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TRIUMF, Canada

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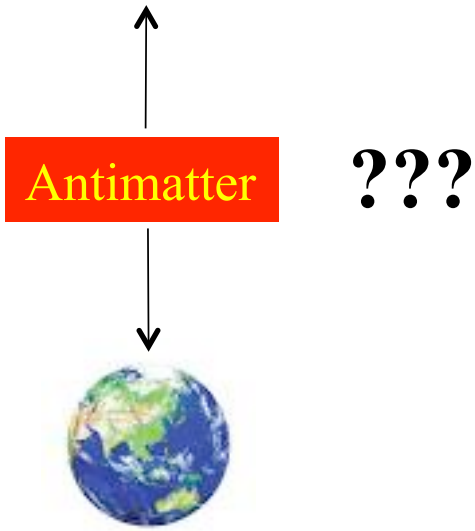
Cockcroft Institute, UK

York University, Canada

ALPHA-g Why: *a simple, fundamental question*

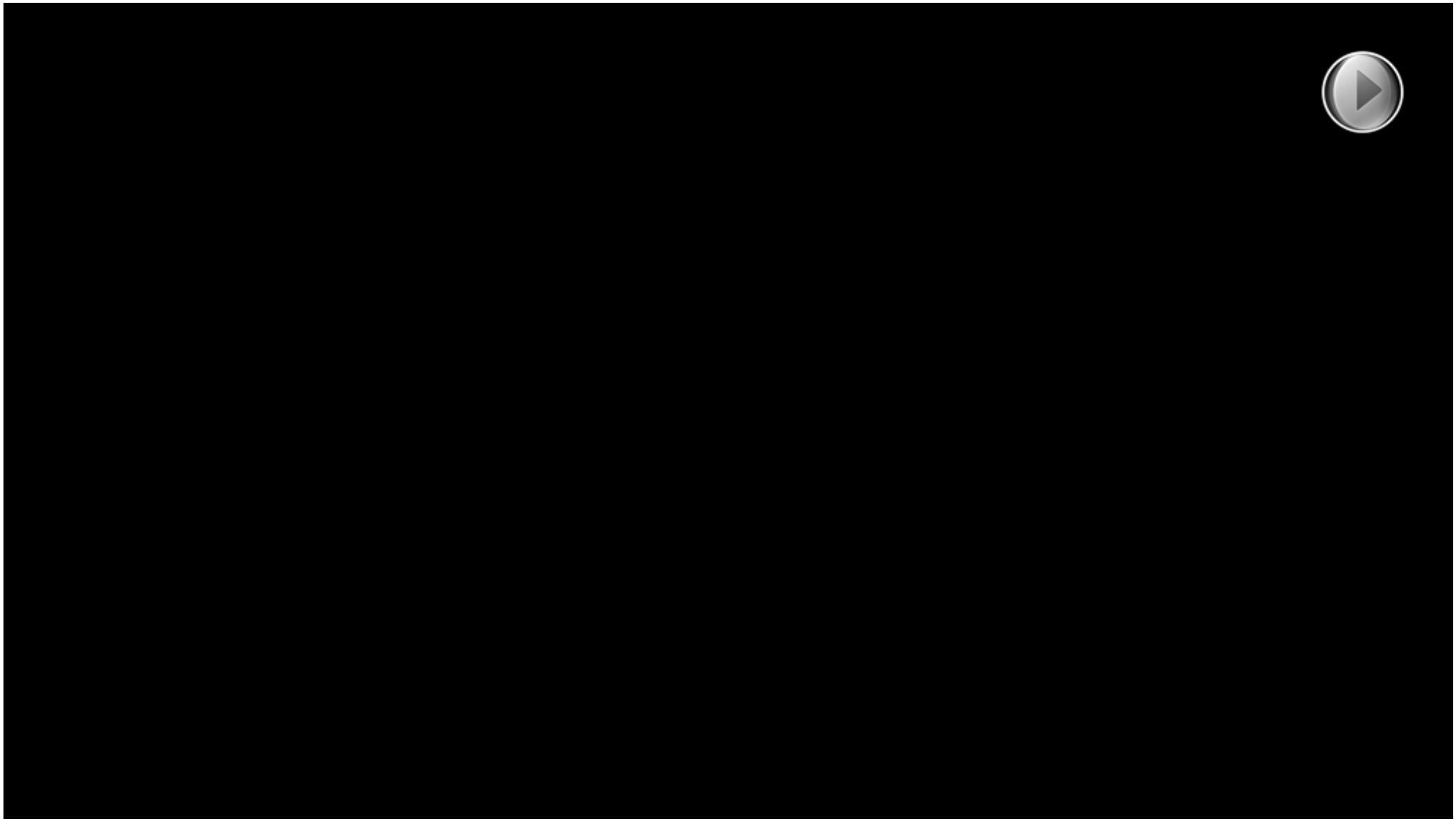


universal gravitational attraction

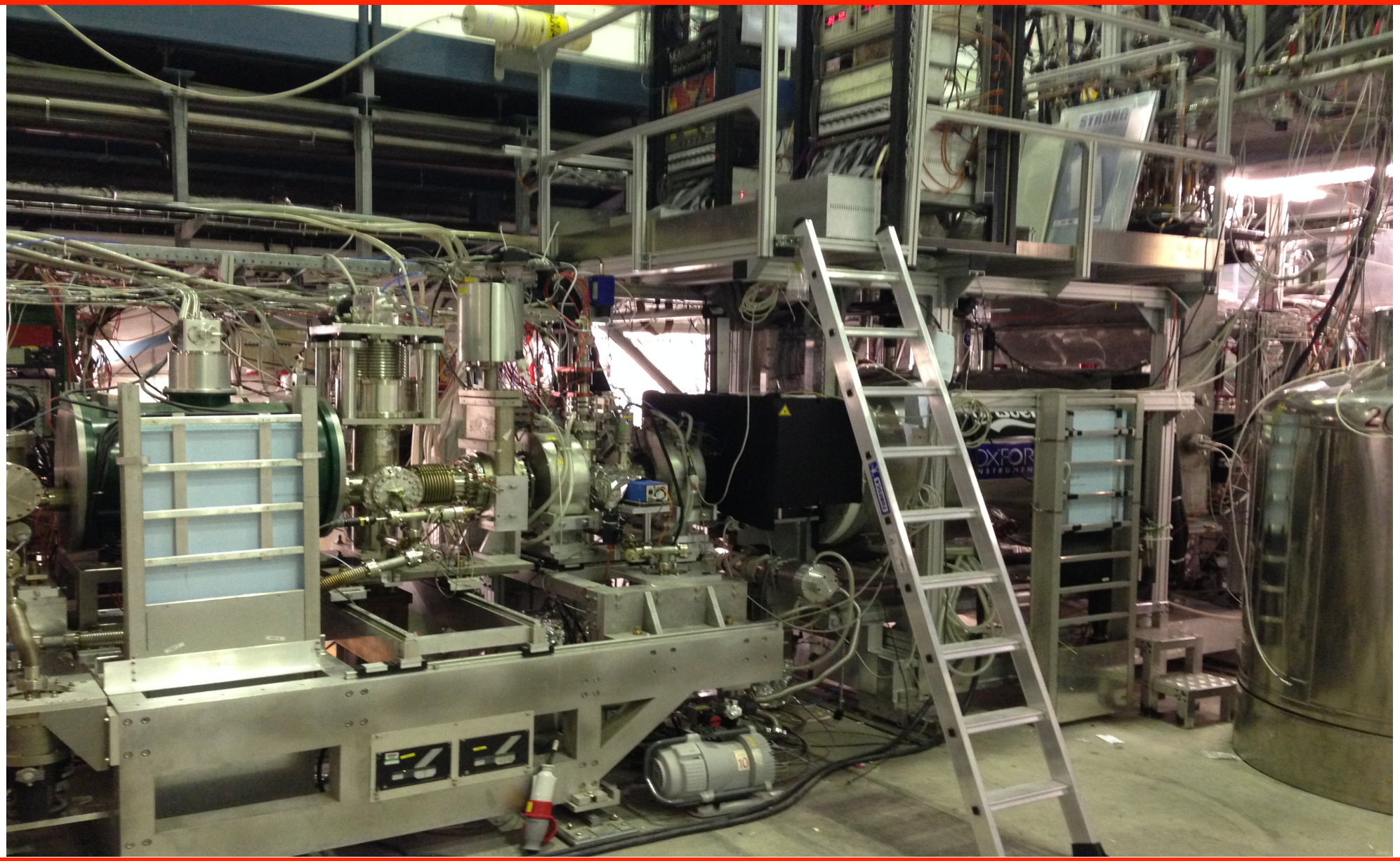
We just don't know…

More specifically: is the acceleration of gravity *exactly the same* for these two cases?

ALPHA Review: Trapping Antihydrogen



ALPHA-2



ALPHA-g: What is it?

nature COMMUNICATIONS

ARTICLE

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Description and first application of a new technique to measure the gravitational mass of antihydrogen

