Results from the ALPS II first science campaign

Shining new light into the dark sector

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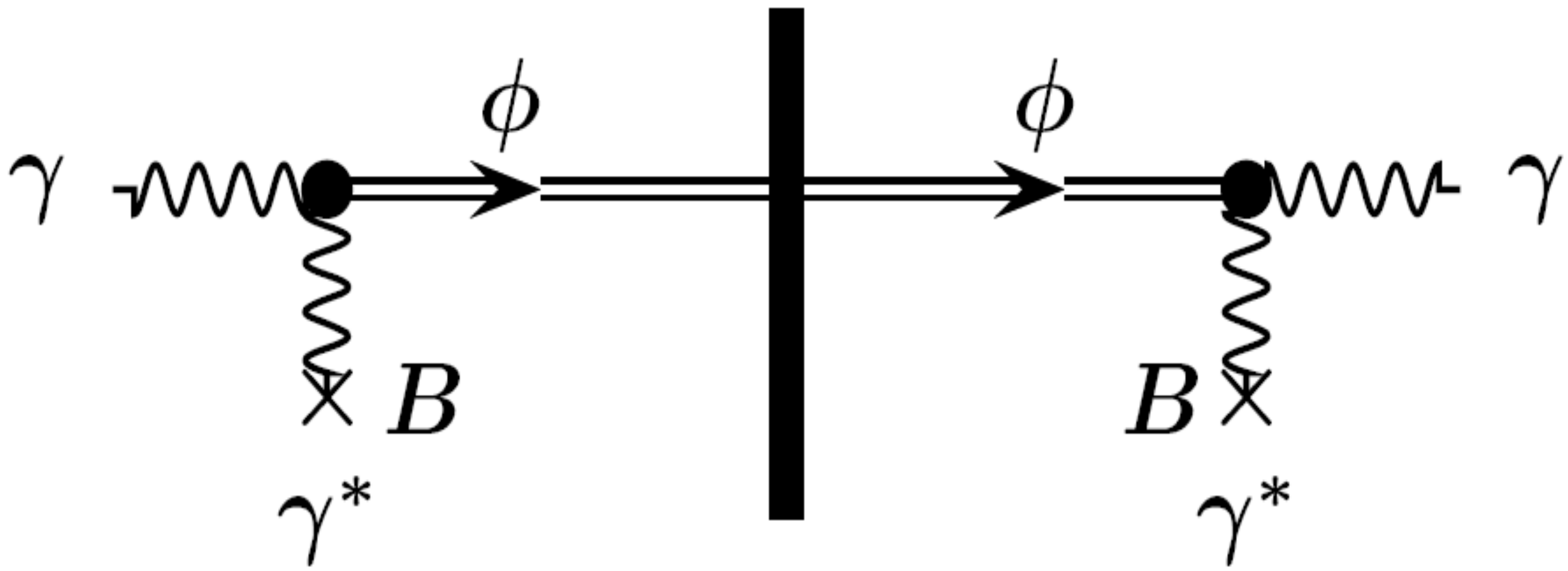
19th Patras Workshop

University of Patras
Patras, Greece
September 16-20, 2024

Light Shining Through a Wall (LSW) Experiments

Light-shinning through a wall concept

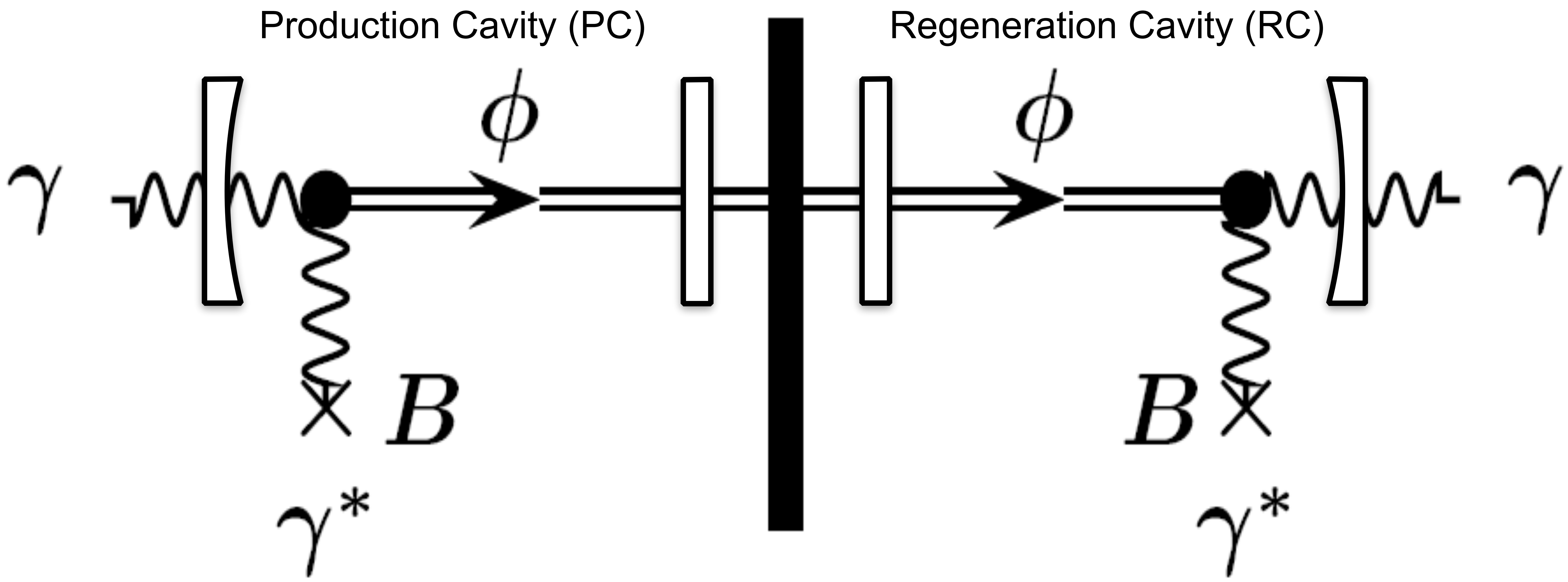
Using the axions coupling to two photons



$$P_\gamma = \frac{1}{16}\left(g_{a\gamma\gamma}BL\right)^4 P_i$$

ALPS II concept

Enhancing LSW with cavities



$$P_\gamma = \frac{1}{16}\left(g_{a\gamma\gamma}BL\right)^4 \eta\, \beta_\mathrm{P}\beta_\mathrm{R}P_i$$

ALPS II concept

First realization of Hoogeveen idea

Nuclear Physics B358 (1991) 3–26
North-Holland

PRODUCTION AND DETECTION OF LIGHT BOSONS USING OPTICAL RESONATORS

F. HOOGEVEEN* and T. ZIEGENHAGEN

Institute of Theoretical Physics, University of Hannover, Appelstrasse 2, 3000 Hannover 1, Germany

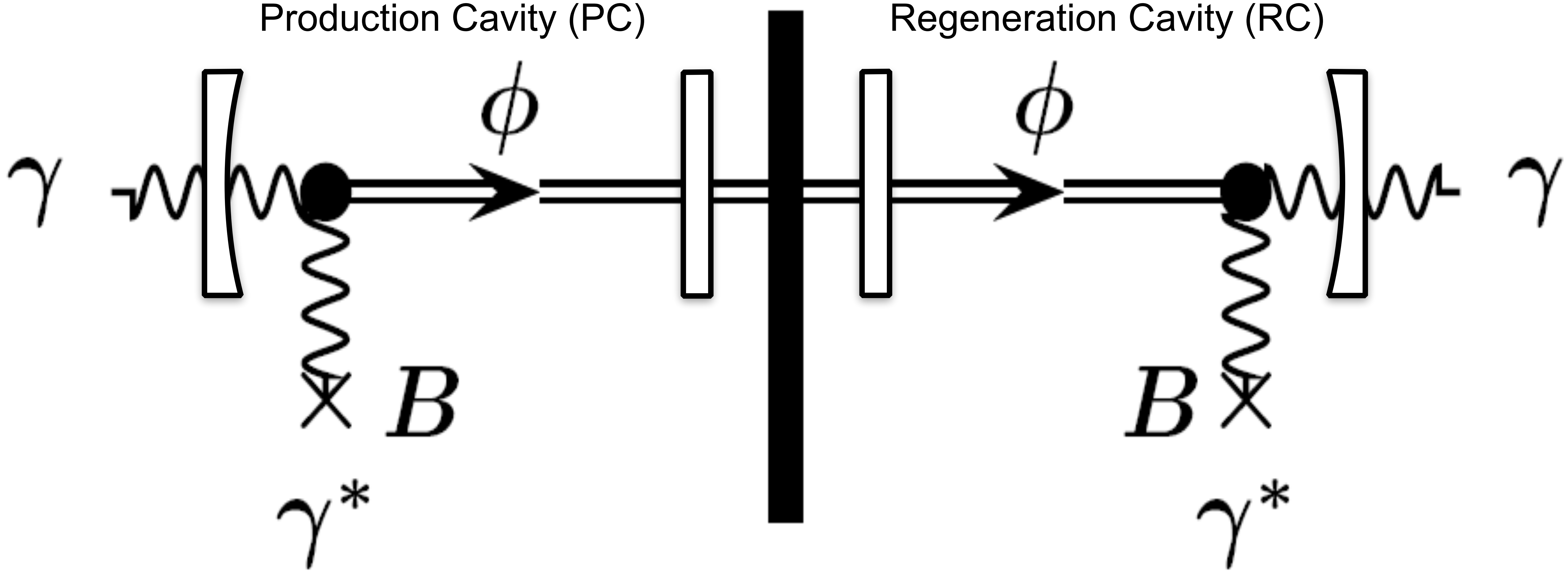
Received 13 December 1990
(Revised 22 February 1991)

Fig. 3. Axion production and detection with two optical resonators.

Calibrating LSW Experiements

ALPS II concept

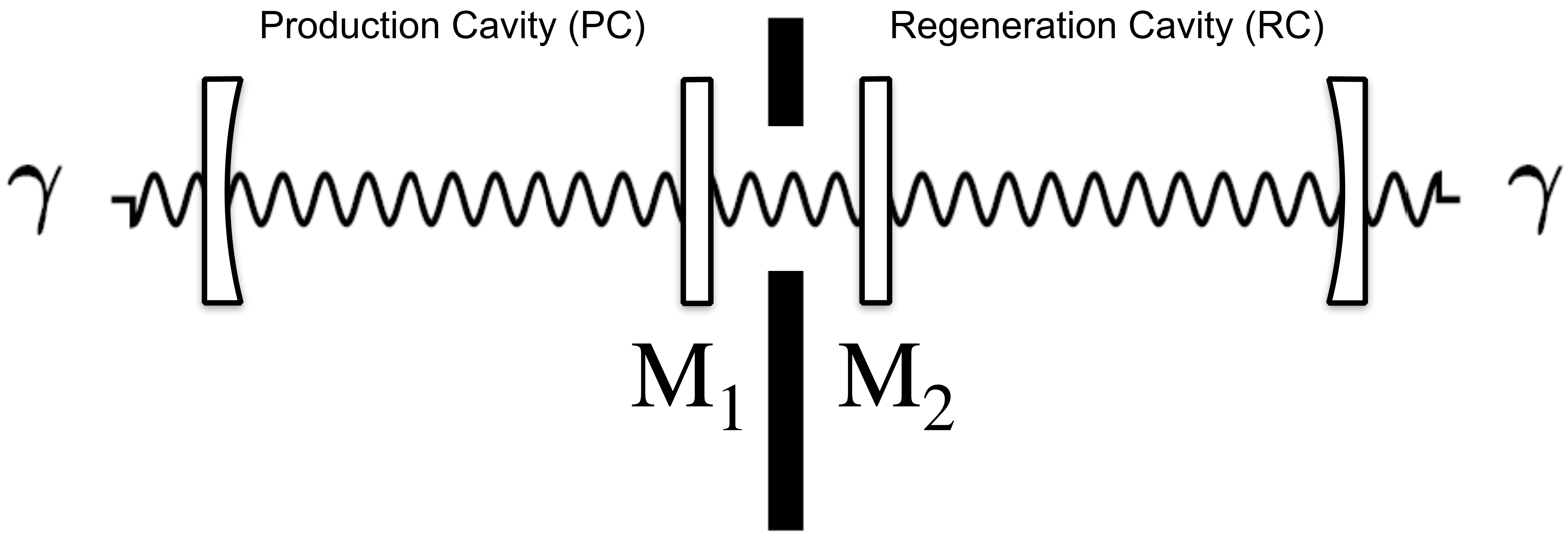
Enhancing LSW with cavities



$$P_\gamma = \frac{1}{16}\left(g_{a\gamma\gamma}BL\right)^4 \eta\,\beta_{\mathrm{P}}\beta_{\mathrm{R}}P_i$$

ALPS II concept

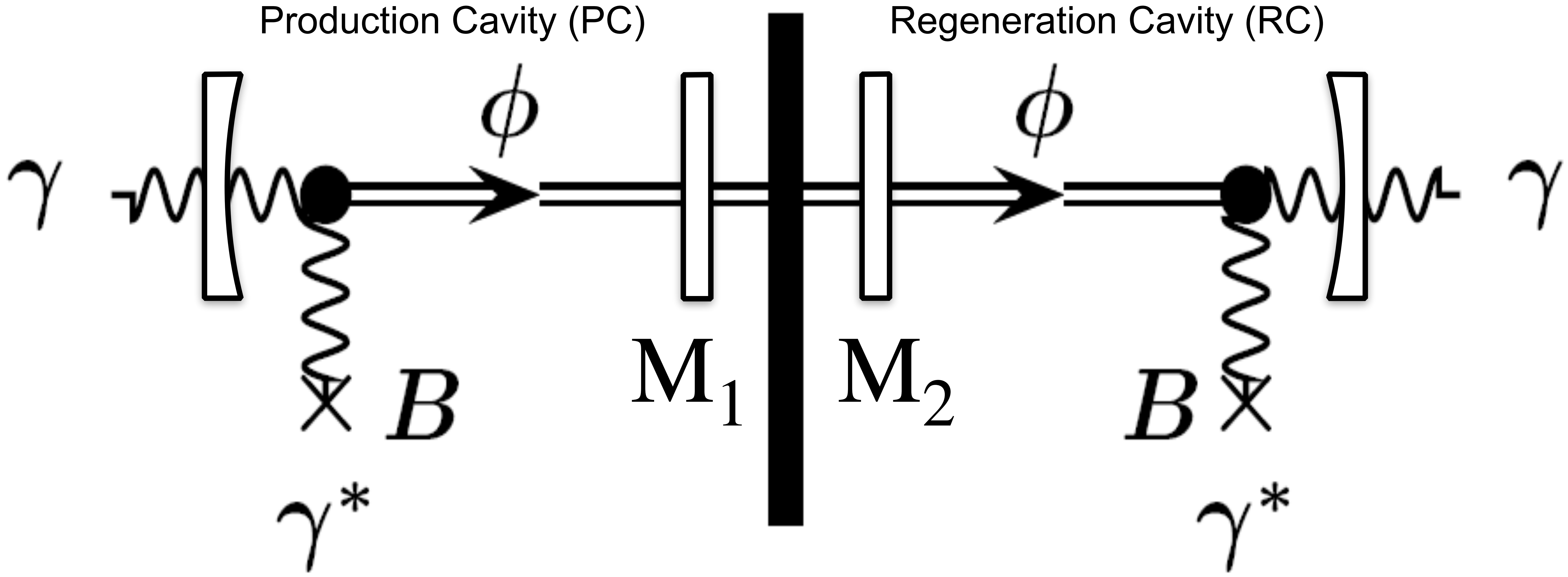
Enhancing LSW with cavities



$$P_{\mathrm{open}} = T_{\mathrm{M}_1} T_{\mathrm{M}_2} \eta\, \beta_{\mathrm{P}} \beta_{\mathrm{R}} P_i$$

ALPS II concept

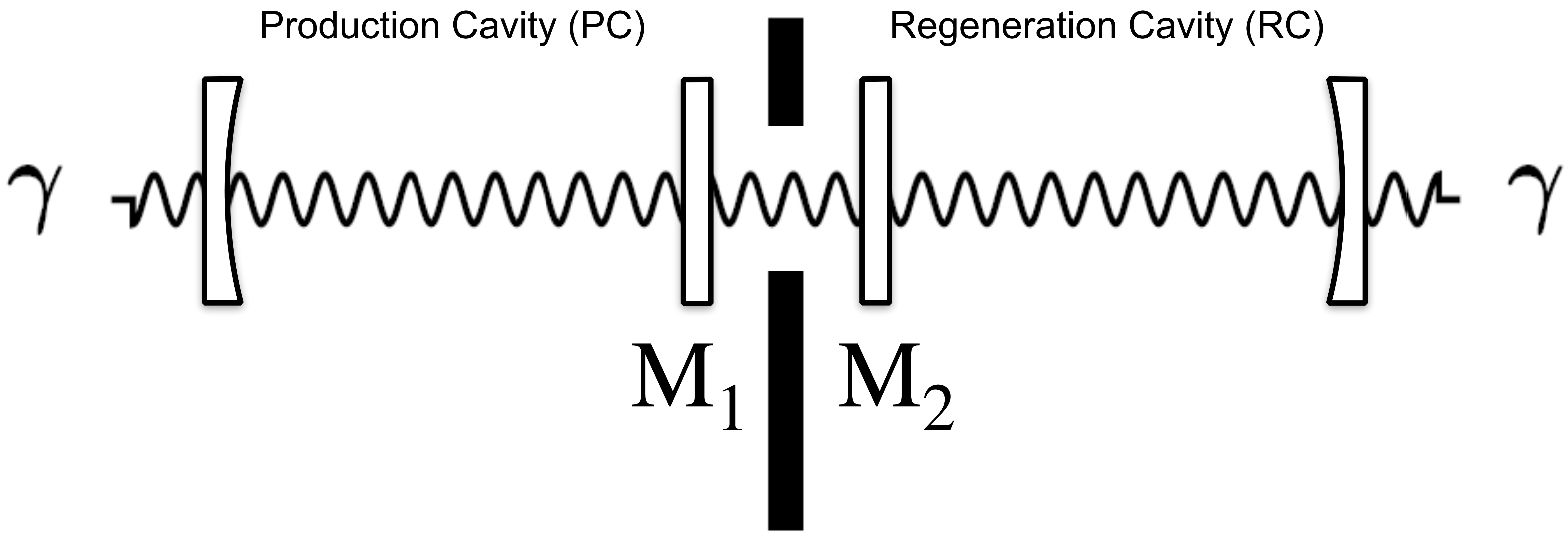
Enhancing LSW with cavities



$$\frac{P_\gamma}{P_{\text{open}}} = \frac{1}{16}\left(g_{a\gamma\gamma}BL\right)^4 \frac{1}{T_{\text{M}_1}T_{\text{M}_2}}$$

