The search for neutron to mirror neutron oscillations at PSI

Nathalie Ziehl,
On behalf of the nn’ collaboration at PSI
ETH Zürich

11. September 2024

Introduction

What is mirror matter?

- Mirror symmetry was proposed by Lee & Yang (1956) to restore Parity in the weak sector.
- Eeach left-handed SM particles gets a right-handed mirror equivalent.
- Mirror matter interacts with ordinary matter only through gravity [1].
- Neutral particles can oscillate into their mass-degenerate mirror partner [2].
  → requires $E_{pot}(n) = E_{pot}(n')$, therefore $B = B'$
  → Earth could have a mirror magnetic field $B' \neq 0$ [3]

[1] I. Yu. Kobzarev, L. B. Okun, I. Ya. Pomeranchuk, Sov. J. Nucl. Phys. 3 (6) (1966), 837–841
[2] Z. Berezhiani, L. Bento PLB 635 (5-6) (2006) 253-259
[3] A. Yu. Ignatiev, R. R. Volkas, Phys. Rev. D68 (2003) 023518.

Introduction

Ok, but why is it interesting?

- n – n’ mixing violates baryon number conservation.
- Mirror matter is dark matter candidate.

Introduction

THE EUROPEAN
PHYSICAL JOURNAL C

Eur. Phys. J. C (2012) 72:1974
DOI 10.1140/epjc/s10052-012-1974-5

Letter

Magnetic anomaly in UCN trapping: signal for neutron oscillations to parallel world?

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5

Introduction

$n \longrightarrow n'$ described for free neutrons by Hamiltonian:

$$\mathrm{H} = \begin{pmatrix} \vec{\mu}_n \mathbf{B} \cdot \sigma & \hbar/\tau_{nn'} \\ \hbar/\tau_{nn'} & \vec{\mu}_n \mathbf{B}' \cdot \sigma \end{pmatrix}$$

$\tau_{nn'}$ oscillation time

$\vec{\mu}_n$ neutron magnetic dipole moment

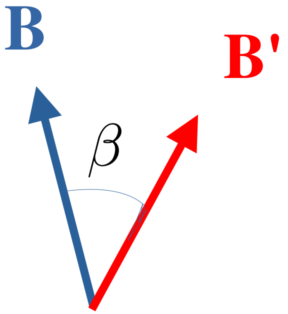
B, B' : magnetic and mirror magnetic field

$n \longrightarrow n'$ oscillation probability:

$$P_{BB'}^{nn'}(t) = \frac{\sin^2[(\omega-\omega')t]}{2\tau_{nn'}^2(\omega-\omega')^2} + \frac{\sin^2[(\omega+\omega')t]}{2\tau_{nn'}^2(\omega+\omega')^2} + \left(\frac{\sin^2[(\omega-\omega')t]}{2\tau_{nn'}^2(\omega-\omega')^2} - \frac{\sin^2[(\omega+\omega')t]}{2\tau_{nn'}^2(\omega+\omega')^2}\right)\cos\beta$$

$n \longrightarrow n'$ oscillation probability:

$$P^{nn'}_{BB'}(t) = P^{nn'}_{BB'}(B, B', \beta, t)$$



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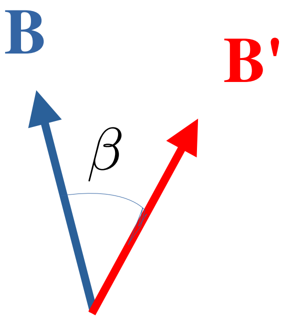

P enhanced by:

- $|\vec{B}| = |\vec{B}'|$ }
- small β }
- long times t

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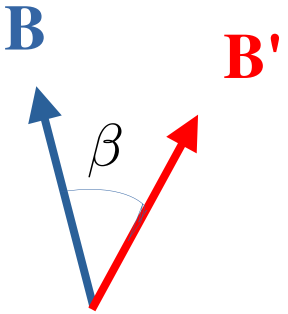

P enhanced by:

- $|\vec{B}| = |\vec{B}'|$
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Requirements

- Magnetic field control
- long lived, storable neutrons (UCN)
- Detector for n'

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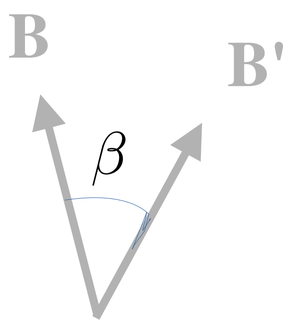

P enhanced by:

- $|\vec{B}| = |\vec{B}'|$
- small β
- long mixing times t

Requirements

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Challenges

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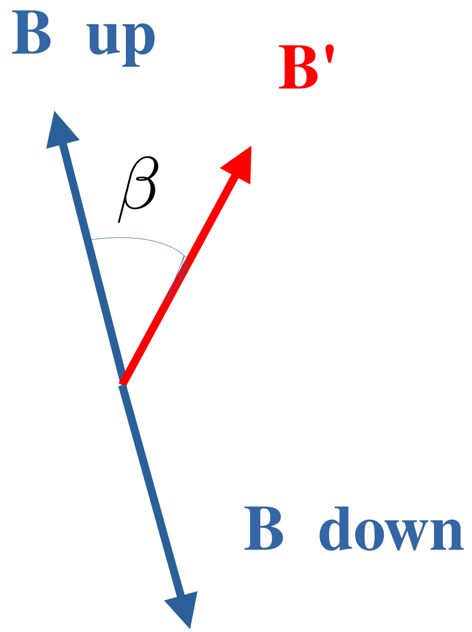
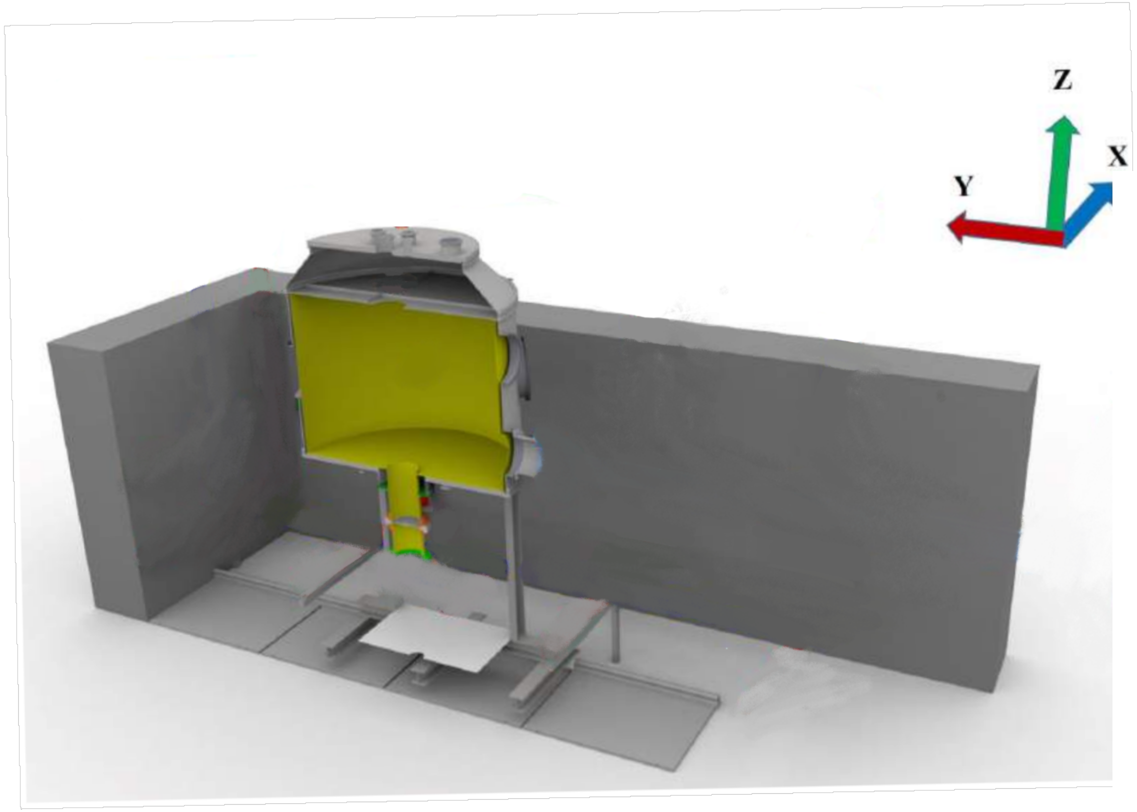
  → no detectors!
  → measure loss of n instead.

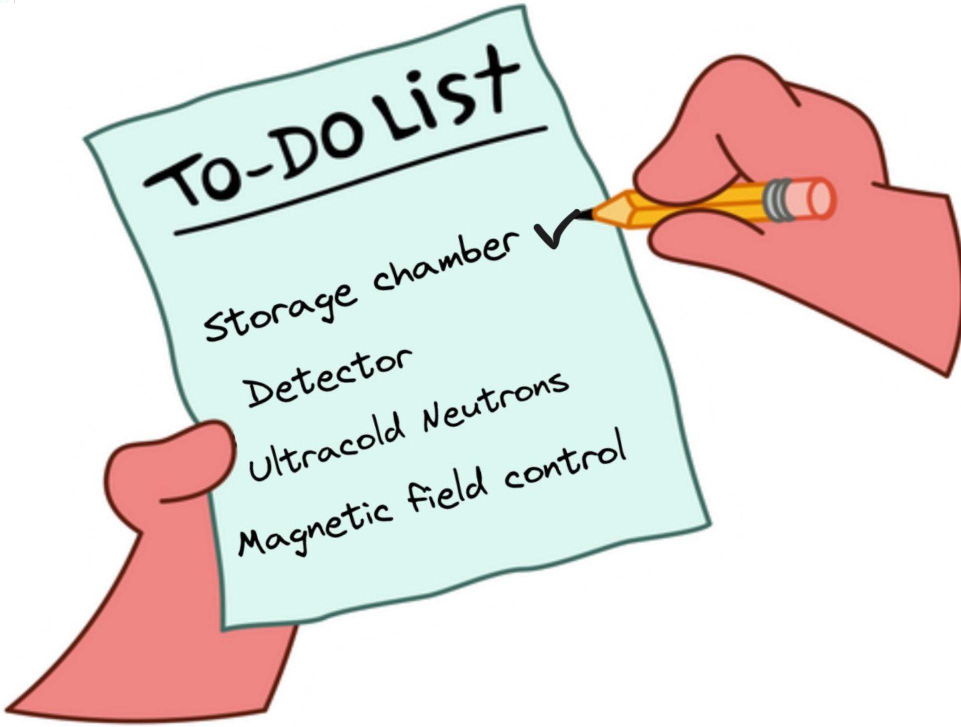
- We don't know B' *at all*.
  → measure at different |B|
  → measure for B and B

