Squeezing PDR

Squeezing Team

September 25, 2015

Why Squeezing

- As much as we all know that reducing quantum noise is not the fastest way to gain BNS Mpc from where we are now, it is really the only thing (we think) we know how to do
- It is also a good way of revealing other noises in the bucket, while pursuing “low frequency” noise hunting
- “High power” is not just the high power laser, it is high power laser + ASC + TCS + PI control
- At some point, squeezing will be easier than increasing the power

Background

- The overall "squeezing" final design, including a filter cavity, targets a 2017, "post-O2" scenario
- Squeezing without filter cavity, can be ready earlier than that, thanks to past/on-going R&D effort
- Several reasons made this "early" option (without filter cavity) interesting, especially for LLO
- **The goal of this PDR is to put squeezing in the SYS pipeline to give us the option of implementing squeezing without a filter cavity sooner than mid 2017, *possibly next year***
- We probably all agree that all the near term post-O1 plans right now are more uncertain than they were before Sep 14, so we won't try to predict a timeline; here we are just saying what is needed to deliver squeezing to the site(s)

About this PDR - I

- There are some modifications to existing components (like Output Faraday, steering optics, septum/ viewports) that need to happen in the vertex to support squeezing injection (beside actual VOPO/SQZ parts)
- We can't imagine an evolution of the squeezing design which won't require those changes
- The main point of this PDR is to put those changes in the SYS pipeline, so that they can be ready to be implemented when there is a vertex vent at the sites (<u>whenever that will be</u>), and can be coordinated with related tasks (for example, fix OFI isolation @ LLO)

About this PDR - II

- The current MIT R&D plan for squeezing will bring to FDR level: VOPO, VOPO suspension, control scheme strategy (part of E. Oelker's PhD thesis) + filter cavity design
- VOPO and VOPO suspension can also be produced at MIT and delivered to the site(s)
- We need additional manpower for tasks like building the in-air parts of the squeezer (finalize electronics/rack/cable plan, build a table enclosure, procure and test electronics, table feedthroughs, slow control, procure optics and opto-mechanical components, other FDR preparation)
- **Electronics** is the main long lead item, unless we can use 3rd IFO components (minimal new design needed, most boards are "copy & paste")

About this PDR - III

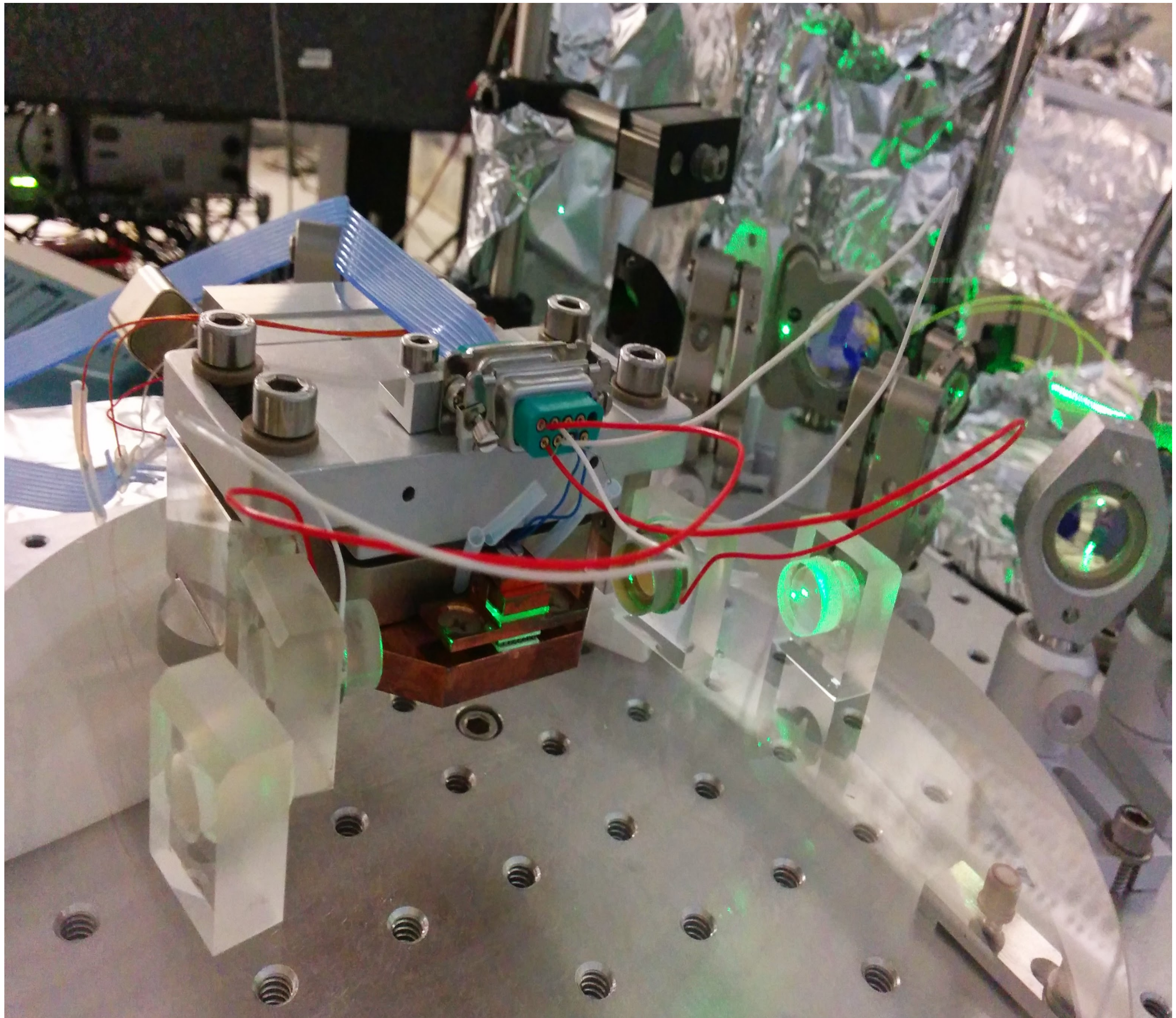
- A lot of the work needed to give the option of implementing squeezing is "off-line" (it doesn't require the interferometer)
- Some of this work can be done by on-site commissioners when commissioning on the interferometer is not happening (for example during observing runs/vents)

