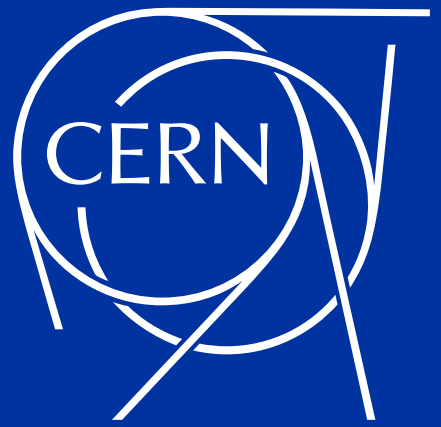
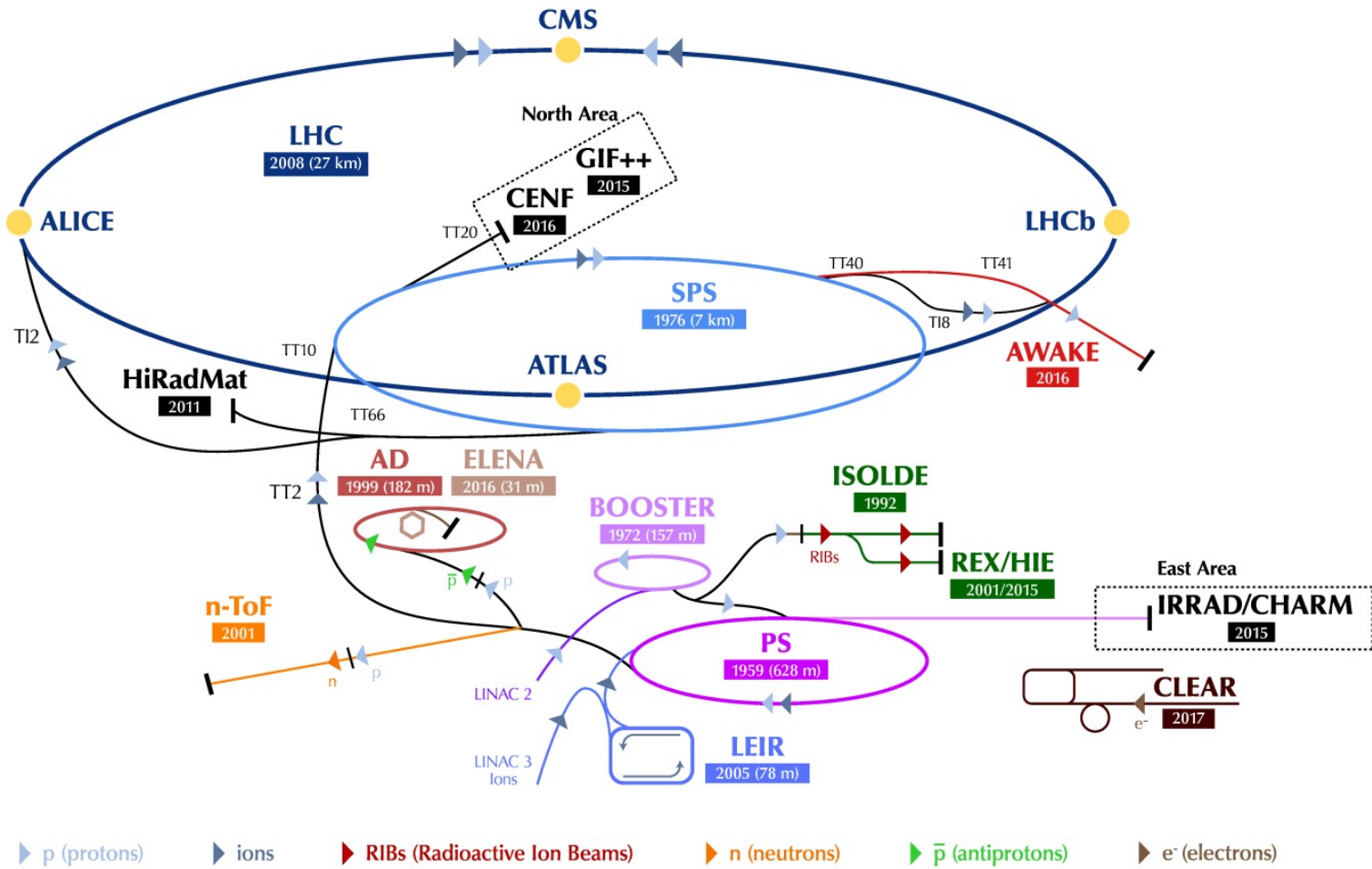


A virtual tour of the antimatter factory at CERN

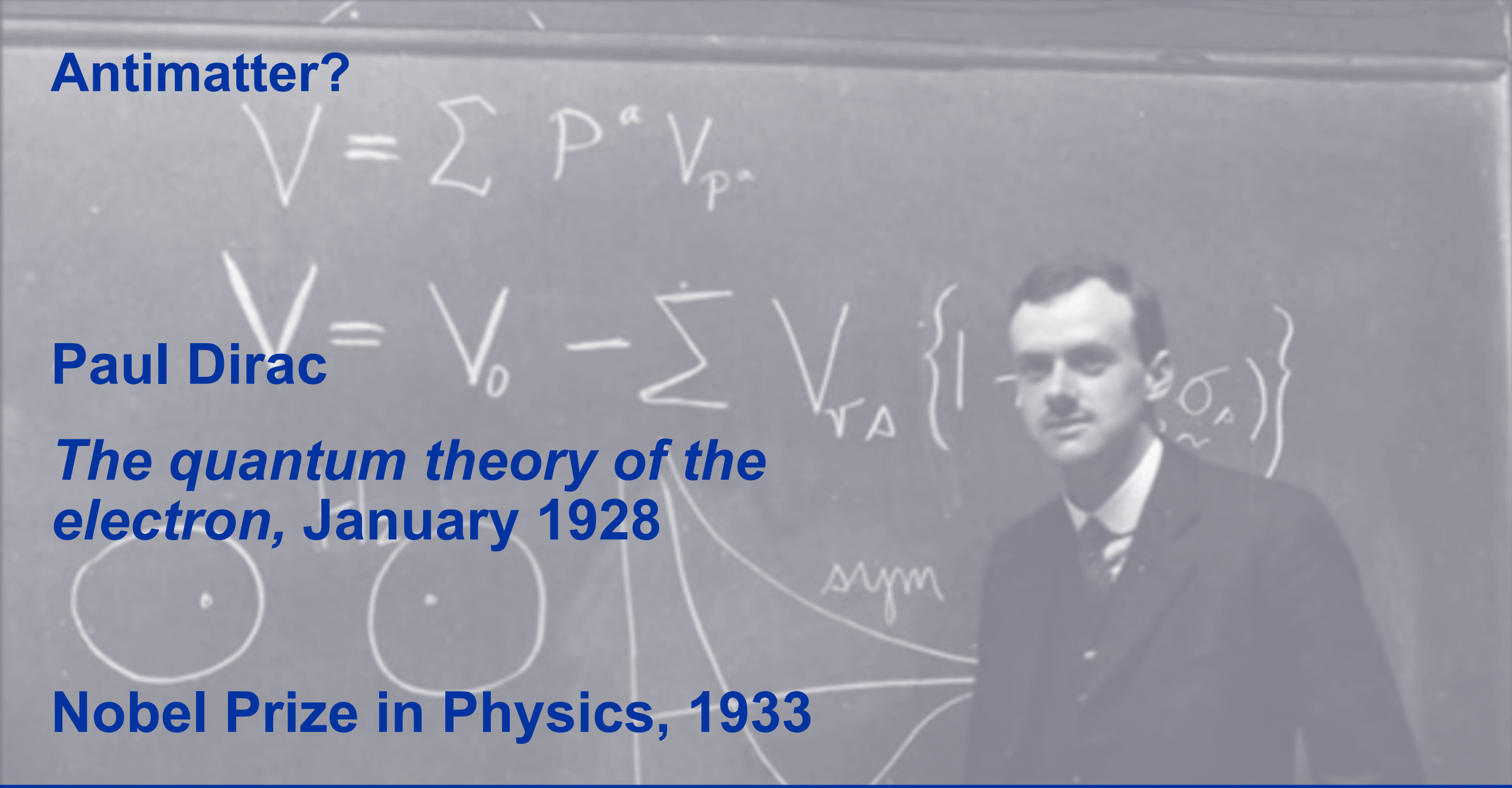
Cristiano Alpigiani

The CERN accelerator complex
Complexe des accélérateurs du CERN



LHC - Large Hadron Collider // **SPS** - Super Proton Synchrotron // **PS** - Proton Synchrotron // **AD** - Antiproton Decelerator // **CLEAR** - CERN Linear Electron Accelerator for Research // **AWAKE** - Advanced WAKefield Experiment // **ISOLDE** - Isotope Separator OnLine // **REX/HIE** - Radioactive EXperiment/High Intensity and Energy ISOLDE // **LEIR** - Low Energy Ion Ring // **LINAC** - LINear ACcelerator // **n-ToF** - Neutrons Time Of Flight // **HiRadMat** - High-Radiation to Materials // **CHARM** - Cern High energy AcceleRator Mixed field facility // **IRRAD** - proton IRRADiation facility // **GIF++** - Gamma Irradiation Facility // **CENF** - CErn Neutrino platForm

Antimatter?



