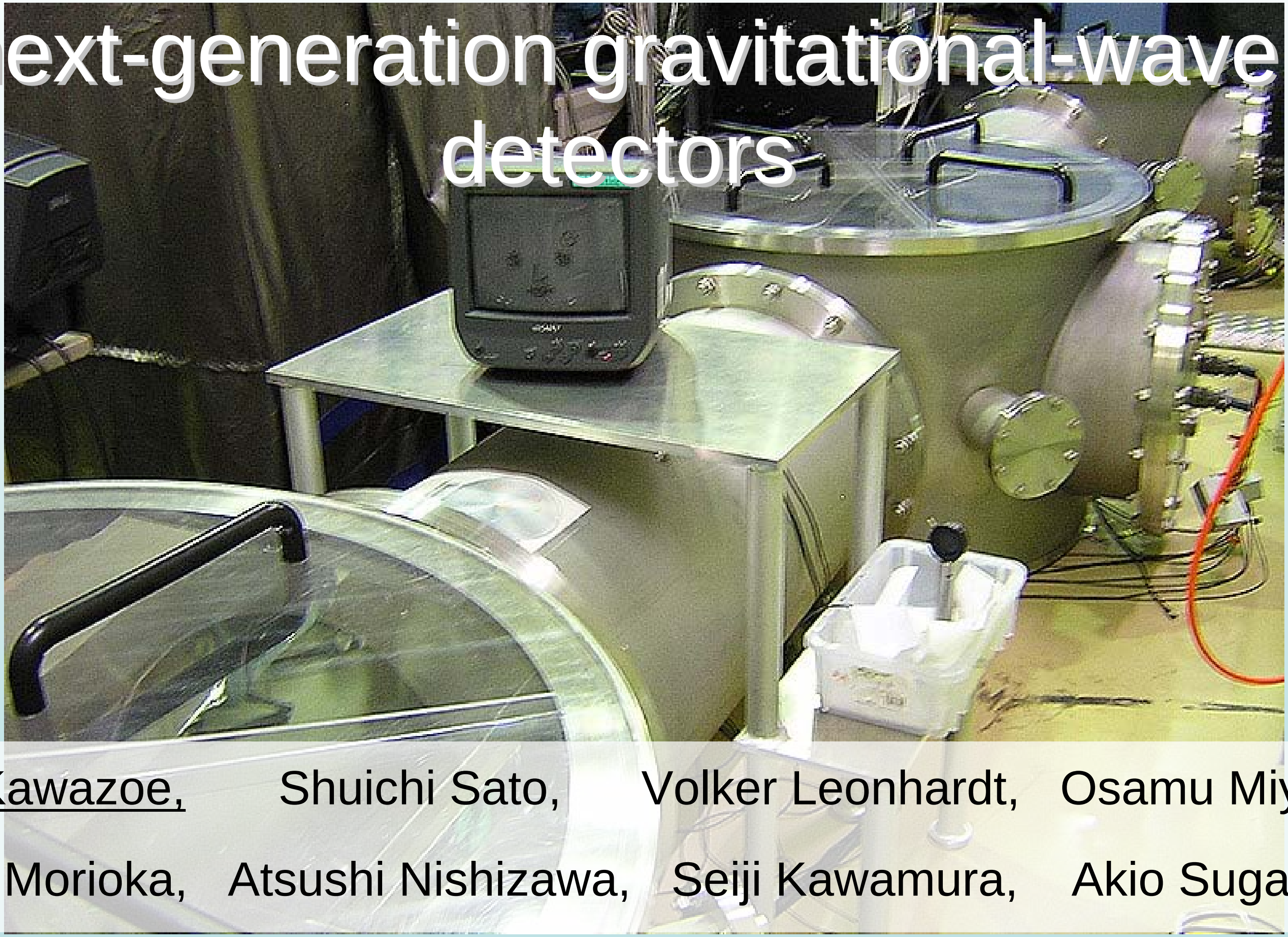
Experimental Demonstration of a control scheme for a tuned RSE interferometer for next-generation gravitational-wave detectors



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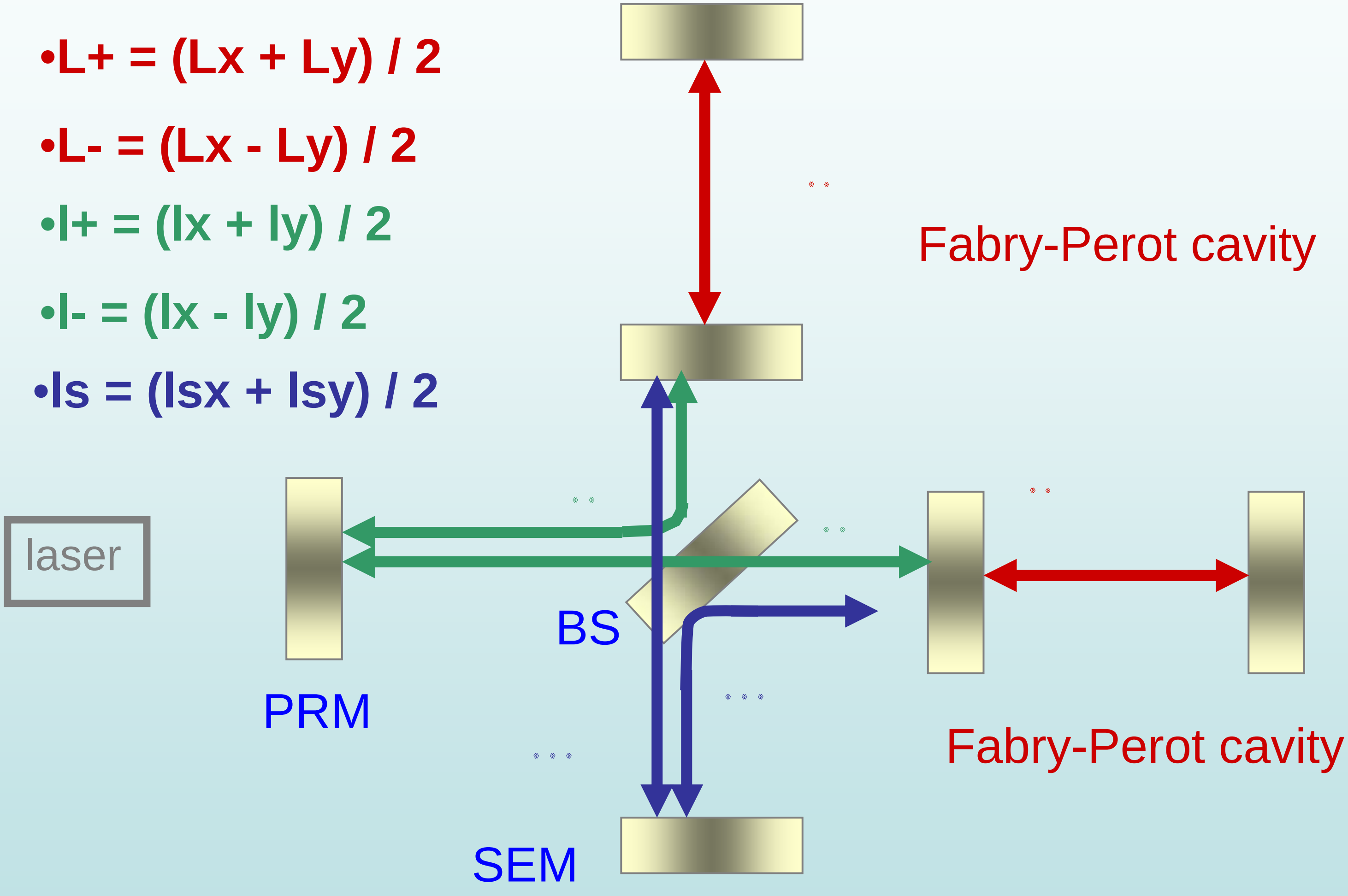
Motivation

