Interferometry for a measurement of vacuum magnetic birefringence

With the ALPSII magnet string

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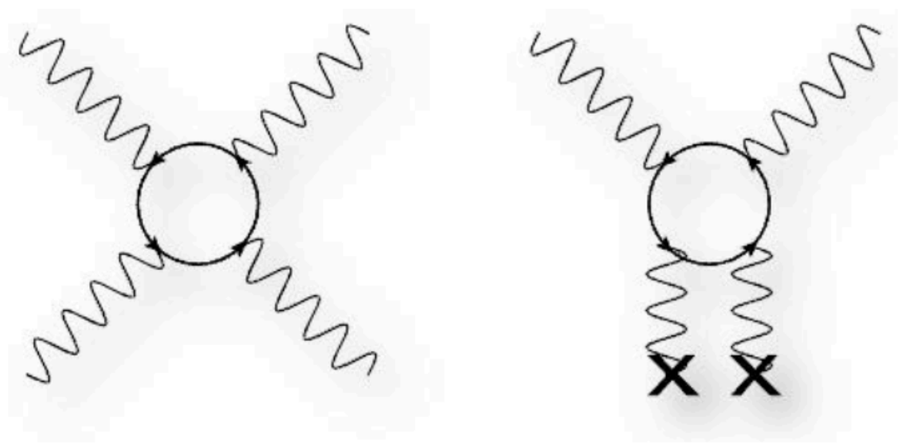
Deutsches Elektronen Synchrotron (DESY)

Introduction to VMB:

A fine subtlety of quantum electrodynamics



- Originally predicted by the four field interactions involving only photons

$$n_{\parallel} - n_{\perp} = 3A_e B^2 \rightarrow \Delta n \approx 3.96 \times 10^{-24}\ \mathrm{T}^{-2}$$

- Supported by Dirac's theory of the positron and the Euler-Kockel-Heisenberg Lagrangian:

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

Main components of a signal

& ALPSII Infrastructure

What we need:

- We measure optical path length differences between orthogonally polarized fields

$$\Delta\Lambda = \Delta n \times L$$

- Generating VMB: $\Delta n_{vmb} \approx 3.96 \times 10^{-24} \times B^2$

- Figure of merit: $\Delta\Lambda \propto B^2 L$

ALPSII experiment at DESY is a light shining through a wall (LSW) axion dark matter search approaching final science runs.

Main components of a signal & ALPSII Infrastructure

What we have:

- HERA superconducting magnet string at DESY, Hamburg Germany

$$B = 5.3 \text{ T} \rightarrow \Delta B^2 = 27 \text{ T}^2$$

with mHz modulation capabilities

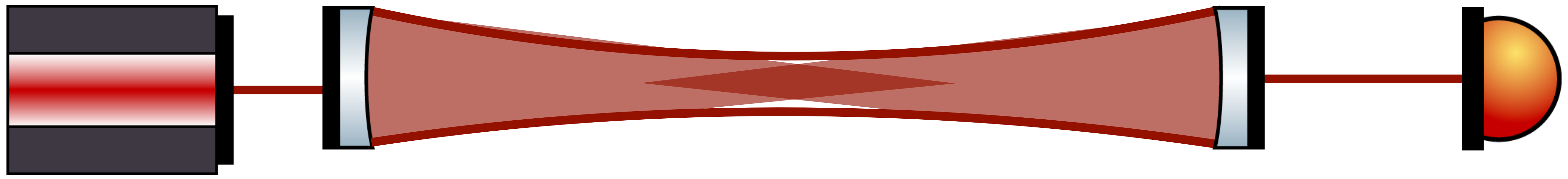
$$L_{\text{magnets}} = 212 \text{ m}$$

- Predicted amplitude in differential path length changes: 2.37×10^{-20}meters.

- Cavity length: **245 m**, with demonstrated lock

ALPSII experiment at DESY is a light shining through a wall (LSW) axion dark matter search approaching final science runs. [2]

Optical cavities



- High finesse optical cavities are widely used tools in experimental physics
    - GW detection, axion searches, & fundamental interactions
- Allows for amplification and frequency stabilization of laser light, with precisely characterized properties

Optical cavity characterization with a mode-matched heterodyne sensing scheme

Aaron D. Spector * [1] and Todd Kozlowski[1]

What we have:

l [m]	FSR	$\mathcal{F}$	Storage Time [ms],	Round Trip losses [ppm]
9	16.29 MHz	101,300	1.99 ms	33
19	7.89 MHz	32,300	1.305 ms	15.1
122.6	1.22 MHz	25,850	6.73 ms	142
245	609 kHz	7065	3.693 ms	675

Free Spectral Range

- The free spectral range of an optical cavity is defined:

$$f_{FSR} = \frac{c}{2L}$$, where L is the length of the cavity.

