Any Light Particle Search II

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for the ALPS II collaboration

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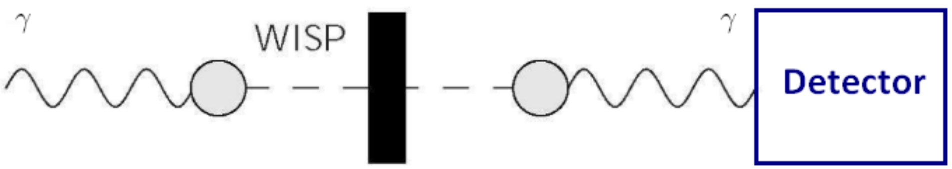
Zaragoza

Any Light Particle Search

Any Light Particle Search experiment looks for **Weakly Interacting Sub-eV Particles** also called **WISPs**.

Axion → Possible solution for the smallness of the **CP violation** in QCD
→ Hints from astrophysics observations

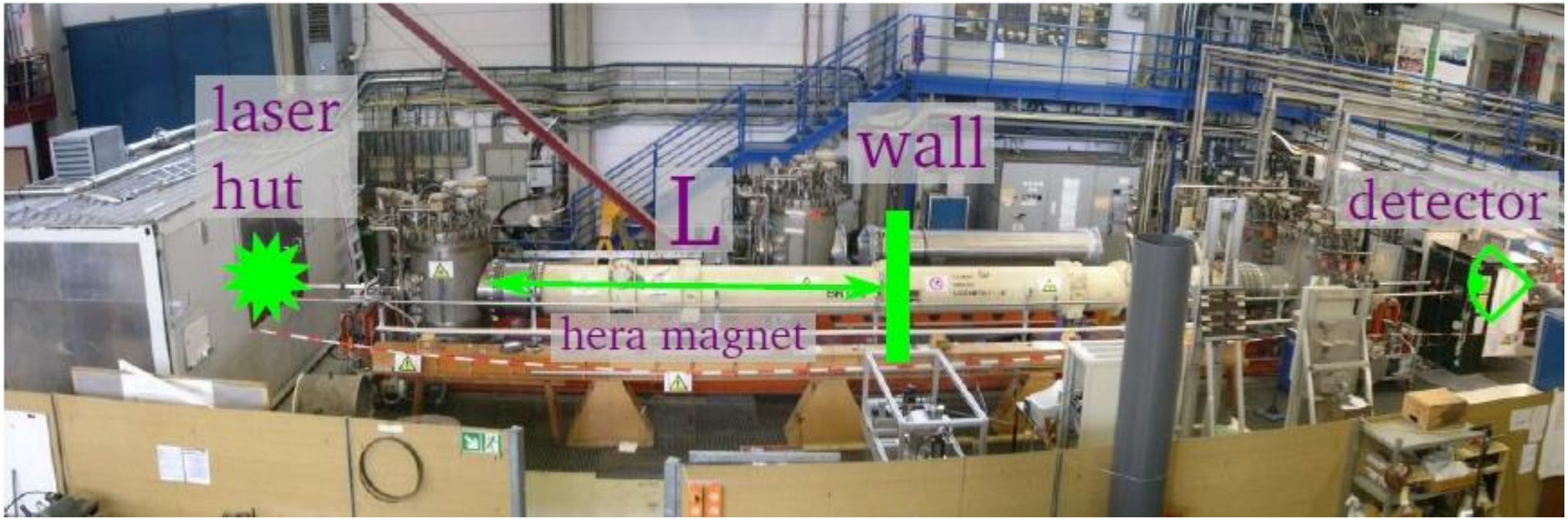


Light shining through the wall experiment:
Photon-mixing + Additional light boson
→ Re-appearance of photons behind the barrier

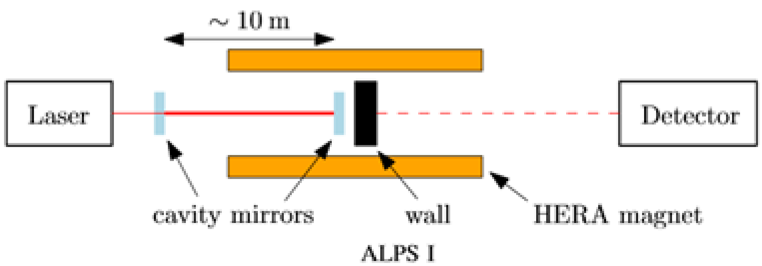
1064 nm laser → 1.17 eV photons
1 photon every few hours

$$\mathcal{P}_{\gamma\to a} = \frac{\omega}{4k_a}\left(g_{a\gamma}BL\right)^2|F|^2 = \mathcal{P}_{a\to\gamma} \qquad k_a^2 = \omega^2 - m_a^2$$

ALPS I



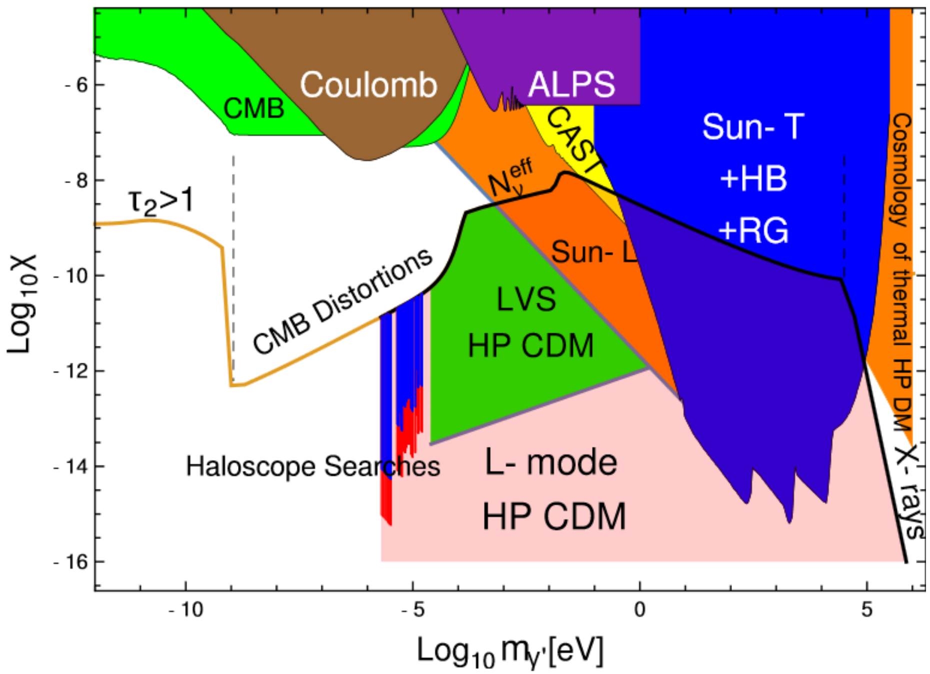
(Source: B. Döbrich)

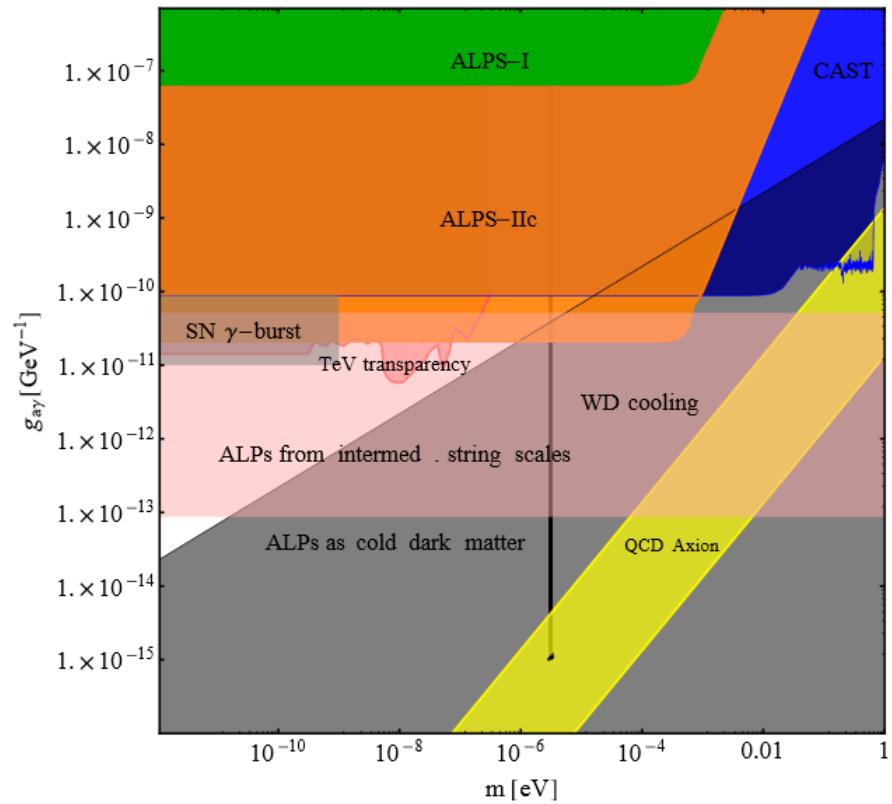


Ehret et al., **New ALPS results on hidden-sector lightweights**, PLB (2010)

