Summary Report
Dark Matter, Dark Photons, Axions
WG Report 2: Axions

Andrei Afanasev
George Washington University, Washington, D.C.

Intense Electron Beams Workshop (June 16-19, 2015)

5 talks presented on axions and axion-like particle searches:

- Gianpaolo Carosi (Livermore) Hunting the Dark Matter Axion with the ADMX
- Derek Kimball (Cal State) CASPEr: the Cosmic Axion Spin Precession Experiment
- Keith Baker (Yale) The dark sector at low and at high energies
- William Wester (Fermilab) Laser Searches for New Particles at Fermilab
- Andrei Afanasev (GWU) Axion Searches Overview

Hunting the Dark Matter Axion with the ADMX experiment

Intense Electron Beam Workshop - Cornell

June 18th, 2015

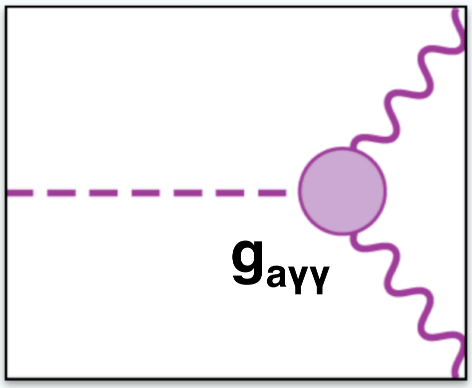
Gianpaolo Carosi

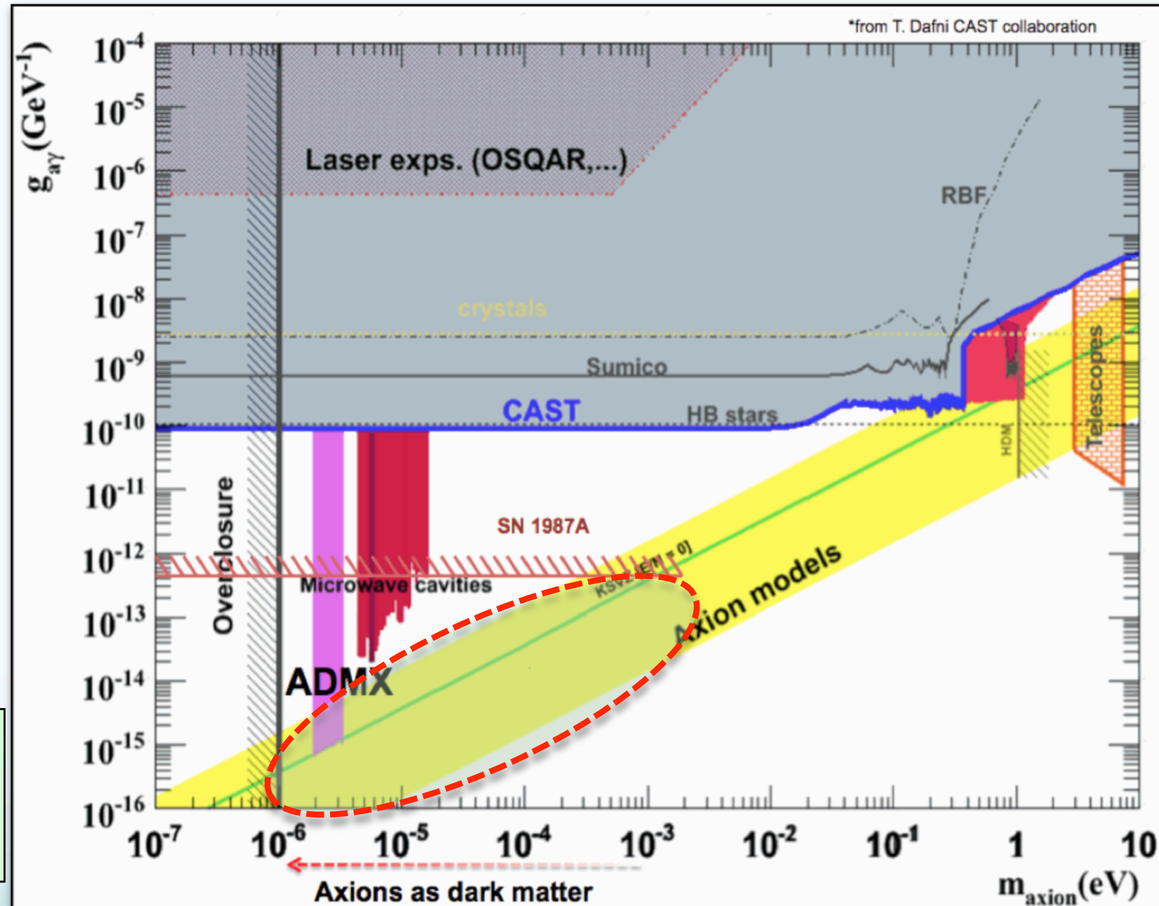
Lawrence Livermore National Laboratory

LLNL-PRES-668218
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

The axion.

- It's a pseudoscalar (π°-like), extremely light and weakly coupled
- 2γ coupling (Primakoff effect) : Key to possible detection



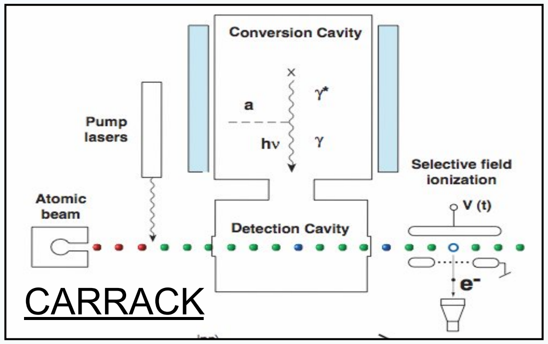


The axion remains a very attractive dark-matter candidate (affirmed by HEPAP, DMSAG, etc)

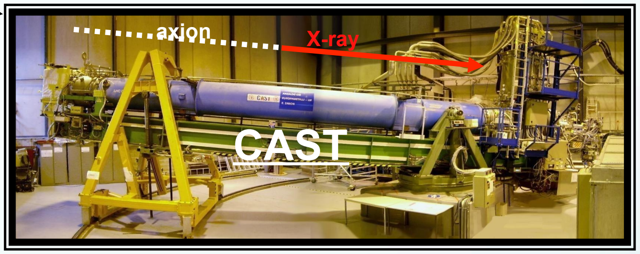
The ADMX axion search is "definitive" and relatively inexpensive

Variety of experiments*…

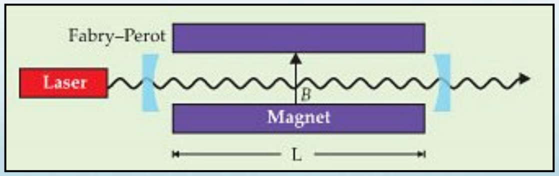
- **Microwave Cavities**
  - Low noise amplifiers (**ADMX**) and Rubidium Atoms (**CARRACK**)
    - Look for dark matter axions (low mass) converting to photons in B-Field
    - **Will focus today on ADMX project.**

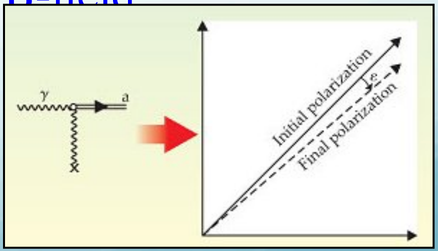


- Solar Observatories
  - X-Ray (**CAST**) and Germanium detectors
    - Look for axions generated from the sun
    - Higher coupling required than for DM axions.



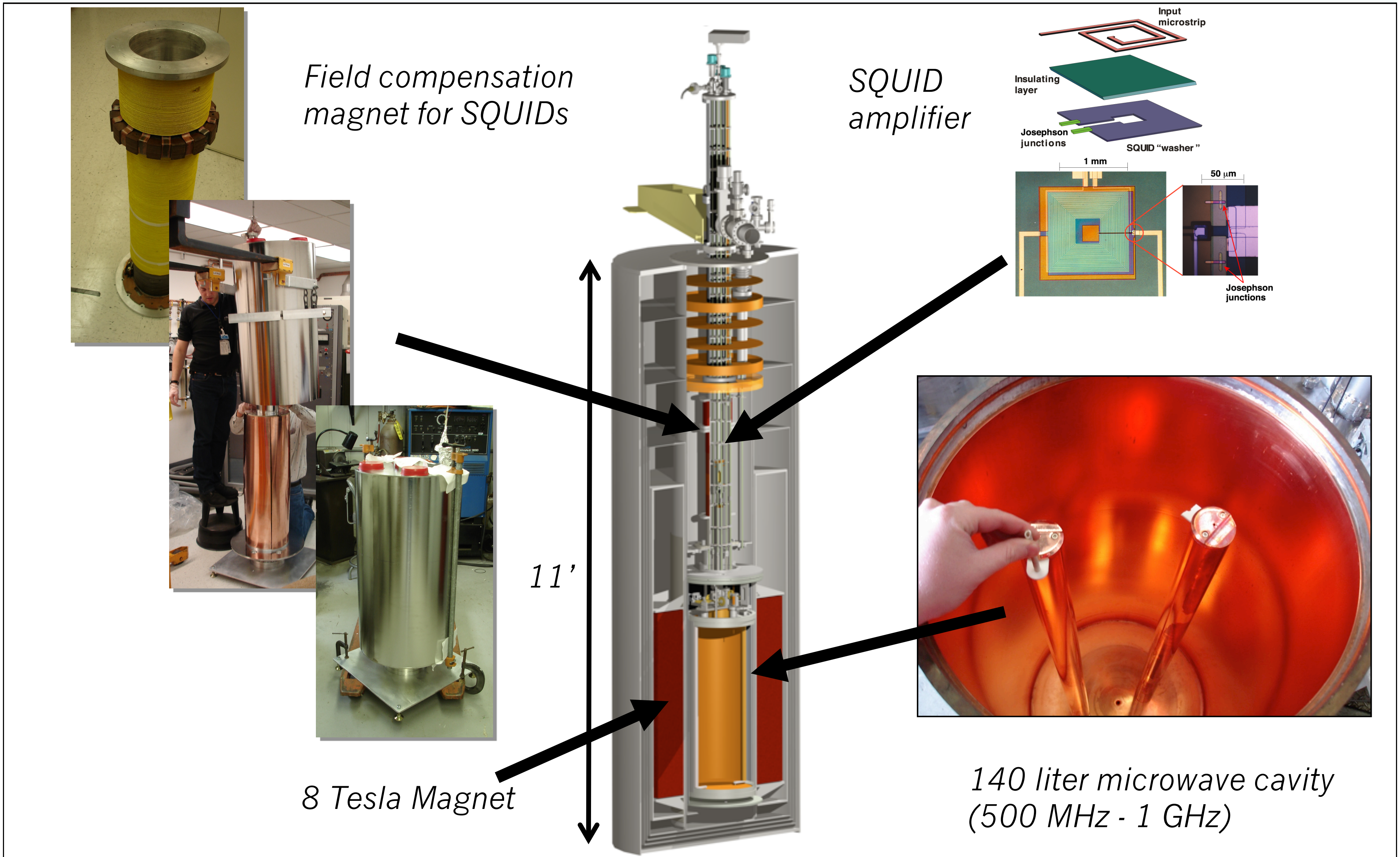
- Lab experiments
  - Photon regeneration and polarization changes (**PVLAS**)
    - Look for production of axions from light passing through B-field
    - Higher coupling required.
    - Ultralight axions (nano-eV) (NMR / LC Circuit)

