Particle accelerators

A. Cianchi

Source	→	Accelerator	→	Target

T_i T_f
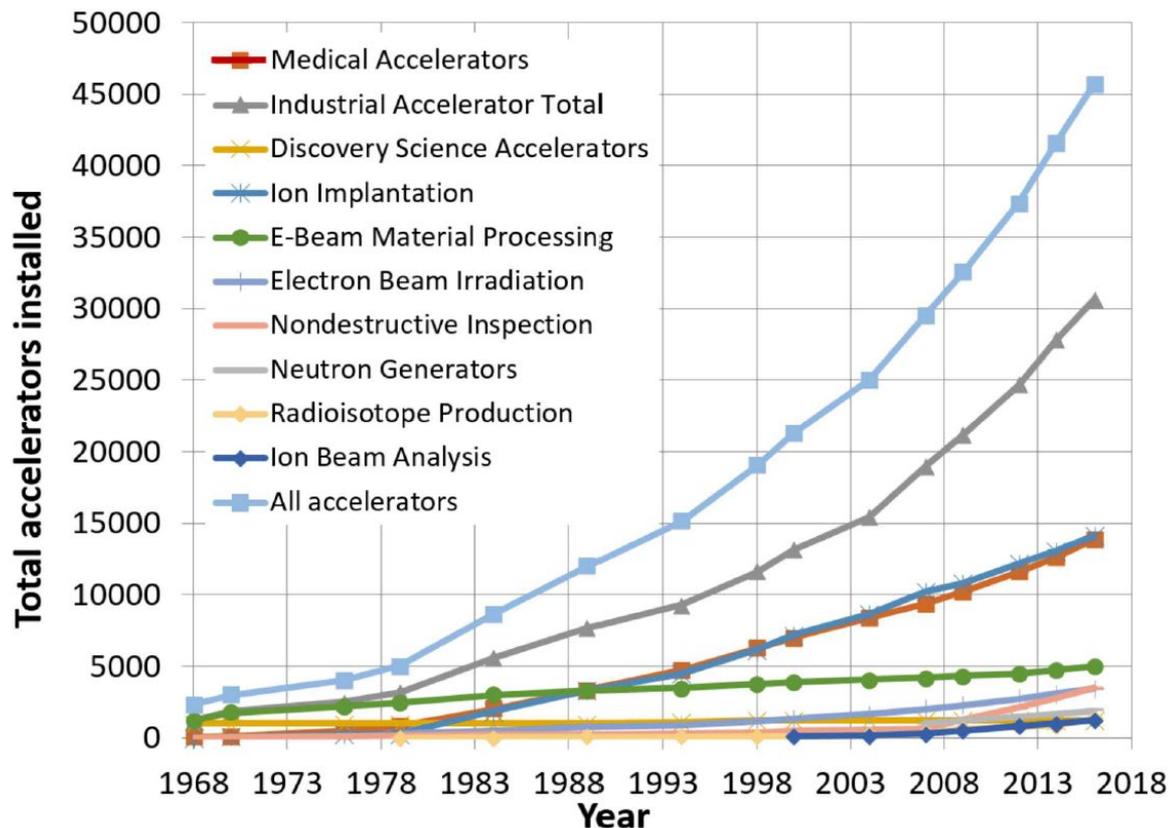
- **It is a device that transfers energy to charged particle by electromagnetic or electrostatic fields. The particles are injected at initial energy of T_i and they arrive to final energy T_f.**

Accelerators in the world

Accelerators Installed Worldwide

Doyle, Barney L., Floyd "Del McDaniel, and Robert W. Hamm. "The Future of Industrial Accelerators and Applications." Reviews of Accelerator Science and Technology 10.01 (2019): 93-116.

- *"A beam of the right particles with the right energy at the right intensity can shrink a tumor, produce cleaner energy, spot suspicious cargo, make a better radial tire, clean up dirty drinking water, map a protein, study a nuclear explosion, design a new drug, make a heat-resistant automotive cable, diagnose a disease, reduce nuclear waste, detect an art forgery, implant ions in a semiconductor, prospect for oil, date an archaeological find, package a Thanksgiving turkey or...*

...discover the secrets of the universe."

