Towards the first axion search results of ALPS II

Li-Wei Wei
Deutsche Elektronen-Synchrotron (DESY)
Hamburg, Germany

XVIII International Conference on Topics in Astroparticle and Underground Physics 2023

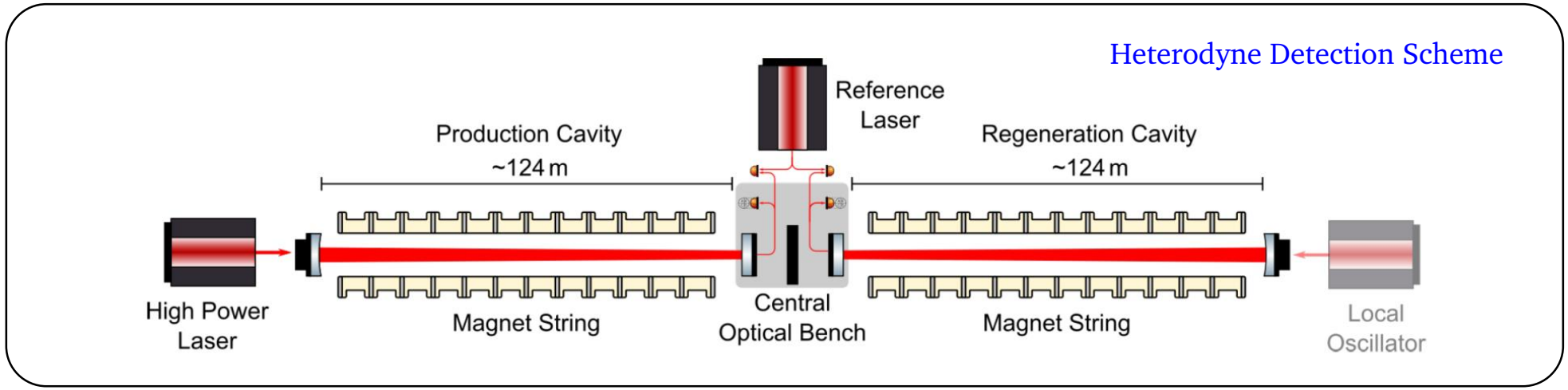
MAX PLANCK INSTITUTE FOR GRAVITATIONAL PHYSICS (Albert Einstein Institute)

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Any **L**ight **P**article **S**earch **II**

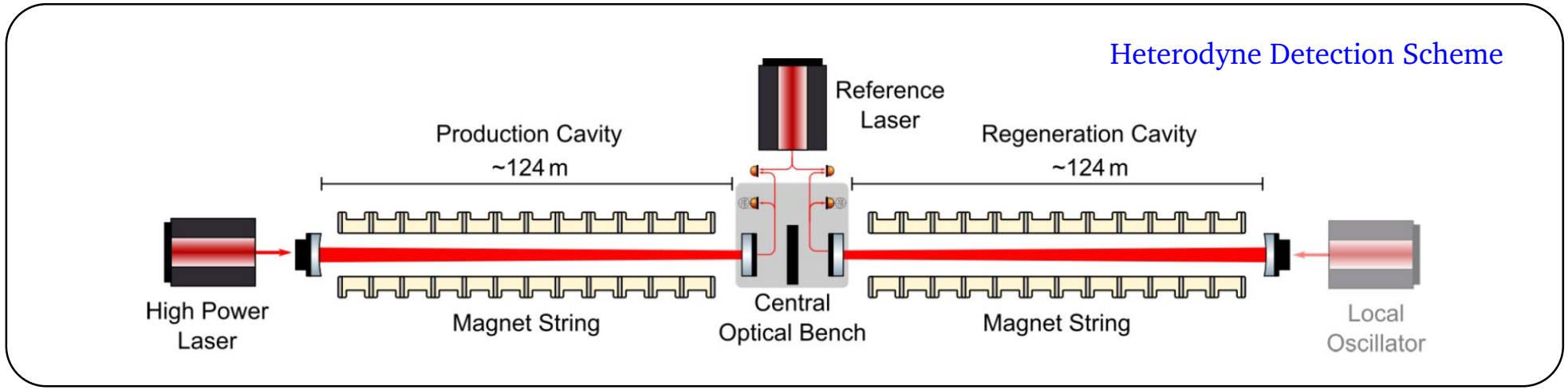
Any Light Particle Search II

Dual optical cavity, resonantly enhanced Light-Shining-through-a-Wall experiment

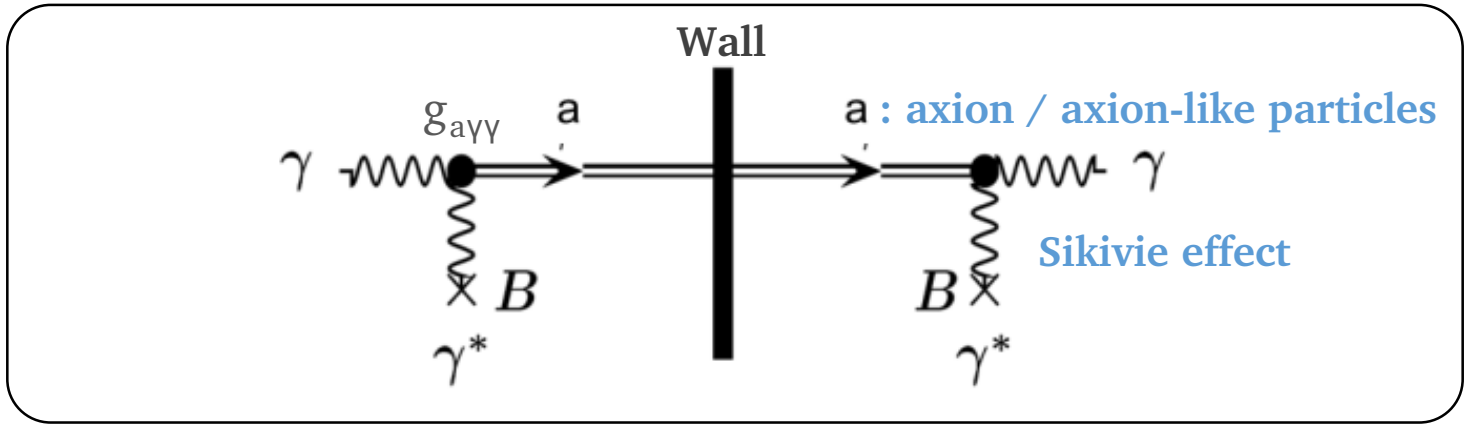


Any Light Particle Search II

Dual optical cavity, resonantly enhanced Light-Shining-through-a-Wall experiment



Search for **axions** / **axion-like particles** via their coupling to **photons** ($g_{a\gamma\gamma}$)



$\gamma \rightarrow a \rightarrow \gamma$

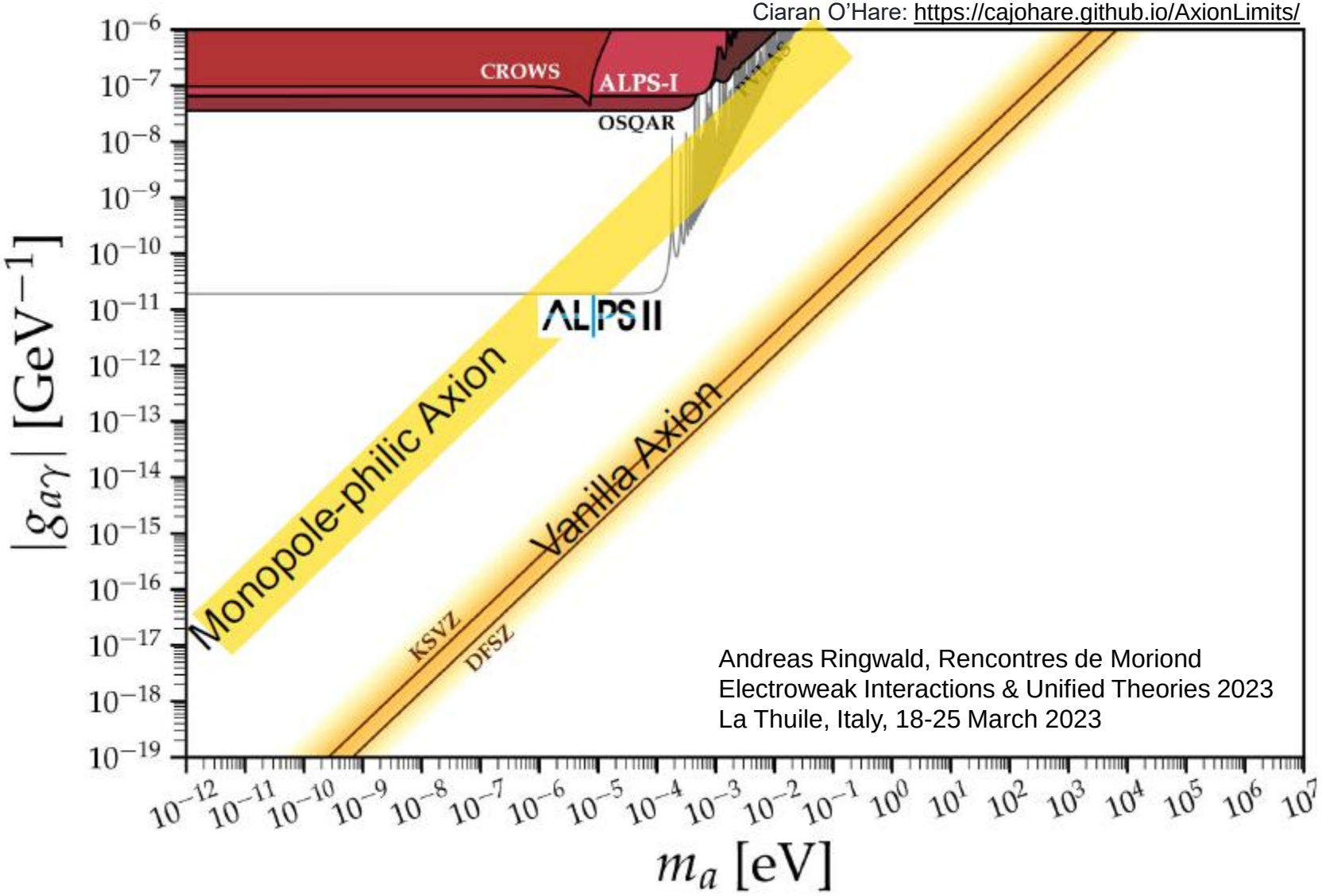
$\gamma \rightarrow ? \rightarrow \gamma$

… any light particle

Photon energy at 1064 nm wavelength ~ 1.2 eV

ALPS II target sensitivity

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



ALPS II target sensitivity

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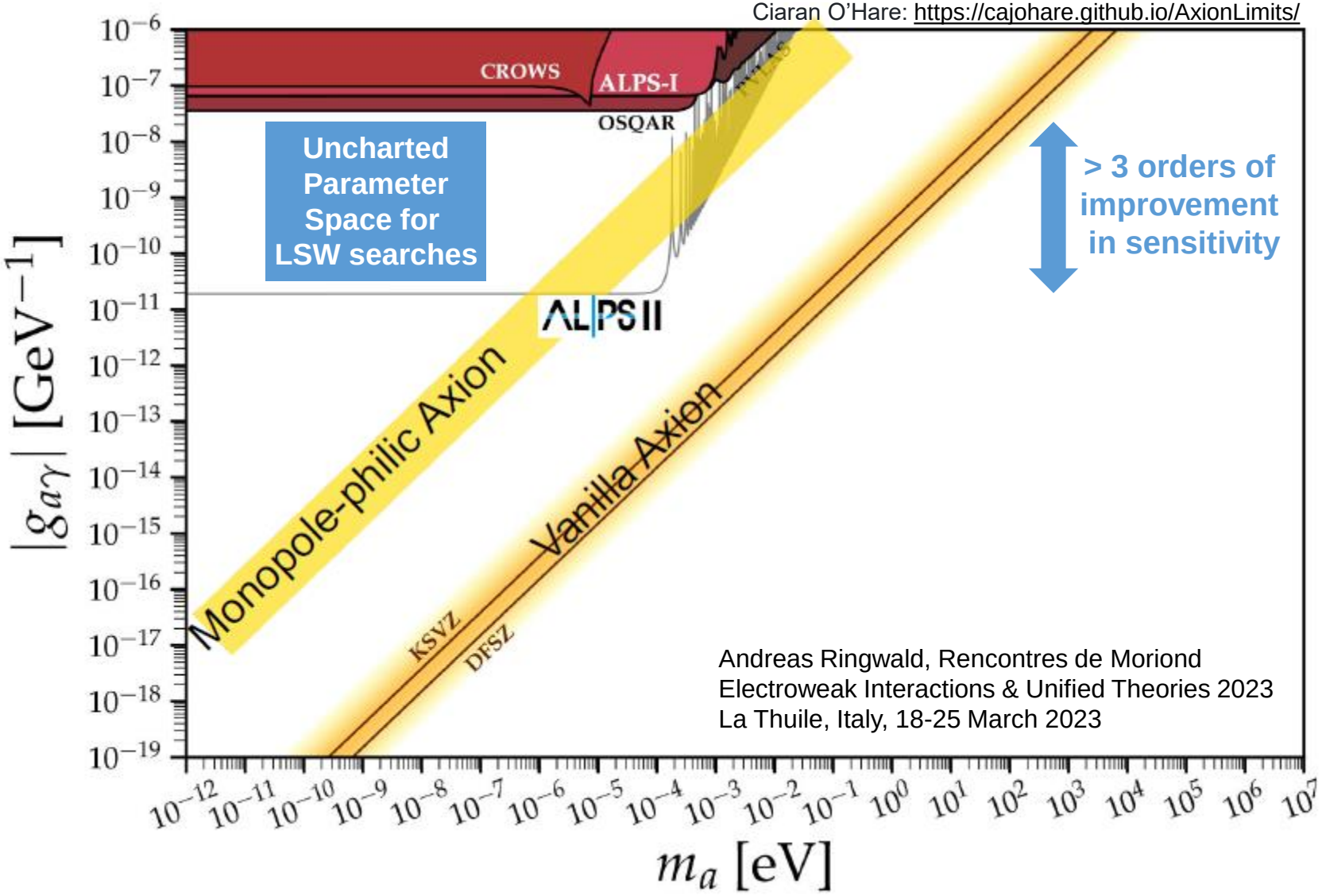
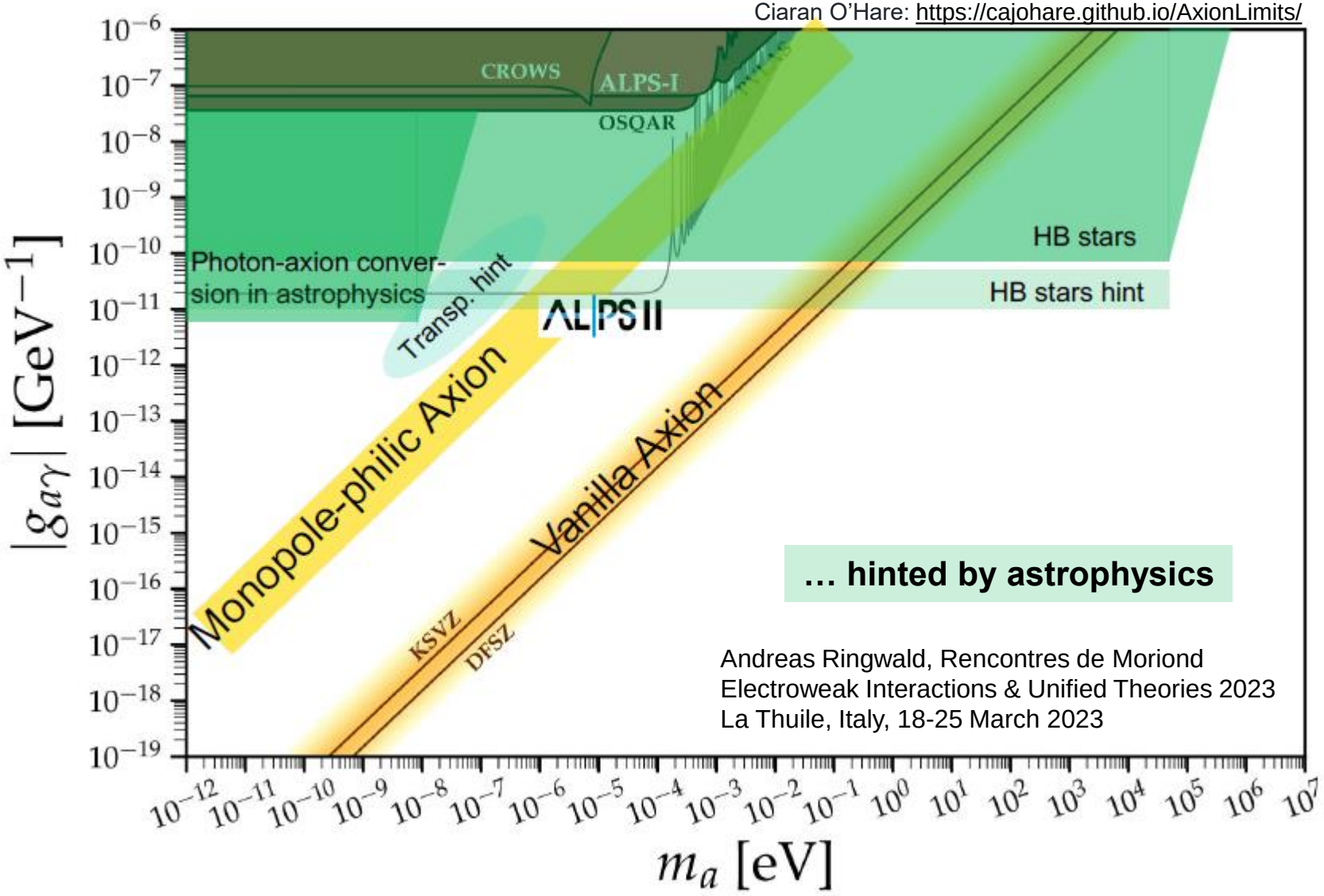


Andreas Ringwald, Rencontres de Moriond
Electroweak Interactions & Unified Theories 2023
La Thuile, Italy, 18-25 March 2023