Paul Dirac

***The quantum theory of the electron*, January 1928**

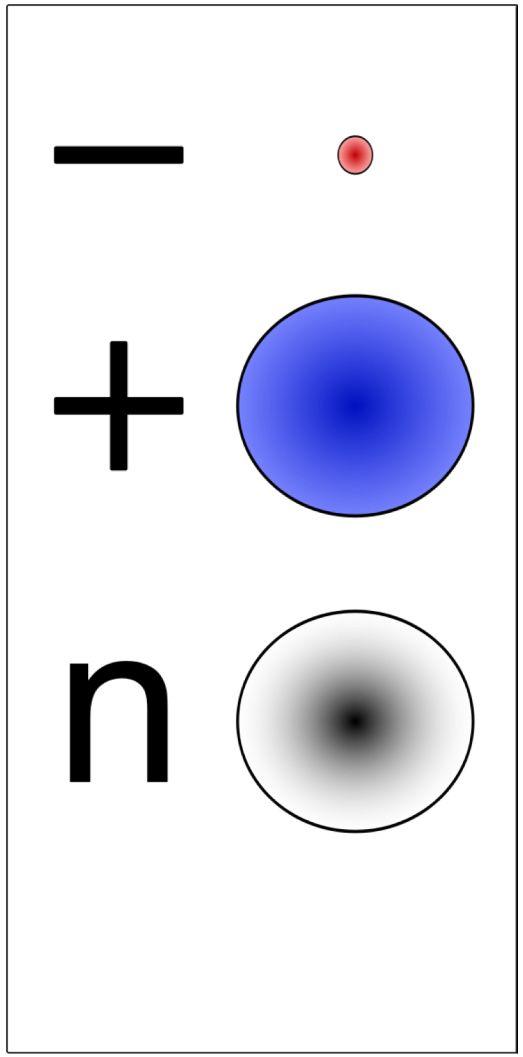
Nobel Prize in Physics, 1933

Antimatter?