R&D

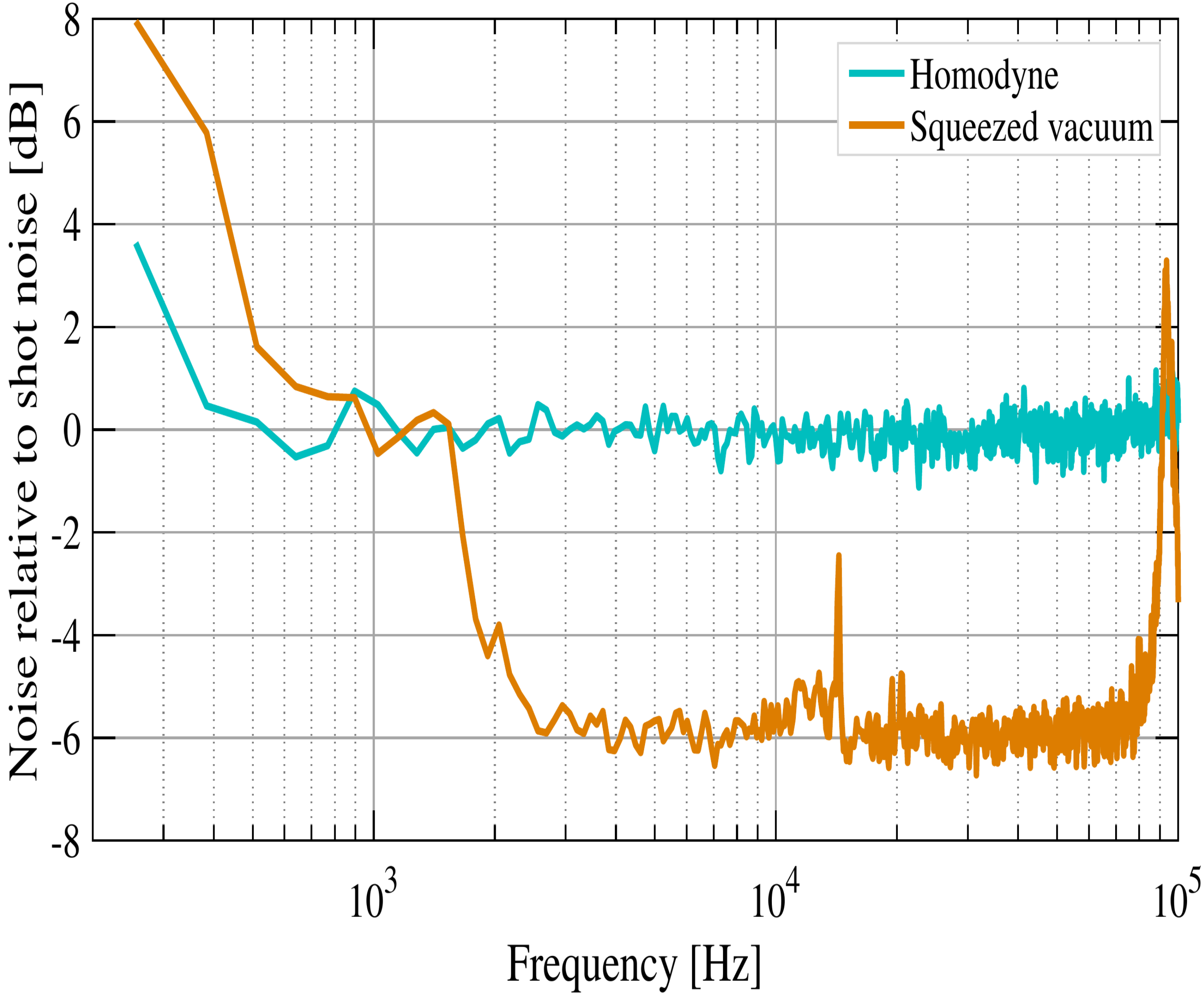
- On going VOPO experiment
- LASTI full scale squeezing injection system proposal

On-going VOPO experiment: in-air tests on-going

Current VOPO experiment



Very first spectrum produced in air, in-vacuum low frequency operation expected in a few weeks



LASTI full scale injection system
Something new - Filter cavity

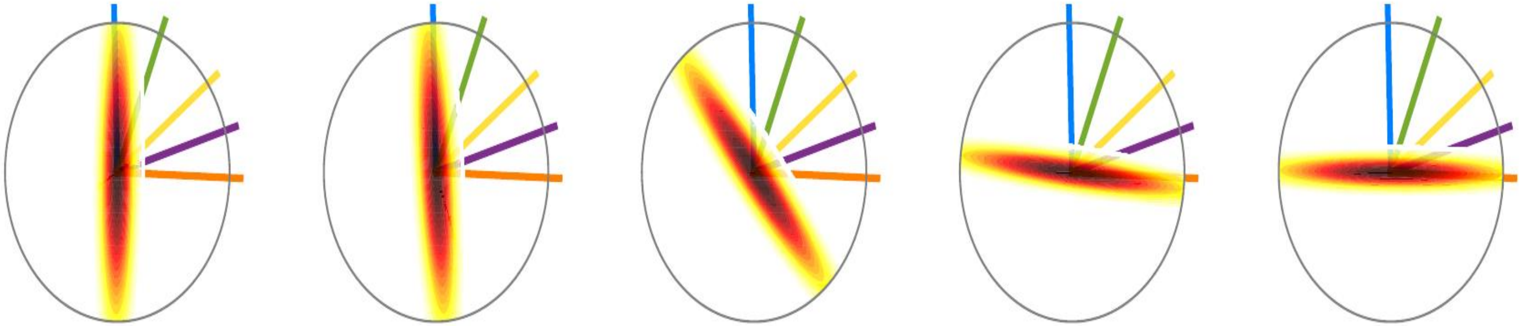
Already demonstrated ellipse rotation at ~2kHz Submitted to PRL

