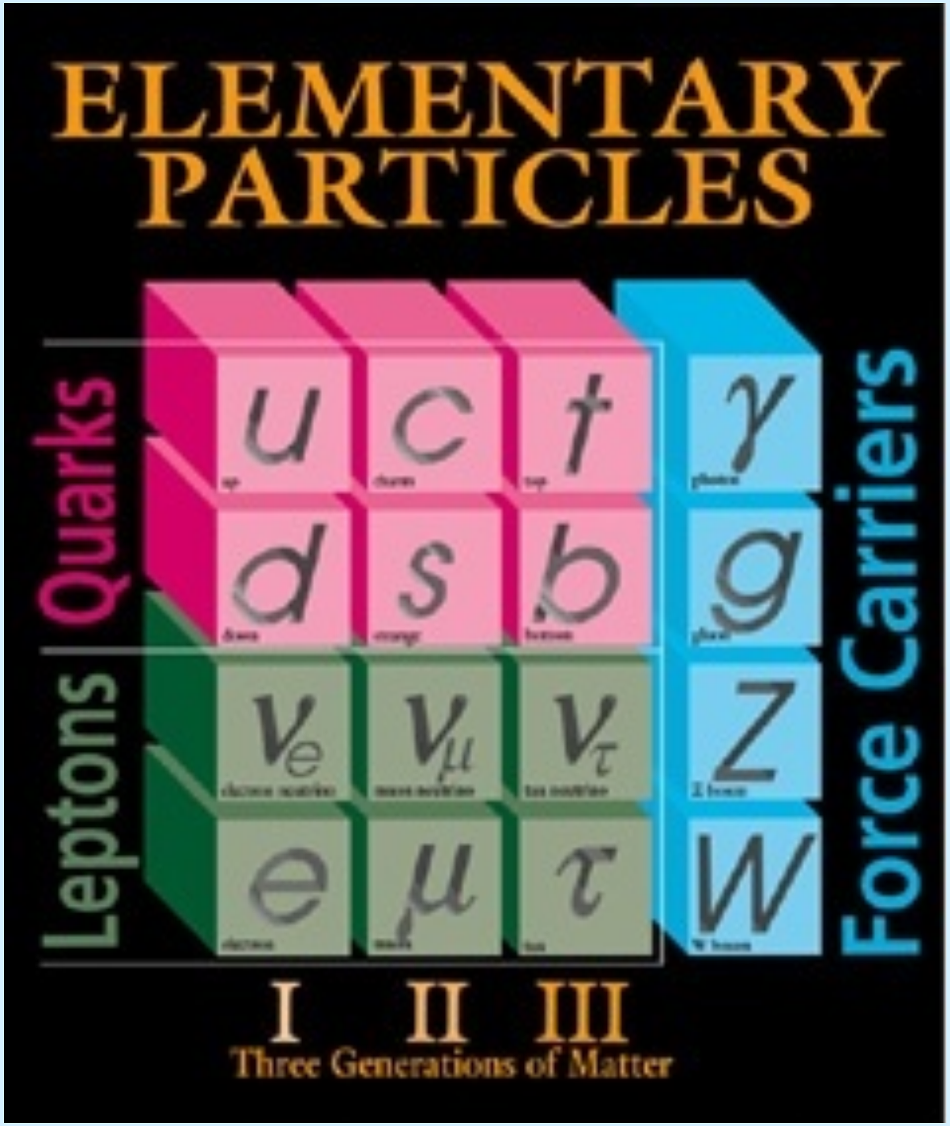
Fermilab – 25+ yrs as the world's most powerful p$\bar{\text{p}}$ smasher!

CERN – now the most powerful pp smasher

What we know



The Standard Model:

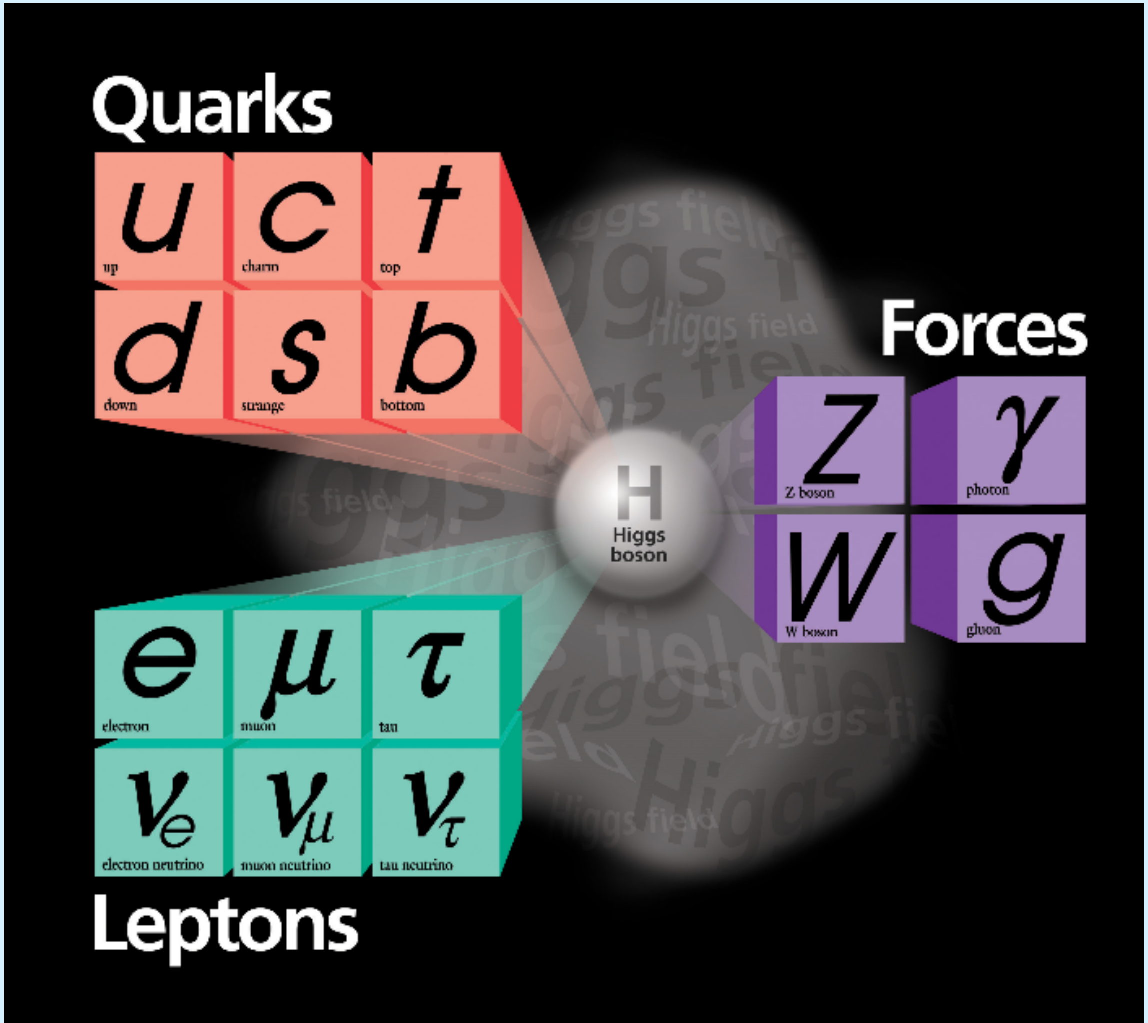
-Quarks
- -Proton: uud
- -Neutrons: udd

-Leptons
- -Electrons
- -Muons (cosmic rays)
- -Neutrinos (beam to MN)

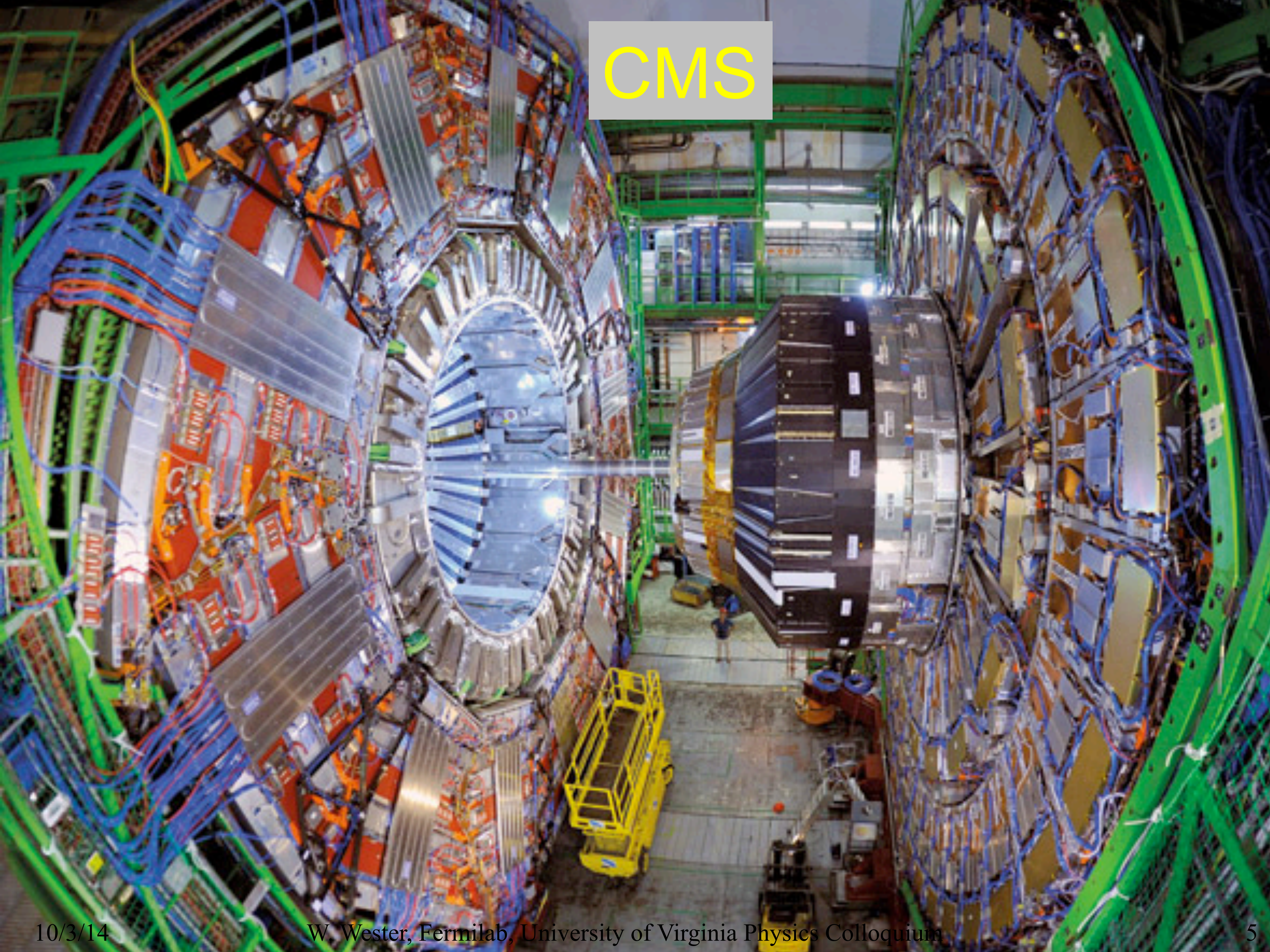
-Force Carriers
- -Photons (Electricity + Magnetism)
- -W/Z's (radioactive decay)
- -Gluons (hold quarks together)

The Higgs Boson

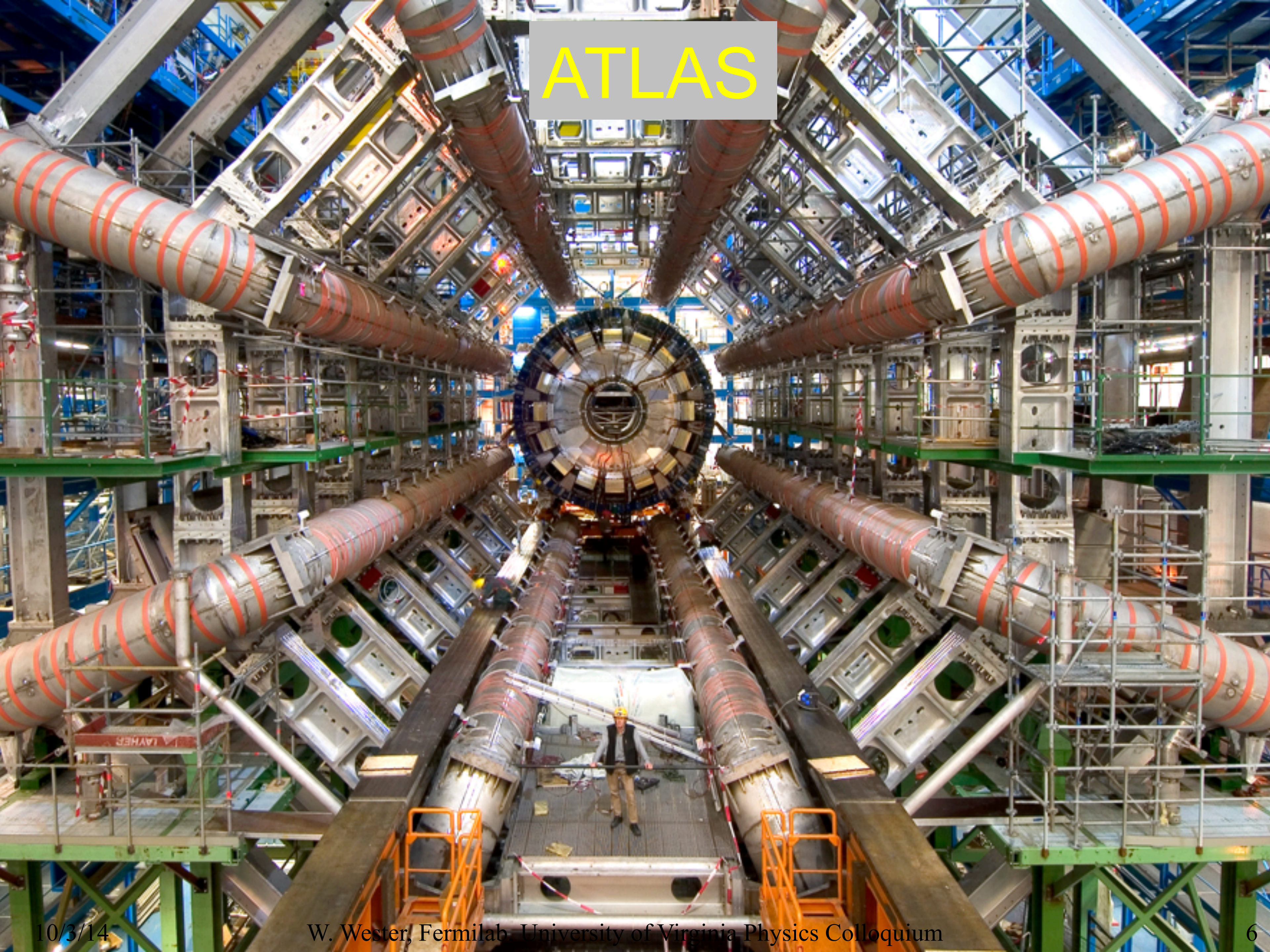
- The Higgs Mechanism is responsible for the breaking of a symmetry giving masses photon and massive W and Z's.



CMS

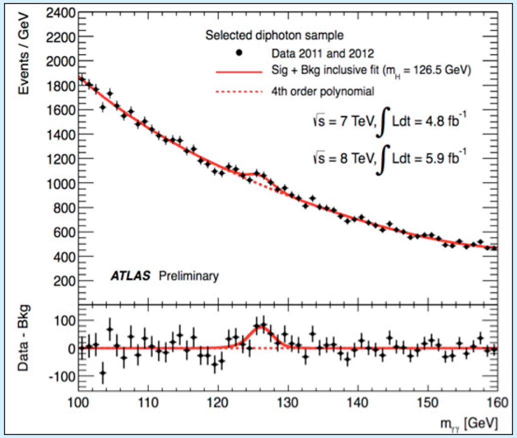


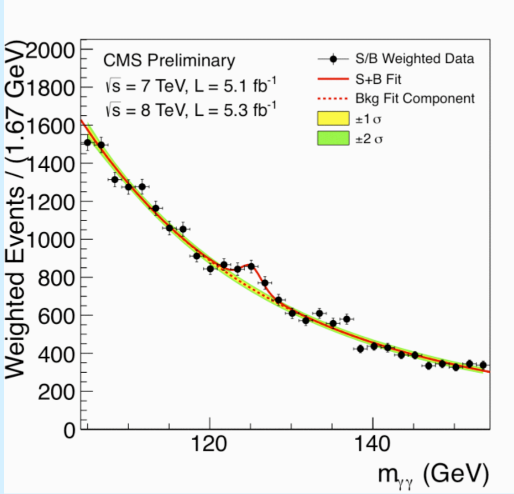
ATLAS



The Higgs Discovery

- July 4th 2012 3AM U Va time: CMS and ATLAS show 5σ discovery evidence of the Higgs





What we don't know

EINSTEIN'S DREAM OF UNIFIED FORCES

Are there undiscovered principles of nature: New symmetries, new physical laws?

How can we solve the mystery of dark energy?

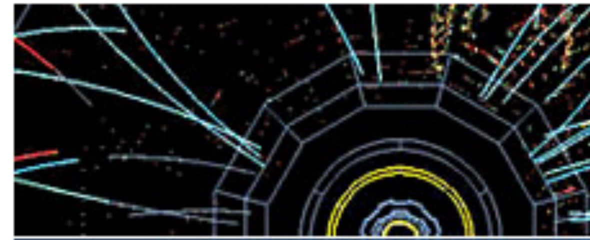
Are there extra dimensions of space?

Do all the forces become one?

THE PARTICLE WORLD

Why are there so many kinds of particles?

What is dark matter? How can we make it in the laboratory?



THE BIRTH OF THE UNIVERSE

How did the universe come to be?

What happened to the antimatter?

Quantum Universe Report

What we don't know

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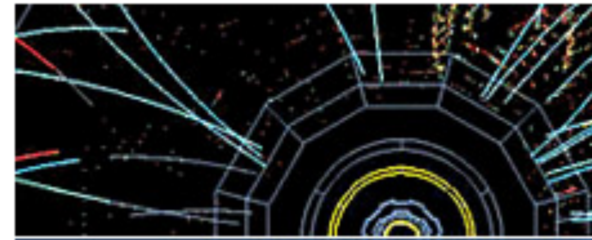

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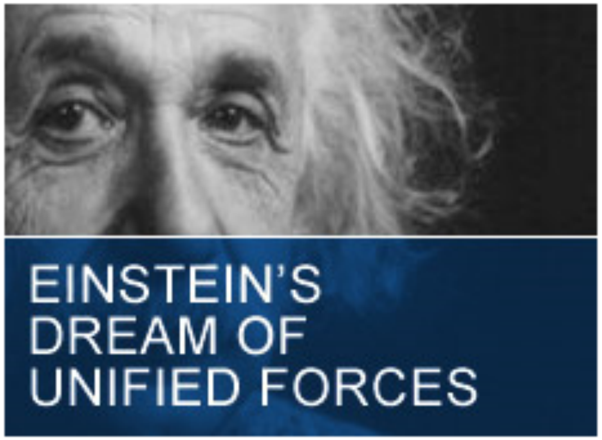

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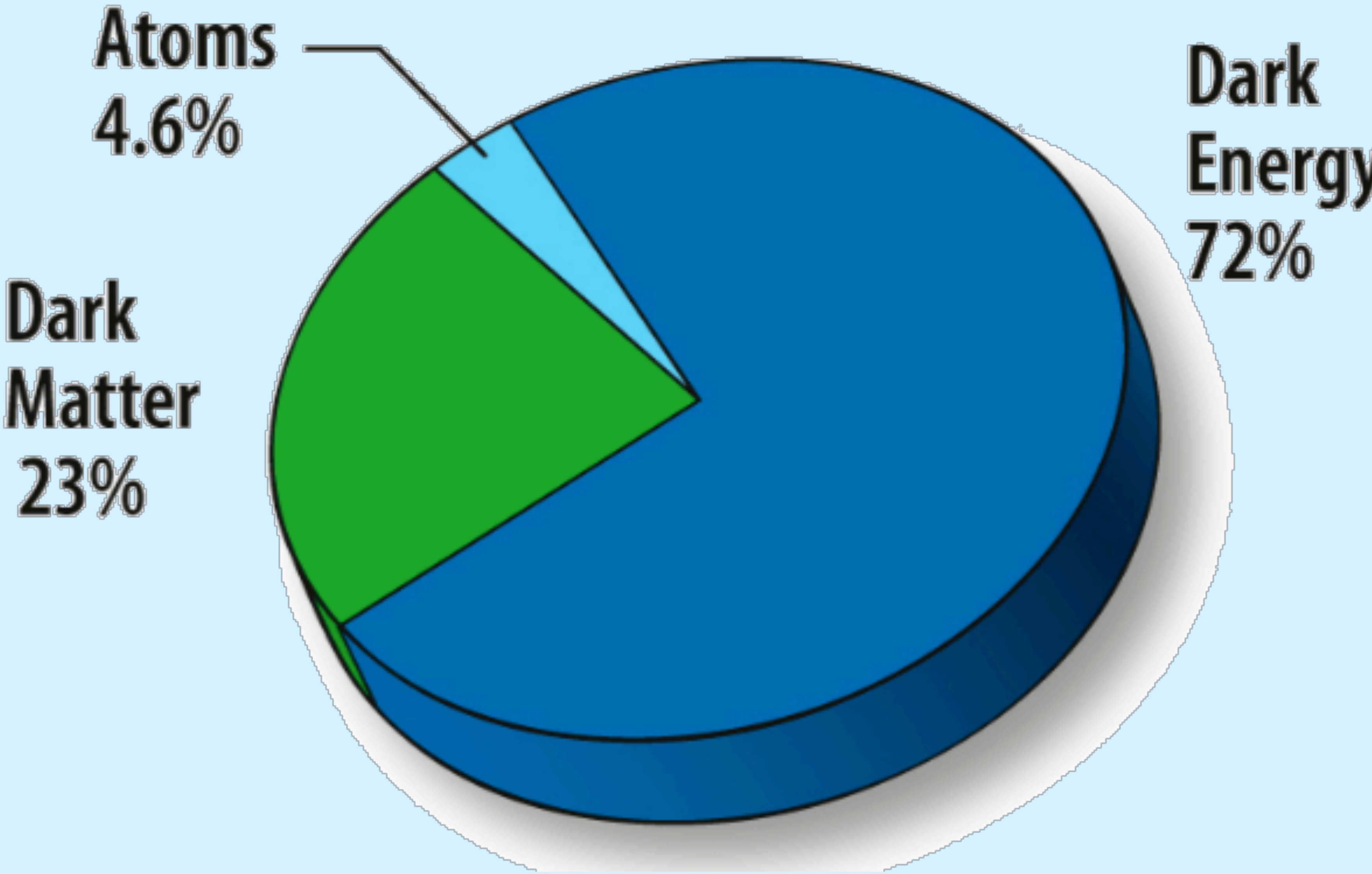
Quantum Universe Report

