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Abstract

In this report we summarize the main physics and experimental points relevant to PVLAS activities. First we cover the elements of physics interest concerning QED and the potentialities in respect to QCD and to very high energy physics. We recall the orders of magnitude of the experimental observables, the basic experimental approach, the main outputs of the measurements performed with the Legnaro set-up at LNL, the needs in terms of sensitivity to achieve measurements of the magnetic birefringence of vacuum within realistic time periods and the needs of absolute calibration of the zero and of the scale of the ellipticity axis in order to be able to reject false signals. We describe the test set-up assembled and running in Ferrara, where the solutions to the aforementioned needs have been implemented and validated. The Ferrara test set-up is a model in reduced scale of the new PVLAS apparatus dedicated to make the first observation of magnetic birefringence of vacuum, for which we are asking the financing for 2011-12. References are given to the most recent papers (or reports we are aware of) concerning the competing experiments BMV in Toulouse, OSQAR at CERN and Q&A at Taiwan.

11-05-2010

Contents

1- Physics of magnetic birefringence of vacuum

Non-linear effects for the propagation of light in vacuum in the presence of electric and/or magnetic fields are absent in classical Maxwell equations, but were predicted already long time ago in the Euler-Heisenberg-Weisskopf Lagrangian [1,2]. Magnetic birefringence of vacuum (MBV) was computed in the framework of quantum field theory in 1971 [3], but so far it has not yet been observed due to the smallness of the effect. In the QED framework MBV is a consequence of polarization, under the influence of the magnetic field, of pairs of virtual charged particles and antiparticles bubbling in vacuum. In terms of Feynman diagrams the dominant term is the light-by-light (lbl) scattering diagram with electrons and positrons in the loop. The contribution of loops of higher-mass virtual lepton pairs ($\mu^+\mu^-$,$\tau^+\tau^-$) is negligible since it scales with the fourth inverse power of the mass. If they exist, light scalar and pseudoscalar particles coupled to photons (e.g. axions, which are potential candidates for light cold dark matter) could contribute to MBV in an observable way, depending on the magnitude of their coupling to two photons [4]. The inverse of the coupling constant to two photons gives the mass scale of the new high-energy physics that would become accessible in this way with low energy optics experiments. The contribution to MBV of lbl scattering terms with a loop of light quarks might become appreciable when experiments will be able to provide precise measurements. The hadronic contribution to MVB might restrict the capability of observing new high energy physics with low energy optics experiments, but uncertainties in the calculation of these QCD effects are large [5].

Observation of MBV is qualitatively important because it would make directly visible at a macroscopic scale a property of physical vacuum. Notice that in MBV the responsible (mainly QED) effects result from interactions distributed coherently in space over long macroscopic distances (as it is the case in g-2 experiments) and not in confined microscopic volumes as it is the case in Delbruck scattering of high energy photons off atomic nuclei. Notice also that the lbl term is the dominant effect in vacuum magnetic birefringence experiments, while in g-2 experiments it is only a correction.

Direct observation of properties of the physical vacuum is important already at a qualitative level because vacuum appears to feature at the microscopic and at the cosmological levels properties whose consequences appear dramatically contradictory: vacuum has the property of expanding on large cosmological scales and of featuring creation and annihilation of virtual particle antiparticle pairs at the microscopic quantum level. The vacuum energy density computed on the basis of the present quantum mechanical description of microscopic vacuum, when integrated over cosmological scales, results in an enormous energy that would cause or should have already caused a big crunch of the universe. This is in violent contradiction with the observations nearly a century old that the universe is expanding and even more with recent observation that the expansion of the universe is accelerating [6].

In absence of light scalars and pseudoscalars coupled to two photons (Fig. 1e)), precise measurements of MBV would provide valuable tests of QED and, depending on the relevance of the contribution of hadronic lbl loops (Fig. 1d)), might contribute to exploit future high precision muon g-2 measurement to spot high energy effects. Hadronic loops contribute to the g-2 effect of the muon in a significant way and therefore it has been necessary to evaluate their contribution in order to assess if discrepancies between the theoretical and experimental results were due to new high energy physics or not. A sophisticated procedure that exploits dispersion relations has permitted to extract the hadronic vacuum polarization contribution from a combination of QCD calculations and measurements of e^+e^- annihilations as a function of c.m. energy [7]. The hadronic lbl contributions to the muon g-2, instead, cannot be related at present to any measurable quantity and calculations have to rely on models. The estimated lbl contribution amounts to about three times the experimental muon g-2 error [8].

Bakalov has reviewed in 1994 the various methods utilized to calculate MBV (Figs. 1a)-c)) starting from QED [9]. MBV and low energy gamma-gamma scattering cross sections are correlated (see refs.4-11 in our ref. 10). The PVLAS experiment has published the lowest upper limit to the lbl scattering cross section [10] using the data of the set-up installed at INFN-LNL (Legnaro National Laboratory). However the 10^{-6} $s^{1/2}$ operational sensitivity of the vertical ellipsometer coupled with the 5 T 1 m long superconducting dipole magnet of the set-up installed at INFN-LNL are not sufficient to observe to the lbl scattering cross section.

Rafelski has discussed in 1994 the hadronic lbl contributions to MBV (Fig. 1d)). He has emphasized that large uncertainties are present in the estimation of the contributions from light quark loops, with differences up to tree orders of magnitudes depending on whether non-perturbative or perturbative approaches are utilized [5]. We are not aware of further theoretical work on the subject. This may be explained by the absence so far of an experimental observation of MBV and by the focusing of theoretical interest in recent years on models to account for the anomalous results reported by PVLAS on the apparent rotation of the polarization plane of a light beam traversing a magnetic field based on 2002-2006 data [11] that were disproved by 2007 data with an improved apparatus [12].

Finally, concerning the possibile existence of scalar/pseudoscalar bosons coupling to two photons (Fig. 1e)), measurements by the CAST collaboration [13] and model dependent assumptions on the possible production of such particles from the sun exclude a large sector of the parameter space (spin zero particle mass m, coupling of the particle to two photons 1/M) where light spin zero particles would contribute in an observable way to MBV.

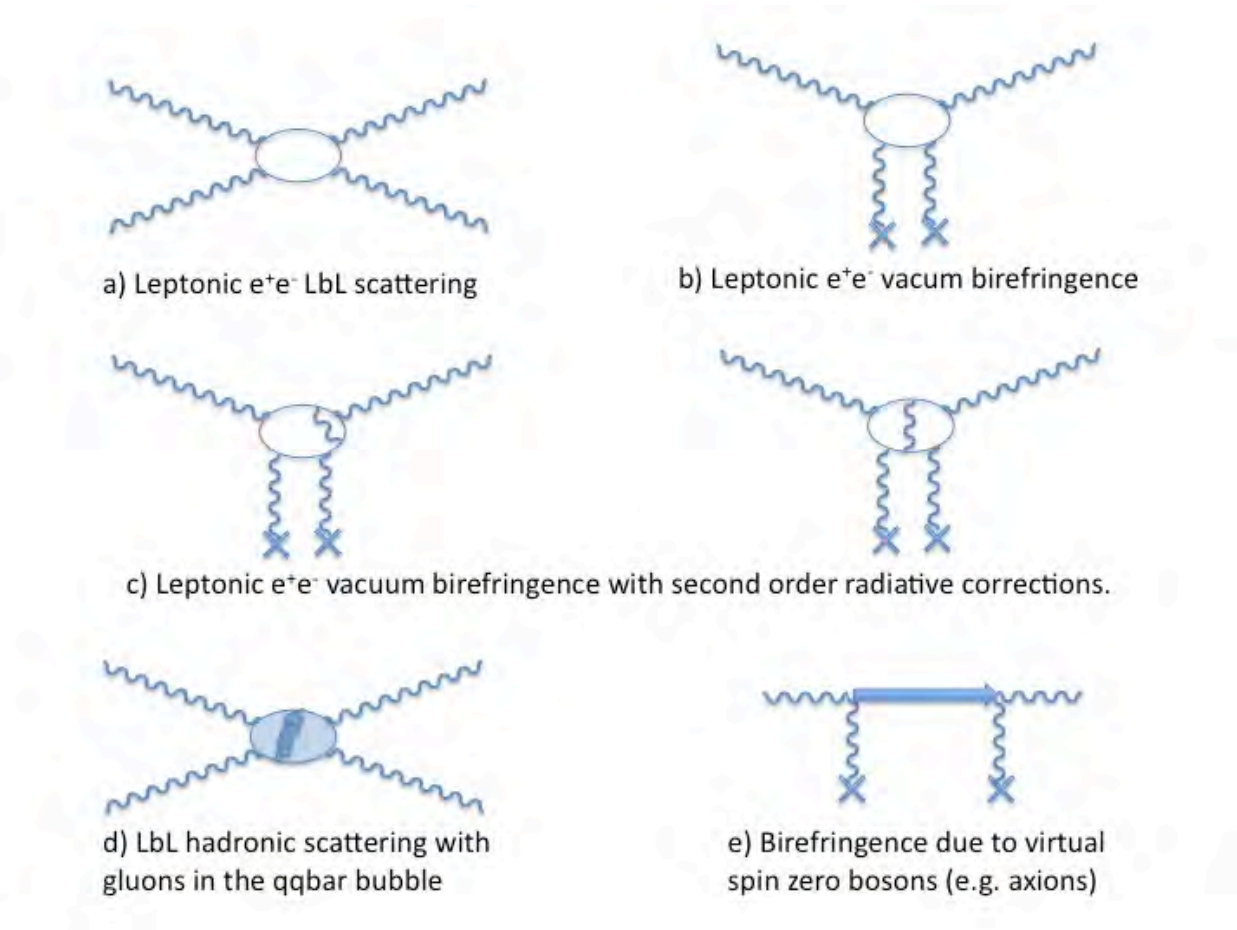

Fig.1: Different contributions to photon-photon interactions. The second order radiative contribution to magnetic vacuum birefringence (diagram c)) is 1.45 % of the first order contribution. The hadronic contribution is extremely difficult to calculate and cannot be estimated from other experiments.

2- Orders of magnitude of the ellipticity signals

An initially linearly polarized light beam which traverses a region of length L with birefringence Δn, will acquire an ellipticity $\boldsymbol{\Psi}$ proportional to the length L of the birefringent region: $\boldsymbol{\Psi = \pi \Delta n L/\lambda}$.

In quantum field theory vacuum magnetic birefringence results from the interaction of photons of the incoming beam with virtual photons of the magnetic field. As mentioned before, these interactions are essentially mediated in the QED framework by e^+e^- virtual loops (Fig. 1b)). The energy density of a magnetic field is proportional to the square of the field intensity B^2, so also the density of the virtual photons is proportional to B^2, and indeed the birefringence effect, which results from the collisions of photons of the incoming light beam with the virtual photons of the magnetic field, is proportional to B^2.

$\boldsymbol{\Delta n = 3A_e B^2}$ where $\boldsymbol{A_e = 1.32\cdot10^{-24}}\ T^{-2}$.

To fix the orders of magnitude, consider that the ellipticity generated by the passage through a 2 m long 2.3 Tesla magnet (λ = 1064 nm) is of the order of $1.2\cdot10^{-16}$.

The MBV effect is additive if the light propagates back and forth through the magnetized region by undergoing **N** reflections [14].

Gases immersed in a static magnetic field feature birefringence. The effect is known as Cotton-Mouton effect [15]. The Cotton-Mouton coefficient of many gases has been measured by several experiments [16]. PVLAS has provided the most accurate measurements for noble gases [17-20]. Depending on the nature of the gas, the induced ellipticity can be positive or negative. The CM effect can be used very effectively to calibrate a MBV experiment by providing the absolute phase of the effect and the amplitude calibration. In absence of MBV, at zero pressure, zero ellipticity is expected. At extremely low pressures, when the CM effect due to residual gases becomes marginal, still unforeseen apparatus effects may mimic an ellipticity signal. A signal phase not aligned or antialigned with that observed for the CM of gases gives unmistakeably an alarm that a spurious effect is occurring.

If **N** is the number of passes through the magnetic field region

$$\boldsymbol{\Psi = N \pi \Delta n_u L/\lambda B^2}$$

where $\boldsymbol{\Delta n_u}$ is difference between the indices refraction for parallel and orthogonal polarized light (of wavelength λ) per $(\text{Tesla})^2$. Some numerical values for $\boldsymbol{\Delta n_u}$ are:

$\Delta n_u^{QED} \approx 4.0\cdot10^{-24}\ T^{-2}$

$\Delta n_u^{He}(1\ atm) \approx 1.8\cdot10^{-16}\ T^{-2}$

$\Delta n_u^{Ne}(1\ atm) \approx 6.9\cdot10^{-16}\ T^{-2}$

$\Delta n_u^{N2}(1\ atm) \approx -2.4\cdot10^{-13}\ T^{-2}$

$\Delta n_u^{O2}(1\ atm) \approx -2.5\cdot10^{-12}\ T^{-2}$

$\Delta n_u^{NO}(1\ atm) \approx 2.1\cdot10^{-11}\ T^{-2}$

3- The PVLAS experimental approach

In the experimental approach of PVLAS [21] an heterodyne technique is adopted in order to enhance the signal over background level, and the light is reflected back and forth **N** times through the magnetized region in order to enhance the effect to be observed.

The ellipticity signal due to MBV is modulated by rotating periodically the direction of the magnetic field in a plane orthogonal to the direction of propagation of the light. This is obtained with a set-up where the dipole magnets that provide the magnetic field normal to the direction of propagation of the light have their bore aligned along the optical axis and rotate around it. The ellipticity signal is modulated at twice the rotation frequency of the magnets, since it depends on the square of the modulus of the magnetic field orthogonal to the light propagation direction.

In order to maximize the number of reflections the light is reflected back and forth **N** times by the mirrors of a Fabry-Perot interferometer (FP) that embraces the magnetized region. **F** being the finesse of the FP, the effective number of reflections is $\mathbf{N = 2F/\pi}$.

This procedure requires to lock the laser frequency to the FP in order to have stable conditions of measurement. An original method based on the Pound –Drever technique is employed to this purpose [22].

In the adopted experimental approach it is imperative to have the system of the rotating magnets well decoupled mechanically and electromagnetically from the laser, the FP and the ellipsometer, in order to avoid modulations of the ellipsometer response generated by the couplings.

For comprehensive presentations see refs. [10,25].

4- Results with the LNL apparatus (2002-2007 data)

The PVLAS set-up at Legnaro had a long development starting in 1992. It features an ellipsometer with a vertical FP with mirrors spaced 6 m apart. A superconductive dipole magnet about 1 m long rotates around the FP axis and is operated with field intensities up to 5.5 T. Running periods after fill of the magnet cryostat with liquid He lasted up to 4 hrs. The optical bench extended vertically for about 8 m and included two black granite optical benches (one above and the second one below the magnet) supported by the same thick floor concrete slab. The top optical bench is supported by four granite pillars. Access to the optical bench above the magnet and to the magnet services was provided before 2007 by a structure of iron tubes. At the end of 2006 the iron structure was removed and an aluminum access structure was installed.

Data from science runs performed before 2007 featured persistent signals that could be interpreted as apparent rotation due to differential absorption [11] and as ellipticity [23-25]. The rotation signals generated quite an interest since, if authentic, would have been the signature of new physics.

After an extended upgrade, the rotation signals disappeared [12]. Also the ellipticity signals at low field (2.3 T) disappeared, while at high field signals were still present but not well reproducible and not compatible with the upper limit derived from the 2.3 T data and the B^2 scaling law [10] and were therefore considered as systematic.

The 2.3 T ellipticity data have provided the best limits for the total cross section of low energy gamma-gamma interactions [10]. Limits on both birefringence and dichroism were also derived respectively as

$\mathbf{\Delta n \leq 1.1\cdot 10^{-19} \Longrightarrow A_e \leq 6.6\cdot 10^{-21}}$

$\mathbf{\Delta\kappa \leq 0.9\cdot 10^{-19}}$

To appreciate the quality of the optical setup one can translate such limits into an ellipticity and a rotation per pass (to be compared with the values obtained with the Ferrara set-up, Fig. 8):

$\boldsymbol{\psi_{PVLAS} \leq 3.1 \cdot 10^{-13}}$ **1/pass**

$\boldsymbol{\alpha_{PVLAS} \leq 2.7 \cdot 10^{-13}}$ **rad/pass**

The operational sensitivity of the LNL set-up over long runs was 10^{-6} rad $s^{1/2}$ for rotations and 10^{-6} $s^{1/2}$ for ellipticities.

Calibrations of the ellipsometer have been made repeatedly. They have provided the most accurate measurements of the CM parameters for light noble gases [17-20]. Runs with He have been made at pressures as low as 0.04 mbar [18].

Concerning the calibration of the ellipticity scale, the LNL set up is still at present the one with the best performances, because it has measured CM of noble gases in pressure windows lower than any other ellipsometer. However the zero of the ellipticity scale in the LNL set-up was typically obtained by extrapolation to zero pressure of CM measurements made at pressures where the signal due to the gas ellipticity was at least one order of magnitude larger than background signals. These background signals present at the exact frequencies where the ellipticity signals appear are due to uncontrolled couplings of the optics to the rotating parts of the apparatus and can fake MBV signals. The use of two twin magnets in the new PVLAS set-up aims at overcoming this weakness of the previous apparatus.

5- The Ferrara test set-up of the new PVLAS apparatus

The experience with the LNL apparatus has demonstrated that two main features are necessary for a reliable observation of MBV. 1) A high sensitivity of the ellipsometer is required to measure the MBV effect in a reasonable time. 2) A direct measurement of the absolute zero of the ellipticity scale is mandatory in order to check against apparatus artifacts that can produce peaks at the frequencies where the MBV effect is expected .

Work at the end of 2008 in Ferrara with a compact ellissometer with no magnet including a 50 cm long FP cavity and all the optical elements installed inside a common **vacuum enclosure supported by a single seismically isolated optical bench has shown that a sensitivity of** $\boldsymbol{2 \cdot 10^{-8}\ s^{1/2}}$ **can be obtained with a FP finesse F=414000 [26-29] as can be seen in figure 2.**

After the successful results with the compact 50 cm long ellipsometer, the test set-up described below has been designed to ascertain and optimize the compatibility of a high finesse high sensitivity ellipsometer with an extended FP long enough to host two rotating magnets along the FP axis. Each magnet is 0.25 m long (field strength > 2 T for L = 0.2 m, max field strength 2.4 T at the center) with a 1.5 cm diameter bore.

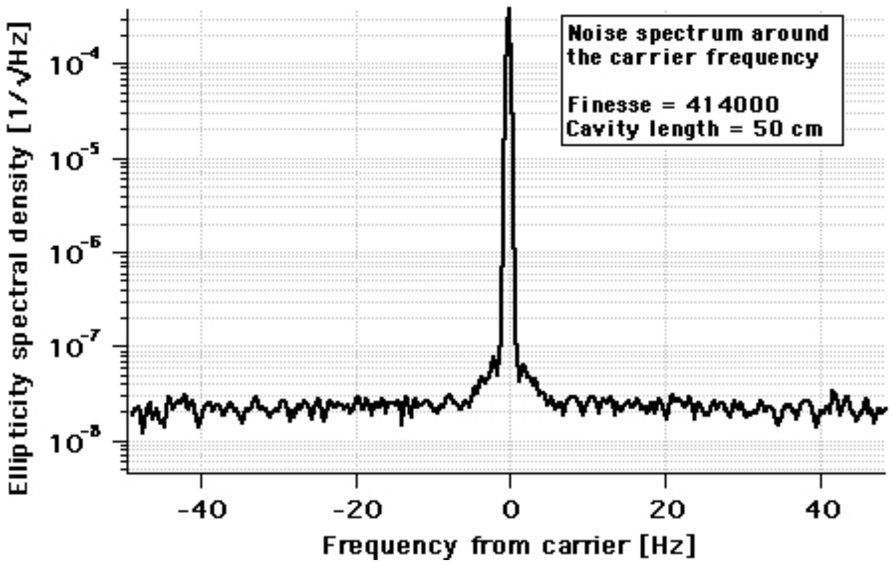

Fig. 2: Ellipticity spectral density around the modulator's carrier frequency. The ellipticity noise is flat for frequencies above about 6 Hz from the carrier.

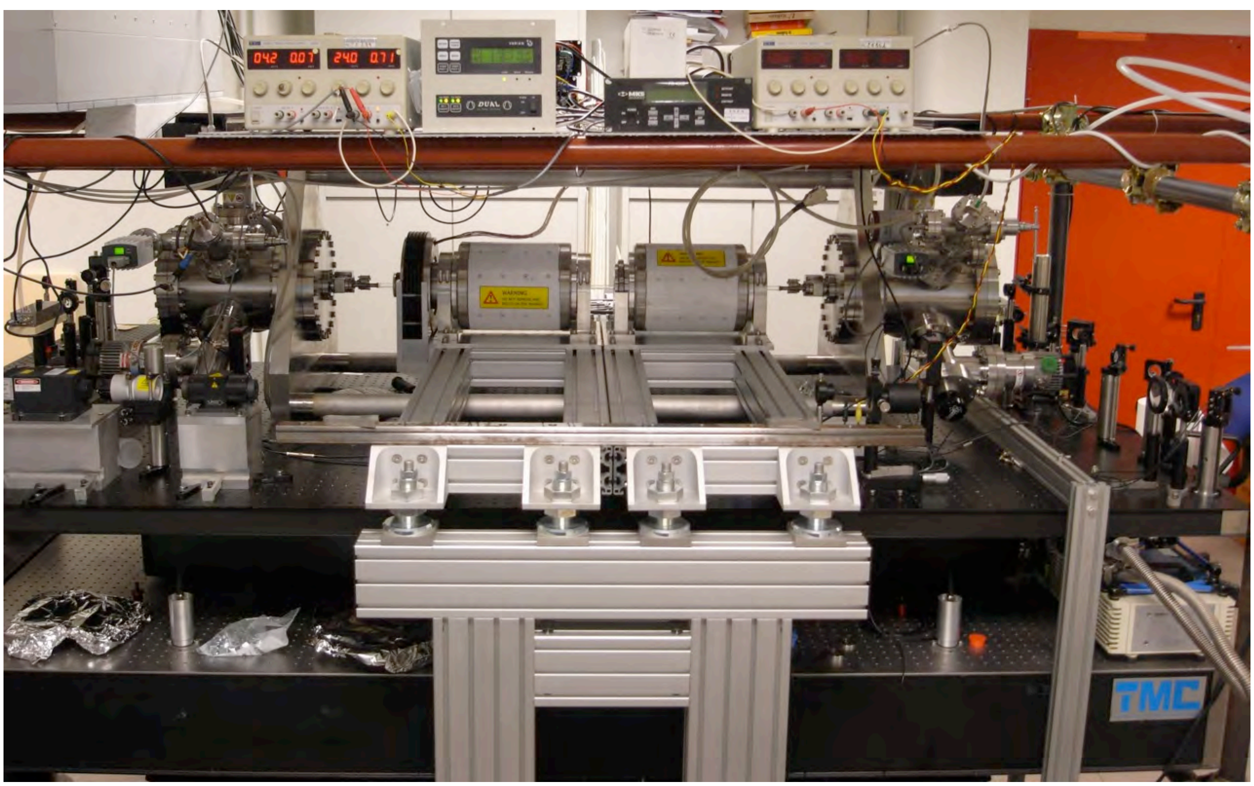

Fig. 3: Picture of the present set-up in Ferrara. The FP is 140 cm long and is supported by a two stage seismic isolation system. The Pyrex tube, 7 mm inner diameter, can be seen passing through the magnets.

