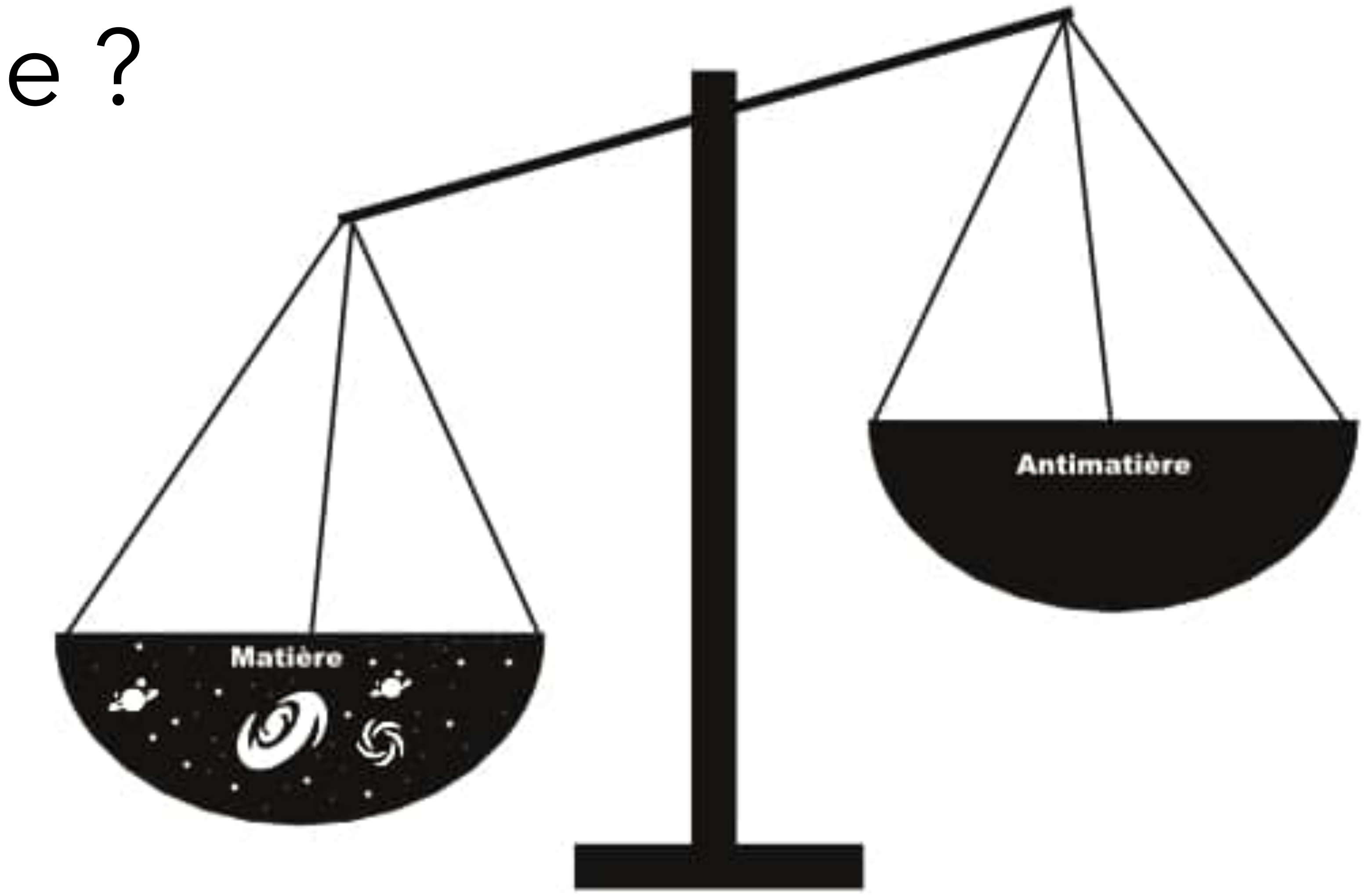
Effect of gravity on antimatter

Results from ALPHA experiment @ CERN

Narei Lorenzo Martinez - AnimaScience - Nov 17th 2023

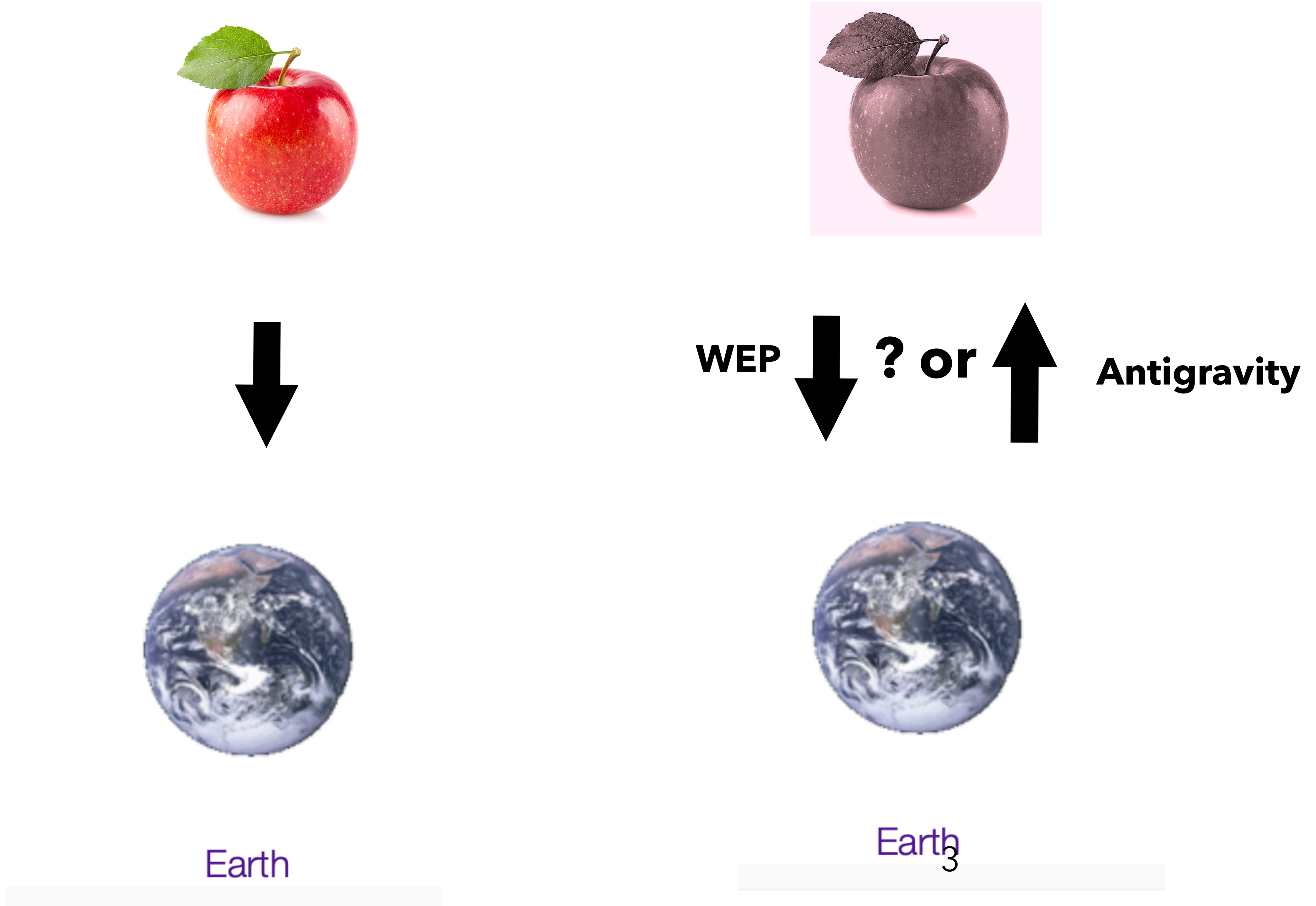
Introduction

- Big-bang prediction: same amount of matter/antimatter created
- However, we exist :-)
  - our existence due to a **small asymmetry in matter/antimatter interactions**
- A ratio ~ 1^9 photon/baryon in universe (matter/antimatter annihilation)
  - give scale of asymmetry -> larger than asymmetries found in b-sector physics
- CPT violation ? Violation of Weak Equivalence Principle ?