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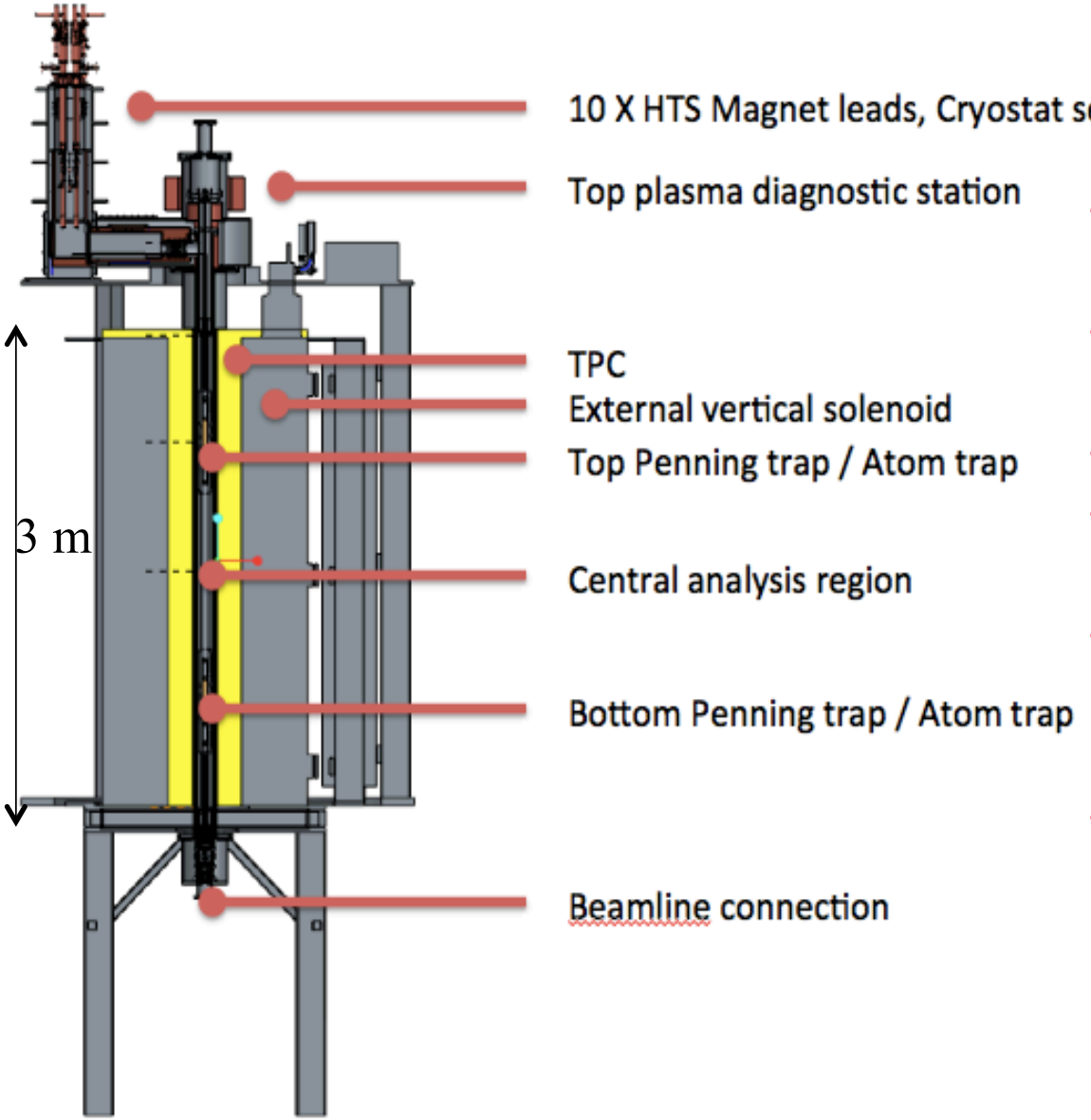
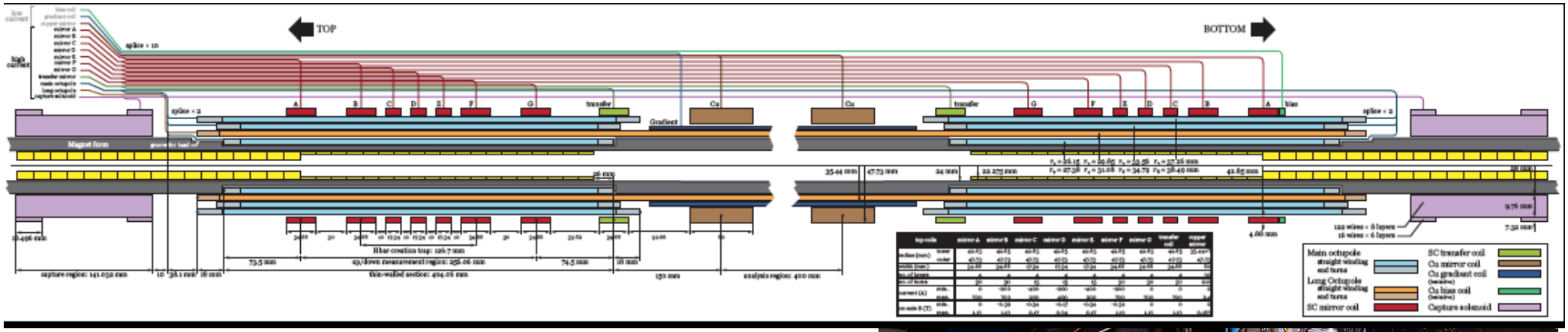
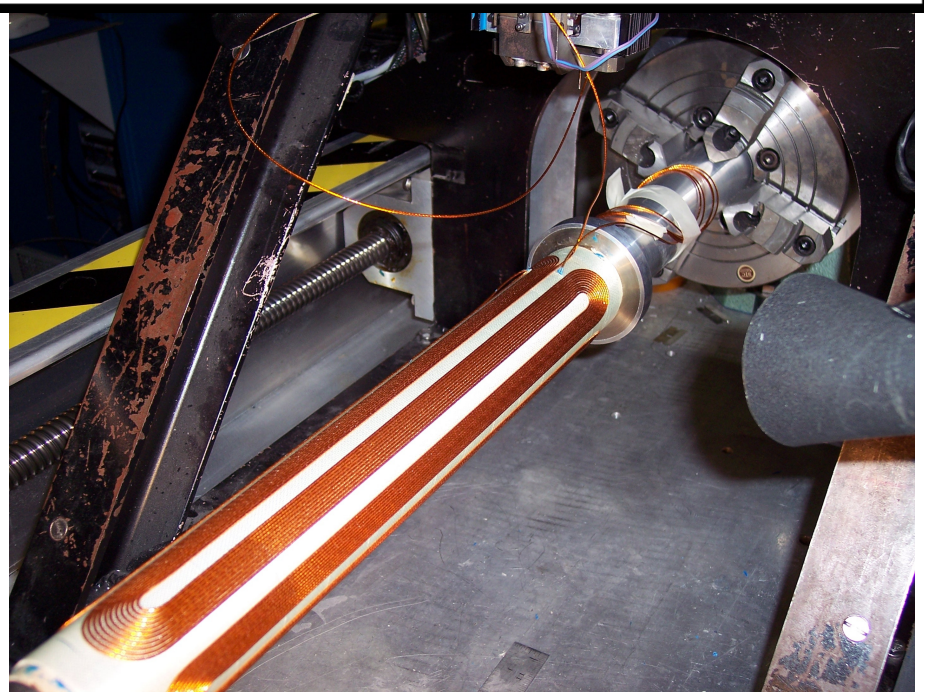
HOW: the ALPHA-g concept



- Because spectroscopy isn't hard enough...
- Trap some hbar; drop it, see where it goes
- Measure the sign of g-bar
- Measure the value of g-bar to 1% (4-5 years)
- Concept fully demonstrated in ALPHA – for horizontal geometry; some systematics already investigated
- Funding from Canada (CFI), DK (Carlsberg)

