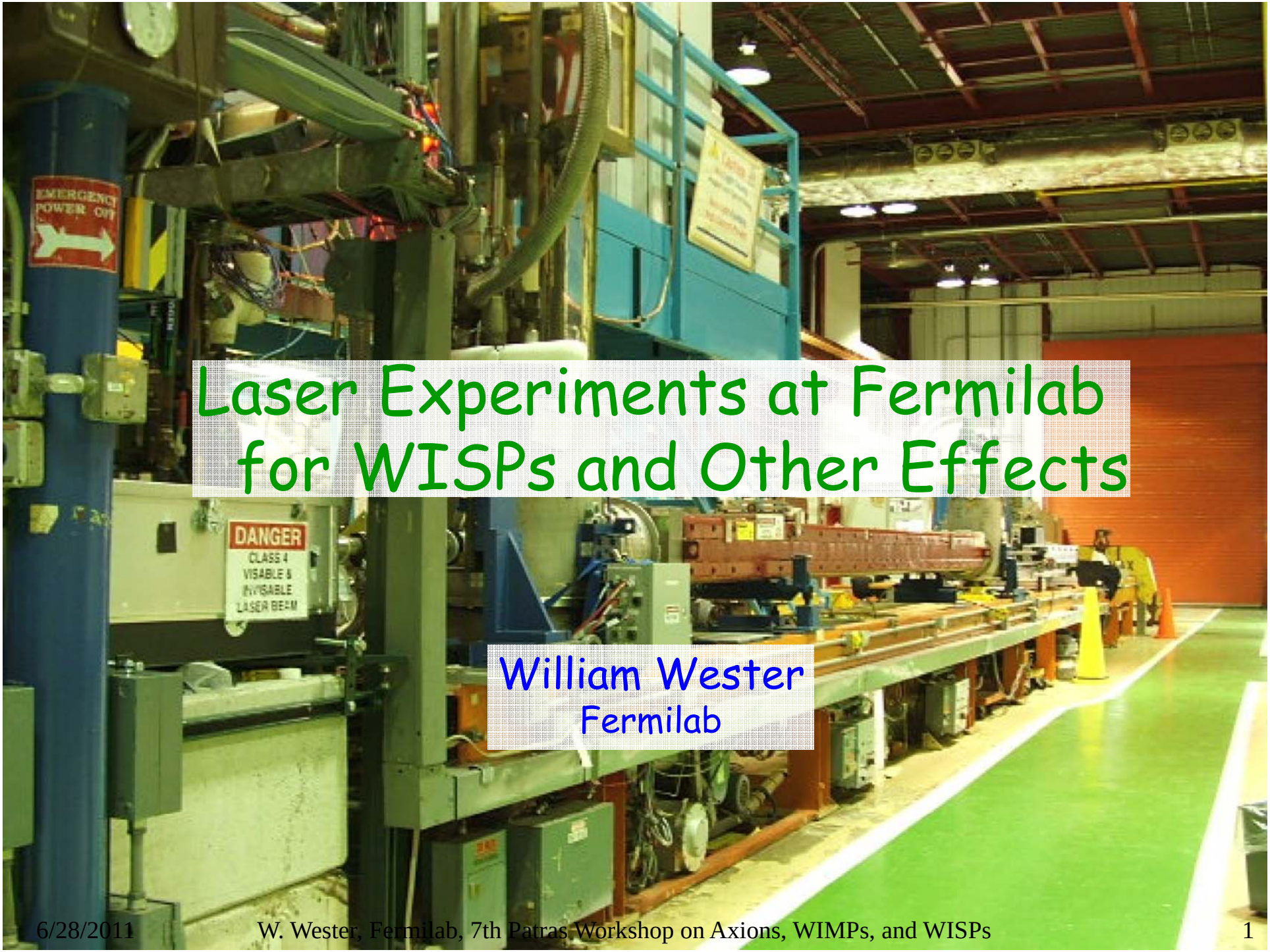


Laser Experiments at Fermilab for WISPs and Other Effects

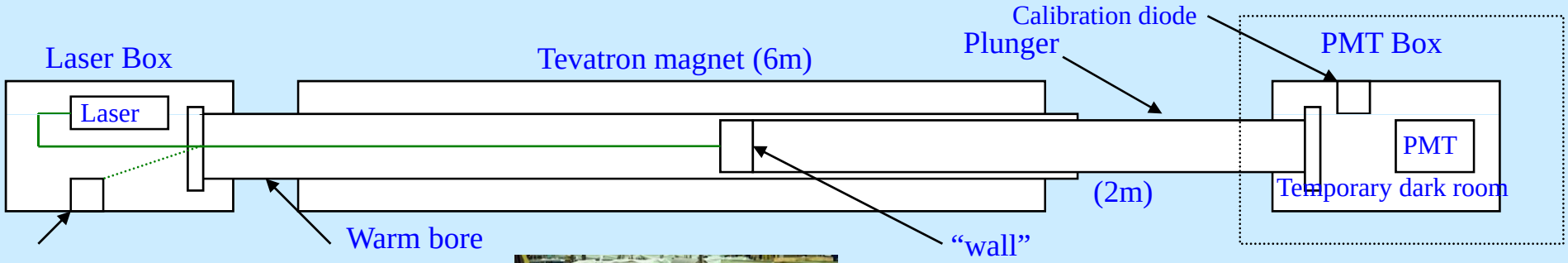
William Wester
Fermilab

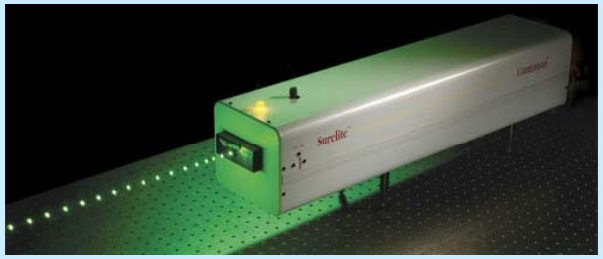
Gamma to milli-eV Search

Light shining through a wall

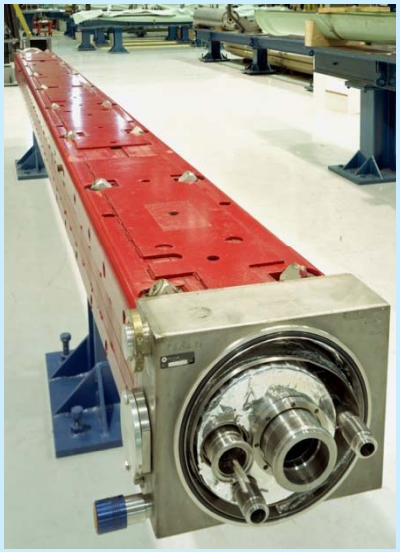
2007 modest effort

Aaron Chou, co-leader, Postdoc on GammeV, now Fermilab Wilson Fellow

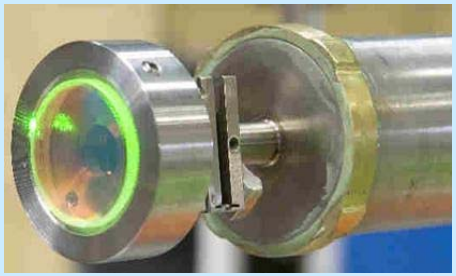




Existing laser in Acc. Div. nearly identical with a similar spare available

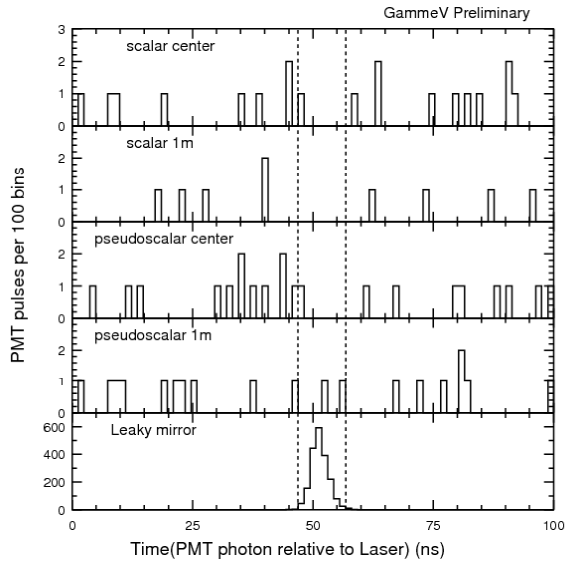


The "wall" is a welded steel cap on a steel tube in addition to a reflective mirror.