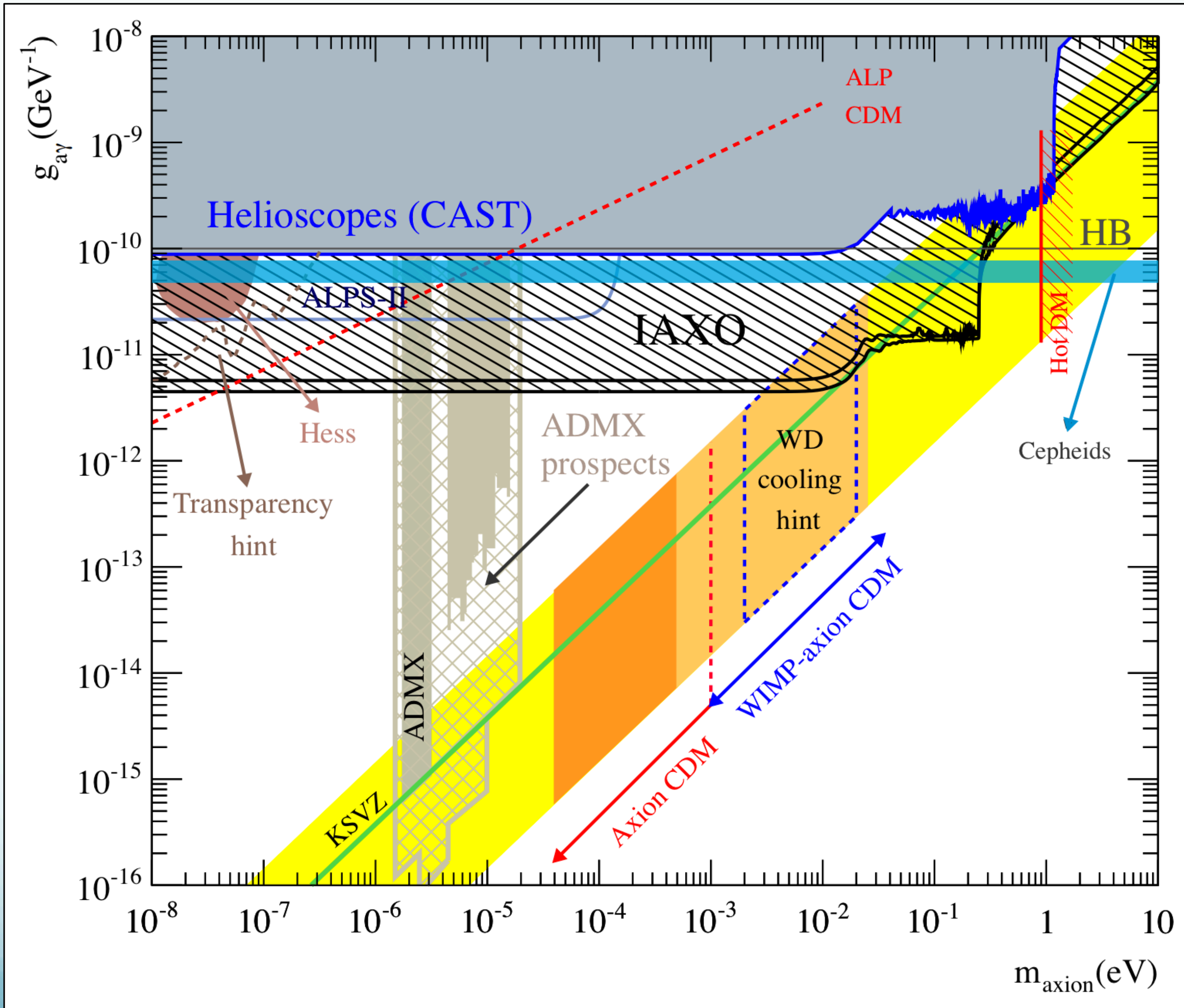




*See August 2010 Physics Today for experimental overview

ADMX Experimental Apparatus





$g_{a\gamma}$ (GeV^{-1})
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
ALP
CDM
Helioscopes (CAST)
HB
ALPS-II
IAXO
Hot DM
Hess
ADMX
prospects
Cepheids
Transparency
hint
WD
cooling
hint
WIMP-axion CDM
ADMX
KSVZ
Axion CDM
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
m_{axion}(eV)

CASPEr: the Cosmic Axion Spin Precession Experiment

Derek F. Jackson Kimball

Heising - Simons Foundation

Axion couplings

$$\frac{a}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu}$$ ← Coupling to electromagnetic field

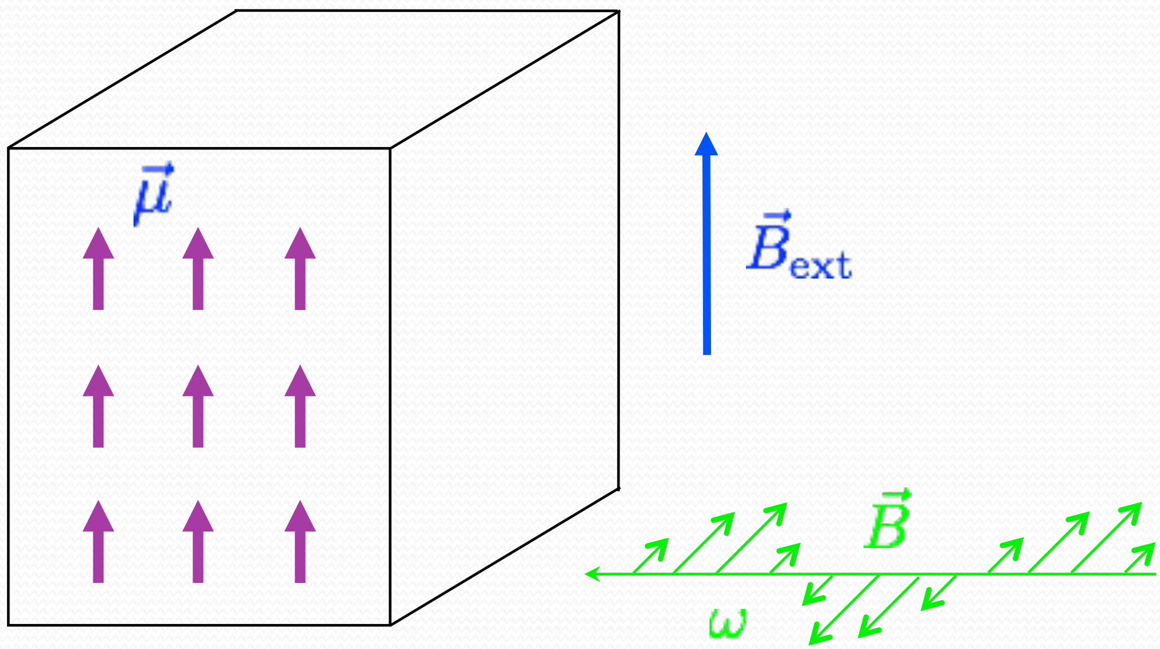
$$\frac{a}{f_a} G_{\mu\nu} \tilde{G}^{\mu\nu}$$ ← Coupling to gluon field

CASPEr Electric

$$\frac{\partial_\mu a}{f_a} \bar{\Psi}_f \gamma^\mu \gamma_5 \Psi_f$$ ← Coupling to fermions

CASPEr Wind

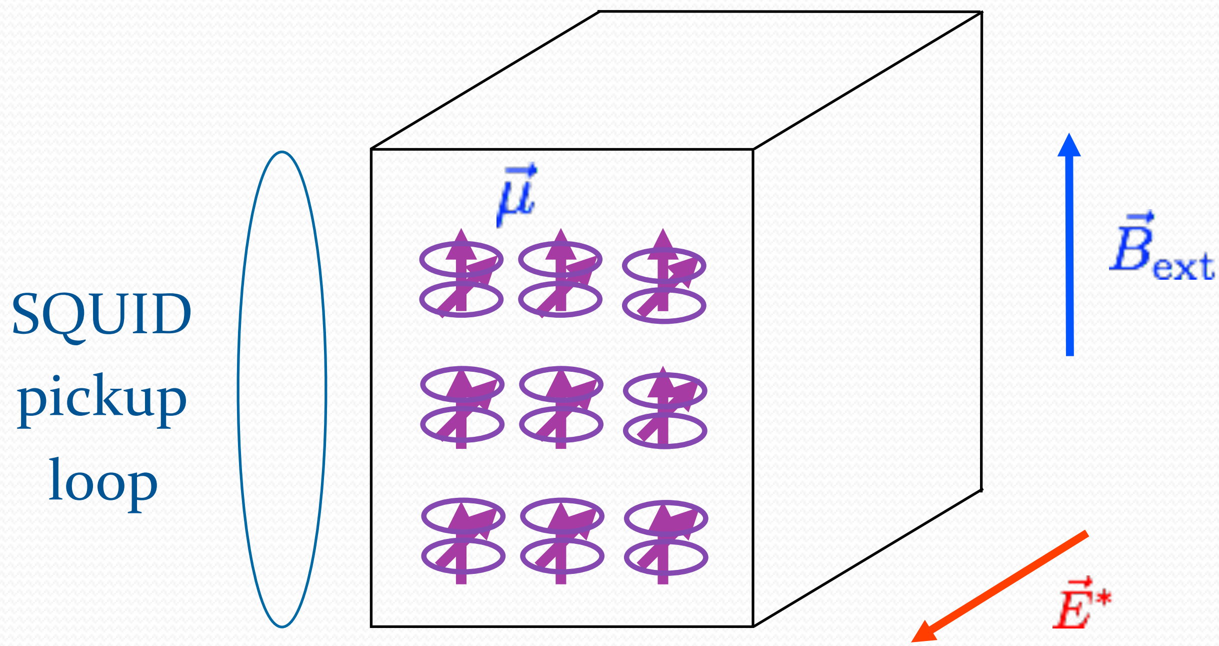
Nuclear Magnetic Resonance (NMR)



