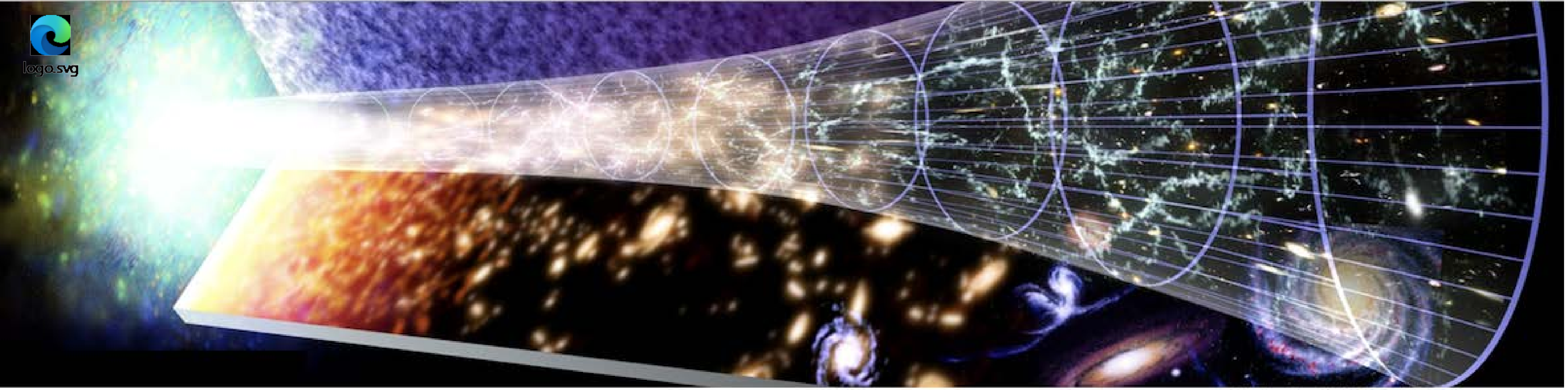


Crédit Photo: Photo © NASA/Novapix / Bridgeman Images

Kick-off GDR CoPhy, LPNHE
17–19 janv. 2023

High Magnetic Fields to Probe the sub-eV range of Particle/Astroparticle Physics – From OSQAR experiments up to new Projects & Perspectives at CERN & CNRS-Grenoble

P. Pugnat, LNCMI-Grenoble/CNRS, EMFL

OSQAR

CERN

GrAHal
Grenoble Axion Haloscopes

LNCMI

EMFL
European Magnetic Field Laboratory

cnrs

UGA
Université Grenoble Alpes

Outline

- Introduction
  - Weakly Interacting Slim Particles (WISPs)* as a possible component(s) of the Cold Dark Matter (CDM)
  - QCD Axion
- OSQAR (LSW/VMB/CHASE)
  - LSW: Light Shining through Wall
    - . Present reference results for Axion and Axion-Like-Particles (ALPs) searches
    - . Future of LSW experiments (ALPSII, OSQAR+/BabyJURA, JURA…)
  - VMB: Vacuum Magnetic Birefringence
  - CHASE: Chameleon Search Experiment
- A New Proposal: The Grenoble Axion Haloscope (GrAHal)
  - Probing QCD Axion Dark Matter with the Grenoble Hybrid Magnet under commissioning phase at LNCMI-Grenoble (Equipex LaSUP)

** Complementary to the "better-known" WIMPs, i.e. Weakly Interactive Massive Particles*

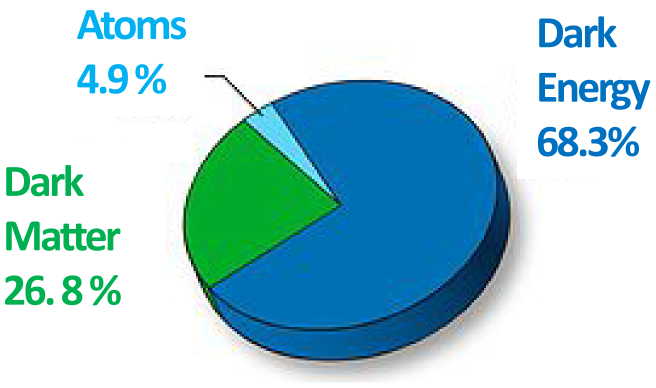
Particle Physics beyond the Standard Model

Among the Biggest Questions in Science…

Mass

WIMPs (SUSY,…)
> 100 GeV

SIMPs (> 25 GeV, 0.1 mbarn)



The Universe energy/matter density
content after Planck (2013)

Λ-CDM
Standard Model
of Cosmology

WISPs (ALPs,…)
Slim/Sub-eV

SISPs (?)
Strongly interacting & Slim

Other interactions

Summary on QCD-DM Axion

Two among the most fundamental problems of Particle Physics & Cosmology can be solved by the discovery of a single particle,

The QCD Axion

- Predicted independently by Weinberg and Wilczek (1978) from the breaking of the Peccei-Quinn symmetry (1977) to solve the strong CP problem, one of the key remaining questions of the Standard Model of Particle Physics, *i.e.* "Why, in view of nEDM < 3.6 x 10^{-26} e·cm @ 95% CL, the QCD seems **<u>not</u>** to break the CP-symmetry ? "

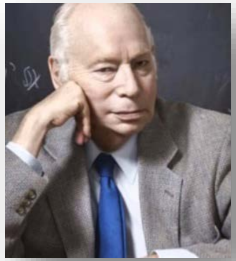
- Axion in the mass range 10^{-6}-10^{-3} eV will also solve the DM problem; it is one of the most serious cold DM candidates & the only non-supersymmetric one, this in the context of **none** signature of SuSy observed so far at the LHC…

- Neutral pseudo-scalar **0^-**

- Axion coupling to photons

$$L_{a\gamma\gamma} = g_{a\gamma\gamma}\, \phi_a\, \boldsymbol{E}\cdot\boldsymbol{B}$$

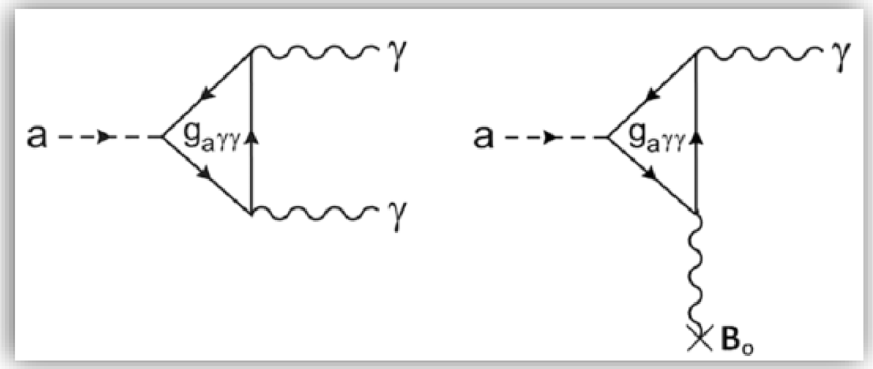
"Cleaning up a long standing problem in theoretical physics" (F. Wilczek, Nobel Laureate in Physics, 2004)



(S. Weinberg, Nobel Laureate in Physics, 1979)

Why High Magnetic Fields & Flux for QCD-DM Axion search ?

- To maximize the conversion of this hypothetical weakly interacting particle to photons, via the inverse Primakoff effect



The key ingredient of most of the experiments

$P_{LSW} \sim g_{a\gamma\gamma}^{4}\, B^4\, L^4$

$P_{Haloscope} \sim g_{a\gamma\gamma}^{2}\, B^2\, V$

This "non-trivial" interaction is related to the chiral anomaly, i.e. a purely quantum phenomenon first studied in particle physics in 1969 (Adler, Bell and Jackiw) to explain the neutral pion decay in 2 photons ($\pi^0 \rightarrow \gamma\ \gamma$) anticipated and observed by Primakoff in 1951.

The puzzle was the anomalous nonconservation of a chiral current, which is today "rejuvenated" in condensed matter physics…

OSQAR Optical Search for QED vacuum magnetic birefringence, Axion & photon Regeneration

OSQAR-LSW, OSQAR-VMB, OSQAR-CHASE

CERN, Geneva, Switzerland
G. Deferne, **P. Pugnat (spokesperson, now at LNCMI-CNRS), A. Siemko**

Charles University, Faculty of Mathematics & Physics, Prague, Czech Republic
M. Finger Jr., M. Finger, M. Slunecka

Czech Technical University, Faculty of Mechanical Engineering, Prague
L. Flekova, J. Hošek, K. Macuchova, M. Virius, J. Zicha

ISI, ASCR, Brno, Czech Republic
A. Srnka

IMEP/LAHC - INPG, 38016 Grenoble, France
L. Duvillaret, G. Vitrant, J.M. Duchamp

IN, CNRS – UGA & INPG, BP 166, 38042 Grenoble, France
R. Ballou

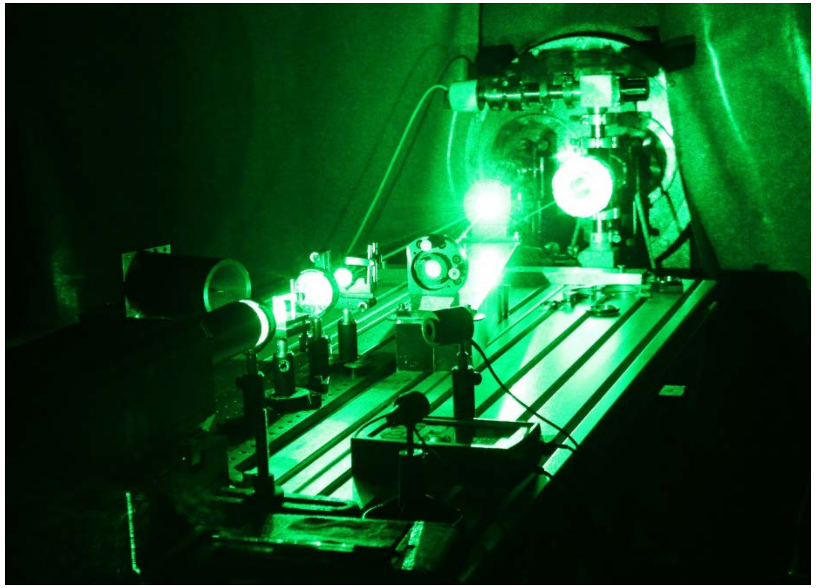
Johannes Gutenberg University of Mainz, Germany
M. Schott, C. Weinsheimer

LASIM , UCB Lyon1 & CNRS, 69622 Villeurbanne, France
J. Morville

LIPhy, UGA & CNRS, 38402 Saint-Martin d'Hères, France
R. Jost, S. Kassi, D. Romanini

Technical Uuniversity of Liberec, Czech Republic
M. Šulc, Š. Kunc, R.Puliček, F.Švec

Warsaw University, Physics Department, Poland
A. Hryczuk, K. A. Meissner (co-spokesperson)

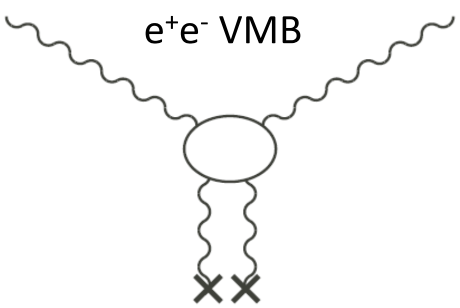


► *Up to 28 Members from 12 Institutes (CERN, Cz, Fr & Po) at its apogee but now in strong decline…*

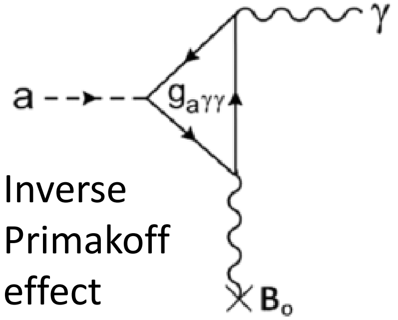
Scientific Motivations in a Nutshell

- **To measure for the 1st time the QED Vacuum Magnetic Birefringence (VMB)** *(Heisenberg & Euler, Weisskopf, 1936) i.e. the vacuum magnetic "anomaly" of the refraction index "n-1"* ~ 10^{-22} in 9.5 T

  "Exploring a new territory with a precision instrument is the key to discovery", Prof. S.C.C. Ting



