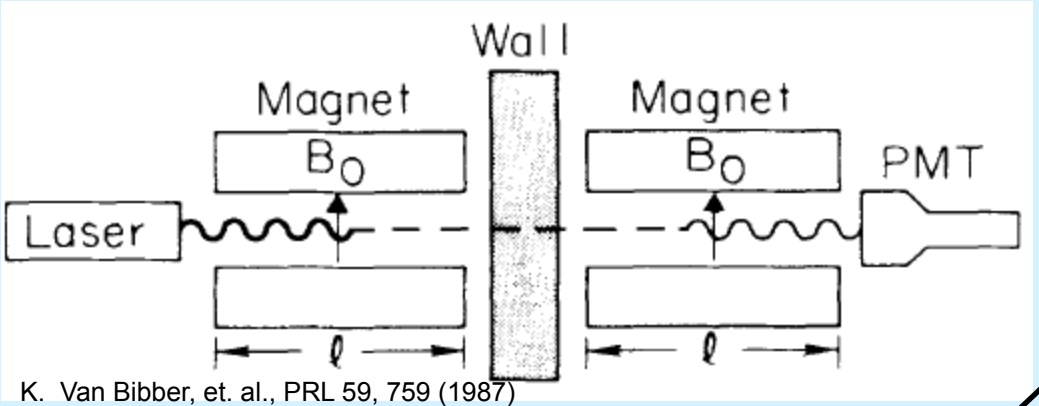
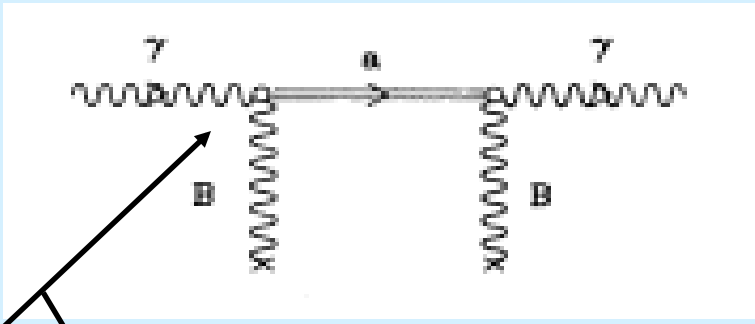
Laser Experiments to Search for Axion-like Particles

William Wester
Fermilab

Light Shining Through a Wall



K. Van Bibber, et. al., PRL 59, 759 (1987)



$$\mathcal{L}_{\rm int} = -\frac{1}{4}\frac{\phi}{M}F_{\mu\nu}F^{\mu\nu} = \frac{\phi}{M}(\vec{E}\cdot\vec{E} - \vec{B}\cdot\vec{B})$$

$$\mathcal{L}_{\rm int} = -\frac{1}{4}\frac{\phi}{M}F_{\mu\nu}\tilde{F}^{\mu\nu} = \frac{\phi}{M}(\vec{E}\cdot\vec{B})$$

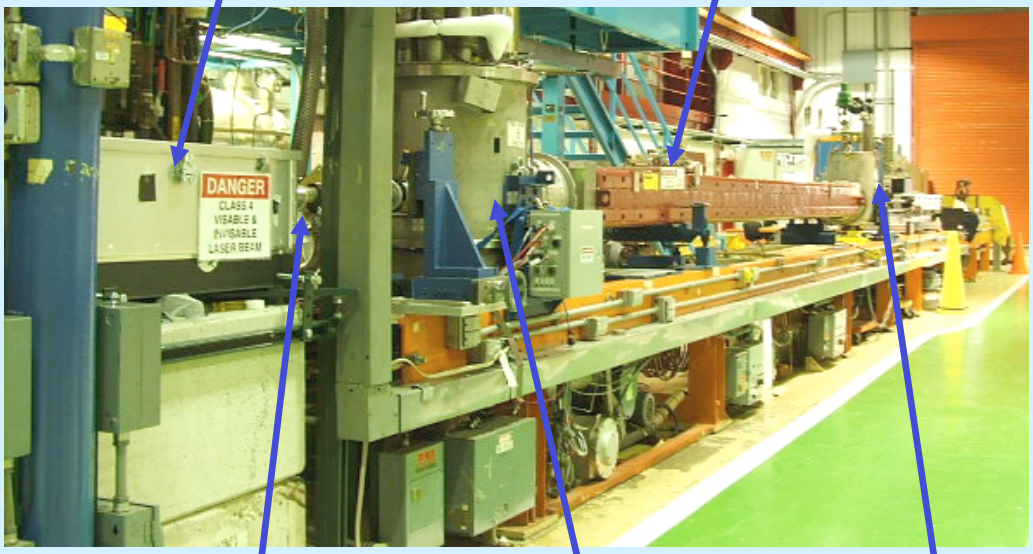
$$P_{regen} = \frac{16B_1^2B_2^2\omega^4}{M^4m_\phi^8}\sin^2\left(\frac{m_\phi^2L_1}{4\omega}\right)\cdot\sin^2\left(\frac{m_\phi^2L_2}{4\omega}\right)$$

