# The First Results from GammeV

## Varying Baseline Axion Like Particle Search at Fermilab

**Jonghee Yoo**
**Fermilab**

**UCLA 2008, 21st February 2008**

# Outline

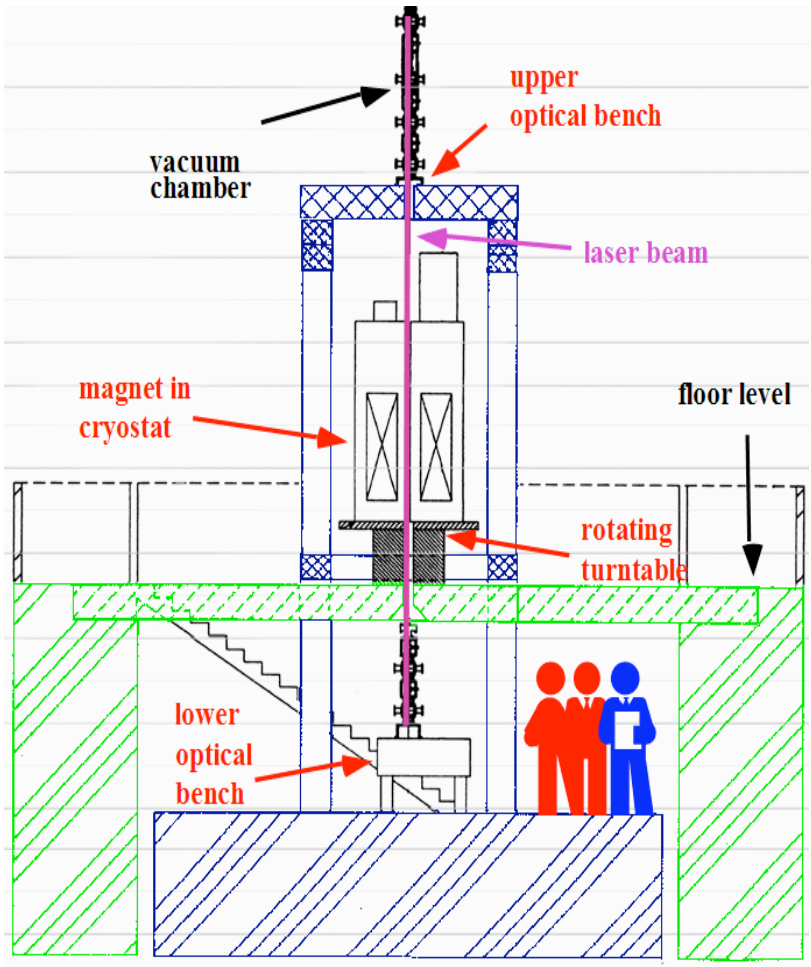


- Introduction : PVLAS Experiment & Results
- Axion Interpretation
- GammeV Experiment
- Data Analysis and Results
- Conclusion

# PVLAS : INFN (Italy), PRL 96, 1110406 (2006)



## PVLAS experiment designed to study magneto-optic property of the vacuum

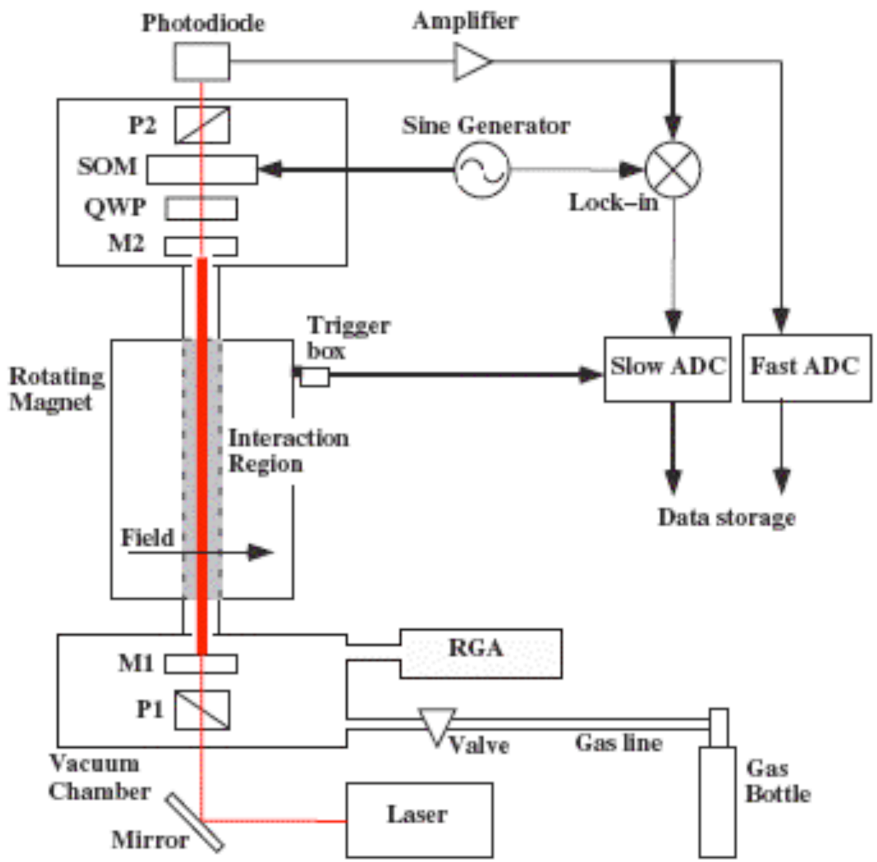


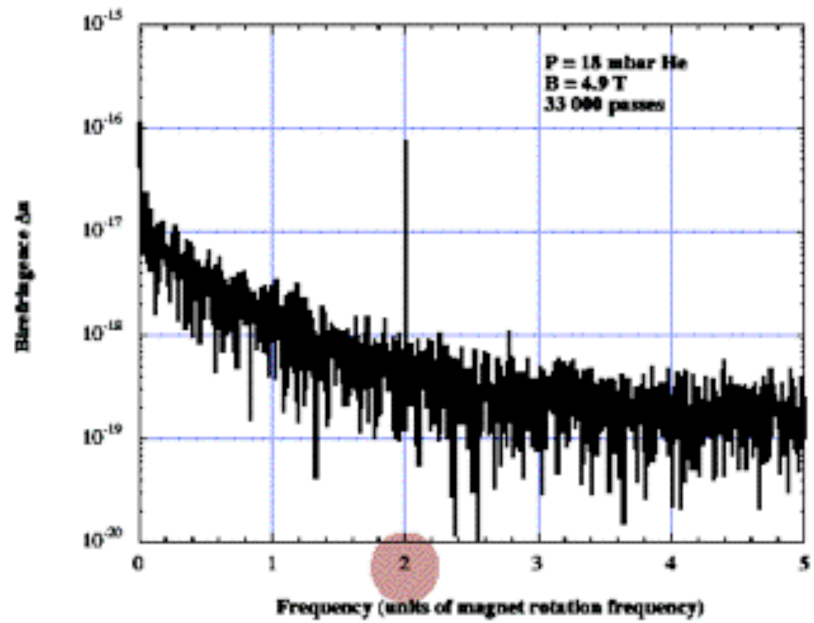

- Laser : NdYAG
  - 1064nm (532nm) 100mW
- Magnet
  - dipole 6T, 4.2K @ 1m field zone
- Cryostat
  - rotation frequency : 0.3Hz
  - warm bore to allow light propagate in the interaction zone
- Fabry-Perot cavity
  - 6.4m length, finesse ~70k

  (optical path in the interaction zone : 60 km)
- Heterodyne ellipsometer
  - ellipticity modulator & high extinction (1e-7) polarizer & 1/4 wave plate
- Detection
  - Photodiode with low noise amplifier

# PVLAS : Calibration

**Search for non-trivial optical properties of vacuum :**
**- dichroism (rotated polarization) and birefringence (induced ellipticity)**