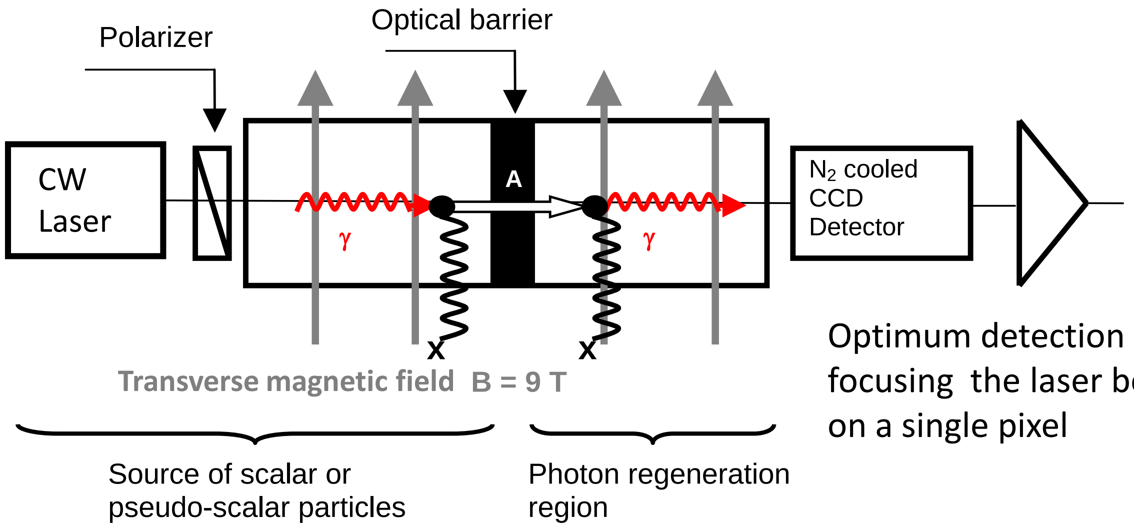
- **To explore the Physics at the Low Energy Frontier** (sub-eV)
  - **Axion** & **Axion Like Particles** *i.e. solution to the strong CP problem (Weinberg, Wilczek, 1978)* & ***Non-SUSY Dark Matter candidates*** *(Abbott & Sikivie; Preskill, Wise & Wilczek, 1983)*
  - **Paraphotons** *(Georgi, Glashow & Ginsparg, 1983)*, **Milli-charged Fermions**
  - **Chameleons** (*Khoury* & *Weltman, 2004*) ***Dark Energy candidate***
  - ***The Unknown*** **… SERENDIPITY, "Why not an abundance of ultralight particles ?"**



- **A complementary way of doing Particle Physics** based on the Laser beam interaction with magnetic fields
- **Spin-offs** in the domain of the metrology of electric & magnetic fields
  - Spin-off : **Start-up created** in 2009 by Prof. L. Duvillaret

    https://www.kapteos.com/

Photon Regeneration
Light Shinning Through Wall (LSW) Principle



Optimum detection by focusing the laser beam on a single pixel

P. Sikivie, PRL 51 (1983) 11415
A.A. Anselm, Sov. J. Nucl. Phys. 42 (1985) 936
K. van Bibber *et al.* PRL 59 (1987) 759

$$\frac{dN_\gamma}{dt} = \frac{P}{\omega}\eta\, P_{\gamma\leftrightarrow A}^{2}$$

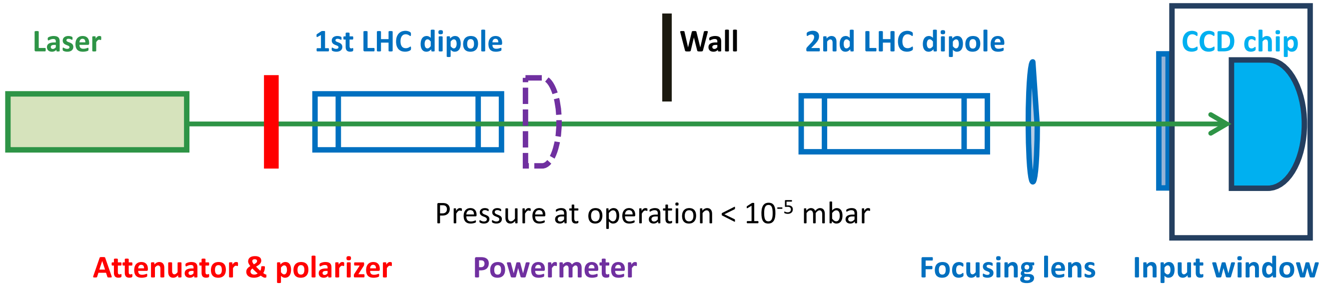
$$\text{with } P_{\gamma\leftrightarrow A} = \frac{1}{4\beta_A\sqrt{\varepsilon}}(g_{A\gamma\gamma}BL)^2\left(\frac{2}{qL}\sin\frac{qL}{2}\right)^2$$

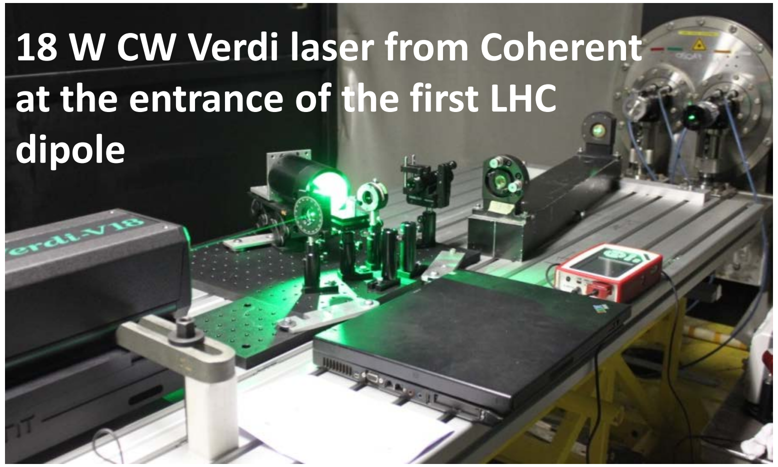
$$\text{and } q = \left|k_\gamma - k_A\right| = \frac{m_A^2}{2\omega} \text{ in vacuum}$$

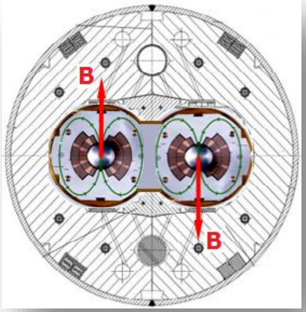
$$\text{Maximum of } P_{\gamma\leftrightarrow A} \text{ for } qL \to 0$$

Exclusion limit for	$g_{A\gamma\gamma}$
B (T)	B^{-1}
Magnetic Length (m)	L^{-1}
Optical power (W)	$P^{-1/4}$
Detector efficiency	$\eta^{-1/4}$
Detection threshold (γ/s)	$dN_\gamma/dt^{\,1/4}$
Time integration	$\Delta t^{-1/8}$

LSW – Experimental





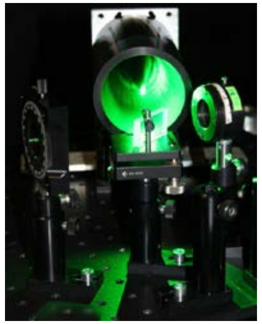


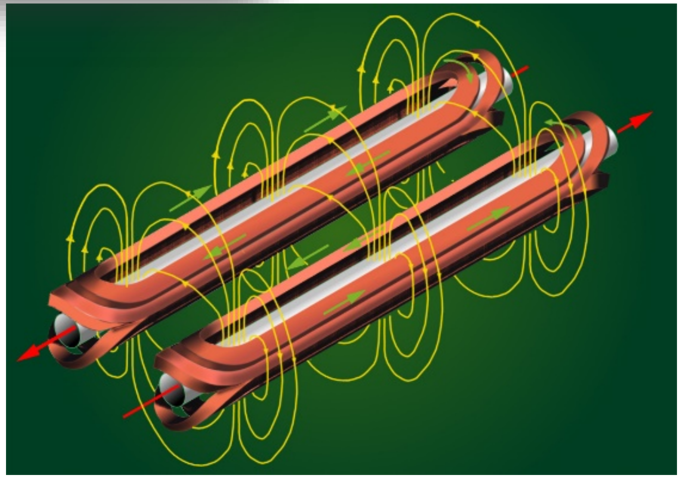
2-in-1 LHC dipole providing 9 T over 14,3 m

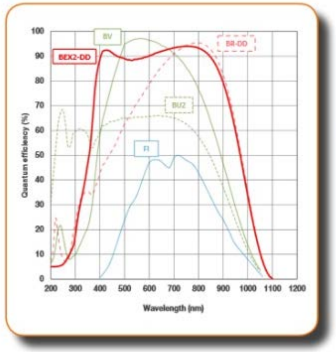
QE = 95 % at 488-514 nm; Dark current < 0.00047 e/Pixel/s @ -100° C; Readout noise: 2.5 e- rms/pixel @50kHz

ANDOR an Oxford Instruments company

Variable beam splitter attenuator with its absorber allowing a reduction of 10^{-3} of the beam power during alignment operations and checks

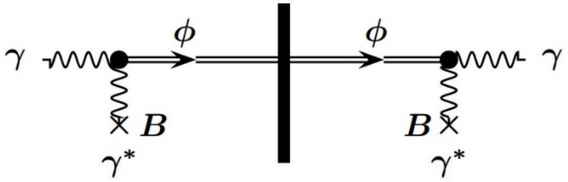


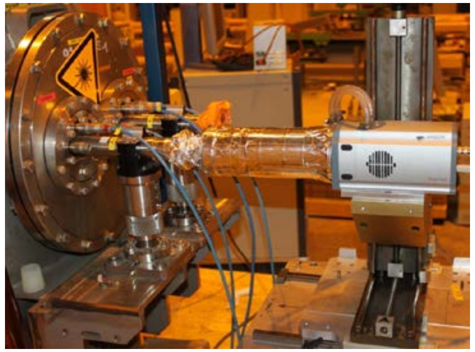




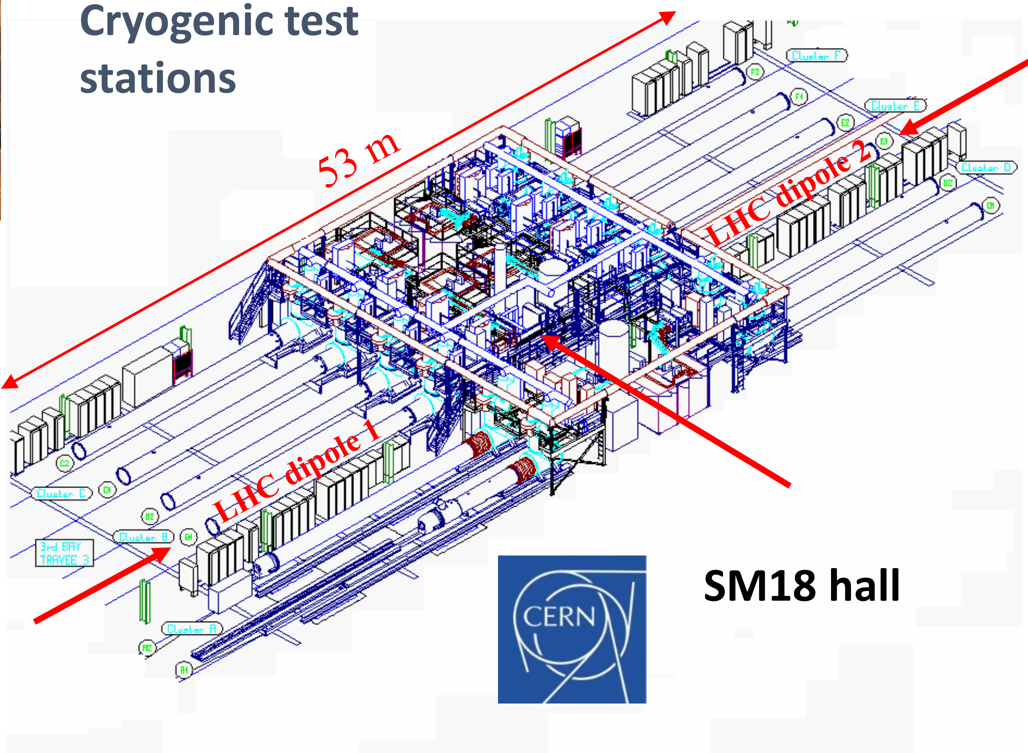
OSQAR -LSW

► *Operation in 2010-14 with 2 aligned 9 T spare LHC dipoles*



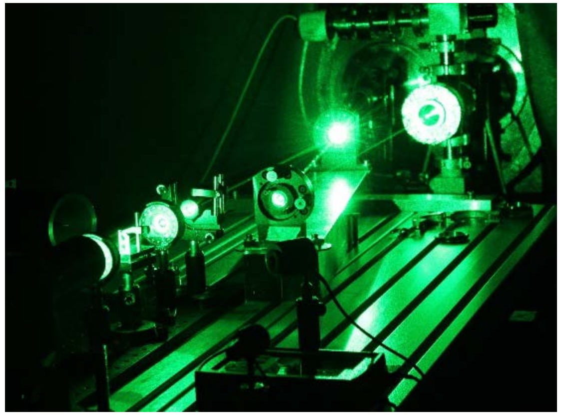


Cryogenic test stations



SM18 hall

Looking for "an invisible light shining through a wall"
K. van Bibber *et al.* PRL **59** (1987) 759

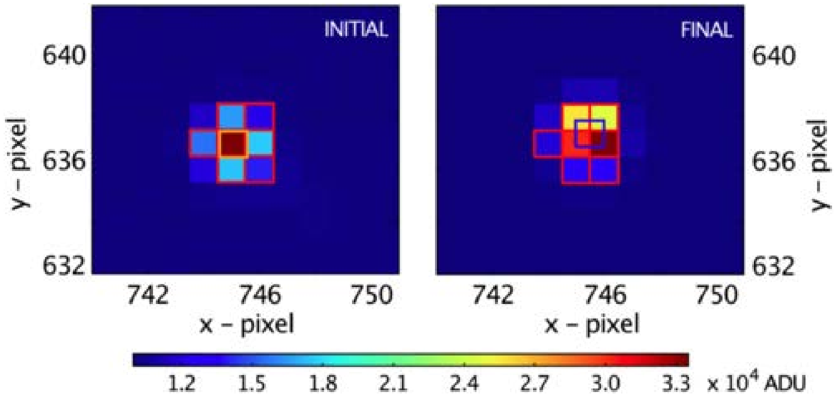


Regular check between data taking of the beam alignement with the CCD ►

OSQAR

No regenerated Photon detected

World leading limits for **model independent** Axion/ALPs searches since 2015



Total number of runs valid for analyses: 60 beam positions for each setup

- Scalar search: **180 hours, 60 runs 2 x 90 minutes**
- Pseudo-scalar search: **180 hours, 59 runs 2 x 90 minutes**

