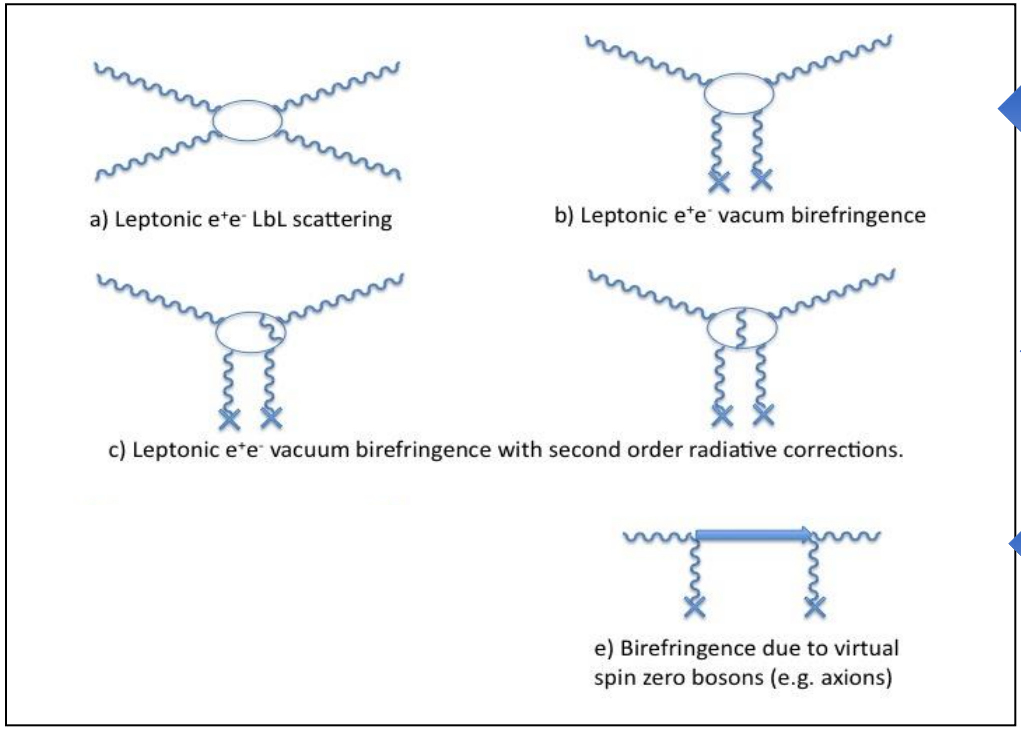
VMB@CERN - Sezioni: FE, PI, LNL

Experimental study of the speed of light in an external field.



Light-by-light interaction and vacuum magnetic birefringence.

Must be there: $\Delta n = 4X10^{-24}\ B^2$ con B in Tesla.

Includes MCPs

Radiative correction 1.45%

Contribution from hypothetical neutral light particles coupling to two photons: ALPs

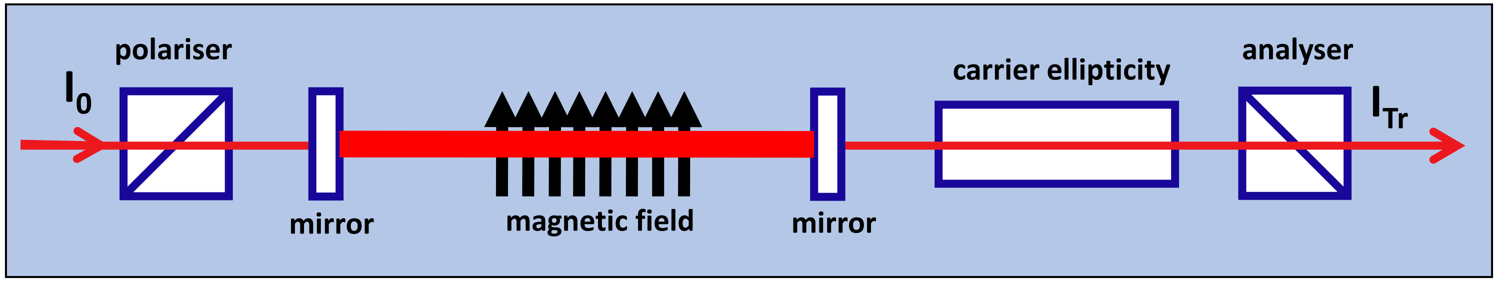
Euler-Kockel-Heisenberg Lagrangian predictes VMB

