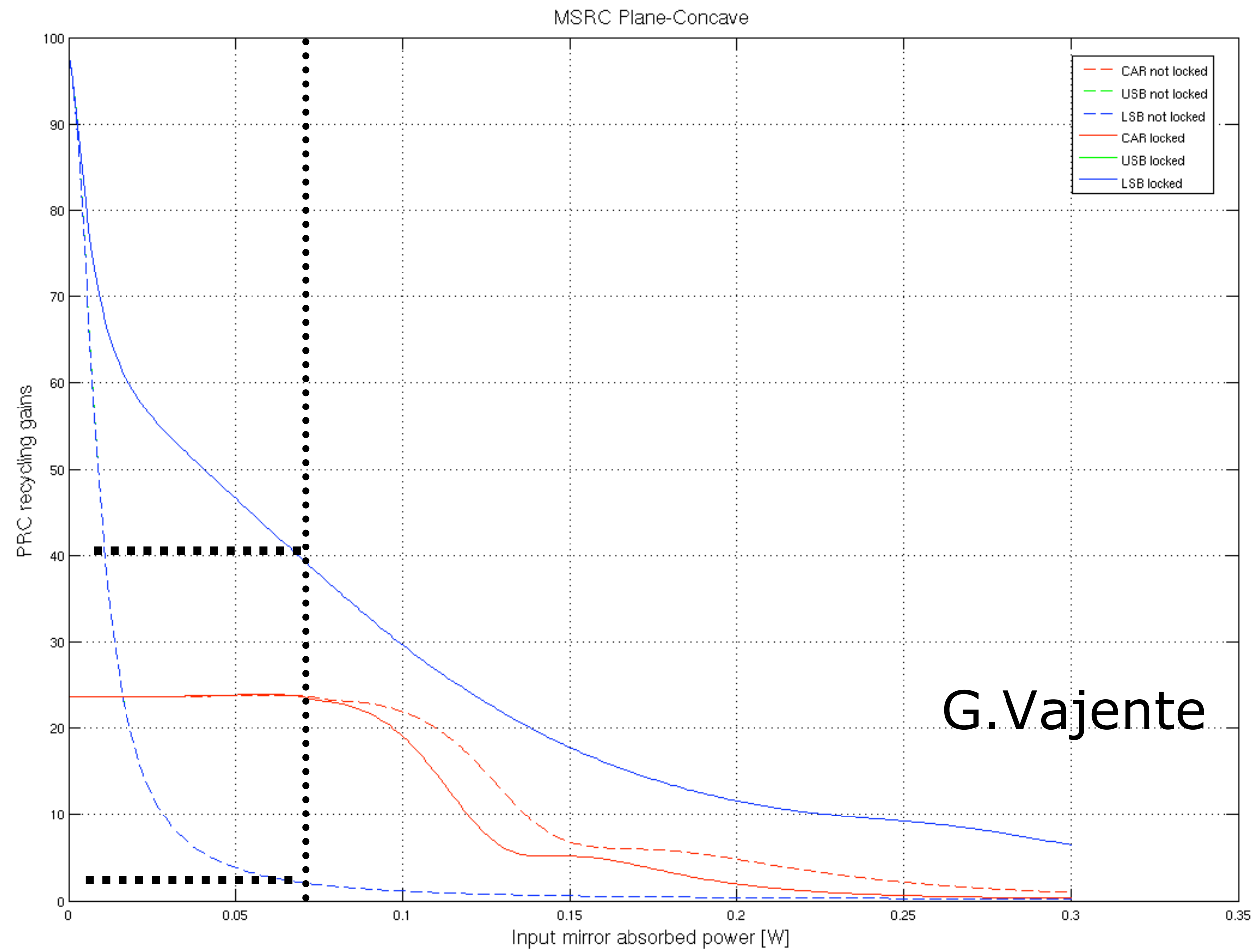
Recycling gain (total power for all modes)

