High Energy Accelerator Chains

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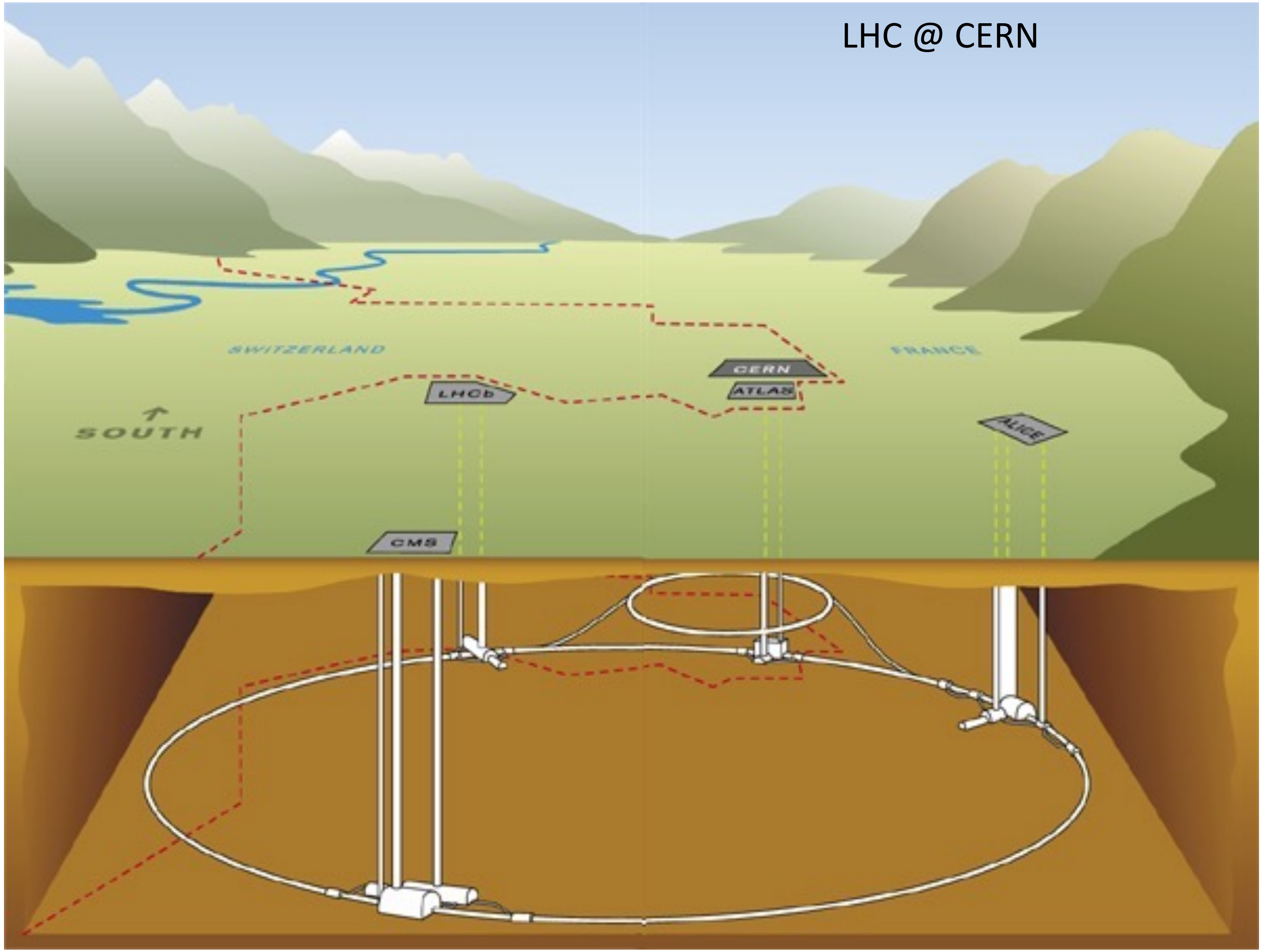
LHC @ CERN

