ALPs search with ALPS II experiment

- status and prospects -

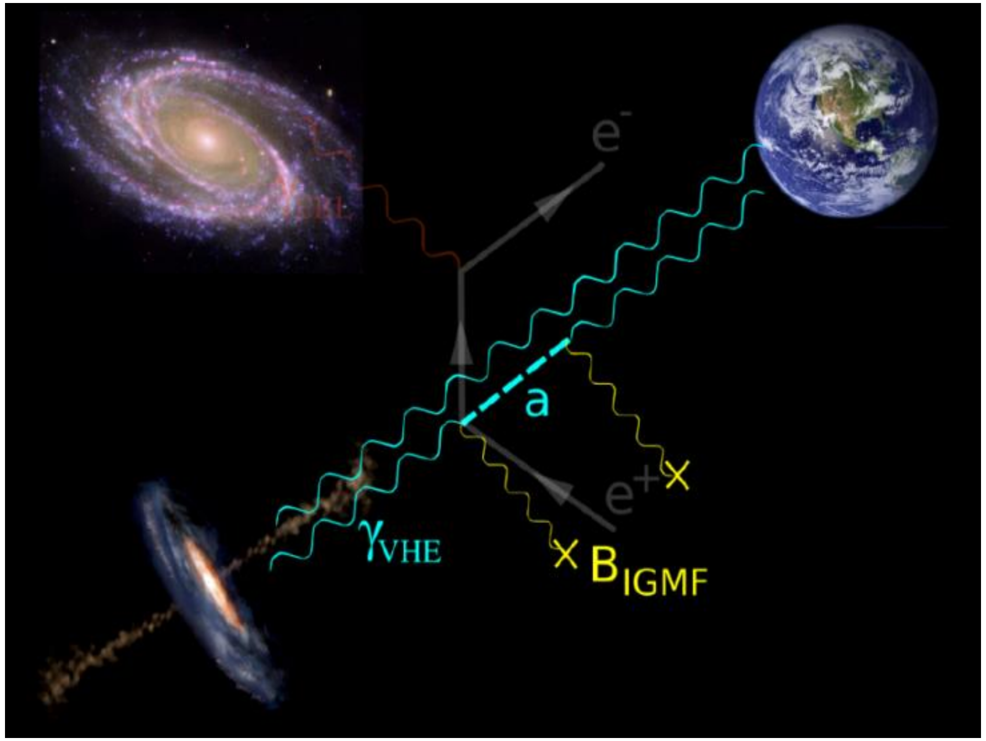
Kanioar Karan, a member of the Cardiff University, for the ALPS collaboration

The 2021 Shanghai particle physics and cosmology symposium

Motivation

- Axion
  - Results from the Standard Model (SM)
  - Predicted to solve the strong CP-problem
  - cosmology: Suitable candidate for dark matter?

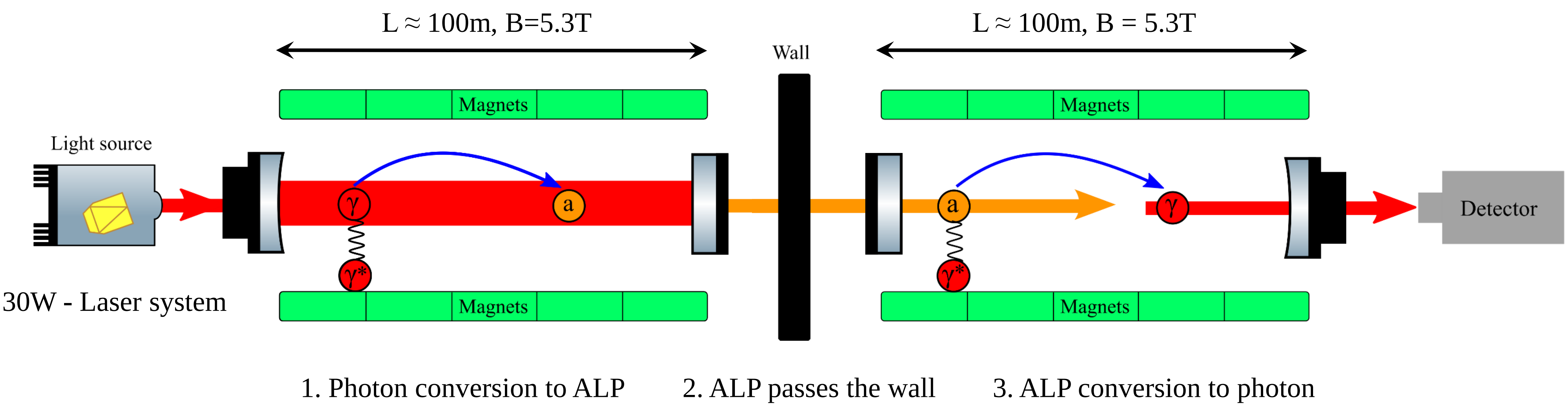
- Axion-like Particles
  - Astrophysical motivations
  - TeV transparency
  - Excess cooling in stellar evolution



M. Meyer, 7th Patras Workshop on Axions, WIMPs and WISPs (2011)

How to probe the existence of ALPs?

ALPS II: A Light-Shining-Through-a-Wall experiment



- Astrophysical hints motive our search parameter
- Regenerated photons:
  - $N \propto P \cdot \left(g_{a\gamma\gamma} \cdot B \cdot L\right)^4$
- Optical cavities to enhances the process
  - $N \propto P \cdot \left(g_{a\gamma\gamma} \cdot B \cdot L\right)^4 \cdot \beta_{PC} \cdot \beta_{RC}$

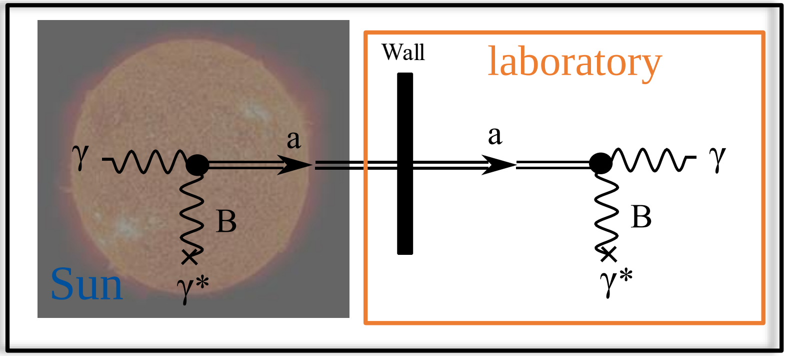
$g_{a\gamma\gamma} = 2 \times 10^{-11}\, GeV^{-1}\ for\ m_a \leq 0.1\, meV$

1 photon / 130,000 years

1 photon / day

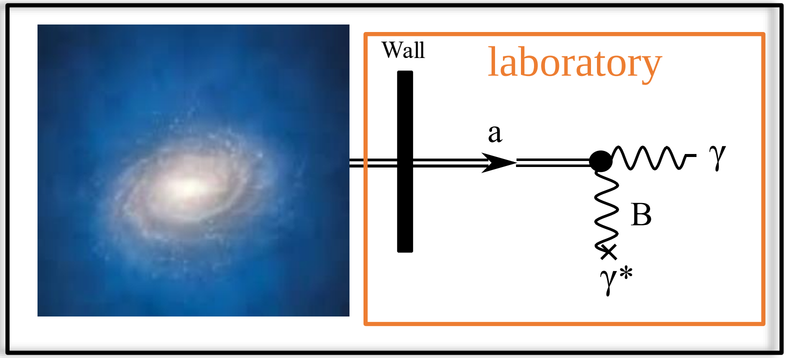
LSW vs. other approaches

- Helioscopes:
  - Telescopes directed towards the sun
  - ALPs-source: stellar core
  - X-ray → X-ray detector



