The road to 10 dB

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GWADW, Girdwood, May 19 2015

LIGO-G1500668

Motivation

ET EINSTEIN TELESCOPE

ET Design Study

ET-0106C-10
issue : 4
date : June 28, 2011
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Parameter	ET-D-HF	ET-D-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10 K
Mirror material	fused silica	silicon
Mirror diameter / thickness	62 cm / 30 cm	min 45 cm/ T
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase	tuned (0.0)	detuned (0.6)
SR transmittance	10 %	20 %
Quantum noise suppression	freq. dep. squeez.	freq. dep. squeez.
Filter cavities	1×10 km	2×10 km
Squeezing level	10 dB (effective)	10 dB (effective)
Beam shape	LG_{33}	TEM_{00}
Beam radius	7.25 cm	9 cm
Scatter loss per surface	37.5 ppm	37.5 ppm
Seismic isolation	SA, 8 m tall	mod SA, 17 m tall
Seismic (for $f > 1$ Hz)	$5 \cdot 10^{-10}\,\mathrm{m}/f^2$	$5 \cdot 10^{-10}\,\mathrm{m}/f^2$
Gravity gradient subtraction	none	none

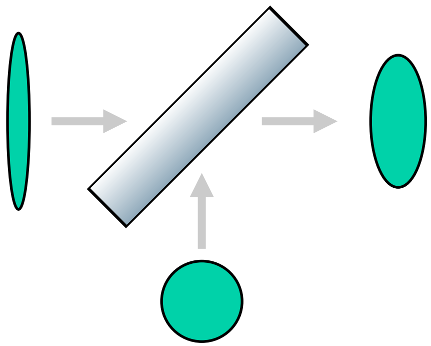
Table 10: Summary of the most important parameters of the ET-D high and low frequency interferometers. SA = super attenuator, freq. dep. squeez. = squeezing with frequency dependent angle.

ET-0106C-10

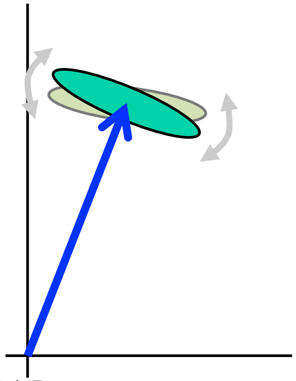
also, all LIGO strawman designs assume around 10 dB observed squeezing

