The ALPHA-\( g \) antihydrogen gravity magnet system

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On behalf of the ALPHA collaboration
Magnetic minimum trap

- Anti-atoms feel a potential $\propto |\vec{B}|$
- $O(1 \text{ Kelvin}) / O(1 \text{ meV})$ confinement with
  2 T octupole + 1 T mirror-coils + 0.65 T uniform Bz
- $>> 100$ antihydrogen atoms
Compensated escape

- Measure gravity by releasing anti-atoms axially
- Escape balance depends on relative coil strength and gravity
- Signal = 7 G
  1% precision = 0.07 G
  in relative field between the two ports
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- 2 cryostats
- All NbTi conductors @ 4 K
- 2 pairs 1000 A hybrid leads
- 15 pairs 150 A leads
- 1 pair 200 A leads
- 20 coils on outer bobbin
- 3 octupoles on inner tube
- 4 correctors
Inner and outer cryostats

~ 7 m tall

LHe reservoir

Antiproton and positron beamline
Inner magnets
~ 2 m

Chris
Octupoles

- Layers of serpentine windings encased in epoxy and fiberglass
- Made at BNL using a CNC wire laying stylus machine
- 11-15 turns × 8 layers
- 1.1 mm dia., max. 1000 A
- Each bi-layer made of an unbroken conductor, spliced outside
- Two circuits overall
Octupoles

- Finite fabrication tolerance
- Measurements need to be resilient
- Simulate by wire model, compare field difference between two ports
- A balance:
  - Error increases with Δz (approach end turns)
  - Gravity signal decreases with Δz
- Coils positioned for max. signal to noise
Octupoles

- Anti-atoms need to be transferred through end turns
- Half of them opposes the background $B_z$, induces $|B|$ weakness near wall
- Near total loss of confinement
- Solution:
  - Shield hole of inner layers with longer outer layers
  - Stagger turns
- $\sim 3\%$ loss of confinement
Coils

- Layers of tight-packed helical coils embedded in epoxy and wrapped with tensioned fibreglass
- Also made at BNL
- 50 – 200 turns × 8 – 12 layers
- Single unbroken conductor per coil
  - Normal coils
    - 0.33 mm dia., max. 130 A
  - Precision coils
    - 0.38 mm dia., max 10 A
Coils

- Wire thickness tolerance → turn count fluctuation → asymmetry between coil pairs
- Shim coils to match pairs
  - Photo for each layer
  - Data obtained: turn count, turn position, layer jump position
  - Pause fab after 2\textsuperscript{nd} coil’s last layer
  - Create wire model and calculate profile, simulate unwinding last turns of 2\textsuperscript{nd} coil
  - Compare normalised profile (normalisation = current freedom)
  - Unwind for real
- Overcome lack of pre-wind control
- Achieve match at all \( r \) to \( 10^{-4} \)
Correctors

• For the balanced escape experiment: bottom and top barriers must match, both on-axis and off-axis
• Ignoring octupole: coils of different axial lengths needed
• In practice:
  – Length has to change during release ramp
  – Instead of altering coil, tweak length by rebalancing some current to (longer) corrector coil
Correctors

- Octupole field introduces further complications
- Corrector octupole: more knobs
- Result: field match to $O(5 \times 10^{-6} \text{T})$
Summary

• A wide range of features to achieve magnetic control for physics
  – Too many to list – come and ask!
• Developing magnetometry
• Developing environmental field solutions
• Finish magnet system fabrication during LS2
• Magnet mapping in LS2
• Physics from 2021
Persistent field

• Enduring current loops induced by change in field
• Not directly controlled
• Past ALPHA traps persistent field ~ 10 G
• Geometry motivated by need to mitigate this
• Strategies:
  – Minimal NbTi in Precision Region
    14 – 24 % of past traps
  – Expansion cooling from Strong Trapping Region
    Make sure anti-atoms survive in shallow trap
  – Fancy new conductors
    63 filaments → 678 filaments per wire
  – Symmetrise magnetic history
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