Search for Axionlike particles with hyper polarized Xe nuclear magnetic resonance

Presented by Arian Dogan - Helmholtz Institute Mainz- Johannes Gutenberg University Mainz

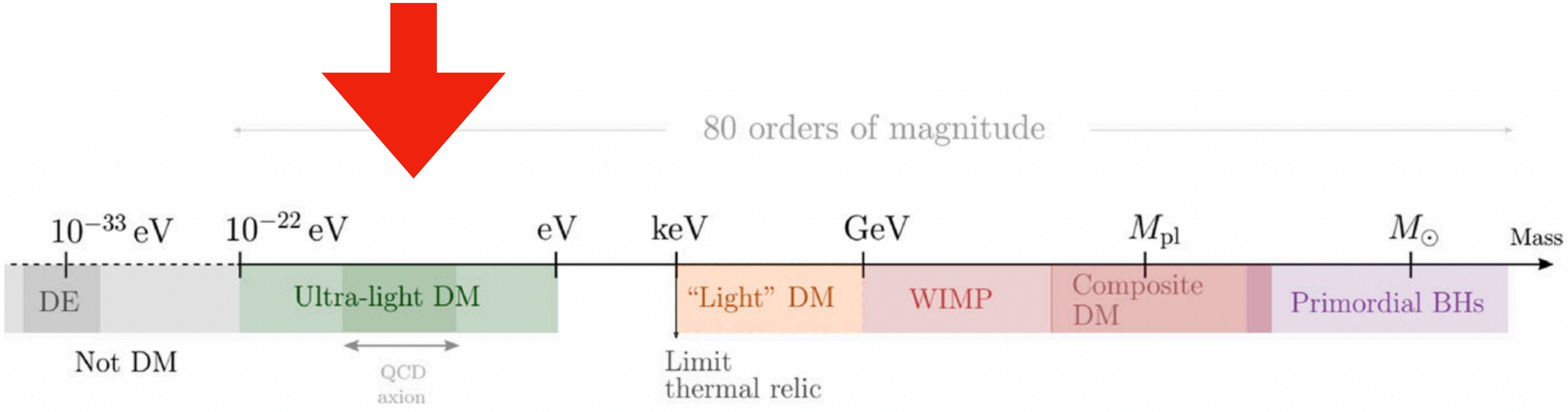
From the Cosmic Axion Spin Precession Experiment (CASPEr) collaboration

2nd General Meeting Cosmic WISPers 2024, Istanbul

Contents

- **Measurement principle of CASPEr-Gradient**
- **How to create a hyperpolarized sample**
- **Dark matter detection setup**
- **Dark matter measurement & Analysis**
- **Results & Conclusion**
- **Outlook**

Cosmic Axion Spin Precession Experiment (CASPEr)



E. G. M. Ferreira et al., Astrophys Rev 29, no. 7 (2021)

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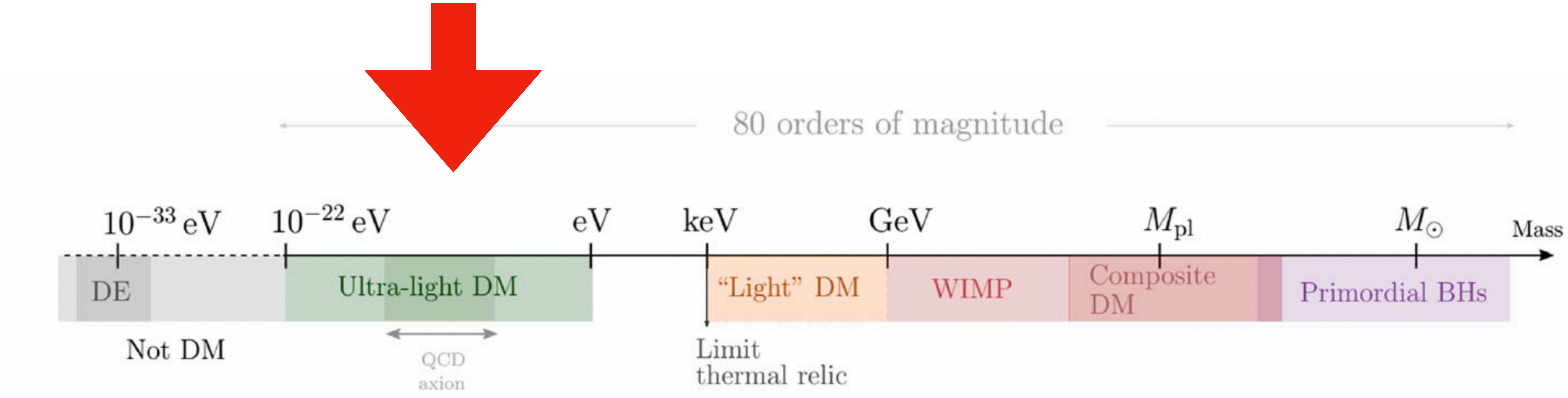

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Couplings between Axionlike Particles (ALPs) and Standard Model particles in CASPEr:

1) ALPs - gluon coupling -> CASPEr-Electric

2) ALPs - fermion coupling -> CASPEr-Gradient

CASPEr-Gradient

Axionlike Particles (ALPs)

- Coupling to nuclear spin $\vec{I}$
- $H = g_{aNN} \vec{\nabla} a(t) \cdot \vec{I}$
- The ALP-gradient $\vec{\nabla} a$ acts as a pseudo-magnetic field
- g_{aNN} as coupling constant and $a(t) = a_0 \cos(\omega \cdot t)$
- The Compton frequency $\omega = \frac{m c^2}{\hbar}$

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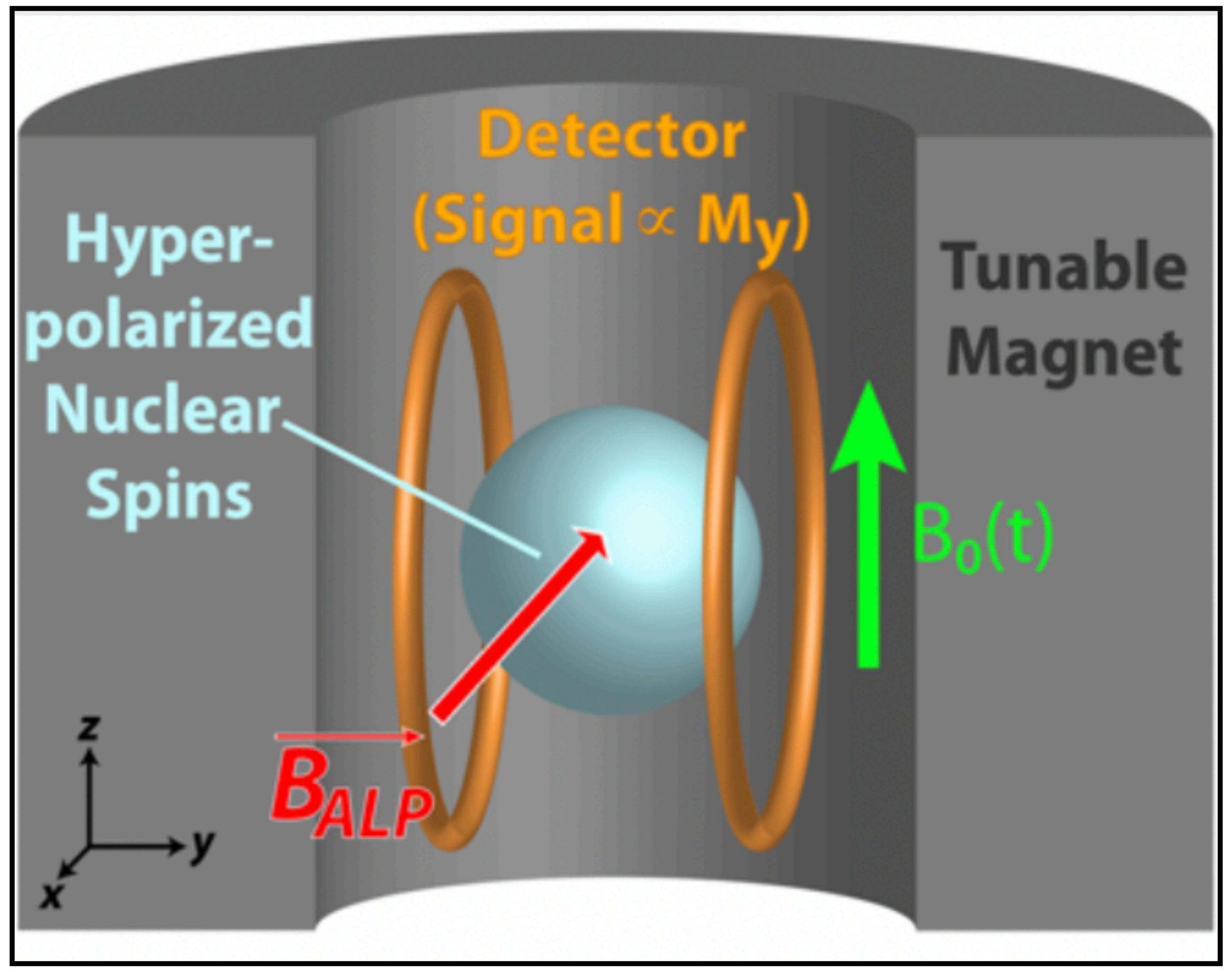

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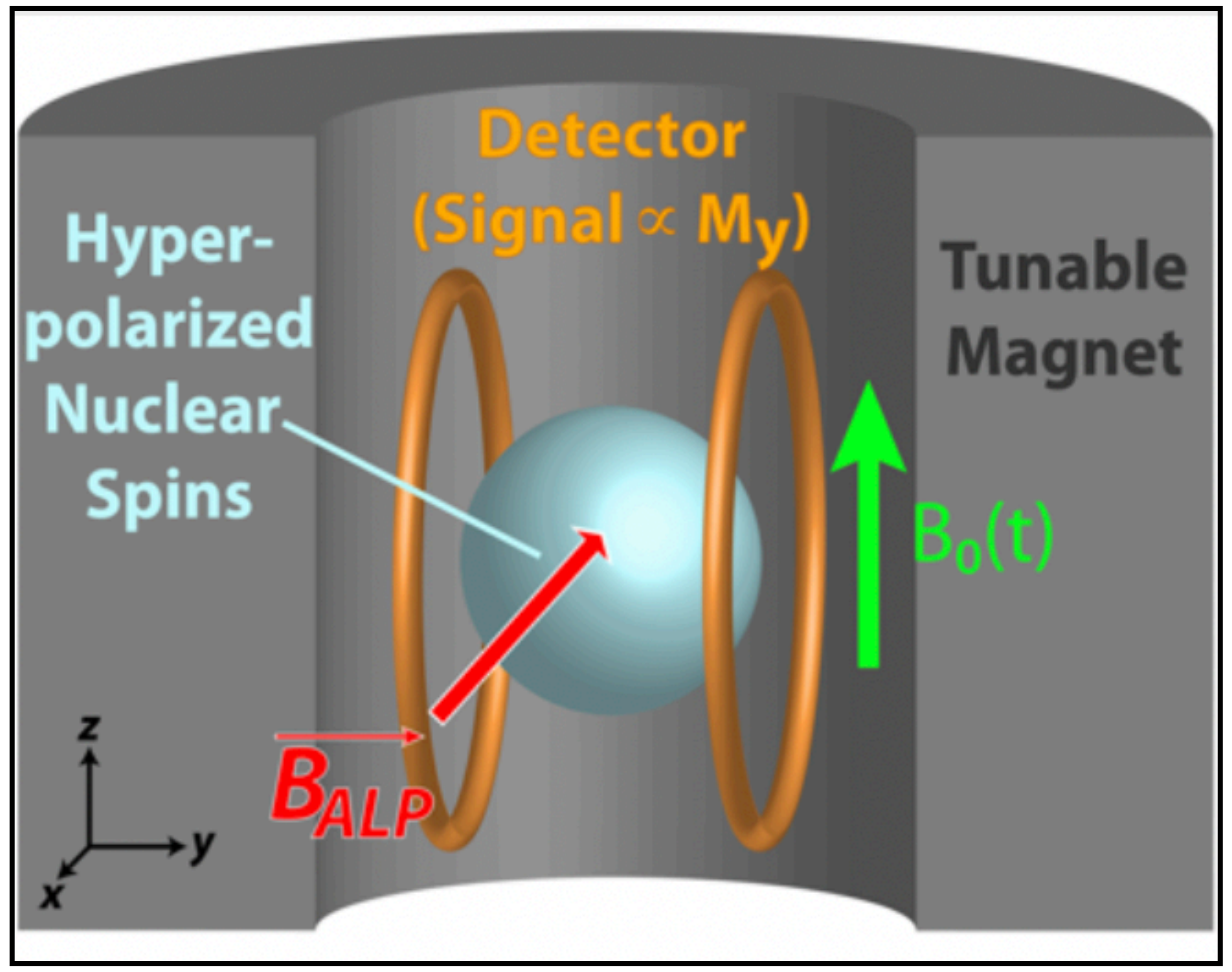
CASPEr-Gradient