-Accelerators for Americas Future
Report, pp. 4, DoE, USA, 2011

- 1 eV: energy of a particle di charge e, initially at rest, after the acceleration by a potential of 1 V

- 1 eV= 1.60219 10^{-19} J

- 1 keV = 10^3 eV ;   1 MeV = 10^6 eV
- 1 GeV = 10^9 eV;   1 TeV = 10^{12} eV

- **Energy of a proton in the LHC: 7 TeV =1.12 x 10^{-6}J**
- the same energy of a body of mass = 1 mg moving at speed = 1.5 m /s (a mosquito!)

$$\gamma = \frac{E + E_0}{E_0}$$

- E_0 Elettrone = 0.511 MeV
- E_0 Protone = 938 MeV
- Elettrone 1 GeV, γ=1958
- Protone 1 TeV, γ=1067

$$E^2_{cm} = \left(\sum_i E_i\right)^2 - \left(\sum_i cp_i\right)^2$$

$$E^2_{cm} = (\gamma_1 m_1 + \gamma_2 m_2)^2 c^4 - (\gamma_1\beta_1 m_1 + \gamma_2\beta_2 m_2)^2 c^4$$

Stationary target

$$\gamma_2 = 1 \quad \beta_2 = 0 \quad \beta\gamma = \sqrt{\gamma^2 - 1}$$

$$E^2_{cm} = (\gamma + 1)^2 m^2 c^4 - (\gamma^2 - 1)m^2 c^4$$

$$E_{cm} = \sqrt{2(\gamma + 1)}mc^2$$

$$E_{avail} = E_{CM} - 2mc^2 = \left(\sqrt{2(\gamma+1)} - 2\right)mc^2$$

Colliding beam

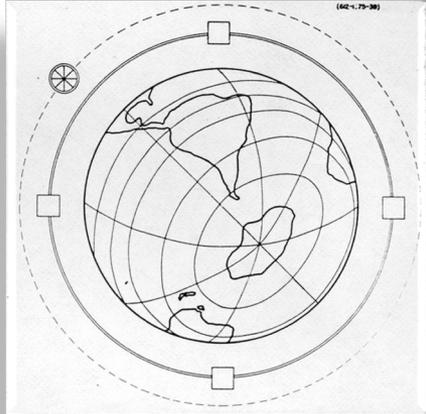$$\gamma_1 = \gamma_2 = \gamma \quad \beta_1 = -\beta_2$$

$$E_{cm} = 2\gamma mc^2$$
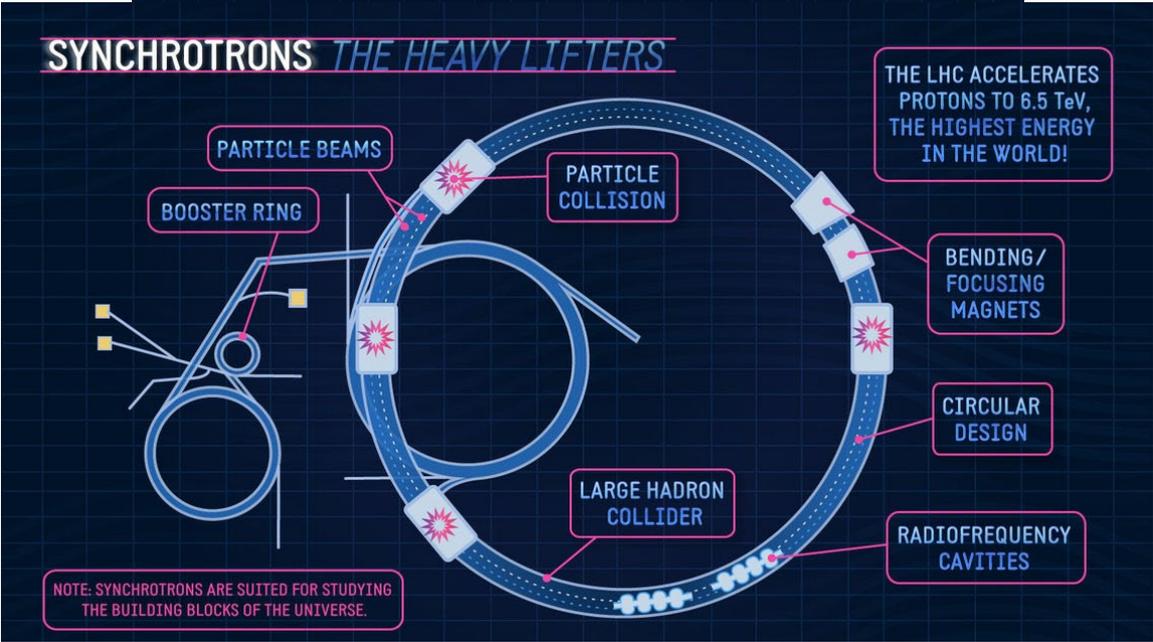
1954 Fermi Globatron