High-QE, low noise, fast PMT module (purchased)

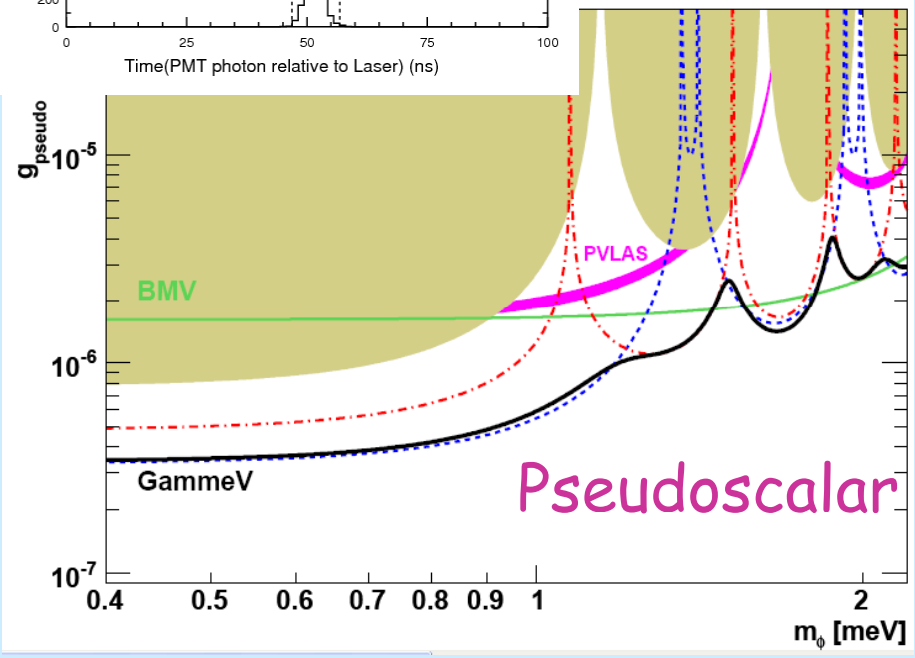
GammeV Limits

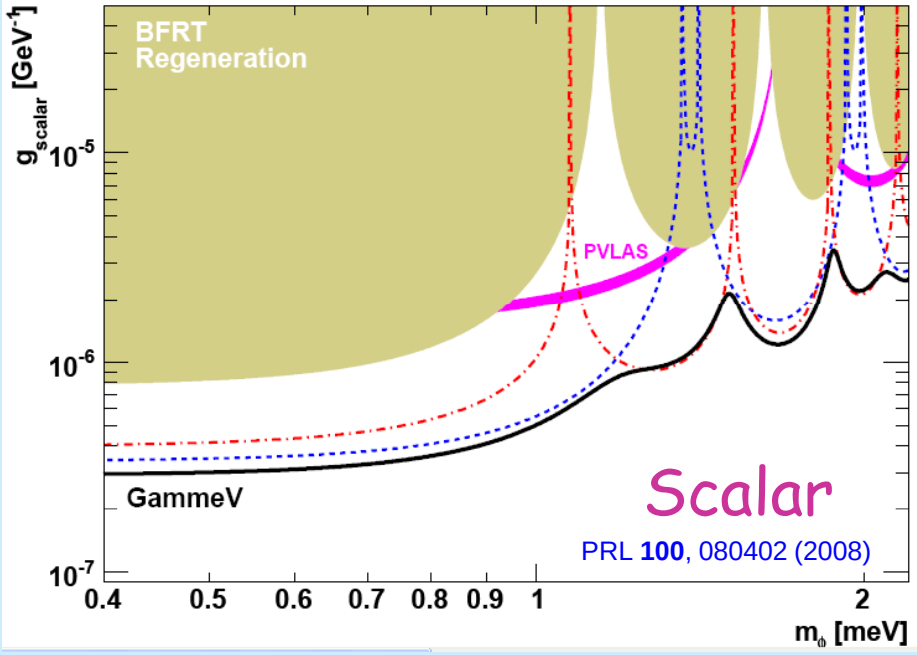


Plunger cleverness allows coverage of entire mass range

Pulsed laser + time correlated single photon counting low bkgd

Focused and we tried to keep things simple – less than a year concept to paper





Chameleons?

- An exotic type of WISP called a chameleon is another possibility and would explain why the sun doesn't burn out in 1000 years.
- A chameleon particle changes it's properties depending on it's environment. In the sun, it might see a strong force and never escape. In vacuum, it might freely propagage.

Chameleons

- An axion-like particle with the property that its properties depend on its environment. In particular, a coupling to the stress energy tensor and a non-trivial potential result in unique properties such as a mass that depends on the ambient matter density: $m_{eff} \sim \rho^{\alpha}$.

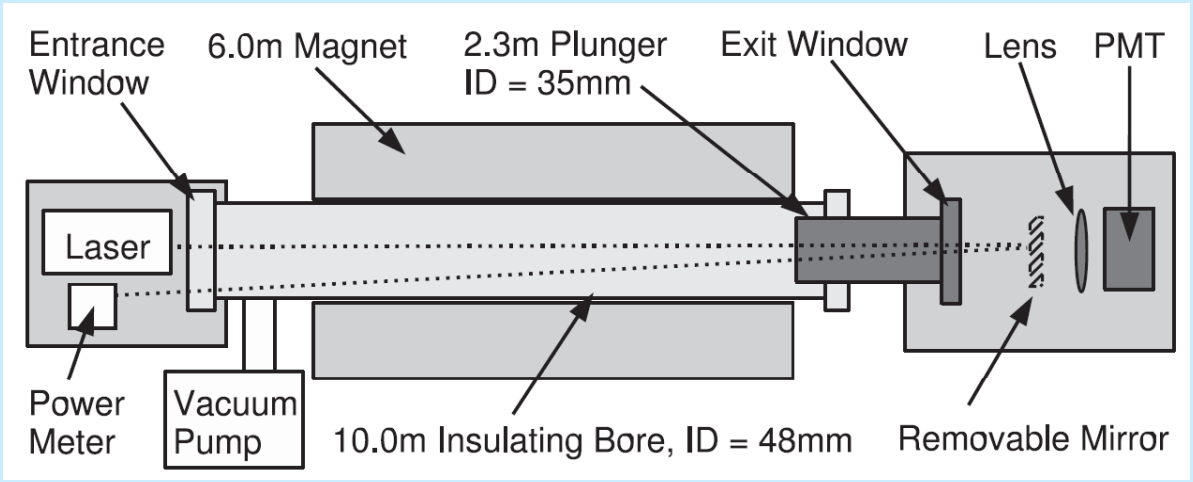
$$\mathcal{L}_{\rm int} = -V(\phi) + \exp\left(\frac{\phi}{M_D}\right) g_{\mu\nu} T^{\mu\nu} - \frac{1}{4}\frac{\phi}{M} F_{\mu\nu} F^{\mu\nu}$$

- Such a field might evade fifth force measurements and could explain how there could be an axion-like particle with a strong photon coupling which evades other bounds.
- The chameleon mechanism (Khoury and Weltman) was originally postulated as a mechanism to account for the cosmic expansion, a possible dark energy particle.

