Precision ellipsometry at PVLAS

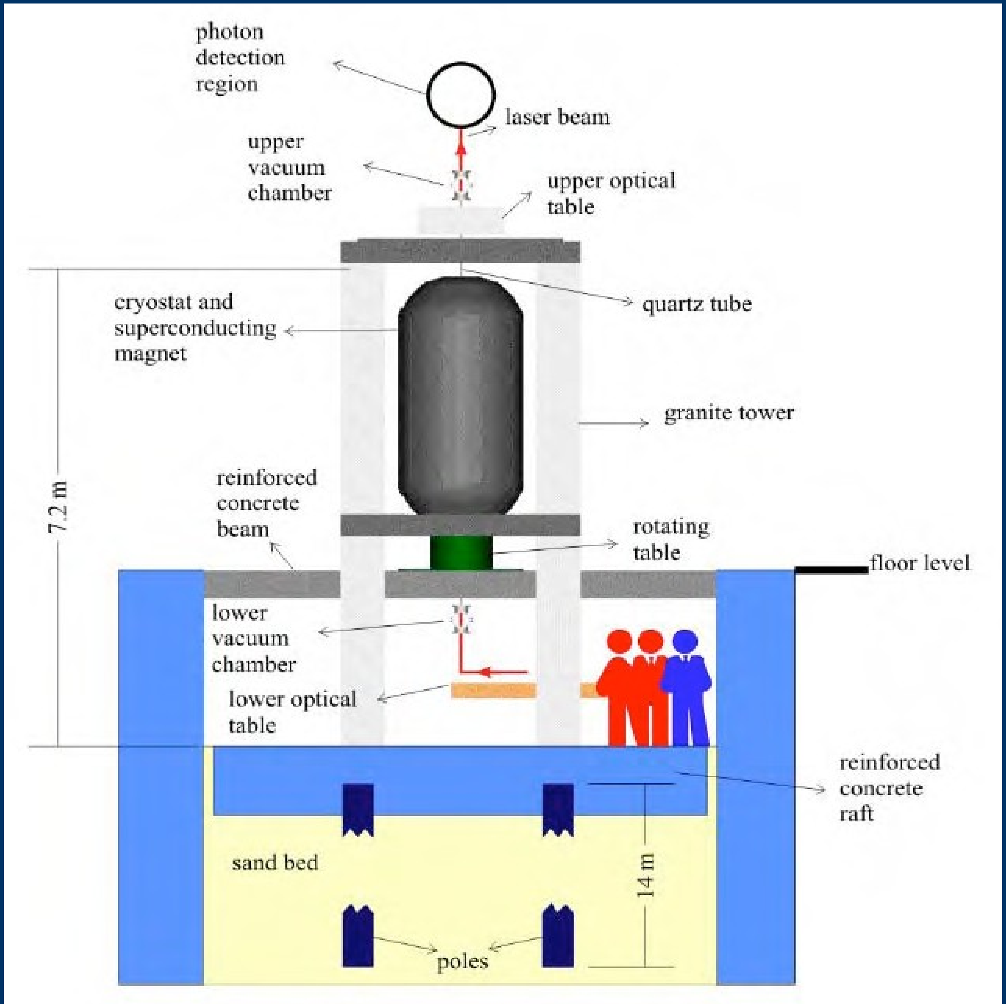
Marin Karuza
University of Trieste and INFN - Trieste

Outline

- Some photos
- An introduction to the ellipsometry
- Precision measurements results (magnetic birefringence in gases)