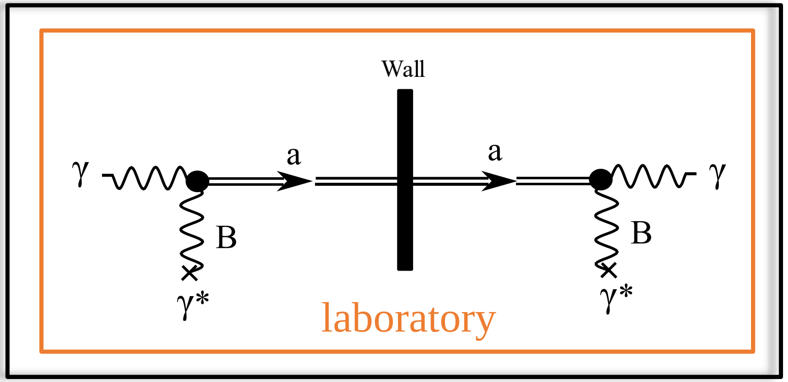
BabyIAXO (DESY), CAST

- Haloscopes:
  - ALPs source: dark matter halo
  - Microwaves → Microwave cavity



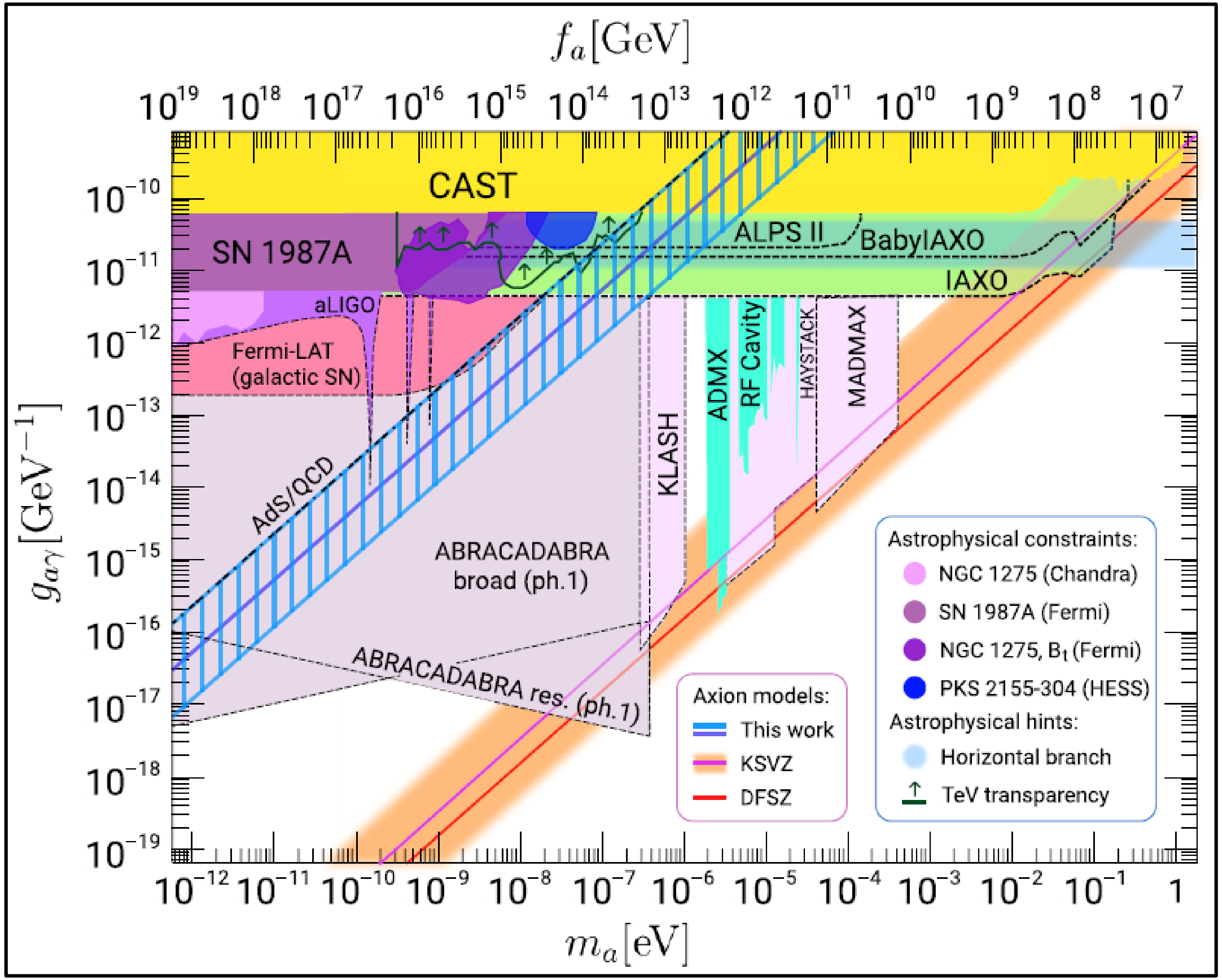
Axion Dark Matter Experiment (ADMX)

- Light-Shining-Through-a-Wall.
  - Pure laboratory based
  - Control of ALPs source
  - Less model dependent



Any Light Particle Search II (ALPS II)

ALPs – parameter space



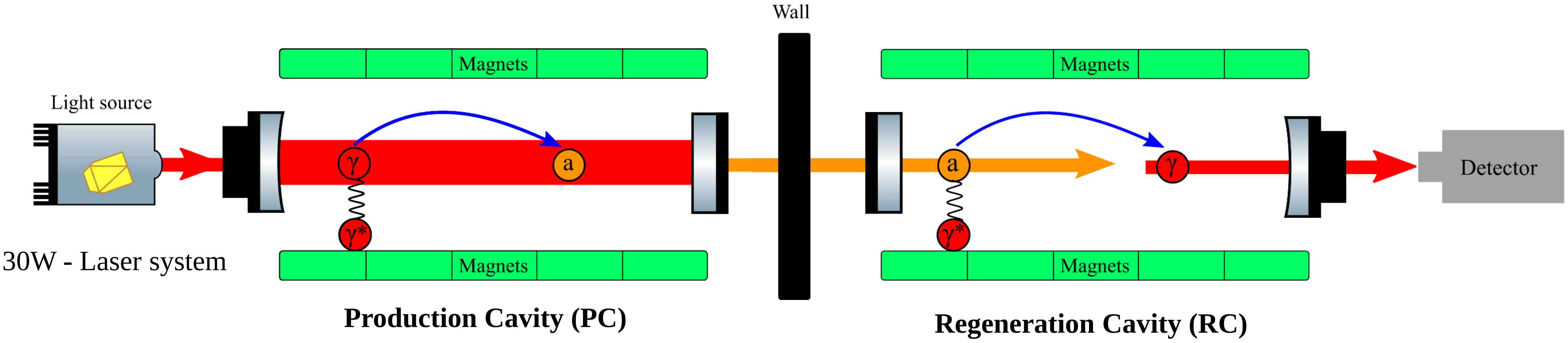
Sokolov and Ringwald, arXiv:2104.02574

ALPS II targets at

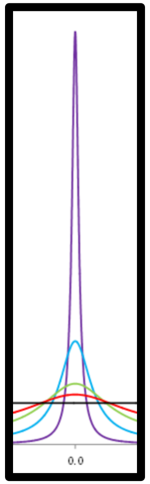
$$g_{a\gamma\gamma} = 2 \times 10^{-11}\ GeV^{-1}$$ **for** $$m_a \leq 0.1$$ **meV**

for astrophysical motivation

ALPS II optical cavities



- Each cavity boost the photons that shine through by a factor β_{PC} ~(Finess/ π)
- Goal: overall power efficiency > 90%
- Laser and the two cavity have to be
  - Resonant
  - Mode-matched
  - aligned