ALPS II concept

Enhancing LSW with cavities



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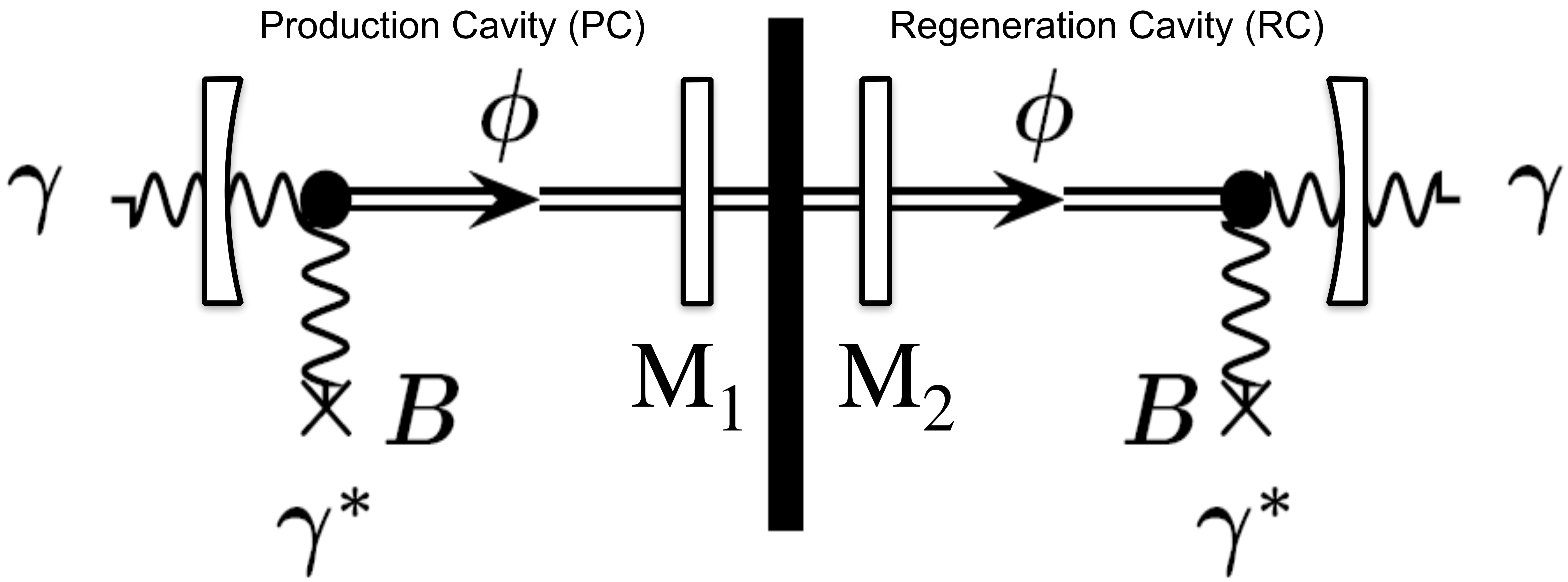
ALPS II concept

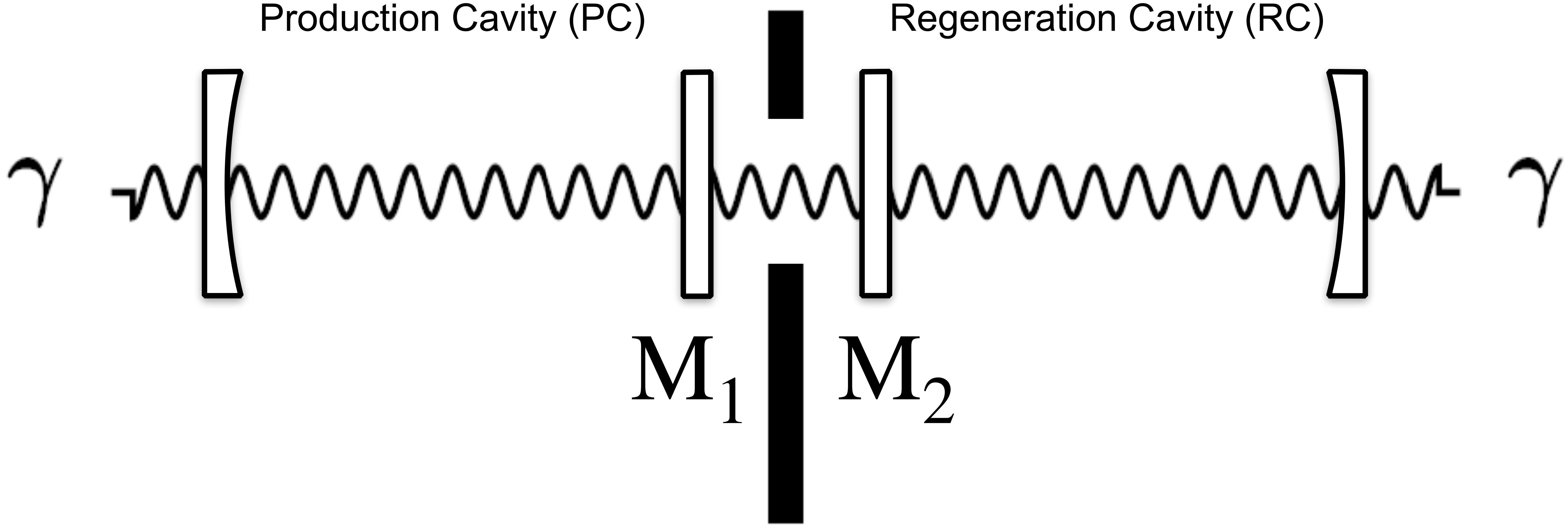
Enhancing LSW with cavities



$$g_{a\gamma\gamma} = \frac{2}{BL}\left(T_{\mathrm{M}_1}T_{\mathrm{M}_2}\frac{P_\gamma}{P_{\mathrm{open}}}\right)^{1/4}$$

ALPS II concept

Enhancing LSW with cavities



$$g_{a\gamma\gamma} = \frac{2}{BL}\left(T_{\mathrm{M}_1}T_{\mathrm{M}_2}\frac{P_\gamma}{P_{\mathrm{open}}}\right)^{1/4}$$

ALPS II

Infrastructure at DESY

Providing the basis for ALPS II

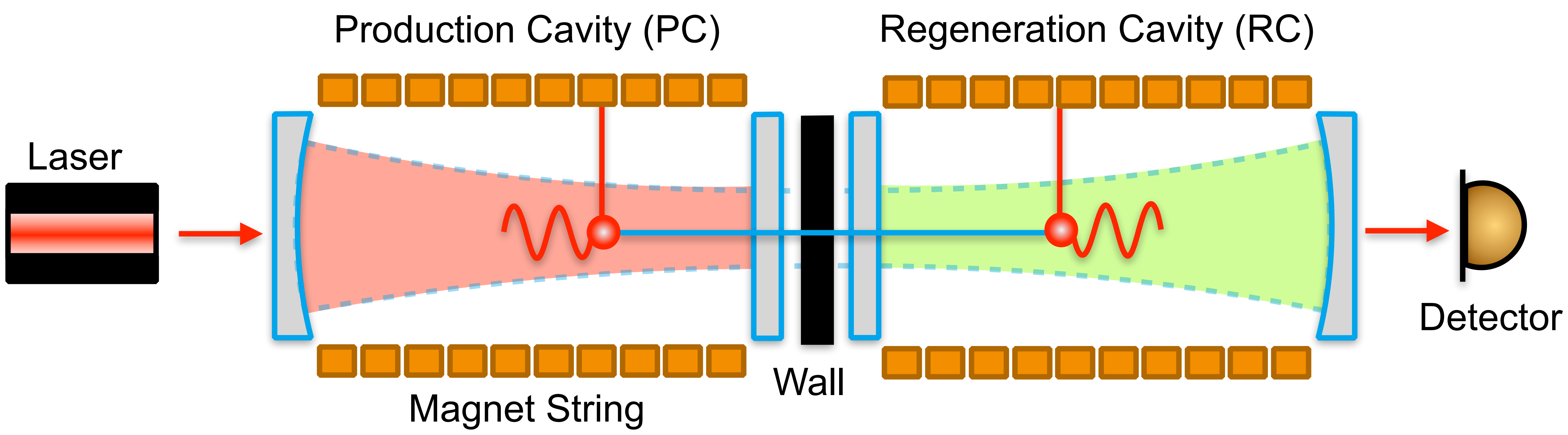
Magnets, tunnel, and infrastructure are the foundation of the experiment

- 2x strings of 12 HERA dipole magnets: 5.3 T, 106 m
  - Cryogenic infrastructure
- 3 clean rooms at the different stations of the experiment

What distinguishes ALPS II

Pushing the sensitivity with precision interferometry

Not just longer magnetic field length

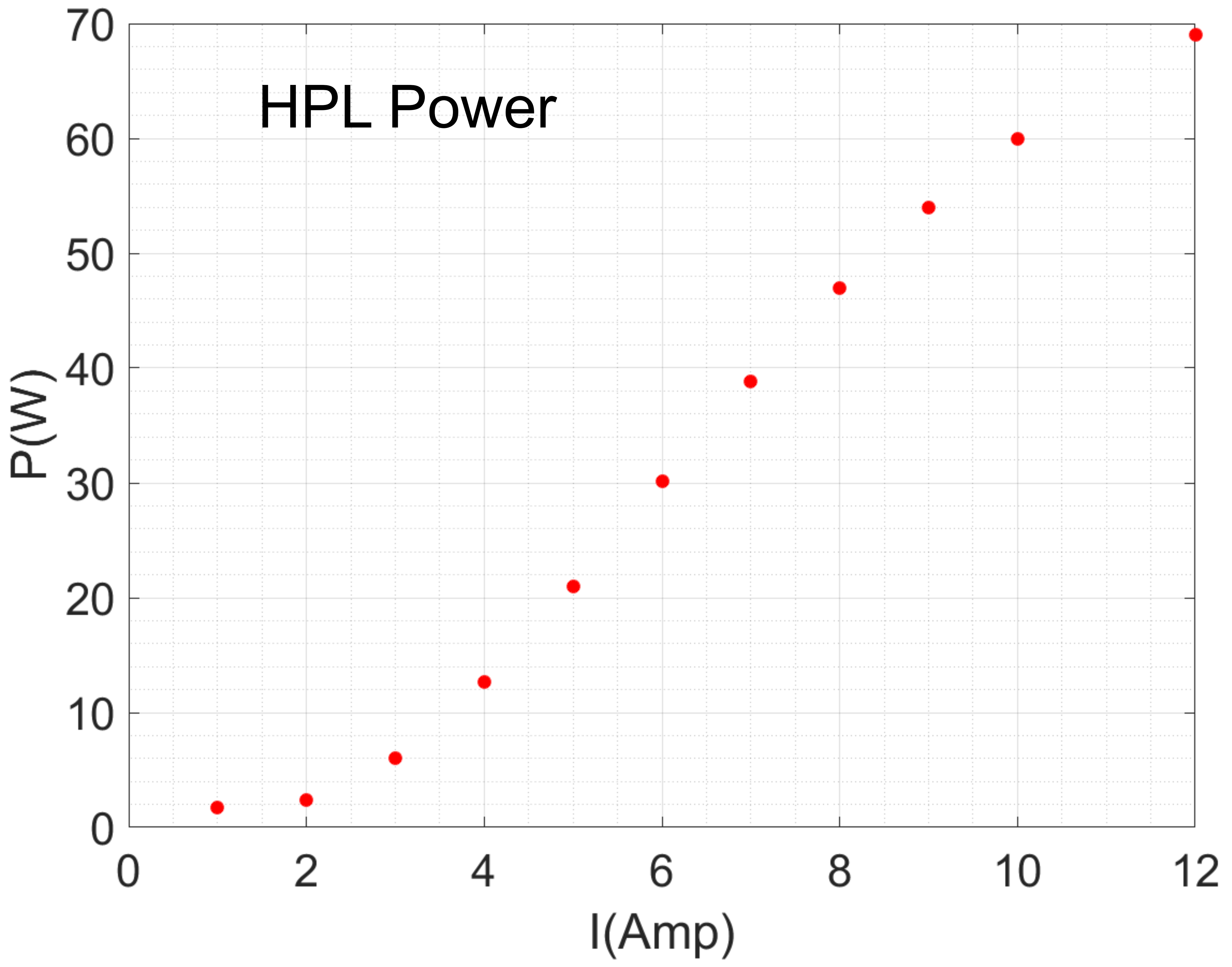


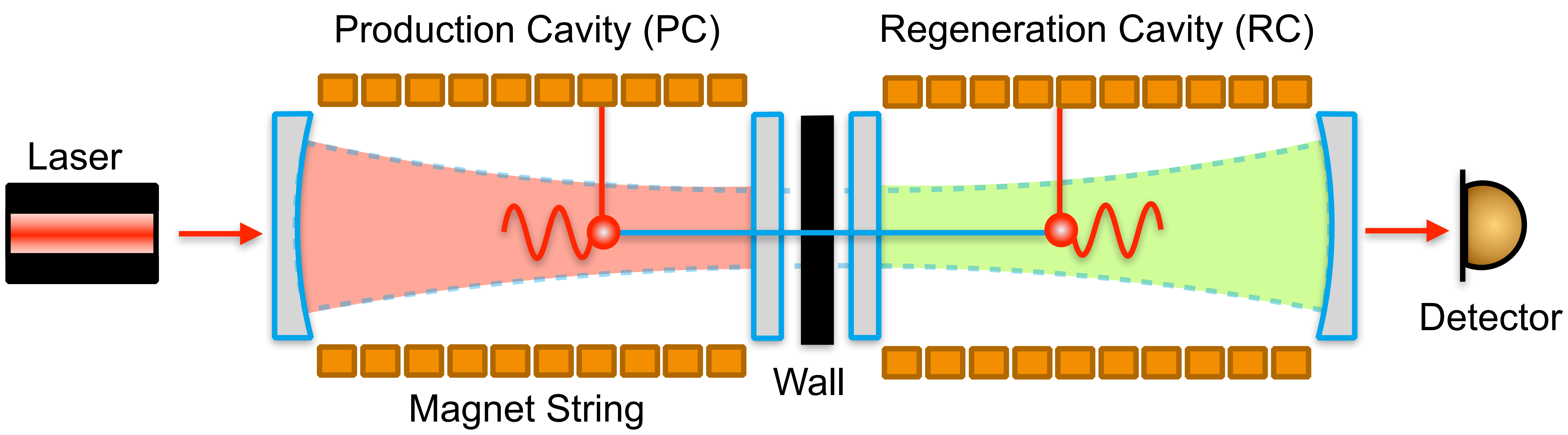
What distinguishes ALPS II

Pushing the sensitivity with precision interferometry

Not just longer magnetic field length

- High power laser (HPL) system (30 W)





