Results from GammeV

Varying Baseline Axion Like Particle Search at Fermilab

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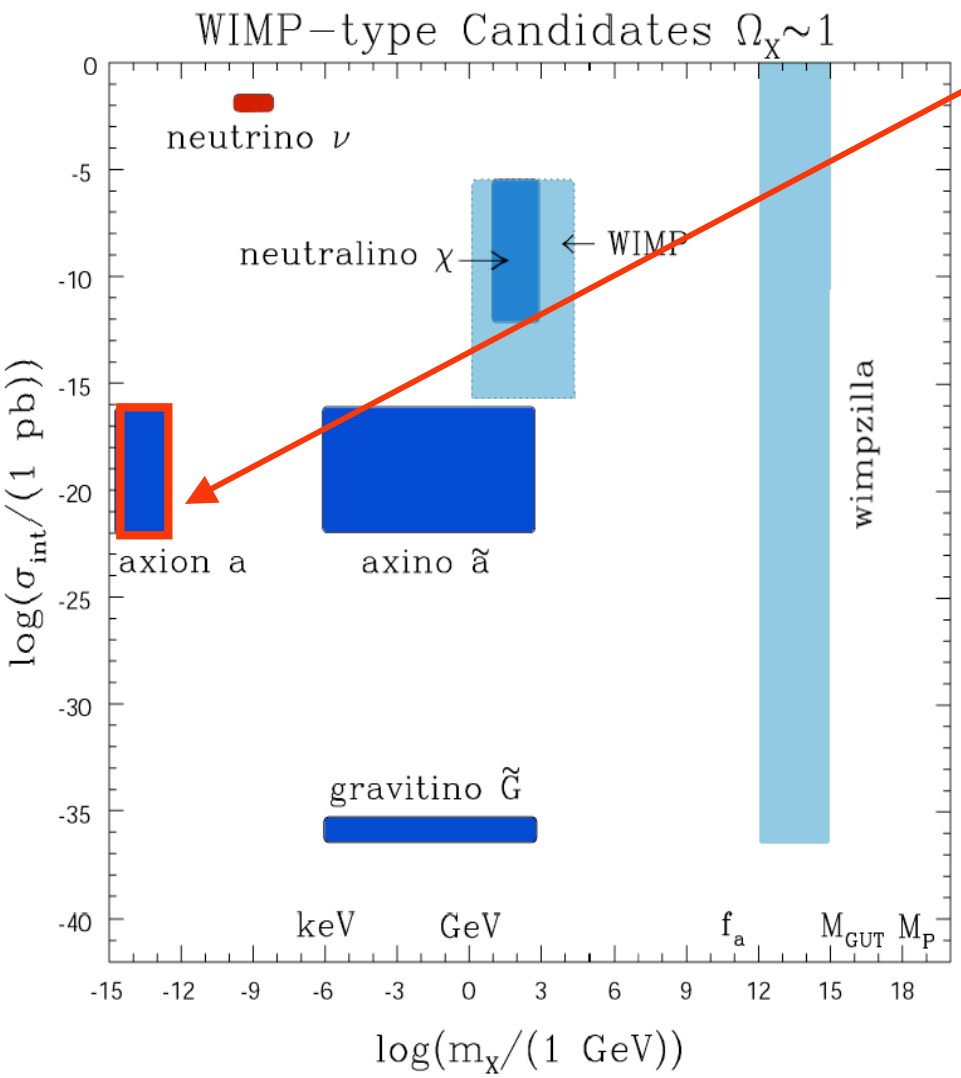
Fermilab

Dark 2007, 27th September 2007
Australia, Sydney

Outline

- Introduction
- GammeV Experiment
- Data Analysis
- Results
- Summary

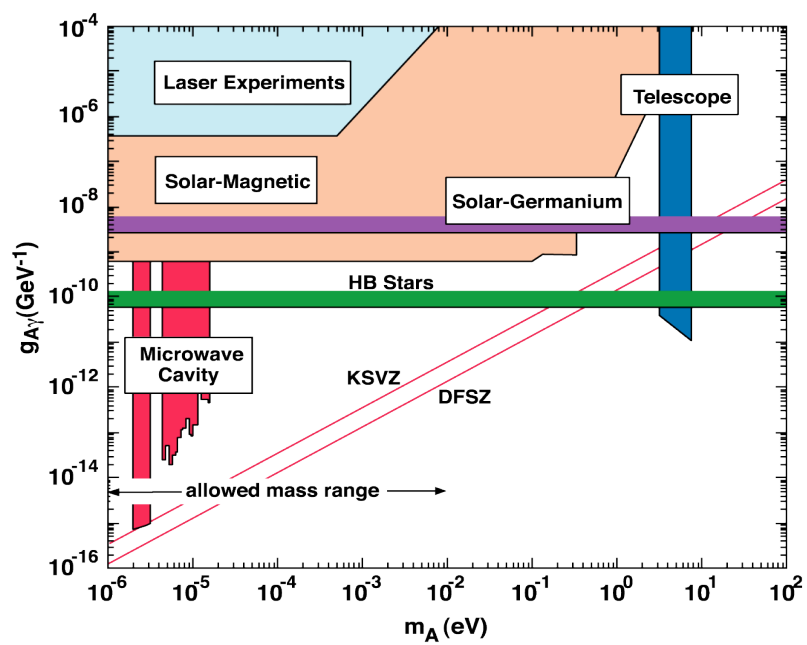
Axions in the Dark Side



Roszkowski

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



Laser Based ALP Search Experiments

name	place	magnet (field length)	laser wavelength power	P_{PVLAS}	photon flux at detector
ALPS	DESY	5 T 4.21 m	1064 nm 200 W cw	$= 10^{-19}$	10/s
BMV	LULI	11T 0.25 m	1053 nm 500 W 4 pulses/day	$= 10^{-21}$	10/pulse
LIPSS	Jefferson Laboratory	1.7 T 1.0 m	900 nm 10 kW cw	$= 10^{-23.5}$	0.1/s
OSQAR (preliminary phase)	CERN	9.5 T 1.0 m 9.5 T 3.3 m	540 nm 1 kW cw	$= 10^{-20}$	10/s
PVLAS (regeneration)	INFN Legnaro	5 T 1 m 2.2 T 0.5 m	1064 nm 0.8 W cw Npass $= 5 \times 10^5$	$= 10^{-23}$	10/s

Fully model independent approach

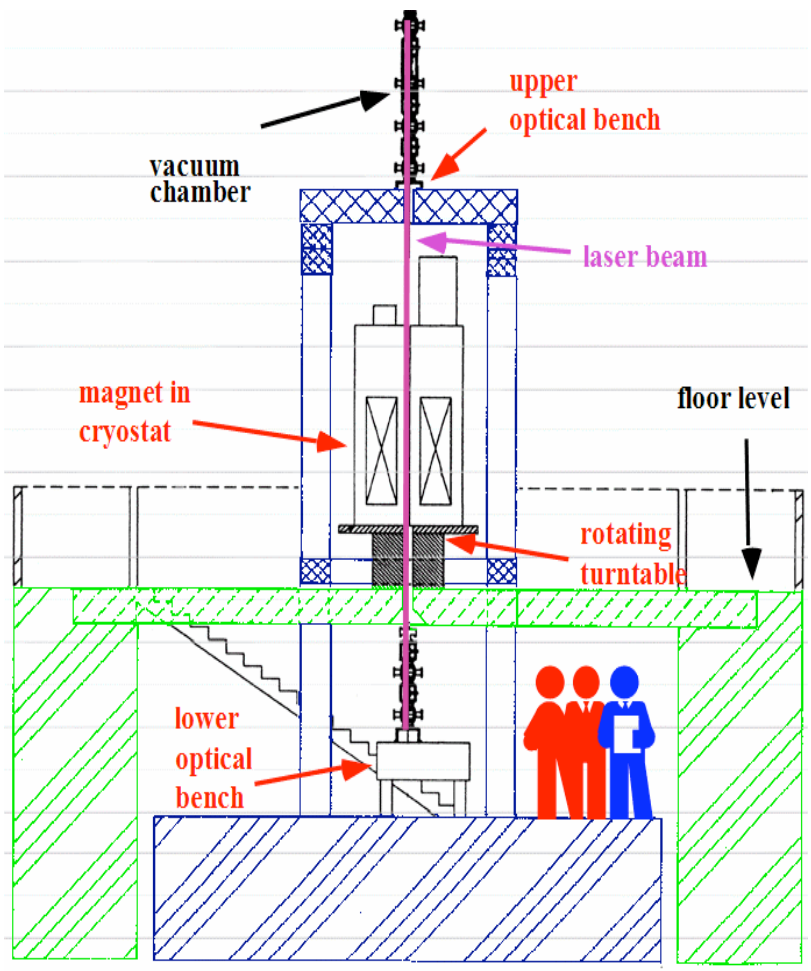
- No need solar-axion or astro-cosmo-axion production model

