Options for ultra-high-frequency gravitational wave detection at DESY

Einstein Telescope Community Meeting Autumn 2022

October 21, 2022

Christoph Reinhardt

HELMHOLTZ

DESY.

GW detection above 10 kHz

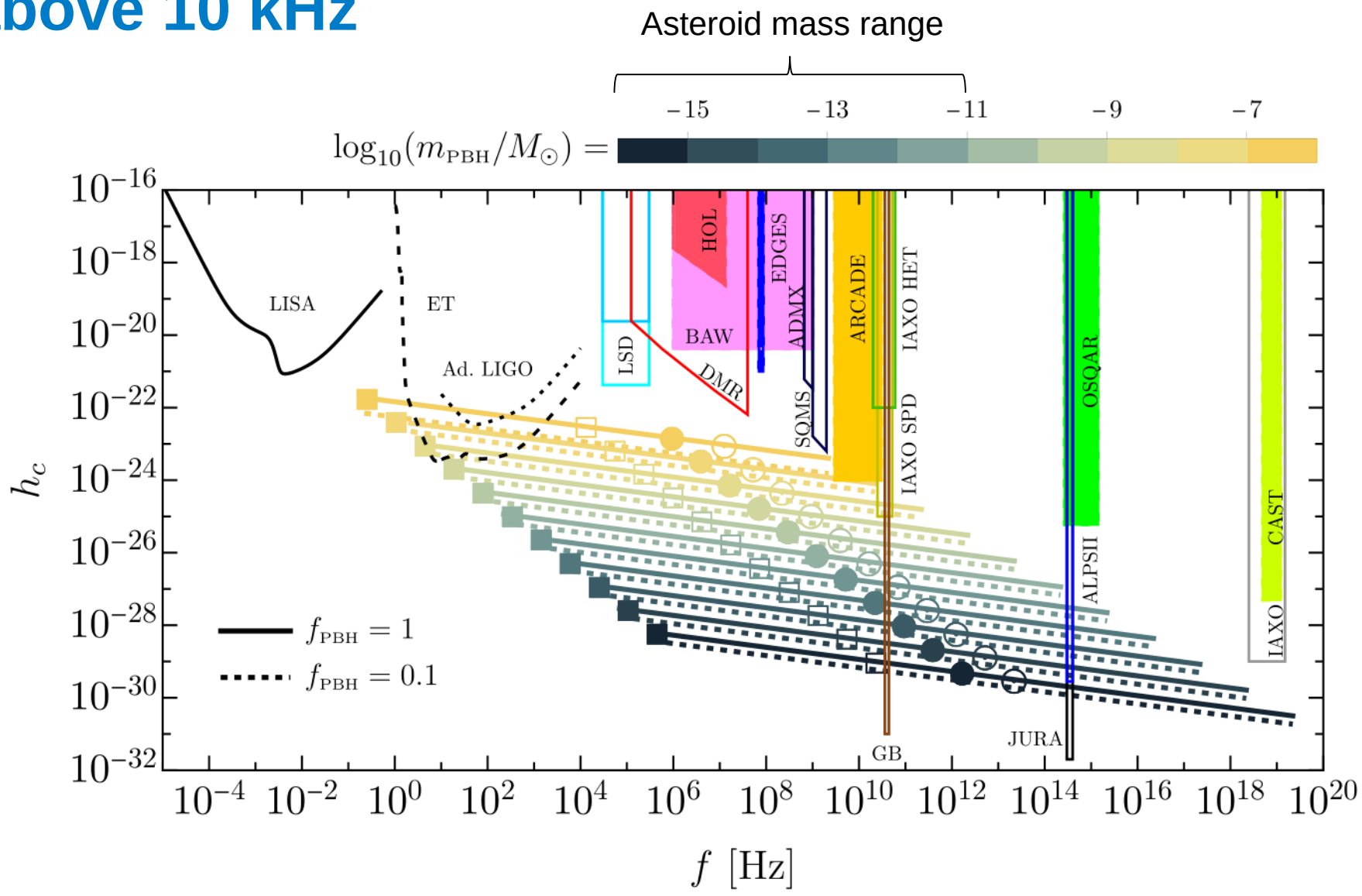
- Primordial Black Holes (PBH) are potential candidates for dark matter
- Possible detection via PBH mergers

