

PVLAS experiment: Measurement of optical properties of quantum vacuum

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PVLAS Collaboration



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PVLAS

Short introduction to PVLAS

- goal of the PVLAS experiment
- experimental technique
- **Recent results**
 - IR laser (1064 nm ~ 1 eV photon energy)
- **Future**
 - photon regeneration

PVLAS Theme and goal

Theme:

Vacuum as a “target”: low energy photon-photon collider

- *QED interactions*
- *other interactions?*

Goal:

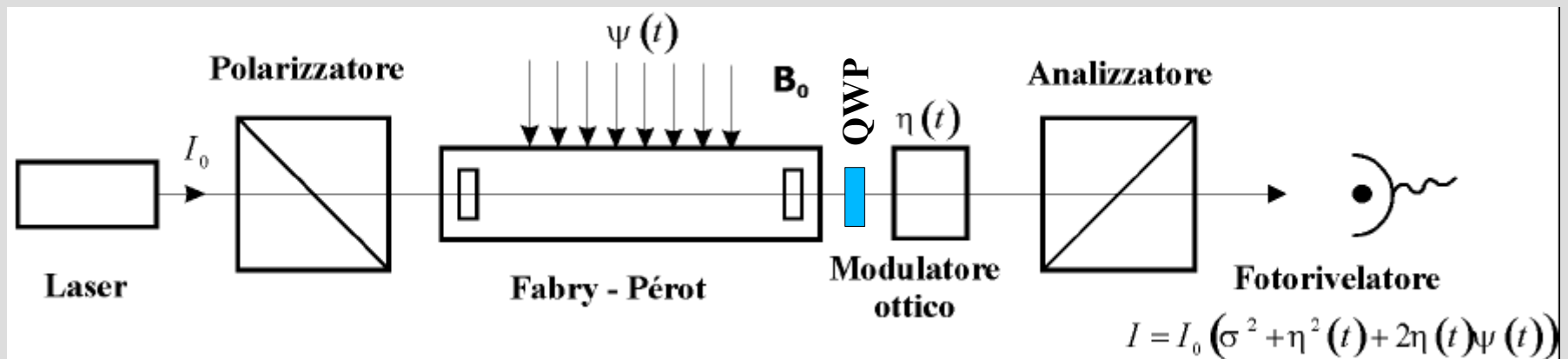
Measure the magnetically induced linear birefringence and optical rotation of the Vacuum element (in practice a gas in the zero-pressure limit)

Possible contributions to macroscopic properties

- *photon-photon scattering*
- *production of: neutral bosons, ?*

PVLAS Experimental apparatus

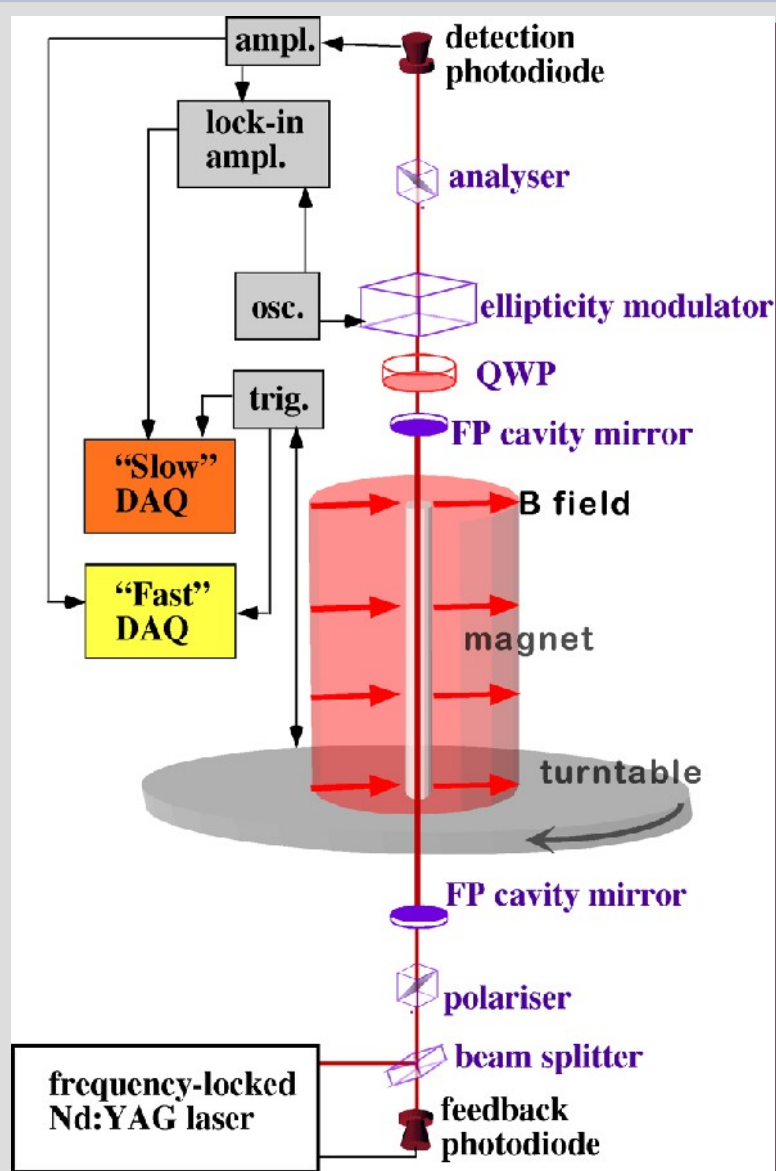
- high sensitivity heterodyne ellipsometer



- *measures changes in light polarization due to magneto-optical properties of the sample*
- *by inserting/removing QWP we can measure rotations/ellipticities*
- *signal dependence:*
 - *magnetic field*
 - *optical path length in the magnetic field region*

PVLAS Experimental apparatus

- high sensitivity heterodyne ellipsometer, main parameters



- 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 nm, 100 mW, 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 (SOM) and high extinction ($\sim 10^{-7}$) crossed polarisers
- time-modulation of the effect

