Magnetic Fields During Gravitational Experiments with Antihydrogen

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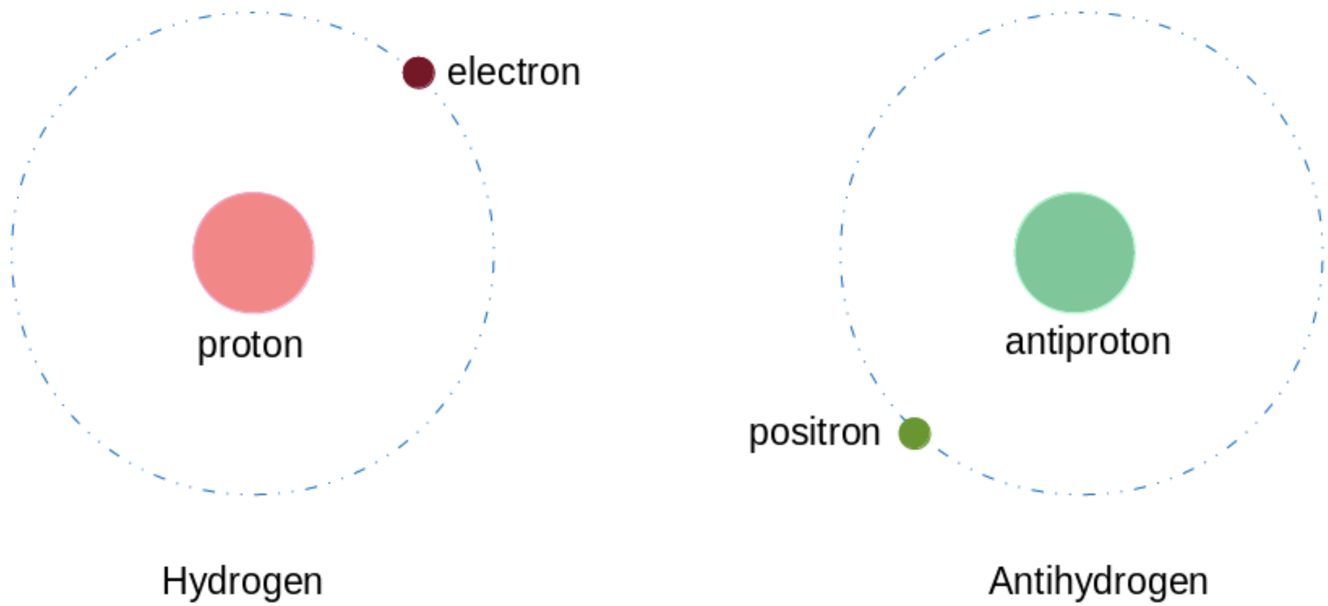
WNPPC

18th February 2023

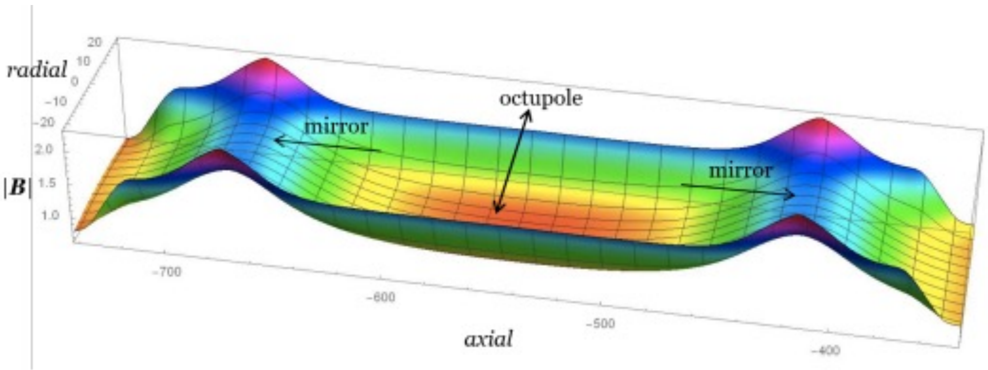
Why study antihydrogen?

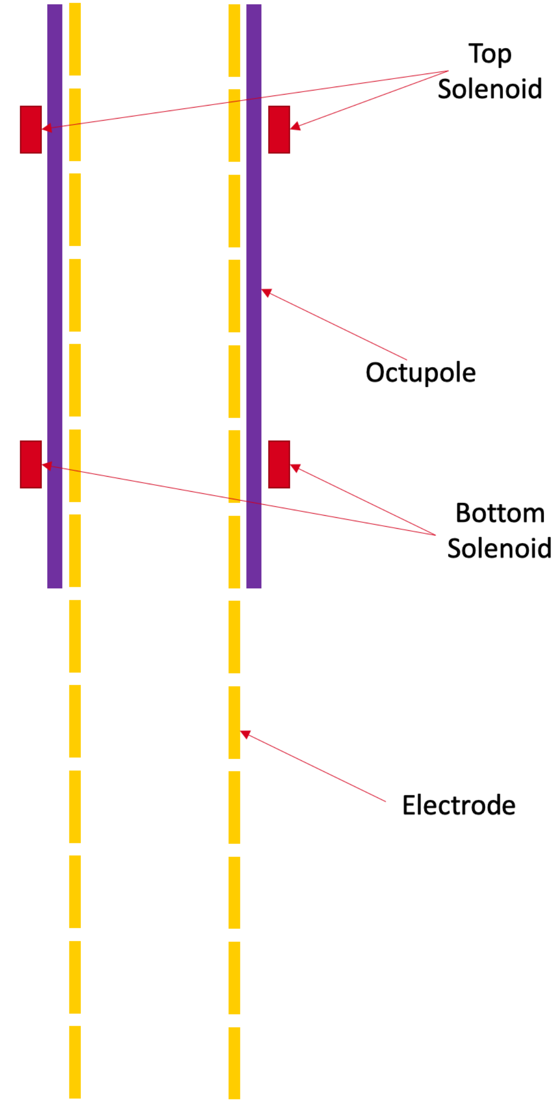


- Hydrogen has been studied extensively through history, comparing to antihydrogen can test fundamental symmetries

- Neutral so allows a test Weak-Equivalence-Principle in free fall experiments -> ALPHAg

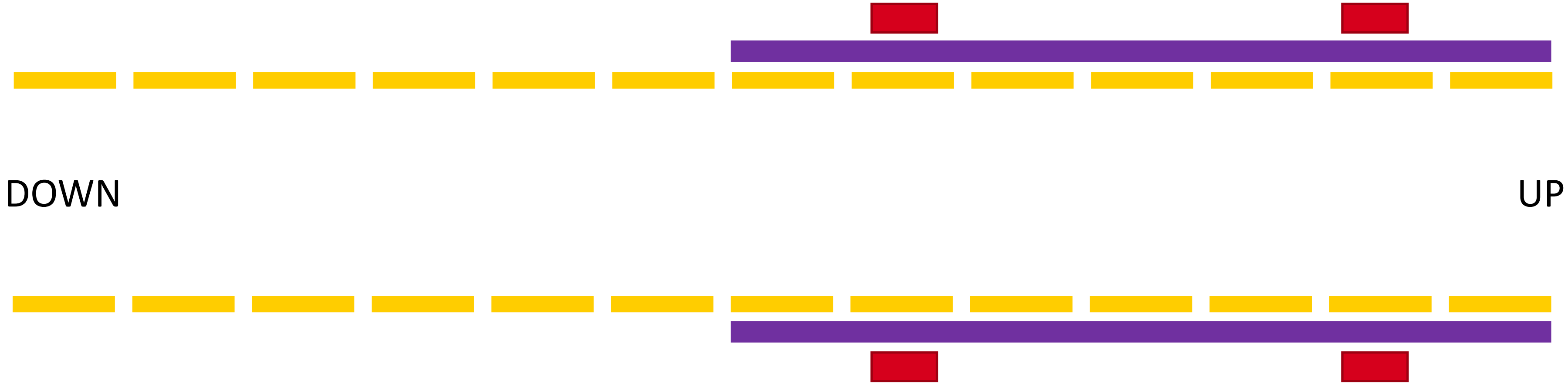
Antihydrogen Laser Physics Apparatus (ALPHA)





