New observations at PVLAS

PVLAS Collaboration

Trieste

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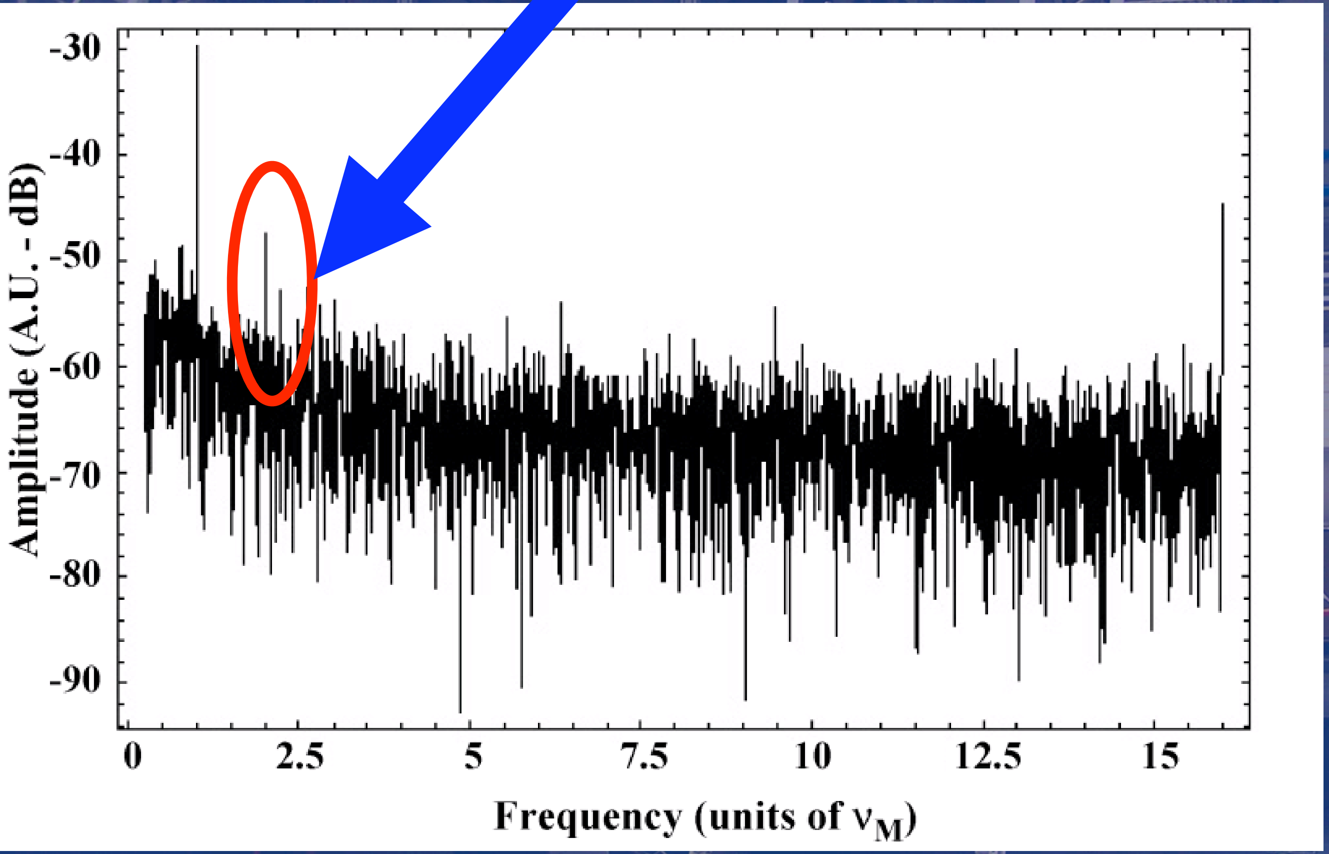
Summary

- Brief history of PVLAS measurements
- Discussion on possible artifact sources
- Apparatus upgrades
- Recent runs with upgraded set-up
- Current activities
- What next?

Pre-history

- The story starts in 2000 at commissioning…

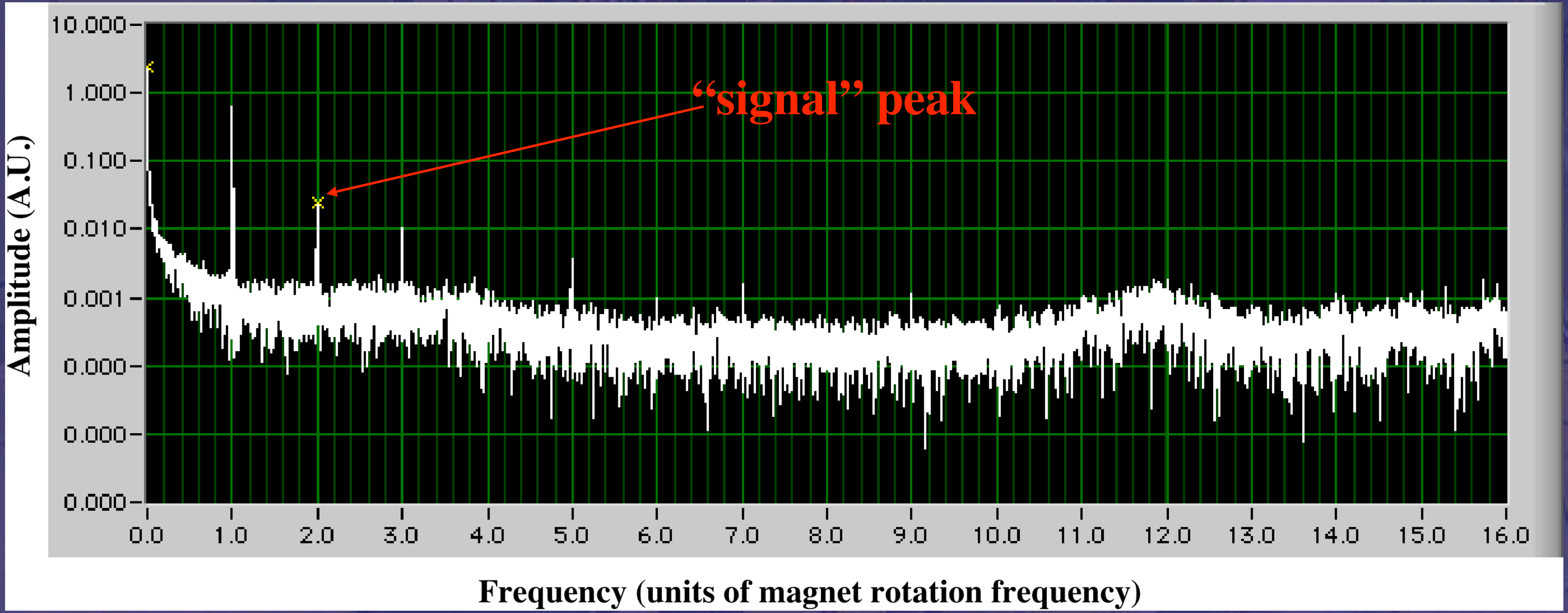
Ellipticity peak in vacuum at 4 T field, λ = 1064 nm and F=100000