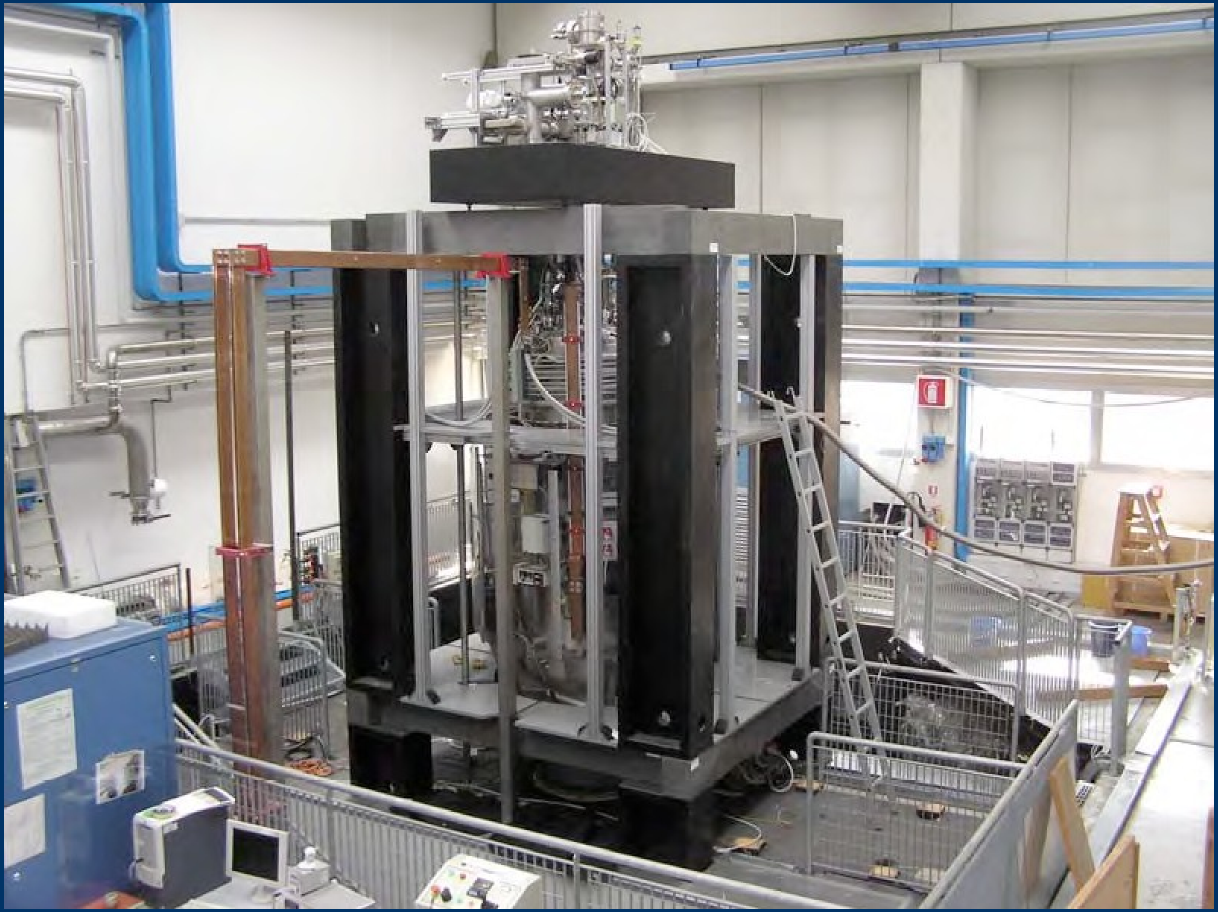
Polarizzazione del Vuoto con LASer

- Focused on a general study of the vacuum in the presence of a megnetic field
- Resonant FP cavity for large amplification factor (> 50 000)
- Large magnetic field (tested up to 7 T)
- Rotating cryostat allows high modulation frequency of the magnetic field (up to 0.5 Hz)
- Optical system mechanically decoupled from the surrounding and rotating systems



First view of the apparatus

- Legnaro site (Italy)



Complete apparatus

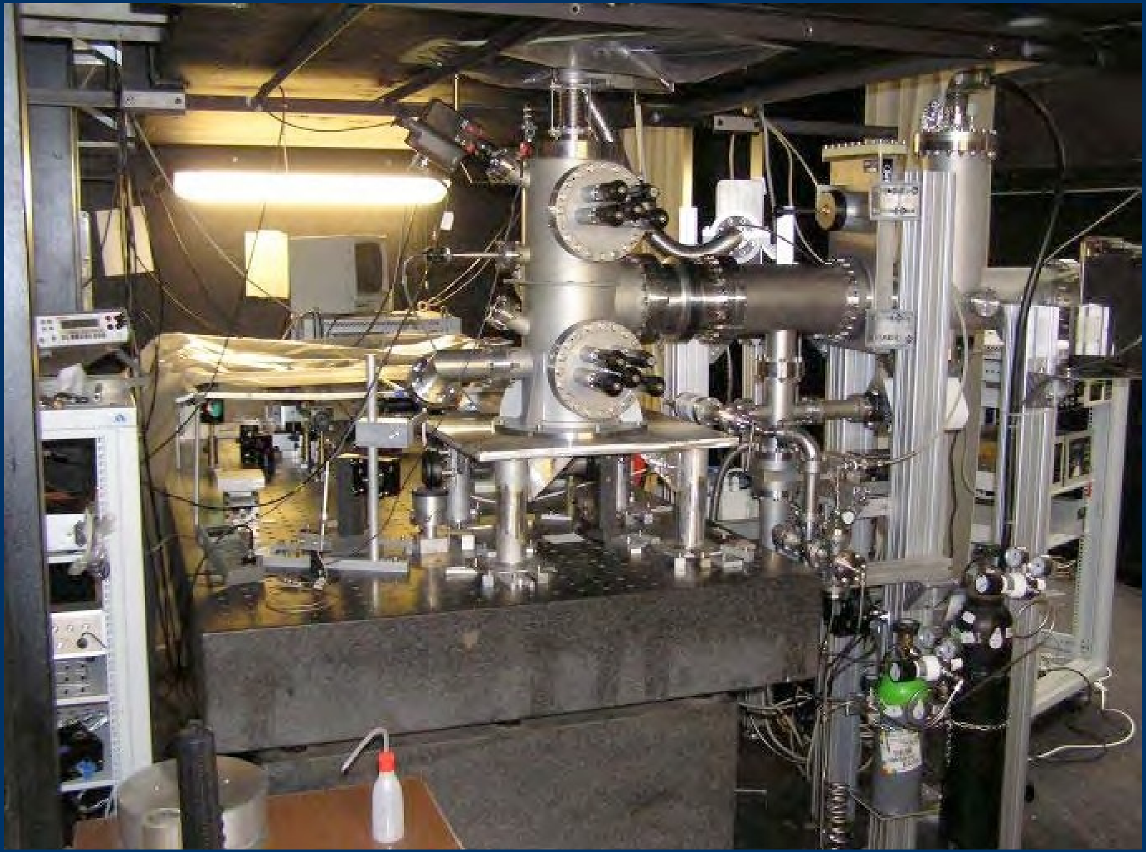
- Apparatus with aluminum access structure