**A calibration with He gas shows clear peak at 2nd harmonics**

# PVLAS Results in Vacuum

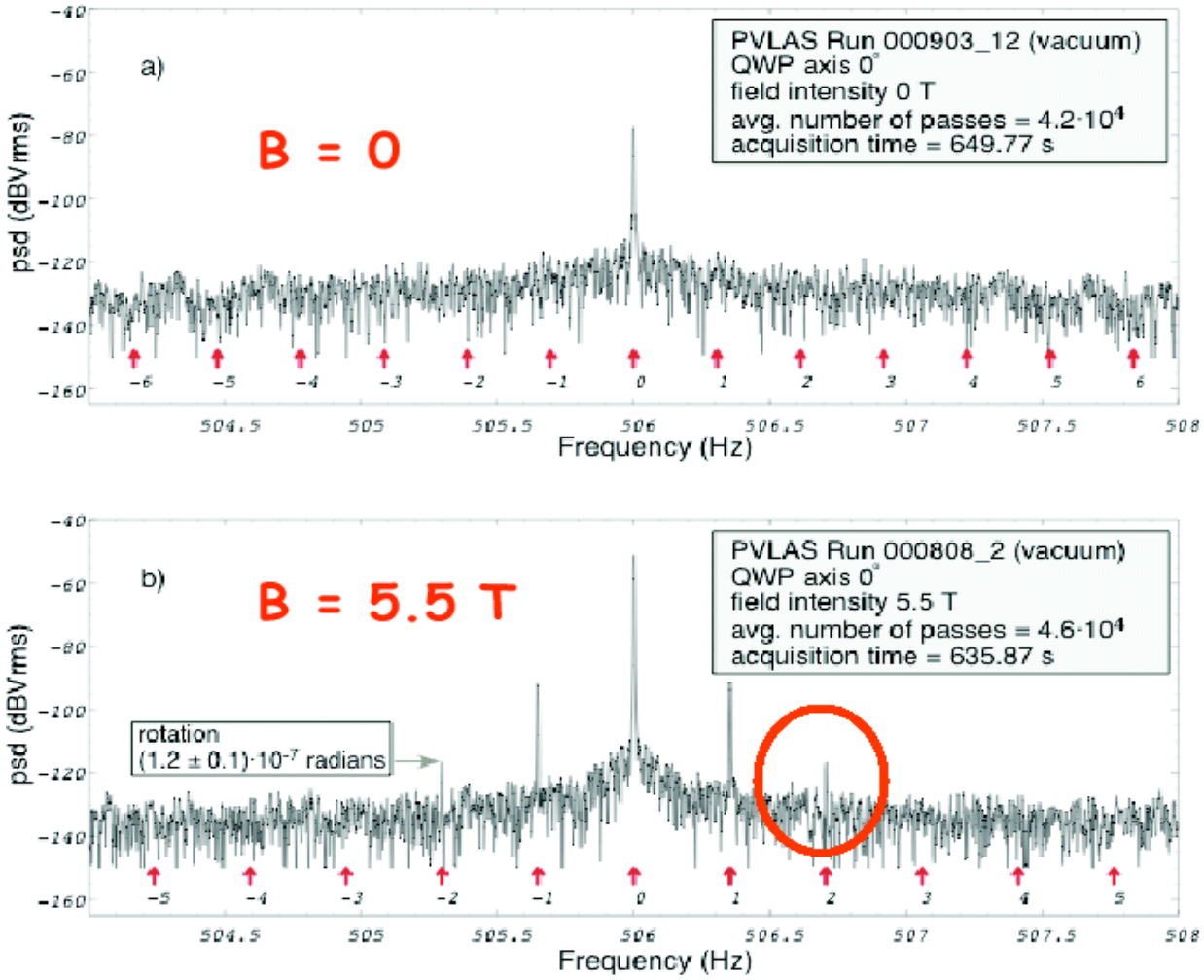


Positive results seen looking at polarization ellipticity generation

Expect signals in 2nd harmonic only when external B-field aligned with either E or B of incident photon

Annoying 1st harmonics are not understood

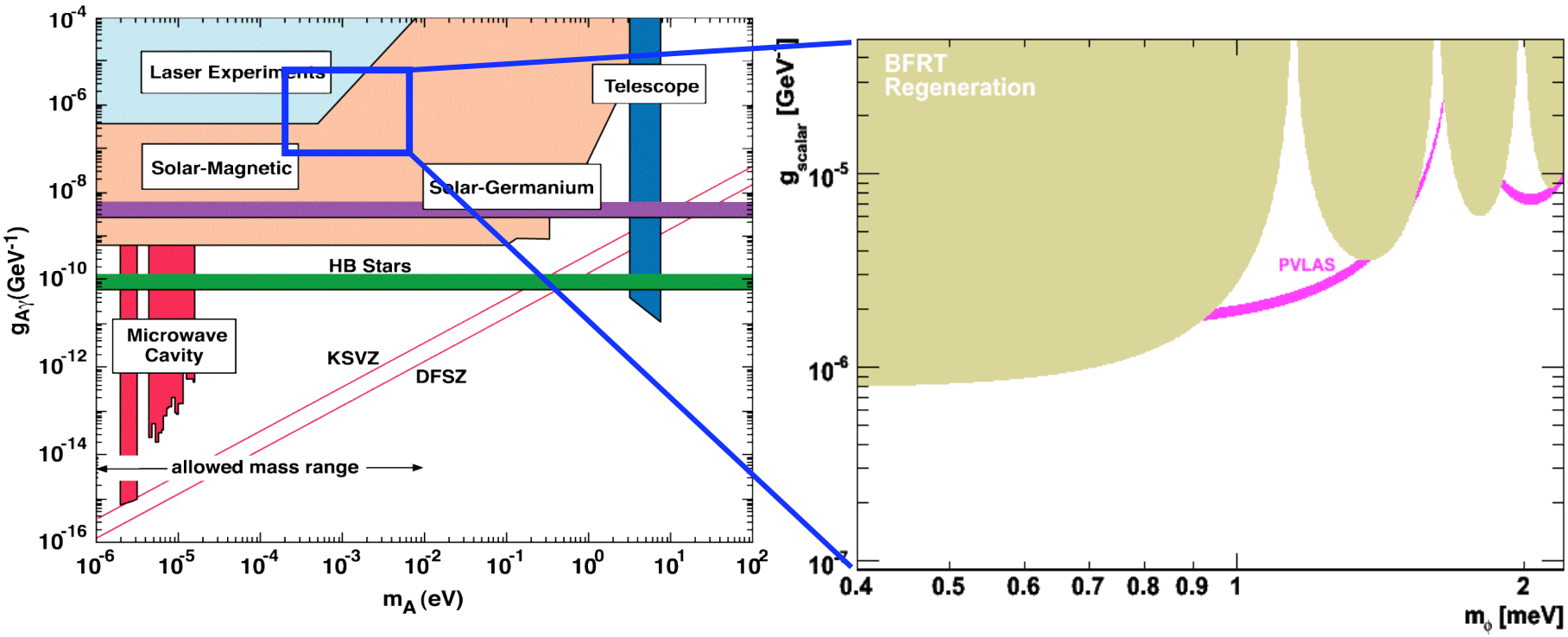
The results are published PRL 96, 1110406 (2006)




➔ Is this an indication of a new particle ?

