

L'expérience BMV

(Biréfringence Magnétique du Vide)

Carlo RIZZO

LCAR-IRSAMC

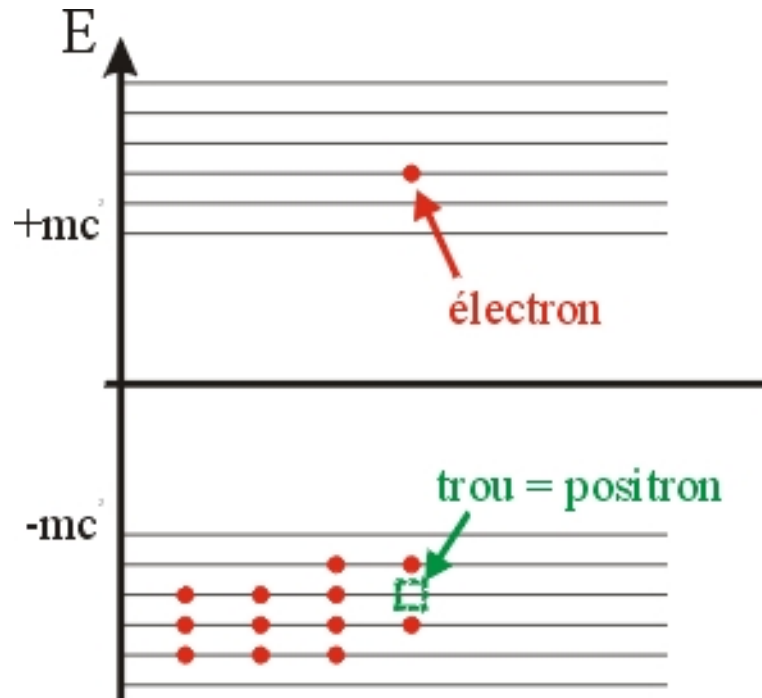
Université Paul Sabatier et CNRS

Toulouse

Plan

- Introduction
- Historique
- Expérience BMV
- La « concurrence »
- Conclusions

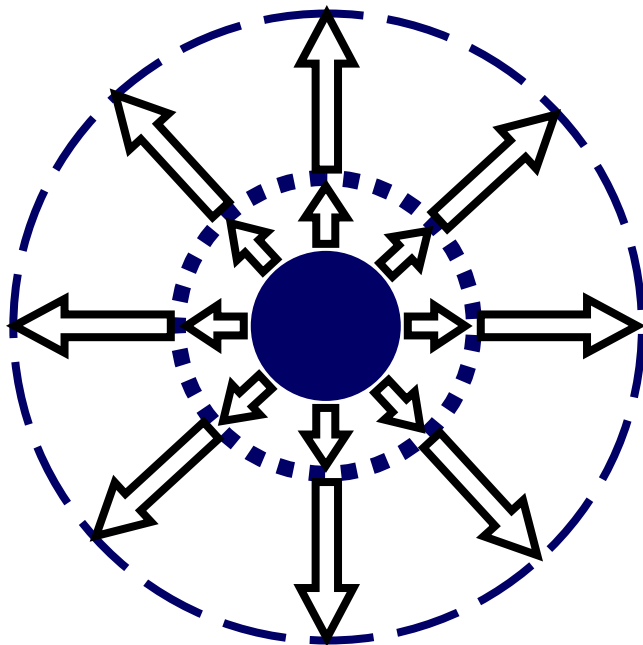
Le modèle de Dirac du Vide Quantique : 1934



« Previously, people have thought of the vacuum as a region of space that is completely empty, a region of space that does not contain anything at all. Now we must adopt a new picture. We may say that the vacuum is a region of space where we have the lowest possible energy. Now, to get the lowest energy we must fill up all the states of negative energy [...] Thus we must set up a new picture of the vacuum in which all the negative energy states are occupied and all the positive energy states are unoccupied. »

P.A.M. Dirac, (1978)

L'expansion de l'univers s'accélère !!!



L'existence de la
densité d'énergie du
vide pourrait expliquer
ce phénomène
mais
sa valeur est au moins
 10^{50} fois trop grande !

Propagation de la lumière dans le vide quantique

Le vide est invariant par Lorentz et CPT, donc

$$L = \frac{1}{2}F + aF^2 + bG^2 + \dots \quad \text{où} \quad F = (\varepsilon_0 E^2 - \mu_0^{-1} B^2); \quad G = \sqrt{\varepsilon_0 \mu_0^{-1}} (\vec{E} \bullet \vec{B})$$

1935-1936 Kochel, Euler, Heisenberg $\frac{b}{a} = 7$

H.Euler et K.Kochel, *Naturwiss.* **23** (1935); W.Heisenberg et H.Euler, *Z. Phys.* **38** (1936) 714

... en présence de B_0 : $n_{par} \neq n_{per}$

$$\Delta n = (b - 4a) \mu_0^{-1} B_0^2$$

$$\Delta n = n_{par} - n_{per}$$

$$\Delta n = 4 \times 10^{-24} B_0^2$$

avec B_0 en Tesla

Z.Bialynicka-Birula et I.Bialynicki-Birula, *Phys. Rev. D* **2** (1970) 2341

Défi expérimental
Ellipticité en $B_0^2 \times L$

Le vide quantique est un milieu optique non linéaire

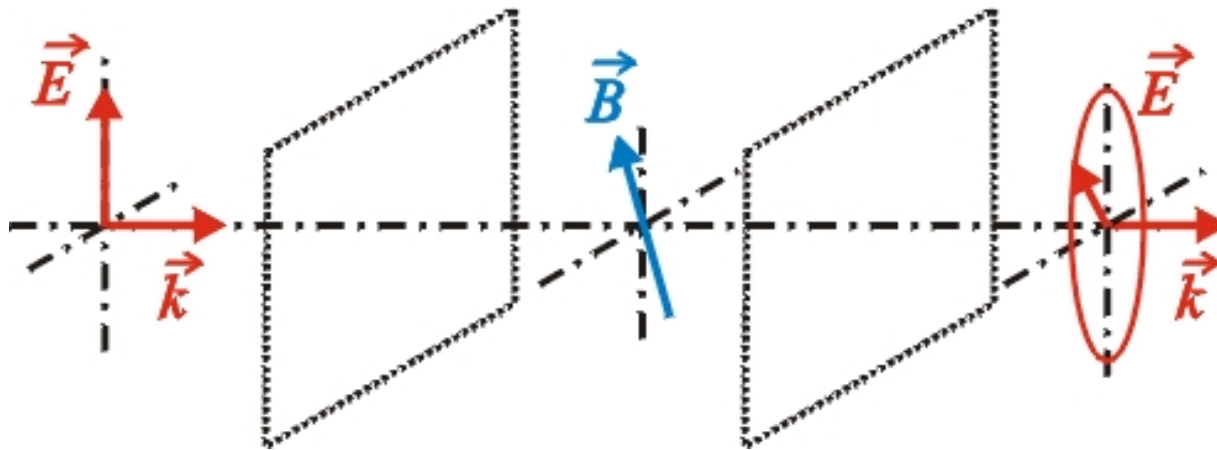
Biréfringence magnétique du vide

ou *effet Cotton-Mouton* : connu depuis 1901 dans les milieux standards

J.Kerr, *Br. Assoc. Rep.* (1901) 568;

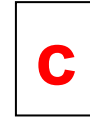
A.Cotton et H.Mouton, *Ct. R. hebd. Séanc Acad. Sci. Paris* **141** (1905) 317,

349; *ibid.* **142** (1906) 203; *Ibid.* **145** (1907) 229



$$\Delta n (\text{vide}) \approx 10^{-8} \Delta n (\text{hélium STP})$$

Propagation dans le vide :



$$\begin{array}{c}
 \text{Photon réel} = \text{Photon nu} + \text{Paire virtuelle } e^+e^- + \dots
 \end{array}$$

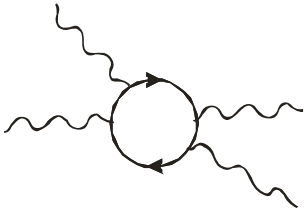
Propagation dans le vide en présence d'un champ

$$\begin{array}{c}
 \text{B}_0 \text{ (ou } E_0\text{)} \\
 \text{+ Paire virtuelle } e^+e^- \text{ + Corrections radiatives + } \dots
 \end{array}$$

$O(\alpha^2)$

$O(\alpha^3)$

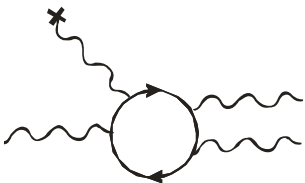
1,5 % du terme d' $O(\alpha^2)$

$O(\alpha^2)$ 

Collisions photon-photon

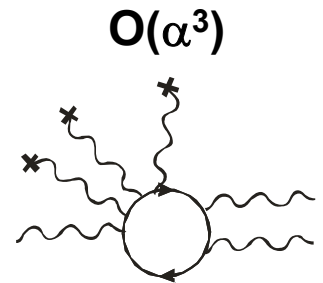
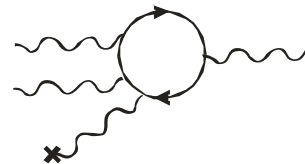
A.L.Hughes et G.E.M.Jauncey, *Phys. Rev.* **36** (1930) 773R.Karplus et M.Neuman, *Phys. Rev.* **83** (1951) 776

Mélange à quatre ondes

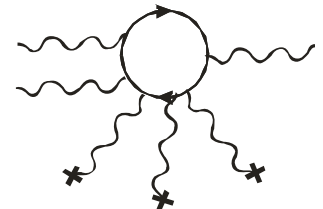
D.Bernard et al, *Eur. Phys. J. D* **10** (2000) 141 => Expérience au LULI $O(\alpha^2)$ 

Photon splitting

Génération de subharmoniques

S.L.Adler et al., *Phys. Rev. Lett.* **25** (1970) 1061 $= 0 !$ \Rightarrow  $O(\alpha^3)$ 

Génération d'harmoniques

Y.I.Ding et A.E.Kaplan, *Int. J. Nonlin. Opt. Phys.* **1** (1992) 51 $= 0 !$ \Rightarrow 

Φ Particule bosonique de faible masse « m », neutre, sans spin

S'il y a un couplage avec deux photons, L peut s'écrire :

(Constante de couplage $g = 1/M$)

Particule pseudoscalaire (*comme les axions de Peccei et Quinn*)

R. Peccei et H.R.Quinn, *Phys. Rev. Lett.* **38** (1977) 1440

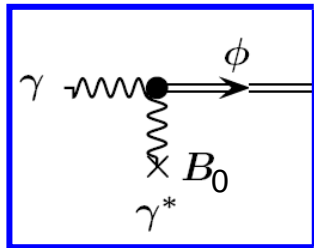
$$L_{ps} = 1/M \Phi G$$

$$F = \left(\varepsilon_0 E^2 - \mu_0^{-1} B^2 \right); \quad G = \sqrt{\varepsilon_0 \mu_0^{-1}} (\vec{E} \bullet \vec{B})$$

Particule scalaire

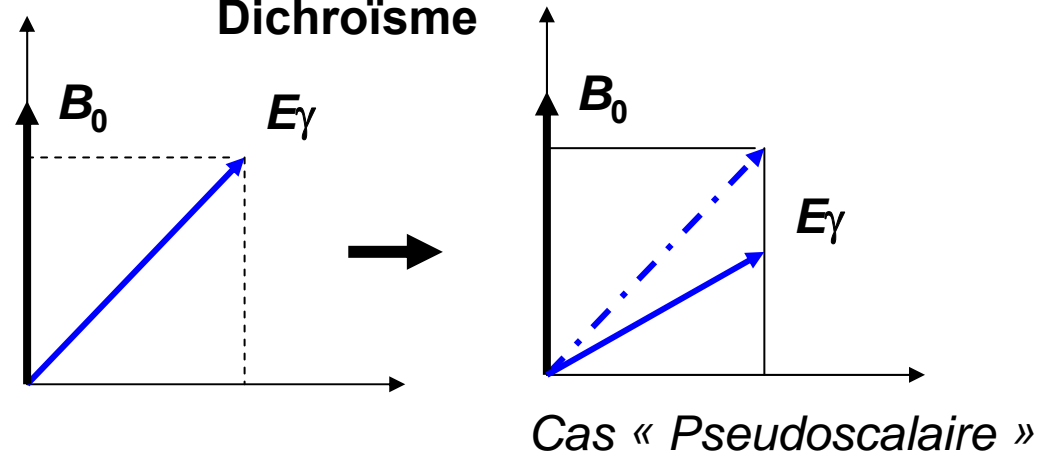
$$L_s = 1/M \Phi F$$

Particule réelle



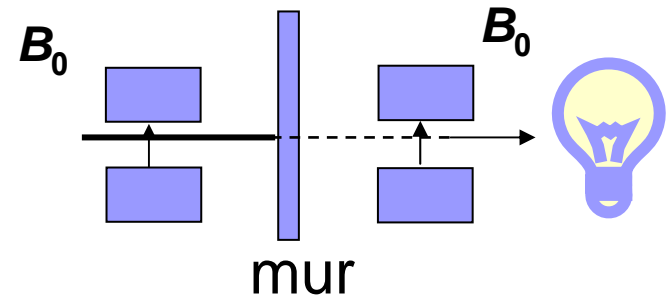
Effets « $B_0 L$ »

Dichroïsme

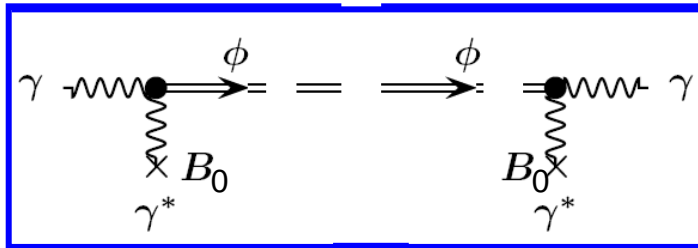


L.Maiani, R.Petronzio et E.Zavattini, *Phys. Lett. B* **175** (1986) 359

Photorégénération

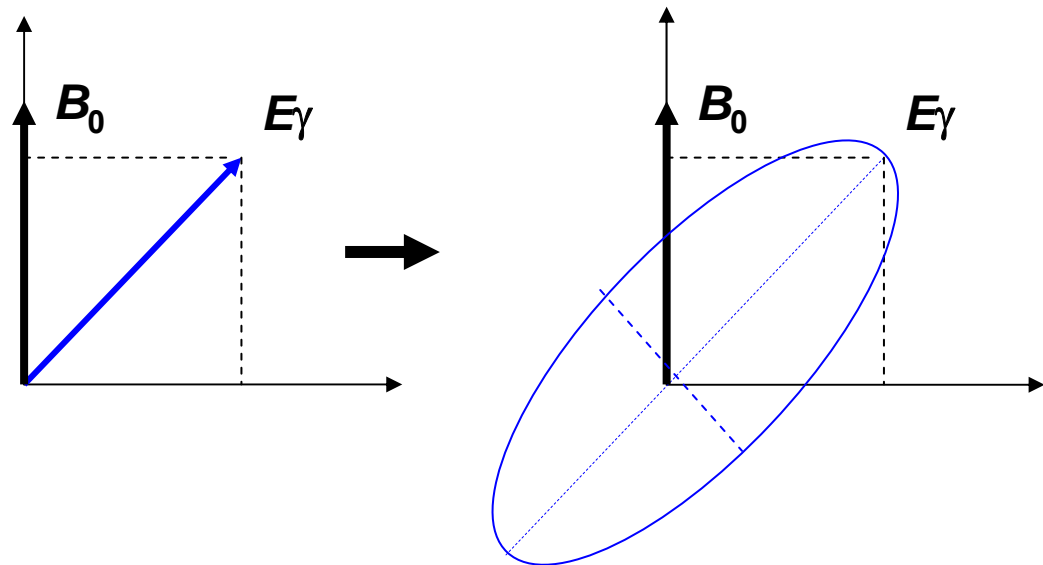


K. Van Bibber et al., *Phys. Rev. Lett.* **59** (1987) 759



Particule virtuelle

Ellipticit 



L.Maiani, R.Petronzio et E.Zavattini, *Phys. Lett. B* **175** (1986) 359

Plan

- Introduction : Biréfringence magnétique du Vide;
Dichroïsme et ellipticité dus aux PBFM,
- Historique Photorégénération des PBFM.
- Expérience BMV
- La « concurrence »
- Conclusions