- **5000 TeV, fixed target 3 TeV cm**

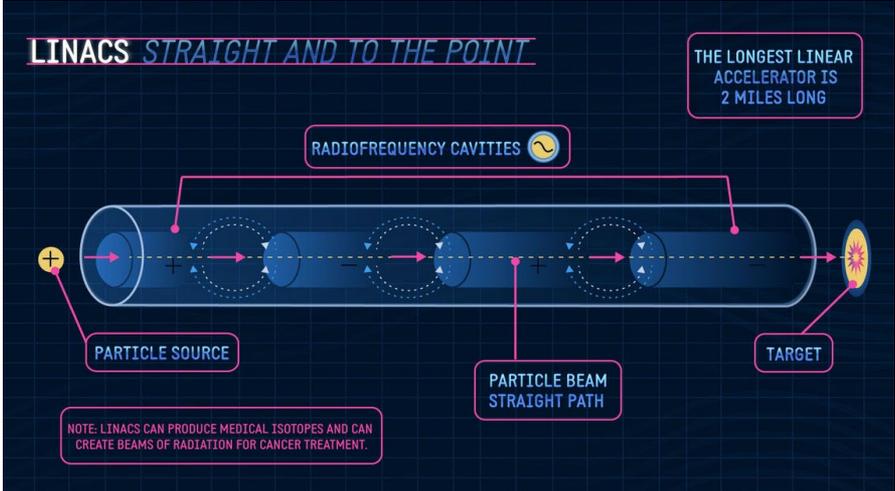**Bruno Touschek**

**AdA the first electron positron storage ring.
Built and operated at Frascati, and later