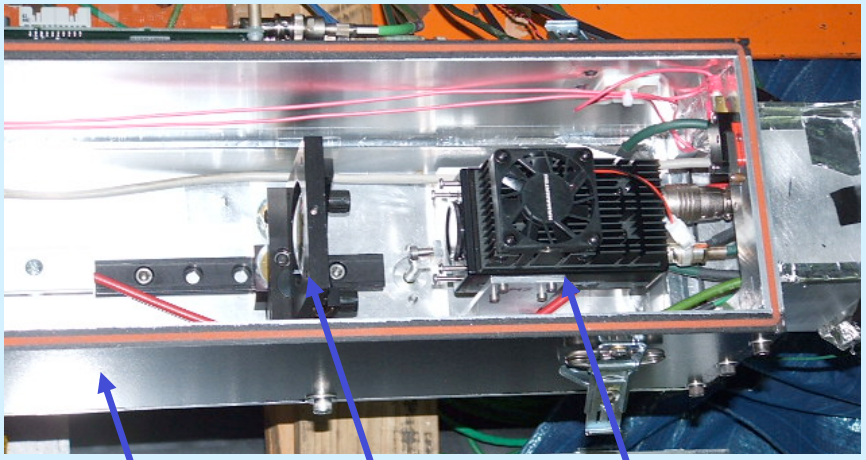
Assuming 5T magnet, the PVLAS "signal", and 532nm laser light

$$P_{regen}^{GammeV} = (3.9\times10^{-21})\times\frac{(B_1/5\text{ T})^2(B_2/5\text{ T})^2(\omega/2.33\text{ eV})^4}{(M/4\times10^5\text{ GeV})^4(m_\phi/1.2\times10^{-3}\text{ eV})^8}$$
$$\times\sin^2\left(\frac{\pi}{2}\frac{(m_\phi/1.2\times10^{-3}\text{ eV})^2(L_1/2.0\text{ m})}{(\omega/2.33\text{ eV})}\right)\sin^2\left(\frac{\pi}{2}\frac{(m_\phi/1.2\times10^{-3}\text{ eV})^2(L_2/2.0\text{ m})}{(\omega/2.33\text{ eV})}\right)$$

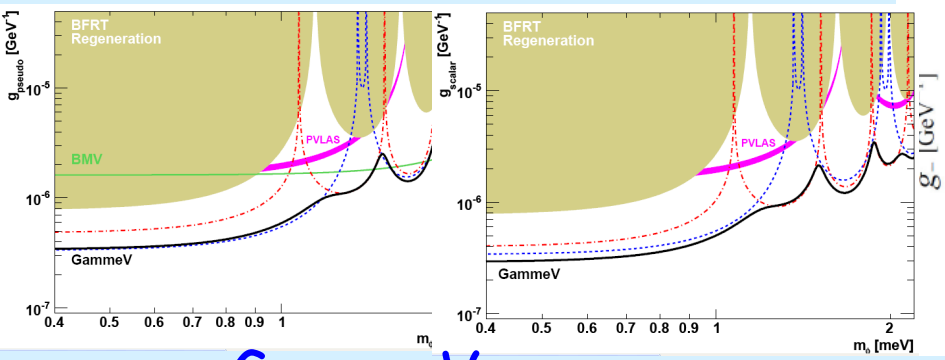
GammeV Apparatus

Gamme**V** was located on a test stand at Fermilab's Maget Test Facility. Two shifts/day of cryogenic operations were supported.