All the components of the optics are fixed either directly onto a single seismically isolated optical bench 2.4 m long and 1.2 m wide or inside two rigidly connected and communicating vacuum chambers, which in turn rest on the optical bench.

The laser and steering optics are installed directly onto the optical bench. The other optical components are hosted in a vacuum enclosure that consists of three components: a) the Polarizer Vacuum Chamber (PVC) that hosts polarizer and first cavity mirror, b) the Analyzer Vacuum Chamber (AVC) that hosts second cavity mirror, photo-elastic modulator (PEM) and analyzer and c) the Pyrex Glass Tube (PGT) that traverses the bore of the two magnets and connects the two vacuum chambers.

Vacuum in the chambers is ensured by means of turbo and ion pumps. PVC and AVC are bolted onto two 4 cm thick triangular stainless steel plates that are rigidly connected by three stiff stainless steel tubes 5 cm in diameter. Both PVC and AVC are equipped with leak valves for the injection of Cotton-Mouton calibration gases

The PGT has an internal diameter of 7 mm compared to the waist of the beam at the center of the cavity of 0.5 mm. The PGT is sealed 'in situ' and is connected to the PVC and the AVC through two high vacuum gate valves.

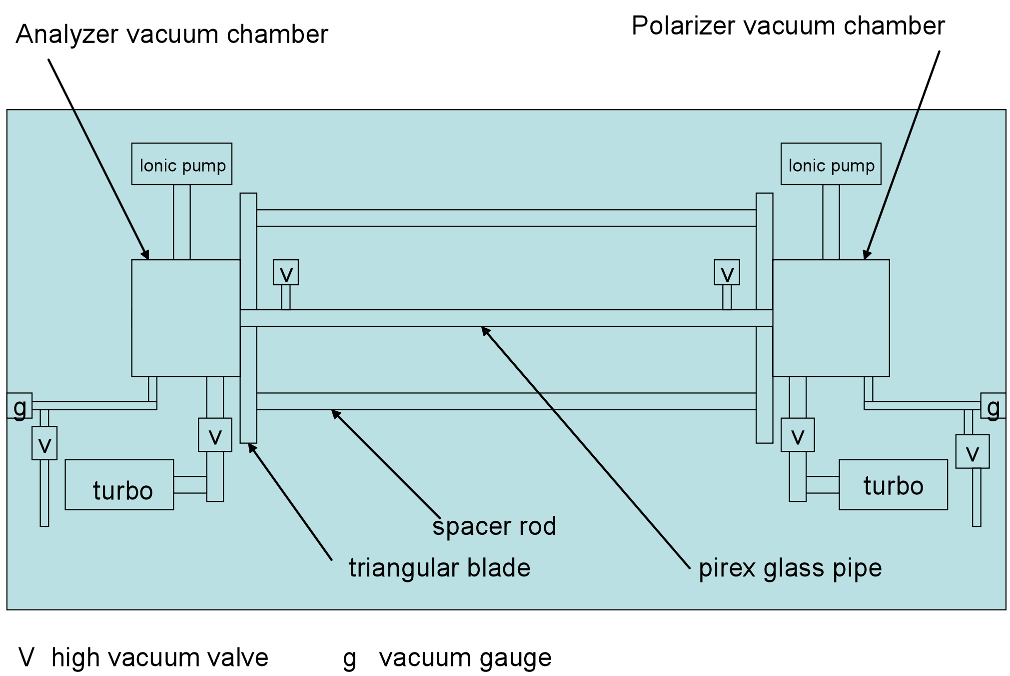

Fig. 4 shows a schematic drawing of the components of the apparatus.

The two identical magnets are permanent dipoles with length 20 cm external diameter 19 cm and 15 mm bore. They are supported by a heavy structure made of extruded aluminum profiles which is totally disconnected from the seismically isolated optical bench and rests directly onto the lab floor. Each of the two magnets is supported by ball bearings at its extremities. The magnet on the analyzer side is connected with a coaxial electric torque motor which puts the magnet in rotation around the axis of its bore. The magnet on the polarizer side is connected mechanically to the other magnet by a custom made joint which couples mechanically the two magnets so that they rotate at the same angular velocity with fixed relative phase. The joint contains a slider made of Teflon that compensates faint misalignements of the rotation axis of the two magnets. The mechanical connection so to allow the magnets to rotate together with their magnetic field orientation parallel or at 90˚. When the magnetic fields are parallel or antiparallel the ellipticity generated in both magnets add up, while when the magnetic fields are perpendicular the two ellipticities cancel. We remark that with the magnets at 90˚ vibrations and potential sources of background signals are the same as in the configuration with parallel fields.

The entire magnet assembly is being encased in a mu-metal enclosure. Furthermore, above the PVC and the AVC we are installing two laminar flow hoods to generate a flux of clean air when the vacuum chambers are opened for interventions.

6- Results of the Ferrara test set-up

After completion of the entire test set-up at the end of April some preliminary test measurements were performed.

Firstly measurements have been performed **without the optical FP cavity** in order to test the quality of the setup and vibration isolation. **A sensitivity of $6 \cdot 10^{-9}$ $s^{1/2}$ was stably obtained at 6 Hz (twice the rotation frequency of the magnets) with the magnets in rotation**. This sensitivity coincided with the expected sensitivity obtained considering the known noise sources. After integrating for about 30 minutes, **no spurious peaks appeared at the frequency of interest with an ellipticity noise floor of $2 \cdot 10^{-10}$**. This is shown in figure 5.

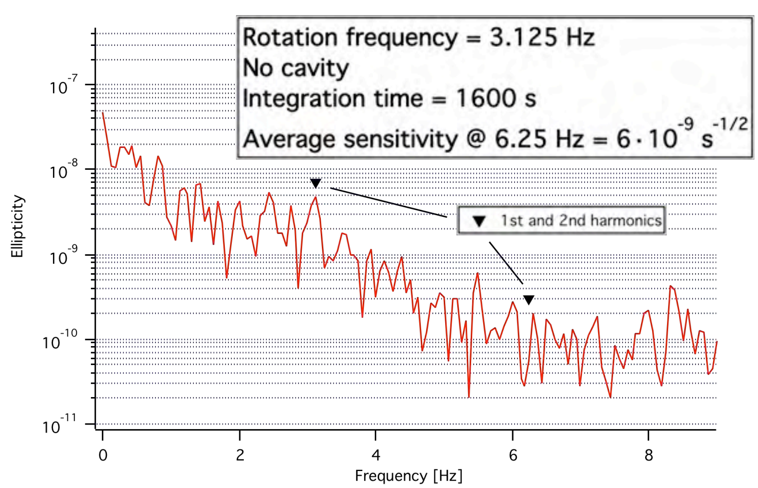

Fig. 5 Ellipticity noise floor measured without the FP cavity mirrors inserted.

Measurements were then performed with the 3000 finesse cavity and a test was performed to check the CM peak suppression by comparing measurements with the magnets aligned and at 90˚. The result is shown in figure 6 demonstrating the absolute zero measurement concept.

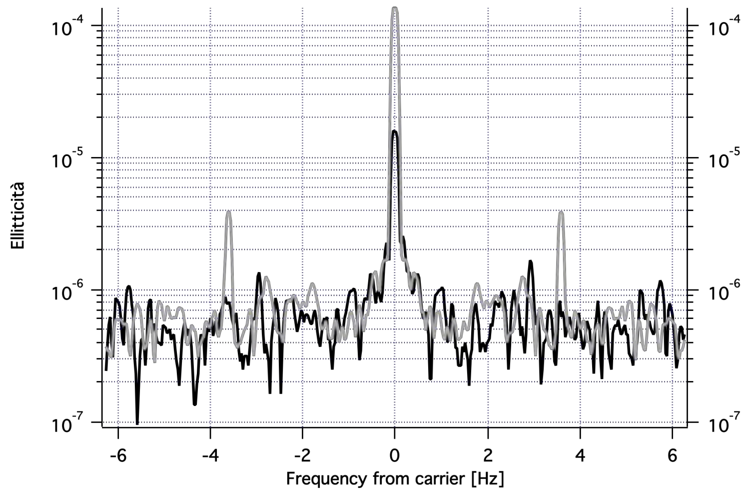

Fig. 6 Comparison of the CM signal with aligned (grey) and perpendicular magnets (black).

Finally the high reflectivity mirrors were installed. Initially a finesse of 245000 was obtained and a first ellipticity run with the magnets in rotation was performed for T = 400 s. The result, shown in figure 7, demonstrates that the present set-up is already better than the old LNL set-up.

After some degassing, due to vacuum, a slightly better finesse of 285000 was obtained as can be seen in figure 8.

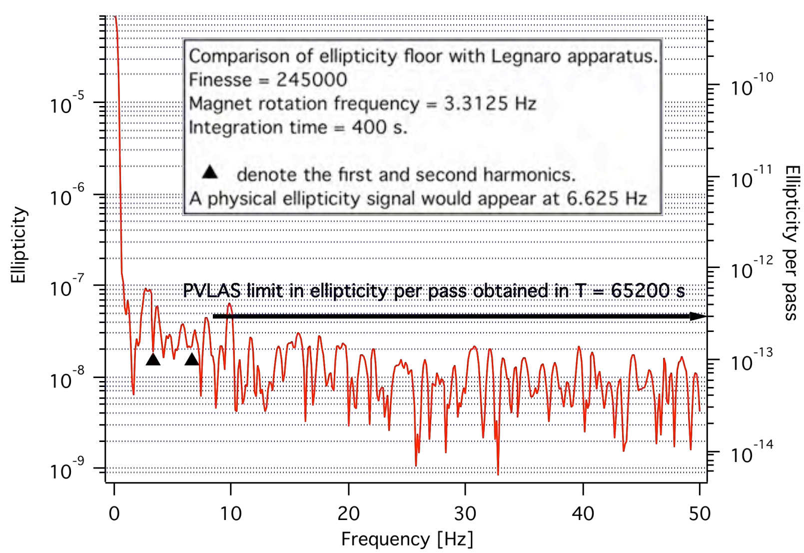

Fig. 7 Ellipticity noise floor with the FP cavity mirrors inserted. Finesse = 245000. A comparison with the best ellipticity limit obtained with the Legnaro set-up is made showing that a significant improvement of the optics has effectively been made. The present measurements sets a 1 sigma limit of $\Delta n \leq 1.3 \cdot 10^{-19}$.

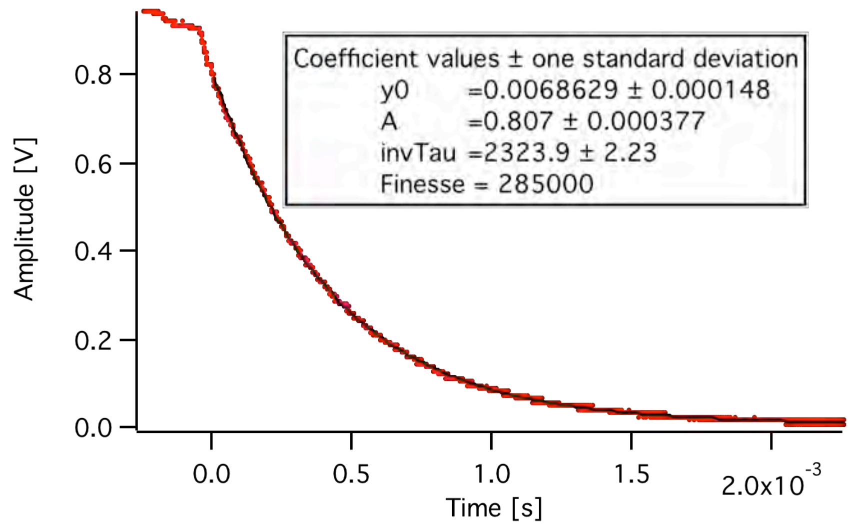

Fig. 8 Decay curve for the high finesse cavity with a superimposed exponential fit, resulting in a finesse of F = 285000.

7 - The new experimental apparatus

During the May-June 2010 meeting, the INFN committee approved the financing of 2 permanent magnets for the new experimental setup. At the end of July the document for starting the bidding process was sent to the INFN central administration for approval. The main parameter requested is that $\int B^2 dl \geq 11\ \mathrm{T^2m}$ over the whole length of the two magnets. The total expected length will be between 1.4 and 2 m.

During the July meeting of the Ferrara INFN section it was agreed that PVLAS could use the clean room located in the big hall of the Ferrara Physics Department. This clean room is large enough to host the whole experimental setup, it will provide also a temperature stabilized and acoustically isolated environment. The clean room will be available for PVLAS with the end of 2010.

The new experimental apparatus will be a scaled-up version of the test set-up in operation in Ferrara.

The design of the final project is being completed. The axis of the FP will be horizontal, all the optics will be supported by a seismically isolated optical bench 4.8 m long. The 4.8 m long seismically isolated optical bench is a commercial item. Some of the main differences/problems we will encounter are the following:

- ≈2.8 m long cavity
- Slightly larger vacuum chamber for hosting the optics

- Large optical table
- Magnet supports
- Logistics for installing the table and magnets
- Use of a 1.8 W Nd:YAG laser available from the Legnaro setup

Furthermore, as much of the equipment already available to the collaboration will be used.

Following these guides, we filled out the funding requests for the new setup to INFN in July.

An important aspect is the chronological order in which the various parts of the apparatus will be procured. This may help for the funding process:

1. Order magnets (by end of 2010)
2. Order optical table + isolation system (could be anticipated to 2010)

3a. Vacuum chambers for optics

3b. Support mechanics for optics

3c. Support system for magnets

4. Movements for ultra high vacuum
5. Optical elements

If point number 2. in the above list can be anticipated to 2010, then a reasonable time schedule could be the following:

2011

- February 2011 - Place orders for the vacuum chambers and UHV movements
- March 2011 - Installation of optical table
- March 2011 - Complete design of magnet support system
- April 2011 - Installation of vacuum chambers
- July 2011 - Begin installation of vacuum movements and rest of optics

If, instead, point number 2 cannot be anticipated to 2010, the above schedule would be:

2011

- February 2011 - Place order for the optical table and the isolation system

- March 2011 - Place orders for the vacuum chambers and UHV movements
- March 2011 - Complete design of magnet support system
- May 2011 - Installation of optical table
- June 2011 - Installation of vacuum chambers
- September 2011 - Begin installation of vacuum movements and rest of optics

Tables of the requested funding for 2011 for the different sections are reported below:

Sigla Loc.	Capitolo	Riunione	Note Alla Richiesta	Rich.	Rich. SJ	Assegn.	Assegn. SJ	Assegn. Dot.	Assegn. Ant.	Assegn. Ant. Dot.
FE	MI	Assegnazioni	Missioni a LNL e Trieste	3.0	0.0	0.0				
		Totale MI		3.0	0.0	0.0	0.0	0.0	0.0	0.0
	ME	Assegnazioni	Contatti con il fornitore dei magneti e contatti con Tolosa - esperimento BMV	5.0	0.0	0.0				
		Totale ME		5.0	0.0	0.0	0.0	0.0	0.0	0.0
	CON	Assegnazioni	Specchi	20.0	0.0	0.0				
		Assegnazioni	Polarizzatori	10.0	0.0	0.0				
		Assegnazioni	lamine lambda/2 e lambda/4	5.0	0.0	0.0				
		Assegnazioni	Testa PEM con antiriflesso	10.0	0.0	0.0				
		Assegnazioni	Meccanica per ottiche fuori dal vuoto	5.0	0.0	0.0				
		Totale CON		50.0	0.0	0.0	0.0	0.0	0.0	0.0
	INV	Assegnazioni	Isolatore Faraday	7.0	0.0	0.0				
		Totale INV		7.0	0.0	0.0	0.0	0.0	0.0	0.0
	APP	Assegnazioni	Banco ottico 4.8mx1.5m + isolamento sismico. Anticipabili al 2010	50.0	0.0	0.0				
		Assegnazioni	5 x rotazioni motorizzate da UHV	20.0	0.0	0.0				
		Assegnazioni	4 x attuatori per allineamento da UHV	10.0	0.0	0.0				
		Assegnazioni	1 tralatore da UHV	5.0	0.0	0.0				
		Assegnazioni	Controlli motori	10.0	0.0	0.0				
		Totale APP		95.0	0.0	0.0	0.0	0.0	0.0	0.0
Totale FE				160.0	0.0	0.0	0.0	0.0	0.0	0.0
Totale Generale PVLAS				160.0	0.0	0.0	0.0	0.0	0.0	0.0

Sigla Loc.	Capitolo	Riunione	Note Alla Richiesta	Rich.	Rich. SJ	Assegn.	Assegn. SJ	Assegn. Dot.	Assegn. Ant.	Assegn. Ant. Dot.
LNL	MI	Assegnazioni	riunioni di collaborazione, missioni a Ferrara per attivita sull'esperimento	12.0	0.0	0.0				
		Totale MI		12.0	0.0	0.0	0.0	0.0	0.0	0.0
	ME	Assegnazioni	contatti scientifici e missioni per controllo fabbricazione magneti permanenti	5.0	0.0	0.0				
		Totale ME		5.0	0.0	0.0	0.0	0.0	0.0	0.0
	CON	Assegnazioni	consumi di laboratorio	5.0	0.0	0.0				
		Totale CON		5.0	0.0	0.0	0.0	0.0	0.0	0.0
	APP	Assegnazioni	2 camere da vuoto per ottiche del FP	10.0	0.0	0.0				
		Assegnazioni	supporti e connessioni tra le 2 camere da vuoto	15.0	0.0	0.0				
		Assegnazioni	passanti da alto vuoto per camere ottiche	5.0	0.0	0.0				
		Assegnazioni	flangie per camere ottiche	5.0	0.0	0.0				
		Assegnazioni	2 valvole da alto vuoto per tubo di connessione tra le due camere ottiche del FP	4.0	0.0	0.0				
		Assegnazioni	sistema di supporto dei magneti permanenti	20.0	0.0	0.0				
		Assegnazioni	motori per rotazione dei magneti permanenti	10.0	0.0	0.0				
		Assegnazioni	schermature magnetiche dei magneti permaneti e dei motori a protezione dell'ottica dell'ellissometro	10.0	0.0	0.0				
		Assegnazioni	getter per vuoto nel tubo di connessione tra le due camere a vuoto	2.0	0.0	0.0				
		Totale APP		81.0	0.0	0.0	0.0	0.0	0.0	0.0
Totale LNL				103.0	0.0	0.0	0.0	0.0	0.0	0.0
Totale Generale PVLAS				103.0	0.0	0.0	0.0	0.0	0.0	0.0

Sigla Loc.	Capitolo	Riunione	Note Alla Richiesta	Rich.	Rich. SJ	Assegn.	Assegn. SJ	Assegn. Dot.	Assegn. Ant.	Assegn. Ant. Dot.
TS DTZ	MI	Assegnazioni	Missioni a LNL e Ferrara	10.0	0.0	0.0				
		Totale MI		10.0	0.0	0.0	0.0	0.0	0.0	0.0
	ME	Assegnazioni	Missioni a Tolosa (BMV) e Ginevra (OSQAR)	3.0	0.0	0.0				
		Totale ME		3.0	0.0	0.0	0.0	0.0	0.0	0.0
	CON	Assegnazioni	Hardware da vuoto	5.0	0.0	0.0				
		Totale CON		5.0	0.0	0.0	0.0	0.0	0.0	0.0
Totale TS DTZ				18.0	0.0	0.0	0.0	0.0	0.0	0.0
Totale Generale PVLAS				18.0	0.0	0.0	0.0	0.0	0.0	0.0

We will describe in detail the requests following the order in which they appear:

FE

- Specchi: these are the Fabry-Perot high finesse cavity mirrors. The cost was estimate from a 2007 batch procurement. In 2007 a batch of high finesse coating with antireflective coating on the backside cost 6300 USD. Substrate costs varied from 150 USD/piece for standard radii of curvature whereas for custom radii the cost was 500 USD/piece. A coating run batch consisted of 17 mirrors. Considering 8 standard and 9 non standard substrates the total cost is 12000 USD corresponding to about 10 keuro + IVA.

TOTAL per batch = keuro 12 keuro

Our intention is to use substrates of different materials (Zerodur, ULE, or SF57T, Suprasil and other more exotic materials) to reduce thermal effects which cause stress and/or variations in index of refraction. We expect these to have a higher cost. This is the reason for the request of 20 keuro instead of 12 keuro. Below is a scatter-plot showing the Stress-Optical coefficient from Schott Glass for different materials

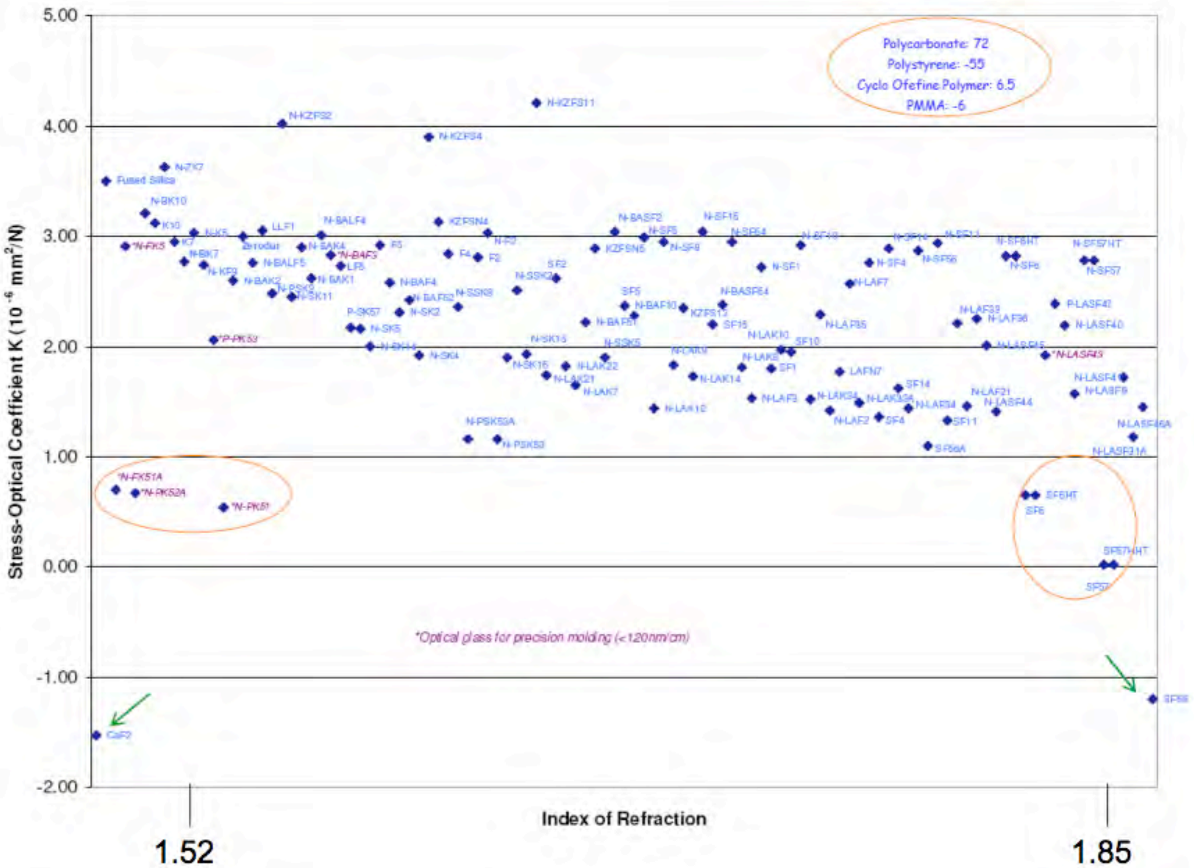

Fig. 9: Stress Optical coefficient for various Schott glasses

Attached is an e-mail with the costs delared above

From: Giovanni Cantatore <cantatore@trieste.infn.it>
Date: 30 October, 2007 14:34:00 GMT+01:00
To: Zavattini Guido <ZAVATTINI@fe.infn.it>
Cc: Cantatore Giovanni <cantatore@trieste.infn.it>, Karuza Marin <karuza@ts.infn.it>
Subject: **Specchi ATF**

Caro Guido,
ieri Marin ha avuto qualche prezzo dalla Advanced Thin Films e possiamo allora fare una ipotesi di acquisto come segue:

Batch n.1
hi-refl. coating per finesse 200000, lambda 1064 nm, A/R coating su backside -> costo $ 6300
n. 12 substrati standard (4 piano-piano, 4 piano-concavo R = 1 m, 4 piano-concavo R = 2 m) a $150 ea. -> $ 1800
n. 5 substrati custom piano-concavi R = 11 m a $500 ea. -> $ 2500

Totale batch n. 1 $ 10600 corrispondenti a 9100 EUR IVA inclusa

Batch n. 2
hi-refl. coating per finesse 200000, lambda 532 nm, A/R coating su backside
substrati come per batch n.1

Totale batch n. 2 $ 10600 corrispondenti a 9100 EUR IVA inclusa

- Polarizzatori: this request is for 2 high exctinction (1e-7) vacuum mounted polarizers with 14.5 mm aperture and antireflective coating from Bernhard-Halle. An offer dating from 2008 is attached. As mentioned in the offer, points 3) and 4) are incompatible.

