Latest PVLAS Results

Guido Zavattini
Università di Ferrara e INFN

On behalf of the PVLAS collaboration

"Hands holding the void"
Alberto Giacometti

Outline

- Motivation
- Experimental technique
- Results
- Future

Legnaro

U. Gastaldi	(g)
G. Ruoso	(l)
G. Petrucci	(h)

Trieste

M. Bregant	
F. Della Valle	(j)
G. Cantatore	(e)
M. Karuza	(m)
E. Milotti	(b)
G. Raiteri	
E. Zavattini	(c)

Ferrara

G. Di Domenico	(k)
G. Zavattini	(n)

Pisa

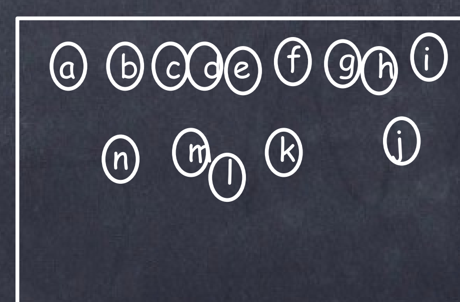
E. Polacco	(a)
S. Carusotto	

Frascati

R. Cimino	(d)

Technical support

S. Marigo	(f)
A. Zanetti	(i)
G. Venier	



Classical Vacuum

Vacuum = total absence of matter

$$L_{EM} = \frac{1}{8\pi}\left(E^2 - B^2\right)$$

$$\vec{D} = 4\pi \frac{\partial L_{EM}}{\partial \vec{E}}$$

$$\vec{H} = -4\pi \frac{\partial L_{EM}}{\partial \vec{B}}$$

$$\vec{D} = \vec{E}$$

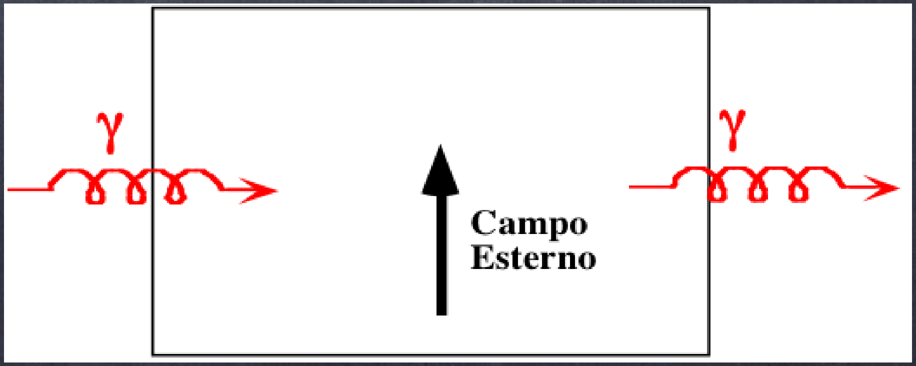
$$\vec{H} = \vec{B}$$

$$\vec{\nabla}\cdot\vec{D} = 0; \quad \vec{\nabla}\times\vec{E} = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t}$$

$$\vec{\nabla}\cdot\vec{B} = 0; \quad \vec{\nabla}\times\vec{H} = \frac{1}{c}\frac{\partial \vec{D}}{\partial t}$$

Maxwell's equations are linear in the fields.

The superposition principle is valid.



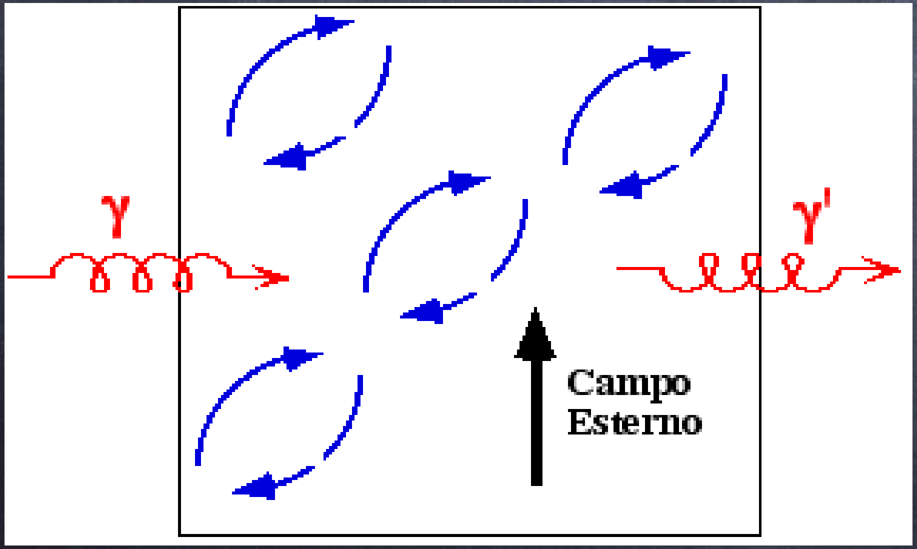
Heisenberg's Uncertainty Principle

$$\Delta E \, \Delta t \approx \hbar$$

Vacuum is a minimum energy state and can fluctuate into anything compatible with the vacuum state.

→

Vacuum must have a structure which can be observed by perturbing and probing it.



- Evidence of microscopic structure of vacuum is known (Lamb Shift g-2)
- Macroscopically observable (small) effects have been predicted since 1936 but have never been directly observed yet.

Aim of the PVLAS experiment

Theme

Scheme

- Vacuum is a physical state and can be treated as a "structured medium"
- Perturb the vacuum state with an external magnetic field
- Use a polarized light beam as a probe to measure the effect of the magnetic field
- Extract information about the structure of vacuum

The propagation of light will be affected by the polarized vacuum fluctuations

We study anisotropies in the index of refraction

$$\Delta n_{vac} = \Delta n - i \Delta k$$

Linear birefringence

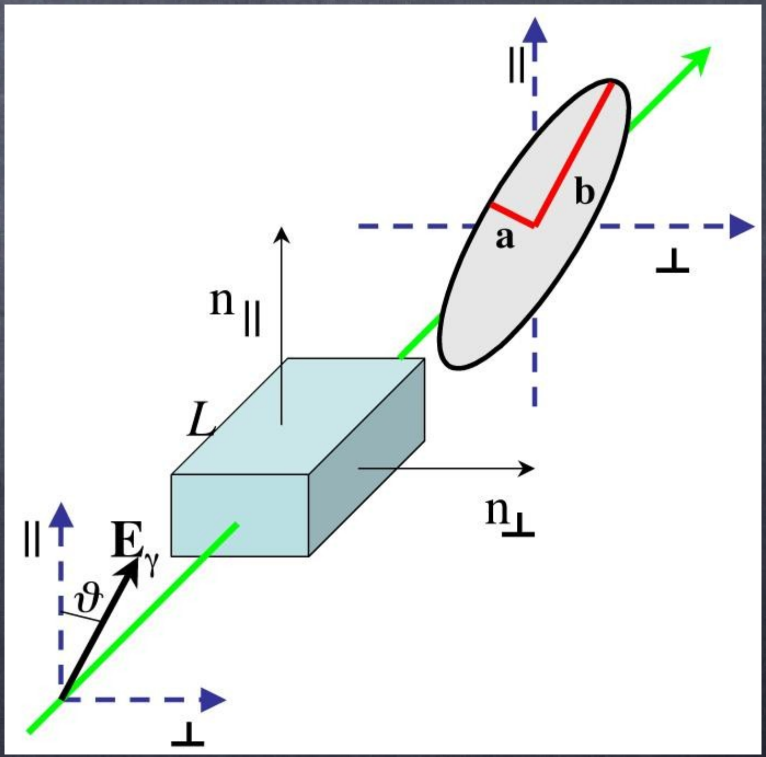
Linear dichroism

Linear birefringence

- A birefringent medium has $\Delta n = n_{\parallel} - n_{\perp} \neq 0$
- A linearly polarized beam propagating through a birefringent medium will acquire an ellipticity Ψ

$$\Psi = \frac{a}{b} = \frac{\pi L \Delta n}{\lambda} \sin(2\vartheta)$$

$$\begin{cases} \Psi > 0 \\ \Psi < 0 \end{cases} \quad \text{for} \quad \begin{cases} n_{\parallel} - n_{\perp} > 0 \\ n_{\parallel} - n_{\perp} < 0 \end{cases}$$

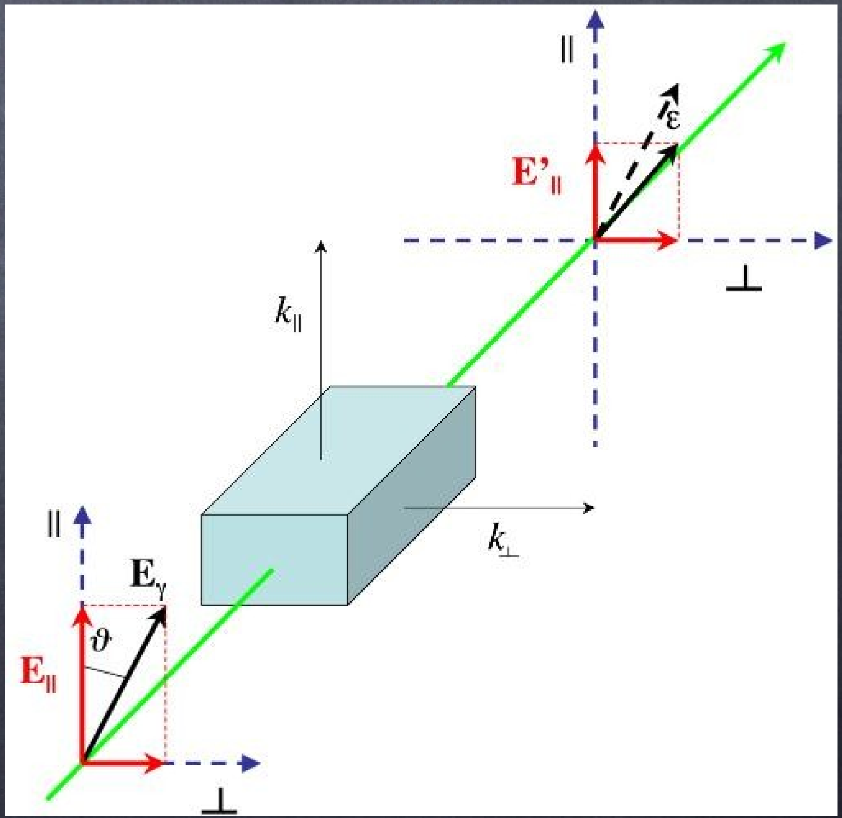


Linear dichroism

- A dichroic medium has a different extinction coefficient for two orthogonal polarizations $\Delta k = k_{\parallel} - k_{\perp} \neq 0$
- A linearly polarized beam propagating through a dichroic medium will acquire an apparent rotation ϵ

Absorption coefficiente: $\Delta\alpha = \frac{4\pi\Delta k}{\lambda}$

$$\epsilon = \frac{\pi L \Delta k}{\lambda} \sin(2\vartheta)$$



Euler-Heisenberg Effective Lagrangian

$$L_{EH} = \frac{1}{8\pi}\left(E^2 - B^2\right) - \frac{\alpha}{8\pi^2}\int_0^\infty d\eta \frac{e^{-\eta}}{\eta}\left[\vec{E}\cdot\vec{B}\frac{\Re\cosh\left(\eta\sqrt{\left(E^2-B^2\right)+2i\left(\vec{E}\cdot\vec{B}\right)}/F_c\right)}{\Im\cosh\left(\eta\sqrt{\left(E^2-B^2\right)+2i\left(\vec{E}\cdot\vec{B}\right)}/F_c\right)} - \frac{F_c^2}{\eta^2} - \frac{E^2-B^2}{3}\right]$$

$$F_c = \frac{m_e^2 c^3}{e\hbar} = \text{critical field;}$$

Eurer and Heisenberg were the first to study the electromagnetic field in the presence of e^+e^- *vacuum fluctuations*

For fields much small than the critical field ($B \ll 4.4\cdot10^{13}$ gauss $E \ll 4.4\cdot10^{13}$ statvolt/cm) one can write

$$L_{EH} = L_{EM} + L_{QED}$$

$$L_{EM} = \frac{1}{8\pi}\left(E^2 - B^2\right)$$

$$L_{QED} = \frac{A_e}{4\pi}\left[\left(E^2 - B^2\right)^2 + 7\left(\vec{E}\cdot\vec{B}\right)^2\right]$$

$$A_e = \frac{1}{90\pi}\left(\frac{\alpha^2 \lambda_e^3}{m_e c^2}\right) = 4/3 \cdot 10^{-32}\ \text{cm}^3/\text{erg}$$

Induce magnetic birefringence of vacuum

By applying the constitutive relations to L_{EH}

$$\vec{D} = 4\pi \frac{\partial L_{EM}}{\partial \vec{E}} \qquad \vec{H} = -4\pi \frac{\partial L_{EM}}{\partial \vec{B}}$$

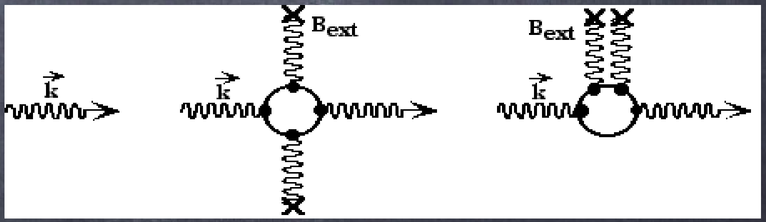
$$\Rightarrow$$

$$\vec{D} = \vec{E} + A_e\left[4(E^2 - B^2)\vec{E} + 14(\vec{E}\cdot\vec{B})\vec{B}\right]$$

$$\vec{H} = \vec{B} + A_e\left[4(E^2 - B^2)\vec{B} - 14(\vec{E}\cdot\vec{B})\vec{E}\right]$$

Light is still described by Maxwell's equations but in media.