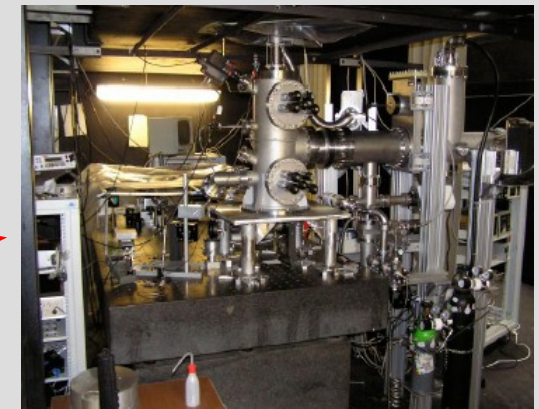
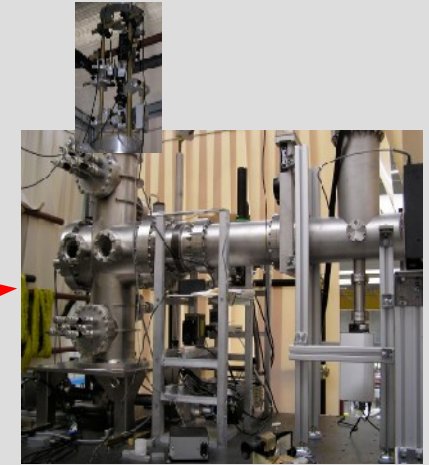
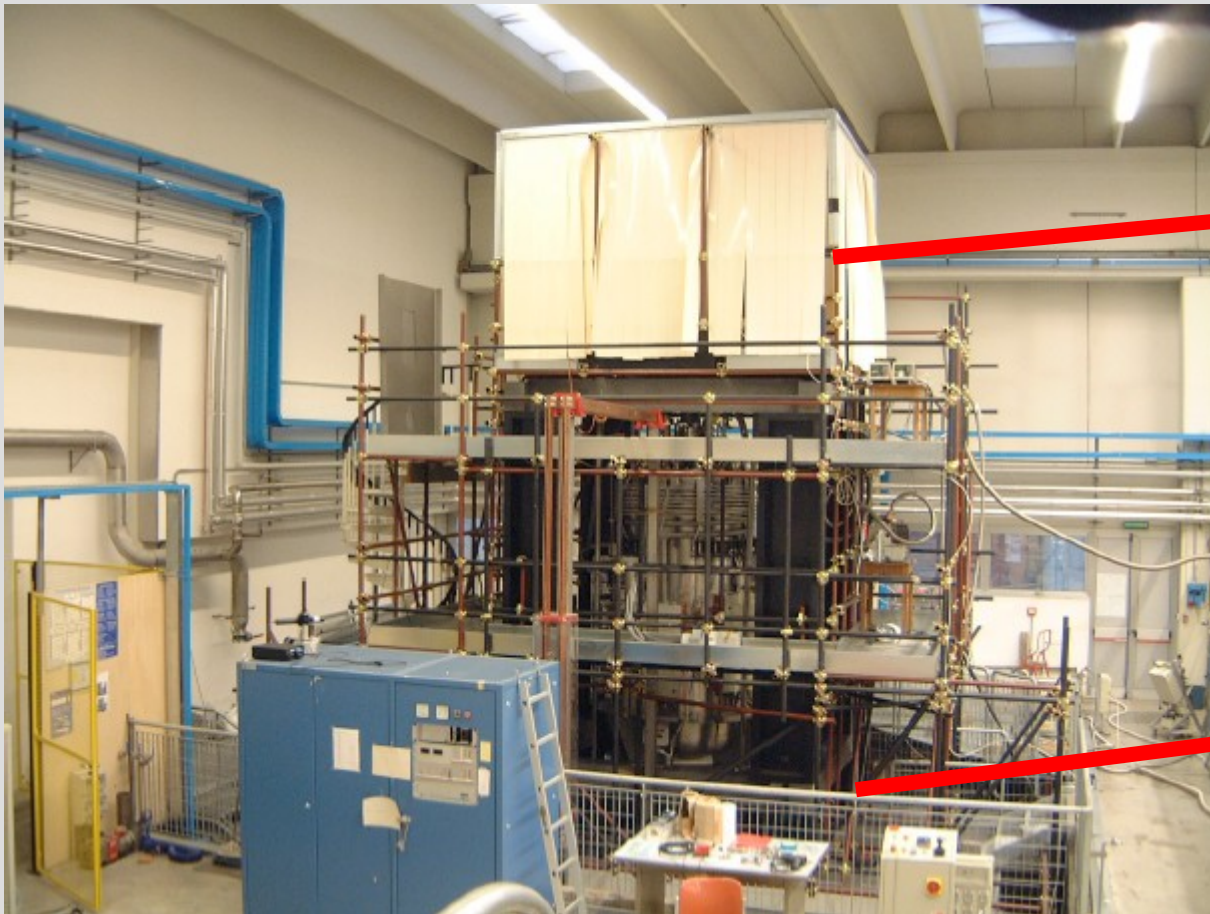
- detection chain

- photodiode with low-noise amplifier

- DAQ

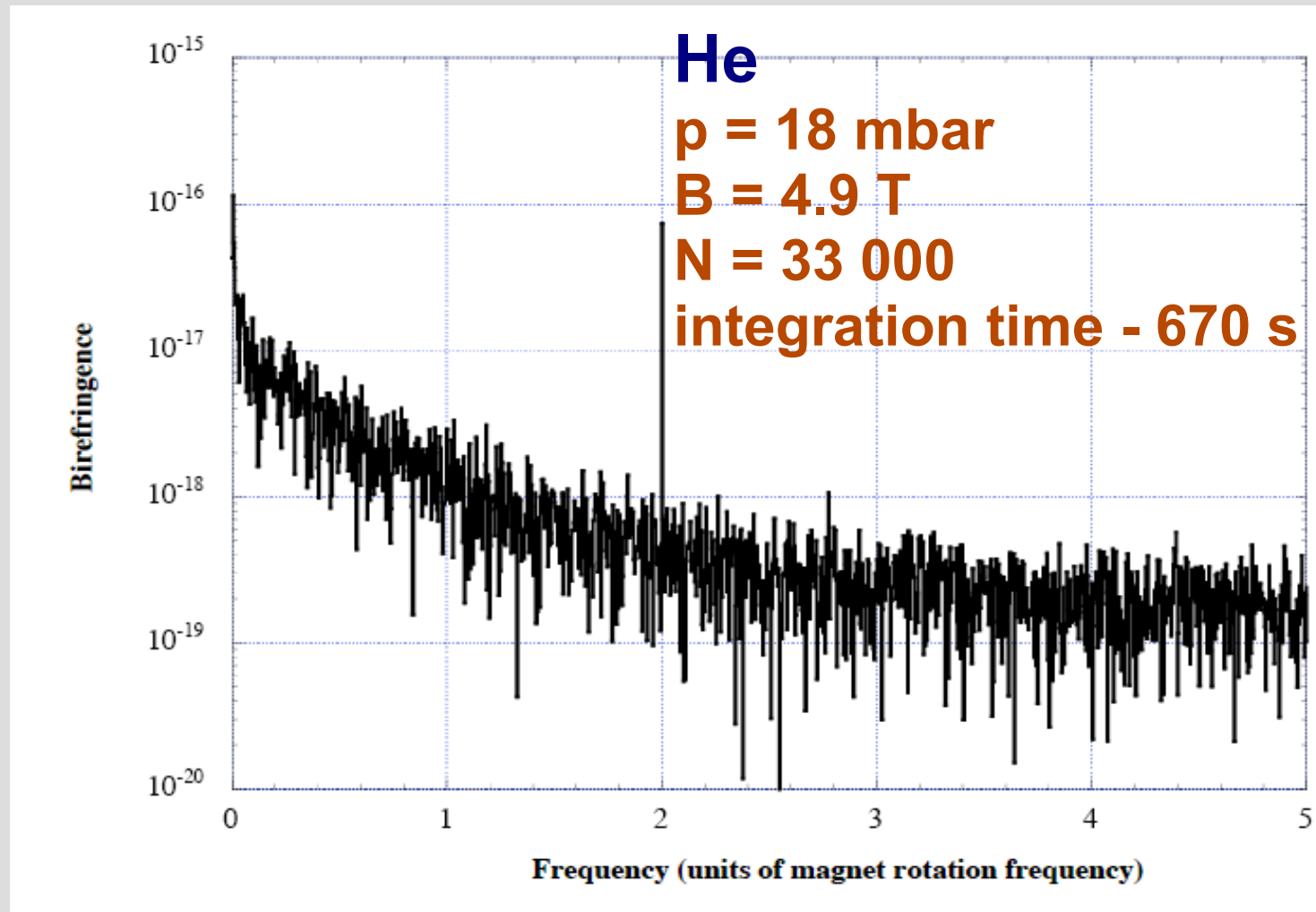
- demodulated at low frequency and phase-locked to the magnetic field instantaneous direction
- high sampling frequency direct acquisition