ALPS II has discovery potential

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

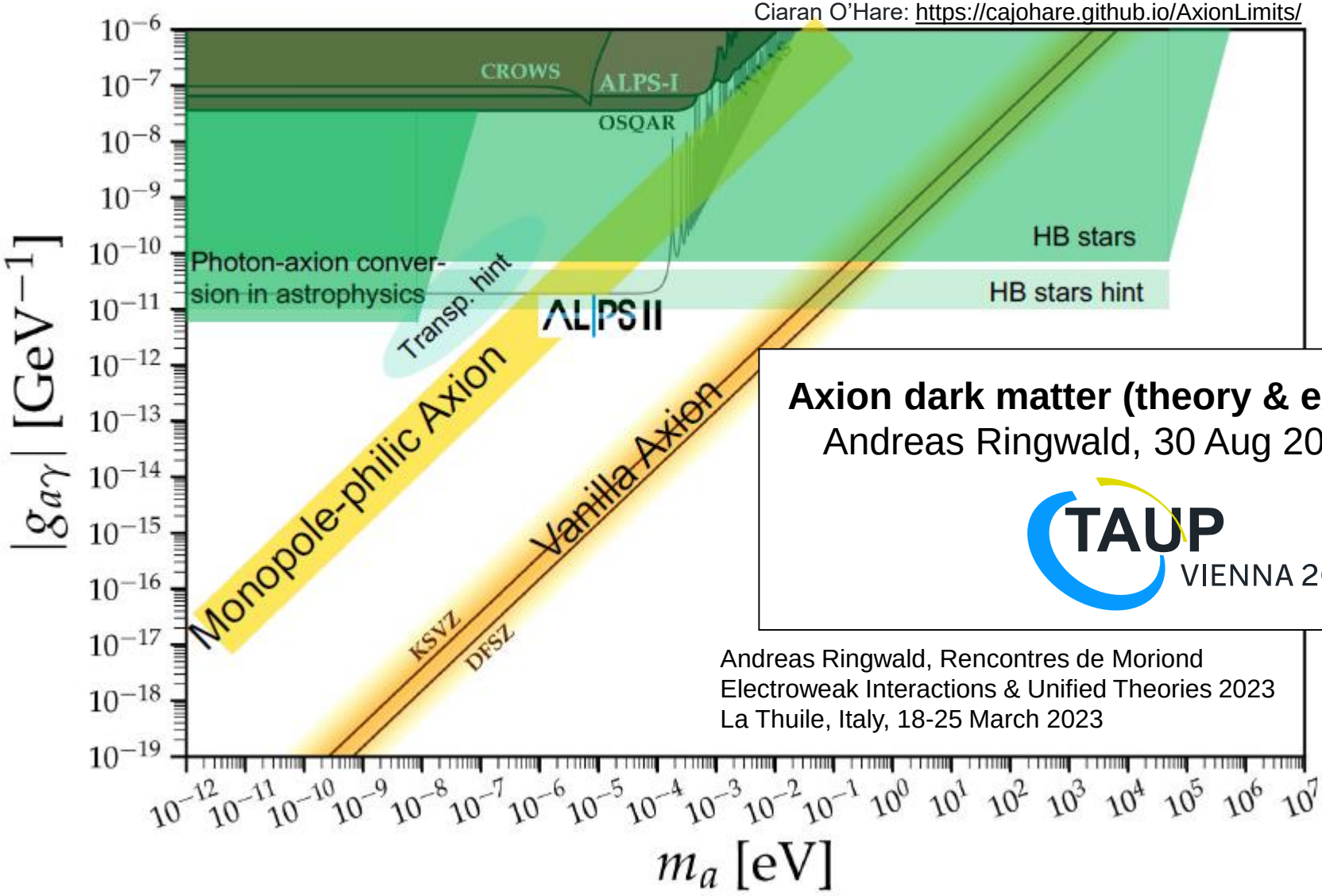


… hinted by astrophysics

Andreas Ringwald, Rencontres de Moriond
Electroweak Interactions & Unified Theories 2023
La Thuile, Italy, 18-25 March 2023

ALPS II has discovery potential

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



Axion dark matter (theory & experiment)
Andreas Ringwald, 30 Aug 2023, 11:00

TAUP VIENNA 2023

Andreas Ringwald, Rencontres de Moriond
Electroweak Interactions & Unified Theories 2023
La Thuile, Italy, 18-25 March 2023

ALPS II is one of the on-site axion search experiments at DESY Hamburg

ALPS II is one of the on-site axion search experiments at DESY Hamburg

with collaboration partners from Denmark, Germany, the UK and the US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PETRA


• HAMBURG
VIENNA •
TAUP
VIENNA 2023


ALPS
HERA North
HERA
(Hadron-Electron Ring Accelerator)
PETRA


DESY.
• HAMBURG
VIENNA •
TAUP
VIENNA 2023
Copenhagen
Gdansk
BRANDENBURG
BERLIN
SAXONY-ANHALT
POLAND
Warsaw
Łódź
GERMANY
THURINGIA
SAXONY
Prague
Krakow
CZECHIA
Nuremberg
BAVARIA
SLOVAKIA
Munich
Bratislava
AUSTRIA
TRENTINO-ALTO ADIGE/SÜDTIROL
FRIULI VENEZIA GIULIA
Ljubljana
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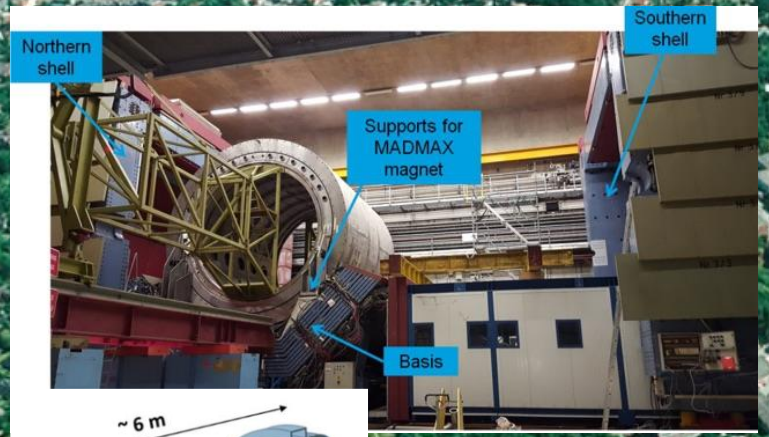
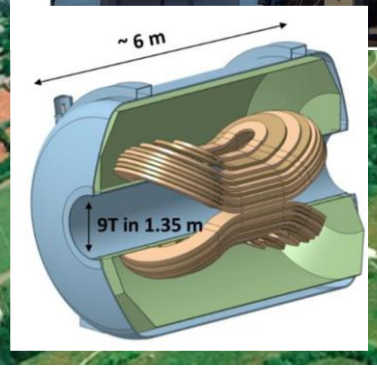
CROATIA
VENETO
Venice
EMILIA-ROMAGNA
Belgrade
BOSNIA AND HERZEGOVINA
SERBIA

ALPS

HERA North

MADMAX





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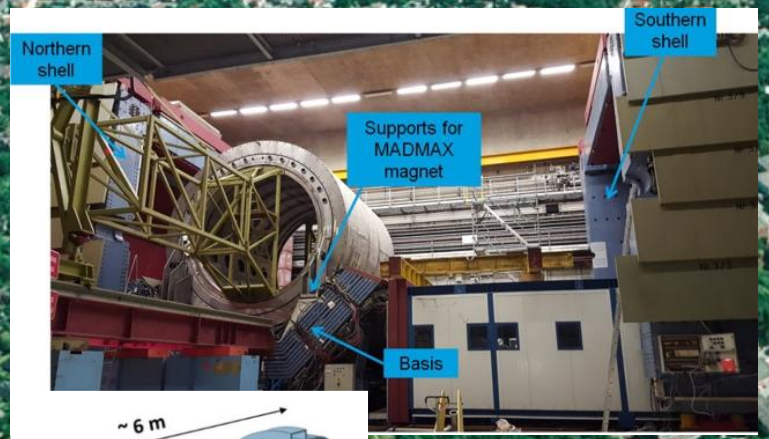
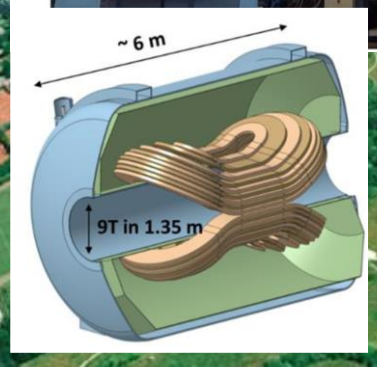
TAUP VIENNA 2023

ALPS

HERA North

MADMAX





HERA

PETRA

How to detect a QCD axion with MADMAX: Introduction and first physics results

Juan PA Maldonado, 31 Aug 2023, 17:30

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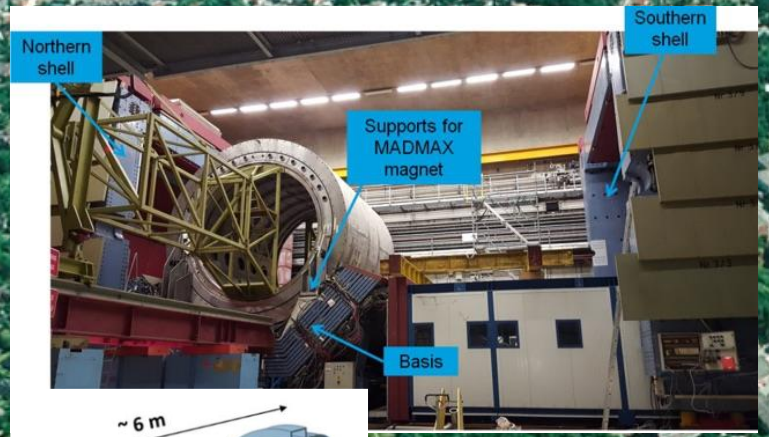
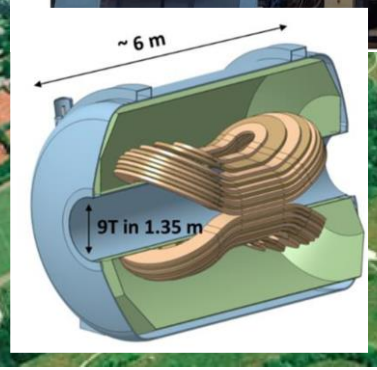
ALPS

HERA North

MADMAX





HERA

HERA South

(Baby) IAXO

PETRA

DESY.

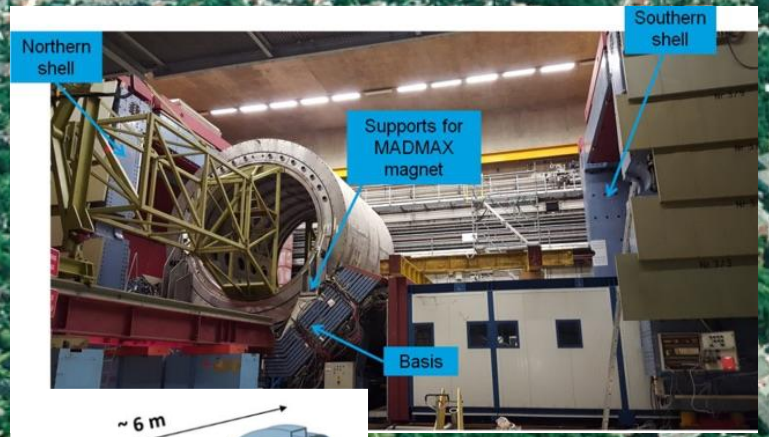
Searches of Axions/ALPS with (Baby)IAXO
JuanAn García, 28 Aug 2023, 16:45