- Plans to use an RSE interferometer in some of the next-generation interferometers for better sensitivities.
  - Adv.LIGO…Detuned RSE
  - LCGT…Tuned RSE (= zero detuning or broadband)
- Controlling DOFs is vital for a detector
  - Control scheme developed for LCGT
  - Can be a back-up design for Adv.LIGO(detuned)
- Prototype experiment to verify the control scheme

Controlling the RSE

5 degrees of freedoms

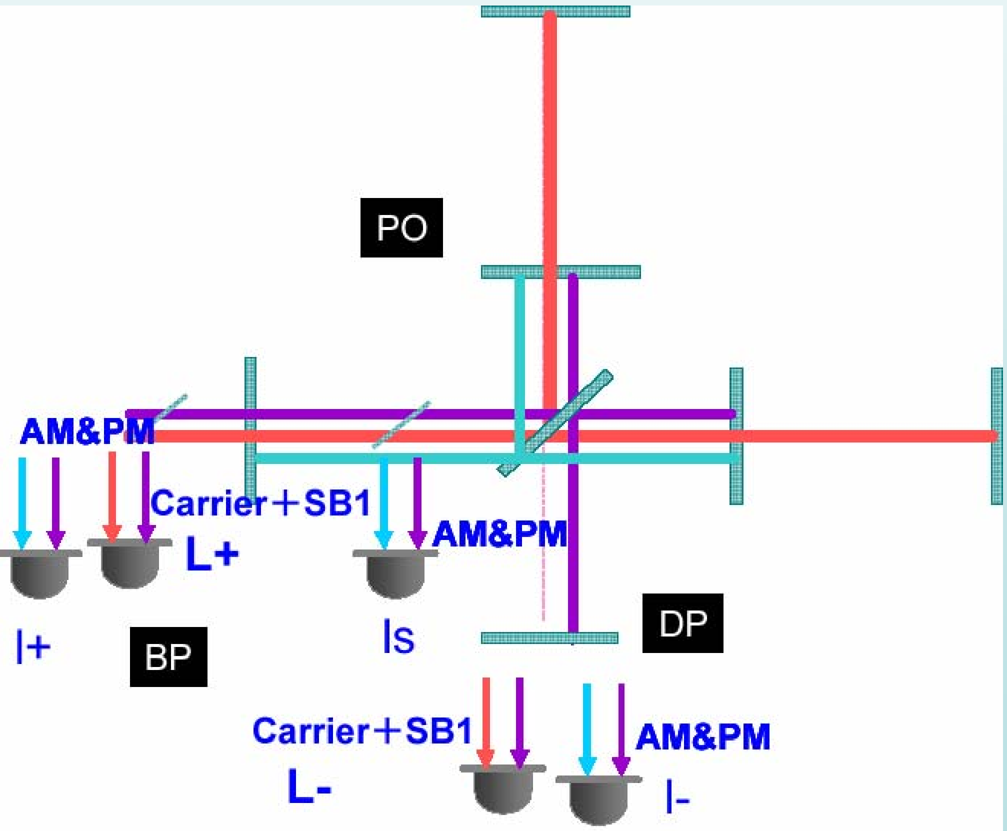
- $L+ = (Lx + Ly) / 2$
- $L- = (Lx - Ly) / 2$
- $l+ = (lx + ly) / 2$
- $l- = (lx - ly) / 2$
- $ls = (lsx + lsy) / 2$



A very complicated control system due to the increased number of DOFs

Control scheme concepts

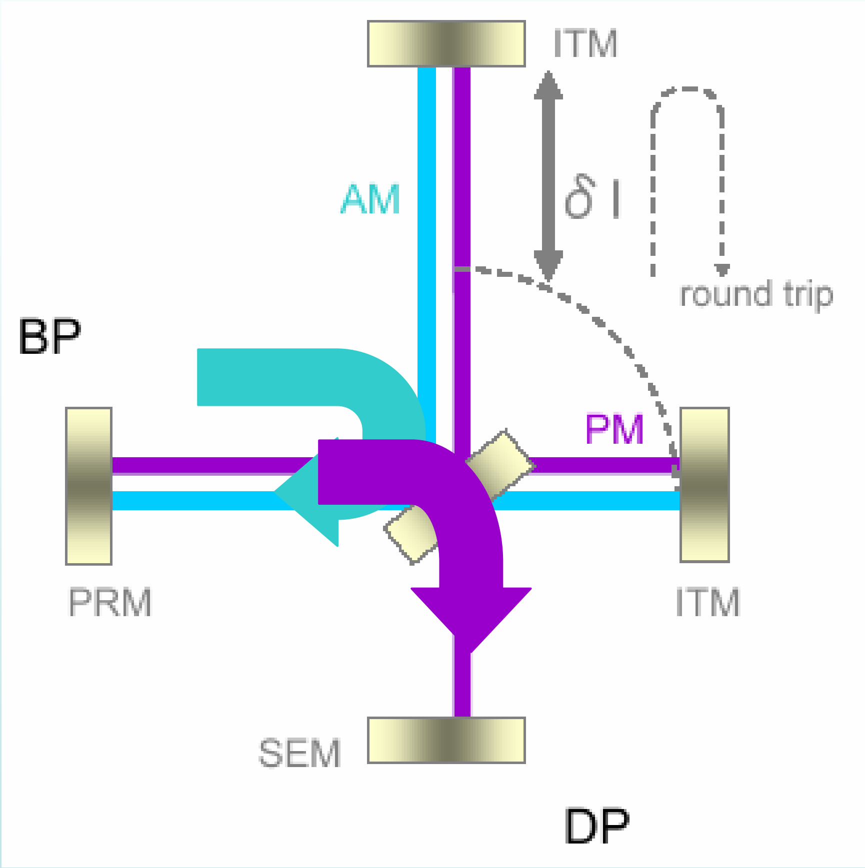
- Fabry-Perot cavities' control signal---beat between the carrier and PM sidebands
- Central part of the RSE--- beat between the AM and PM sidebands



