Sensing and Controls for Power-Recycling of TAMA300

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and

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Introduction

- Power recycling for TAMA300

  Experiment begins this autumn.

  This Talk:

  Motivation for TAMA300 recycling

  Length sensing/control system

  Lock acquisition

Purpose of recycling on TAMA300 (1)

- Why no power recycling up to now

  Earlier operation as a gravitational wave detector

  ~ We could start the operation in 1999 Spring

  Every system for FPMI is strongly related with the recycled version

  ~ Length control with frontal modulation

  => subset of the recycled version

  ~ Calibration method

  Making development easier

  ~ Noise hunting

  ~ Longer lock duration

  ~ Simpler diagnoses/analyses

Purpose of recycling on TAMA300 (2)

- Scientific motivation

  Power recycling improves the senstivity of TAMA

  ~ not only substantially

  but also practically

- Technical challenge

  Integrating the experiences

  ~ past recycled prototypes and non-recycled TAMA

  Investigating behaviours of IFO under power recycling

  ~ detector diagnoses / data quality evaluation

  Experiencing power-recycling with longer arms

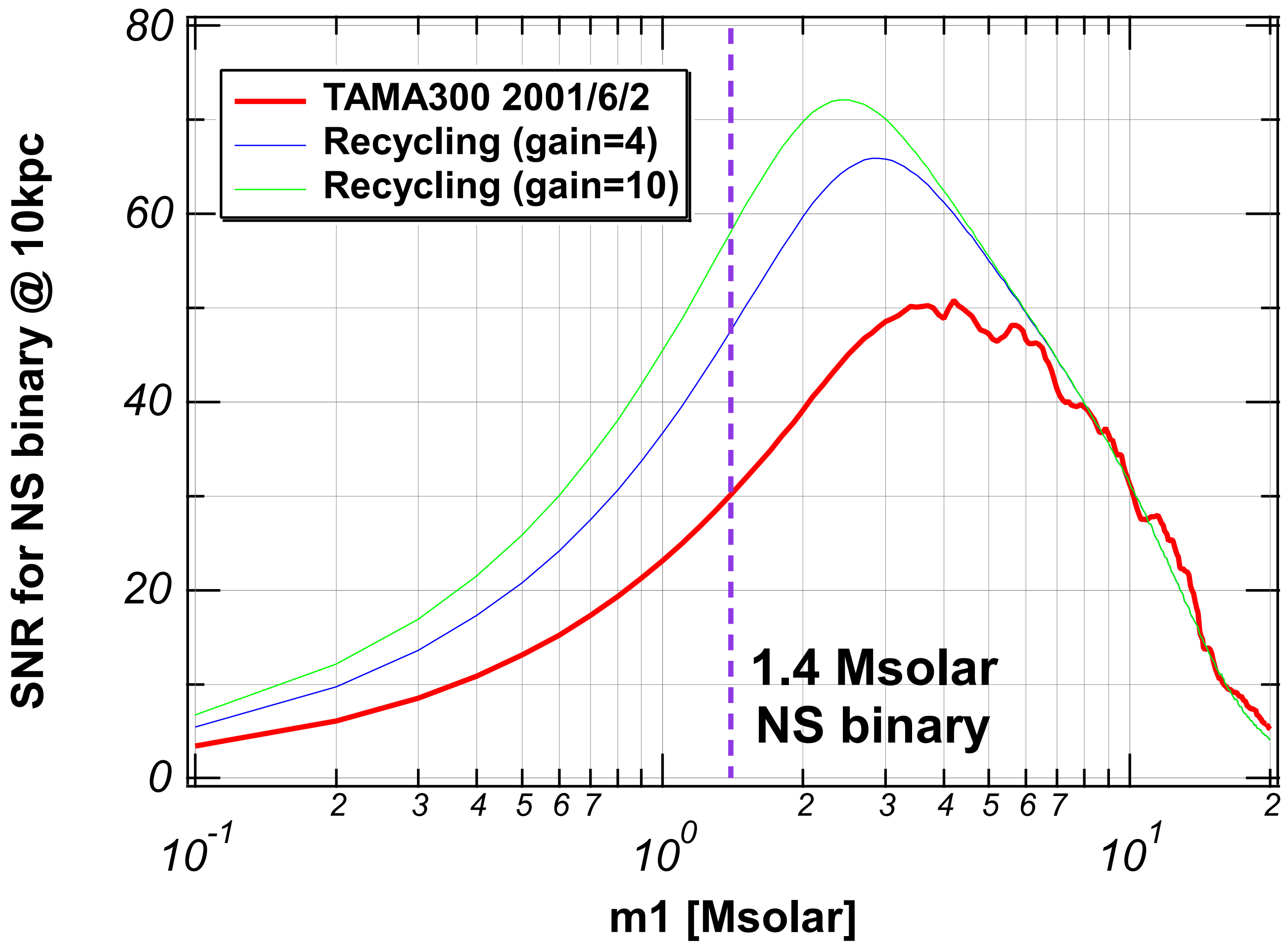
  ~ prospect to LCGT

Increasing SNR with power recycling

- Reduction of read-out noise

Even with the current level of technical noises,

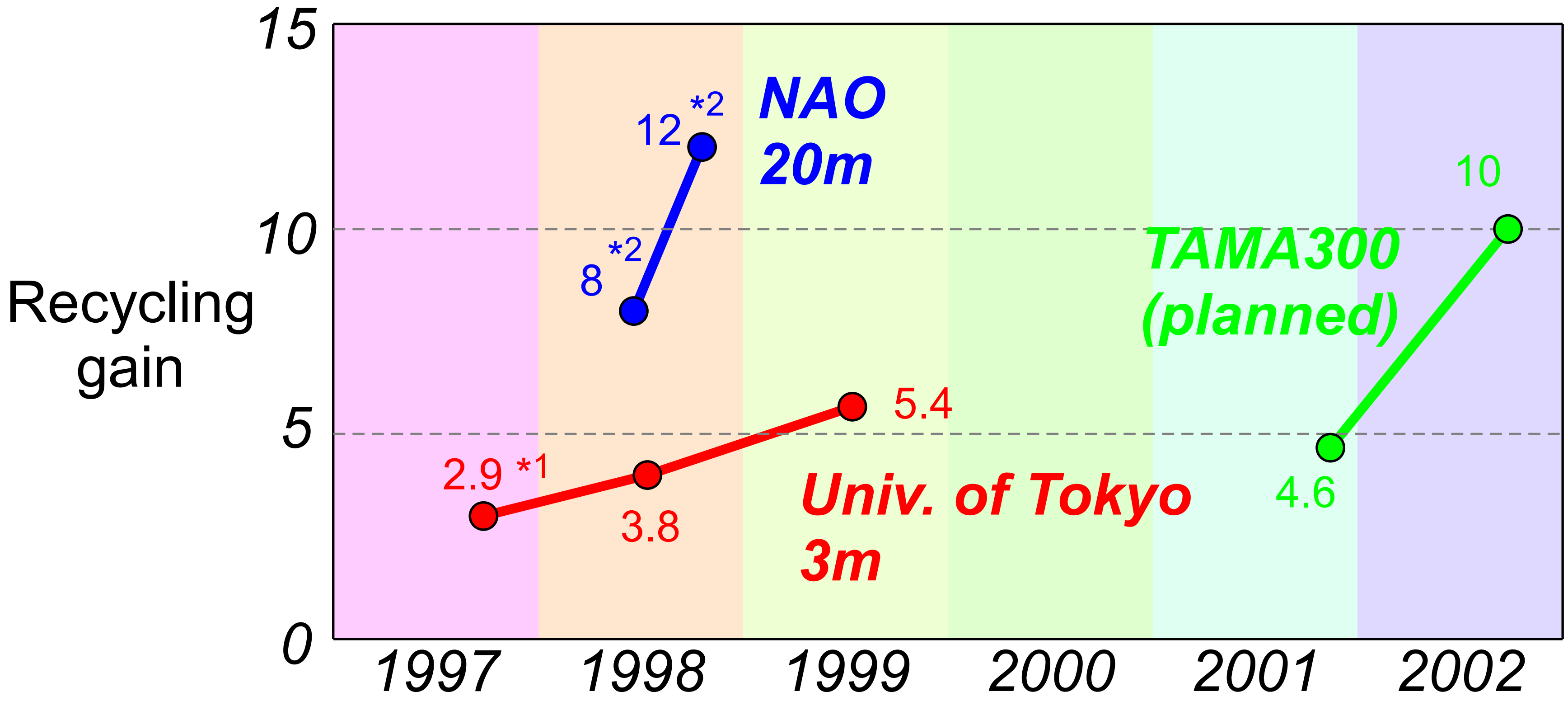
power-recycling is expected to improve SNR to NS binary coalescence