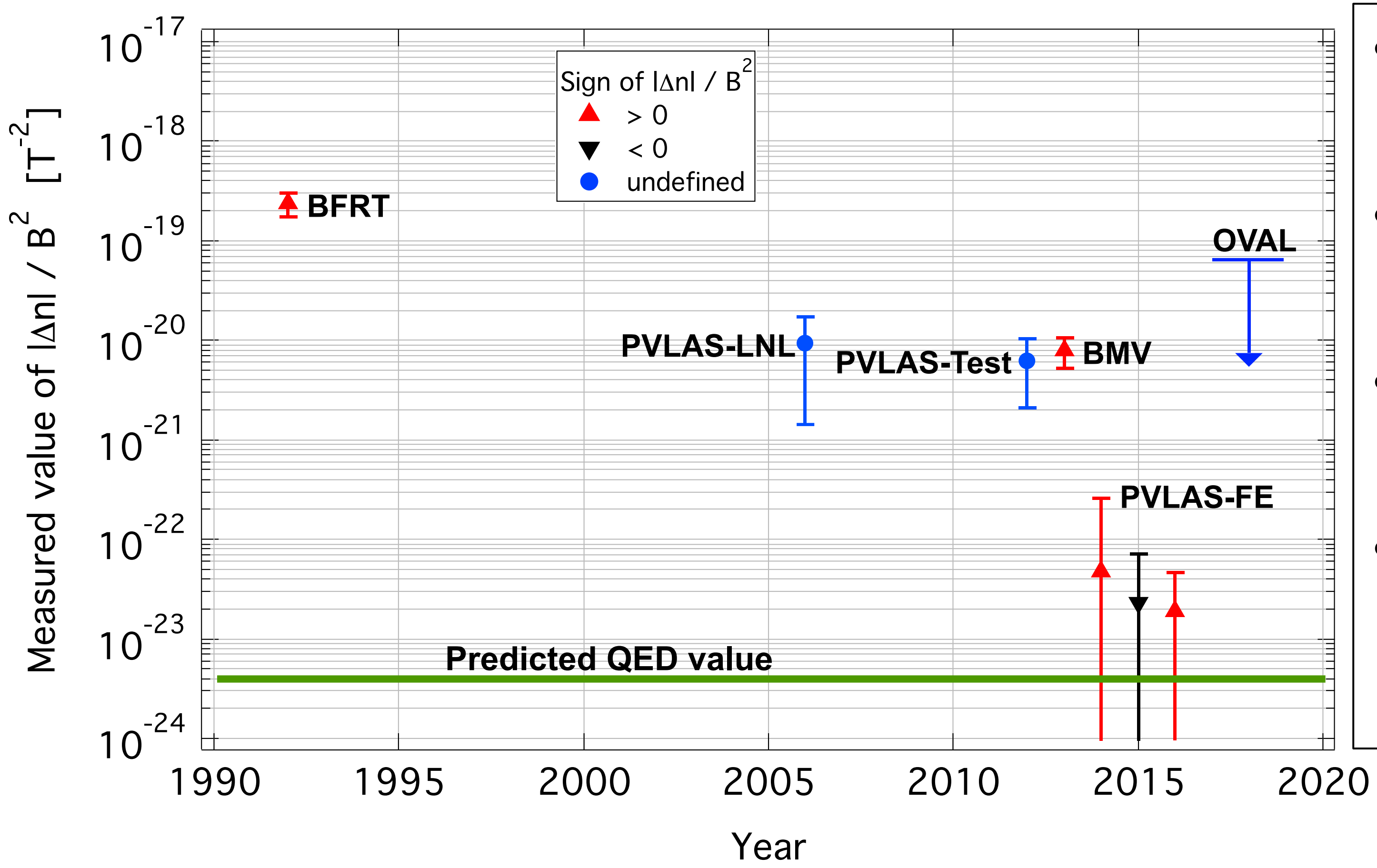
$$\mathcal{L}_{\rm EK} = \frac{1}{2\mu_0}\left(\frac{E^2}{c^2} - B^2\right) + \frac{A_e}{\mu_0}\left[1\left(\frac{E^2}{c^2} - B^2\right)^2 + 7\left(\frac{\vec{E}}{c}\cdot\vec{B}\right)^2\right] + \ldots$$

$$A_e = \frac{2}{45\mu_0}\frac{\alpha^2 \lambda\!\!\!^{-}{}_e^3}{m_e c^2} = 1.32\times 10^{-24}\ \mathrm{T}^{-2}$$

$$\Delta n = 3 A_e B_{\rm ext}^2$$

Results of PVLAS in Ferrara





- Permanent magnets allowed careful debugging of systematics.
- Intrinsic thermal noise from the mirrors limited the sensitivity
- Optical path difference sensitivity: ΔD = $4 \cdot 10^{-19}$ m/√Hz
- The PVLAS - Ferrara result remains the most sensitive measurement yet performed.

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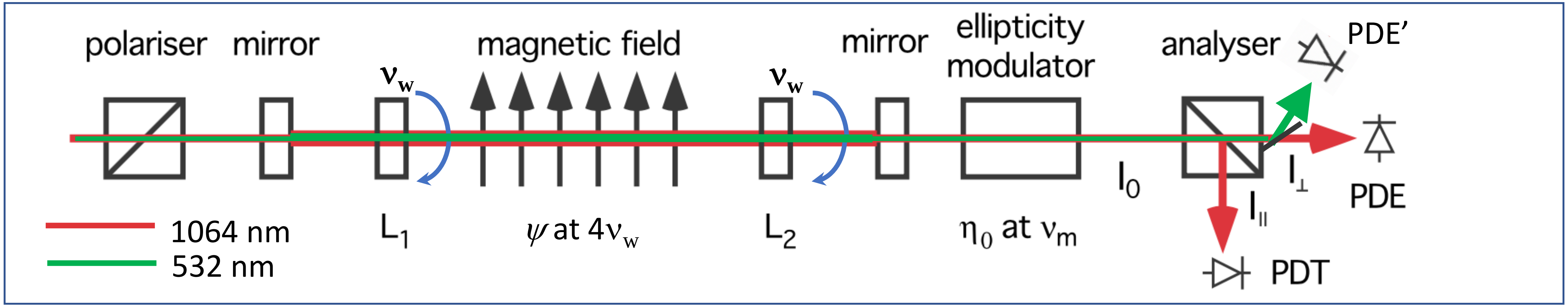
Scheme for VMB@CERN: two co-rotating half-wave plates *inside* the F.P.



