APNS: Alignment and Pointing Noise Suppression

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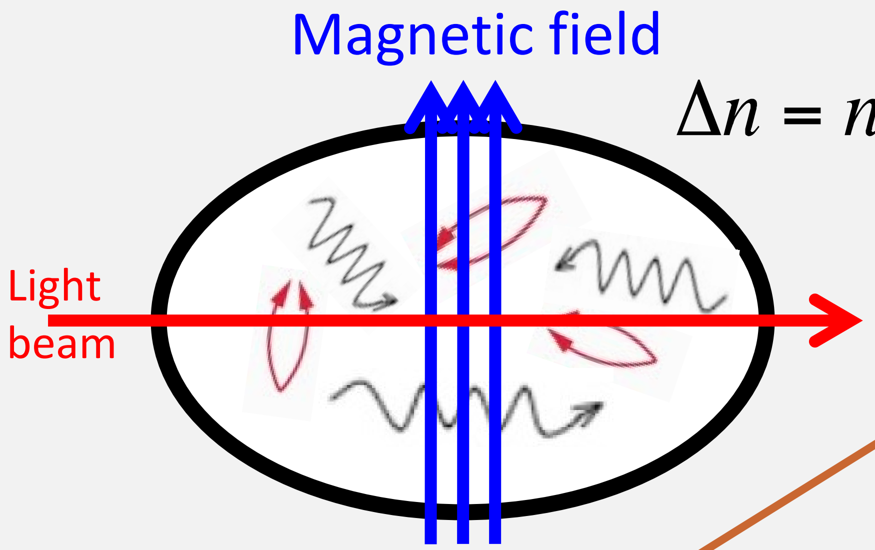
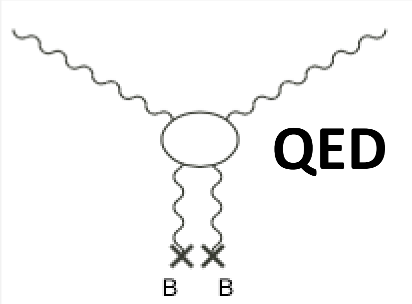
OPTICAL PROPERTIES OF QUANTUM VACUUM

Vacuum is structured and has properties that can be studied experimentally.



$$\Delta n = n_{\parallel} - n_{\perp}$$



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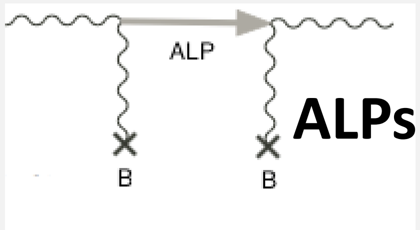
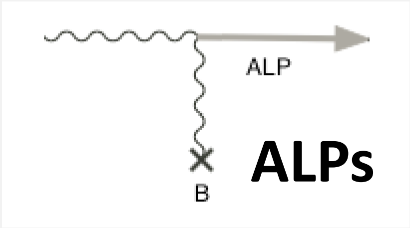
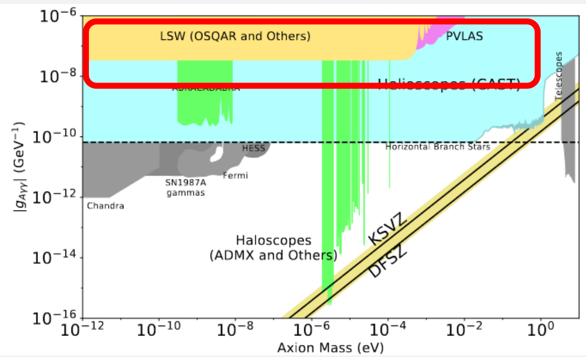


