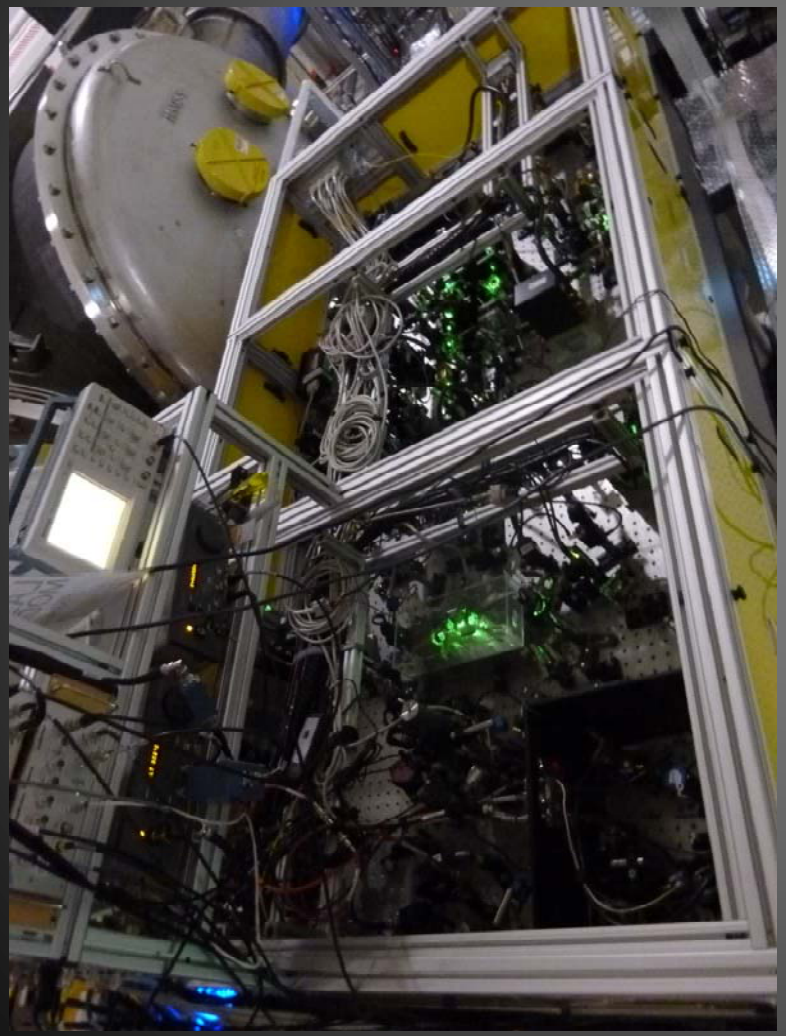
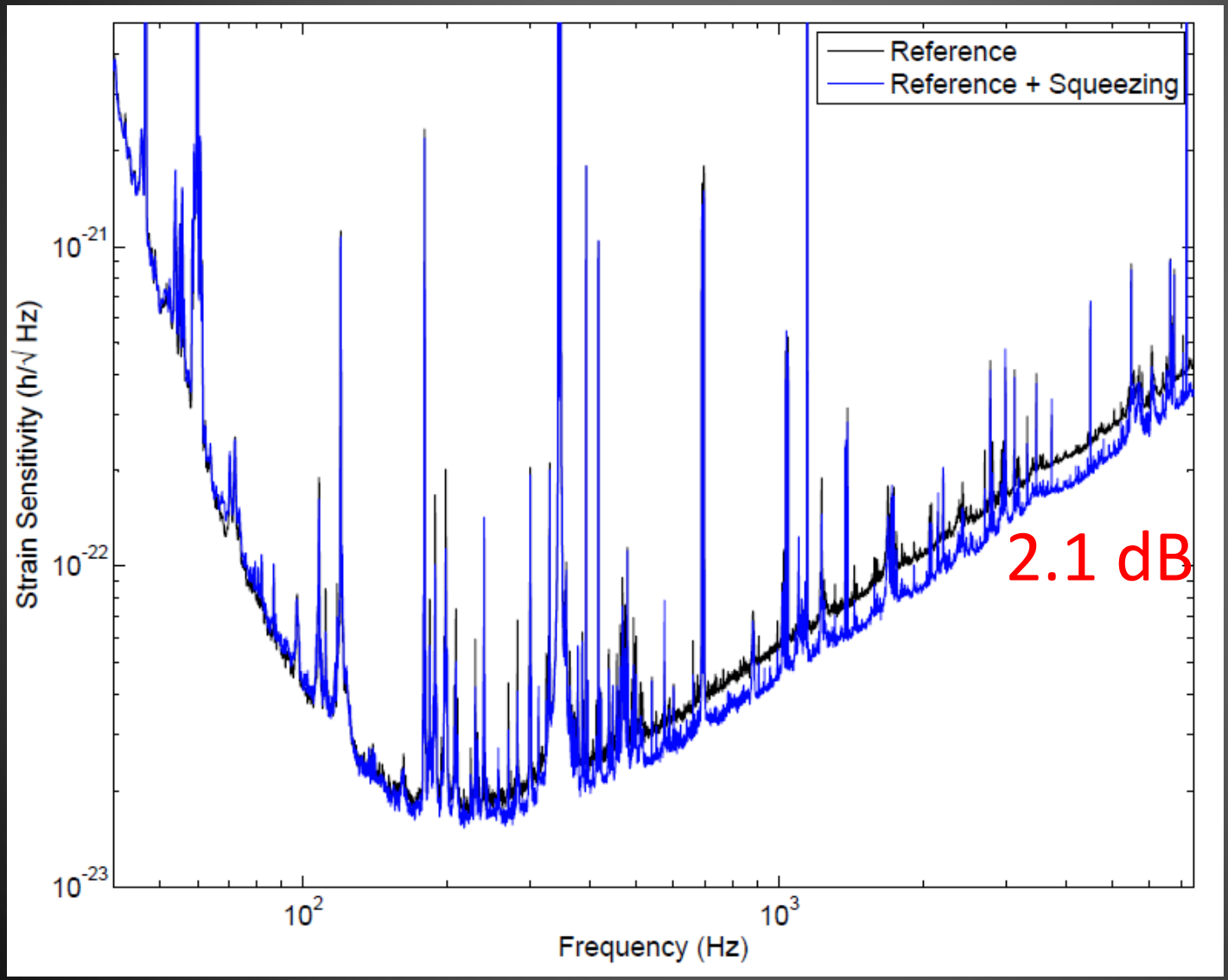
Enhanced LIGO with squeezing: Lessons Learned for Advanced LIGO and beyond

