Graduate School Particle Detectors

Cluster of Excellence PRISMA+ Precision Physics, Fundamental Interactions and Structure of Matter

SUPAX

First Results of a new Haloscope Setup at Mainz and Prospects for Detecting Ultra High Frequency Gravitational Waves

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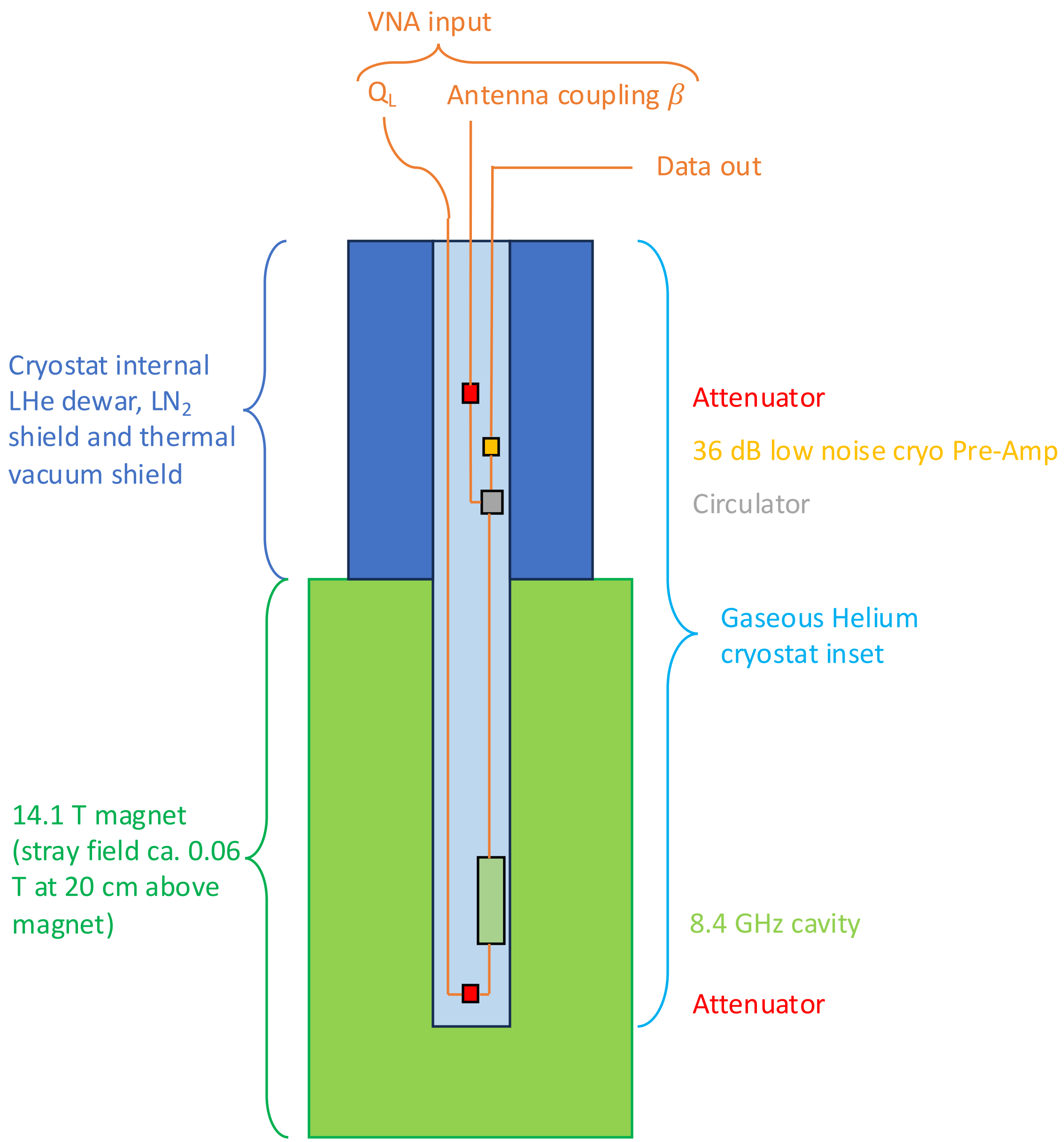
Experimental Setup

- Cryostat
  - Holds up to 9 liters of LHe
  - Thermal shielding by LN_2 & vacuum
- Magnet (Prof. Budker, CASPEr)
  - Homogenous B-field along vertical axis of max. 14.1 T
  - Stray field ca. 60 mT at 20 cm above magnet
- Pre-Amp
  - 36 dB Gain
  - 3.6 K thermal noise
- Circulator
  - Used for cavity & antenna characterization
  - Prevents cable reflections
  - Max. external B-field 0.15 T
- Attenuators
  - Stop 300 K noise from outside

