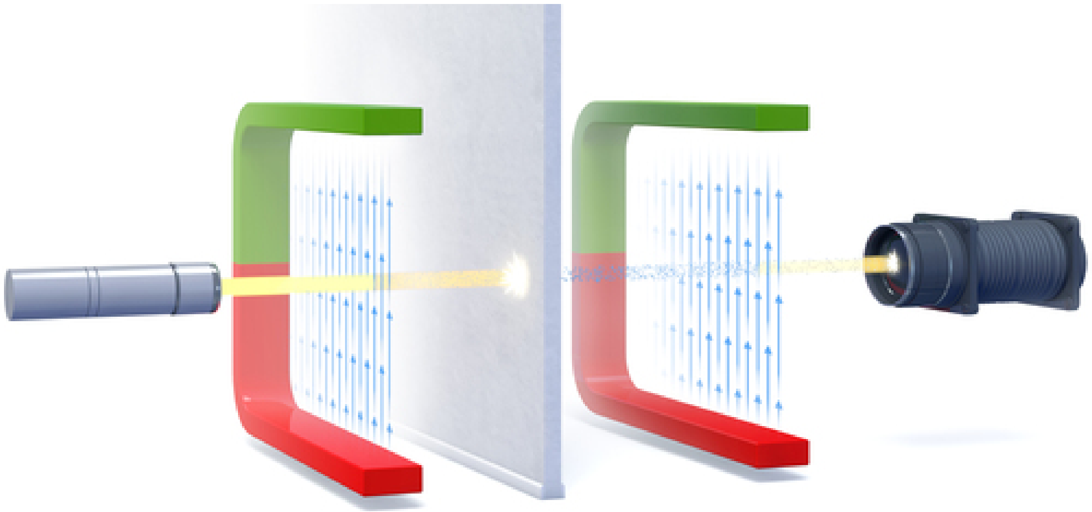
Any Light Particle Search II (ALPS II)

Overview and Status report

Aaron Spector
PRC Open Session
March 21, 2017

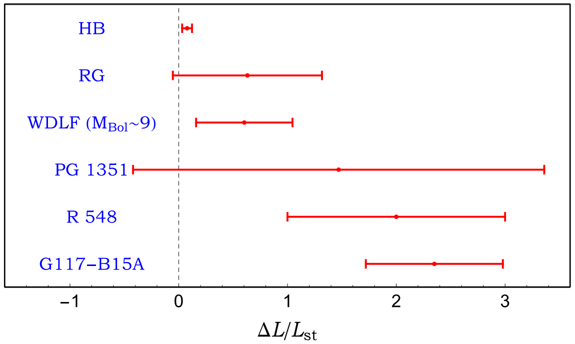
Overview

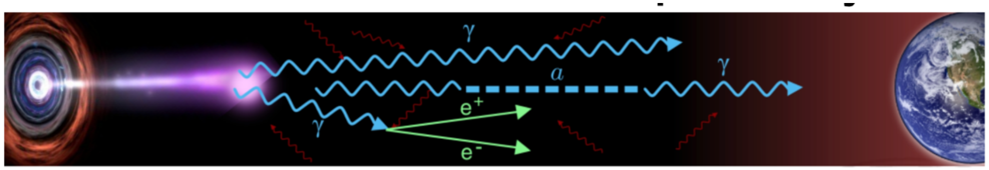
- Introduction to Axions and Axion Like Particles (ALPs)
  - Hints of these particles in astrophysical observations
- Light Shining through a wall style experiments
- ALPS II
  - Overview
  - Spatial overlap
  - Dual resonance
  - Optics progress
  - Detection schemes
  - Magnets
  - Future challenges and plans



Axions and Axion like particles (ALPs)

- Axion and ALPs would explain various astrophysical phenomena
  - Stellar cooling excesses
  - TeV transparency
  - Cold dark matter candidate

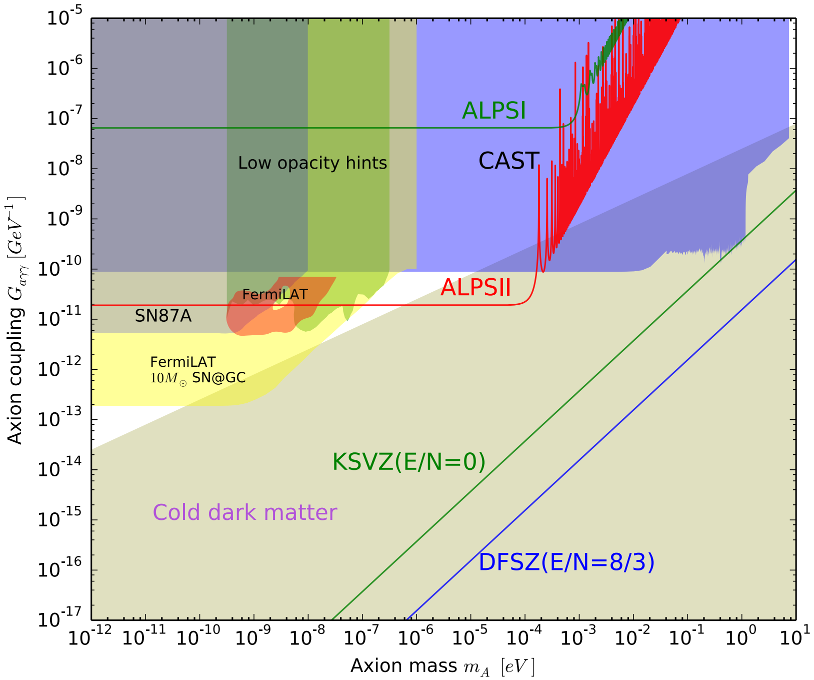




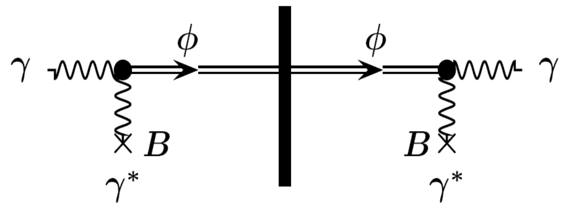
- Coupling between ALPs and photons

$$\mathcal{L}_{a\gamma\gamma} = -\frac{1}{4} g_{a\gamma}\, a\, F_{\mu\nu}\tilde{F}^{\mu\nu} = g_{a\gamma}\, a\, \vec{E}\cdot\vec{B}$$

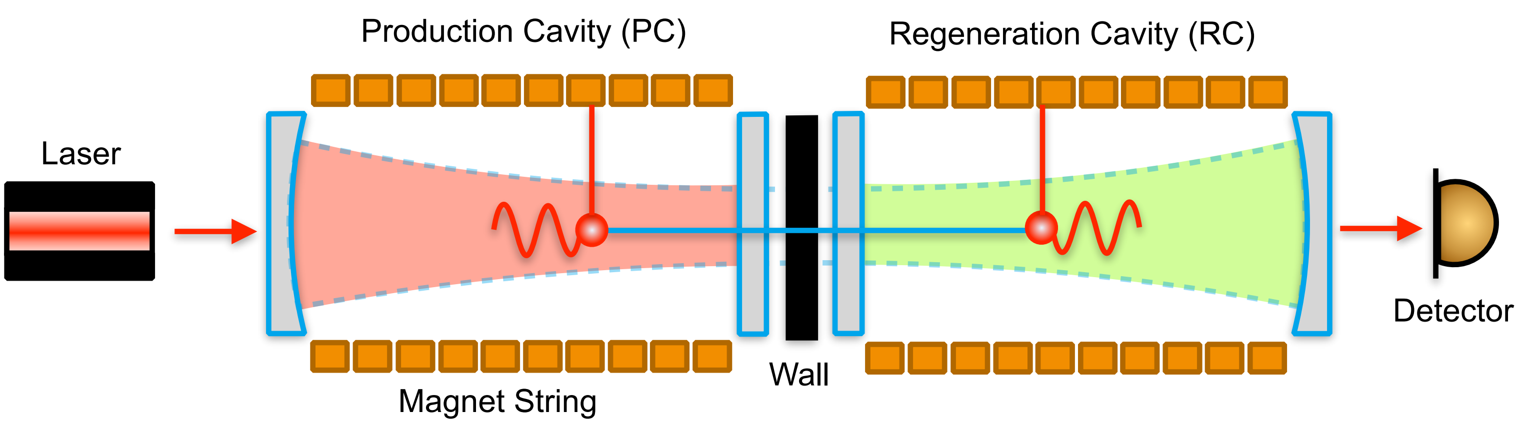
  - Presence of B-field necessary for photons to couple to ALPs



Light Shining Through a Wall

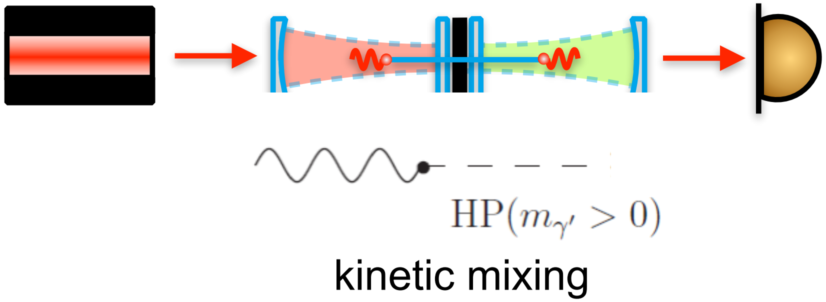
- Light Shining through a Wall approach to search for ALPs
  - Primakov effect: 