Inspiral source

$h_{c,\mathrm{insp}} = 2f\tilde{h}(f)$

From Detector PSD

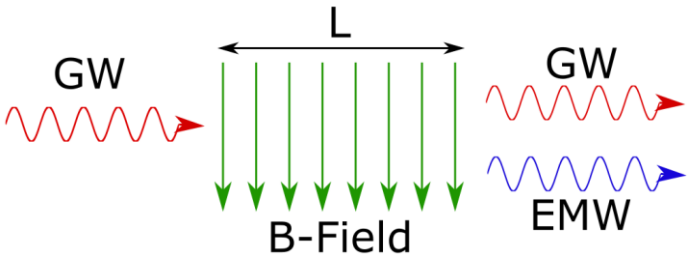
$h_{c,n} = \sqrt{fS_n(f)}/(T_{\mathrm{obs}}\Delta f)^4$



[1] Franciolini, G., Maharana, A., & Muia, F. (2022). The Hunt for Light Primordial Black Hole Dark Matter with Ultra-High-Frequency Gravitational Waves. *arXiv preprint arXiv:2205.02153*
[2] Aggarwal, Nancy, et al. "Challenges and opportunities of gravitational-wave searches at MHz to GHz frequencies." *Living reviews in relativity* 24.1 (2021): 1-74

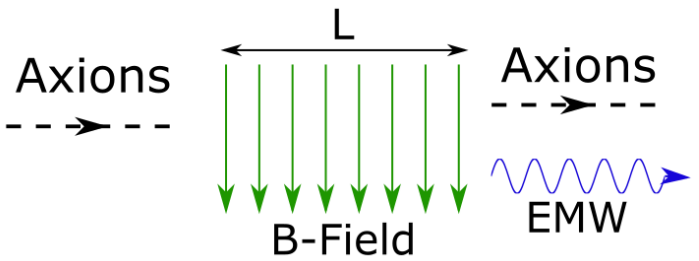
Magnetic conversion

Inverse Gertsenshtein Effect



$$P_f \propto (f \cdot h)^2 (B \cdot L)^2$$

Sikivie: axion to photon conversion



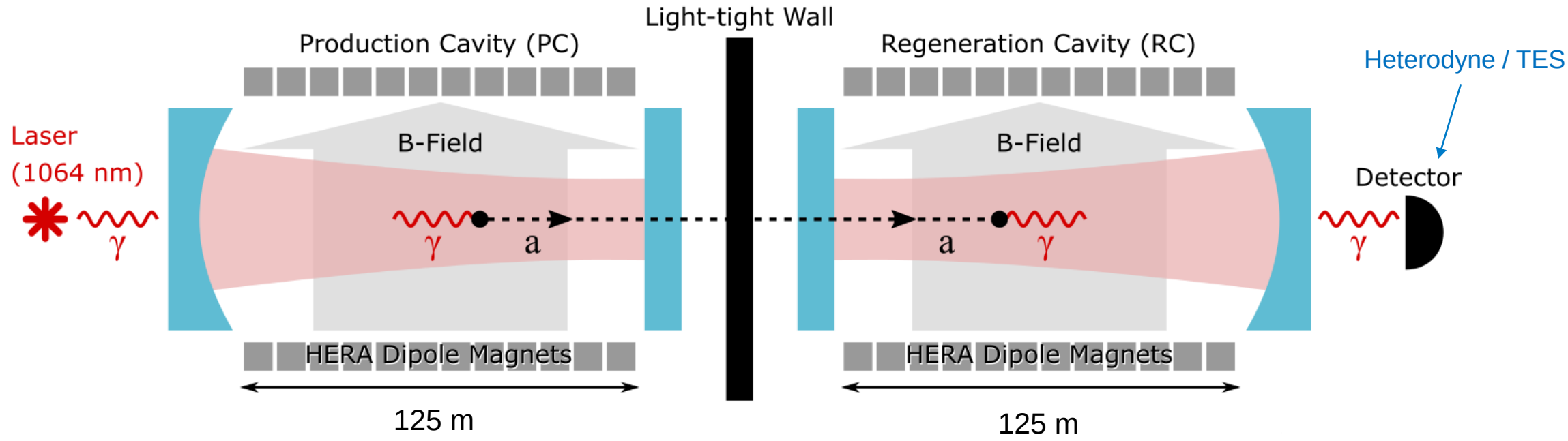
$$P_{a\to\gamma} \propto g_{a\gamma\gamma}^2 (B \cdot L)^2$$