$$\Delta n_{QED} = 3A_e B^2 = 4\times10^{-24}$$ @ 1 T magnetic field

VACUUM MAGNETIC BIREFRINGENCE





Model independent search for 'light' DM

$$\Delta\tilde{n} = \Delta n_B + i\,\Delta\kappa_B$$

BIREFRINGENCE DICHROISM

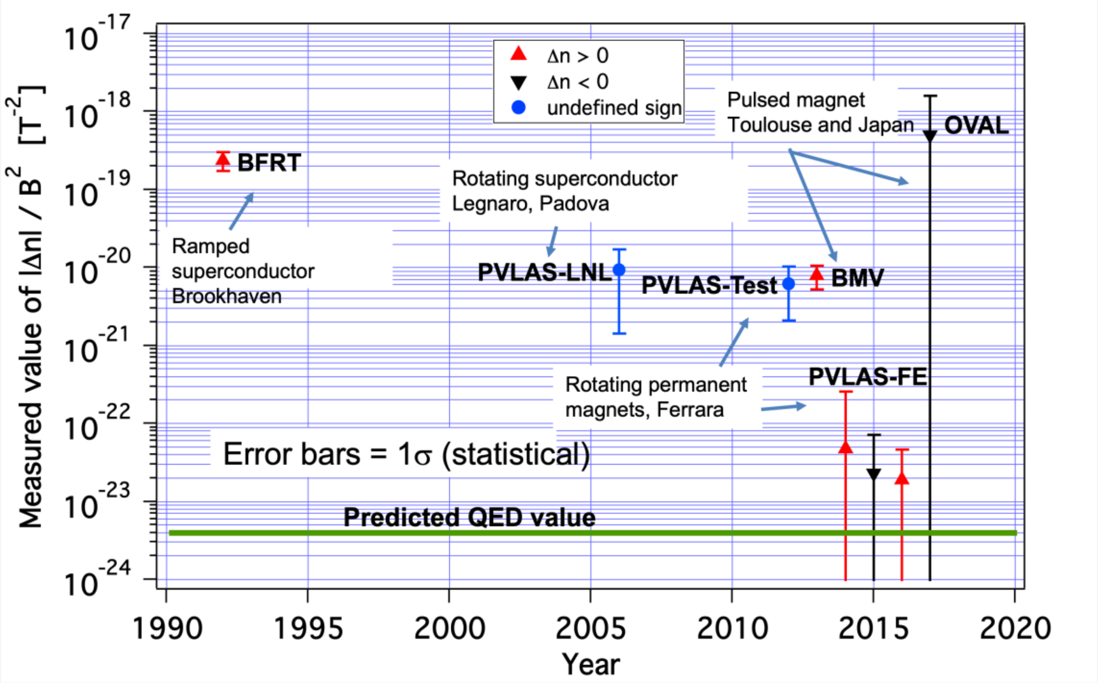
POLARIMETRY

Experimental method:

- Perturb with an external B field
- Probe with a (polarised) light beam
- Detect changes in the polarisation state

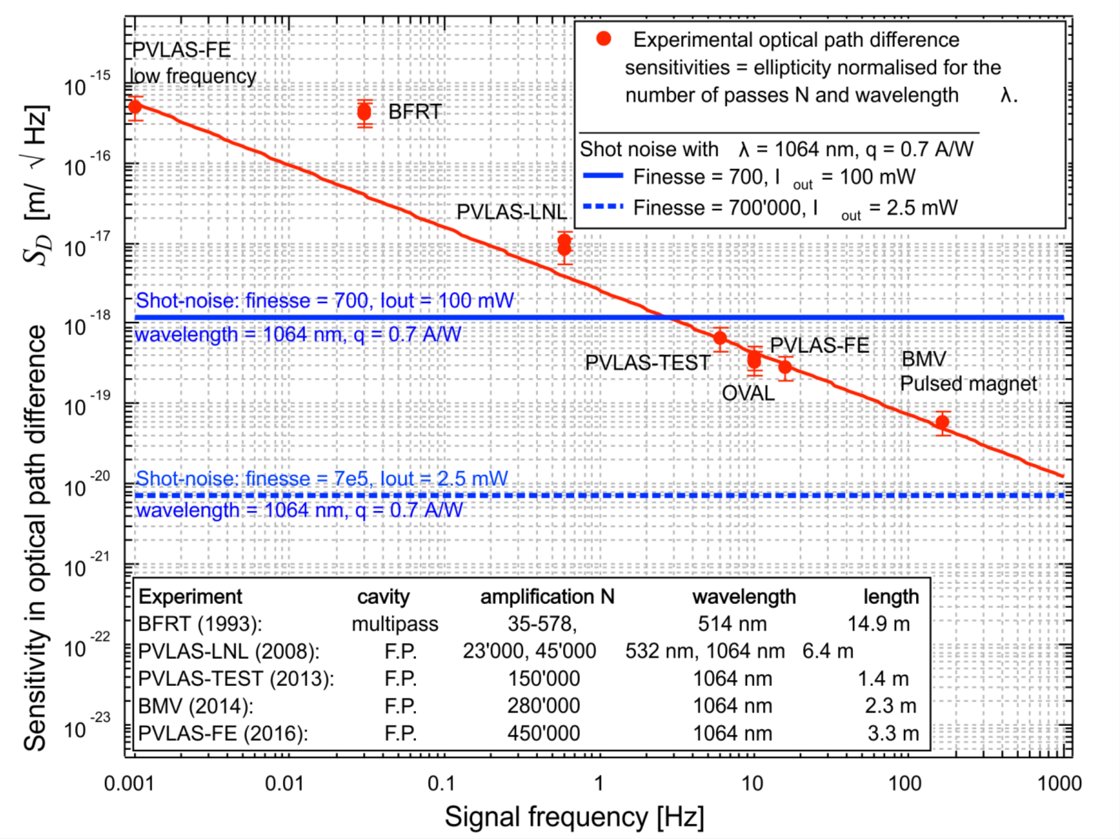
Key ingredients:

High magnetic field	signal α B^2
Long optical path	optical cavity
High sensitivity polarimeter	signal modulation



PVLAS permanent magnets B^2 L≈ 10 T^2 m

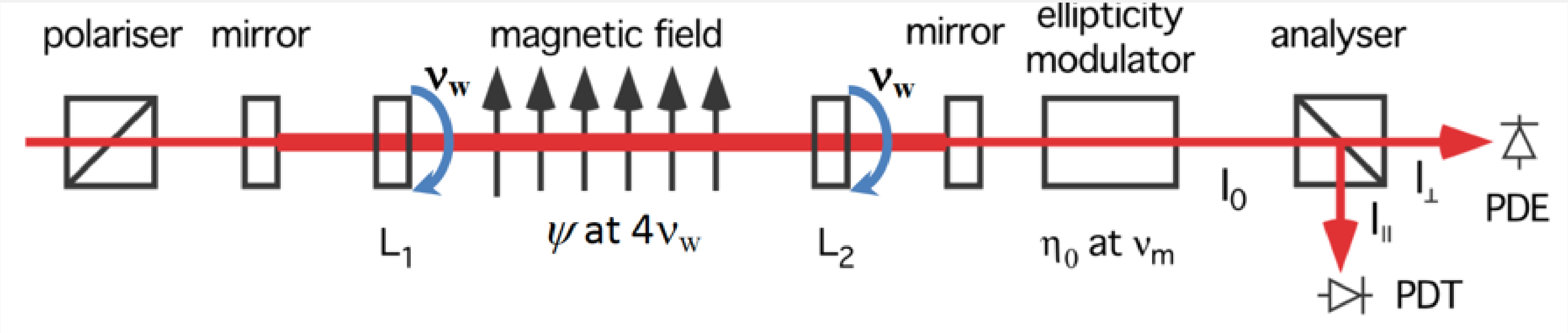
LHC dipole magnet B^2 L≈ 1200 T^2 m



VMB@CERN

Increase the B field! → superconducting magnet (LHC dipole magnet $B^2 \approx 81\ T^2$)

CANNOT BE MODULATED FAST ENOUGH!!