Chameleon Search

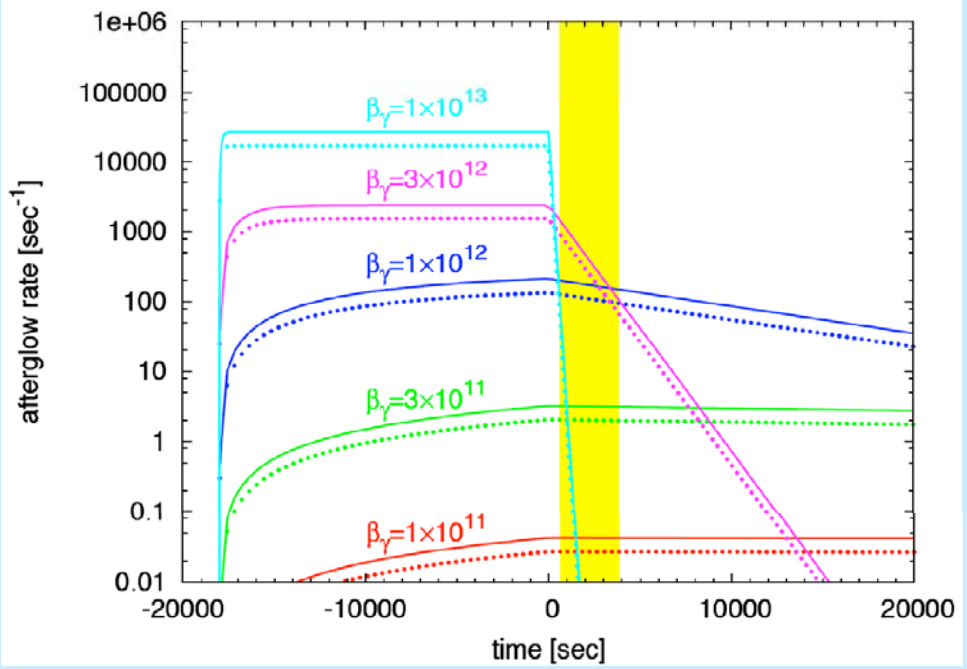
- GammeV Apparatus

  Replace the wall with a straight-through tube with an exit window



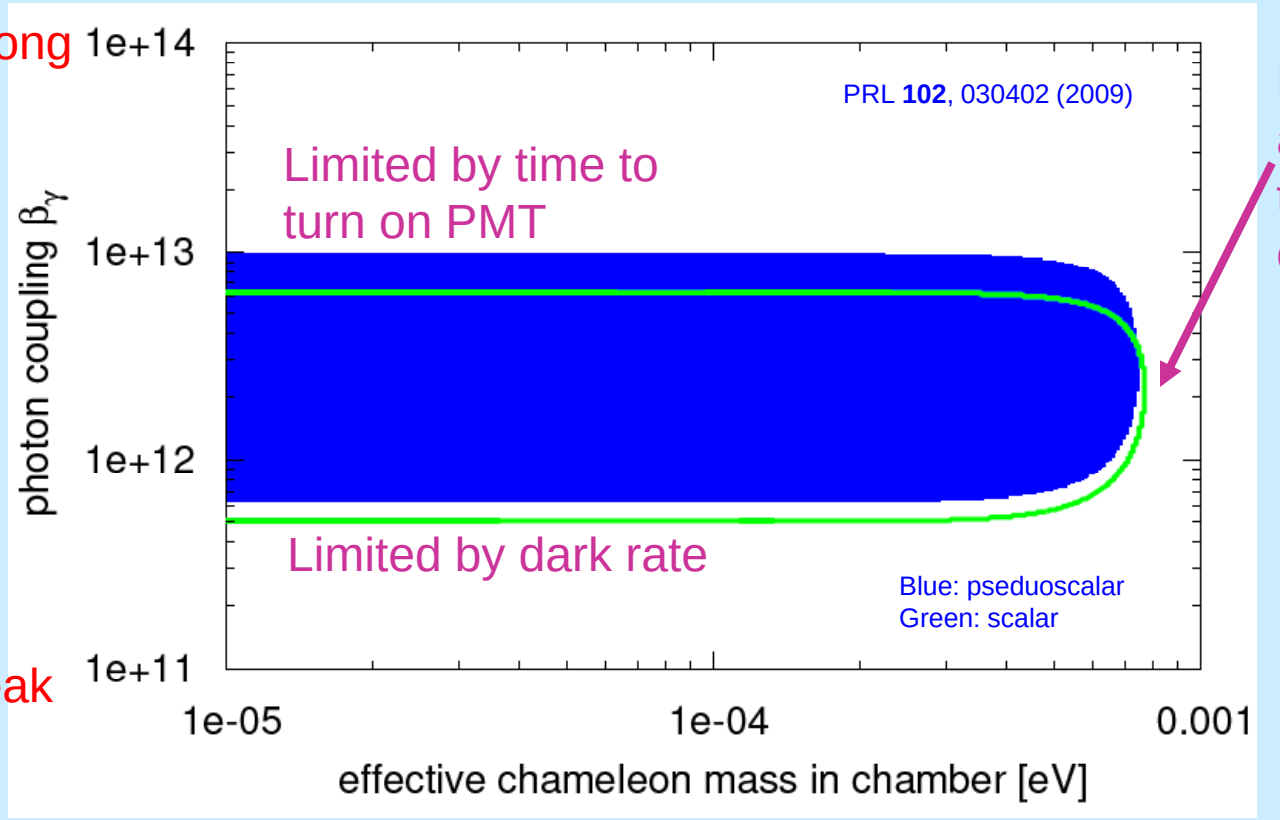
- Procedure

  Turn on pulsed laser for 5hrs using both polarizations. Turn off laser and look for an afterglow above PMT dark rate, either constant or exponentially decaying depending on the photon coupling.



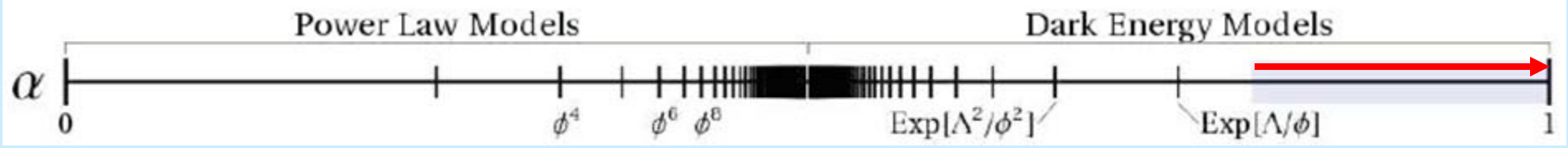
Chameleon Results

- Coupling of photons vs m_{eff} in a region of validity



Reduced sensitivity at higher masses due to experimental configuration

Also, uncertainties in the vacuum levels limit sensitivity of possible potentials, with $m_{eff} \sim \rho^{\alpha}$, > 0.8.



Recent effort (2010)

Jason Steffen
Postdoc on GammeV, now on the job market

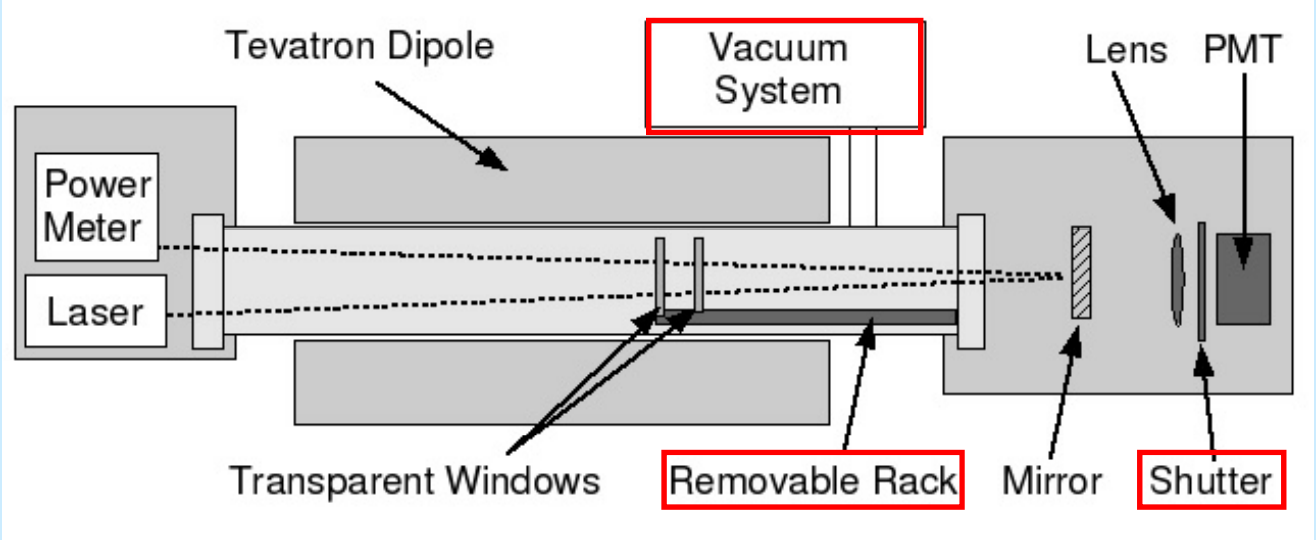
- GammeV – CHASE: Chameleon Afterglow Search

Improve vacuum (cryo pump) and monitoring.

Use a shutter to switch to PMT readout quickly.

Use a run plan that with lower B fields in case the coupling is strong.

Use a lower noise PMT.