PVLAS Experimental apparatus



PVLAS Test measurements

- Cotton – Mouton in gas, birefringence

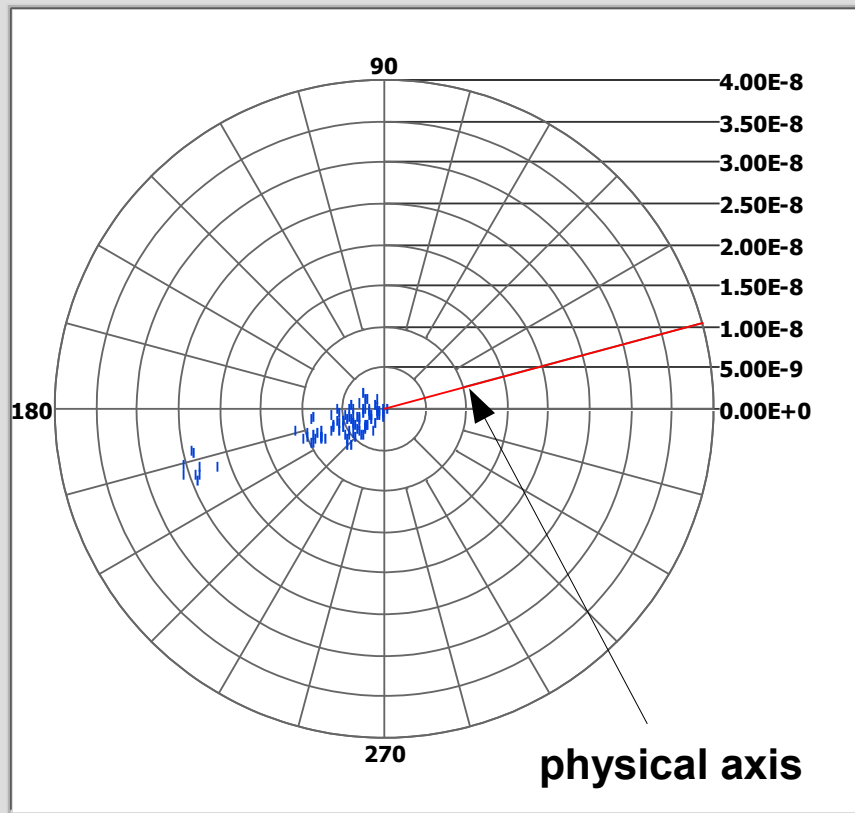


[M. Bregant et al., *Chemical Physics Letters*, Vol. 410, 2004]