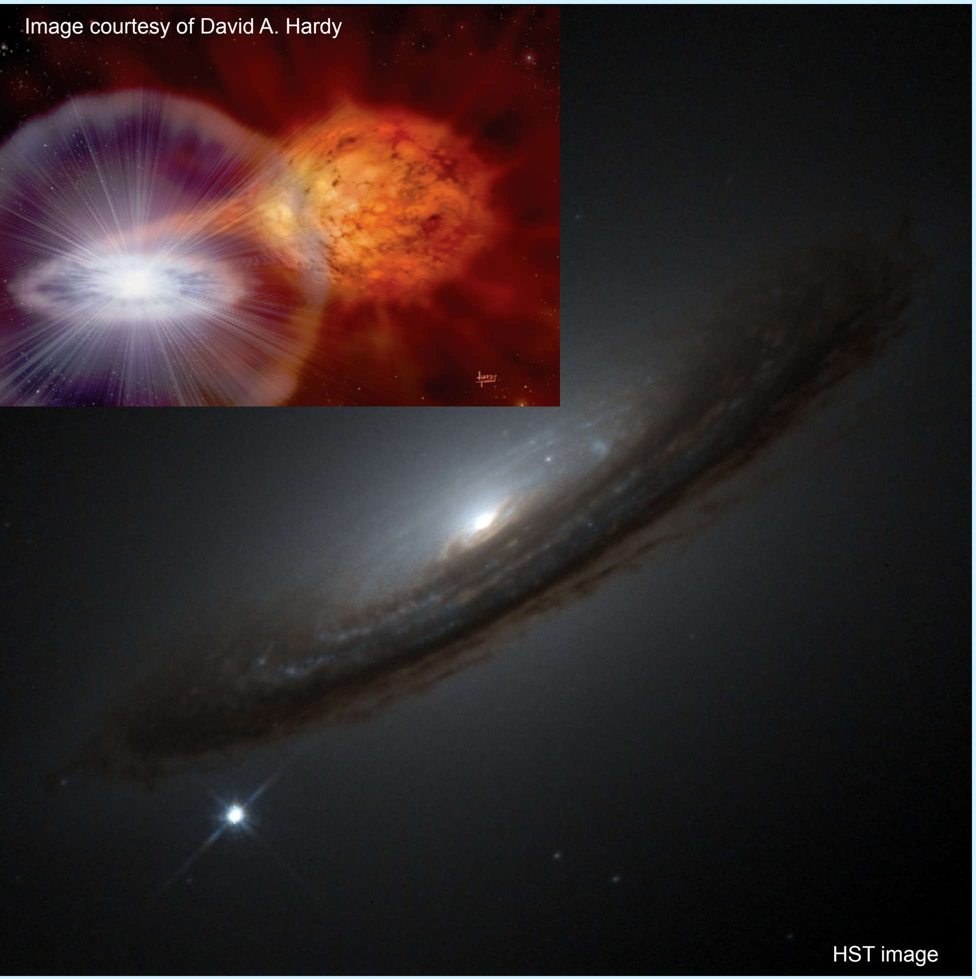
Our understanding about the universe is not complete



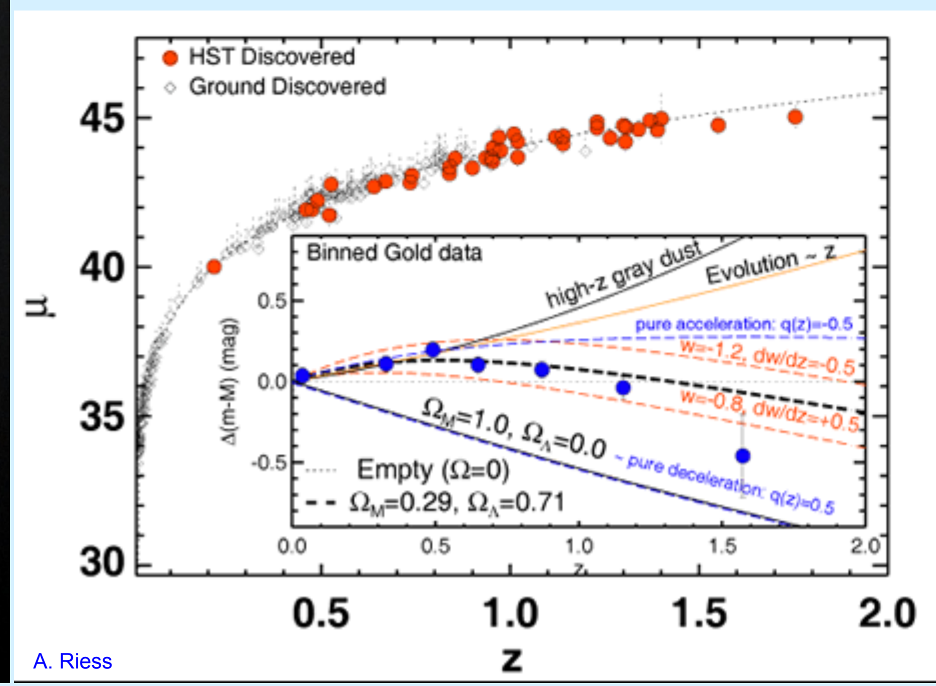
Two Darth Mysteries:
Dark Matter and Dark Energy

Dark Energy –
~72% of the energy in the Universe

Big surprise in 1998, distant supernova appear dimmer than expected because the universe's expansion is accelerating!

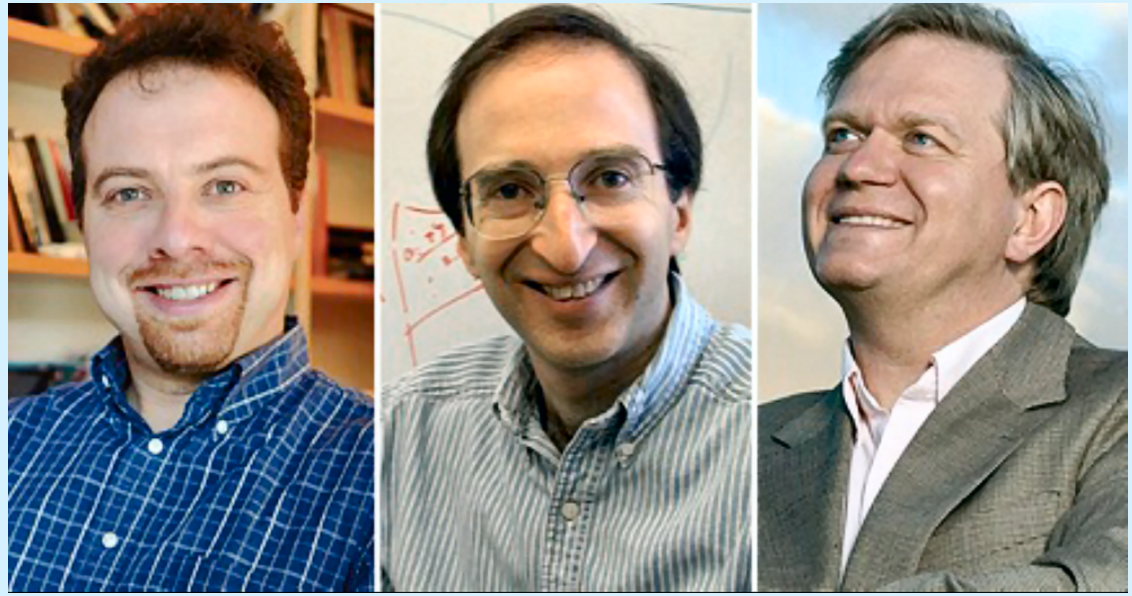


Use Type Ia supernova and plot the brightness difference as a function of distance (z)



2011 Nobel Prize in Physics

http://www.nobelprize.org/nobel_prizes/physics/medal.html

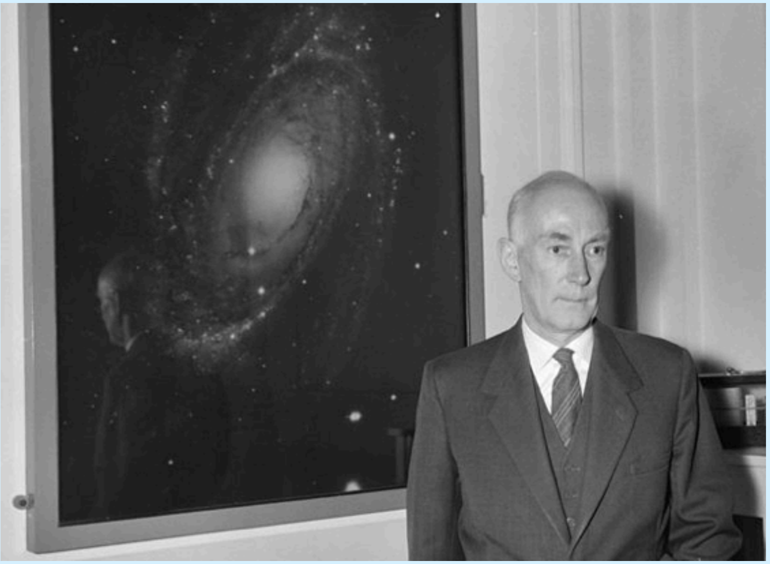


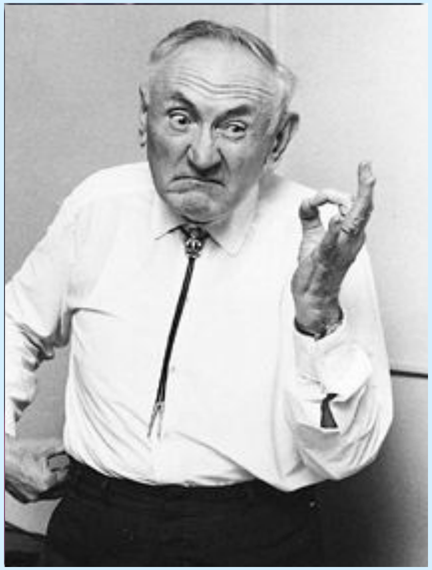
Adam Riess Saul Perlmutter Brian Schmidt

for the discovery of the accelerating expansion of the Universe through observations of distant supernovae

Now, what is the nature of dark energy?

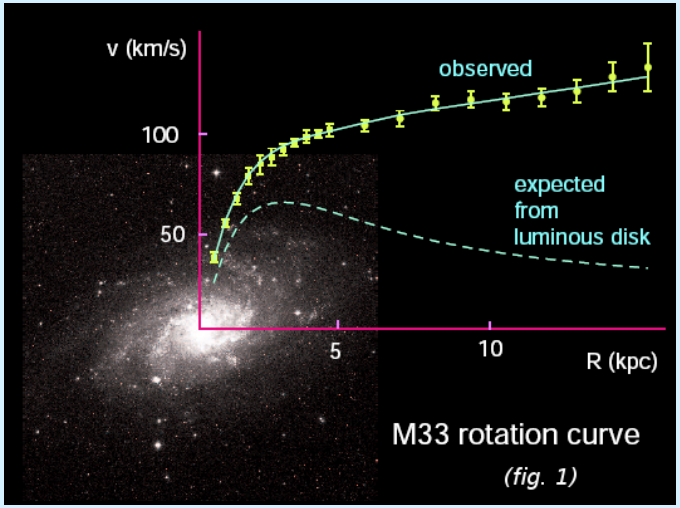
Dark Matter



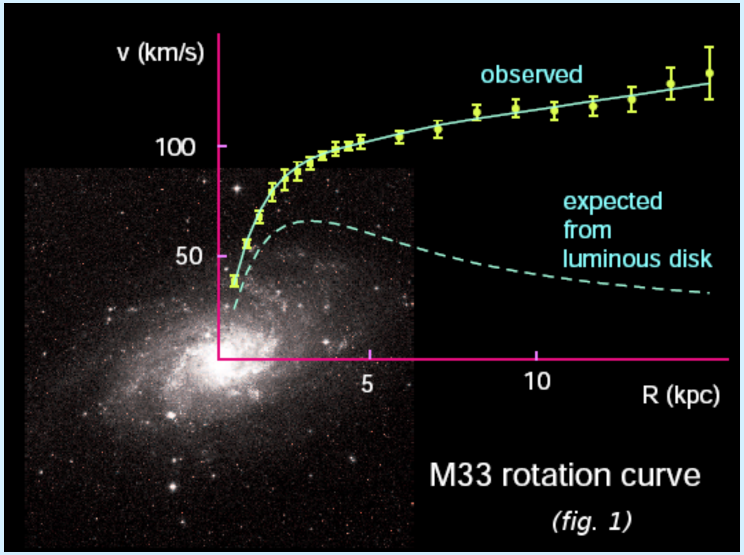


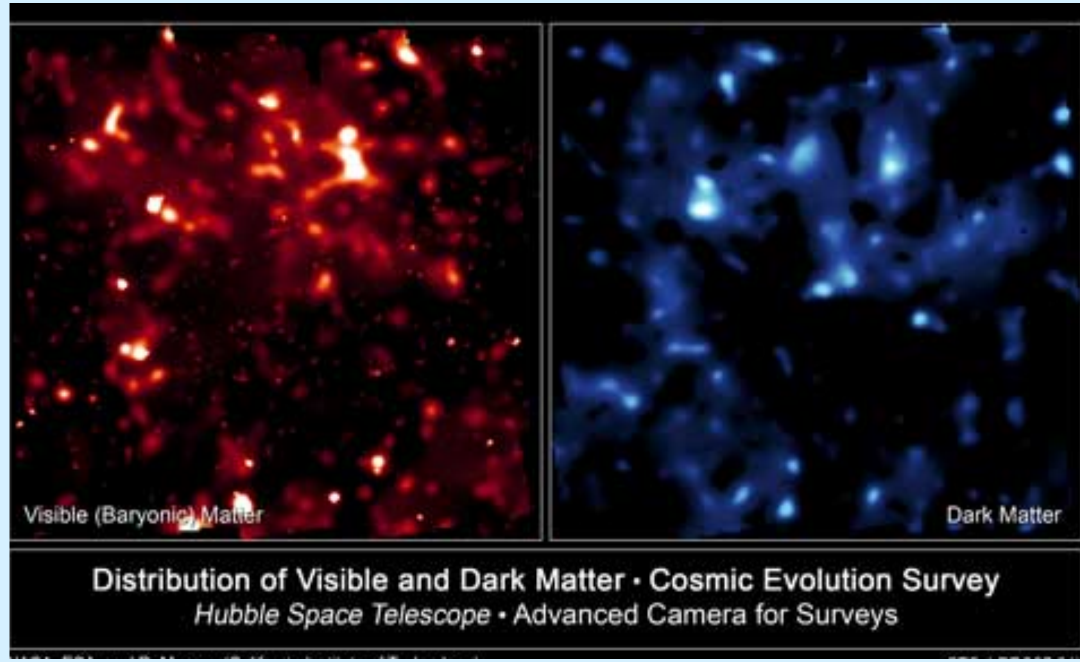
1930s: Jan Oort and Fritz Zwicky notice the amount of light in galaxies and clusters of galaxies underestimate the amount of matter

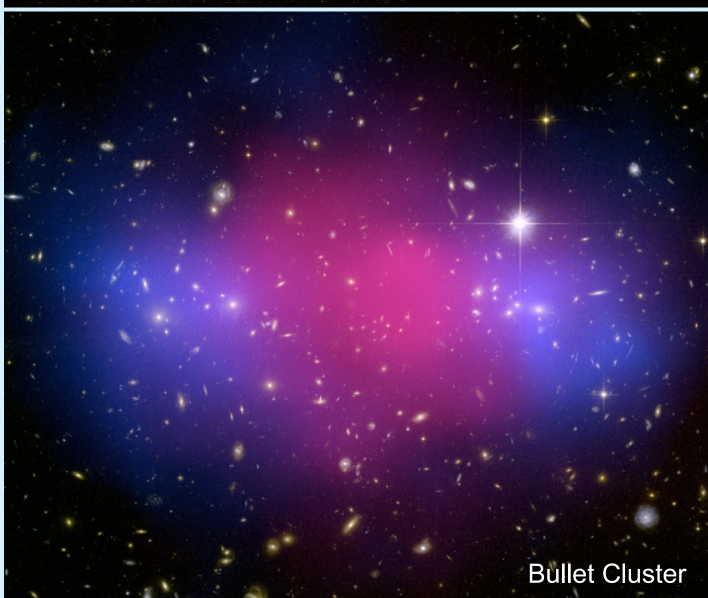
1975-80: Vera Ruben makes precise measurements of the velocities of stars around nearby galaxies firmly establishing "dark matter"



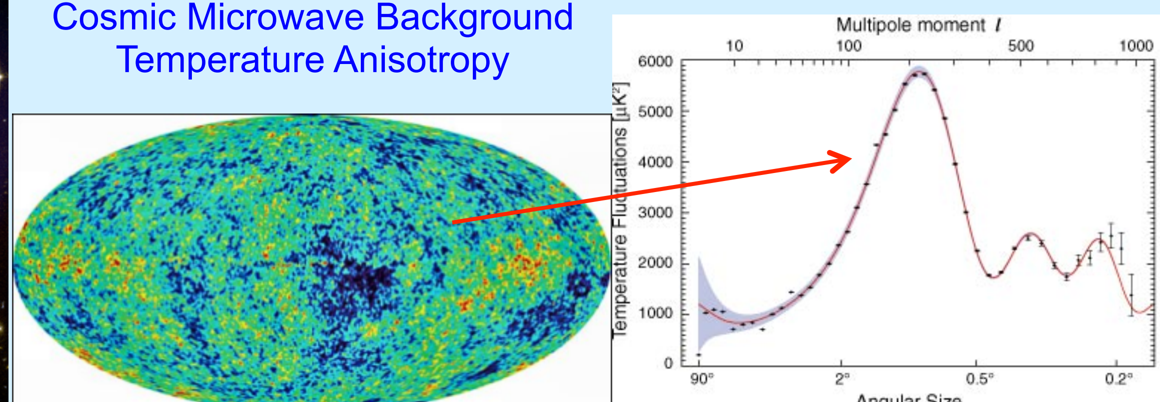
Evidence for Dark Matter exists on a variety of scales





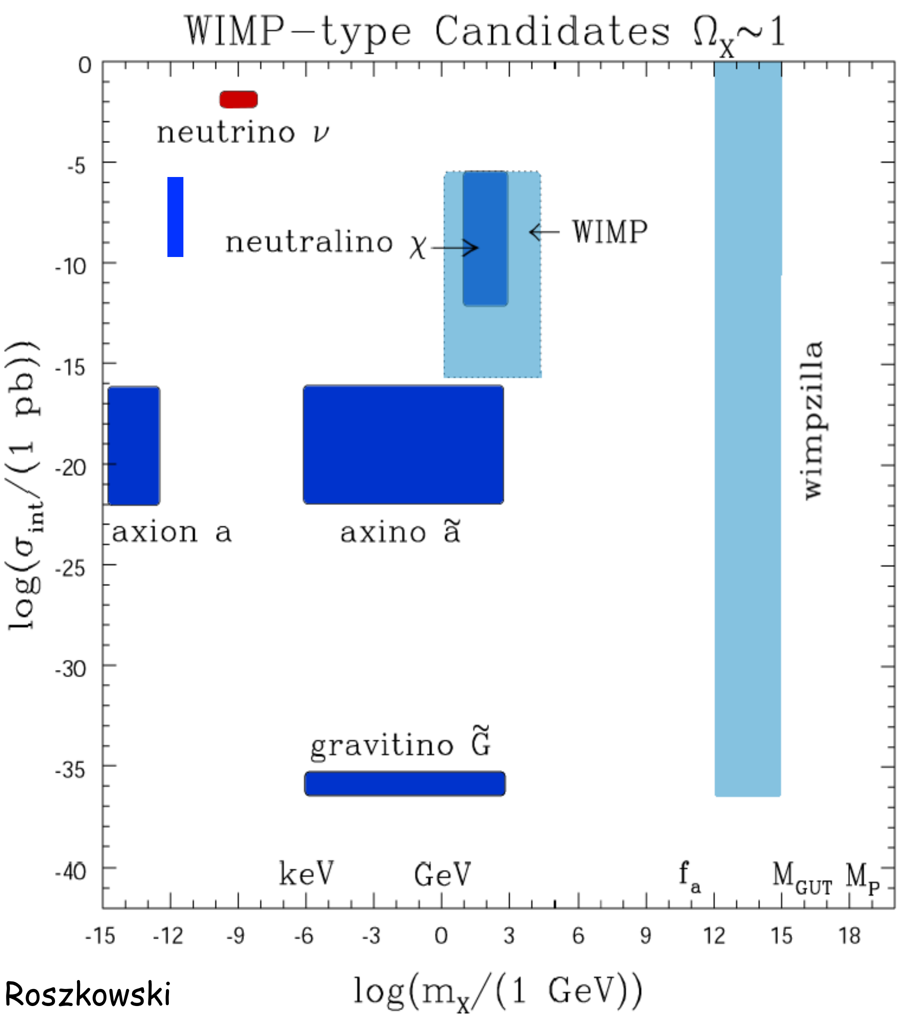


Cosmic Microwave Background Temperature Anisotropy



Dark Matter

What is the particle nature of dark matter?