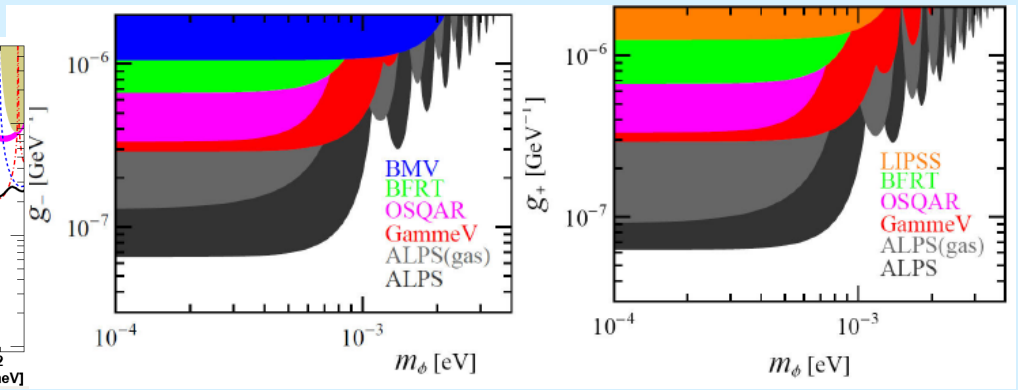


World-wide effort to probe $g_{\alpha\gamma\gamma}$ ~ 10^{-7} GeV^{-1}



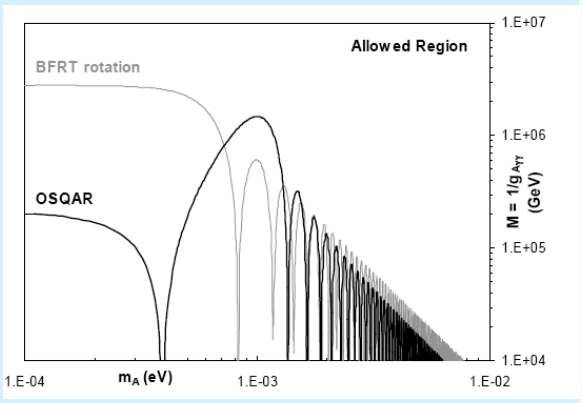
GammeV @FNAL

PRL **100**, 080402 (2008)



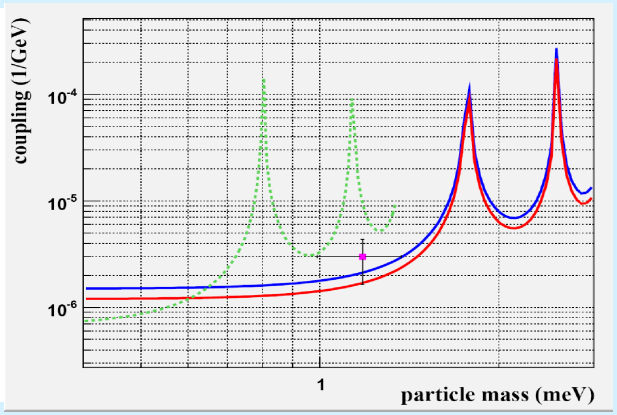
ALPS @DESY

PLB 689, **149** (2010)



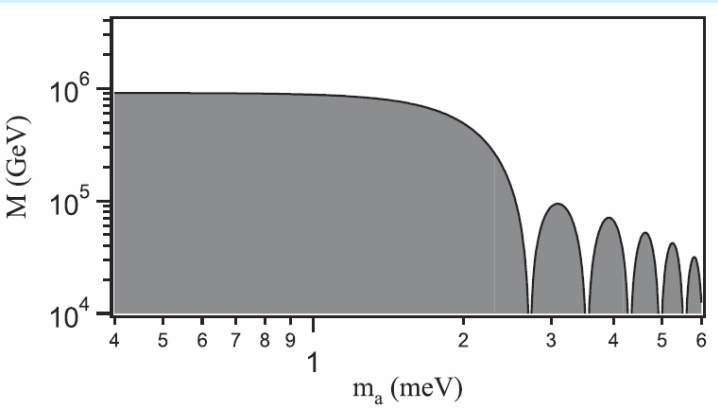
OSQAR @CERN

PRD **78**, 092003 (2008)
Note: with N_2 gas



LIPSS @JLab

scalar only
PRL **101**, 120401(2008)