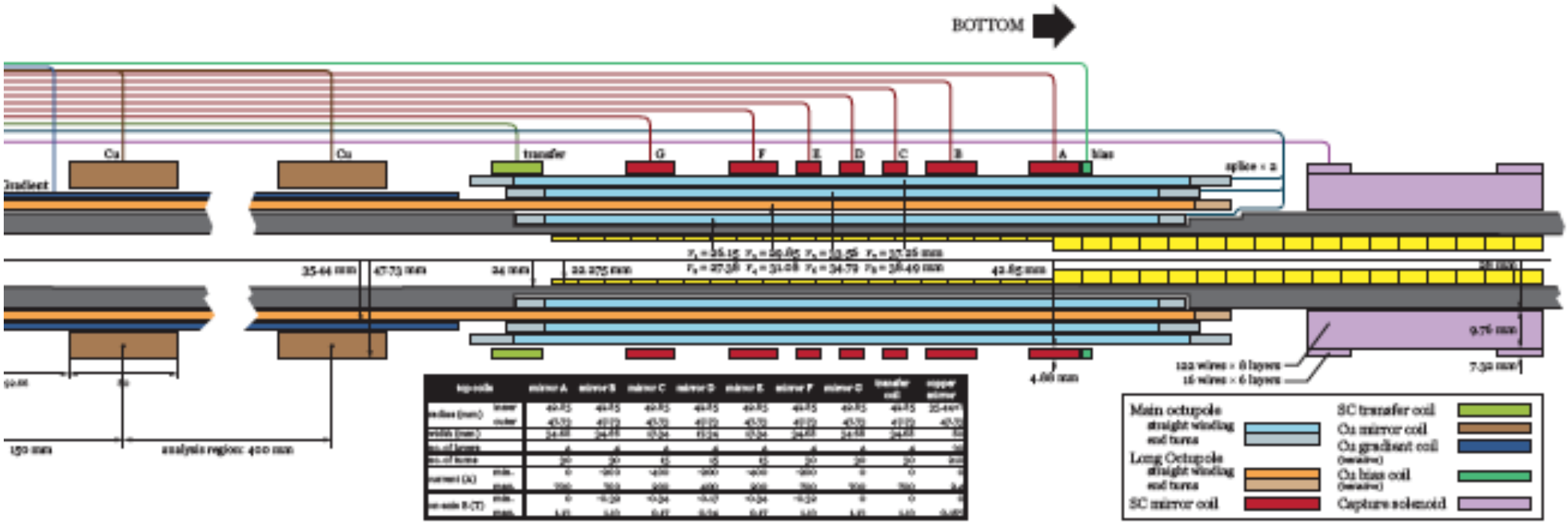
ALPHA-g Magnets and Penning Traps

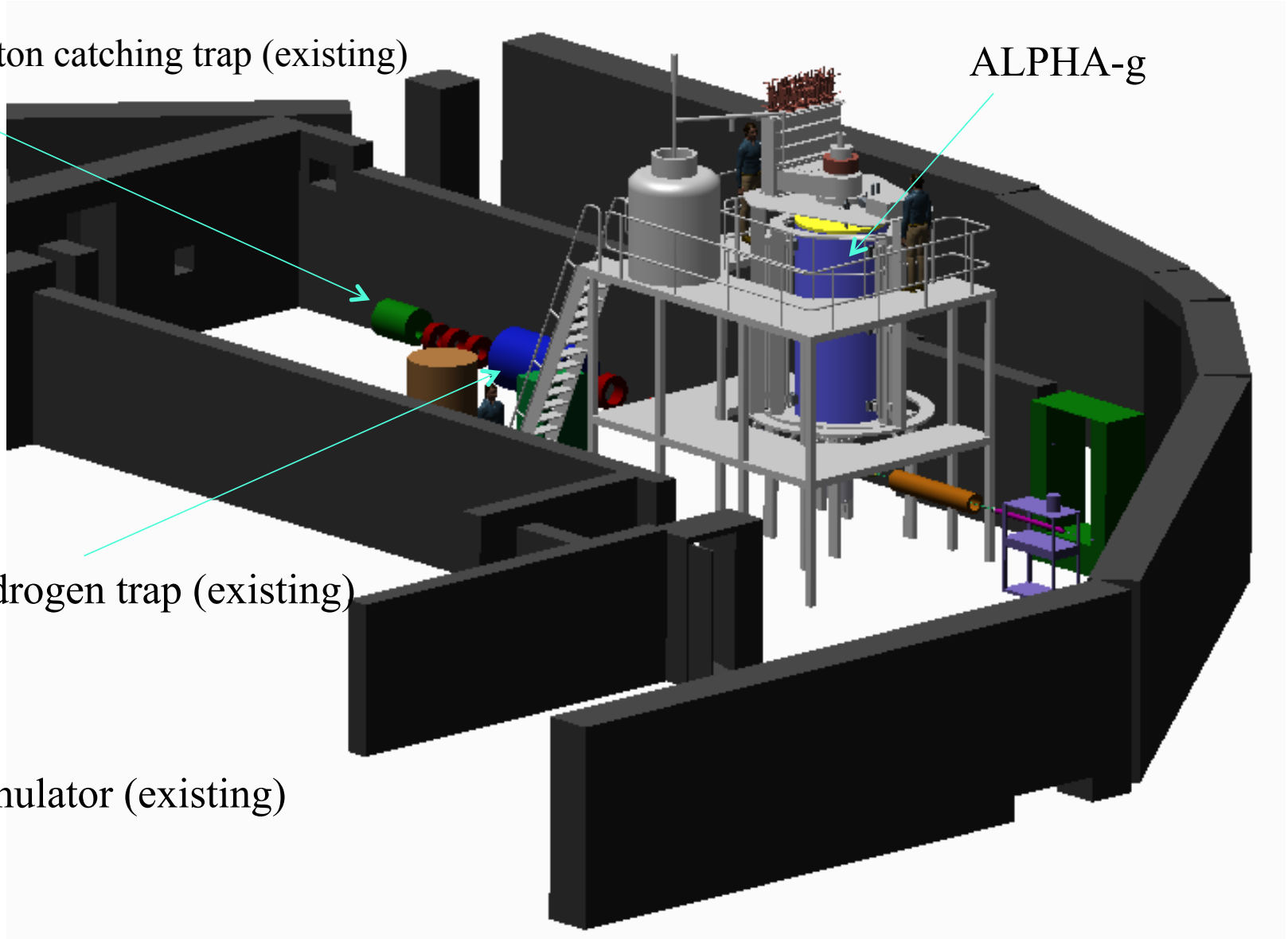




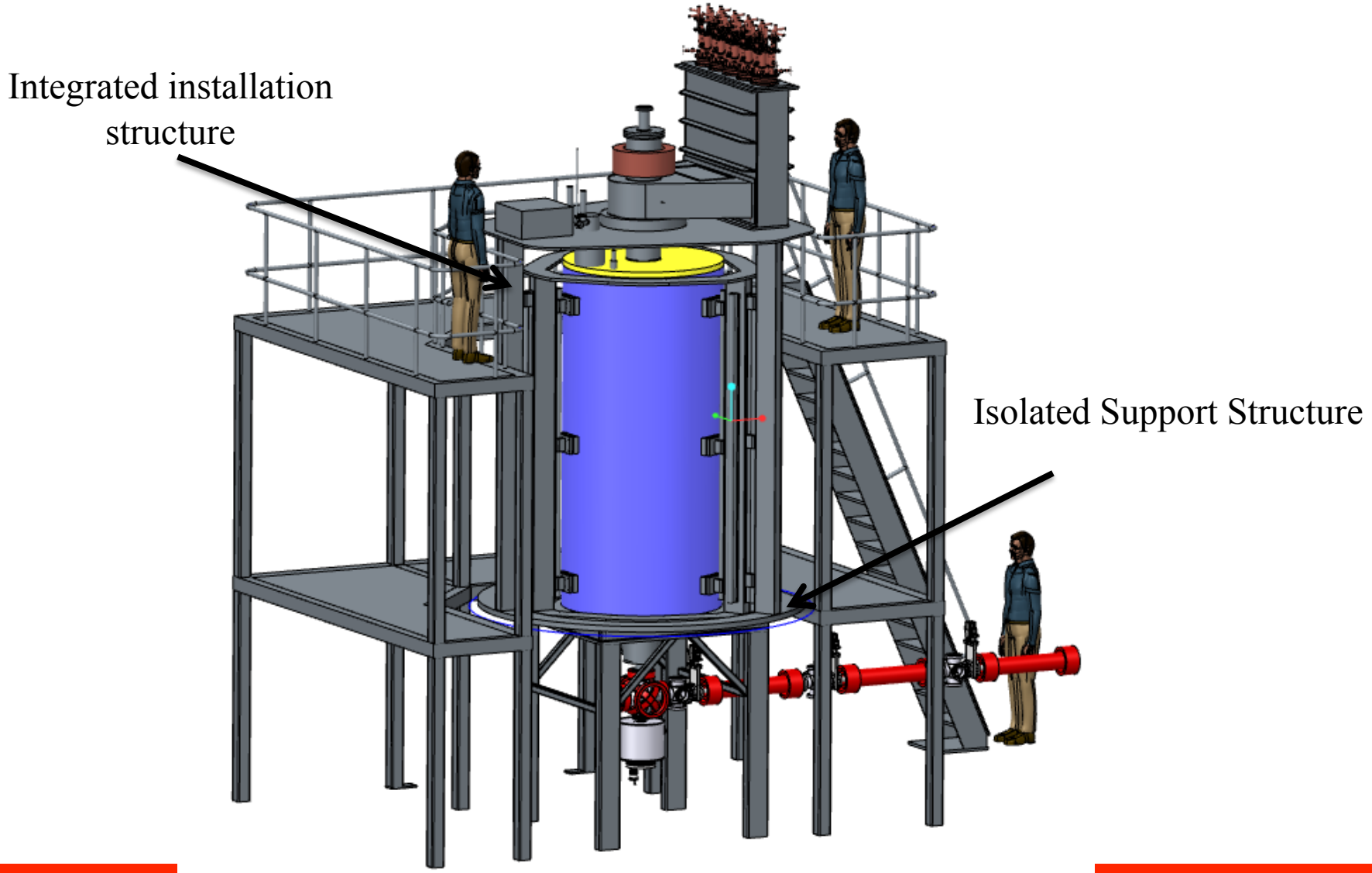
Design by ALPHA (C. So, J. Fajans);
fabrication by BNL