- Circumference: 27 km

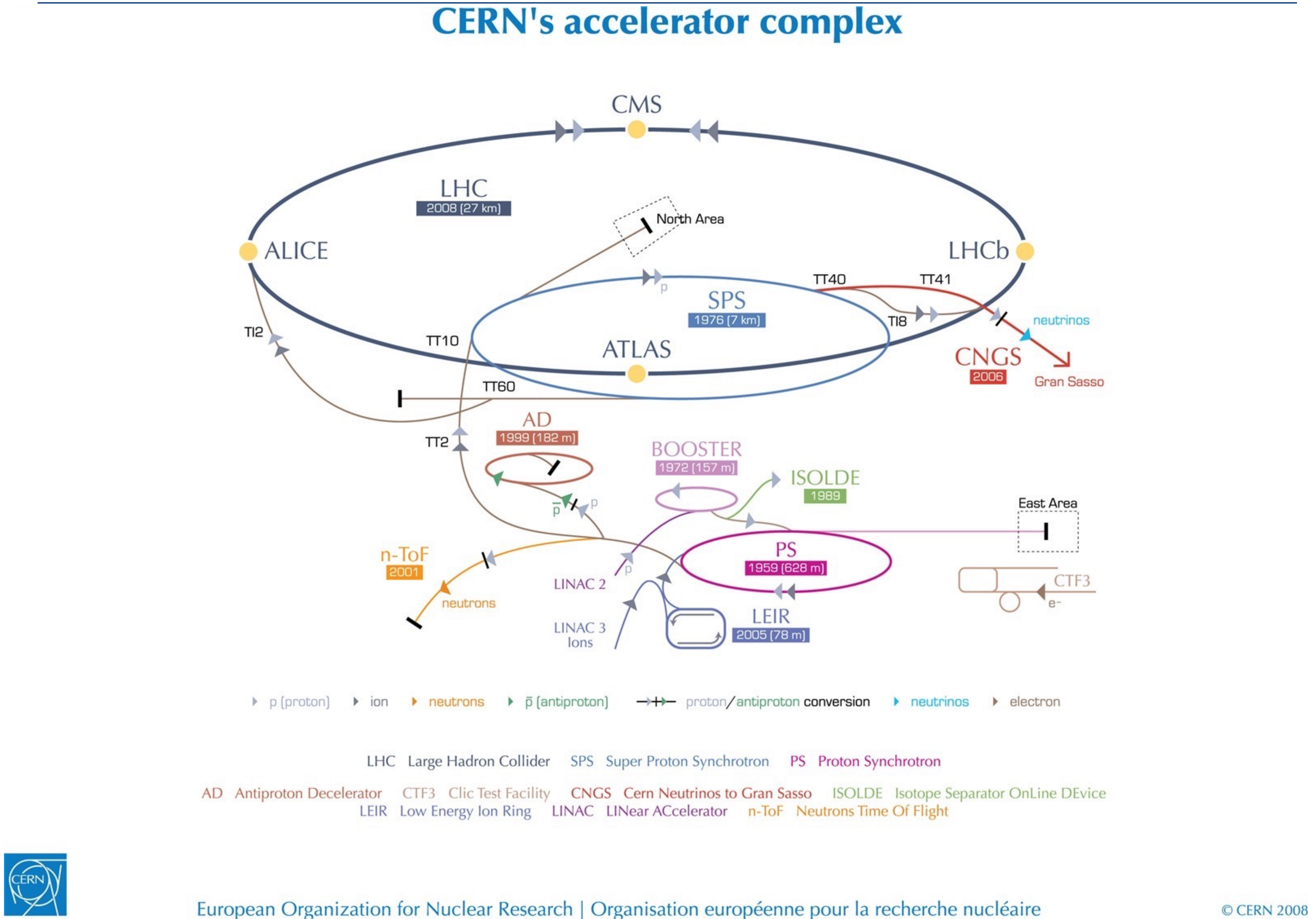
- Current proton kinetic energy: 6.5 TeV
  - 99.999999% of speed of light
  - 3 m/s slower than light

- Current total energy in beam: 336 MJ
  - Equivalent to an aircraft carrier moving at 5.8 MPH

