

The vacuum magnetic birefringence experiment

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CNRS UPR 3228

Vacuum magnetic birefringence: predicted by QED

- Vacuum polarization

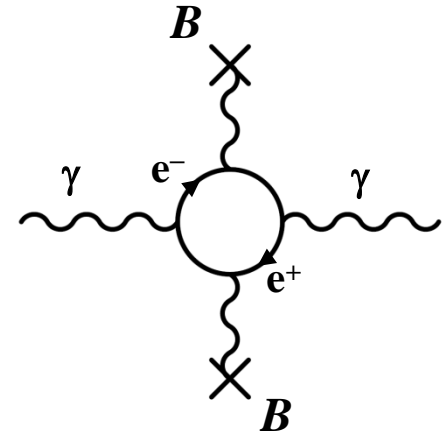
→ *nonlinear interaction between electromagnetic fields*

- Calculated in the 70's:

$$\Delta n = \frac{2}{15} \frac{\alpha^2 \hbar^3}{m_e^4 c^5} \frac{B^2}{\mu_0}$$

$$\Delta n = k_{\text{CM}} B^2 \quad \text{with} \quad k_{\text{CM}} \approx 4 \cdot 10^{-24} \text{ T}^{-2}$$

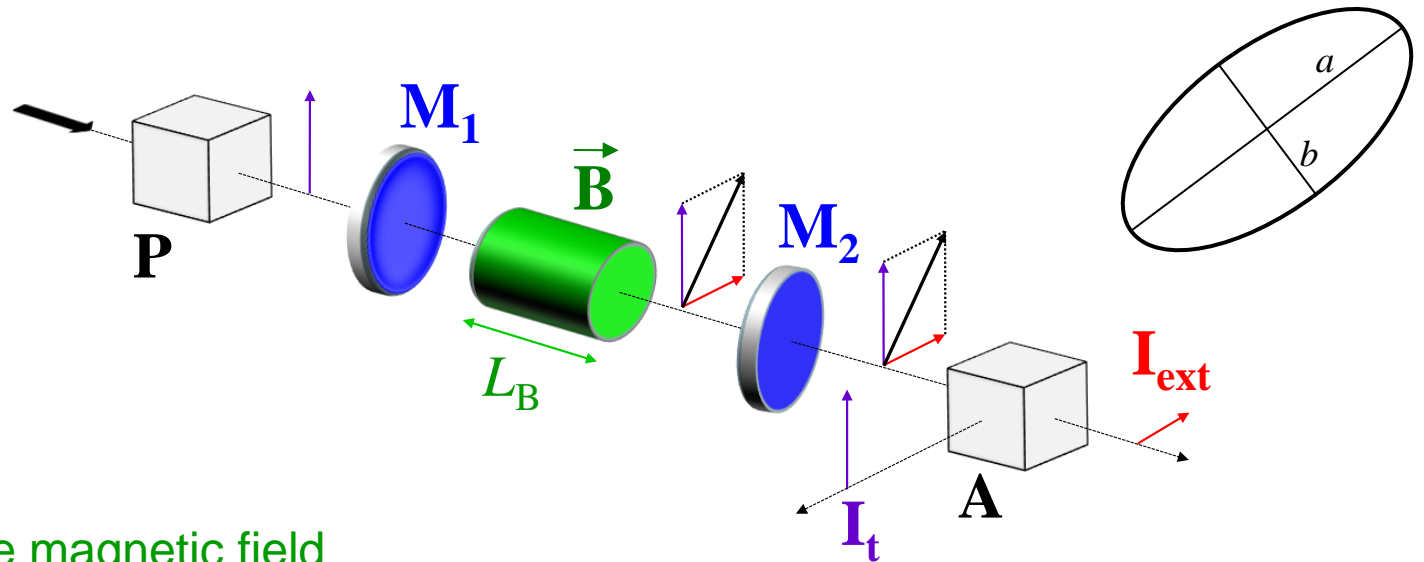
Never observed !
QED test



Principle of the experiment

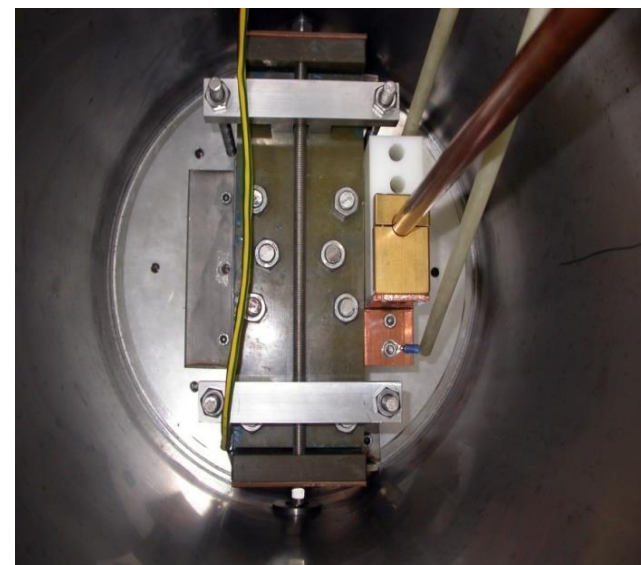
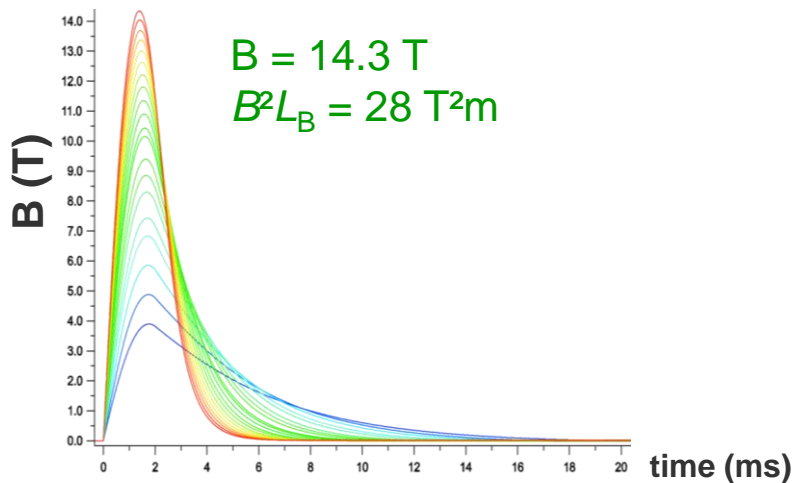
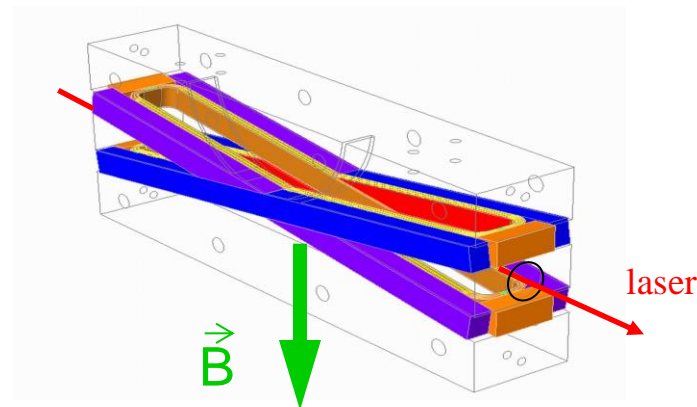
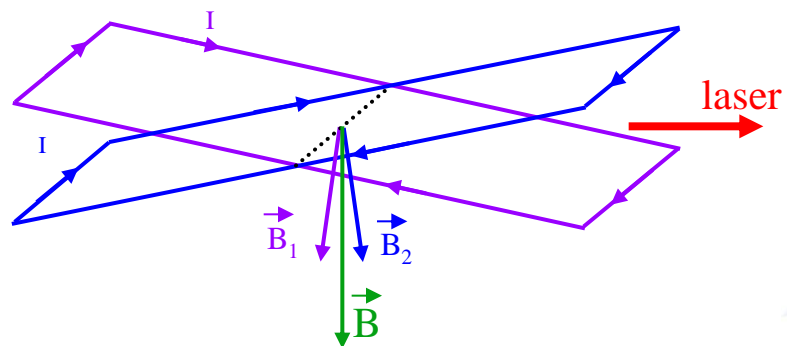
Ellipticity measurement :
$$\Psi = \frac{\pi}{\lambda} k_{\text{CM}} \left(\frac{2F}{\pi} \right) B^2 L_B$$

