Simulation of a dual recycled interferometer in e2e framework

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in collaboration with
LIGO Caltech e2e and 40m groups

GWADW Elba 2006

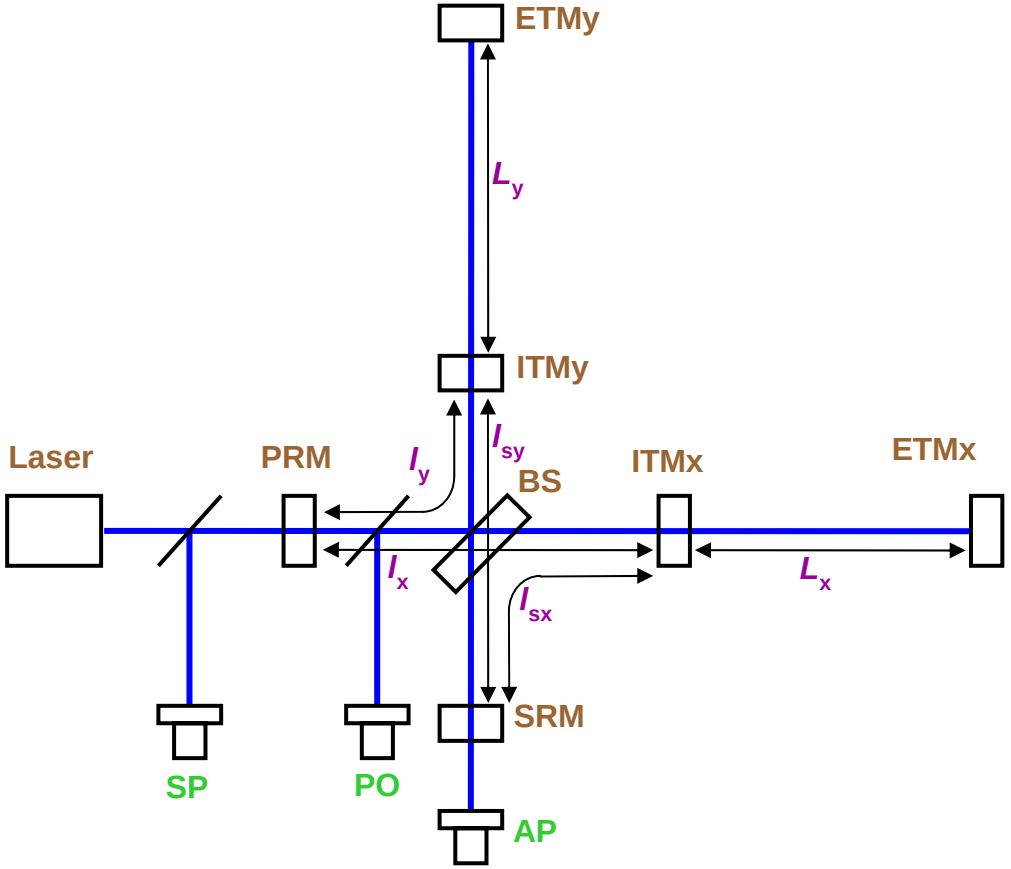
LIGO-G060289-00-R

Motivation

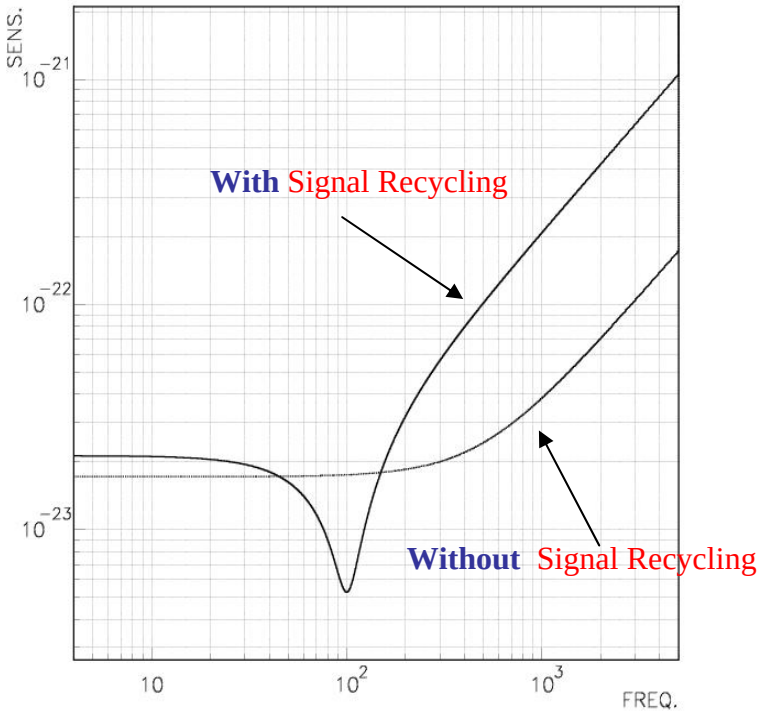
- ***signal recycling*** option for Advanced Virgo
  - time domain simulation using e2e (*Hiro's talk*)
  - acquisition of knowledges about a dual recycled interferometer on 40m site (*Osamu's talk*)

DUAL-RECYCLED INTERFEROMETER

Common of arms : $L_+ = (L_x + L_y) / 2$
Differential of arms : $L_- = (L_x - L_y) / 2$
Power recycling cavity : $l_+ = (l_x + l_y) / 2$
Michelson : $l_- = (l_x - l_y) / 2$
Signal recycling cavity : $l_s = (l_{sx} + l_{sy}) / 2$



Sensitivity

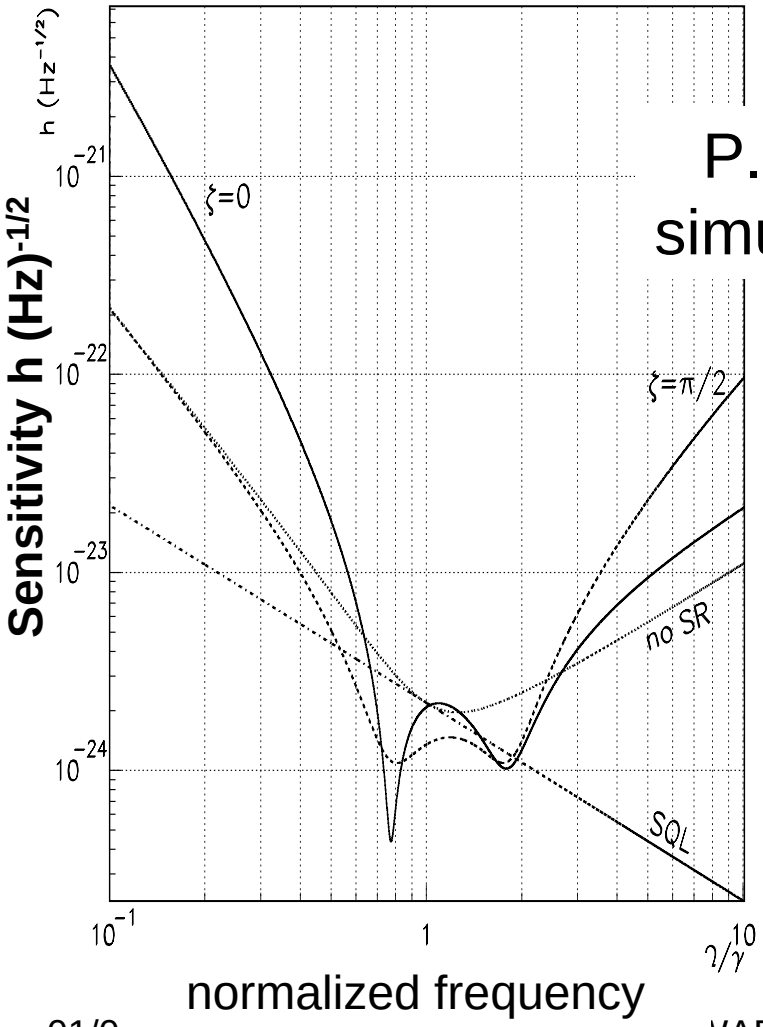


better sensitivity in an optimized frequency band

(naive view)

