Antimatter at CERN

J. Schoonwater | 1-11-2024

Swansea University
Prifysgol Abertawe

Searches related to antimatter headlines

1 gram of antimatter **explosion**

what is antimatter **used for**

antimatter **bomb price**

antimatter **uses**

antimatter **power**

how is antimatter **made**

how much antimatter **to destroy earth**

is antimatter **real**

Goooooooooooogle

1 2 3 4 5 6 7 8 9 10 Next

Conspiracy theorists claim CERN has unleashed 'hell on Earth' in its latest antimatter experiment

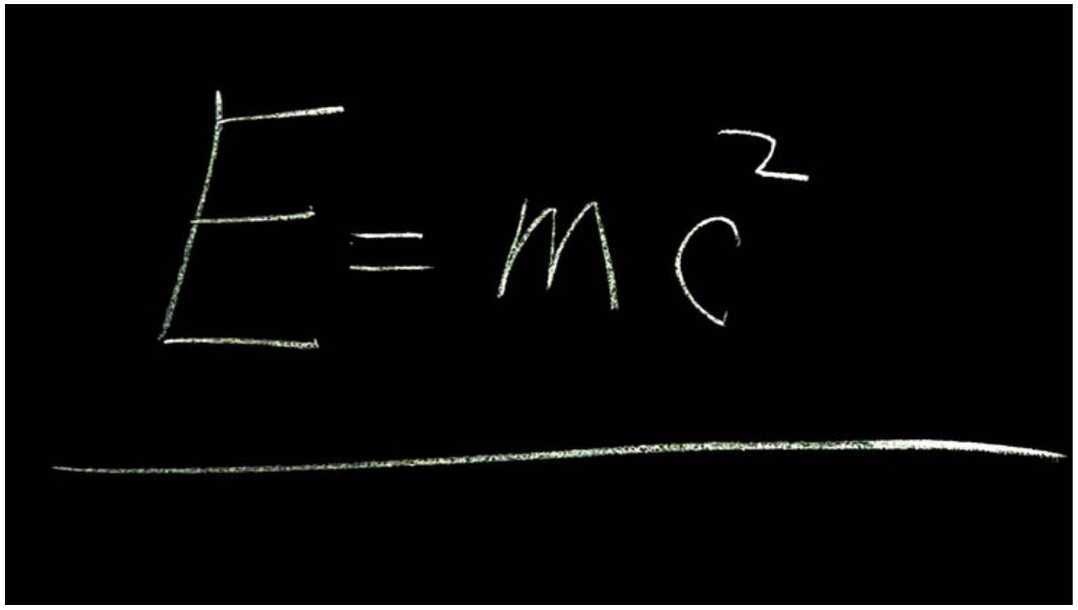
- Scientists have used a laser to tickle atoms of antimatter and make them shine
- Researchers have spent decades to figure out how to create antimatter
- This week they managed it, and trapped it for long enough to perform tests
- Now a Christian 'truther' publication has called CERN the 'antichrist' for performing these experiments

By MAILONLINE REPORTER
PUBLISHED: 18:00 BST, 22 December 2016 | **UPDATED:** 22:54 BST, 22 December 2016

What is antimatter?

For more than half a century physicists have believed that the Universe is made of both matter and antimatter....

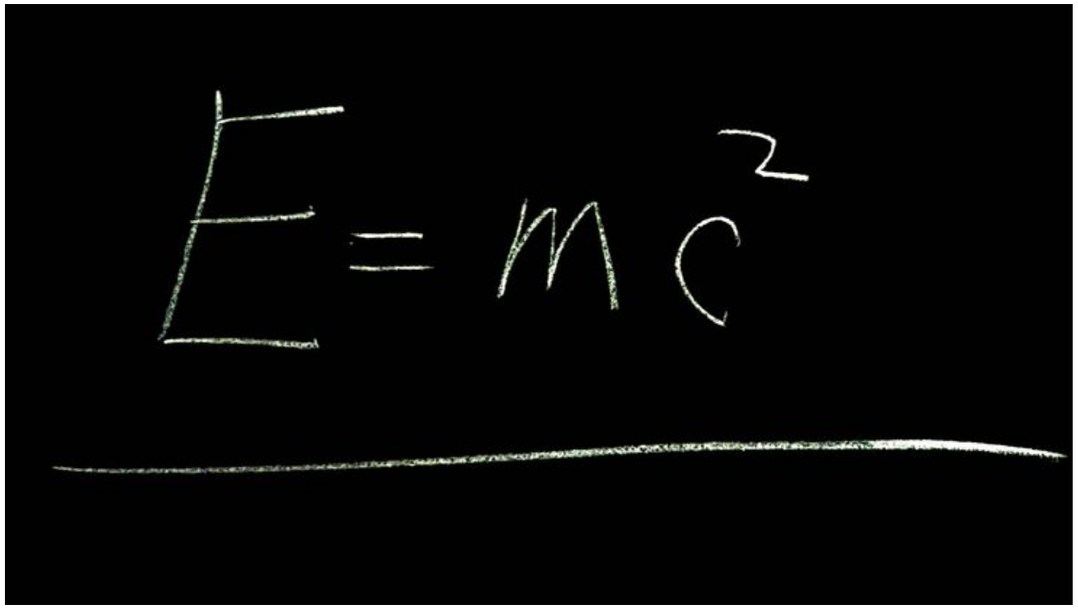
Back in 1928...



Can these two be compatible?

$$i\hbar\frac{\partial}{\partial t}\left|\Psi\right\rangle = \hat{H}\left|\Psi\right\rangle$$

Back in 1928...



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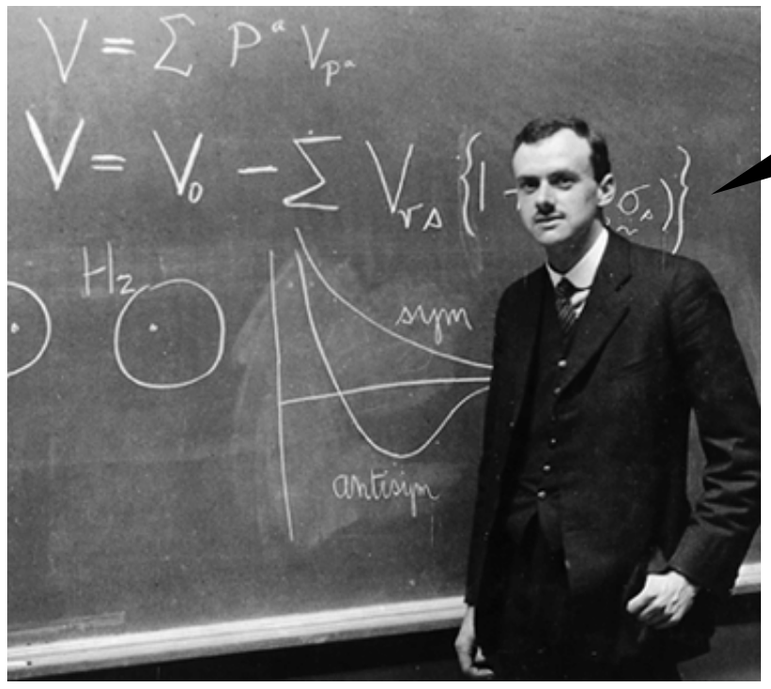
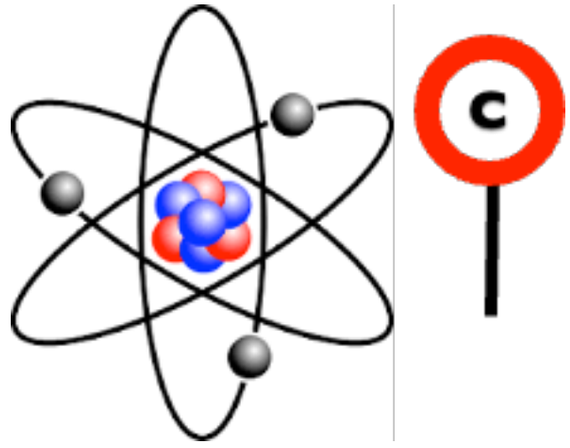


Yes! Even inside atoms electrons have a speed limit.



Paul Dirac

The Dirac equation

$$\left[\left(ih\frac{\partial}{c\,\partial t}+\frac{e}{c}\,\mathrm{A}_0\right)^2+\Sigma_r\left(-ih\frac{\partial}{\partial x_r}+\frac{e}{c}\,\mathrm{A}_r\right)^2+m^2c^2\right]\psi=0, \qquad (1)$$

The Quantum Theory of the Electron.

By P. A. M. Dirac, St. John's College, Cambridge.

(Communicated by R. H. Fowler, F.R.S.—Received January 2, 1928.)

The Dirac equation

The wave equation

$$\left[\left(ih\frac{\partial}{c\,\partial t}+\frac{e}{c}\,\mathrm{A}_0\right)^2+\Sigma_r\left(-ih\frac{\partial}{\partial x_r}+\frac{e}{c}\,\mathrm{A}_r\right)^2+m^2c^2\right]\psi=0, \qquad (1)$$

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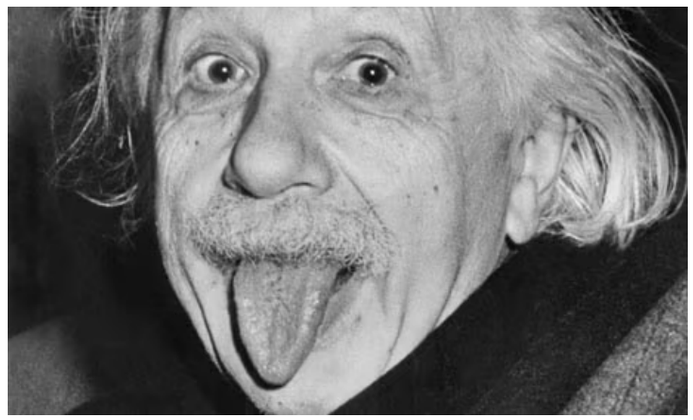

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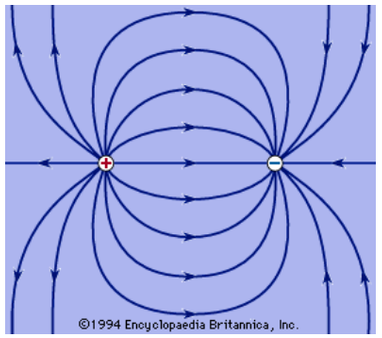

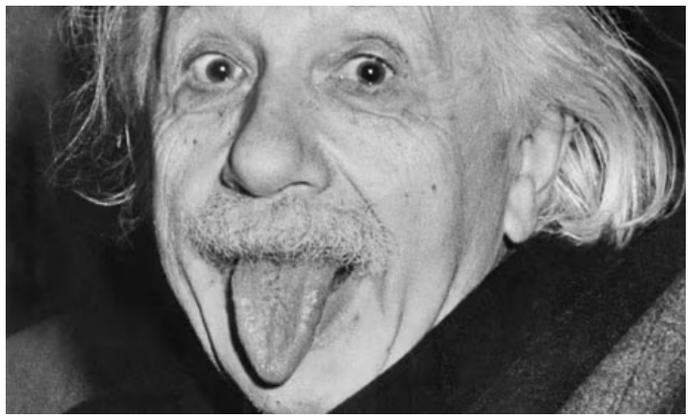

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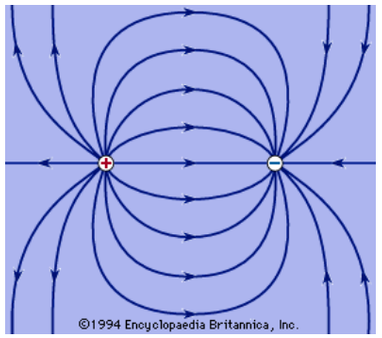
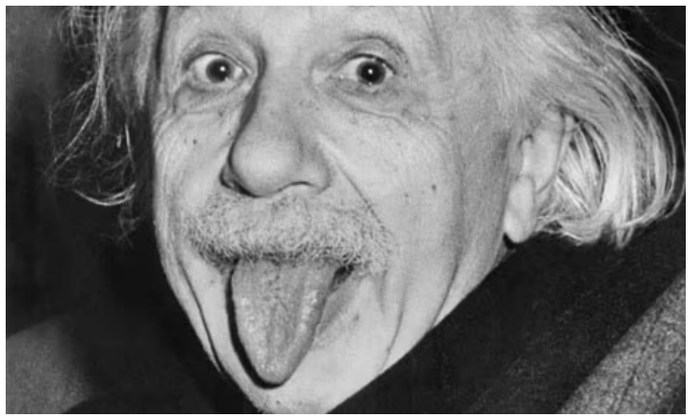
The Dirac equation

The square tells us that the equation works for positive and negative charges!

The wave equation

$$\left[\left(ih\frac{\partial}{c\,\partial t}+\frac{e}{c}\,\mathrm{A}_0\right)^2+\Sigma_r\left(-ih\frac{\partial}{\partial x_r}+\frac{e}{c}\,\mathrm{A}_r\right)^2+m^2c^2\right]\psi=0, \qquad (1)$$





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Antimatter was born

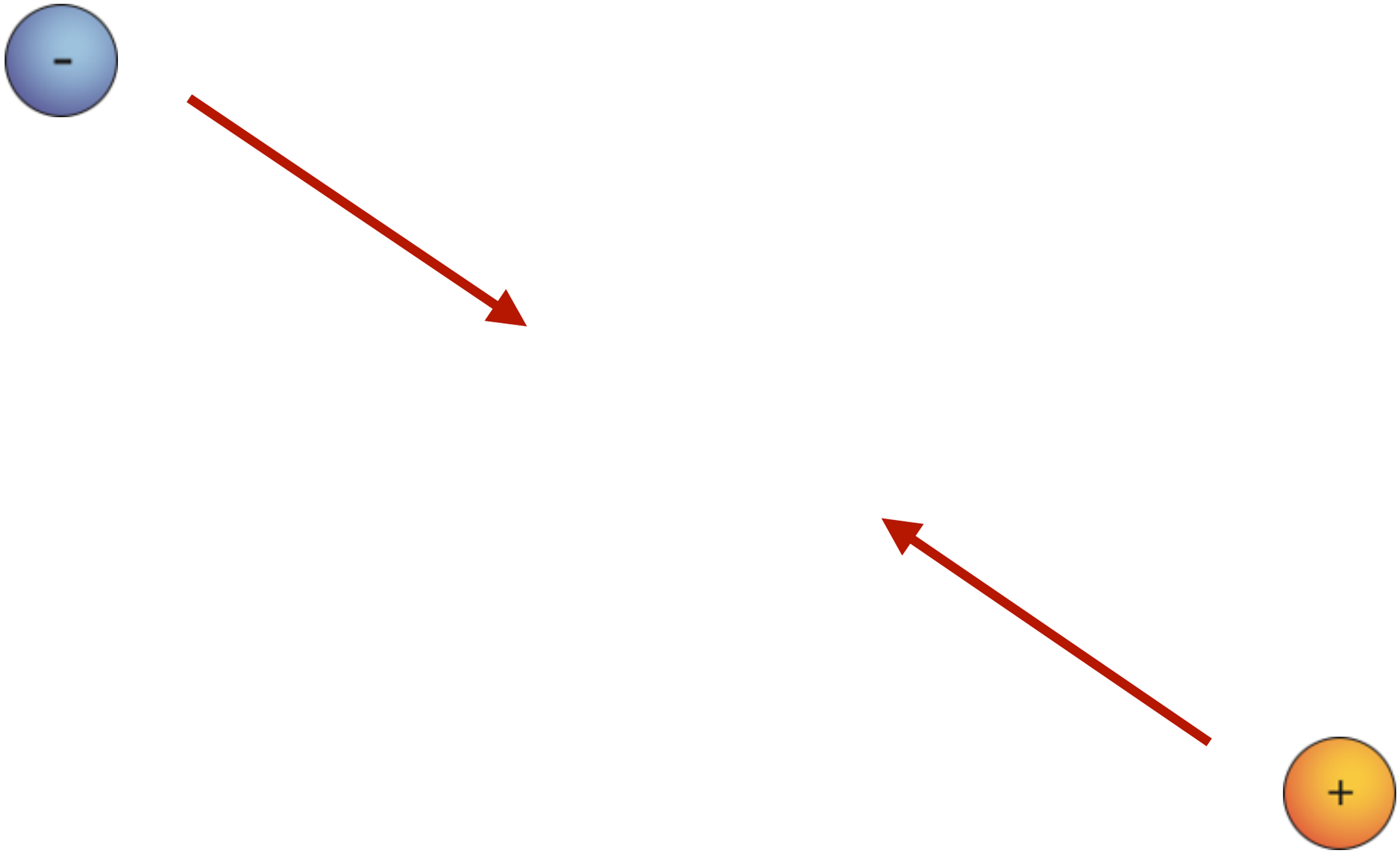
	Electron	Proton
Matter:		
	e^-	P

Antimatter was born

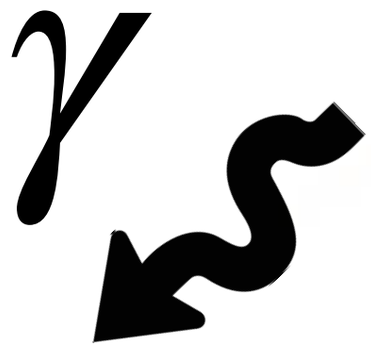
	Electron	Proton
Matter:		
	e^-	P

	Positron (1928)	Antiproton (1955)
Antimatter:		
	e^+	$\bar{P}$

When matter meets antimatter...



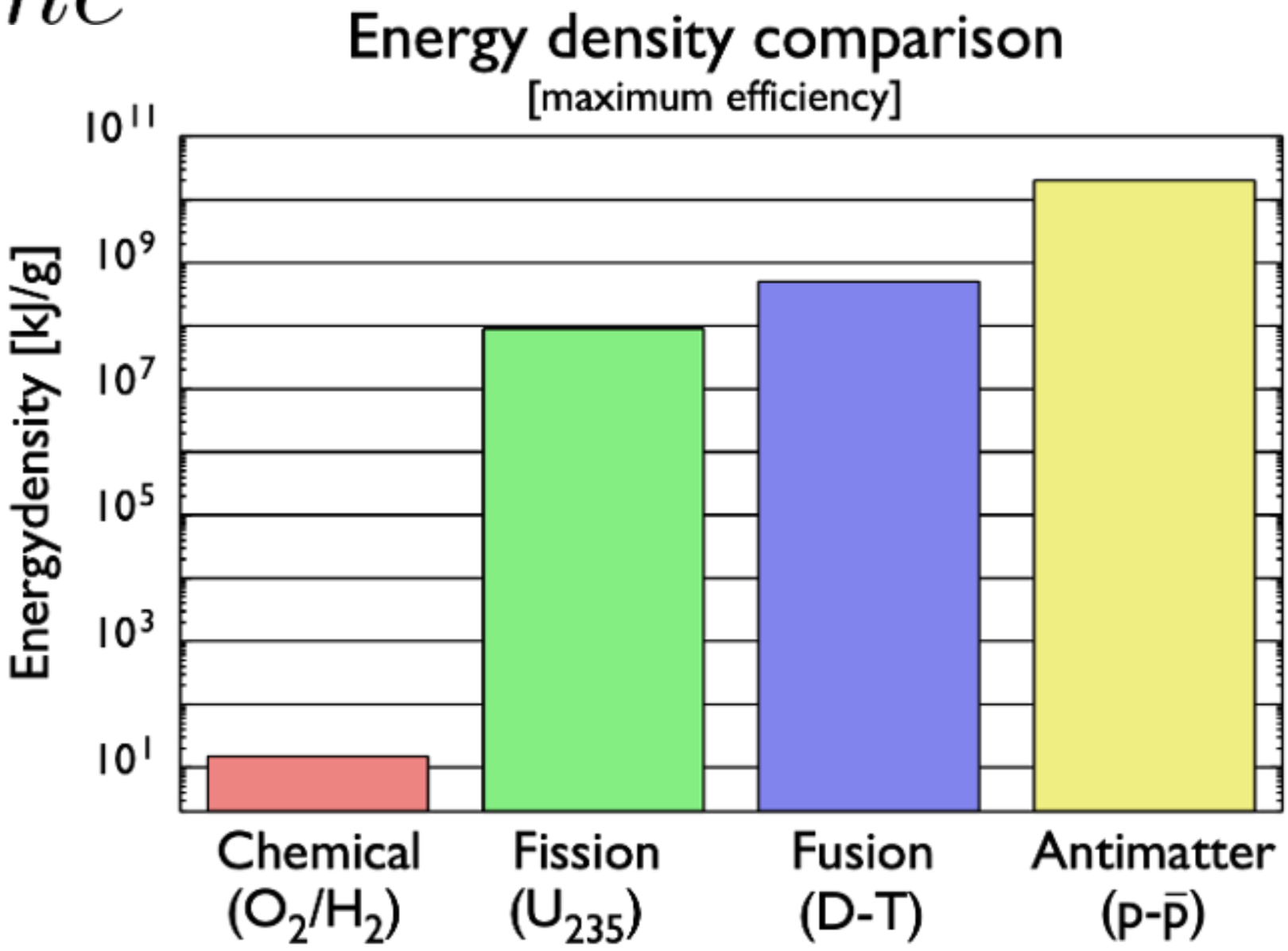
… annihilation!



