STATUS AND PLANS OF THE OSQAR EXPERIMENT

Miroslav Sulc

on behalf of OSQAR collaboration

OSQAR

Outline

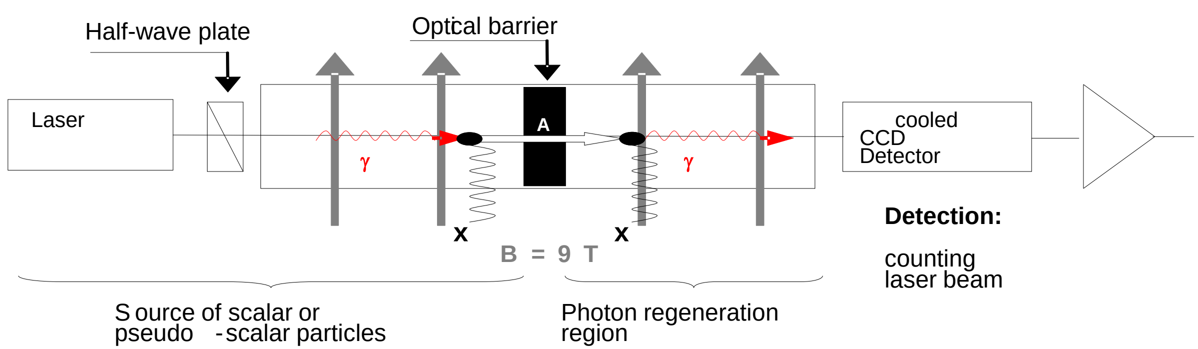
- OSQAR laser experiments
  - Photon regeneration data analysis
  - Vacuum Magnetic Birefringence
  - Chameleon search
- Cavities and OSQAR - ALPS collaboration
- Conclusion

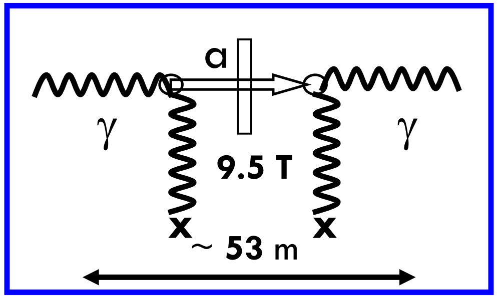
Optical Search for QED vacuum magnetic birefringence, Axions and photon Regeneration

Three distinct laboratory experiments in strong magnetic field

1) The photon regeneration effect (photon – axion and axion - photon conversion) is looked for as a Light Shining through the Wall.
2) The Vacuum Magnetic Birefringence, predicted by the QED, could be measured for the first time.
3) Chameleon search looks as measurement of afterglow of light, as the photons convert to trapped chameleons and reconvert back to photons in magnetic field, streaming through the windows of the vacuum chamber.

Photon regeneration effect 2014

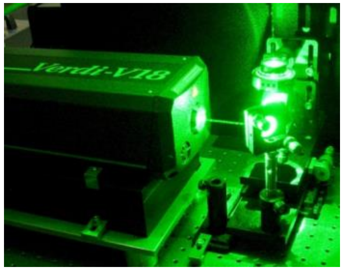




Half-wave plate changes light polarization in respect to magnetic field

- Parallel – pseudoscalar
- Perpendicular - scalar

Adjustments to improve the experiment sensitivity



18 W CW Verdi laser from Coherent

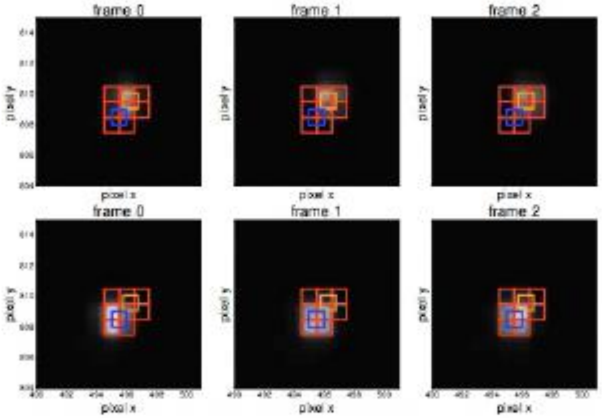
Laser beam was concentrated to very small spot. Optics must allow a change of intensities about 13 orders for switching between alignment and measurement mode without laser spot movement.

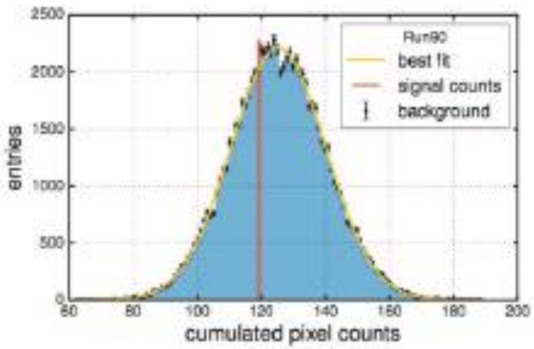
The CCD detector

Run 2014 analysis University of Mainz in Germany and deeply cross-checked at the CNRS/UJF-Grenoble-1 in France

- We find laser positions in start at end of run
- Define signal region
- Remaining pixels, which are not exposed to possible ALPs signals, are clustered in sizes that correspond to the signal region and the distribution of their cumulated counts gives the estimate of the expected background for the signal region.
- Corect temperature induce inhomogenities
- Remove incristic inhomegenities in gain
- Exclude cosmic ray hits and hot pixels

Laser spot movement and signal region

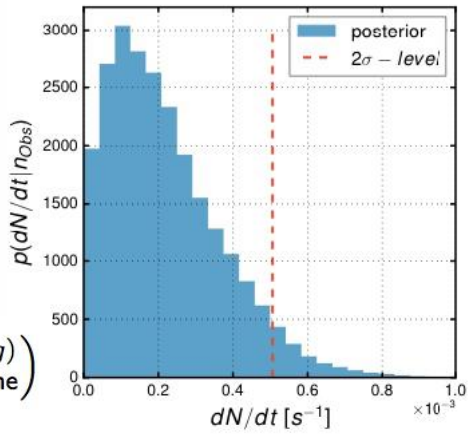


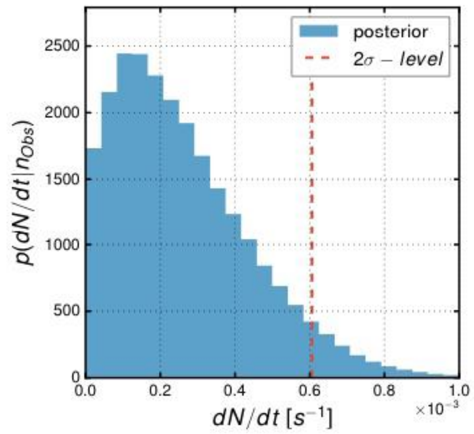


Combining Data of Different Runs

- We have different sized regions in each run
- - **Bayesian inference** crate combined likelihood model of all valid frames

$$\mathcal{L} = \prod_{\text{frame}} \text{Gauss}\left(N_{\text{frame}} \middle| \text{Pois}\left(\frac{dN}{dt} \cdot t_{\text{frame}}\right) + \mu_{\text{frame}}^{(bkg)}, \sigma_{\text{frame}}^{(bkg)}\right)$$