Sensitivity of a dual recycled IFO

(quantum noise) compared to the Power Recycled IFO sensitivity and to the SQL



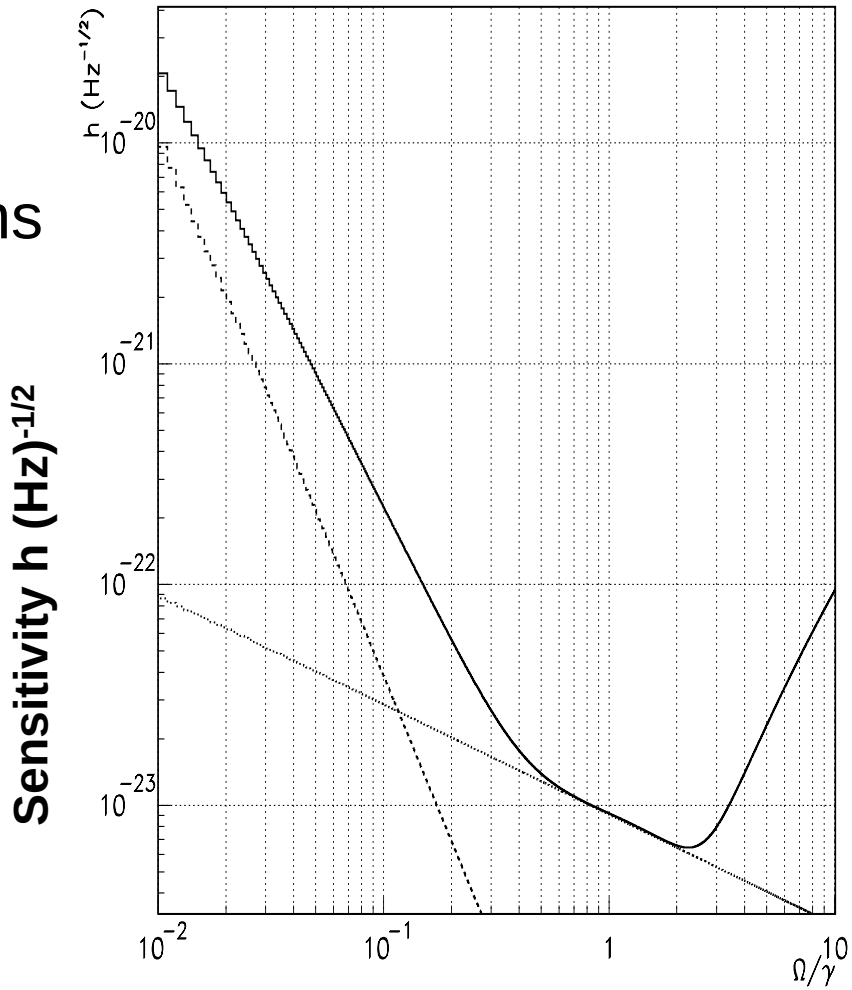
P. Hello simulations

Sensitivity of a dual recycled IFO

dashed line: pendulum thermal noise

dotted line: mirror thermal noise

solid line : total thermal noise



Dual-recycled interferometer in the world

Already installed:

- **40m** @ **CalTech** with Fabry-Perot cavities
- **GEO600** @ **Germany** without Fabry-Perot cavities
- **4m** @ **NAOJ**

Note: 10m @ **Glasgow** has *signal recycling* cavity but it is **not dual**

Not yet existing:

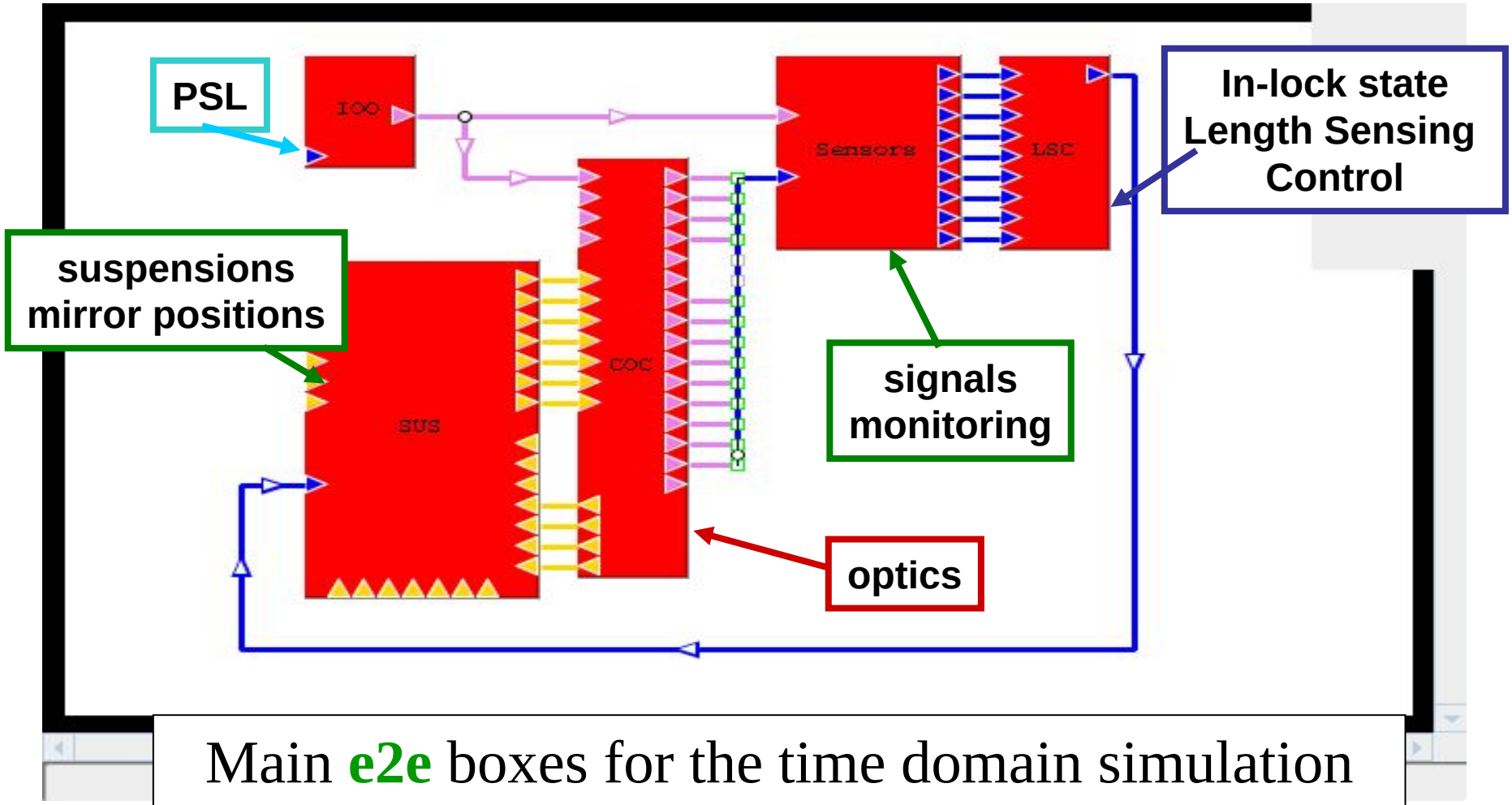
- **AdvLIGO** @ **United States** with Fabry-Perot cavities
  - same configuration than 40m
- **Advanced Virgo**
- **LCGT** @ **Japan** (broadband RSE)
- Table-Top experiment @ **ANU**