NMR resonant spin flip when Larmor frequency

$$2\mu B_{\text{ext}} = \omega$$

EDM coupling to axion plays role of oscillating transverse magnetic field



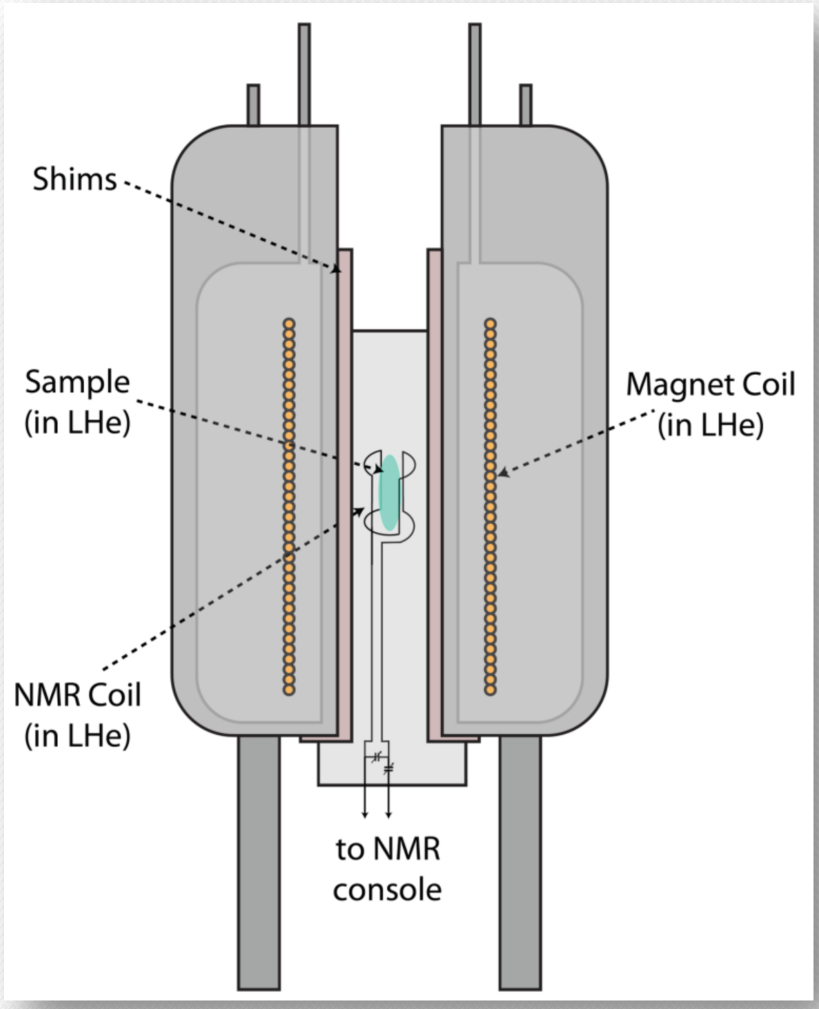
Larmor frequency = axion mass ➔ resonant enhancement.

Experimental strategy

(1) Thermally polarize spins in a cryogenic environment at high magnetic field (10 T);

(2) Scan magnetic field from 10 T → 0 T; Larmor frequency decreases from 45 MHz;

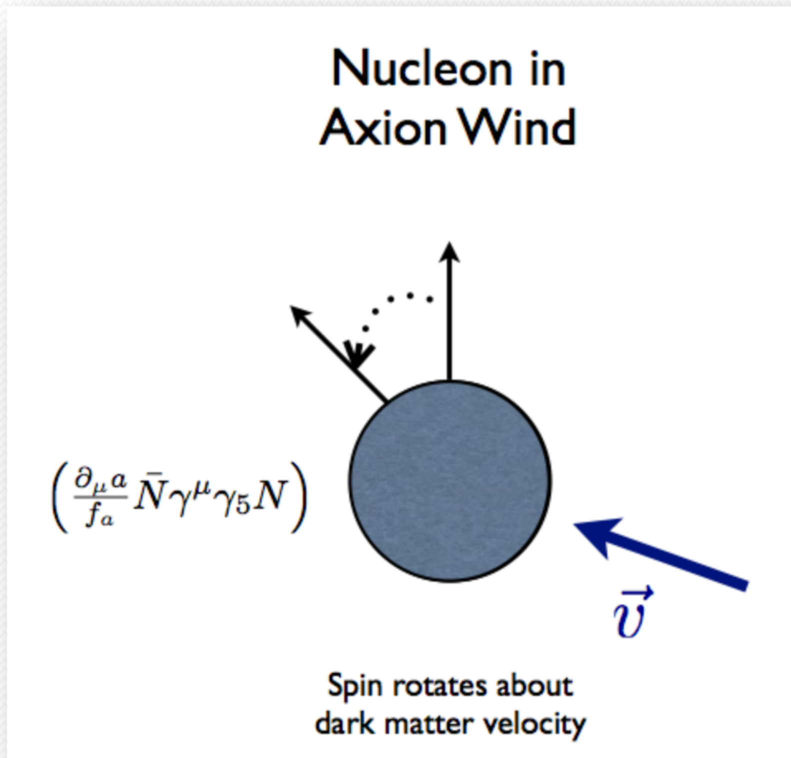
(3) Integrate for about 20 ms at each frequency, a complete scan takes around 1000 s ≈ T_1 to complete.

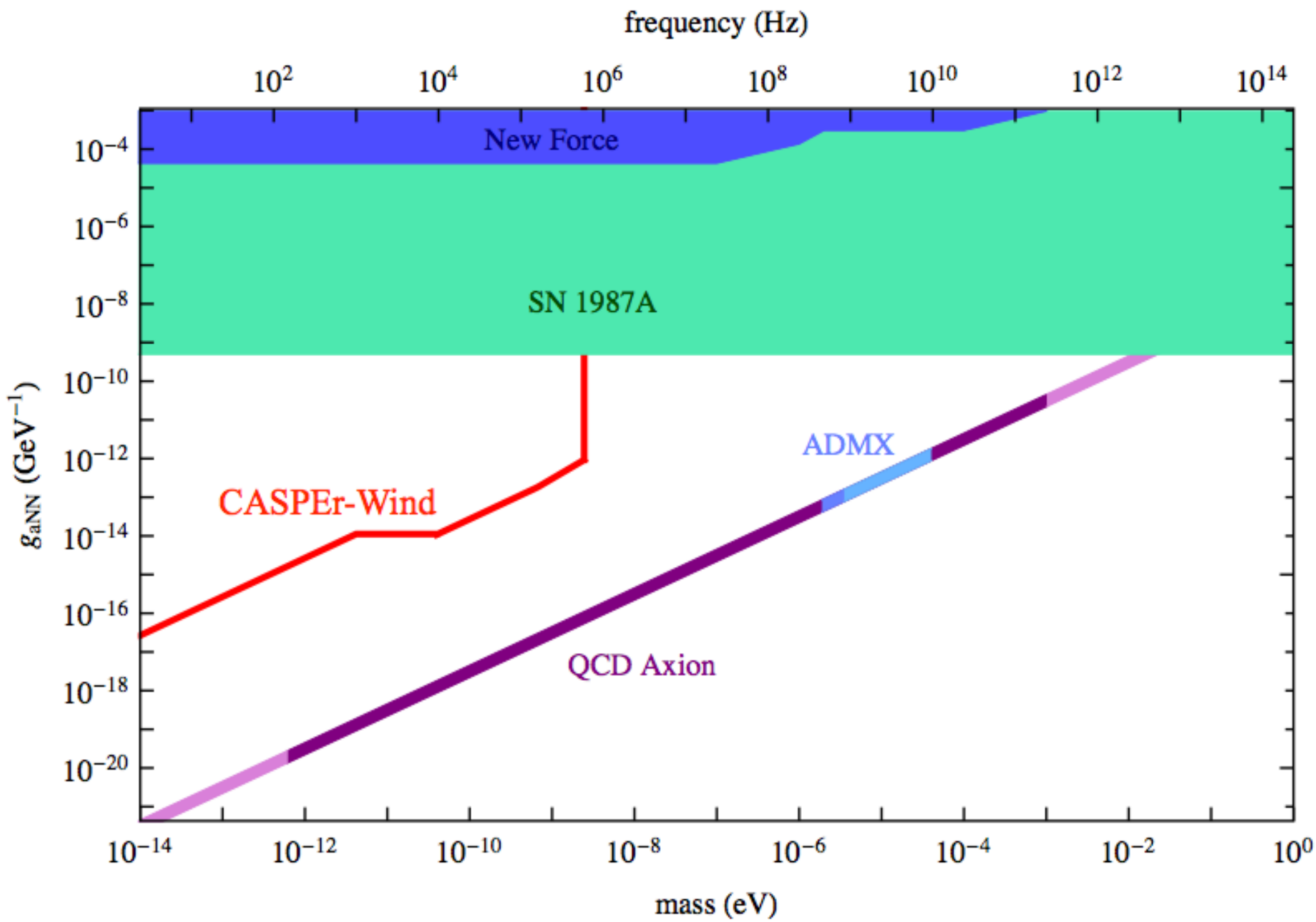


Axion/ALP-induced spin precession (axion wind)

Nonrelativistic limit of the axion-fermion coupling yields a Hamiltonian:

$$H_{\text{wind}} \approx g_{aNN} \nabla a \cdot \boldsymbol{\sigma}_N \ .$$





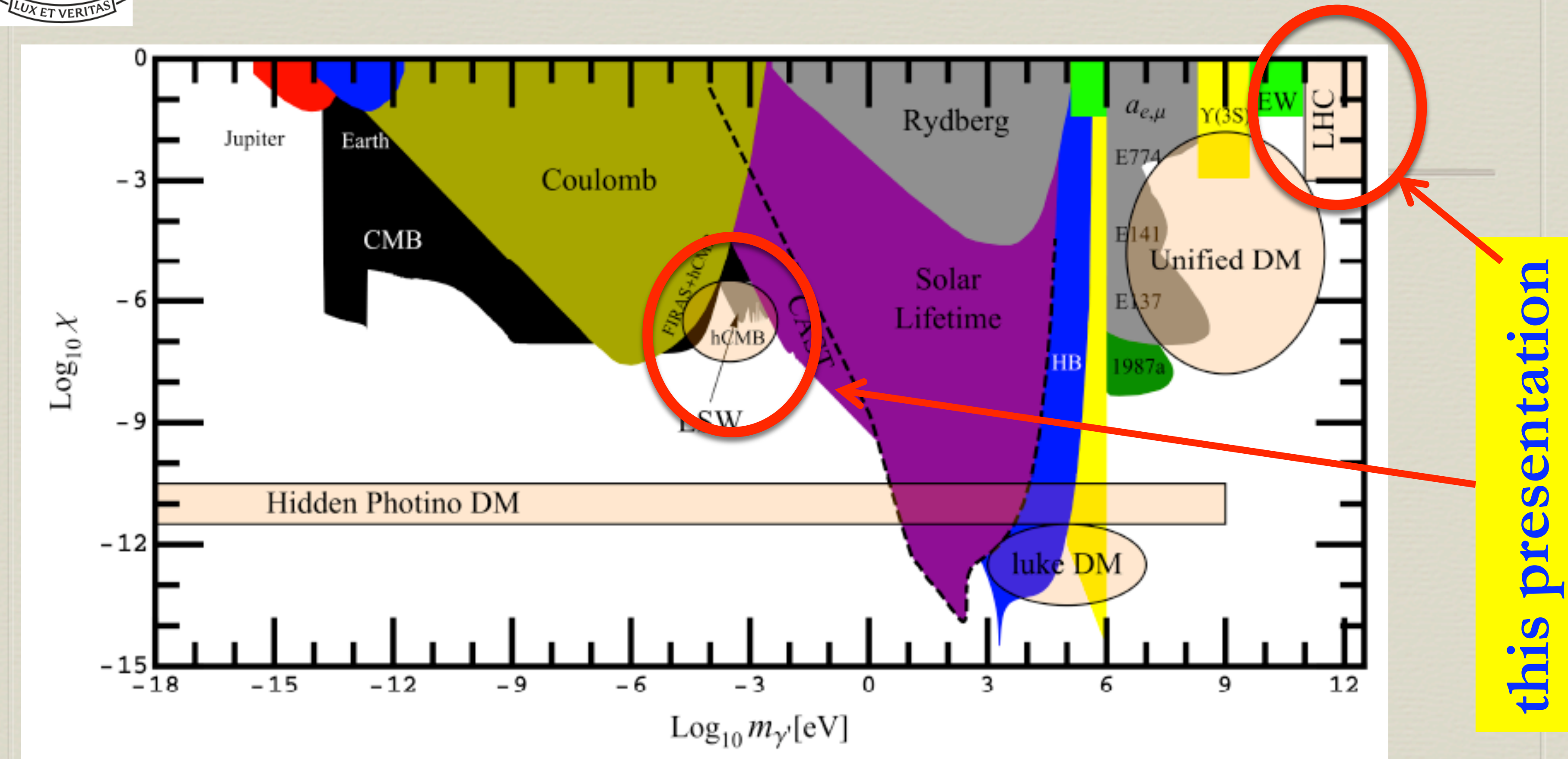
Experimental sensitivity

dark sector searches using photons and Higgs bosons

O. K. Baker
Yale University

IEB workshop
June 18, 2015

γ-γ_d and Z-Z_d kinetic mixing
J. Jaeckel, A. Ringwalk arXiv:1002.0329

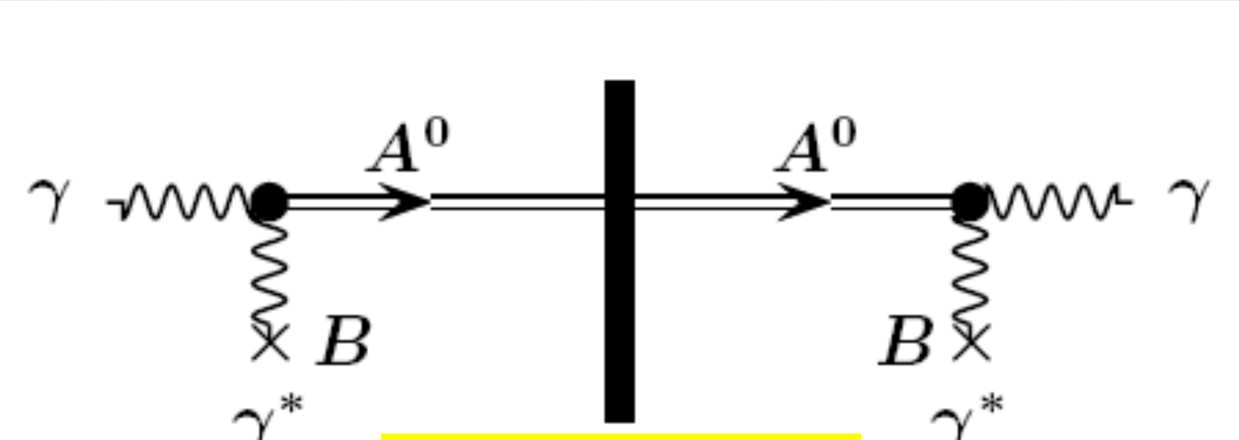


- large unexplored regions of the landscape
- multiple techniques and strategies
- worldwide search effort

light shining through a wall

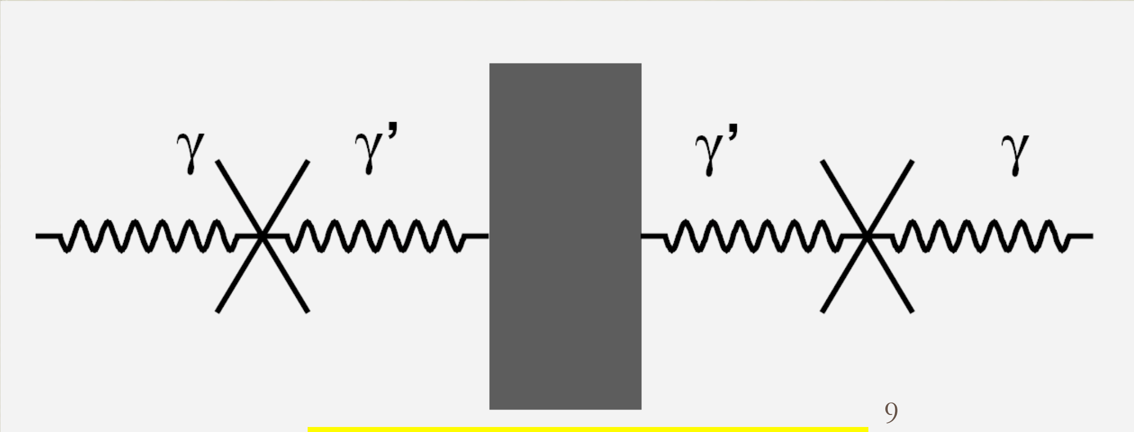
can suppress background by over 20 orders of magnitude ! ! !

kW lasers, cavities, ultra low noise detectors, . . .



magnetic field present

- couple polarized laser light with magnetic field
- Sikivie (1983); Ansel'm (1985); Van Bibber et al (1987)

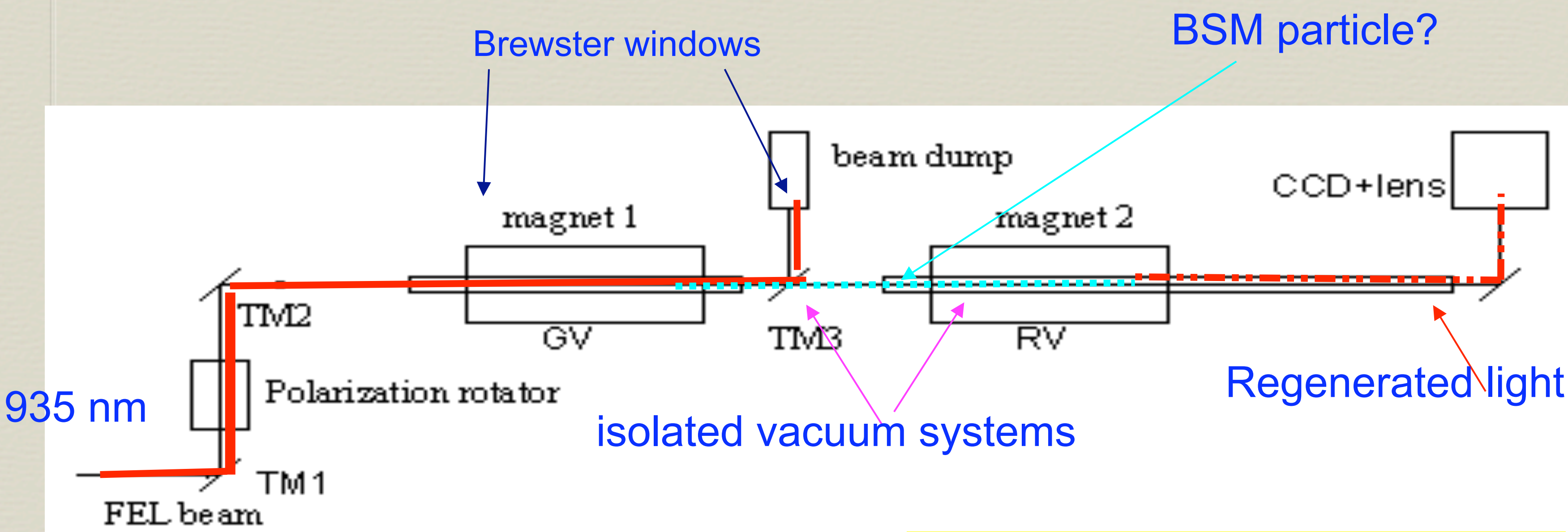


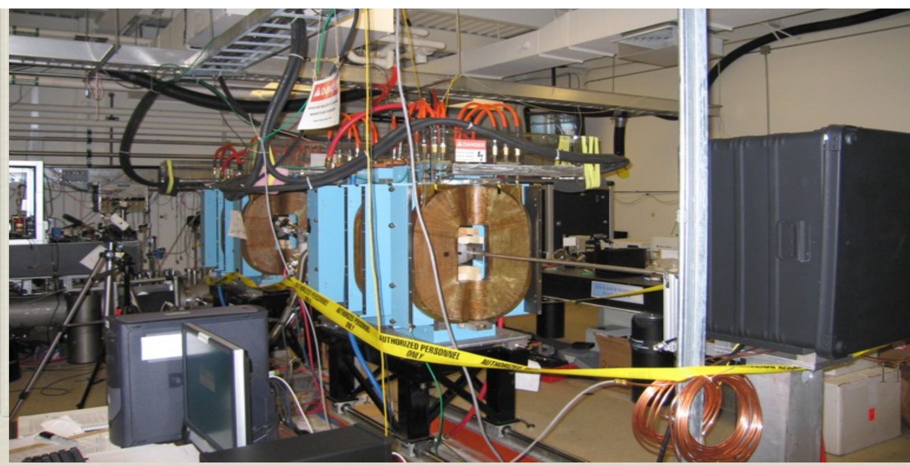
no magnetic field required

- kinetic mixing
- no magnetic field required
- Afanasev et al (2009)