The floor @ 360 degrees

- Control "room", apparatus, power supply

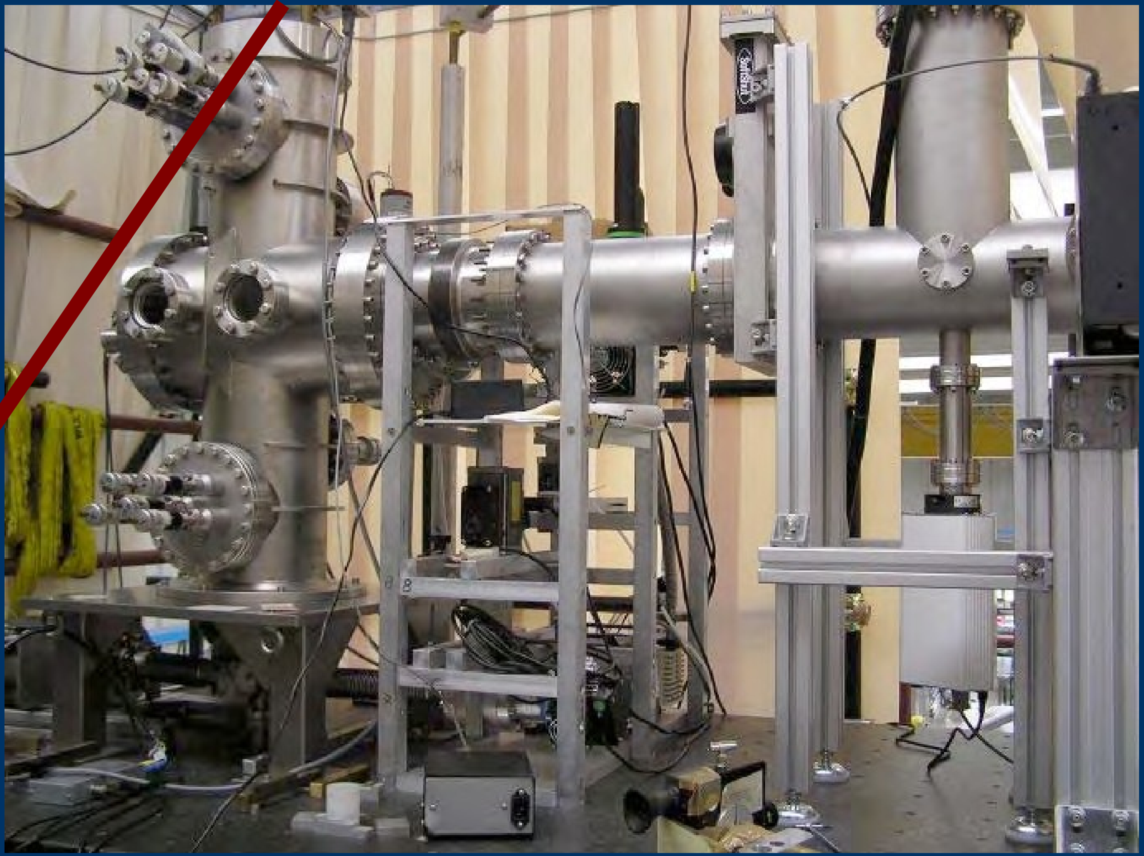
Lower optical bench

- Light preparation and injection in the cavity



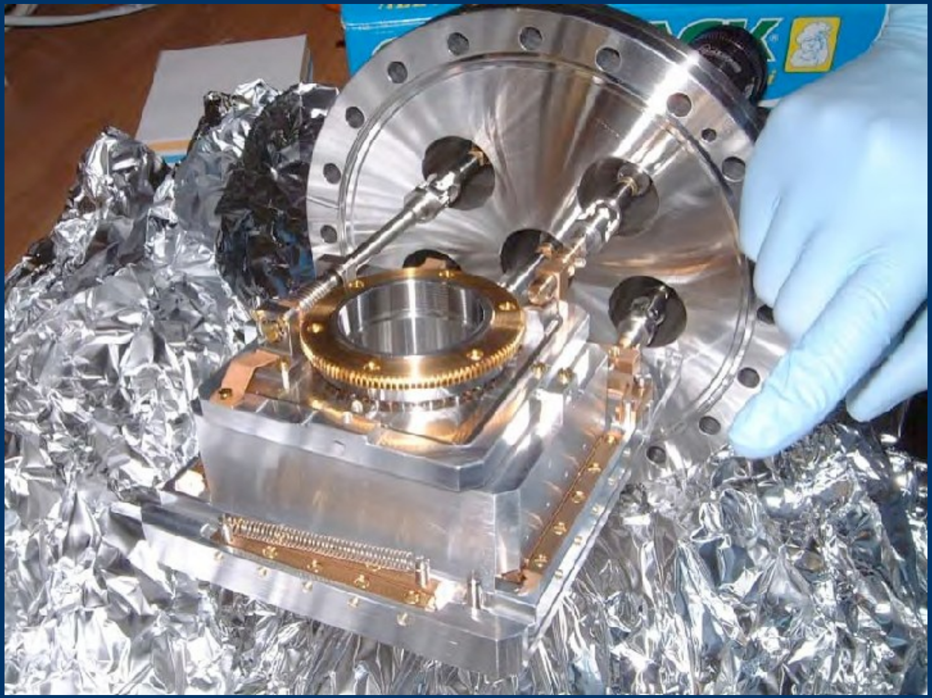
Upper optical bench

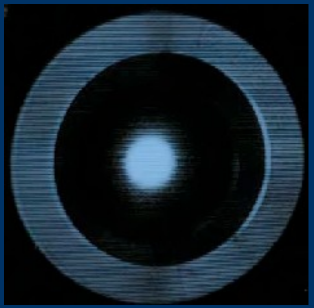
- Light detection and signal acquisition



Photos #1

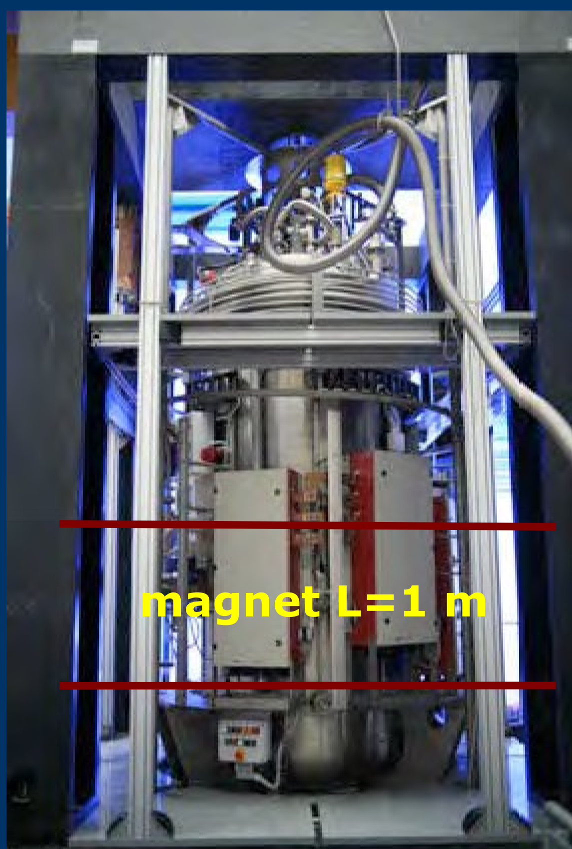
- Flange with mirror holder and mechanical feedthrough, test cavity and resonant modes