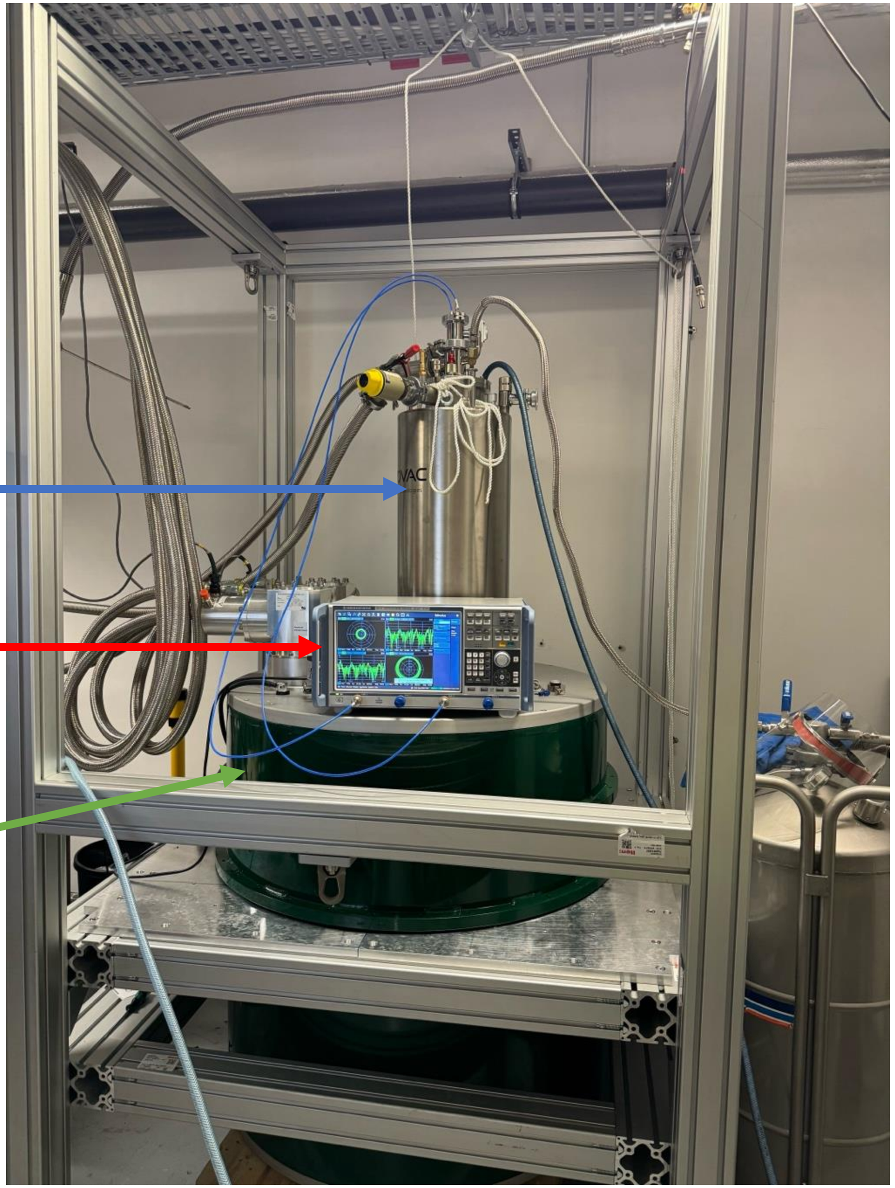


Experimental Setup

Liquid Helium Cryostat

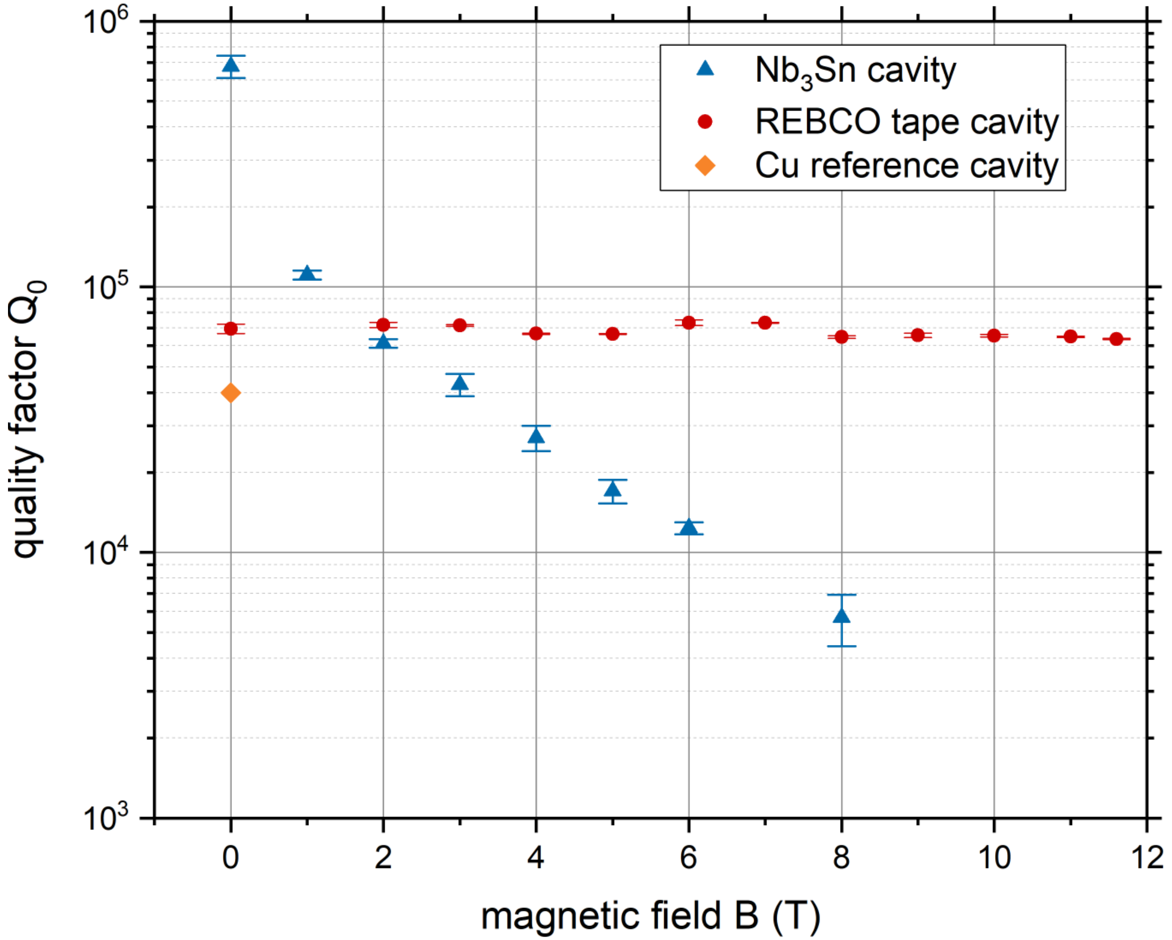
Vector Network Analyzer (VNA)
Used for cavity characterization

14T magnet



RF Superconductivity and magnetic fields

- Usual superconductors often very susceptible to external magnetic fields
- Unfortunate since $P_{sig} \propto B^2 Q$
- REBCO & YBCO HTS show good performance in magnetic fields
  → very high Q factors
- Problem: most layered tapes cannot be properly applied to rounded surfaces



J. Golm et. al (RADES)
https://arxiv.org/abs/2110.01296

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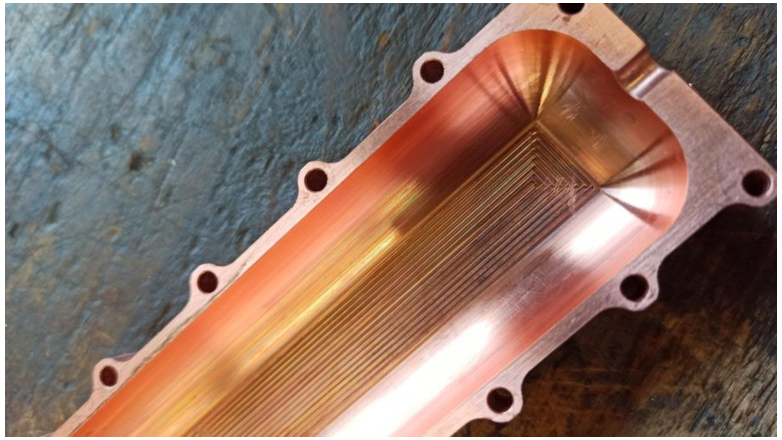
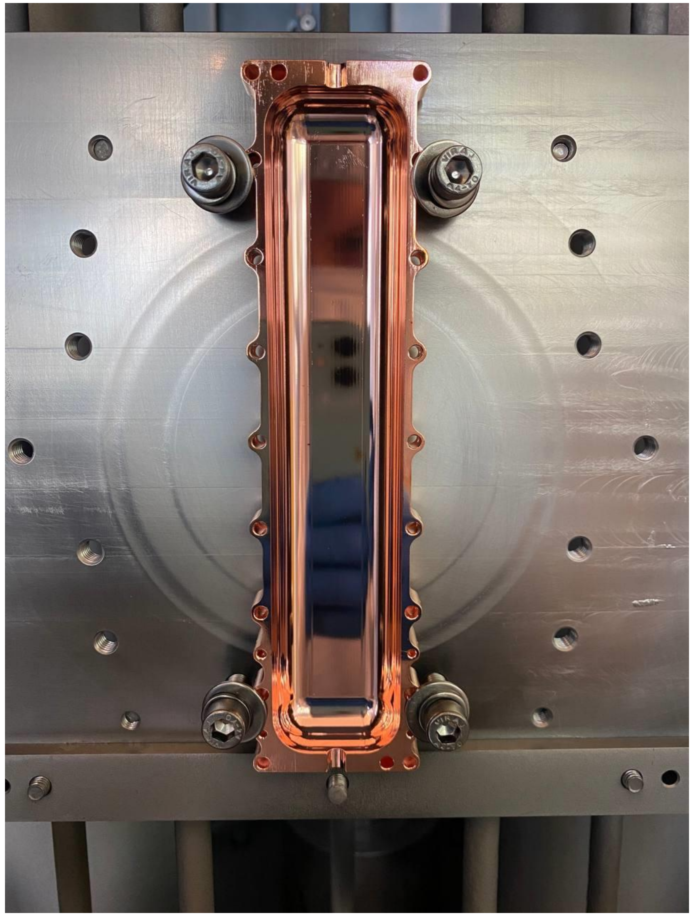
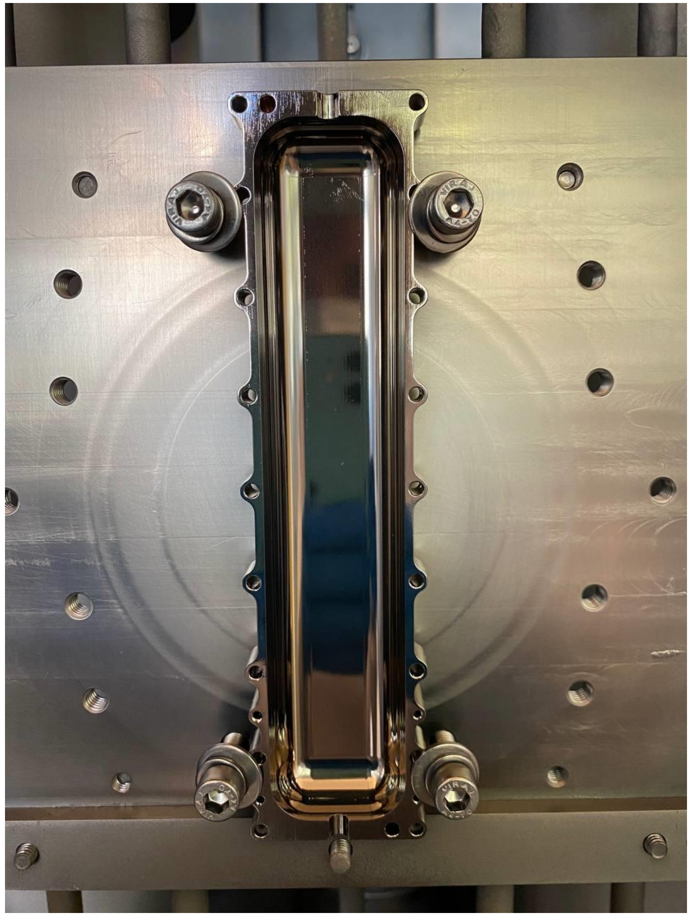
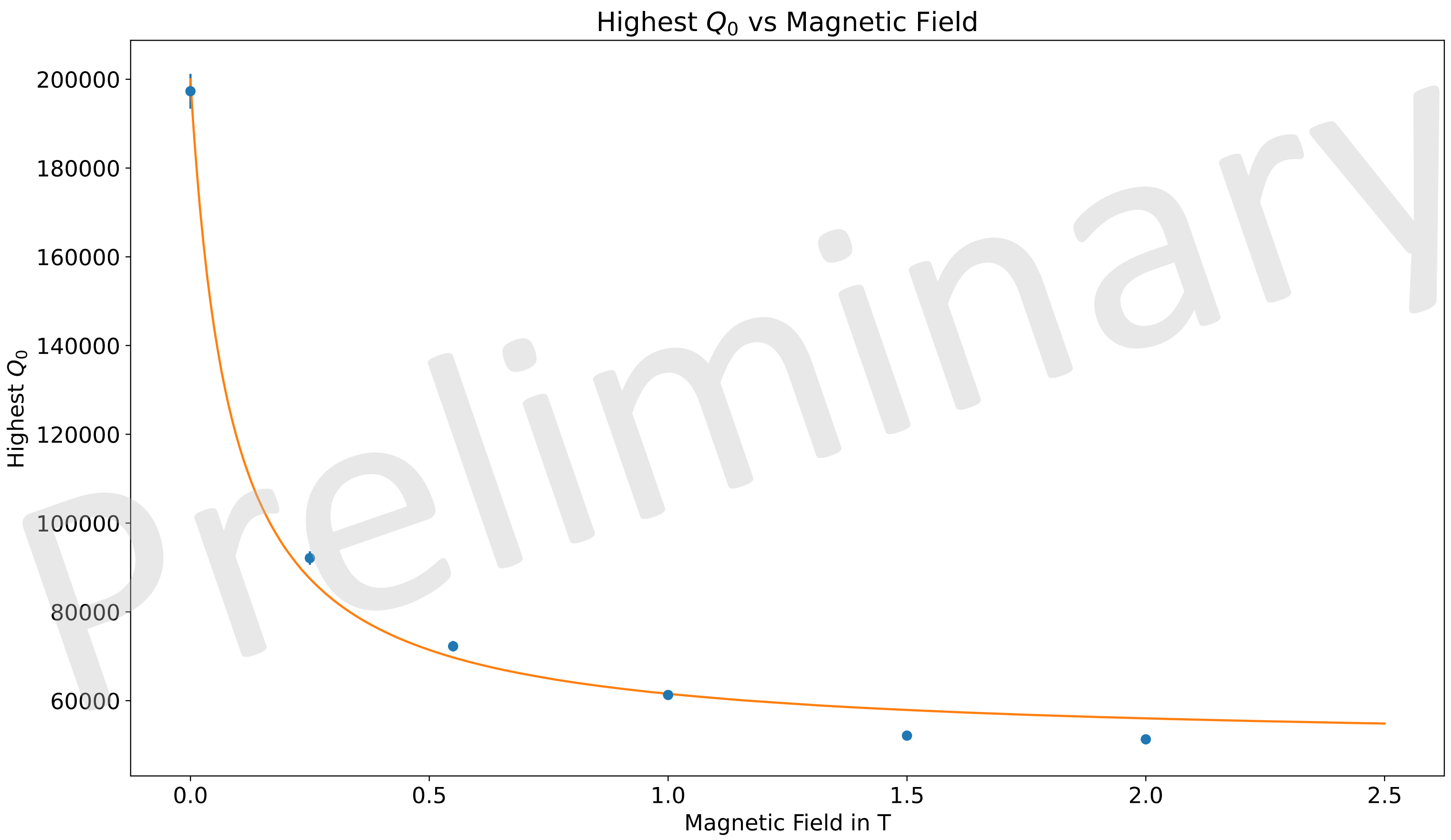