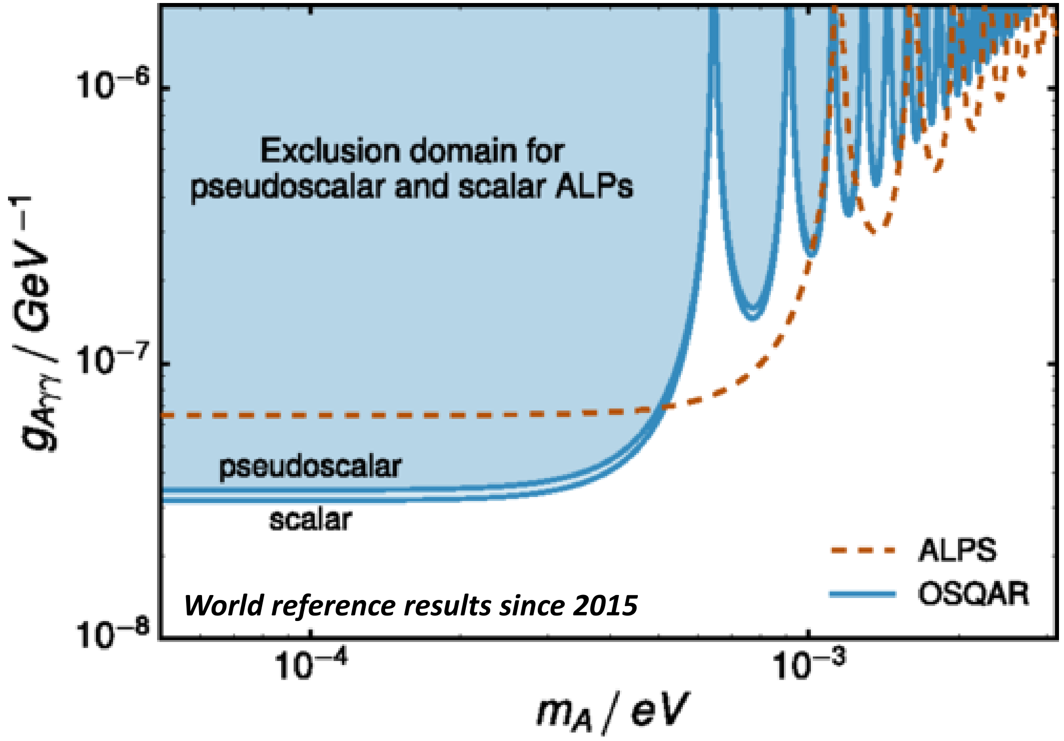
Bayesian analysis of the recorded counts after the cleaning of the cosmic contamination

Likelihood model

$$\mathcal{L} \propto \prod_i \mathcal{N}\left(N_i \,\middle|\, \mathcal{P}\left(\frac{dN}{dt} \cdot t_i^{\exp}\right) + \mu_i^{\mathrm{bkg}}, \sigma_i^{\mathrm{bkg}}\right)$$

For *model independent* ALPs searches with $m_A < 2 \cdot 10^{-4}$eV **@ 95% CL**

- Pseudo-scalar particules (axion), $\mathbf{E}_\gamma$ // **B**
  - . *sensitivity of 0.64 mHz*
  - . ***$g_{A\gamma\gamma} < 3.5 \cdot 10^{-8}$ GeV^{-1}***
- Scalar ones, $\mathbf{E}_\gamma \perp \mathbf{B}$
  - . *sensitivity of 0.45 mHz*
  - . ***$g_{A\gamma\gamma} < 3.2 \cdot 10^{-8}$ GeV^{-1}***



Detection sensitivity in the visible of 10^{-22} W

*R. Ballou, P. Pugnat et al. (OSQAR), Phys. Rev. D **92**, 092002 (2015), arXiv:1506.08082*

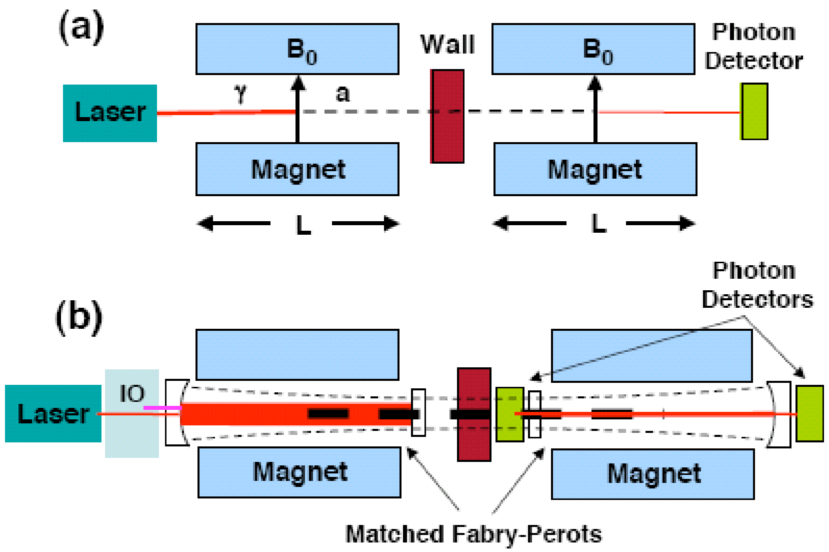
OSQAR

Perspectives (ALPSII, OSQAR+/BabyJURA, JURA)

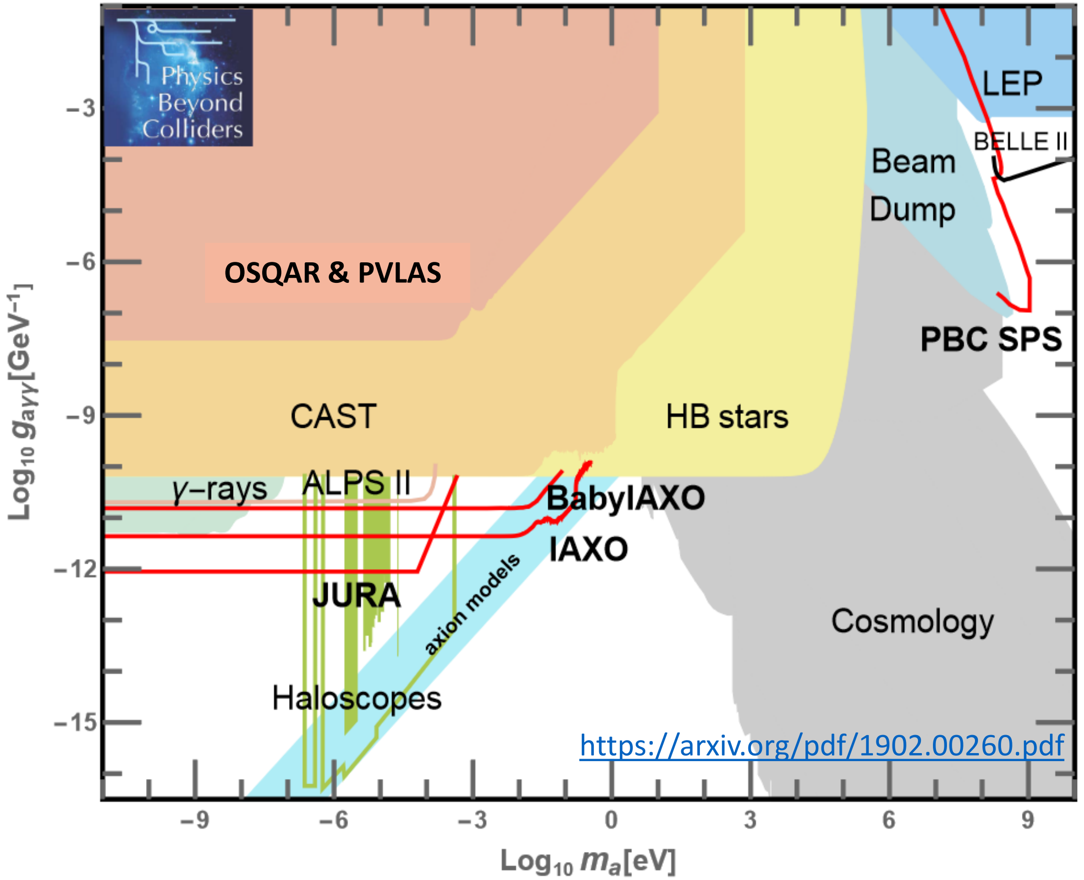
Phys. Rev. Lett. **98**, 172002 (2007)

Resonantly Enhanced Axion-Photon Regeneration

P. Sikivie,[a,b] D.B. Tanner,[a] and Karl van Bibber[c]
[a] Department of Physics, University of Florida, Gainesville, FL 32611, USA
[b] Theoretical Physics Division, CERN, CH-1211 Genève 23, Switzerland
[c] Lawrence Livermore National Laboratory, Livermore, CA 94550, USA



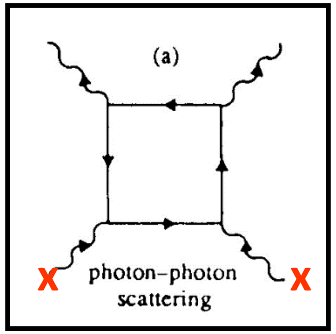
See also F. Hoogeveen and T. Zizgznhagen, Nuc. Phys. B **358**, 3 (1991)



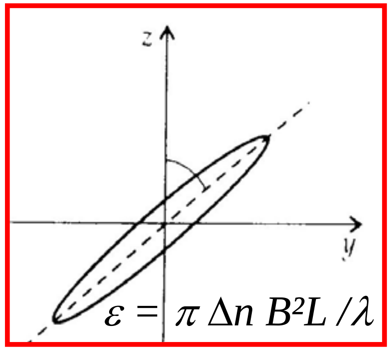
► ***ALPSII*** *under commissioning at DESY with (12 + 12) Hera dipoles of 5 T , i.e. 240 m long experiment*

► ***OSQAR+*** *under discussions within the CERN/PBC in the framework of JURA with for example (4 + 4) LHC Dipoles, i.e. 150 m long as a first step (NB: At CERN more than 30 spare 9 T LHC dipoles of 15 m long for JURA ?…)*

Toward Measurements of the VMB - Cotton-Mouton Effect of GN_2



A linear polarized light becomes "slightly" elliptical



$\varepsilon = \pi \Delta n B^2 L / \lambda$

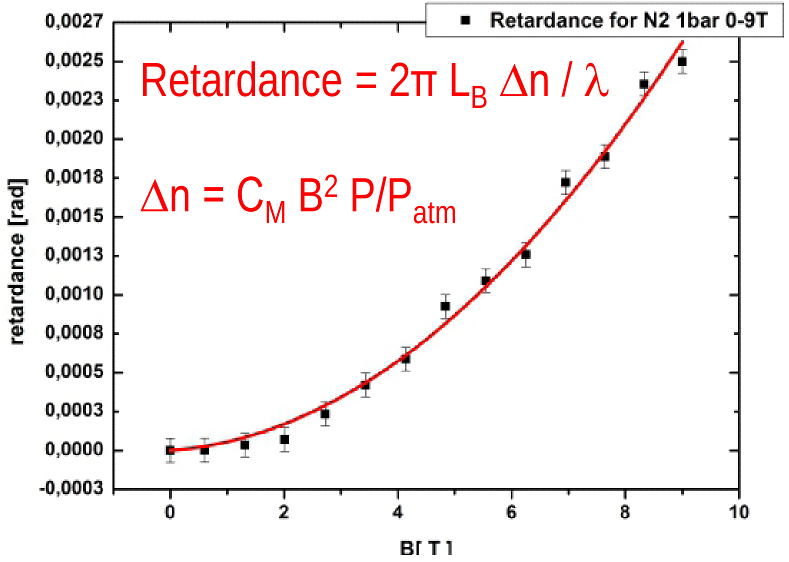
With axion/ALPS : birefringence & linear dichroism:

$$\varepsilon \approx \frac{B^2 l^3 m^2}{96 \ \omega \ M^2} \sin 2\phi$$

$$\theta \approx \frac{B^2 l^2}{16 \ M^2} \sin 2\phi$$

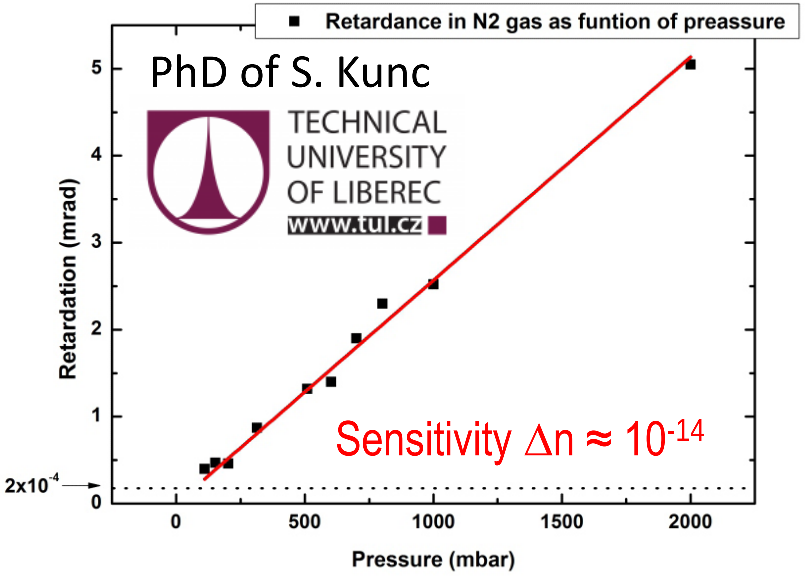
L. Maiani et al. Phys. Lett. 175B (1986) 359

