# *Antimatter doesn't float up, but I wish it did*

**Marcelo Bovill**

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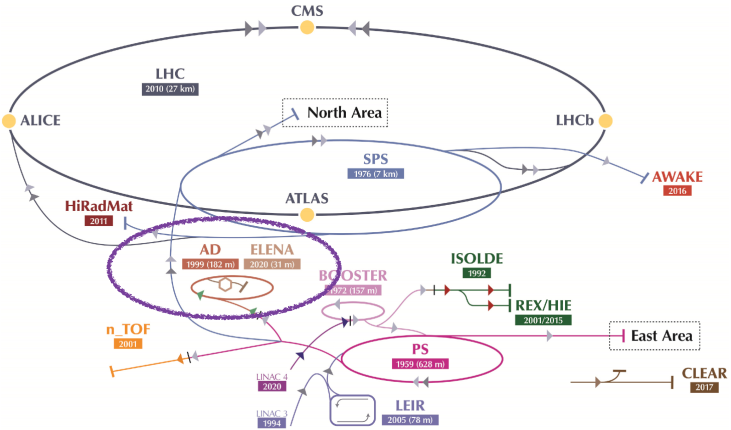
- **Weak Equivalence Principle (WEP)**[1] ⇒ all massive particles (and antiparticles) should act the same under gravity.
- **do anti-apples fall just like apples do?**



[1] Image credit: The Renaissance Mathematicus, 2019, Accessed: 12/03/2024, https://thonyc.wordpress.com/2019/12/25/christmas-trilogy-2019-part-i-would-the-real-mr-newton-please-stand-up/

# Where do we get our antimatter from?

- Protons collide with a fixed metal target $\Rightarrow$ **antiprotons**.
- **Positrons** are produced from radioactive isotopes (i.e. $\beta^+$)[2,1]



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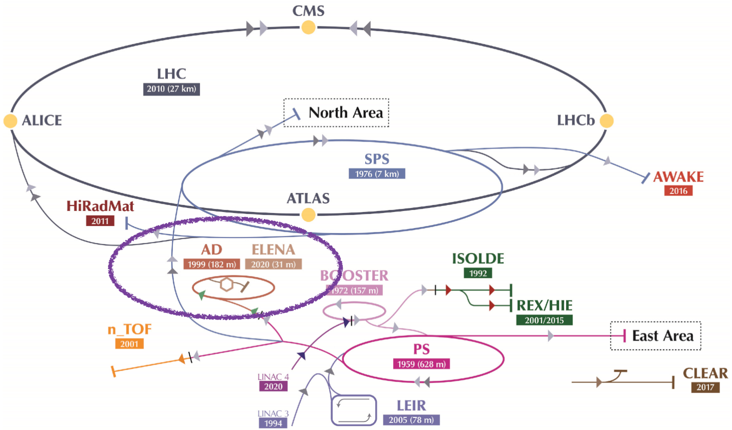
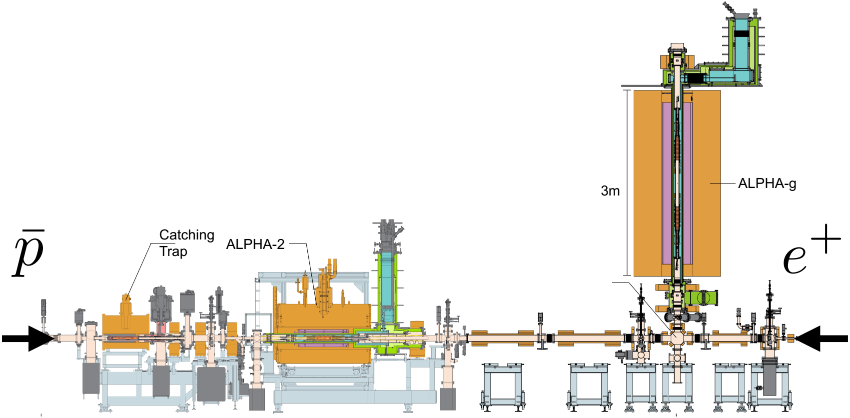


# Trapping Antihydrogen

- Antiprotons are cooled in a Penning trap, with $\sim \frac{1}{15}$ of antiprotons from ELENA being trapped[2]
- Merged with the positrons to form antihydrogen within ALPHA-g and **trapped in a magnetic field**[1]