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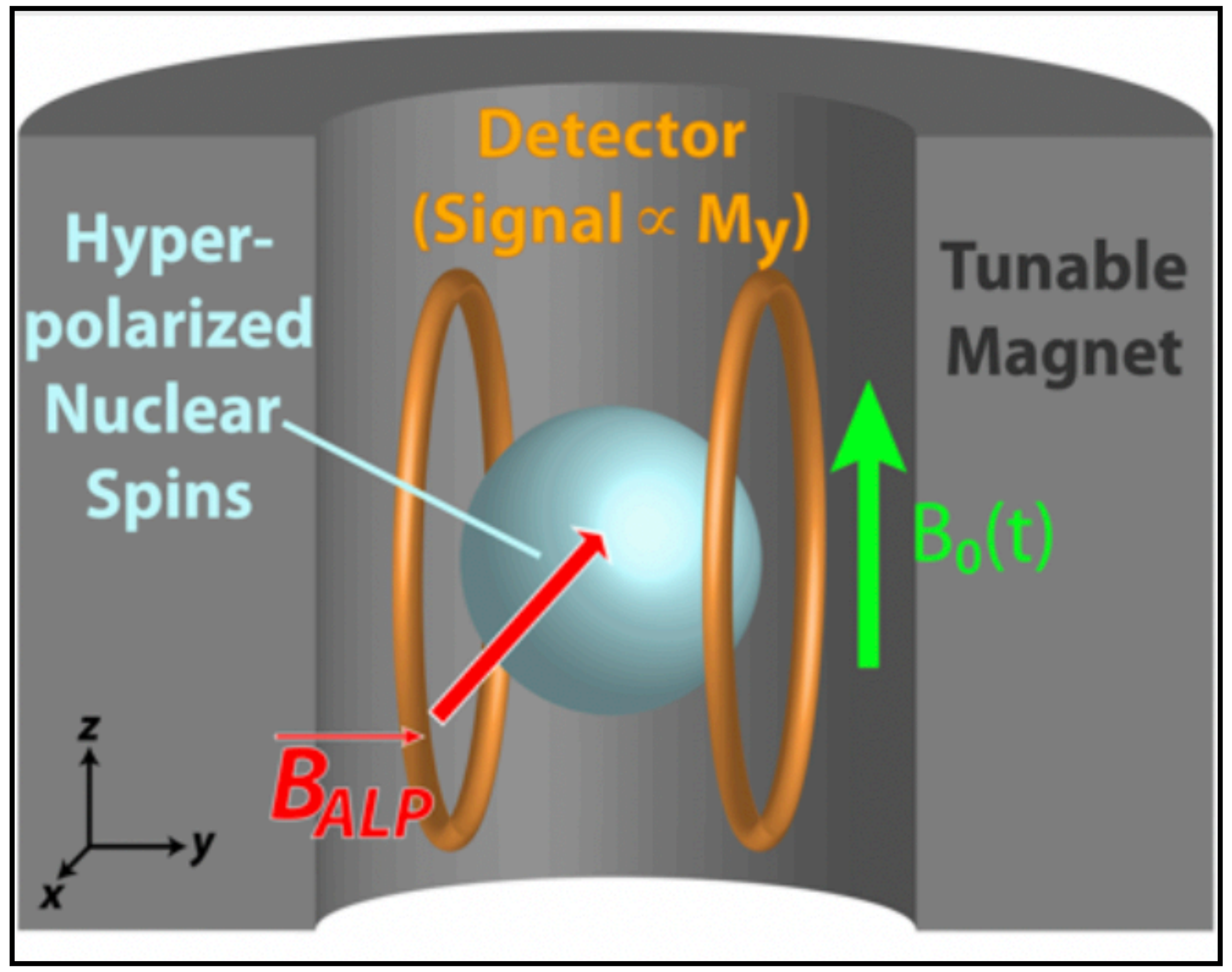
Measured signal

- $|S(t)| \propto \gamma^2 \rho P$
- γ=gyromagnetic ratio, ρ=spin density, P=polarization

CASPEr-Gradient



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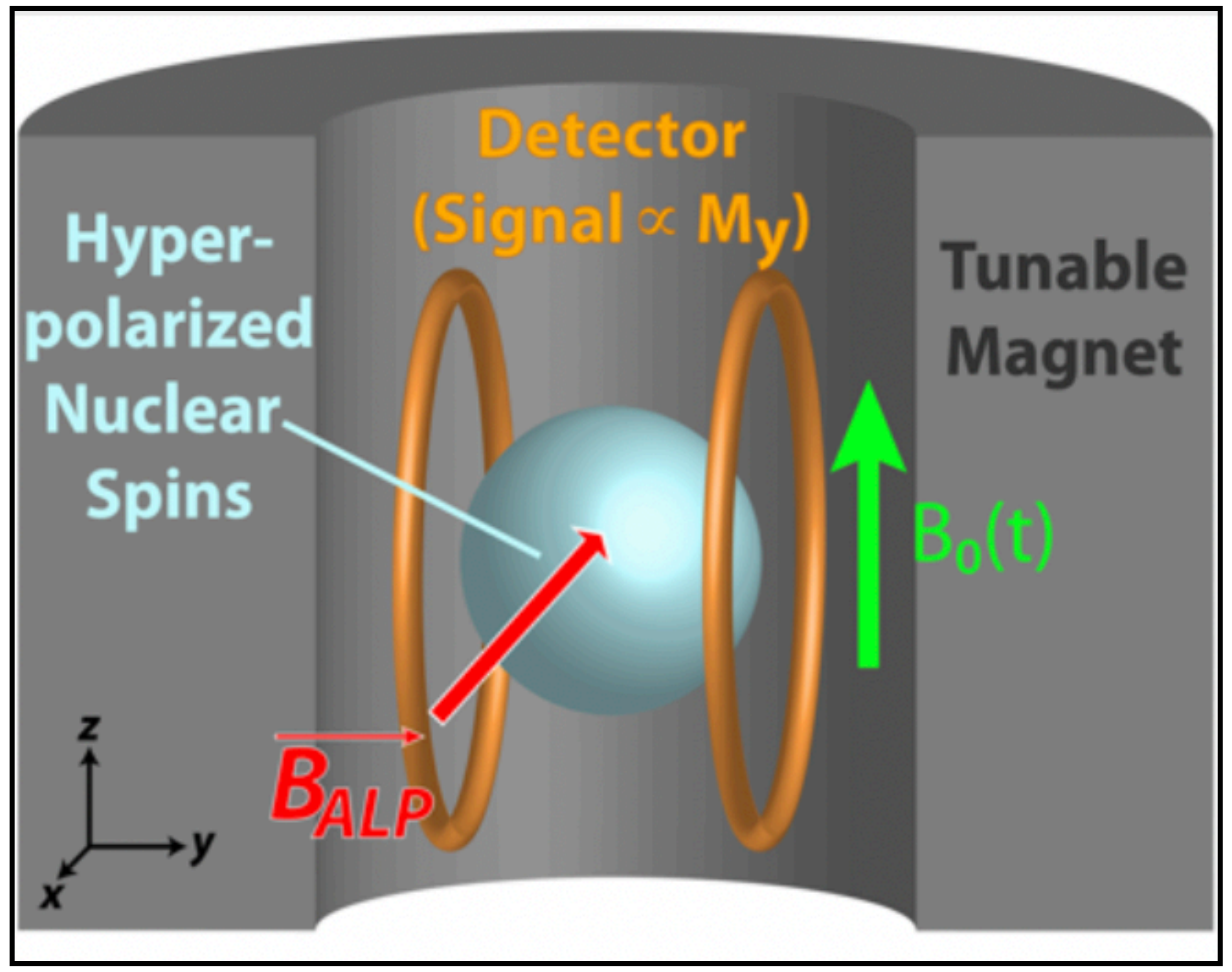
- Thermal polarization

$$P_{Xe} \approx \frac{\gamma_{Xe}\,\hbar\,B_0}{2\,k_B\,T} \approx 3 \cdot 10^{-7} \text{ at } T = 300\text{ K} \,\&\, B_0 = 1\text{ T}$$

CASPEr-Gradient



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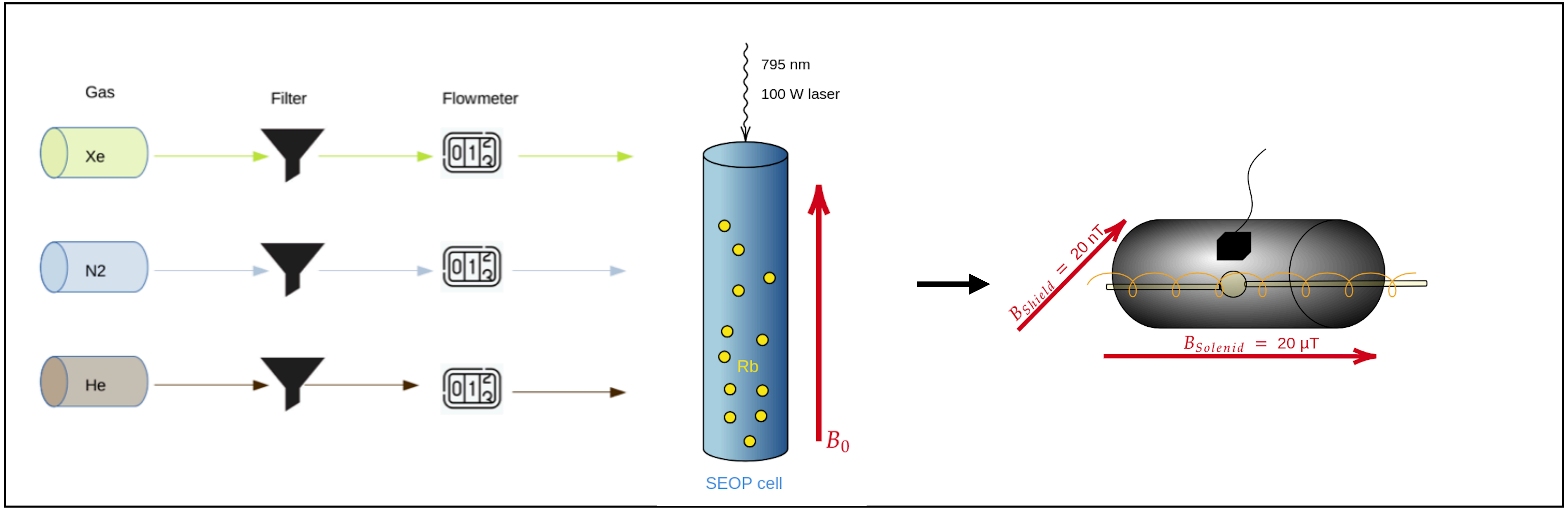
- Spin Exchange Optical Pumping (SEOP)
  1. Polarization of Rb (circularly polarized light)
  2. Transfer of angular momentum from Rb to Xe

Hyperpolarization of Xenon & polarization determination



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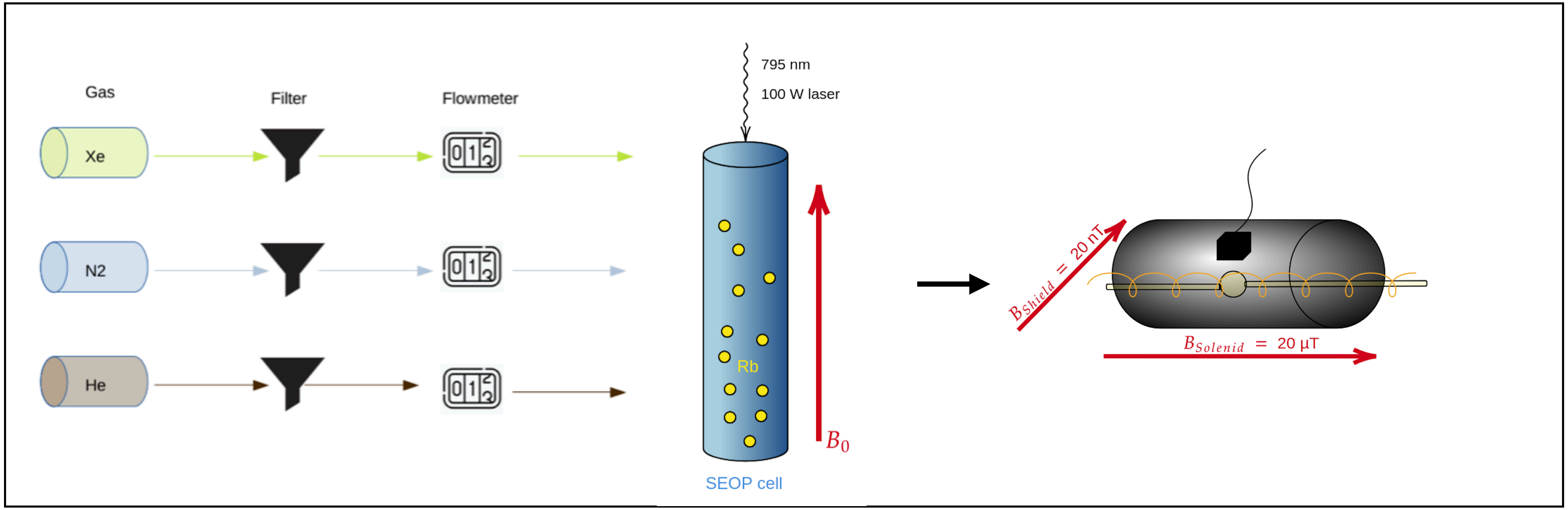

Measured Polarization

Magnetic shield with a magnetometer:
In continuous flow mode 10 %

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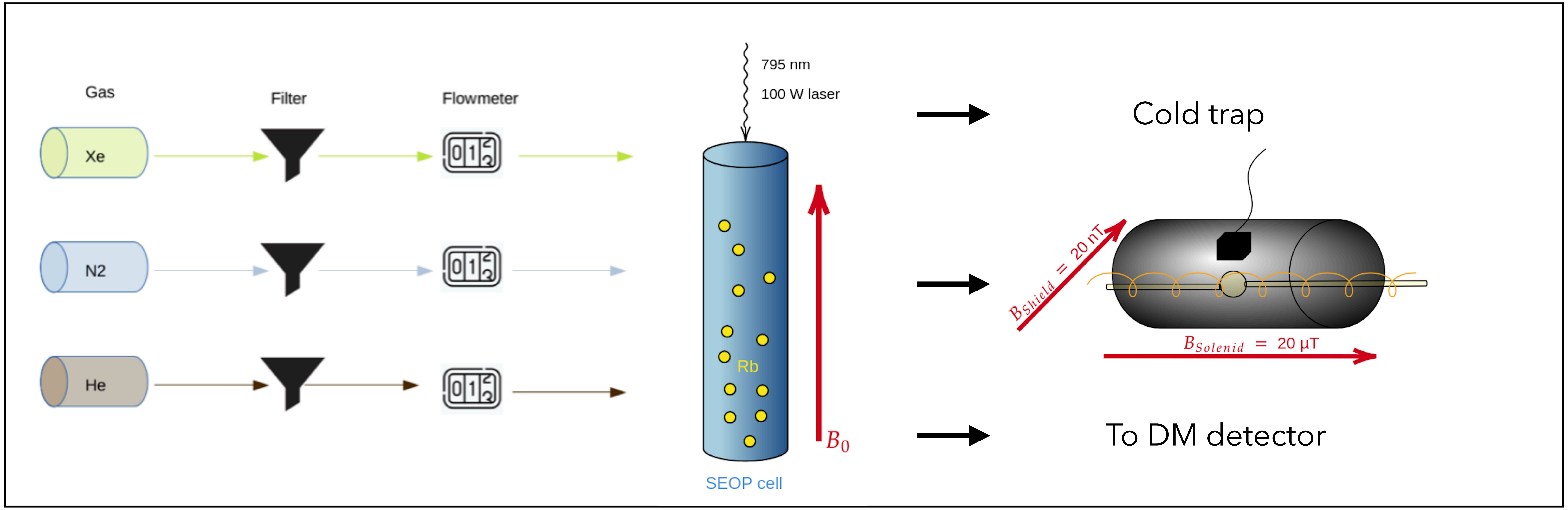


