The ALPHA-g antihydrogen gravity magnet system

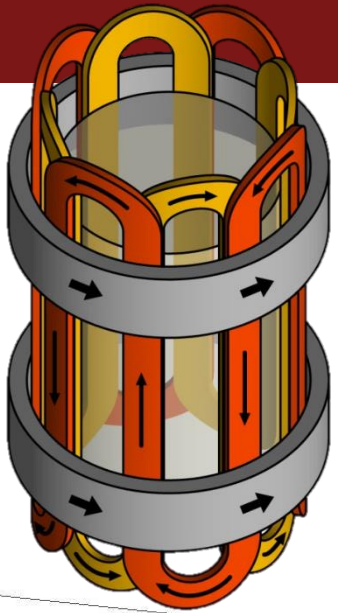
MT26, 9-23-2019

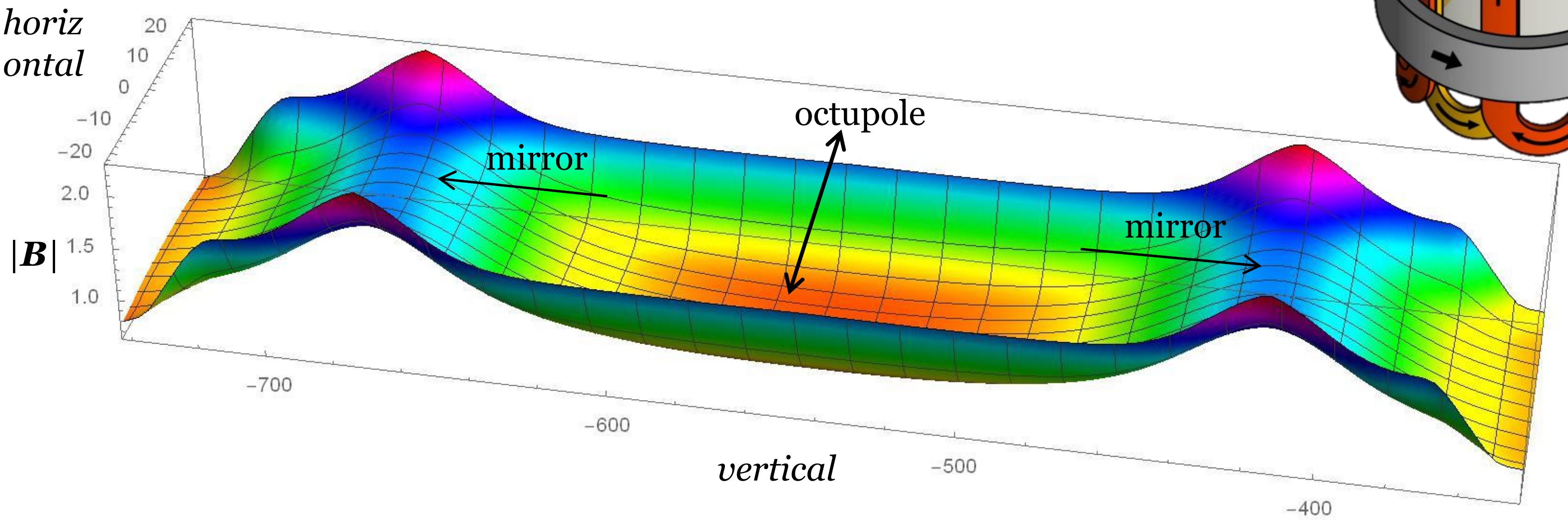
Chukman So / TRIUMF

On behalf of the ALPHA collaboration

Magnetic minimum trap

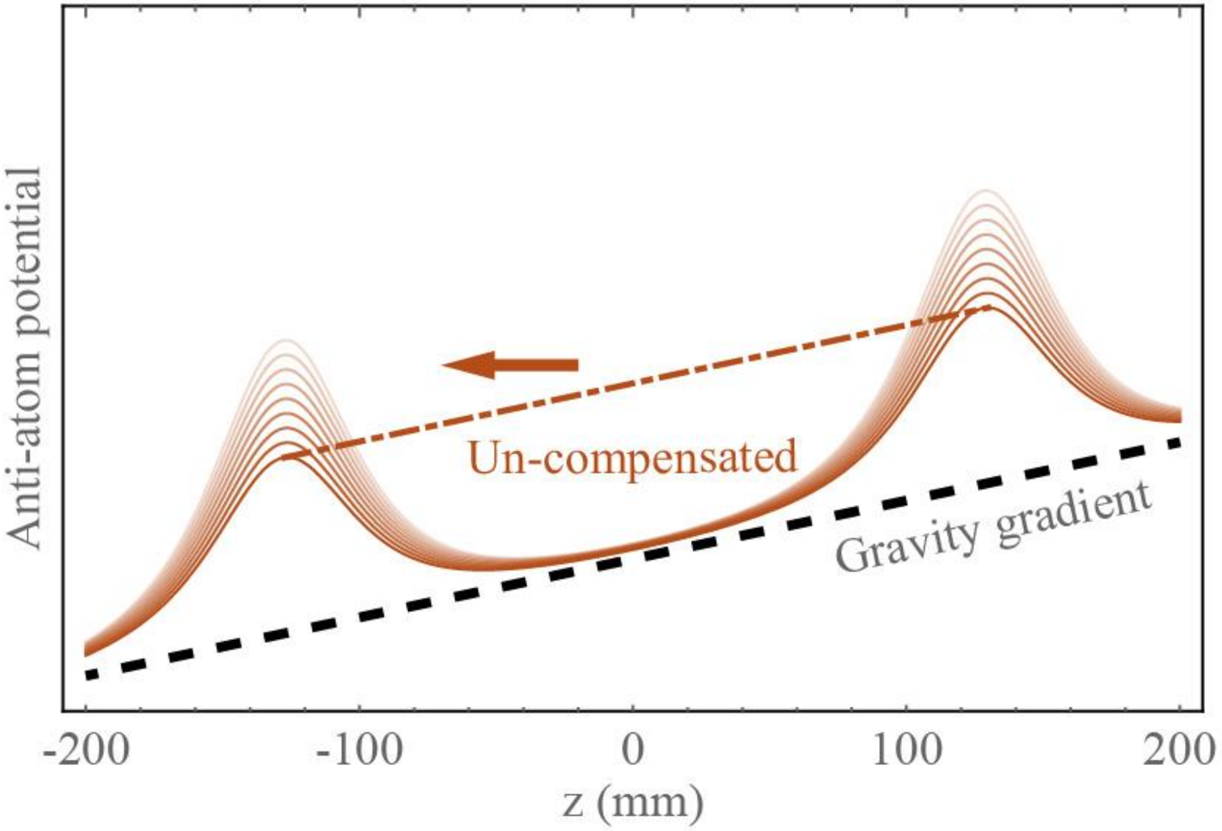
- Anti-atoms feel a potential $\propto \left|\vec{B}\right|$
- O(1 Kelvin) / O(1 meV) confinement with
  2 T octupole + 1 T mirror-coils + 0.65 T uniform Bz
- >> 100 antihydrogen atoms





