STATUS AND PLANS OF THE OSQAR EXPERIMENTS

Stepan Kunc

on behalf of OSQAR collaboration

123rd Meeting of the SPSC, 18 October 2016, CERN

Outline

- **Introduction of OSQAR experiments**
  - OSQAR laser based experiments - LSW, VMB & CHASE
- **OSQAR activities in 2016**
  - Ongoing studies and developments to upgrade OSQAR – LSW experiment
    - Optical layout and cavity locking scheme
    - Design of 20 m long resonator for OSQAR LSW
    - Vibration measurements and analysis in SM18 prior to cavity implementation
  - Results from the 2015 OSQAR-CHASE runs, data analysis and conclusion
    - Expected signal
    - Results and conclusion
- **OSQAR objectives for 2017**
  - Chameleon Run 2017
  - First test of 20 m long production cavity in SM18
- **Conclusion, Perspectives & Requirements for 2017**

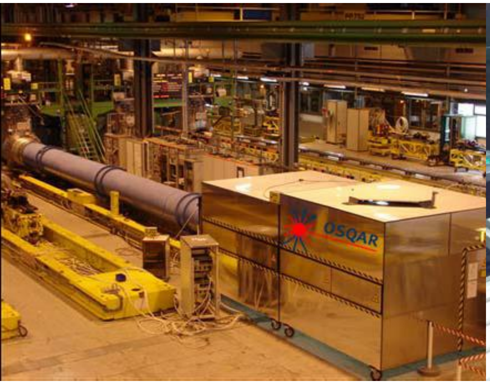
Optical **S**earch for **Q**ED vacuum magnetic birefringence, **A**xions and photon **R**egeneration

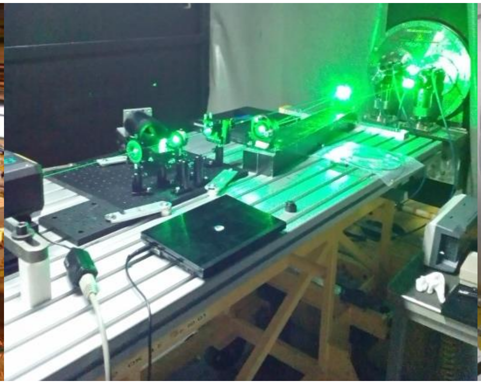
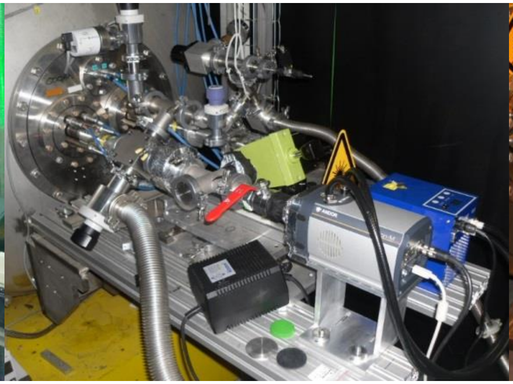
Three laser laboratory experiments in strong magnetic field, using 2 spare LHC magnets an infrastructure of test hall SM 18 at CERN

1. The photon regeneration effect (photon – axion and axion - photon conversion) is looked for as a Light Shining through the Wall. Latest results in 2015 (run 2014), next run in 2018,2019