- Conduct high precision differential cavity length measurements between $\hat{s}$ and $\hat{p}$ polarizations resonant inside cavity
  - Extract FSR changes due to magnet induced birefringence within δf_{FSR}

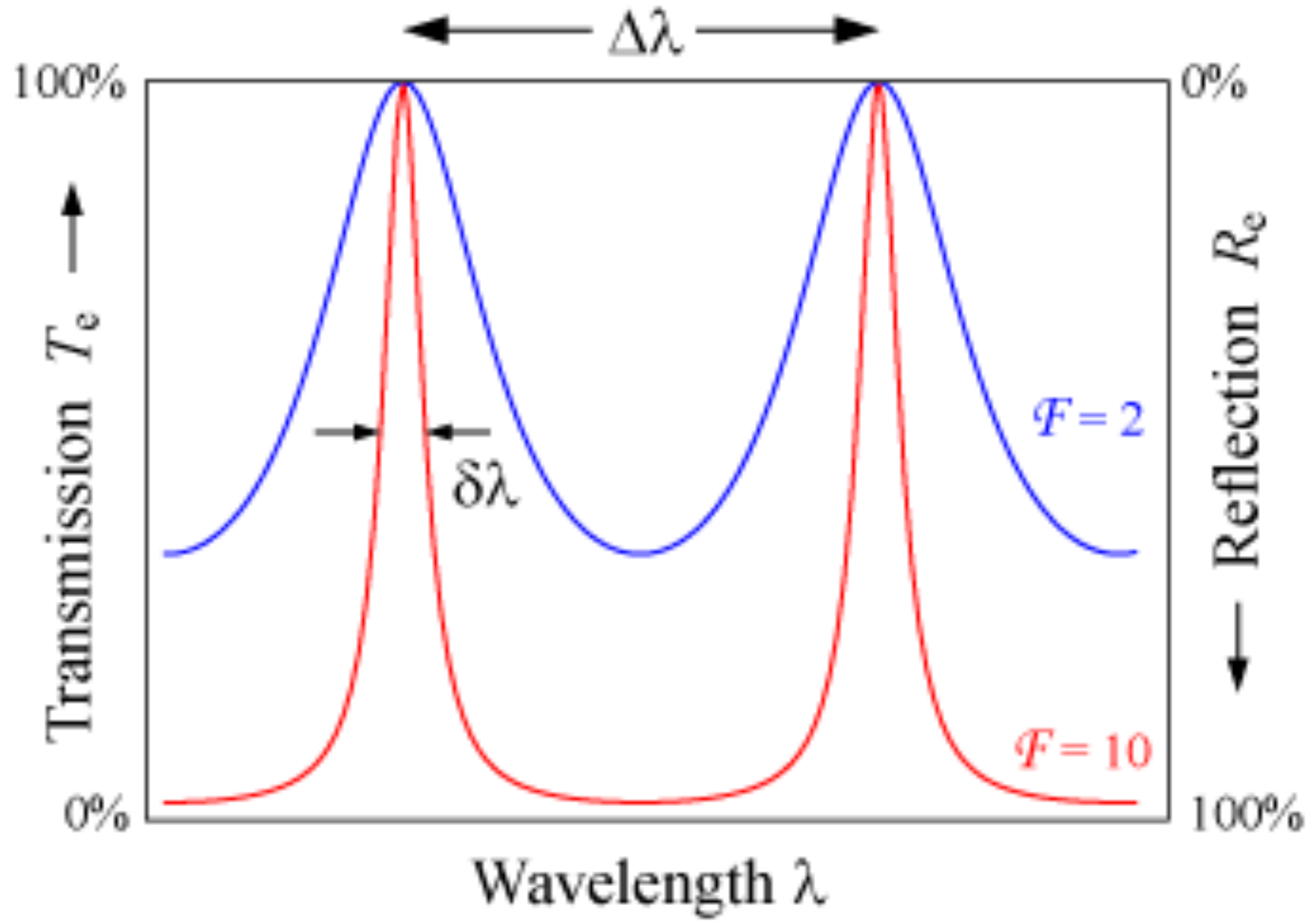


Figure: Free spectral range of optical cavity shown as transmission (left) or reflection as a function of wavelength.