Probe various scientific interest

- Precision measurement of QED
- Any scalar / pseudo-scalar / paraphotons / milli-charged particles
- Magneto optical properties of the vacuum

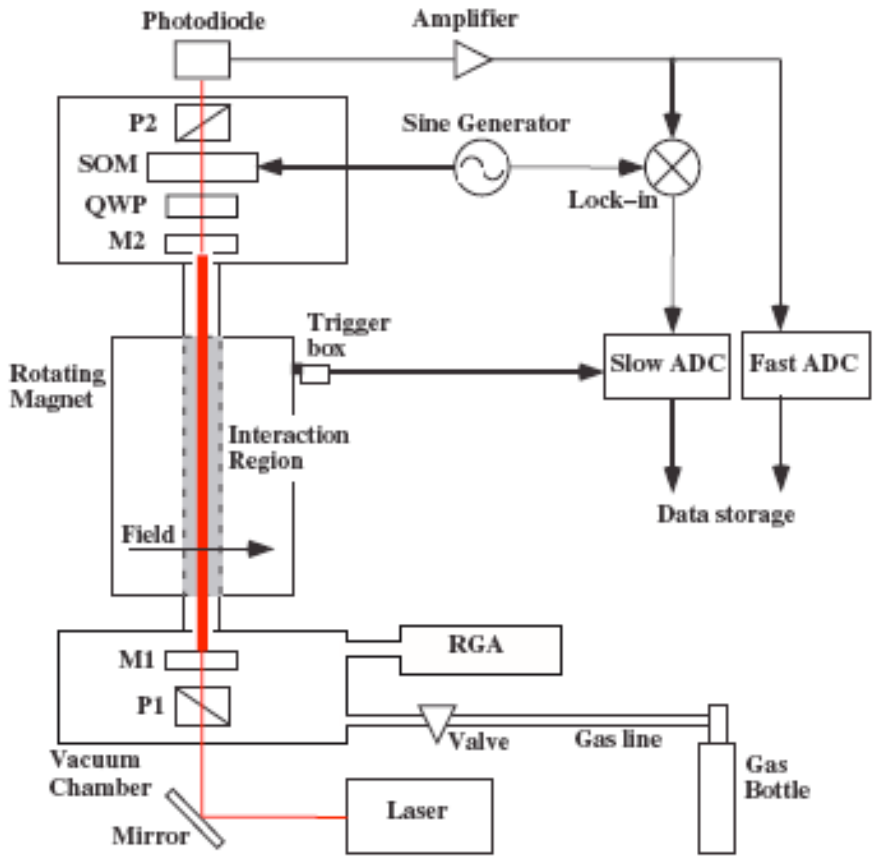
PVLAS : INFN

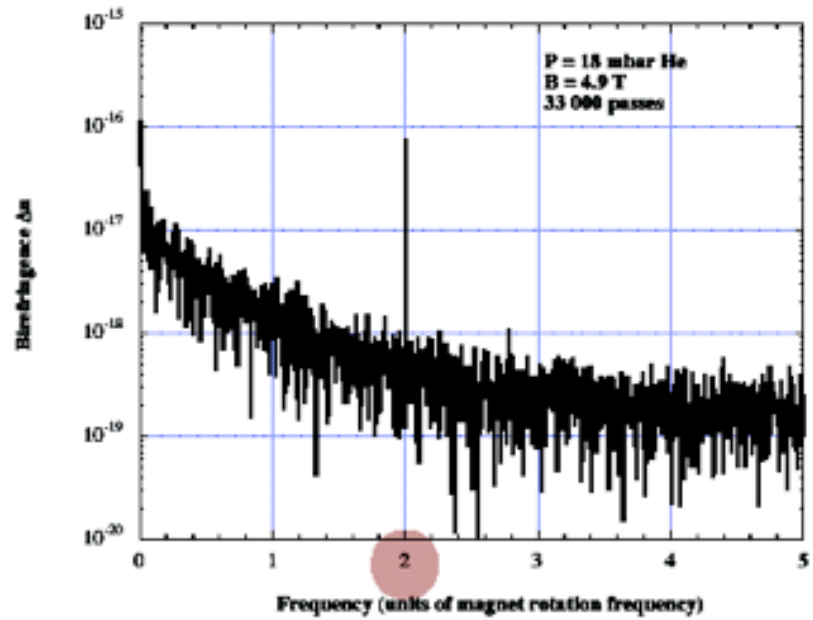
PVLAS experiment designed to study magneto-optic property of the vacuum



- Magnet
  - dipole 6T, 4.2K @ 1m field zone
- Cryostat
  - rotation frequency : 0.3mHz
  - warm bore to allow light propagate in the interaction zone
- Laser
  - 1064nm (532nm) 100mW
- Fabry-Perot cavity
  - 6.4m length, finesse ~100k
  (optical path in the interaction zone : 60 km)
- Heterodyne ellipsometer
  - ellipticity modulator & high extinction (1e-7) polarizer & 1/4 waver plate
- Detection
  - Photodiode with low noise amplifier

PVLAS : Calibration





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

PVLAS Results in Vacuum

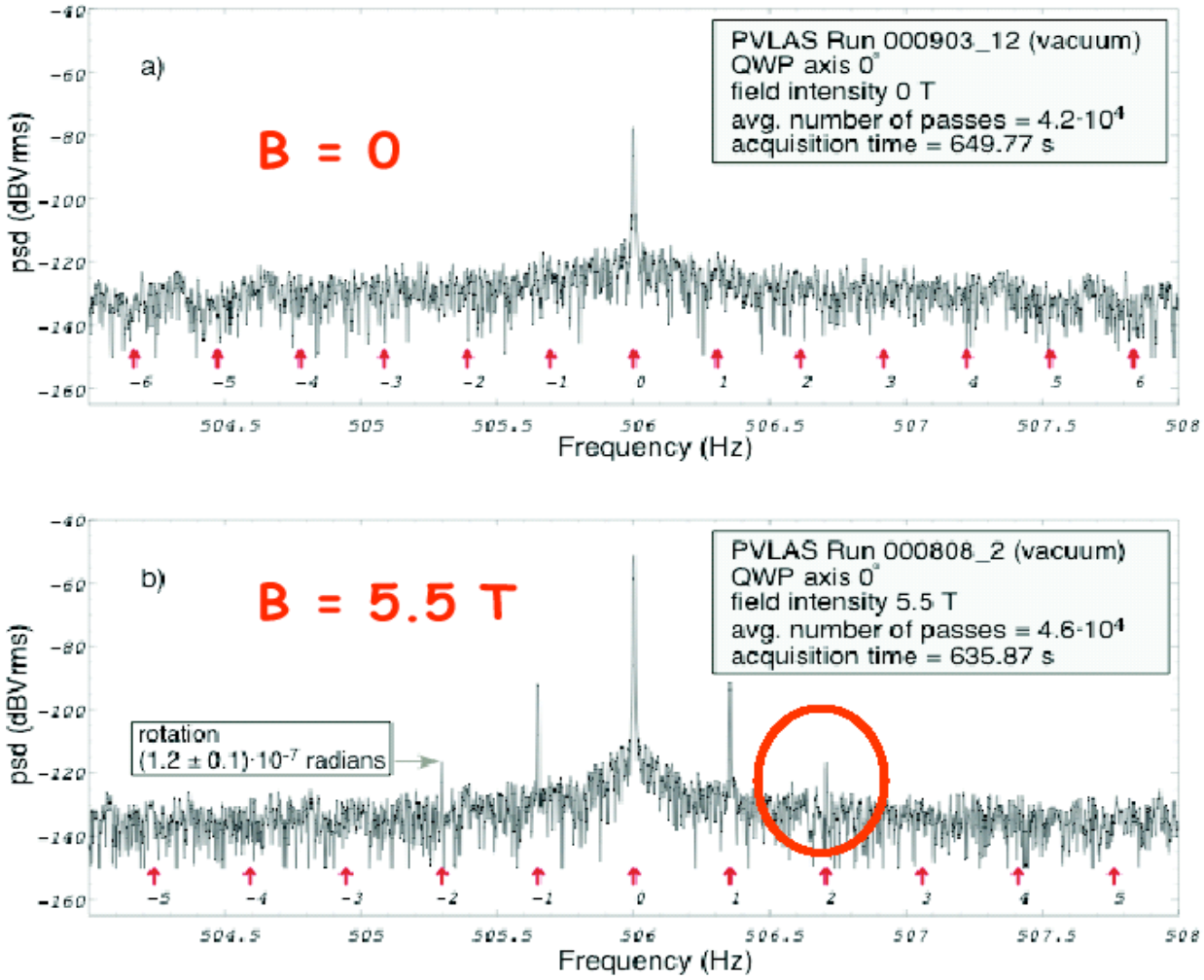
Observed rotation :
3.9±0.5×1e-12 rad/pass