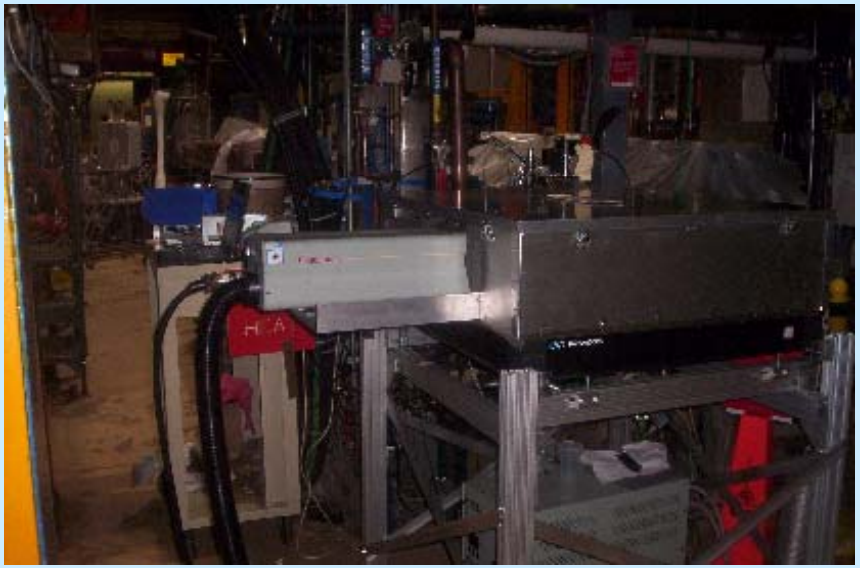


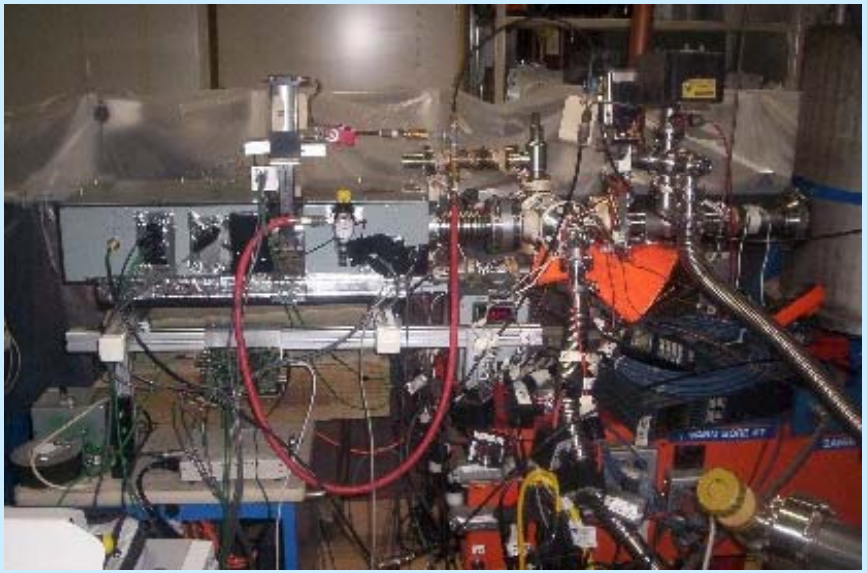
Employ the “dish rack” to effectively have 4.7m, 1m, 30cm magnetic field regions -a bit of cleverness similar to the plunger idea to be initially sensitive to a wider range of chameleon masses.

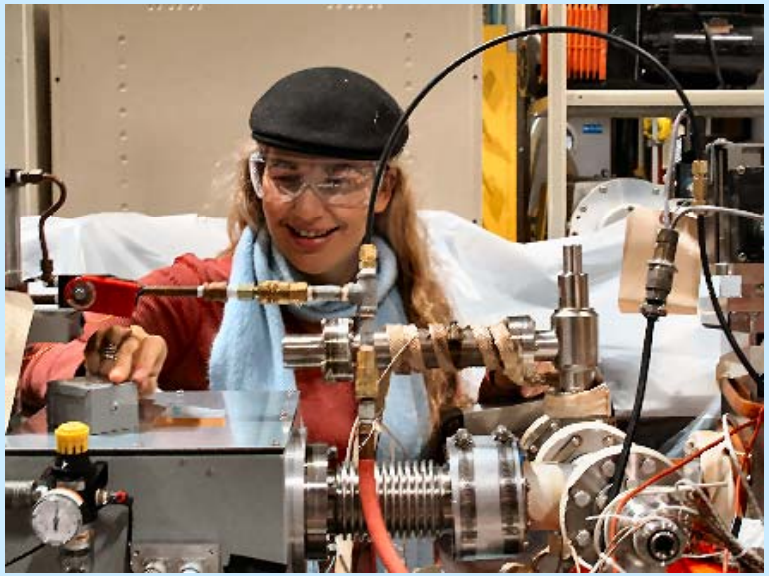
GammeV-CHASE

Amanda Weltman
Univ of Capetown

Amol Upadhye
Argonne National Lab







GammeV-CHASE

Amanda Weltman
Univ of Capetown

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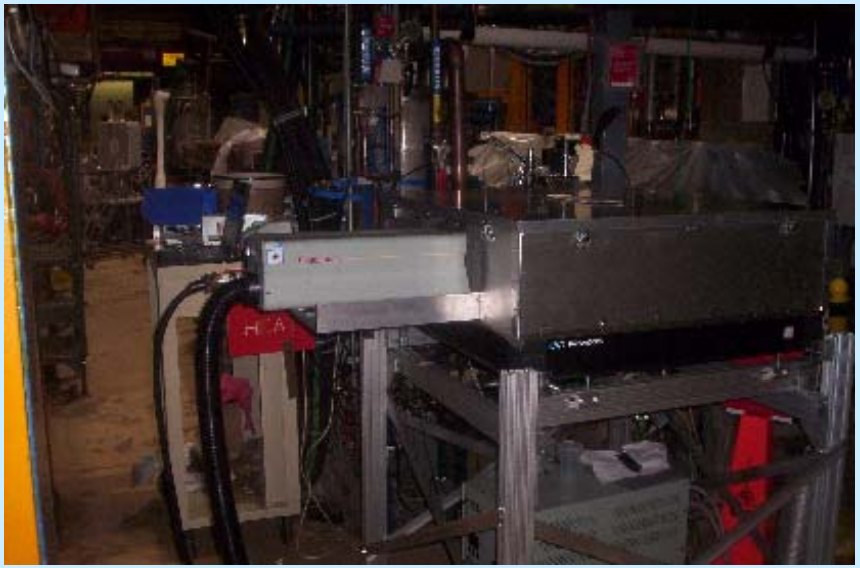
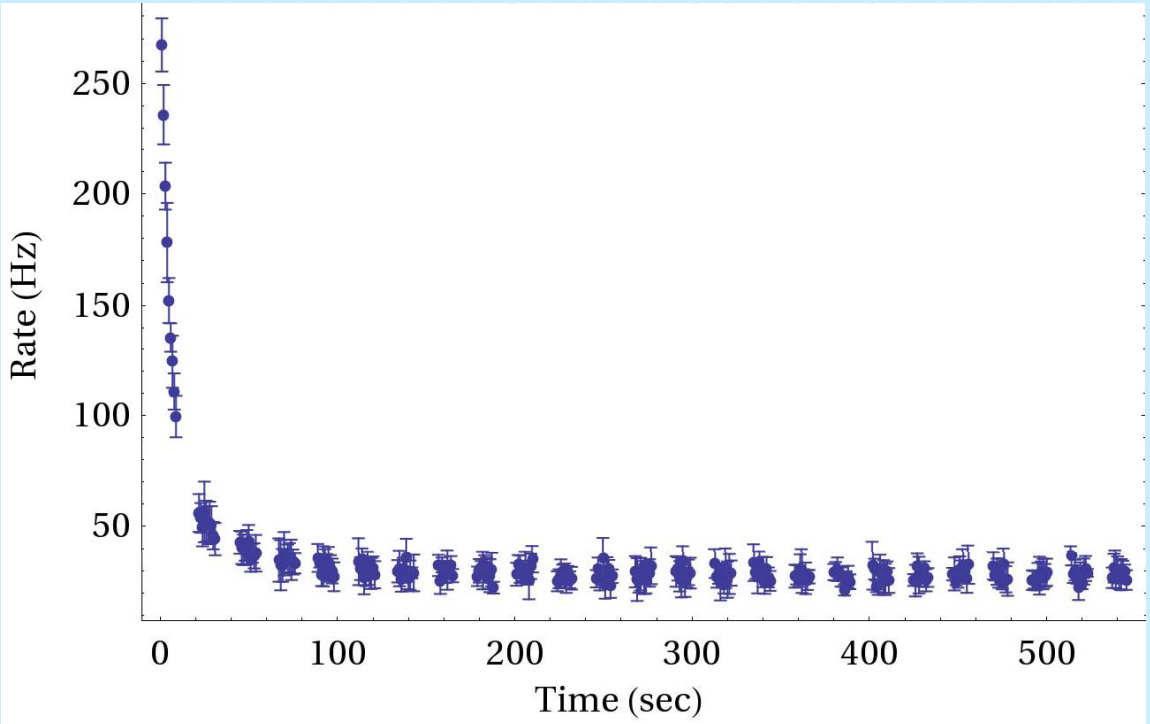
Argonne National Lab

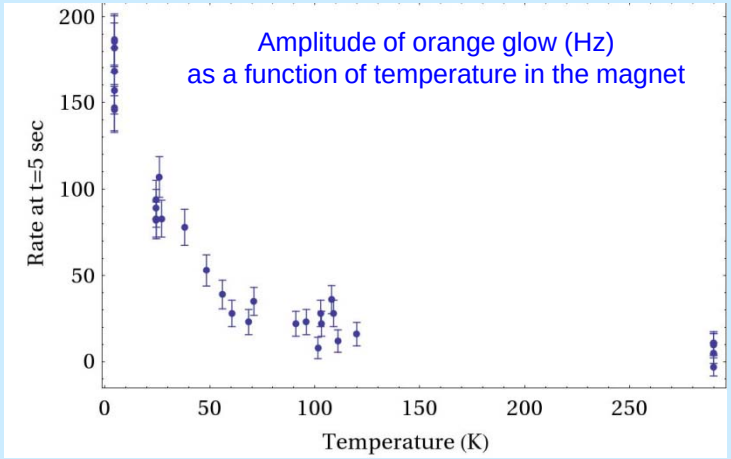


Happy String Theorist
Hard at Work!