Results of coated cavity



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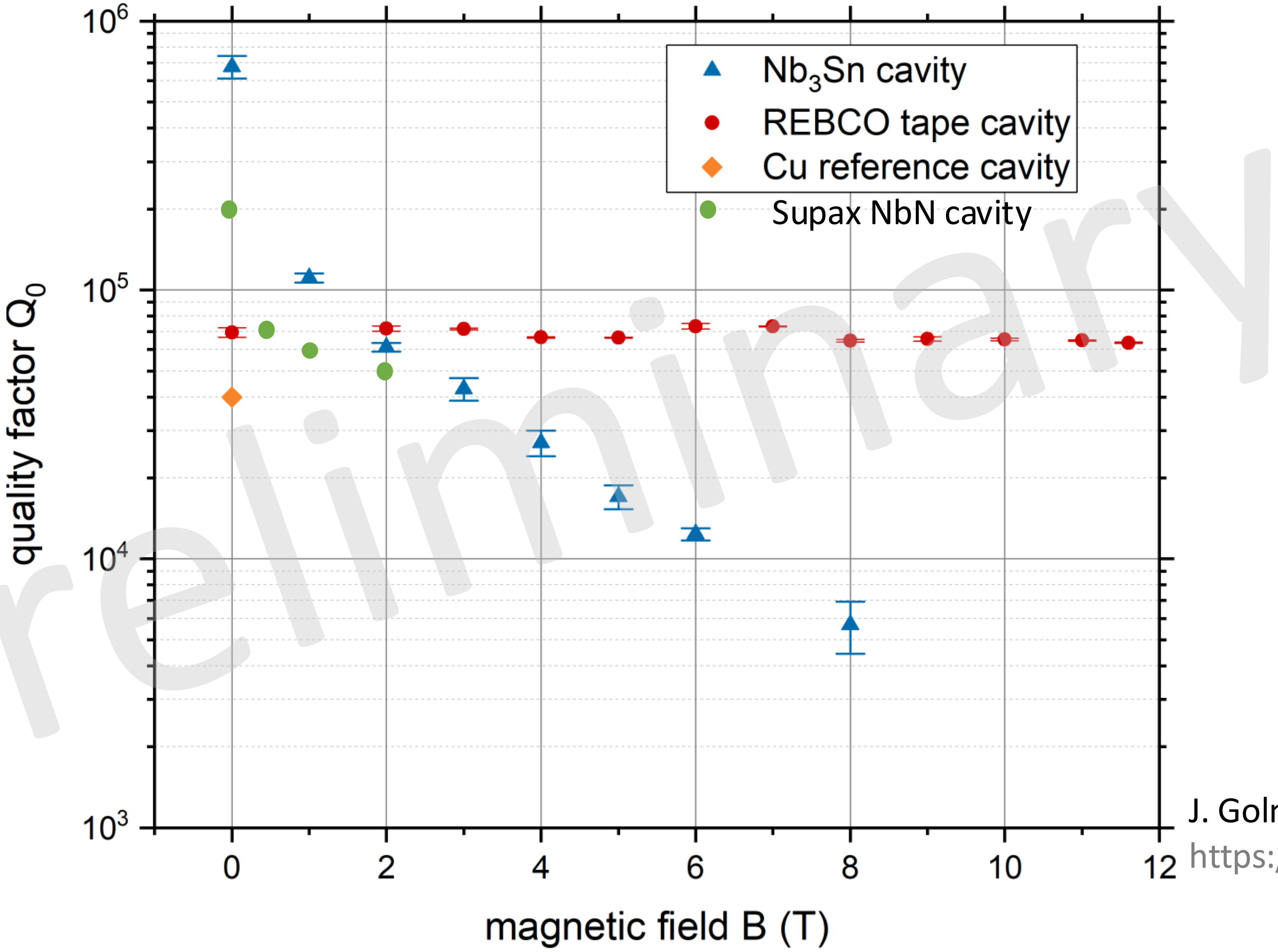