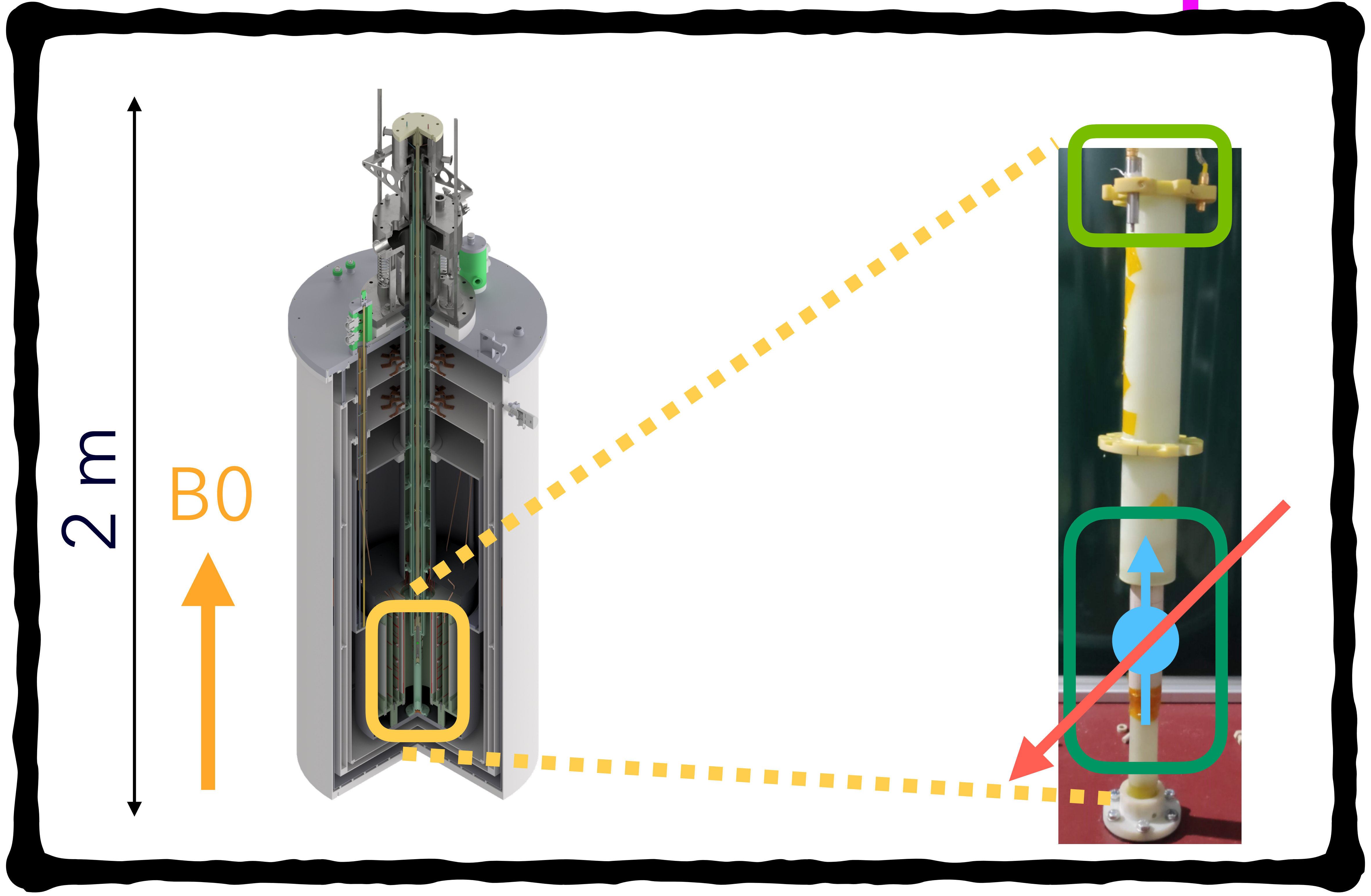
Measured Polarization

Magnetic shield with a magnetometer:
In continuous flow mode 10 %

Further advantage of hyperpolarized Xenon:

1) Liquid at 160 K
2) Long T1 time (~1h)
3) Long T2 time of (~ 100 s)

ALP detection setup



- Nb superconductor (0.1 T)
- SQUIDS for detecting
- Nuclear spins (thermally polarized methanol/hyper polarized xenon)
- Pickup coils, Excitation coil, Helmholtz coils
- ALP field $a(t) = a_0 \cos(\omega \cdot t)$

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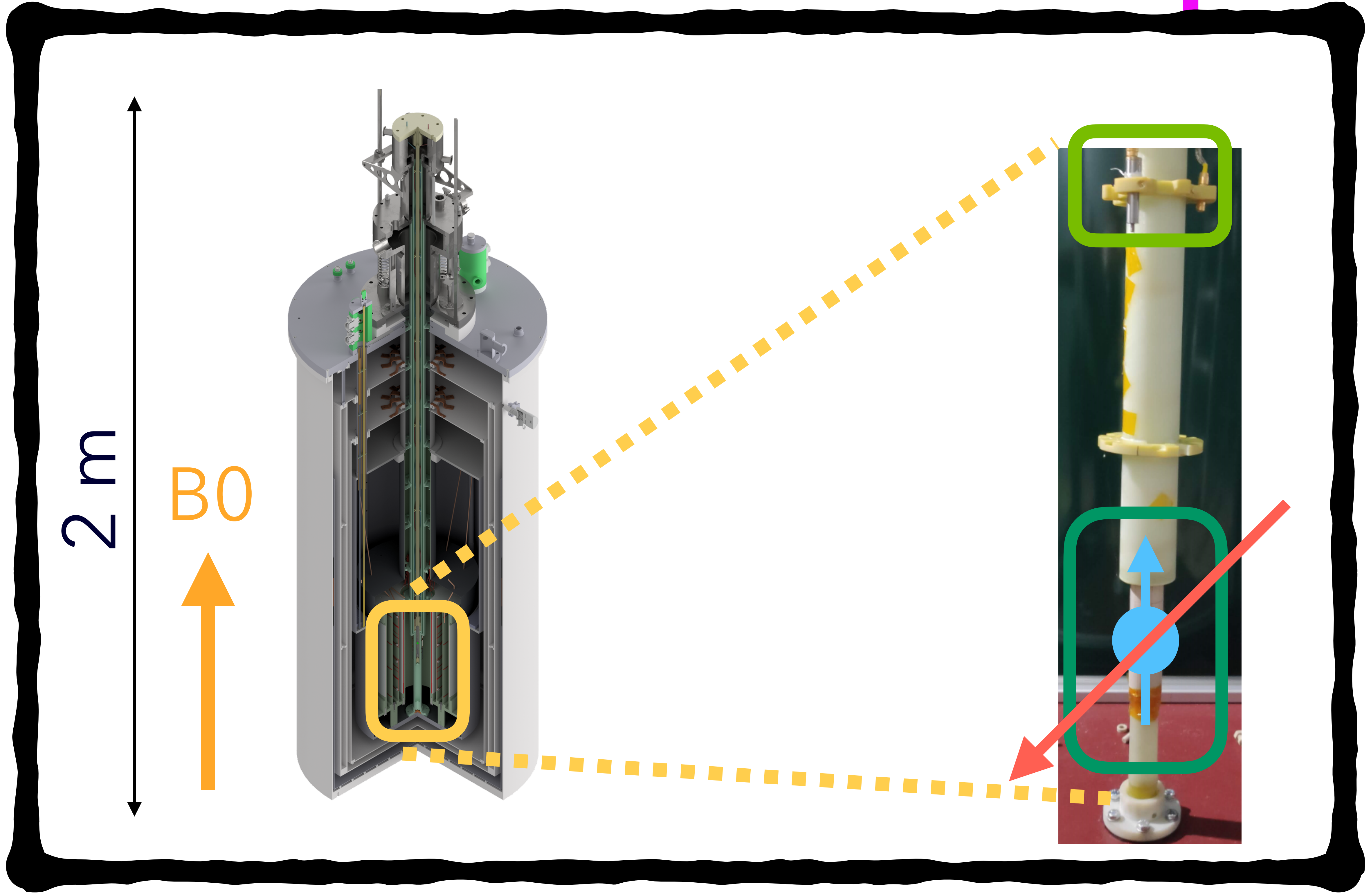

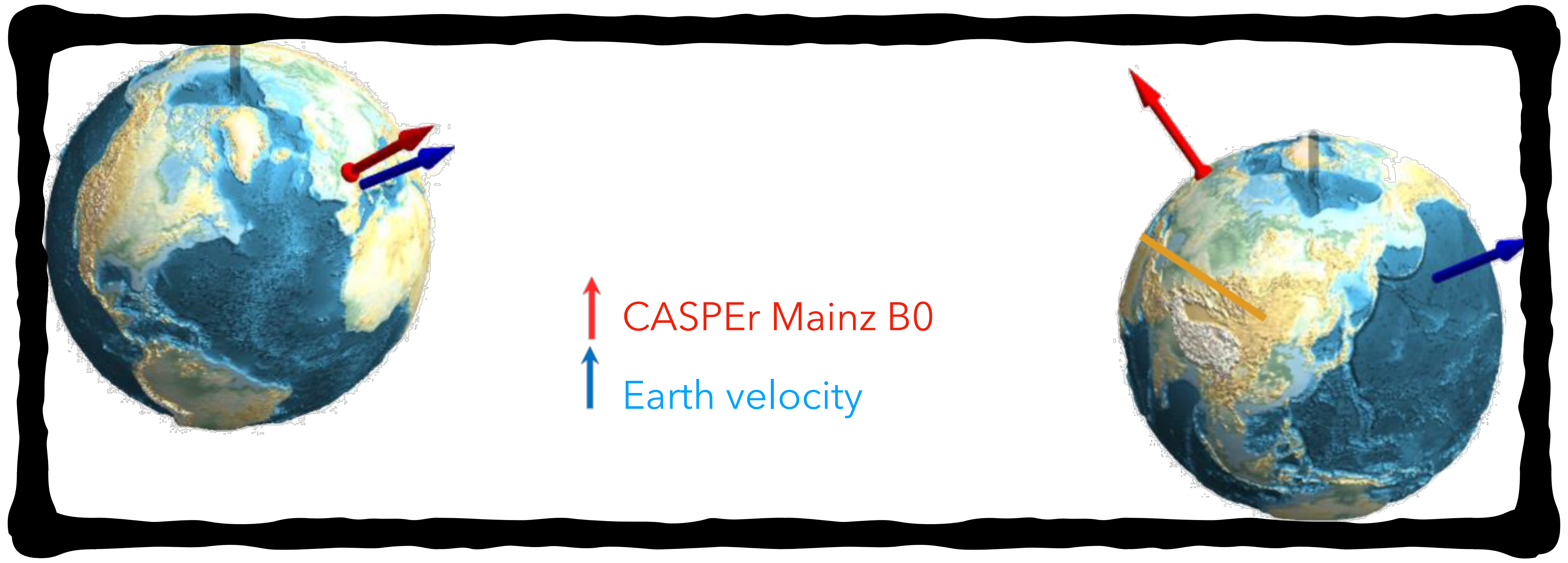

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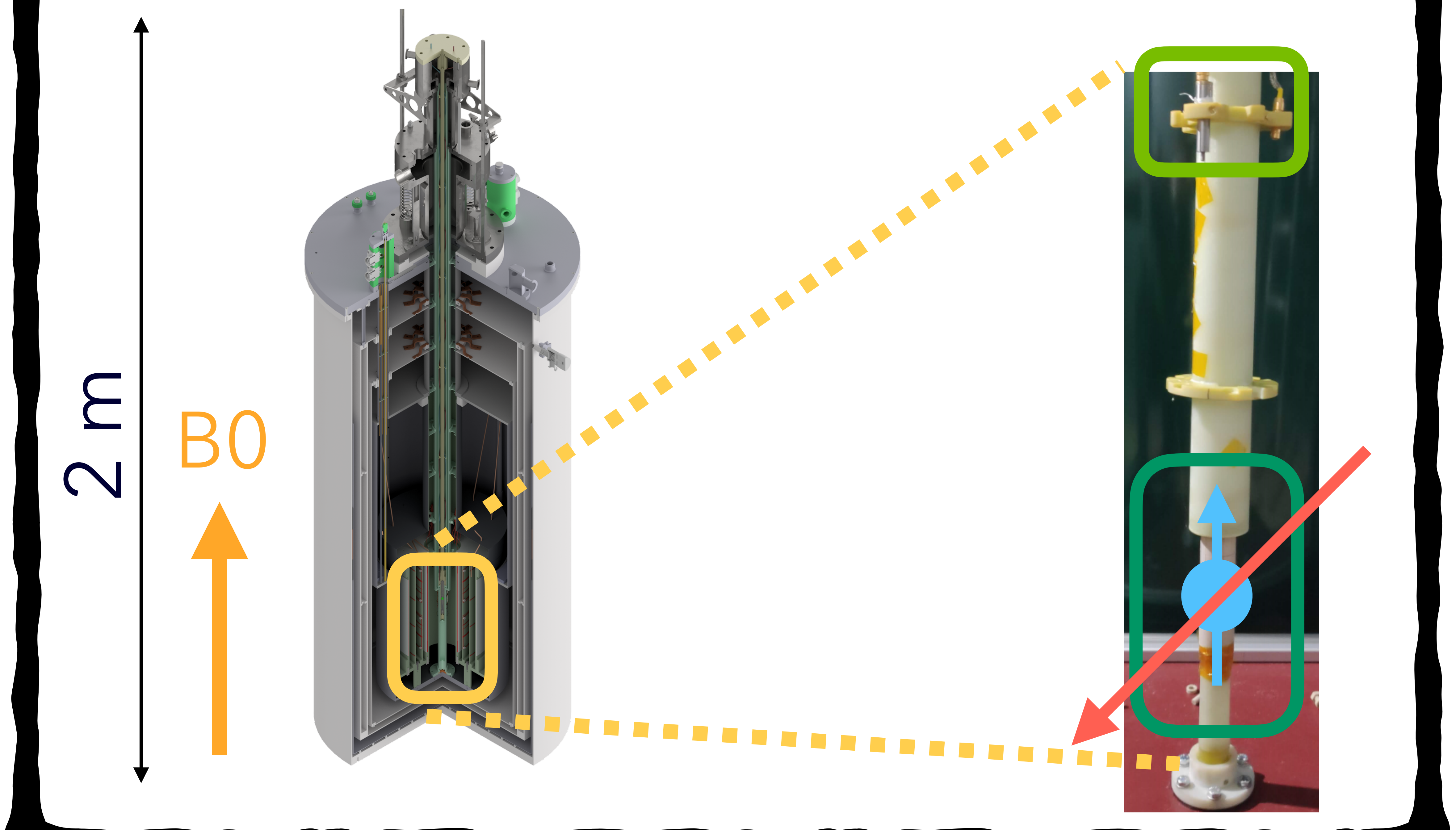

