

High Energy Accelerator Chains



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LHC @ CERN

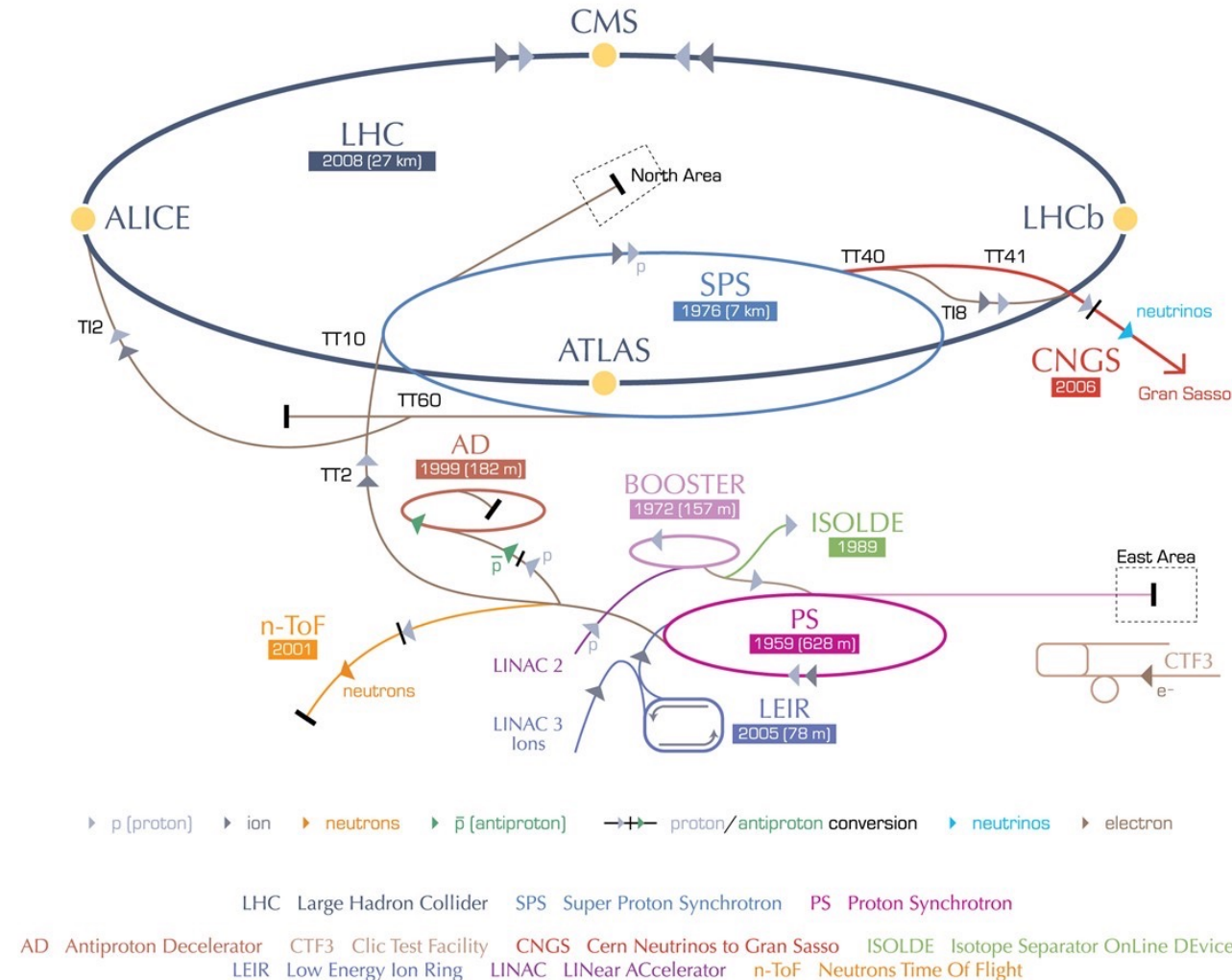
- Circumference: 27 km
- Current proton kinetic energy: 6.5 TeV
 - 99.999999% of speed of light
 - 3 m/s slower than light
- Current total energy in beam: 336 MJ
 - Equivalent to an aircraft carrier moving at 5.8 MPH



The diagram illustrates the LHC @ CERN facility. The top half shows a surface map of the region between Switzerland and France, with a dashed red line indicating the path of the LHC tunnel. Key locations marked include CERN, ATLAS, CMS, LHCb, and ALICE. A blue river and green mountains are also depicted. The bottom half shows a cross-section of the underground tunnel, with the LHC ring and various experimental detectors (CMS, ATLAS, LHCb, ALICE) shown in cross-section.