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

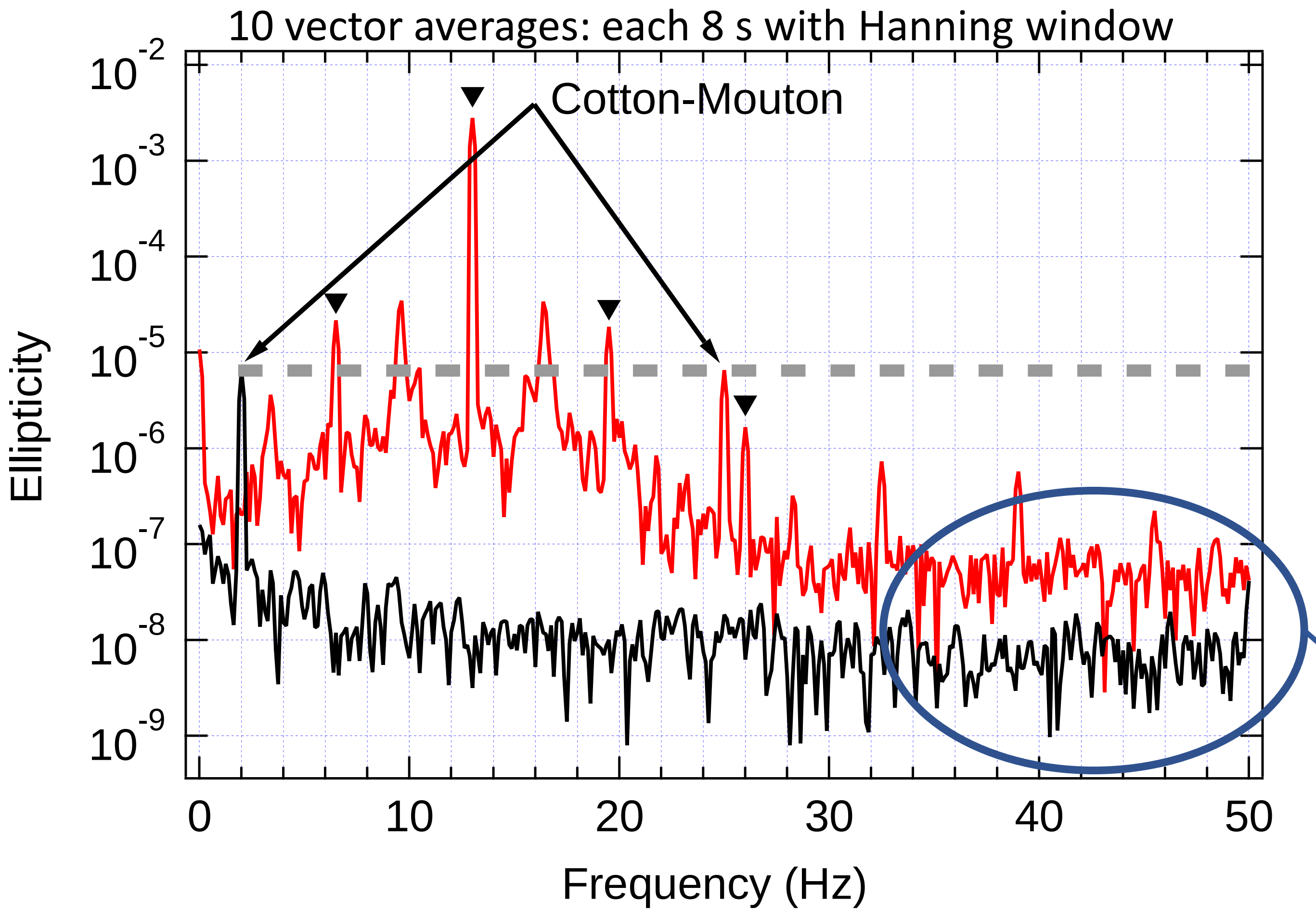
$\alpha_{1,2}$ are the phase errors from π of the two HWPs and $\phi(t)$ is their rotation angle

- Allows the use of (quasi) static superconducting fields ≈ 9 T
- Demonstrated shot-noise sensitivity N ≈ 1000 with two NON rotating commercial HWPs inside the Fabry-Perot
- Demonstrated stable locking of the laser to the F.P. with the rotating HWPs @ 2.0 Hz with no active HWP control.
- Resonant 1064 nm beam carries the VMB signal
- Non resonant 532 nm beam (HWP -> FWP) allows independent positioning/orientation of the rotating wave plates
- Modulate (≈ mHz) the LHC magnetic field to separate the unavoidable 4th harmonic generated by the rotating HWPs
- Improve sensitivity by actively controlling alignment of HWPs to minimize $N\alpha_{1,2}$. To be implemented.
- The LHC dipoles at CERN continue to be the best present opportunity to maximize B^2L

Two co-rotating HWPs (no F.P.): Cotton-Mouton effect of air

Comparison of ellipticity spectra in air in two cases:

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



The signal 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.

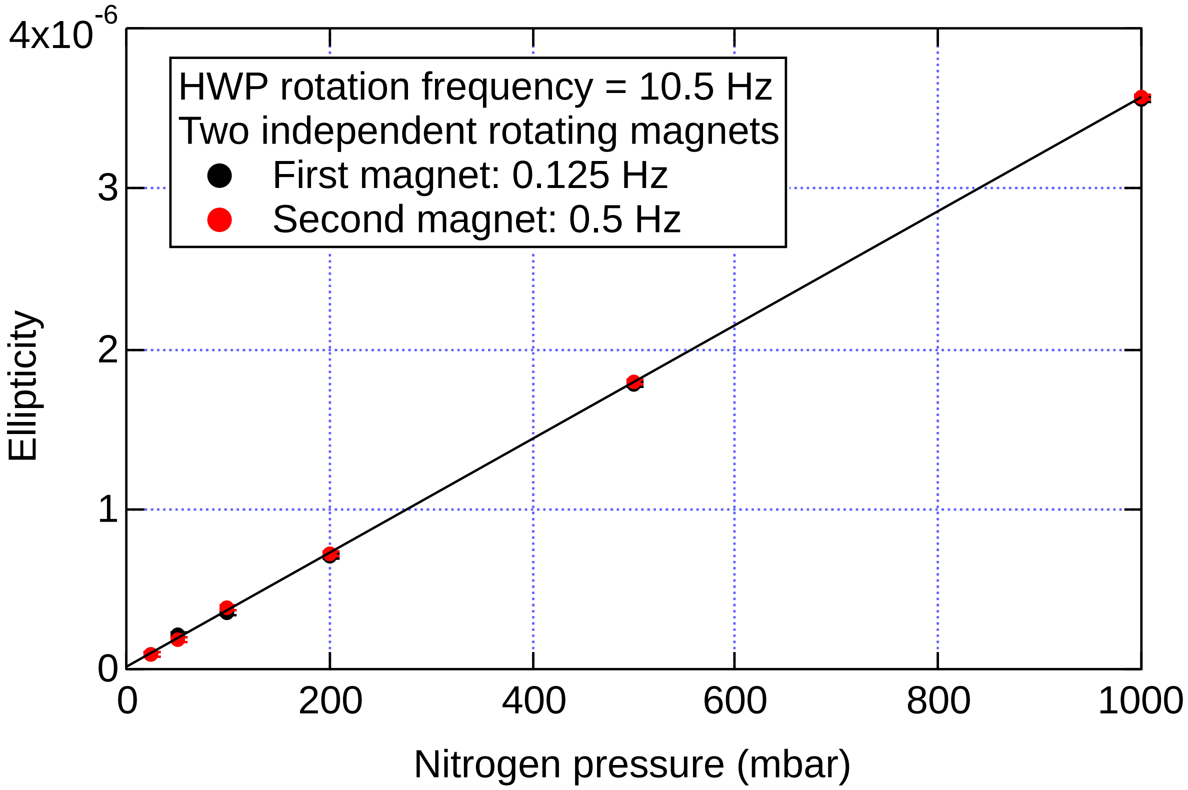
Magnetic field must be modulated:

- How narrow is the systematic signal at 26 Hz?
- How fast can the LHC dipole be ramped?

The difference in noise is due to the degraded extinction caused by the rotating HWPs.

Cotton-Mouton effect in Nitrogen gas @ 1064 nm (no F.P.)

Polarimeter was put in vacuum and pure N_2 gas was injected



- Most precise measurement of the Cotton-Mouton effect in N_2 gas.
- The scheme with two co-rotating HWPs + slowly modulated field works

Cotton-Mouton unitary birefringence

$$\Delta n_u^{(1064\ \mathrm{nm})} = (2.380 \pm 0.007^{(\mathrm{stat})} \pm 0.024^{(\mathrm{sys})}) \times 10^{-13}\ \mathrm{T}^{-2}\mathrm{atm}^{-1}$$

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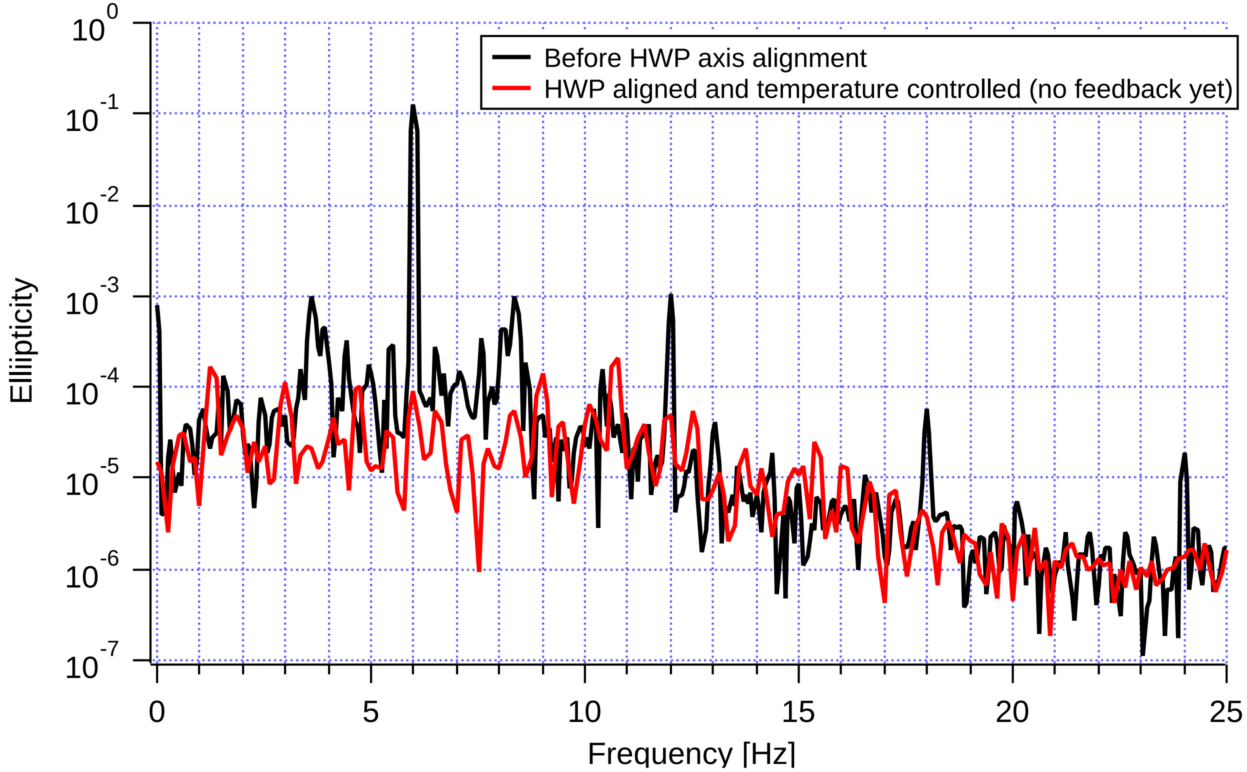
Temperature control of HWPs