→ Opportunity for exploiting synergies between detectors for axions and UHF GWs

Gertsenshtein, M. E. (1962). Wave resonance of light and gravitional waves. *Sov Phys JETP, 1962, 14: 84*, *85*

Sikivie, P. (1983). Experimental tests of the" invisible" axion. *Physical Review Letters*, *51*(16), 1415

ALPS II: concept & parameters



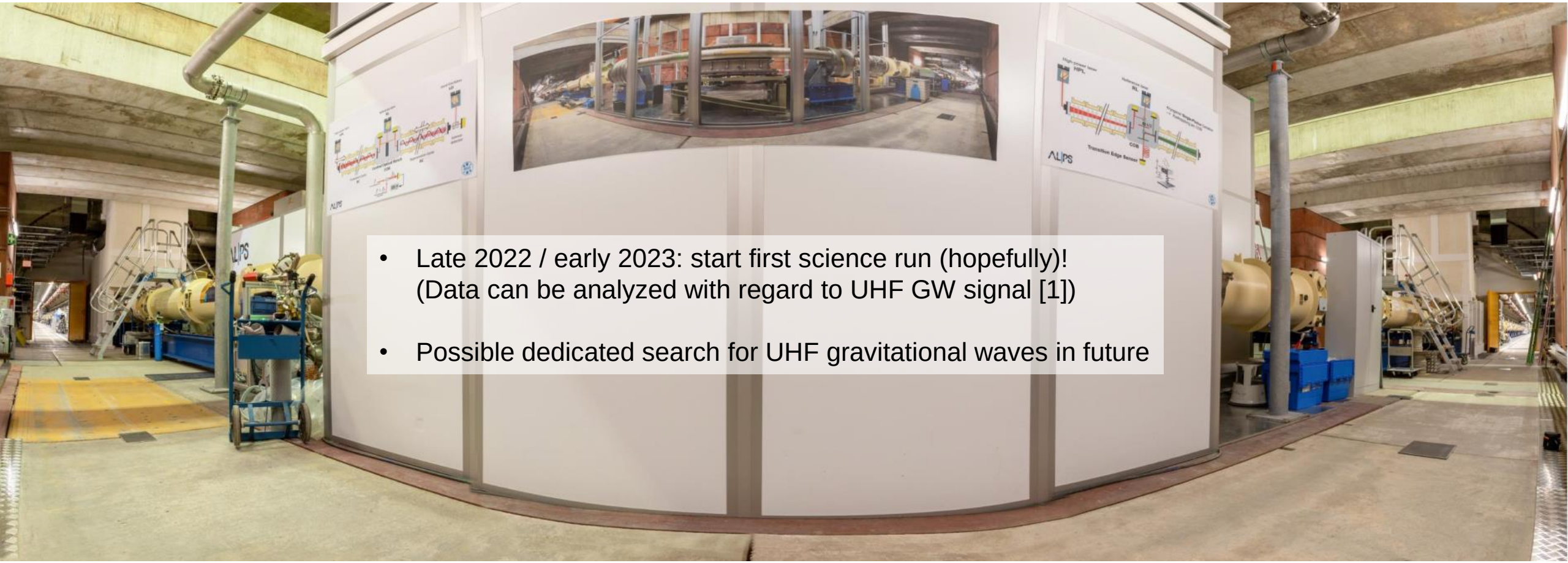
Some key parameters

Laser power	30 W
Circulating power (PC)	150 kW
Finesse	Up to 100,000
Light storage time (RC)	6 ms
Magnets	Field: 5.3 T