moved to take advantage of a more powerful source of positrons in France.**
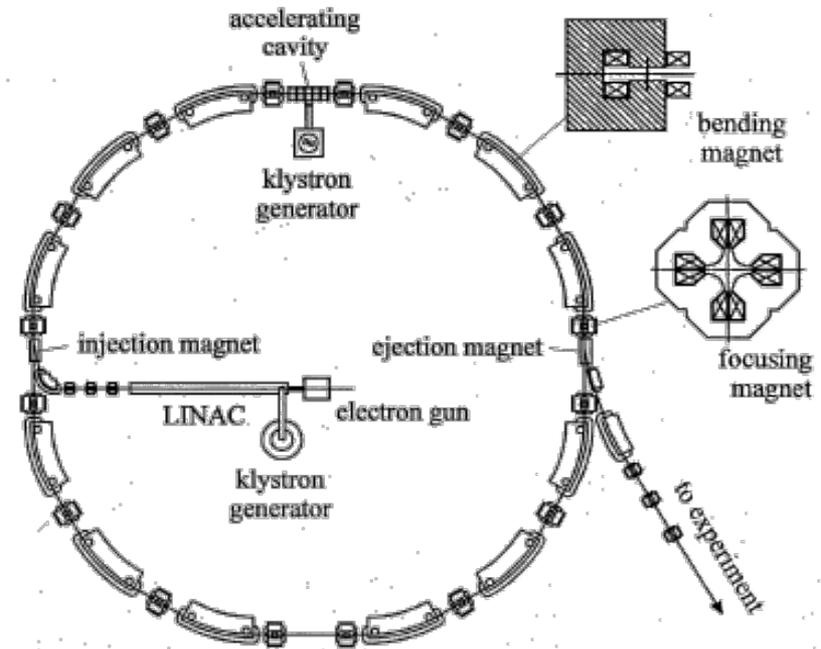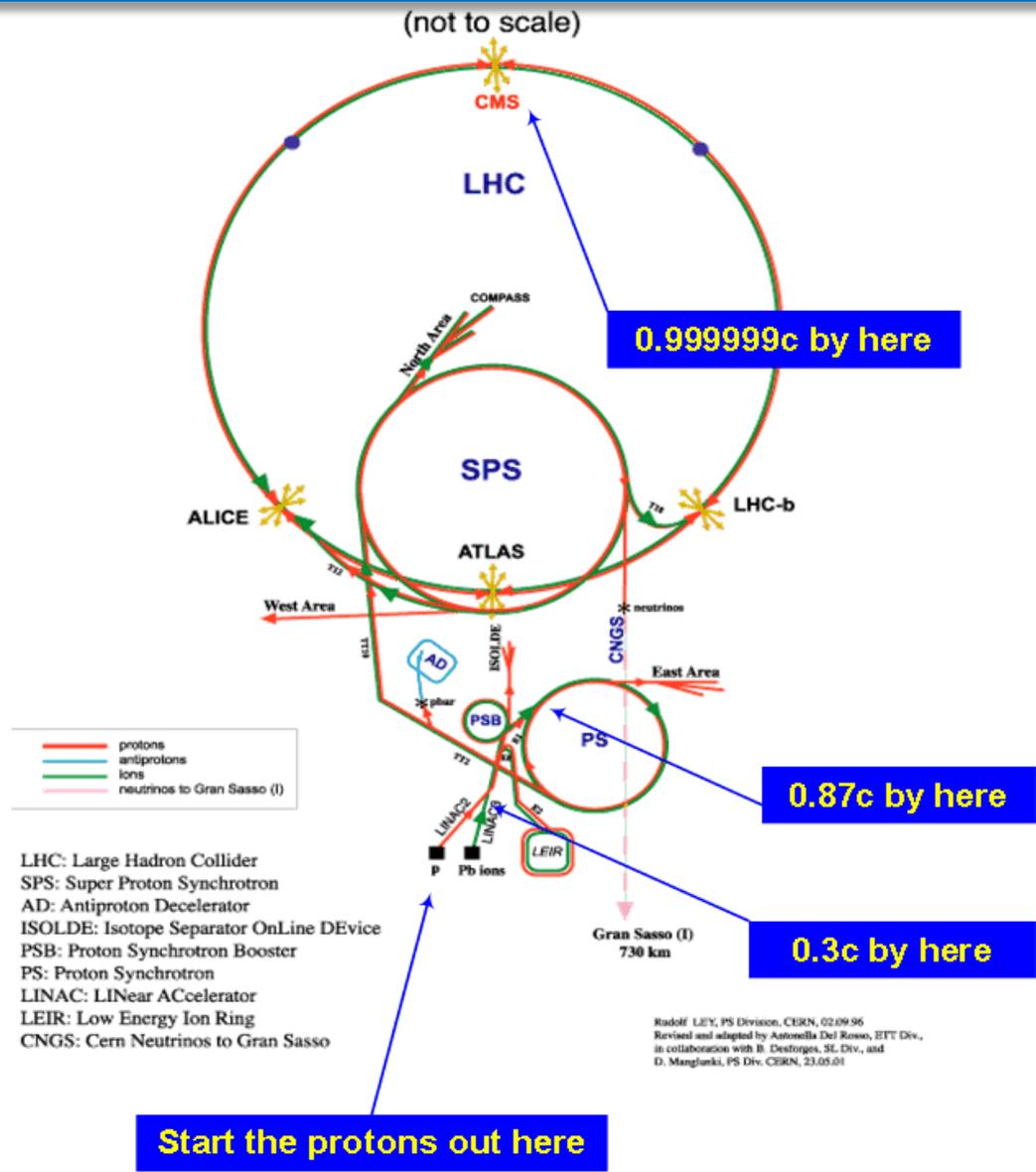
Linar vs circular accelerator