L. Roszkowski

Dark Matter

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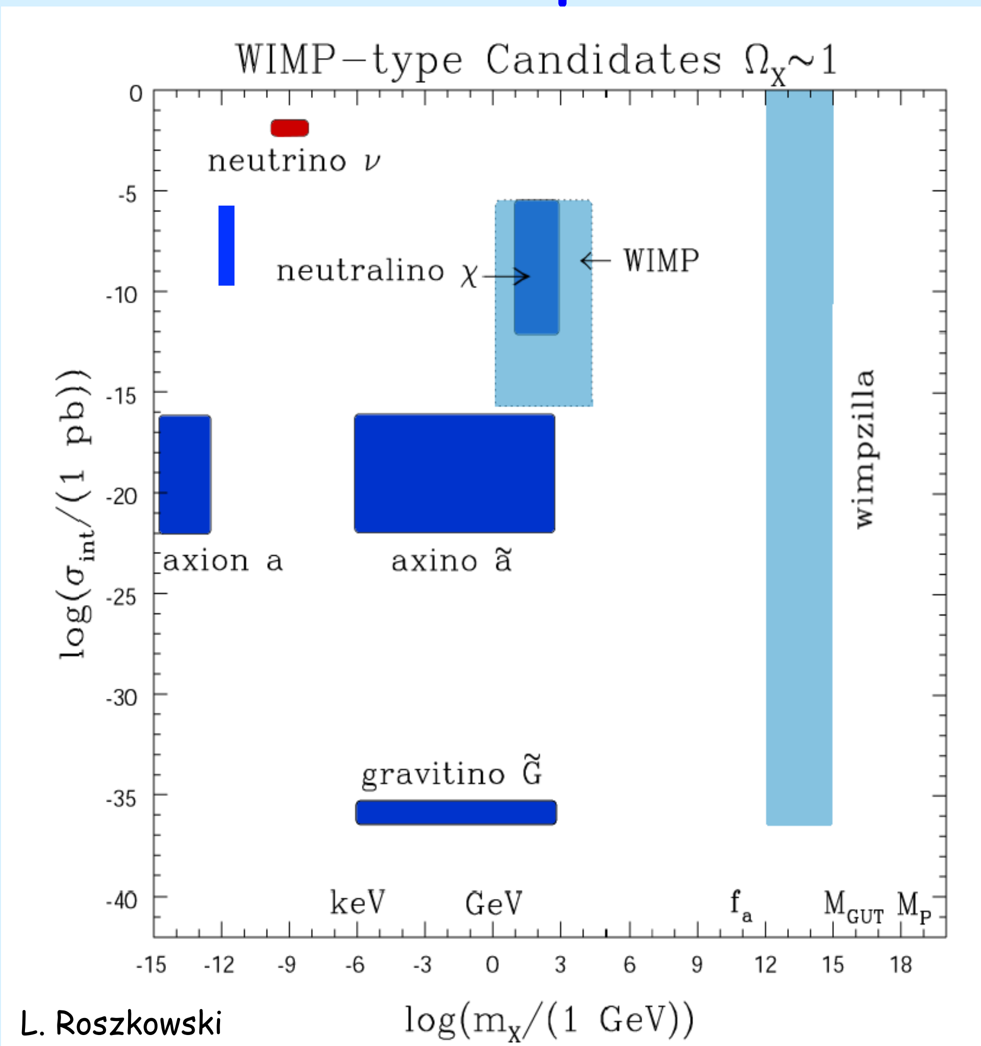
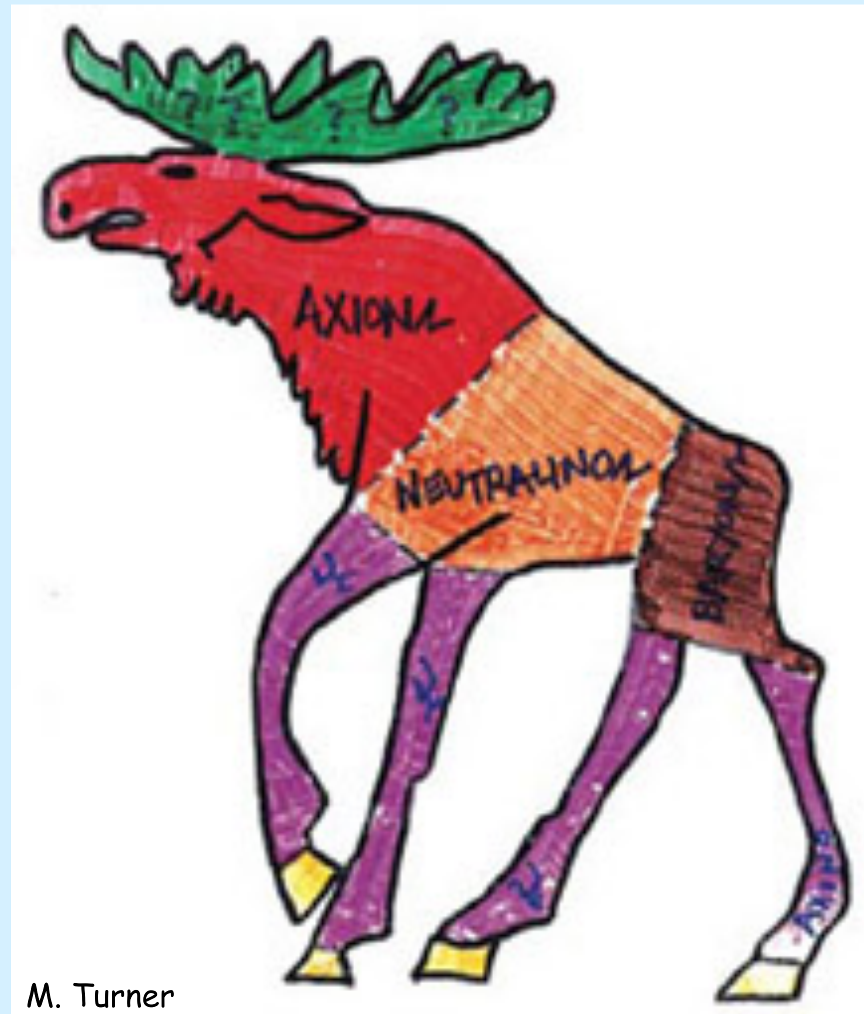


L. Roszkowski

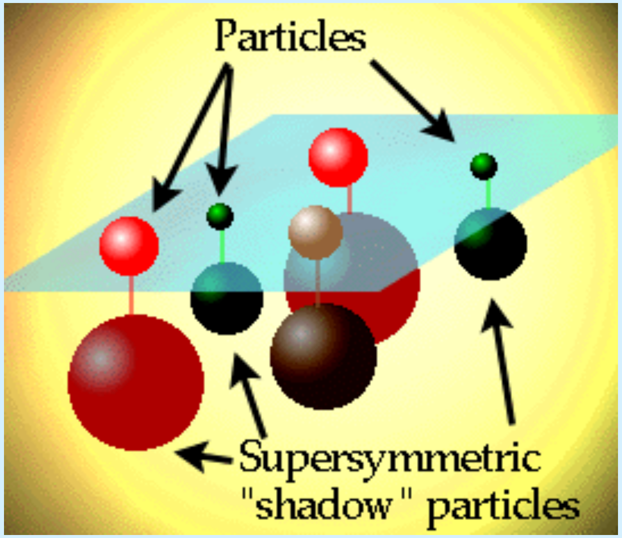


M. Turner

WIMPs

Weakly Interacting Massive Particles

- Supersymmetry is a compelling theory



Supersymmetry (SUSY) can explain:

1) The hierarchy problem
2) The abundance of dark matter in the universe
   "The WIMP Miracle!"
3) Unification of the strong and electroweak forces

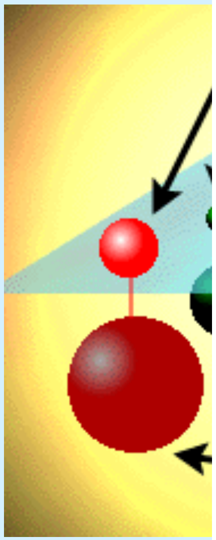
SUSY candidates have mass 10 – 1000 GeV

- Active area of research
  - At Colliders to produce new WIMP particles
  - At underground labs to see interactions in detectors
  - Looking in space for signs of annihilation photons

WIMPs

We … les

- Su…



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• Looking in space for signs of annihilation photons

The New York Times **Science**

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315 Physicists Report Failure In Search for Supersymmetry

By MALCOLM W. BROWNE
Published: January 05, 1993

1993

Three hundred and fifteen physicists worked on the experiment.

Their apparatus included the Tevatron, the world's most powerful particle accelerator, as well as a $65 million detector weighing as much as a warship, an advanced new computing system and a host of other innovative gadgets.

But despite this arsenal of brains and technological brawn assembled at the Fermilab accelerator laboratory, the participants have failed to find their quarry, a disagreeable reminder that as science gets harder, even Herculean efforts do not guarantee success.

In trying to ferret out ever deeper layers of nature's secrets, scientists are being forced to accept a markedly slower pace of discovery in many fields of research, and the consequent rising cost of experiments has prompted public and political criticism.

To some, the elaborate trappings and null result of the latest Fermilab experiment seem to typify both the lofty goals and the staggering difficulties of "Big Science," a term coined in 1961 by Dr. Alvin M. Weinberg of Oak Ridge National Laboratory. Some regard such failures as proof that high-energy physics, one of the biggest avenues of big science, is fast approaching a dead end.

WIMPs

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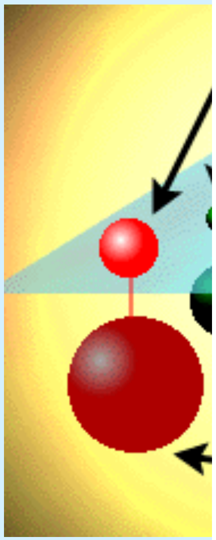

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The New York Times **Science**

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5315 Physicists Report Failure In Search for Supersymmetry

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Published: January 05, 1993 2014

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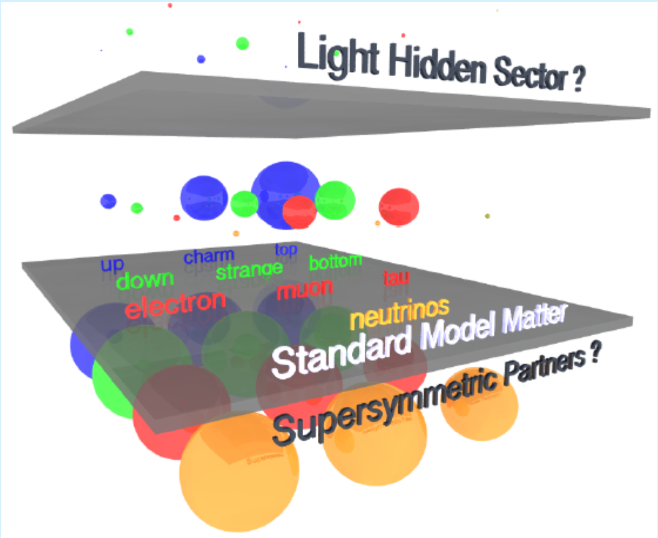
non-WIMPy Dark Matter

Weakly Interacting Slim Particles

- A Hidden Sector is a compelling theory



A Hidden Sector can explain:

1) Aspects of string theory
2) Why the New Physics has been elusive
3) Many possible new observables

Scales from μeV to > 10^{15} GeV

- A renewed area of research
  - Large areas of phase space are unexplored
  - Modest scale experiments can produce results
  - Maybe the dark matter candidates come from here

Outline

- The Axion particle – a highly motivated WISP
- "Light shining through a wall" and milli-eV masses
  - GammeV
  - Axion-like Particle – a dark matter candidate
- "Particles in a Jar"
  - GammeV-CHASE
  - Chameleons – a dark matter + dark energy particle!
- Search for a "dark photon"
  - Mini-BooNE dark matter
- Future Prospects and Conclusions

Axions

- Postulated in the late 1970s as a consequence of not observing CP violation in the strong interaction.

$$L_{CP} = -\frac{\alpha_s}{8\pi}\underbrace{(\Theta - \arg\det M_q)}_{0\leq\overline{\Theta}\leq 2\pi}\,\mathrm{Tr}\,\tilde{G}_{\mu\nu}G^{\mu\nu}$$

Raffelt

- The measurement of the electric dipole of the neutron implies $\overline{\Theta} < \sim 10^{-10}$. => Strong CP Problem of QCD
  - This is very much on the same order of an issue with the Standard Model as the hierarchy problem that motivates supersymmetry.
  - Axions originate from a new symmetry that explains small $\overline{\Theta}$

Bjorken "Axions are just as viable a candidate for dark matter as sparticles"

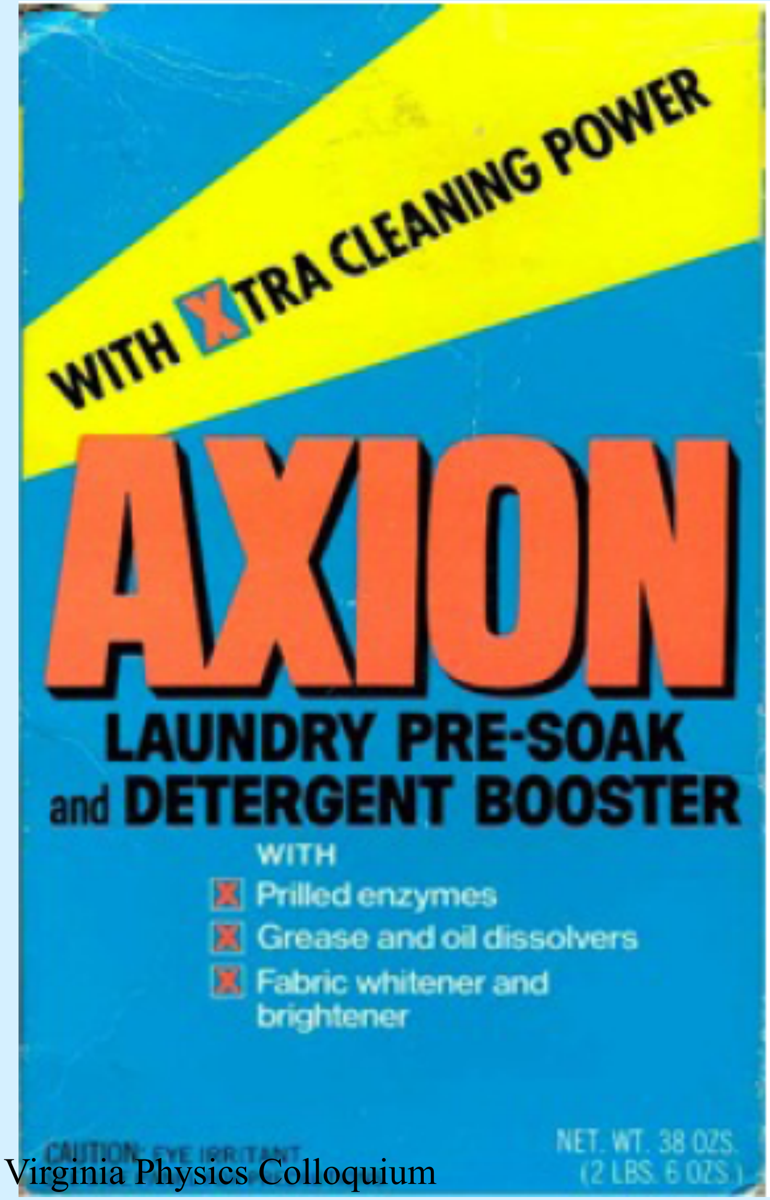
Wilczek "If not axions, please tell me how to solve the Strong-CP problem"

Witten "Axions may be intrinsic to the structure of string theory"

WW+K van Bibber

Axions

- Axions "clean-up" the strong-CP problem!



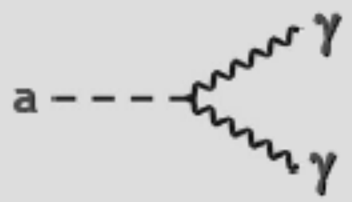
Axions and Axion-like particles

- Axion mass related to the pion mass: $m_a \sim m_\pi f_\pi / f_a$
- Axions couple to two photons

Photon coupling

$$L_{a\gamma} = -\frac{g_{a\gamma}}{4} F\tilde{F} a = g_{a\gamma} \vec{E} \cdot \vec{B} a$$

$$g_{a\gamma} = \frac{\alpha}{2\pi f_a}\left(\frac{E}{N} - 1.92\right)$$



Raffelt

- An *axion-like-particle* (ALP) is a more general particle that can arise from either a pseudoscalar or scalar field, ϕ, and no longer has the connection to the pion.

pseudoscalar

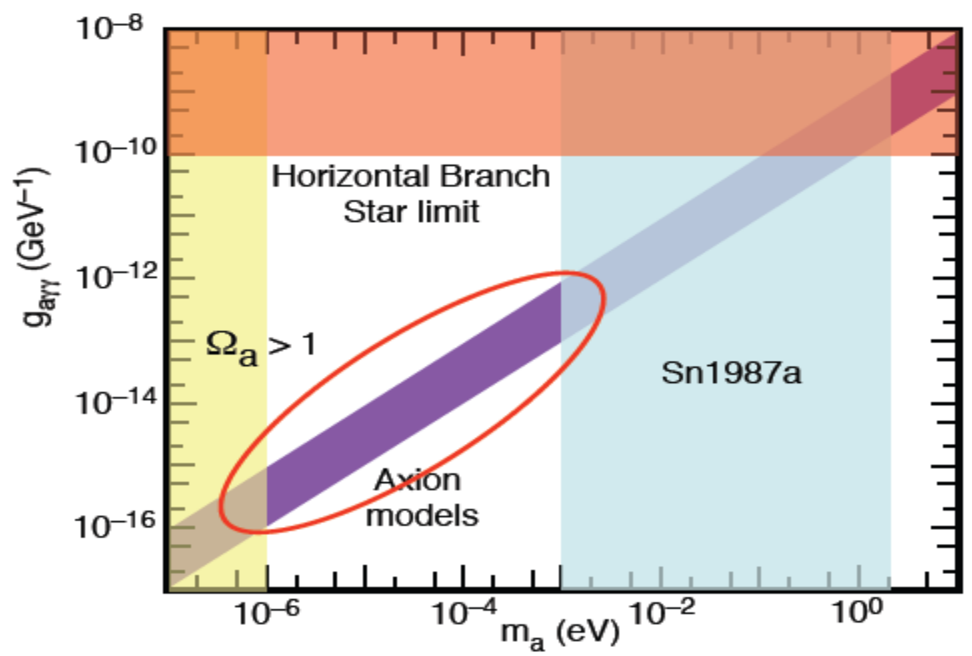
$$\mathcal{L}_{\text{int}} = -\frac{1}{4}\frac{\phi}{M} F_{\mu\nu} \widetilde{F}^{\mu\nu} = \frac{\phi}{M}(\vec{E} \cdot \vec{B})$$

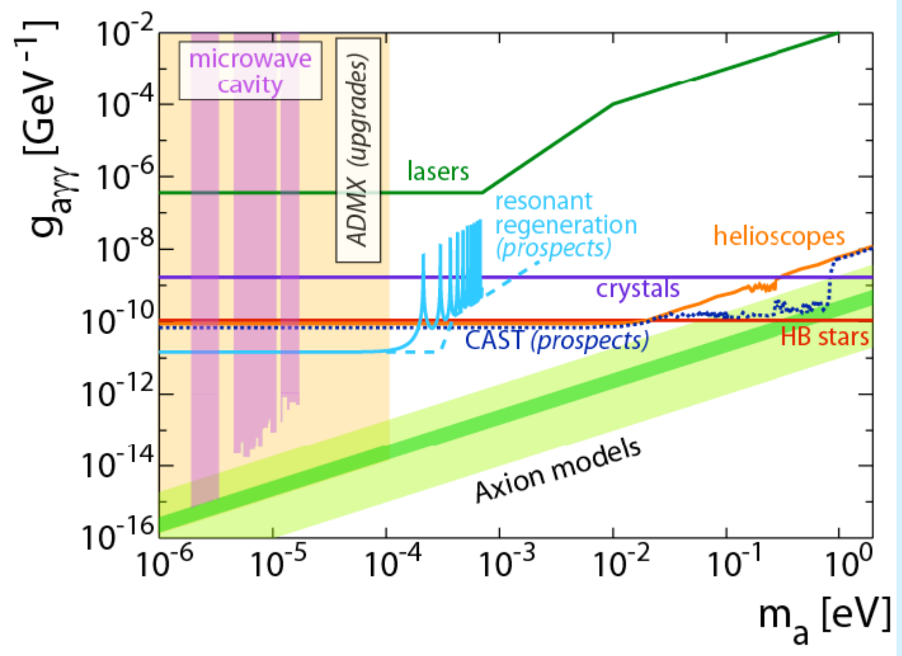
scalar

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

Searches for Axions

- QCD Axion parameters are constrained by cosmological and experimental measurements
  - Stars don't burn out, SN1987A events+energy are OK, and axions aren't all the mass of the universe.
  - Low mass limits set by microwave cavities and higher mass axions are excluded by solar telescopes



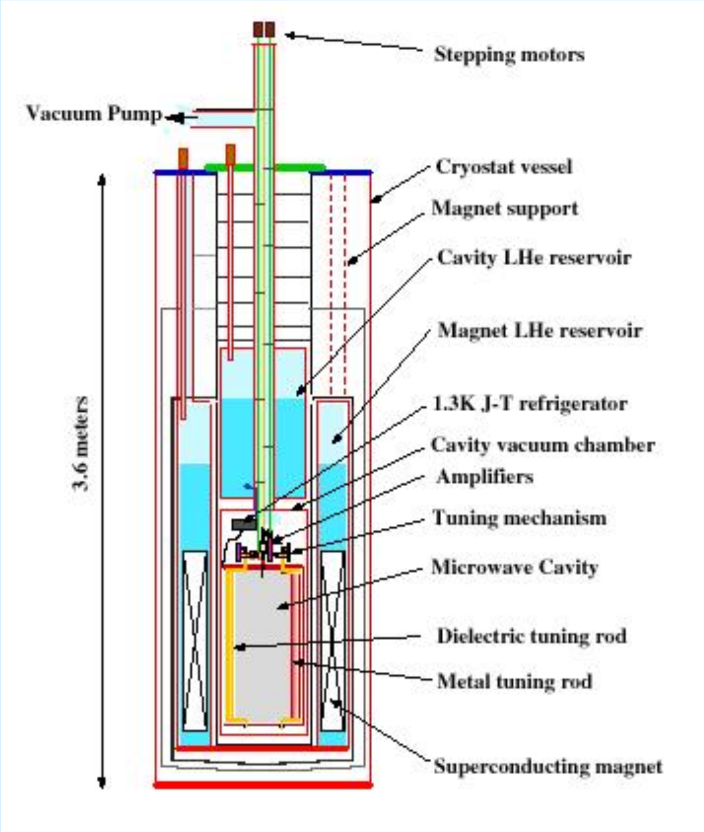


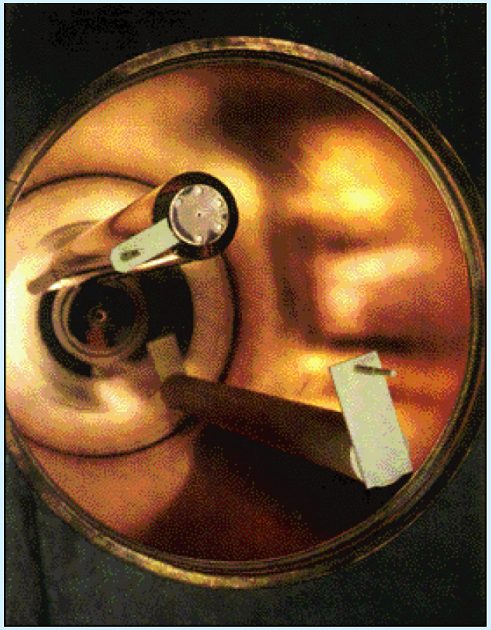
K van Bibber

PDG

ADMX Experiment

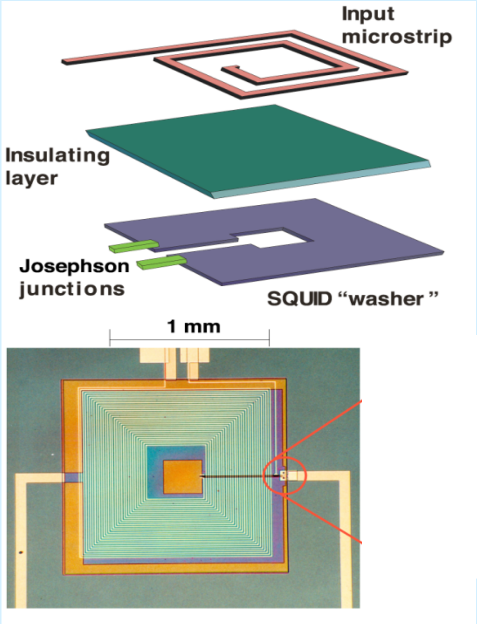
- Axion Dark Matter Experiment
  - Tunable microwave cavity in B field looking for dark matter axions converting into a detectable photons.