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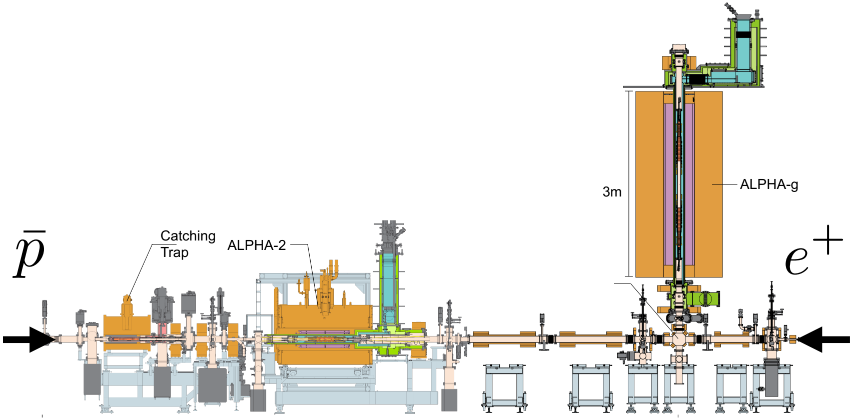
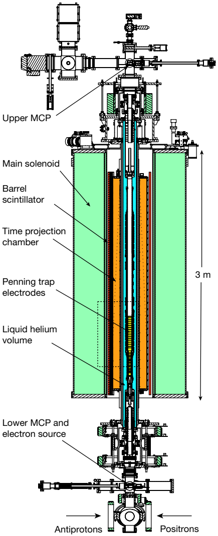


# ALPHA-g

- Antihydrogen atoms released by simultaneously ramping down the current in the magnetic coils.
- Annihilation products (e.g. pions) tracked in a **rTPC**.
- Expected **80** % of annihilation products in the lower half of the detector[1]



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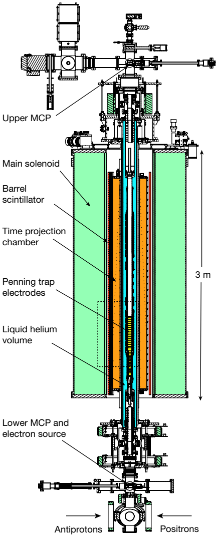

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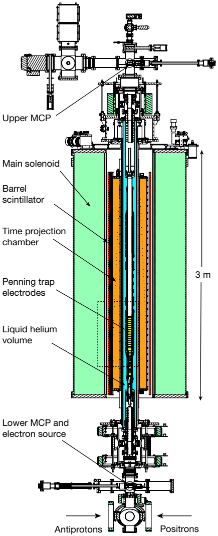
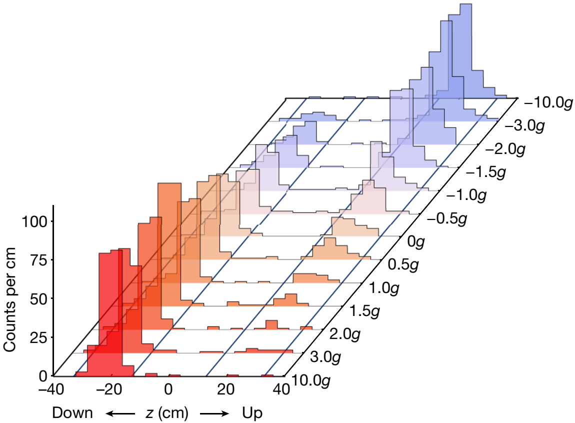


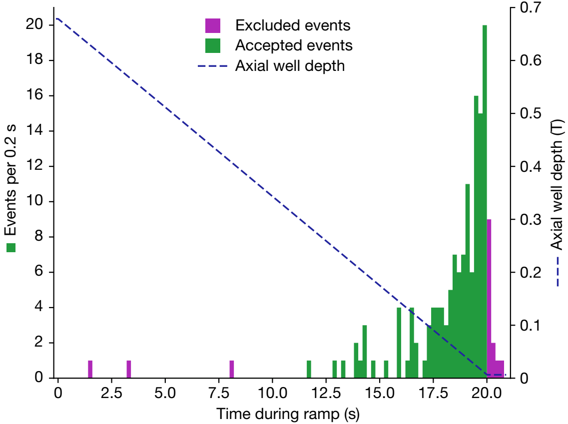
# Measuring g

- Repeated for different imposed biases (downward acceleration due to the magnetic field).
- E.g. A bias of $-1g$ would counteract gravity, resulting in equal annihilations in the upper and lower regions of the detector[1].