ALPHA-g Magnets and Penning Traps



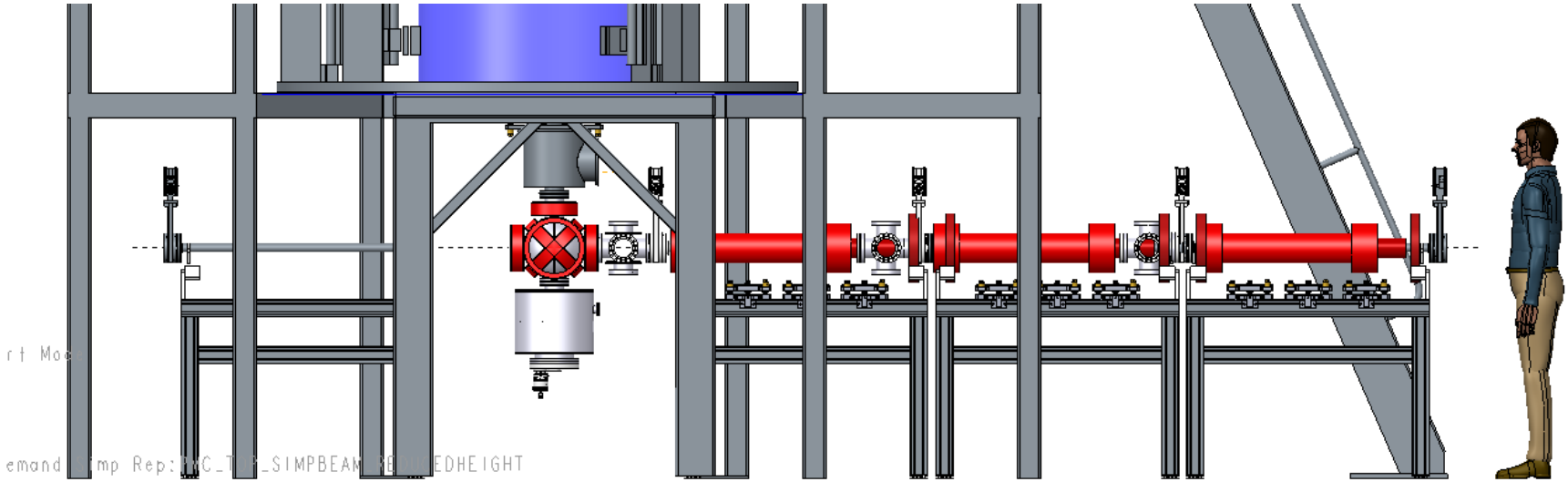

ALPHA-2 antiproton catching trap (existing)
ALPHA-g
ALPHA-2 antihydrogen trap (existing)
Positron accumulator (existing)