Quick recap on talks from Chukman, Pooja, and Gareth

Cartoon schematic to guide us

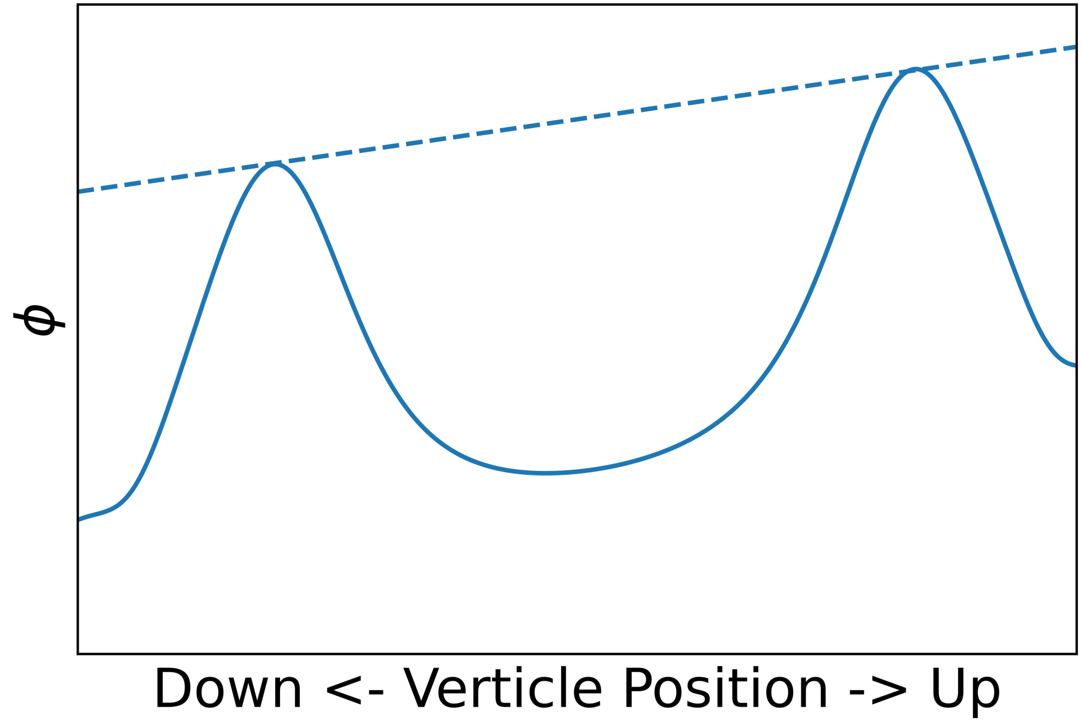


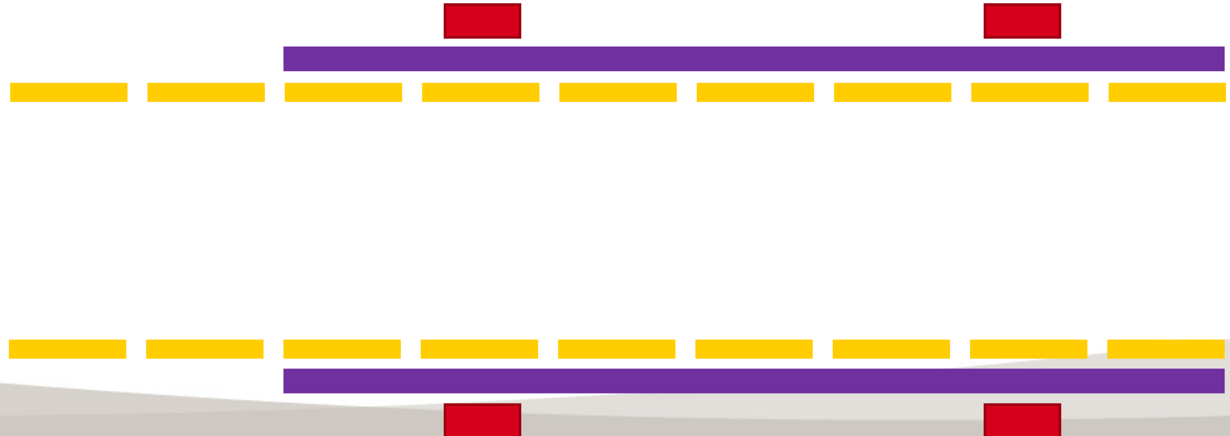
Assuming gravity acts the same on matter and antimatter

$$\phi = \mu_B B \; - \; mgh$$

$$\Delta\phi = -mg\Delta h$$

$$\Delta B \sim 4 \times 10^{-4}\; T$$





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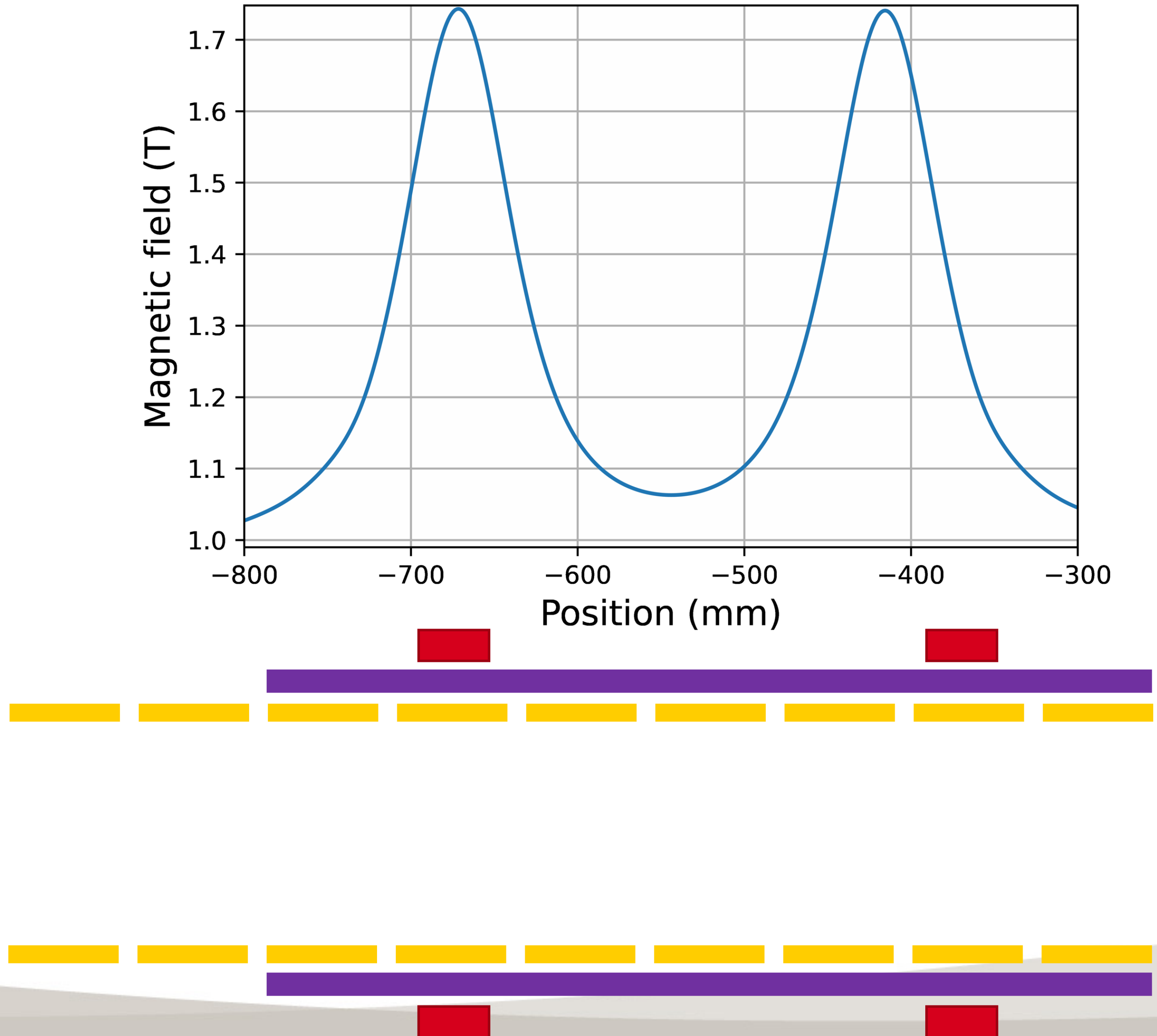