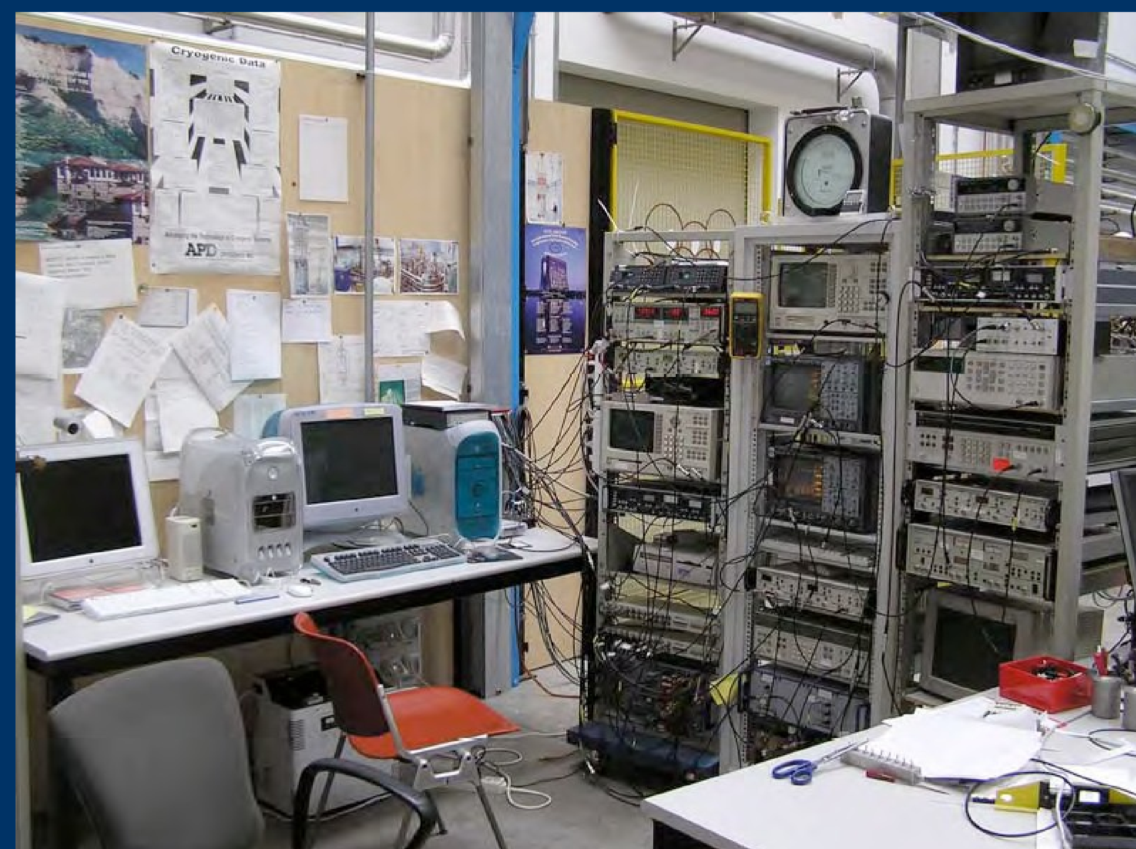




Photos #2

- Cryostat and control "room"



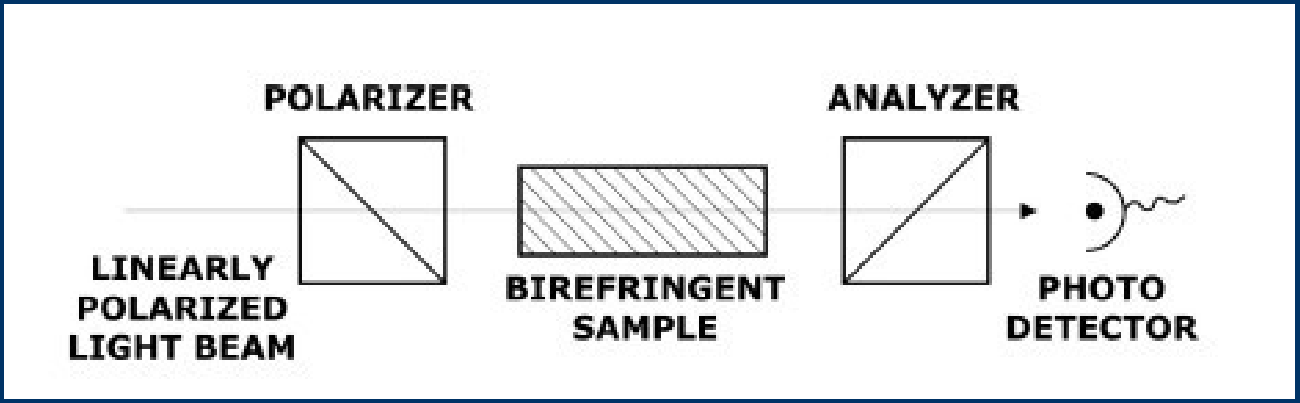


Measurement run procedure

- Preliminary operations
  - Precooling with LN2
  - Cooling and filling with LHe
- Measurement phase
  - LHe refill
  - Magnet energized
  - Closing coil circuit and connection removal
- Data acquisition
  - Photodiode current and control signals
  - Triggers used to reconstruct the absolute direction of the magnetic field
  - Fourier spectrum of the PD current at twice the rotation frequency - signal