Two unexpected systematics

- About 1-2 Hz of photons from the ion pump
- An orange glow … a background (no B field dependence)

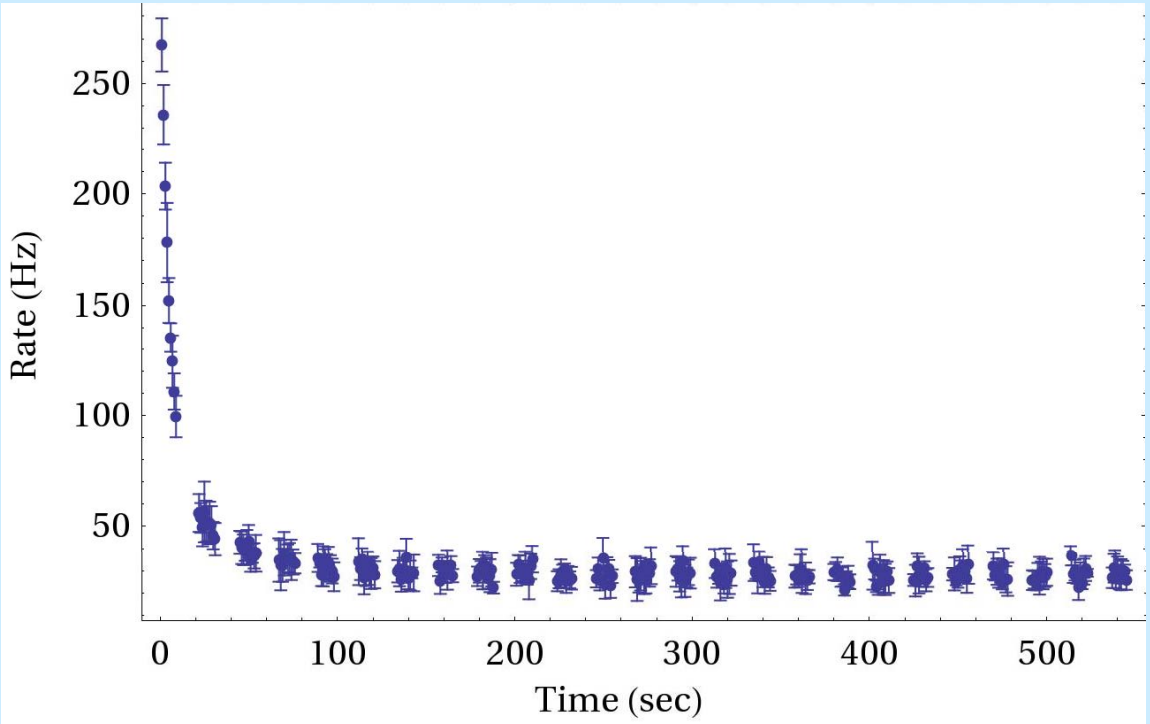


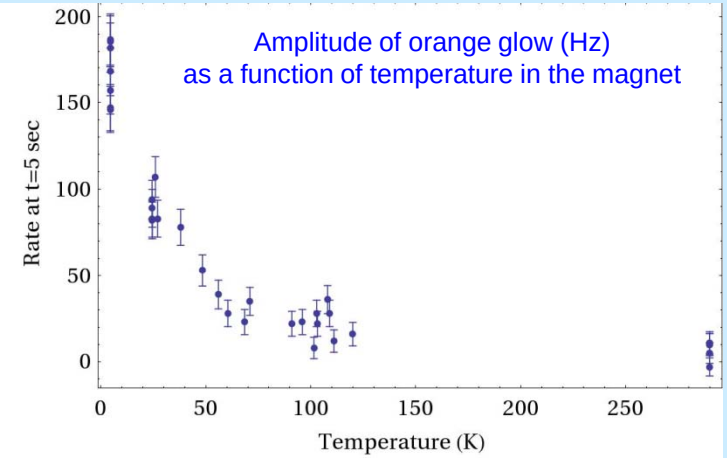


Afterglow rate has a strong temperature dependence

Two unexpected calibration sources!

- About 1-2 Hz of photons from the ion pump
- An orange glow … a background (no B field dependence)



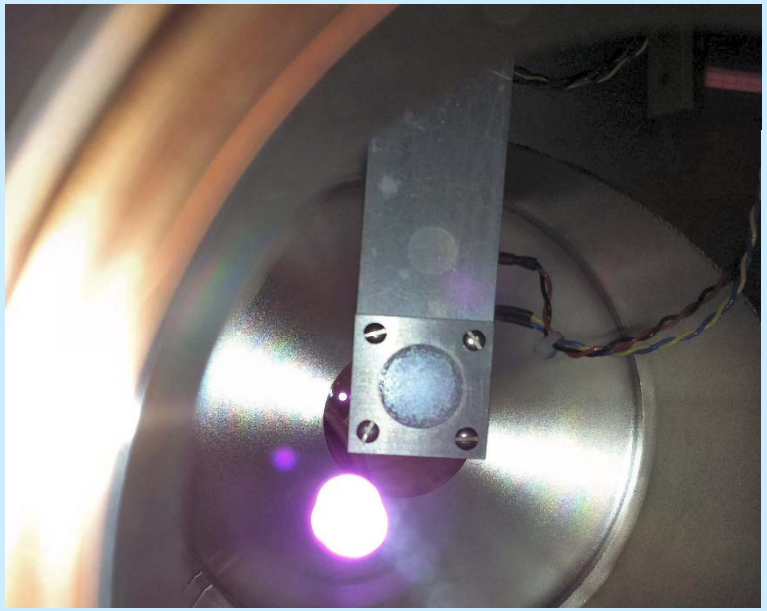


Afterglow rate has a strong temperature dependence

- We can detect photons at a low ~1Hz rate
- We are sensitive to exponential time structures

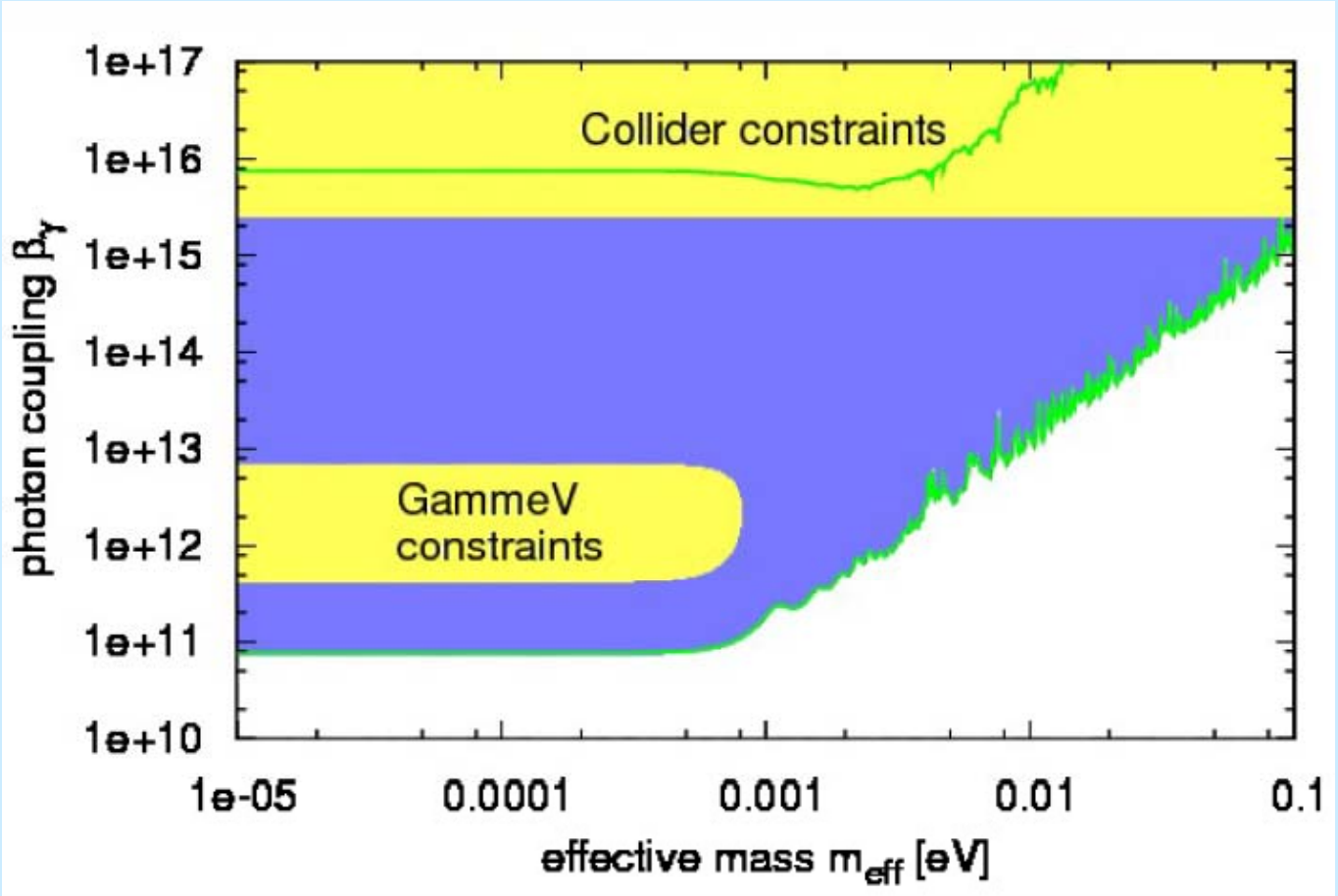
Orange glow

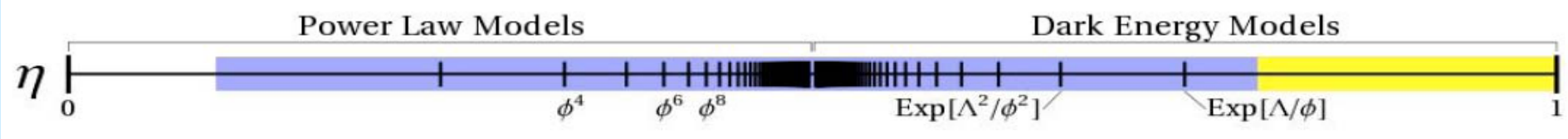
- Most likely known luminescence of vacuum grease
  - We observed green laser into vacuum grease turned orange but did not see the glow when this sample was exposed in our apparatus at room temperature
  - We built a separate apparatus and observed we could "grow" stuff on a cryogenically mounted window.
  - We discovered a paper describing the main features of our observation: ~10s decay time, orange, intensity temp. dependent to cryogenic temps



- D. W. Cooke and B. L. Bennett, "Long-lived luminescence from commonly used Apiezon compunds," J. of Luminescence **65**, 283 (1996)
- Important (and appreciated) that these things get reported!