$$A = \frac{N_{B\uparrow} - N_{B\downarrow}}{N_{B\uparrow} + N_{B\downarrow}}$$



Experimental Setup





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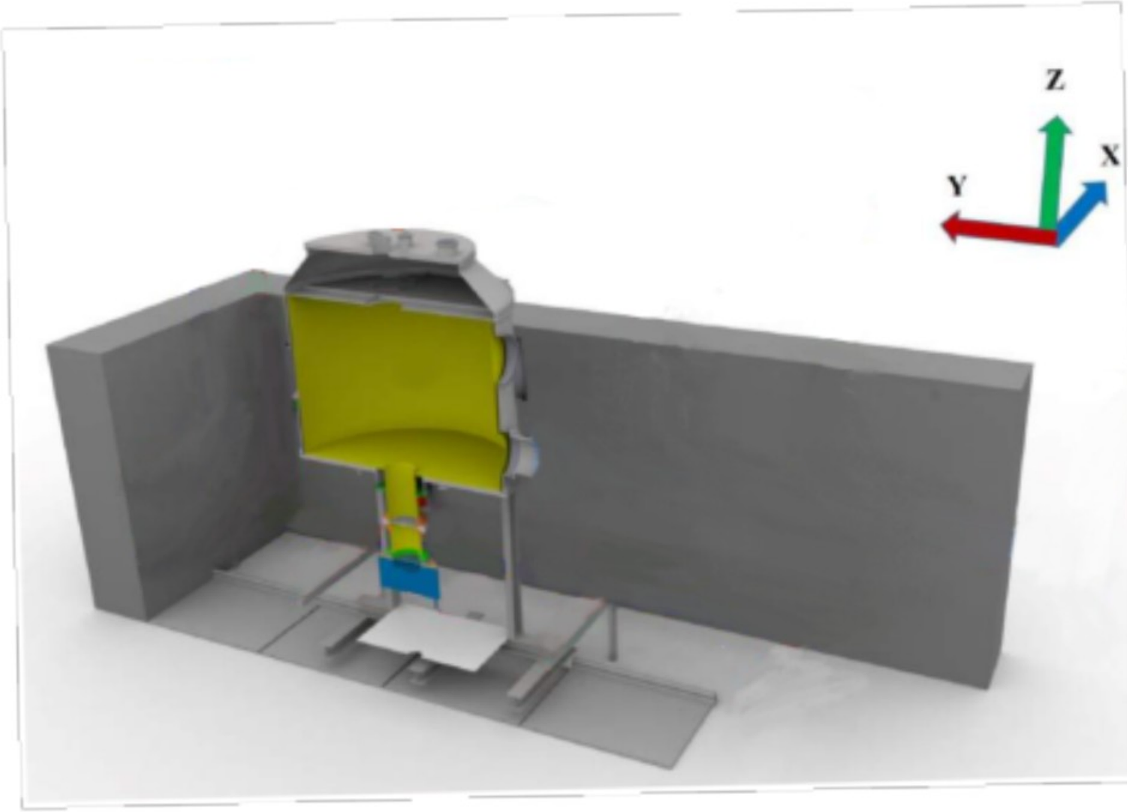

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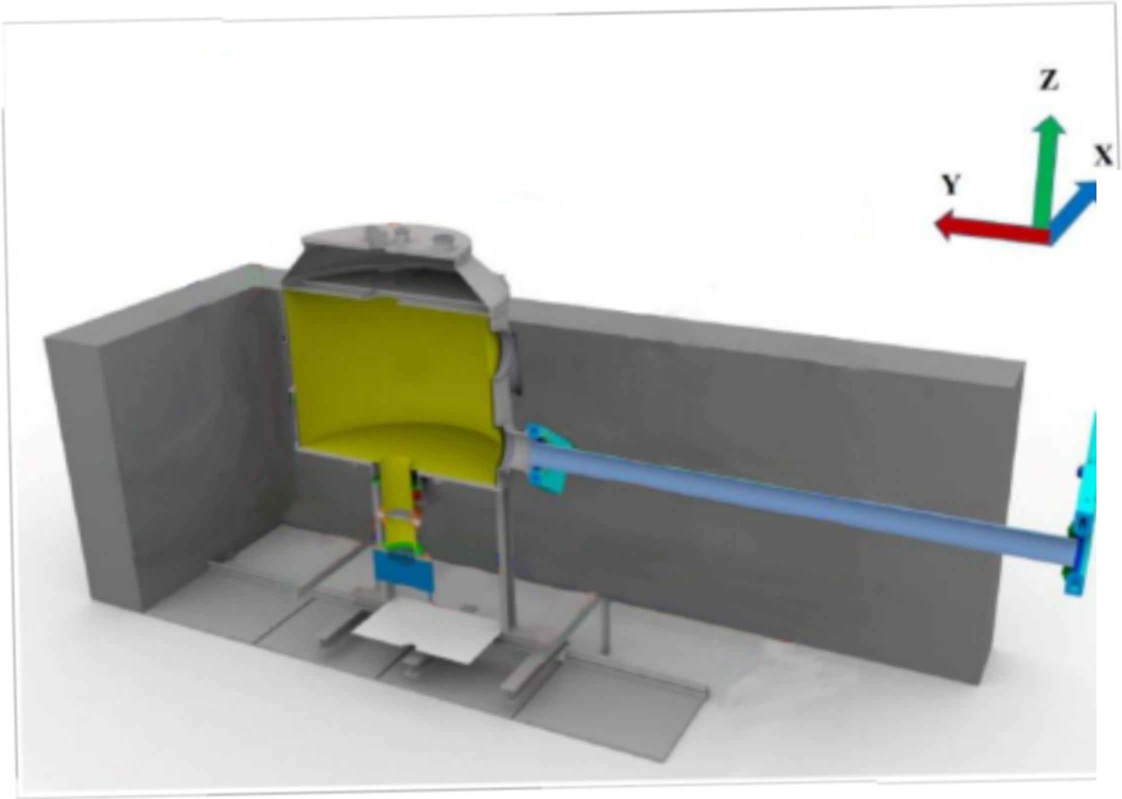