Laser	532 nm
Optic setup	10 m production cavity
Magnet	9m, 5T HERA dipole
Detector	CCD Camera (PIXIS)

From ALPS I to ALPS II



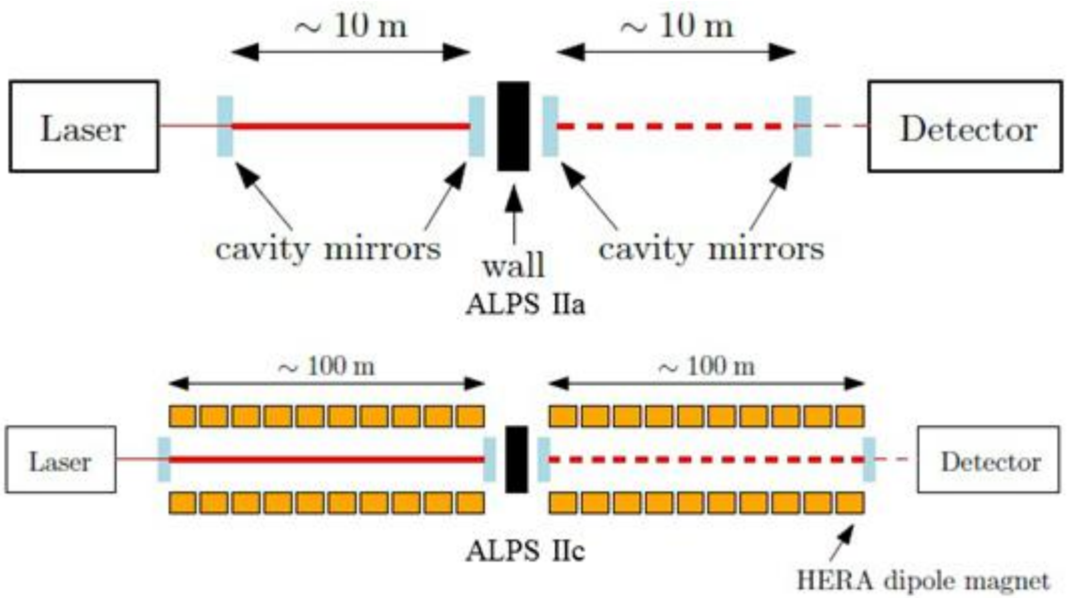


ALPS II

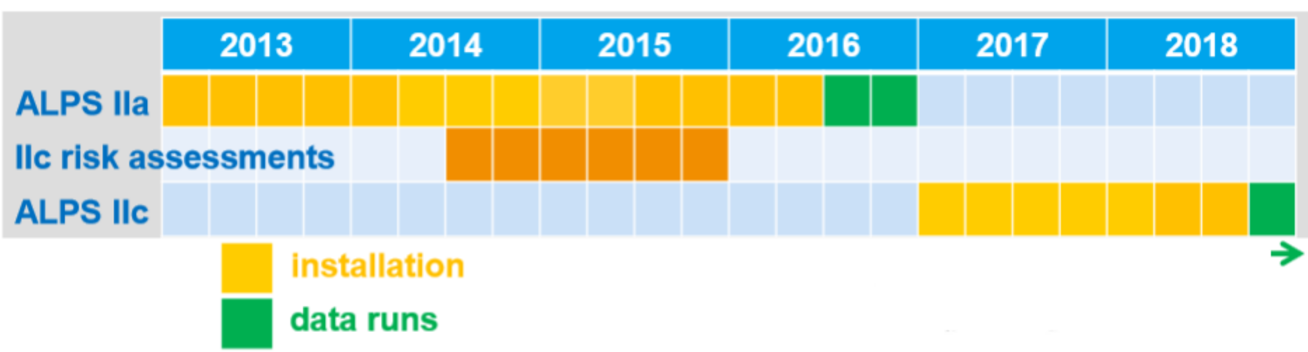
parameter	scaling	ALPS I	ALPS IIc	sens. gain
$B\,L$ (total)	$g_{a\gamma} \propto (B\,L)^{-1}$	22 Tm	468 Tm	21
PC built up ($P_{\text{laser,eff.}}$)	$g_{a\gamma} \propto \beta_{\text{PC}}^{-1/4}$	1 (kW)	150 (kW)	3.5
rel. photon flux $\dot{n}_{\text{prod}}$	$g_{a\gamma} \propto \dot{n}_{\text{prod}}^{-1/4}$	1 (532 nm)	2 (1064 nm)	1.2
RC built up β_{RC}	$g_{a\gamma} \propto \beta_{\text{RC}}^{-1/4}$	1	40,000	14
detector eff. DE	$g_{a\gamma} \propto DE^{-1/4}$	0.9	0.75	0.96
detector noise DC	$g_{a\gamma} \propto DC^{1/8}$	$1.8 \cdot 10^{-3}\,\text{s}^{-1}$	$10^{-6}\,\text{s}^{-1}$	2.6
combined				3082

$$S(g_{a\mu}) \propto \frac{1}{BL}\left(\frac{DC}{T}\right)^{1/8} \cdot \left(\frac{1}{\eta \dot{N}_{\text{Pr}} \beta_{PC} \beta_{RC}}\right)^{1/4}$$