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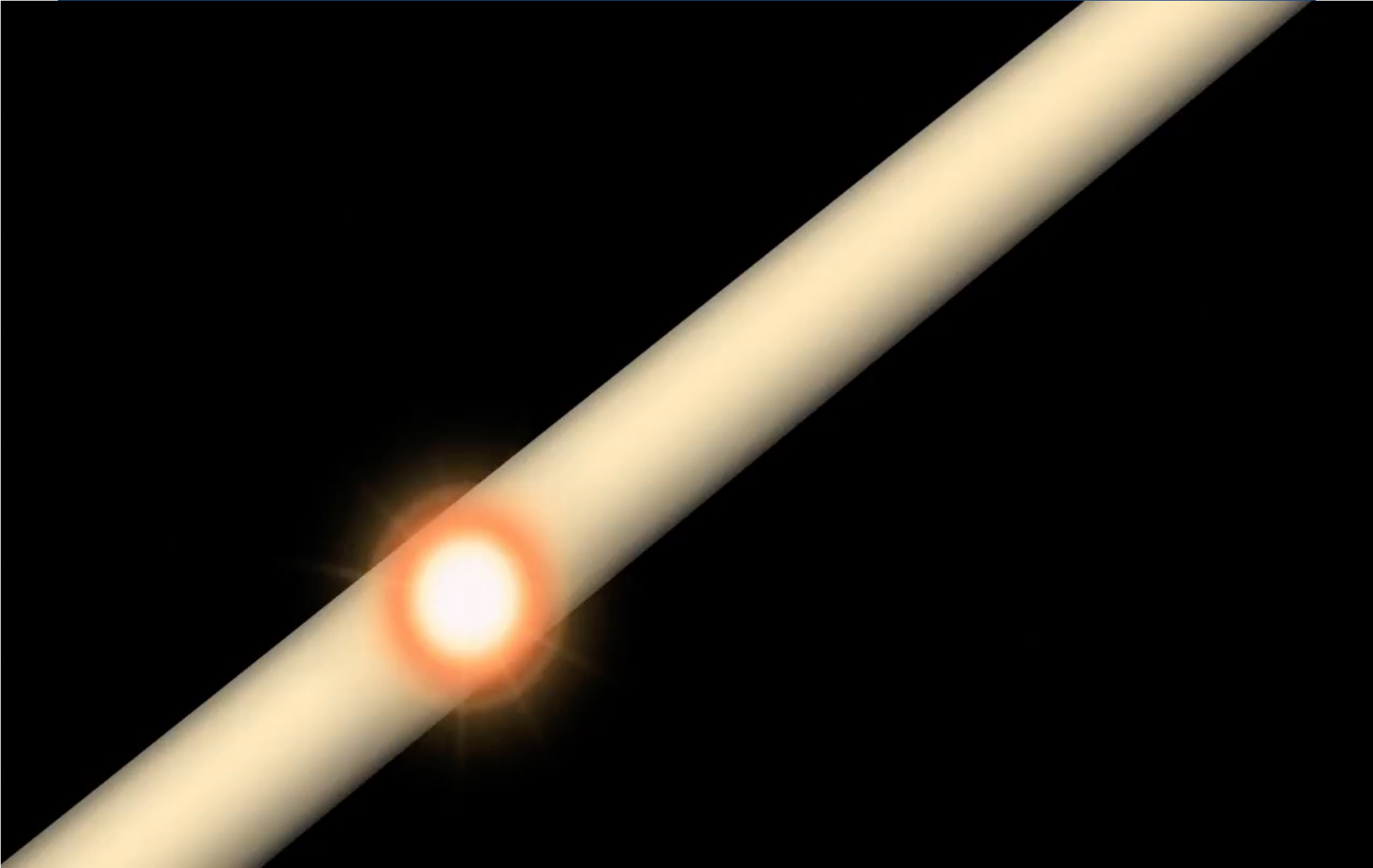
CERN's accelerator complex



