The ALPS II Experiment at

Current Status

Friederike Januschek, DESY,
on behalf of the ALPS II collaboration

PATRAS Workshop
Freiburg, 6.6.19

Albert Einstein Institute Hannover

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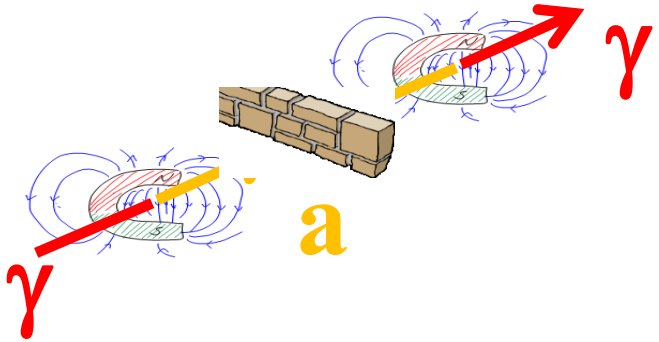
ALPS

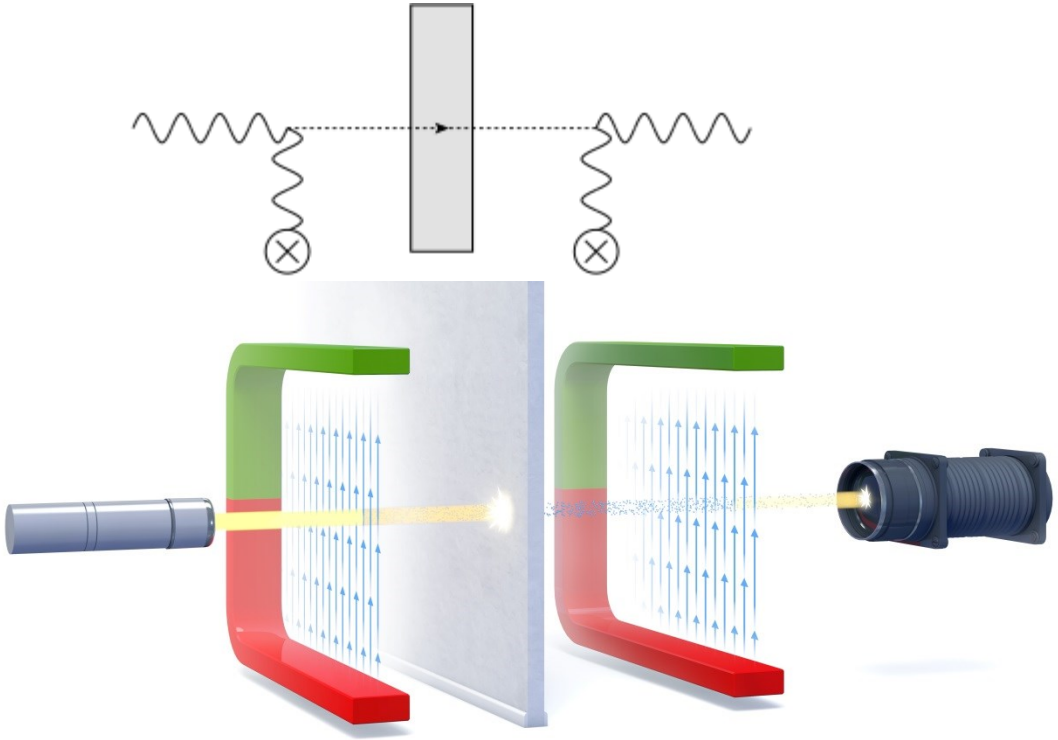
DESY.

Outline

- ALPS II
  - LSW Concept
  - Sensitivity
  - Optics
  - Magnets
  - Detectors
  - Infrastructure
  - Outlook