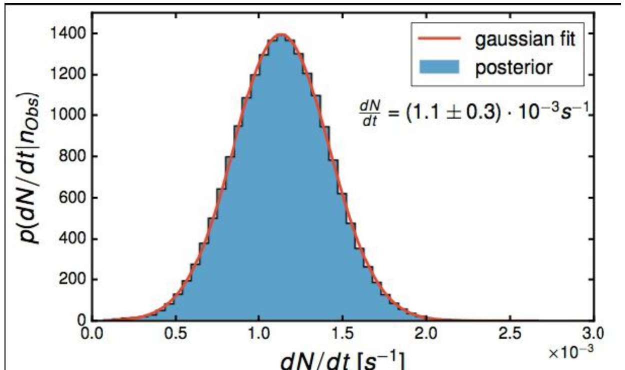


The sensitivity from of the background and the recorded photon – flux **dN/dt = 0.45 mHz** for scalar and **0.64 mHz** for PS is given as the Bayesian threshold of non detection at 95%.

Impose fake signal at 2δ level (1.0x10^{-3} photons/s) on each recorded frame at the background region and repeat analyses

Look at posterior distribution of reconverted photon rate with the imposed fake signal

Observed dN/dt = 1.1±0.3 mHz



World leading limits in laboratory based LSW Axion/ALPS searches

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

Scalar search: **180 hours, 60 runs 2x 90 minutes**

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

Periodic check during data taking of the beam alignment with the CCD

Pressure at operation $< 10^{-5}$ mbar

pseudo-scalar:

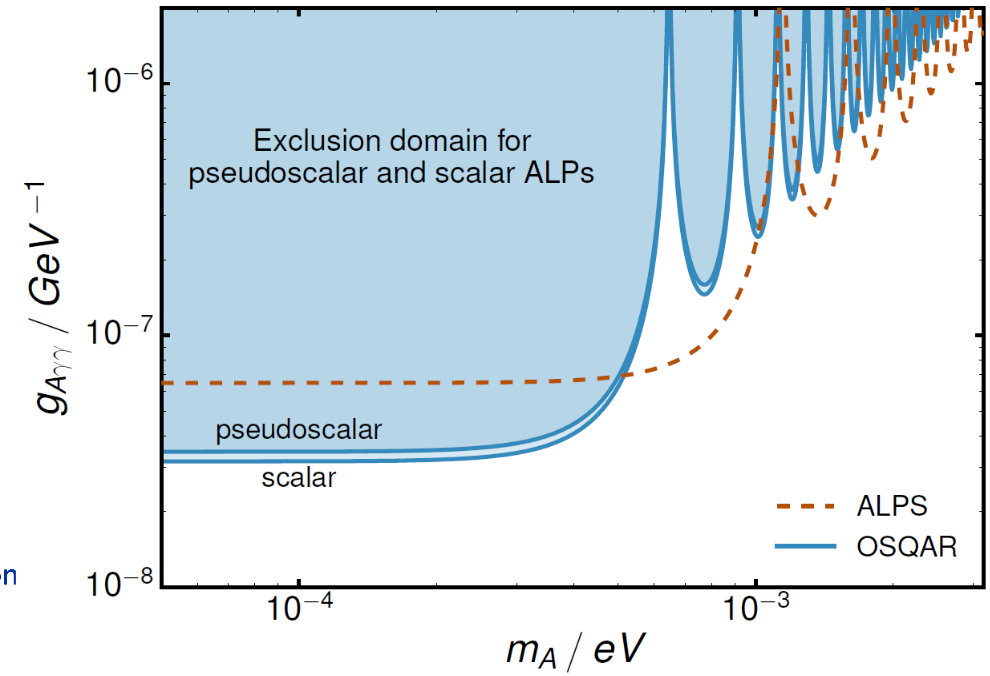
$g_{A\gamma\gamma} < 3.5 \cdot 10^{-8} GeV^{-1}$

scalar:

$g_{A\gamma\gamma} < 3.2 \cdot 10^{-8} GeV^{-1}$

for the pseudo scalar and scalar searches for $m_A < 2 \cdot 10^{-4} eV$

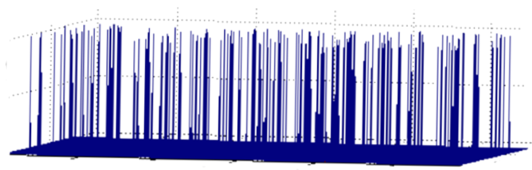
R. Ballou *et al.* (OSQAR collaboration), "New Exclusion Limits for the Search of Scalar and Pseudoscalar Axion-Like Particles from Light Shining Through a Wall", accepted for publication in Phys. Rev. D (2015), arXiv:1506.08082



Correlation analysis in progress

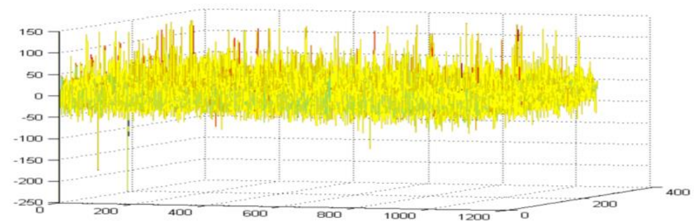
Data on CCD (filtered cosmic)

- 60 measurement in different beam spot positions
- Typical σ = 3.3 per 1 pixel
- 5400 s exposition time



Correlation mask (60 positions)