Target sensitivity

1 photon / day

ALPS II at HERA hall North



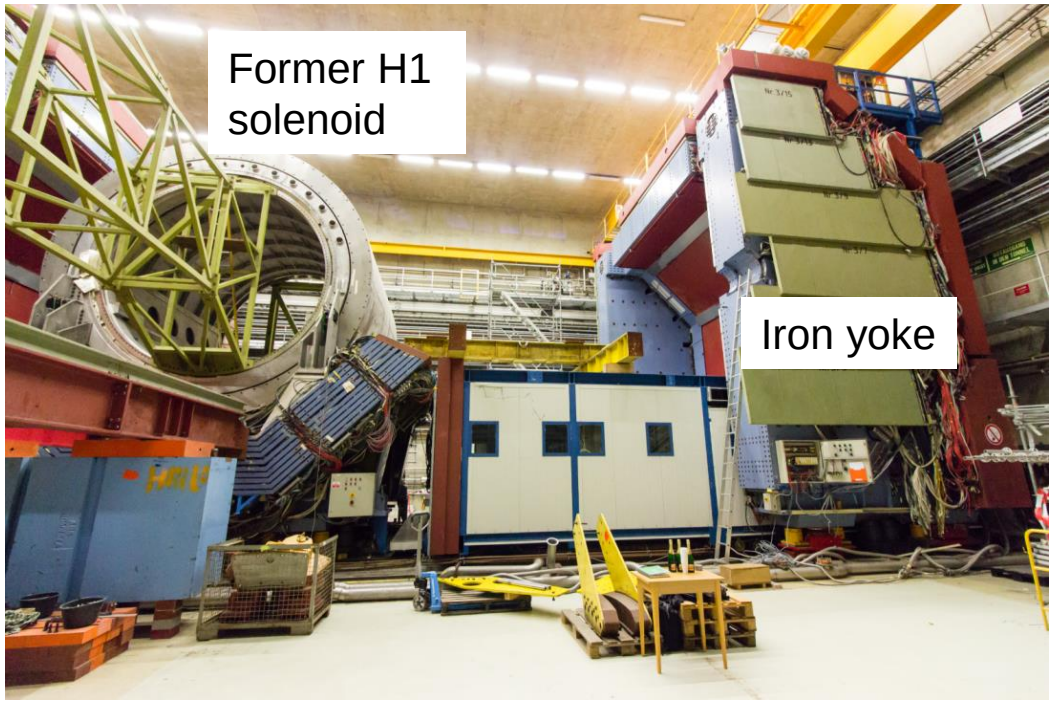
- Late 2022 / early 2023: start first science run (hopefully)!
  (Data can be analyzed with regard to UHF GW signal [1])
- Possible dedicated search for UHF gravitational waves in future