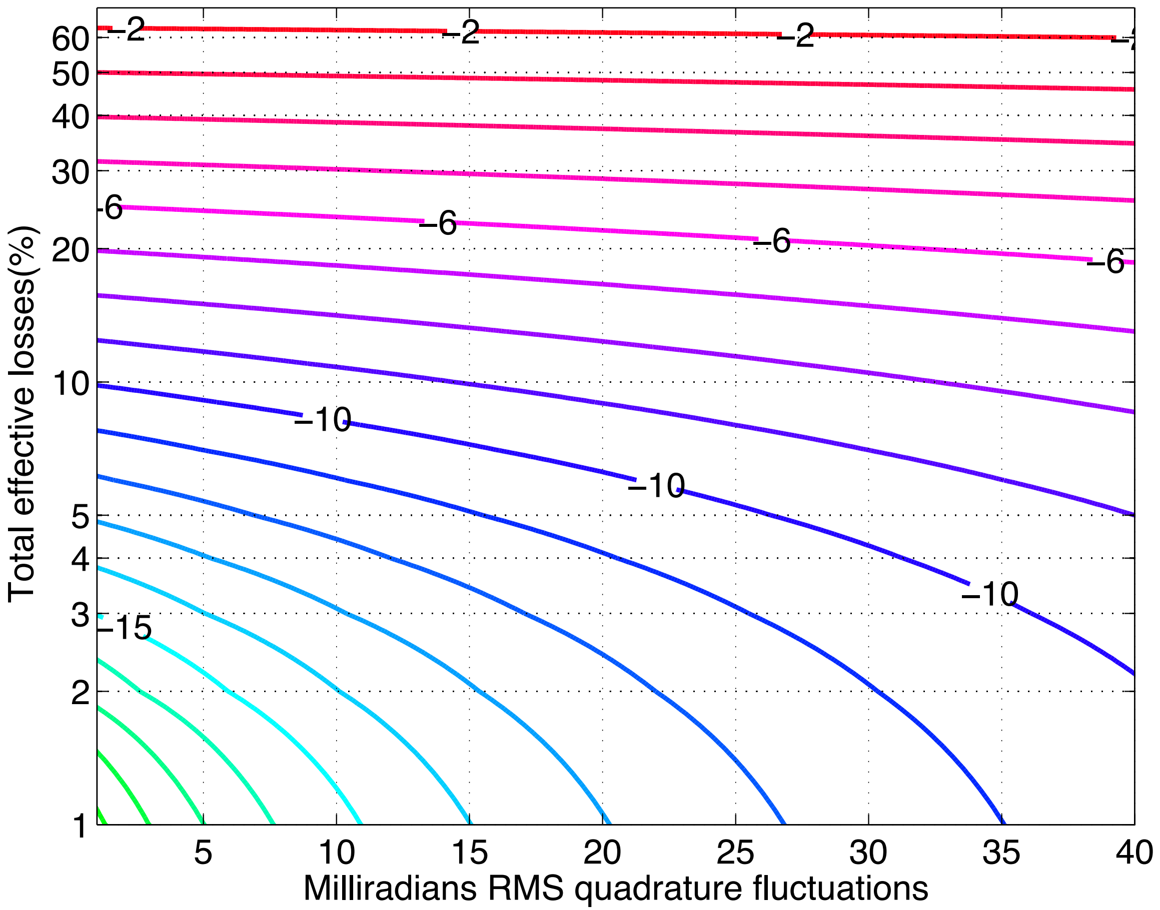
The main challenges

1. losses



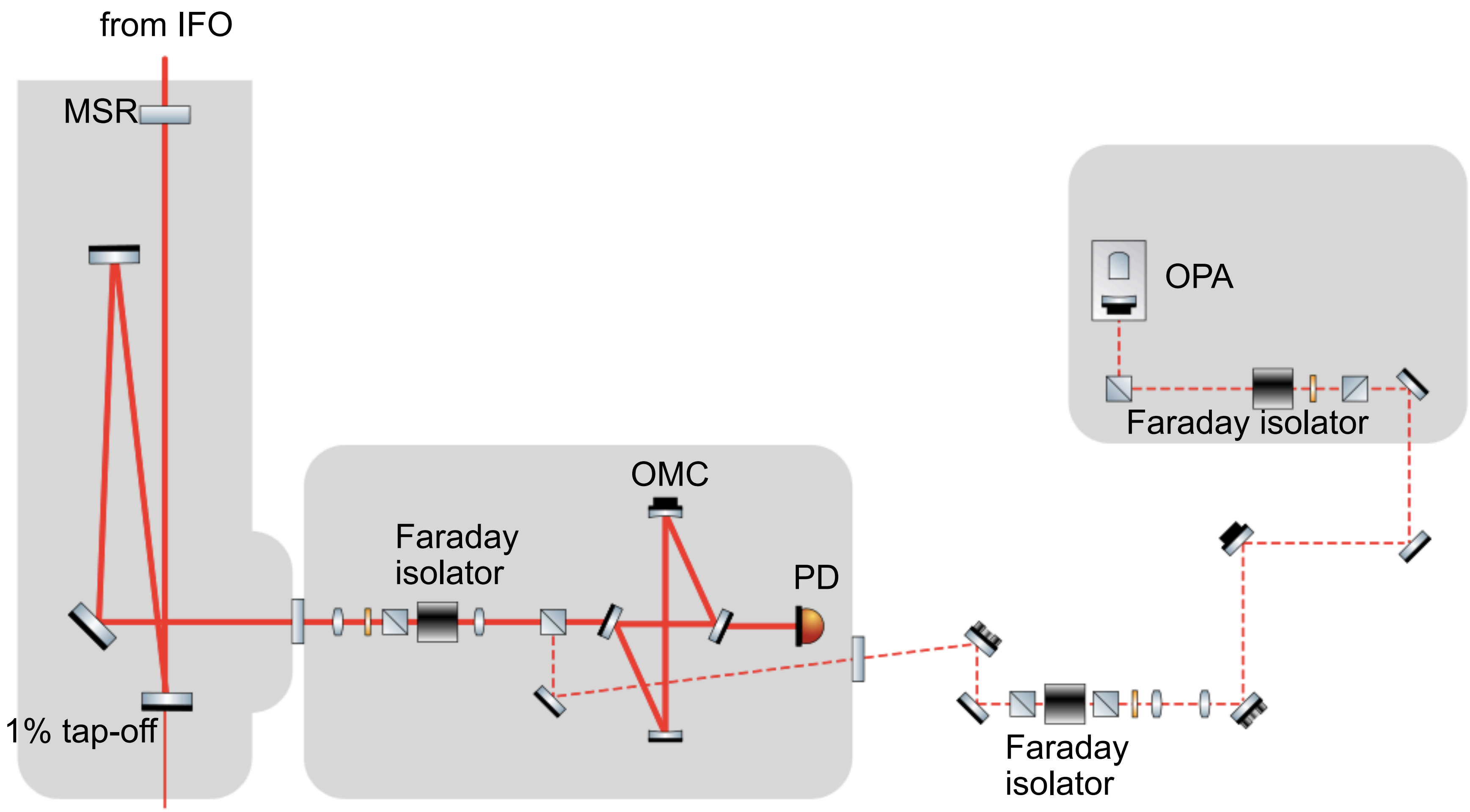
2. phase noise





S. Dwyer et al., 2013

The injection path

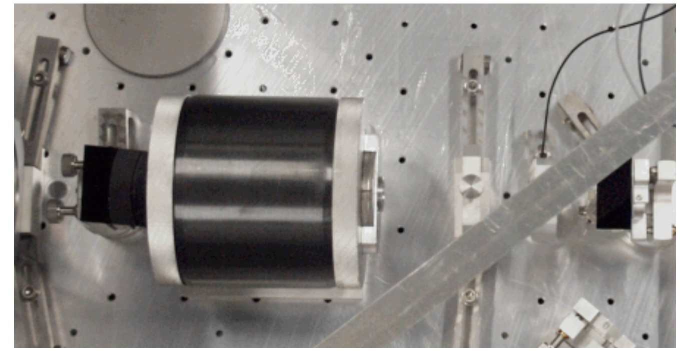


Loss budget

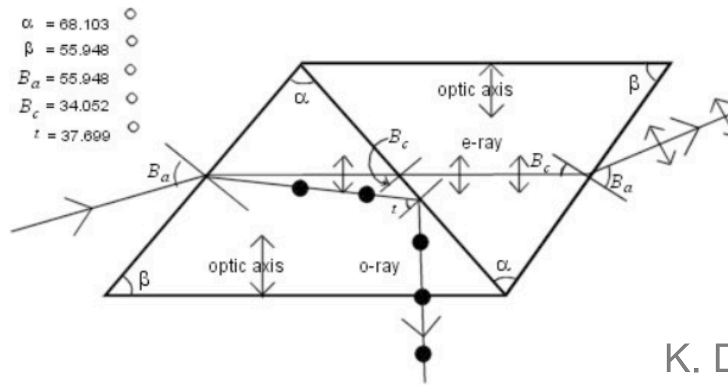
component	achieved at GEO (at some point)	goal (numbers from Strawman Team Red)
OPA internal loss	5%	3%
Faraday isolator (rotator + 2 PBS’)	4 · 2%	3 · 0.8%
loss on IFO reflection	1% (estimated)	1%
mode matching to OMC	4%	1%
OMC internal loss	2%	0.5%
PD quantum efficiency	1%	0.5%
filter cavity	–	1%
tap off	2 · 1%	–
total	21% (40% observed)	9%

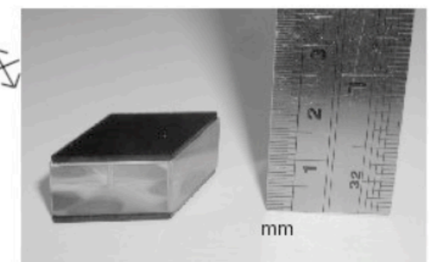
source: ↑
LIGO-T1200046-v1

Low loss Faraday isolators



- current GEO Faraday rotators have 0.6% single pass loss
- PBS cubes show up to 1% loss





- Glasgow PBS design: 220 ppm
- need redesign if we care for both polarizations

K. D. Skeldon et al., 2000

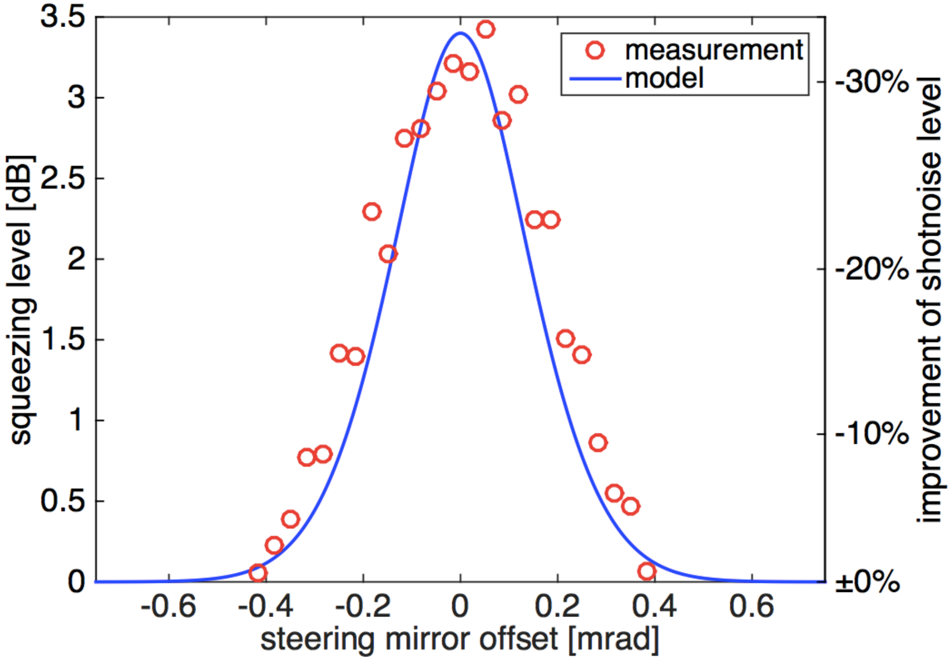
- isolator design at the University of Florida based on optimized IFI design: 0.4% loss