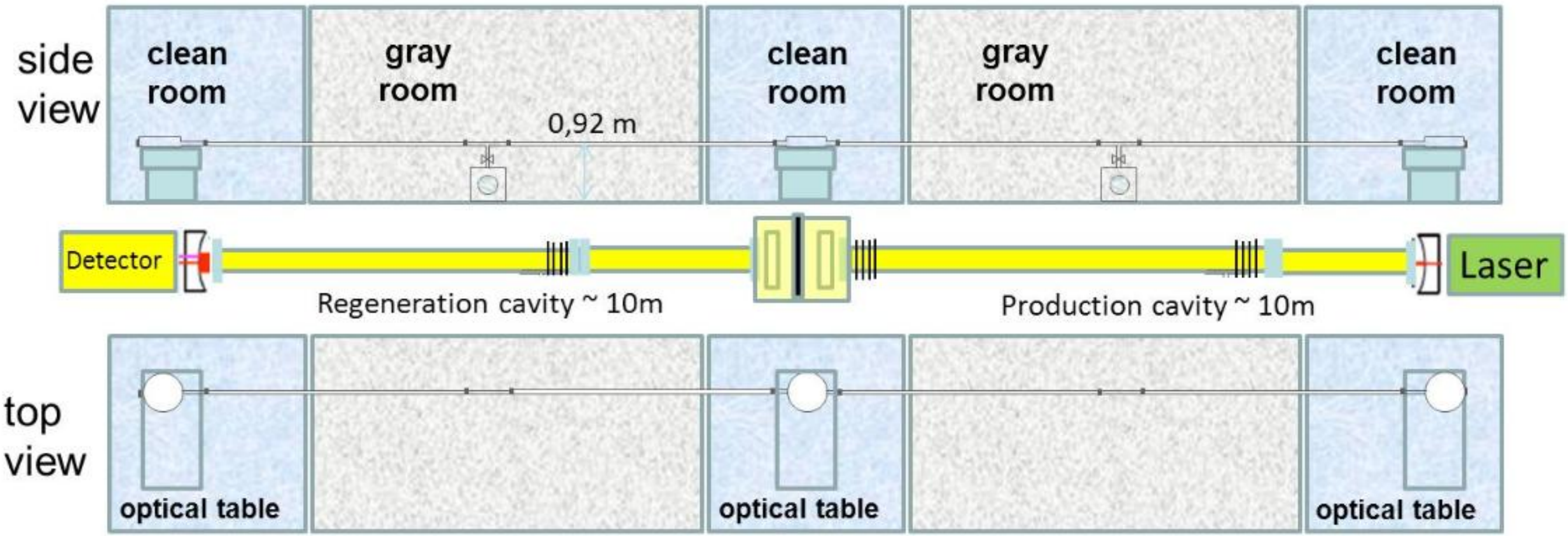
ALPS II Schedule



ALPS IIc in 2018
in the HERA tunnel



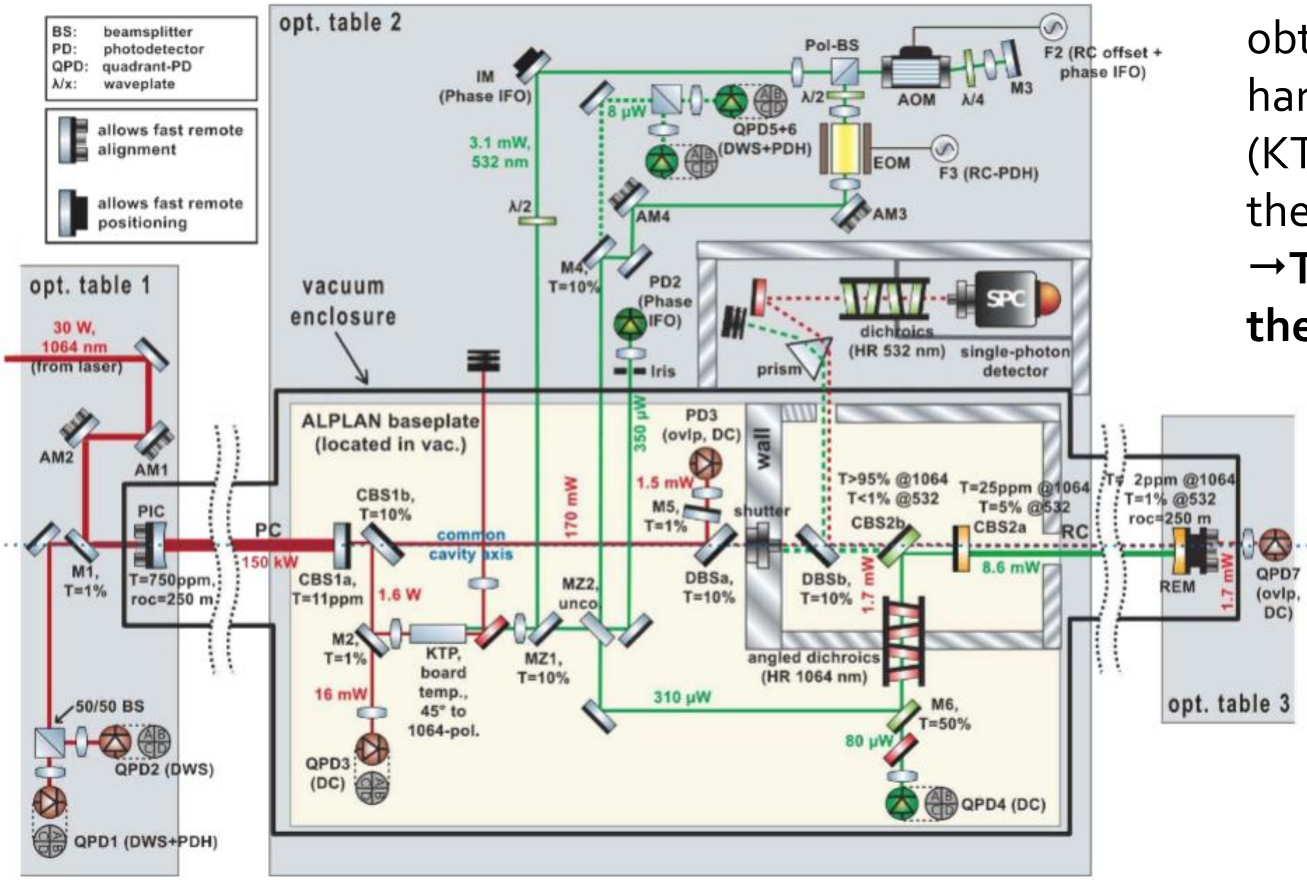
ALPS IIa - setup



LASER	35 W, 1064 nm (Class 4 laser)
LASER TYPE	Master Oscillator Power Amplifier (MOPA)
PB PC	5000
PB RC	40000
VACUUM	10^{-6} mbar

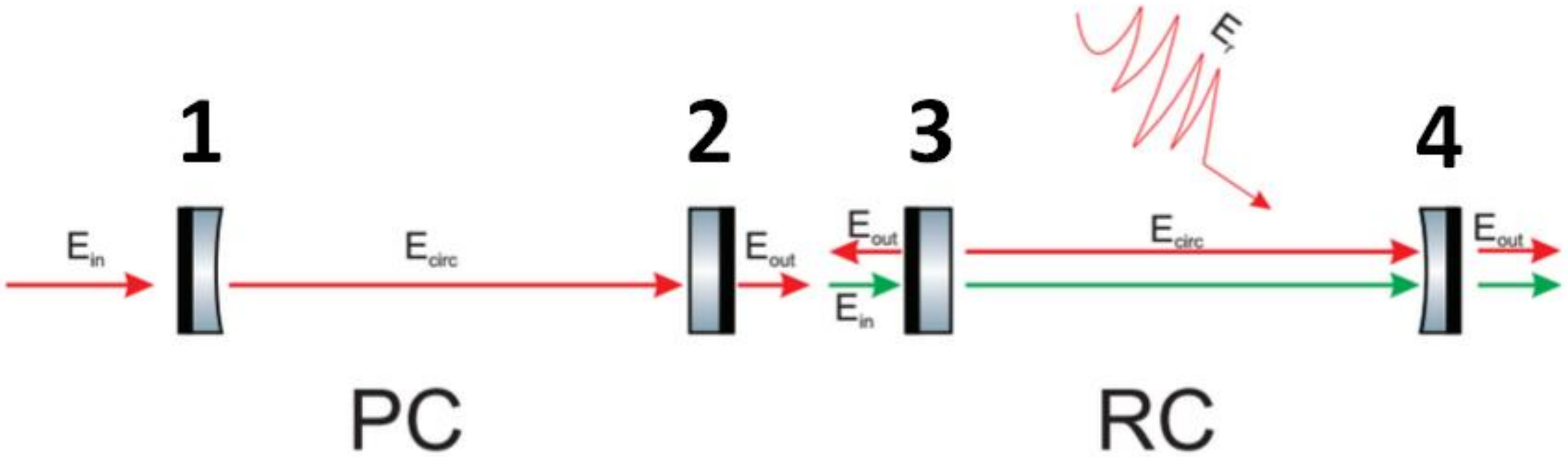
Optics

Optical Layout for ALPS II



Auxiliary green beam obtained via second harmonic generation (KTP crystals) from the IR production.
→**Test resonance of the RC**.

Auto alignment

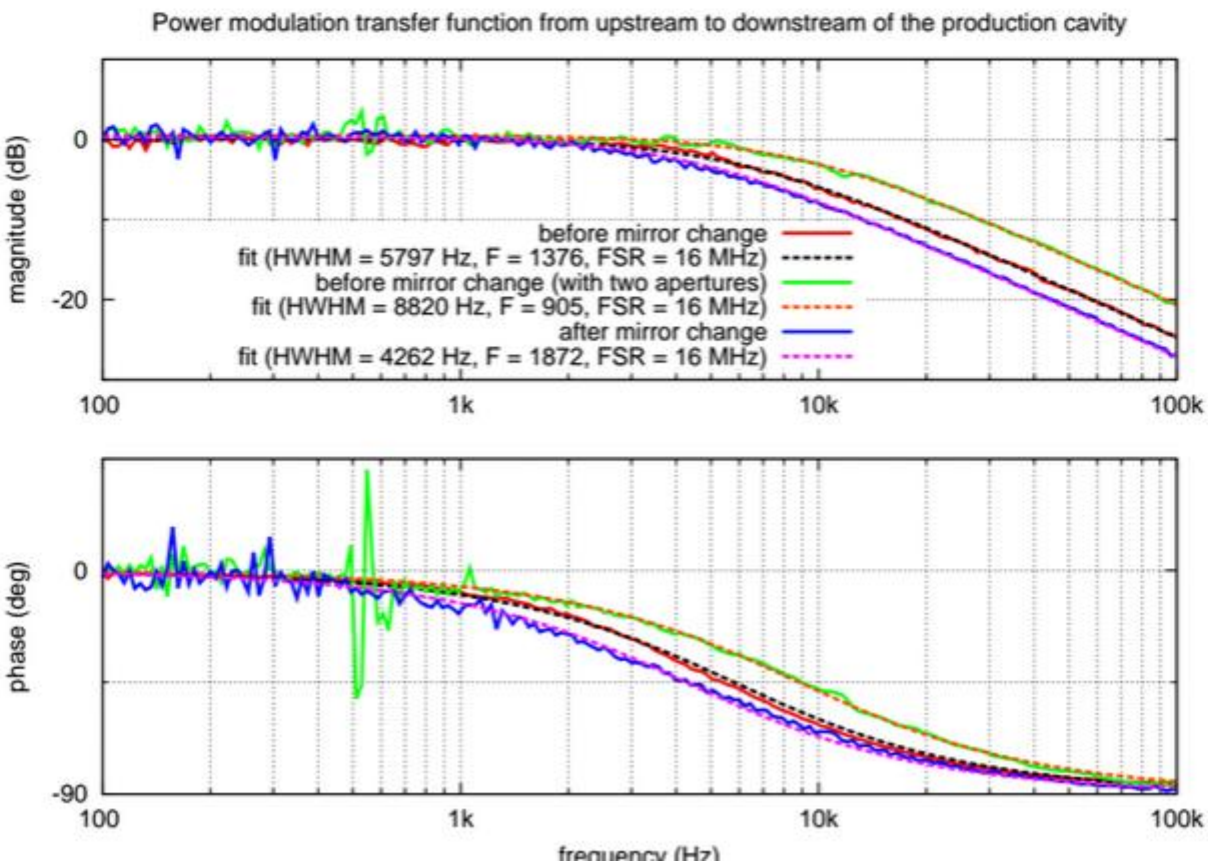


The PC and the RC needs to be in the same modal phase in order to reach the highest PB (aiming for 95% mode overlap).