Modulate the VMB signal using two co-rotating half waveplates (HWP) inside the cavity

$\alpha_{1,2}$ are the phase errors from π of the two HWPs and $\phi(t)$ is their rotation angle

$$\Psi(t) = \Psi_0 \sin 4\phi(t) + N\frac{\alpha_1}{2}\sin 2\phi(t) + N\frac{\alpha_2}{2}\sin(2\phi(t) + 2\Delta\phi)$$

Signal is at 4th harmonic of the rotation

Waveplate defects have different frequency components

$$\alpha = \alpha^{(0)} + \alpha^{(1)}\cos\phi + \alpha^{(2)}\cos 2\phi$$

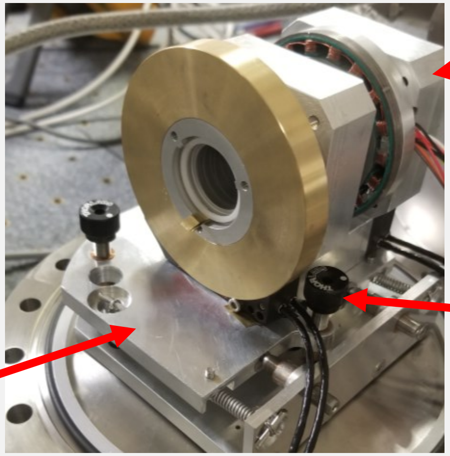
APNS PROJECT

("Alignment and Pointing Noise Suppression")

OBJECTIVES:

1. Control the alignment of the optics inside the cavity to reduce noise and systematics.

Waveplate alignment system



Motor

(Fine) Piezo actuator

(Coarse) alignment plate

2. Develop an automatic alignment system for a cavity built around a LHC magnet (SM18: noisy environment).

Differential wavefront sensing

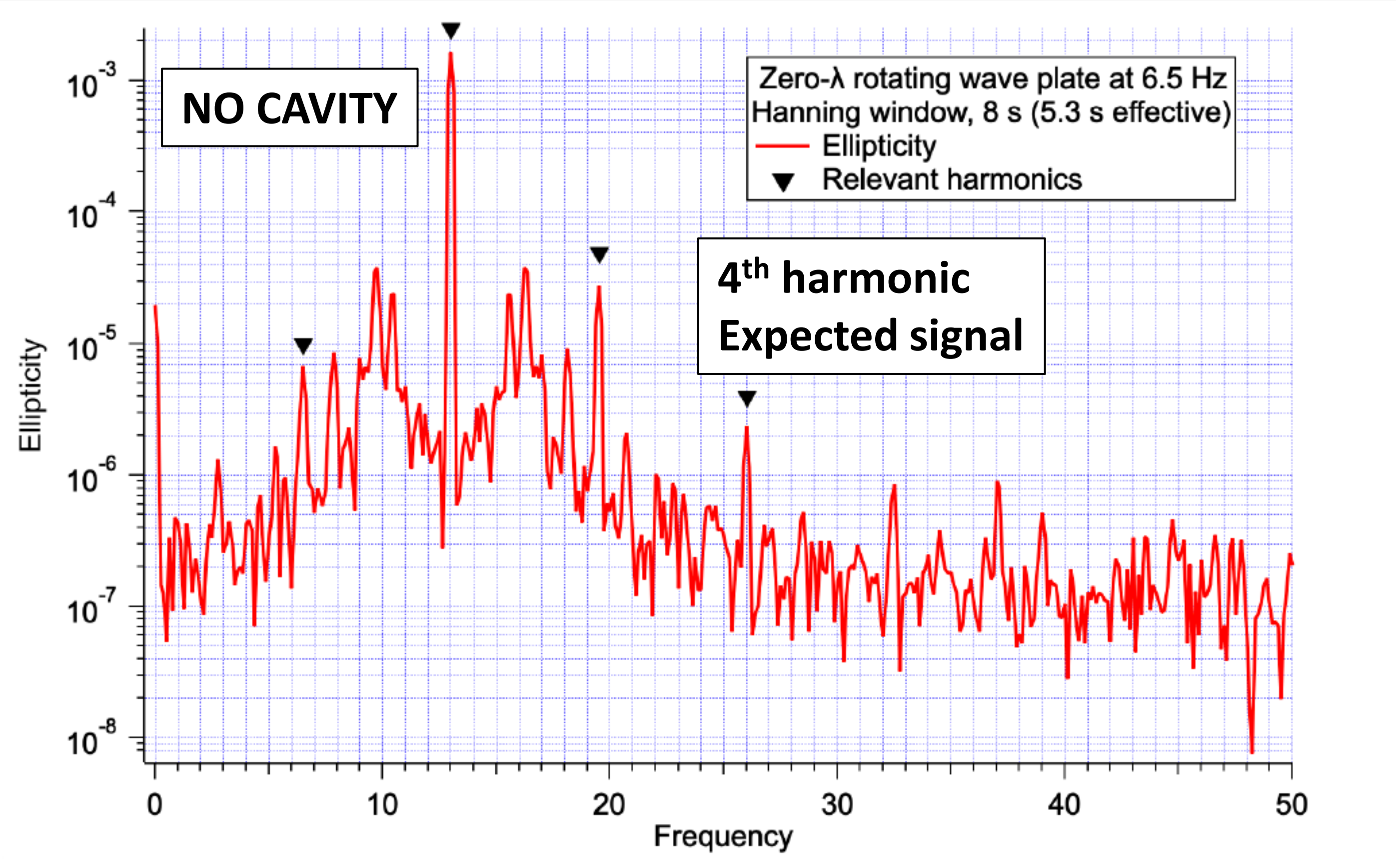
(technique developed in GW interferometry)