- Fabry-Perot control signal are bigger by the high finesse
- Can separate FP control signal and the central control signal by not using the carrier for the central part

The central part control strategy

--- Michelson Asymmetry



For AM sidebands: 2.l = n.
(n = 1,2,3…)

For PM sidebands:
2.l = (2m+1)/2 . (m= 0,1,2…)

Due to the Michelson Asymmetry
AM all reflect from the Michelson part
PM all transmit though the Michelson part

Cavity length design

AM resonant inside PRC
PM resonant inside PRC+SEC

Contrasting behavior in the Michelson part → as little as possible signal coupling

The sensing signal matrix

Theoretical signal matrix (DC)
With the prototype parameters

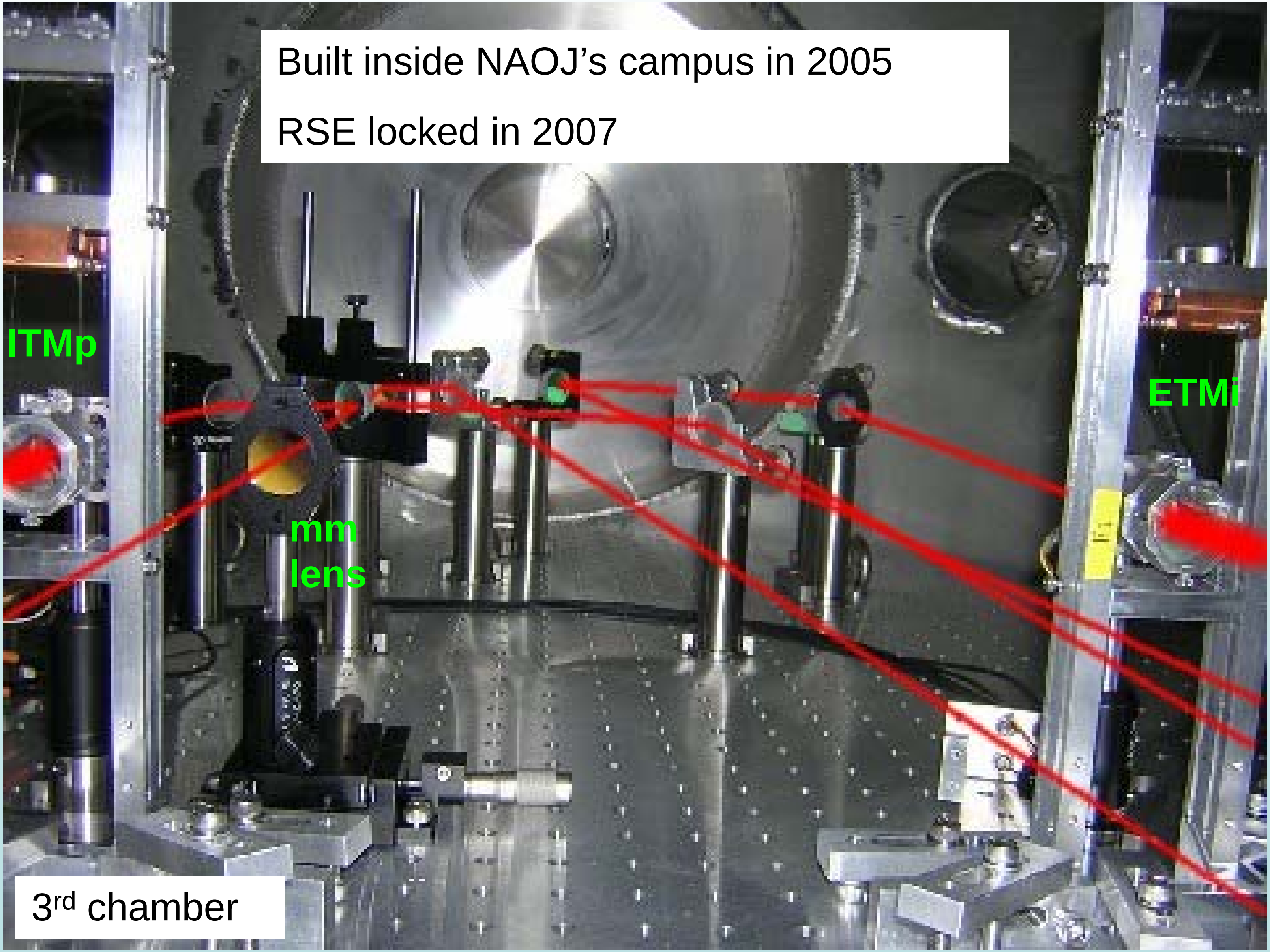
Fabry-Perot signals are clear from other signals.

	L+	L-	l+	l-	ls
BP	1	8.0 e−6	−2.6 e−2	6.2 e−4	
DP	−2.2e−8	1	1.4 e−8	1.3 e−2	2.0 e
BP(DD)	−4.9 e−2	−1.1 e−4	1	−8.6 e−3	−5.3
DP(DD)	−1.0 e−4	7.6 e−2	1.4 e−3	1	1.1
PO(DD)	−1.5 e−1	−1.2 e−2	1.1	−2.2 e−2	[illegible]