  - Photons in B-field couple to ALPS and traverse optical barrier
  - ALPS in B-field convert back to photons and are detected
- Optical cavities resonantly enhance probability of ɣ ➜ a ➜ ɣ

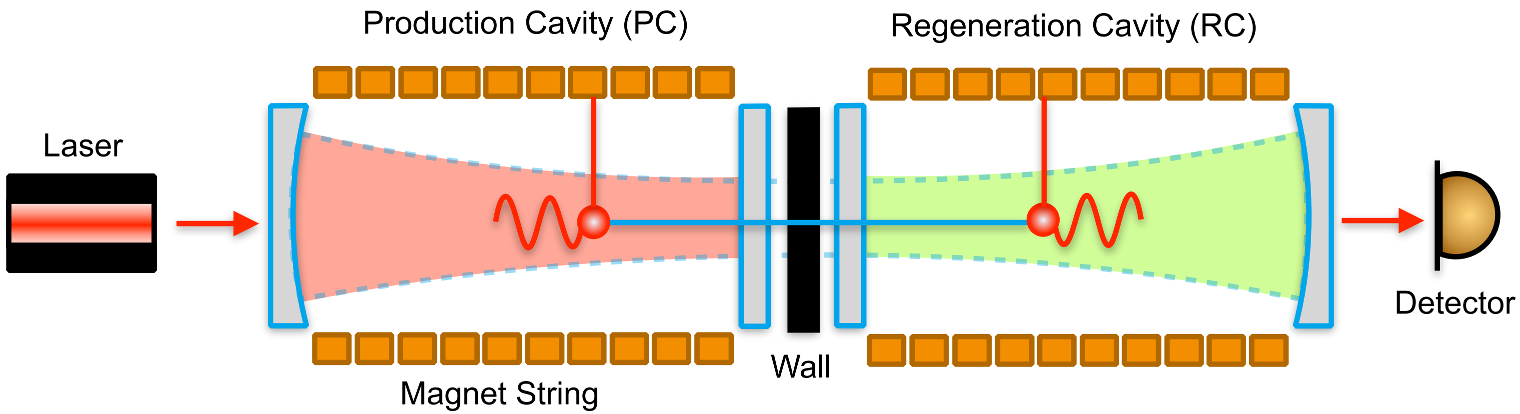


ALPS II

- ALPS II will take place in two stages (both use 1064 nm NPRO laser)
- ALPS IIa:
  - 10 m cavities, no magnet string
  - Sensitive to Hidden Photons

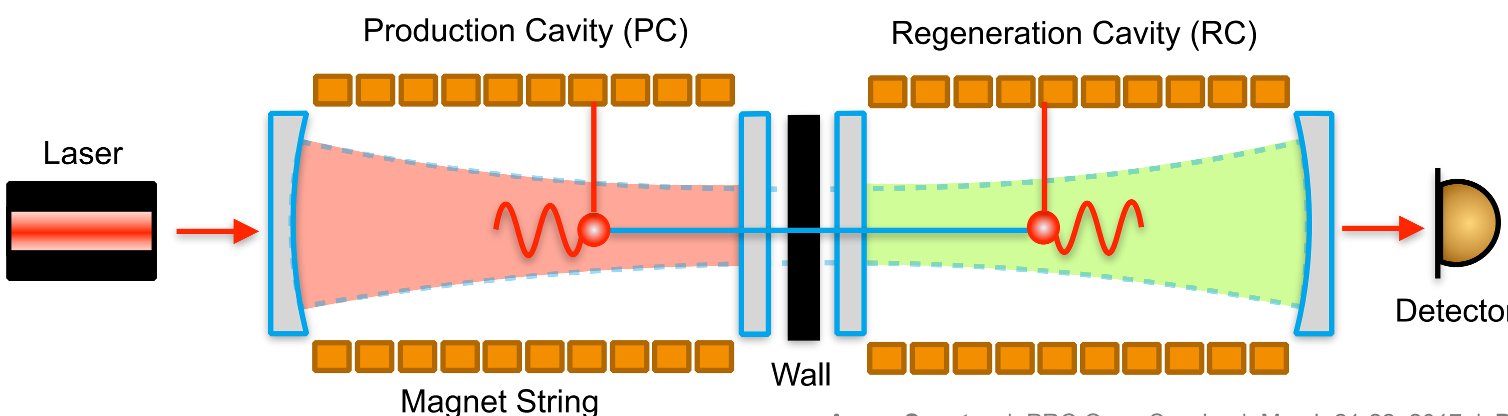


- ALPS IIc:
  - 100 m cavities
  - 5.3 T HERA dipole magnets (10 per cavity for 468 Tm)



ALPS II optics concept

- Production cavity → increase number of photons interacting with B-field
  - 150 kW circulating power of 1064 nm light
- Regeneration cavity boosts probability of a → γ
  - Power buildup factor of 40,000
- Must maintain dual resonance of the cavities
- Must maintain spatial overlap of the cavities
  - ALP field preserves spatial Eigenmode of the photon generating it



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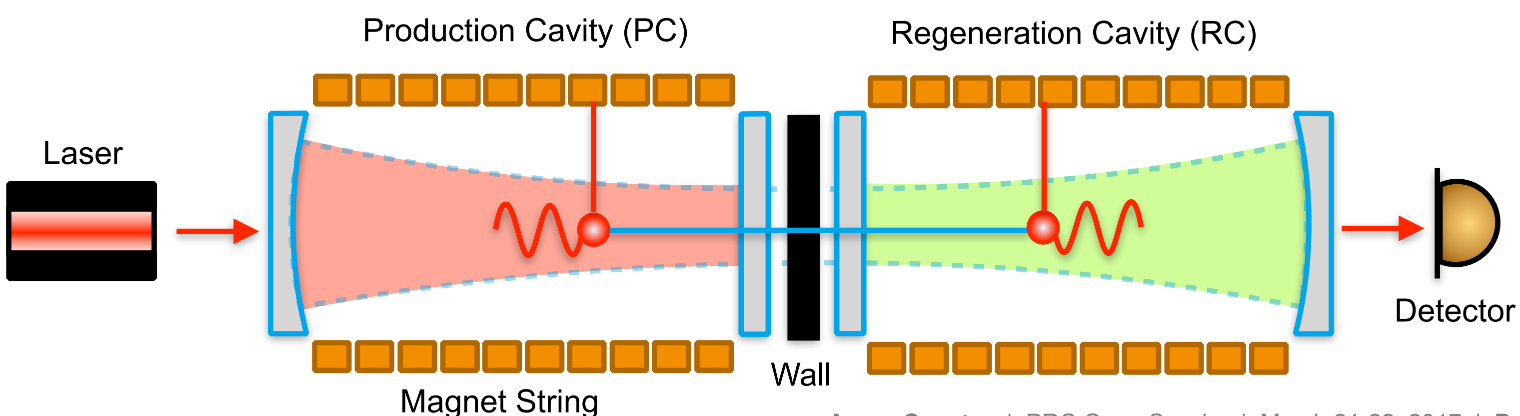
- Two independent detection methods with TES and heterodyne scheme