Optical Simulations with:

Finesse 2

http://www.gwoptics.org/finesse/

VMBCERN SETUP



FREQUENCY DOMAIN

FEATURES:

- 'Large bump' centered around 2nd harmonic
- Broadband noise
- Peaks at various harmonics (triangles) are due to the rotating waveplate
- Presence of peak at 4th harmonic

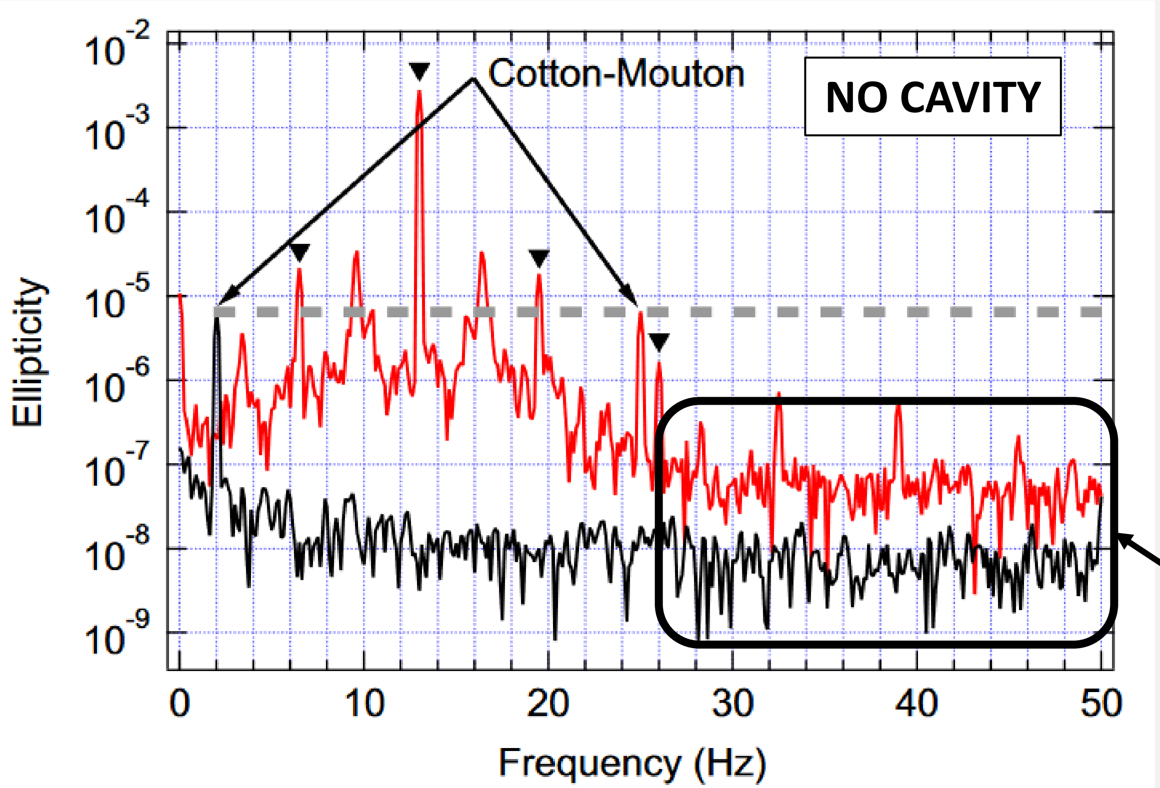
<u>POSSIBLE SHOWSTOPPER!</u>

COTTON-MOUTON OF AIR

Cotton-Mouton effect: Magnetic birefringence in gasses

Found a workaround: MODULATE THE MAGNETIC FIELD!

10 vector averages: each 8 s with Hanning window



- **Red** – magnet rotating at 0.5 Hz and HWPs at 6.5 Hz
- **Black** – magnet rotating at 1 Hz and non-rotating HWPs

The peak in **red** at 25 Hz is due to the Cotton-Mouton of air and has the same amplitude as the signal in **black** at 2 Hz.

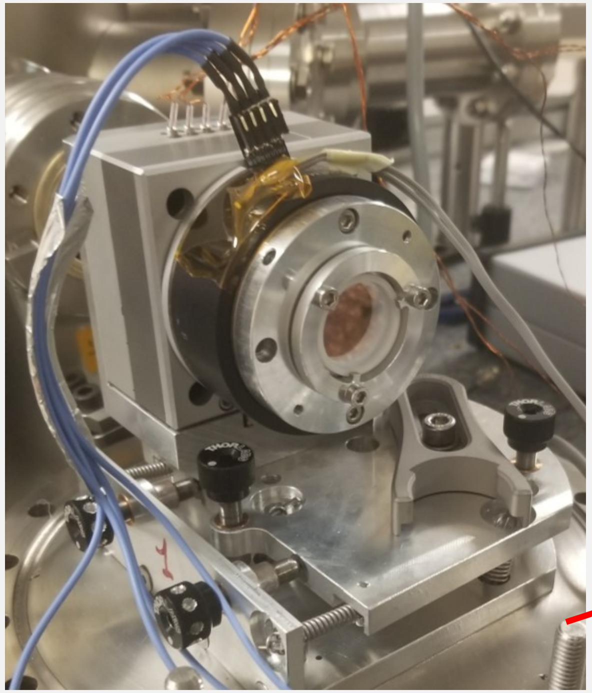
The difference in noise is due to the relative phase (rotation) noise of the HWPs motors.