Experimental apparatus

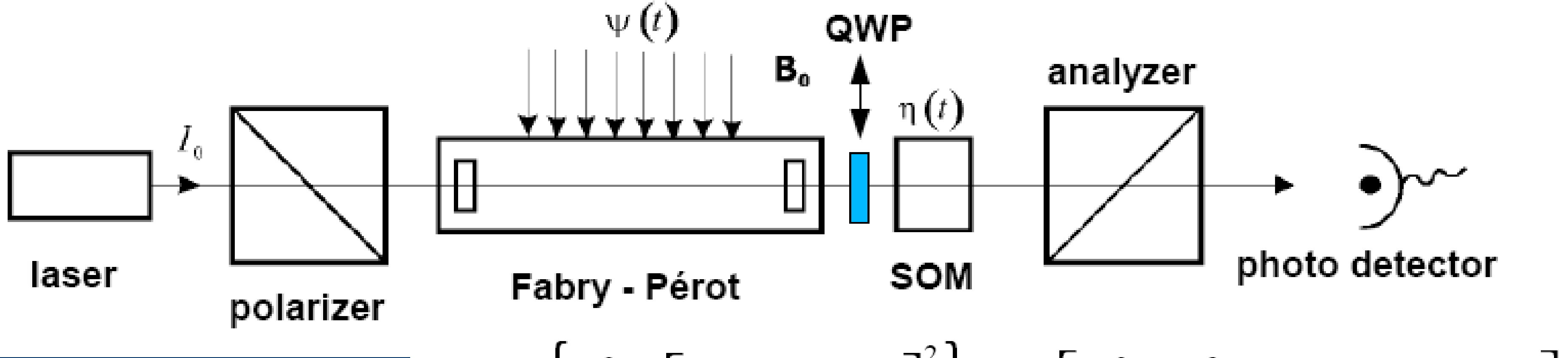
- Ellipsometer
- Measures changes in light polarization
  - Static detection impossible



$$I = I_0 (\sigma^2 + \psi^2)$$

Experimental apparatus

- High sensitivty heterodyne ellipsometer
- Measures changes in light polarization due to magneto-optical properties of the sample
- Signal dependence:
  - magnetic field intensity
  - path length in the magnetic field region
  - Angle between light polarization and field $2\Theta(t)$

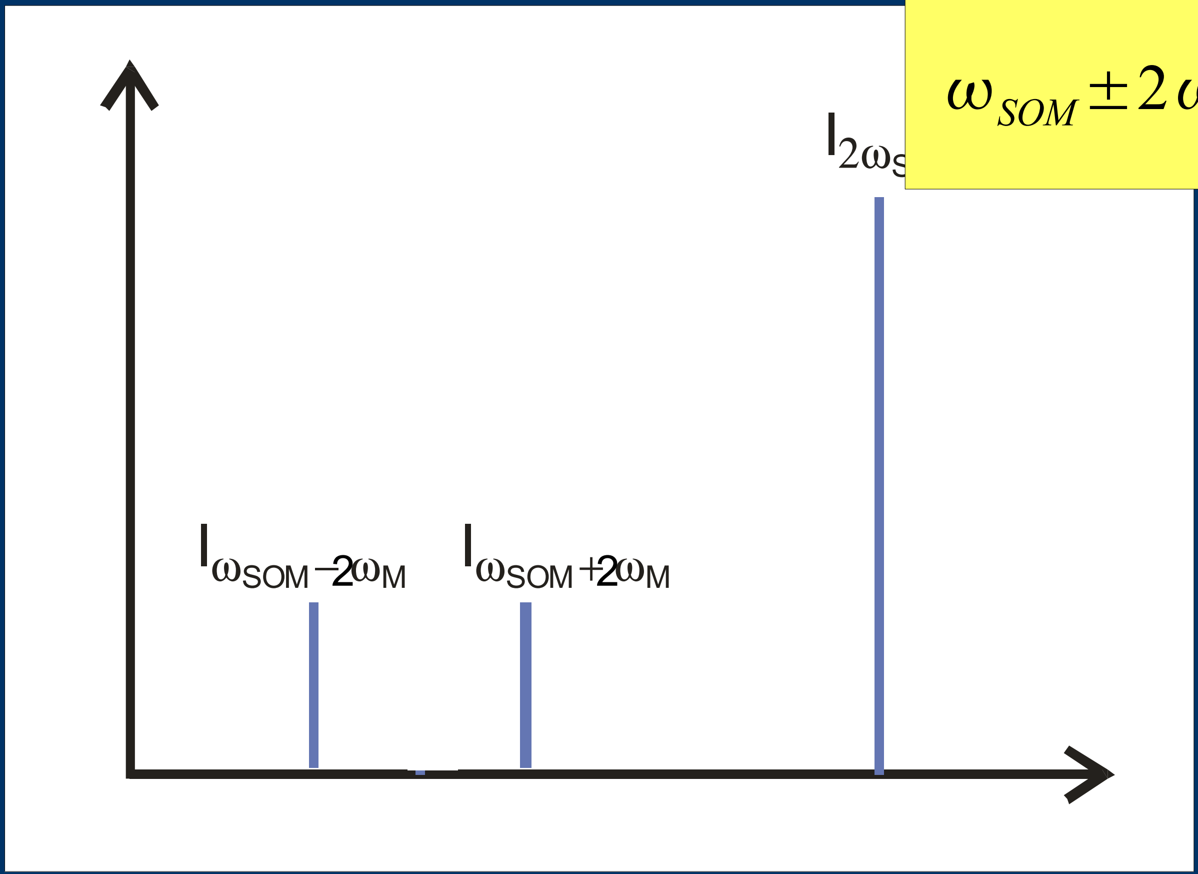


$$I = I_0\left\{\sigma^2 + \left[\psi(t)+\eta(t)\right]^2\right\} \simeq I_0\left[\sigma^2 + \eta^2(t) + 2\eta(t)\psi(t)\right]$$