Light-shining-through-a-wall in a nutshell

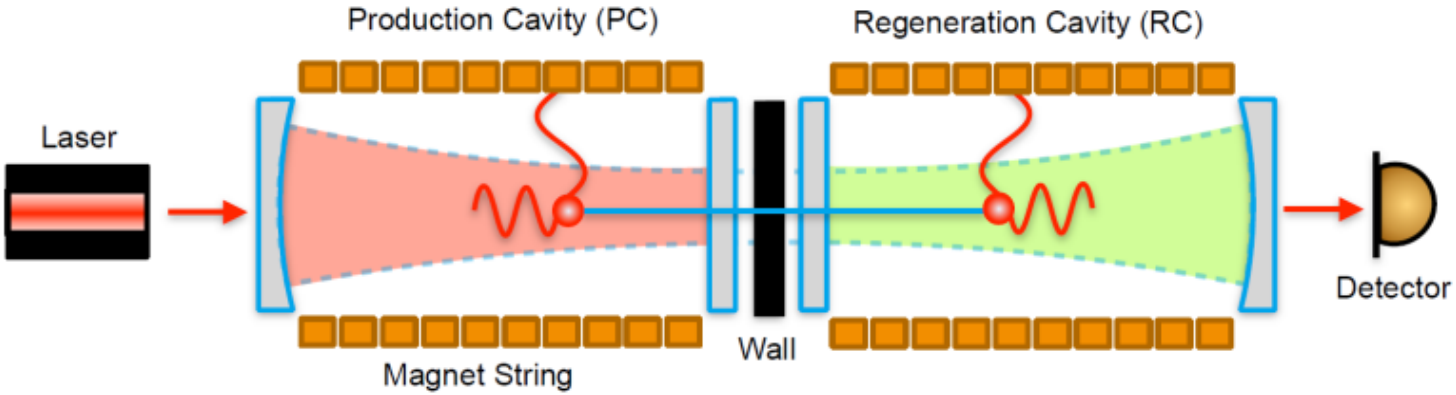


Optics Magnets Detector

- Light is shone on an opaque wall
- Photons convert into axions/ALPs in a magnetic field and pass the wall
- Behind the wall, the axions/ALPs convert back to photons in a magnetic field
- Light is detected by a detector

$$P_{\gamma \leftrightarrow a} = \frac{1}{4}\frac{\omega}{k_a}(g_{a\gamma}BL)^2 \cdot |F|^2$$

ALPS II @ DESY in Hamburg



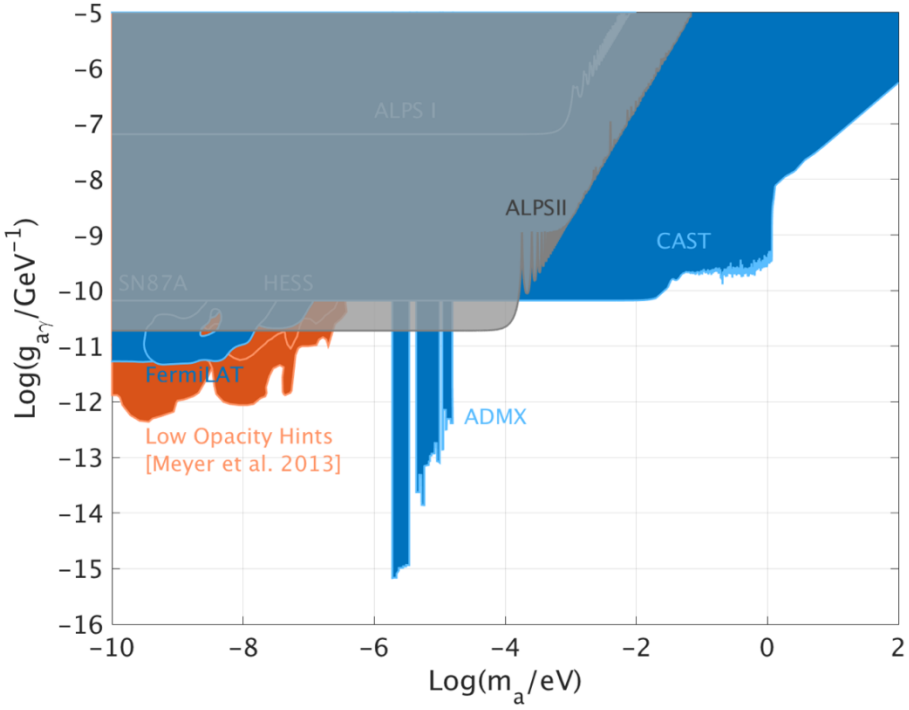
Originally: 10+10 dipole magnets from the HERA proton accelerator

Production cavity and regeneration cavity, mode matched

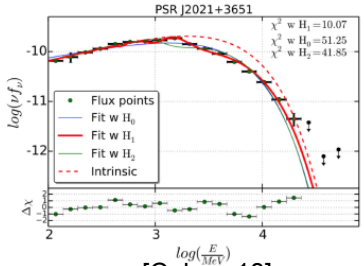
$$P_{\gamma\to\phi\to\gamma} = \frac{1}{16}\cdot\mathcal{F}_{PC}\mathcal{F}_{RC}\cdot(g_{a\gamma\gamma}Bl)^4 = 6\cdot10^{-38}\cdot\mathcal{F}_{PC}\mathcal{F}_{RC}\cdot\left(\frac{g_{a\gamma\gamma}}{10^{-10}GeV^{-1}}\frac{B}{1\,T}\frac{l}{10m}\right)^4$$

Optics **Magnets** **Detector**

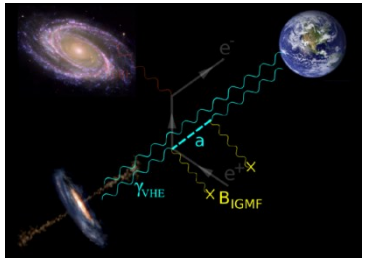
ALPS II Sensitivity



- ALPS II plans to reach about a factor of 3000 in sensitivity compared to ALPS I
- ALPS II will not probe the QCD axion band
- ALPS II can reach into a region where ALPs could be CDM
- ALPS II will probe part of the region with important astrophysical hints