RF SB in PRC: overlap with carrier



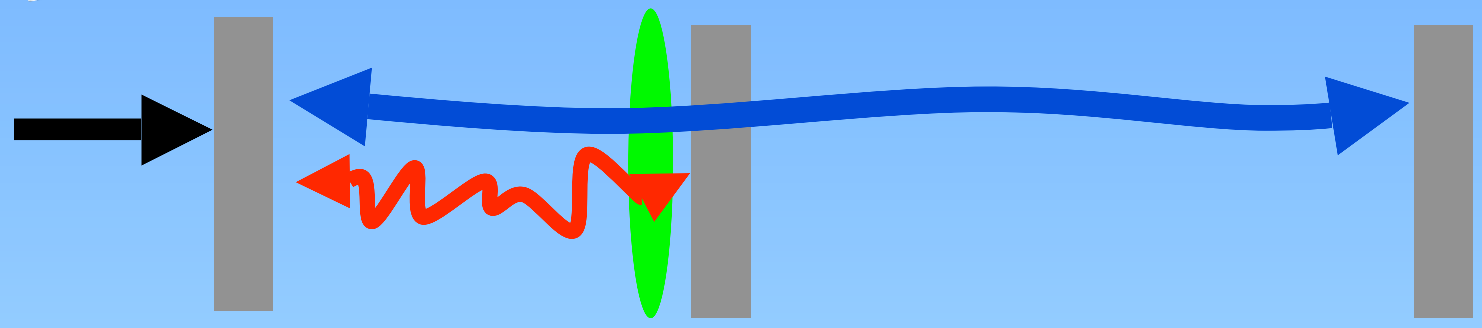
40 km thermal lens G_rec ~25%

RF SB in PRC: locking point



For f=40 km, Maximizing SB ~50%, Not moving NE ~a few %

Locking point issue



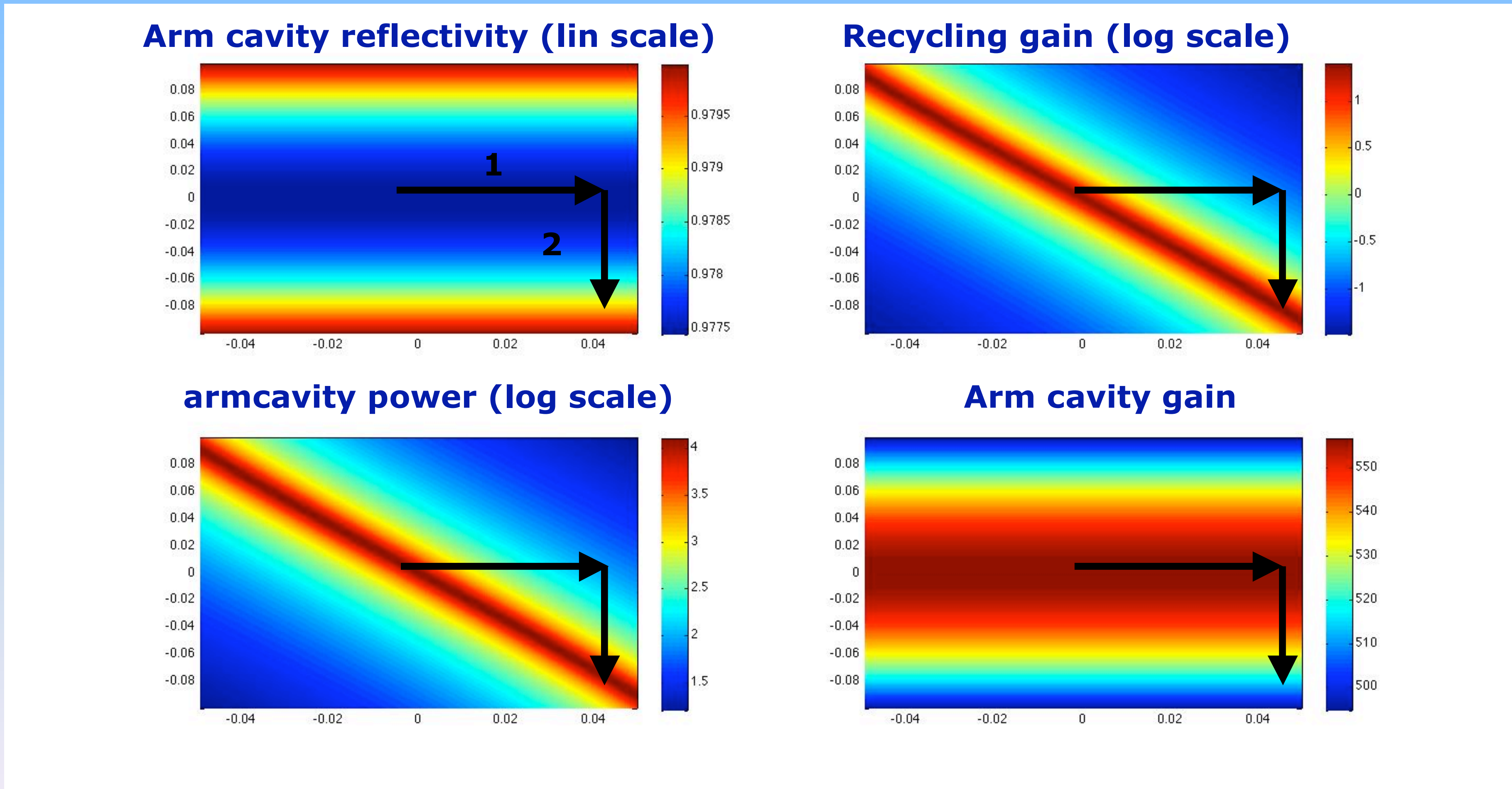
Hypothesis: the thermal lensing (or error in PR ROC) does not change the arm-cavity length

2 possibilities to recover the field resonances:

- Recover CAR resonance changing only PR length
  - Drawback: SB not in the optimal point
- Recover SB resonance by changing PR length and recover CAR resonance changing arm length (CARM)
  - Drawback: arm cavity slightly detuned for carrier

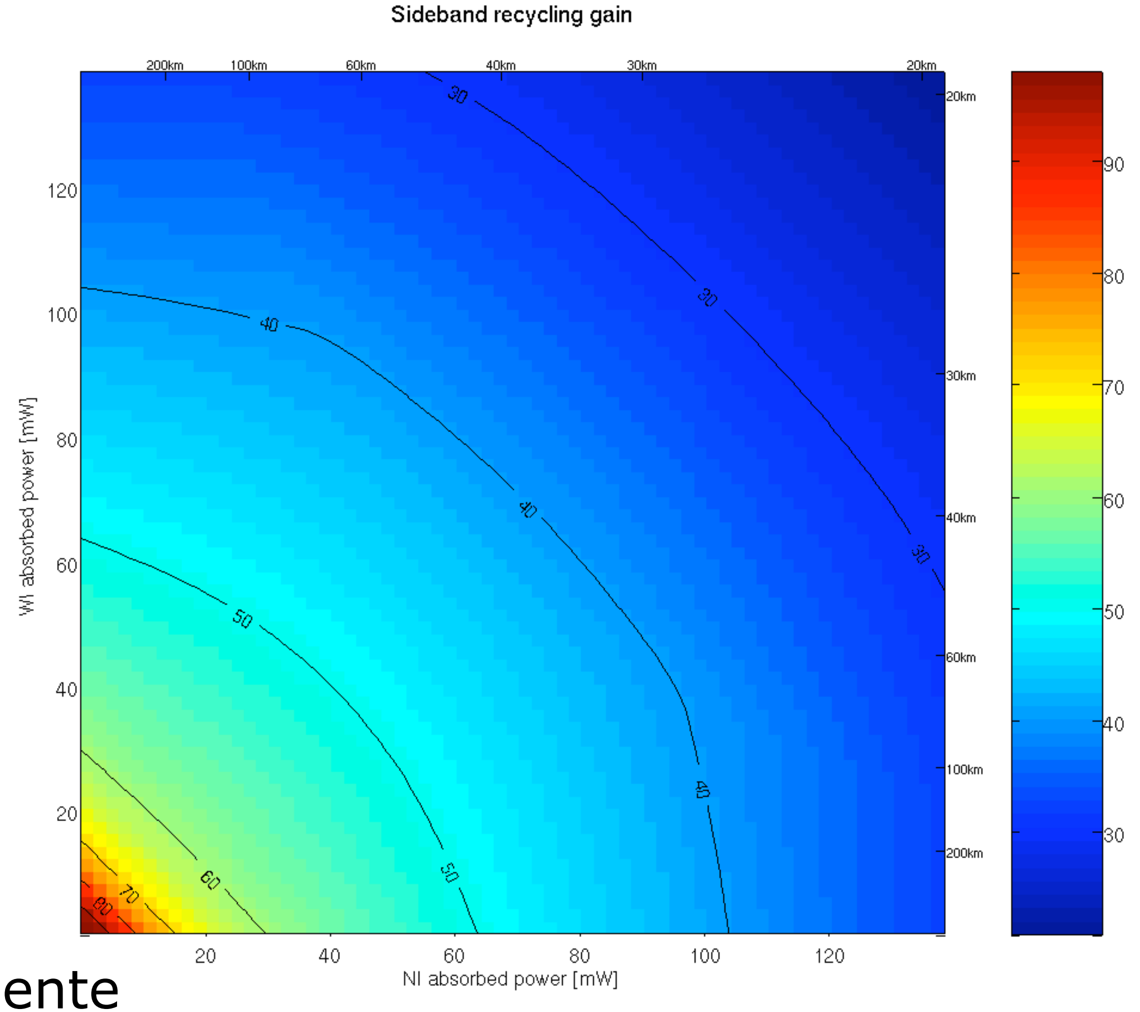
Consequences of moving CARM to be better understood