Expect signals in
2nd harmonic only

Annoying 1st harmonics
are not understood

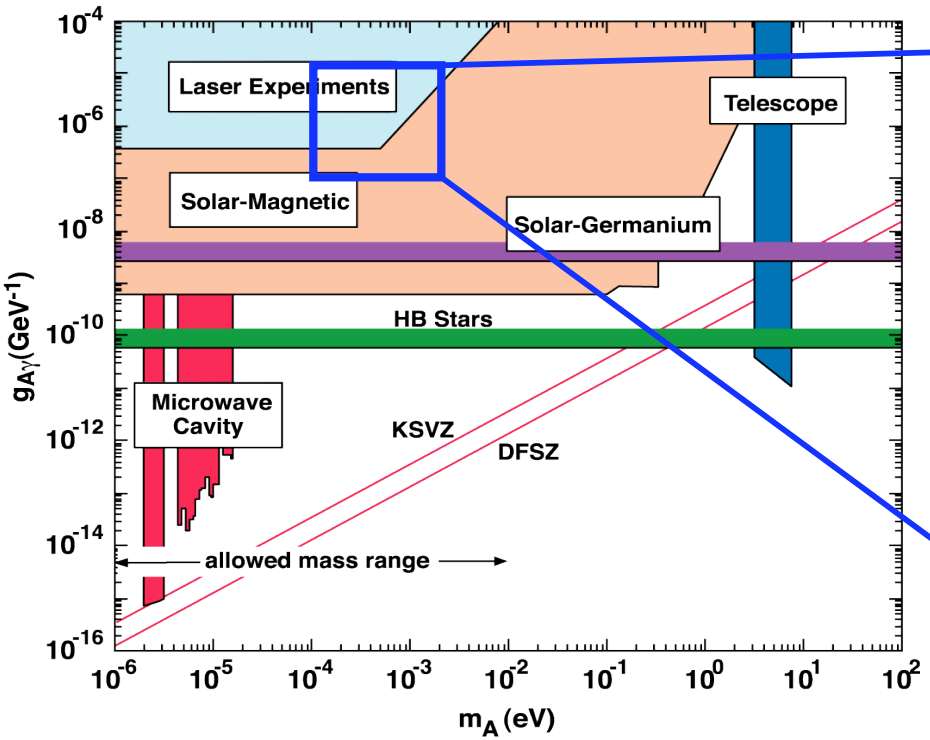
<u>The results are published</u>
PRL 96, 1110406 (2006)

<u>ICHEP2006</u>
Anormalous rotation
& ellipticity (532nm)
reported

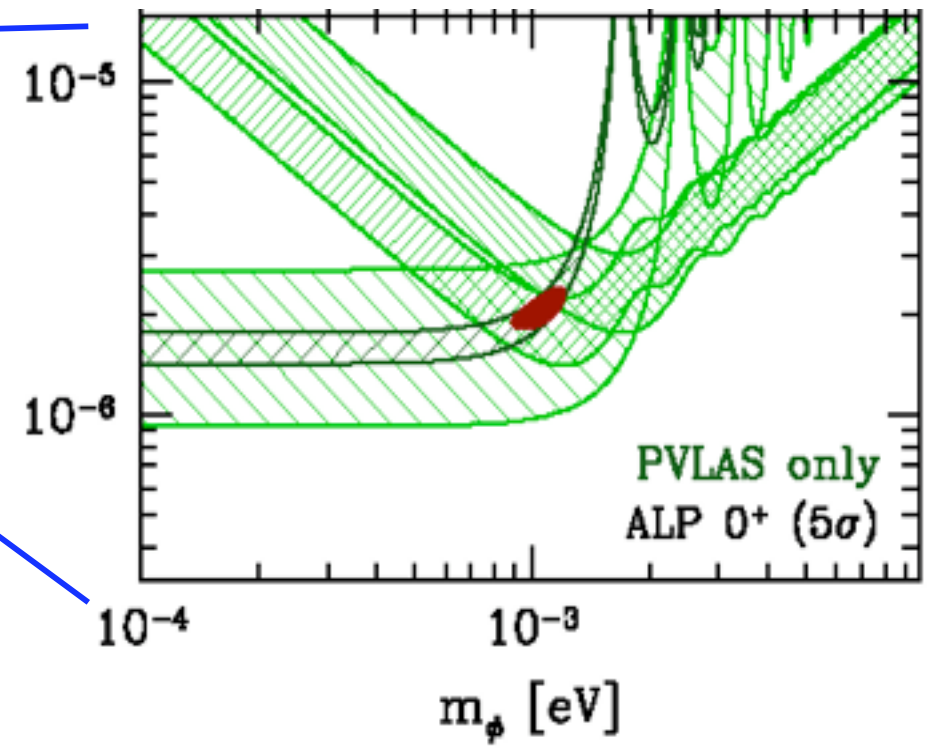


➔ Is this an indication of a new particle ?

PVLAS : Interpretation



PRD 75, 035011 (2007)

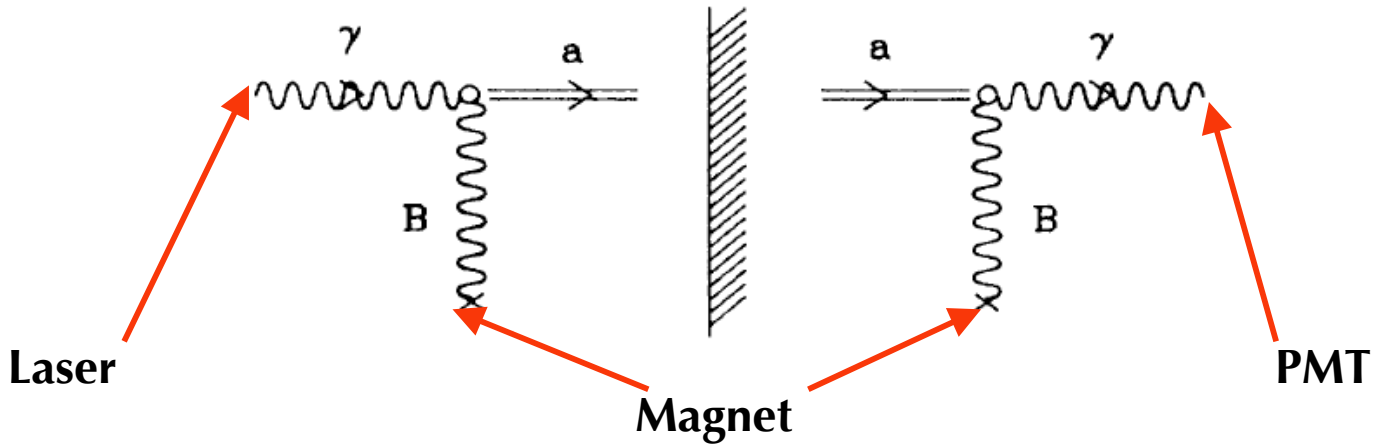


If one interpret the result as ALP

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, unless coupling is suppressed at high T or high density.

Early 2007 @ Fermilab Cafeteria



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

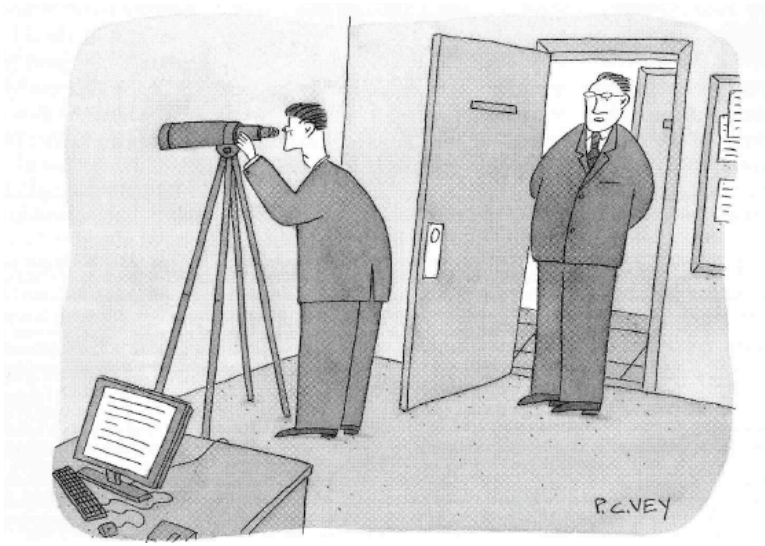
$$P_{regen}^{GammeV} = (3.9 \times 10^{-21}) \times \frac{(B_1/5\,\mathrm{T})^2 (B_2/5\,\mathrm{T})^2 (\omega/2.33\,\mathrm{eV})^4}{(M/4 \times 10^5\,\mathrm{GeV})^4 (m_\phi/1.2 \times 10^{-3}\,\mathrm{eV})^8}$$
$$\times \sin^2\left(\frac{\pi}{2}\frac{(m_\phi/1.2 \times 10^{-3}\,\mathrm{eV})^2 (L_1/2.0\,\mathrm{m})}{(\omega/2.33\,\mathrm{eV})}\right)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