Using cyclotron frequency for magnetometry

$$f_c = \frac{q\ B}{2\ \pi\ m}$$

f_c for electrons at 1 T ~ 28 GHz

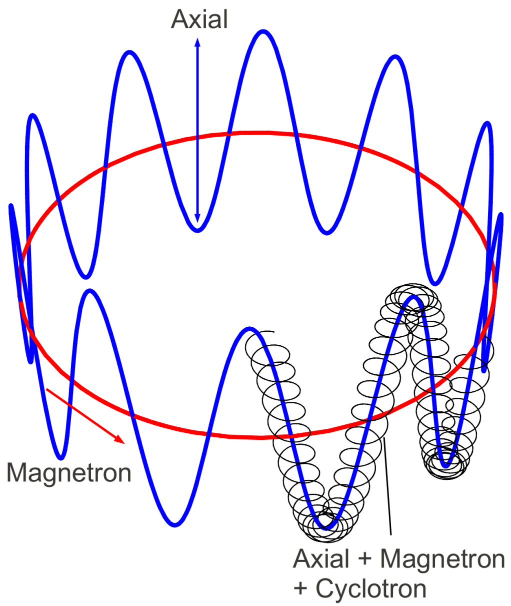


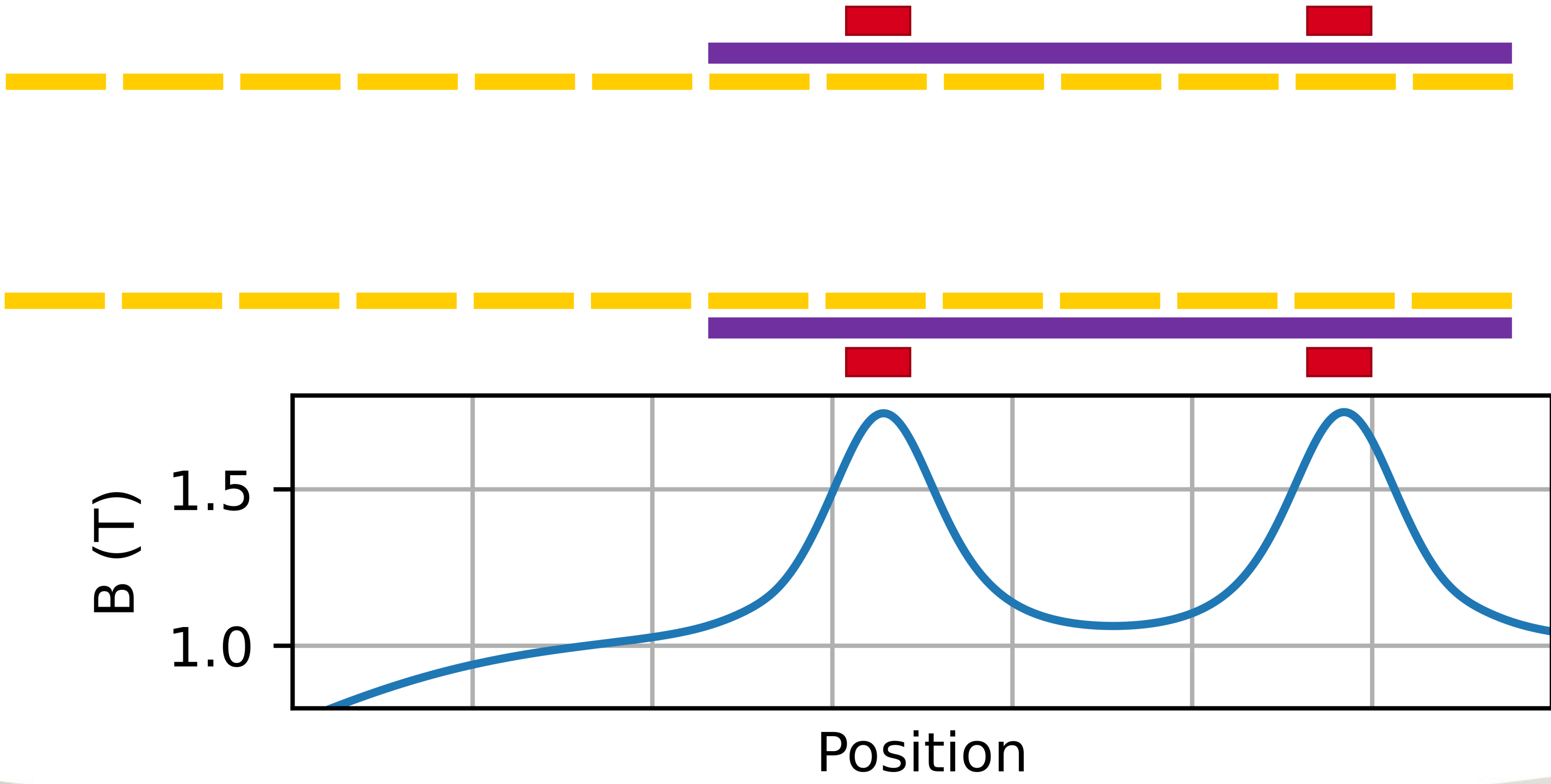
Image credit: T.Friesen

But…the cyclotron motion isn't all that happens in a Penning trap

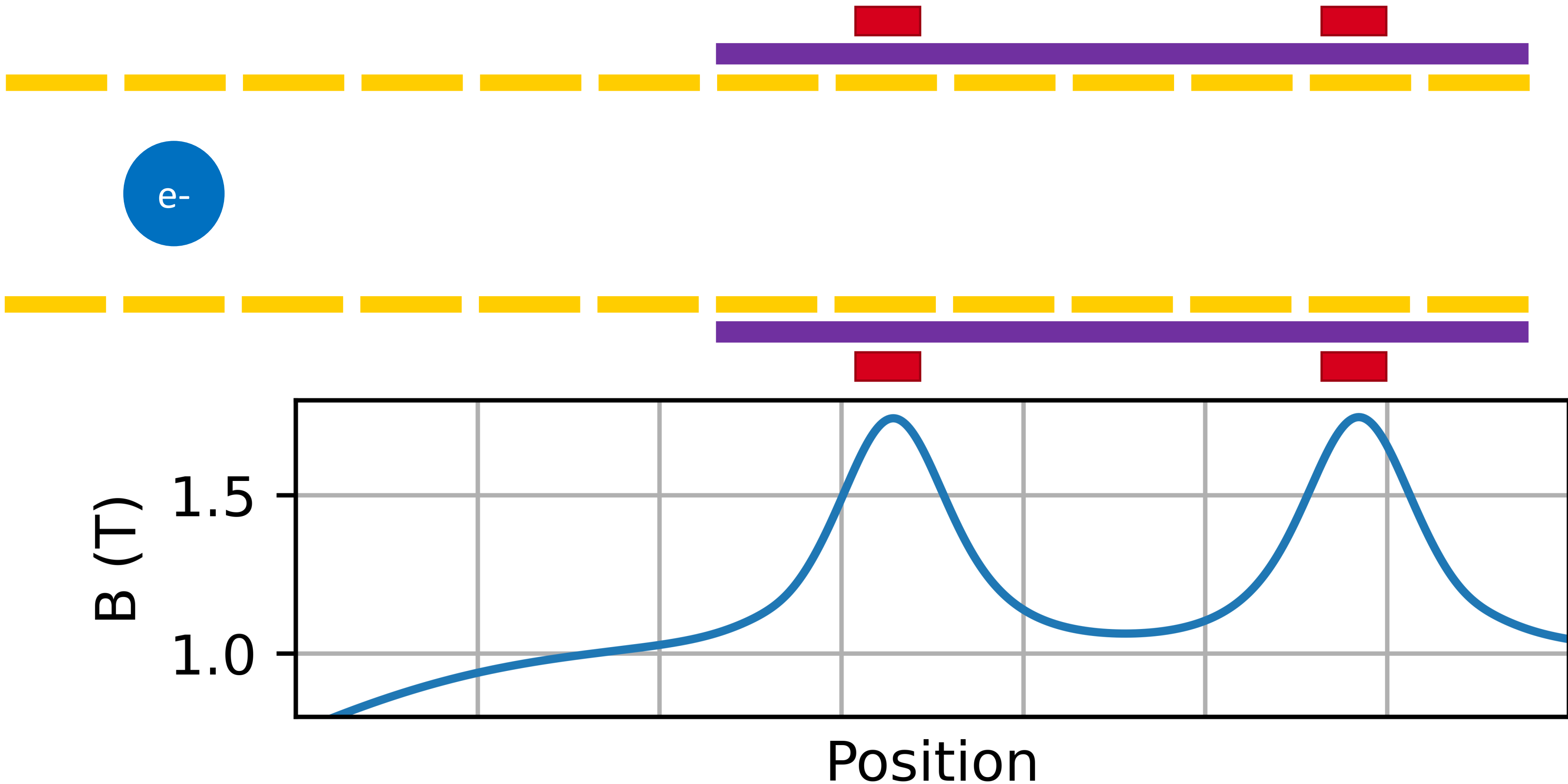
Axial frequency ~ 10 - 50 MHz

Magnetron frequency ~ 100 - 300 kHz

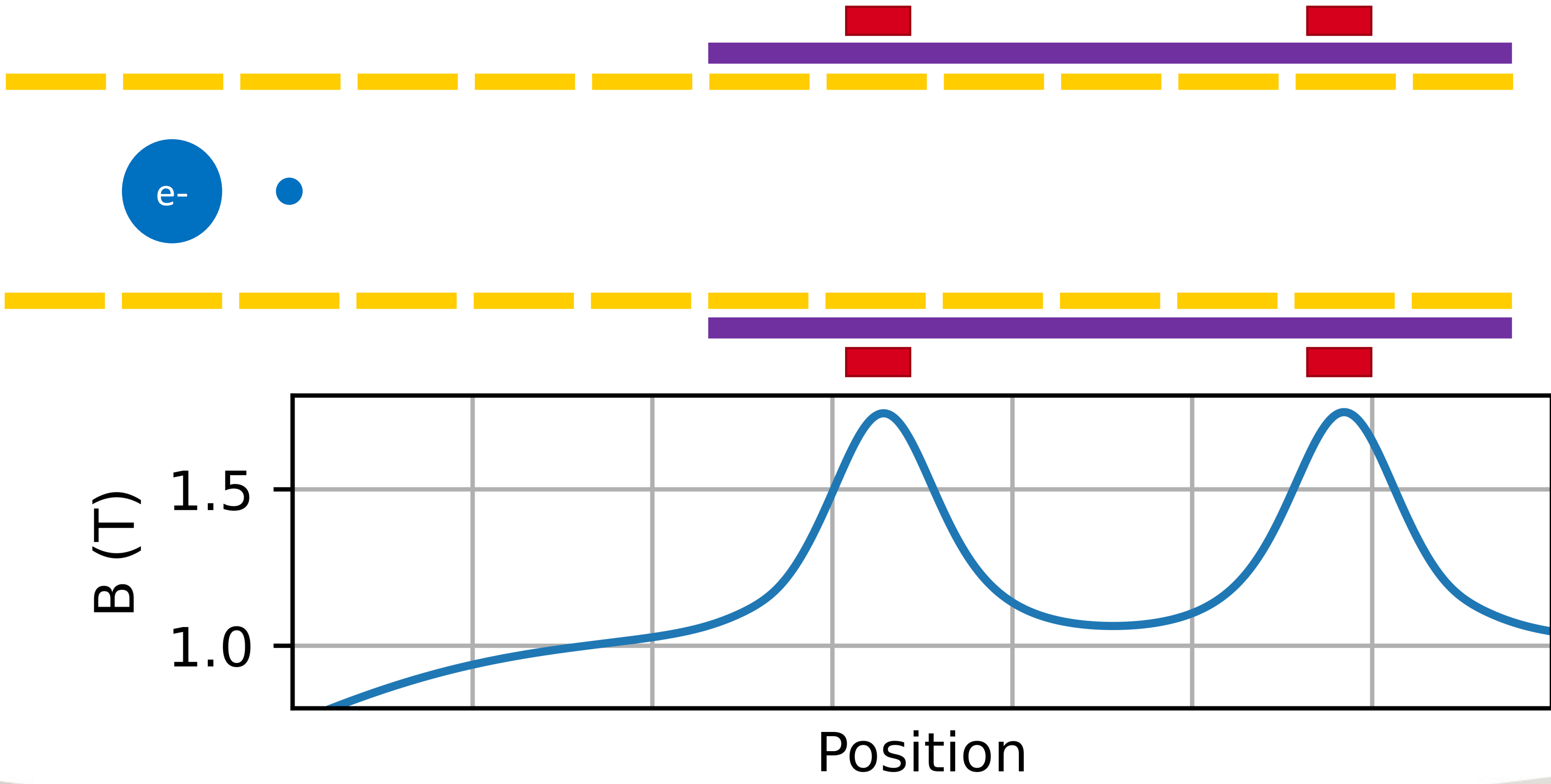
What is Electron cyclotron resonance magnetometry?