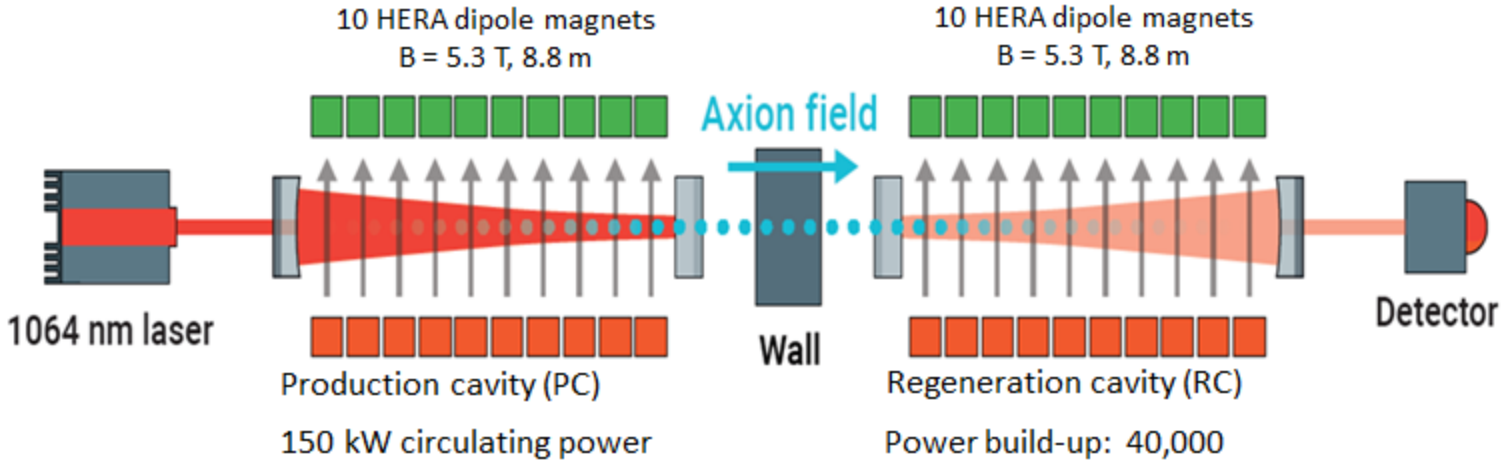


[Calore 18]



[Manuel Meyer 12]

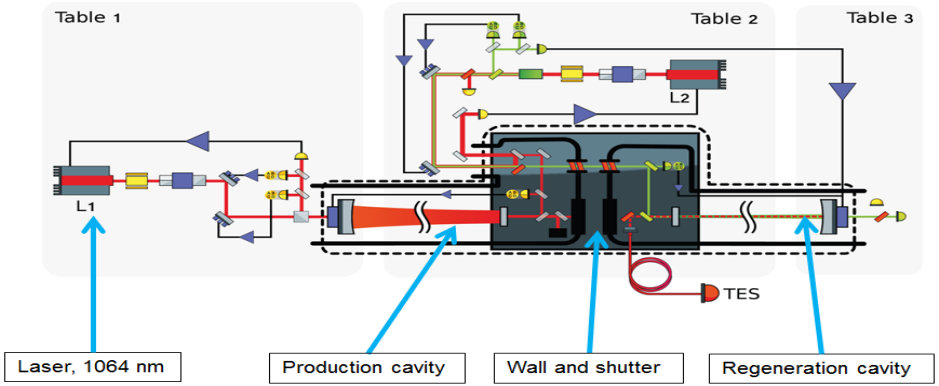
Optics



Mode-matched cavities:

- **Production Cavity** increases circulating power before wall
- **Regeneration Cavity** resonantly enhances reconversion probability of ALPs into photons

Optics: Challenges



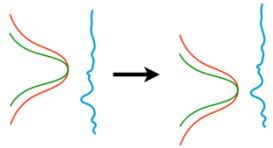
- High power operation in production cavity
- High finesse cavity for photon regeneration
- Dual cavity lock
- Cavity alignment over long times
- Light tightness and shutter

