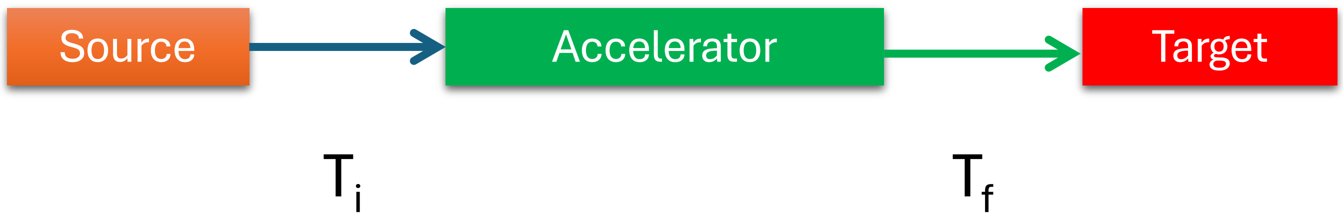
Particle accelerators

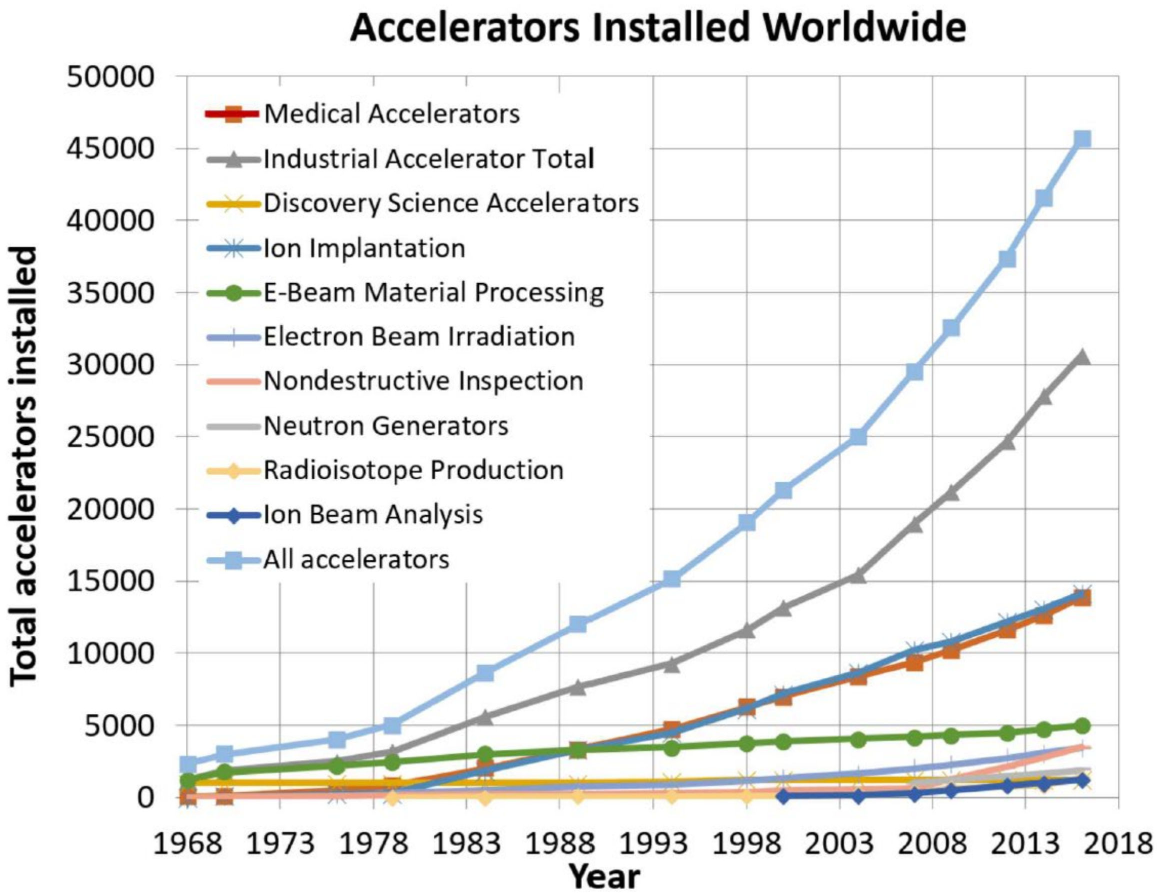
A. Cianchi

What is an accelerator?



- 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



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.

Università di Roma Tor Vergata

Next time someone asks you what accelerators are for

- *"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

Units

- 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!)