GammeV CHASE Recent Results



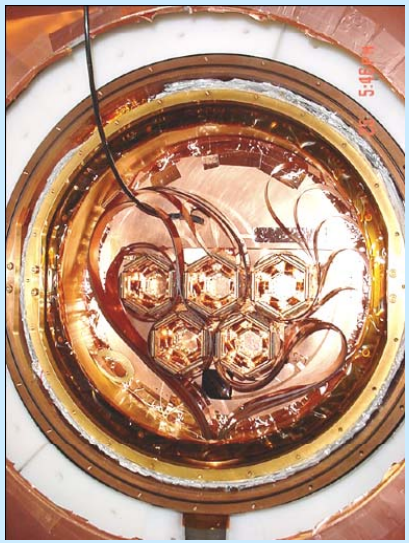


Expectations: A. Upadhye, J. Steffen, A. Weltman, Phys. Rev. D **81**, 015013 (2010) Results: Phys.Rev.Lett.**105**:261803,2010

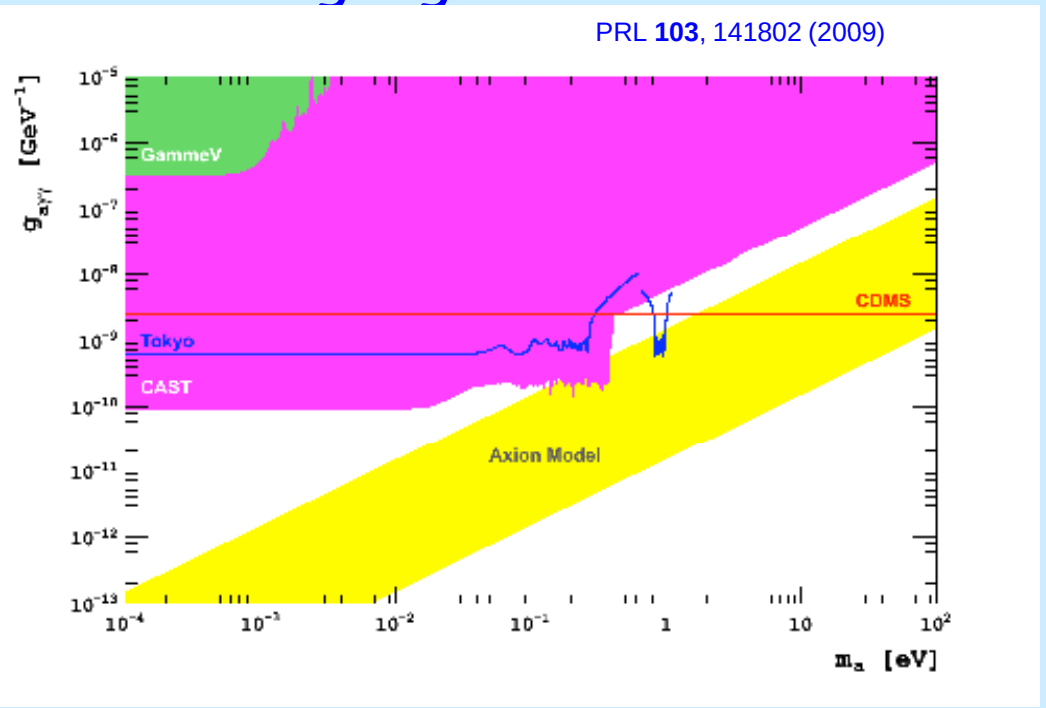
Bragg scattering

Jonghee Yoo
Postdoc on GammeV, now
Fermilab Wilson Fellow

- Use CDMS crystals with known alignment towards the sun. Search for coherent scattering signal of ALPs.



PRL **103**, 141802 (2009)



- Future improvements are difficult. Even a factor of 4500 increase in sensitivity (larger detector, integrate longer, track the sun) might improve the limit by a small factor of a few (many things scale as the 1/8th power).

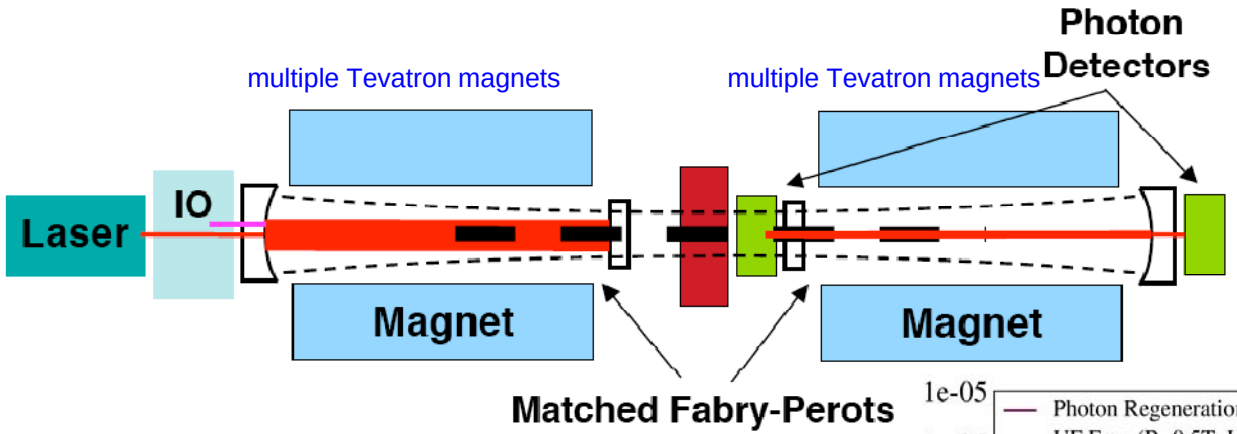
Solid Xenon R&D

- Solid Xenon reported to have ~1.5x more scintillation light than Liquid Xenon – to be re-measured. Also, faster electron drift expected. Overall better energy resolution for phonons.
- 2010: Solid Xenon produced. Not frozen Xenon ice.
- 2011: In progress, automated growth facility and check of scintillation light.
- Applications to coherent neutrino scattering and/or 00νβ decay.

Solid Xenon R&D utilizes Fermilab infrastructure also employed for Liquid Argon DM detector R&D.

Enhanced LSW

Resonantly enhanced axion-photon regeneration

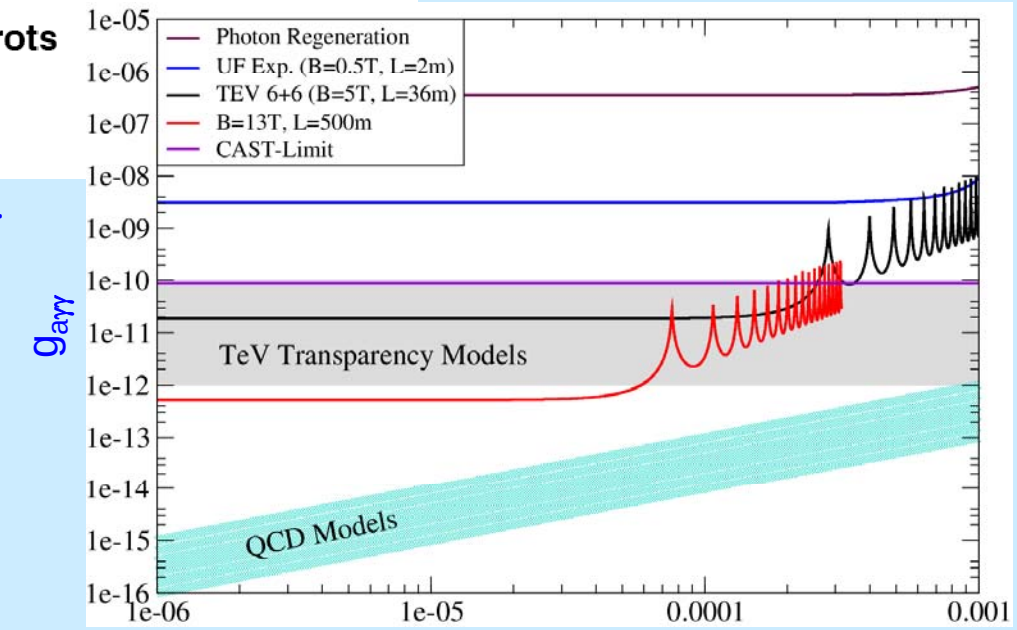


F. Hoogeveen and T. Ziegenhagen, Nucl. Phys. B **358**, 3 (1991)
Mueller, Sikivie, Tanner, van Bibber, Phys. Rev. D **80**, 072004 (2009)
Phys. Rev. Lett. **98**, 172002 (2007)

Probability of regeneration goes as the product of finesse's: $\mathcal{F}\mathcal{F}$

Possibility that this technique might exceed star / CAST limits.