Laser
 $\lambda = 1064 \text{ nm}$

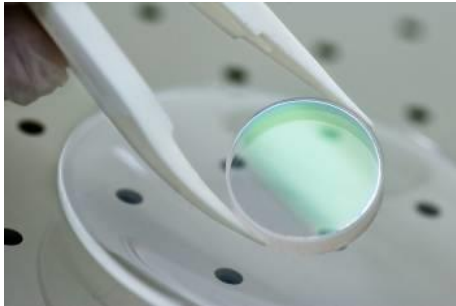


- High transverse magnetic field
- Fabry-Pérot cavity : increase the optical path in B
- P and A : polarizers crossed at maximum extinction
- B at 45° compared to polarizers' direction

Unconventional magnets developed at LNCMI : Xcoil



Fabry-Pérot cavity



	VIRGO	FVLAS	aLIGO	Birefringence Magnétique du Vide
L_c	3 km	6.4 m	4 km	2.27 m
τ	159 μ s	442 μ s	970 μ s	1.08 ms
$F = \frac{\pi c \tau}{L_c}$	50	70 000	230	450 000
$\Delta\nu = \frac{c}{2L_c F}$	1 kHz	360 Hz	164 Hz	147 Hz

➔ One of the **sharpest** cavities in the world

ANALYSIS :

- We calculate :

$$Y(t) = \frac{I_{\text{ext}}(t)/I_{\text{t,f}}(t) - \text{DC}}{2|\Gamma|} = \gamma \Psi(t) + \gamma \frac{|\varepsilon| \theta_F(t)}{|\Gamma|} + \frac{\Psi^2(t)}{2|\Gamma|} + \frac{\theta_F^2(t)}{2|\Gamma|}$$

Measured before the shot \rightarrow $2|\Gamma|$
 $\gamma = +1$ si $\Gamma > 0$
 $\gamma = -1$ si $\Gamma < 0$

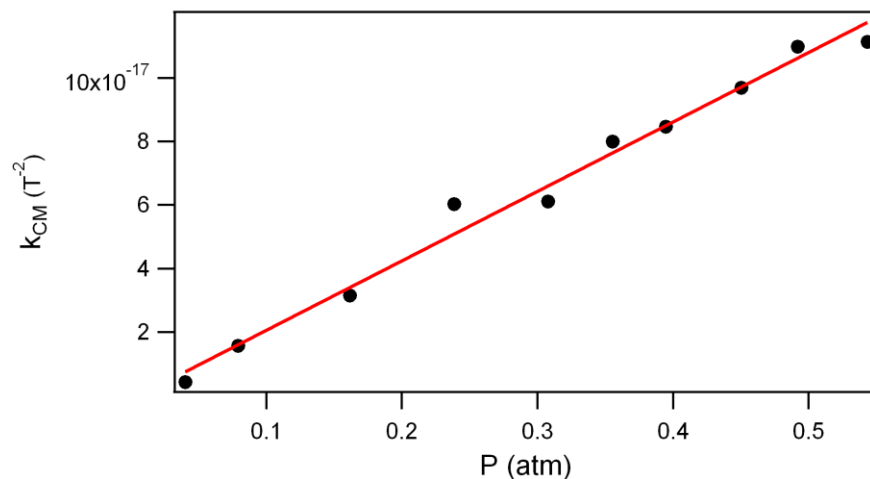
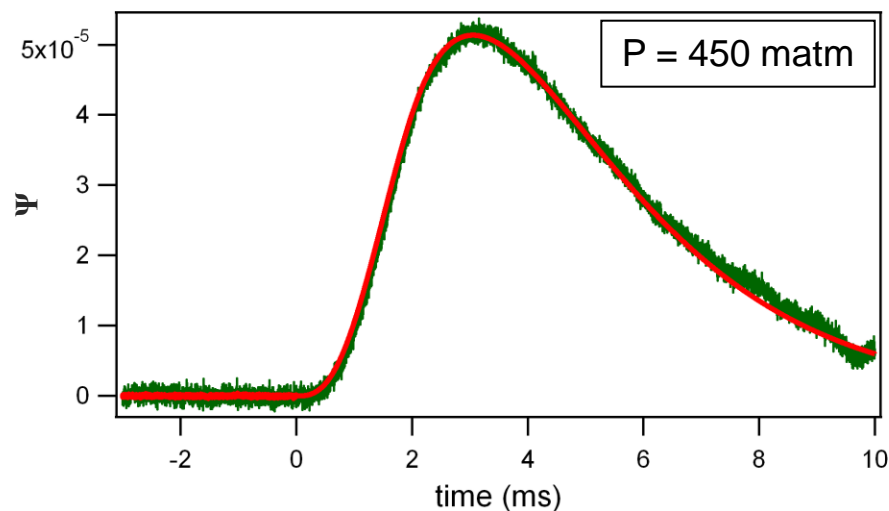
- Variable parameters :