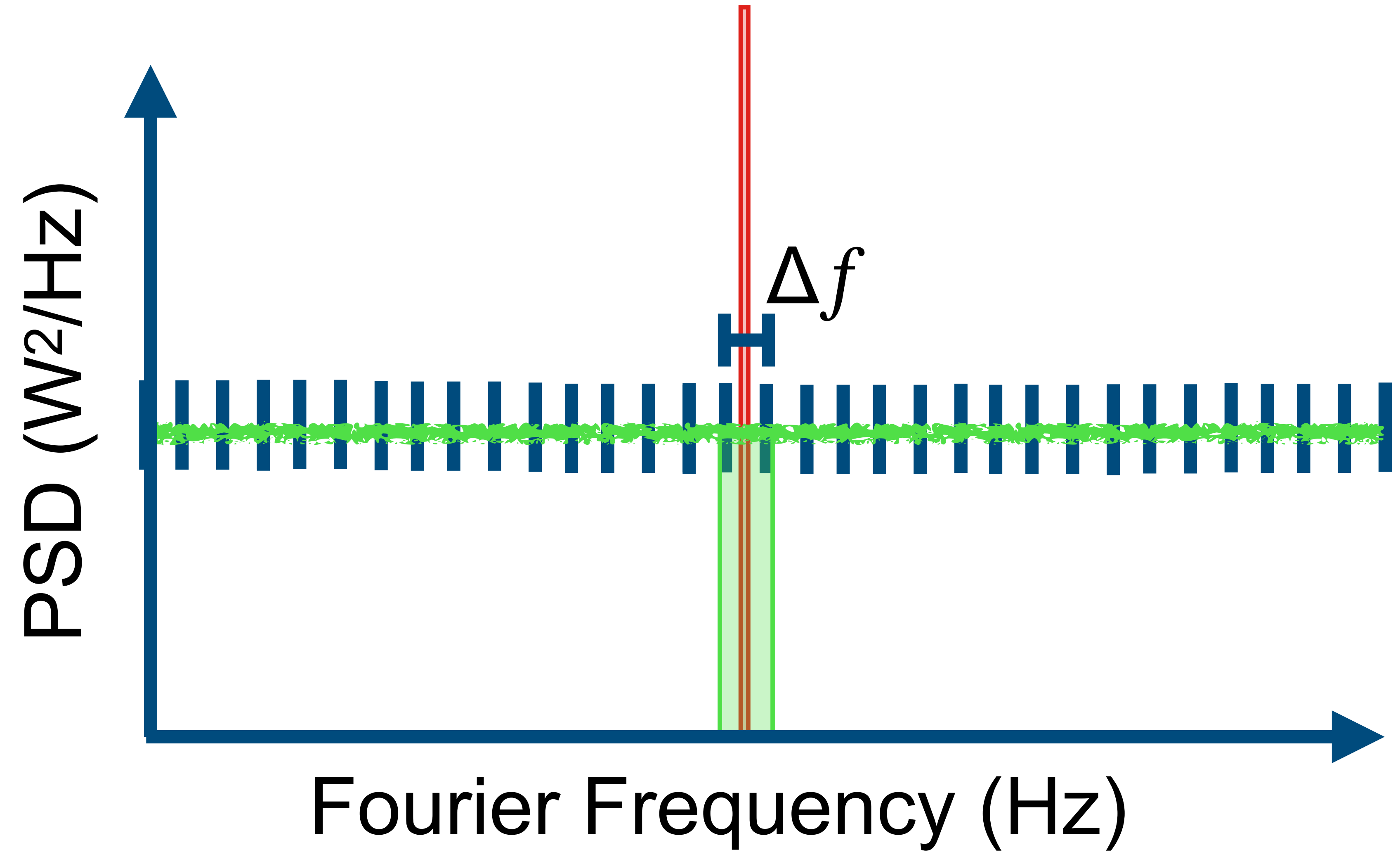
What distinguishes ALPS II

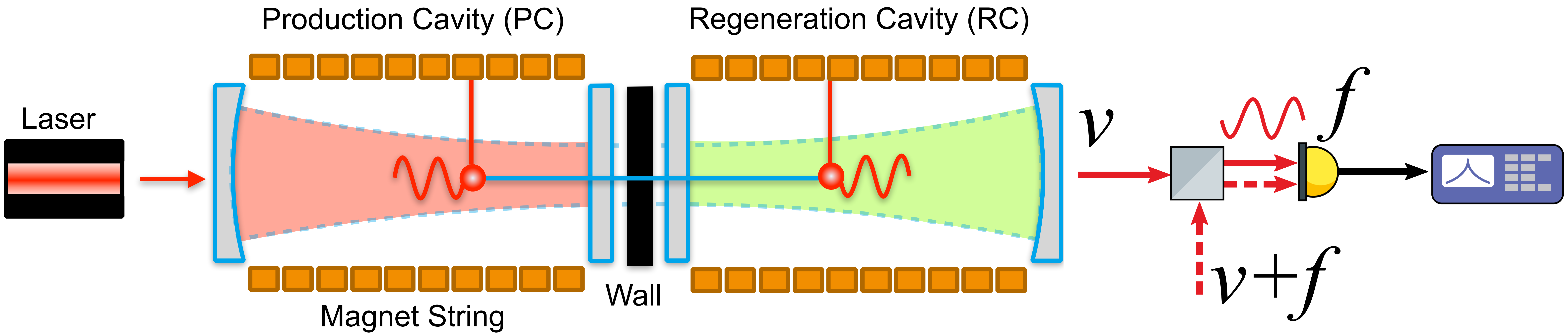
Pushing the sensitivity with precision interferometry

Not just longer magnetic field length

- High power laser (HPL) system (30 W)
- Heterodyne detection system ($\Delta f \sim 1\,\mu$Hz)

$$P(t) = P_\nu + P_{\nu+f} + 2\sqrt{P_\nu P_{\nu+f}}\cos(2\pi f t - \phi)$$





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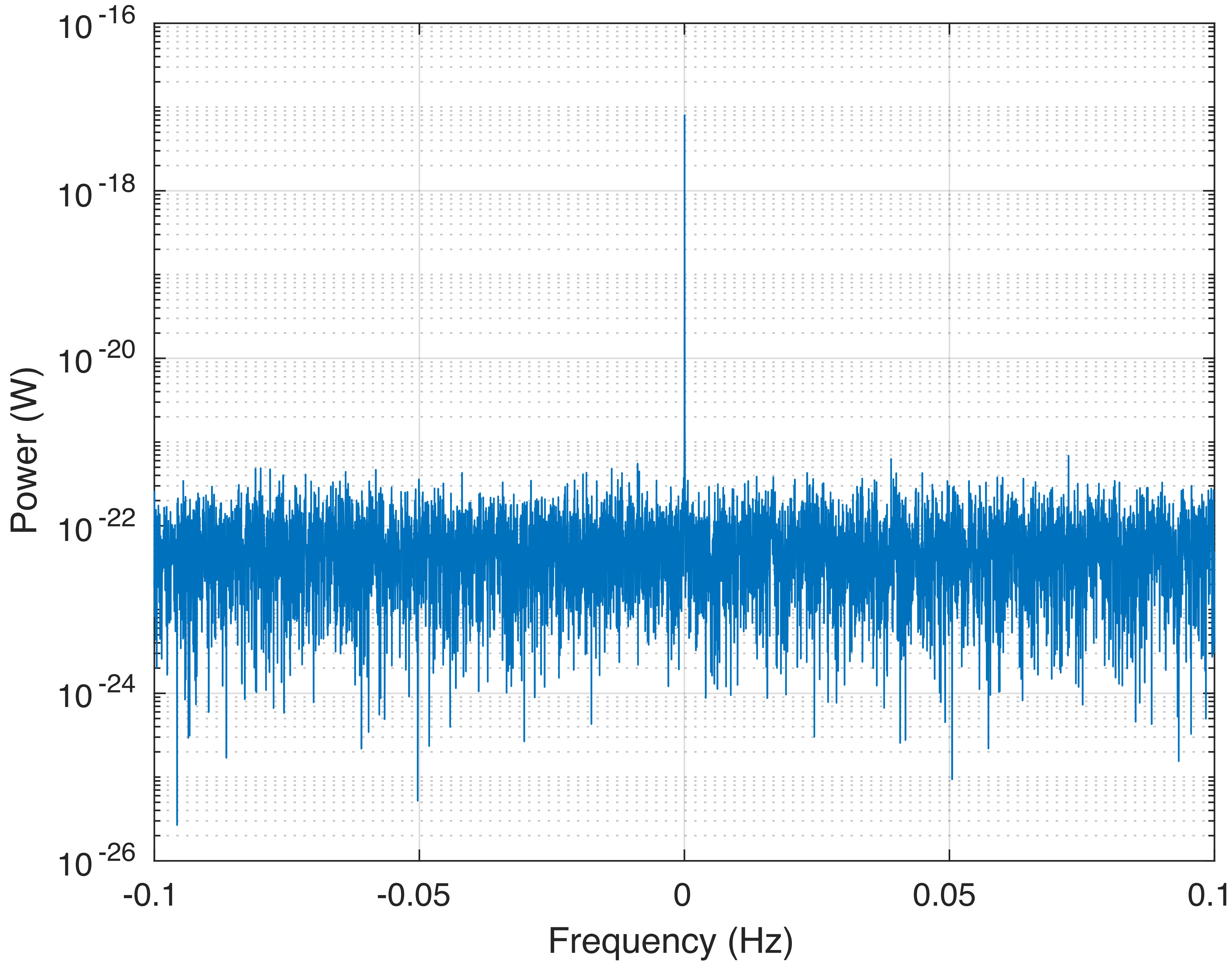
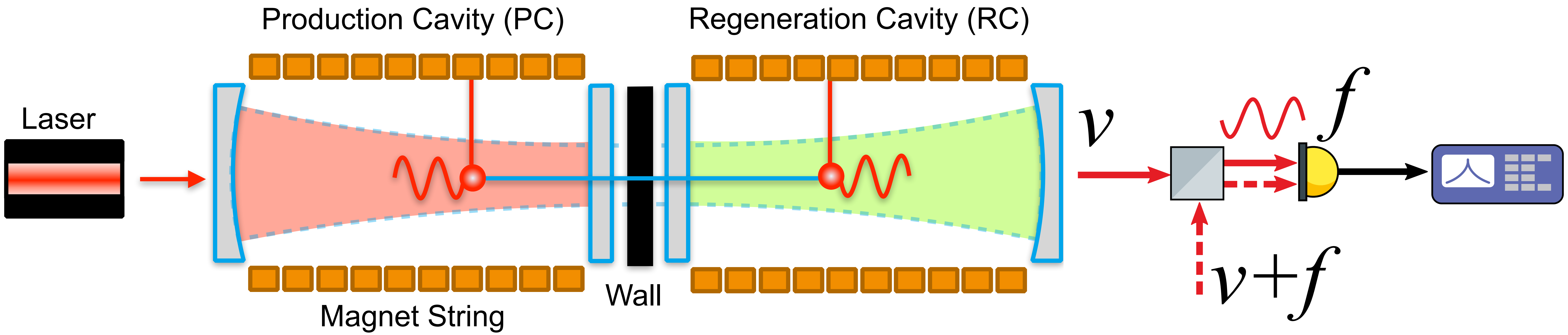


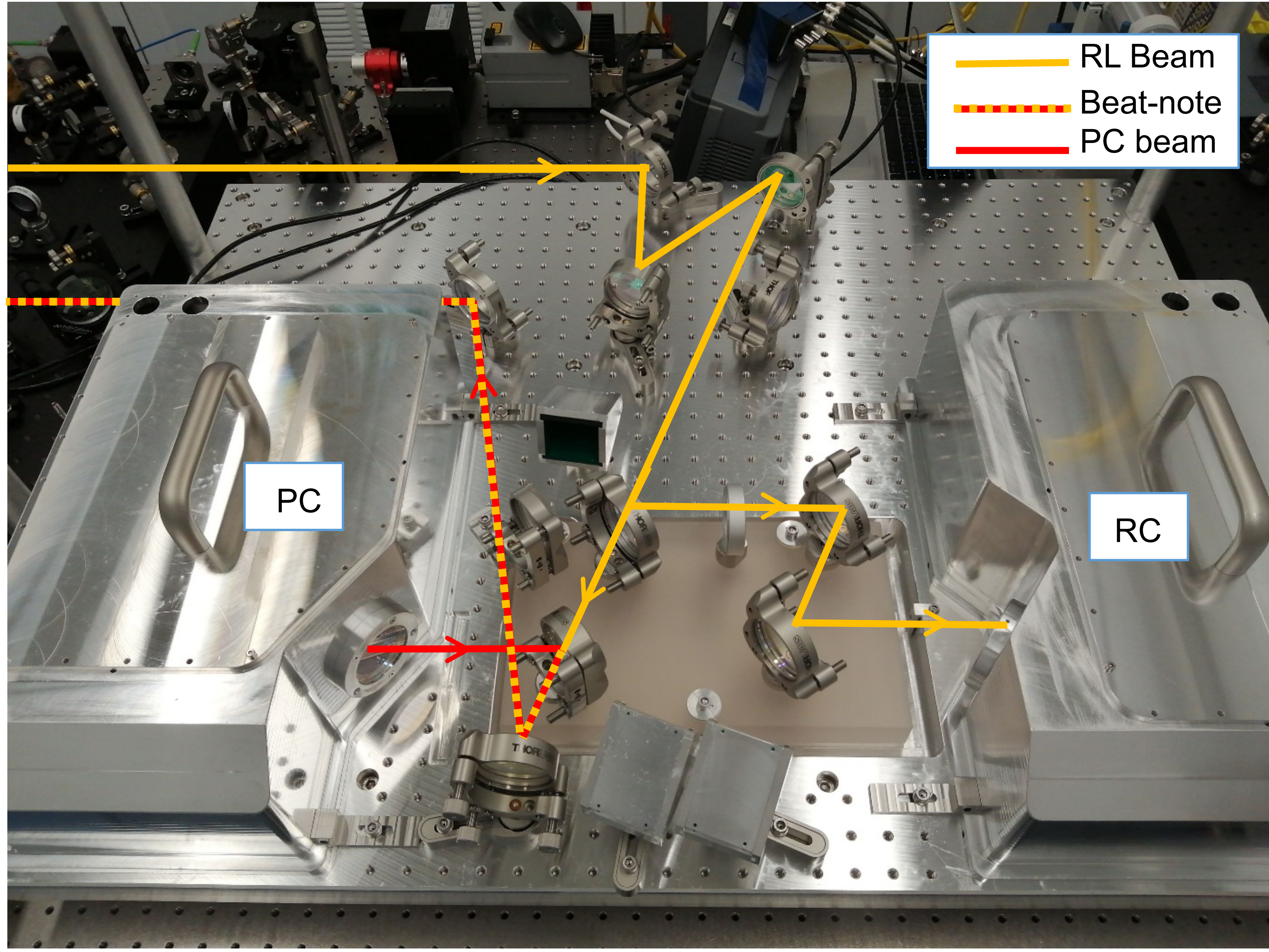


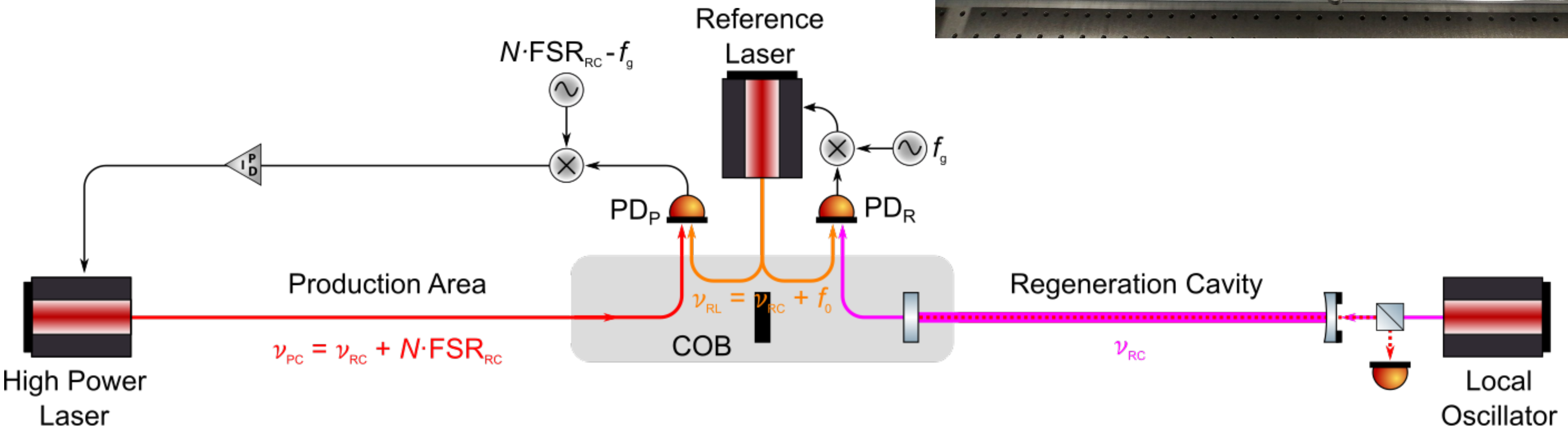
What distinguishes ALPS II

Pushing the sensitivity with precision interferometry

Not just longer magnetic field length

- High power laser (HPL) system (30 W)
- Heterodyne detection system ($\Delta f \sim 1\,\mu\text{Hz}$)
- Central optical bench



