

# Commissioning of ALPHA-g at CERN

**WNPPC 2019**

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14.02.2019

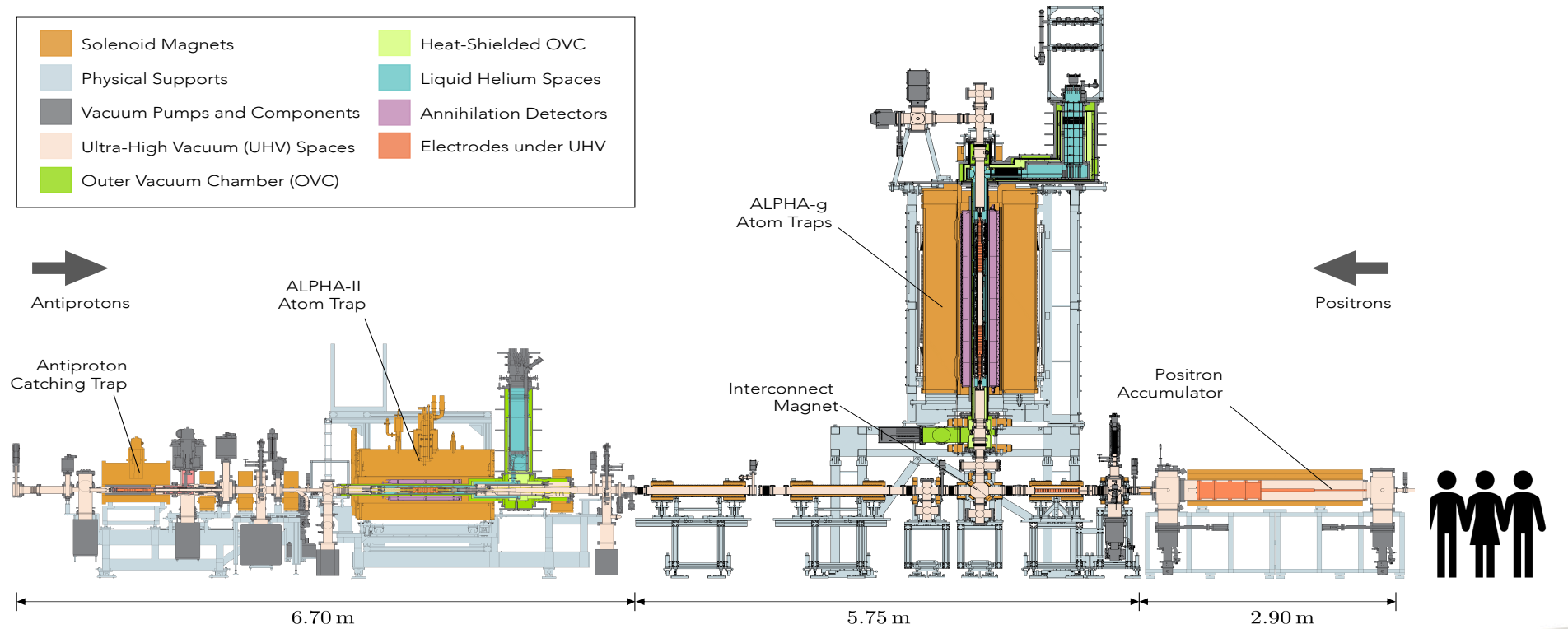
## ALPHA-g overview

- Antihydrogen is produced and confined in a magnetic well
- Magnetic fields are ramped down and antihydrogen is “dropped”