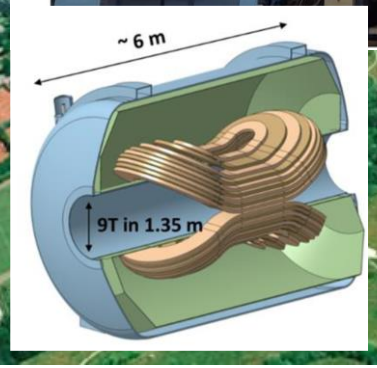
TAUP VIENNA 2023

ALPS

HERA North

MADMAX



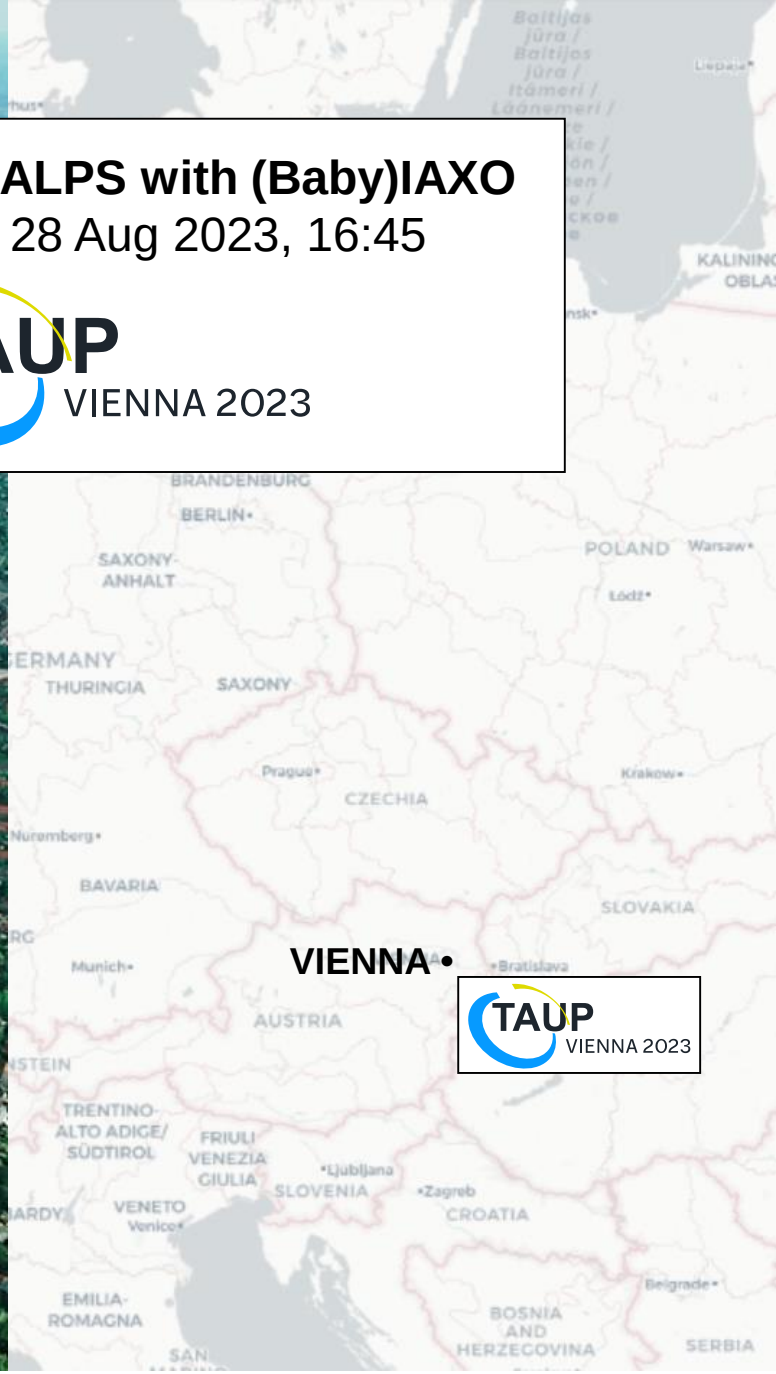


HERA South

(Baby) IAXO

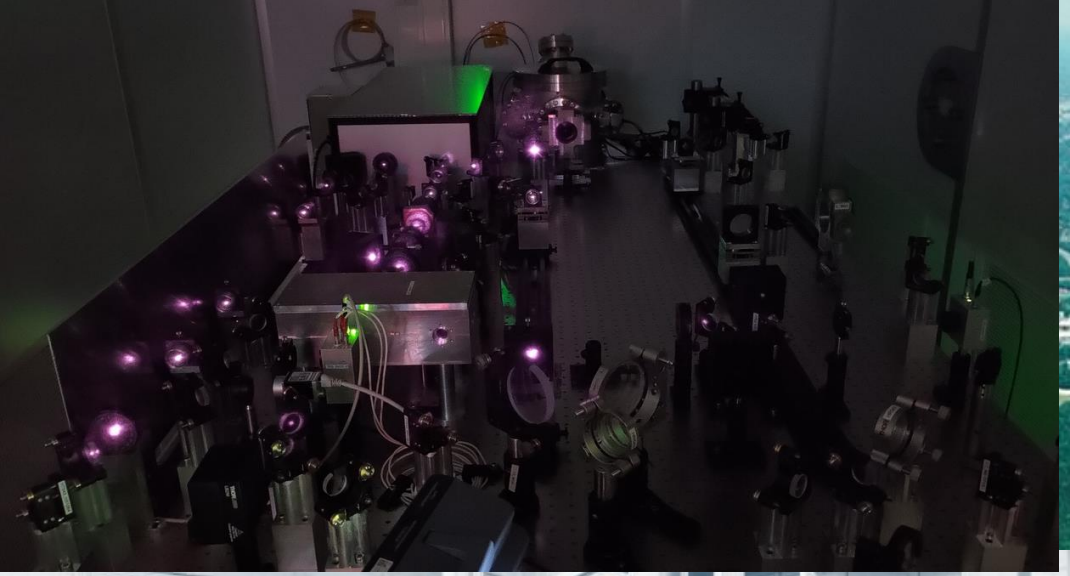
HERA

PETRA



ALPS

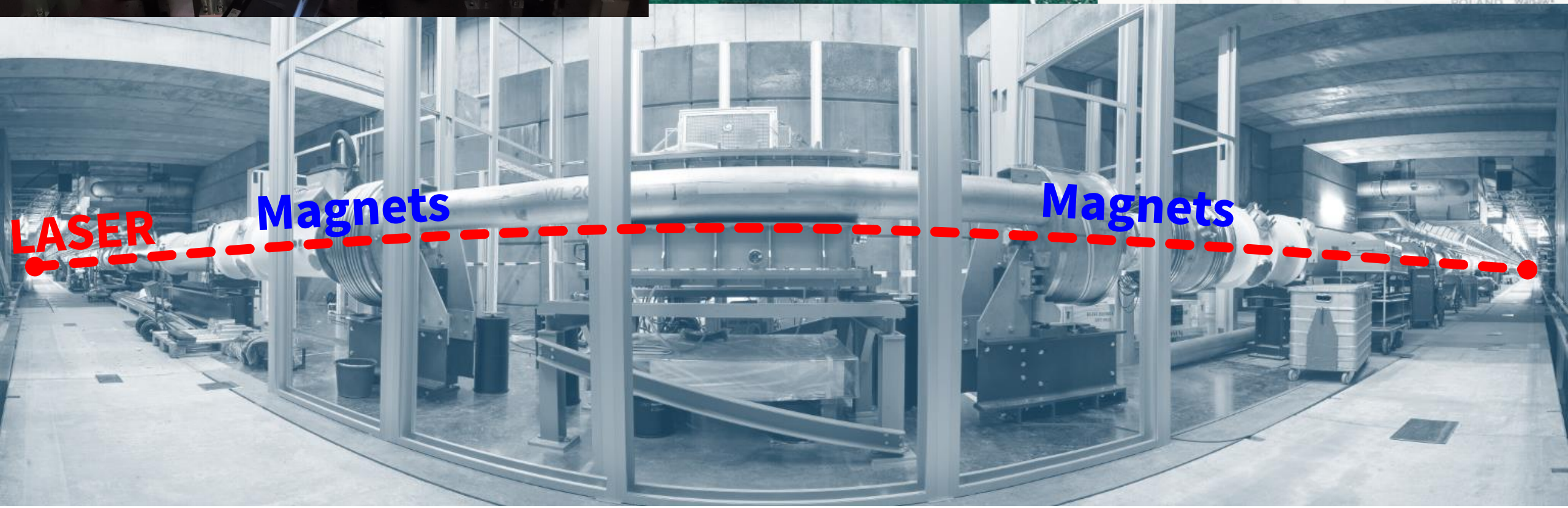
HERA North

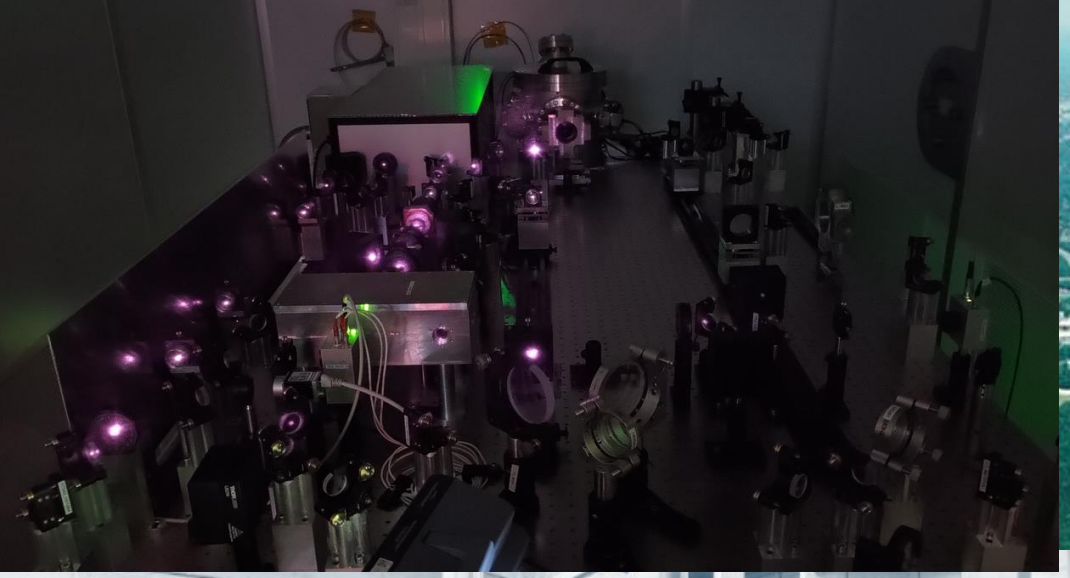


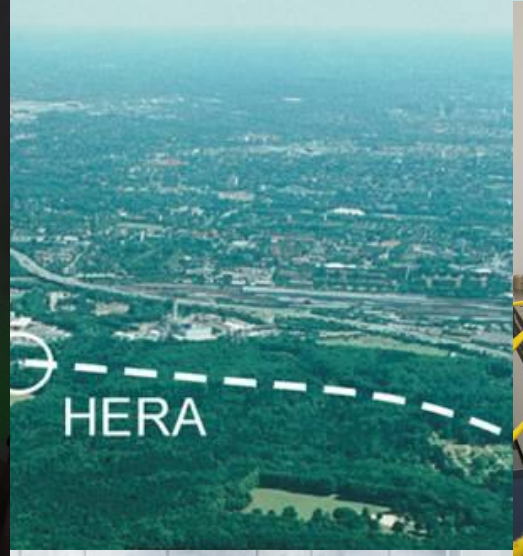

HERA

DESY.

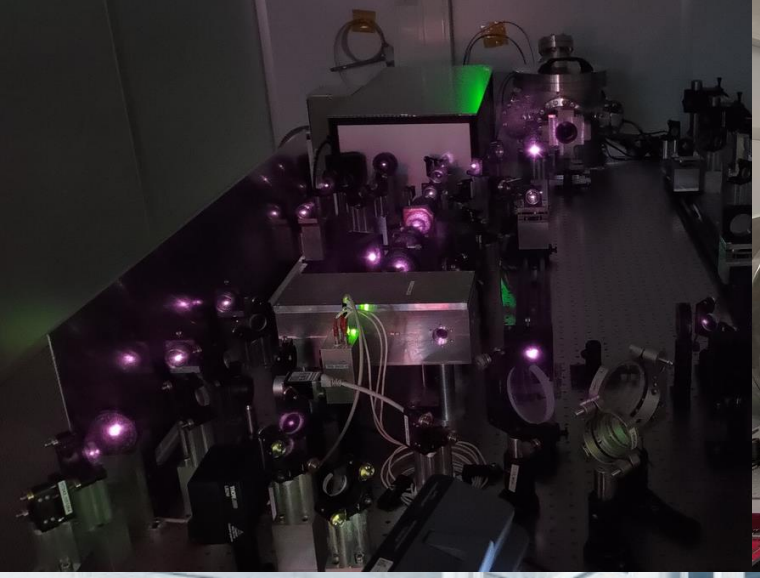

• HAMBURG
MECKLENBURG-
BRANDENBURG
BERLIN
Copenhagen
Gdansk

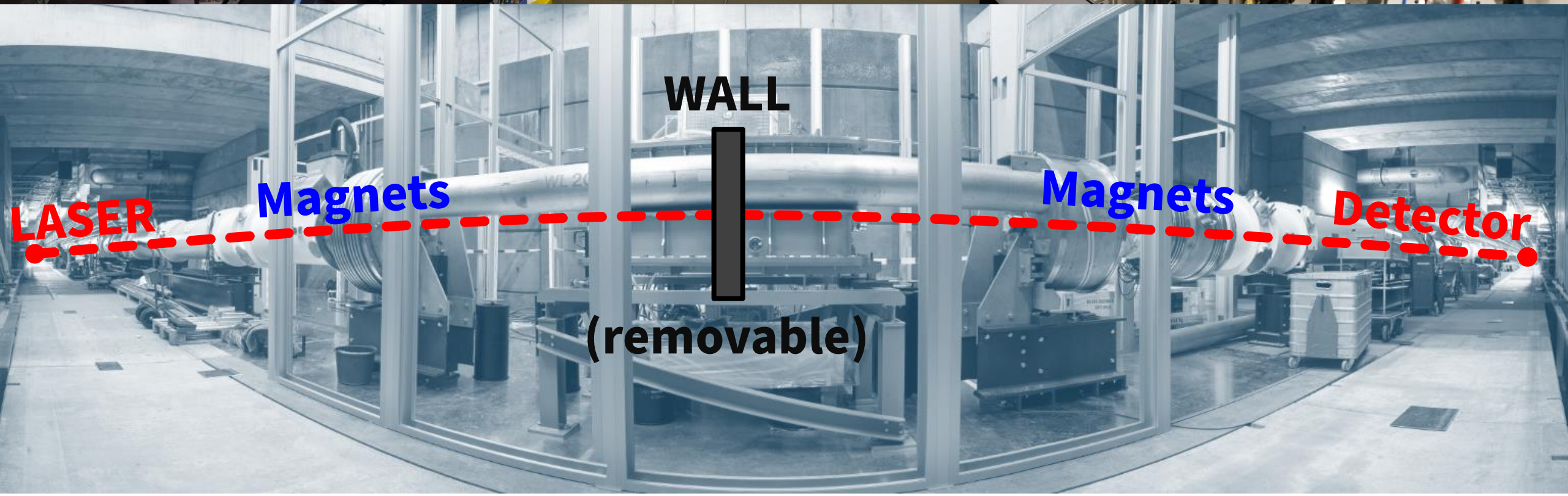

LASER
Magnets
Magnets

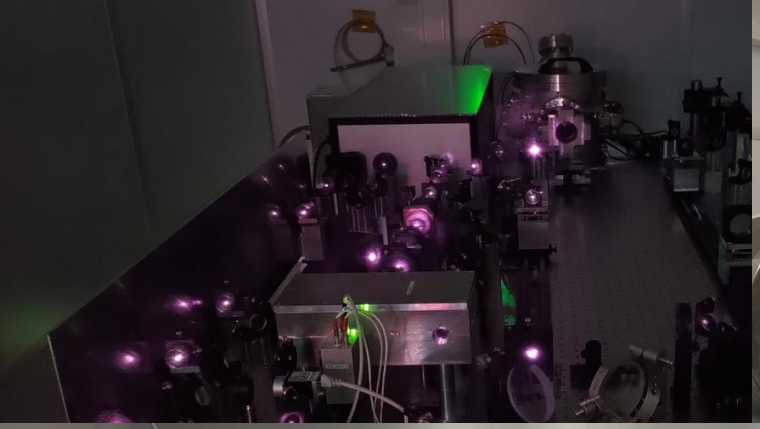


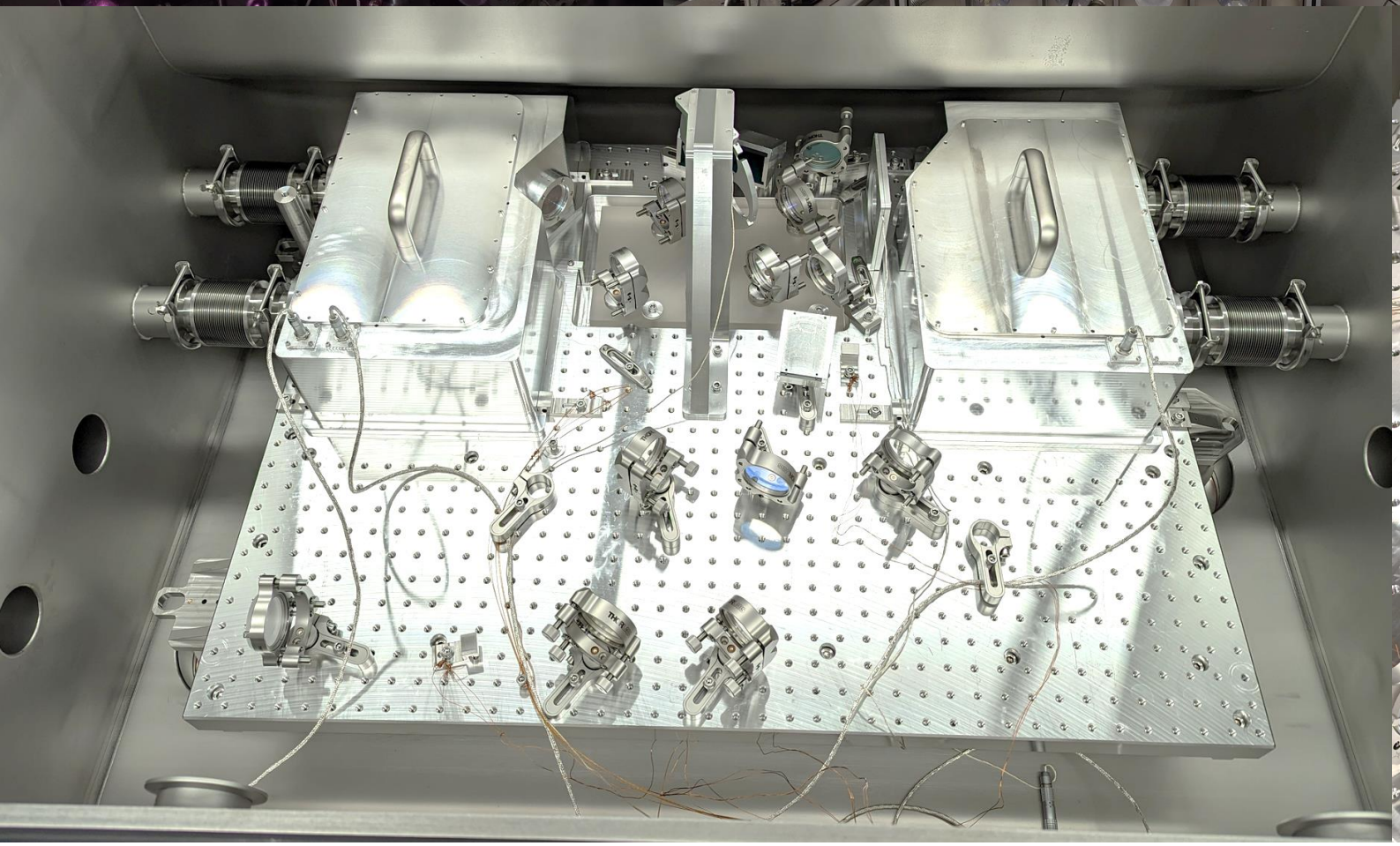
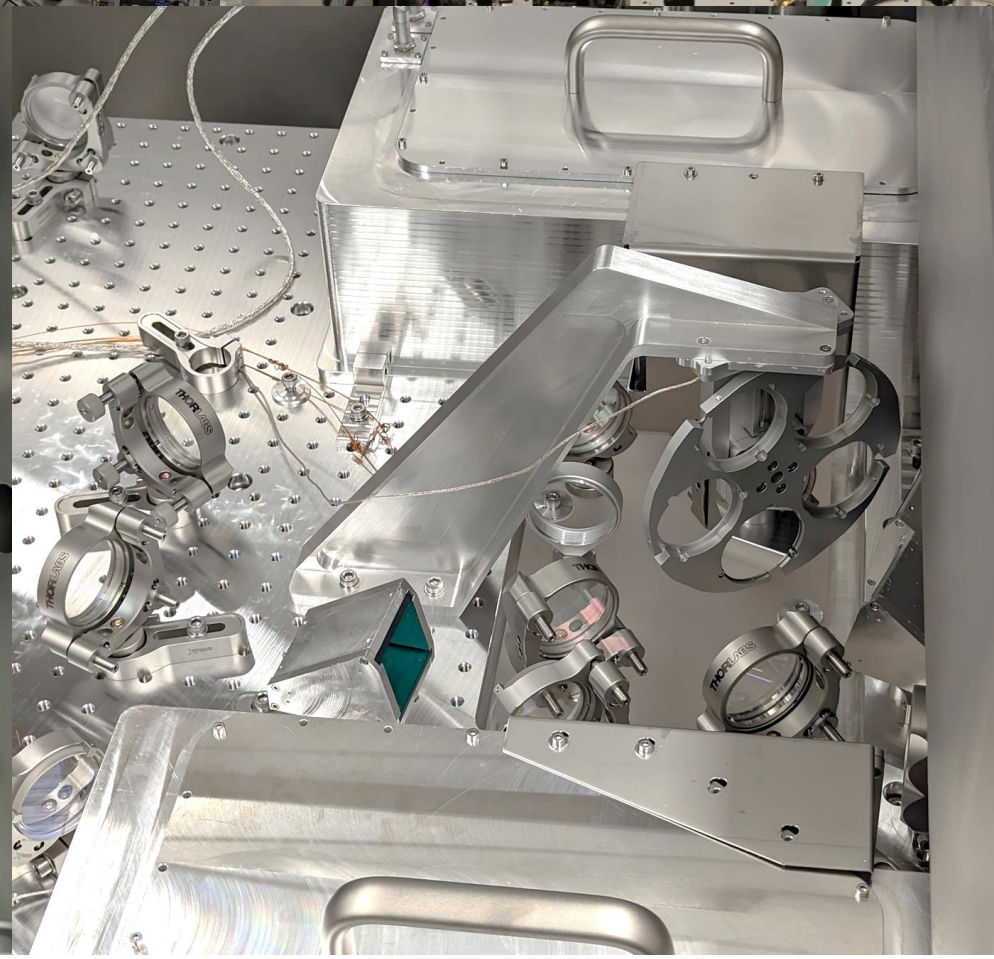