Enhanced LIGO with squeezing

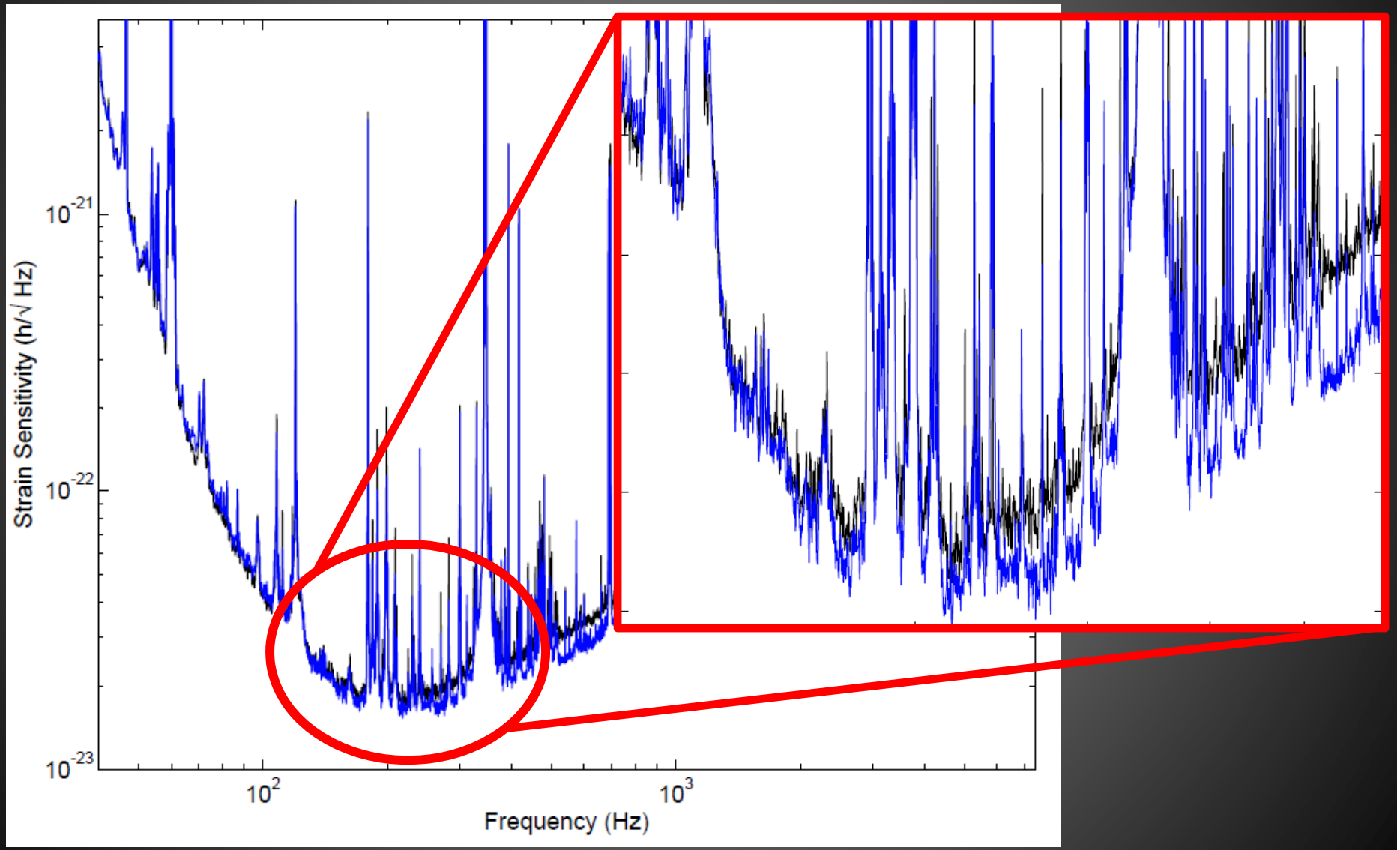


Advanced LIGO with squeezing

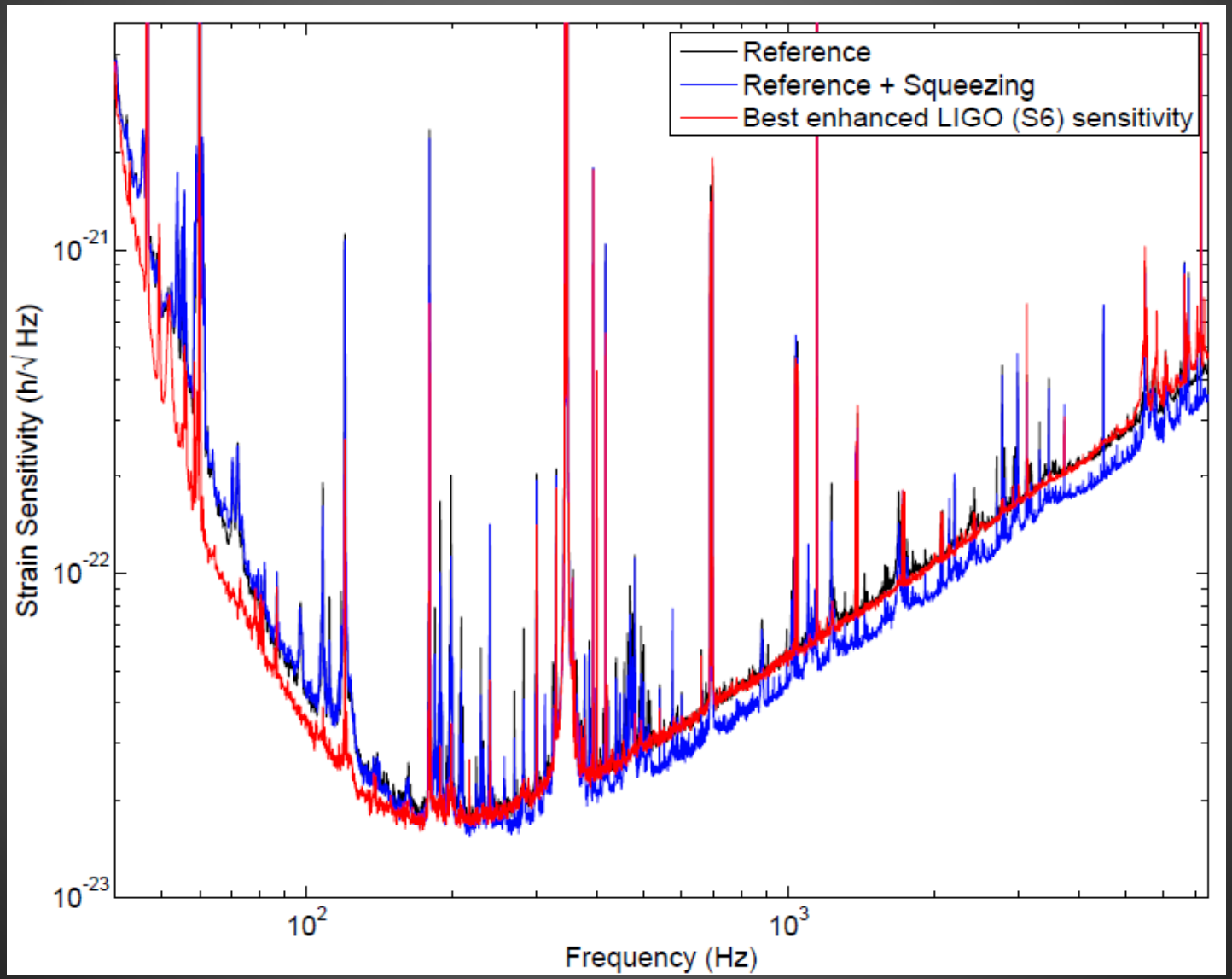
Enhanced LIGO with squeezing



Enhanced LIGO with squeezing



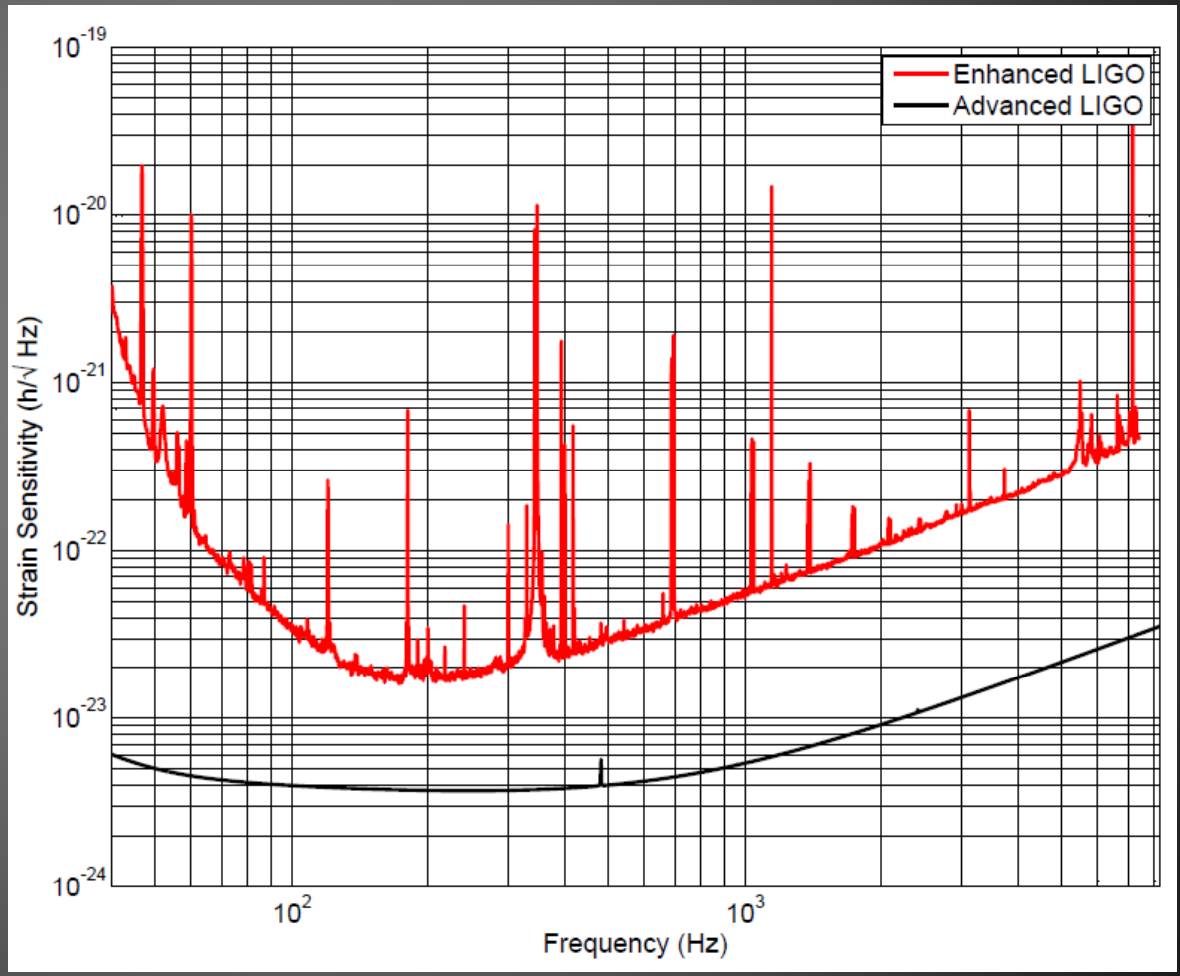
Best broadband sensitivity



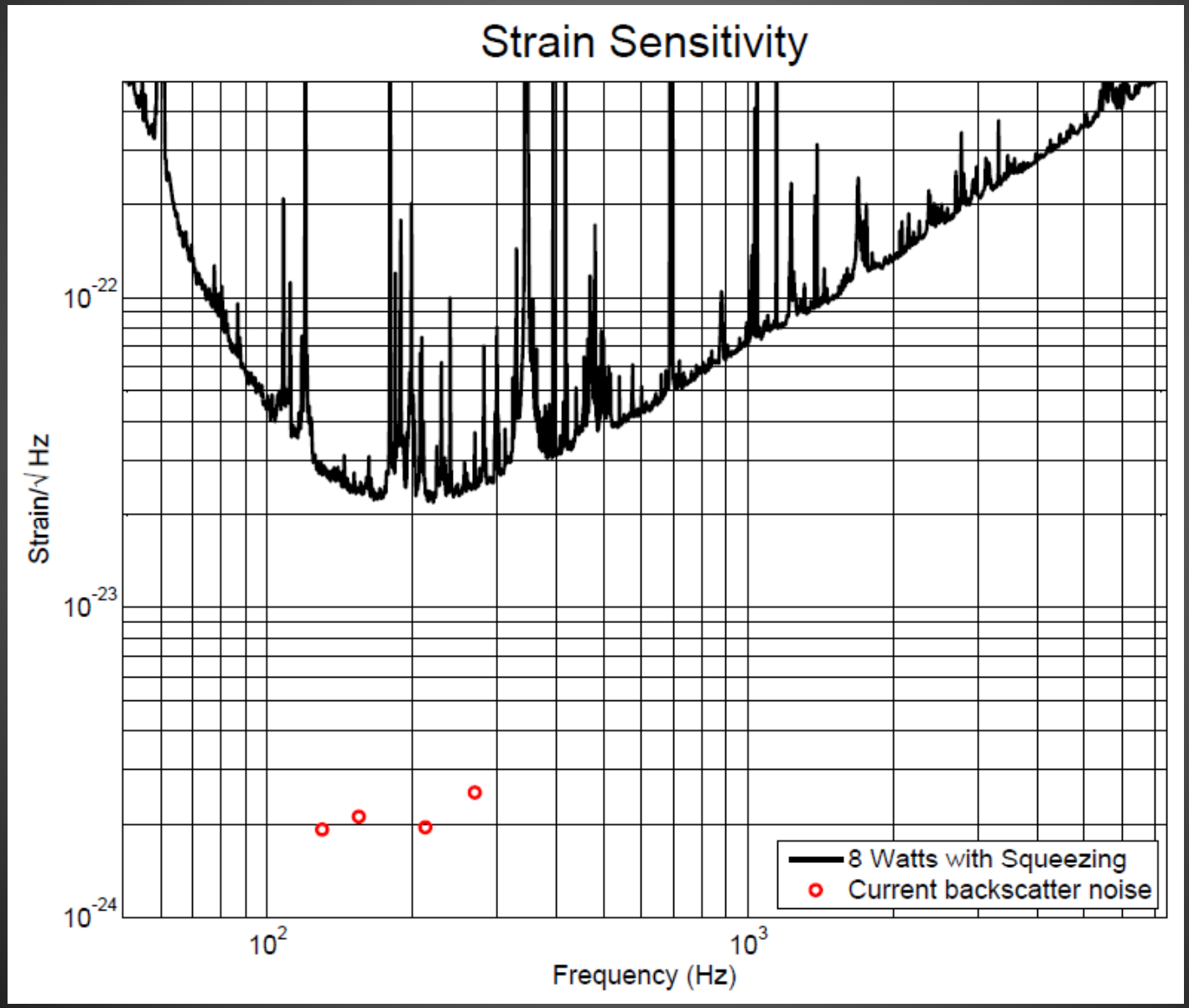
Requirements for Advanced LIGO + squeezing

- Frequency dependent squeezing angle

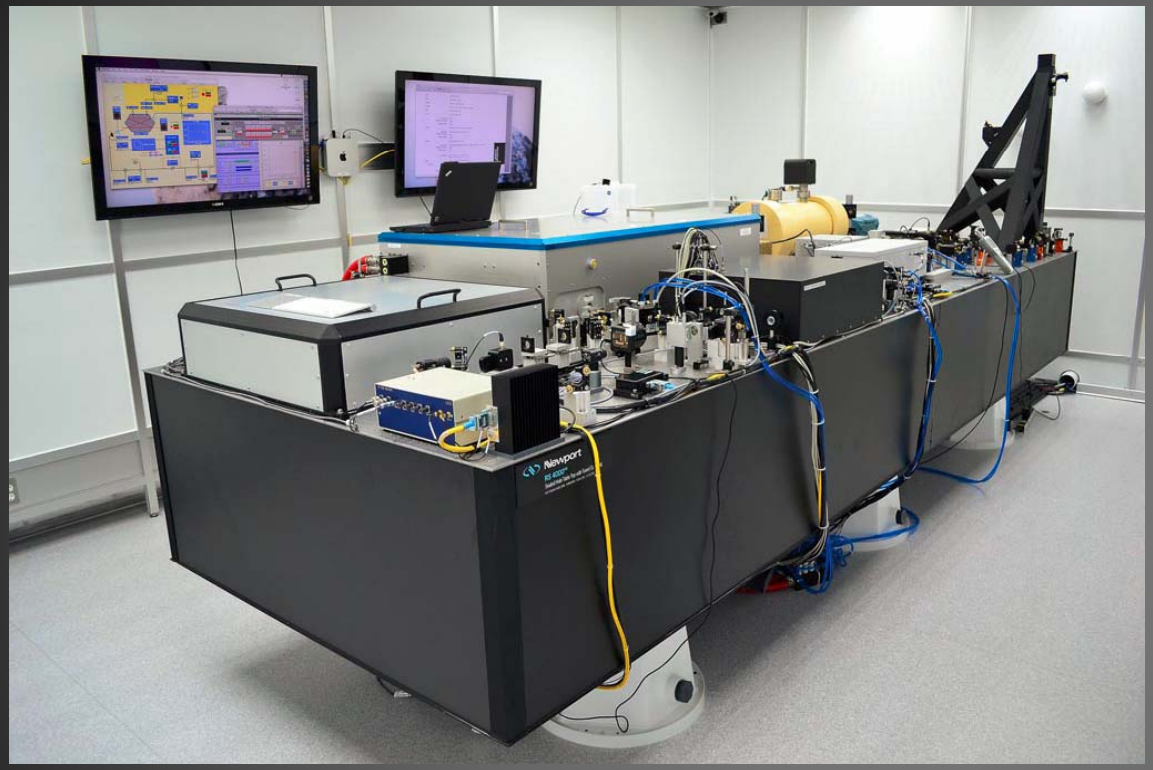
  (Jan Harms and Patrick Kwee talks)
- More sensitive to acoustic noise added by squeezing
- Higher level of squeezing desired



