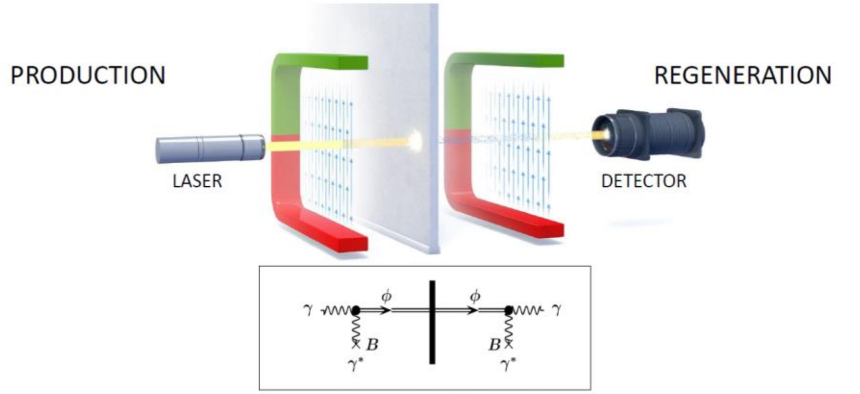
Towards New Particle Discoveries:
the ALPS-II Experiment Shines Soon



Sikivie 1983, Van Bibber et al. 1987

Ayman Hallal

University of Florida

for the
ALPS collaboration

EPS-HEP Conference
online conference
July 26-30 2021

Motivation

- ALPS II: Any Light Particles Search
  - Light-Shining-through-Wall (LSW) experiment
  - model independent

- Axion-Like Particles:
  - potential dark matter candidates
  - could explain astrophysical phenomena that are not explained by the standard model: e.g. TeV transparency and Stellar cooling excess

Motivation

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  - Light-Shining-through-Wall (LSW) experiment
  - model independent

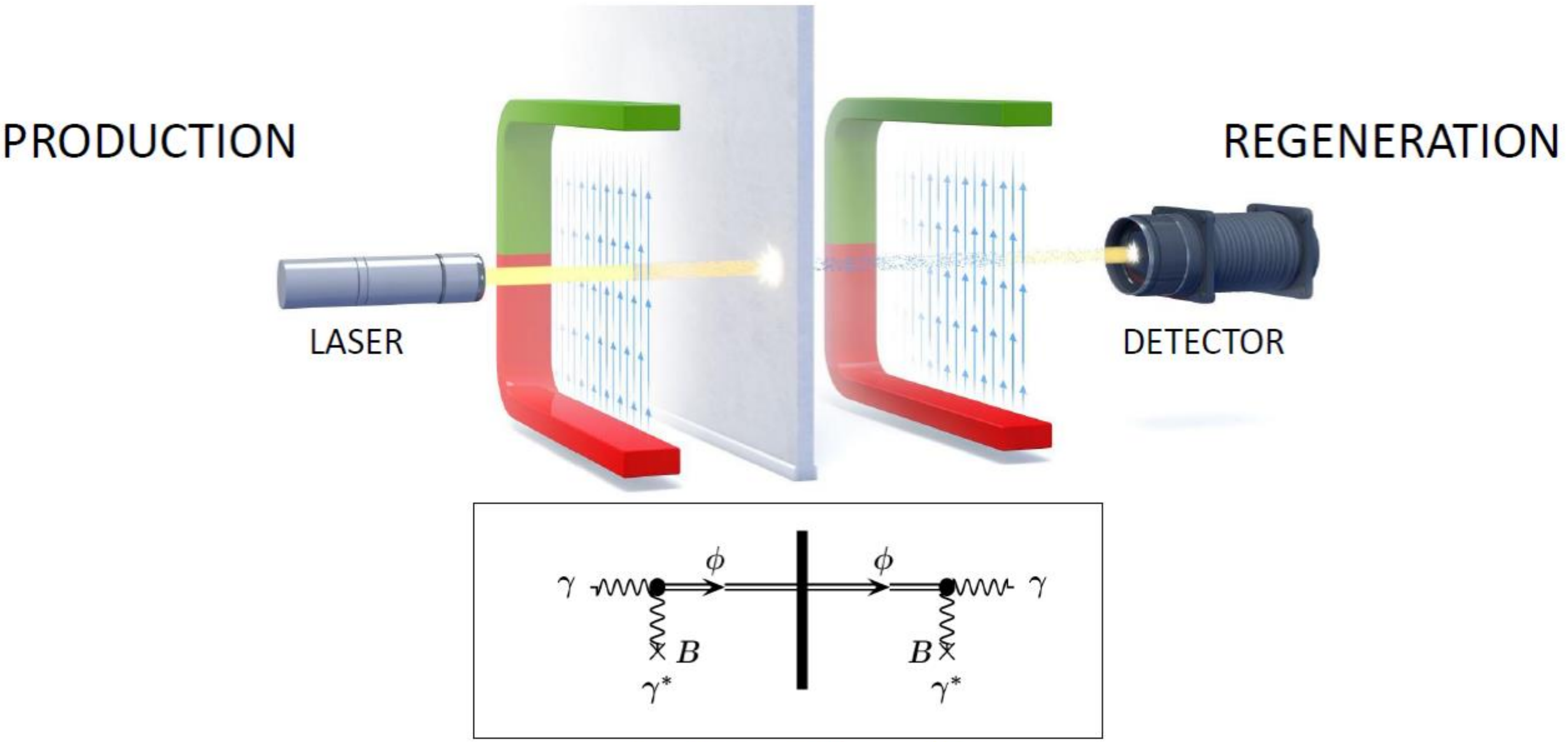
ALPS-II could reach the QCD Axions !
New fundamental research:

Di Luzio, L., Gavela, B., Quilez, P. *et al.* An even lighter QCD axion. *J. High Energ. Phys.* **2021,** 184 (2021). https://doi.org/10.1007/JHEP05(2021)184

Sokolov, A.V., Ringwald, A. Photophilic hadronic axion from heavy magnetic monopoles. *J. High Energ. Phys.* **2021,** 123 (2021). https://doi.org/10.1007/JHEP06(2021)123

- Axion-Like Particles:
  - potential dark matter candidates
  - could explain astrophysical phenomena that are not explained by the standard model: e.g. TeV transparency and Stellar cooling excess
- Photophilic axions couple strongly with photons:
  - further increases motivation for ALPS-II

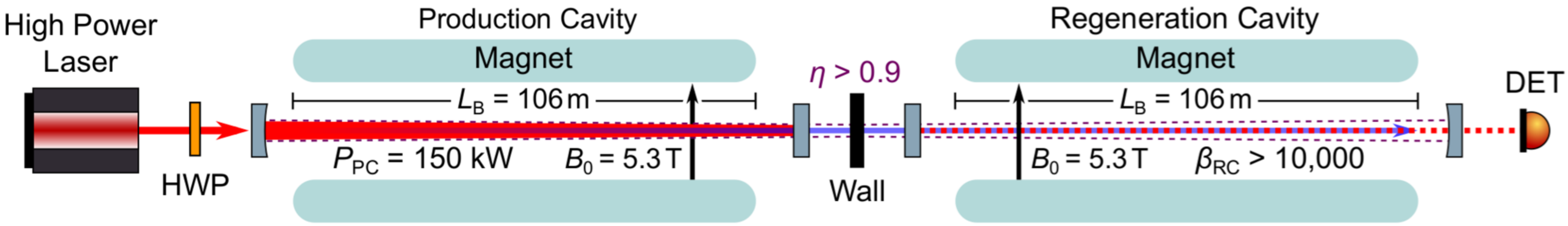
ALPS: a Light-Shining-through a Wall Experiment