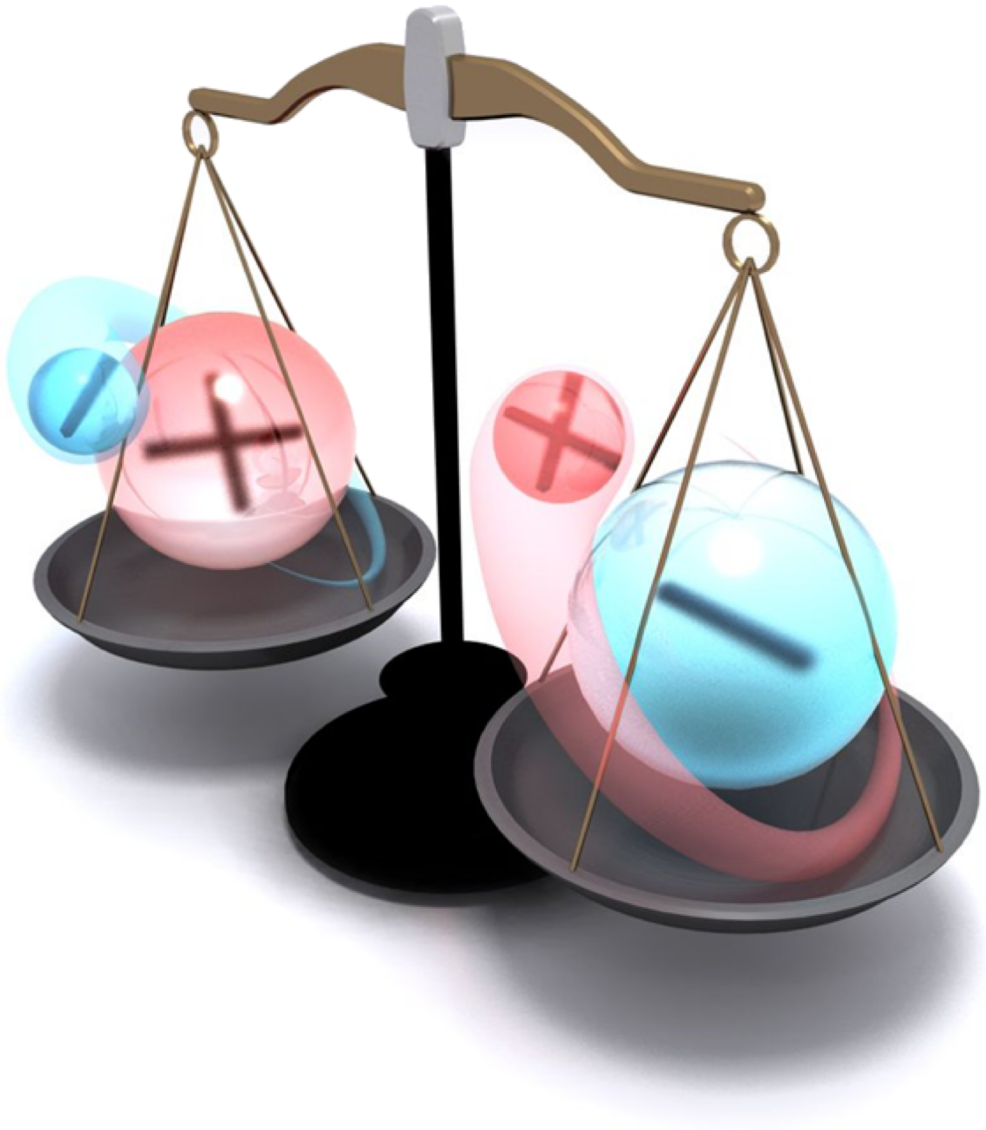
electron

proton

neutron

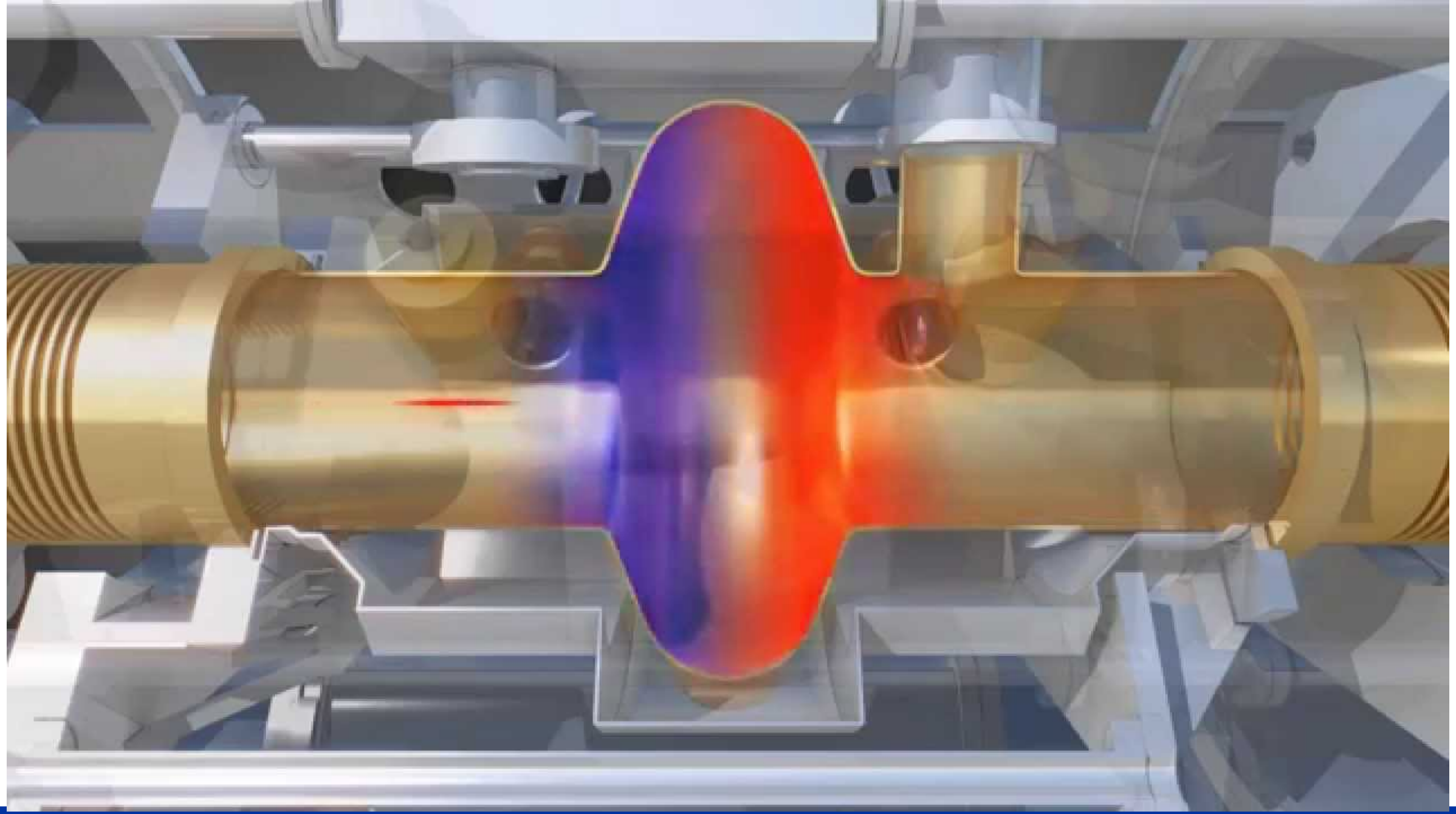


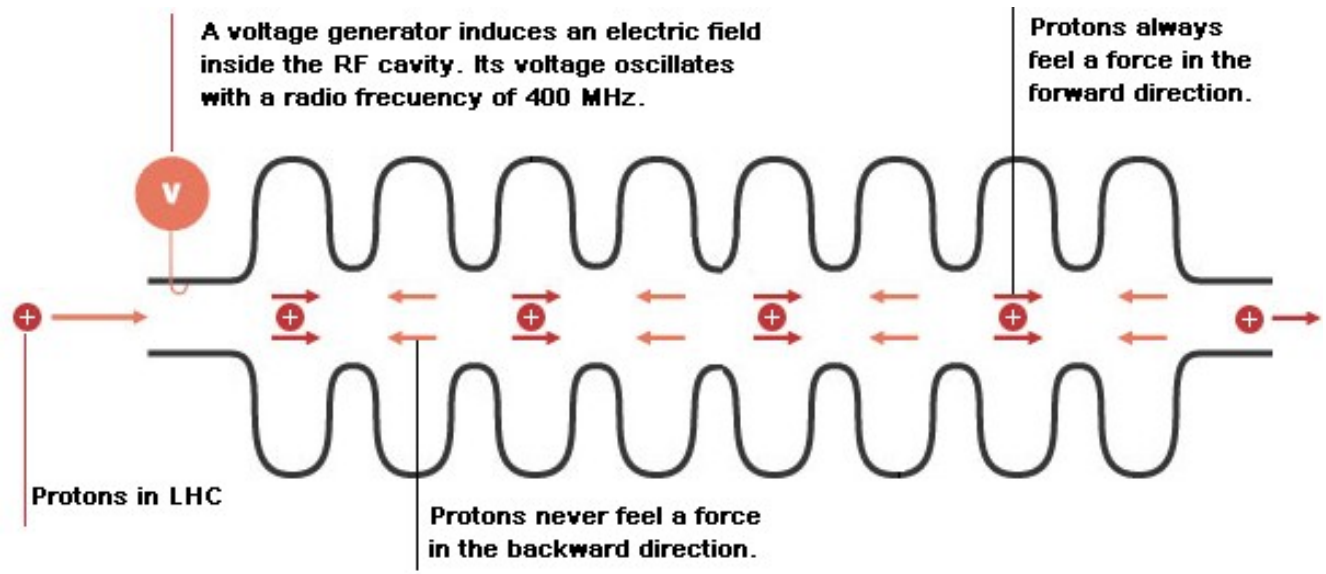
Antimatter?



How do we address this question at CERN?

How do we address this question at CERN?





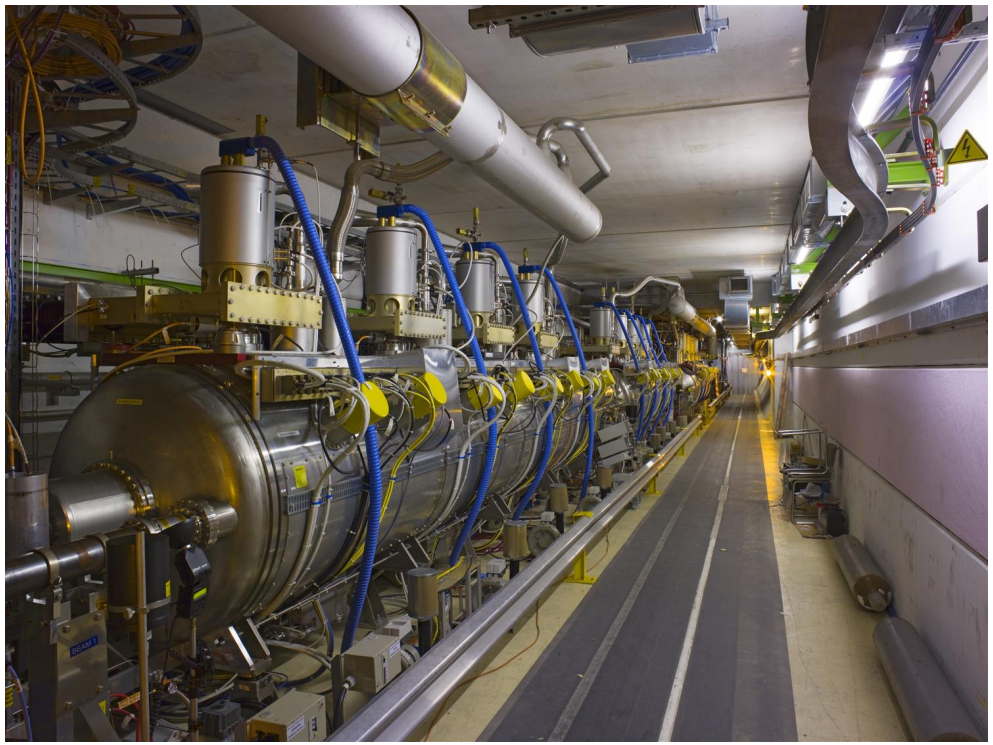
- Each cavity delivers 2MV
- Accelerating field of 5 MV/m @ 400 MHz
- Cavities operate @ 4.5 K

- Every proton passing through the RF cavities is affected for

$$2 \cdot 8\ \text{MV} = 16\ \text{MV}$$

so it receives an extra energy of 16 MV.

- Since every proton goes around 11245 laps per second the total energy received per second is:



$$(16\ \text{MeV/lap}) \cdot (11245\ \text{laps/s}) = 1.8 \cdot 10^5\ \text{MeV/s} \equiv 0.18\ \text{TeV/s}$$

- From SPS every proton enters LHC with 0.45 TeV, so the amount of energy that cavities has to provide is

