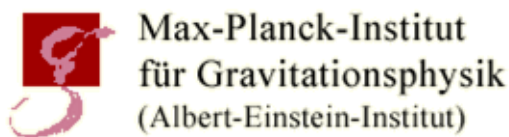


ALPS II cavity control with a surrogate field: model and experiment

Li-Wei Wei*, Hal Hollis, Aaron Spector, Dennis Schmelzer, Jan Hendrik Pöld, Ethan James Taylor, Kanioar Karan and Benno Willke

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Leibniz
Universität
Hannover

ALPS Collaboration Partners

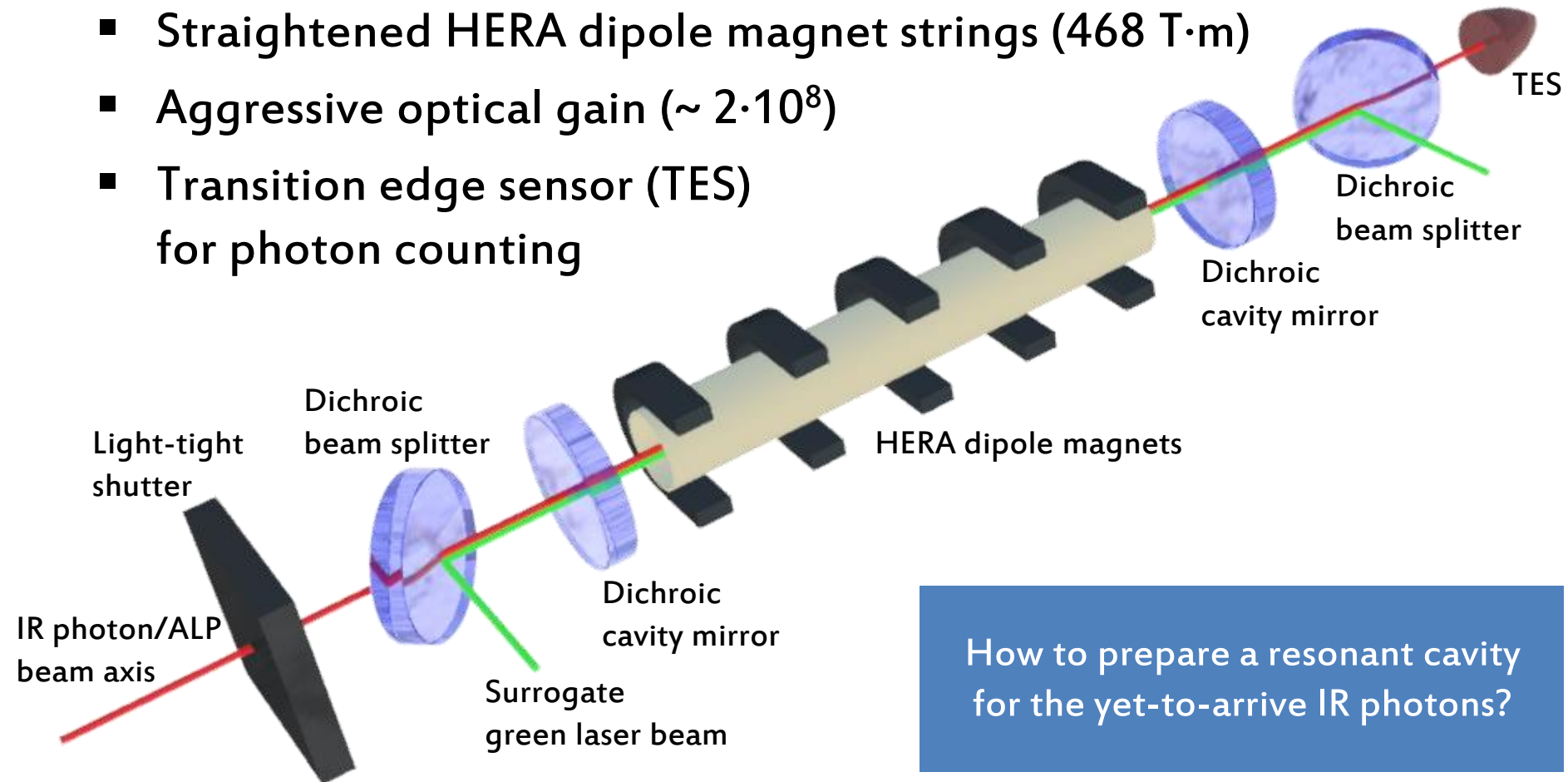
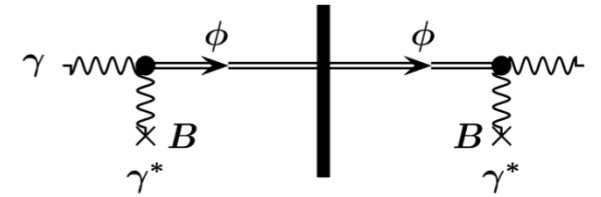