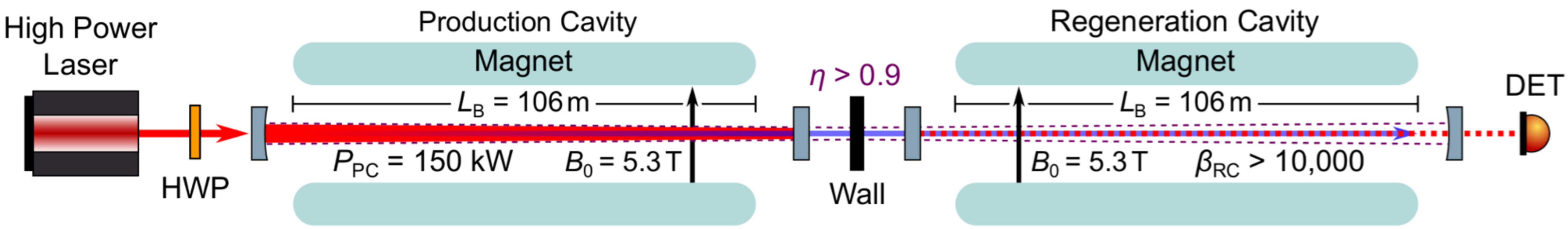
Sikivie 1983, Van Bibber et al. 1987

- pure laboratory setting —> Model Independent
- Axions-Photons mixing in magnetic field (the Primakoff/Sikivie-effect)

ALPS II Overview



ALPS II Overview



ALPS II:

- 5.3 T over 106m
- $P_{PC} > 150\text{kW}$ of circulating power in Production cavity (Goal $> 1\text{MW}$)
- $\beta_{RC} > 10{,}000$ of Power build up ratio in the Regeneration cavity (Goal $> 40{,}000$)
- $\eta > 0.9$ of power coupling efficiency between the two Cavities

Number of regenerated photons:

$N_s = \eta^2 N_{PC} \beta_{RC} \frac{1}{16} (g_{a\gamma\gamma} BL)^4$ **= few photons per week !** Detected with Heterodyne or TES detectors

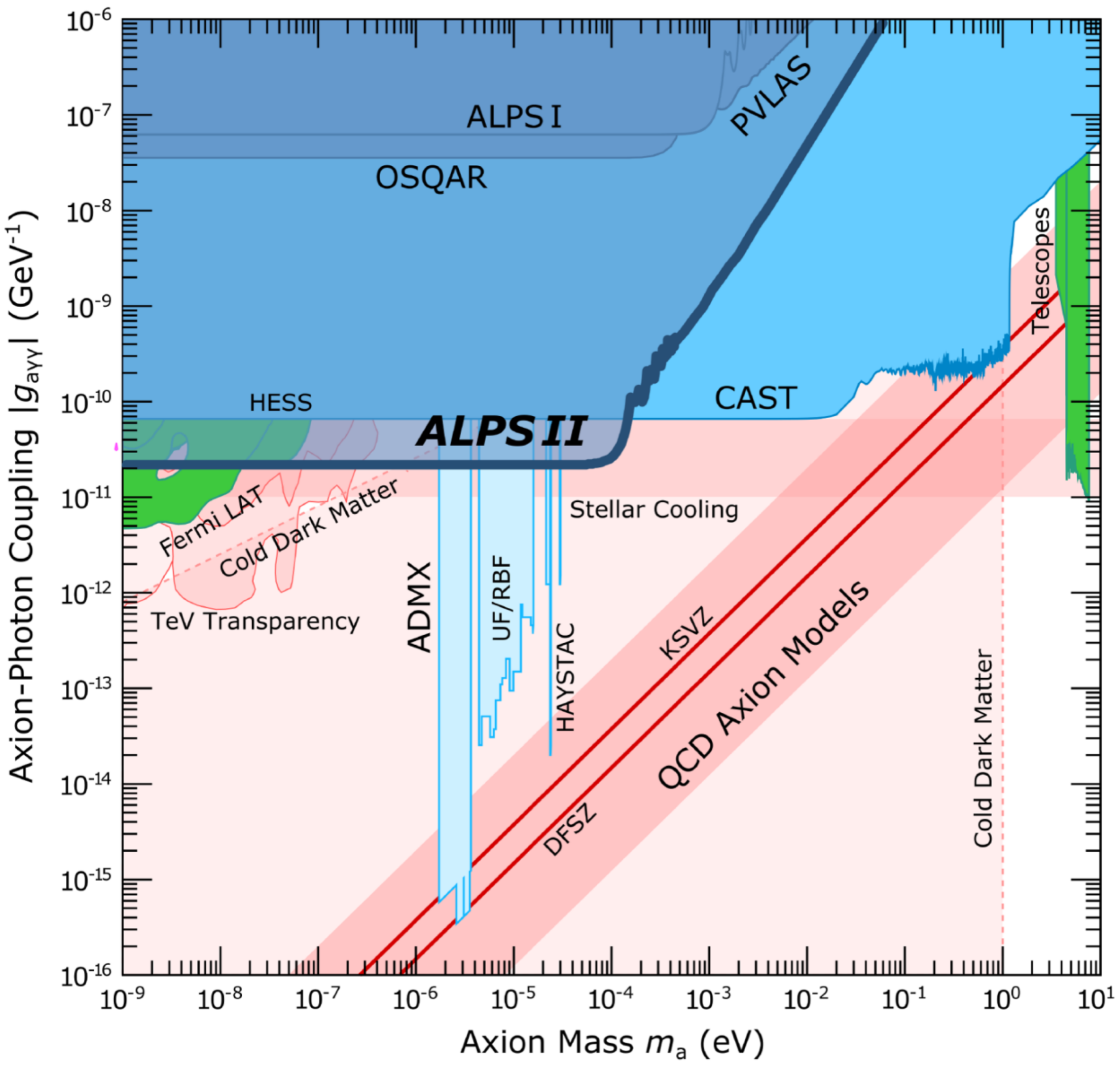
Innovative optics increases regenerated photon rate by 12 orders of magnitude!

ALPS II Sensitivity

ALPS II: designed to detect less than 10^{-5} ph/s of regenerated photons (10^{-24} W)
→ $g_{a\gamma\gamma} = 2 \times 10^{-11}\ \mathrm{GeV}^{-1}$ for $m_a \leq 0.1$ meV