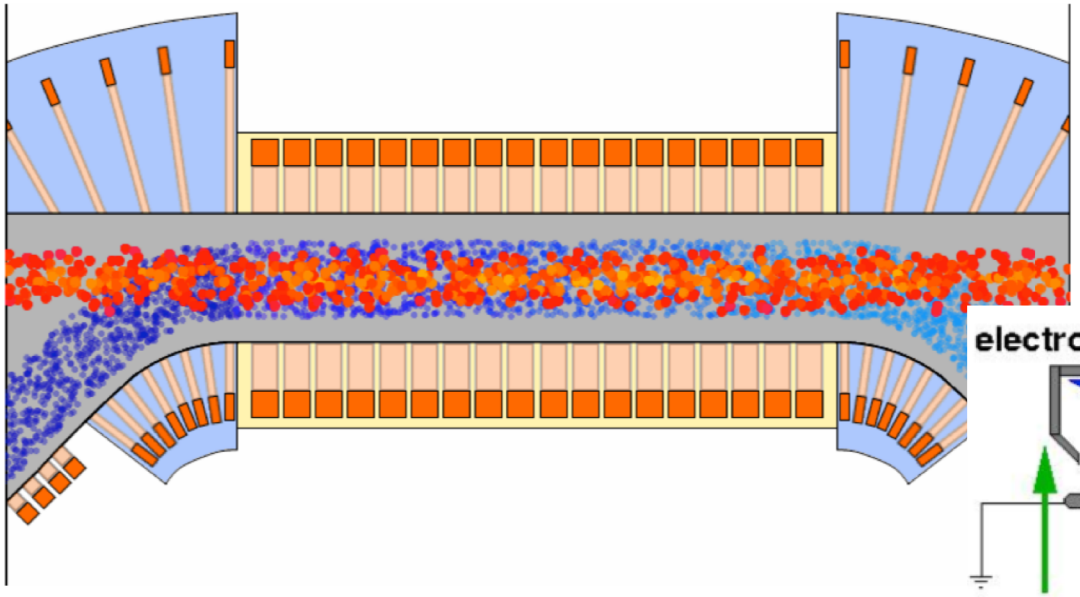
$$7 - 0.45 = 6.55\ \text{TeV}$$

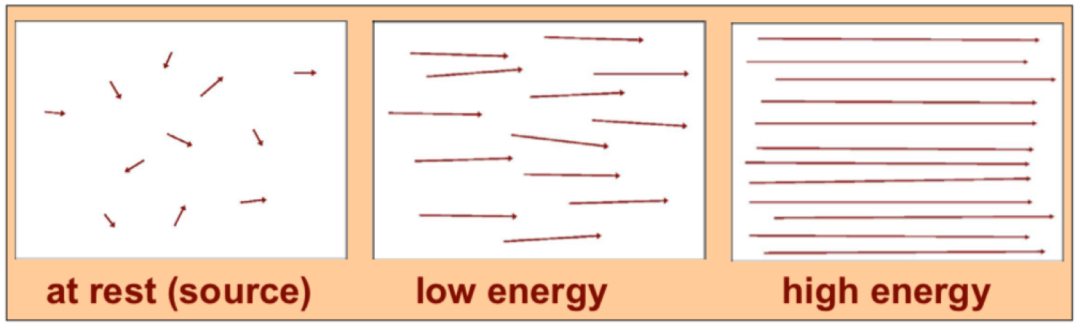
- The length of time required to accelerate the beam to full energy is

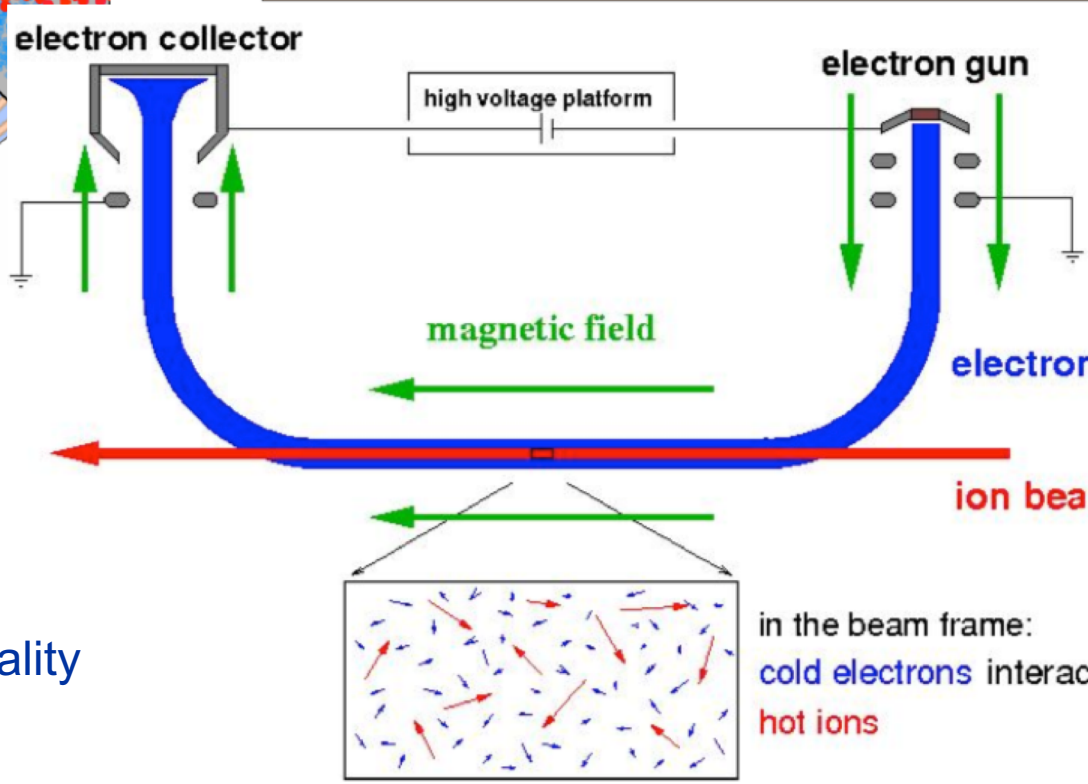
$$6.55\ /\ 0.18 = 36.4\ \text{s}$$

- The right results is about 20 minutes, this is due to the fact the proton is not fully affected by the total voltage of the cavity. It is also important to keep bunches compact to increase the chance of collision.
- The RF frequency must always be an integer multiple of the revolution frequency

$$\nu_{RF} = \text{K} \cdot \nu_{rev}$$







$v_{e//} = v_{i//}$

$E_e = m_e/M_i \cdot E_i$

e.g. :220 keV electrons cool 400 MeV/u ions

electron temperature

$k_B T_\perp \approx 0.1$ eV

$k_B T_{//} \approx 0.1$ - 1 meV

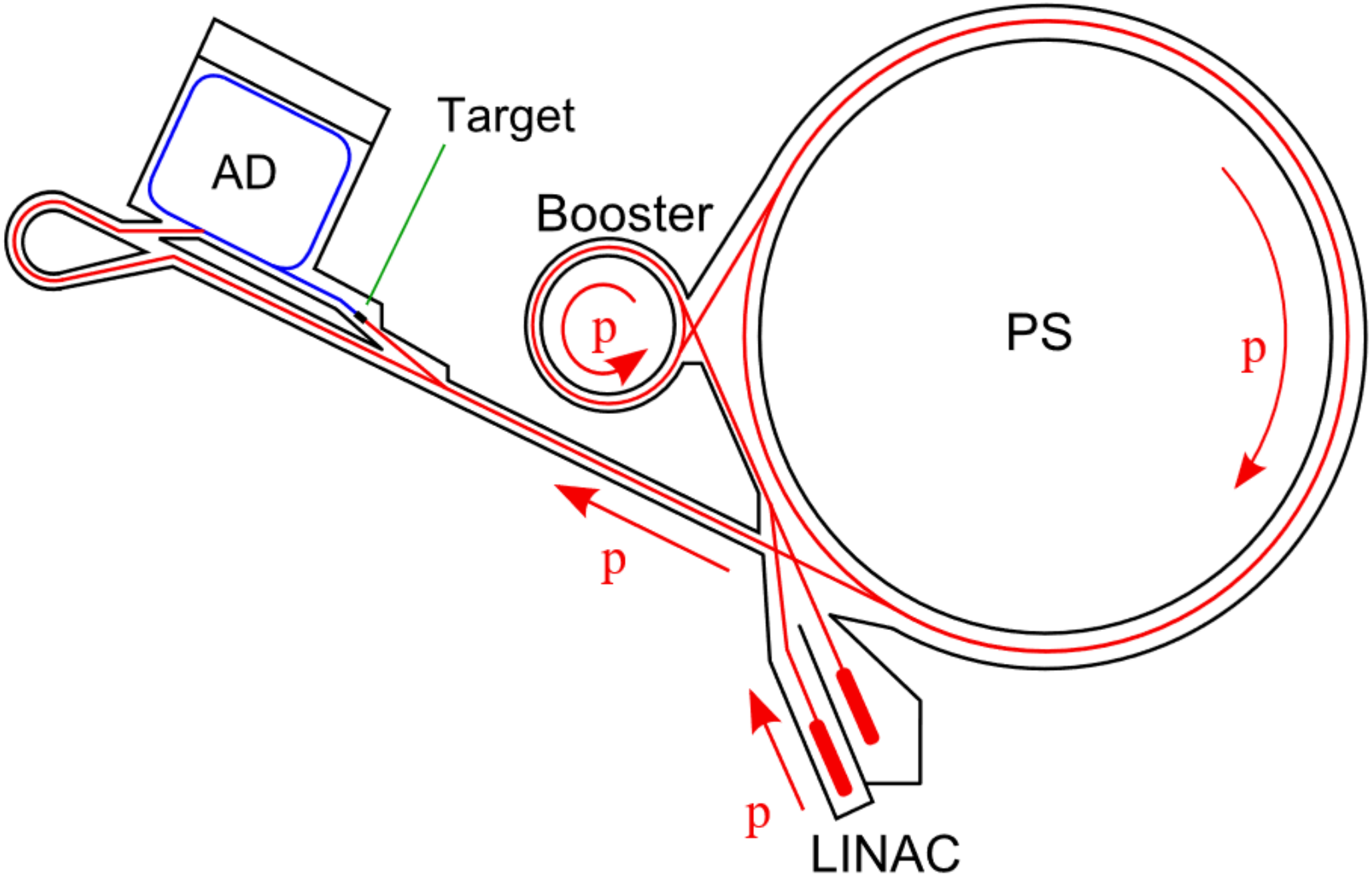
- Many processes can heat up the beam
  - ✓ Space charge, intra-beam scattering, internal targets, residual gas
- Electron cooling allows Improved beam quality
  - ✓ Precision experiments
  - ✓ Luminosity increase