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 : run time ~ 3 hours

Total budget request
$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 ~ $(2\times10^{-3}\,\text{eV})^4$
  - **Neutrinos**
    - $(\Delta m_{21})^2 = (9\times10^{-3}\,\text{eV})^2$
    - $(\Delta m_{32})^2 = (50\times10^{-3}\,\text{eV})^2$
  - **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**

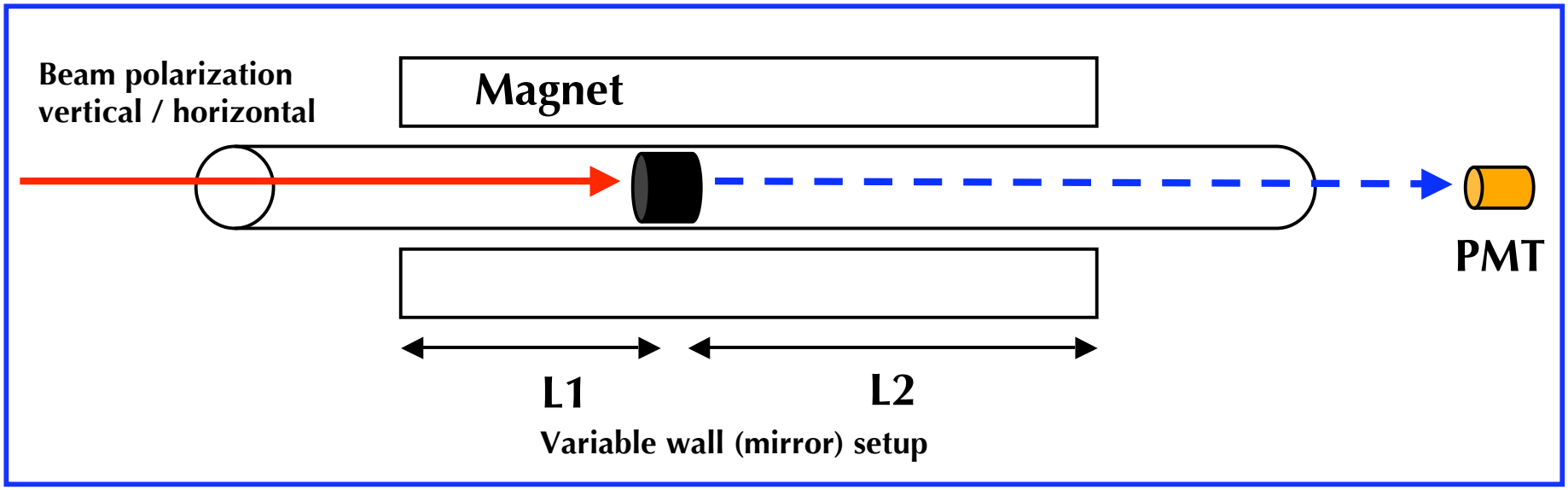


GammeV Collaboration

Aaron Chou (Co-spokes person)
William Wester (Co-spokes person)
Al Baumbaugh
Dick Gustafson
Yilda Irizarri-Valle
Peter Mazur
Jason Steffen
Ray Tomlin
Xi Yang
Jonghee Yoo

And we relied on technical support from Fermilab

GammeV experiment



Pseudoscalar

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

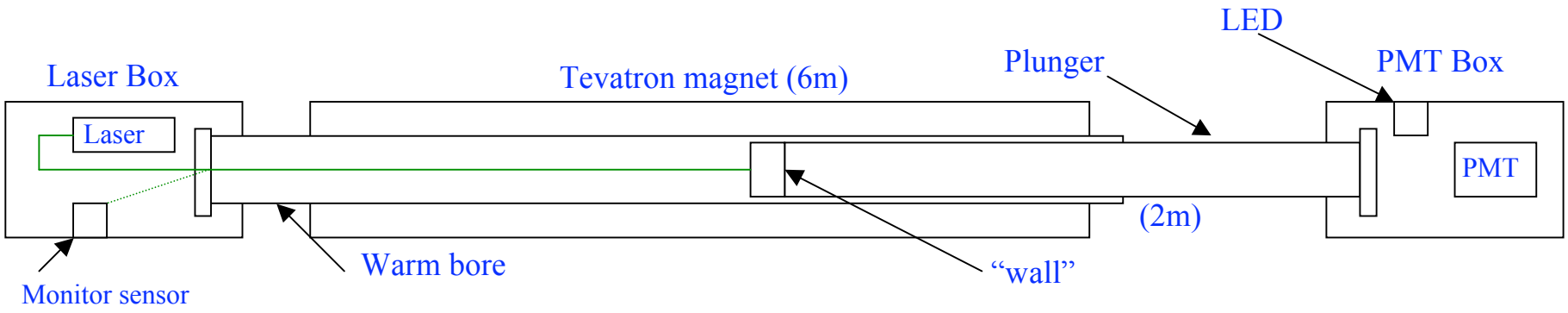
Scalar

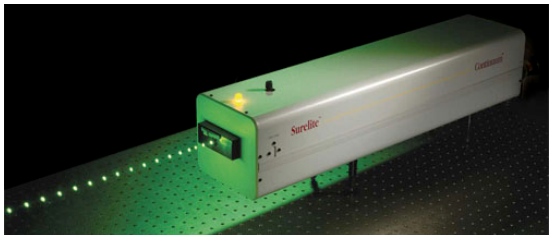
$$\mathcal{L}_{\rm int} = -\frac{1}{4}\frac{\phi}{M}F_{\mu\nu}F^{\mu\nu} = \frac{\phi}{M}(\vec{E}\cdot\vec{E}-\vec{B}\cdot\vec{B}).$$

Photon regeneration

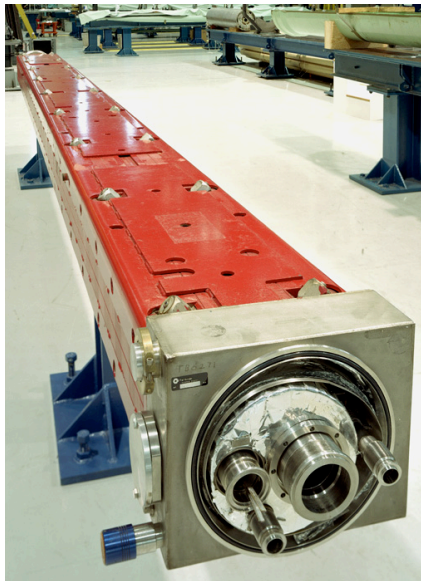
$$P_{regen} = \left(\frac{4B^2\omega^2}{M^2(\Delta m^2)^2}\right)^2\left(\sin\frac{\Delta m^2 L_1}{4\omega}\right)^2\left(\sin\frac{\Delta m^2 L_2}{4\omega}\right)^2$$

GammeV experiment setup

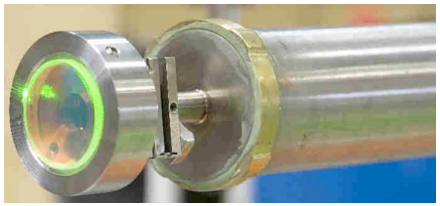




Surelite Nd:YAG
1064nm (doubled 532nm)
160mJ/pulse, 3.2W @ 20 Hz
Pulse width = 5 nsec