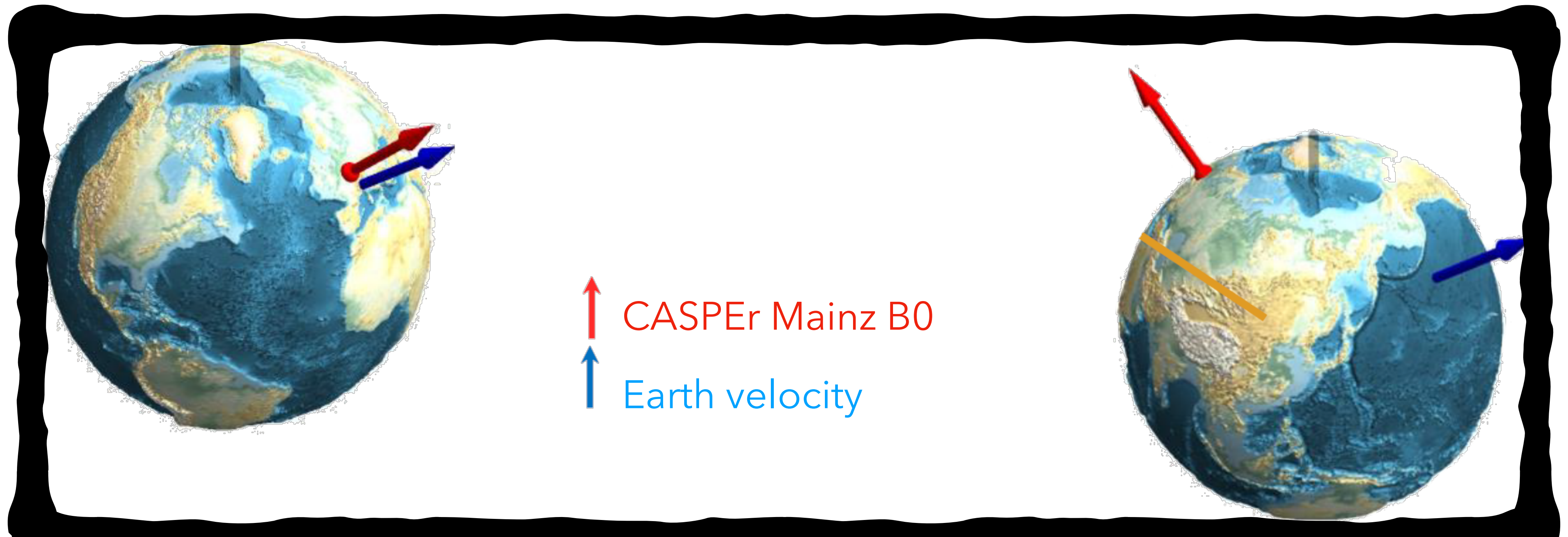

Decoherent ALPs

$$\tau_c = \frac{c^2}{\pi \, \nu_a \, v_a^2}$$ „coherence time“

c speed of light, ν_a Compton frequency of ALPs, v_a velocity of ALPs

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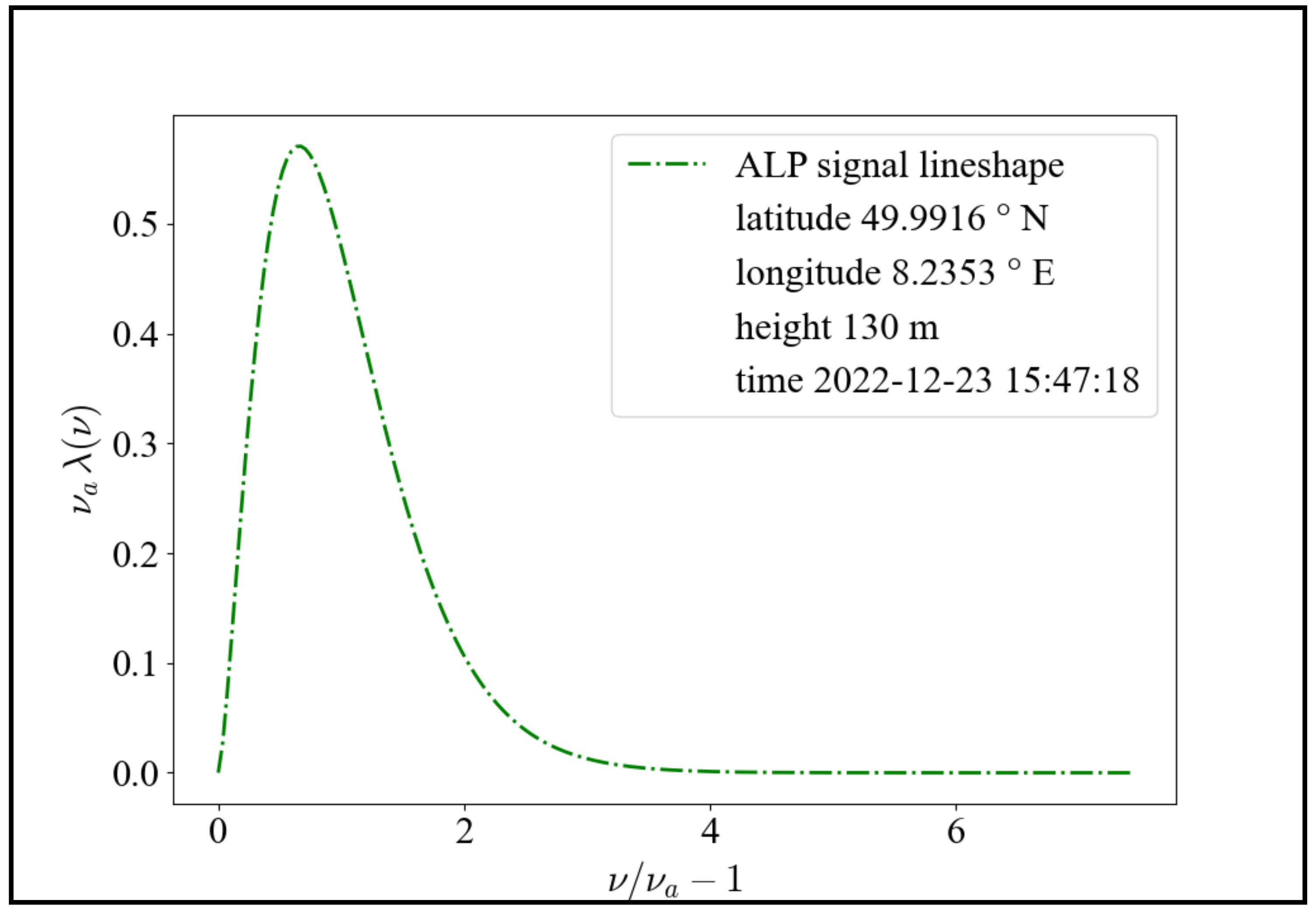

PHYSICAL REVIEW D 105, 035029 (2022)

DM search with a thermally polarized methanol sample

Sample and setup characterization:

- T_2^* time
- T_2 time Carr-Purcell-Meiboom-Gill pulse sequence
- Larmor frequency
- Magnetization

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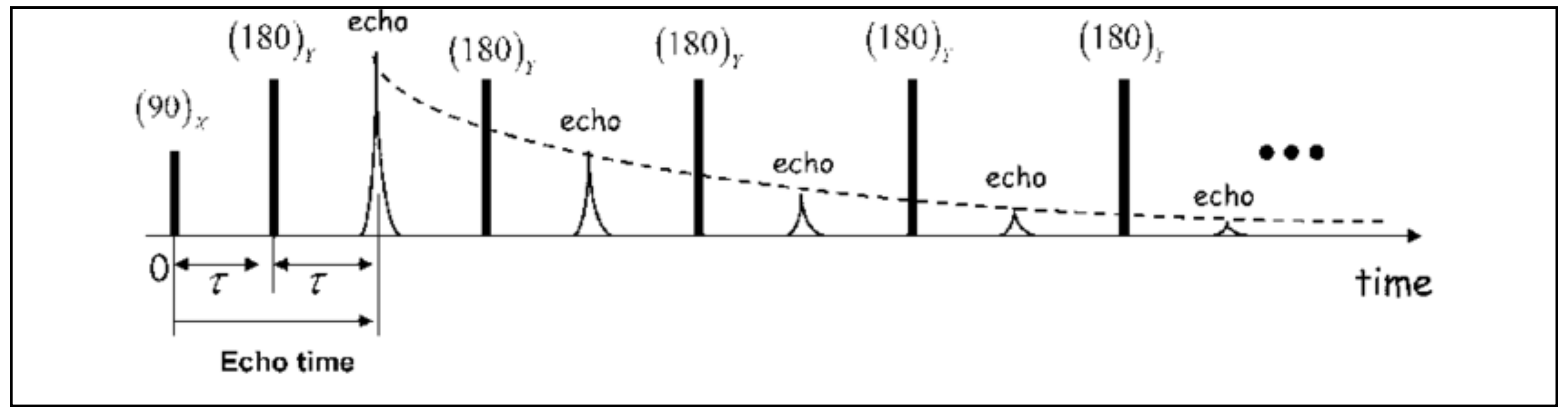
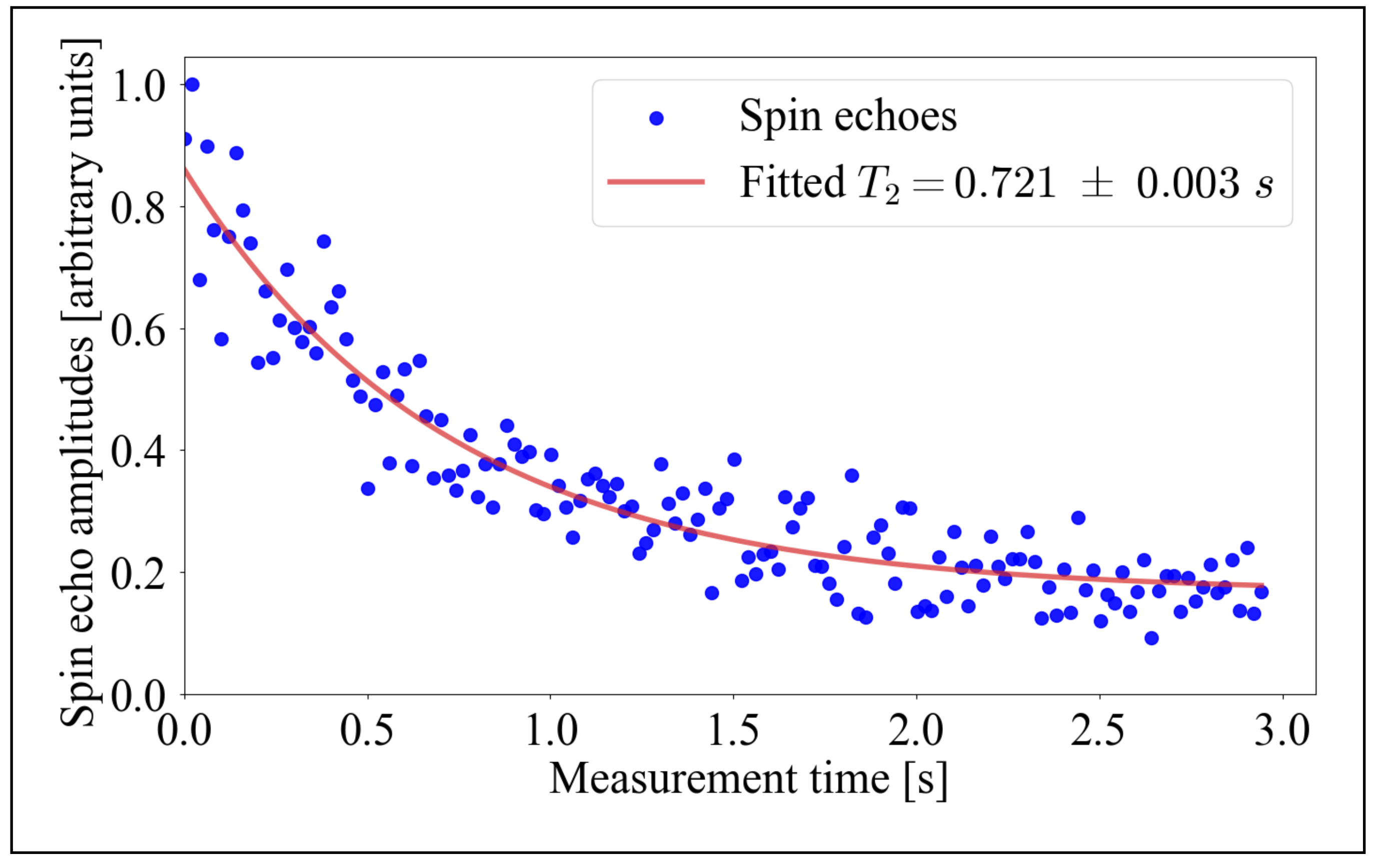
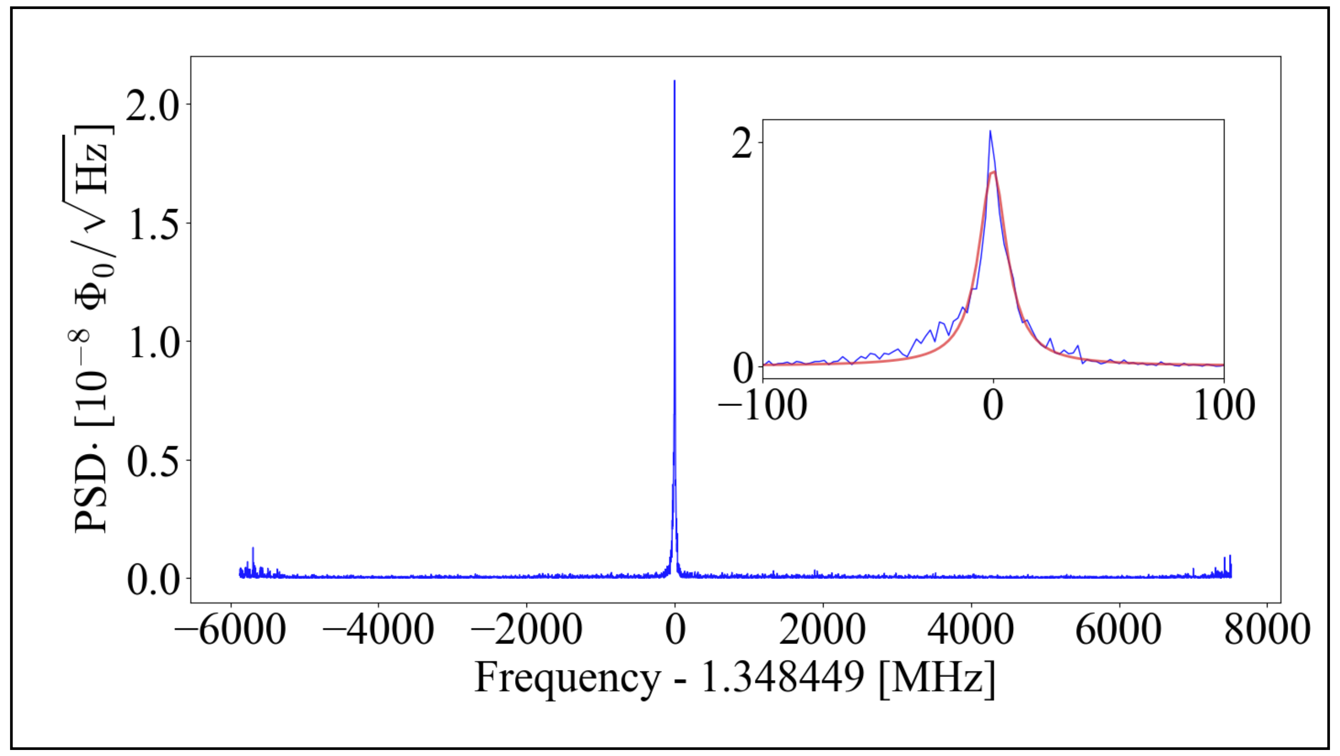
Preliminary plots