Still far from the VMB signal even with a Fabry-Perot cavity of finesse 10^4-10^5, *i.e.* $\Delta n \approx 10^{-22}$ in 9.5 T



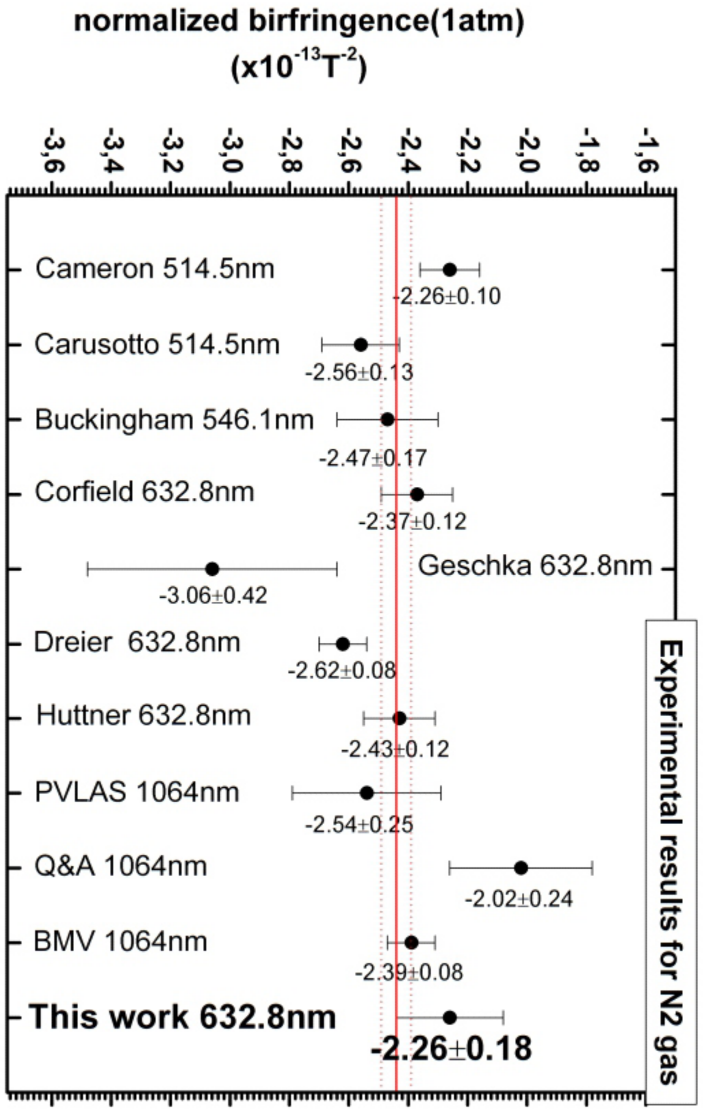
Retardance = $2\pi L_B \Delta n / \lambda$

$\Delta n = C_M B^2 P/P_{atm}$

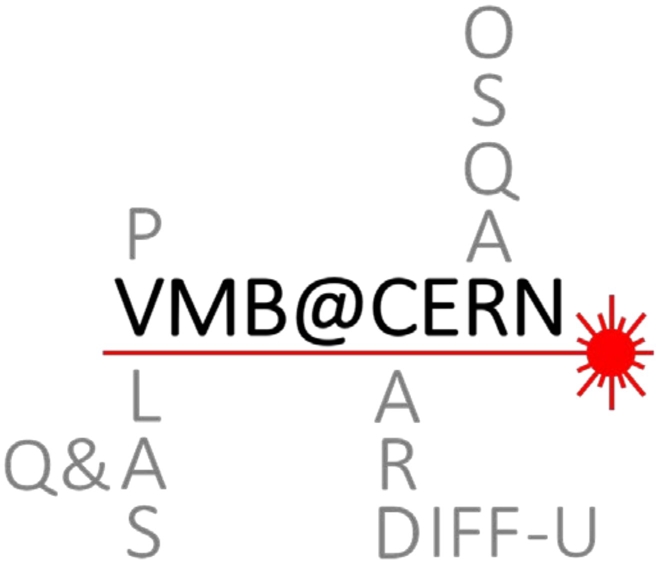


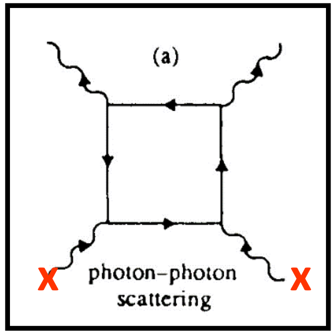
PhD of S. Kunc

Sensitivity $\Delta n \approx 10^{-14}$



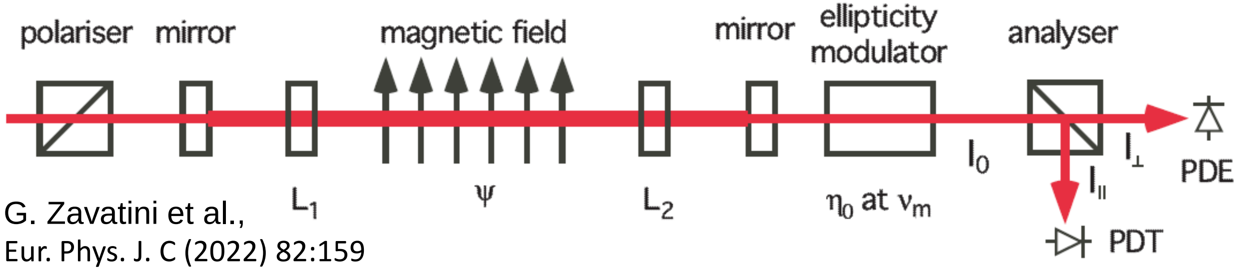
The birth of a meta-collaboration @ Human scale





Proposed modulation scheme
L1,2 : rotating half-wave-plates
PDE : Extinction Photodiode
PDT : Transmission Photodiode.

With a single LHC dipole at 9.5 T, VMB detected with SNR = 1 in less than 1 day of integration.



G. Zavatini et al.,
Eur. Phys. J. C (2022) 82:159

See also P. Pugnat, L. Duvillaret et al., Czech. J. Phys. 55, A389 (2005)

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

http://cds.cern.ch/record/2649744/files/SPSC-I-249.pdf

CERN-SPSC-2018-036 / SPSC-I-249
03/12/2018

Letter of Intent to measure Vacuum Magnetic Birefringence: the VMB@CERN experiment

R. Ballou[1)], F. Della Valle[2)], A. Ejlli[3)], U. Gastaldi[4)], H. Grote[3)], Š. Kunc[5)], K. Meissner[6)], E. Milotti[7)], W.-T. Ni[8)], S.-s. Pan[9)], R. Pengo[10)], P. Pugnat[11)], G. Ruoso[10)], A. Siemko[12)], M. Šulc[5)] and G. Zavattini[13)]*

[1]Institut Néel, CNRS and Université Grenoble Alpes, Grenoble, France
[2]INFN, Sez. di Pisa, and Dip. di Scienze Fisiche, della Terra e dell'Ambiente, Università di Siena, Siena (SI), Italy
[3]School of Physics and Astronomy, Cardiff University, Cardiff, UK
[4]INFN, Sez. di Ferrara, Ferrara (FE), Italy
[5]Technical University of Liberec, Czech Republic
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[8]Department of Physics, National Tsing Hua University, Hsinchu, Taiwan, ROC
[9]Center of Measurement Standards, Industrial Technological Research Institute, Hsinchu, Taiwan, ROC
[10]INFN, Lab. Naz. di Legnaro, Legnaro (PD), Italy
[11]LNCMI, EMFL, CNRS and Université Grenoble Alpes, Grenoble, France
[12]CERN, Genève, Switzerland
[13]Dip. di Fisica e Scienze della Terra, Università di Ferrara and INFN, Sez. di Ferrara, Ferrara (FE), Italy

1st discussion within PBC in May 2017 & presented to the SPSC-127

Introduction to Chameleons

- Chameleon: Hypothetical scalar particle with a variable effective mass, which is an increasing function of the ambient energy density *[J. Khoury and A. Weltman, Phys. Rev. D 69, 044026 (2004)]*.

- New kind of particle providing **a phenomenological explanation of dark energy** as a scalar field evolving in an effective potential, the minimum of which depends on the local matter density in such a way that the experimental constraints of 5th force and violation of equivalence principle are relaxed.

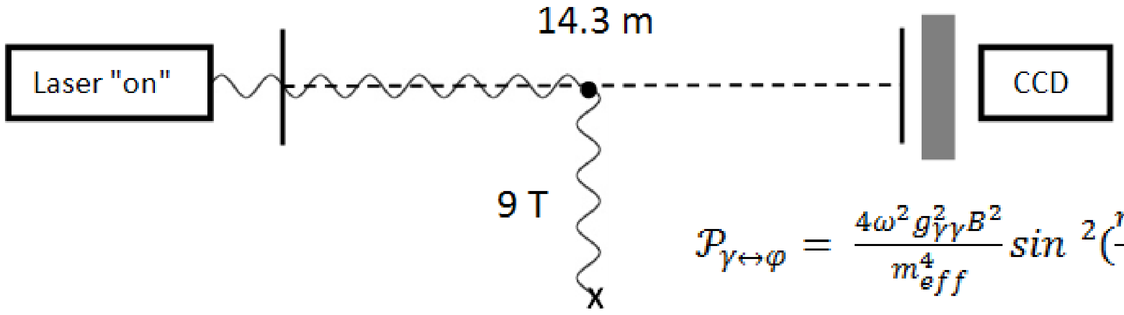
- Based on the coupling to photons, chameleons can manifest through an afterglow signal or a **magneto-phosphorescence of the quantum vacuum**, *i.e.* a remaining luminescence after the lighting is switched off.

OSQAR

CHASE (Chameleon Afterglow Search Experiment)

Phase 1: Filling the “jar” with chameleons produced from the interaction of real photons with virtual ones (Primakoff effect)

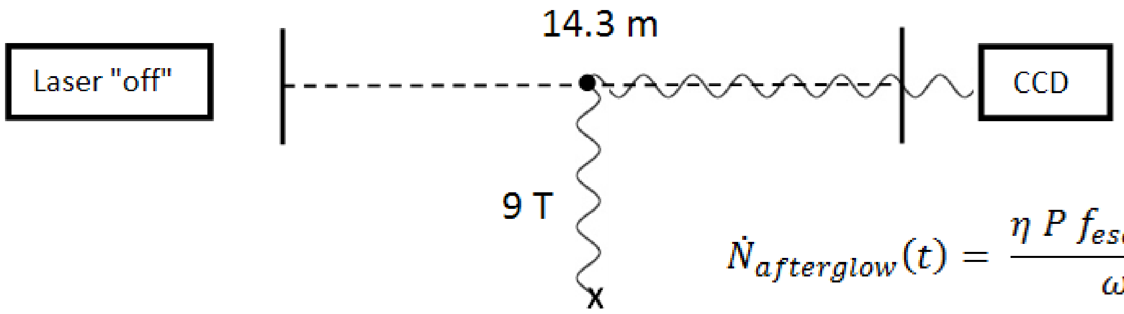
M. Ahlers et al., Phys. Rev. D 77, 015018 (2008)
H. Gies, D. F. Mota, and D. J. Shaw, Phys. Rev. D 77,025016 (2008)



$$\mathcal{P}_{\gamma\leftrightarrow\varphi} = \frac{4\omega^2 g_{\gamma\gamma}^2 B^2}{m_{eff}^4} \sin^2\left(\frac{m_{eff}^2 L}{4\omega}\right)$$

*G. Raffelt and L. Stodolsky. Phys. Rev. D **37**, 1237–1249 (1988)*

Phase 2: Emptying the “jar” and detection of “afterglow” regenerated photons (inverse Primakoff effect)