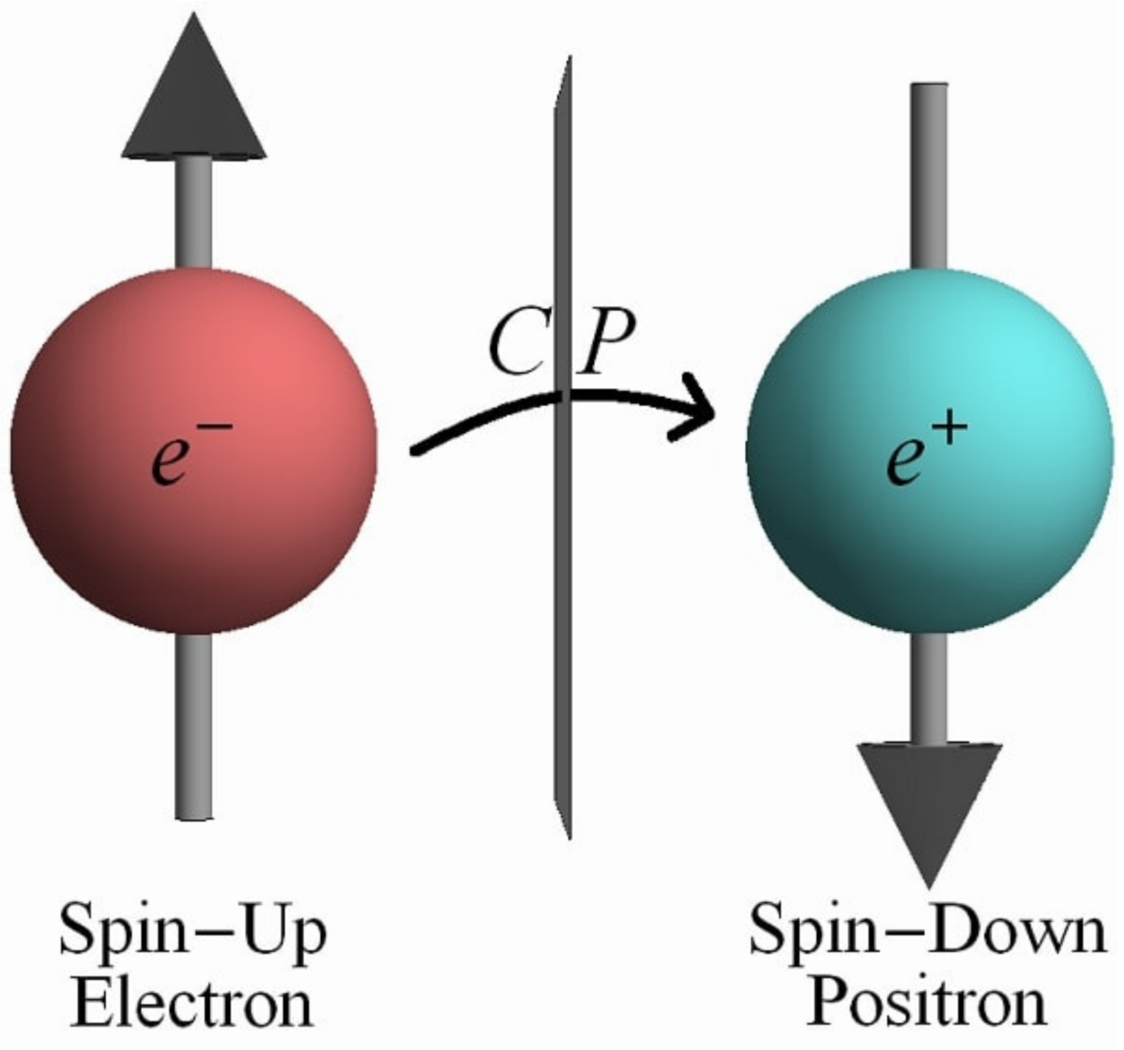
Introduction

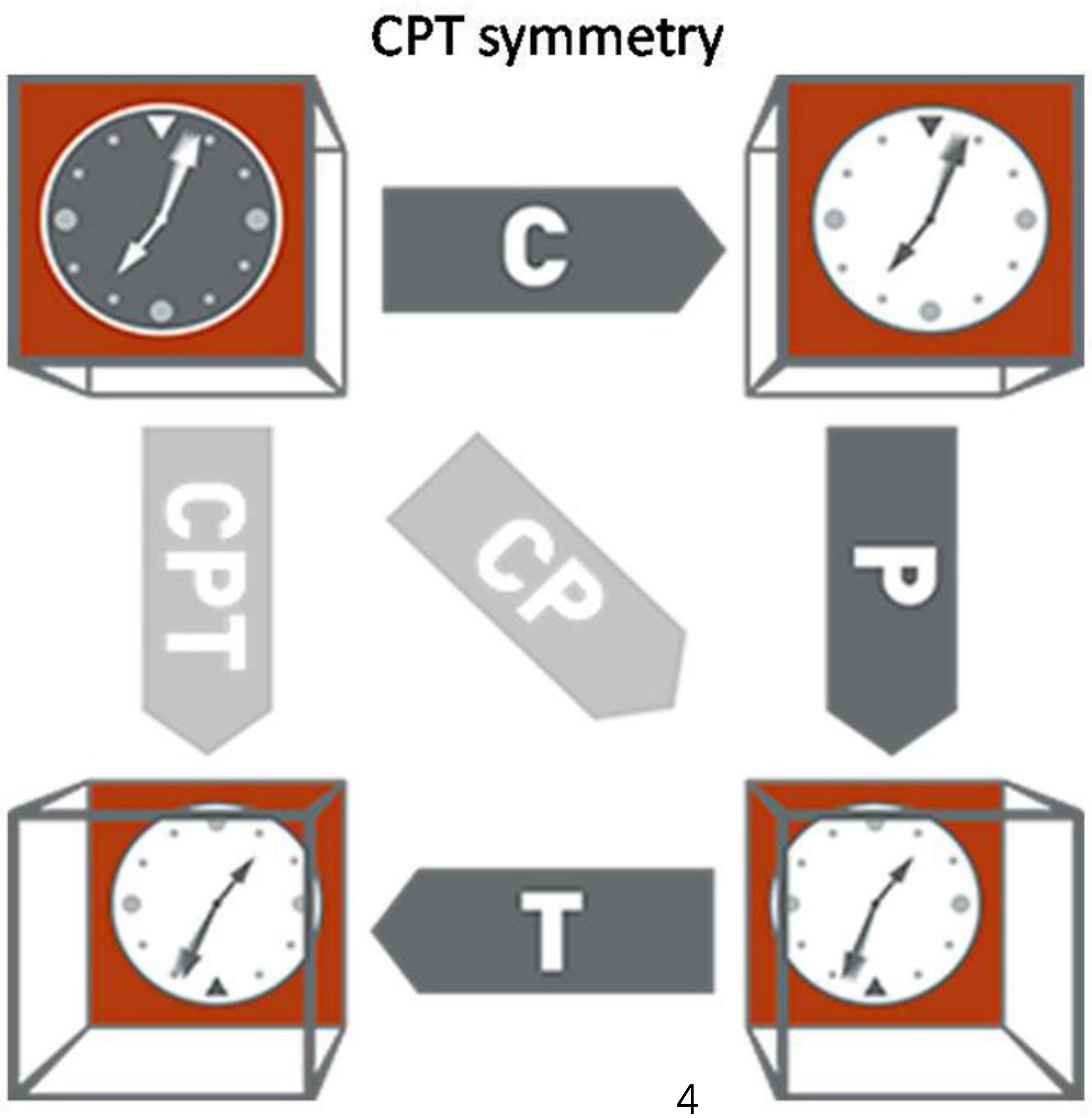
- **1915: weak equivalence principle (WEP, Einstein)** : all masses react identically to gravity, independent of their internal structure
  - antimatter falling like matter ? or antigravity ?
  - note: antimatter predicted in **1928** by Dirac, and positron discovered in **1932**

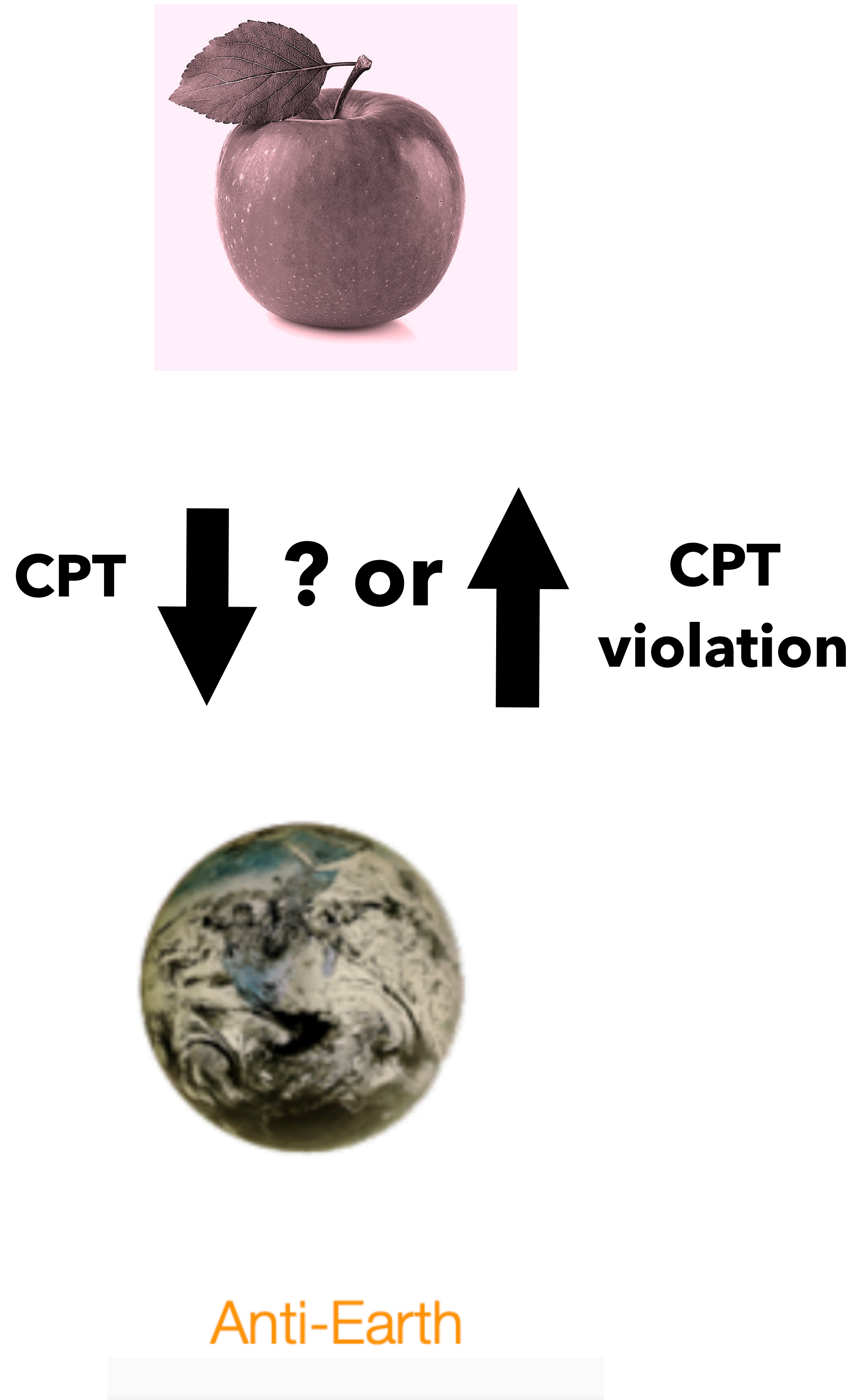


Introduction

- **CPT symmetry (charge-parity-time)**: antimatter- antimatter interaction should be the same as matter-matter interaction