2. The Vacuum Magnetic Birefringence,
predicted by the QED, could be measured for the first time. Next run 2019/2020

3. Chameleon search - looks as measurement of afterglow of light. Run 2015 Next 2017

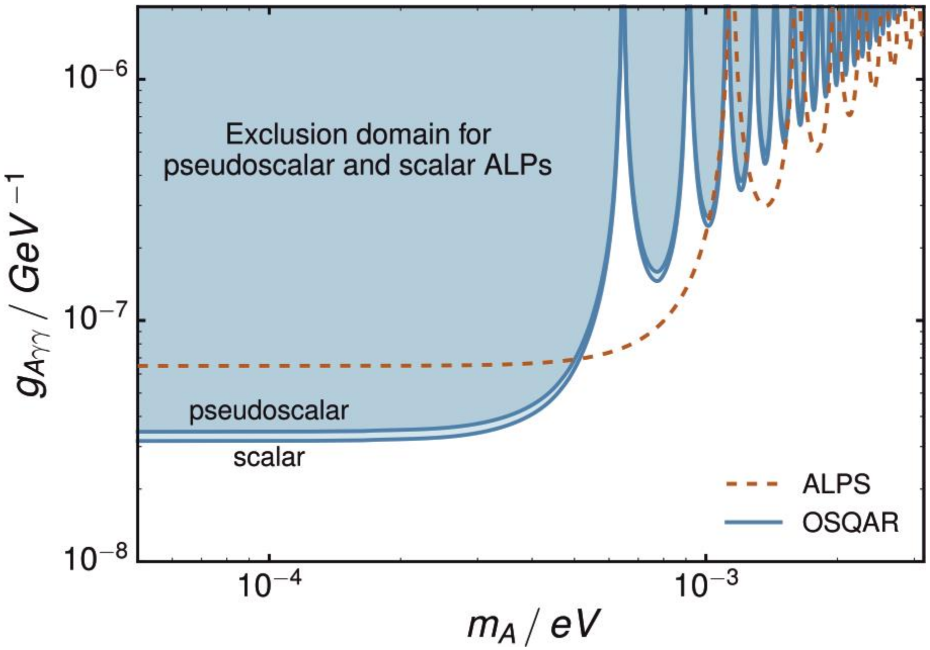


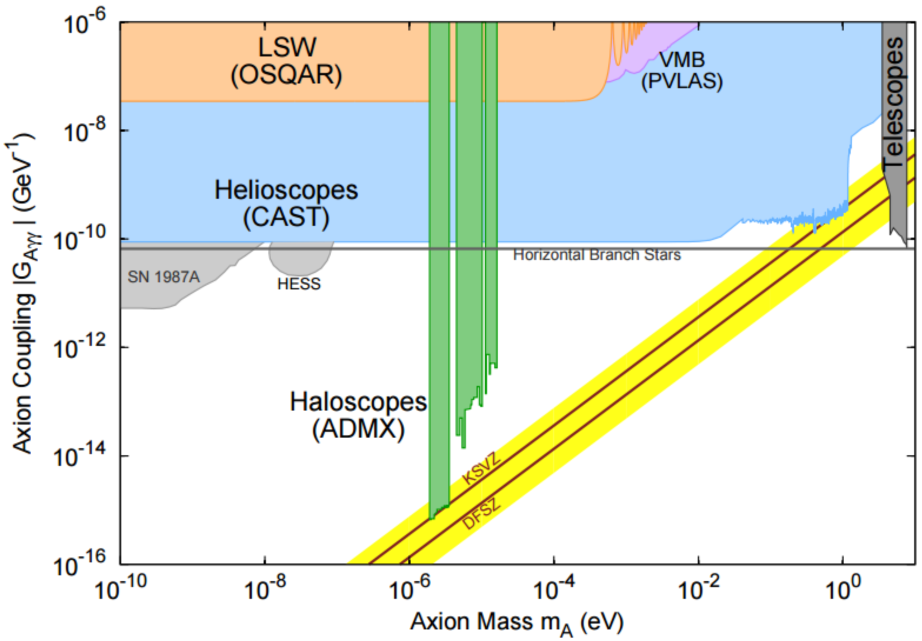

Status of OSQAR experiments

1. Light shining trough the wall – LSW

- World leading limits in LSW experiments for Axion/ALPS searches (2015)
- R&D for production cavity; proposal submitted to funding agencies (AxCal, GACR)



"New exclusion limits on scalar and pseudoscalar axionlike particles from light shining through a wall," Phys. Rev. D 92(9), 092002 (2015).



http://pdg.lbl.gov/2015/reviews/rpp2015-rev-axions.pdf; PDG Data Group, AXIONS AND OTHER SIMILAR PARTICLES, 2016