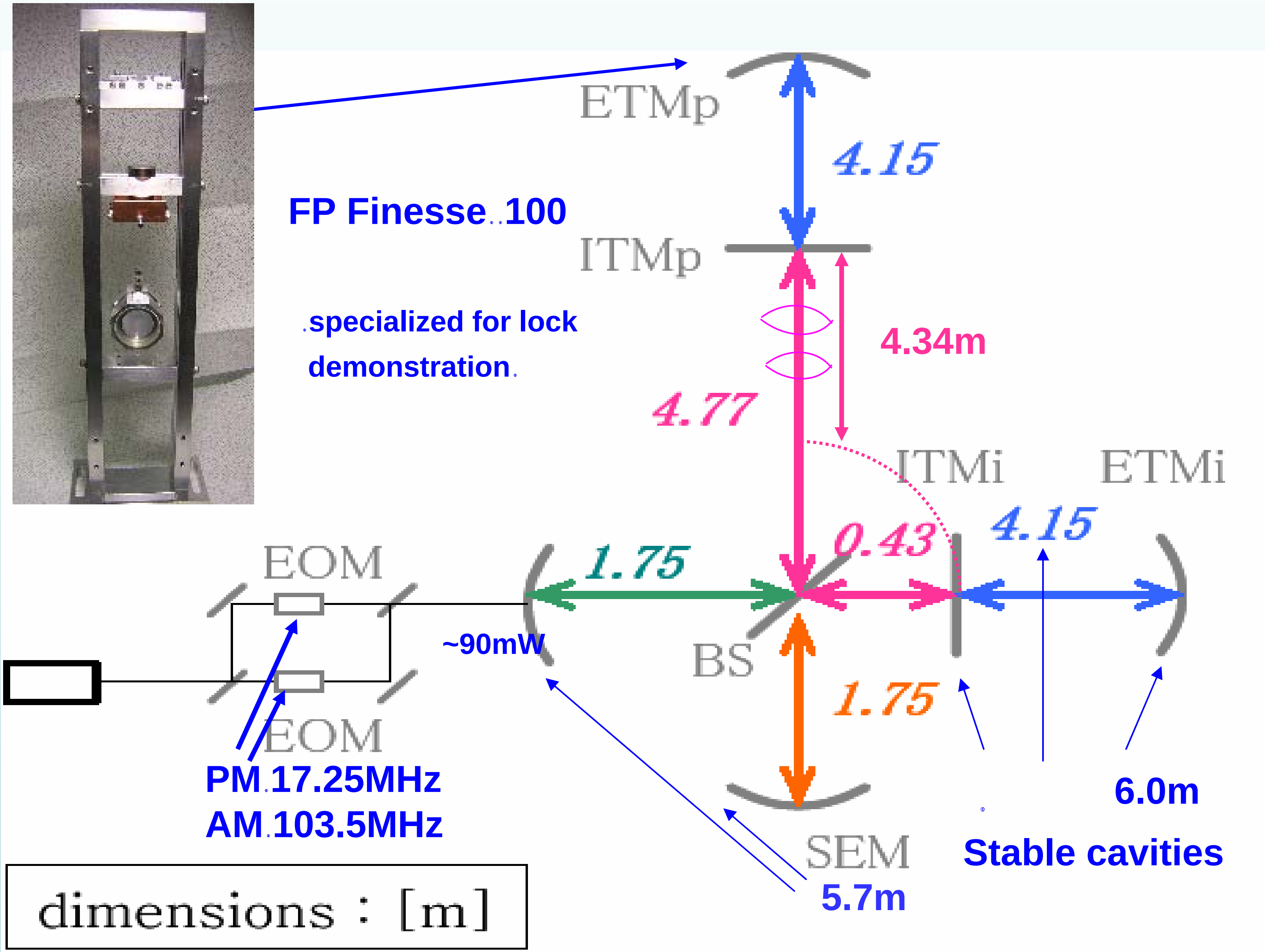
These 6 are small

Linearly independent matrix.