Experimental apparatus

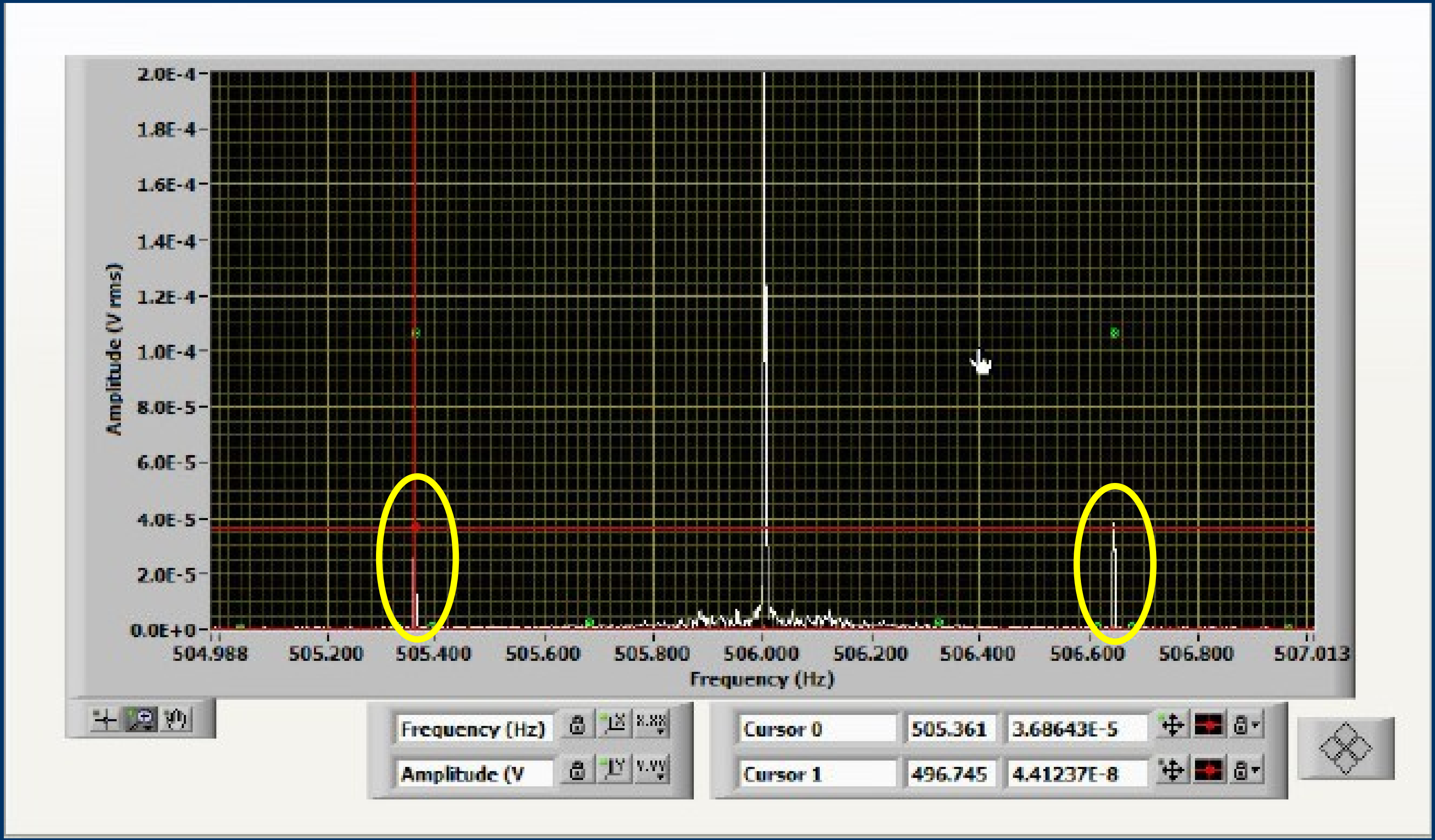
- Spectrum example and frequency components of interest

Frequency	Intensity/I_0	Phase
$2\omega_{SOM}$	η_0^2	$2\theta_{SOM}$
$\omega_{SOM} \pm 2\omega_{MAG}$	$\eta\psi\frac{2F}{\pi}$	$\theta_{SOM} \pm 2\theta_{MAG}$