Acoustic Noise Coupling



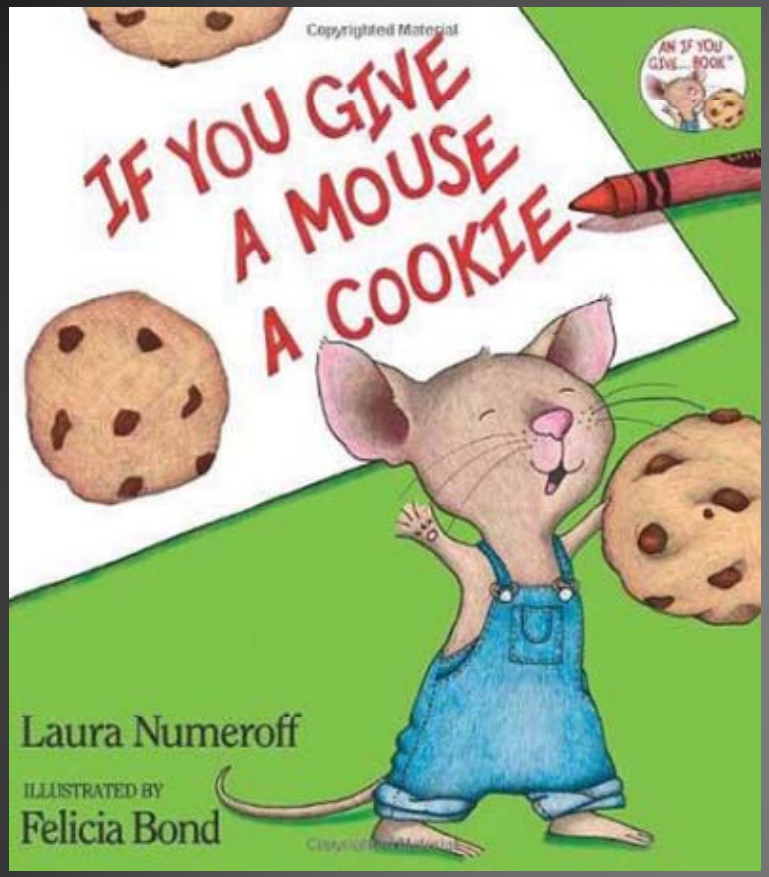
Mitigate Acoustic couplings



Reduce relative motion between squeezer and interferometer

Advanced LIGO Pre Stabilized Laser enclosure and table: Factor of 10 reduction in motion demonstrated

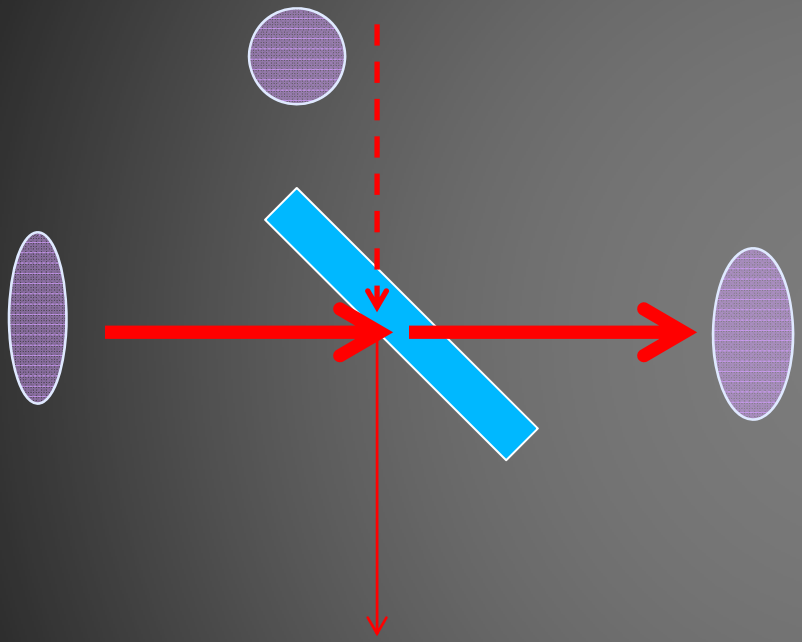
Other options:
Improved isolation from Faradays (factor of 3)
Move OPO in vacuum onto seismic isolation table

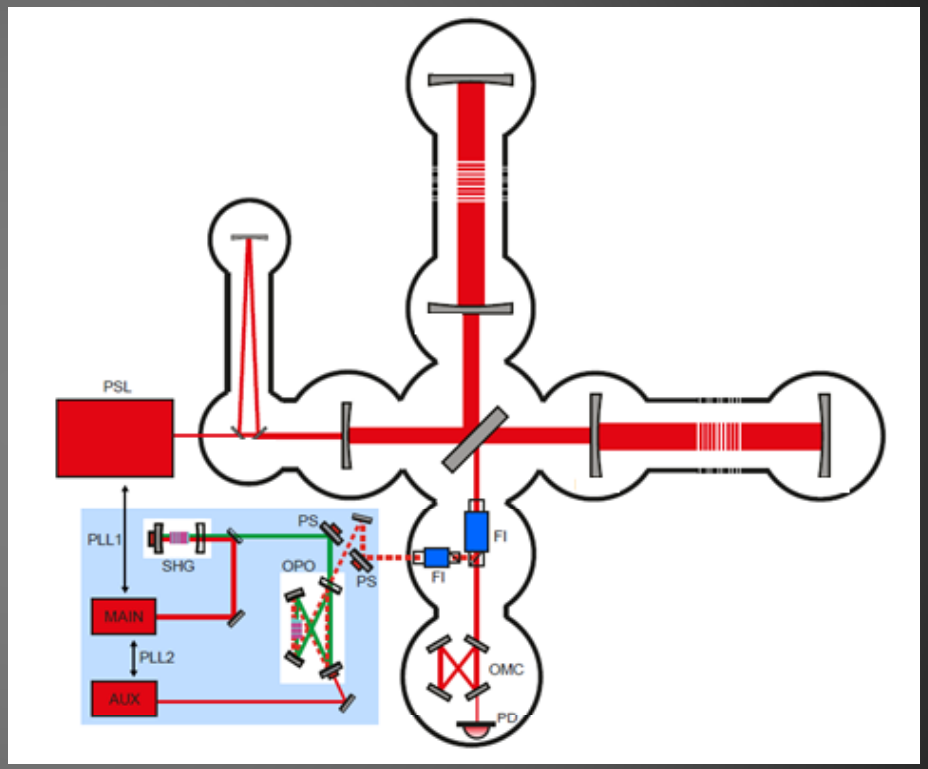


You want more than 2 dB of noise reduction!

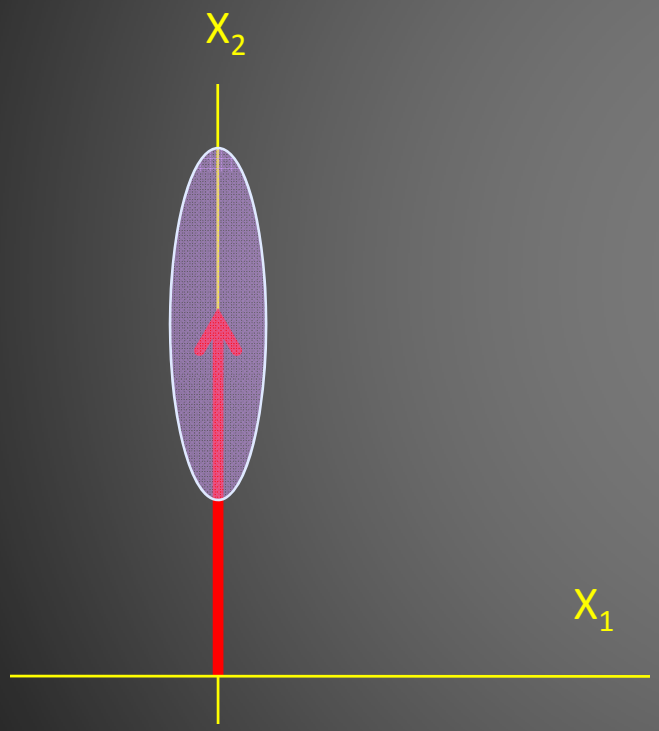
Losses and phase noise will limit the performance of a squeezer for Advanced LIGO