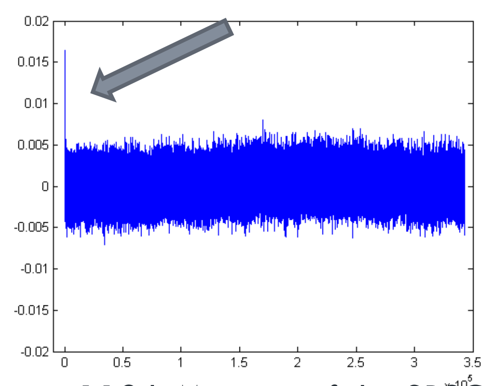
- f=100 in expected photon position
- f=1 other pixels

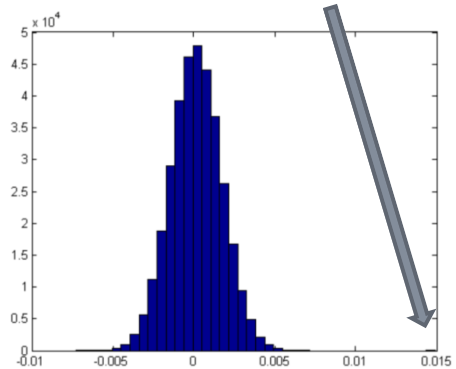


Simulation

When signal appears (100 photons) normalised correlation coefficient will increases if the mask has the same position as expected photons