LHC tunnel



High Energy Accelerator Chains

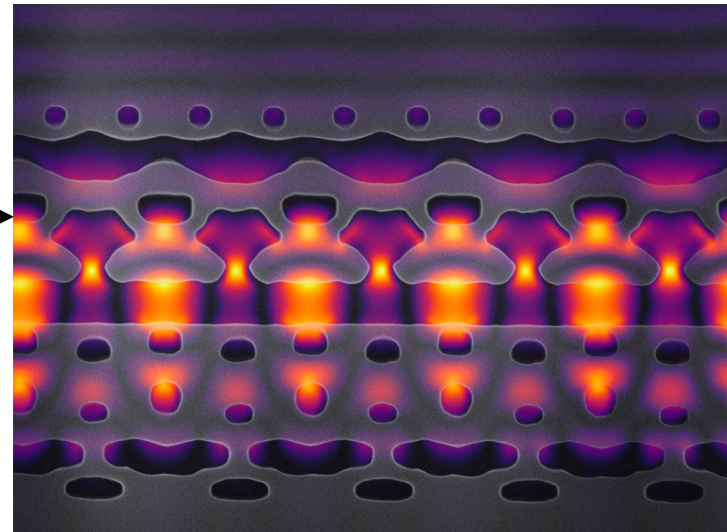


Future accelerator technologies

- Plasma Wakefield accelerators
 - Electron beams, can reach tens of GeV with high intensity in short distances
- On-chip particle accelerators
 - Build accelerator structure on a microchip
 - Electron beams, reach 1 keV with laser-driven beams
 - Use the fact that light can impart energy into electrons

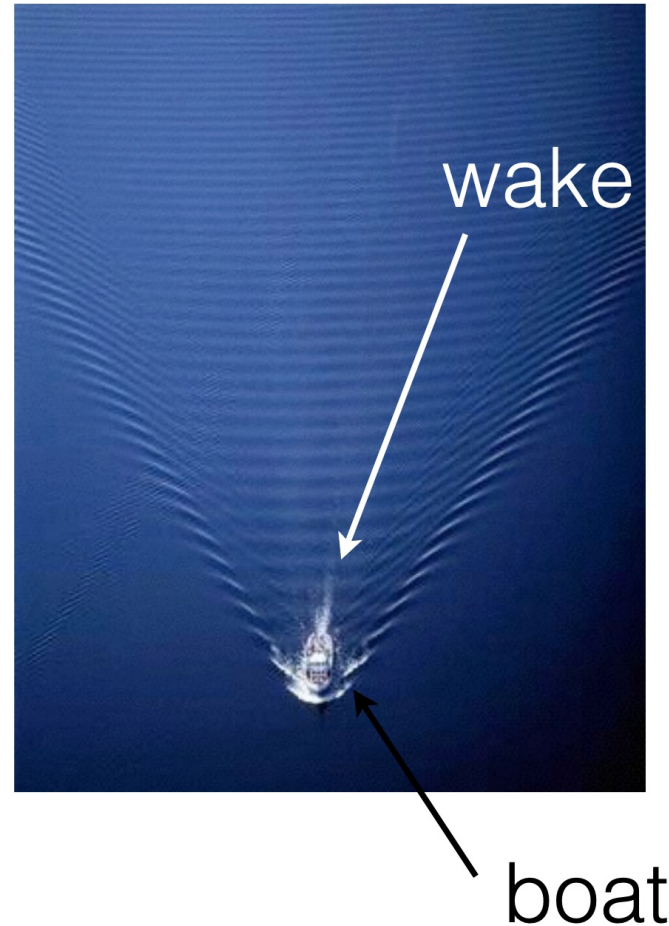
<https://science.sciencemag.org/content/367/6473/79/tab-pdf>

Electron channel
(beam pipe)