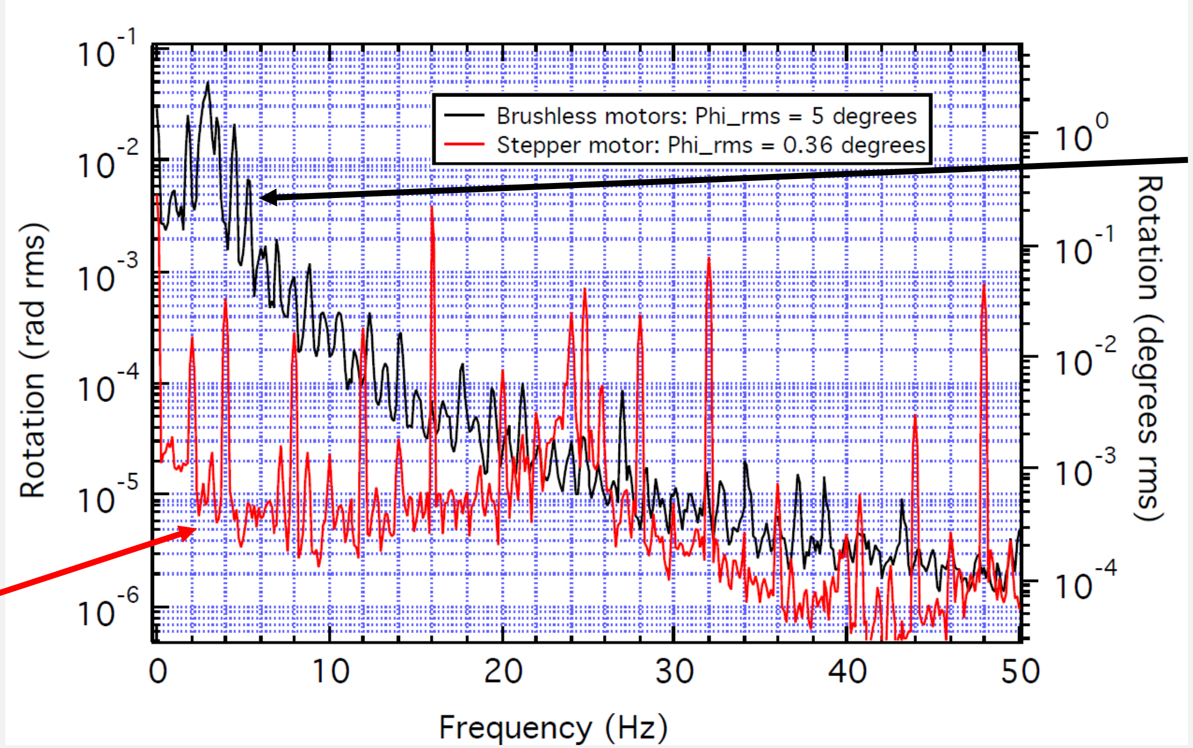
WAVEPLATE MECHANICS

New stepper motors with a more accurate rotation (absolute phase) control

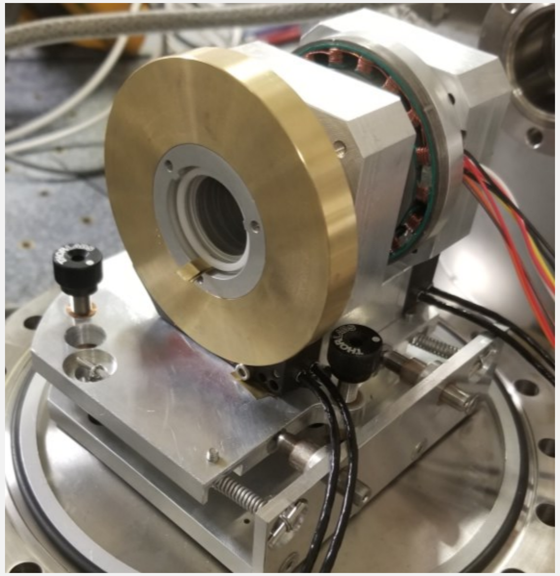
- relative rotation rms noise between the two HWPs was improved by a factor ≥ 10

