Axion Search at JLab FEL

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For the LIPSS Collaboration

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Jefferson Lab

NSF

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LIght Psuedoscalar or Scalar particle Search → LIPSS

LIPSS Collaboration:

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O.K. Baker and M. Minarni (Yale University)

The Motivation

- PVLAS Collaboration* has measured a rotation of light wave polarization in a strong magnetic field.
- The interpretation of the result leads to the existence of chargeless, spinless and very light particle and a candidate particle for dark matter, commonly called axion.
- This claim needs to be confirmed or refuted
- Free Electron Laser (FEL) at Jefferson Lab provides dipole magnets and tunable and high average power pulsed laser, components needed for AXION experiment.

*E. Zavattini *et al*. , PRL 96, 110406 (2006)

What is The Axion?

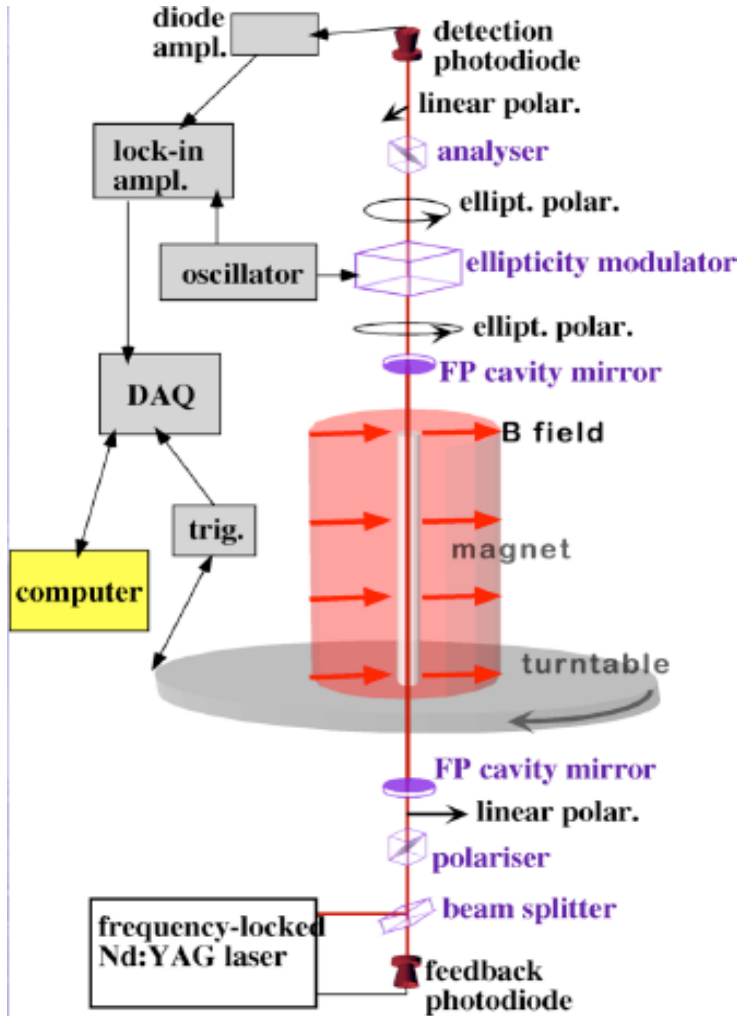
- a light pseudo-scalar particle resulting from Peccei - Quinn mechanism to enforce strong CP conservation
- has predicted mass range: $10^{-6} < m_a < 10^{-3}$ eV
- its properties; light/very low mass, weakly interacting with normal matter and bosonic particle make it a candidate for Dark Matter.
- one of proposed particles (axion-like particles-ALPs) arises if there is a global continuous symmetry that is spontaneously broken in vacuum.
- massive axion discovery still solves the strong CP problem, but not the dark matter problem. Search for light axions needed (< eV)

PVLAS Experiment

Dipole magnet 6T, 1 m field zone, rotating at 0.3 Hz

Nd:YAG Laser 1064 nm, 100mW

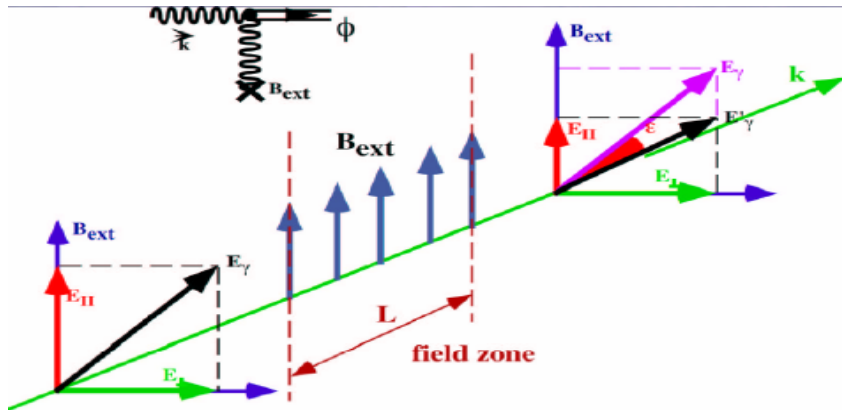
Fabry-Perot Optical Cavity, 6.4 m length F~100000