Losses destroy squeezing



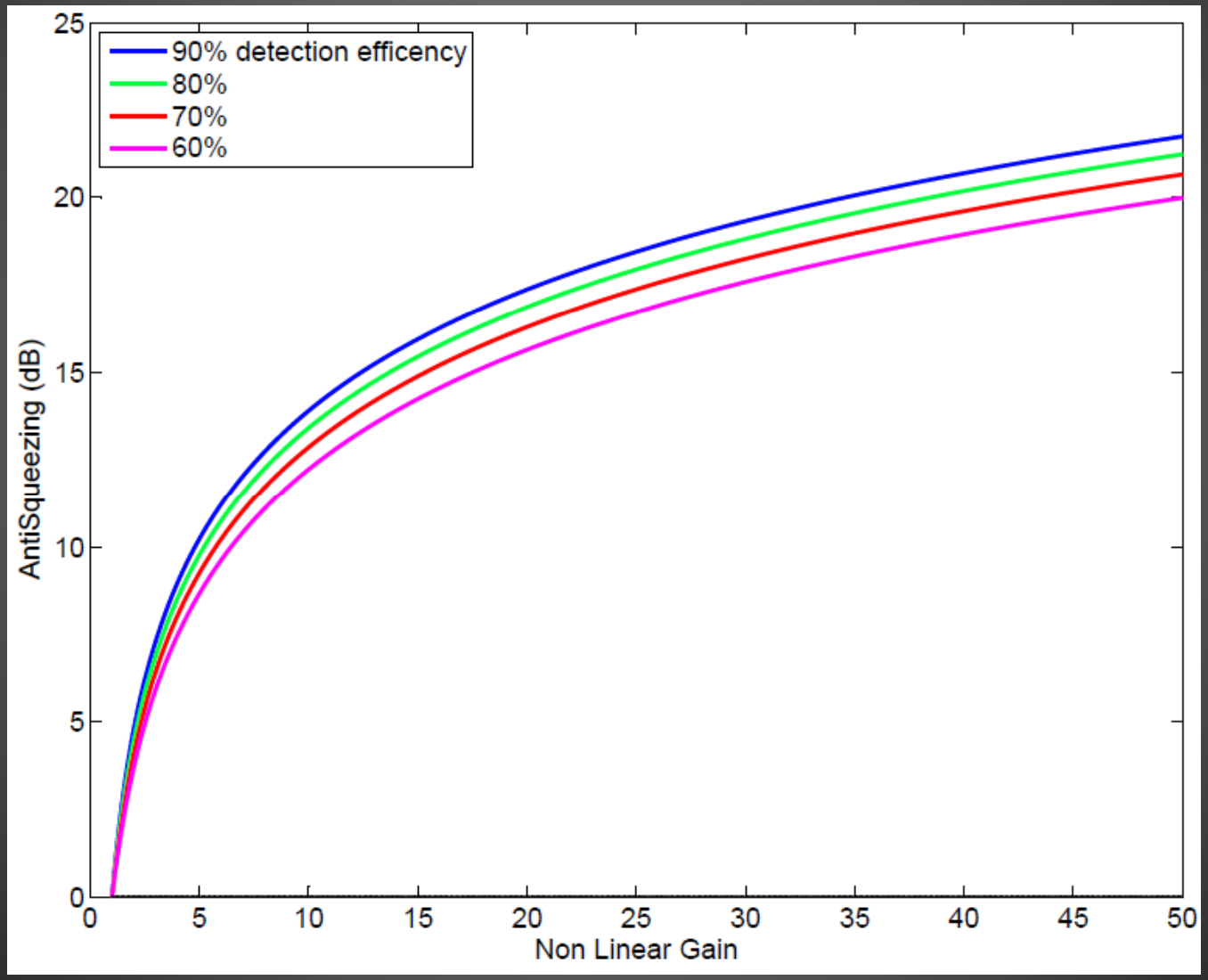


Phase Noise

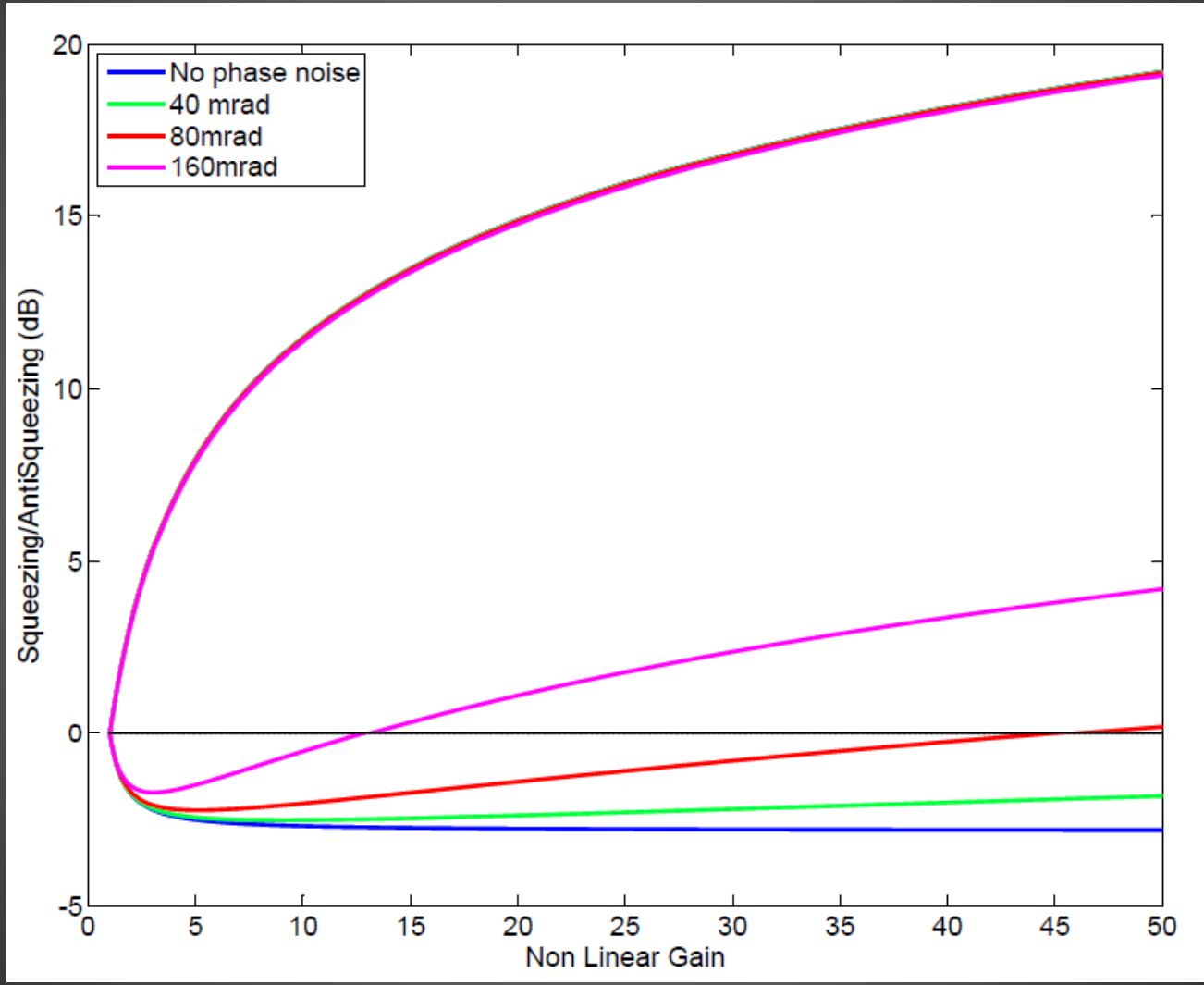


- Phase noise of the squeezing angle mixes squeezed and antisqueezed quadrature
- Total rms phase noise decreases the level of squeezing broadband

Total losses ($1-\eta_{esc}\eta_{det}$)

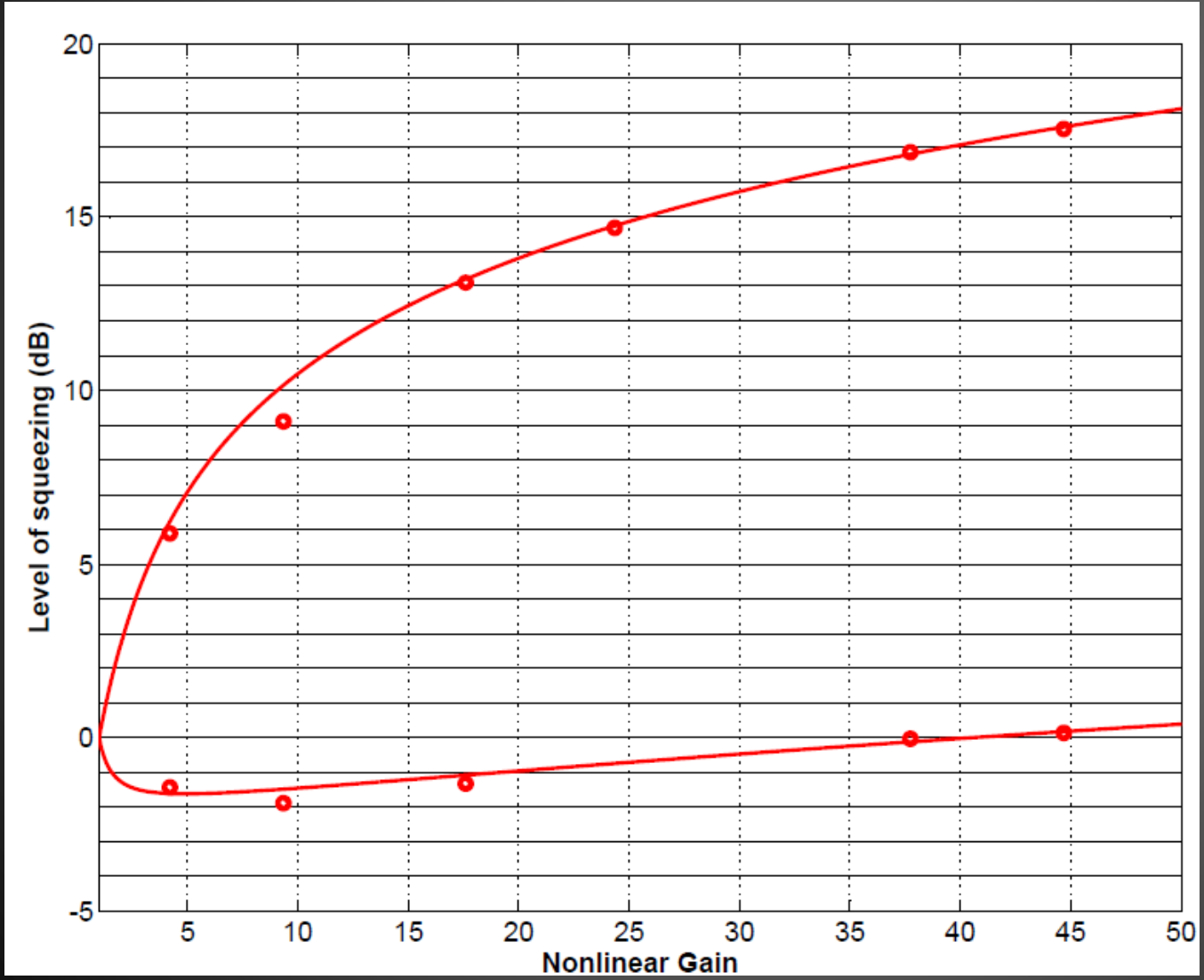


Total Phase Noise



Increasing the amount of anti squeezing allows us to measure total phase noise accurately.

H1 as a squeezing detector

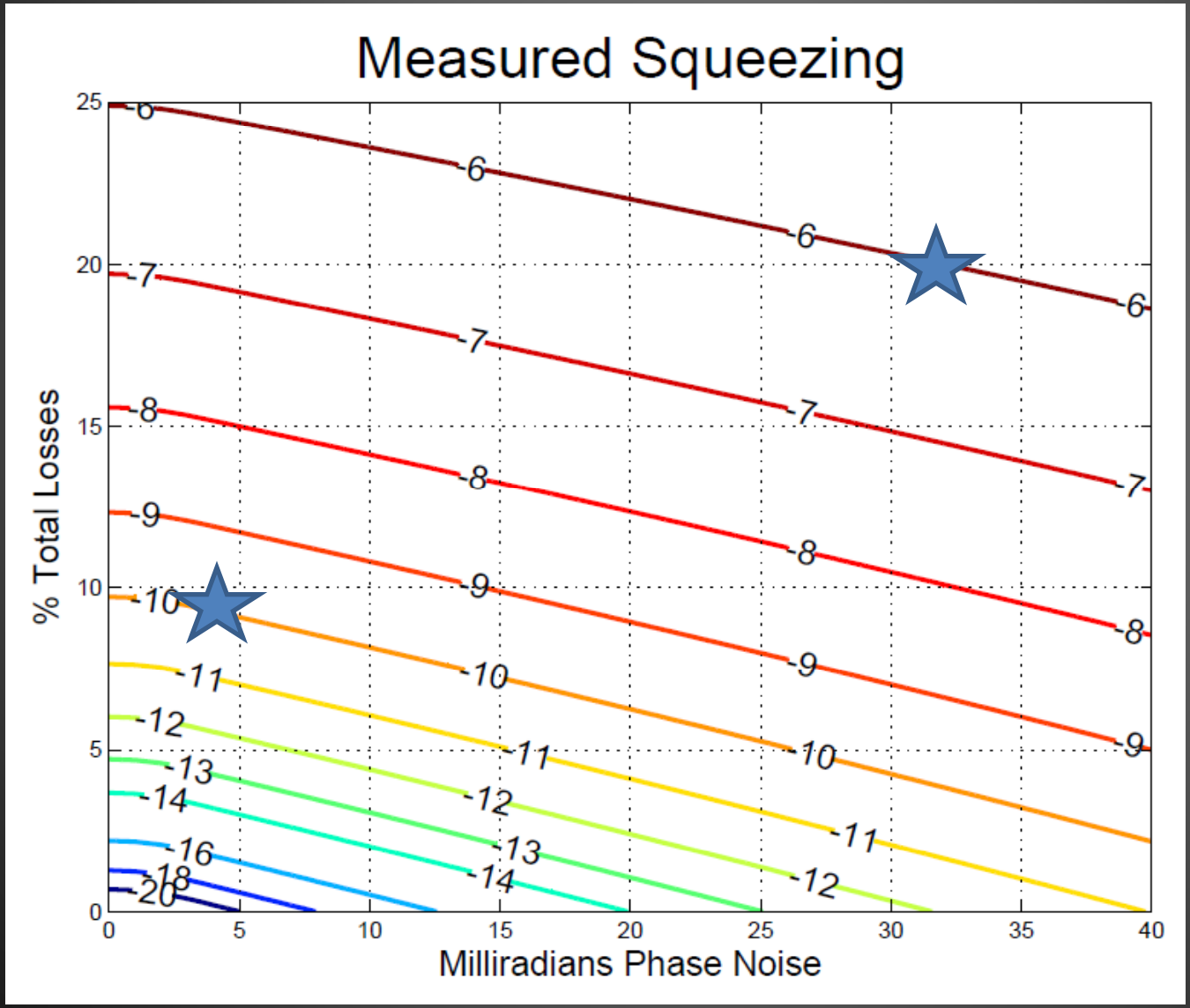


60% losses, 80 mrad phase noise in this example

55-60% total losses during H1 experiment

37 mrad rms phase noise at best

Paths to better squeezing



Non linear gain optimized for best high frequency squeezing, maximum pump power 80% of threshold