- Verified model
- Need to scale to ~100 Hz (2.5 from finesse, 8 from length)

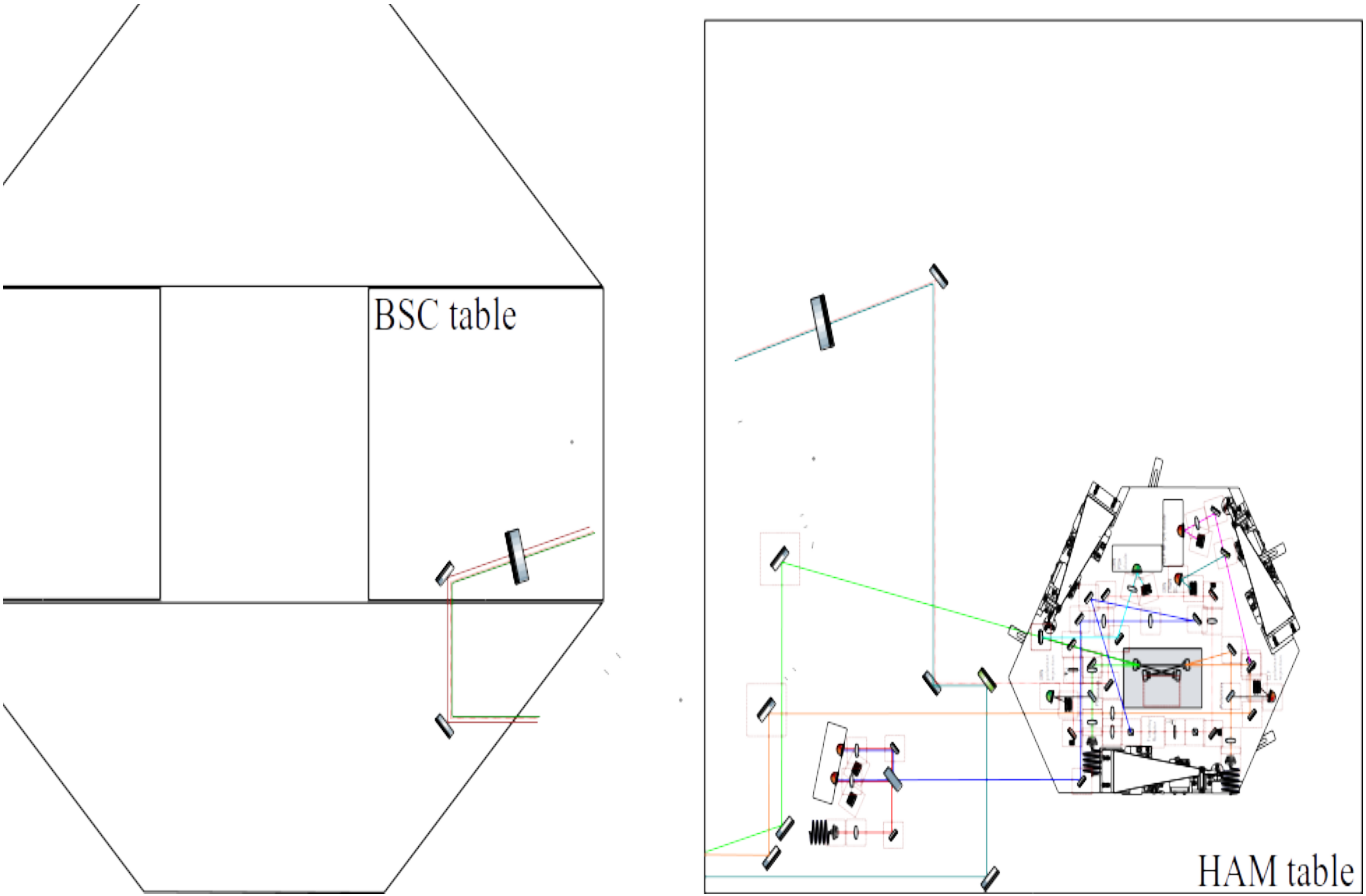
Build a 16 m cavity between BSC and HAM chambers at LASTI

- Full-scale prototype i.e.16 m is good enough PHYSICAL REVIEW D 88, 022002 (2013)
- Single-stage suspension on HAM-ISI is sufficient PHYSICAL REVIEW D 90, 062006 (2014)

Integrated testing with VOPO



LASTI proposed layout



LASTI Full Scale Injection System Budget

Full scale filter cavity with squeezing injection in LASTI			FY2016	FY2016	FY2017	FY2017	FY2018	FY2018
Tip-tilts (x2)*		0	0%	0	100%	0	0%	0
Filter cavity optics**		20000	100%	20000	0%	0	0%	0
VOPO Suspension		35000	90%	31500	10%	3500	0%	0
OPO cavity + cavity optics	include OPO optics for 2 aLIGO squeezers	40000	50%	20000	50%	20000	0%	0
OPO Oven improvements		10000	100%	10000	0%	0	0%	0
Fibers + fibers feedthrough	include fibers for 2 aLIGO squeezers	45000	100%	45000	0%	0	0%	0
Electronics***		10000	30%	3000	40%	4000	30%	3000
Optics***		5000	30%	1500	40%	2000	30%	1500
Opto-mechanics***		5000	30%	1500	40%	2000	30%	1500
Alignment picomotors		10000	0%	0	100%	10000	0%	0
Feedthroughs/Cables		20000	100%	20000	0%	0	0%	0
Green WFS (optional)	TBC		0%	0	0%	0	100%	0
TOTAL REQUEST (FY2016-FY2018)		**200000**		**152500**		**41500**		**6000**

-- This budget assumes that we can get 2 tip-tilts from aLIGO spares (12 in storage, not including 3rd IFO)

-- Osems too

Optical fibers status and plan:

- Investigated PM fibers and custom made feedthrus.
- Current solution is to use SM fibers polyimide coated and Vacom feedthrus. Standard telecom wavelengths (633nm and 1310nm). We do see higher order mode buildup. Manageable but not ideal.
- Talking with manufacturers (Fibercore) about custom batch at 532nm and 1064nm (10k$ to 20 k$ per batch, 1km MOQ, 8 weeks delivery). See specs below. Also in touch with Vacom for making feedthrus at those wavelengths.
- Need to develop a solution for the fiber routing, in-air insulation, in vacuum protection…
- Patchcords currently made in house. Could be made by Vacom ($700ea)
- Must ramp up on the testing. Need feedthrus ($1000ea) and fibers dedicated to these tests.
- Need to improve our handling procedure (systematic cleaning, microscopes check, caps changes…)

Polyimide coated custom batch:

For Wavelengths From 450nm - 1550nm	SM450[1]	SM600	SM750	SM800 (5.6/125)	SM980 (4.5/125)	SM980 (5.8/125)
Design Wavelength[2] (nm)	488 514	633 680	780	830	980 1550	980 1064 1550
Cut-Off Wavelength (nm)	350 - 450	500 - 600	610 - 750	660 - 800	870 - 970	870 - 970
Numerical Aperture	0.10 - 0.14				0.17 - 0.19	0.13 - 0.15
Mode Field Diameter[4] (μm)	3.3 3.4	4.3 4.6	5.3	5.6	4.5 7.5	5.8 6.2 10.4
Attenuation[6] (dB/km)	≤ 50	≤ 15	≤ 5		≤ 2	
Proof Test (%)	1, 2 or 3 (100, 200 or 300 kpsi)					
Fiber Diameter (μm)	125 ± 1					
Core Cladding Concentricity (μm)	≤ 0.75		≤ 1.0		≤ 0.50	
Coating Diameter (μm)	245 ± 5%					
Coating Type	~~Dual Acrylate~~					

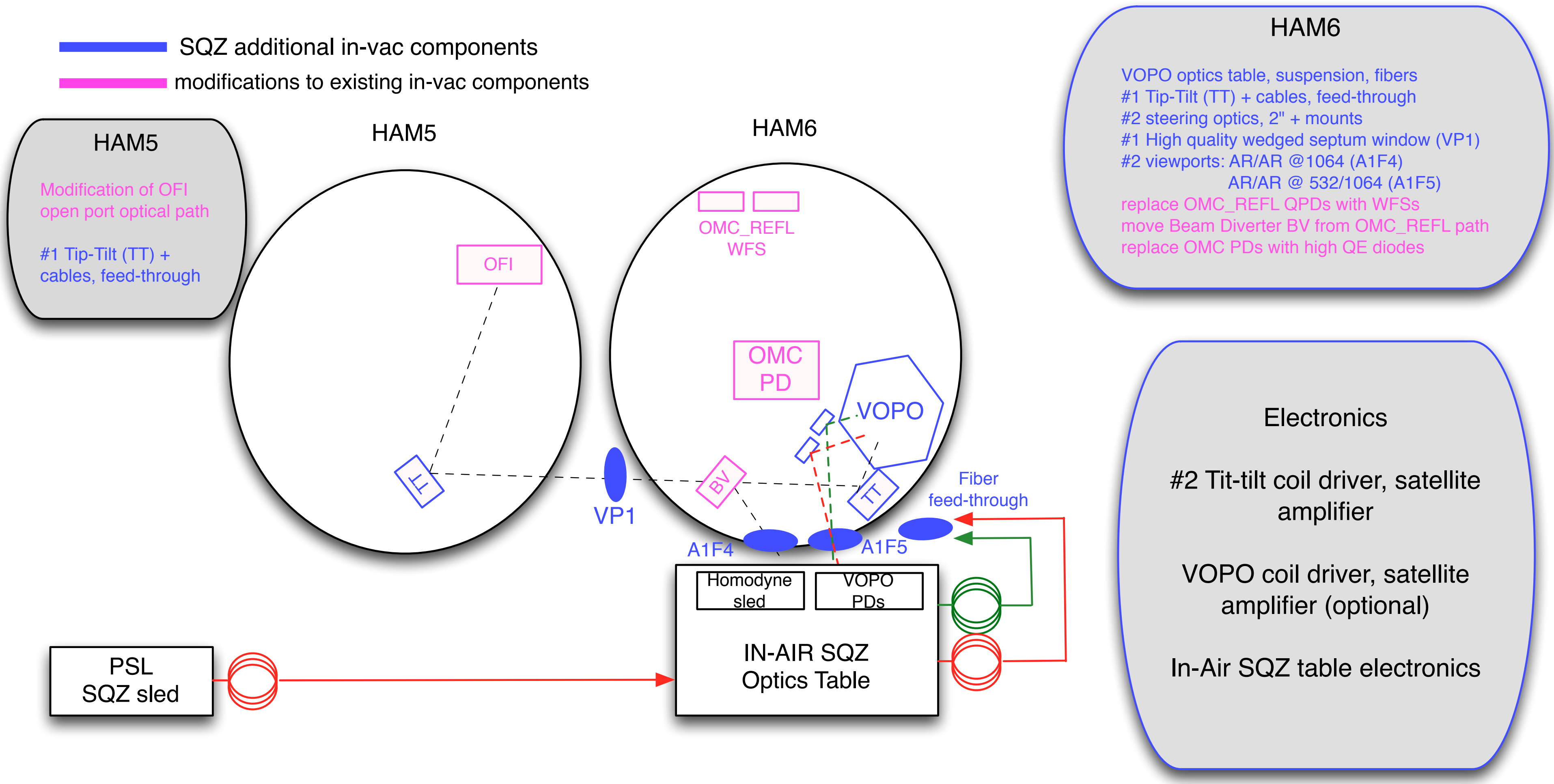
	Cost per Unit	Qty	Total
Fiber bacthes	$ 10,000.00	2	$ 20,000.00
633nm Feedthrus (spares for VOPO 1)	$ 965.00	2	$ 1,930.00
1310nm Feedthrus (spares for VOPO 1)	$ 965.00	1	$ 965.00
532nm Feedthrus (aLIGO R&D)	$ 965.00	5	$ 4,825.00
1064nm Feedthrus (aLIGO R&D)	$ 965.00	4	$ 3,860.00
In-Vacuum Patchcords	$ 645.00	10	$ 6,450.00
In-air Patchcords	$ 150.00	10	$ 1,500.00
Couplers, Optics for testing, Routing R&D, Fibers handling, inspection, Cleaning material, Misc…	$ 5,000.00	1	$ 5,000.00
			$ 44,530.00