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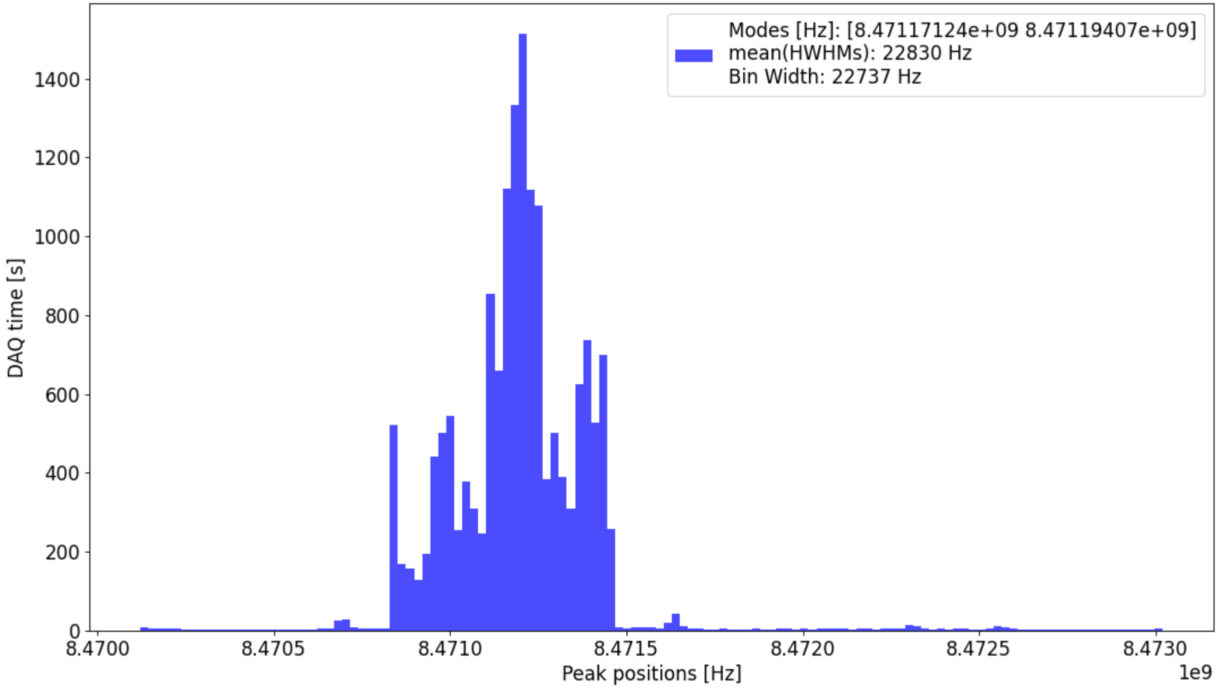
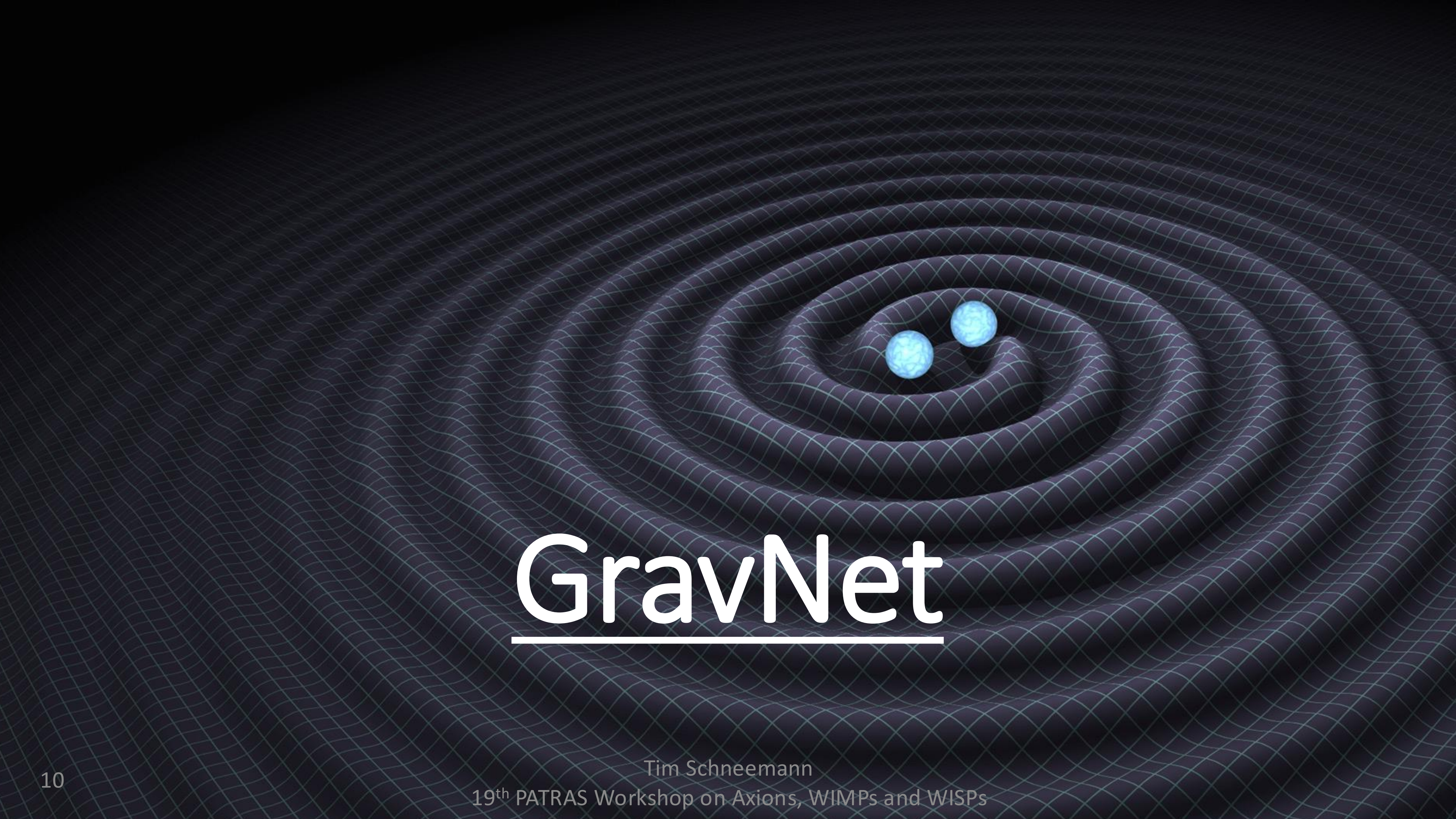
Data taken w/o B-field

- 3 runs with total of 16,440sec (4.5h)
- Keeping pressure constant (+- 1mbar) essential to hold peak position
- Histogram with bin width of average HWHM of peaks
- > 15 mins over 5 bins

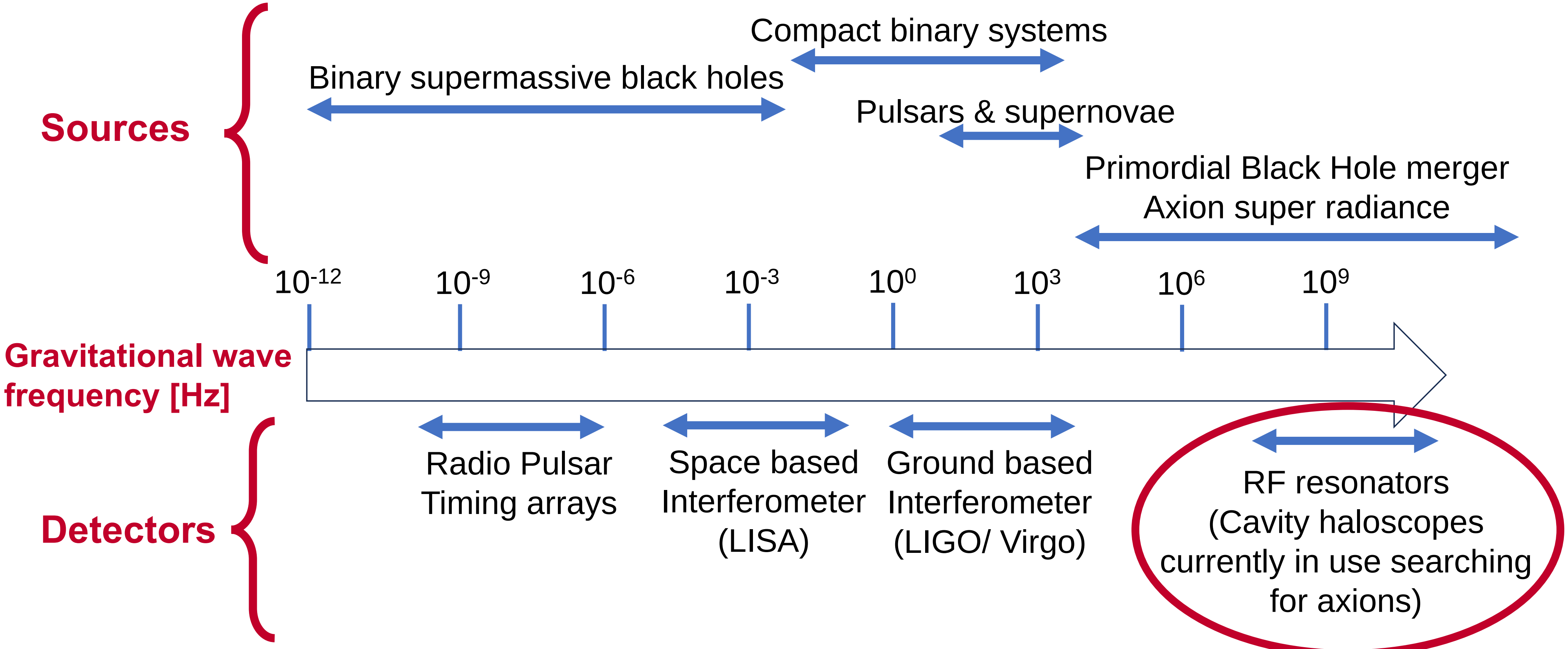
  → Should give exclusion range of 110kHz width with competitive limit (Q_L > 120k)