Expériences avec un interféromètre de Michelson-Morley

• 1889 – 1898 : Morley, Boston, USA,
 $B_0 = 0,165 \text{ T}$, $\Delta n < 10^{-8}$

• 1930-1940 : Farr et Banwell,
 Nouvelle Zelande,
 $B_0 = 2 \text{ T}$, $\Delta n < 10^{-9}$

E.Morley, H.Eddy et D.C.Miller, *Bul. Western Reserve U.*
1 (1898) 50

C.C.Farr et C.J.Banwell, *Proc. Roy. Soc. London A*.137
 (1932) 275

C.J.Banwell et C.C.Farr, *Proc. Roy. Soc. London A*.175
 (1940) 1

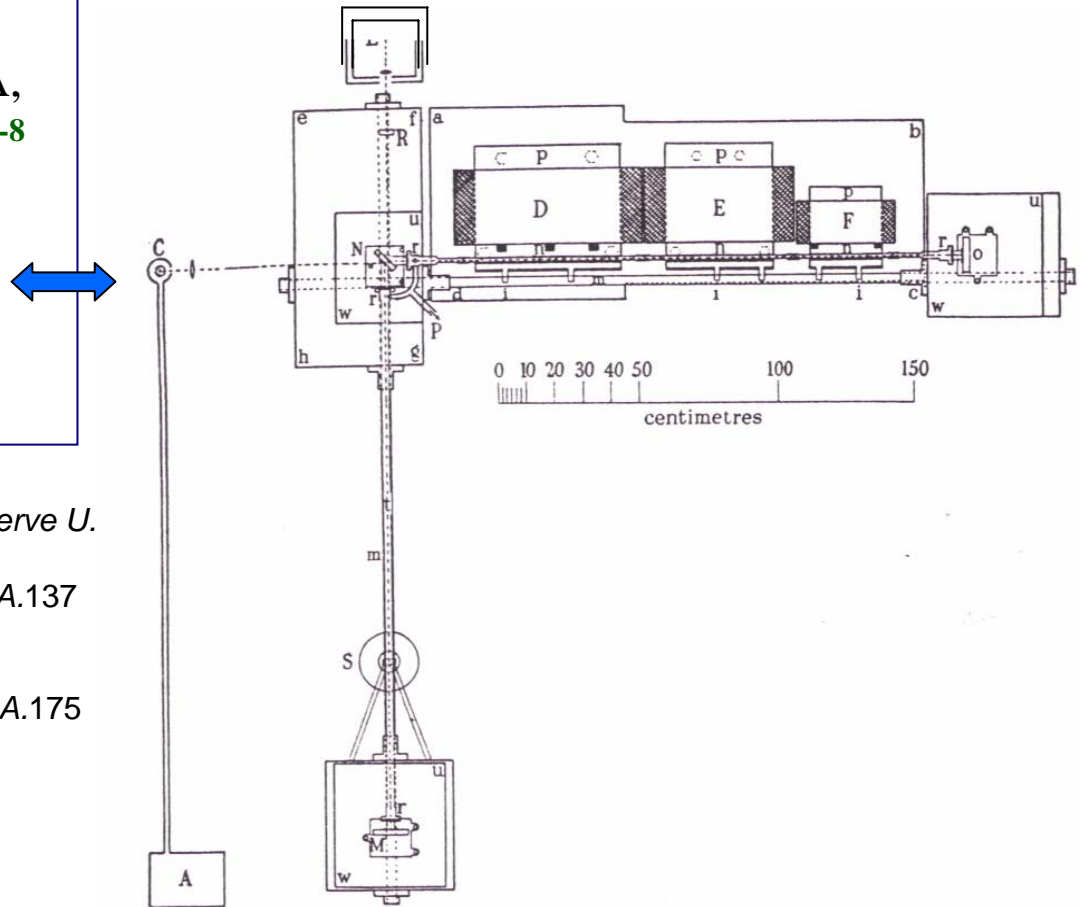


FIGURE 1

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

E. IACOPINI and E. ZAVATTINI

CERN, Geneva, Switzerland

Volume 85B, number 1

PHYSICS LETTERS

30 July 1979

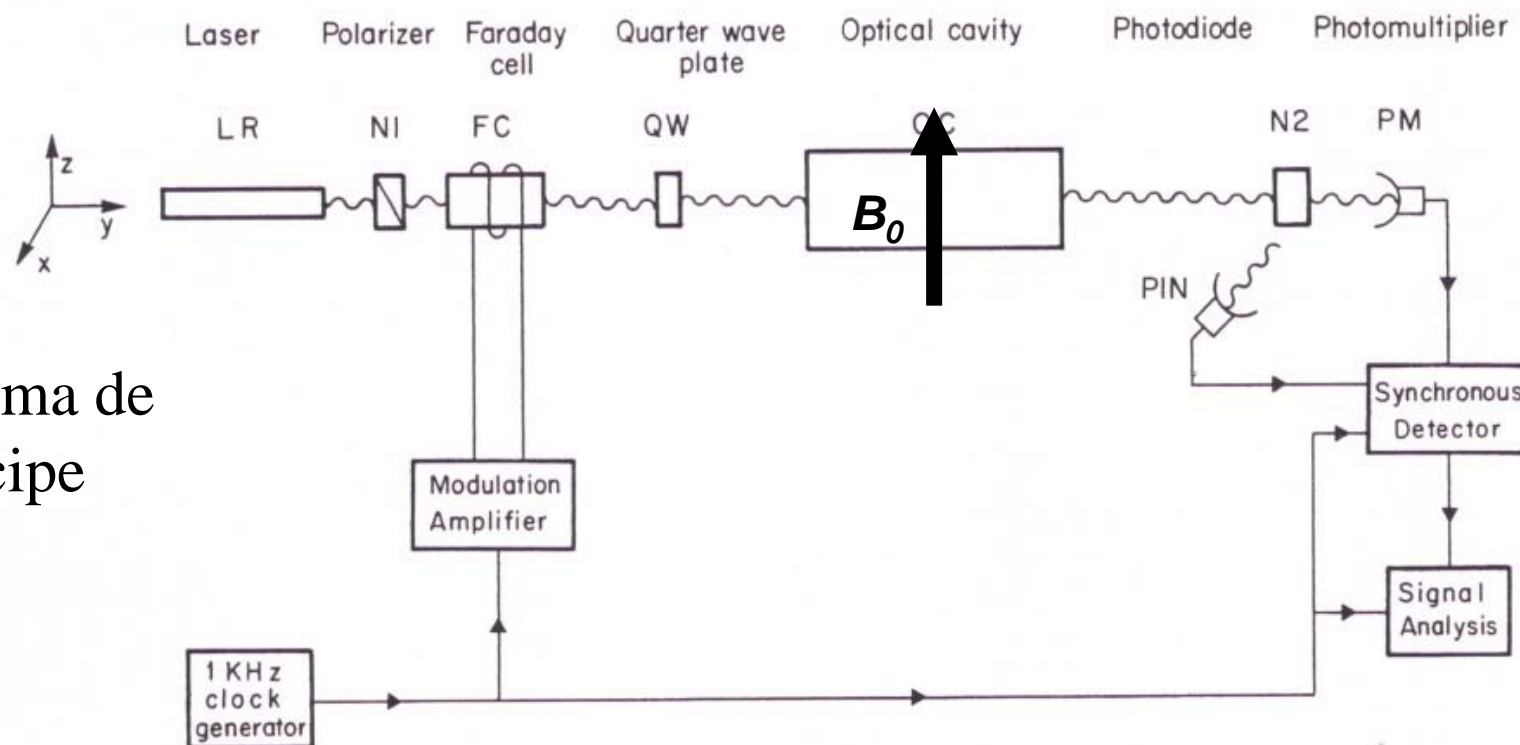


Schéma de
principe

Fig. 3. Principle elements of the experimental apparatus.

Brookhaven-Rochester-Fermilab-Trieste collaboration : 1988-1993

A.C.Melissinos, E.Zavattini *et al.*

Expérience montée aux
Brookhaven National Laboratories
Upton, NY, USA

Cavité optique « multipass » :
500 passages dans le champ

$$B_0 L \approx 16 \text{ Tm}$$

$$B_0^2 L \approx 35 \text{ T}^2\text{m}$$

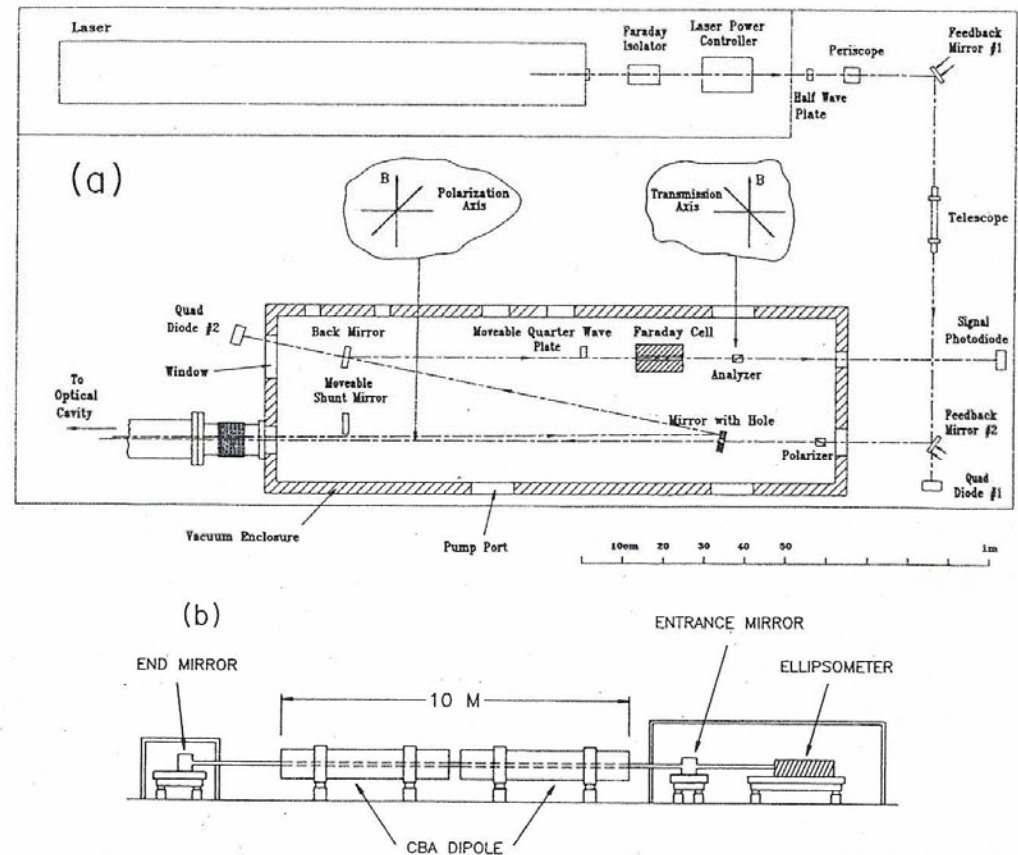


FIG. 4. (a) Schematic view of the ellipsometer; the volume inside the hatched area is evacuated. (b) Layout of the experiment and of the superconducting magnets.

TABLE II. Best sensitivities achieved with the feedback system operating.

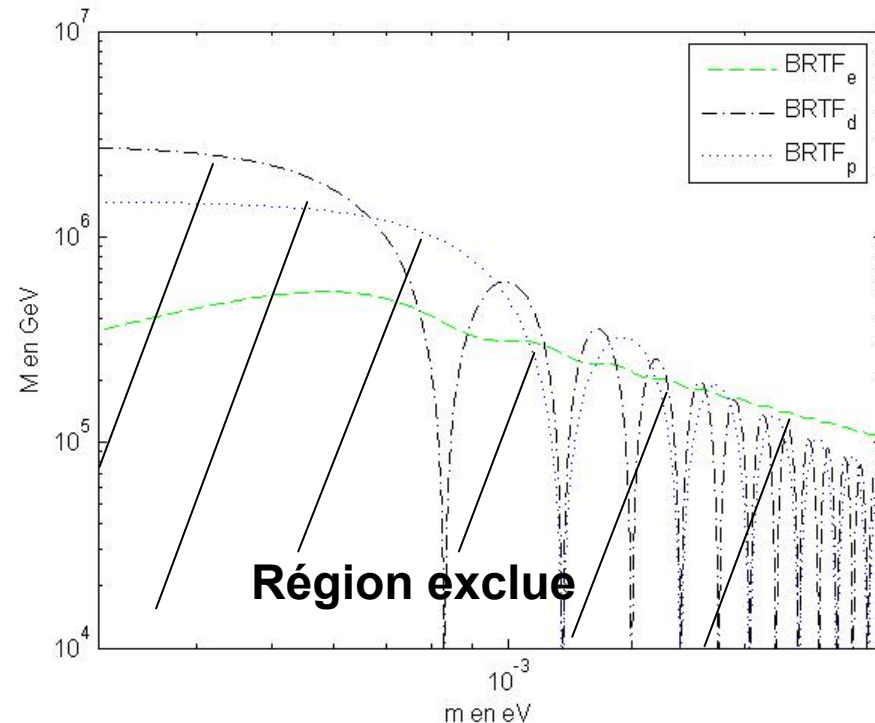
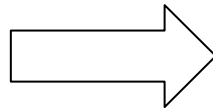
Number of reflections	Rotation or ellipticity	Number of averages	Measured rms noise level (rad)	Achieved sensitivity (rad/ $\sqrt{\text{Hz}}$)
Shunt	Rotation	48	4.3×10^{-11}	7.6×10^{-9}
Shunt	Ellipticity	25	2.0×10^{-10}	2.6×10^{-8}
34	Rotation	66	1.6×10^{-10}	3.3×10^{-8}
34	Ellipticity	25	2.0×10^{-9}	
254	Rotation	40	4.2×10^{-10}	6.7×10^{-8}
578	Ellipticity	13	5.1×10^{-8}	1.5×10^{-6}

Ellipticité < 2.0×10^{-9}

$$\Delta M < 28 \cdot 10^{-19} \text{ T}^{-2}$$

Mesures de :

Ellipticité
Dichroïsme
Photorégénération



Proposal

Measurement of the Magnetically-Induced QED Birefringence of the Vacuum
and An Improved Laboratory Search for Axions

Siu Au Lee, William M. Fairbank, Jr. and Walter H. Toki
Department of Physics, Colorado State University
Fort Collins, Colorado 80523

John L. Hall
Joint Institute for Laboratory Astrophysics
University of Colorado and The National Institute of Standards and Technology
Boulder, Colorado 80309

Tariq S. Jaffery
Superconducting Super Collider Laboratory
Waxahachie, Texas 75165

Patrick Colestock, Vernon Cupps, Hans Kautzky, Moyses Kuchmir and Frank Nezri
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

Submitted to
Fermi National Accelerator Laboratory

March 28, 1995

Spokesperson:

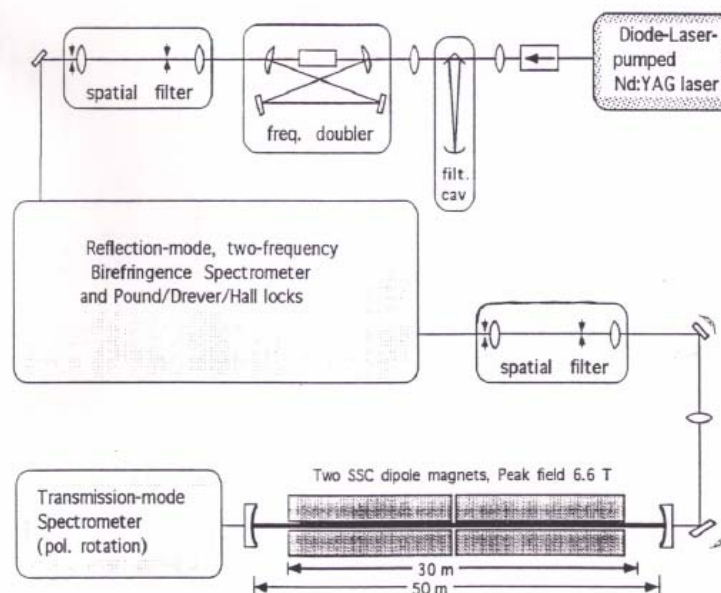
Siu Au Lee
Phone: (303) 491-6389
FAX: (303) 491-7947
Email: salee@lamar.colostate.edu