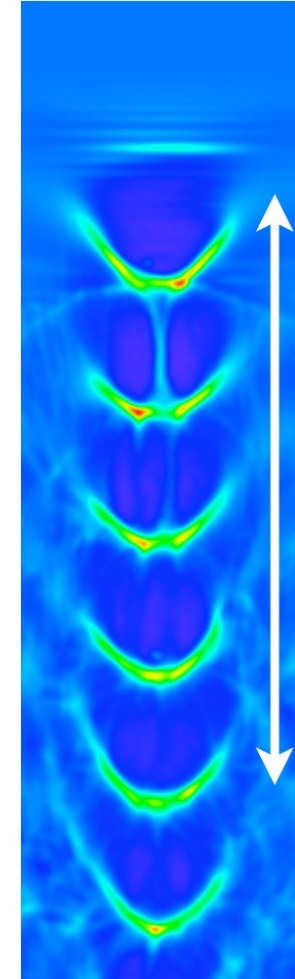


Plasma Wake Field accelerator

- Plasma: gas has sufficiently high temperature that some of the orbital electrons can move freely
- Wake on water:
 - A boat pushes water out of the way as it moves
 - The water rushes back in behind the boat
 - Produces large-amplitude waves
- Wake in plasma:
 - An electron beam or a laser of very high intensity pushes electrons out of the way
 - The electrons rush back in behind the laser
 - Produces large-amplitude waves