Experience on power recycling

- Recycling gain

~ achieved in past prototypes in Japan and planned for TAMA300



Power recycling for TAMA300 ~ within our experiences except for its length

*1 M. Ando, et al, Phys. Lett. A 248 (1998) 145
*2 S. Sato, et al, Appl. Opt. 39 (2000) 25, 4616

Strategy

- Divided into two phases ~ low gain and high gain

1st step: Low gain recycling (R$_{RM}$~48%, G~4.6)

Target: Easier lock acquisition

=> Possibility of earlier full operation / observation

=> Feeding back information to design of high gain recycling

=> Establishing techniques for detector diagnoses / data analyses

2nd step: High gain recycling (R$_{RM}$~90%, G~10)

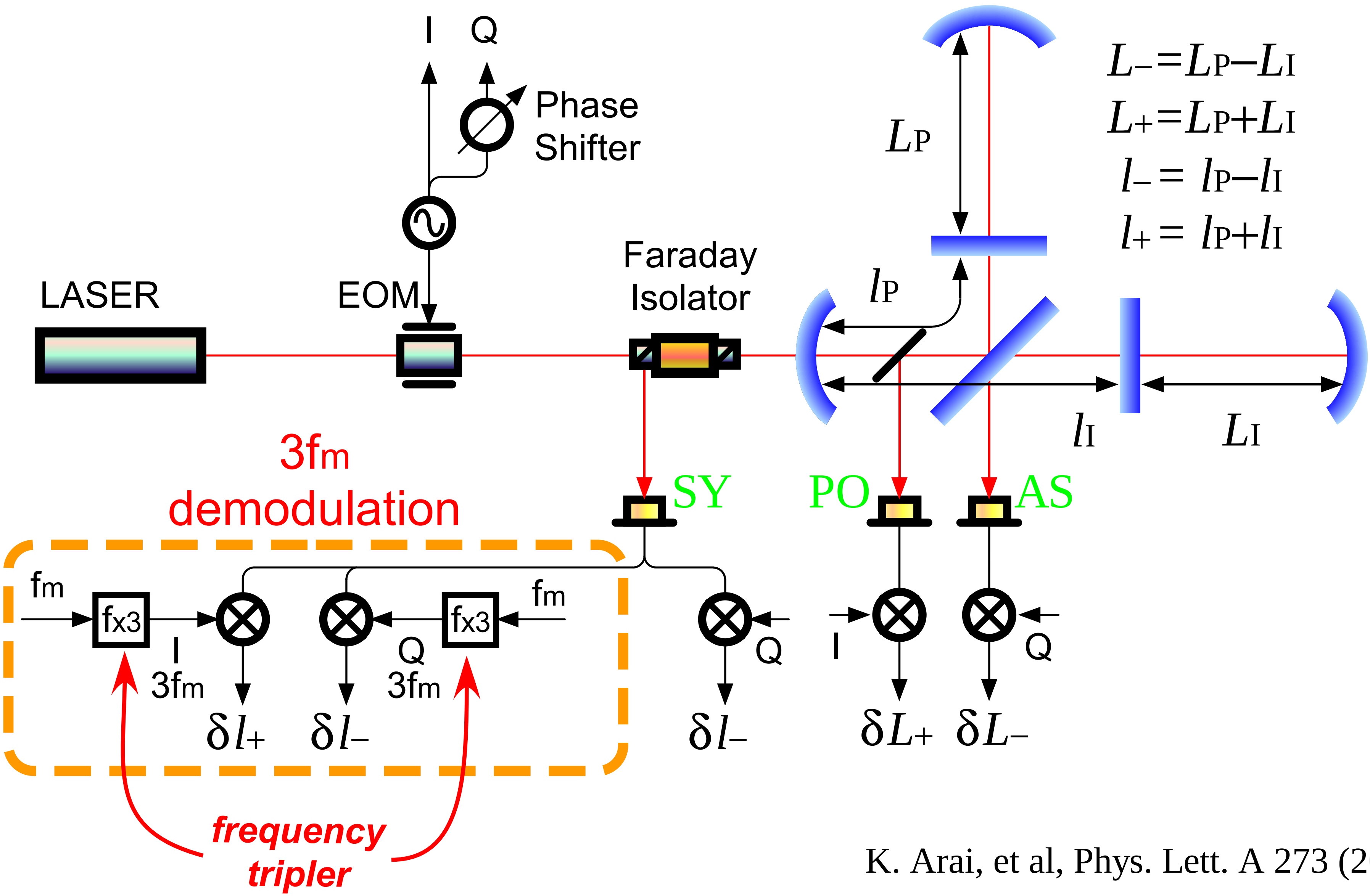
Target:

Optimization of optical parameters / control system

Improvement of the detector toward ultimate performances

Length sensing

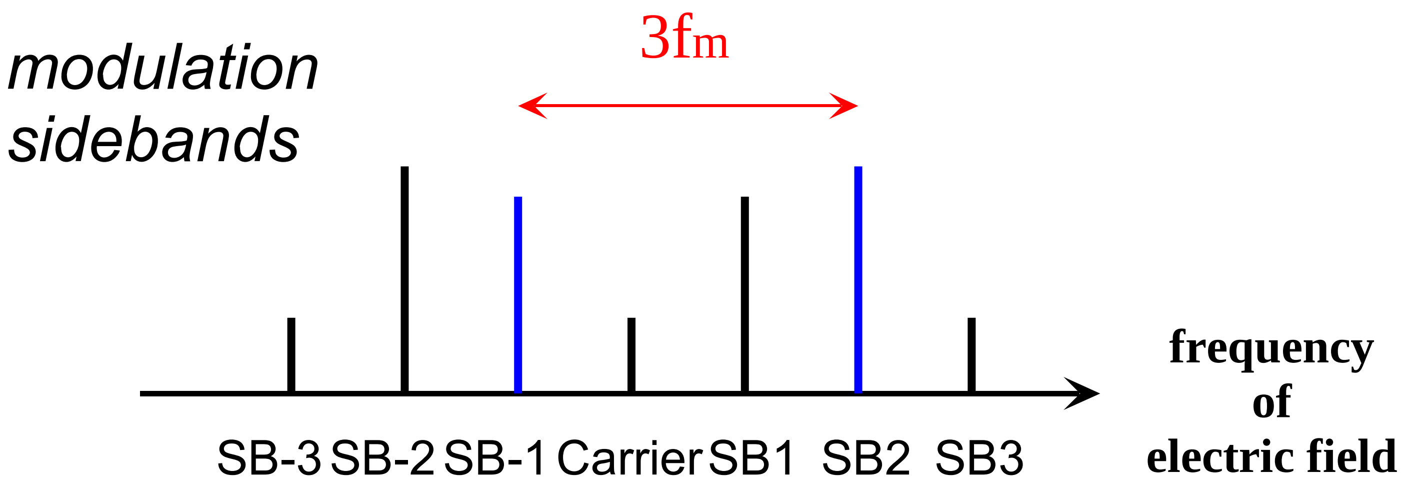
Frontal modulation + 3rd harmonic demodulation



K. Arai, et al, Phys. Lett. A 273 (2000) 15

3rd harmonic demodulation

- Photocurrent at the $3f_m$ ~ beating of SB2 and SB-1



- Robust extraction of δl_+ and δl_-

Contribution of carrier audio-sidebands (mainly by δL_+)

→ Reduced

Amplitudes and signs

→ Less dependent on the couplings of CA and SB1

Extracted signal

●Well-diagnalized signals (low gain recycling)

Port	Demod	Phase	L-	L+	l-	l+
Dark	fm	Q	1	3.0e-4	3.0e-3	1.0e-6
Pick-off	fm	I	1.5e-4	1	2.4e-7	5.0e-5
Bright	3fm	Q	1.0e-2	2.3e-2	1	3.6e-2
Bright	fm	Q	1.5e-2	6.2e-1	1	1.6e-3
Bright	3fm	I	1.5e-4	6.5e-2	1.2e-3	1

●Shot noise limit (low gain recycling)