ALPS-I (2010): a 20m baseline experiment with no regeneration cavity

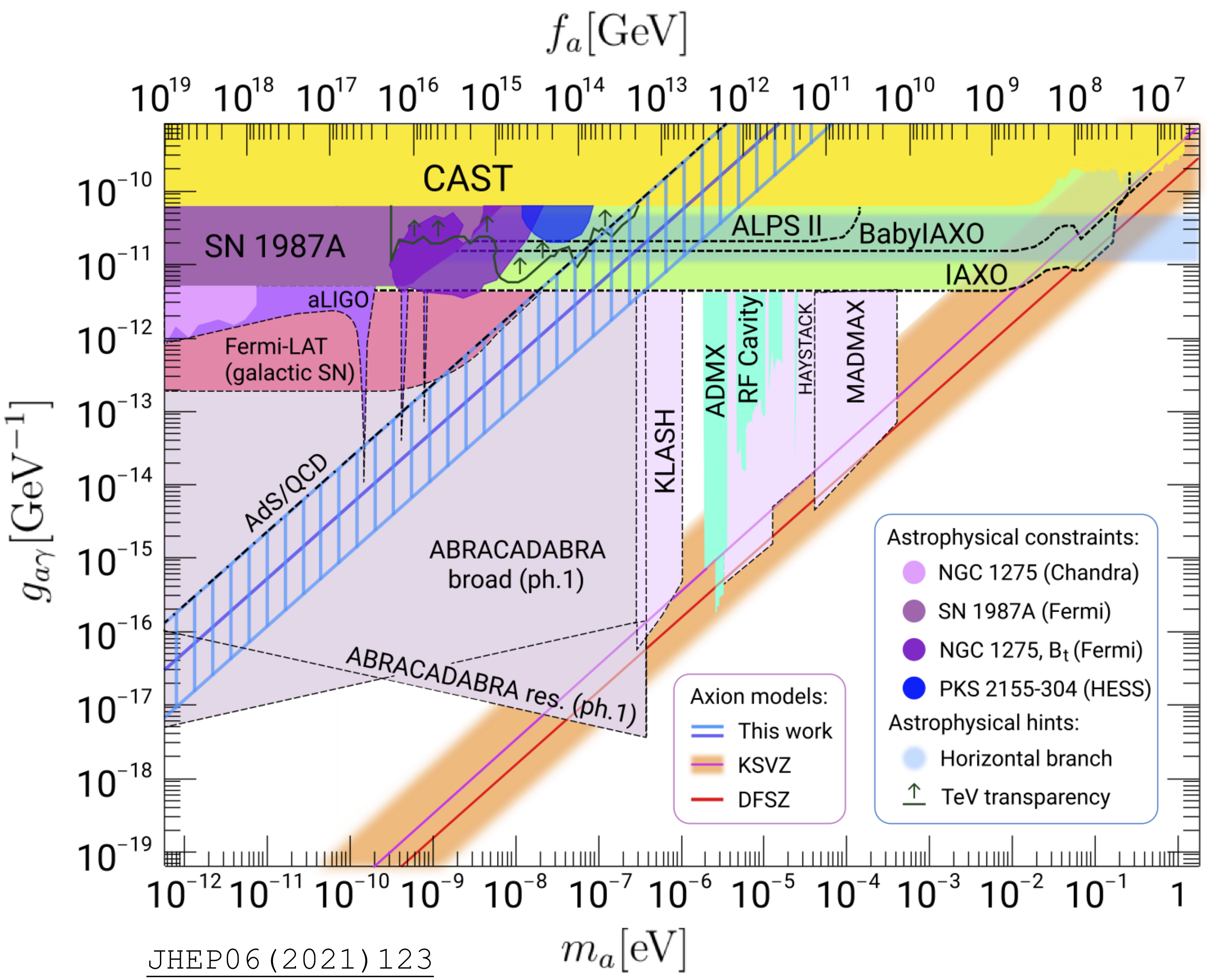
arXiv:2009.14294v3



ALPS II Sensitivity

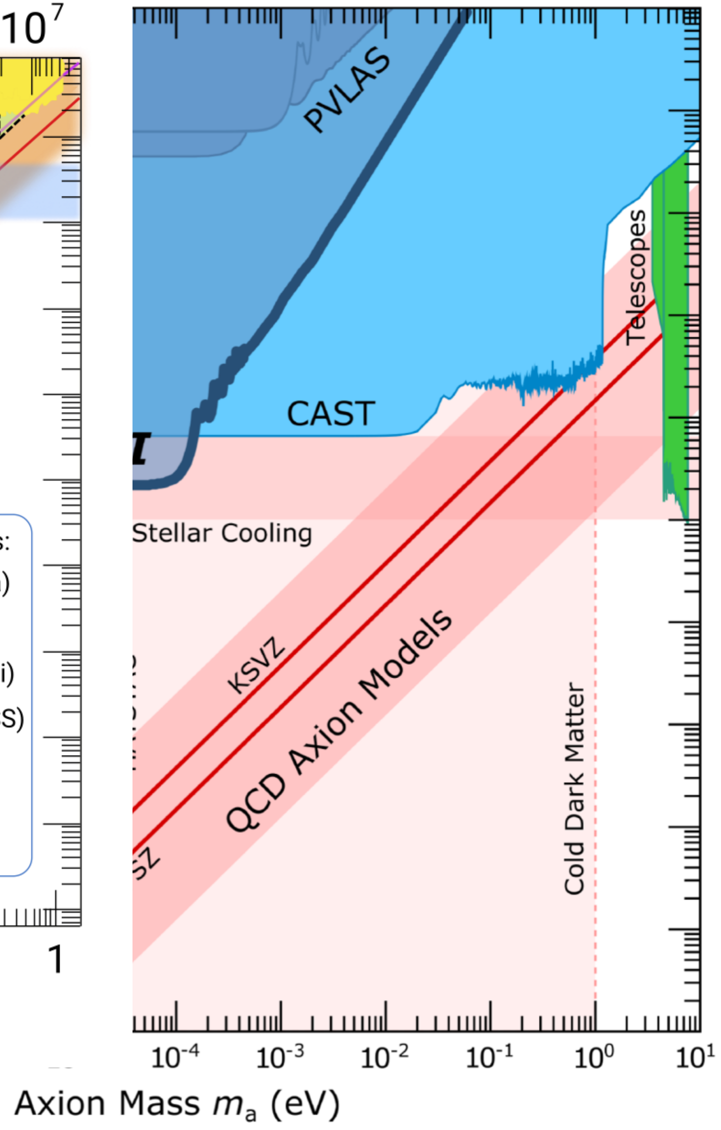
ALPS II: desig
regenerated |
→ $g_{a\gamma\gamma} = 2$