High Q cavity

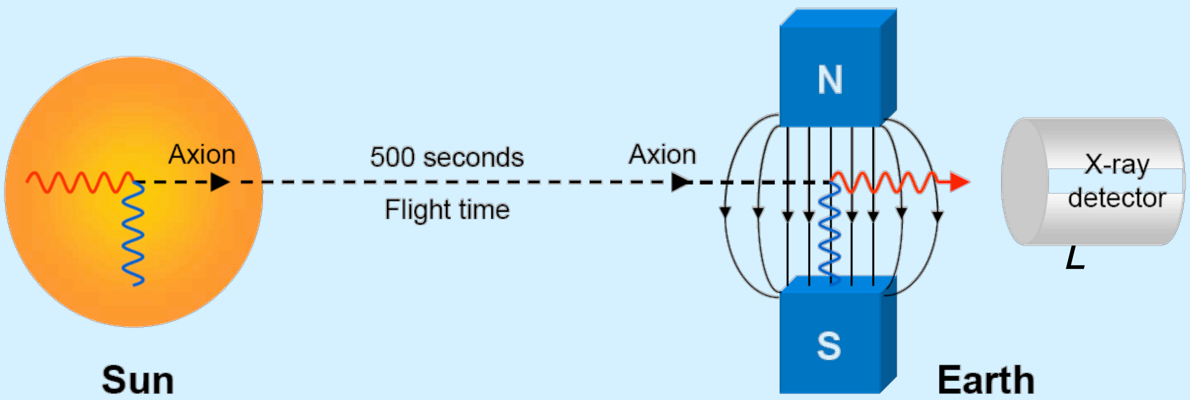
ADMX

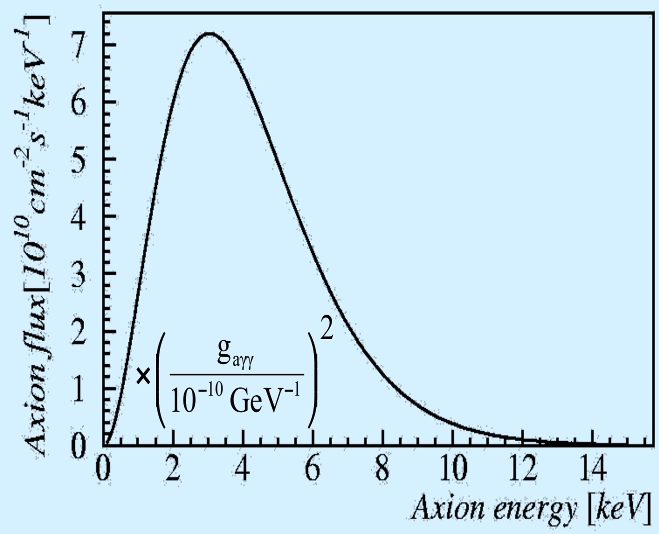


SQUID
for receiver

CAST Experiment

- CERN Axion Solar Telescope



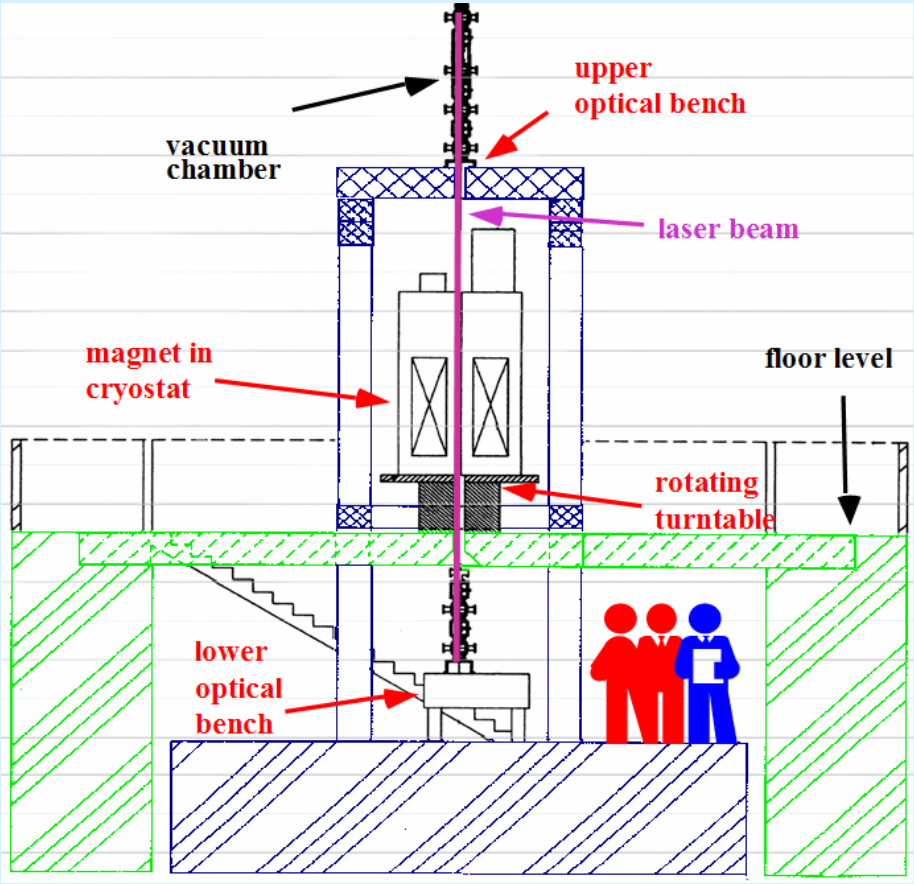


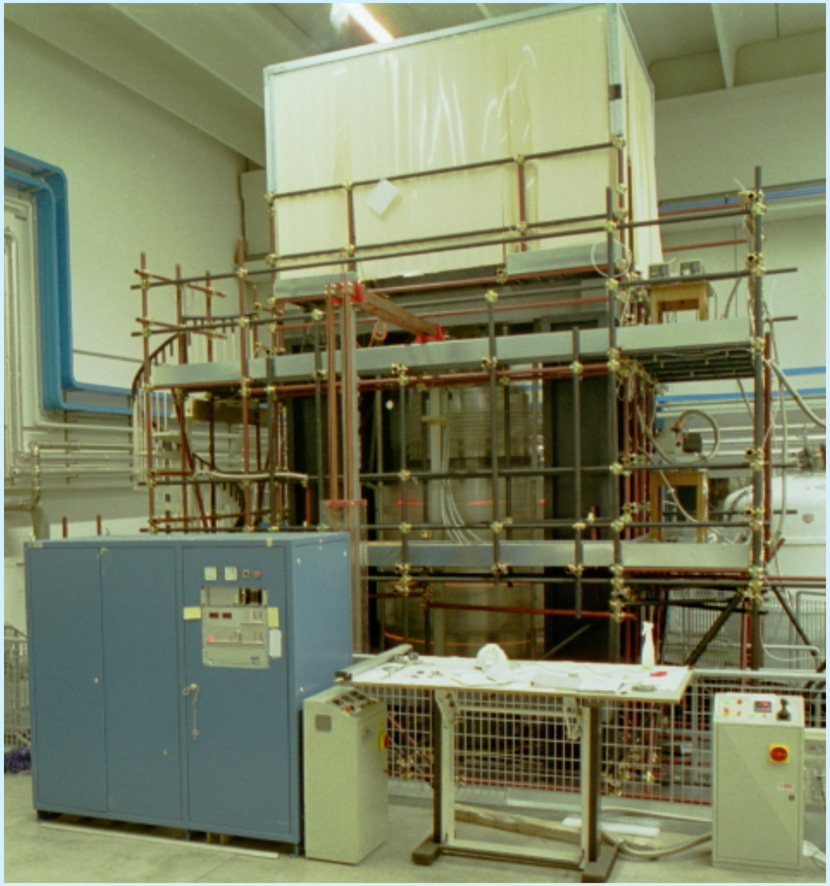
Point LHC dipole toward the sun.
Detect possible X-rays from axion reconversion.

CAST

PVLAS Experiment

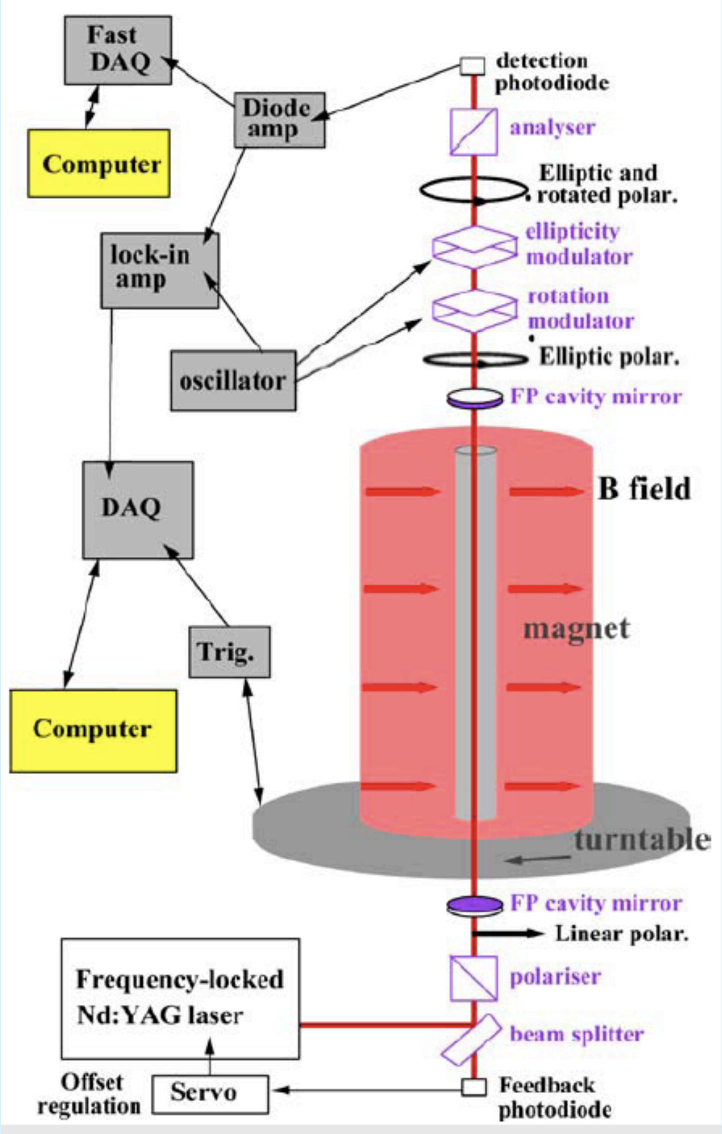
- Designed to study the vacuum by optical means: birefringence (generated ellipticity) and dichroism (rotated polarization)



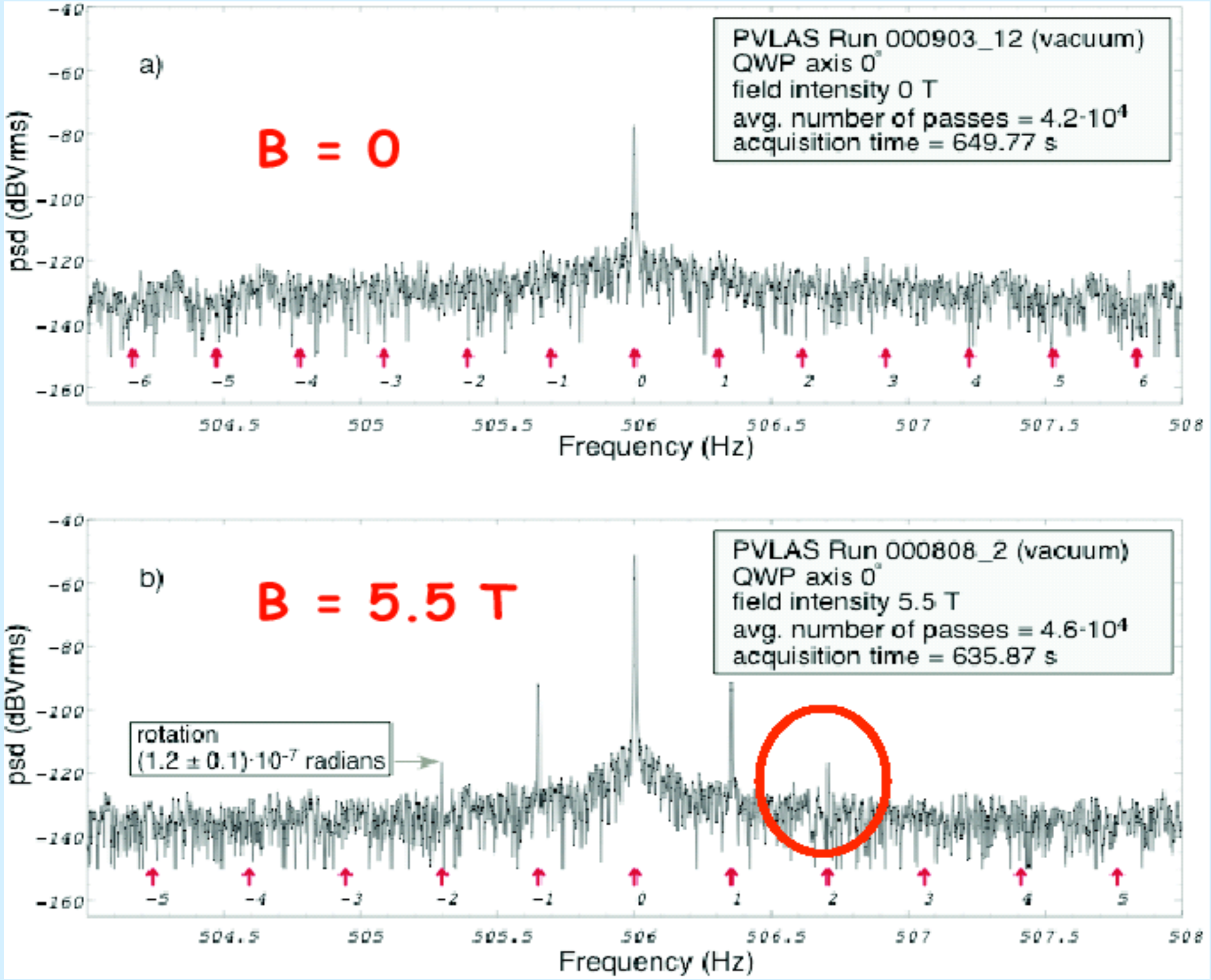


PVLAS Experiment

- Rotating SC magnet (½ Hz)
- Modulators (500 Hz)
- ¼ wave plate to switch between ellipticity and rotation
- Optical cavity to amplify path length in B field
- Expect signals in 2nd harmonic only when B_{ext} field is aligned with either E or B of the γ
- Cross-checks including with birefringent gasses



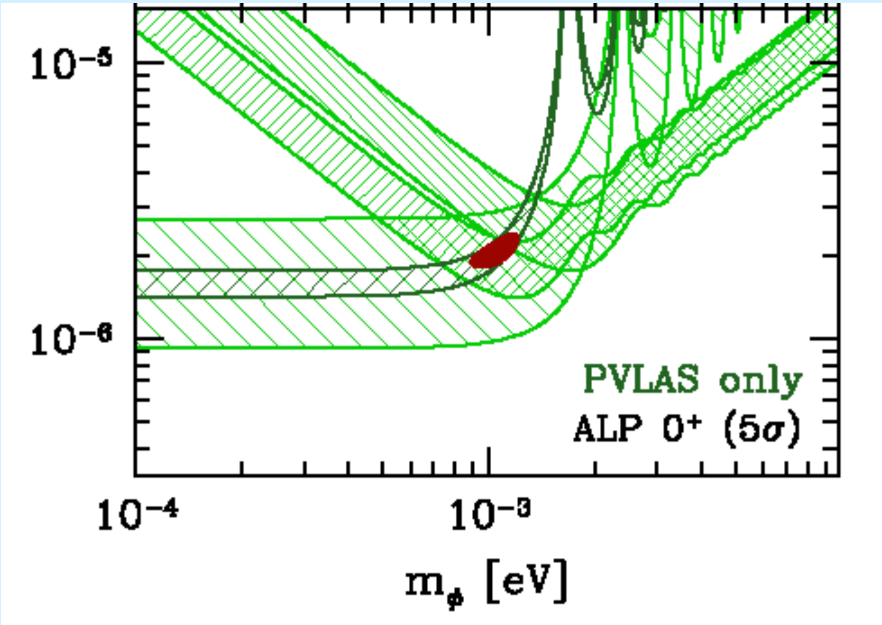
PVLAS Rotation Results

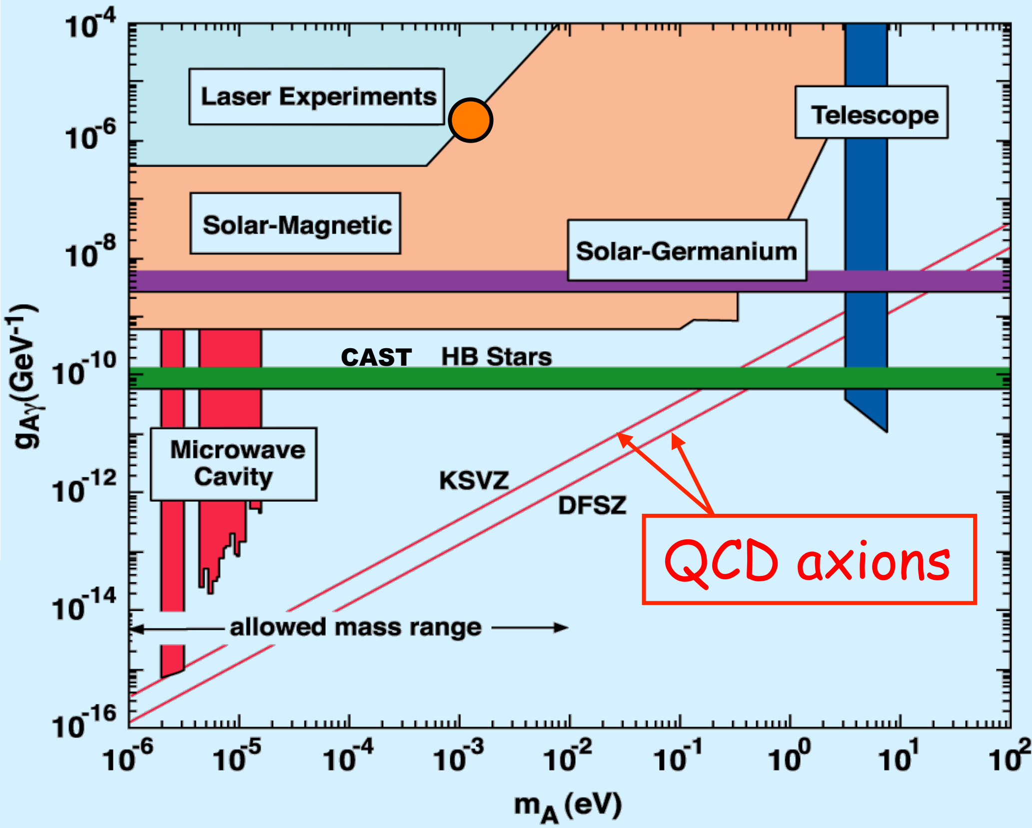


PRL 96, 110406, (2006)

PVLAS ALP Interpretation

A new axion-like particle with mass at 1.2 meV and $g \sim 2 \times 10^{-6}$ is consistent with rotation and ellipticity measurements.

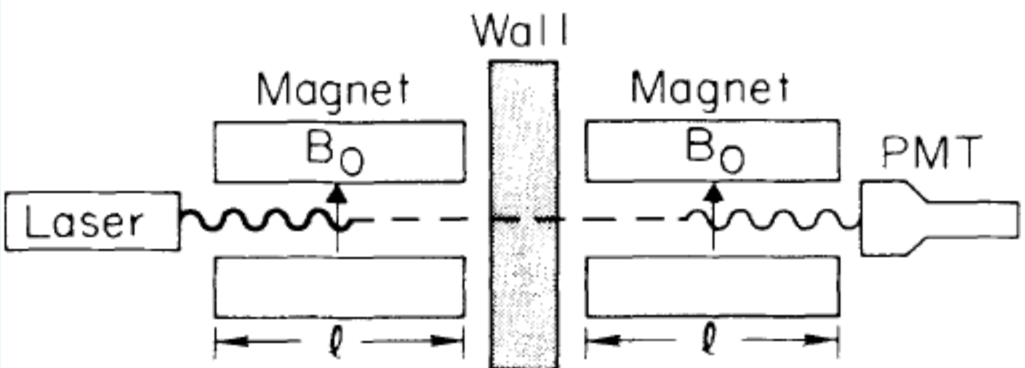




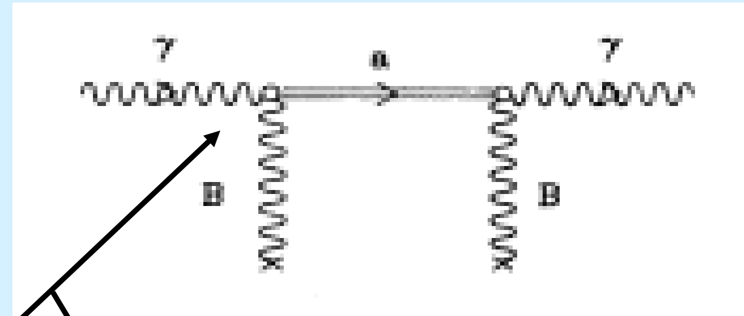
Additional data by PVLAS has since no longer seen the anomalous effects. However, the source of the anomaly has not been clarified.

PRD **77**, 032006 (2008)

Light Shining Through a Wall Experiment



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



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

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

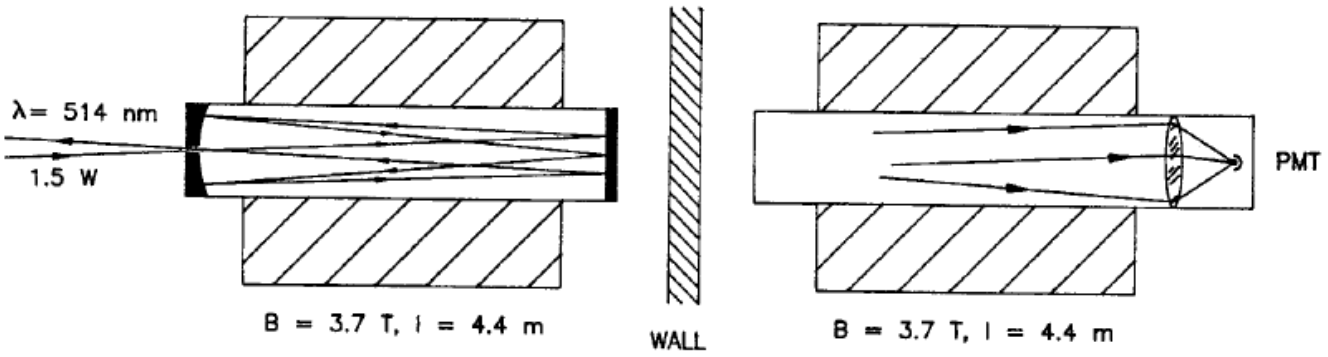
$$P_{regen} = \frac{16 B_1^2 B_2^2 \omega^4}{M^4 m_\phi^8} \sin^2\left(\frac{m_\phi^2 L_1}{4\omega}\right)\cdot \sin^2\left(\frac{m_\phi^2 L_2}{4\omega}\right)$$

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

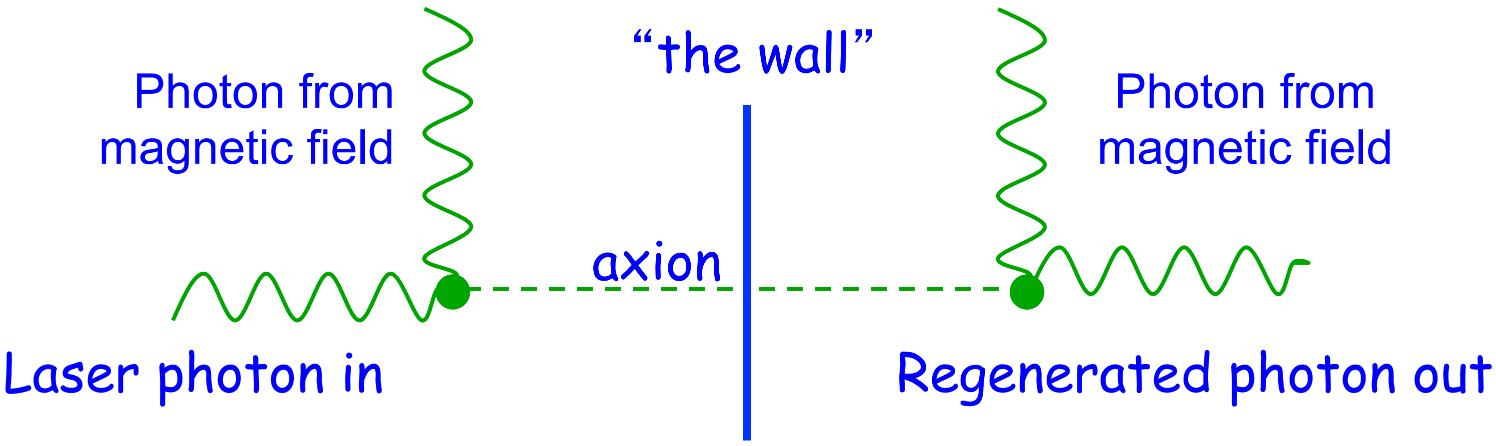
$$P_{regen}^{GammeV} = (3.9\times 10^{-21}) \times \frac{(B_1/5\ \mathrm{T})^2 (B_2/5\ \mathrm{T})^2 (\omega/2.33\ \mathrm{eV})^4}{(M/4\times 10^5\ \mathrm{GeV})^4 (m_\phi/1.2\times 10^{-3}\ \mathrm{eV})^8}$$
$$\times \sin^2\left(\frac{\pi}{2}\frac{(m_\phi/1.2\times 10^{-3}\ \mathrm{eV})^2 (L_1/2.0\ \mathrm{m})}{(\omega/2.33\ \mathrm{eV})}\right) \sin^2\left(\frac{\pi}{2}\frac{(m_\phi/1.2\times 10^{-3}\ \mathrm{eV})^2 (L_2/2.0\ \mathrm{m})}{(\omega/2.33\ \mathrm{eV})}\right)$$