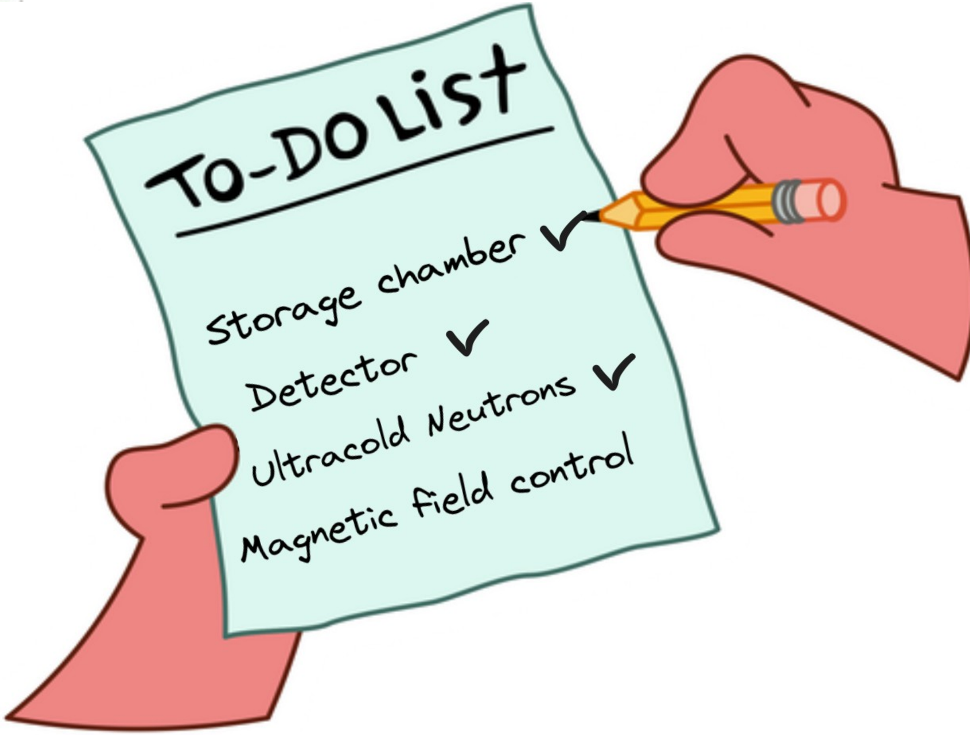

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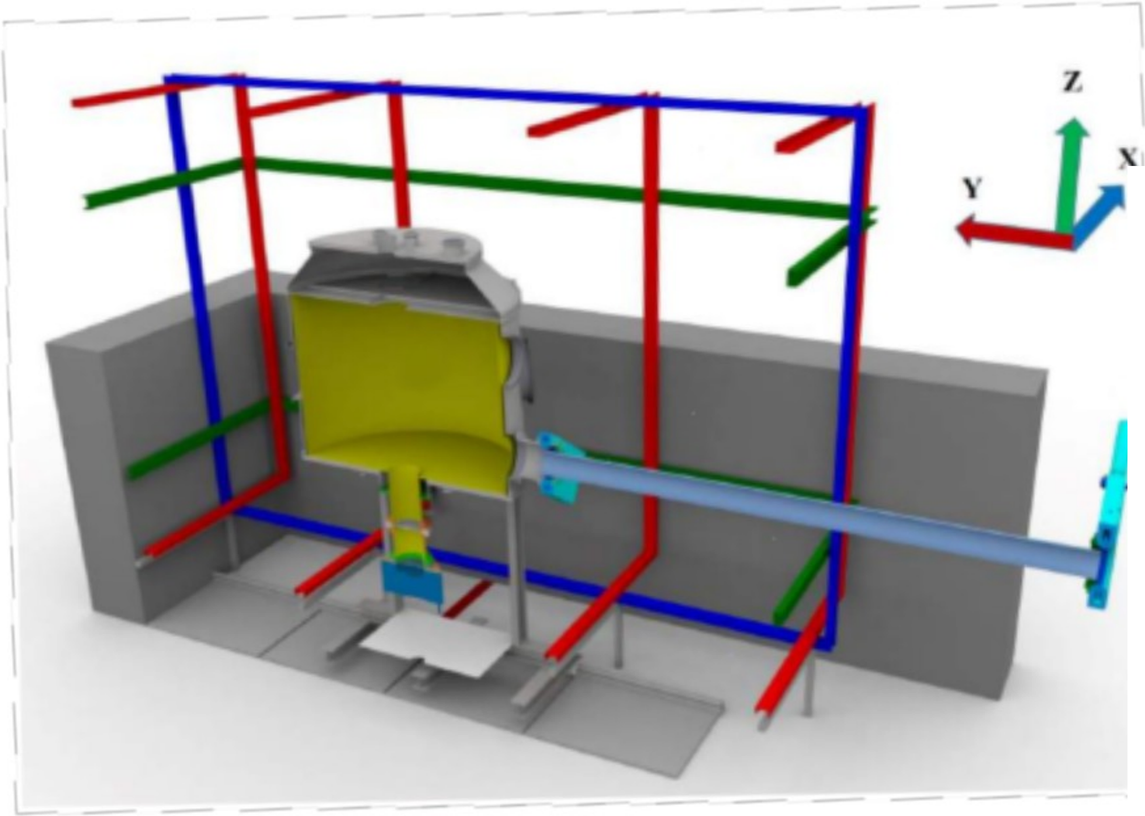
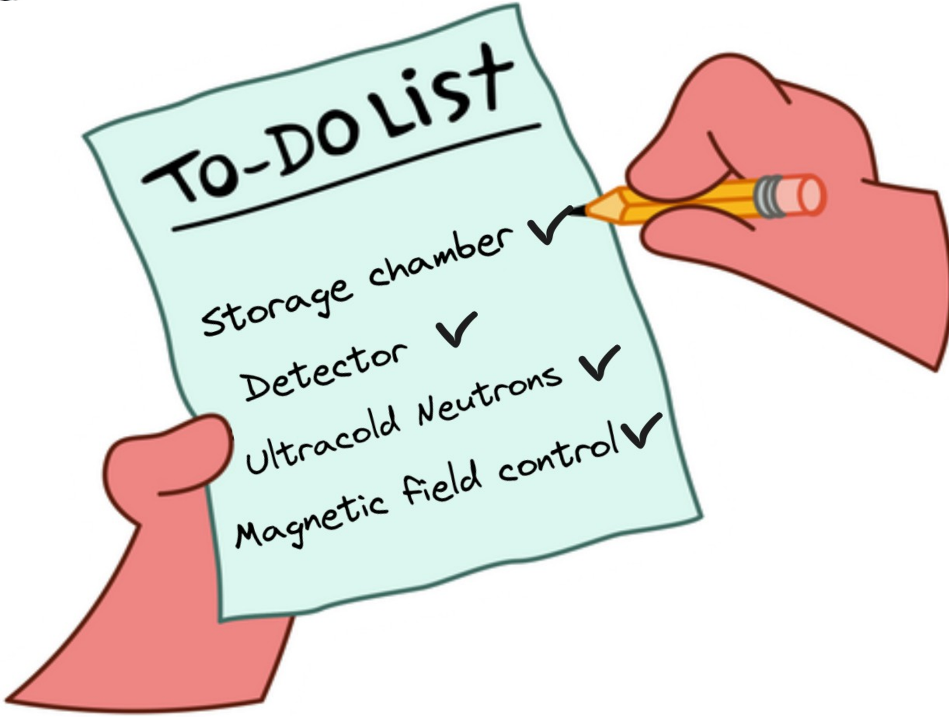
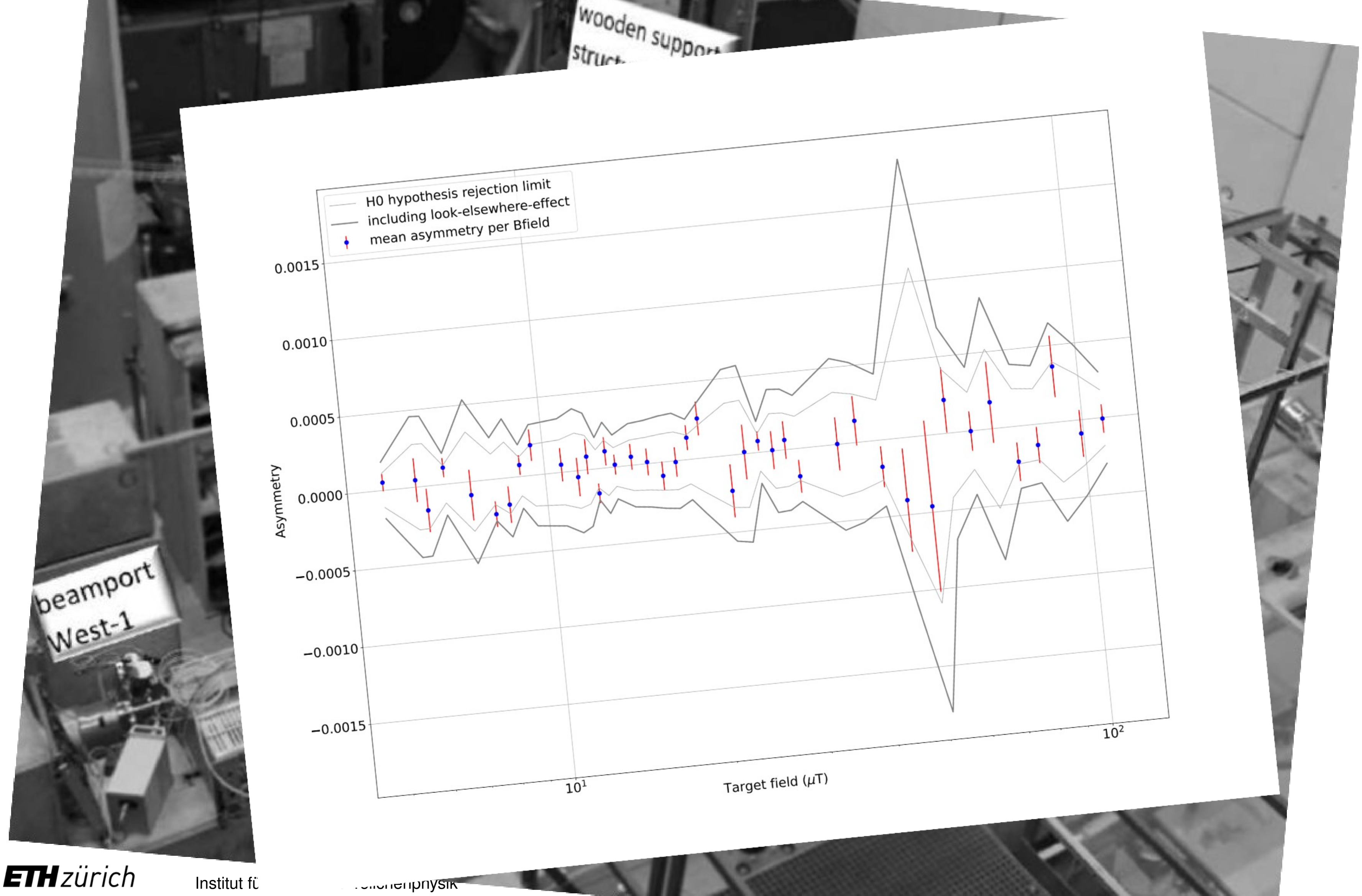
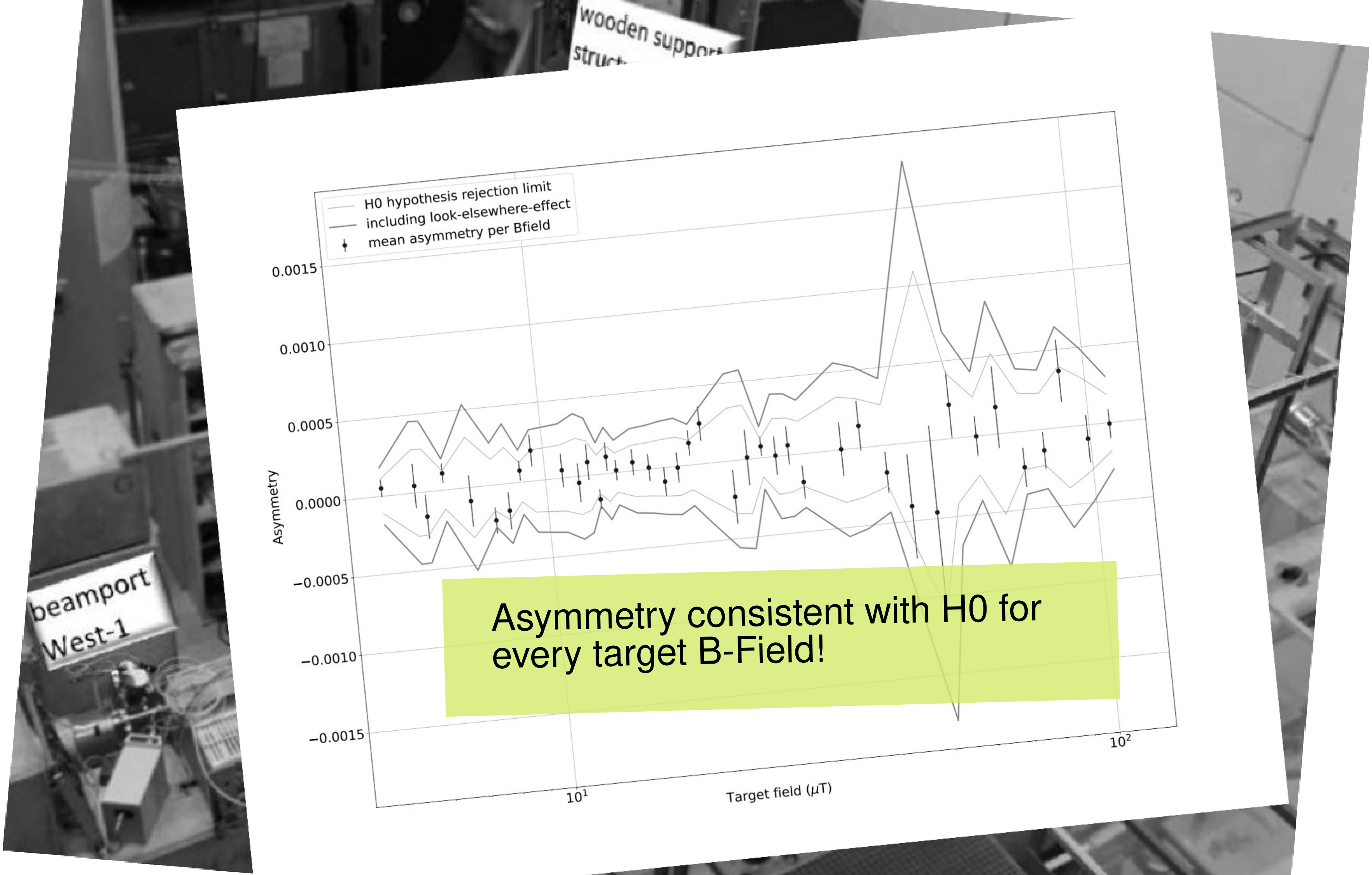






beamport
West-1
H0 hypothesis rejection limit
including look-elsewhere-effect
mean asymmetry per Bfield
Asymmetry
Target field (μT)



Asymmetry consistent with H0 for every target B-Field!