M2 and M3 → Fixed position
M1 and M4 → Piezo mount for compensation of ambient vibrations

Beam alignment towards cavities → Control beforehand the cavity

PB for production cavity

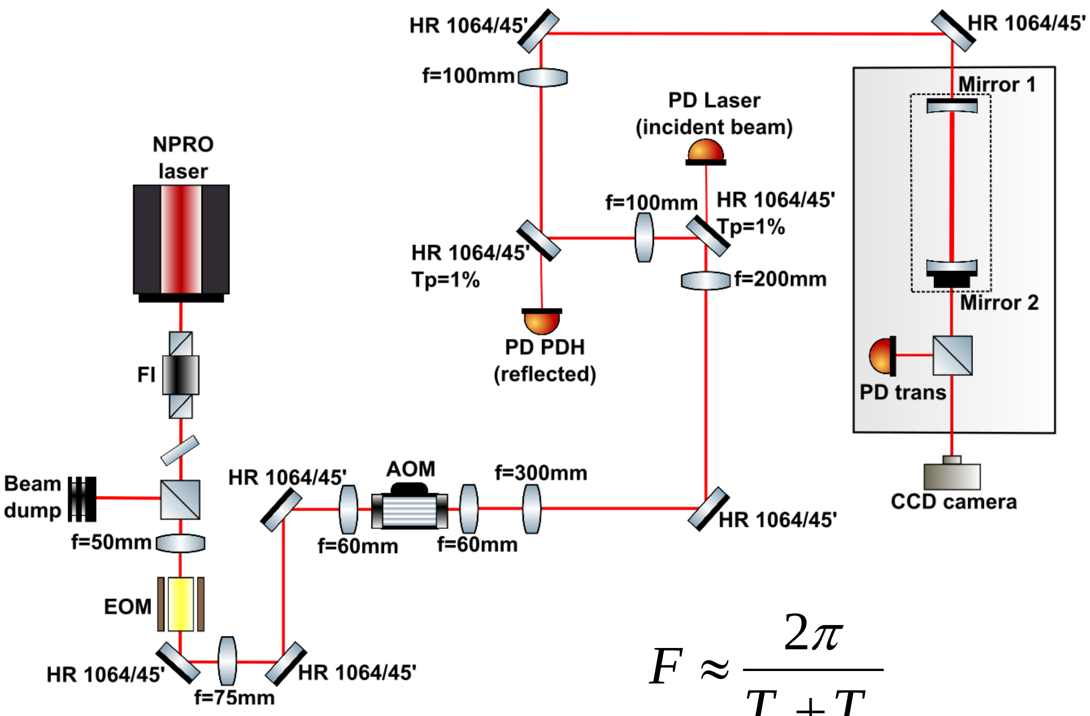


The PB of the production cavity is not sufficient (< 5000).

Possible sources:

- **Coating of the mirrors**
- **Cleanliness of the mirrors**
- **Alignment**
- **Clipping in the vacuum system**

Mirrors quality testing



$$F \approx \frac{2\pi}{T_1 + T_2}$$

- Optical loss of the high-reflectivity mirrors is a critical parameter.
- Use of a cavity ring-down technique to characterize them.
- Finesse values for each cavities are currently measured using this technique.

$$PB = \frac{F}{\pi}$$

Reachable Power Build Up (PB) depends on the cavity finesse (F)

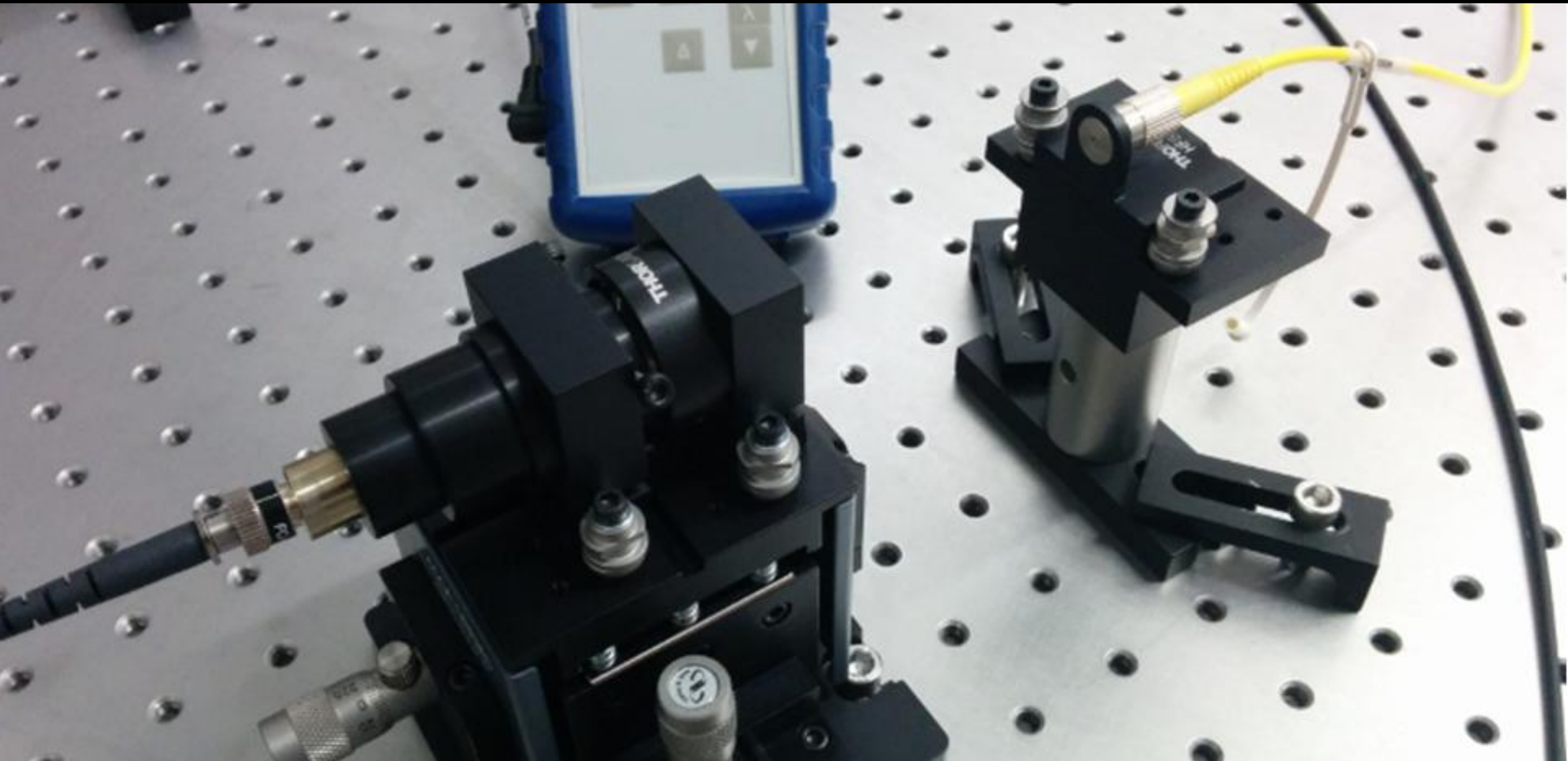
Results and outlook

Mirror 1	Mirror 2	Losses	Finesse
750 ppm	68 ppm	800 ± 30ppm	8600 ± 400
2 ppm	68 ppm	192 ± 30ppm	34000 ± 5000
68 ppm	68 ppm	213 ± 35ppm	30000 ± 5000