Locking point isssue



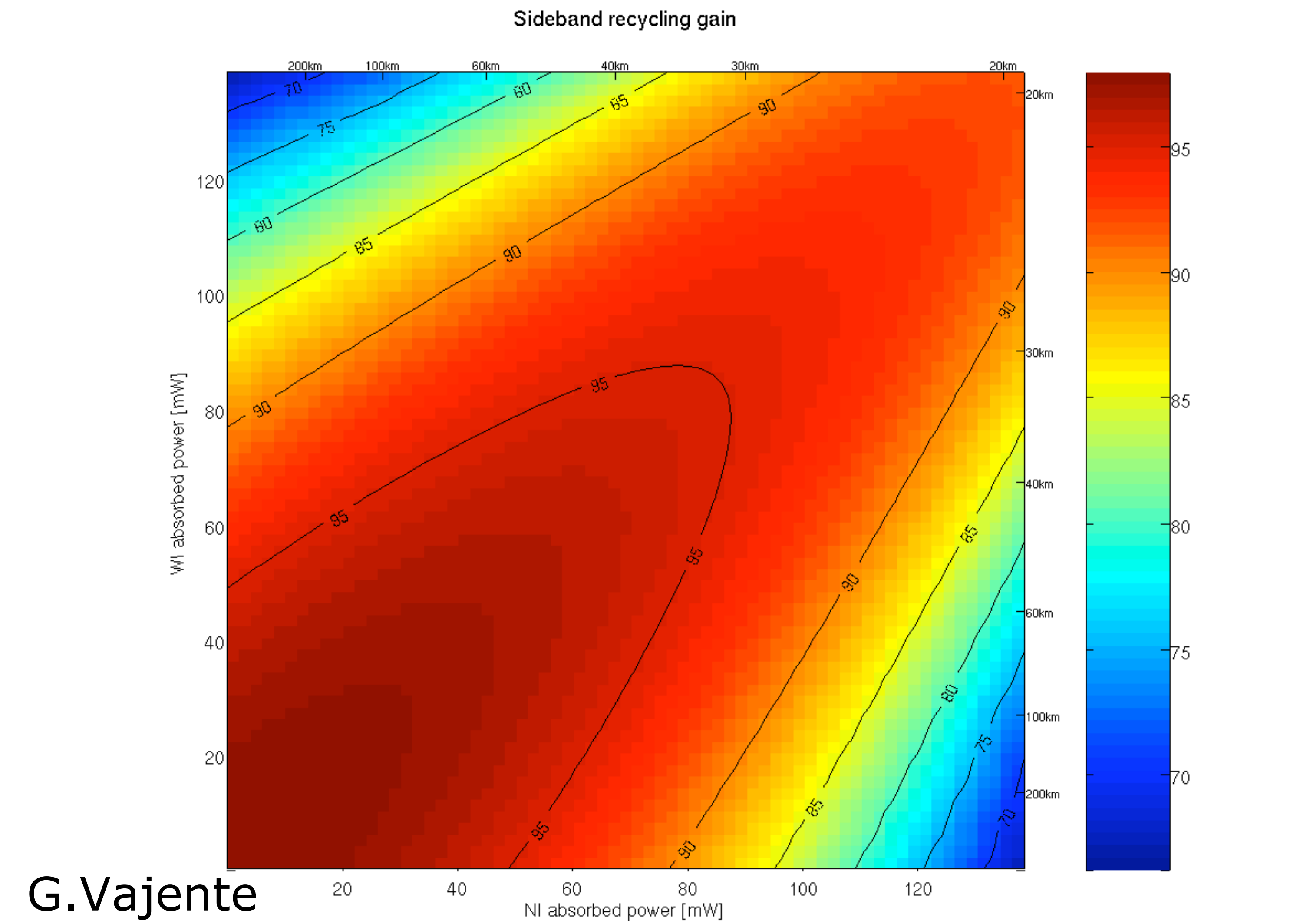
X ΔPR (microns) Y ΔNE (nm)

RF sidebands in PRC - marginally stable, complete interferometer



G.Vajente

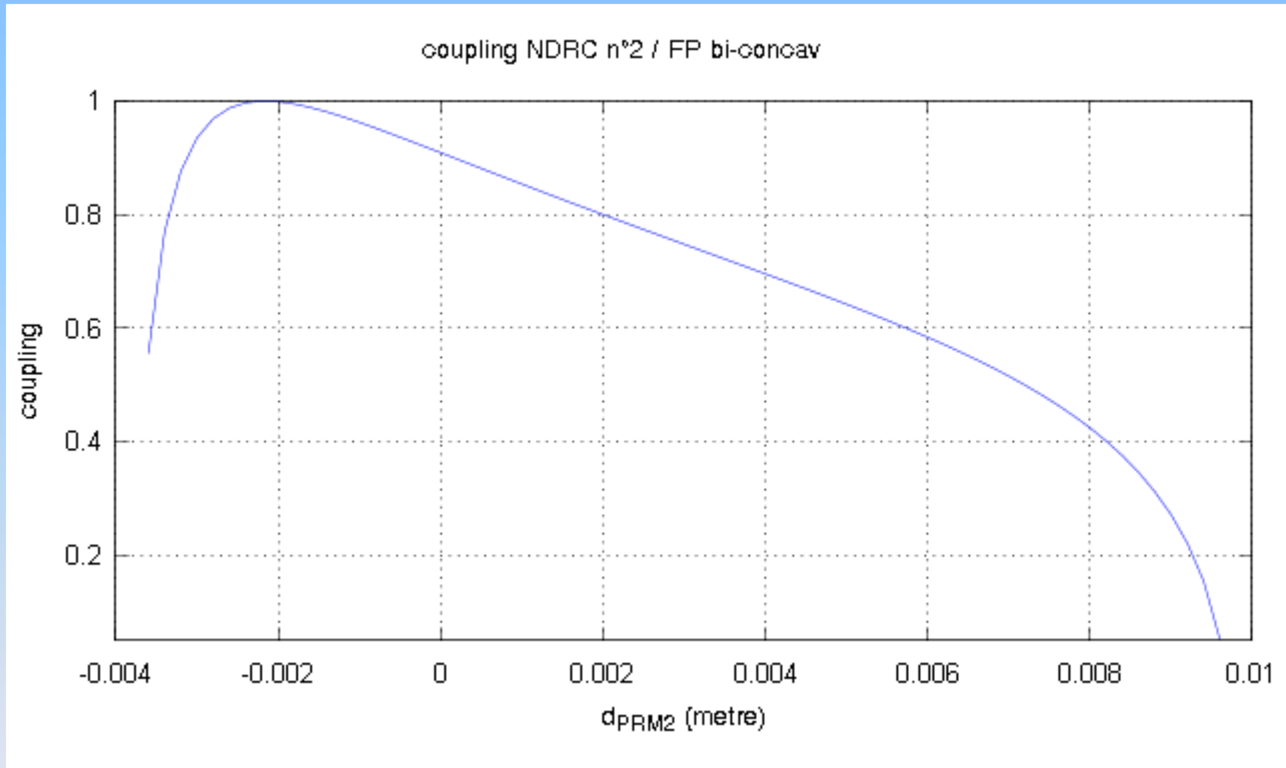
RF sidebands in PRC- stable, complete interferometer