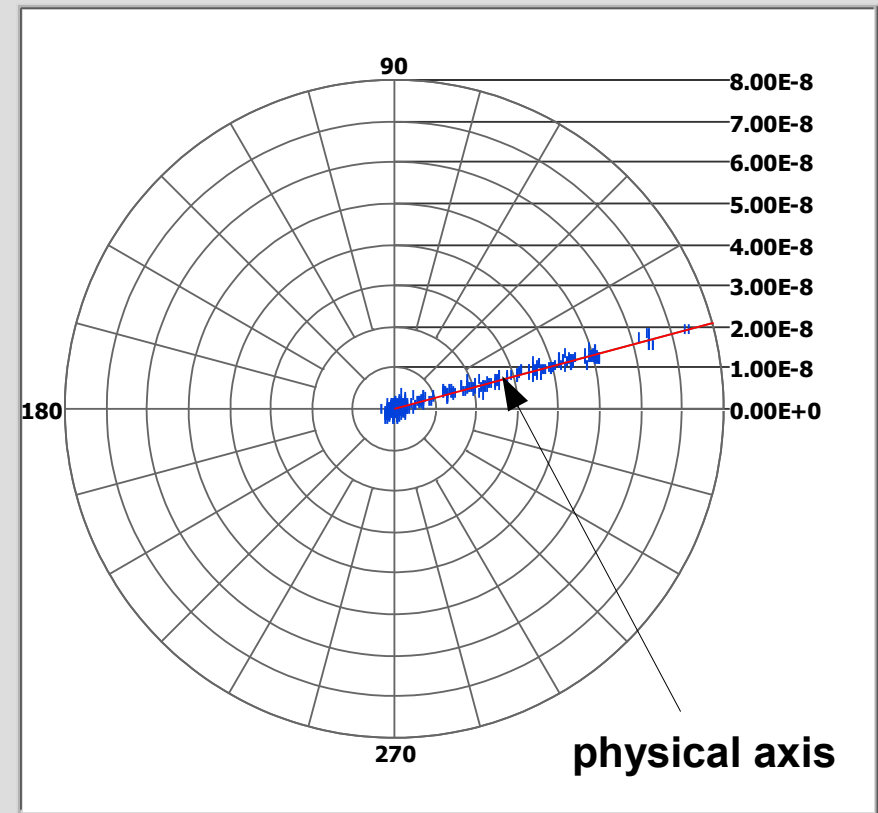
PVLAS Test measurements

- Cotton – Mouton in gas, phase and amplitude information

N_2



He

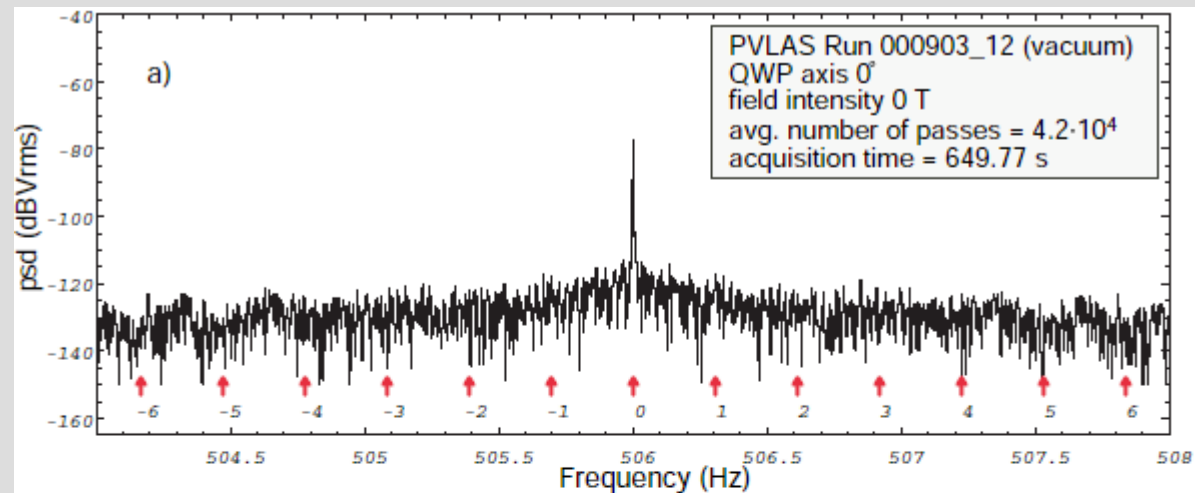


- points represent 100 s long data records, various gas pressures, $B=5.5 T$
- phase and amplitude information
- all points lie on the physical axis

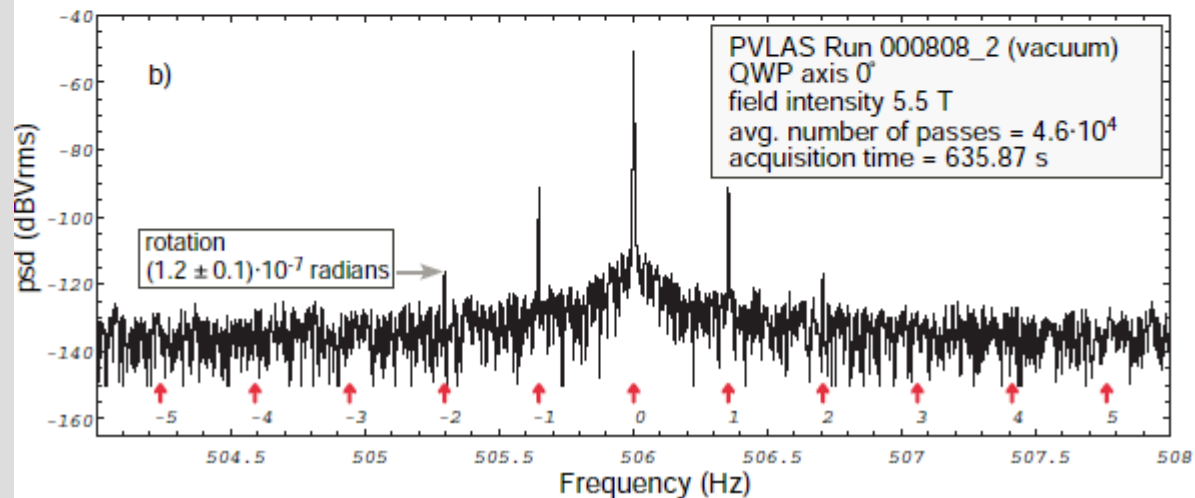
PVLAS IR results

- rotation in vacuum, spectra comparison

magnet off

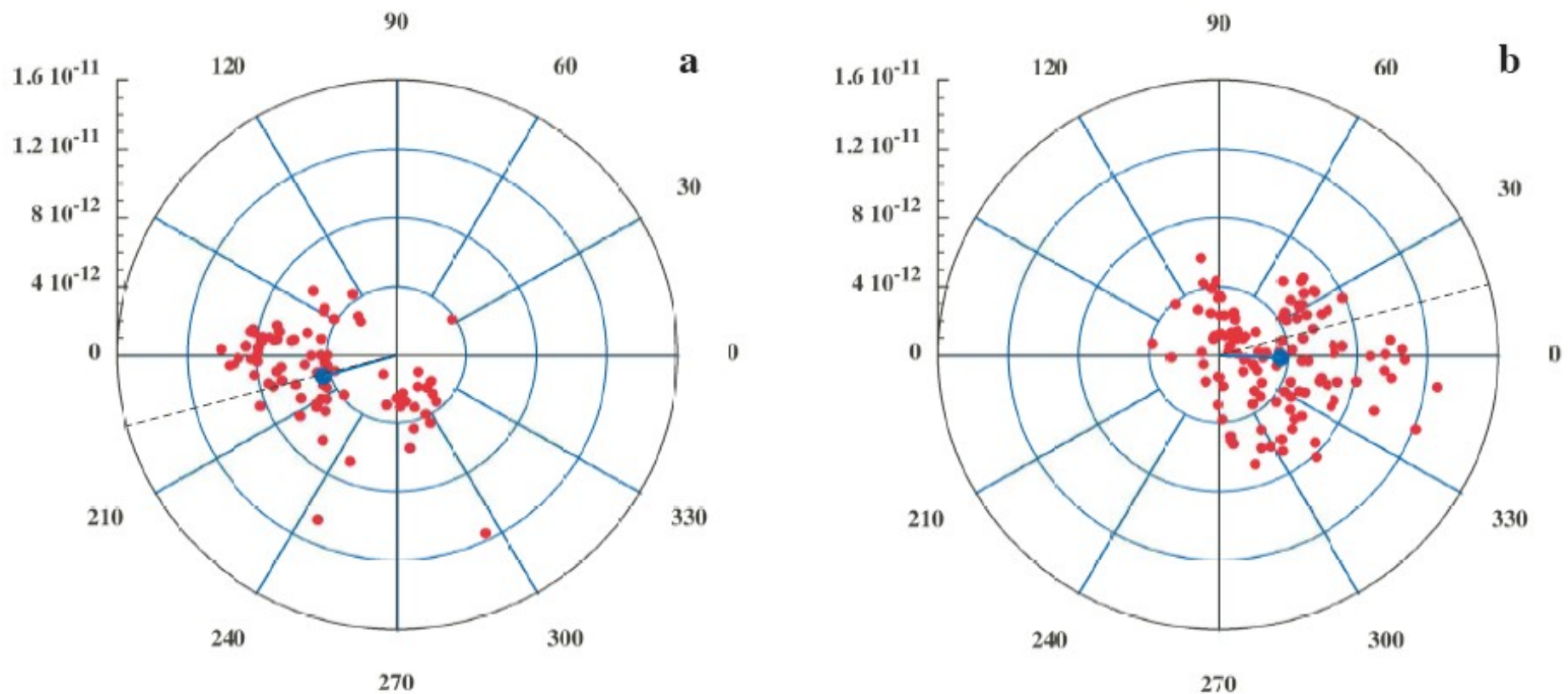


magnet on



PVLAS IR results

- points represent 100 s long data records
- data taken at 5 T, with 44000 passes in the FP cavity