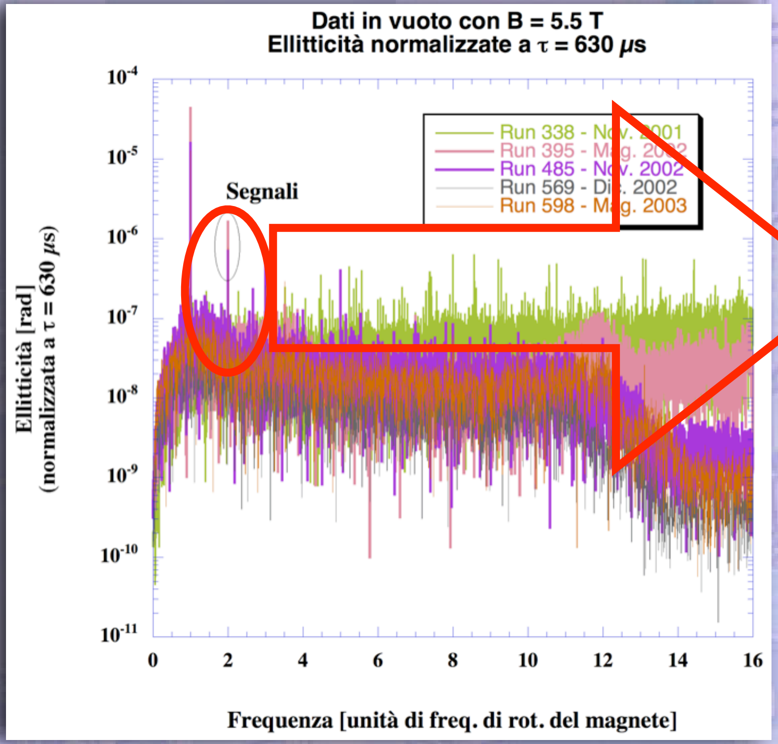
From the proceedings of the Trieste QED2000 conference

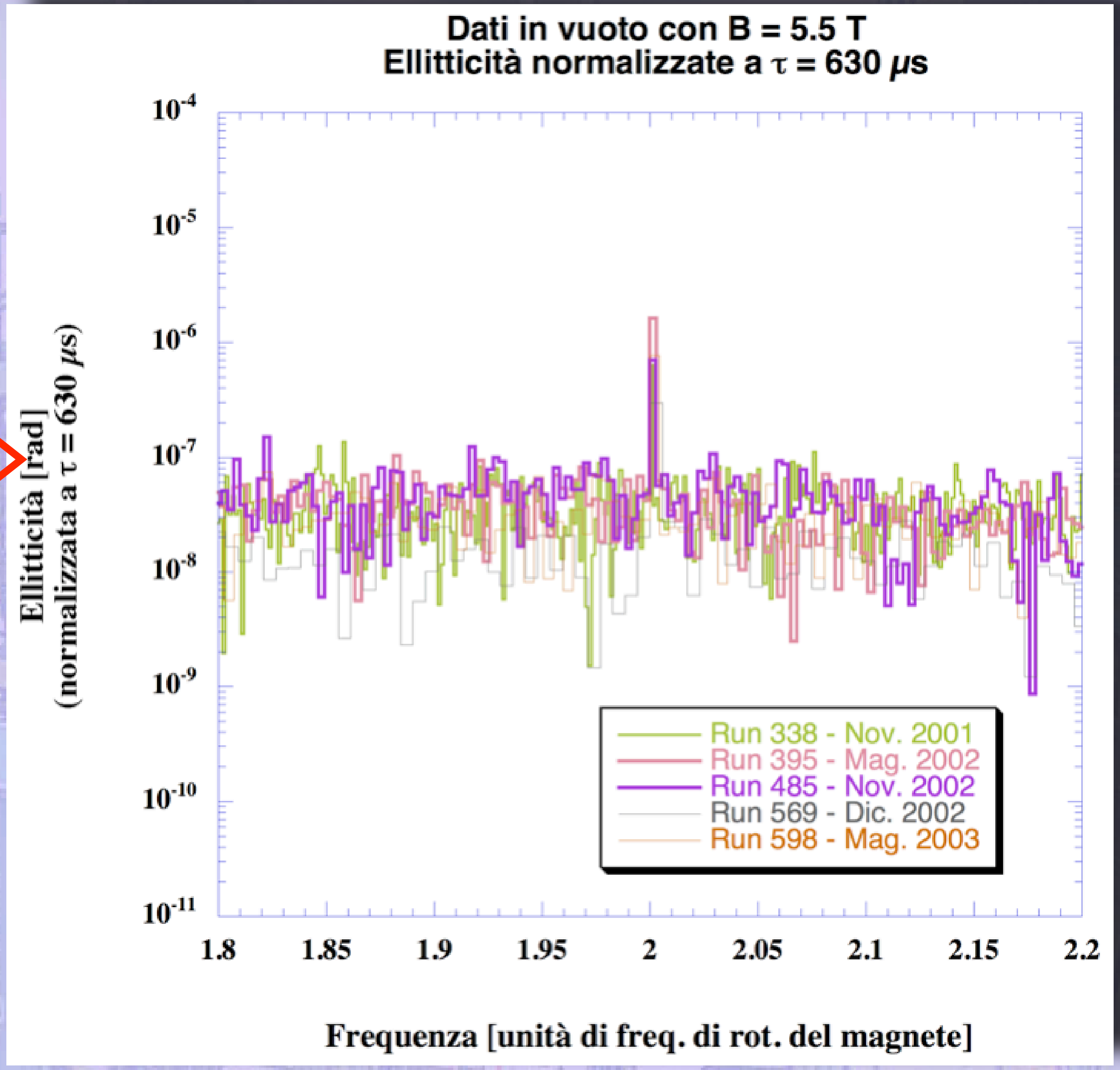
Sample spectrum in vacuum

- The spectrum was obtained in the following conditions
  - pneumatic vacuum ~10^{-7} mbar
  - field intensity 6 T
  - no QWP -> ellipticity spectrum
  - magnet rotation frequency 0.33 Hz
- A "signal" appears at twice the magnet rotation frequency, that is were a "physical" signal should appear –> peak amplitude ~10^{-7} rad