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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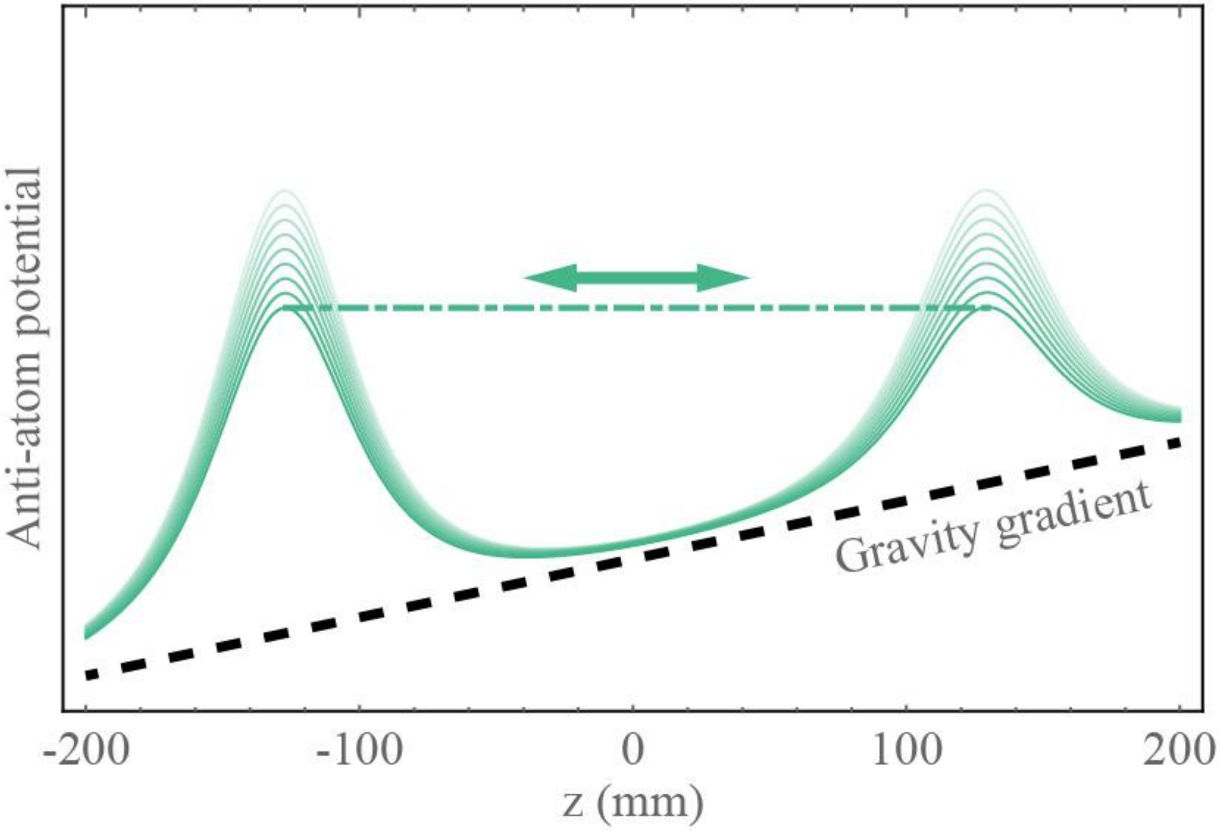