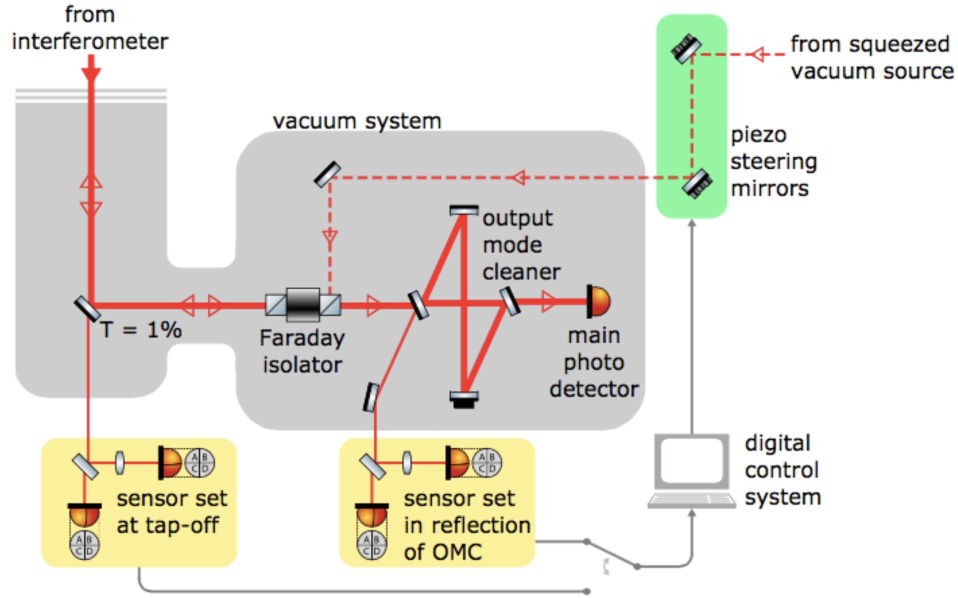
Isolator element	*Optical loss (ppm)*
Prism polarizer (per element/total)	250/500
HWP reflection (per face/total)	300/600
HWP absorption	50
TGG reflection (per face/total)	500/1000
TGG absorption (12 mm crystal)	1800

Table 2: Approximate optical loss of each component in an improved low loss Output Faraday Isolator design. Altogether, these specifications lead to roughly 0.4% single pass loss.