- **The solution is to keep the radius constant**
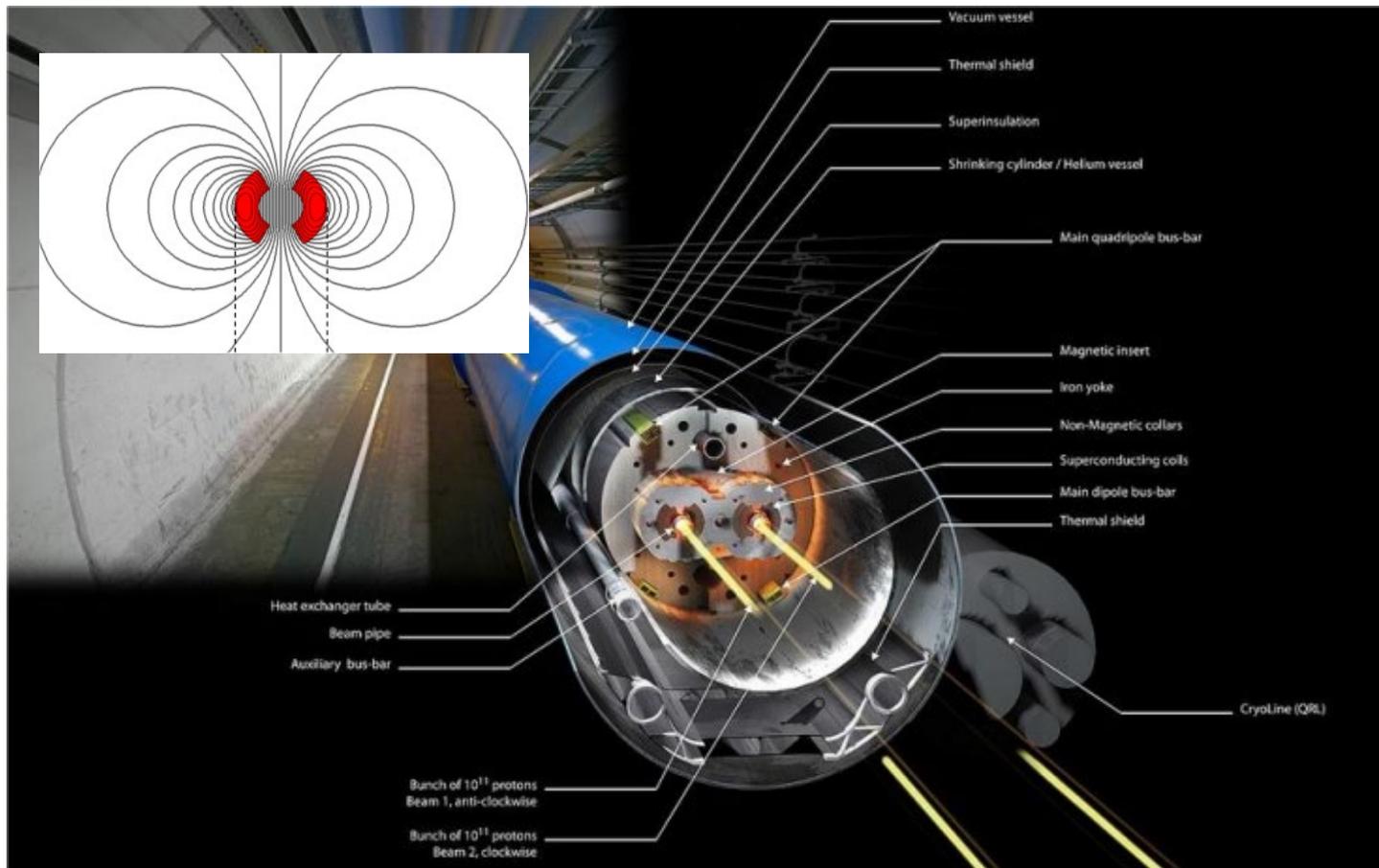- **The magnetic field is generated by small magnetic element around the ring**

$$\frac{1}{R} = \frac{eB}{p}$$

(not to scale)

CMS

LHC

COMPASS

North Area

0.999999c by here

SPS

ALICE

ATLAS

LHC-b

West Area

neutrinos

East Area

CNGS

AD

ISOLDE

PSB

PS

0.87c by here

LINAC2

LINAC3

LEIR

P   Pb ions

protons
antiprotons
Ions
neutrinos to Gran Sasso (I)

0.3c by here

LHC: Large Hadron Collider
SPS: Super Proton Synchrotron
AD: Antiproton Decelerator
ISOLDE: Isotope Separator OnLine DEvice
PSB: Proton Synchrotron Booster
PS: Proton Synchrotron
LINAC: LINear ACcelerator
LEIR: Low Energy Ion Ring
CNGS: Cern Neutrinos to Gran Sasso