Jefferson Lab and the Free Electron Laser

LIPSS at JLab experiment schematic





150 fs wide pulses

<75 MHz rep rate

100 % df

935. +/- 15 nm

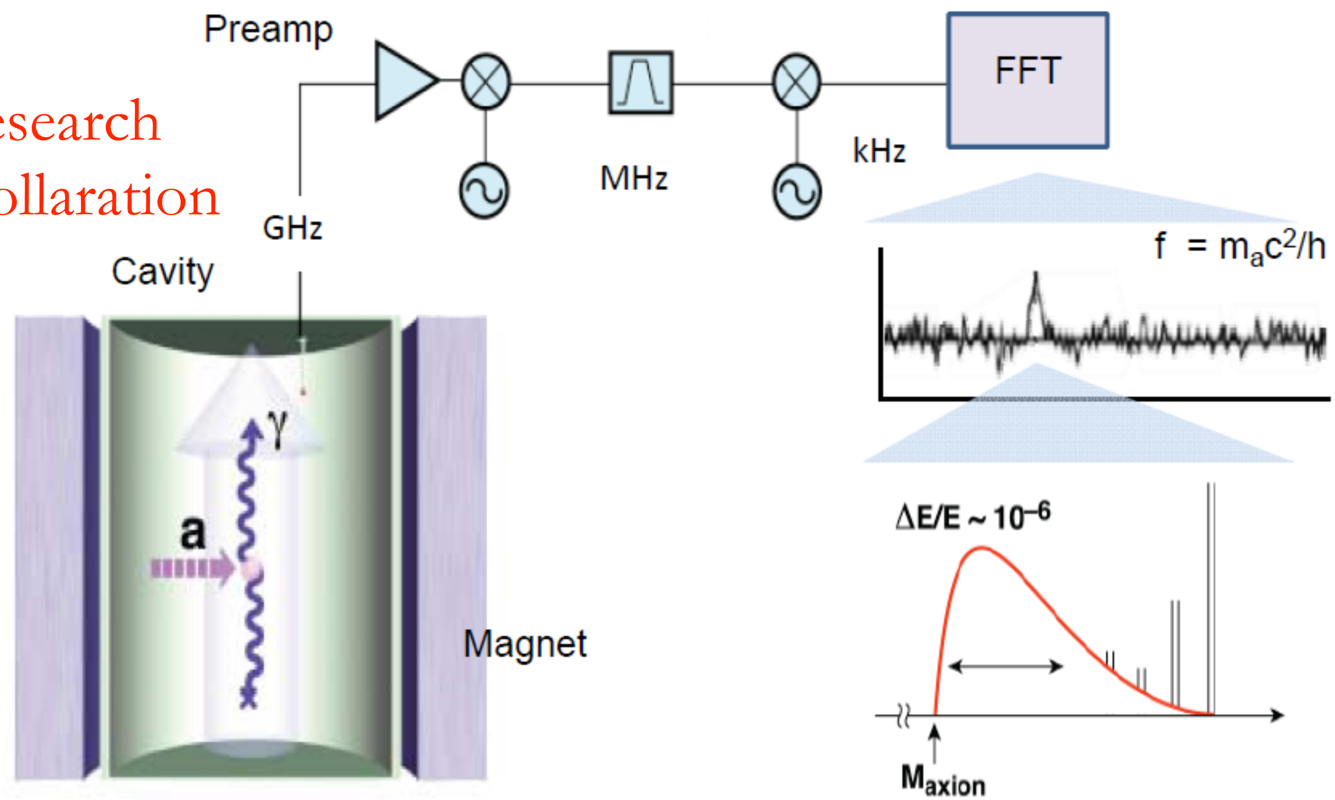
200 (→400) watts avg power

>99% linearly polarized

dark matter axion and ALP search using microwaves

pioneering research by ADMX collaration

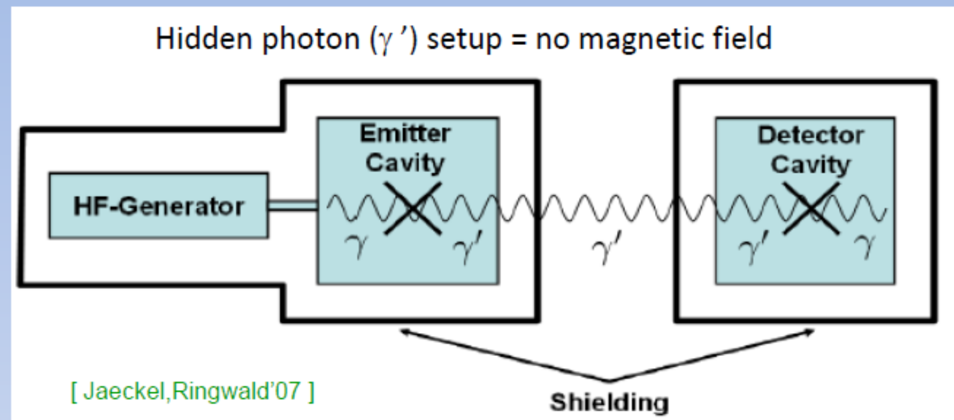
The Microwave Cavity Search for DM Axions (Pierre Sikivie, 1983)

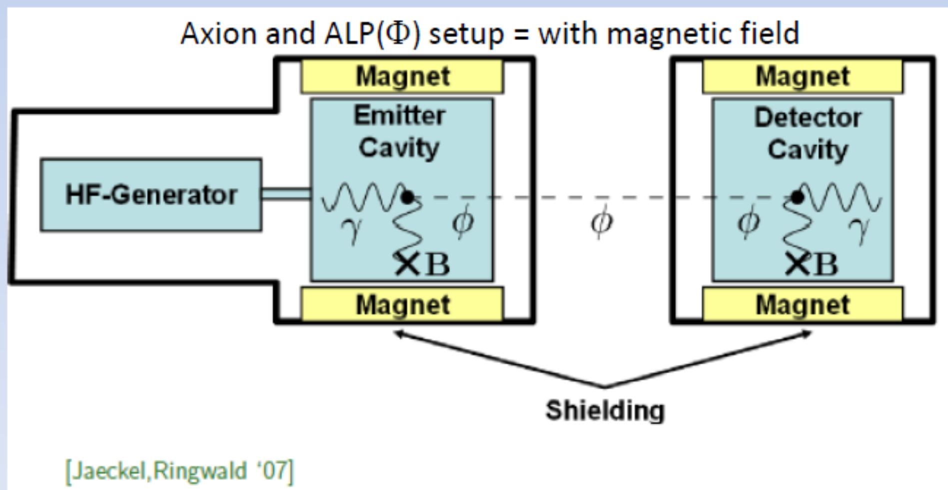


$$P_{sig} \propto (B^2 V Q_{cav})(g^2 m_a \rho_a) \sim 10^{-23}\,W \qquad s/n = \frac{P_{sig}}{kT_{sys}}\sqrt{\frac{t}{\Delta\nu}}$$

lsw resonant cavity searches

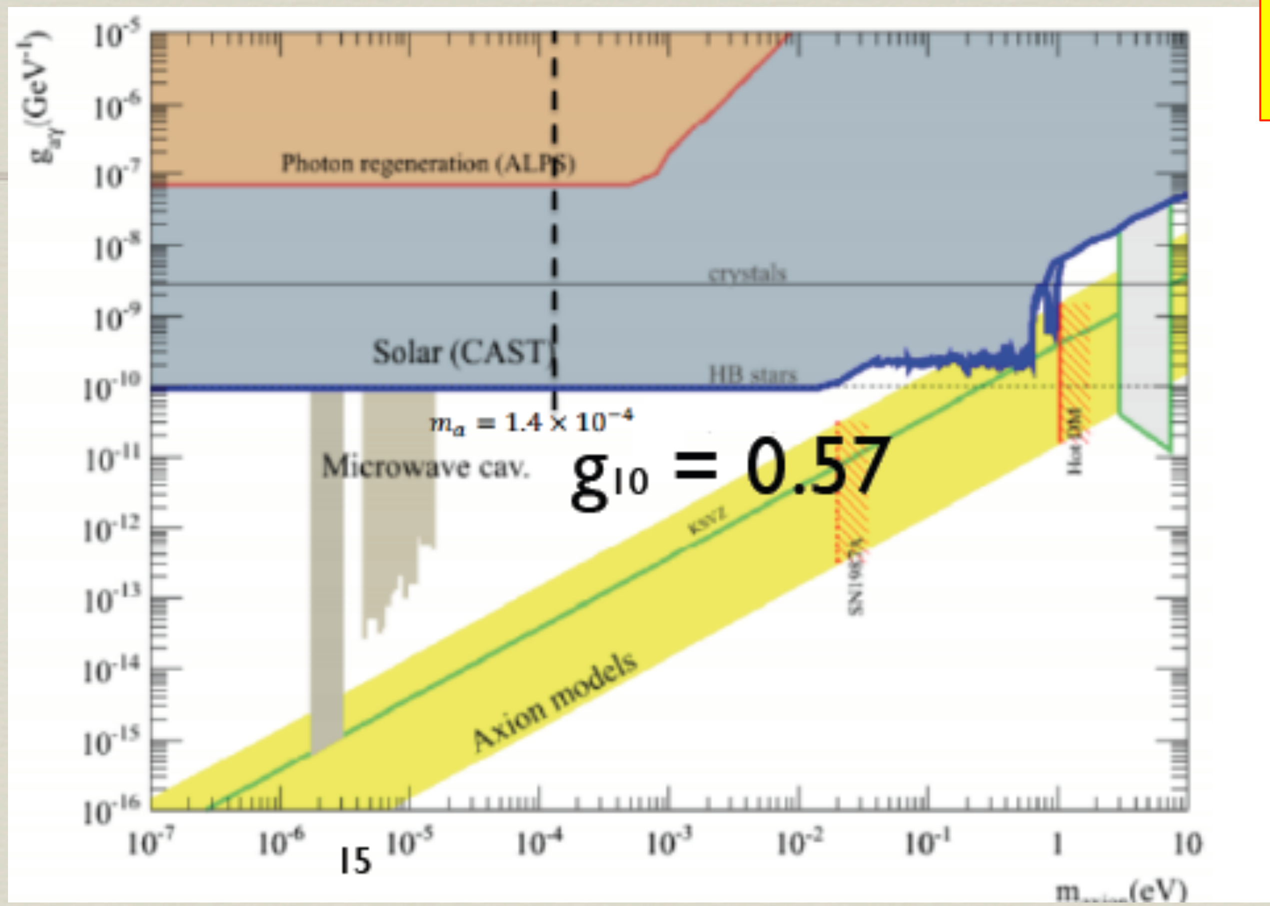
- Idea: exploit microwave cavities instead of optical resonators [Hoogeveen '92; Jaeckel,Ringwald'07; Caspers,Jaeckel,Ringwald '09]
- With current technology, expect increased sensitivity in certain mass range
- First test experiments have already been done (Livermore; Perth), or are set-up (Daresbury; Yale)