Deputy Spokesperson:

Frank Nezrick
Phone: (708) 840-4604
FAX: (708) 840-3867
Email: frank_nezrick@qmgate.fnal.gov

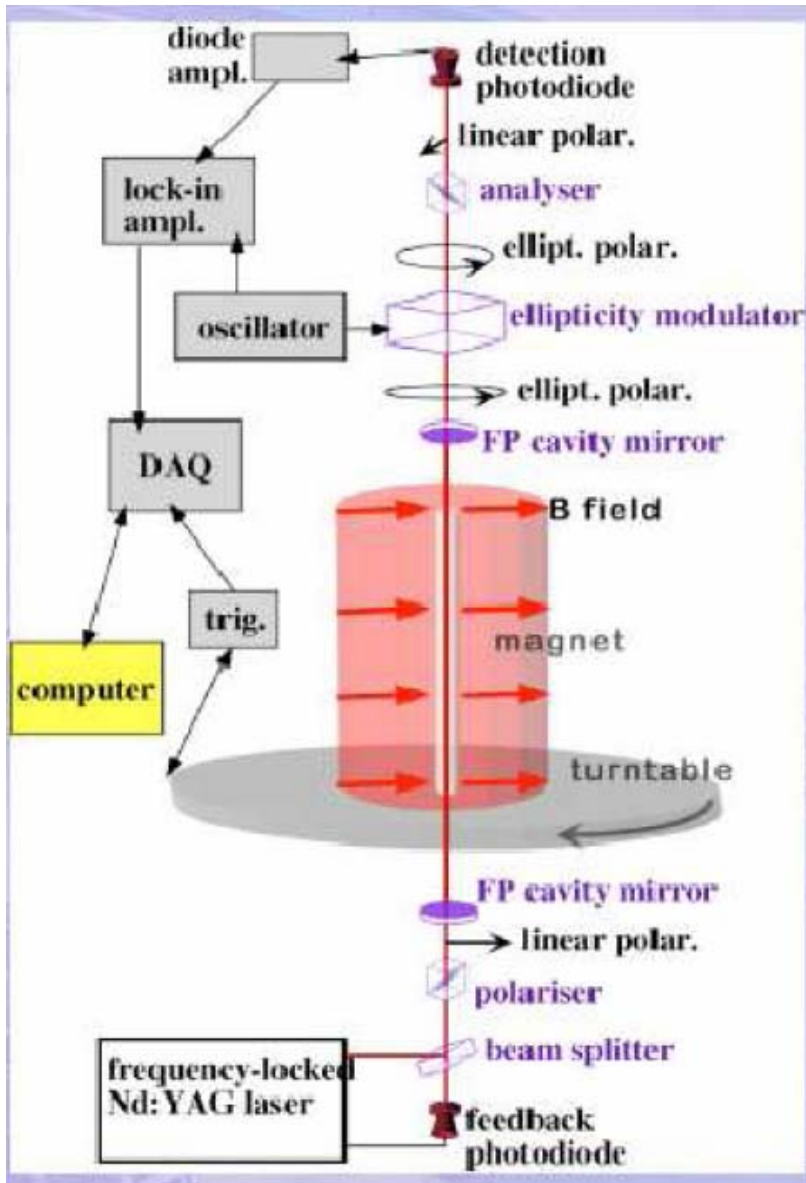
Proposition d'expérience au FERMILAB :

Pas acceptée !



Aimant du SSC

J.L.Hall, J.Ye, L-S.Ma, *Phys. Rev. A* **62** (2000) 013815



Expérience Polarizzazione del Vuoto con LASer (PVLAS) : 1992 – en cours

E.Zavattini *et al.*

$$B_0^2 L = 25 \text{ T}^2 \text{m}$$

$$B_0 L = 5 \text{ Tm}$$

Finesse de la cavité = 70 000

fréquence de modulation 0.6 Hz

Sensibilité = $10^{-7} \text{ 1}/\sqrt{\text{Hz}}$

Laboratori Nazionali di Legnaro, INFN

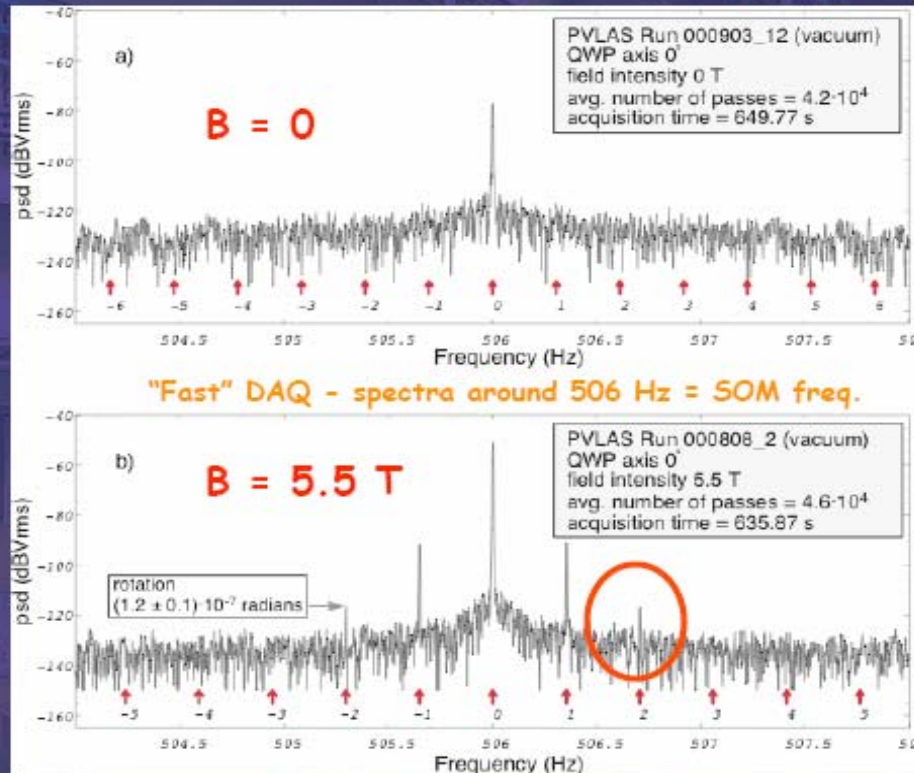


PVLAS hall at LNL





Vacuum rotation measurements (amplitude) II



- Signal observed in Vacuo with $B \neq 0$ and cavity present
- Data clusters in polar plane change sign under a QWP axis exchange
- The average rotation vector lies along the physical axis

The signal corresponds to a "true" rotation (dichroism) with amplitude $(3.9 \pm 0.5) \times 10^{-12}$ rad/pass

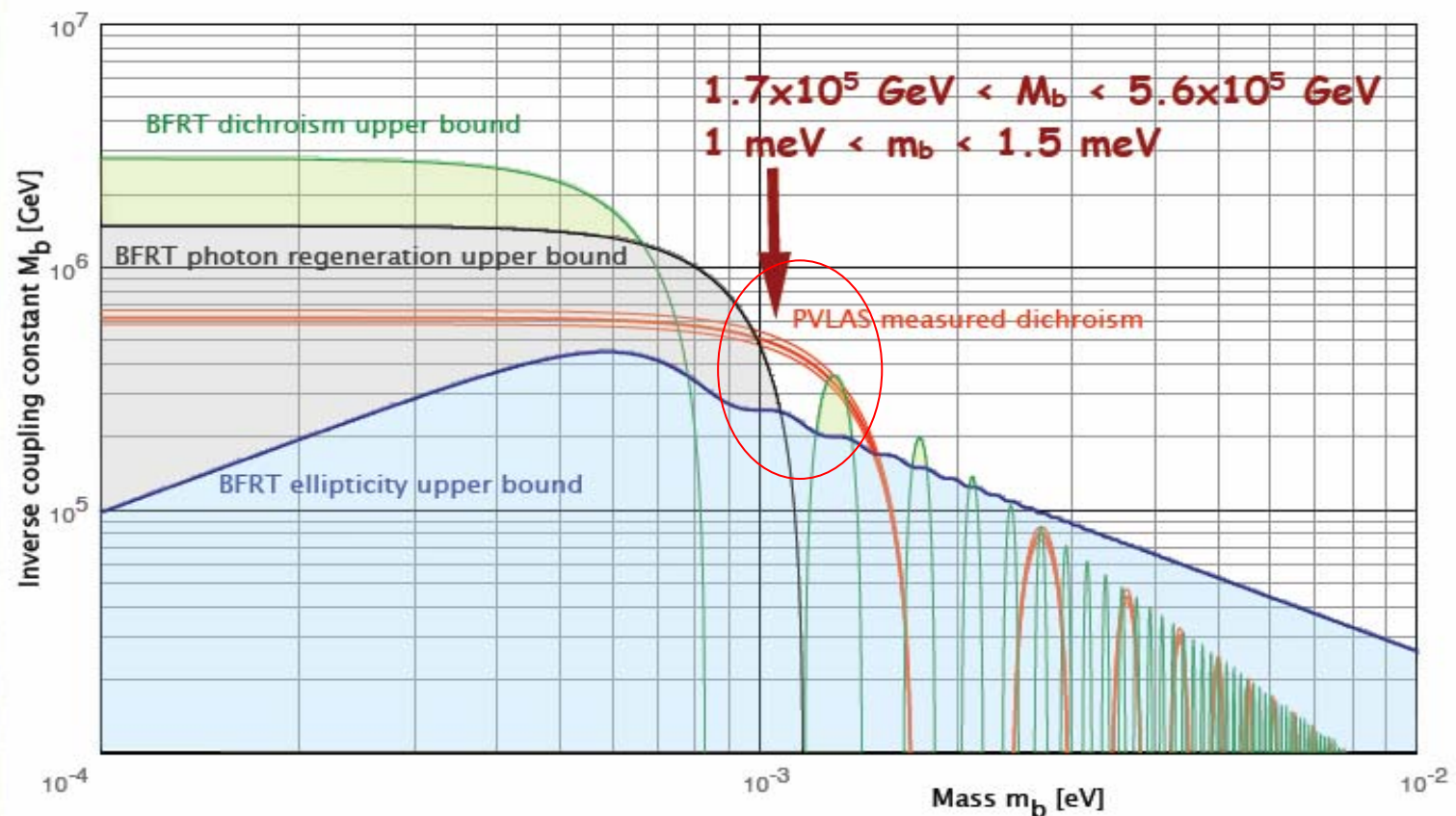
G. Cantatore - PVLAS Coll.- Axion Training 2005 - CERN