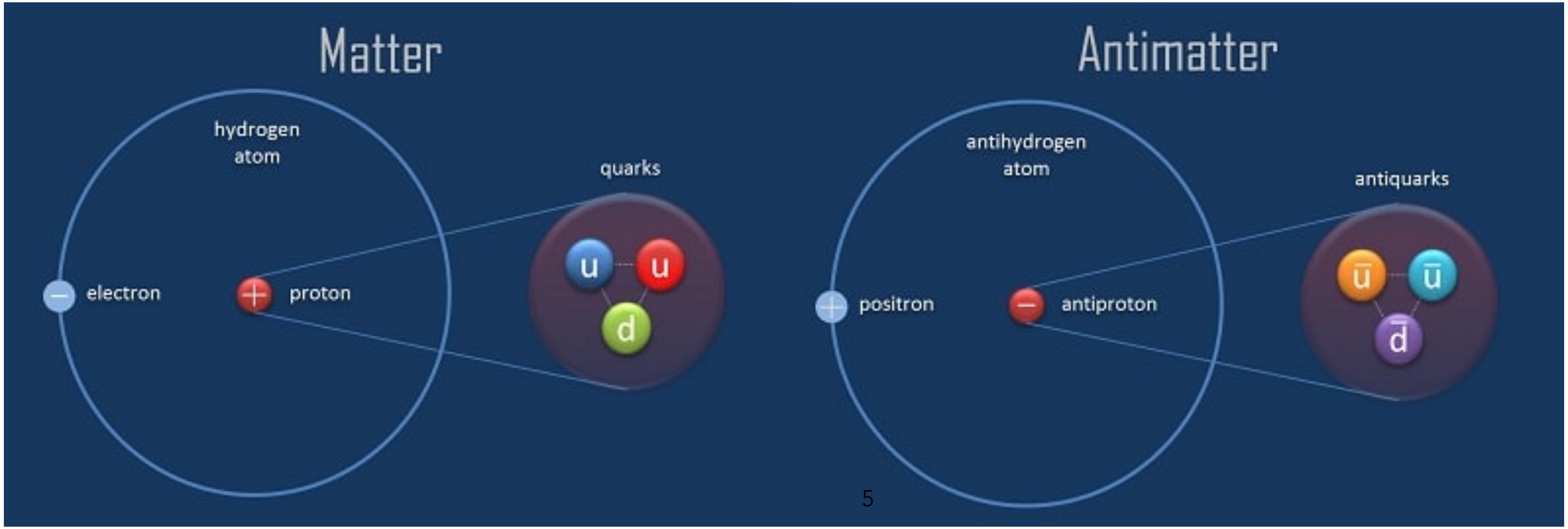






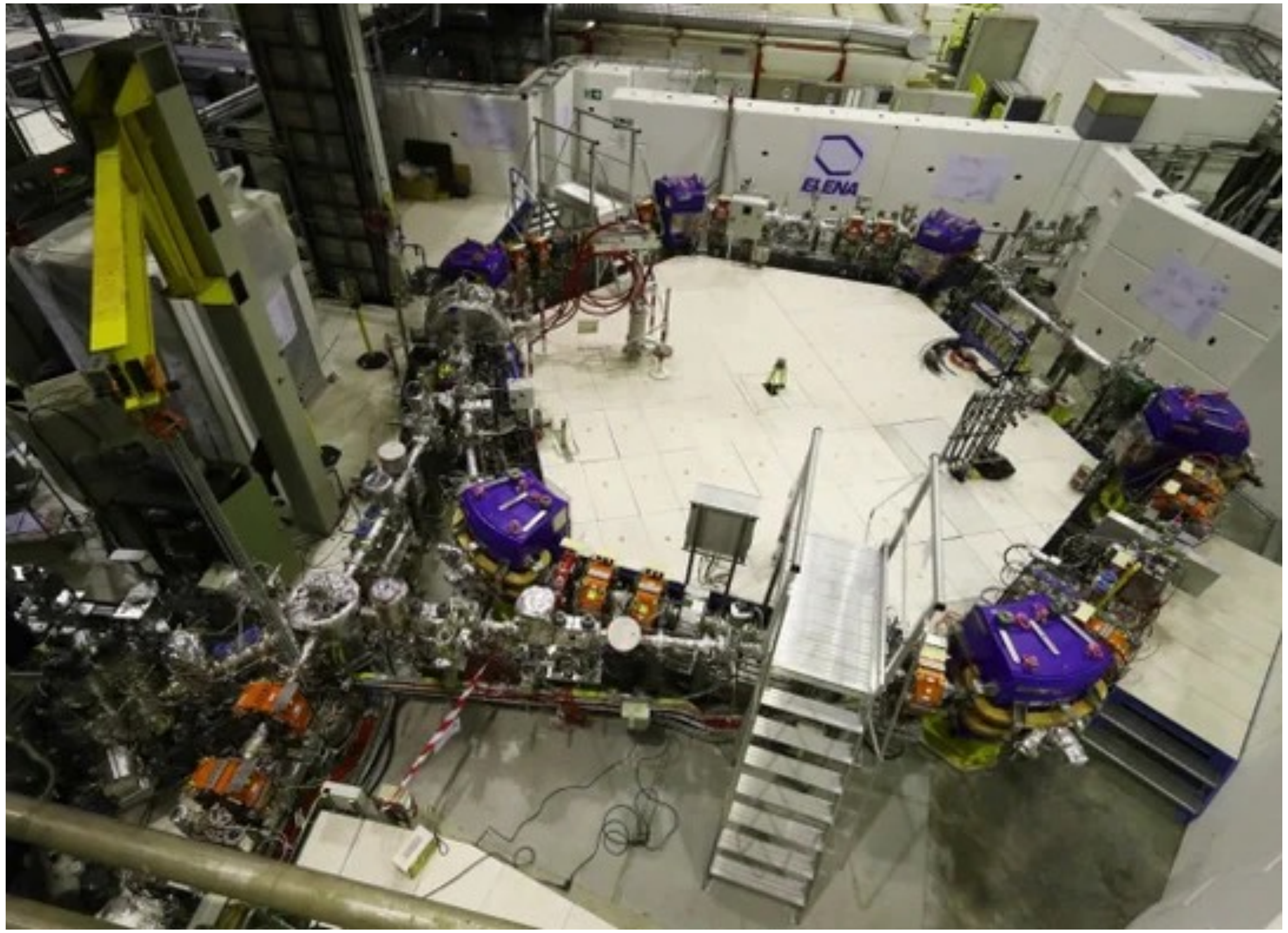
Testing WEP

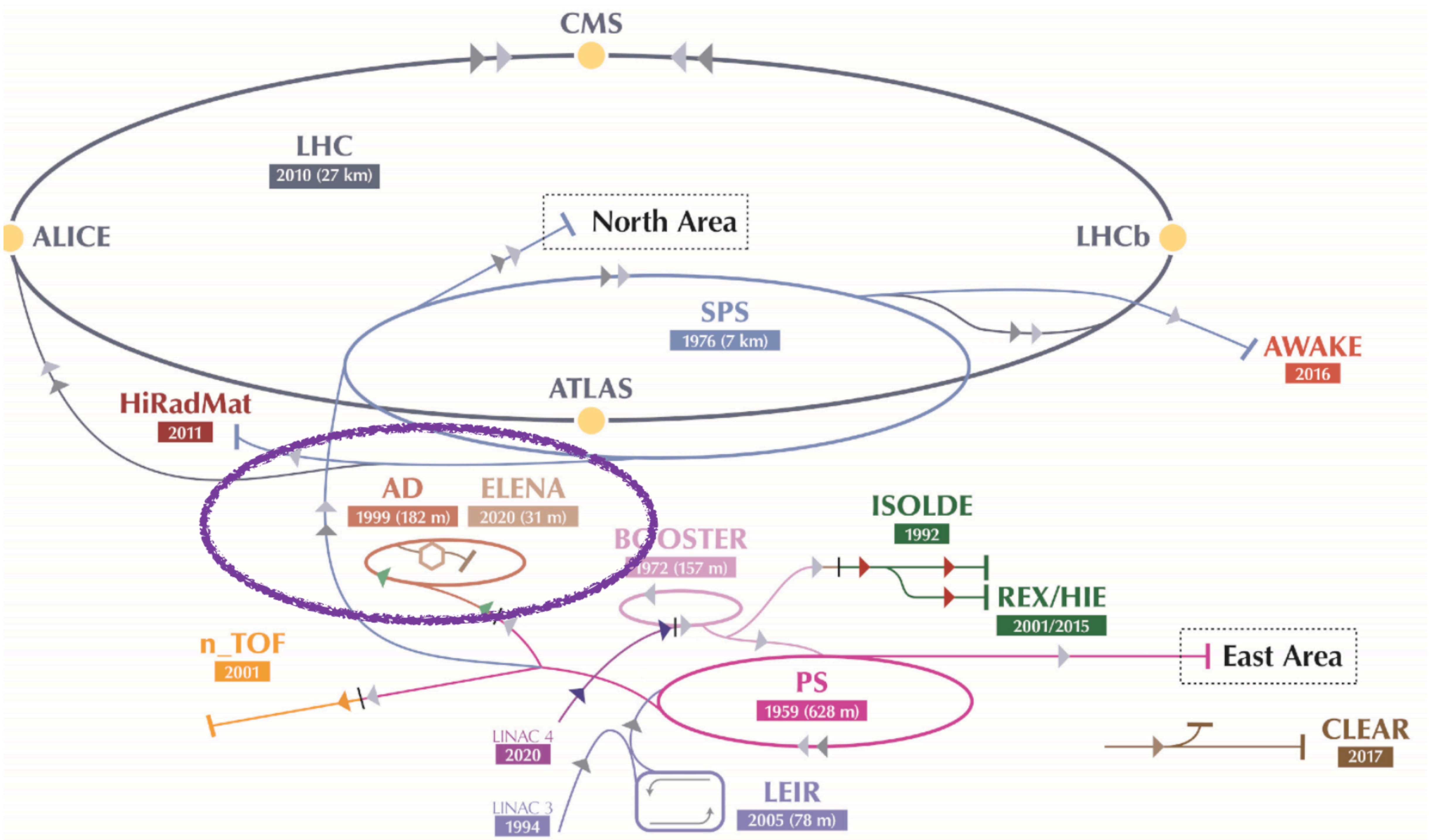
- **Testing on antimatter is challenging**
  - very difficult to produce massive antimatter objects !
  - gravitation effet on a single anti-atom equivalent to 10^{-7} V.m^{-1}
  - have to control magnetic field at level of 10^{-10} T !
- Simplest (and most massive) anti-object we can produce is **anti-hydrogen atom**