ALP dark matter

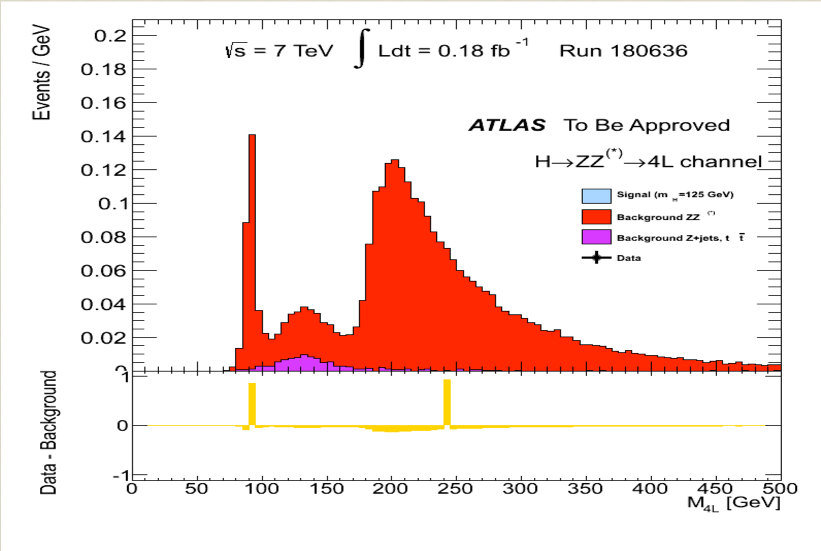
ymce pilot run



dark matter could be axion-like particles

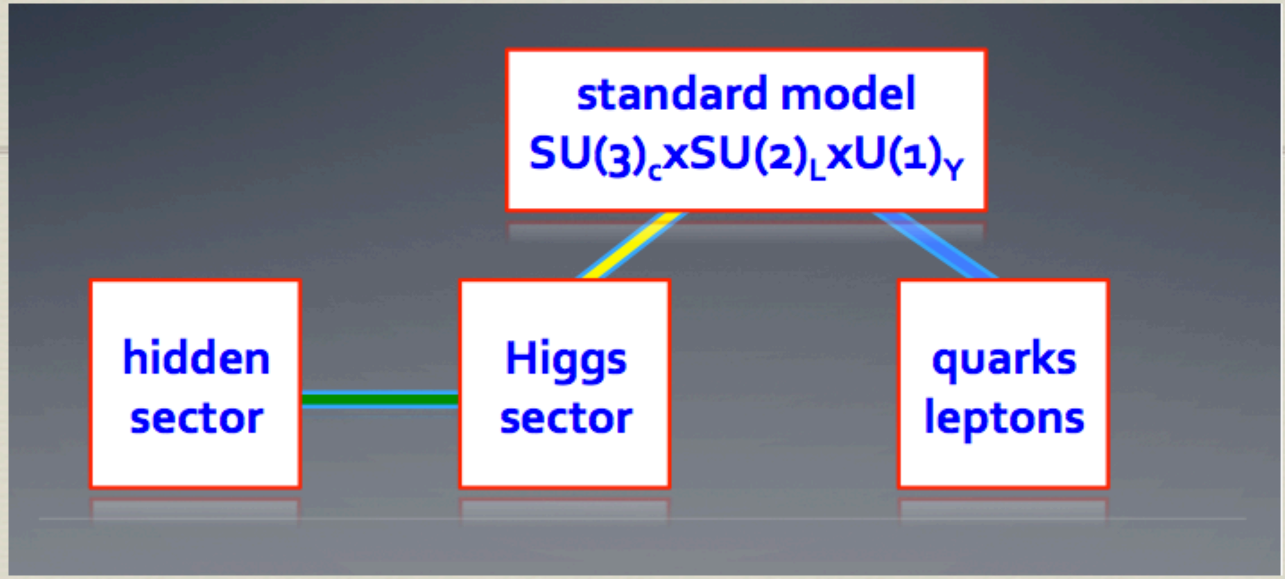
Ana Malagon, doctoral dissertation, Yale (2014)

dark sector searches using the Higgs boson

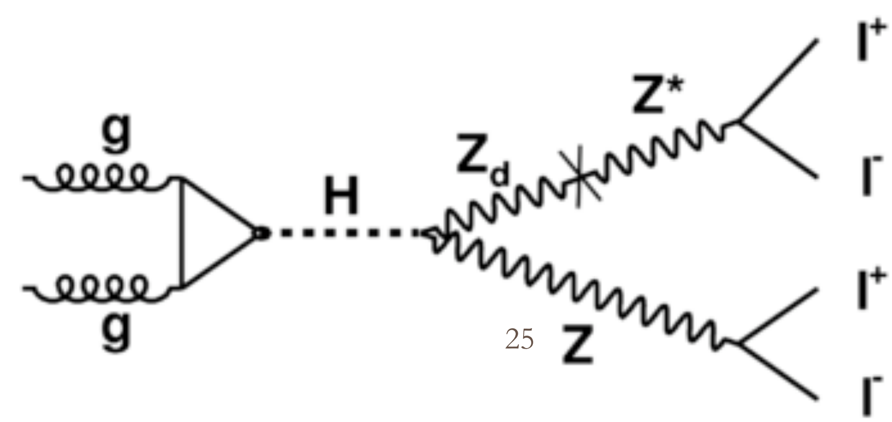


https://espace.cern.ch/atlas-phys-higgs-htogamgam/Lists/Hgg Moriond 2013/Attachments/46/mass_animation_ZZ4L.gif - mass-animation

physics motivation



H. Davoudiasl, H-S Lee, I. Lewis, W.J. Marciano, PRD 88, 015022 (2013)



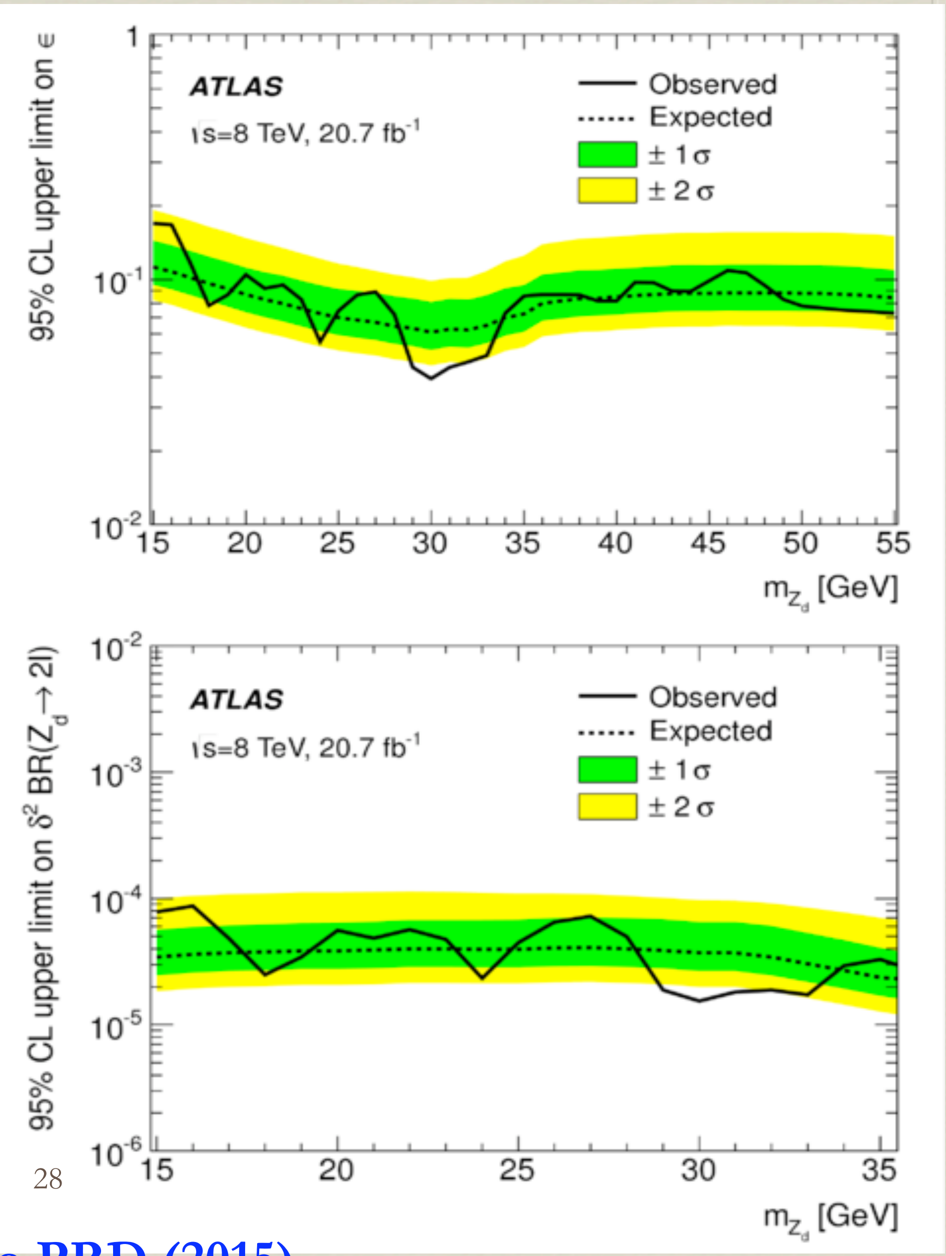
one possibility,
as an example

Higgs a portal to the hidden or "dark" sector

95% CL exclusion limits

kinetic mixing parameter

mass mixing parameter



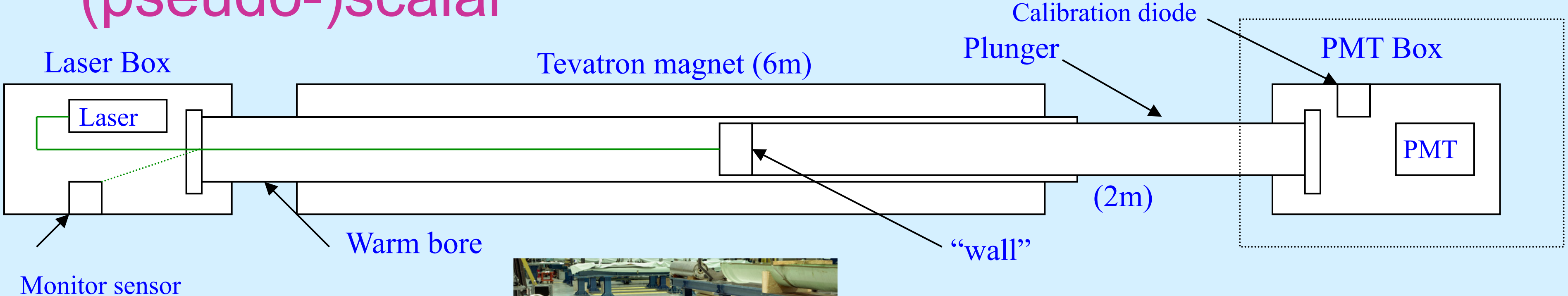
submitted to PRD (2015)

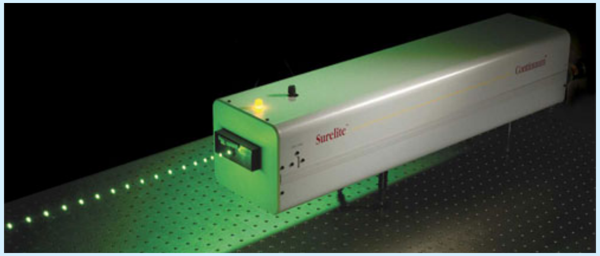
Laser Searches for New Particles at Fermilab

William Wester
Fermilab

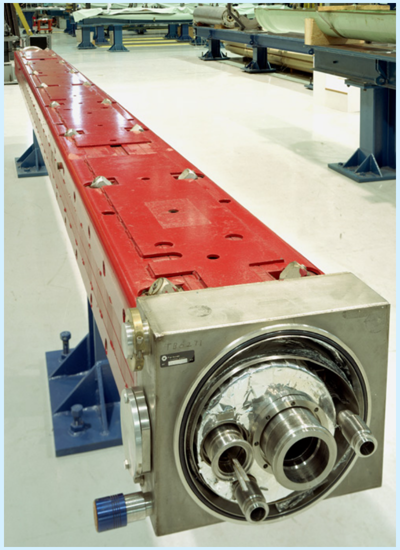
GammeV Experiment

Search for evidence of a milli-eV particle in a light shining through a wall experiment to unambiguously test the PVLAS interpretation of an axion-like (pseudo-)scalar