Loss goals

	Past	Present	Future
3 faraday passes	5% each	3% each	Aim for all less than 0.2%
Signal recycling cavity@100 Hz		2.5% (Tsrm=35%)	
Squeezer mode matching to OMC	30%	4%	
OMC transmission	19%	1%	
Total losses	55-60%	20%	
Detected Squeezing	2+dB	6dB	10-15dB

Based on tally of 11 different loss sources

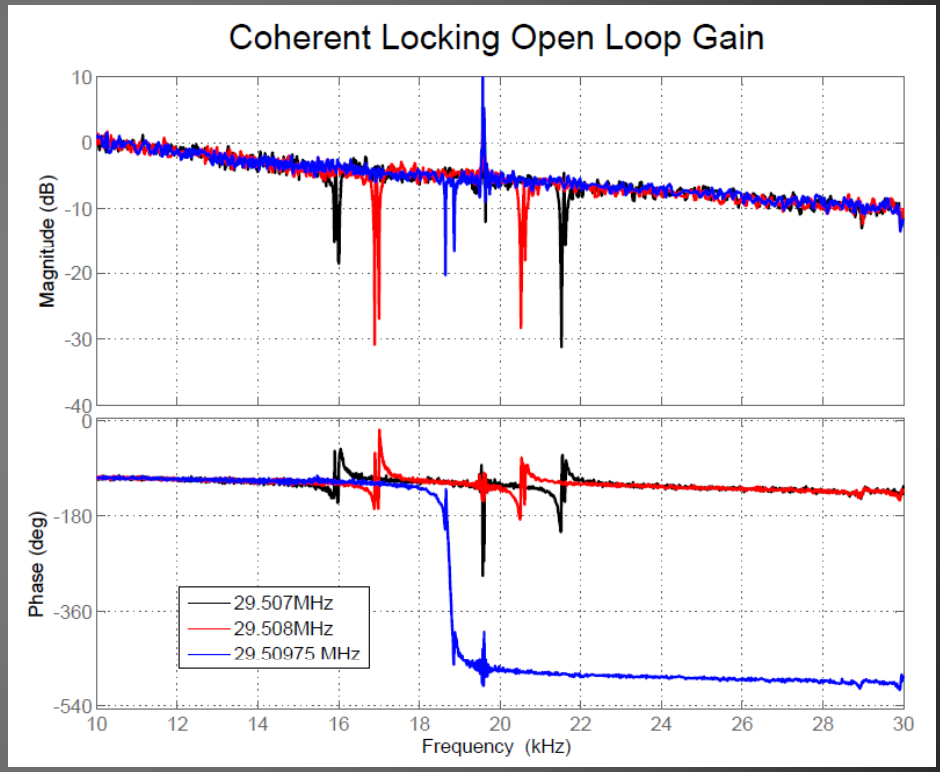
Phase Noise goals

	Past	Present	Future
RF sidebands	1.3 mrad	same	Reduce all to less than 1 mrad
Sources on squeezer table	≤22		
Beam jitter	30 mrad		
Total phase noise	37mrad		
Detected Squeezing	2+dB	6dB	10-15dB

Our sensor for the squeezing angle is sensitive to alignment, couples beam jitter to phase noise

Phase noise control

- Bandwidth is limited to 10kHz by arm cavities
- Need to mitigate phase noise at the source
- Changes to control scheme and in vacuum OPO may be necessary for 10-15 dB of squeezing



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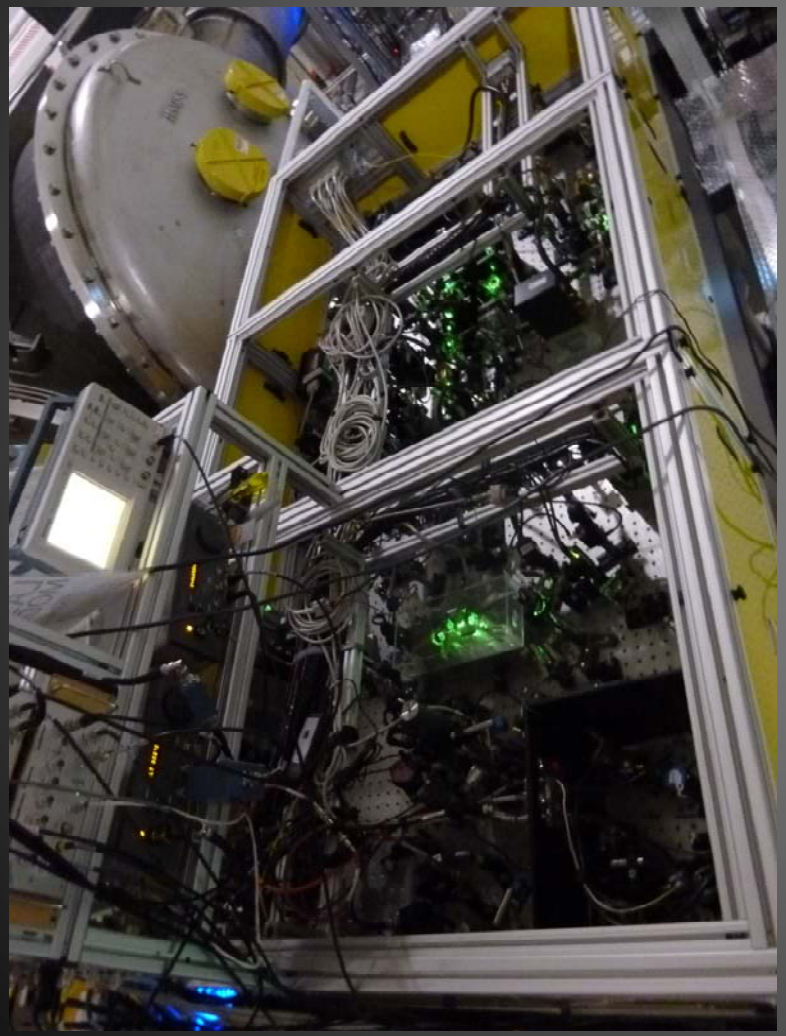
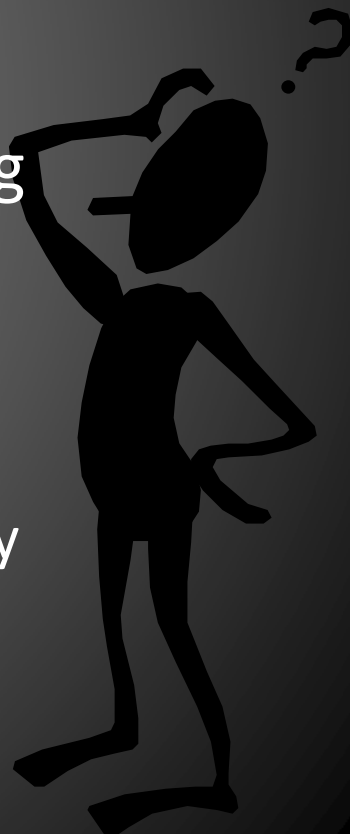


Advanced LIGO with squeezing

Give us 6 months,
a million dollars
For risk mitigation/
faster science running

Auto alignment
Long term stability



Squeezing beyond Advanced LIGO

- Filter Cavities
- Reduce all interferometer losses
  - remote or active mode matching
  - development of low loss faradays
- Reduce phase noise
  - Rethinking control scheme
  - OPO in vacuum

Thank you!

LHO: Daniel Sigg, Keita Kawabe, Robert Schofield, Cheryl Vorvick, Dick Gustafson, Max Factourovich, Grant Meadors, everyone else at LHO

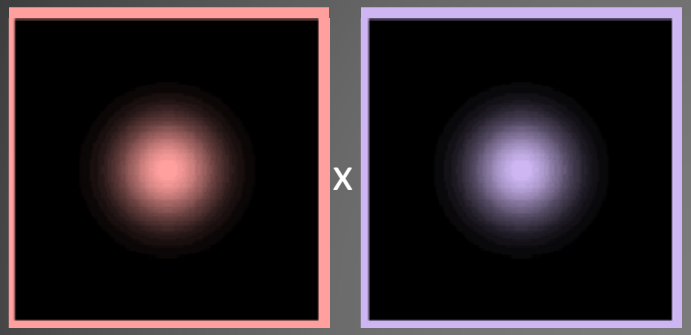
MIT: Lisa Barsotti, Nergis Mavalvala, Nicolas Smith-Lefebvre, Matt Evans

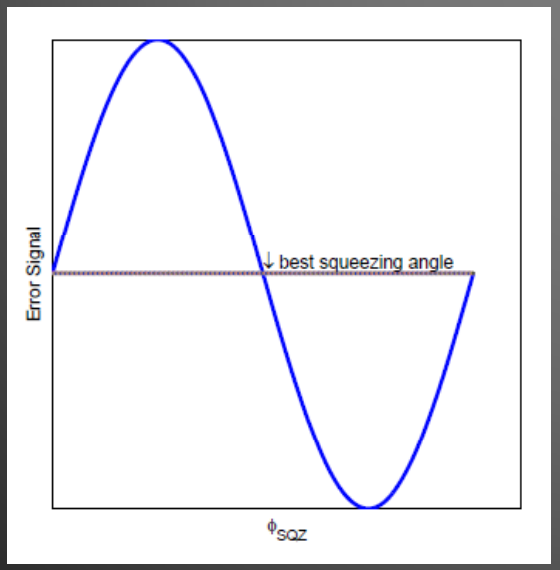
ANU: Sheon Chua, Michael Stefszky, Conor Mow-Lowry, Ping Koy Lam, Ben Buchler, David McClelland

AEI:Alexander Khalaidovski, Roman Schnabel

Coherent locking of squeezing angle inject frequency shifted sideband with coherent amplitude