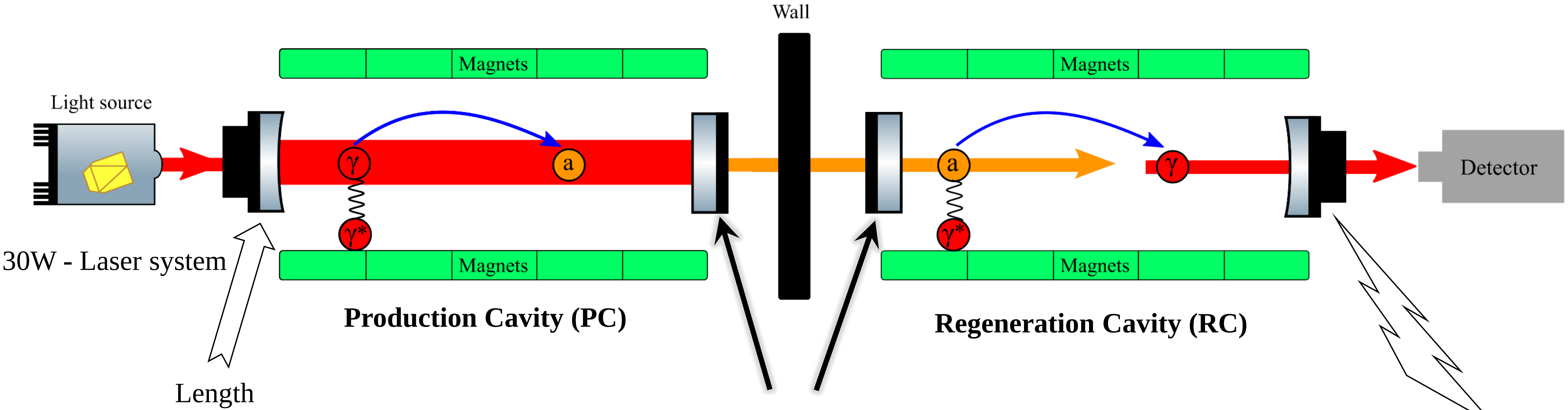
$$\epsilon \equiv \epsilon_1 + \epsilon_2 \approx \frac{|U_1|^2}{|U_0|^2} + \frac{|U_2|^2}{|U_0|^2}$$

$$\approx \left(\frac{\delta\alpha_{\text{cig}}}{\theta_{0,\text{cig}}}\right)^2 + \left(\frac{\delta x_{\text{cig}}}{w_{0,\text{cig}}}\right)^2 + \left(\frac{\delta z_{0,\text{cig}}}{2 \cdot z_R}\right)^2 + \left(\frac{\delta w_{0,\text{cig}}}{w_{0,\text{cig}}}\right)^2$$

$$\leq \left(\frac{5\ \mu\text{rad}}{56.5\ \mu\text{rad}}\right)^2 + \left(\frac{0.1\ \text{mm}}{6\ \text{mm}}\right)^2 + \left(\frac{1\ \text{m}}{2 \cdot 106\ \text{m}}\right)^2 + \left(\frac{0.2\ \text{mm}}{6\ \text{mm}}\right)^2$$

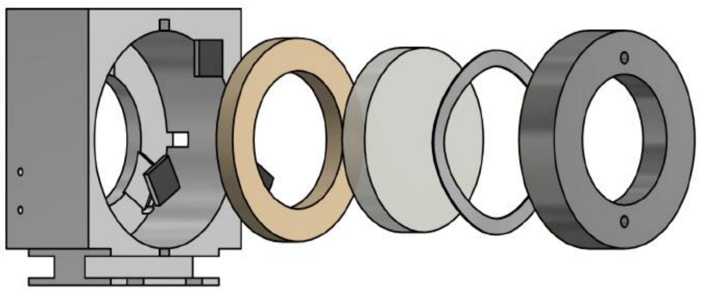
$$\approx 0.78\% + 0.28\% + 0.0022\% + 0.11\% \approx 1.17\%,$$

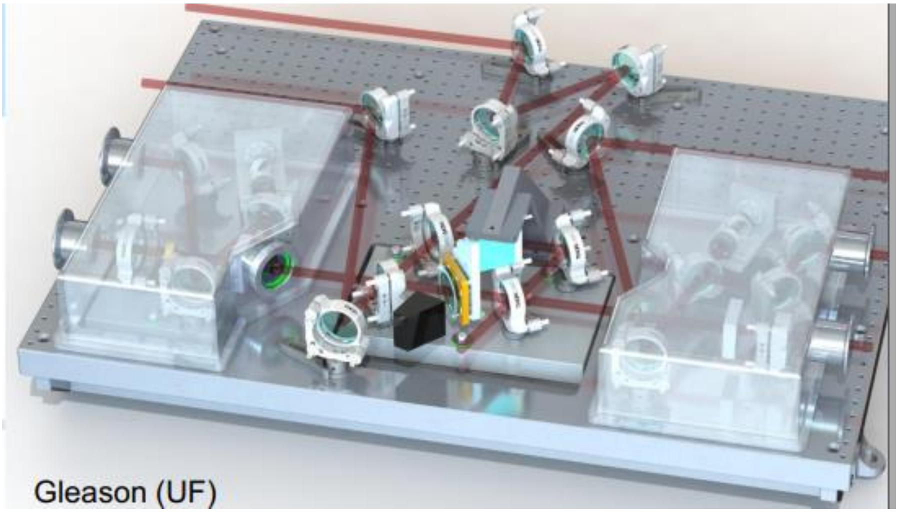
ALPS II optical cavities



High angular and lateral stability requiered

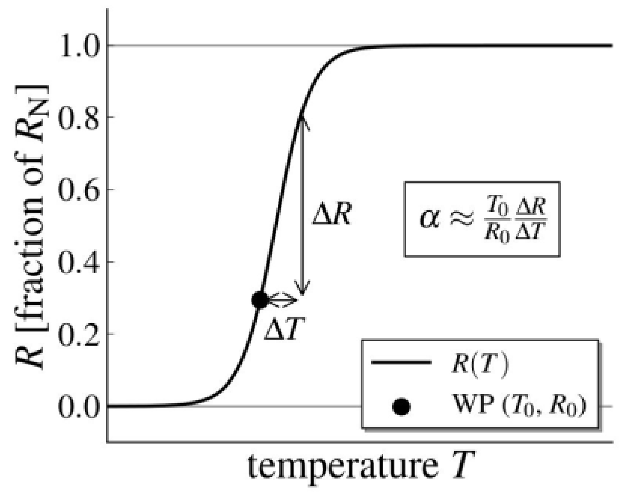
Custom length actuator allows for ~ 4kHz bandwidth