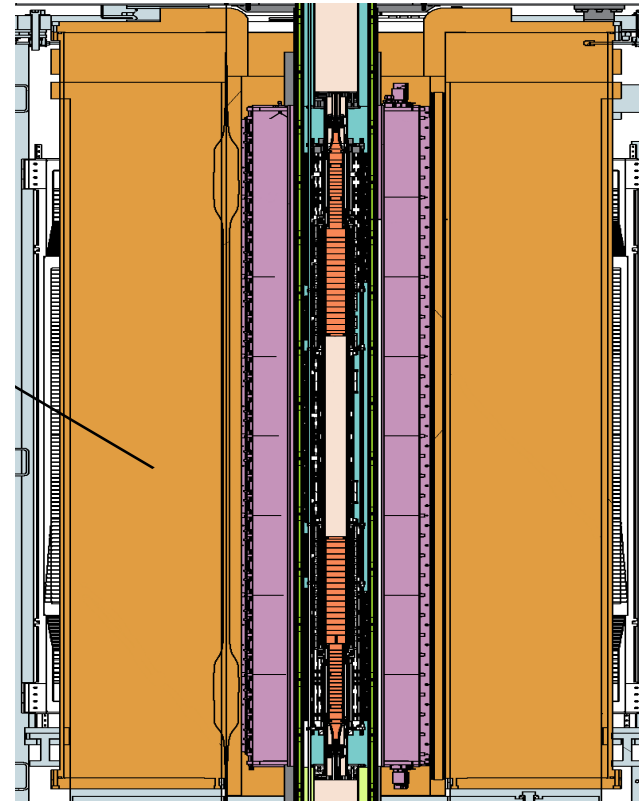
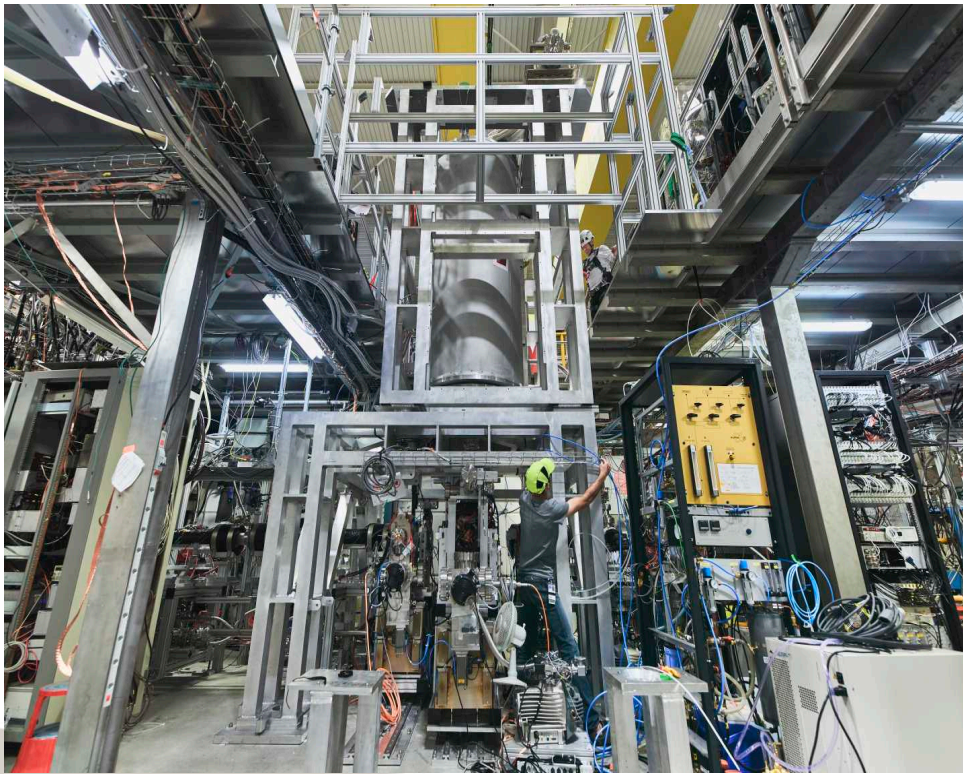
Aims:

1. Make an “up vs down” measurement of  $H$  in free fall
2. Measure the gravitational mass of  $H$  to 1%

# ALPHA



# ALPHA-g

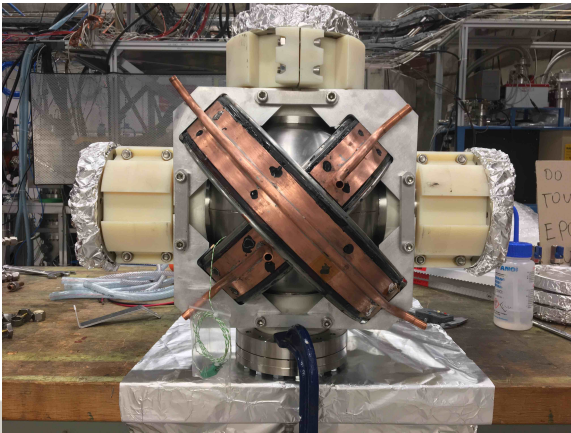
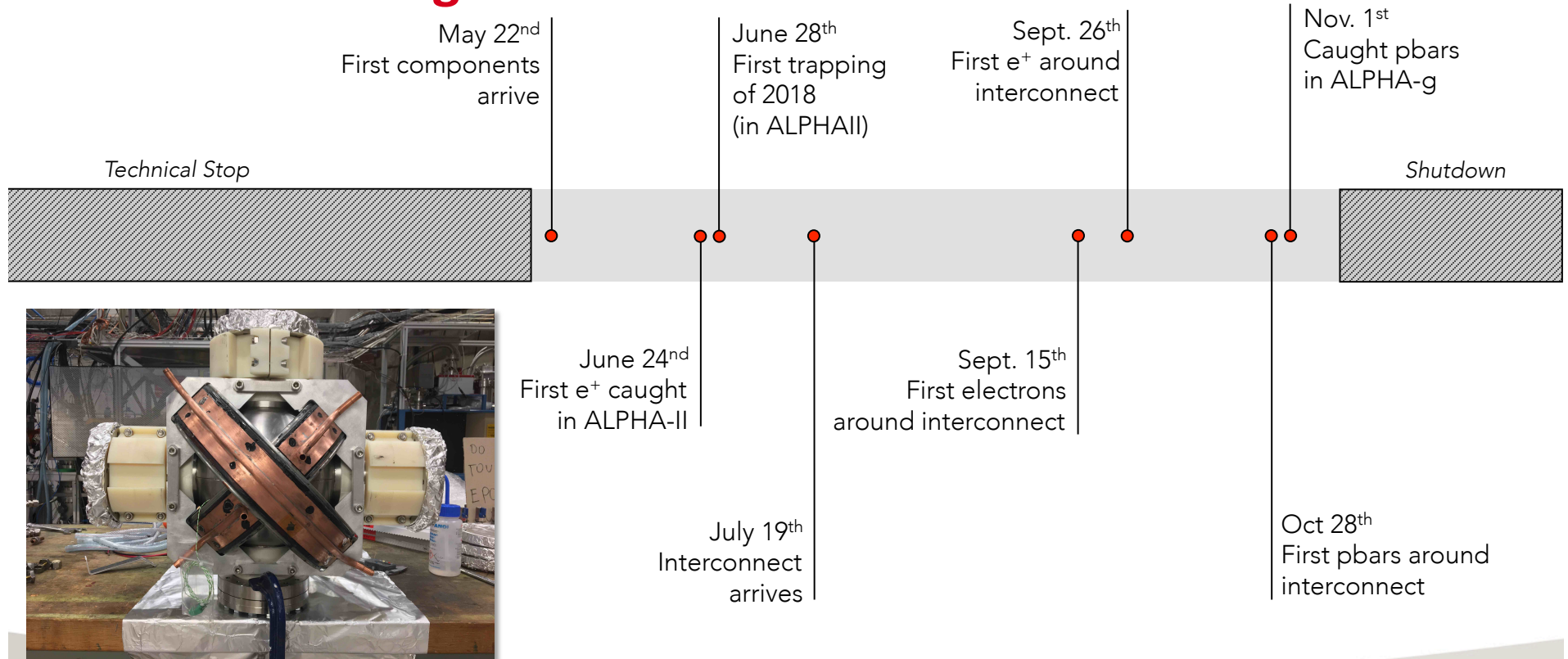