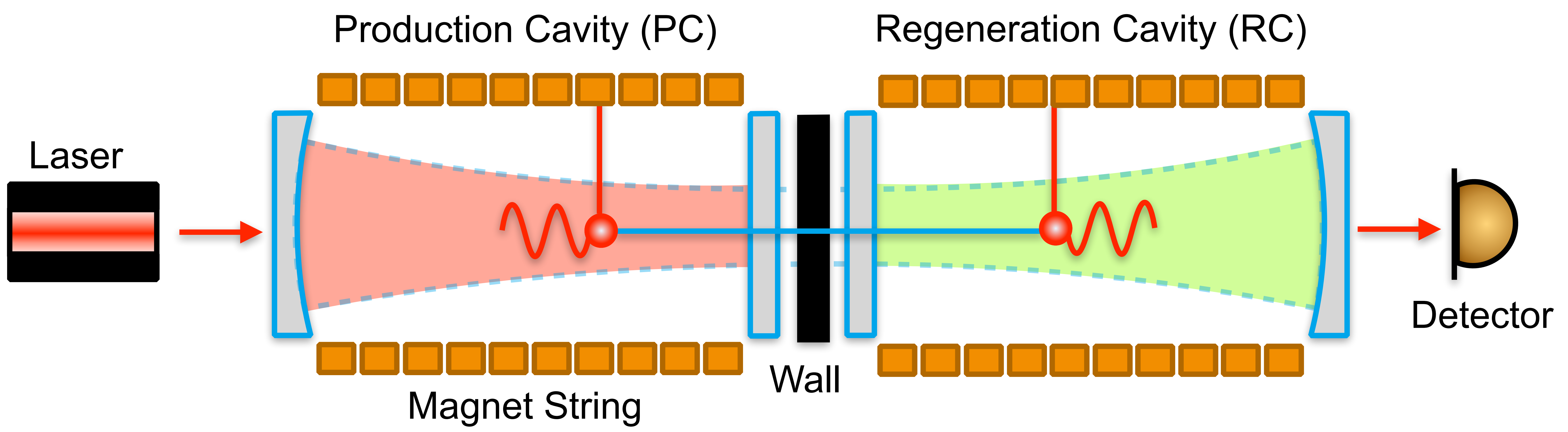


What distinguishes ALPS II

Pushing the sensitivity with precision interferometry

Not just longer magnetic field length

- High power laser (HPL) system (30 W)
- Heterodyne detection system ($\Delta f \sim 1\,\mu\text{Hz}$)
- Central optical bench
- World record regeneration cavity

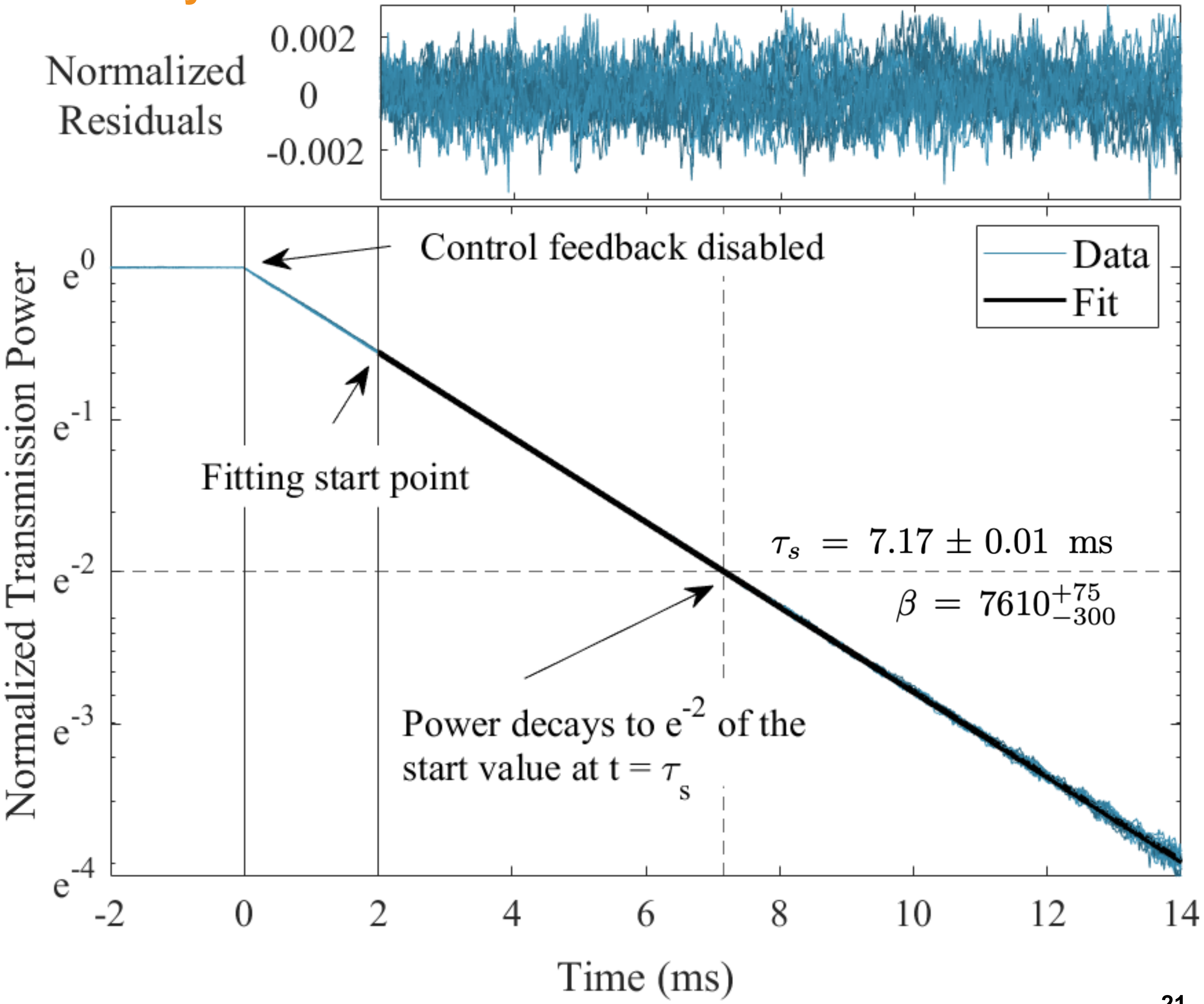


What distinguishes ALPS II

Pushing the sensitivity with precision interferometry

ALPS II Regeneration Cavity

- World record storage time: 7.17 +- 0.01 ms
  - Power buildup of 7610
- Robust control system maintains cavity lock for days
- Characterization of storage time via mirror maps

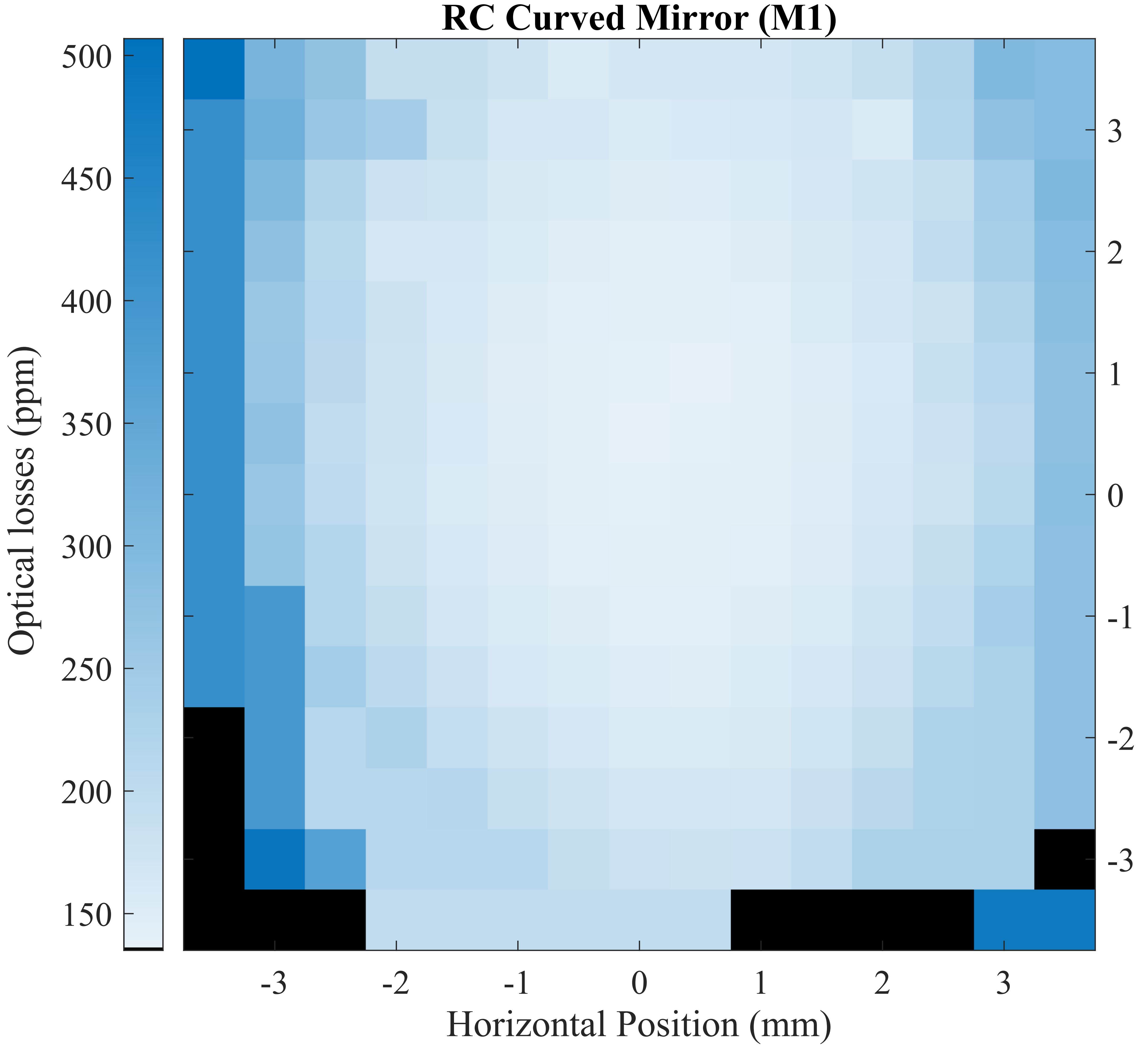


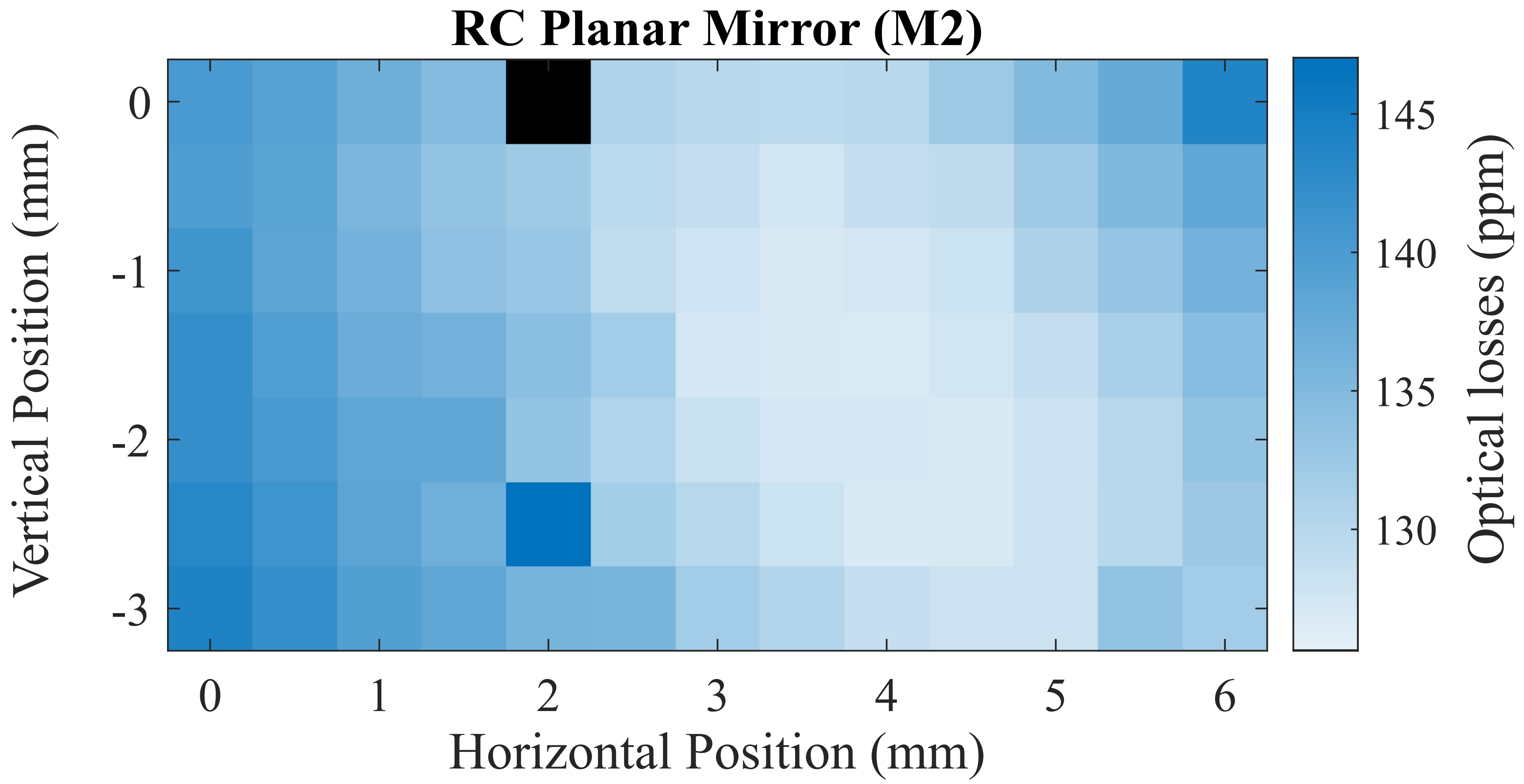
arXiv:2408.13218v1 [physics.optics] 23 Aug 2024

What distinguishes ALPS II

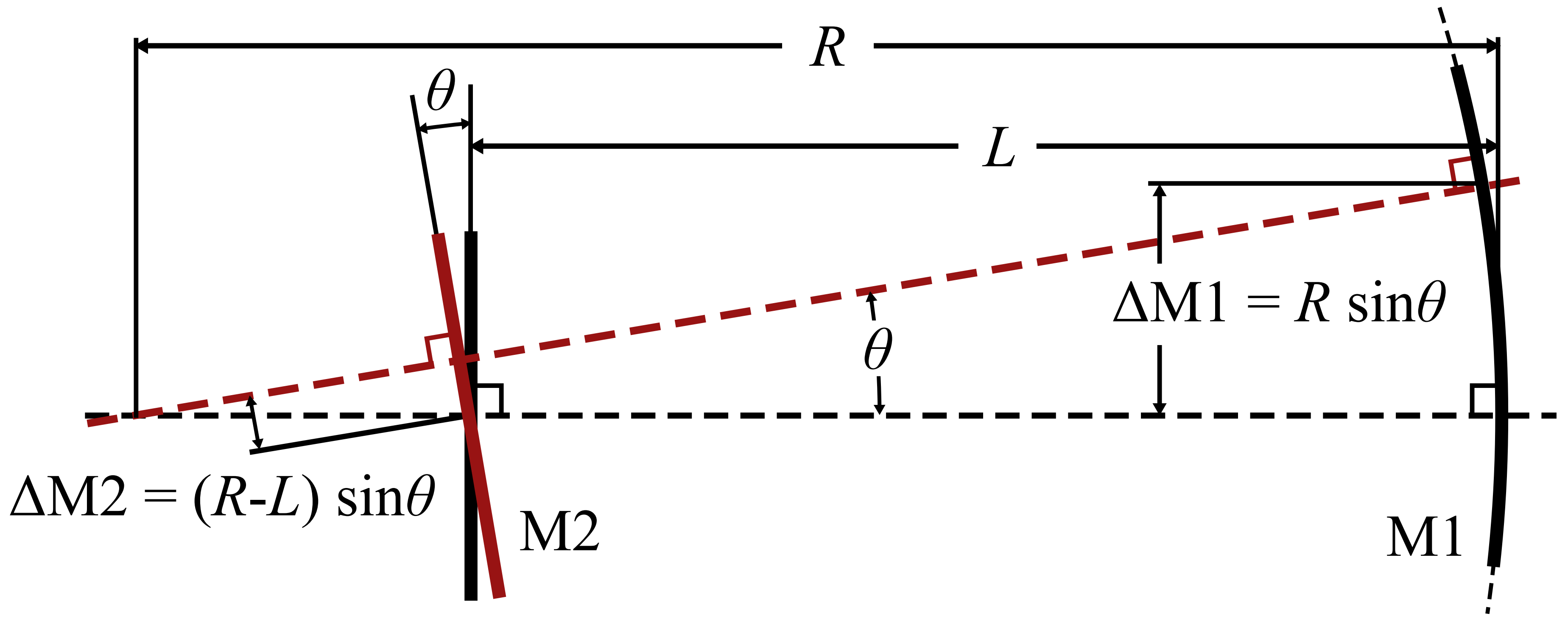
Pushing the sensitivity with precision interferometry