OUTLINE

e2e simulation

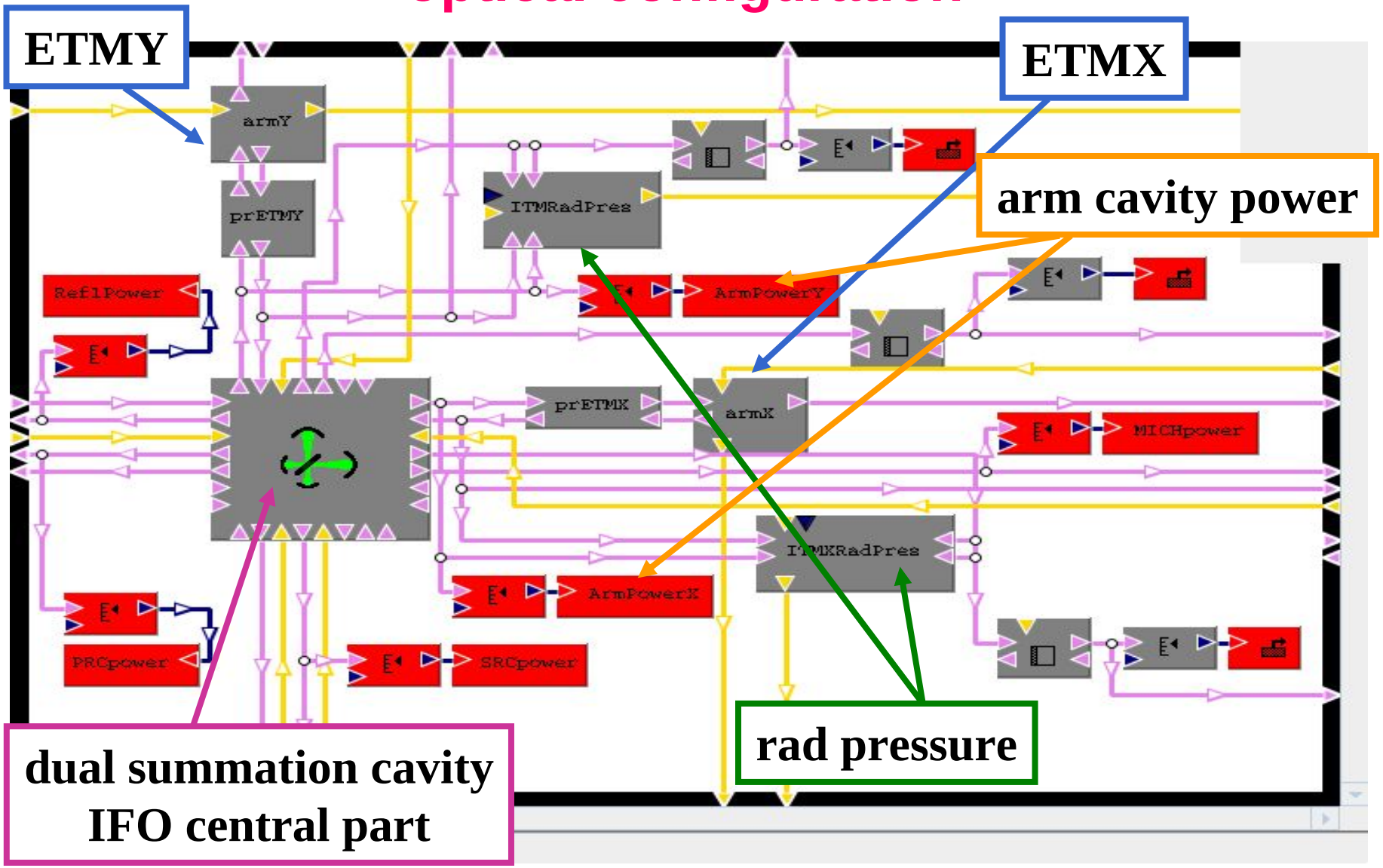
- **40m / advanced LIGO configuration**
  - ✓ main **e2e** boxes
  - ✓ main results
    - optical plant validation - equilibrium fields, transfer functions
      - Large use of TWIDDLE
    - error signals sweeps
    - 40m optical response (with optical spring)
    - in-lock state for 5 dof with a realistic seismic noise
    - Mach-Zehnder noise for the 40m IFO
    - relative mirror velocity reconstruction
- **application to a possible Advanced Virgo configuration**
  - equilibrium fields (for a given set of parameters)
  - optical plant validation (for a given set of parameters)
  - optical response

e2e SIMULATION: 4Om/AdvLIGO package



Main **e2e** boxes for the time domain simulation of a Dual Recycled Fabry-Perot Michelson IFO