Port	Demod	Phase		Shotnoise level (m/Hz$^{1/2}$)	
Dark	fm	Q	L-	$1.2 \times 10^{-19} = 4.0 \times 10^{-22}$ 1/Hz$^{-1/2}$	
Pick-off	fm	I	L+	$1.2 \times 10^{-18} = 1.0 \times 10^{-6}$ Hz/Hz$^{-1/2}$	
Bright	3fm	Q	l-	1.4×10^{-14}	for lock
Bright	fm	Q	l-	2.0×10^{-16}	for operation
Bright	3fm	I	l+	2.8×10^{-15}	

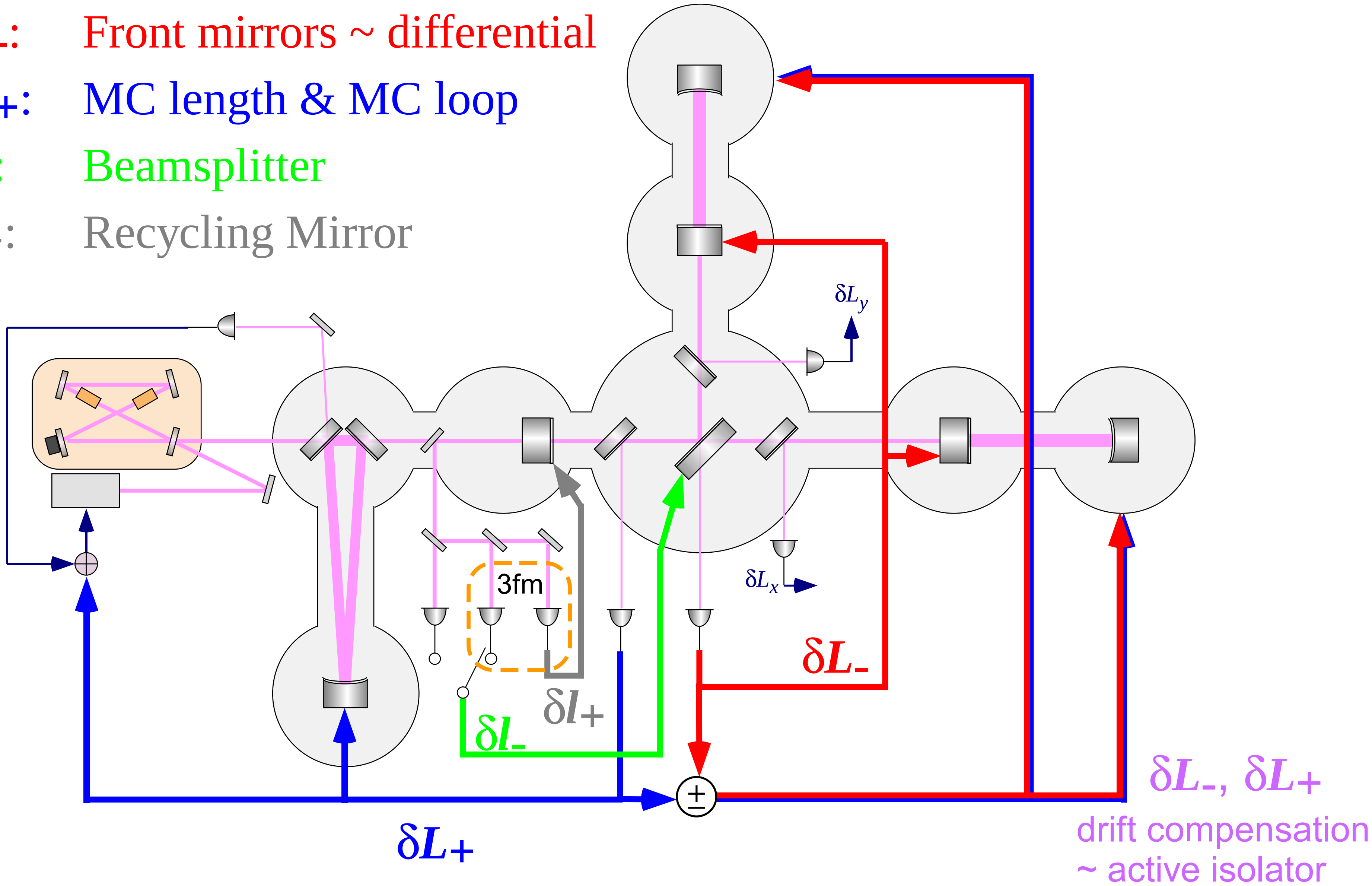
Control topology

δL_-: Front mirrors ~ differential

δL_+: MC length & MC loop

δl_-: Beamsplitter

δl_+: Recycling Mirror