ALPS-I (2010)
regeneration



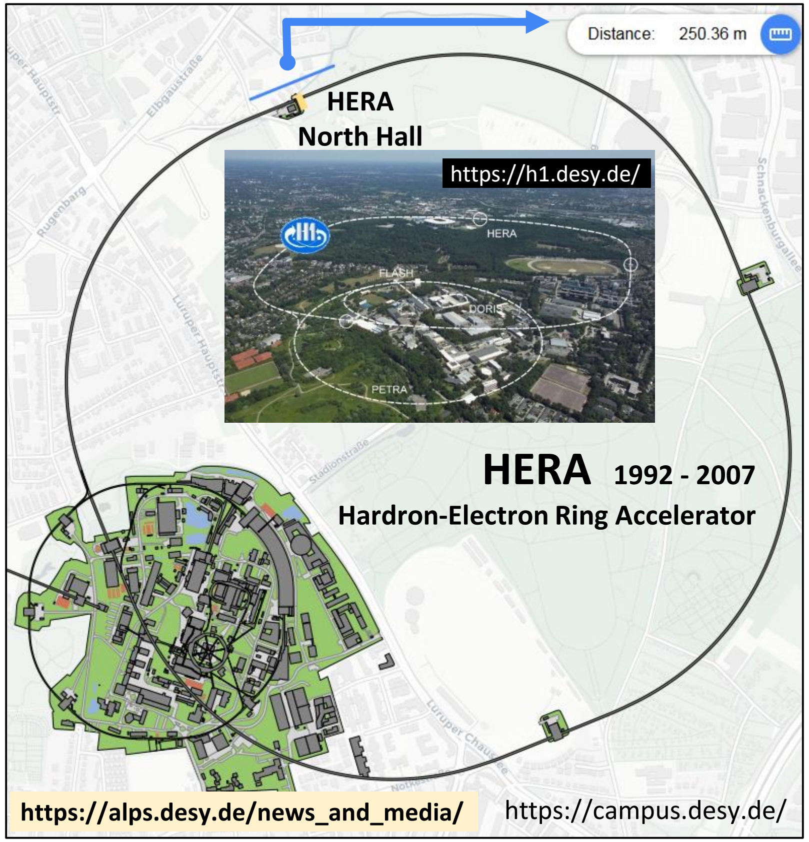
JHEP06(2021)123

arXiv:2009.14294v3

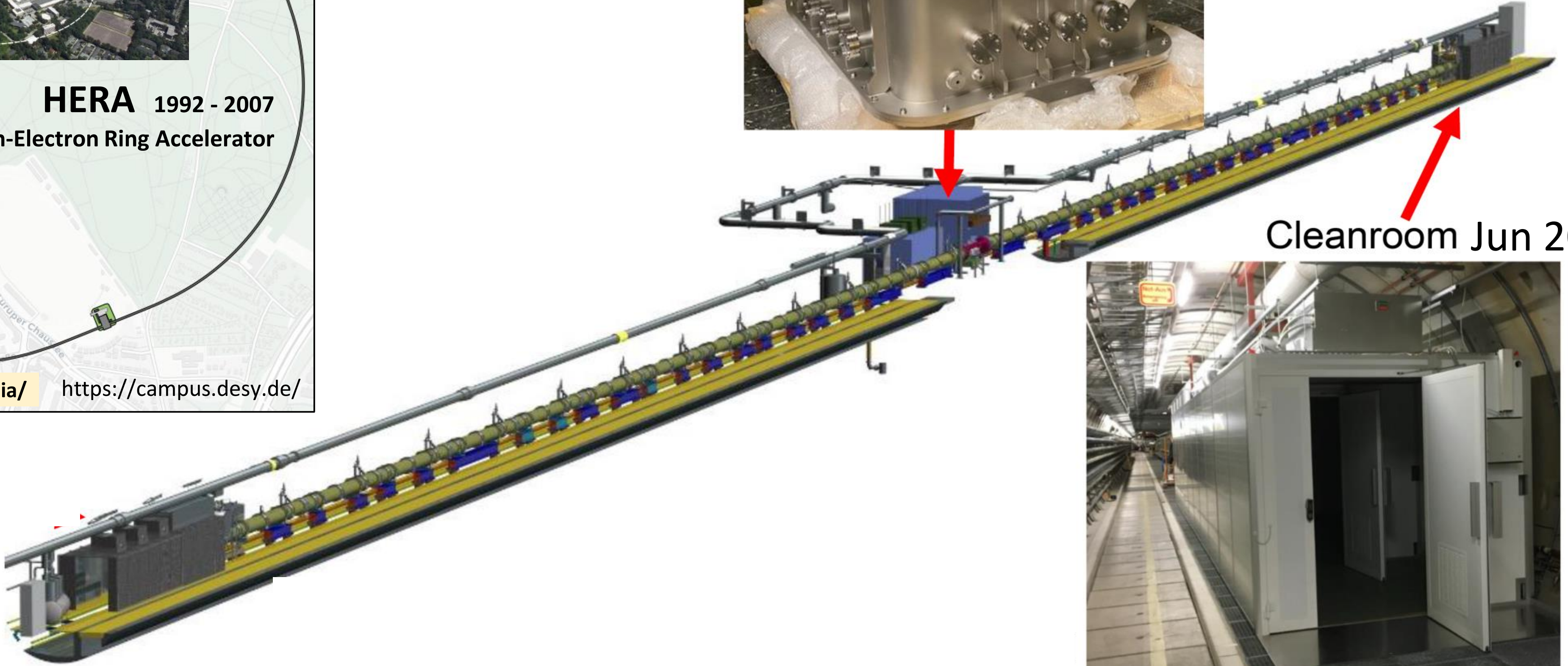


Site Installation

~ ALPS II baseline

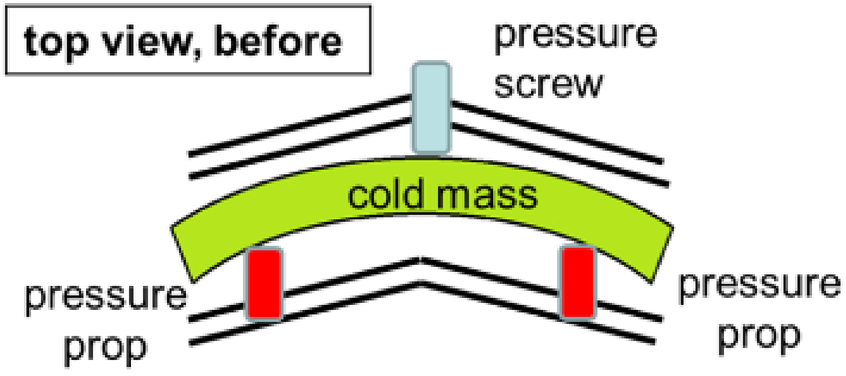


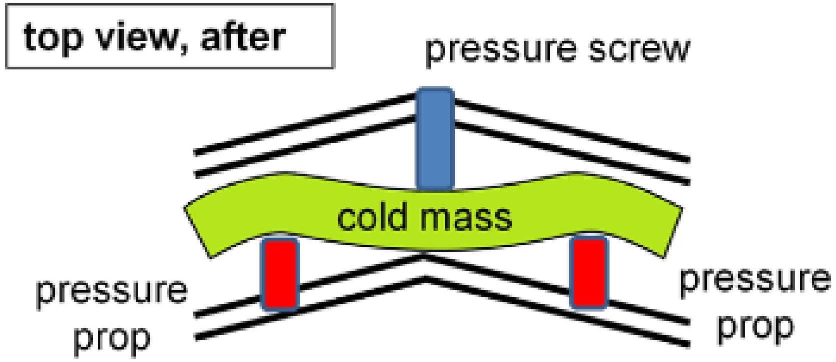
Central vacuum tank

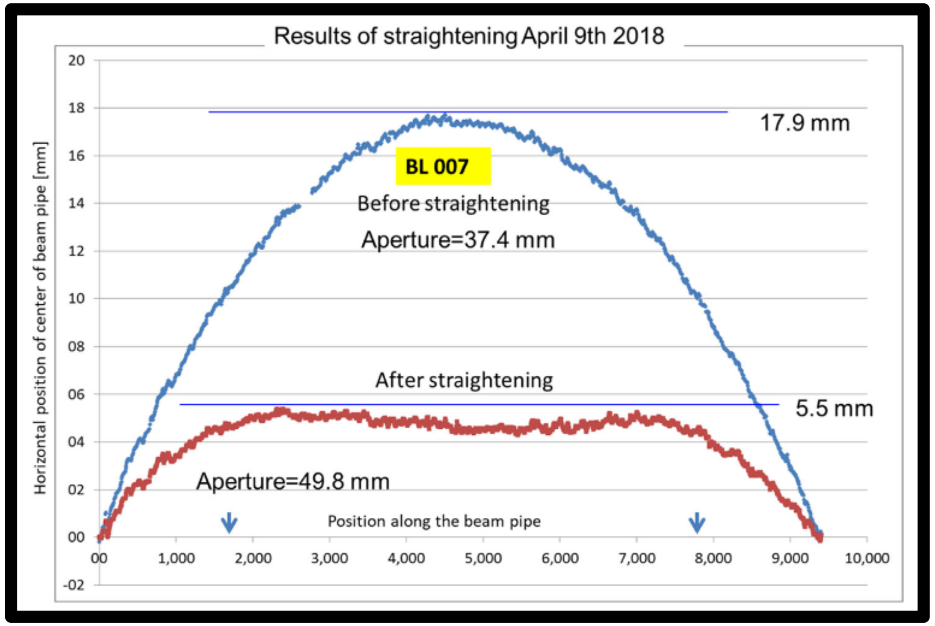


Cleanroom Jun 2020