superposition of a cold intense electron beam with the same velocity

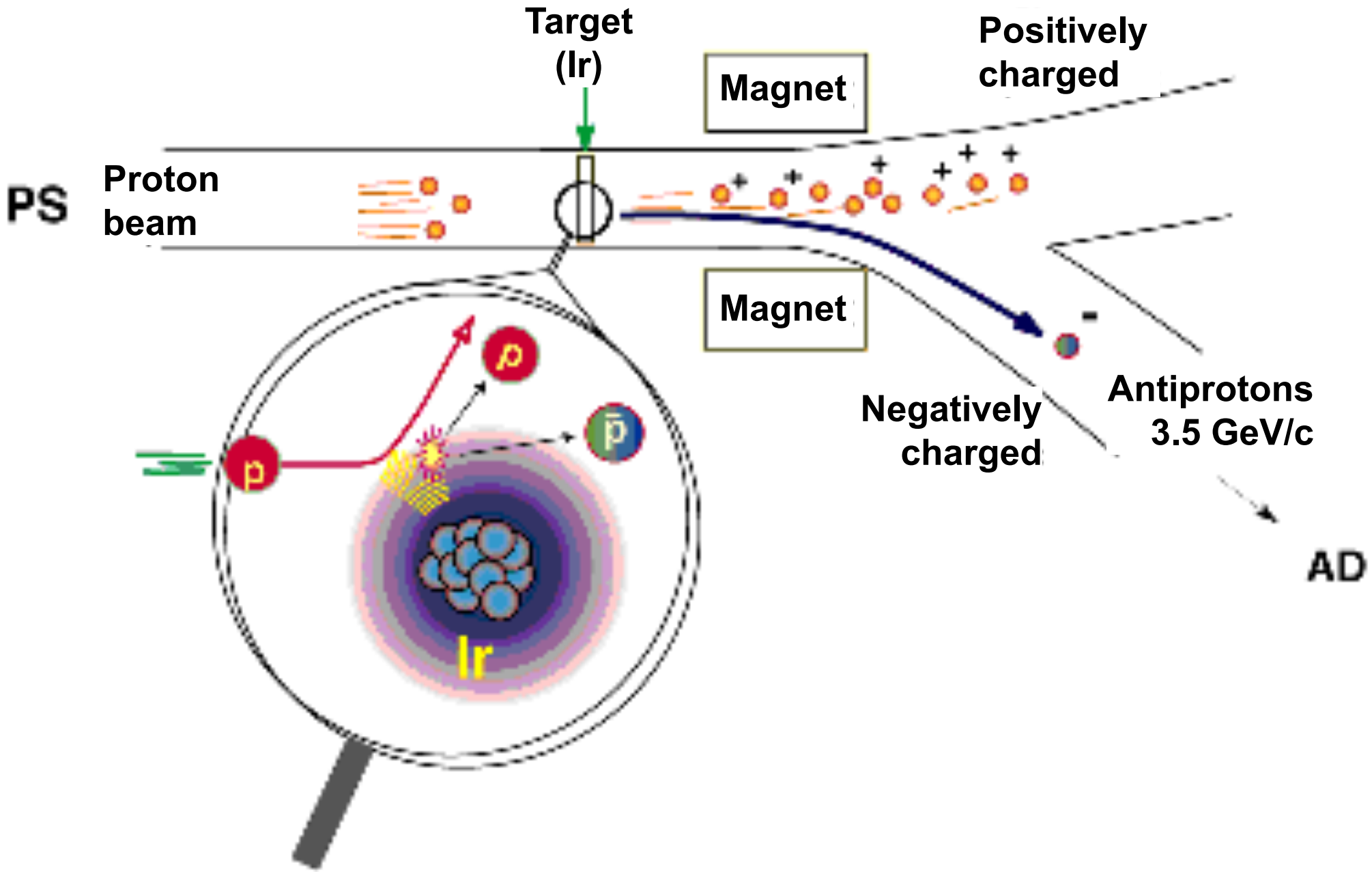
momentum transfer by Coulomb collisions

cooling force results from energy loss in the co-moving gas of free electrons

How do we address this question at CERN?


AD
Target
Booster
p
PS
p
p
p
LINAC

The iridium target


Target
(Ir)
Magnet
Positively
charged
PS
Proton
beam
Magnet
Negatively
charged
Antiprotons
3.5 GeV/c
AD
p
p
p̄
Ir