They are no longer linear in the field



$$\Downarrow$$

If $\begin{cases} \vec{E} = \vec{E}_{rad} \\ \vec{B} = \vec{B}_{rad} + \vec{B}_{ext} \end{cases}$ and $\vec{B}_{rad} \ll \vec{B}_{ext}$

Linearly polarized light passing through a transverse magnetic field

$$\begin{cases} \epsilon_{\|} = 1 + 10 A_e B_{ext}^2 \\ \mu_{\|} = 1 + 4 A_e B_{ext}^2 \\ n_{\|} = 1 + 7 A_e B_{ext}^2 \end{cases} \qquad \begin{cases} \epsilon_{\perp} = 1 - 4 A_e B_{ext}^2 \\ \mu_{\perp} = 1 + 12 A_e B_{ext}^2 \\ n_{\perp} = 1 + 4 A_e B_{ext}^2 \end{cases}$$

$$\Delta n = 3 A_e B_{ext}^2 \approx 4 \cdot 10^{-23} B_{ext}^2 \quad (B_{ext} \text{ in Tesla})$$

$$\Delta n = 10^{-22} \text{ for } B_{ext} = 5T \;\Rightarrow\; \Psi \approx 10^{-11}$$

- $v \neq c$
- anisotropy

A_e can be determined by measuring the magnetic birefringenc of vacuum

Light by light scattering

- Very low energy photon-photon scattering is proportional to $A_e^{\,2}$.

$$\sigma_{\gamma\gamma}^{[1]} = \frac{1}{45^2}\,\frac{973}{5}\,\frac{\alpha^4}{\pi}\left(\frac{\hbar\omega}{m_e c^2}\right)^6\left(\frac{\hbar}{m_e c}\right)^2 = \frac{4\pi}{5}\,\frac{973\,\hbar^2}{c^4}\,\omega^6 A_e^{\,2}$$

At 1064 nm $\sigma_{\gamma\gamma} = 1.8\cdot10^{-65}$ cm^2

Direct limits have been given by Bernard et al. [2]: $\sigma_{\gamma\gamma} < 1.5\cdot10^{-48}$ cm^2

[1] Duane et al. Phys Rev D vol. 57 p. 2443 (1998)

[2] D. Bernard et al. The Eurpean Phyical Journal D, vol. 10, p. 141 (1999)

Photon splitting

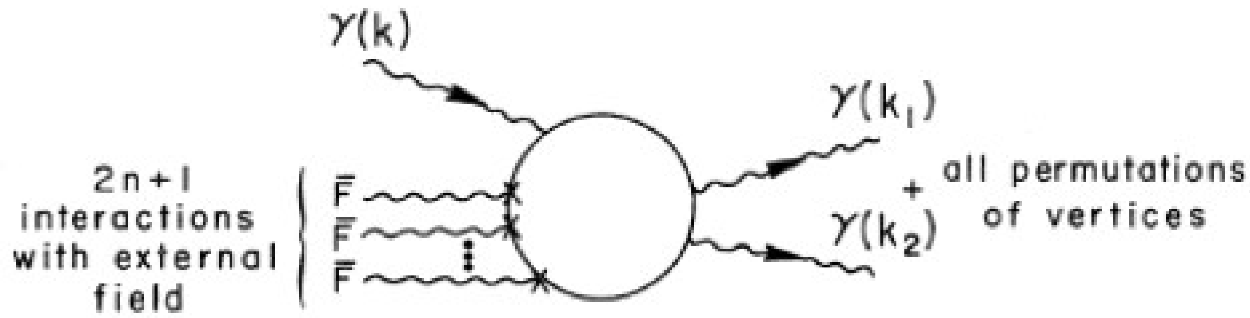


FIG. 1. Ring diagram for photon splitting involving $2n+1$ interactions with the external field.

$$\kappa[(\parallel)\rightarrow(\parallel)_1+(\parallel)_2]=\frac{\alpha^3}{60\pi^2}\left(\frac{48}{315}\right)^2\left(\frac{\omega}{m}\right)^5\left(\frac{\bar{B}\sin\theta}{B_{cr}}\right)^6 m=0.39\left(\frac{\omega}{m}\right)^5\left(\frac{\bar{B}\sin\theta}{B_{cr}}\right)^6\ \mathrm{cm}^{-1},$$

$$\kappa[(\parallel)\rightarrow(\perp)_1+(\perp)_2]=\frac{\alpha^3}{60\pi^2}\left(\frac{26}{315}\right)^2\left(\frac{\omega}{m}\right)^5\left(\frac{\bar{B}\sin\theta}{B_{cr}}\right)^6 m=0.12\left(\frac{\omega}{m}\right)^5\left(\frac{\bar{B}\sin\theta}{B_{cr}}\right)^6\ \mathrm{cm}^{-1},$$

$$\kappa[(\perp)\rightarrow(\parallel)_1+(\perp)_2]+\kappa[(\perp)\rightarrow(\perp)_1+(\parallel)_2]=2\kappa[(\parallel)\rightarrow(\perp)_1+(\perp)_1].$$

- With B=5.5T and $\omega/m = 1/511000$ one finds $\Delta k \approx 6\cdot10^{-83}\ \mathrm{cm}^{-1}$
- With l_{eff} = 60 km => Dichroism induced rotation $\approx 2\cdot10^{-76}$ rad

What else?

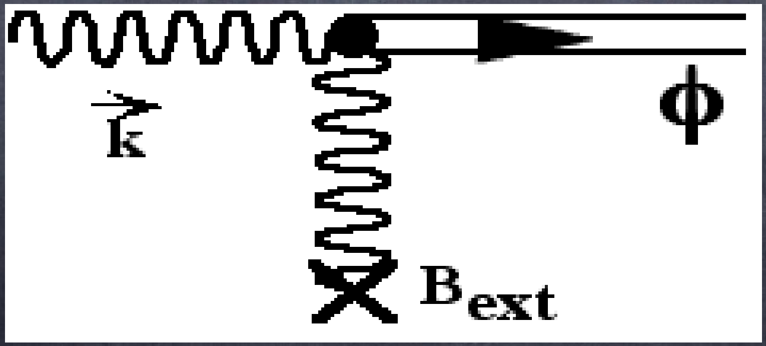
One can add extra terms to the E-H effective lagrangian to include contributions from hypothetical neutral light particles coupling to two photons.

$$L_p = \frac{1}{M_p}\phi\left(\vec{E}_\gamma \cdot \vec{B}_{ext}\right)$$

Pseudoscalar

$$L_s = \frac{1}{M_s}\sigma\left(\vec{B}_\gamma \cdot \vec{B}_{ext}\right)$$

scalar



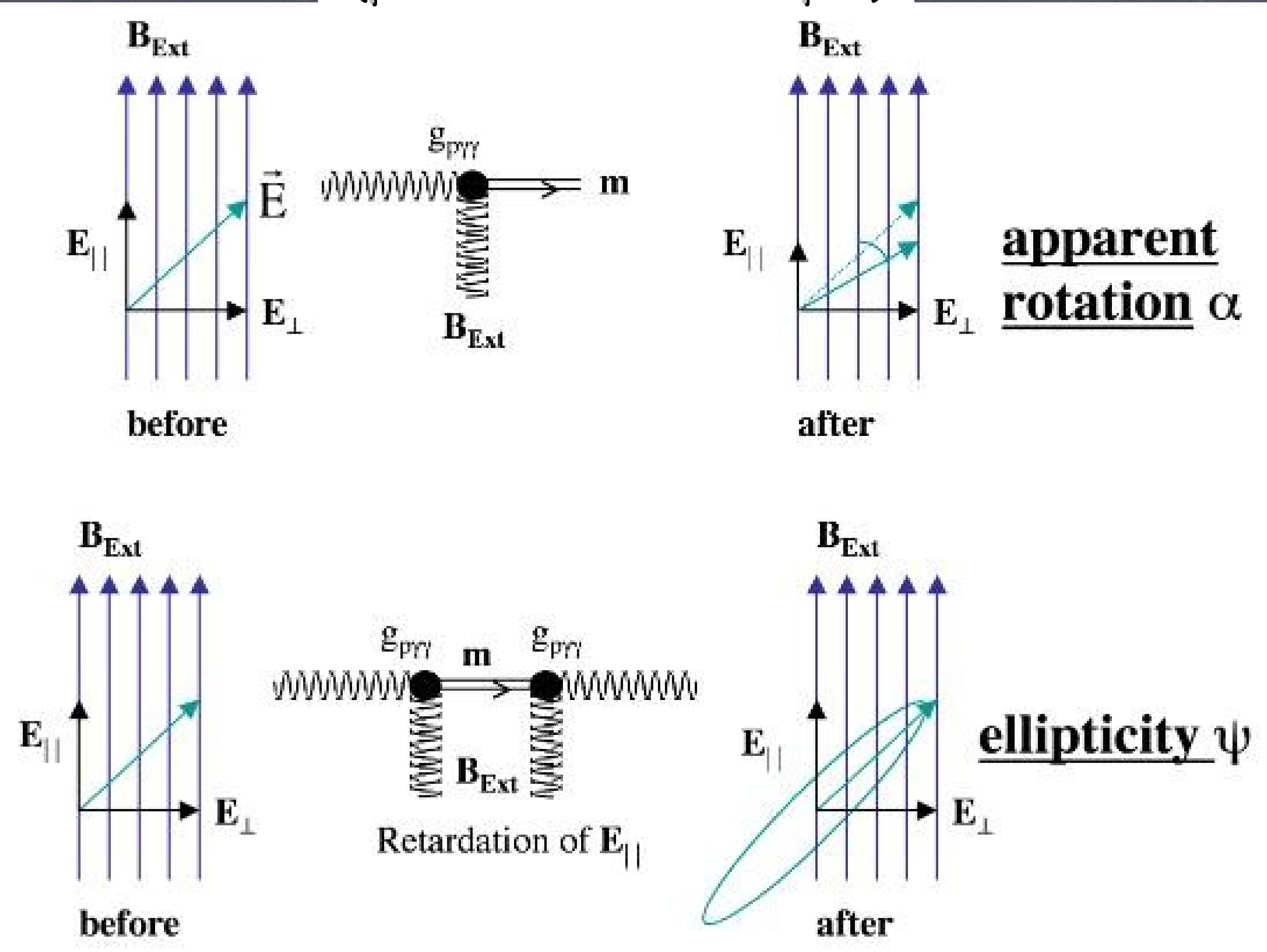
[L.Maiani, R. Petronzio, E. Zavattini, Phys. Lett B, Vol. 173, no.3 1986]
[E. Massò and R. Toldrà, Phys. Rev. D, Vol. 52, no. 4, 1995]

Propagation of a photon in an external field

(pseudoscalar example)

dichroism Δk
- photon splitting
- real particle production

birefringence Δn
- vacuum fluctuation
- virtual particle exchange



Summing up

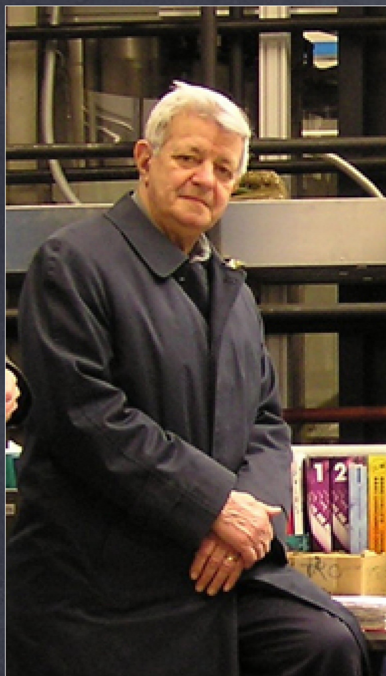
Experimental study of vacuum as a physical medium

- magnetic field perturbation
- linearly polarized beam of light as a probe
- detect changes in the polarization state

Key ingredients

- very small effects
- high magnetic field
- longest possible optical path
- heterodyne detection

First experimental proposal '79



Volume 85B, number 1 PHYSICS LETTERS 30 July 1979

EXPERIMENTAL METHOD TO DETECT THE VACUUM BIREFRINGENCE INDUCED BY A MAGNETIC FIELD

E. IACOPINI and E. ZAVATTINI
CERN, Geneva, Switzerland

Received 28 May 1979

In this letter a method of measuring the birefringence induced in vacuum by a magnetic field is described: this effect is evaluated using the non-linear Euler–Heisenberg–Weisskopf lagrangian. The optical apparatus discussed here may detect an induced ellipticity on a laser beam down to 10^{-11}.

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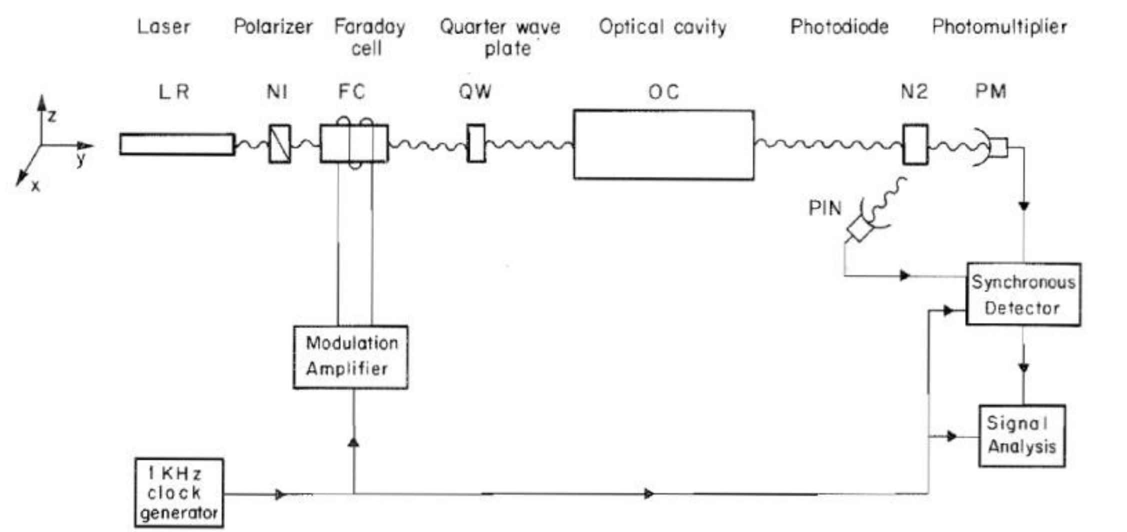