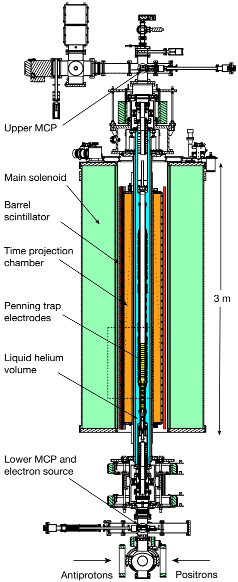
# Selections

- Events with $z-$position more than 0.2 m from the coil centres or that were between the mirror coil centres were removed.
- Events emerging between 10-20 s from the ramp-down were accepted.
- Selections were determined from $\pm 10g$ trials[1].



# Reconstruction and Calibration

- $\pm 10g$ trials also used to calibrate the efficiencies of the upper and lower detector regions.
- **Cosmic ray background** suppressed using **topological** information from the rTPC and **barrel scintillator**.
- Asymmetries in the background field were corrected for using a measurement-based model[1].



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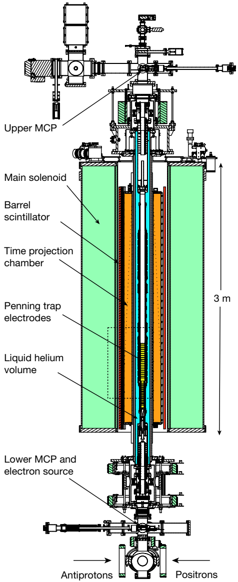

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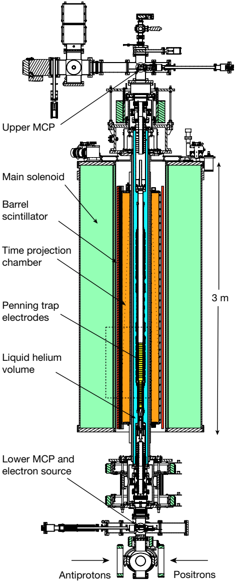
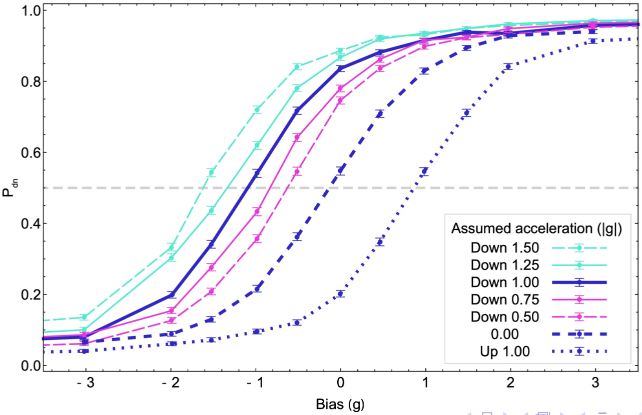


# Simulations

- Simulations ran for different values of the acceleration due to gravity of the antihydrogen.
- The probabilities of an antihydrogen atom escaping downwards, $P_{dn}$, were plotted against the bias[1].



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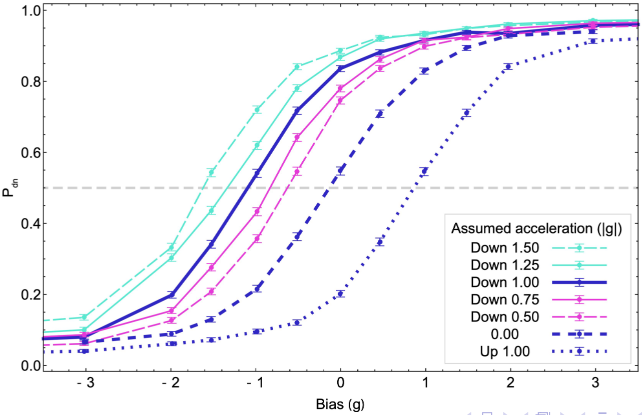
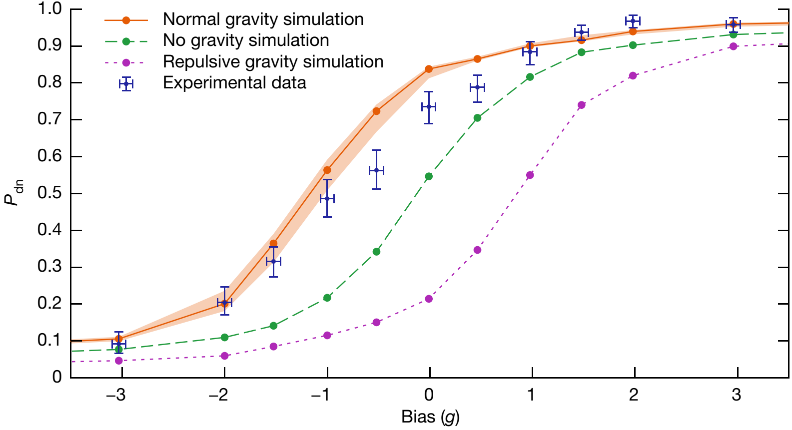