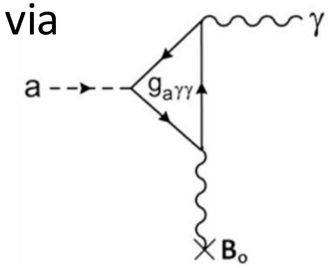
GravNet

GravNet: Using Axion Haloscopes for GW detection

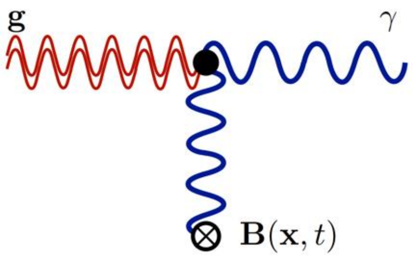


GravNet: Sensitivity to gravitational waves

Axions	Gravitational Waves
• RF cavity in magnetic field • Resonant excitation of cavity eigenmode • Axion conversion into photon via Primakoff effect • Signal strength:	• RF cavity in magnetic field • Resonant excitation of cavity eigenmode • GW conversion into photon via inverse Gertsenshtein effect • Signal strength:



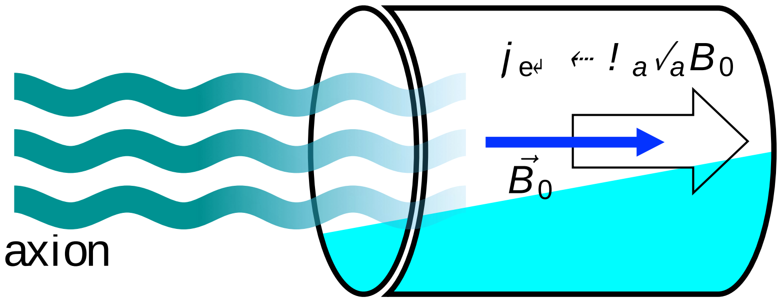
$$P_{\mathrm{sig}} = \kappa g_{a\gamma\gamma}^2 \frac{1}{m_a} B_e^2 \rho_{\mathrm{DM}} V Q_0 C^2$$



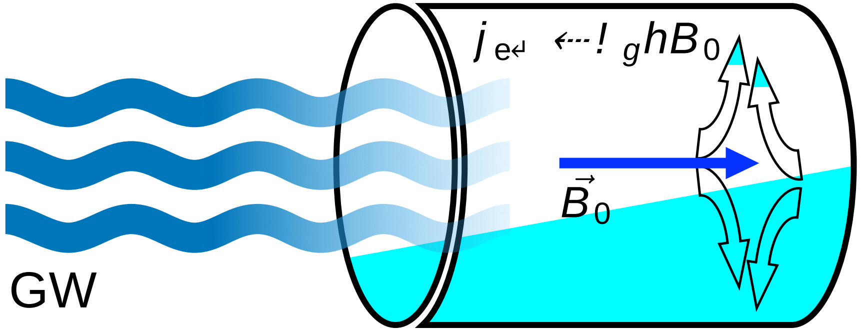
$$P_{sig} = \frac{1}{2} Q \omega_g^3 V^{5/3} (\eta_n h_0 B_0)^2 \frac{1}{\mu_0 c^2}$$

GravNet: Sensitivity to gravitational waves

Axions	Gravitational Waves



- Preferred mode: TM_{010}
- Current dependent on B-field direction
- Contributing effects:
  - Direct conversion via Primakoff effect



arXiv:2112.11465

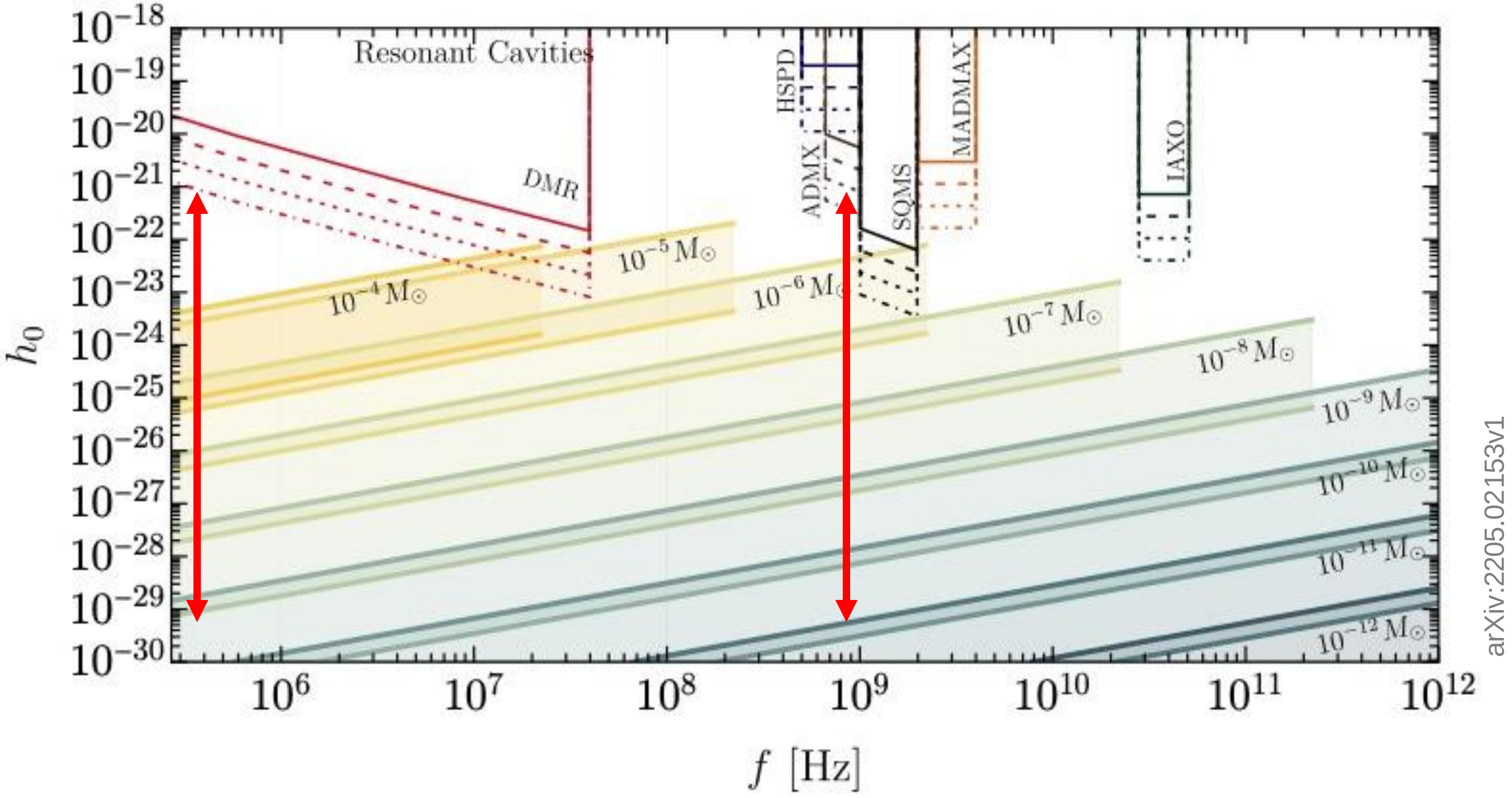
- Preferred mode: TM_{020}
- Current dependent on GW propagation direction
- Contributing effects:
  - Direct conversion via Inverse Gertsenshtein effect
  - Resonant deformation of cavity by GW (Oscillating magnetic flux → excitation of EM field)

GravNet: Challenges of haloscopes for GW detection

- Many axion haloscope experiments recast axion $g_{a\gamma\gamma}$ limits into GW strain h_0 limits
- Limitation on integration time often neglected
  - Signals have duration of seconds (at best)
  - Integrating over $\mathcal{O}$(15min) of data will classify the signal as noise
  - Signals are transient, not frequency stable
- Recasts must consider signal coherence time when analysing integrated data in frequency realm (as is usual in axion searches)