G.Vajente

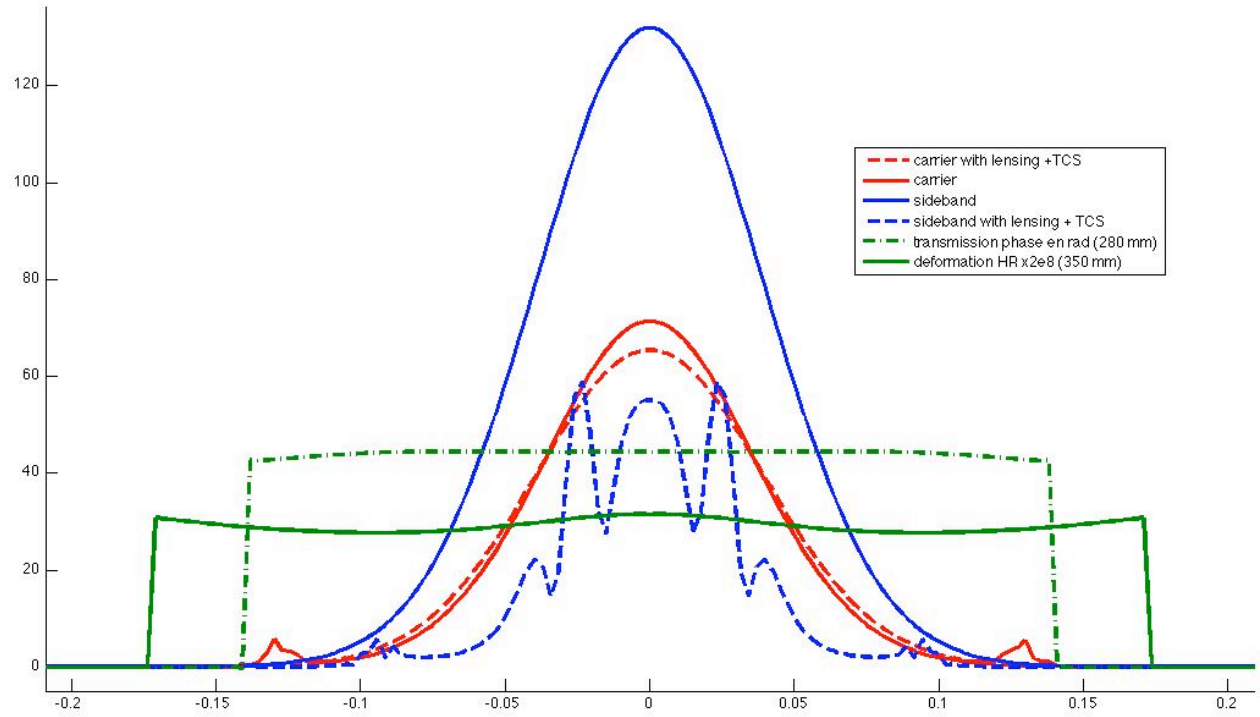
No astigmatism

Telescope adjustment



R.Bonnand/R.Flaminio

SIS: thermal effects

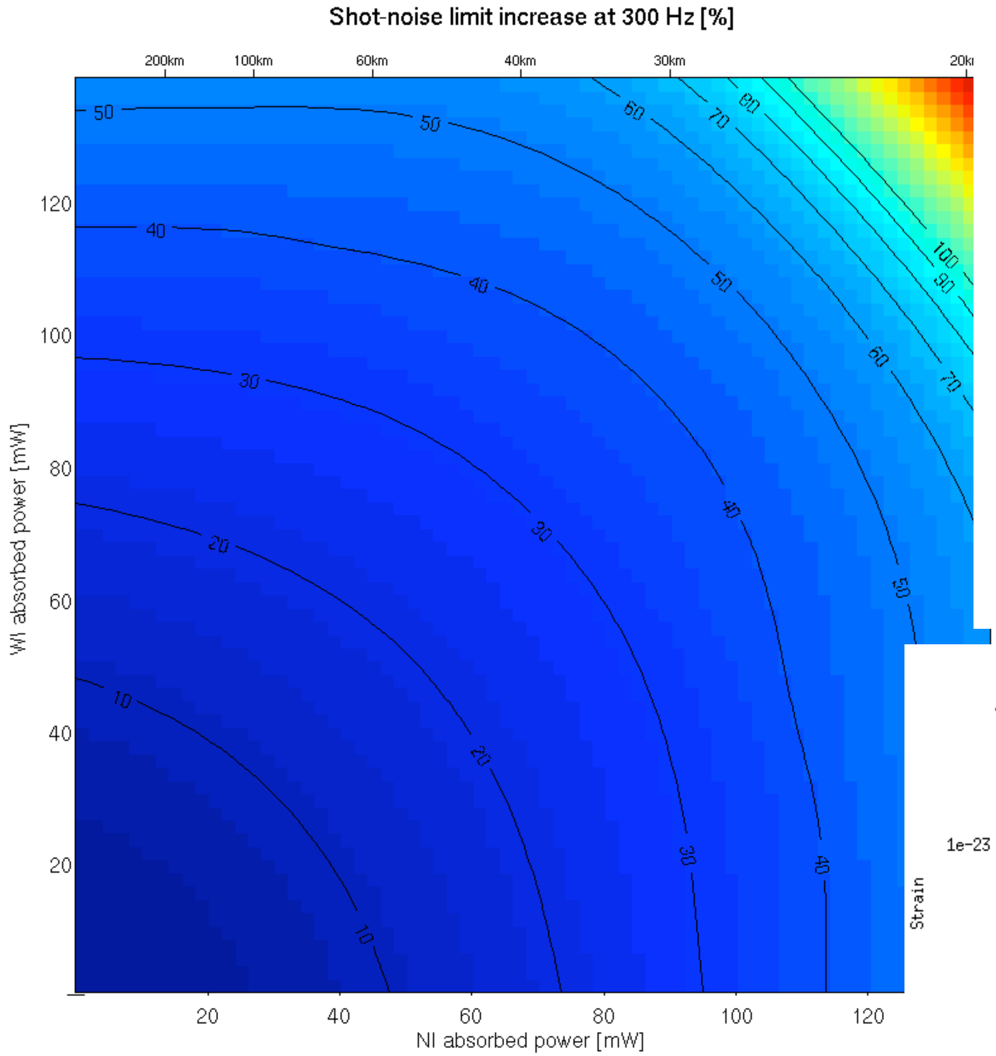


Real thermal +TCS maps in bi-concave cavities + marginally stable recycling cavities

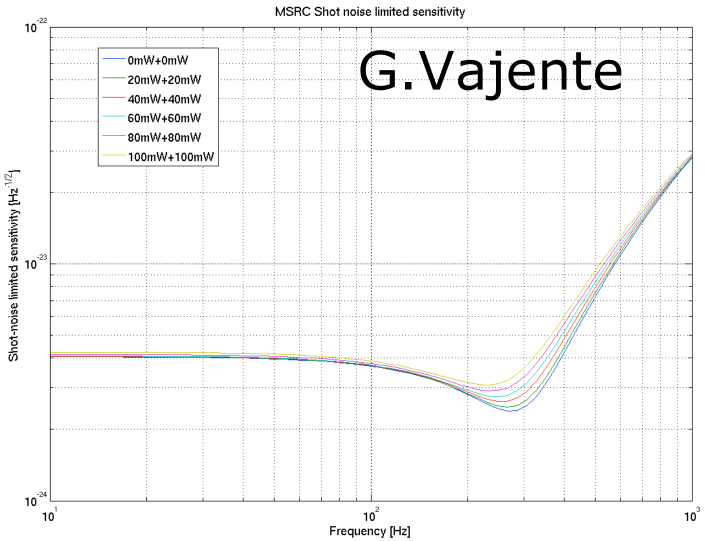
RF sidebands in marginally stable cavities - summary