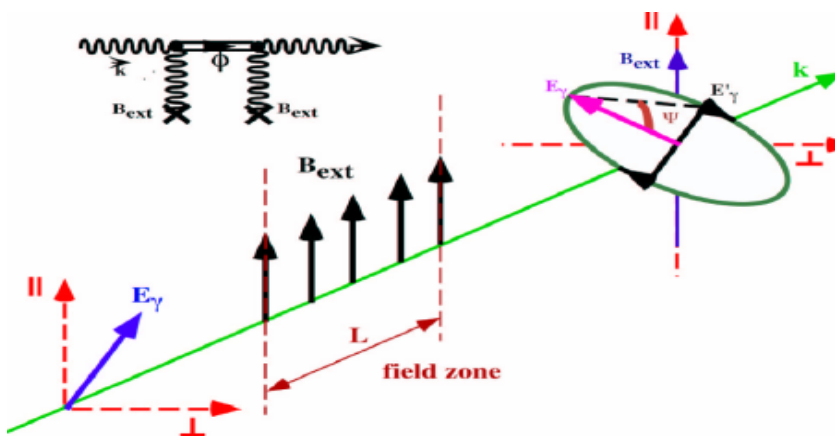
http://www.ts.infn.it/experiments/pvlas

PVLAS Experiment

- In PVLAS experiment, a linearly polarized laser beam traverses a vacuum region where a strong magnetic field is present
- Two processes have been observed, Dichroism (plane polarization rotation) and Elipticity (polarization orientation change)



Dichroism

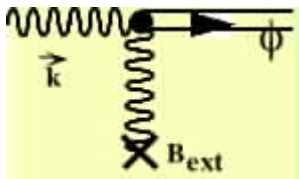


Ellipticity

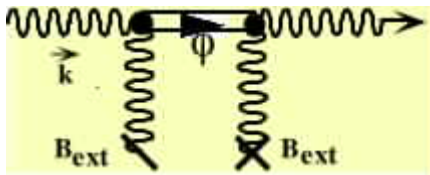
http://www.ts.infn.it/physics/experiments/pvlas/

Interpretation of PVLAS Experiment

The rotation of polarization is due to production of
a light zero neutral boson (LNB) from two photons coupling



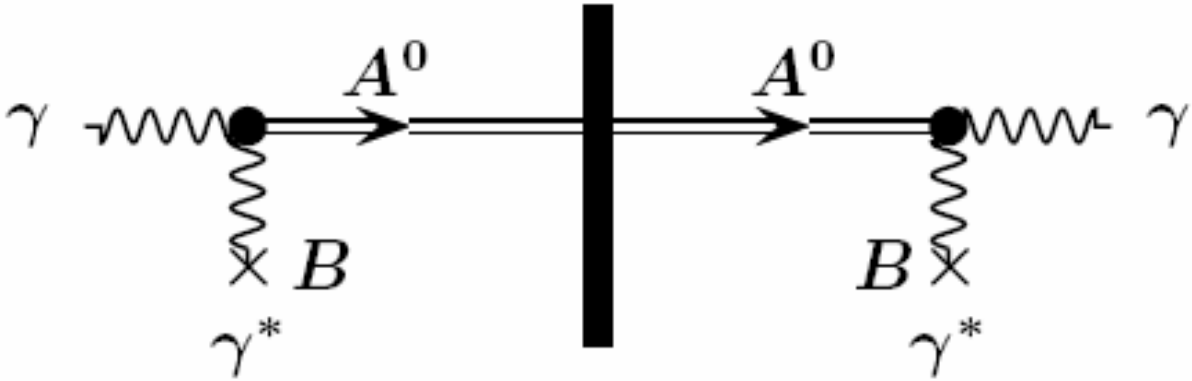
The ellipticity is due to the interaction between a photon and a virtual photon to produce a virtual particle and the particle then decays into a photon and a virtual photon



http://www.ts.infn.it/physics/experiments/pvlas/

Light shining through a wall

A mechanism proposed for axion like particles (ALP) or light neutral boson (LNB) - photon regeneration



A beam of photons traverses a vacuum in a strong magnetic field, a fraction of these photons will couple with virtual photons of the magnetic field into LNB. The LNB particles propagate freely through an optical wall traversing a second vacuum with another magnetic field and transform back into photons.

Sikivie (1983), Anselm(1985), and Van Bibber et al (1987)

Conversion Factor

The probability that a photon converts into an ALP or LNB and vice versa for a constant magnetic field is given as