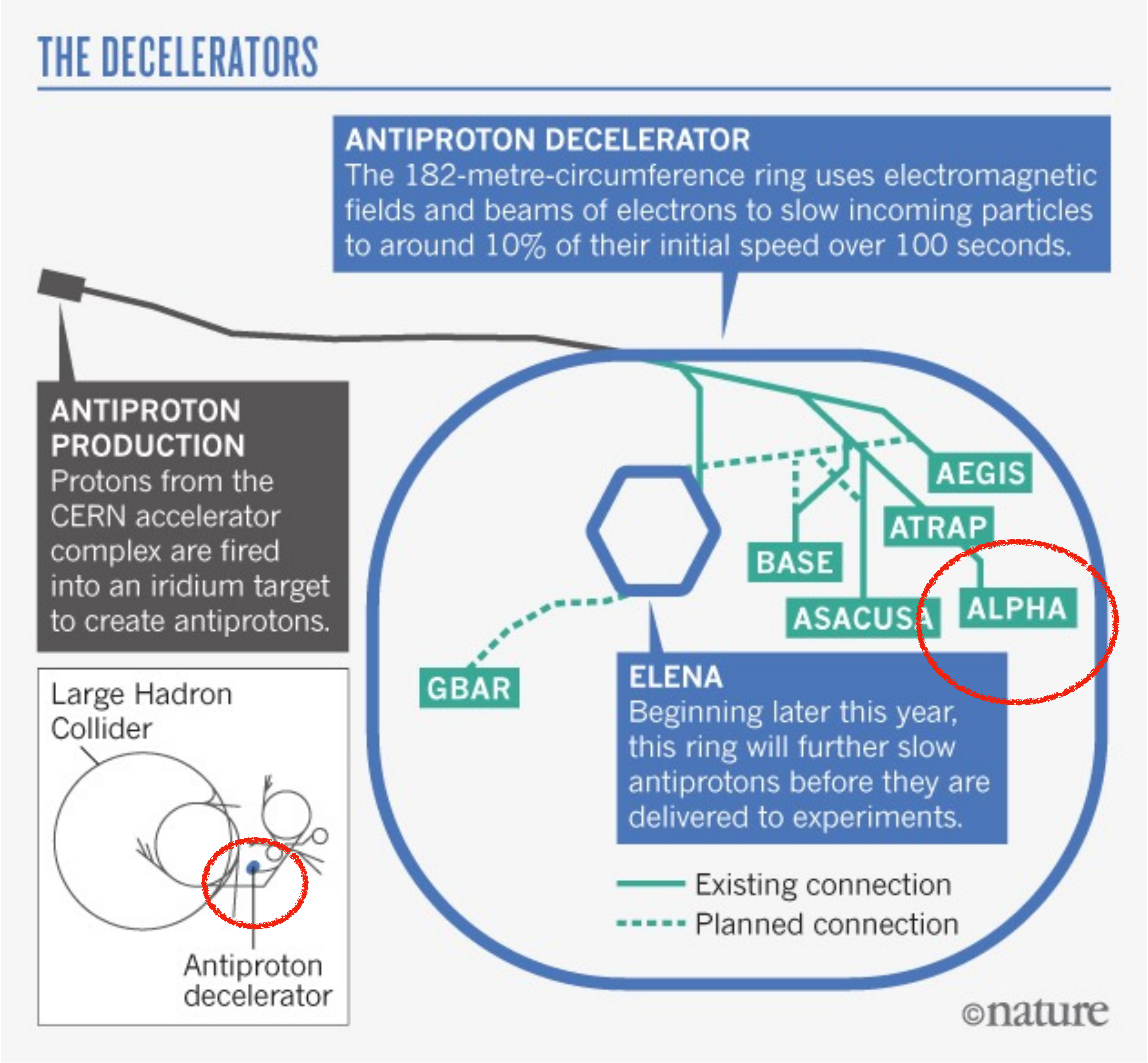
Antimatter factory at CERN

- Use protons produced from Proton-Synchrotron
- AD: Antiproton Decelerator
- Elena (2020): Extra Low ENergy Antiproton





ALPHA experiment



- ALPHA: **A**ntihydrogen **L**aser **Ph**ysics **A**pparatus
- ALPHA = 18 institutions, 60 members
- Setup in 2005
- First experiment being able to trap anti-hydrogen for a « long » period (16 minutes) in 2011

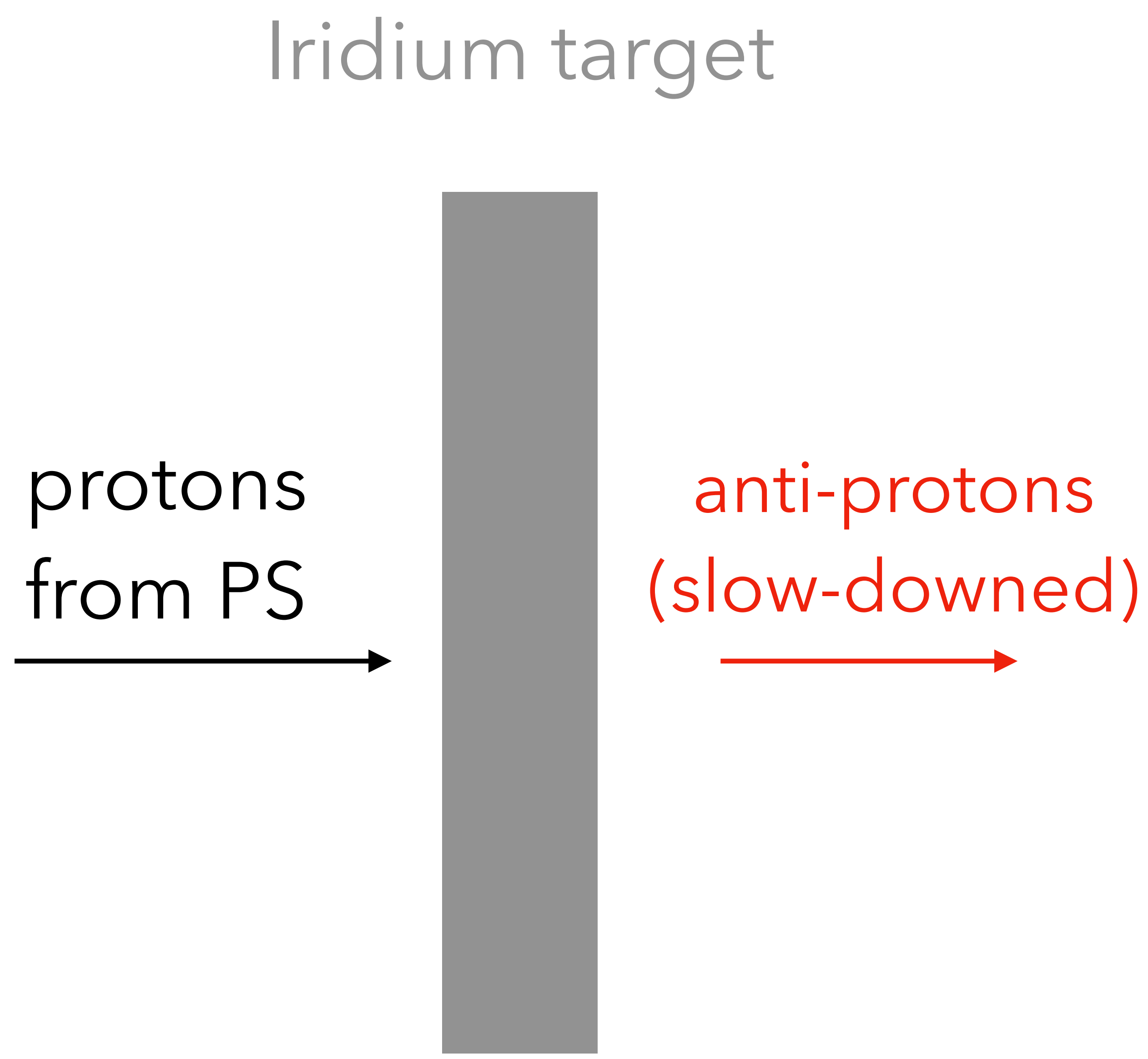
A bit of story of anti-hydrogen

(all results from ALPHA !)

- **2011**: antihydrogen trapped for 16 minutes : link (Nature)
- **2012**: first measurement of fine anti-hydrogen spectrum : link (Nature)
  - same as hydrogen one, within uncertainties !
- **2021**: first time anti-hydrogen are cooled down using laser: link (Nature)
- **2023**: first gravity experiment on anti-hydrogen: link (Nature)