GravNet

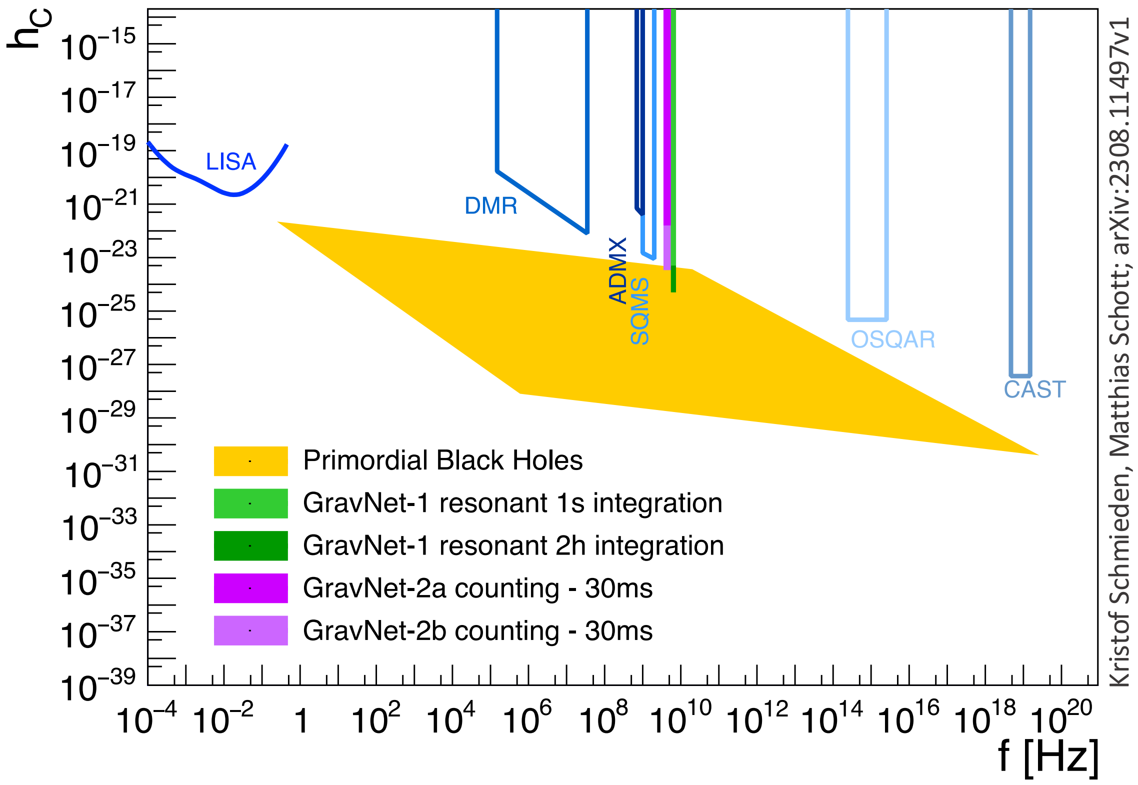
Expected sensitivity of different experiments and strain of PBH mergers of different masses



Example: For ADMX the assumed integration times correspond to PBH signals of mass $m_{PBH} = (10^{-9}, 10^{-10}, 10^{-11}, 10^{-12})M_\odot$

GravNet

- Use several cavities instead of one
- Analyse time series instead of spectra (!)



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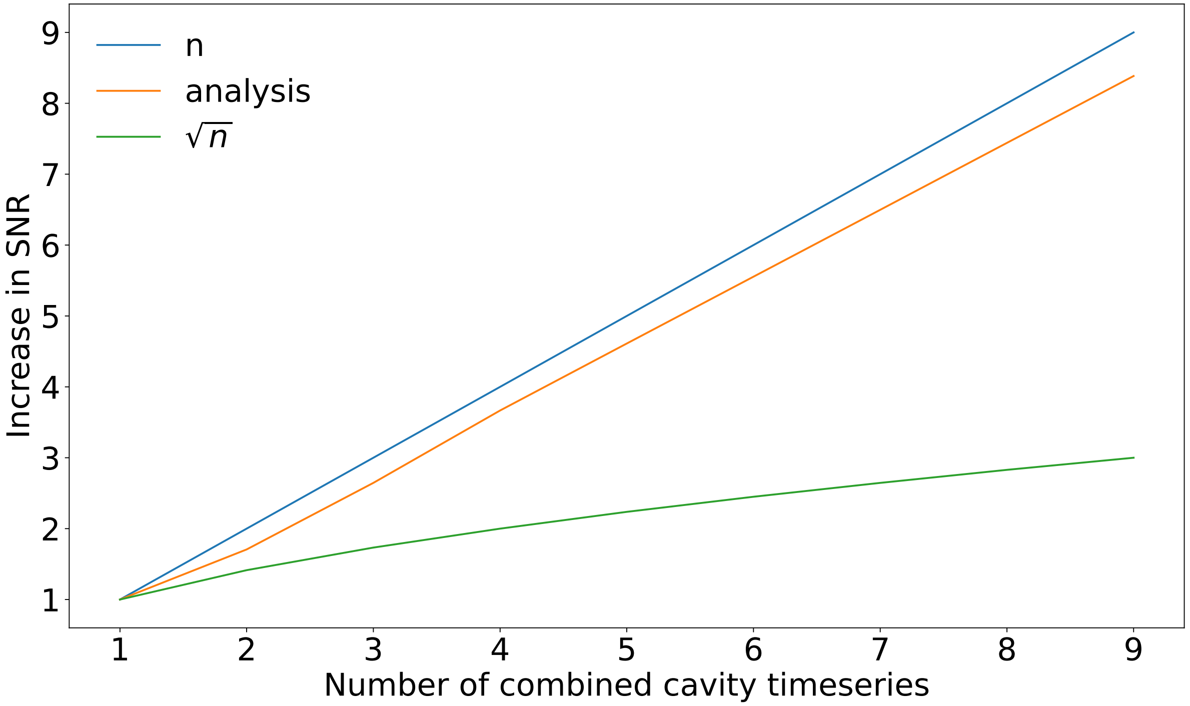
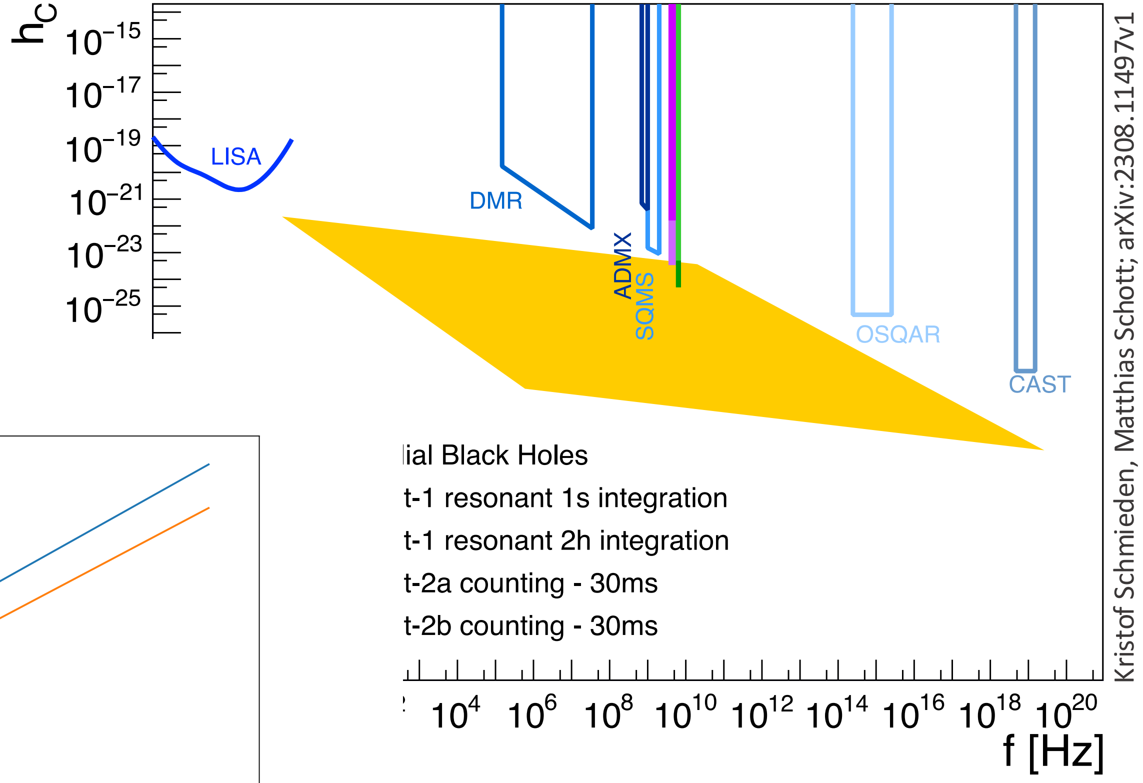
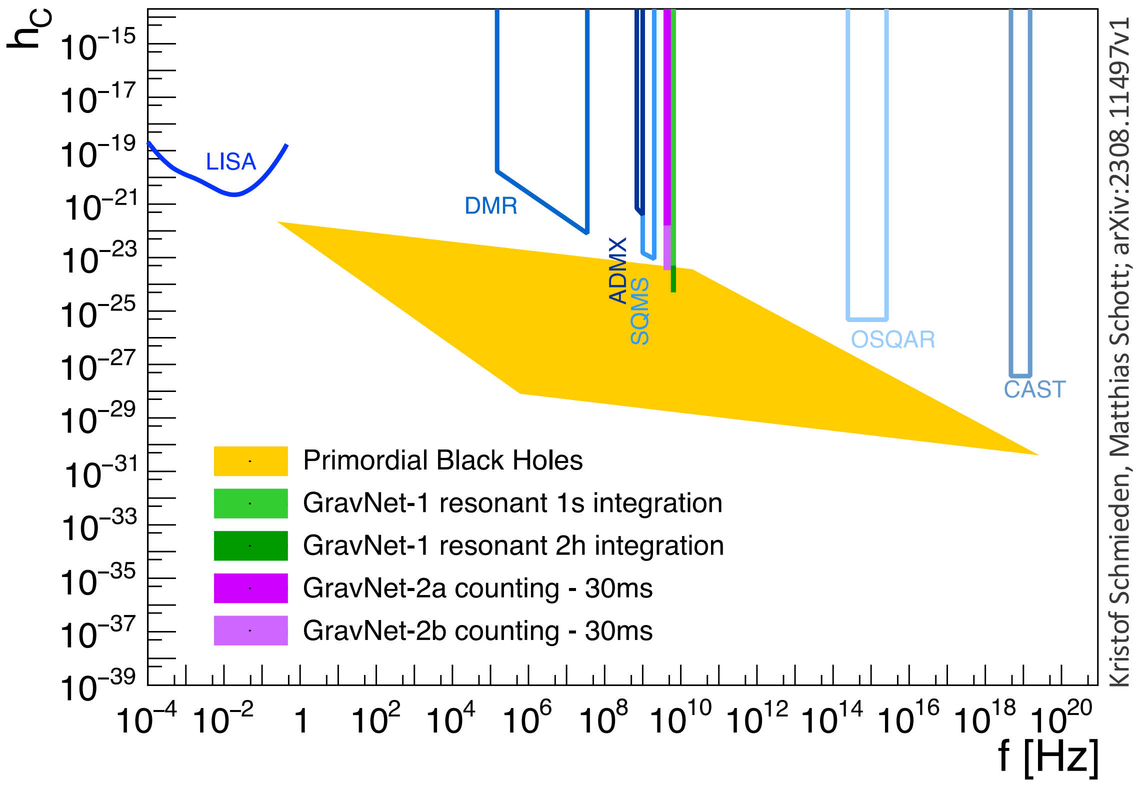