Gran Sasso (I)
730 km

Rudolf LEY, PS Division, CERN, 02.09.96
Revised and adapted by Antonella Del Rosso, ETT Div.,
in collaboration with B. Desforges, SL Div., and
D. Manglunki, PS Div. CERN, 23.05.01

Start the protons out here

Beyond 2T → Superconductive magnets

- 2835 bunches with $1.15 * 10^{11}$ protons each;
- 332 MJ per beam;
- 1232 dipoles of 8.3 T;
- more than 400 quadrupoles;
- 0.58 A per beam
- Energy up to 14 TeV in the center of mass;
- Luminosity 10^{34} cm^{-2} s^{-1};
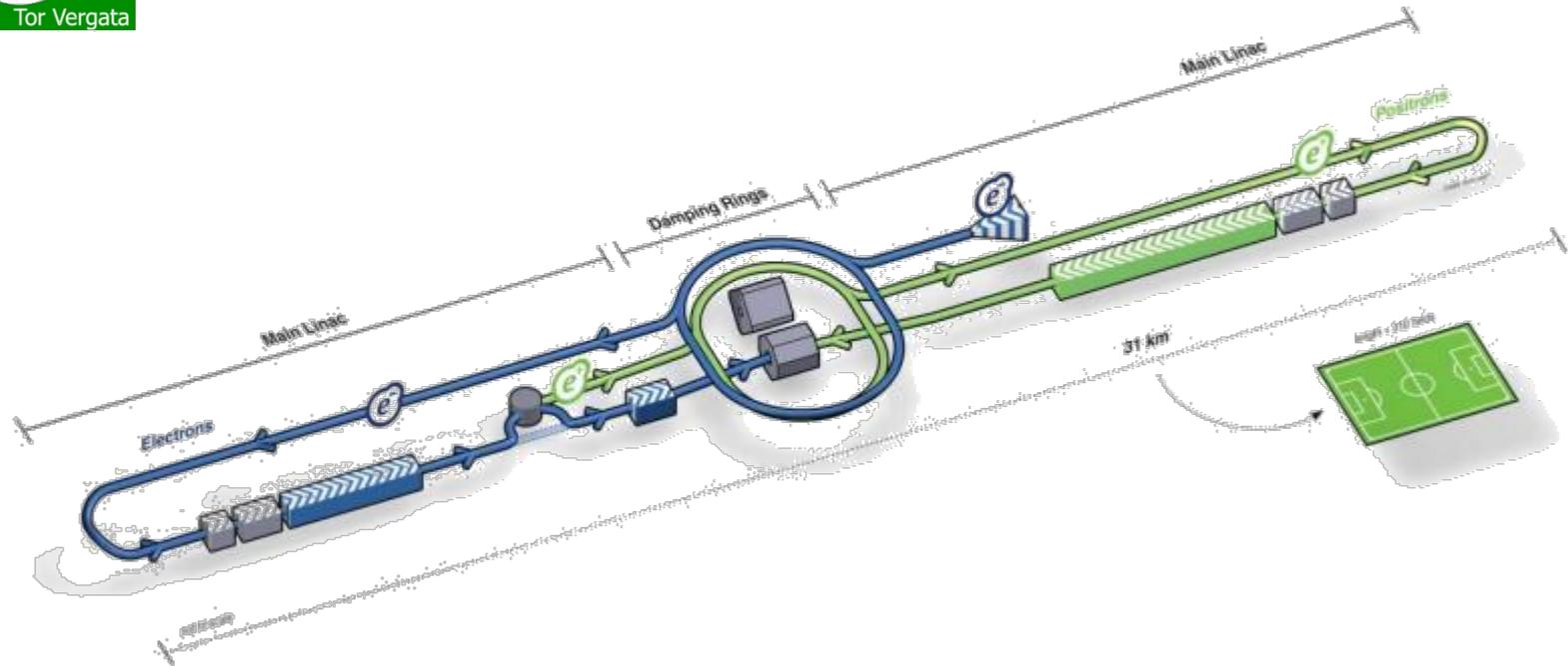
- Energy of A380 at 700 km/h corresponds to energy stored in the LHC magnet system!
- Sufficient to heat up and melt 12 tons of copper!