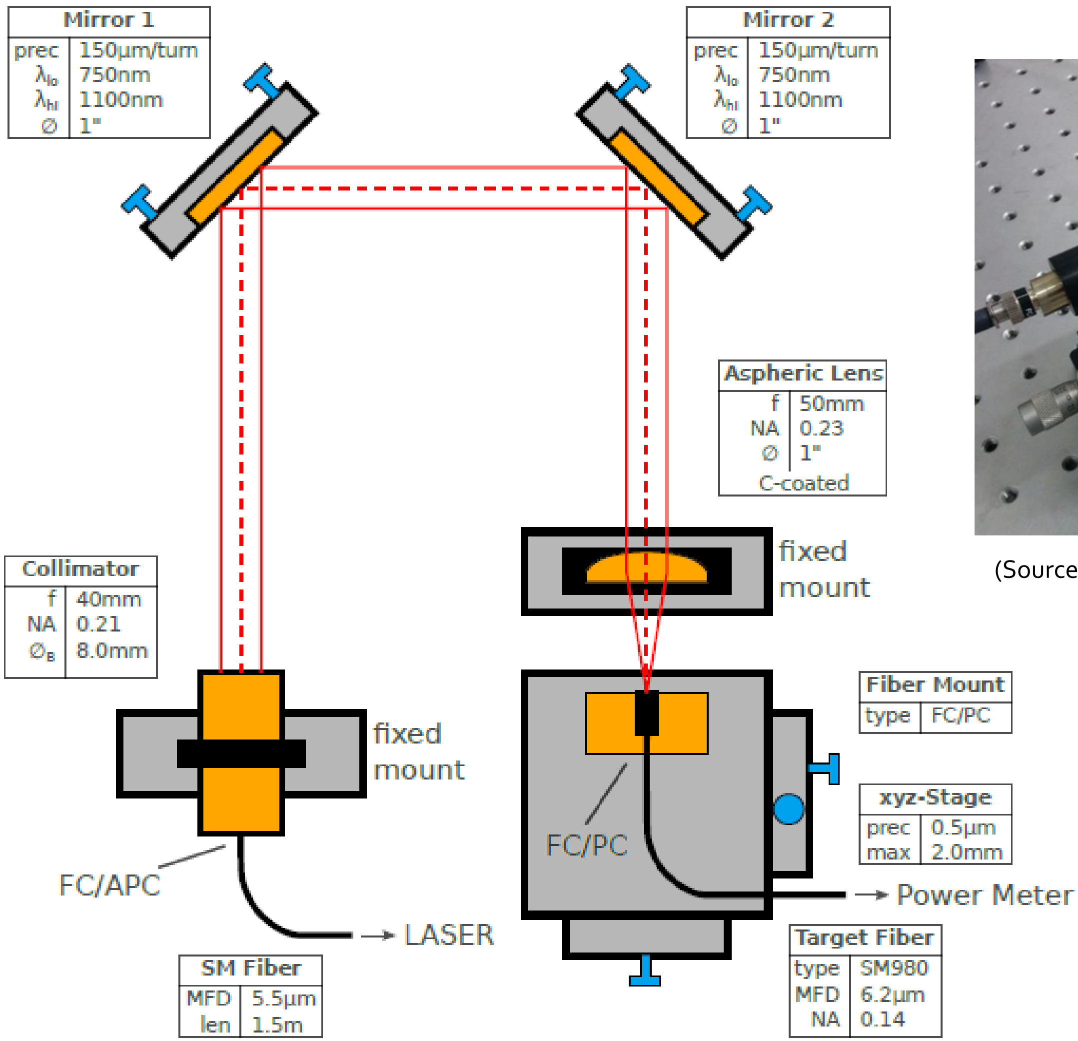
⇨ **The mirrors are corresponding to the specs for small cavities and small laser beam radius.**

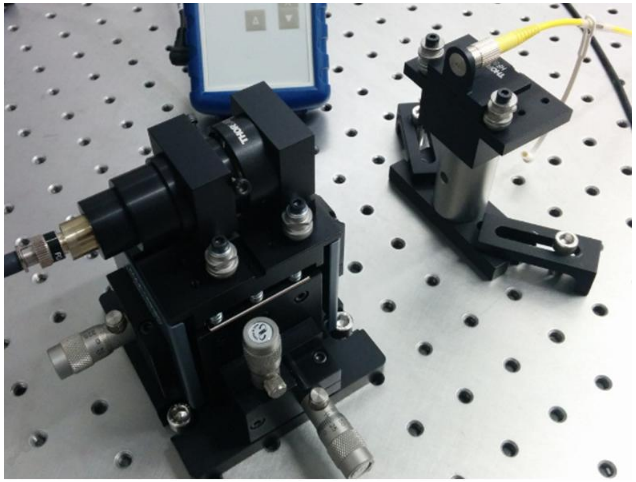
All the mirrors are currently tested with a beam with a larger radius in order to enlarge the tested region on the surface of the mirrors.

Coupling of the beam



Setup

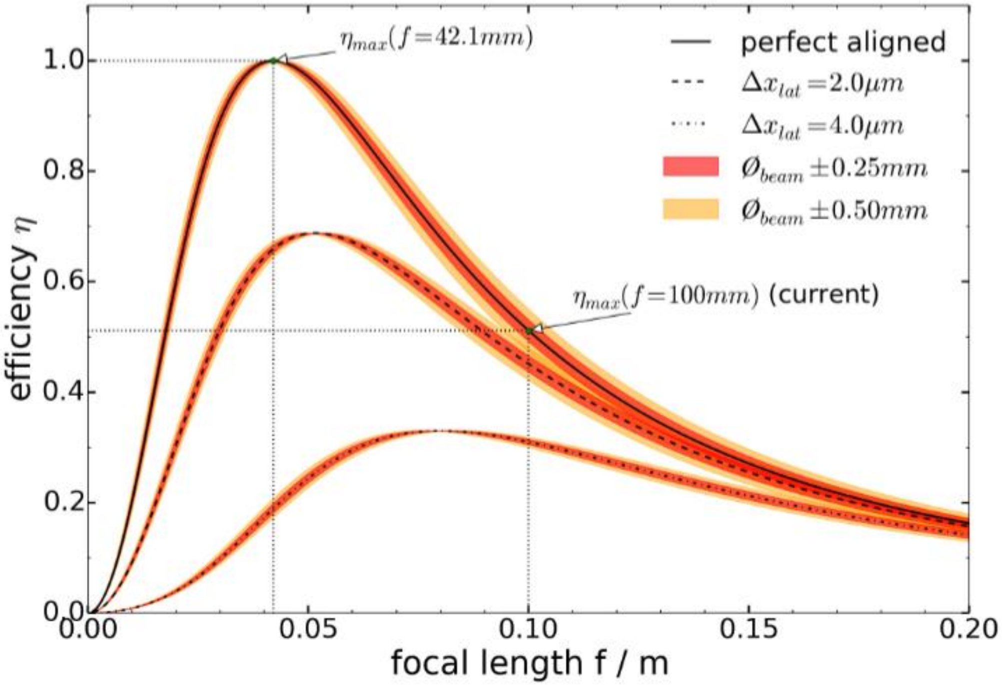




(Source: C. Weinsheimer)