2 such polarizers will be needed: Total = 6854 euro + IVA = 8220 Keuro. With a slight price increase we are asking for 10 keuro.

Bernhard Halle Nachfl. GmbH

Optische Werkstätten

seit 1873

Bernhard Halle Nachfl. GmbH · Hubertusstraße 10 · 12163 Berlin

Mr Guido Zavattini, PhD
Dipartimento di Fisica
Università di Ferrara
Via Saragat 1, Blocco C
44100 Ferrara
Italy

Hubertusstr. 10, D-12163 Berlin
Telefon: (030) 797 42 96-0
Telefax: (030) 791 85 27
http://www.b-halle.de
e-mail: bhn@b-halle.de

Bankkonto:
Berliner Bank AG, Berlin
Nr.: 24 68077 000
BLZ 100 200 00

Ihre Zeichen	Ihre Nachricht	unsere Zeichen	Datum
-	14/02/08	bm a082109	18 February 2008

Dear Sir,

reference is made to your e-mail dated Febrary 14, 2008 for which we thank you. In the following we are pleased to offer:

1) 2 pcs. Glan Polarizing prisms, air spaced, made of calcite with two side windows (no high power), λ_{sym} = 700 nm, 15 x 15 mm, mounted, free aperture 14,5 mm, without adhesive tape or cement, in a special holder made from aluminium without black anodizing, outer diameter 25 mm, **PGL 15.2** but in a special holder

price per piece € 2.390,00

2) additional price for the extinction ratio 10E-7, **PGL 0.7**
price per piece € 507,00

3) additional price for interferometer quality, **PGL 0.1**
price per piece € 535,00

4) additional price for the anti reflection coating of the entrance windows with double layers for 1064 nm

total price for 2 pcs. € 530,00
time of delivery: about 3-4 months

However we would like to draw your attention to the fact that we cannot guarantee for the good interferometer quality after anti reflection coating.

Should you have any more questions, or if we can be further assistance to you, please do not hesitate to contact us again.

Sincerely yours
B.HALLE NACHFL. GMBH
Optical Workshop
i.A. [signature]

Bernhard Halle Nachfl. GmbH, Amtsgericht Charlottenburg, HRB 51 228, Geschäftsführer Dr. Axel Frank. USt.-Id-Nr. (VAT-No.) DE 811638637

- Lamine quarto d'onda e mezz'onda: these are zero order plates. Their price can be found on the CVI website and are attached below:

Each plate (half wave and quarter wave plates have the same costs) costs 452 euro + IVA. Considering 4 of each one finds 4330 keuro. This justifies the 5keuro request.

- Testa PEM: this is for a new photoelastic modulator with antireflective coating, vacuum compatible and magnetic compatibility. I hope to recieve a written price soon. During 2009, TS bought a PEM with the Dotazioni2, with a cost of 5900 euro. I suspect the Trieste pem is not vacuum, nor magnetic nor antireflective. For this reason we estimate 10 keuro.

- Isolatore Faraday: An offer for a 60 db two stage isolator is shown below. The cost is 4500 euro + IVA = 5.5 keuro. The offer is attached below and is from a year ago and we are asking for 7 keuro.

From: Micos talia GmbH <ufficiovendite@micos.it>
Subject: **offerta n° 4376.1M**
Date: 13 January, 2009 13:03:55 GMT+01:00
To: zavattini@fe.infn.it
3 Attachments, 4.1 KB

MICOS ITALIA Gmbh

MOTION CONTROL & OPTICS

ITALIAN BRANCH
via s. protaso, 39
I - 20010 bareggio (MI)
tel. +39.0290363318
fax +39.0290366186
http://www.micos.it
email: info@micos.it

Dipartimento di Fisica - Università di Ferrara
Via Saragat, 1, blocco C
44100 Ferrara FE
c.a. Dr. Guido Zavattini

Tel. +39 0532 974299
Fax. +39 0532 974210

Bareggio, 13/01/2009

OFFERTA n° 4376.1M

Ns. Riferimento: **richiesta per Faraday Isolators Linos**
Vs. Riferimento: **Richiesta di offerta del 13/01/09**

Egr. Dr. Zavattini,
Le invio di seguito offerta come da sua gentile richiesta:

Pos.	Num.	Descrizione	€/cad	€/Totale
1	1	**84501037001** (pag. 665) - OPTICAL ISOLATOR FI-1060-5SC: Extreme compact design, TGG crystal (high Verdet constant), Access to blocked beam Isolation, guaranteed/typical (dB)>30/38-42 Transmission at design wavelength (%)>90 Transmission at boundry wavelength (%)>85	€ 3.358,00	€ 3.358,00
2	1	**84501031000** (pag. 668) - OPTICAL ISOLATOR FI-1060-5SI, Isolator with 5 mm Aperture, SI serie, Isolation guaranteed / typical (dB) >30/38-40, Transmission at design wavelength (%) >90, Transmission at boundry wavelength (%) >85	€ 3.208,50	€ 3.208,50
3	1	**84501061004** (pag. 677) - OPTICAL ISOLATOR FI-1060-TI - 5mm Aperture Two Stage Faraday Isolators (non-tunable) TI-Serie Wavelength (nm) 1060, Isolation (dB) >60, Transmission (%) >80	€ 4.554,00	€ 4.554,00
4	1	**spese di imballo e spedizione merce**	€ 30,00	€ 30,00
			Totale:	**€ 11.150,50**

Condizioni di Vendita:	
Fatturazione:	100% alla spedizione della merce
Pagamento:	30 gg data fattura bonifico bancario
Consegna:	4 sett circa DRO (per pos. 1 e 2) a stock pos. 3
Spedizione:	vedere testo
Imballo:	vedere testo
Porto:	f.co destinatario con addebito spese di spedizione
Validità offerta:	30 gg
Iva:	20% esclusa
Garanzia:	12 mesi f.co fabbrica

A sua disposizione per eventuali chiarimenti.
Cordiali saluti

- Banco ottico: the optical bench is a 4.8 m x 1.5 m x 45 cm antimagntic bench with a 6 post leveling-isolation system (also non magnetic). The offer is shown below. By adding points 1, 3 and 4 one gets 40.6 keuro + IVA = 48.7 keuro.

dB electronic instruments srl

20161 Milano - Via Teano, 2
Tel. 02 6469341/2/3 - 6466222 - Fax 02 6456632
www.db-electronic.it - E-mail: sales@dblaser.it

Offerta di vendita

Vs. Riferimento: richiesta telefonica

Validità Offerta: 30 giorni

Pagamento: RD6 Rimessa Diretta a 60 gg. D.F.

Merce resa: F.co Vs. indirizzo scaricato a terra

Garanzia: 1 anno dalla data di spedizione

Consegna: Appross. 10-12 settimane

Spett.le:

I. N. F. N.
Sezione di Ferrara
c/o Polo Scientifico Tecnologico
Edificio "C" - Via Saragat, 1
44100 FERRARA (FE) (IT)

Codice nominativo	Partita IVA o codice fiscale	Data documento	Numero documento	Versione	
INFNFE	IT 04430461006	21/09/2010	74/10	1	Pag. 1 di 1

Voce	Modello e descrizione Fornitore: **TMC**	U.M.	Quantità	Prezzo	Importo E.U.
1	**714-778-12R** Non magnetic Clean top II optical tops, 1500 x 4800 x 450mm, maximum dry damping, 25mm centers - M6	n.	1	24.900,00	24.900,00
2	**14-61H-46** 6-post systems with tiebars, 1500 x 4800mm, gimbal piston isolator without casters	n.	1	4.500,00	4.500,00
3	**14NM-61H-46** 6-post systems with tiebars, non magnetic, 1500 x 4800mm, gimbal piston isolator without casters	n.	1	8.300,00	8.300,00
4	**Complete PEPS VX II System** For the table above	n.	1	7.400,00	7.400,00
5	**SPESE DI TRASPORTO INCLUSE**				

La presente quotazione è redatta sulla base del rapporto EURO/$ 1,3200 +/- 2%
Al momento della fatturazione se la variazione di tale rapporto sarà superiore o inferiore al 2%, Vi addebiteremo o accrediteremo la differenza.
N.B. - Per ordini inferiori a €250.00 Vi verranno addebitati €50.00 per spese di importazione e gestione ordini.

Totale offerta EUR 45.100,00
I.V.A. esclusa

Dati Tecnici come da Cataloghi Case Costruttrici

L'acquirente si impegna a non riesportare la merce fuori dal territorio italiano, salvo approvazione da parte della nostra Società.

Capitale Sociale 50.000 EURO - C.C.I.A.A. 914021 - Iscrizione Reg. Società Trib. Milano 164685/3995/35 - Partita IVA e Codice Fiscale 02302390154

This justifies the 50 keuro request

- 5 x rotazioni per UHV: the 5 rotation motorized mounts for UHV are necessary for the 2 polarizers, 1 PEM, 1 mirror and 1 quarter wave plate (necessary for dichroism measurements instead of ellipticities). An offer for mounts for 1e-6 mbar are attached below (2.07 keuro each). The critical part is the motor which will increase the cost to about 3 keuro each. For 5 mounts this results in 15 keuro + IVA = 18 keuro. This justifies the 20 keuro request with a slight overhead.

From: miCos Italia - ufficio vendite <ufficiovendite@micos.it>
Subject: ***MAYBE*** offerta n° 4177.4 M
Date: 20 November, 2006 12:24:34 GMT+01:00
To: Vito Carassiti <carassiti@fe.infn.it>
Cc: Guido Zavattini <zavattini@fe.infn.it>
3 Attachments, 4.8 KB

MICOS ITALIA Gmbh

MOTION CONTROL & OPTICS

ITALIAN BRANCH
via s. protaso, 39
I - 20010 bareggio (MI)
tel. +39 0290363318
fax +39 0290366186
http://www.micos.it
email: info@micos.it

INFN sezione di Ferrara
Via Saragat, 1 c/o Polo Scientifico Tecnologico - blocco C
44100 Ferrara FE
Tel. +39 0532 974299
Fax. +39 0532 974210

Bareggio, 20/11/2006

OFFERTA n° 4177.4 M

Ns. Riferimento: **controller scontato**
Vs. Riferimento: **rotatori per vuoto**

Egr. Carassiti
Le invio di seguito offerta come da gentile richiesta:

Pos.	Num.	Descrizione	€/cad	Sconto	€/Totale
1	3	**3216Z004** (pag. internet) - VACUUM POSITIONERS RS-40 SM Vacuum 10^-6 mbar Rotation stage prepared for vacuum , standard motor with vacuum lubrication, 1.5 m teflon wire	€ 2.067,00	3%	€ 6.014,97
2	3	**DB9pk/pn** DB9 female vacuum connector with set of pins	€ 232,54	5%	€ 662,74
3	3	**ZMS08016** (pag. -) - MOUNTING AND TESTING 1 axis feedthrough wiring, wiring of one axis (motor and end of run or encoder) on a given electrical feedthrough. (il sistema proposto prevede un passante a vaschetta a 9 pin, da voi fornito, per ciascun asse)	€ 130,00	0%	€ 390,00
4	3	**720090101** (pag. /) - MOTOR CABLE mk SMC-pci_eco_pollux HD-15 (VGA) motor cable 28M, 3m	€ 105,75	3%	€ 307,73
5	1	**71709009**** (pag. 5.047) - SMC SERIES SMC Corvus-eco 3-axes Microstep controller 24V 1.2A with integrated joystick Desktop-Case standard amplifier 24 V 1.2 A RS232 and USB interface Joystick integrated Vmax: 15 revolutions/s (200 step motor)	€ 3.065,20	15.38%	€ 2.593,77
6	1	**spese di imballo e spedizione merce**	€ 30,00		€ 30,00
				Totale:	**€ 9.999,21**

**NB
Il controller è proposto con un forte sconto perché si tratta di un'unità demo usata "coi guanti" un paio di volte in fiera (come nuova).

Condizioni di Vendita:	
Fatturazione:	100% alla spedizione della merce
Pagamento:	30 gg data fattura bonifico bancario
Consegna:	8 -10 sett DRO (cercando di anticipare)
Spedizione:	vedere testo
Imballo:	vedere testo
Porto:	f.co vs. sede
Validità offerta:	60 gg
Iva:	20% esclusa

- 4 attuatori per allineamento cavita': 2 of each of these actuators will be mounted on each of the cavity mirror mounts. These are motorized with controllers. We have an offer for 1e-6 mbar actuators from Thorlabs. It is attached below:

dB electronic instruments srl

20161 Milano - Via Teano, 2
Tel. 02 6469341/2/3 - 6466222 - Fax 02 6456632
www.db-electronic.it - E-mail: sales@dblaser.it

Offerta di vendita

Vs. Riferimento: Vs rich. fax del 01/03/10
Validità Offerta: 60 giorni
Pagamento: RD6 Rimessa Diretta a 60 gg. D.F
Merce resa: F.co Vs. indirizzo scaricato a terra
Garanzia: 1 anno dalla data di spedizione
Consegna: Appross. 2 - 3 settimane

Spett.le:
I. N. F. N.
Sezione di Ferrara
c/o Polo Scientifico Tecnologico
Edificio "C" - Via Saragat, 1
44100 FERRARA (FE) (IT)

Codice nominativo	Partita IVA o codice fiscale	Data documento	Numero documento	Versione	
INFNFE	IT 04430461006	01/03/2010	569/10	1	Pag. 1 di 1

Voce	Modello e descrizione Fornitore: **THORLABS**	U.M.	Quantità	Prezzo	Importo E.U.
1	**Z606V** 6 mm Vacuum-Rated Actuator, 1/4"-80 Thread	n.	2	424,10	848,20
2	**TPS001** 15 V Power Supply Unit for a Single T-Cube	n.	2	22,20	44,40
3	**TPS002** ±15 V/5 V Power Supply Unit for up to 2 T-Cubes	n.	1	93,30	93,30
4	**TCH002** T-Cube Controller Hub and Power Supply Unit	n.	1	645,40	645,40
5	**SCONTO 5% DA APPLICARE**				
6	**SPESE DI TRASPORTO INCLUSE**				

La presente quotazione è redatta sulla base del rapporto EURO/$ 1,4000 +/- 2%
Al momento della fatturazione se la variazione di tale rapporto sarà superiore o inferiore al 2%, Vi addebiteremo o accrediteremo la differenza.
N.B. - Per ordini inferiori a €250.00 Vi verranno addebitati €50.00 per spese di importazione e gestione ordini.

Totale offerta EUR 1.631,30
I.V.A. esclusa

Dati Tecnici come da Cataloghi Case Costruttrici

L'acquirente si impegna a non riesportare la merce fuori dal territorio italiano, salvo approvazione da parte della nostra Società.

THORLABS · Crystal Technology, Inc. · KOHERAS · TMC · JENOPTIK · Elliot Scientific · Kaston · OptoSigma · Laser Quantum · Laser Technologies · SP Spectral Products · OZ Optics · LAMBDA Research Optics, Inc. · CASIX · CVI

Capitale Sociale 50.000 EURO - C.C.I.A.A. 914021 - Iscrizione Reg. Società Trib. Milano 164685/3995/35 - Partita IVA e Codice Fiscale 02302390154

The cost of these, including the controllers, is 2 keuro + IVA. Equivalent actuators for 1e-8 mbar are not available from Thorlabs and more expensive ones will be needed. Prices for similar items range from 1 keuro - 1.5 keuro each + controllers. This is the justification for the 10 keuro for these actuators.

- Controlli motori: this is for the rotation mounts (not the actuators). Each controller costs 3065 euro. With IVA the total cost is 7356 euro. We rounded to 10 keuro.

LNL

- 2 camere da vuoto per ottiche FP: the cost of these is estimated from the offers below. The request is for slightly larger (DN250 mm) vacuum chambers sustained by robust supports as shown in figure 11 below. In figure 11, the cylindrical vacuum chamber has been virtually removed to show the inside mechanics. We will be using viewports with antireflective coatings. The relative offer for these is also attached.

For the present test set-up in Ferrara the cost of the 2 chambers is principally due to POS A, POS B and POS D of the offer below without considering the viewports which will be discussed below. The cost for the 2 chambers including the end caps was about 5 keuro. Passing to a DN250 size, the price doubles: 10 keuro.

KENOSISTEC

Sede Legale e Unità Operativa

Sede Amministrativa e Operativa
Viale delle Scienze, 23 20082 Binasco (Milano)

e-mail info@kenosistec.it

web site www.kenosistec.it

OFFERTA

OFF K1312008	**DATA 03-12-2008**

Spett.
Università di Ferrara
Dipartimento di Fisica
Via Saragat, 1 Blocco C
44100 Ferrara

VS RICHIESTA: Dr. Federico Evangelisti		VALIDITA' : 60GG
CONSEGNA: 3-4 settimane	RESA: Franco vs. sede	IMBALLO: incluso
PAGAMENTO	60 gg d.f.	
GARANZIA	12 mesi dalla consegna	

Come da Vs gentile richiesta siamo lieti di farVi pervenire la ns. migliore offerta per il seguente materiale:

Pos A
Camera servizi come da disegno PL-003
Prezzo Unità: Euro 1.100,00 + IVA
Prezzo Due Unità: Euro 2.000,00 + IVA

PosB
Camera chiusura come da disegno PL-004
Prezzo Unità: Euro 562,50 + IVA
Prezzo Due Unità: Euro 1.100,00 + IVA

PosC
DN40CF-DN16CF Zero lenght adaptor PN: 150055
Prezzo Unità: Euro 64,00 + IVA
Prezzo Due Unità: Euro 128,00 + IVA

PosD
DN200CF-DN40CF Zero lenght adaptor PN: 150091
Prezzo Unità: Euro 271,00 + IVA
Prezzo Quattro Unità: Euro 1.000,00 + IVA

PosE
DN40CF Non-magnetic 316LN Flange glass viewport PN: 1210101
Prezzo Unità: Euro 534,00 + IVA
Prezzo Due Unità: Euro 1.000,00 + IVA

PosF

Pag. 1 di 2

As for the supports and viewports with antireflective coating the cost can be estimated from the the next offers. Each viewport costs about 2.7 keuro + IVA for a total of 4.1 keuro on a DN200 flange. With the slightly larger flange, but maintaining the same window size, the cost will increase. We estimate 6 keuro.

KENOSISTEC

Prof. Guido Zavattini
Dipartimento di Fisica
Università di Ferrara
Via Saragat 1
44100 Ferrara
Italy

Monday, March 08, 2010

MDC Quote Reference CQ10-0216

Dear Prof. Zavattini,

Thank you for your enquiry regarding vacuum components. I now have pleasure in providing you with the following quotation. To ensure that we process your order exactly to the stated prices and terms please state the above quotation number on all future correspondence with regards to this enquiry.

Item Ref.	Description	Qty	Price Each	Total
VPZ200/150QVAR	DN200CF Flange with 136m view diameter fused silica optic, bakeable to 200 C max, and VAR anti-reflective coating on both sides of optic, tuned for 1064nm	1	€ 2,721.00	€ 2,721.00
	Total of Goods (Ex Works)			€ 2,721.00
	Shipping (UPS Airfreight (8kg))			€ 66.00
	Total including Shipping			€ 2.787.00

Delivery : *7 weeks from receipt of order at time of quotation.*
Price : *In Euro excludes VAT, total includes shipping.*
Terms : *60 days net for established accounts, subject to credit limit approval*
Quote valid : *60 days (E & OE)*

Quote subject to MDC Vacuum Products Ltd terms and conditions of sale, copy available upon request.

Please Address your order to :-

MDC Vacuum Limited
3 Horsted Square, Bellbrook Business Park
Uckfield, East Sussex, United Kingdom
TN22 1QG

Bank Details: Barclays Bank Plc
1 Churchill Place
Canary Wharf
London, E15 5HP
United Kingdom

Account No: 63756499
Sort Code = 20-00-00
Swift code = BARCGB22
IBAN = GB23 BARC 2000 0063 7564 99
MDC Vacuum Limited VAT Number = 978 7571 44

Yours sincerely,

Phil Marston
Technical Support Engineer
pmarston@mdcvacuum.co.uk

cntr. sig ....

As for the supports an estimate can be made from the 'consuntivo PRIN'. In the right most column one can read the highlighted entry regarding the two triangles on the Ferrara setup made by CINEL. We will need 4 equivalent structures instead of the present 2: a total of about 8.6 keuro. A bit of overhead gives 10 keuro.

14. Dati complessivi relativi al programma

	(numero)
partecipazioni a convegni pertinenti:	
in Italia	
all'estero	
articoli pertinenti pubblicati:	
su riviste italiane con referee	
su riviste straniere con referee	3
su altre riviste italiane	
su altre riviste straniere	
comunicazioni a convegni/congressi internazionali pertinenti	
comunicazioni a convegni/congressi nazionali pertinenti	
rapporti interni	
brevetti depositati	

15. Tabella delle spese sostenute

Voce di spesa	Spese rimodulate	Pagato		Residuo da saldare (già fatturato)	Cifra impegnata	Totale spese sostenute	Descrizione (elementi contabili a giustificazione) (max 4000 Car. per ogni voce)
		I anno	II anno				
Materiale inventariabile	42.584	7.785	34.676			42.461	Supporti motorizzati per ottiche (BFI Optilas, 7785.00 Euro, Mand. 305 del 14/04/2008, Fatt. 380 1315 del 04/03/2008), Flange di supporto da vuoto per ellissometro (CINEL, 4308.00 Euro, Mand.18 del 03/02/2009, Fatt. 22 del 31/01/2009), Pompa da vuoto ionica (Varian, 4140.00 euro, Mand. 21 del 03/02/2009, fatt.

The total for the large vacuum system pieces adds up to an estimated cost of 26 keuro. This accounts for the first 2 voices under LNL.