Three resonance heterodyne readout

Reading VMB through the lines

1. Lock three fields to the same optical cavity, at orthogonal polarizations: 1 $\hat{p}$ and 2 $\hat{s}$ fields

2. Read out the relative beat notes between the three fields with a 4th laser: heterodyne readout

3. The relative changes of the beat notes correspond to the frequency splitting due to vmb: $\Delta\nu_\theta$

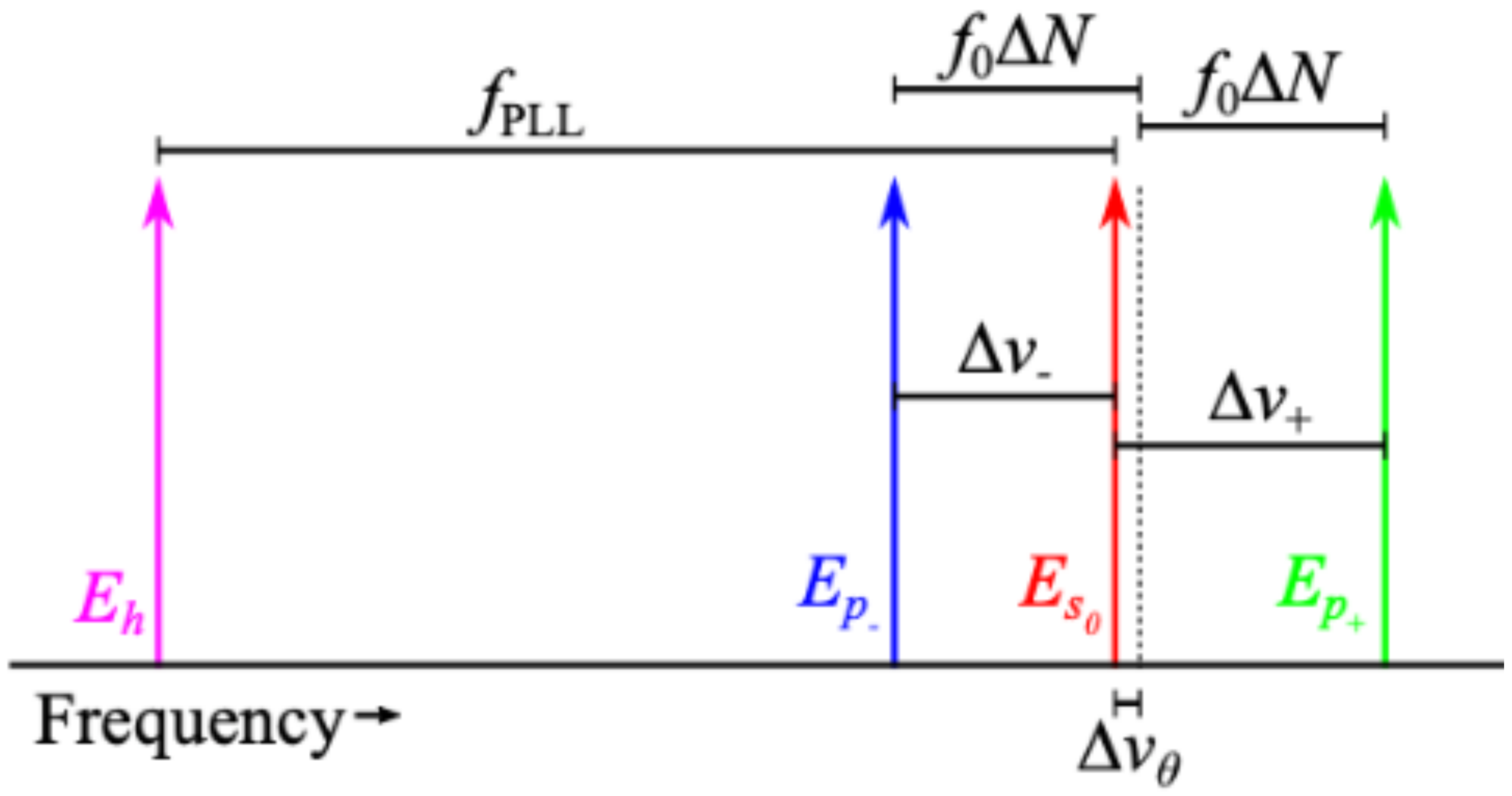
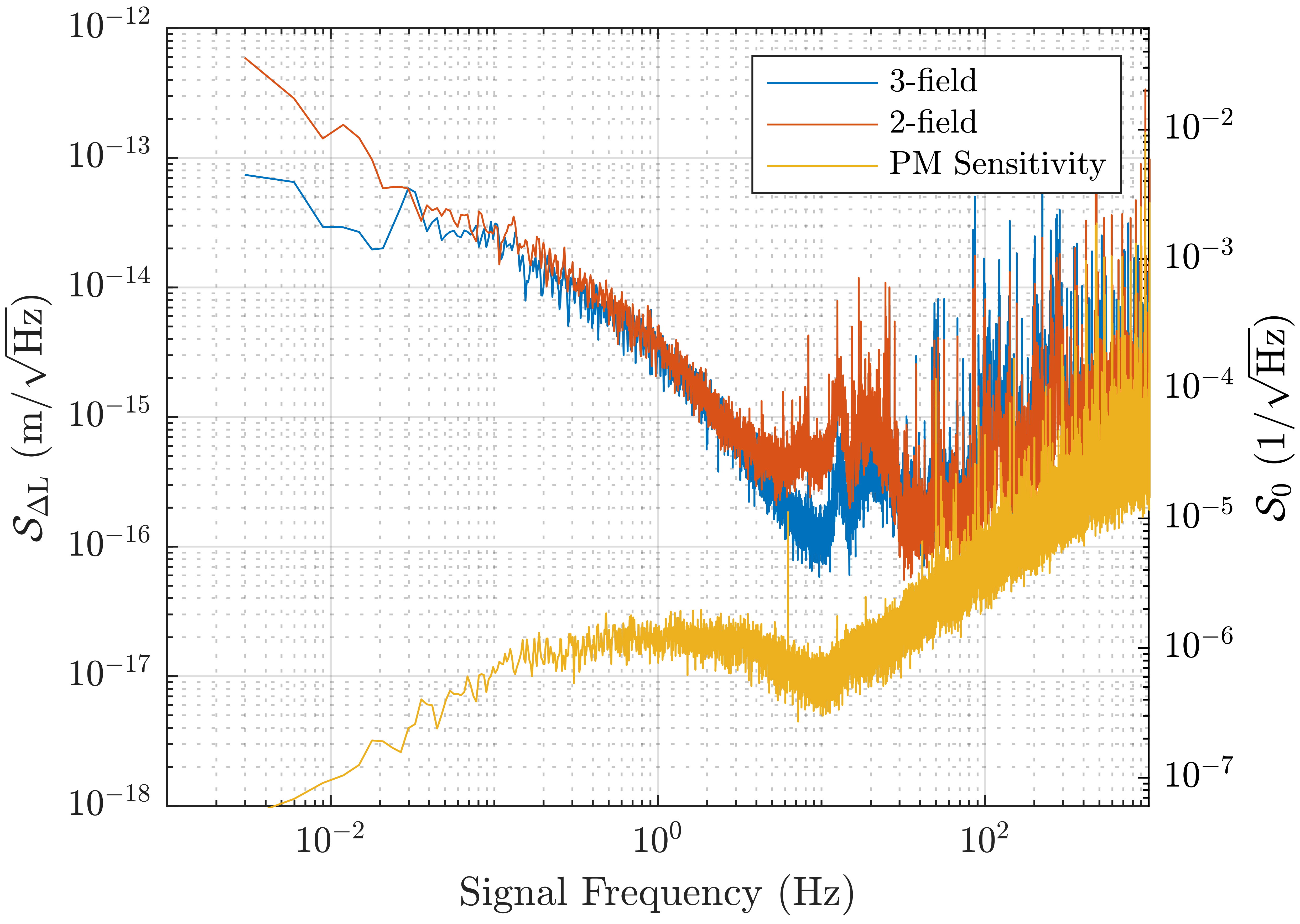


Figure: 4 resonance readout in frequency space.
Pink: LO

20m VMB prototype status

- Earlier this year: simultaneous locks of two fields from the same laser of orthogonal polarizations
    - Read out static birefringence of the cavity
- Now: Demonstrated 3 laser fields locked to different resonances of the same optical cavity
    - Allows for cavity length noise suppression



Whats next:

- Suppression of RAM via active or passive feedback to the EOMs in all 3 paths
- Introduce 4th laser for heterodyne readout of the beat notes
- Demonstration of sensitivity required of the metrology system for a measurement of VMB with the ALPSII magnet string

Thank you!

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