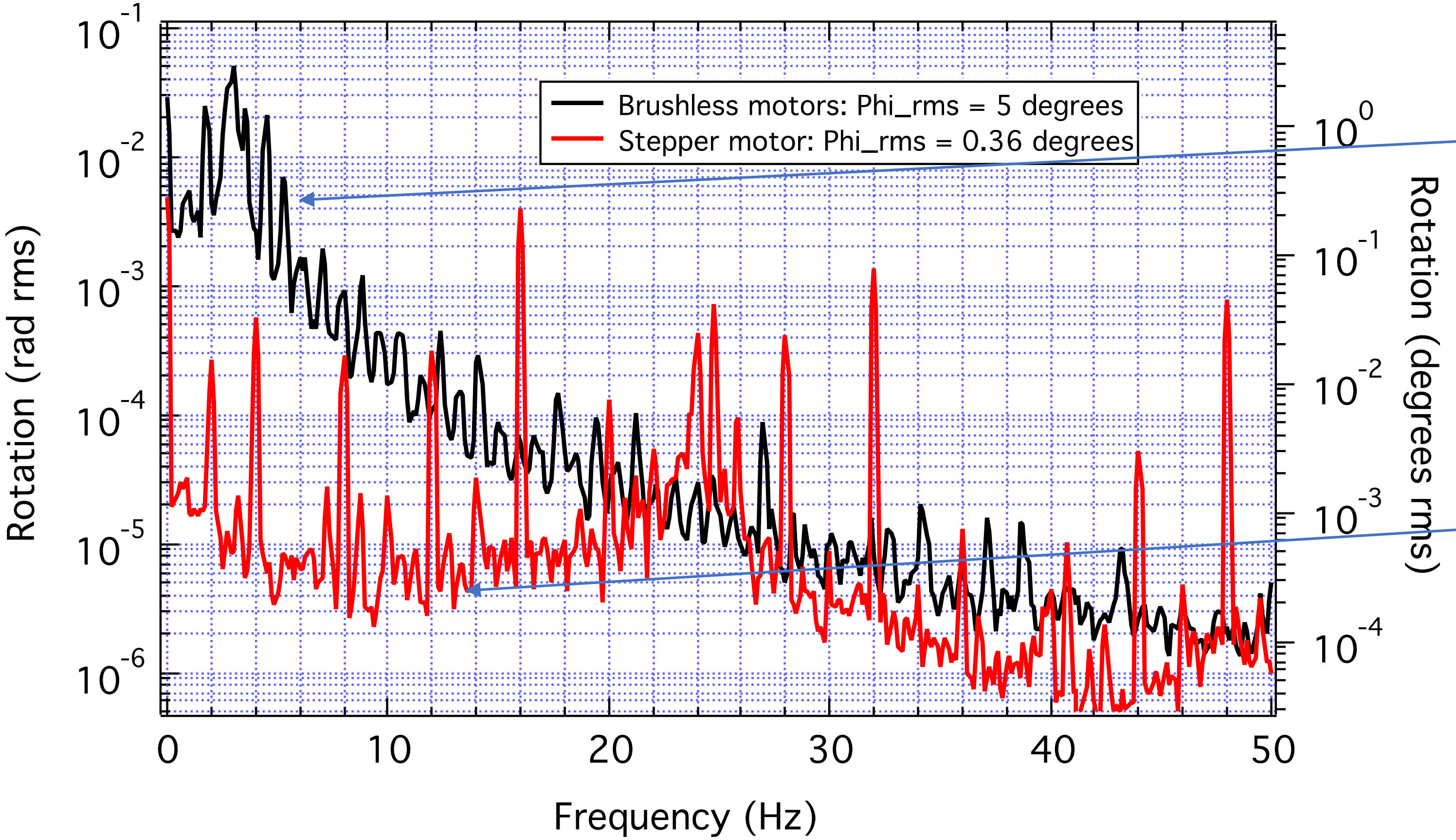
- Installed ring heaters in front of the two HWPs
- There are conditions for the temperature of the two HWPs for which the large ellipticity peak due to $\alpha^{(0)}{}_{1,2}$ can be reduced by more than a factor 1000.
- Depends on the HWP relative orientation to minimise $\alpha^{(0)}{}_2 - \alpha^{(0)}{}_1$ and on temperature
- To reach $N\alpha^{(0)}_{\text{tot}} \ll 1$ with $N \approx 1000$ we need $\alpha^{(0)}_{\text{tot}} \ll 10^{-3}$

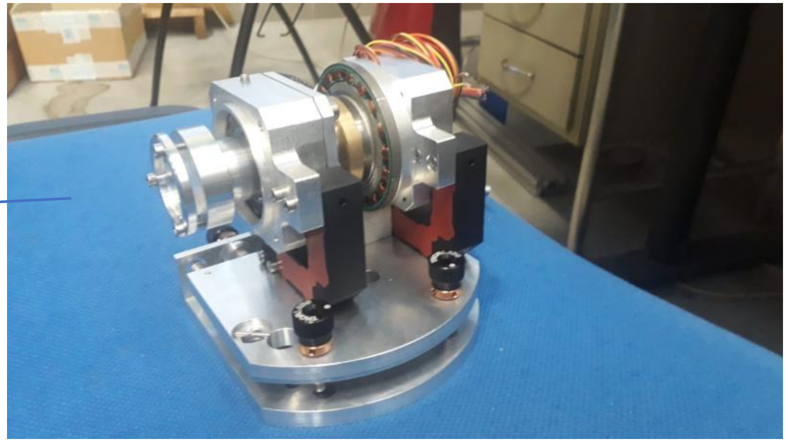


- Successfully controlled the temperature of the HWPs to reduce the dominant peak.
- No feedback but the condition remained stable for several hours
- Temperatures must be well defined before installing the F.P.
- A feedback will be implemented
- More accurate stepper motors are also being implemented

Relative phase error: brushless vs. stepper motors

Synchronised rotation of two HWPs.