Mirror Maps of the ALPS II Regeneration Cavity





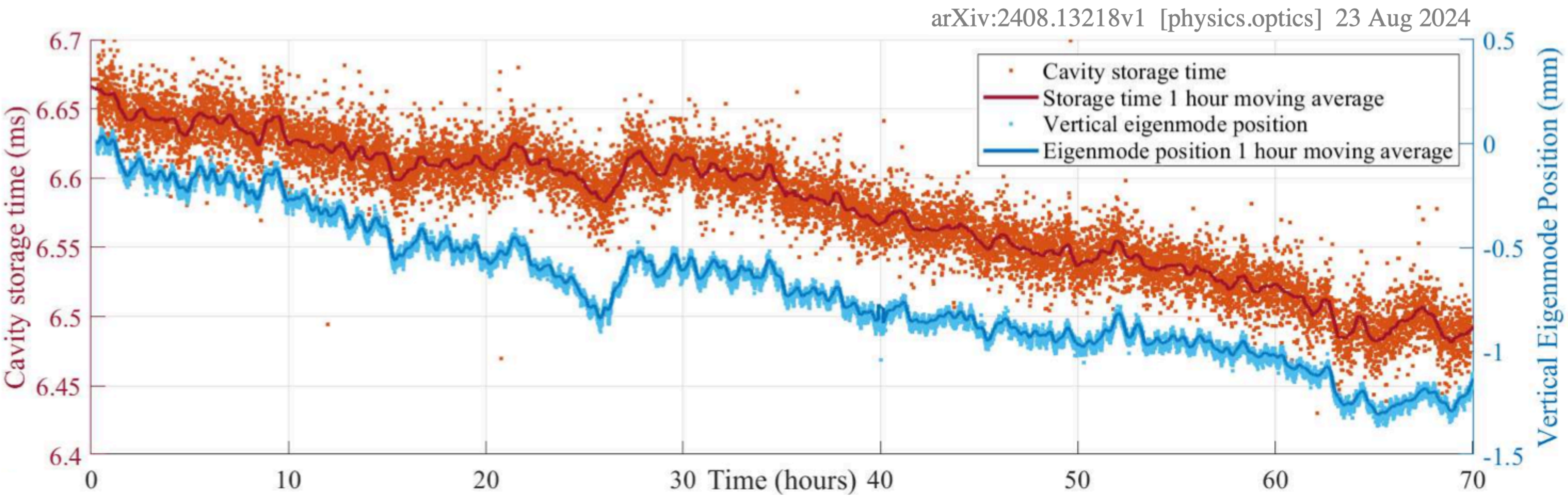
(b)



What distinguishes ALPS II

Pushing the sensitivity with precision interferometry

Trend in the Storage Time of the ALPS II Regeneration Cavity



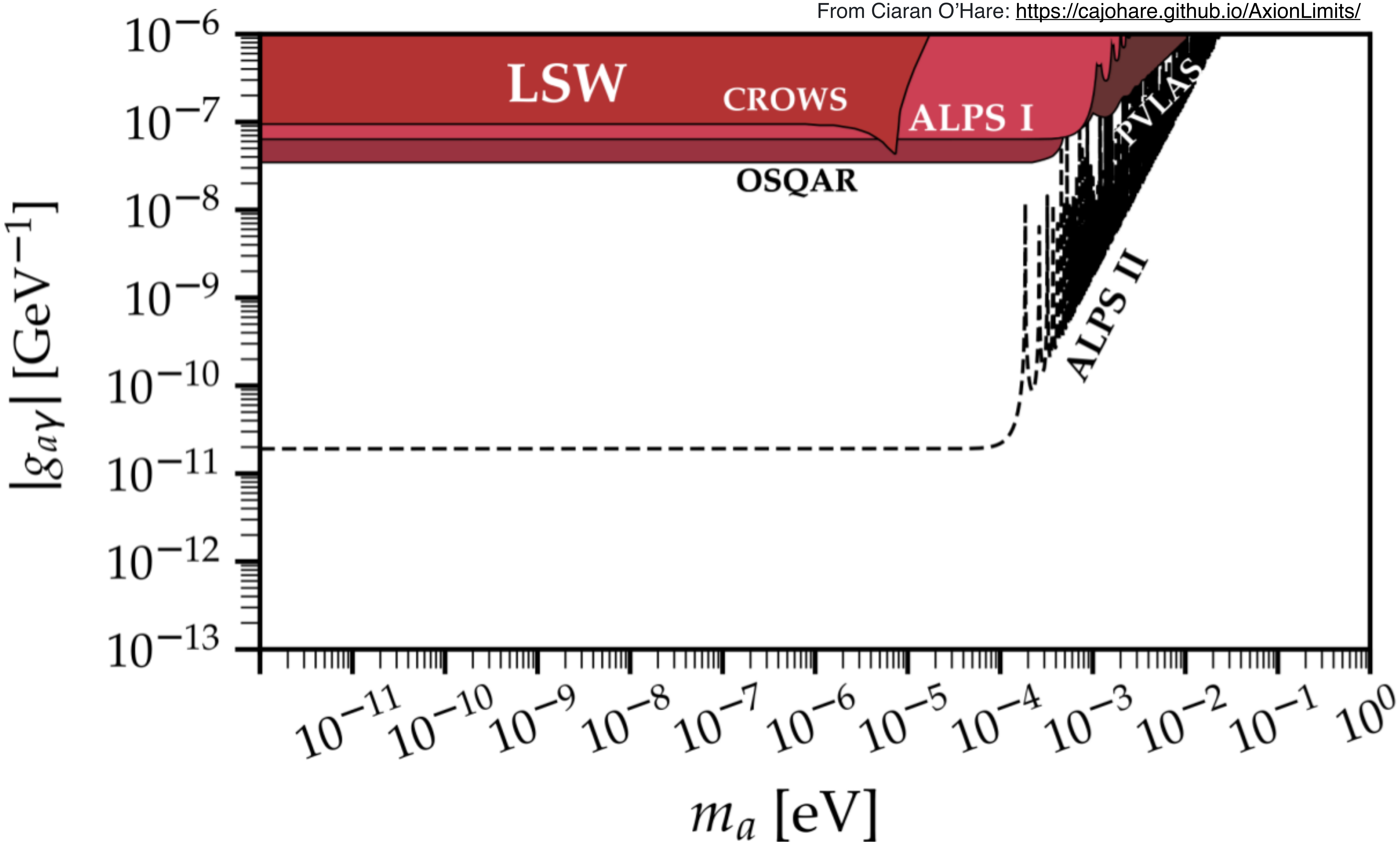
What distinguishes ALPS II

Pushing the sensitivity with precision interferometry

Target: $g_{a\gamma\gamma}$ > 2×10^{-11} GeV^{-1}

- > 3 orders more sensitive than previous LSW setups
- ‘Model independent’ search

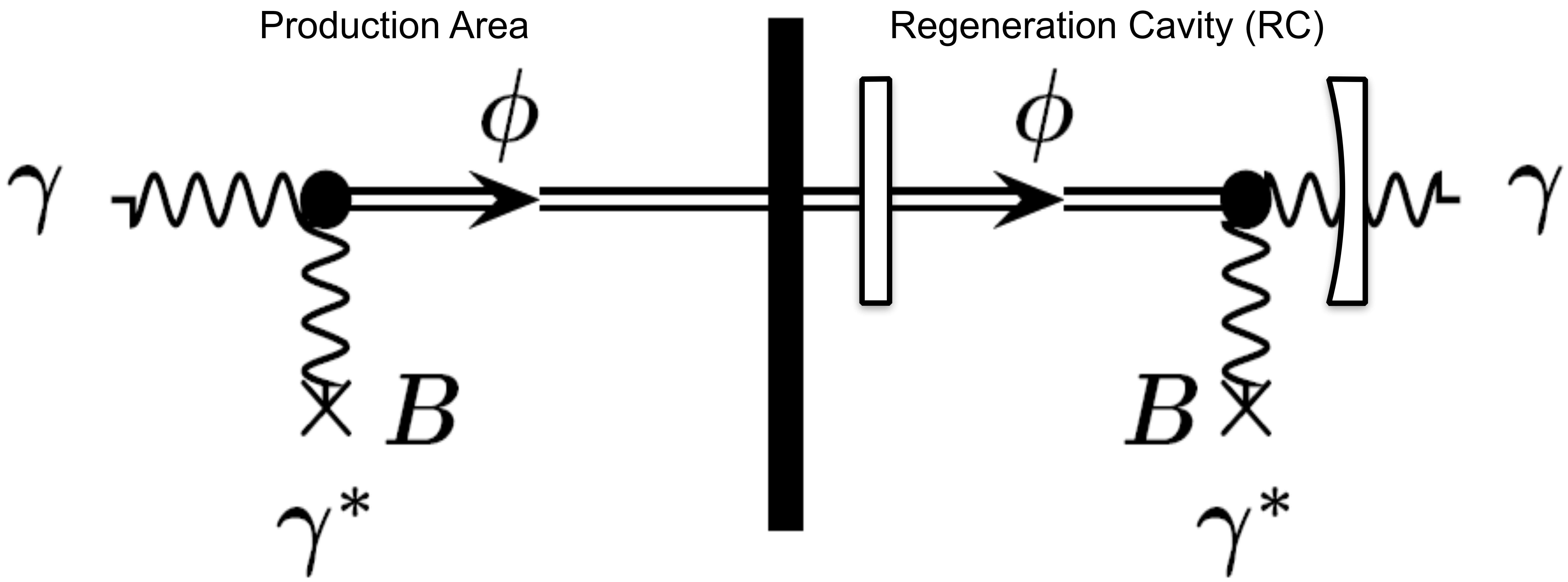
From Ciaran O’Hare: https://cajohare.github.io/AxionLimits/



ALPS II First Science Campaign

ALPS II first science campaign

Simplifying the optical system



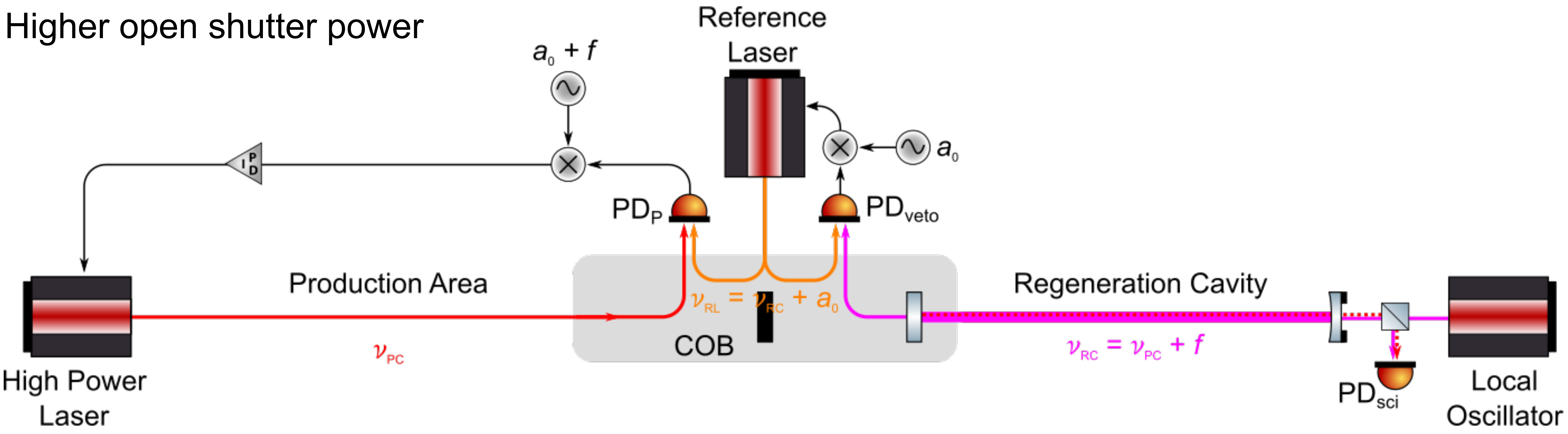
$$P_\gamma = \frac{1}{16}\left(g_{a\gamma\gamma}BL\right)^4 \eta\,\beta_{\mathrm{R}} P_i$$

ALPS II first science run

Simplifying the optical system

Operate without production cavity

- Simplifies control system
  - Feedback directly to laser frequency rather than PC length
- Light injected to COB increased by a factor of 40x
  - Faster identification of ‘light leaks’
  - Higher open shutter power



Infrastructure at DESY

Providing the foundation for ALPS II

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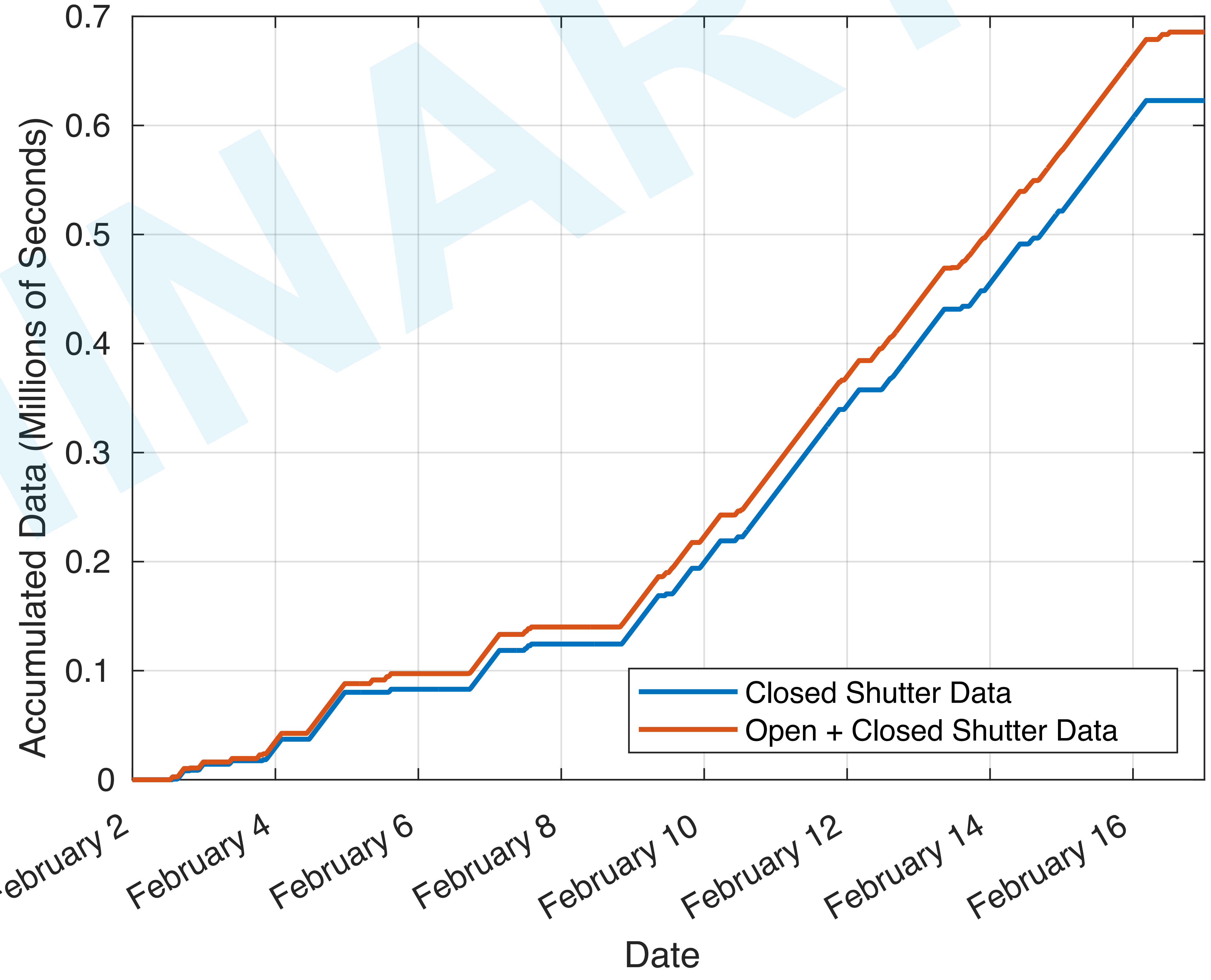
First science campaign performance

Taking a first look

Scalar Run from February 2 - 16

- Laser polarization orthogonal to magnetic field
- Acquired > 620,000 s of closed shutter data
- Acquired > 60,000 s of open shutter data
- Average total coupling: 0.54
- Average power build up: 6700