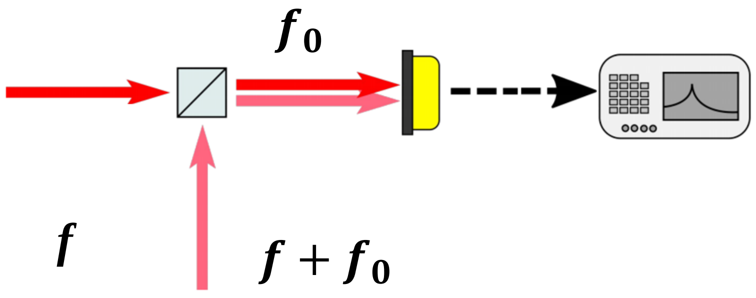




ALPS II detectors

- Challenges:
  - Very low photon rate
  - Low energy photon detection
  - Low background rate
- Transition edge sensor
  - Single-photon counting
  - Resistance measurement of a chip whose temperature is kept at the threshold of superconductivity
  - Requires cryogenic environment
- Heterodyne detection
  - Filed detection
  - Coherent sum of the signal
  - Requires long term phase coherence of signal

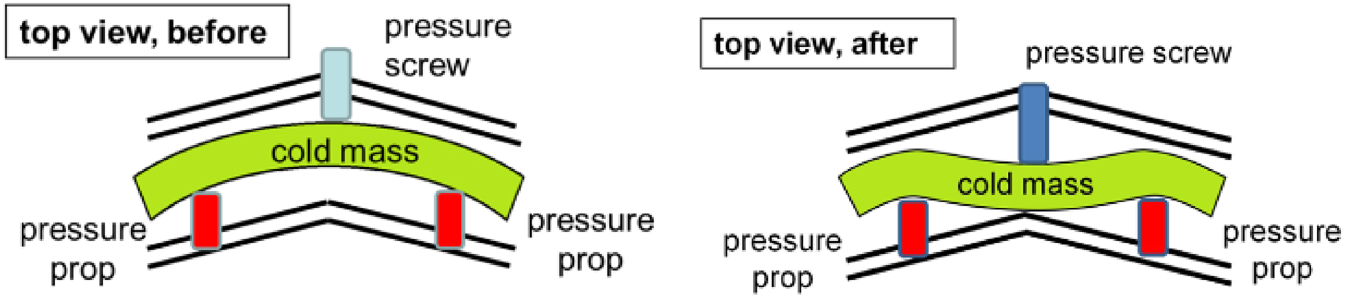


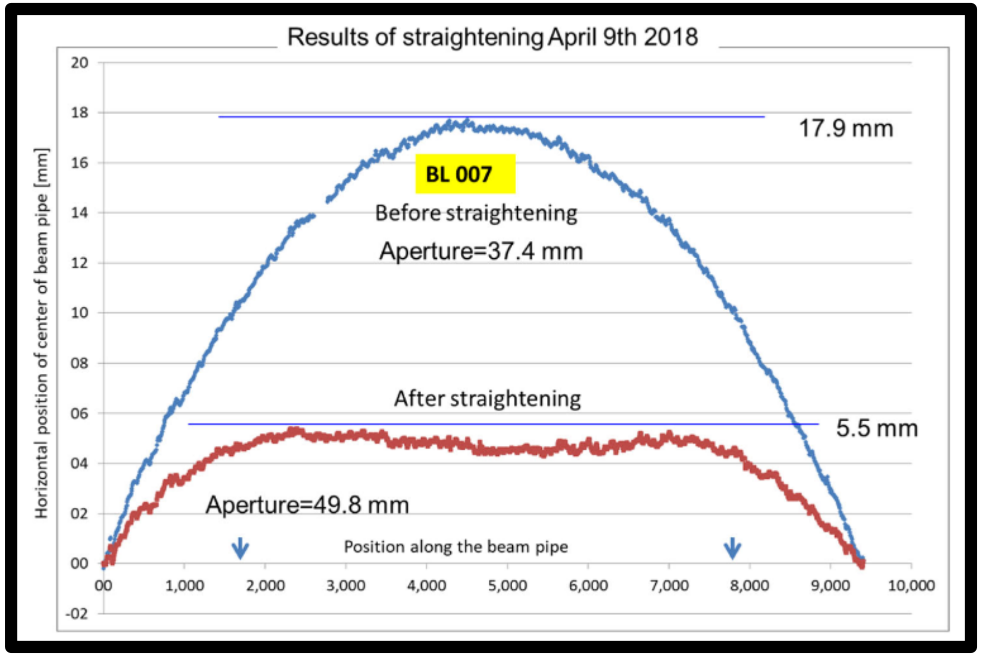


Both schemes require a different setup and control system

ALPS II magnets

- A string of 12 HERA dipole magnets

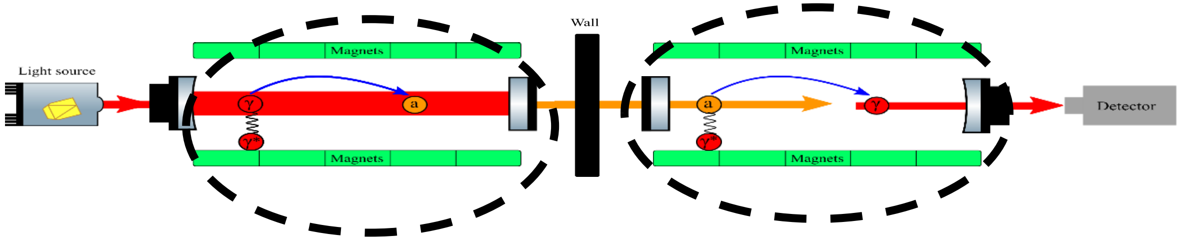




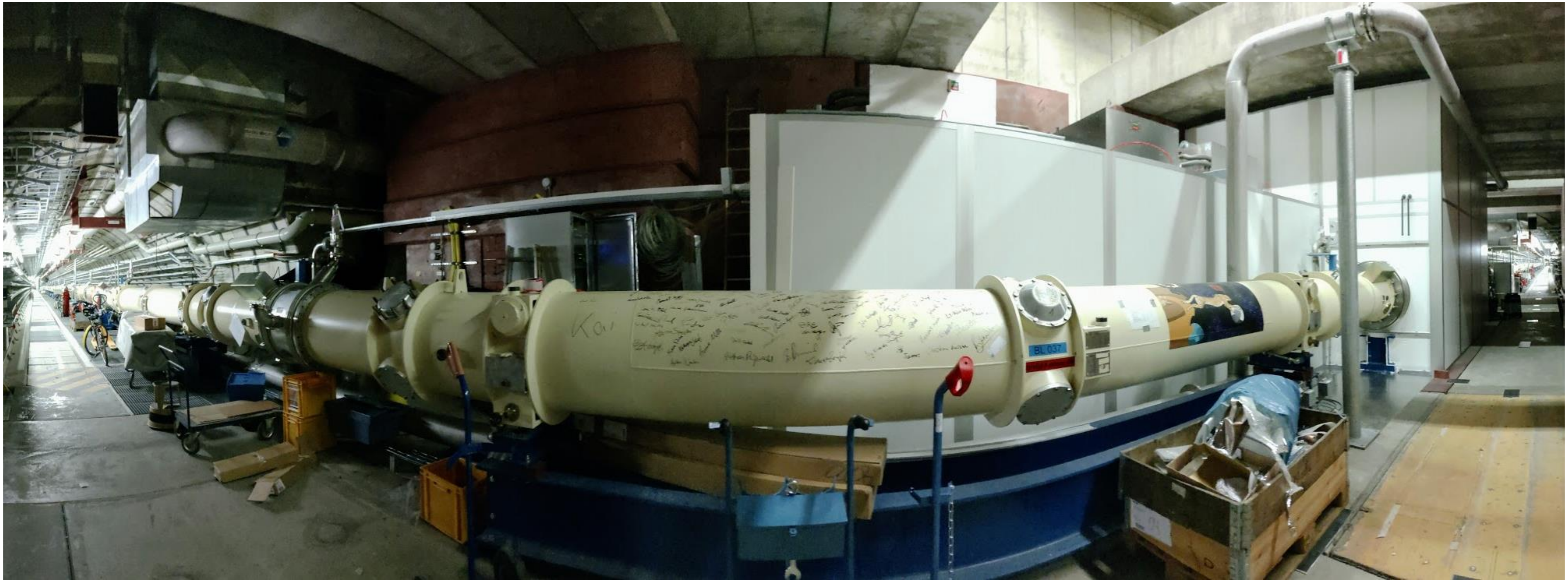
Albrecht et al., Straightening of superconducting HERA dipoles for the any-light-particle-search experiment ALPS II
EPJ Techniques and Instrumentation volume 8, Article number: 5 (2021)