# PVLAS : Axion Interpretation





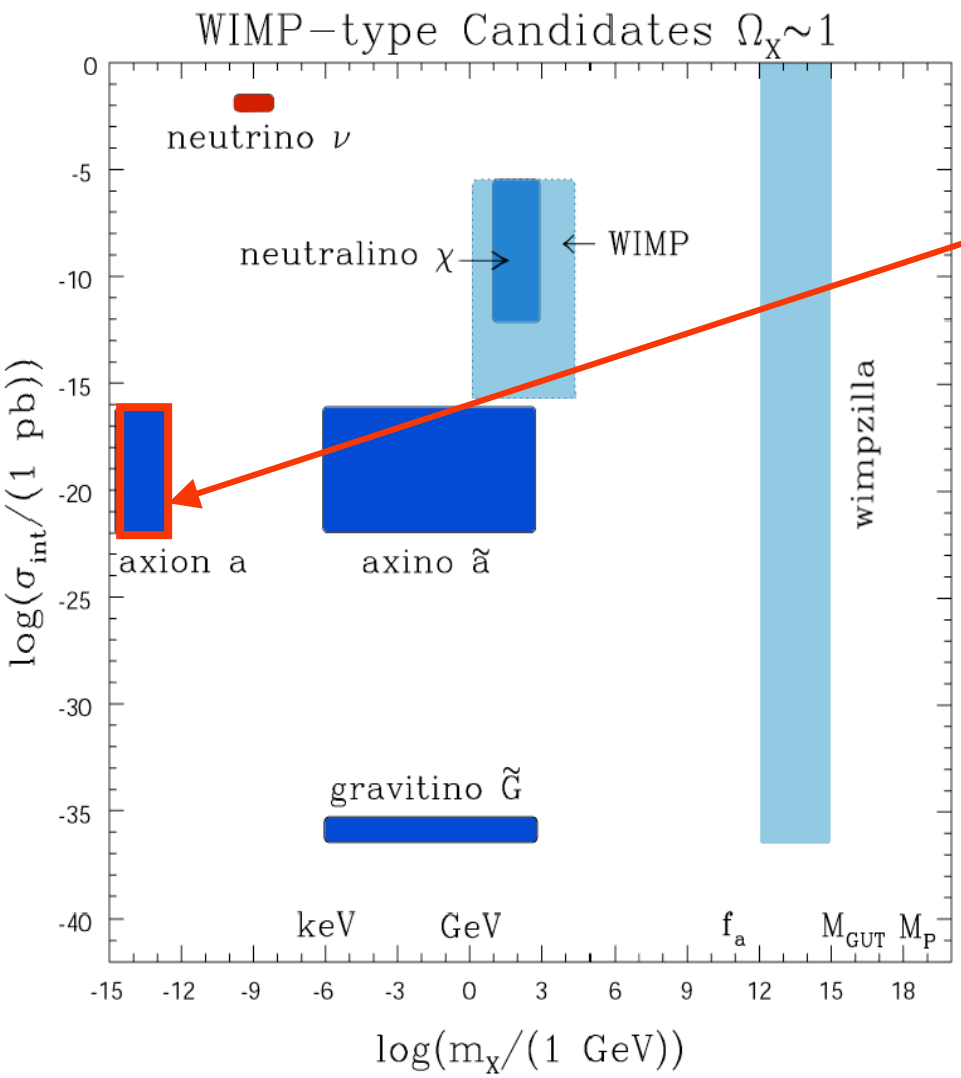

**If one interprets the PVLAS result as ALP**

**Scalar particle with mass 1.2 meV and $g \sim 2\times10^{-6}$ GeV$^{-1}$ is consistent with rotation and ellipticity measurements**

**In contradiction with CAST and star cooling limits, unless coupling is suppressed at high T or high density.**
**The Sun lives only 1000 years…**

# Axions in the Dark Side





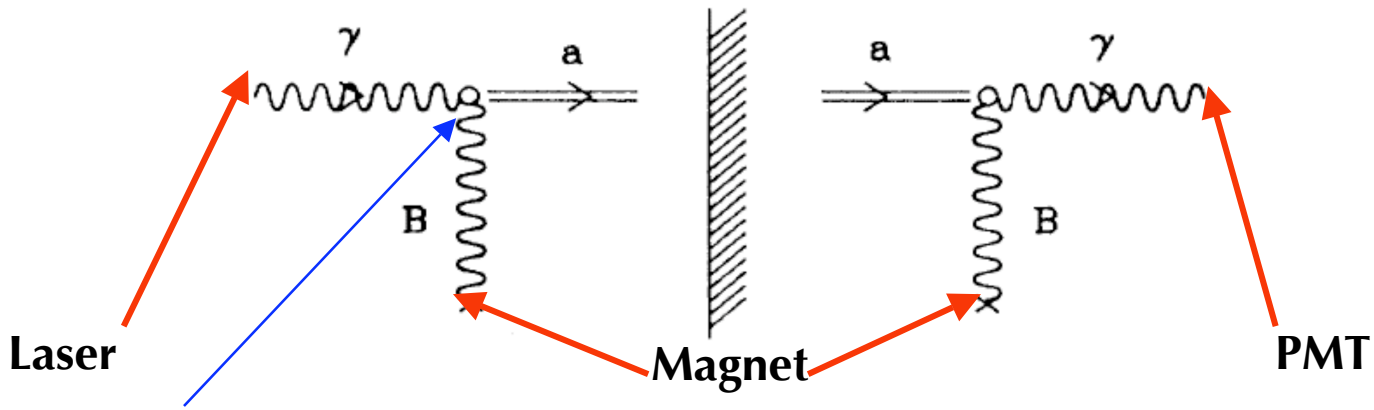

## Axions

- Solve strong CP problem by Peccei-Quinn U(1) SB
- Cold dark matter candidate within Standard Model
  Small masses : ueV ~ meV
  but they are non-thermal relics

**L. Roszkowski**

# 2007 @ Fermilab






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

**If we take the PVLAS results seriously : 1.2 meV and M = 4e5 GeV**

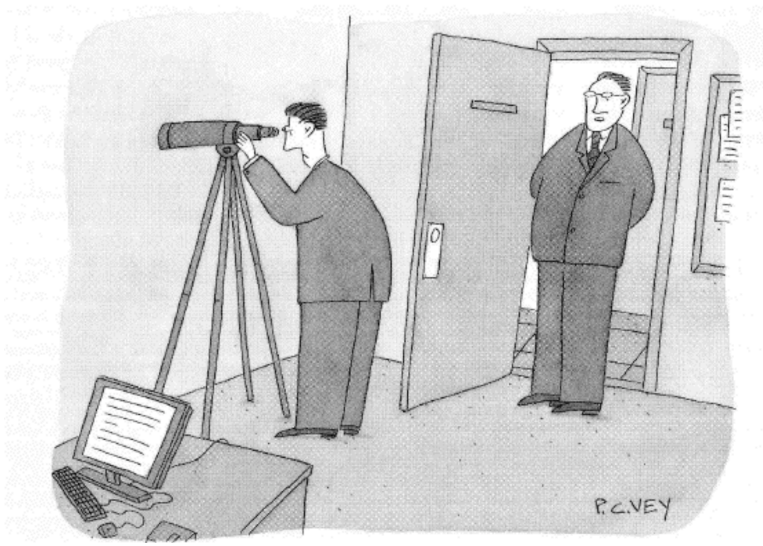
$$P_{regen}^{GammeV} = (3.9\times10^{-21})\times\frac{(B_1/5\,\mathrm{T})^2(B_2/5\,\mathrm{T})^2(\omega/2.33\,\mathrm{eV})^4}{(M/4\times10^5\,\mathrm{GeV})^4(m_\phi/1.2\times10^{-3}\,\mathrm{eV})^8}$$
$$\times\sin^2\left(\frac{\pi}{2}\frac{(m_\phi/1.2\times10^{-3}\,\mathrm{eV})^2(L_1/2.0\,\mathrm{m})}{(\omega/2.33\,\mathrm{eV})}\right)\sin^2\left(\frac{\pi}{2}\f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

**Nd:YAG laser : 3.2W laser (E=2.33eV), 5e18 ph/sec**
**Tevatron magnet : 5T**
**PMT : 100Hz dark count rate, 40%Q.E.**
**$R_{noise}$= 20Hz x 5ns x 100Hz = 1e-5 Hz, $R_{sig}$= 2e-3Hz**
**In order to have 5 sigma results : time ~ 1e4 sec**

**Total budget request**
**Fermilab / PPD**
**$30,000**

- **Dark Sector in the Universe has an interesting scale in the $10^{-3}$ eV (meV) range that arises also in other particle physics phenomenon**

  - **Dark Energy density**
    - $\Lambda^4 = 7\times10^{-30}$ g/cm$^3$ ~ (2 meV)$^4$
  - **Neutrinos**
    - $(\Delta m_{21})^2 = (9\text{ meV})^2$
    - $(\Delta m_{32})^2 = (50\text{ meV})^2$
  - **See-saw with the TeV scale**
    - meV ~ TeV$^2$/M$_{planck}$
  - **Dark Matter Candidates**
    - **Certain SUSY particles (low mass gravitino)**
    - **Axions and axion-like particles**