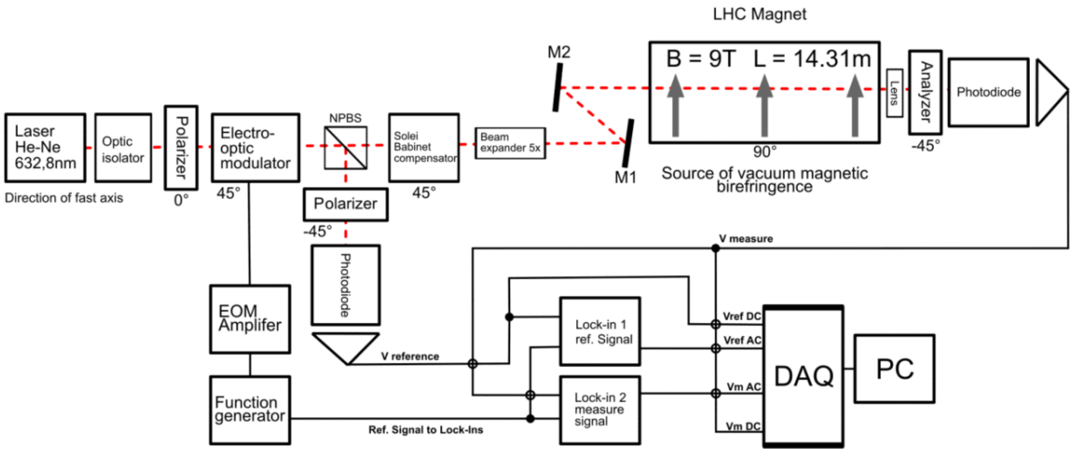
Normalised correlation coefficient

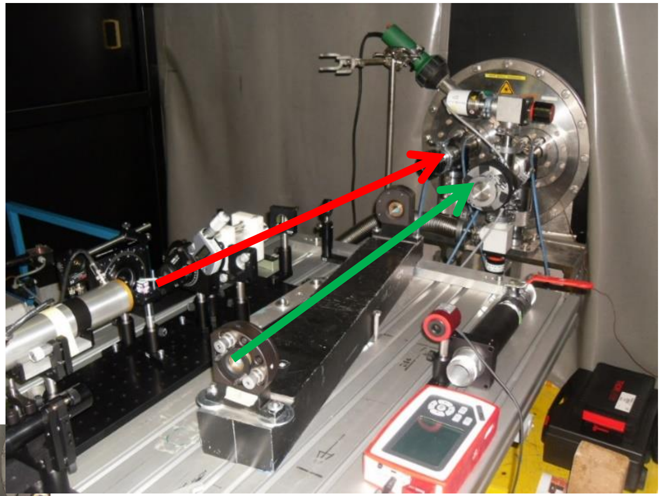




VMB

measurement of the Gas Magnetic Birefringence of N2





PhD of Stepan Kunc

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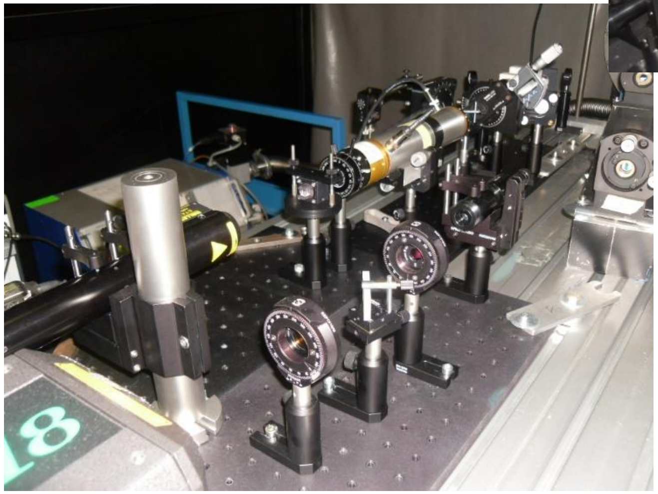
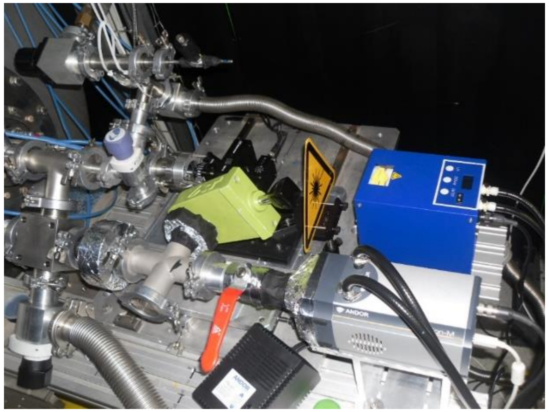
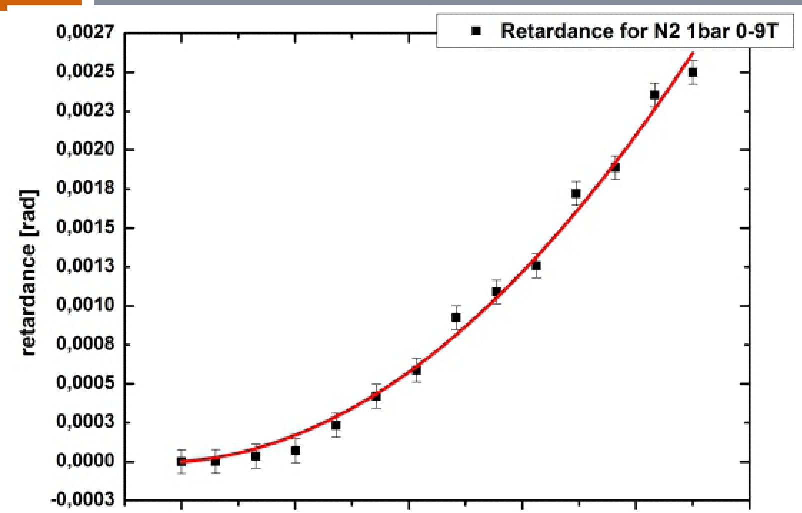
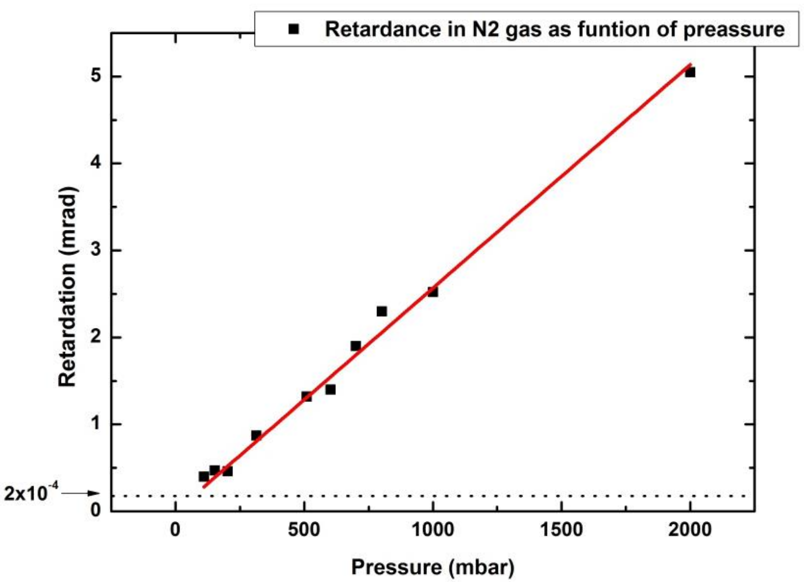




The second aperture at 2015 was used for GBM

Measurements of the Cotton-Mouton Effect in N_2

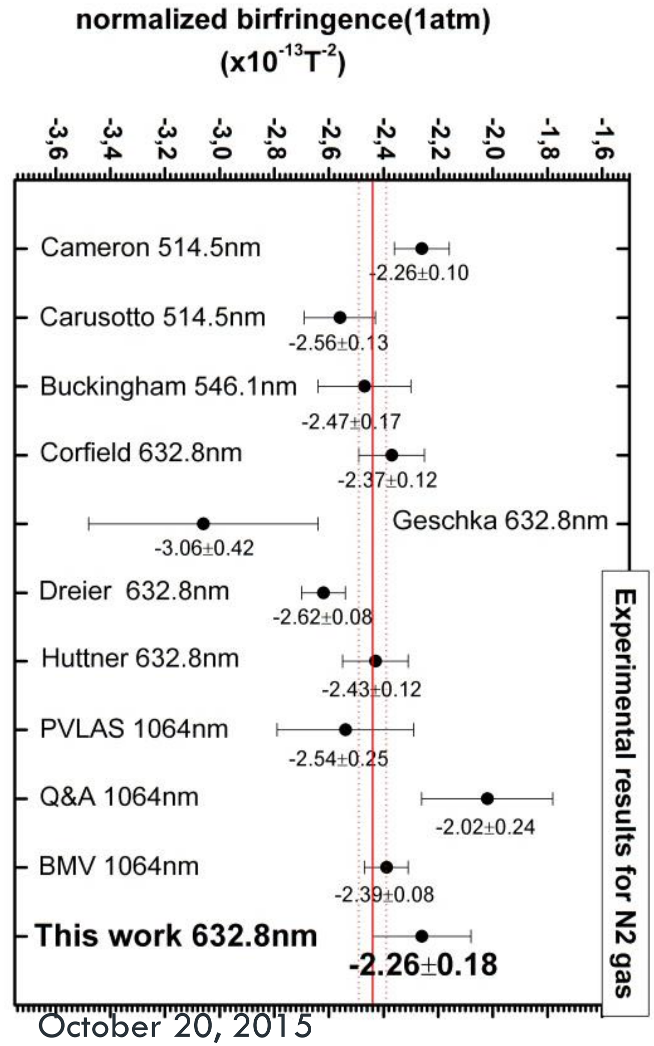




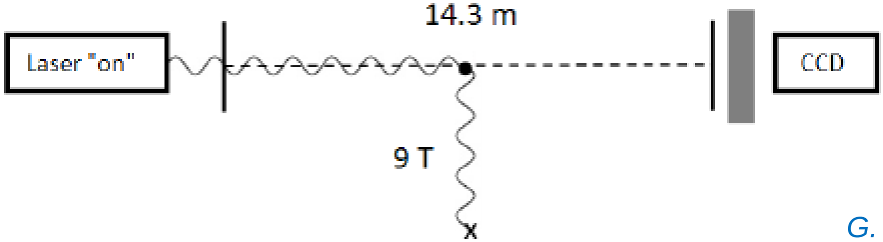
Retardance = $2\pi \, L_B \, \Delta n / \lambda$

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

Sensitivity $\Delta n \approx 10^{-14}$
Still a long way before measuring the VMB, *i.e.* $\Delta n \approx 10^{-22}$ in 9.5 T, even with a Fabry-Perot cavity of finesse 10^4-10^5



OSQAR - CHASE (Chameleon Afterglow Search Experiment)



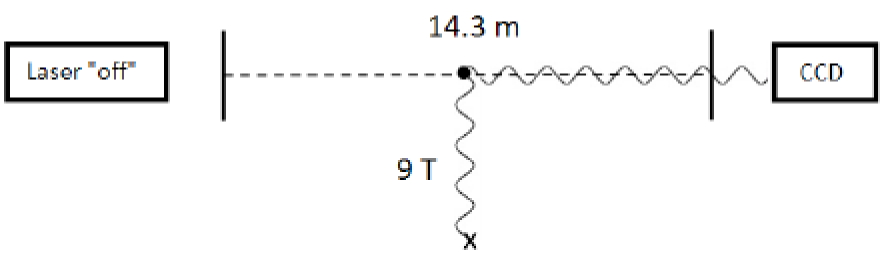
- Search of Chameleons - SISPs particles
- Filling the jar with chameleons, produced by interaction of real photons with virtual ones – Primakoff effect