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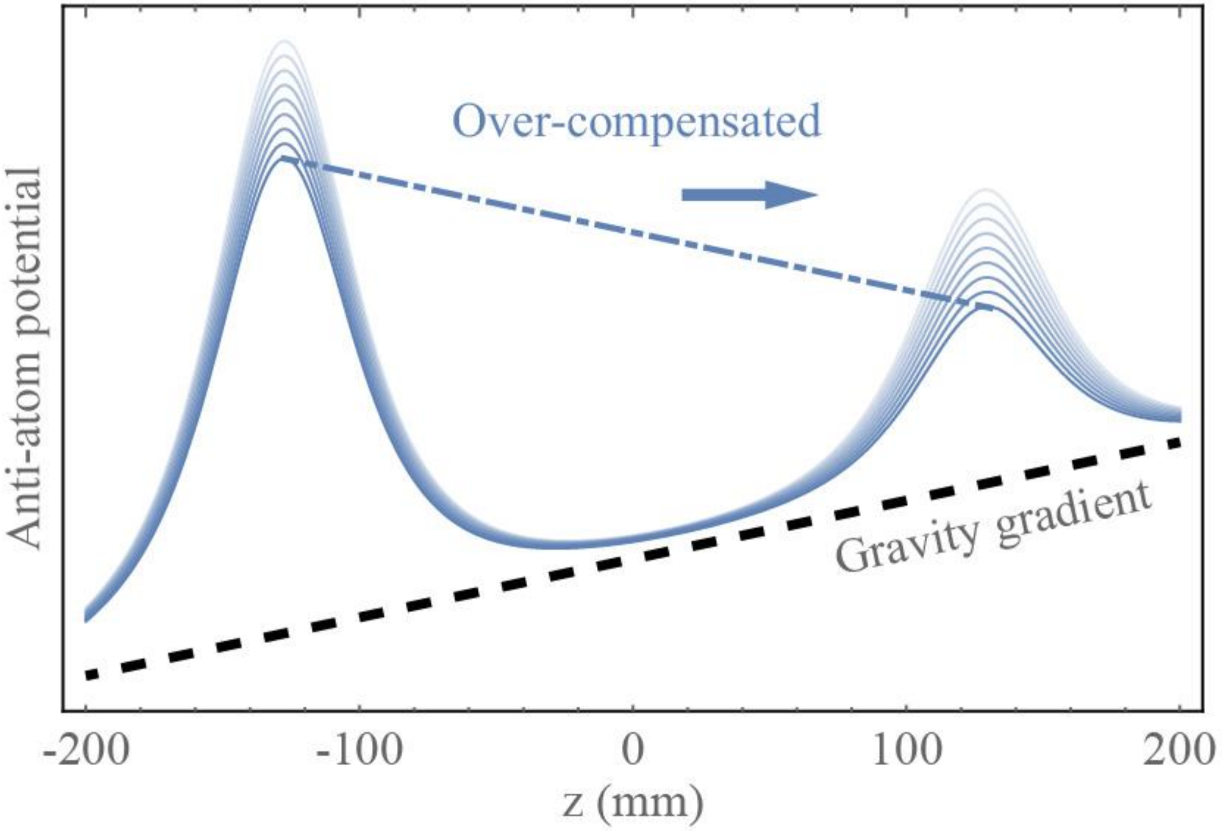
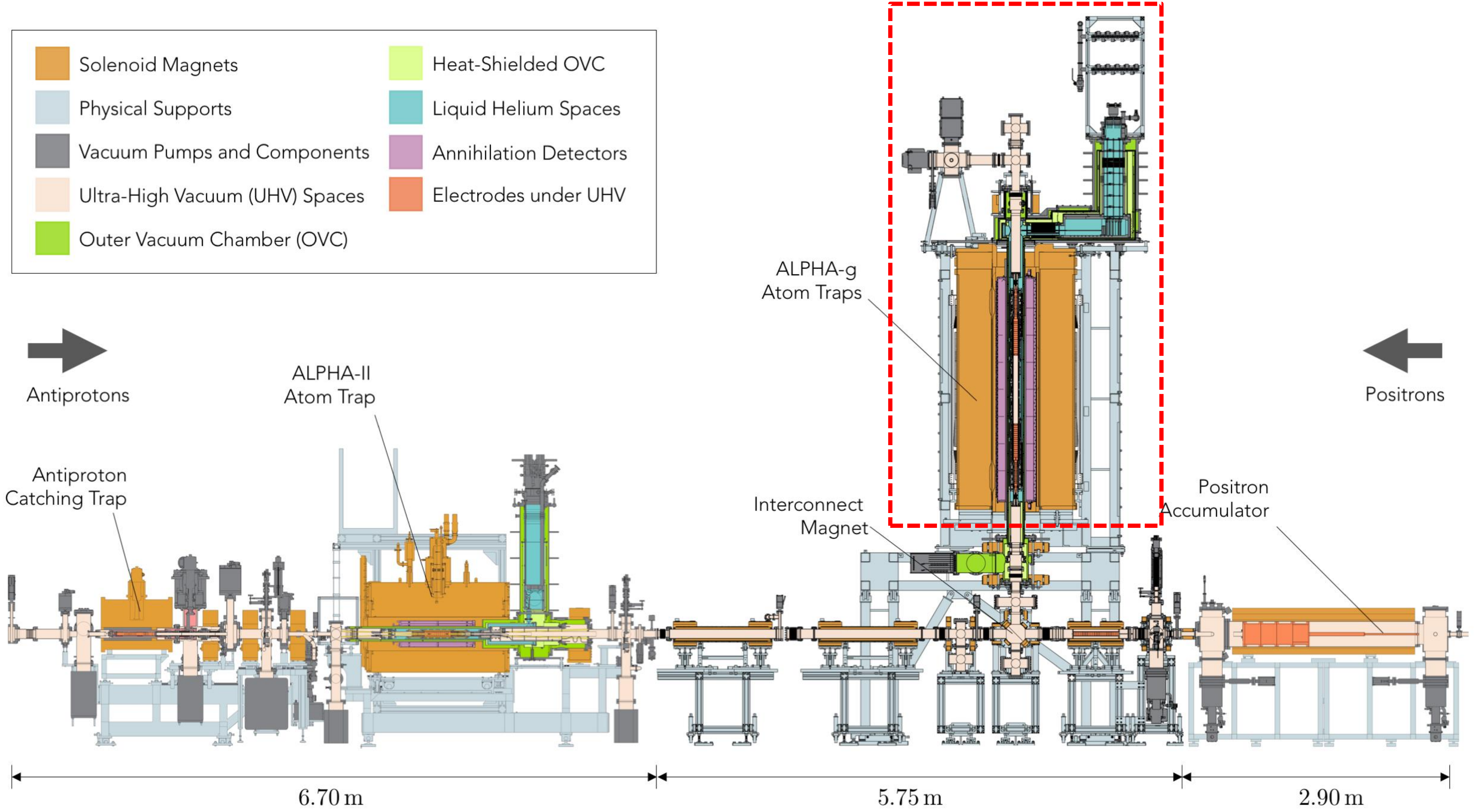
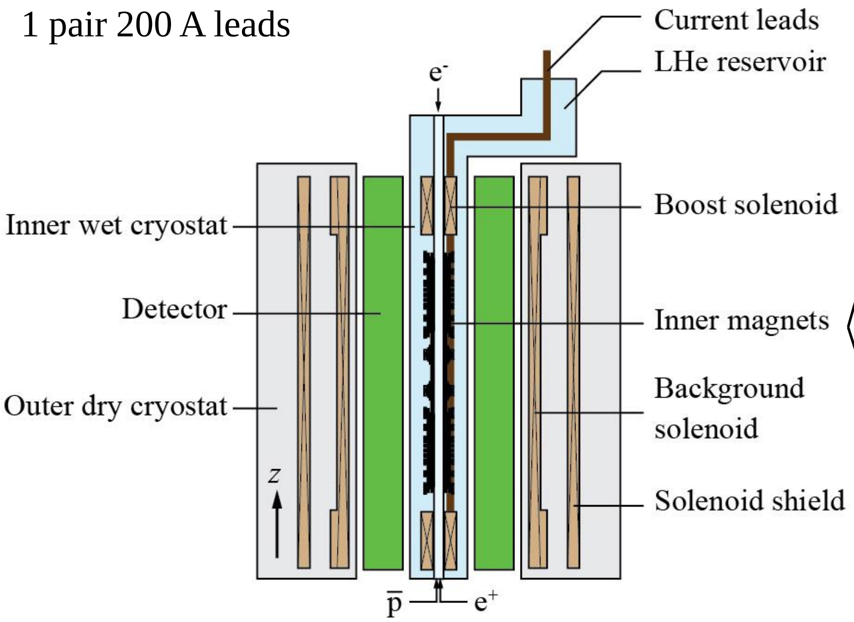
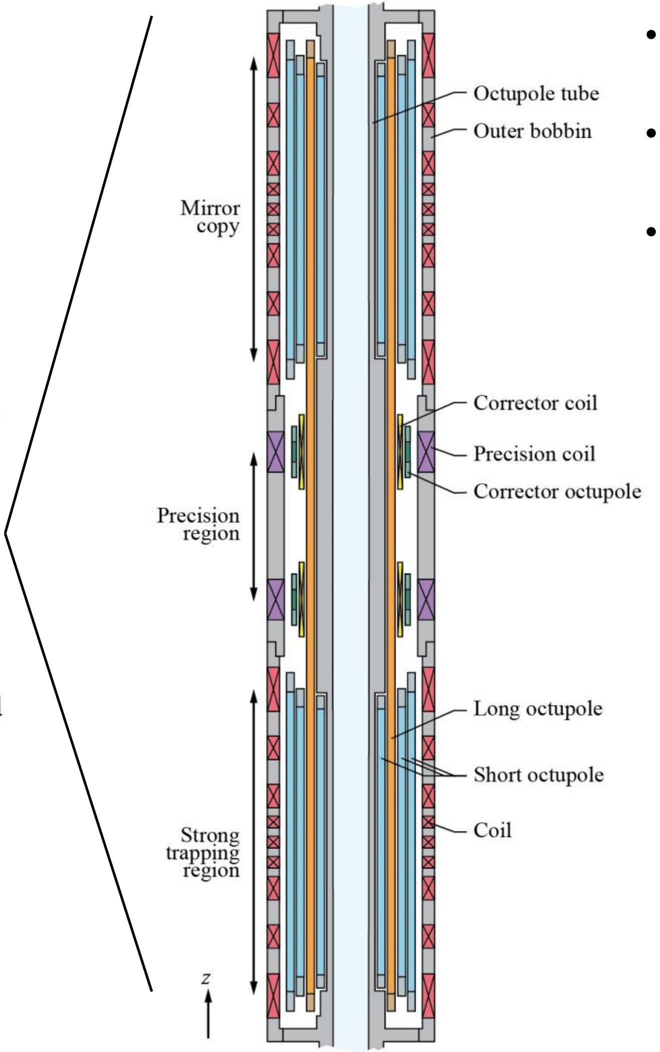