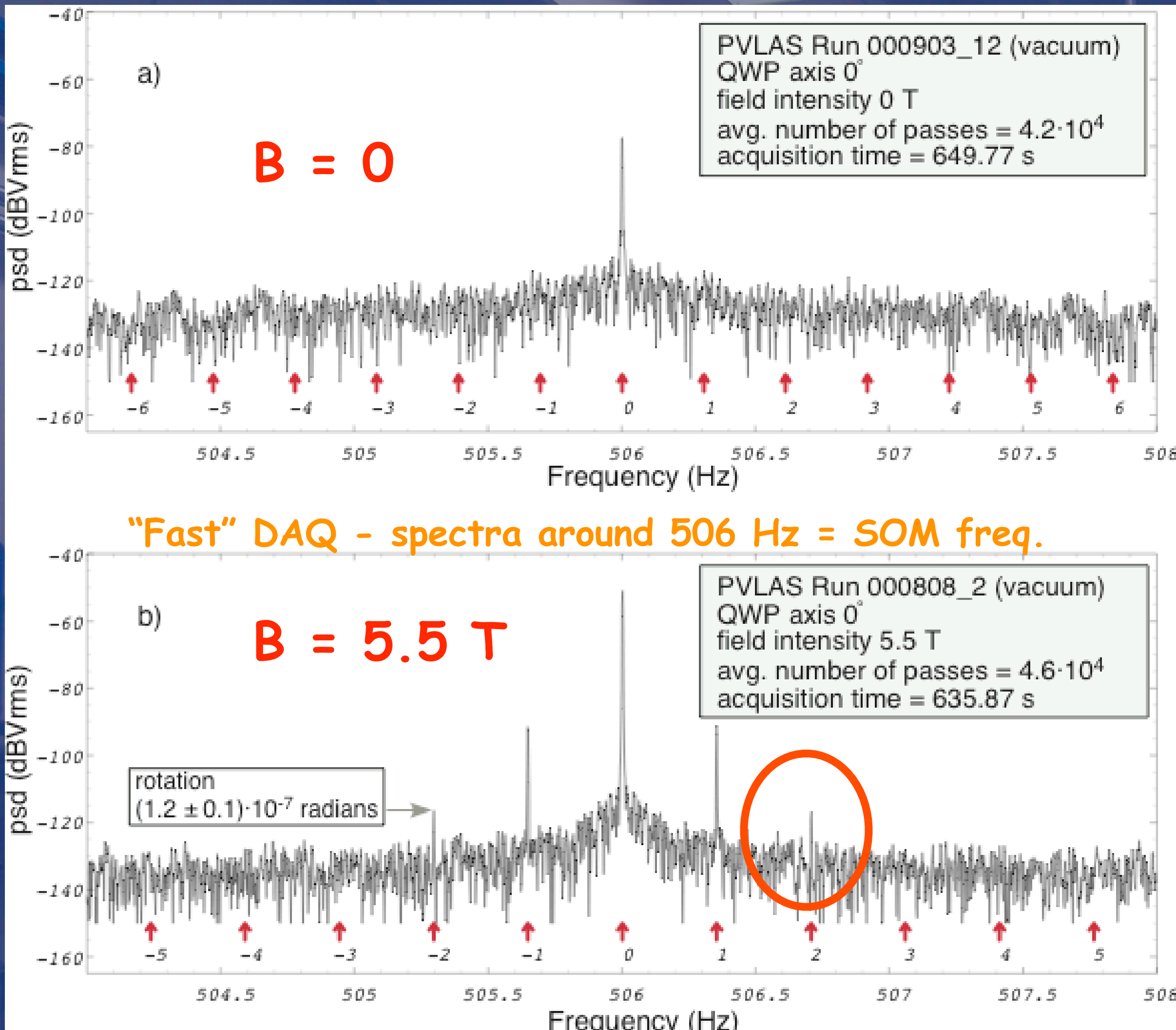
Vacuum observed signals





Ellipticity signals are shown here
Dichroism signals have the same appearance

Published data (2006) at 1064 nm



The rotation signal corresponds to a "true" rotation (dichroism) with amplitude
$(3.9 \pm 0.5) \times 10^{-12}$ rad/pass

Similar results (although unpublished) were found for ellipticity

- Signal observed in Vacuo with $B \neq 0$ and cavity present
- Data clusters in polar plane change sign under a QWP axis exchange
- The average rotation vector lies along the physical axis

Initial strategy

- Prove that peaks observed in the photodiode current spectrum are due to actual changes in the light polarization state
- Investigate "obvious" possible sources of instrumental artifacts which could mimick the signals

"Direct" instrumental sources

Candidate	Test	Comment
residual gas (ellipticity)	pressure and RGA measurements	excluded
fringe field-induced mirror coating magnetic birefringence/ rotation (rotation and ellipticity)	published data and direct measurements	excluded note: possible source of ellipticity/rotation at Ω_{mag}
electrical pick-up (rotation and ellipticity)	measurement without the cavity	excluded
diffusion from magnetised surfaces (ellipticity)	pinhole insertion	excluded
fringe field-induced polarizer/ QWP movement (ellipticity)	measurement without the cavity	excluded
spurious field-induced SOM birefringence	measurement without the cavity	excluded

Direct effect of fringe magnetic fields on optical components

- The Verdet constants for dielectric multilayer mirrors have been directly measured: $2\cdot10^{-11}$ rad/G/reflection for the reflecting layers and 10^{-6} rad/G/cm for the substrate (0.8 cm thickness)
- For horizontal fields the induced ellipticity is $\sim10^{-17}$ rad/G^2/reflection
- Using the typical measured values of the fringe fields one sees that direct field effects:
  - cannot explain the second harmonic peaks both in rotation and in ellipticity
  - can explain the first harmonic in rotation

Typical fringe field values

Field comp.	Vertical		Horizontal	
Harmonic	1-Ω	2-Ω	1-Ω	2-Ω
Upper Mirr.	0.5 G	$8\cdot10^{-4}$ G	2.5 G	$2\cdot10^{-3}$ G
Lower Mirr.	"	"	2.5 G	10^{-2} G

Estimated/measured comparison

	Rotation		Ellipticity
Harmonic	1-Ω	2-Ω	2-Ω
Estimated	$1.8\cdot10^{-6}$	$2.5\cdot10^{-9}$	$6\cdot10^{-12}$
Measured	$2.9\cdot10^{-6}$	$3\pm2\cdot10^{-8}$	$2\cdot10^{-8}$
		$2\cdot10^{-7}$	$2\cdot10^{-7}$

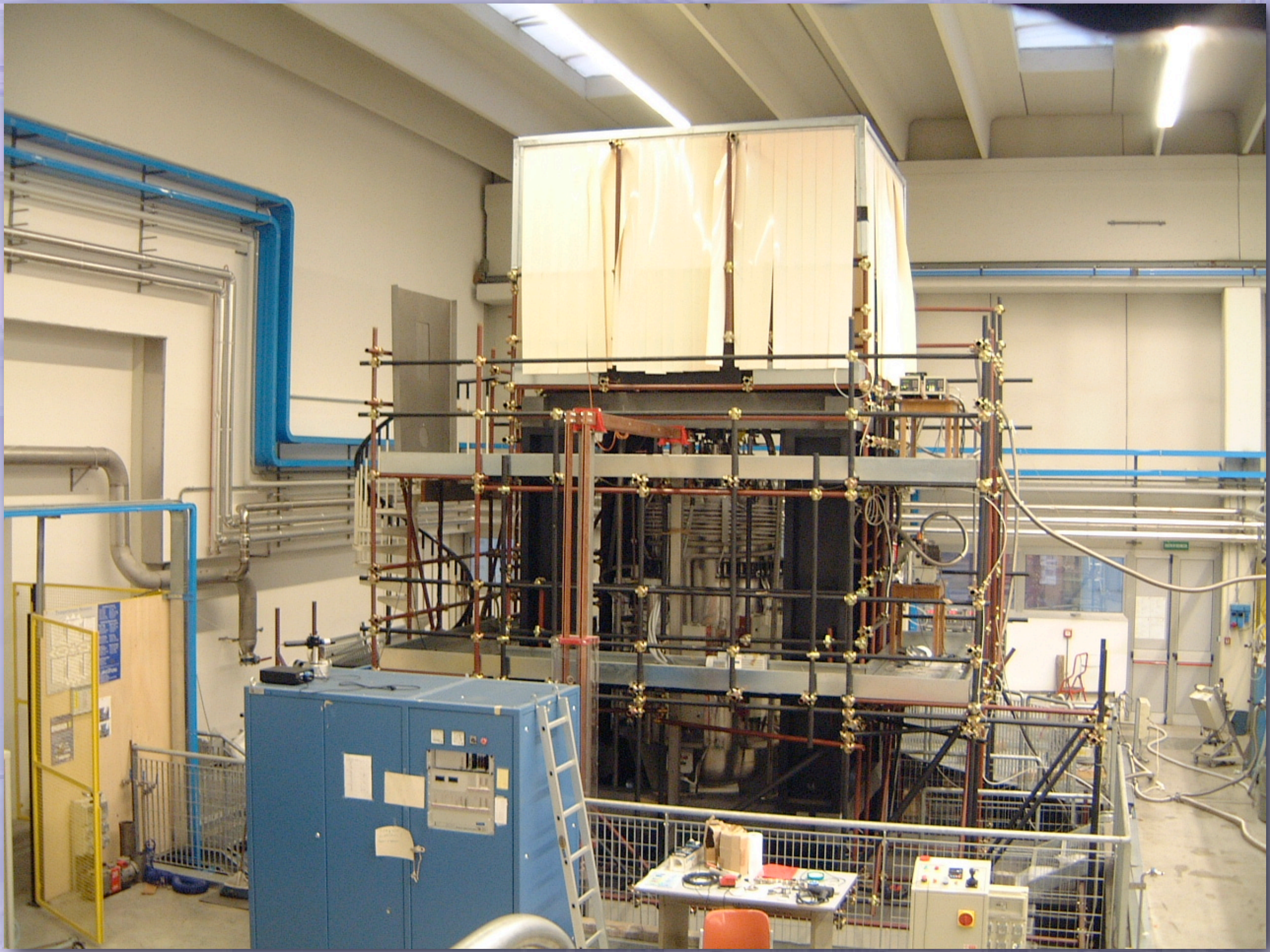
Initial success

- Signal is indeed found to be due to actual polarization changes
- "Direct" sources of artifacts are excluded
- Furthermore, signal origin is localized within the Fabry-Perot cavity
- Lingering doubts:
  - fringe fields of the order of a few Gauss are present when running at 5 T, what is their effect?
  - could they cause an "indirect" spurious coupling between field and polarization effects?