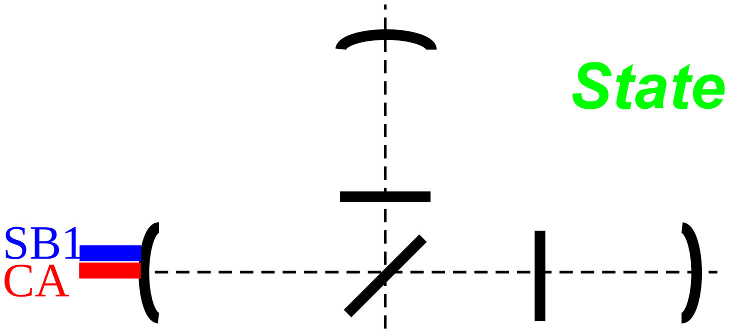


Lock acquisition

- Procedure 1 ~ Standard (LIGO like)

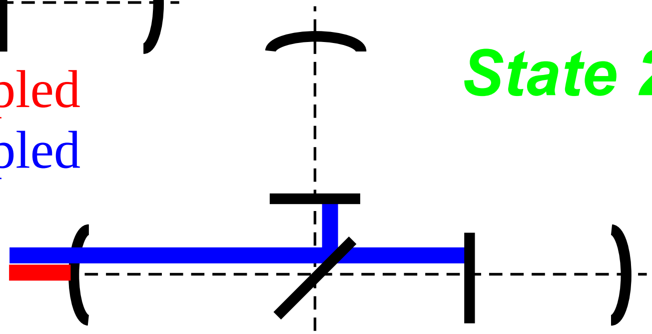
State 1

Drastic increase of the inner power
Change of the couplings to the IFO
=> change in optical gains and signal sign



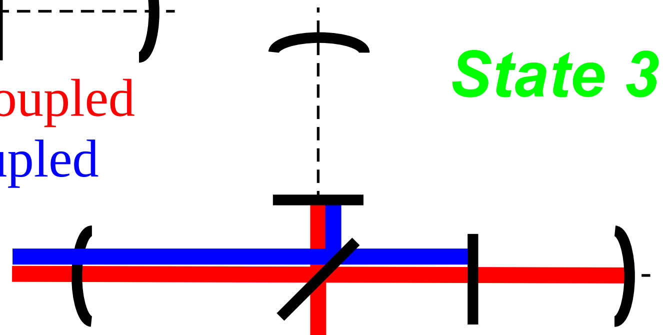
CA G0=0, under-coupled
SB1 G1=0, under-coupled

State 2



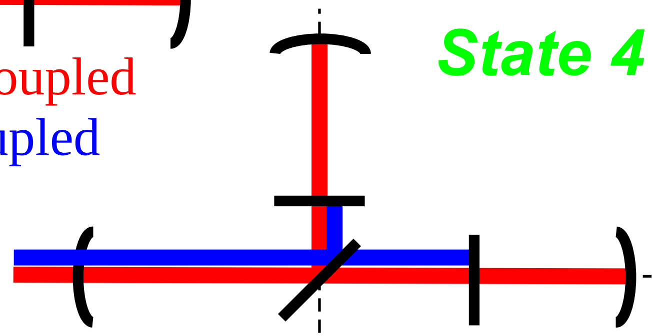
CA G0=0.18, under-coupled
SB1 G1=4.4, over-coupled