Light Shining through a wall

- Brookhaven, Fermilab, Rochester, Trieste (1992)

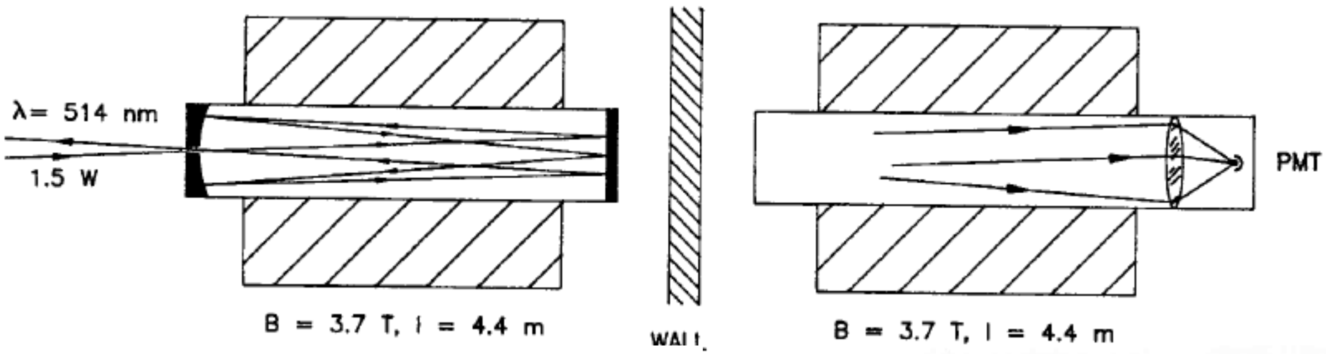


Light shining through a wall

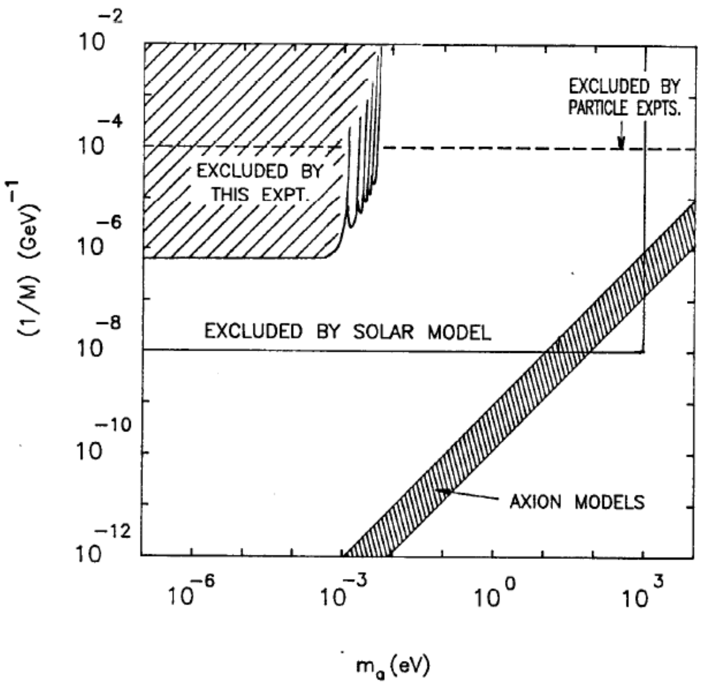


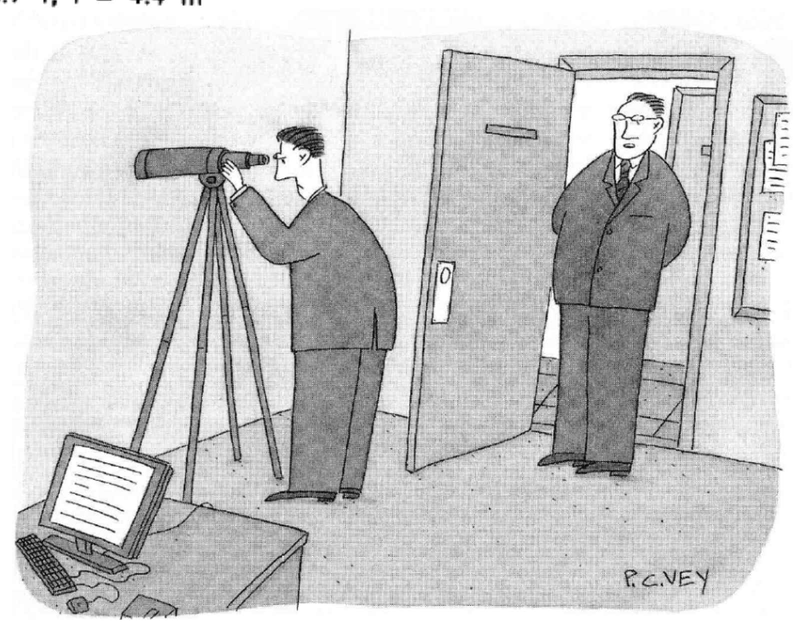
Light Shining through a wall

- Brookhaven, Fermilab, Rochester, Trieste (1992)



Light shining through a wall

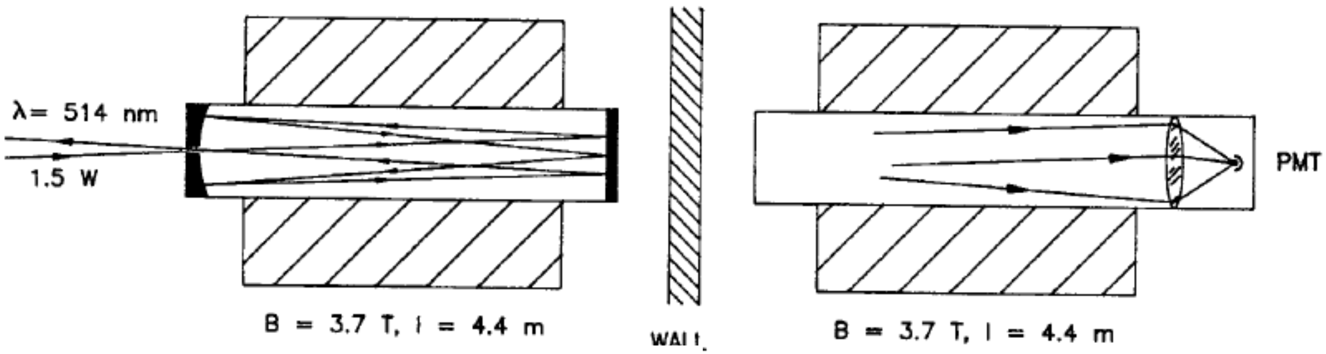




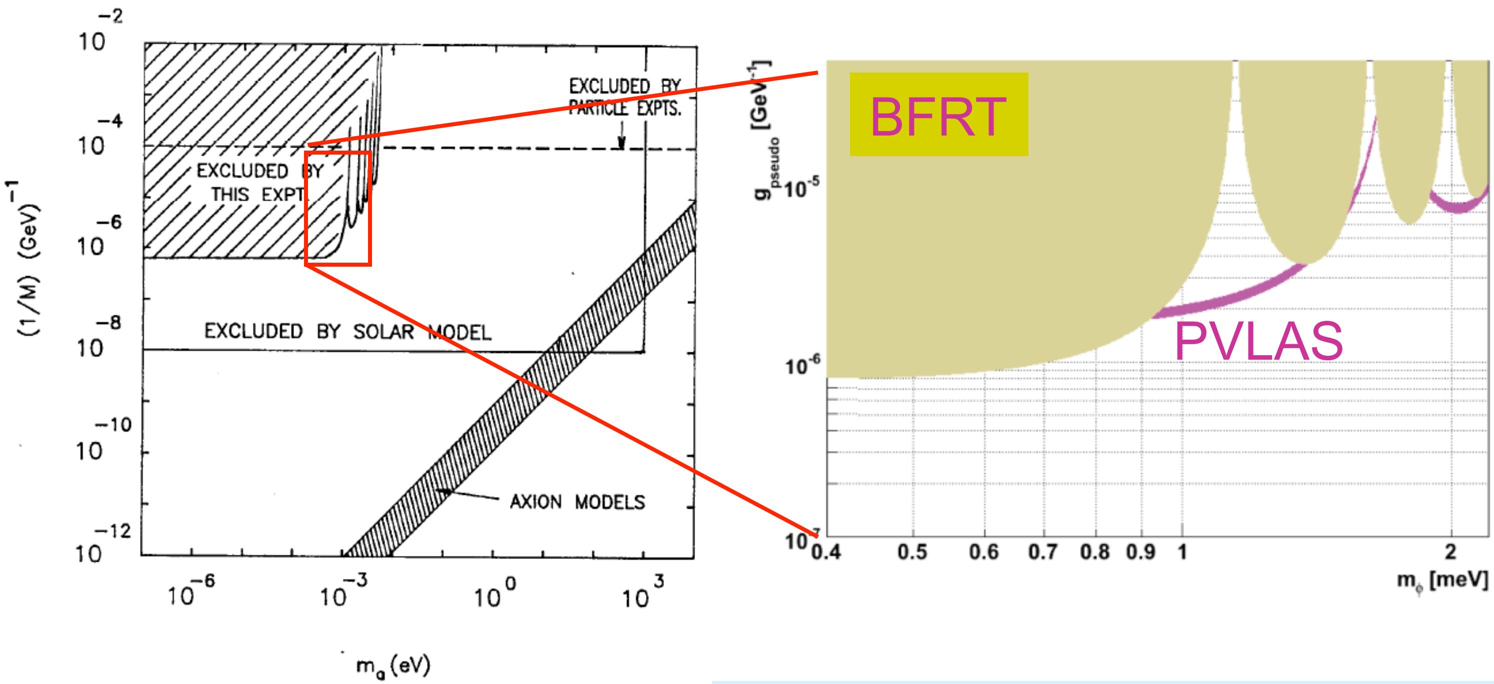
New Yorker

Light Shining through a wall

- Brookhaven, Fermilab, Rochester, Trieste (1992)



Light shining through a wall



BFRT is not sensitive in the PVLAS region of interest.

GammeV Collaboration

A. Baumbaugh, A. Chou[*], Y. Irizarry-Valle[†], P. Mazur, J. Steffen, R. Tomlin, W. Wester[*], Y. Xi[‡], J. Yoo
Fermi National Accelerator Laboratory
Batavia, IL 60510

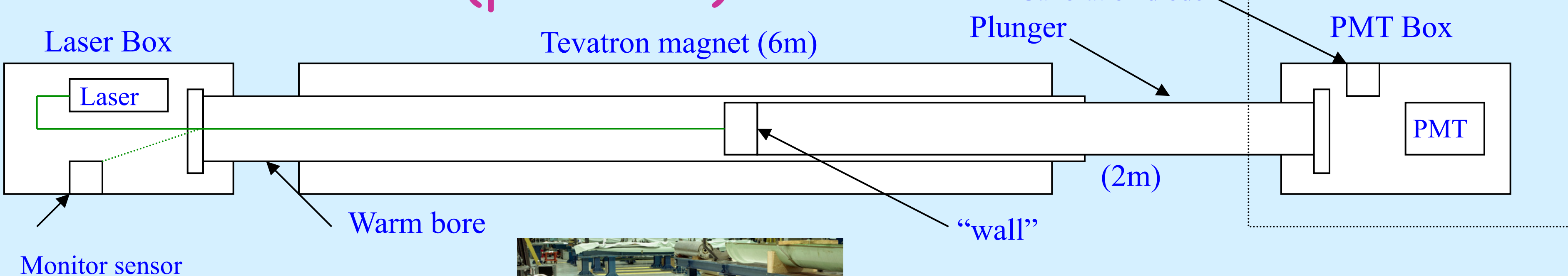
D. Gustafson
University of Michigan
Ann Arbor, MI 48109

Ten person team including a summer student, 3 postdocs, 2 accelerator / laser experts, 4 experimentalists (nearly everyone had a day job) PLUS technical support at FNAL

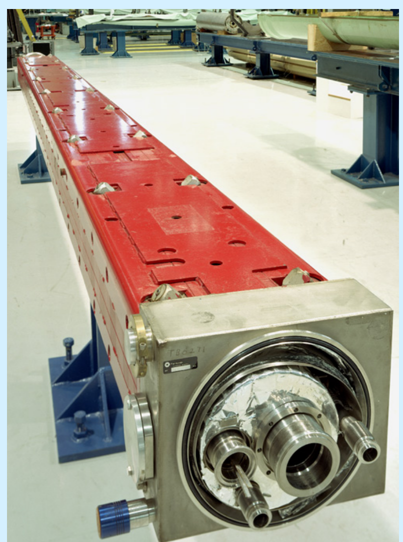
Nov : Initial discussion and design (Aaron Chou, WW leaders)
Apr : Review and approval from Fermilab ($30K budget!)
May : Acquire and machine parts
Jun : Assemble parts, test electronics and PMT calibration
Jul : First data but magnet and laser problems
Aug : Start data taking in earnest
Sep : Complete data taking and analysis
Jan : PRL Accepted

Gamme**V** 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

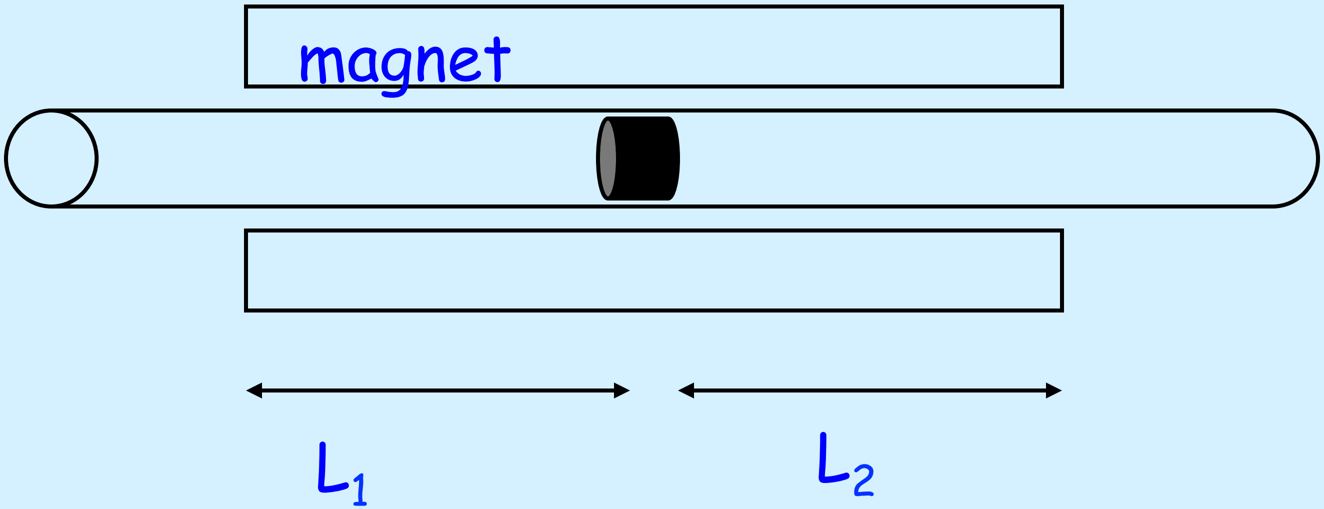


The "wall" is a welded steel cap on a steel tube in addition to a reflective mirror.

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

Vary wall position to change baseline: Tune to the correct oscillation length

A unique feature of our proposal to cover larger m_ϕ range



$$P_{\gamma\to\phi} = \frac{4B^2\omega^2}{M^2(\Delta m^2)^2}\left(\sin\frac{\Delta m^2 L}{4\omega}\right)^2$$

L = distance traversed in B field

$$P_{regen} = \left(\frac{4B^2\omega^2}{M^2(\Delta m^2)^2}\right)^2\left(\sin\frac{\Delta m^2 L_1}{4\omega}\right)^2\left(\sin\frac{\Delta m^2 L_2}{4\omega}\right)^2$$

Vary wall position to change baseline: Tune to the correct oscillation length

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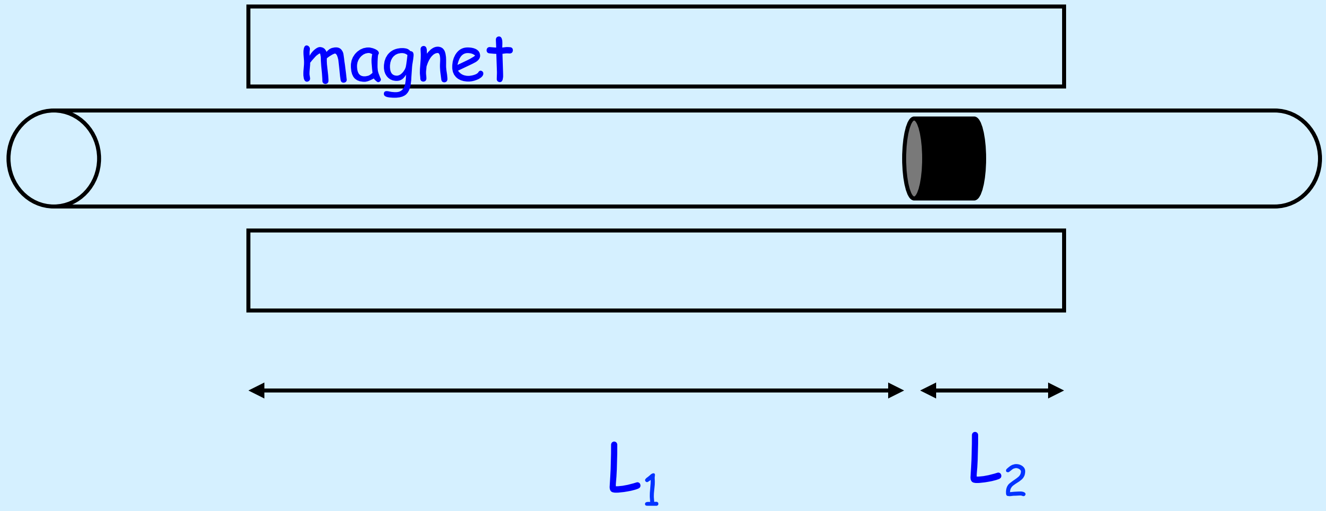

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Apparatus

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

Laser box

Tevatron magnet

Vacuum port

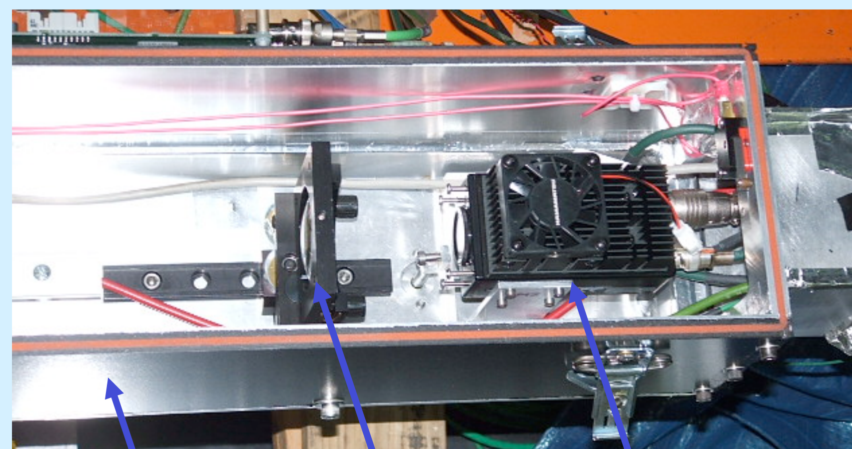
Cryogenic magnet feed can

Cryogenic magnet return can

Cryogenic magnet return can

Vacuum tube connected to plunger

PMT box

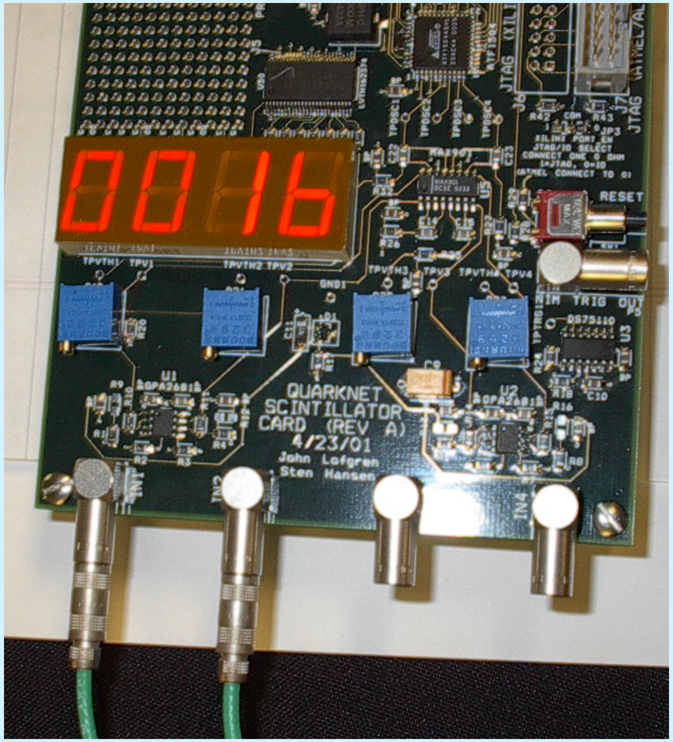


PMT box

Lens

PMT

Data acquisition



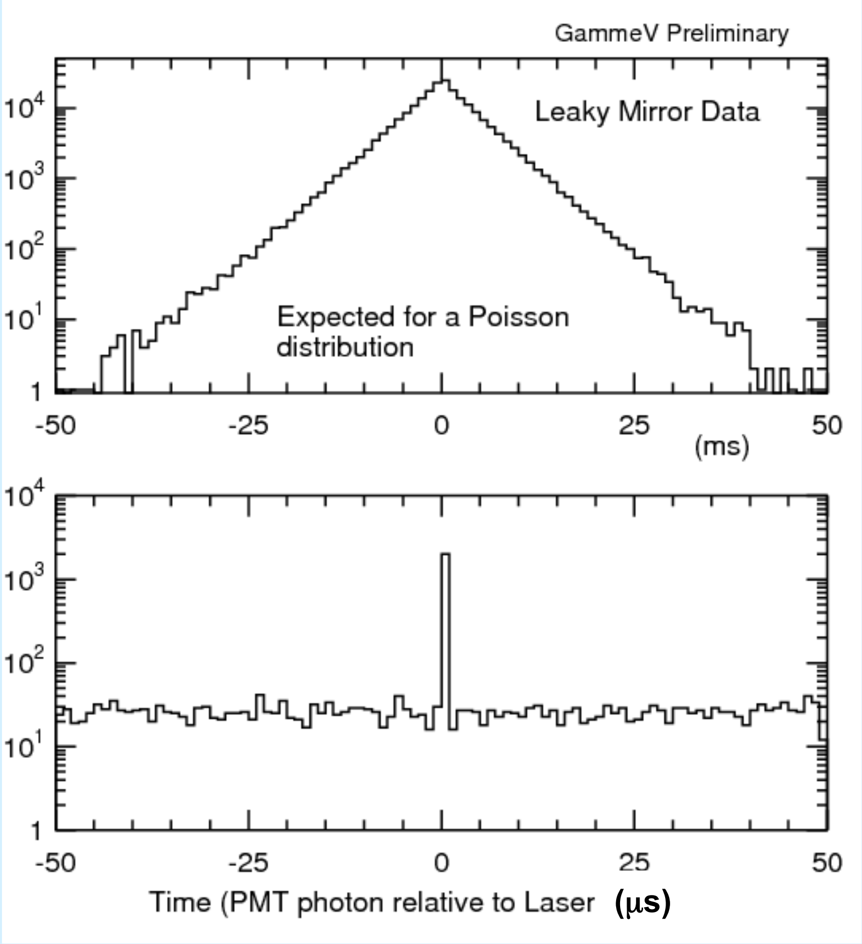
- QuarkNet timing cards
  - Built by Fermilab for Education Outreach (High School cosmic ray exp' ts.)
  - Interfaces to computer via USB (Visual Basic software for our DAQ)
- Four inputs, phase locked to a GPS 1pps using a 100MHz clock that is divided by eight for 1.25ns timing.
- Boards also send firing commands to the laser and LED pulser system
- Digital oscilloscope recorded PMT signals for LED photons and for rare coincidences.