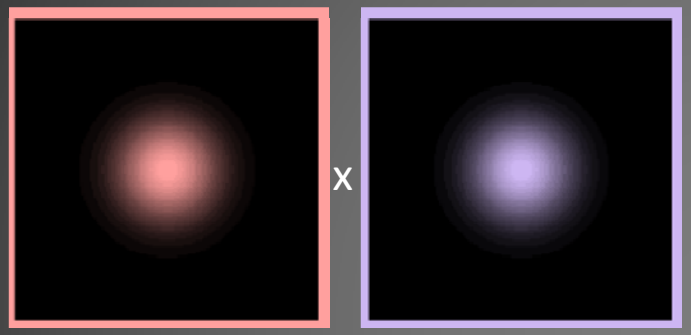
IFO carrier SQZ sideband



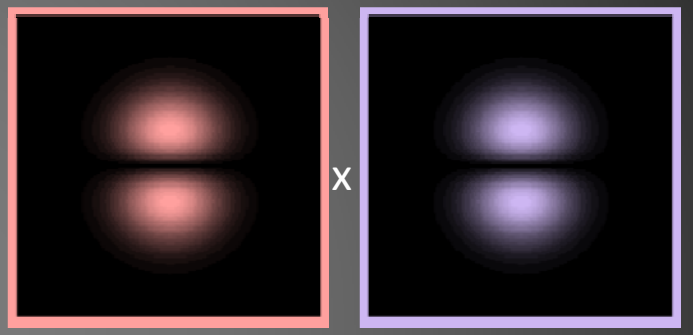


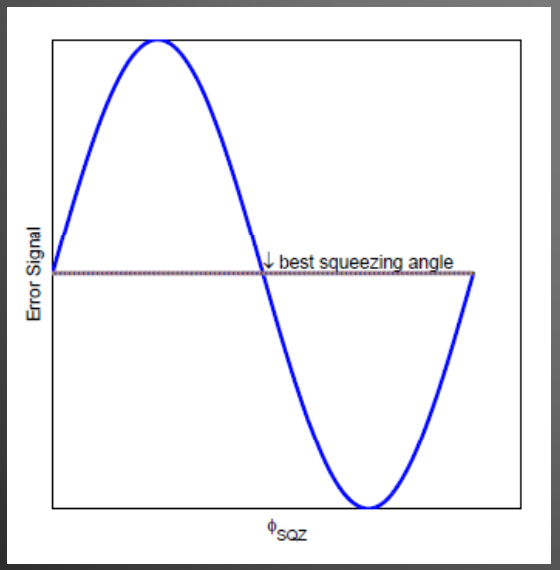
Squeezing angle error signal

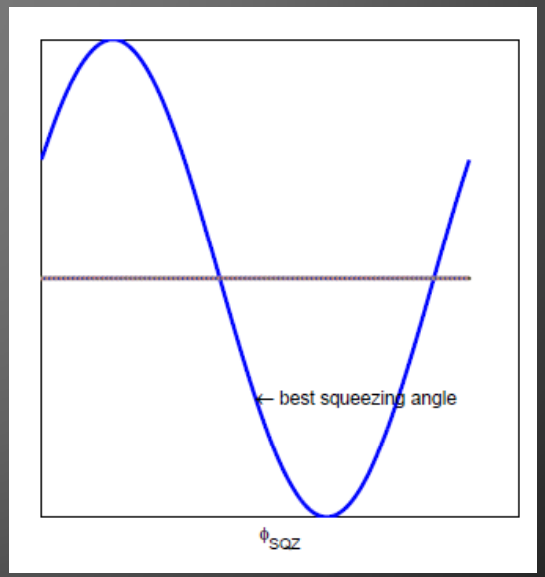
IFO carrier SQZ sideband



IFO carrier SQZ sideband

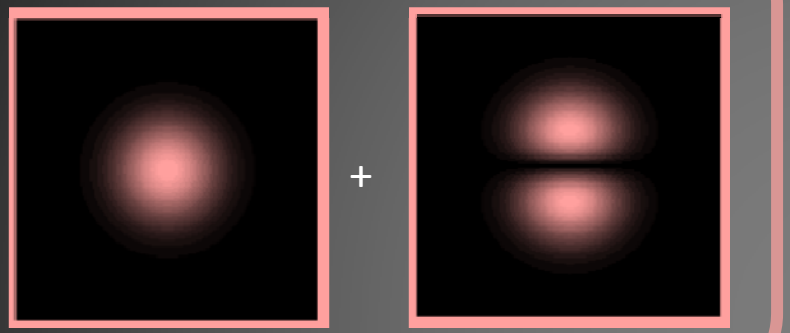




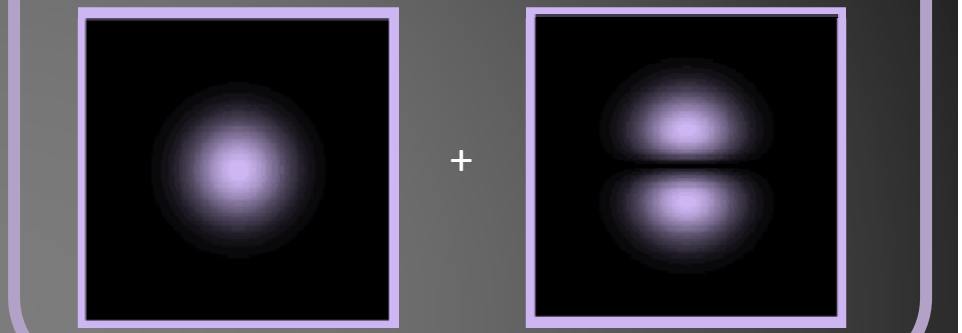


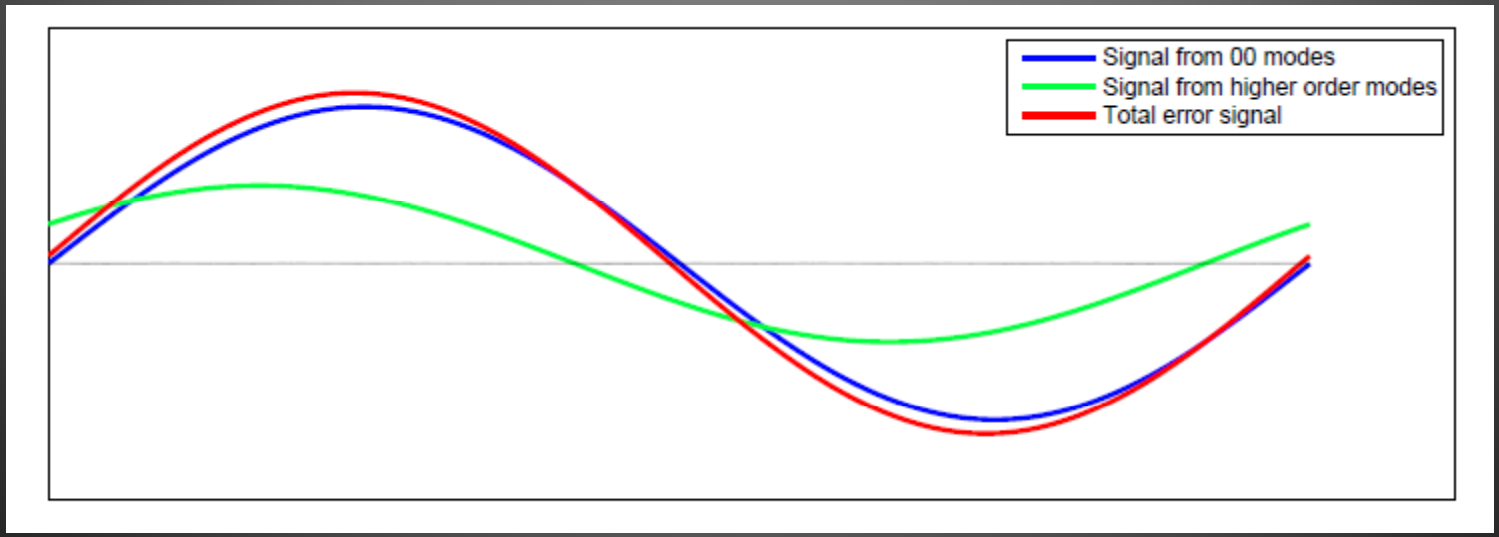
Squeezing angle error signal

IFO carrier

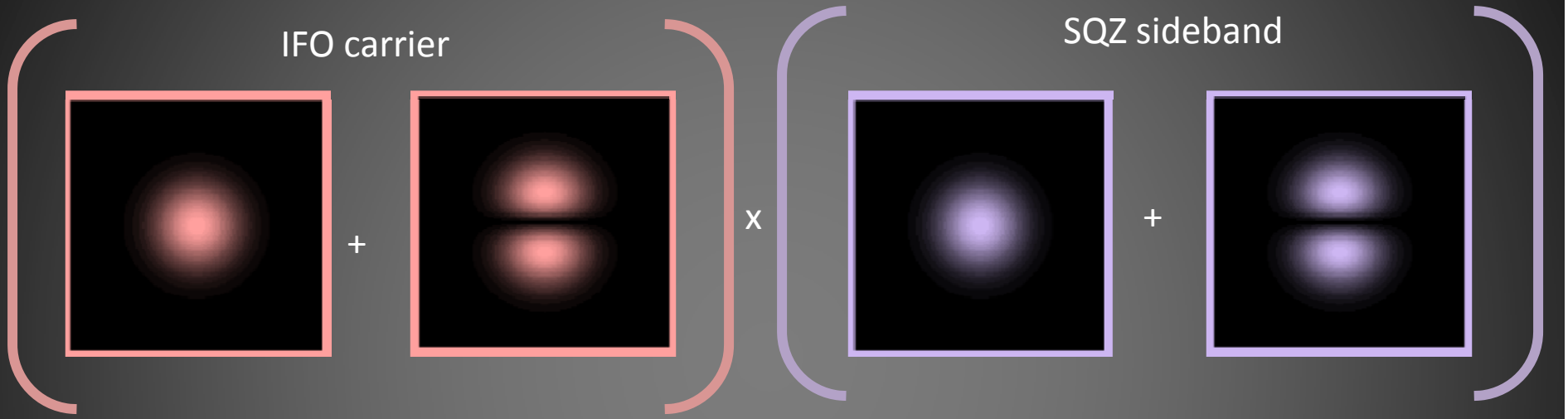


SQZ sideband



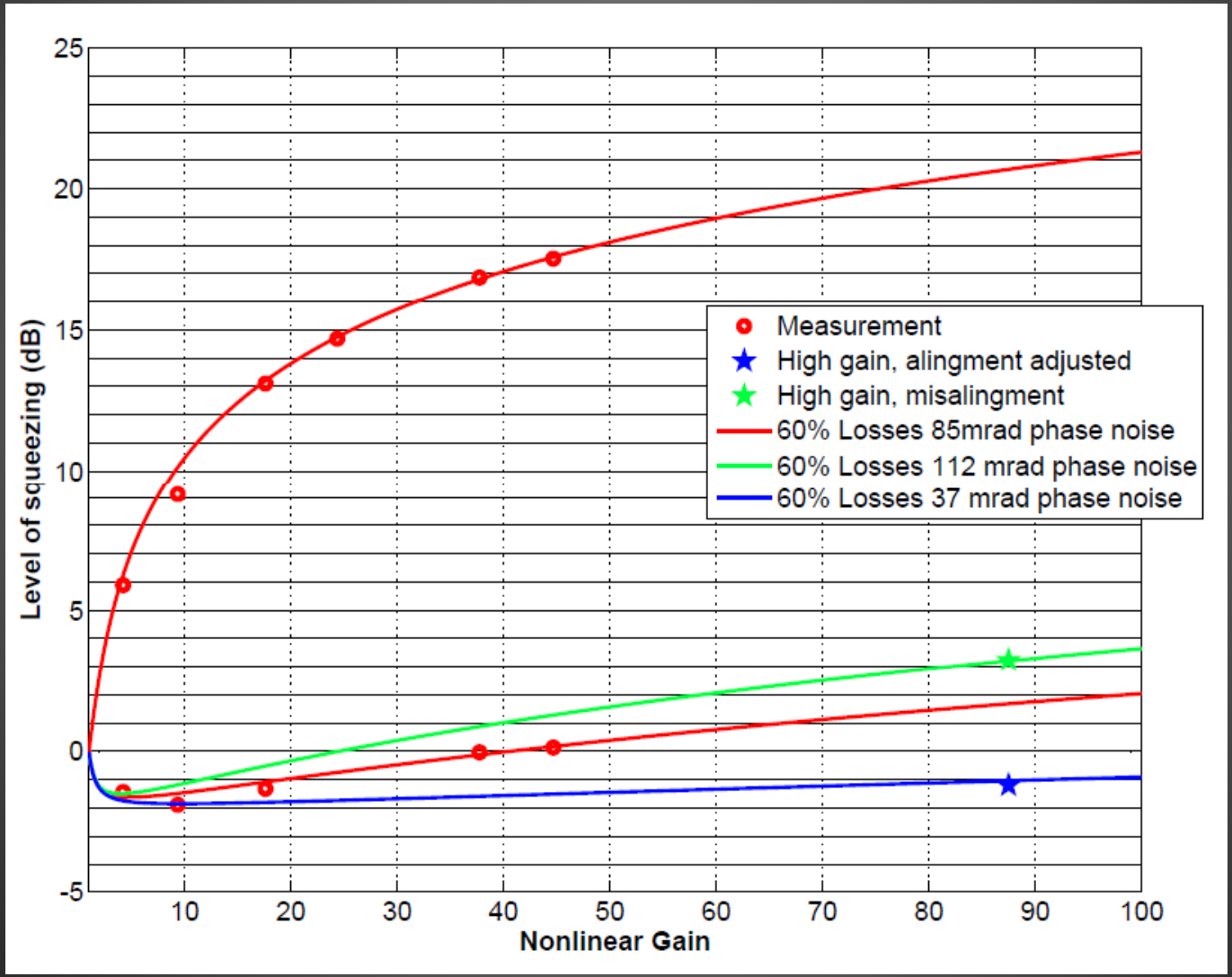


Squeezing angle error signal



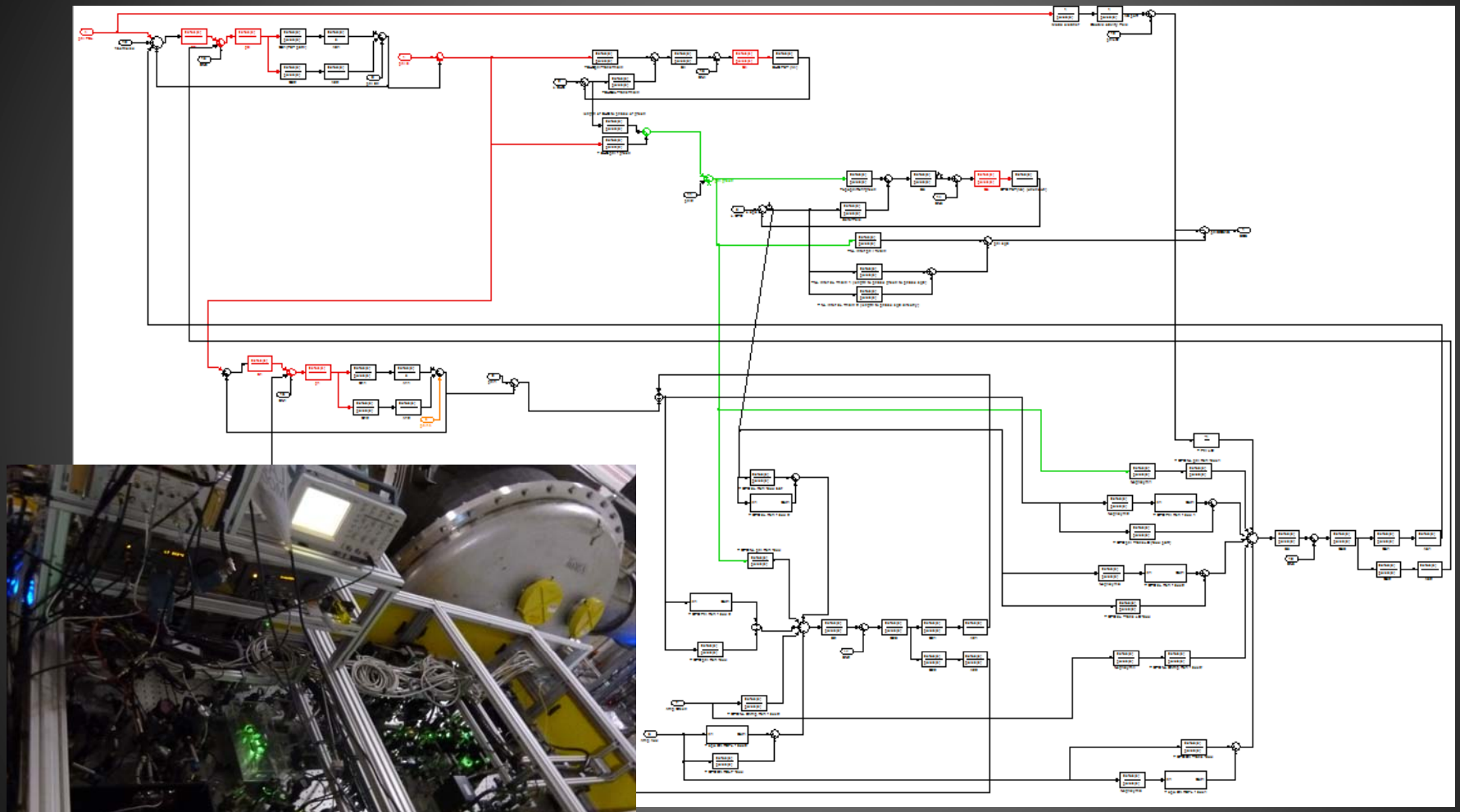