Optics: Results

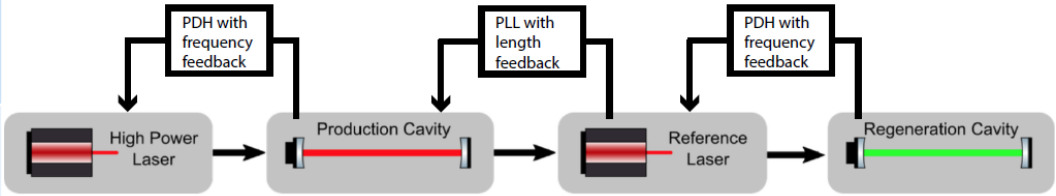
Posters by Li-Wei Wei and Kanioar Karan

	Goal	Status
Injected power	30 W	32 W
PC circulating power	150 kW	50 kW
RC power buildup factor	40,000	26,000
Relative mirror alignment	< 5 urad	< 1 urad
Spatial (field) overlap	> 95%	>98.5%
RC length stabilization	<0.6 pm	<0.6 pm

- Several design values already achieved.
- Investigation of dichroic noise

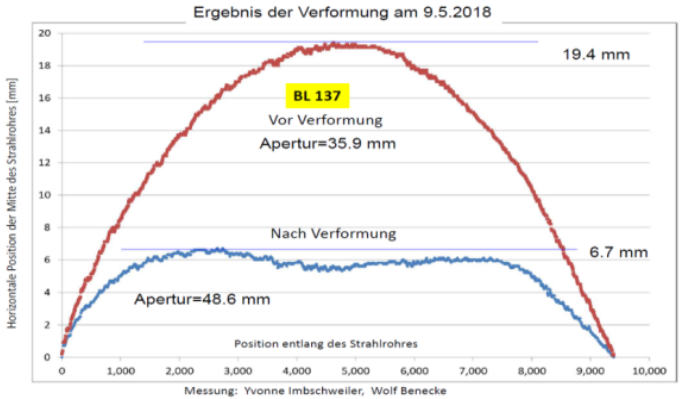


- One of the main tasks recently: feasibility study for longer magnet string



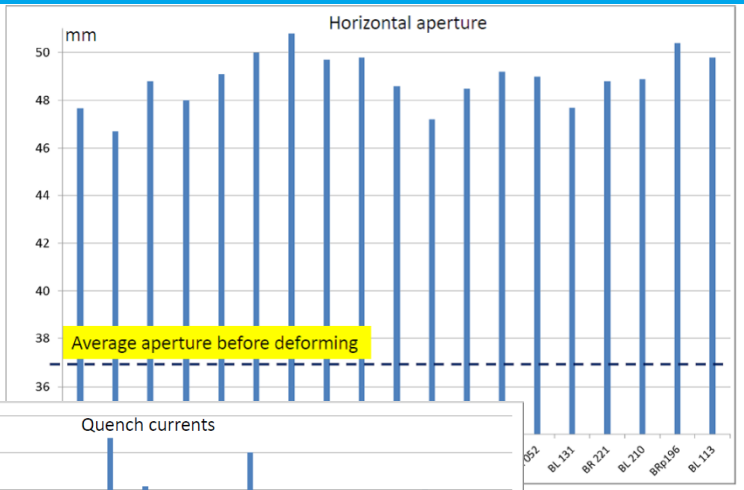
ALPS II main components: magnets from HERA

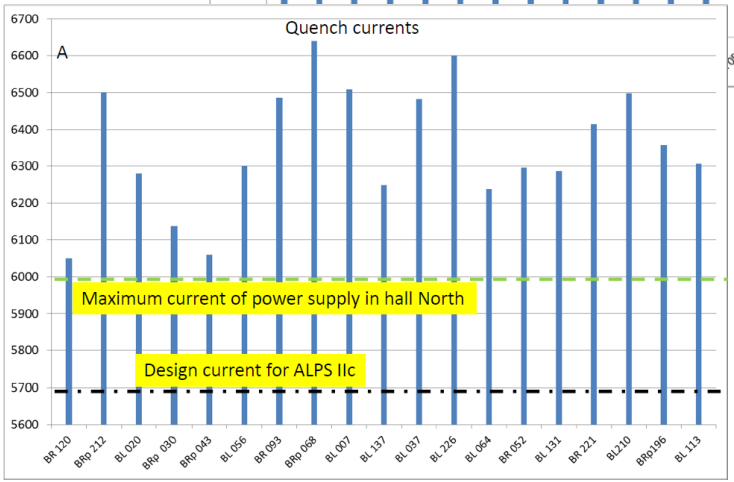
- Original plan: 10+10 dipoles from HERA, each 5.3 T on 8.8 m.
- Power build-up of cavities limited due to clipping losses because of magnet aperture.
- Magnets need to be straightened to achieve larger aperture compared to 35 mm (before straightening)