DM search with a thermally polarized methanol sample

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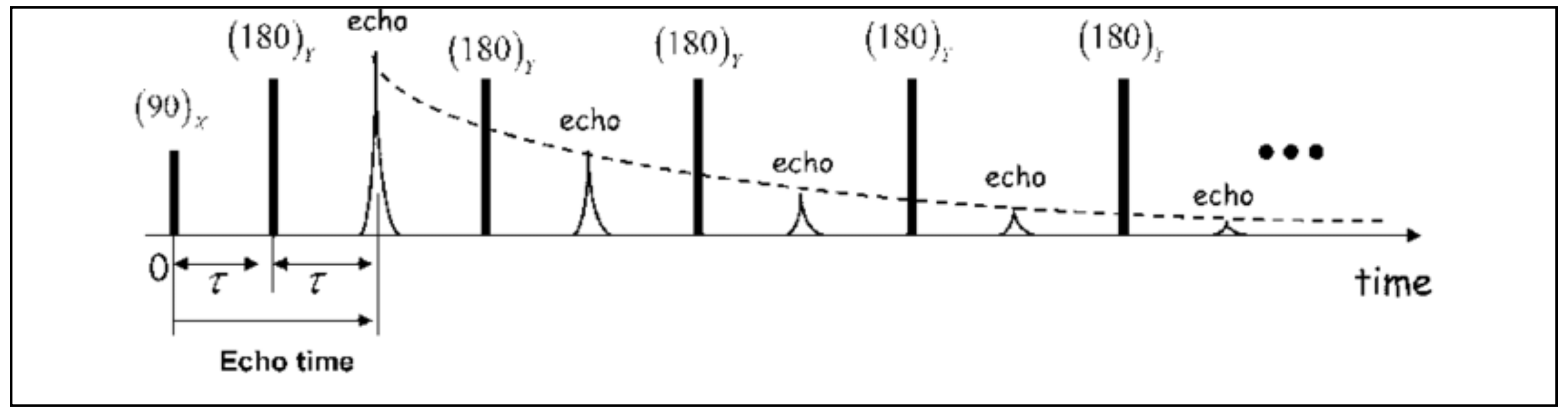
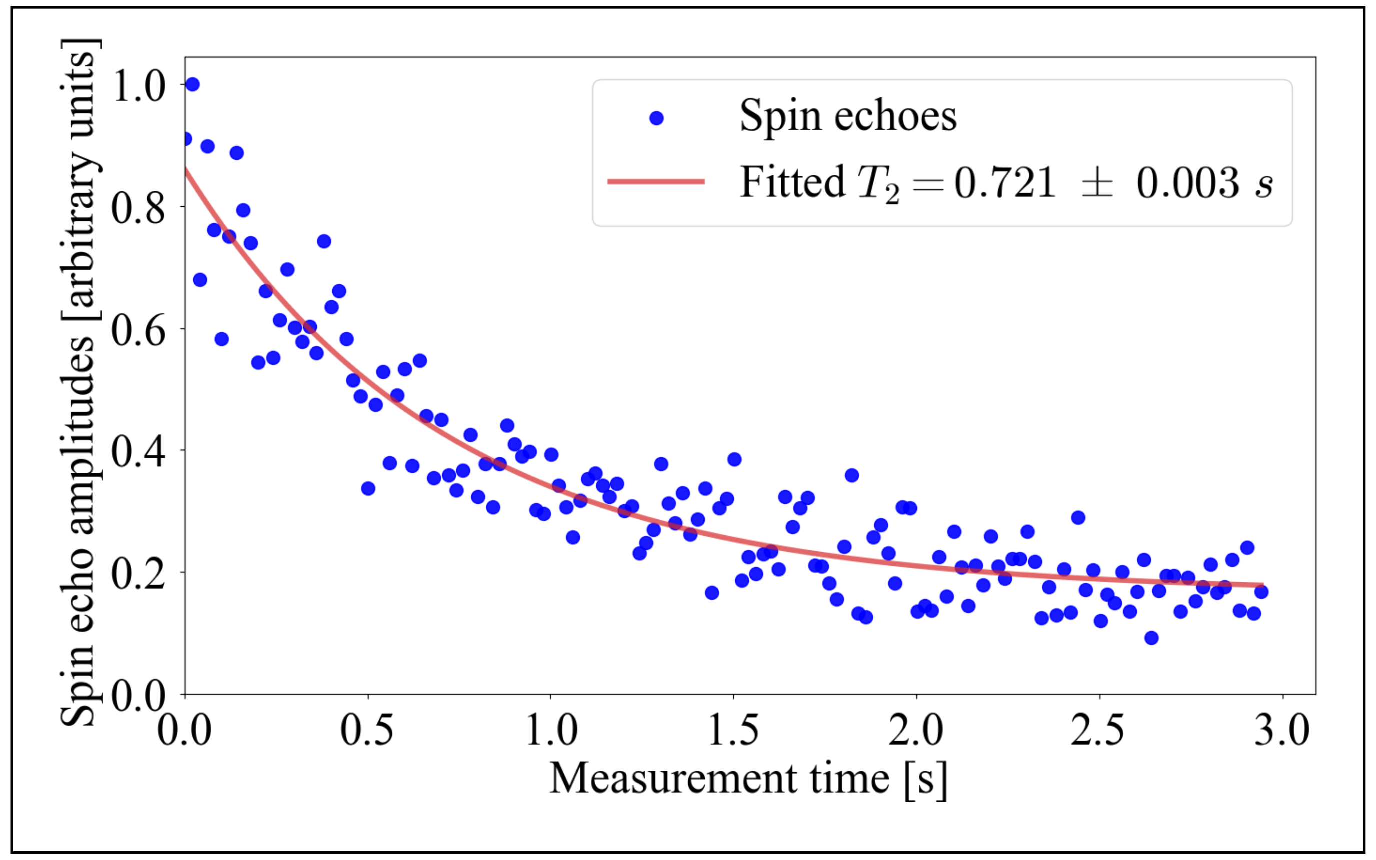
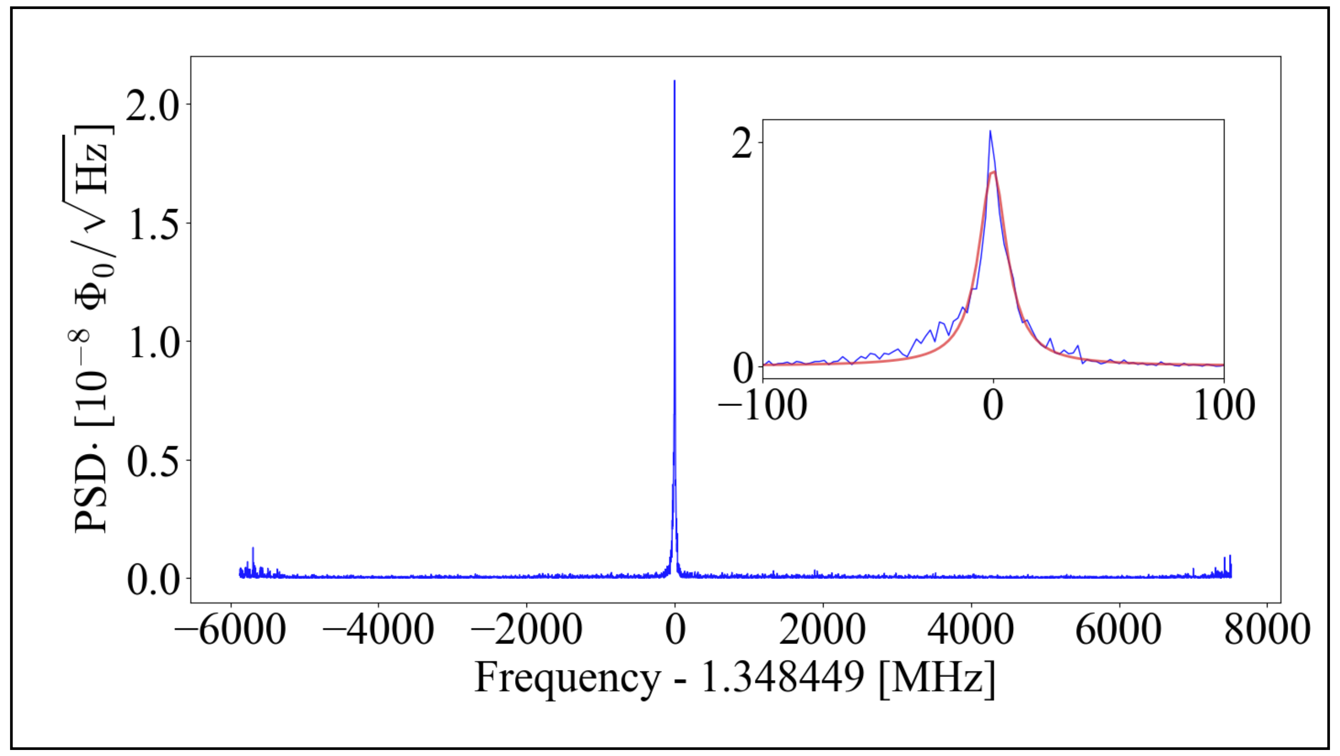
100 s of DM search

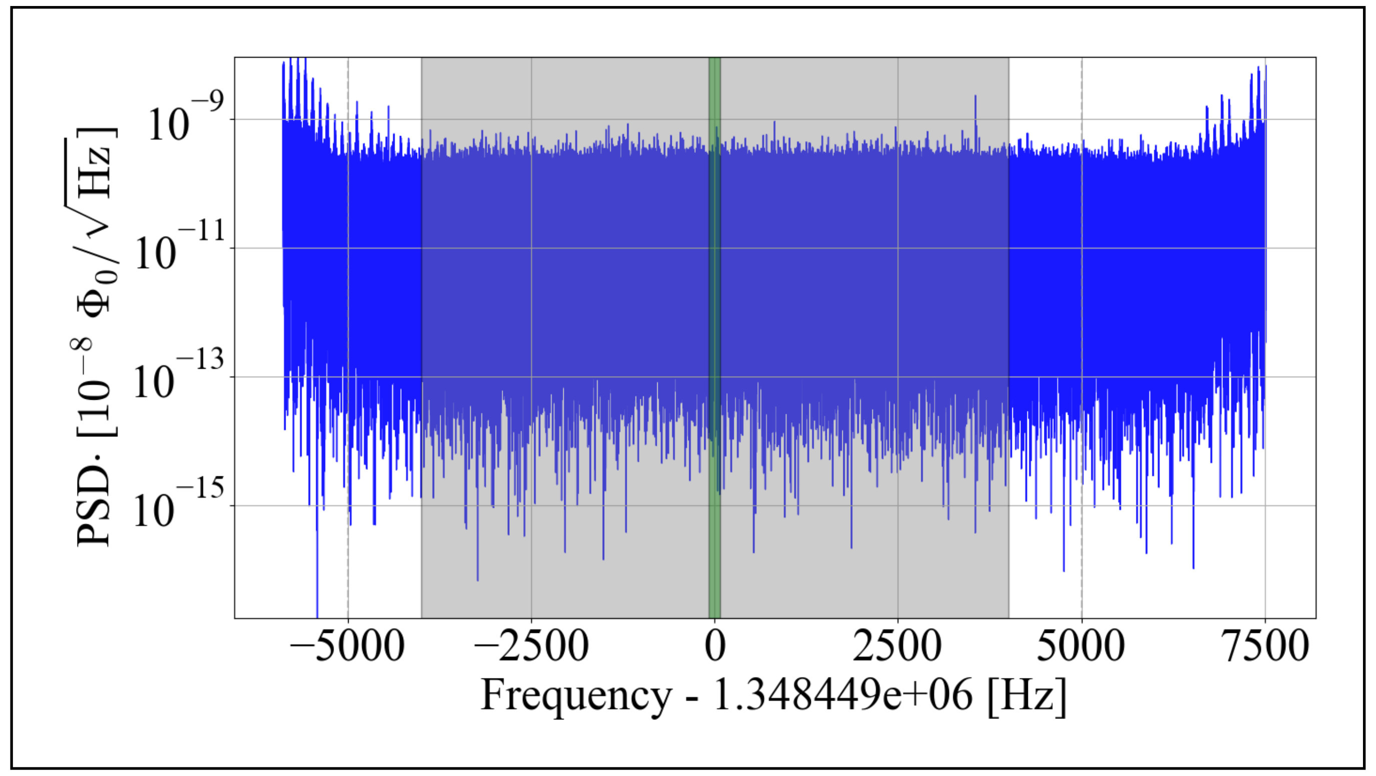
Ramp up leading field
-> increasing Larmor frequency by 6 Hz