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

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

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)

If the energy ω is lower than the effective mass m_{eff} $(\beta_{m\rho}\rho_m)$ of the chameleon field inside the matter that encloses the vacuum then the produced chameleon particles will be trapped inside the vacuum

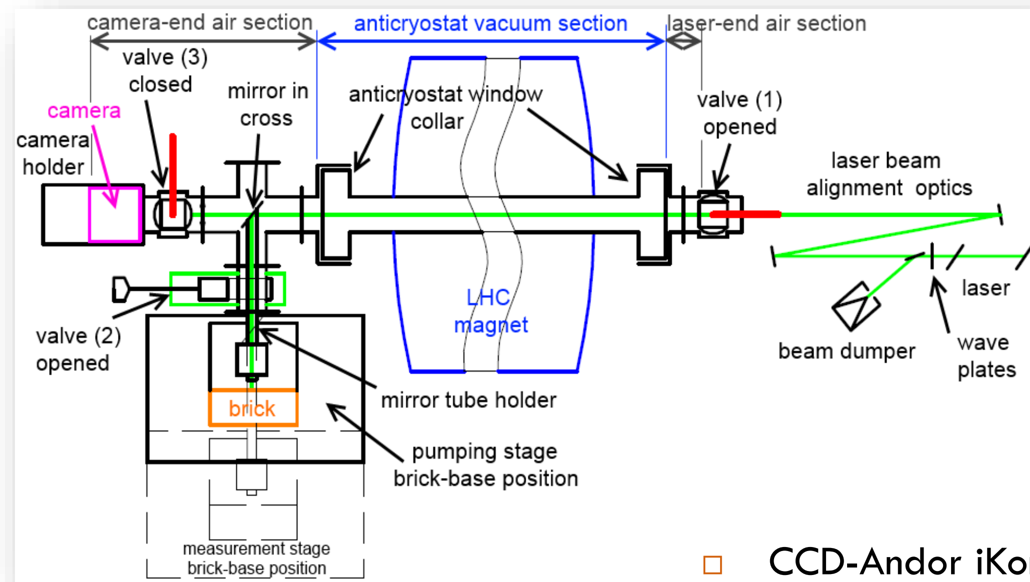


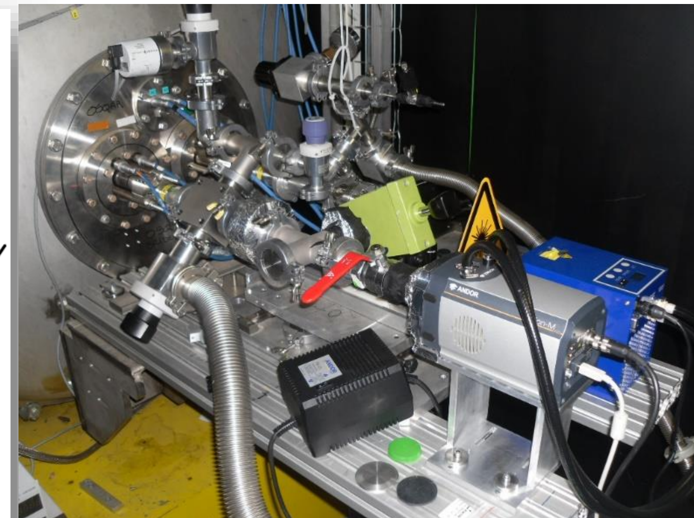
- The only way then for these particles of escaping from their trap is to wait for being transmuted back into photons, which gives rise to an afterglow effect thereby providing an experimental mean for detecting the chameleons

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

A.S. Chou et al., Phys. Rev. Lett. **102** 030402 (2009)
A. Upadhye, J. H. Steffen, and A.S. Chou, PHYSICAL REVIEW D 86, 035006 (2012)

OSQAR – CHASE 2015 - new optical system





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

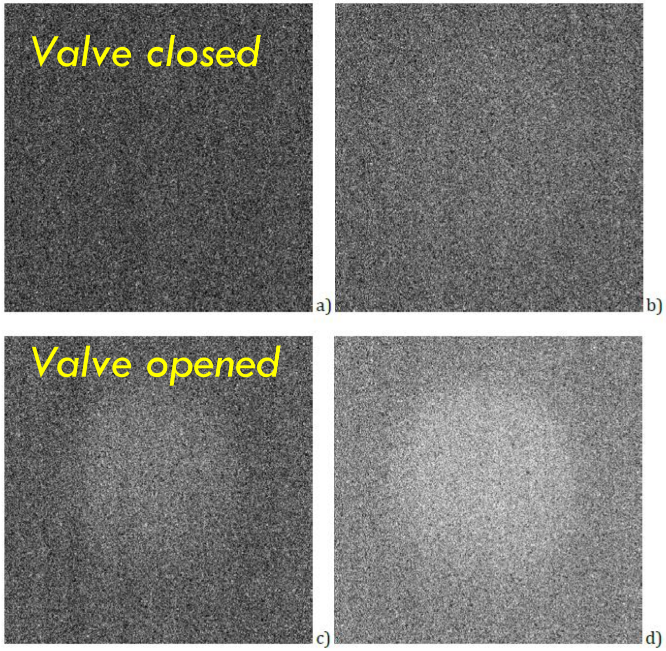
The sensitivity of our detection system is **(0.65 ± 0.03) ADU/photon** for all detection system

- CCD-Andor iKon-DU934P-BV Back- Illuminated USB CCD Camera has been rented.
- The CCD sensor is composed of a 2D array of 1024 x 1024 square pixels of 13 µm size.
- The quantum efficiency of the CCD at 550 nm is 95 %,
- The typical readout noise at 50 kHz is equal to 2.9 e-/pixel
  the dark current < 0.00012 e-/pixel/s at -100°C.