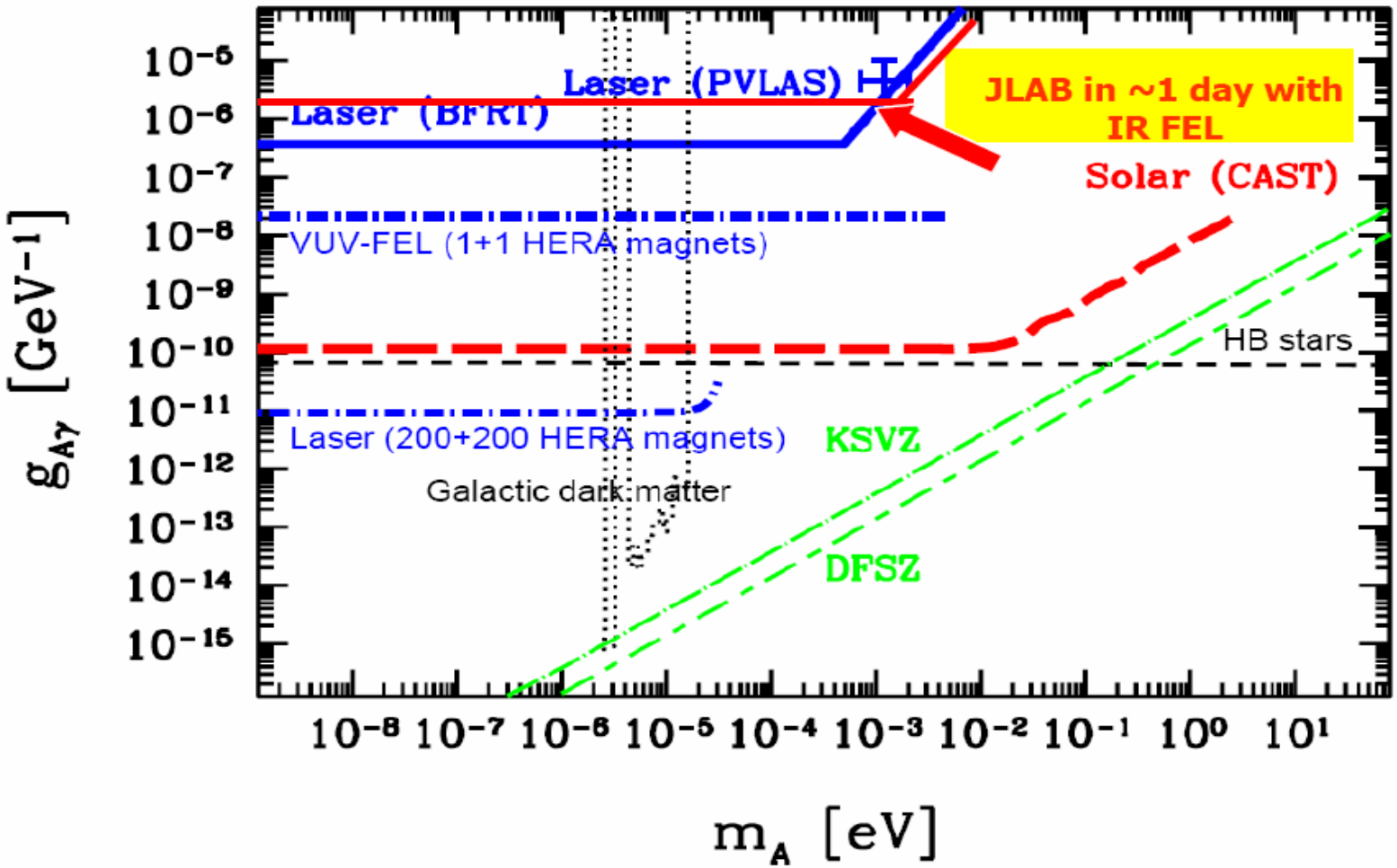
$$P \approx \tfrac{1}{4}(gBL)^2 \{\sin (m^2L/4\omega)/(m^2L/4\omega)\}^2$$

g = coupling constant
B = magnetic field strength
L = magnetic length
ω = light wavelength
m = LNB mass

The maximum conversion probability , $P \sim (gBL)^2$ is attained at small momentum transfer which corresponding to a small ALP or LNB mass.