High Energy Accelerator Chains

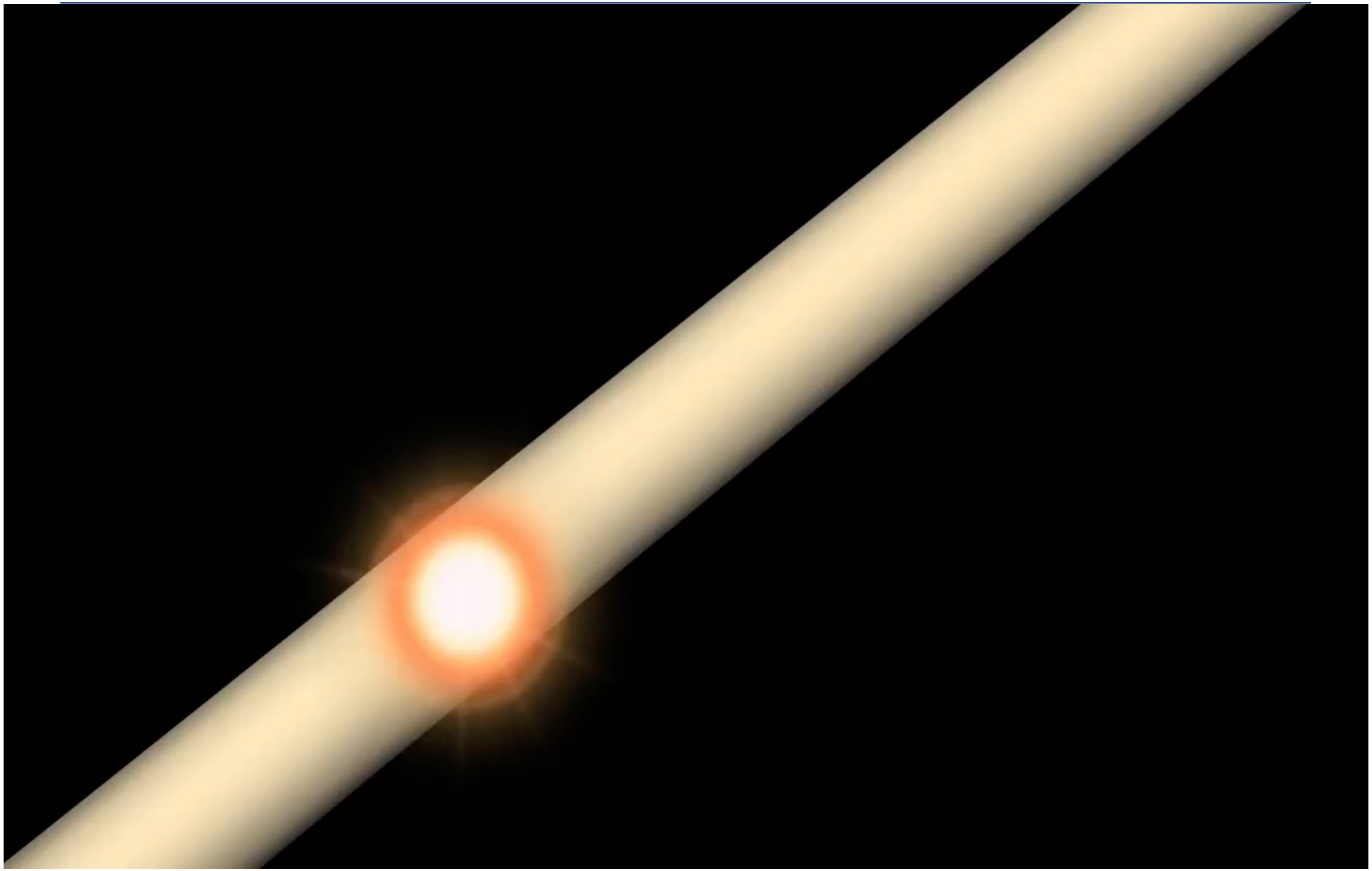


High Energy Accelerator Chains



LHC tunnel

High Energy Accelerator Chains

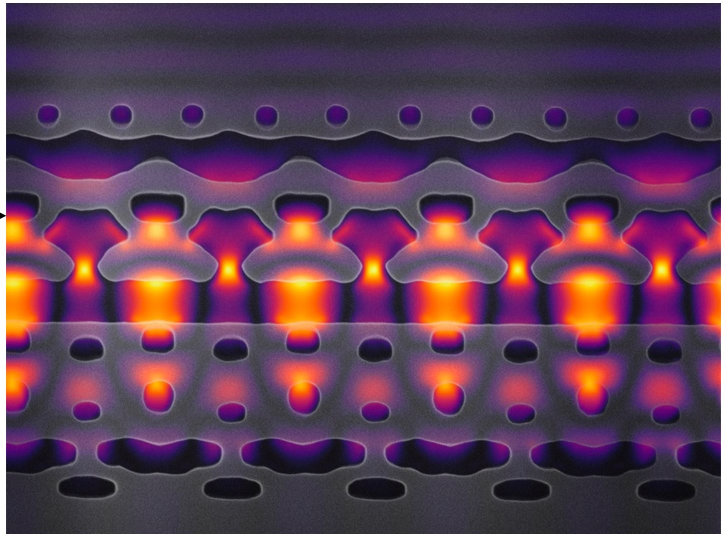