Preliminary plots









DM search with a thermally polarized methanol sample

Sample and setup characterization:

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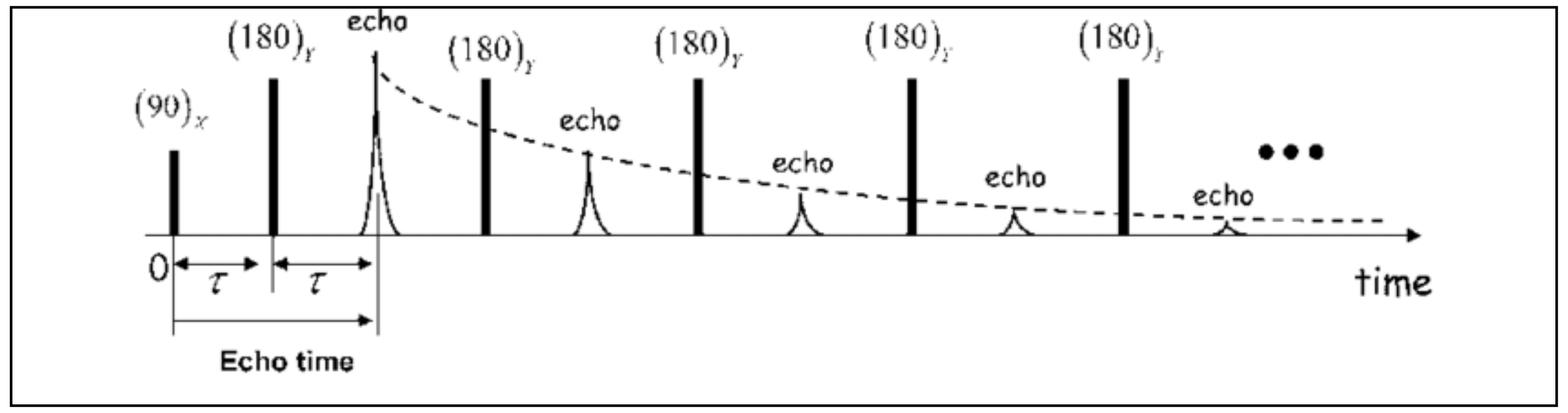
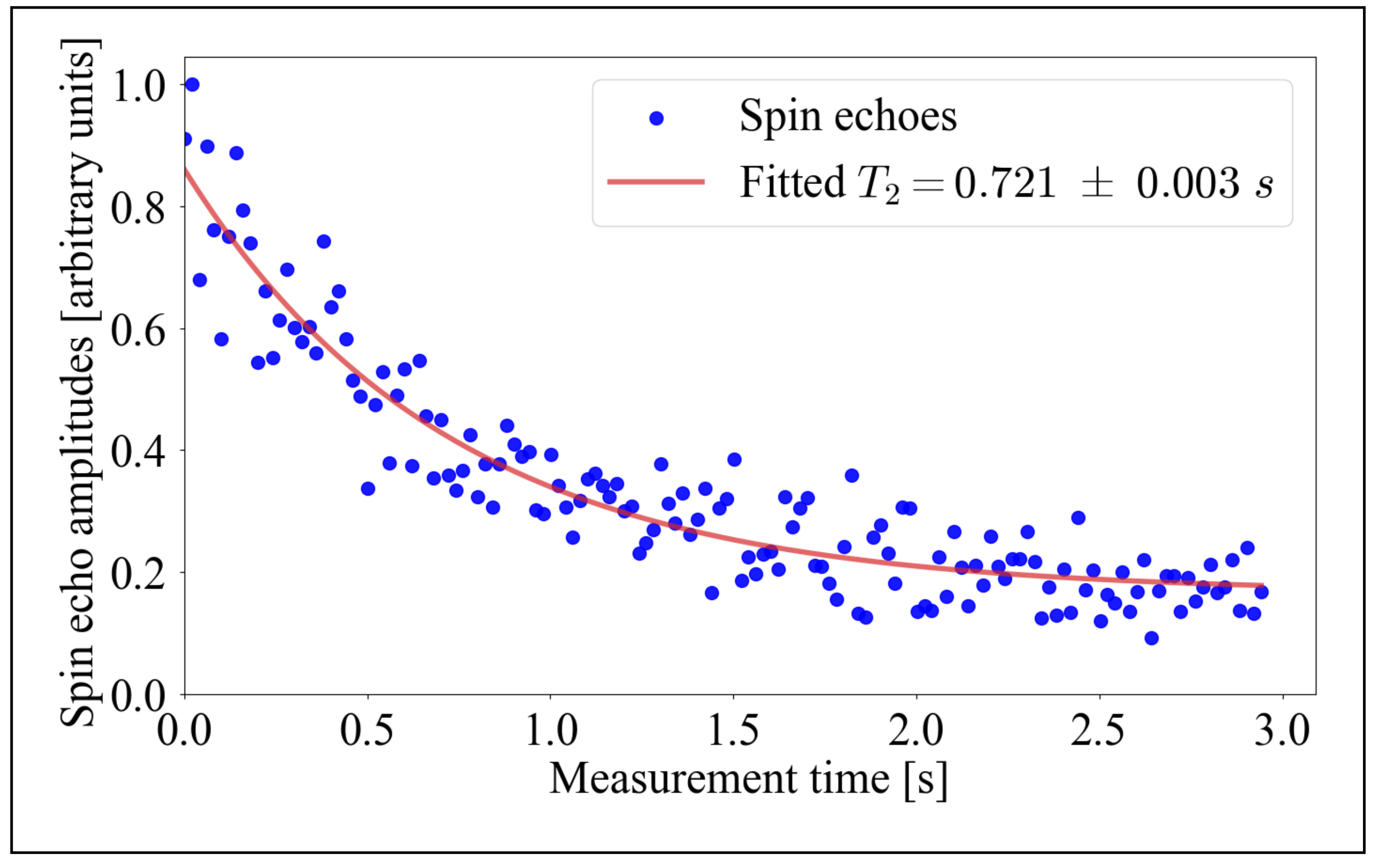
100 s of DM search

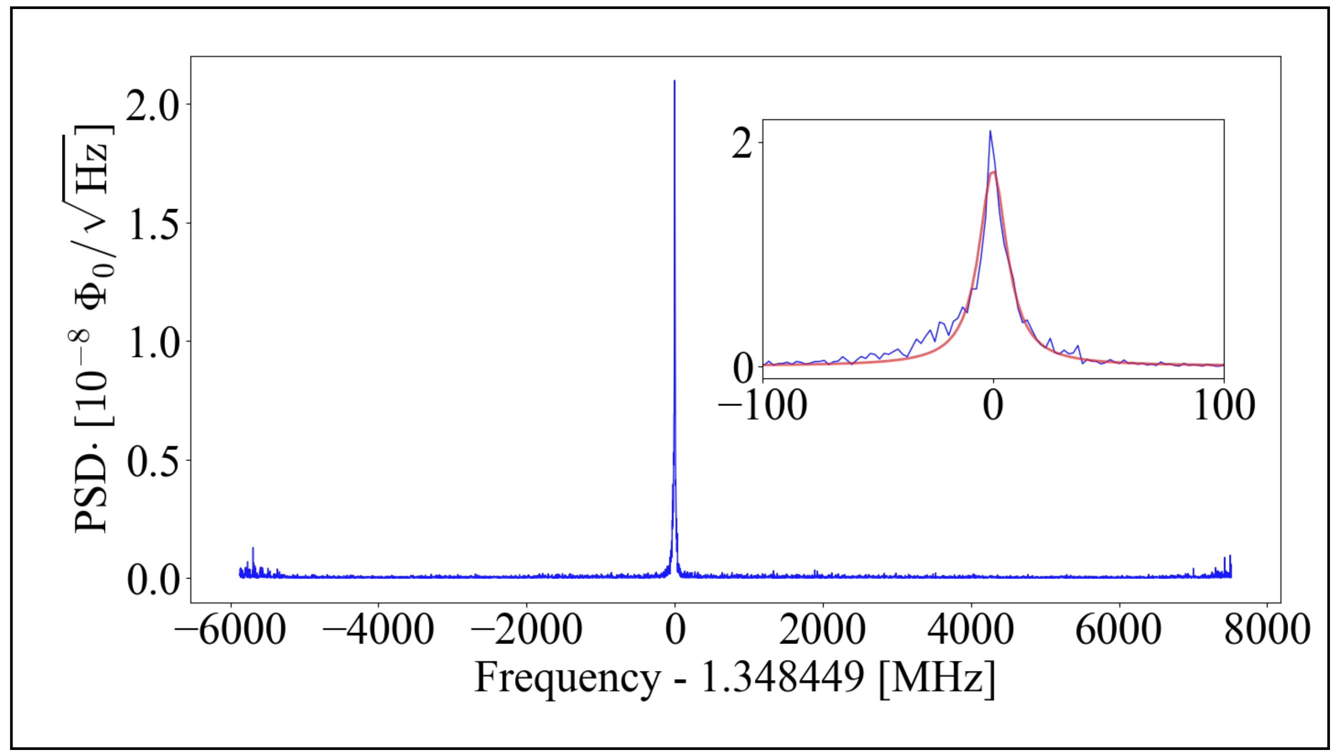
40 x

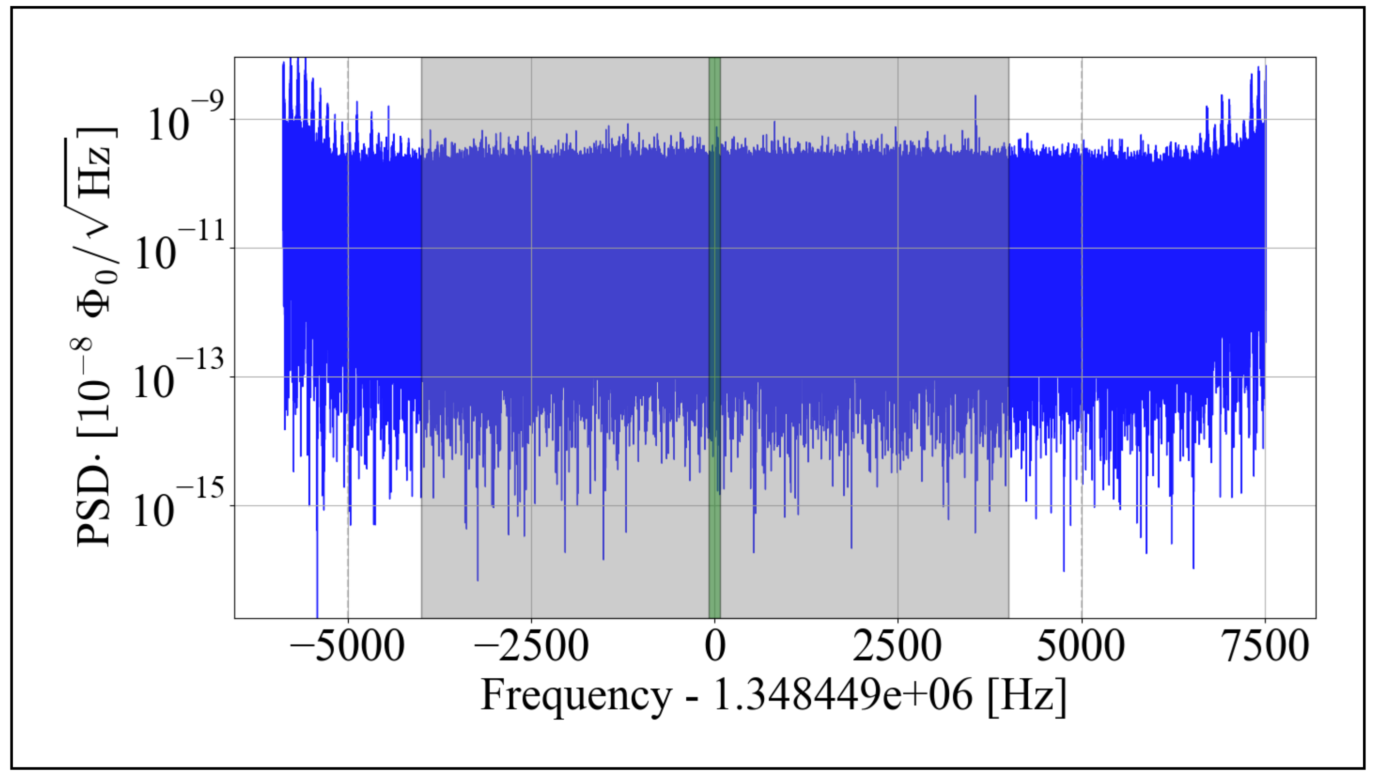
Ramp up leading field
-> increasing Larmor frequency by 6 Hz

Preliminary plots



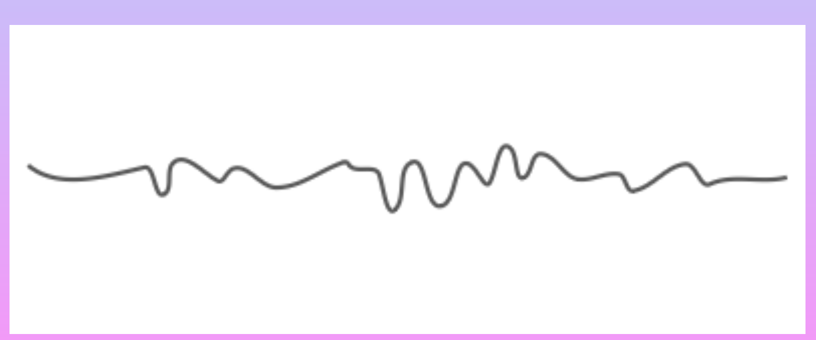






Analysis

Power Spectral Density (PSD)
100 s of DM search



Analysis

SNR enhancement:

1) Savitzky-Goaly Filter
   Removes features with much smaller/wider line width.