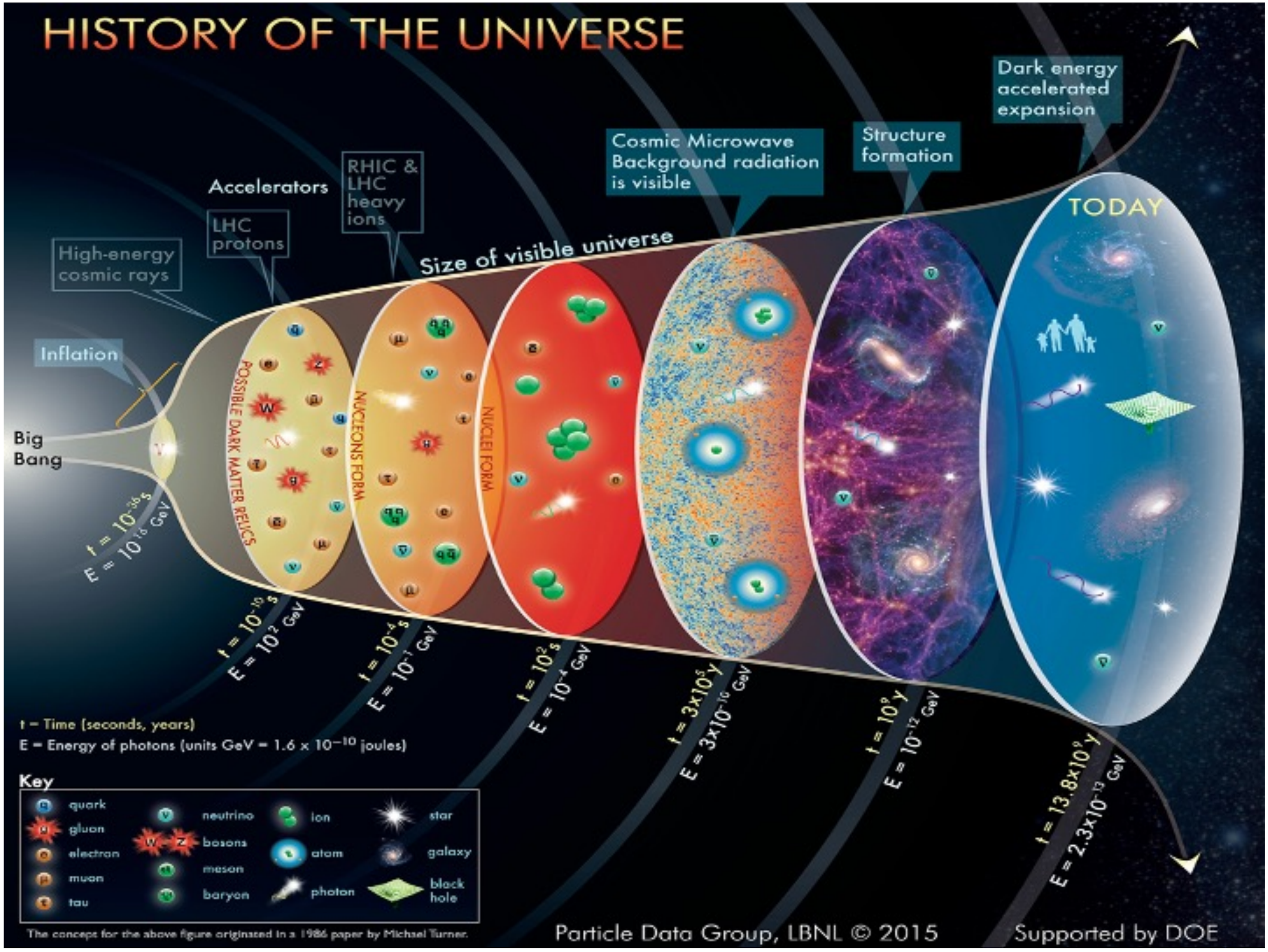
$$E = mc^2$$

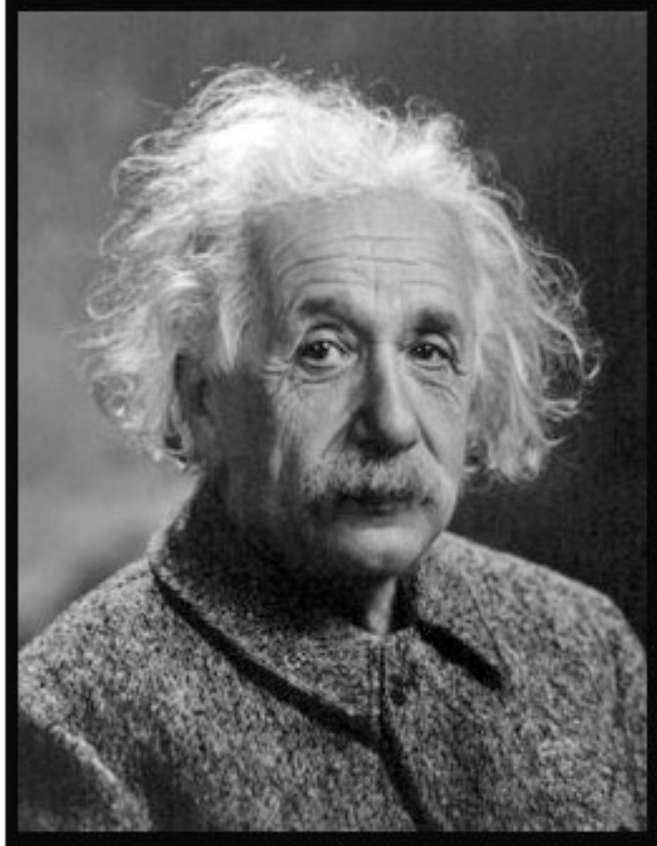
Possible energy source?

$$E = mc^2$$



It is very very difficult to keep antimatter contained


HISTORY OF THE UNIVERSE
Dark energy accelerated expansion
Cosmic Microwave Background radiation is visible
Structure formation
TODAY
Accelerators
RHIC & LHC heavy ions
LHC protons
High-energy cosmic rays
Size of visible universe
Inflation
Big Bang
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
t = 10^-36 s
E = 10^16 GeV
t = 10^-10 s
E = 10^2 GeV
t = 10^-4 s
E = 10^-1 GeV
t = 10^2 s
E = 10^-4 GeV
t = 3x10^5 y
E = 3x10^-10 GeV
t = 10^9 y
E = 10^-12 GeV
t = 13.8x10^9 y
E = 2.3x10^-13 GeV
t = Time (seconds, years)
E = Energy of photons (units GeV = 1.6 x 10^-10 joules)
Key
quark
gluon
electron
muon
tau
neutrino
bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
The concept for the above figure originated in a 1986 paper by Michael Turner.
Particle Data Group, LBNL © 2015
Supported by DOE



On the big Bang theory: For every one billion particles of antimatter there were one billion and one particles of matter. And when the mutual annihilation was complete, one billionth remained - and that's our present universe.

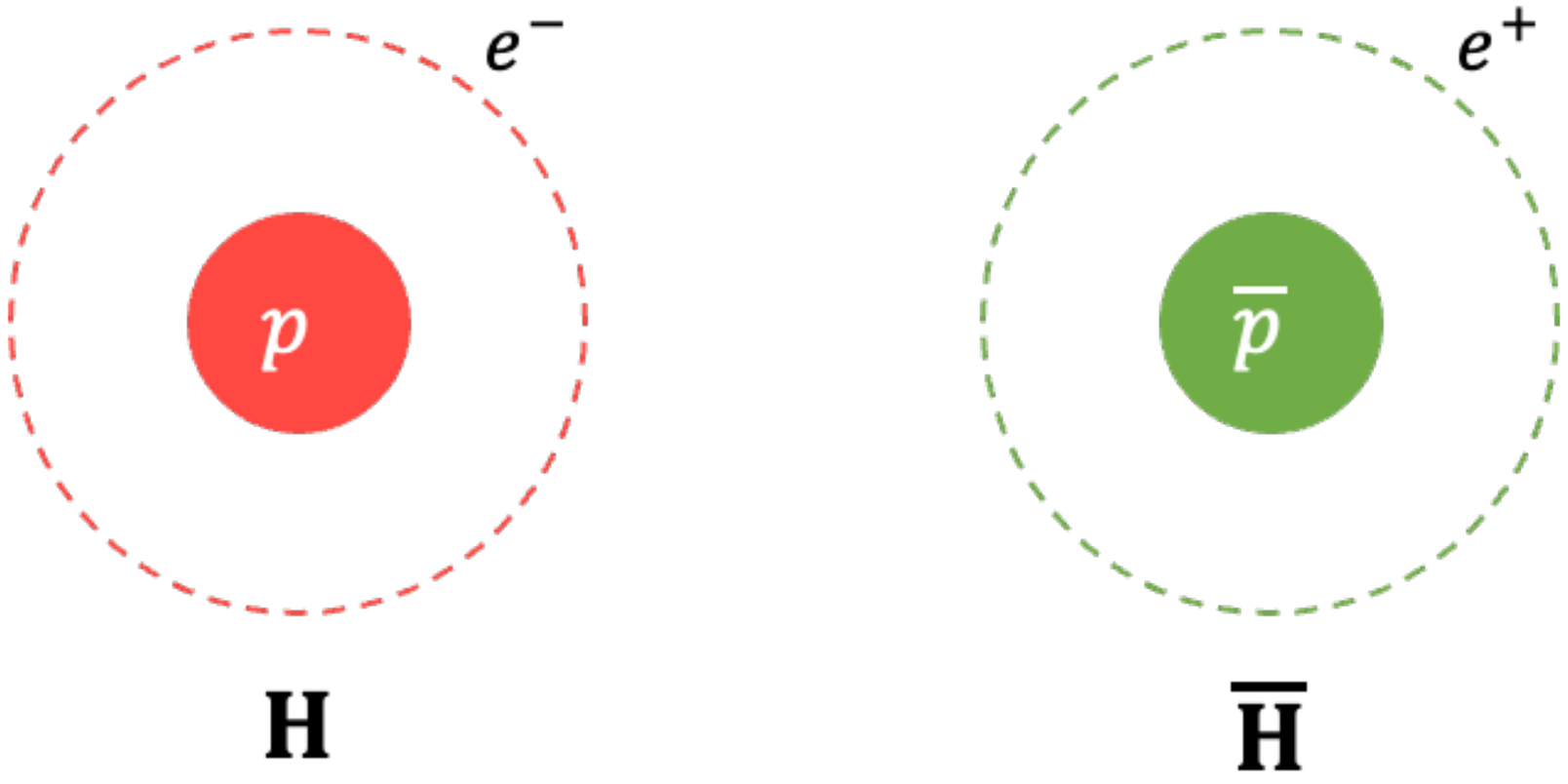
(Albert Einstein)

One of the greatest puzzles in physics

Summary so far:

- We have discovered that each particle has **a twin of opposite charge**
- Particles are created in **matter-antimatter pairs.**
- We have no idea what really happened at the big bang.

Can we make atoms out of antimatter?



Yes! And it's happening right here at CERN!


Trondheim
SWEDEN
FAROE ISLANDS
Reinheimen National Park
NORWAY
Tampere
Saint Petersburg
Turku
Helsinki
Tallinn
Bergen
Uppsala
Oslo
Stockholm
ESTONIA
Lindesnes
Gothenburg
LATVIA
Cairngorms National Park
Baltic Sea
LITHUANIA
Vilnius
North Sea
Glasgow
DENMARK
Copenhagen
Kaliningrad
BELARUS
Belfast
Nationalpark Schleswig-Holsteinisches Wattenmeer
Grodno
UNITED KINGDOM
IRELAND
Dublin
Liverpool
Hamburg
Białystok
Szczecin
Bydgoszcz
Brest
Warsaw
Bremen
Berlin
Birmingham
NETHERLANDS
Poznań
POLAND
Hannover
Łódź
Lublin
Rotterdam
Elbe
Wrocław
London
Leipzig
Dresden
Lviv
Antwerp
Düsseldorf
Cologne
GERMANY
Katowice
Kraków
English Channel
Lille
BELGIUM
Elbe
CARPATHIAN MOUNTAINS
Frankfurt
CZECHIA
Brno
LUXEMBOURG
SLOVAKIA
Rouen
Reims
Vienna
Paris
Strasbourg
Budapest
Cluj-Napoca
Rennes
Munich
AUSTRIA
HUNGARY
ROMANIA
Nantes
Dijon
Zürich
Timişoara
SWITZERLAND
ALPS
SLOVENIA
FRANCE
Geneva
Belgrade
Bay of Biscay
Lyon
Milan
Venice
CROATIA
Grenoble
Turin
SERBIA
Bordeaux
BOSNIA AND HERZEGOVINA
Niš
Bologna


HC 27km

- **C**entre
- **E**uropéen pour la
- **R**ecerche
- **N**ucléaire

European Centre for Nuclear Reseach

Member States of CERN

Member States (date of accession)

- Austria (1959)
- Belgium (1953)
- Bulgaria (1999)
- Czech Republic (1993)
- Denmark (1953)
- Finland (1991)
- France (1953)
- Germany (1953)
- Greece (1953)
- Hungary (1992)
- Israel (2014)
- Italy (1953)
- Netherlands (1953)
- Norway (1953)
- Poland (1991)
- Portugal (1986)
- Romania (2016)
- Serbia (2019)
- Slovakia (1993)
- Spain (1961-1968, 1983-)

(Estonia 2024)

- Sweden (1953)
- Switzerland (1953)
- United Kingdom (1953)

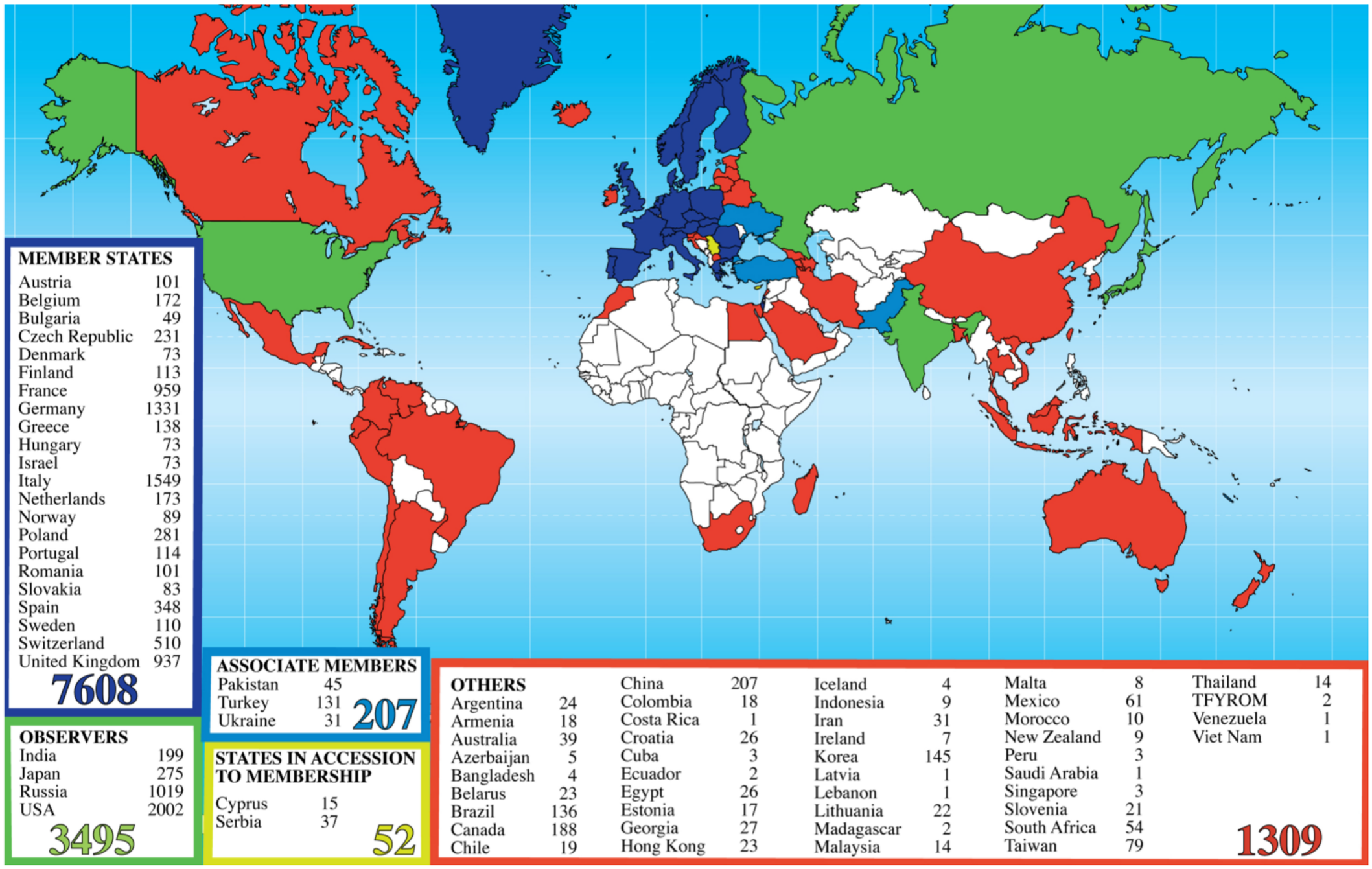
States in accession to Membership and Associate Members

- Croatia (2019)
- Cyprus (2016)
- India (2017)
- Lithuania (2018)
- Pakistan (2015)
- Slovenia (2017)
- Turkey (2015)
- Ukraine (2016)

(Croatia 2019)

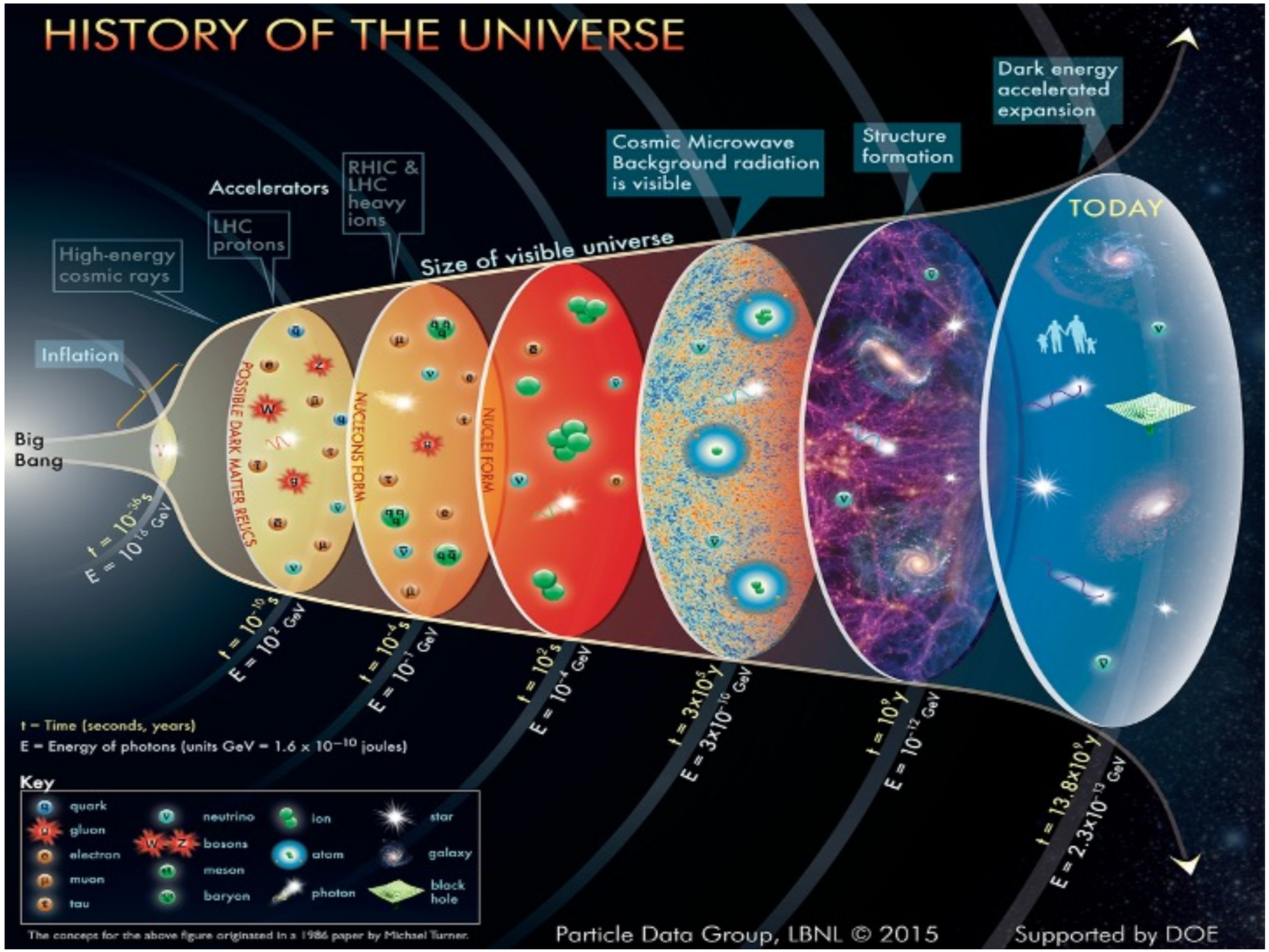
CERN is a world wide collaboration

- 15000 people
- 24 member states
- Instutes from $>$ 80 countries!