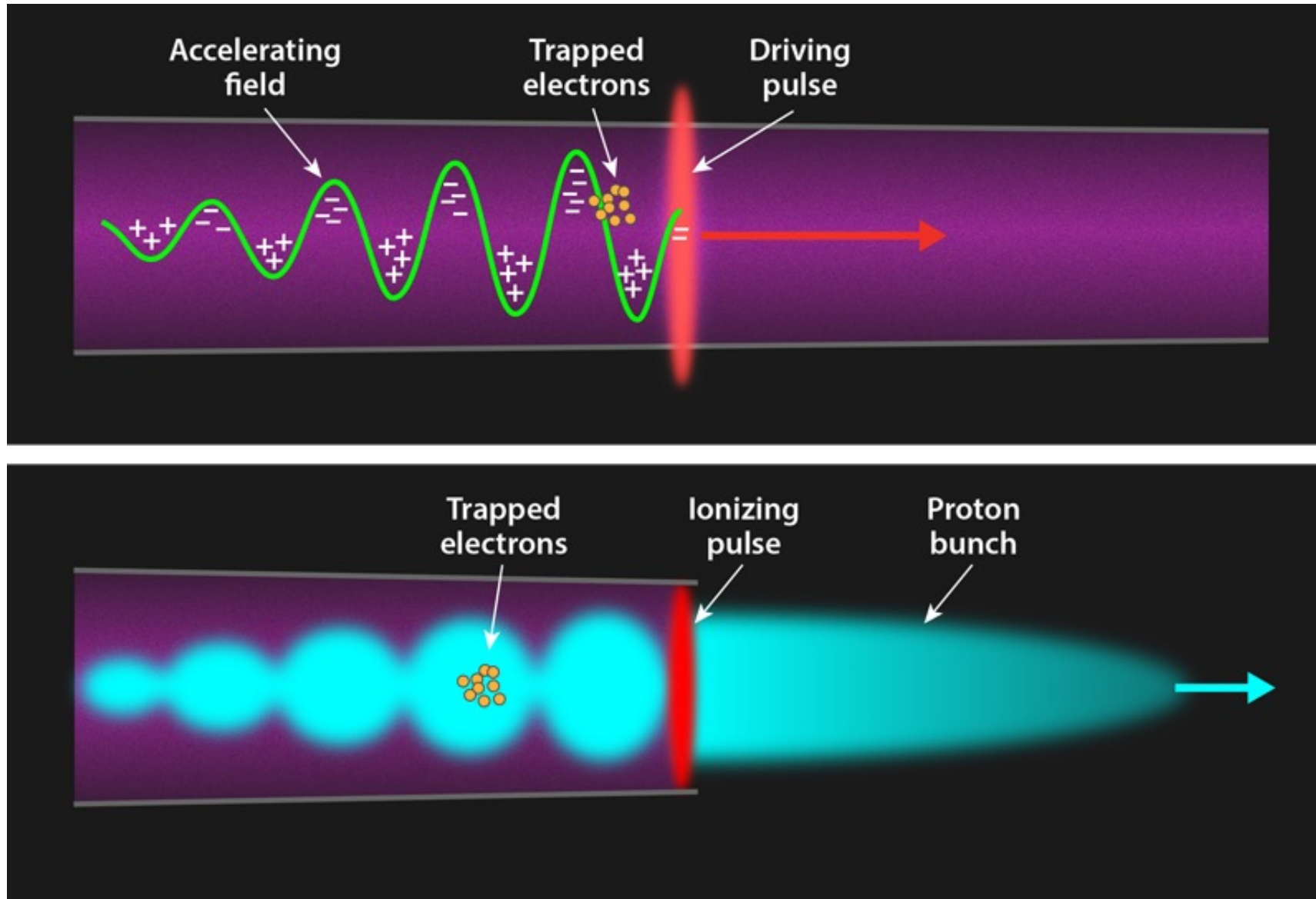
Electron in a plasma



50 μm

Can reach 100GeV/m

Plasma Wake Field accelerator

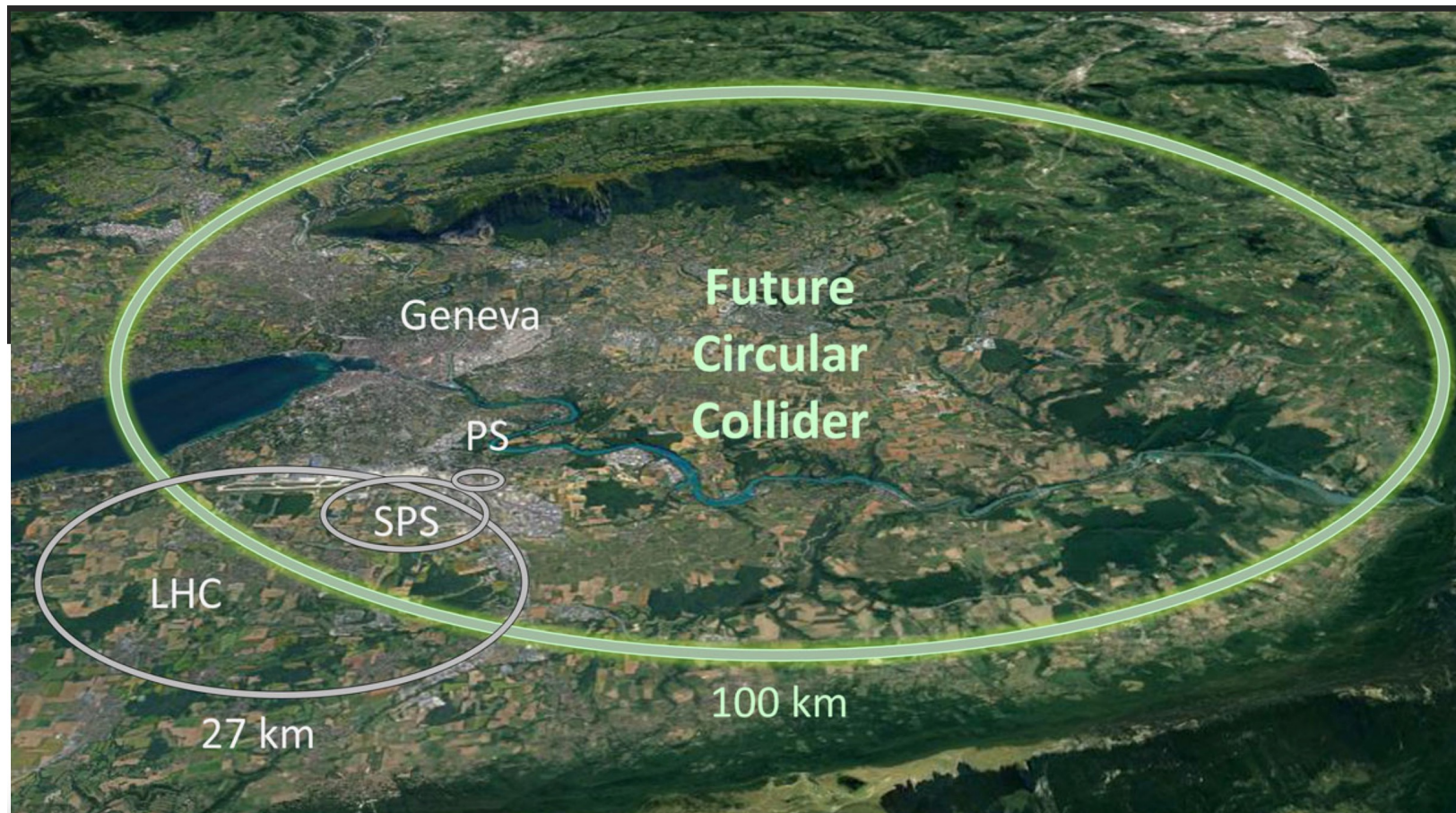


What collider will we build next?