Magnet Straightening Status

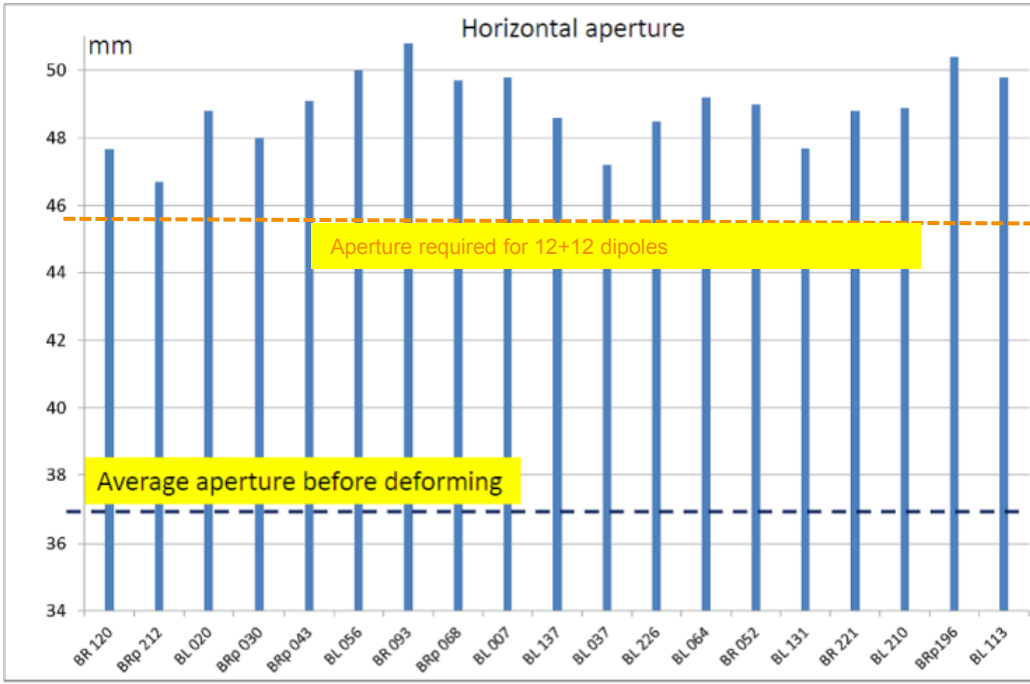
- By now 20 dipoles from HERA have been straightened, all successfully
- The average aperture is about 48 mm (!)
- All quench currents after deformation are above the maximum current of the power supply
- Stable operation also tested successfully





Magnet: Change of Plans

- Due to the big success in straightening the magnets (i.e. big apertures), it was investigated to increase the number of magnets to 24
- Regenerated photon rate doubles when the magnetic field times length product increases by 20 %.
- An investigation showed that the benefits exceed the risks
- Decision: ALPS II will use 24 magnets
- Taken from spare magnets, additional spares to be taken out of accelerator and straightened.



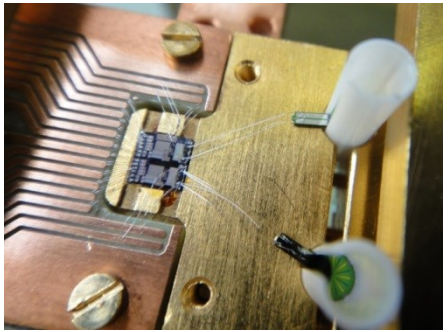
ALPS detector requirements

Detector Challenges

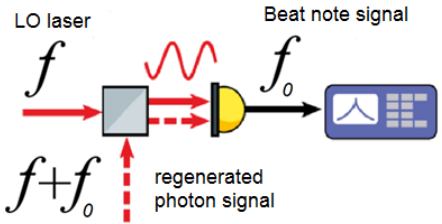
- Able to detect extremely low rates (about 10^{-4} s^{-1}) of 1064 nm photons, i.e. about 1 eV of photon energy
- Low noise, low background rate
- High efficiency
- Long-term stability

➔ Two detection concepts for ALPS II: heterodyne detection and transition edge sensor
➔ Plan to employ both detection methods

TES

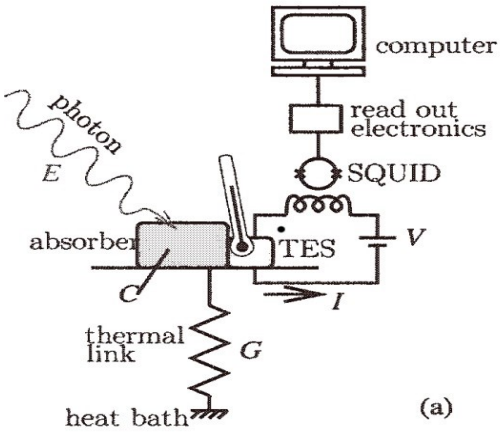


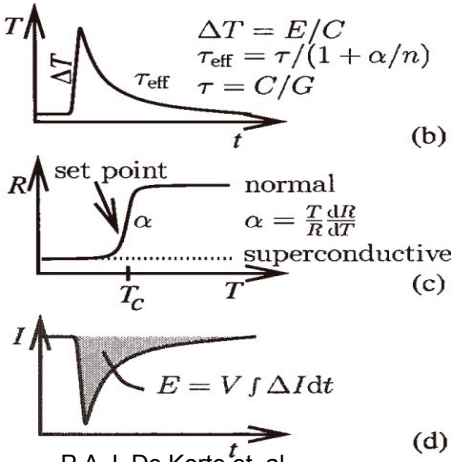
Heterodyne



Transition Edge Sensor

- TES: superconducting sensor, operating in the superconducting transition region
- Photon sensitive absorber is connected to a TES thermistor, TES current read out by SQUID
- Absorption of photon causes rise of temperature, then cools down again
- Thus current changes, which can be read out by SQUID
- Integrated current signal is proportional to photon energy