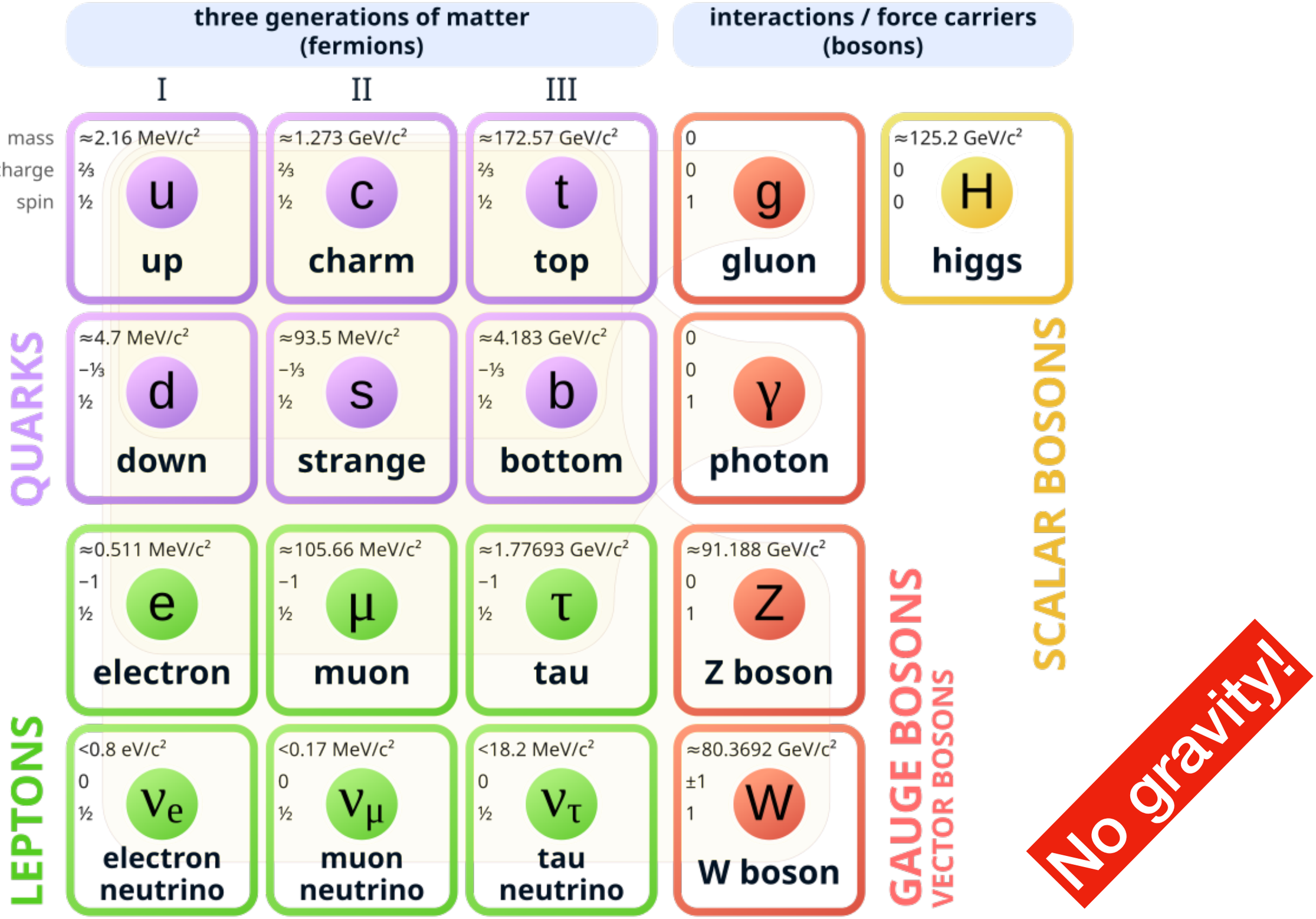


Why CERN?

What happened at the beginning of the universe?



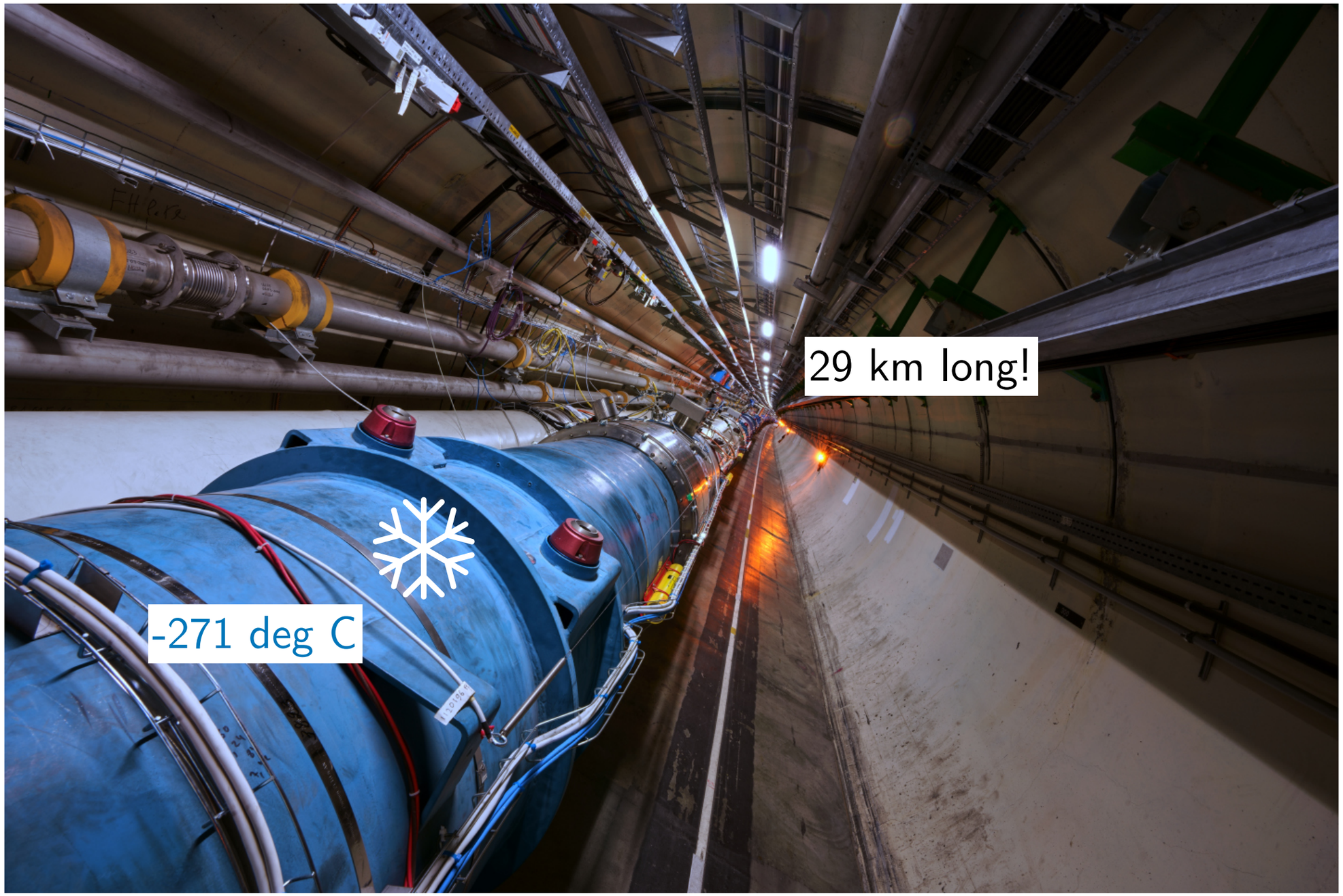
Standard Model of Elementary Particles

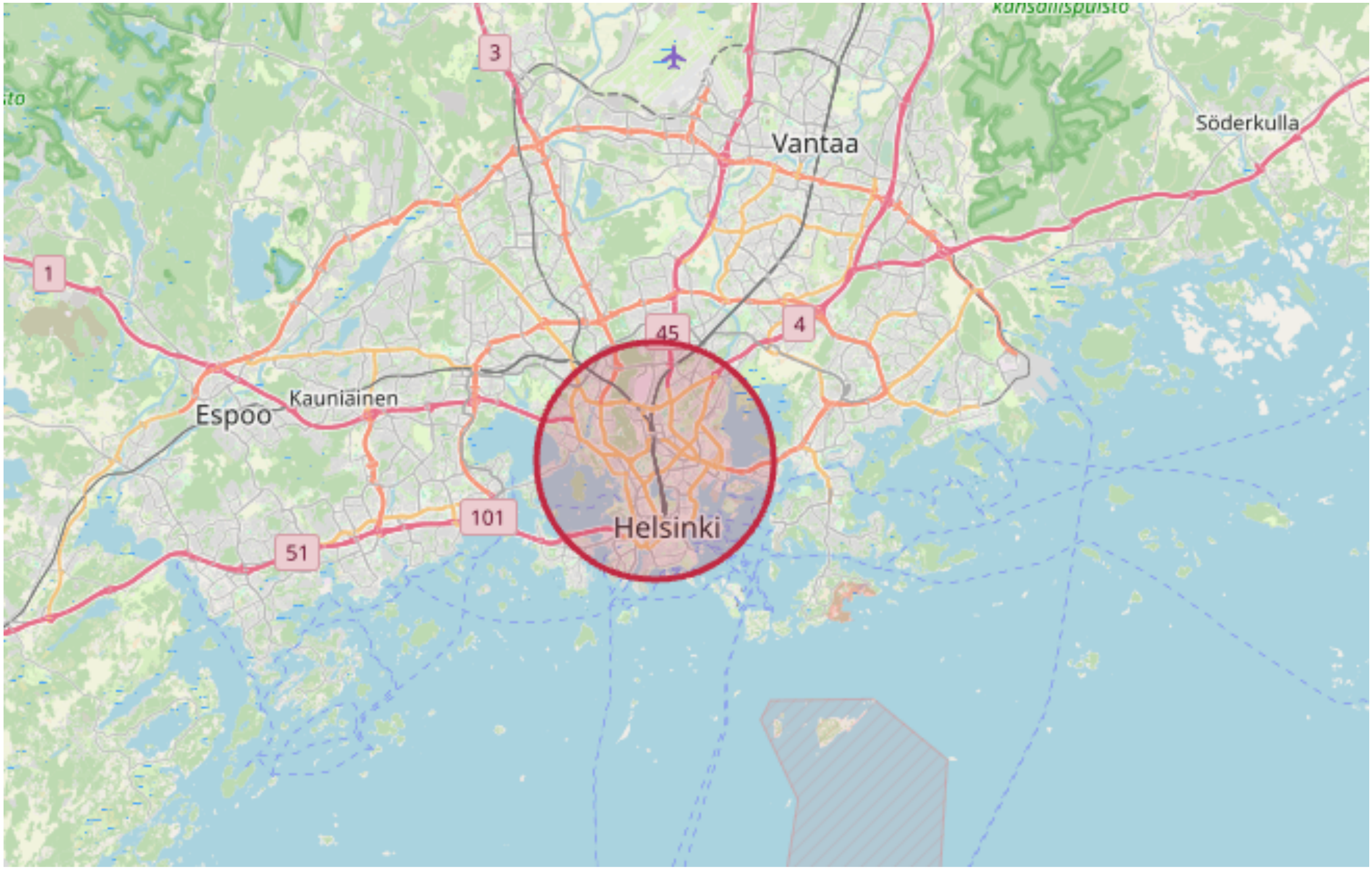


CERN has the tools to study this stuff

To study the smallest things in the universe, you need the biggest machine on earth

- There are > 30 000 particle accelerators in the world!
- The LHC is by for the most powerful one
- Started in 2008

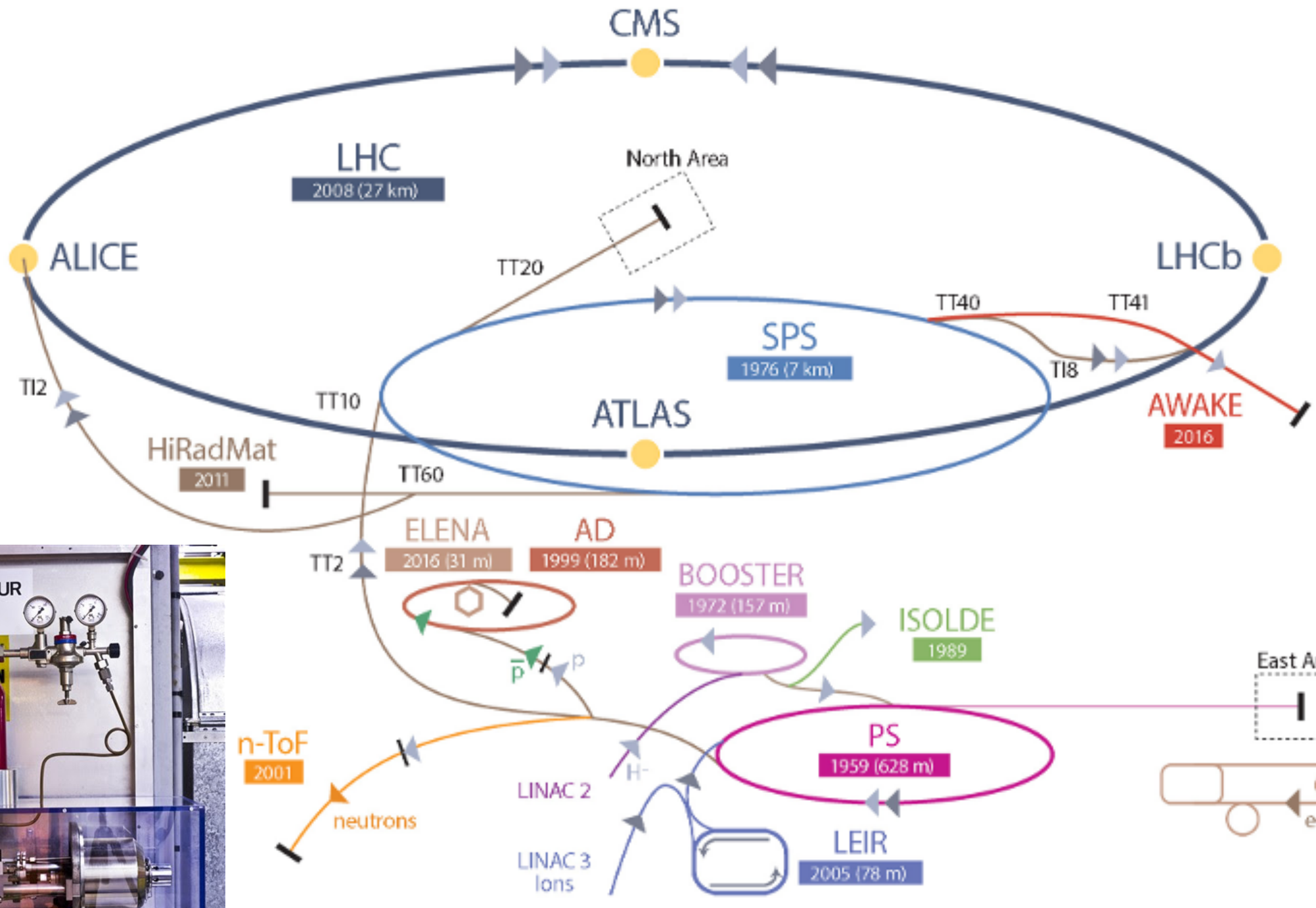




https://natronics.github.io/science-hack-day-2014/lhc-map/

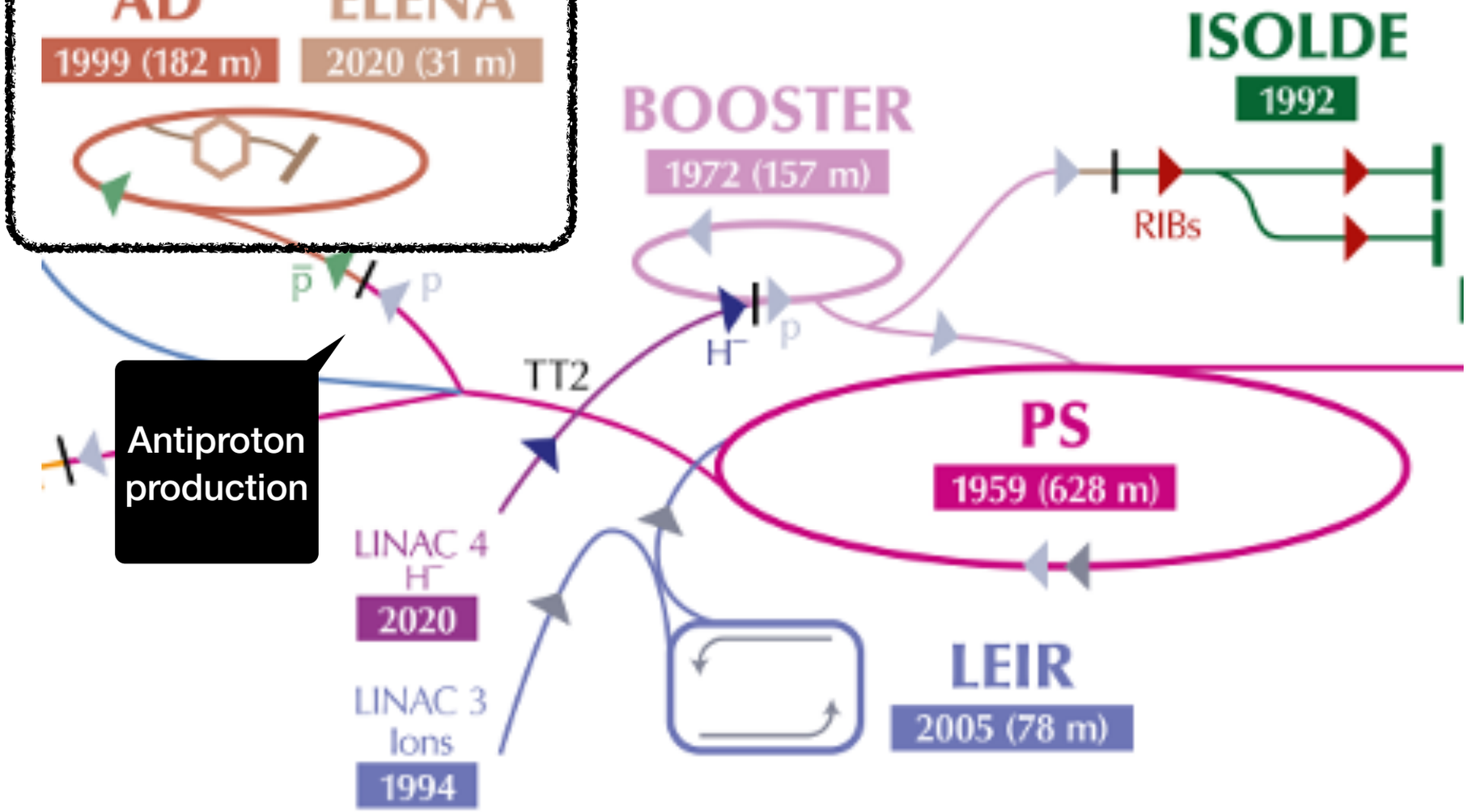

This is all we need to produce and store antimatter!

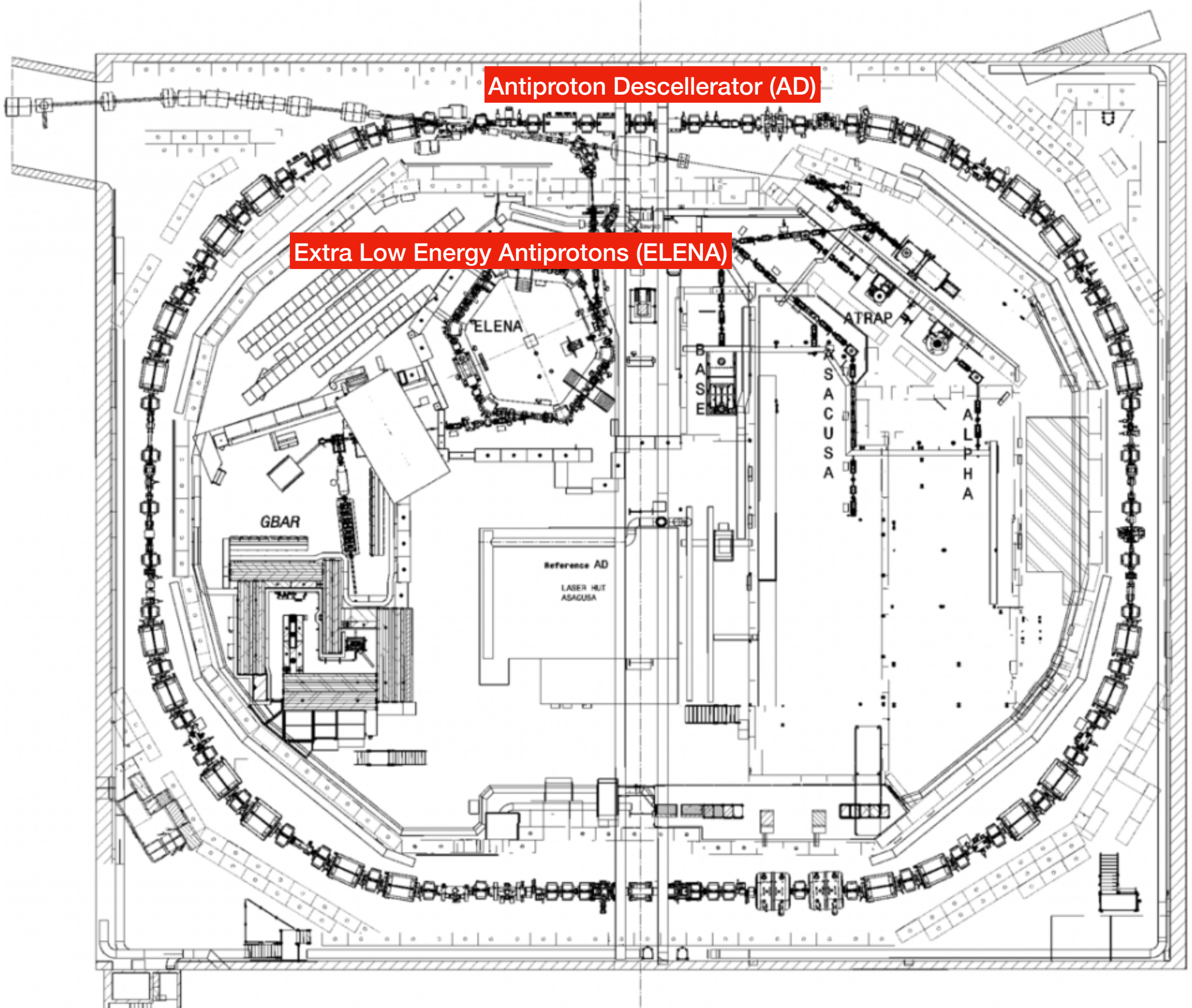
CERN has many accelerators...