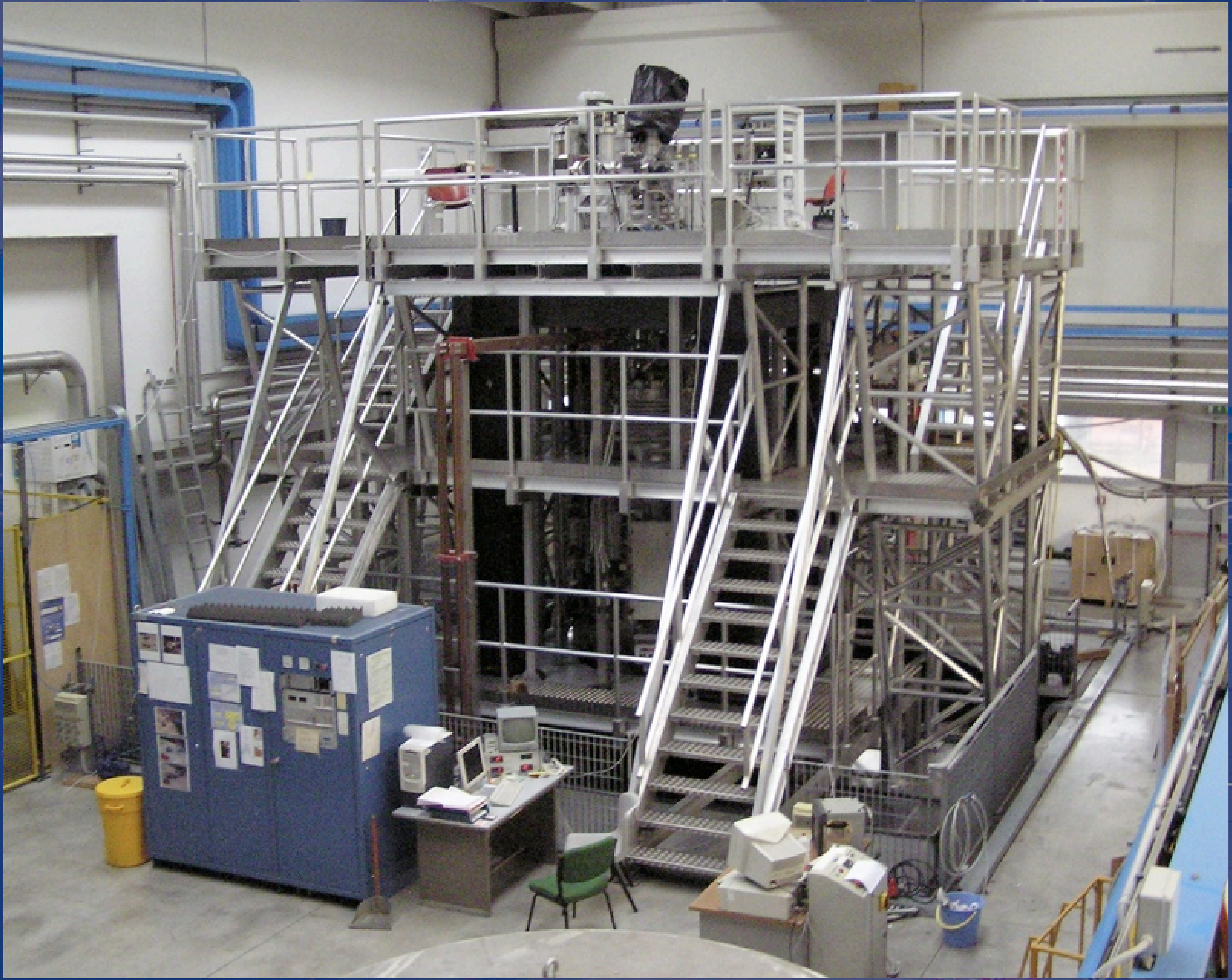
Step 2

- Assume that fringe fields are responsible for some yet-unknown indirect effect
- Upgrade apparatus with the aim of minimizing the supposed influence of the fringe fields
- List of upgrades:
  - switched laser (Lightwave 100 mW -> Innolight 800 mW)
  - new aluminum access structure
  - new better shielded coaxial cables
  - mu-metal shielding of locking circuit
  - Helmholtz coils around cavity mirrors
  - initial fixed polarization rotated by 54°
  - new compressor for He gas recovery -> better efficiency -> longer runs