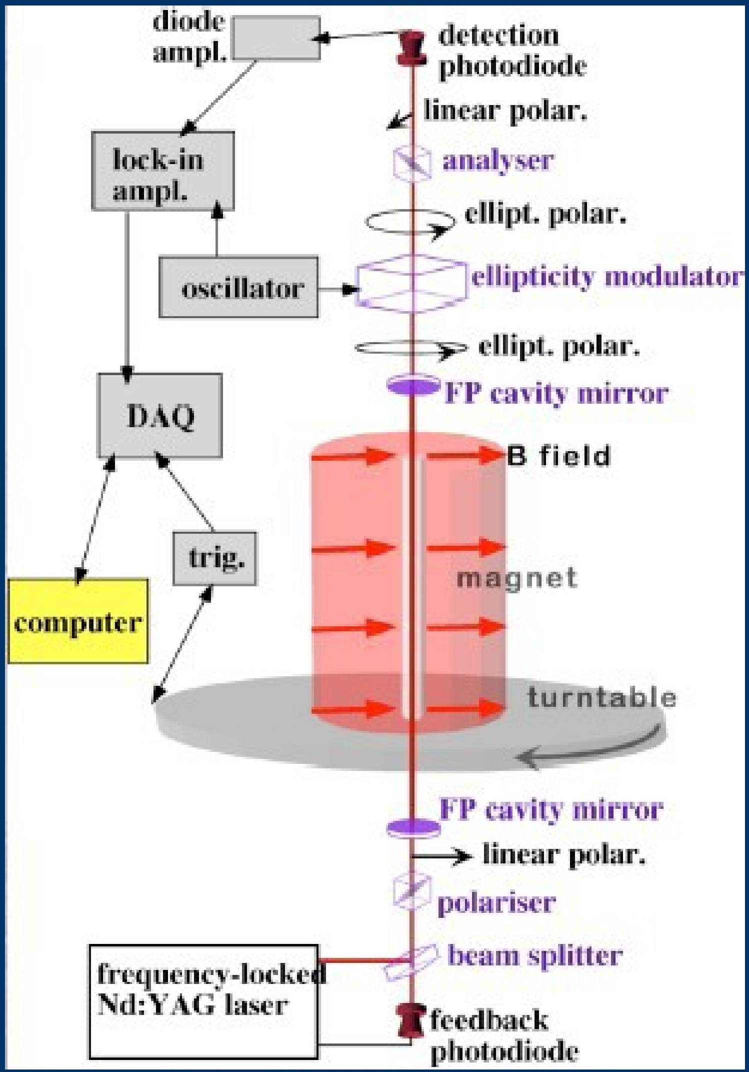


Precision ellipsometry

- Cotton – Mouton effect in He gas



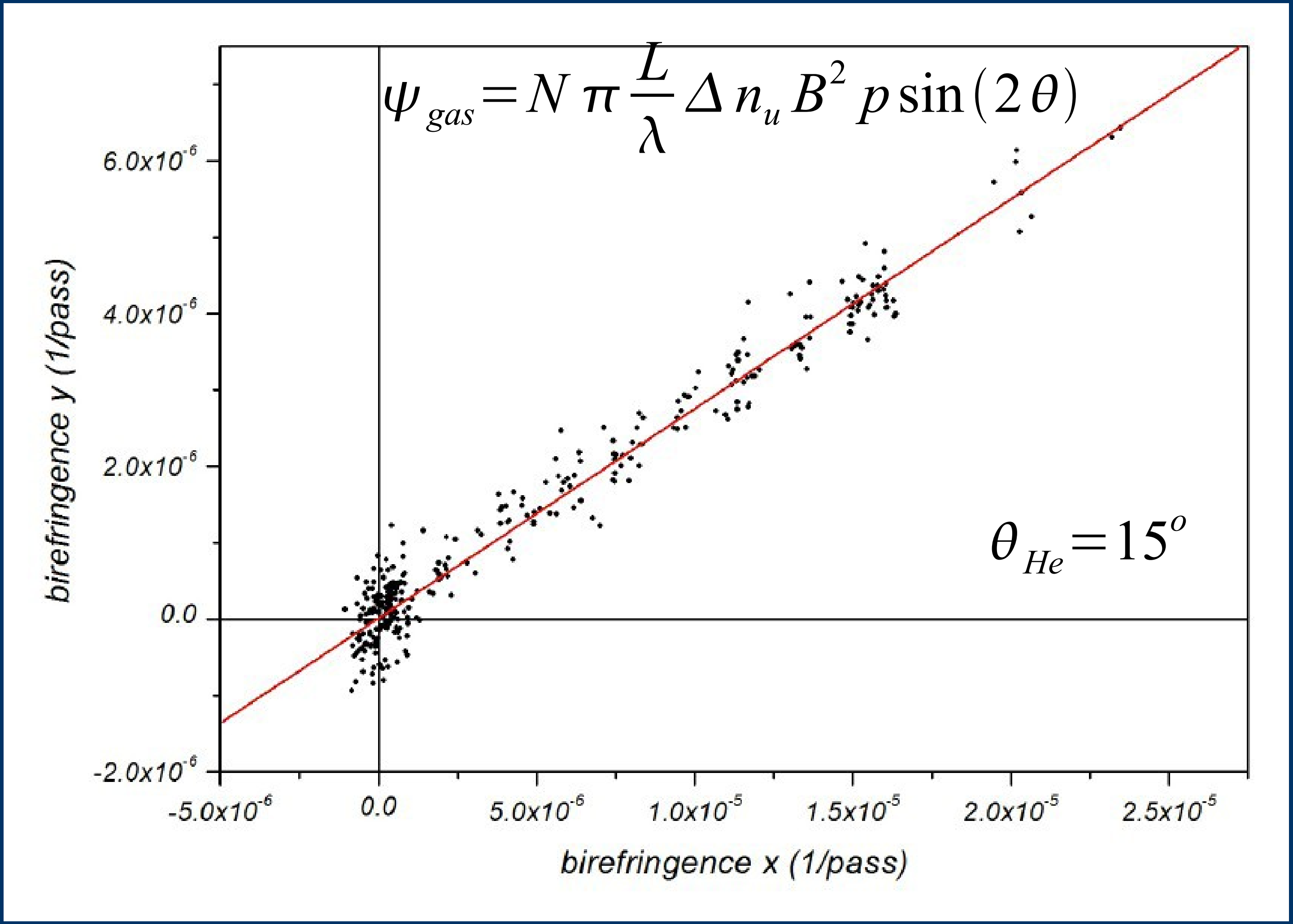
Experimental apparatus - scheme



- Main parameters of the apparatus
- *Magnet*
  - dipole, 6 T, temp. 4.2 K, 1 m field zone
- *Cryostat*
  - rotation frequency ~300 mHz, sliding contacts, warm bore to allow light propagation in the interaction zone
- *Laser*
  - 1064/532 nm, frequency-locked to the F.-P.
- *Cavity*
  - Fabry-Perot optical cavity
  - 6.4 m length, finesse ~100000, optical path in the
  - interaction region ~ 60 km
- *Heterodyne ellipsometer*
  - ellipticity modulator (Stress Optical Modulator – SOM) and high extinction (~10-7) crossed polarisers
  - time-modulation of the effect
- *Detection chain*
  - photodiode with low-noise amplifier
- *DAQ*
  - demodulated at low frequency and phase-locked to the magnetic field instantaneous direction
  - high sampling frequency direct acquisition