Radiation from Pirani vacuum gauge

- Surprising radiation from Pirani vacuum gauges was observed at ring region on CCD. It is obvious that our optical focusing system can focus the diffuse light to the area with diameter smaller than is one side length of CCD chip.
- We measure count distribution and total intensity with the time of exposition 5000 s, without binning. We subtracted readout noise 2.077 count per single pixel and dark current noise $9 \cdot 10^{-5}$ count/s. Resulting signal an CCD from Pirani was ranging from $2 \cdot 10^{-4}$ count/s to $7 \cdot 10^{-4}$ count/s.

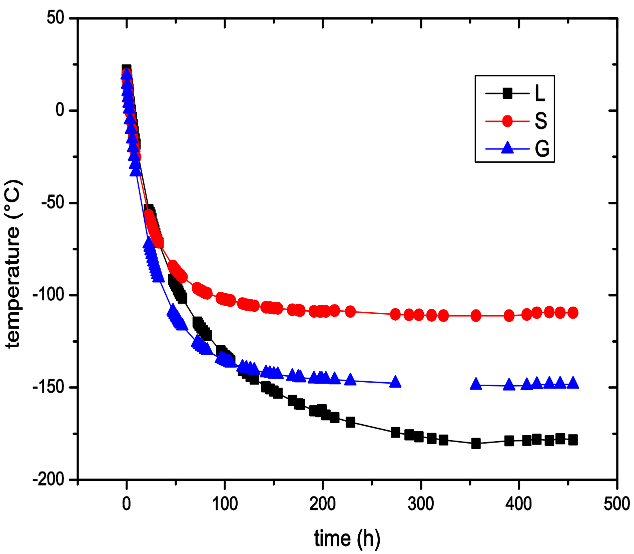
Pirani at magnet entrance magnet exit



Exposure time of 5000 s
The data were corrected from cosmic contamination.
The data were collected before cryopumping.

Vacuum inside the anticryostat

- When anticryostats has been switched-off, temperature time decay has been much longer than anticipated
- Stable conditions in temperature and pressure have been reached after 400 h (-178°C and -110°C)
- Pressure gauges have indicated 1.7 10^{-6} and 1.9 10^{-6} mbar at the laser and CCD side, respectively.
- Although such values are much larger than expected, chameleon runs have been performed with valves of the pumping groups and vacuum gauge closed.



Reflection coefficient of anticryostat pipe

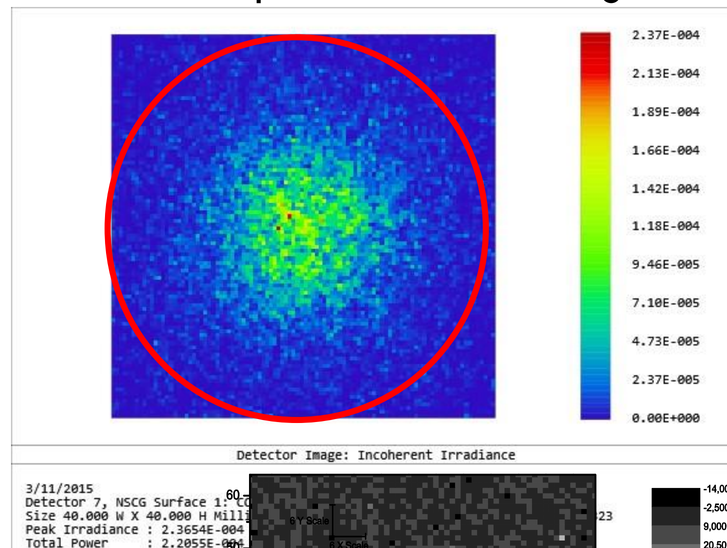
Photon distribution at output window of magnet

One laboratory and two in-situ measurement were performed

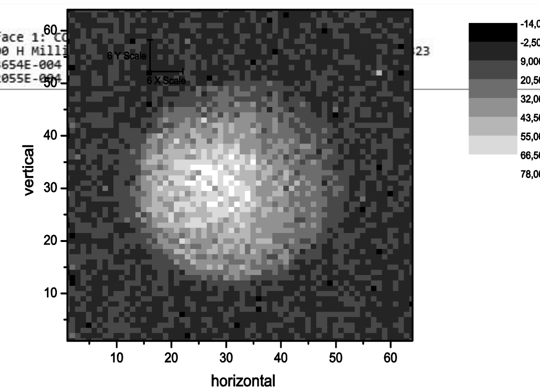
Laboratory test give 35% reflection for incidence angles up to 70 degrees

1] The glass diffuse plane, placed at the input to anticryostate was illuminated by incoherent standard lamp source.

Zemax simulation



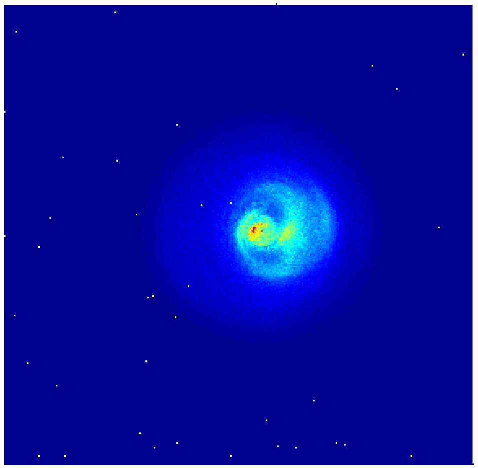
Real experiment



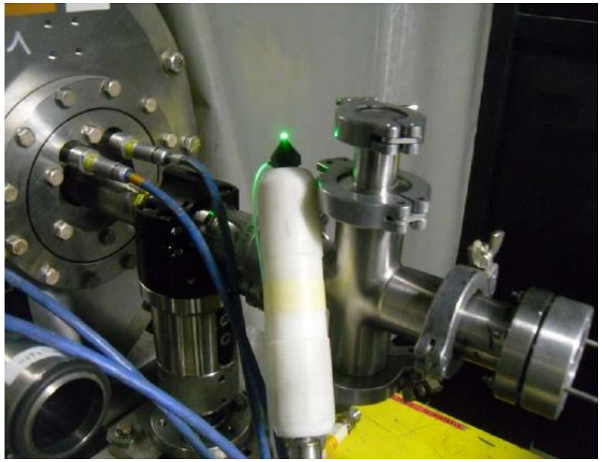
Good agreement in distribution, absolute value must be still checked

Reflection coefficient of pipe

- 2) Dedicated measurements have been started using punctual photon source, to measure the collection efficiency and check simulation results.
- Source of diffused light -ceramic ball with fiber input
- Can be placed inside pipe at chosen distances from CCD.