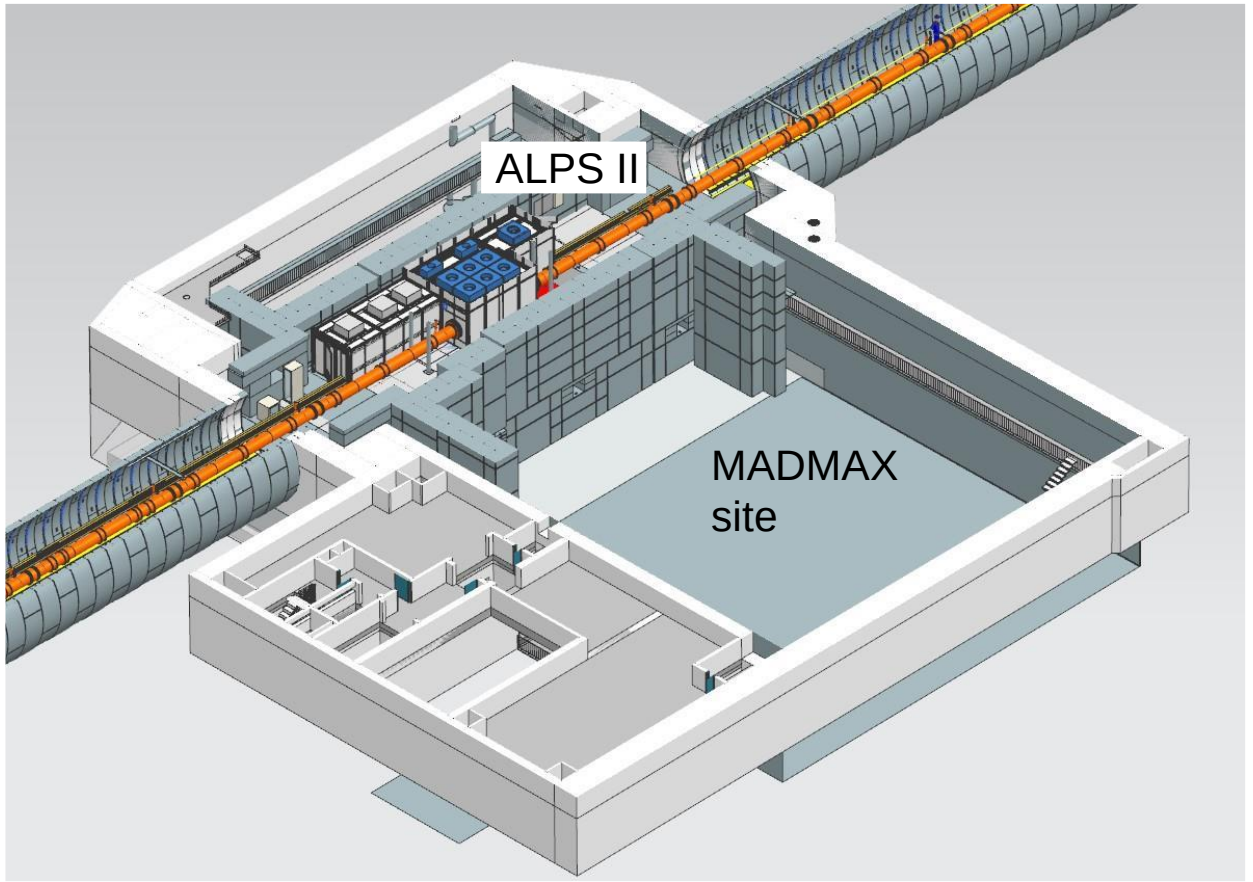
[1] Ejlli, Aldo, et al. "Upper limits on the amplitude of ultra-high-frequency gravitational waves from graviton to photon conversion." *The European Physical Journal C* 79.12 (2019): 1-14 (initial work on ALPS I)

Cryoplatform at HERA hall North

- Distribution system of liquid helium (at ~ 4.5 K)
- Supply for up to three experiment (e.g., MADMAX)
- Located 30 m underground
- Dimensions: height = 16 m, area = 1222 m²

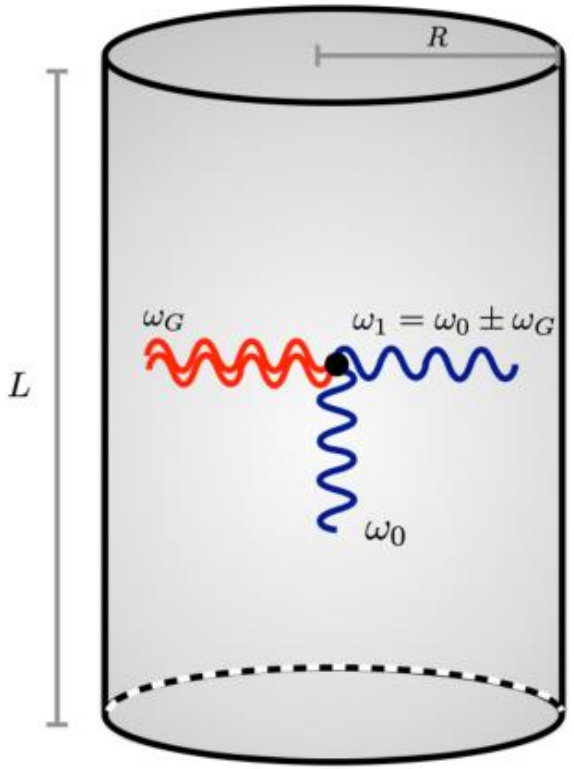
→ Possible realization of dedicated UHF GW experiments