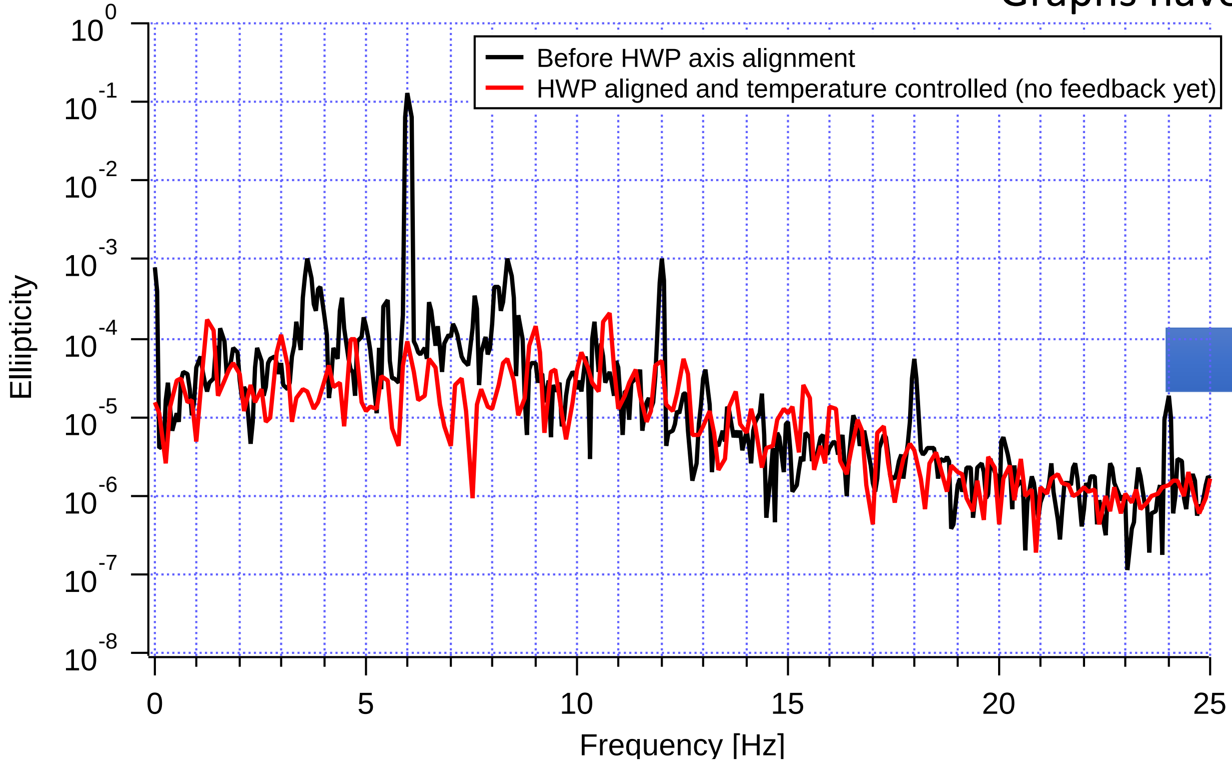


Extinction ratio with stepper motors (no cavity): $\sigma^2 \approx 5 \cdot 10^{-6}$. Good.

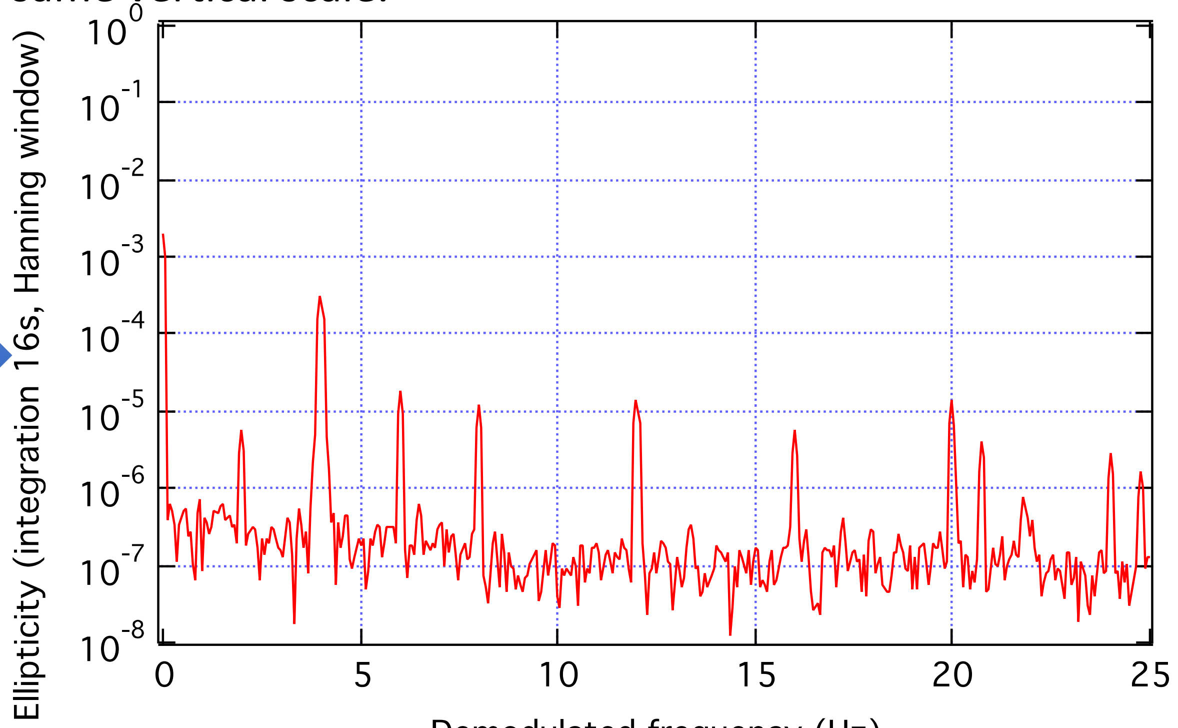
Sensitivity: brushless vs. stepper motors

- Preliminary adjustments of each wave plate with the 532 nm laser => reduced 1st, 3rd and 4th harmonics also a 1064 nm
- Temperature control of one of the rotating HWPs has reduced 2nd harmonic systematic peaks such that $N\alpha_{1,2} \ll 1$ with $N \approx 300$

Graphs have the same vertical scale.