EJT was visiting from University of Wyoming via UF's IREU program

15TH PATRAS WORKSHOP ON
AXIONS, WIMPS AND WISPS
ALBERT-LUDWIGS-UNIVERSITÄT
FREIBURG, GERMANY, 3-7 JUNE 2019

Any Light Particle Search II

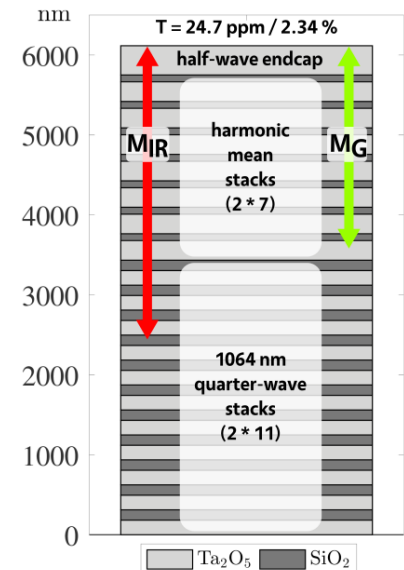
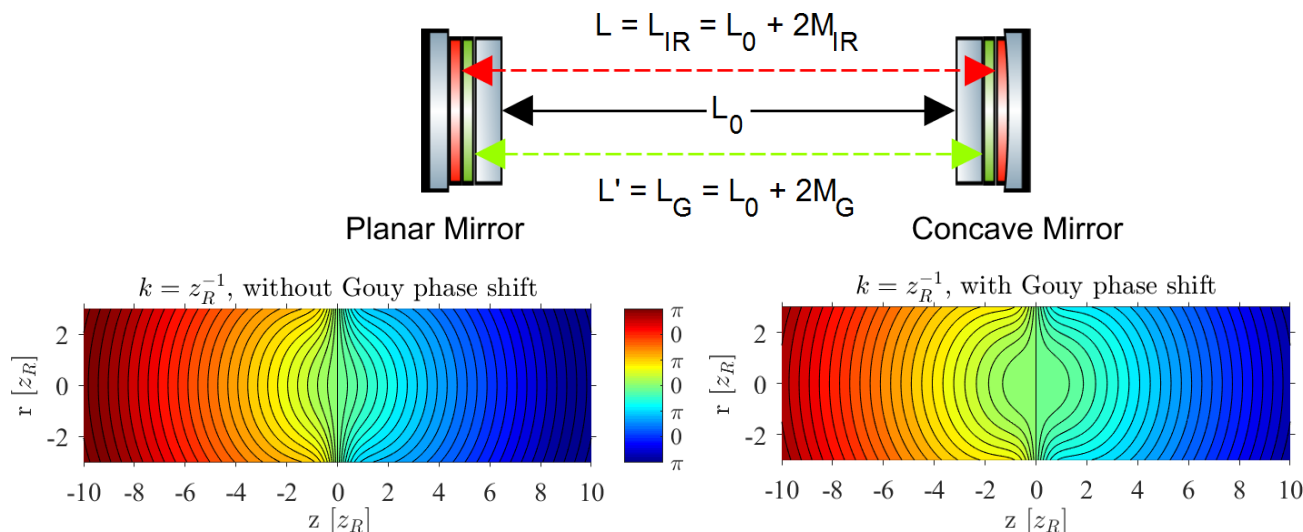
- Light-shining-through-a-wall?
- Sensitivity goal: $2 \cdot 10^{-11} \text{ GeV}^{-1}$
- Straightened HERA dipole magnet strings (468 T·m)
- Aggressive optical gain ($\sim 2 \cdot 10^8$)
- Transition edge sensor (TES) for photon counting



How to prepare a resonant cavity
for the yet-to-arrive IR photons?