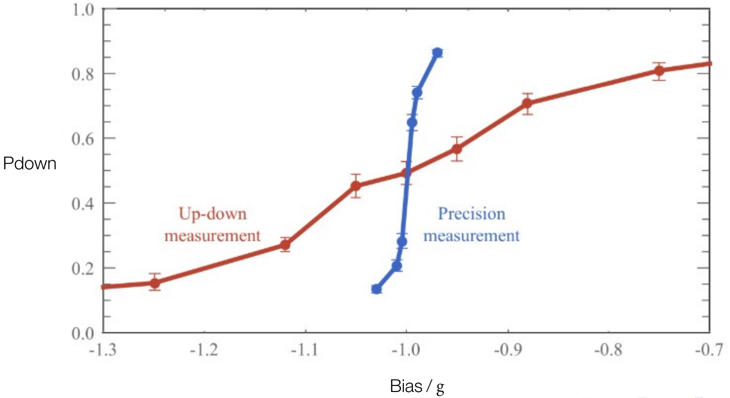
# Analysis and Results

- From a likelihood fit to the data,
  $\bar{g} = (0.75 \pm 0.13(\text{statistical} + \text{systematic}) \pm 0.16(\text{simulation}))g^1$.
- $\bar{g} \leq 0$ excluded at $\sim 3.5\sigma$.



# Future Extensions

- The main goal is improving the precision on $\bar{g}$, effectively steepening the $P_{dn}$-bias curves[2]
- Cool anti-atoms further; **Doppler laser cooling**.
- At higher precision better simulations will also be required.
- Competing experiments: **GBAR42 and AEgIS43**[1]



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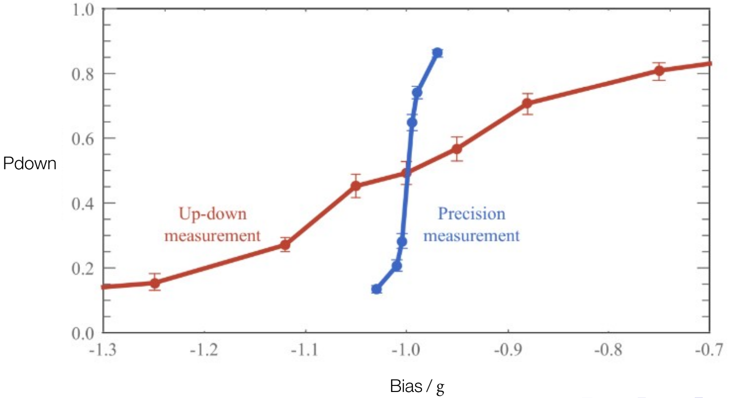

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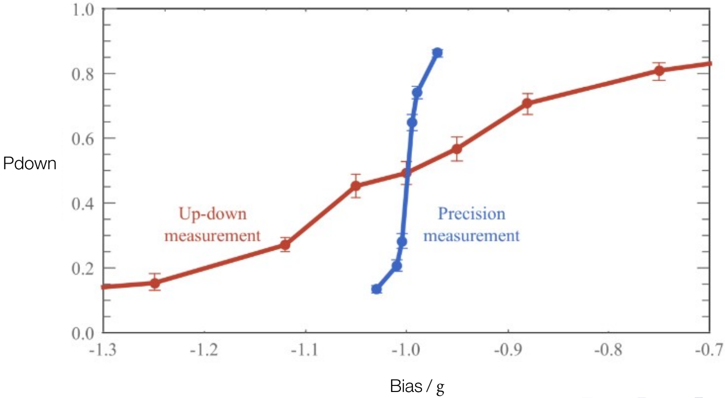

# Summary/Conclusions

- Measured value of $\bar{g}$ is consistent with a downward acceleration of $1g$.
- Antihydrogen is shown to fall under gravity with a p-value of $2.9 \times 10^{-4}$.
- This result paves the way for precision tests of the WEP[1].

# References


[1] E. K. Anderson and et al. "Observation of the effect of gravity on the motion of antimatter". In: *Nature* 621.7980 (Sept. 2023), pp. 716–722. DOI: 10.1038/s41586-023-06527-1.

[2] William Bertsche. *Antimatter gravitation studies with trapped antihydrogen*. Accessed: 12/04/2024. Oct. 2023. URL: https://indico.cern.ch/event/1334474/.