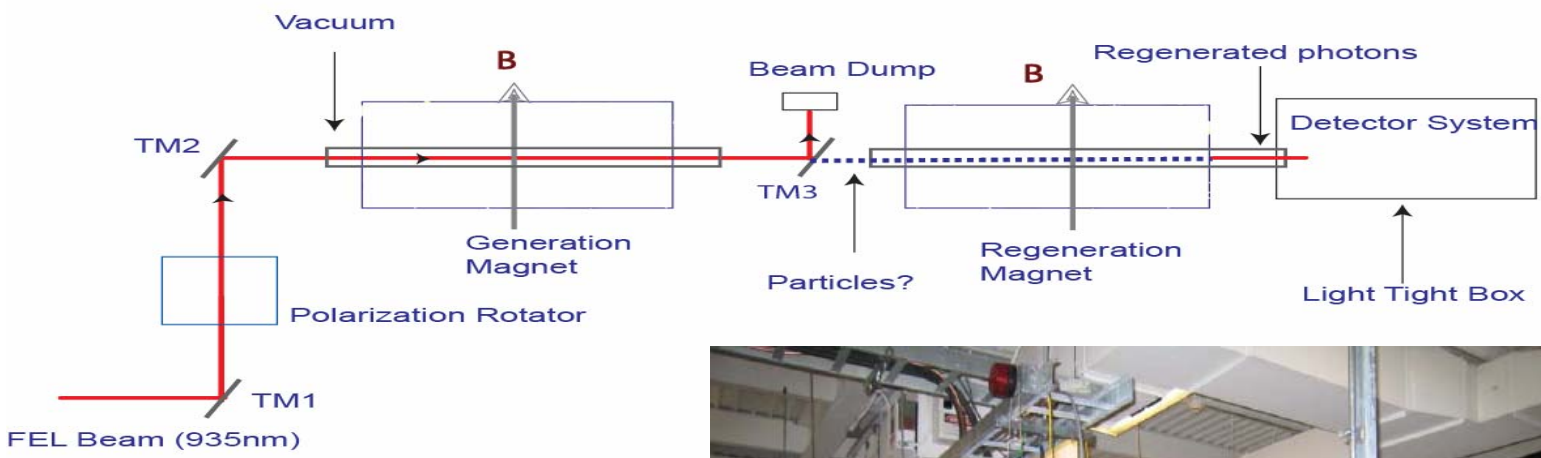
Courtesy O.K. Baker

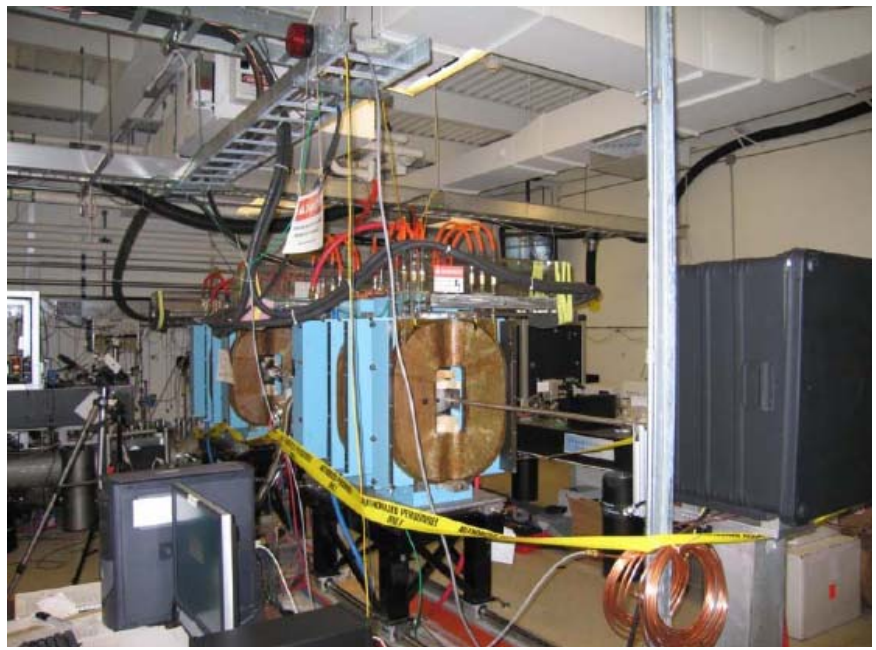
PVLAS and Other Experiments



Courtesy O. K. Baker

Experiment Setup





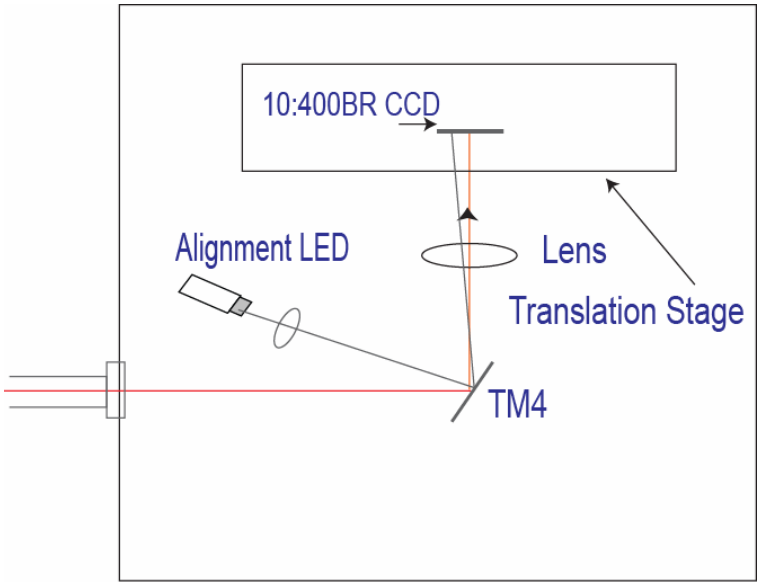
Beam Power = 130-230 W

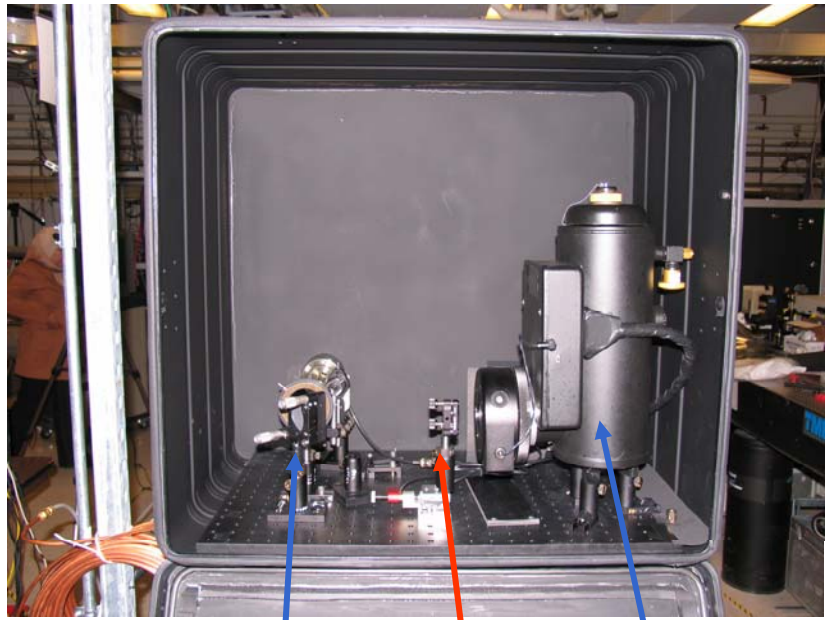
Beam Wavelength = 935 nm

Beam Diameter~6-8mm

Magnets B = 1.74T, L~1m

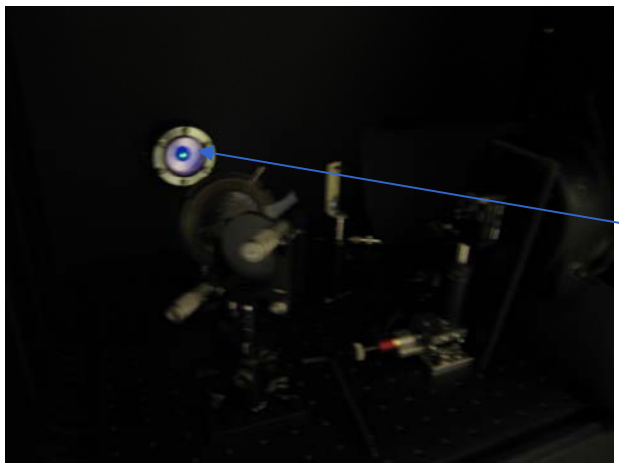
Detector System





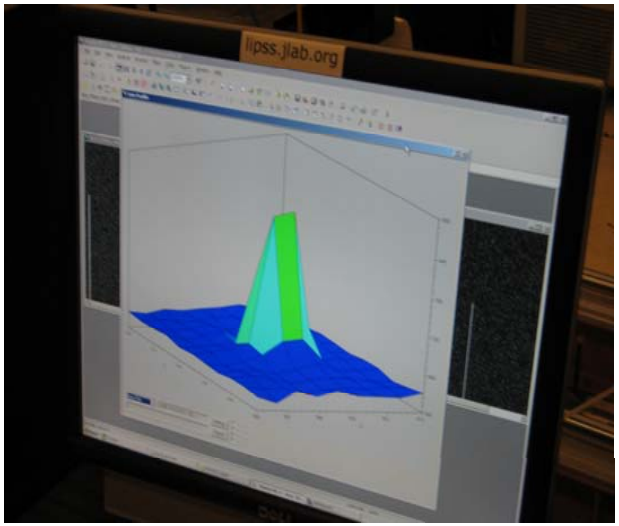
mirror lens

Spec10:400BR-LN
CCD camera



FEL Alignment Beam