Future accelerator technologies

- 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

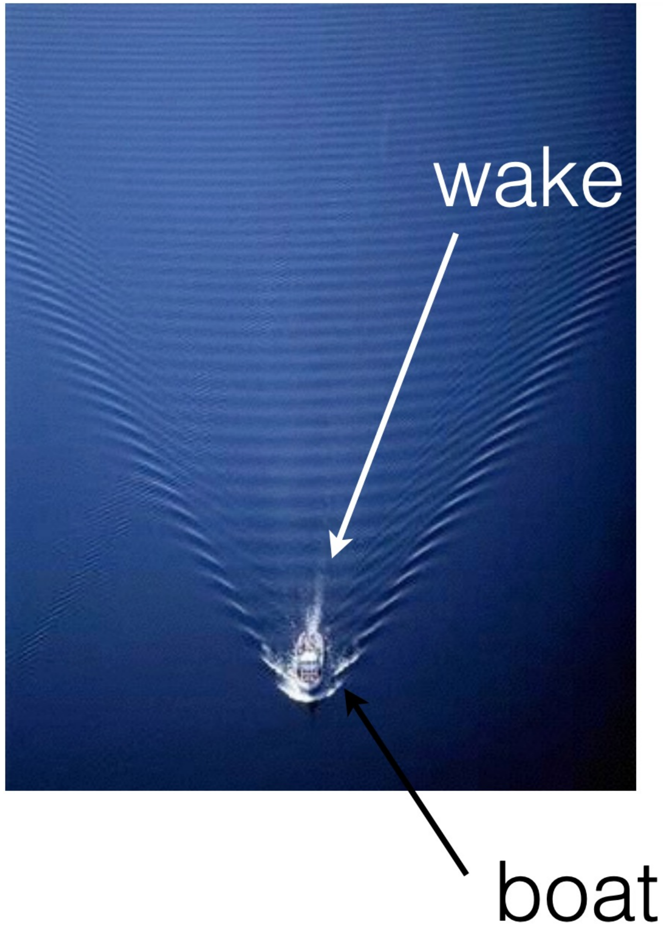
https://science.sciencemag.org/content/367/6473/79/tab-pdf

Electron channel
(beam pipe)