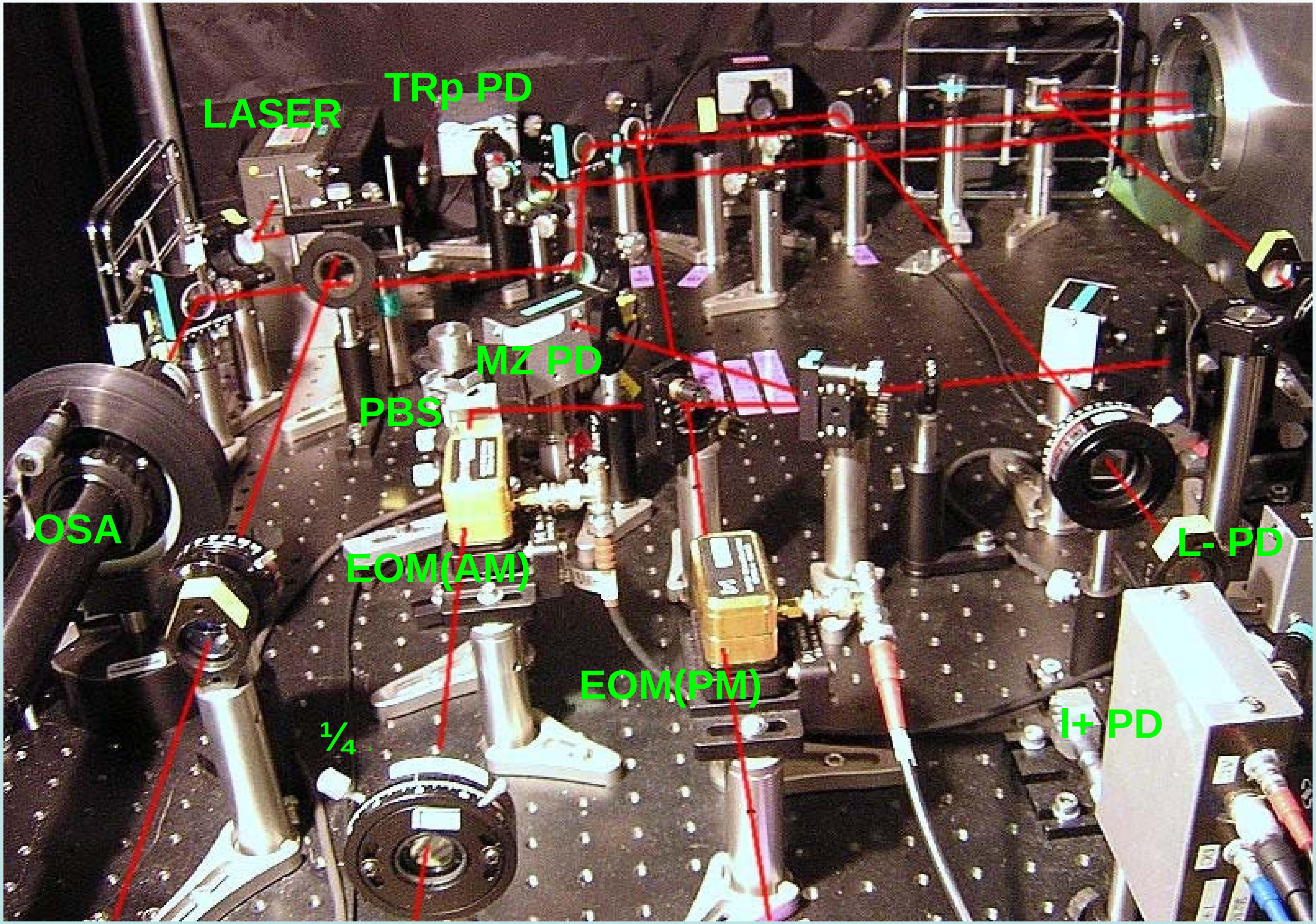
Prototype RSE experiment



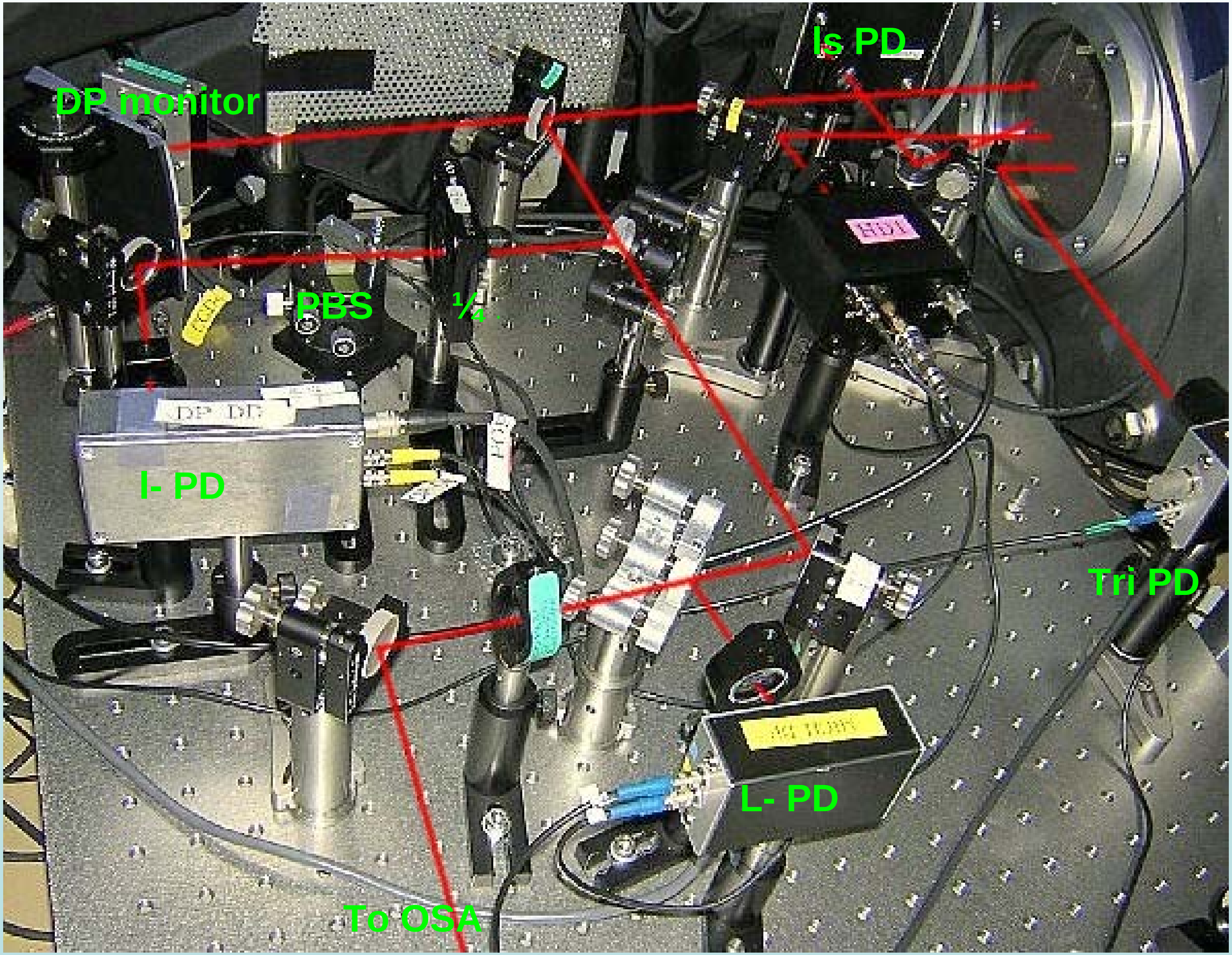
Optical layout, and Parameters



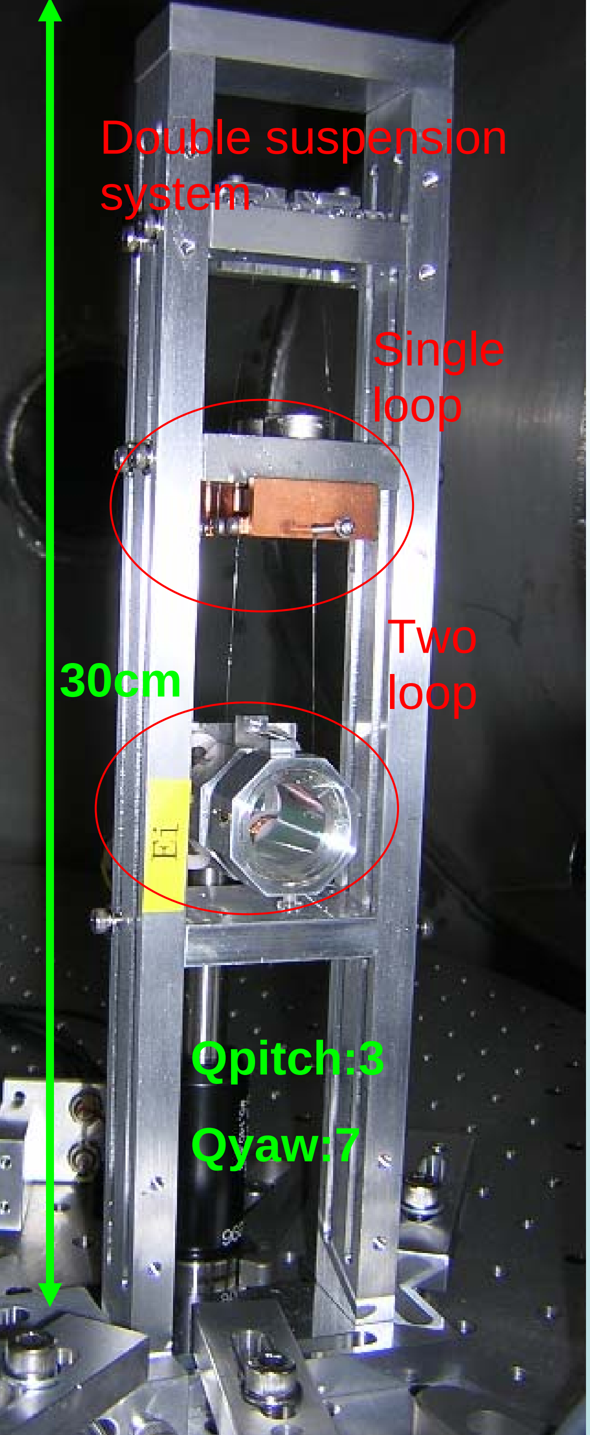
Mainly Input table, plus some detection ports