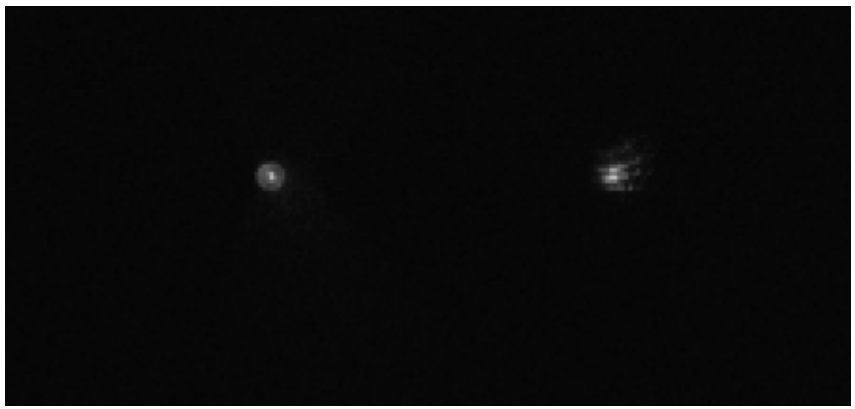
Why Focusing The Regenerated Beam



- To Increase S/N
- To ease binning process in order to avoid cosmic rays

Beam Spot on CCD

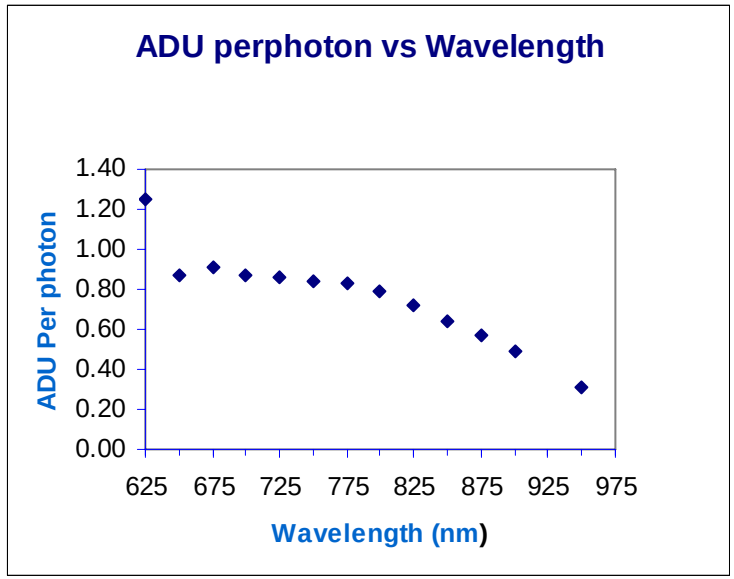
~ 30 um ~ 1 pixel



Focused LED light and Alignment Greene laser light on CCD

CCD Camera Sensitivity

- PI-Acton Spec 10:400BR LN
- 1340x400 imaging arrays, each 20X20 μm pixels area
- Cryogenic cooled to -120ºC to get low dark current~1-4 e/pix/hour for long exposure time
- High gain ~ 0.9 ADU/electron
- Good Quantum Efficiency ~ 35% at 935nm