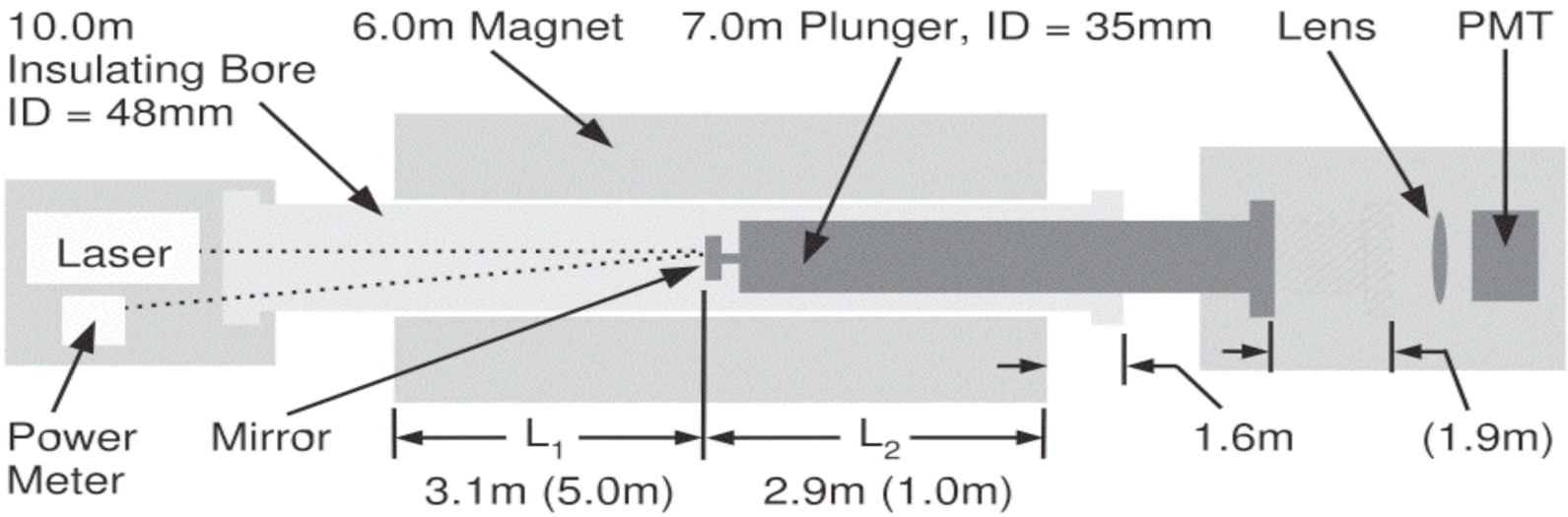
# GammeV Collaboration

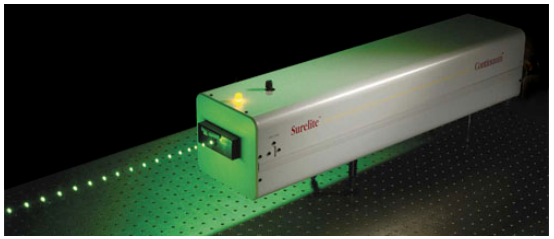
**Aaron Chou, William Wester, Al Baumbaugh, Dick Gustafson, Yilda Irizarri-Valle, Peter Mazur, Jason Steffen, Ray Tomlin, Xi Yang and Jonghee Yoo**

**We relied on technical support from Fermilab**

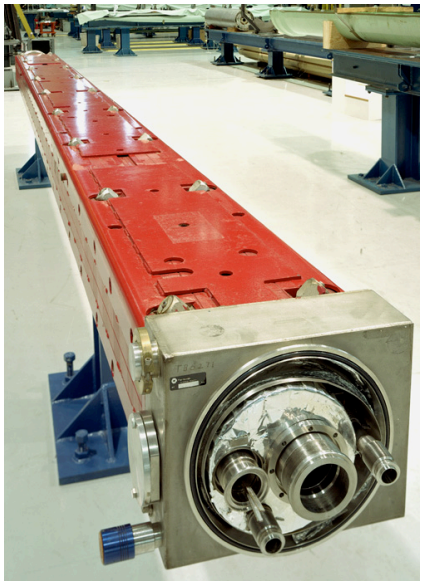
# GammeV experiment setup



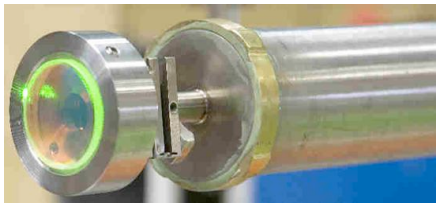


**Laser : Surelite Nd YAG**
**1064nm (doubled 532nm)**
**160mJ/pulse, 3.2W @ 20 Hz**
**Pulse width = 5 nsec**



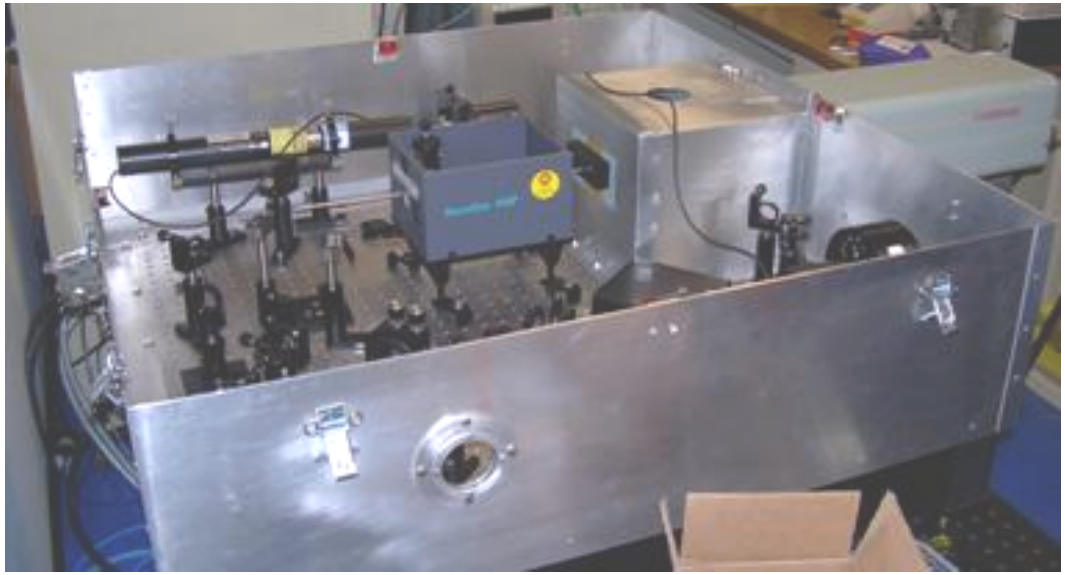
**Tevatron dipole : B=~5T**



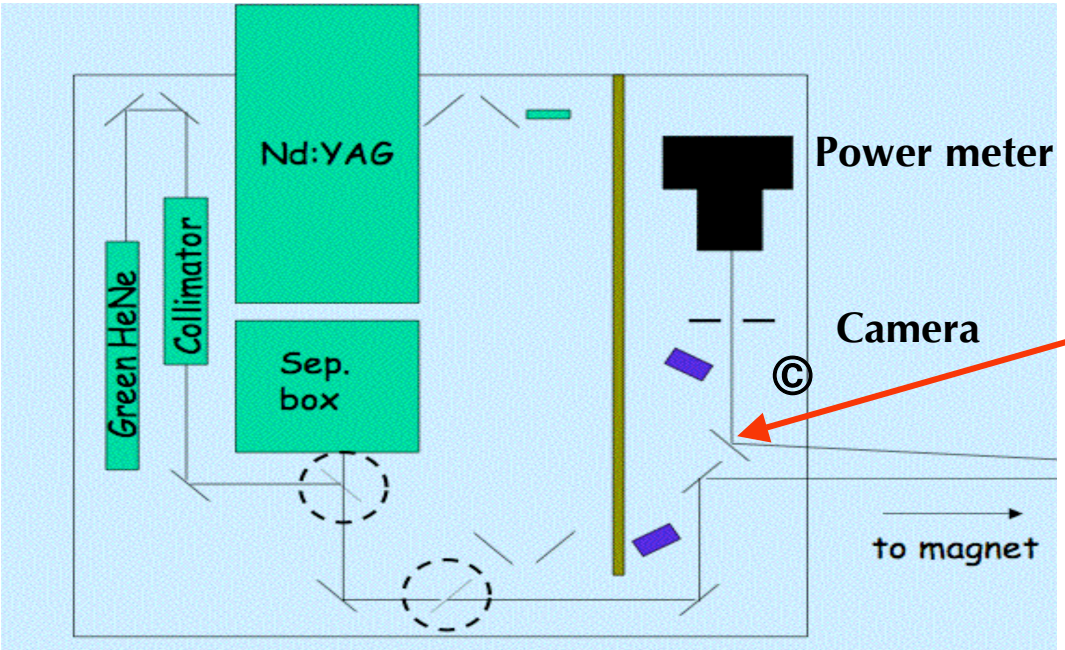
**Wall : concave mirror**
**Coated for high power**
**green laser light**
**10m focal length**