www.ts.infn.it/experiments/pvlas

26



BFRT and PVLAS results on the m_b - M_b plane

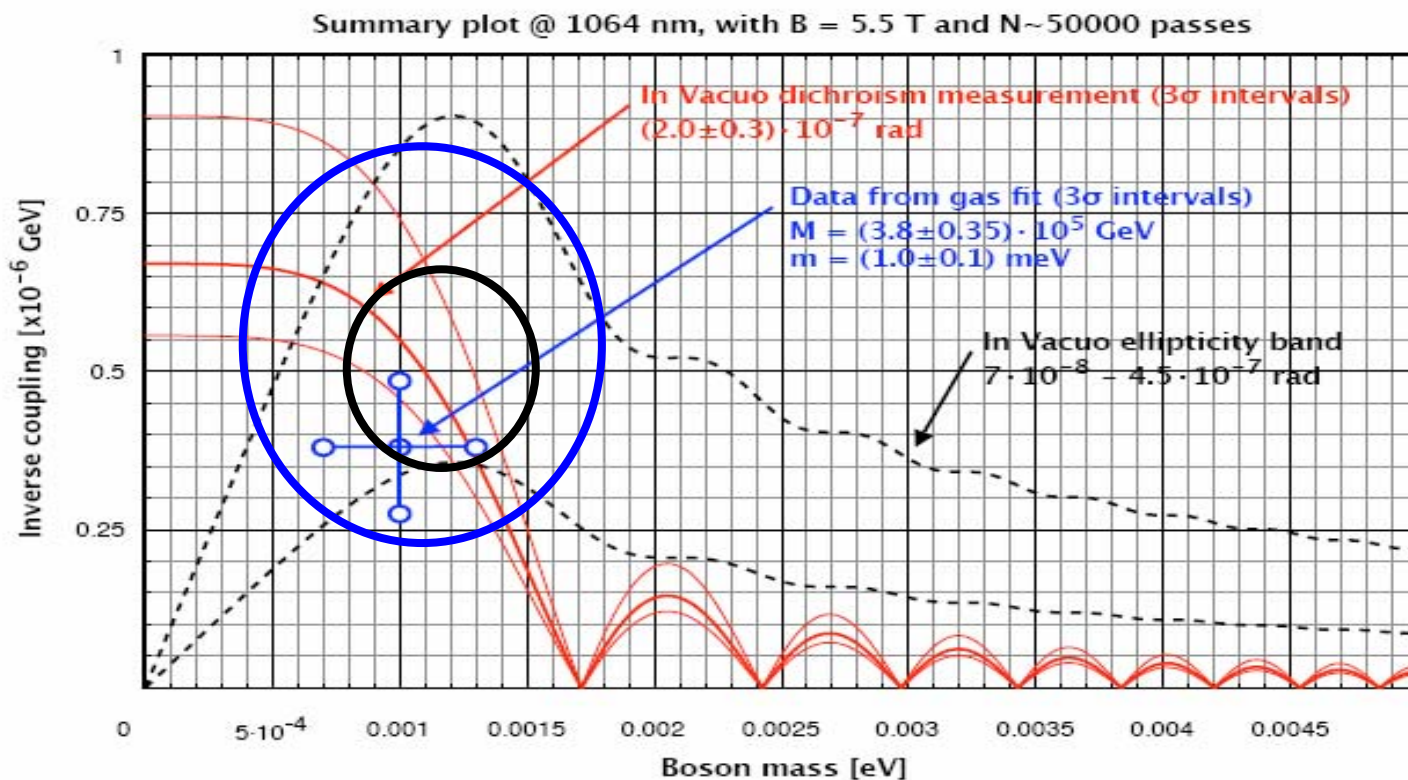


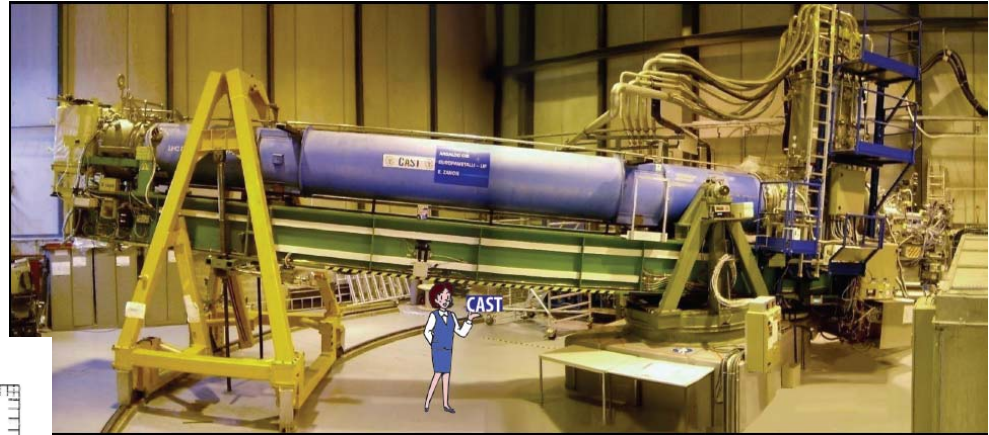
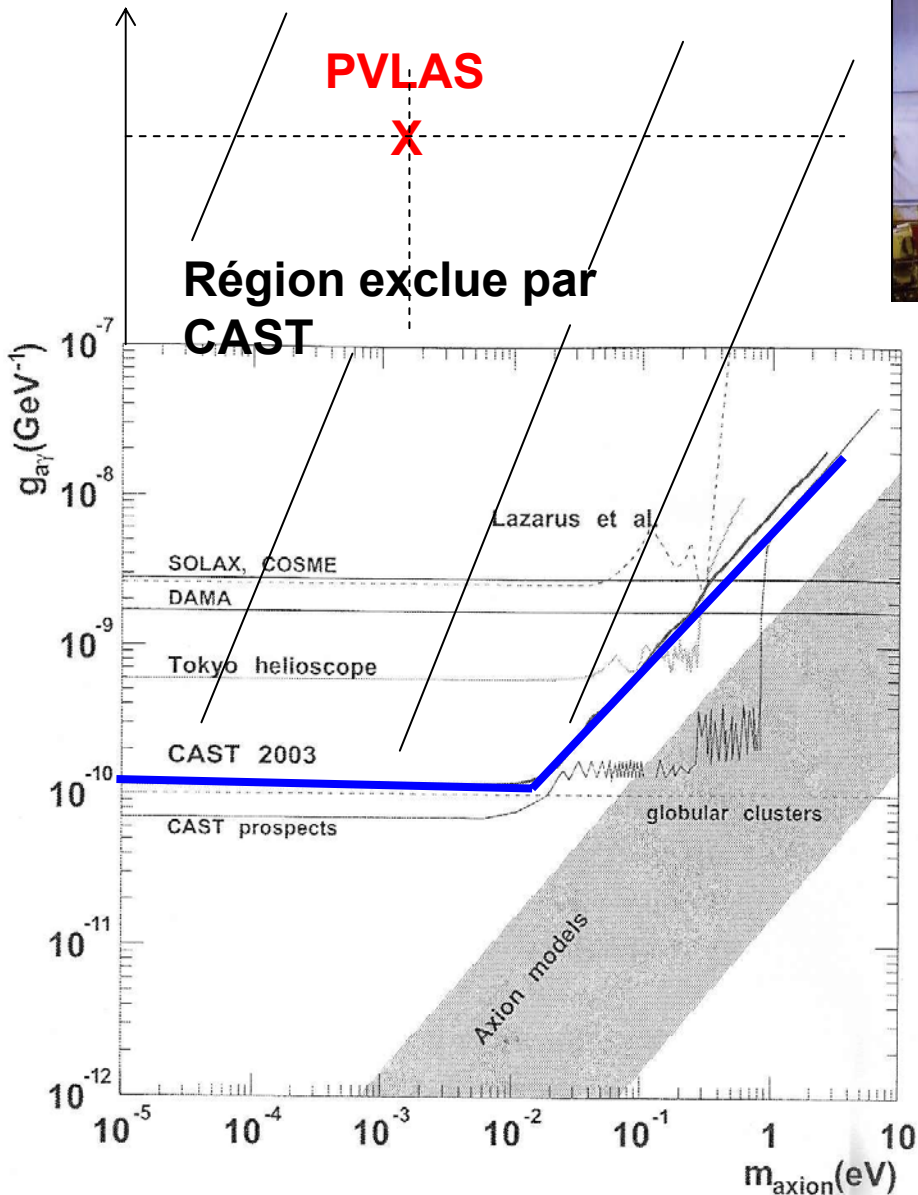
... l'ellipticité ?

Scalaire ou Pseudoscalaire ? ... ?



Speculative global view





CAST

Cern Axion Solar Telescope

K.Zioutas, et al., *Phys. Rev. Lett.* **94** (2005) 121301

Nouvelle(s) théorie(s) ? :

E.Masso et J.Redondo, *J. of Cosmology and Astroparticle Physics*, **9** (2005) 015

Nouvelle(s) expérience(s) ? :

Plan

- Introduction
- Historique : BRFT (limites), PVLAS (effet ?)
- Expérience BMV
- La « concurrence »
- Conclusions

L'expérience **BMV**

Laboratoires concernés :

Laboratoire **C**ollisions **A**grégats **R**éactivité, Toulouse :

G. Bailly, B. Pinto da Souza (Ph-D), S. Faure, L. Polizzi, C. Rizzo, C. Robilliard, G. Trénec, J. Vigué.

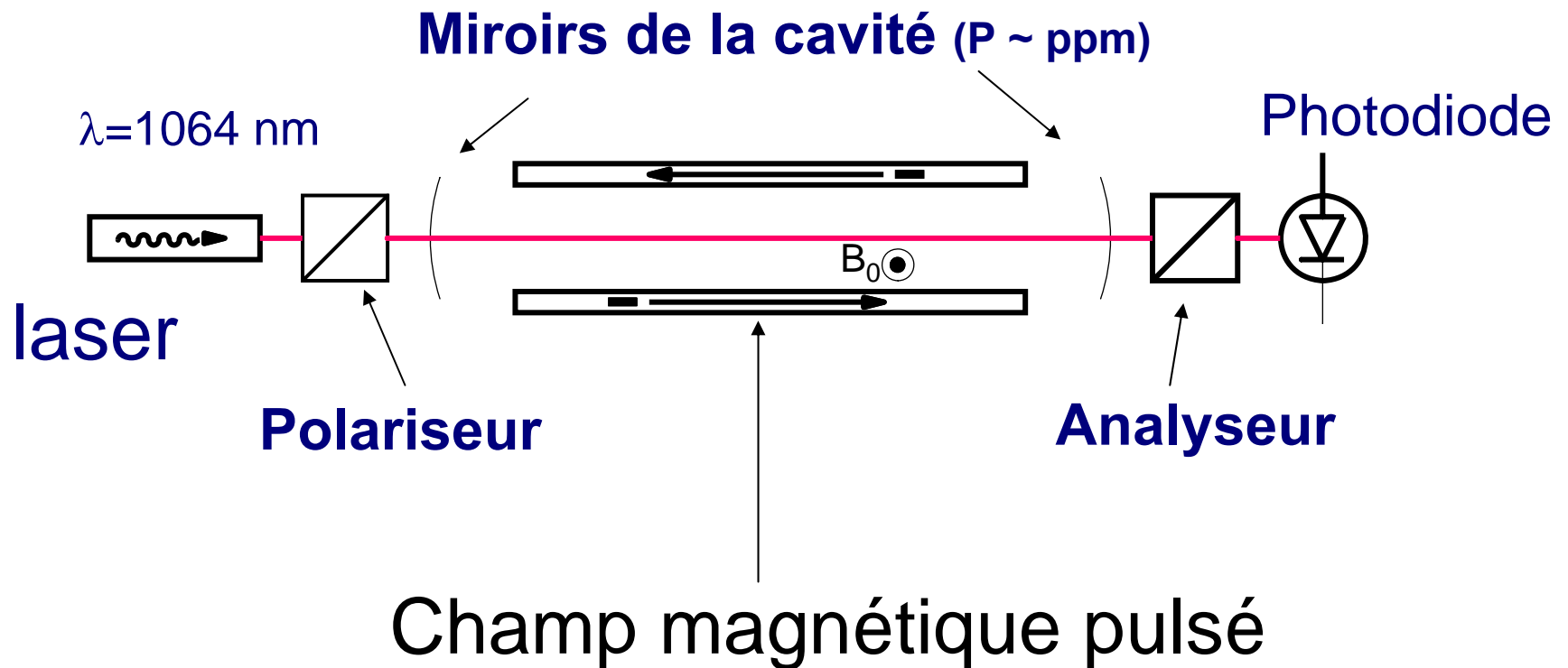
Laboratoire **N**ational **C**hamps **M**agnétiques **P**ulsés, Toulouse:

S. Batut (Ph-D), R. Battesti, S. George, B. Griffe, M. Nardone, O. Portugall, G. Rikken.

Laboratoire **M**atériaux **A**vancés -**VIRGO**, Lyon :

P. Ganau, , J-M. Mackowski, C. Michel, A. Remillieux, L. Pinard.

Schéma de l'expérience



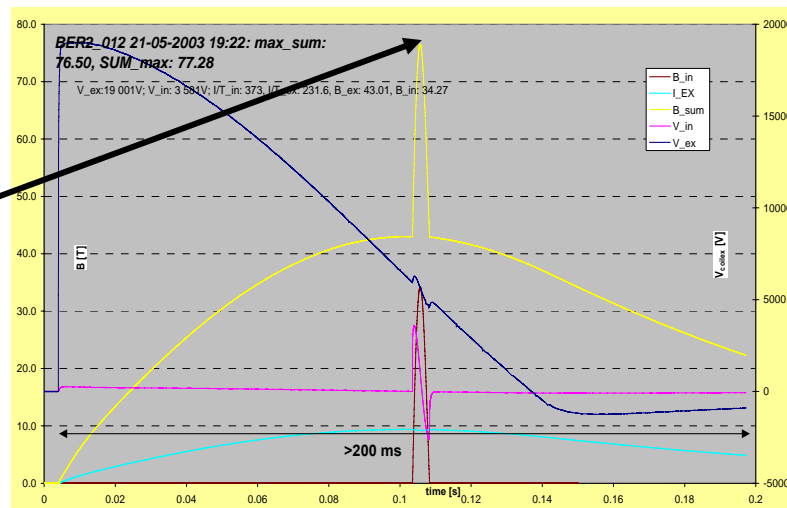


LNCMP :

record européen de champ magnétique

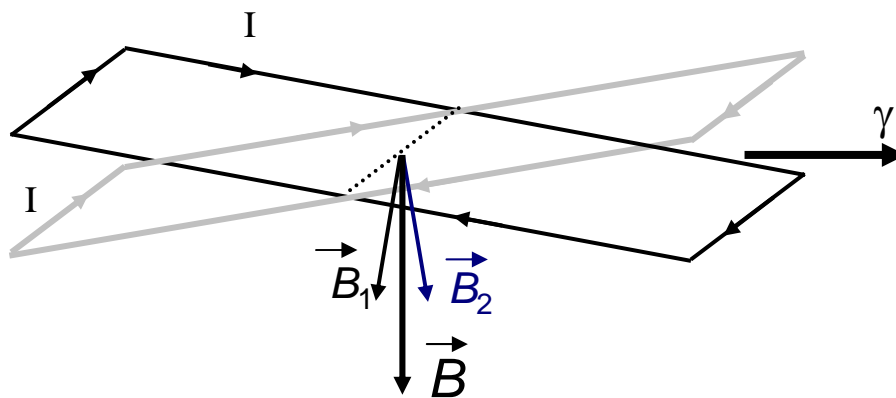
Générateur
24 kV, 14 MJ
65 kA courant limite

77,3 T



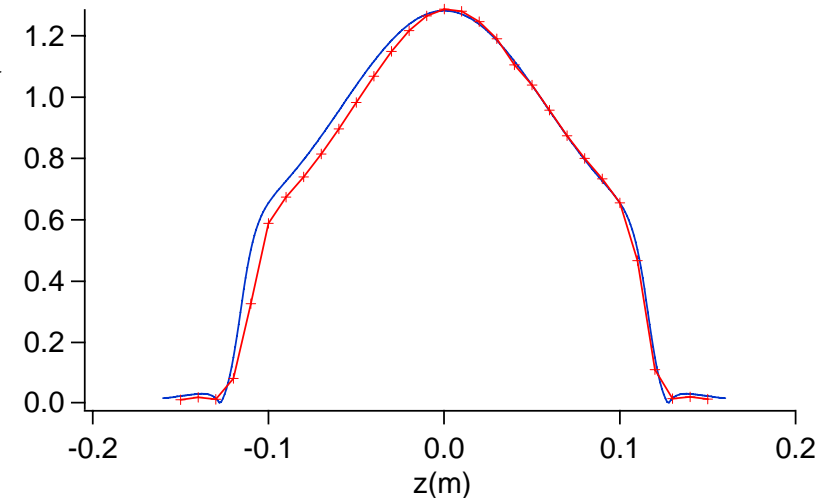
Dessin de la bobine : X-coil

objectif 2007: $\left\{ \begin{array}{l} \text{Champ magnétique transverse} \\ B_0^2 L > 30 \text{ T}^2\text{m} \end{array} \right.$

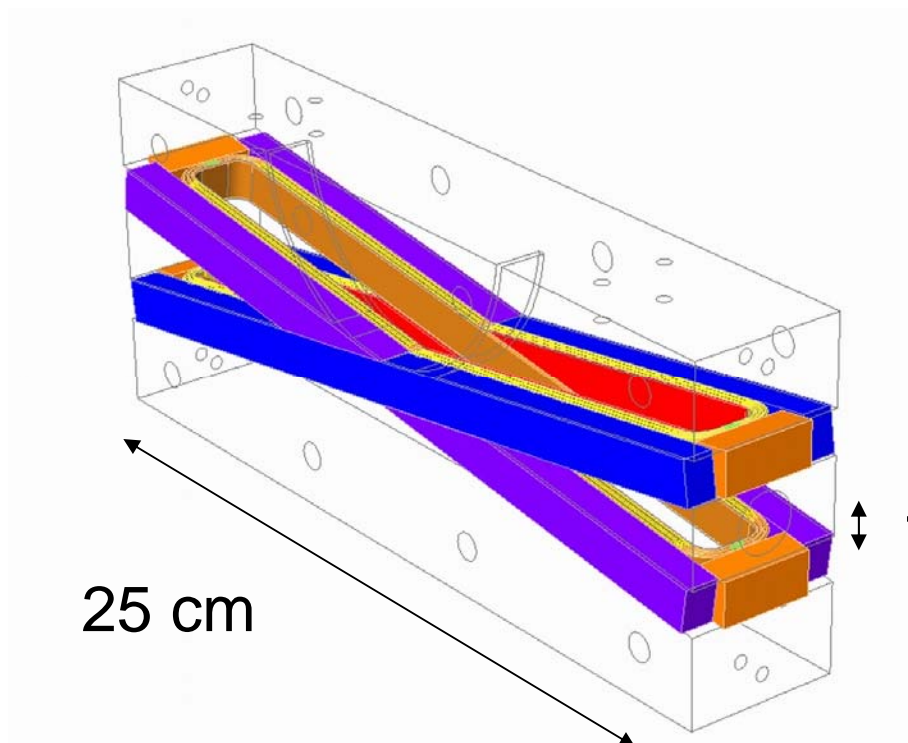


Bobine en X

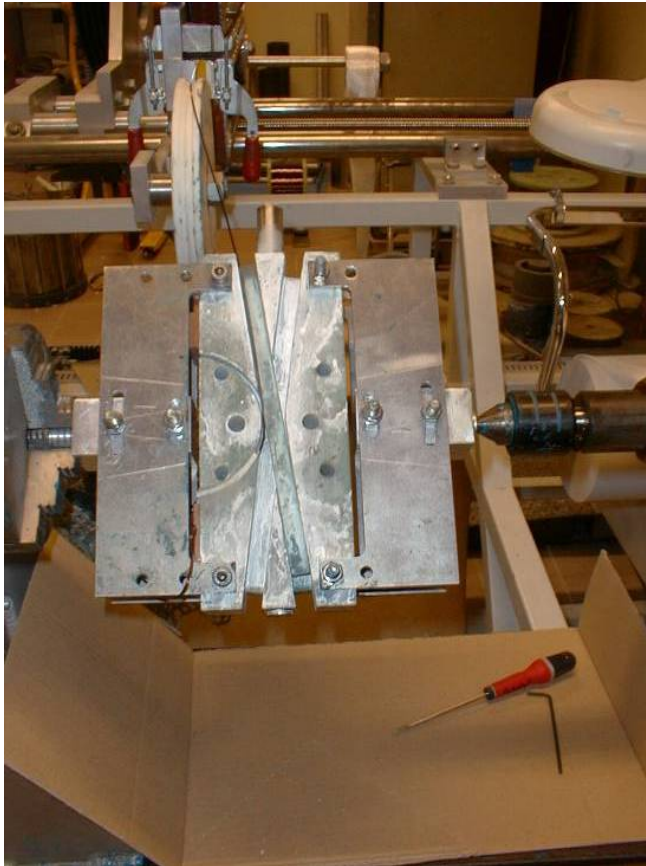
$$B^2 L / I^2 = 2,25 \times 10^{-7} \text{ T}^2\text{m}/\text{A}^2$$