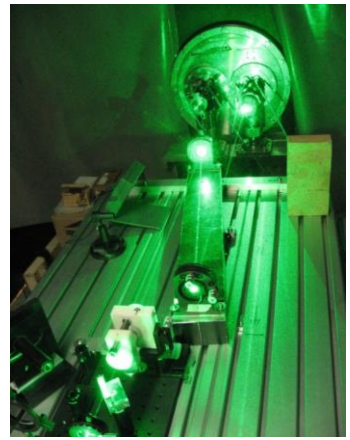
Photon distribution at CCD, ball is placed 15 m from CCD

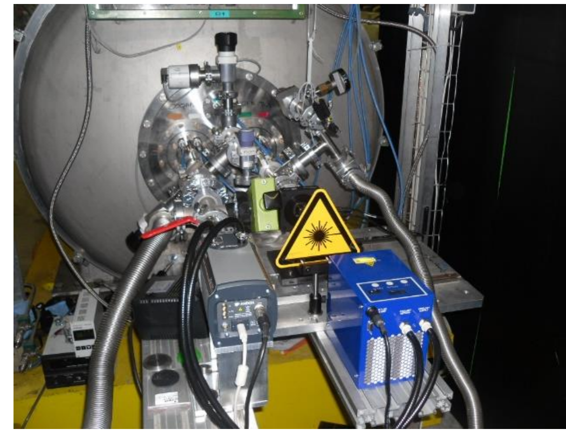


Effect of pipe curvature at horizontal photon distribution. Preliminary analyses from all images confirm averaged reflection coefficient is below 0.35% for incidence angles up to 70 degrees.
Diffused light after more than three reflections can contribute only little to total number of detected photons.

OSQAR – CHASE run 2015

Magnetic filed 9 T
laser power 18.5 W
valves to Pirani gauges closed
valves to pumps closed

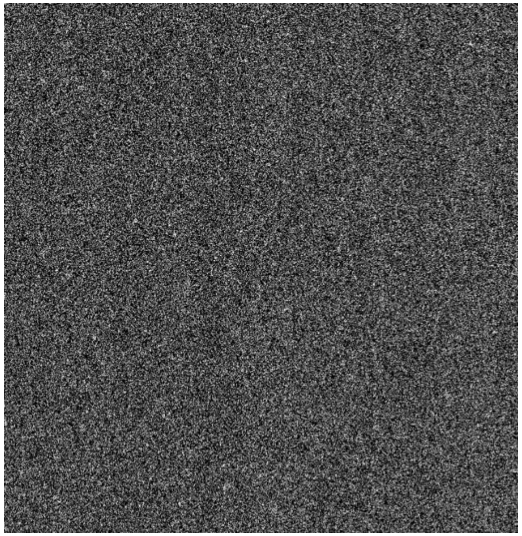




Run	Production time [s]	Exposure times [s]	Total exposure time [s]	Starting pressure [10^{-6} mbar]	Ending pressure [10^{-6} mbar]
1	900	50s 100s 200s 400s	750	2.5	2.8
2	900	50s 100s 200s 400s	750	3.9	4.0
3	900	50s 100s 200s 400s	750	4.6	4.8
4	900	50s 100s 200s 400s	750	4.6	4.8
5	17400	50x800 s	40000	2.1	4.7
6	39600	43x1000 s	43000	1.9	4.8
7	39000	43x1000 s	43000	1.7	4.7
8	39000	40x1000 s	40000	1.8	5.0

Preliminary data analysis from the Run 2015

- Quantitative analysis of the recorded data is currently being performed.
- An analytic estimate of the expected afterglow signal with respect to chameleon mass and coupling to photons is being implemented similarly as for the GammeV-CHASE experiment by computing the chameleon decay rates during filling and during afterglow, from the chameleon-photon oscillation probability under magnetic field



- taking account of the bouncing effects of the particles on the walls and reflection coefficient
- Zemax simulations

Preliminary data analysis from the Run 2015

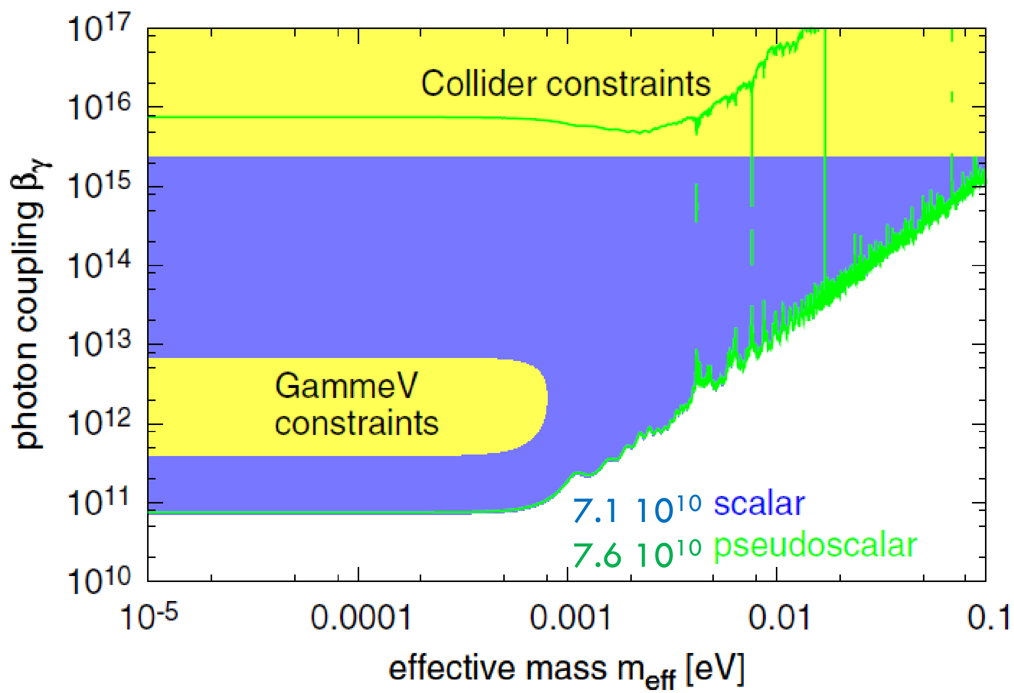
Analysis more delicate than LSW experiment (more model dependent)

Non-magnetic afterglow observed by GammeV-CHASE for t ≤ 120 s

$\beta_g = g_{gg} \; M_{Pl} \sim B^{-1} \; P^{-1/4} \; \eta^{-1/4}$

With the increases of
B from 5 T to 9 T,
P from 3.5 W to 18.5 W,
η from 0.29 to 0.95