LASTI Full Scale Injection System - Summary

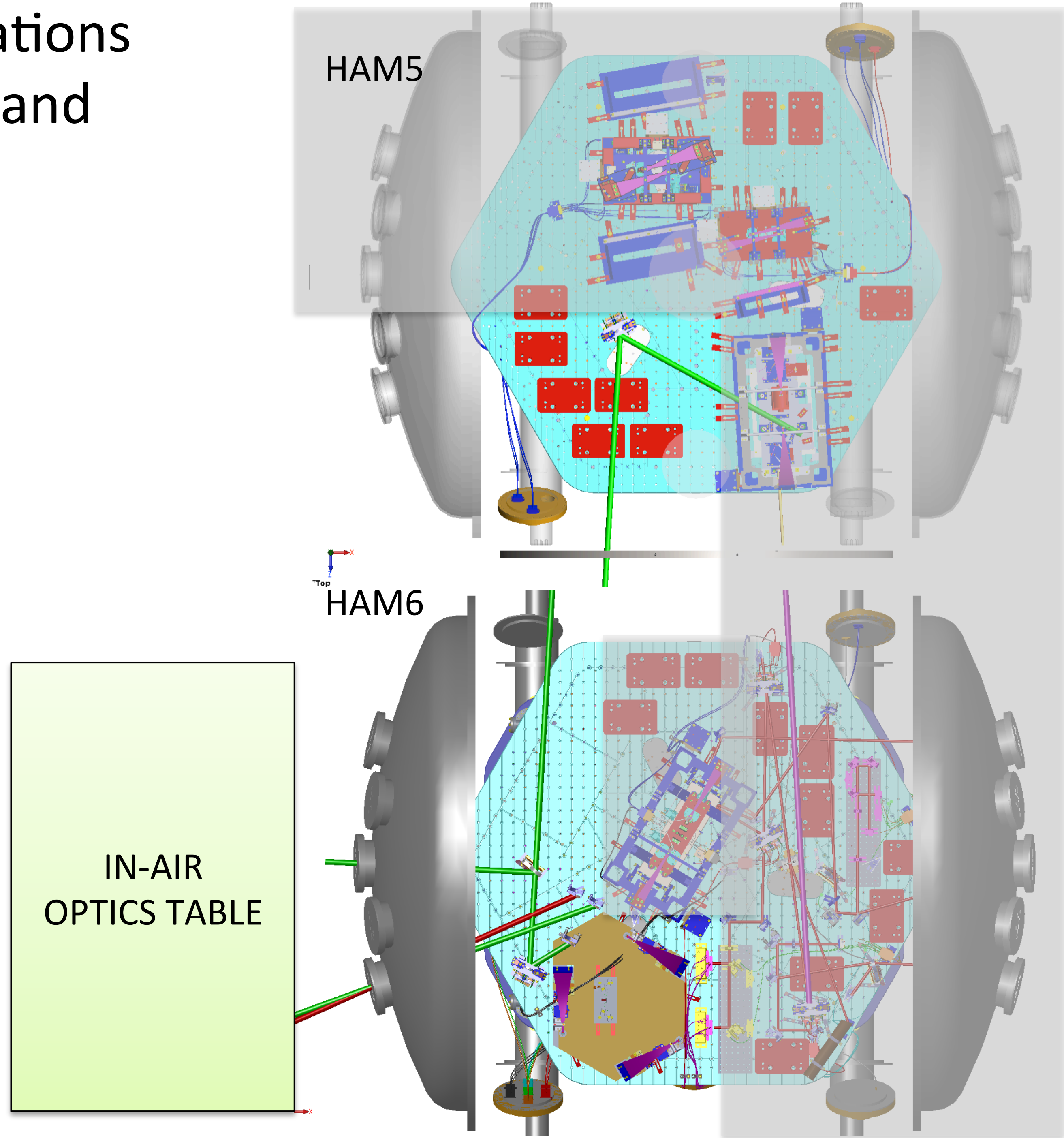
- Large fraction of the budget support VOPO and VOPO suspension final development to prepare for FDR
- Fibers and OPO cavity optics are long lead items; R&D budget will cover parts for aLIGO as well (need to revised cavity optics budget)
- Plan to re-use existing hardware as much as possible (from H1 squeezer, current VOPO experiment and 2m filter cavity set-up)
- People (full time):
  - John, Fabrice → main near term focus will be to support VOPO development
  - Maggie, Haocun (new grad-student)
  - 1 additional post-doc starting in January (Lee)
- This will become main LIGO Lab/MIT R&D project, many part time contributors (Lisa, Peter, Matt, Rich, Ken, Myron, Seb once AMD at FDR stage)

PDR
"Early" squeezing
(no filter cavity)
for aLIGO

Block Diagram (E1500359)



In-vacuum modifications to existing HAM5 and HAM6 layout



- Proposed implementation has in-air homodyne detector and OPO photo-detectors in air, that's why the table is near HAM6
- A 3' x 8' table gives same clearance as IOR table near HAM2

Status of HAM5 components

1. Output Faraday:
   - Need minor opto-mechanical modifications to support squeezing injection
   - These modifications could be done on the 3rd IFO unit
   - For L1, this could be coupled with producing a new unit with improved isolation
   - Optional: Koji's recent measurement of loss in each component can be used to inform path for reducing loss

2. Tip-tilt (12 spare tip-tilts in storage):
   - no development needed, but need plan for cables, feed-through, electronics

Status of VOPO components in HAM6

1. VOPO Suspension:

- PDR design (E1500383, D1500295)
- Preparation for FDR will be informed by MIT R&D tests

  ➔ request is for **$35k R&D money** to build one unit which will then be used in LASTI
  (estimate assumes we can get spare aLIGO osems)