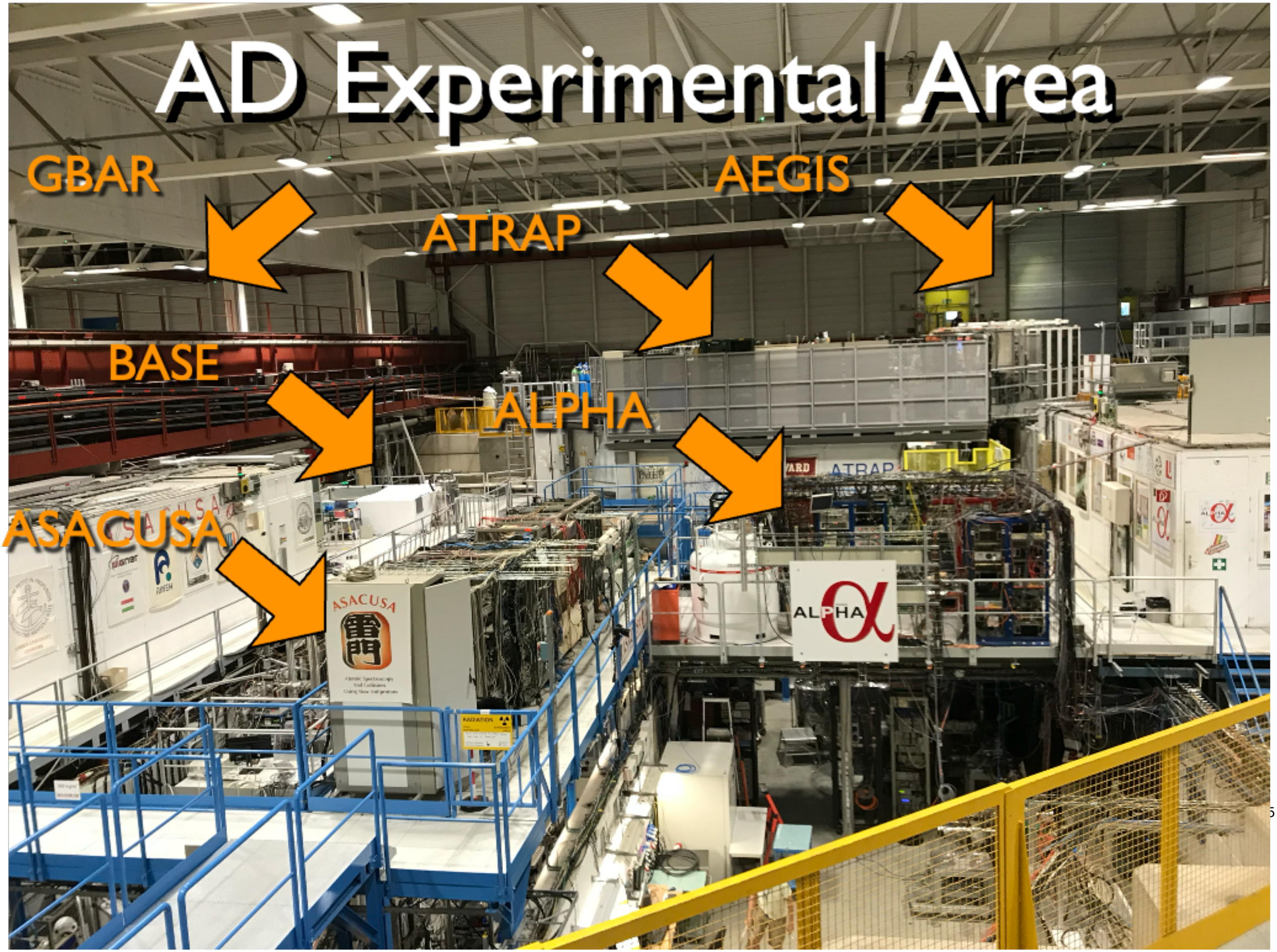
… but we only need a few

All experiments in the *Antimatter Factory* make use of antiprotons



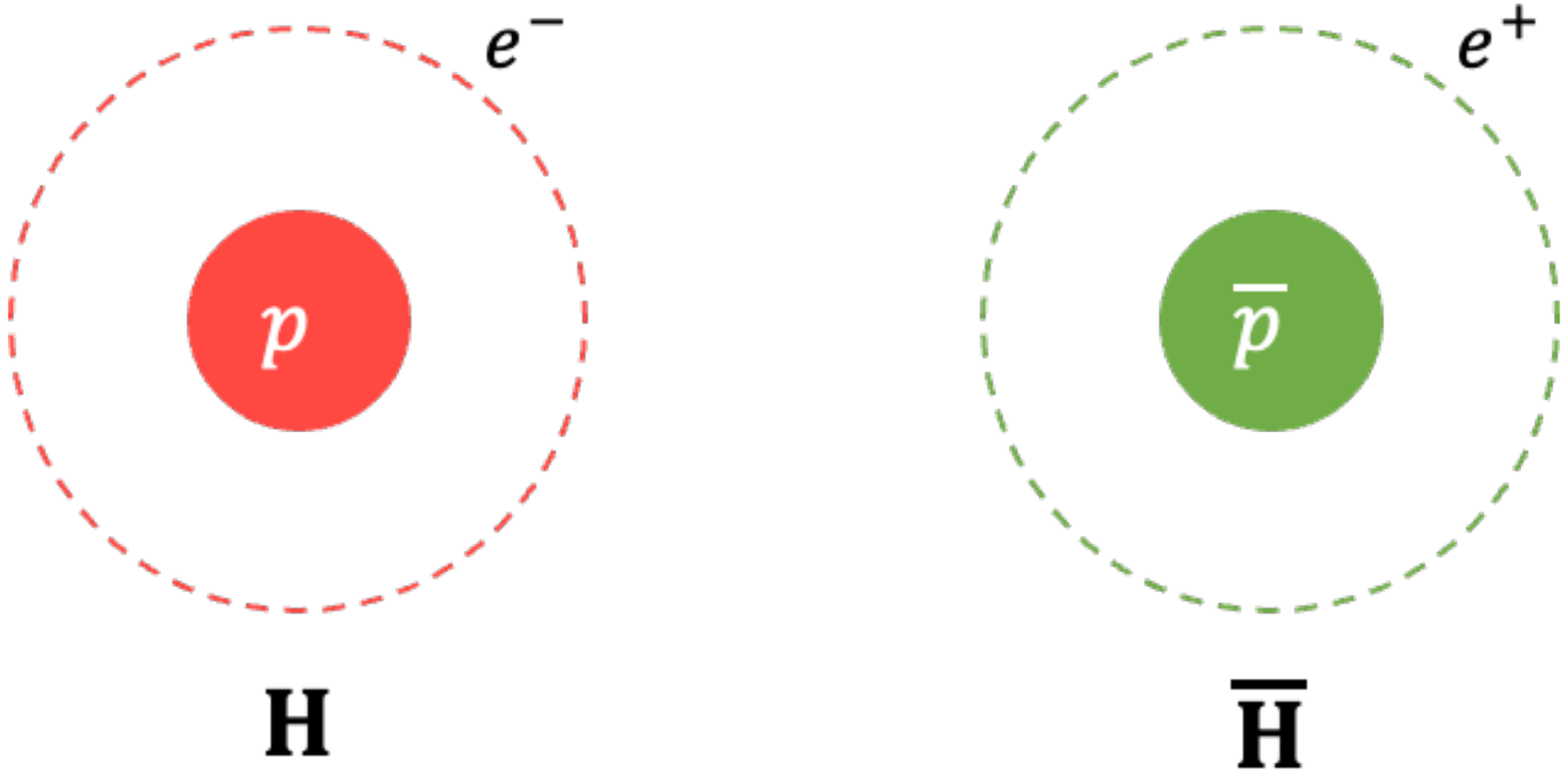

Antiproton Descellerator (AD)
Extra Low Energy Antiprotons (ELENA)
ELENA
ATRAP
BASE
ASACUSA
ALPHA
GBAR
Reference AD
LASER HUT
ASACUSA

AD Experimental Area



The Antihydrogen Laser Physics Apparatus (ALPHA)

Aim: Making precise comparisons between **hydrogen** and **antihydrogen.**



... But making and storing antihydrogen is more difficult than you think

So what about the positrons?

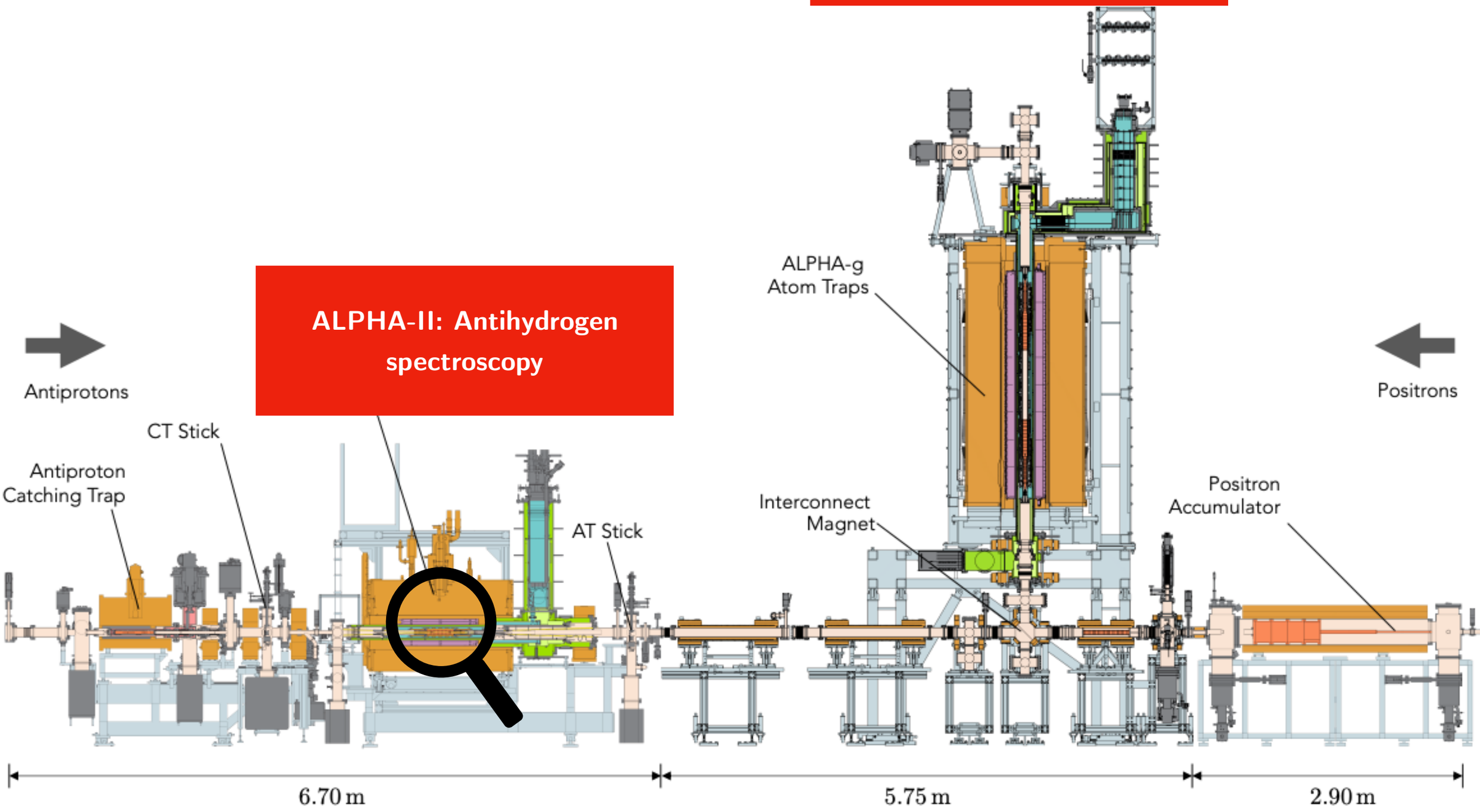
Positrons are failry easy to obtain: use a radioactive isotope that is a β^+ emitter

- Potassium-40 can be found in Bananas (15 positrons / sec)
- But sodium-22 works a bit better (10^6 positrons / sec)

$$^{22}\mathrm{Na} \rightarrow {}^{22}\mathrm{Ne} + e^+ + \nu_e + \gamma$$

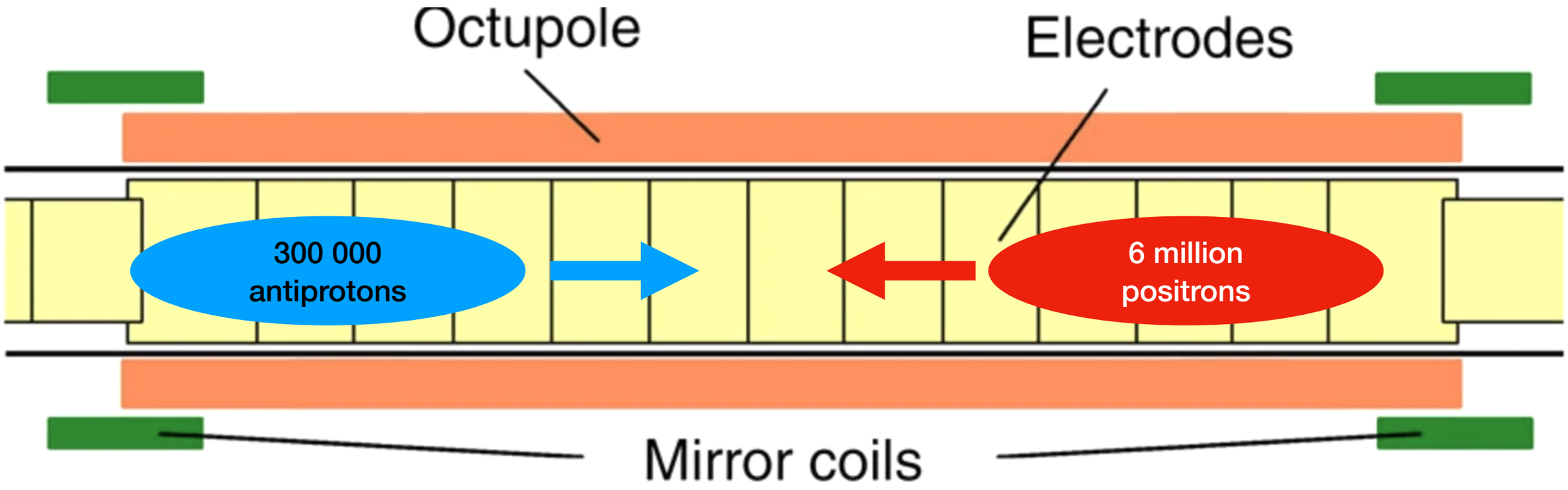
ALPHA-g: Gravitational measurements

ALPHA-II: Antihydrogen spectroscopy



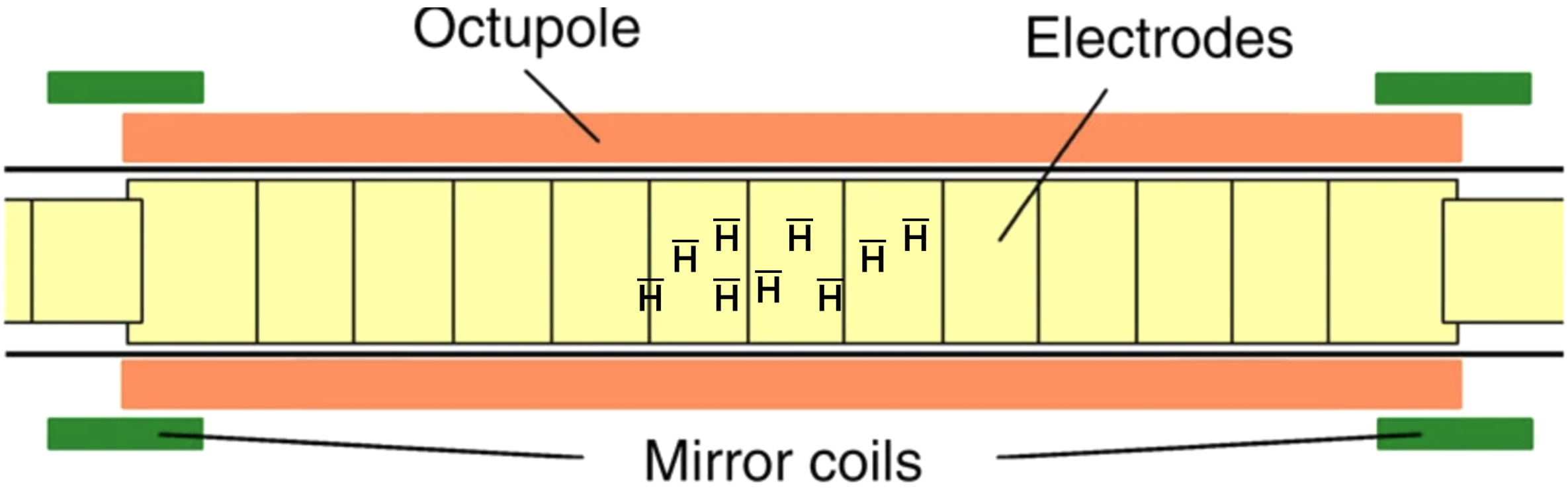
Making antihydrogen

Mix antiprotons and postitrons at low energy using a ***charged particle trap.***



Making antihydrogen

200 000 antihydrogen atoms made! But now we have to hold on to them...

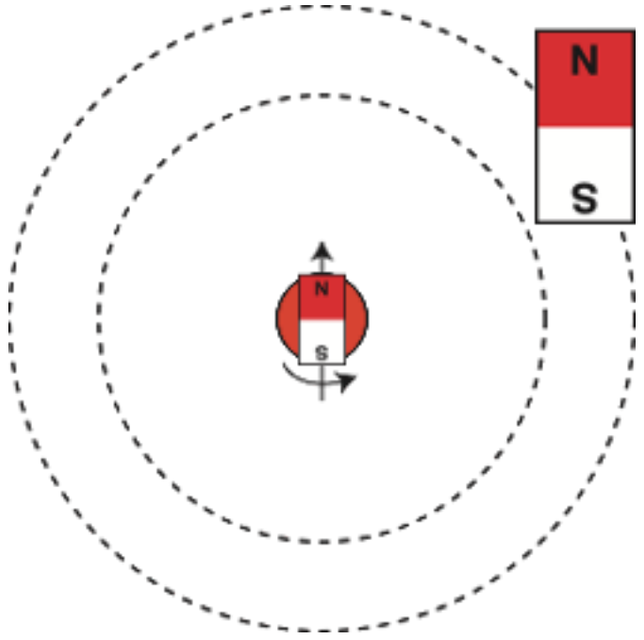


Antihydrogen in a bottle

(Anti)hydrogen atoms have **zero charge**: One positive and one negative particle.

Atoms are neutral and have a little internal magnetic field

And you need a strong magnet!



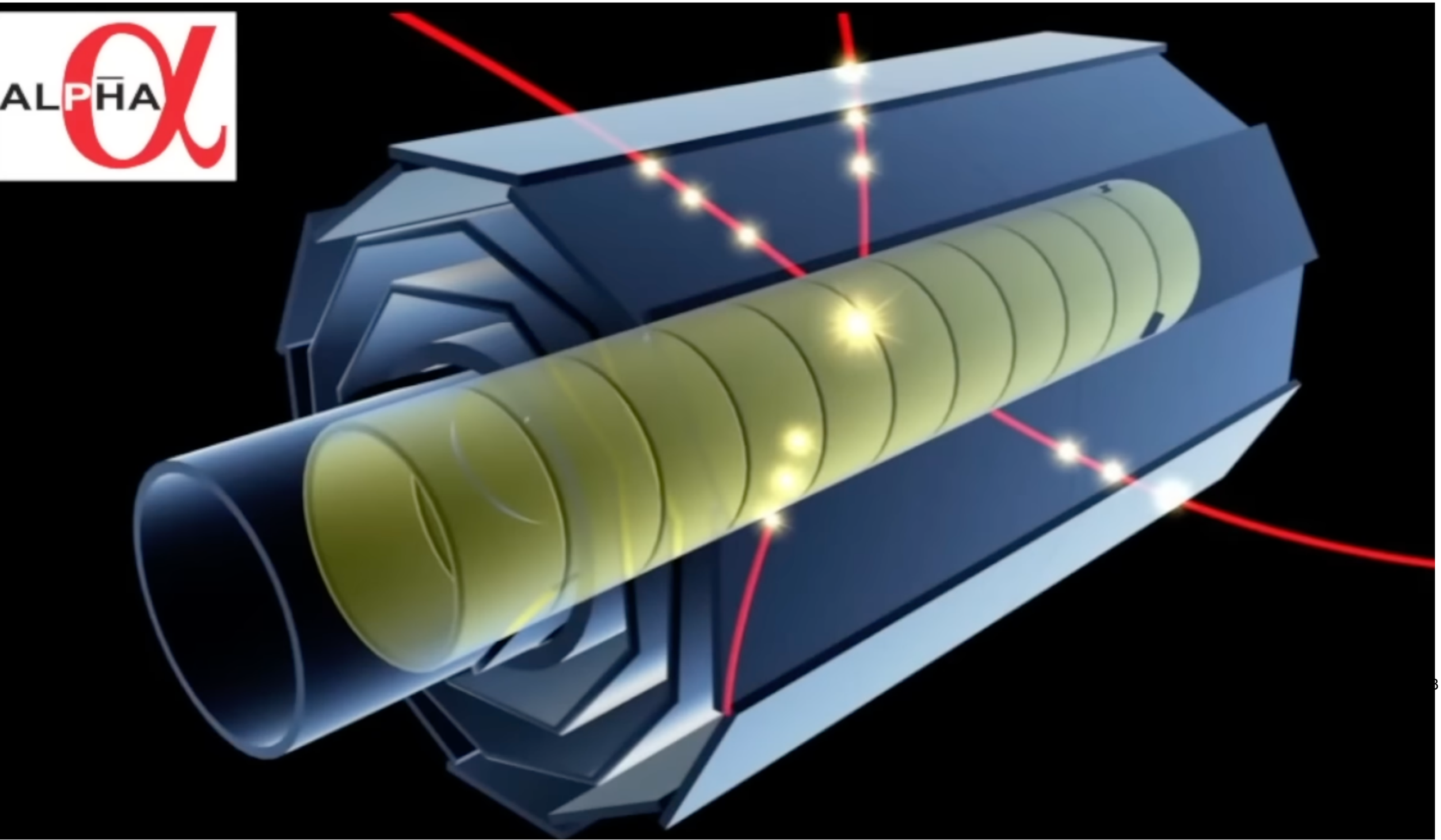
Antihydrogen in a bottle

(Anti)hydrogen atoms have **zero charge**: One positive and one negative particle.