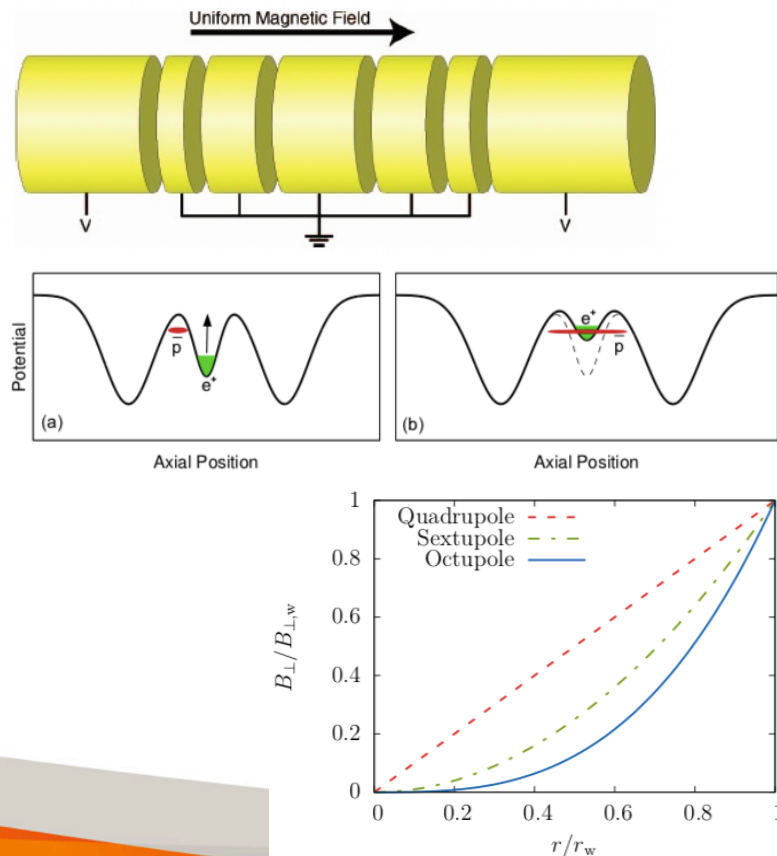
## Challenges in measuring (anti)gravitational effects

- Neutral particle is required ( $F_g / F_{EM} \sim 10^{-36}$  for two protons  $10^{-10}$  m apart) - producing antihydrogen is a complex process
- Gravitational potential difference of  $H < 1$  Gauss over 40 cm – need magnetic field stability and uniformity within this limit
- Accurate measurements of magnetic fields in situ are difficult – need to know to above limit