γ factor

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

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

Collider vs fixed target

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

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

Stationary target

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

$$E_{cm}^2 = (\gamma + 1)^2 m^2 c^4 - \left(\gamma^2 - 1\right) m^2 c^4$$

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

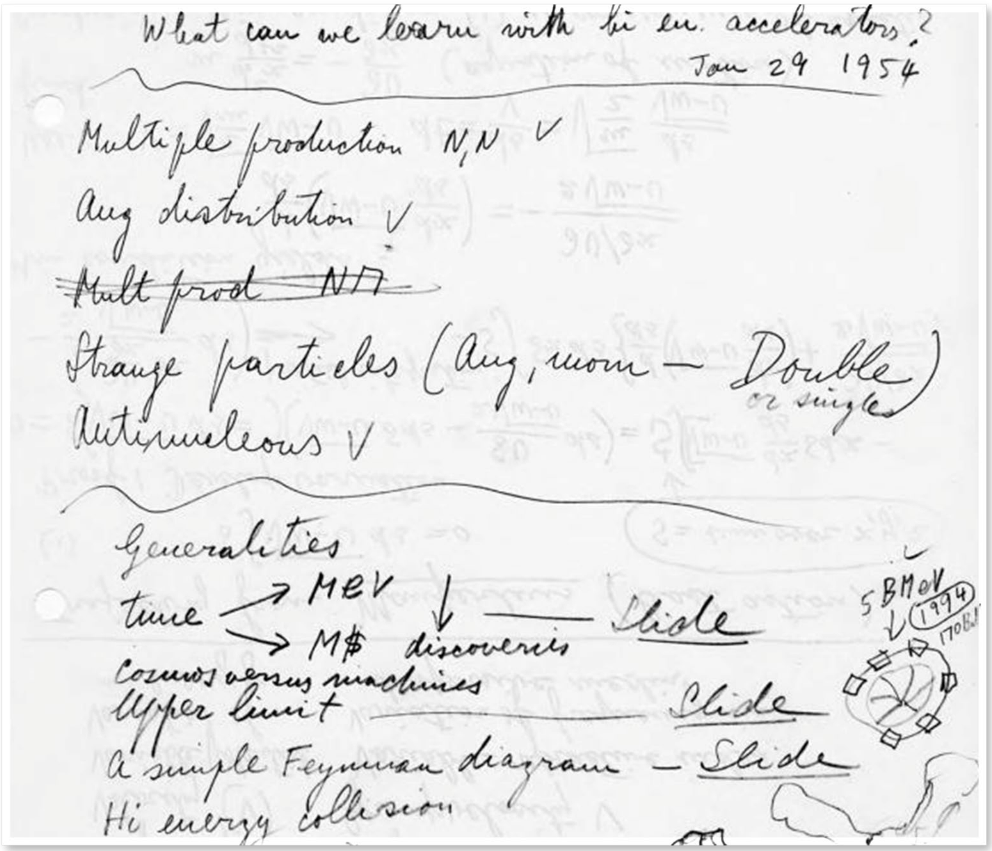
$$E_{avail} = E_{CM} - 2mc^2 = \left(\sqrt{2(\gamma + 1)} - 2\right) mc^2$$

Colliding beam

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

$$E_{cm} = 2\gamma mc^2$$

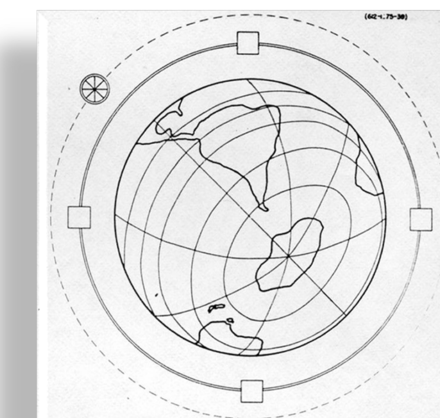
1954 Fermi Globatron


What can we learn with hi en. accelerators?
Jan 29 1954

Multiple production N,N ✓
Ang distribution ✓
~~Mult prod NN̄~~
Strange particles (Ang, mom — Double or single)
Antinucleous ✓