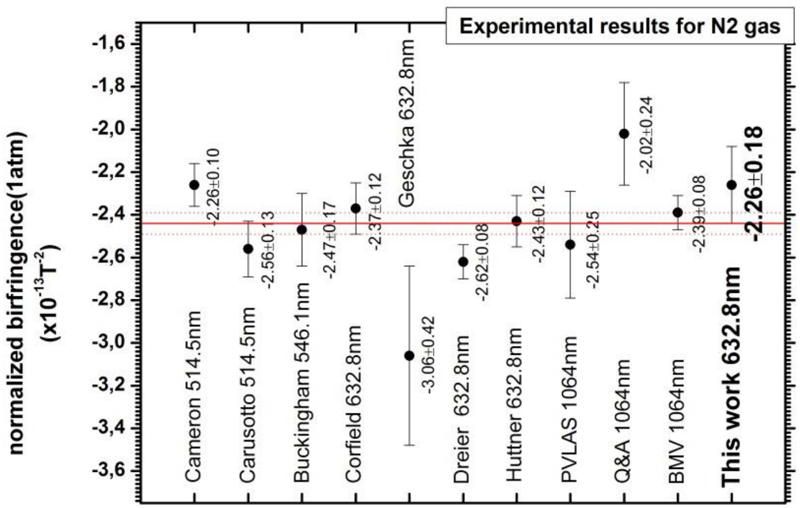
Status of OSQAR experiments

2. Vacuum magnetic birefringence

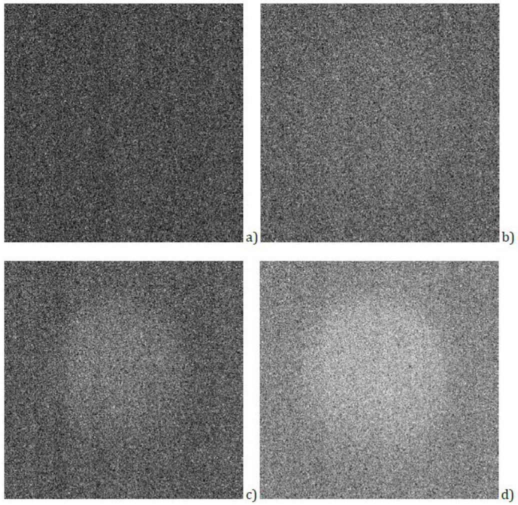
- Sensitivity of $\Delta n \approx 1.6 \cdot 10^{-14}$, single pass and no magnet modulation
- Sensitivity of $\Delta n \approx 10^{-22}$ needed, new set-up development for static fields

3. Chameleon searches – CHASE

- Analysis of all possible origins for the spurious signals observed is ongoing
- Preparation of the 2017 run



Kunc, S., Sulc, M., "High sensitive method for optical birefringence measurement,", Spie-Int Soc Optical Engineering, Bellingham, 94420O (2015).



Surprising radiation from Pirani vacuum gauges was observed at ring region on CCD.

OSQAR-LSW activities in 2016

1. Ongoing studies and developments to upgrade OSQAR – LSW experiment

2. Production flux
Increase of laser power – pulsed laser in KW regime ?
Increase of wavelength - infrared ?
Use resonant cavity for power build –up
$g \sim 1/P_{inc}^{1/4}$; $g \sim 1/\lambda^{1/4}$

4. Detector
Better efficiency
Low dark count rate
Longer measurement
$g \sim 1/\varepsilon^{1/4}$; $g \sim 1/n_d^{1/8}$; $g \sim 1/t_m^{1/8}$

Weakest detectable coupling to photons

$$g = \frac{1}{B\,L}\sqrt{2}\,\sqrt[4]{\frac{h\,c\cdot SNR}{15\,P_{inc}\,PB_p\,\lambda}}\cdot\sqrt[8]{\frac{n_{dark}}{t_m}}$$

1. Magnetic field region
L – effective length of magnetic field
B – magnetic induction of the field
B and L are fixed for OSQAR
$g \sim 1/(BL)$

3. Regeneration cavity
Resonant enhancement of regenerated signal
Never realized in an experiment (ALPS II)
$g \sim 1/PB^{1/4}$

Upgrade of OSQAR-LSW by using a resonant cavity

Optical layout and cavity locking

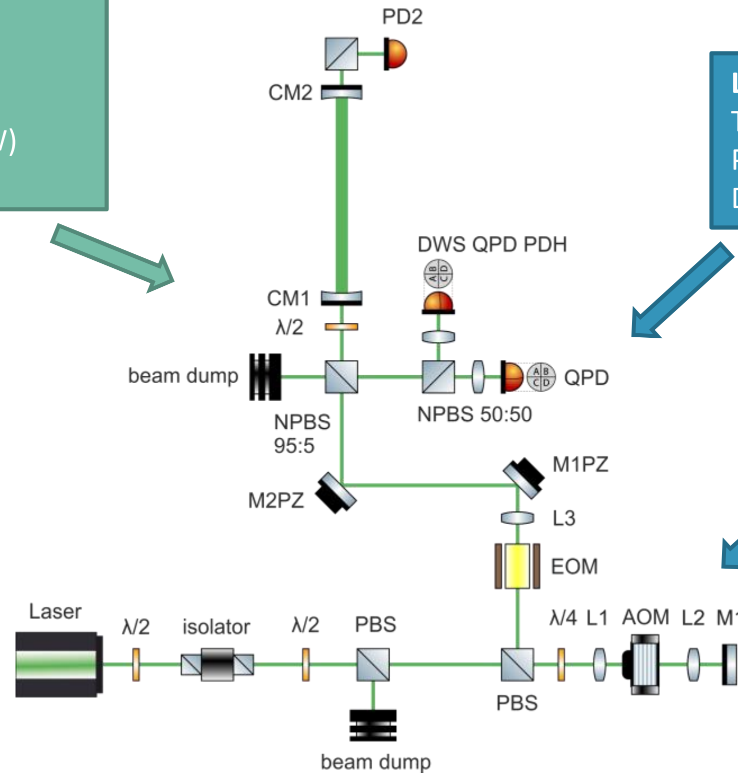
In the first stage of LSW resonator development we will start with test cavity