R. Goetz, LIGO-T1500187

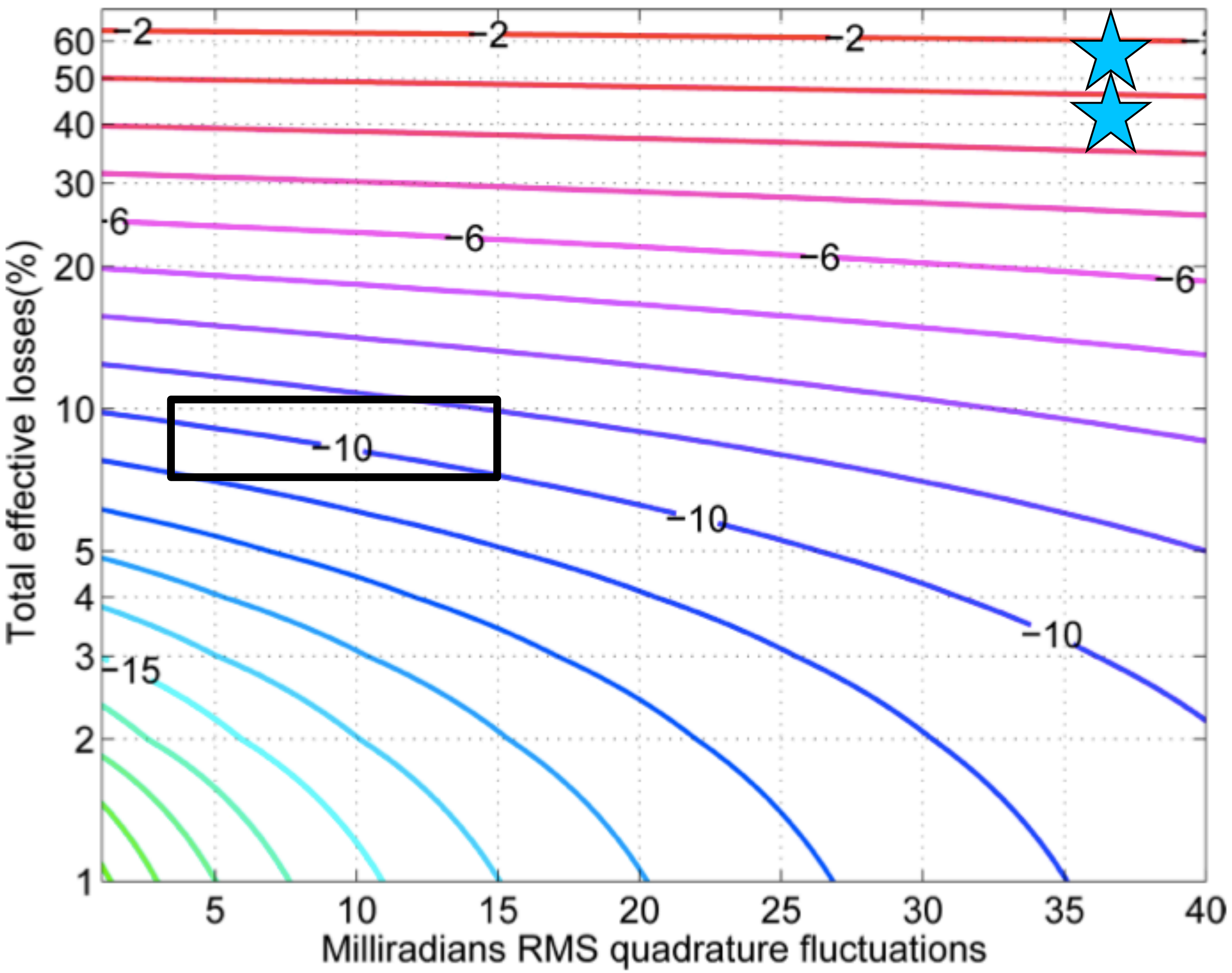
Alignment control





E. Schreiber et al., LIGO-P1500056

The phase noise roadmap

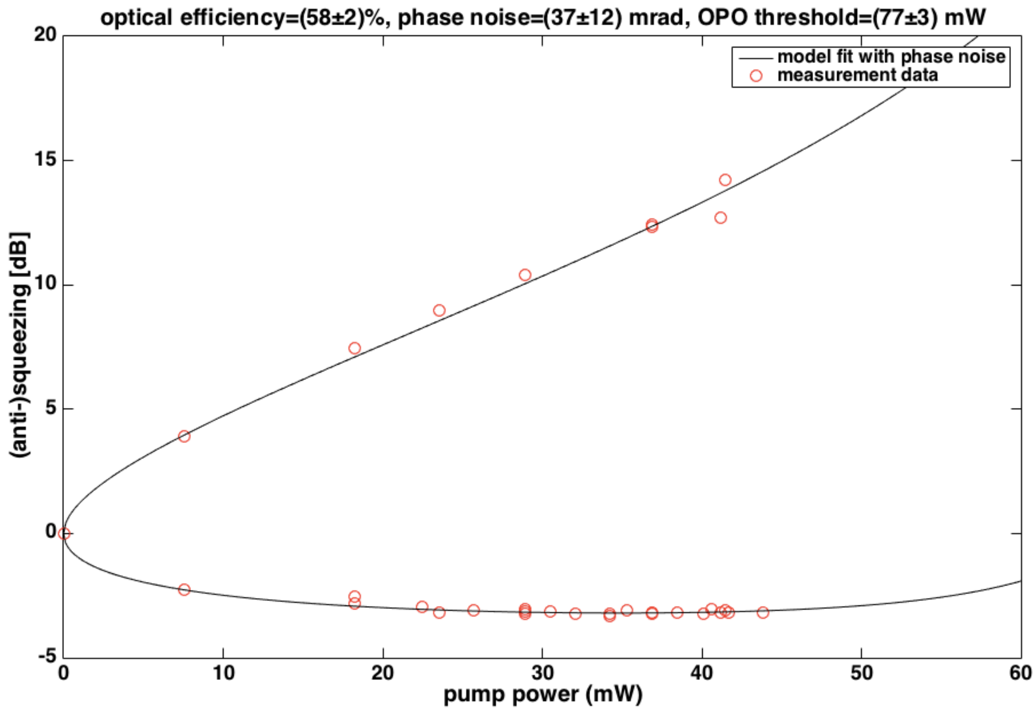


Dwyer et al. Optics Express, Vol. 21, Issue 16 (2012)

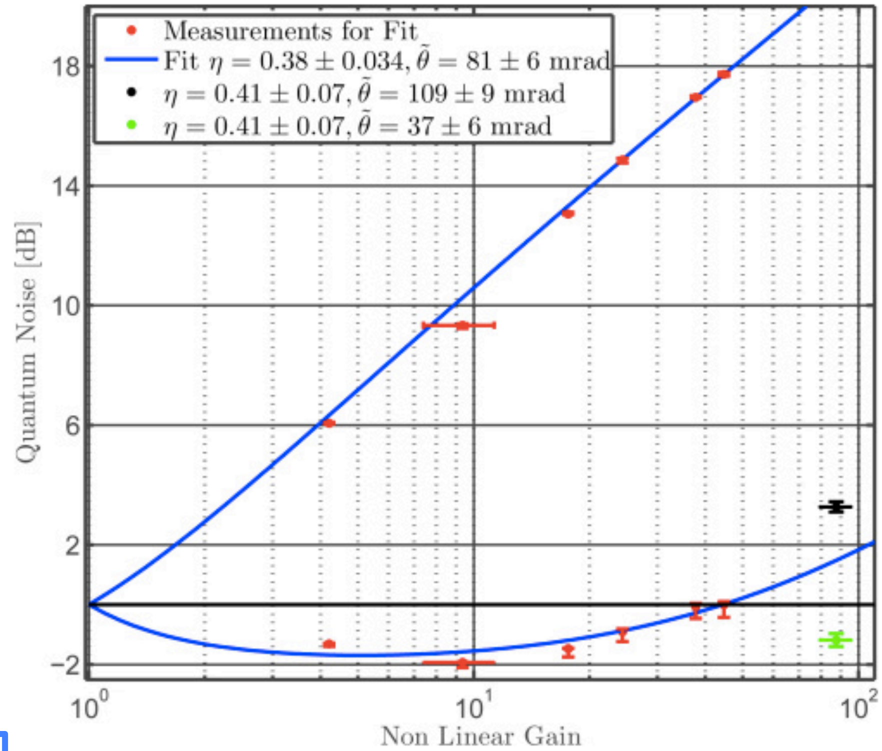
Total phase noise (current detectors)

Out-of-loop measurements of total phase noise

GEO:



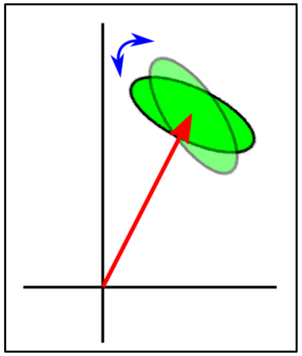
LIGO:



Both sites: ~37 mrad rms (!)