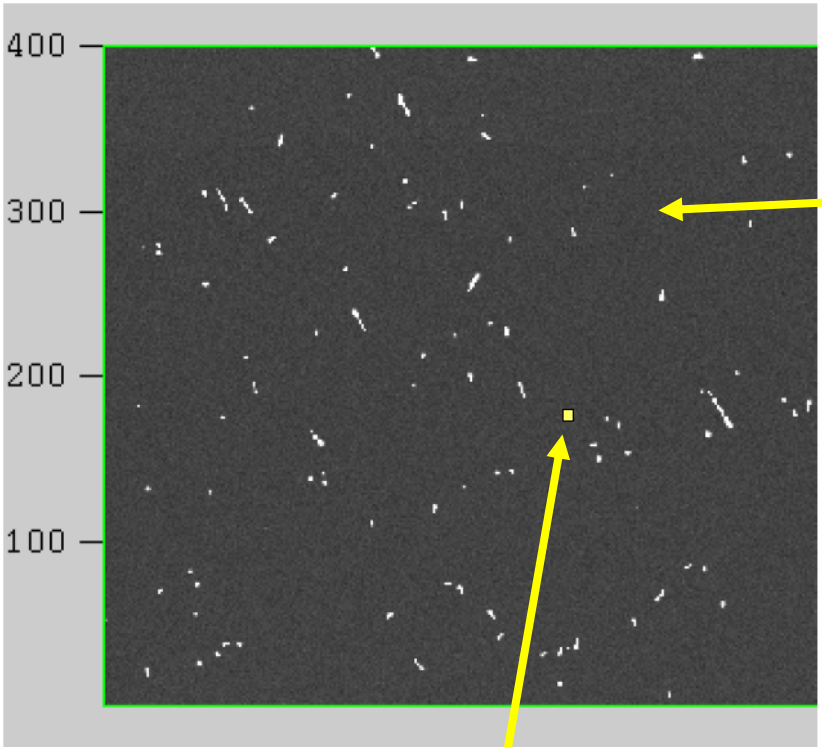


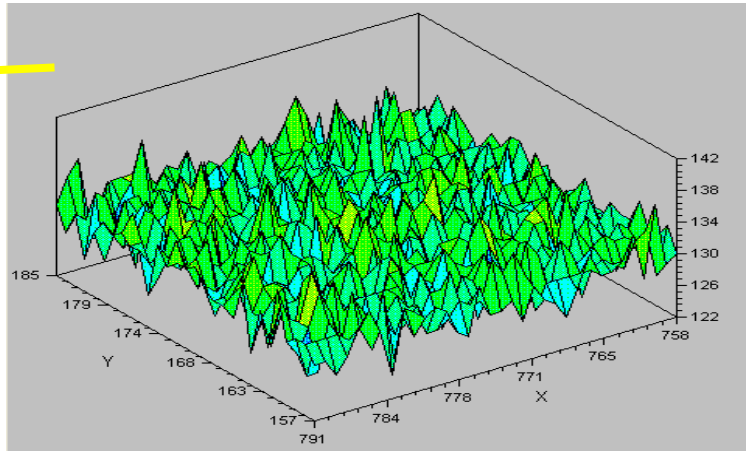
- **PI-Acton CCD Data Sheet**
- **ADU = Analog Digital Unit**

Run C

- Run C was the first run with adequate monitoring, both polarization, parallel and perpendicular to magnetic field were tried, the parallel part failed due to vacuum leak.
- The perpendicular part (scalar boson) had 13 two-hour runs with 12 runs gave useful data
- **~12 MJ** of photons were delivered in 12 good 2-hour runs which had ~130 W average power.
- The only detectable sources of uncertainty were read noise and dark current.
- Lessons learned for better future runs

Typical CCD Image





Typical background signal in 3D

Portion of 2 hour exposure time, seen are dots and streaks due to cosmic rays, the yellow square is the area of interest (9x9 pixels), the signal region is 5X5 pixels. 2% probability of cosmic ray hitting the area of interest.

Courtesy Kevin Beard and K. McFarlane

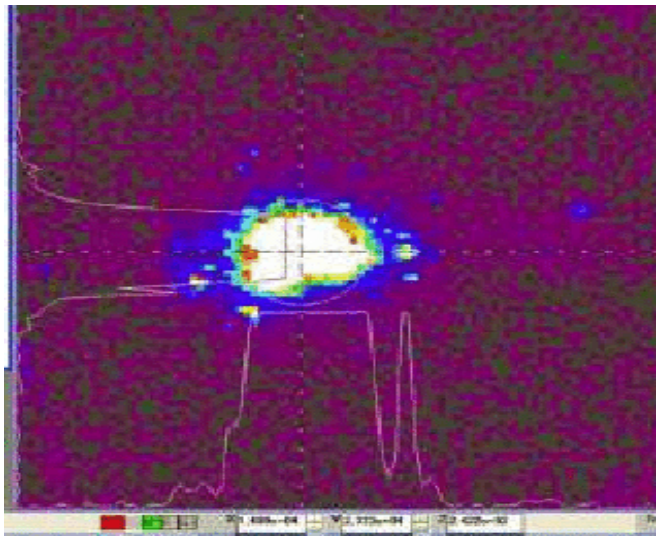
Summary

- The LIPSS experiment has had some experimental runs using FEL beams at 930-935nm since last year and has one successful Run (Run C) for scalar configuration.
- It is not yet sensitive enough to test PVLAS Claim, based on our preliminary analysis
- Lessons learned with well –understood improvement for future test.

Future Plan with FEL Beam

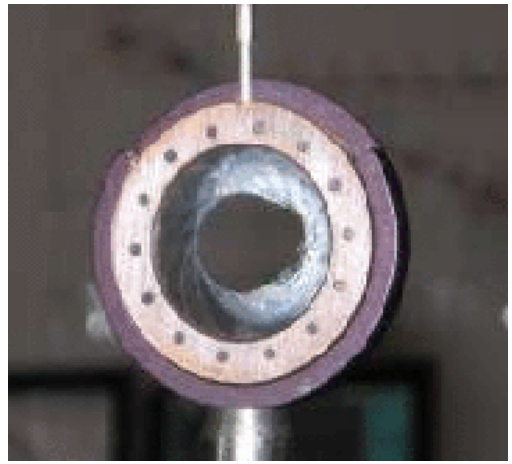
- Have another run with higher power ~1kW with newly-improved- coated cavity mirrors, the mirrors arrived last week, expected to have FEL beam and run before Spring 2008!!.
- Develop a better monitoring and steering system for FEL beam going into the experiment setup (Pointing Stability).
- Have a robust vacuum monitoring system.
- Run the experiment for both polarizations.