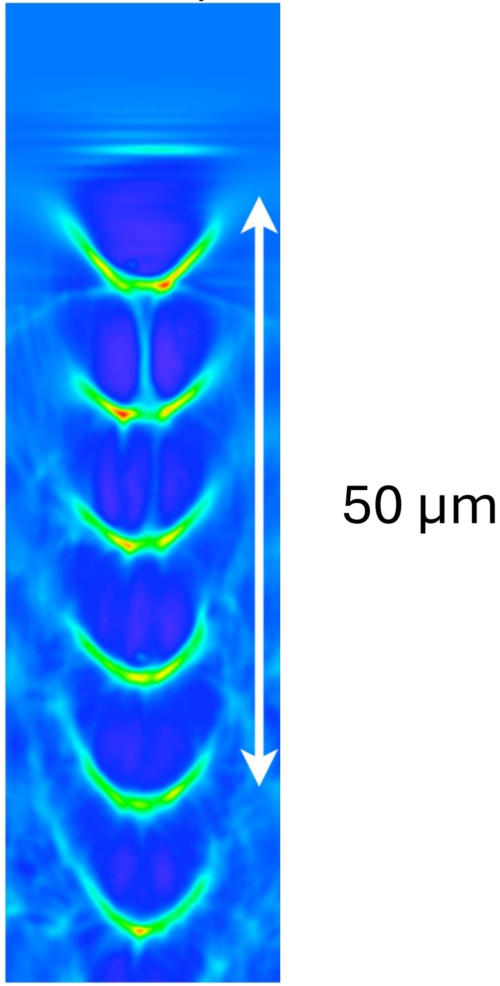


Plasma Wake Field accelerator

- 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

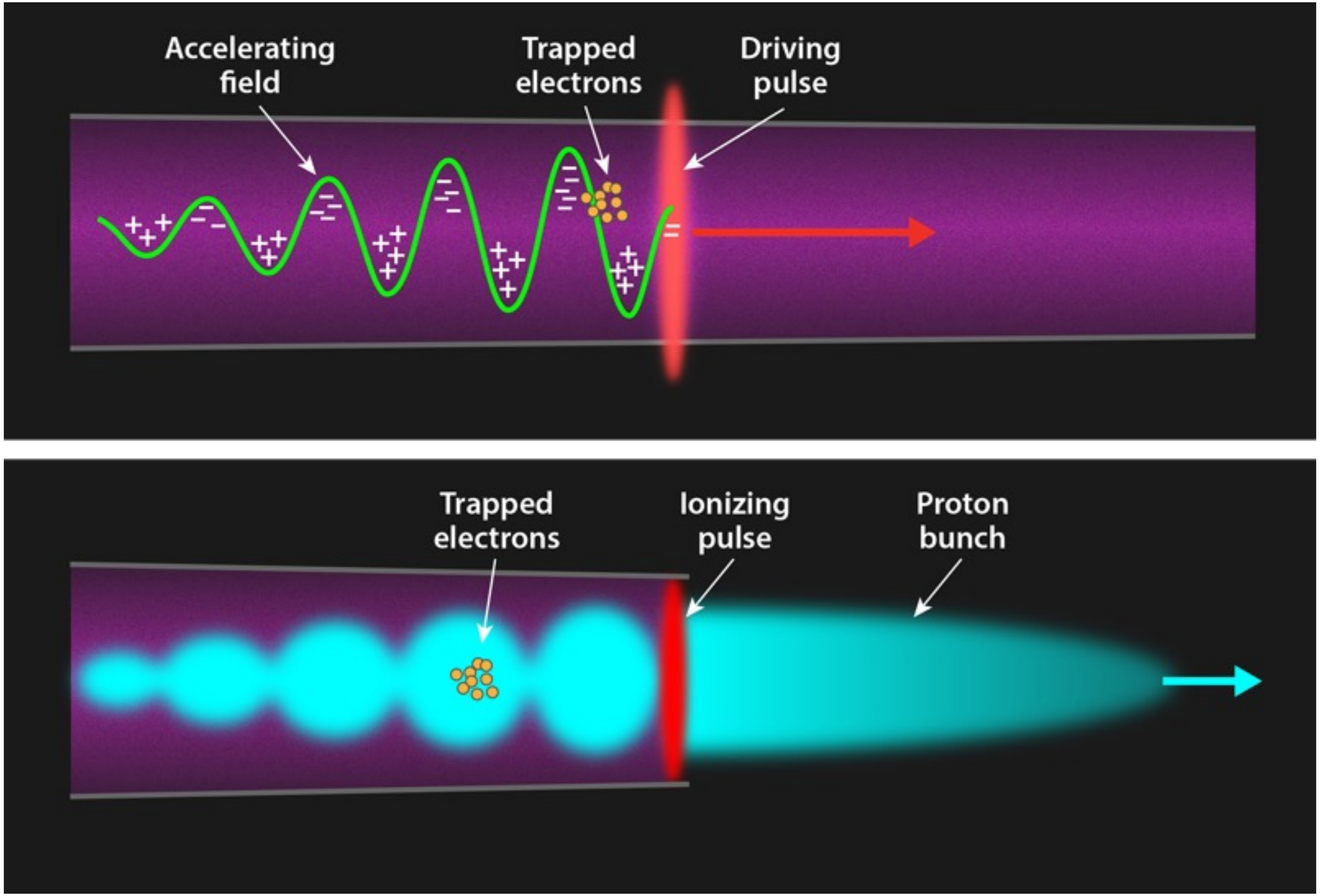