P.A.J. De Korte et. al., Proceedings of SPIE, pages 779-789, 2002

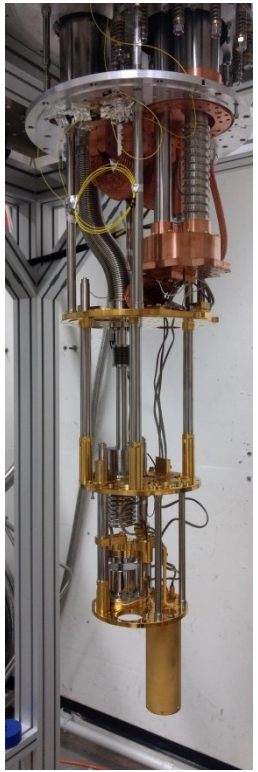
ΔT ≈ 100 μK

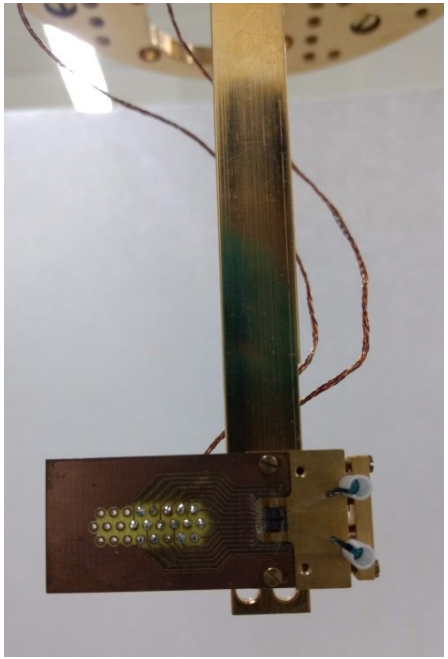
ΔR ≈ 1 Ω

ΔI ≈ 70 nA

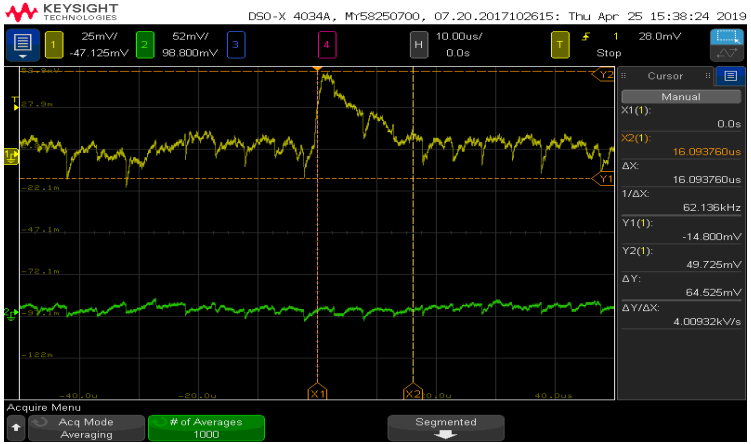
Single photon counting

TES Detector: results





- ✓ TES detector installed and operated successfully at ALPS detector lab in cryostat
- ✓ Noise studied, sources eliminated/reduced
- ✓ First light seen, 1064 nm photons detected
- ✓ Optimised module currently being installed



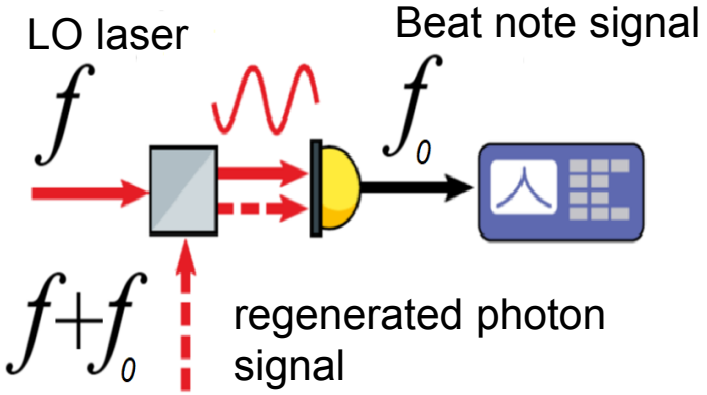
Heterodyne detection

Poster by Todd Kozlowski/Dave Tanner

- Interfere regenerated field with a much stronger frequency shifted LO laser field