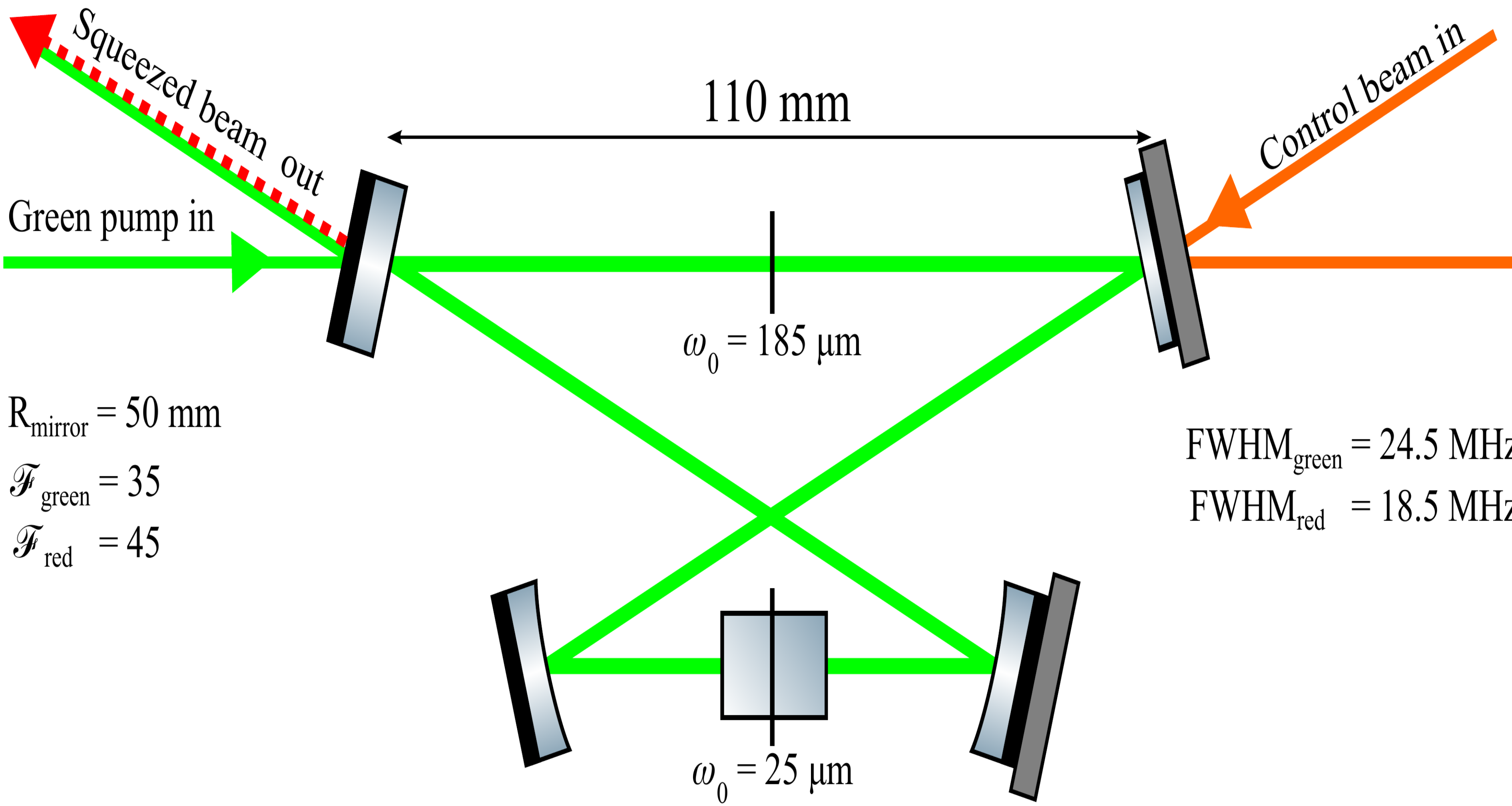
2. VOPO optics/opto-mechanics (PDR:E1500361)

- **OVEN**: one oven based on ANU design is under test right now; improved version under design ➔ request is for **$7k R&D money** to build one "final" unit which will then be used in LASTI
- **FIBERS**: a lot of testing done, converged on vendors (very challenging)
  ➔ request if for **$45k R&D money** for final development (LONG LEAD ITEM)

CAVITY: glass unit under test right now, based on ANU design; optimized optical parameters chosen, test of mechanical layout to simplify construction

➔ request is for **$20k R&D money** to build one "final" unit which will then be used in LASTI