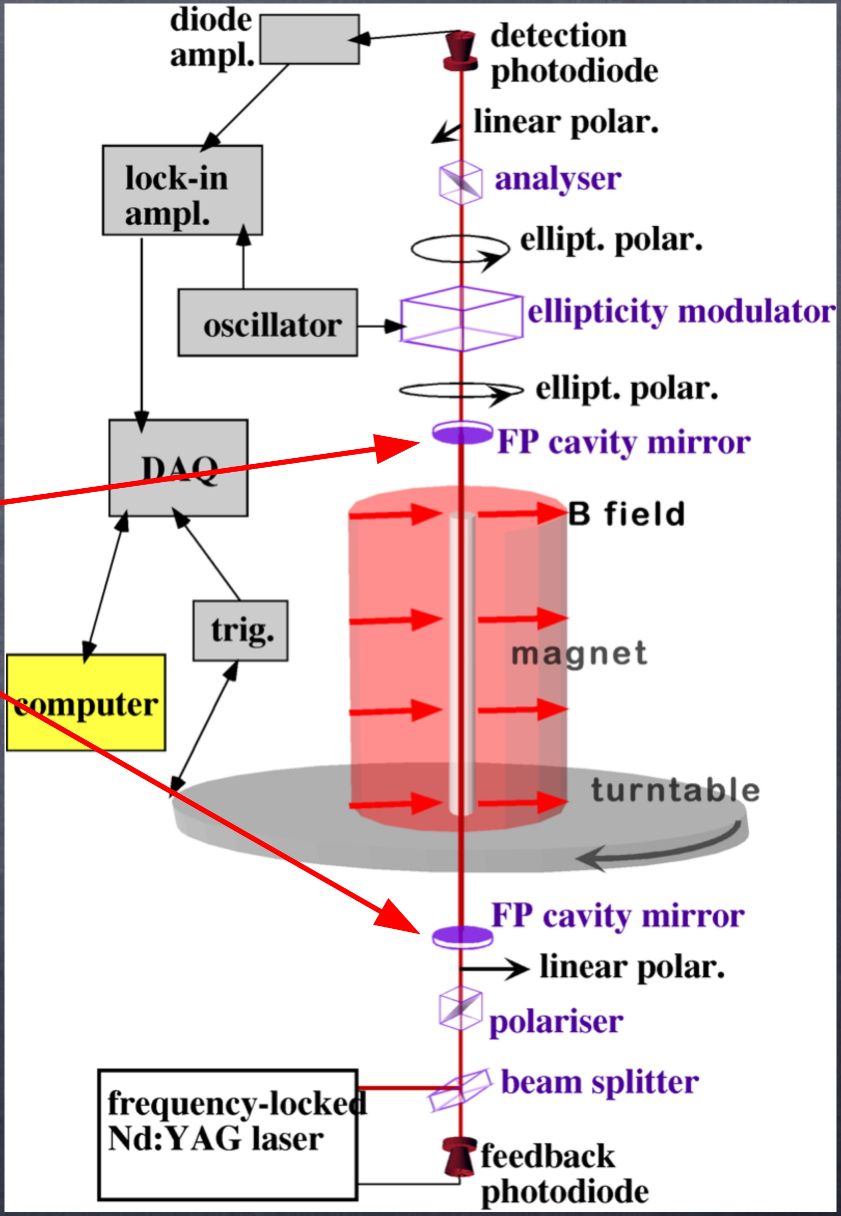
Fig. 3. Principle elements of the experimental apparatus.

First experimental scheme to measure magnetically induced vacuum birefringence with ellipsometric techniqes

PVLAS setup

Main parameters of the apparatus

- **magnet**
  - dipole, 5.5 T, temp. 4.2 K, 1 m field zone
- **cryostat**
  - rotation frequency ~300 mHz, warm bore to allow light propagation in the interaction zone
- **laser**
  - 1064 nm, 100 mW, frequency-locked to the F.-P. cavity
- **Fabry-Perot optical cavity**
  - 6.4 m length, finesse ~100000, optical path in the interaction region ~ 60 km
- **heterodyne ellipsometer**
  - ellipticity modulator (SOM) and high extinction (~10^{-7}) crossed polarisers + Quarter Wave Plate (QWP)
  - time-modulation of the effect
- **detection chain**
  - photodiode with low-noise amplifier
- **DAQ**
  - Slow: demodulated at low frequency and phase-locked to the magnetic field instantaneous direction
  - Fast: high sampling frequency direct acquisition



PVLAS schematic drawing

- The granite tower (blue in the drawing) supports the upper optical bench and is mechanically isolated from the hall (in green)
- The turntable, holding the magnet, rests on a beam fixed to the floor (green in the drawing)

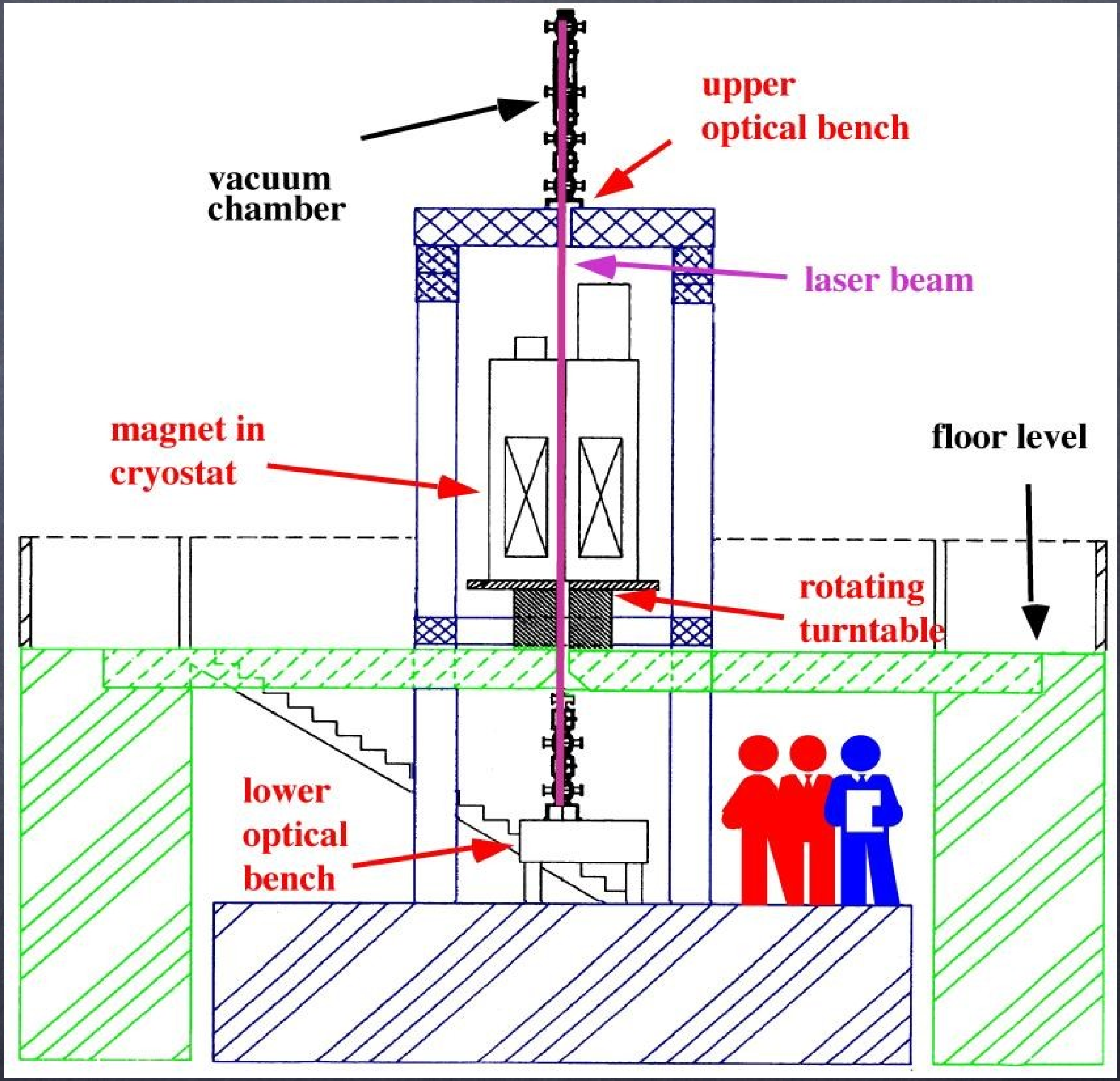
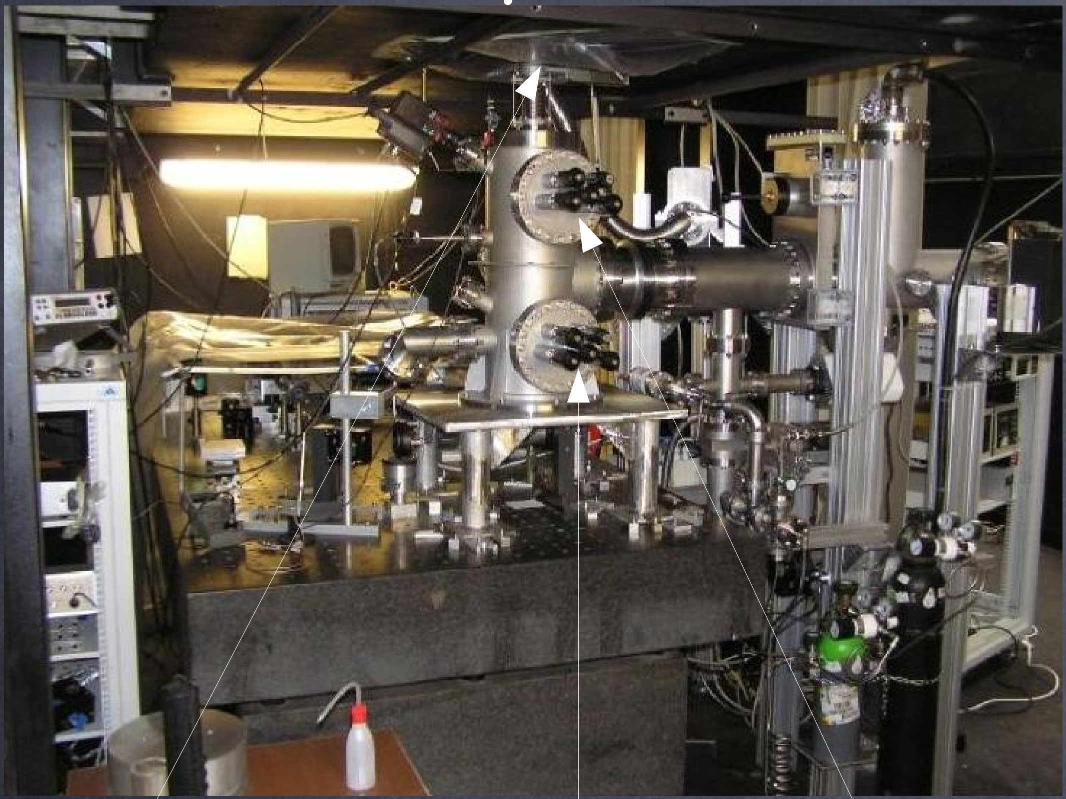