Test cavity parameters:
Finesse F = 200
Length L = 1 m
Confocal ROC = -20m
Laser Coherent Verdi V5 (532 nm CW 5W)
Test in DESY(Hamburg) end of 2016

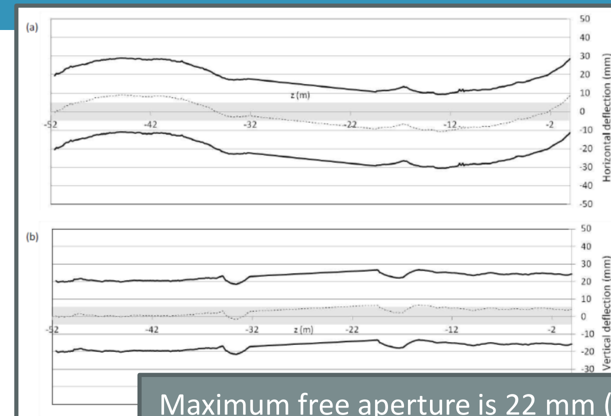
Locking schemes:
Tilt locking
PDH locking
Differential wave front sensing

AOM
In double pass configuration
To control frequency of incident light to the resonator for locking

Verdi V5
Free running stability
3-5 MHz up to 20 ms
30-50 MHz up to 50 s
150 MHz up to 1000 s
No piezo tuning



Design of full length 20m cavity in SM18

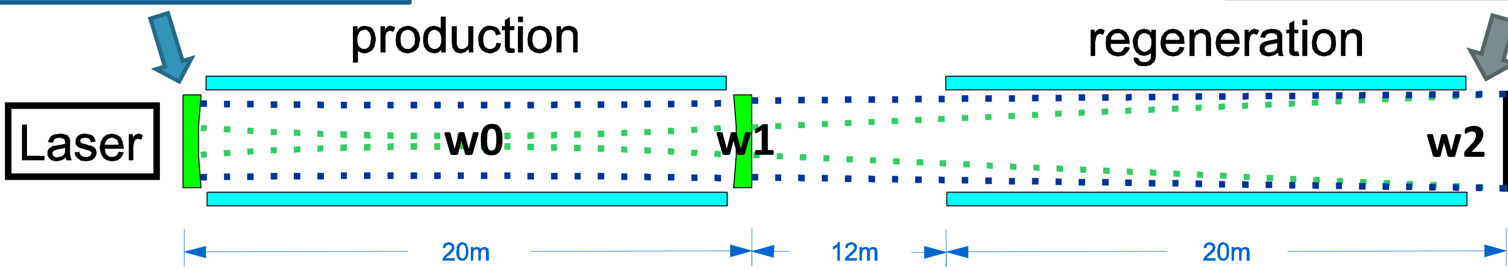


SM18 cavity parameters
Finesse F = 200
Power build-up = 70 (impedance matched)
Length L = 20 m
Laser Verdi W5-18 x Mephisto Mopa (1 kHz over 100ms, 1064 nm)

Waist w0 from 0.57 mm to 10.98 mm

ROC from -10.3 m to -57000 m
Concentric to quasi parallel

Maximum free aperture is 22 mm (25 mm), maximum beam radius 11 mm (in $1/e^2$)



ROC = -20 m – confocal cavity – best stability
w0 = 1.3 mm w1 = 1.8 mm w2 = 5.3 mm
For power build up of 70 the corresponding power density on the mirrors is 7-25 kW/cm²
For power build up of 1000 in the second stage corresponding power density is 98-355 kW/cm² possible damage of the mirrors

Vibration measurement and analysis in SM18 for cavity implementation

The key parameters for cavity locking are frequency stability of the laser & mechanical stability of the optical cavity

Main sources of noise in SM18
- Acoustic noise
- Seismic and mechanical noise
- Thermal drifts – between day and night