ALPS II Magnet String



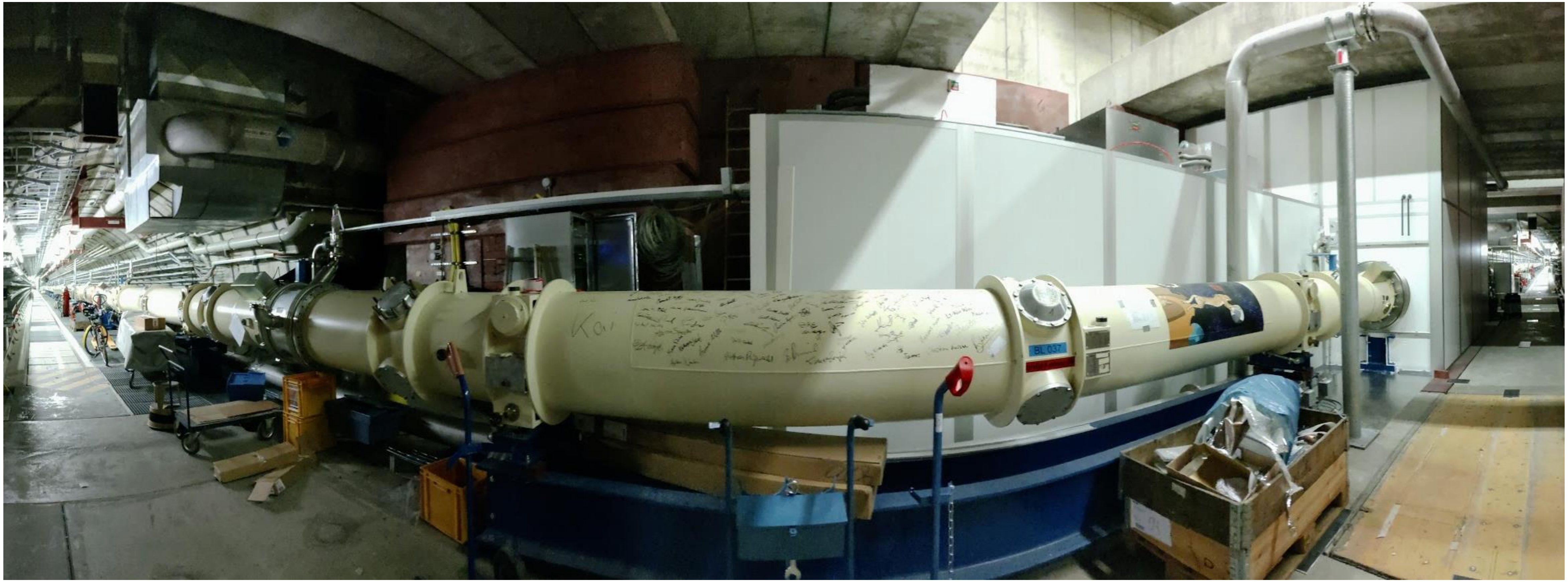




Albrecht et al., Straightening of superconducting HERA dipoles for the any-light-particle-search experiment ALPS II
EPJ Techniques and Instrumentation volume 8, Article number: 5 (2021)

ALPS II Magnet String

Oct 2020



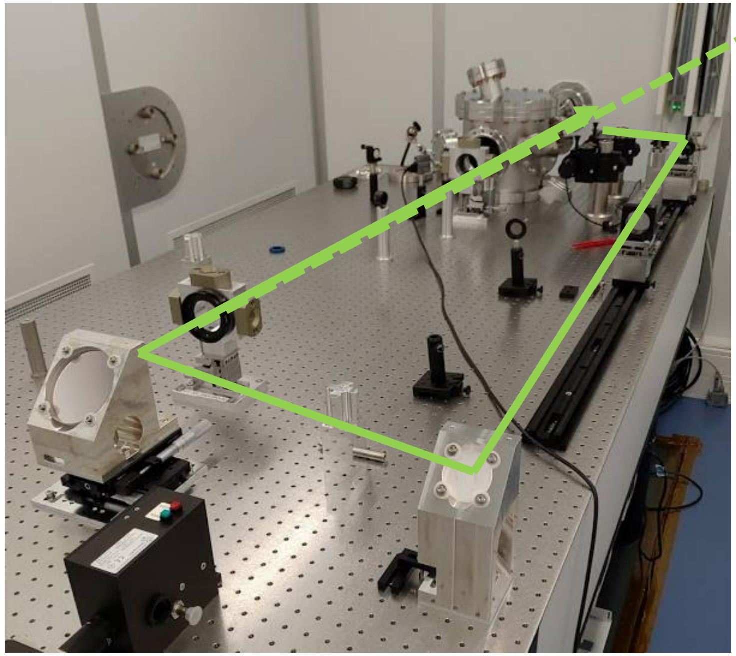
Panoramic view of HERA North Hall – DESY