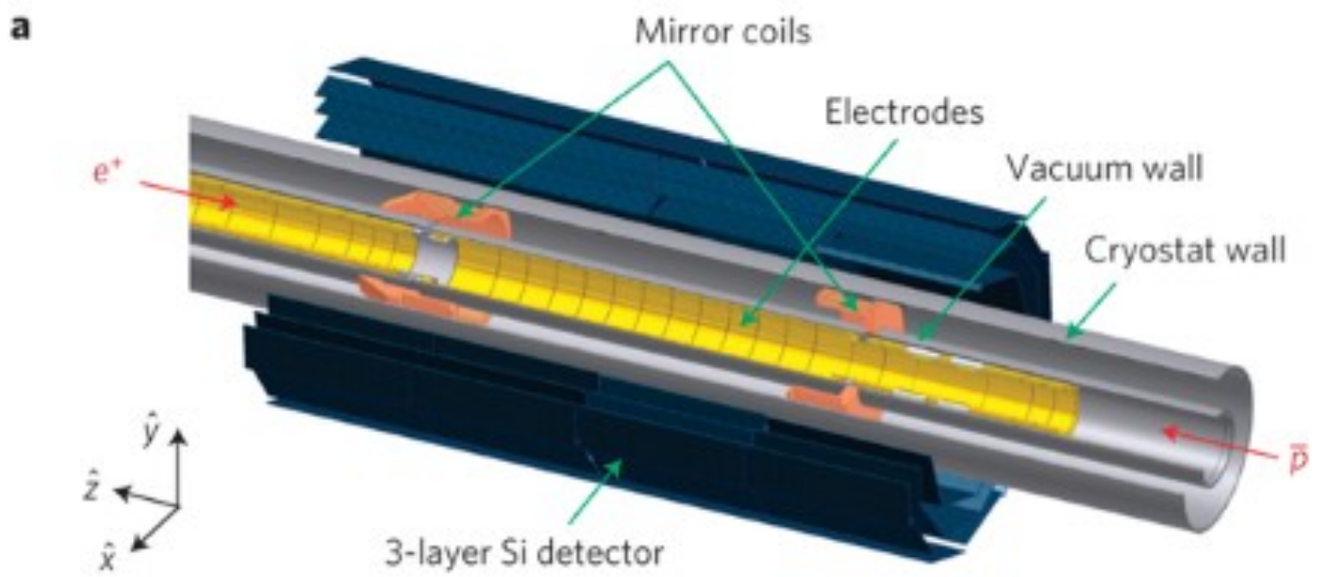
Atoms are neutral and have a little internal magnetic field

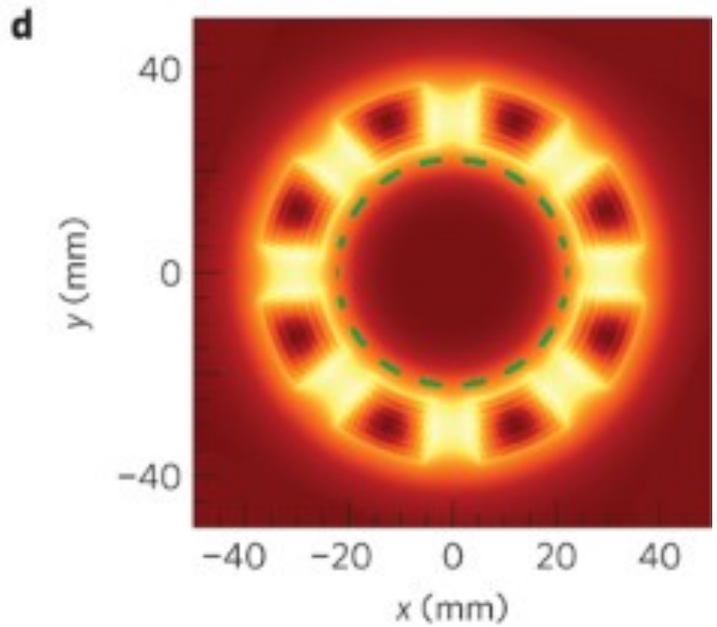
And you need a strong magnet!

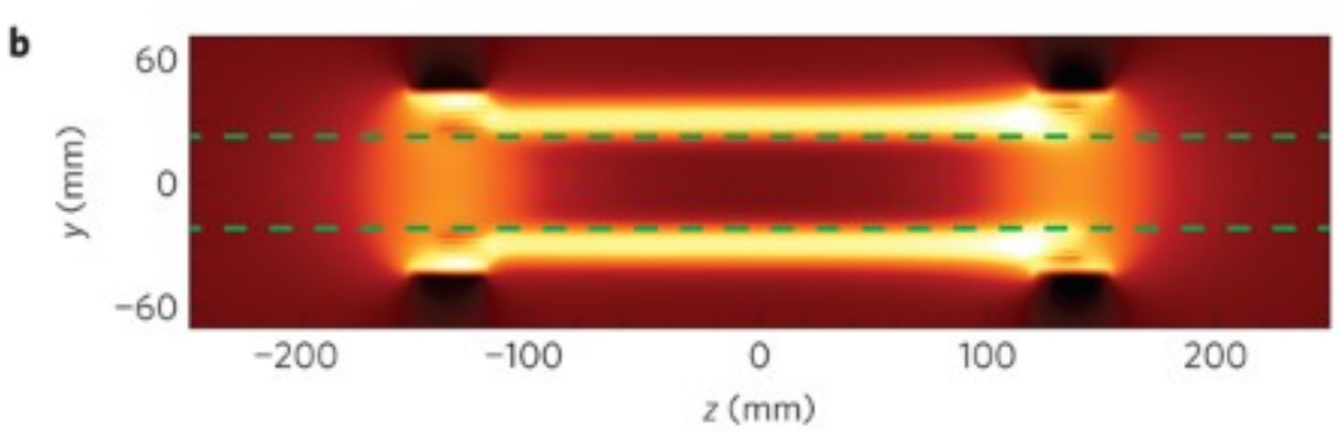
Most of them go too fast and hit the wall. We loose the majority of atoms...

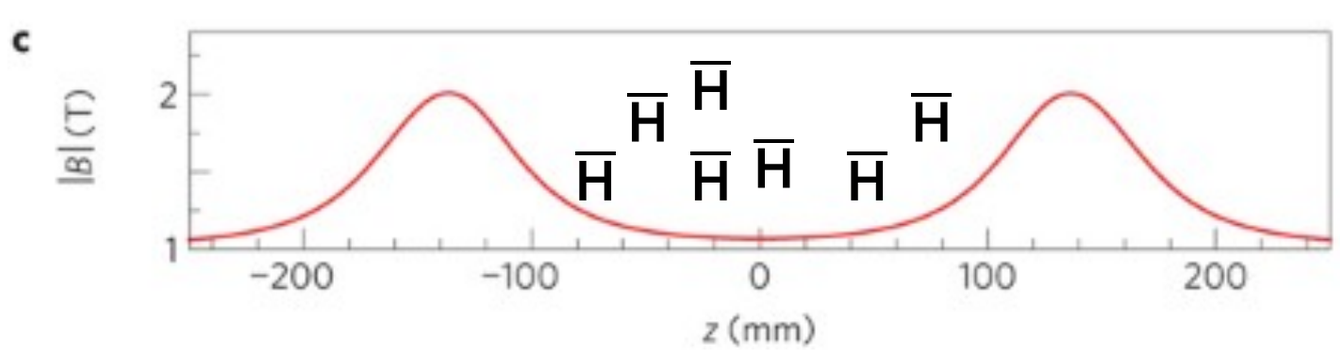


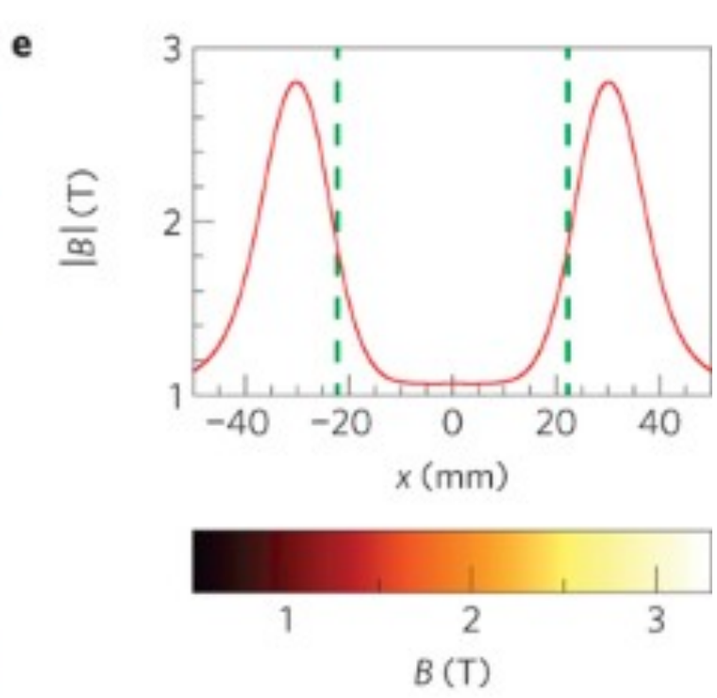
But the ones that are slow (cold) enough, can be trapped!



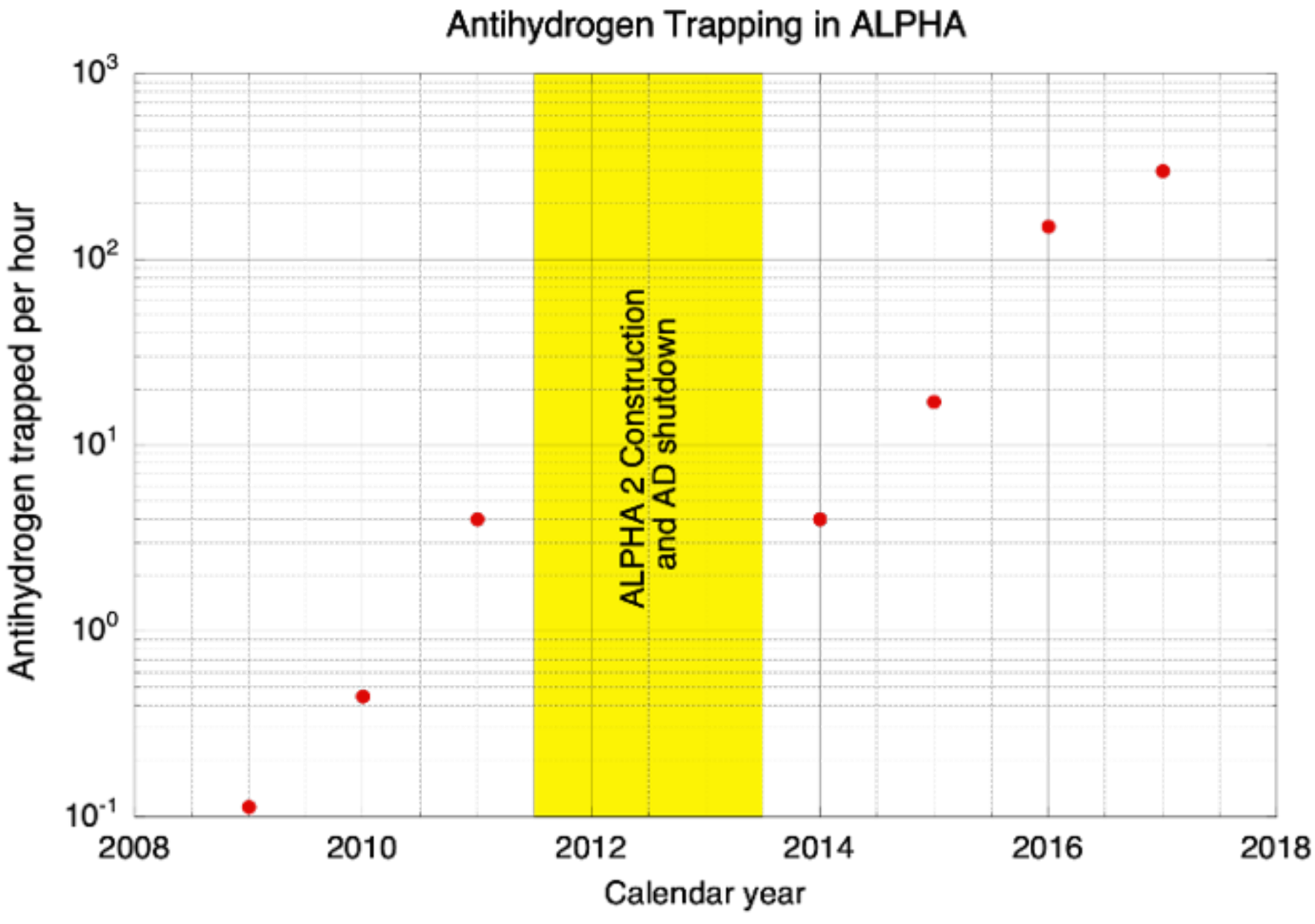








Trapping rate has been increasing ever since



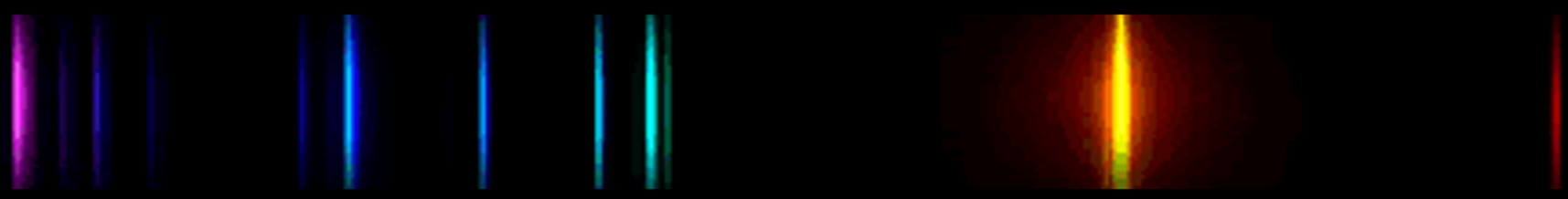
Congratulations! You have trapped antimatter atoms!

How do you know you have it? How do you study it?

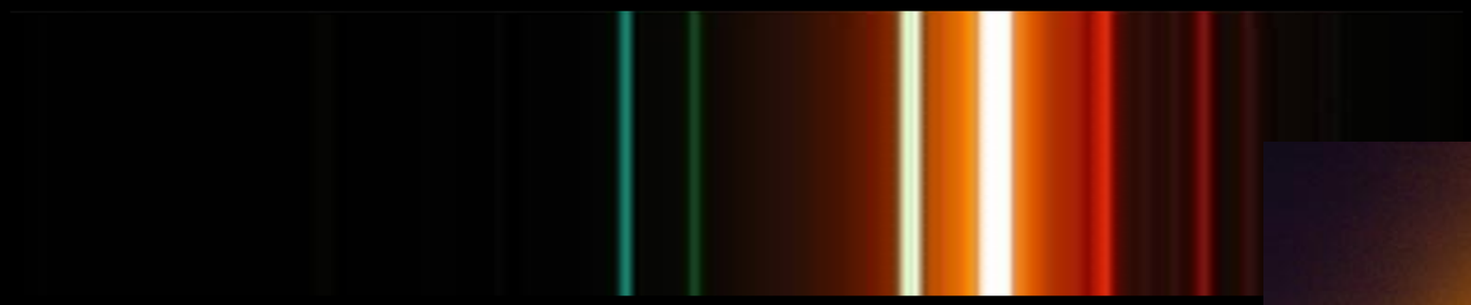
What atom do we have in our trap?

Mercury

Helium



Sodium

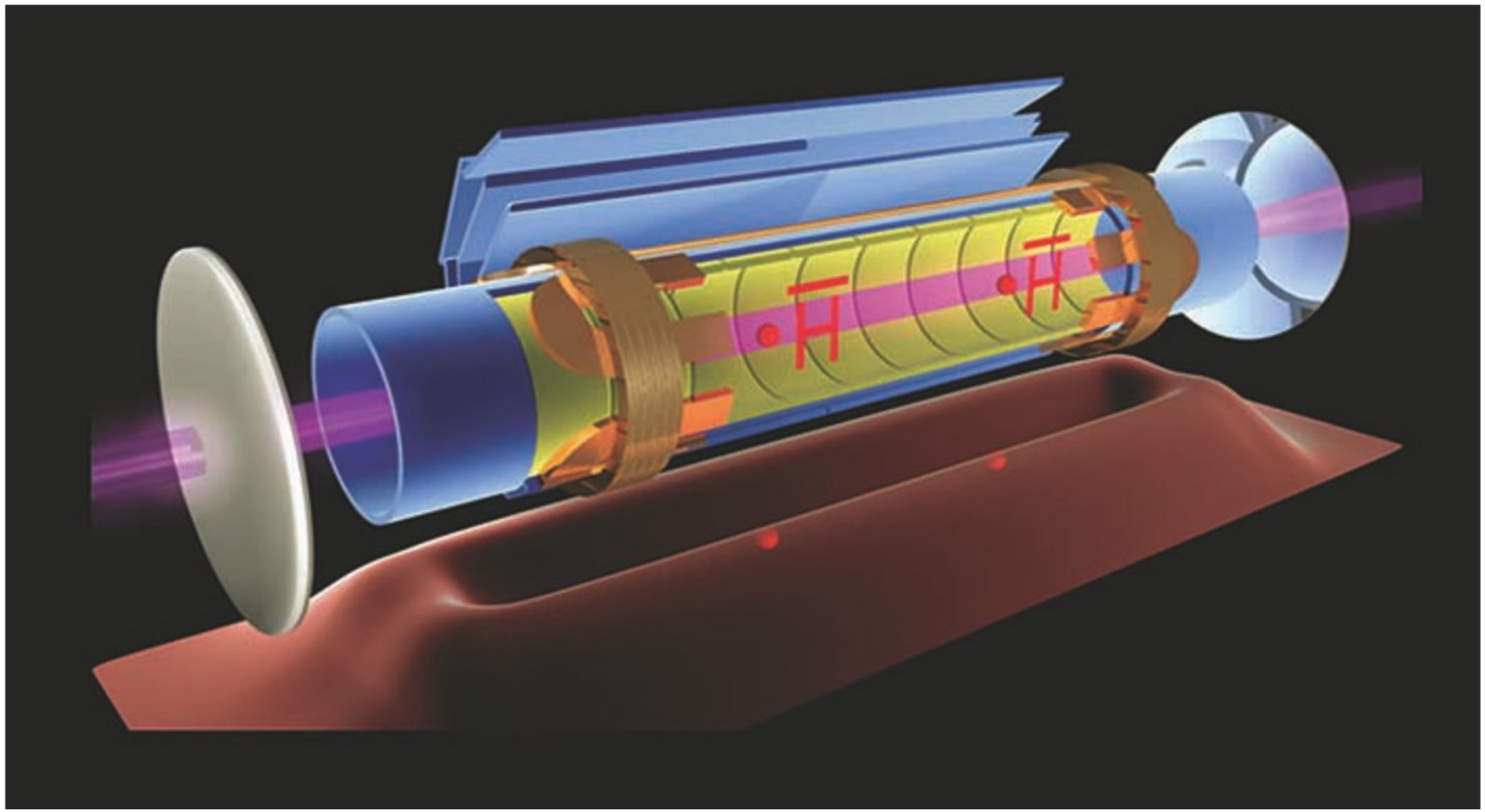


What atom do we have in our trap?