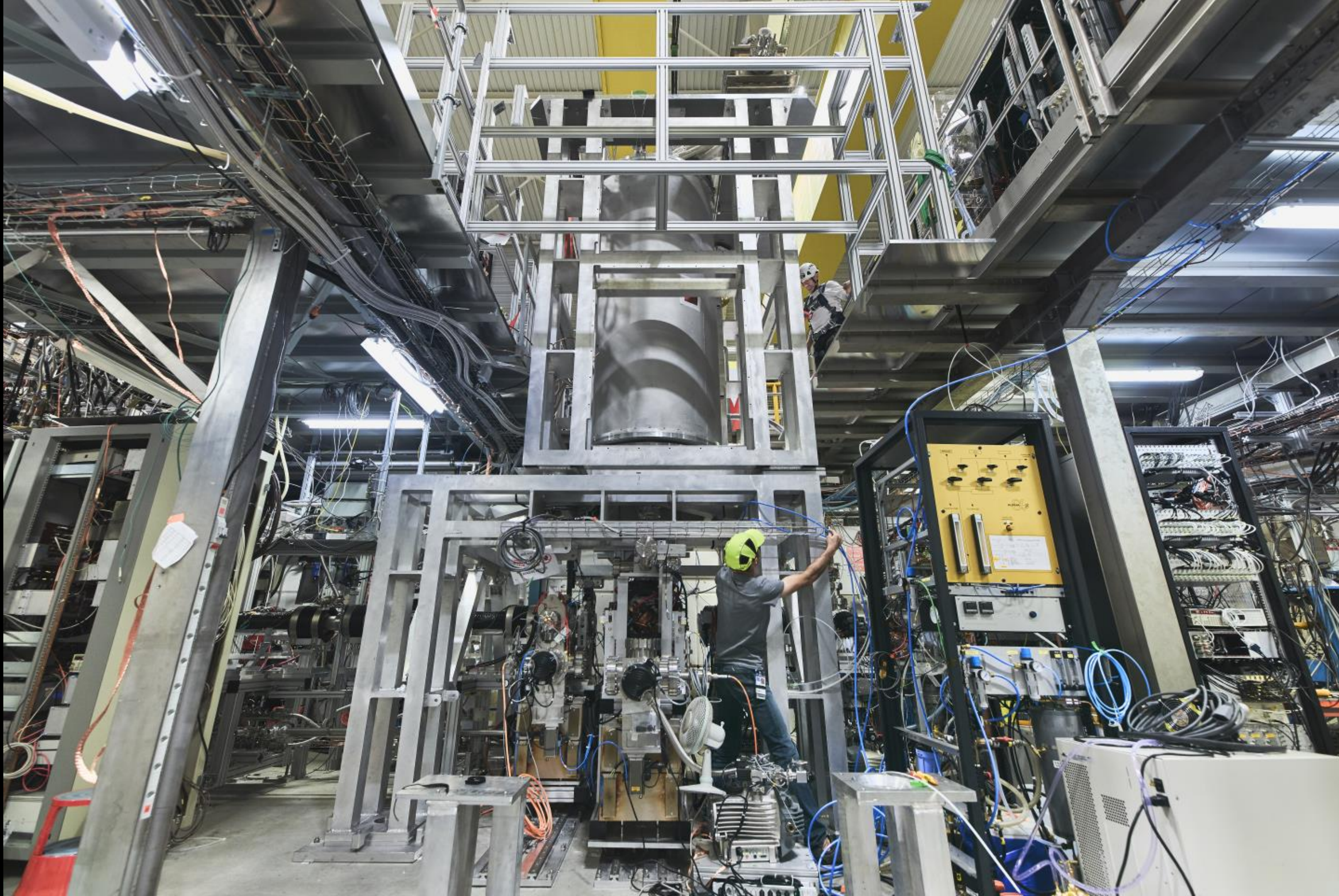
Solenoid Magnets
Physical Supports
Vacuum Pumps and Components
Ultra-High Vacuum (UHV) Spaces
Outer Vacuum Chamber (OVC)
Heat-Shielded OVC
Liquid Helium Spaces
Annihilation Detectors
Electrodes under UHV
ALPHA-g Atom Traps
Antiprotons
Positrons
ALPHA-II Atom Trap
Antiproton Catching Trap
Interconnect Magnet
Positron Accumulator
6.70 m
5.75 m
2.90 m