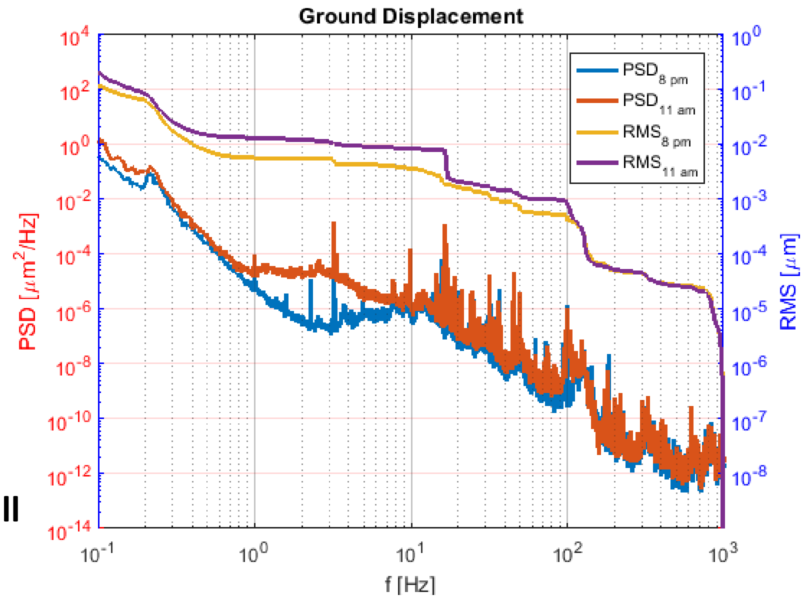
Noise affects both the stability of the laser and optical cavity

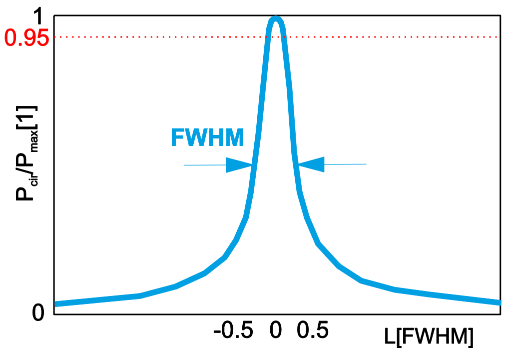
Noise in acceptable level with some spurious high peaks that will unlock the cavity (proper isolation system)

Feedback system with bandwidth about 10 kHz to compensate the laser frequency & vibration instabilities of the cavity

To achieve 95% of resonance mistuning has to be in order of 1/10 of FWHM – F = 200 for L = 20 m

$\Delta L_{95\%}$ = 133 pm ; $\Delta \nu_{95\%}$ = 3.8 kHz



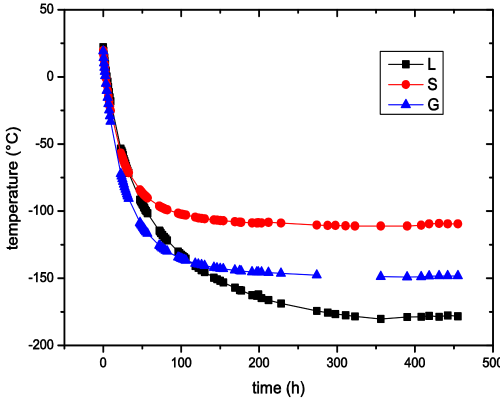


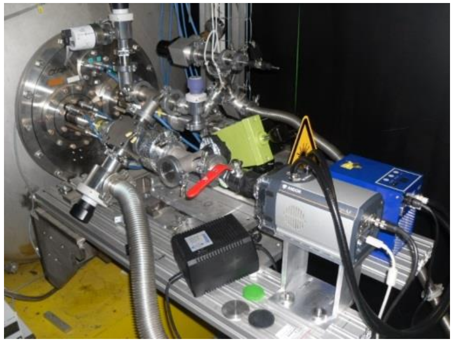
OSQAR activities in 2016 CHASE

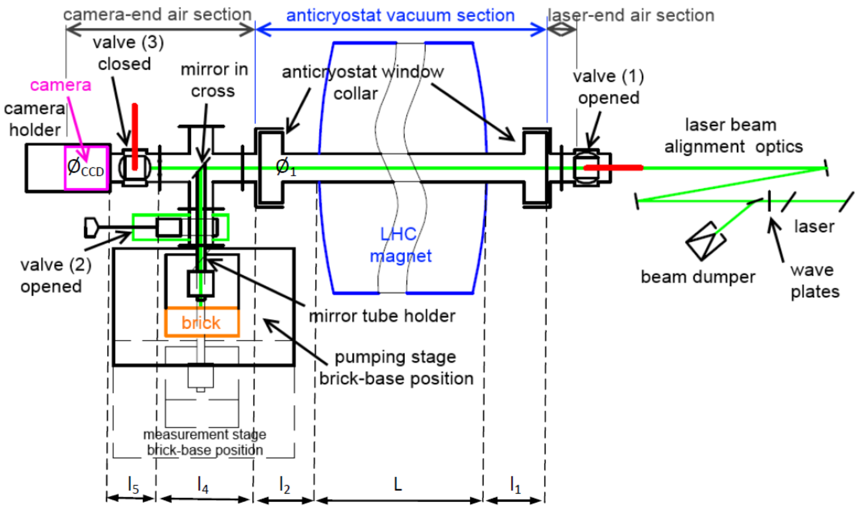
2. Results from the 2015 OSQAR-CHASE runs, data analysis and conclusion