Coupling Efficiency 53 %

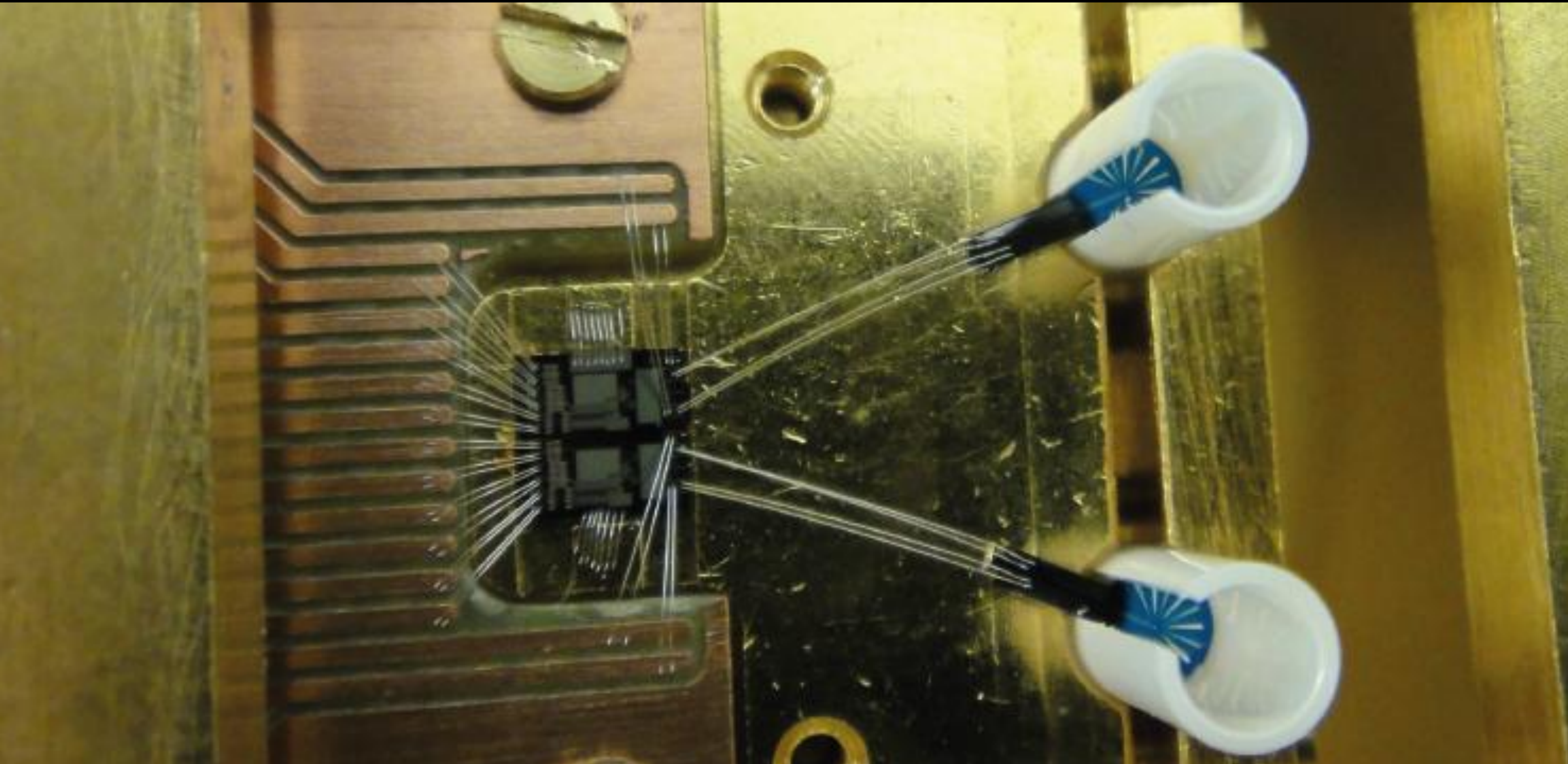
Latest results



The highest value is currently obtained for a lens with f= 35 mm (matching expectations).

The efficiency reached is lower than what was expected. The beam quality of the test laser is currently tested using a knife edge unit.

Detector



Technical challenges for the detector

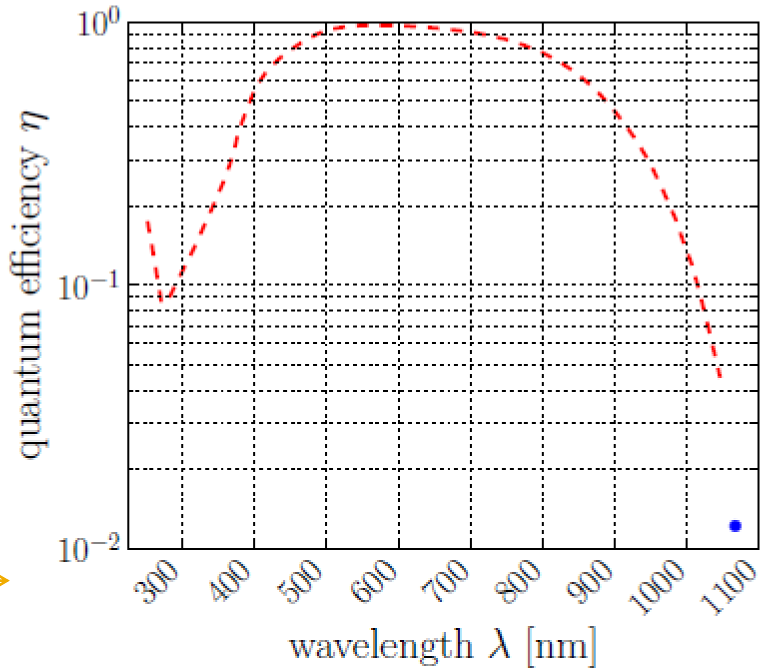
⇨ **Low energy (1.17 eV) and low rate (1 photon every few hours).**

1) **High efficiency**
2) **Low dark count rate**
3) Long-term stability
4) Good energy resolution
5) Good time resolution

CCD in ALPS II

PIXIS 1024B CCD camera	
Dark current	10^{-3} e$^-$ / *pixel* / sec
Efficiency (1064 nm)	1.2 %
Long term stability	☑
Good energy resolution	☒
Good time resolution	☒

Low efficiency due to the proximity of the wavelength to the Si band gap energy.

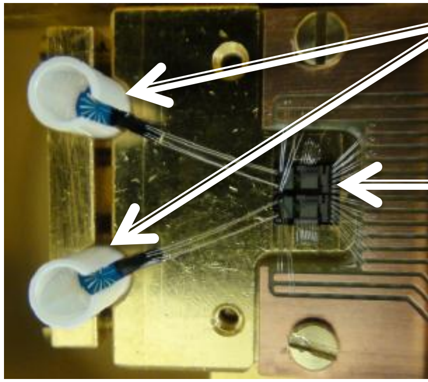


Von Seggern JE, *Constraining Weakly Interacting Slim Particles with a Massive Star and in the Laboratory*, Dissertation, Univ. Hamburg, 2014

Transition Edge Sensor

NIST
PTB

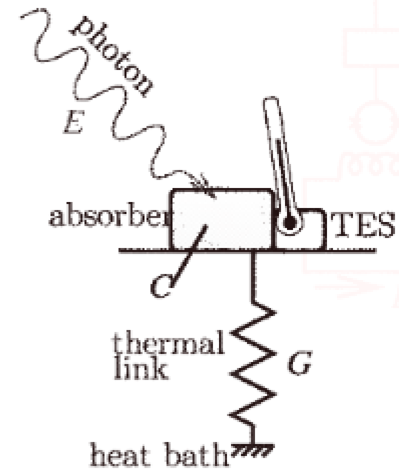
*Two channels module (3 cm * 3 cm)*



TES

SQUID

TES: Microcalorimeter measuring the temperature difference ΔT of the absorber material.



Tungsten chip (25 x 25 µm , 20 nm)	
Tc ≈ 140 mK	

A.E. Lita, A.J. Miller, S.W. Nam, *Counting near-infrared single photons with 95 % efficiency*, Opt Expres. 2008

NIST W-TES	
Efficiency (1064 nm)	95 %
Dark current	10^{-4} sec^{-1}
Long term stability	☑
Good energy resolution	< 8%
Good time resolution	☑

Photon absorption to signal output

Absorption of a photon (1.17 eV)
→ $\Delta T \approx 0.1$ mK

↓ Electro Thermal Feedback

Superconducting transition R ↑
($R \approx 1\ \Omega$)

↓

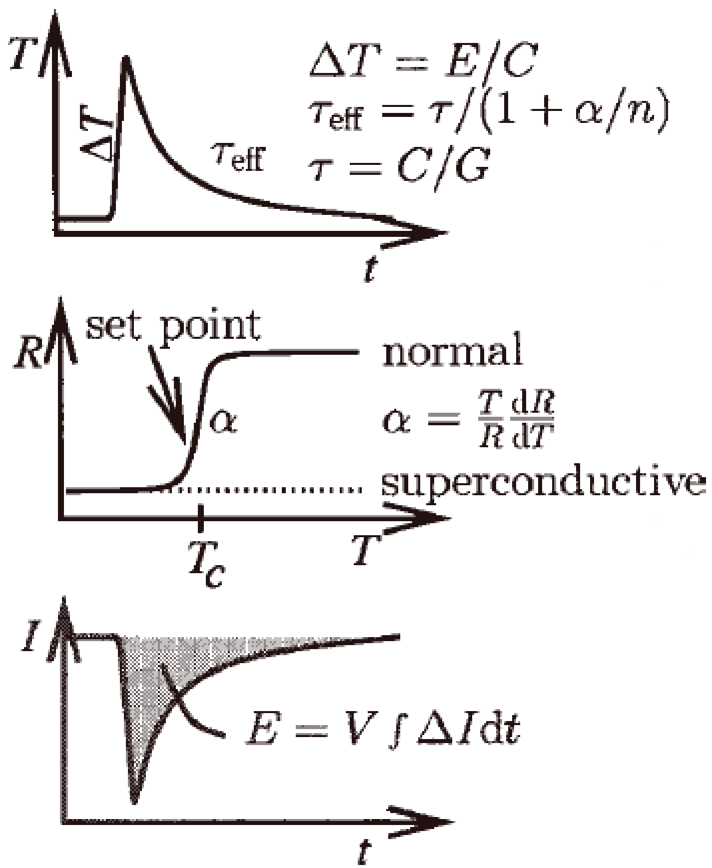
TES electrical circuit
($I \approx 70$ nA)