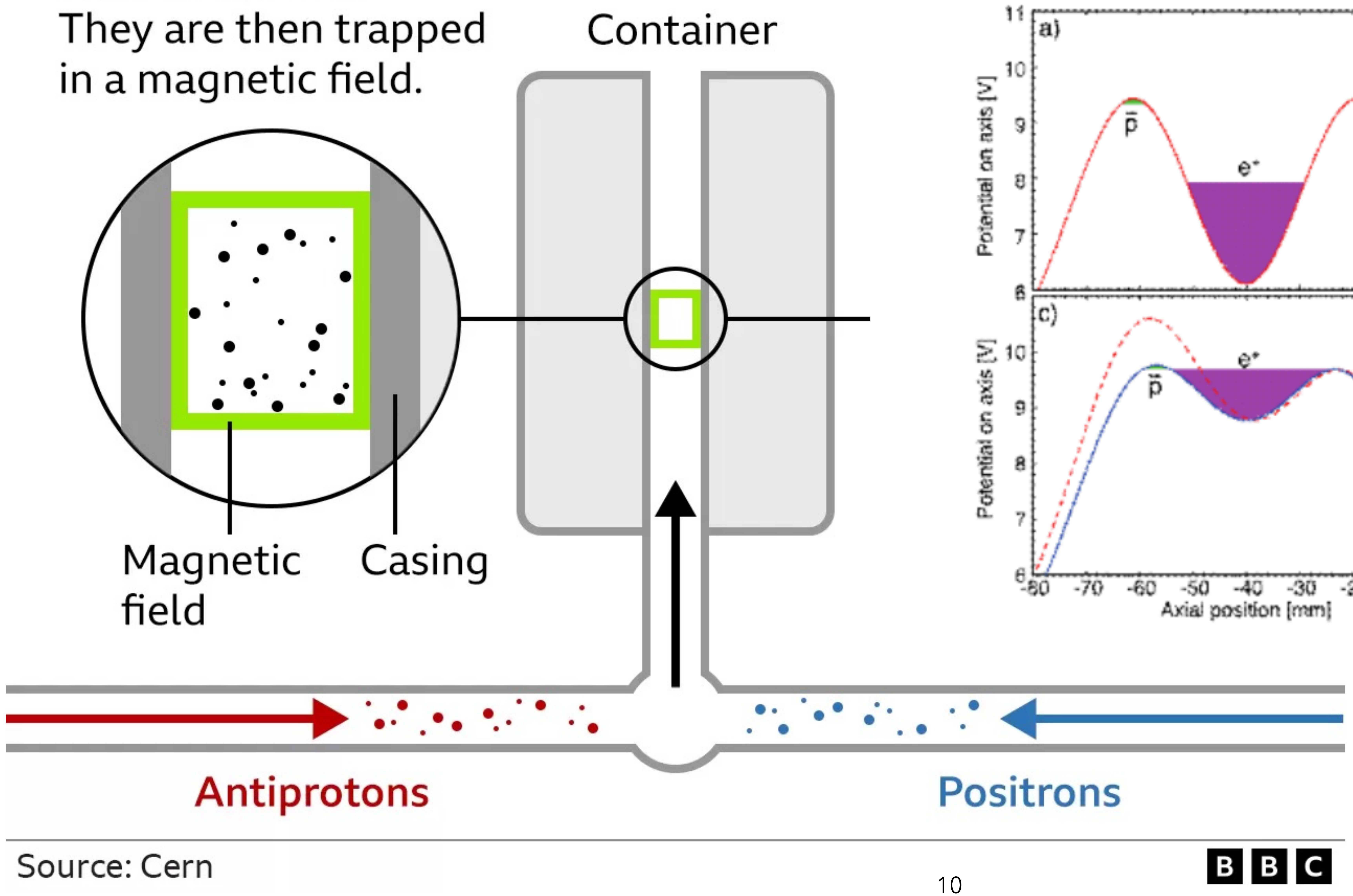
How anti-hydrogen is produced

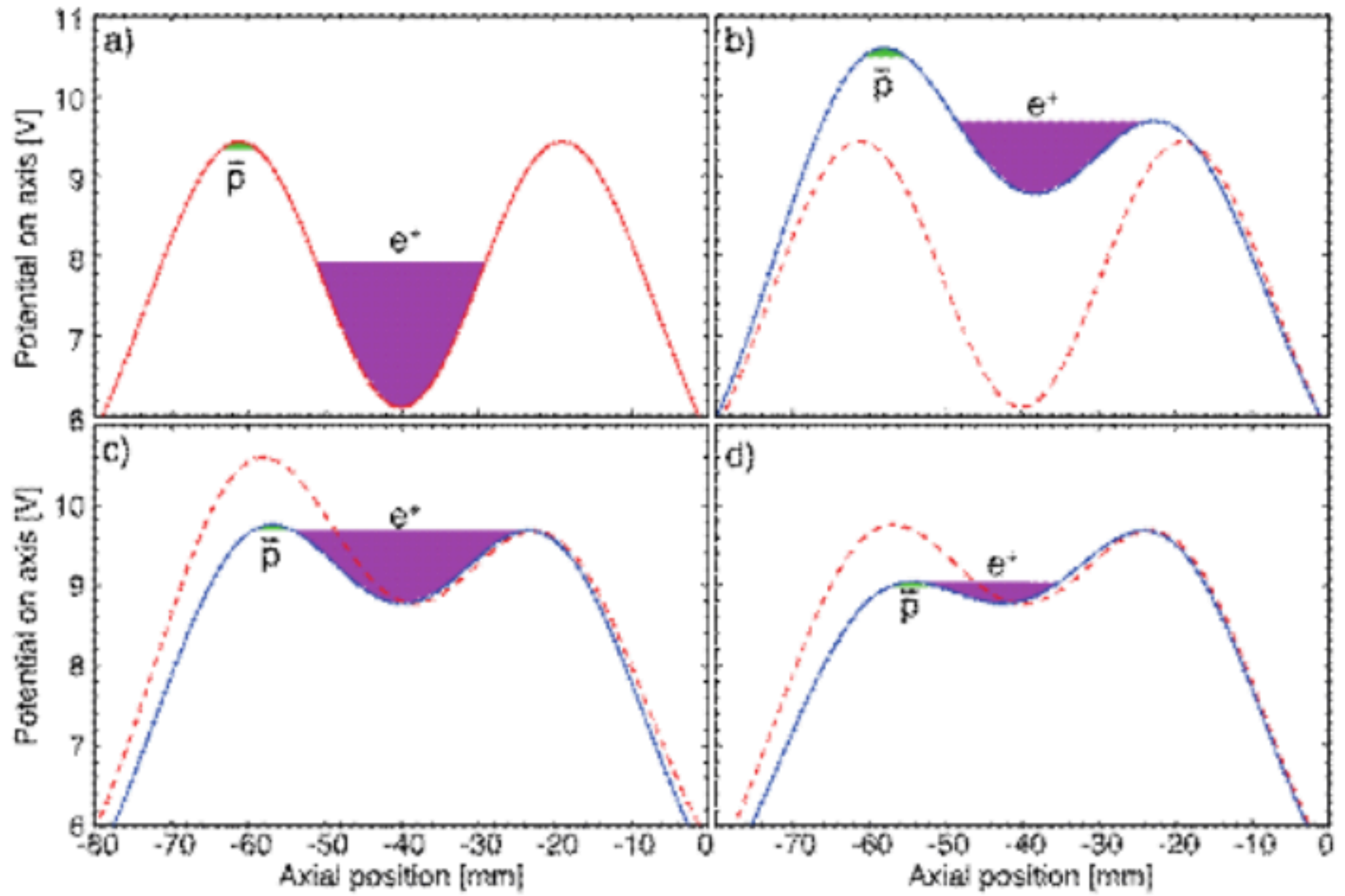
- **Anti-protons:**
  - AD produce a beam with antiprotons from iridium target and decelerate them
  - ELENA cool down even further -> antiprotons go down to 100 keV
    - 5.10^6 protons/minute
- **Positrons** from Na^{22} source