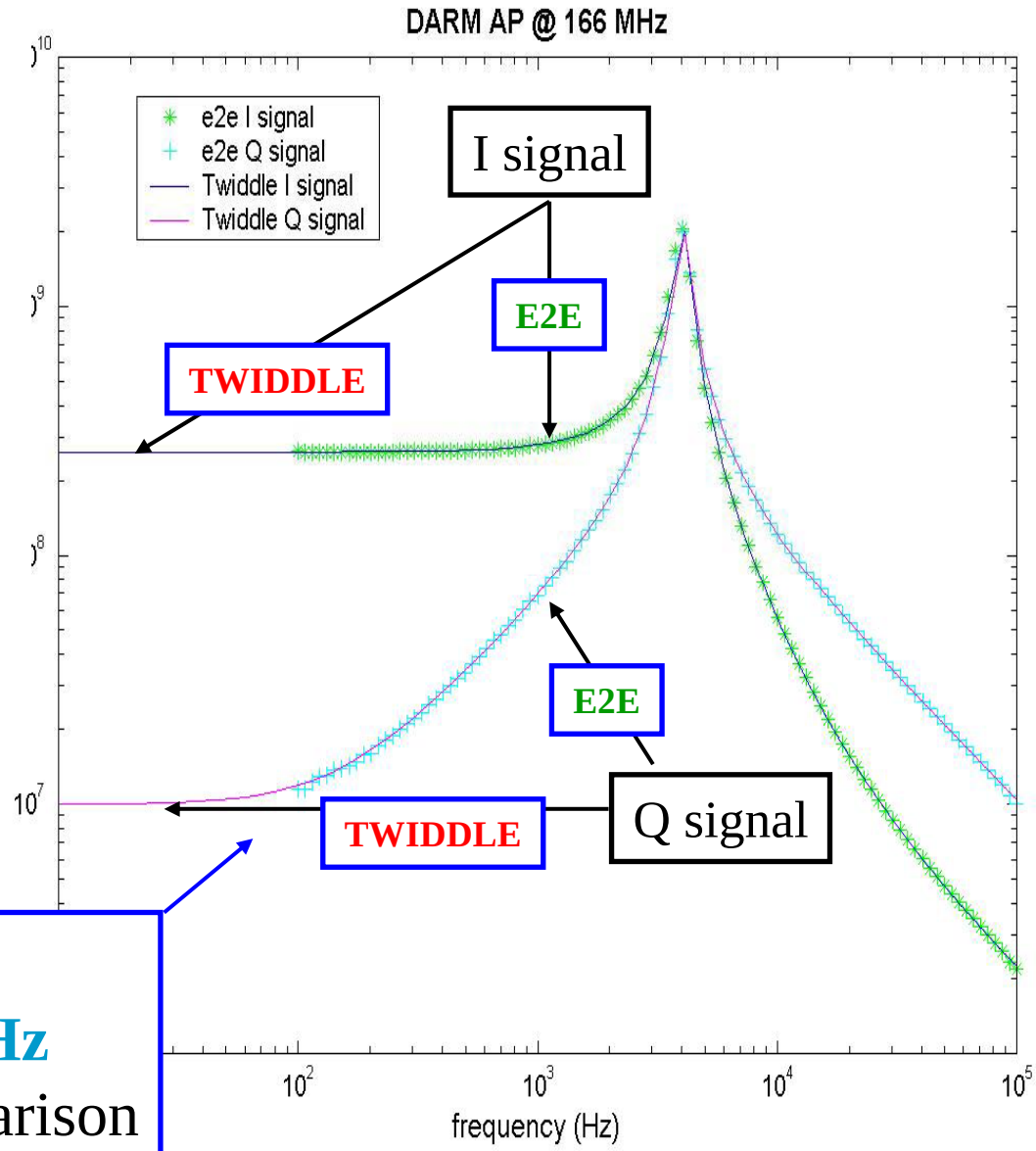
e2e SIMULATION: 4Om/AdvLIGO package
optical configuration



e2e SIMULATION: 4Om/AdvLIGO package

• **e2e** validation of DC fields comparing with **TWIDDLE** results: good agreement !

• **e2e** transfer functions simulations (and comparison with **TWIDDLE** ones) of DOF at **SP**, AP and **PO** shaking the end mirrors with *white noise* at different demodulation frequencies : (33,133,166,199) MHz

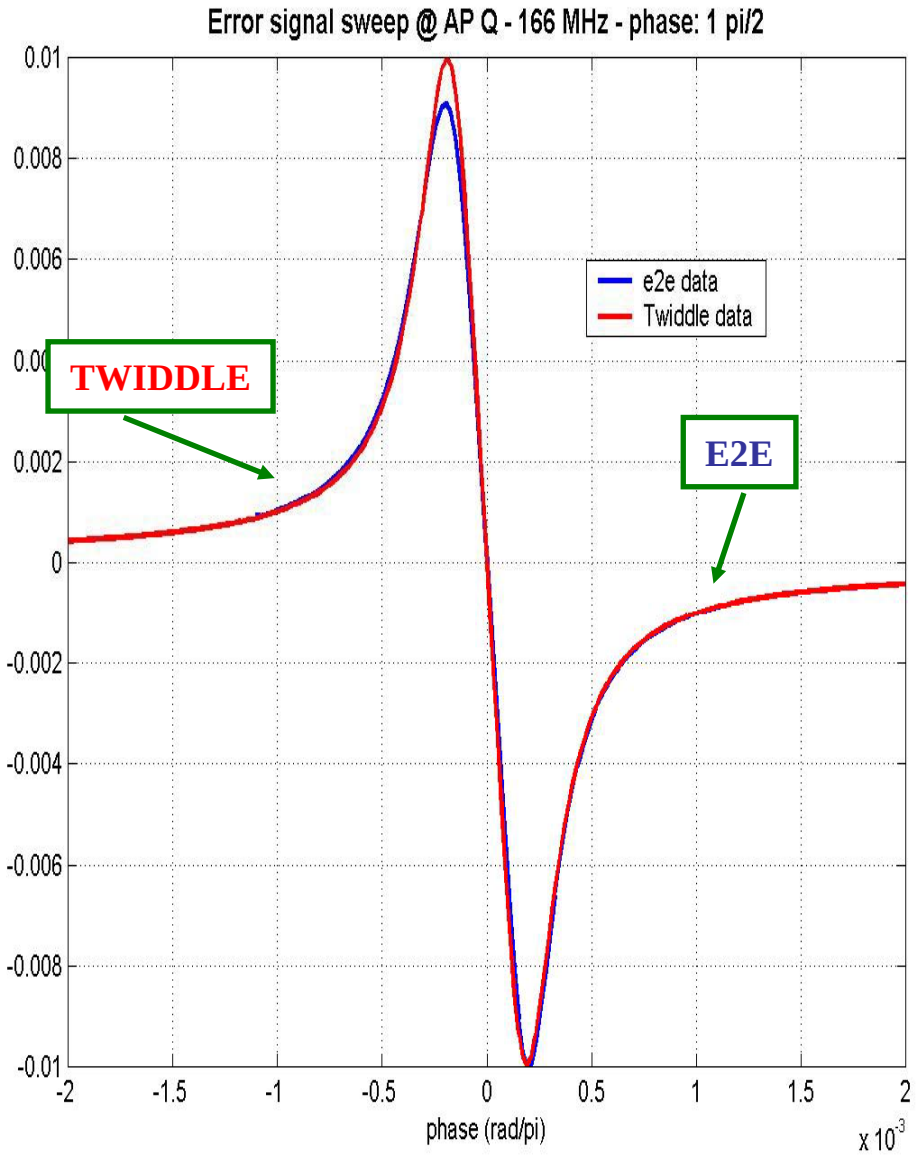


Example:
DARM @ **AP 166 MHz**
TWIDDLE and e2e comparison

e2e SIMULATION: 4Om/AdvLIGO package

Error signal sweeps at 10^{-9} m/s for the 40m IFO with the **E2E** simulation (and comparison with **TWIDDLE**) to validate the static case