ALPHA-g Structure



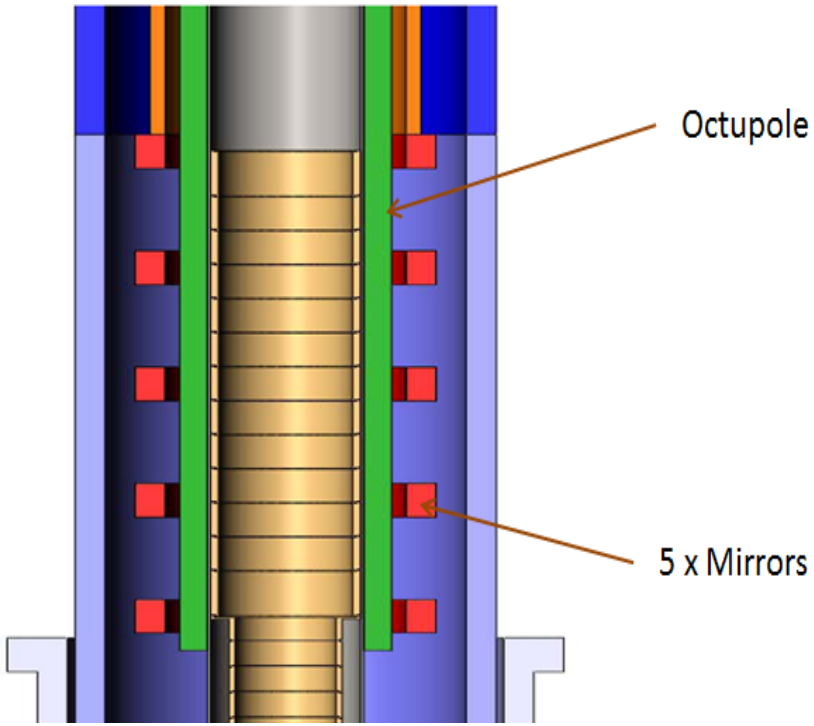
Beam Lines

- 5 Modules, 6.5m in total length; design ALPHA/RAL
- Gate valves between each
- Contain
  - Beamline Magnets
  - Pumping stations
  - Diagnostics



Phase 1 Demonstration: the sign of g-bar (2017-2018)

- Use a trap similar to ALPHA-2, but vertically oriented
- Release atoms by lowering mirror coil currents in 10 s
- Simulations predict that 71% of antihydrogen atoms released come out the bottom, assuming 'normal' gravity
- We need of order 1000 hbar, released and detected to determine if gravity is normal (statistics only)
- **NB: ALPHA-2; September 22-30 2016: 1419 trapped hbar released and detected**



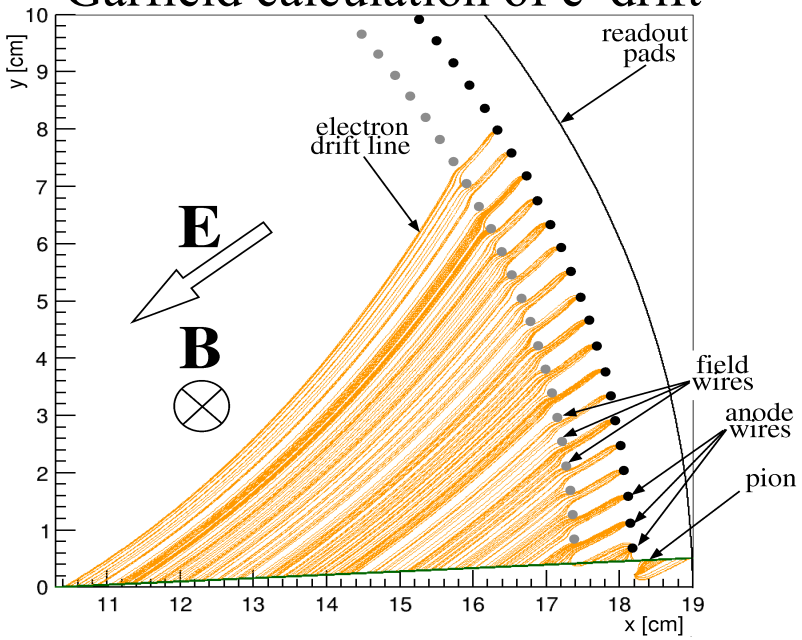
More accurate measurement: Expansion and transfer to analysis region

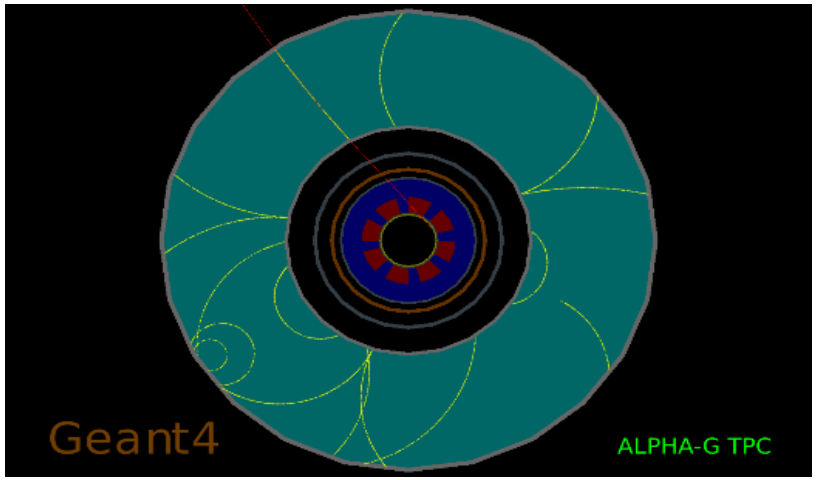
- About 17% of atoms remain
- Temperature is now about 50 mK
- Copper analysis coils to reduce persistent current effects on field
- Cancel gravity with a gradient coil 18 G/m
- Same slow release experiment (10 s)
- Analysis of position distribution to determine g-bar
- Will use *in situ* magnetometry to measure fields
- We have conducted extensive simulations, including the effects of systematic errors
- Long-term measurement program after LS2
- Potential to use cold atoms of *matter* to 'calibrate' ALPHA-g
- Potential for laser cooling of trapped hbar to improve accuracy (pulsed Lyman-alpha light)