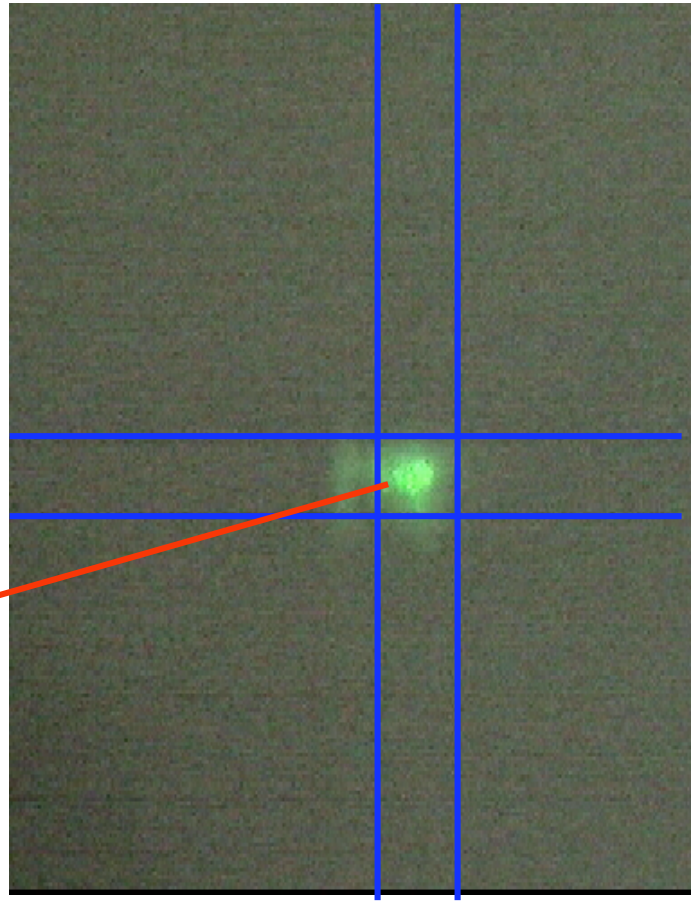
**Hamamatsu H7421**
**GaAsP, QE=40%**
**Dark Count= 100 Hz**

# GammeV : Laser Box



**Reflected beam spot monitor**
**Camera image from laser box**

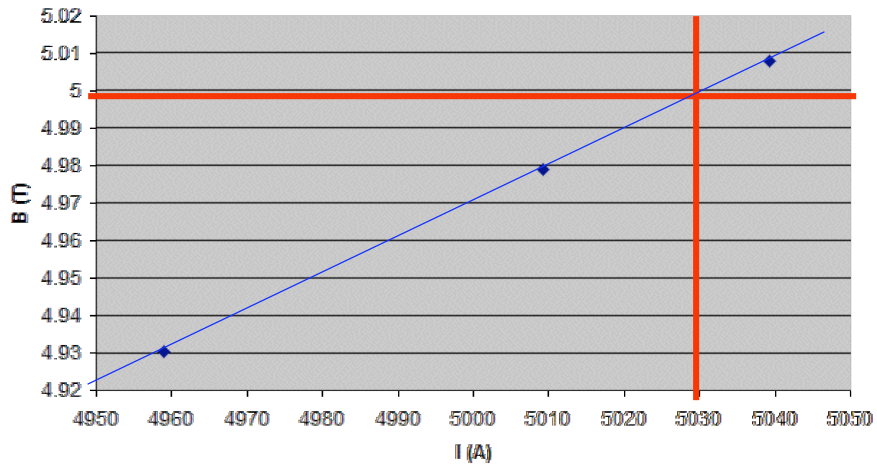


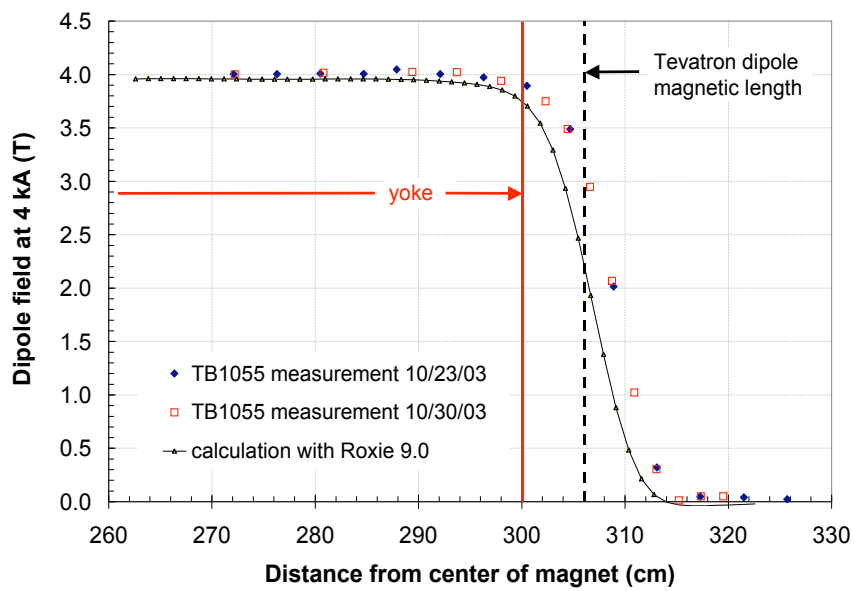



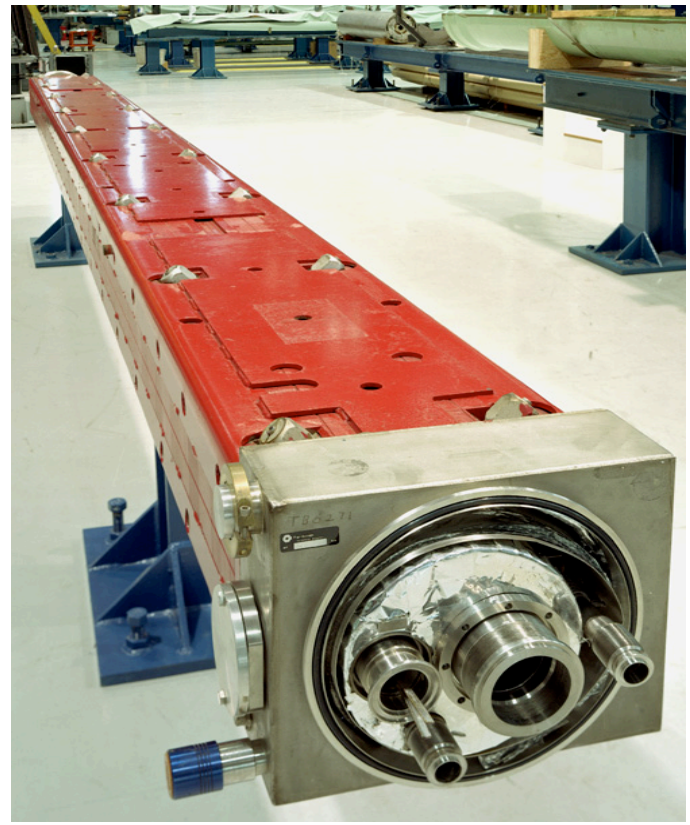
# GammeV : Tevatron Magnet (TC1206)