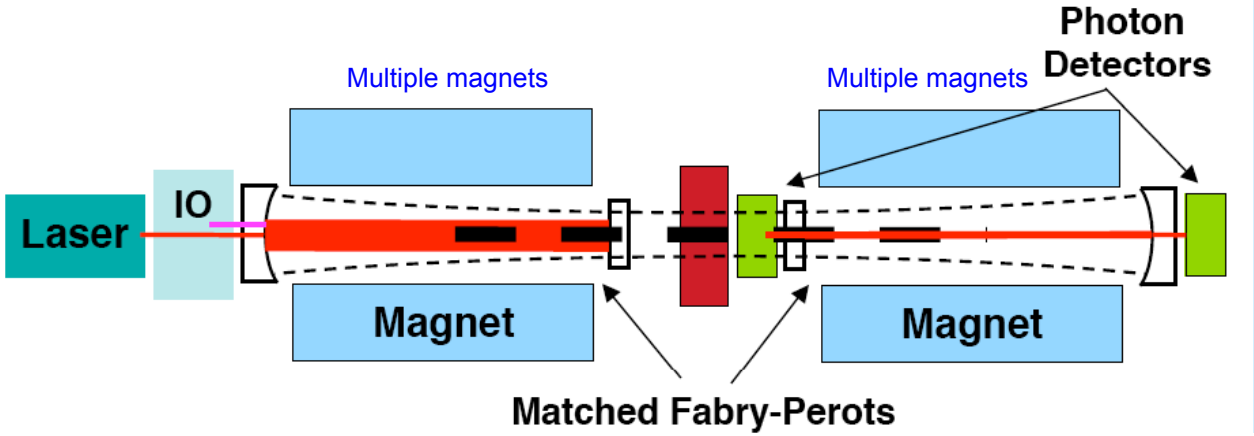
BMV @France

pseudoscalar only
1st results: PRL **99**, 190403 (2007)
Final results: PRD **78**, 032013 (2008)

8/2/13

REAPR: Future LSW

Resonantly enhanced axion-photon regeneration



F. Hoogeveen and T. Ziegenhagen, Nucl. Phys. B **358**, 3 (1991)
Mueller, Sikivie, Tanner, van Bibber, Phys. Rev. D **80**, 072004 (2009)
Phys. Rev. Lett. **98**, 172002 (2007)

Prob(regeneration):

Linearly:

magnetic field length

¼ - root:

0-bkgd int time

finesse factor: $\mathcal{FF}$

$\mathcal{F}$ factor of 10^5

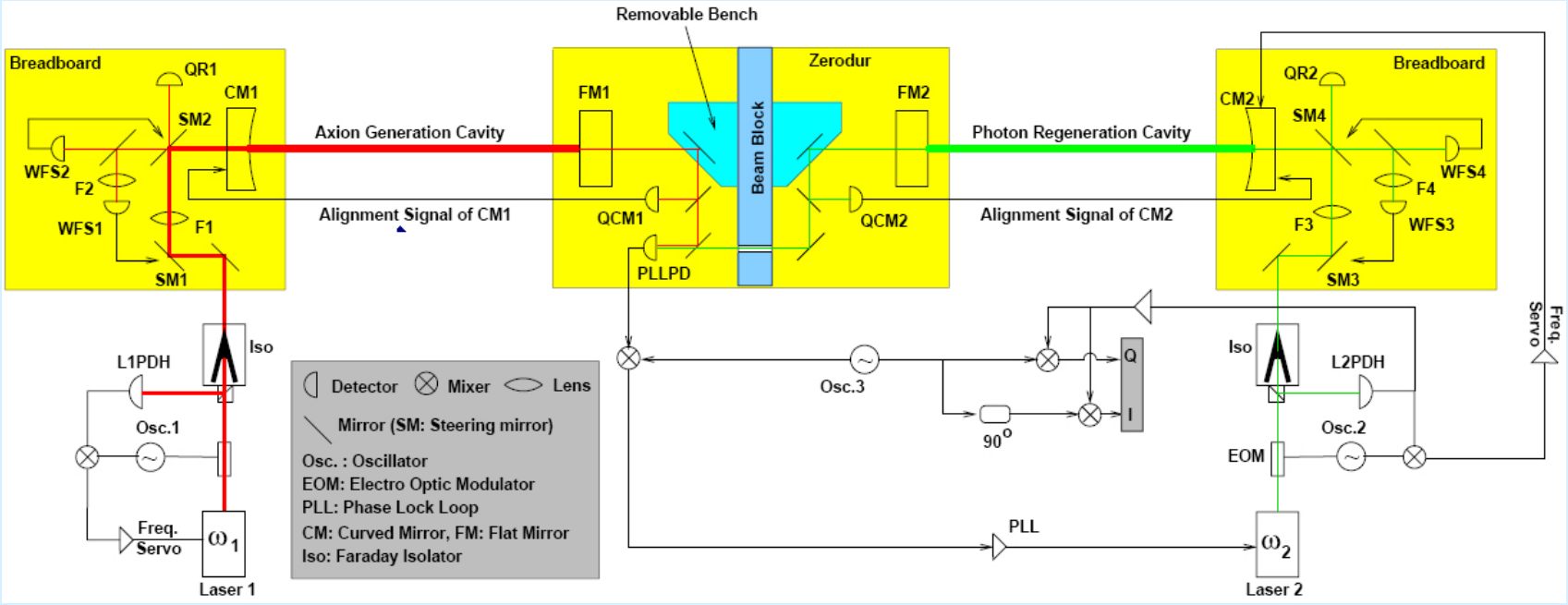
Production cavity:

High finesse amplifies forward moving photons x $\mathcal{F}$

Regeneration cavity:

Resonnant enhancement provides another power of $\mathcal{F}$

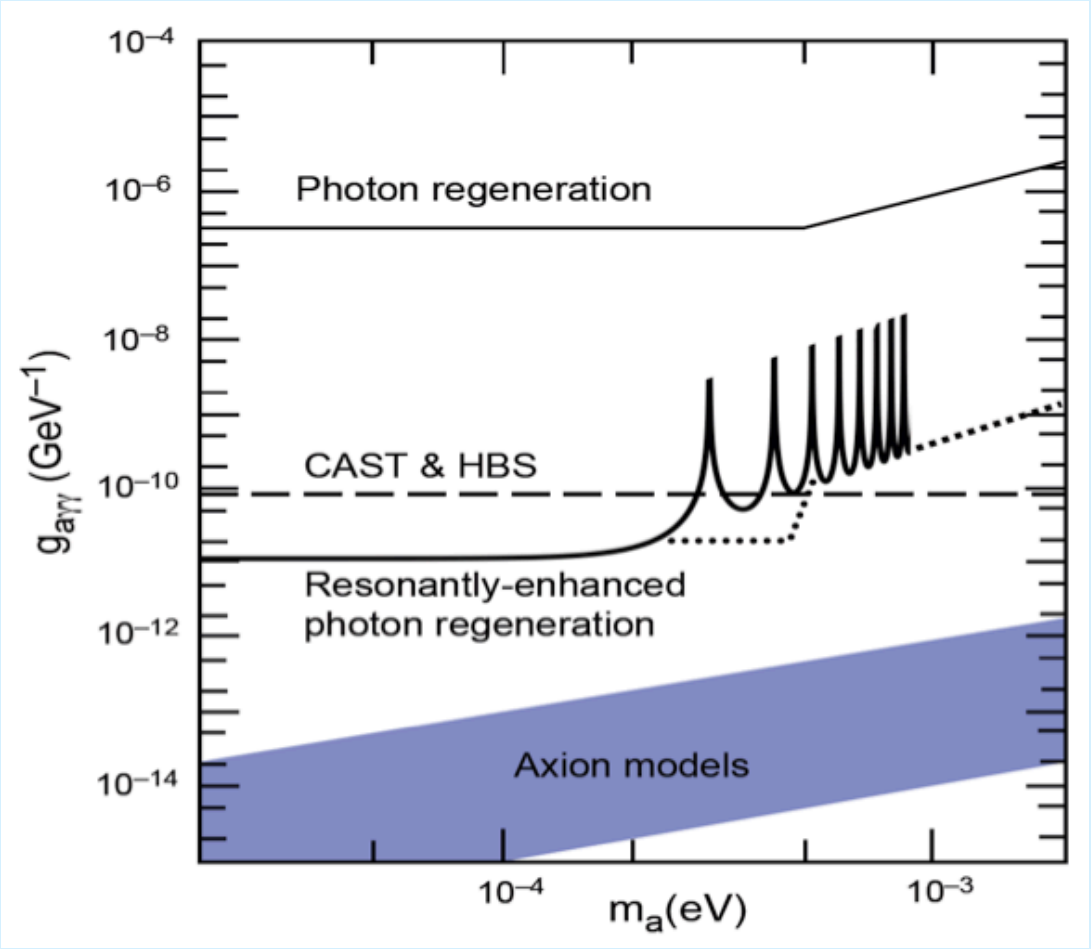
Strawperson optical design



- Use two lasers.
- Laser 1 injects power into generation cavity
- Laser 2 is offset locked to Laser 1
- Offset frequency Ω = integer * FSR of the cavities
- Regeneration cavity is PDH locked to Laser 2
- Laser 2 used to for heterodyne readout of signal in regeneration cavity