50mm aperture after straightening

Current status: magnets are installed

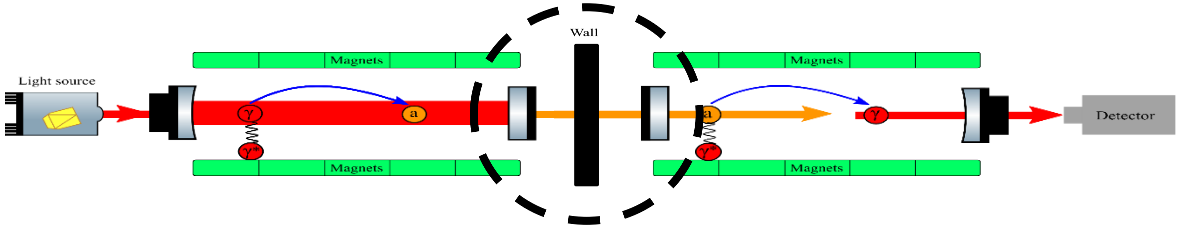


Current status: magnets are installed



All magnets are installed and aligned

Current status: Central Optical Bench

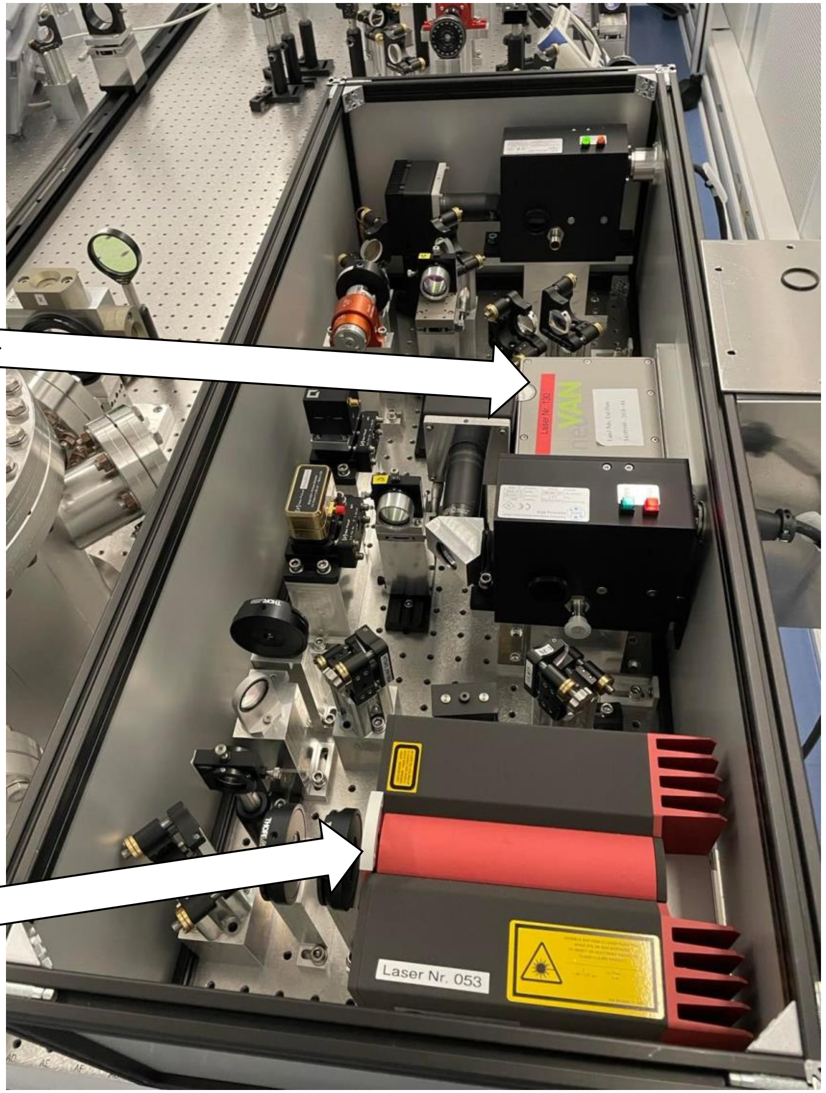


- **COB installation procedure successfully tested**
- **COB assembly is ongoing**