Hints that a coupling of 10^{-11} might be interesting from observations of unexpected high energy gamma rays that somehow propagate despite background IR photons.



GRIM REPR

"This time we mow the axion down for good"

R&D Plans

- Fermilab – develop the requirements and expected performance of long cavities and determine the scope of using a long string of Tevatron magnets
  - 40m long cavity and specially coated mirrors
  - Tevatron to end by Oct 2011 … we're on the list, "don't throw the magnets away."
- Univ of Florida – develop cavity locking scheme
  - Initial designs and concepts are being studied.
    - See talk by G. Mueller at Axion 2010
  - Possible proposal (including graduate student) to develop the locking scheme and required control system and to perform a table top experiment using Fermilab supplied permanent magnets (0.5T).

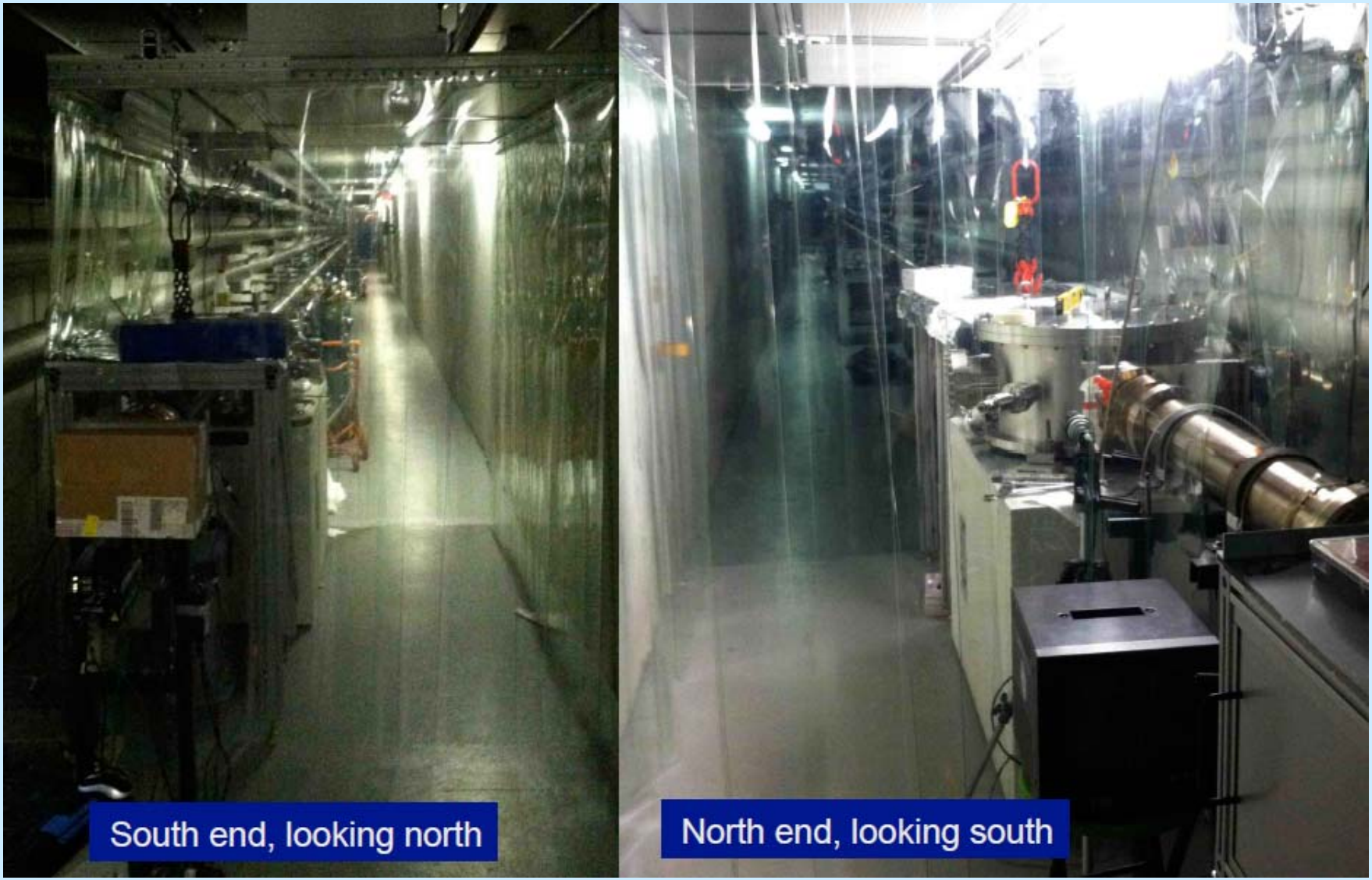
Tevatron Magnets

- Besides those in the Tevatron, there are existing spares

40m optical cavity

- Generic detector R&D for long-baseline high finesse cavities for future axion efforts and for the holometer
- Fermilab has vacant beamlines – empty tunnels
- Procured a 40m long vacuum system and utilized a world class vacuum group to re-clean and install the system
  - Very stringent requirements on residual hydrocarbons
- Procured lasers, optics, and other infrastructure to carry out the tests.
  - Alignment procedures
  - Measurement of finesse relative to mirror characteristics
    - Try to achieve > x1000 at first. Ultimately, we need ~10^5!
  - Measurements of the laser noise spectrum
  - Tests of locking schemes, environmental conditions such as vibrations and ground motions

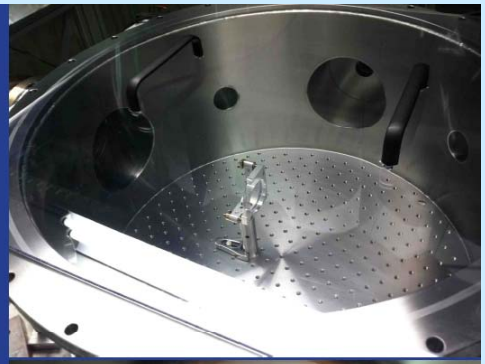
40 m cavity installed

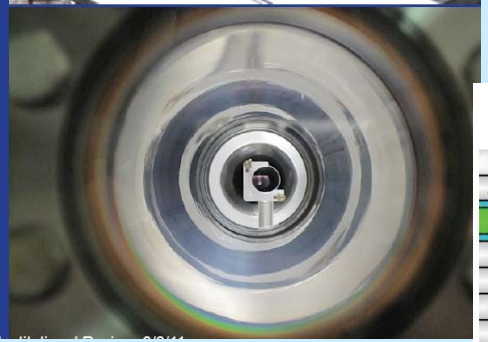


40 m cavity in lock

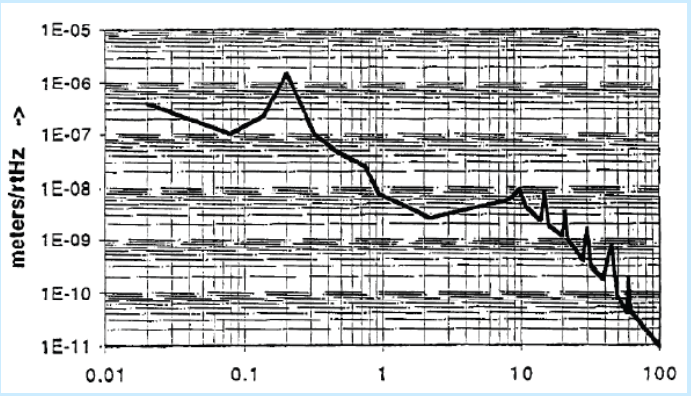
End station vacuum vessels hold custom optical cavity mirrors and eventually beamsplitters