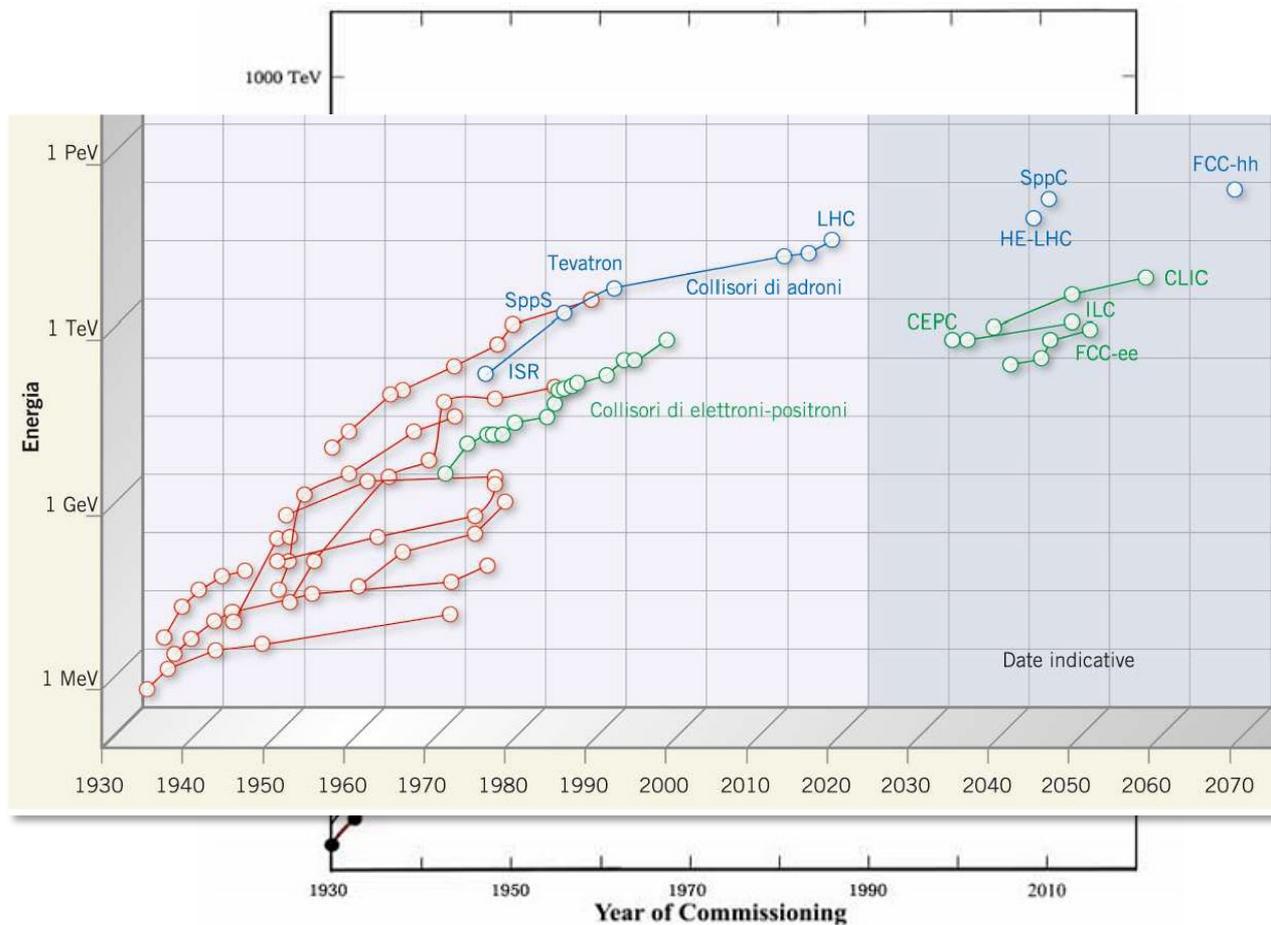- Magnets power (600 MJ) + Beam Power (362 MJ) about 1 GJ

Linac collider

few magnets, many cavities → need efficient power production

• higher gradient → shorter linac

• single pass → need small cross-section

• exceptional beam quality, alignment and stabilization

2025

20??