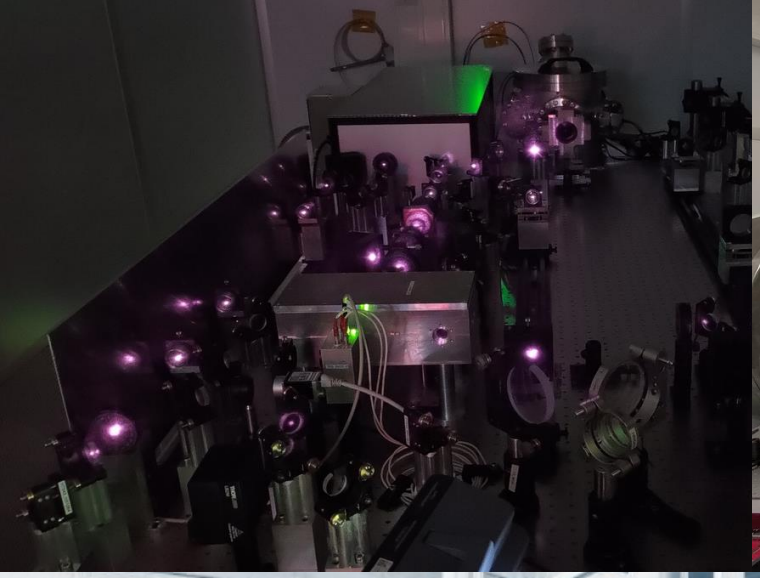
LASER Magnets Magnets Detector

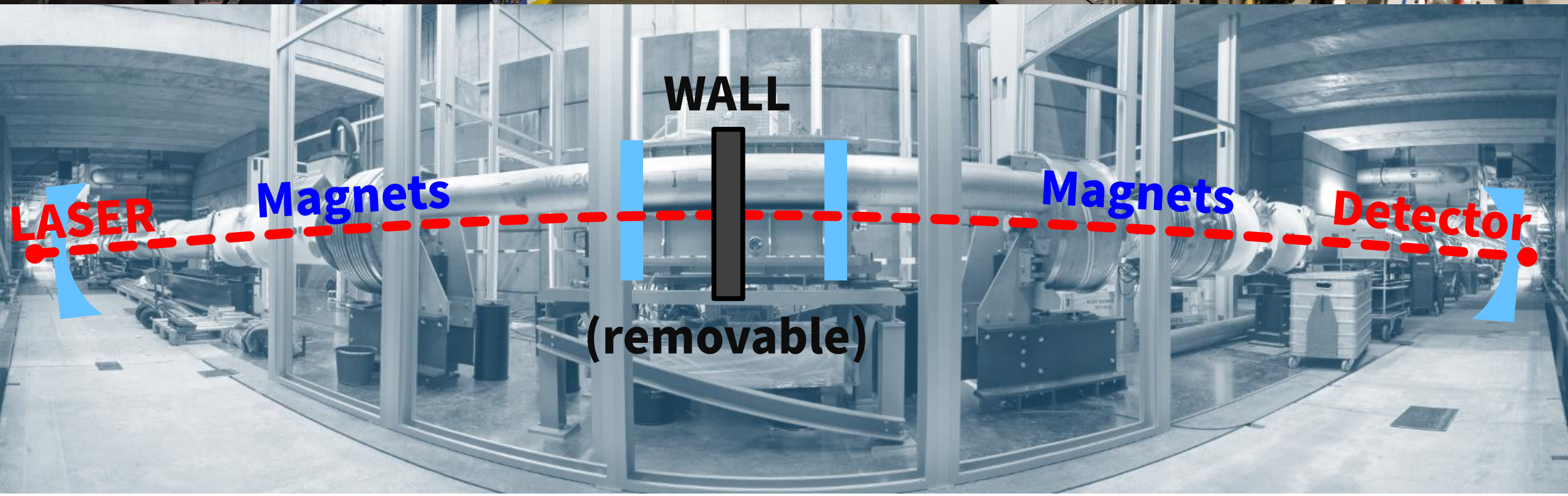


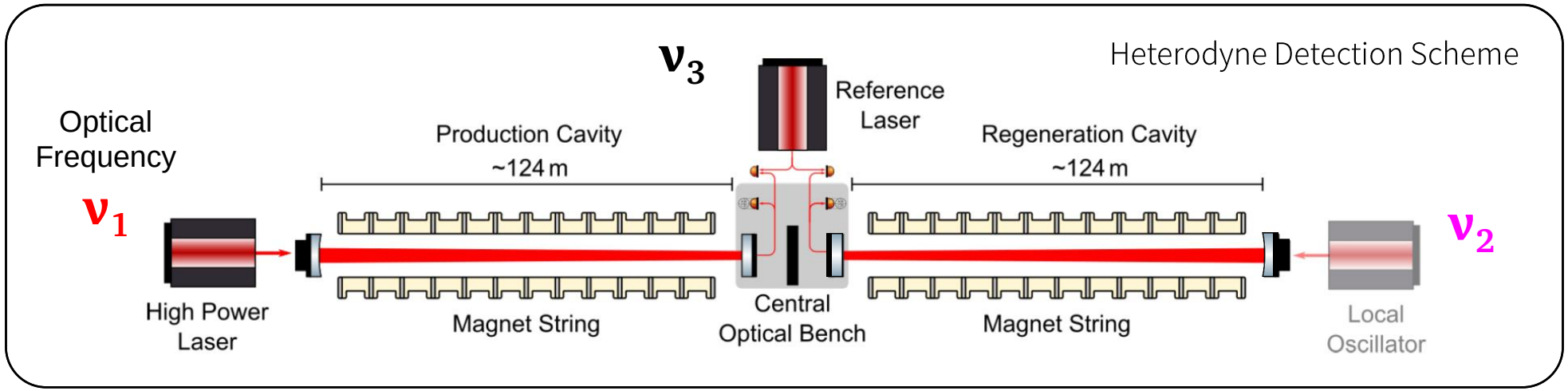

WALL
LASER
Magnets
Magnets
Detector
(removable)

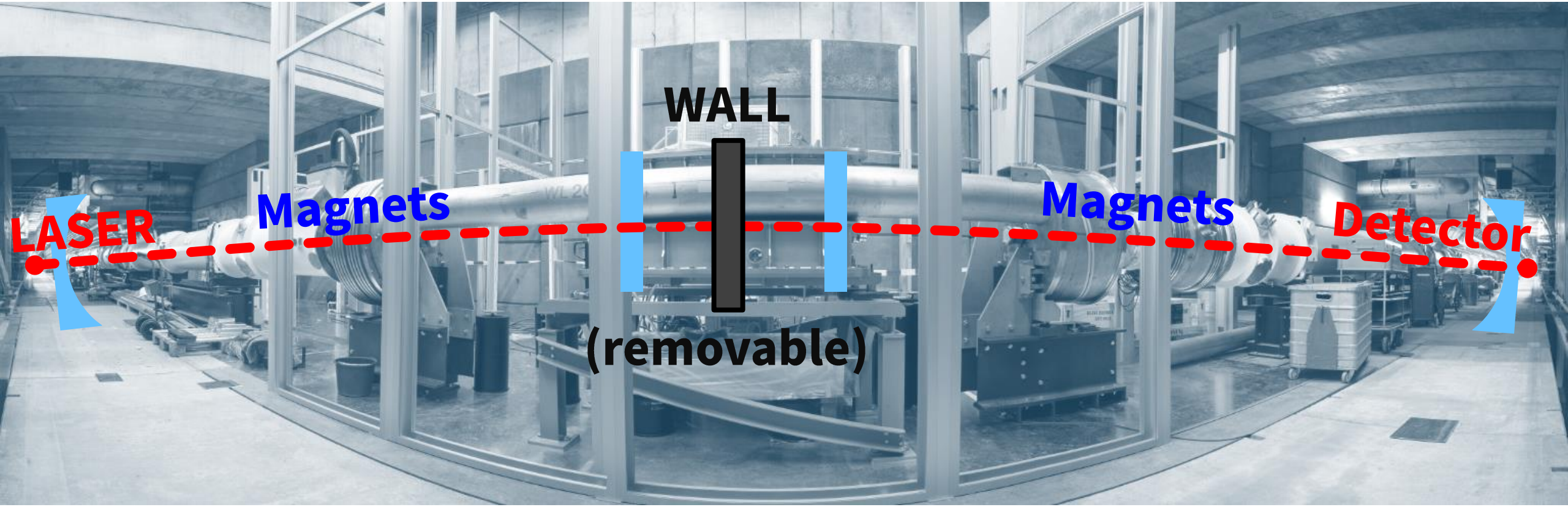


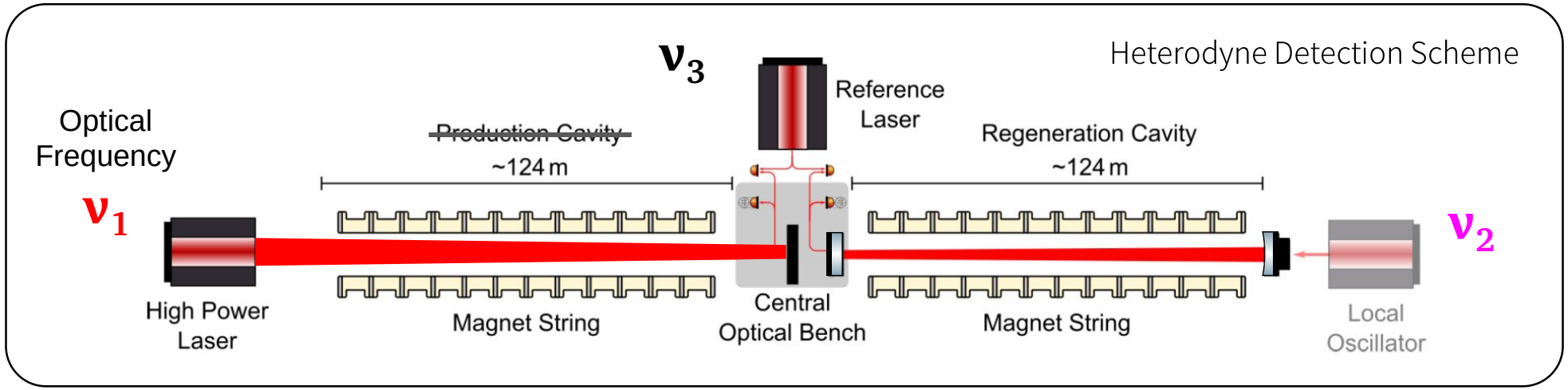







WALL
LASER
Magnets
Magnets
Detector
(removable)


Heterodyne Detection Scheme
ν_3
Reference Laser
Optical Frequency
ν_1
Production Cavity
~124 m
Regeneration Cavity
~124 m
ν_2
High Power Laser
Magnet String
Central Optical Bench
Magnet String
Local Oscillator


WALL
LASER
Magnets
Magnets
Detector
(removable)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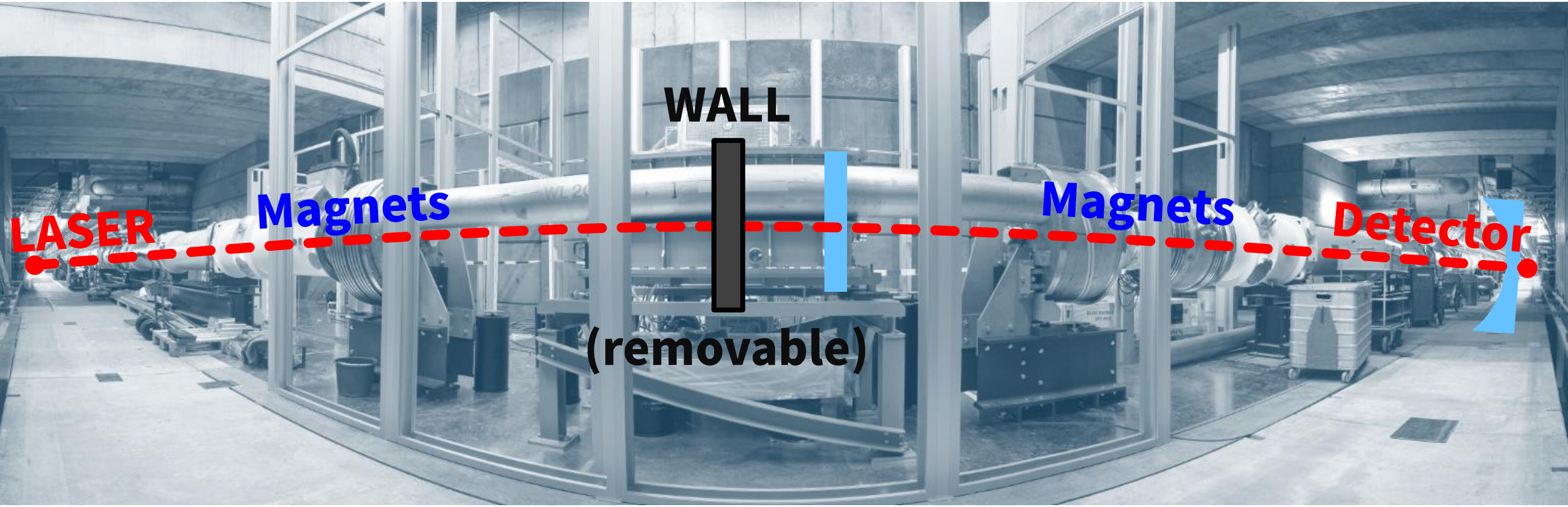
WALL
LASER
Magnets
Magnets
Detector
(removable)

2022
Sept

Installation of the experiment completed

2022
Sept

2023
May

First data

Installation of the experiment completed

ALPS I results published
2010 May

ALPS II project R&D approved
2013 Feb

First magnet in the tunnel
2019 Oct

First cleanroom ready
2020 Jun

2020 Oct
All magnets installed and aligned

First optical table ready
2020 Dec

2021 Apr
First laser beam through the magnets

First power-on of the magnets
2022 Mar

2022 Sept
Installation of the experiment completed

2023 Apr
Final safety clearance

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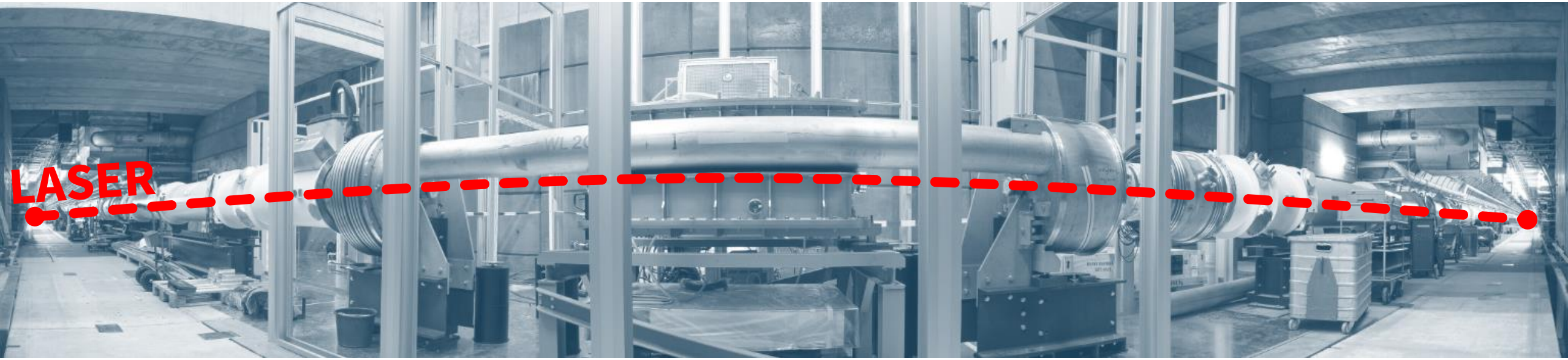
2023 May
First data

End of 2023
Initial Science Run

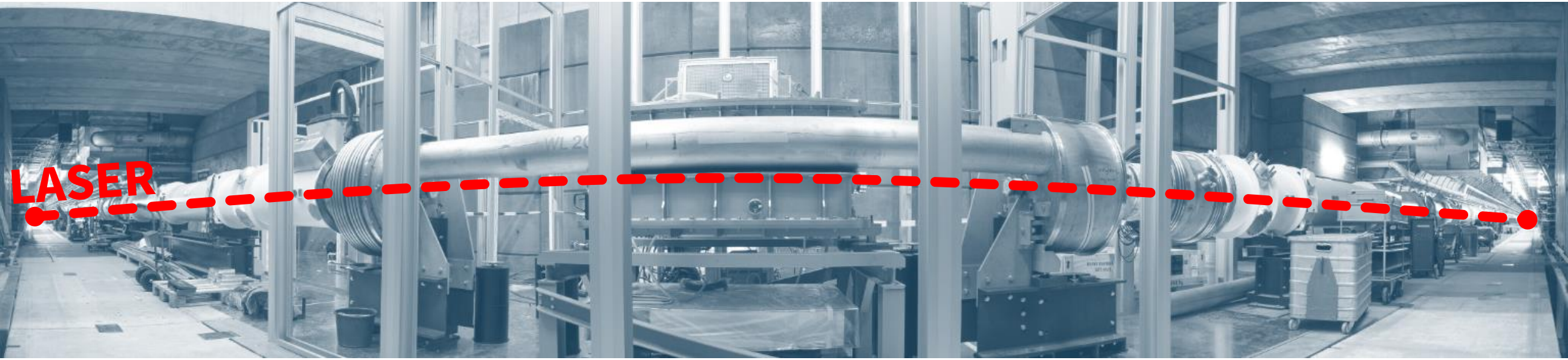
Sensitivity boosters: the ABCDs of ALPS II