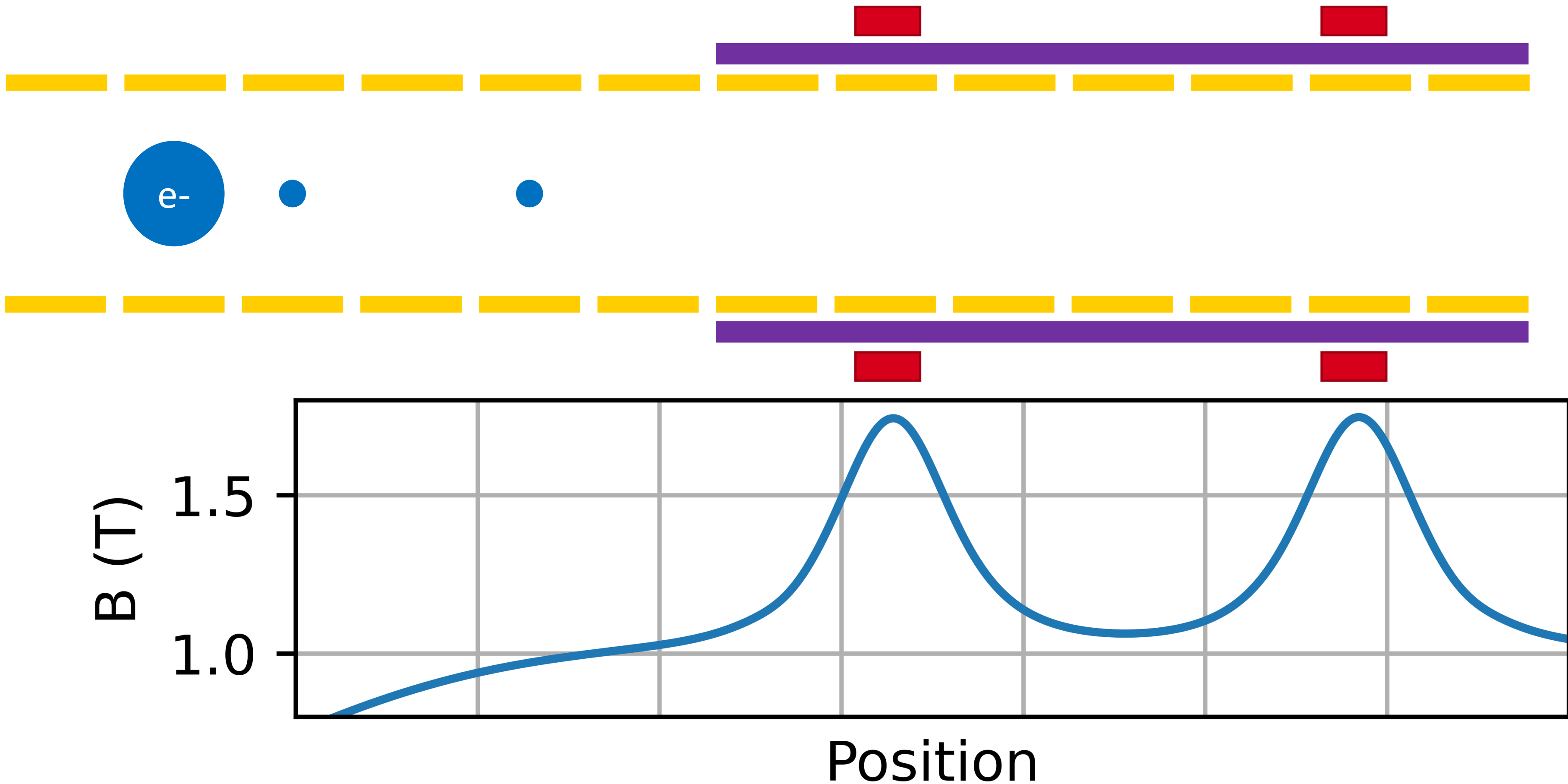
Get an electron plasma



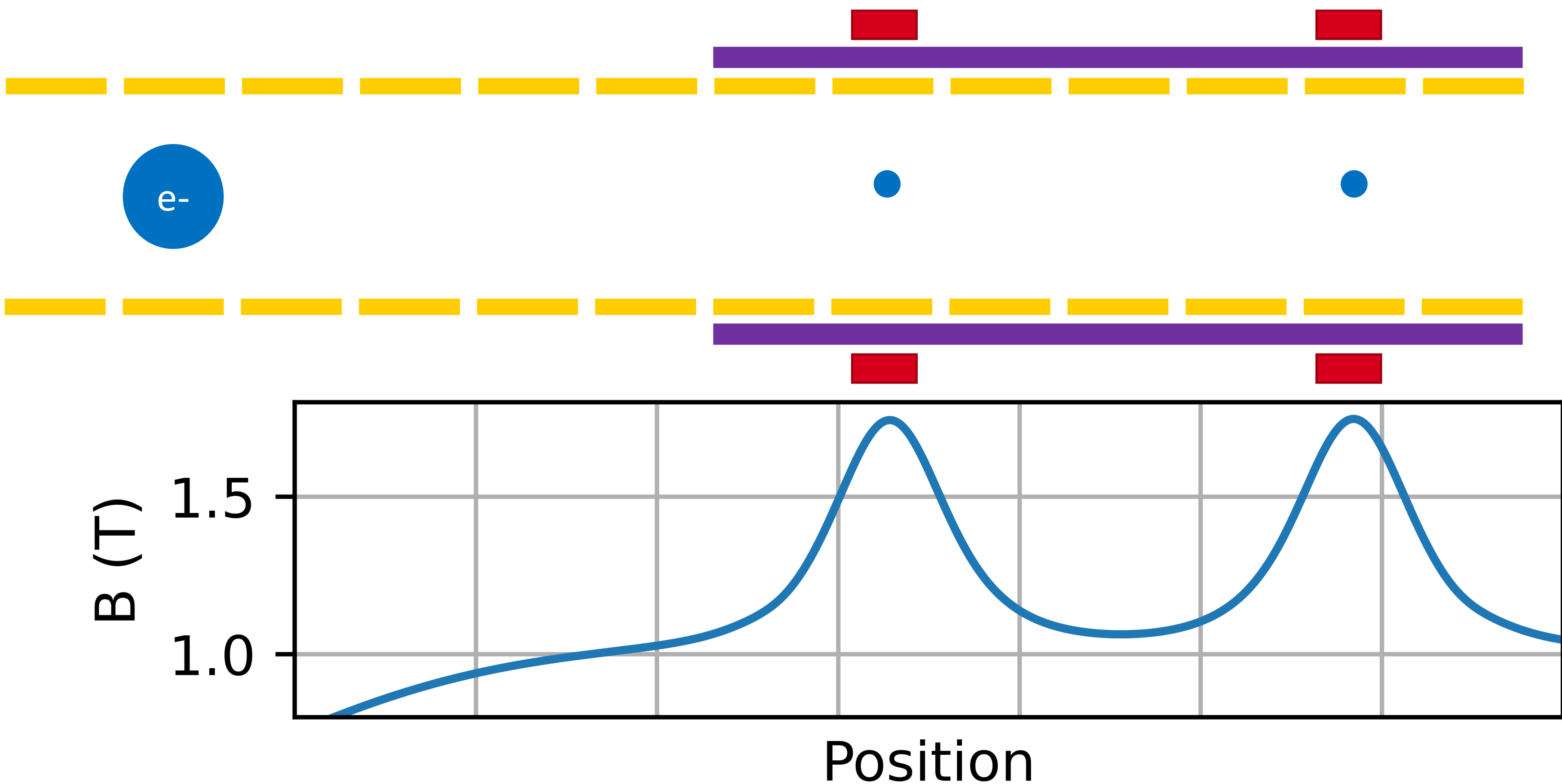
Remove a small "scoop" of electrons



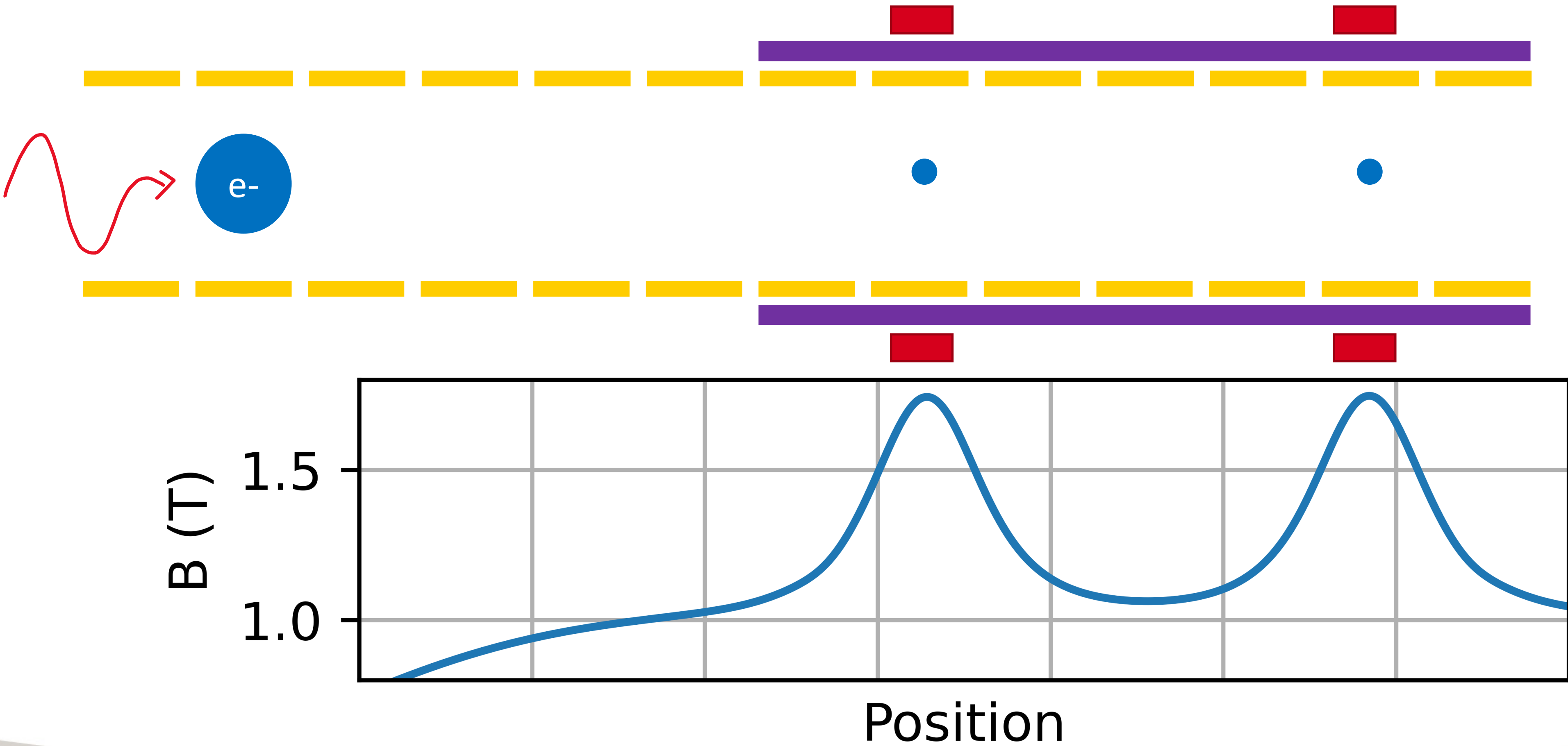
And another



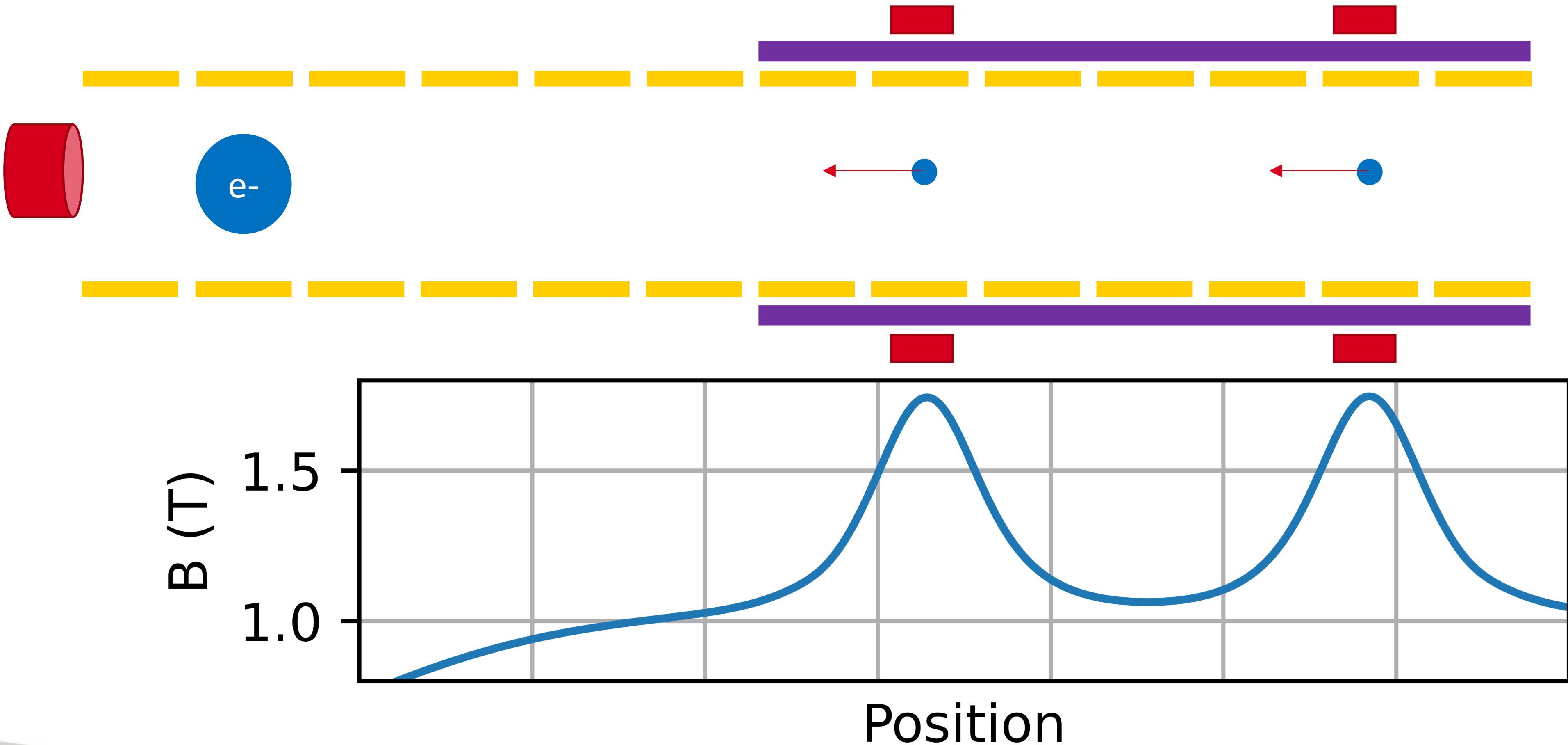
Move to target location



Irradiate with a microwave pulse



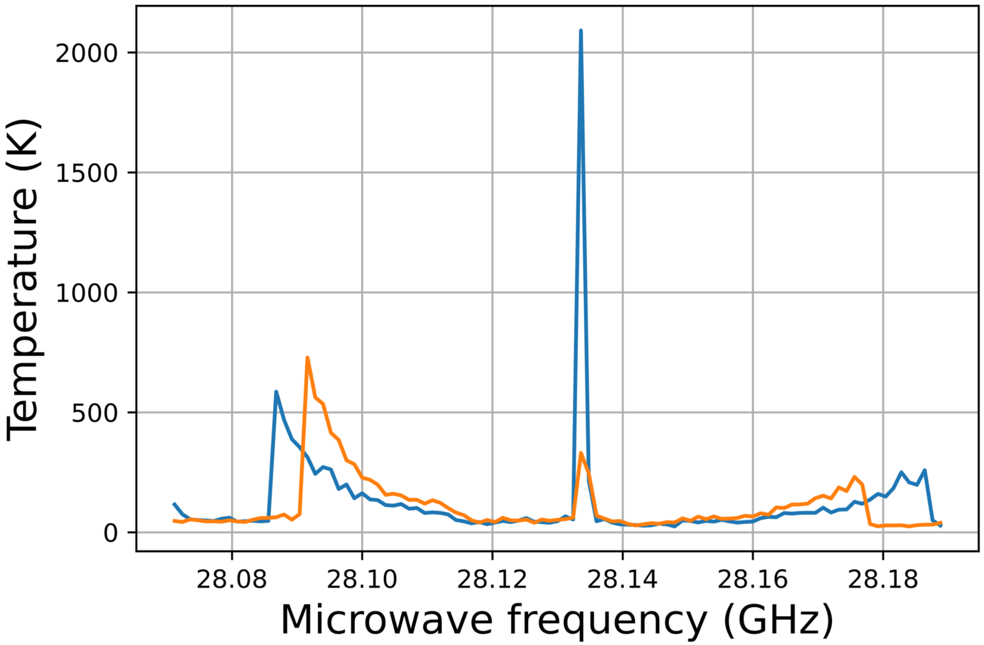
Measure temperature of electron "scoops"



Electron Cyclotron Resonance (ECR) Magnetometry with a Plasma Reservoir
E. D. Hunter, A. Christensen, J. Fajans , T. Friesen, E. Kur, and J. S. Wurtele (2019)

An example of ECR spectra

- Narrow central peak = f_c
- Precision related to peak width
- Broad, asymmetric sidebands from electrons axial frequency