Antiprotons from PS

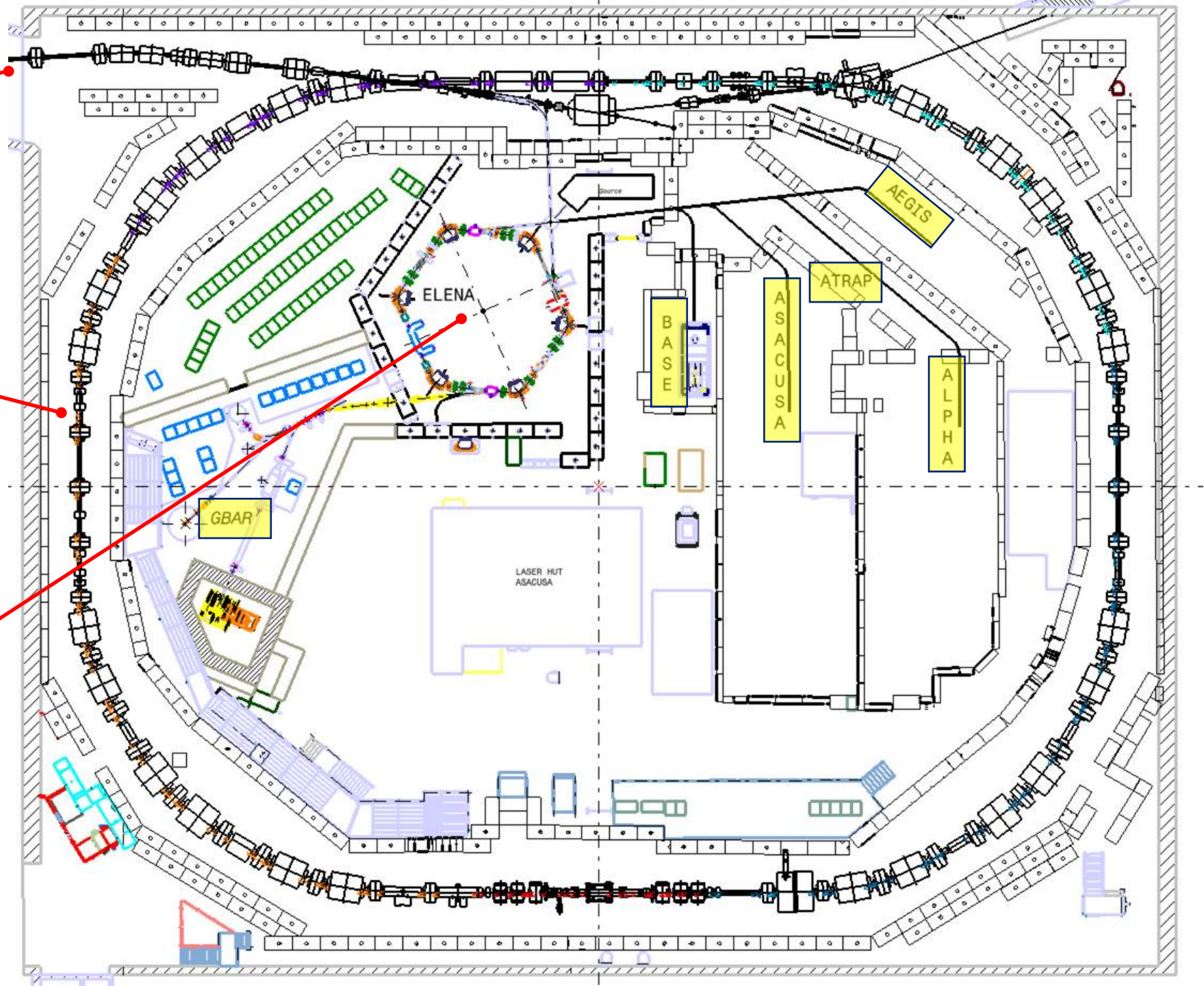
Energy: 3.5 GeV

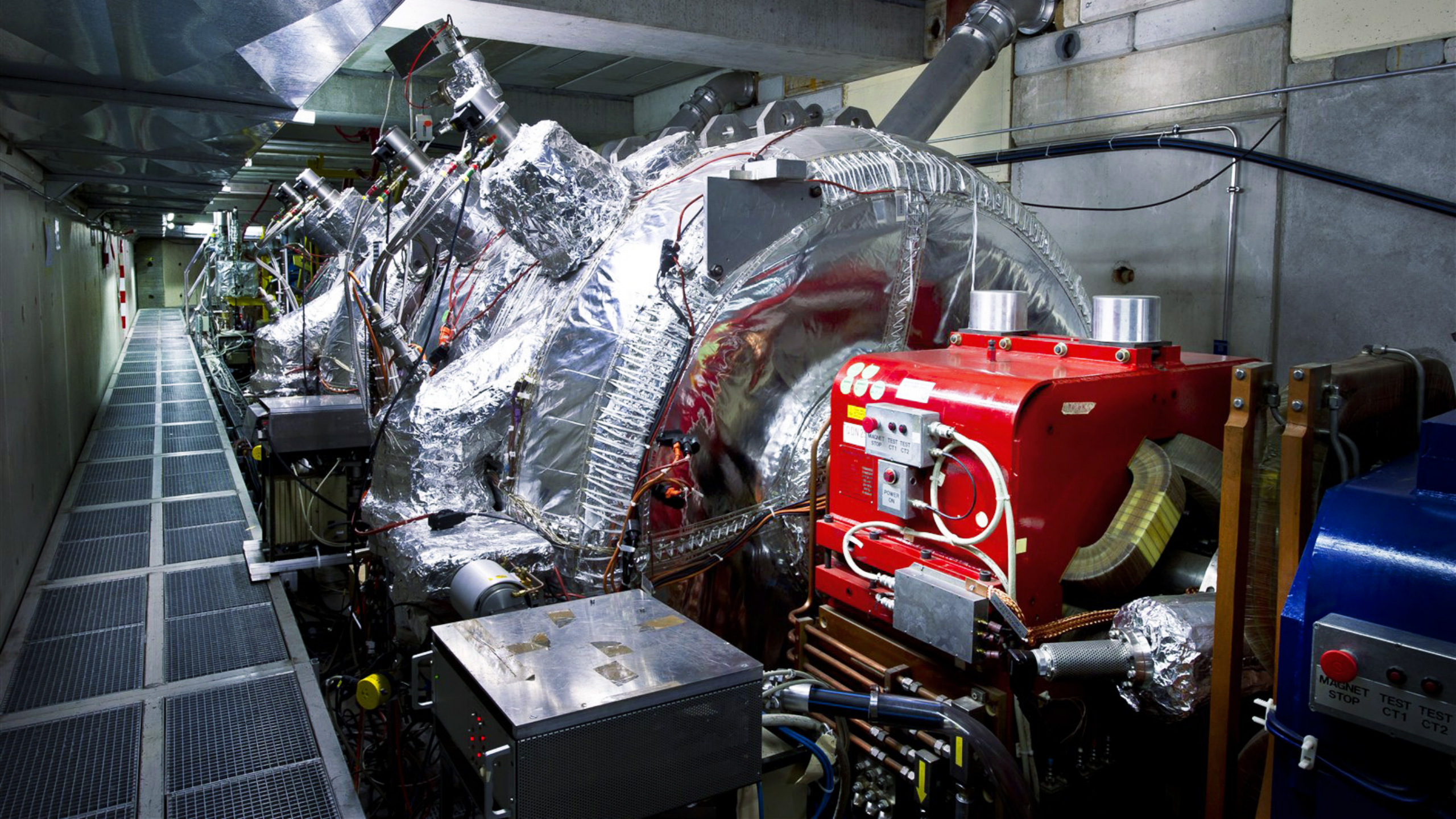
AD
Antiproton Decelerator

Start: 2000
Length: 182 m
Energy: 5.3 MeV

ELENA
Extra Low
ENergy Antiproton

Start: 2021
Length: 30 m
Energy: 0.1 MeV

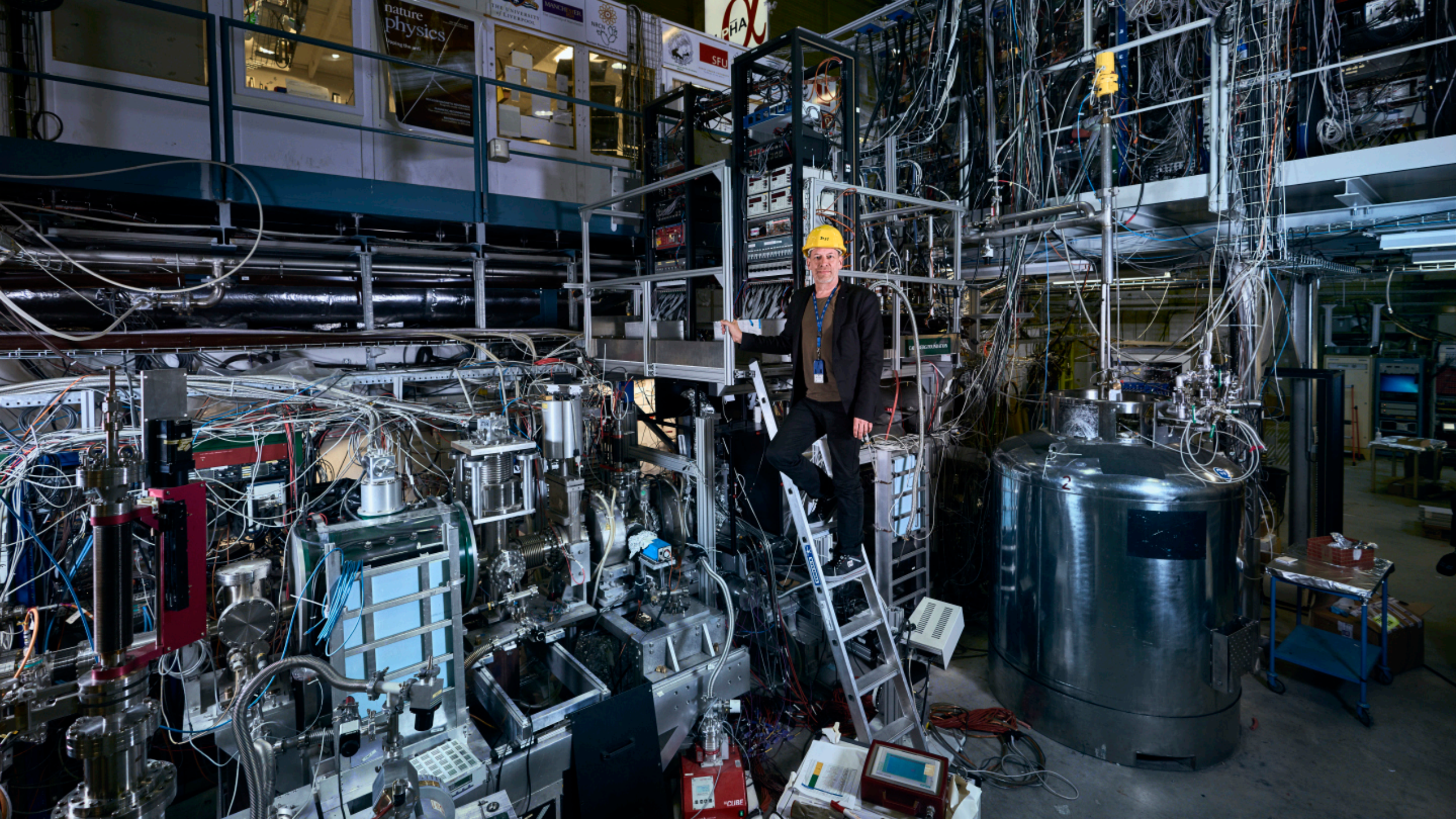


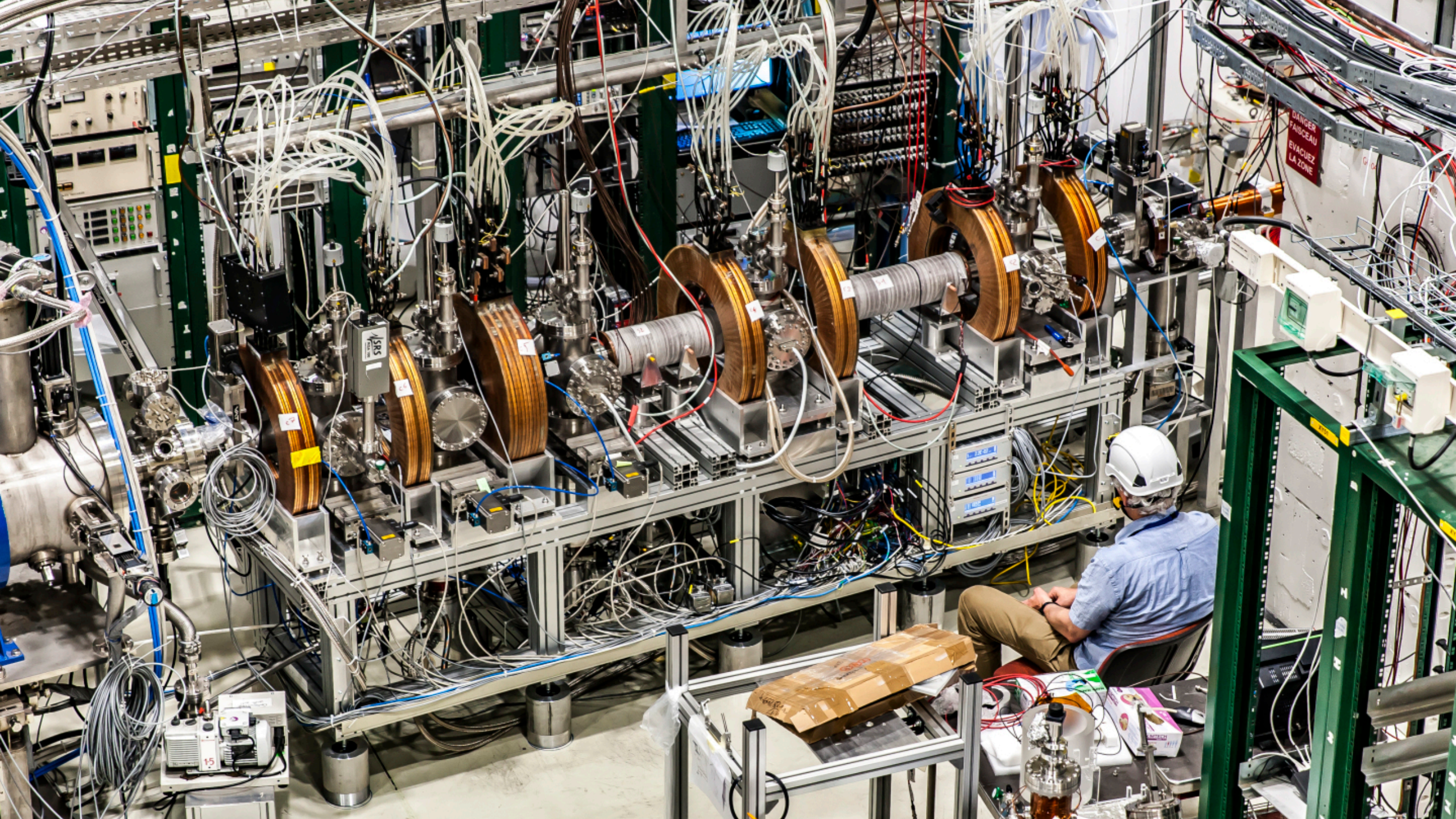

MAGNET STOP
TEST CT1
TEST CT2
POWER ON

The experiments

	ALPHA	ATRAP	ASACUSA	BASE	AEGIS	GBAR
Approved	2005	1997	1997	2013	2008	2012
Data Taking	2006	2002	2002	2014	*Soon*	*Soon*
Countries	8	4	8	3	11	9
Institutes	16	6	19	7	23	16
Researchers	57	31	51	41	113	87
Main goals	Compare hydrogen and antihydrogen (*spectroscopy)*	Compare hydrogen and antihydrogen (*spectroscopy)*	Compare the *hyperfine structure* of hydrogen and antihydrogen	Compare the *magnetic moments* of matter and antimatter.	Study effects of Earth's gravity on antimatter	Study effects of Earth's gravity on antimatter
Highlight	Jun 2011: trapped antiprotons for 16 minutes	Mar 2013: magnetic moment measurement	Nov 2016: measure the mass of antiproton	Jun 2014: first observations		