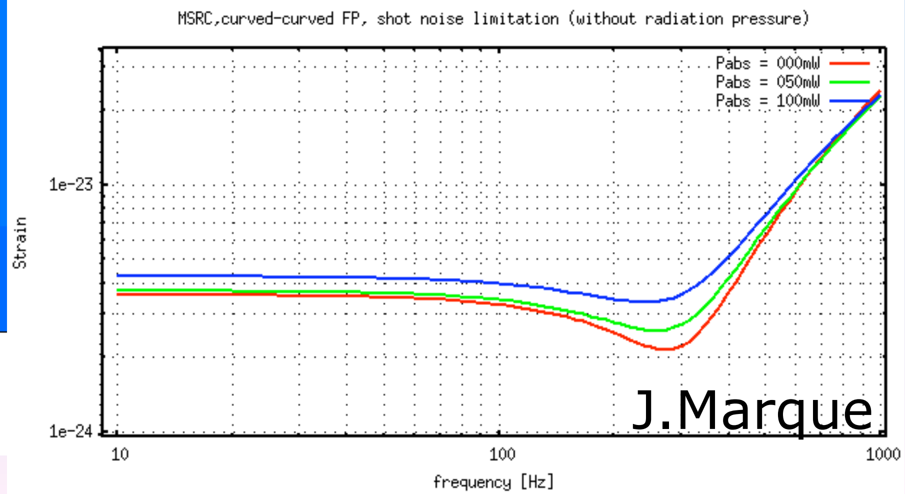
- With 40 km focal length (plano-concave)
  - ~ 40 % recycling gain (~ 20% on TEM00) - **Gabriele's code-** CARM adjusted - similar results with **Finesse, Julien** (a few % if CARM is not adjusted)
  - 50% **Romain/Raffaele, ABCD matrix**
  - a few % - **SIS** (PR ROC error) - CARM not adjusted
- With 250 km focal length (plano-concave)
  - ~ 60 % recycling gain(~ 30% on TEM00) - **Gabriele's code** - CARM adjusted
  - ~20% on TEM00 (PR ROC error) - **SIS** - CARM not adjusted
- Real thermal maps (bi-concave)
  - a few % - **SIS** - CARM not adjusted