State 3



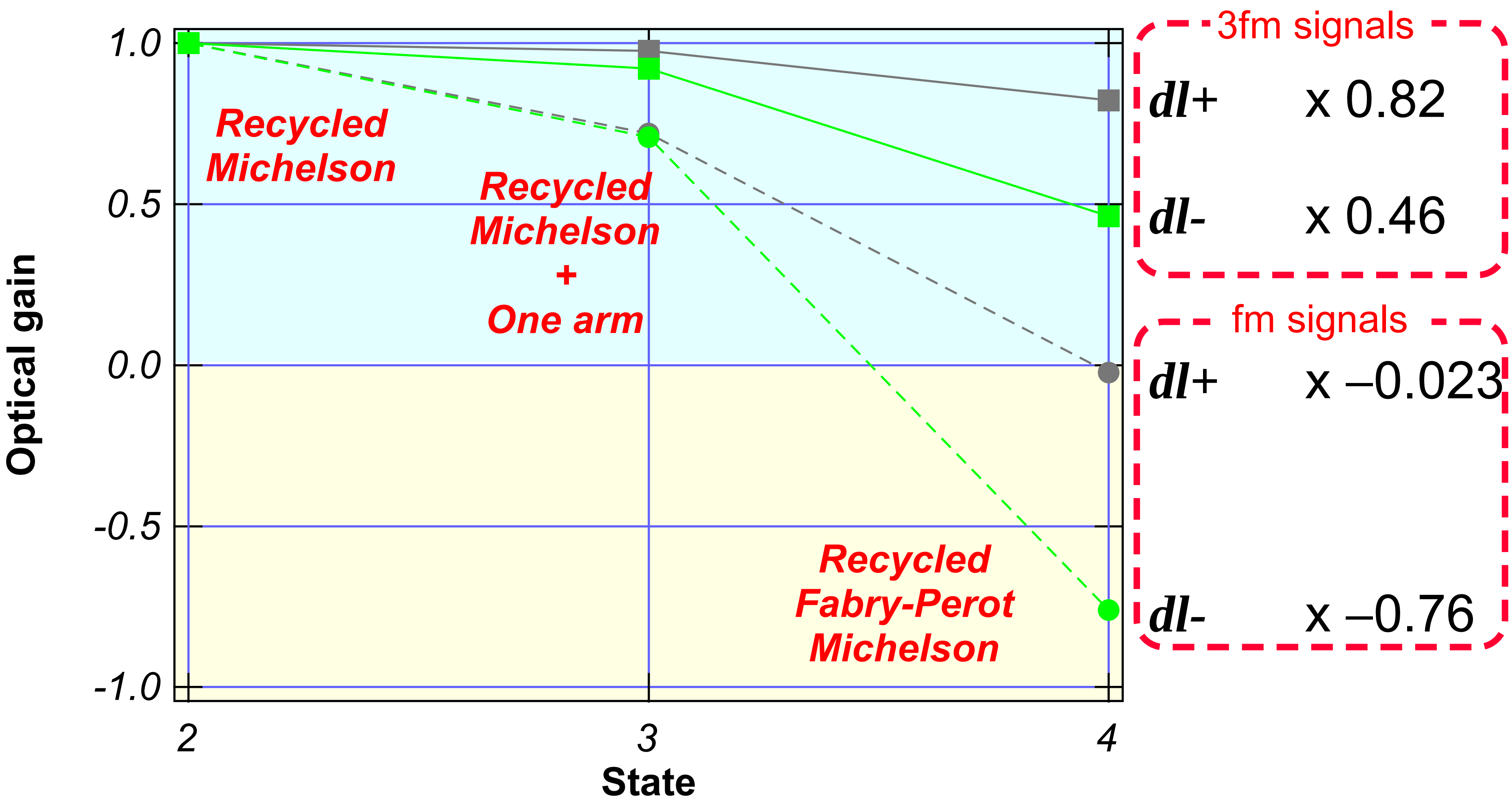
CA G0=0.51, under-coupled
SB1 G1=4.4, over-coupled

State 4



CA G0=4.6, over-coupled
SB1 G1=4.4, over-coupled

Gain variation / Sign flip (Recycling1)