ASACUSA
HARVARD
ATRAP
ASACUSA
ASACUSA
H4
H2

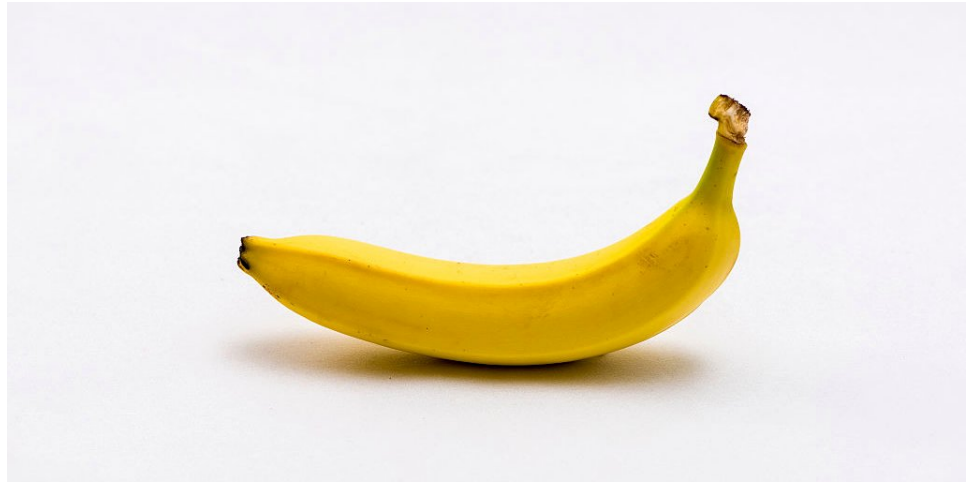

nature physics

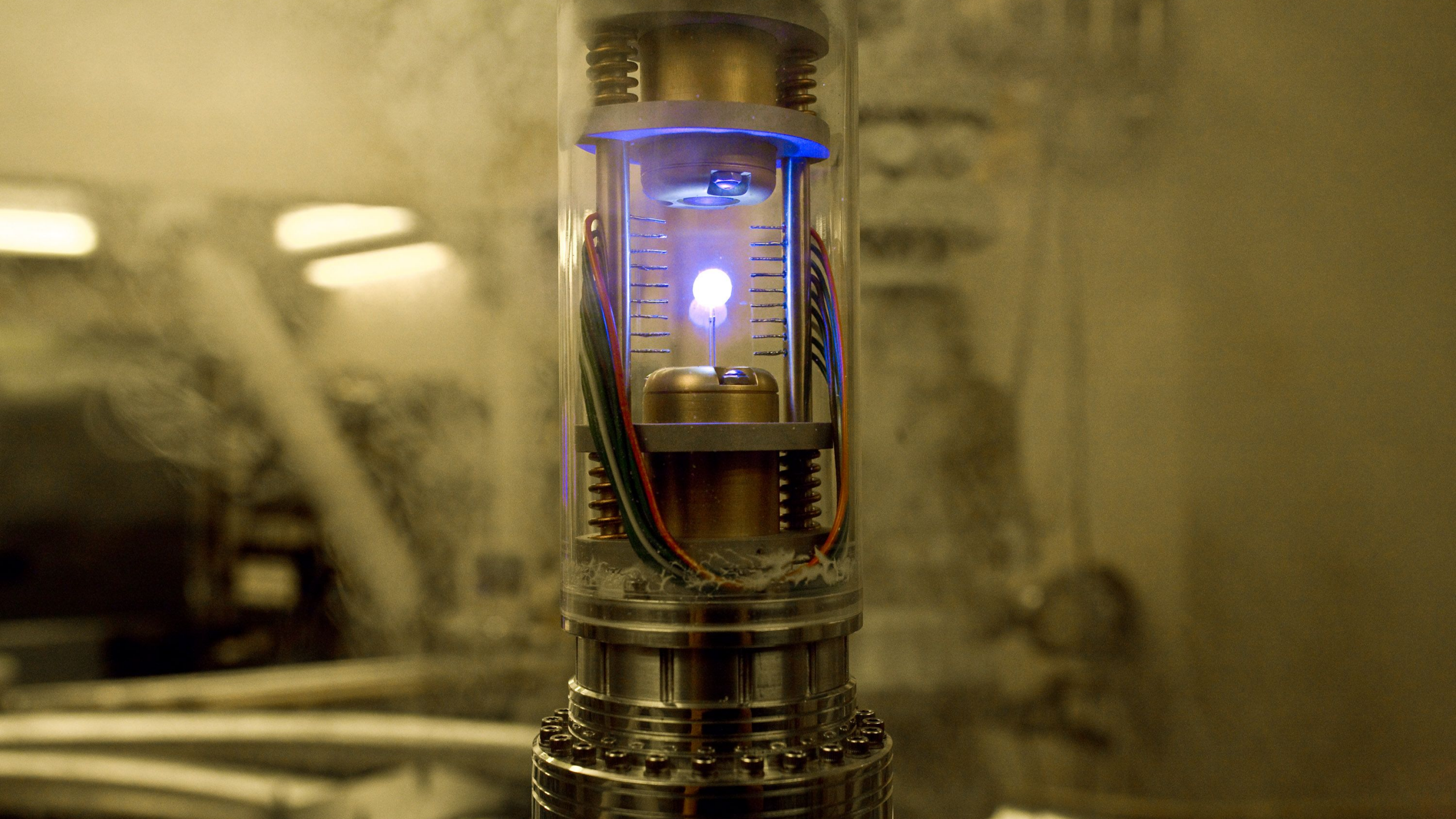

DANGER
FAISCEAU
EVACUEZ
LA ZONE

Natural antiparticles

- A person weighting 80 kg produces 180 e^+ per hour from the desintegration of Potassium-40, a natural isotope

- A banana produces 10 e^+ per second

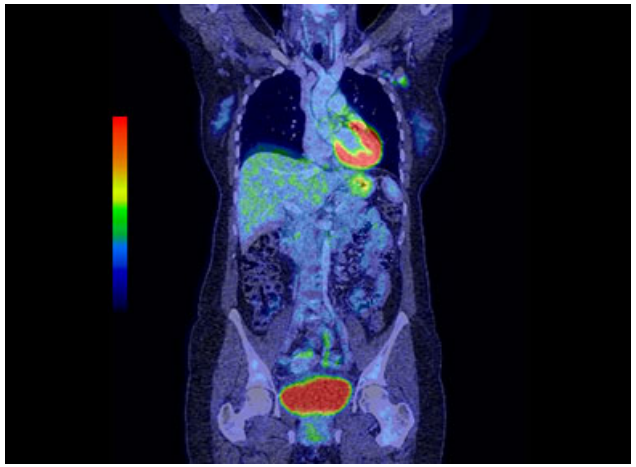




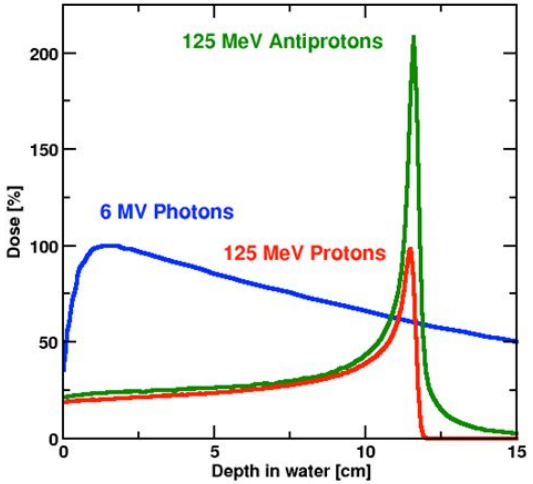
Practical use…

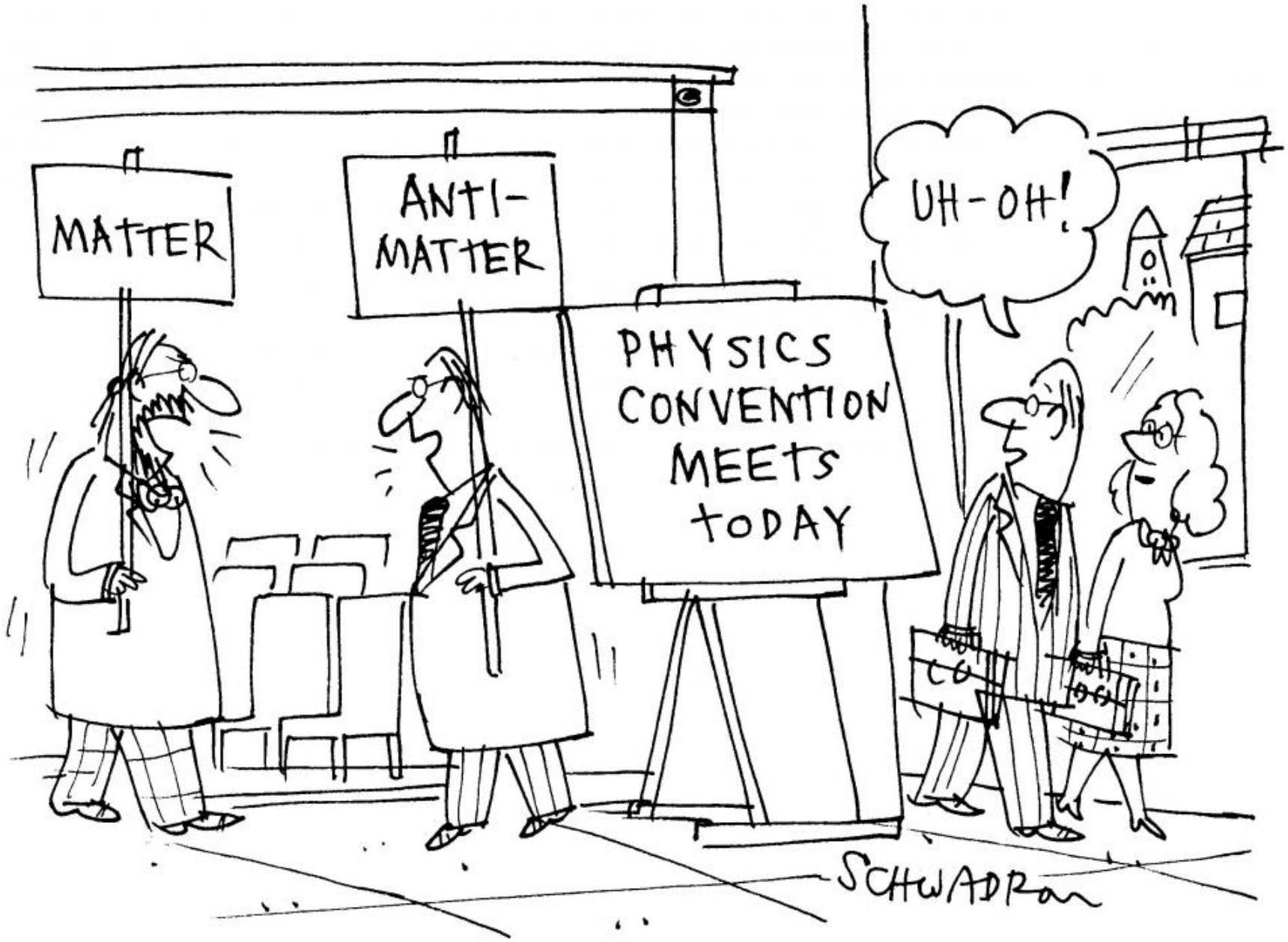
1g of antimatter contains 90 TJ of energy (~21 kT of TNT)
(enough to power a car 1000 times around the world)
but producing 1g of antimatter at CERN at current production rate
would take1 billion years
would cost 2 000 000 000 000 000 €

PET (Positron Emission Tomography)



Antiproton Therapy




MATTER
ANTI-
MATTER
PHYSICS
CONVENTION
MEETS
TODAY
UH-OH!
SCHWADRON