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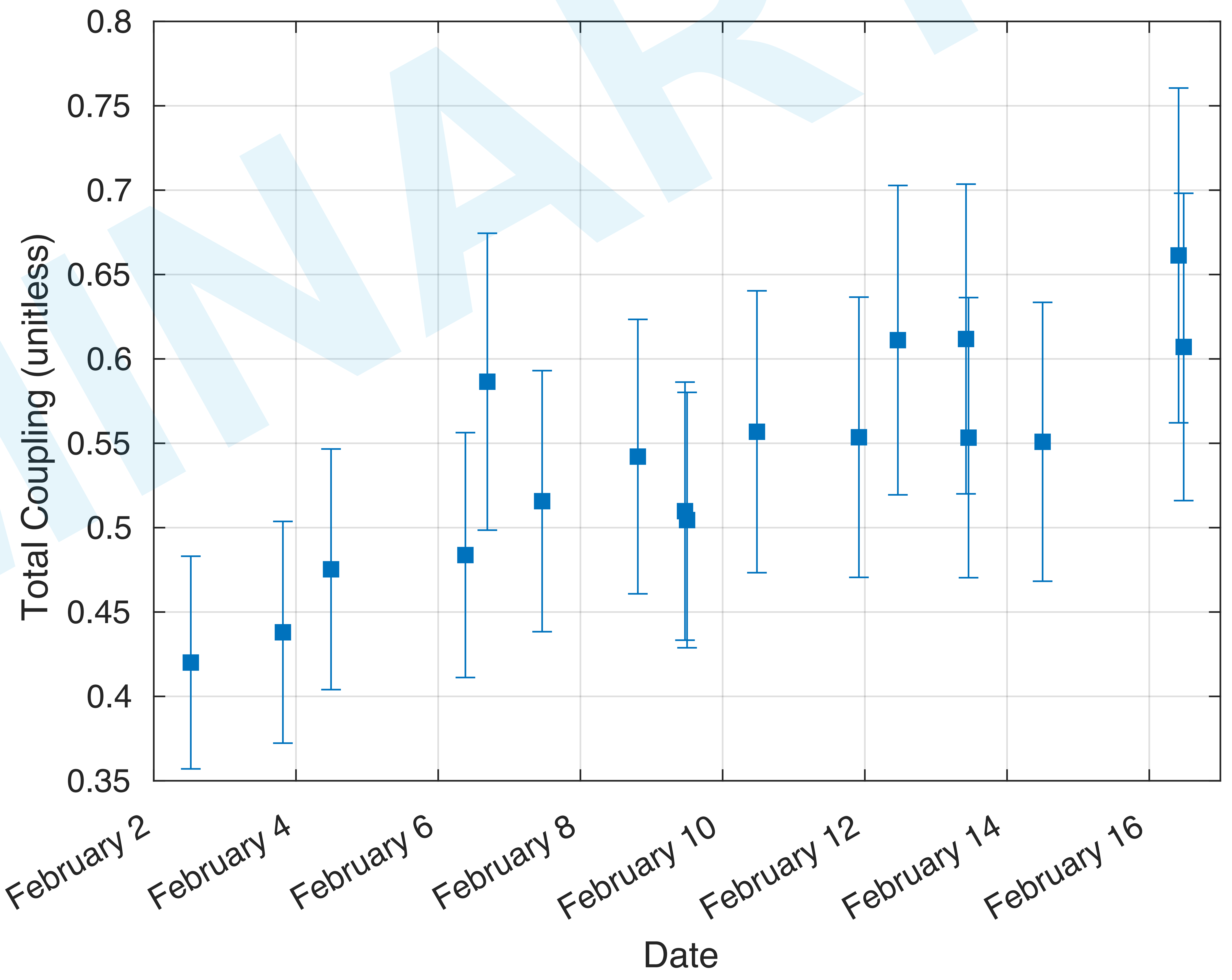
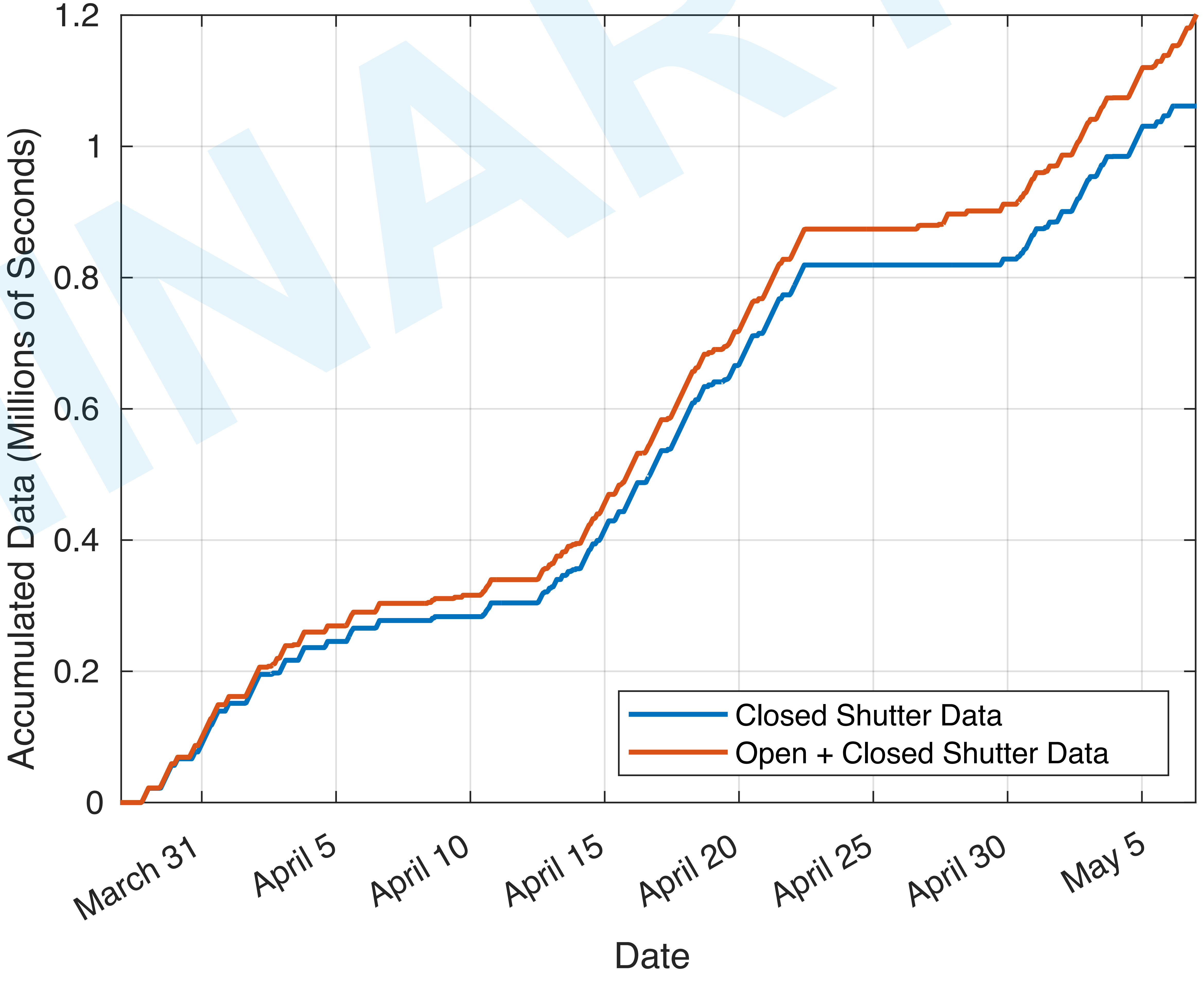


First science campaign performance

Taking a first look

Pseudo Scalar Run from March 30 - May 6

- Laser polarization parallel to magnetic field
- Acquired > 1,060,000 s of closed shutter data
- Acquired > 130,000 s of open shutter data
- Average total coupling: 0.49
- Average power build up: 6500



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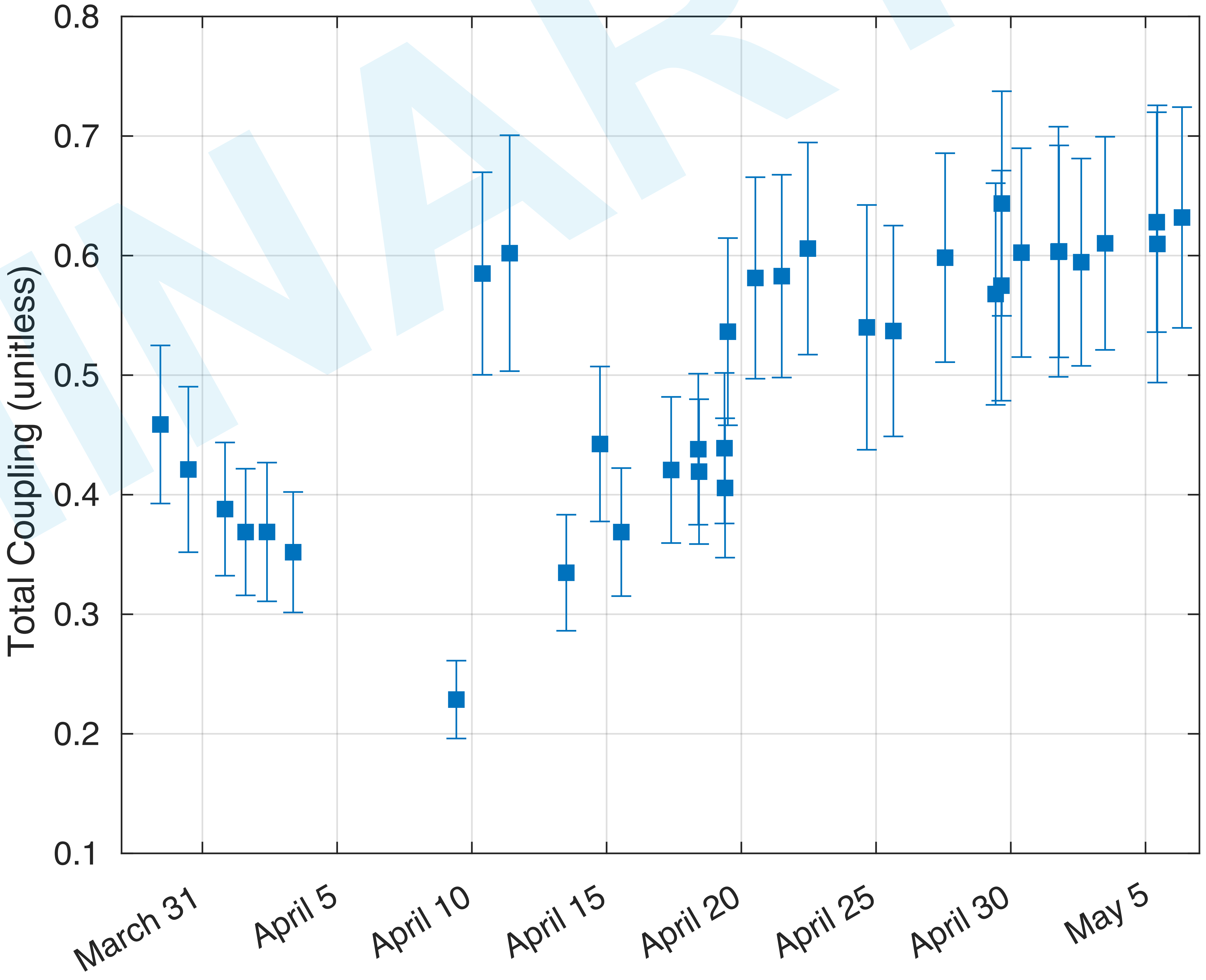


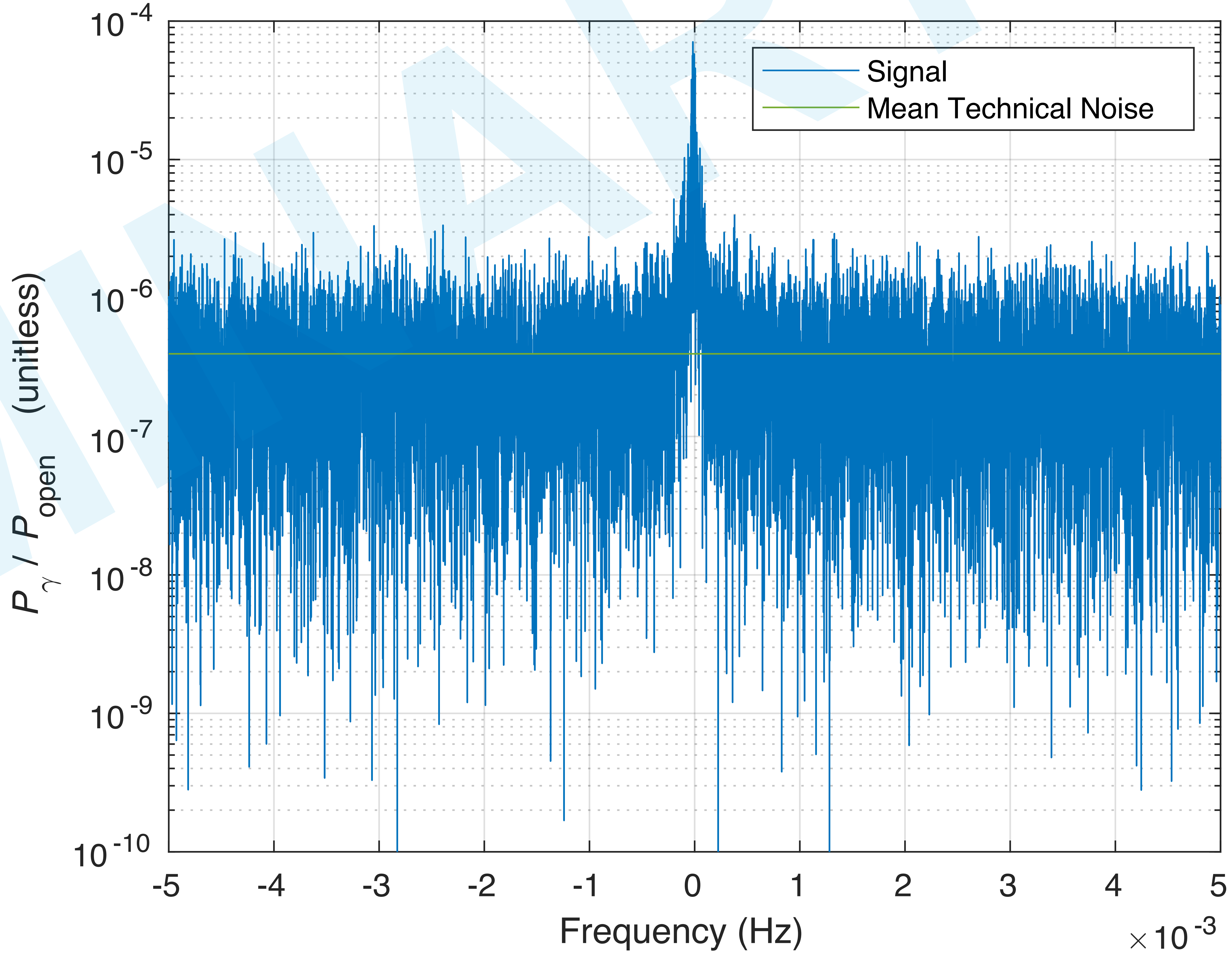
Results

First science campaign results

Taking a first look

Scalar Run from February 2 - 16

- Limited by stray light
  - For frequencies < 100 uHz away from signal bin
  - -5 mHz to 5 mHz shown here



$$g_{a\gamma\gamma} = \frac{2}{BL}\left(T_{\mathrm{COB}}\frac{P_\gamma}{P_{\mathrm{open}}}\right)^{1/4} \qquad T_{\mathrm{COB}} \simeq 9 \times 10^{-23}$$

PRELIMINARY

First science campaign results

Taking a first look

Scalar Run from February 2 - 16

- Limited by stray light
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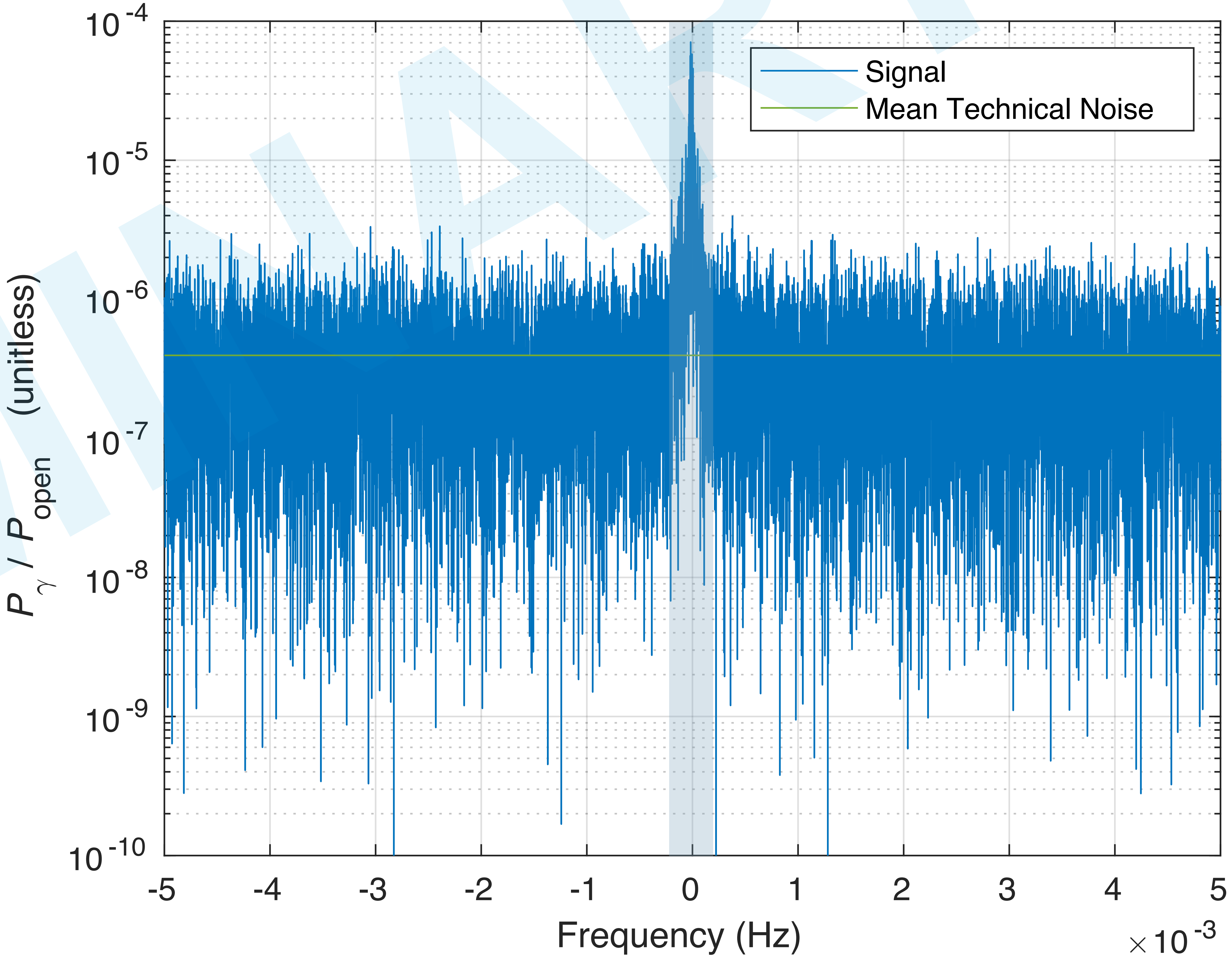


$$g_{a\gamma\gamma} = \frac{2}{BL}\left(T_{\mathrm{COB}}\frac{P_\gamma}{P_{\mathrm{open}}}\right)^{1/4}$$