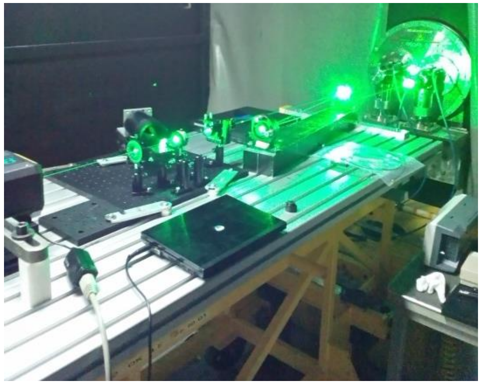
The 2015 OSQAR – CHASE experimental conditions

- One LHC spare magnet B = 9 T and L = 14.3 m
- Anticryostat with two BK7 windows with high antireflection coating
- Photon source – Verdi V18 – 18 W CW 532 nm
- New CCD Andor iKon DU934P BV – 1024x1024, 95% QE, 2.9 e-/pixel , 0.0003 e-/pixel/s
- The whole set up (windows, lenses, camera window, A/D) efficiency of 0.65 ± 0.03
- Complete new cleaning, all components leak tests for high vacuum
- Two turbomolecular pumps and cryopumping (400 h)









Expected signal CHASE

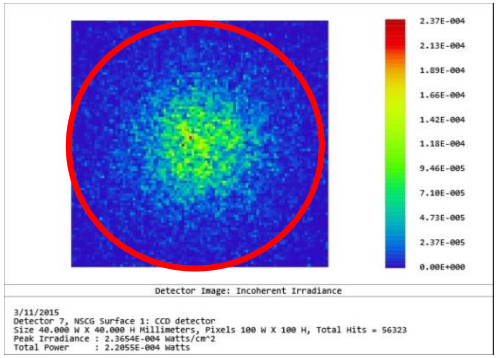
Three different approaches have been conducted in parallel to superpose a Chameleon fake signal in the background to determine the experiment sensitivity:

1. Analytical calculation based on the ray tracing modelling,
2. Simulation with optical design software Zemax,
3. Experimental fake signals coming from measurements with the CCD of a well characterized diffuse light signal

From laboratory and in-situ measurements reflection coefficient of anticrostat is 35% up to 70 degrees.

To define the region of interest ROI approx. ¼ of CCD

2.



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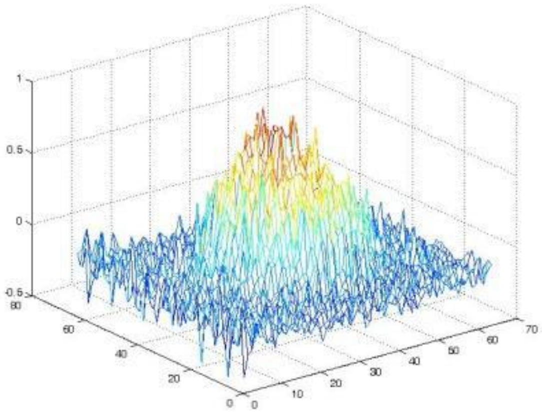
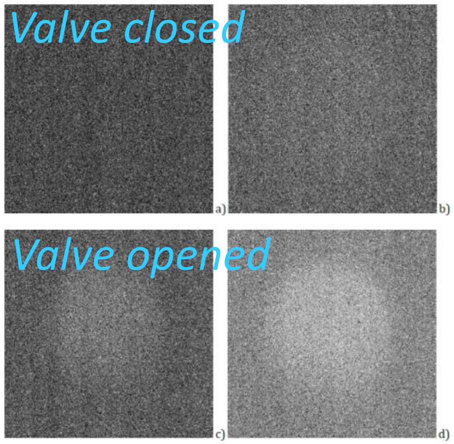


Data taking CHASE

Data taking procedure similar to Game V

- Magnetic filed 9 T
- laser power 18.5 W
- Pirani gauge valves closed – avoiding fake signal
- Pump valves closed – avoiding pumping chameleons
- Time delay about 100 s between laser OFF and CCD acquisition start