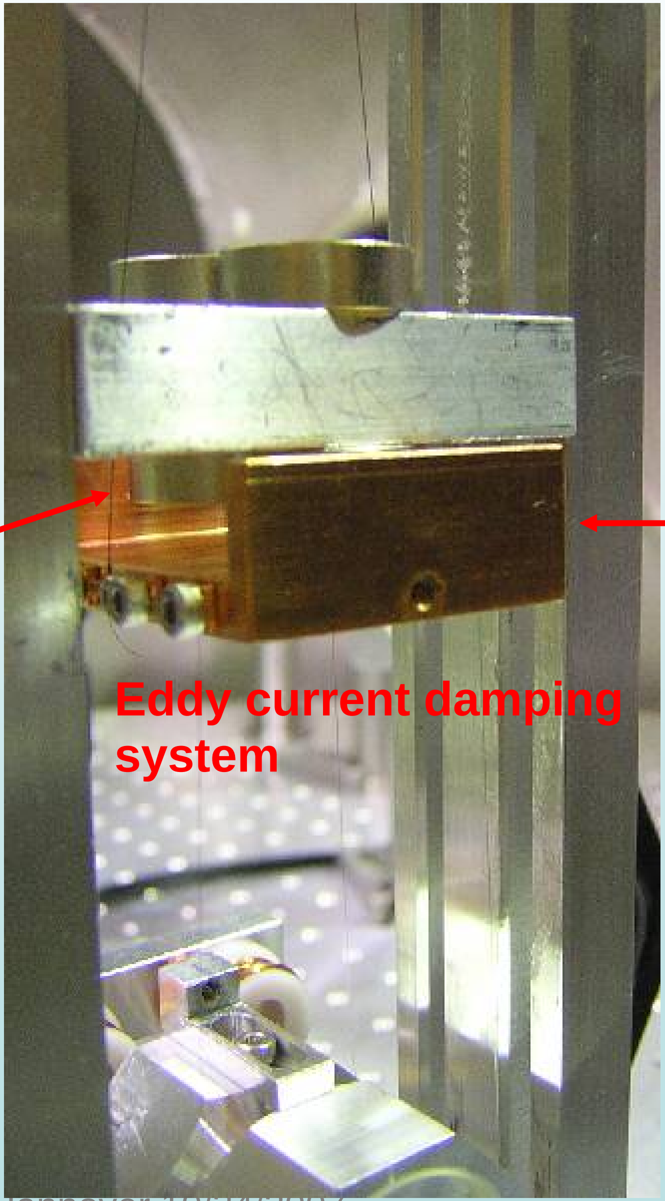


Detection ports

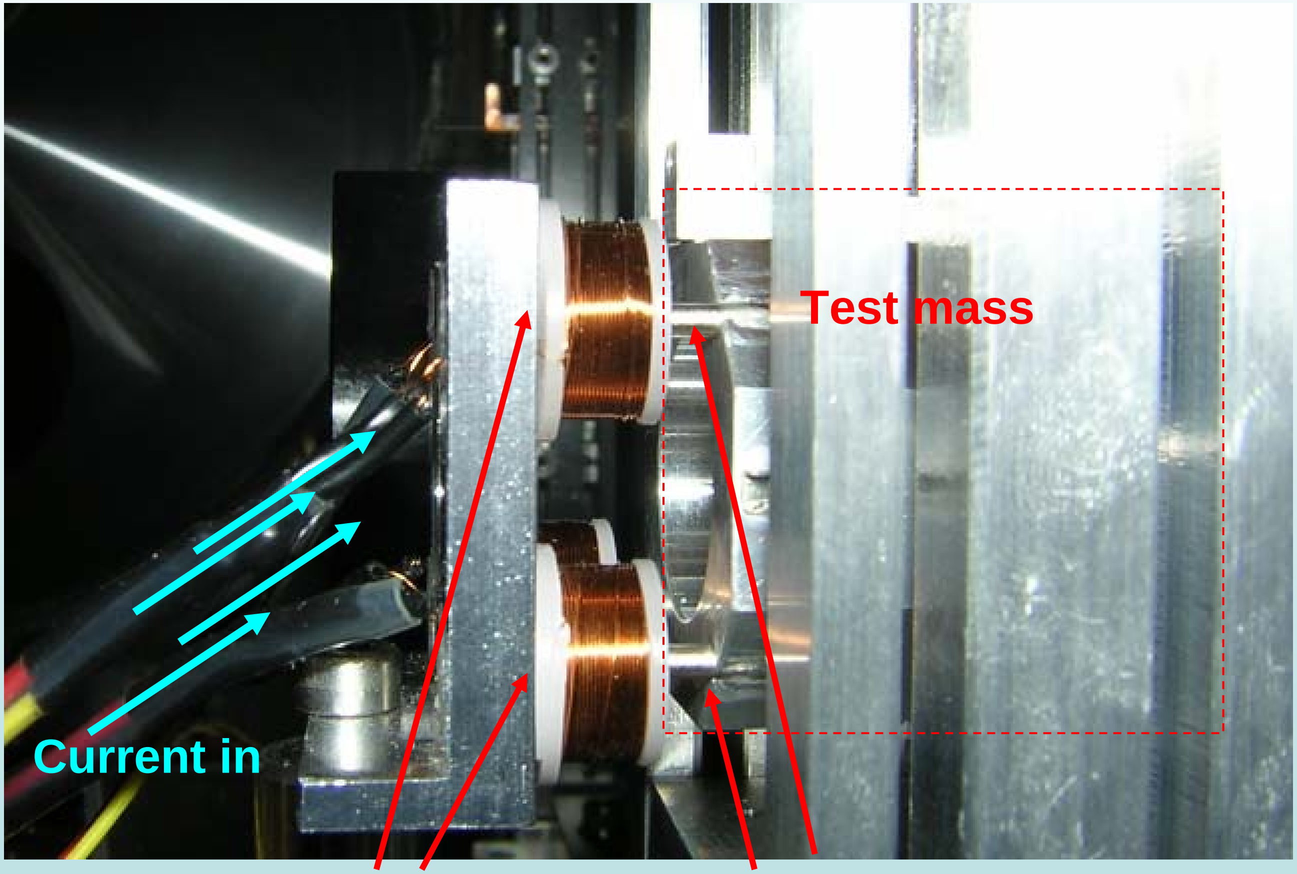


Suspension system





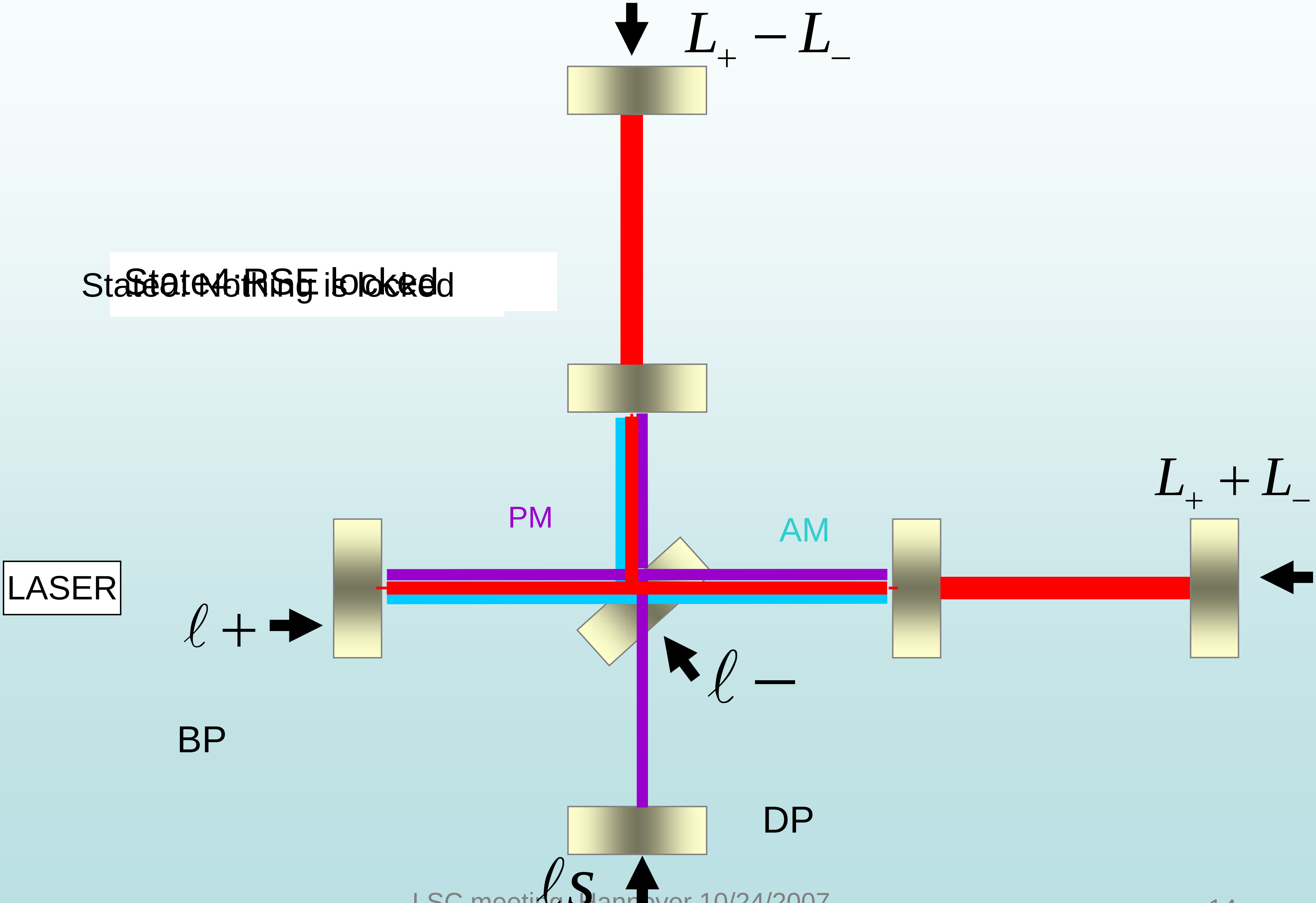
Suspension system
DC alignment



Actuator coils x4