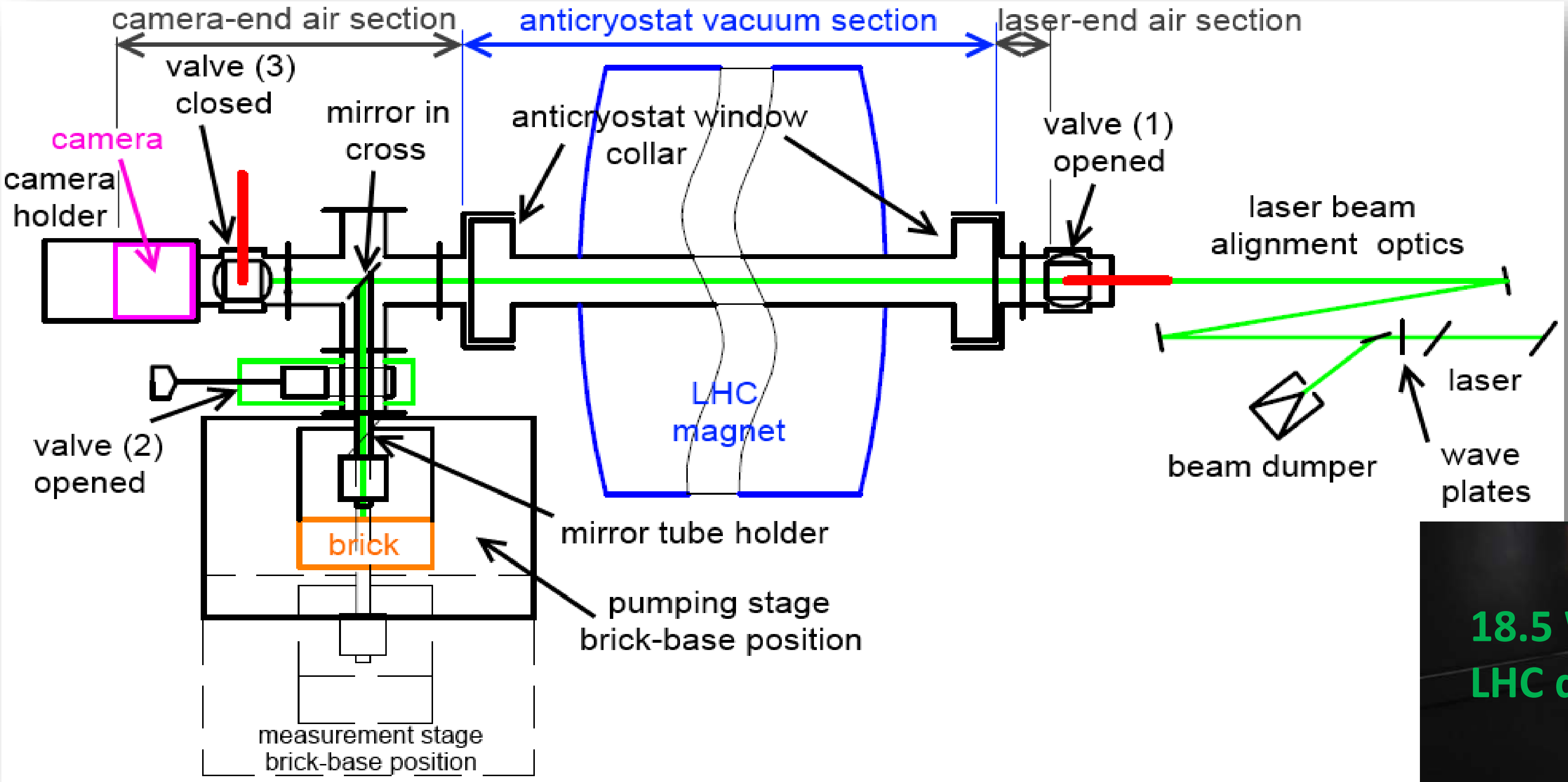


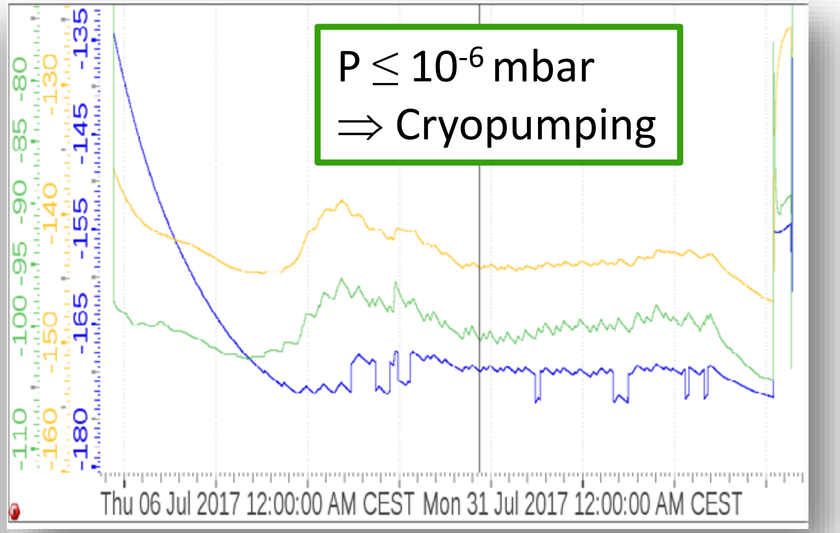
$$\dot{N}_{afterglow}(t) = \frac{\eta\, P\, f_{esc}\, f_{vol}\, \mathcal{P}_{\gamma\leftrightarrow\varphi}{}^2\, c}{\omega\, \Gamma\, L_{total}} (1 - e^{-\Gamma \Delta t}) e^{-\Gamma t}$$

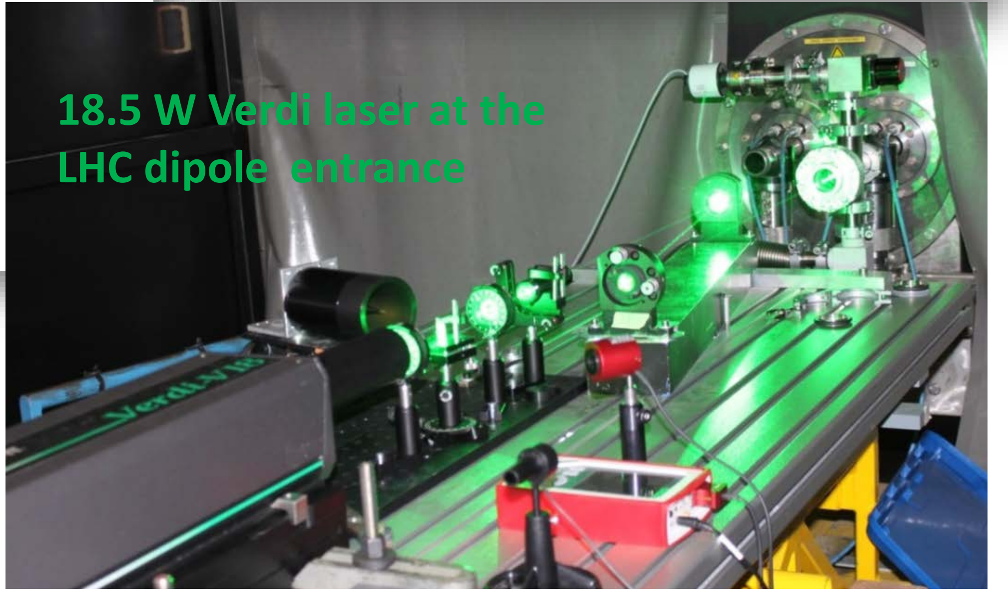
A.S. Chou et al., Phys. Rev. Lett. **102** 030402 (2009)

http://cds.cern.ch/record/2001850/files/SPSC-P-331-ADD-1.pdf

Successful Experimental Run in 2017





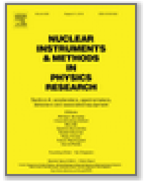


	Phase 1: Chameleon filling	Phase 2: Photon Detection
Valve 1	Open	Close
Valve 2	Open	Close
Valve 3	Close	Open

- Typical durations of phases 1&2: ¼ -11 h
- Measured switching time between phases 1&2 : 6-20 s

2017 Raw Data

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

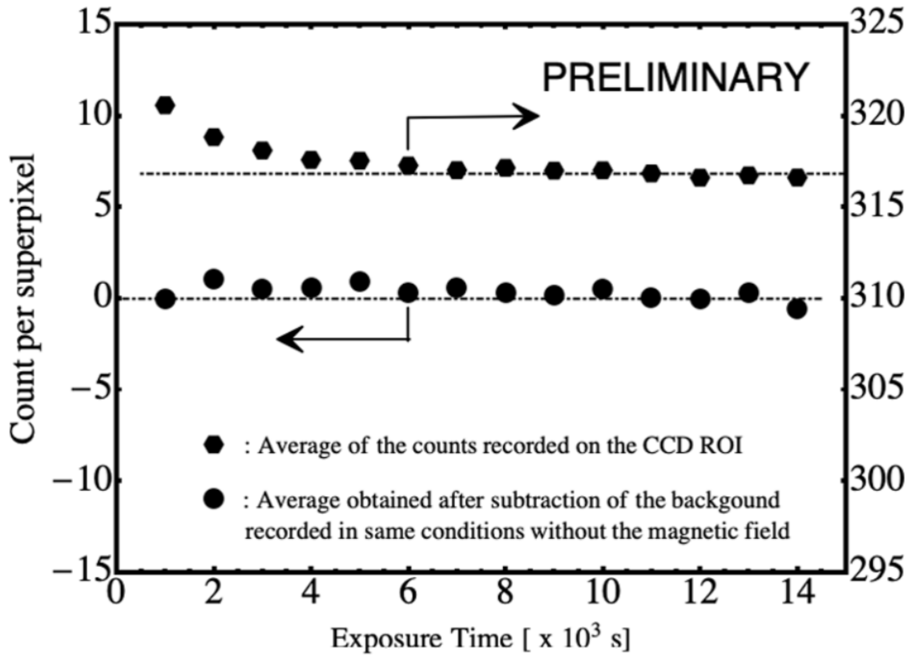


Volume 936, 21 August 2019, Pages 187-188

https://hal.ird.fr/INPG/hal-01991788 https://doi.org/10.1016/j.nima.2018.11.065

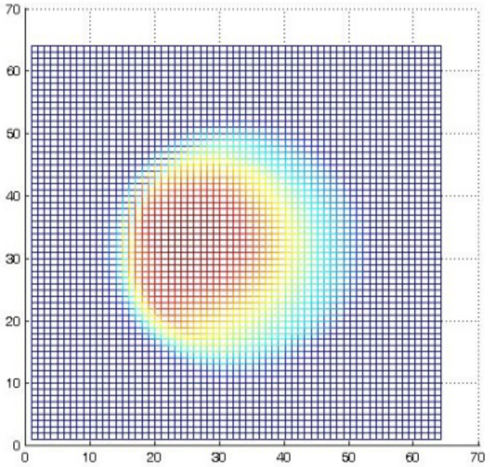
OSQAR chameleon afterglow search experiment

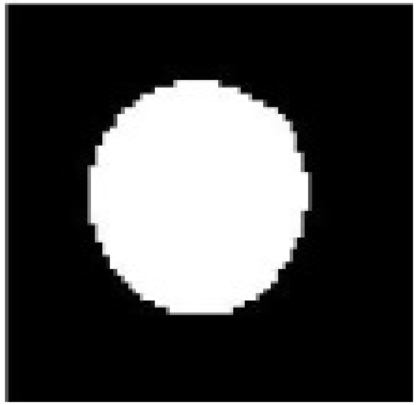
M. Sulc [a], P. Pugnat [b], R. Ballou [c], G. Deferne [d], J. Hosek [e], S. Kunc [a], A. Siemko [d]



OSQAR-CHASE 2017 experimental run for scalar Chameleon search

Definition of the ROI with a diffuse light source (*CCD sensitive area of 13 x 13 mm^2*) used for data reduction (Detection efficiency & noise characterisation)





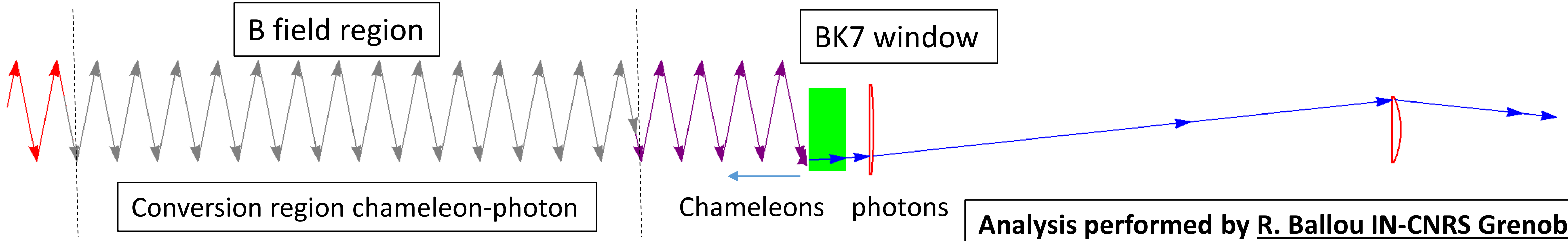
- Afterglow signal observed but non-magnetic as it dissapear after background substraction recorded with exactly the same configuration and protocole without magnetic field

- Negative results also obtained for pseudo-scalar search

- The quantitative analysis to define exclusion plots is not straightforward **and more complex than anticipated** with several Chameleon potentiels to consider

Data Analysis – Method

Phase 2, *i.e.* Afterglow photon emission, in the 2-point path approximation, *i.e. 3D* axisymmetry path



Analysis performed by R. Ballou IN-CNRS Grenoble
More details in OSQAR-CHASE proposal & Addendum as well as OSQAR Annual Reports 2018-2021
GammeV-CHASE: *Phys. Rev.* ***D*** *86, 035006* (2012)