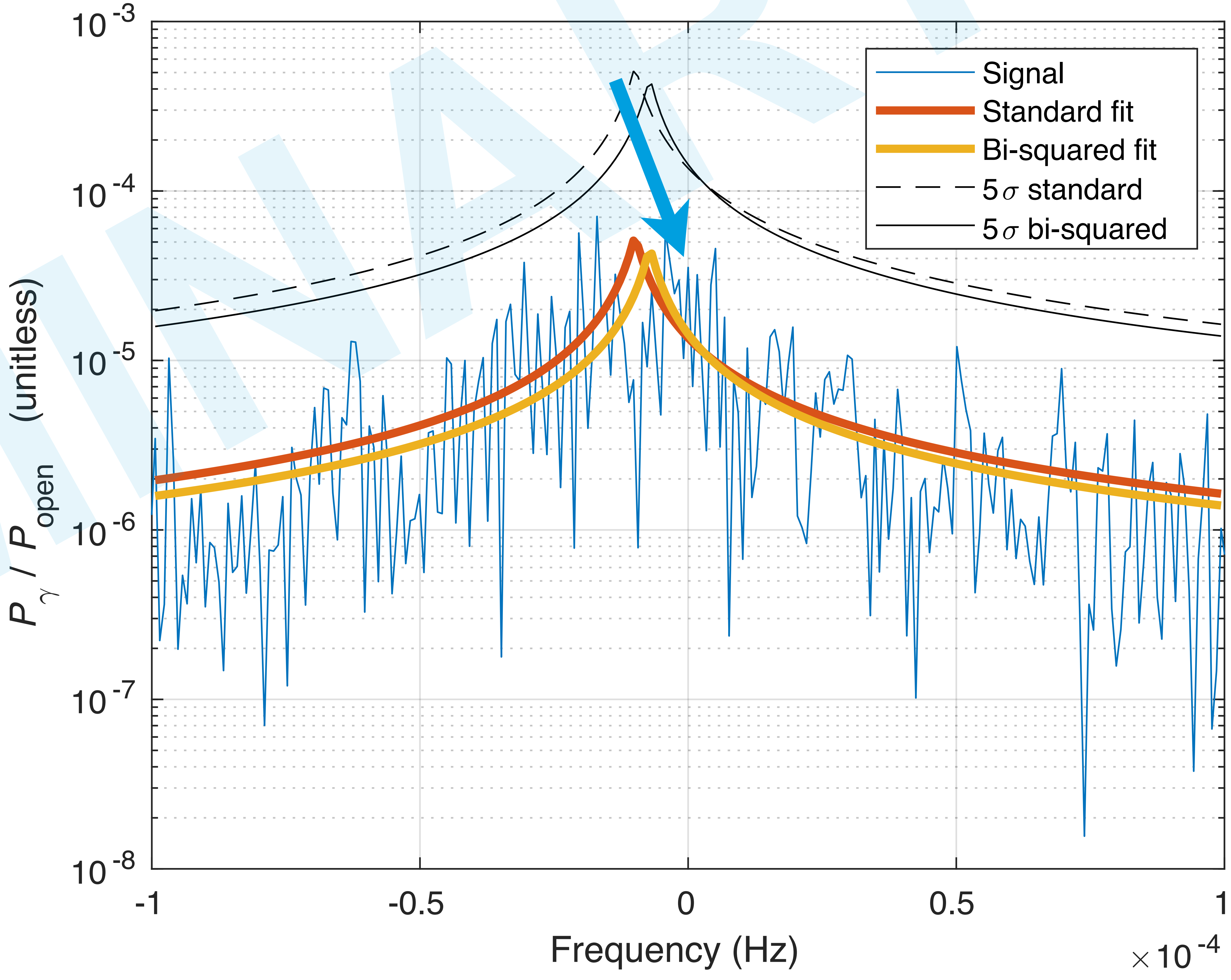
$$T_{\mathrm{COB}} \simeq 9 \times 10^{-23}$$

First science campaign results

Taking a first look

Scalar Run from February 2 - 16

- Limited by stray light
- Stray light model fit to data
  - Background: $P_\gamma / P_{\text{open}} = 1.4 \times 10^{-5}$
  - Signal: $P_\gamma / P_{\text{open}} = 3.5 \times 10^{-5}$



$$g_{a\gamma\gamma} = \frac{2}{BL}\left(T_{\text{COB}}\frac{P_\gamma}{P_{\text{open}}}\right)^{1/4}$$

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Taking a first look

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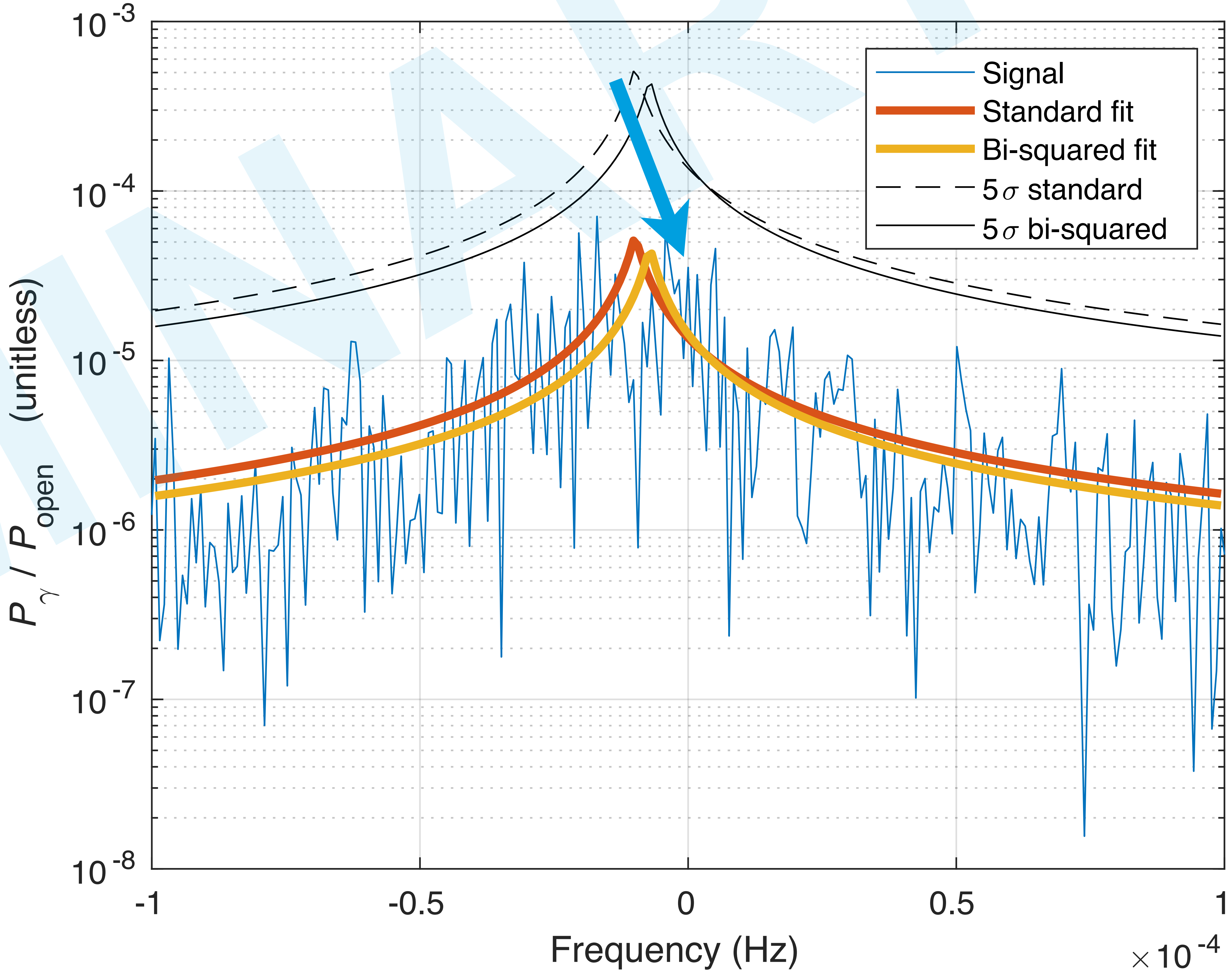
  - Background: $P_\gamma / P_{\text{open}} = 1.4 \times 10^{-5}$
  - Signal: $P_\gamma / P_{\text{open}} = 3.5 \times 10^{-5}$
- 95% C.L. exclusion limit:
  - $g_{a\gamma\gamma} \lesssim 1.5 \times 10^{-9}\,\text{GeV}^{-1}$



$$g_{a\gamma\gamma} = \frac{2}{BL}\left(T_{\text{COB}}\frac{P_\gamma}{P_{\text{open}}}\right)^{1/4} \qquad T_{\text{COB}} \simeq 9 \times 10^{-23}$$

First science campaign results

Taking a first look

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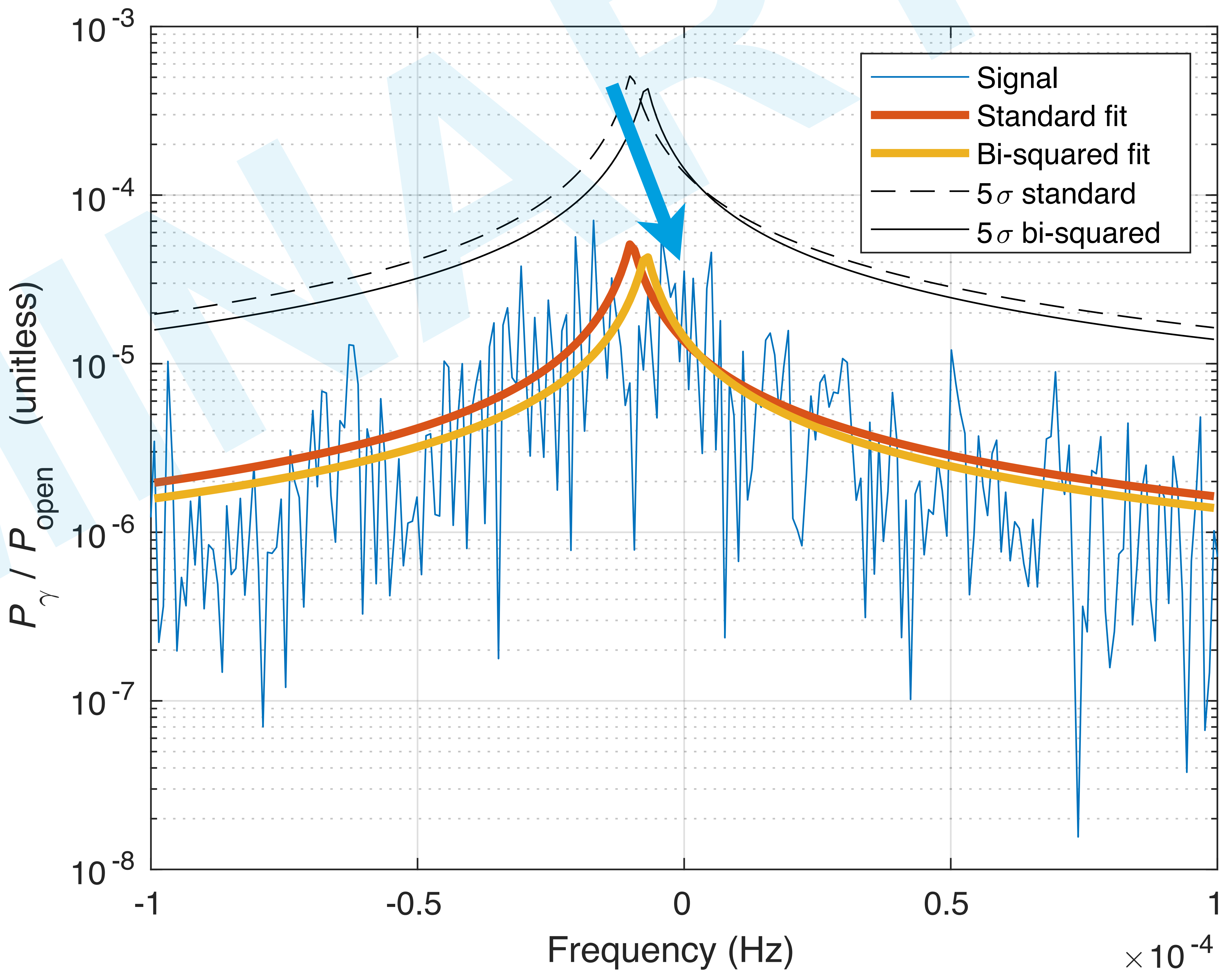
  - Background: $P_\gamma / P_{\text{open}} = 1.4 \times 10^{-5}$
  - Signal: $P_\gamma / P_{\text{open}} = 3.5 \times 10^{-5}$
- 95% C.L. exclusion limit:
  - $g_{a\gamma\gamma} \lesssim 1.5 \times 10^{-9}\,\text{GeV}^{-1}$
- (Scalar signal not expected due to current exclusion limits)

$$g_{a\gamma\gamma} = \frac{2}{BL}\left(T_{\text{COB}}\frac{P_\gamma}{P_{\text{open}}}\right)^{1/4} \qquad T_{\text{COB}} \simeq 9 \times 10^{-23}$$

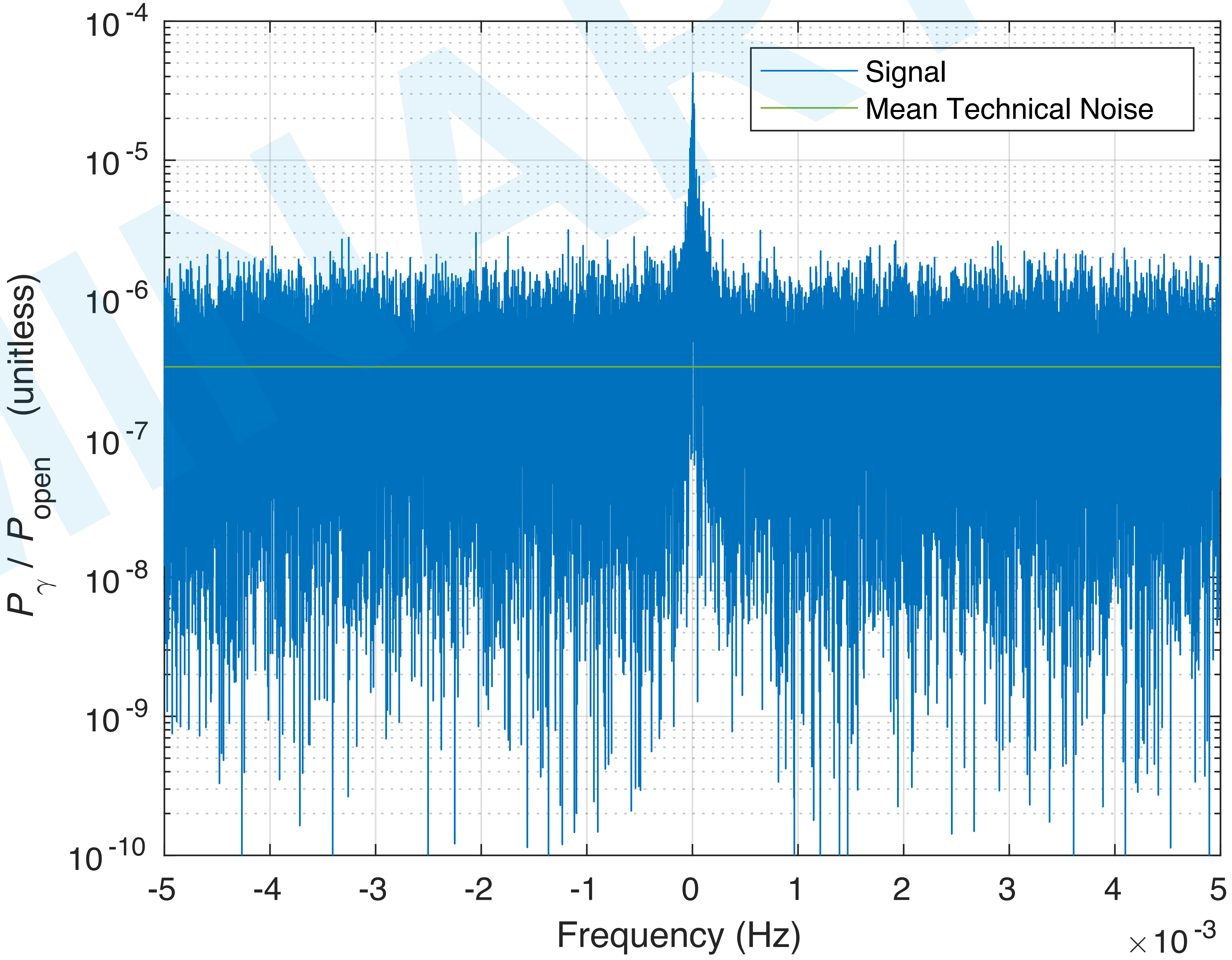


First science campaign results

Taking a first look

Pseudo Scalar Run from March 30 - May 6

- Limited by stray light



$$g_{a\gamma\gamma} = \frac{2}{BL}\left(T_{\mathrm{COB}}\frac{P_\gamma}{P_{\mathrm{open}}}\right)^{1/4}$$