NEW

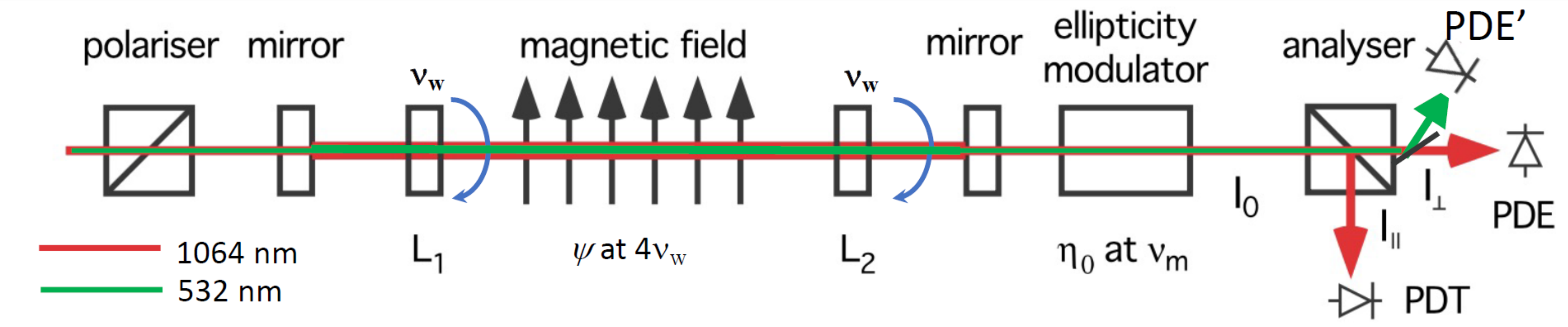




OLD



GREEN



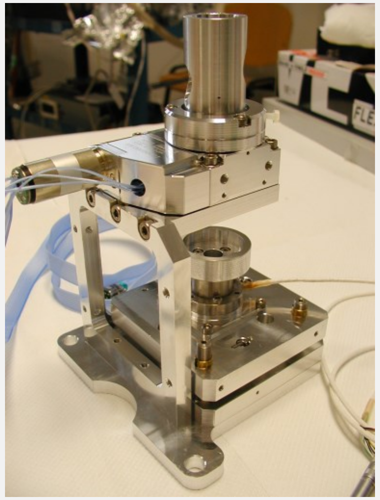
Auxiliary laser beam @ 532 nm (HWP -> FWP) allows real-time control of the systematics due to the rotating HWPs

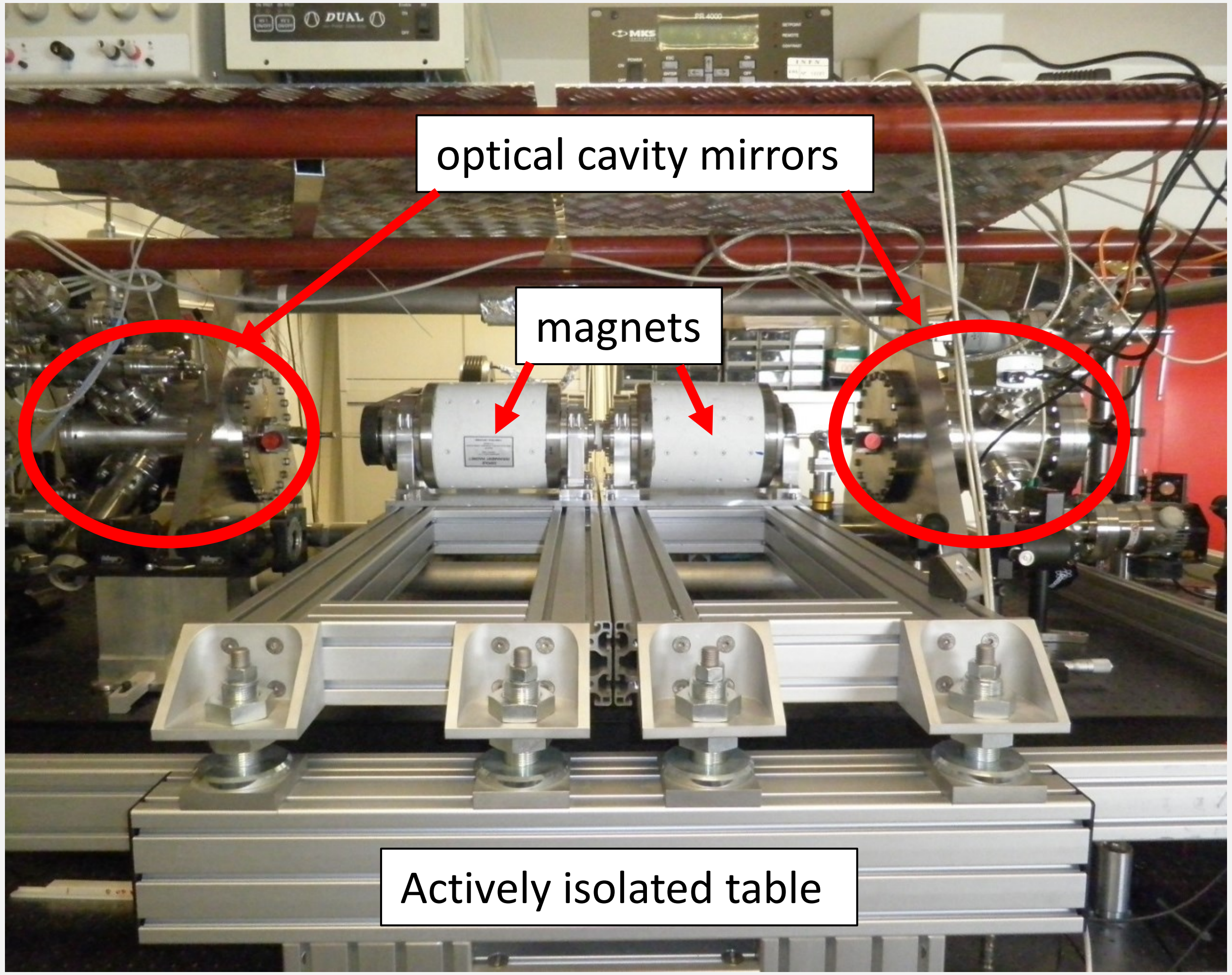
- Further reduction of harmonics → Demonstrated locking (noisy) of the cavity with the rotating HWPs