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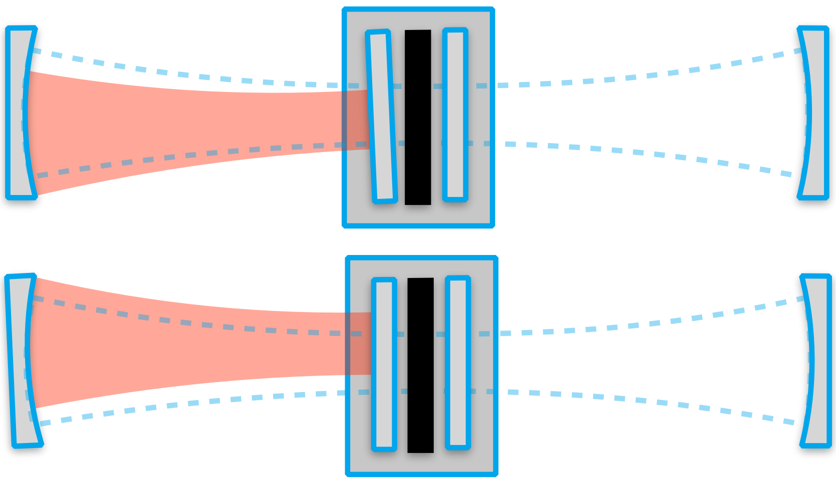
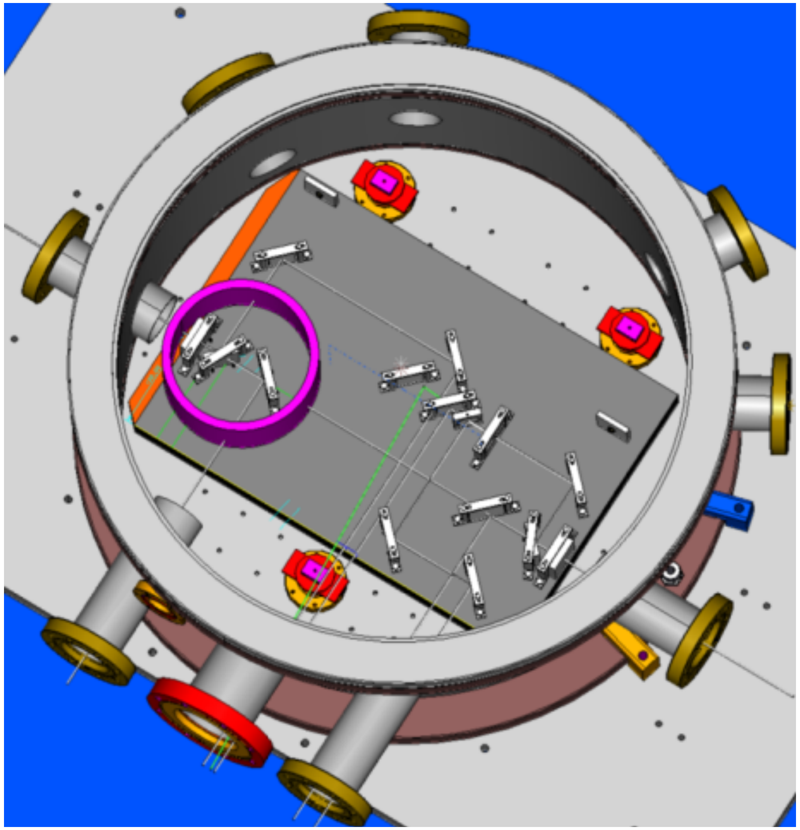
- Two independent detection methods with TES and heterodyne scheme
- Number of photons regenerated at detector port:

$$N_{\gamma\to\phi\to\gamma} = \frac{1}{16}\eta^2 \beta_{\mathrm{PC}}\beta_{\mathrm{RC}}\frac{P_{\mathrm{laser}}}{E_\gamma}\left(g_{\alpha\gamma}BL\right)^4 \tau$$

Spatial Overlap

- RC must maintain 95% spatial overlap with the PC Eigenmode
  - Central breadboard (CBB) used to maintain alignment
  - Active alignment of end mirrors



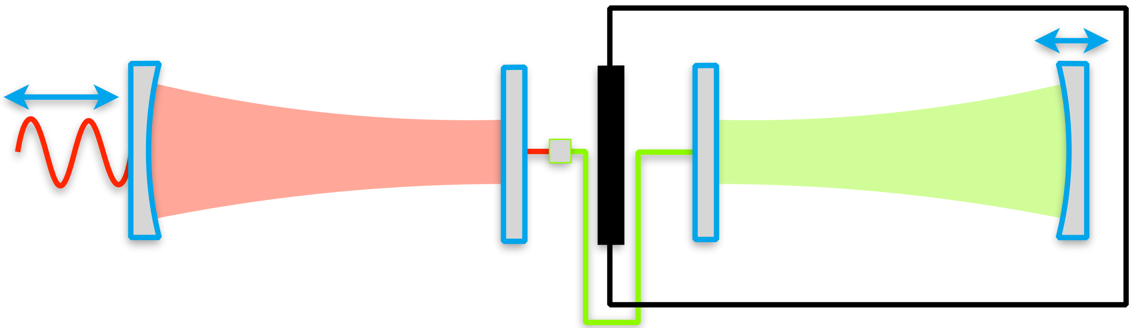


- CBB demonstrated alignment stability in long term measurement
  - RMS alignment drift < 1 µrad

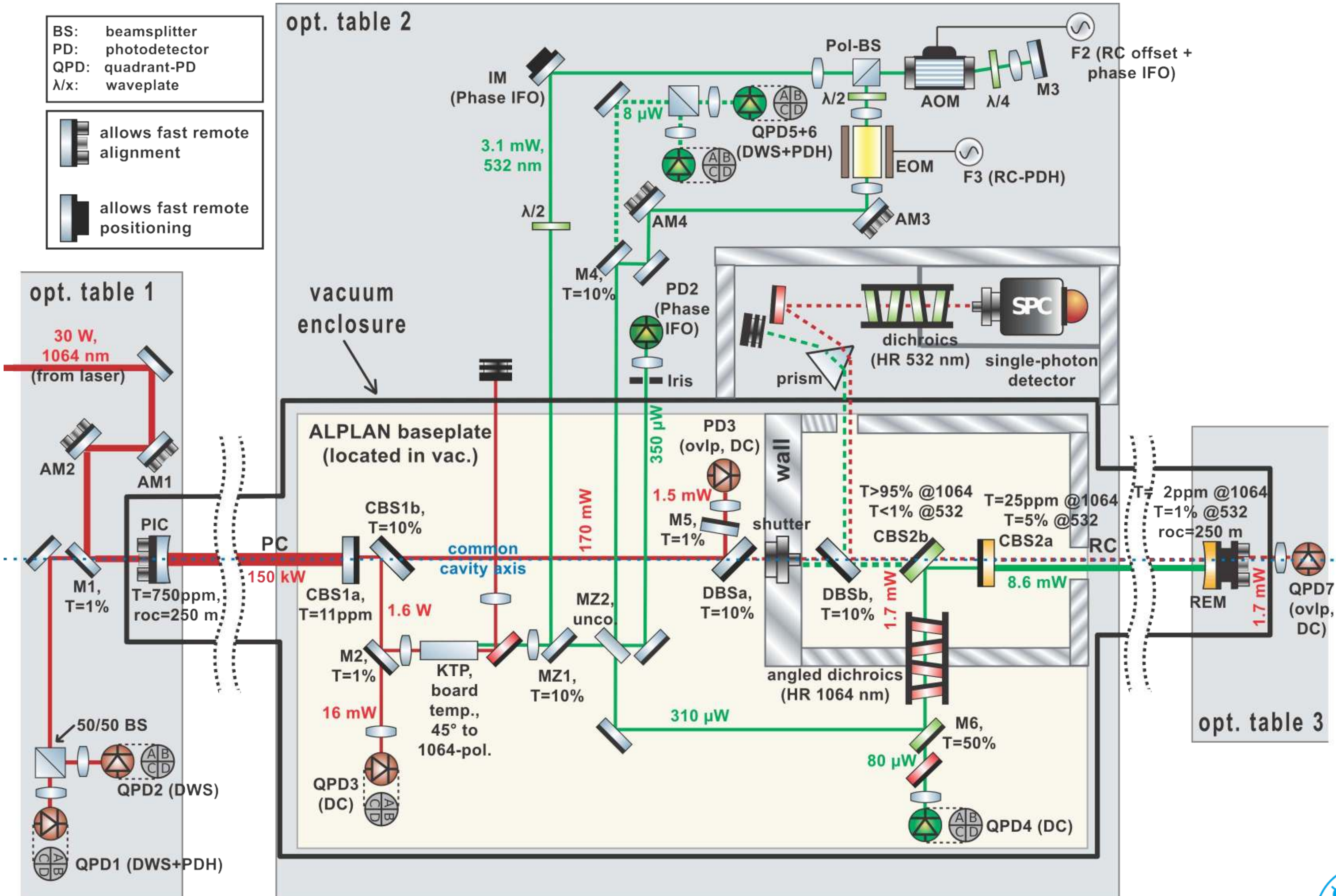
Dual Resonance

- 95% of light from PC must couple to RC
  - Line-width of RC for 1064 nm: 12.5 Hz (ALPS IIc)
    - RC RMS frequency noise must be < 1.4 Hz (ALPS IIc)
    - RC RMS length noise must be < 0.5 pm (ALPS IIc)