- After “HLLHC” = High Luminosity LHC
- 30 collisions each time the beams meet -> 140 collisions

Bigger Circular Collider? - FCC

“Future Circular collider” = FCC



Start as e+e- collider

Potentially later update to p+p

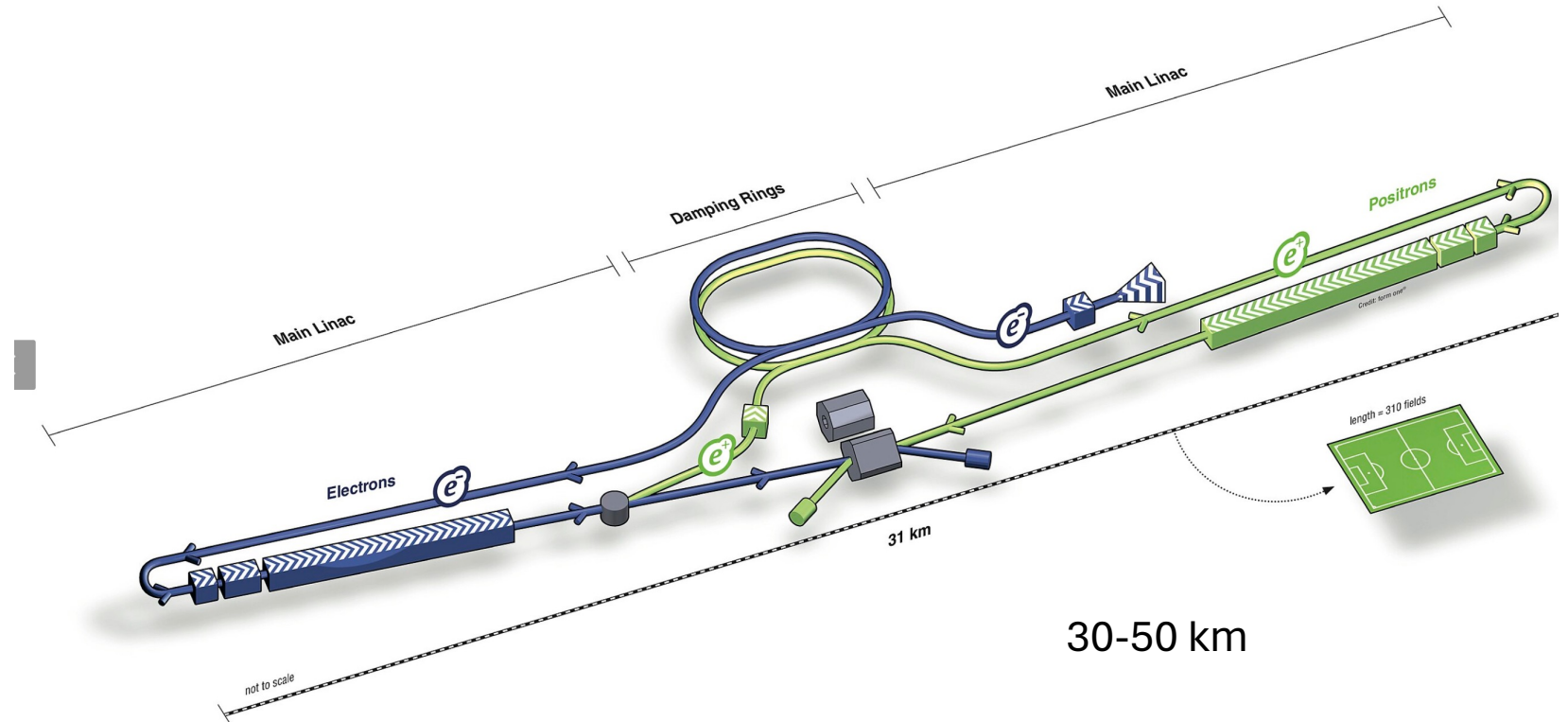
Similar story from LEP -> LHC

Very difficult – will need magnets 33% stronger than current state of the art (16 T) -> may not exist for 20+ years