- Static misalignments will cause a change in the demodulation phase needed to detect the maximum squeezing
- Beam jitter will add phase noise, especially when beating against a static misalignment.

Phase noise reduced by changing IFO alignment



Auto alignment may reduce phase noise, keep it more stable

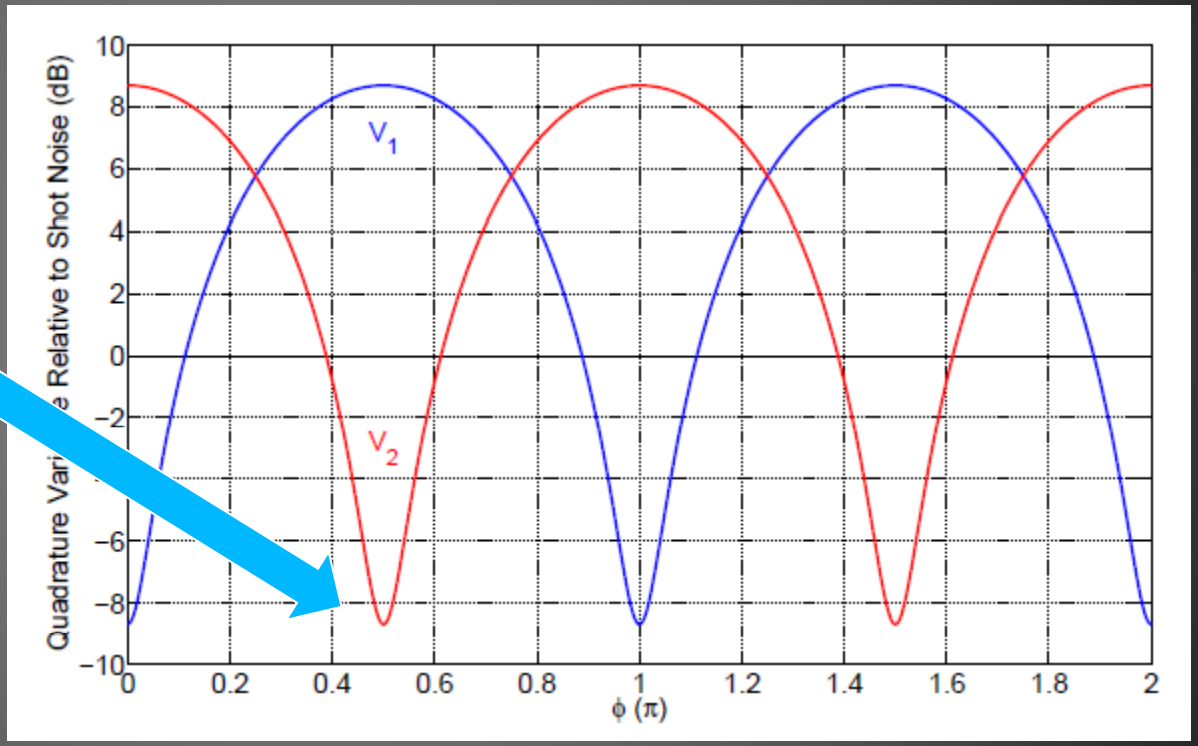
Control Scheme



Modeled before construction of the squeezer to understand phase noise propagation

Phase Noise

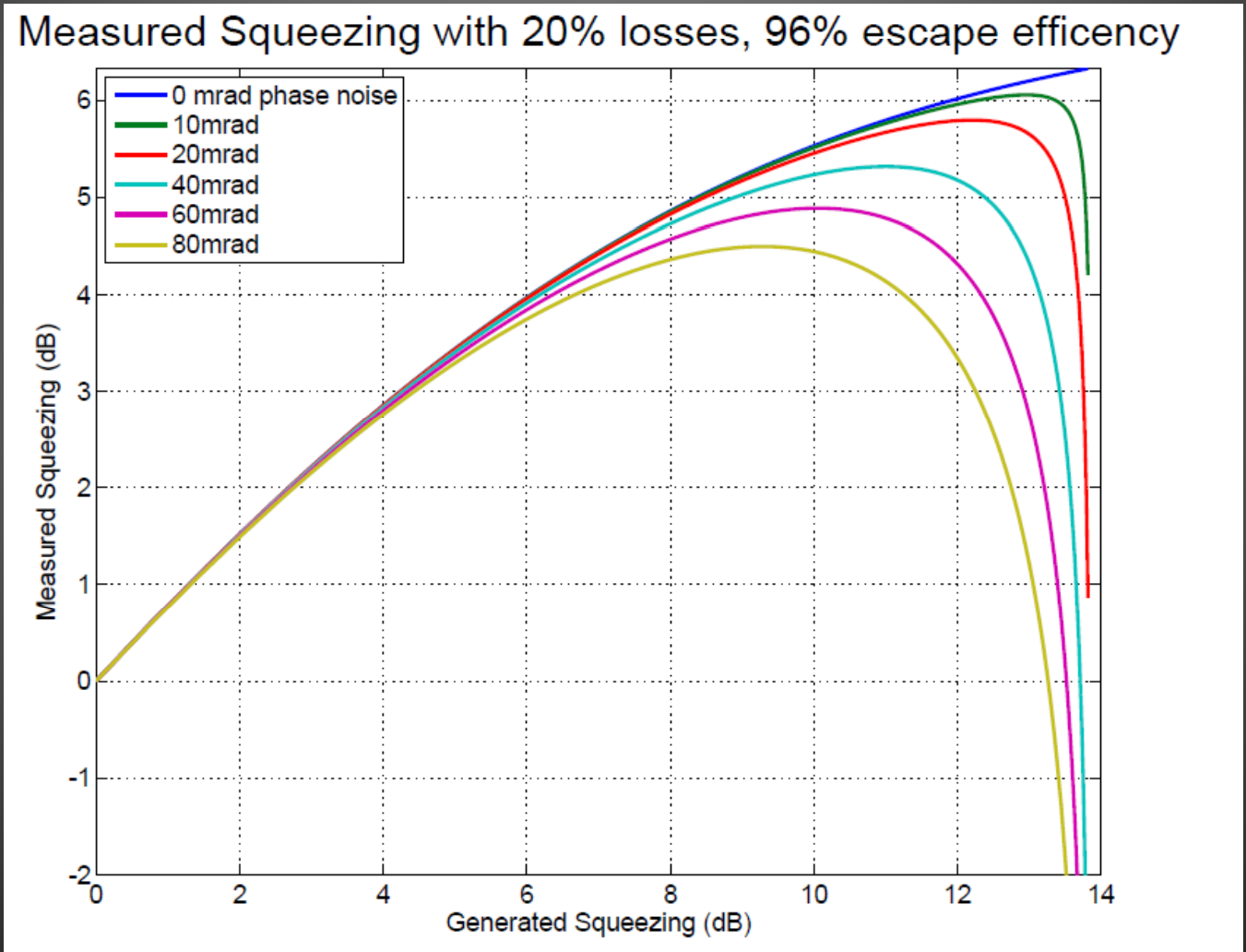
Operating point is at a minimum, any fluctuation leads to an increase in noise