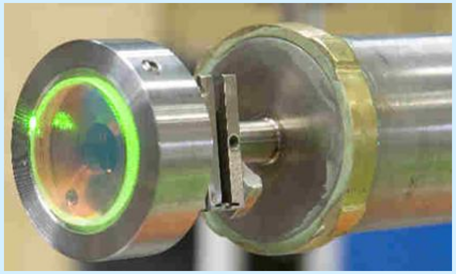




Existing laser in Acc. Div. nearly identical with a similar spare available



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

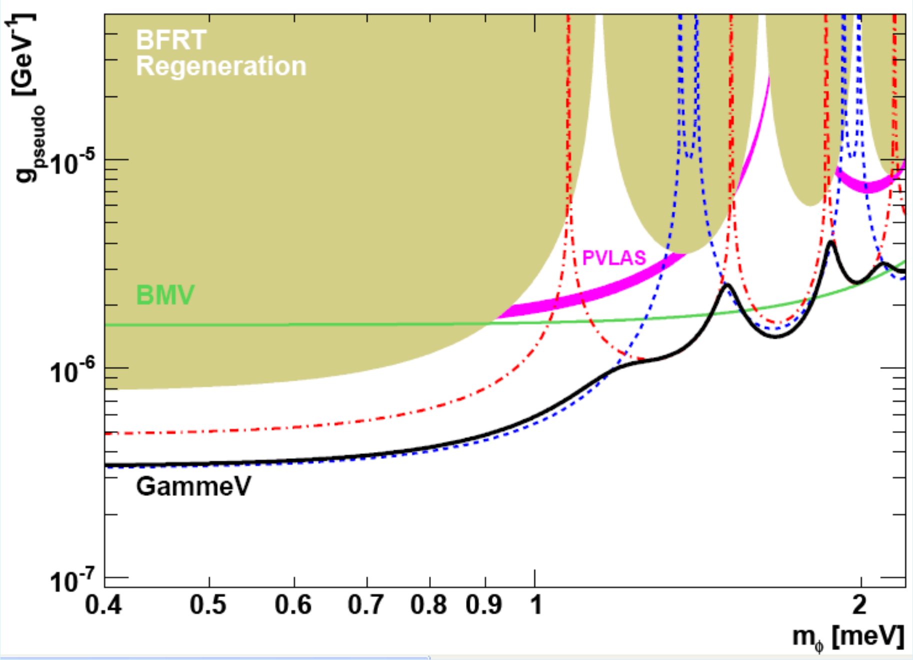


High-QE, low noise, fast PMT module (purchased)

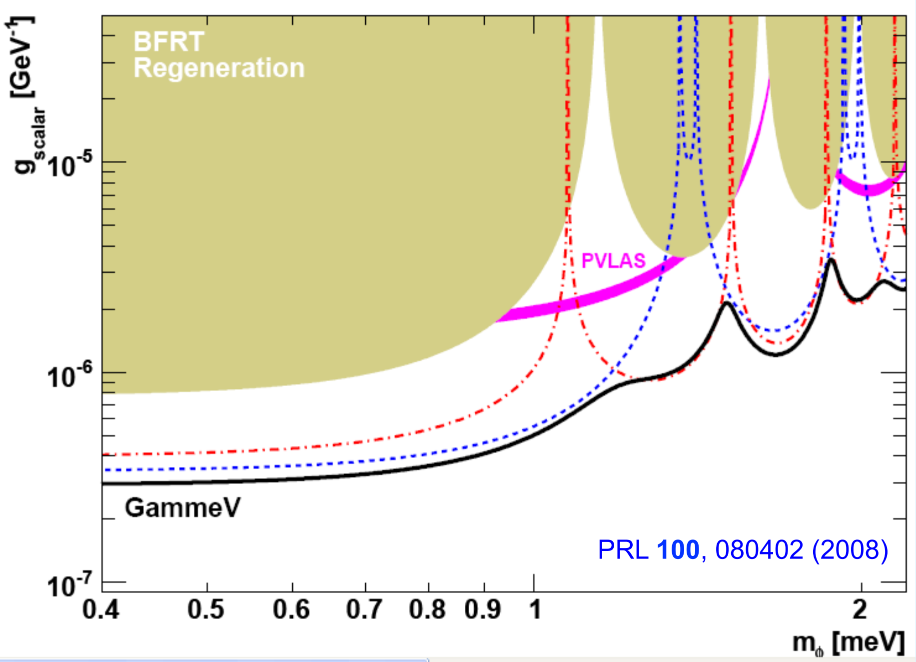
GammeV Limits

- Results are derived. We show 3**s** exclusion regions and completely rule out the PVLAS axion-like particle interpretation by more than 5**s**.

Pseudoscalar



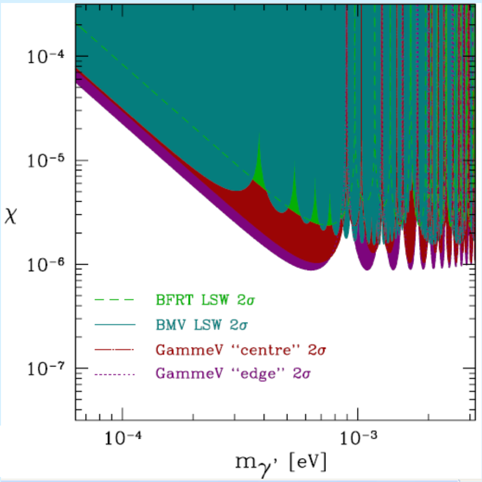
Scalar



- Job is done. Limit generally improves slowly (8^{th} root) vs. longer running time, or increased laser power, etc.

Other new particles

A dark photon could also cause light to shine through a wall even without an external magnetic field. The GammeV null result can also be interpreted as sensitivity for a new U(1) dark photon.



Phys. Rev. **D77**, 095001 (2008)

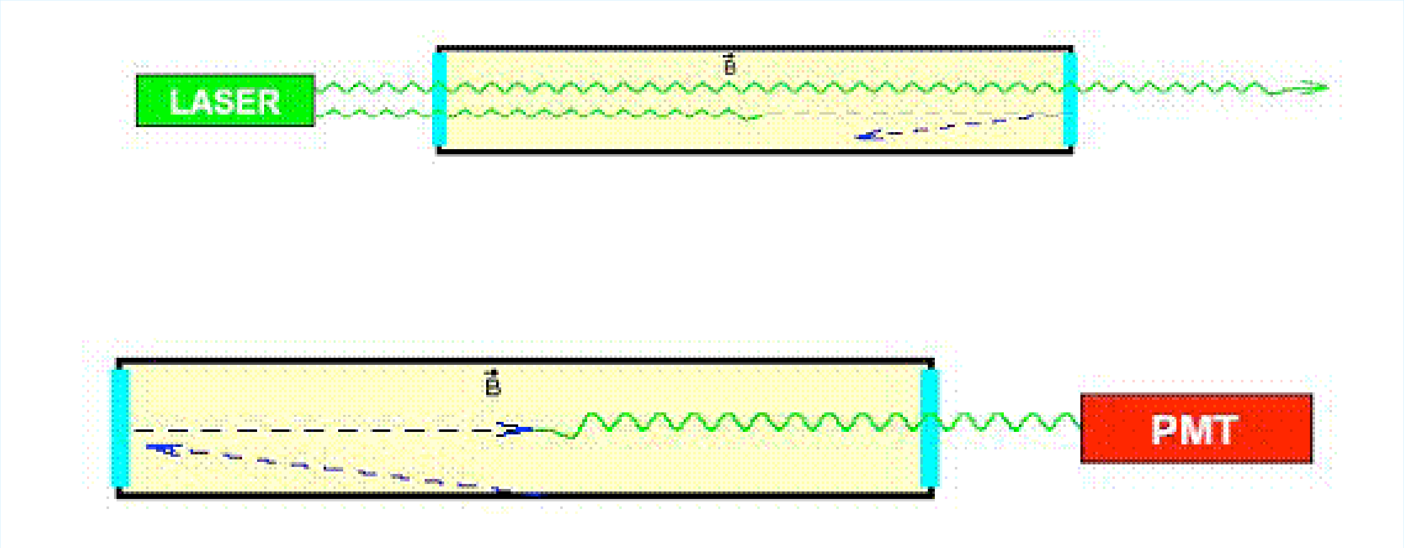
- An exotic type of new particle called a chameleon – a scalar – Tensor interaction results in a particle whose properties depend on it's environment.

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

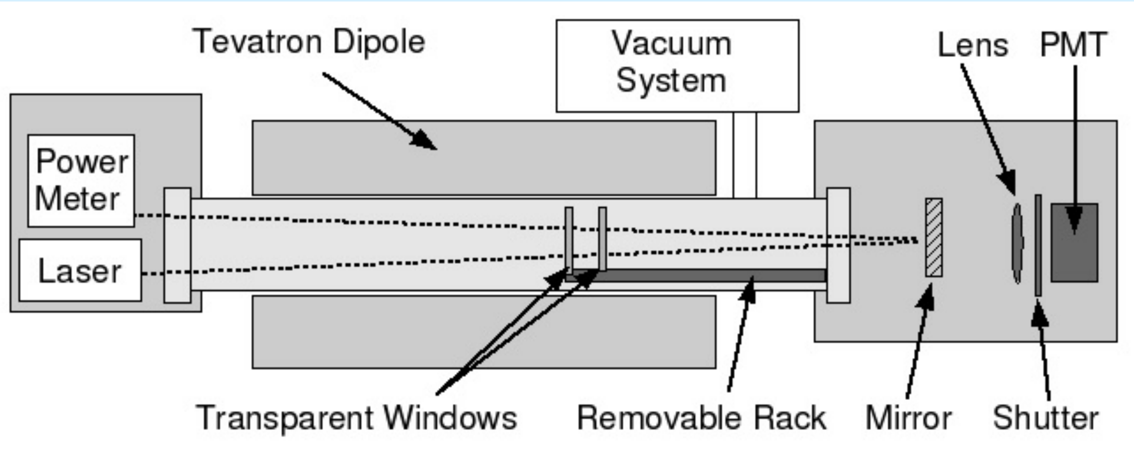
- The chameleon mechanism (Khoury and Weltman) was originally postulated as a mechanism to account for the cosmic expansion – i.e. "a dark energy particle".