Electron in a plasma



Can reach 100GeV/m

Plasma Wake Field accelerator



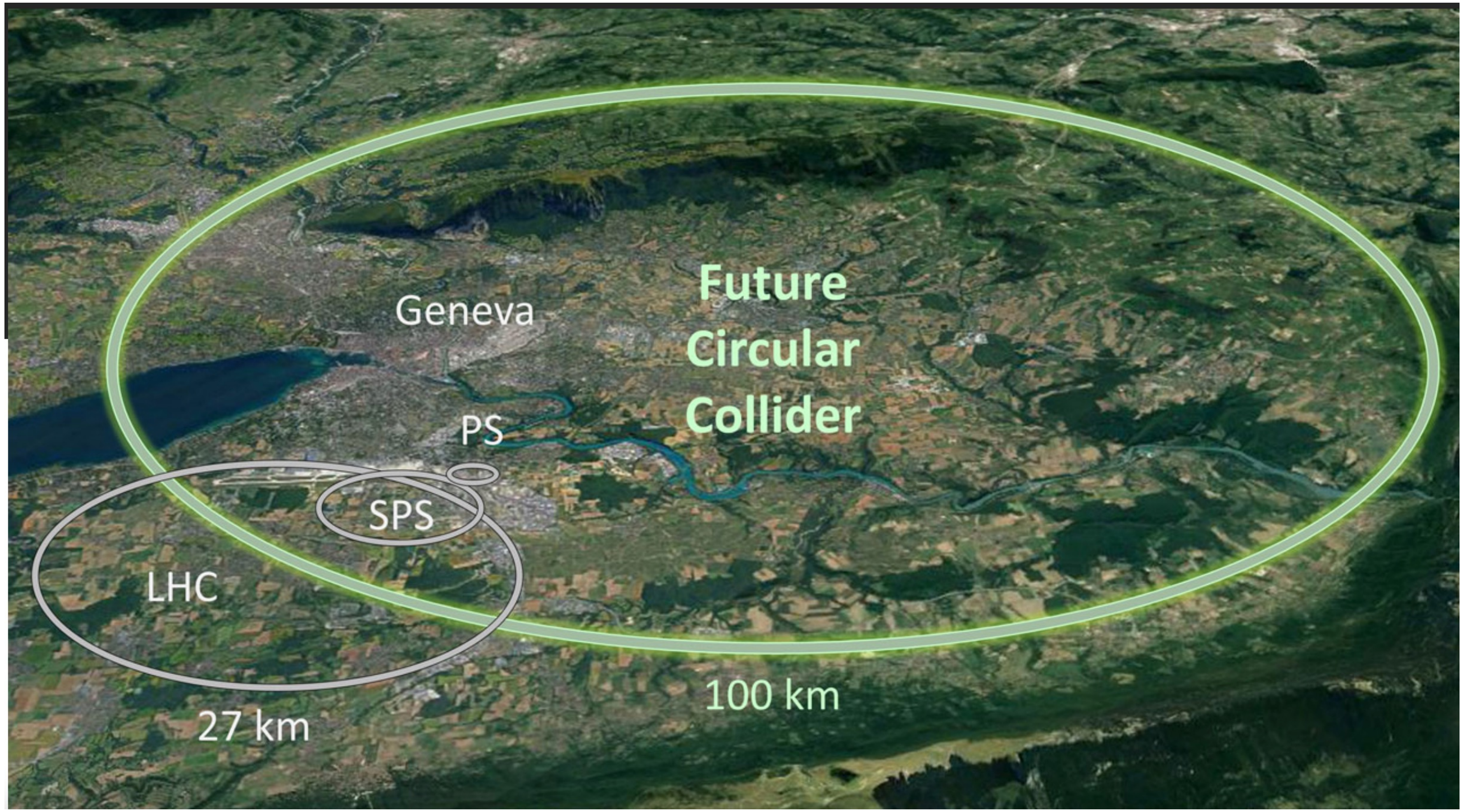
What collider will we build next?