LASER $\vec{B}$ **OPTICAL CAVITIES** **SINGLE-PHOTON DETECTOR**

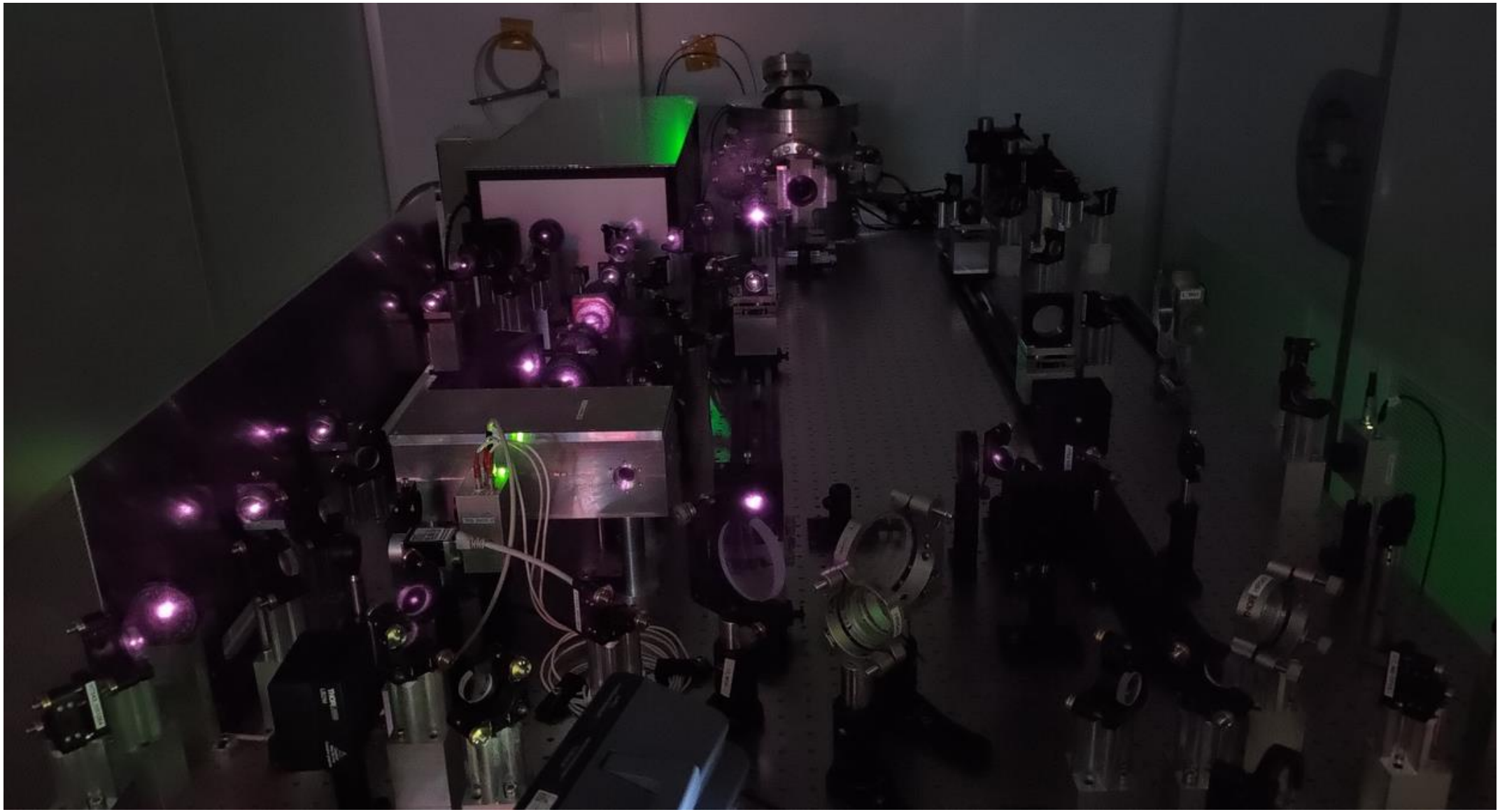


Sensitivity boosters: the ABCDs of ALPS II

(A) 40 W laser at 1064 nm $\approx 2 \times 10^{20}$ photons per second



(A) 60 W laser (~ 40 W injected to the experiment)



Sensitivity boosters: the ABCDs of ALPS II

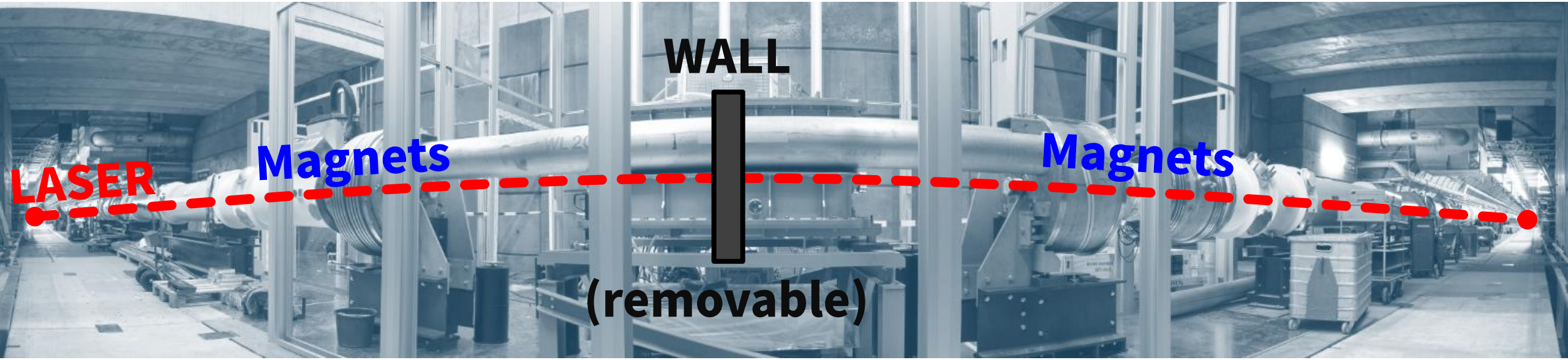
(A) 40 W laser at 1064 nm $\approx 2 \times 10^{20}$ photons per second

(B) Probability of $\gamma \leftrightarrow a$ conversion in a magnetic field

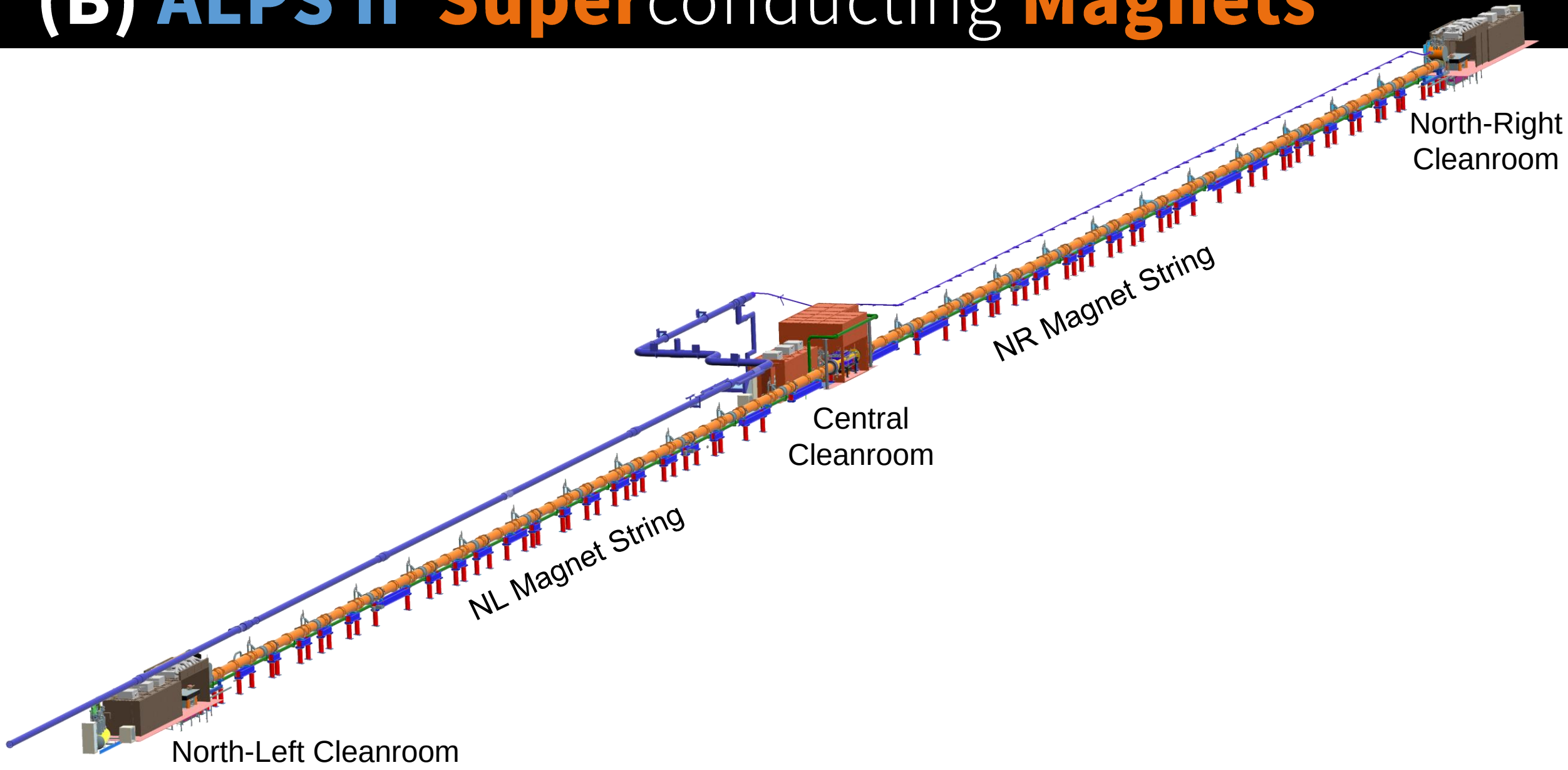
$$\text{Prob}(\gamma \leftrightarrow a) \approx 3 \times 10^{-17} \times \left(\frac{B \cdot L}{560\ \text{tesla} \cdot \text{meter}}\right)^2 \times \left(\frac{g_{a\gamma\gamma}}{2 \times 10^{-11}\ \text{GeV}^{-1}}\right)^2$$

$A \times B^2 \approx 1.8 \times 10^{-13}$ photon/s

≈ 1 photon every 150000 years



(B) ALPS II Superconducting Magnets



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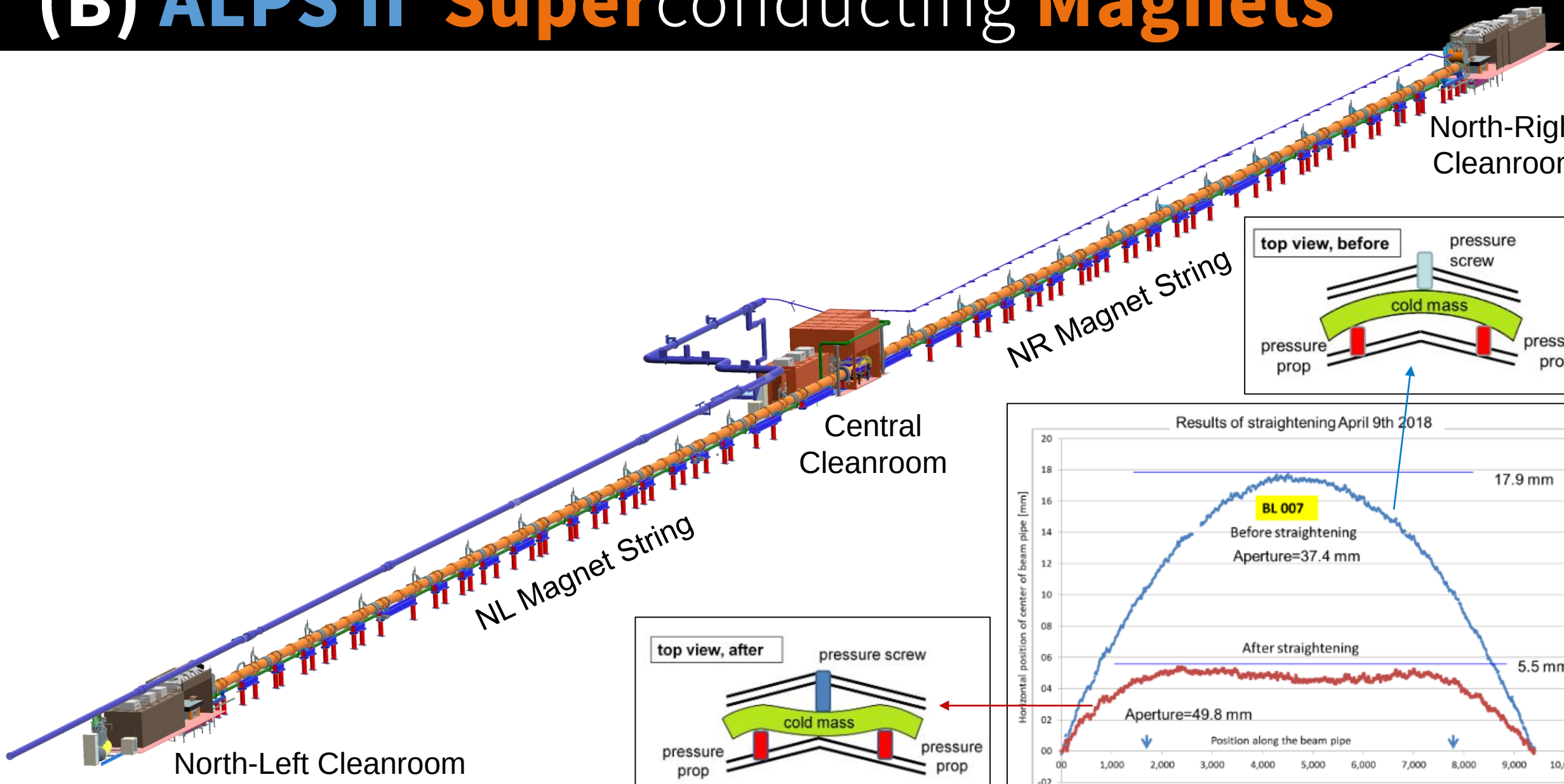
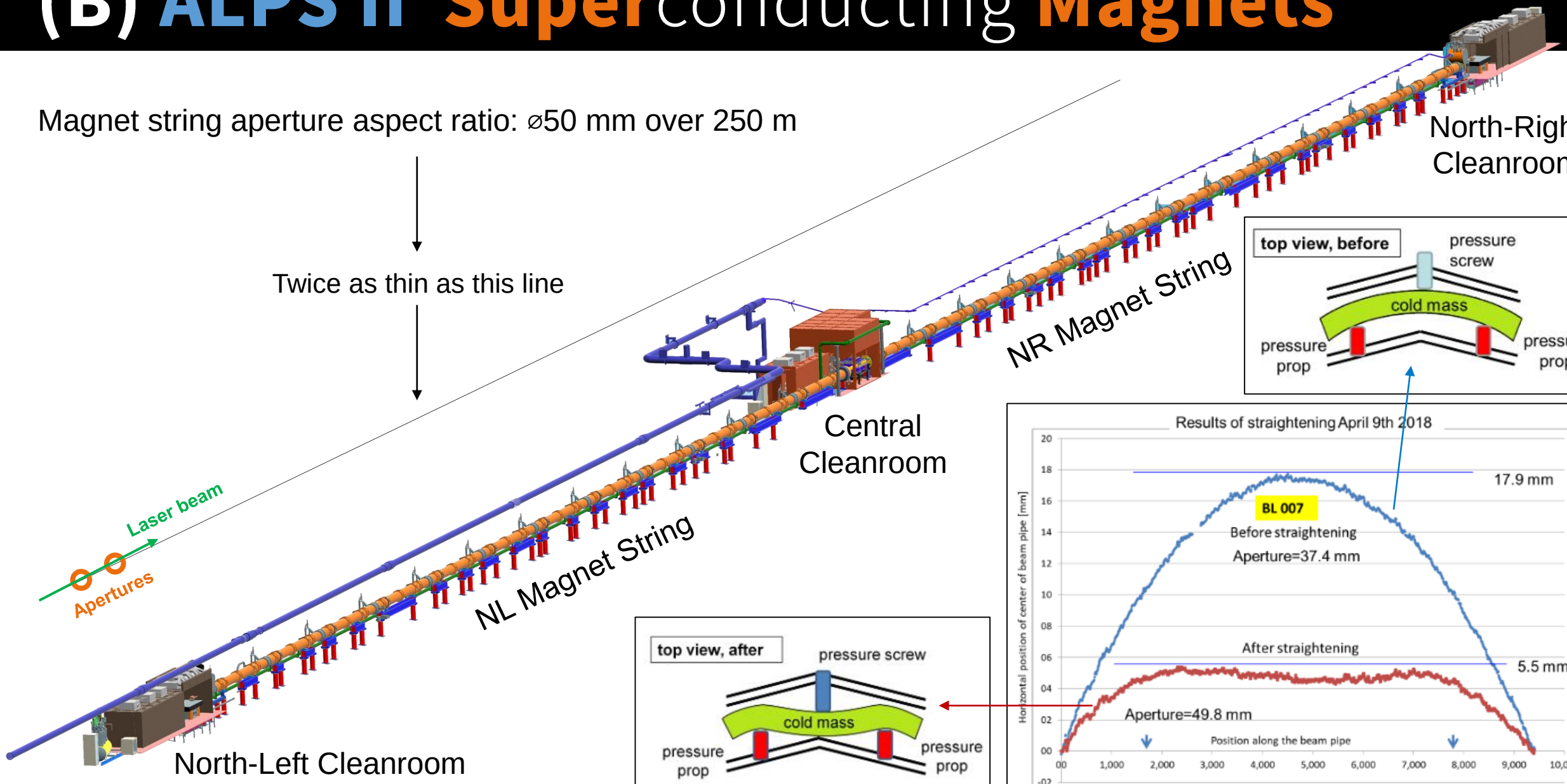