The flux of afterglow photons as a function of time can be modeled as:

$$S_{AFT}(t) = \eta \frac{F_\gamma \, P_{\phi\leftrightarrow\gamma} \, \Gamma_{AFT}}{\Gamma_{DEC}} \left(1 - e^{-\Gamma_{DEC}\,\tau_{Prod}}\right) e^{-\Gamma_{DEC}\, t}$$

$\eta = 0.65$ *is the* overall detection efficiency

$$\mathcal{P}_{\phi\leftrightarrow\gamma} = \left(\frac{2\beta_\gamma}{kM_P {m_{eff}}^2}\right)^2 |\,\vec{k}\wedge(\vec{B}\wedge\vec{k})\,|^2 \sin^2\left(\frac{{m_{eff}}^2\, t}{4k}\right)$$

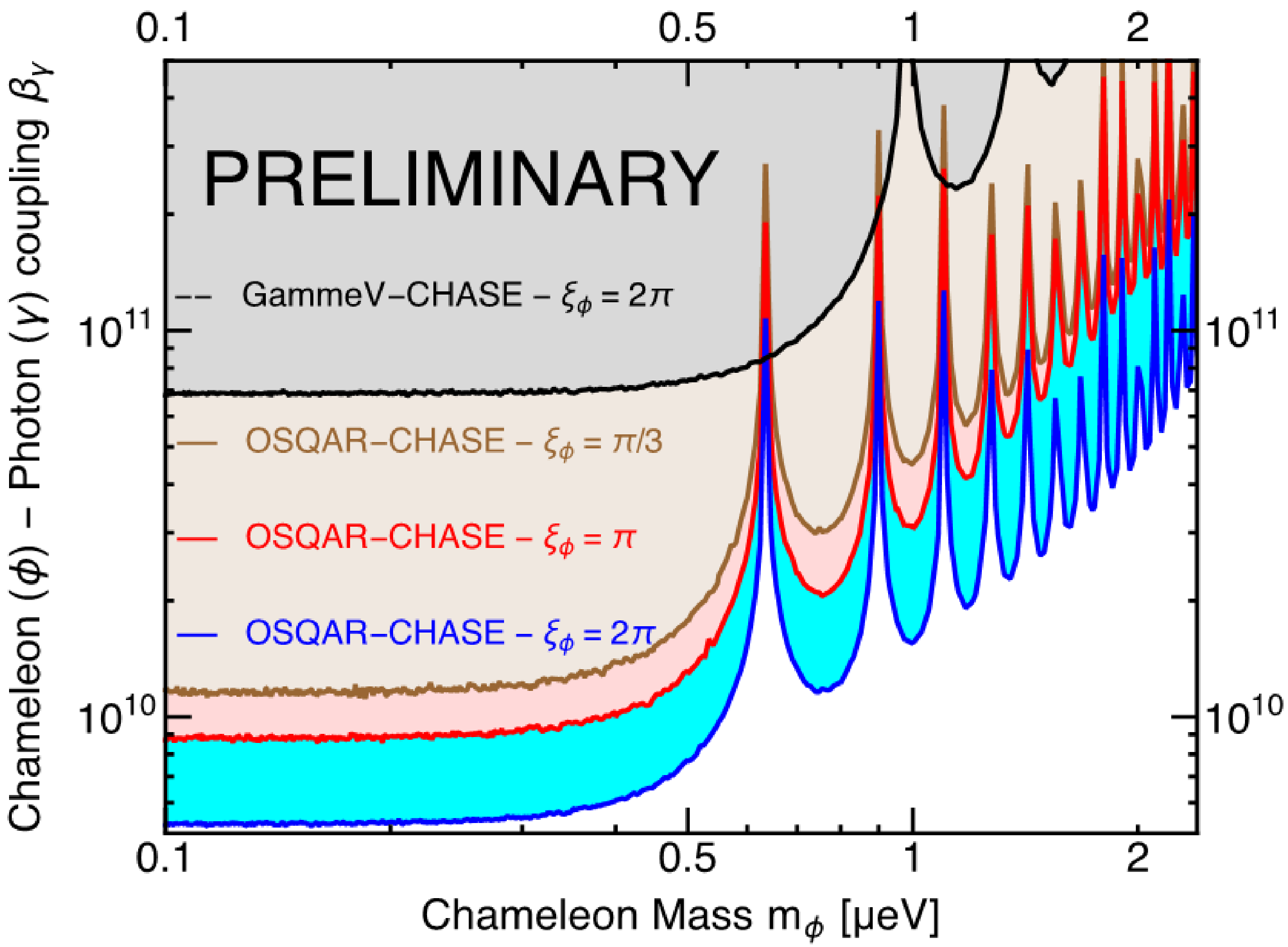
$$\Gamma_{\substack{DEC\\AFT}} = \frac{1}{4\pi\,\Sigma}\int d\Sigma \int d\Omega\; P_{\substack{DEC\\AFT}} \frac{\cos\theta}{L_T} \quad \textit{with} \quad P_{DEC} = P_{ABS}^{Bexit} + \left|\vec{\psi}_\gamma^{Bexit}\right|^2$$

$$\textit{and} \quad P_{AFT} = \left(\left|\left(\vec{\psi}_\gamma^{Bexit}.\vec{S}\right) A_S^{N-N_R}\right|^2 + \left|\left(\vec{\psi}_\gamma^{Bexit}.\vec{P}\right) A_P^{N-N_R}\right|^2\right) P_{DET}$$

S & P = polarization state
$A_{S,P}$ = reflection coefficient

Computation cross-checked & validated from GammeV-CHASE results (*cf.* https://cds.cern.ch/record/2691980/files/SPSC-SR-260.pdf)

Data Analysis - Output (1/2)

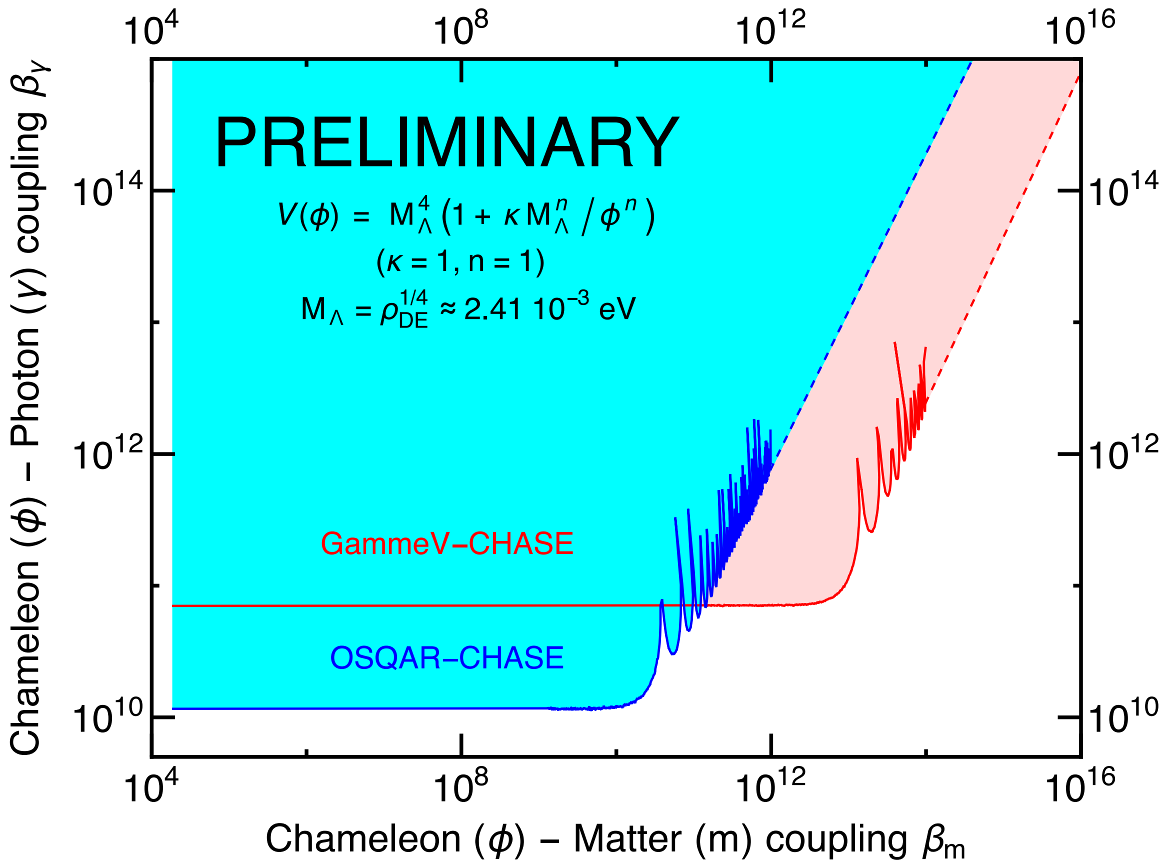


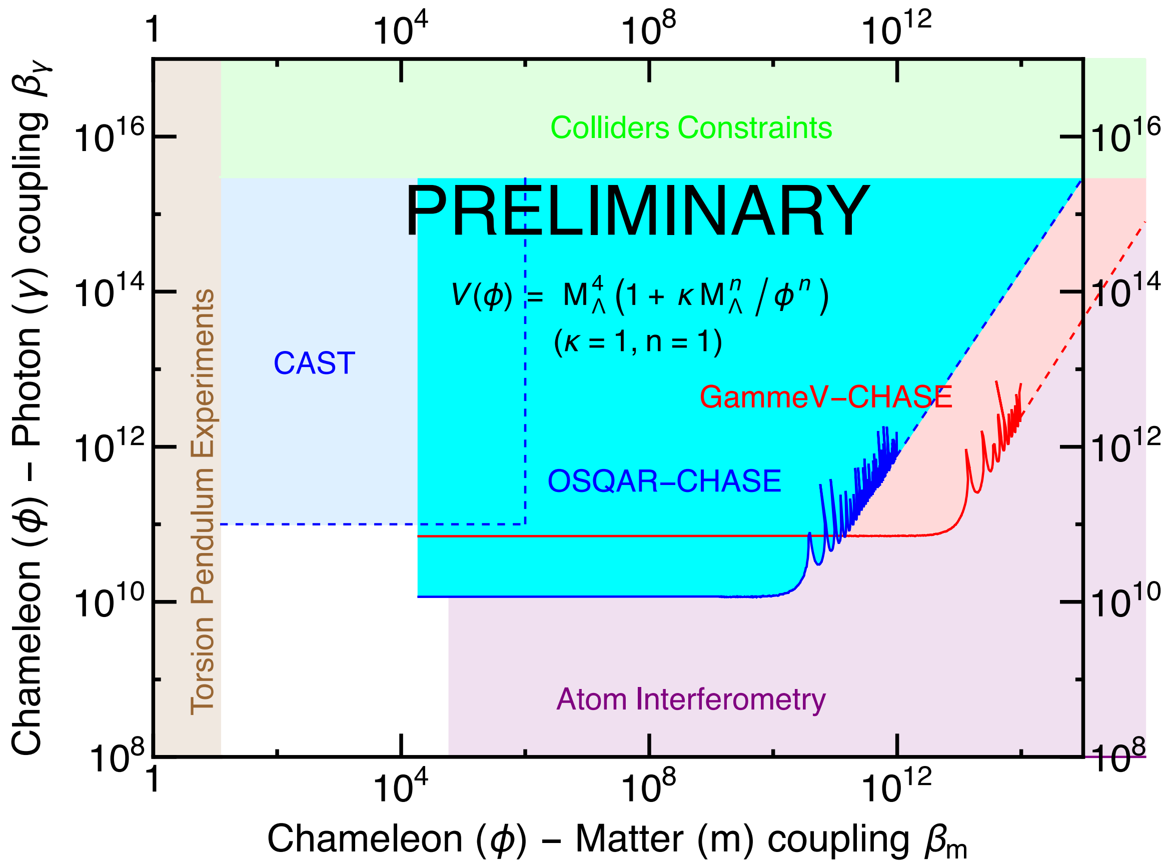
Exclusion limits in the parameter space (**chameleon mass m_ϕ , chameleon-photon coupling β_γ**), deduced from no signal observation and detector noise in the OSQAR-CHASE data collected in summer 2017 with the experimental setup using two focusing optical lenses, for different chameleon phase shifts ξ_ϕ at each bouncing on the walls.

These shifts depend on the chameleon potential, more precisely $\xi_\phi = n\pi/(n-2)$ for $V = g\ \phi^n$, $\xi_\phi = n\pi/(n+2)$ for $V = g\ \phi^{-n}$ and $\xi_\phi = \pi$ for $V = M_\Lambda^4[1 + e^{-\kappa\phi/M_\Lambda}]$.