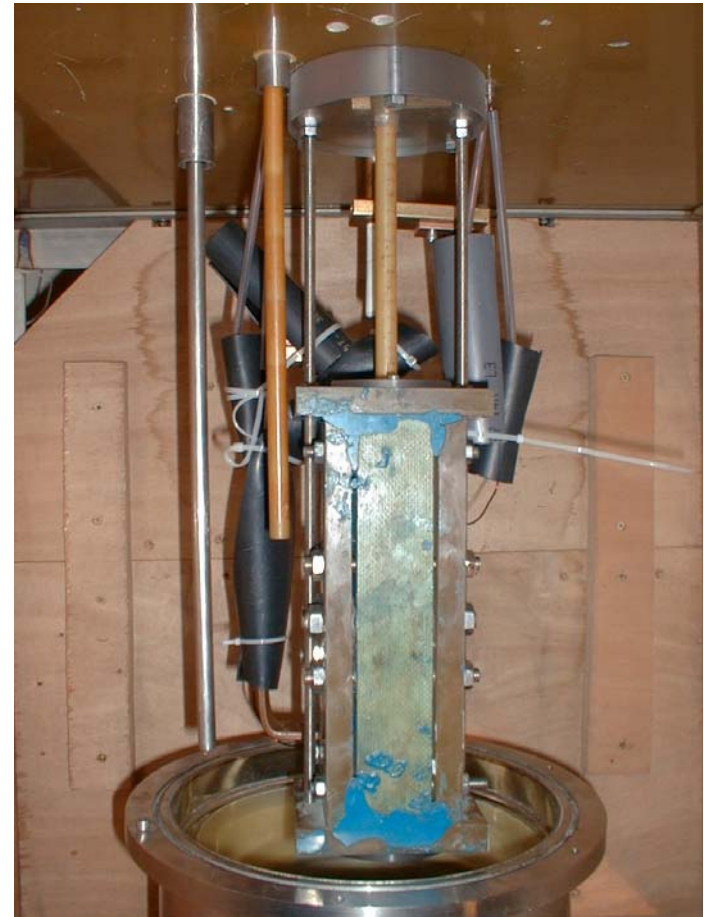
Prototype de la bobine



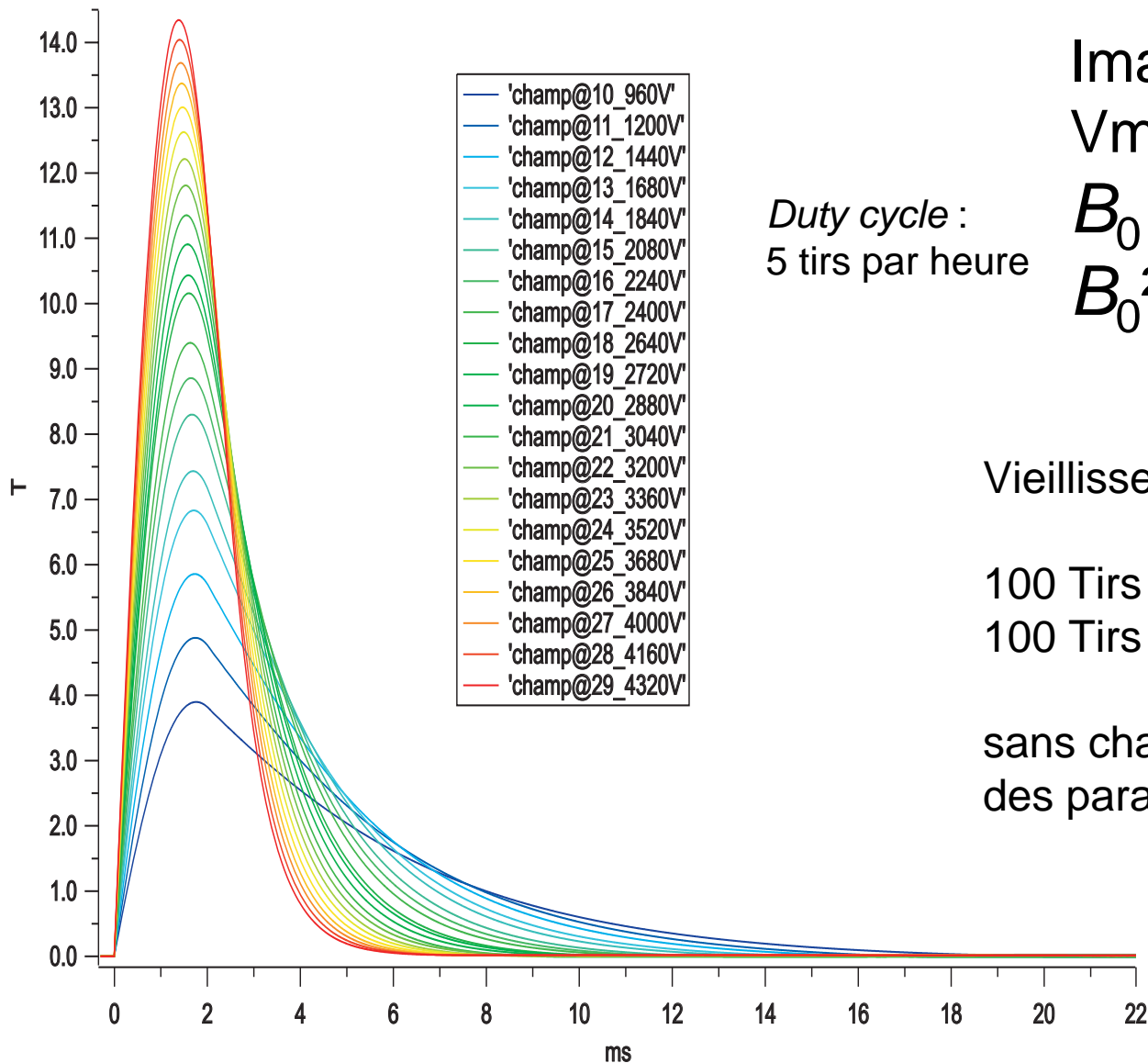
X coil



Bobinage



Test à la température
de l'azote liquide



$$I_{\max} = 8\,300\text{ A}$$

$$V_{\max} = 3\,700\text{ V}$$

$$B_0 = 14,3\text{ T}$$

$$B_0^2 L = 28\text{ T}^2\text{m}$$

Duty cycle :
5 tirs par heure

Vieillissement de la bobine :

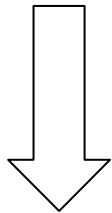
100 Tirs à 11,5 T

100 Tirs à 12,5 T

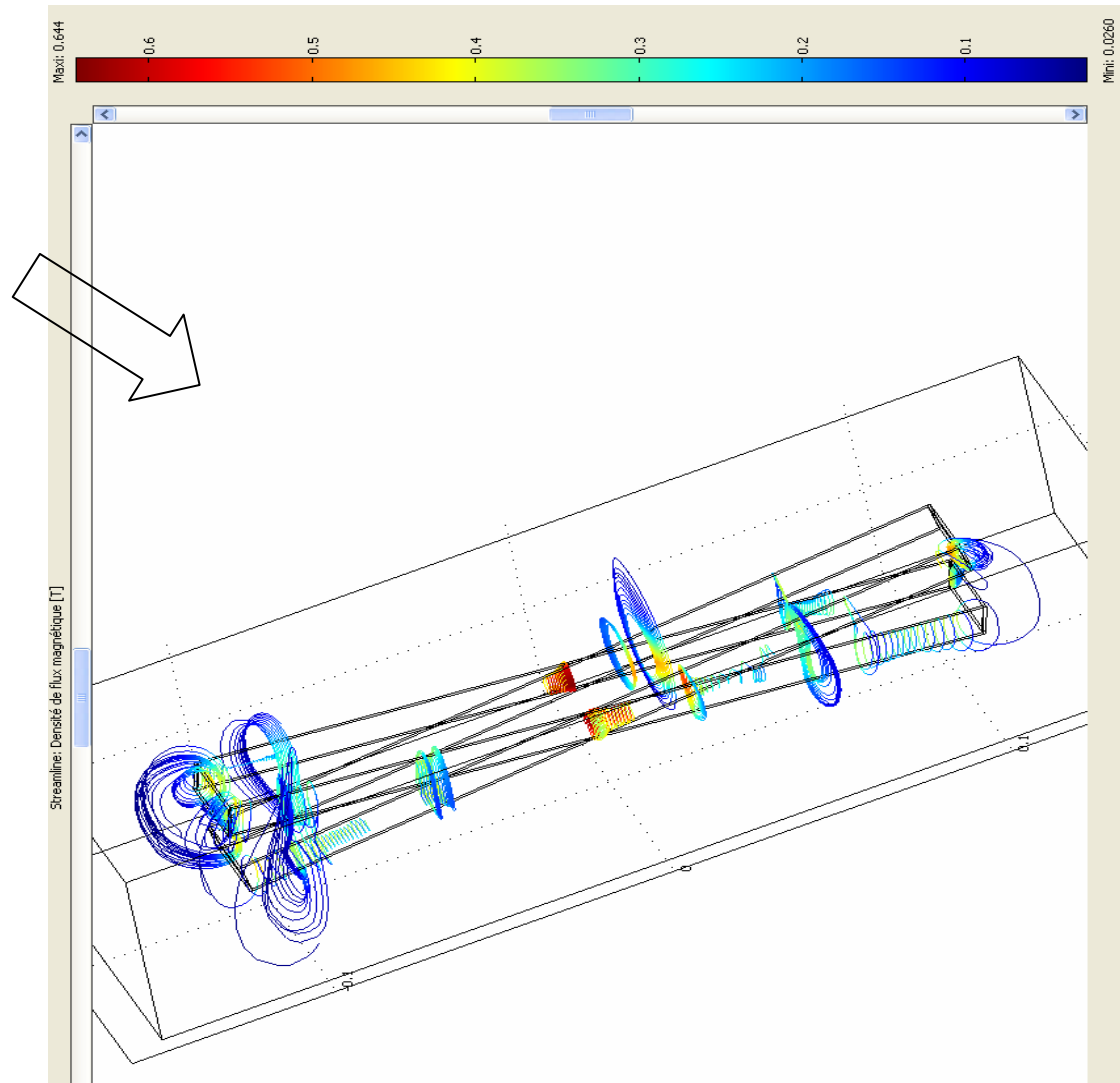
sans changement appréciable
des paramètres électromagnétiques

Prochaines étapes :

- Etudes des forces et des contraintes
- Nouvelle bobine en fil de cuivre renforcé



25 T



Cavité optique résonnante Fabry-Perot

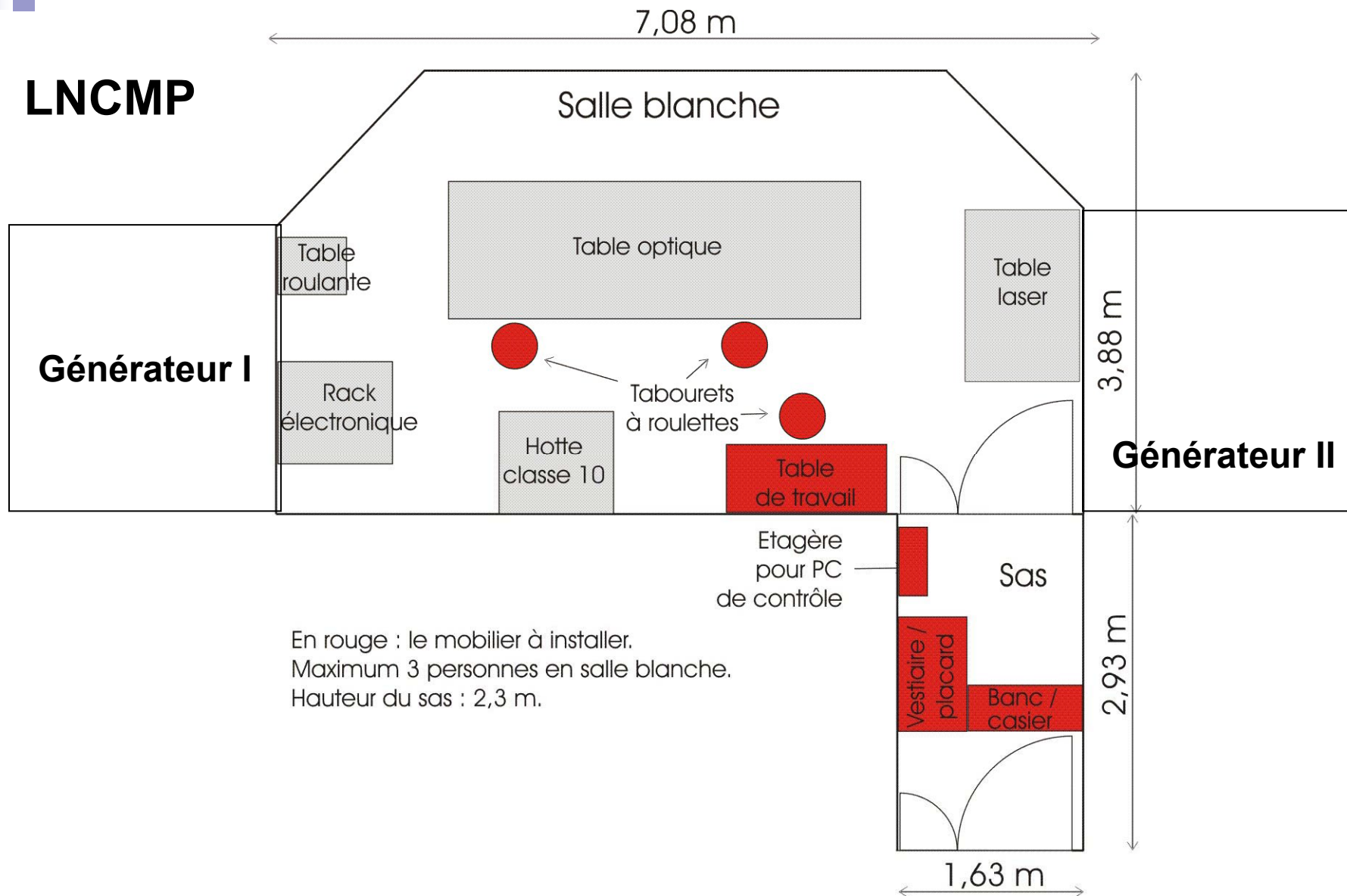
- Ellipticité due à un passage dans le champ magnétique est multipliée par $2F/\pi$.
- Biréfringence due aux miroirs
- Nécessité d'asservir le laser à la cavité : méthode de Pound-Drever-Hall