# Commissioning timeline



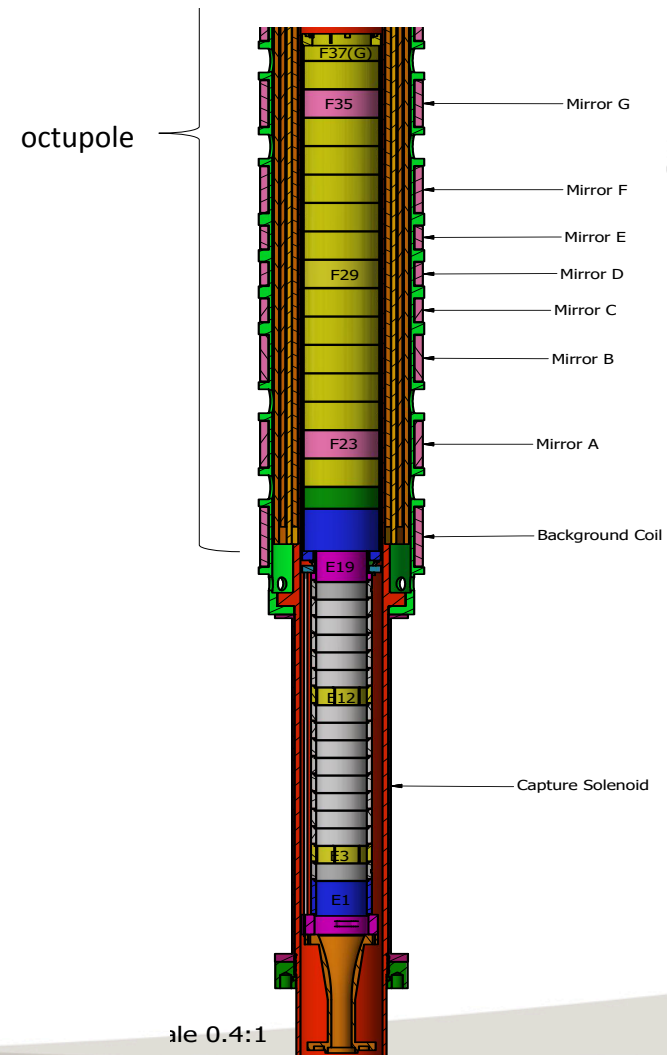
## $H$ trapping in ALPHA recap



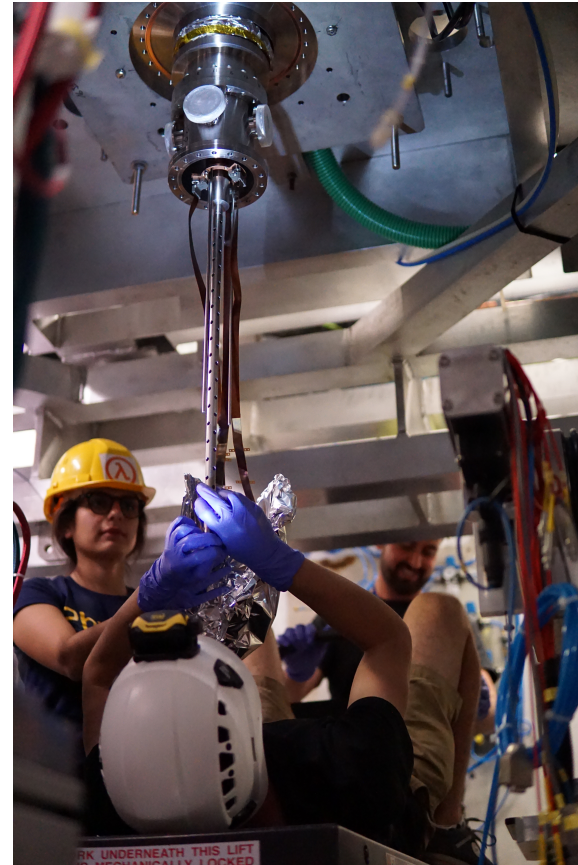
- Cylindrical electrodes produce an  $E$  which can confine  $p$  and  $e^+$  axially, solenoid provides radial trapping
- Plasmas manipulated to overlap and mix  $\rightarrow H$  production
- $H$  is neutral, can no longer be confined by Penning trap- need magnetic trap
- Trap depth is radially dependent ( $B \propto r^3$ ) – use "thin" electrodes in  $H$  region

## Design of the ALPHA-g trap

- 2 x 36 electrode stack (1-19 normal, 20-36 thin)
- Gold plated aluminium electrodes individually isolated by ruby beads
- Heat sunk to liquid Helium cryostat
- Flexible circuits connected to low and high pass filters
- “Mirror coils” (short solenoids) give axial confinement
- Octupole gives radial confinement