- direction of \vec{B}
- sign of Γ : can be switched by rotating the mirrors

4 series of shots : $Y_{>>}$, $Y_{><}$, $Y_{<<}$, $Y_{<>}$

→ Linear combinations to extract $\Psi(t)$

Cotton-Mouton effect of helium gas :

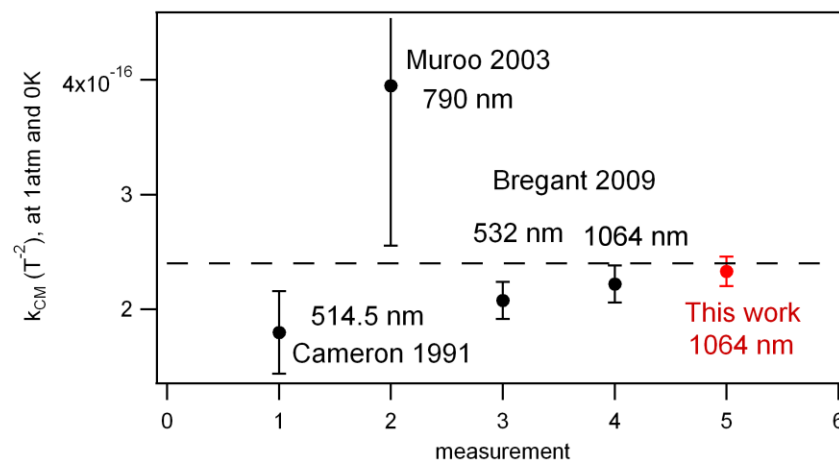


$$k_{CM} = (2.19 \pm 0.12) \times 10^{-16} \text{ T}^{-2} \cdot \text{atm}^{-1} \text{ at } 293\text{K}$$

to be published

Theoretical prediction :

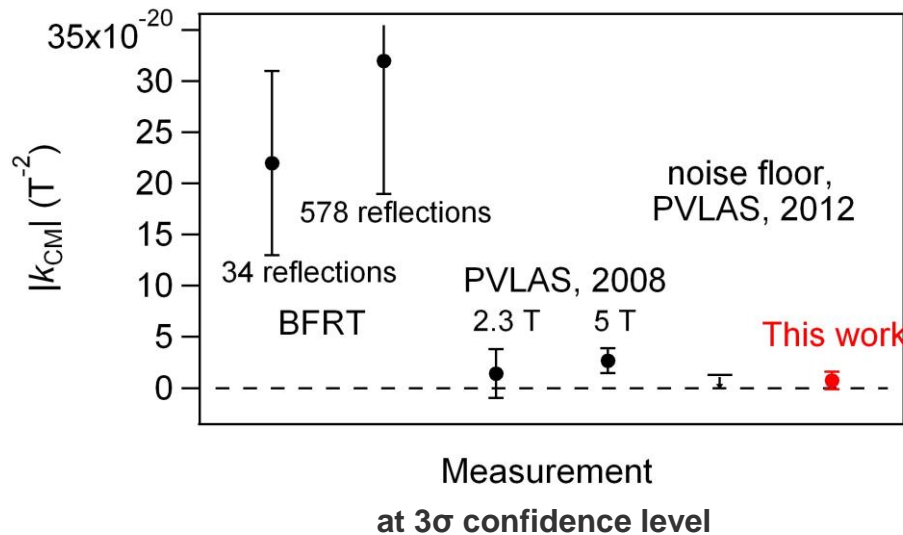
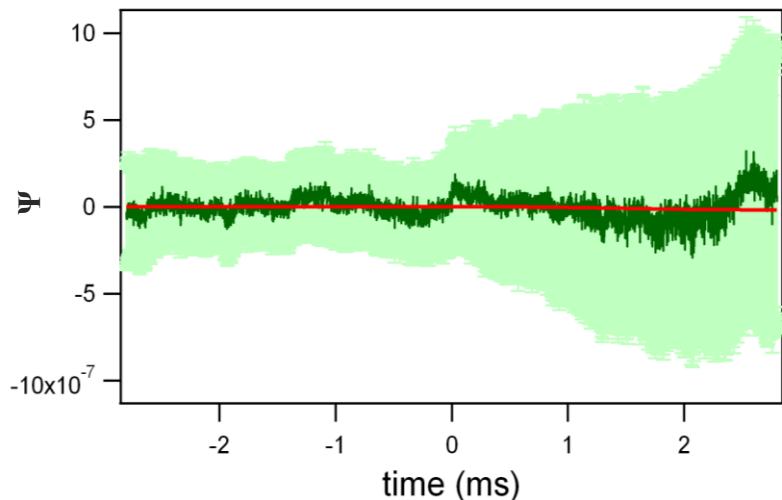
$$k_{CM} = (2.237 \pm 0.009) \times 10^{-16} \text{ T}^{-2} \cdot \text{atm}^{-1}$$