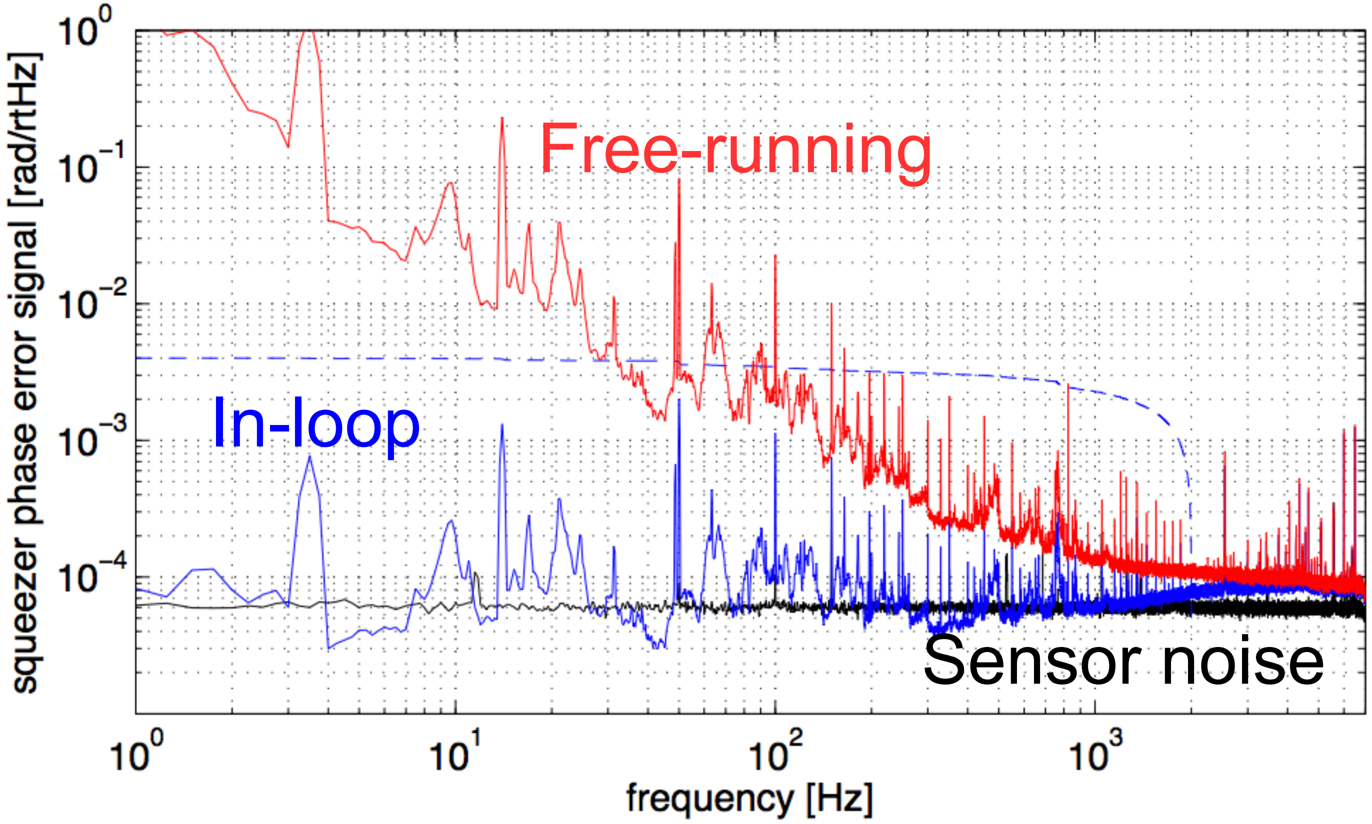
Dwyer, PhD thesis (2013)

Phase noise budget



source	rms phase [mrad]
in-loop: up to 2 kHz	4
audio: 2 kHz – 45 kHz	13
RF: 14.9 MHz MI sidebands	6.7
RF: 9 MHz SRC sidebands	5.5

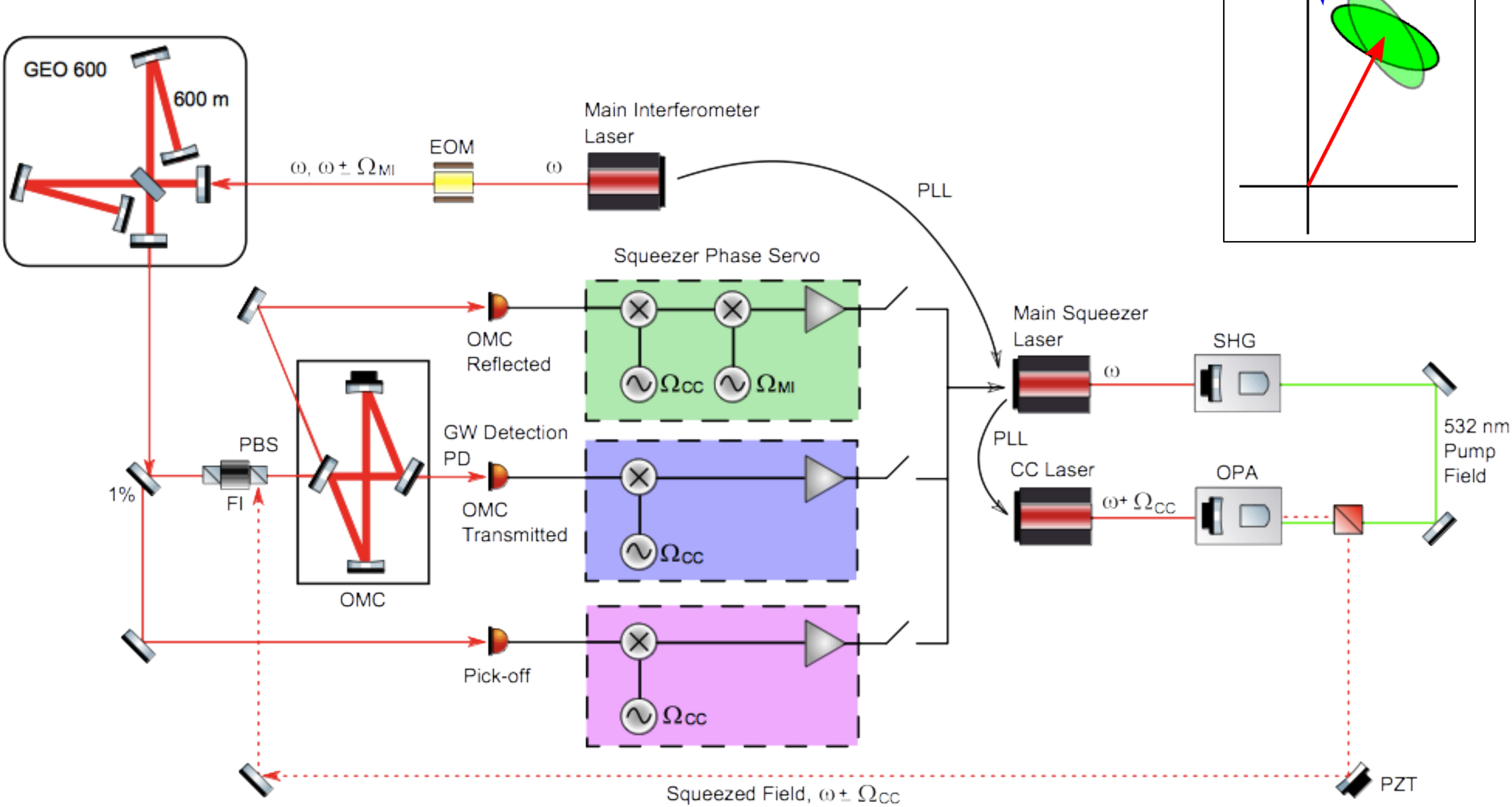
Total accounted-for phase noise = 16 mrad rms



(LIGO accounted-for phase noise = ~ 25 mrad rms)