Superconducting radio frequency (SRF) cavities

- Passing GW with frequency $\omega_G = |\omega_0 - \omega_1|$ can deform cavity walls and transfer energy from pump to signal mode
- Targetting $\omega_G \sim 10^6$ to 10^8 Hz
- EM-coupling (GW - photon mixing, Gertsenshtein effect) also possible
- Expertise available at DESY
- DESY cryopolatform possible site for GW detector prototype (starting from 2026)



Berlin, A., Blas, D., d'Agnolo, R. T., Ellis, S. A., Harnik, R., Kahn, Y., & Schütte-Engel, J. *In preparation*.

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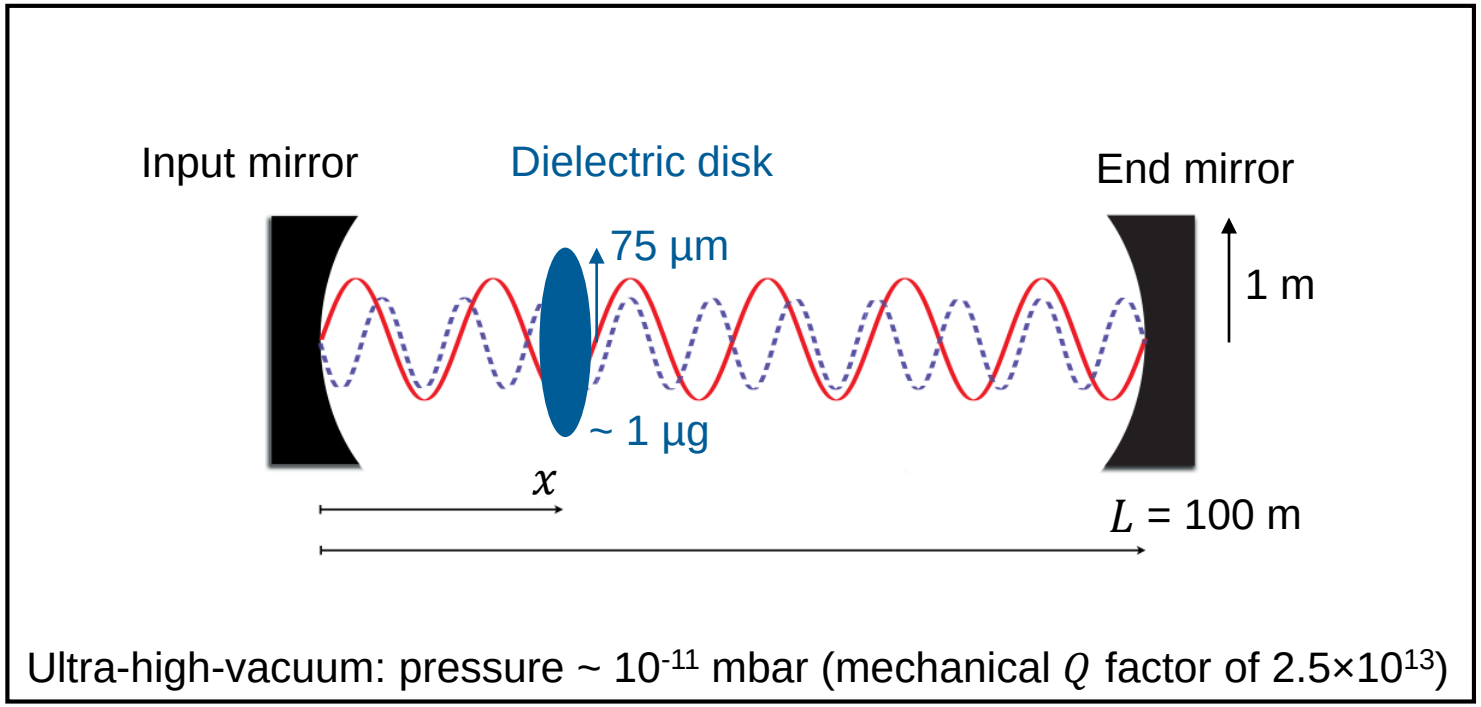
MAGO Collaboration

gr-qc/0502054 Ballantini et al.