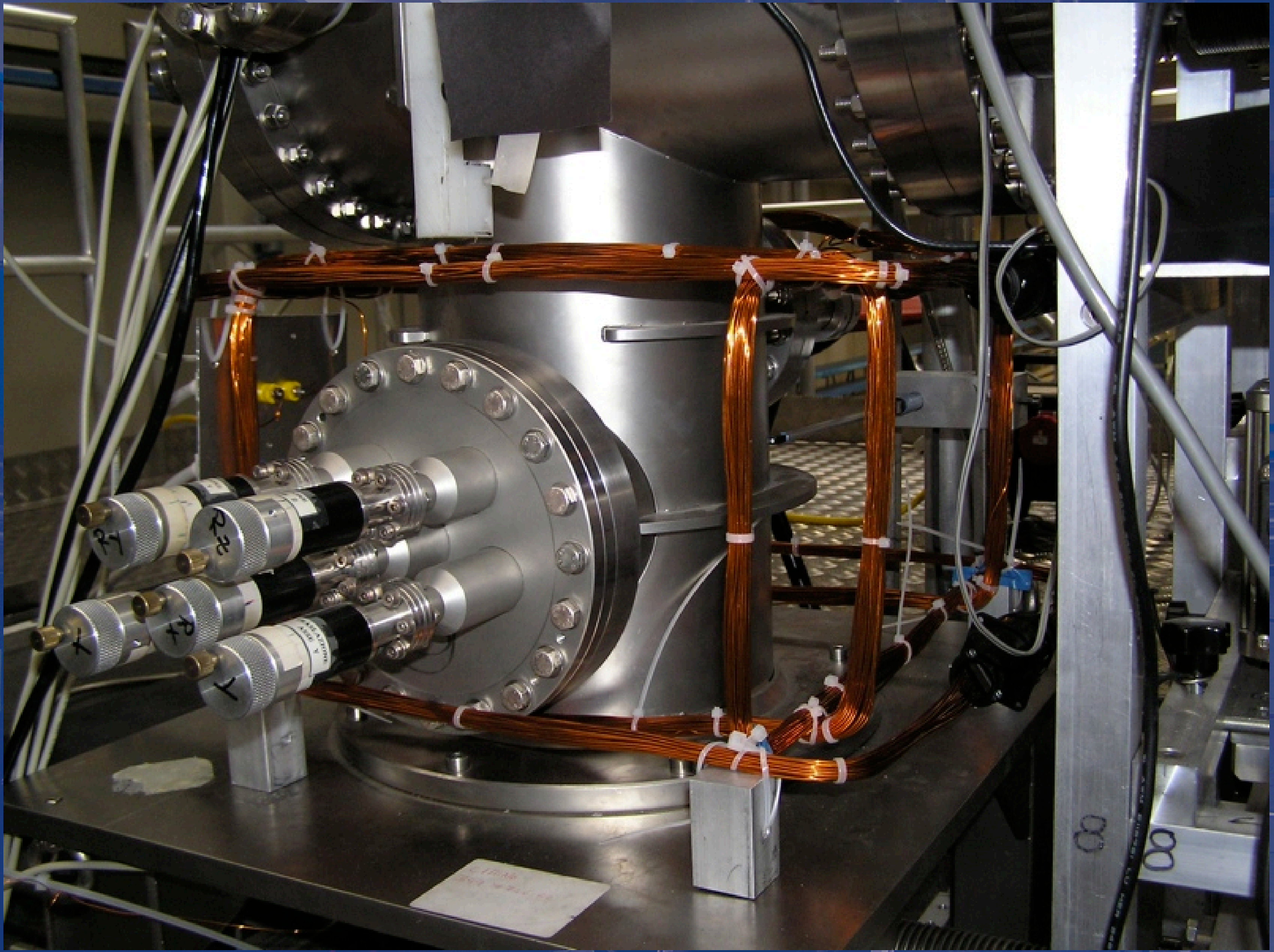
PVLAS hall at LNL



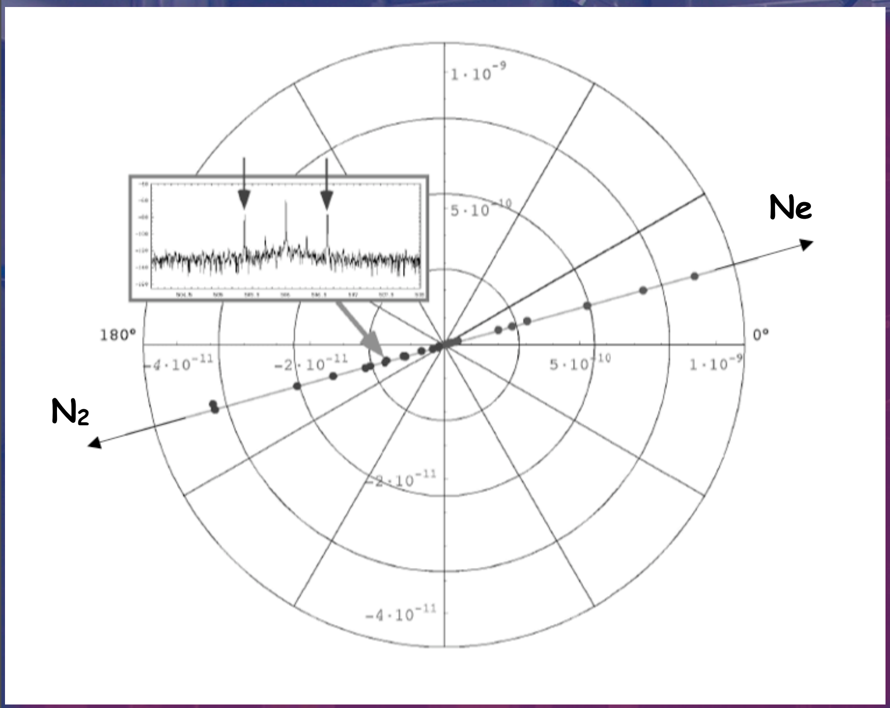
Aluminum access structure



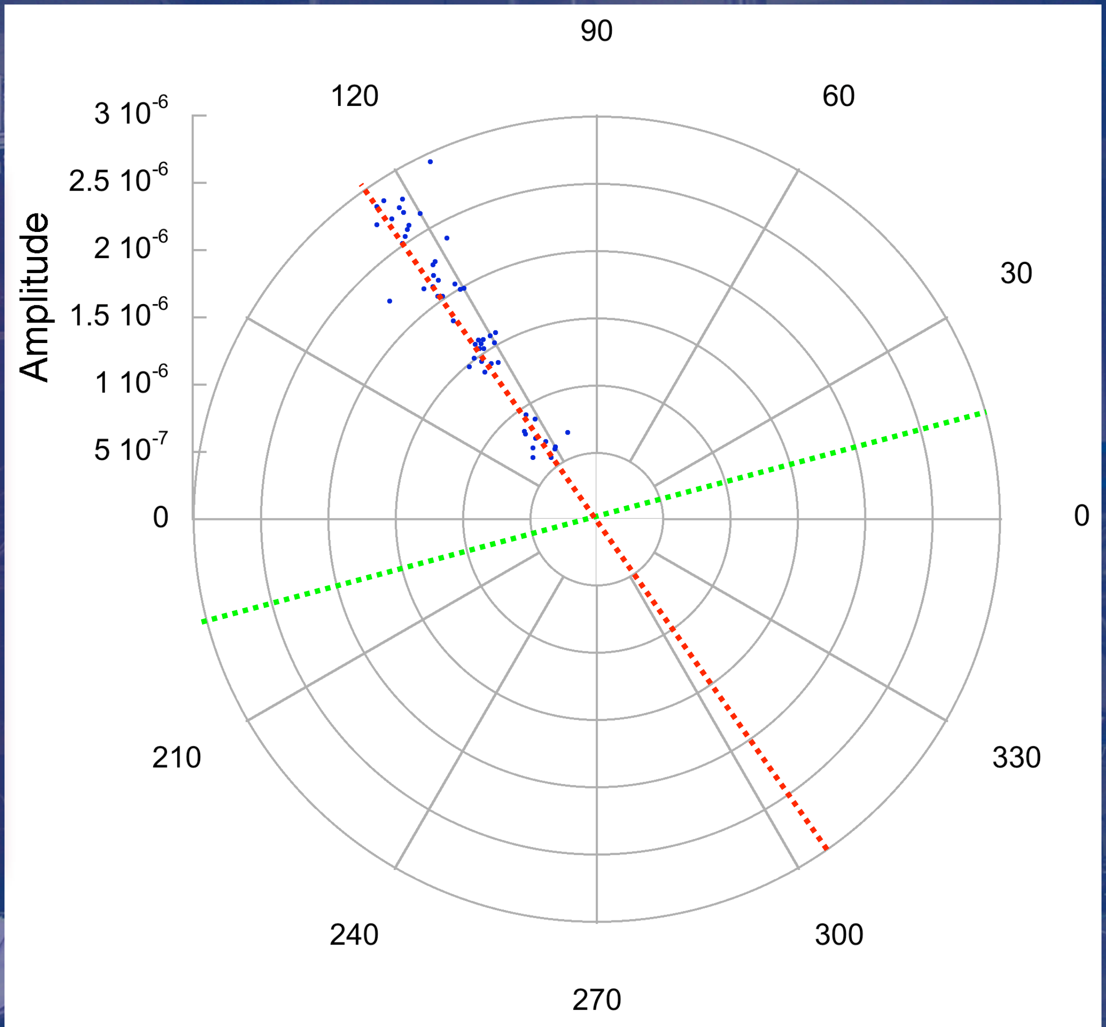
Helmoltz coils



Checks with Cotton-Mouton in He gas

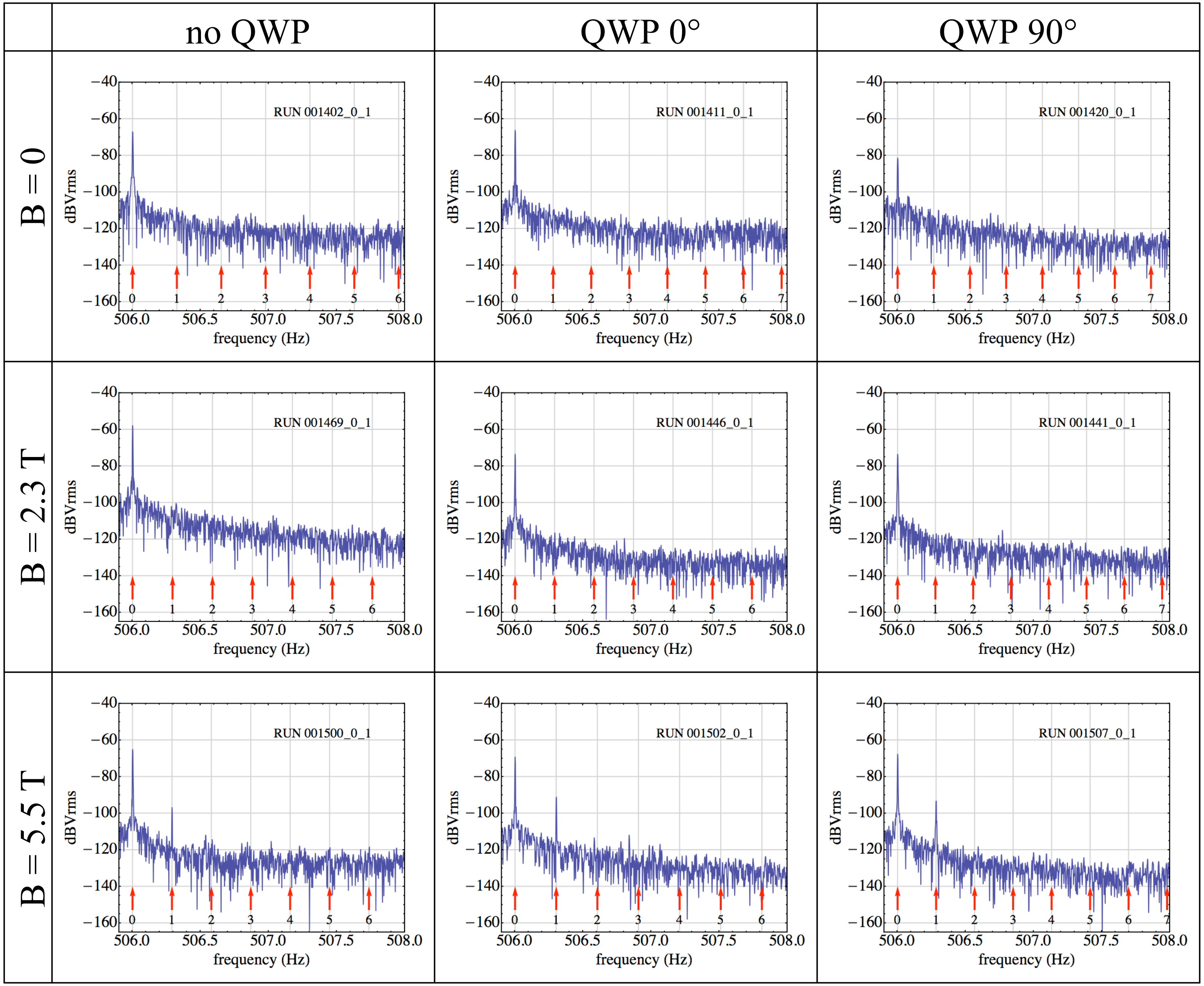


Old initial polarization direction



New initial polarization direction: measured physical axis rotates by 108° as it should

Graphical summary of vacuum measurements



Let us summarize...

- The signals observed in 2006 (and before) are due to actual changes in the light polarization state
- Direct sources of instrumental artifacts are excluded and attention is focussed on fringe fields and on possible indirect sources
- Several upgrades to the apparatus are then made with the main intent of reducing the supposed effects of fringe fields
- Data are taken in the new configuration at 2.3 T, when no fringe fields escape the magnet iron yoke, and at 5 T, to duplicate previous mesurements
- Preliminary observations
  - no peaks in rotation and ellipticity are observed when running at 2.3 T
  - no rotation peak is observed also at 5 T (ellipticity statistics are too low for a definite statement at 5 T)

Questions

- Where have the peaks gone?
  - Is the magnet actually on? Yes! Gas data prove that the apparatus is working
  - Is there an indirect source of artifacts which was present before and has now gone away?
- What can we check?
  - make a list of indirect sources and try to excite them first externally and then by a local controlled magnetic field
  - go back to the pre-upgrade configuration, where possible, and see if the signals reappear

"Indirect" instrumental sources