Model by J. Fajans, Berkeley

ANNIHILATION DETECTOR

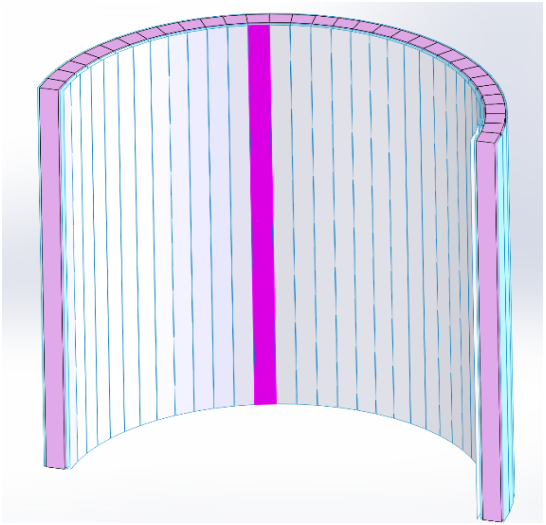
Garfield calculation of e^- drift





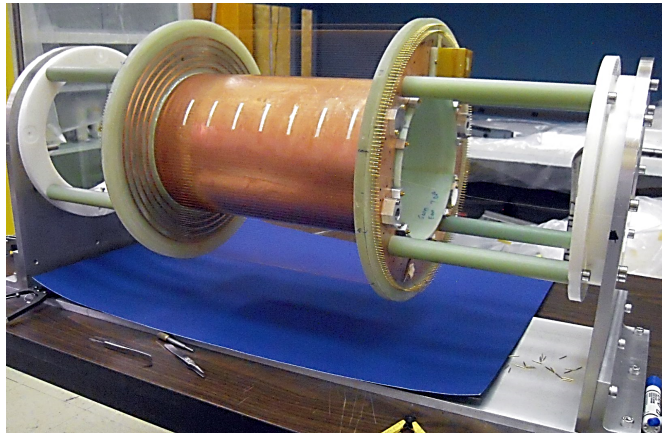
1 Hbar annihilation event

- Position sensitive detection: a key feature for ALPHA's success
- Important ALPHA-g requirements
  - Large volume (> 2 m active length)
  - Efficient cosmic rejection
- Our solution
  - Radial drift TPC for tracking
  - Cosmic veto via SiPM based scintillator barrel

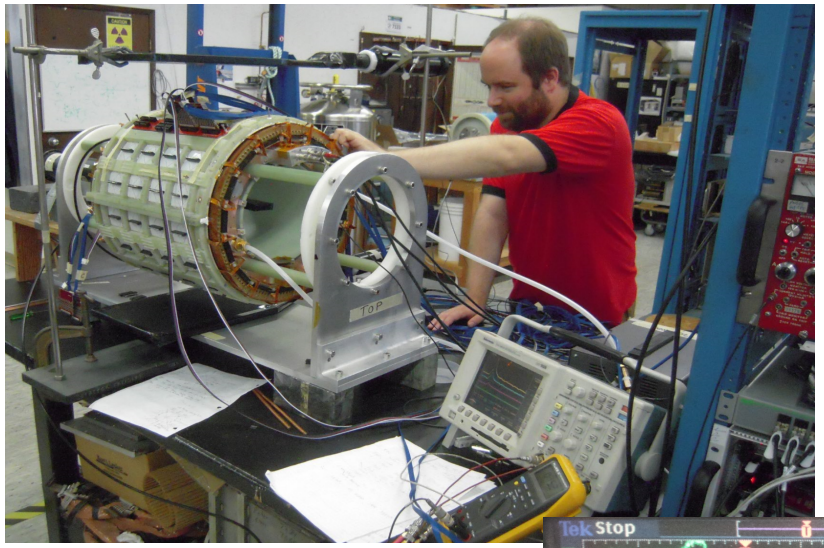


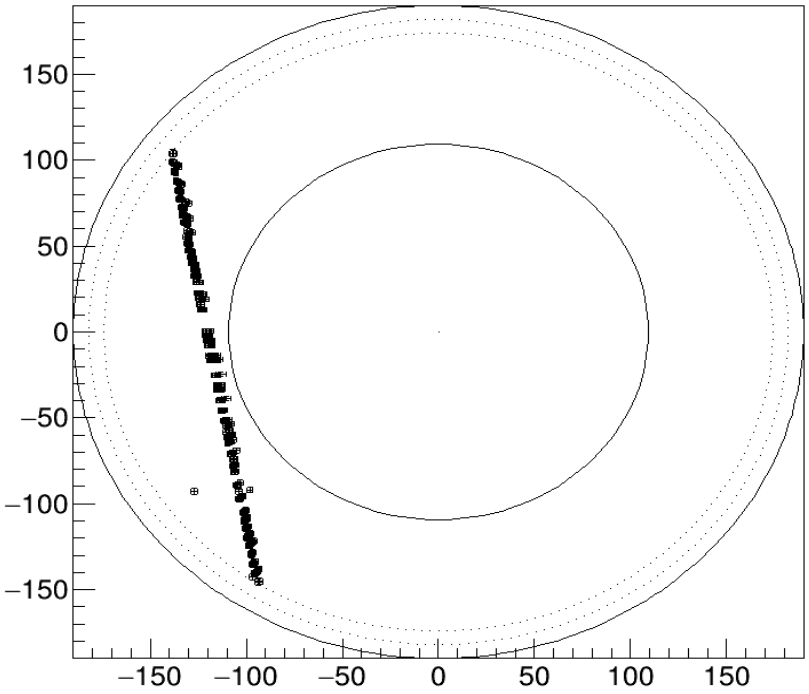
Scint. barrel surrounding TPC

Radial TPC Prototype, Cosmic Test



- Prototype: 1/8 length, full radial size
- Cosmic test: anode RO partially instrumented
- Cathode RO firmware under development



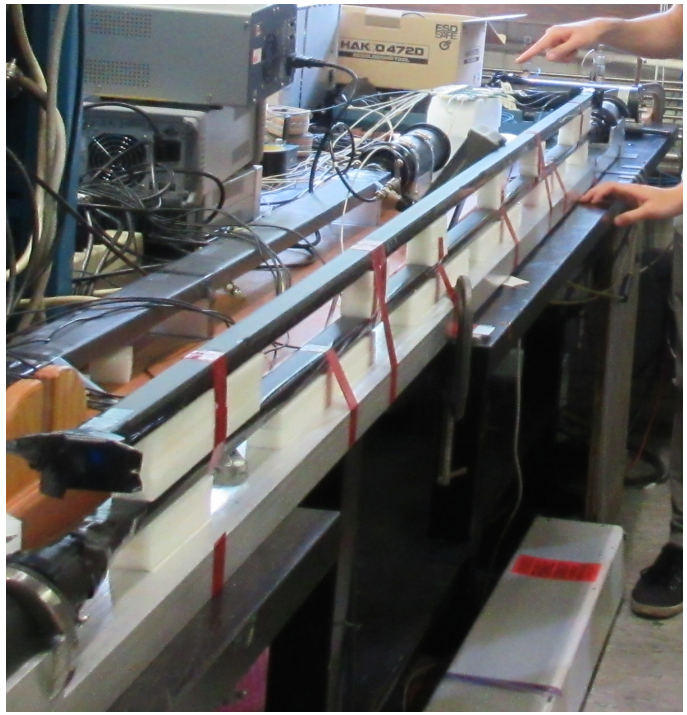


Reconstructed Cosmic Rays (no B field)