- Passanti: these are electrical feedthroughs for the numerous motors

- 2 valvole per sezionare il tubo da vuoto: these are 2 small gate valves with roughing port to isolate the vacuum tube and flux clean gas using the roughing ports. An offer for these is given below. We estimated 4 keuro including IVA.

thermionics laboratory, inc.

Sezione di Ferrara dell'
Istituto Nazionale di Fisica Nucleare
Via Saragat, 1
c/o Polo Scientifico Tecnologico-blocco C
44100 Ferrara
Italy
All'attenzione Responsabile Unico del Procedimento (RUP) Federico Evangelisti
Phone: 390532974296
Email: evangelisti@fe.infn.it

January 20, 2010

Quotation Number: QH1001006
Quotation Valid for 60 days

Dear Mr. Evangelisti,

Thank you for your inquiry. We are pleased to quote:

Item No.	Qty	Description	Thermionics Part No.	Unit Price	Total
1	2	Custom flanged gate valve according to drawing. 5/8" ID gate valve with viton bonnet, manual actuation and metric tapped port flanges. Sealing side has tube and rotatable 2.75" CF port flange. Other side is standard 1.33 CF port flange and roughing port with non-tapped CF133 flange. Flange face to flange face distance is less than 55mm.	G0058-100-19(275R133)-1200	$1,625.00	$3,250.00
2	2	Bellows assembly, 3/4" nominal OD. 1.33CF flanges.	FX-075	$105.00	$210.00
				Subtotal	$3,460.00
		Shipping, Handling and Insurance to destination (CIF)			$300.00
				Total	$3,760.00

Ship date: 4-6 weeks ARO
FOB: Hayward, CA USA 94545
Terms: Net 60 OAC

Michael Ricks
Vice President Sales & Marketing
Thermionics Vacuum Products
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- Sistema di supporto per i magneti: the cost of the permanent magnet support is estimated from the cost of the present system supporting the two small permanent magnets of the Ferrara test setup apparatus. Each magnet currently weighs about 60 kg and are each about 30 cm long and 20 cm in diameter. The future magnets will weigh at least 5 times as much and will be between 4 to 5 times longer. This leads to a significantly larger system. The present system cost 5300 euro + IVA = 6.4 Keuro (see offer below from 2009). We estimate about 20 keuro. This is due to the higher (factor 2) and wider (factor 4) structure which will need to support heavier (factor 5) magnets (see figure 10 below).

25-11-2008 17:52 DA-ITEM srl +0390354510017 T-555 P.001/001 F-247

item italia

SPETT.LE
Università degli Studi di Ferrara
Dipartimento di Fisica
Polo Tecnologico-Via Saragat 1, Blocco C
44100 FERRARA FE
ITALIA

DESTINAZIONE MERCE
Dipartimento di Fisica dell'Università di Ferrara

Polo Tecnologico-Via Saragat 1, Blocco C
44100 FERRARA FE

OFFERTA

(per favore indicare il nostro numero d'offerta in caso di Vostro gradito Ordine)

NUMERO	DATA	VS RIFERIMENTO	DATA RIF.	PAGINA
1653	25-11-2008	RDO - mail	21-11-2008	1

VALIDITA' GIORNI	NS RIFERIMENTO	CODICE CLIENTE
60	Gasparini Fabio	1.3.2.1.1279

CODICE	DESCRIZIONE PRODOTTO	Q.TA	PREZZO	%SC	TOTALE
M.0.811.66	SUPPORTO MAGNETE montato Rif.Vs.dis. PL001 realizzato in Al-profilati ed accessori del sistema MB. Profilato 80x80 leggero, n°32 set standard di collegamento, n°4 calotte 80x80. N.B.: Ulteriori componenti non descritti esclusi, a cura cliente. Data approntamento: Da definire	1	430,00		430,00
M.0.811.67	APPOGGIO SUPPORTI MAGNETI montato Rif.Vs.dis. PL002 realizzato in Al-profilati ed accessori del sistema MB Profilato 120x80 leggero, 160x80 leggero, n°8 squadre 160x160 acciaio e relativi set di fissaggio, n°4 piedini di regolazione D80 M16x100, n°4 inserti ammortizzatori D80, n°4 piastre di base 80x80 M16, n°4 calotte 120x80, n°4 calotte 80x80. N.B.: Ulteriori componenti non descritti esclusi, a cura cliente. Data approntamento: Da definire	1	3.040,00		3.040,00
0.0.480.91	Livellatore a terra D80, M33x80 1 set. Data approntamento: Da definire	8	110,32		882,56
0.0.026.16	Tassello scorr. 8 acciaio MB 1 pz. Data approntamento: Da definire	100	0,54		54,00

- COSTO TRSPORTO: € 180,00
- COSTO IMBALLO: € 20,00

PER APPROFONDIMENTI E DEFINIZIONI COMMERCIALI, CONTATTARE NS. AGENTE DI ZONA.
Sig. Chiesa Andrea 333/40.00.871 oppure 035/45.100.11

Vi informiamo che in occasione delle festività natalizie item resterà chiusa dal giorno 24/12/08 al 06/01/09 compreso.

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PAGAMENTO	BANCA D'APPOGGIO
B.B. 60 gg. d.f. fine mese	00000.00000

AGENTE	MODALITA' DI CONSEGNA	IMBALLO	PESO KG
SIG. CHIESA ANDREA (07)	Porto franco con add. in fattura	ESCLUSO	227,50

TOTALE MERCE	I.V.A.
4.406,56	881,31
SCONTO CASSA	TOTALE OFFERTA
0,00	5.287,87

- Motori per rotazione magneti permanenti: we will need 2 motors capable of rotating the 2 permanent magnets at about 5 Hz. In the present Ferrara setup we ordered 2 motors with controllers which should be have the torque necessary to keep the new magnets in rotation. The total costo was 7.7 keuro (see highlighted 'consuntivo PRIN' below). A slight overhead leads to 10 keuro and justifies our request.

							600211337 del 19/01/2009) Isolatore Faraday (Micos, 5500.80 Euro, Mand. 15 del 03/02/2009, fatt. 03/2009 del 20/01/2009 + Mand. 16 del 03/02/2009, Fatt. 03/2009 del 20/01/2009), 7773.60 euro (PHASE motion control, Mand. 28 del 03/02/2009, fatt. 90067 del 30/01/2009 + Mand. 29 del 03/02/2009 Fatt. 90067 del 30/01/2009), due magneti permanenti dipolari lunghi 25 cm ciascuno con foro di 15 mm e campo di 2.3 Tesla (Institute of Electrical Engineering Chinese Academy of Sciences, 9200 Euro, Mand. 483, Fattura 424 del 20/05/2008 e Mand. 1108, Fattura 1111 del 12/11/2008), Camera servizi da vuoto + 2 flange vetro da vuoto P/N 1210101 + DN40CF-DN16CF zero length adaptor (Kenosistec, 3753.60 euro, Mand. 47 del 05/02/2009, fatt. 011 del 29/01/2009)
Grandi Attrezzature	0					0	
Materiale di consumo	4.400	1.300	3.227			4.527	Kit memoria per Power PC G5

- Schermatura magnetica per magneti permanenti: lastly we estimated the cost of the magnetic shielding for the magnets to be 10 keuro. An aluminum structure supporting the mu-metal sheets (already available from PVLAS) will be built. Here we present only an estimate of the cost.

2011 will therefore be the year in which the new apparatus will be assembled in the Ferrara clean room.

The Pyrex tube connecting the vacuum chambers will be longer to be compatible with longer magnets. Provisions will be made to have a support stemming from the optical bench between the two magnets to limit sagging if necessary.

The two identical permanent dipole magnets will be each 1 m long with a central field of 2.3 Tesla, or will be shorter if higher fields will be achievable under the condition that at equal price the integral of the B^2L will be maintained equal to 5.5 T^2m (for each magnet). Permanent dipole magnets with lengths in excess of 1 m have been produced with central fields of 2.3 Tesla for the Q&A experiment. We have contacted several potential vendors. We report in Appendix 1 relevant technical and financial information obtained from preliminary contacts with potential vendors. Critical parameters regarding the magnets' technical specifications are magnet bore, length, field intensity in the magnet centre, stray field characteristics, magnet weight and allowed rotation speed. It will be necessary to handle two magnets weighting a few hundreds of kilos each for their installation in the middle of the FP.

To ensure good and reproducible running conditions it will be necessary to operate in a temperature stabilized clean room to reduce thermal drifts and to ensure maximum cleanliness when using the high finesse mirrors. These conditions will be ensured by the clean room in Ferrara.

Some technical drawings made by the technical service in Ferrara of the future setup are shown below.

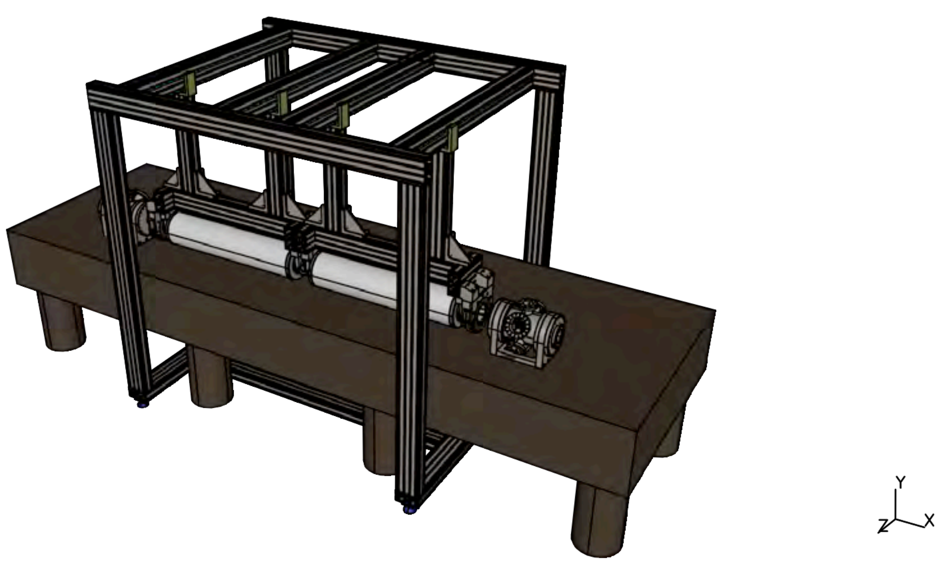

Fig. 10: Drawing of the new pvlas apparatus

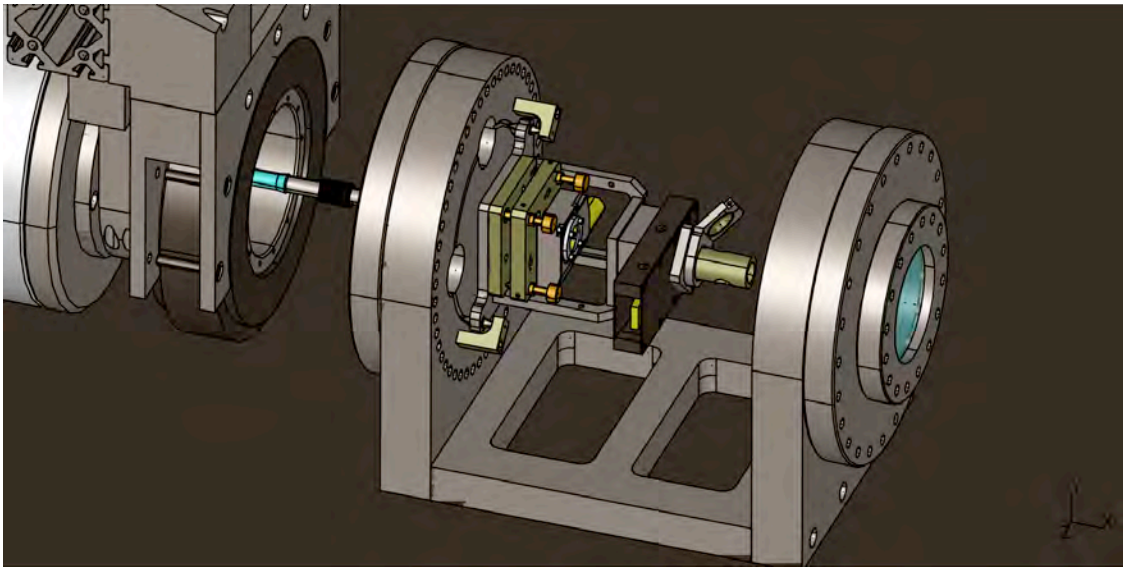

Fig. 11: Detail of the optical mechanics

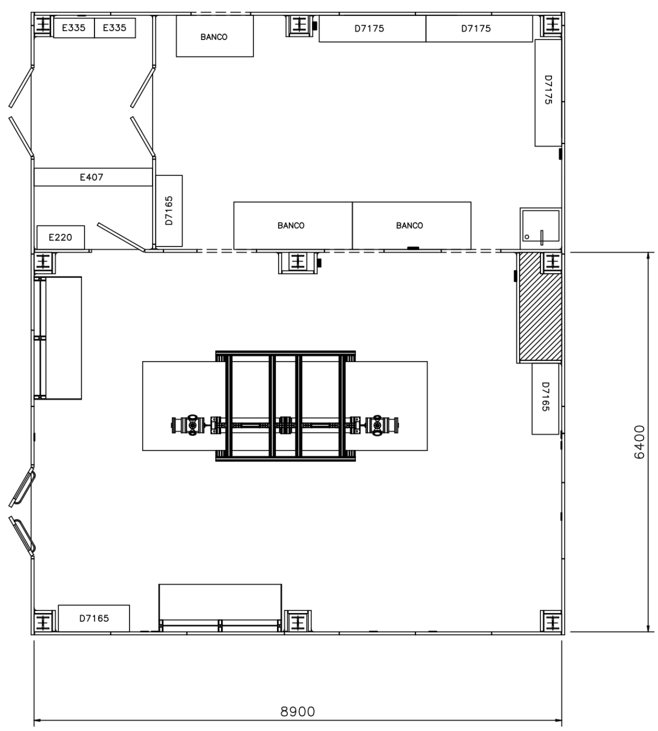

Fig. 12: Clean room showing the pvlas apparatus

It must be noted that the present test system will be continually worked on to acquire understanding of the ellipsometer and searching for noise sources.

The following year will be dedicated to commissioning and hopefully towards the end of 2012 we will have some first sensitivity tests. The costs for 2012 will be principally running costs. These include travel, consumables, and a minimum of equipment in the case of necessity. It must be anticipated that a reference cavity may be necessary. One can therefore summarize

2012 - commissioning of the new apparatus

Costs:

1. Travel - 35 keuro
2. Consumables - 20 keuro
3. Equipment/maintenance - 20 keuro
4. (Reference cavity - 25 keuro)

Total: 75 keuro + (25 keuro)

2013 - Running

This will be the year in which we will run the experiment, improving limits on magnetic birefringence of vacuum and hopefully measure the QED signal.

Costs:

1. Travel - 35 keuro
2. Consumables - 20 keuro
3. Equipment/maintenance - 20 keuro

Total: 75 keuro

We would like to stress that for the PVLAS collaboration the end of 2013 is considered a deadline for a final assessment of the experiment. The PVLAS collaboration has made a series of R&Ds especially during the last few years during which significant improvements have been made compared to the original LNL setup. We believe that whatever the result reached, it will be a best effort.

At the moment the PVLAS collaboration has published a vacuum magnetic birefringence limit which is about a factor 5000 above the QED expected value. With a sensitivity equivalent to the one of the Ferrara test setup integrated with the two small magnets we expect to improve the present PVLAS limit by at least a factor 100. If the sensitivity of the new apparatus will reach the observed sensitivity (publication attached as appendix 3) of $2\cdot10^{-8}$ $1/\sqrt{Hz}$, obtained with a small prototype ellipsometer, then we expect to reach the QED value during 2013.

8 - Competing experiments

There are three competing experiments that aim at performing the first measurement of MBV and use different techniques .

Q&A in Taiwan [30] uses permanent rotating dipole magnets to modulate the MBV and an ellipsometer with a FP to maximize the number of passes through the magnetic field. They have the mirrors of the FP installed in two distant vacuum chambers suspended with attenuators of ambient vibrations of the type developed for interferometric gravitational wave detectors. The separation of the two optical halves seems to limit the sensitivity of their apparatus. At the moment the finesse is below 10^5.

OSQAR at CERN [31] uses a LHC dipole magnet 15 m long that can reach a 9 T field. The ellipsometer will exploit a FP to maximize the number of reflections and a novel optical technique to modulate the MBV effect. Since it is not feasible to set the LHC magnet in rotation and a modulation of the LHC magnet field intensity could be achieved only at a very low frequency, the experiment foresees to modulate the polarization of the light entering the ellipsometer by setting in rotation the polarization plane. According to our experience in this set-up the rotation of the polarization will generate a very large signal due to the intrinsic birefringence of the FP mirrors.

BMV in Toulouse [32] will not use the heterodyne technique to enhance the signal to noise ratio, but will work in homodyne. They will maximize the signal level by using an extremely high intensity magnetic field. This is obtained by employing pulsed magnets (few milliseconds), 40 cm long, that have already reached peak intensities in excess of B = 15 T, L = 0.5 m total length. Duty cycle seems to be the limit in this system: repetition rate is 5 shots/hour. At present the finesse is ≈ 10^5. Their present sensitivity is a few 10^{-7} $s^{1/2}$. Assuming an improvement of a factor 10 this would imply:

$$T = \left[2\cdot 10^{-8} \Big/ \left(\frac{2F}{\pi} \right) \left(\frac{3\pi L A_e B^2}{\lambda} \right) \right]^2 = 5.7\cdot 10^4\, s$$

corresponding to ≈ $28\cdot 10^6$ pulses (pulse duration = $2\cdot 10^{-3}$). With the repetition rate this implies 650 years of continuous datataking.

All these experiments use, as PVLAS, the Cotton-Mouton effect to calibrate their apparatus. Helium is the gas with the lowest CM parameter. Measurements of the CM effect of He gas at low pressure are the most difficult ones to perform and permit to assess and compare the performances of the different ellipsometers. At present the best performances are still those achieved by the PVLAS apparatus installed at LNL in Legnaro [18].

9 - Conclusions and request

- Measurements with the 50 cm long FP have shown the feasibility of an ellipsometer with 10^{-8} $s^{1/2}$ sensitivity and finesse in excess of F = $4\cdot 10^5$.

- Measurements are in progress with the test set-up with 140 cm long FP. They are showing the compatibility of the ellipsometer with a system of two rotating permanent dipole magnets. A sensitivity of 6 10^{-9} $s^{1/2}$ has been measured with magnets in rotation and no cavity. With low reflectivity mirrors and finesse F = 3000 a sensitivity of a few 10^{-8} $s^{1/2}$ has been achieved with magnets in position and in rotation. In first measurements with high reflectivity mirrors a sensitivity around 10^{-7} $s^{1/2}$ with a finesse F = $2.45\cdot10^5$ has been measured with the two magnets in rotation and parallel fields. **The ensemble of these results indicates that the goal of achieving a sensitivity of 10^{-8} $s^{1/2}$ and finesse around F = $4\cdot10^5$ can be achieved.**

Assuming an ellipsometer featuring F = $4\cdot10^5$ and $2\cdot10^{-8}$ $s^{1/2}$ sensitivity, in the new experiment with the two magnets set with parallel magnetic fields with L = 2 m, N = $3\cdot10^5$, B^2= 5 T^2 the expected QED MBV ellipticity will be $\Psi = N \pi \Delta n L/\lambda \approx 3\cdot10^{-11}$ where $\Delta n = 3A_eB^2 = 2\cdot10^{-23}$ @ 2.3T and it will be observable at the 1 sigma level in 5 days of running time.

Measurements of comparable duration with magnets at 90^0 will be necessary to ascertain the zero of the ellipticity scale.

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Appendix 1: The twin permanent dipole magnets

The configuration for the twin permanent dipole magnet system is shown in Fig.1. Two magnets of a cylindrical shape are installed along a horizontal axis, separated by a gap, and in such a way that they can rotate up to 5 Hz. The dipole field is uniformly distributed in their 20 mm diameter central bore.

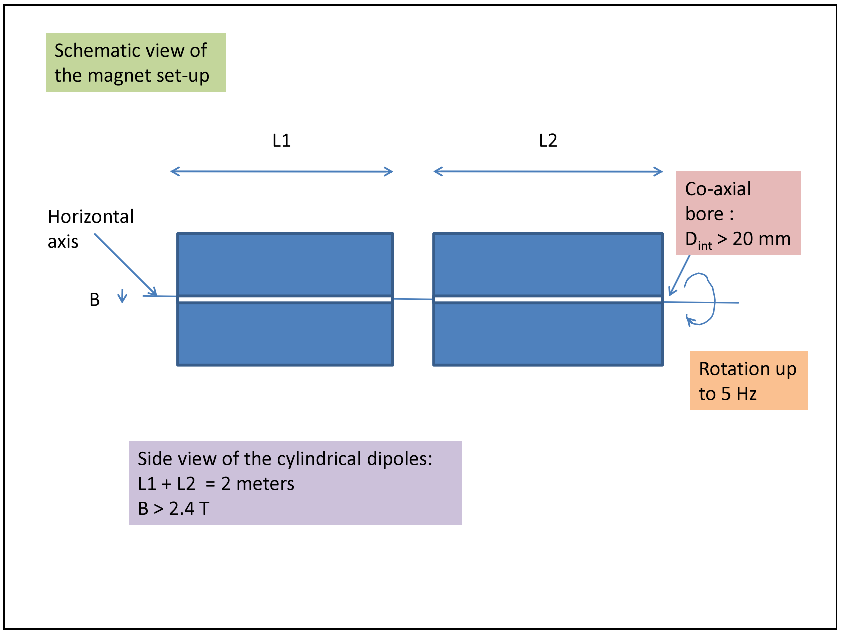
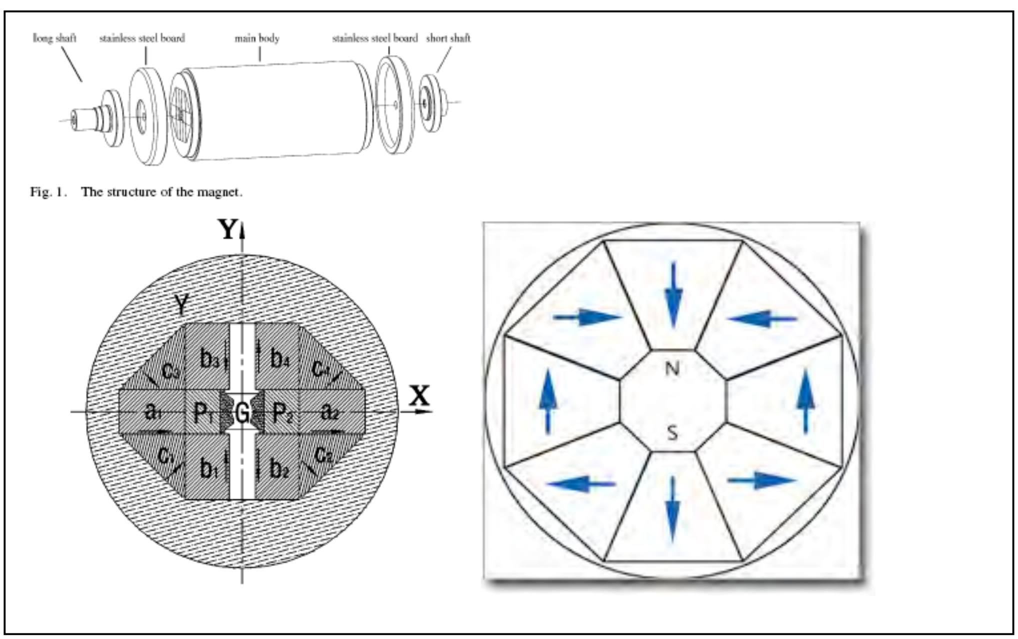


Figure 1 Schematic view of the dipole magnet set-up



The two magnets will rotate simultaneously at the given frequency with their magnetic filed vector parallel or making an angle of 90 degree (see text). The magnets are realized using Nd Fe B syntherized powder, magnetized as in in Fig. 2a and Fig. 2b , depending on the manufacturer, in such a way to produce a homogeneous field of 2.3 T or higher.