Candidate	Test	Comment
fringe field-induced modulation of the frequency-locking circuit offset (rotation and ellipticity)	modulate offset	can generate rotation and ellipticity at the modulation frequency
fringe field-induced amplitude modulation of the SOM carrier signal	AM modulation of the SOM sine-wave excitation	- can generate both first and second harmonics of the modulation frequency (the second only if modulation deep enough) - cannot be excited by a local field of a few Gauss
fringe field-induced amplitude modulation of laser intensity	modulate pump diode current	same as the above
fringe field-induced mechanical movements	modulate by moving 40 kg inertial mass	can generate a birefringence at the modulation frequency

Partial answers

- No definite answer yet on where the peaks have gone
- Indirect sources
  - only two of them can generate a second harmonic of the excitation frequency if this is not already present
  - local fields of a few G, larger than those actually present when running at 5 T, do not excite a response
- Conclusion: the signals at 5 T are not produced by a"simple"conspiracy of direct and indirect effects, but there must be some higher order combination of two, or even more, sources acting together
- Other checks
  - Fringe field amplitudes at mirror position have not changed
  - Room temperature tests with old laser show no difference -> will carry out "cold" tests
  - impossible to go back with cables and structure
  - circuit shielding has been put in and taken out with no appreciable effect
  - rotation of the initial polarization should have no effect -> will go back to previous position for next run