U.Chicago graduate students
R.Lanza, L.McCuller





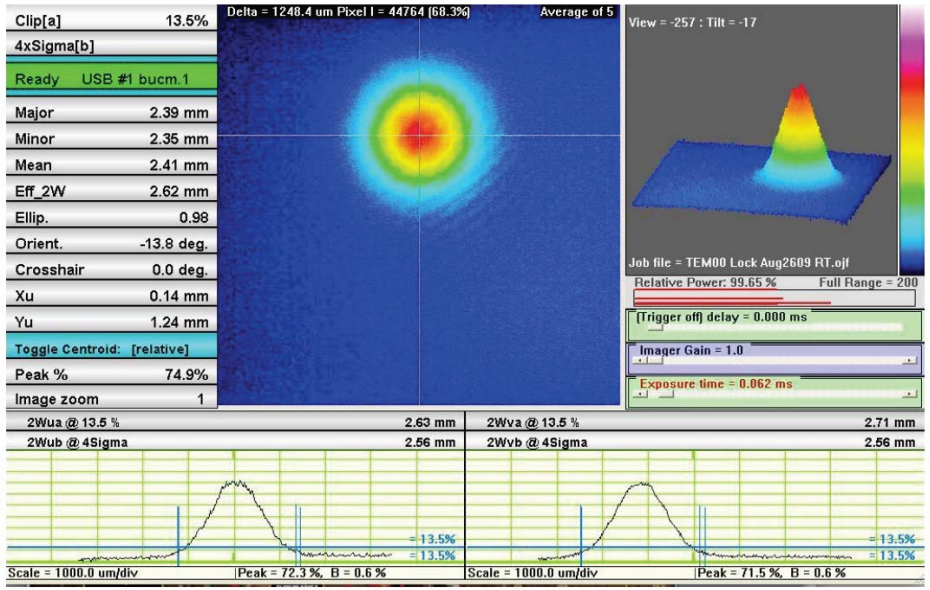
Seismic Noise



Spot on input mirror

Spot on end mirror

TEM00 cavity mode



And now for something completely different …

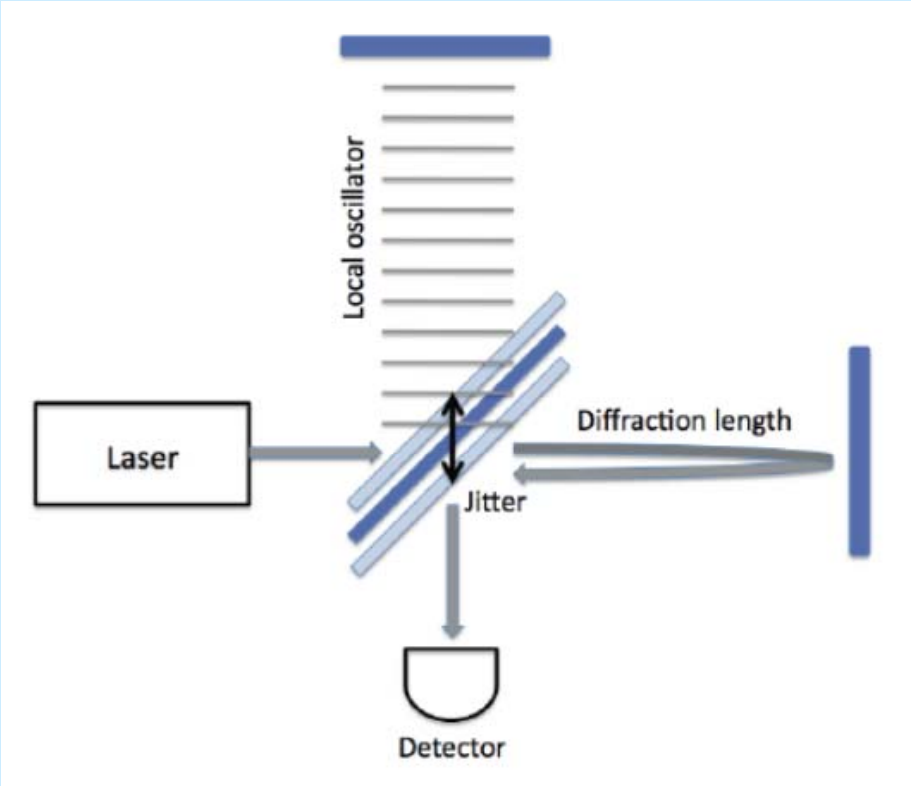
A holographic world is blurred by diffraction

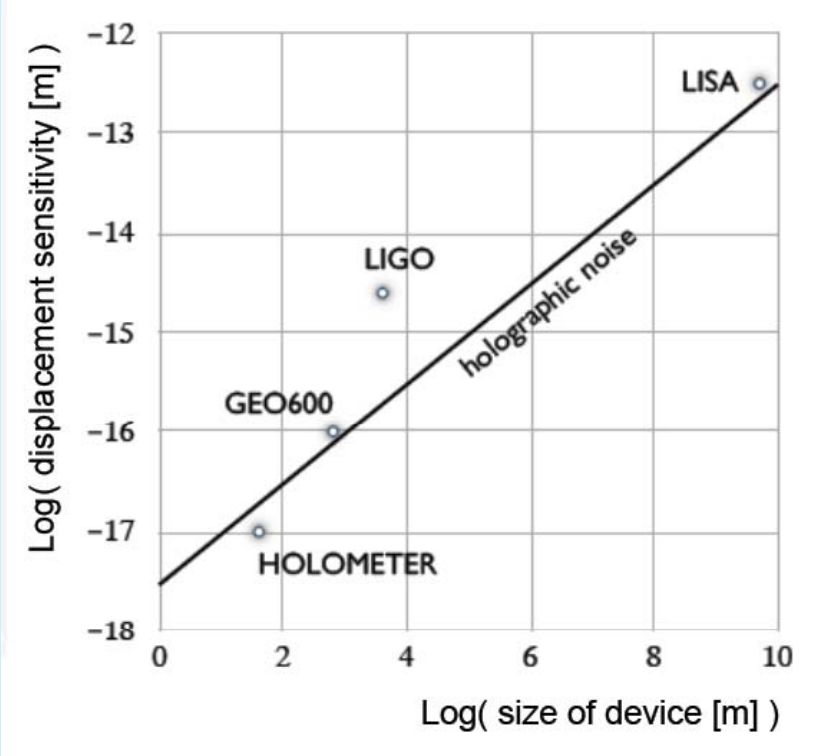
Can we detect this blurriness in our apparently 3-dim world?

C. Hogan

Holographic Noise

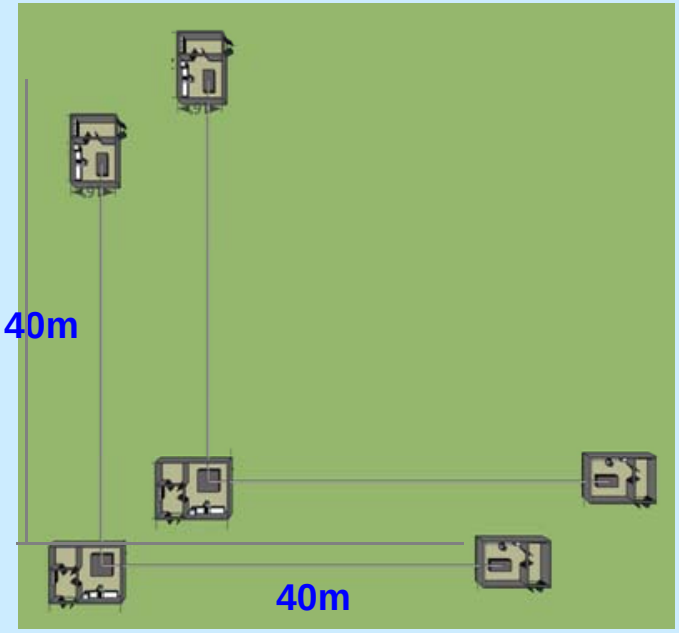
- The R&D for a high finesse long optical cavity applies to an experiment using a theoretical idea from Craig Hogan
  - Holographic noise: a new jitter of space time due to Planck scale effects -> shear not strain





A Quantum Holometer

- A proposed experiment is to build two interferometers with ~40m arms to search for the correlated holographic noise and to observe its predictable decorrelation when the geometry of the interferometer is re-arranged.



$$l_P = \sqrt{\hbar G_N / c^3} = 1.616 \times 10^{-33}\text{cm}$$

$$\Delta x_\perp^2 > l_P L$$

C. Hogan, "Holographic Noise in Interferometers"
http://arxiv.org/abs/0905.4803
C. Hogan, "Interferometers as Holographic Clocks"
http://arxiv.org/abs/1002.4480

- A collaboration includes the Univ of Chicago and LIGO experts at MIT. Now DOE fully funded!

Holometer next steps

- Last winter, foundational pads installed for the 1st arm at right angles to the current 40m cavity
- 2 Lasers are in house, fancy optics (mirrors and beam splitters) are on order
- 2nd vacuum system has vendor competition for cleanliness
- Work on feedback control software using 40m cavity
- Work on real time data acquisition system and correlate to photodiodes looking for rf frequency sources

Conclusions

- Fermilab has published results on axion-like particles and chameleons. New results on chameleons are now also published in the past year.
- Next experiments are much more ambitious and we are starting to get experience with optical cavities and interferometers.
- New ideas are frequent and might lead to experiments not yet thought of such as holographic noise.
- **G**amme**V** has trained two postdocs (now Wilson fellows) and the third postdoc, Jason Steffen, lead the **G**amme**V**-CHASE experiment. In addition, we worked with two young theorists who now have permanent jobs!

gammev.fnal.gov holometer.fnal.gov