physics/0004031 Bernard, Gemme, Parodi, Picasso

Sensitivity: 6×10^{-21} $\mathrm{Hz}^{1/2}$ from 1.8 to 2.2 kHz (near mech. resonance, quantum limited amplifier)

Levitated Sensor Detector (Northwestern University)



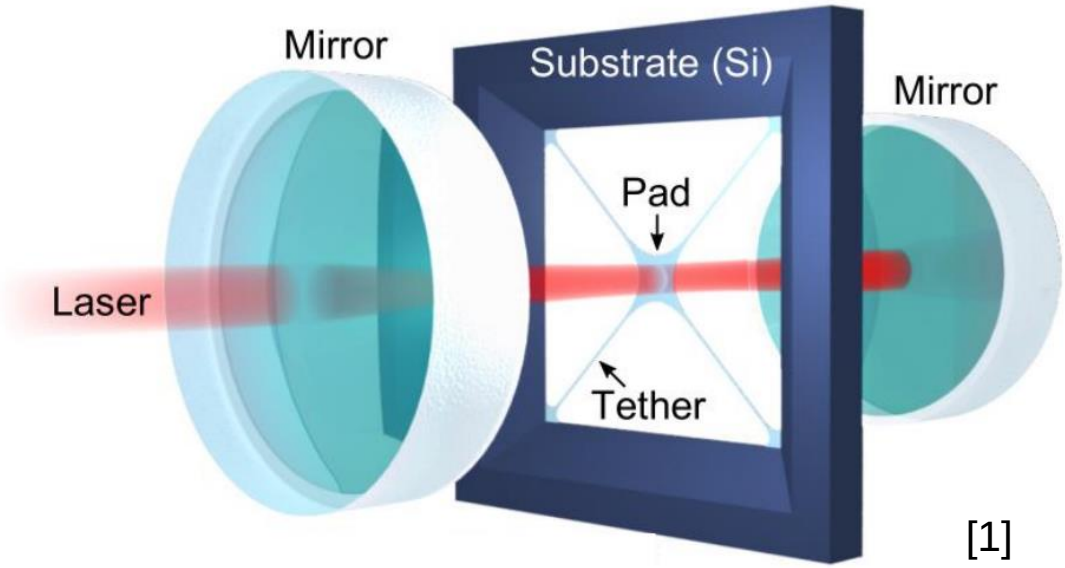
[Arvanitaki et al. 2013]
[Aggarwal et al. 2020]

1-meter prototype under construction at NWU (first pilot run planed in ~ 2 years)

Levitated Sensor Detector with Membrane

Complementary approach: partially-levitated membrane

- Allows to reduce mirror radius, enabling to rely on established mirror technology
- Membrane Q factor similar to levitated stacks, results in comparable sensitivity
- Membrane's connection to a substrate enables straight forward handling and installation in the cavity
- Current ALPS II location would allow for a 100-m-scale experiment