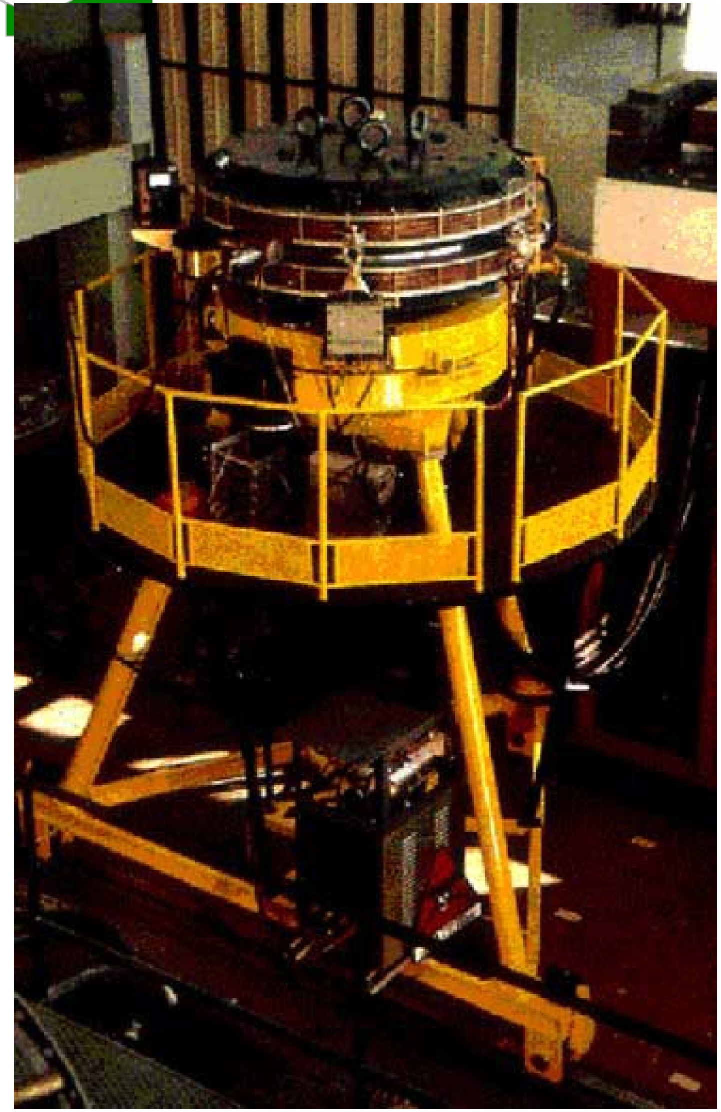
Generalities
time → MeV ↓ — Slide
→ M$ discoveries
Cosmos versus machines
Upper limit — Slide
A simple Feynman diagram — Slide
Hi energy collision