Objectif 2007 : $F > 200\,000$

Miroirs très performants grâce
au LMA-VIRGO de Lyon



Salle blanche

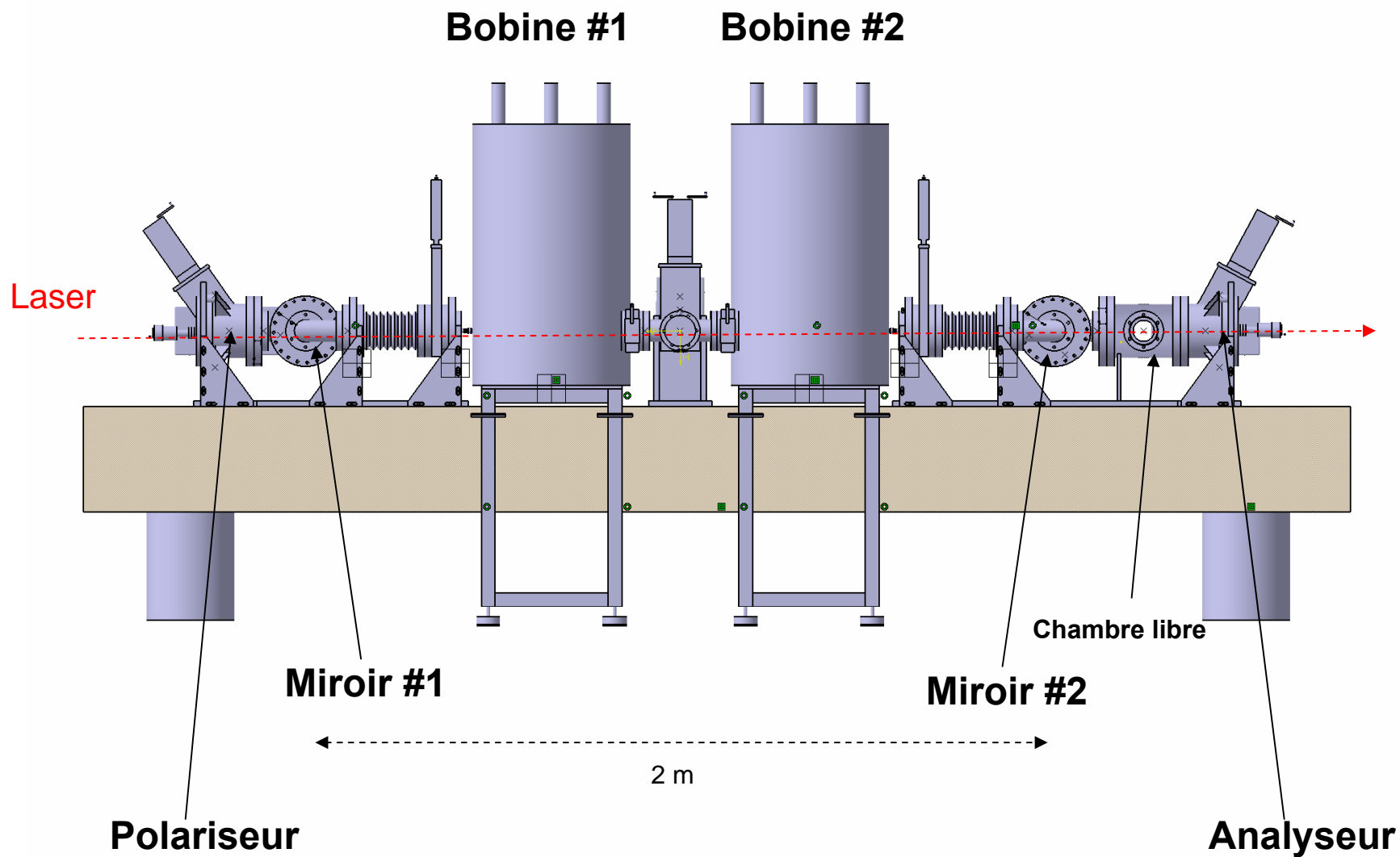




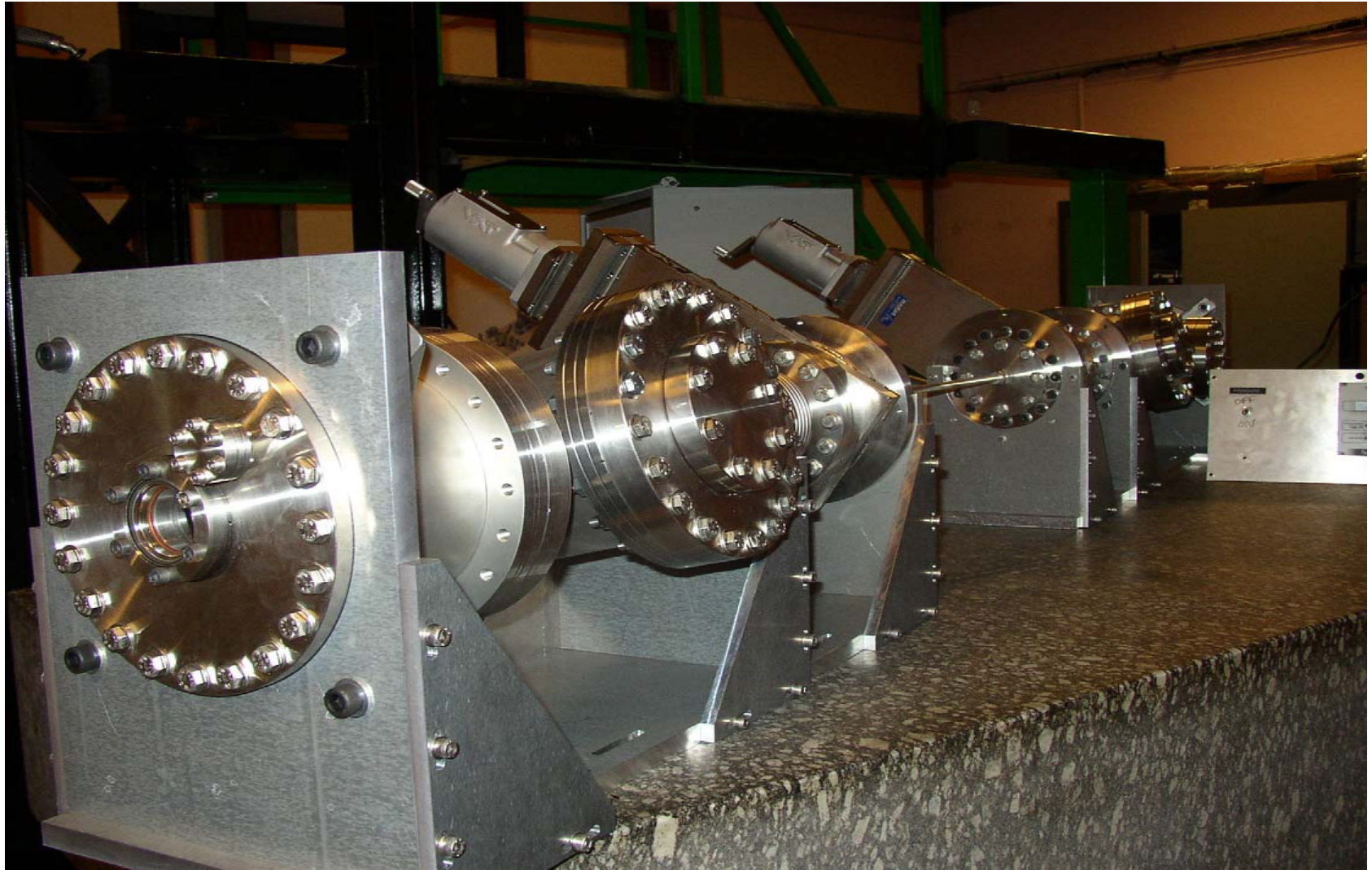
Salle blanche au LNCMP

On y travaille
« fully equipped »





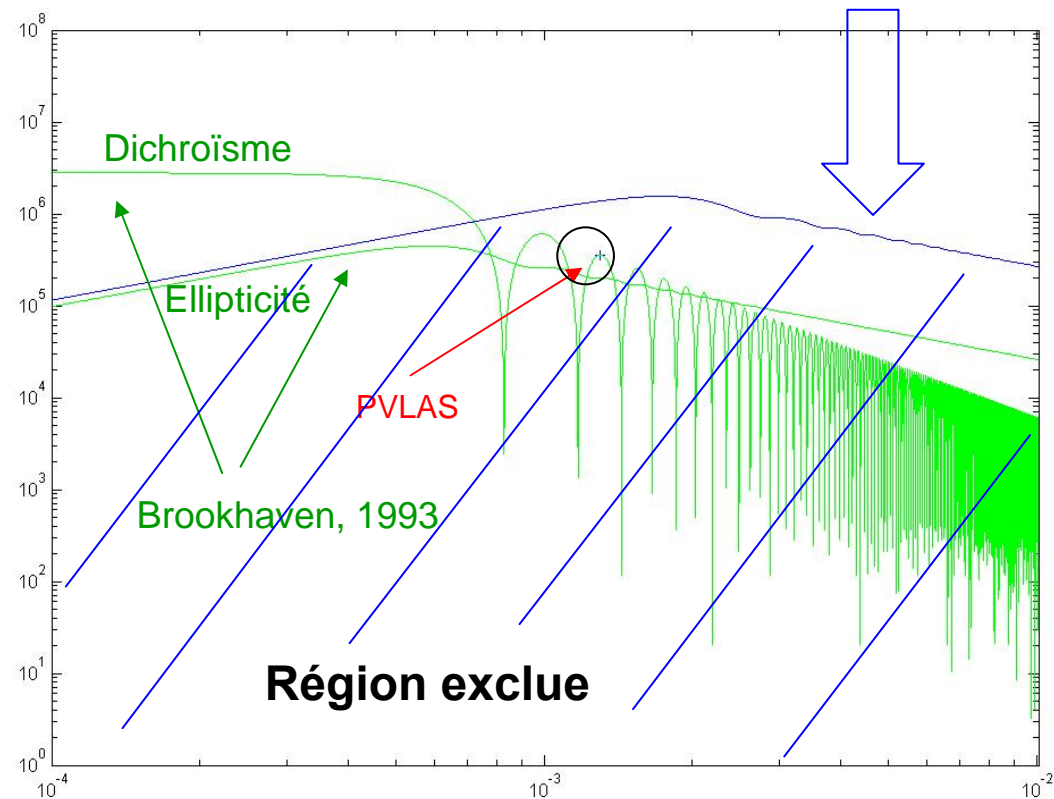
Tests de pompage en cours au LCAR



- $B_0 L = (2 \times) 2,5 \text{ Tm}$; $B_0^2 L = (2 \times) 21 \text{ T}^2 \text{m}$
- finesse = 200 000
- Sensibilité = $10^{-8} / \text{Hz}^{1/2}$

BMV, 30 tirs, 1 jour

Test des résultats de PVLAS



Plan

- Introduction théorique
- Historique
- Expérience BMV : opérationnelle été 2006,
test de PVLAS en 2007
- La « concurrence »
- Conclusions

Q&A (Quantum electrodynamics test & search for Axion Center for gravitation and cosmology, National Tsing Hua University of Taiwan

W-T Ni

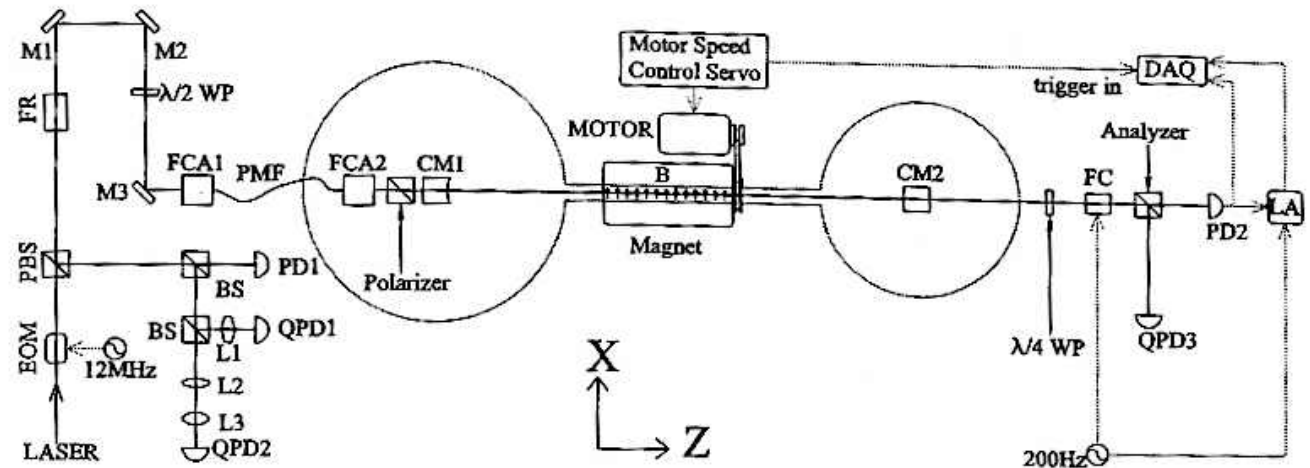


Figure 1. Experimental Setup. EOM electro-optical modulator; $\lambda/2$ WP half-wave plate; $\lambda/4$ WP quarter-wave plate; L1, L2, L3 lenses; M1, M2, M3 reflection mirrors; PBS polarizing beam splitter; BS beam splitter; FR Faraday rotator; FCA1, FCA2 fibre coupler assemblies; PMF polarization maintaining fibre; CM1, CM2 cavity mirrors; B magnetic field; PD1, PD2 photodetectors; QPD1, QPD2, QPD3 quadrant photodiodes; FC Faraday cell; DAQ data acquisition system; LA lock-in amplifier.

Aimant permanent de **2,5 T**, de longueur **5 m**, tournant à **10 Hz**.

Cavité Fabry-Pérot de **finesse 100 000**.

The Q & A Experiment

—Dipole Permanent Magnet

› Technical Requirement



Central transverse B field	2.0 T
Homogeneity of B field	< 1% within a cylinder of 4 mm diameter
Axial component of B field	< 0.1% of central B field
Rotation Speed	≤ 10 revolution-per-second
Effective magnetic space	diameter of 25 mm, length of 600 mm
Magnetic-flux-leakage	B At 10 mm away from main body ≤ 0.0001 T

QED 2005 Workshop
2005/Jun/05~09

—Fabry-Perot Interferometer

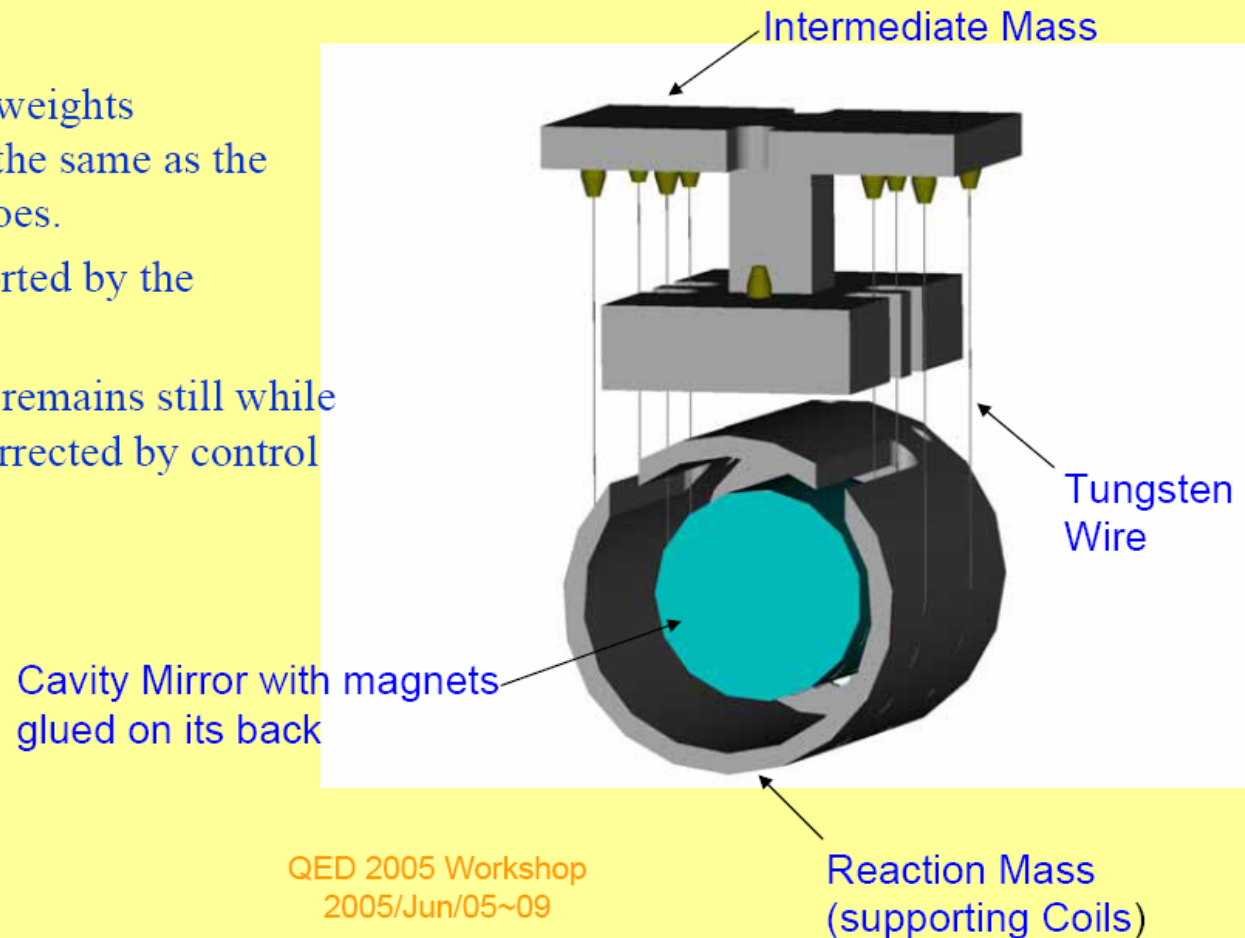
- Length: 3.5 m (Extendable to 7 m)
- Cavity Mirror Diameter: 50 mm
- R.O.C. of Cavity Mirror: 5 m and plano
- Laser: 1064 nm, frequency tunable, ~700mW
- Free Spectral Range: ~43 MHz
- Finesse: 17000 → 12000 → 7000
(will be restored by cleaning or replacing)

The Q & A Experiment

—Suspension System

›double pendulum

- Reaction mass weights approximately the same as the cavity mirror does.
- Coils are supported by the reaction mass.
- Center of mass remains still while the mirror is corrected by control loop.