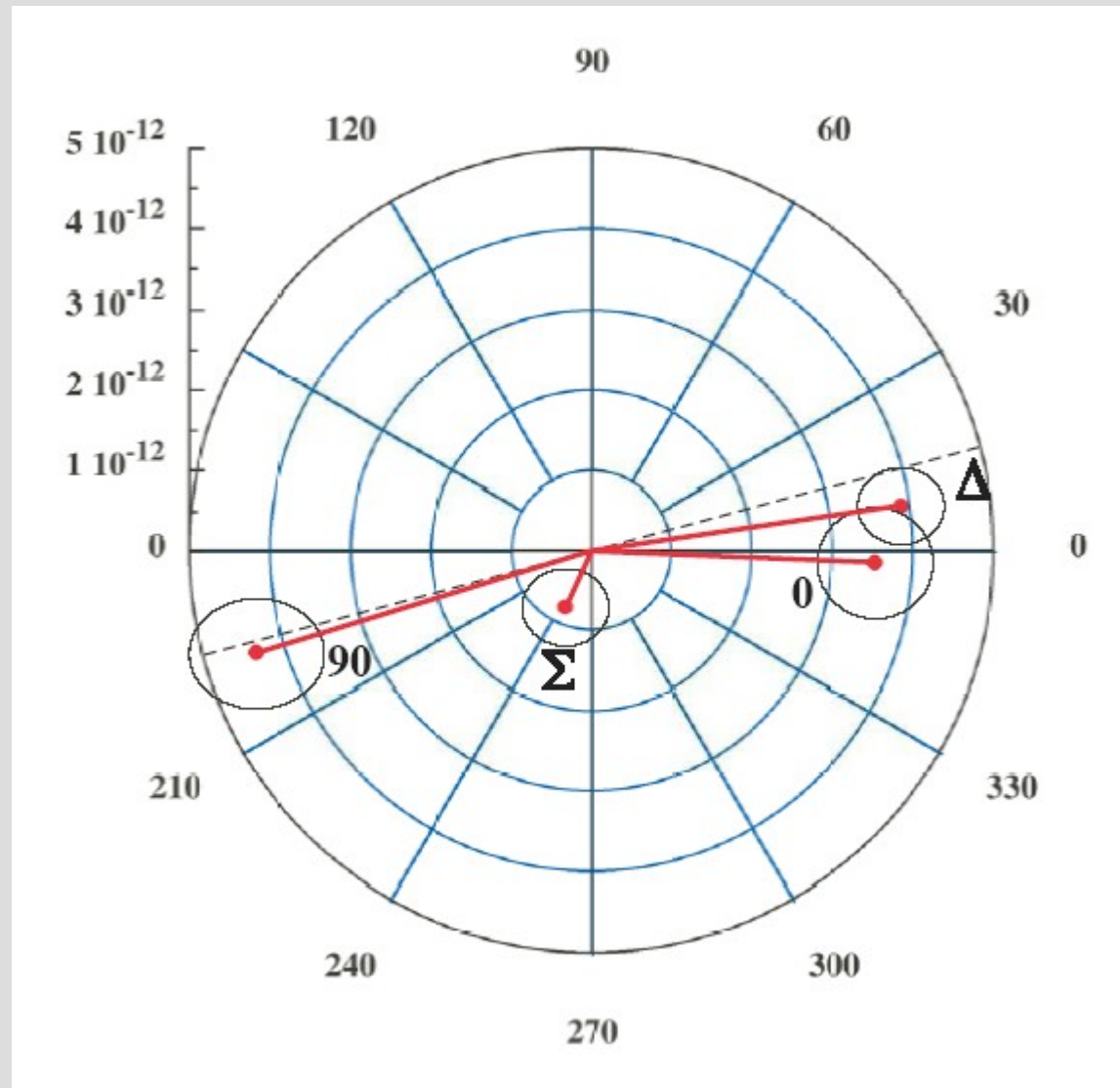
Note the sign change of the distribution under a QWP axis exchange

PVLAS IR results

- IR average, rotation vectors

	0°		90°		Δ		Σ	
	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>
	3.51	-0.15	-4.16	-1.26	3.83	0.55	-0.33	-0.70
σ_{stat}	0.07	0.07	0.07	0.07				
σ_{tot}	0.24	0.23	0.28	0.23	0.18	0.16	0.18	0.16

$$\rho_0 = (3.9 \pm 0.5) \cdot 10^{-12} \text{ rad/pass}$$



[E. Zavattini et al., hep-ex/0507107, PRL accepted]

PVLAS Discussion on IR results

Diagnostic tests made

- *excluded*

- *electrical pick-up*
- *residual gas pressure*
- *mirror coating birefringence*
- *polarizer movement (Faraday?)*
- *diffusion from magnetised surfaces*