Photo gallery I

Lower optical bench



Quartz tube

Polarizer

Bottom mirror

Upper Optical bnech

Photodiode

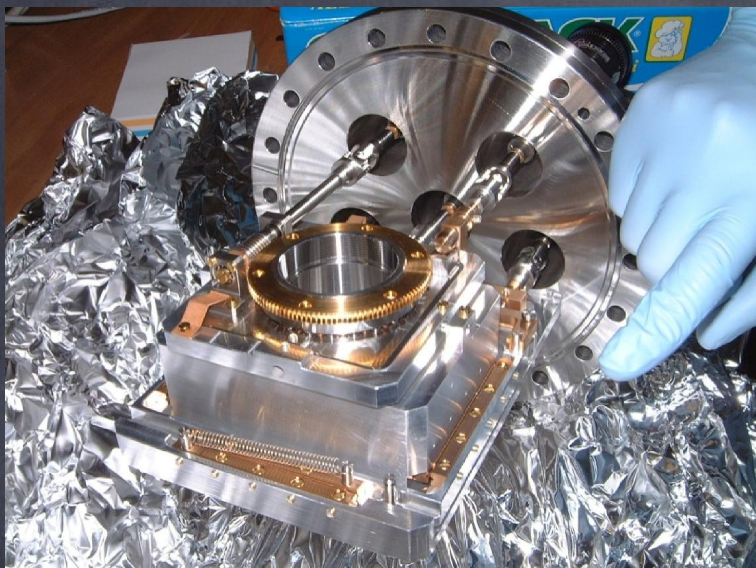
Spatial filter

Analyzer

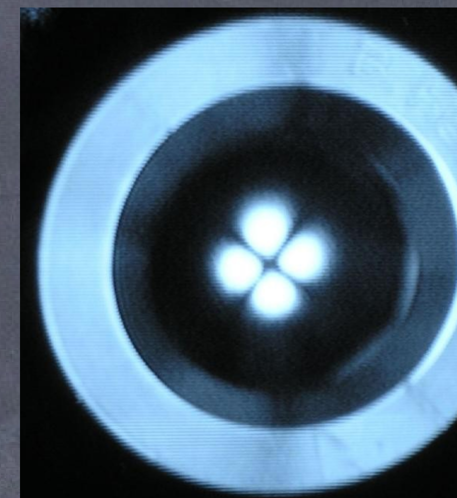
Modulator

Upper mirror

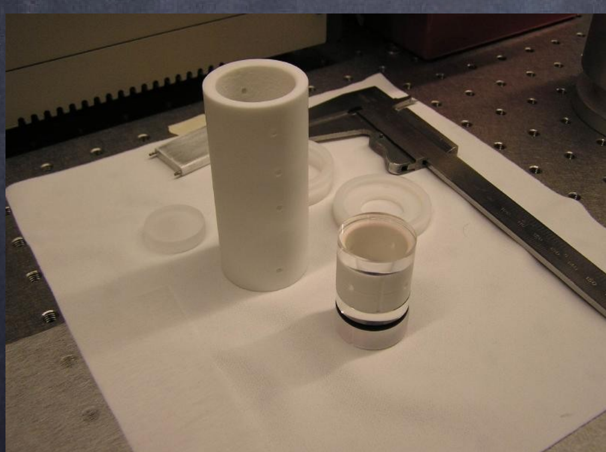
Photo gallery II



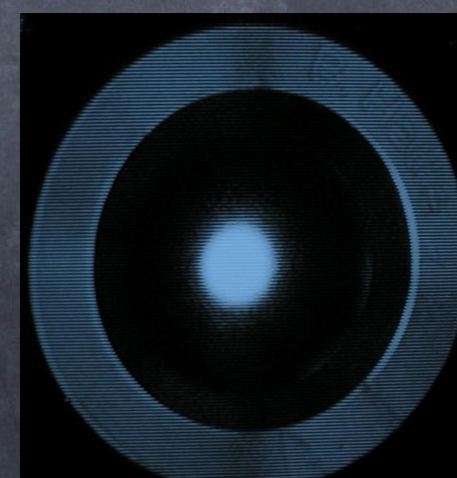
Mirror mount



Mode TEM_{11}

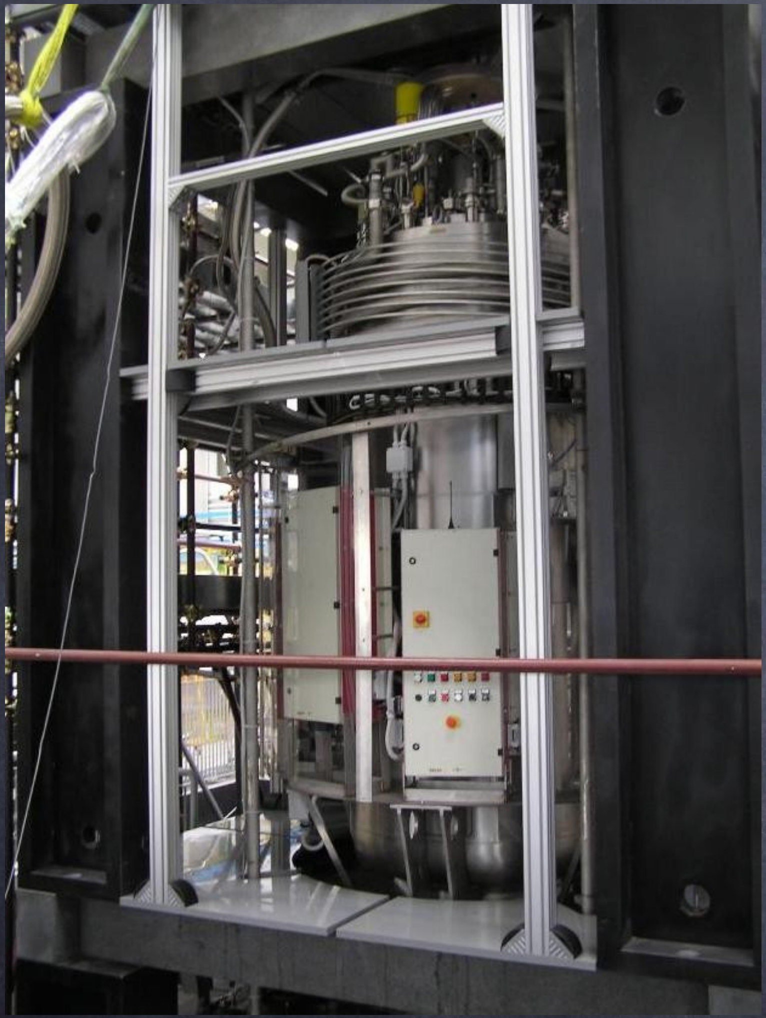


Short test cavity

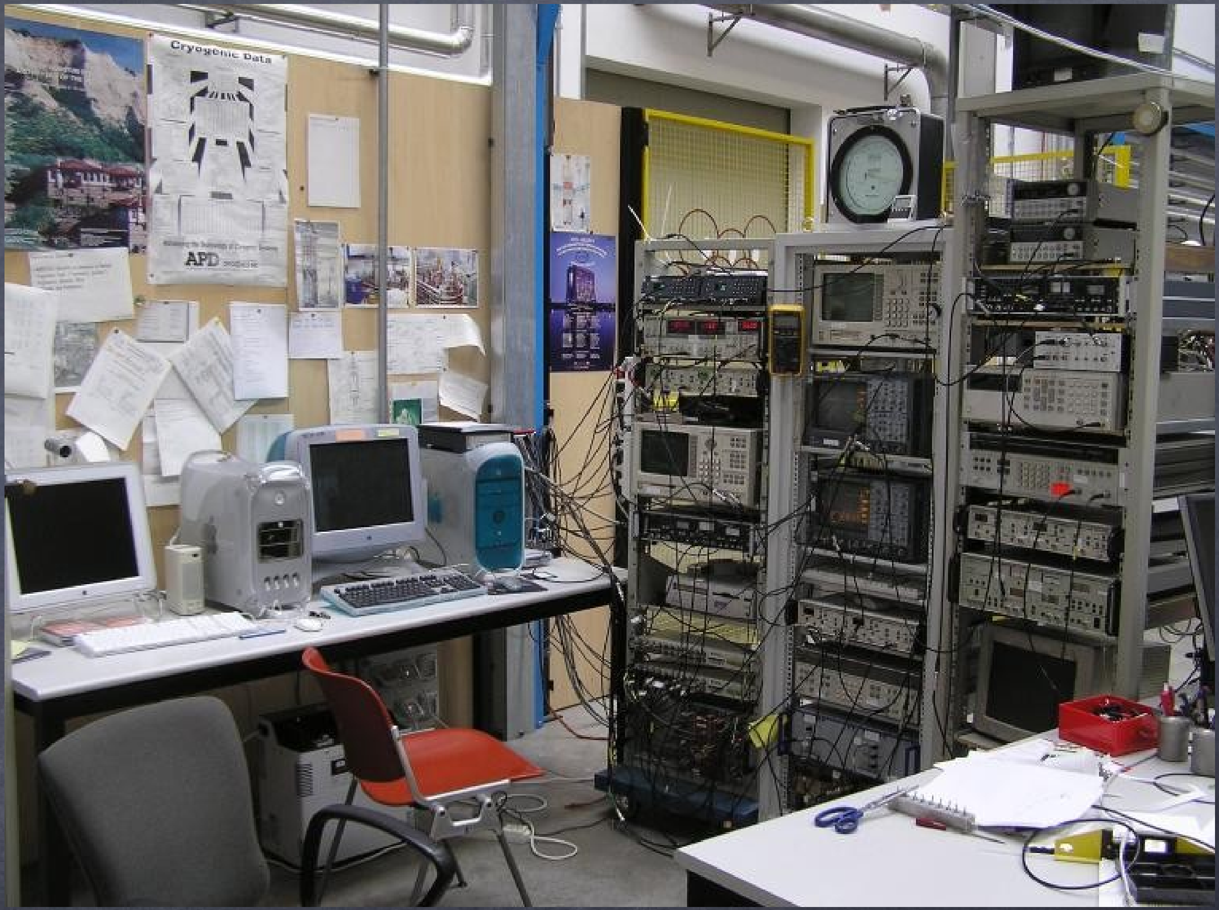


Mode TEM_{00}

Photo gallery III



Cryostat

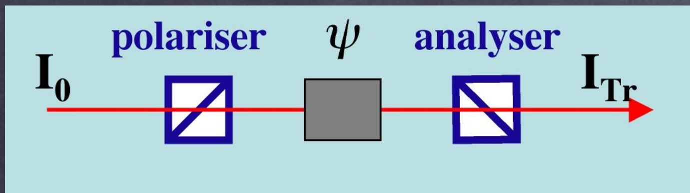


Control room

Apparato

Experimental Hall

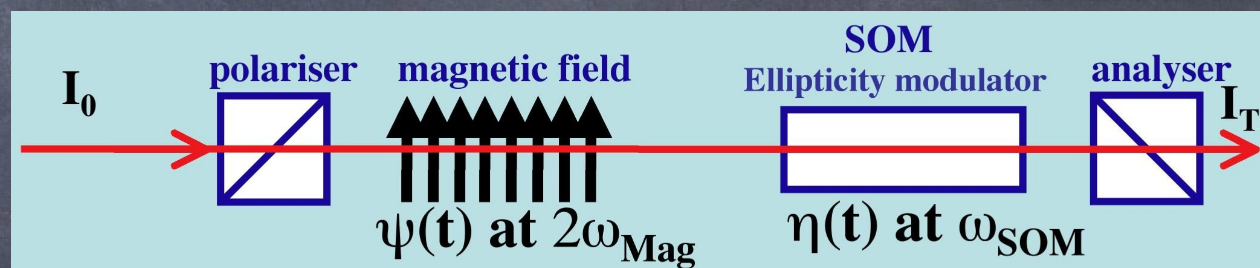
Ellipticity measurement



Static detection excluded $I_{Tr} = I_0\left(\sigma^2 + \psi^2\right)$

With the heterodyne technique one modulates Ψ at Ω_{Mag} and makes it beat with a calibrated time varying elliptcity $\eta(t)$ with pusation ω_{SOM} . This allows

- Ψ to be linearized
- have less 1/f noise



$$I_{Tr} = I_0\left[\sigma^2 + \left(\psi(t) + \eta(t)\right)^2\right] = I_0\left[\sigma^2 + \left(\psi(t)^2 + \eta(t)^2 + \underline{2\psi(t)\eta(t)}\right)\right]$$

Main frequency components are a $\omega_{SOM} \pm 2\Omega_{Mag}$ and $2\omega_{SOM}$

From 2ϑ dependence of Ψ

Ellipticity measurements II

In practice, nearly static rotations/ellipticities α_s generate a 1/f noise around ω_{SOM}.

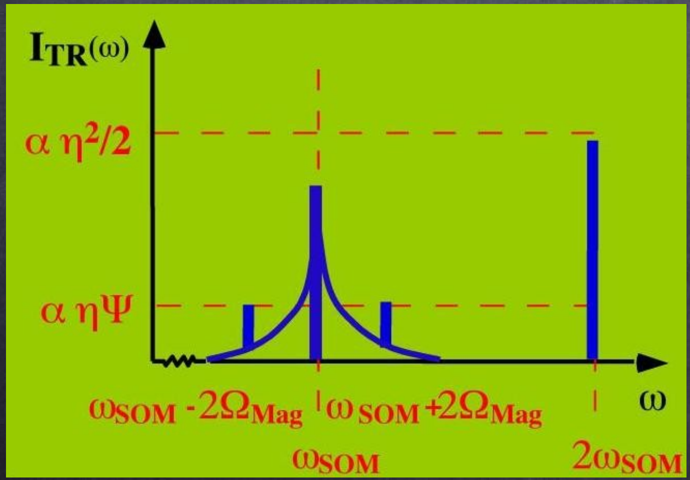
$$I_{Tr} = I_0\left[\sigma^2 + \left(\psi(t) + \eta(t) + \alpha_s\right)^2\right] =$$

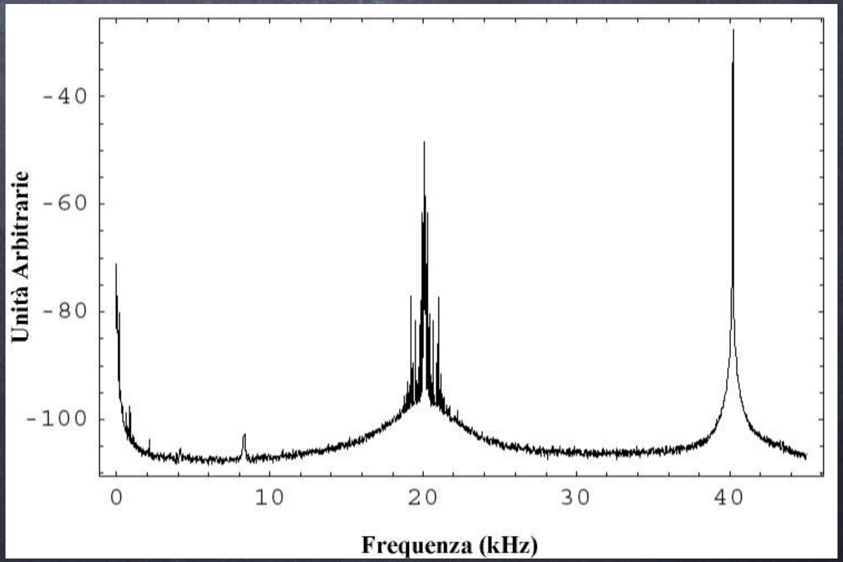
$$= I_0\left[\sigma^2 + \left(\eta(t)^2 + 2\psi(t)\eta(t) + 2\alpha_s\eta(t) + \ldots\right)\right]$$

Normalization

Desired signal

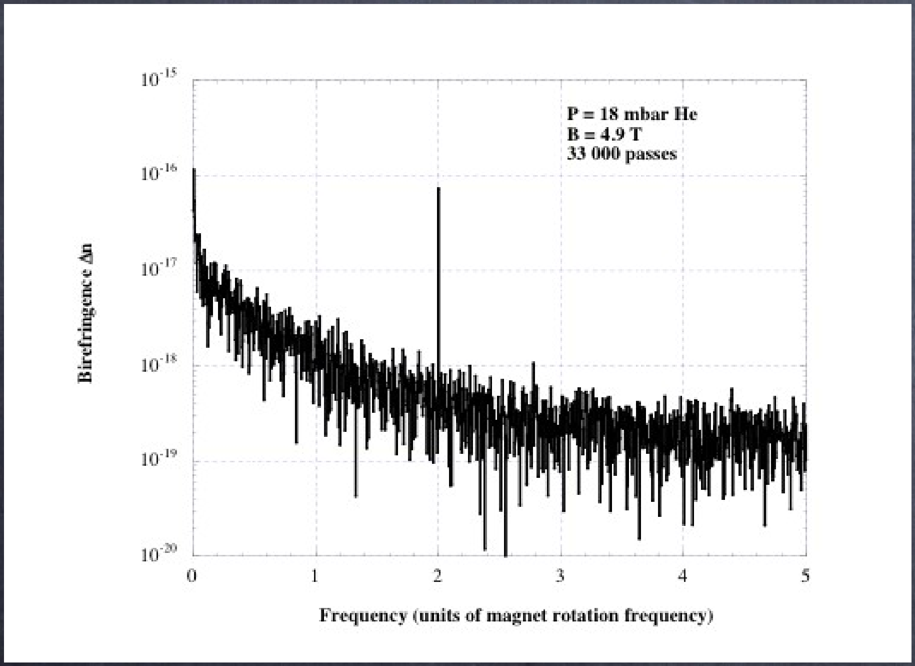
Birefringent noise



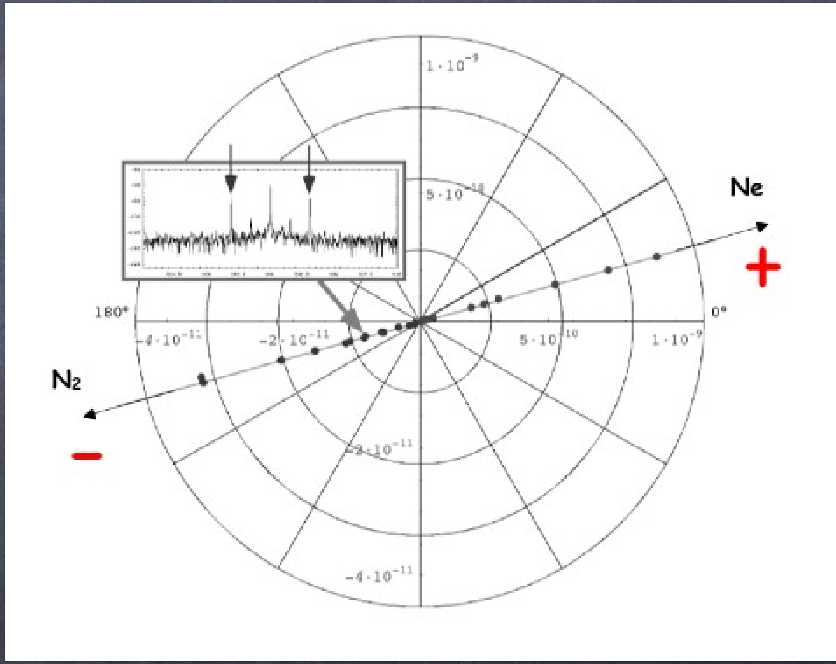


Gas phase and amplitude calibration

- Signal amplitudes given by the ellipsometer can be checked by measuring the magnetic birefringence (Cotton-Mouton effect) of gases
- Signal phases are checked by plotting data in a phase-ampitude polar plane: points corresponding to different gas pressures must lie on a straight line