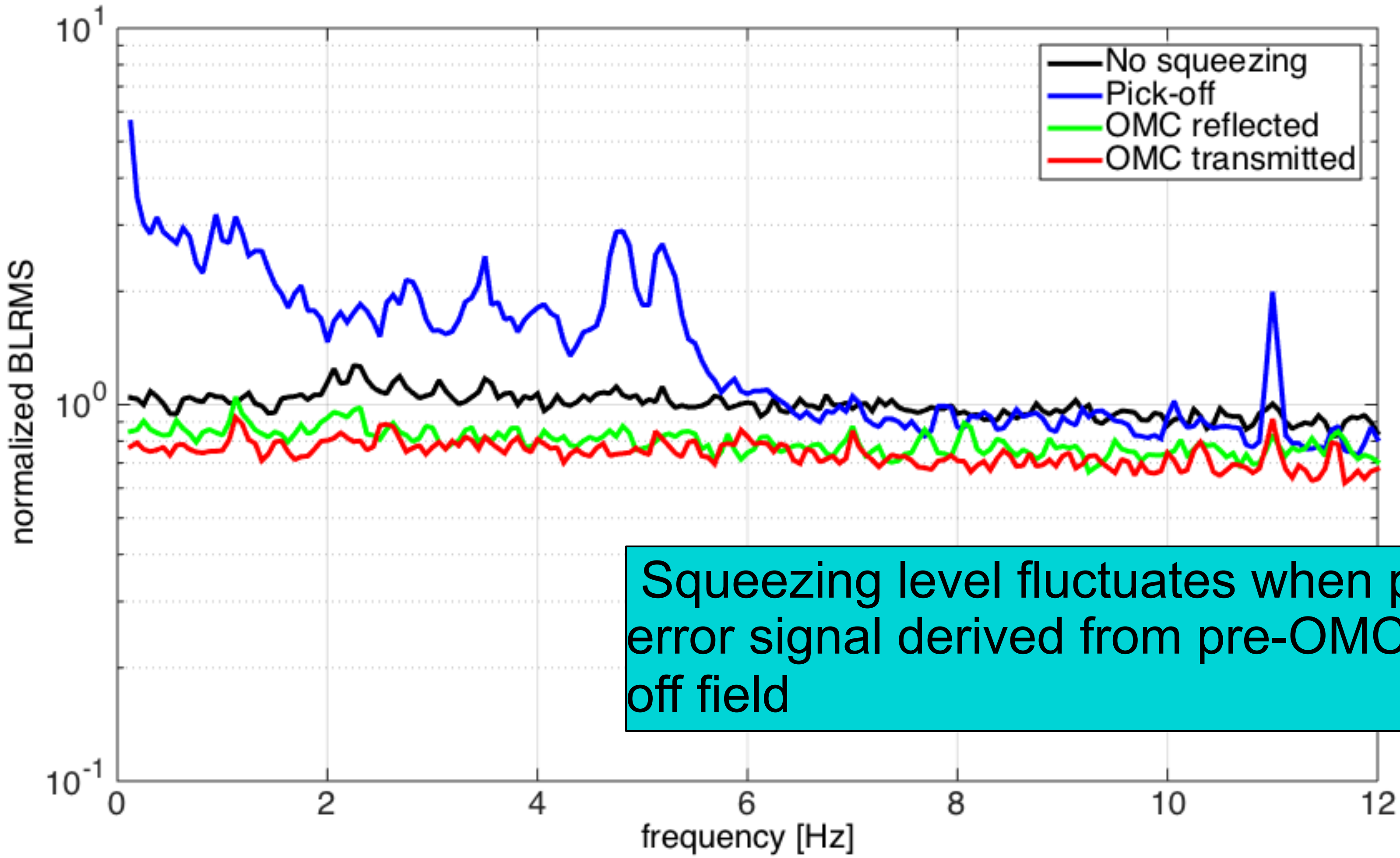
Both interferometers observe excess phase noise.

Squeezing phase error signal: 3 choices



New signals = stable squeezing

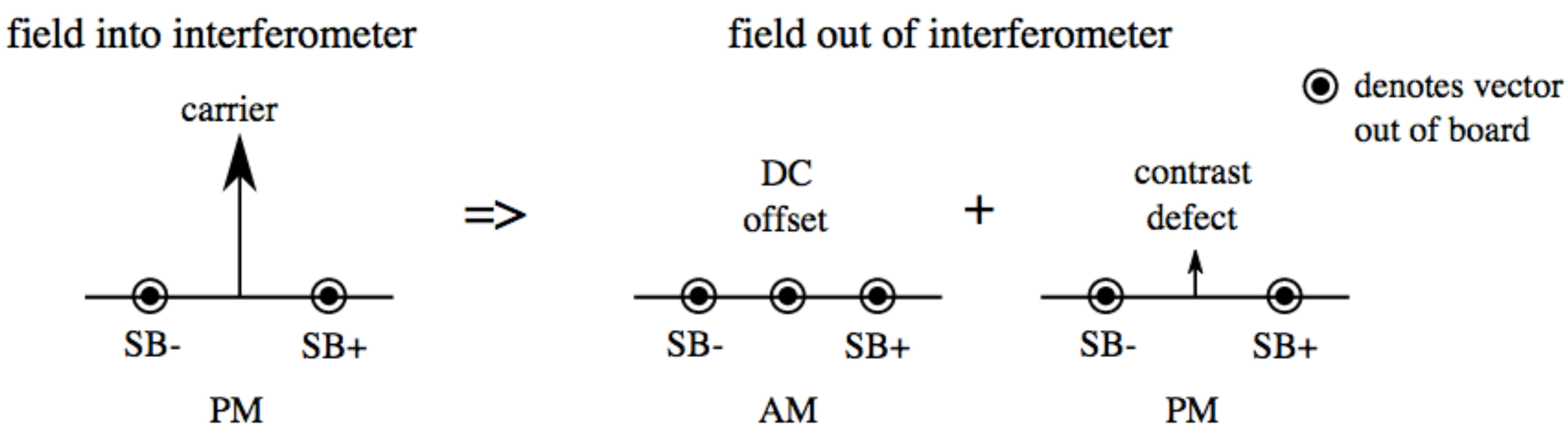
- Stability of h(t) from 4 kHz – 5 kHz (a shot-noise-limited region)



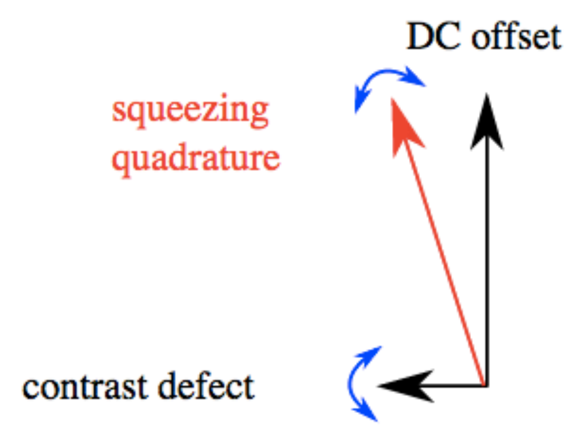
Squeezing level fluctuates when phase error signal derived from pre-OMC pick-off field