Example:
DARM @ AP 166 MHz
TWIDDLE and **E2E** comparison



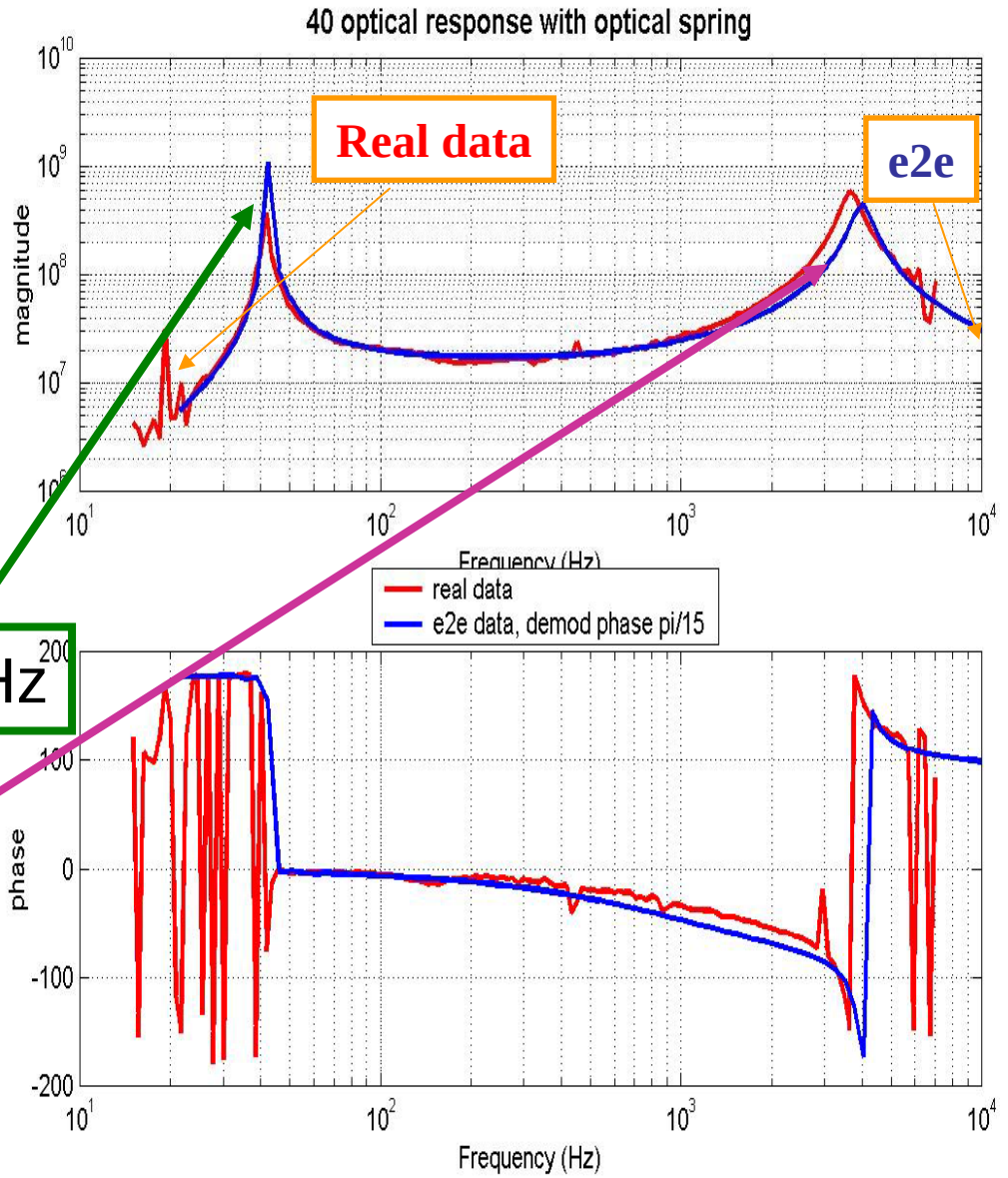
e2e SIMULATION: 4Om/AdvLIGO package

40m optical response
@ AP 166 MHz
(Dark Port)