SNR loss-marginally stable

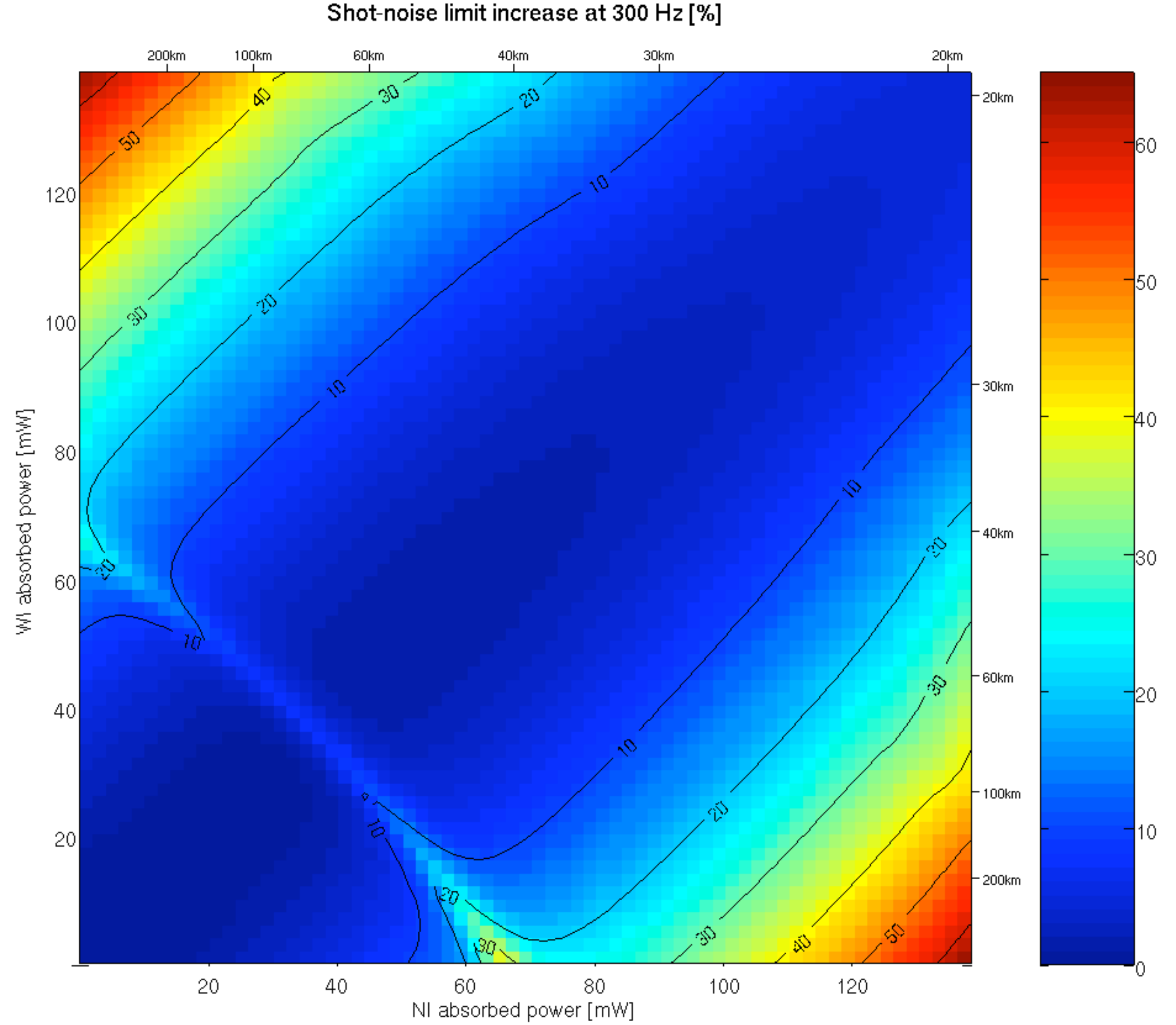


G.Vajente



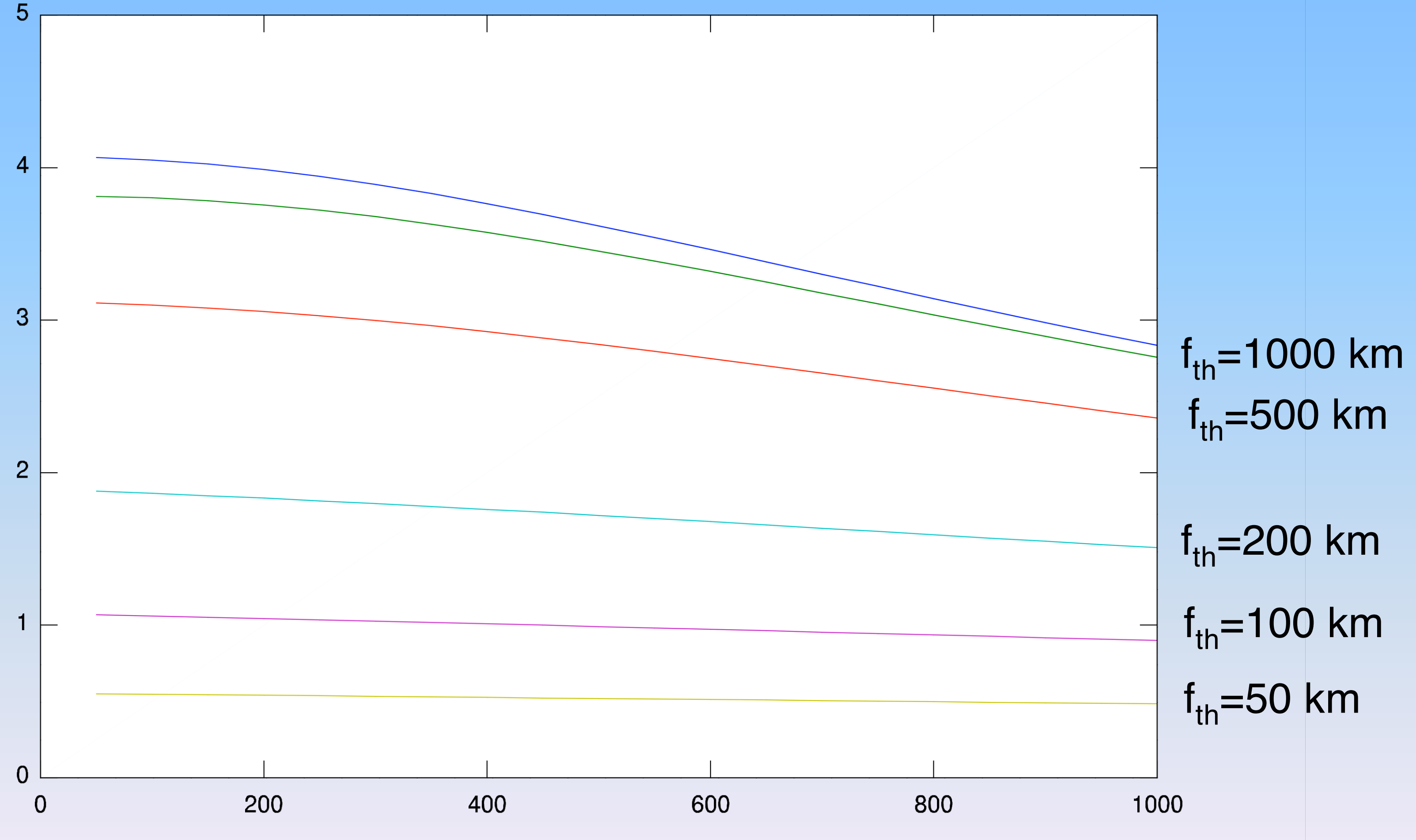


SNR loss - stable



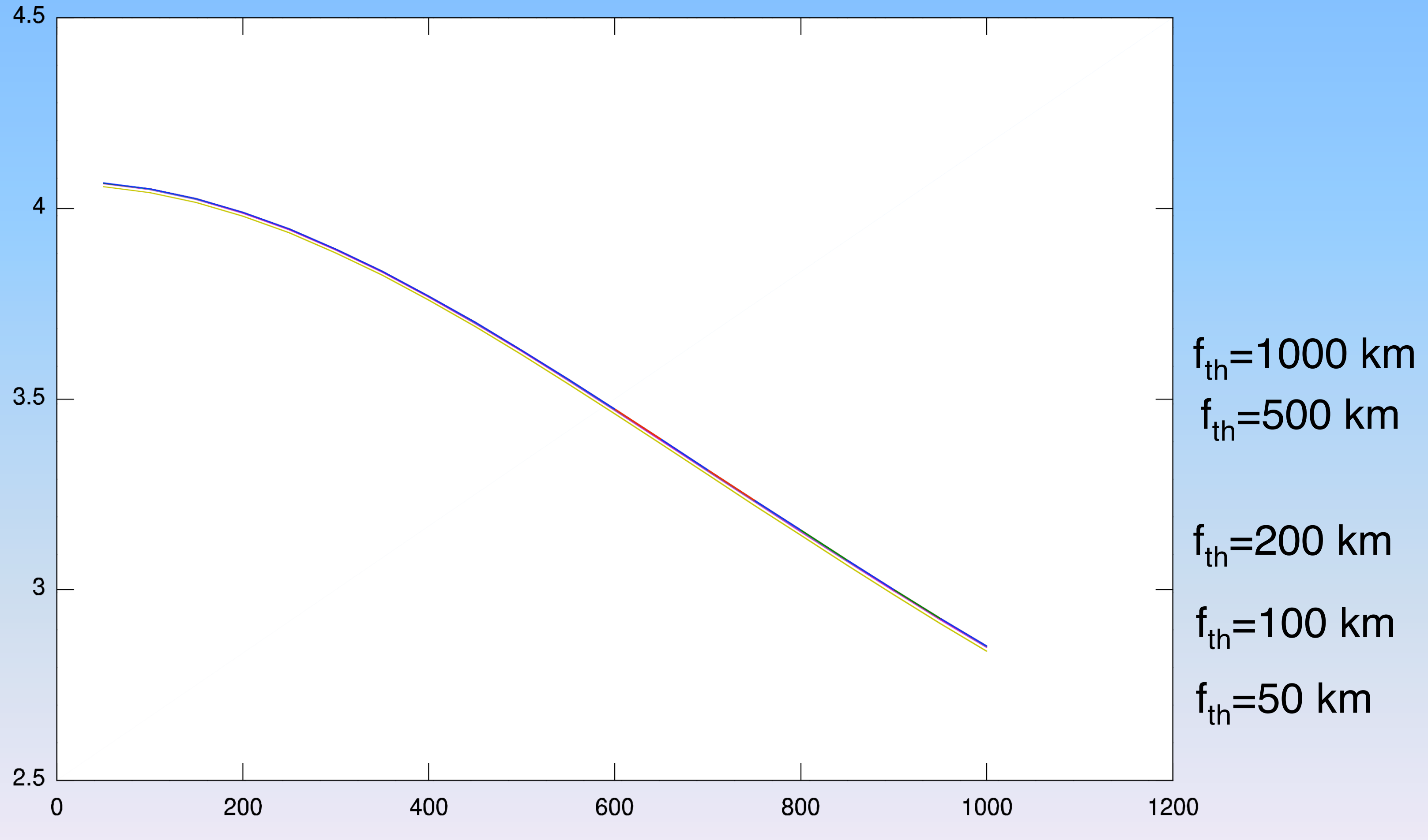
G.Vajente

Signal loss - marginally stable



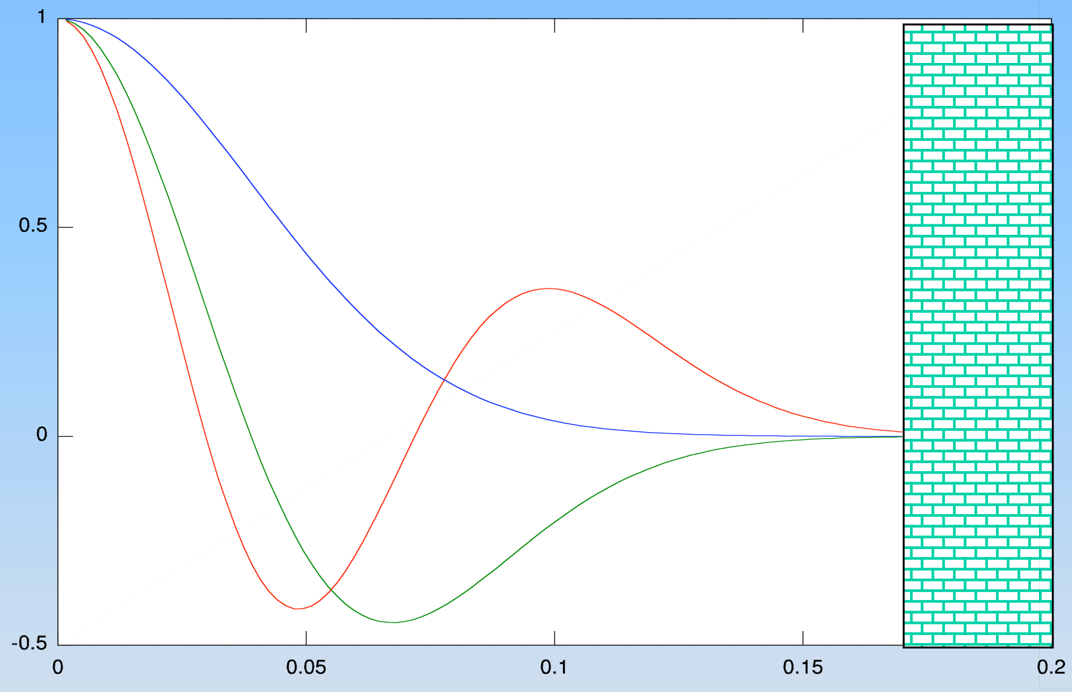
R.Flaminio-preliminary

Signal loss - stable

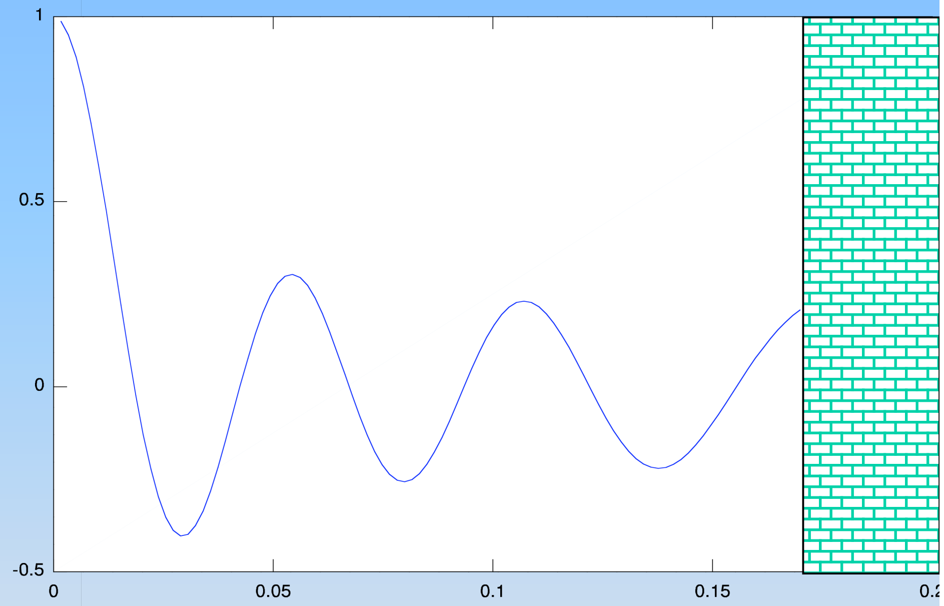


R.Flaminio-preliminary

Size of the modes:limitation or advantage



LG00, LG01, LG02