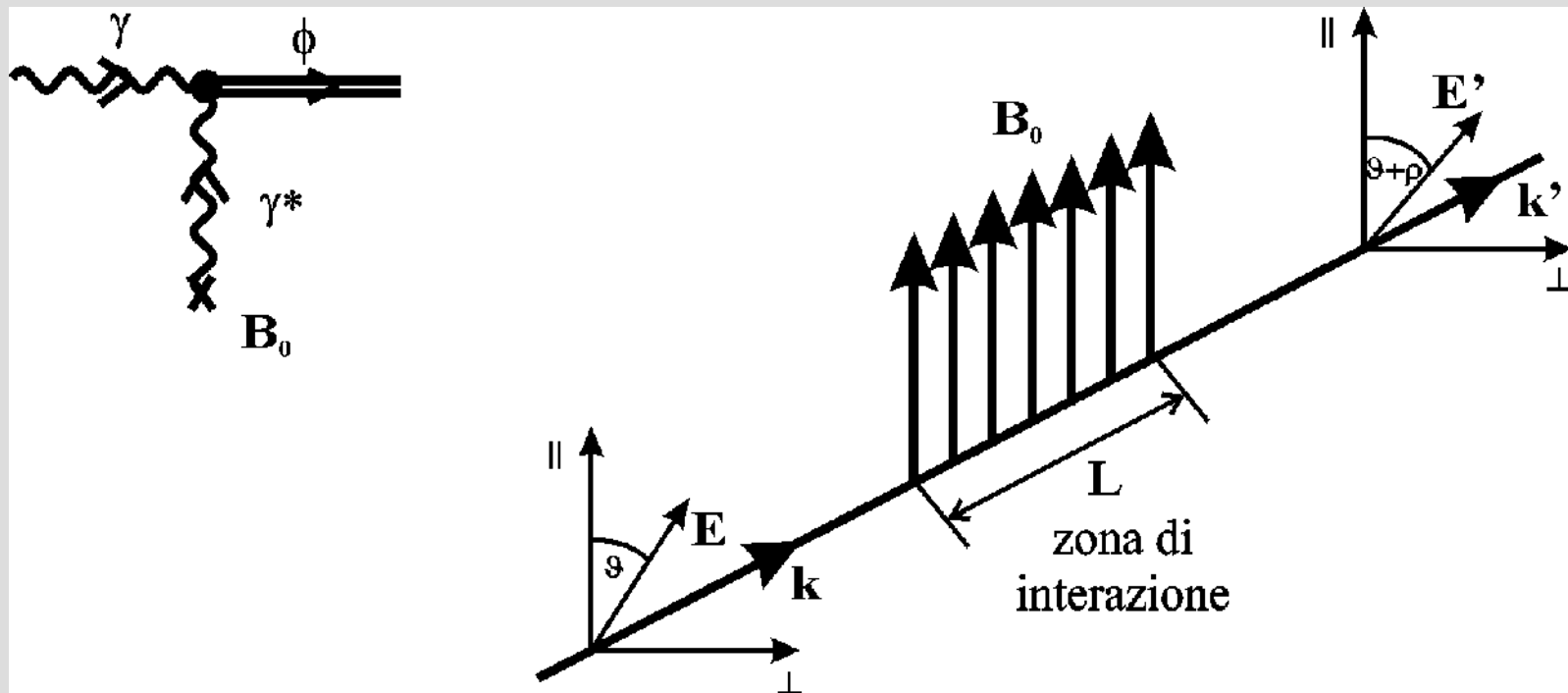
- *open questions*

- *beam pointing instability?*
- **presence of a true physical signal?**

PVLAS Possible interpretation

- light scalar/pseudoscalar boson production

$$\rho_\phi = g_{\phi\gamma\gamma}^2 \frac{2\mathcal{F}B_0^2\omega^2}{\pi m_\phi^4} \sin^2\left(\frac{m_\phi^2 L}{4\omega}\right) \sin(2\vartheta) \simeq g_{\phi\gamma\gamma}^2 \frac{\mathcal{F}B_0^2 L^2}{8\pi}$$

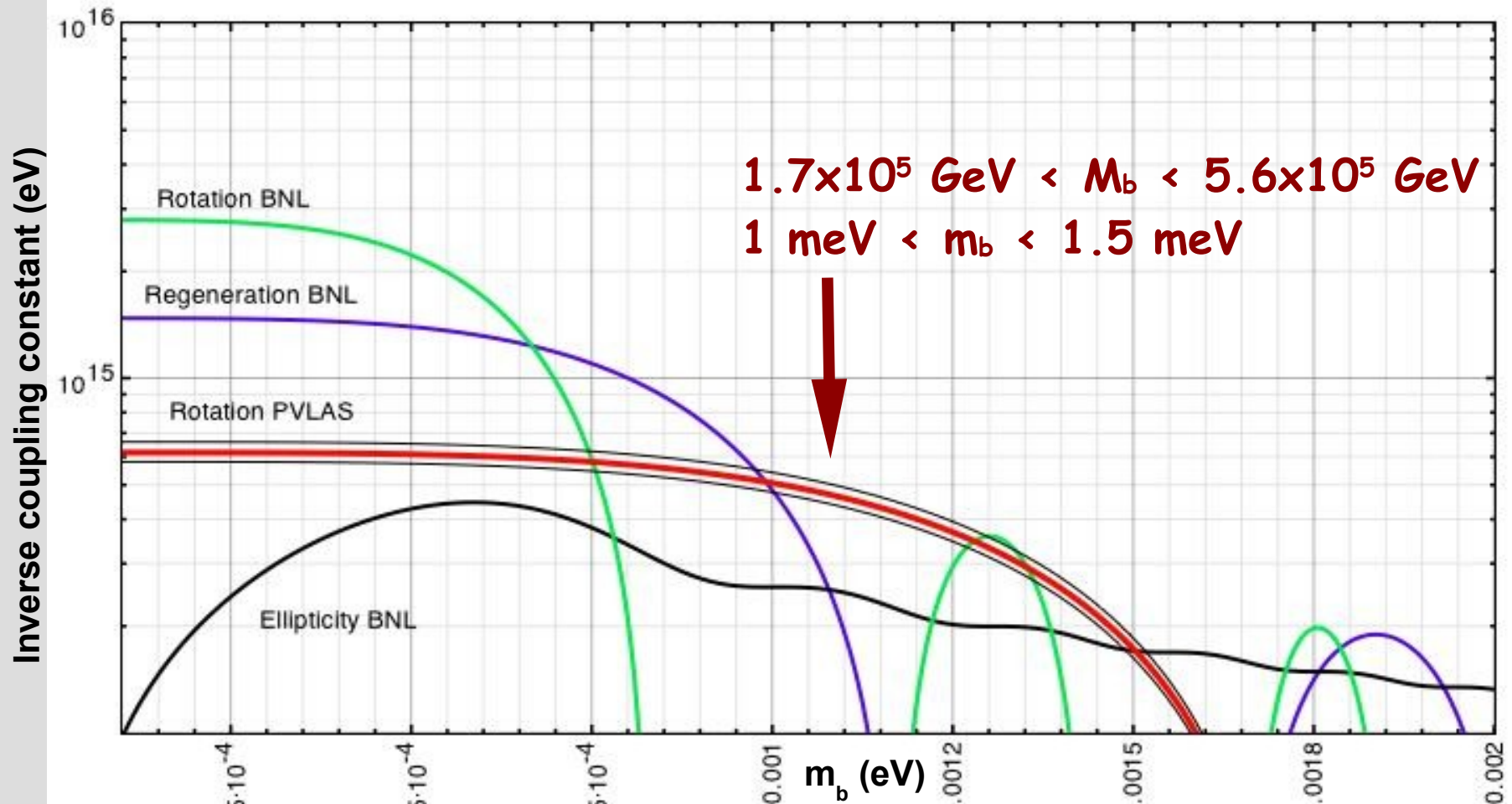


[L.Maiani, R. Petronzio, E. Zavattini, Phys. Lett B, Vol. 173, no.3 1986]

[E. Massò and R. Toldrà, Phys. Rev. D, Vol. 52, no. 4, 1995]