Phase noise from RF sidebands

squeezing ellipse orientation must match angle of interferometer output field

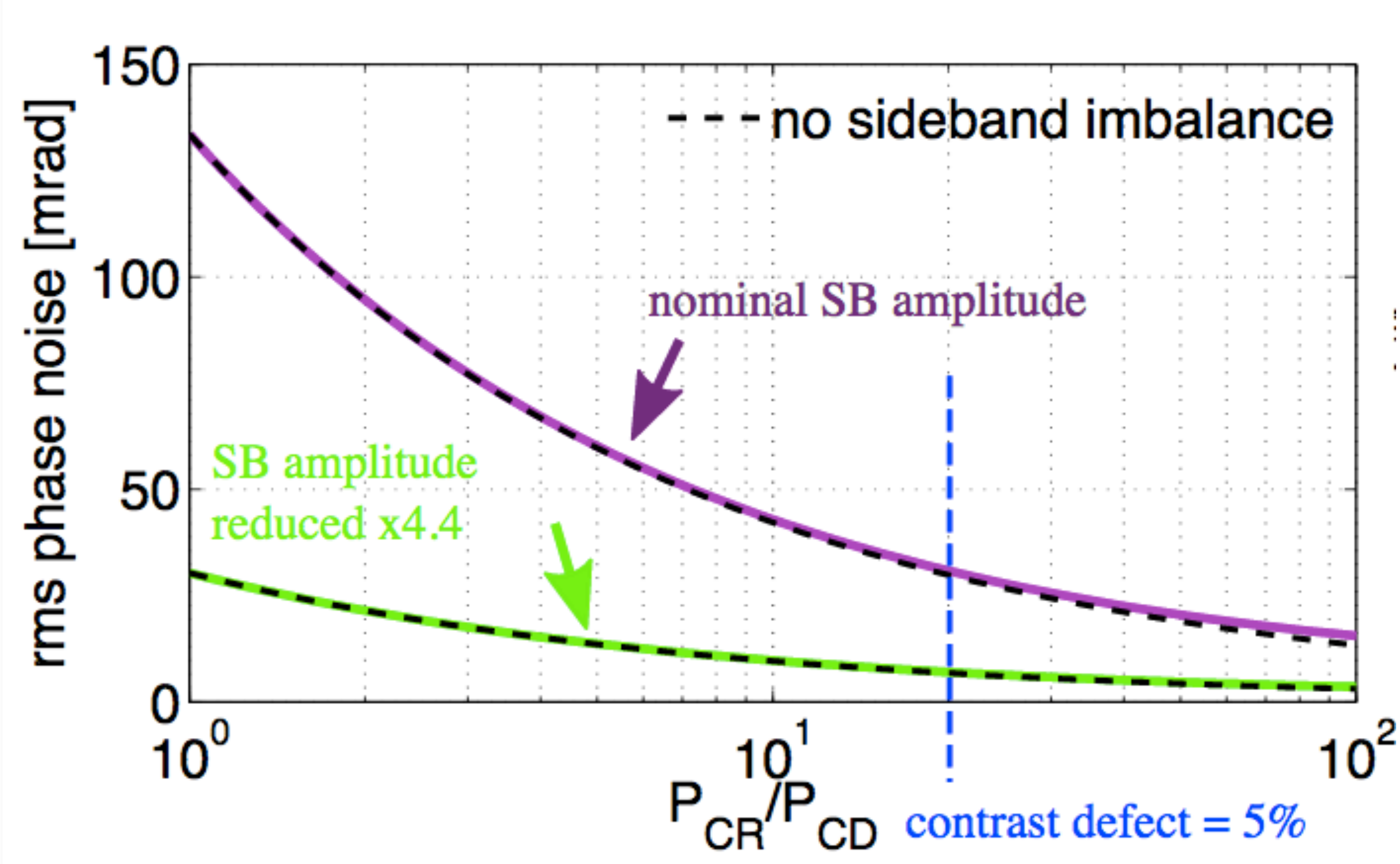


RF sidebands at the output port modulate the DC offset and contrast defect fields, generating phase noise