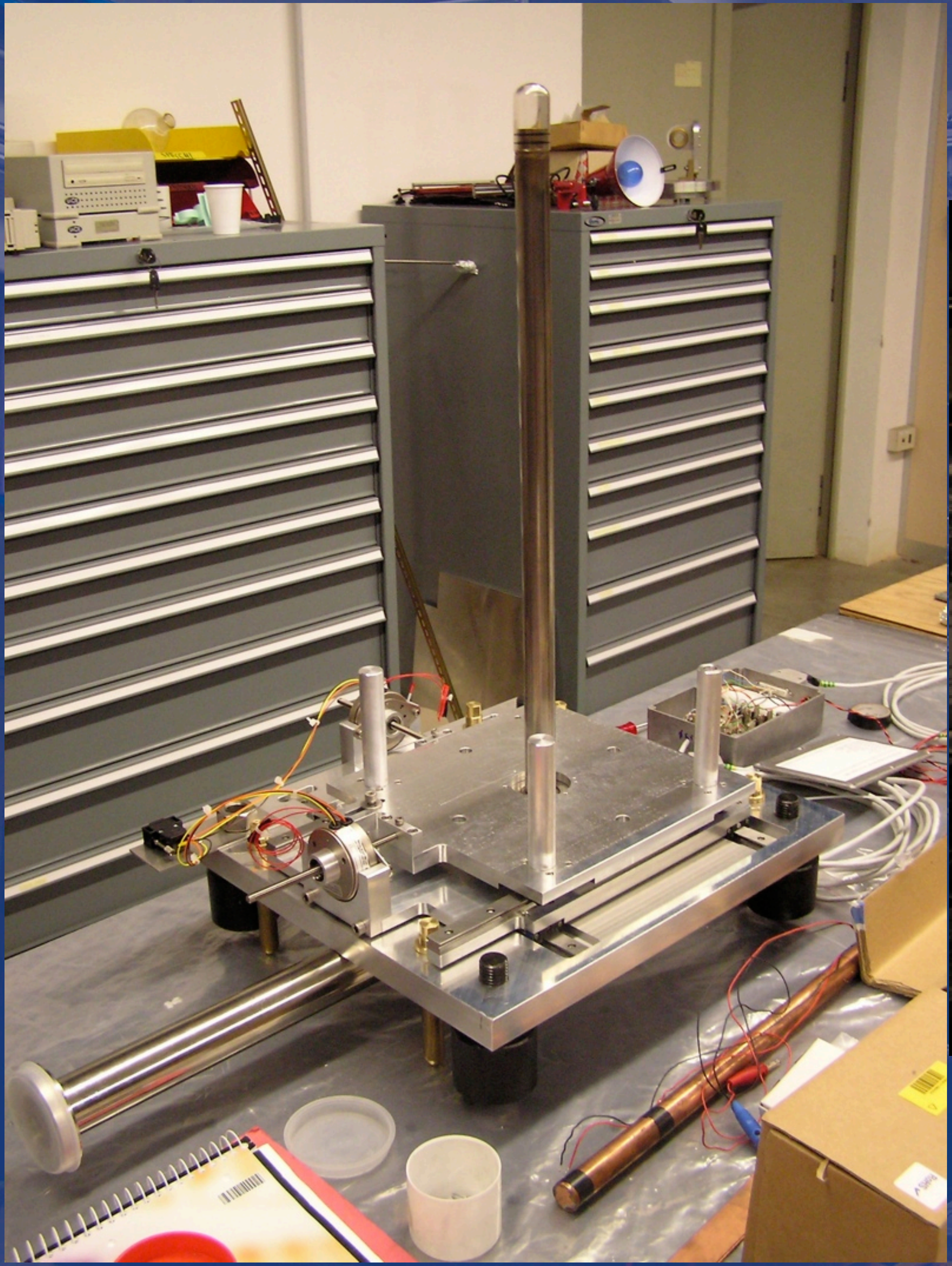
Current activities

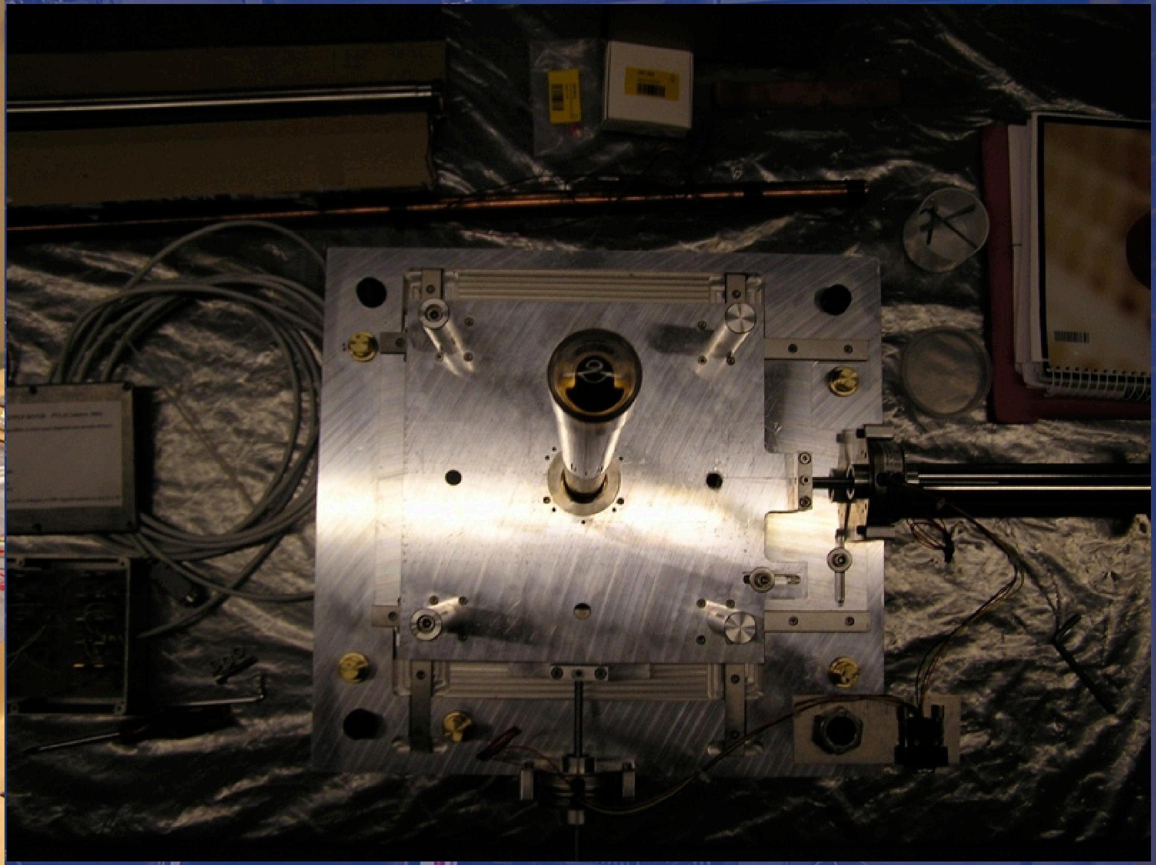
- Write-up of new results
- "Room temperature" tests at LNL (see previous table)
- Upcoming "cold" run (end of June)
  - repeat vacuum ellipticity and rotation measurements
  - no cavity measurements
  - field re-mapping inside the magnet
  - further diagnostic tests

Programs for second half of 2007

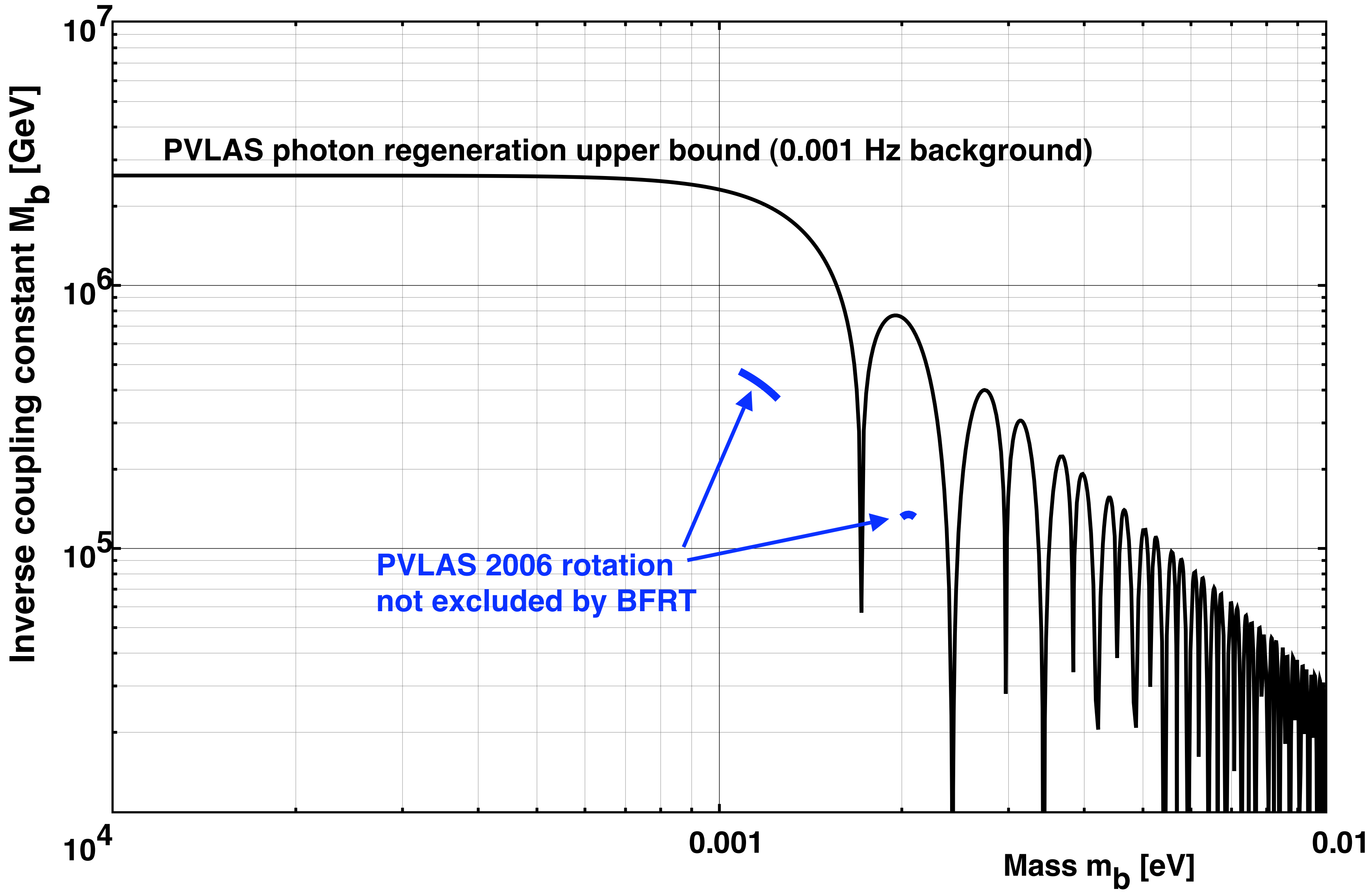
- Three "cold" runs
  - June-July -> completion of tests
  - October -> further tests + regeneration commissionins
  - November-December -> regeneration science runs
- understanding of instrumental artifacts
- tests of regeneration apparatus and detector
- regeneration measurements
  - "physical" answer to the interpretation of old signals
  - new bounds in the m-M plane