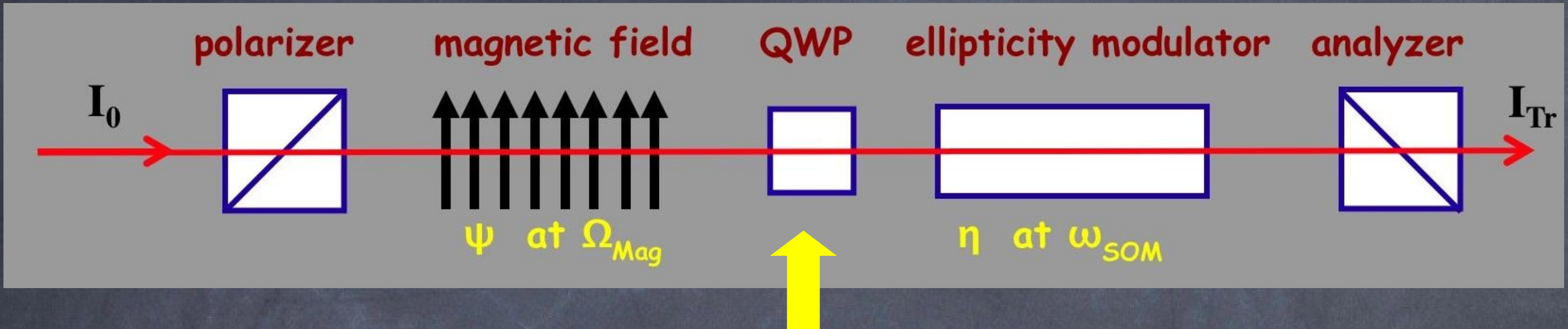


The expected signal (magnetic birefringence of a gas in this case) appears at twice the magnet rotation frequency (here 0.6 Hz)



Data points (taken at several pressure values <mbar for N_2, 1-20 mbar for Ne) align along a straight line determined by the apparatus geometry and by the position of the initial polarisation

Dichroism measurements



A QWP can be inserted to transform a rotation into an ellipticity with the same amplitude. Two positions for the QWP slow axis: 0° and 90°.

$$\varepsilon(t) \quad \Rightarrow \quad \begin{cases} \Psi(t) & \text{for } \vartheta_{QWP} = 0^\circ \\ -\Psi(t) & \text{for } \vartheta_{QWP} = 90^\circ \end{cases}$$

Main frequency component appear at $\omega_{SOM} \pm 2\Omega_{Mag}$ and $2\omega_{SOM}$

Dichroism (rotation) measurements and ellipticity measurements are independent

Sensitivity

- I.R. laser up to 60 mWatt power leaving the cavity

Theoretical shot noise: $\sqrt{\dfrac{4e}{I_0 q}} = 4 \cdot 10^{-9} \dfrac{1}{\sqrt{Hz}}$

Present noise: $\approx 5 \cdot 10^{-7} \dfrac{1}{\sqrt{Hz}}$

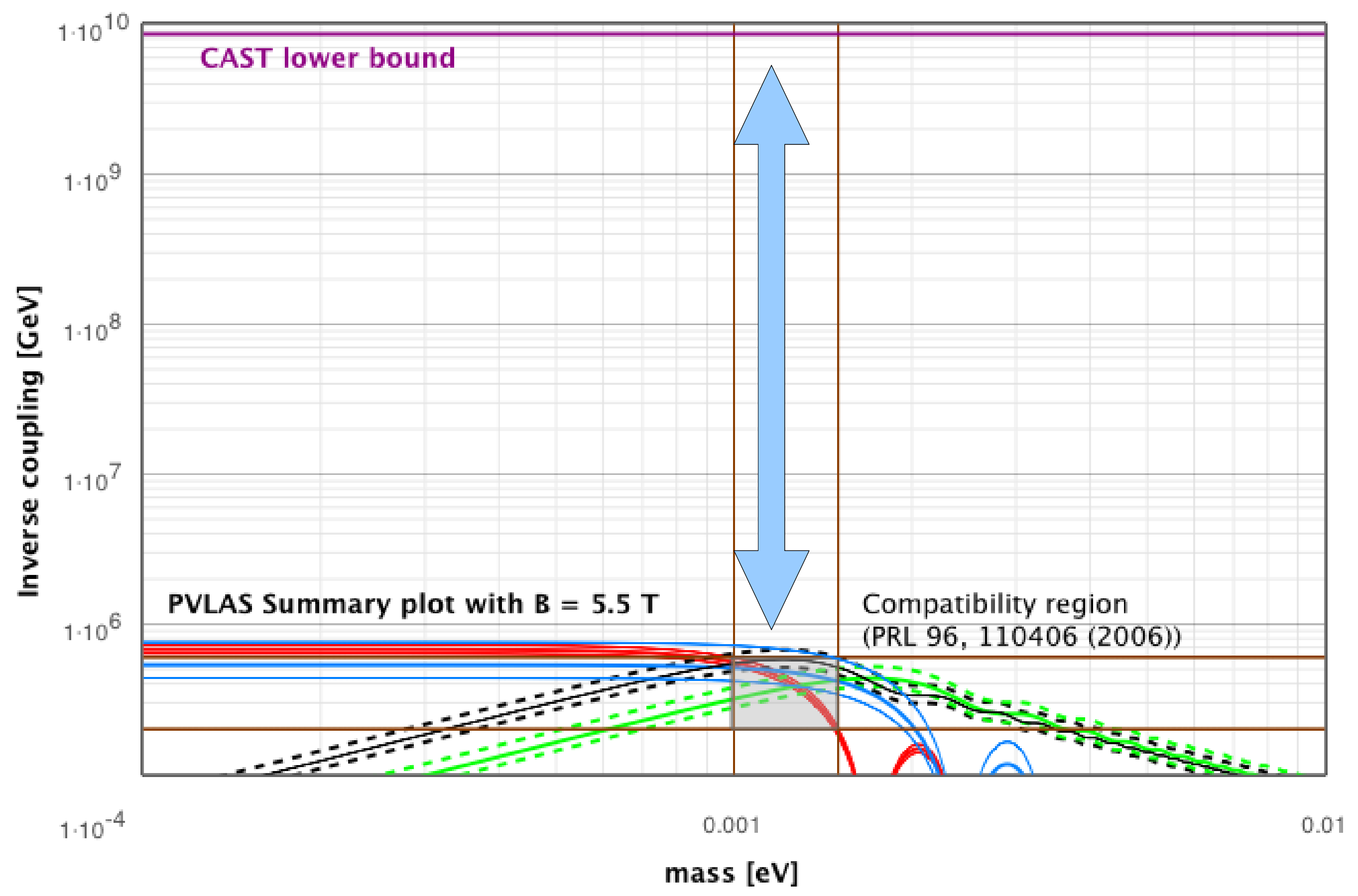
QED signal with $5{\cdot}10^4$ passes B=5T: $\Psi = 1.5 \cdot 10^{-11}$

Results before 2007

- Since 2000 a 'large' rotation signal ($2 \cdot 10^{-7}$ rad) was present indicating a dichroism induced by the external magnetic field
- The signal could not be due to 'standard' physics such as QED (QED does not generate measurable dichroism)
- Lengthy systematic error searches did not find the cause
- Some corss checks acutally indicated that the signal was of physical origin -> ALP, MCP, anomalous photon splitting
- We therefore published the rotation measurement on PRL
- Having a possible particle interpretation, several direct appearance experiments were started and many interesting theoretical papers were published to overcome the CAST – PVLAS discrepancy

Comparison with CAST

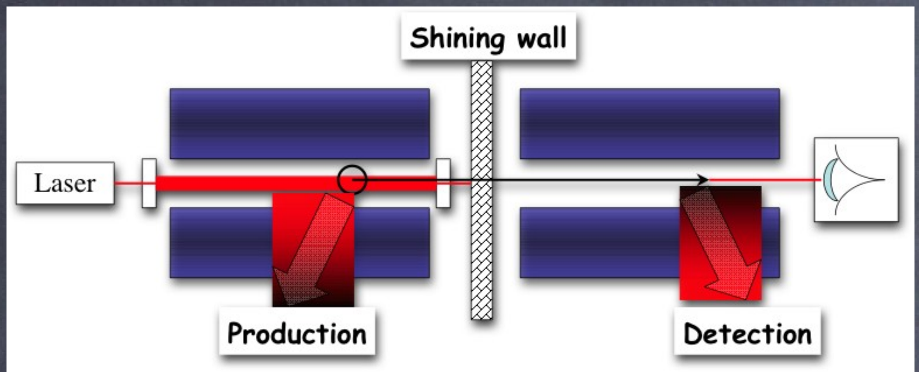
CERN Axion Solar Telescope

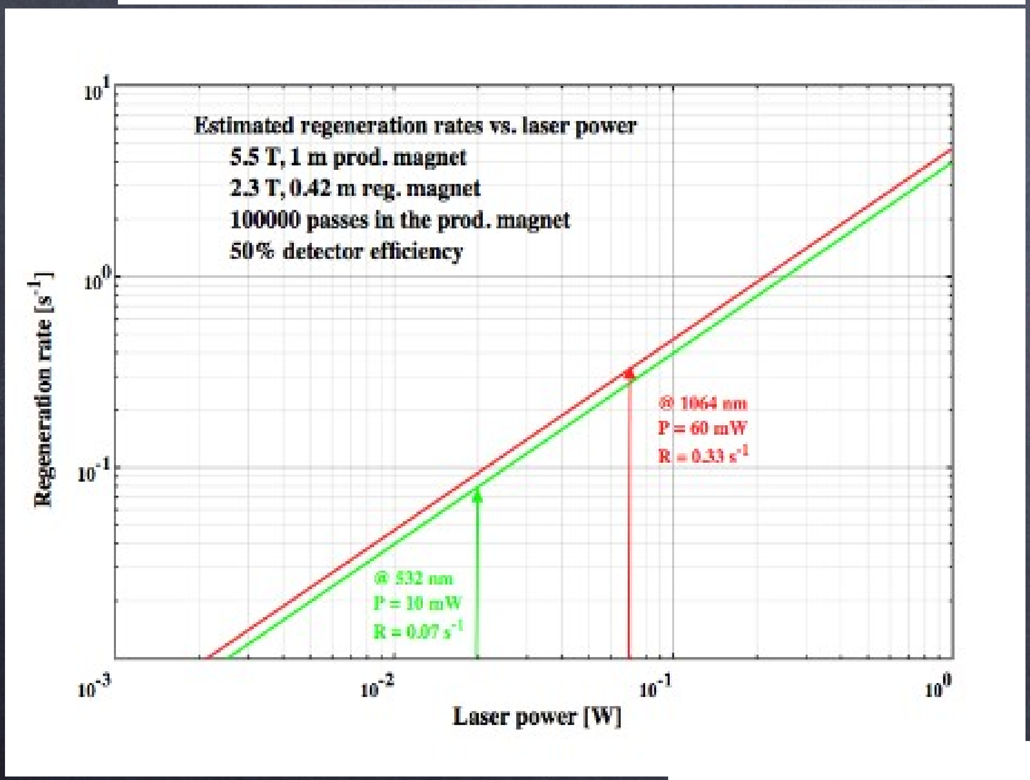


After 2006

- A dichroism implies the loss of photos. Disappearance measurements are different
- Exclude/confirm with a direct appearance measurement different
  - photon splitting — done
  - regenerazione — preparation
- Upgrade apparatus and study possible systematic errors
  - New access structure in aluminium — done, irreversible
  - new coaxial cables — done, irreversible
  - different laser — done, reversible
  - magnetic shield of feedback electronics and mirrors — done, reversible
  - longer runs at lower fields — done, reversible

Regeneration





Second 50 cm long, 2.3 T permanente magnet below optical bench

Standard detectors have low efficiencies and high dark count in NIR

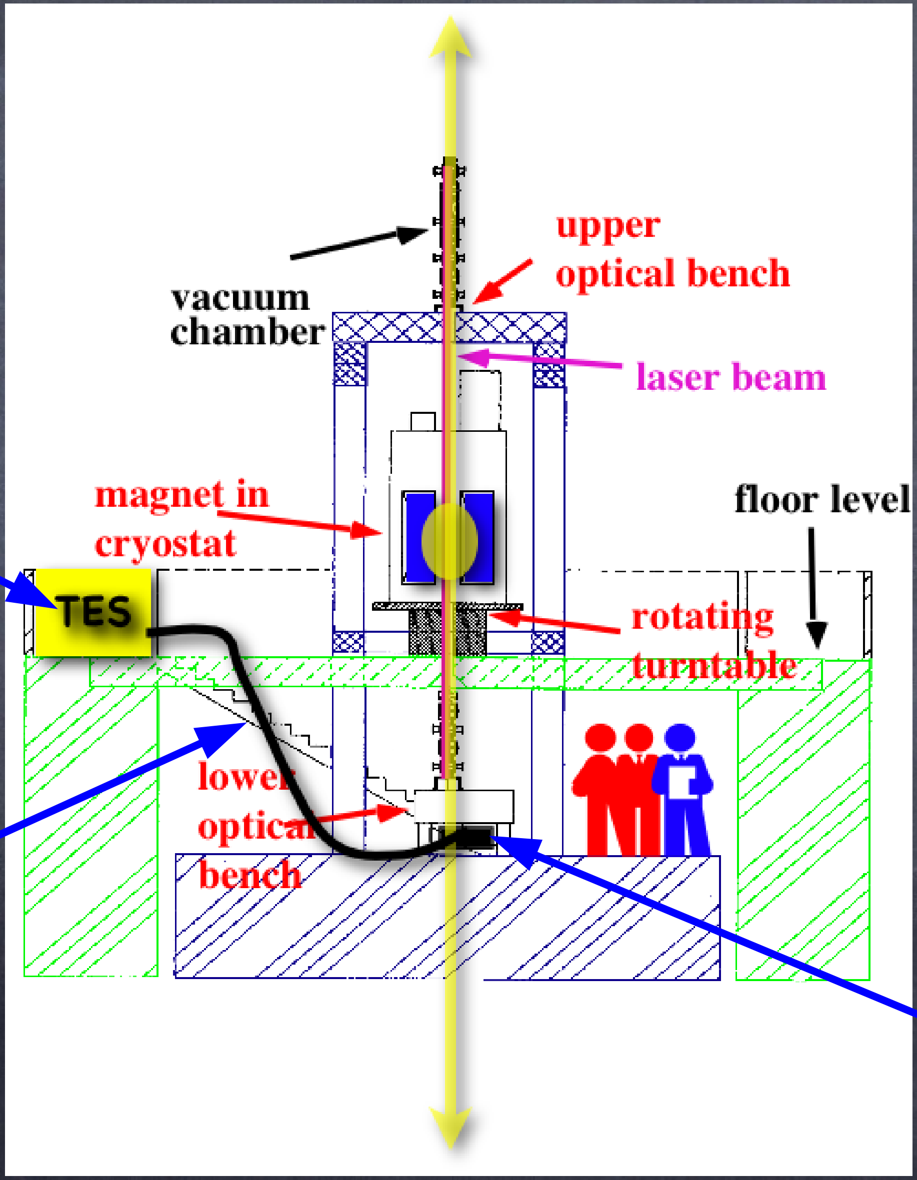
Low power with green laser

F. Gatti si developing a TES for our purpose

$$R = \frac{W}{\omega}\frac{N}{2}\left(P_{\gamma\leftrightarrow a}\right)^2 = \frac{1}{16}\frac{W}{\omega}\frac{N}{2}\left(\frac{B_0 L}{M}\right)^4\left(\frac{\sin(x)}{x}\right)^4$$