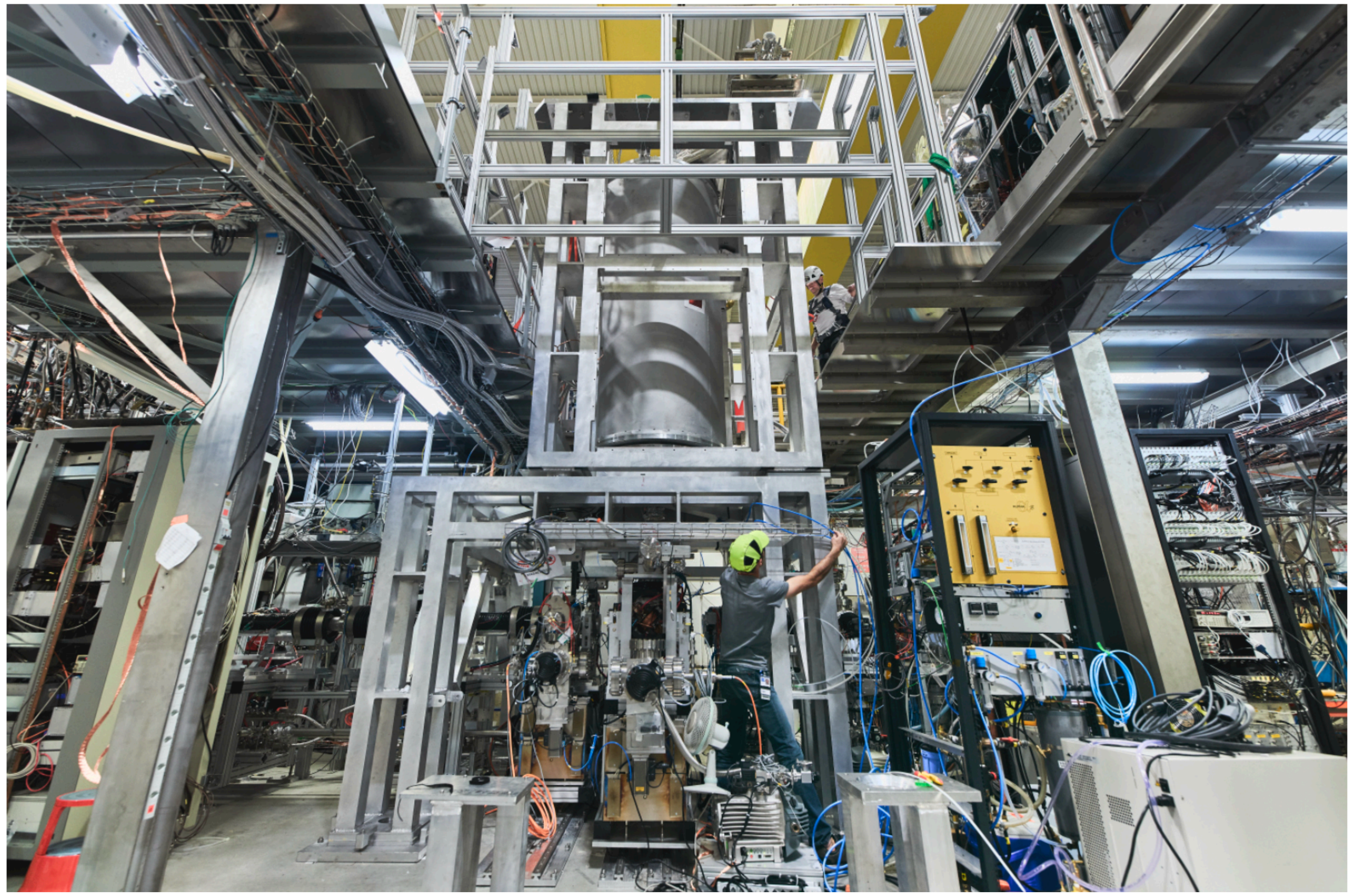
How anti-hydrogen is produced

1. The antiparticles are combined to form antiatoms. They are then trapped in a magnetic field.

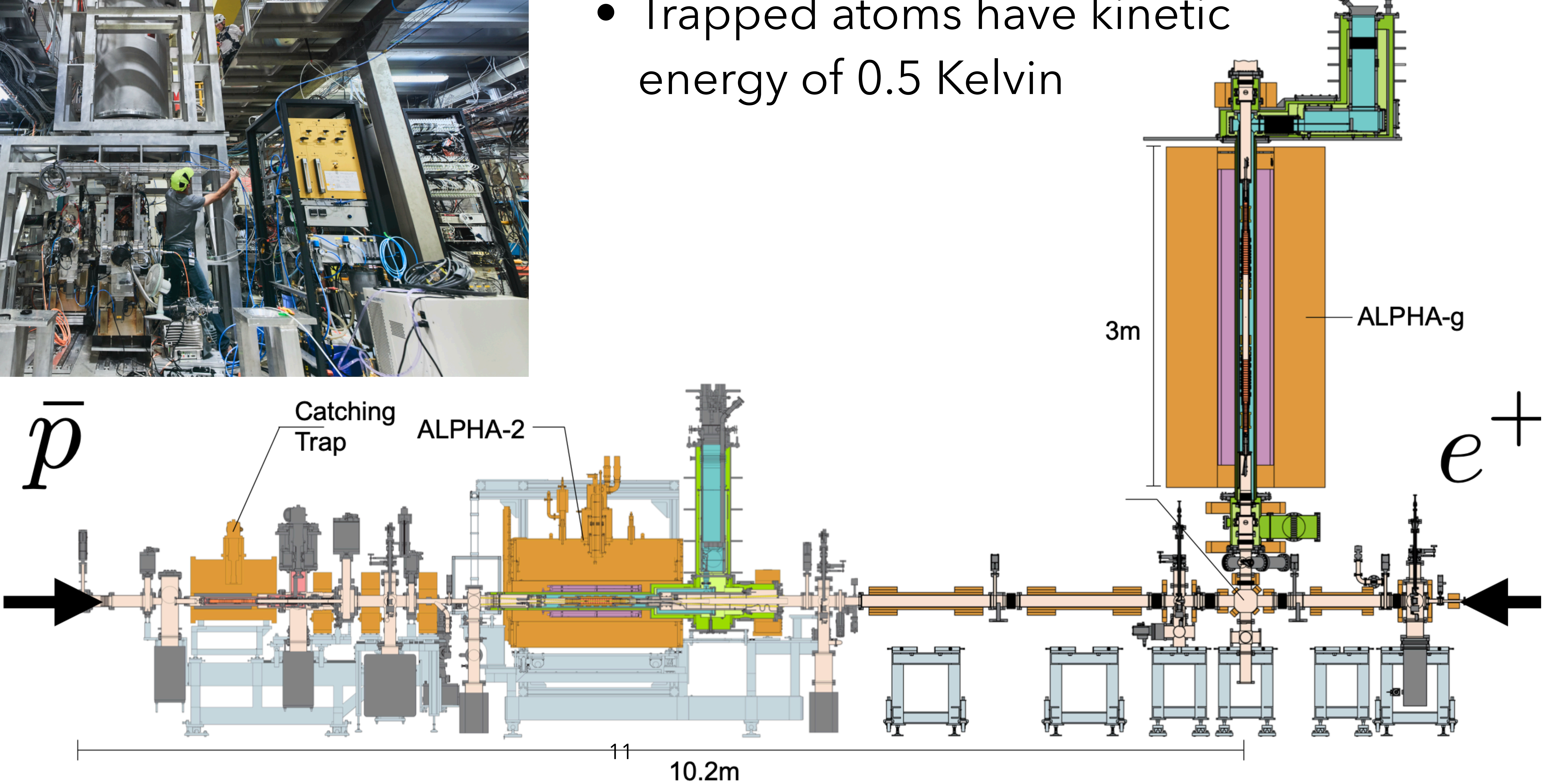




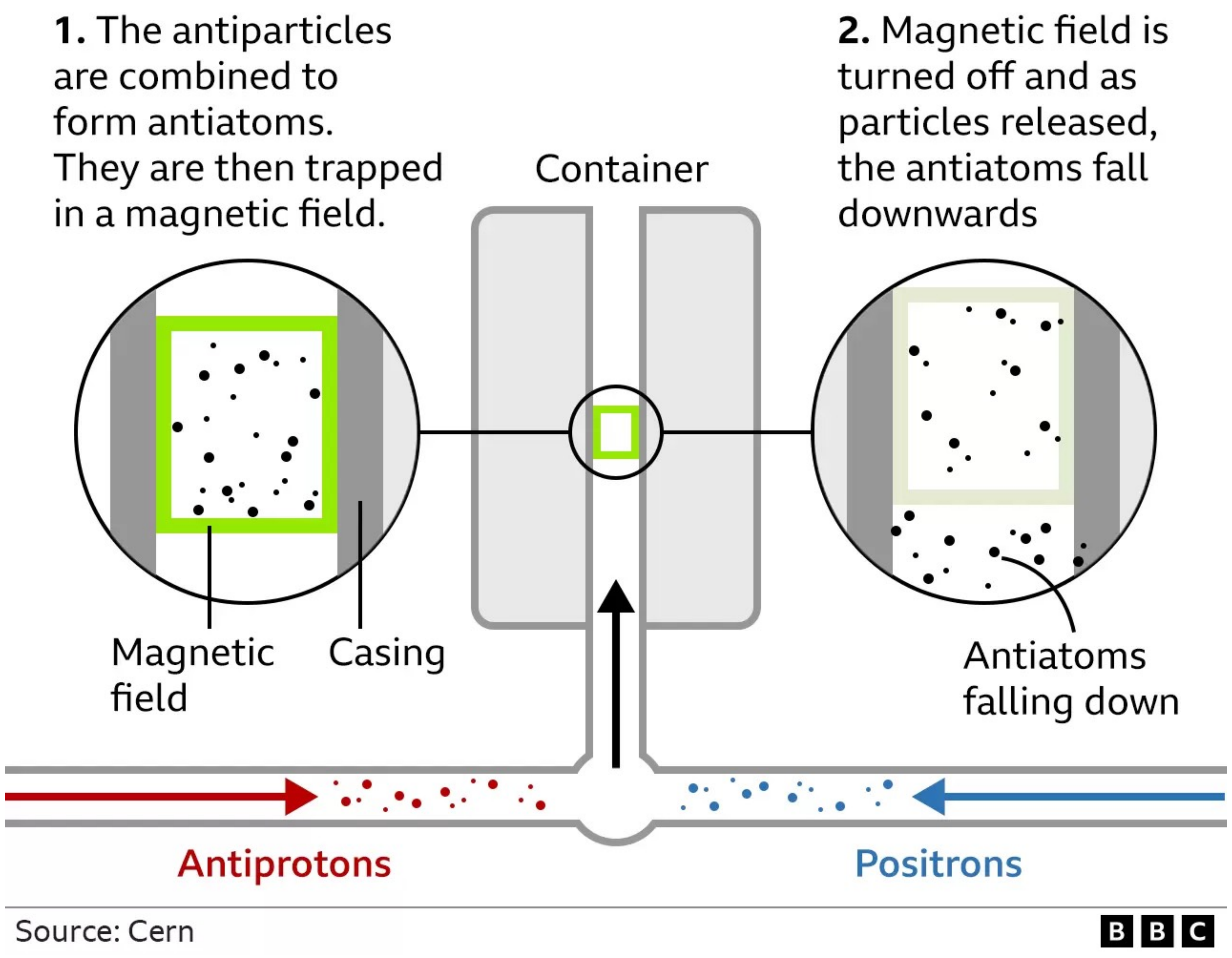
ALPHA-g experiment



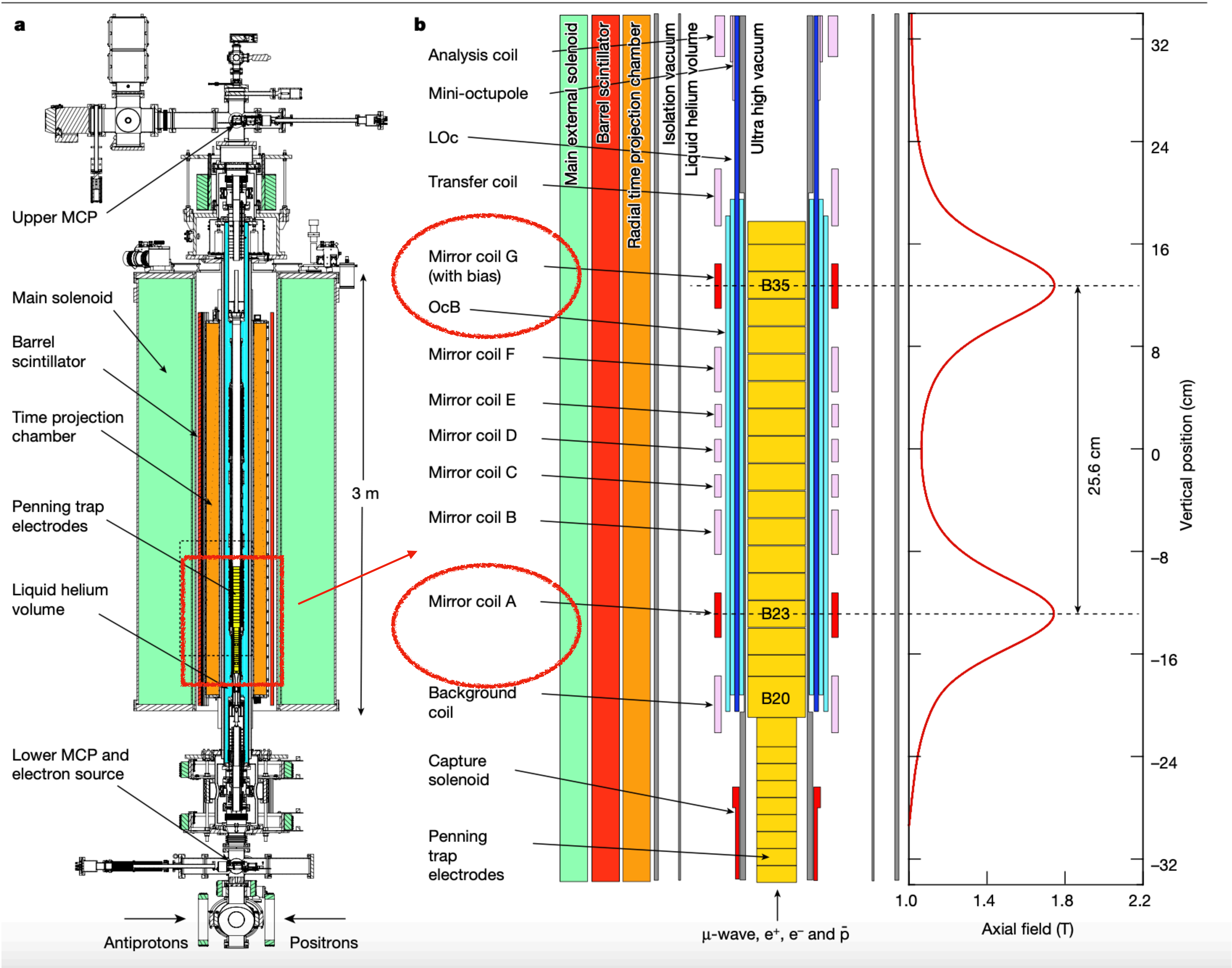
- Build in 2018
- Trapped atoms have kinetic energy of 0.5 Kelvin