  ➔ beat frequency measurement

- Beat note carries information on photon rate of the regenerated signal

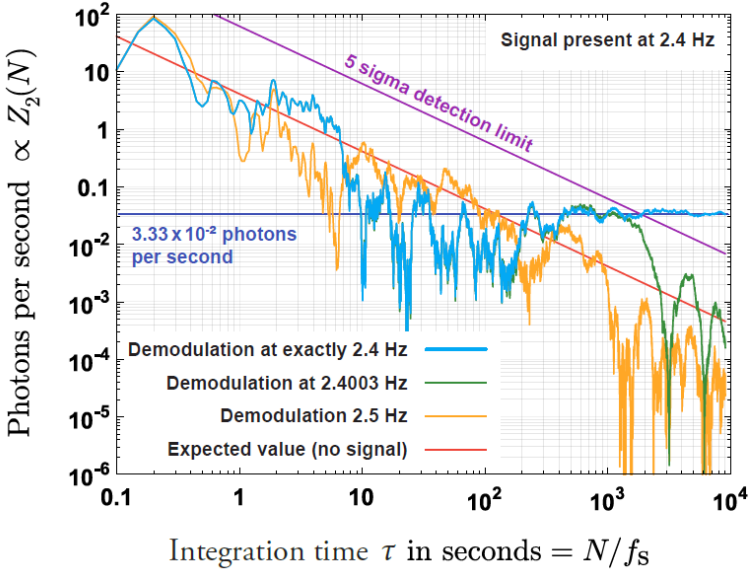


$$\left|\sqrt{\bar{P}_{\mathrm{LO}}}e^{i(2\pi f t+\phi_1)}+\sqrt{\bar{P}_{\mathrm{weak}}}e^{i[2\pi(f+f_0)t+\phi_2]}\right|^2 =$$

$$\bar{P}_{\mathrm{LO}}+\bar{P}_{\mathrm{weak}}+2\sqrt{\bar{P}_{\mathrm{LO}}\bar{P}_{\mathrm{weak}}}\cos\left(2\pi f_0 t+\Delta\phi\right)$$

- Signal coherently sums over time
- Noise averages out
- Can reach shot noise limit

Heterodyne: Results



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

- Testbed studies recently published:

  PRD 99 022001 (2019)]

  - Test signal of 3.3* 10^{-2} photons/second

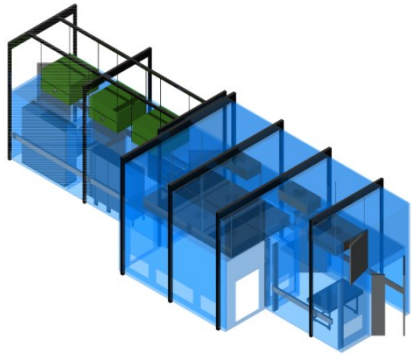
    (6.4 x 10^{-21} W) detected
  - Noise measurement consistent with no noise, Integrated noise floor below 2 x 10^{-24} W (equivalent to about 10^{-5} photons/s)
- Challenge: Phase change between the regenerated photon field and a LO laser < 0.1 cycles over ~ 2 weeks

ALPS II Site/Infrastructure

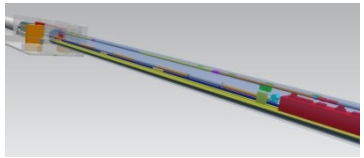
Construction is ongoing

- The HERA tunnel section in HERA North has been cleared.





- Cryogenic system layout adapted to 24 magnets
- Layout of cleanrooms has been finalized ➔ call for tender
- In general: very nice progress, slightly delayed due to change to 24 magnets