Lessons learned

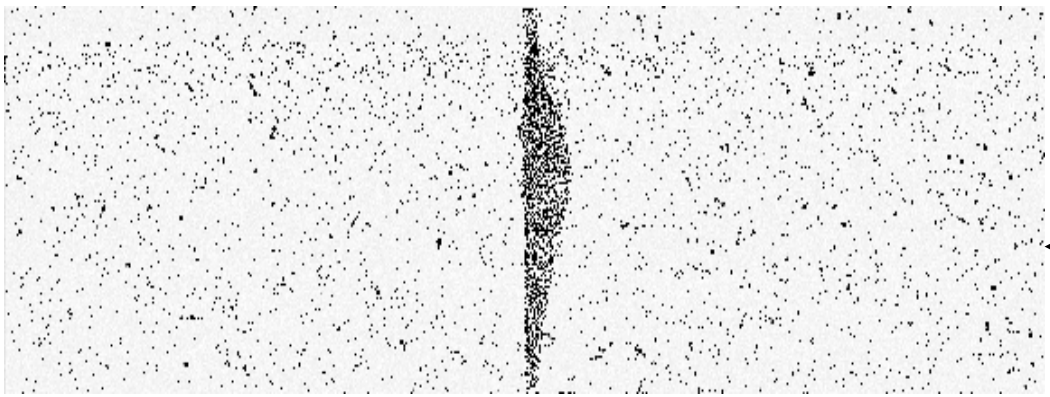


Need to control

The beam directions

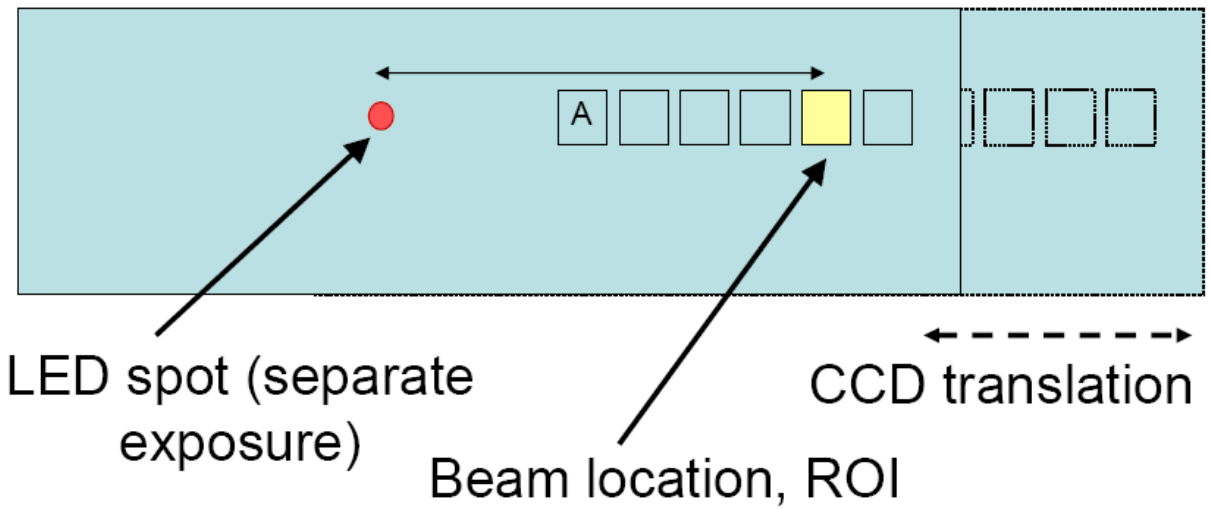


Because of wandering FEL beam



Forgot to turn off the LED

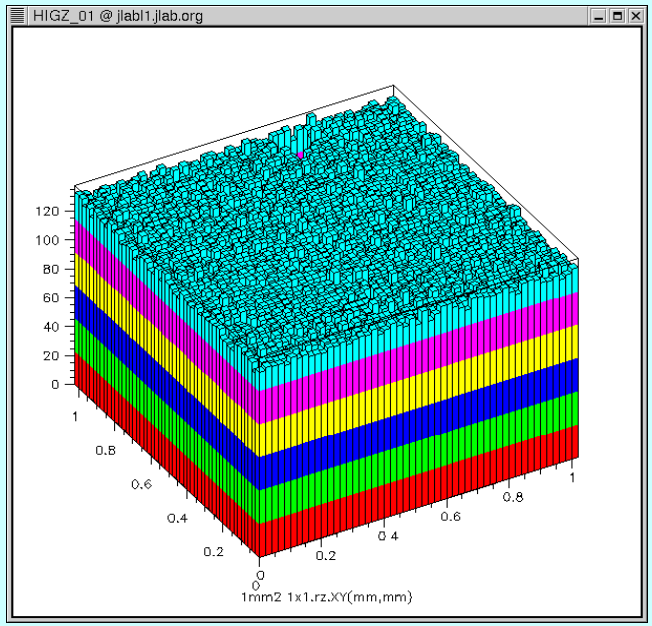
Data Taking Example



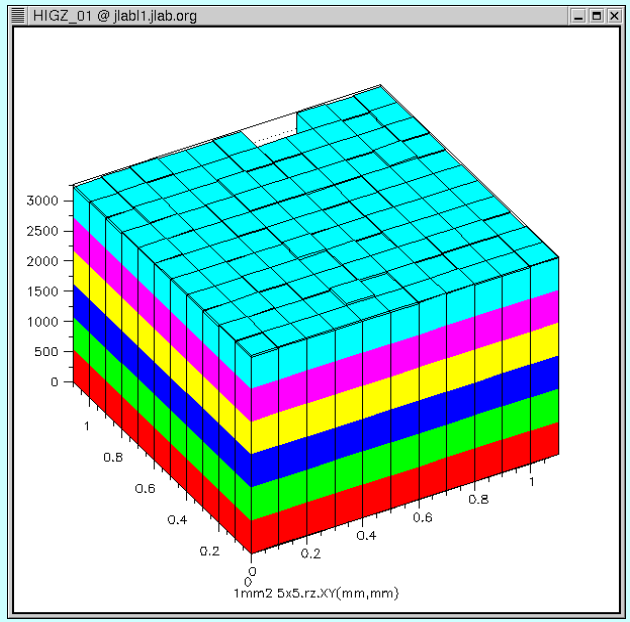
Each exposure has the beam on a different set of pixels (step is 10 pixels). This corrects for hot and insensitive pixels, if any.