$$T_{\mathrm{COB}} \simeq 9 \times 10^{-23}$$

First science campaign results

Taking a first look

Pseudo Scalar Run from March 30 - May 6

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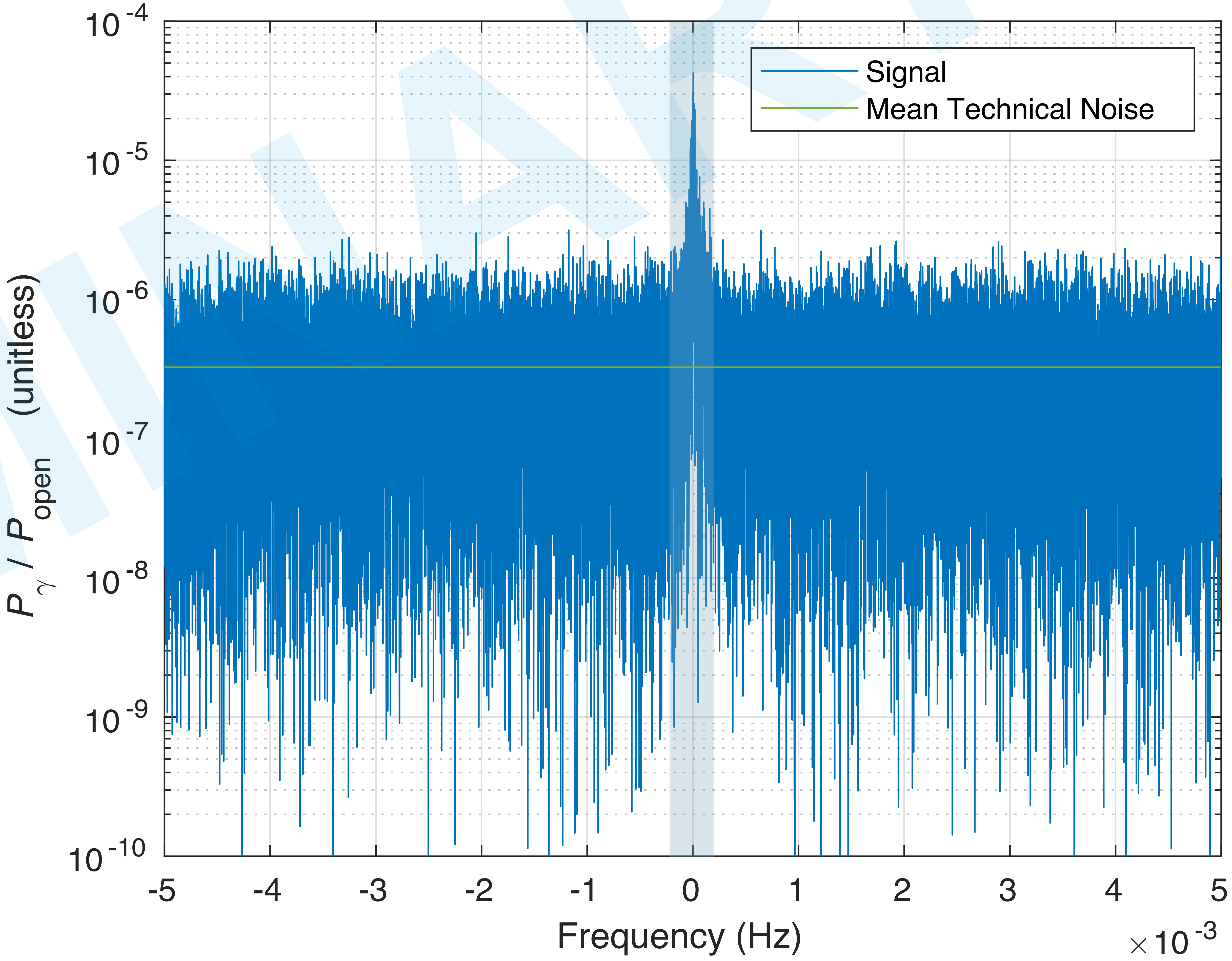

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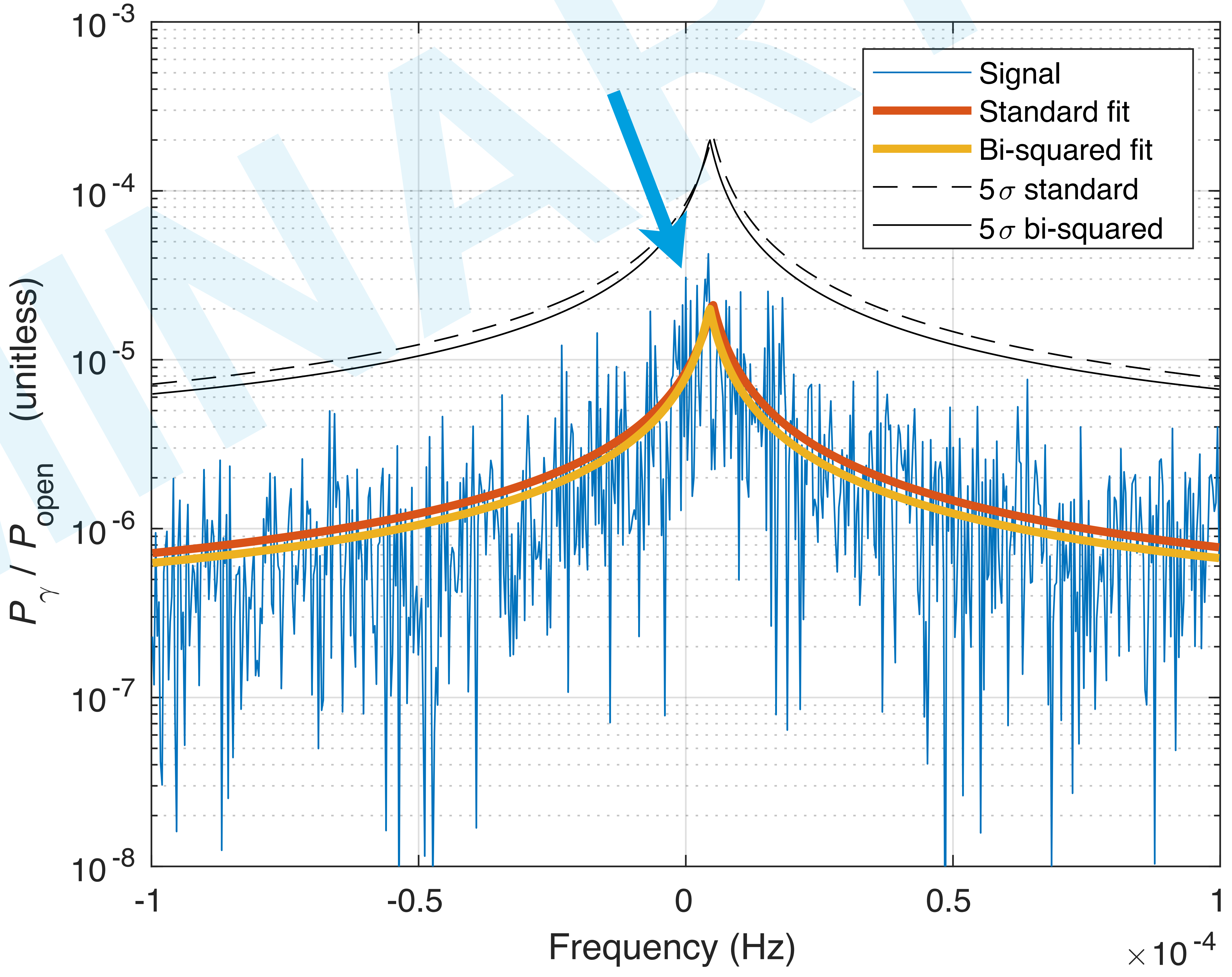
First science campaign results

Taking a first look

Pseudo Scalar Run from March 30 - May 6

- Limited by stray light
- Stray light model fit to data
  - Background: $P_\gamma / P_{\mathrm{open}} = 0.8 \times 10^{-5}$
  - Signal: $P_\gamma / P_{\mathrm{open}} = 3.1 \times 10^{-5}$



$$g_{a\gamma\gamma} = \frac{2}{BL}\left(T_{\mathrm{COB}}\frac{P_\gamma}{P_{\mathrm{open}}}\right)^{1/4}$$

$$T_{\mathrm{COB}} \simeq 9 \times 10^{-23}$$

PRELIMINARY

First science campaign results

Taking a first look

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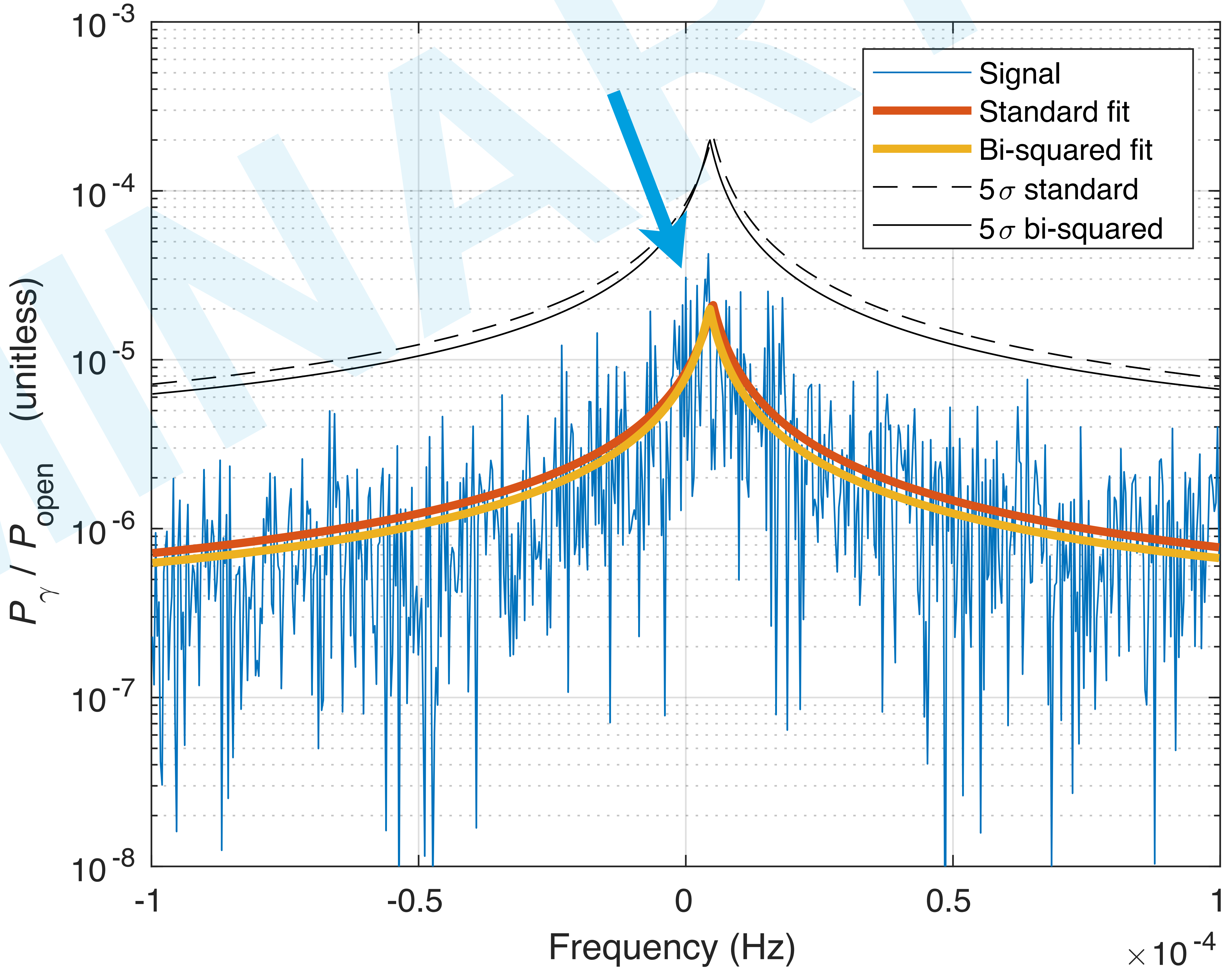
- Limited by stray light
- Stray light model fit to data
  - Background: $P_\gamma / P_{\text{open}} = 0.8 \times 10^{-5}$
  - Signal: $P_\gamma / P_{\text{open}} = 3.1 \times 10^{-5}$
- 95% C.L. exclusion limit:
  - $g_{a\gamma\gamma} \lesssim 1.3 \times 10^{-9}\,\text{GeV}^{-1}$

$$g_{a\gamma\gamma} = \frac{2}{BL}\left(T_{\text{COB}}\frac{P_\gamma}{P_{\text{open}}}\right)^{1/4}$$

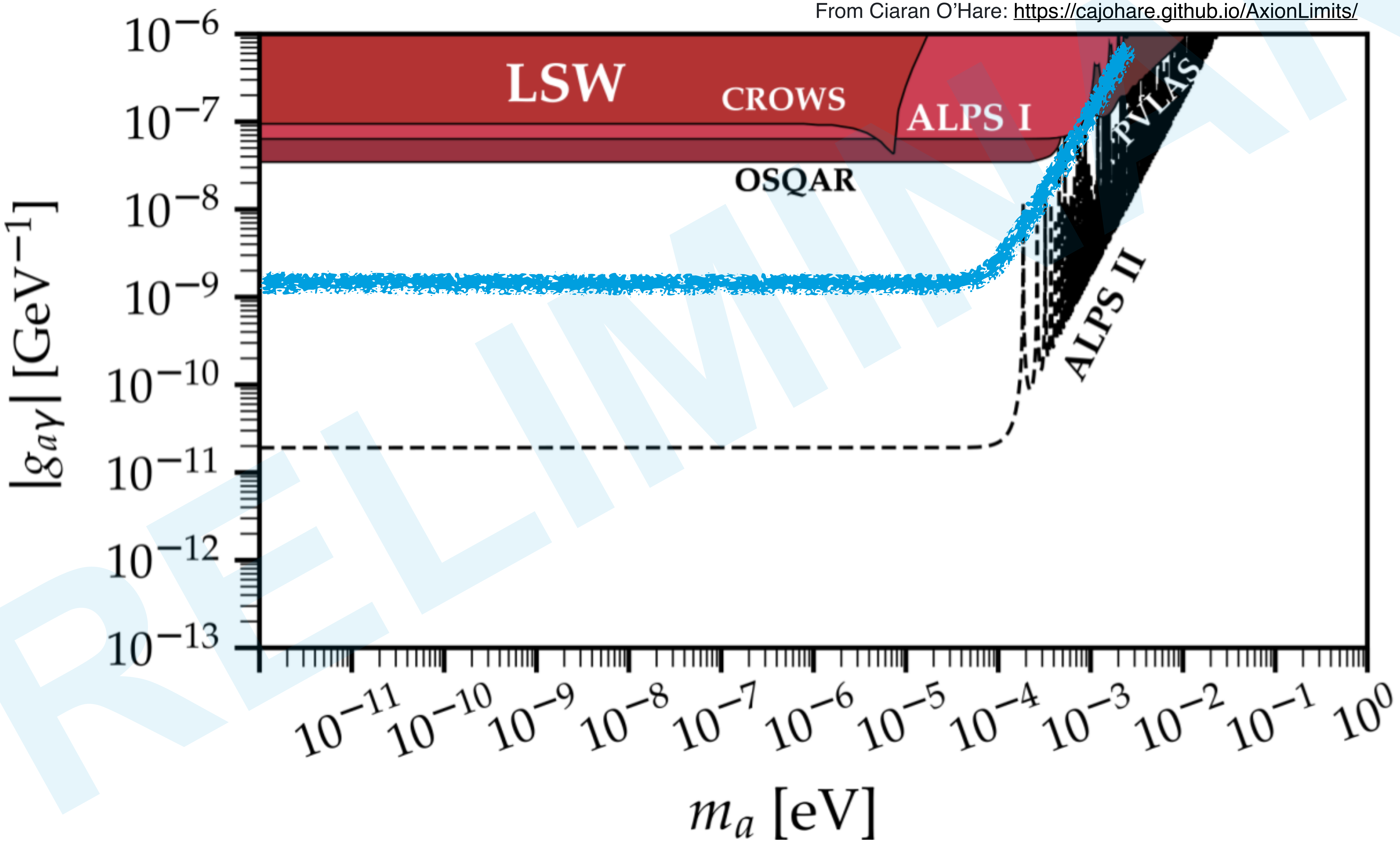
$$T_{\text{COB}} \simeq 9 \times 10^{-23}$$



Preliminary exclusion limits

A factor of ~50 improvement from ALPS I

From Ciaran O'Hare: https://cajohare.github.io/AxionLimits/



Plans

Next steps

Upgrading the system to increase the sensitivity

Looking forward

- Current work: Publish analysis and results from first science campaign
- Work to be done in the upcoming years:
  - Commissioning/science run with production cavity (target: 2000x beyond ALPS I limit)
  - Commissioning/science run with upgraded cavity optics (target: $g_{a\gamma\gamma} > 2\times10^{-11}$ GeV^{-1})
- Future work:
  - Commissioning/science run with optical system for TES detector
  - Vacuum magnetic birefringence search
  - High frequency gravitational wave search
  - Axion dark matter search