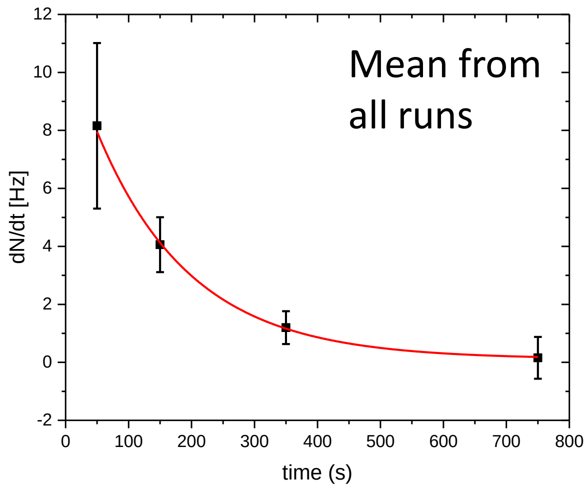


Run	Production time [s]	Exposure times [s]	Total exposure time [s]	Starting pressure [10^{-6} mbar]	Ending pressure [10^{-6} mbar]
1	900	50s 100s 200s 400s	750	2.5	2.8
2	900	50s 100s 200s 400s	750	3.9	4.0
3	900	50s 100s 200s 400s	750	4.6	4.8
4	900	50s 100s 200s 400s	750	4.6	4.8
5	17400	50x800 s	40000	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

Results and sensitivity

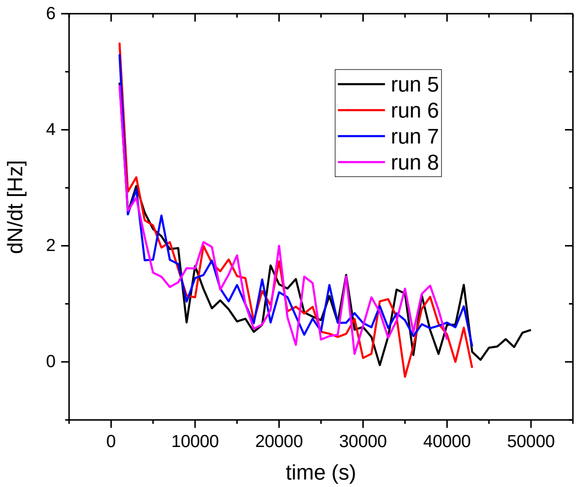
Short time runs

- Signal with exponential decay was observed for all short time runs
- It has an amplitude (10.8 ± 0.7) Hz and decay rate (6.7 ± 0.4)· 10^{-3} Hz
- Similar to GammeV
  J. H. Steffen et al., Phys. Rev. D **86**, 012003 (2012)



Long time runs

- Similar decay was observed for long time runs, but decay rate (2.3 ± 0.3))· 10^{-4} Hz
- It has an amplitude (4.3 ± 0.4) Hz

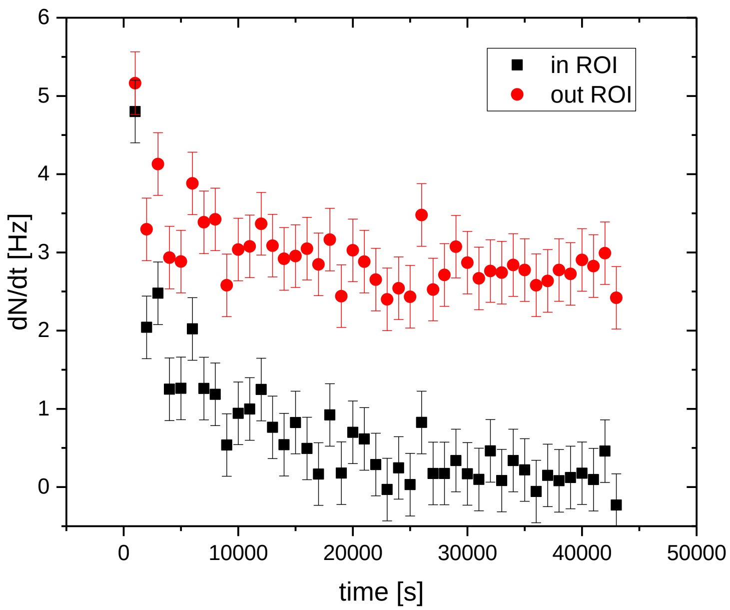


Problem with afterglow signal

The precise origin of this afterglow is yet unknown

Possible explanations are:

- Vacuum cleanliness – critical parameter, contaminants deposited on the inner part of anticryostate and windows (cleaned)
- Thermoluminiscence of window – the 532 nm and maybe small amount of harmonics of this laser can produce excited states, populate traps, with similar decay characteristic
  - is tested at the laboratory
- CCD was heated, irradiated by thermal IR photons more at long runs,
  - The decay is inhomogeneous in CCD, it seems that dark current is more suppressed in the central region, cooling by Peltier element
  - The false signal at long runs has smaller amplitude but higher offset outside ROI