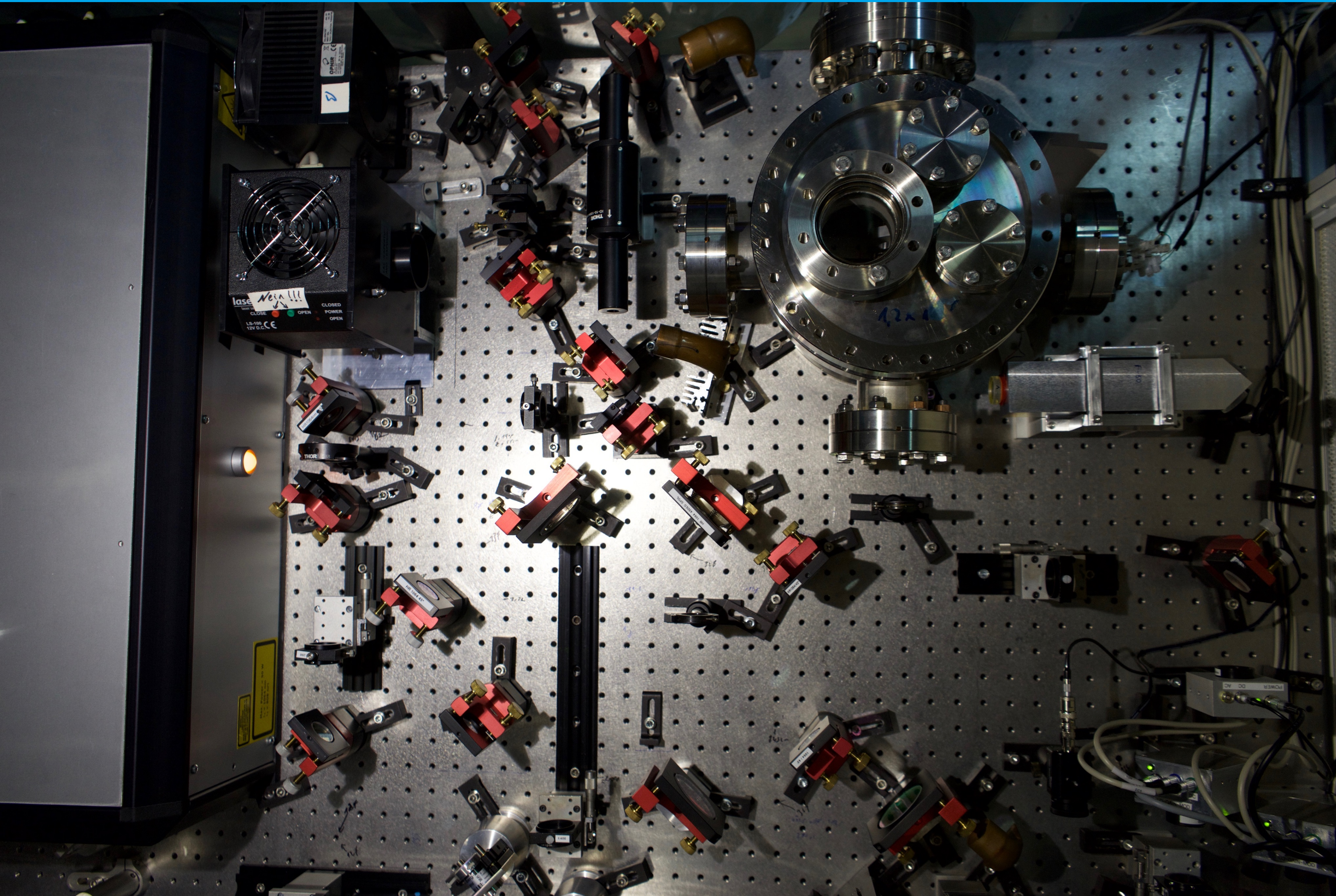
- Length stabilization system for the RC
  - RC length actuated, tracks changes in length of the PC



ALPS II Optical Layout



Optical Layout Table 1



Production Cavity

- Must maintain power build of 150 kW in fundamental mode
  - 30 W input power (amplified NPRO at 1064 nm)
  - Design power build up factor of 5000
  - Frequency stabilization and automatic alignment systems
- Tested optics subsystems on 20 m confocal cavity

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Characterization of optical systems for the ALPS II experiment

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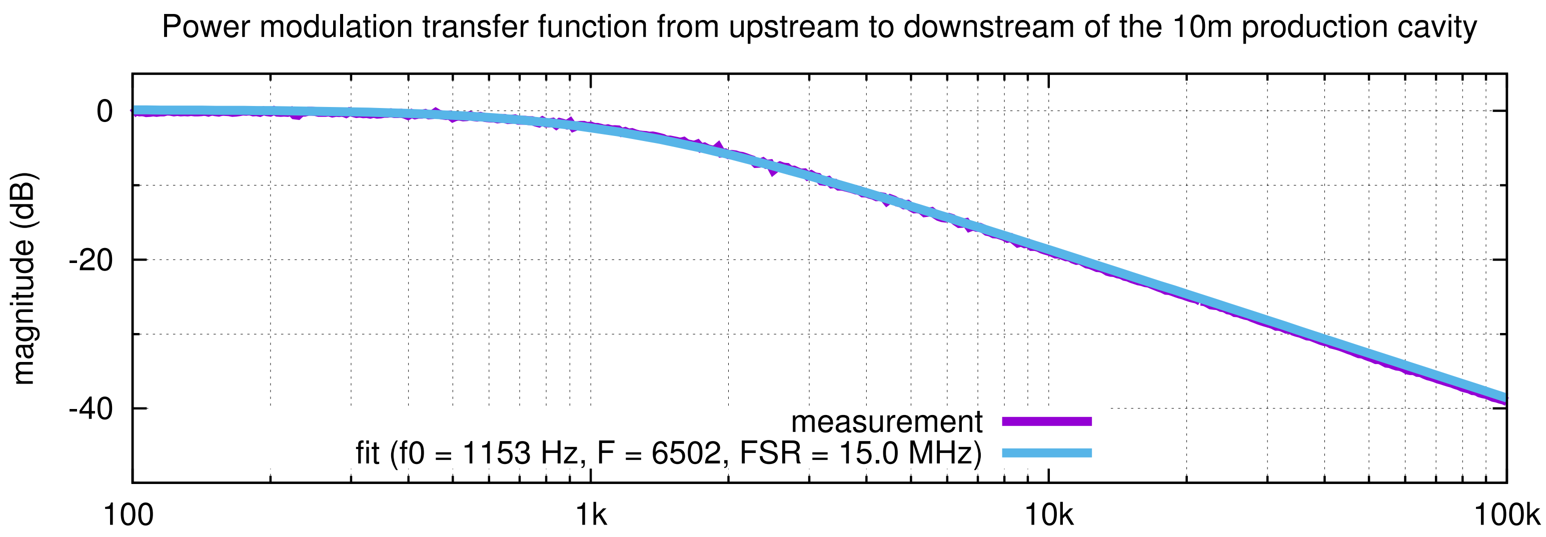
Production Cavity

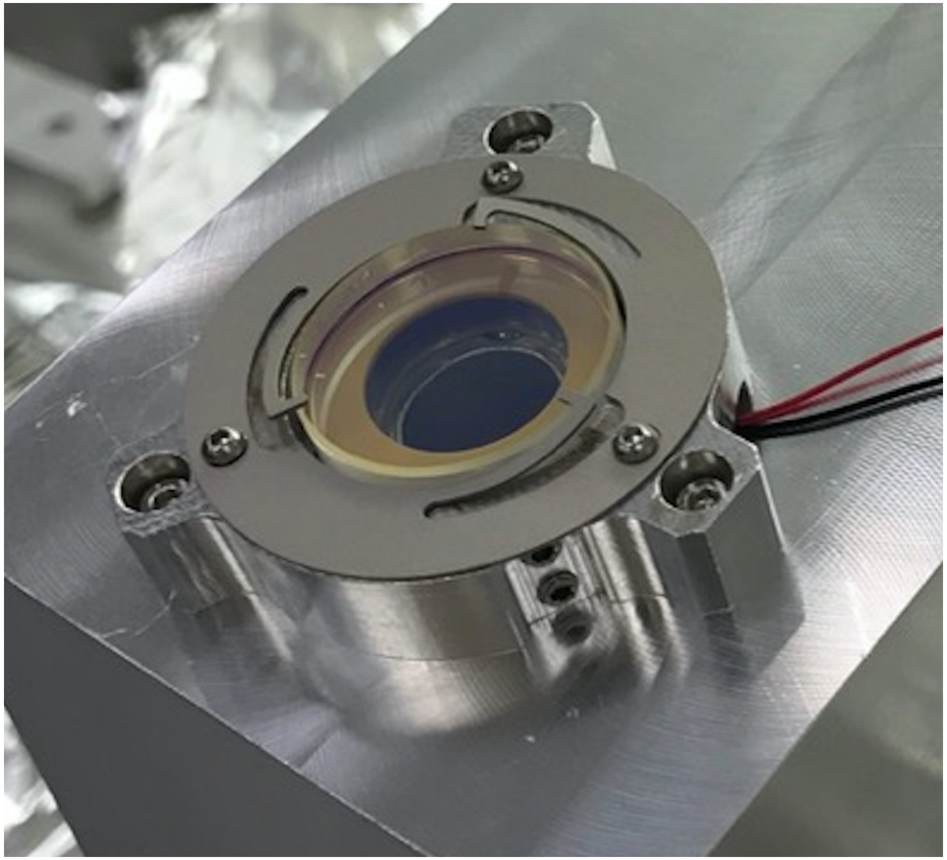
- Measured power build up factor of 4000 at 0.5 W input power
  - Losses of 77 ppm



- High Power operation with 30 W input power
  - 50 kW stable operation
  - Thermal effects ➜ reduce circulating power

Regeneration Cavity

- Designed power build up factor of 40,000
  - Measured power build up factor of 14,000
  - 55 ppm losses
  - Similar to the PC losses
- Currently designing control electronics for RC length stabilization system
  - Seismic noise studies
  - 5 kHz bandwith
  - Fast actuator