Time the laser pulses (20Hz) and time the PMT pulses (120Hz). Look for time correlated single photons. All pulses are ~10ns wide.

	Ch0	Ch1	Ch2	Ch3
PMT Quark Net	PMT pulse	LED pulse	Scope trigger	Isochro nous CLK
Laser Quark Net	Laser Photo diode	Laser Splash	Laser Synch pulse	Isochro nous CLK

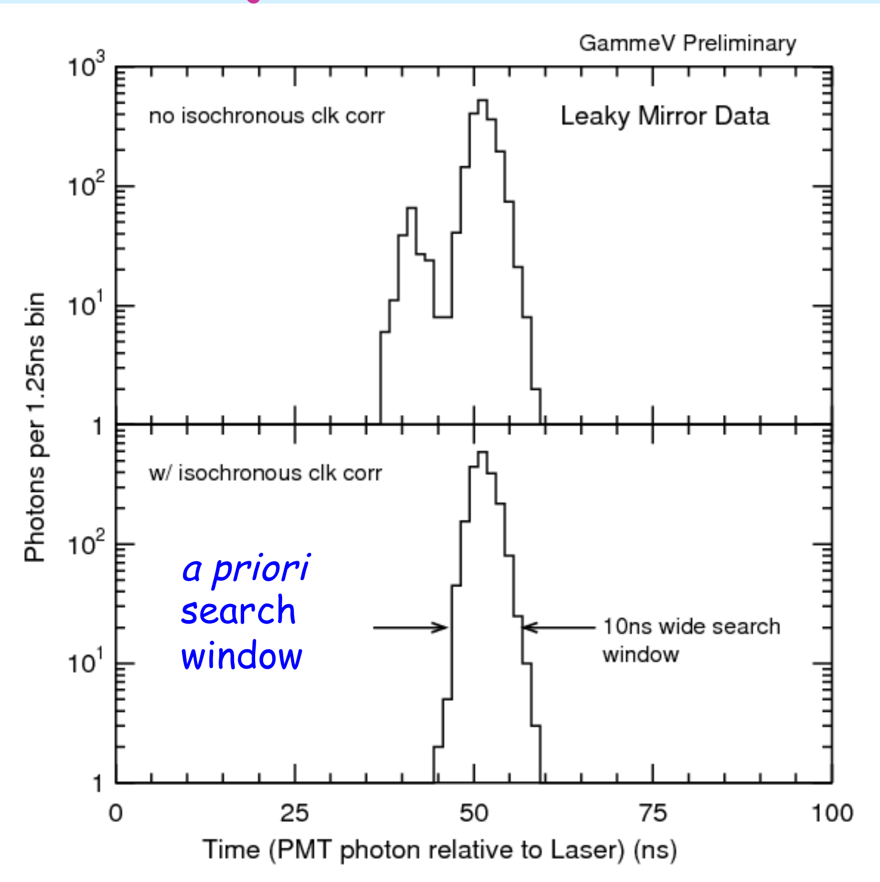
Calibration

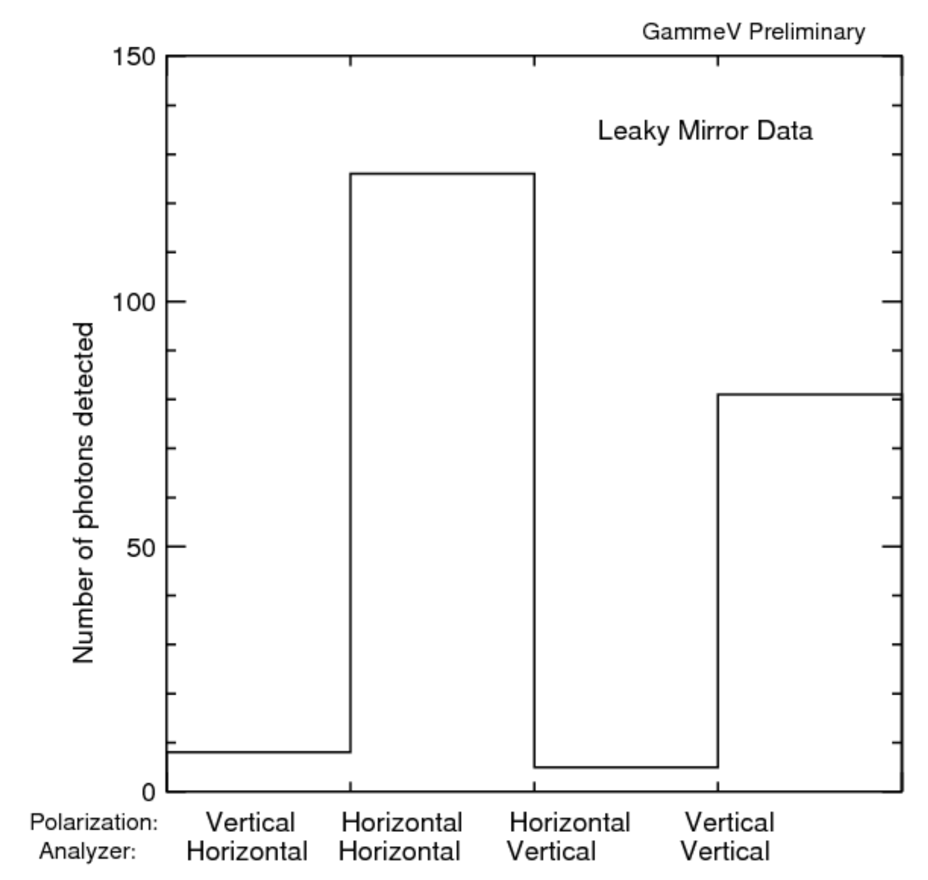
- "Leaky mirror" data involves sending the laser directly into our PMT after attenuation so that we get about 1 photon per 100 pulses.
  - Two mirrors leak $\sim 10^{-6}$ through
  - 10 micron pin hole captures $\sim 10^{-6}$
  - Neutral density filters give $\sim 10^{-7}$
- Look at the PMT pulse closest to a laser pulse and plot the time difference.
  - Poisson distribution
  - Nearly flat over short times <<ms
- Real photons show up!



Calibration

- Use the "Leaky Mirror" data to verify both the absolute timing and the sensitivity to polarization.
- The isochronous pulse to both QuarkNet boards can be used to remove a 10ns jitter.



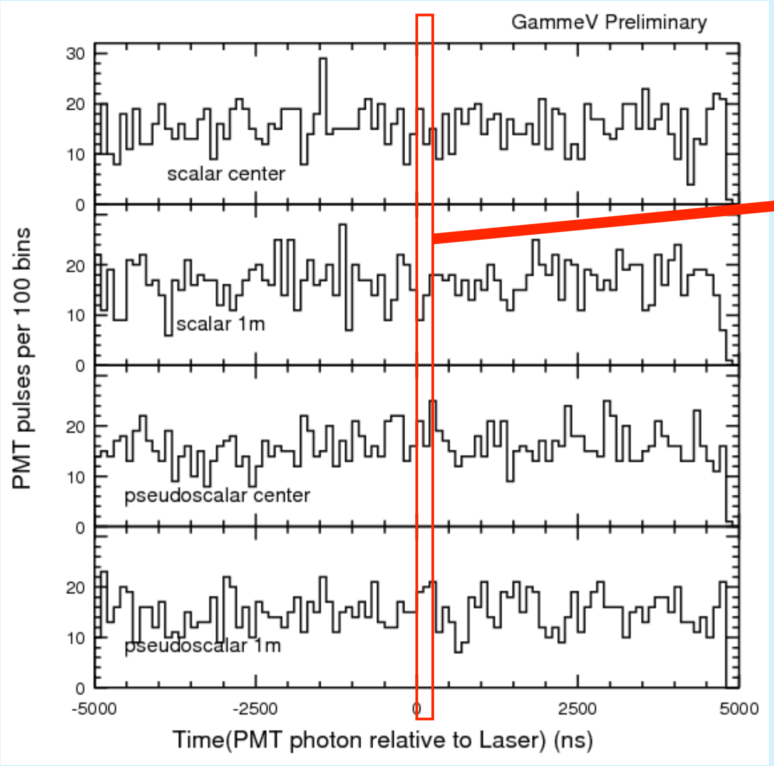


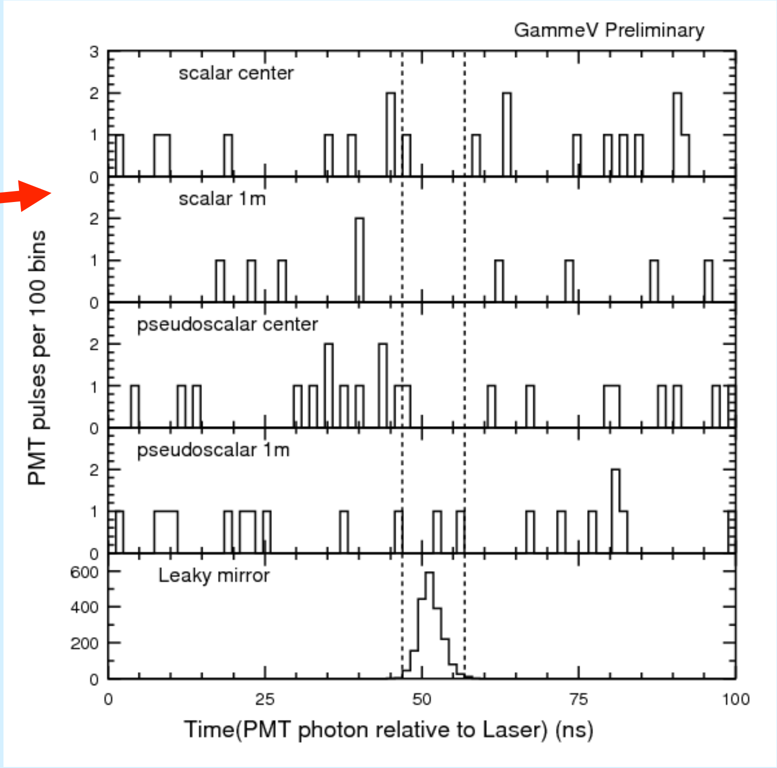
GammeV Procedure

- Take data in four configurations
  - Scalar (with ½-wave plate) with the plunger in the center and at 1m
  - Pseudoscalar also with the plunger in the center and 1m positions
- In each configuration, acquire about 20 hours of magnet time or about 1.5M laser pulses at 20Hz.
  - Monitor the power of the laser using a power meter that absorbs the laser light reflected back into the laser box using NIST traceable calibration to +/-3%
- Total efficiency (25 +/- 3)%
  - PMT detection efficiencies from factory measurements QE x CE 39% x 70% = 27%
  - Measured attenuation in BK7 windows and lens: 92%
- Background in a 10ns wide search region is estimated by counting the events in a 10,000ns wide window around all the laser pulses and dividing by 1000.

GammeV Results

Spin	Position	# Laser pulse	# photon / pulse	Expected Background	Signal Candidates
Scalar	Center	1.34 M	0.41e18	1.56±0.04	1
Scalar	1 m	1.47M	0.38e18	1.67±0.04	0
Pseudo	Center	1.43M	0.41e18	1.59±0.04	1
Pseudo	1m	1.47M	0.42e18	1.50±0.04	2

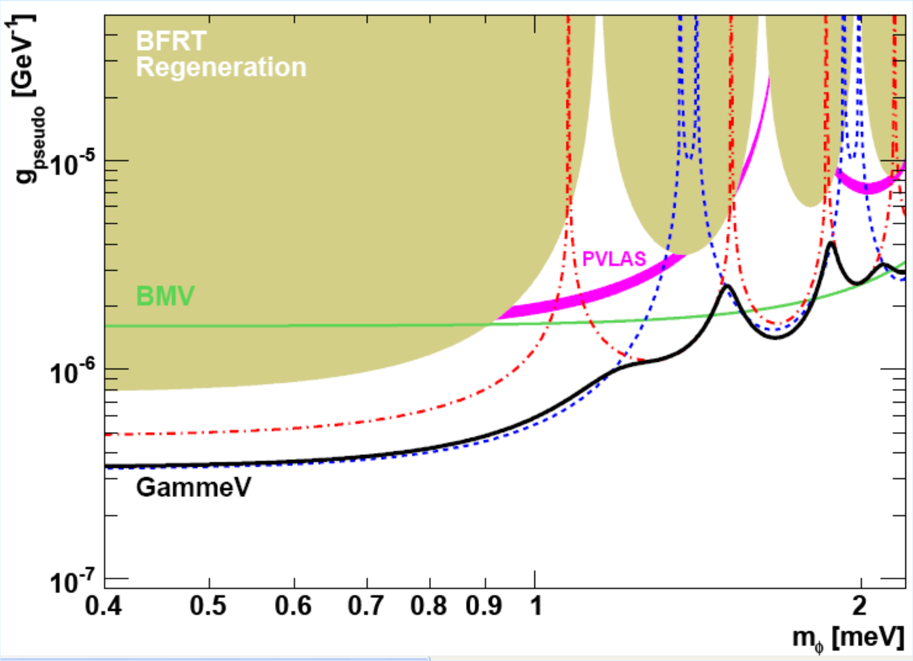




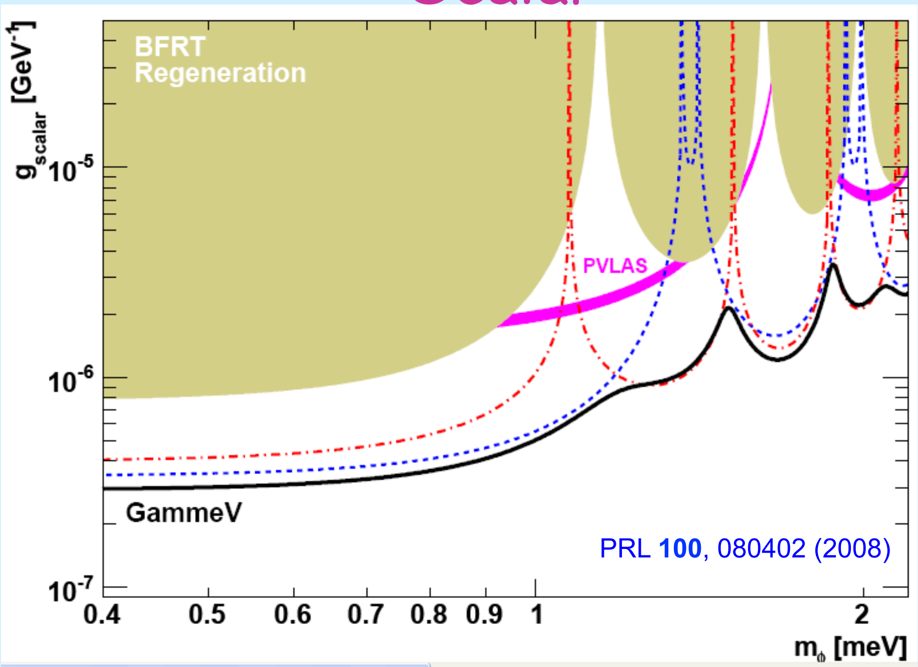
GammeV Limits

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

Pseudoscalar

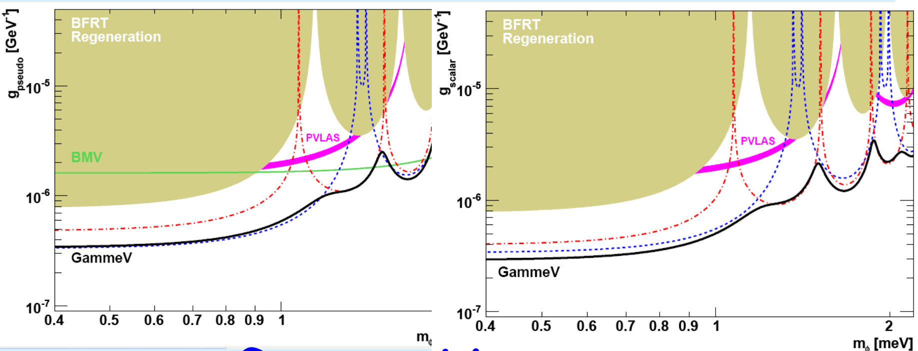


Scalar



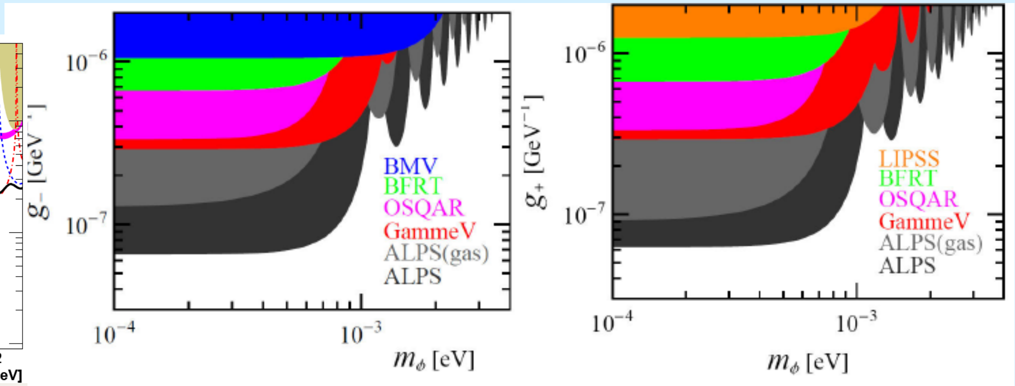
- Job is done. Limit generally improves slowly (4^{th} root) vs. longer running time, or increased laser power, etc.

World-wide effort - null results



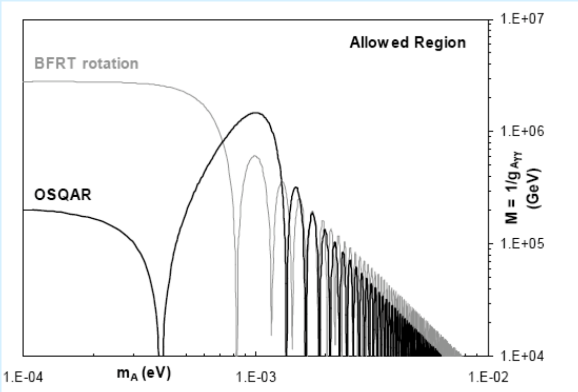
GammeV @FNAL

PRL **100**, 080402 (2008)



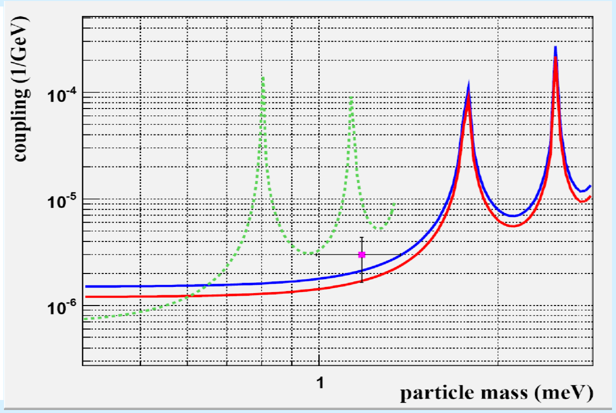
ALPS @DESY

PLB 689, **149** (2010)



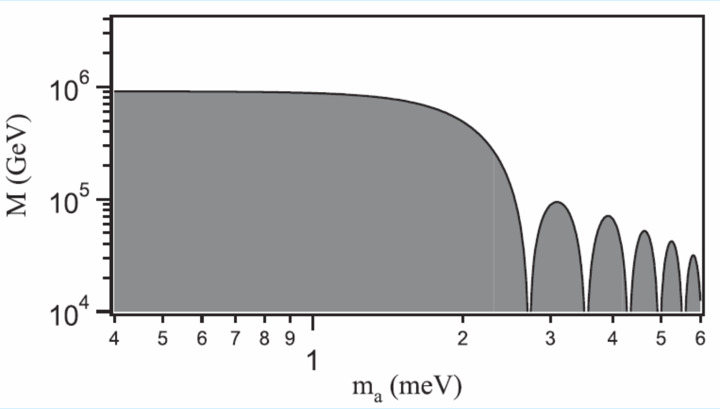
OSQAR @CERN

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



LIPSS @JLab

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

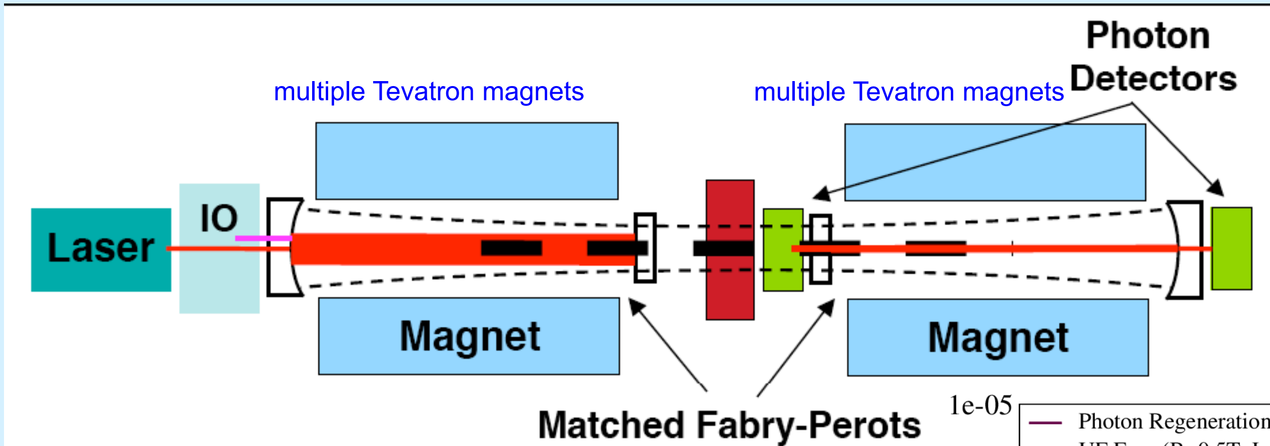


BMV @France

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

Future LSW

Resonantly enhanced axion-photon regeneration

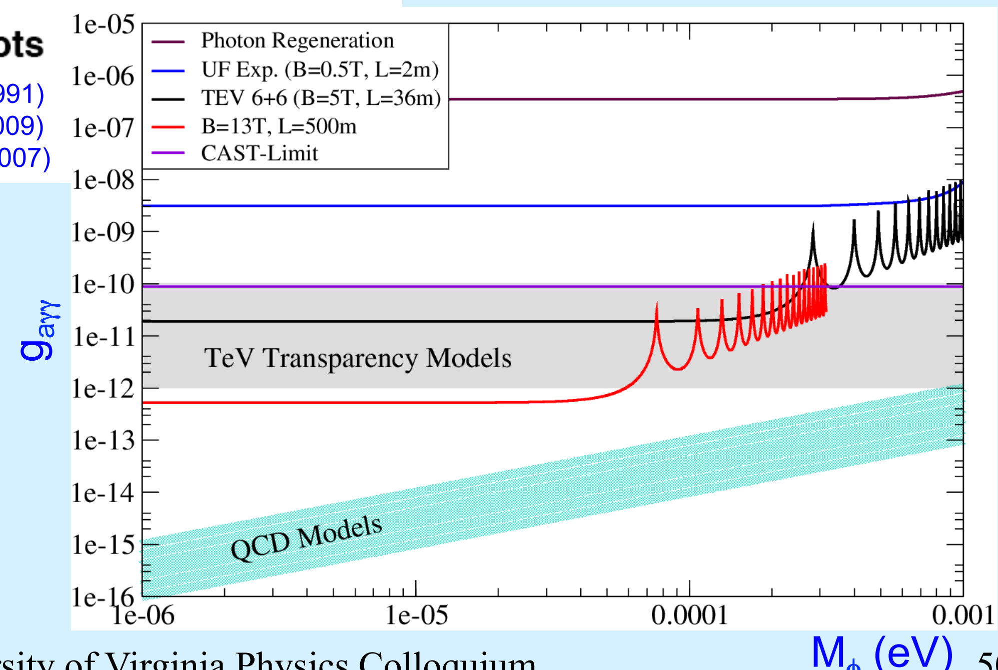


F. Hoogeveen and T. Ziegenhagen, Nucl. Phys. B **358**, 3 (1991)
Mueller, Sikivie, Tanner, van Bibber, Phys. Rev. D **80**, 072004 (2009)
Phys. Rev. Lett. **98**, 172002 (2007)

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.