BRUSHLESS MOTORS

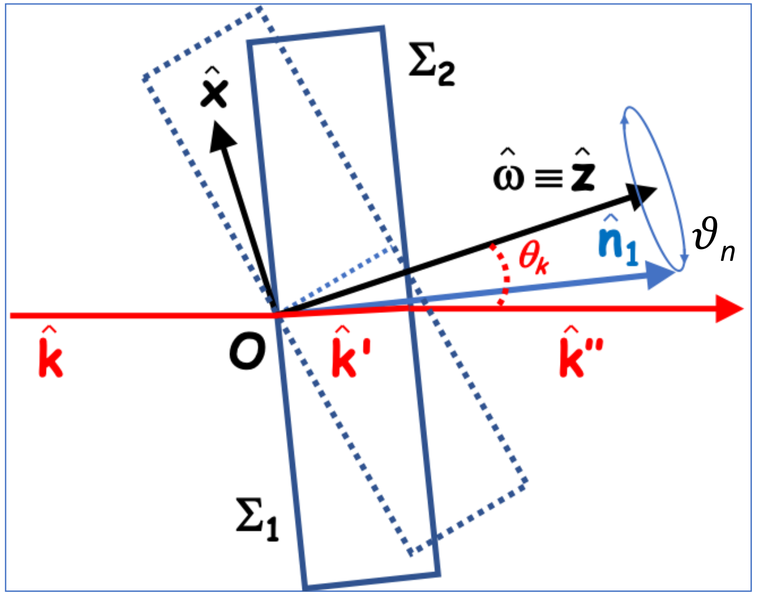


STEPPER MOTORS

Note the higher frequency with respect to the stepper motor

Wave-plate alignment issues

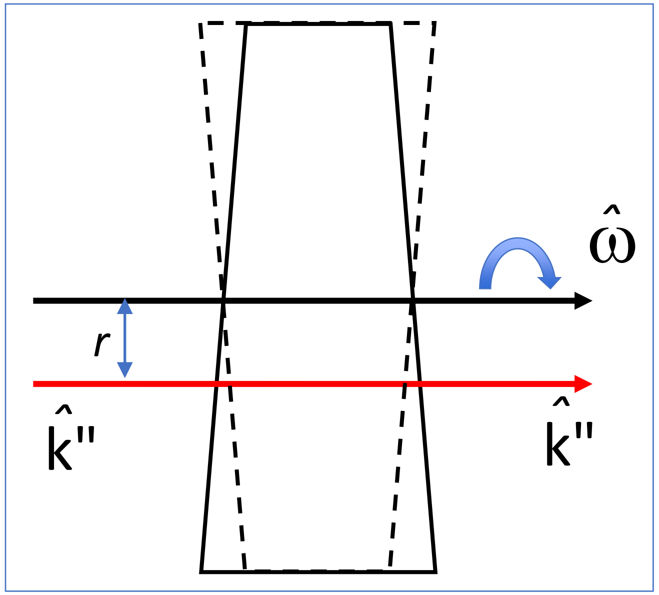
Temperature dependence of $\alpha^{(0)}_{1,2} = \frac{2\pi}{\lambda}(\Delta n D)(\mathrm{T})$



ALIGNMENT

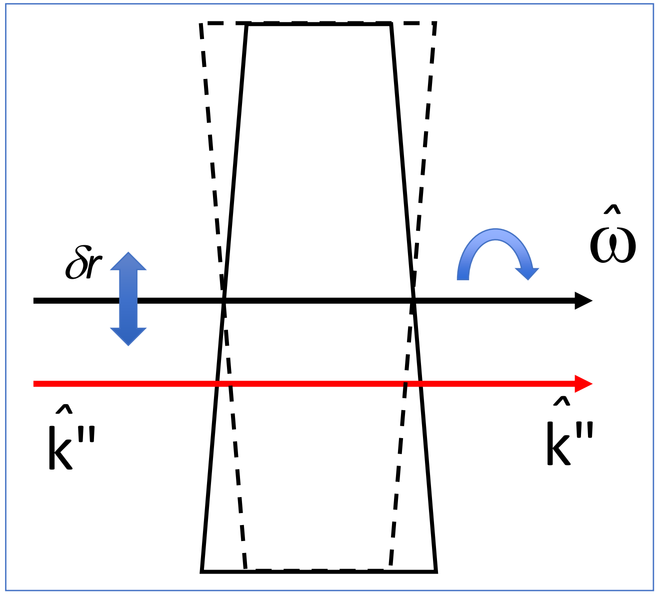
$$\alpha^{(1)}_{1,2} \approx \frac{2\pi}{\lambda}\Delta n \frac{D}{n^2}\vartheta_n\vartheta_k$$

$$\alpha^{(2)}_{1,2} \approx \frac{2\pi}{\lambda}\Delta n \frac{D}{4n^2}\vartheta_n^2\vartheta_k^2$$