Data Analysis - output (2/2)

Focus on chameleon – photon vs. chameleon – matter coupling for the inverse power law chameleon dynamic potential



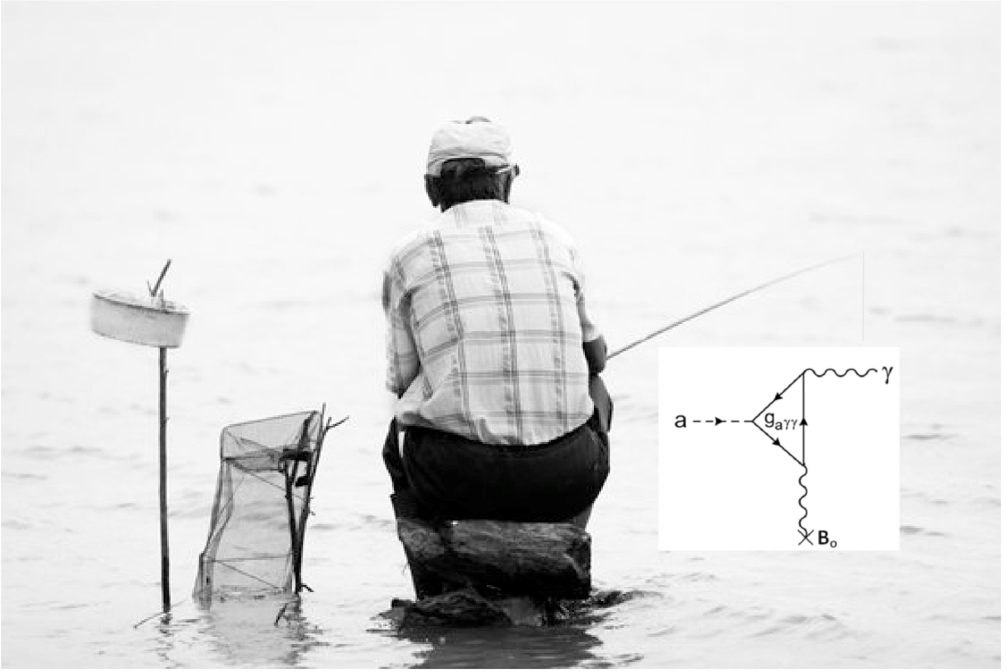


Analysis will be completed in 2023 with 3D modelling & Bayesian or matched filtering statistics approach to define new exclusion limits

GrAHal

Grenoble Axion Haloscopes

institut NÉEL	LNCMI	LPSC Grenoble Théorie
R. Ballou	P. Pugnat	J. Quevillon
T. Grenet	R. Pfister	C. Smith
P. Perrier	S. Krämer	K. Martineau
N. Roch		A. Barrau
L. Planat	
P. Camus	
C. Bruyère	



Few Words from P. Sikivie (Proposed in 1983, Rev. Mod. Phys. 93, 015004)

Visit of Olympie during 2nd Patras Workshop 2006 in Greece

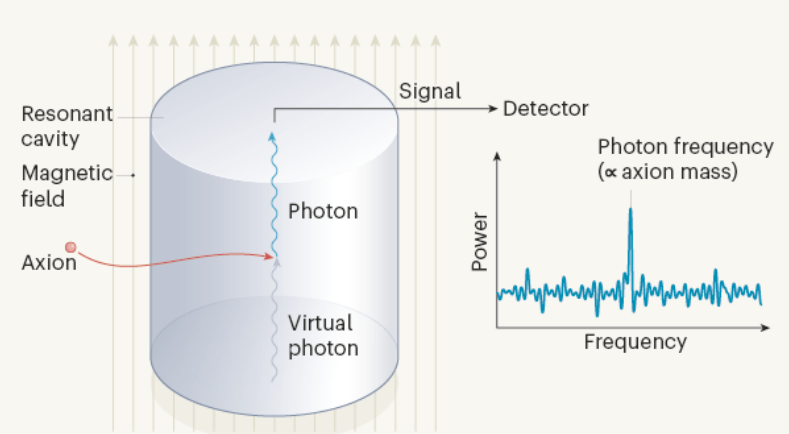
Axion electrodynamics

$$\nabla \cdot \mathbf{E} = g_{a\gamma\gamma} \mathbf{B} \cdot \nabla a$$

$$\nabla \times \mathbf{B} - \partial_t \mathbf{E} = g_{a\gamma\gamma} \left(\mathbf{E} \times \nabla a - \mathbf{B} \partial_t a \right)$$

$$\nabla \times \mathbf{E} + \partial_t \mathbf{B} = 0$$

$$\nabla \cdot \mathbf{B} = 0$$



I. G. Irastorza, *Nature* **590**, 226-227 (2021)

“ Most importantly, the cavity experiment uses a variety of technologies - microwave engineering, ultra-low noise receivers in a high magnetic field environment, cryogenics - which are not typically used by high energy physicists and which had to be specially developed.

… Feynman's advice to young scientists aspiring to great discoveries. He said: "You have to develop your own tools". ”

https://ep-news.web.cern.ch/content/qa-pierre-sikivie

Context of GrAHal
Grenoble Axion Haloscopes

Key expertise at CNRS-Grenoble for High magnetic fields, Extreme Low Temperatures & Quantum Detectors

CNRS
UGA Université Grenoble Alpes

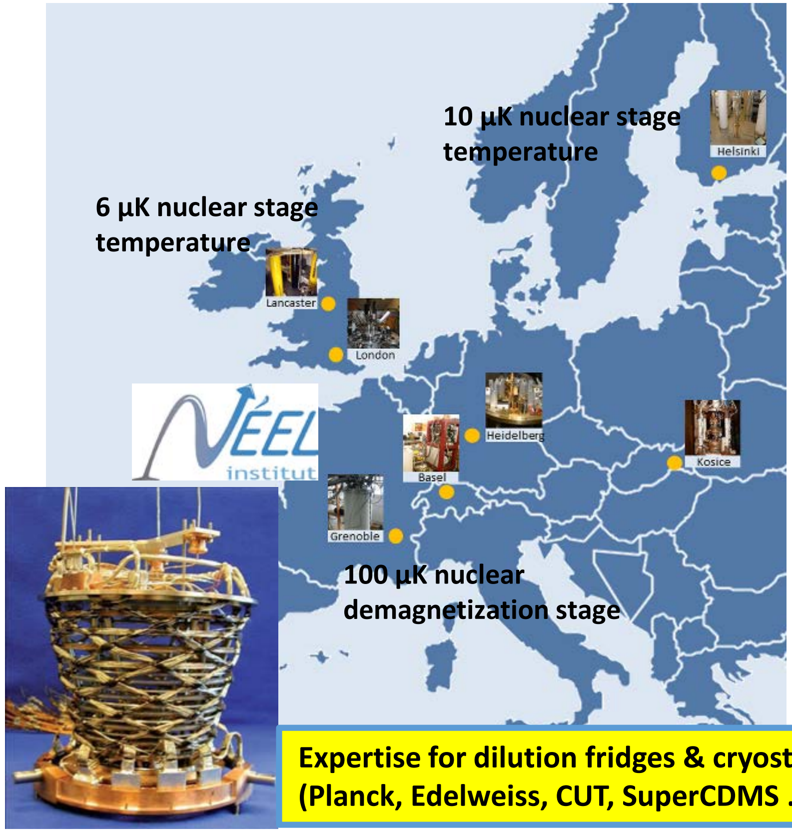
EMFL European Magnetic Field Laboratory
LNCMI

Dresden/LNCMI-Toulouse, pulsed up to 95/91 T, 1-10 ms
Nijmegen/**LNCMI-Grenoble**, DC up to 38/36 T,
Projects 45/43+ T
https://emfl-users.lncmi.cnrs.fr/SelCom/proposals.shtml

European Microkelvin Platform

20 leading ultralow temperature physics & technology Institutes in Europe including 7 submilliK facilities

http://emplatform.eu/about/facilities

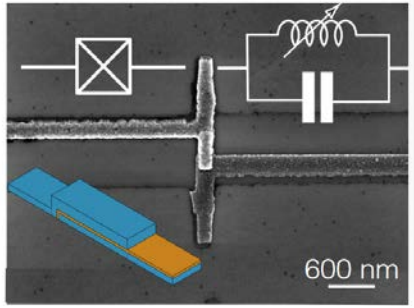


Expertise for dilution fridges & cryostats (Planck, Edelweiss, CUT, SuperCDMS …)

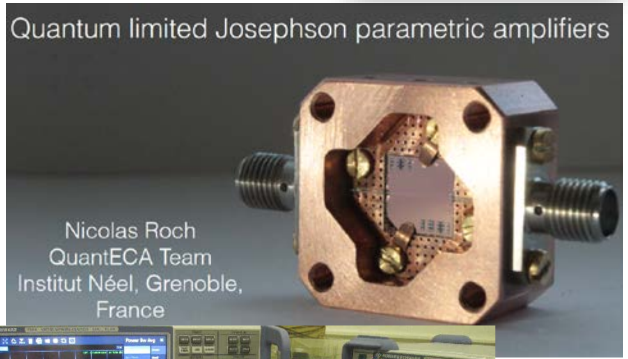
NÉEL institut

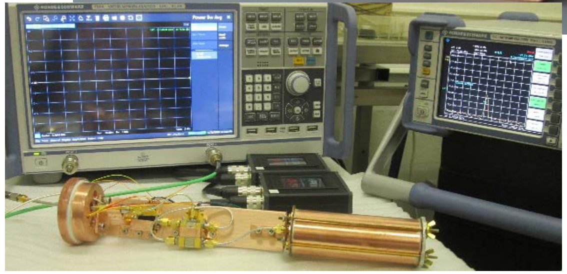
JPA Achievements

https://www.cnrs.fr/cnrsinnovation-lalettre/actus.php?numero=743



$$1\ \mathrm{GHz} < f_o < 10\ \mathrm{GHz}$$
$$G \geq 20\ \mathrm{dB}$$
$$BW \sim 2\ \mathrm{GHz}$$
$$T_N \gtrsim \frac{h f_o}{2k_B}$$
$$P_{1dB} \sim -100\ \mathrm{dBm}$$



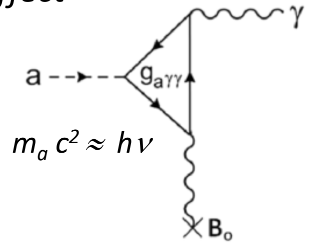


GrAHal

Grenoble Axion Haloscopes

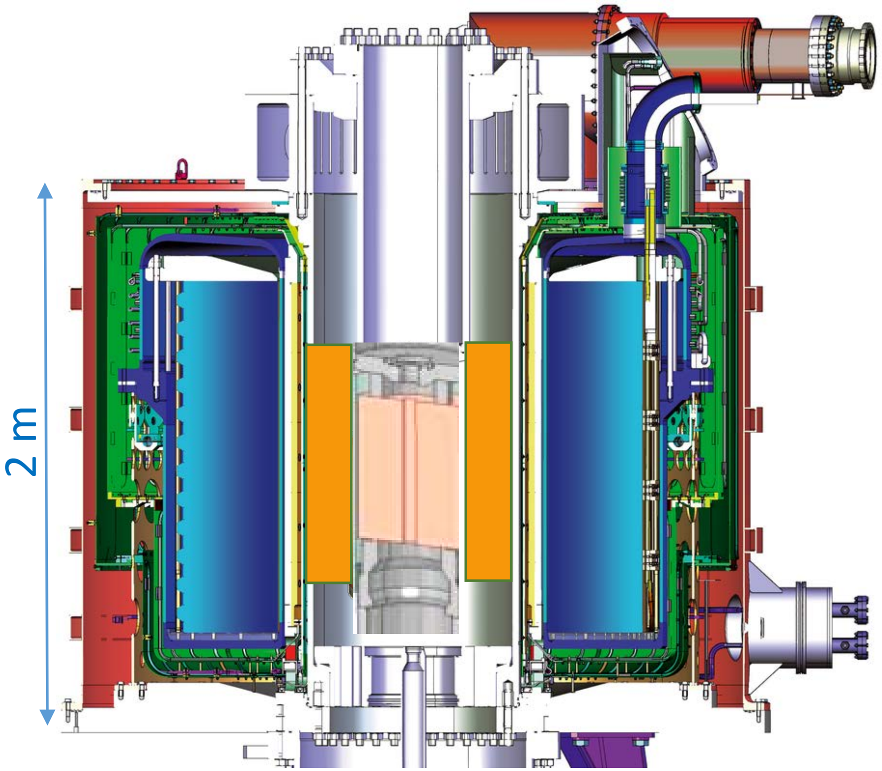
►Initiative presented during the 1st PBC Techno WG meeting in Sept 2017 (https://indico.cern.ch/event/667744/)