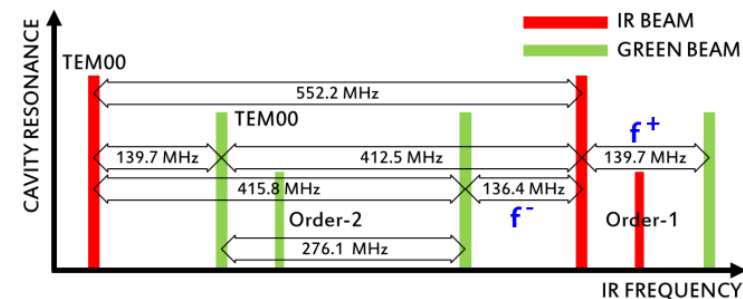
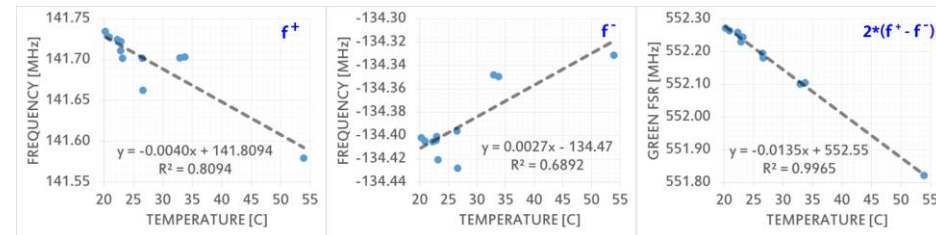
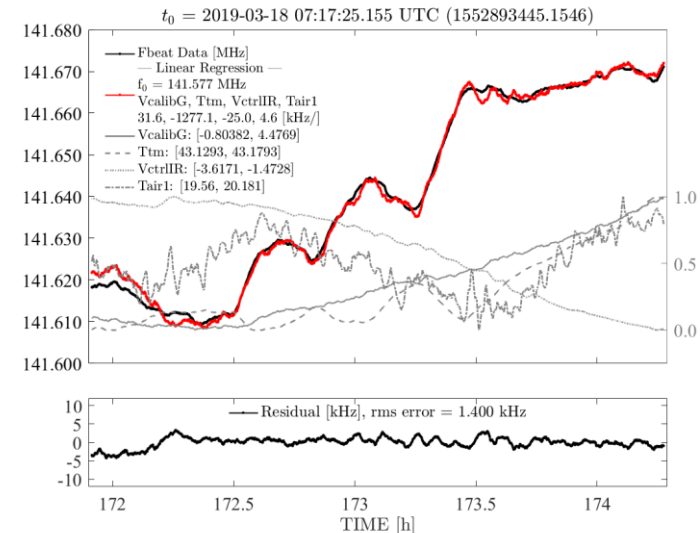
Dichroic cavity control

- Exact harmonic fields generally do not resonate simultaneously with a given cavity
 - Material property: mirror coating reflection phase / penetration depth
 - Gaussian (laser) beam property: Gouy phase shift
- A frequency offset f is anticipated for ALPS II resulting in quasi-harmonic fields
 - Harmonic relation via nonlinear optics (second-harmonic generation)
 - Offset via tunable circuits (PLL) based on stable oscillators (e.g. TCXO)
- ALPS II requires better than 1 Hz cavity resonance
 - Whatever f is, it should not change by more than 1 Hz during data run
 - On top of which we have to produce f accurately and precisely



Fidelity of the surrogate: constraining f

- Dedicated coating design and fabrication
 - Optimized temperature-dependence with Monte-Carlo simulations on tolerances
- Dichroic cavity experiment to test the coating
- Equally (or even more) prominent effects
 - Coating wavelength dependence
 - Penetration depth difference (depends on cavity configuration)
- Numerical simulation
 - Pictures the highly entangled system
 - Matches analytic analysis (with approximates and linearization)



Thank you.

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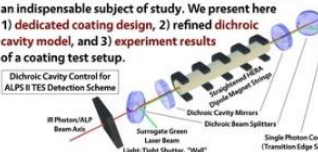


ALPS II cavity control with a surrogate field: model and experiment

Li-Wei Wei^a, Hal Hollis^b, Aaron Spector^c, Dennis Schmelzer^d, Jan Hendrik Pöld^d, Ethan James Taylor^d, Kanioar Karan^a and Benno Willke^a
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Introduction

ALPS II aims at ALP-photon coupling sensitivity $g_{\text{ALP}} \sim 2 \cdot 10^{-11} \text{ GeV}^{-1}$ that translates into some 2 photons/day in the experiment design. Aggressive optical resonant gain ($\sim 2 \cdot 10^3$) is anticipated and a dichroic cavity control scheme is proposed to be in line with the transition edge sensor required for ALPS II, the mirror coatings are an indispensable subject of study. We present here 1) dedicated coating design, 2) refined dichroic cavity model, and 3) experiment results of a coating test setup.