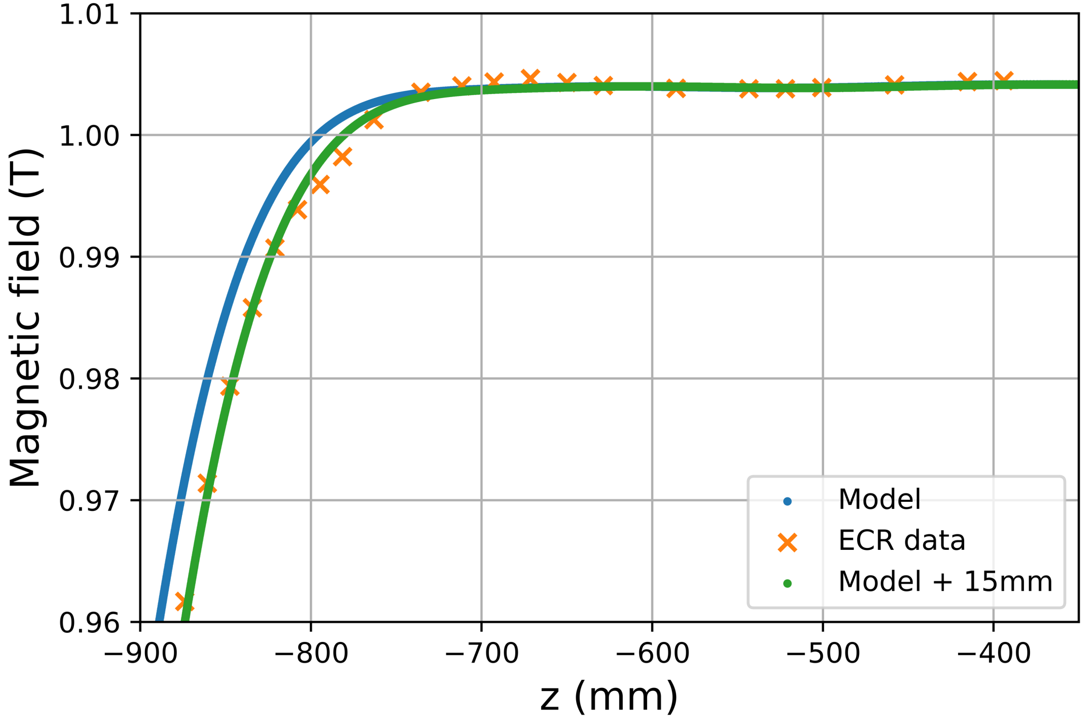


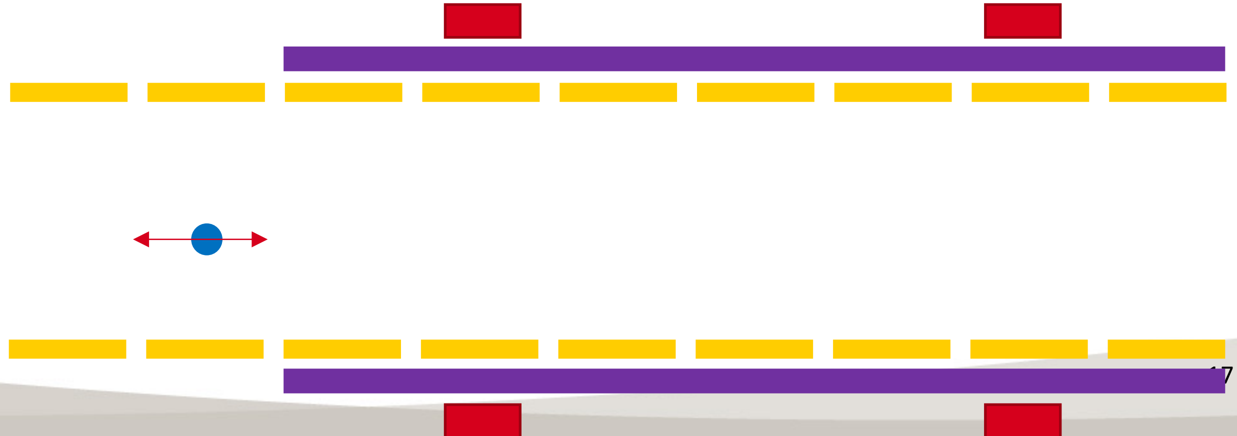
How do you understand the magnetic environment?

- What is the background field?
- How does the field respond to applied current for each magnet?
- Where is the maxima of each magnet?
- Are there any uncontrolled fields?