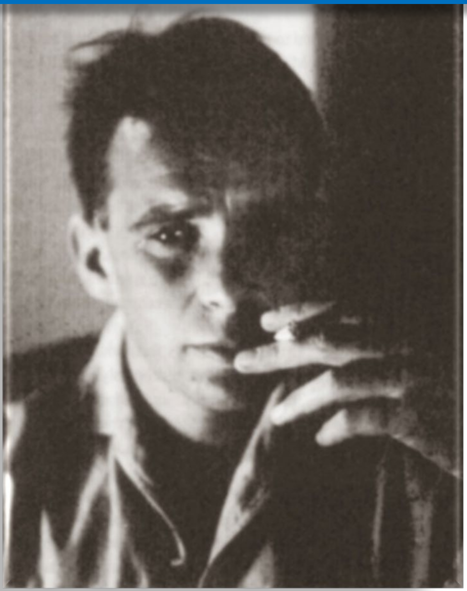
5 BMeV (1994) 170B$



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

First e^+e^-

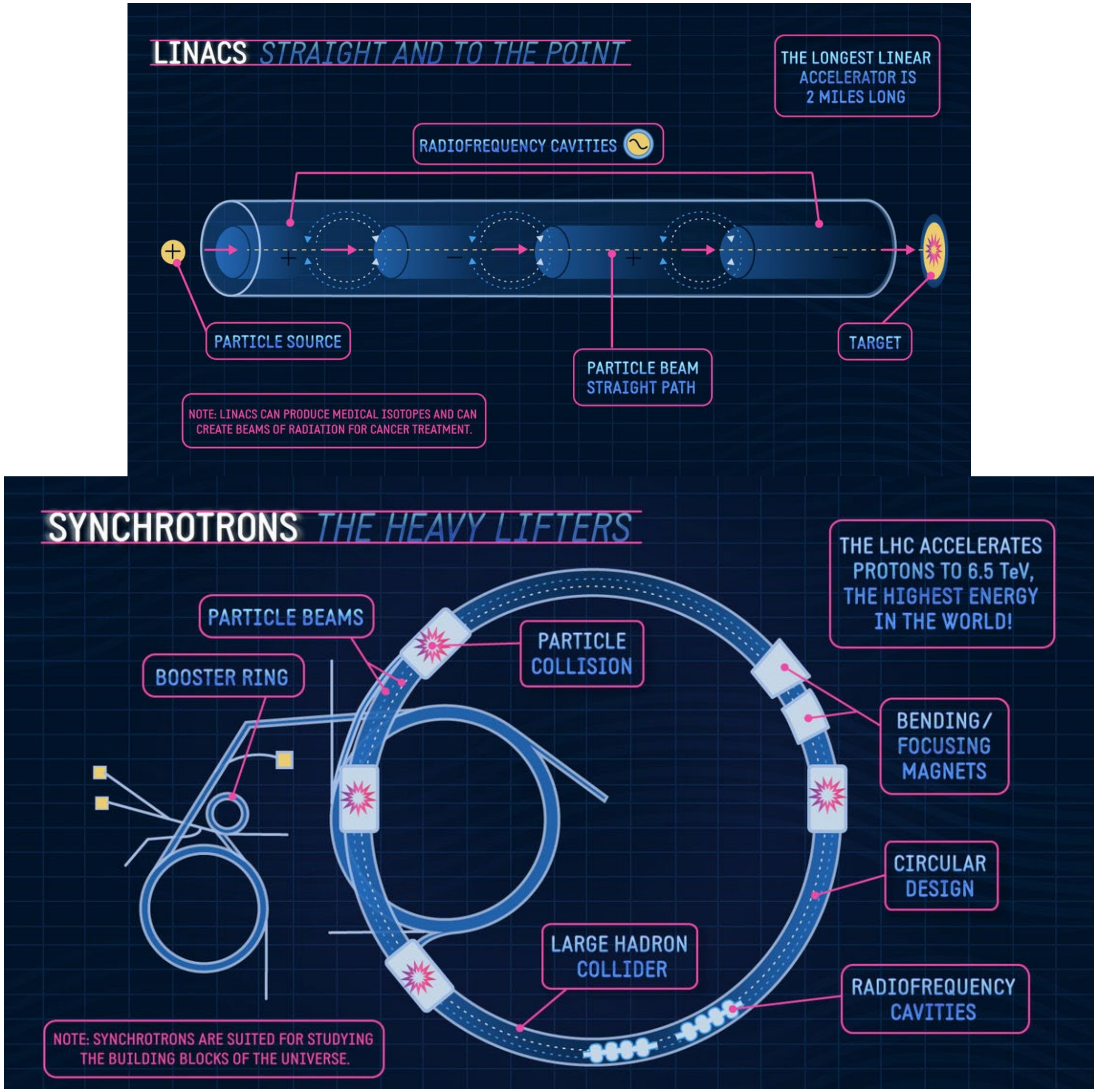




Bruno Touschek

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.