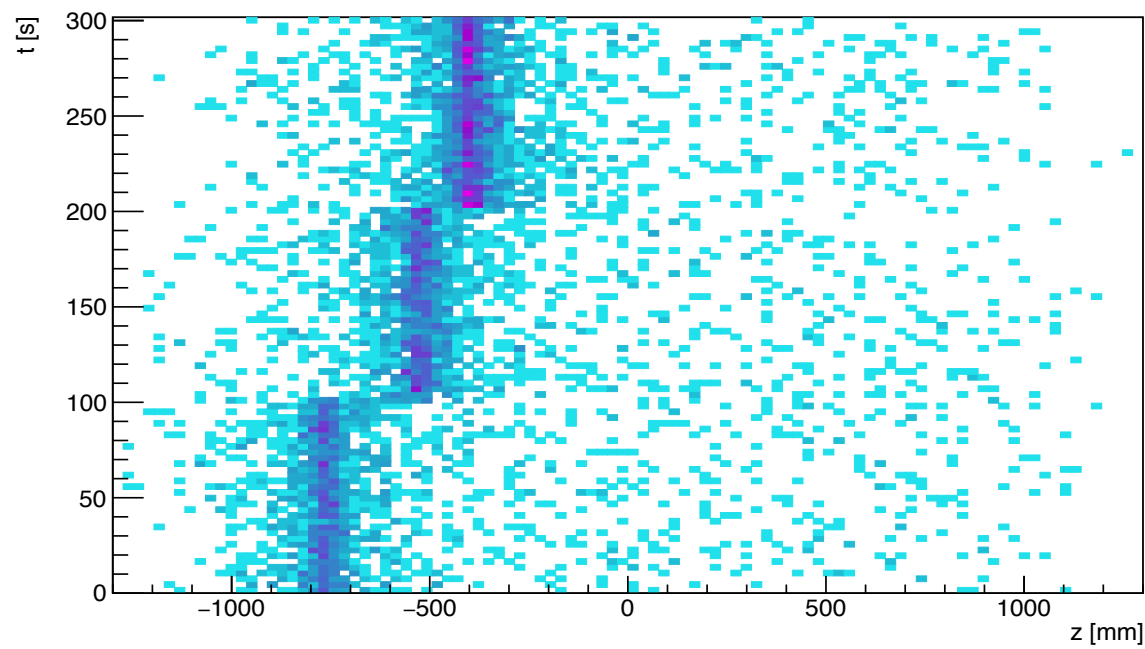


## Assembly and insertion



# Commissioning with $p$

Z-T Vertex



## Magnetometry in ALPHA-g

- Hall probes, NMR probes used along rTPC and trap magnets

In situ:

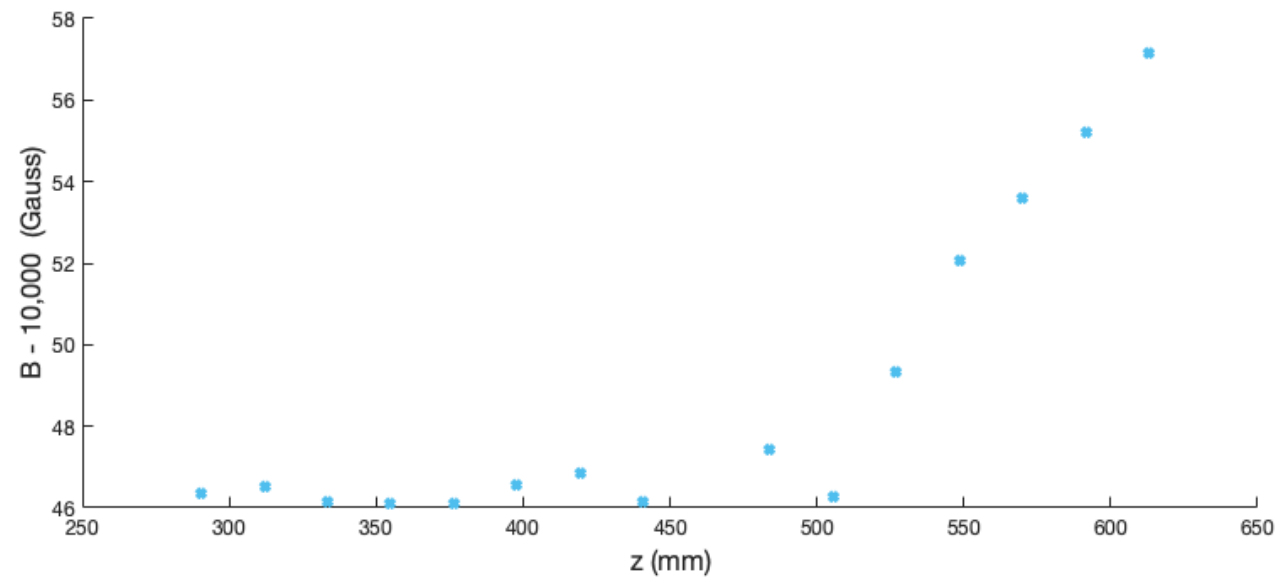
- Electrons in a magnetic field have cyclotron motion at a resonant frequency