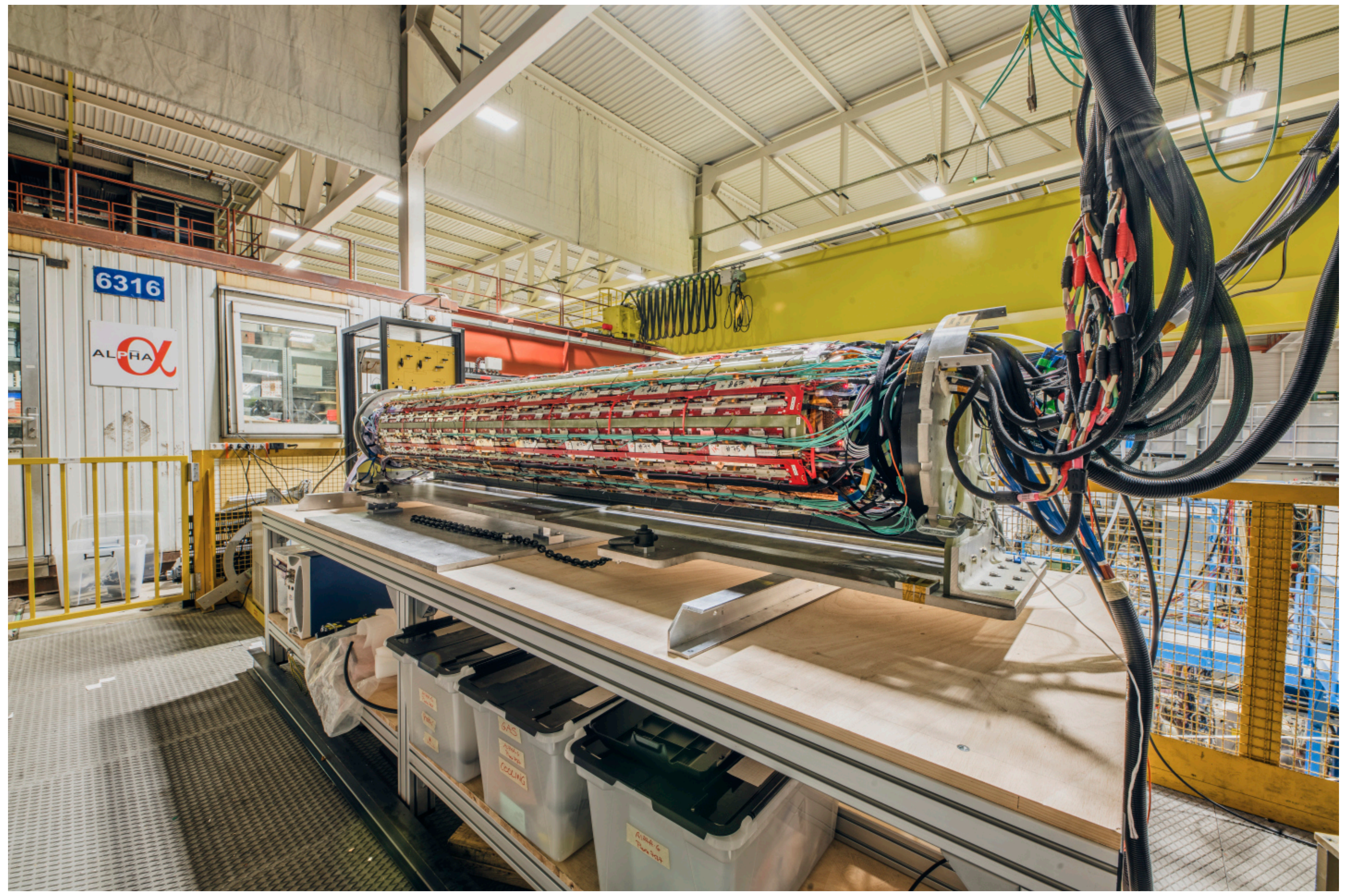
Measurement of gravity of anti-hydrogen



- Gravity is expected to be manifested as a difference in the number of annihilation events from anti-atoms escaping via the top or the bottom of the trap
- About 100 atoms trapped in ~4h



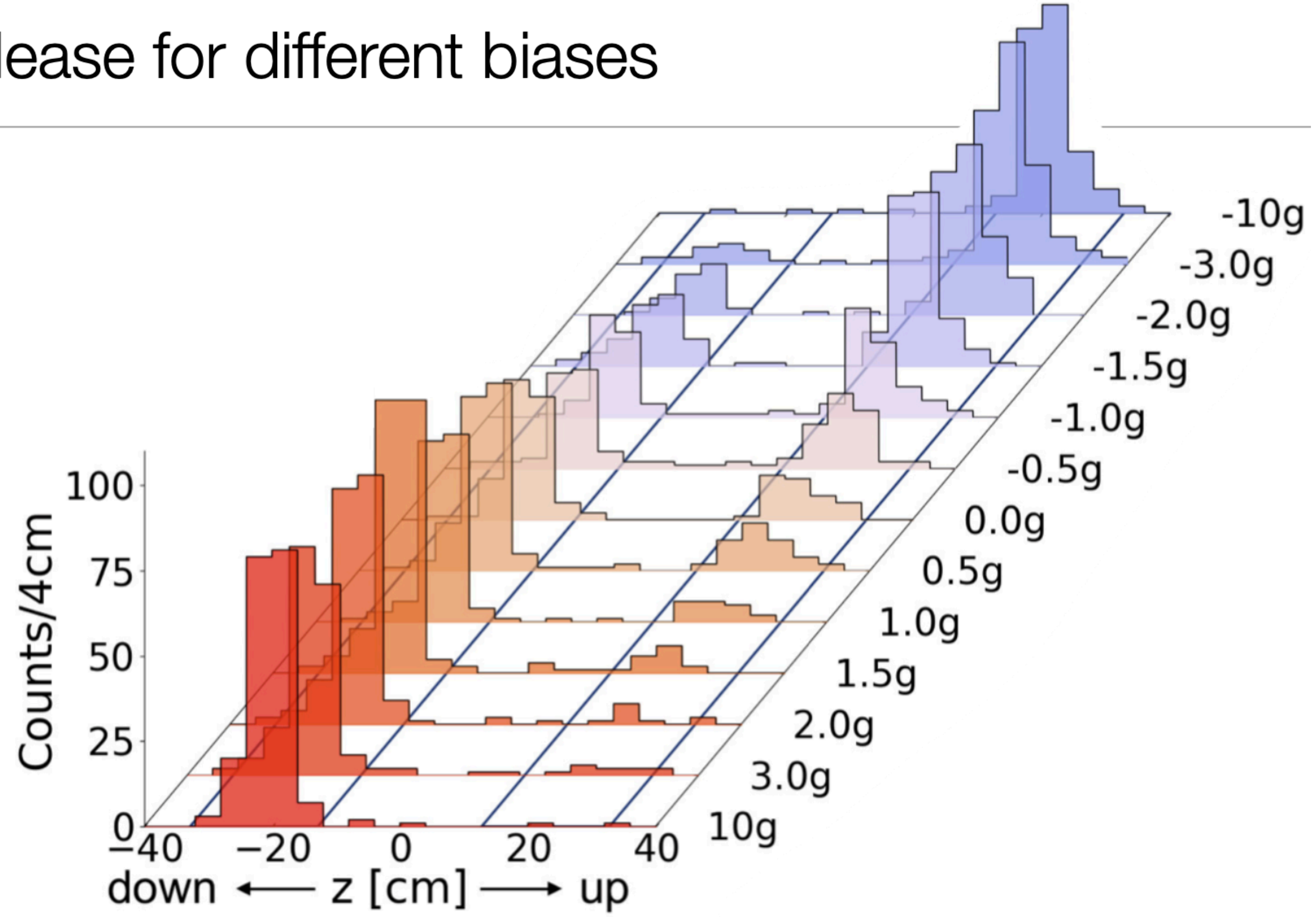
- Anti-atoms escape either on top of the trap (solenoid mirror coil G) or bottom (solenoid mirror coil mirror A) and then annihilate on walls of the apparatus
- Annihilations and positions reconstructed using ALPHA-g radial time projection chamber (rTPC) detector



Effect of magnetic field

- Very difficult to control perfectly magnetic field in every place at each instant
- Vertical gradients in magnetic field magnitude can mimic effect of gravity
  - g = 9.81 m.s-1^{2} equivalent to a vertical magnetic field gradient of 1.77×10^{-3} T.m^{-1} acting on hydrogen atom in ground state
- A calibration of effect is made with several g values

Release for different biases



Results

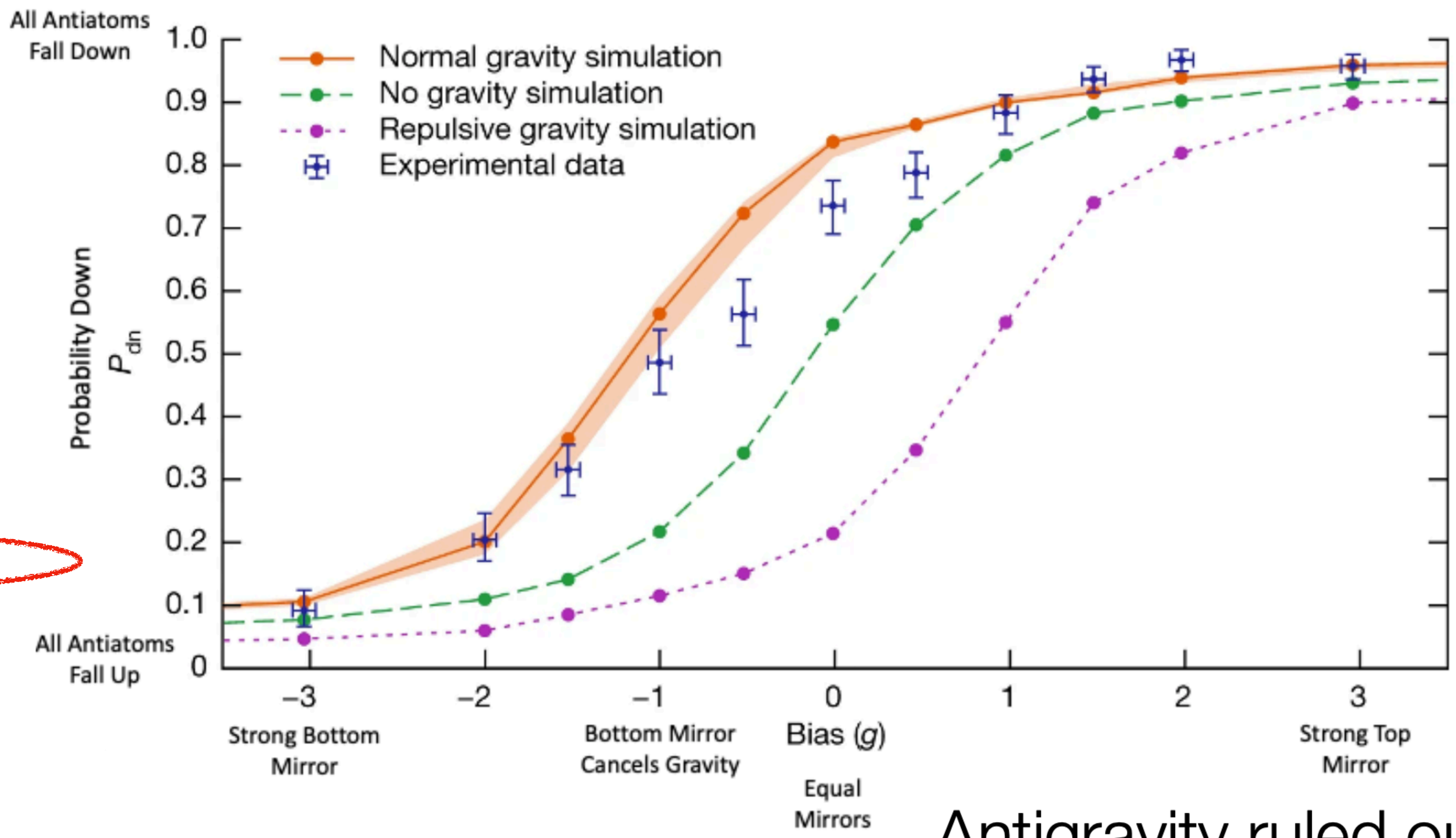
- probability for an anti-hydrogen atom to escape downwards

.