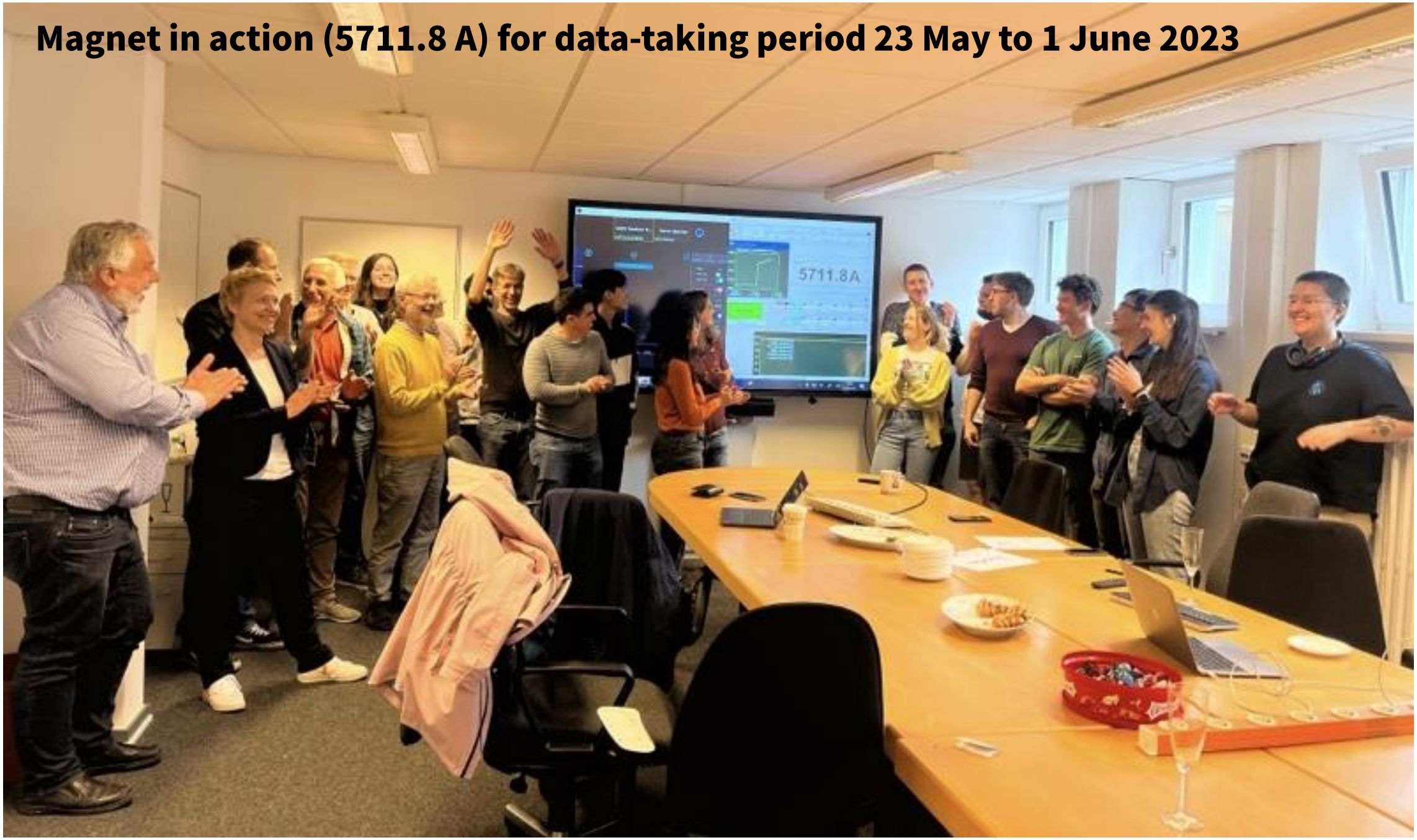
(B) ALPS II Superconducting Magnets

Magnet string aperture aspect ratio: ⌀50 mm over 250 m

Twice as thin as this line



Magnet in action (5711.8 A) for data-taking period 23 May to 1 June 2023



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$A \times B^2 \approx 1.8 \times 10^{-13}$ photon/s

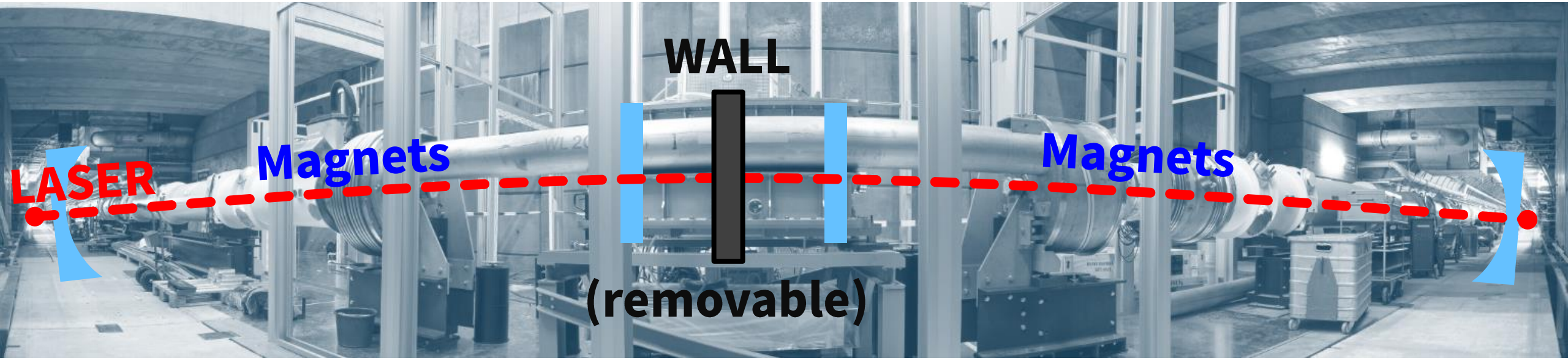
≈ 1 photon every 150000 years

(C) Resonant gain of optical cavities, β

$$\beta \approx 10000 \times \left(\frac{100\ \text{ppm}}{\text{Mirror Transmissivity}}\right)$$ for a lossless symmetric cavity

$A \times B^2 \times C^2 \approx 1.8 \times 10^{-5}$ photon/s

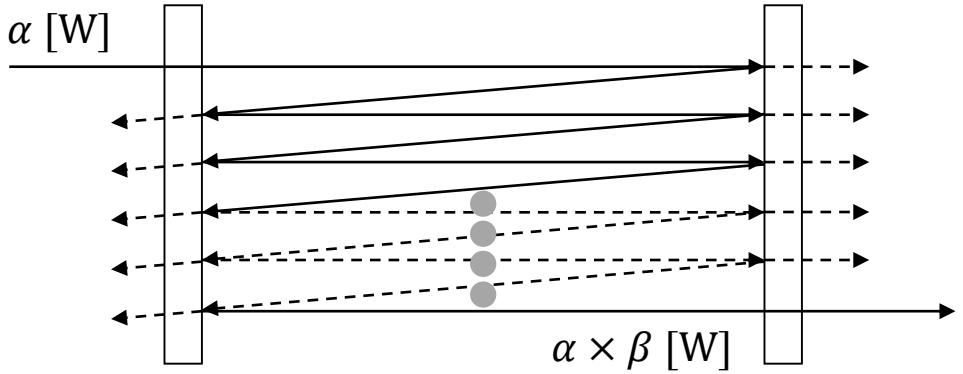
≈ 1.6 photons per day

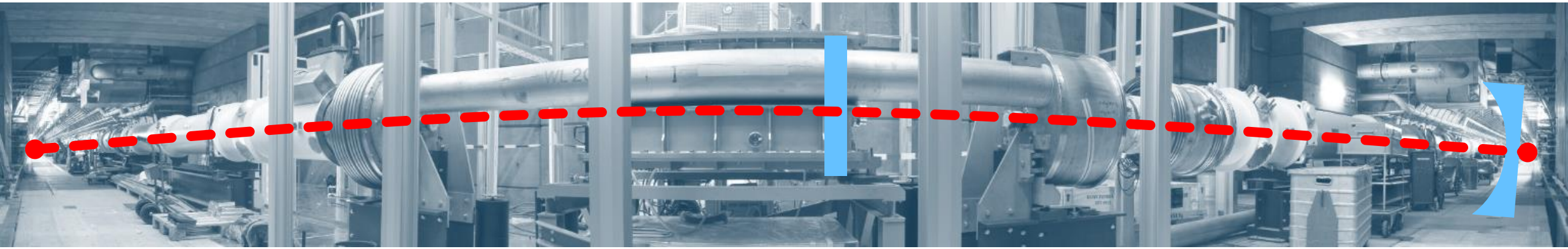


(C) ALPS II Regeneration Cavity

The axion-photon signal is resonantly enhanced with a cavity by the power build-up factor **β**

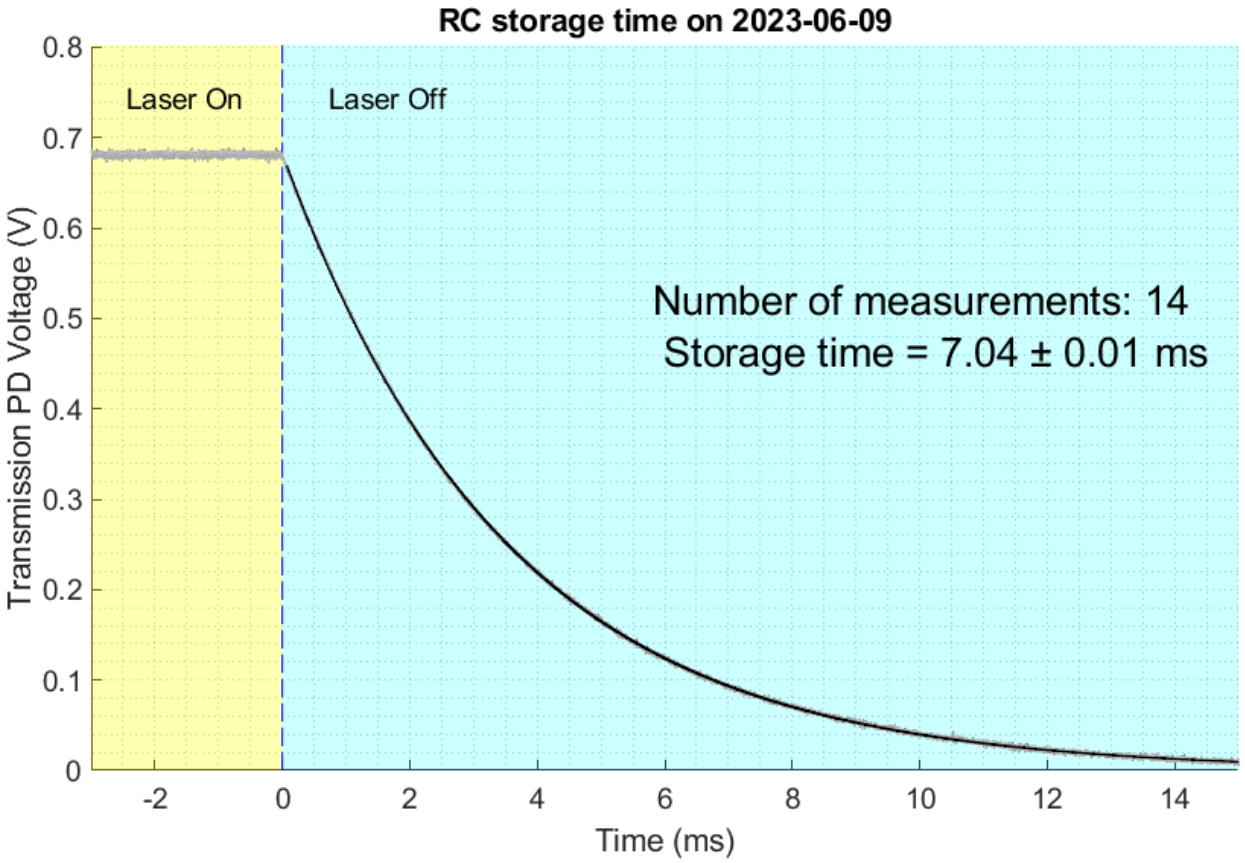
$$\beta \propto \frac{\text{Input Mirror Transmissivity}}{(\text{Cavity Roundtrip Loss})^2}$$

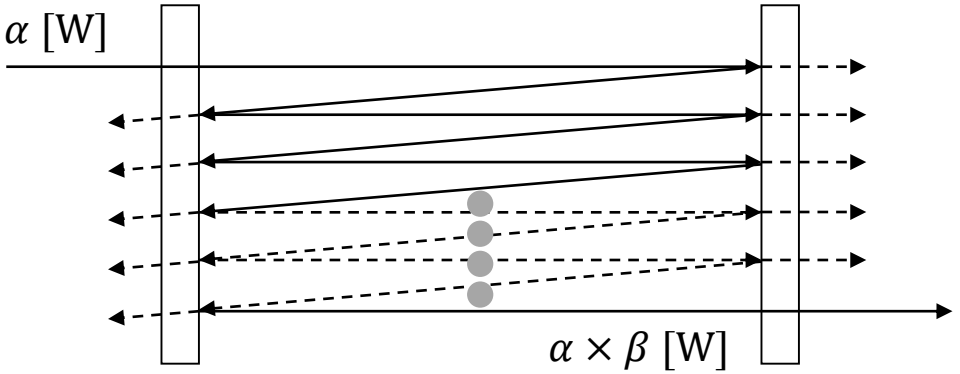


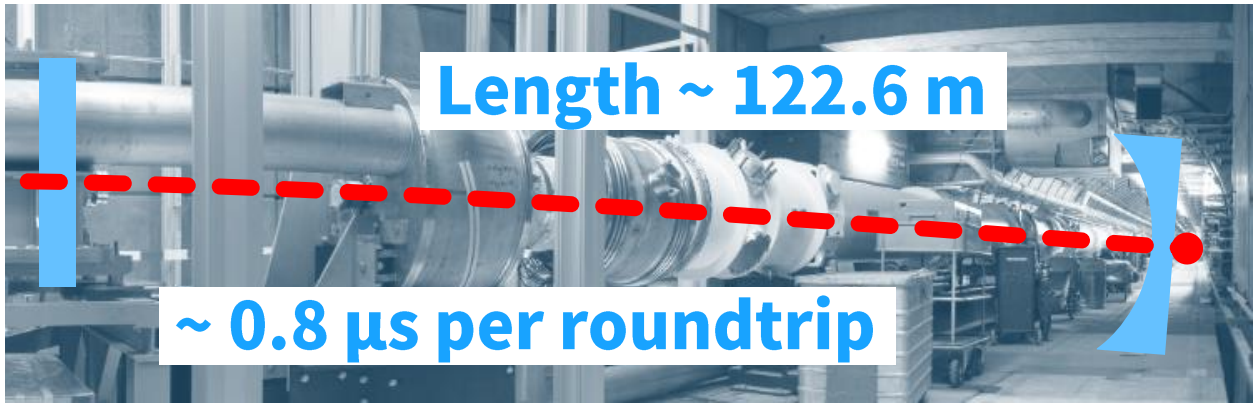


(C) ALPS II Regeneration Cavity

Record-long storage time of a two-mirror optical cavity of > 7 millisecond

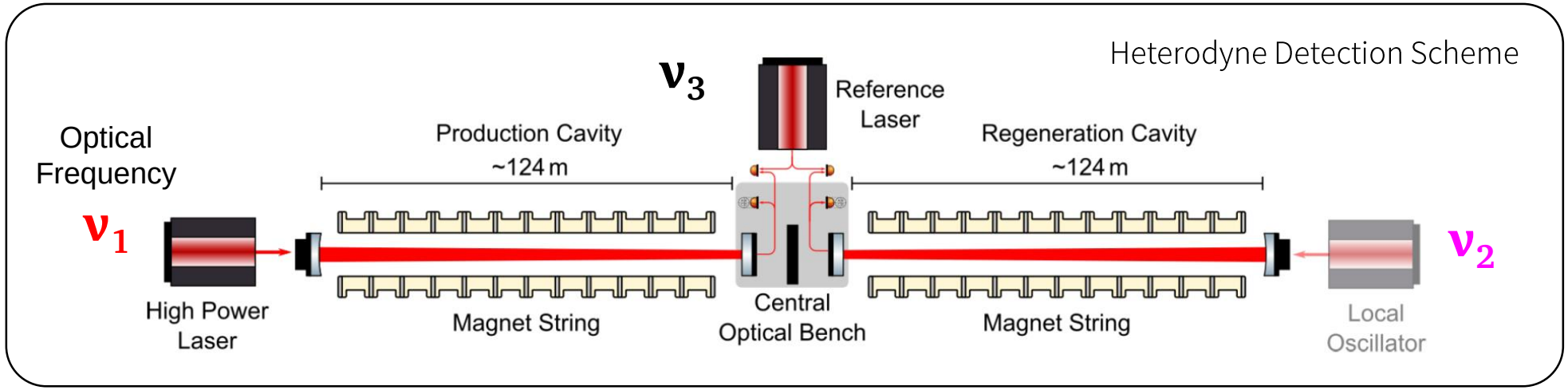






(D) Heterodyne Detection Scheme

Detection of a 2-photon-per-day flux



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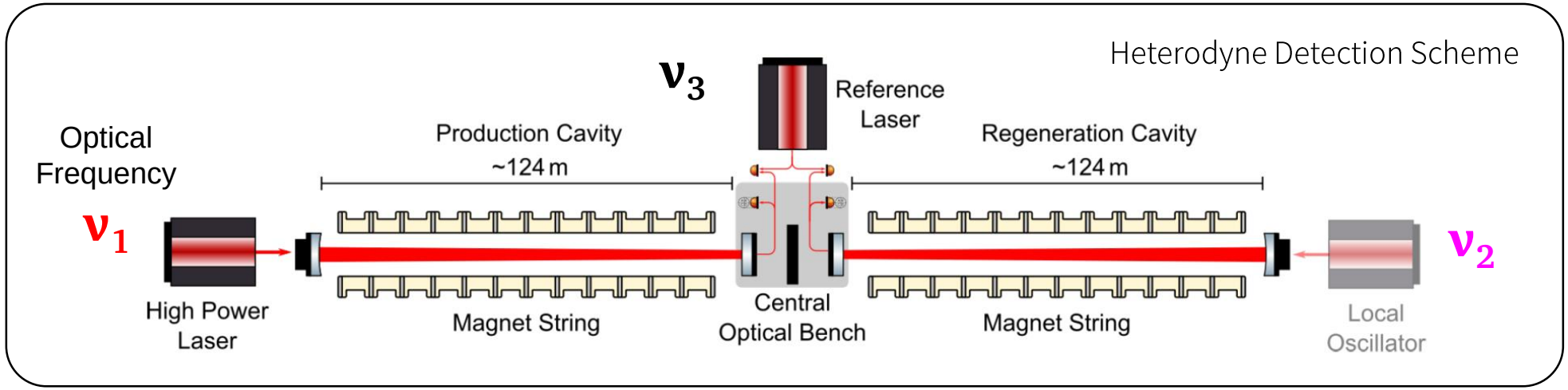
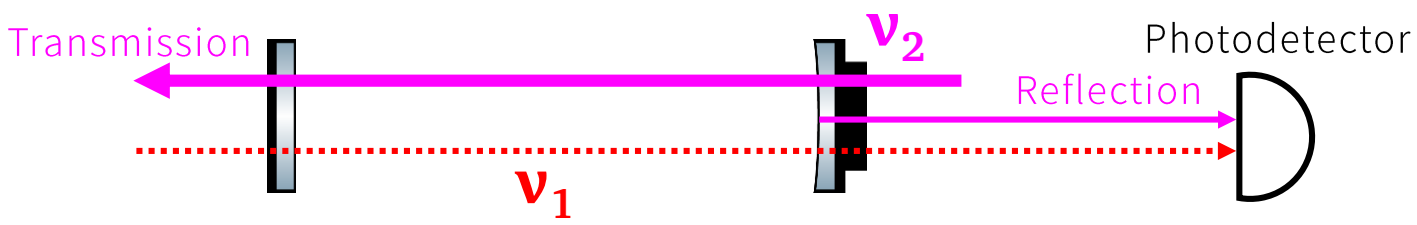