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 go through a regeneration process.

Chameleons

- A WISP 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: $m_{eff} \sim \rho^{\alpha}$.

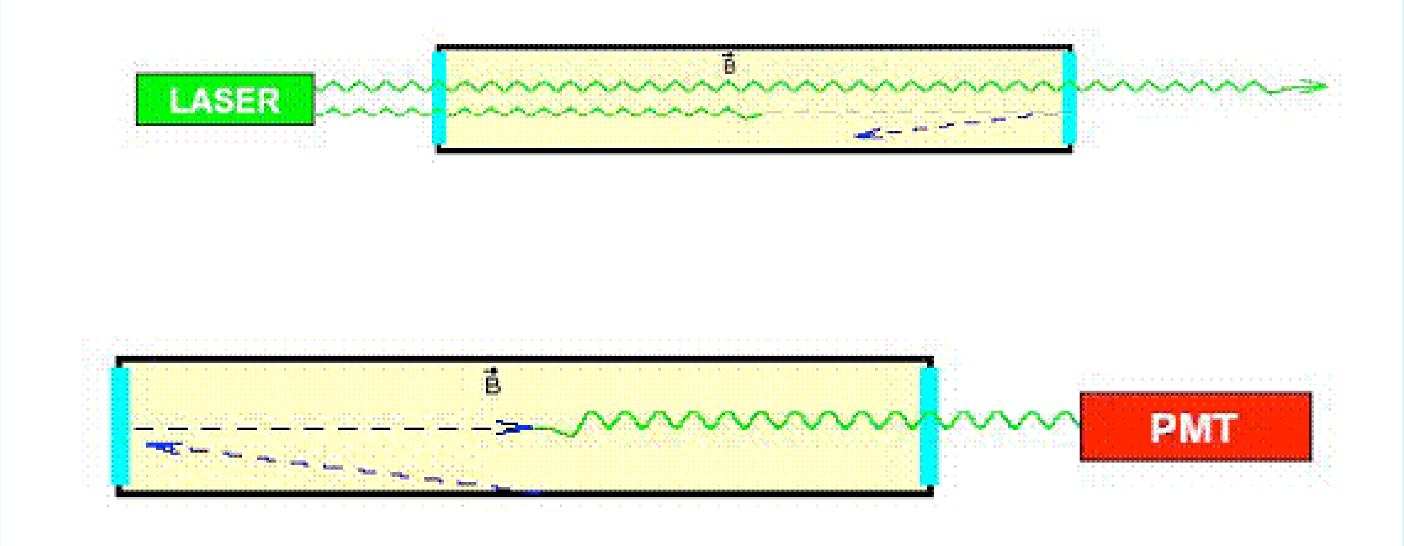
$$\mathcal{L}_{\rm int} = -V(\phi) + \exp\left(\frac{\phi}{M_D}\right) g_{\mu\nu} T^{\mu\nu} - \frac{1}{4}\frac{\phi}{M} F_{\mu\nu} F^{\mu\nu}$$

- 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 dark energy particle".

“Particle in a Jar”

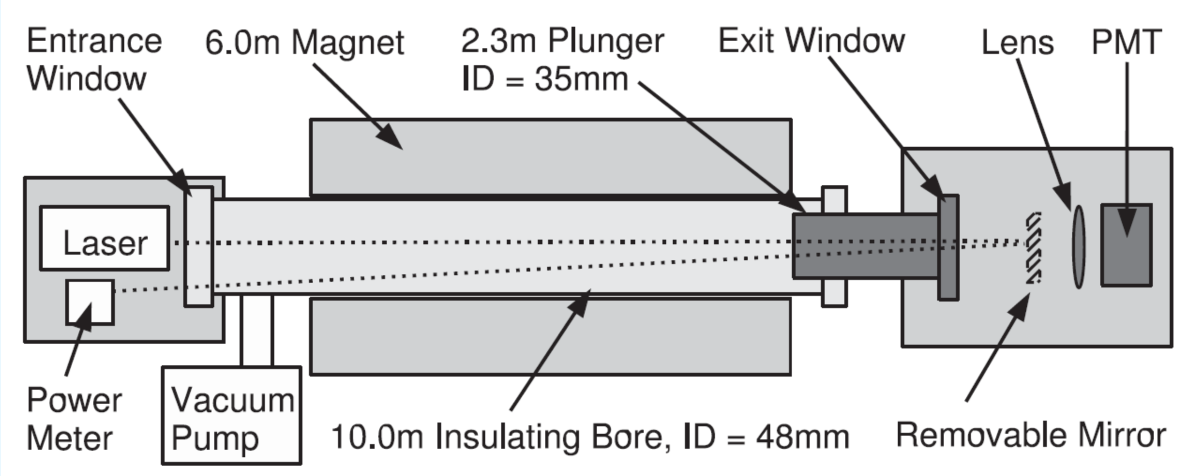
- Chameleon properties depend on their environment – effective mass increases when encountering matter.
  - A laser in a magnetic field might have photons that convert into chameleons which reflect off of the optical windows. A gas of chameleons are trapped in a jar.
  - Turn off the laser and look for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



Chameleon Search

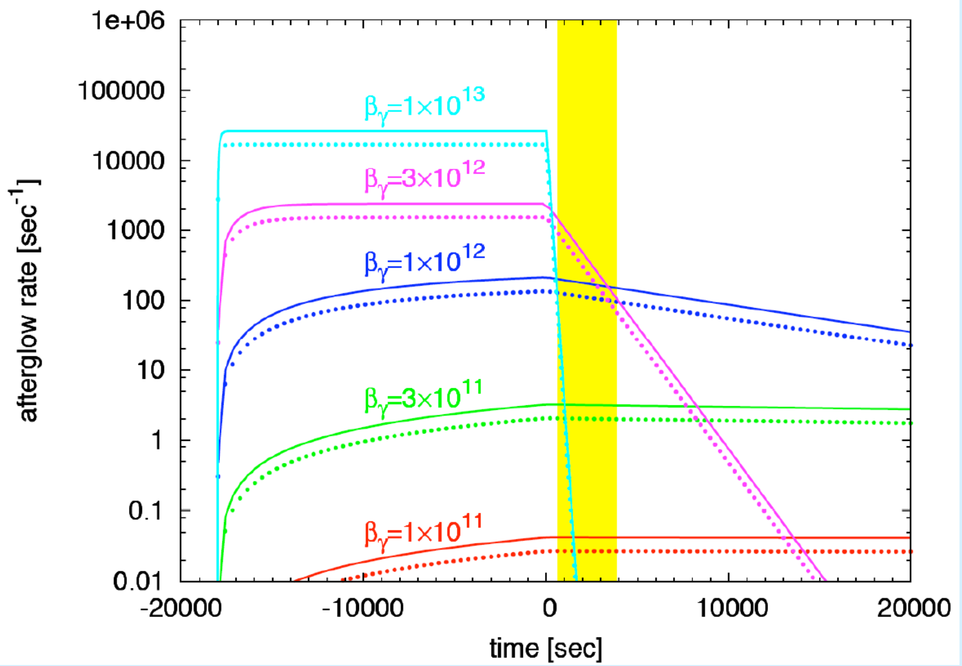
- **G**amme**V** Apparatus

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



- Procedure

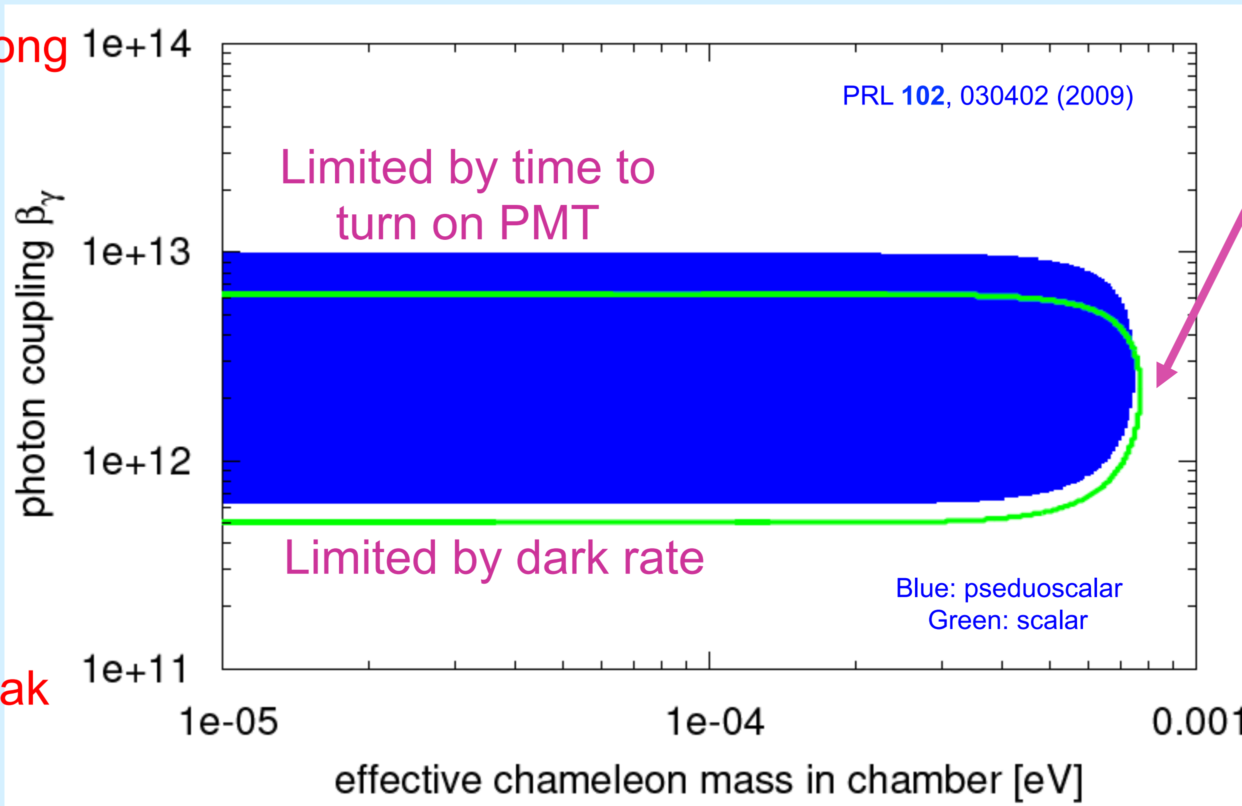
  Turn on pulsed laser for 5hrs using both polarizations. Turn off laser and look for an afterglow above PMT dark rate, either constant or exponentially decaying depending on the photon coupling.



Chameleon Results

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

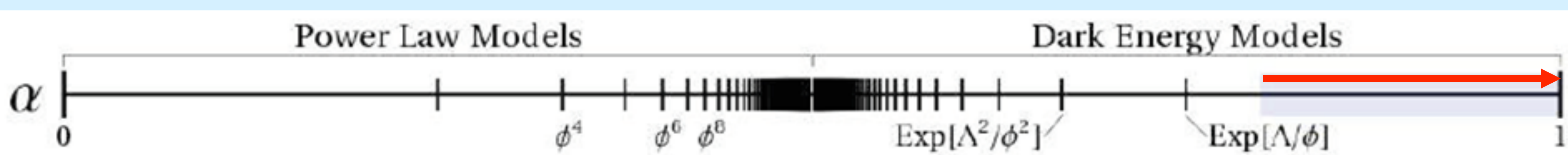
Strong



Weak

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.



Dedicated experiment

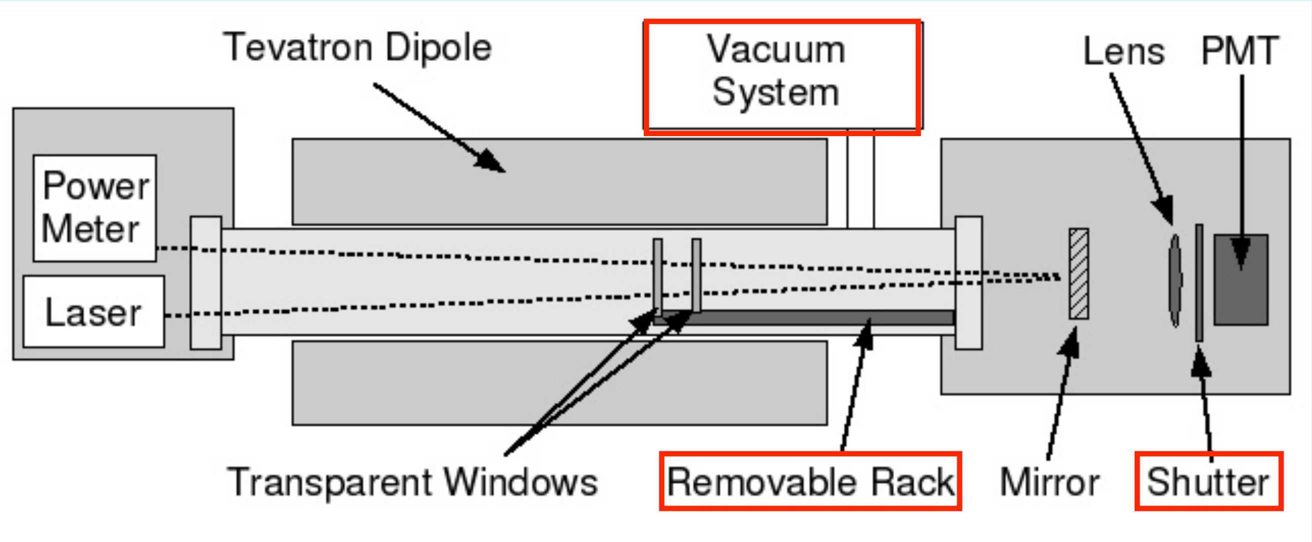
- GammeV – CHASE: Chameleon Afterglow Search

Improve vacuum (cryo pump) and monitoring.

Use a shutter to switch to PMT readout quickly.

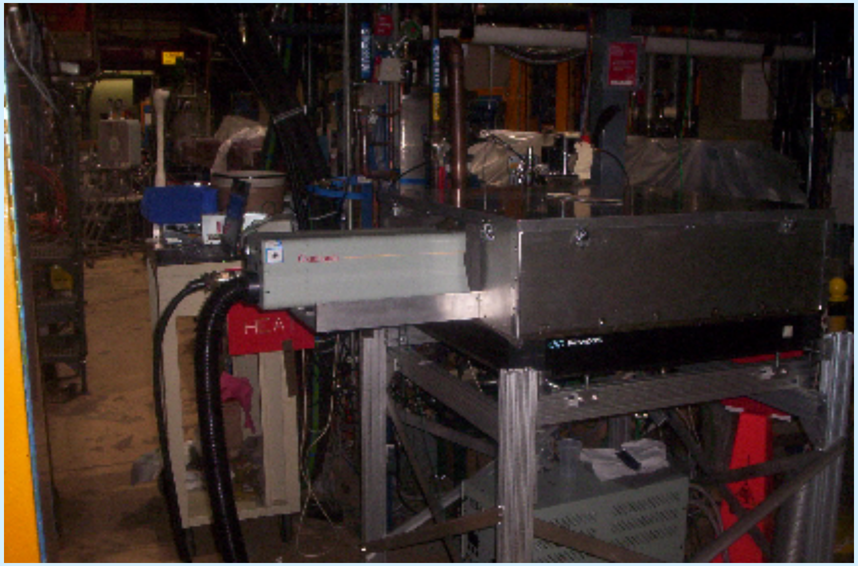
Use a run plan that with lower B fields in case the coupling is strong.

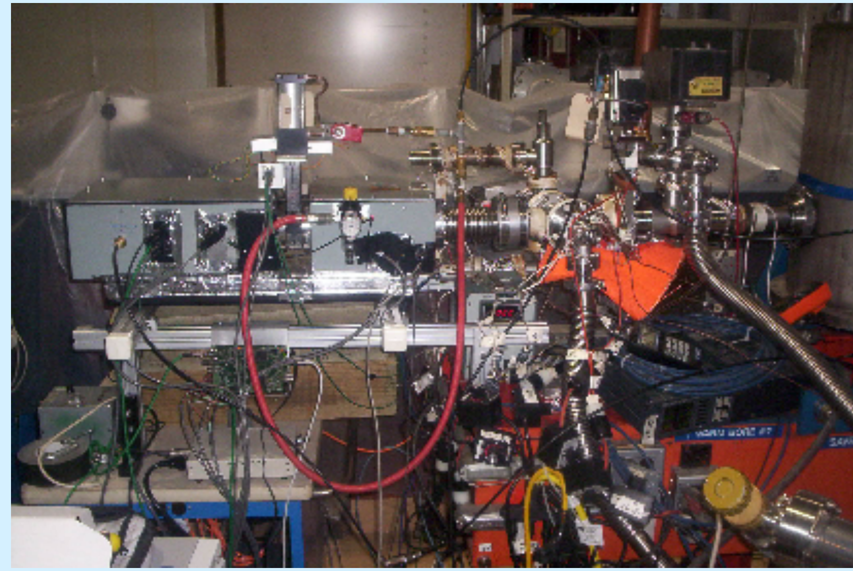
Use a lower noise PMT.

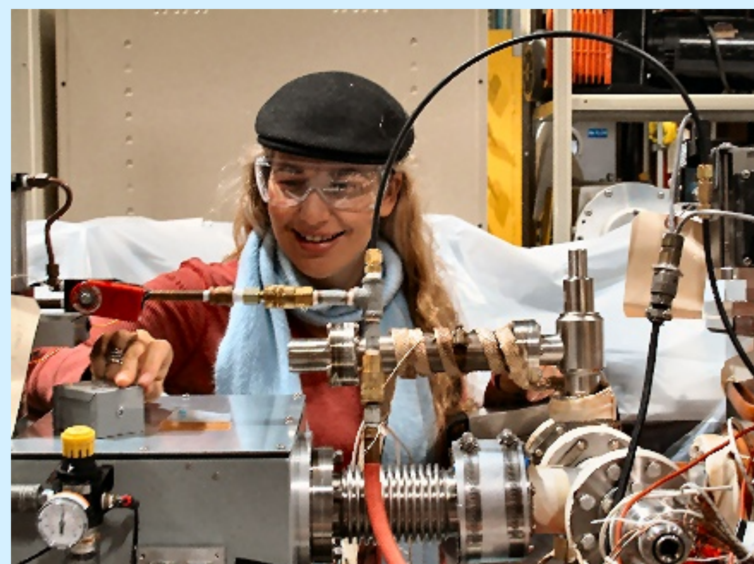


Employ the "dish rack" to effectively have 4.7m, 1m, 30cm magnetic field regions -a bit of cleverness similar to the plunger idea to be initially sensitive to a wider range of chameleon masses.

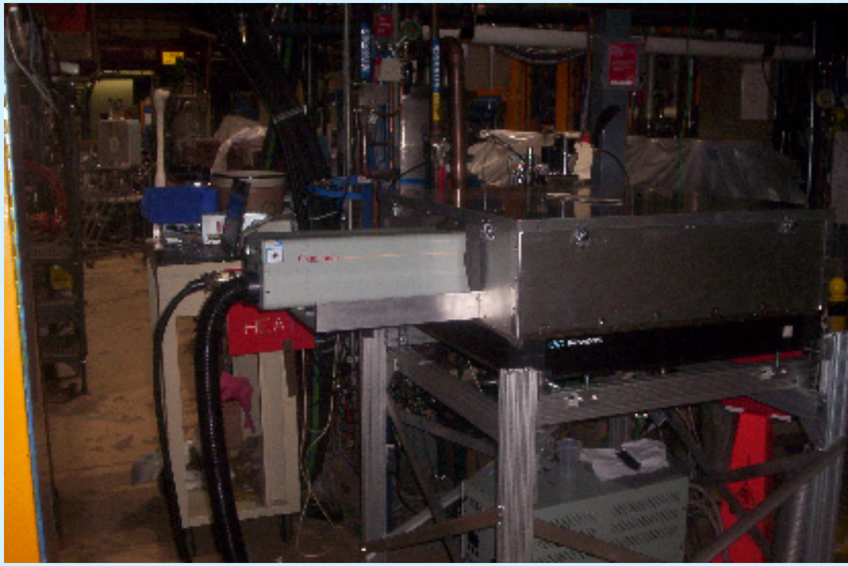
GammeV-CHASE

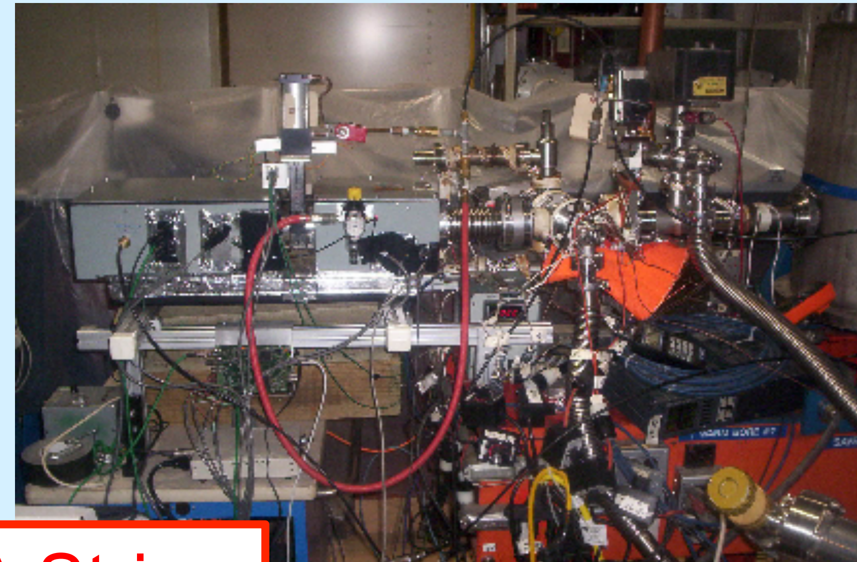






GammeV-CHASE

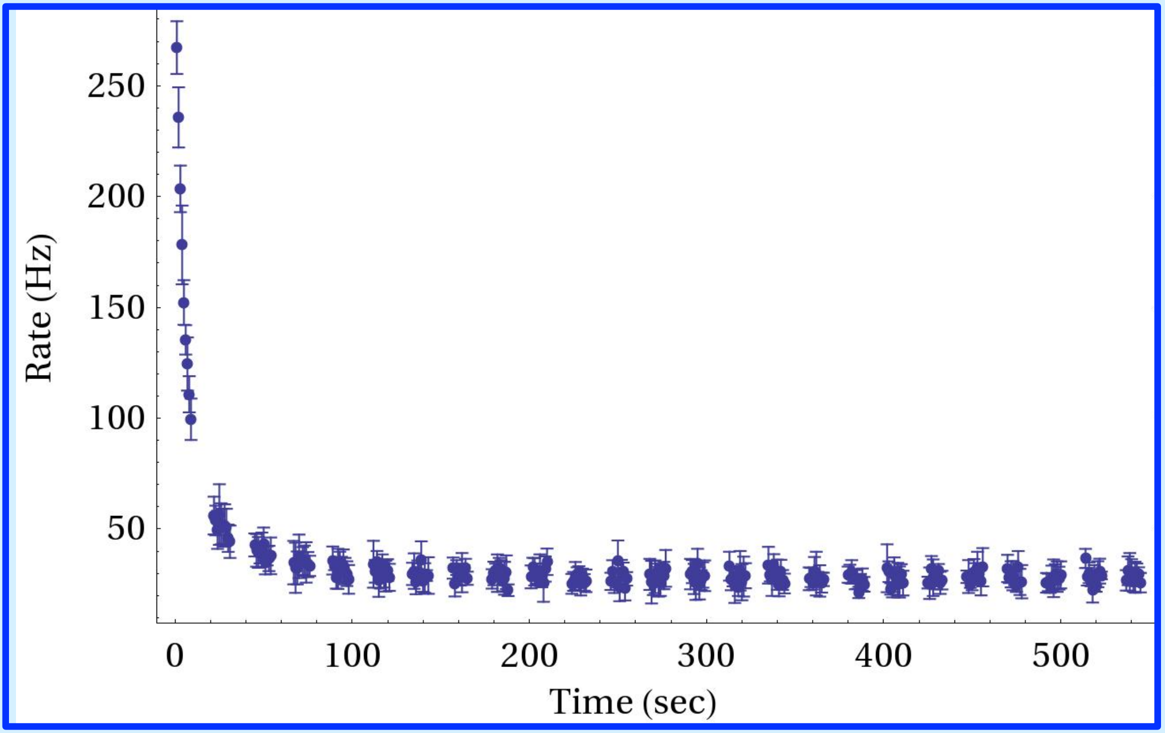


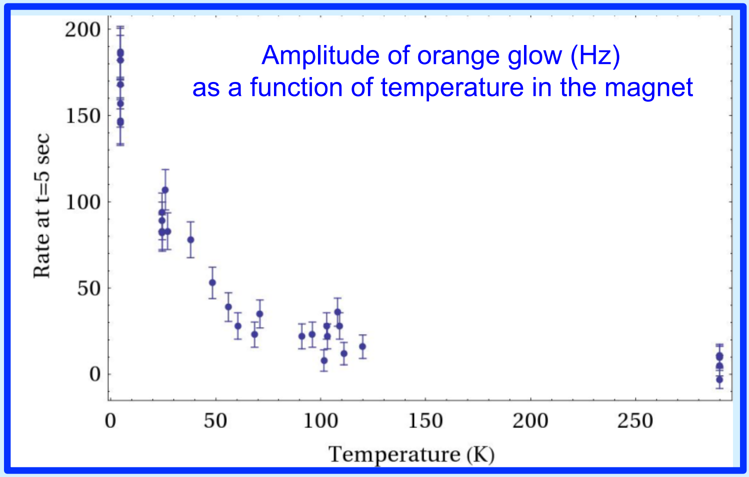


A String Theorist!