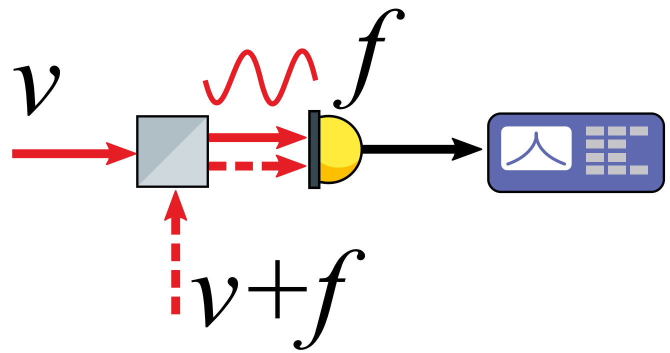


Optics Status Summary

	Requirement	Status
PC circulating power	150 kW	50 kW
RC power buildup factor	40,000	14,000
CBB mirror alignement	< 5 µrad	< 1 µrad
Spatial overlap	> 95%	work ongoing
RC length stabilization	< 0.5 pm	work ongoing

Detection Schemes

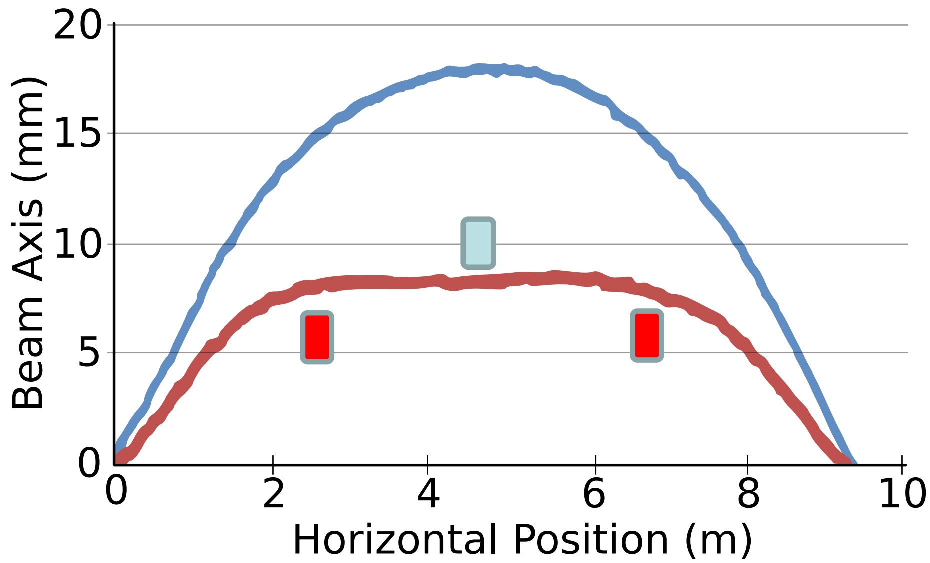
- TES detector still in development
- Heterodyne detector being developed at the University of Florida
- Interference beat note between measurement signal and local oscillator
  - Phase relation between measurement signal and LO fixed
  - Coherently sum by demodulating at difference frequency

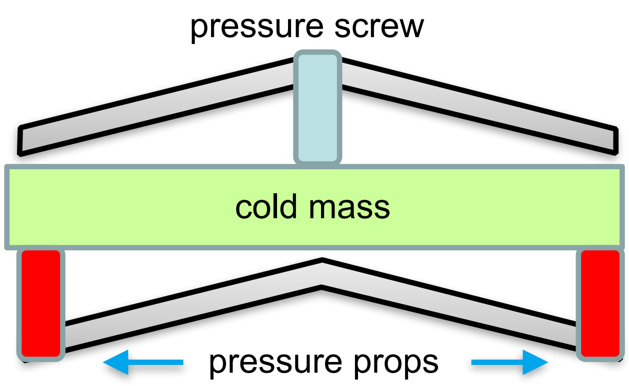


  - Demonstrated long term data run with no spurious signals from ADC

Magnets

- Using HERA dipole magnets
  - 5.3 T superconducting magnets
  - 600 m radius of curvature
    - Unbend cold mass
    - 2 have been unbent
    - Successfully operated
  - 48 mm free aperture