Heterodyne → $\nu_1 \neq \nu_2$



$$P_1 + P_2 + 2 \cdot \sqrt{P_1 \cdot P_2} \cdot \cos[2\pi(\nu_1 - \nu_2)t]$$

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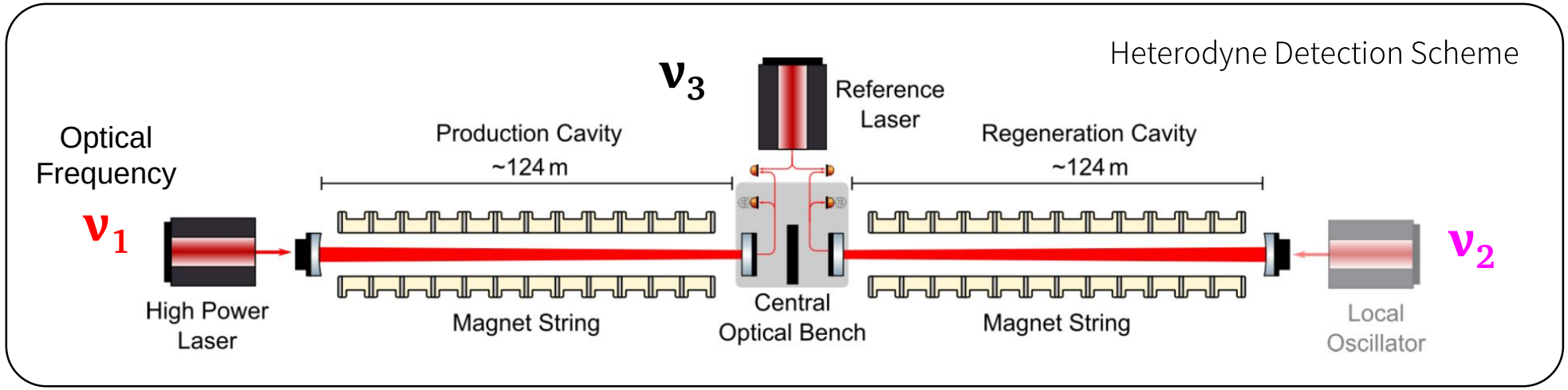

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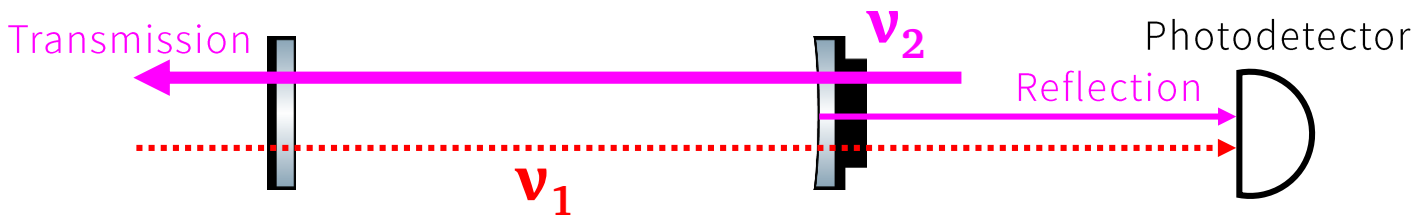
Cavity resonance condition

$$2 \cdot L = N \cdot \lambda, \quad \nu = N \cdot \frac{c}{2L}$$

Free **S**pectral **R**ange

1.22263 MHz



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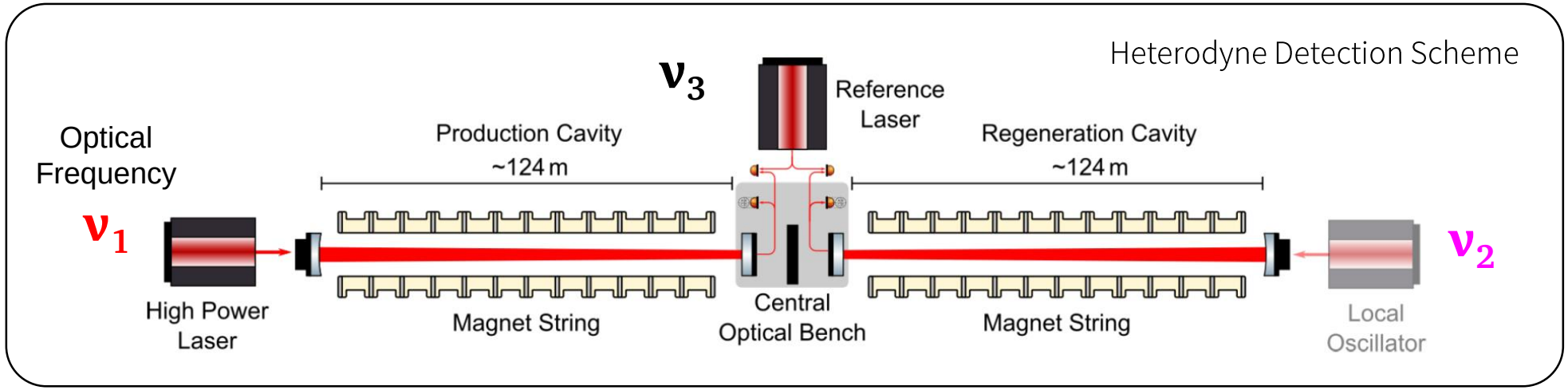

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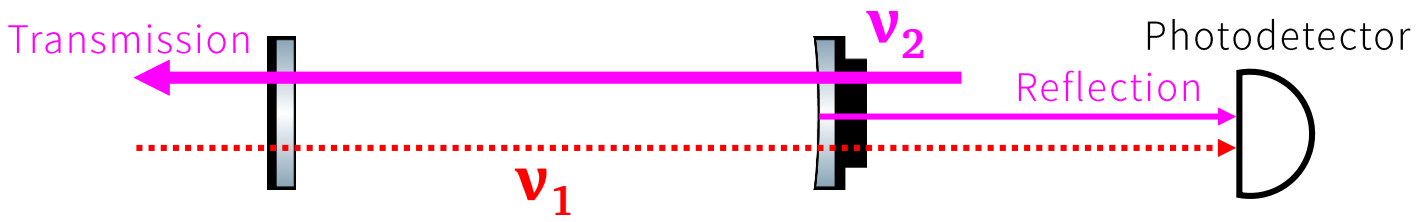
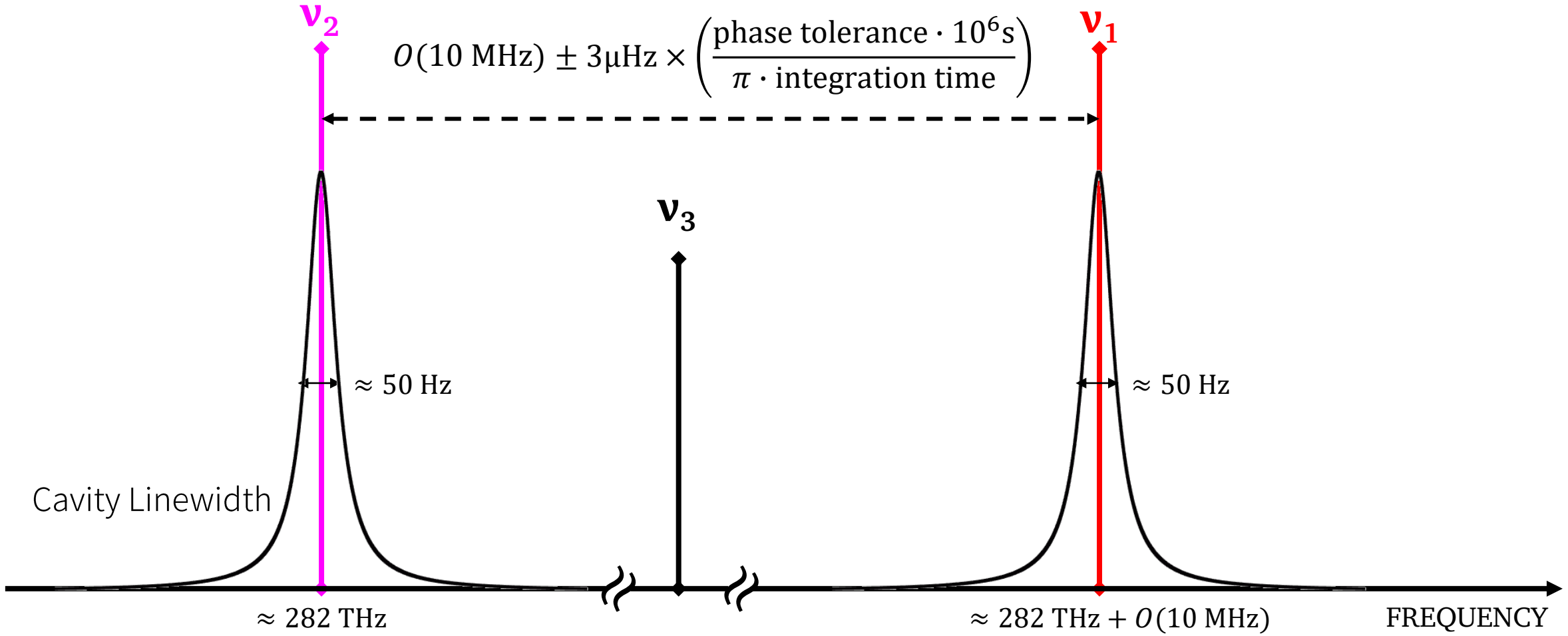


$$P_1 + P_2 + 2 \cdot \sqrt{P_1 \cdot P_2} \cdot \cos[2\pi(\nu_1 - \nu_2)t]$$

$$\nu_1 = \nu_2 + x \cdot FSR$$ coherence property

Frequency requirements for heterodyne detection

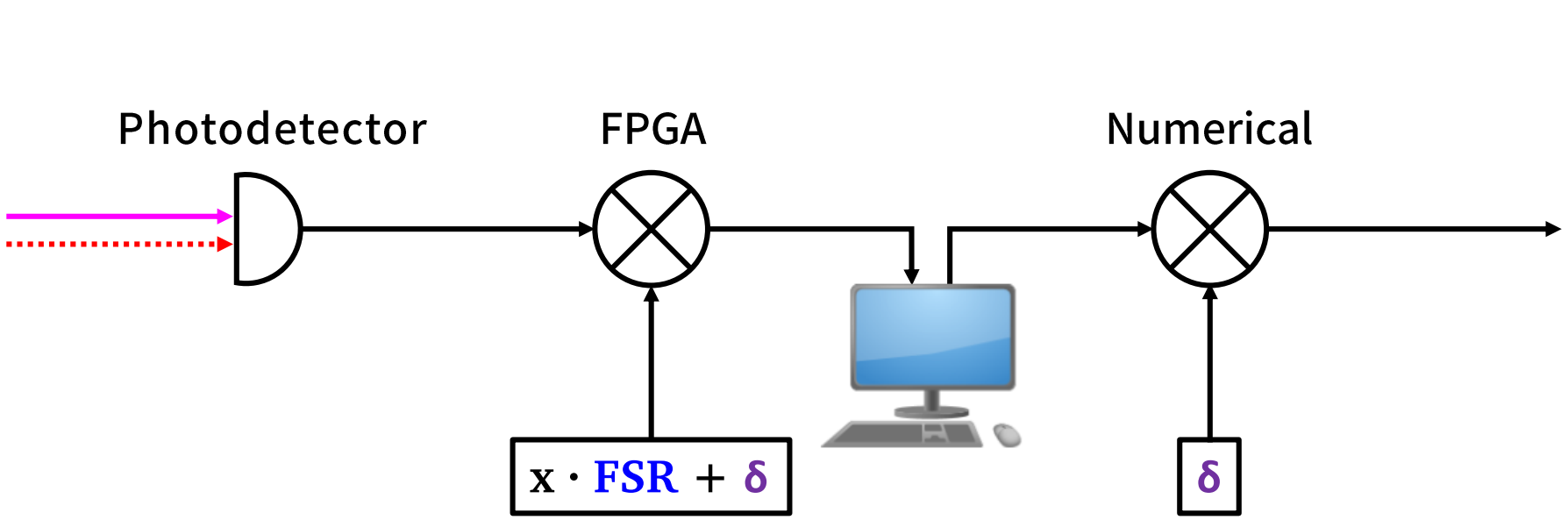


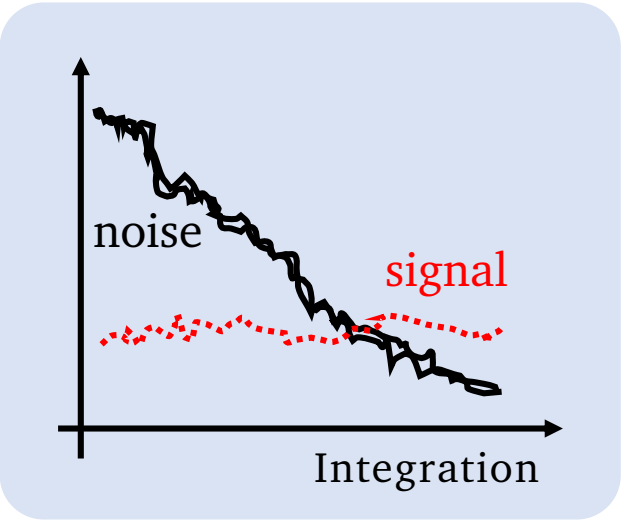
Minimizing **heterodyne** dark count rate

- Electromagnetic Interference:
  - Middleman Laser at $\boldsymbol{\nu_3}$

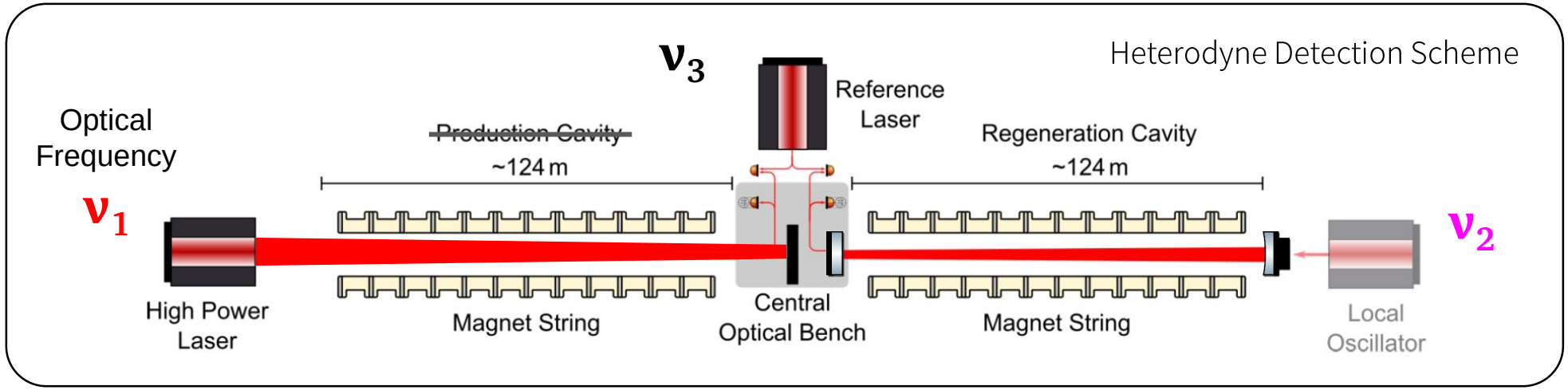
Minimizing **heterodyne** dark count rate

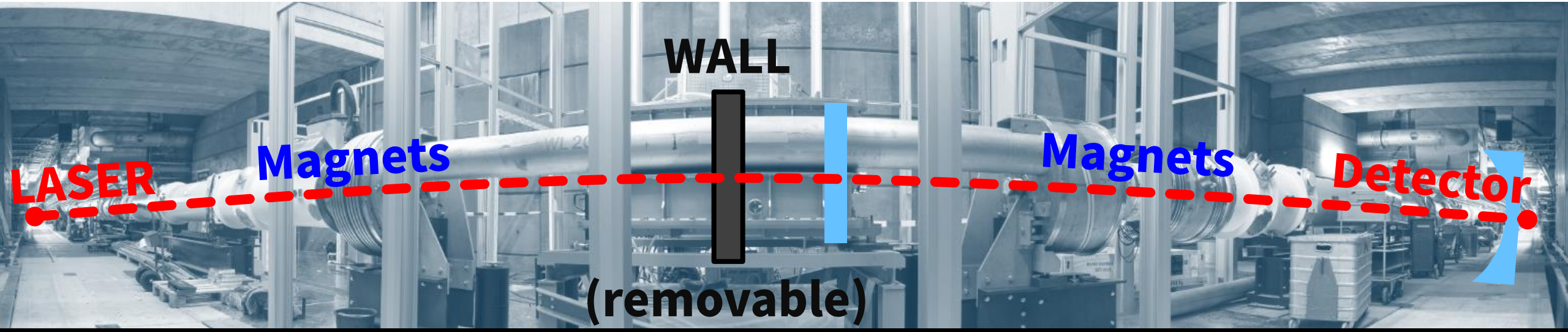
- Electromagnetic Interference:
  - Middleman Laser at ν_3
  - Double Demodulation





ALPS II optics setup for Initial Science Run





Production Cavity is absent → 40 times more light on the COB, facilitates stray light hunting

ALPS II optics setup for Initial Science Run

(A) 40 W laser at 1064 nm $\approx 2 \times 10^{20}$ photons per second

(B) Probability of $\gamma \leftrightarrow a$ conversion in a magnetic field

$$\mathrm{Prob}(\gamma \leftrightarrow a) \approx 3 \times 10^{-15} \times \left(\frac{B \cdot L}{560\ \mathrm{tesla} \cdot \mathrm{meter}}\right)^2 \times \left(\frac{g_{a\gamma\gamma}}{2 \times 10^{-10}\ \mathrm{GeV}^{-1}}\right)^2$$