Regeneration setup

Transition Edge Sensor (TES) for photon detection



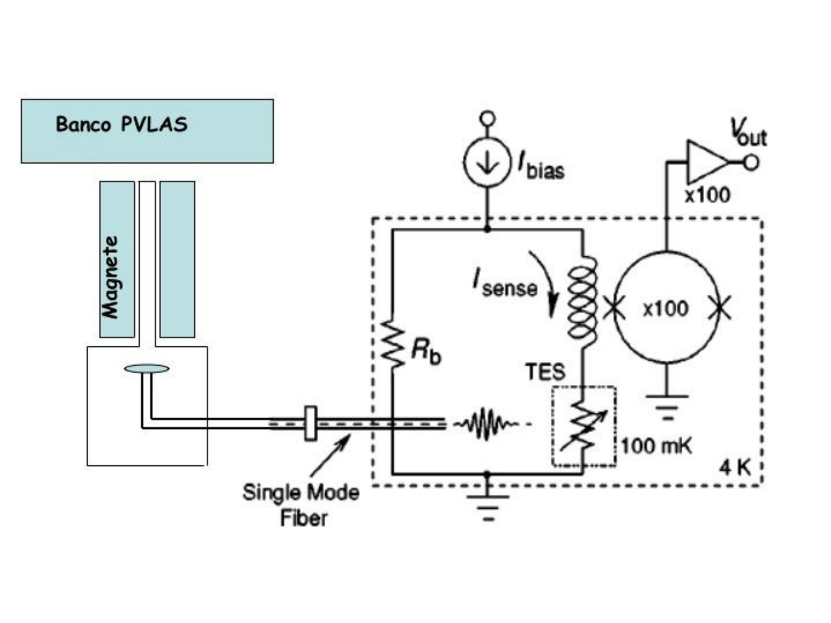
Optical fiber

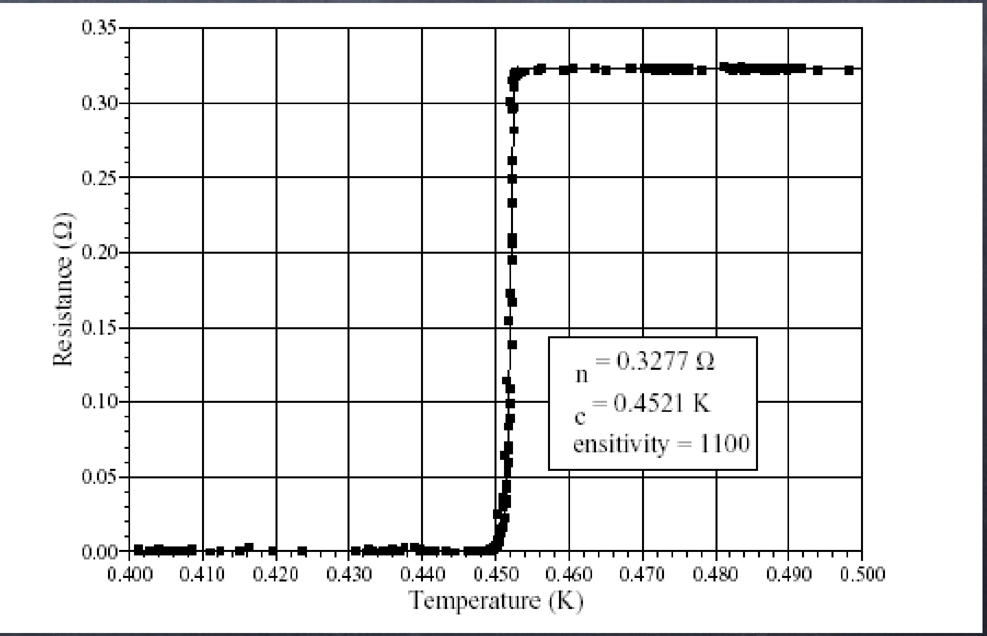
Second regeneration magnet below optical bench

TES

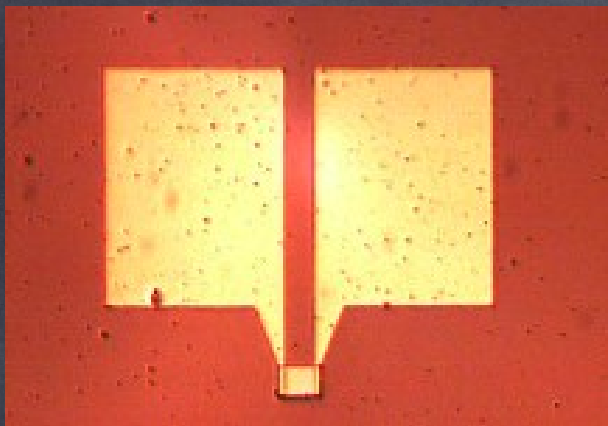
- Transition Edge Sensor
  - Works as a bolometer
  - cryogent temperature (100mK)
  - potentially no background
  - spectroscopic ability

- Photon transport
  - fiber optic
  - 1064 nm filter

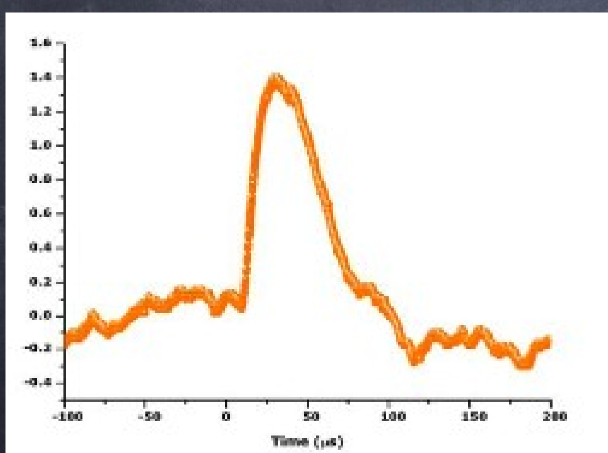




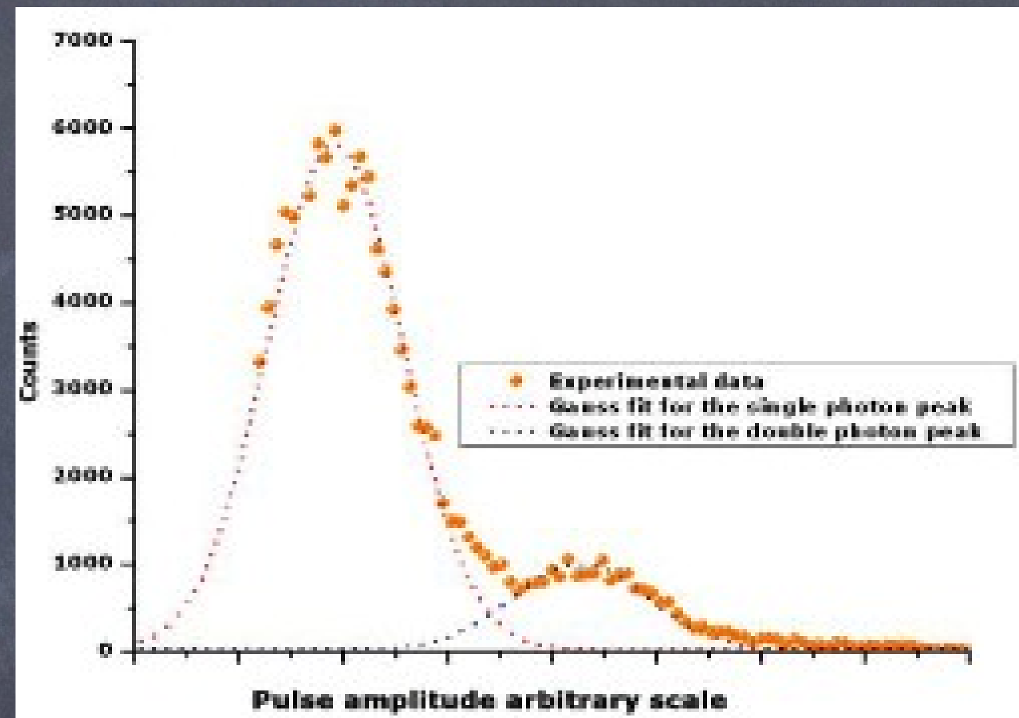
TES con luce 450 nm



TES di 25x25 μm^2 con pad in alluminio

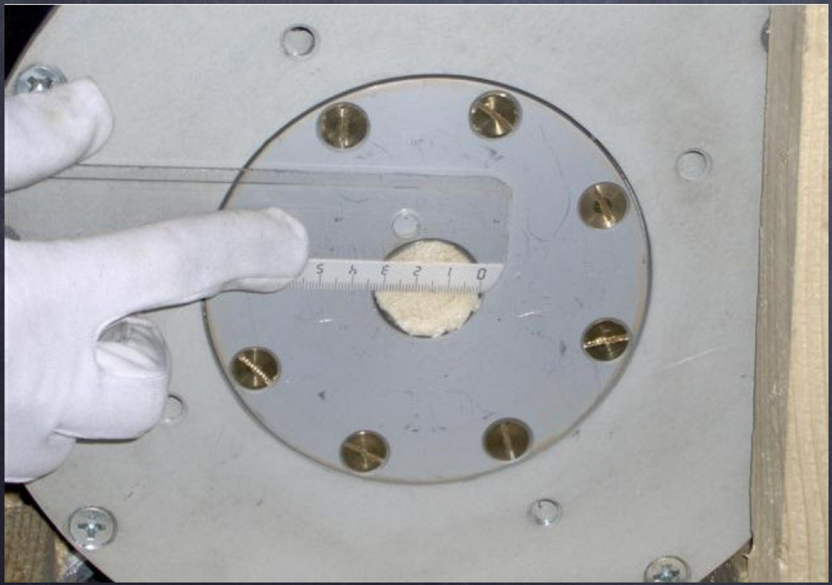


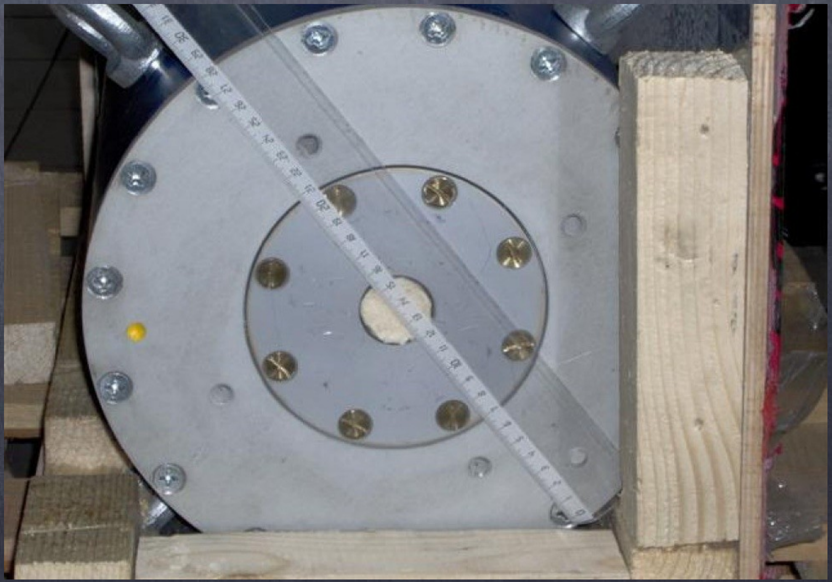
Impulso singolo fotone da 450 nm



Spettro di singolo e doppio fotone

the permanent magnet



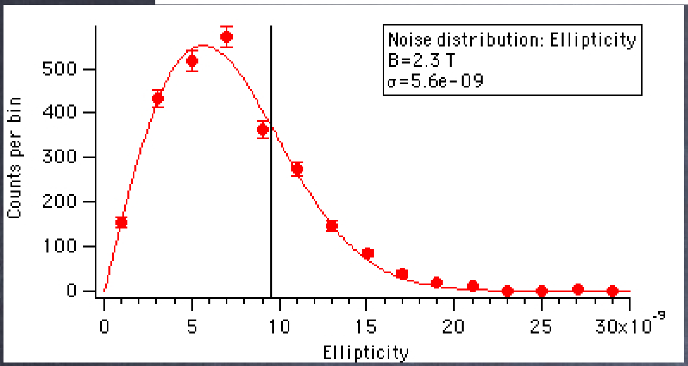


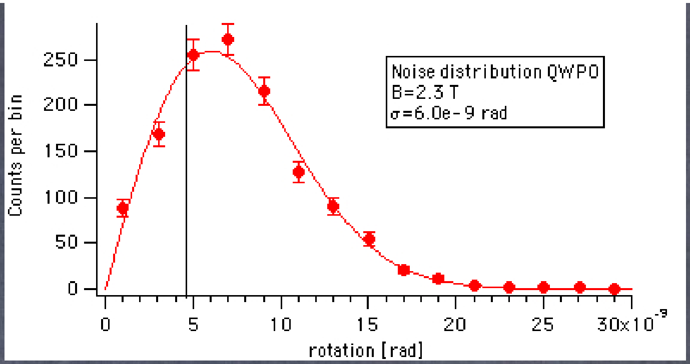
2007 Measurements

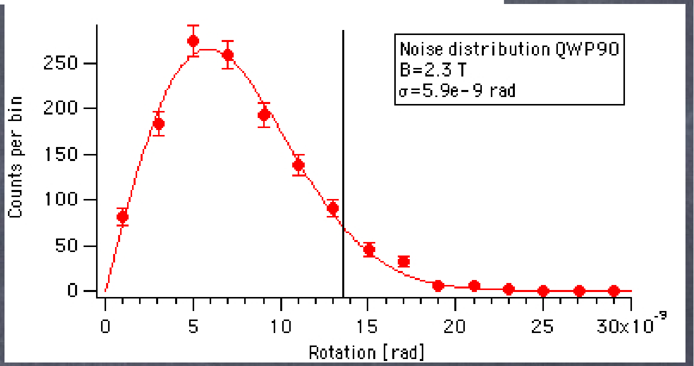
- Having recognised the stray field as a possible source of systematic effects we took long measurements at 2.3 T. At this field intensity the stray field is absent
  - Ellipticity
  - Rotation with QWP 0°
  - Rotation with QWP 90°
- The duration of these measurements were chosen so as to exclude/confirm the 5.5 T published data assuming a B^2 dependence. In the case of an exclusion, the 1 sigma had to be 10 times below the expected signal.