What does that mean?

Set limit on oscillation time

$$\tau_{nn'} = \frac{1}{\sqrt{2|<A_B>|}} |F_A^0(B, B') + F_A^1(B, B') \cos b + F_A^2(B, B) \sin b \cos a + F_A^3(B, B) \sin b \sin a)|^{\frac{1}{2}}$$

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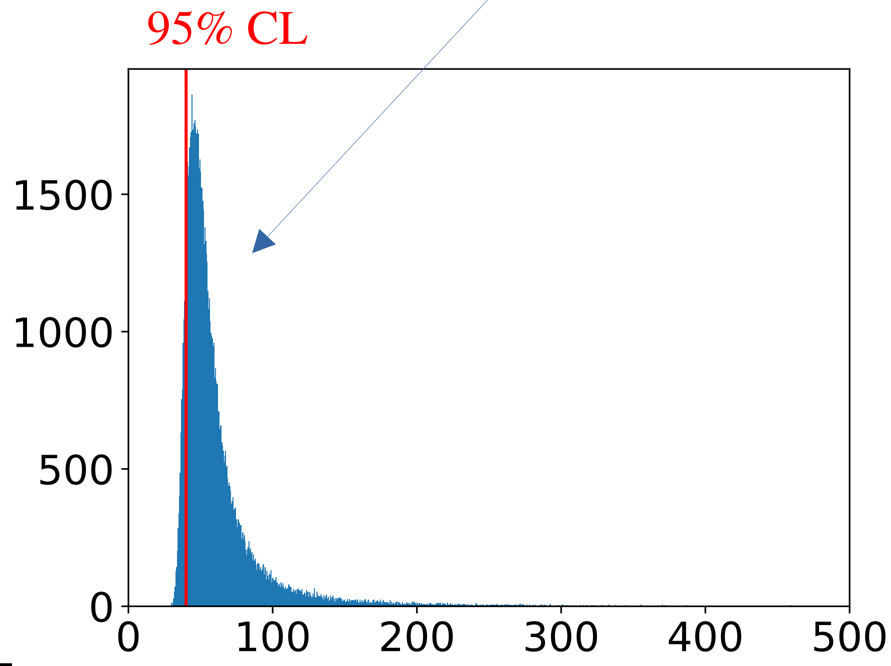
Set limit on oscillation time $\tau_{nn'} = \frac{1}{\sqrt{2|<A_B>|}} |F_A^0(B, B') + F_A^1(B, B') \cos b +$

$$F_A^2(B, B) \sin b \cos a + F_A^3(B, B) \sin b \sin a)|^{\frac{1}{2}}$$



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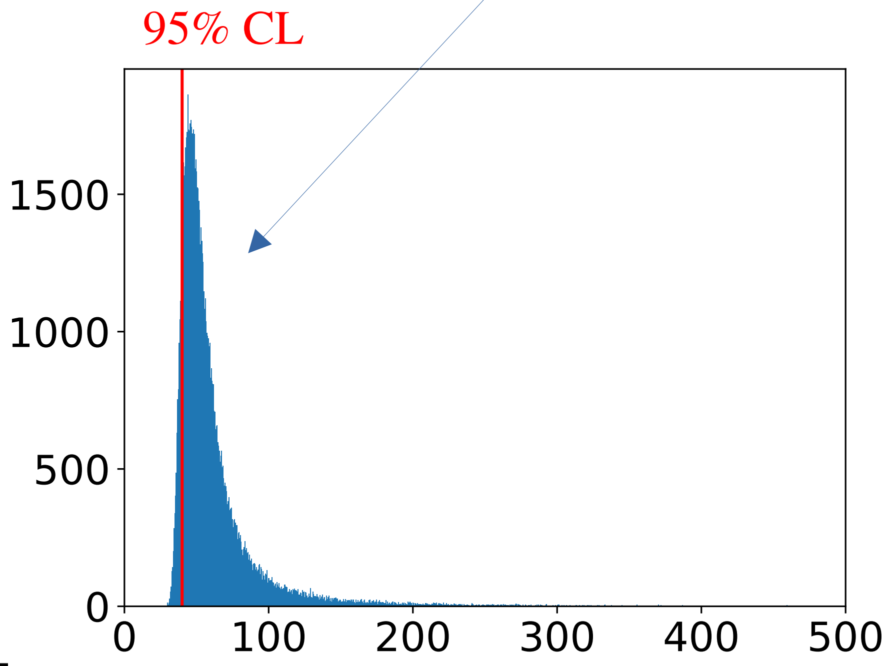

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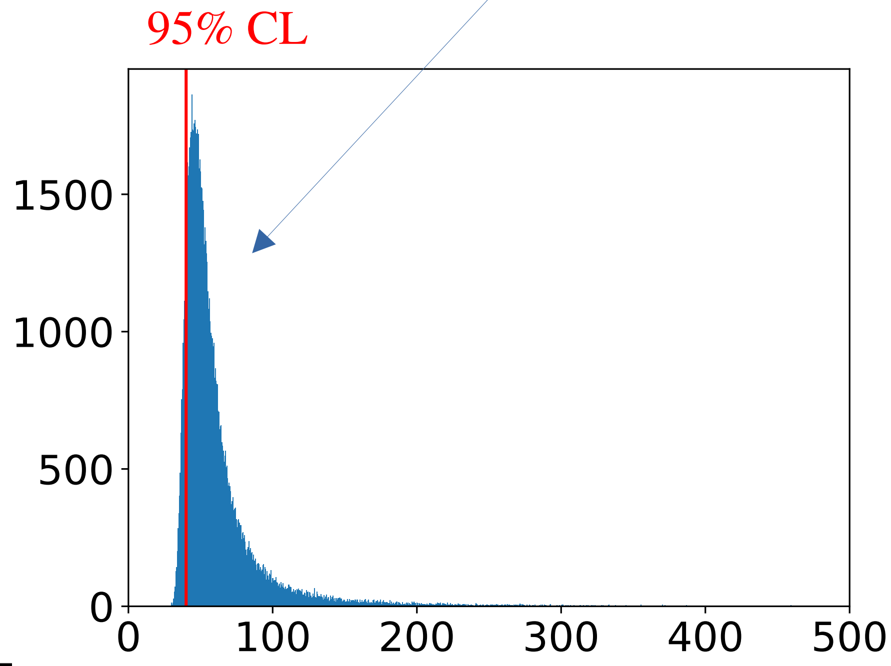
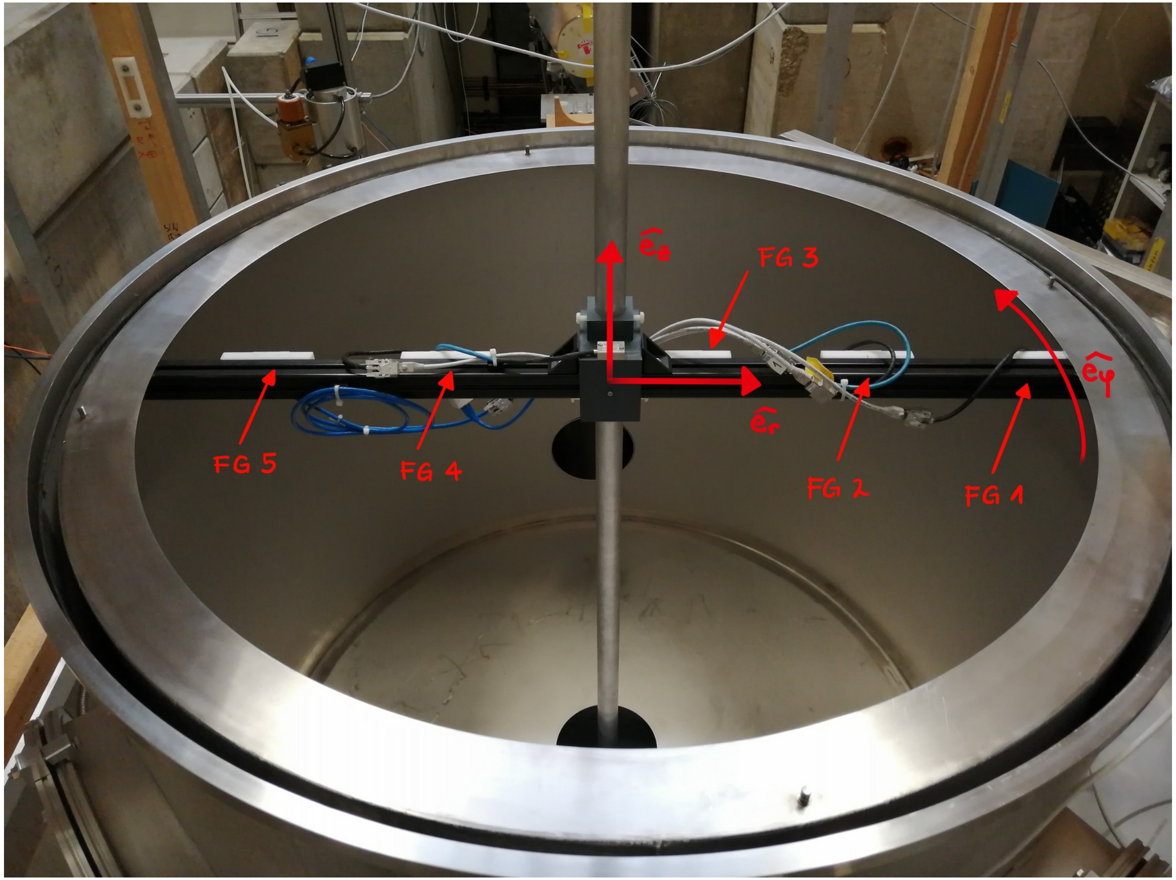
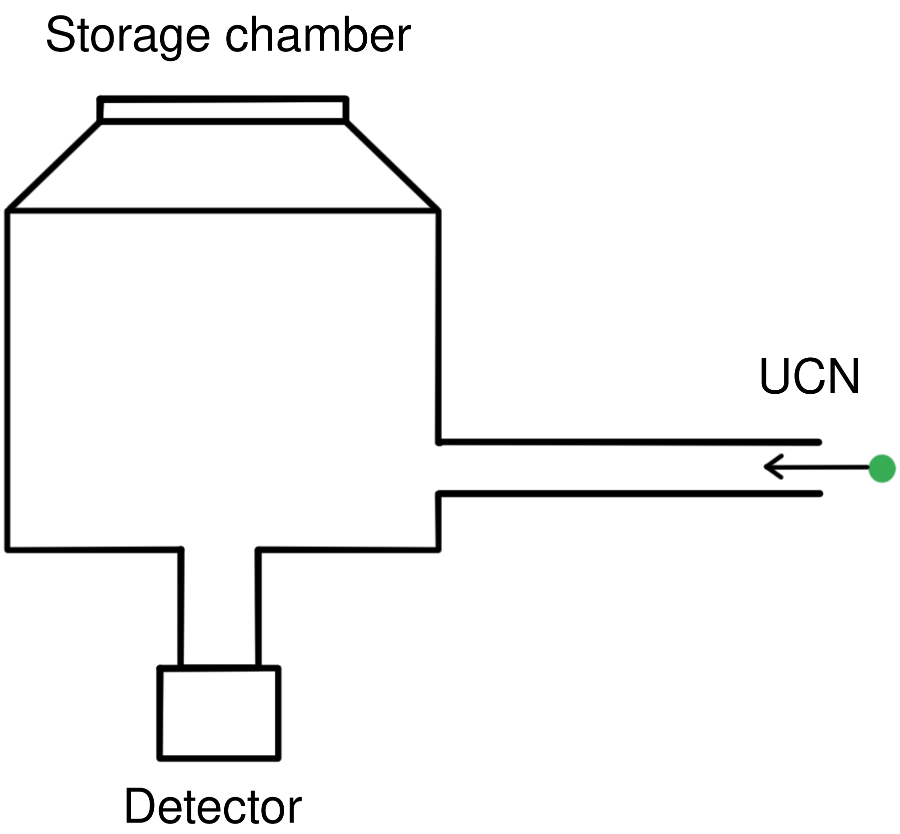