VOPO Optical Cavity design



Optical changes relative to H1

Changed ROC of curved mirrors:
38 mm → 50 mm

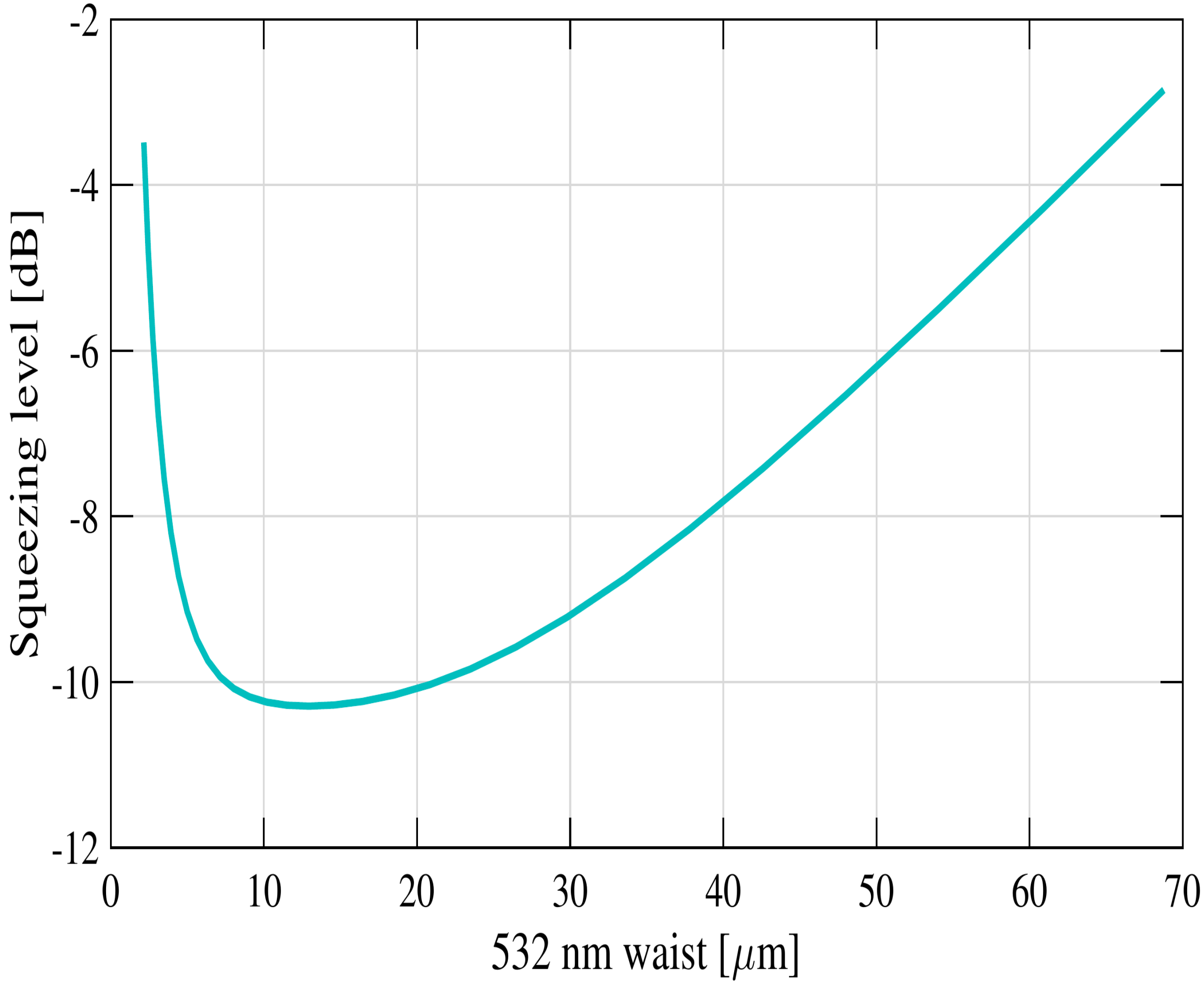
+ Slightly larger cavity
+ Slightly larger spot size
+ Better g factors
+ Easier to build