Hydrogen

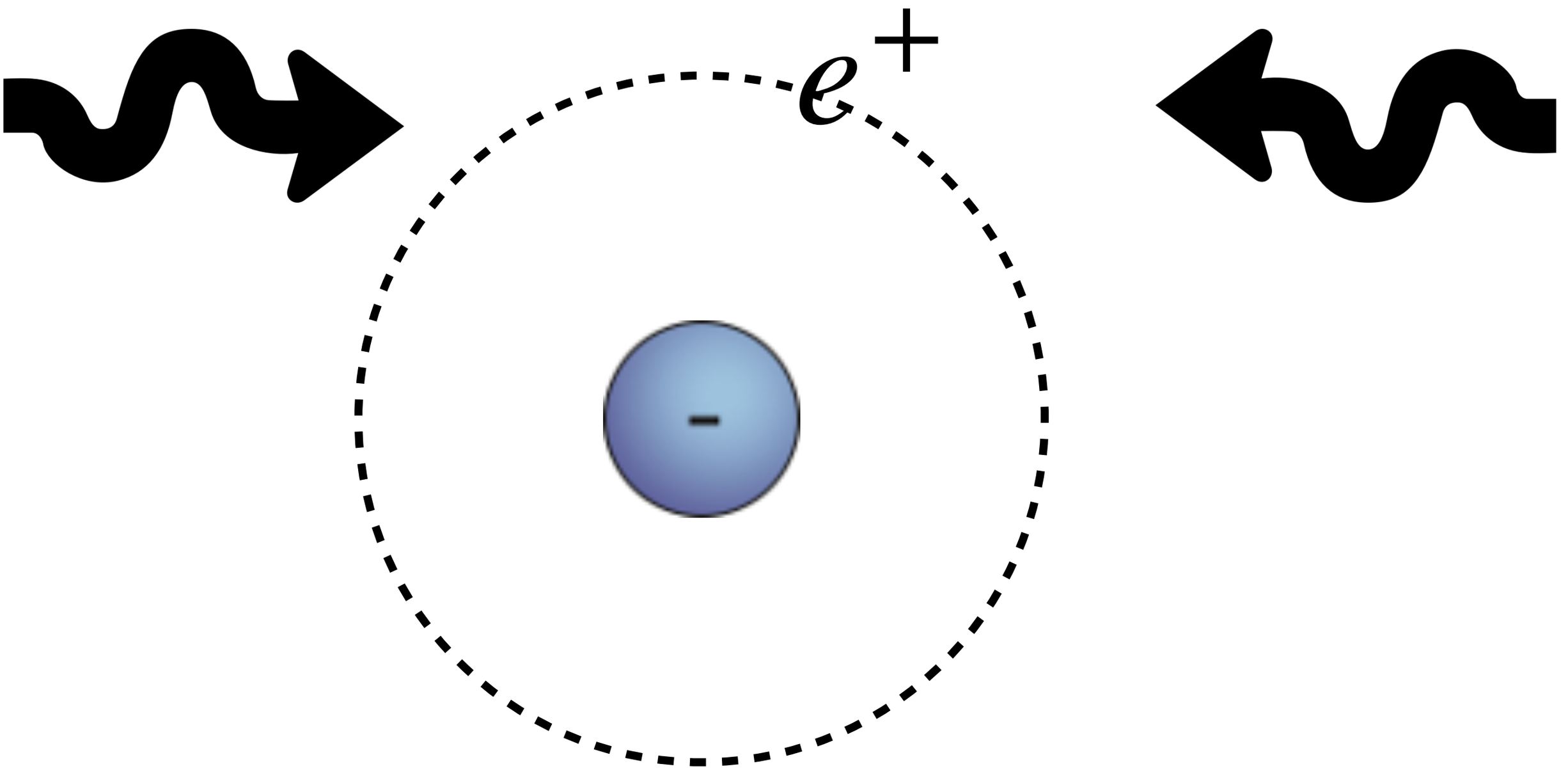
Does antihydrogen have the same spectrum as regular hydrogen?

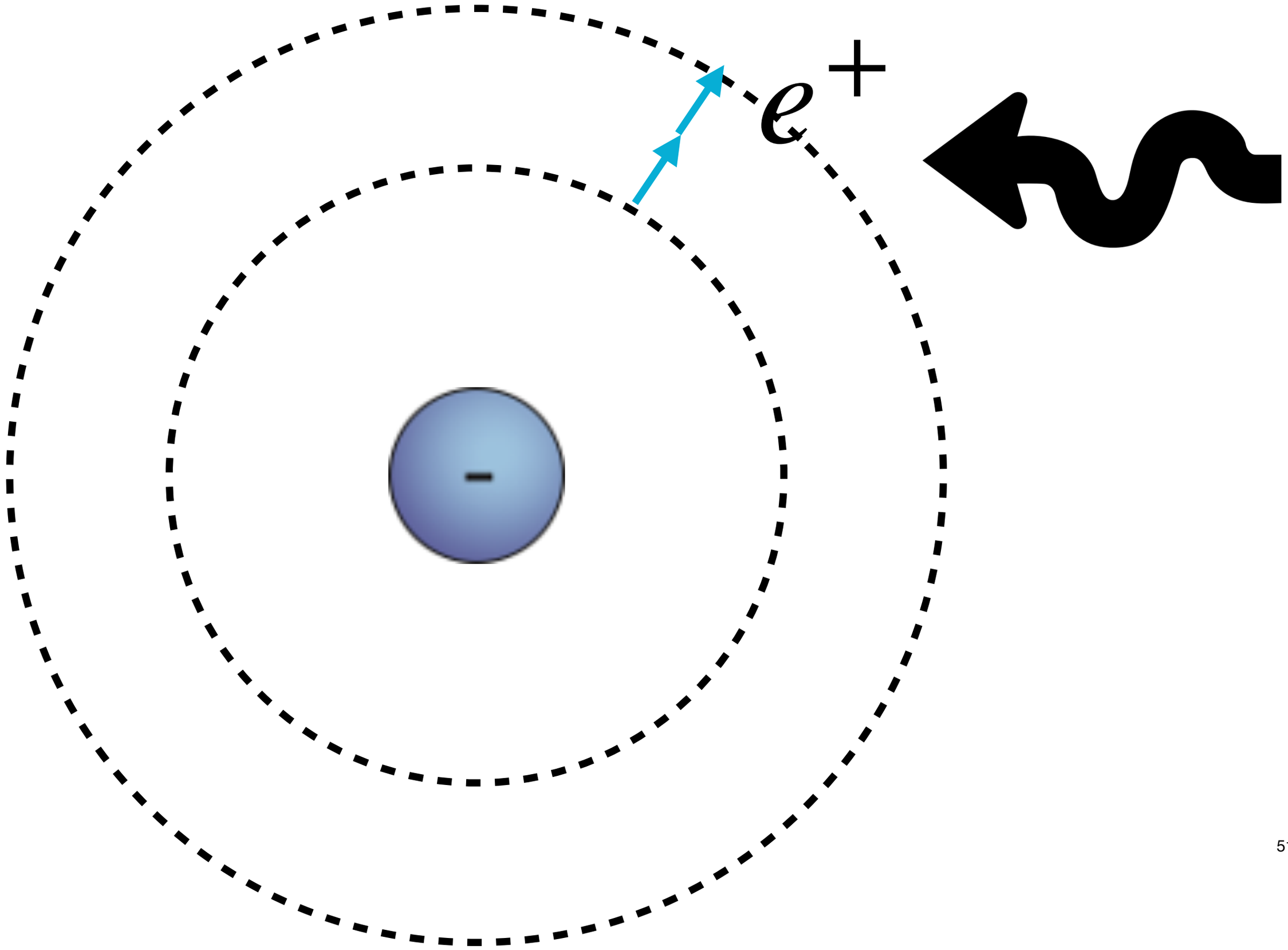
Laser spectroscopy of antihydrogen



243 nm photon

243 nm photon

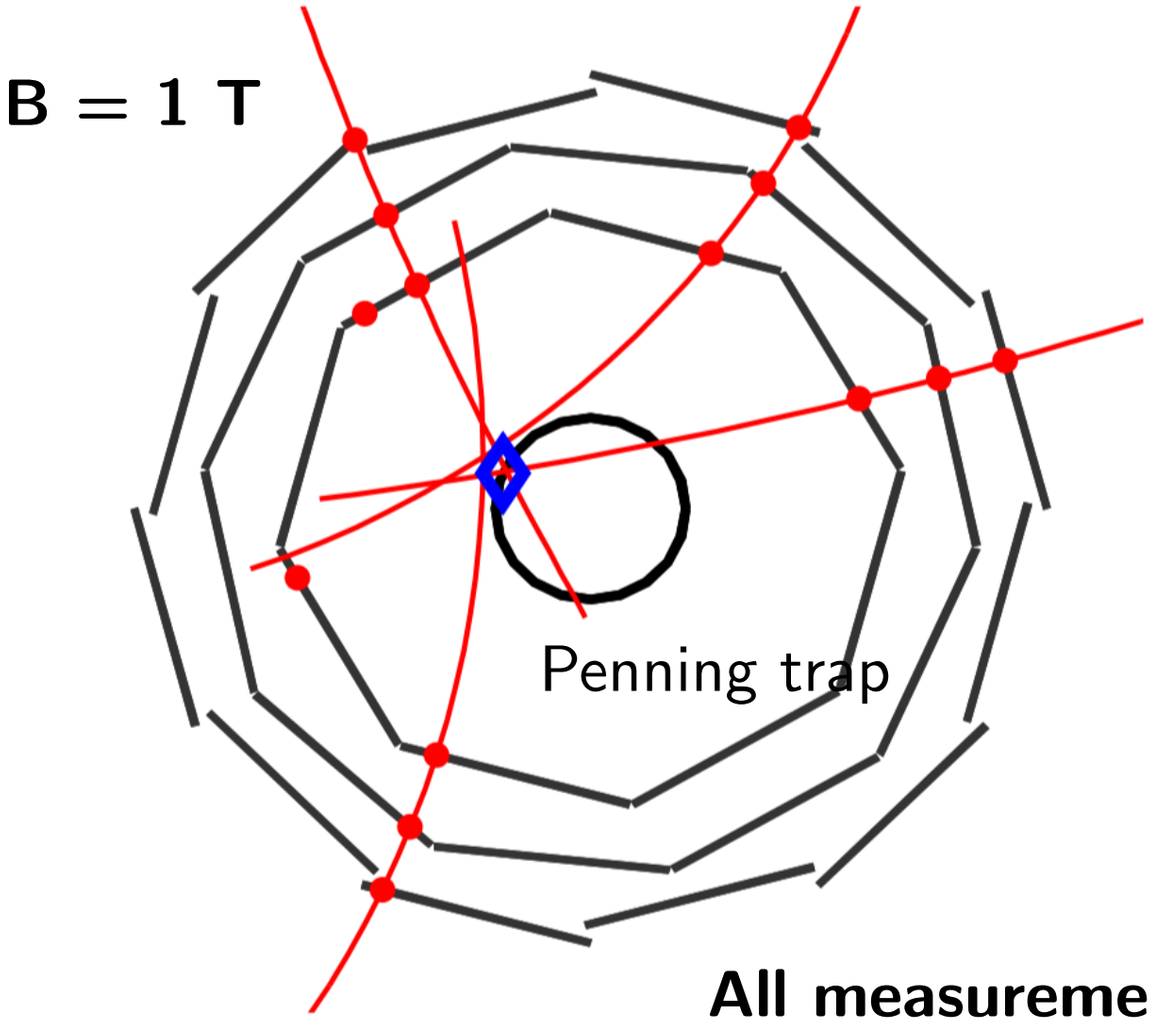



e^+
−

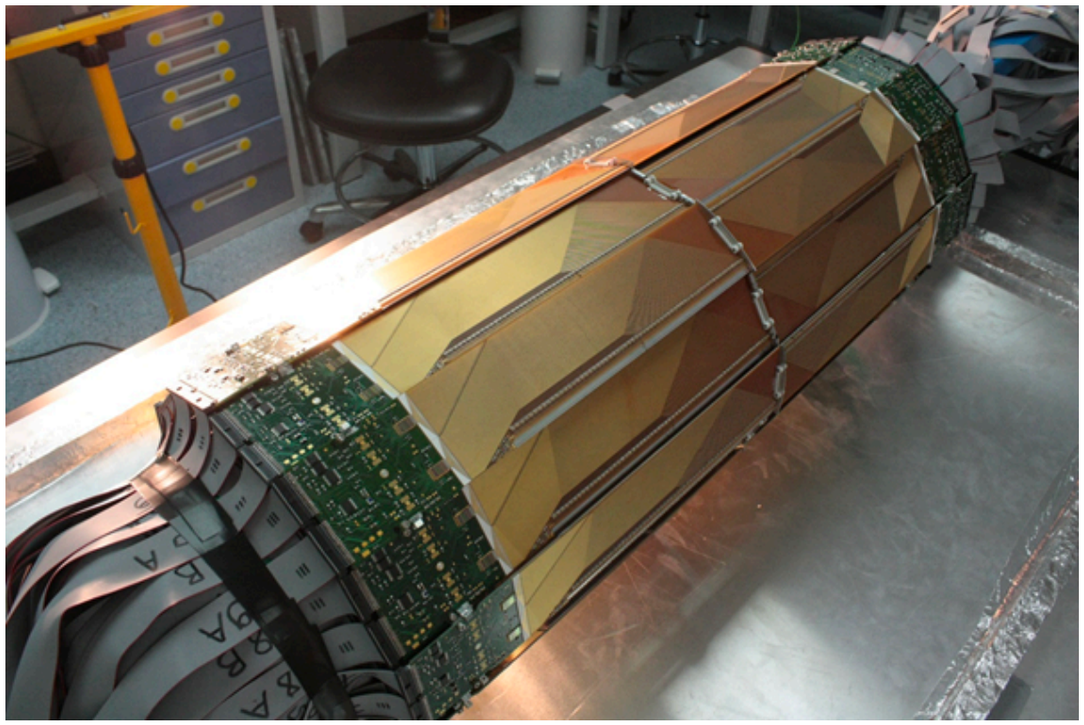
3rd photon ionises the atom and the antiproton falls out of the magnetic trap