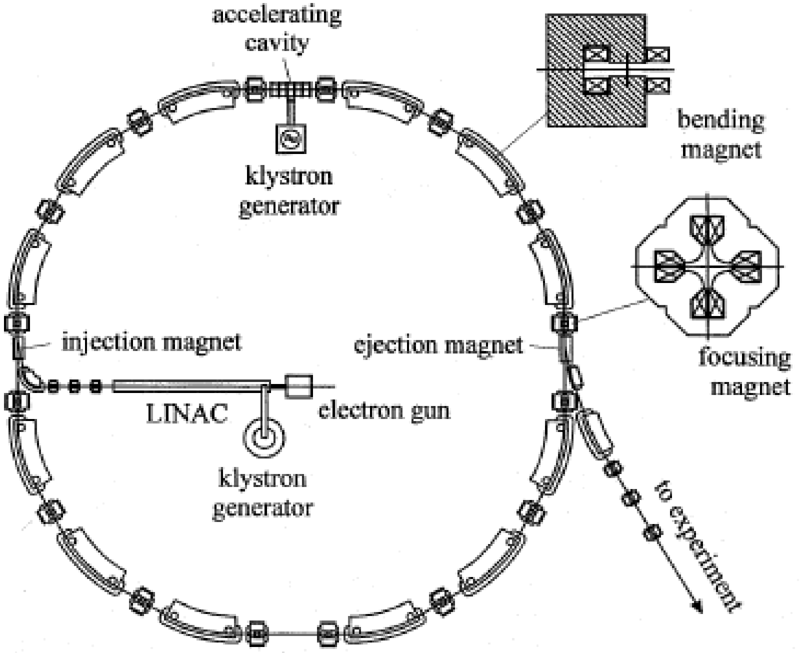
Linar vs circular accelerator



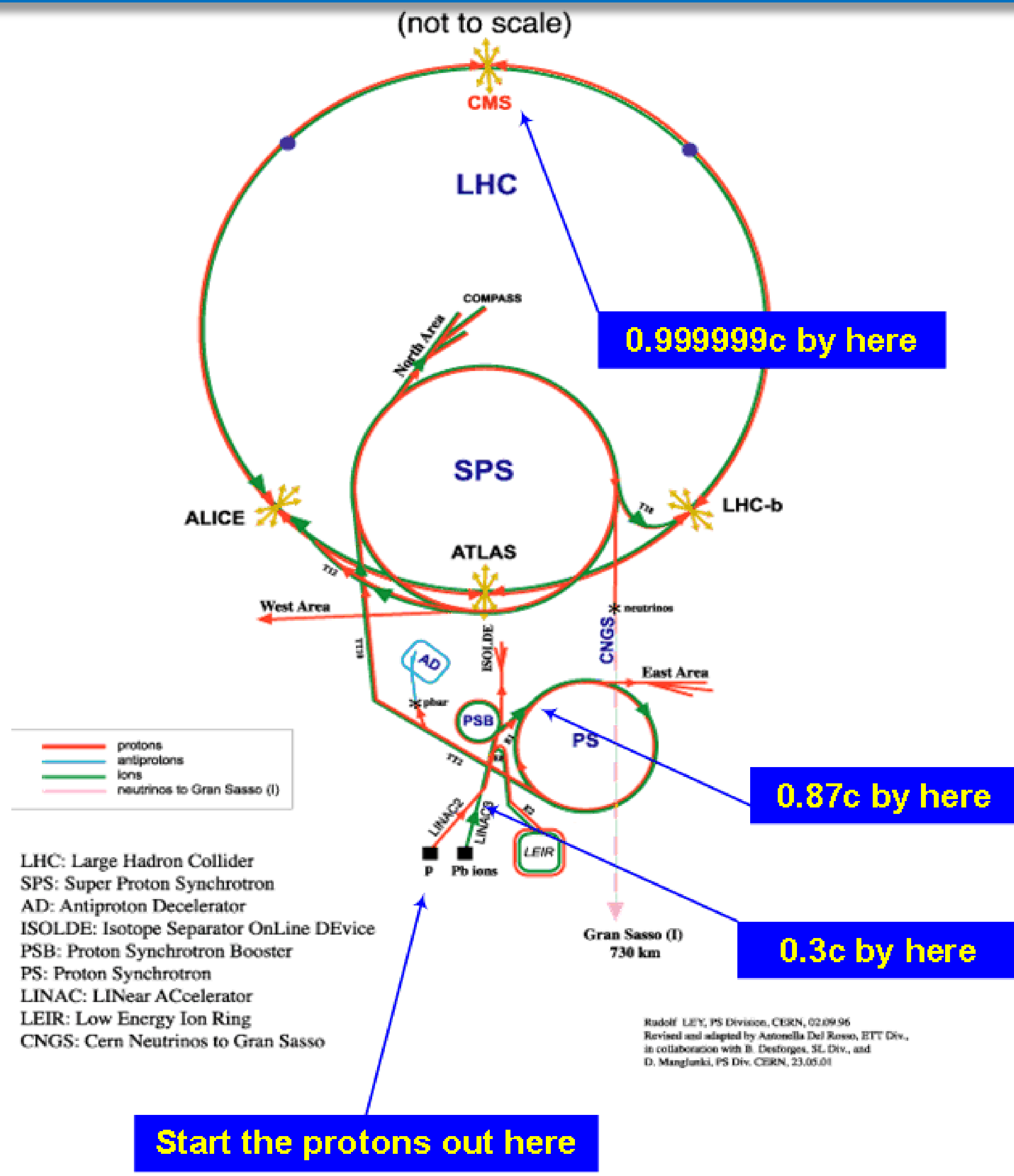
Synchrotron

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

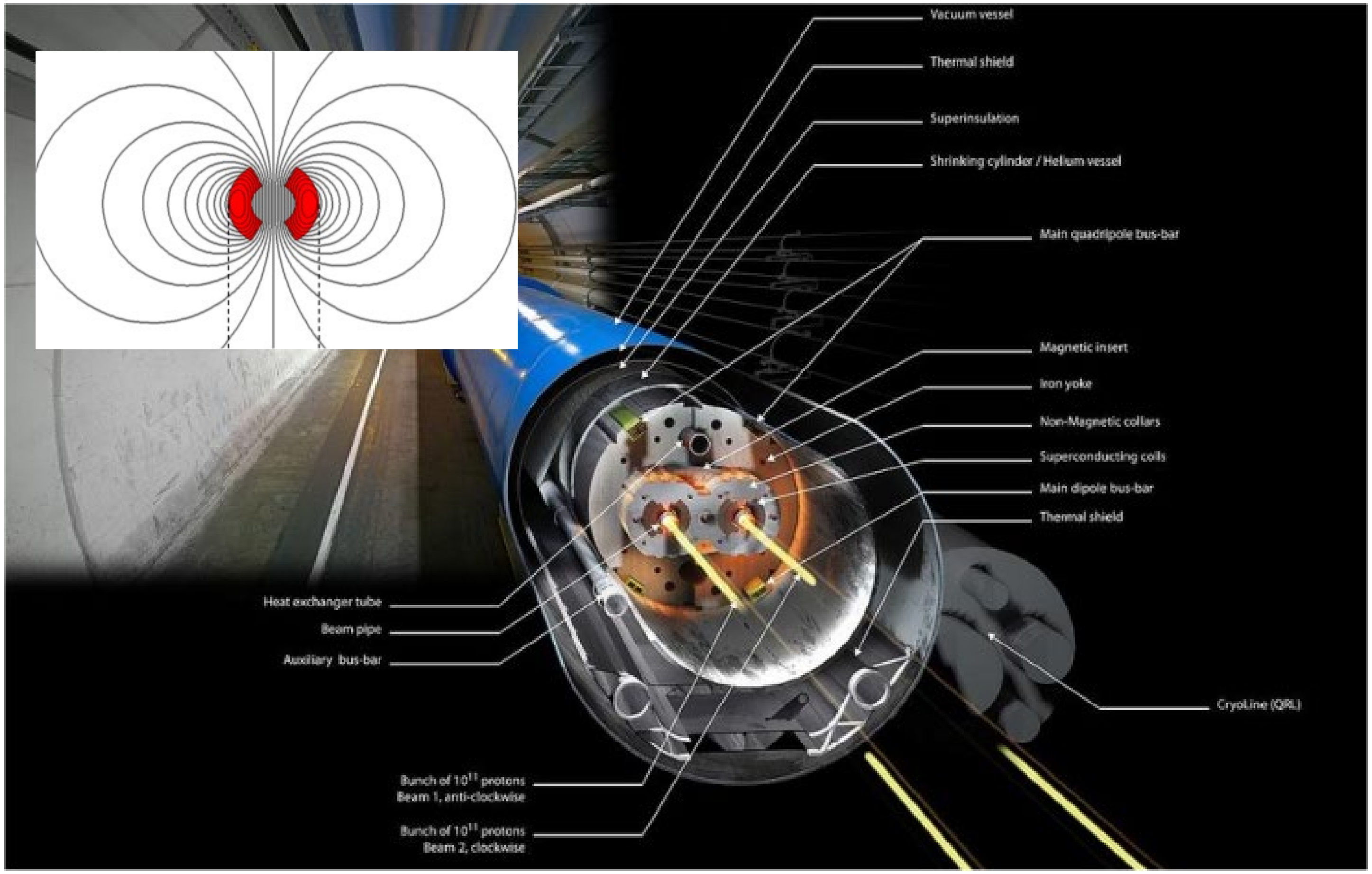
$$\frac{1}{R} = \frac{eB}{p}$$



LHC


(not to scale)
CMS
LHC
COMPASS
North Area
0.999999c by here
SPS
ALICE
ATLAS
LHC-b
West Area
neutrinos
CNGS
ISOLDE
AD
pbar
East Area
PSB
PS
0.87c by here
protons
antiprotons
ions
neutrinos to Gran Sasso (I)