Goda

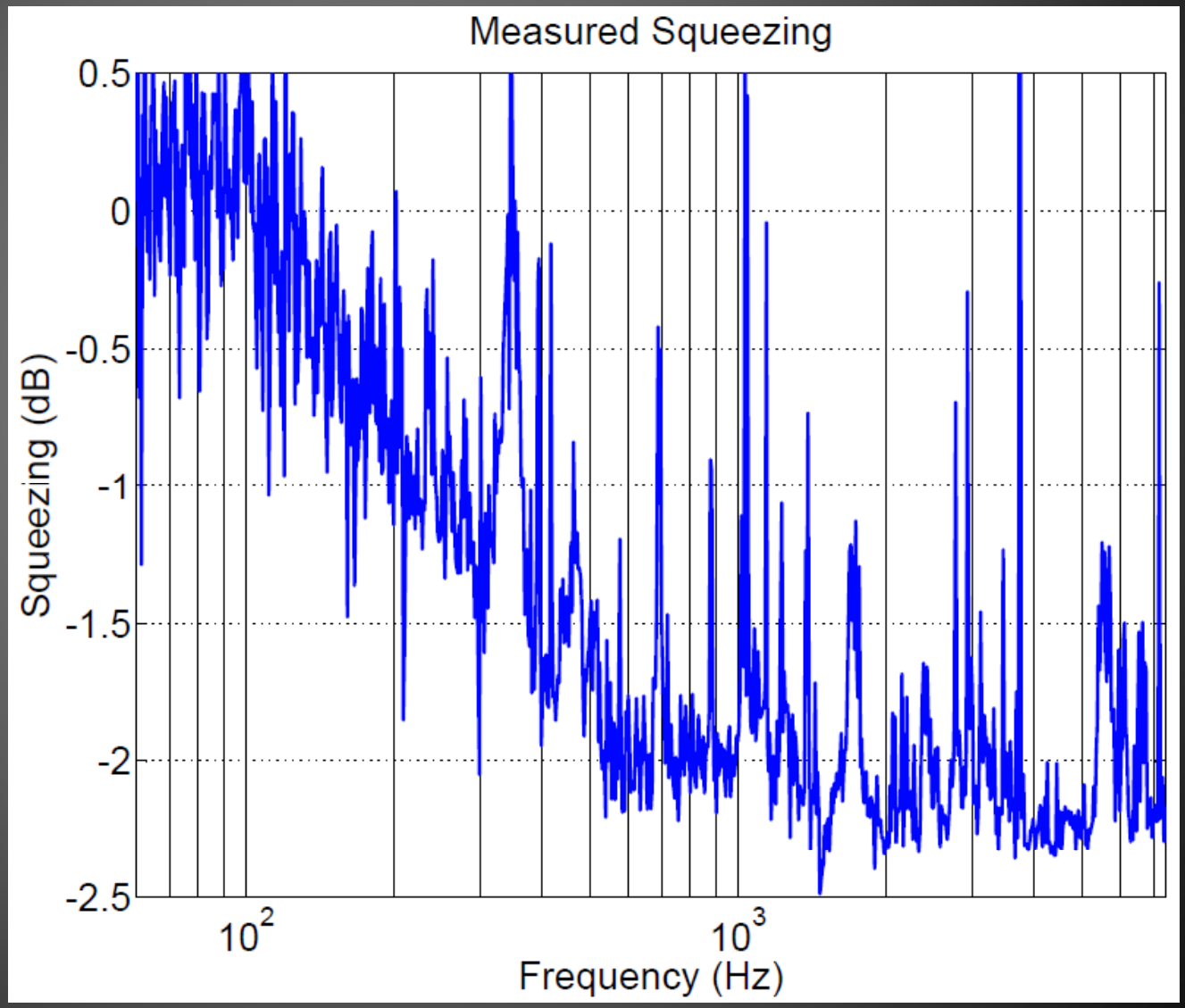
For higher levels of squeezing, the “dip” gets steeper so phase noise has a larger effect

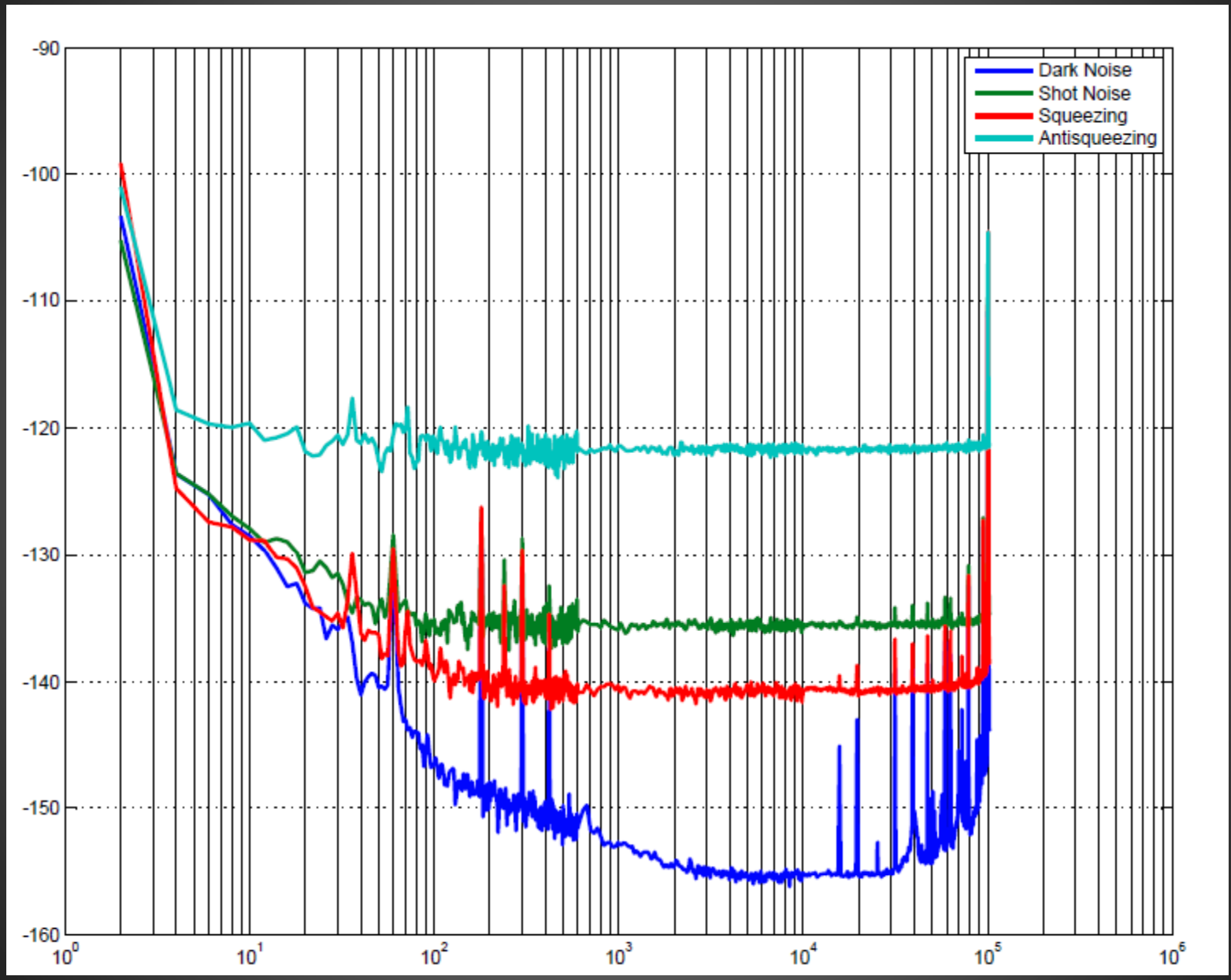
Phase Noise also limits squeezing

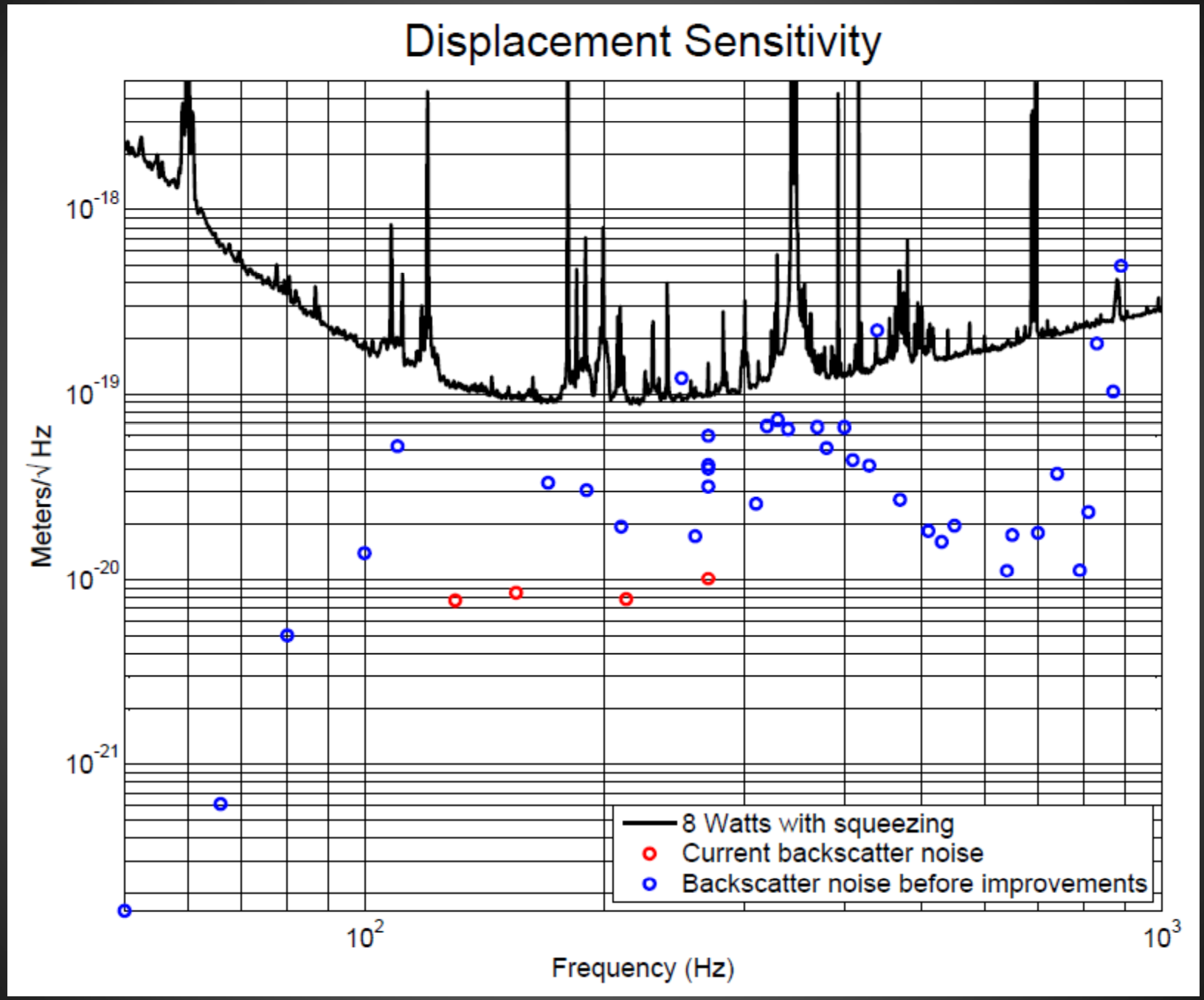


Squeezing Results

- 2.25 dB quantum enhancement
- Some squeezing down to nearly 100 Hz
- Technical noise from IFO causes peaks




Dark Noise
Shot Noise
Squeezing
Antisqueezing
-90
-100
-110
-120
-130
-140
-150
-160
10^0
10^1
10^2
10^3
10^4
10^5
10^6


Displacement Sensitivity
Meters/√ Hz
10^-18
10^-19
10^-20
10^-21
10^2
10^3
Frequency (Hz)
8 Watts with squeezing
Current backscatter noise
Backscatter noise before improvements

A squeezer table