2) Matched filter
   Using information about the expected signal predict the potential ALP signal

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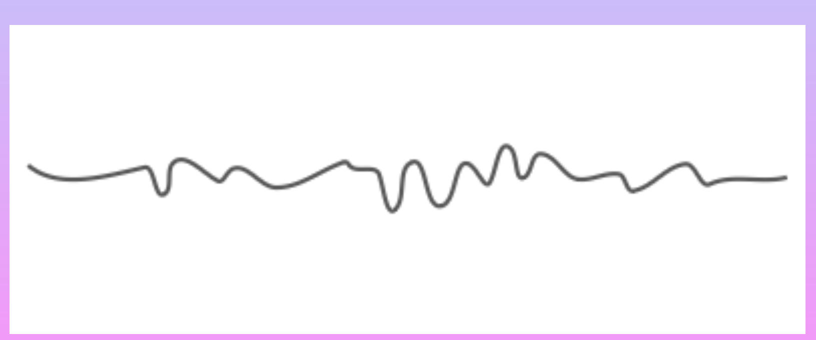

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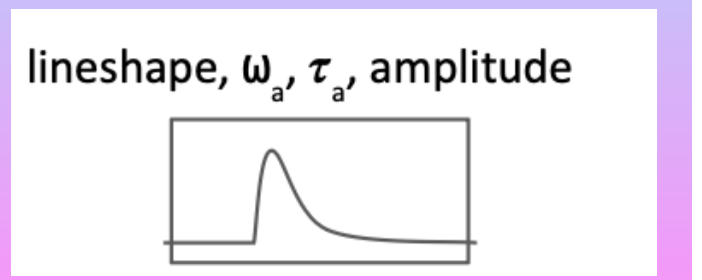

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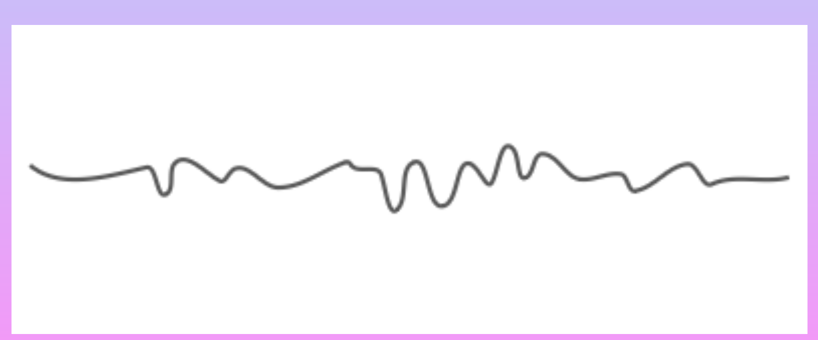

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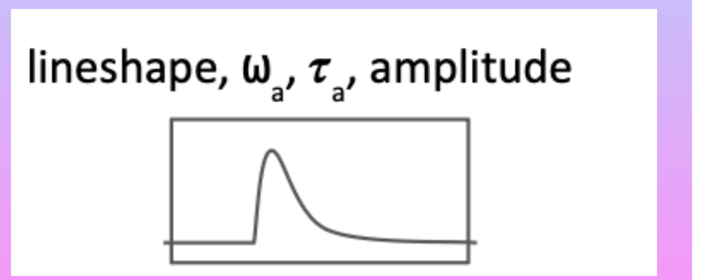
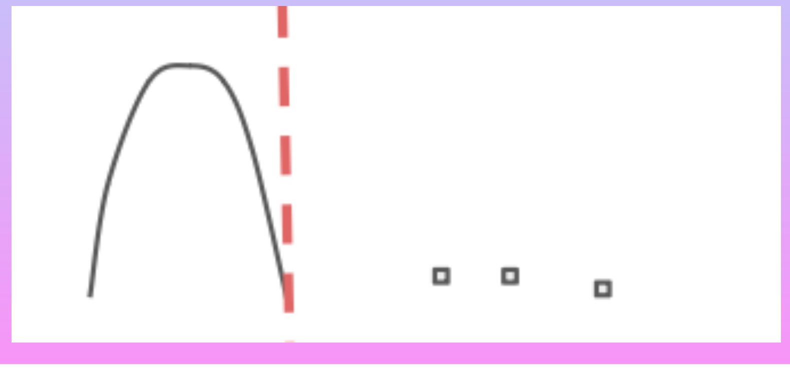


Make histogram

Define a treshold



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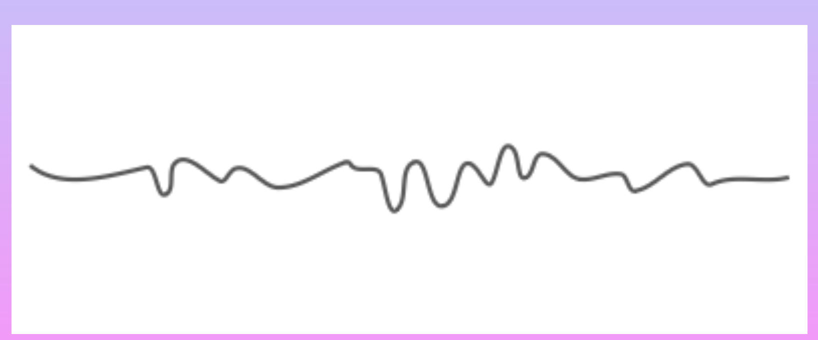

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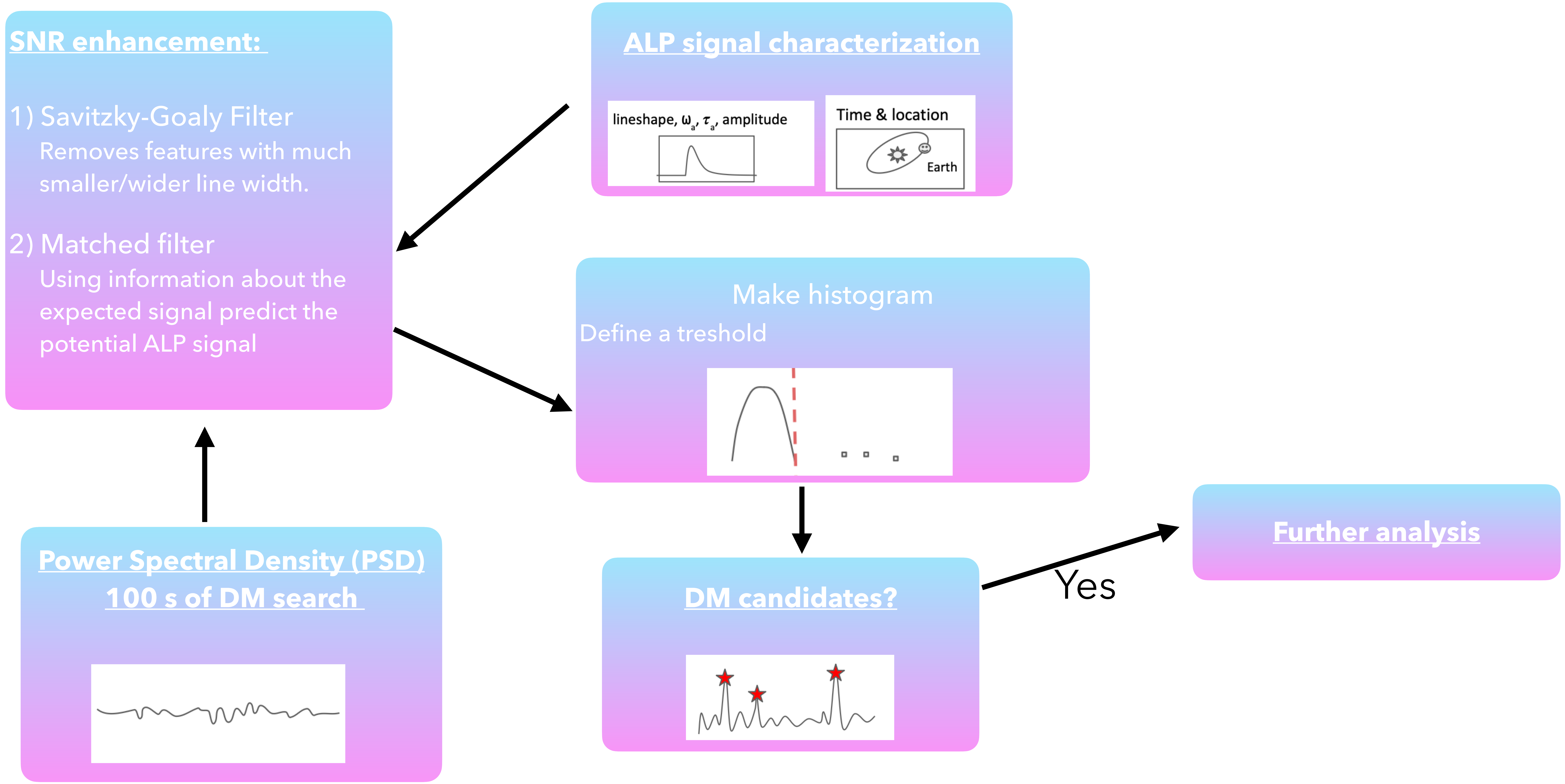

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ALP signal characterization
lineshape, ω_a, τ_a, amplitude
Time & location
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Make histogram
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Power Spectral Density (PSD)
100 s of DM search
DM candidates?
Yes
Further analysis

Analysis

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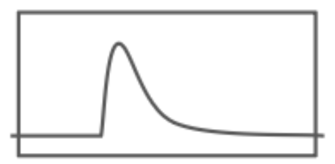

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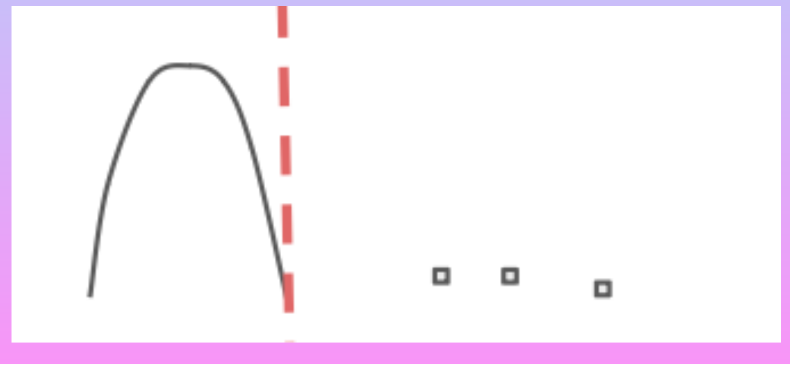

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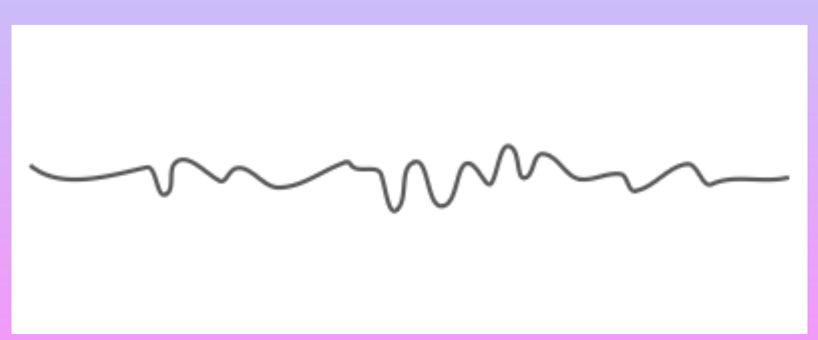

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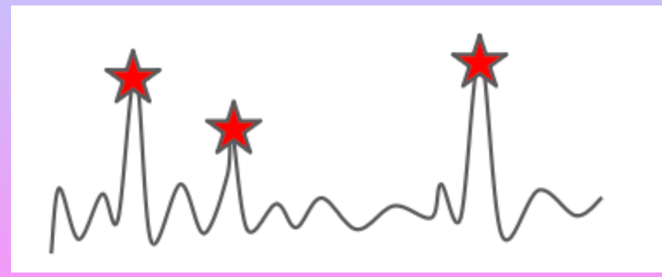