LINAC2
LINAC3
LEIR
p
Pb ions
0.3c by here
Gran Sasso (I)
730 km
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
Start the protons out here

Beyond 2T → Superconductive magnets



Oh my GOD

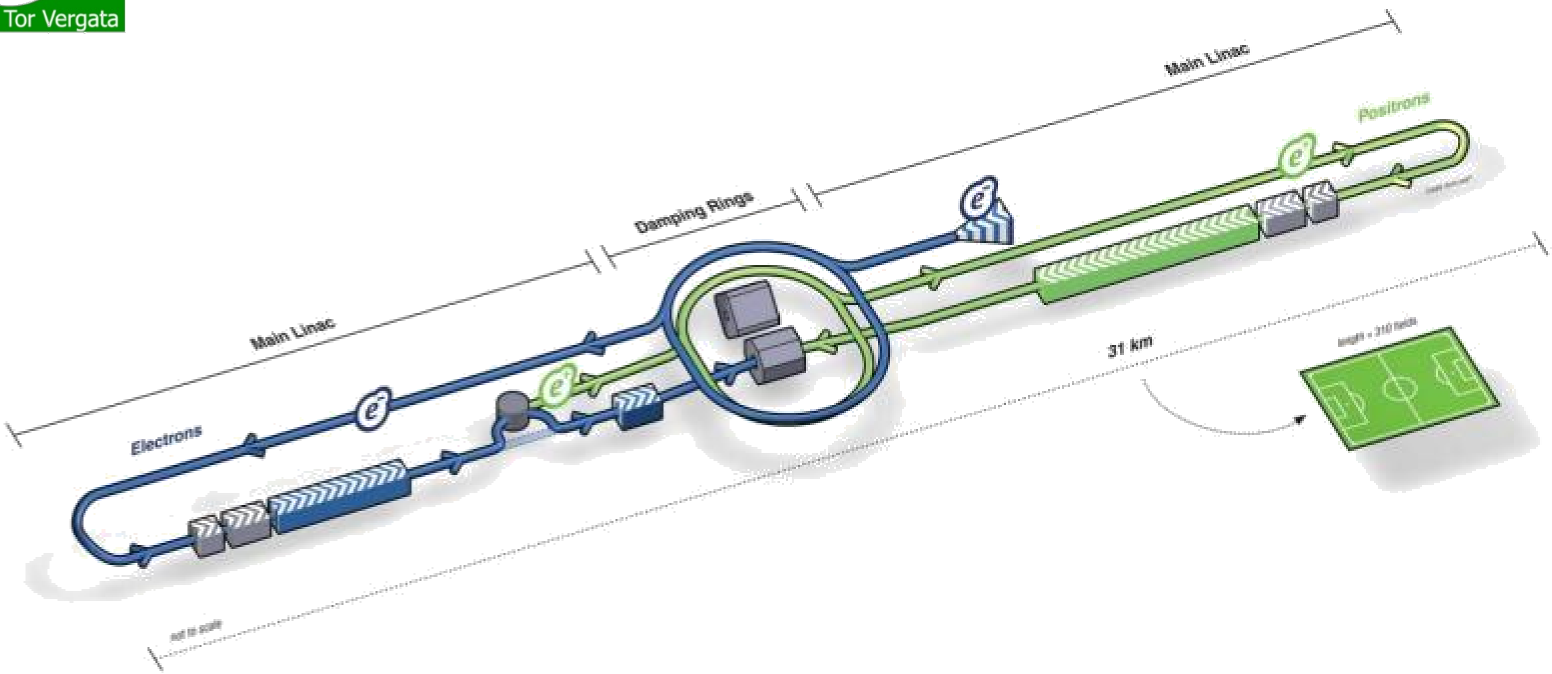
- 2835 bunches with 1.15 $*10^{11}$ protons each;
- 332 MJ per beam;
- 1232 dipoles of 8.3 T;
- more than 400 quadrupoles;
- 0.58 A per beam
- Energy up to 14 TeV in the center of mass;
- Luminosity 10^{34} cm^{-2} s^{-1};