$$P_{BB'}^{nn'}(t) = P_{BB'}^{nn'}(B,B',\beta,t)$$

Magnetic field mapping



Determining the oscillation probability



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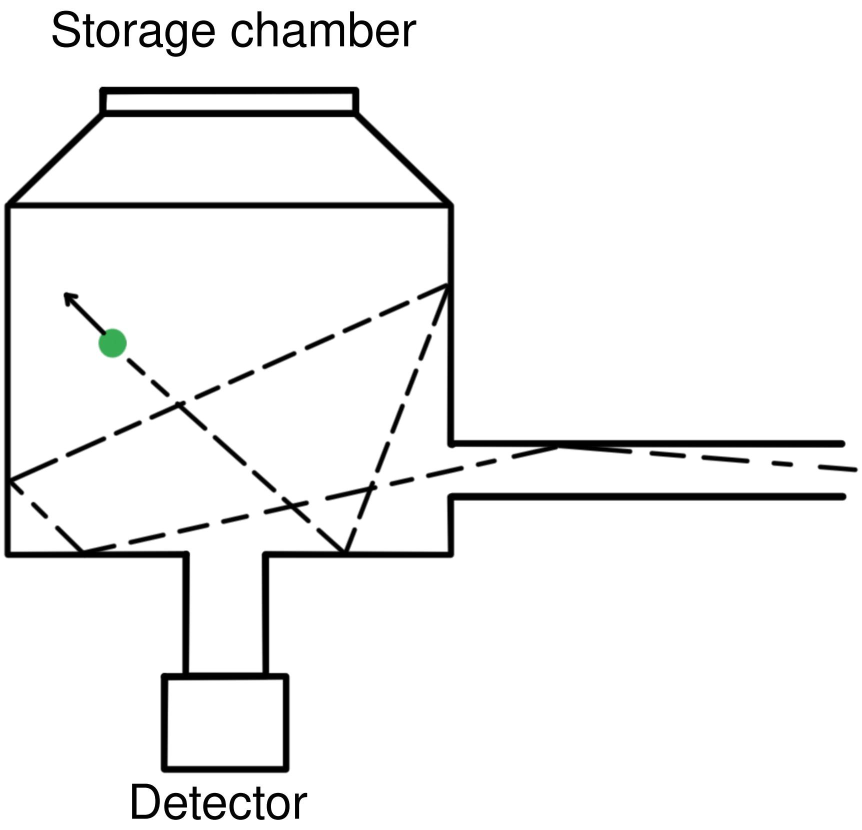

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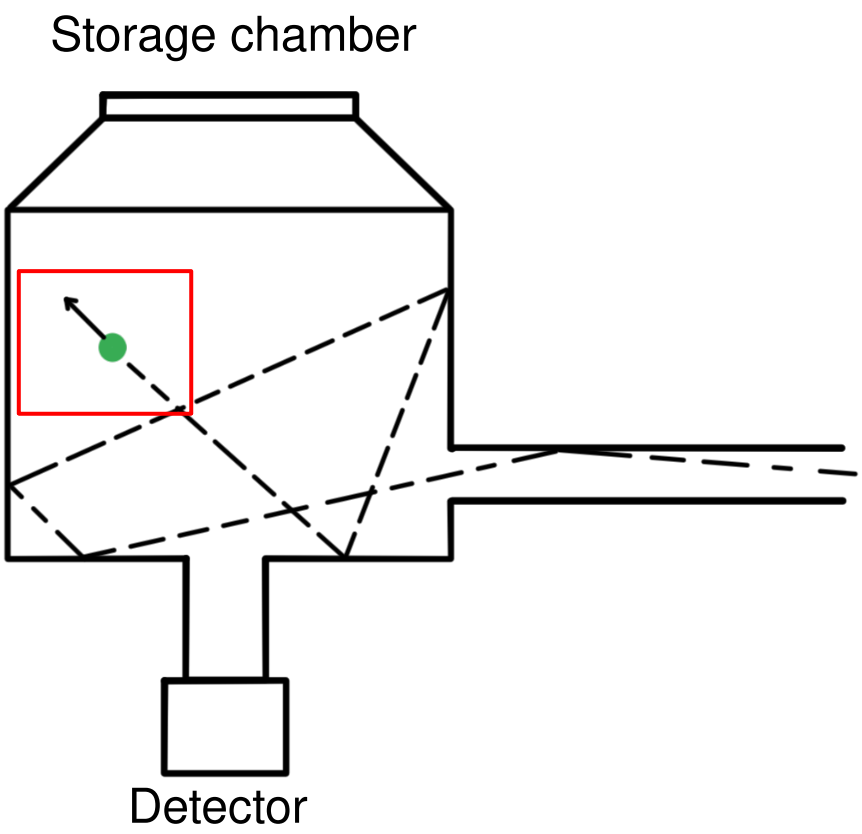

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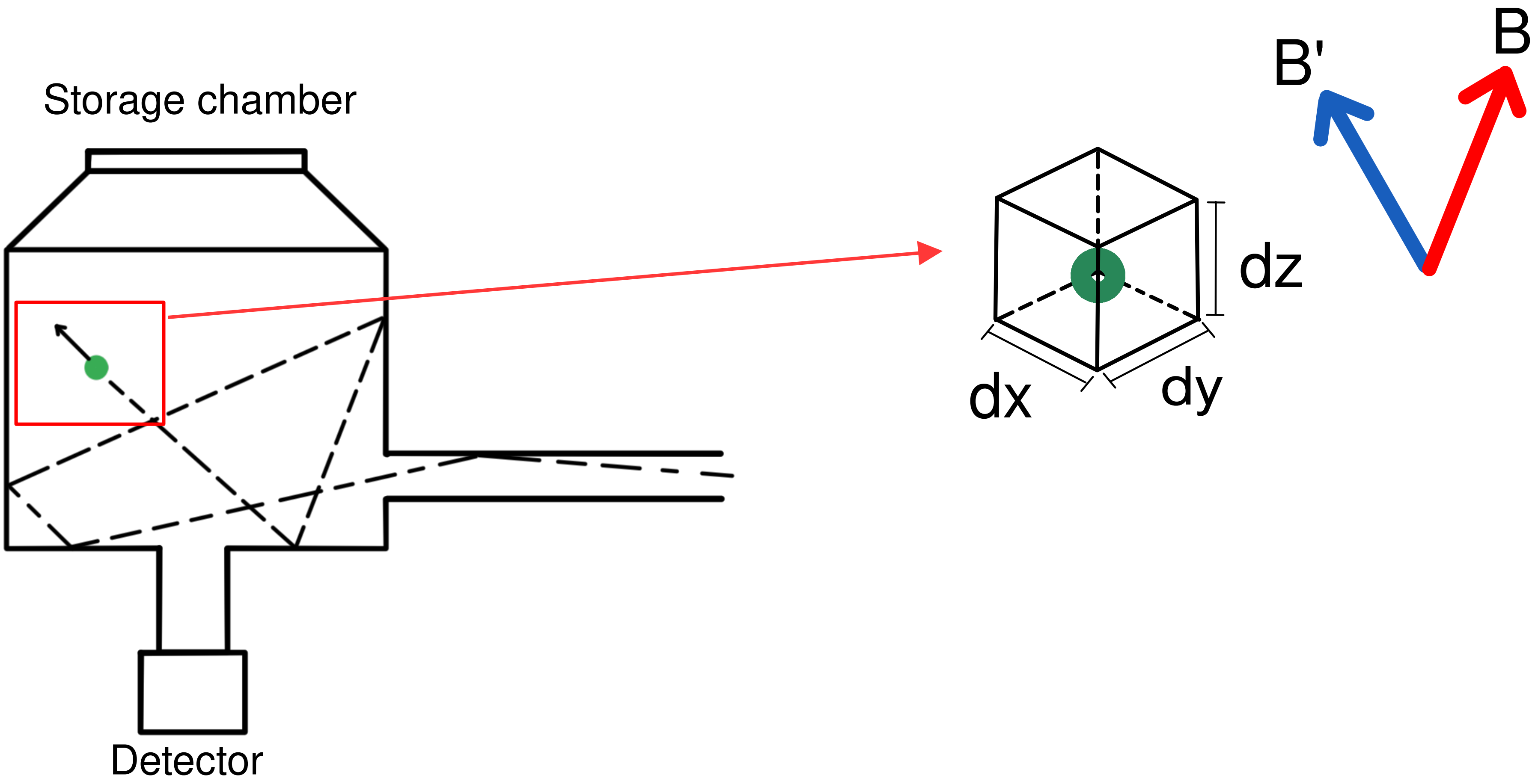