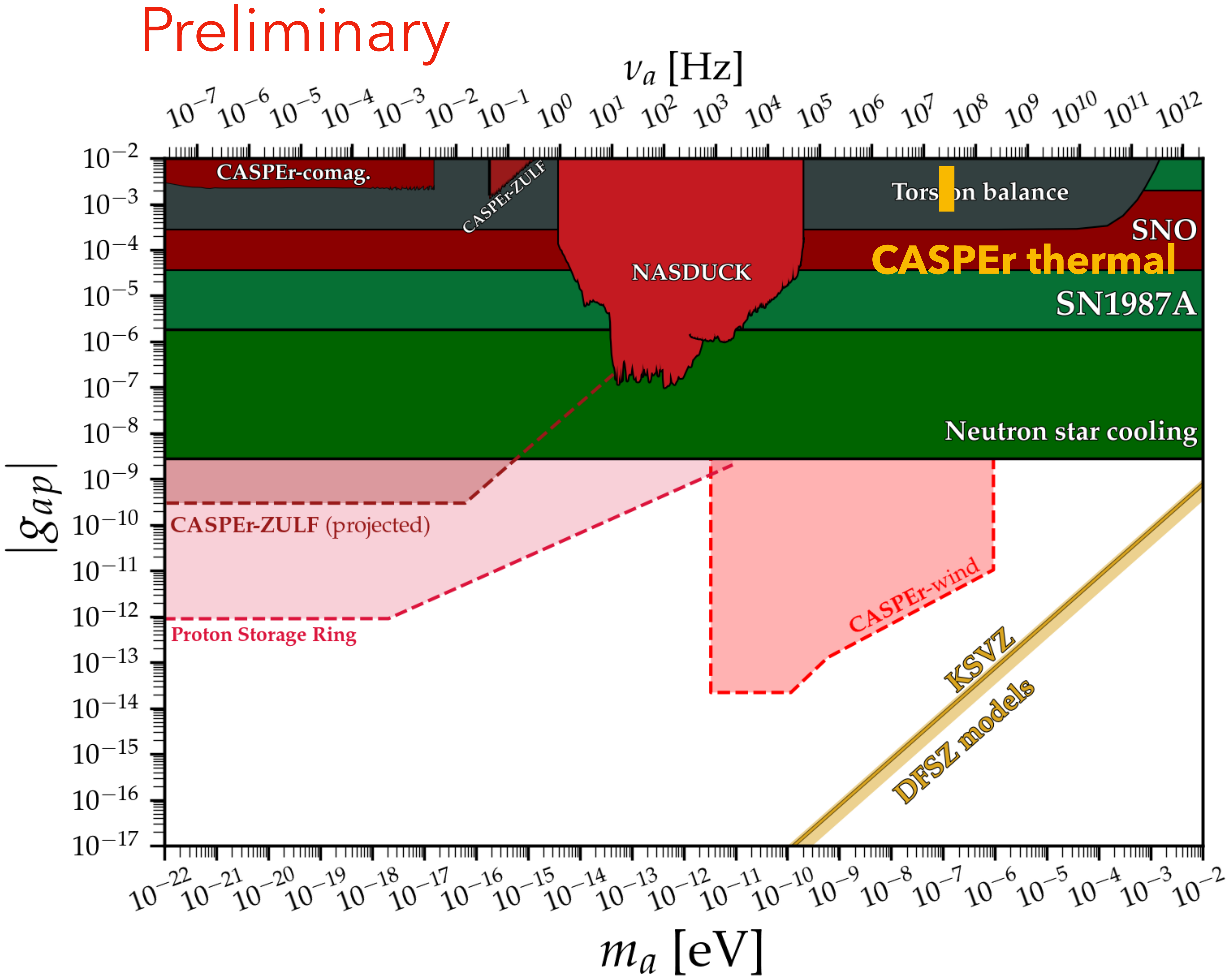
Yes

Further analysis

No

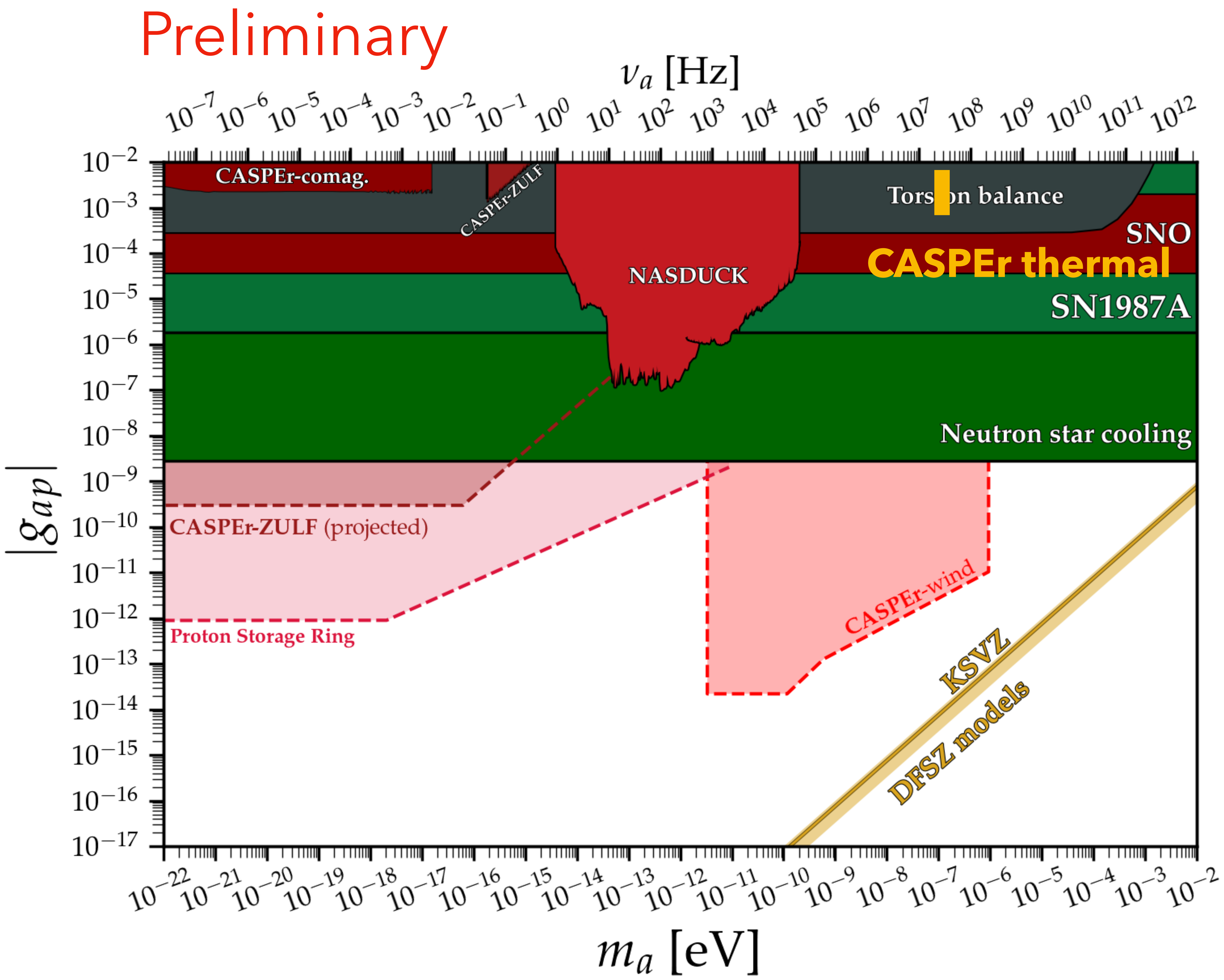
Exclusion limit

Results & Conclusion



D.F. Jackson Kimball, arXiv, 2018

Results & Conclusion



D.F. Jackson Kimball, arXiv, 2018

1) Low field setup: frequency range KHz - MHz

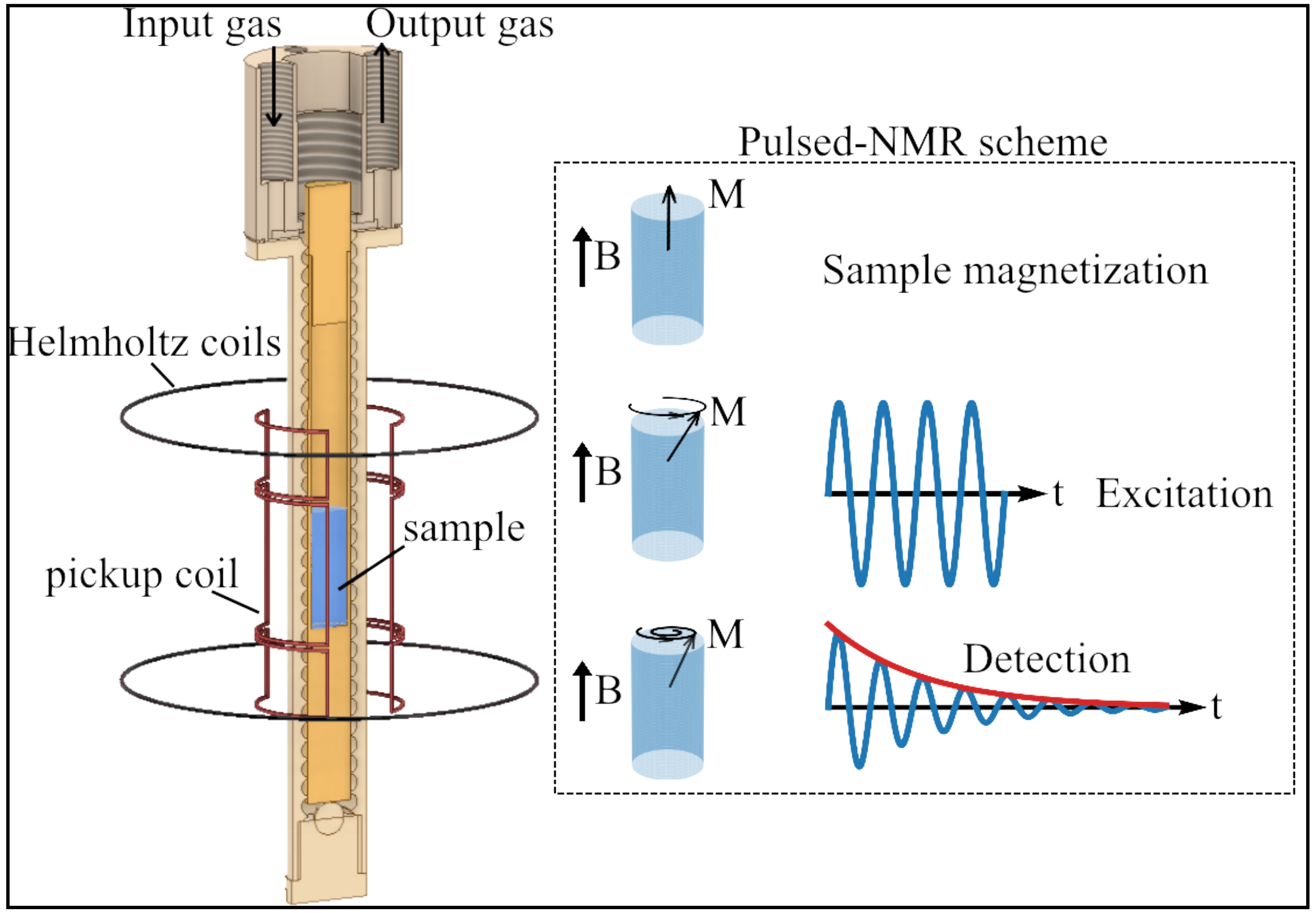
2) High field setup: frequency range - 600 MHz

3) DM search & analysis works for a 240 Hz frequency range

Outlook

- **Transfer HP Xe to Low field setup (0.1 T)**
  -> Will increase sensitivity by 6 orders of magnitude
  -> As an alternative higher thermally polarized sample

Liquify Xenon



Outlook

- **Transfer HP Xe to Low field setup (0.1 T)**
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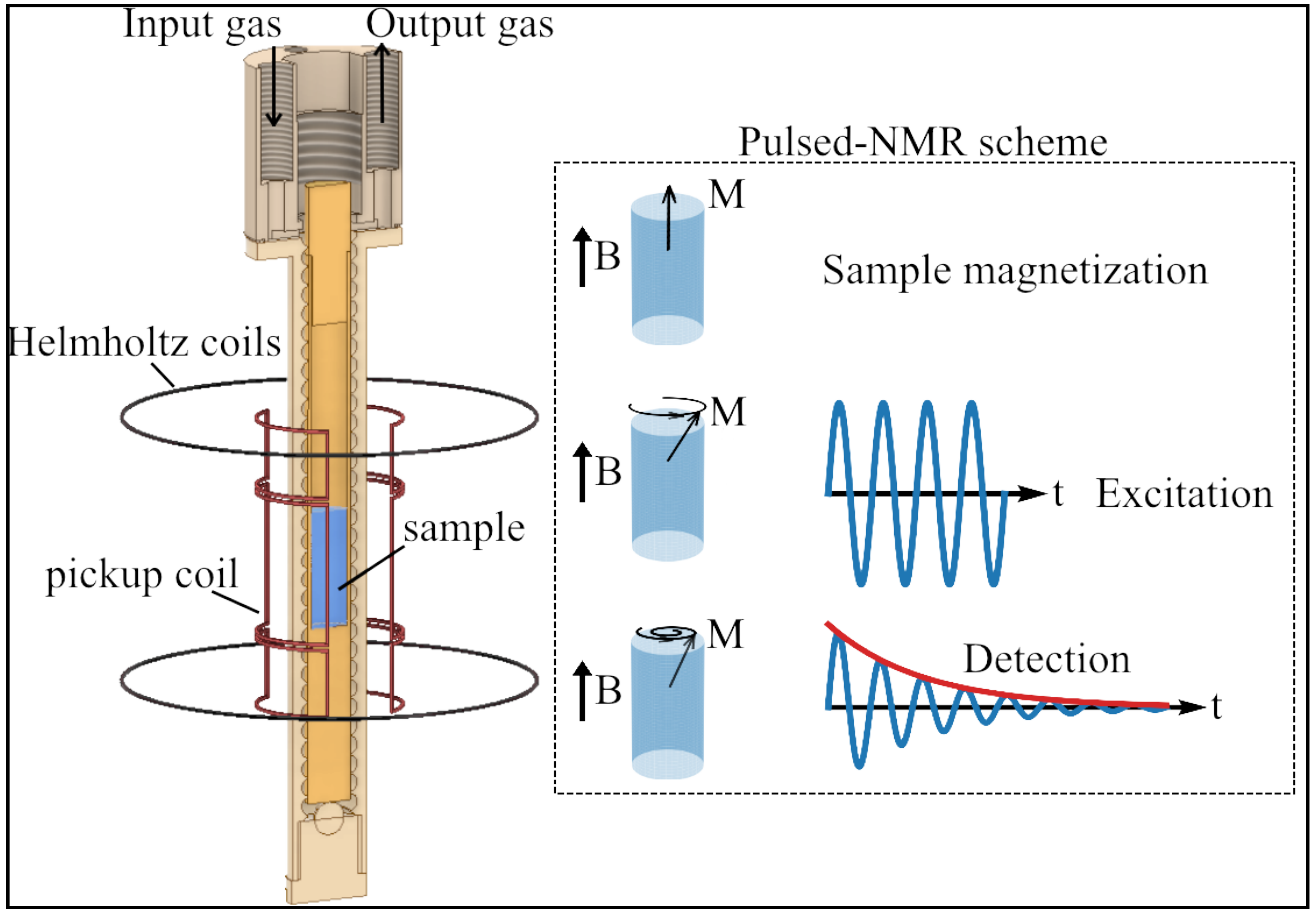
- **Transport of hyperpolarized Xe to the High field setup (14 T) or using other candidates**

Liquify Xenon



Our Team

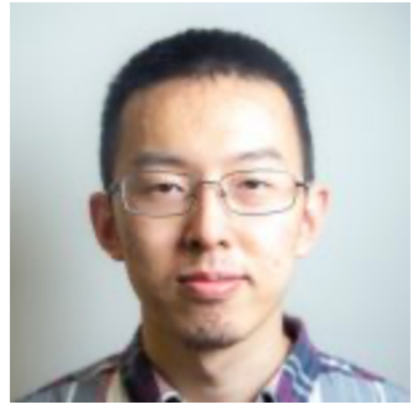

Prof. Dr. Dmitry Budker


Dr. Arne Wickenbrock


Dr. Hendrik Bekker


Dr. Younggeun Kim


Dr. Jonathan Agil

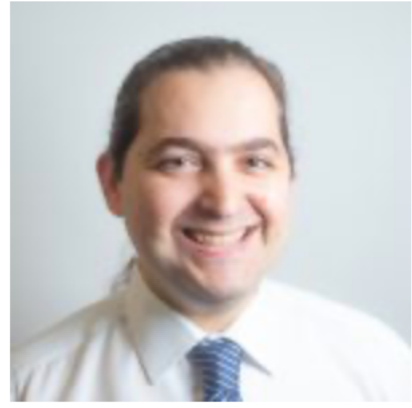

Yuzhe Zhang


Olympia Maliaka


Julian Walter


Malavika Uni


Arian Dogan


Ophir Ruimi