Detecting antihydrogen

π vertices

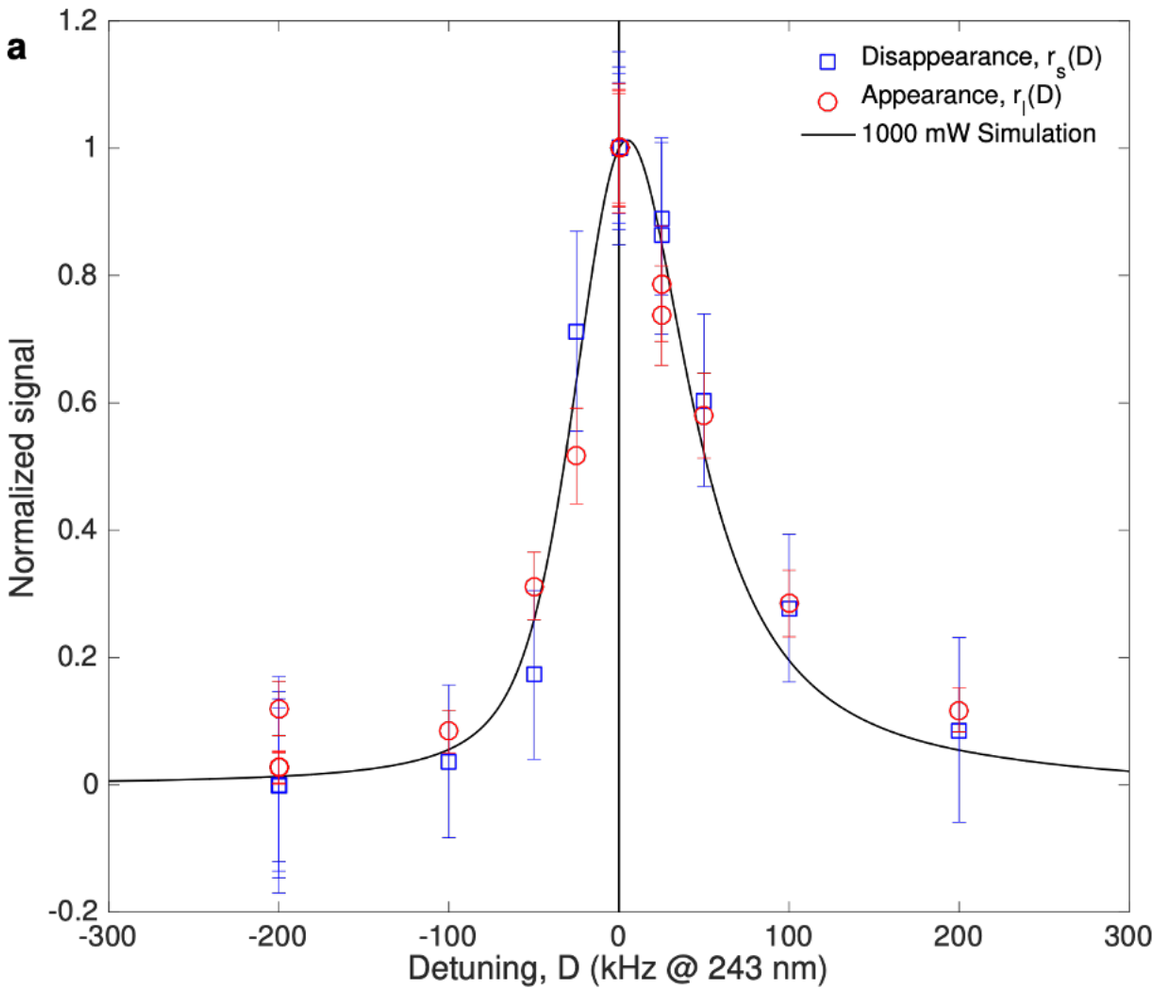


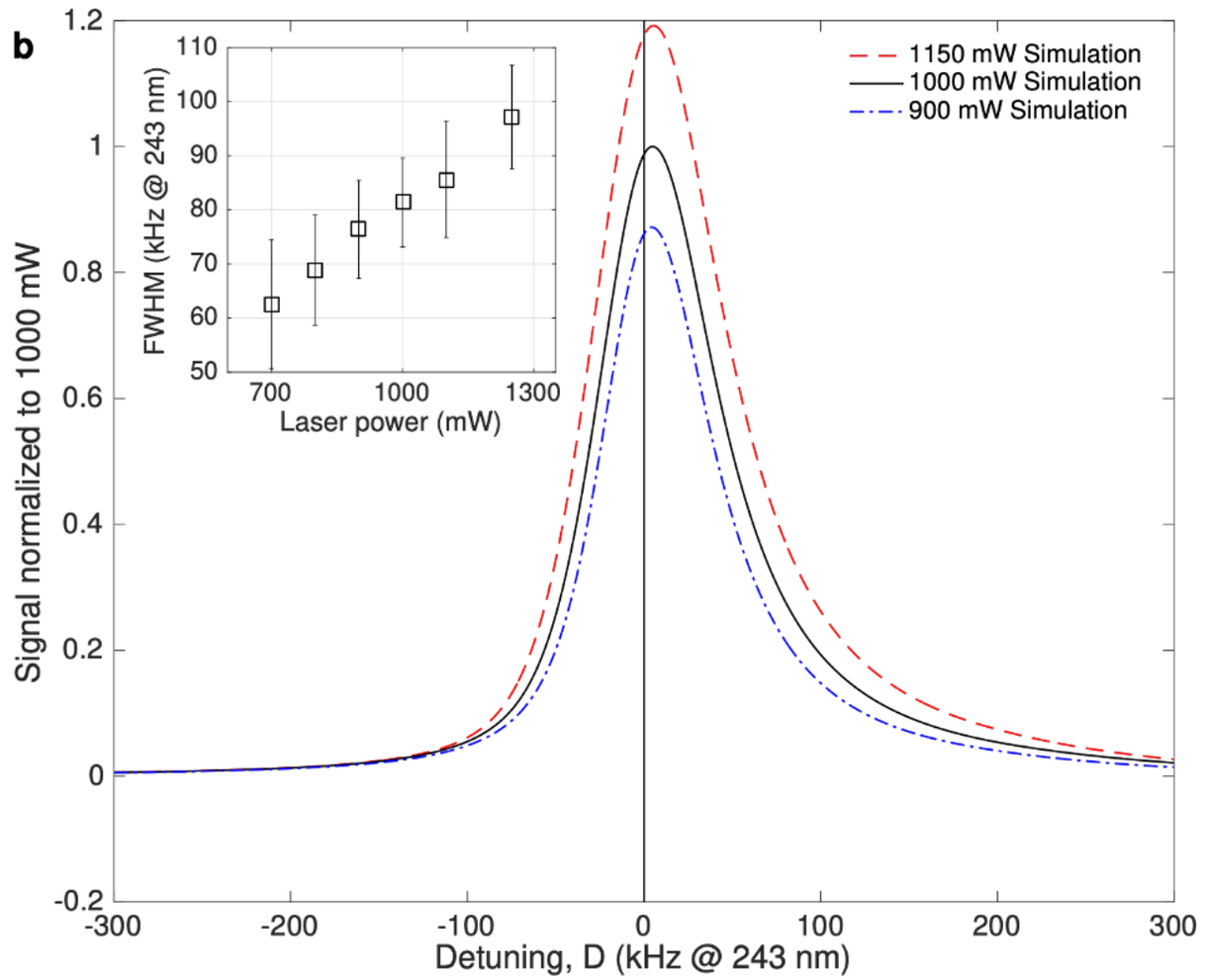
Silicon vertex detector



All measurements are destructive

1S-2S spectroscopy of antihydrogen

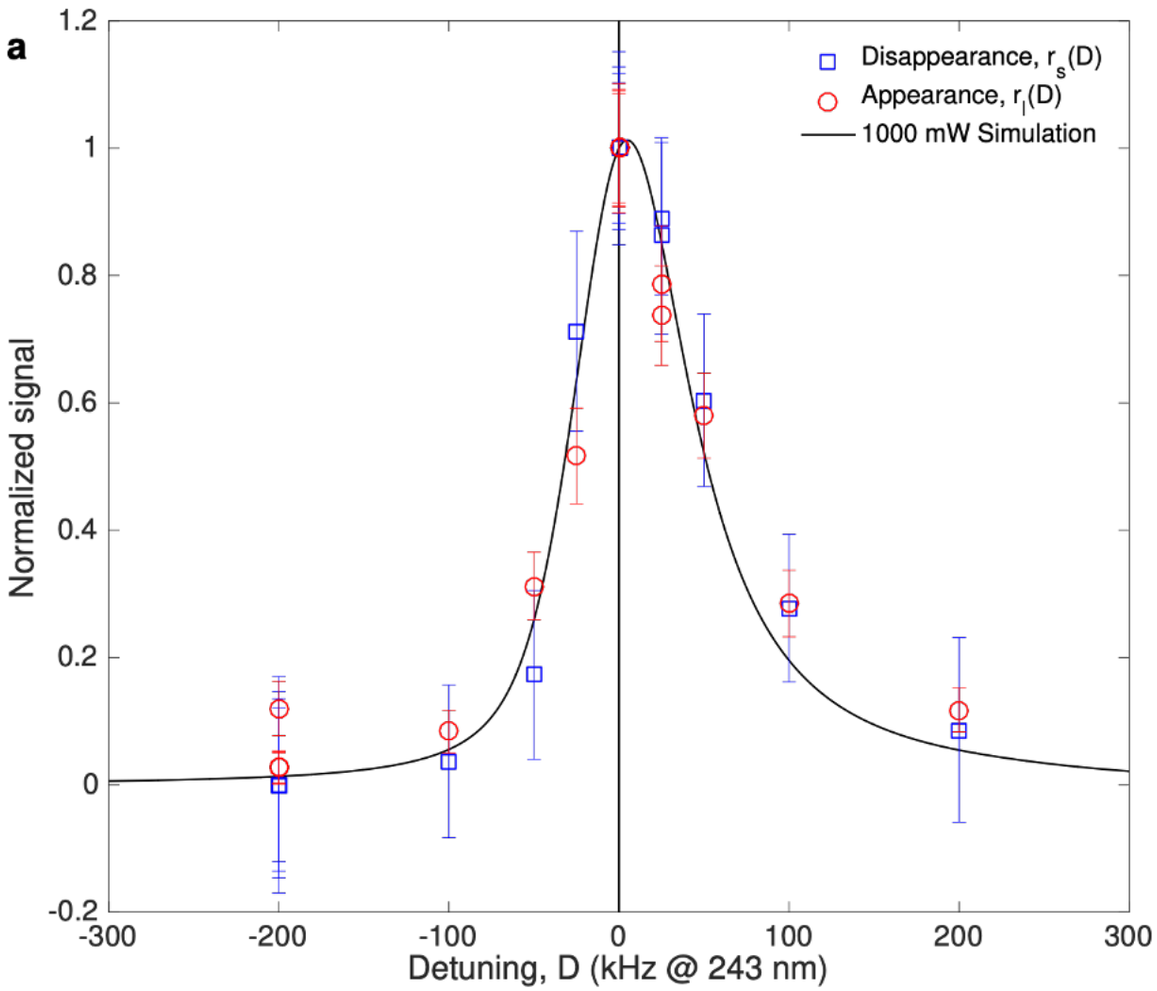


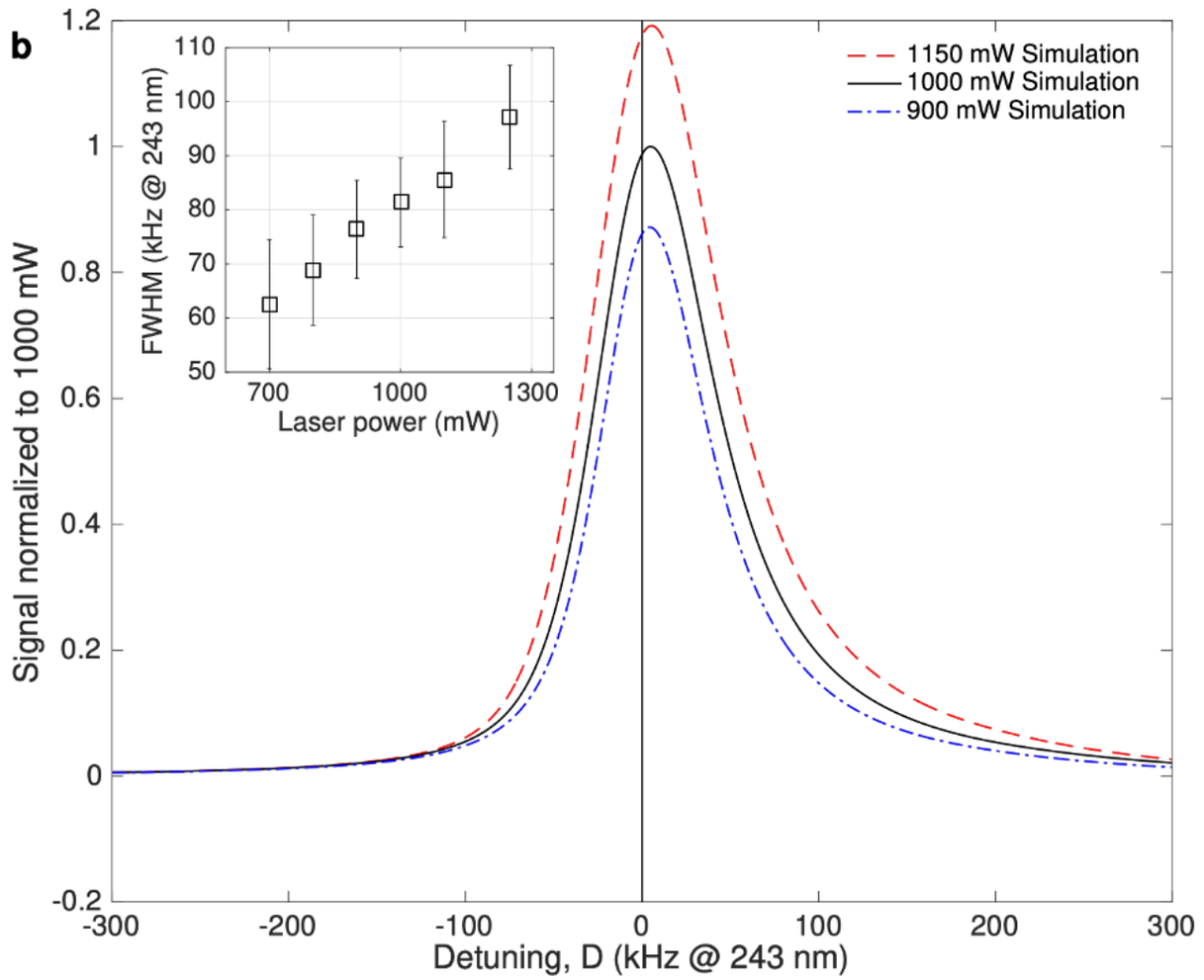


Measured : 2 466 061 103 079.4 (5.4) kHz

Expected (hydrogen) : 2 466 061 103 080.3 (0.6) kHz

1S-2S spectroscopy of antihydrogen



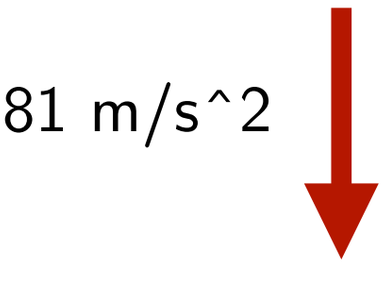


Measured : 2 466 061 103 079.4 (5.4) kHz
Expected (hydrogen) : 2 466 061 103 080.3 (0.6) kHz

Precision : 2×10^{-12}

What about gravity?

g = 9.81 m/s^2



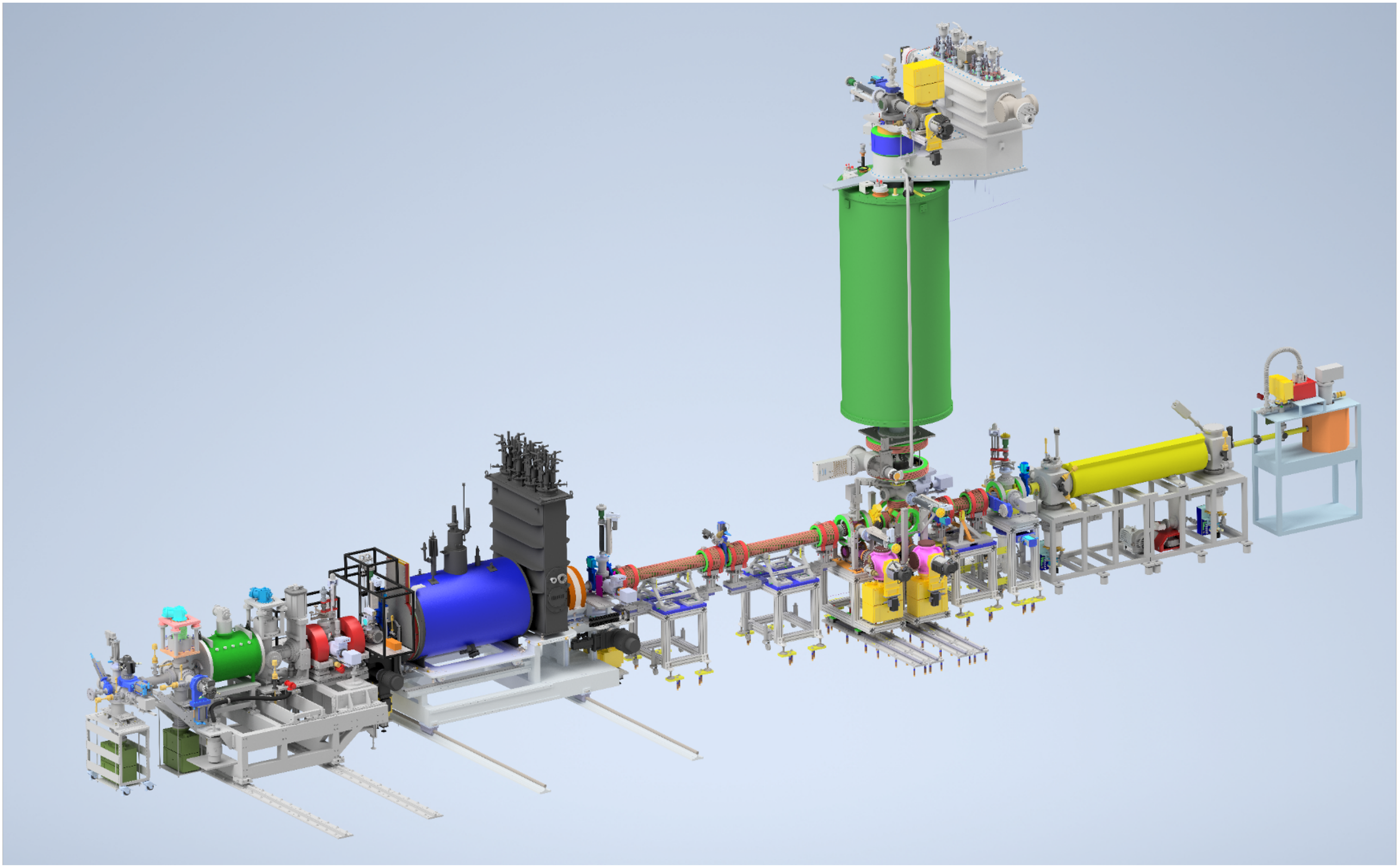
What about gravity?

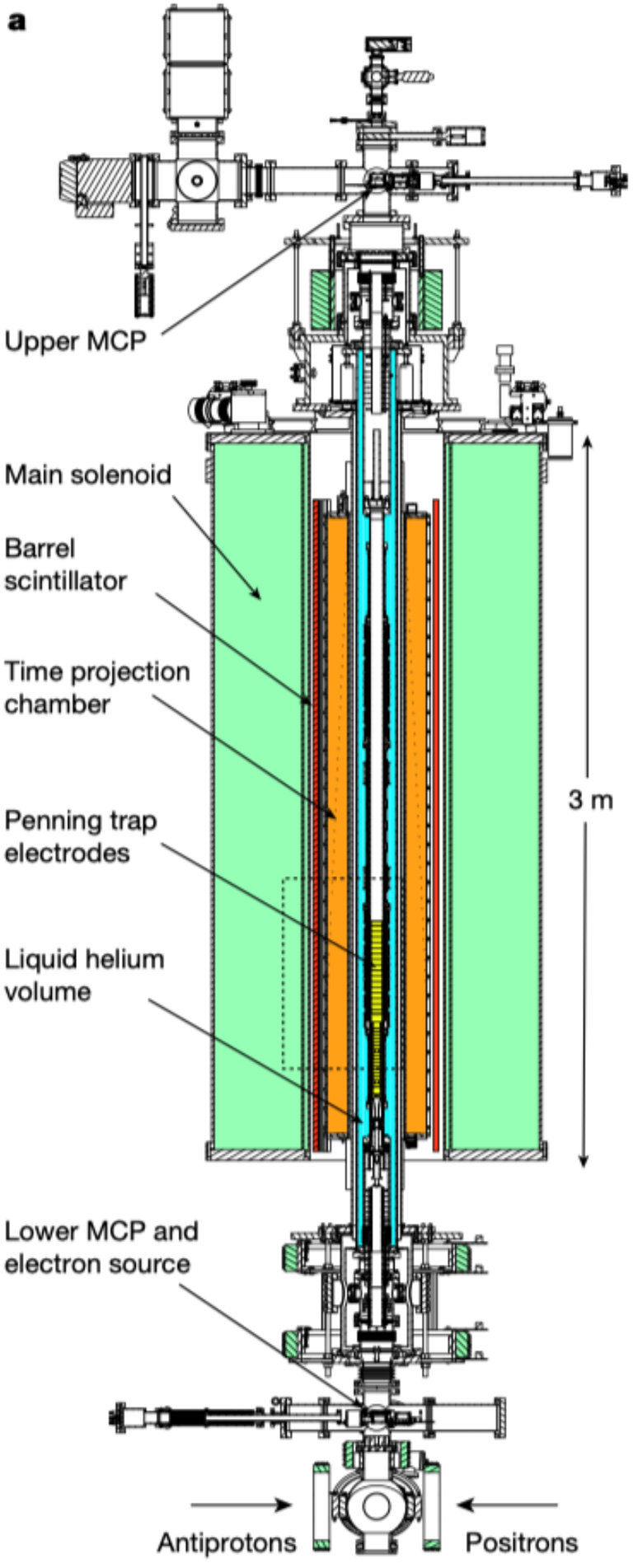
?

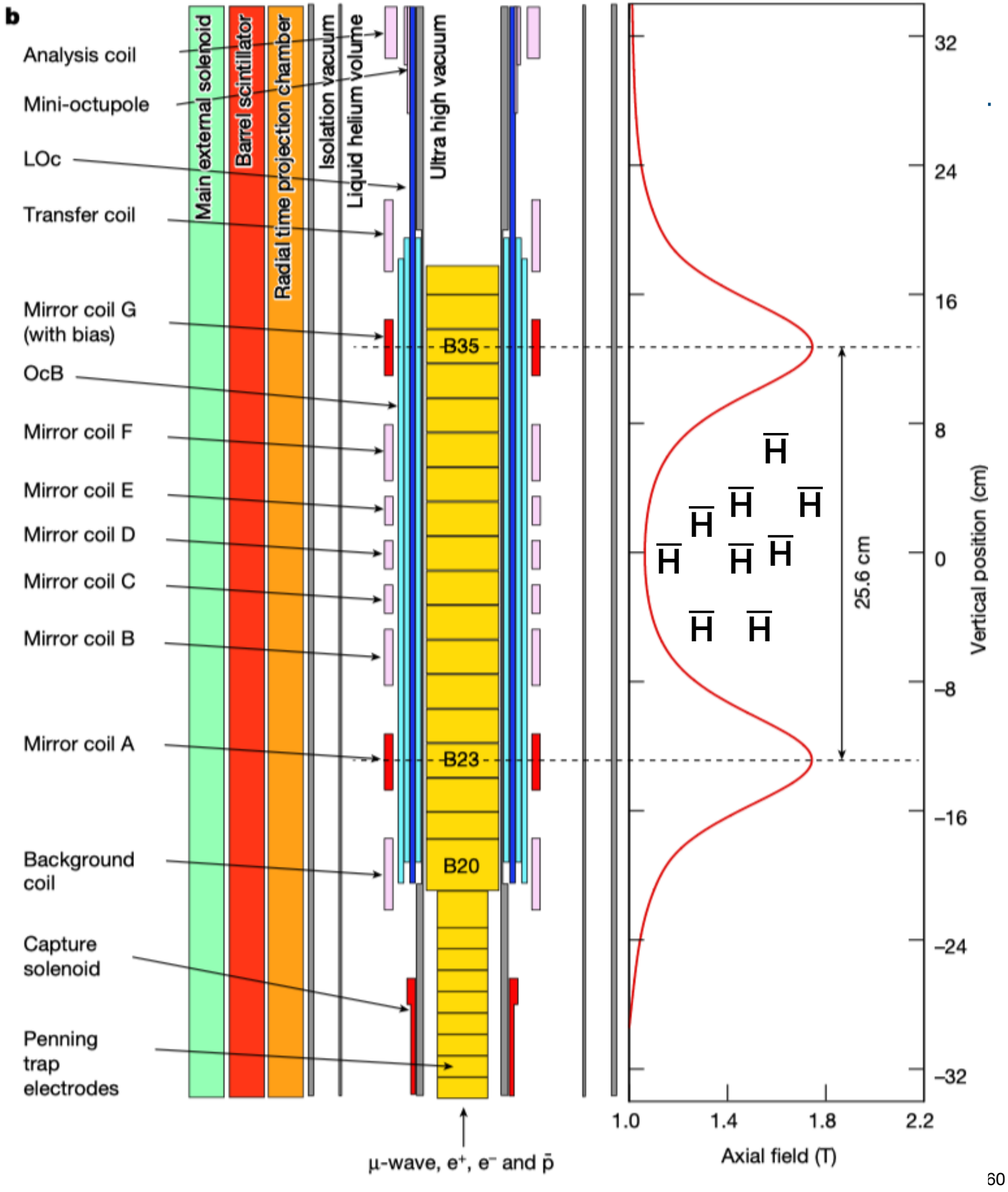
g = 9.81 m/s^2

Do matter and antimatter behave the same in a gravitational field?

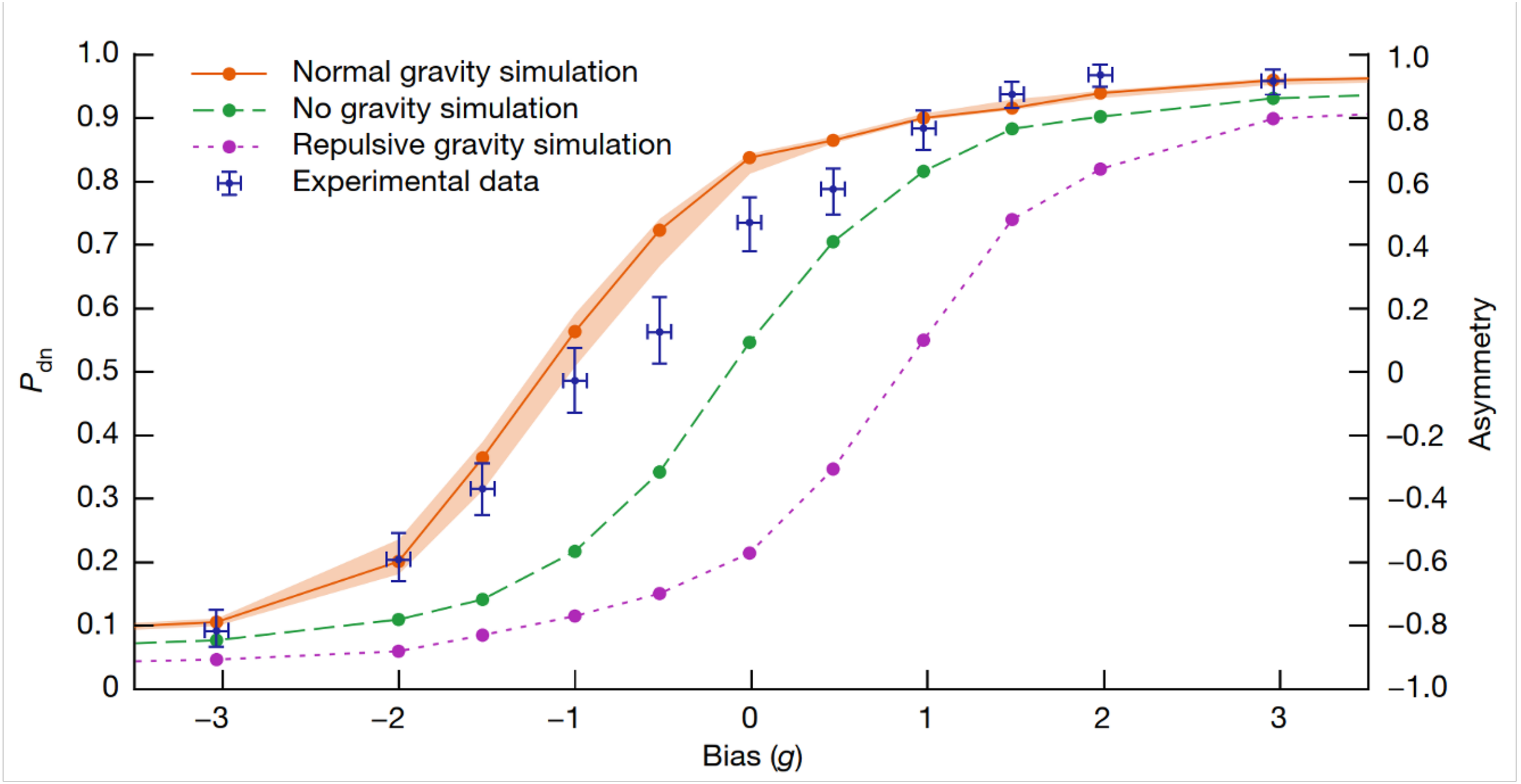
ALPHA-g




a
Upper MCP
Main solenoid
Barrel scintillator
Time projection chamber
Penning trap electrodes
Liquid helium volume
Lower MCP and electron source
3 m
Antiprotons
Positrons


b
Analysis coil
Mini-octupole
LOc
Transfer coil
Mirror coil G (with bias)
OcB
Mirror coil F
Mirror coil E
Mirror coil D
Mirror coil C
Mirror coil B
Mirror coil A
Background coil
Capture solenoid
Penning trap electrodes
Main external solenoid
Barrel scintillator
Radial time projection chamber
Isolation vacuum
Liquid helium volume
Ultra high vacuum
B35
B23
B20
μ-wave, e+, e− and p̄
25.6 cm
32
24
16
8
0
−8
−16
−24
−32
Vertical position (cm)
1.0
1.4
1.8
2.2
Axial field (T)