Courtesy K. McFarlane

The important of Binning



1 X 1



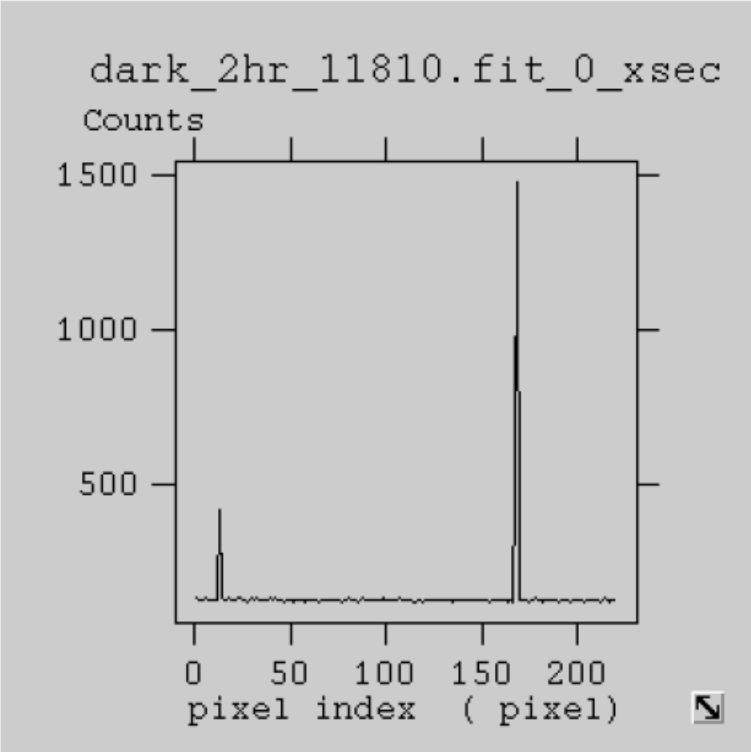
5 X 5

1mm X 1mm region

binning *can* be done **on chip *before*** readout to minimize noise,
but one must choose the binning wisely to optimize the signal

Courtesy Kevin Beard

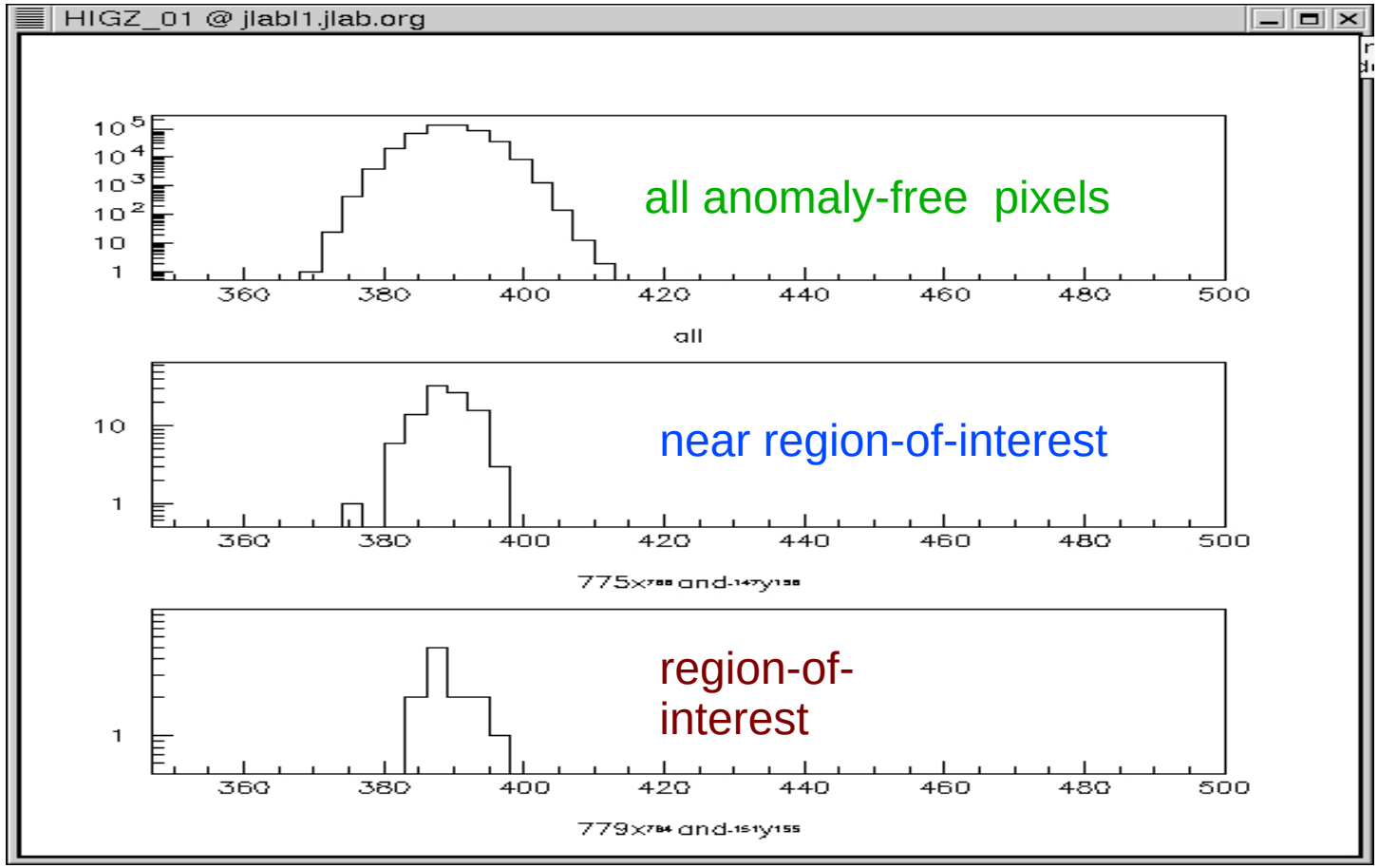
Cosmic Rays Reduction



Easily detected and avoided.
Each ROI is 9x9 pixels, and the signal region is the central 5x5 area. A 2-pixel guard ring is adequate to eliminate cosmic ray background.

Courtesy K. McFarlane

Data Analysis



Not sensitive enough yet to see a signal at the level expected on the basis of the PVLAS result

Courtesy Kevin Beard