The configuration, called Halbach-like (left) or Halbach (right) is such that the stray field outside the cylindrical envelope is less than 2 Gauss.

Table 1. Summary of the budgetary price available

Manufacturer	Delivery Time	Budgetary price	weight
AMT&C (RU)	90 days	183 (155) kEuro	470 (410) kg
Inst. Electr. Eng. (China)	8 months	95 kEuro	600-825 kg
SISRAM (Vacuumschmelze)	NA	92 kEuro + 4.5 kEuro	Ca. 150-200 kg
SISRAM (Vacuumschmelze) 3Tesla 0.7 m	NA	108 kEuro + 4.5 kEuro	Ca. 150 kg or less

In Table 1 a very recent preliminary survey result is shown. It can be seen that the minimum bare cost is around 100 kEuros + 20% IVA. Also the weight is different according to the geometry chosen by the potential manufacturer, with the related consequences on the ancillary mechanical structure.

An interesting technical offer proposed by the Vacuumschmelze supplier, where they claim the capability to realize a higher magnetic field (3 Tesla), which would imply a shorter length.

It has to be noted that the Chinese manufacturer has already realized similar dipoles, while the two others possible suppliers have not yet.

Appendix 2

	TECHNICAL SPECIFICATIONS FOR TWO PERMANENT MAGNETS FOR THE EXPERIMENT PVLAS	*27/07/2010* *VERSION 1.0*

Two high field permanent dipole magnets for the experiment PVLAS

1	Specifications	R.Pengo			27/07/2010
REV.	*Description*	*Written by*			*Date*

Corresponding author: Ruggero Pengo ruggero.pengo@lnl.infn.it

Table of Contents

Nomenclature

PVLAS	Polarizzazione del Vuoto con LASer
INFN	*Istituto Nazionale di Fisica Nucleare*
INFN-LNL	INFN-*Laboratori Nazionali di Legnaro*
INFN-Ferrara	INFN- Sezione di Ferrara
TS	*Technical Specification*

1. Introduction

1.1. General

PVLAS (Polarizzazione del Vuoto con Laser) is an experiment started at INFN-LNL using a superconducting rotating magnet. The collaboration wants to take advantage of the newly available high field permanent dipole magnets to simplify the experimental set-up. The new set-up will be installed at INFN-Ferrara, about 80 km south of LNL. The aim of the experiment is to measure the effects induced on the vacuum by an external magnetic field using polarized Laser photons. An optical resonating cavity is inserted in a rotating dipole magnetic field.

1.2. The experimental set-up (schematic)

The experimental set-up is schematically shown in Fig.1: two high field permanent magnets with a dipole field are placed horizontally along their symmetry axes and they can rotate up to 5 Hz. Inserted in their central bores is a glass (Pyrex) tube where high pneumatic vacuum (better than 10^{-7} mbar) is produced. In the tube a laser beam optical cavity is built, i.e. the photons can go back and forth in phase achieving a “finesse” up to 400.000, while the magnets rotate without touching the tube. The two magnets rotate at the same frequency, with their field vectors either parallel or orthogonal. In the latter case the effect of one magnet is canceled by the other. The optical cavity is mounted on an actively damped optical table, while the support of the magnets is mechanically decoupled. In Fig.2 the actual test set-up with small magnets is shown.

1.3. The magnets specifications

It is requested that the dipole magnets have a uniform magnetic field in the central bore. The magnet will have physical length (from flange to flange) L_1 and L_2, with $L_1 = L_2$.
Their intensity should be such that:

- $Squared\ Field\ Integral = \int_{-\infty}^{+\infty} B^2 dL \geq 11.0\ [T^2 m]$
- i.e. for each: $Squared\ Field\ Integral = \int_{-\infty}^{+\infty} B^2 dL \geq 5.5\ [T^2 m]$
- $L_{1,2} \leq 1.00\ m$
- $D_{bore} \geq 18mm$ if $L_{1,2} < 0.85$ m
- $D_{bore} \geq 20mm$ if $L_{1,2} > 0.85$ m
- The diameter of the central bore D_{bore} should be intended as free light passage during rotation.

  As an example the two magnets could be realized as:

- 3 T (or higher) with an effective length of 700 mm each magnet
- 2.4 T (or higher) with an effective length of 1000 mm each magnet
- The central bore should have a diameter of at least 18 mm for 3 T and of 20 mm for 2.4 T.
- With the same Squared Field Integral=11.0 [T^2.m] given above, **the magnet system with the shorter length will be preferred**

The field should be as homogeneous as possible inside the bore.

2. General conditions

2.1. Scope of the call for tender and extent of the supply

This specification defines the requirements for the design, manufacture, inspection, installation at INFN-Ferrara, and commissioning and performance tests of the magnets.
The magnets to be supplied, described in detail in chapter 3, consist of the following items:

- A pair of permanent dipole magnets with the specified dimensions. The magnets should be housed in a cylindrical casing ending on both (left and right) sides with two parallel flanges;
- The flanges will have six threaded holes to allow the coupling of the motors. Details of the holes will be given to the contractor.
- The magnets with their case should be balanced to avoid vibrations during the rotation;
- The magnet construction should be compatible with their rotation at a frequency of at least 5 Hz;
- Documentation will include the calculated field distribution along the symmetry axes, and the stray field map outside the cylindrical casing from the center to 500 mm outward. The field intensity maps should be given in logarithmic scale.
- Complete documentation including operation conditions and maintenance procedures (if any). In particular the range of operating temperature and rotational speed must be specified

2.2. Items to be included in the tender

All tenders must include the following:

- All equipment needed for the transport from the manufacturer premises to INFN-Ferrara
- all work involved in carrying out the specified tests prior to shipment
- all work involved in inspections by an independent inspection authority and the corresponding test certificates;
- the packing, shipping, insurance and transport to INFN-Ferrara
- transport cost should include the necessary obligations related to items carrying high magnetic field
- the complete technical documentation for the magnets including instructions for handling;

2.3. Outline of time schedule

The Bidder must attach to his Tender a detailed time schedule with as a starting date the contract signature. This document will be checked every second month for the duration of the contract. INFN reserve the right to inspect the contractor premises during the construction of the magnets and for the preliminary acceptance there at the completion of the construction.

2.4. Penalties

Penalties will be applied on delays of delivery and commissioning as defined in the Tender Form Documents.
No compensation will be accepted in the case of insufficient performance. If the supply cannot achieve the specified performance during the reception tests the Contractor will have to upgrade the supply at his own cost until the specified performance is reached. The provisional acceptance will only be pronounced after all reception tests are completed having demonstrated that the specified performance has been reached.

2.5. Responsibility of the Contractor

The Contractor must accept to take full responsibility for the design, construction, reception tests of the magnet system he delivers for the PVLAS experiment.
INFN will not provide any equipment or raw materials needed for the construction of this Magnetic System.
INFN-LNL shall have free access during normal working hours to the manufacturing or assembly sites, including any sub-contractor premises, during the contract period.
All Tenders are deemed to comply fully with the requirements of this specification unless they clearly state on which points they do not comply and give a complete list of the differences.
The Bidder is free to propose alternative solutions, provided that the deviations from this specification, together with the technical or financial reasons and advantages, are clearly indicated in the tender. Such alternative solutions shall always be made in addition to the basic Tender which must comply fully with the specification. However, INFN reserves the right to reject the proposed alternative solutions without any justification.
The Contractor must ensure and demonstrate to INFN that his equipment is suitable in all respects for the requirements of this specification.
The Contractor shall be solely responsible and liable for all layout, drawings, designs, specifications, reports, protocols, calculations or other documentation or information produced or prepared by the Contractor (and whether based upon data, information or documentation provided by INFN or by any third party). Where the Contractor seeks or is obliged to seek INFN's approval or agreement to any matter or thing, the giving or confirming of the same by INFN shall not in any way derogate from the Contractor's duties, obligations or liabilities under the contract, nor diminish any liability on his part in respect thereof.
For all major components (in particular magnetic elements) a list of subcontractors (if any) must be proposed and approved by INFN. Any change of sub-contractor during the execution phase of the contract must be approved by INFN.
All parts availability for the delivered Magnetic System must be guaranteed for at least five years.
The technical documentation for the delivered Magnetic System must be available for at least ten years.
The technical information requested with this Tender is summarized in the following chapters.

2.6. Presentation and content of the tender

Tenders must be in English. The Bidder must submit three copies of the full set of documents. Each Bidder must submit a technical documentation including:

- diagrams showing field mapping, in linear scale, inside the central bore;
- diagrams showing field mapping, in logarithmic scale, outside the central bore up to 500 mm radially from the center
- a description of the main construction principles and features of the various components,;
- layout drawings showing the overall dimensions and the weight of all relevant components
- assembly and sectional drawings of all relevant components and equipment to be delivered showing essential features with main dimensions, and indicating the materials used;
- a description of safety principles proposed;
- a time schedule for the design, fabrication, assembly, delivery and test sequence, showing the critical path of the planning;
- a list of all proposed subcontractors as requested in the Tender Form;
- a list of spare parts (if any) deemed necessary for efficient operation and maintenance, with detailed prices;
- information on CAE/CAD techniques which will be applied for design, manufacturing and documentation;

Tenders which do not include the complete information listed above may be rejected for lack of technical credibility.

3. Performance of the magnetic system

3.1. General

- The two magnets together must be capable to supply:

$$Squared\ Field\ Integral = \int_{-\infty}^{+\infty} B^{\,2} dL \geq 11.0\ [T^2 m]$$

i.e. for each: $Squared\ Field\ Integral = \int_{-\infty}^{+\infty} B^{\,2} dL \geq 5.5\ [T^2 m]$

e.g. 3 T on a length of 700 mm each or 2.4 T along a length of 1000mm each.

The clear aperture of the bore during rotation must be

- $D_{bore} \geq 18mm$ if $L_{1,2} < 0.85$ m
- $D_{bore} \geq 20mm$ if $L_{1,2} > 0.85$ m

The Magnetic System (a scheme is provided in Fig.1) will have to operate in several operating modes according to the needs of the PVLAS experiment. A gap of 100-200 mm is foreseen between the two magnets.
Two operation modes are identified:

- Two magnets are rigidly coupled and they rotate up to 5 Hz with their field vector parallel
- Two magnets are rigidly coupled and they rotate up to 5 Hz with their field vectors forming a 90^0 angle

The design of this Magnetic System must be done for a long term operation without any maintenance. Furthermore, this design must be oriented at achieving high operating reliability.

Performances as listed in chapter 3.2 through 3.4 must be guaranteed. These values will be verified during the performance test.

3.2. Performance of the magnet system

3.2.1 Vibrations level

Each magnet must be balanced in order to avoid vibration interference with the other components. The problem of damage to equipment and piping induced by vibrations must be given highest attention already at the design stage.
The Bidder must explain his strategy on how to localize and eliminate dangerous excitations.

3.2.2 Magnet casing

Each magnet casing must be equipped with a flange at both ends. Each flange should be orthogonal to the horizontal axes. Parallelism of the two flanges will be checked at the acceptance test and should be less than 0.1 mrad. On the flange a series of 6 threaded blind holes should present for the coupling of both the motor and the twin magnet. Each threaded hole with M8 thread on a radius to be agreed with the contractor.

3.2.3 Driving motors

The driving motors are not part of the supply. Could be quoted as an option by the bidder.

3.2.4 Coupling

The rigid mechanical coupling of the two magnets is not part of the supply. Could be quoted by the bidder as an option.

3.3 Measuring points

The Bidder is invited to suggest the measuring points to verify the field inside the central bore along the total length.

3.4 Magnets interfaces

3.4.1 Connections to the Magnets

The casing of each magnet must be cylindrical. At both ends each magnet must have a flange with six threaded holes.

4 Mechanical design requirements

4.2 General operating conditions

The design of the equipment and the choice of components must be adapted to the operating conditions of the magnet system, namely:

- The magnets must be suitable for continuous operation for periods of up to 8'000 hours per year. Any maintenance required during this time must be specified (if any) by the bidder.
- The magnetic field should be guaranteed for at least five years

4.3 Design codes and principles

4.3.1 Lifting and handling

All equipment for lifting and handling delivered with the supply must comply with CE requirements.

4.3.2 Pressure vessels

Mechanical components such as the casing subject to magnetic pressure must comply with the safety requirements.

4.3.3 Choice of materials

All materials and components used in the construction of the Magnetic System must be new and suitable for the use for which they are intended. The specifications for the materials of the main components will be subject to approval by INFN. The choice of any non-metallic material must be done in accordance with CE regulations.

4.3.4 Quality design and manufacture

The Magnetic System is to be designed and manufactured in accordance with generally applied quality standards and techniques used (state of the art). A preference will be given for the contract to the bidder that can prove that he has established a quality assurance procedure equivalent to ISO 9001 or higher.

4.3.5 Additional design requirements

In addition to the requirements of the codes of practice specified above, the Bidder must conform to the following special requirements:

- Metric dimensions must be used for bolting, tubing and fittings.
- The maximum and minimum operating temperature of the magnets must be given.

4.4 Cleaning and surface treatment

All surfaces subject to corrosion (if any) must be protected by an appropriate coating.

4.5 Sensors and measuring instruments

All the instrumentation equipment (if any) proposed by the contractor has to be approved by INFN

.

5 INFN environment

5.2 Transport and installation at INFN

The Contractor must organize:
- the transport of all the supplies to the PVLAS site at INFN which is on Italian territory,
- its connection to the interfaces with INFN services.

The Magnetic System components must be carefully packed for transport and their value covered by a transport insurance.
All machined surfaces are to be protected.

6 Inspection, tests and documentation

6.2 General conditions

The Bidder must include in his Tender a proposal for the program of tests to be carried out during manufacture. The final program will be decided in discussion between INFN and the successful Bidder.
Once approved, the Contractor will be entirely responsible for carrying out this program.
The Contractor shall inform INFN of the dates of all important tests at least two weeks in advance.
The Contractor shall create a file of all non-conformities and concession requests encountered during the period between signature of the contract and provisional acceptance of the Magnetic System and any of these non-conformities must be approved by INFN.
All material or manufacturing faults detected during the tests are to be remedied by the Contractor at his own cost.
INFN representatives must be afforded free access to the Contractor’s and subcontractor’s works, offices and laboratories during manufacture and testing, including free access to all relevant documents.
Design and manufacturing of the system components must be verified and tested in accordance with the relevant international codes or the equivalent relevant national.
.

6.3 Inspection of welds

All welds (if any) must conform to the requirements of the construction code chosen.

.

6.4 Inspection and functional tests of components

After mechanical assembly the Contractor should invite INFN for an inspection.
When the global documentation of the Magnetic System is available, INFN will carry out the inspection and tests.
Delivery to INFN will be authorized only after the successful completion of these tests and required repairs if any.

6.5 Test of main components prior to delivery at INFN

6.5.1 Tests of the mechanical parts

Each magnet will be inspected with regard to its dimensions: in particular the parallelism of the end flanges will be measured.

6.5.2 Tests of the magnetic field mapping

Each magnet will be inspected and its field measured:

- Along its horizontal axes
- Outside the casing up to 500 mm radially from the symmetry center in the central bore.

6.5.3 Test of the balance

The contractor should propose a way to measure the magnets balancing.

6.6 Documentation

All documents must be submitted in three copies, of which one must be in a form suitable for reproduction. The technical documents must be in English. The operation and maintenance manuals must be in English.
Engineering drawings prepared by the Contractor for the execution of the contract must be supplied both in paper and electronic form.
All documentation has to be prepared in accordance with the relevant European or International standards and codes. Within ten working days after receipt of a document for approval by INFN, one copy will be returned to the Contractor marked for approval or showing the modifications which may be required. If no copy is received in due time, tacit approval can be assumed. Approval given by INFN does not release the Contractor from the responsibility of fulfilling the requirements stipulated in this specification.
In the final documentation, the quality and safety documents must be separated from the other technical documents.

6.6.1 Documents in computer-readable file

All documentation supplied to INFN must as well be made available in computer-readable form.
Drawings shall be prepared with a CAD system and in accordance to ISO drawing standards. They shall be delivered in form of plot files in HPGL language.
For all other documents, the following software shall be used:

- Microsoft Word 97® or higher for text documents;
- Microsoft Excel 97® or higher for lists;

- Microsoft Project 98® or higher for schedules;

The Contractor is responsible for the transfer of his documents to the above mentioned formats.

6.6.2 Delivery of documents

The timetable for the delivery of all documents will be determined jointly before the signature of the contract. The supply of the complete and updated documentation will be a condition for the Provisional Acceptance Certificate.
Documents to be submitted for the Production Release Review (PRR):
Through this PRR, the Contractor shall provide the following documents for approval prior to any fabrication or ordering from subcontractors:
1. General layout drawings for the Magnet System, showing the dimensions, weights of the main components;
2. All the manufacturing drawings for all items to be supplied;
3. The manufacturing inspection and test plan, covering all aspects of the supply;
4. The detailed work planning, including a list of milestones, the follow-up of progress and the continuous updating of this plan;
5. The Quality Assurance Plan, covering all work and supplies (including subcontractor's supplies);
6. Detailed specifications and data sheets for components, in particular those supplied by subcontractors;
Organization and timing of this Review are the responsibility of the Contractor and shall be compatible with the INFN's contract schedule and INFN delivery program.
Documents to be submitted for approval prior to any test of equipment and at least one month prior to the delivery to INFN:
7. Final assembly drawings of all components with parts lists indicating the materials used with important details, main dimensions and weights; assembly drawings of inner and outer parts of the supply;
8. All relevant information on subcontracted equipment, such as copies of order, user's manuals, drawings, etc.
9. The detailed final test program;
10. The detailed operation manual;
11. The detailed maintenance plan.
Documents to be submitted for approval regularly during the period between signature of the contract and provisional acceptance of the Magnetic System:
12. Every second month, a progress report must review the situation; this report can be replaced by minutes of a joint INFN / Contractor progress meeting/videoconference to be organized by the Contractor;
13. Major manufacturing problems or any difficulty likely to affect the agreed time schedule must be reported immediately to INFN;
14. Reports on all tests carried out in the factory and at INFN; inspection reports and material certificates. Results of tests must be reported to INFN not later than one week after the test has been successfully or unsuccessfully carried out.
Documents to be submitted for approval at least eight months prior to the delivery of the Magnetic System to INFN
15. A detailed description of all safety principles proposed;
16. The final revision of the total documentation including all references to non-conformities and concession requests accepted by INFN.

7 Reception tests at INFN

Commissioning and reception tests for Provisional Acceptance of the Magnetic System will be undertaken only when all the tests have been successfully completed and all specified documents have been supplied.
Reception tests are defined as tests performed after the commissioning runs to verify the performance of the equipment, under all aspects e.g. mechanical and magnetic performance, safety requirements and control behavior, as specified in this document.
All commissioning runs and performance tests must be carried out at INFN by their personnel and under the responsibility of the Contractor.
The detailed test procedures are to be defined by the Contractor in agreement with this chapter and shall be approved by INFN.
The reception tests shall be completed within 3 weeks after the starting date of the tests.
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8 Guarantee

On successful completion of performance tests on the Magnetic System and reception of all specified documents, INFN will issue a Provisional Acceptance Certificate. The Contractor must guarantee the equipment he has supplied for a period of two years or 16'000 hours of operation, whichever comes first, starting from the date of this certificate.
The Contractor must guarantee that all equipment supplied will continue to conform to the requirements of this specification and in particular will maintain the performance defined there. The Contractor is therefore to undertake to restore at his cost any variation from the specification or loss of performance which occurs or becomes evident during the guarantee period whether the fault lies in equipment of his own manufacture or that of his subcontractors.
At the end of guarantee period INFN will issue a Final Acceptance Certificate.

9 List of figures

Figure 1Schematic lay-out of the magnetic system

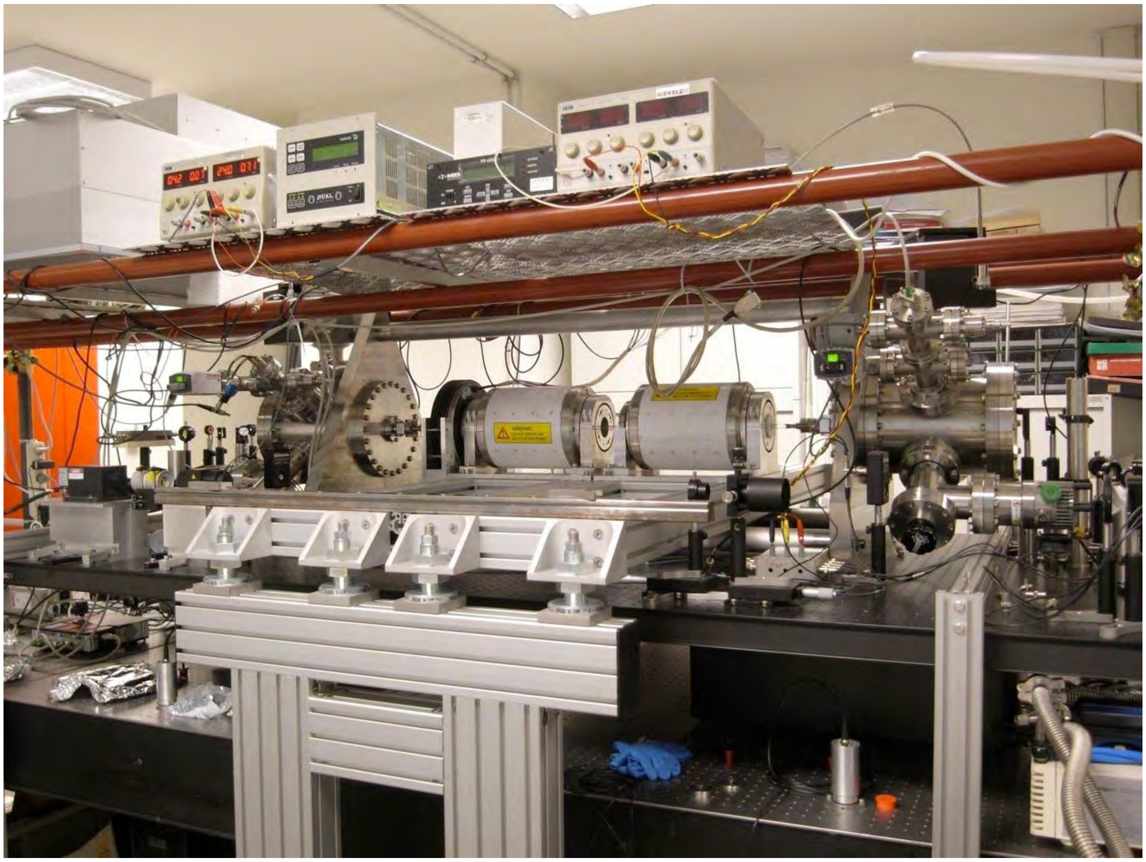
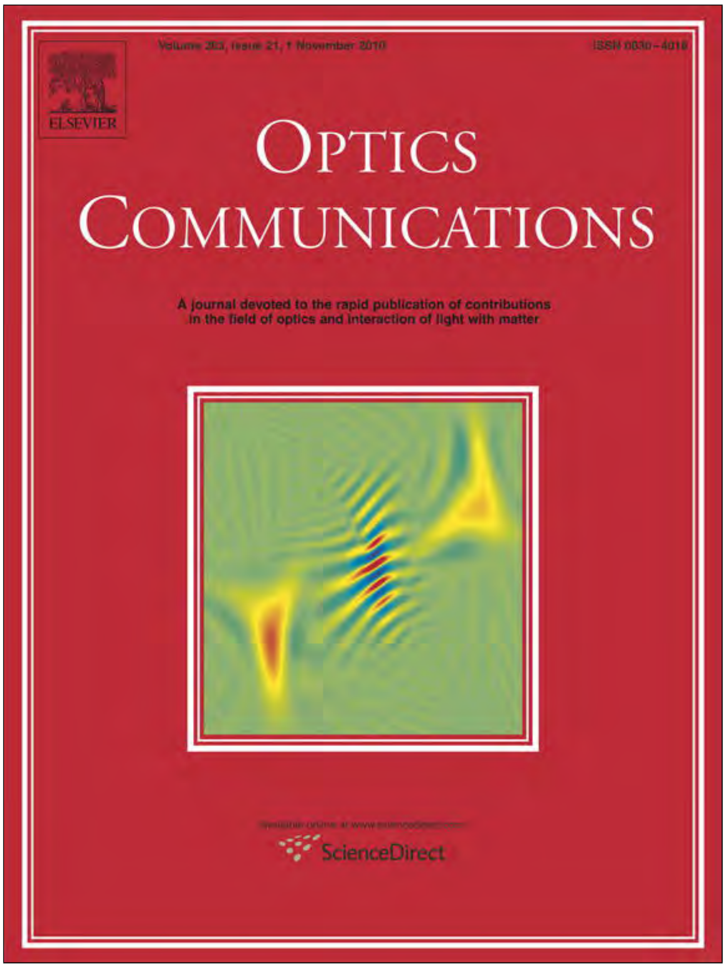


Figure 2 The actual test set-up. The length of each dipole magnet is only 300 mm.