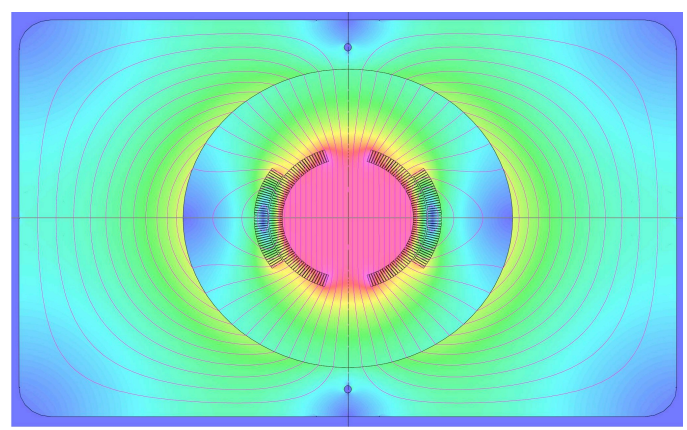


**Operating B-field : 5030A = 5T**



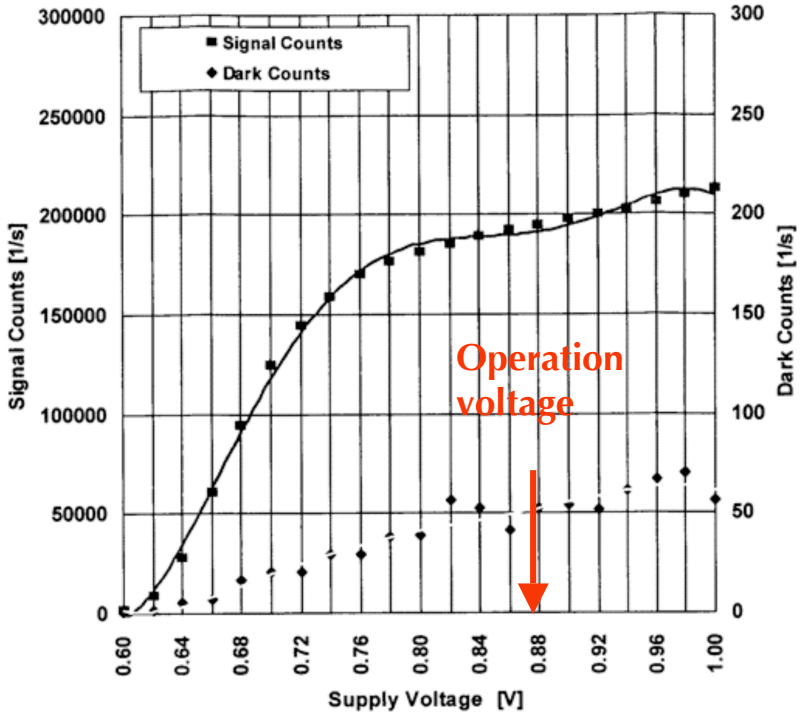



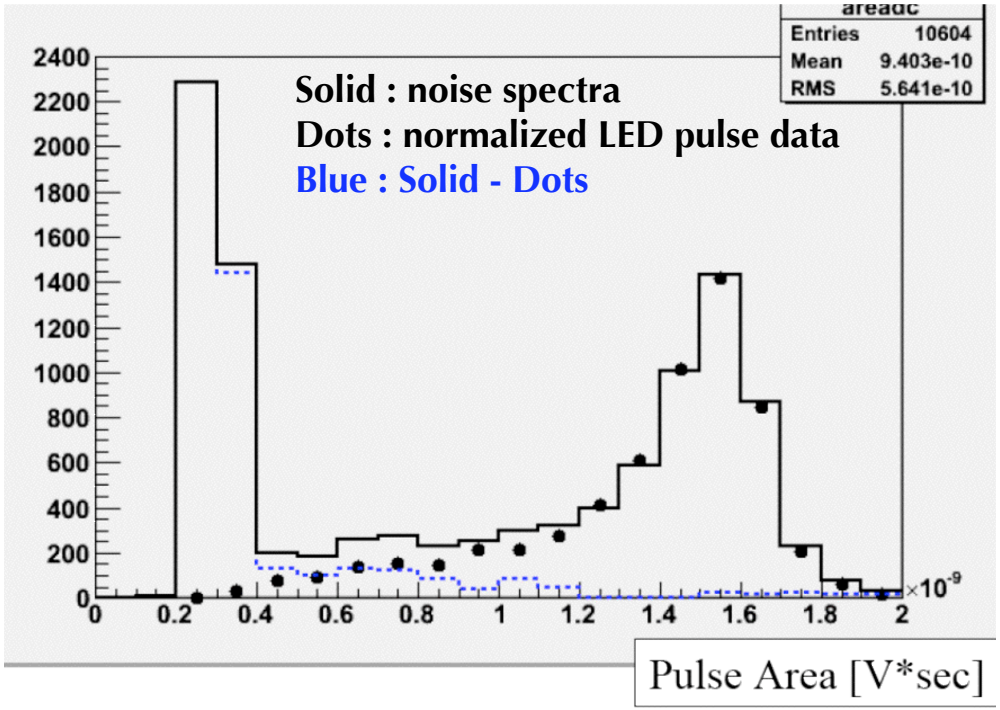





# GammeV : PMT

**Hamamatsu H7422P-40**
**GaAsP photocathode : QE = 39%**
**Built-in thermoelectric cooler**
**~100Hz Dark count rate in room temperature**

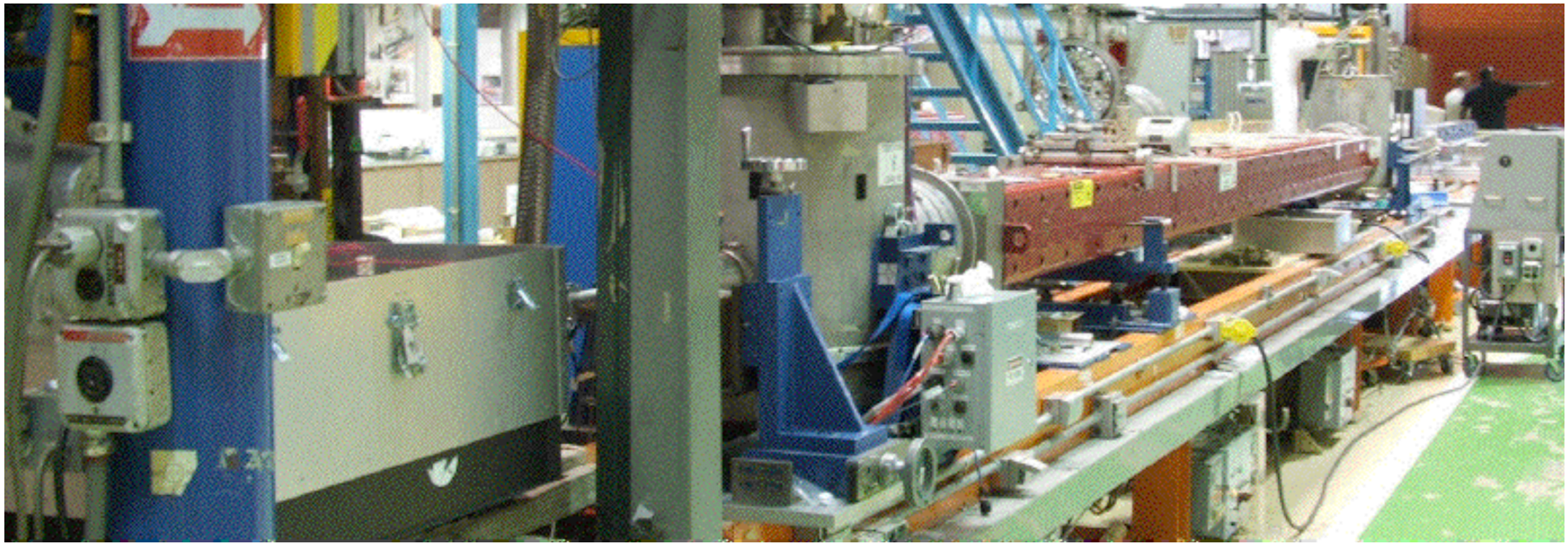


# Experiment Timeline



2006.03 : PVLAS results published at PRL
2006.11 : Experiment design
2007.04 : Review and approval from Fermilab
2007.05 : Acquire and machine parts
2007.06 : Assemble parts, test electronics and PMT calibration
2007.07 : First data but magnet and laser problems
2007.08 : Start data taking in earnest
2007.09 : Complete data taking and preliminary analysis
2007.10 : Accurate systematic uncertainty study
2007.11 : GammeV ALP search paper submitted to PRL
2008.01 : GammeV results accepted for publication at PRL



# Data taking

## Experiment modes

- Leaky mirror mode : set coincidence timing window
- Polarization (controlled by 1/2 wave plate)
  - Vertical E-field : Pseudo-scaler coupling search (E◆B)
  - Horizontal E-field (1/2 wave plate) : Scalar coupling search (B◆B)
- Mirror position : 3 m (center) or 1 m into the warm bore
  - Vary the path length of the magnetic field
    to control sensitive parameter space of the photon-axion coupling

## Experiment monitoring

- Beam path accuracy checked at the beginning and at the end of each run
- Laser power (~3W) and coolant temperature (41°) monitor
- Reflected beam spot monitor : Video camera in the laser box
- PMT event rate monitor : ~130Hz
- Vacuum level monitor : ~1e-4 torr