↓

SQUID (inductive coupling)

↓

$\Delta V_{out} \approx 50$ mV



TES environment in ALPS II

CLOSED

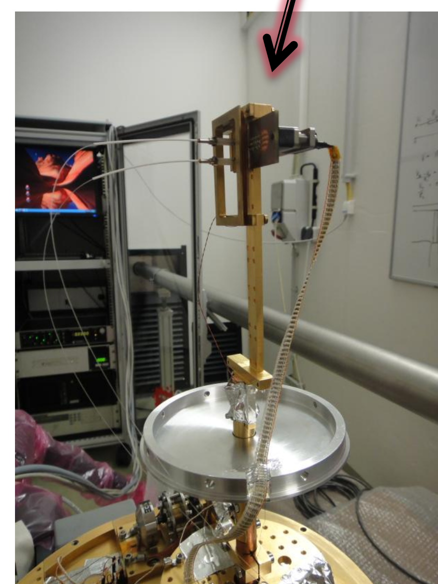
Adiabatic Demagnetization Refrigerator (ADR)

OPENED

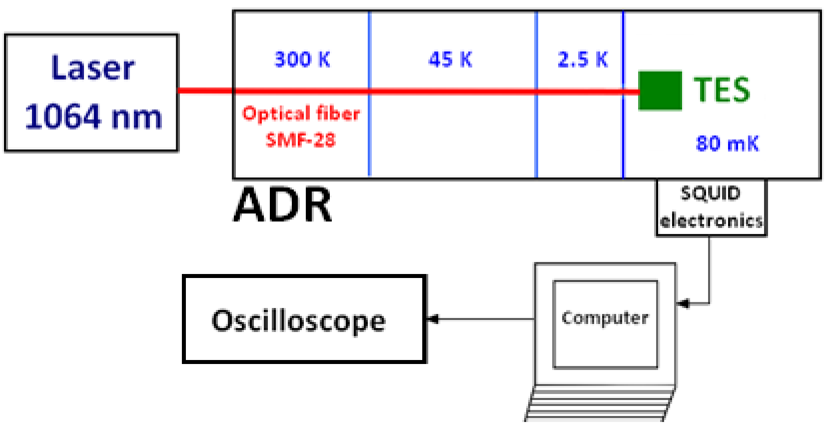
Transition Edge Sensor (80 mK)

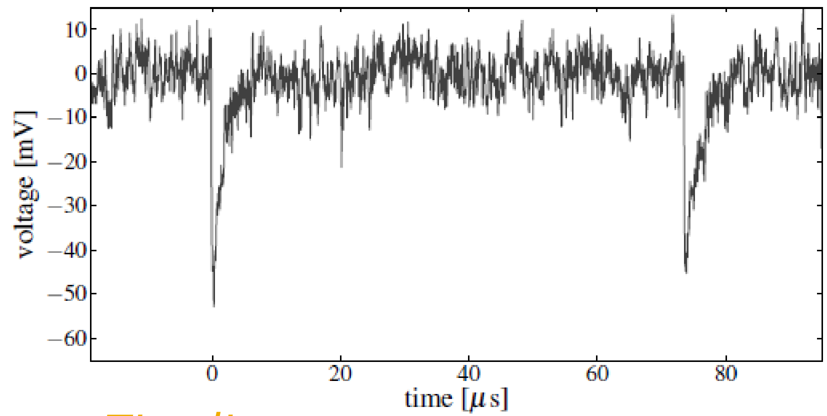
4K - plate

77K - plate



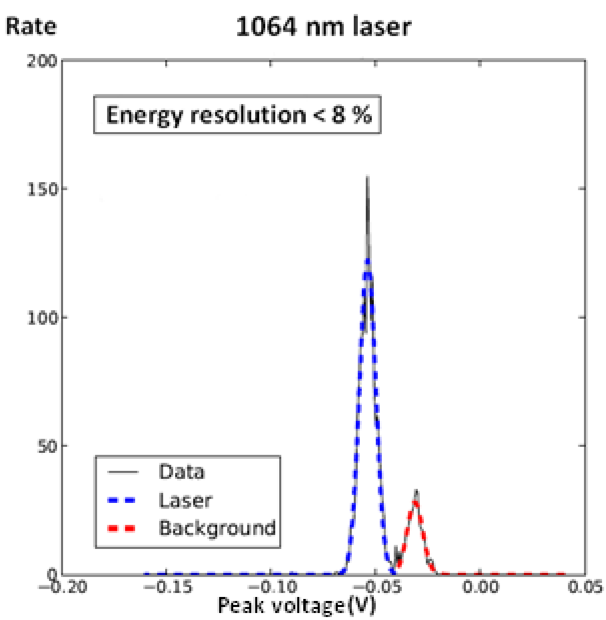
Single photon events





Timelines

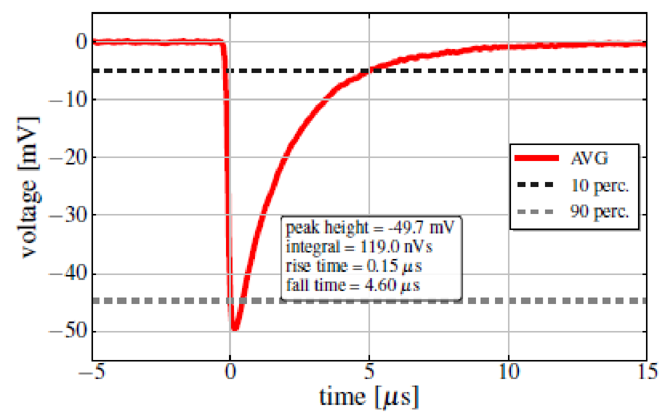
(source: J. Dreyling)