PVLAS Possible interpretation

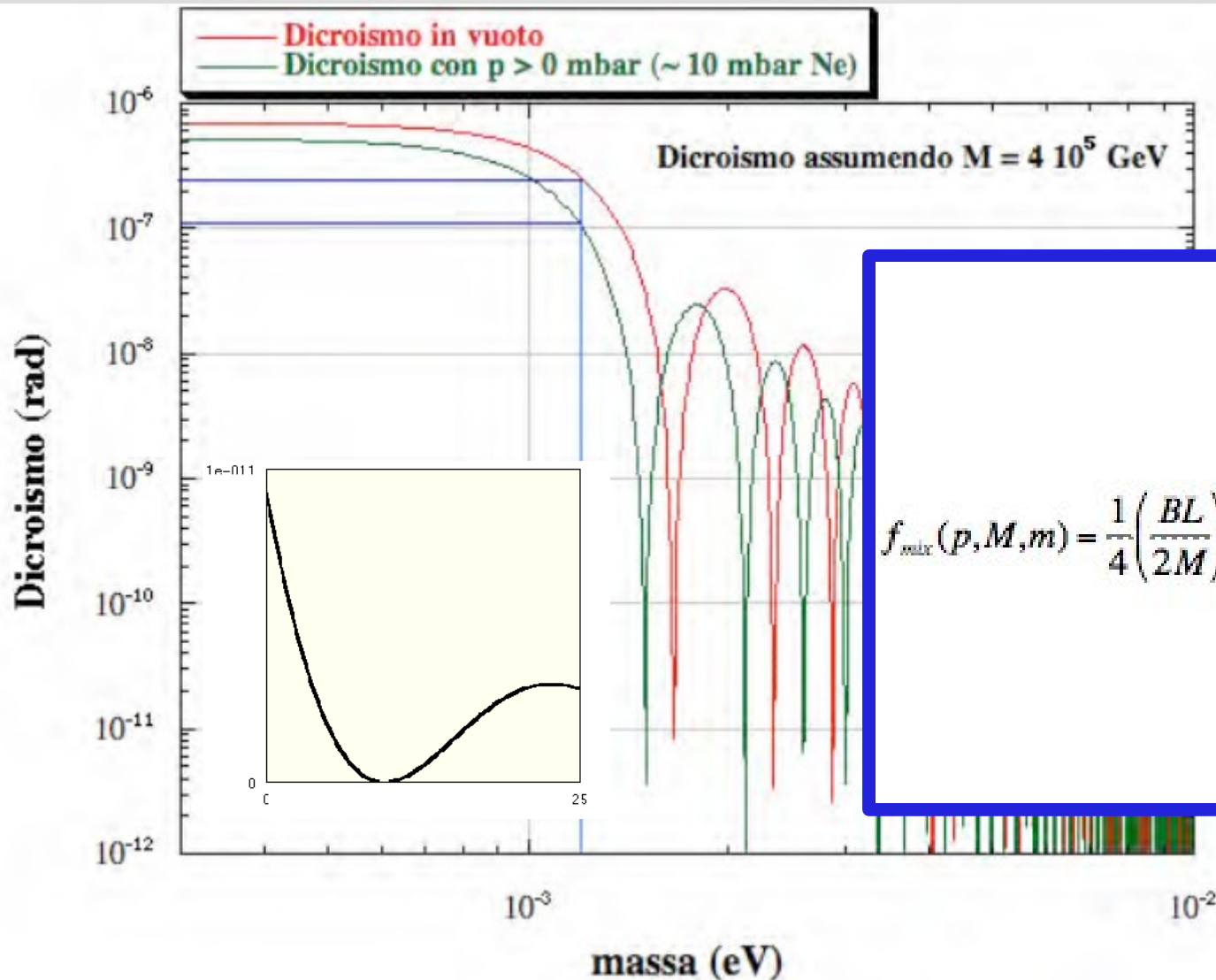
- comparison with previous measurements



BFRT see [R. Cameron et al., Phys. Rev. D 47, 3707 (1993)]