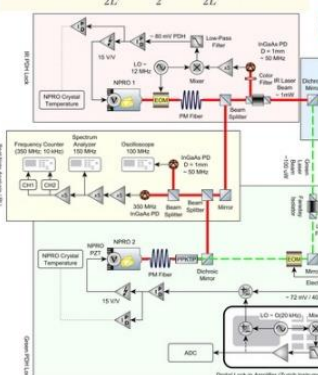
Dichroic Cavity Control for ALPS II TES Detection Scheme

Dichroic Mirror Coating and Cavity

- Coating temperature dependence optimized
- Manufacture error (random, systematic, chip) Monte Carlo analysis
- Penetration depth and cavity resonance
- Beat note frequency comb and Temperature Dependence Measurements

Test Dichroic Cavity Setup, Beat Note Frequency Comb and Temperature Dependence Measurements

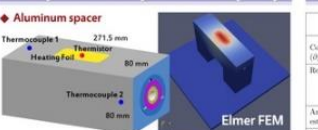
- Plano-concave linear cavity in low-vacuum
- Aluminum spacer with heat foil and temperature sensors
- Pound-Drever-Hall locks in IR and quasi-harmonic green
- IR beat note carries info on cavity dichroic properties:

$$f = \nu' - \nu = \frac{c}{2L'} \cdot \frac{(N' + 2\Psi')}{2} - \frac{c}{2L} \cdot \frac{(N + 2\Psi)}{2}$$


Test Dichroic Cavity Setup

Cavity Thermodynamic Property

- Aluminum spacer
- Thermal time constant $\sim 5.6 \text{ h}$



Eimer FEM

Beat Note Frequency Stability

Coating (ppm)	Differential Penetration Depth	Differential Temperature Dependence	Differential Wave-length Dependence
$\frac{\partial}{\partial T} \left(\frac{N}{2} - \frac{N'}{2} + \Psi - \Psi' \right) \text{ CTE}$	$\frac{\partial}{\partial \lambda} \left(\frac{N}{2} - \frac{N'}{2} + \Psi - \Psi' \right) \text{ CTE}$	$\frac{\partial}{\partial T} \left(\frac{N}{2} - \frac{N'}{2} + \Psi - \Psi' \right) \text{ CTE}$	$\frac{\partial}{\partial \lambda} \left(\frac{N}{2} - \frac{N'}{2} + \Psi - \Psi' \right) \text{ CTE}$
Remark: $L_c(T)$ and $M(T)$ are described separately and therefore do not necessarily scale proportionally with temperature $f(L(T))$.	Remark: Coating reflection phase is temperature dependent and affects $f(L(T))$.	Remark: Coating reflection phase is temperature dependent and affects $f(L(T))$.	Remark: Coating reflection phase is temperature dependent and affects $f(L(T))$.
Analysed estimate: -2.79 MHz/K for f' $+2.73 \text{ MHz/K}$ for f''	Analysed estimate: -2.79 MHz/K for f' $+2.73 \text{ MHz/K}$ for f''	Analysed estimate: -2.79 MHz/K for f' $+2.73 \text{ MHz/K}$ for f''	Analysed estimate: -2.79 MHz/K for f' $+2.73 \text{ MHz/K}$ for f''
Numerical simulation: -2.79 MHz/K for f' $+2.73 \text{ MHz/K}$ for f''	Numerical simulation: -2.79 MHz/K for f' $+2.73 \text{ MHz/K}$ for f''	Numerical simulation: -2.79 MHz/K for f' $+2.73 \text{ MHz/K}$ for f''	Numerical simulation: -2.79 MHz/K for f' $+2.73 \text{ MHz/K}$ for f''

Conclusions

Experiment is motivated by ALPS II requirements to measure the temperature dependence of a custom specialty coating. Wavelength dependence and penetration depth difference however also play significant roles that may have to be considered in future coating designs. Beat note frequency for a doubly-resonant dichroic cavity is modelled and explains well the experiment observations. Numerical simulations are set up to aid further experiment designs including ALPS II and JURA (Joint Undertaking in Research on Axion-Like Particles).

Although preliminary, coating manufacture tolerance is estimated from the experiment results and complies with vendor specifications.

For ALPS II our experiment suggests coating design and cavity length stabilization be considered as a whole.

Bibliography

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Any Light Particle Search - <https://alps.desy.de/>