QED 2005 Workshop
2005/Jun/05~09



Laboratory Experiments for Axion Search using Decommissioned LHC Superconducting Dipoles

2005 December 1st

L. Duvillaret¹, M. Finger Jr.², M. Finger², M. Král^{3,4}, K.A. Meissner⁵,
P. Pugnát³, D. Romanini⁶, A. Siemko³, M. Šulc⁷, J. Zicha⁴

¹ *IMEP, INPG – UJF & CNRS, 38016 Grenoble Cedex-1, France*

² *Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic*

³ *CERN, Geneva, Switzerland*

⁴ *Czech Technical University, Faculty of Mechanical Engineering, Prague, Czech Republic*

⁵ *Warsaw University, Poland*

⁶ *LSP, Université J. Fourier – Grenoble-1 & CNRS, 38402 Saint-Martin d'Hères, France*

⁷ *Technical University of Liberec, Czech Republic*

QED Test & Axion Search using decommissioned LHC superconducting dipole magnet(s)

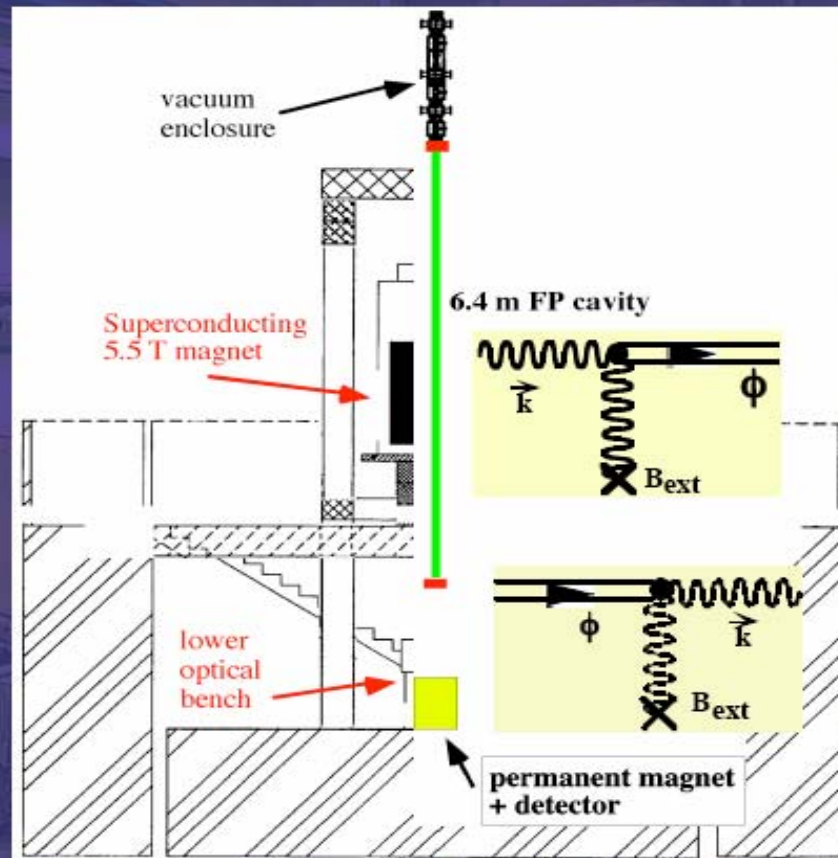
- Ideal integration are within a superconducting dipole magnet use in accelerator for HEP
- With this respect, LHC superconducting dipoles *are within the most powerful at present:*
 - $B_{\max} \approx 9.76 \text{ T @ } 1.9 \text{ K}$
 - Magnetic Length: 14.3 m
i.e. $B^2 L \approx 1360 \text{ T}^2 \text{ m}$

\Rightarrow *Big interest in using LHC decommissioned prototypes*





Photon regeneration test at PVLAS permanent magnet



Downward propagating particles

Photon Regeneration from Pseudoscalars at X-Ray Laser Facilities

R.Rabadan, A.Ringwald, et K.Sigurdson, *Phys. Rev. Lett.*, **96** (2006) 110407

– Towards a Large Scale Axion Photon Regeneration Experiment –

3

- **Conversion probability** of photon send along magnetic field:

$$P_{\gamma \leftrightarrow \phi} \approx \frac{1}{4} g^2 B^2 \ell^2 \left(\frac{\sin \left(\frac{m_\phi^2 \ell}{4\omega} \right)}{\frac{m_\phi^2 \ell}{4\omega}} \right)^2$$

HERA dipole ($B\ell = 50 \text{ Tm}$):



- ⇒ **Photon regeneration** optimal
- for large $B\ell \Rightarrow$ recycle dipole magnets from accelerators

– Towards a Large Scale Axion Photon Regeneration Experiment –

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- **Powerful free-electron lasers (FEL)** already/soon available:

name?	ω [eV]	when?
VUV-FEL at TTF	10–200	2004
LCLS	10^4	2005–2008
XFEL	200– 10^4	2005–2011

TTF: TESLA Test Facility (DESY)

LCLS: Linac Coherent Light Source (SLAC)

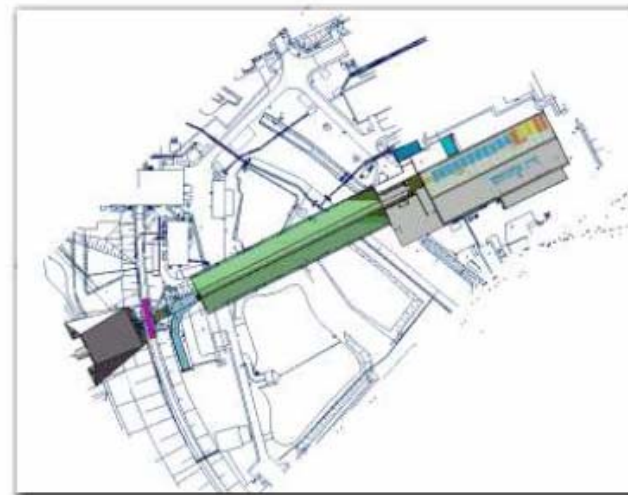
- First generation experiment may start next year

⇒ Study of feasibility underway ...

[Tschentscher, AR '05]

A. Ringwald (DESY)

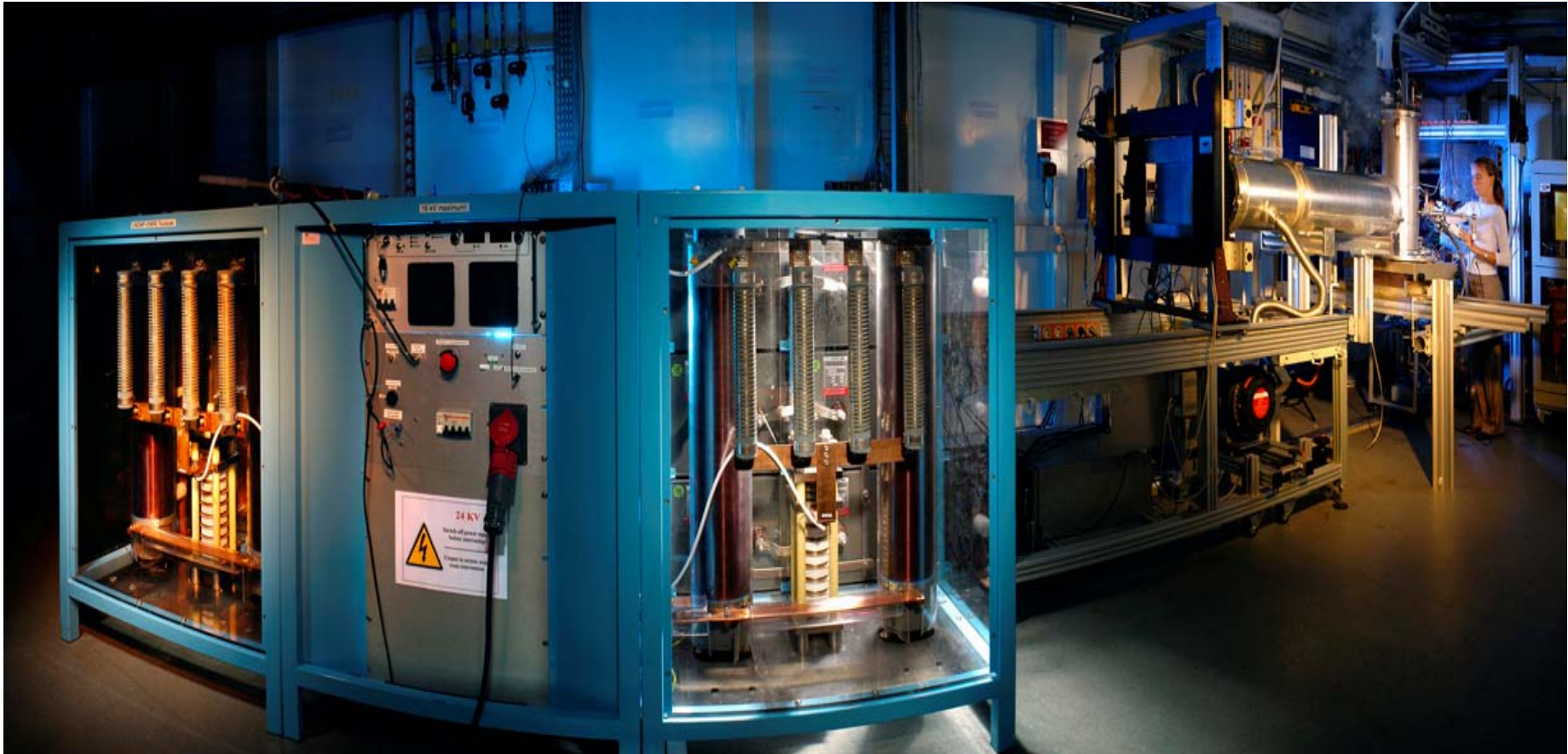
VUV-FEL at TTF:



Workshops on Future Axion Searches, CERN

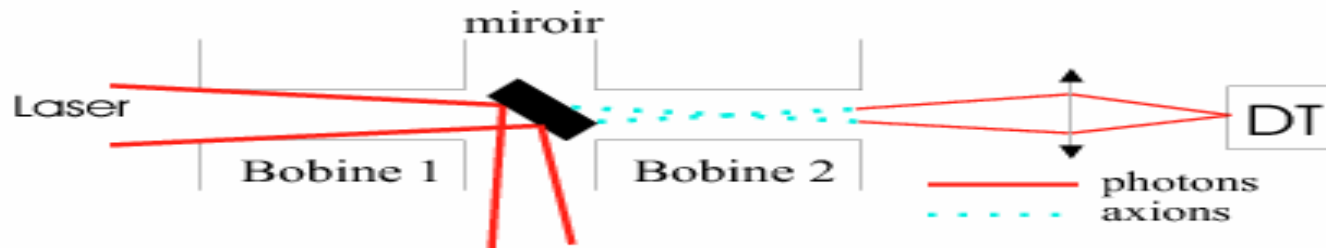
Photorégénération au LULI grâce aux bobines pulsées de BMV

Générateur transportable



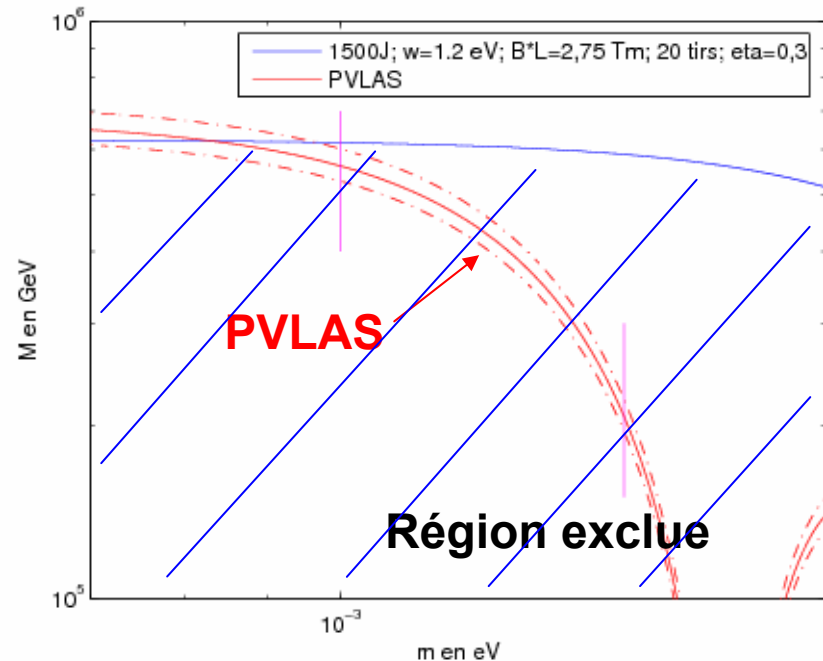
24 kV; $3 \times (1,2)^3 \text{ m}^3$

Schéma expérimental



Limites après 20 tirs de 1500 J
chacun (5 jours)

Contact pris,
demande d'accès en préparation



Collisions photon-photon au Rutheford Appleton Laboratory

arXiv:hep-ph/0510076 v1 6 Oct 2005

Using high-power lasers for detection of elastic photon-photon scattering

E. Lundström*, G. Brodin, J. Lundin, M. Marklund
Department of Physics, Umeå University, SE-901 87 Umeå, Sweden

R. Bingham, J. Collier, J.T. Mendonça, P. Norreys
Rutherford Appleton Laboratory, Chilton, Didcot OX11 0QX, Oxfordshire, UK
(Dated: October 7, 2005)

The properties of four-wave interaction via the nonlinear quantum vacuum is investigated. The effect of the quantum vacuum is to generate photons with new frequencies and wave vectors, due to elastic photon-photon scattering. An expression for the number of generated photons is derived and using state-of-the-art laser data it is found that the number of photons can reach detectable levels. In particular, the prospect of using the high repetition Astra Gemini system at the Rutherford Appleton Laboratory is discussed. The problem of noise sources is reviewed, and it is found that the noise level can be reduced well below the signal level. Thus, detection of elastic photon-photon scattering may for the first time be achieved.

PACS numbers: 12.20.Fv, 42.65.-k, 42.50.Xa

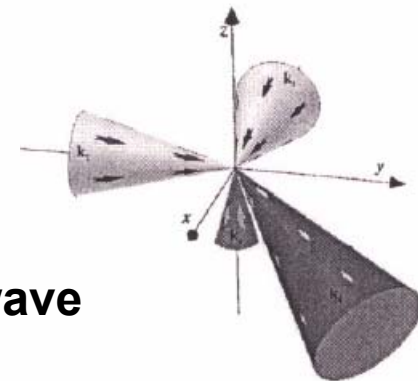


FIG. 1: Configuration of the incoming laser beams and the direction of the scattered wave for the suggested three-dimensional configuration of wave vectors, which satisfies the matching conditions (5).