G. Mueller (D. Tanner, Univ of FL, DOE Intensity Frontier Workshop)

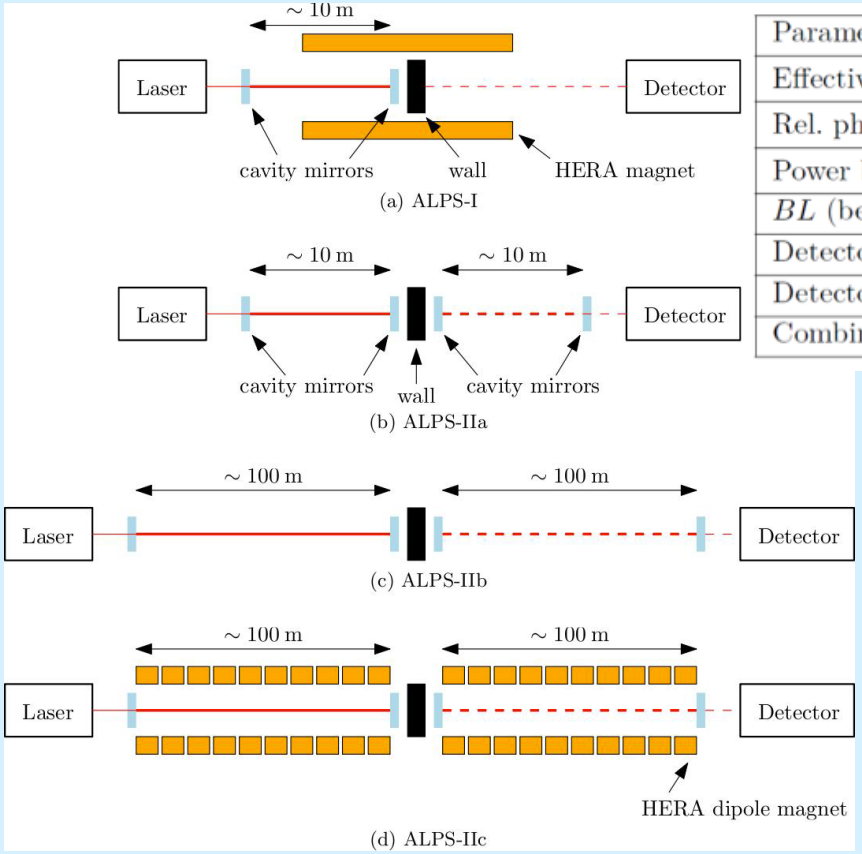
Possible reach



Baseline design with BL=180 Tesla-meters, with F=3 10^5 , P=10W, Integration time T=30 days.

ALPS-II at DESY

Any Light Particle Search (axion-like and low mass hidden γ's)



Parameter	Scaling	ALPS-I	ALPS-IIc	Sens. gain
Effective laser power P_{laser}	$g_{a\gamma} \propto P_{\text{laser}}^{-1/4}$	1 kW	150 kW	3.5
Rel. photon number flux n_γ	$g_{a\gamma} \propto n_\gamma^{-1/4}$	1 (532 nm)	2 (1064 nm)	1.2
Power built up in RC P_{RC}	$g_{a\gamma} \propto P_{reg}^{-1/4}$	1	40,000	14
BL (before& after the wall)	$g_{a\gamma} \propto (BL)^{-1}$	22 Tm	468 Tm	21
Detector efficiency QE	$g_{a\gamma} \propto QE^{-1/4}$	0.9	0.75	0.96
Detector noise DC	$g_{a\gamma} \propto DC^{1/8}$	$0.0018\,\text{s}^{-1}$	$0.000001\,\text{s}^{-1}$	2.6
Combined improvements				3082

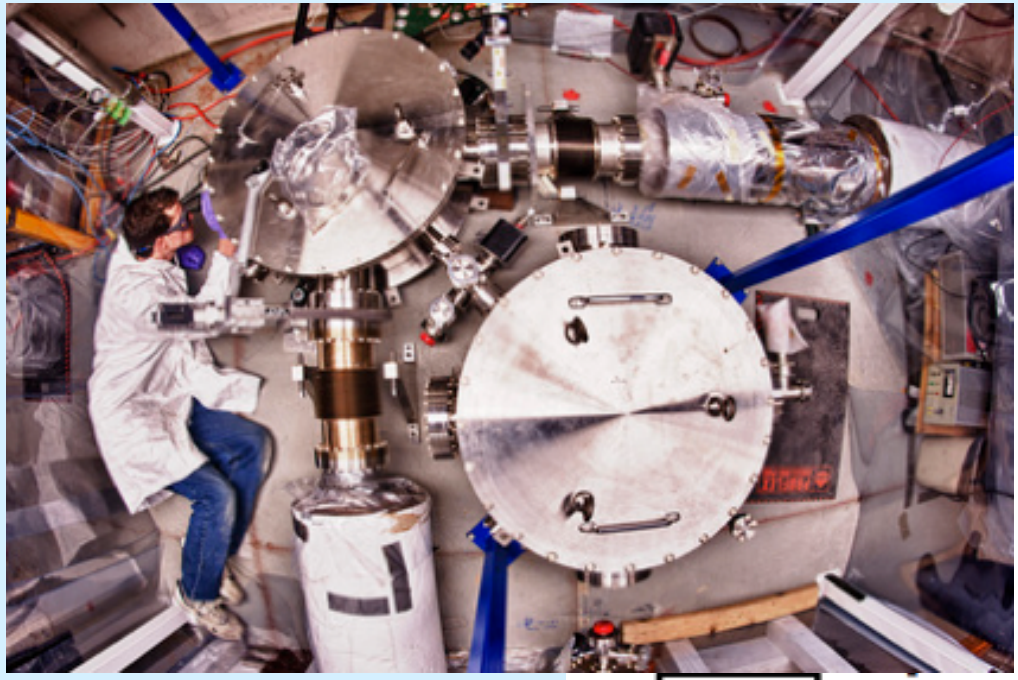
DESY: ALPS-IIa and ALPS-IIb have beenapproved with ALPS-IIc with HERA magnets targeted for 2017.