$A \times B^2 \approx 2 \times 10^{-9}$ photon/s

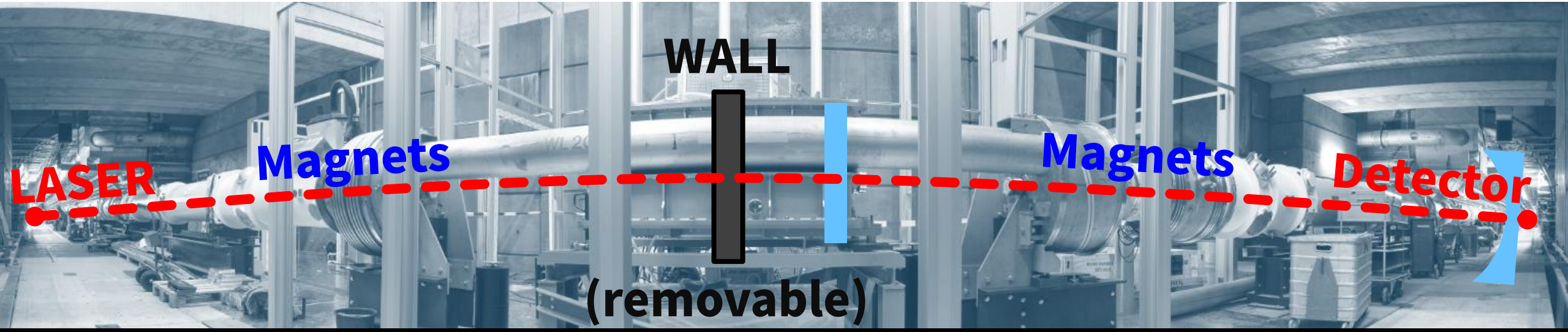
≈ 1 photon every 15 years

(C) Resonant gain of Regeneration Cavity, β_{RC}

$\beta_{RC} \approx 5000$ for optimal SNR on the heterodyne detector

$A \times B^2 \times C^1 \approx 2 \times 10^{-5}$ photon/s

≈ 0.8 photon per day



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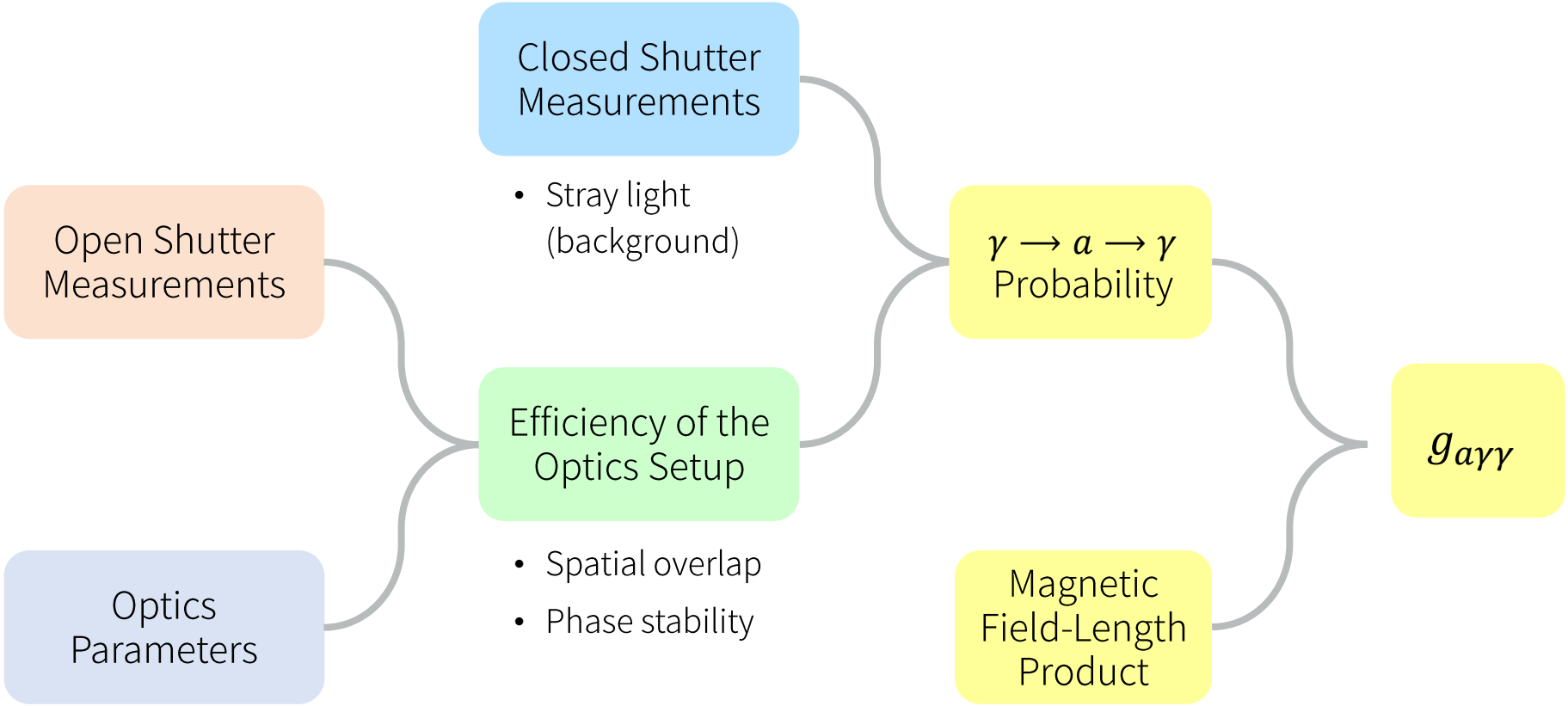
ALPS II science run



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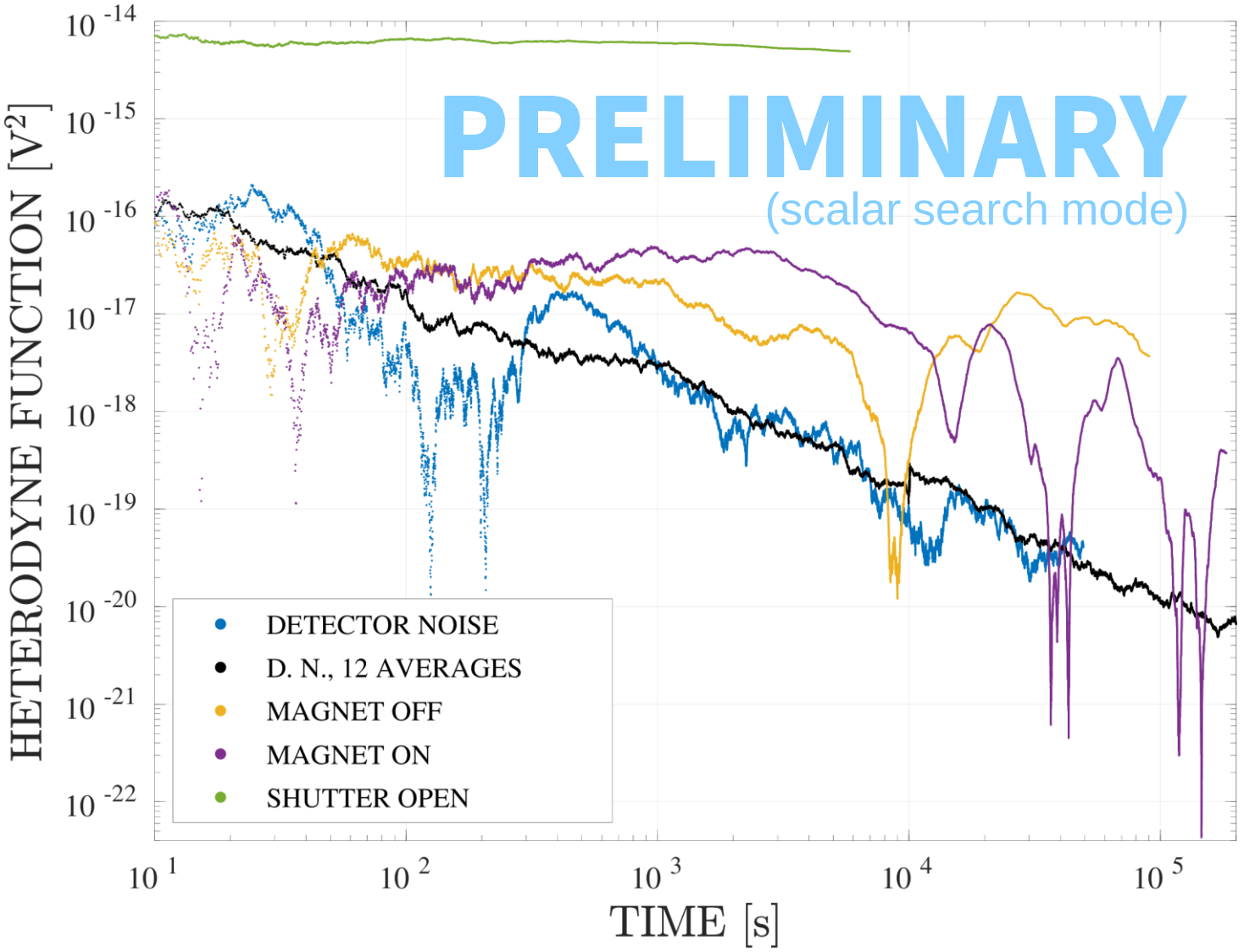
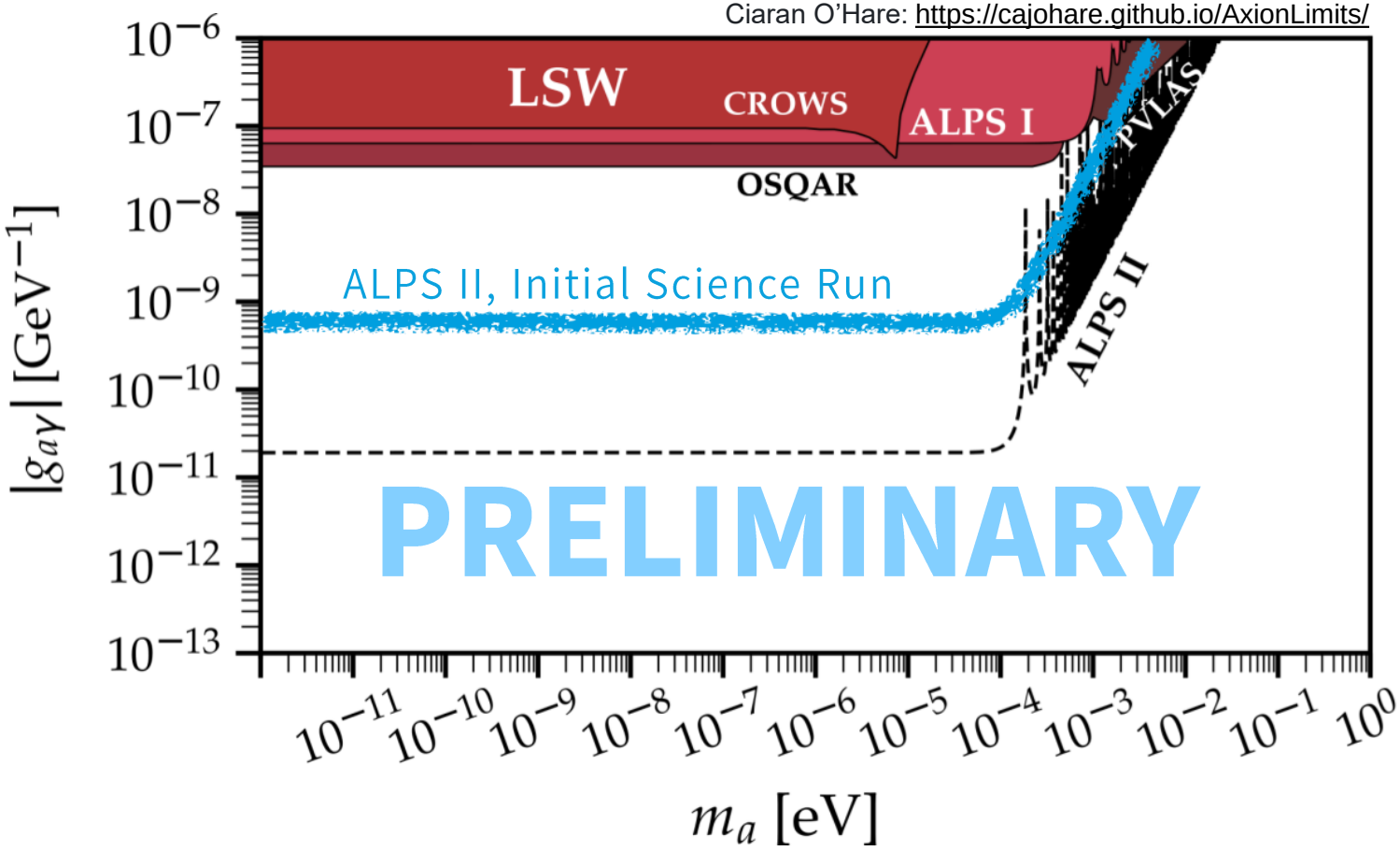
Initial Science Run, first measurements



Initial Science Run sensitivity reach

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



Next steps

Automation

Background Reduction / De-phasing

2024

Initial Science Run

- 1 million second stretches of data
- Improved calibration
- Scalar / pseudo-scalar searches

$$g_{a\gamma\gamma}\,\phi\left(\vec{B}^2-\vec{E}^2\right) \qquad -g_{a\gamma\gamma}\,\phi\,E\cdot B$$

Upgraded Cavity Mirrors

Production Cavity

ALPS I results published
2010 May

ALPS II project R&D approved
2013 Feb

First magnet in the tunnel
2019 Oct

First cleanroom ready
2020 Jun

2020 Oct
All magnets installed and aligned

First optical table ready
2020 Dec

2021 Apr
First laser beam through the magnets

First power-on of the magnets
2022 Mar

2022 Sept
Installation of the experiment completed

2023 Apr
Final safety clearance

2023 May
First data

End of 2023
Initial Science Run

2024
Optics upgrade, Production Cavity commissioning

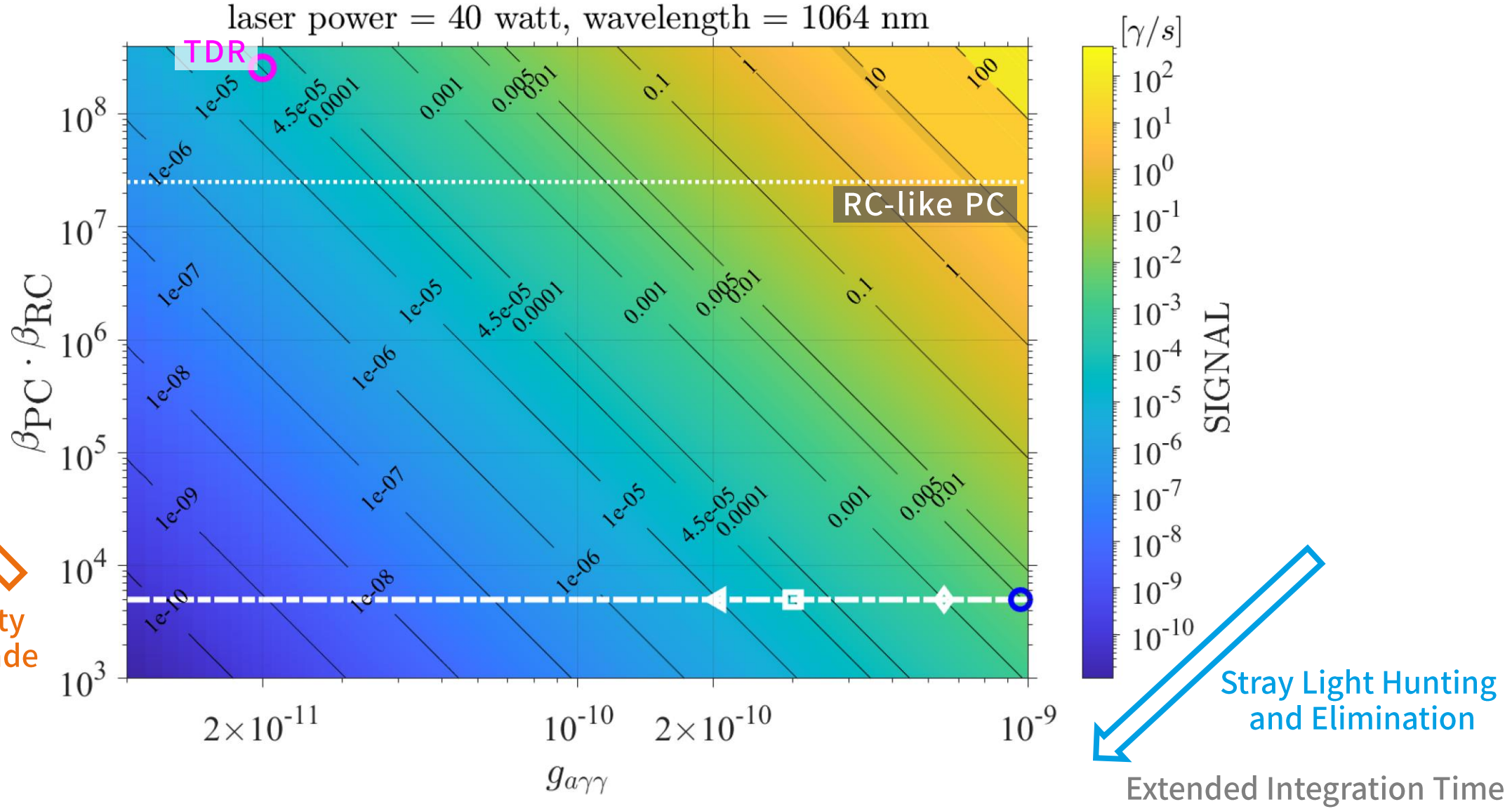
Beyond ALPS II
Design sensitivity TES detection scheme

Thank you

Li-Wei Wei
Deutsche Elektronen-Synchrotron
li-wei.wei at desy.de

HELMHOLTZ DESY. ALPS

Initial Science Run **Sensitivity** and **Outlook**



Production Cavity and Optics Upgrade

Stray Light Hunting and Elimination

Extended Integration Time