POWER IN THE LHC

- 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



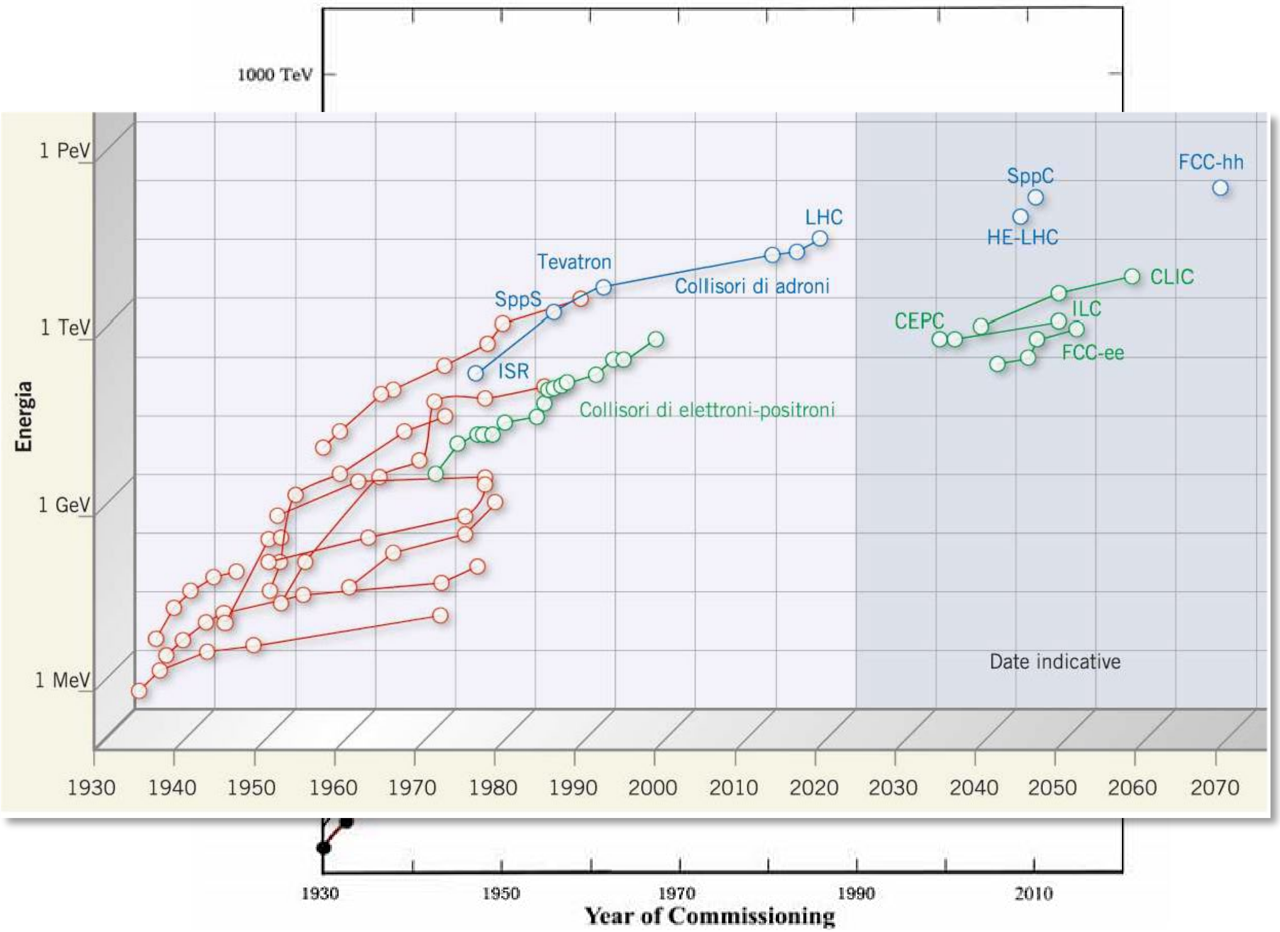
few magnets, many cavities → need efficient power production