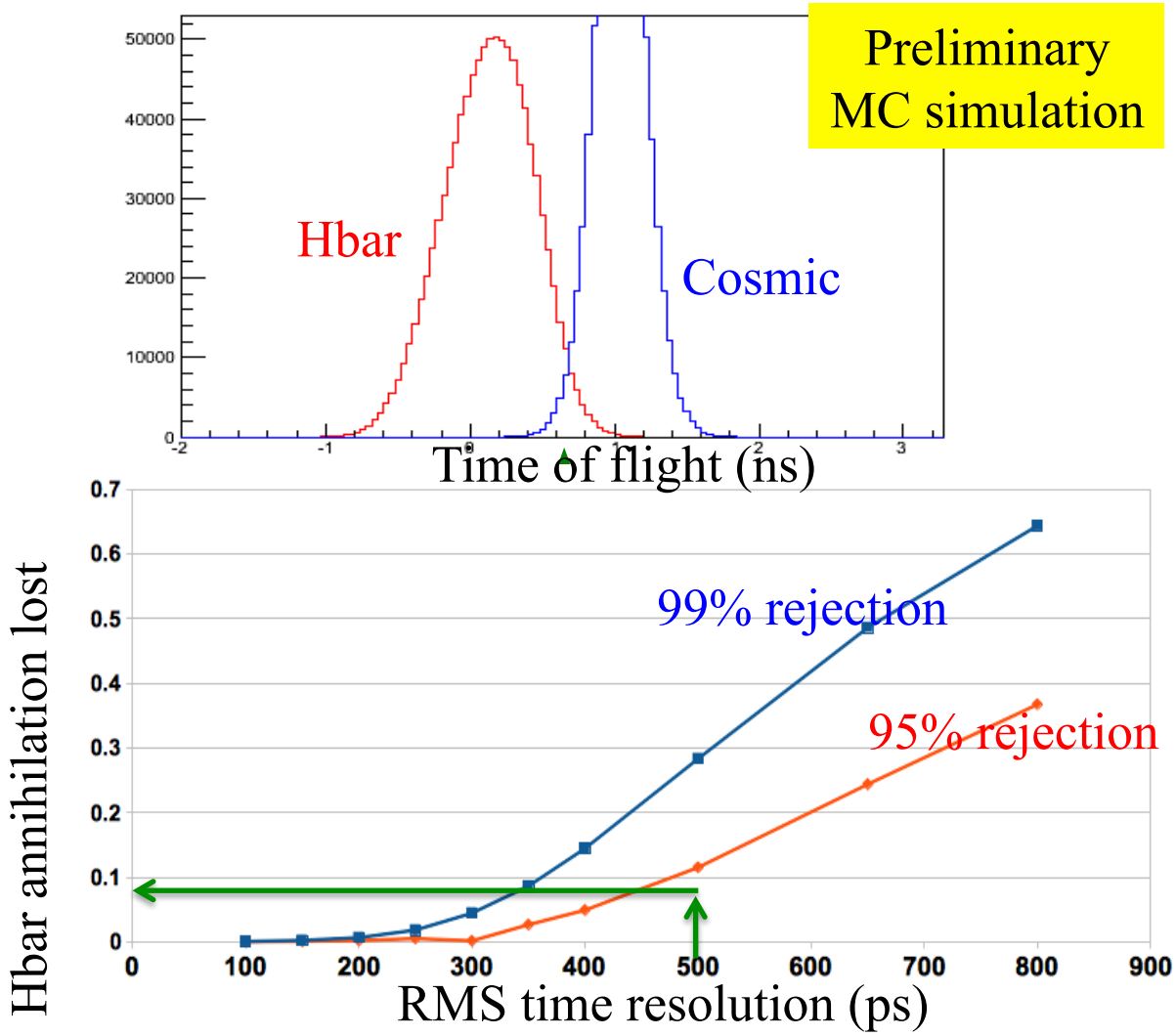
Anode signals

COSMIC REJECTION STRATEGY

- Cosmic rejection via TOF (in add. to TPC topology)
- Scint. readout by SiPM
- Prototype being tested



Scintillator bar prototype



For 500 ps resolution, 95% cosmic rejection expected while keeping ~90% of Hbars

Magnetometry

Three different applications

- Sensors close to the TPC for field monitoring
- Sensors in the liquid helium volume for monitoring *reproducibility* of mirror fields
- Movable probe *in vacuo* for precision axial field mapping

- Three separate NMR probes being developed at UBC/Simon Fraser
- Prototypes exist, being tested
- We also use measurement of charged particle cyclotron frequencies to measure **B**

Some costs:

Main subsystems (estimates only):

External solenoid	**1.6 MCHF**
Cryostat and vacuum systems	**1.7 MCHF**
Internal (atom trap) magnets	**1.3 MCHF**
Detector and DAQ	**2.4 MCHF**
Beamlines	**1.6 MCHF**
Magnetometry	**0.2 MCHF**
Penning traps and controls	**0.4 MCHF**
Total:	**9.2 MCHF**

Funding already approved: 13.2 MCHF

ALPHA Zone

Scheduling Milestones

- **Begin expansion of existing ALPHA zone – end of run 2016**
- **Arrival of beamline modules at CERN – April 2017**
- **Relocation of ALPHA-2 positron source – April-May 2017**
- **Arrival of cryostat, solenoid, rTPC at CERN – September-October 2017**
- **First tests with particles by end of run 2017**