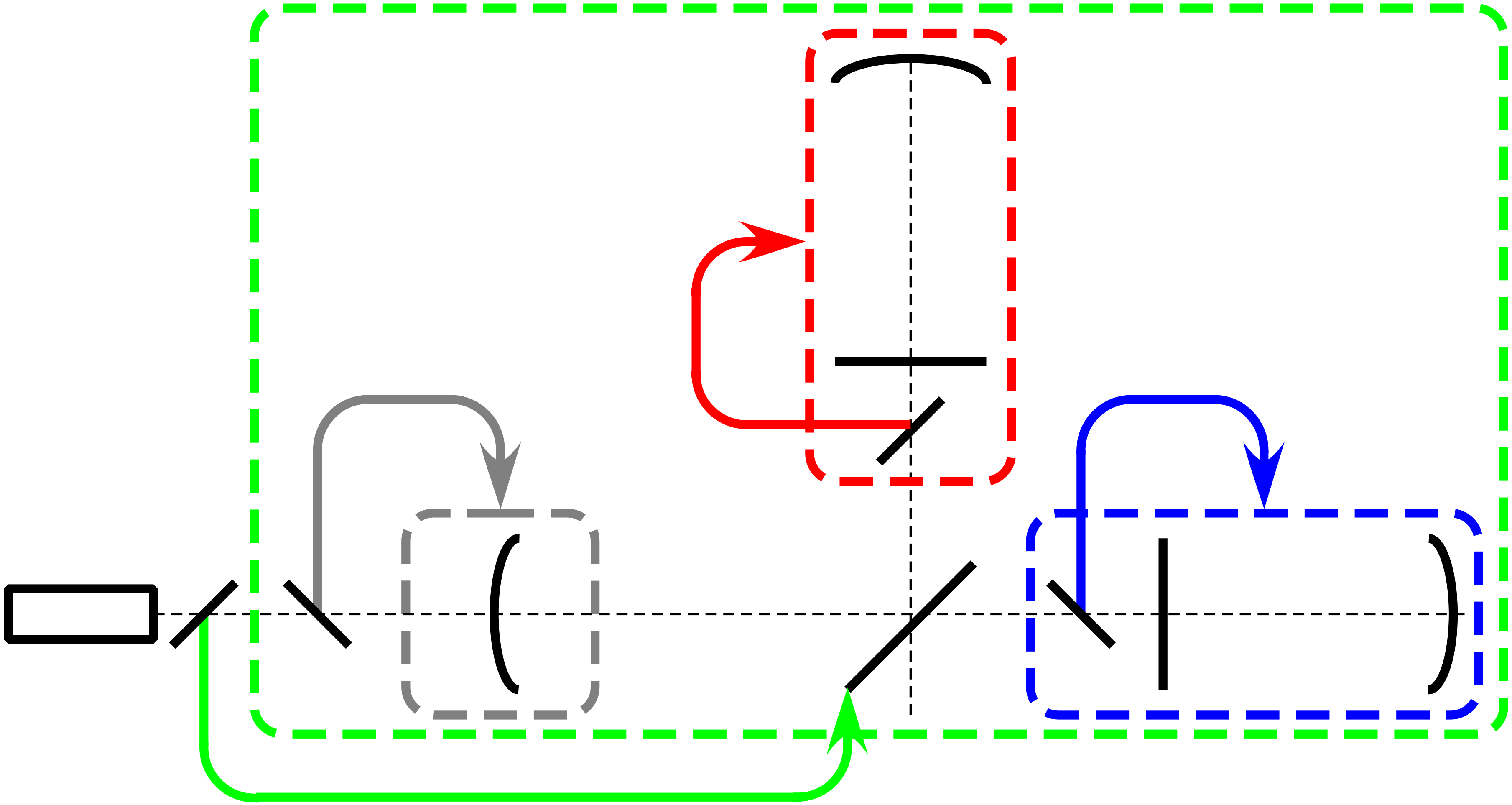
No sign flip and less gain changes with 3fm signals

~ no need of adaptive servo system (variable gain adj., dynamic sign change)

Lock acquisition

- Procedure 2 ~ Using pick-off signal (Pound-Drever-Hall technique like)

This technique worked fine in the prototypes,
particularly when the recycling gain was low.



Mixing of arm PDH signals

- Recycling makes arm length signals mixed at the last moment of the acquisition

mixing of 0%

... two PDH signals are independent

100%

... two PDH signals become equivalent

TAMA Recycling1 (G=4.6)

mixing = 50% still independent in some extent

(TAMA Recycling2 (G=10)

mixing = 85% need careful treatment)

Summary

- Power-recycling for TAMA300
  - Motivation
    - Expected to improve the sensitivity to NS binaries
    - Integrate our experiences with TAMA and the prototypes
  - 2 step strategy: low gain (G~4.6) and high gain (G~10)
    - Expect earlier full operation
    - Chance to optimize the system
  - Length sensing: 3rd harmonic demodulation scheme
    - Robust extraction of dl+ and dl-
  - Lock acquisition: try 2 different procedures
    - Using frontal modulation signals
    - Using arm reflections with pick-off mirrors