Appendix 3: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Towards a direct measurement of vacuum magnetic birefringence: PVLAS achievements

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ABSTRACT

Nonlinear effects in vacuum have been predicted but never observed yet directly. The PVLAS collaboration has long been working on an apparatus aimed at detecting such effects by measuring vacuum magnetic birefringence. Unfortunately the sensitivity has been affected by unaccounted noise and systematics since the beginning. A new small prototype ellipsometer has been designed and characterized at the Department of Physics of the University of Ferrara, Italy entirely mounted on a single seismically isolated optical bench. With a finesse $F=414{,}000$ and a cavity length $L=0.5$ m we have reached the sensitivity of $\psi=2\cdot10^{-8}\,1/\sqrt{\mathrm{Hz}}$ given the laser power at the output of the ellipsometer of $P=24$ mW. This record result, very close to the predicted limit, demonstrates the feasibility of reaching such sensitivities, and opens the way to designing a dedicated apparatus for a first detection of vacuum magnetic birefringence.

1. Introduction

Vacuum magnetic birefringence and elastic light–light scattering have been predicted many years ago. Both effects are associated to the electron-positron vacuum fluctuations and can be calculated in the framework of the Euler–Heisenberg–Weisskopf effective Lagrangian L_{EHW} (S.I. units) [1]:

$$L_{EHW} = \frac{1}{2\mu_0}\left(\frac{\vec{E}^2}{c^2}-\vec{B}^2\right) + \frac{A_e}{\mu_0}\left[\left(\frac{\vec{E}^2}{c^2}-\vec{B}^2\right)^2 + 7\left(\vec{E}\cdot\vec{B}\right)^2\right] \tag{1}$$

where the parameter A_e describing the nonlinear behavior is

$$A_e = \frac{2}{45\mu_0}\frac{\alpha^2\bar{\lambda}_e^3}{m_e c^2} = 1.32\times10^{-24}\mathrm{T}^{-2}. \tag{2}$$

As a consequence, it can be shown that a region filled with a uniform magnetic field B_0 becomes birefringent [2,3] and that the difference in the index of refraction for linear polarization parallel and perpendicular to the field is

$$\Delta n = 3A_e B_0^2 \tag{3}$$

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which for a 2.3 T magnetic field results in $\Delta n=2.1\cdot10^{-23}$. Similarly one can also calculate the total elastic light–light scattering cross section for unpolarized light, which is proportional to A_e^2:

$$\sigma_{\gamma\gamma}^{(QED)}(\hbar\omega) = \frac{973\mu_0^2}{20\pi}\frac{\hbar^2\omega^6}{c^4}A_e^2. \tag{4}$$

For $\lambda=1064$ nm this cross section is $\sigma_{\gamma\gamma}=1.8\cdot10^{-69}$ m^2.

These values show the extreme difficulty of measuring such effects and explain why they still have to be measured. At present the best limits have been obtained by the PVLAS experiment and can be summarized in the parameter A_e measured with a field strength $B_0=2.3$ T:

$$\begin{aligned} A_e^{(PVLAS)} &< 6.6\cdot10^{-21}\mathrm{T}^{-2}@1064\mathrm{nm} \\ A_e^{(PVLAS)} &< 6.3\cdot10^{-21}\mathrm{T}^{-2}@532\mathrm{nm}. \end{aligned} \tag{5}$$

The average measured sensitivity to ellipticity of the apparatus present at the Laboratori Nazionali di Legnaro, Padova, Italy during long runs was about $\psi^{(PVLAS)}\approx1\cdot10^{-6}\,1/\sqrt{\mathrm{Hz}}$, a factor between 50 and 100 worse than the predicted sensitivity [4]. This is shown in Fig. 1, where the sensitivity is plotted as a function of the ellipticity modulation amplitude (see Apparatus and method section below), for both $\lambda=1064$ nm and $\lambda=532$ nm.

The Legnaro ellipsometer was designed to host a powerful superconducting magnet in a LHe cooled cryostat [4]. Given the low duty cycle of the cryogenic system it would have been impossible not only to refine the published limits, but also to improve the sensitivity of the ellipsometer

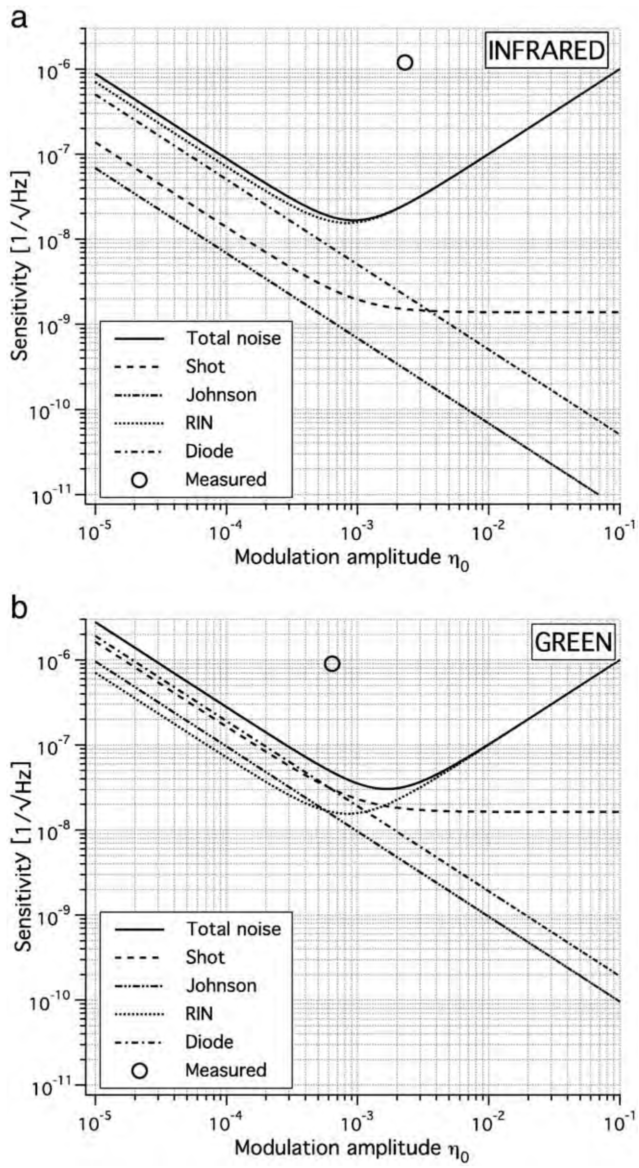

Fig. 1. Calculated and measured ellipticity sensitivity of the PVLAS apparatus at Legnaro, for the $\lambda = 1064$ nm (a) and the $\lambda = 532$ nm (b) cases. Shot-noise, Johnson noise, residual intensity noise (RIN), and photodiode noise contributions are shown separately. In black is shown the total noise. The circle indicates the measured sensitivity.

itself. The PVLAS collaboration has therefore implemented a scaled down tabletop version of the ellipsometer without any magnet, with the aim of reducing the main noise sources affecting this type of measurements and trying to reach a high finesse coupled with a high sensitivity.

2. Apparatus and method

The working principle of these ellipsometers is shown in Fig. 2. A polarizer **P** defines the linear polarization of the incoming laser beam.

Table 1
Main Fourier components in the intensity signal at the output of the ellipsometer. All symbols are defined in the main text.

Frequency	Fourier component	Intensity/I_0
DC	I_{DC}	$\sigma^2+\alpha_{DC}^2+\eta_0^2/2$
Ω	I_Ω	$2\alpha_{DC}\eta_0$
$\Omega\pm\omega$	$I_{\Omega\pm\omega}$	$\Psi\eta_0$
2Ω	$I_{2\Omega}$	$\eta_0^2/2$

Two mirrors **M1** and **M2** define a Fabry–Perot optical cavity with very high finesse F. Part of the region between the mirrors is filled by a transverse magnetic field and the ellipticity ψ acquired in a single pass is multiplied by a factor $2F/\pi$: $\Psi = \psi(2F/\pi)$. After mirror **M2** a photoelastic modulator **MOD** adds a known ellipticity $\eta(t) = \eta_0\cos(\Omega t)$ to the already acquired total ellipticity Ψ. After the modulator an analyzer **A**, rotated at 90° with respect to **P**, selects the electric field component perpendicular to the input polarization. The transmitted light is then detected by a low noise photodiode.

The magnetically induced ellipticity Ψ is varied in time with frequency ω. In the Legnaro setup this was obtained by rotating the dipole magnet around its axis. Slowly varying birefringences are also present in all optical elements; we indicate with $\alpha(t)$ the related ellipticity; moreover polarizers are non ideal and have extinction ratio σ^2. The total measured intensity can therefore be written as

$$I_{out} = I_0\left\{\sigma^2 + \eta(t)^2 + 2\eta(t)\alpha(t) + 2\eta(t)\Psi(t) + \ldots\right\}. \quad (6)$$

The introduction of the modulator linearizes the effect $\Psi(t)$, which would otherwise be quadratic. Since the ellipticity $\Psi(t)$ varies sinusoidally with angular frequency ω and the modulation with angular frequency Ω then the main Fourier components in the photodiode current are those reported in Table 1.

If the signal Ψ is above the noise it can be extracted from the observed spectrum as the average value of the sideband signals $I_{\Omega\pm\omega}$:

$$\Psi = \frac{1}{2}\left(\frac{I_{\Omega+\omega}}{\sqrt{2I_0 I_{2\Omega}}} + \frac{I_{\Omega-\omega}}{\sqrt{2I_0 I_{2\Omega}}}\right). \quad (7)$$

Several experimental efforts – both present and past – are based on this principle. The first was the BFRT collaboration (Brookhaven, Fermilab, Rochester, and Trieste) [5]. In their setup a multipass non resonant cavity was used. Current experiments all use Fabry–Perot cavities since the number of equivalent passes can be as high as 260,000 (reported here). One aspect, which is common to all these experiments, is that the theoretical sensitivity could not be reached with the optical path multipliers inserted. In Table 2 we report the sensitivities of the different efforts with the corresponding number of passes. Current experiments that aim to measure vacuum magnetic birefringence are BMV [8], OSQAR [9], and Q&A [6]: OSQAR is not listed in the table because it has not yet reported its sensitivity at the time of this writing.

Following the schematic layout of Fig. 2, a new compact benchtop ellipsometer was assembled at the Department of Physics of the University of Ferrara, Italy, to study the noise sources and the

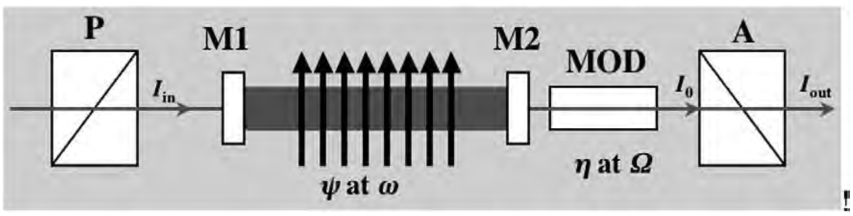

Fig. 2. Scheme of principle of the ellipsometer; all the components shown except the magnet are kept in high vacuum. In the ellipsometer reported here the magnet is not present at all.

Table 2
Rotation and ellipticity sensitivity of various experimental efforts using ellipsometers with optical path multipliers.

Experiment	Number of passes	Ellipticity/rotation sensitivity ($\frac{1}{\sqrt{\mathrm{Hz}}}$)	Sensitivity without cavity ($\frac{1}{\sqrt{\mathrm{Hz}}}$)	Δn ($\frac{1}{\sqrt{\mathrm{Hz}}}$)
BFRT [5]	254	$7\cdot10^{-8}$ at 30 mHz (rotation)	$7\cdot10^{-9}$ at 30 mHz (rotation)	$1.6\cdot10^{-17}$
Q&A [6]	18,600	10^{-6} at 13 Hz (ellipticity)		$9\cdot10^{-18}$
PVLAS LNL [4]	45,000	10^{-6} at 0.6 Hz (ellipticity)		$1.1\cdot10^{-18}$
J. Hall [7]	26,000	$3\cdot10^{-5}$ at 2 mHz (ellipticity)		$8\cdot10^{-16}$
BMV [8]	80,000	10^{-7} (ellipticity) (pulsed magnet)		$2.7\cdot10^{-18}$
PVLAS Ferrara	260,000	$2\cdot10^{-8}$ at 5 Hz (ellipticity)	$5\cdot10^{-9}$ at >2 Hz (ellipticity)	$5\cdot10^{-20}$

performance of ellipsometers based on Fabry–Perot cavities. In this ellipsometer the distance between the mirrors was $L=50$ cm. All optical elements of the ellipsometer, including the polarizer, cavity mirrors, modulator and analyzer, were mounted on a single breadboard. The entire breadboard was then inserted in a vacuum chamber. The polarizer **P**, entrance mirror **M1**, and analyzer **A** were mounted on motorized rotating mounts for polarization alignment and to achieve the best possible extinction ratio with the cavity inserted. We used the standard Pound–Drever–Hall method to lock the laser to the cavity but with the laser itself being used as the optical phase modulator [10]. The laser is a 200 mW Innolight Nd:YAG 1064 nm laser.

The vibrational nature of the noise in the Legnaro ellipsometer has been suspected for a long time. The new setup, therefore, was designed to be used both with and without seismic isolation; the basic seismic isolation uses pneumatic legs, which act as a low-pass filter with a cutoff frequency of about 5 Hz. At first, for a less critical setup, we used a cavity with finesse about $F=3000$. After achieving the best possible result, we mounted higher finesse mirrors. The mirrors were cleaned with pure ethanol immediately before insertion in the vacuum chamber. The beam–cavity coupling was optimized, and we reached a value of $F=414{,}000$, as can be seen in Fig. 3. We also achieved an input coupling of 75% with a total transmission of 25%.

The achievable sensitivity as a function of the modulation amplitude can be determined from the experimental parameters of the 50 cm long ellipsometer [4] for both the high and low finesse configurations. These are reported in Fig. 4. In principle, in the high finesse configuration a sensitivity of about $3\cdot10^{-9}1/\sqrt{\mathrm{Hz}}$ should be achievable. As can be seen in Fig. 4, right, due to the low-pass filter nature of the high finesse cavity, residual intensity noise at the modulator carrier frequency of 50 kHz is greatly suppressed with respect to the low finesse case.

3. Results

In Fig. 5 we report the acceleration spectral densities for the optical bench used. The top curve corresponds to the vertical acceleration when the seismic isolation is inactive. The two lower curves correspond to the vertical and horizontal accelerations of the bench with the isolation active. In the frequency range 5 Hz–50 Hz there is a suppression factor between 10 and 50. As far as the present work is concerned the region of interest is between 5 Hz and 20 Hz.

Fig. 6 shows the ellipticity spectral density for the low finesse configuration both with and without seismic isolation. There is a clear improvement of about a factor 10 in the frequency range of interest

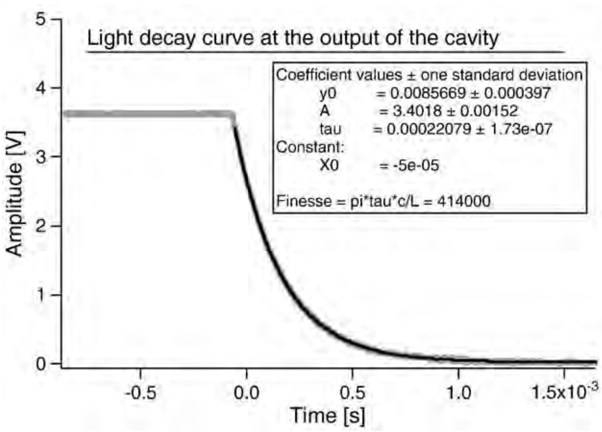

Fig. 3. Light decay curve at the output of the high finesse cavity (gray) with superimposed an exponential fit (black curve). Given the cavity length of about $L=50$ cm the resulting finesse was $F=414{,}000$.

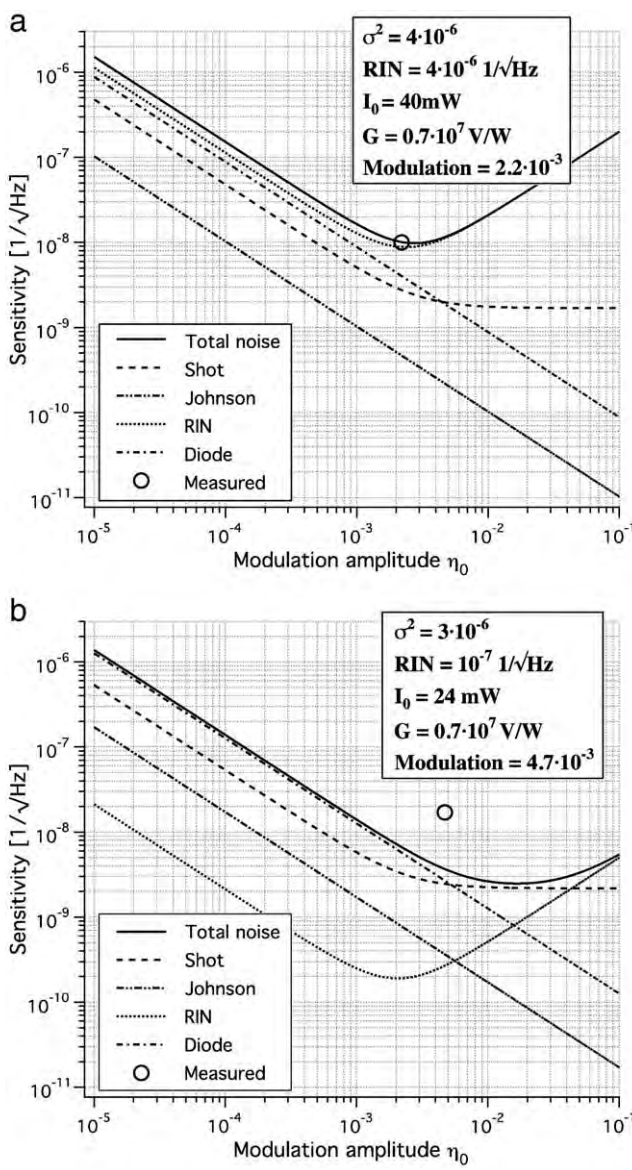

Fig. 4. Ellipticity sensitivity plots for the low finesse (a) and high finesse (b) configurations as a function of the modulation amplitude. Shot-noise, Johnson noise, residual intensity noise (RIN), and photodiode noise contributions are shown separately. In black is shown the total noise. The circle indicates the measured ellipticity sensitivity.

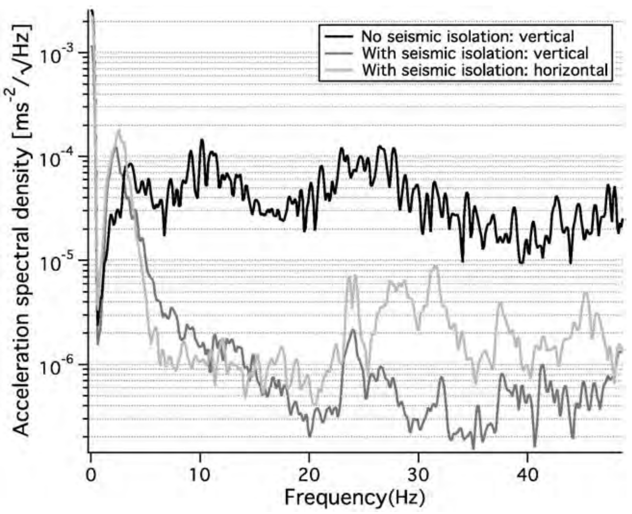

Fig. 5. Measured acceleration spectral densities. The top black curve corresponds to the configuration with the seismic isolation turned off whereas the dark gray and light gray curves correspond respectively to the vertical and horizontal accelerations with the seismic isolation turned on.