WEDGE β

$$\alpha^{(1)}_{1,2} \approx \frac{2\pi}{\lambda}\Delta n \; r \; \beta$$

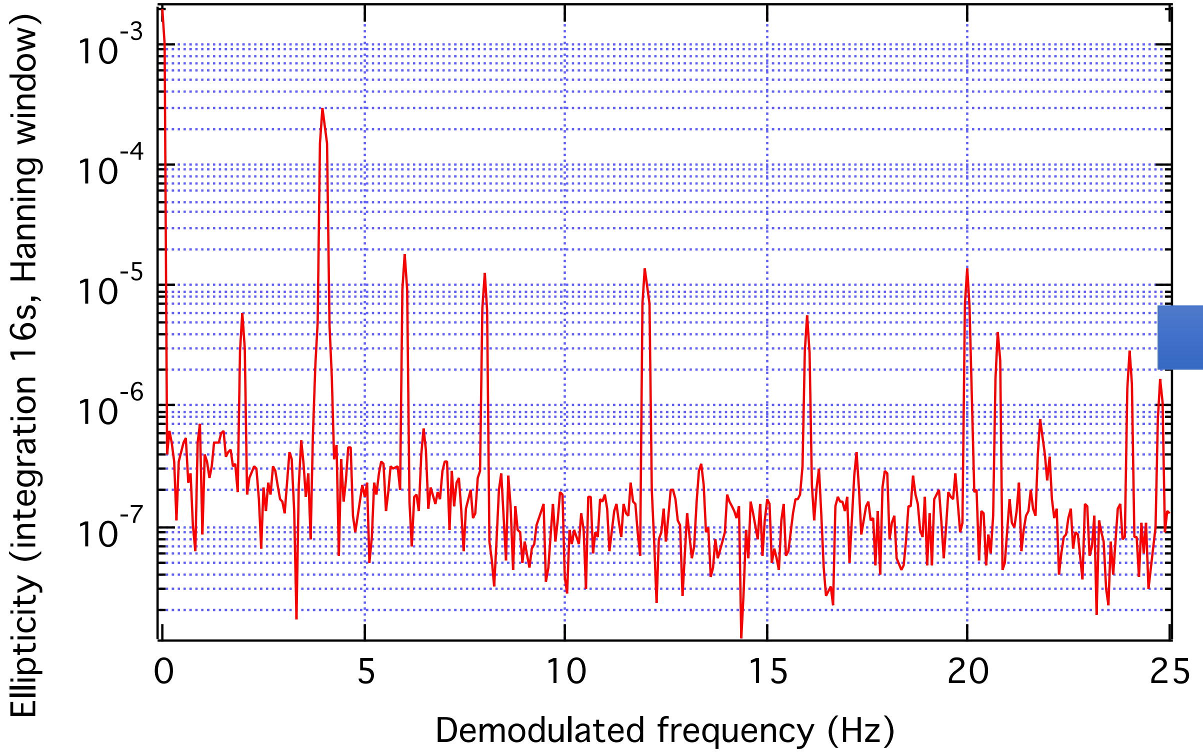


WEDGE + OSCILLATION @ ν_w

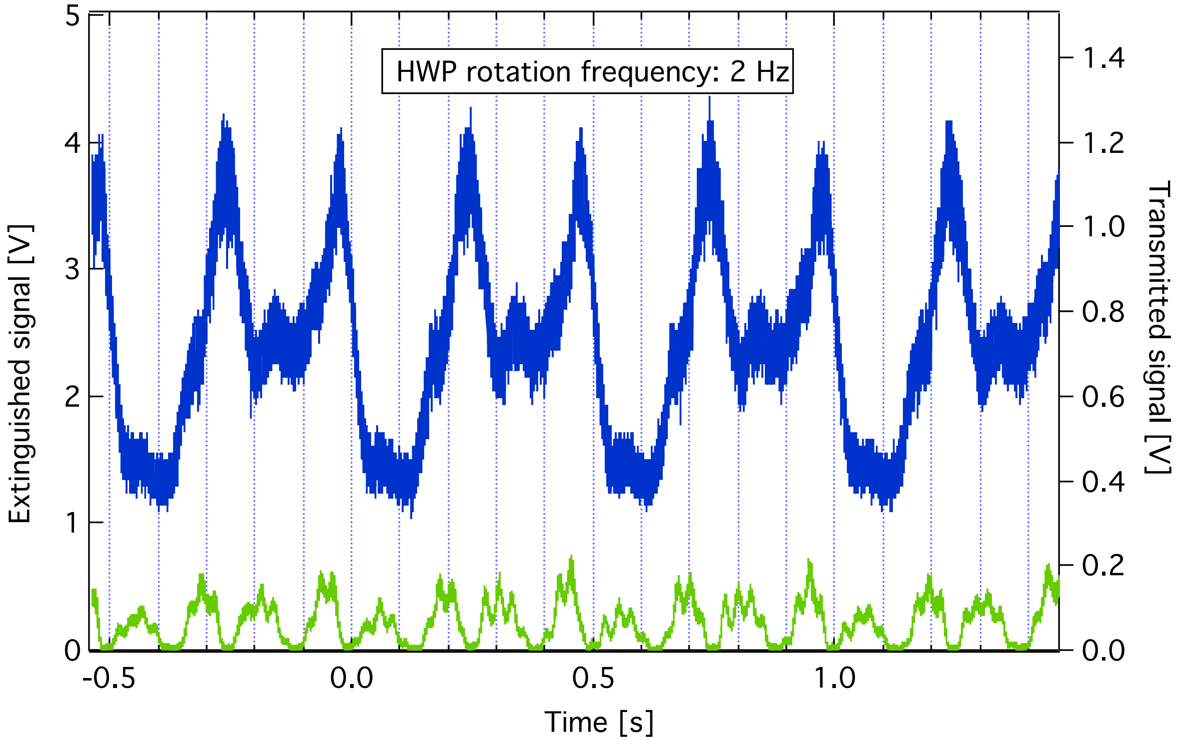
$$\alpha^{(2)}_{1,2} \approx \frac{2\pi}{\lambda}\Delta n \; \delta r \; \beta$$

Fabry-Perot: first stable laser-locking with rotating HWPs

Preliminary adjustments and temperature control of the rotating HWPs have reduced systematic peaks such that $N\alpha_{1,2} \ll 1$ with $N \approx 300$



First lock



Intensity modulation dominated by dust on the HWPs.
Apparatus was in air. No particular attention to cleanliness yet.

Lavori 2023

- 2022 è l'ultimo anno di R&D. Chiediamo l'approvazione dell'esperimento da fare al CERN
- Individuati due importanti sistematici dovuti alla rotazione delle due lamine mezz'onda. Trovato come mitigarli.
- Agganciato con successo la cavità con le due HWP all'interno
- Abbiamo sottomesso un Conceptual Design Report alla CSN 2 per fare l'esperimento al CERN.
- Entro 2022 verrà sottomesso il proposal al CERN. Reazione molto positiva dal comitato SPS del CERN.
- Nel periodo fine 2022 – 2023
  - Implementare un feedback sul posizionamento delle lamine in rotazione
  - Studiare la possibilità di ruotare a ≈ 10 Hz
  - Scrivere il proposal per l'SPS committee
  - Riprendere contatti con il CERN per iniziare gli studi sul magnete

Numeri 2022

<u>9 Ricercatori – 4.4 FTE</u>

Ferrara:	M. Andreotti	15%
	G. Di Domenico	40%
	G. Zavattini	60% Resp. Naz. (OK per regole CSNII)
	G. Messineo	0% (100% UE-Fellini)
LNL:	R. Pengo	0% (pensione)
	G. Ruoso	40%
Pisa (Siena):	F. Della Valle	100%
	C. Marinelli	40%
	E. Mariotti	45%

Richieste sia per il servizio elettronico che per il servizio di meccanica (realizzazione + progettazione) vedi presentazione Alessandro e Angelo

Numeri 2023

Richieste finanziarie per Ferrara

Missioni:

Viaggi verso Siena, LNL e CERN:	2 keuro + 10 keuro

Consumo:

Elementi ottici, consumo per vuoto:	10 keuro

Apparati:

Motori nuovi, elettronica feedback, laser 4.5 micron:	40 keuro

Totale per Ferrara: 62 keuro