First Light

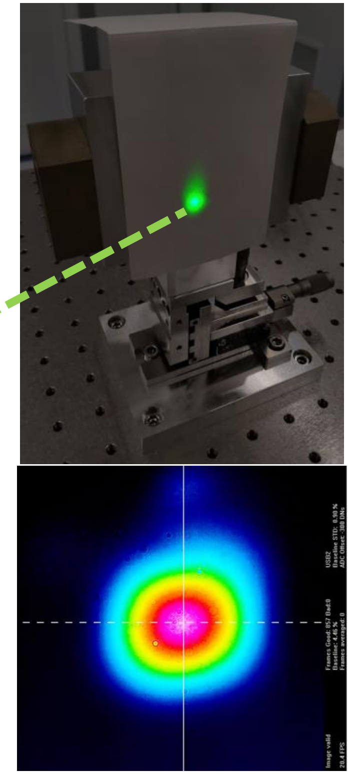
Initial Alignment done in Apr/May 2021

24 dipole Magnet string

North Right side

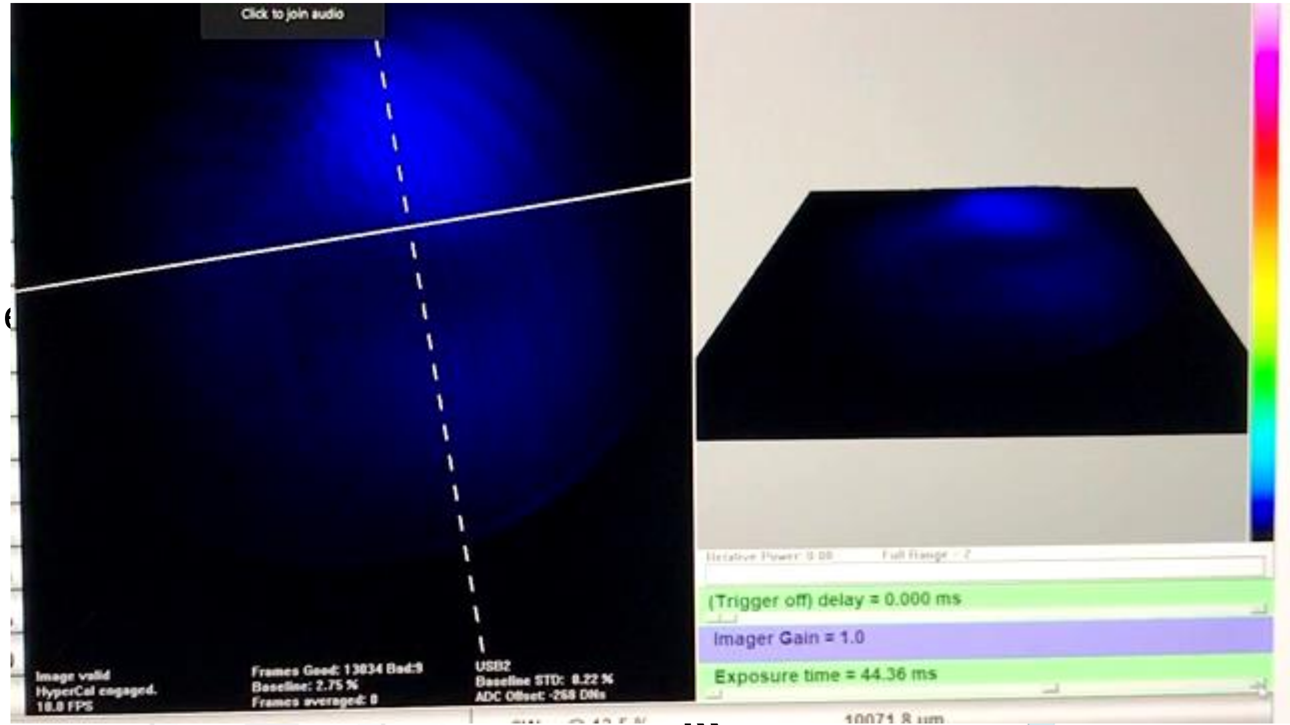


North Left side



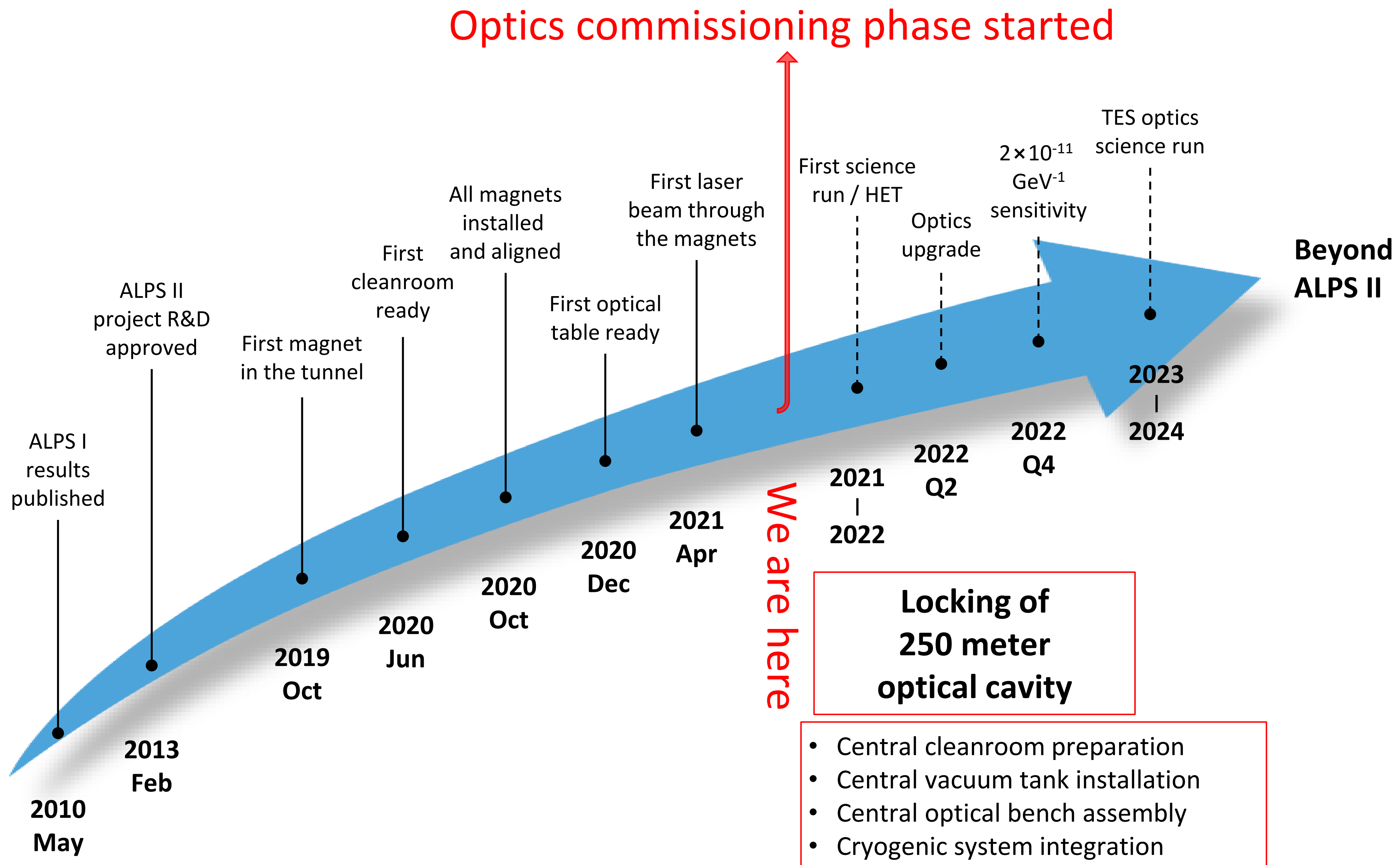
250 m cavity lock

first flashes observed in Jun 2021



- evaluation of the initial alignment
- characterizing the control systems
- characterizing the environmental noise in the tunnels

Timeline

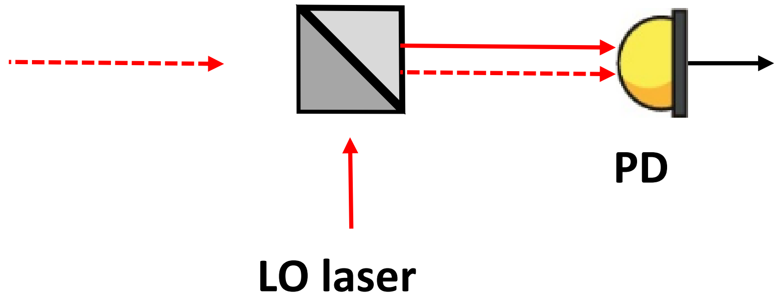


Locking of 250 meter optical cavity

- Central cleanroom preparation
- Central vacuum tank installation
- Central optical bench assembly
- Cryogenic system integration

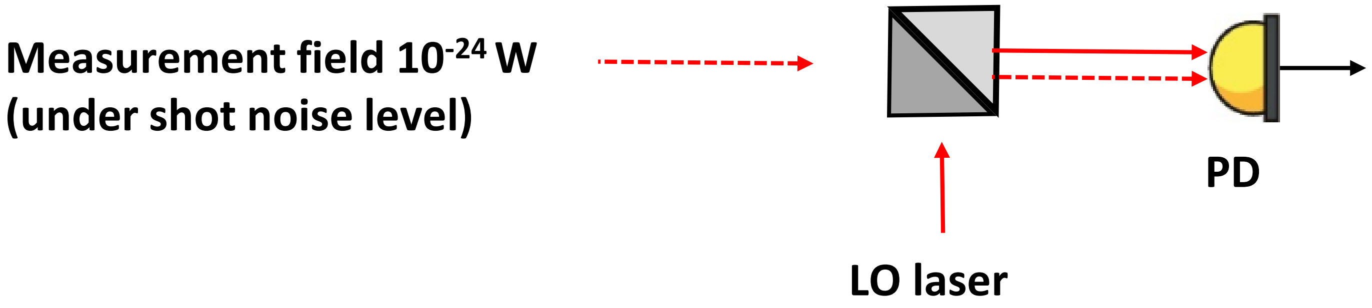
First Science Run: Heterodyne detection

Measurement field 10^{-24} W (under shot noise level)



- **I/Q demodulations**
- **Coherently sum of signal**
- **Noise sum incoherently**

First Science Run: Heterodyne detection



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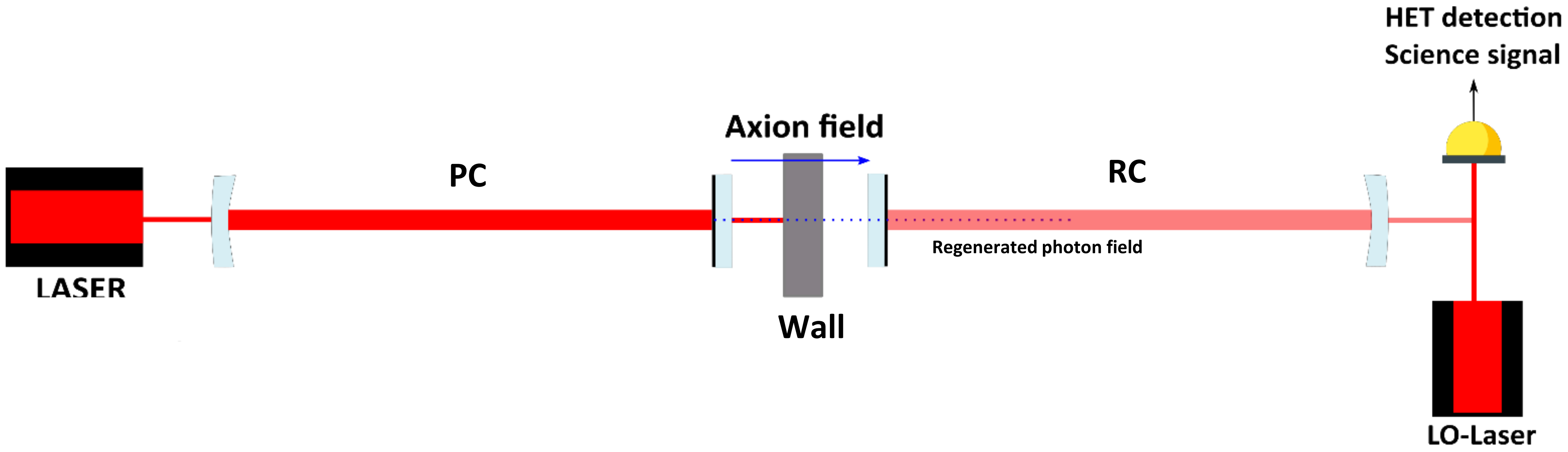