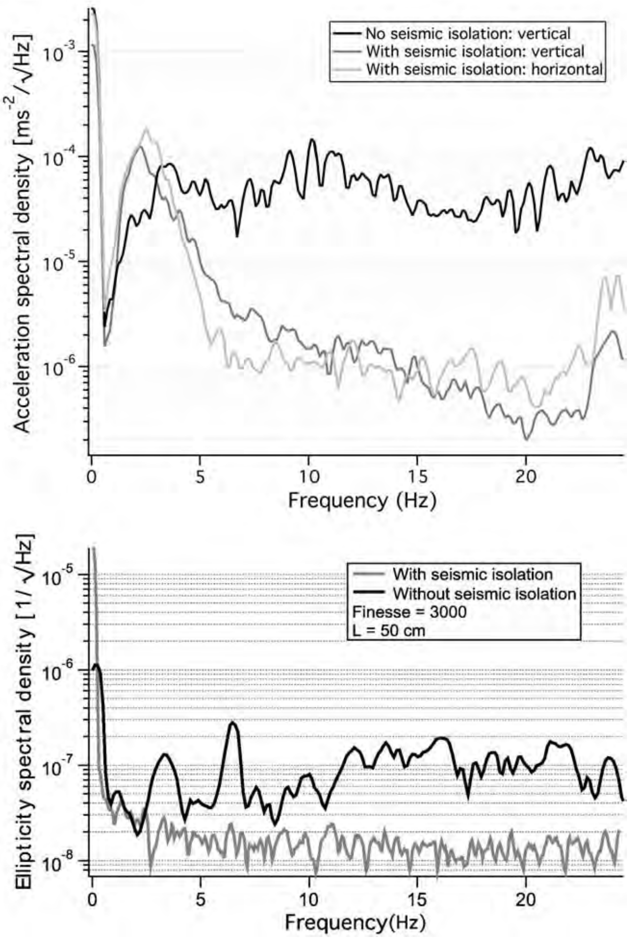

Fig. 6. Comparison between the spectral densities of acceleration and ellipticity for the low finesse ellipsometer. (Upper panel) The same acceleration data of Fig. 5 are shown. (Lower panel) Ellipticity is plotted as a function of frequency measured from the modulator carrier frequency; only the upper side of the spectrum is shown. The black curve corresponds to the configuration with seismic isolation turned off whereas the gray curve corresponds to the configuration with the seismic isolation turned on.

when the seismic isolation is turned on. We also remark that when the seismic isolation is turned on most spectral structures disappear and the noise is flat in the frequency range of interest. Although the seismic isolation helps reducing noise, there is no direct visible relationship between the structures in the acceleration and ellipticity spectral densities. The average noise of the single sided spectrum (only frequencies above Ω) between 5 Hz and 20 Hz is $1.4{\cdot}10^{-8}1/\sqrt{\text{Hz}}$ and averaging with the other half of the spectrum one obtains a sensitivity of

$$\Psi_{3000} = 1 \cdot 10^{-8} \frac{1}{\sqrt{\text{Hz}}}. \tag{8}$$

The measured value is represented in Fig. 4 as an empty circle along with the predicted sensitivity. It is clear that with the low finesse cavity we have reached the best possible value for the sensitivity, limited mainly by the residual intensity noise at the modulation frequency.

In Fig. 7 we show the spectral density of ellipticity noise for the cavity with finesse $F = 414{,}000$. Again the noise spectrum is flat and the noise around the carrier frequency is $2.6{\cdot}10^{-8}1/\sqrt{\text{Hz}}$. By averaging the upper and lower parts of the spectrum we obtain the record sensitivity

$$\Psi_{414000} = 1.8 \cdot 10^{-8} \frac{1}{\sqrt{\text{Hz}}}. \tag{9}$$

Considering a cavity length of $L = 50$ cm this implies a sensitivity in birefringence of

$$\Delta n_{414000} = 4.6 \cdot 10^{-20} \frac{1}{\sqrt{\text{Hz}}}. \tag{10}$$

4. Discussion and developments

Although the achieved sensitivity is extremely good, it is still about 7 times worse than the shot noise limit, as can be seen in Fig. 4. Fig. 6 shows that seismic noise is important and must be eliminated, because it elevates the noise floor, however the mechanical and the ellipticity spectra are different, and therefore there is not a direct link between seismic noise and ellipticity sensitivity. This is unlike what we observed in the apparatus in Legnaro, where mechanical and ellipticity spectra were very similar. Moreover, as Fig. 7 shows, noise is so flat and structureless that we can conclude that it cannot have a seismic or mechanical origin. Indeed these kinds of noises are typically not flat. Furthermore the measured noise fluctuations are not symmetric around the carrier frequency and must therefore be an

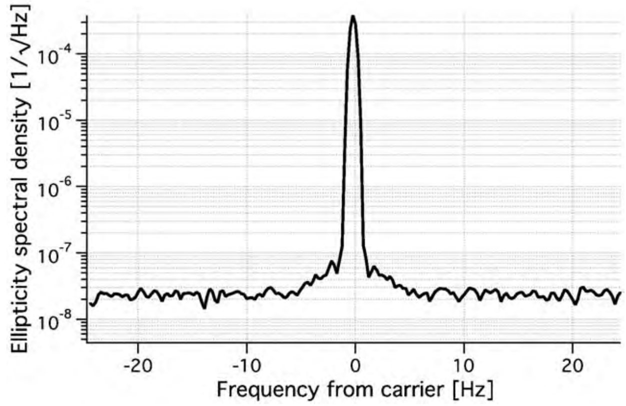

Fig. 7. Spectral density of ellipticity noise around the carrier frequency for the cavity with finesse $F = 414{,}000$.

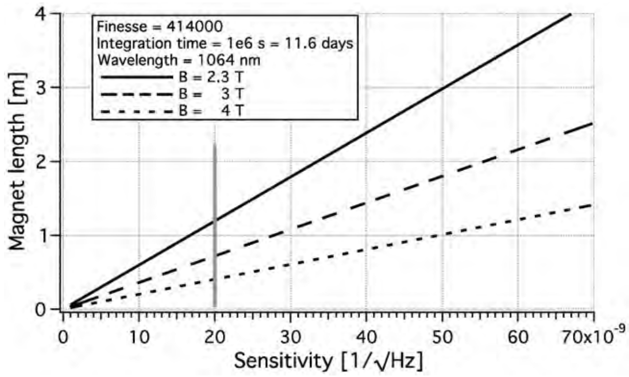

Fig. 8. Plots of the necessary magnetic field length as a function of sensitivity to reach a signal to noise ratio of 1 in a time $T = 10^6$ s. Three different field strengths are shown: 2.3 T, 3 T and 4 T. The gray vertical line indicates the experimentally reached ellipticity sensitivity reported in this paper.

independent noise floor present at and near the carrier frequency. The origin of this noise is presently under study.

Magnets cannot be inserted in the 50 cm ellipsometer with which we have obtained this record sensitivity. Thus a new and slightly longer prototype compatible with the insertion of two dipole magnets has been constructed and is under test. If a similar sensitivity to the one discussed above will be achieved with magnets in place, this will open the way to the construction of a final system for a first vacuum magnetic birefringence measurement. Magnet rotation may introduce additional seismic noise, however a proper damping structure and mechanical isolation should be sufficient to stop vibrational motions induced by the magnet, as was already demonstrated with the Legnaro apparatus. We plan to introduce magnetic field shielding and to encase the magnets to avoid acoustic noise and air drafts.

In Fig. 8 we show the magnetic field length as a function of sensitivity which is necessary to reach a signal to noise ratio of 1 in a reasonable integration time of $T \approx 10^6$ s. The figure makes it clear that a very high sensitivity is mandatory to make the actual measurement feasible.

5. Conclusion

In this paper we have reported the sensitivity improvement obtained with a 50 cm long ellipsometer based on a Fabry–Perot optical cavity. The fundamental conclusion is that, for reaching good sensitivities, the optical bench must be globally isolated from seismic noise. With a system having a finesse of $F = 3000$ we were able to reach the theoretical sensitivity calculated from the experimental parameters. With the system having a finesse $F = 414{,}000$ a sensitivity of $\Psi_{414000} = 1.8 \cdot 10^{-8} 1/\sqrt{\mathrm{Hz}}$ was obtained, which is a record result, although still larger than the theoretically expected value. Considering a length of $L = 50$ cm this sensitivity implies a birefringence sensitivity of $\Delta n = 4.6 \cdot 10^{-20} 1/\sqrt{Hz}$.

We believe that the findings reported in this paper are a step forward in the effort of reaching the first measurement of nonlinear QED effects in vacuum.

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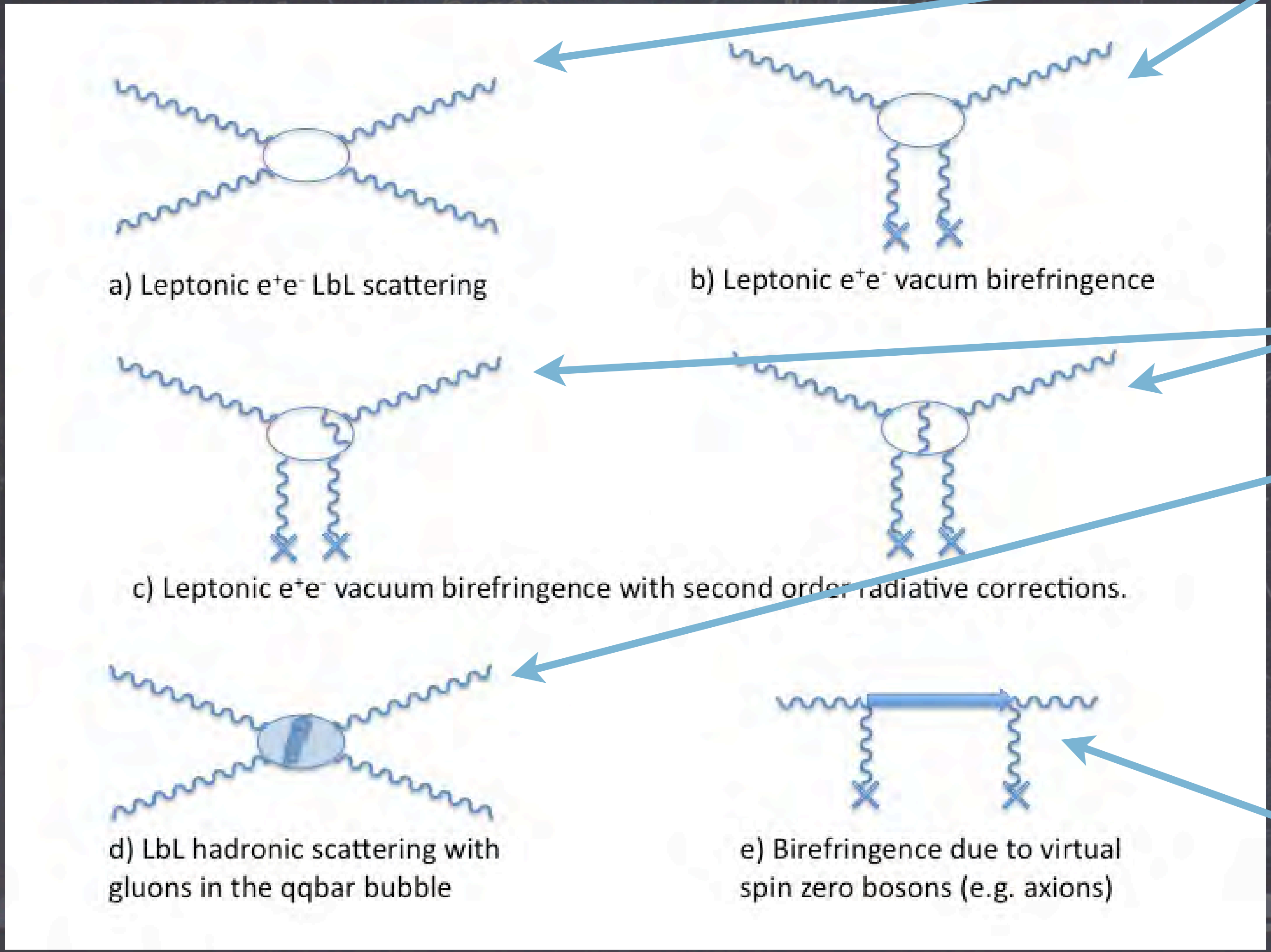
Appendix 4:

PVLAS report

Guido Zavattini - pvlas collaboration

"Hands holding the void"
Alberto Giacometti

Fisica



- Descritto da Lagrangiana Euler-Heisenberg. Ci deve essere. Comprende anche MCP
- Correzione 1.45%
- Contributi adronici non riconducibile ad altre misure indirette. Problema aperto nel g-2 del muone
- Contributi di particelle nuove che si accoppiano a due fotoni.

$$\Delta n_{QED} = 3A_eB^2 = 4\cdot 10^{-24}B^2\ T^{-2}$$

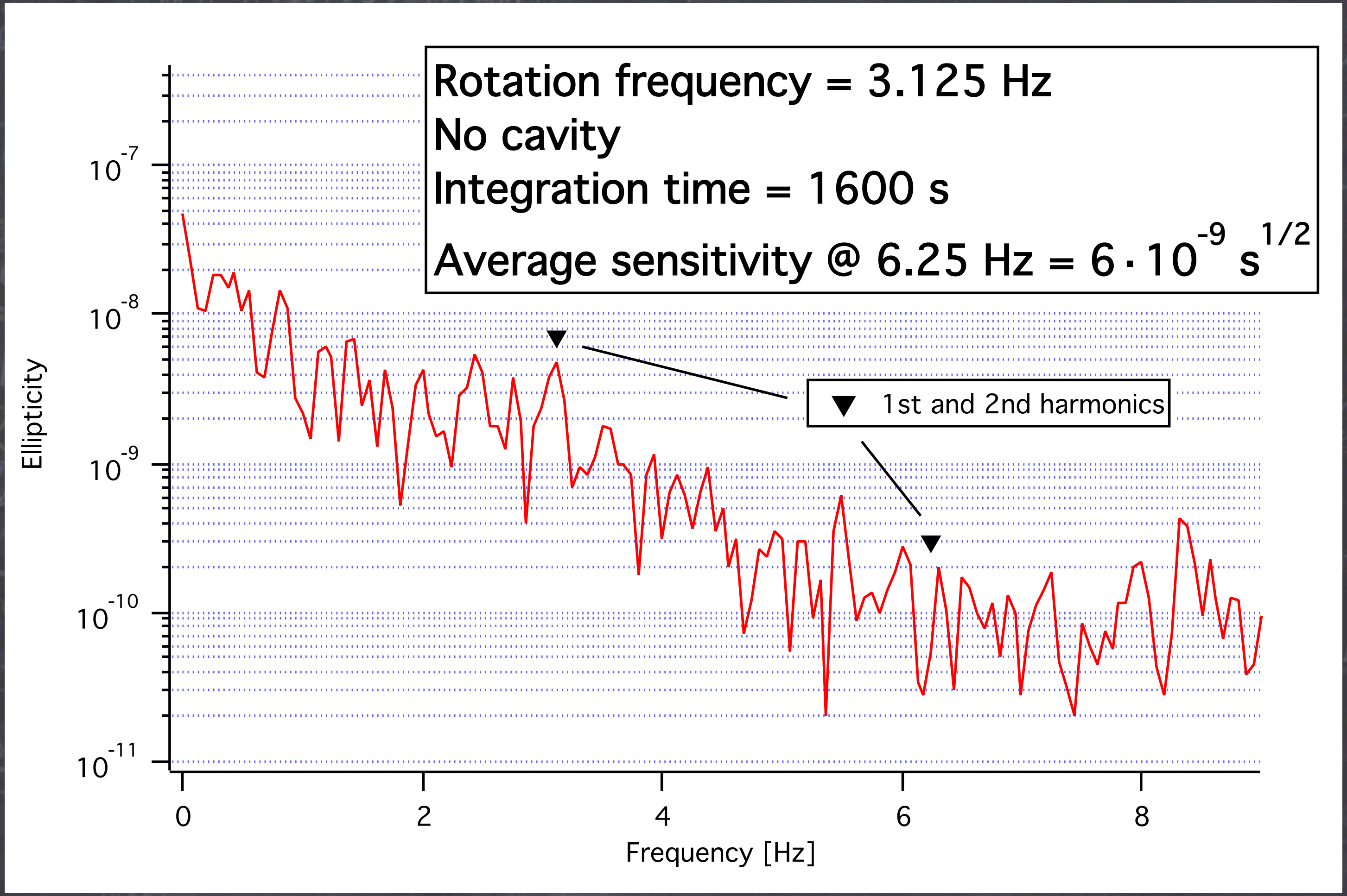
Cronologia da Ottobre-Aprile

- Montato tubo inox con magneti in linea
  - prime misure senza cavità e con cavità a finesse bassa
  - prima dimostrazione che l'insieme dell'apparato funziona

- Montato tubo in vetro (Sergey Atutov ci salda il tubo in loco) con magneti in linea
  - prime misure senza cavità: sensibilità = $6 \cdot 10^{-9}\ 1/\sqrt{Hz}$
  - prime misure con cavità a finesse bassa: sensibilità = $1.5 \cdot 10^{-8}\ 1/\sqrt{Hz}$

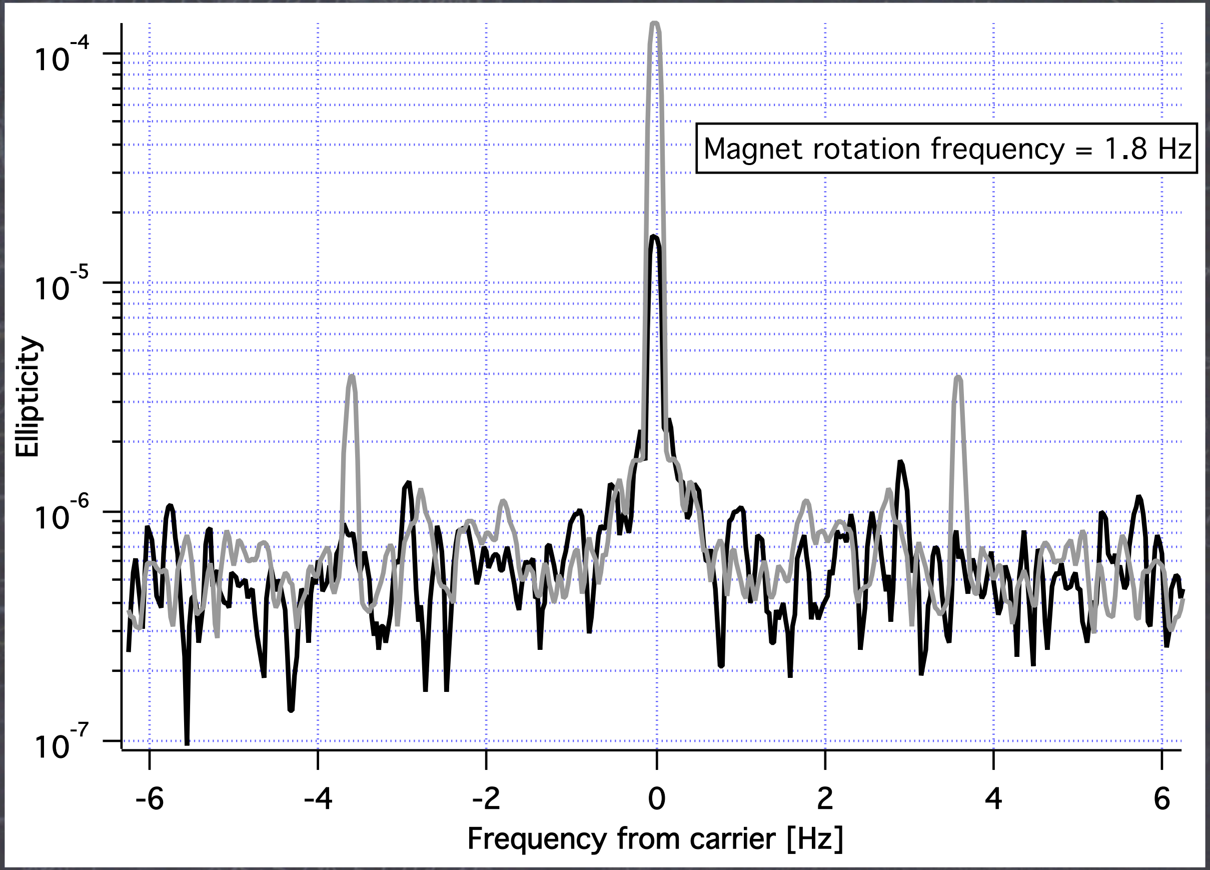
- Giunto che permette di agganciare meccanicamente i magneti a 0 e 90 gradi 'assorbendo' disallineamenti meccanici
  - Misure Cotton-Mouton con bassa finesse per verificare la cancellazione dell'effetto con i magneti a 90 gradi.

Aprile 2009



- Misura di 1600 s senza cavità e con i magneti in linea a 0 gradi. La sensibilità media sulla misura era di $6 \cdot 10^{-9}$ $1/\sqrt{Hz}$

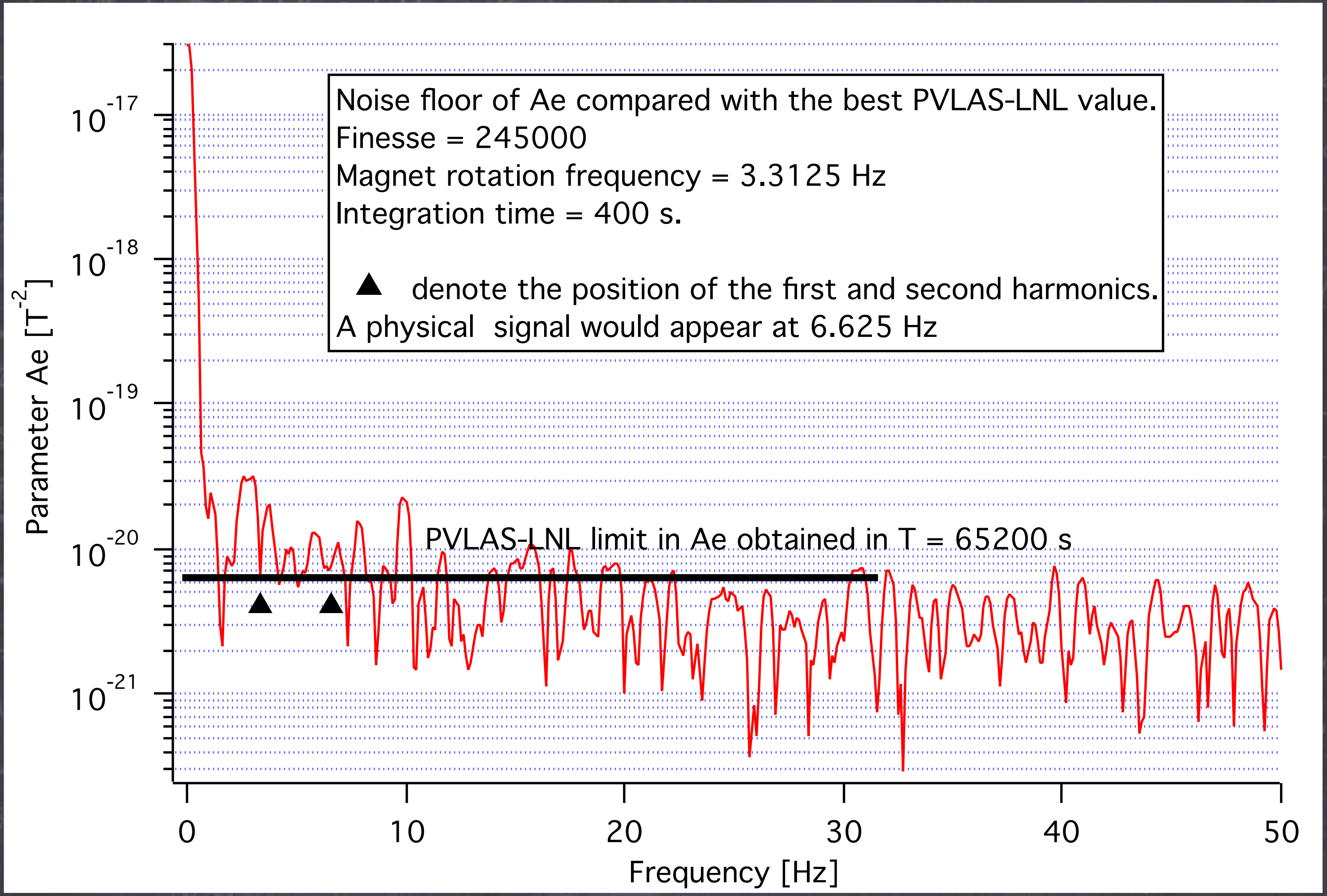
Aprile 2009



In grigio, magneti a 0 gradi
In nero, magneti a 90 gradi

- Con finesse 3000 abbiamo dimostrato la cancellazione dell'effetto con i magneti a 90 gradi.