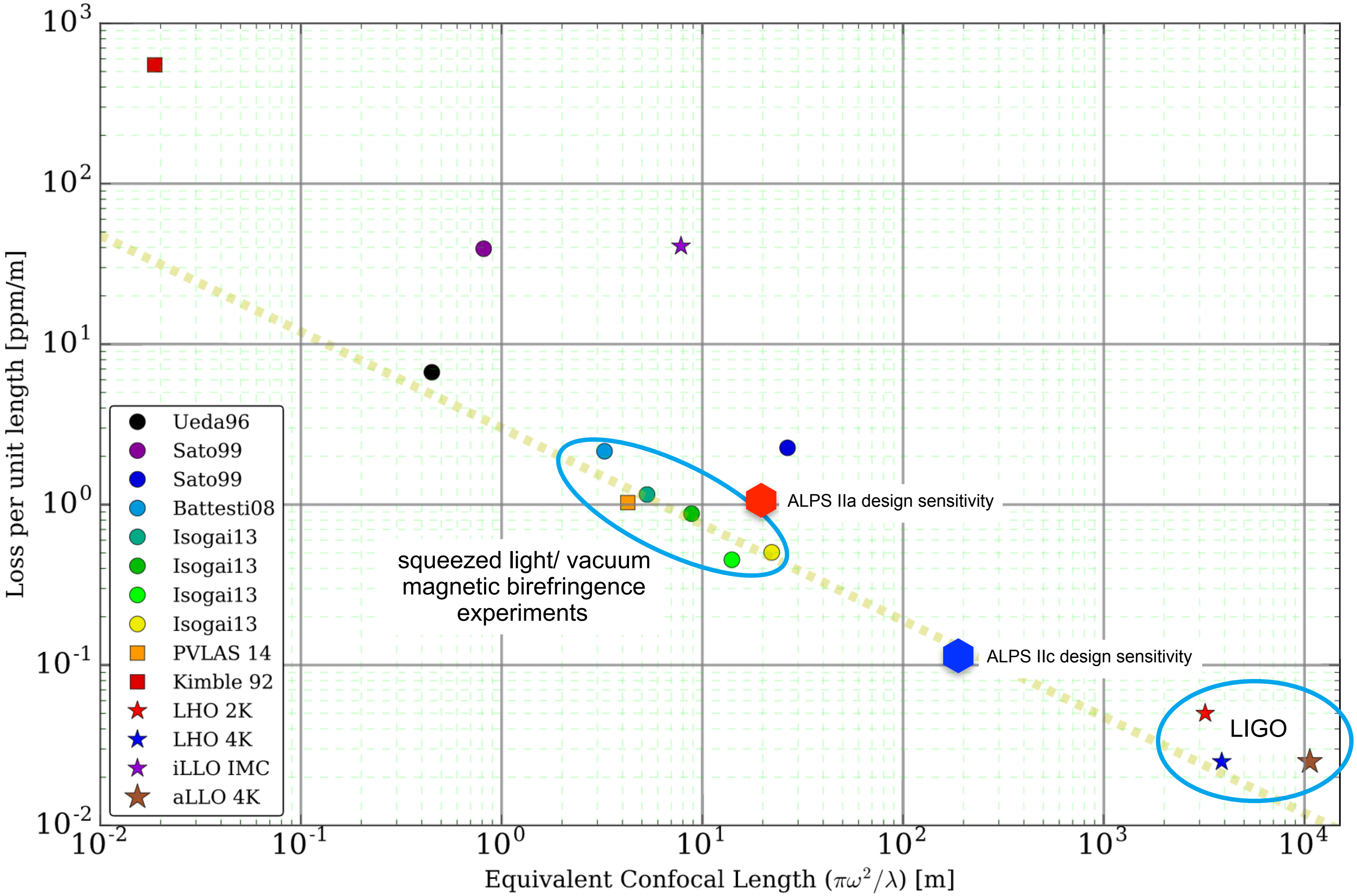




Summary and Timeline

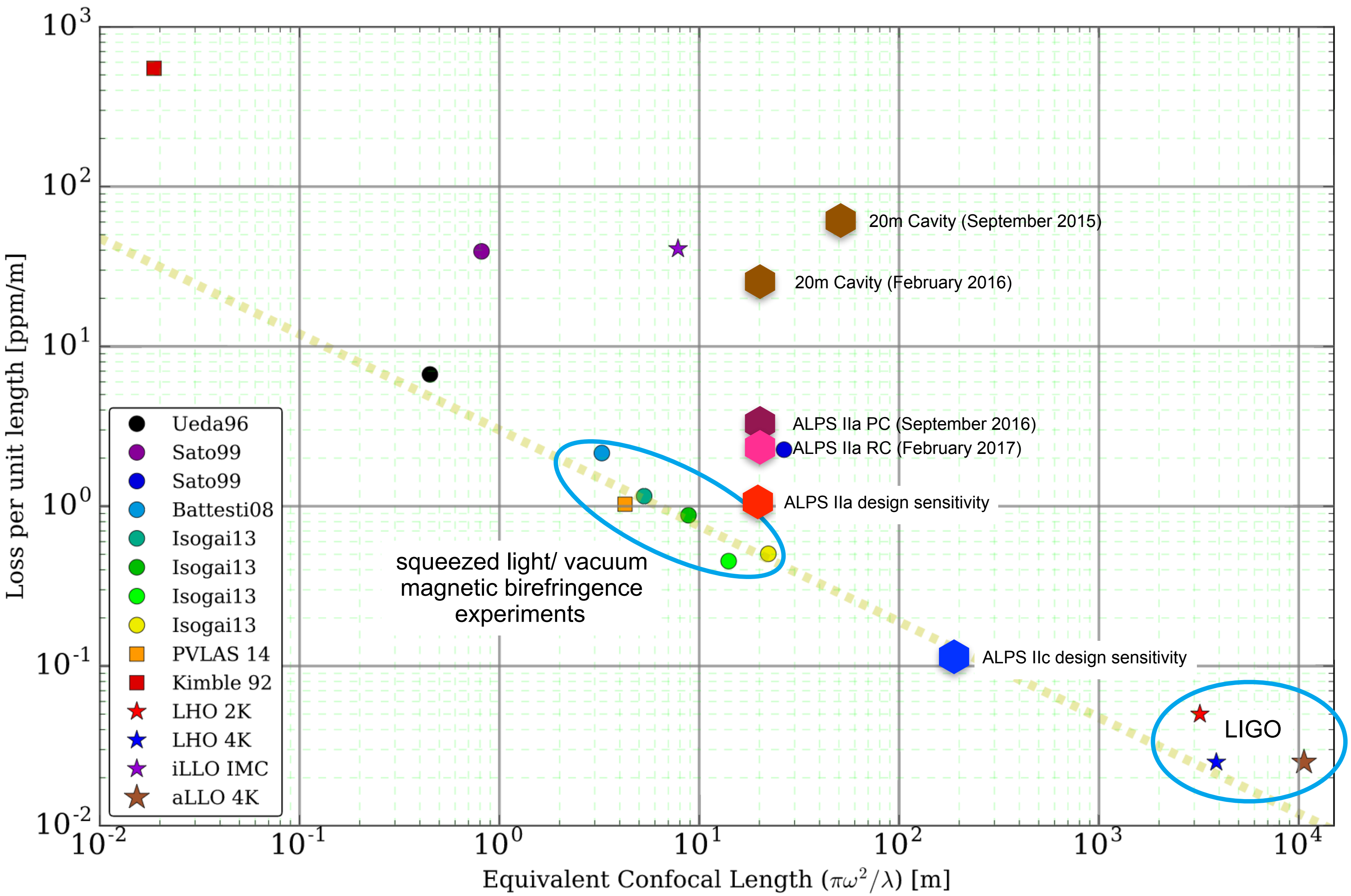
- Optics work progressing
  - Production cavity circulating power
  - Measurement of regeneration cavity power build up factor
  - CBB demonstrates alignment stability
- Detectors in development
- Timeline
  - Clearing HERA tunnel begins in May
  - ALPS IIc optics commissioning beginning 2019
  - ALPS IIc data runs in 2020

Long baseline optical resonators



plot from LIGO T-1400226-v6

Long baseline optical resonators



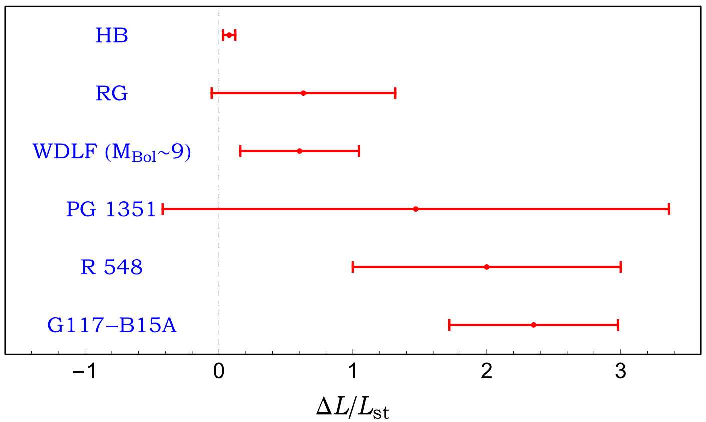
plot from LIGO T-1400226-v6

Thanks for listening!

- Any questions

Stellar energy loss excess

- WDs, RGs, and HB systematically cool more efficiently than expected
  - Axion or ALP coupling to photons and electrons best explains excesses



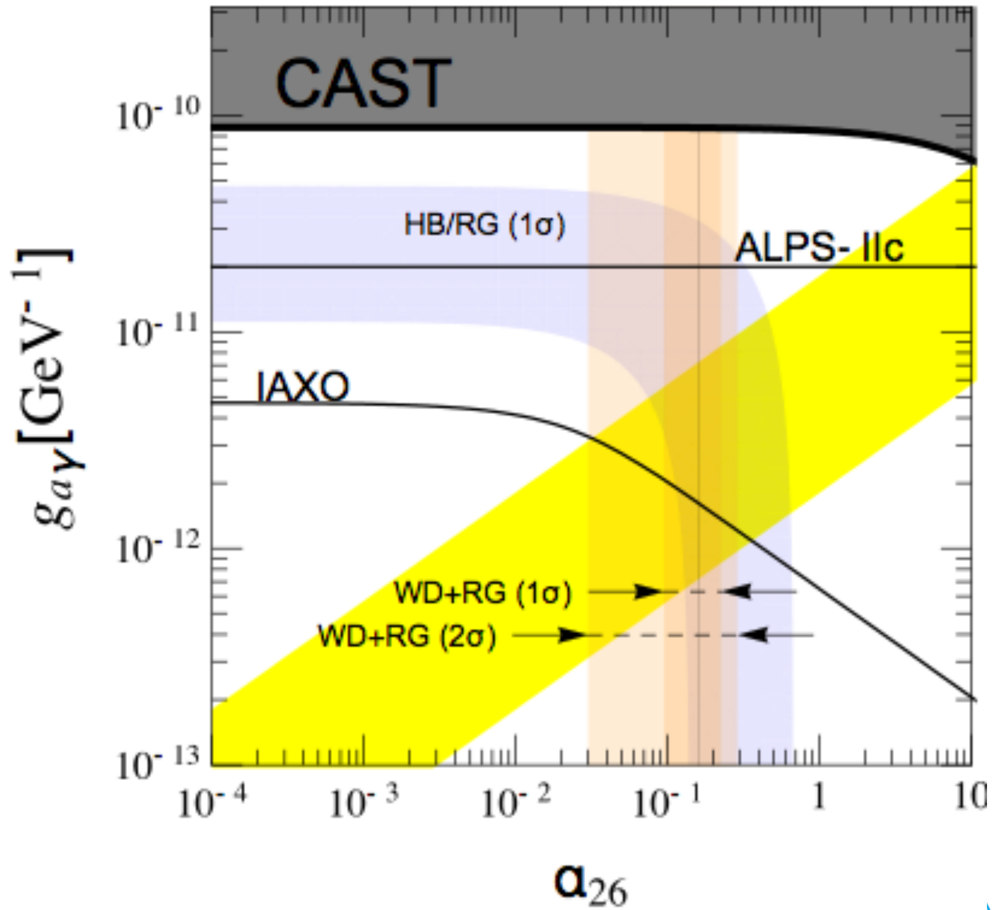
<u>best fit</u>:

$$g_{ae} = 1.5 \times 10^{-13}$$

$$g_{a\gamma} = 0.14 \times 10^{-10}\,\mathrm{GeV}^{-1}$$

χ^2_{min}/d.o.f. = 1.14

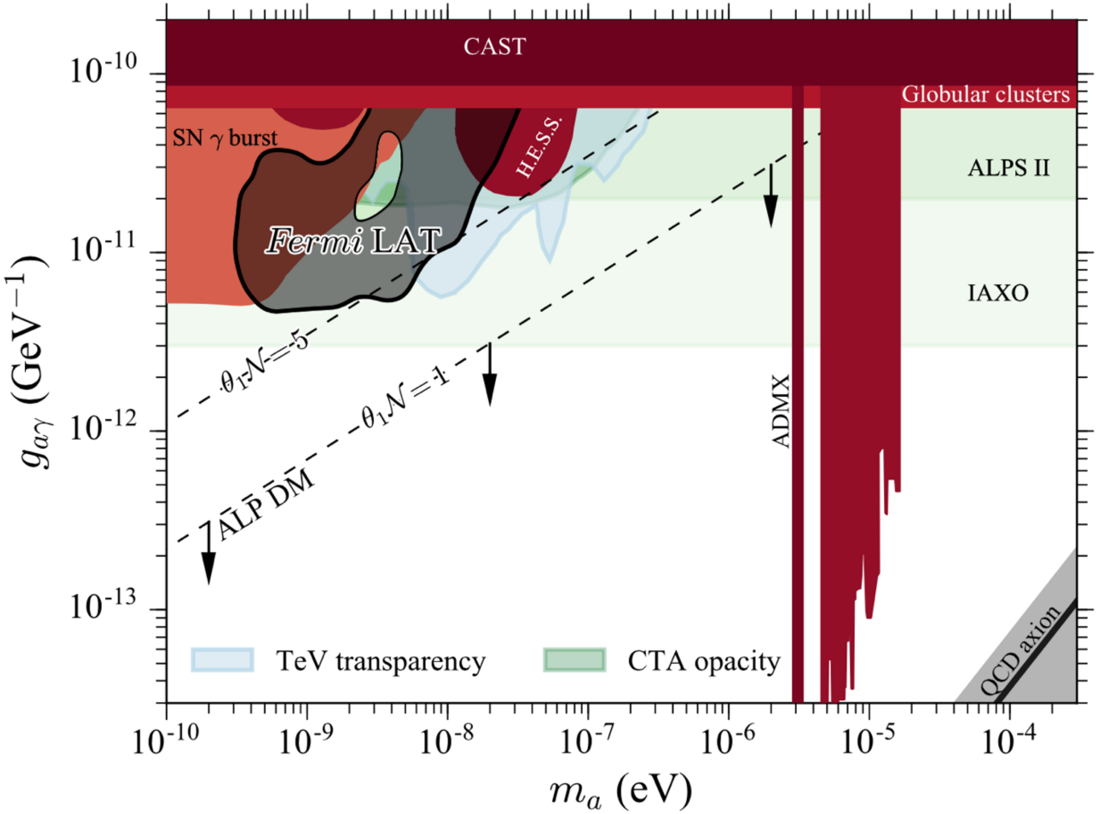
$$\alpha_{26} = g_{ae}^2/(4\pi)/10^{-26}$$

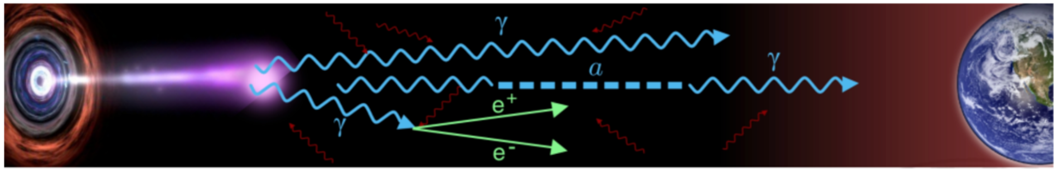


DESY

TeV Transparency

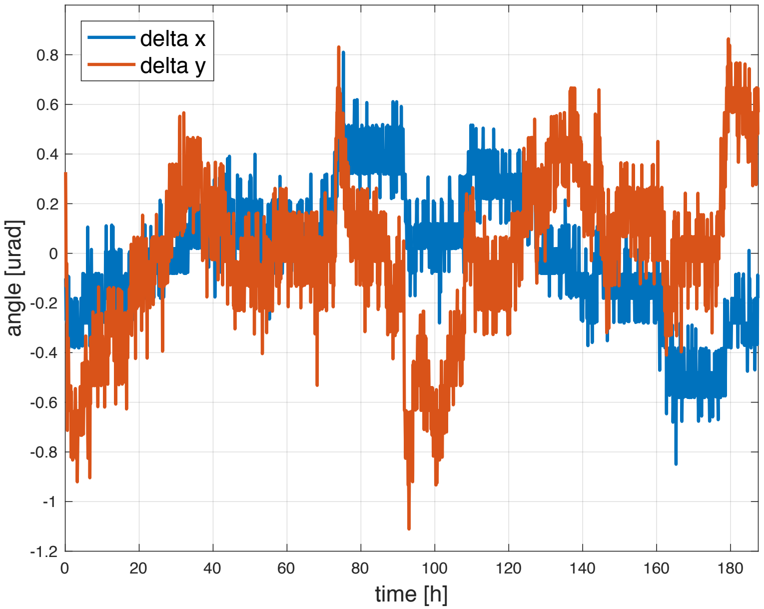
- Energetic photons undergo pair production
  - Expected to attenuate high energy photons from extra-galactic sources
  - Intergalactic space appears transparent for these photons
  - Coupling to axions of ALPs could explain this





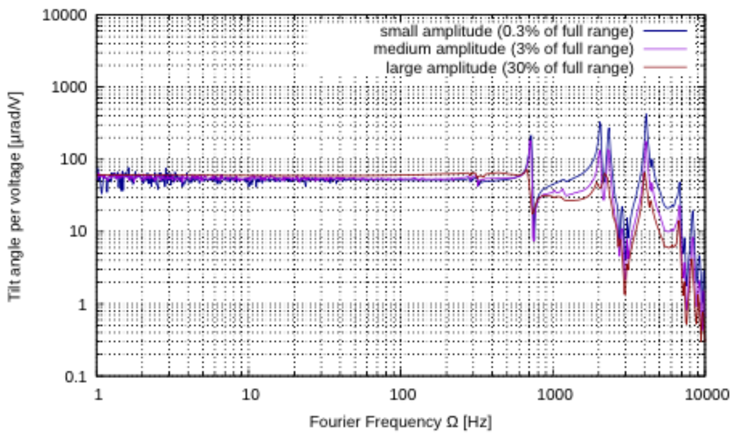
Spatial Overlap

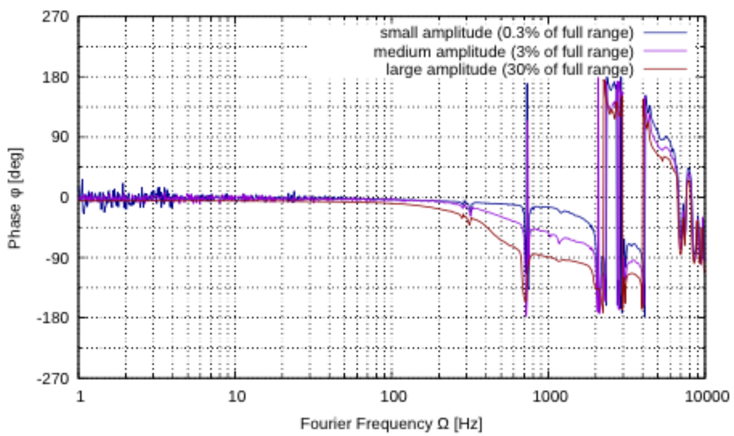
- Must maintain 95% spatial overlap with the PC
  - Central breadboard used to maintain alignment
    - RMS alignment requirement: 5 urad (ALPS IIc)
  - Active alignment of end mirrors
- Measured alignment drift of PC RC mirrors on central breadboard
  - RMS < 1 urad
- Aligned RC with PC transmitted beam as alignment reference
  - Frequency stabilized PC
  - Observed flashes of fundamental mode in transmission of the RC