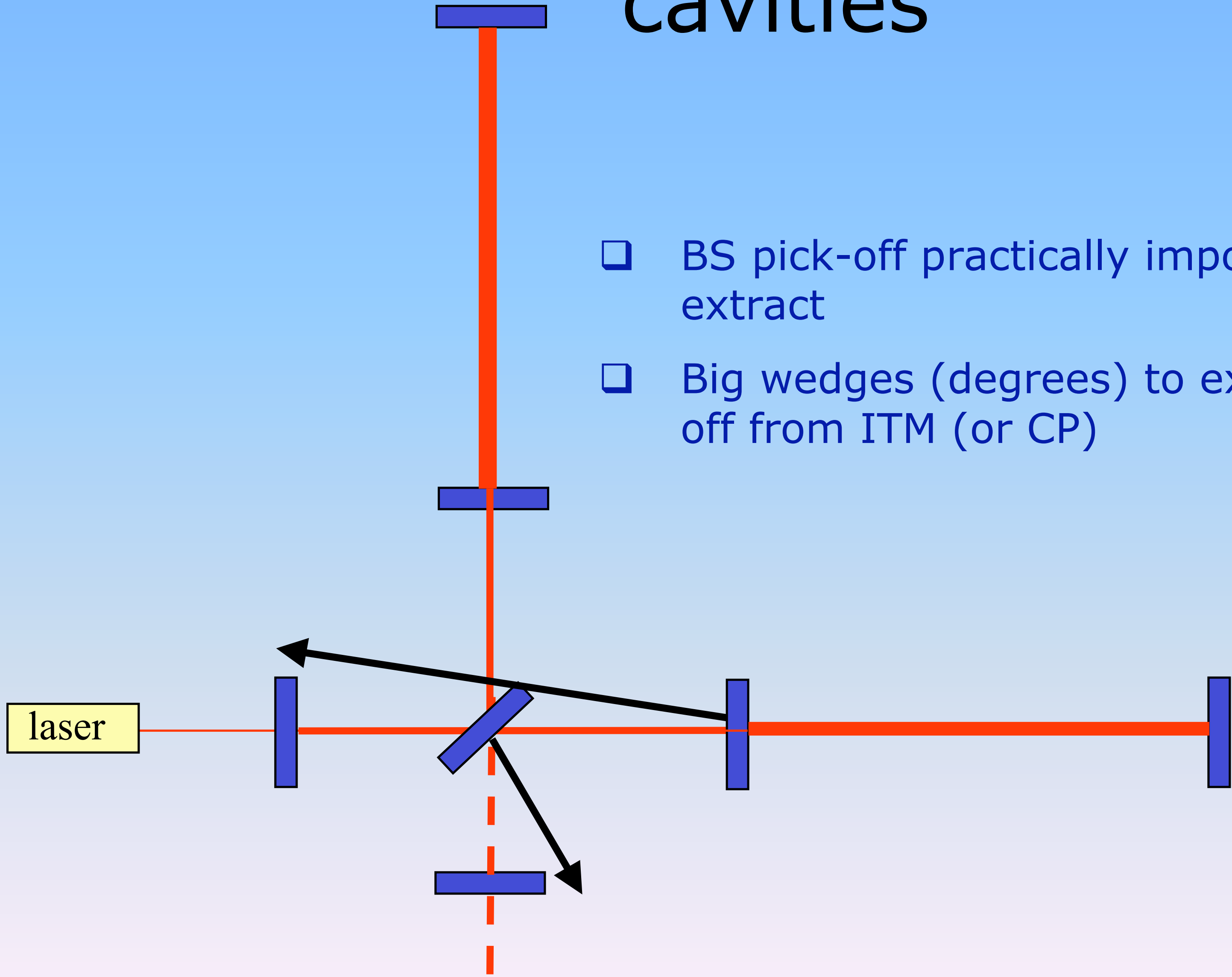


LG06

R.Flaminio-preliminary

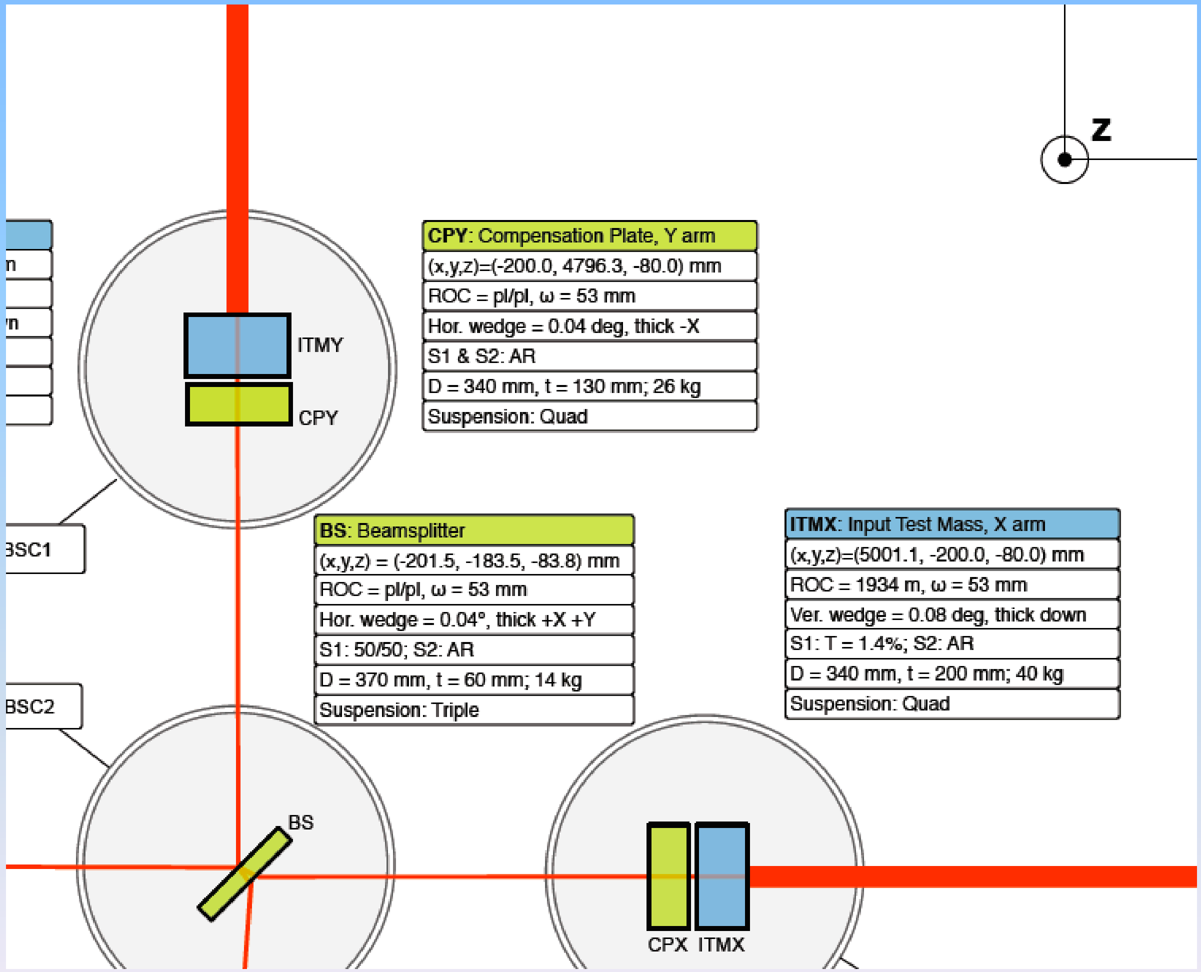
Pick-off extraction

Pick-off in marginally stable cavities

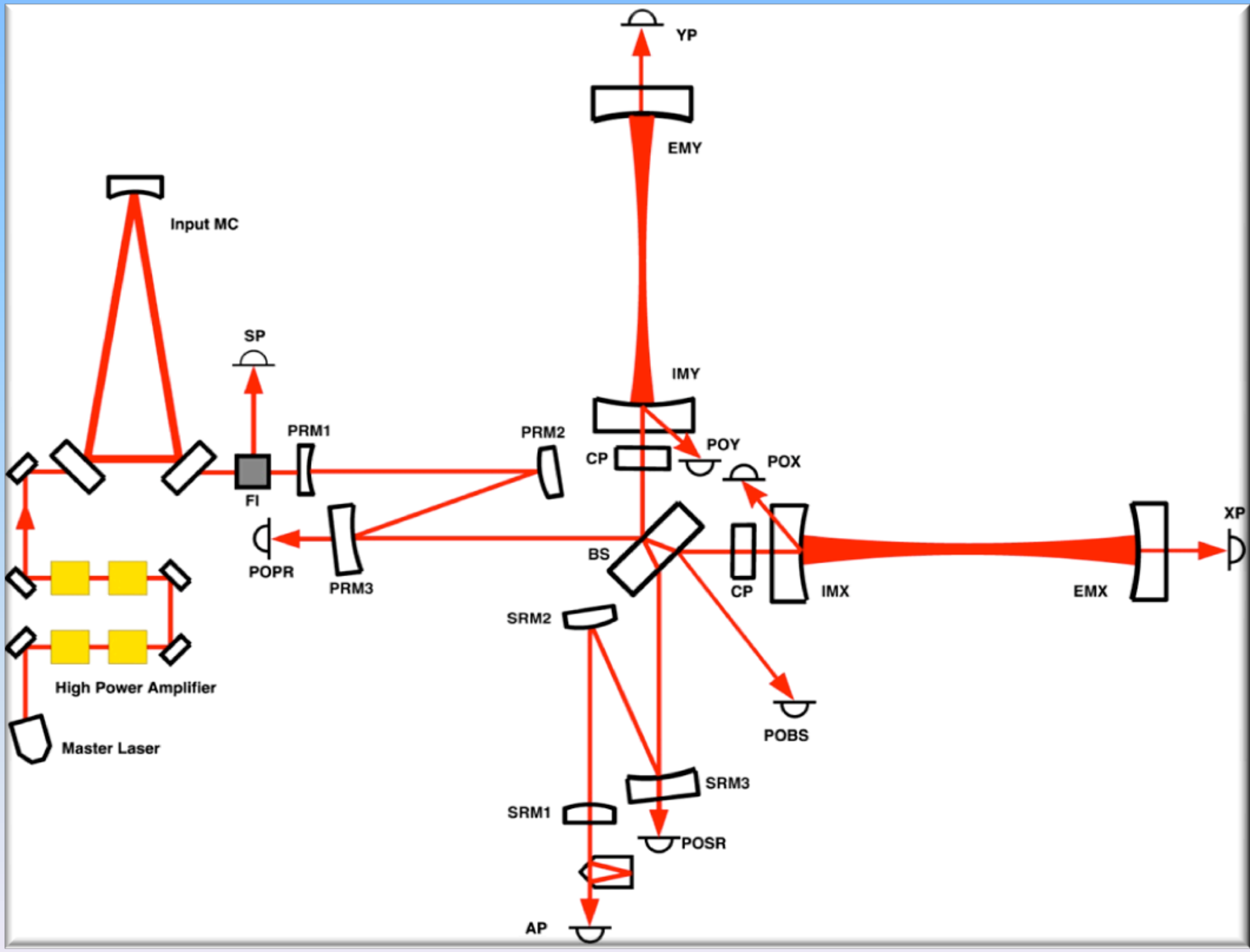


- BS pick-off practically impossible to extract
- Big wedges (degrees) to extract pick-off from ITM (or CP)

Wedges in aLIGO



Pick-off with stable cavities



Conclusions

- Stable cavities confirmed to be much better from optical point of view
  - RF sidebands **OK**
  - SNR loss **OK**
  - Possibility to adjust RM3-RM2 length to optimize matching
  - Pick-off extraction **OK**
  - *Astigmatism issues and differential heating effects to be better investigated*
- Marginally stable cavities
  - **Big decrease** of the RF audio sidebands gain (only ~20% coupled in TEM00 with 40 km focal length, CARM adjusted) - real TCS maps and other defects can give lower coupling
  - *No final results on SNR loss - work in progress*