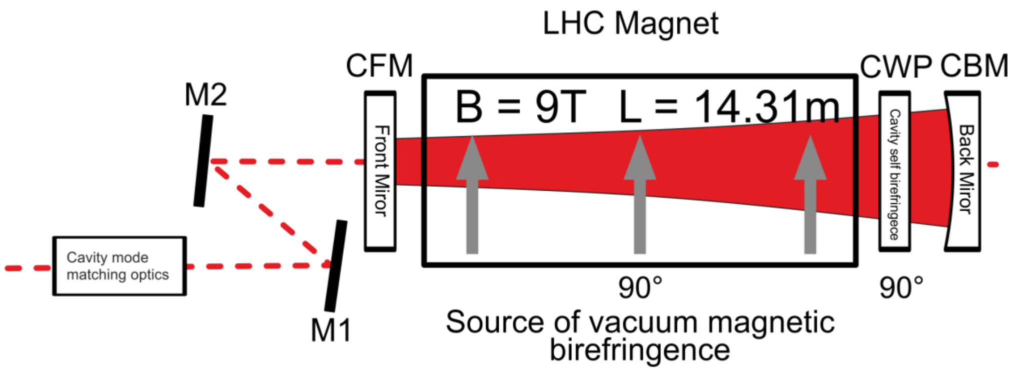
decrease
R from 0.56 to 0.35
The limit for β_g *can be lowered by a factor 3-4 assuming all other parameters unchanged*



Present reference results from GammeV-CHASE
*J. H. Steffen et al., PRL **105**, 261803 (2010)*

Cavity for Photon Regeneration

Aim - to profit from the large laser intracavity optical power



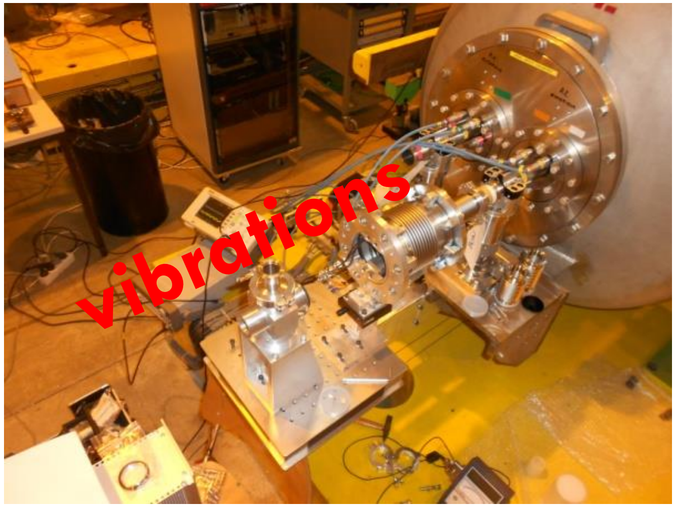
- R&D have started for VMB, He-Ne laser.
- It is based on the same mechanics, vacuum and electronic parts.
- High quality mirror layers are necessary

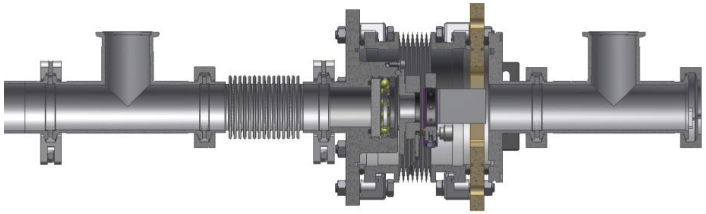
- The implementation of the resonantly-enhanced conversion scheme* with two long length cavities is challenging with one of the main technical difficulties resulting from the design and realization of active locking systems for two high-finesse Fabry-Perot cavities

* P. Sikivie, D. B. Tanner, and Karl van Bibber, Phys. Rev.Lett. 98, 172002 (2007).
* G. Mueller, P. Sikivie, D.B. Tanner and K. van Bibber, Phys. Rev. D 80, 072004 (2009).

Seismic control system

- Dedicated seismic control system similar to the one used for the LIGO and Virgo interferometers has to be developed and implemented.
- To speed-up the required specific R&D in this field, dedicated collaboration with ALPS and more specifically with experts from the Advanced LIGO pre-stabilized laser subsystem, is under discussions.





CERN SM18 hall - some sources of vibrations from the cryogenic and vacuum systems, from air-conditioning, traffic

OSQAR-ALPS collaboration

- Meeting at DESY, the 8-9 June 2015
- Meeting at CERN, 17-18 September 2015
- Report the 2 following possibilities
  - 1) Common OSQAR-ALPS for LSW with 2 LHC dipoles & ALPIIc optics. Mutual benefits of OSQAR/ALPS at CERN are not obvious especially for ALPS.
  - 2) An intermediate alternative, minimizing the impact on ALPIIc can be to develop and install only one Fabry-Perot cavity at CERN (gain by a factor of 10 on the di-photon coupling constant, IR laser with TES detector required because of constraints coming from the high power Fabry-Perot cavity).

Conclusion

Photon regeneration

the best exclusion LSW limit for axions and axion like particles

pseudo-scalar: $g_{A\gamma\gamma} < 3.5 \cdot 10^{-8} GeV^{-1}$, scalar: $g_{A\gamma\gamma} < 3.2 \cdot 10^{-8} GeV^{-1}$

VMB

refractive index difference $\Delta n \approx 1.6 \cdot 10^{-14}$ can be measurable at LHC magnets at CERN without cavity

Cavities are needed for real progress at PR and VMB experiments

Chameleons

We expect increase of the present reference exclusion limit of photon -chameleon coupling constants

Perspectives & Requirements for 2016

- For 2016, the experimental run will still focus to the chameleon search with a modification of the experimental set-up.
- The request from the collaboration concerns the possibility of using one of the LHC dipoles at 1.9 K committed for OSQAR together with dedicated resources for a minimum experimental run duration of 6 weeks.

THANK YOU FOR YOUR ATTENTION

Acknowledgements

The OSQAR collaboration would like to thank the CERN-TE teams of the SM18 test hall (MSC-TF, CRG-OD, VSC-LBV) for their valuable technical contributions and efficient devotion for the operation of both LHC dipoles dedicated to OSQAR as well as the management of CERN-TE department for his continuous support.