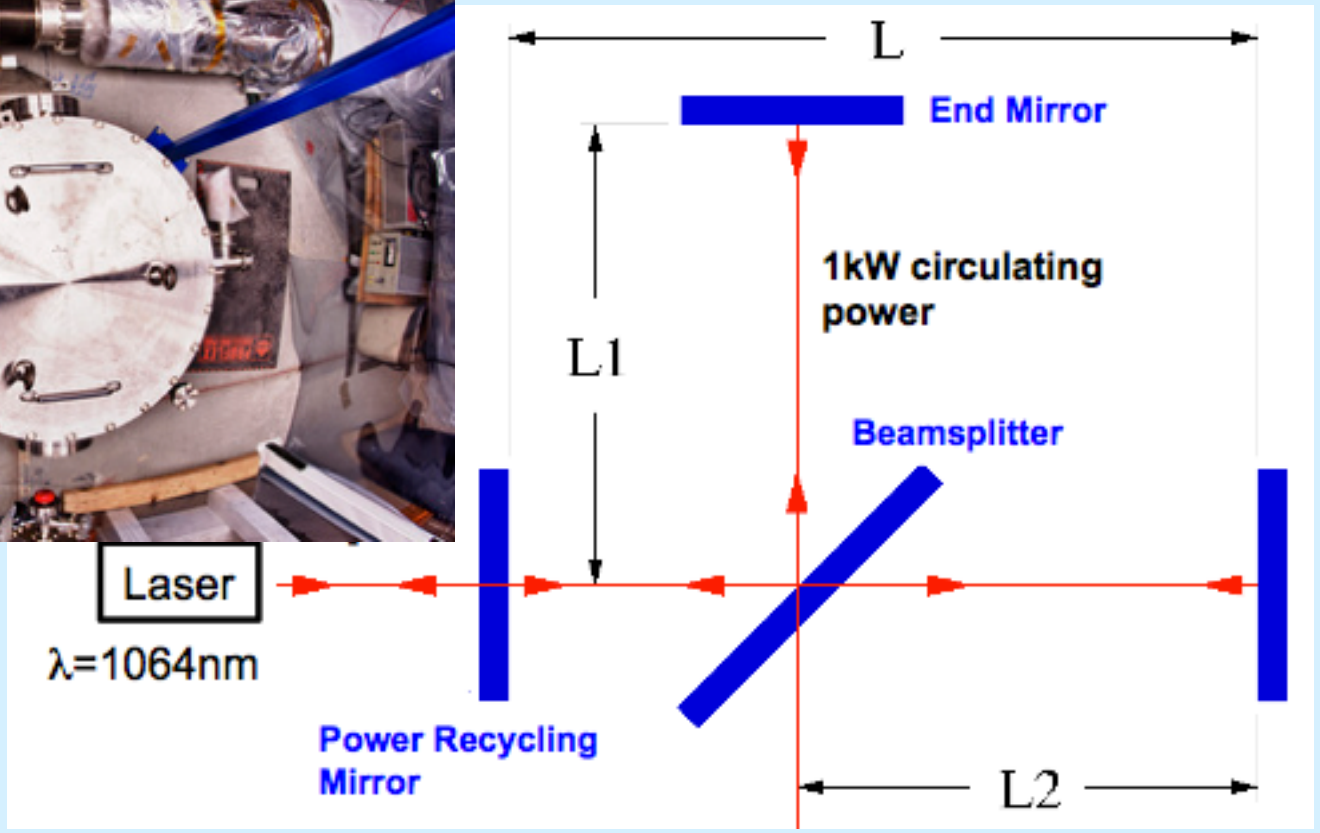
US: R&D proposal for optical bench is in preparation. Long baseline cavity work with the holometer. Discussions to use Tevatron magnets but no specific plans.