Key point: We are always interested in the differences bottom/top

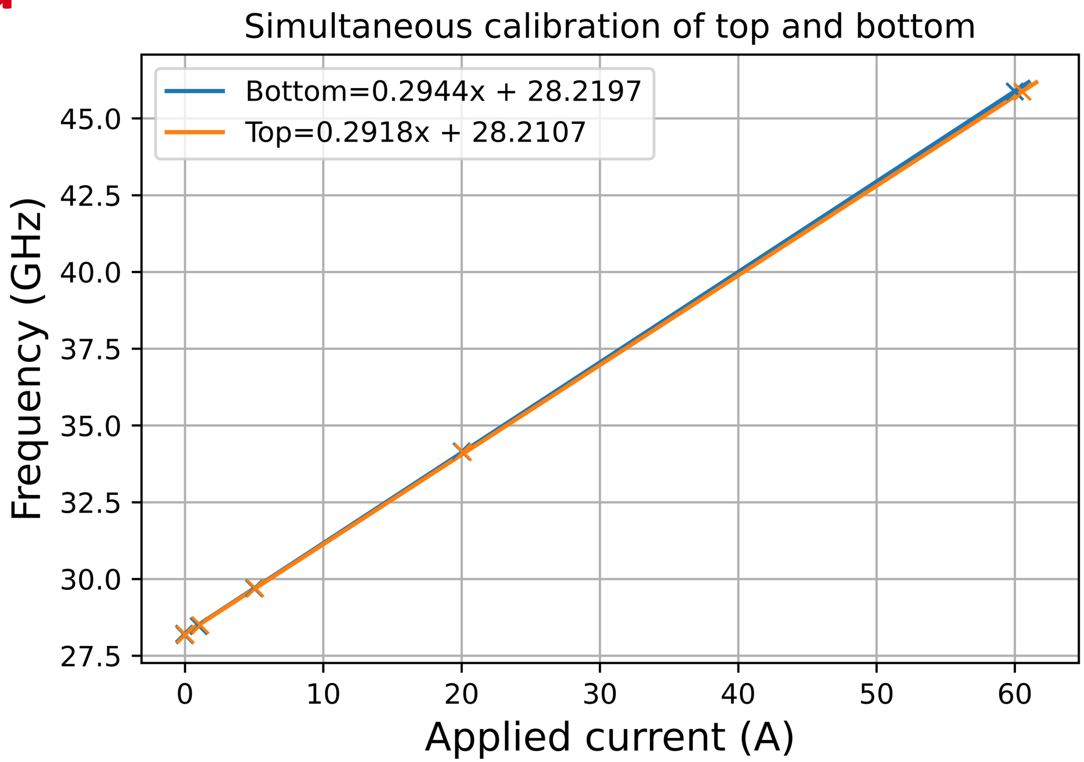
Field mapping the background magnet

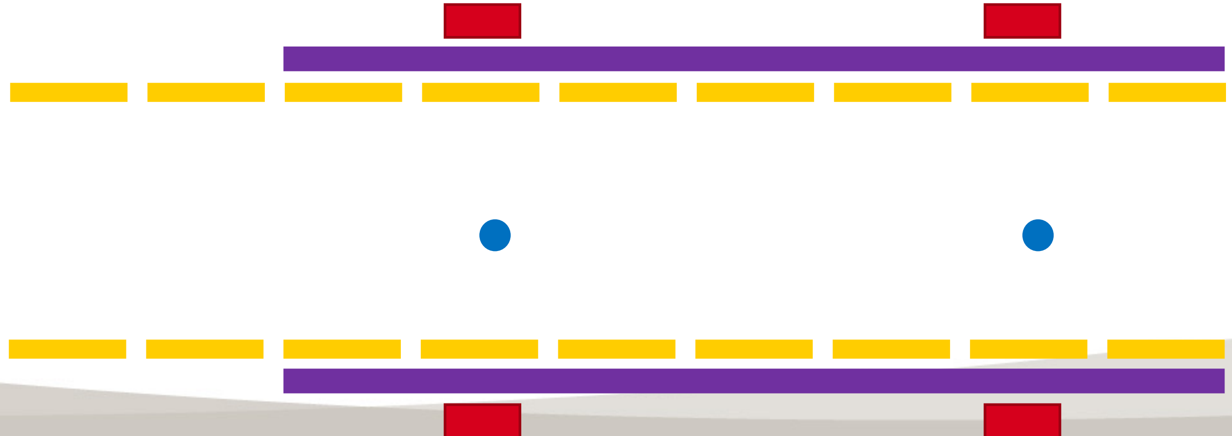




10^{-4} T = 1 Gauss = 2.8 MHz

Calibrating magnetic field to current applied





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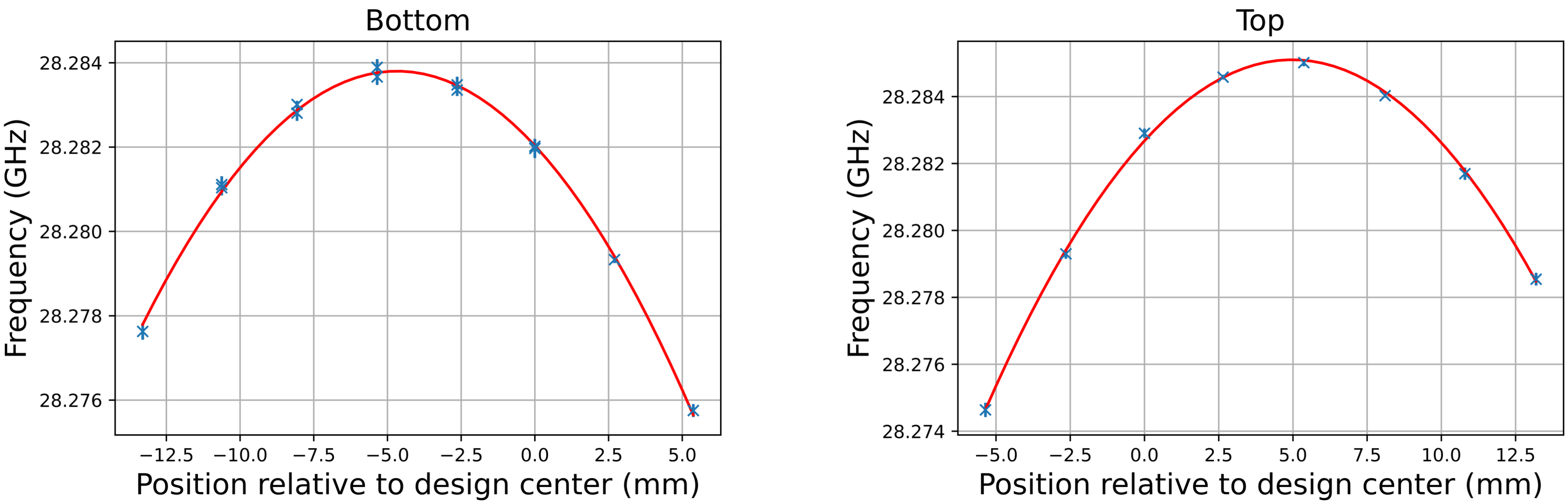
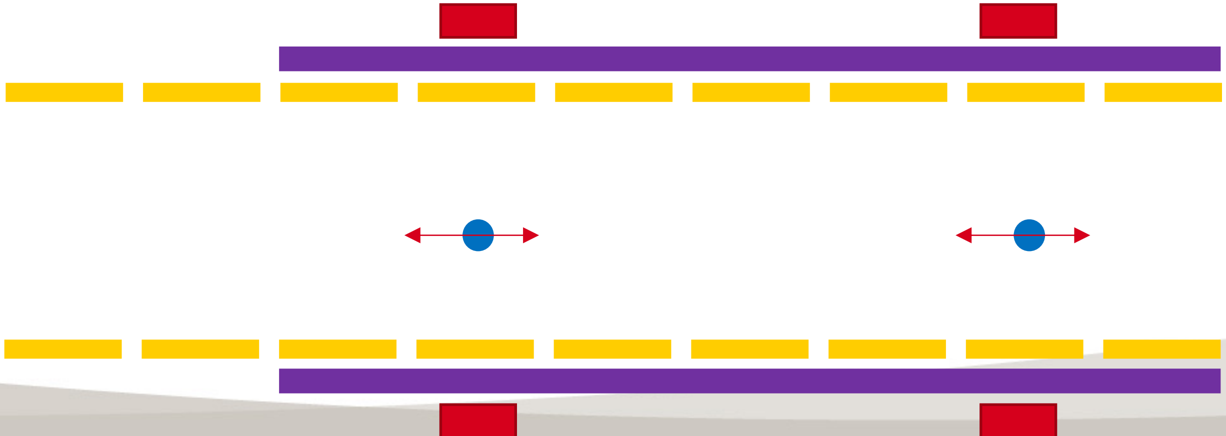
Mapping out the on axis maxima of a solenoid





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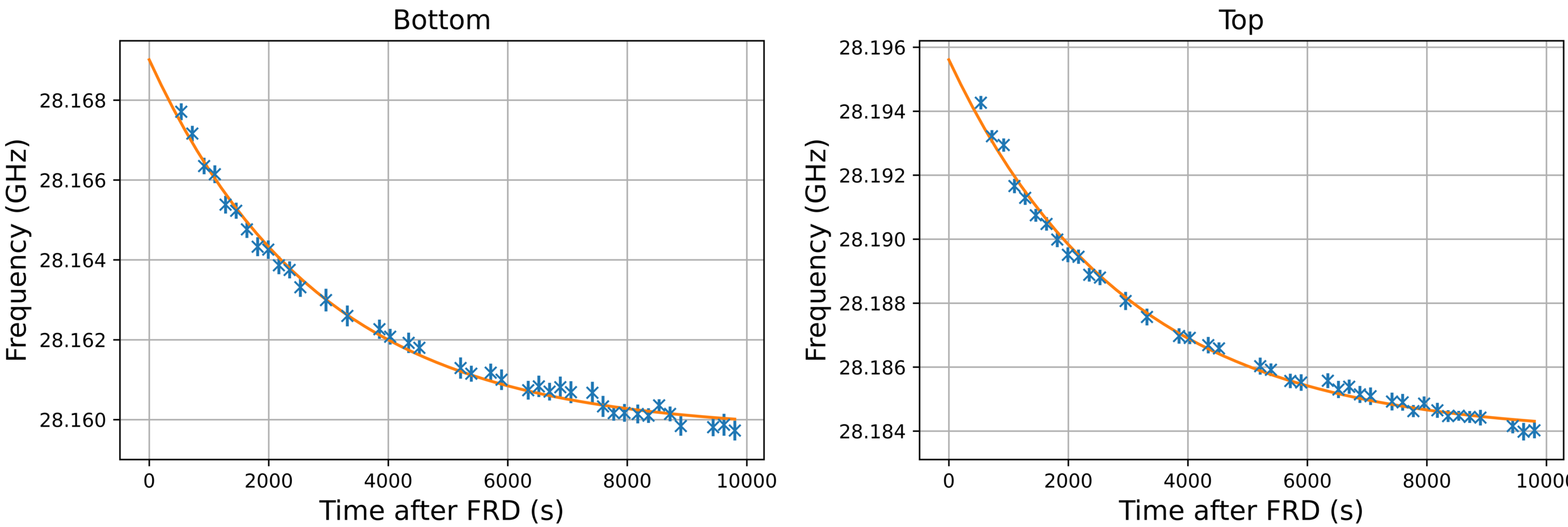
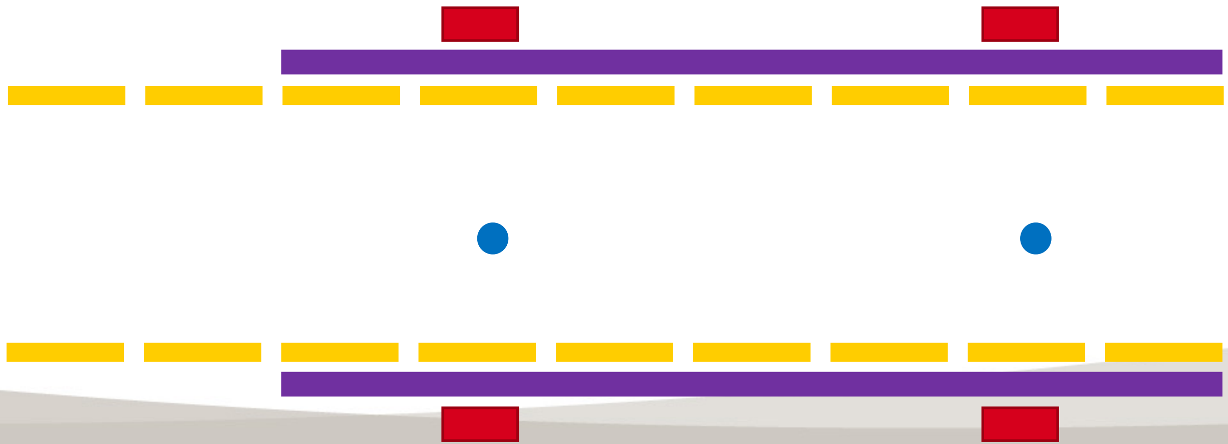
Measure decaying induced fields





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Summary

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- Antihydrogen properties are a powerful test of fundamental theories
- ALPHA requires precise magnetic field measurement
- In situ magnetometry technique has been developed in ALPHA to reach required precision
- We have show precision measurements in:
  - High fields
  - High field gradients
  - Mapping along an axis
  - Changing fields over time
- We are in a great position for an ALPHAg measurement!

Thank you to:

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Significant improvements to ECR capabilities

- Measure in multiple locations simultaneously
- Resolution better than 10^{-4} T (even in high field gradients of a few 10^{-4} T/mm)
- Stable plasmas for repeatable measurements over months
- On axis field mapping with resolution < 1mm
- Available range: 0.5 – 1.78 T (14 – 50 GHz)
  - Low frequency end not tested