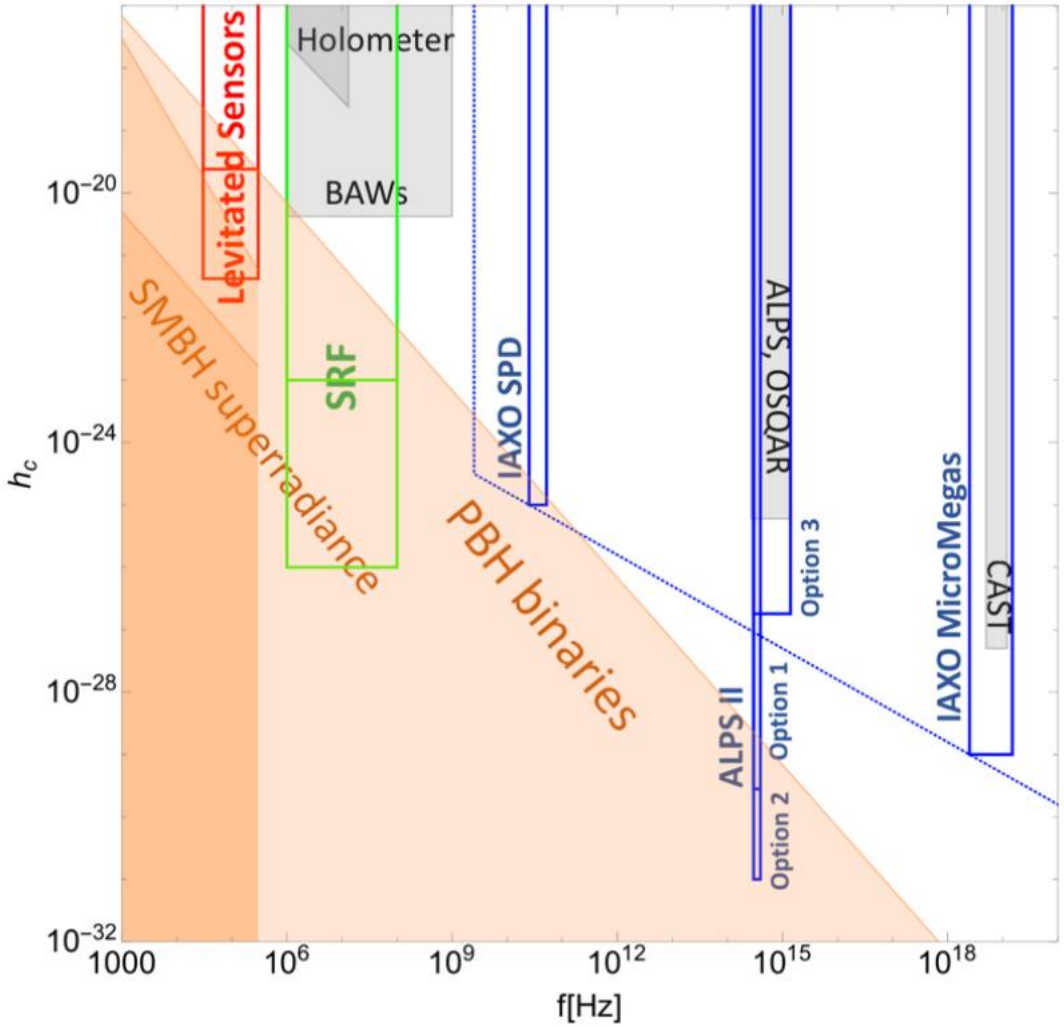


[1]

(Membrane with trampoline geometry shown as an example. Optimal geometry to be identified)

[1] Reinhardt, C., Müller, T., Bourassa, A., & Sankey, J. C. (2016). Ultralow-noise SiN trampoline resonators for sensing and optomechanics. *Physical Review X*, *6*(2), 021001

Sensitivity estimate



Opportunities for Local High-Frequency Gravitational Wave (HFGW) Experiments, Report FH Gravitational Wave Study Group, [Behnke, Grojean, Lindner, Moortgat-Pick, Peters, Reinhardt, Ringwald, Spector]

Conclusion

- Strongly growing interest in GW detection above 10 kHz
- Opportunities, e.g, to gain insights in the early universe and investigate DM candidate
- Synergies between axion experiments and UHF GW detectors
  - „Default sensitivity“ via magnetic conversion
  - Plans for realizing optimized UHF GW sensitivity
  - Prospects for dedicated UHF GW detectors
- Possibilities for infrastructures such as DESY cryoplatform to host dedicated UHF GW detectors

Thank you

Christoph Reinhardt
christoph.reinhardt@desy.de
+49-40-8998-5055