Regeneration apparatus





Expected upper bound from regeneration



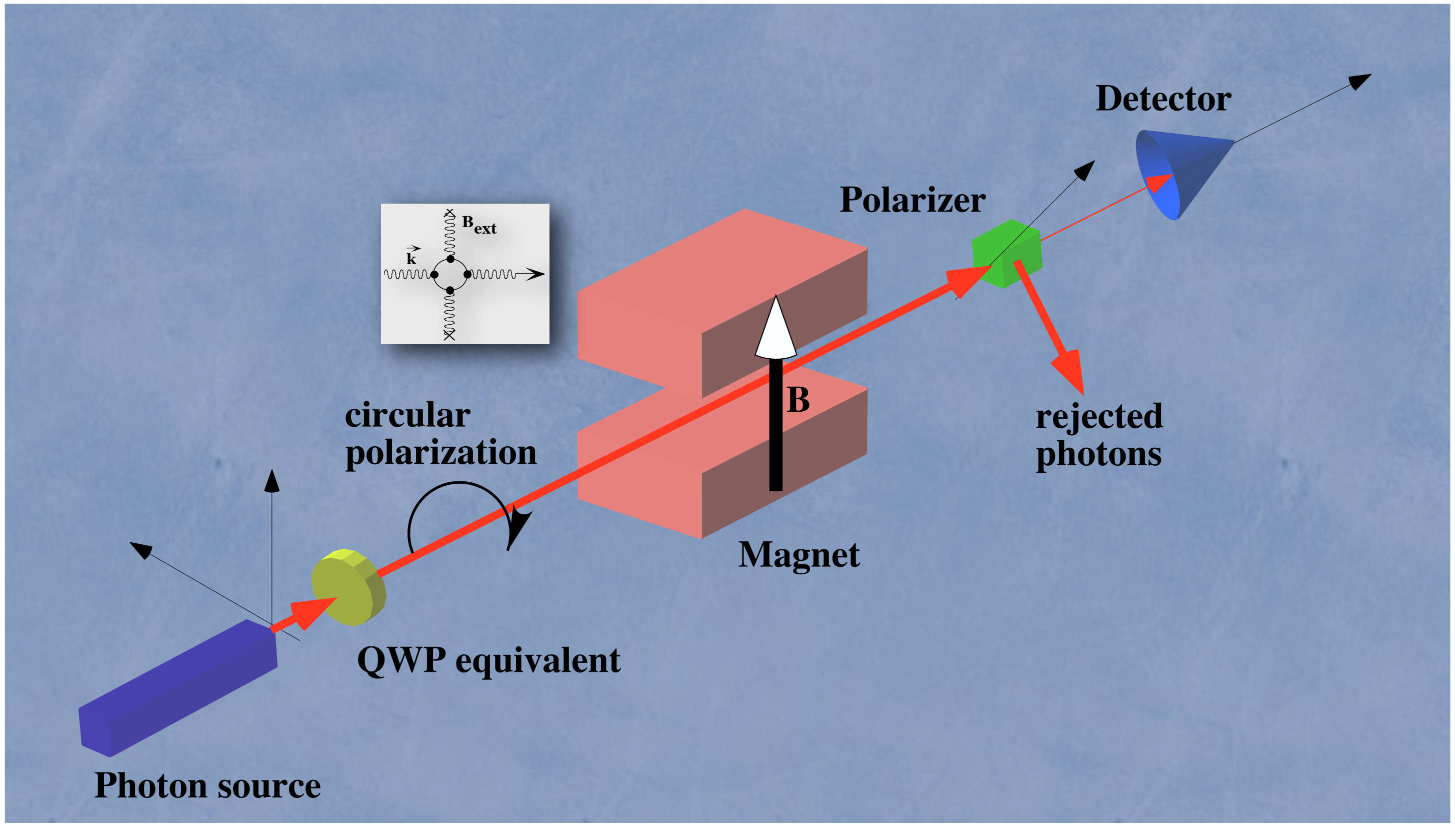
Where do we go from here?

- The apparatus has been actually improved, since artifacts have disappeared
- Barring last minute surprises the attention now goes back to fighting to lower the noise floor
- Possible approach
  - implement several feedback schemes to actively stabilize the optics
  - improve on the SOM modulator
  - better mirrors with higher reflectivity and lower intrinsic birefringence
  - use fiber optics to stay away from fringe fields
- Goal: reach a sensitivity of at least 10^{-8} rad/ $\sqrt{\text{Hz}}$
- Question: is there an intrinsic sensitivity limit for this type of measurement technique and has it already been reached?

Future approaches

- Question: is there an intrinsic sensitivity limit for this type of measurement technique and has it already been reached?
- If yes, the answer might be to move up in energy (keV-MeV range) to FEL-like photon sources
  - larger effects (in some cases)
  - large photon fluxes
  - beat noise through single photon conting
  - possibility to use pulsed sources and pulsed fields
- Challenge: how to measure polarization to a sufficient level of precision (one part in 10^{-8} is standard with visible photons)
- Strategy: look around for a suitable photon source and learn how to measure polarization for high-energy photons

Idealized "high-energy" photo scattering experiment



Relevant quantities

- Use Mueller matrix formalism to represent action of optical elements (including the magnetic field) on Stokes vectors representing the polarized photon beam
[...omissis...]

$$\Delta = \frac{\pi}{\lambda} L \Delta n \approx \left(2 \cdot 10^{-17}\right) \left(\frac{E_\gamma}{\mathrm{eV}}\right) \left(\frac{L}{\mathrm{m}}\right) \left(\frac{B^2}{\mathrm{T}^2}\right).$$

$$\text{signal} = R_{on} - R_{off} = N_\gamma \frac{(1-\epsilon^2)}{2} sin 2\Delta \qquad \text{noise} = \sqrt{N_\gamma \frac{(1+\epsilon^2)}{2}}$$

$$\boxed{\mathrm{SNR} = \sqrt{2}\Delta \frac{(1-\epsilon^2)}{\sqrt{1+\epsilon^2}} \sqrt{N_\gamma} \sqrt{T}}$$

Assuming Δ<<1 and polarizer with unit transmittivity

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If experiments had been easy somebody else would have already done them...