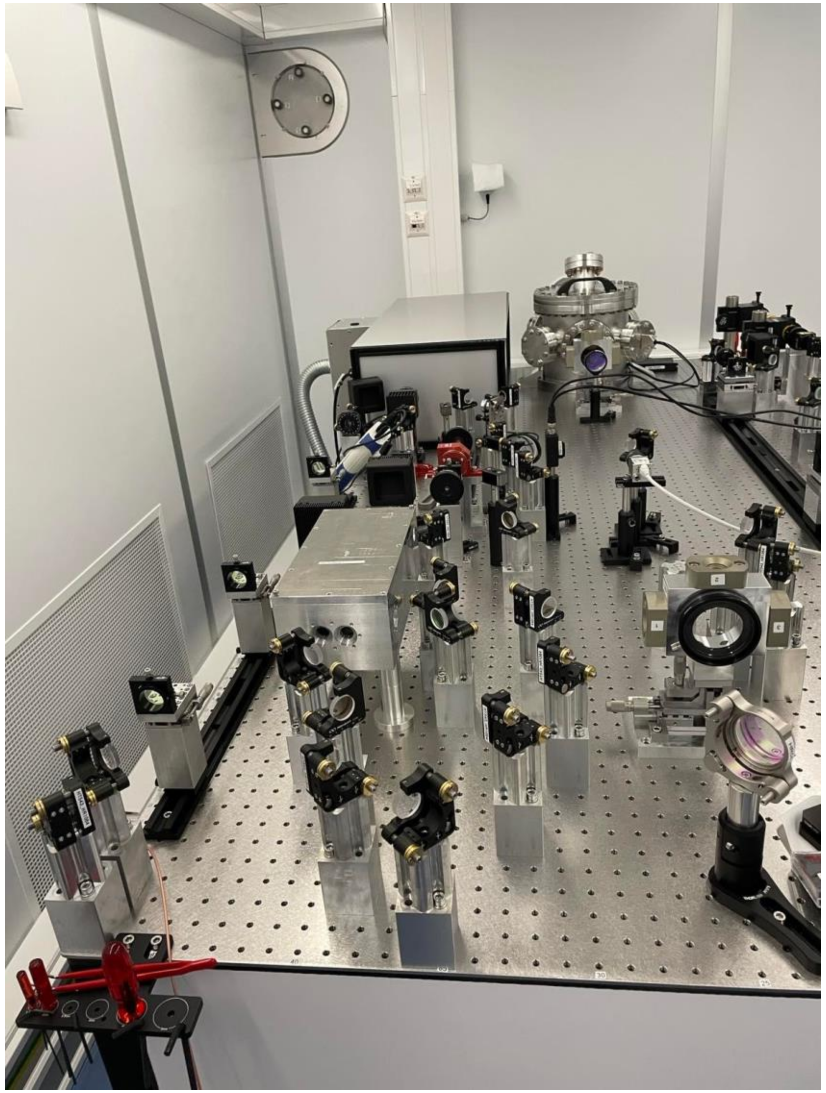
Current status: High Power Laser

Amplifier stage

1064nm NPRO

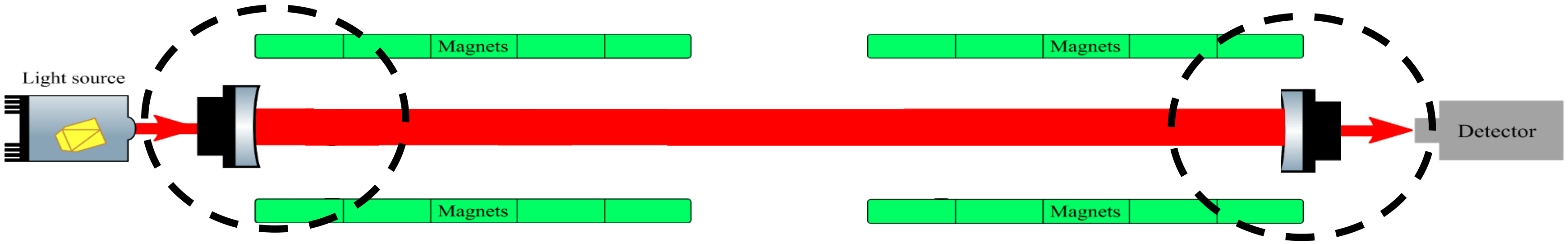


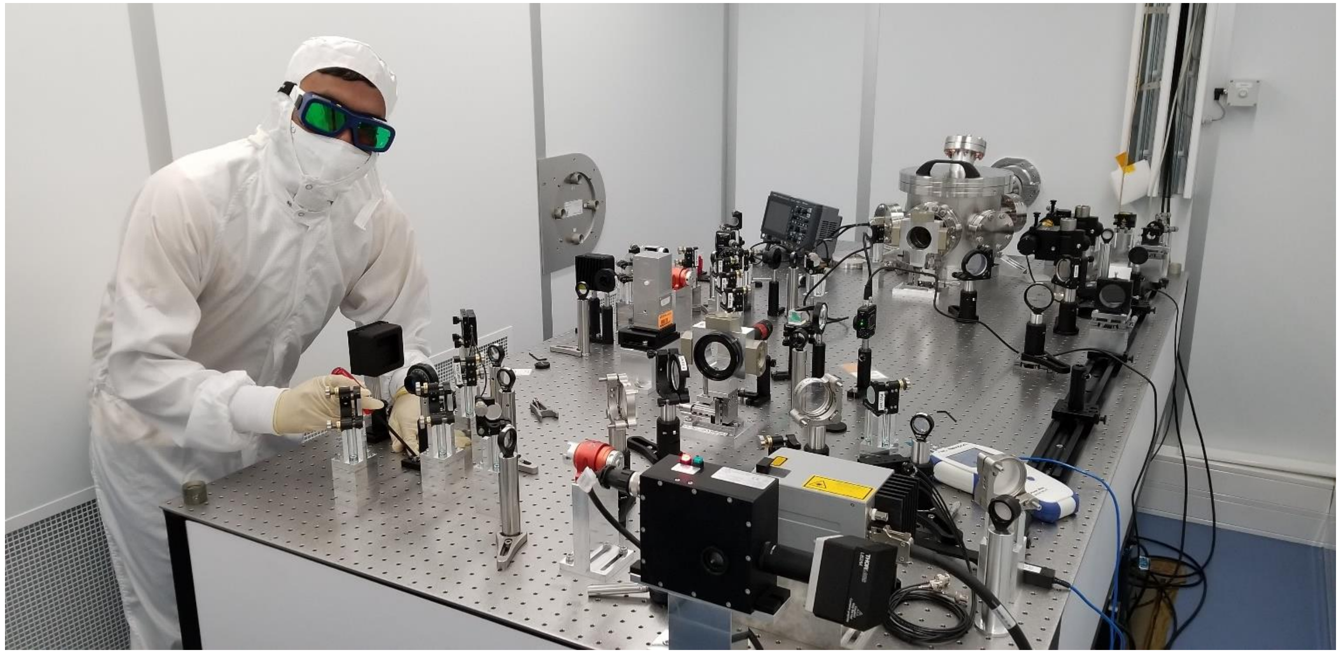
- **Hight Power Laser is installed and provides ~ 70W**