- 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



LHe reservoir

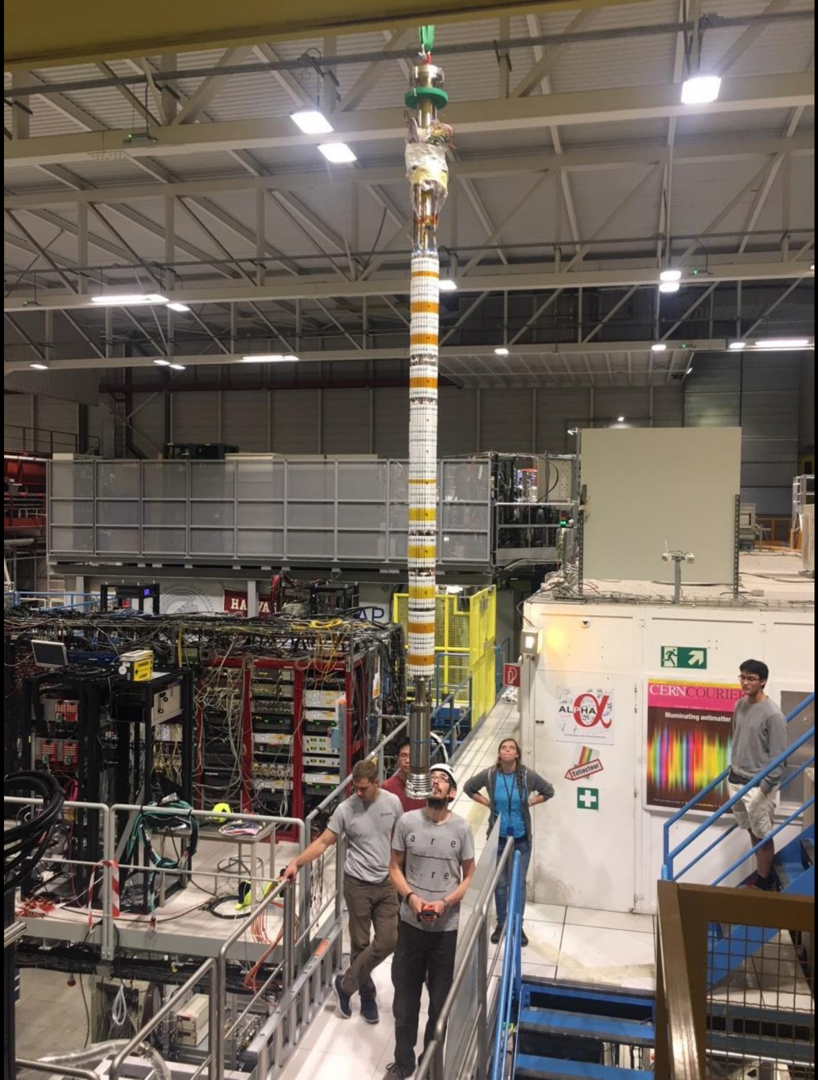
Inner and outer cryostats

Antiproton and positron beamline

~ 7 m tall

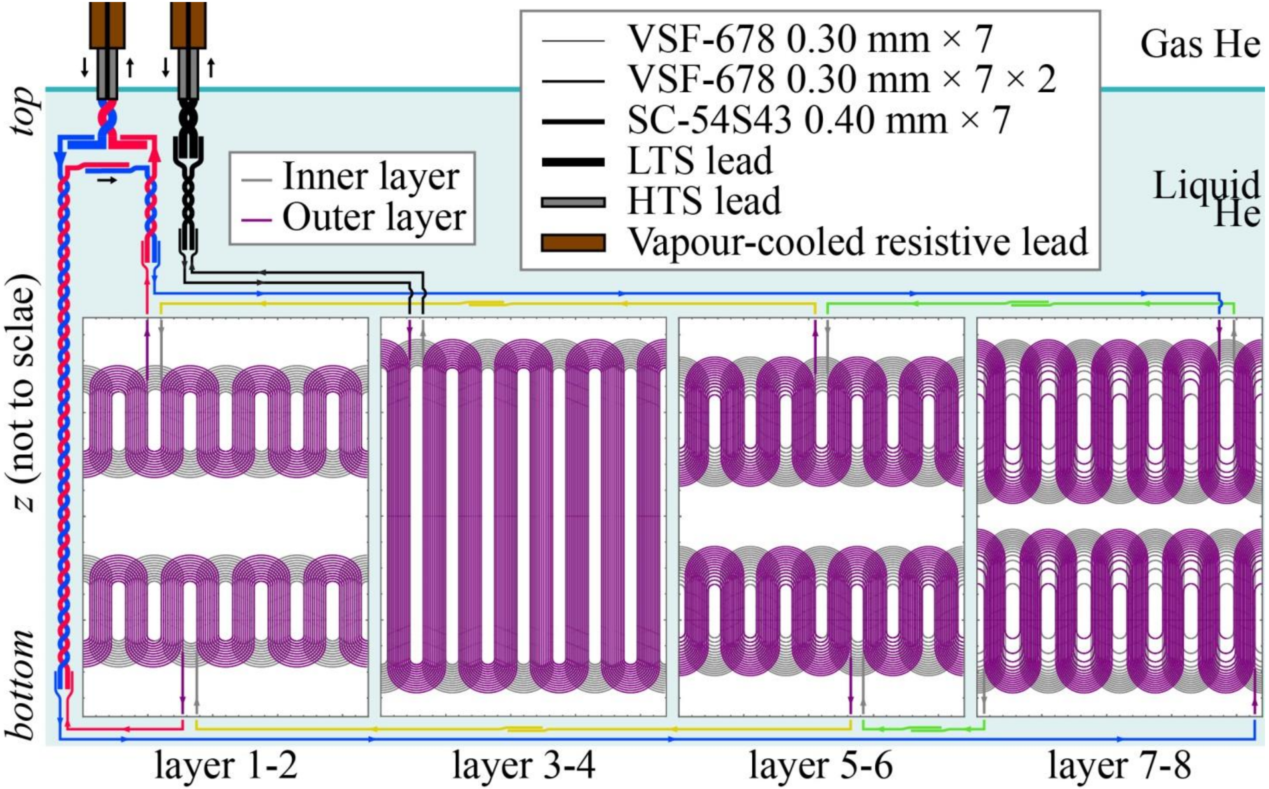
Inner
magnets
~ 2 m

Chris



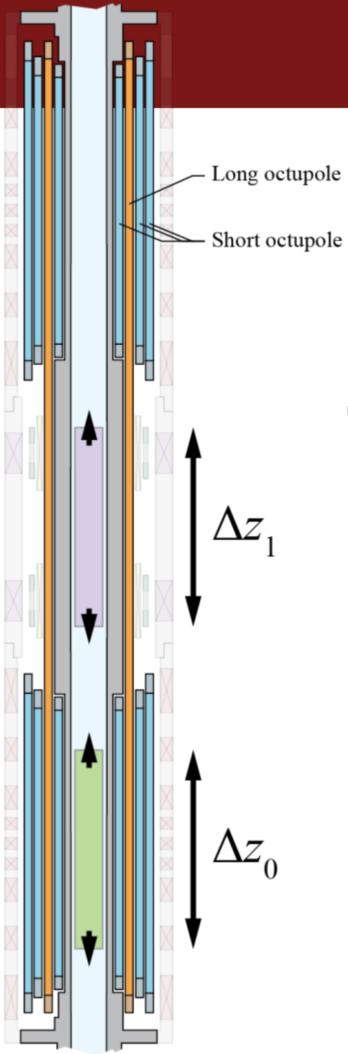
Octupoles

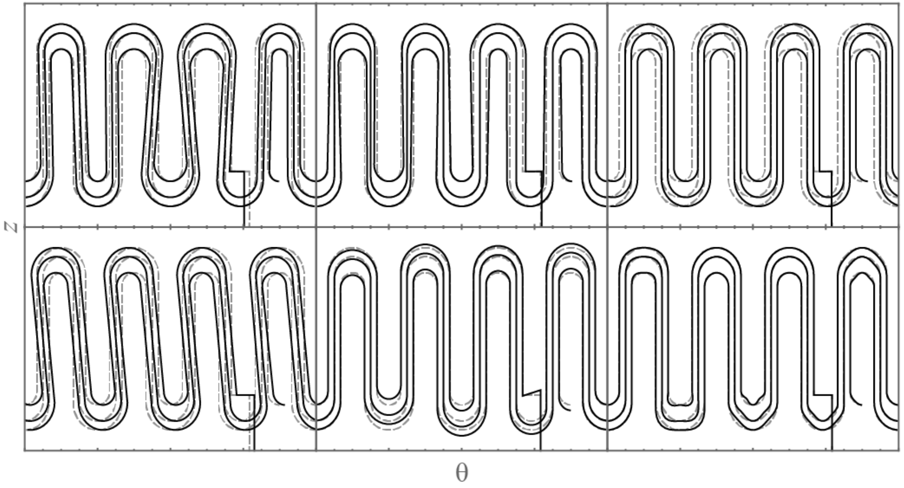
- Layers of serpentine windings encased in epoxy and fibreglass
- Made at BNL using a CNC wire laying stylus machine
- 11-15 turns × 8 layers
- 1.1 mm dia., max. 1000 A
- Each bi-layer made of an unbroken conductor, spliced outside
- Two circuits overall