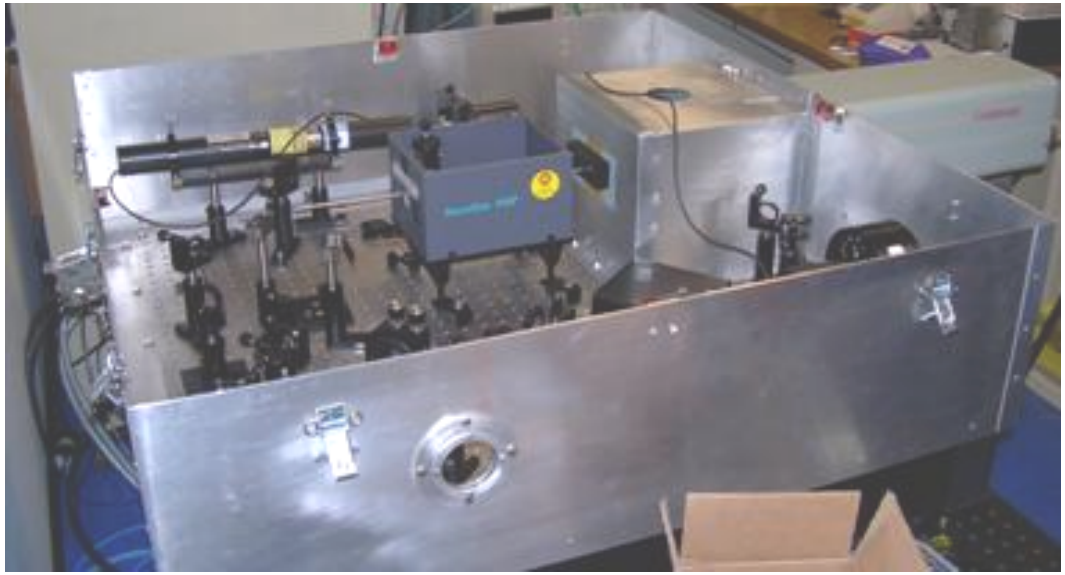
Tevatron dipole : B=5T

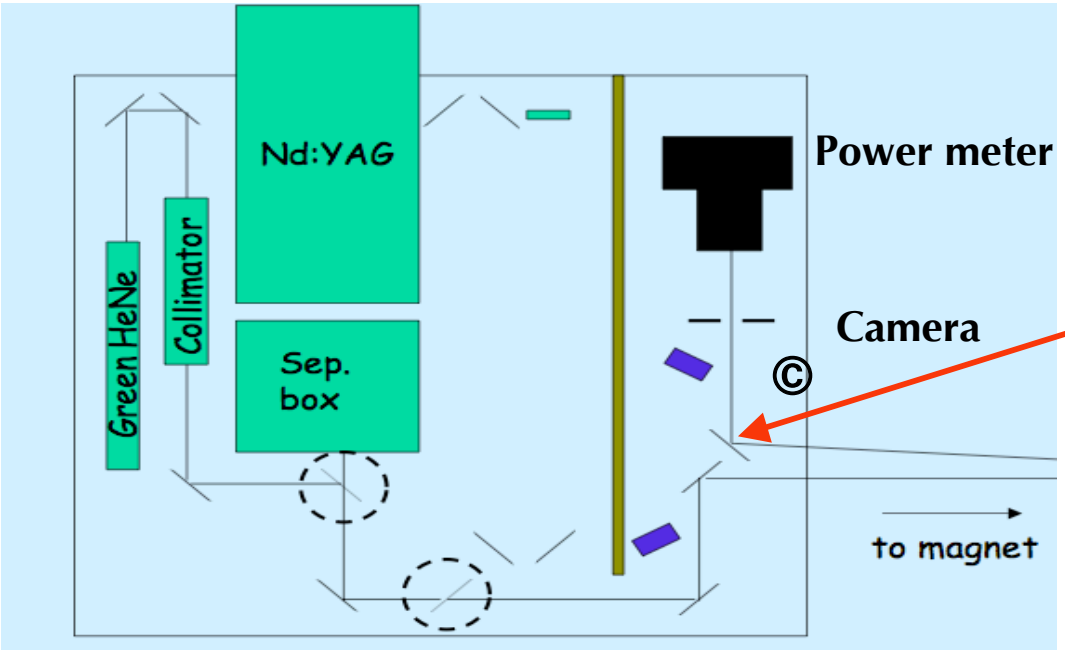


Wall : concave mirror
Coated for high power
green laser light
10m focal length

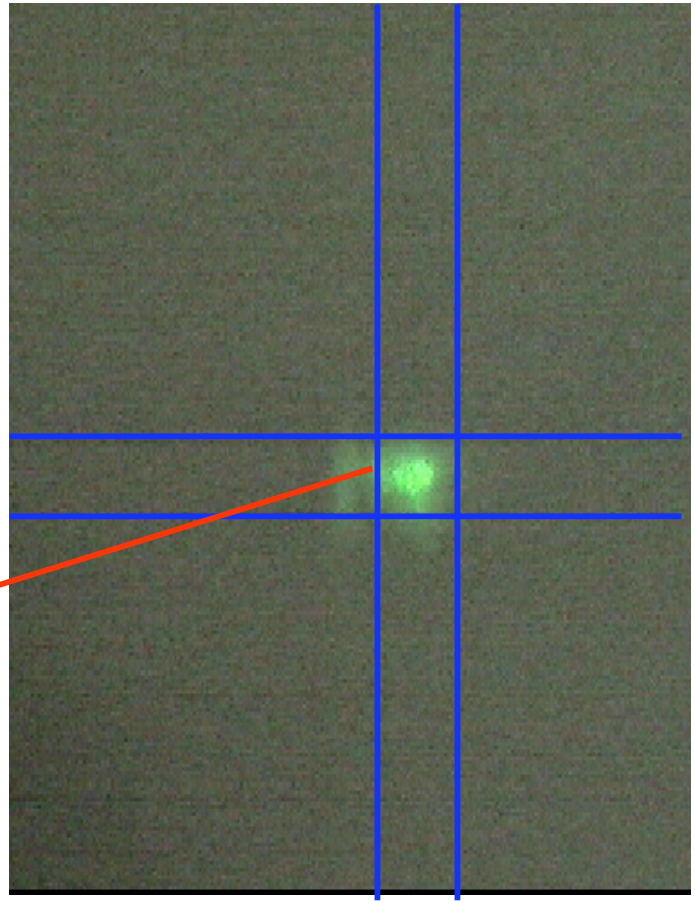
Hamamatsu H7421
GaAsP, QE=40%
Dark Count= 100 Hz

GammeV : Laser Box



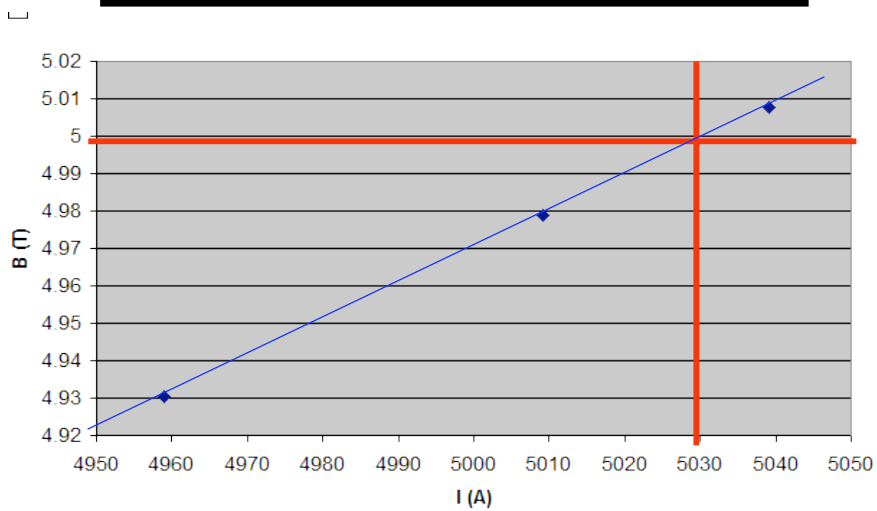


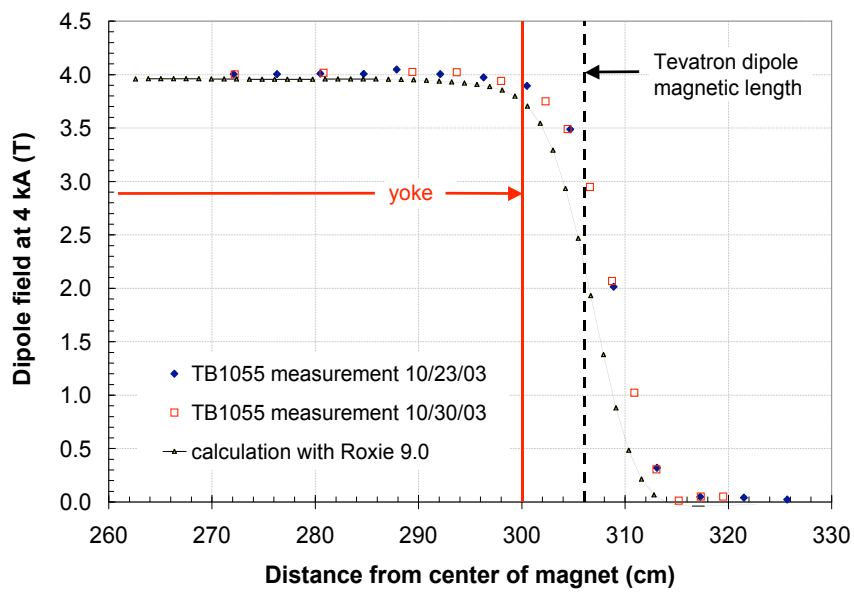
Reflected beam spot monitor
Camera image from laser box