- Slightly larger cavity
- Slightly larger spot size

Green finesse: 17→ 35

+ Filtering of PDH sidebands
+ Lower input power required

- Amplification of input power fluctuations



VOPO Mechanical design

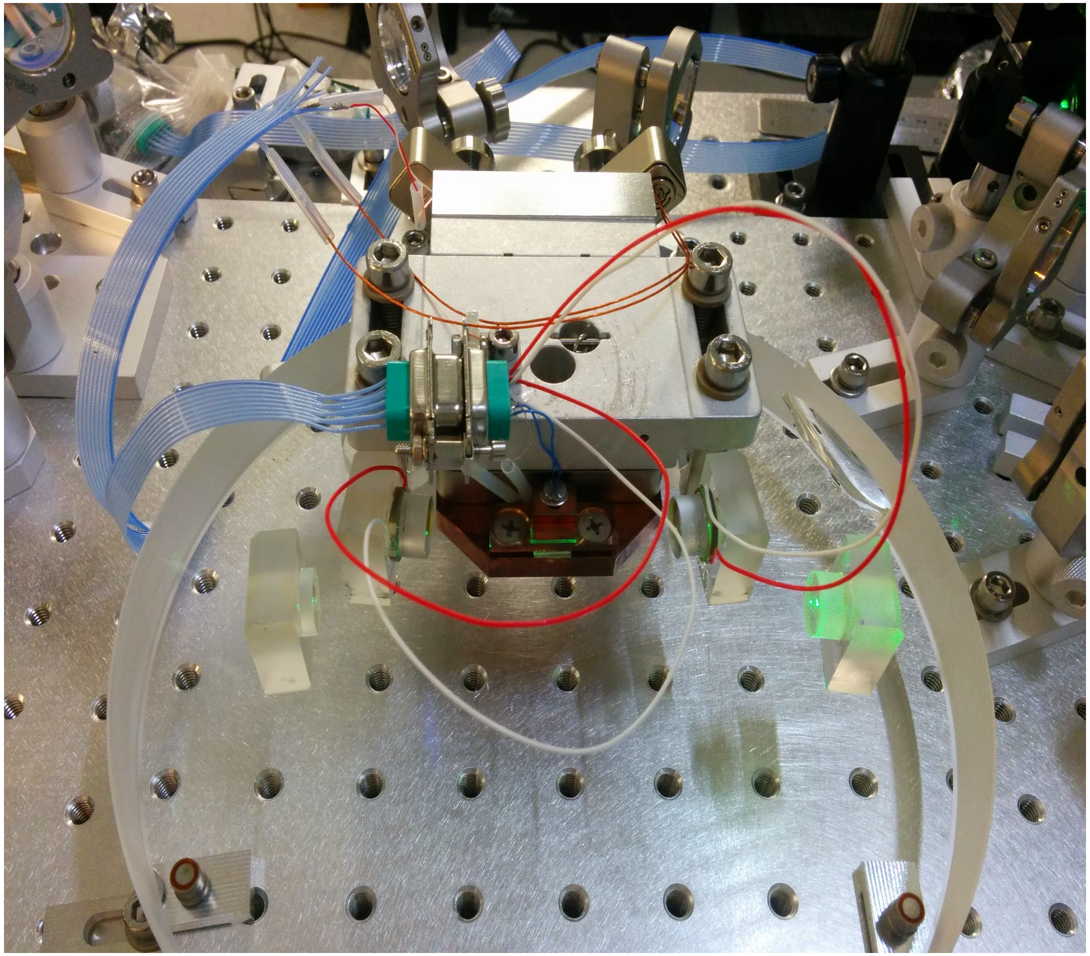
Length noise = phase noise

Decided against OMC-style monolithic design

Recent experience with optical contacting

- Glue and/or different construction technique
- Lower CLF frequency

In vacuum using fixed mounts

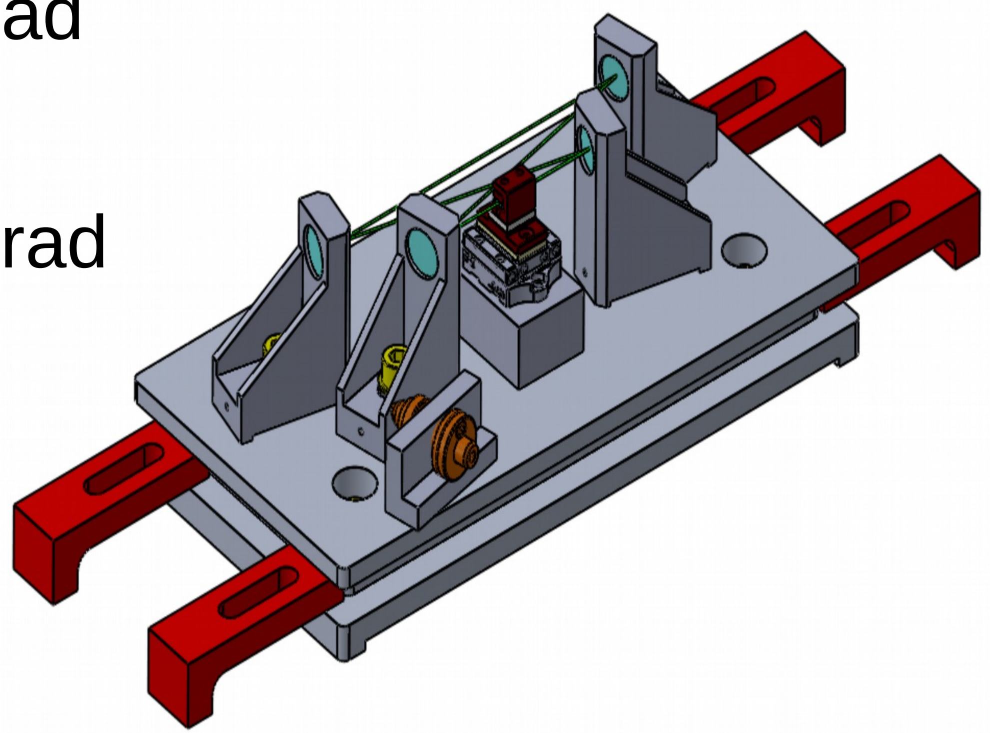


Mechanical design

- Phase noise (goal for 10 dB ~10 mrad)
  - H1 phase noise ~20 mrad
  - OMC style ~0.1 mrad
  - H1 new CLF freq. ~3 mrad

- Use OPO as reference cavity
  - OMC style

    $1\mathrm{Hz}/\sqrt{\mathrm{Hz}}$ @ 100 Hz



VOPO long lead items

- Crystals (already ordered on VOPO R&D money; it doesn't make sense to order less than 5, process is very long)
- Fibers
- OPO cavity Optics: not extremely long lead item, but while we buy optics for the LASTI unit it would make sense to buy more for 3 units + spares

Status of In-Air table

- R&D effort is focused on squeezing control scheme design
  - Noise model for VOPO experiment on-going (E. Oelker); simplified scheme to replace control laser with double AOMs also under testing
  - Double AOMs is the only change we might envision incorporating to the baseline design
- We have 2 squeezers at MIT (one is the H1 squeezer with in-air OPO, one has VOPO); LASTI filter cavity experiment will incorporate VOPO in H1 squeezer

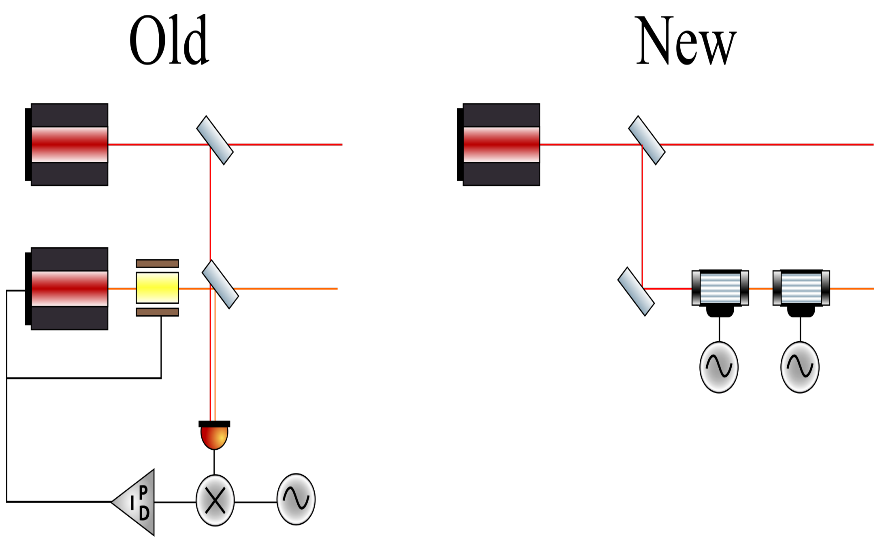
➔ R&D part ready soon, at which point we will need additional manpower for completing FDR of in-air table for the sites, ready for 24/7 operations; then for procurements, assembly, commissioning

➔ Most of components can be bought even before FDR; they won't change (optics, opto-mechanics, many electronics boards, etc); none of optics/opto-mechanics is really "long lead item", but there are many components

Future developments

Control scheme baseline design utilises proven technology
Possible improvements/simplifications under testing at MIT

- Replace CLF PLL with (double) AOM (happening now)
- Replace pump laser with direct sample of (doubled) PSL and AOMs
- Eliminates expensive lasers and fiddly phase locks



Summary

- We need R&D money now to move forward, especially with final development for VOPO/ VOPO suspension (FY2016 ~ $150k)
- Some long lead items (fiber, OPO optics) for the sites incorporated in R&D budget
- To preserve the "early squeezing" option, we need to put some tasks in the SYS pipeline:
  - Additional manpower will be required for FDR level design
  - On site effort required for
    - in chamber work (HAM5, 6)
    - in-air tables