Heterodyne detection

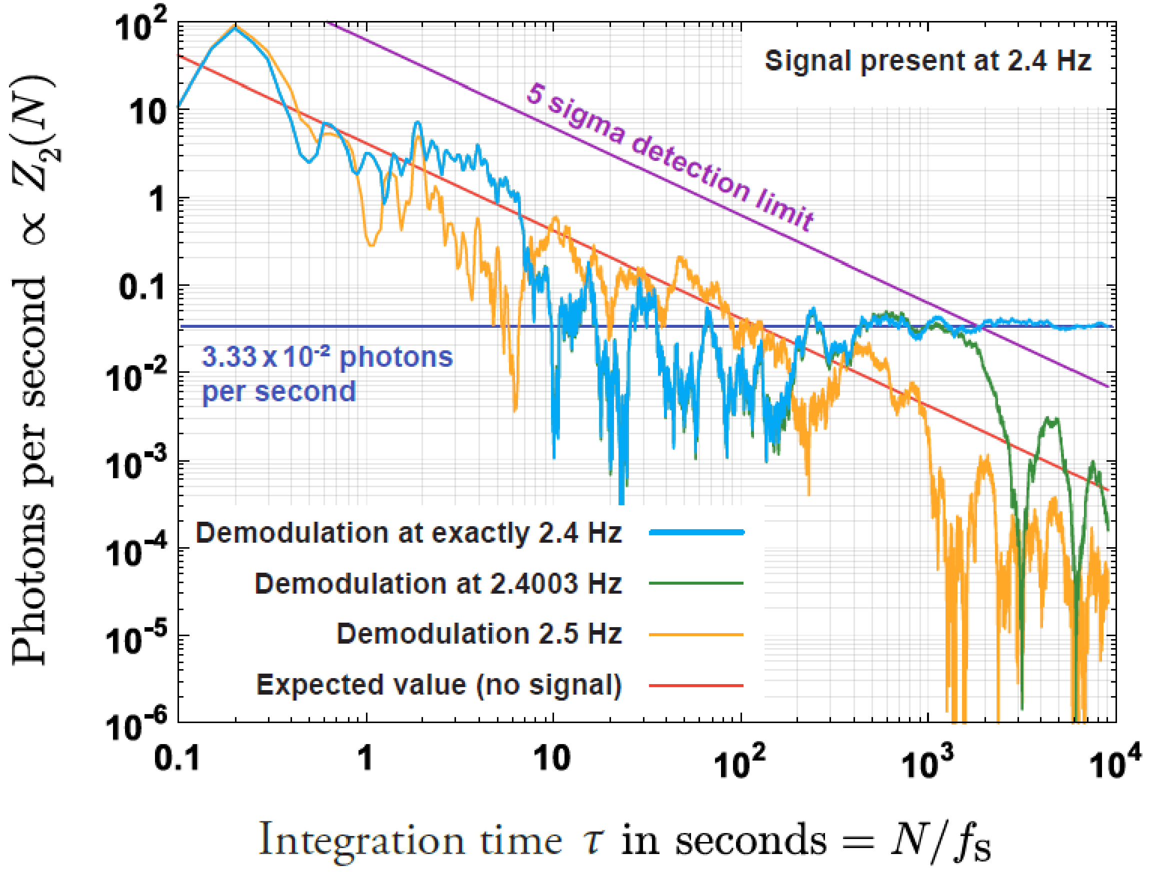
- **Optical Testbed for HET detector**
  We use EOM to generate very small side band signals (6.3 x 10^{-21} W)

- **Shot noise limited falls as 1/τ**

- **Crossing of 5σ confidence level indicates detection of coherent signal**
  Signal measured at 3.33 x 10^{-2} photons/s

- **Demodulating at a different frequency,** signal is not detected

- Integrated noise floor below 2 x 10^{-24} W (equivalent to about **10^-5 photons/s**)



[Z. Bush et al., **PRD 99** 022001 (2019)]

Transition Edge Sensor (TES) Detector

Single-photon calorimeter with SQUID electronic readout

For more details:

TES Detector for ALPS II
26 Jul 2021, 15:30, EPS-HEP Conference 2021

Parallel session talk Detector R&D and Data Handling T12: Detector R&D and Data Handling

Speaker
Rikhav Shah (ALPS)

Summary

ALPS II experiment will shine soon !

- ALPS II searches for Axion-Like Particles
- new QCD Axion models could be in reach of the ALPS II sensitivity
- all 24 HERA dipole magnets were been installed and straightened
- first light passed through ~210 m long magnet strings
- optics commissioning started recently
- first science run is happening soon …

Thank YOU

The University of Florida group is supported by:
NSF: PHY-1802006
Heising Simons: 2015-154, 2020-1841

Backup slides

ALPS-II Design, Requirements

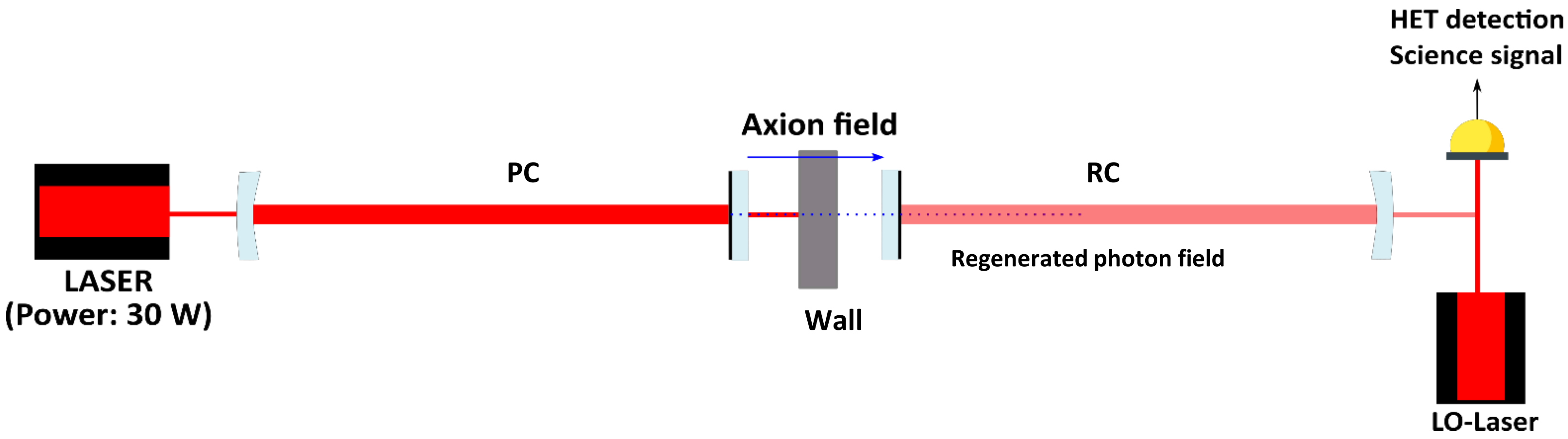
Dual resonance:

- 95 % of spatial overlap efficiency (< 100 µm laterally and <10 µrad angularly)
- < 4 Hz RMS of relative frequency noise

Stray light contamination < 10^{-24} W (less than 10^{-4} photon/s)