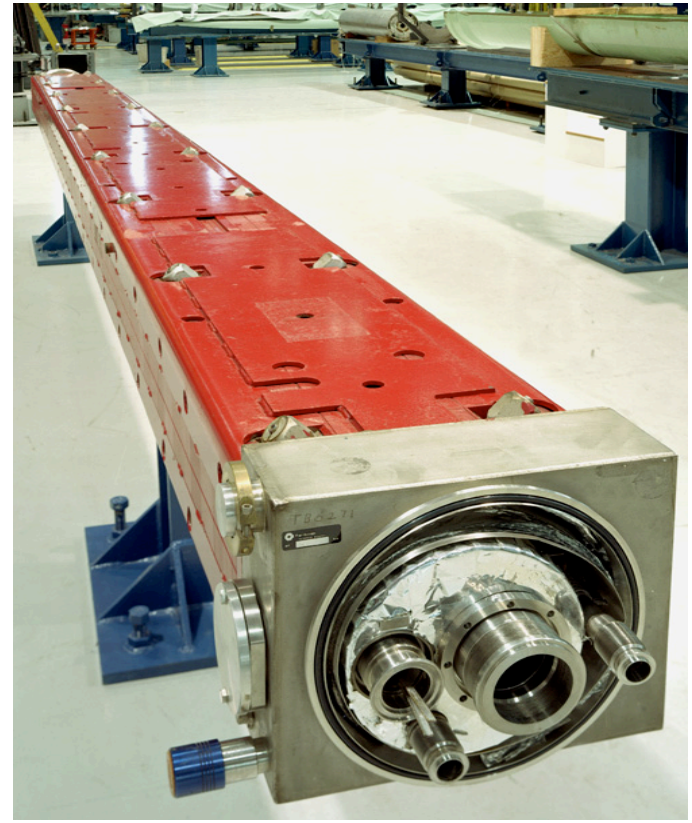


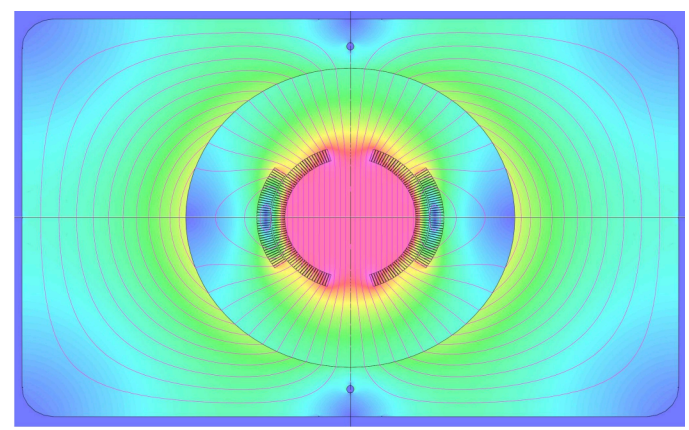
GammeV : Tevatron Magnet (TC1206)

Operating B-field : 5030A = 5T



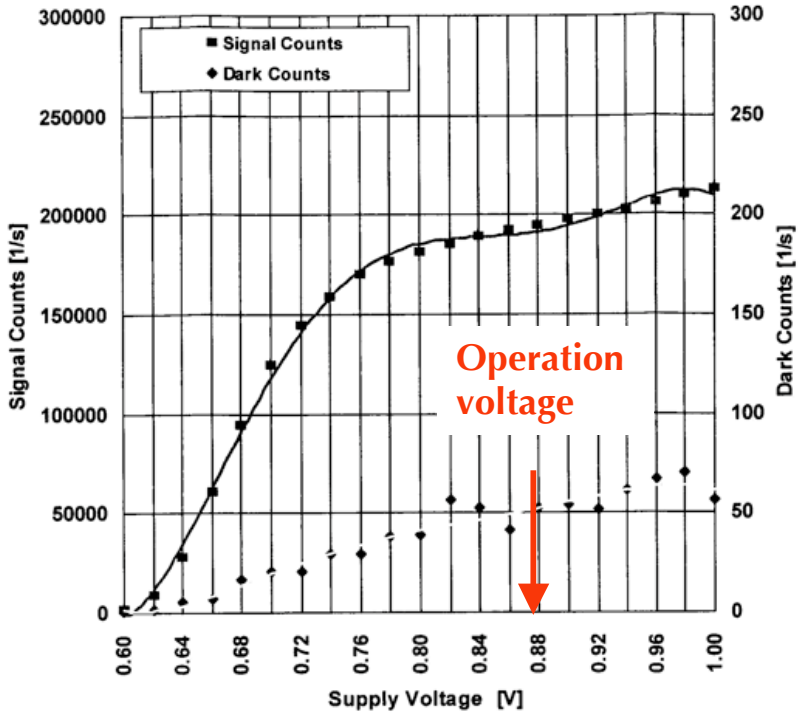


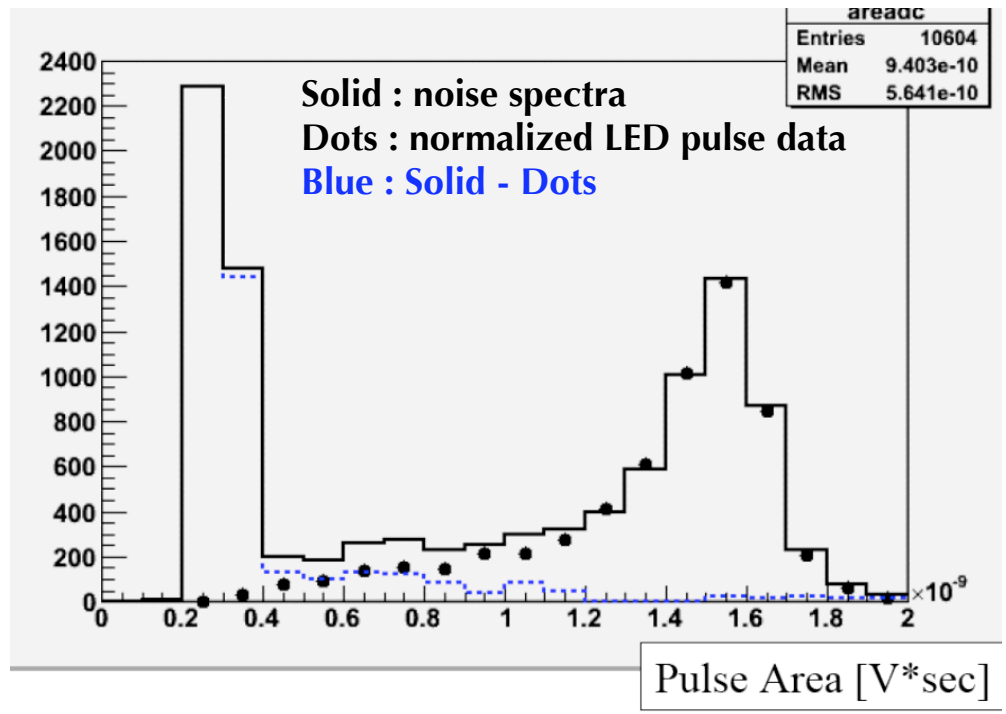




GammeV : PMT

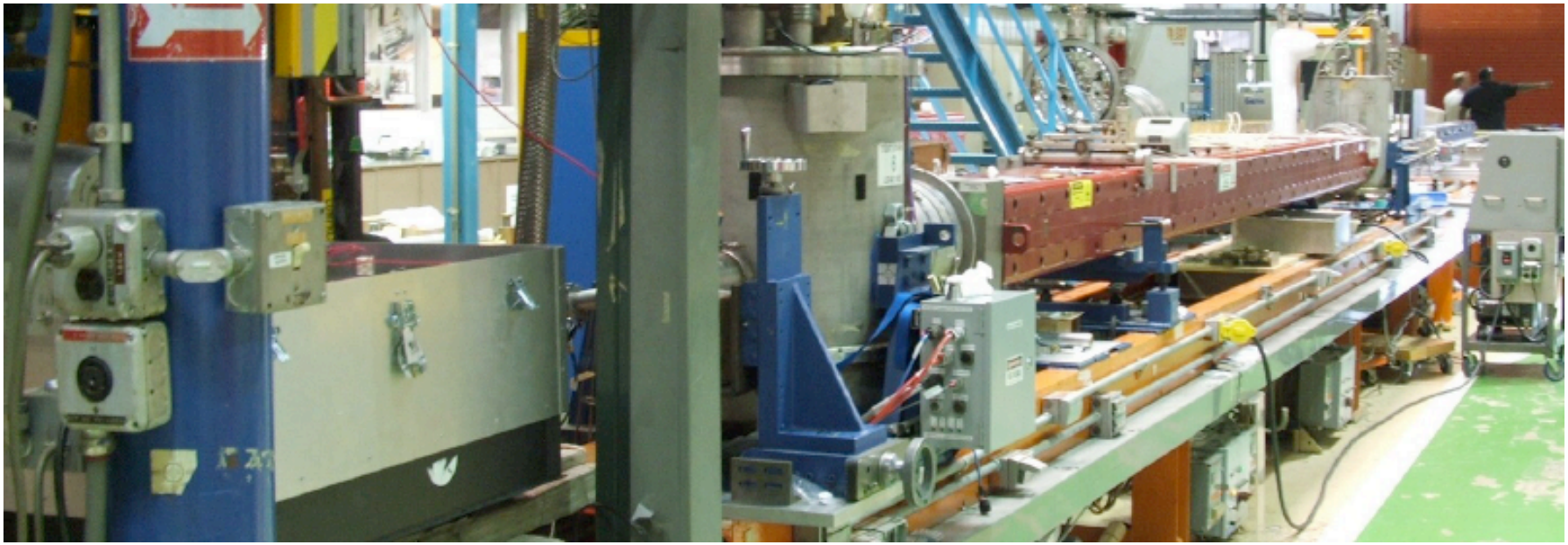
Hamamatsu H7422P-40
GaAsP photocathode : QE = 40%
Built-in thermoelectric cooler
~100Hz Dark count rate