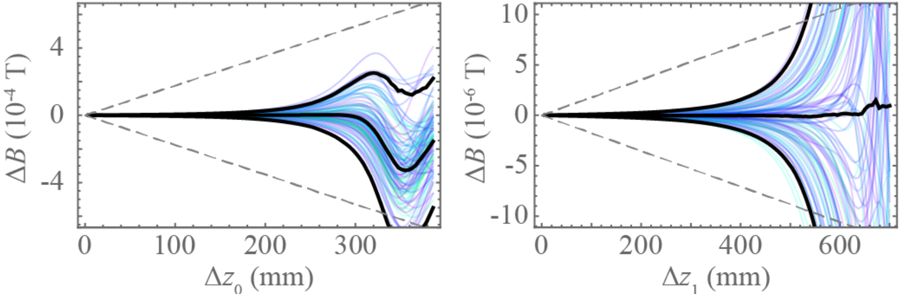


Octupoles

- 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

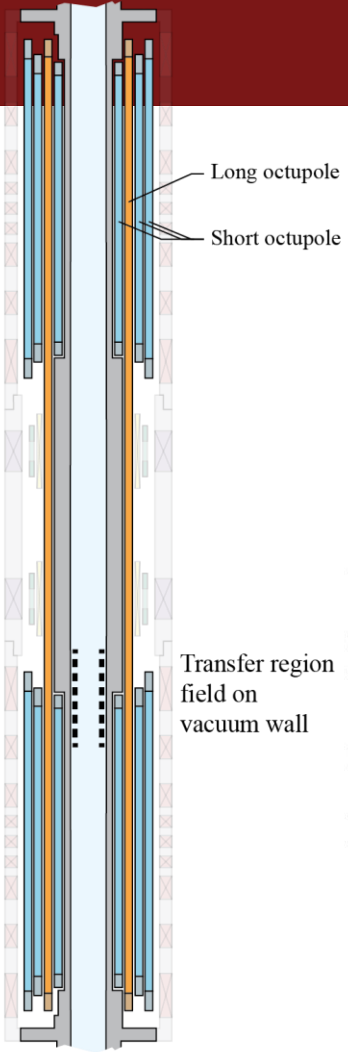


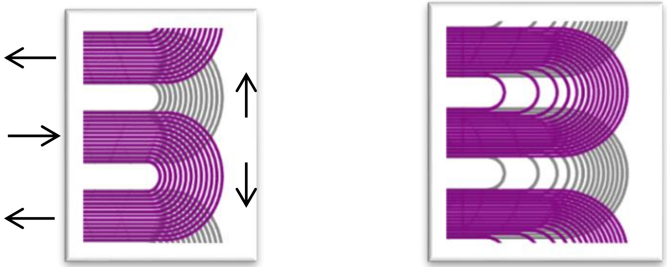


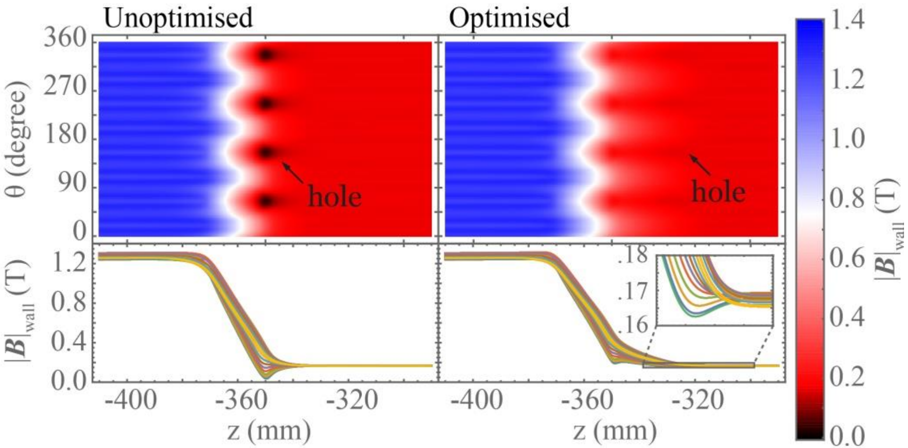


Octupoles

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

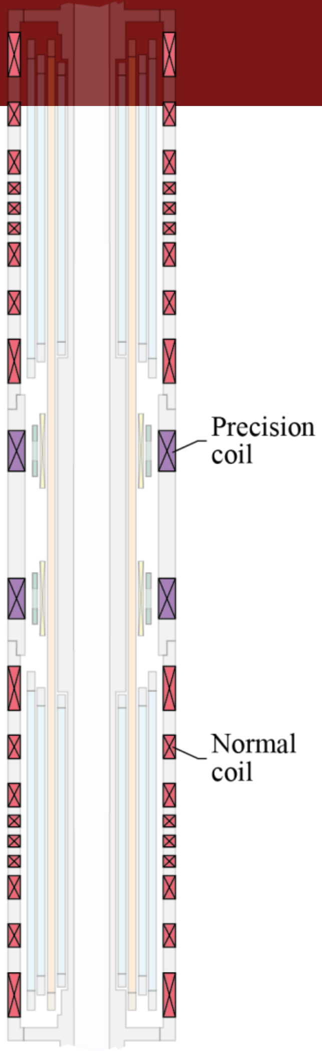


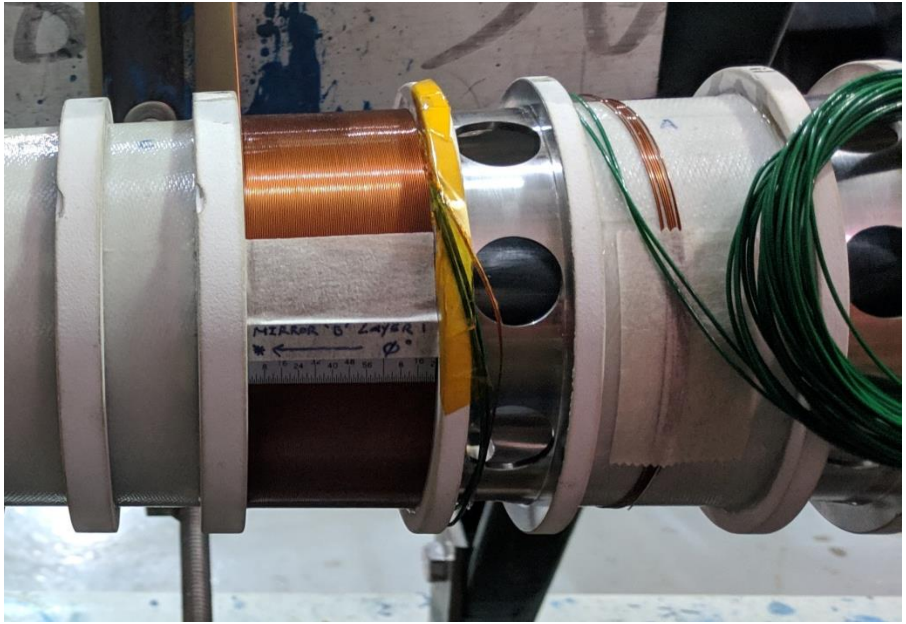




Coils

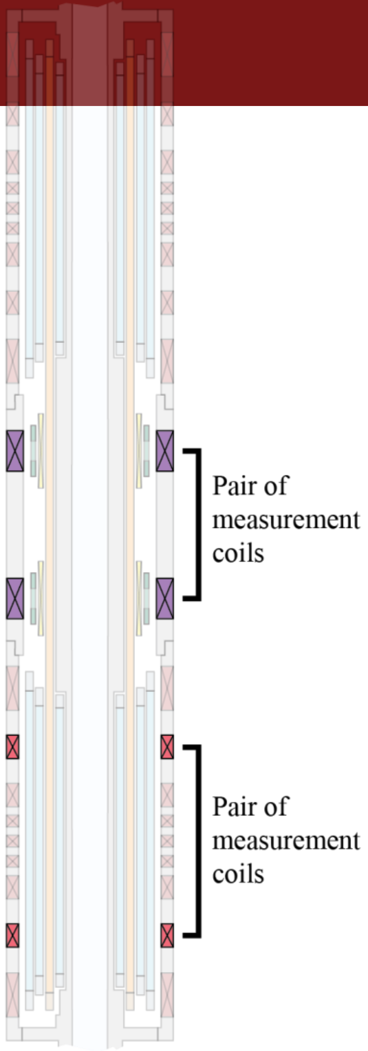
- Layers of tight-packed helical coils embedded in epoxy and wrapped with tensioned fibreglass
- Also made at BNL
- 50 – 200 turns × 8 – 12 layers