DWS TEST SETUP

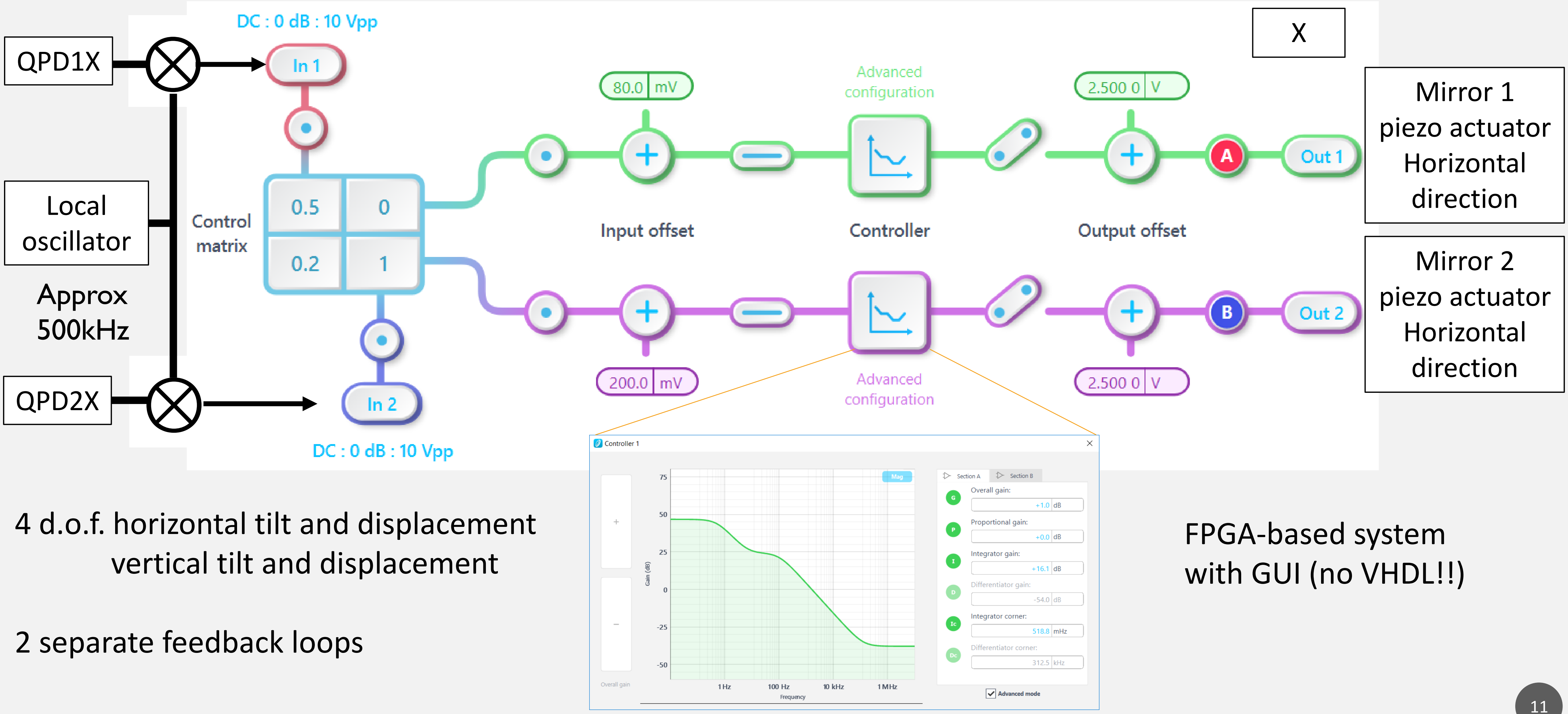
Polarimeter with Differential Wavefront Sensing

- 1.4 m Fabry-Perot optical cavity F = 3000
- Quadrant photodiodes to generate error signals for the alignment
- Vacuum-compatible actuators to move the cavity and beam injection optics





ALIGNMENT FEEDBACK



4 d.o.f. horizontal tilt and displacement
vertical tilt and displacement

2 separate feedback loops

FPGA-based system with GUI (no VHDL!!)

- <u>Molecular beams for electron EDM search</u>

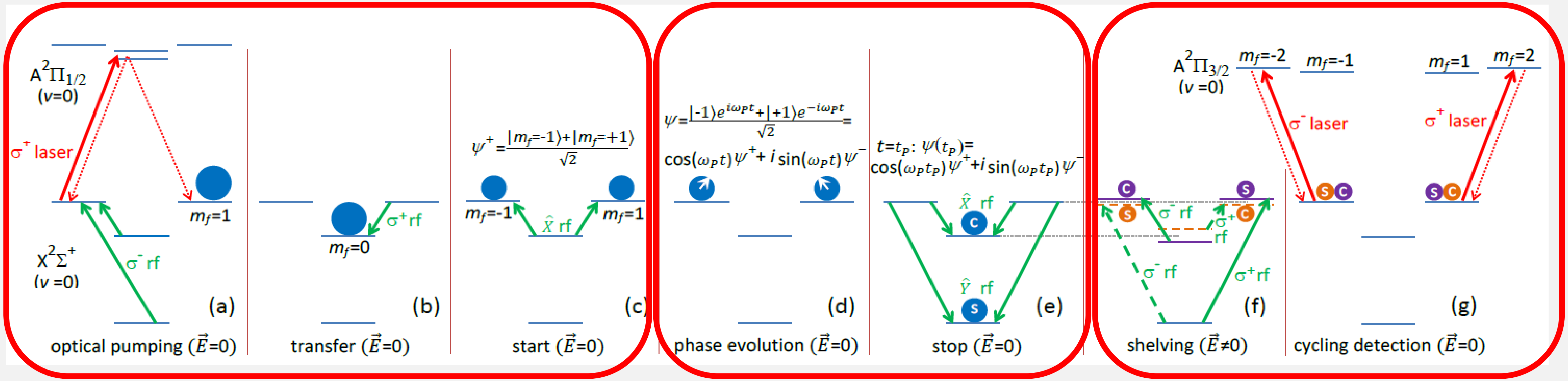
$^{138}Ba^{19}F$ molecules in a solid parahydrogen matrix (N ≈ 10^{13} BaF molecules / cm^3)