- Cameron 1991 : R. Cameron *et al.*, *Phys. Rev. A* **157**, 125 (1991)
- Muroo 2003 : K. Muroo *et al.*, *J. Opt. Soc. Am. B* **20**, 2249 (2003)
- Bregant 2009 : M. Bregant *et al.*, *Chem. Phys. Lett.* **471**, 322 (2009)

Cotton-Mouton effect of vacuum :

More than 100 shots, B = 6.5T



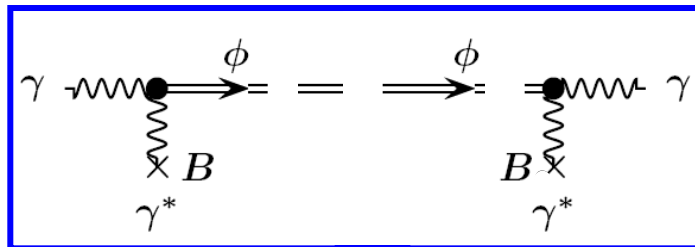
Measurement : $k_{CM} = (-7.4 \pm 8.7) \times 10^{-21} \text{ T}^{-2}$ at 3σ confidence level

→ 3 orders of magnitude from the QED measurement

BFRT Collaboration : R. Cameron *et al.*, *Phys. Rev. D* **47**, 3707 (1993)
 PVLAS, 2008 : E. Zavattini *et al.*, *Phys. Rev. D* **77**, 032006 (2008)
 PVLAS, 2012 : G. Zavattini *et al.*, *Int. J. of Mod. Phys. A* **27**, 1260017 (2012)
 A. Cadène *et al.*, *arXiv:1302.5389* (2013)