GravNet

- Use several cavities instead of one
- Analyse time series instead of spectra (!)
- Additional information for the phase (necessary for phase alignment anyway)
- 10 setups at 1s integration time $h_0 \sim 10^{-23}$
- Extra: If setups are scattered globally propagation direction (and therefore source) can be extrapolated



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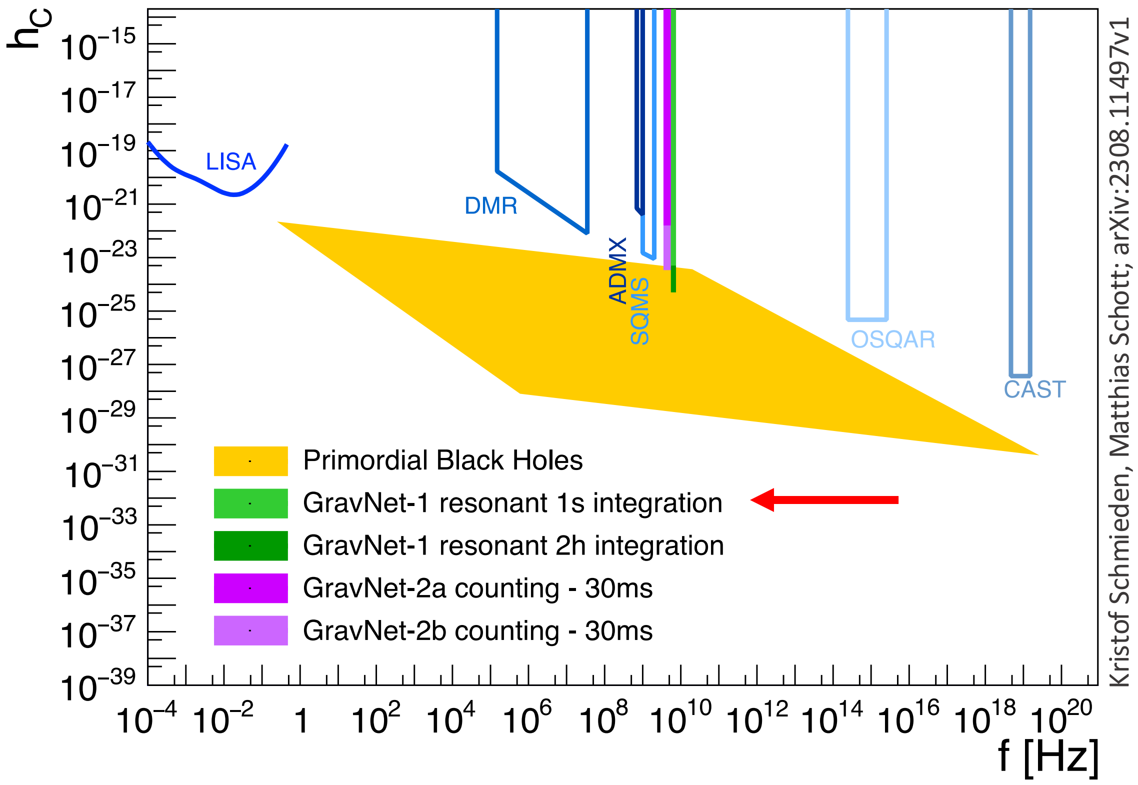
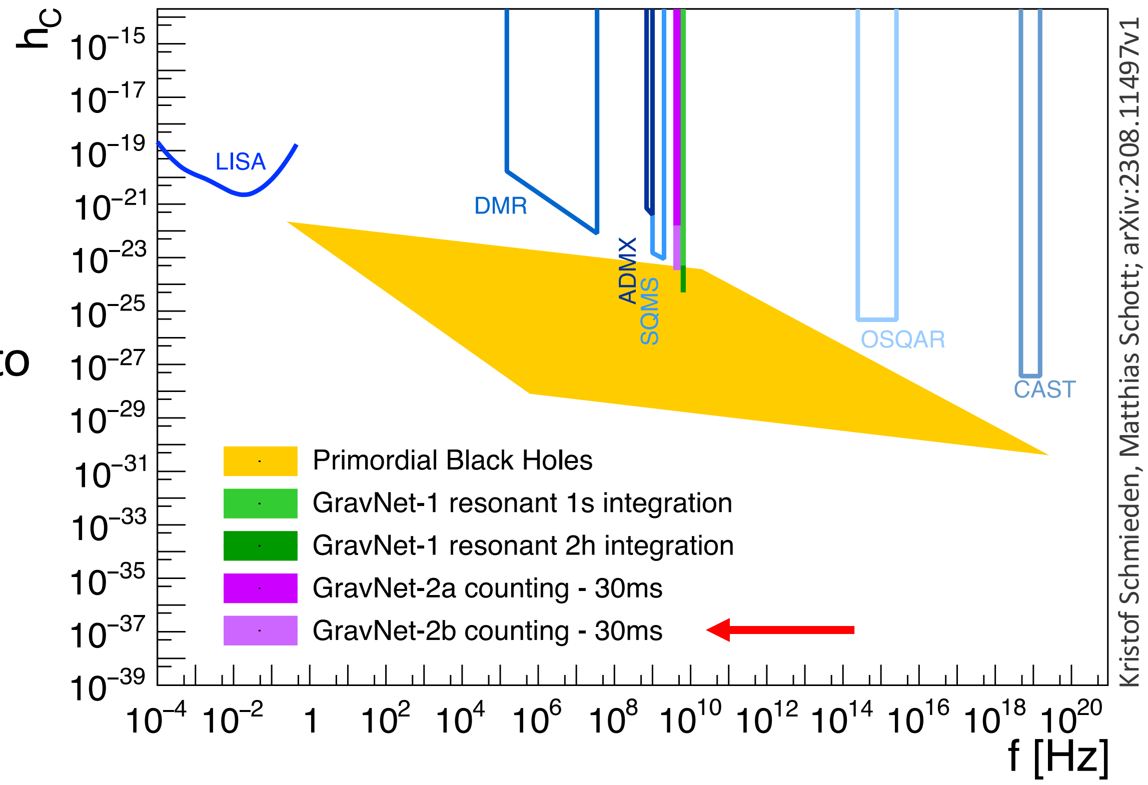


Tim Schneemann

19^{th} PATRAS Workshop on Axions, WIMPs and WISPs

GravNet (visions)

- Employ single photon counting
  - Reduction of necessary integration time from 1s to 30ms without significant loss in sensitivity
- Necessary for source triangulation
- Cavities at different frequencies to observe transient signal