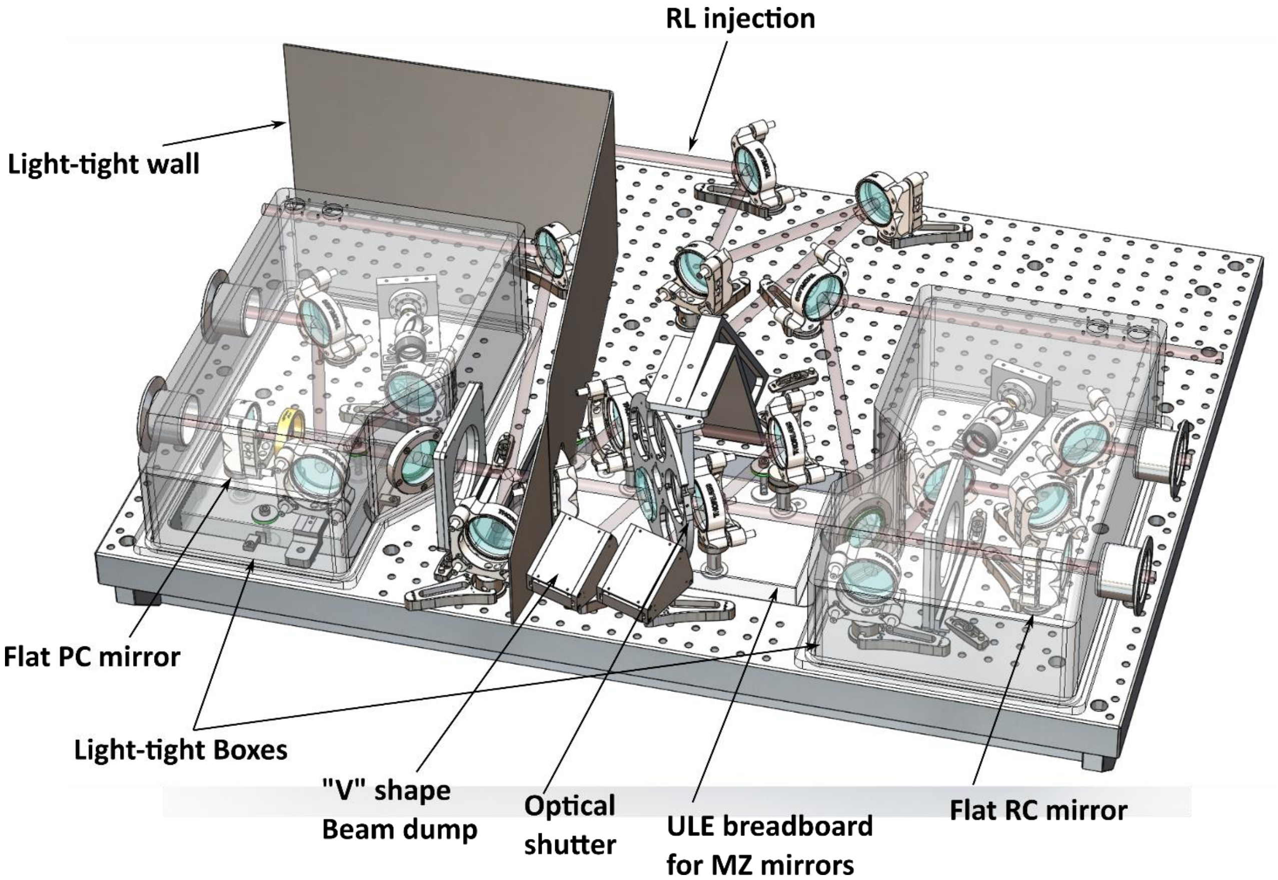
Phase coherence in HET detection:

- Relative phase coherence between regenerated photon field and LO-laser < 0.1 rad over ~20 days

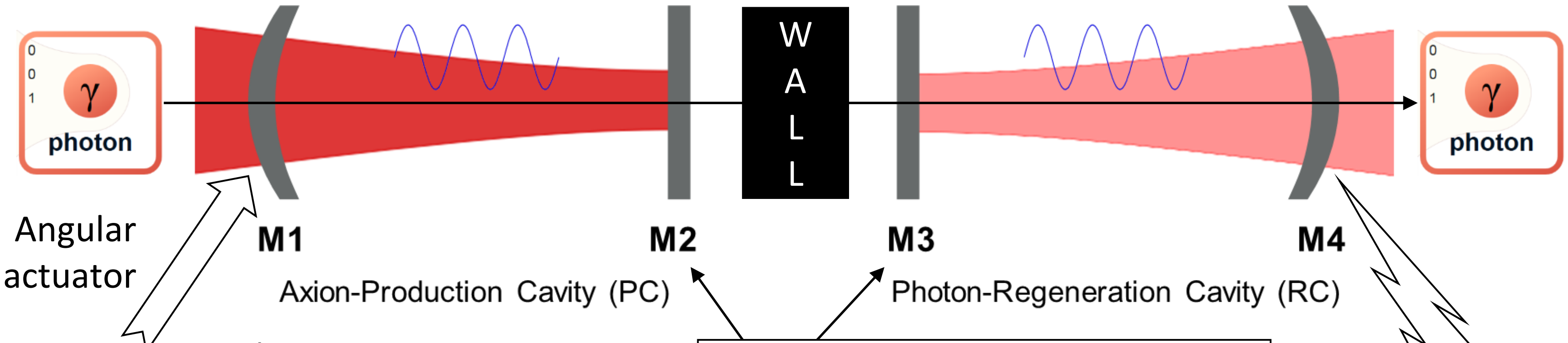


Central Optical Bench

- **Main plate:** Al material
- **Weight:** 67 kg with stiffener in the bottom
- **Size:** 100 cm (L) x 75 cm (W)
- Low Drift Kinematic mirror mounts
- Motorized Filter wheel with HR mirror as optical shutter



Dual Resonance



Angular actuator

Length actuator

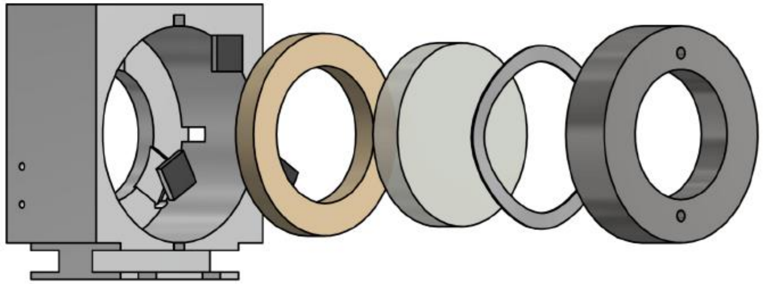
Passive stability (30 nm, 2urad) & spatial overlap QPD test

Kulkarni et al., Appl. Opt. 59, 6999 (2020)
Wei et al., Appl. Opt. 59, 8839 (2020)

Seismic perturbation

Site survey and projection study

Custom length actuator allows for ~ 4 kHz bandwidth; expected to meet ALPS II needs.

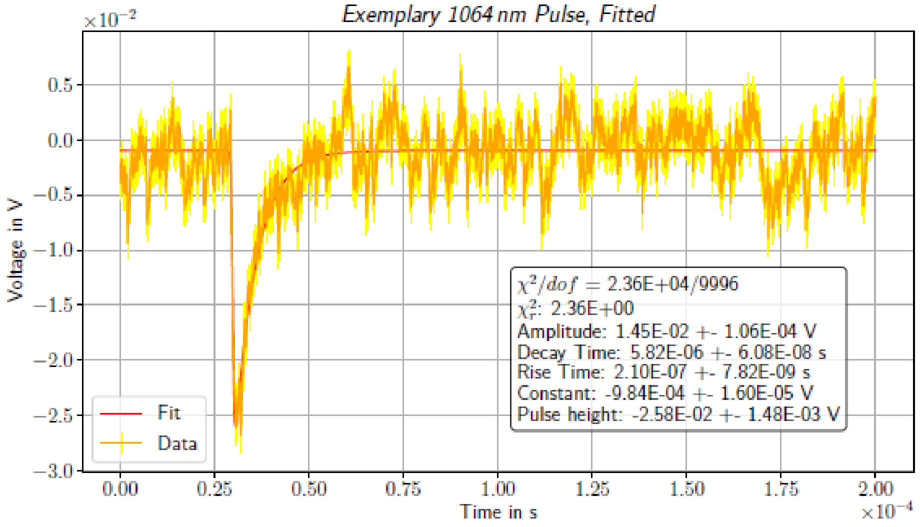


Richard C. G. Smith, PhD Thesis, Leibniz Universität Hannover (2020)

TES detection system

Single-photon calorimeter with ~ 10% energy resolution

- **Bias at superconducting transition edge**
- **Single-photon energy drastically changes resistance**
- **SQUID electronics readout**
- **Dark count rate ≤ 7.5 uHz,**
  92% acceptance at 1064 nm **(data analysis pipeline only; signal injection loss will dominate)**



Internal structure of the dilution refrigerator

Rikhav Shah, TES Detector for ALPS II, DPG 2021

Close up of the detector module with the TES in the white ferrules

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

DESY.