- Single unbroken conductor per coil
  - Normal coils
    0.33 mm dia., max. 130 A
  - Precision coils
    0.38 mm dia., max 10 A

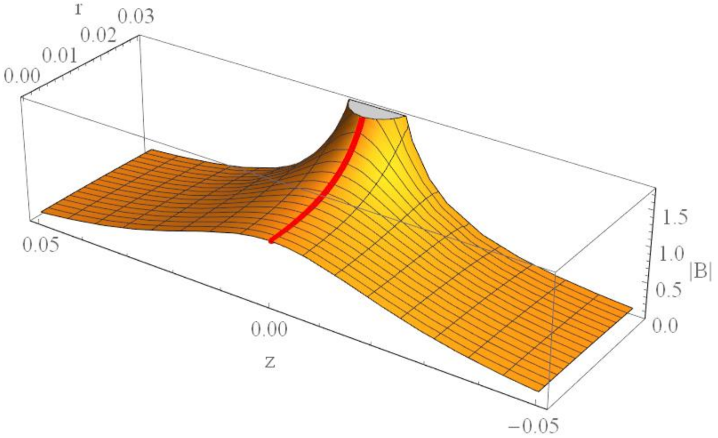


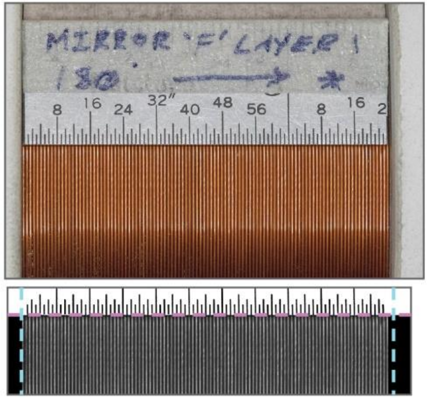


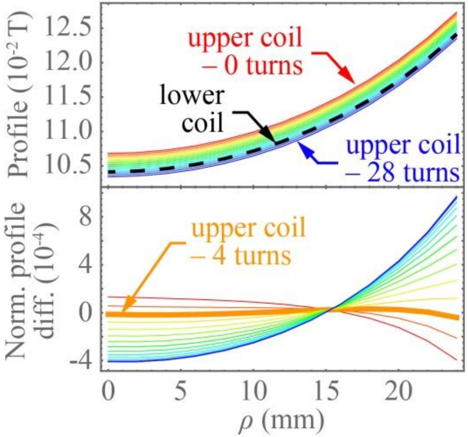
Coils

- 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 2nd coil's last layer
  - Create wire model and calculate profile, simulate unwinding last turns of 2nd coil
  - Compare normalised profile (normalisation = current freedom)
  - Unwind for real
- Overcome lack of pre-wind control
- Achieve match at all r to 10^{-4}