PVLAS Mixing

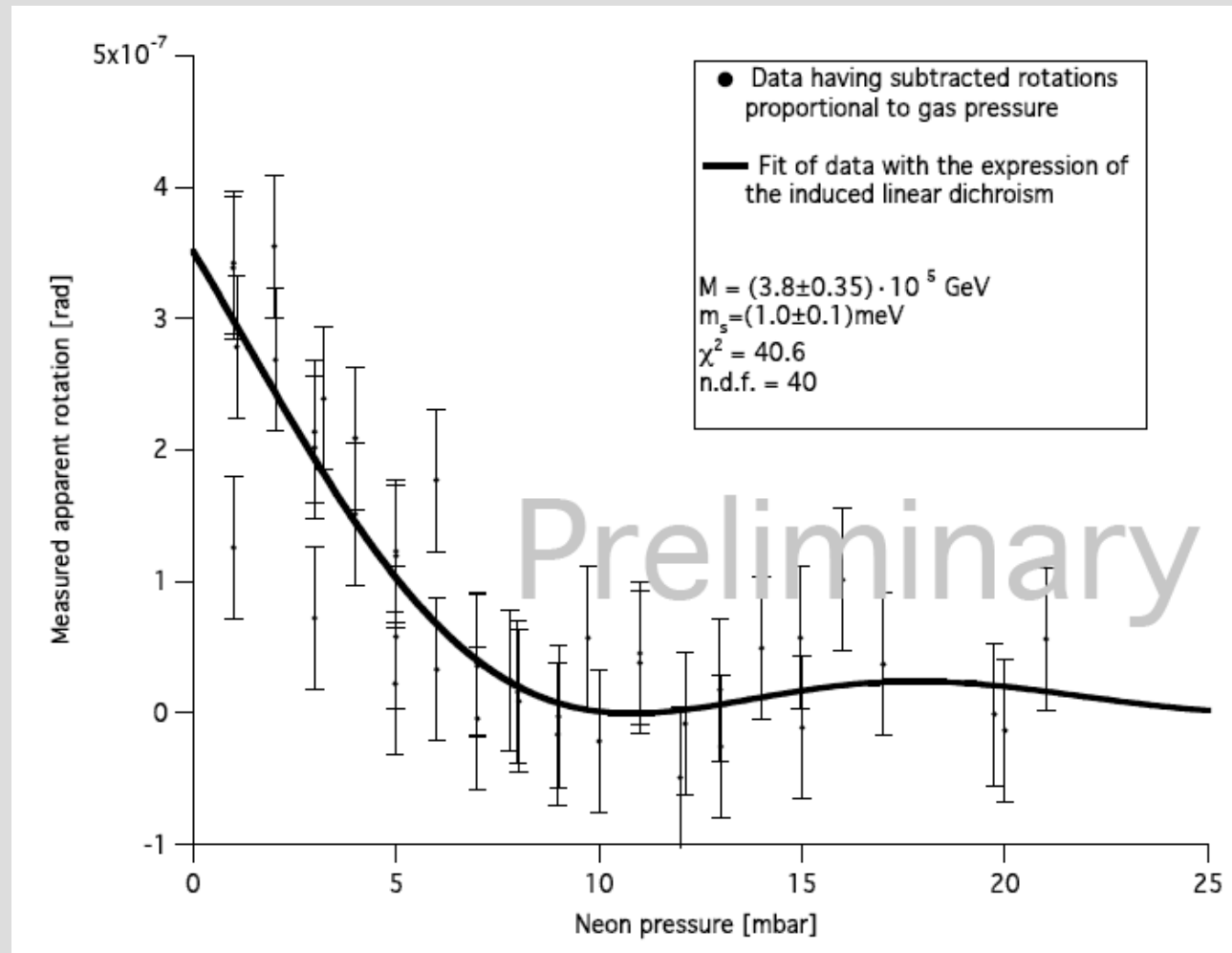
- rotation in gas



$$f_{\text{mix}}(p, M, m) = \frac{1}{4} \left(\frac{BL}{2M} \right)^2 \frac{\left[\sin \left(\frac{\left(\frac{2p_{\text{gas}}(n_{\text{gas}} - 1)\omega^2}{P_{\text{atm}}} + m^2 \right) L}{4\omega} \right) \right]^2}{\left(\frac{2p_{\text{gas}}(n_{\text{gas}} - 1)\omega^2}{P_{\text{atm}}} + m^2 \right) L}$$

PVLAS Mixing?

- rotation in gas, IR Data



- subjected to further investigation
- systematic effects subtracted – linear and under control

PVLAS Recent developments

- **incident photon energy changed**

1064 nm (~1 eV) infrared > 532 nm (~2 eV) green

- **2 runs** (60 hours of data acquisition)

 - *sensitivity worse than IR*

- *analysis in progress, **effect present***

- *up to now results are compatible with IR measurements*

PVLAS Physical tests

Photon regeneration

- *already done at BNL*

[R. Cameron et al., Phys. Rev. D 47, 3707 (1993)]

- *to be done with PVLAS apparatus*

- *ongoing project*

- *DESY*

[R. Rabadan, A. Ringwald and K. Sigurdson, "Photon regeneration from pseudoscalars at X-ray laser facilities," arXiv:hep-ph/0511103]

[U. Kötz, A. Ringwald and T. Tschentscher, "Production and detection of axion-like particles at the VUV-FEL: A study of feasibility," in progress]

PVLAS Photon regeneration scheme

PVLAS parameters

production

1 m

5.5 T

10^{22} photons in cavity

regeneration

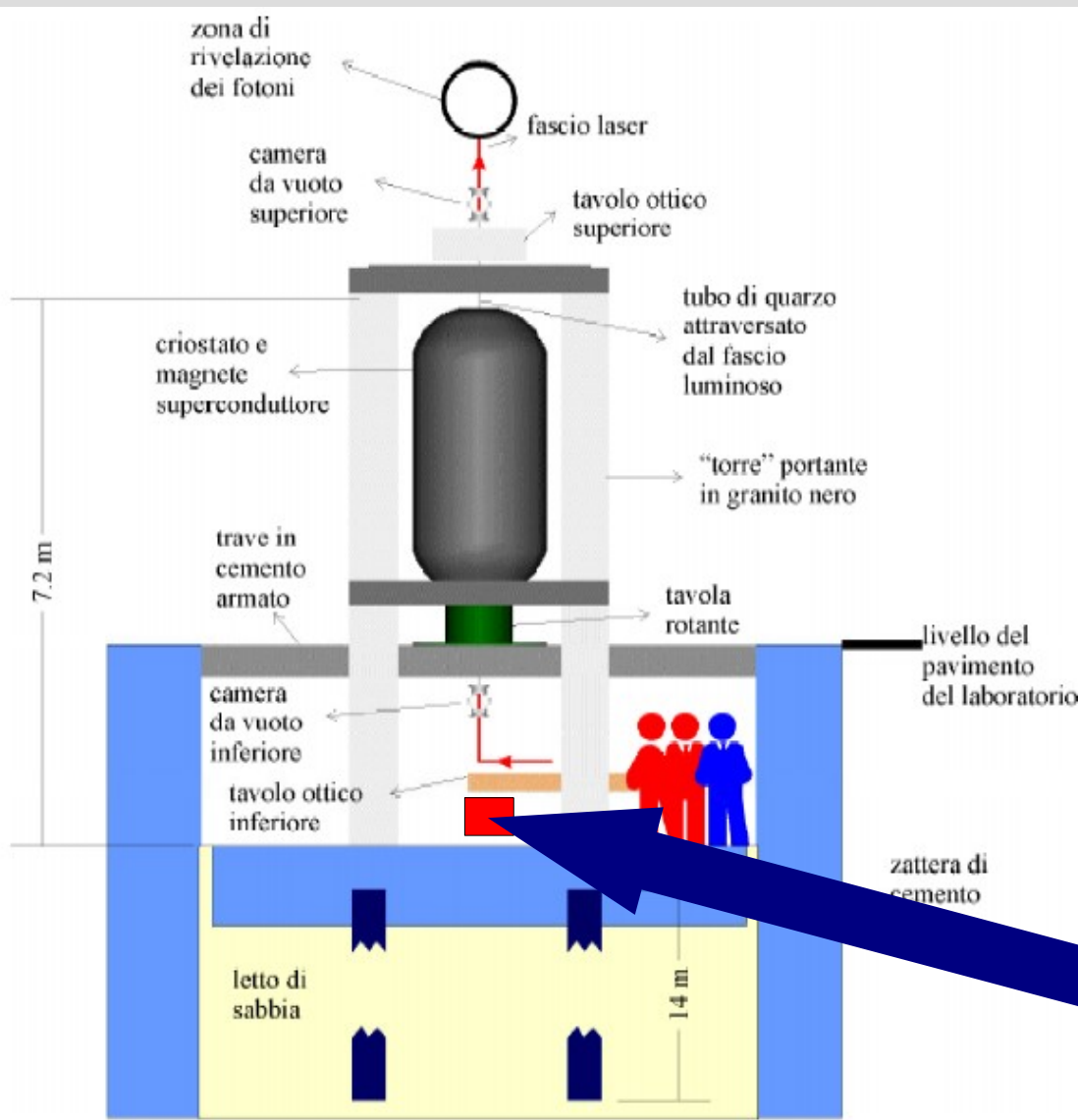
0.5 m

2.5 T

counting rate

1 photon/s

magnet, photon regeneration region
detector



PVLAS Conclusions

- *we have an unexpected rotation signal whose physical origin has yet to be determined*
- *up to now, compatibility between results with two different wavelengths (analysis in progress)*
- *now, IR run:*
 - *more photons in cavity*
 - *different photon source*
 - *confirmation of previous results?*
- *near future:*
 - *new amagnetic access structure*
- *not so distant future:*
 - *powerful physics test*
(photon regeneration at PVLAS)

PVLAS The End