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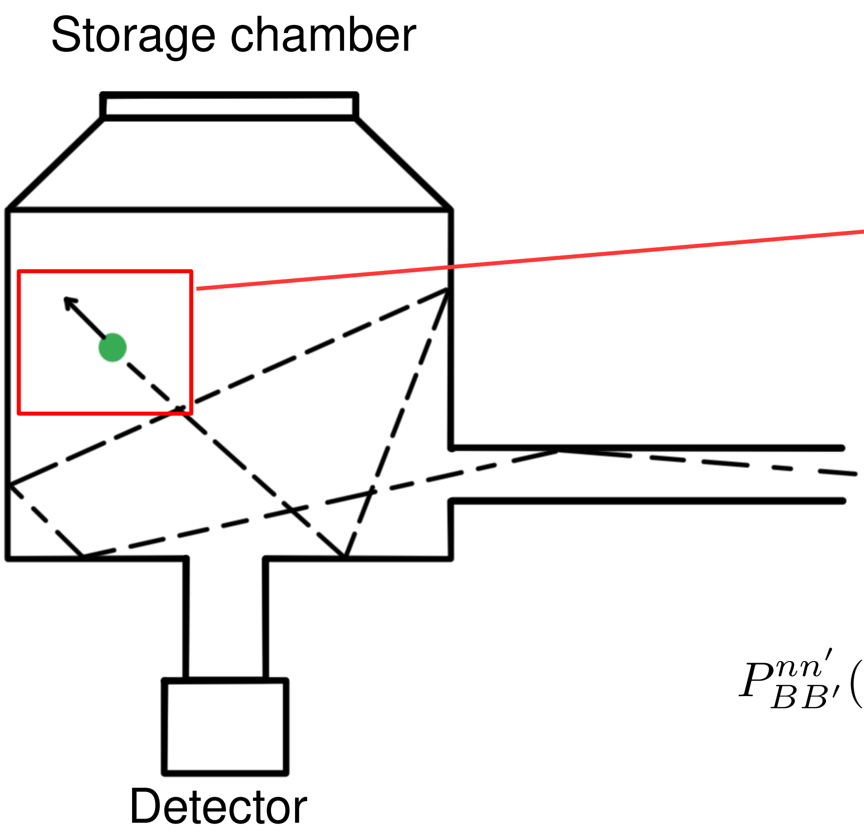

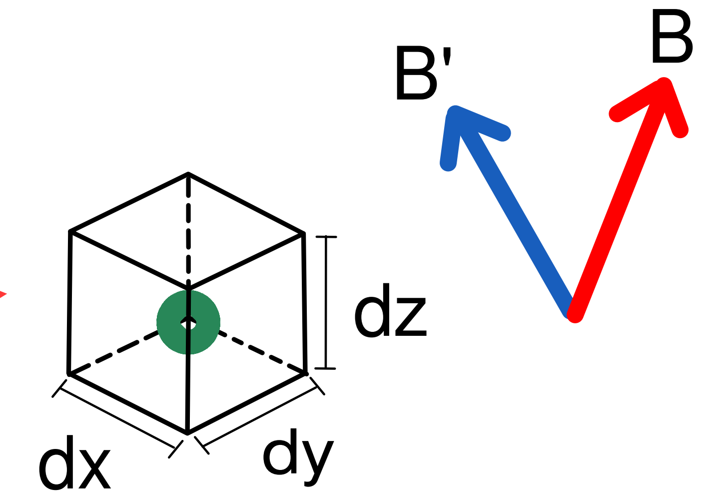

$$P_{BB'}^{nn'}(t) = \frac{\sin^2[(\omega - \omega')t]}{2\tau_{nn'}^2(\omega - \omega')^2} + \frac{\sin^2[(\omega + \omega')t]}{2\tau_{nn'}^2(\omega + \omega')^2} + \left(\frac{\sin^2[(\omega - \omega')t]}{2\tau_{nn'}^2(\omega - \omega')^2} - \frac{\sin^2[(\omega + \omega')t]}{2\tau_{nn'}^2(\omega + \omega')^2}\right)\cos\beta$$

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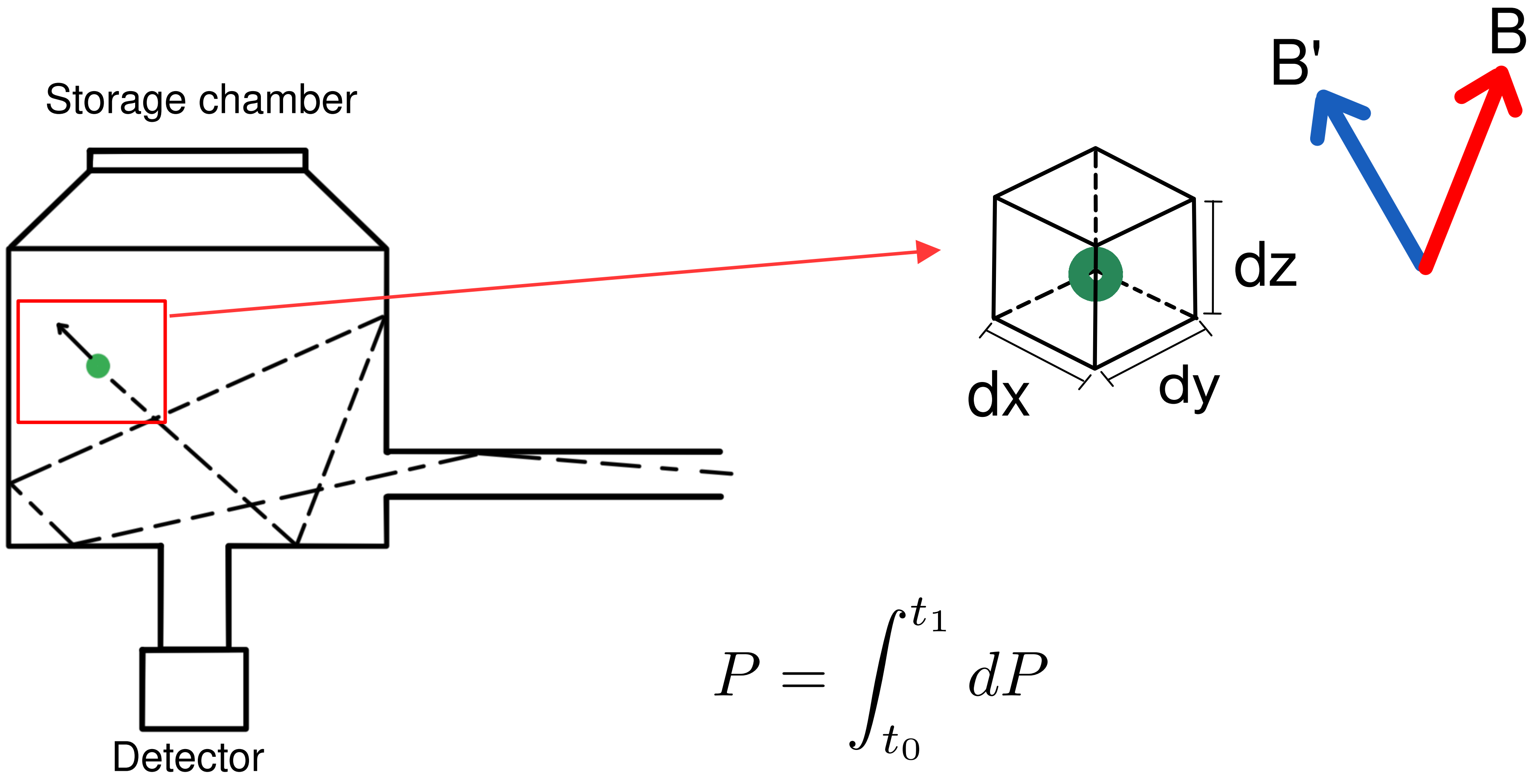
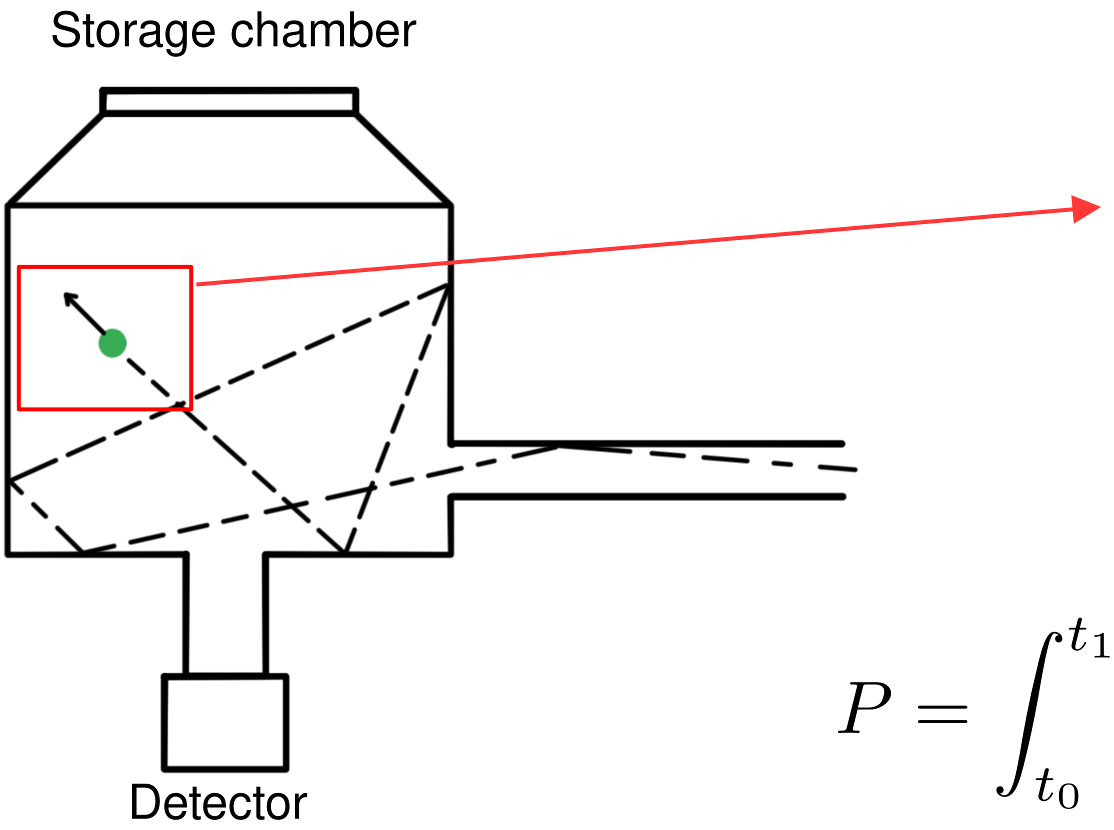
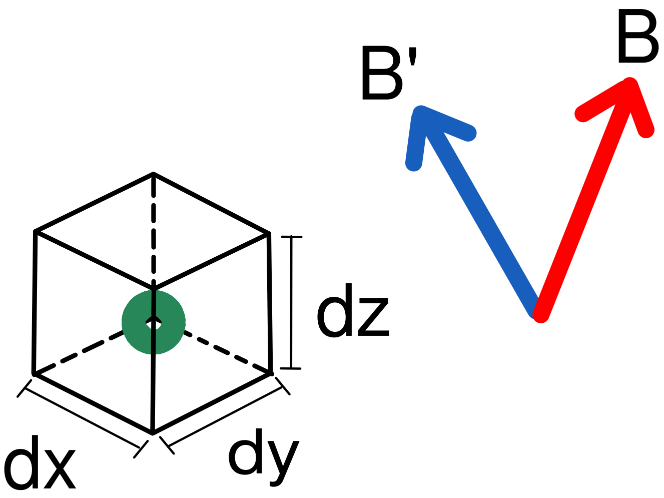