Actuator magnets x4

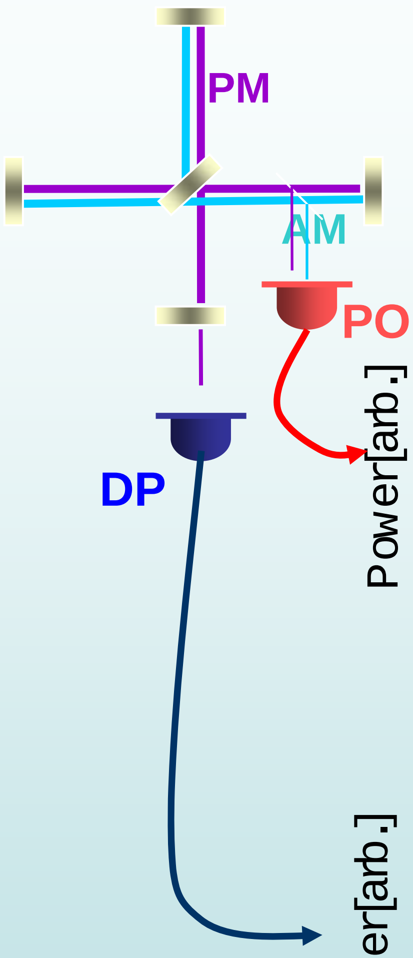
Lock of the tuned RSE: Lock state



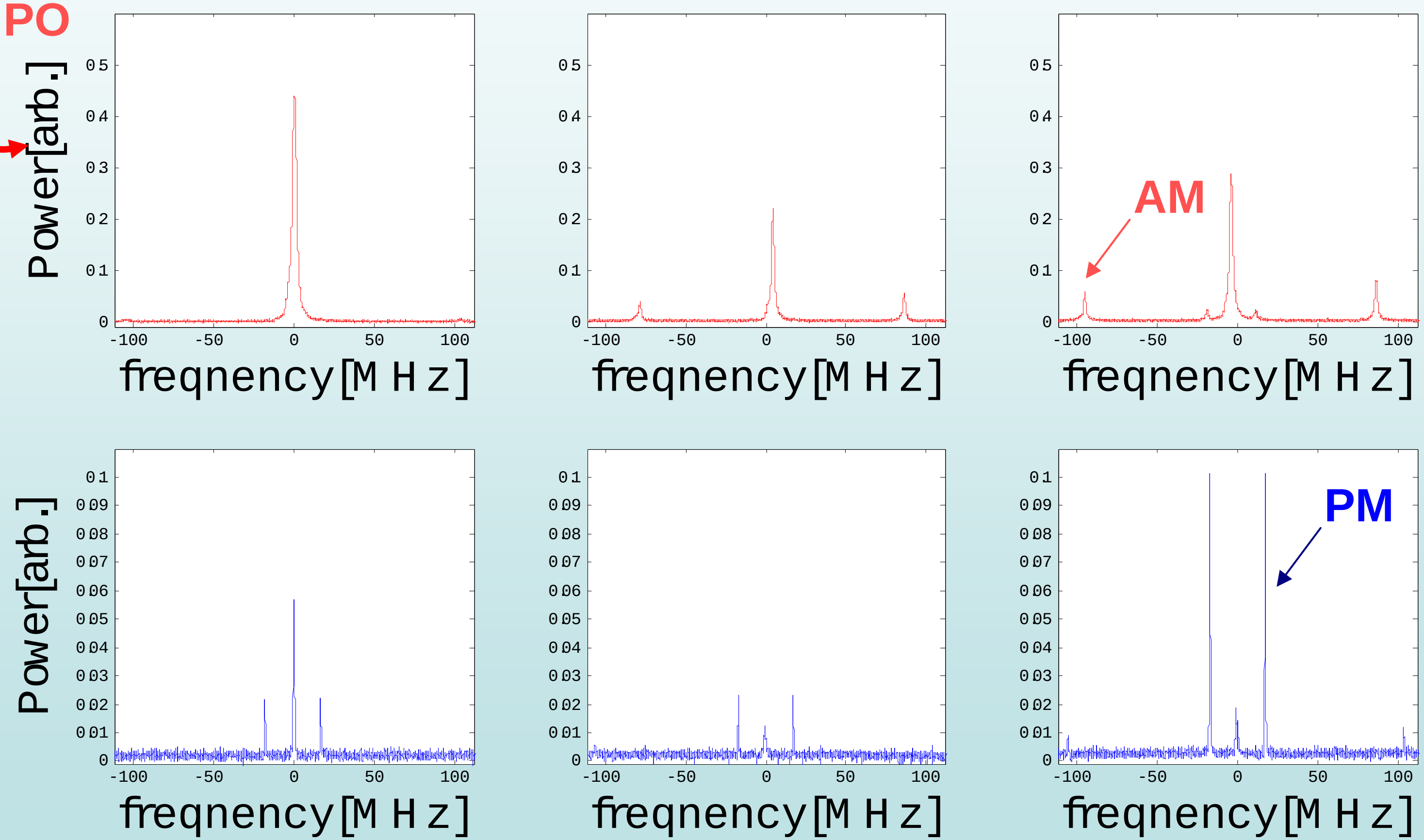
0: not controlled 1: I- locked 2 : I-, I+ locked 3: I-, I+, Is (central part) locked