Experiment Schedule

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 analysis : first result report



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 : ~100Hz
- Vacuum level monitor : ~1e-3 torr

Beam coincidence time

Beam coincidence time is estimated using leaky mirror setup

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

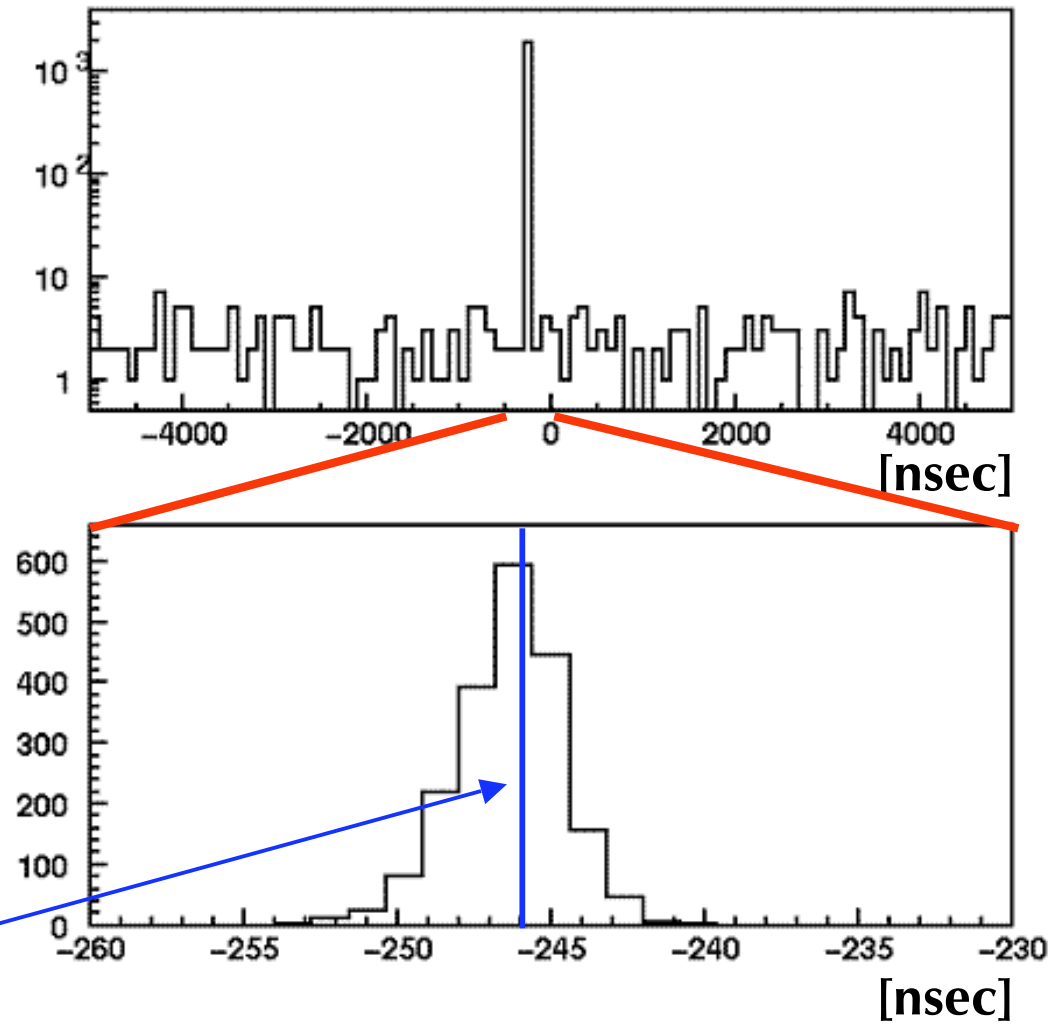
Reflect out most of the photons
- Reflect 99.9% of photons at the laser box
- Reflect 99.9% of light at the PMT box

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

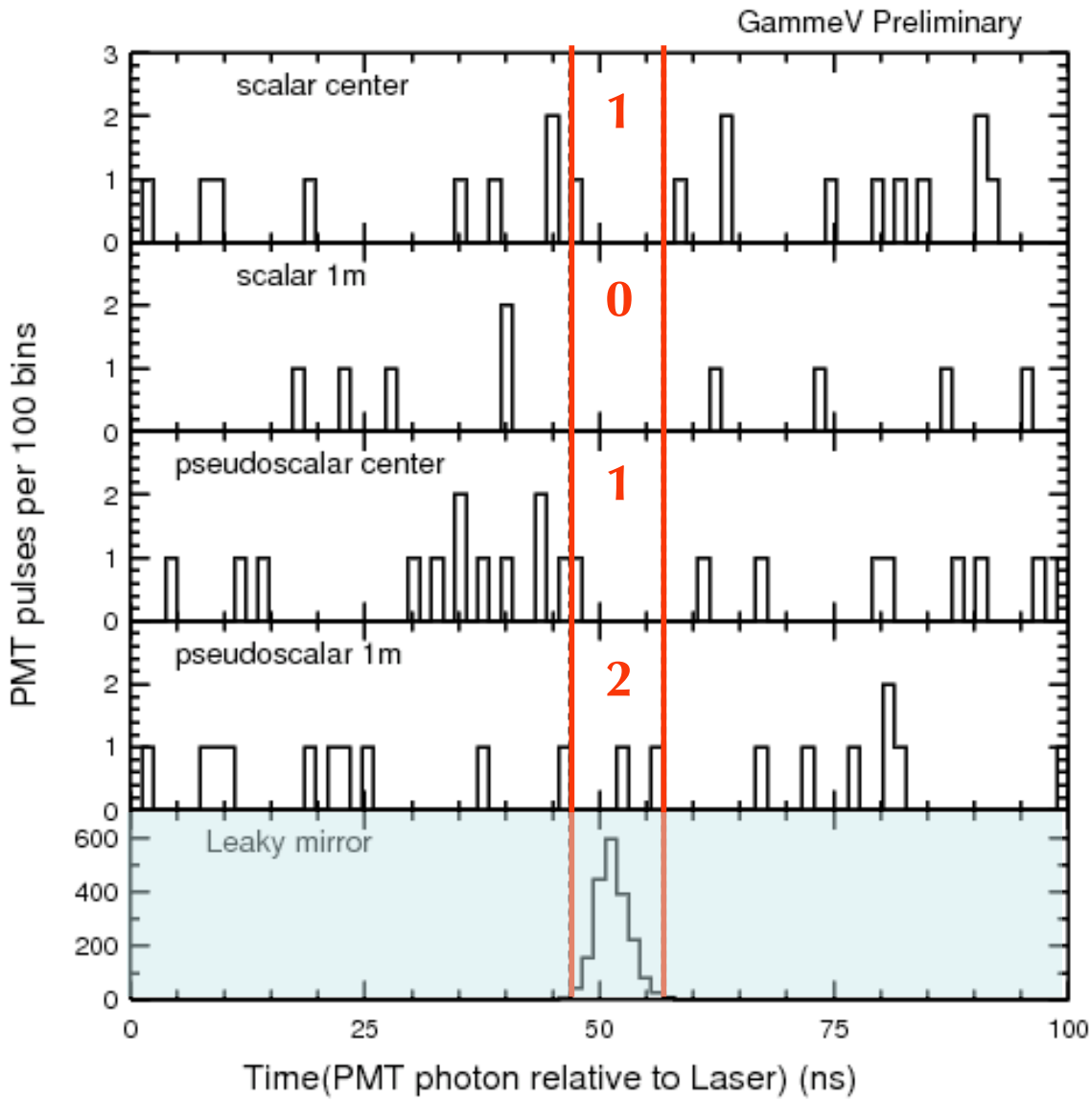
➔ Reduction factor of photons : 1e-19
(1 photon per every 100 pulses)