2.3T Results

Histogram of the ellipticity amplitude noise around $2\Omega_{Mag}$



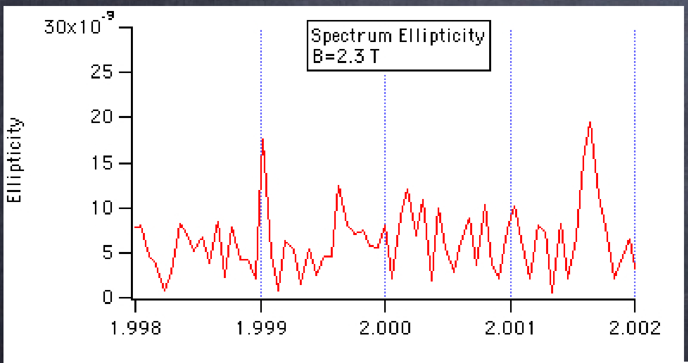


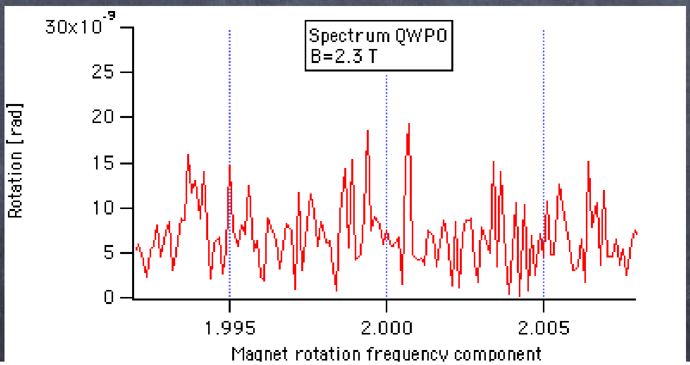


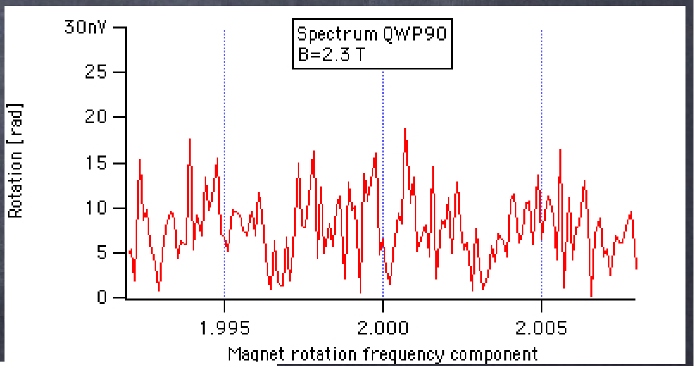
Ellipticity, 2.3T

Rotation, 2.3T, QWP 0°

Rotation, 2.3T, QWP 90°







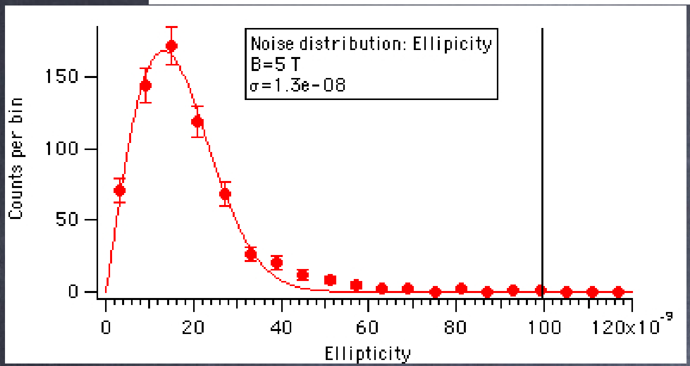
Ellipticity amplitude spectrum around $2\Omega_{Mag}$

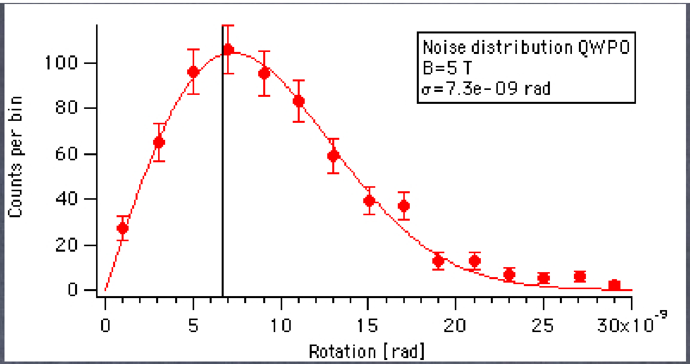
2007 Measurements II

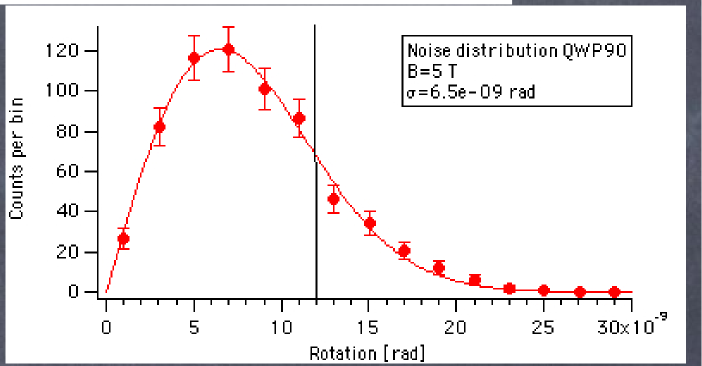
- Having found only limits at 2.3 T we repeated the measurements at 5 T
  - Ellipticity
  - Rotation with QWP 0°
  - Rotation with QWP 90°

5T results

Histogram of the ellipticity amplitude noise around $2\Omega_{Mag}$



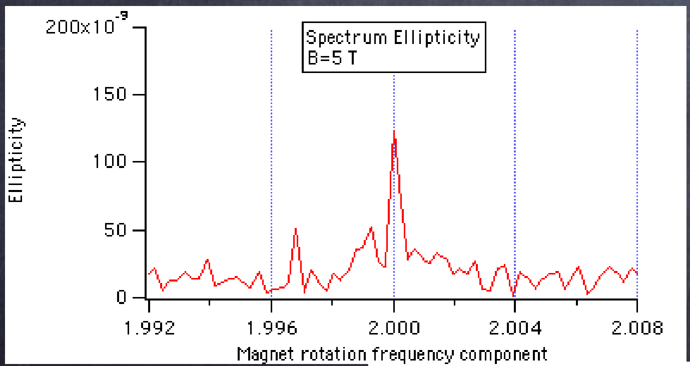


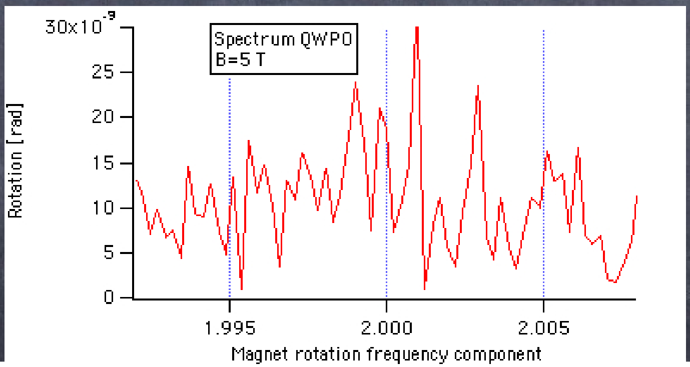


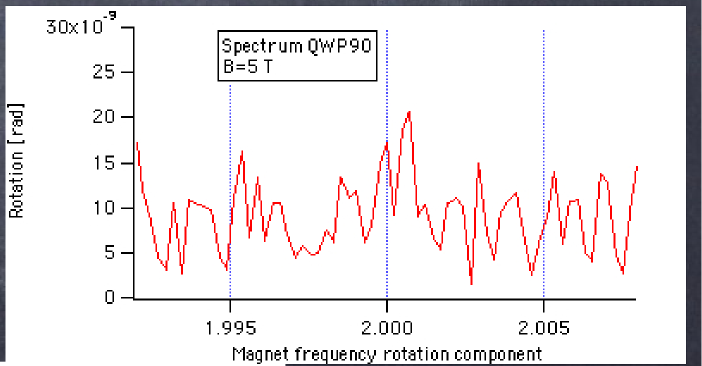
Ellipticity, 5T

Rotation, 5T, QWP 0°

Rotation, 5T, QWP 90°







Ellipticity amplitude spectrum around $2\Omega_{Mag}$

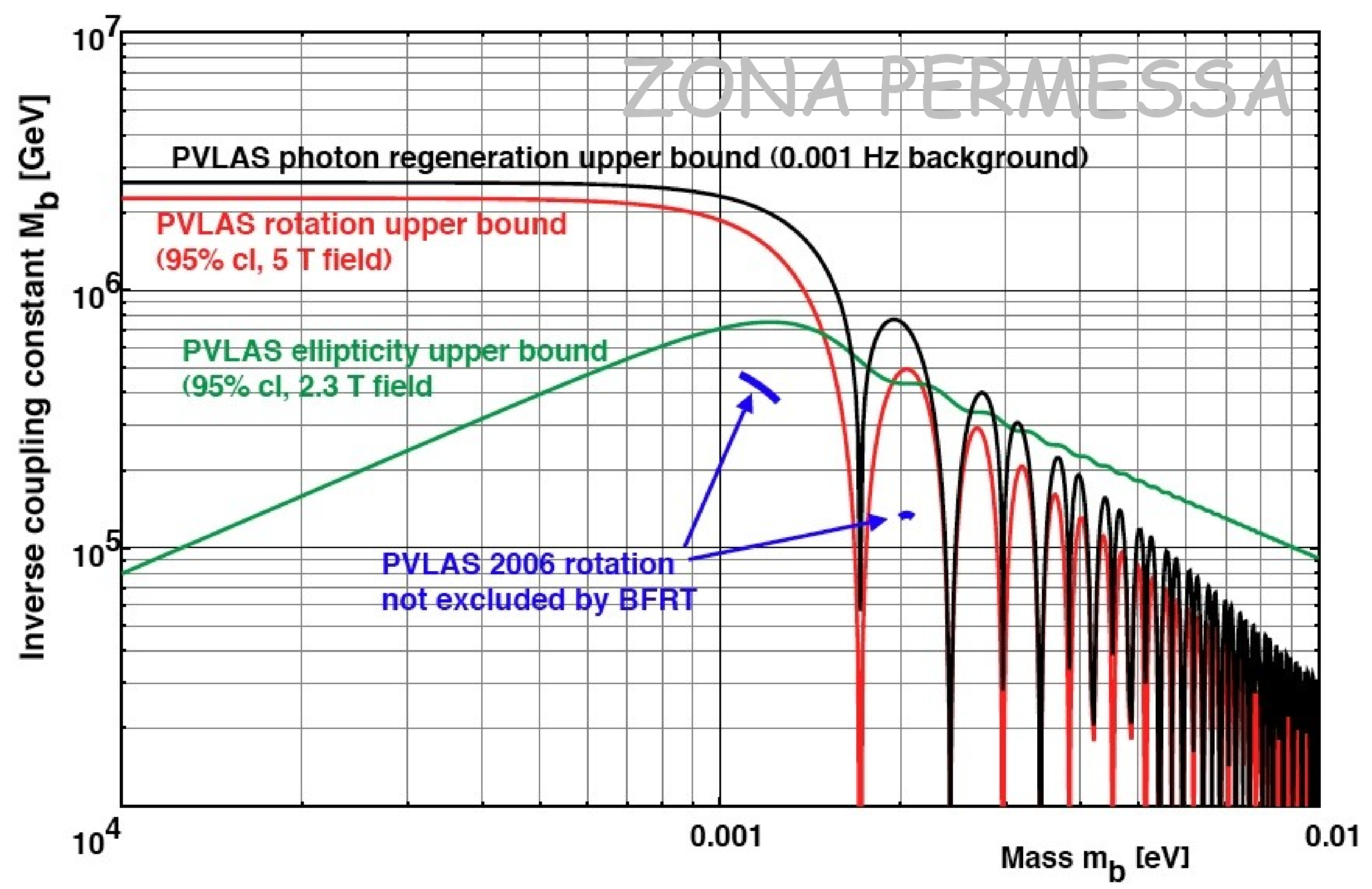
5T ellipticity

- signal @ 5T: $\Psi_{5T} = (9.8 \pm 0.9) \cdot 10^{-8}$
- standard deviation @ 2.3T: $\sigma_{2.3T} = 5.6 \cdot 10^{-9}$
- expected signal @ 2.3T: $\Psi_{2.3T} = \Psi_{5T} \left(\frac{2.3}{5} \right)^2 = 2.1 \cdot 10^{-8}$
- Rayleigh cumulative distribution $c.d.f. = 1 - e^{\left(\frac{-x^2}{2\sigma^2} \right)}$

Probability = 1.0 · 10^{-3} → peak excluded

New limits on ALP

arXiv:0706.3419



Exclusion plot in the mass-inverse coupling constant plane.

Rotation @ 5T

Ellipticity@2.3T

In black the expected limit from the regeneration

Ellipticit and rotation limits at 95% c.l.