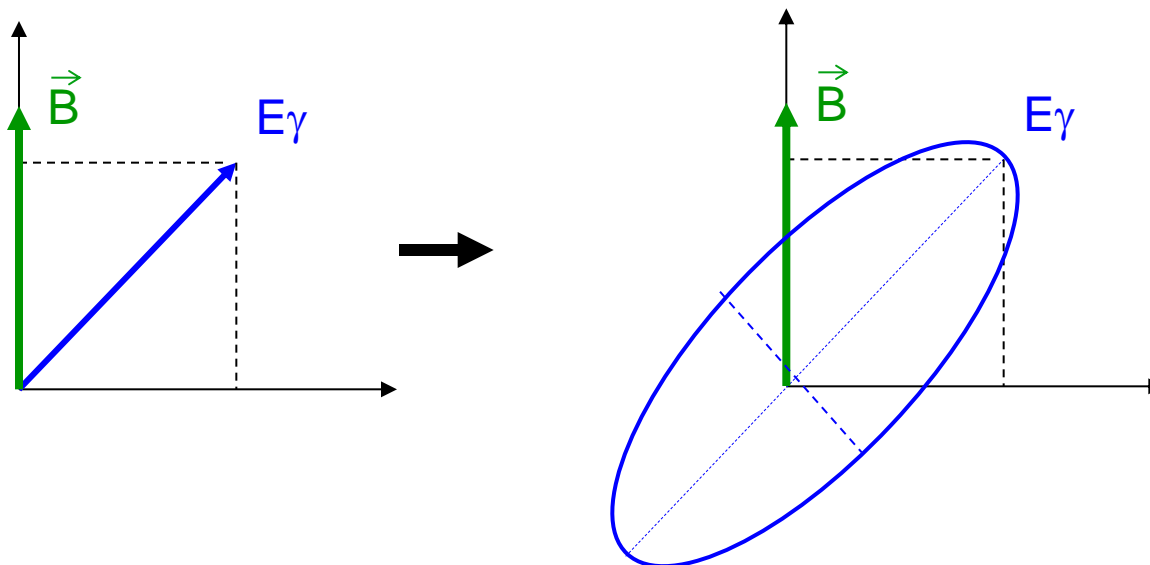
By-product : beyond standard model

Axion : pseudoscalar, spinless, chargeless particle coupling with two photons



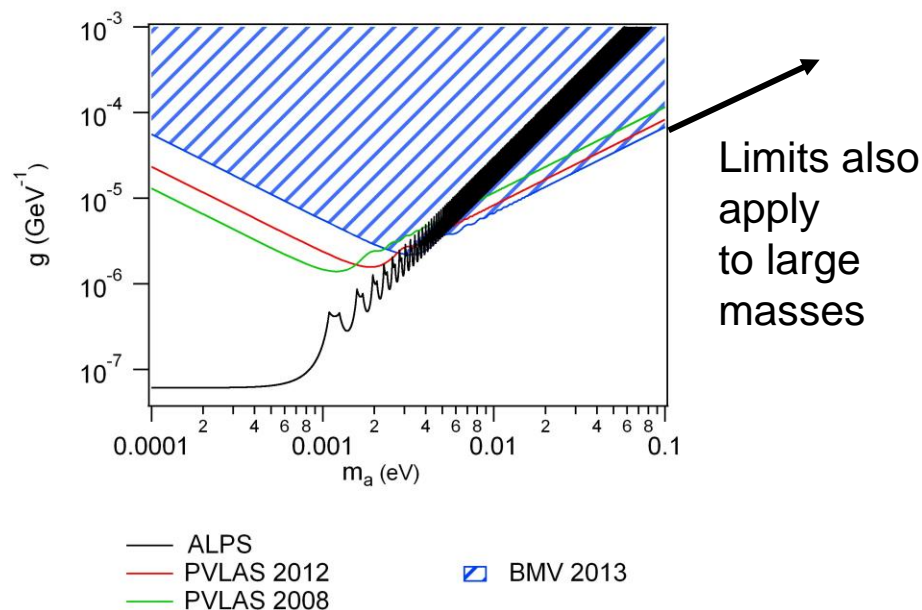
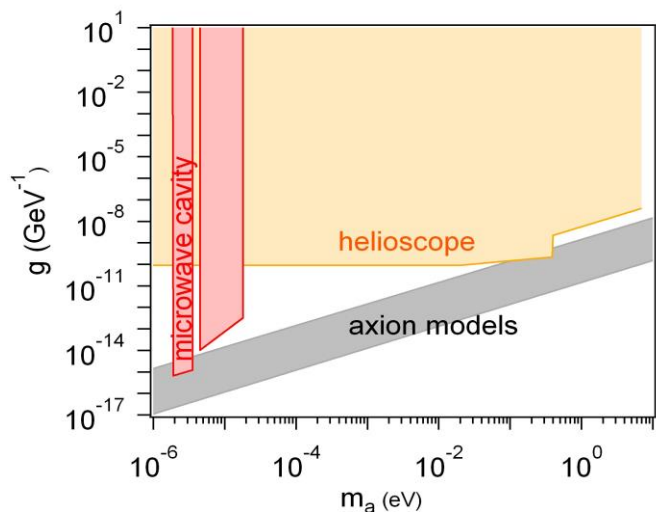
Virtual particle

Ellipticity :



By-product : beyond standard model

- Axion source :
 - solar origin : CAST
 - cosmic origin : ADMX
- Detection on earth
 - Axion source and detection on earth :
 - light shining through the wall : ALPS



CAST :E. Arik et al, J. Cosm. Astropart. Phys. **02**, 8 (2009)
 ADMX : S. J. Asztalos et al., Phys. Rev. Lett. **104**, 041301 (2010)

ALPS : K. Ehret et al., Phys. Lett. B **689**, 149 (2010)
 PVLAS, 2008 : E. Zavattini *et al.*, Phys. Rev. D **77**, 032006 (2008)
 PVLAS, 2012 : G. Zavattini *et al.*, Int. J. of Mod. Phys. A **27**, 1260017 (2012)

Perspectives : → Goal : 10^{-22} T⁻²/pulse

Vacuum QED measurement : 1000 pulses (2 months)

- Increase the transverse magnetic field : 2 XXL-coil, operational before the end of the year



$$B^2 L_B > 300 \text{ T}^2\text{m}$$

- Improvement of the optical sensitivity : new setup



Thank you for your attention



See poster for more details