International Linear Collider - ILC

No need to worry about synchrotron radiation in a linear collider

“Higgs factory” – study the details of the Higgs particle



Muon Collider

- Circular accelerator with muons
- 200 times heavier than electrons, so muons emit about two billion times less synchrotron radiation
- Can reach higher energies than similar sized e+e-
- Radius required is much smaller than a proton-proton collider
 - If you collide composite particles like protons, likely only two of the quarks will interact, so some of the energy is lost (~10% into new particles)
 - If you collide particles that are not composite e/μ all of the energy is transferred
- Challenges:
 - short lifetime of muon at rest
 - producing large numbers of muons in small bunches

$$P = \frac{q^2 c \gamma^4}{6\pi\epsilon_0 r^2}$$

$$\gamma = \frac{E}{mc^2}$$

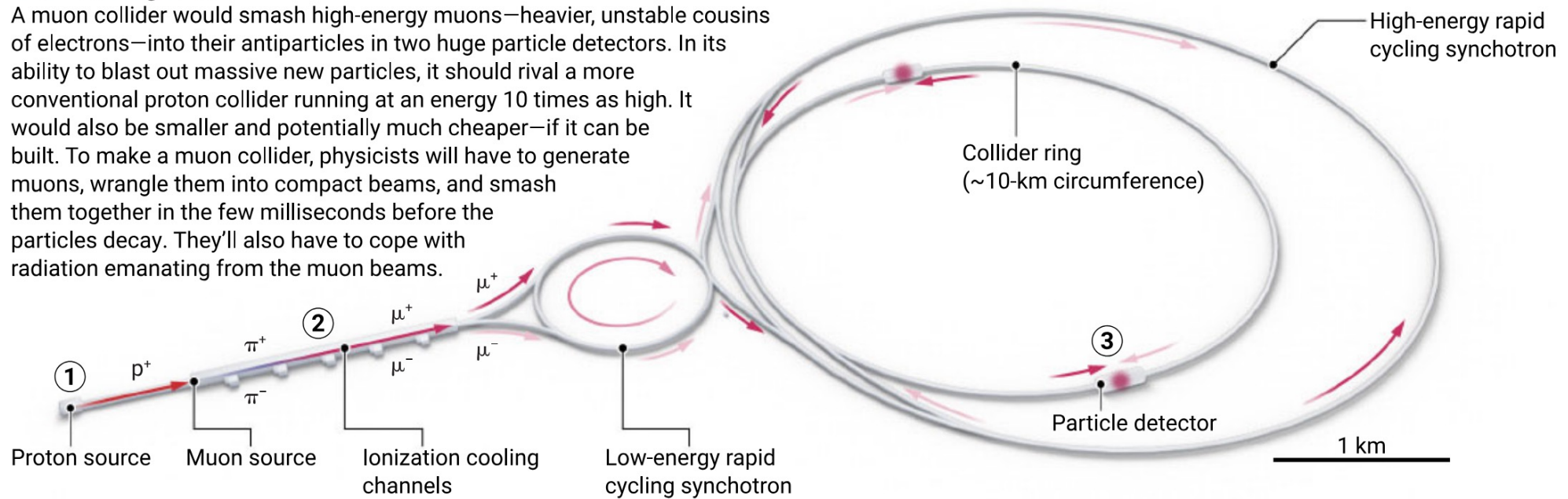


<https://www.science.org/content/article/muon-collider-could-revolutionize-particle-physics-if-it-can-be-built>