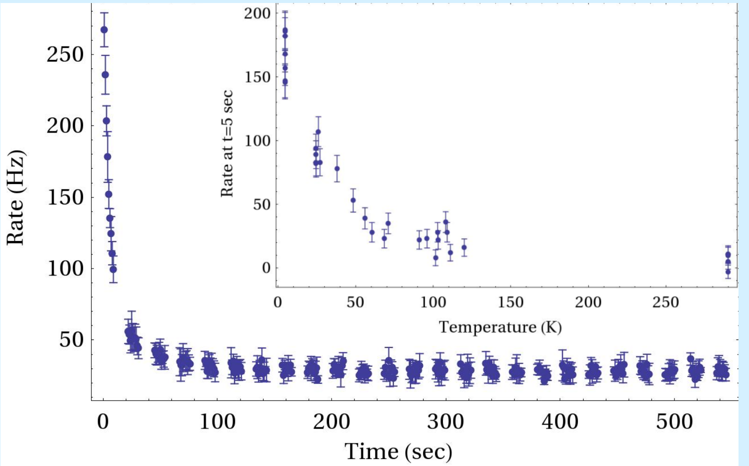
“Particle in a Jar” / Afterglow

- Chameleon properties depend on their environment – effective mass increases when encountering matter.
  - A laser in a magnetic field might have photons that convert into chameleons which reflect off of the optical windows. A gas of chameleons are trapped in a jar.
  - Turn off the laser and look for an afterglow as some of the chameleons convert back into detectable photons.



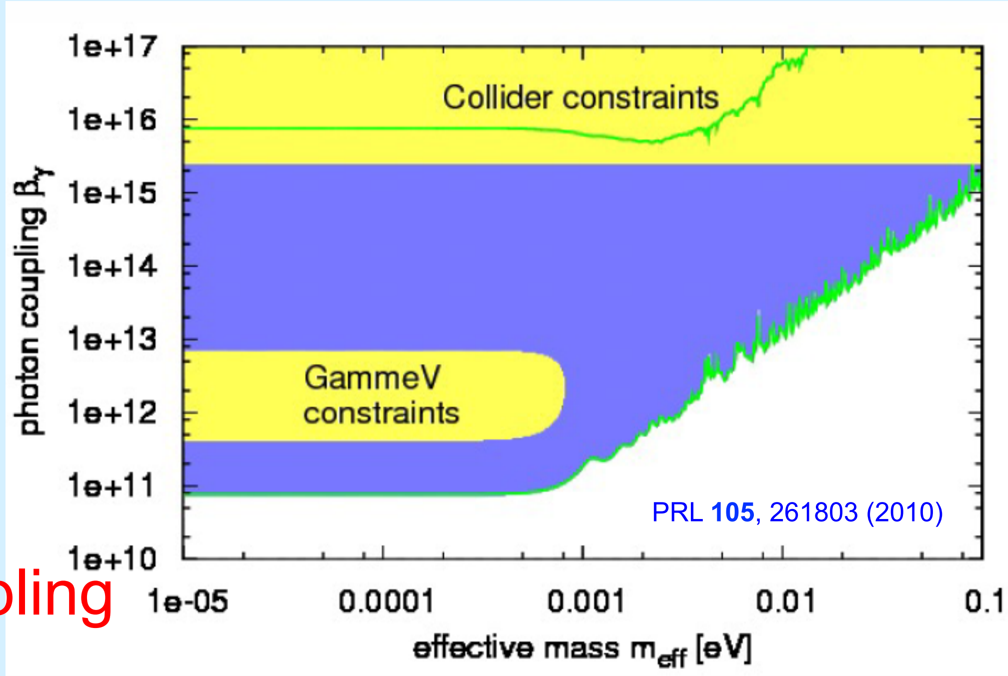
CHASE: Chameleon Afterglow Search





When we started to take data, we observed an afterglow that did not depend on B field (so, no evidence for chameleons). The afterglow rate did depend on temperature in a manner similar to vacuum grease.

First limits for chameleons coupling to photons.



Axion Searches Overview

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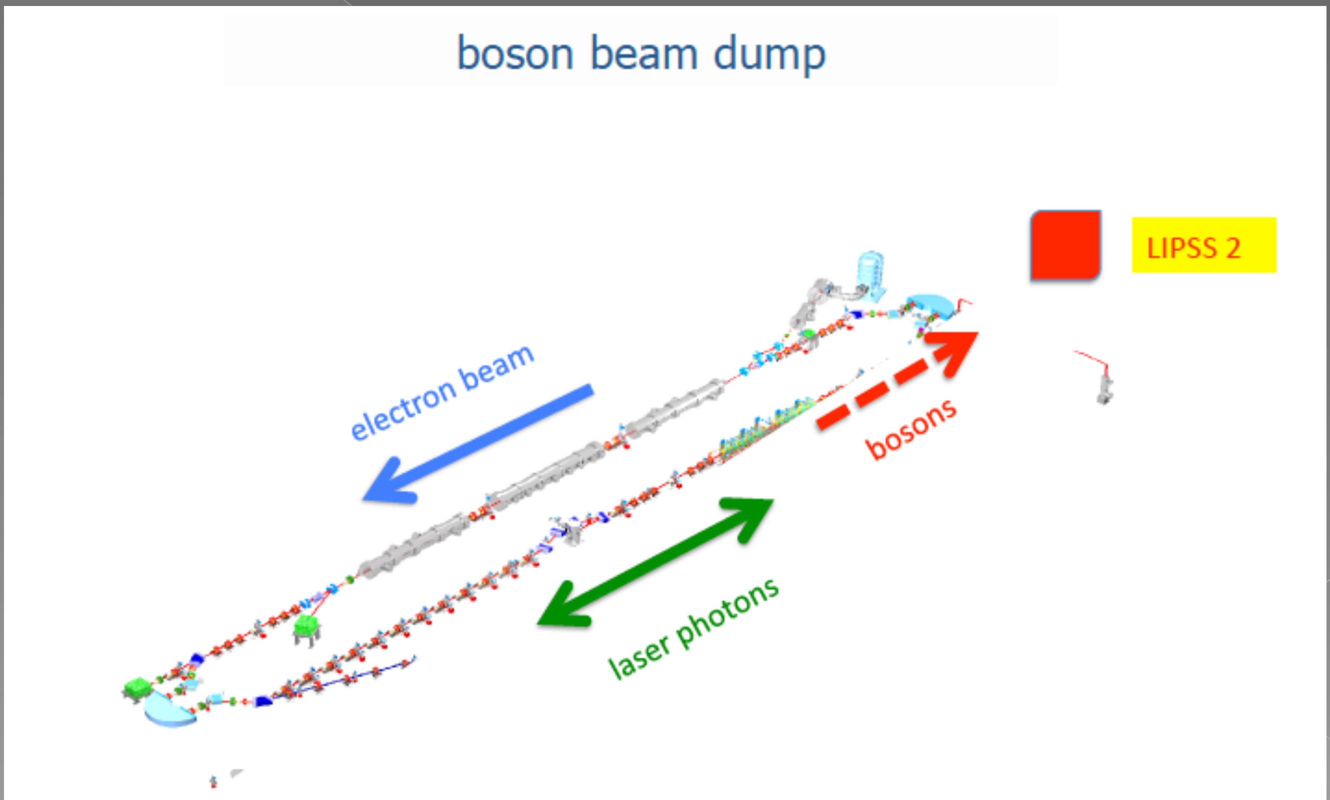
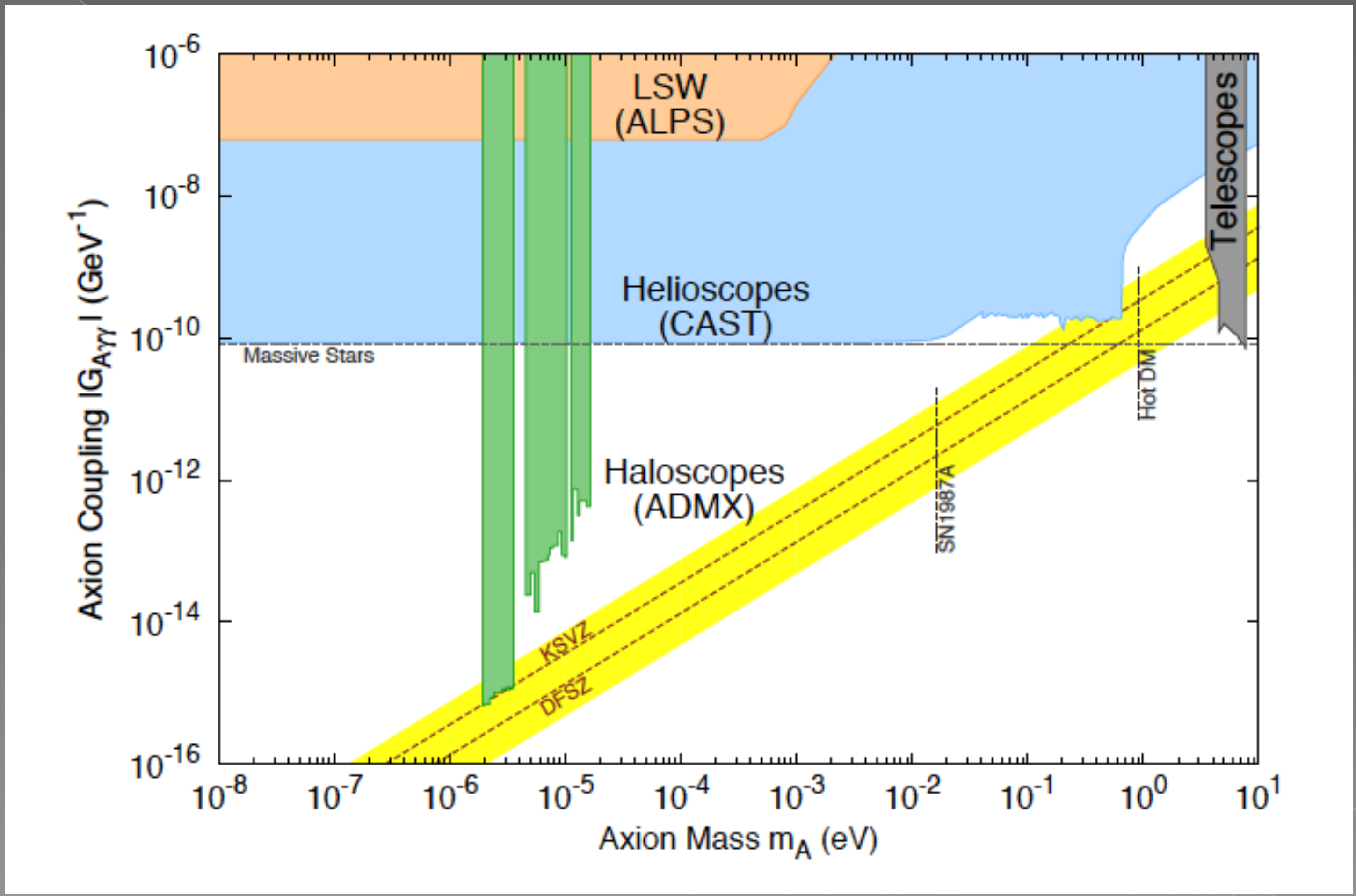
Low-mass Paraphoton Search

- Evaluated for JLAB FEL, see Baker's talk at Searching for a New Gauge Boson at Jlab, September 20-21, 2010

(mass < 25 keV)



Axion Parameters (PDG14)



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Combined Exclusion Ranges (PDG14)