40m real data and **e2e** comparison

optical spring peak @ 40Hz

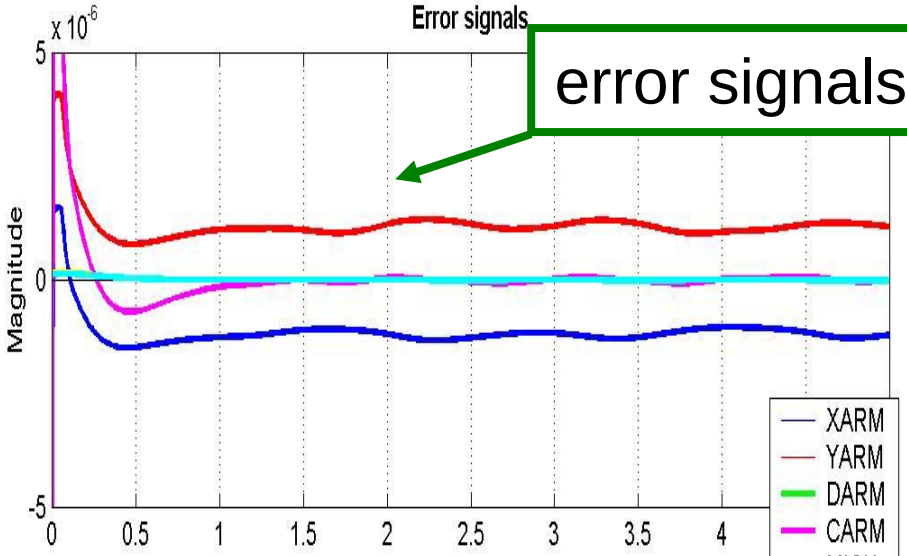
RSE peak @ 4 kHz



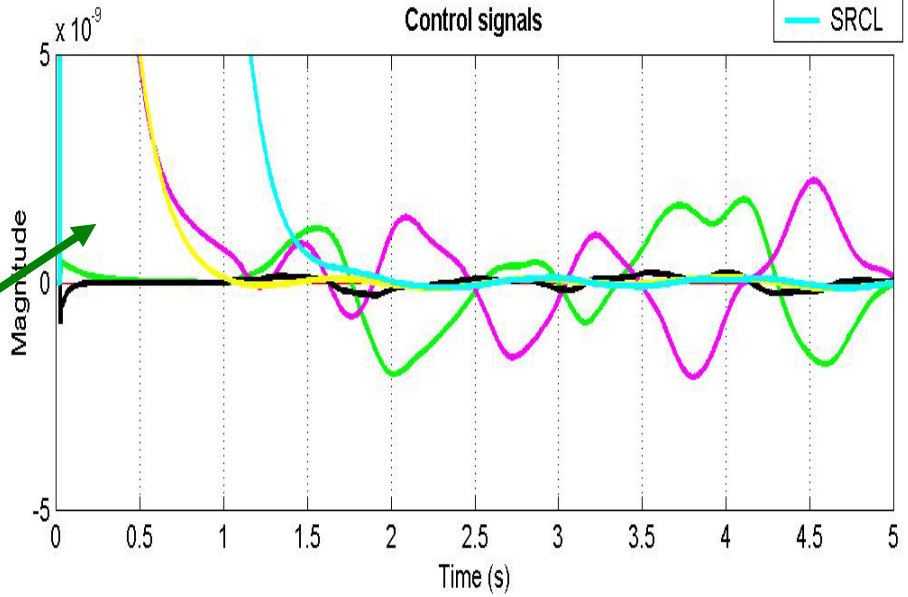
e2e SIMULATION: 4Om package

40m in-lock state :
5 DOF controlled
with radiation pressure

DARM : AP 166 MHz
CARM : POX+POY 33 MHz
MICH : AP 33 MHz
PRC : SP 133 MHz
SRC : POX 199 MHz

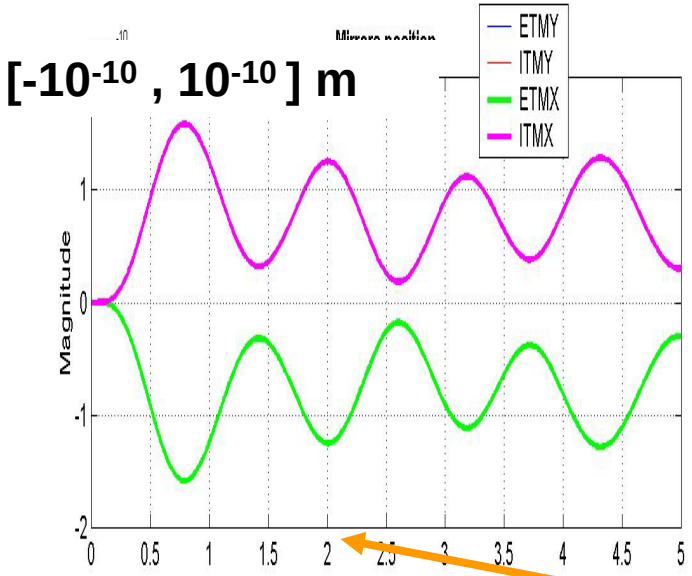


error signals

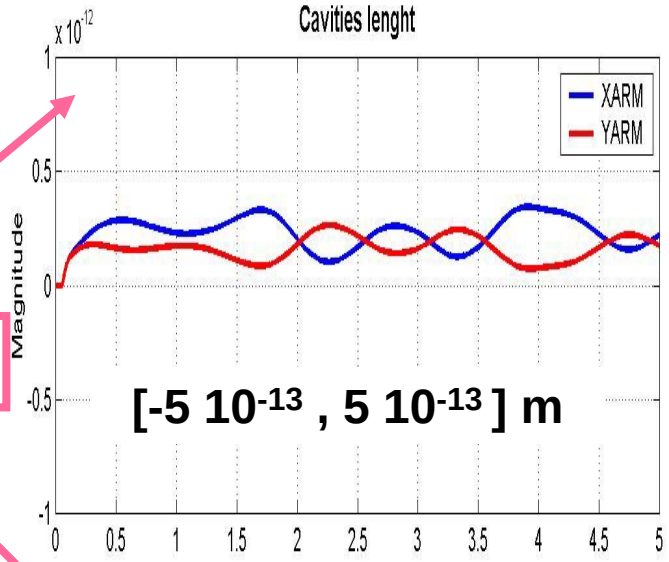


control signals

e2e SIMULATION: 4Om package



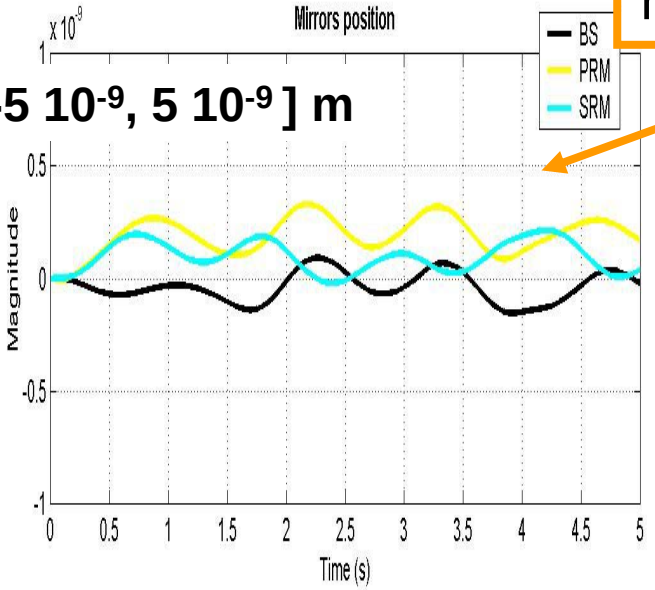
[-10^{-10} , 10^{-10}] m



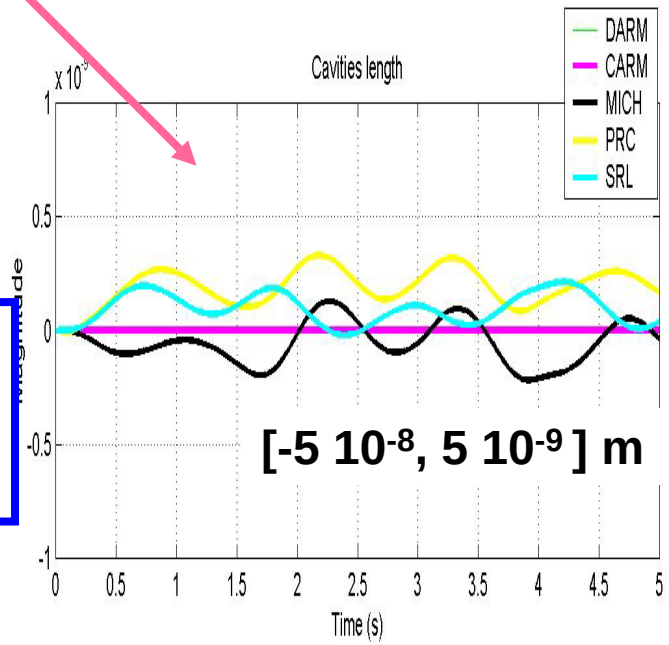
[-5 10^{-13} , 5 10^{-13}] m