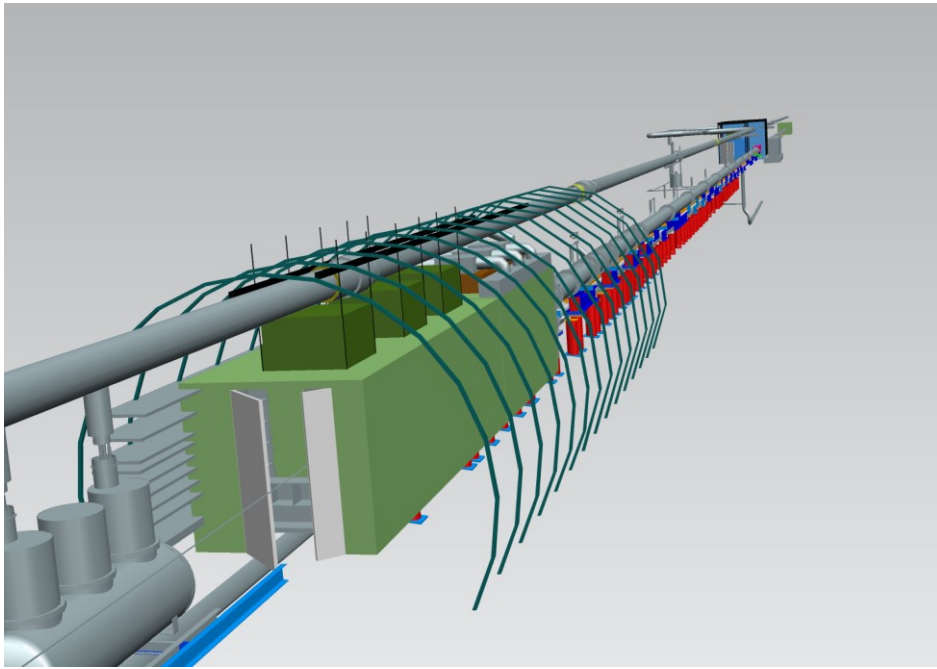


ALPS II schedule

ALPS II will be located in the tunnel of the HERA accelerator, around HERA North.

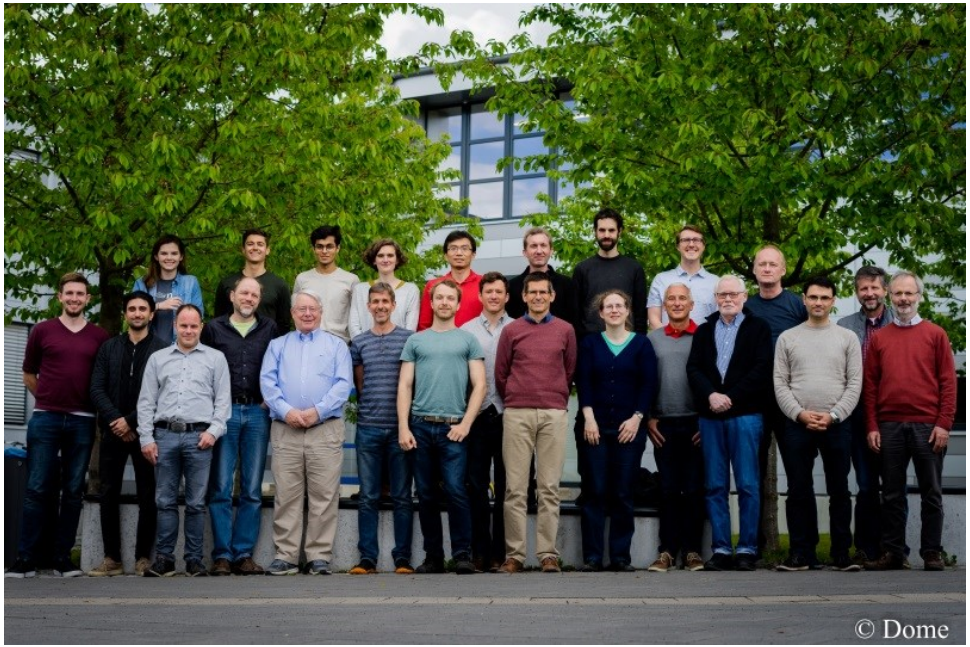
Timeline:

- Construction finished end of 2020 ➔ first light
- First data run in 2021
- Installation of 2nd optics setup to switch the detection scheme
- Second data run planned for 2022



ALPS II: aiming for start-up in 2020/2021 @ DESY in HH

Collaboration



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Significant funding support also by the

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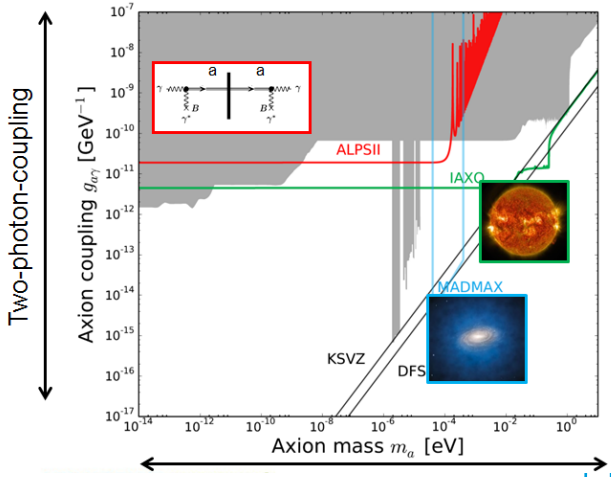

Summary

- ALPS II will look for axion-like particles reaching regions of several astrophysical hints using the light-shining-through-a-wall method
- ALPS II developments in optics, magnets, detectors and infrastructure successful and on track
- ALPS II has increased the number of magnets planned to be used in the experiment to 24 magnets (12 on each side), thus increasing its sensitivity by about 20%
- ALPS II construction is ongoing and planned to finish within 2020
- Looking forward to exciting axion/ALP physics!