Preliminary data analysis from the Run 2015

Analysis more delicate than LSW experiment (more model dependent)

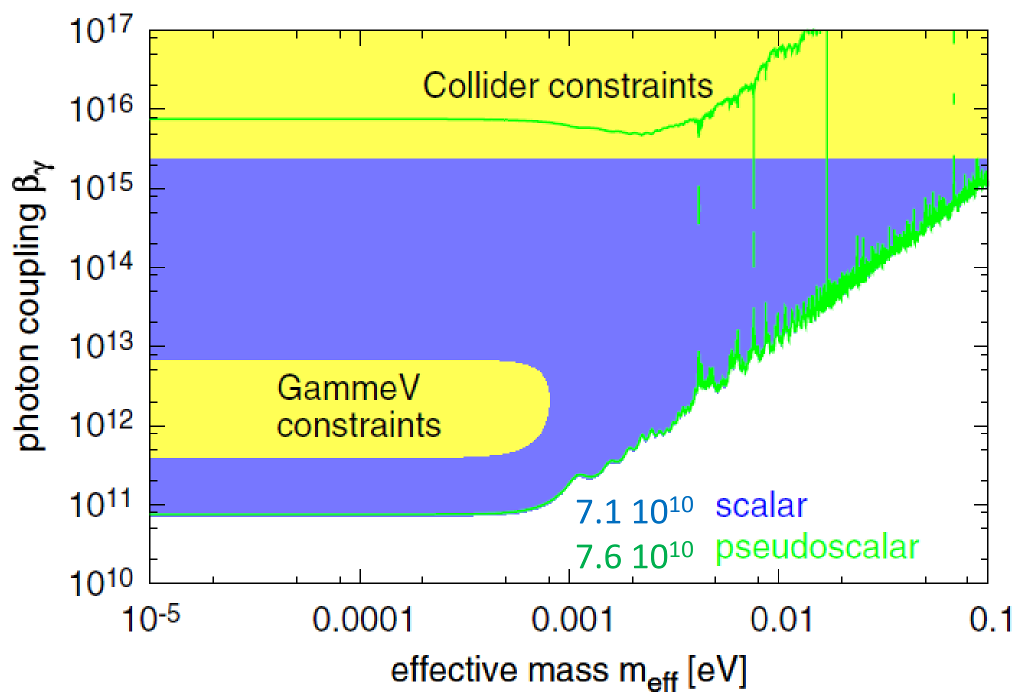
A. Upadhye, J. H. Steffen, and A.S. Chou, PHYSICAL REVIEW D 86, 035006 (2012)

Non-magnetic afterglow observed

$$\beta_\gamma = g_\gamma \cdot M_{Pl} \sim B^{-1} P^{-1/4} \eta^{-1/4}$$

With the increase of
B from 5 T to 9 T,
P from 3.5 W to 18.5 W,
η from 0.29 to 0.65
Detected photon rate sensitivity from 1.35 Hz to 0.6 Hz
And decrease
R from 0.56 to 0.35

The limit for β_γ can be divided 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)*

OSQAR Objectives for 2017

1. **OSQAR-LSW : Preparatory phase**
   - Build and implement production cavity – AxCal proposal (ANR-DFG)
   - **To build cavity in 2017 depends on funding AxCal, CAGR**
   - With target to make LSW run in 2018
   - Cavity of finesse F = 200 improve LSW limit by **factor 2-3**
   - Cavity F = 200 increases the VMB ellipticity to be measured by **factor 10^2**

2. **OSQAR-CHASE : Preparatory phase and new experimental run**
   - Improve GammeV-Chase limit by a **factor of 3-4**
   - UHV shall be reached in the LHC dipole aperture – improvement / 2015 runs
   - New procedure to re-enforce the cryopumping
   - Second detector in front of magnet PMT or CCD sensitive in IR – for chameleon fragmentation – in collaboration with CAST

Conclusion, Perspectives & Requirements for 2017

In 2017 we will focus on OSQAR-CHASE runs

- Reaching the UHV
- Using a second detector IR sensitive
- Better understanding all sources of noise and signal observed

In addition a 20 m long cavity of F = 200 is expected to be implemented to make OSQAR-LSW runs in 2018 or later as a function of the results of our grant applications

The improvement of OSQAR-LSW & OSQAR-VMB experiments relies on the developments of long resonant cavities

The request from the collaboration concerns the possibility of using one of the spare LHC dipoles at 1.9 K committed for OSQAR together with dedicated resources for minimum experimental run duration of 6 weeks preferably from July to September.

THANK YOU FOR YOUR ATTENTION