cavities length

mirror positions



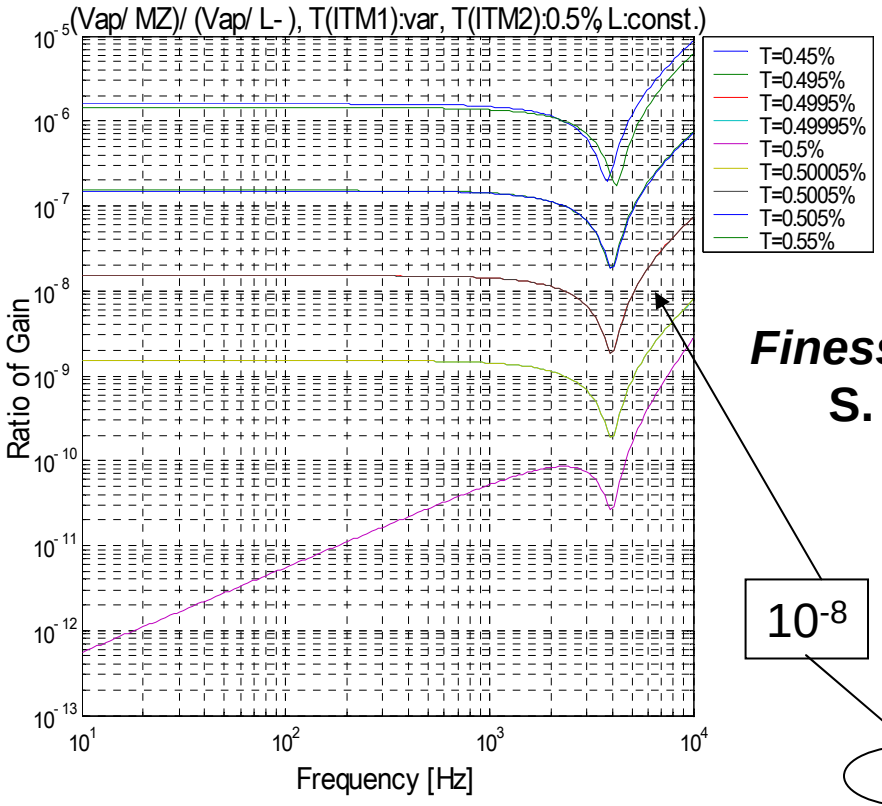
[-5 10^{-9}, 5 10^{-9}] m

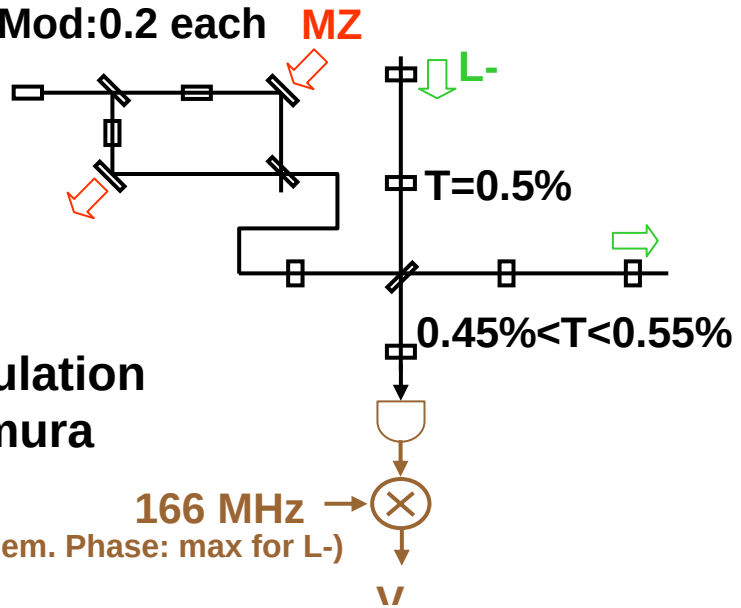


[-5 10^{-8}, 5 10^{-9}] m

40m
in-lock state
5s simulation

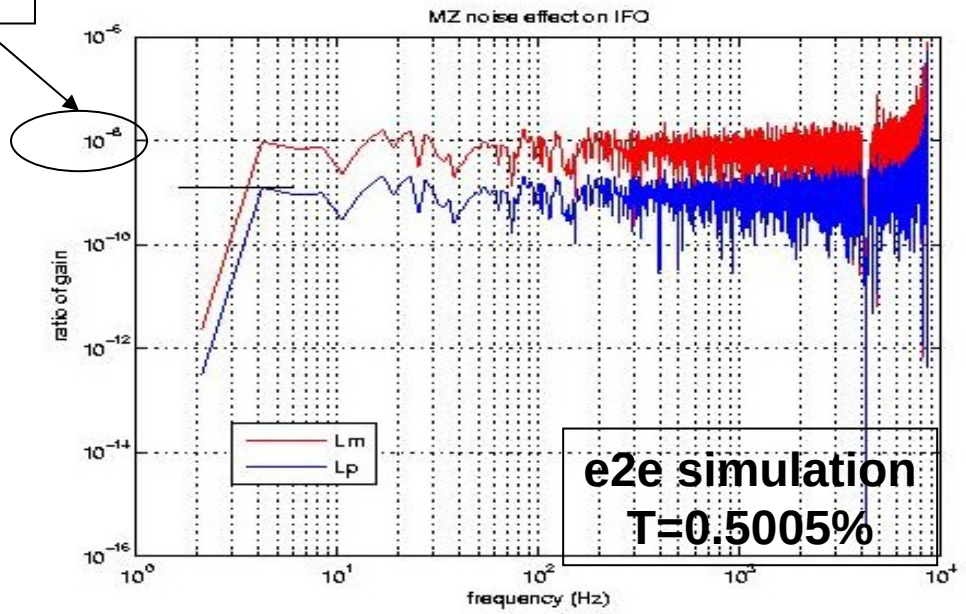
Mach-Zehnder noise for the detuned RSE interferometer





***Finesse* simulation**
S. Kawamura

10^{-8}



Effect of MZ Noise in terms of L-

$$= \frac{\text{(Transfer Function from MZ to Vap)}}{\text{(Transfer Function from L- to Vap)}}$$

The mechanism gives 10^{-6} coefficient. The MZ noise should be suppressed to 10^{-13} m/rHz in order to suppress the L- noise to 10^{-19} m/rHz.