Meas. Type	2.3 T	5 T
Rotation	$1.0 \cdot 10^{-8}$ rad	$1.2 \cdot 10^{-8}$ rad
Ellipticity	$1.4 \cdot 10^{-8}$	

Editorial note su PRL

PRL **99,** 129901 (2007) PHYSICAL REVIEW LETTERS week ending 21 SEPTEMBER 2007

Editorial Note: Experimental Observation of Optical Rotation Generated in Vacuum by a Magnetic Field [Phys. Rev. Lett. 96, 110406 (2006)]

E. Zavattini, G. Zavattini, G. Ruoso, E. Polacco, E. Milotti, M. Karuza, U. Gastaldi, G. Di Domenico, F. Della Valle, R. Cimino, S. Carusotto, G. Cantatore, and M. Bregant

(PVLAS Collaboration)

(Received 7 August 2007; published 20 September 2007)

DOI: 10.1103/PhysRevLett.99.129901 PACS numbers: 12.20.Fv, 07.60.Fs, 14.80.Mz, 99.10.Np

The observed vacuum optical rotation signal reported in [1] has now been excluded by more recent results from the PVLAS Collaboration [2], which show that it was due to an instrumental artifact and was not of physical origin. These new data therefore also exclude the possible interpretation of the signal reported in [1], as caused by the existence of a light, neutral, spin-zero particle.

[1] E. Zavattini *et al.*, Phys. Rev. Lett. **96**, 110406 (2006).
[2] E. Zavattini *et al.*, arXiv:0706.3419.

Photoregeneration - Toulouse

No light shining through a wall : new results from a photoregeneration experiment

C. Robilliard[1], R. Battesti[2], M. Fouché[1], J. Mauchain[2], A.-M. Sautivet[3], F. Amiranoff[3], and C. Rizzo[1]
[1]*Laboratoire Collisions Agrégats Réactivité, UMR 5589 CNRS - Université Paul Sabatier Toulouse 3, IRSAMC, 31062 Toulouse cedex 9, France.*
[2]*Laboratoire National des Champs Magnétiques Pulsés, UMR5147 CNRS-INSA-UPS, 143 Avenue de Rangueil, 31400 Toulouse cedex, France.*
[3]*Laboratoire pour l'Utilisation des Lasers Intenses, École Polytechnique, CNRS, CEA, UPMC, 91128 Palaiseau, France.*
(Dated: September 17, 2007)

Recently, axion-like particle search has received renewed interest. In particular, several groups have started "light shining through a wall" experiments based on magnetic field and laser both continuous, which is very demanding in terms of detector background. We present here the 2σ limits obtained so far with our novel set-up consisting of a pulsed magnetic field and a pulsed laser. In particular, we have found that the axion-like particle two photons inverse coupling constant M is $< 8 \times 10^5$ GeV provided that the particle mass $m_a \sim 1$ meV. Our results definitively invalidate the axion interpretation of the original PVLAS optical measurements with a confidence level greater than 99.9%.

arXiv: 0707.1296v3

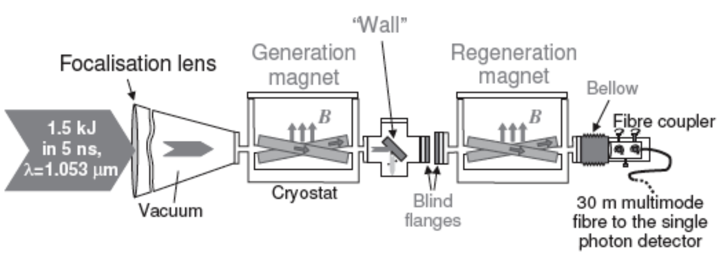


FIG. 1: Scheme of our experimental setup.

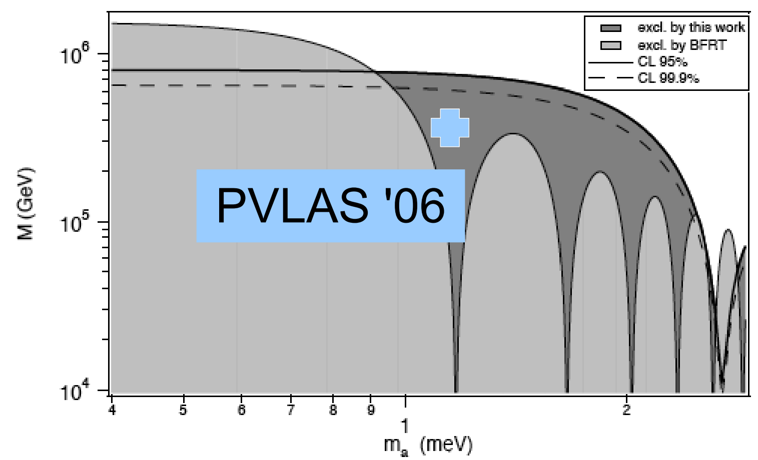


FIG. 4: 95% confidence level limits on the axion-like particle two photons inverse coupling constant M as a function of the axion-like particle mass m_a obtained thanks to our null result (dotted line). The area below our curve is excluded. Our limits are compared to the 95 % confidence level exclusion region obtained by the BFRT photon regeneration experiment [10].

First direct exclusion

Limits on light-light scattering

From our 2.3T ellipticity measurements we can give a new limit on $\sigma_{\gamma\gamma}$

$$\Psi_{2.3T} = \frac{2F}{\pi}\frac{\pi\, 3A_e B^2 L}{\lambda} \leq 1.4\cdot 10^{-8}$$

F = 45000

L = 1064nm

B = 2.3T

$A_e < 6.6\cdot 10^{-29}$ cm^3/erg

$$\sigma_{\gamma\gamma}^{[1]} = \frac{1}{45^2}\frac{973}{5}\frac{\alpha^4}{\pi}\left(\frac{\hbar\omega}{m_e c^2}\right)^6\left(\frac{\hbar}{m_e c}\right)^2 = \frac{4\pi}{5}\frac{973\hbar^2}{c^4}\omega^6 A_e^2 \quad \text{(cgs)}$$

$$\sigma_{\gamma\gamma} < 4.5\cdot 10^{-58}\ cm^2$$

Noise issue

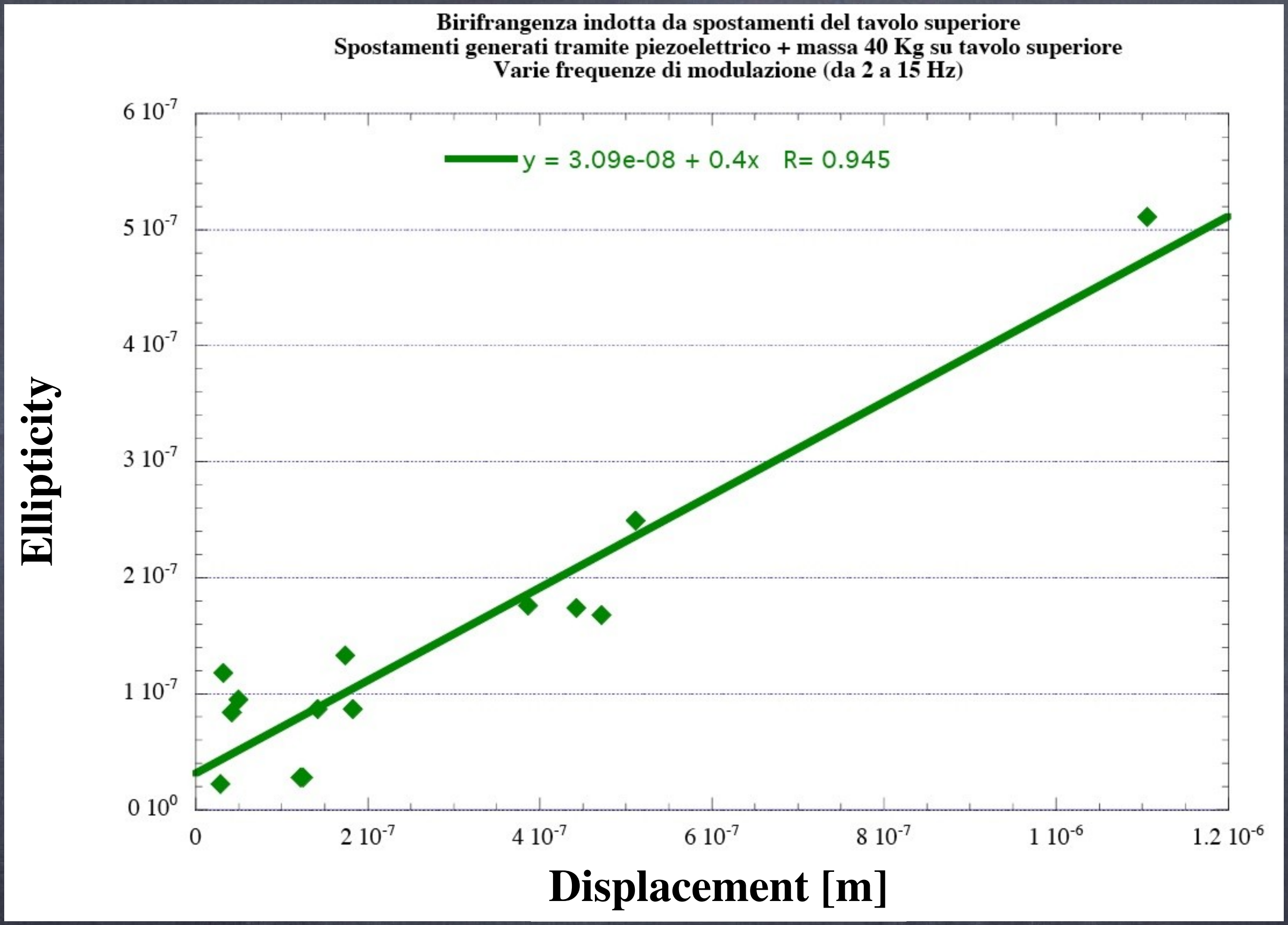
- Exclusion of the published signal (something is still present in ellipticity at 5T) brings us back to the original aim of the experiment
- Noise must be improved
  - Now: ≈ $5 \cdot 10^{-7}$ $1/\sqrt{Hz}$
  - QED signal ≈ 10^{-11} (3 metri, 2.3 T, perm. mag.)
- With a plausible 10^{5} s integration time we need a sensitivity of $f = 3 \cdot 10^{-9}$ $1/\sqrt{Hz}$ (shot noise with 50 mW)
- An improvement of a factor <u>100</u>! is needed. How? Is it possible? Do we have ideas?

Noise issues II

Some critical points have been found and will be studied:

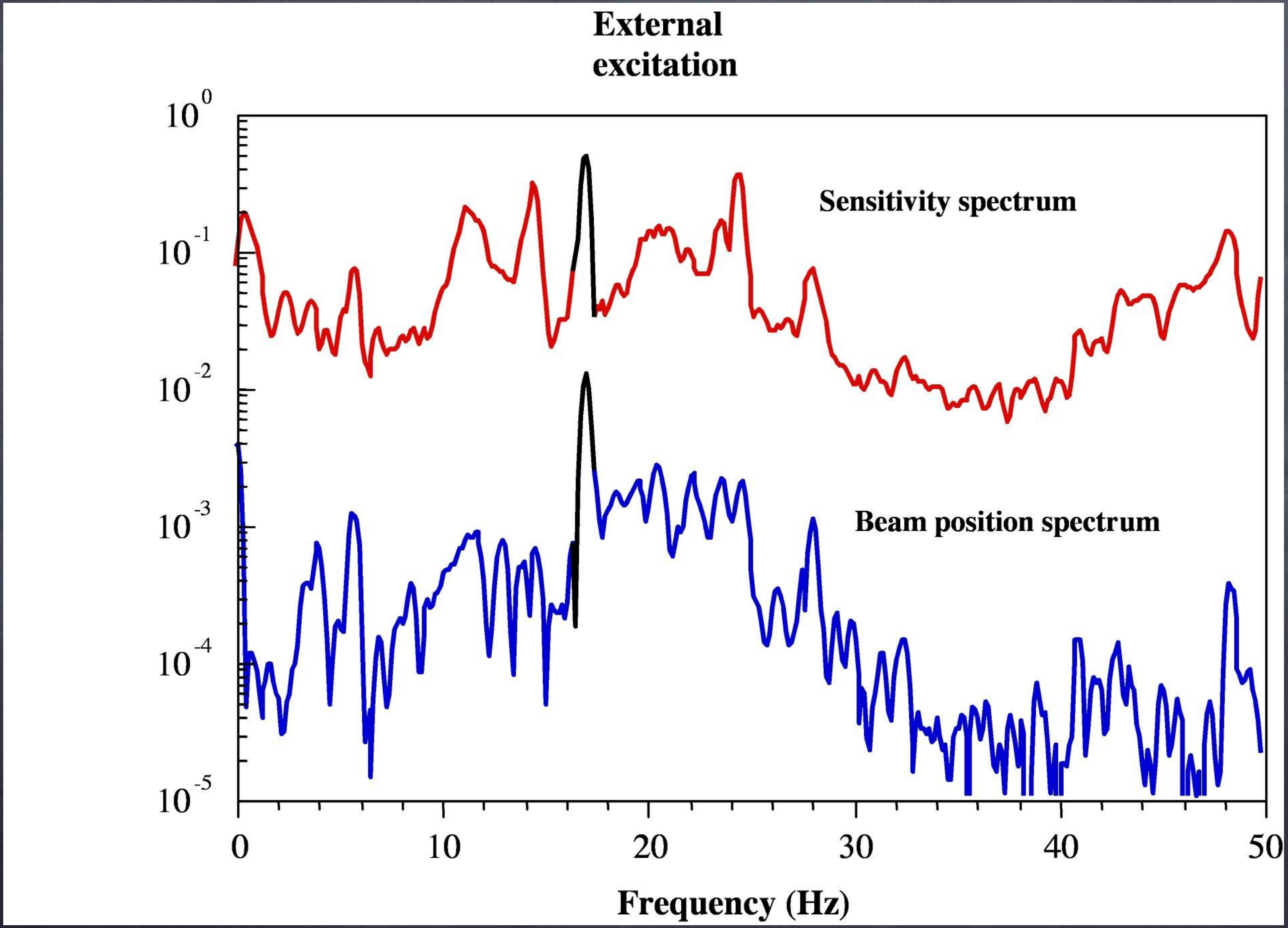
- Vibration induced noise of the granite tower
  - Will be made more rigid and maybe we will implement a feedback system
- Thermal effect on the mirrors
- Automatic alignment of the cavity
- Eliminate modulator?
- Electronic/photodiode noise
- ....

Movement - Ellipticity



- Slope is about 0.4 m^{-1}
- Reach $3 \cdot 10^{-9}$ $1/\sqrt{Hz}$ implies $\approx 10^{-8}$ $m/\sqrt{Hz}$

Vibration - ellipticity



Comment

2008 will give us the important opportunity to make significant modifications to the apparatus and perform tests which, in the past, were considered too risky due to the necessity of maintaining the integrity of the system.

Future

- Subject is still of great interest: proliferation of experiments and theoretical papers (≈60 on AIP cite our 2006 PRL)
- Which is the best way to continue is not completely clear. The noise source must be understood.