•higher gradient → shorter linac

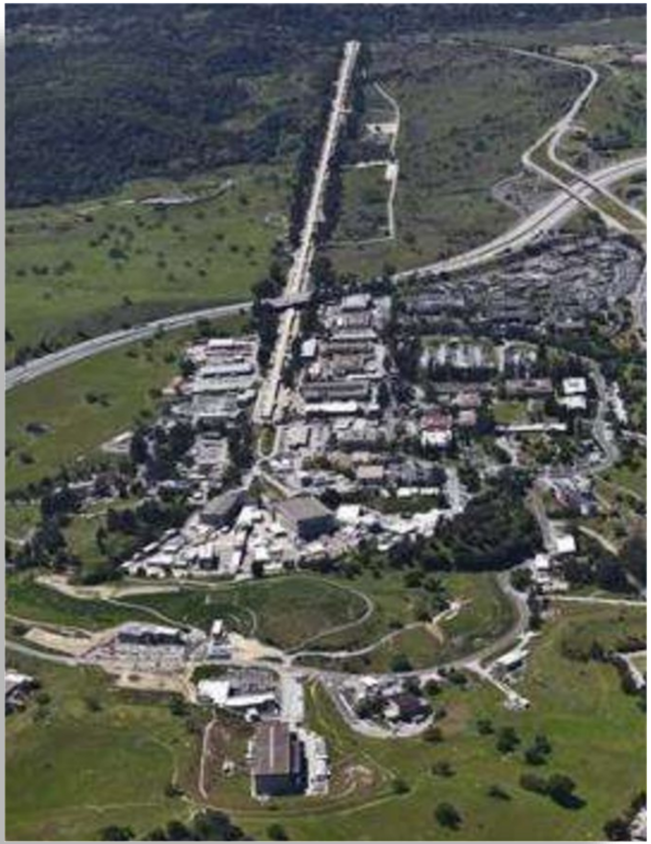
•single pass → need small cross-section

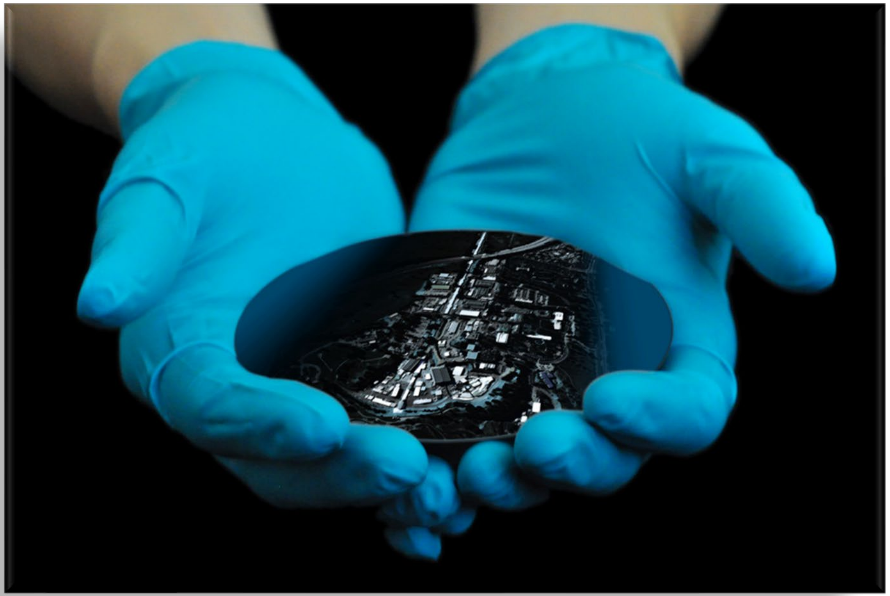
•exceptional beam quality, alignment and stabilization

Accelerator history



SLAC Now and Tomorrow?





2023

20??