$$f_{\downarrow ECR} = eB/2\pi m$$

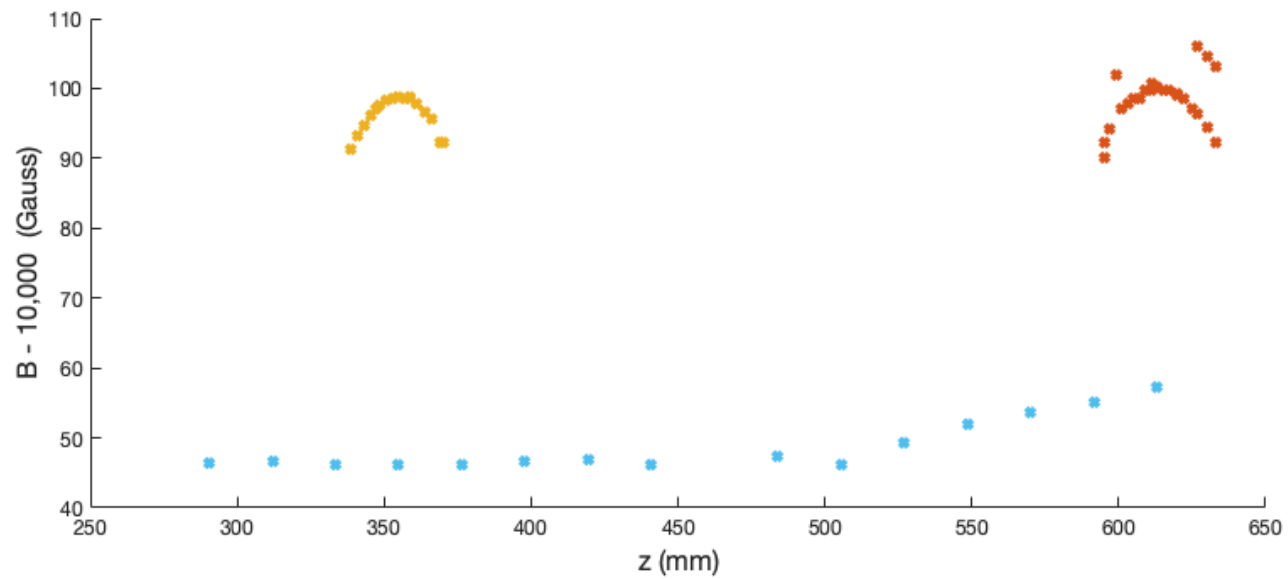
- $f_{\downarrow ECR} \sim 28 \text{ GHz}$  for electrons  $\rightarrow$  microwaves
- Cyclotron frequency can be driven by a pulsed microwave field (over a frequency range), increasing the electrons temperature at resonance



## Initial ECR data in ALPHA-g



## Initial ECR data in ALPHA-g



## Outlook

- Lower Penning-Malmberg trap in ALPHA-g is operational
- $p$  and  $e^{\uparrow+}$  trapped, manipulate and detected in ALPHA-g
- Initial magnetometry data obtained
- Make “up vs down” measurement soon after CERN long shutdown
- Working towards 1% measurement

## Thank you to:



- TRIUMF & CERN
- UofC
- Everyone in ALPHA
- NSERC
- CFI
  - + AB, BC, ON match



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