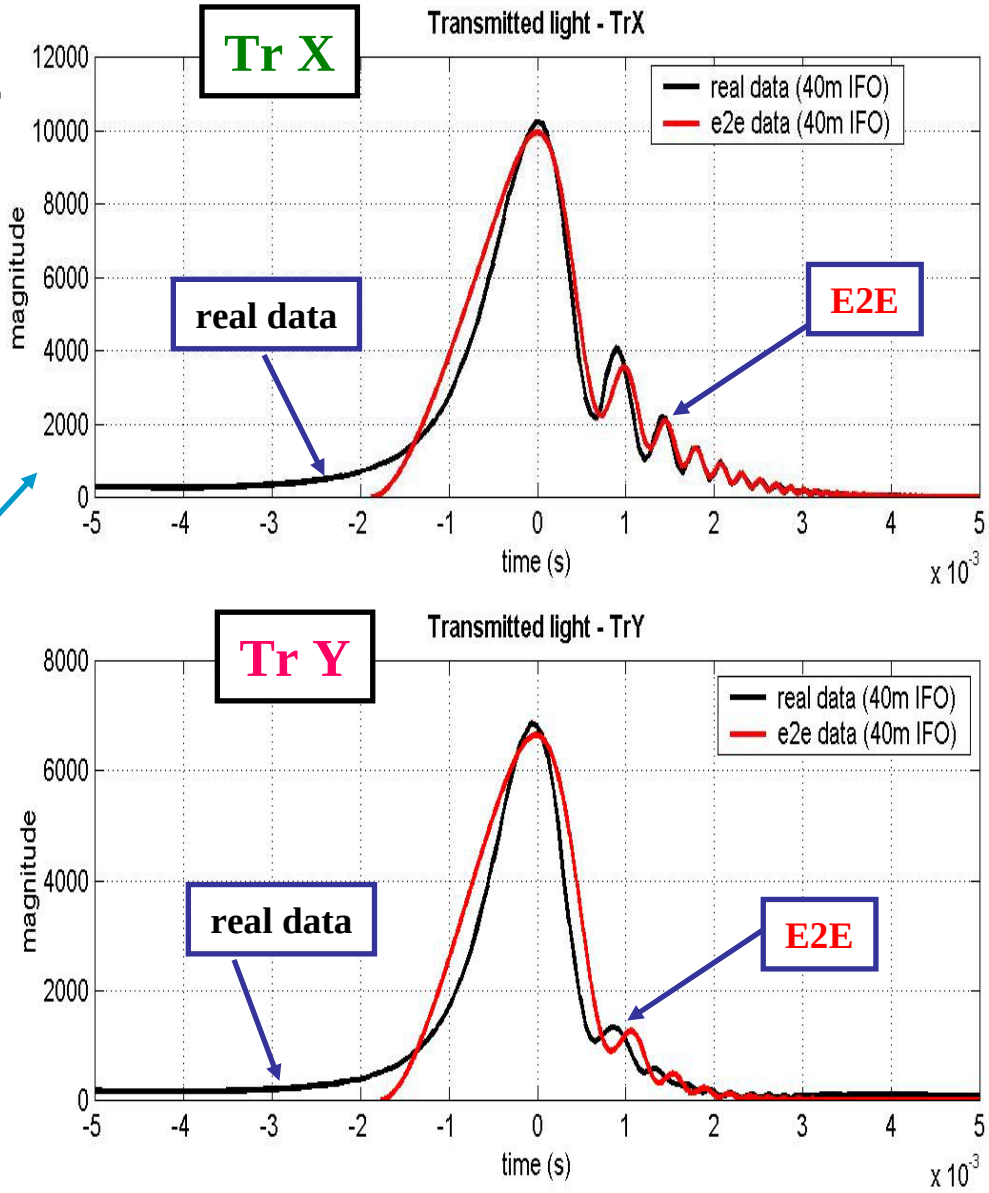
e2e SIMULATION: 4Om package

Real data have been used to estimate relative mirror velocity for both the arms:

V_{xarm}= (0.35 ± 0.13) µm/s

V_{yarm}= (0.26 ± 0.13) µm/s

Comparison between real data (black) and e2e simulated data (red) of the transmitted light for both the arms (full IFO): the mirror velocities used in e2e simulation are the values obtained fitting the real data



e2e SIMULATION:
application to a possible dual recycled Virgo

Laser Power =100 W
Demod frequency = 6.26 MHz

Arm Length = 3 km
PRM2BS = 6 m
SRM2BS = 6 m
BS2ITMN = 5.6 m
BS2ITMW = 6.5 m

Actual Virgo losses

Detuning phase = 0.1 pi/2 for SRC

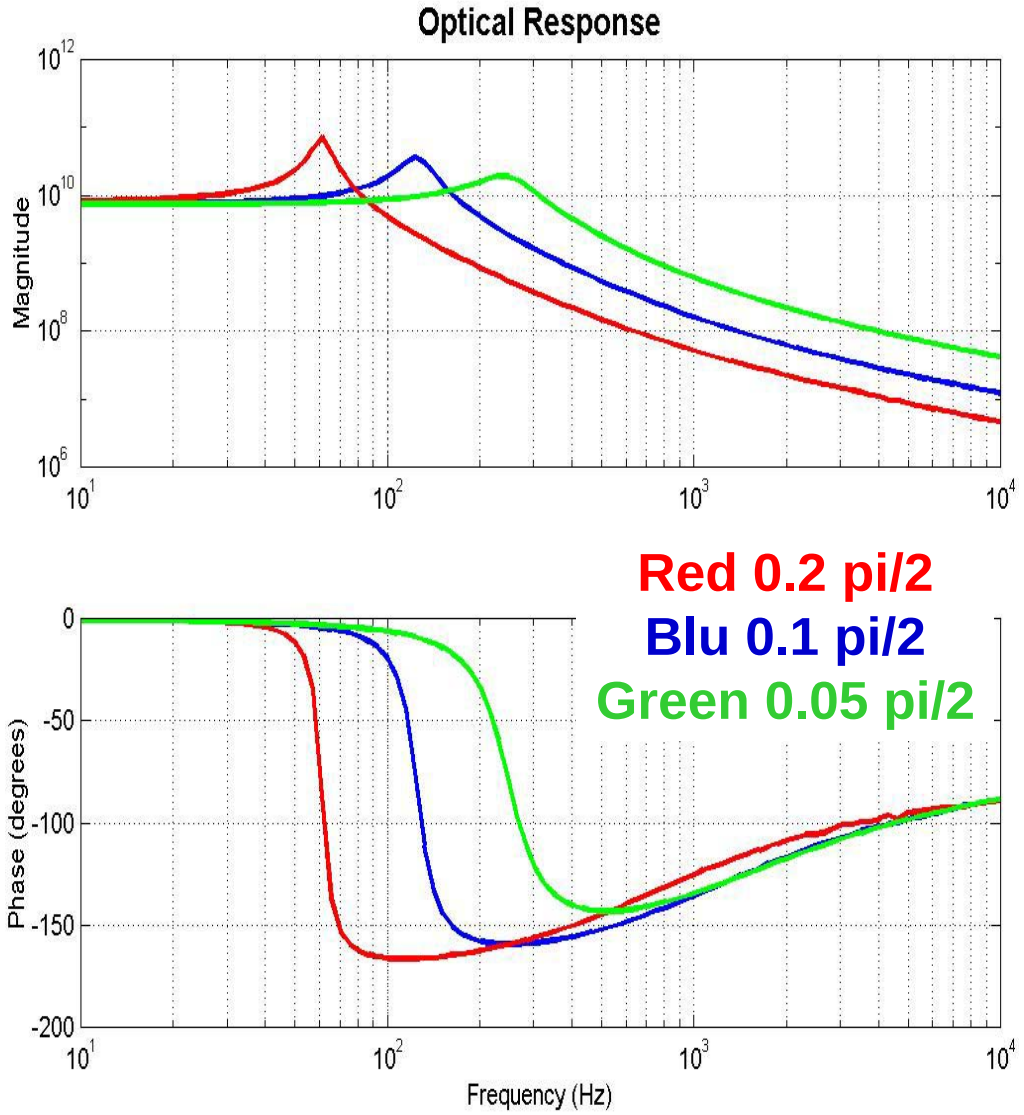
e2e *optical configuration*
validation of DC fields
for a given set of parameters

SRC power	**0.16**	**W**
PRC power	**2713**	**W**
MICH power	**1349**	**W**
West Arm power	**1**	**MW**
North Arm power	**1**	**MW**

e2e SIMULATION:
application to a possible dual recycled Virgo

optical response
@ Dark Port

Investigation of the RSE peak for different SRC detuning phases



Conclusions

- e2e package ready to investigate the behavior of the interferometers in time domain
  - ✓ **40m** : optical configuration, in-lock state
  - ✓ **«possible» Advanced Virgo** : optical configuration

- use of the e2e package to establish the suitable parameters optical configuration for Advanced Virgo and comparison with a SIESTA model (to be implemented) and eventually other available programs

Further steps

- **e2e simulation for the 40m**
  - Lock acquisition strategies investigation
  - DC readout investigation

- **e2e simulation applied to a dual recycled Virgo**
  - Length Sensing Control (LSC) implementation
    - Optical response including optical spring
  - SuperAttenuator (SA) implementation
  - Lock acquisition strategies investigation