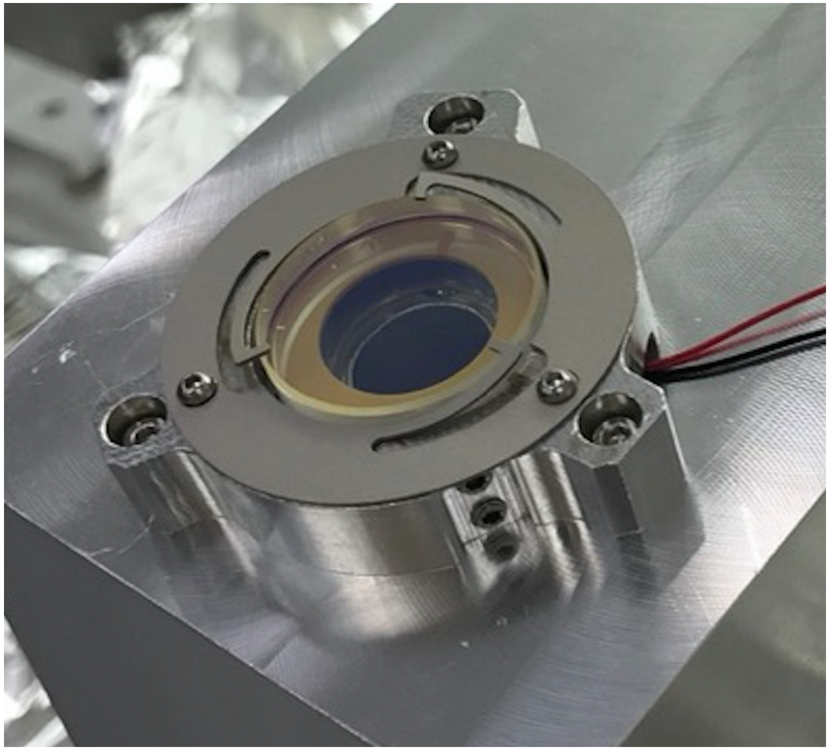


Length Stabilization

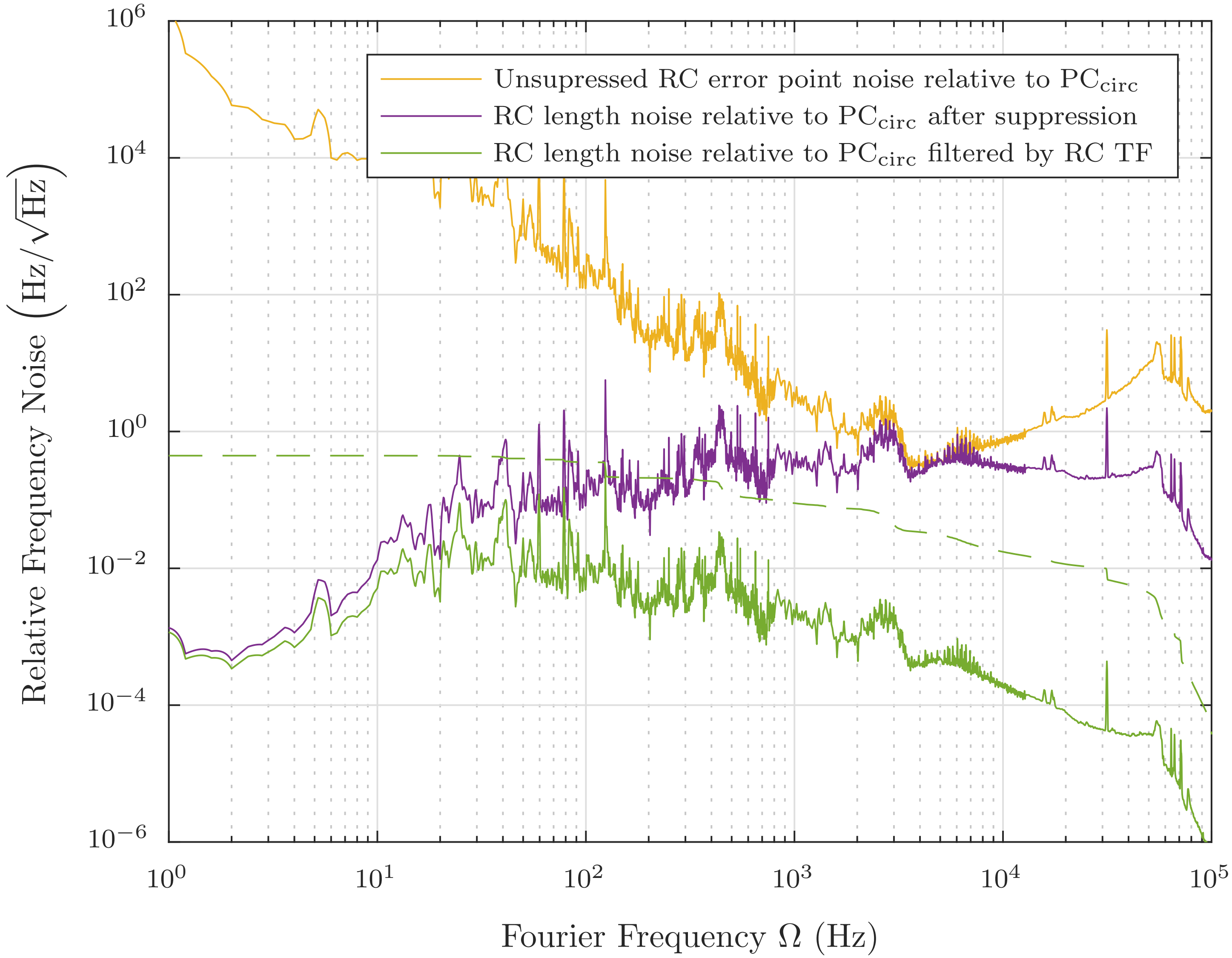
- RC RMS length noise must be < 0.5 pm (ALPS IIc)
  - Filter by RC transfer function
  - Must obtain bandwidth of at least 5 kHz in control loop





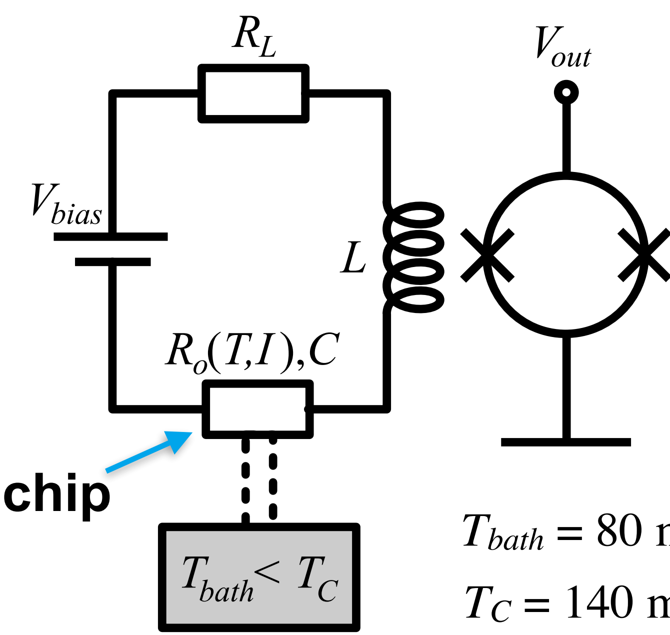


Projected Length Noise Spectrum



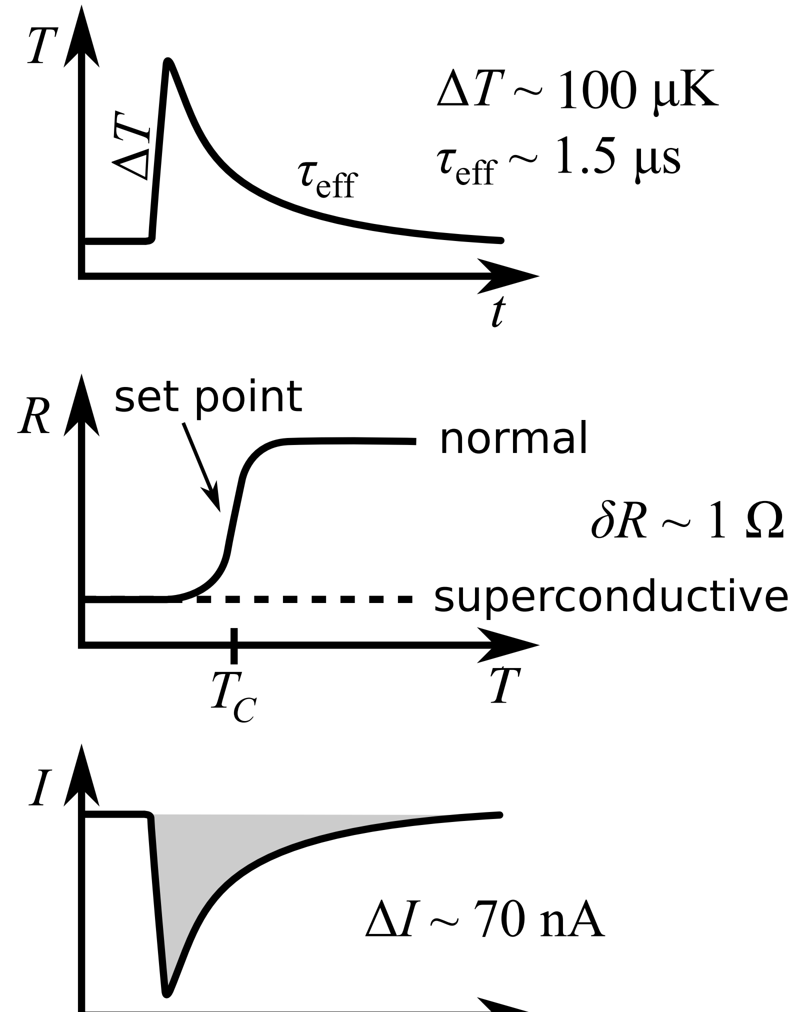
Detection Schemes

- Transition Edge Sensor (TES)
  - Microcalorimeter measuring temperature change induced by particle/photon on absorber
    - 25 x 25 µm tungsten chip
  - SQUID readout



$T_{bath} = 80$ mK

$T_C = 140$ mK



Based on sketch from [de Korte et al. (2003), Proc. SPIE 4851]

Heterodyne Detection

- Interference beat note between measurement signal and local oscillator
  - Phase relation between measurement signal and LO fixed
  - Coherently sum by demodulating
    - SNR = square root of N_S
  - Demonstrated 2 week data run with no spurious signals from ADC

$$S = |E_{SO}e^{i(\omega_1 t+\phi)} + E_{LO}e^{i\omega_2 t}|^2$$
$$= E_{LO}^2 + 2E_{LO}E_{SO}\cos(\Omega t + \phi)$$

$$S_I = 2\sqrt{N_{LO}N_S}\cos\phi$$

$$S_Q = 2\sqrt{N_{LO}N_S}\sin\phi$$

$$S_\Sigma = \sqrt{S_I^2 + S_Q^2} = 2\sqrt{N_{LO}N_S}$$

$$\sigma_\Sigma = \sqrt{\sigma_I^2 + \sigma_Q^2} = 2\sqrt{N_{LO}}$$

$$\frac{S_\Sigma}{\sigma_\Sigma} = \sqrt{N_S}$$