# Beam coincidence time

## Beam coincidence time is estimated using leaky mirror setup

3 Watt of powerful pulse laser light
(~1e17 photons/pulse)

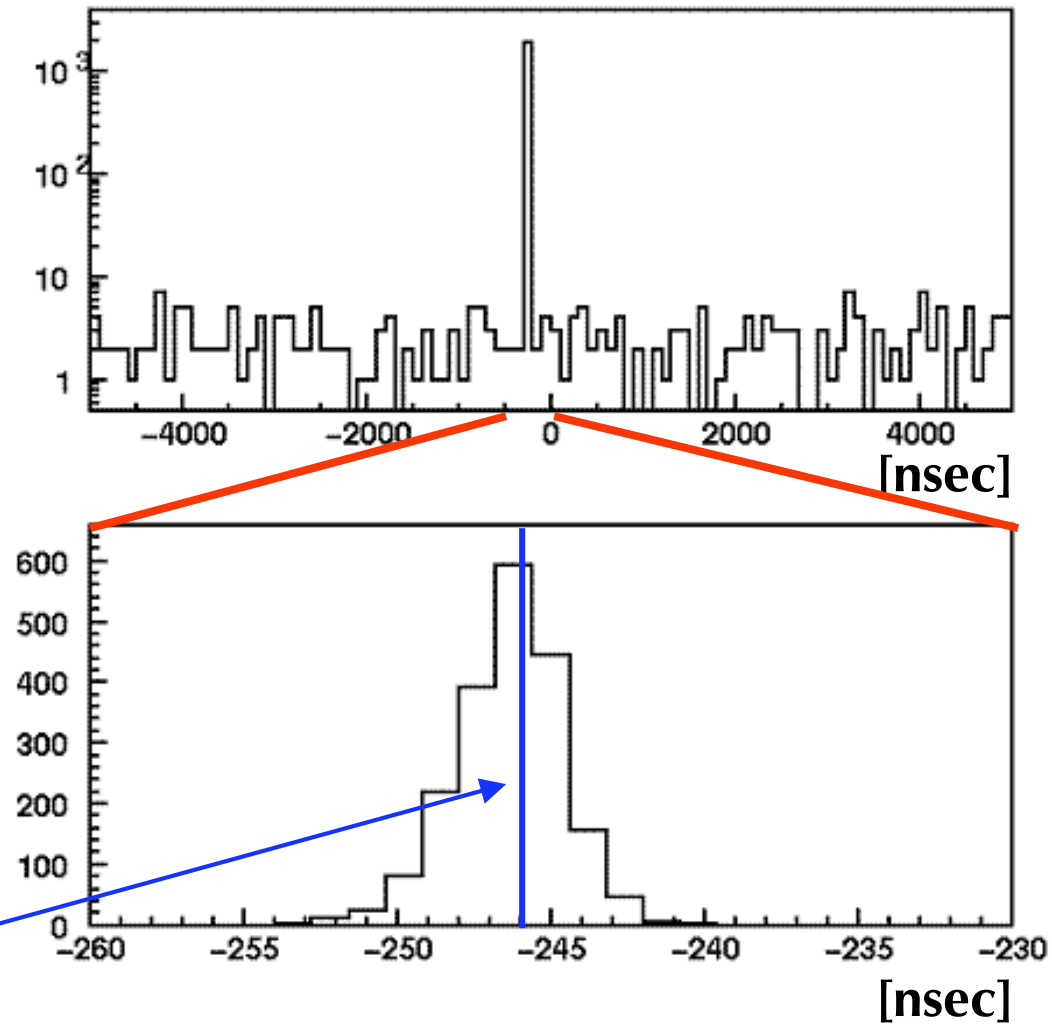
**Reflect out most of the photons**
- Reflect 99.9% of photons at the laser box
- Reflect 99.9% of light at the PMT box

**In front of the PMT cathode**
- 10 micron pin hall
- Two ND filters (OD7 absorptive)

➔ Reduction factor of photons : 1e-19
~1 photon per every 100 pulses

**Time constants**
- Time sync delay : 158 nsec
- Cable delay : 40 nsec
- Time of flight : 48 nsec

158 + 40 + 48 (nsec) = 246 nsec



# Look at the axion search data

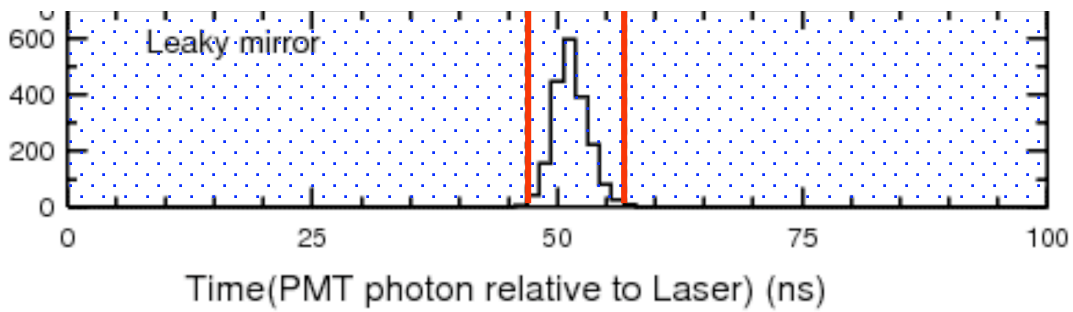


**Blind Analysis**

**10 nsec signal time window fixed before take a look at the axion search data**

**Background Side Band**

**Background in a 10 nsec signal region is estimated based on 10,000 nsec wide window**



# Results



- All the data combined for each run mode
- [# Photons] = [Total # laser pulse] x [Power meter read out]

| Spin | Position | # Photons | Exp. Background | Signal |
|---|---|---|---|---|
| Scalar | Center | 6.3e23 | 1.6±0.04 | 1 |
| Scalar | 1 m | 6.4e23 | 1.7±0.04 | 0 |
| Pseudo | Center | 6.6e23 | 1.6±0.04 | 1 |
| Pseudo | 1m | 7.1e23 | 1.5±0.04 | 2 |

* No statistically significant indication of ALP signal observed

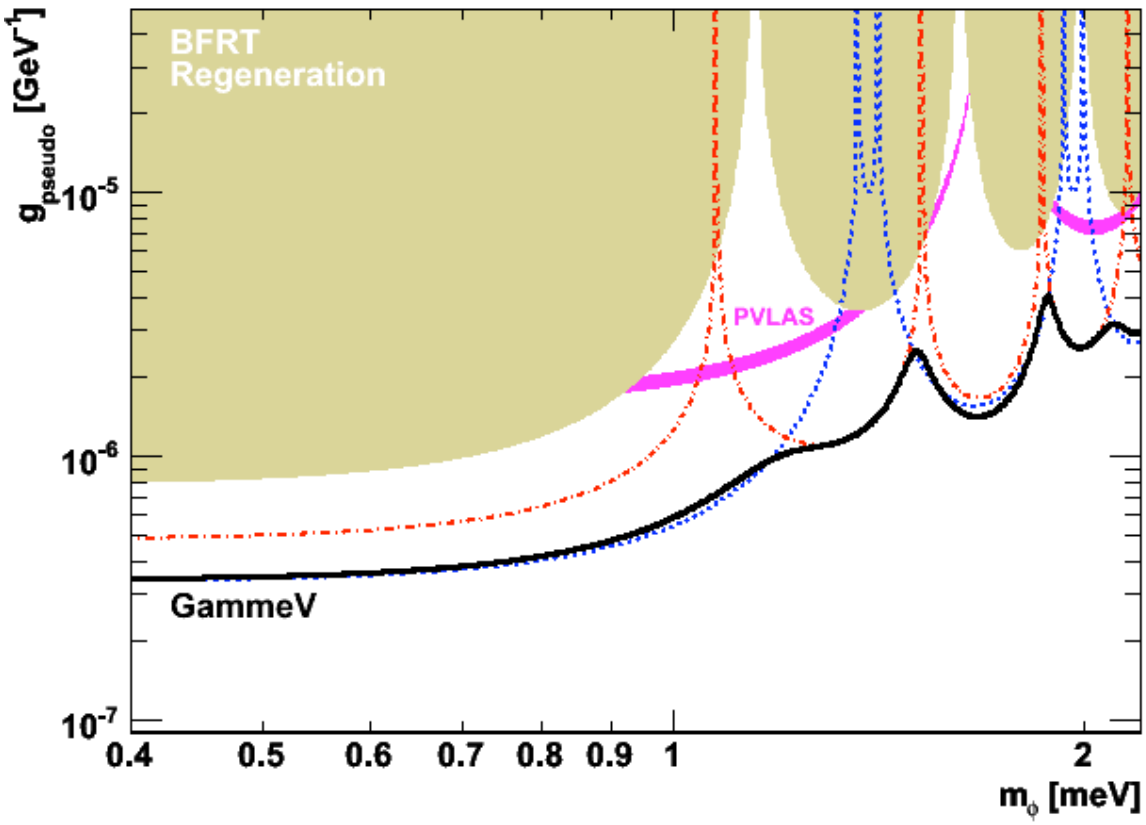
## Detection efficiency : 25±3%

- Factory measured PMT Q.E. = 39%, C.E = 70%
- Optical transport eff. = 92%
- Single photon trigger eff. = 99.4%