ALPHA-g: Results



1 g = 9.81 m/s^2 **downwards**

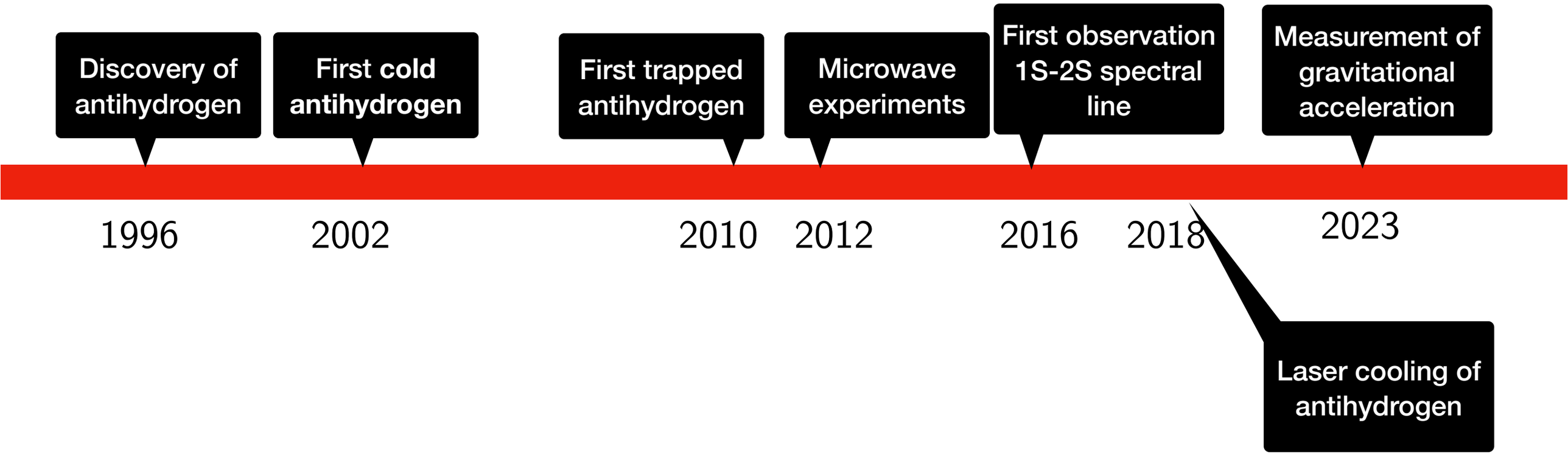
ALPHA-g: Results

$$a_g = (0.75 \pm 0.13 \pm 0.16)g$$

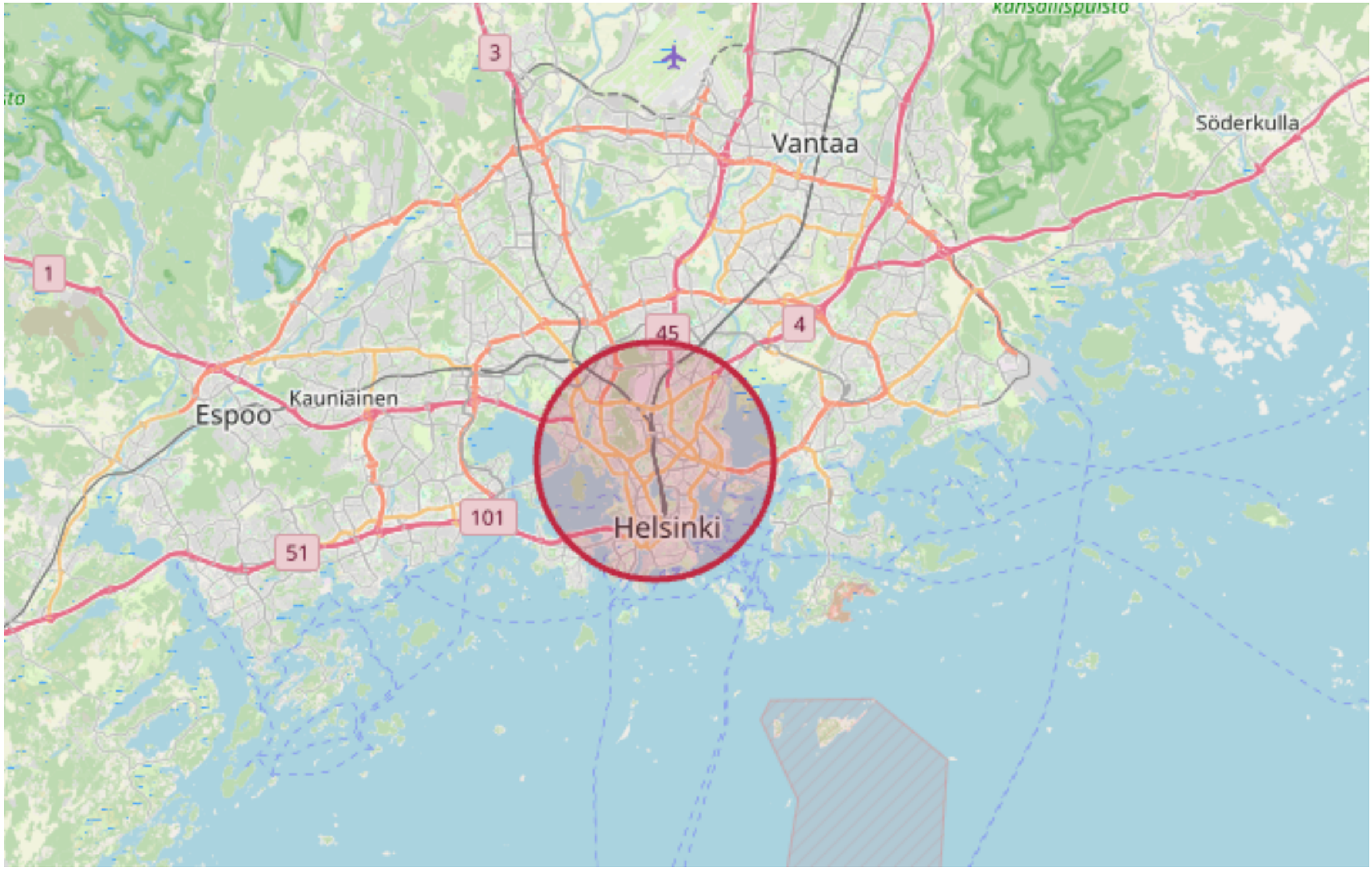
1 g = 9.81 m/s^2 **downwards**

Consistent with downward gravitational acceleration of 1g for antihydrogen

Timeline of physics at ALPHA

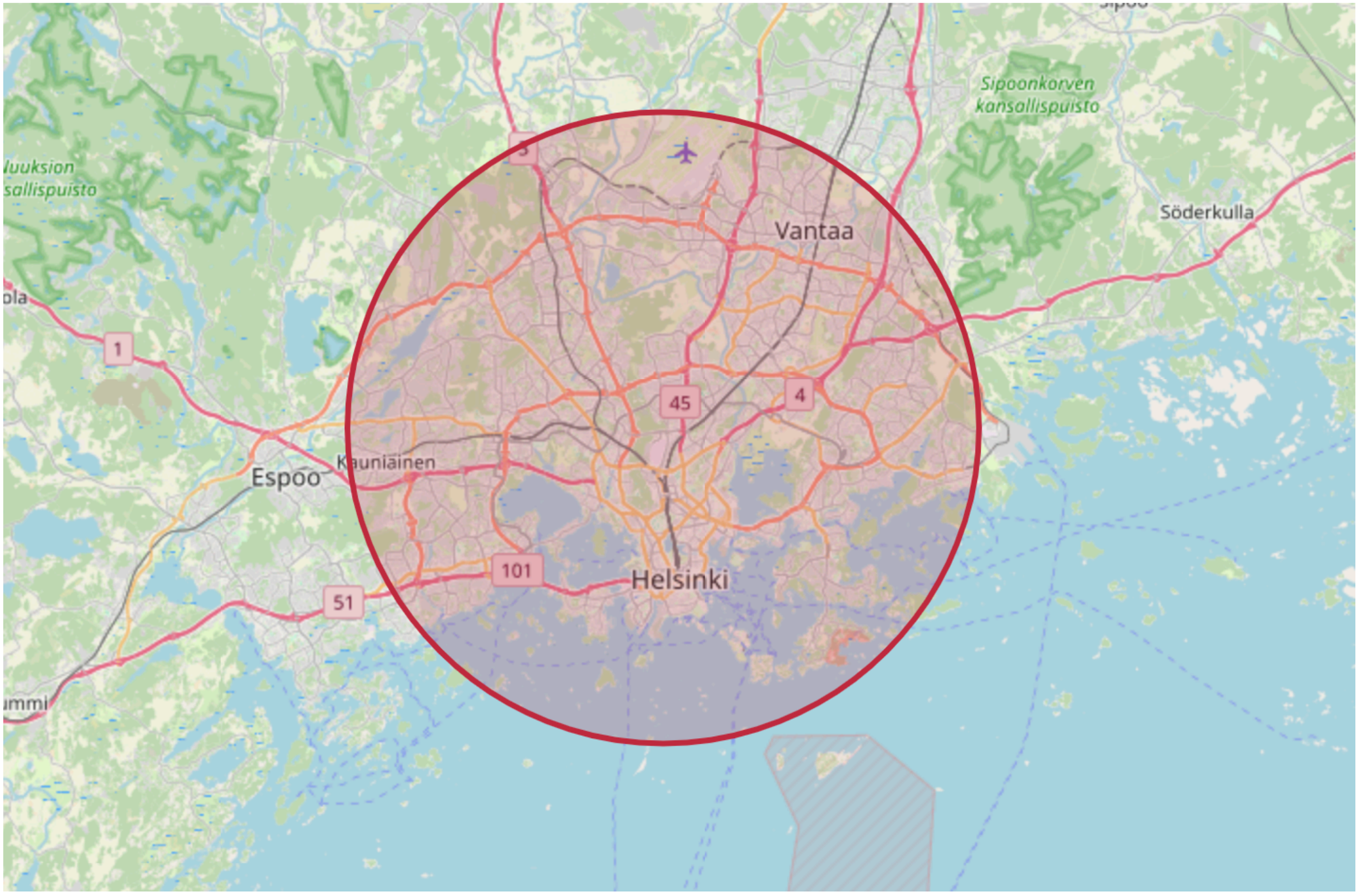


Reminder: the LHC is a big machine (29 km)

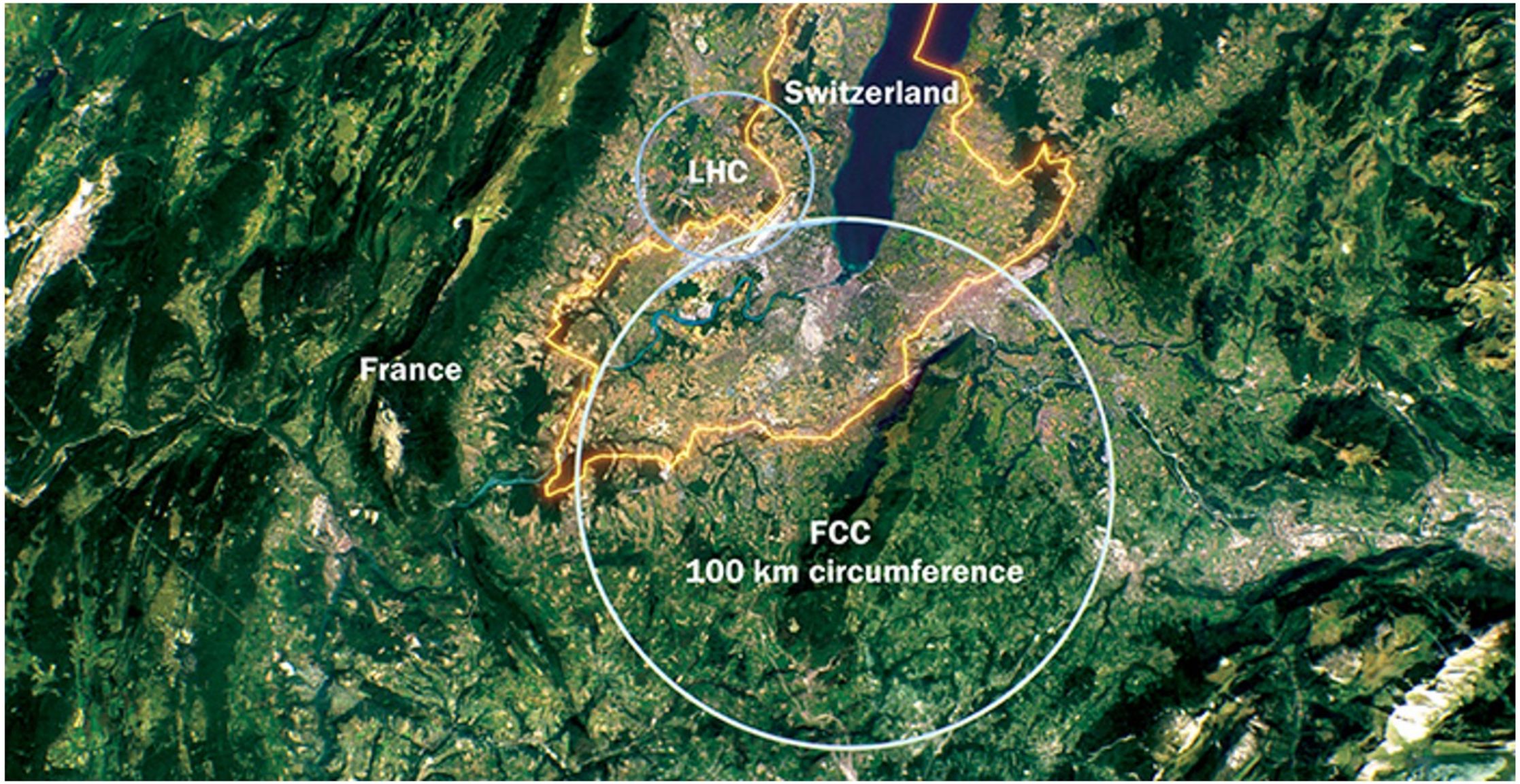


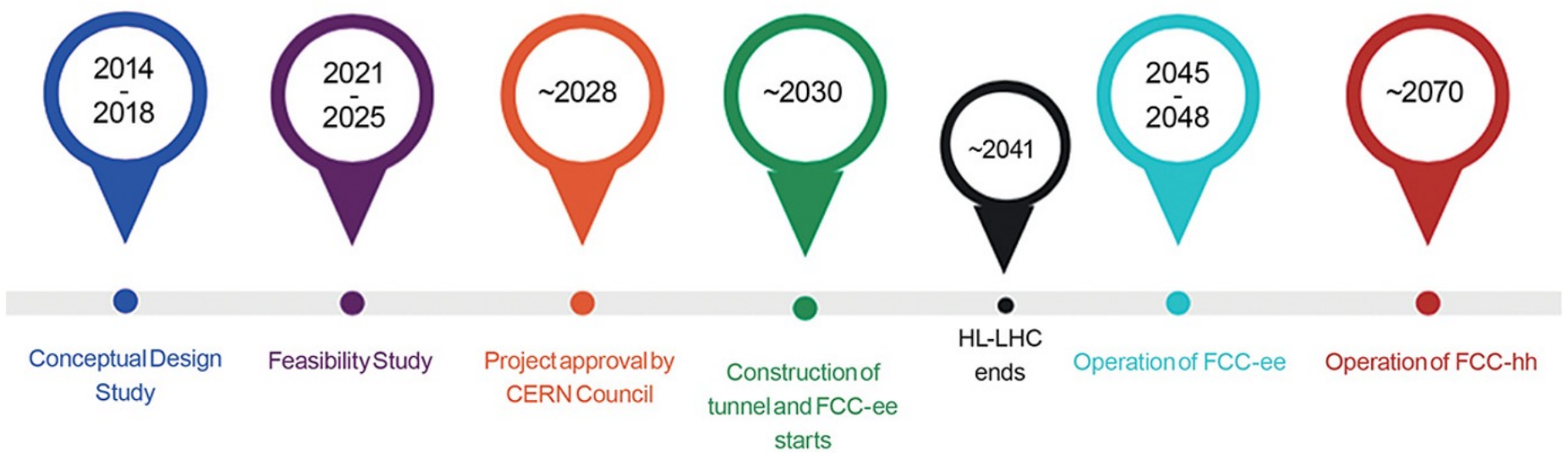
https://natronics.github.io/science-hack-day-2014/lhc-map/

The Future Circular Collider will be 100 km long

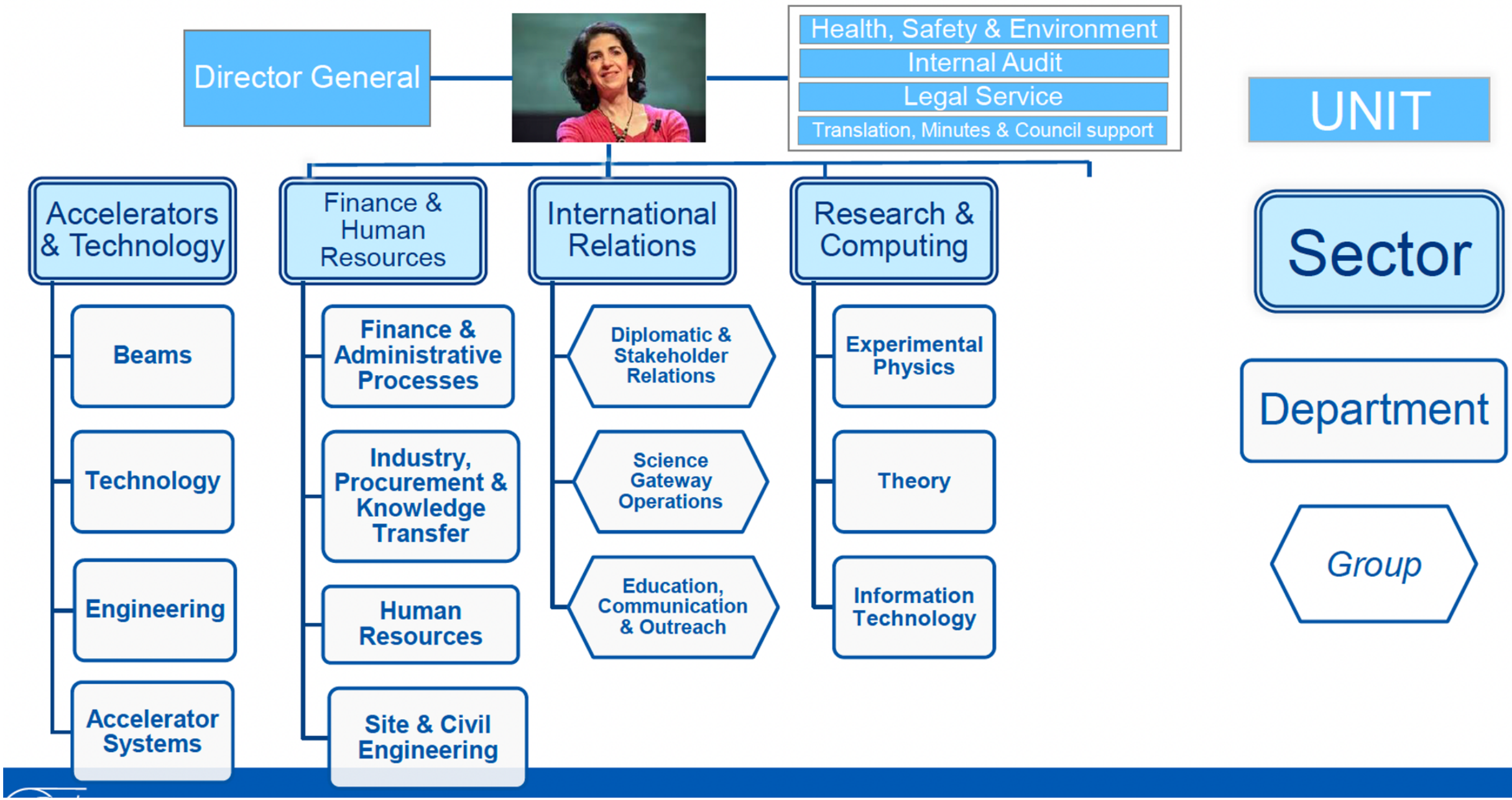


Opportunities at CERN





Opportunities at CERN



Opportunities at CERN

We offer ~ **300** positions annually

CERN
Summer Student Programme

"Can't imagine a better way to spend my summer"

FIELDS: Physics, engineering, computing

ELIGIBILITY: 3 years of full-time studies at university level

LENGTH: 8 to 13 weeks, during the summer

FEATURES:
- High-quality lecture programs
- A technical project with a CERN supervisor, visits and workshops
- Living allowance , incl. health insurance
- Accommodation in CERN hostel

Opens for applications in the Autumn, Selection in March
Open to Non Member State students

Opportunities at CERN

We offer ~ **240** positions annually

CERN
Technical Student Programme

"It's a great place to start a career, it's a great place to learn new skills and make new friends"

Selections in May and December

FIELDS: Applied physics, engineering, computing

LENGTH: 4 to 12 months

ELIGIBILITY: 18 months of technical undergraduate studies

FEATURES: A technical project with a CERN supervisor

A living allowance, incl. health insurance

Thank you!

www.alpha.web.cern.ch