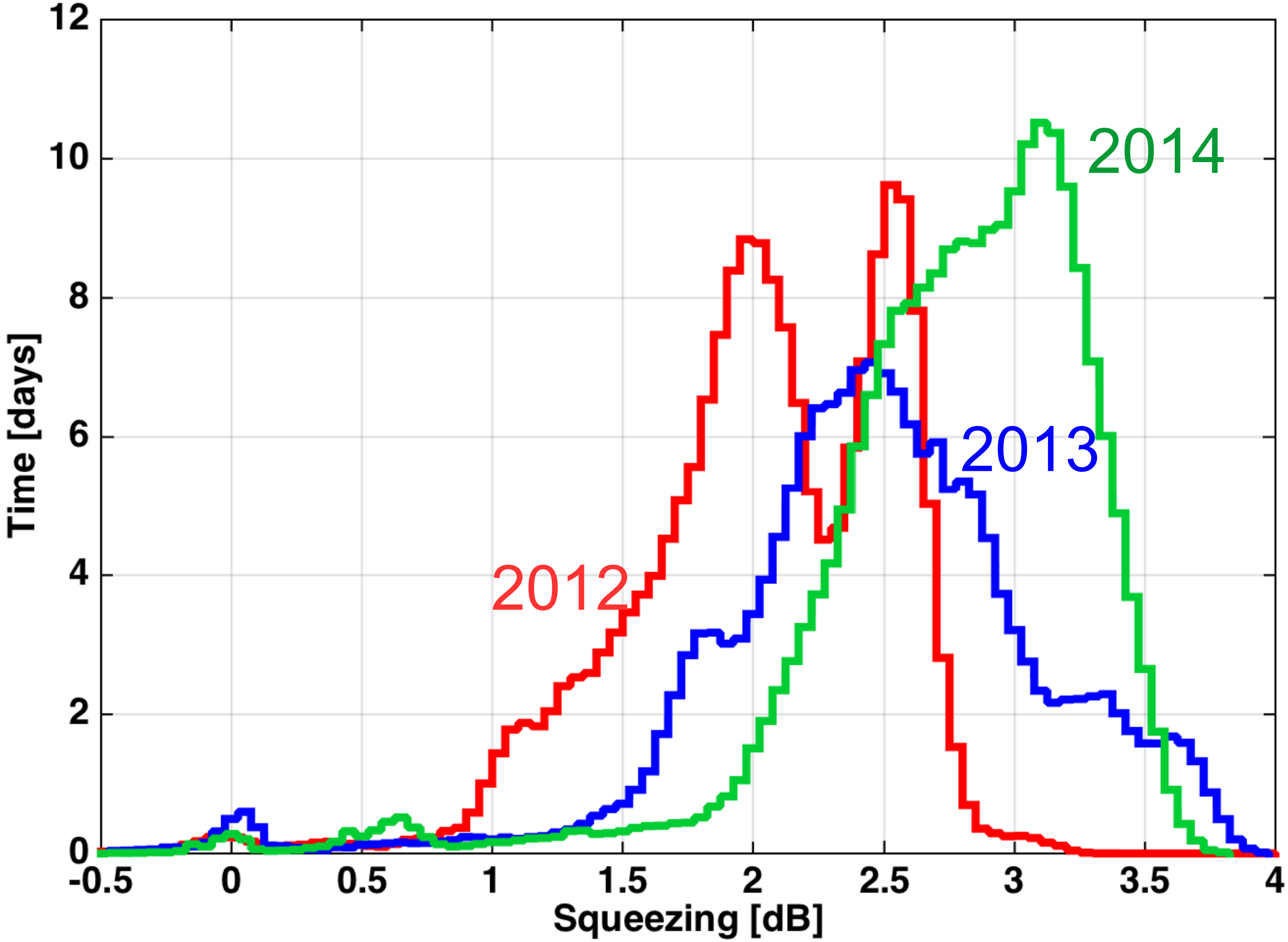


Phase noise from RF sidebands

Example: GEO 14.9 MHz Michelson sidebands

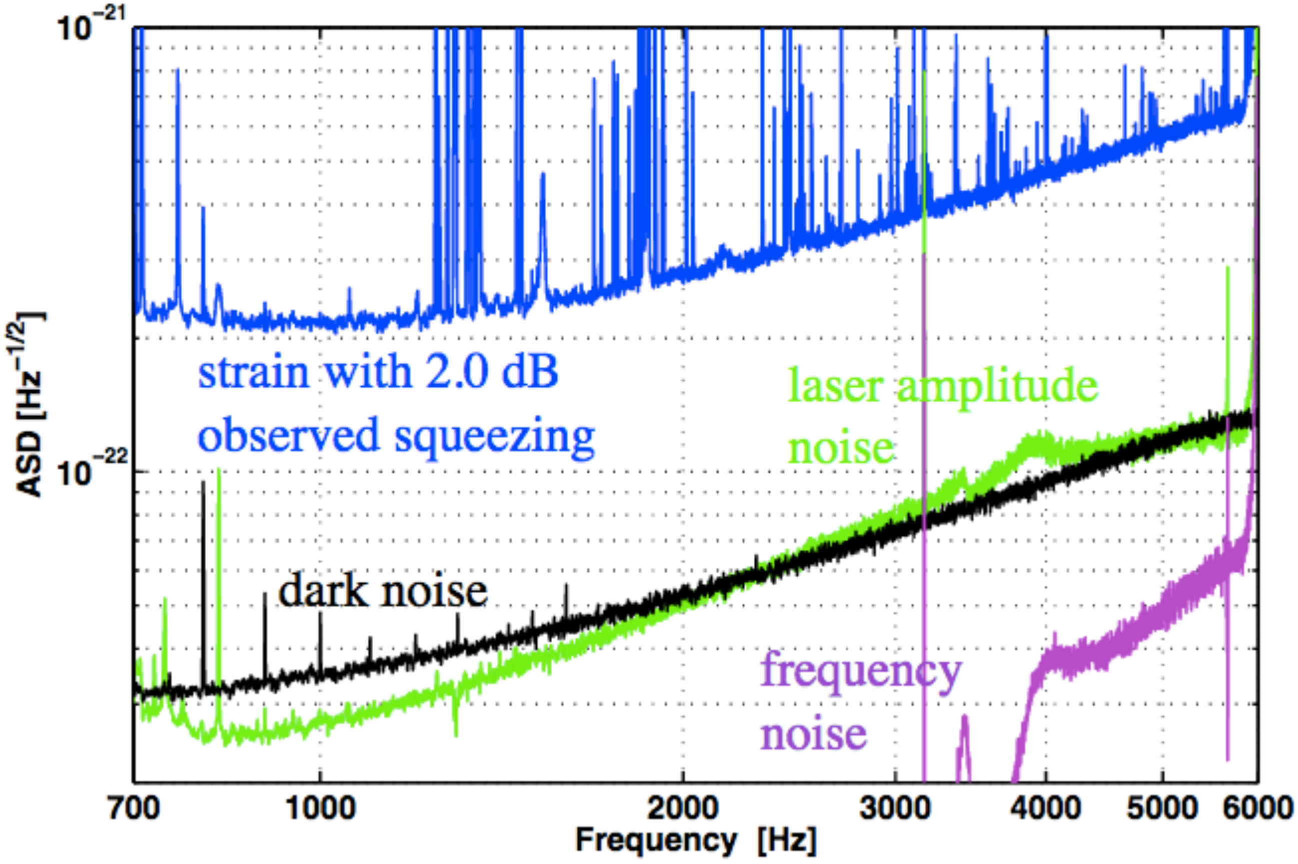


3 years of squeezing



Adapt the interferometer design

Don't forget about other noise sources

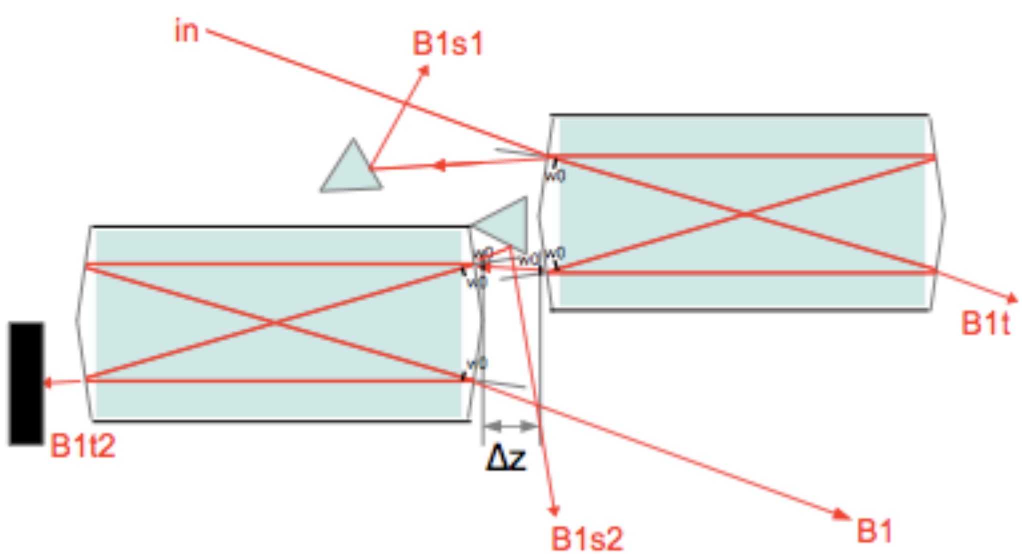


Actual squeezing level: 2.4 dB

2 OMCs a la Virgo?

Reduce losses and phase noise from RF sidebands

– 2 OMCs in series
-- low finesse → low losses
-- double pole → sufficient filtering of RF sidebands



Virgo has already demonstrated 96% transmission through both OMCs

Advanced Virgo TDR
VIR–0128A–12

Summary and open questions

For 10 dB of squeezing:
– Phase noise must be reduced from ~35 mrad to ~10 mrad
– Optical losses must be reduced from ~40% to ~8%

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In what other ways can we adapt the interferometer to be compatible with 10 dB squeezing?

- 2 OMCs?
- can we minimize pick-offs for other control beams?
- can we make use of OMC reflection for ifo alignment?
- ?
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