Muon Collider

A smashing idea

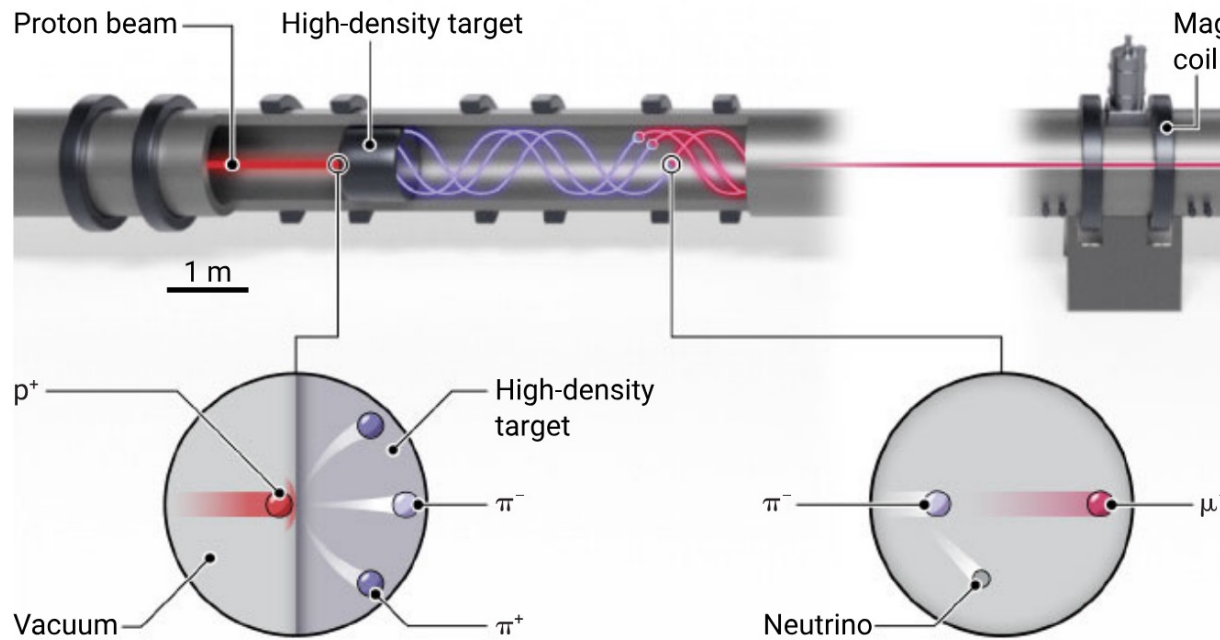
A muon collider would smash high-energy muons—heavier, unstable cousins of electrons—into their antiparticles in two huge particle detectors. In its ability to blast out massive new particles, it should rival a more conventional proton collider running at an energy 10 times as high. It would also be smaller and potentially much cheaper—if it can be built. To make a muon collider, physicists will have to generate muons, wrangle them into compact beams, and smash them together in the few milliseconds before the particles decay. They'll also have to cope with radiation emanating from the muon beams.



Muon Collider

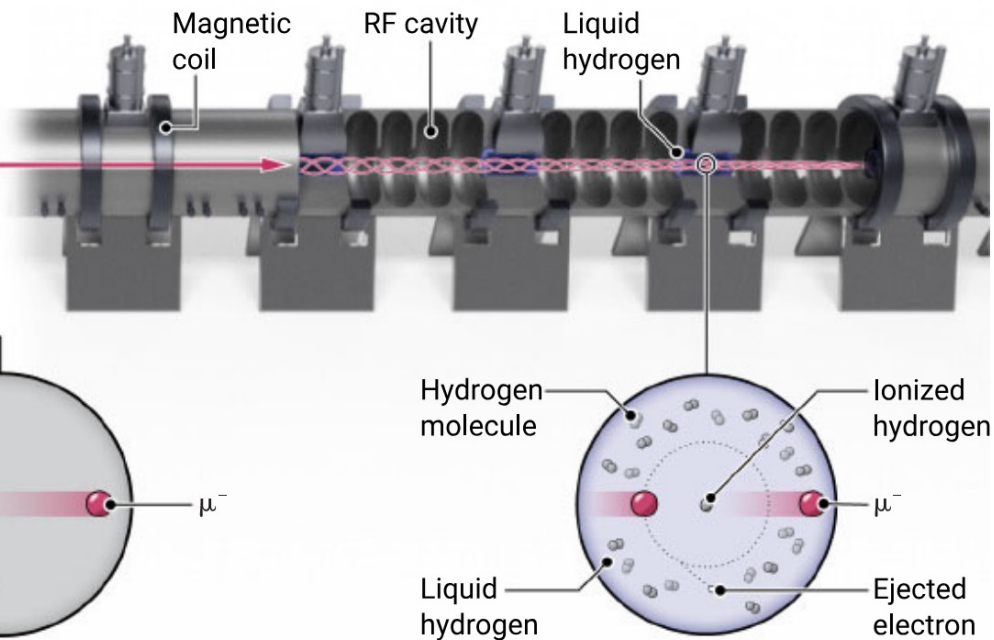
1 Making muons

Protons (p^+) fired into a graphite target would generate negatively charged pions (π^-), which would decay in flight to make negatively charged muons (μ^-). The collisions would also yield positive pions (π^+), which would decay into positively charged antimuons (μ^+).



2 Bunching them into beams

The muons would pass through a material such as liquid hydrogen and lose energy as they ionize the atoms. The loss would make them swirl in a magnetic field in ever-tighter spirals while RF cavities would accelerate them in one direction, forming a compact beam. Realizing such ionization cooling may be physicists' biggest challenge.



Then measure in detectors