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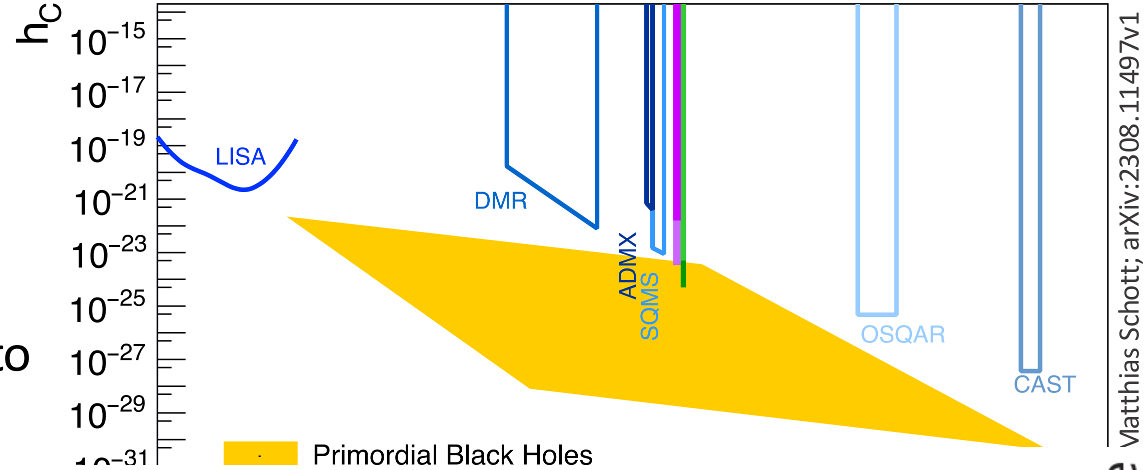

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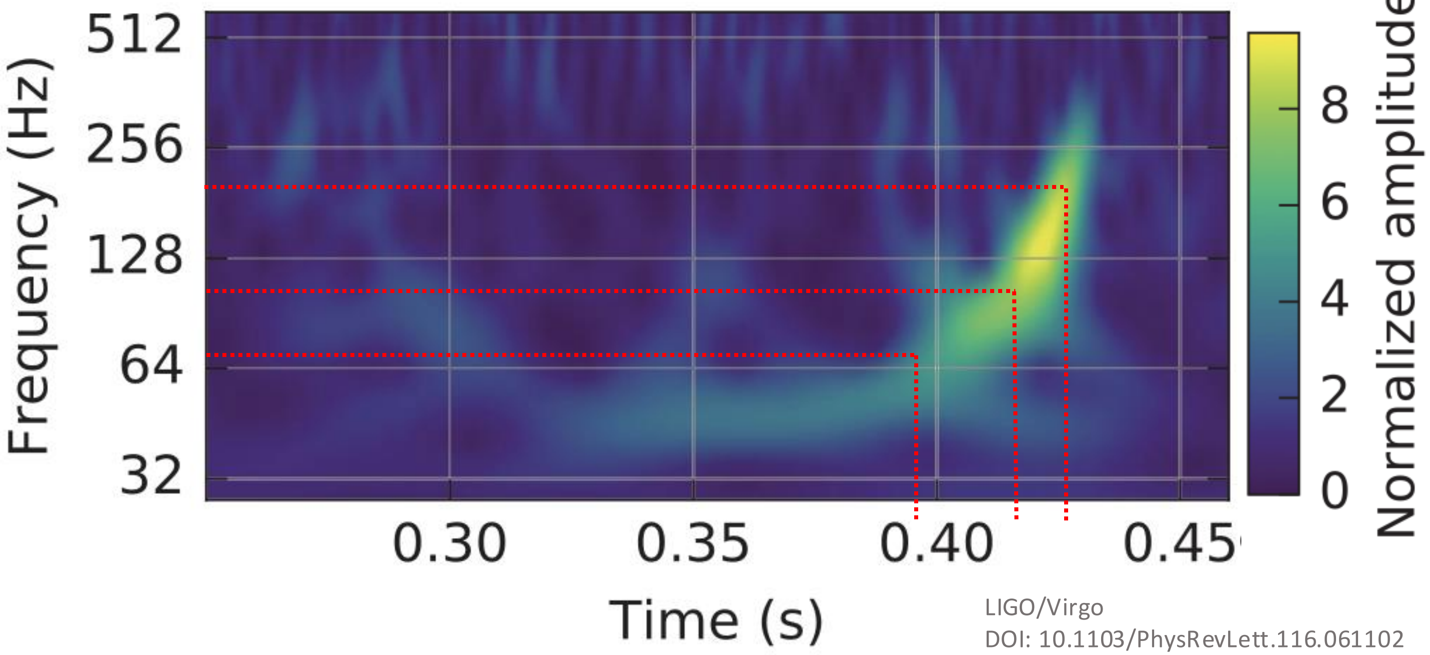
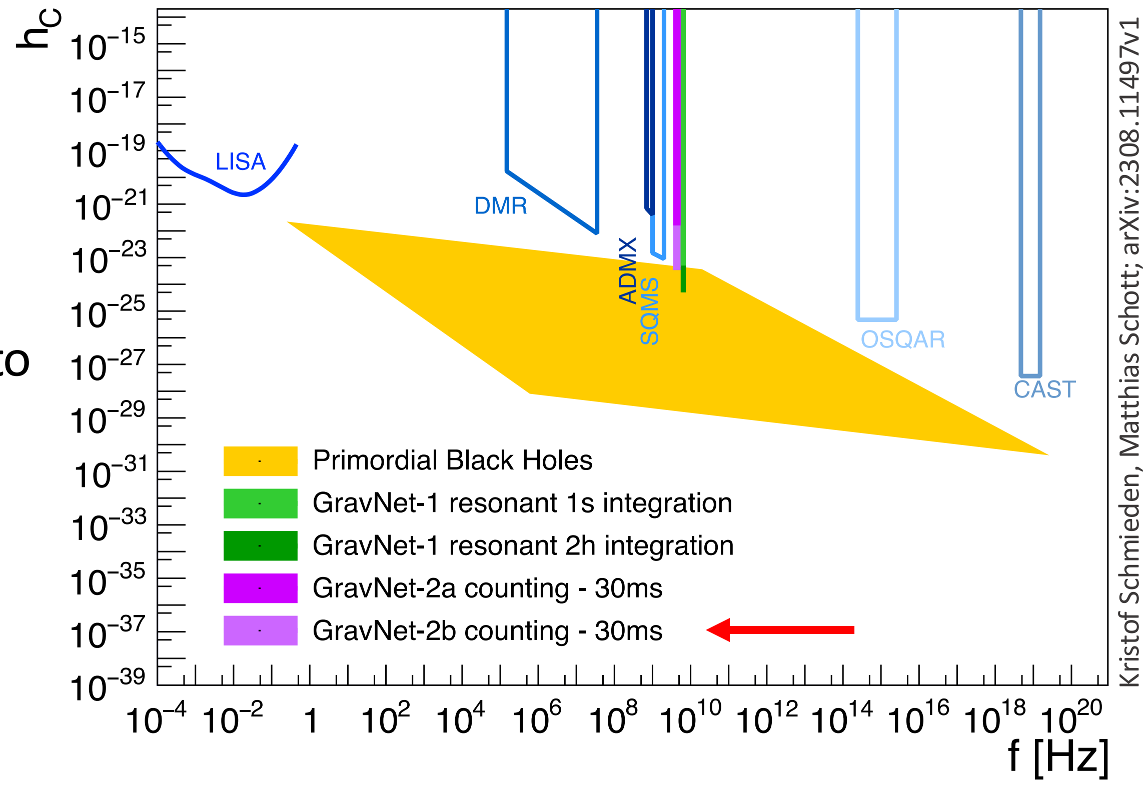


LIGO/Virgo
DOI: 10.1103/PhysRevLett.116.061102

GravNet (visions)

- Employ single photon counting
  - Reduction of necessary integration time from 1s to 30ms without significant loss in sensitivity
- Necessary for source triangulation
- Cavities at different frequencies to observe transient signal
- Use of neural networks searching for signal shapes



Acknowledgements

Dmitry Budker, Arne Wickenbrock & Hendrik Bekker

for allowing us to use the CASPEr magnet for axion & GW searches

RADES collaboration

for valuable discussions and the opportunity to coat our cavity @ Uni Siegen

Conclusion

- Don't try NbN in magnetic fields
- First 0.1MHz range DP limit for SUPAX soon
- First axion limit later this year
- Gravitational waves of PBH mergers can be detected with existing axion cavity setups
- Global network of GW detectors + new analysis approach enables necessary sensitivity with $\mathcal{O}(10\text{ms})$ integration times
- Interested parties for collaboration welcome to talk to us

Thank you for your attention!