Attualmente



- Con finesse 245000 abbiamo integrato per alcuni minuti per vedere la qualità del sistema.
- Sensibilità = $2 \cdot 10^{-7}$ $1/\sqrt{Hz}$

Foto attuale

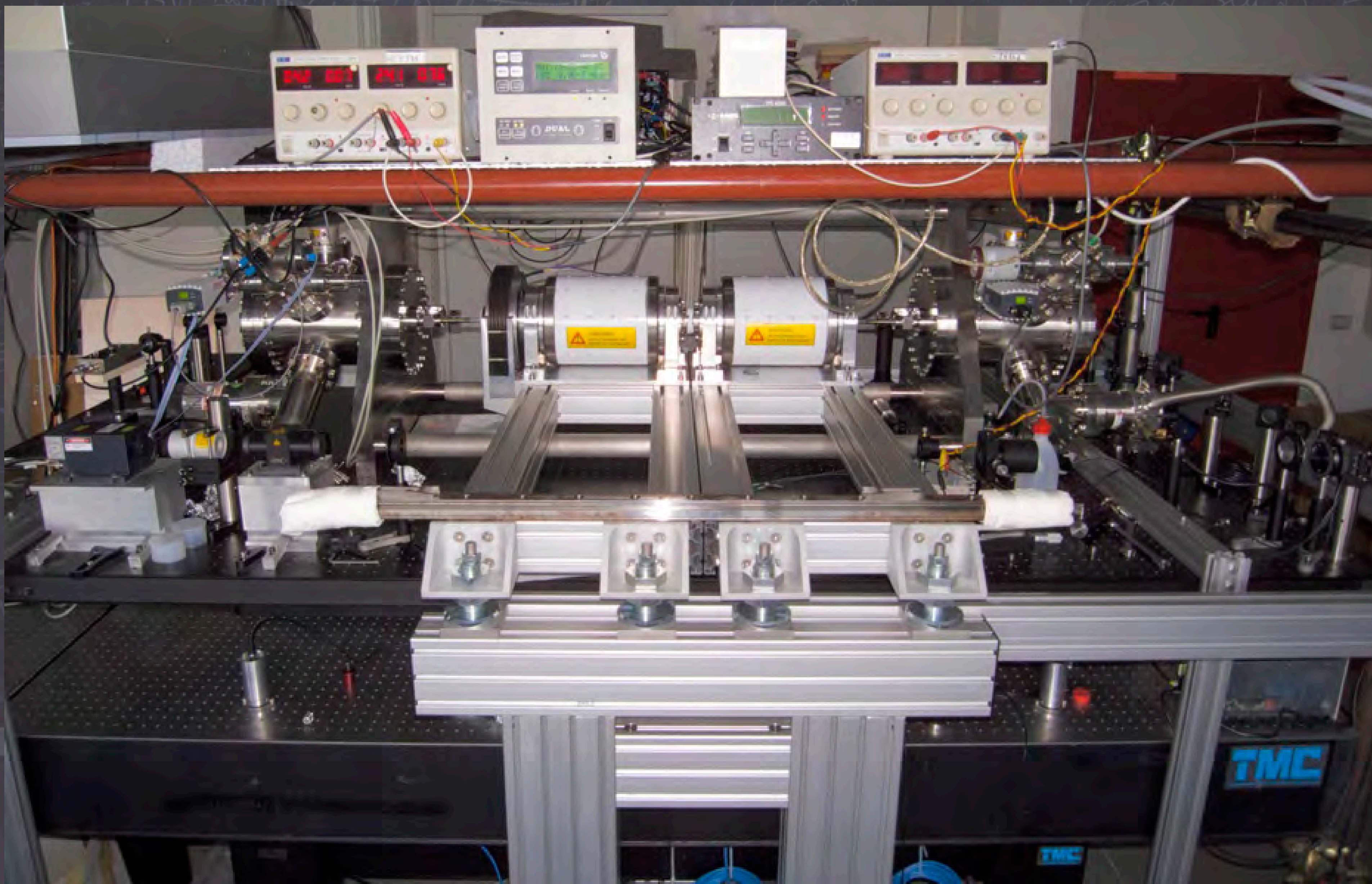


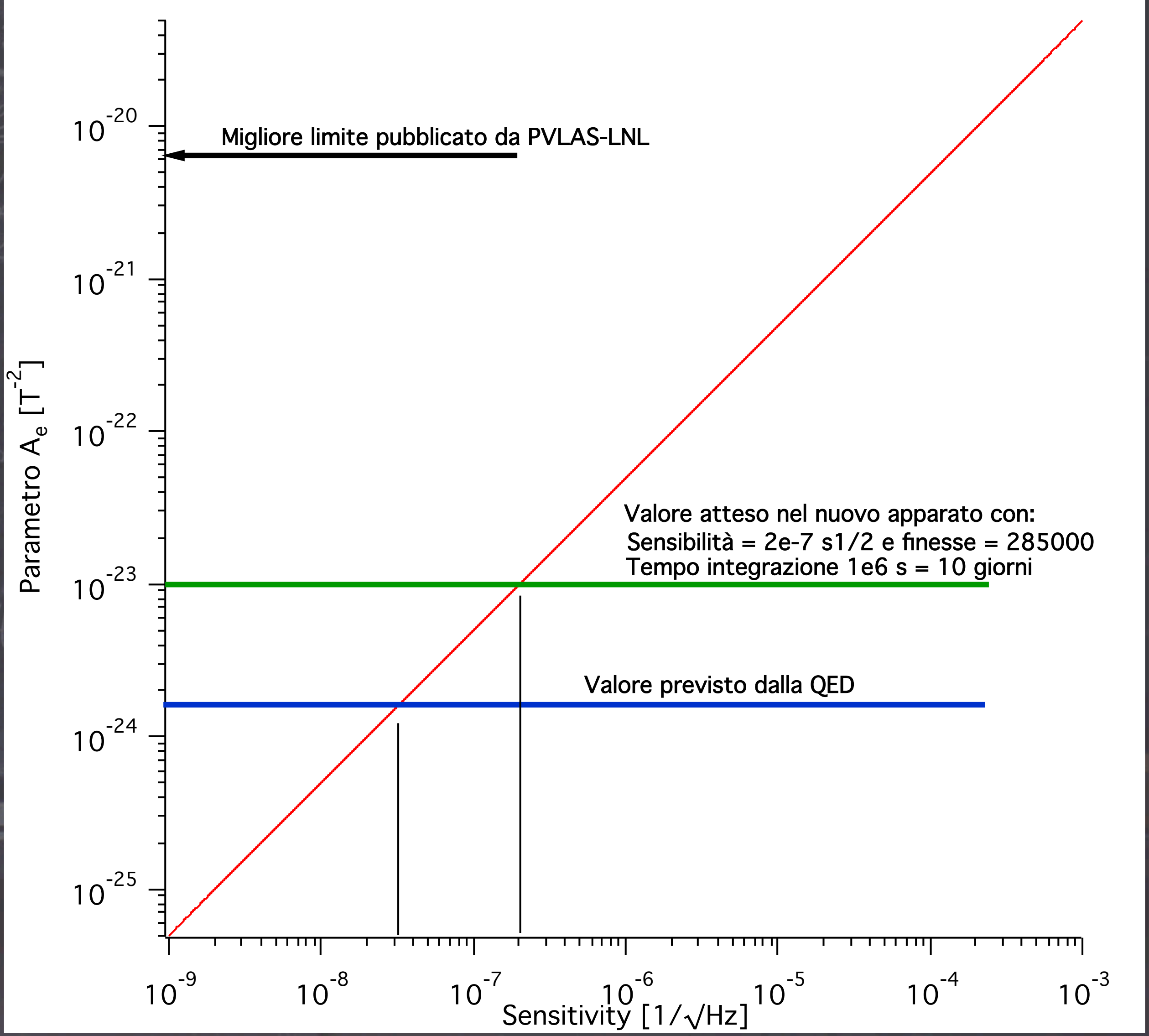
Foto attuale: giunto

Spazio parametrico da colmare

$$\mathcal{L}_{\text{EH}} = \frac{1}{2\mu_0}\left(\frac{\vec{E}^2}{c^2} - \vec{B}^2\right) + \frac{A_e}{\mu_0}\left[\left(\frac{\vec{E}^2}{c^2} - \vec{B}^2\right)^2 + 7\left(\frac{\vec{E}}{c}\cdot\vec{B}\right)^2\right]$$

$$\Delta n = 3A_eB^2$$

- Con i parametri attuali sull'apparato di test portati sul nuovo apparato si colmano quasi 3 ordini di grandezza in A_e



Concorrenza

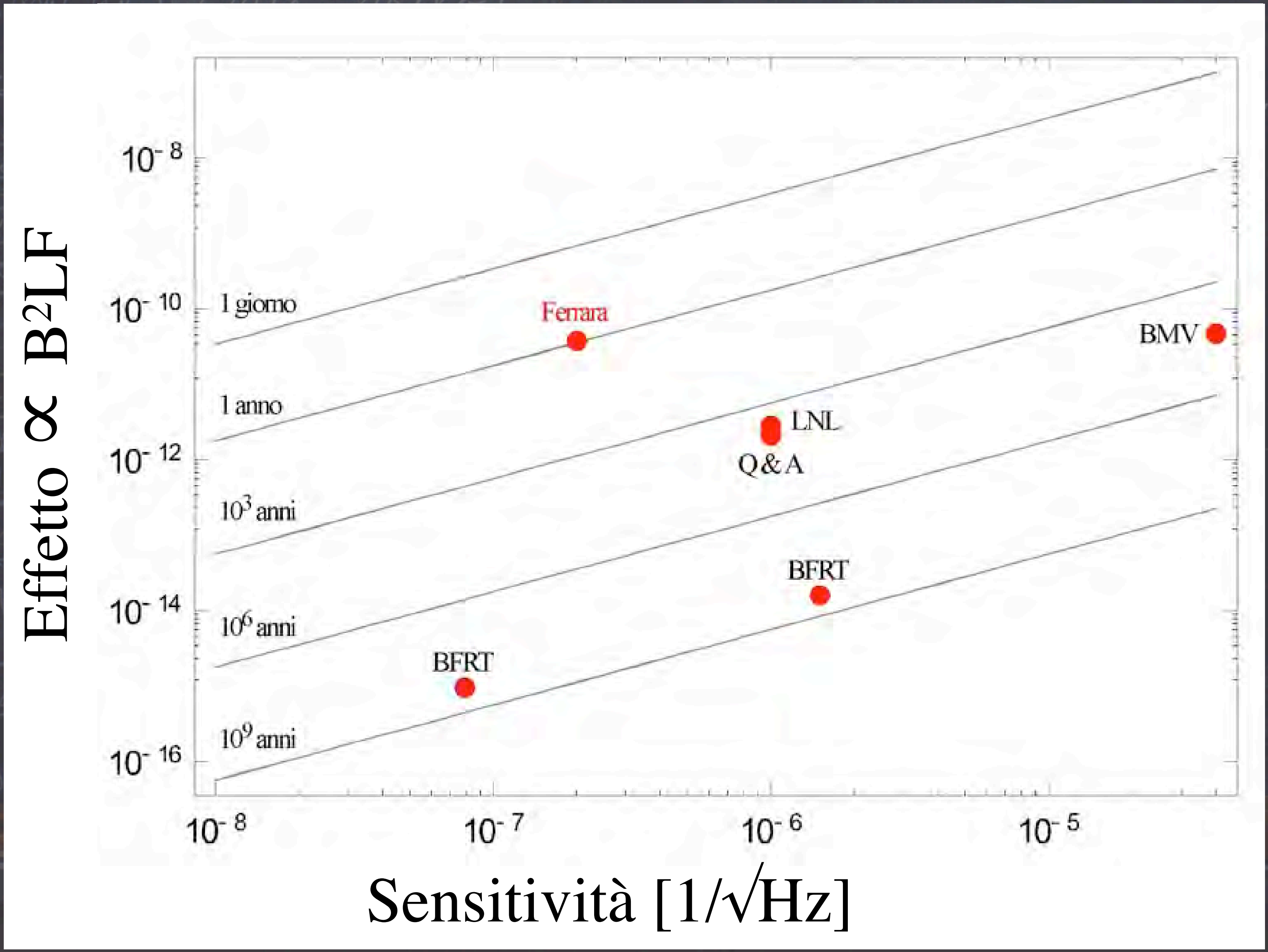
- Q&A experiment - Taiwan
  Sensibilità 10^{-6} $1/\sqrt{Hz}$, con F = 30000, campo 2.3 T, L = 180 cm, 1 magnete. Banchi ottici separati.
  $T_{QED} = 2\cdot10^{11}$ s = 6800 anni

- BMV experiment - Toulouse
  Sensibilità ≈ 10^{-7} $1/\sqrt{Hz}$ con F = 130000, campo impulsato qualche ≈ 2 ms, 100 T^2m, 1 colpo/12 min => sensibilità efficace = $5\cdot10^{-5}$ $1/\sqrt{Hz}$
  $T_{QED} = 3.8\cdot10^{11}$ s = 12000 anni

- OSQAR experiment - CERN
  Sensibilità = ??? Magnete di LHC lungo 15 m, 10 T, Finesse ≈ 1000, banchi ottici separati. Magnete non modulabile. Assumendo sensibilità = 10^{-7} $1/\sqrt{Hz}$,
  $T_{QED} = 7.8\cdot10^{7}$ s = 2.5 anni

- PVLAS
  Sensibilità $2\cdot10^{-7}$ $1/\sqrt{Hz}$, con F = 285000, campo 3 T, L = 1.4 m, 2 magneti. Banco unico.
  $T_{QED} = 5\cdot10^{7}$ s = 1.7 anni

Concorrenza



Come incrementare segnale

$$T_{misura} \propto (\text{segnale})^{-2} \propto (\lambda/B^2LF)^2$$

- Dimezzare la lunghezza d'onda: 532 nm. Laser disponibile. La nostra esperienza è che la qualità degli specchi è leggermente peggiore. Oggi la qualità è forse migliorata. Fattore 4 in T_{misura}.

- Allungare la zona di campo magnetico aggiungendo un terzo magnete. Per questo motivo sarebbe bene scegliere da subito i magneti da 3 T e 0.7 m ciascuno. Di più diventerebbe complicato per la lunghezza totale dell'apparato. Fattore 2.25 in T_{misura}.

- Aumentare ancora la finesse, (raddoppiare?). Fattore 4 in T_{misura}.

- Fattore di riduzione totale 18 => $T_{misura} \approx$ 35 giorni

- Se ritrovassimo sensibilità = $2 \cdot 10^{-8}$ $1/\sqrt{Hz}$ e finesse 400000 con 2 magneti da 3T lunghi 0.7 m => T_{misura} = 7.7 giorni

Commenti

- L'apparato e le soluzioni adottate rendono PVLAS ancora il migliore apparato al mondo
- La derivata molto positiva nello sviluppo dell'apparato prosegue
- I proponenti sono convinti della validità dell'apparato proposto e dei risultati di fisica comunque ottenibili
- C'è un crescente numero di proposte per lo studio del vuoto non lineare (non solo con misure di birifrangenza ma anche con misure di diffusione fotone-fotone)

Opzioni magneti

Table 1Summary of the budgetary price available

Manufacturer	Delivery Time	Budgetary price	weight
AMT&C (RU)	90 days	183 (155) kEuro	470 (410) kg
Inst. Electr. Eng. (China)	8 months	95 kEuro	600-825 kg
SISRAM (Vacuumschmelze)	NA	92 kEuro + 4.5 kEuro	Ca. 150-200 kg
SISRAM (Vacuumschmelze) 3Tesla 0.7 m	NA	108 kEuro + 4.5 kEuro	Ca. 150 kg or less

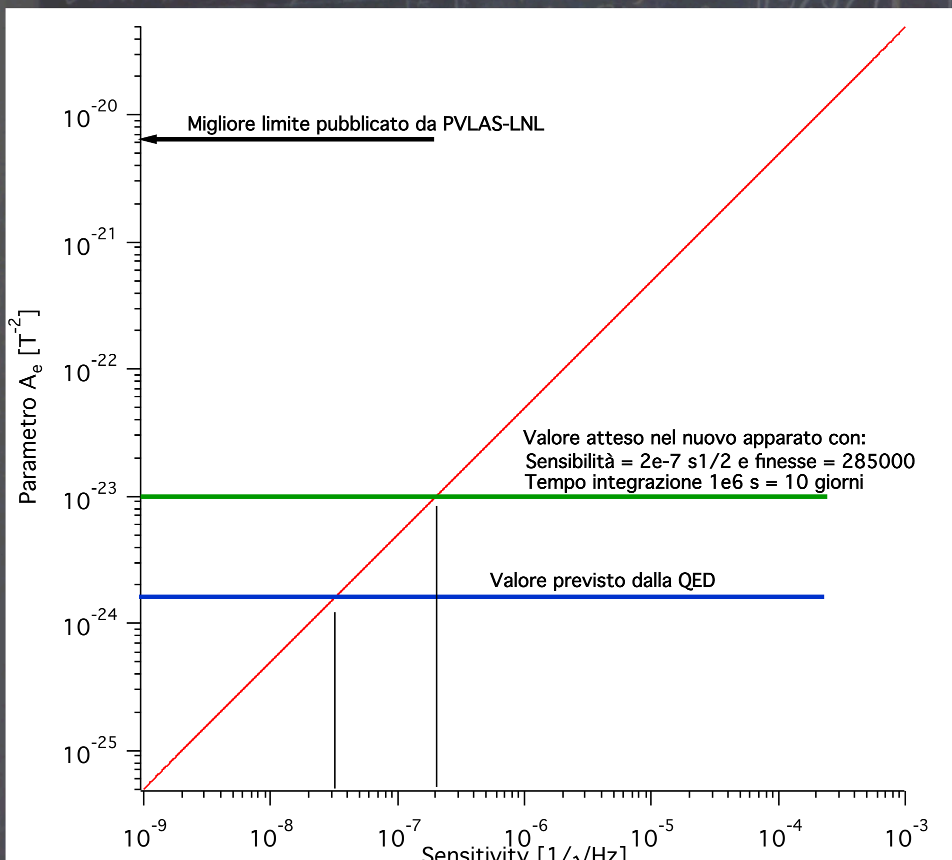
Saremmo orientati verso il magnete costruito dalla Vacuumschmelze. In particolare quello da 3T ma più corto. La ditta è molto interessata a questa costruzione. Sono venuti a Ferrara a vedere l'apparato.

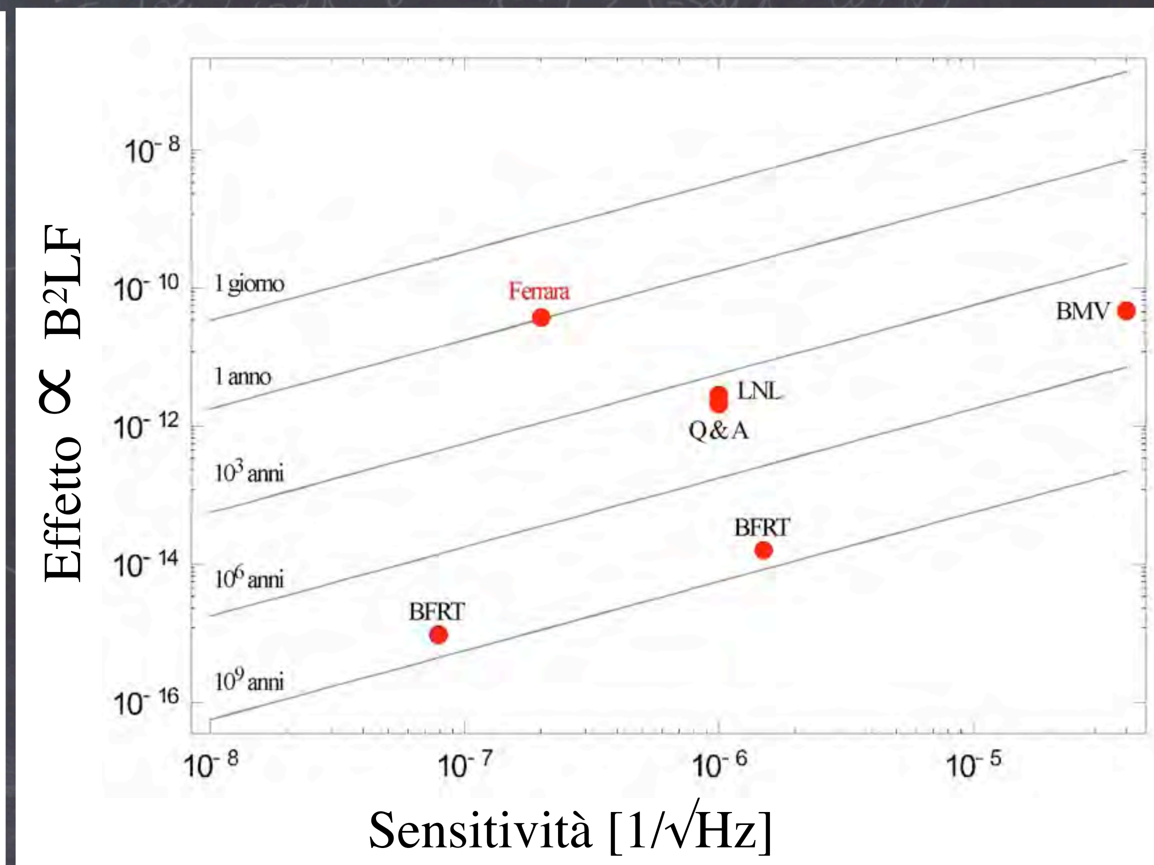
Sblocco s.j.

Sigla Loc.	Capitolo	Note Richiesta	Rich.	Rich. Sj	Assegn. Sett	
						Sj
FE	APPARATI	Banco ottico lungo 4.2m con gambe pneumatiche	26.0			26.0
		Breadboard lungo 4.2m con banchi isolamento Minus-k	30.0			30.0
		3 Motori per ultra alto vuoto con controllo	15.0			15.0
		Meccanica dell'elissometro e camere da vuoto	20.0			20.0
TOT						91.0
LNL	APPARATI	Set di due magneti permanenti dipolari ciascuno con lunghezza 1m, diametro dell'internal bore superiore a 2 cm, campo superiore a 2.3 Tesla	120.0			40.0
		supporti magneti permanenti + motori	20.0			20.0
		Schermature dell'elissometro		10.0		10.0
TOT						70.0
TOT GENEARALE						161.0

Piano finanziario 2011-2012

- 2010 - sblocco s.j.
  - Avviamento gara magneti nuovi: 40 keuro
  - Acquisto banco ottico finale motori e meccanica da ultra alto vuoto: 120 keuro
  - Disegno CAD finale meccanico
- 2011
  - Completamento acquisto magneti: 80 - 100 keuro
  - Acquisti e montaggio meccanica del nuovo ellissometro: circa 150 keuro
  - Spese correnti (MI, ME, consumi)
- 2012
  - Spese di run


Migliore limite pubblicato da PVLAS-LNL
Valore atteso nel nuovo apparato con:
Sensibilità = 2e-7 s1/2 e finesse = 285000
Tempo integrazione 1e6 s = 10 giorni
Valore previsto dalla QED
Parametro A_e [T^{-2}]
Sensitivity [1/√Hz]
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}


Effetto ∝ B^2LF
Sensitività [1/√Hz]
1 giorno
1 anno
10^3 anni
10^6 anni
10^9 anni
Ferrara
BMV
LNL
Q&A
BFRT
BFRT
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-8}
10^{-7}
10^{-6}
10^{-5}