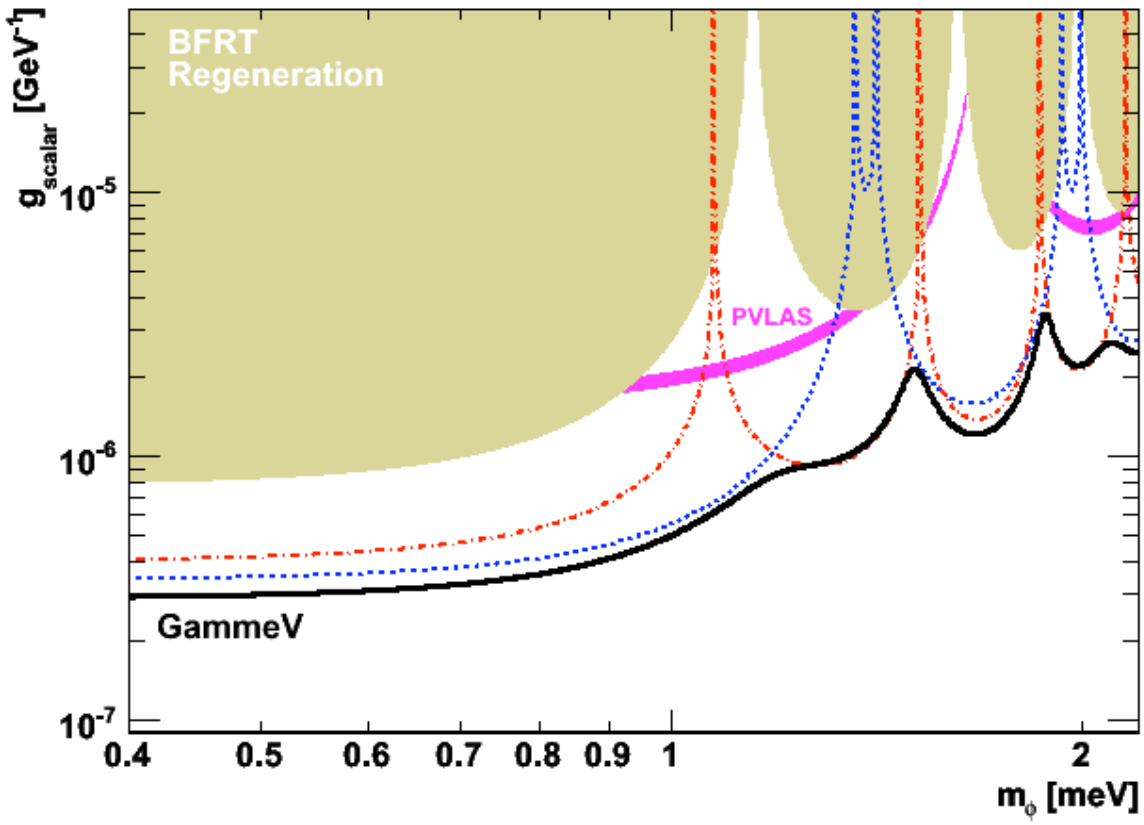
## Systematic uncertainty

- Photon transport and detection = 12% □
- Photon counting (power meter read out) = 3%

## Vertical E field mode (parallel to B field)



## Horizontal E field mode (perpendicular to B field)



# Fermilab Today : It's really today



http://www.fnal.gov/pub/today/

## Fermilab *Today*

Thursday, February 21, 2008

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### Furlough Information

New furlough information, including an up-to-date Q&A section, appears on the furlough Web pages daily.

### Calendar

**Thursday, Feb. 21**
THERE WILL BE NO PHYSICS AND DETECTOR SEMINAR THIS WEEK
**2:00 p.m.**
Computing Techniques Seminar - FCC1
Speaker: D. Yocum, Fermilab
Title: The FermiGrid High Availability System
**2:30 p.m.**
Theoretical Physics Seminar - Curia II
Speaker: C. Oleari, Universita di Milano-Bicocca
Title: Matching NLO Calculations with Parton Showers: The POsitive-Weight Hardest Emission Generator (POWHEG)
**3:30 p.m.**

### Contest

#### Play safe, win Fermilab gear

The first batch of safety signs went up at laboratory entrances October 2007.

Have you seen those safety signs at the entrances to the laboratory, and said, "I can do that." Well, here is your chance to prove it. Show off your safety know-how and catchy wit to win a prize in Fermilab's second safety slogan contest.

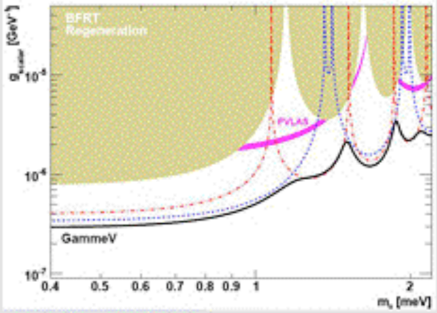
Messages should focus on how to prevent accidents on laboratory property or how to protect the environment through recycling, conservation and preservation. Slogans should have Fermilab specific themes and not general safety tips.

Accident avoidance and environment-friendly messages will appear on display signs at the three site entrances.

Some of the slogans posted so far include:

### Special Fermilab Result of the Week

#### Axion result all washed up




New limits from the GammeV collaboration excluding a region of axion-like particles in the milli-eV mass range versus the coupling to photons. These limits surpass earlier regeneration limits from BFRT and exclude the suggested region of interest from PVLAS results.

Members of the GammeV experiment at Fermilab, beat other research teams across the globe in a race to refute claims of a 2006 discovery of an axion particle, a possible dark matter candidate.

GammeV collaborators proved that the reported signature of the new particle by the Italian PVLAS experiment was an anomaly, not a discovery. And GammeV collaborators refuted the data in near record time on a shoe-string budget.

# Conclusion



- Axionlike Particle interpretation of PVLAS results excluded by > 5 sigma
- BMV experiment also excluded PVLAS results with 99%CL
- PVLAS new data does not observe the ellipticity any more and concludes there is likely an instrumental artifact (hep-ex/0706.3419)
- The first results from GammeV ALP serach data is published in PRL
- The 2nd phase of GammeV experiment result, a Chameleon search, is coming soon.

PHYSICAL REVIEW LETTERS

**Search for Axionlike Particles Using a Variable-Baseline Photon-Regeneration Technique**

A. S. Chou,[1,2] W. Wester,[1] A. Baumbaugh,[1] H. R. Gustafson,[3] Y. Irizarry-Valle,[1] P. O. Mazur,[1] J. H. Steffen,[1] R. Tomlin,[1] X. Yang,[1] and J. Yoo[1]

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[2]*Center for Cosmology and Particle Physics, New York University, 4 Washington Place, New York, New York 10003, USA*

[3]*Department of Physics, University of Michigan, 450 Church Street, Ann Arbor, Michigan 48109, USA*

(Received 24 December 2007)

We report the first results of the GammeV experiment, a search for milli-eV mass particles with axionlike couplings to two photons. The search is performed using a "light shining through a wall" technique where incident photons oscillate into new weakly interacting particles that are able to pass through the wall and subsequently regenerate back into detectable photons. The oscillation baseline of the apparatus is variable, thus allowing probes of different values of particle mass. We find no excess of events above background and are able to constrain the two-photon couplings of possible new scalar (pseudo-scalar) particles to be less than $3.1 \times 10^{-7}$ GeV$^{-1}$ ($3.5 \times 10^{-7}$ GeV$^{-1}$) in the limit of massless particles.