$$P = \int_{t_0}^{t_1} dP$$

Determining the oscillation probability



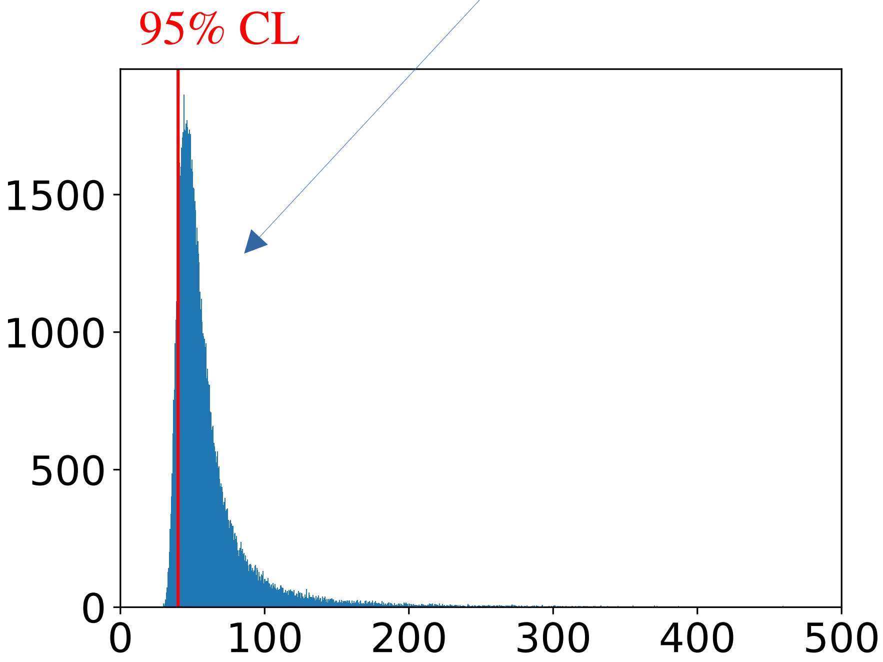


$$P = \int_{t_0}^{t_1} dP + \int_{t_1}^{t_2} dP + \ldots$$

What does that mean?

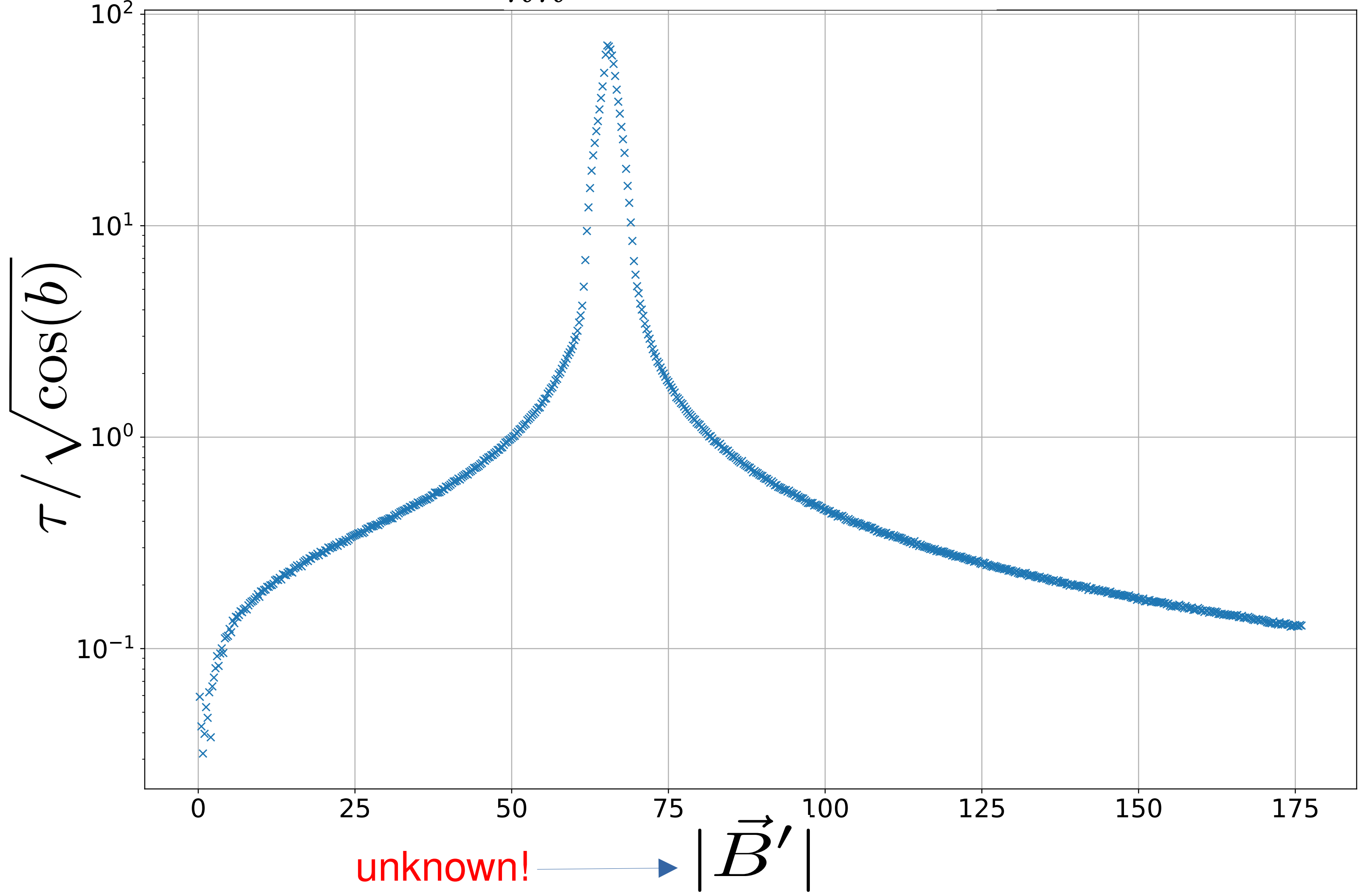
Set limit on oscillation time

$$\tau_{nn'} = \frac{1}{\sqrt{2|<A_B>|}} |F_A^0(B,B') + F_A^1(B,B')\cos b + F_A^2(B,B)\sin b \cos a + F_A^3(B,B)\sin b \sin a|^{\frac{1}{2}}$$