Two unexpected systematics

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

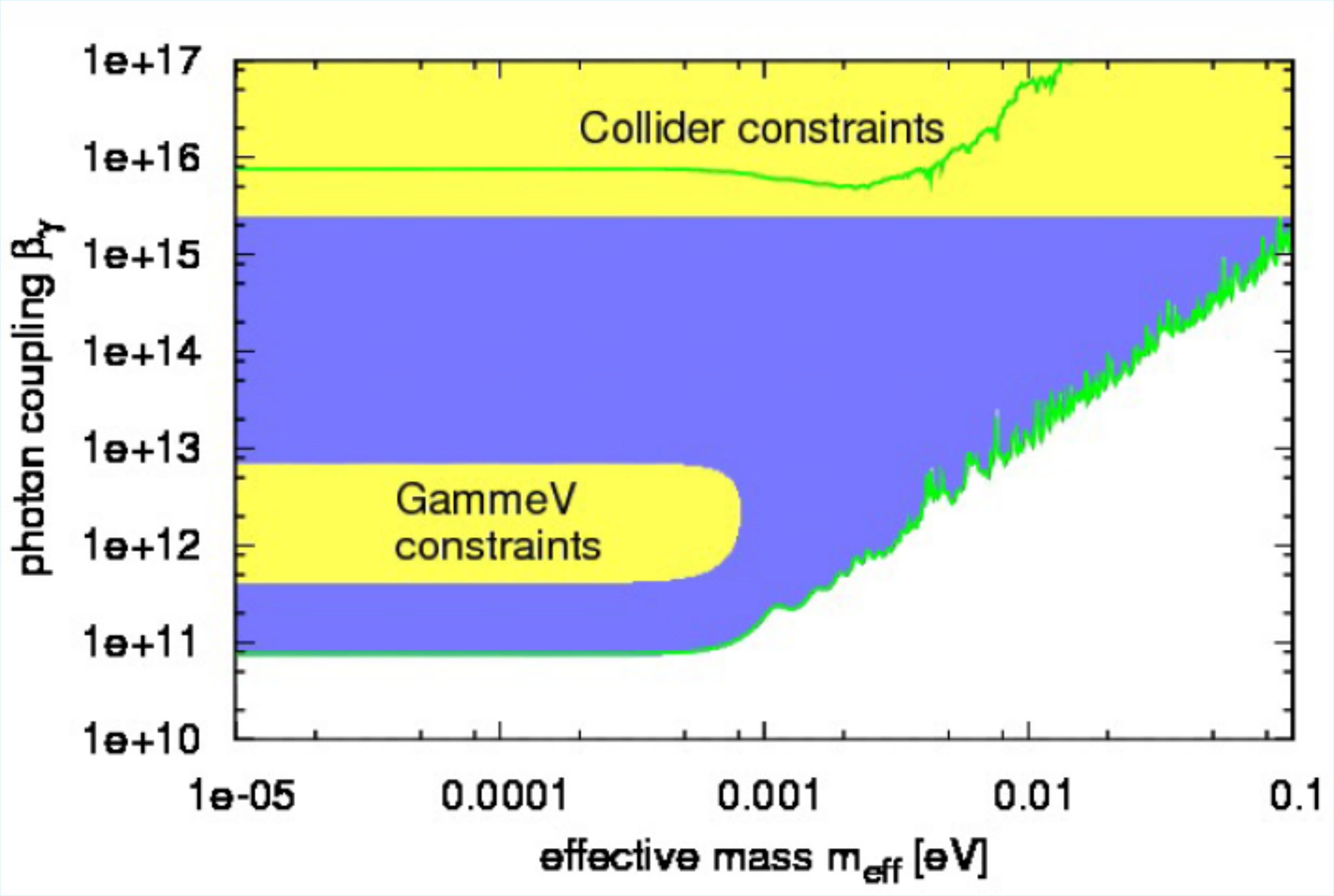


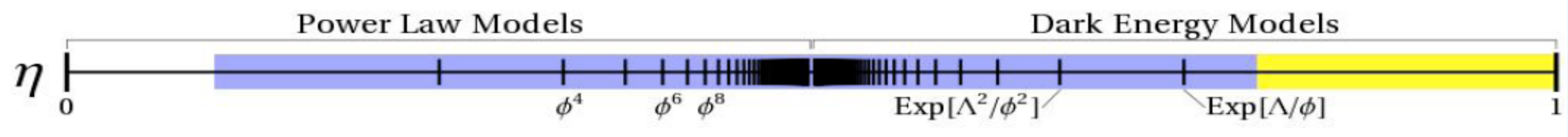


Afterglow rate has a strong temperature dependence

- Literature search revealed that certain vacuum greases can exhibit such a long-lived low temperature glow.

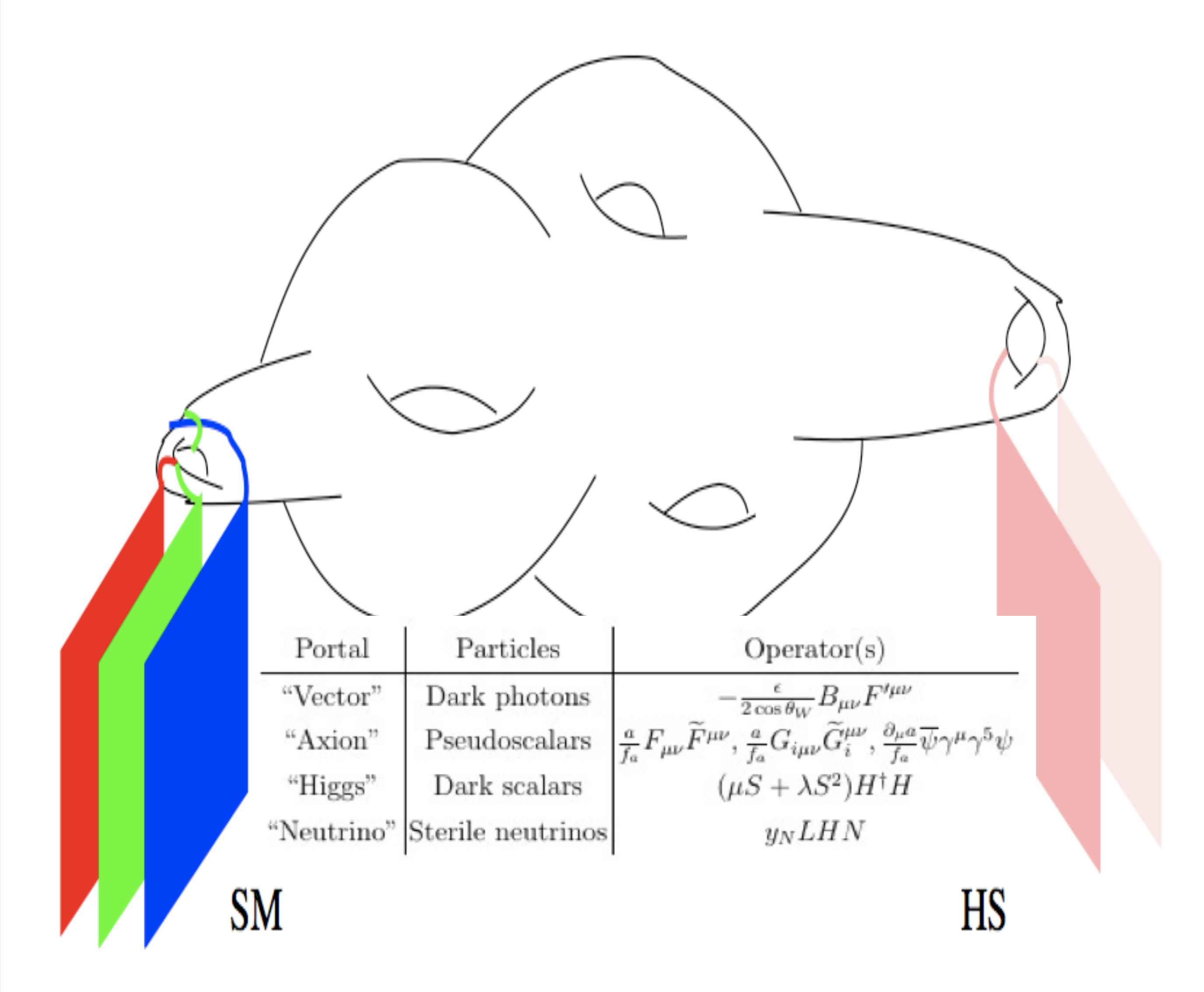
GammeV CHASE
Recent Results





arXiv: 1010.0988 [hep-ex]

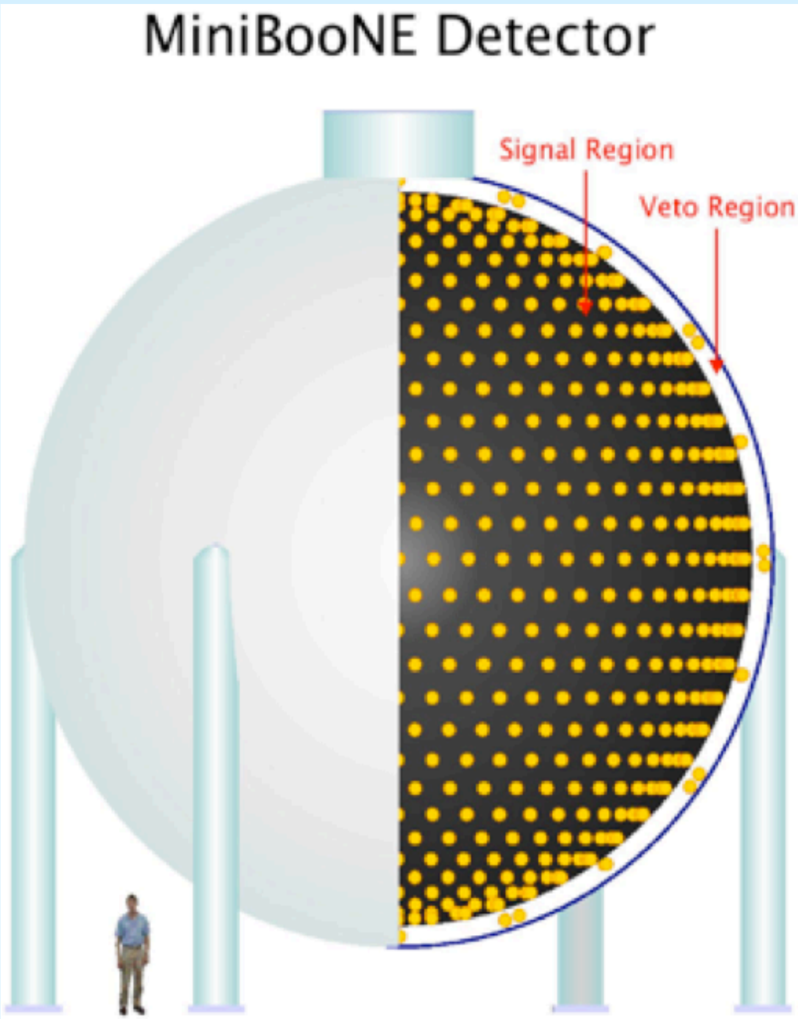
Portals to the dark sector



Portal	Particles	Operator(s)
"Vector"	Dark photons	$-\frac{\epsilon}{2\cos\theta_W} B_{\mu\nu} F'^{\mu\nu}$
"Axion"	Pseudoscalars	$\frac{a}{f_a} F_{\mu\nu}\widetilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i\mu\nu}\widetilde{G}_i^{\mu\nu}$, $\frac{\partial_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$
"Higgs"	Dark scalars	$(\mu S + \lambda S^2)H^\dagger H$
"Neutrino"	Sterile neutrinos	$y_N LHN$

$100M Search for Dark Photons

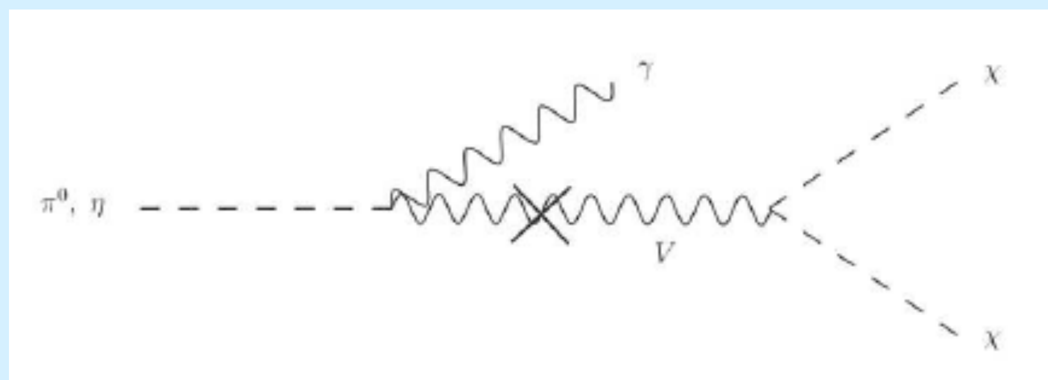
Essentially “for free” using an existing Neutrino detector!



Stable detector for more than 10yrs.

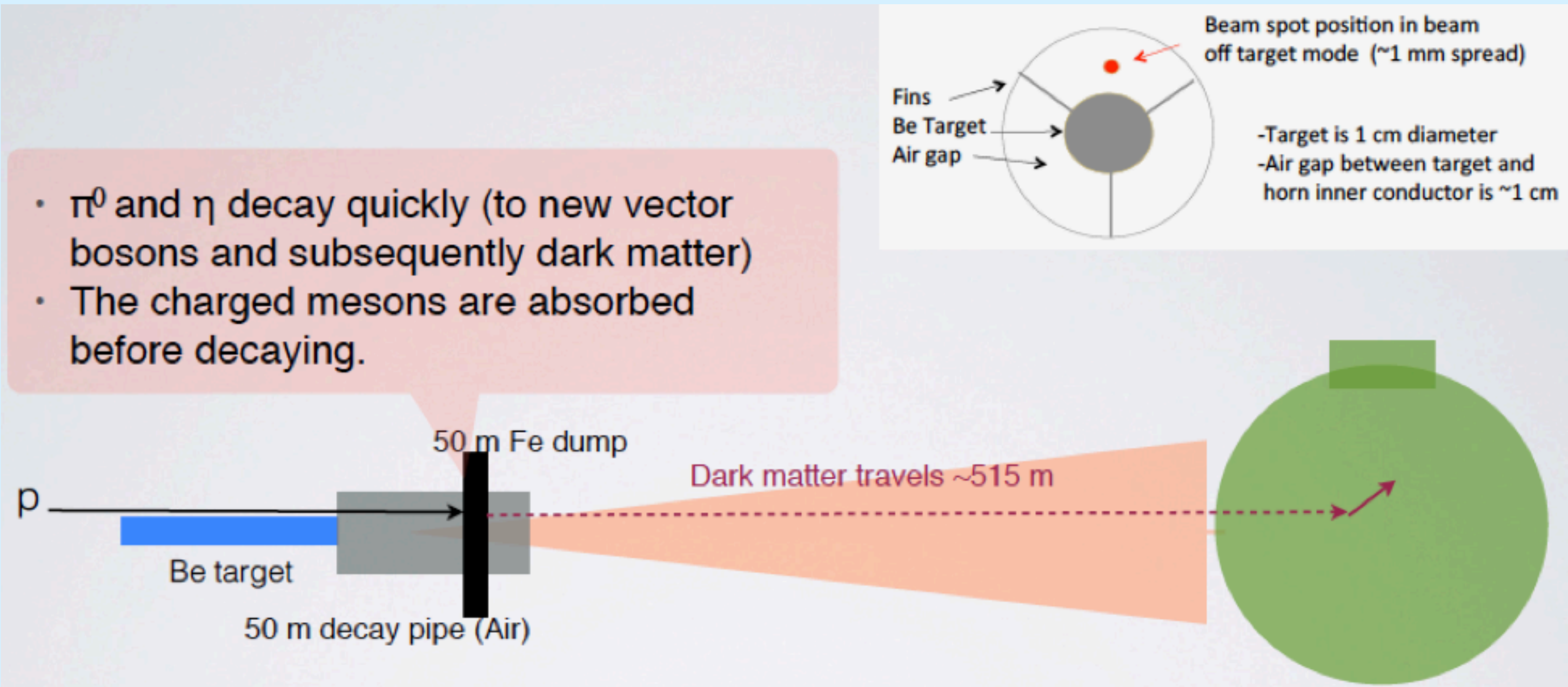
Successfully completed it’s studies of neutrino’s and anti-neutrino’s.

New run approved to look for dark matter. Sensitive to a “dark photon” that could mediate a g-2 anomaly.



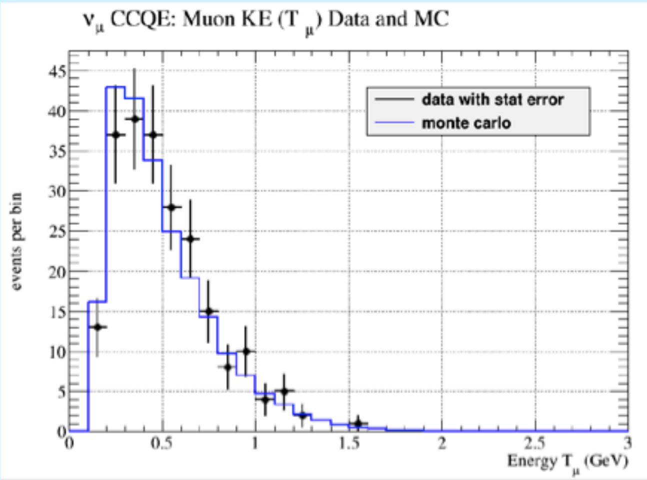
Beam "off target" running

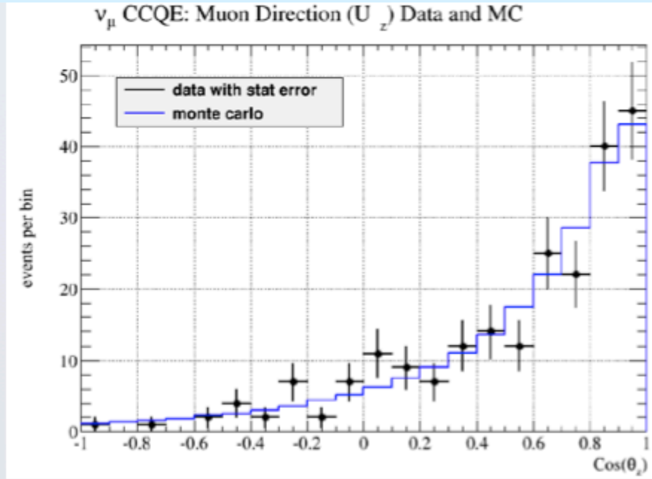
Neutrino's are a background. Suppress them by x40 by running the experiment in a "beam dump" mode missing the target/horn.



Preliminary Results

Run ended 1 month ago. Use about 1/6th the data to understand the events and then unblind looking at the rest of the data.





Demonstrate that charged neutrino interactions make sense

Standard NCE selection

- Only one subevent
- Veto Hits < 6
- Tank Hits > 12
- $44\ \mu <$ Time of Event $< 65\ \mu s$ (inside beam window)
- Proton/Electron Time Likelihood Ratio < 0.42
- Nuclear Recoil Radius Position < 5 m
- 35 MeV $<$ Nuclear Recoil Energy < 250 MeV

Preliminary results with 3.19×10^{19} POT

	# events
Cosmics	177
ν bkg	107.8
Total Bkg	284.8 ± 18 (sys.)
Data	282 ± 17 (stat)

Table 1 : Comparing data to backgrounds all events that pass cuts


NOT YET THOUGHT OF
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sterile ν
heavy Majorana ν
fractionally charged
milli-charged
monopole
shadow matter
mirror symmetry
milli-weak
superweak
Weinberg's 3HD
spontaneous CP
triplet Higgs
doubly charged Higgs
type I
type II
vectorlike family
4th gen
5th gen
6th gen
S,T,U
pseudo NGB
Majoron
axion
familon
NGB
axino
saxion
composite W,Z
contact int.
string
NMSSM
MSSM
technicolor
hypercolor
supercolor
extended TC
techni-GIM
composite Higgs
TC-TC
worm hole
extra dim
H Murayama


NOT YET THOUGHT OF
Expierments too!
H Murayama