4:RSE locked (longest ~15min. disturbed by human activity)

Lock of the tuned RSE: Evaluation of lock



Optical Spectrum Analyzed at PO, and DP



0&1 | 2 | 3

(1: l- 2: l-, l+ 3: central part)

Measured signal matrix preliminary

	L+	L-	l+	l-	ls
BP	1	5.6 e-2	-5.0 e-2	3.5 e-2	1.1 e-2
DP	4.5e-2	1	1.3 e-2	-8.3 e-2	9.7 e-3
BP(DD)	-2.8 e-1	-7.1 e-2	1	-3.6 e-1	-1.5 e-1
DP(DD)	4.6 e-2	-1.6 e-1	1.6 e-1	1	6.2 e-2
PO(DD)	-6.5 e-1	3.3 e-1	9.2 e-1	-3.6	1

- Dem. phase set to maximize the desired signal
- Source:3.3kHz

Needs better lock quality for further discussion..

Results and future work

Control of a tuned RSE interferometer was successfully demonstrated.

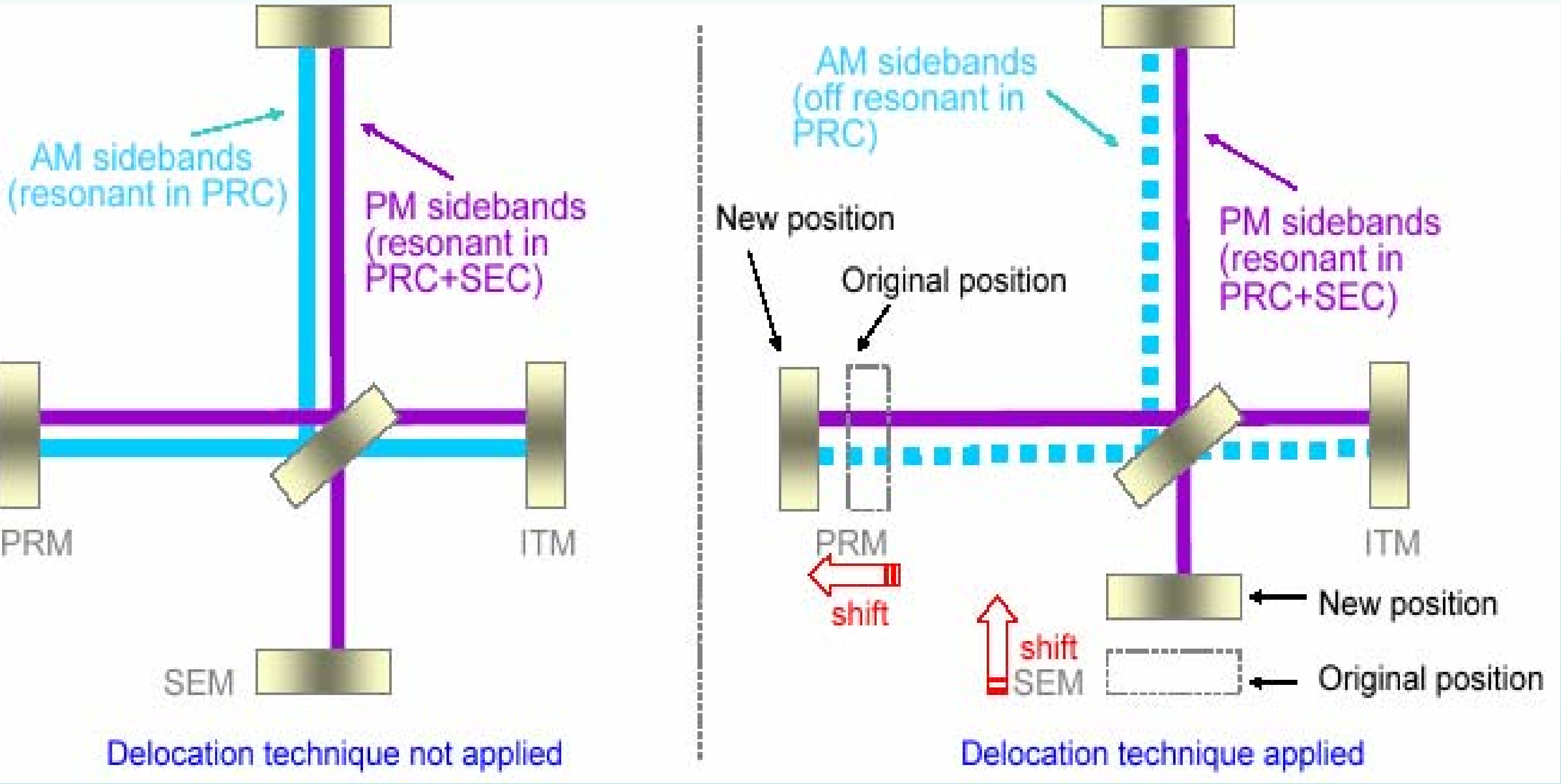
- FP cavities with L+, and L-.
- Central part with double mod-demod.

Lock acquisition scheme for LCGT is verified with this control scheme.

Future work:

- Further investigation of the signal matrix (further diagnolazation, possible application of the delocation scheme, shot noise sensitivity as a detector after the lock is acquired)
- Measurement of the optical gain matrix with better lock quality.

Delocation scheme



Diagnolized signal matrix

Table 1. Normalized control signal matrix

	$L+$	$L-$	$l+$	$l-$	ls
BP(SD)	1	8.0×10^{-6}	-2.6×10^{-2}	6.2×10^{-4}	1.3×10^{-2}
DP(SD)	-2.2×10^{-8}	1	1.4×10^{-8}	1.3×10^{-2}	2.0×10^{-8}
BP(DD)	-4.9×10^{-2}	-1.1×10^{-4}	1	-8.6×10^{-3}	-5.3×10^{-1}
DP(DD)	-1.0×10^{-4}	7.6×10^{-2}	1.4×10^{-3}	1	1.1×10^{-5}
PO(DD)	-1.5×10^{-1}	-1.2×10^{-2}	1.1	-2.2×10^{-2}	1

Table 2. Normalized diagonalized control signal matrix

	$l+$	$l-$	ls
PO(DD)	1	-4.2×10^{-3}	5.5×10^{-4}
DP(DD)	2.2×10^{-3}	1	-5.6×10^{-5}
PO(DD)	5.0×10^{-4}	-1.1×10^{-7}	1