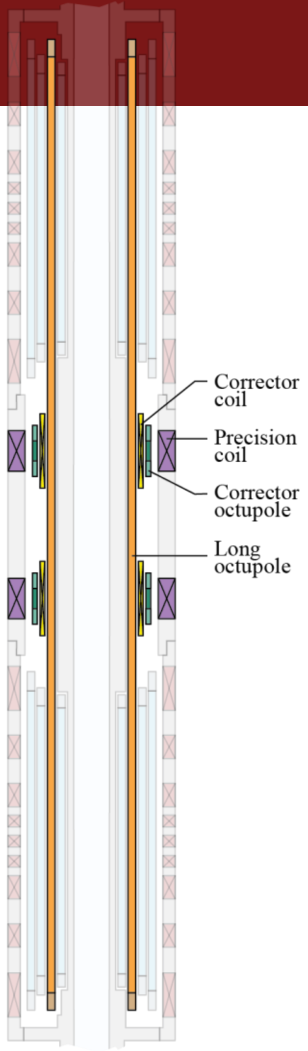


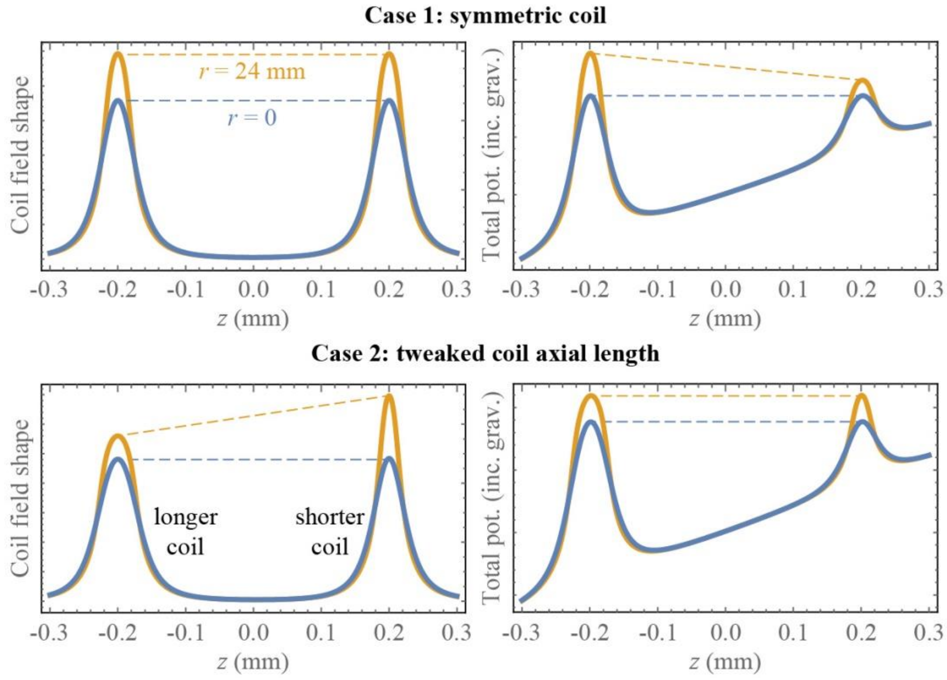




Correctors

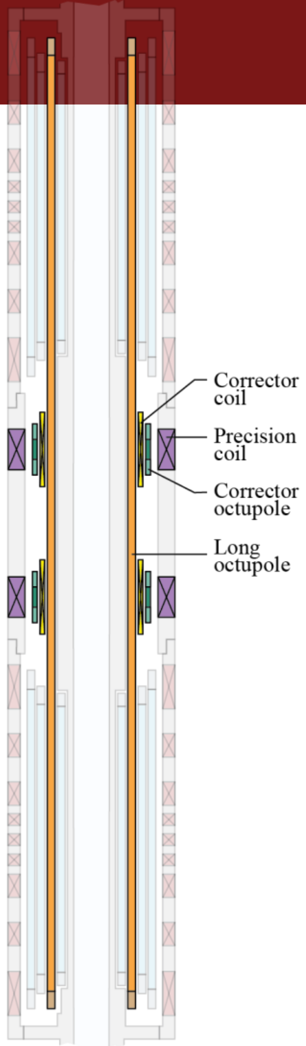
- For the balanced escape experiment: bottom and top barriers must match, both on-axis and off-axis
- Ignoring octupole: coils of different axial lengths needed
- In practice:
  - Length has to change during release ramp
  - Instead of altering coil, tweak length by rebalancing some current to (longer)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

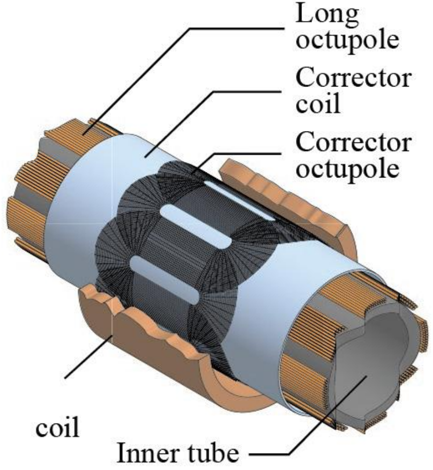


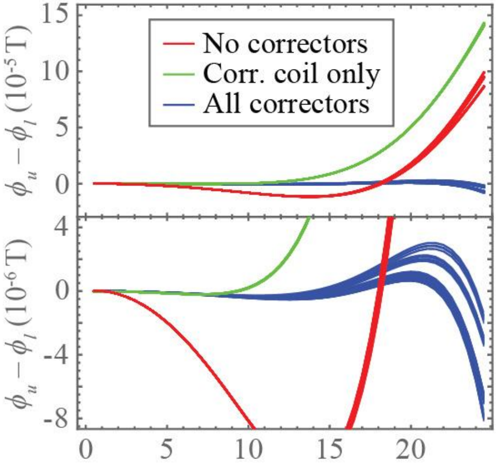


Correctors

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

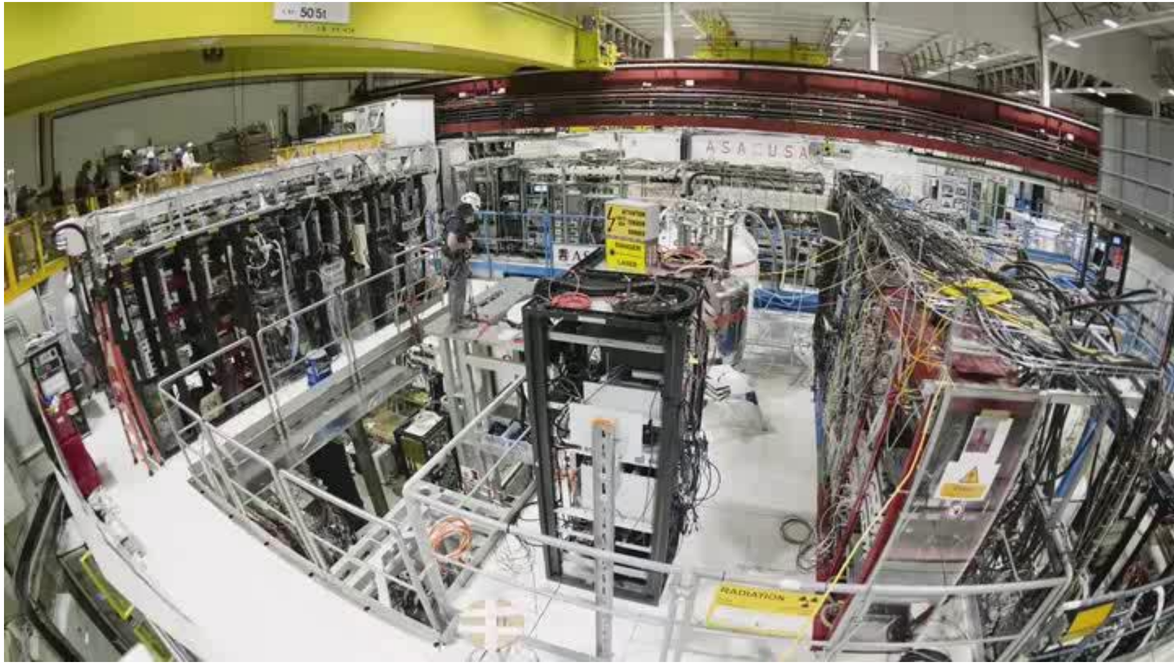






Summary

- 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



End

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
    mirror copy on top