$$\phi = (g\mu_B B \pm d_e E_{eff})T/\hbar$$

PRECESSION ANGLE

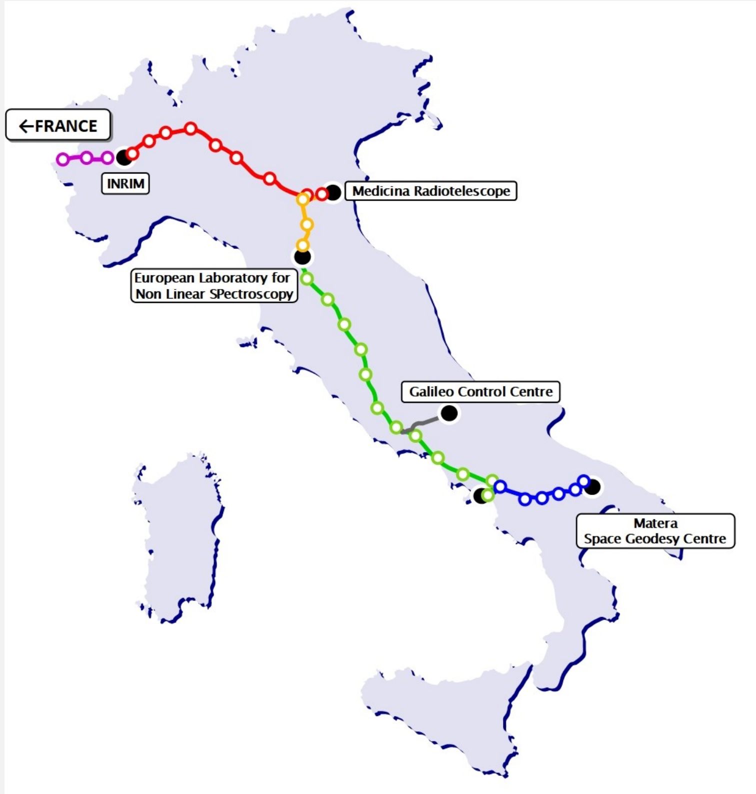
E_{eff} = effective electric field inside the molecule
T = electron spin precession time

EDM measurement using laser-induced fluorescence spectroscopy [A. Vutha et al., PRA 98, 032513 (2018)]



STATE PREPARATION EVOLUTION MEASUREMENT

SECONDMENT INO (II)

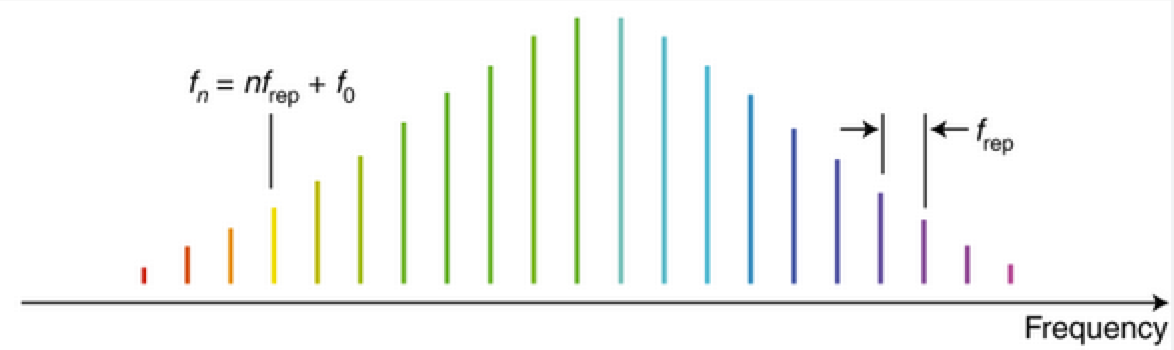


- Optical frequency standards

A 642 km-long fiber link from INRIM (Turin) delivers to LENS (Florence) a 1542-nm ultrastable laser beam locked to a hydrogen maser.
The hydrogen maser is periodically compared with a cryogenic Cs fountain (primary frequency standard at INRIM).

Stability ≈ 3×10^{-15} @ 1 s

An optical frequency comb transfers the stability and accuracy of the near-IR reference to other wavelength domains.



APPLICATIONS:
High precision molecular spectroscopy
Fundamental Physics research

CONCLUSIONS

ACTIVITY HIGHLIGHTS:

1. Built a test polarimeter equipped with Differential Wavefront Sensing
2. Improved rotating waveplate mechanics
3. New approach (workaround): modulation of magnetic field
4. Realtime sensing of waveplate systematics
5. Demonstrated locking (noisy) of the cavity with the rotating HWPs

CLOSING REMARKS ON MY FELLOWSHIP

- Managing funds independently was a great career "achievement".
- Secondment ~~gave me the chance~~ to explore new research topics.
  "forced" me to find time