Time constant
- GPS time sync delay : 158 nsec
- Cable delay : 40 nsec
- Time of flight : 48 nsec

158 + 40 + 48 (nsec) = 246 nsec



Look at the ALP search data



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

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

Results

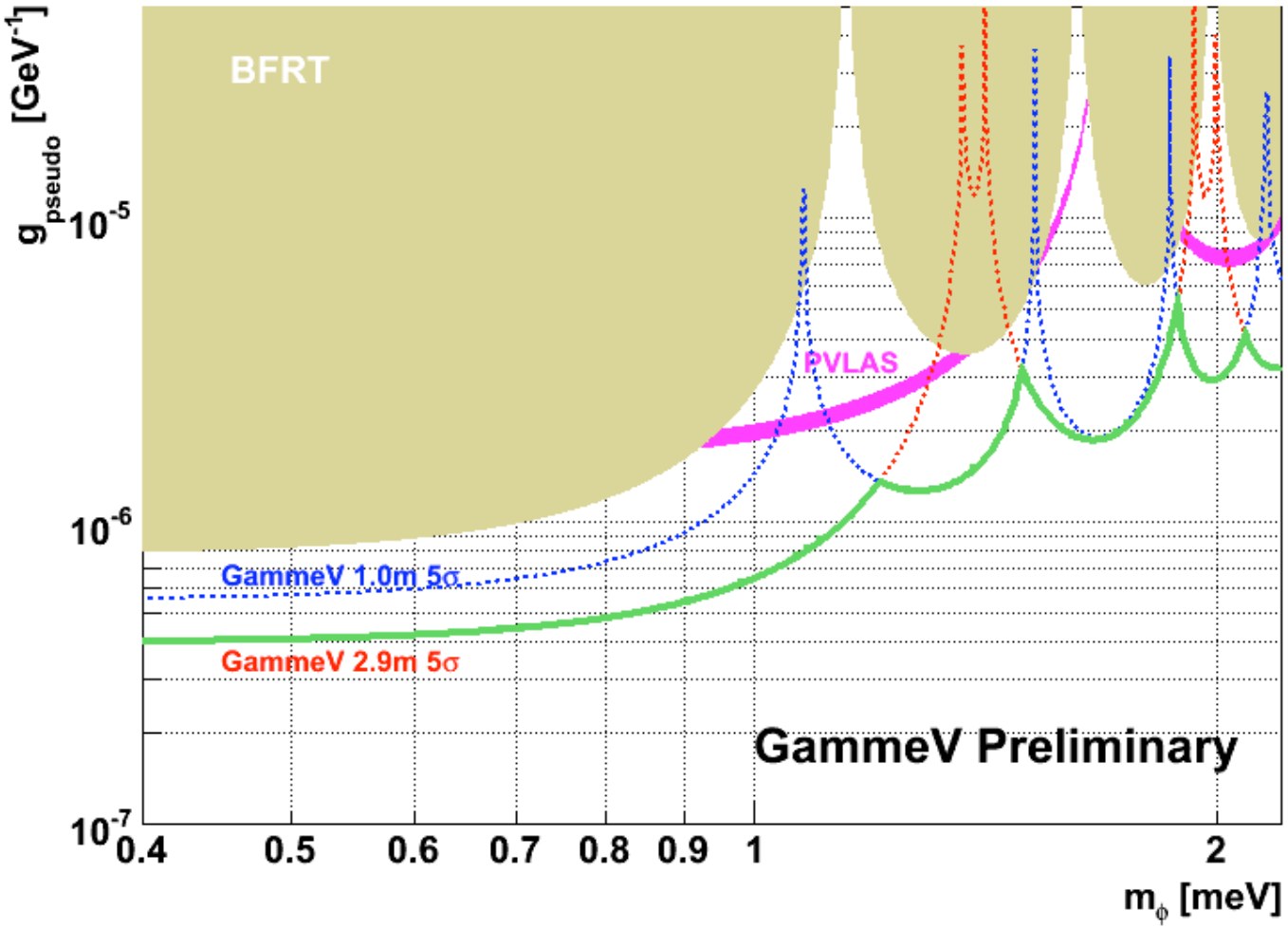
- All the data combined for each run mode
- Systematic uncertainty is understudy

Spin	Position	# Laser pulse	# photon / pulse	Expected Background	Signal
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	0.41e18	1.50±0.04	2

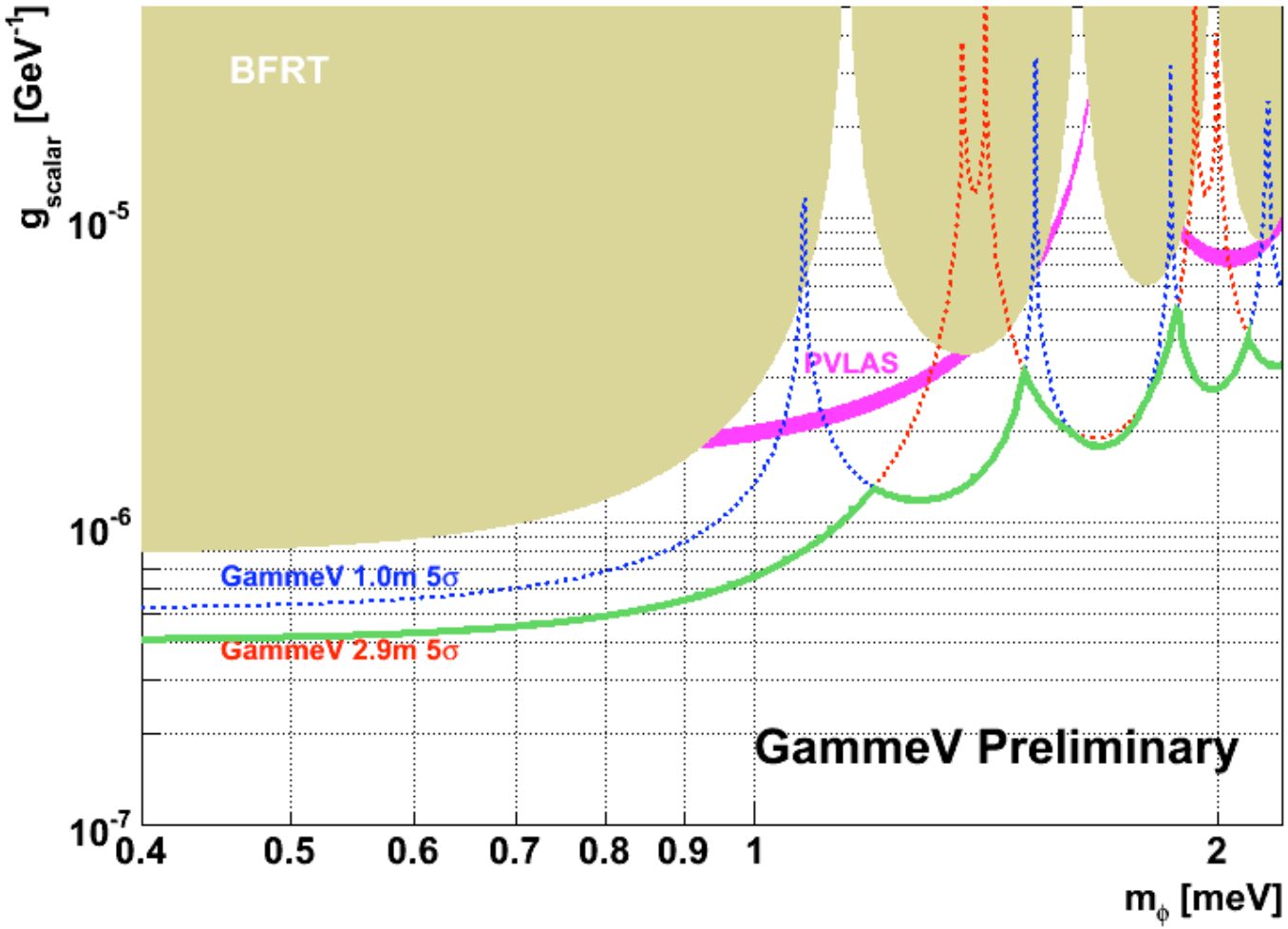
* Efficiency estimated : 0.36±0.09 (0.4 Q.E. x 0.9 abs. at windows and lens)

* No statistically significant indication of a signal observed

Interpretation : Pseudo-Scalar



Interpretation : Scalar



Conclusion

- The first preliminary results from GammeV ALP search reported
- ALP interpretation of PVLAS results excluded by > 5 sigma
- Systematic uncertainty check is under way
- PVLAS reported new results with upgraded conditions (hep-ex/0706.3419)
  The new results completely exclude the previously published results

http://gammev.fnal.gov