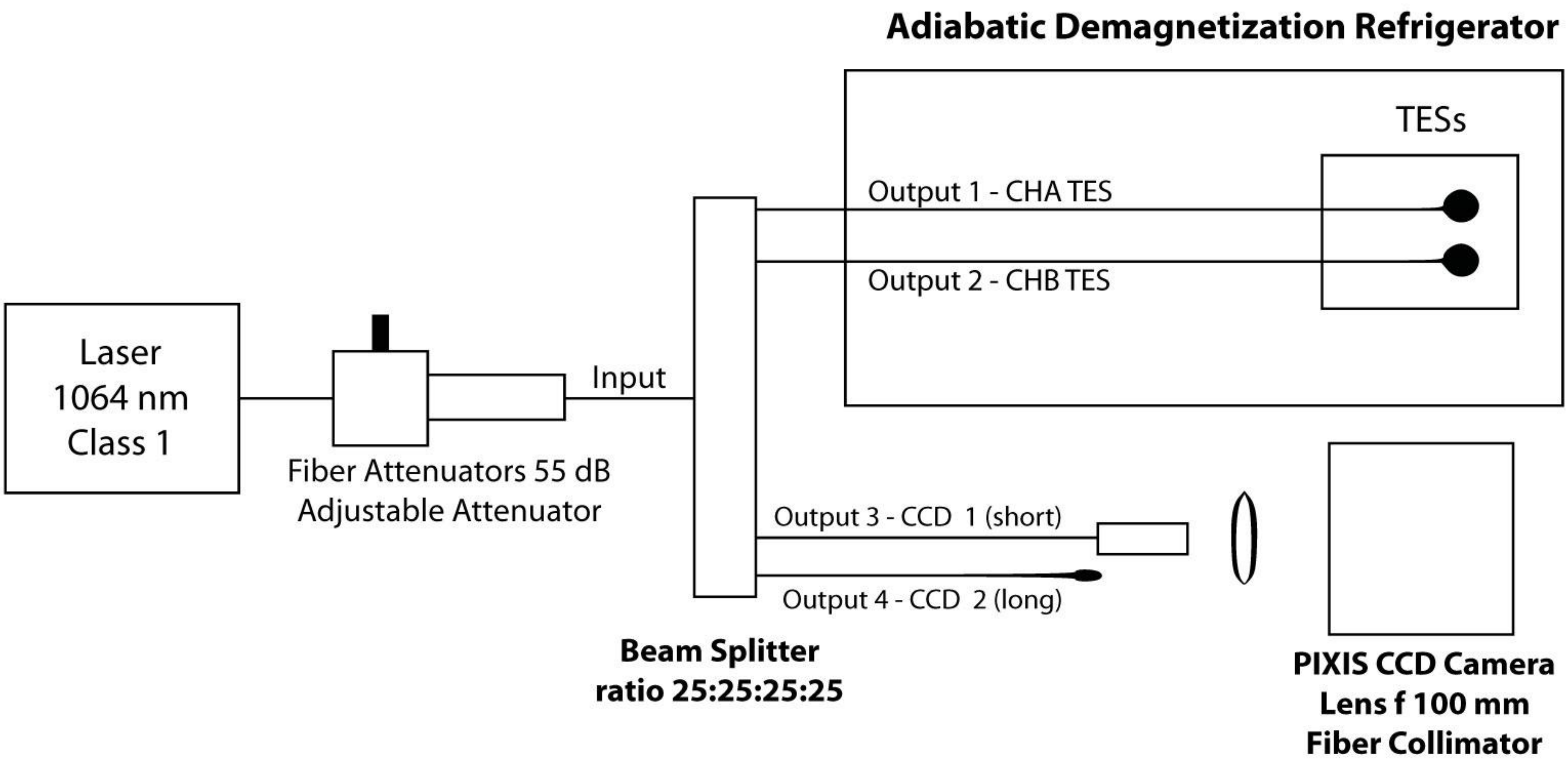
Histogram of peak voltages

Average pulse

(source: J. Dreyling)

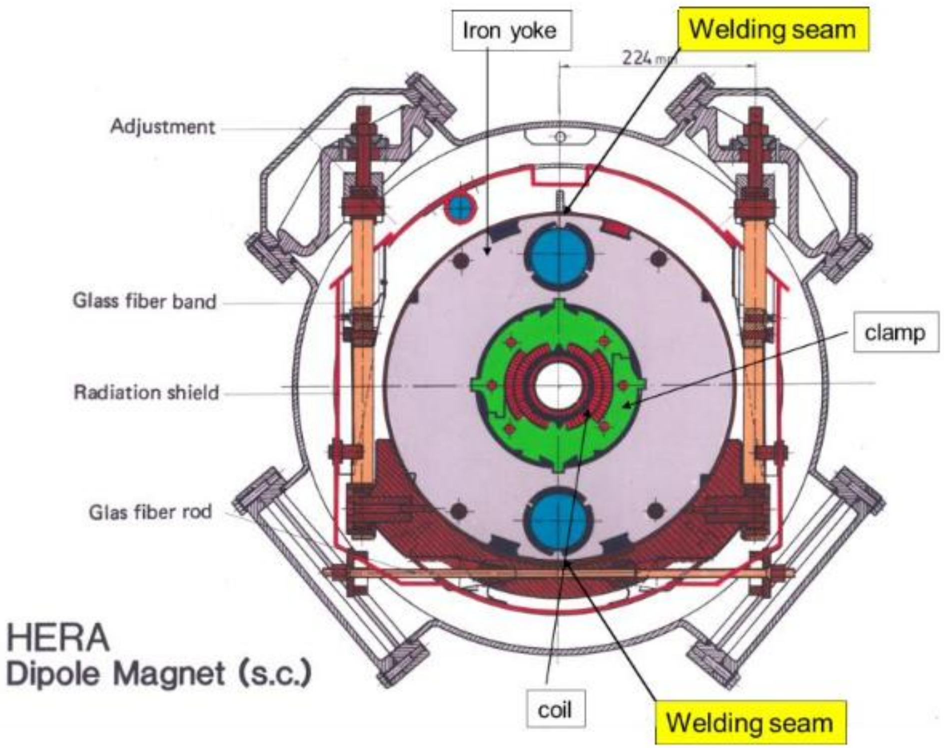


Detection efficiency



Magnets for ALPS II c

Magnet



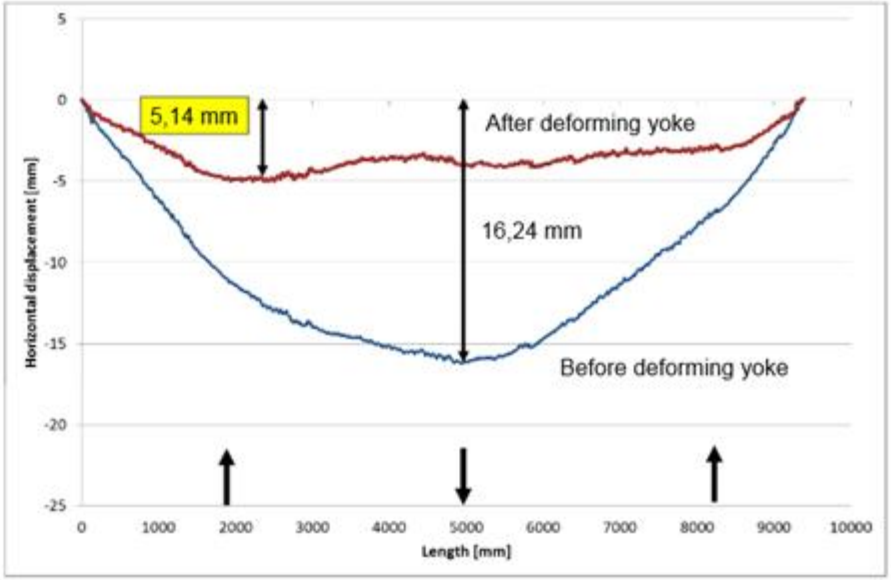
The power build up of the cavities depends highly on the aperture.

Hera magnets are bent
→ Small aperture (35 mm)

This aperture would allow us to have only 4+4 dipoles (10 + 10 forseen).

⇨ Straighten magnets

Magnet



Unbending of the magnets

Straightening force applied by pressure screw in the middle of the magnet (cold mass).

Deformation successful, yielding 90% of maximum aperture.
Magnet still working perfectly, quench current even slightly increased.

Summary

- ALPS II experiment (DESY, Hamburg) follows the light-shining through the wall concept.
- ALPS II aims at an increase in sensitivity of 3000 compared to ALPS I, mainly by a regeneration cavity and more magnets.
- Basics of the optics setup have been demonstrated but the specifications are still to be reached.
- A tungsten Transition Edge Sensor operated below 100 mK has been successfully used to detect single-photons in the near-infrared.

ALPS II TDR: arXiv:1302.5647
Characterization, 1064 nm photon signals and background events of a tungsten TES detector for the ALPS experiment: arXiv:1502.07878v1

Outlook

⇨ **First ALPS II data taking in 2016.**

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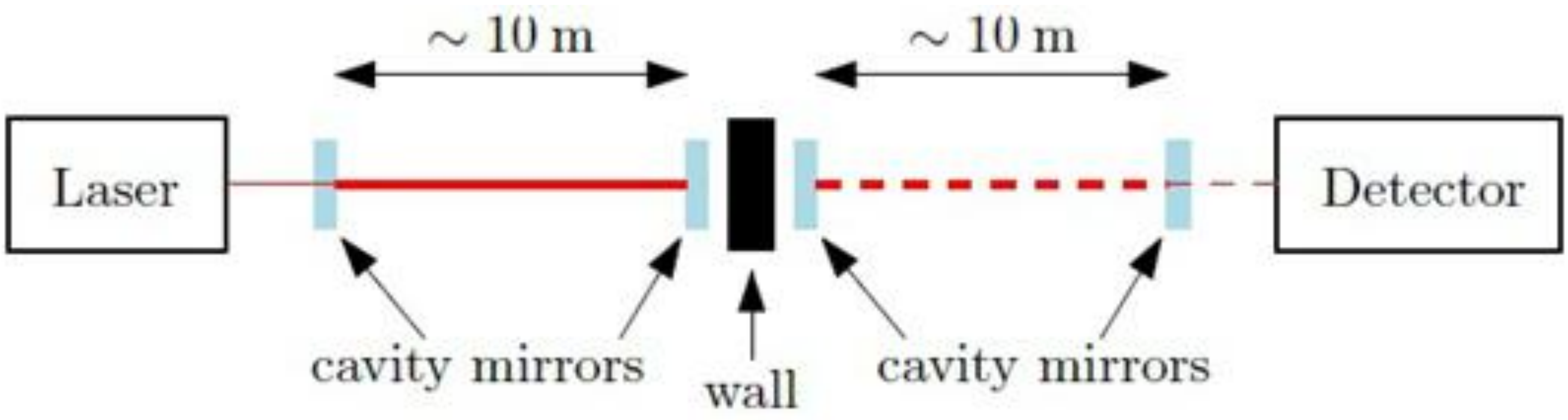

Thank you for your attention !