CERN: Long standing effort, OSQAR, continues as well.

Holometer at Fermilab

Build two nested 40m interferometers to test for possible holographic noise – a Planck scale jitter in space time





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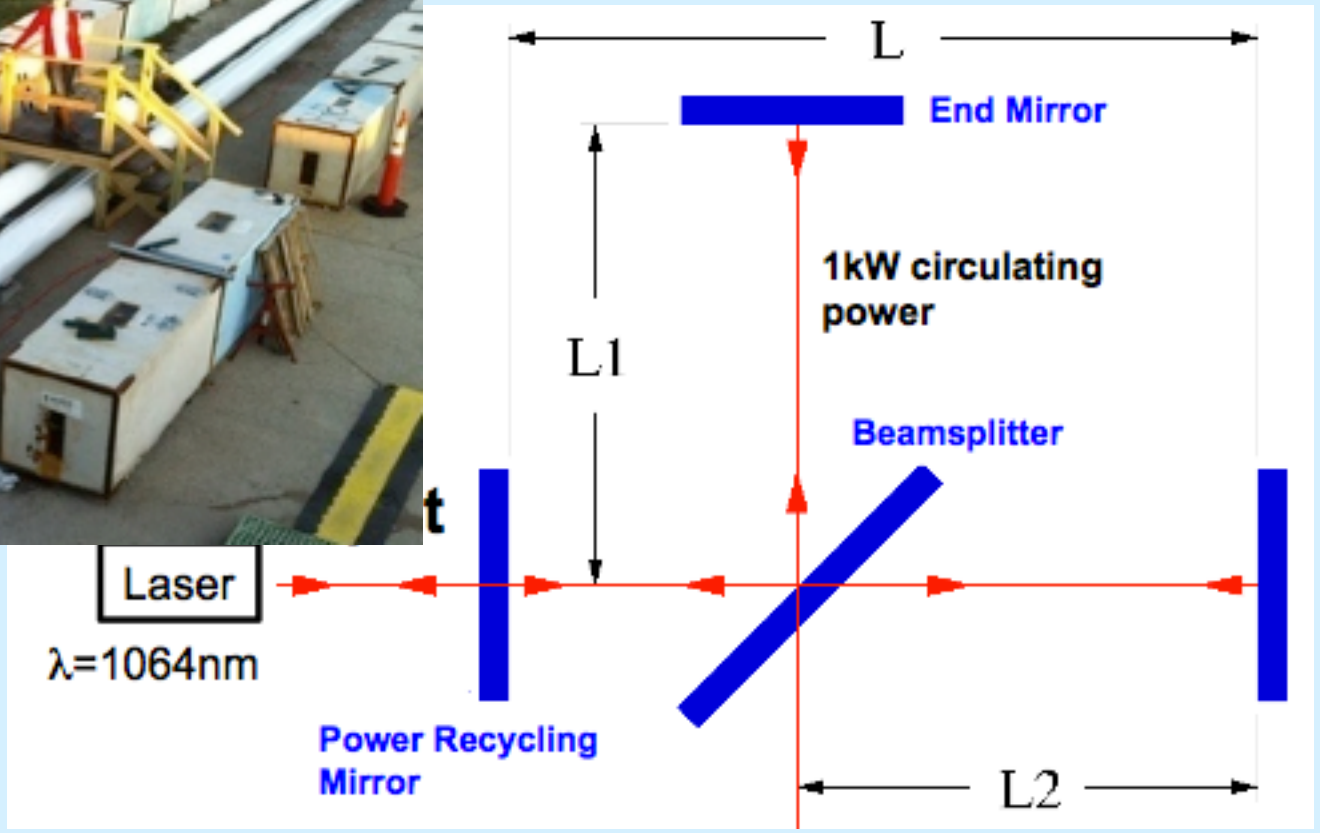

Some additional points

- We will hear about a re-arrangement of the GammeV apparatus to search for chameleons and the axion-like searches described also have sensitivity to low mass hidden photons.
- There have been other cavity based ideas to look for interactions with DM particles or make use of high magnetic field gradients to look for new particles. These ideas have not been realized in practical experiments, but ideas should continue.
- The photon is a particle too! Even a small laser can produce more photons than electron or proton accelerator. Advanced optical detection techniques can be utilized. The photon is a special particle with the potential to connect to hidden U(1)'s or extremely high energy mass scales.