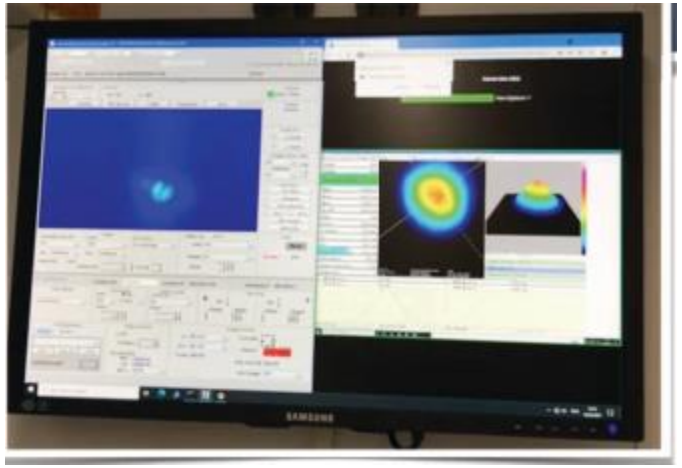


- **Alignment and mode-matching to the Production Cavity is on going**

Current status: 250m cavity commissioning

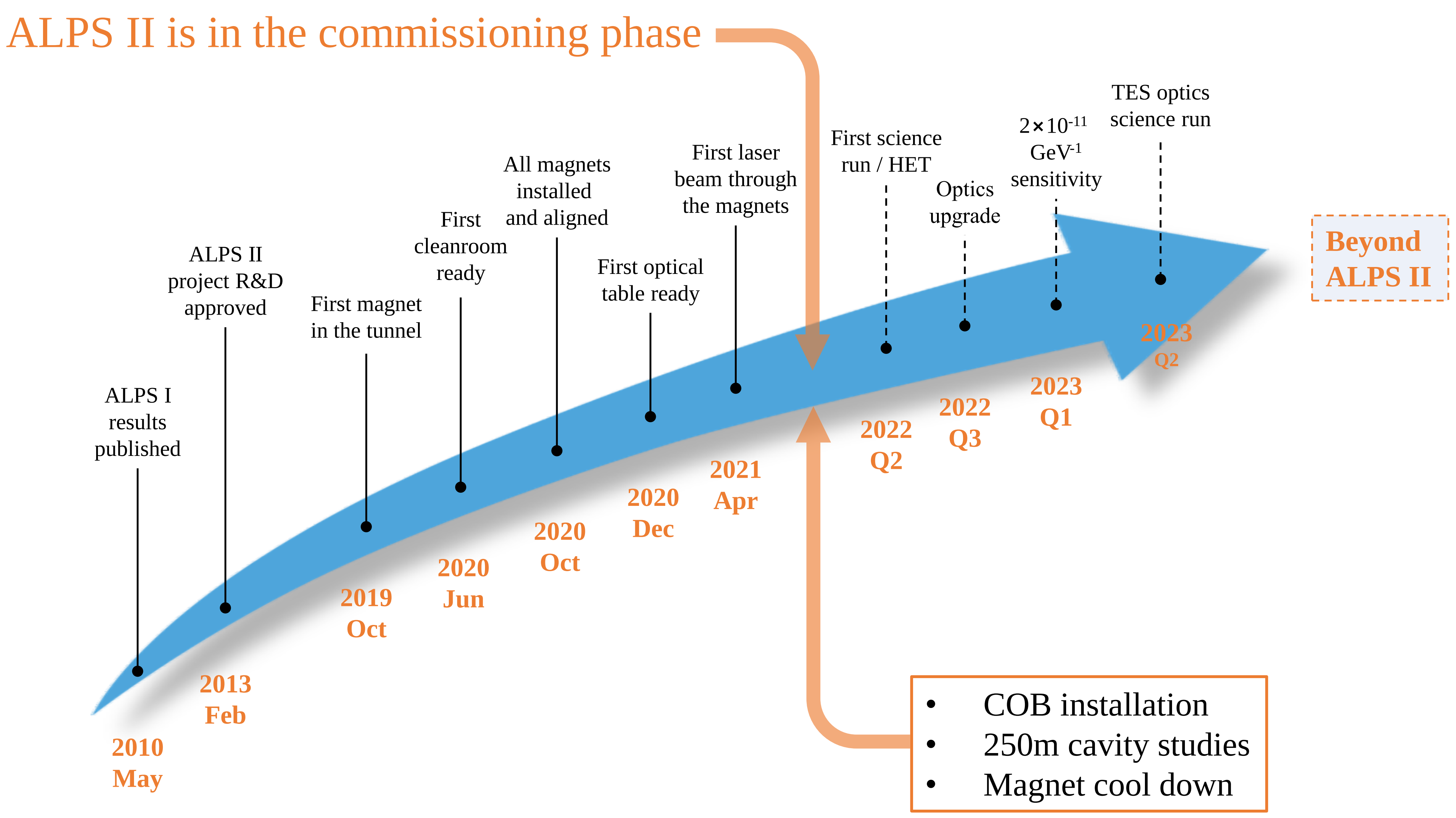






- LO frequency stabilized to a 250m optical cavity
- Remote control
- Characterization of environmental noise and optics on going

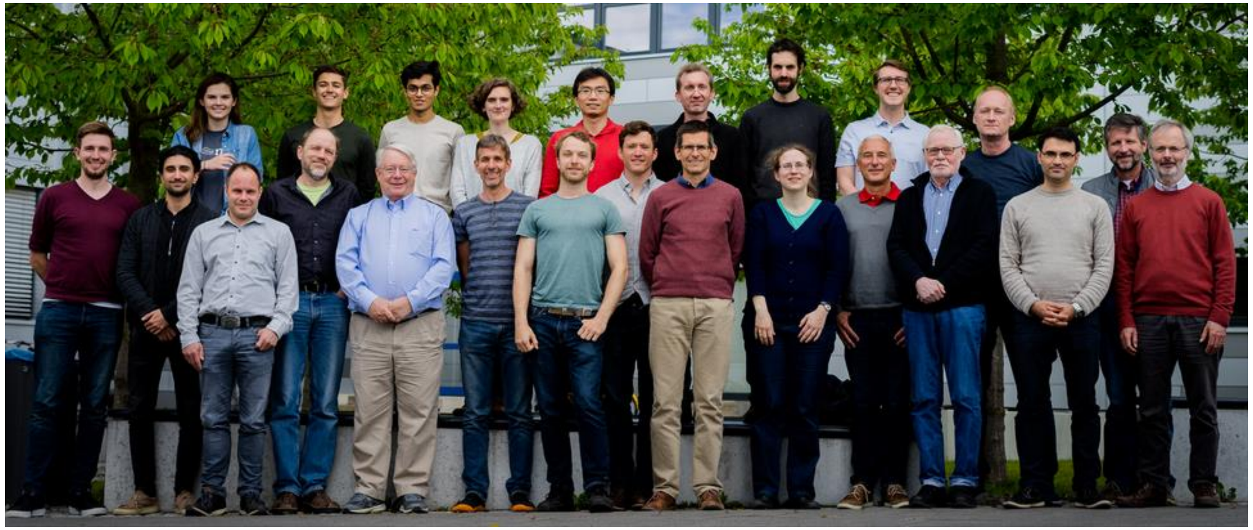
Timeline



ALPS II is in the commissioning phase
ALPS I results published
2010 May
ALPS II project R&D approved
2013 Feb
First magnet in the tunnel
2019 Oct
First cleanroom ready
2020 Jun
All magnets installed and aligned
2020 Oct
First optical table ready
2020 Dec
First laser beam through the magnets
2021 Apr
First science run / HET
2022 Q2
Optics upgrade
2022 Q3
2×10-11 GeV-1 sensitivity
2023 Q1
TES optics science run
2023 Q2
Beyond ALPS II
• COB installation
• 250m cavity studies
• Magnet cool down

Collaboration

- ALPS II is a joint effort of:
  - DESY, University of Hannover, Cardiff University, University of Florida, Mainz University, University of Hamburg
- With support from:
  - NSF, Heising-Simons Foundation, DFG, Volkswagen Stiftung, UKRI