- 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

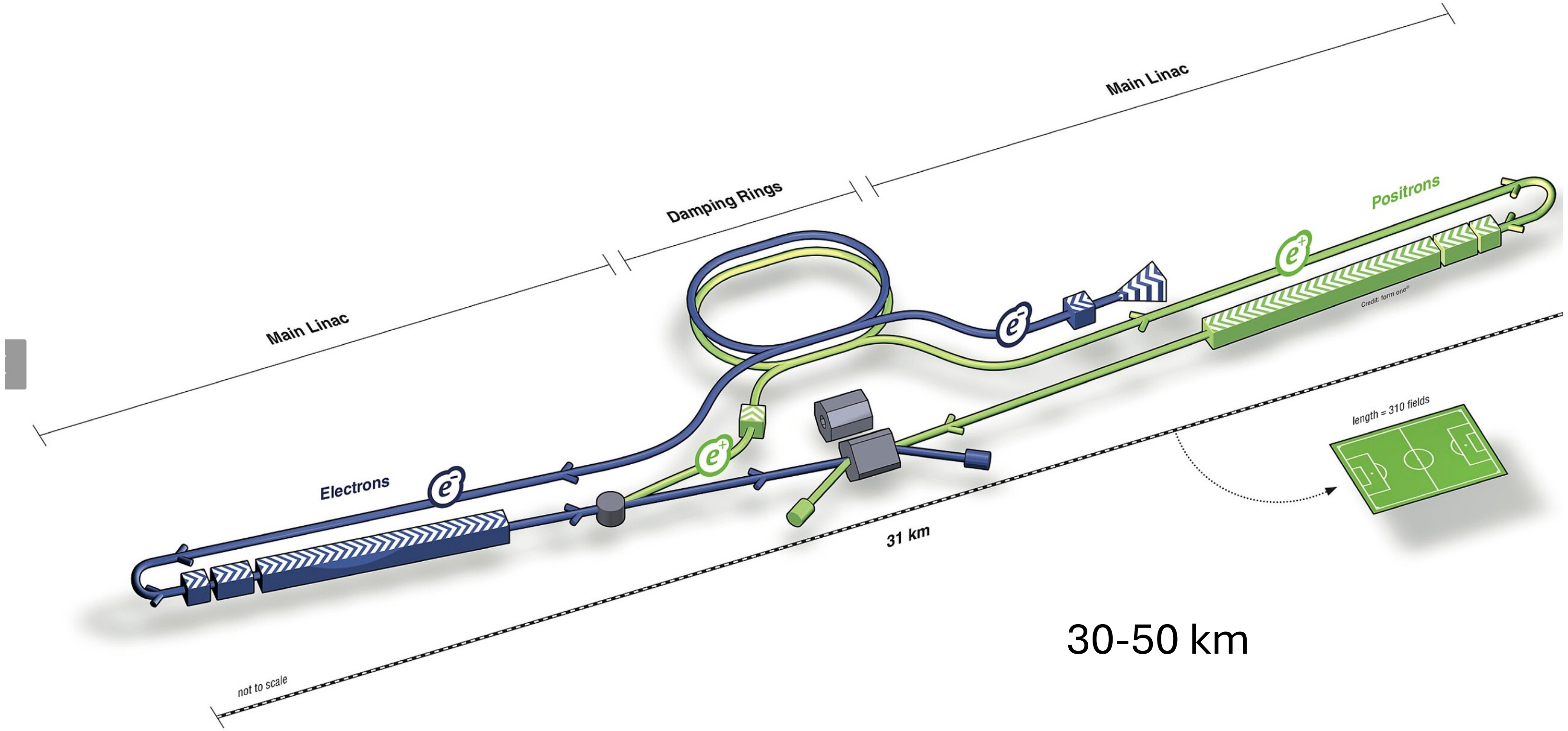
Very difficult – will need magnets 33% stronger than current state of the art (16 T) -> may not exist for 20+ years

https://www.science.org/content/article/european-physicists-boldly-take-small-step-toward-100-kilometer-long-atom-smasher

International Linear Collider - ILC

No need to worry about synchrotron radiation in a linear collider

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



30-50 km

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

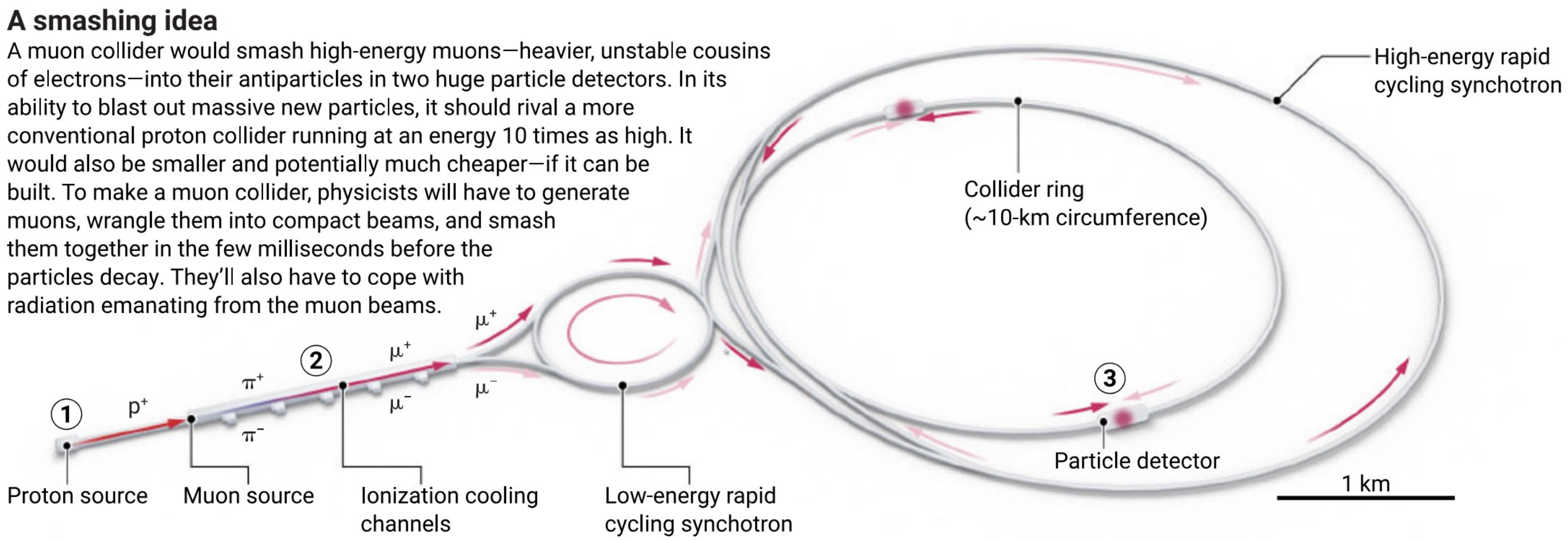
$$P = \frac{q^2 c \gamma^4}{6\pi\epsilon_0 r^2}$$