Precision ellipsometry

- Cotton – Mouton effect in He gas



Precision ellipsometry

- Cotton – Mouton effect in He gas
  - Stability of the apparatus (measurements in 1 year)

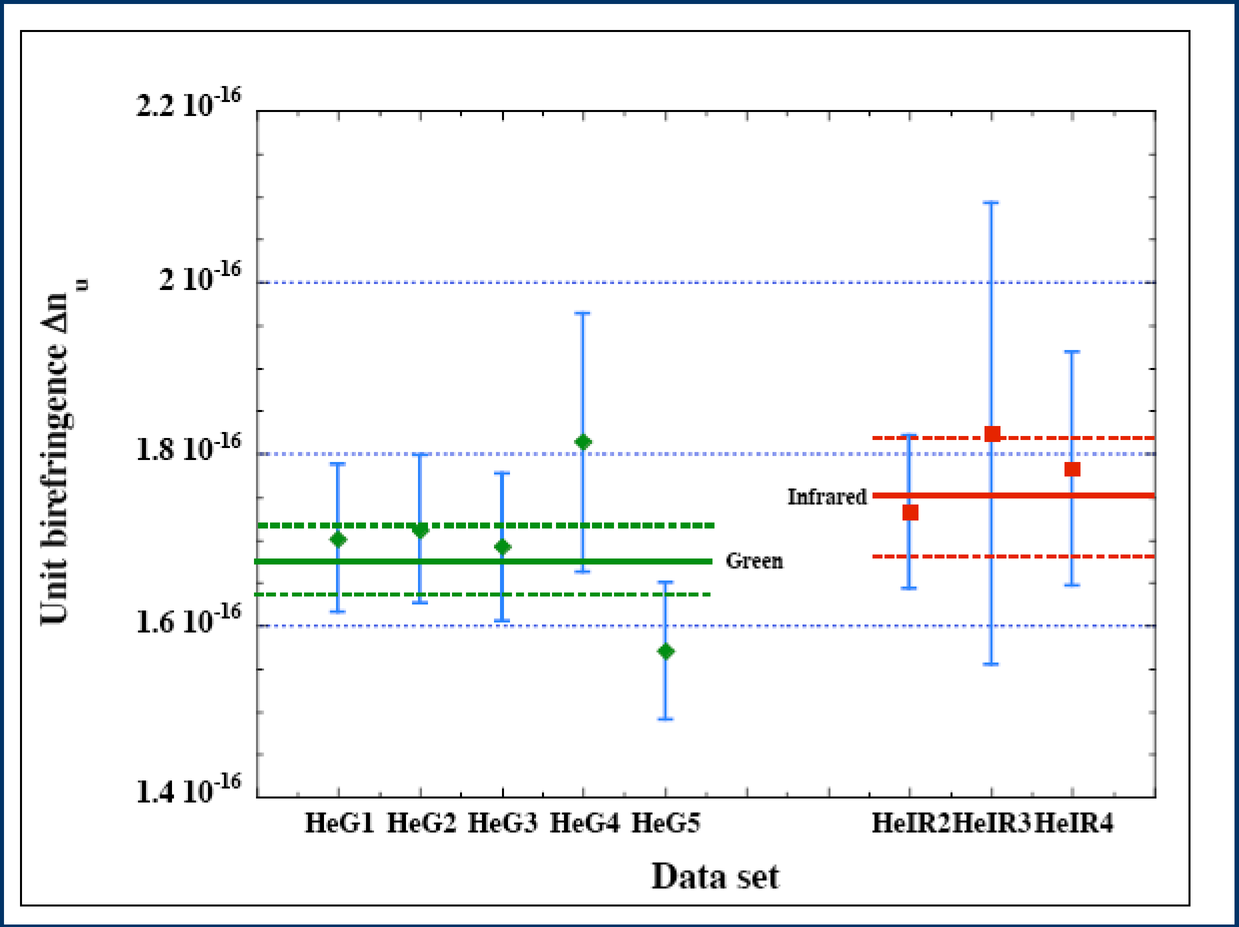
theory

$\Delta\eta$ 1.0287

experiment

0.81±0.04

$$\Delta n = \frac{B^2 p}{4\epsilon_0}\frac{\Delta\eta}{kT}$$



Precision ellipsometry

- Cotton – Mouton effect in N_2 gas
  - Amplification factor control

$$\theta_{N2} = 195^o$$

$$\Delta n_u(N_2) = -(2.4 \pm 0.1) \cdot 10^{-13}$$

With cavity τ = 510 μs , d = 6.4 m, B = 5.0 T, p = 0.5 mbar $\psi = 3.77 \cdot 10^{-4}$

$$N = 2\frac{\tau \cdot c}{d} = 47800$$

MEASURED

EXPECTED

$$N = 48150$$

Without cavity, B = 5.3 T, p = 85.7 mbar $\psi = 1.52 \cdot 10^{-6}$

Precision ellipsometry

- Cotton – Mouton effect in noble gases

Gas	Δn_u (T ~ 290 K, λ = 1064 nm)
Xenon	$(2.44 \pm 0.22) \cdot 10^{-15}$
Kripton	$(8.61 \pm 0.35) \cdot 10^{-15}$
Helium	$(1.75 \pm 0.07) \cdot 10^{-16}$

2003, 2004 IR, 1064 nm, 100 mW	2005 Green, 532 nm, 100 mW	2006 IR, 1064 nm, 800 mW
• Ellipsometer performing properly • Published precise mea-surement on Cotton – Mouton effect	• Ellipsometer performing properly • Published precise mea-surement on Cotton – Mouton effect	• Ellipsometer performing properly