Light diffraction by a strong standing electromagnetic wave

arXiv:hep-ph/0602039v1 3 Feb 2006

A.Di Piazza, K.Z.Hatsagortsyan, et C.H.Keitel

Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Nouveau schéma avec des lasers femto

PHYSICAL REVIEW A **70**, 033801 (2004)

Ultrafast resonant polarization interferometry: Towards the first direct detection of vacuum polarization

Andre N. Luiten* and Jesse C. Petersen†

School of Physics, The University of Western Australia Nedlands, Western Australia 6907, Australia

(Received 25 February 2004; published 2 September 2004)

Vacuum polarization, an effect originally predicted nearly 70 years ago, is still yet to be directly detected despite significant experimental effort. Previous attempts have made use of large liquid-helium cooled electromagnets which inadvertently generate spurious signals that mask the desired signal. We present an approach for the ultrasensitive detection of optical birefringence that can be usefully applied to a laboratory detection of vacuum polarization. The technique has a predicted birefringence measurement sensitivity of $\Delta n \sim 10^{-20}$ in a 1 s measurement. When combined with the extreme polarizing fields achievable in this design we predict that a vacuum polarization signal will be seen in a measurement of just a few days in duration.

DOI: 10.1103/PhysRevA.70.033801

PACS number(s): 42.50.Xa, 12.20.Fv, 42.62.Eh, 42.25.Lc

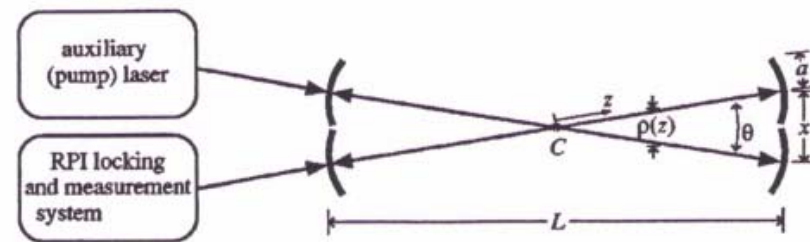


FIG. 2. Measurement scheme for optically induced birefringence.

Plan

- Introduction théorique
- Historique
- Expérience BMV
- La « concurrence » 2nd Joint ILIAS-CAST-CERN axion
Training Workshop May 2006, Patras
- Conclusions

Merci à PVLAS

Bientôt des nouveaux résultats : **BMV** *et al.*

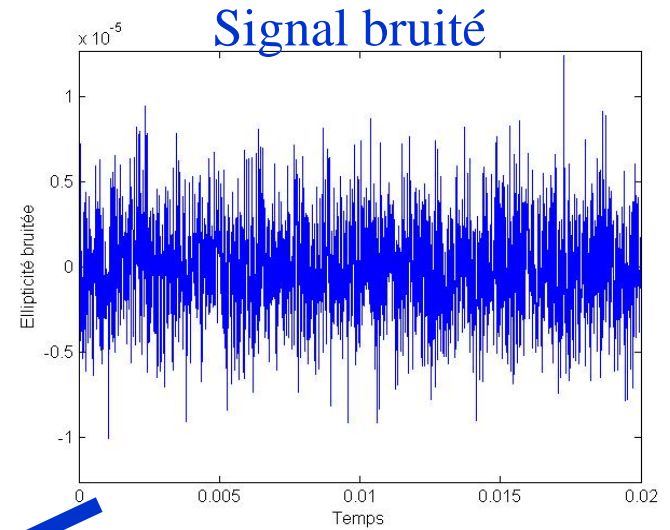
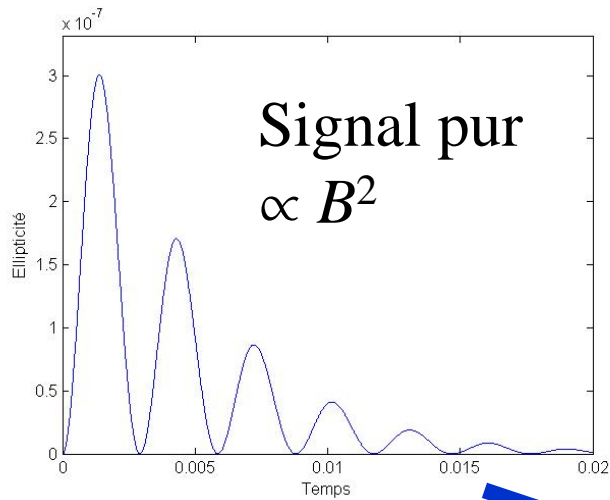
Lasers de plus en plus puissants => optique non-linéaire du vide quantique

L'expérience BMV

(Biréfringence Magnétique du Vide)

Carlo RIZZO

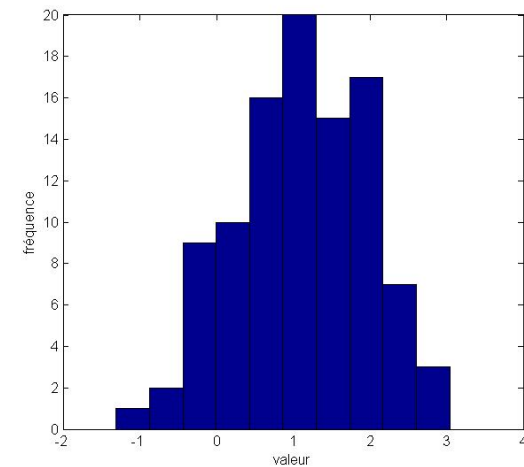
LCAR-IRSAMC
Université Paul Sabatier et CNRS
Toulouse

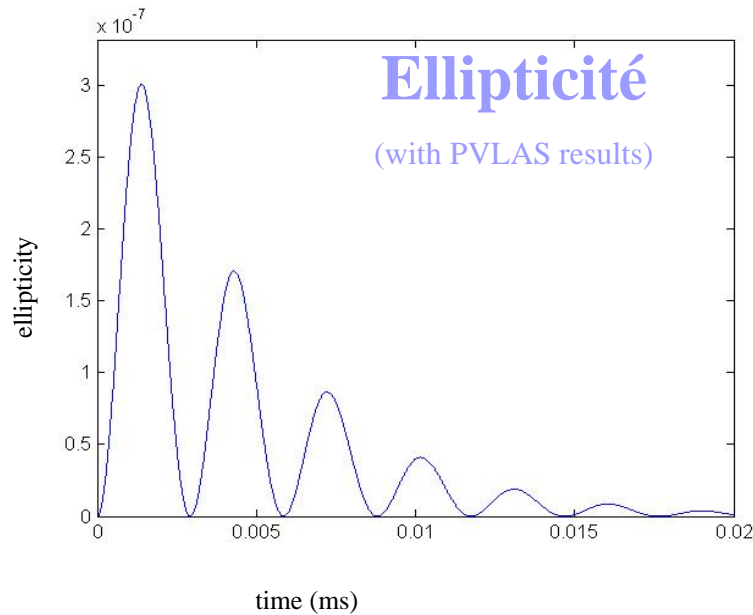


Corrélation



Simulation de 100 tirs
(20 heures)





Sensibilité attendue

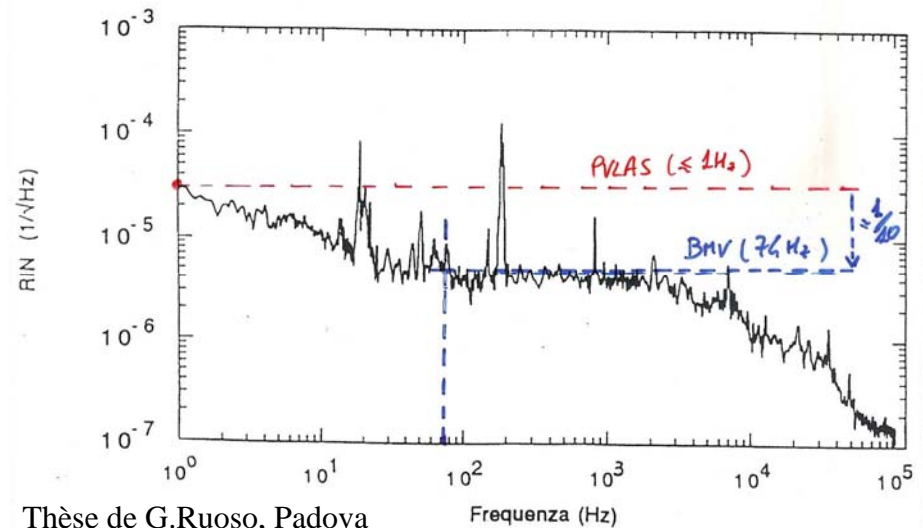
$$\Psi_s \sim 10^{-8} 1/\sqrt{\text{Hz}}$$

Sensibilité « shot noise » (10 mW)

$$\Psi_s \sim 2.10^{-9} 1/\sqrt{\text{Hz}}$$

Pseudo-Fréquence du signal

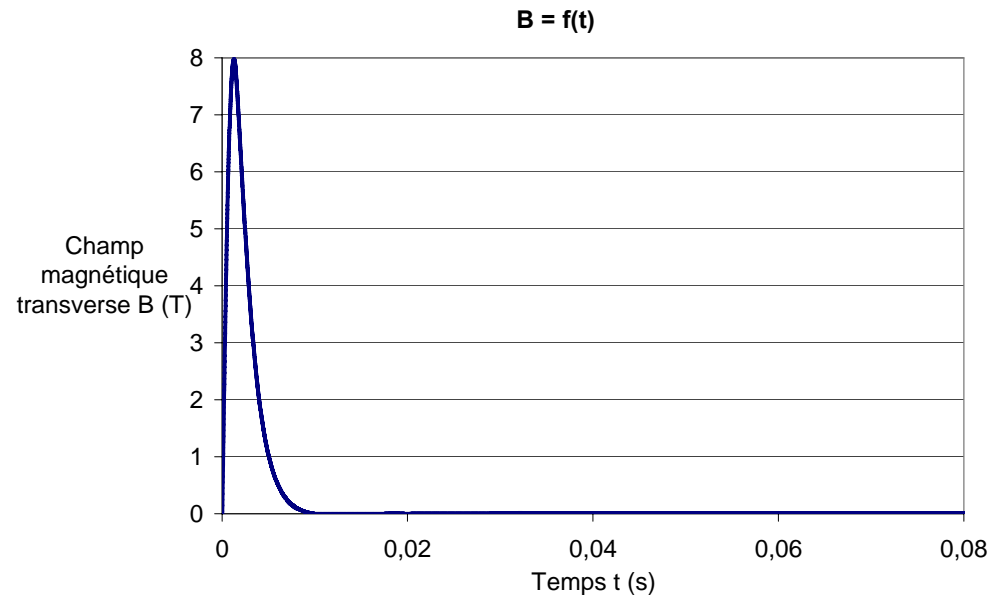
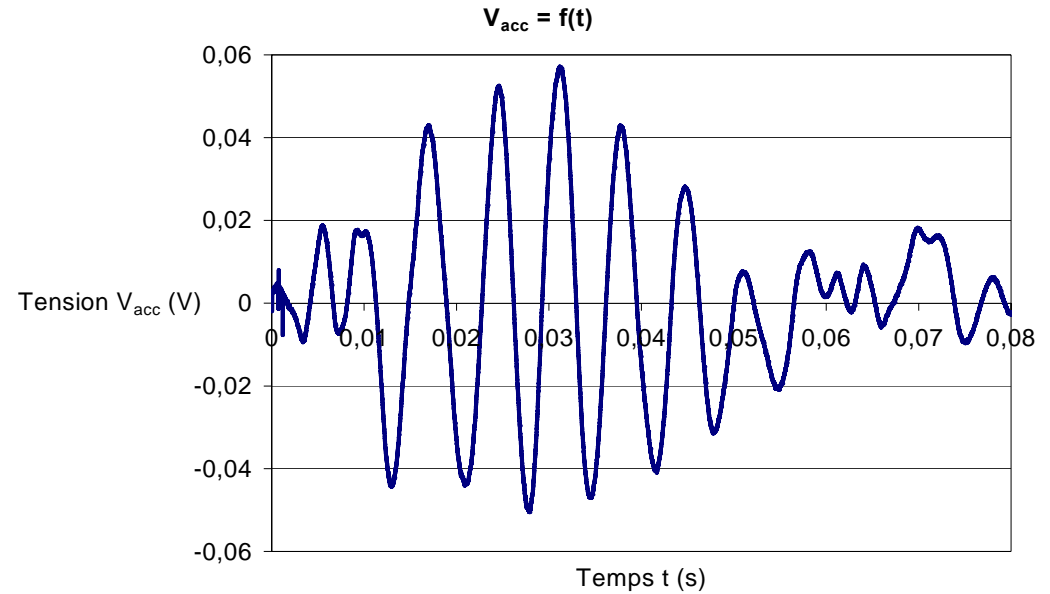
$$2\nu_b \sim 100 \text{ Hz}$$

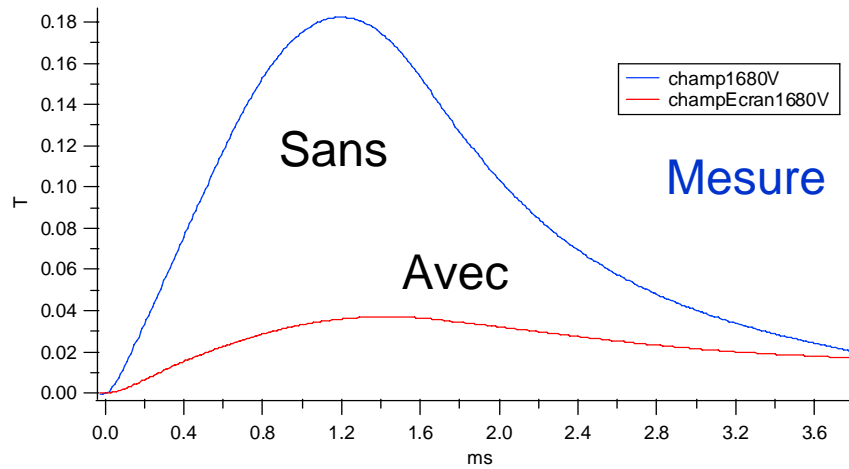


Étude préliminaire
des vibrations induites
par le tir au niveau du
sol

Vibrations

Champ





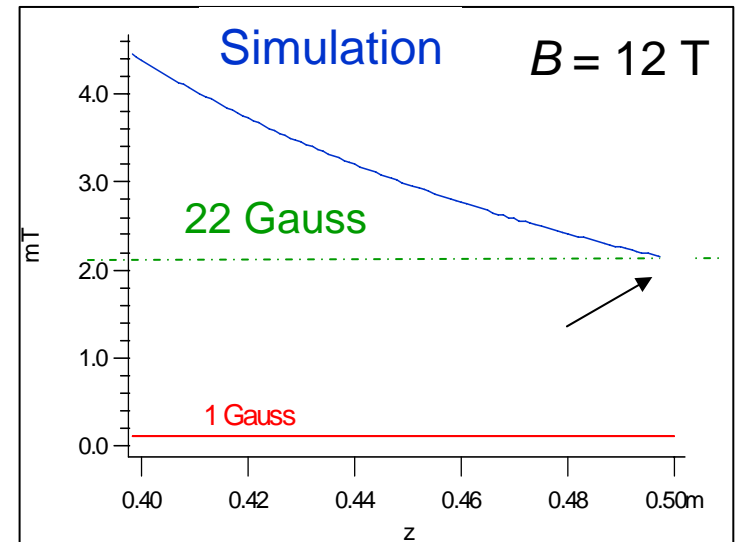
Test d'écrantage
avec une plaque de
cuivre de 4 mm
d'épaisseur : $20\% * B$

Les miroirs sont biréfringents magnétiques :

$$\Psi_m \sim 10^{-9} / T^2 \text{ par réflexion}$$

$\Rightarrow B(\text{miroirs}) < 3 \text{ G}$ pour un effet $< 10^{-10}$.

Avec deux plaques : $20\% * 20\%$ de
22 Gauss = 0,9 Gauss restants



Gaz résiduels

Effet Cotton-Mouton des gaz usuels :

- He $\rightarrow 1.10^{-3}$ mbar
- H₂ O, H₂ $\rightarrow 2.10^{-5}$ mbar
- N₂ $\rightarrow 1.10^{-6}$ mbar
- O₂ $\rightarrow 1.10^{-7}$ mbar
- C_xH_y $\rightarrow 1.10^{-8}$ mbar

(pression partielle max pour un effet de 1 % de celui attendu (en 2007))

Bruits divers :

- bruits non corrélés à B : éliminés par détection homodyne ;
- bruits induits directement par B : liés à $\frac{\partial B}{\partial t} \Rightarrow$ éliminés car déphasés ;
- bruits induits par B via un autre phénomène : à voir...