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

International MUON Collider Collaboration

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

Muon Collider



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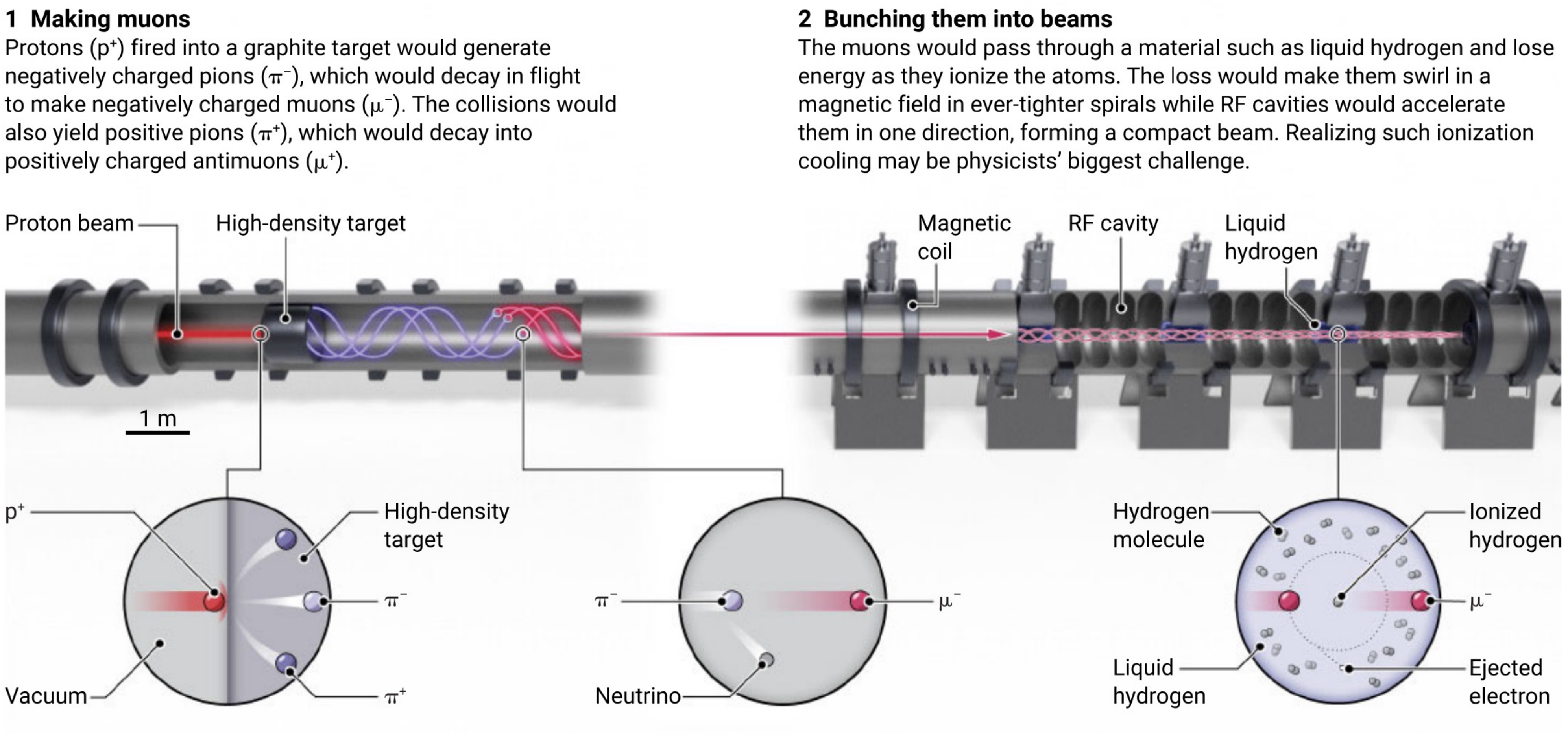
Muon Collider



Then measure in detectors

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