Table 3 | Uncertainties in the determination of $a_{\bar{g}}$

	Uncertainty	Magnitude (g)
Statistical and systematic	Finite data size	0.06
	Calibration of the detector efficiencies in the up and down regions	0.12
	Other minor sources	0.01
Simulation model	Modelling of the magnetic fields (on-axis and off-axis)	0.16
	Antihydrogen initial energy distribution	0.03

Summary of the uncertainties involved in the determination of the gravitational acceleration $a_{\bar{g}}$. The uncertainties are one standard deviation and are expressed in units of the local acceleration of gravity for matter (9.81 m s^{-2}). See Methods for the details.



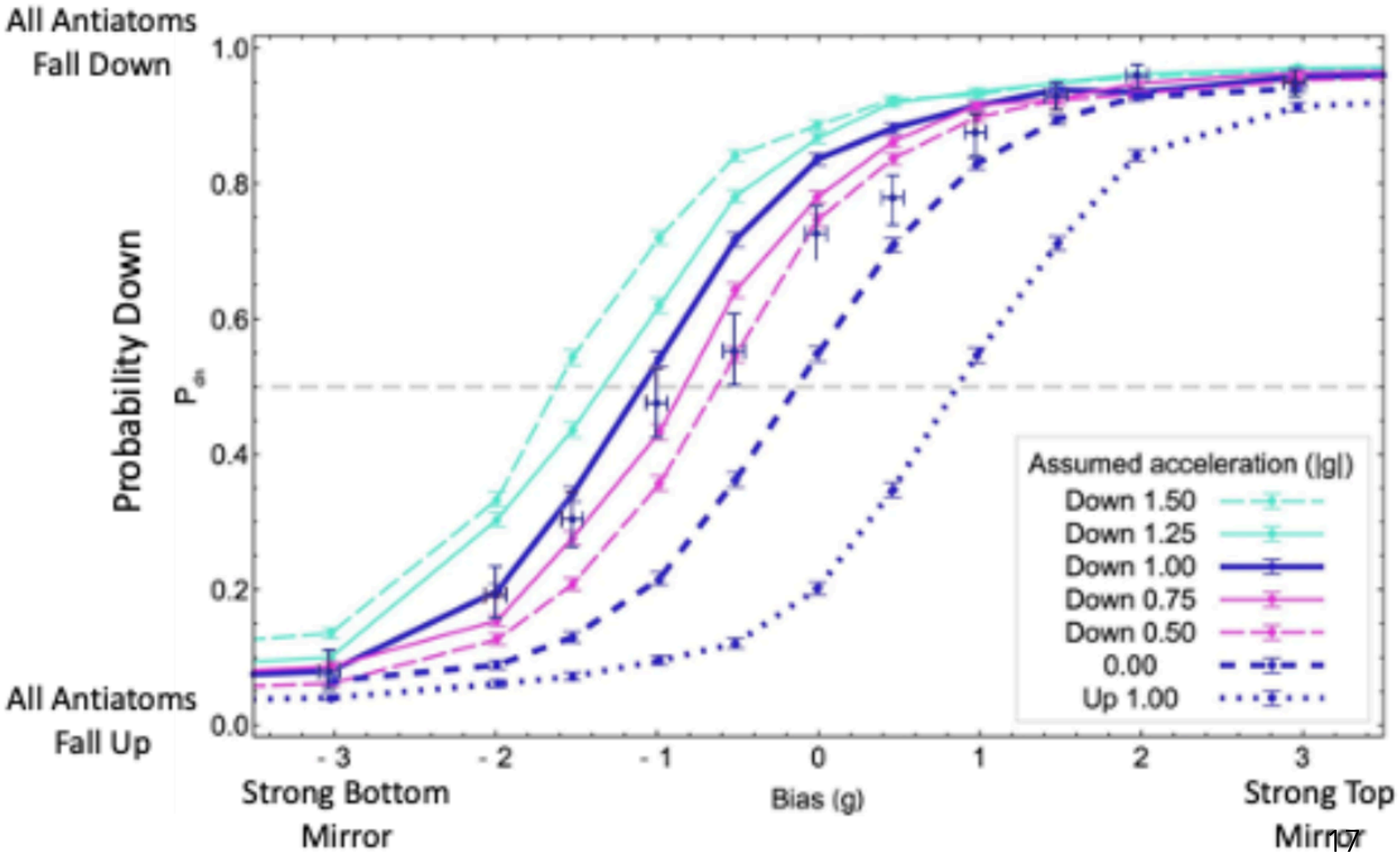
Antigravity ruled out!

Nominal bias (g)	Number of trials	N_{up} (events)	N_{dn} (events)	Events during LOc ramp-down
−3.0	7	151.7	16.5	199.2
−2.0	7	128.7	33.5	168.2
−1.5	6	128.9	57.7	192.0
−1.0	7	69.7	62.5	183.2
−0.5	7	55.7	67.5	201.2
0	7	36.7	94.5	144.2
0.5	7	36.7	124.5	177.2
1.0	7	17.7	119.5	185.2
1.5	6	13.9	180.7	234.0
2.0	7	6.7	163.5	228.2
3.0	7	7.7	147.5	199.2
−10.0	6	142.9	0.7	169.0
10.0	6	−0.1	185.7	213.0

The number of events for anti-atoms escaping either up or down is tabulated for each bias series. These events occur in the time window 10–20 s during the ramp-down and lie within the z-regions illustrated in Fig. 3. Also shown is the number of events due to antihydrogen atoms that escape when the long octupole magnet is ramped down. All values are corrected for the expected cosmic ray background. Counting uncertainties are not listed but are used in the global determination of P_{dn} in Fig. 5. The background per trial was 0.18 ± 0.01 events in the top region and 0.21 ± 0.01 events in the bottom region. The background per trial for the LOc ramp-down window (duration 13.1 s) was 0.83 ± 0.02 events. The $\pm 10g$ entries are for the calibration trials (see text).

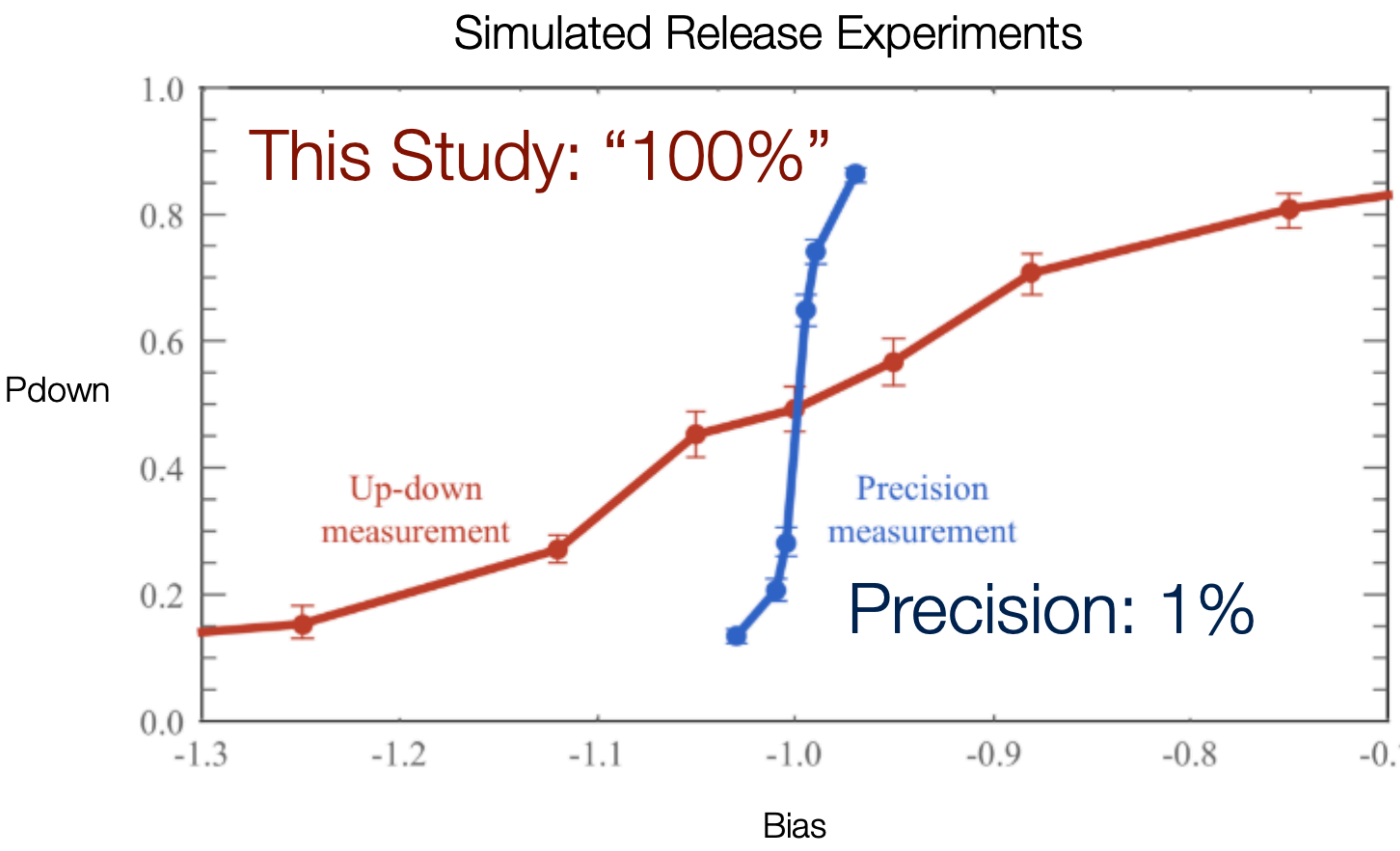
Measurement of g

$$\bar{g} = [0.75 \pm 0.13 \text{ (statistical + systematic) } \pm 0.16 \text{ (simulation)}]\, g$$



Future

Measure magnitude of g as precisely as possible



References

- Reference:
  - https://www.nature.com/articles/s41586-023-06527-1
  - https://indico.cern.ch/event/1334474/attachments/2743401/4772931/Bertsche_CERN_EP_2023.pdf
  - https://alpha.web.cern.ch/