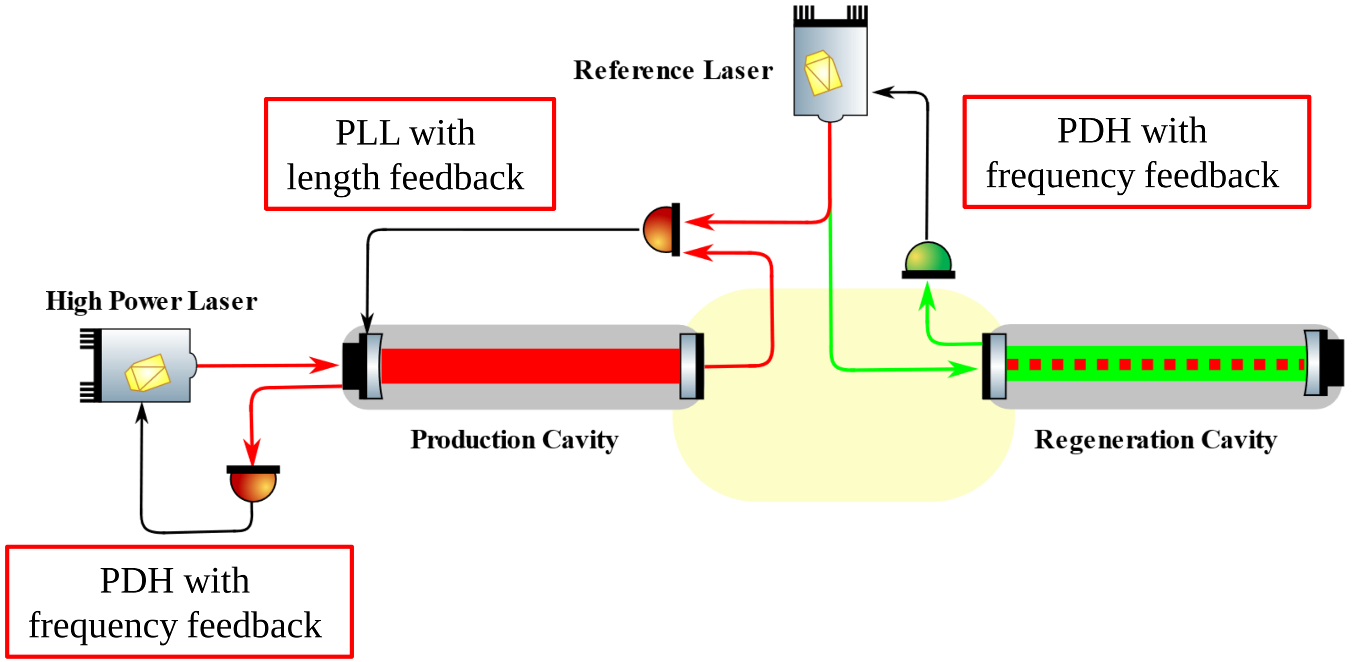


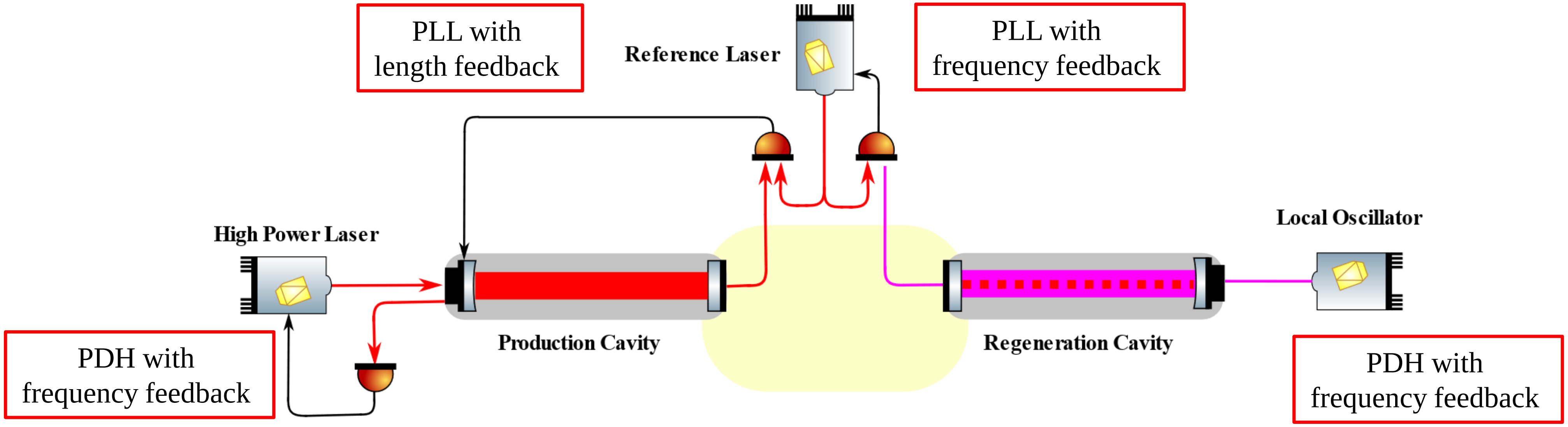
Conclusion

- ALPS II is a light-shining-through-a-wall experiment at DESY in Hamburg comprising superconducting magnets and state-of-the-art optics
- The ALPS II site will be fully operational in the first half of 2022
- Commissioning on going
- Science run is anticipated in the second half of 2022
- Implementation of the second decoction scheme will follow

Backup

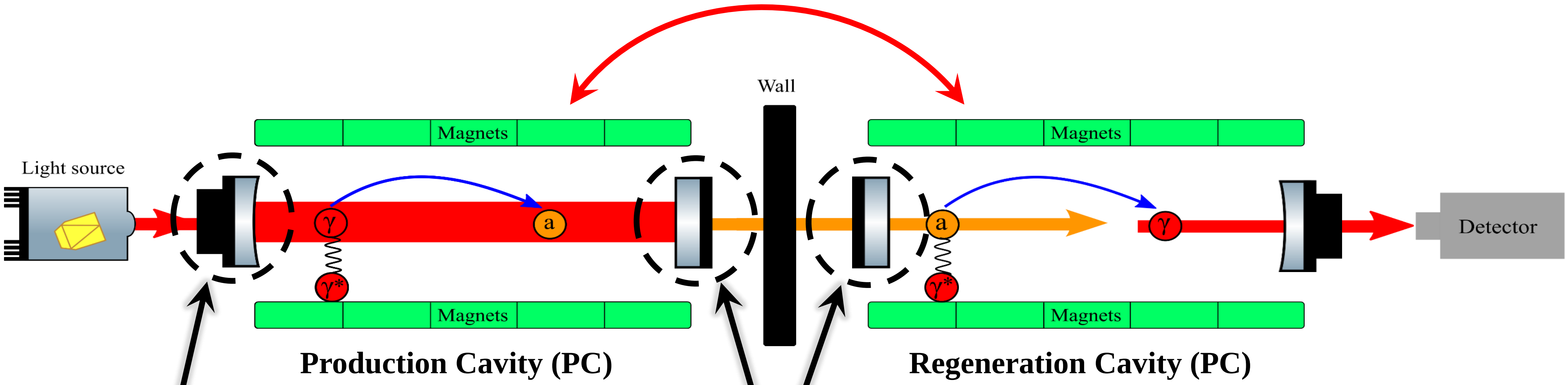
ALPS II: Control challenges



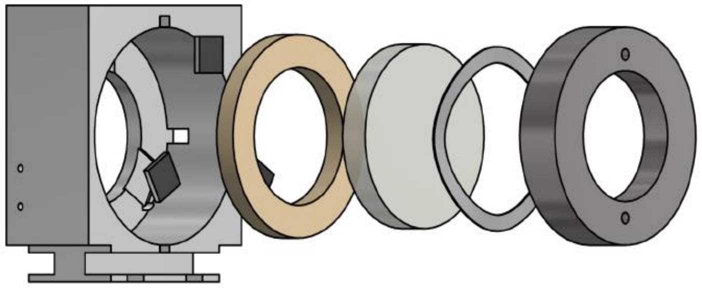


ALPS II: optics challenges

Goal: overall power efficiency > 90%



Custom length actuator allows for ~ 4kHz bandwidth

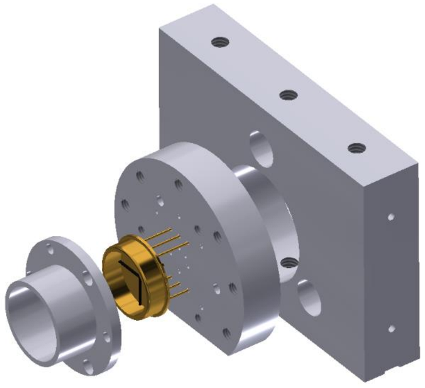


Richard C. G. Smith, PhD Thesis,
Leibniz Universität Hannover (2020)

Angular stability: < 5μrad

L.-W. Wei, K. Karan, and B. Willke;
Appl. Opt. 59, 8839 (2020)

Lateral stability: < 100μm



L.-W. Wei, K. Karan, and B. Willke;
Appl. Opt. 59, 8839 (2020)