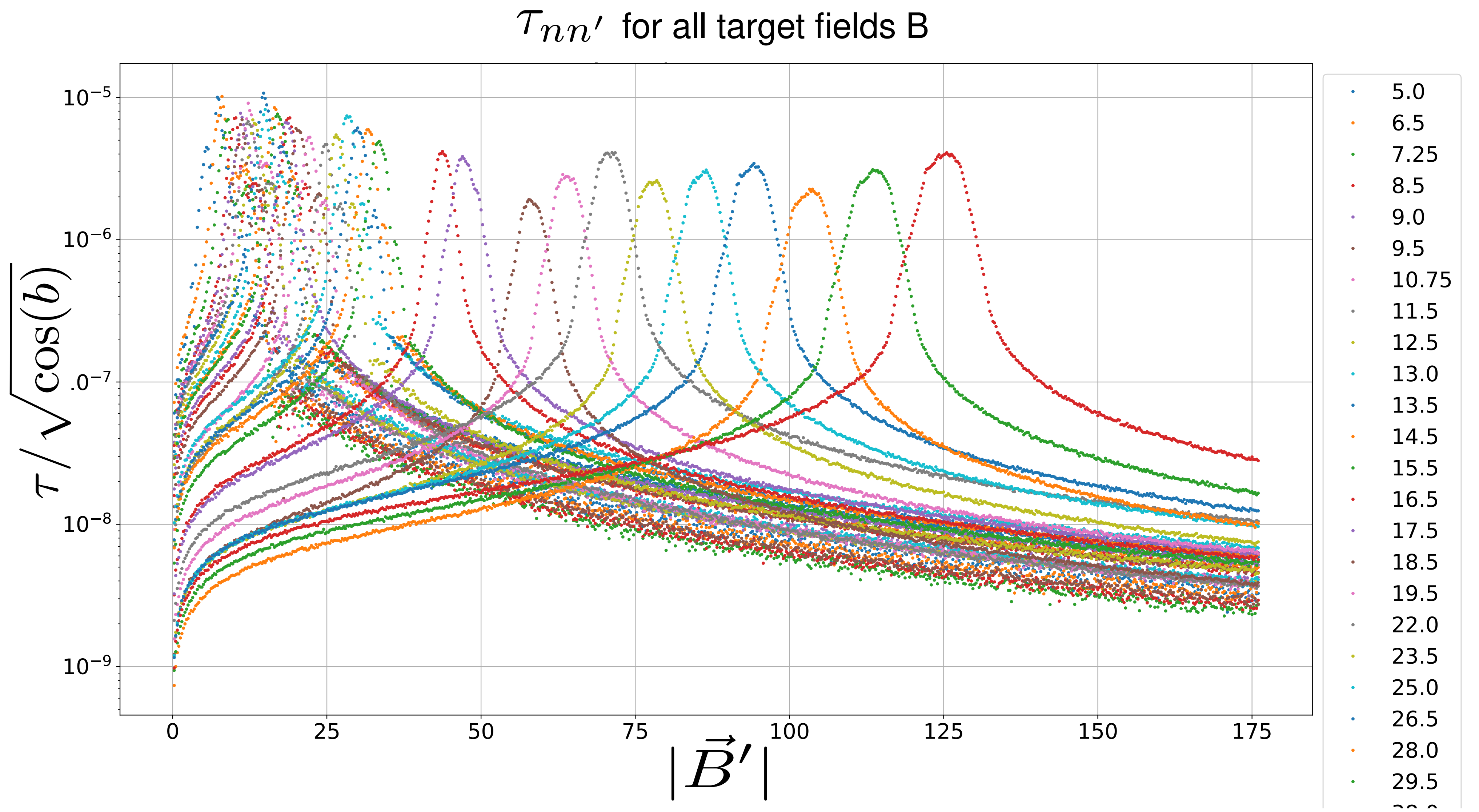


$$P_{BB'}^{nn'}(t) = P_{BB'}^{nn'}(B,B',\beta,t)$$

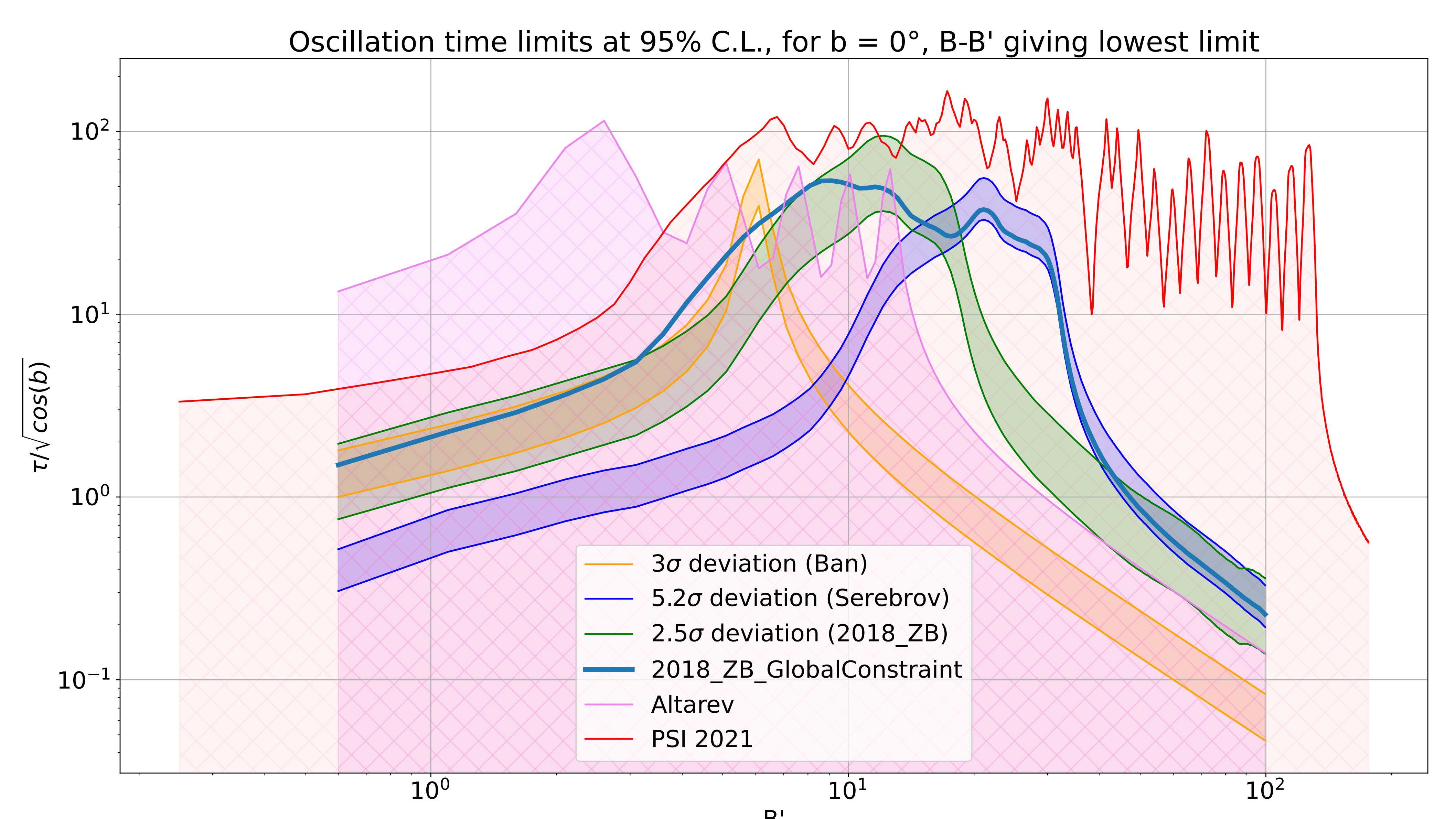
$\tau_{nn'}$ for one target field B



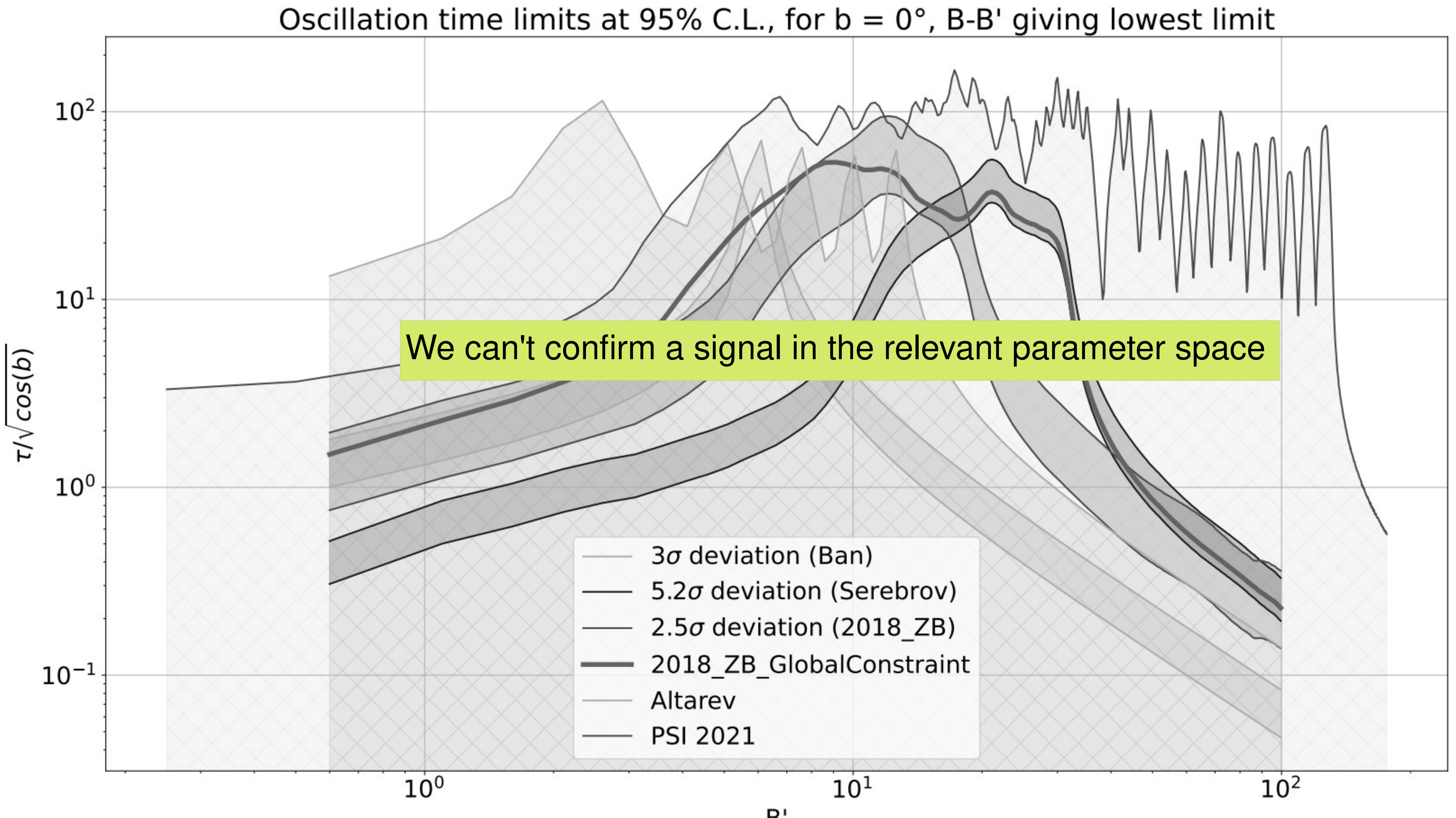
ET



$\tau_{nn'}$ for all target fields B
$\tau\,/\sqrt{\cos(b)}$
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
0
25
50
75
100
125
150
175
$|\vec{B}'|$
5.0
6.5
7.25
8.5
9.0
9.5
10.75
11.5
12.5
13.0
13.5
14.5
15.5
16.5
17.5
18.5
19.5
22.0
23.5
25.0
26.5
28.0
29.5



Oscillation time limits at 95% C.L., for b = 0°, B-B' giving lowest limit
$\tau/\sqrt{cos(b)}$
10^2
10^1
10^0
10^{-1}
10^0
10^1
10^2
B'
3σ deviation (Ban)
5.2σ deviation (Serebrov)
2.5σ deviation (2018_ZB)
2018_ZB_GlobalConstraint
Altarev
PSI 2021


Oscillation time limits at 95% C.L., for b = 0°, B-B' giving lowest limit
$\tau/\sqrt{cos(b)}$
10^{2}
10^{1}
10^{0}
10^{-1}
10^{0}
10^{1}
10^{2}
B'
We can't confirm a signal in the relevant parameter space
3σ deviation (Ban)
5.2σ deviation (Serebrov)
2.5σ deviation (2018_ZB)
2018_ZB_GlobalConstraint
Altarev
PSI 2021

Questions?

Integral of tau as a function of a, b for B = 5.0 μT