Inverse Primakoff Effect



Sikivie's haloscope, i.e. with RF cavity

$$P \;\alpha\; g_{a\gamma\gamma}^2 B_0^2 V < 10^{-21}\ W$$



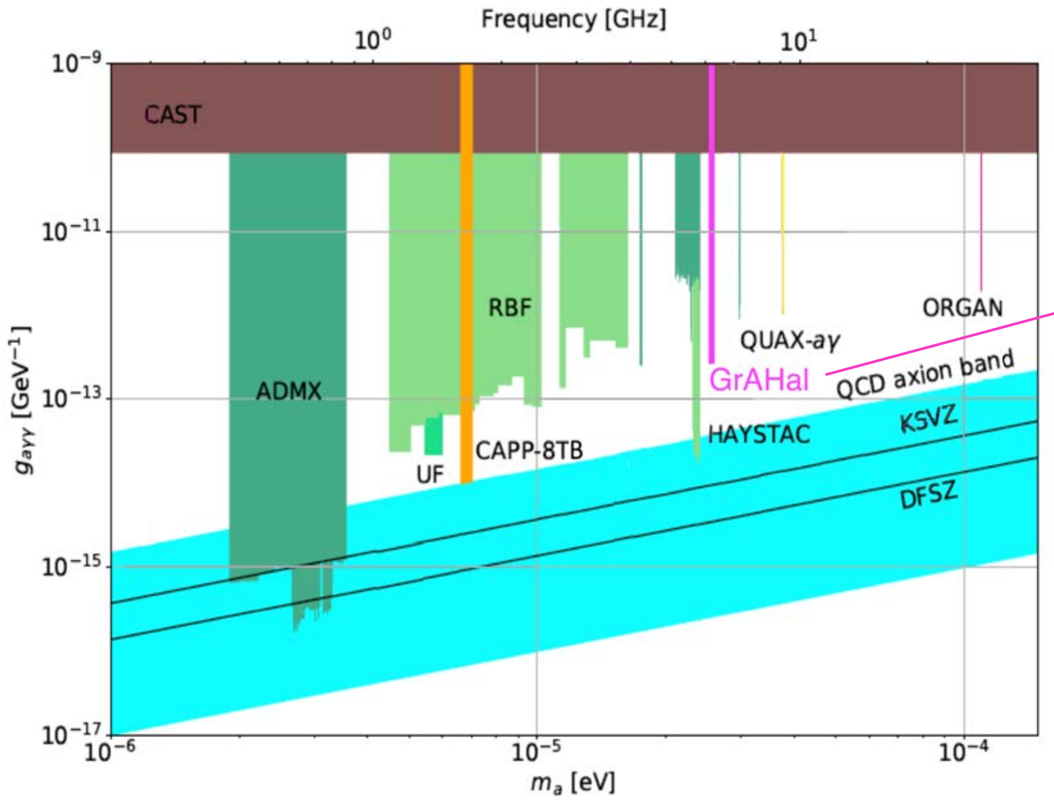
Scientific case within the European Strategy of Particles Physics (ESPP)
https://www.nature.com/articles/s41567-020-0838-4

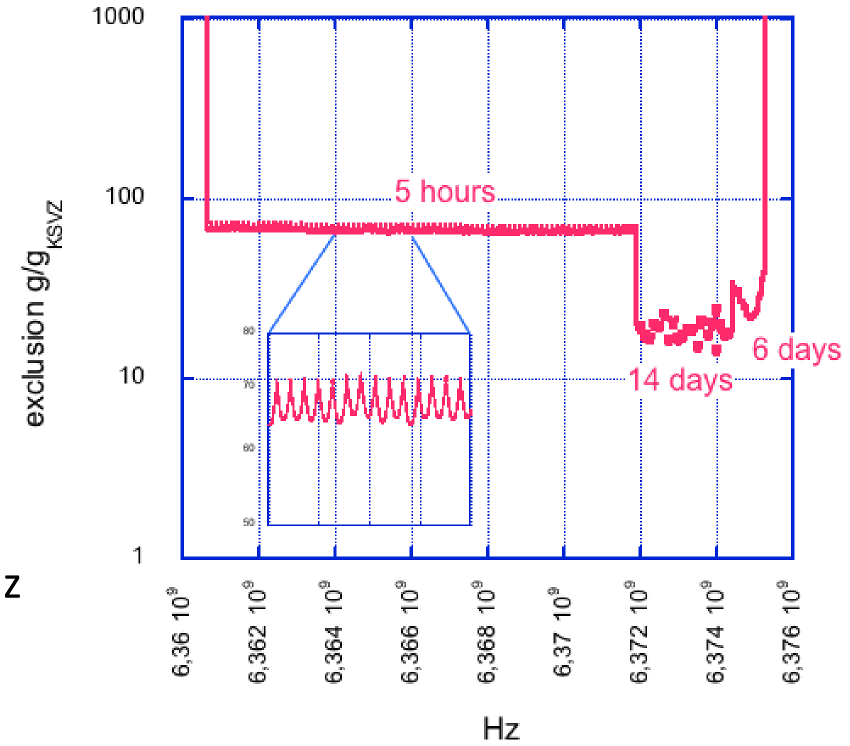
Field	Warm dia.	RF-cavity dia.	Frequency	Axion mass
43 T	34 mm	20 mm	11.5 GHz	47.2 μeV
40 T	50 mm	34 mm	6.76 GHz	27.8 μeV
27 T	170 mm	86 mm	2.67 GHz	11 μeV
17.5 T	375 mm	291 mm	0.79 GHz	3.2 μeV
9.5 T	800 mm	675 mm	0.34 GHz	1.4 μeV

LNCMI

Grenoble Hybride in the commissioning phase, operation end of 2023

GrAHal 1st Measurement Run Ended

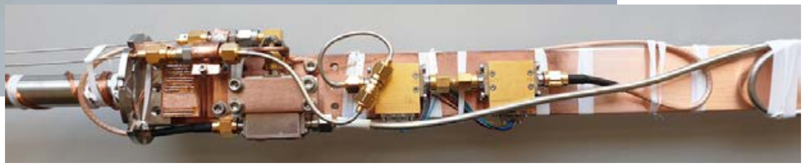




14 T @ 4 K
around 6.375 GHz
i.e. 26.37 µeV

The RF-cavity resonant frequency was tuned & scanned by varying the GHe pressure around the cavity :

- **For the range 1-1200 mbar, excursion Δf = 20 MHz, i.e. ~ 0.1 µeV**
- **Sensitivity in the range of 20-25 x KSVZ @ 4.4 K**
- Detailed data analysis in progress

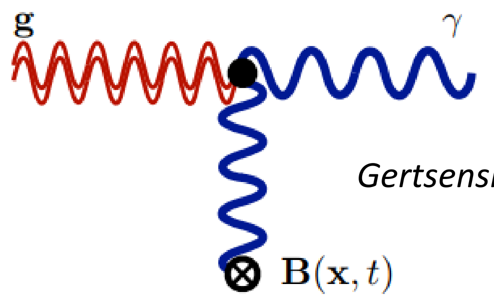


T. Grenet et *al.*

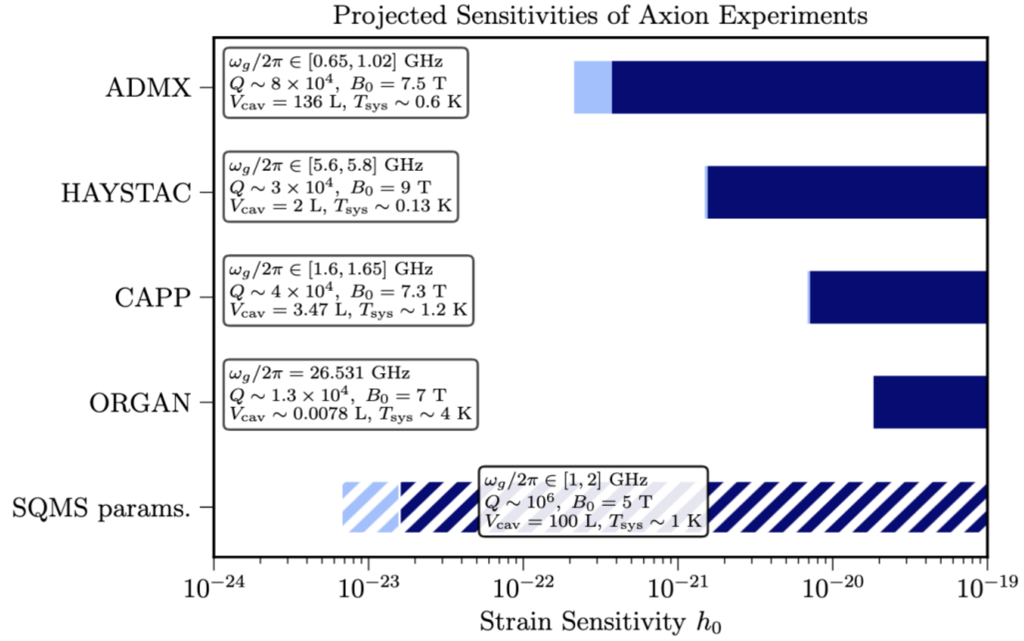
NÉEL institut

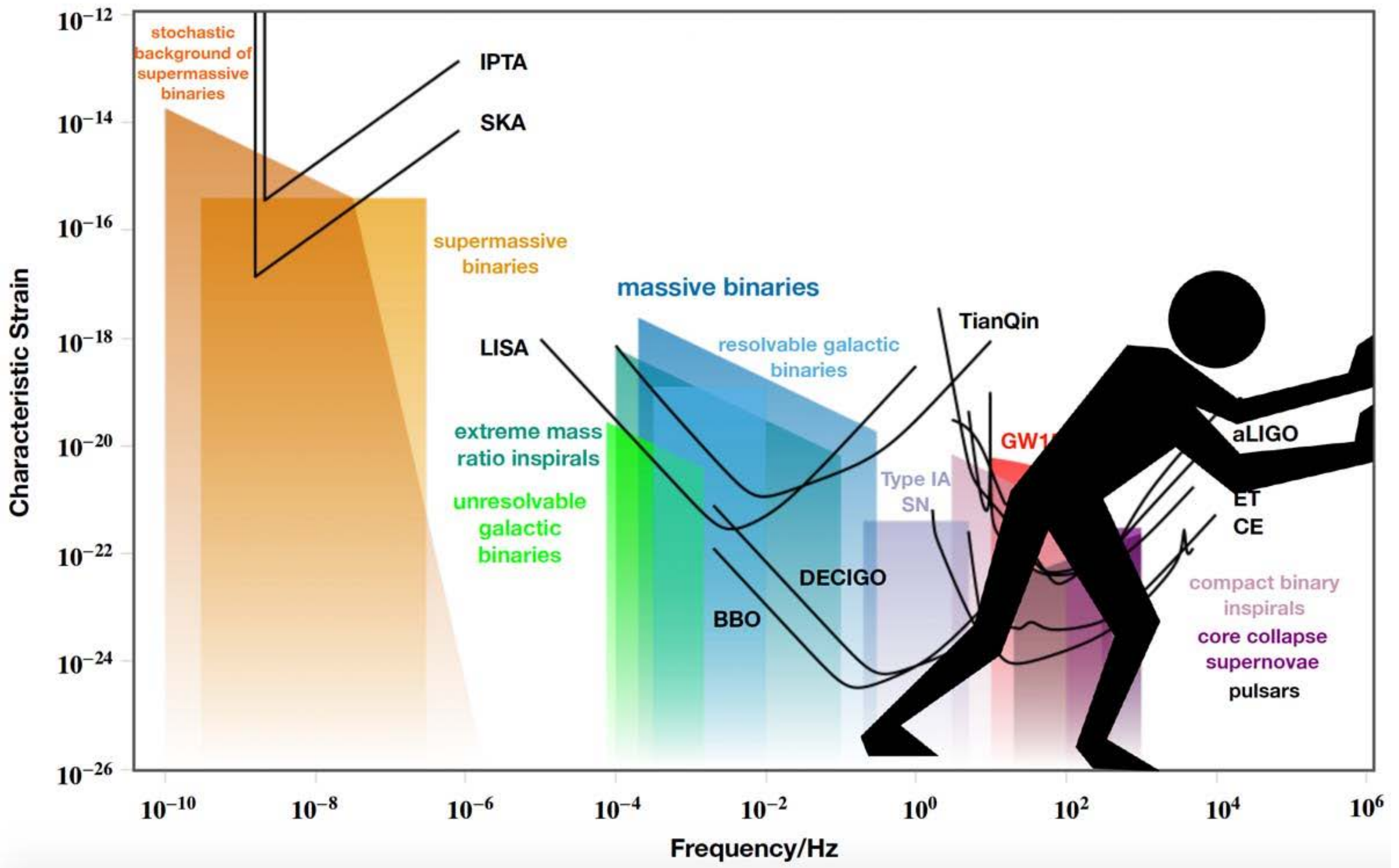
https://arxiv.org/abs/2110.14406

► Toward “Gravitational wave & Axion Haloscopes (?)”



Will be more visible on other RF modes of the cavity than the TM_{010}, like TM_{121} & TE_{212} with strain sensitivity in $B_0 V^{5/6}$
https://arxiv.org/abs/2112.11465





https://cerncourier.com/a/exploring-the-early-universe-with-gravitational-waves/

The most promising region for probing the early universe exists in the ultra-high frequency (UHF) region, which is currently beyond the reach of existing detectors, namely LIGO-Virgo-KAGRA interferometers…

Studies from GrAHal theory group (A. Barrau, K. Martineau) have started to determine awaited sensitivities,…

More information / Outline

Few references

- "High magnetic fields for fundamental physics", https://arxiv.org/pdf/1803.07547.pdf
- OSQAR, https://ep-news.web.cern.ch/content/osqar-experiment-sheds-light-hidden-sector-cerns-scientific-heritage , https://arxiv.org/abs/1506.08082
- GrAHal, https://arxiv.org/abs/2110.14406
- VMB@CERN, https://cds.cern.ch/record/2649744

CERN PBC Study Group

- https://pbc.web.cern.ch/
- https://indico.stfc.ac.uk/event/268/attachments/522/909/Vallee_PBC_RAL.pdf
- https://www.nature.com/articles/s41567-020-0838-4

New EU COST Action : COSMIC WISPers in the Dark Universe: Theory, astrophysics and experiments

- https://www.cost.eu/actions/CA21106/ (Chairman/Co-Chair, MoU, Objectives)
- ***You can apply to working groups from*** https://www.cost.eu/actions/CA21106/#tabs+Name:Working%20Groups%20and%20Membership
- *Kick-off Meeting at Rome* 23-24 February 2023, https://agenda.infn.it/e/CosmicWispersKickOff