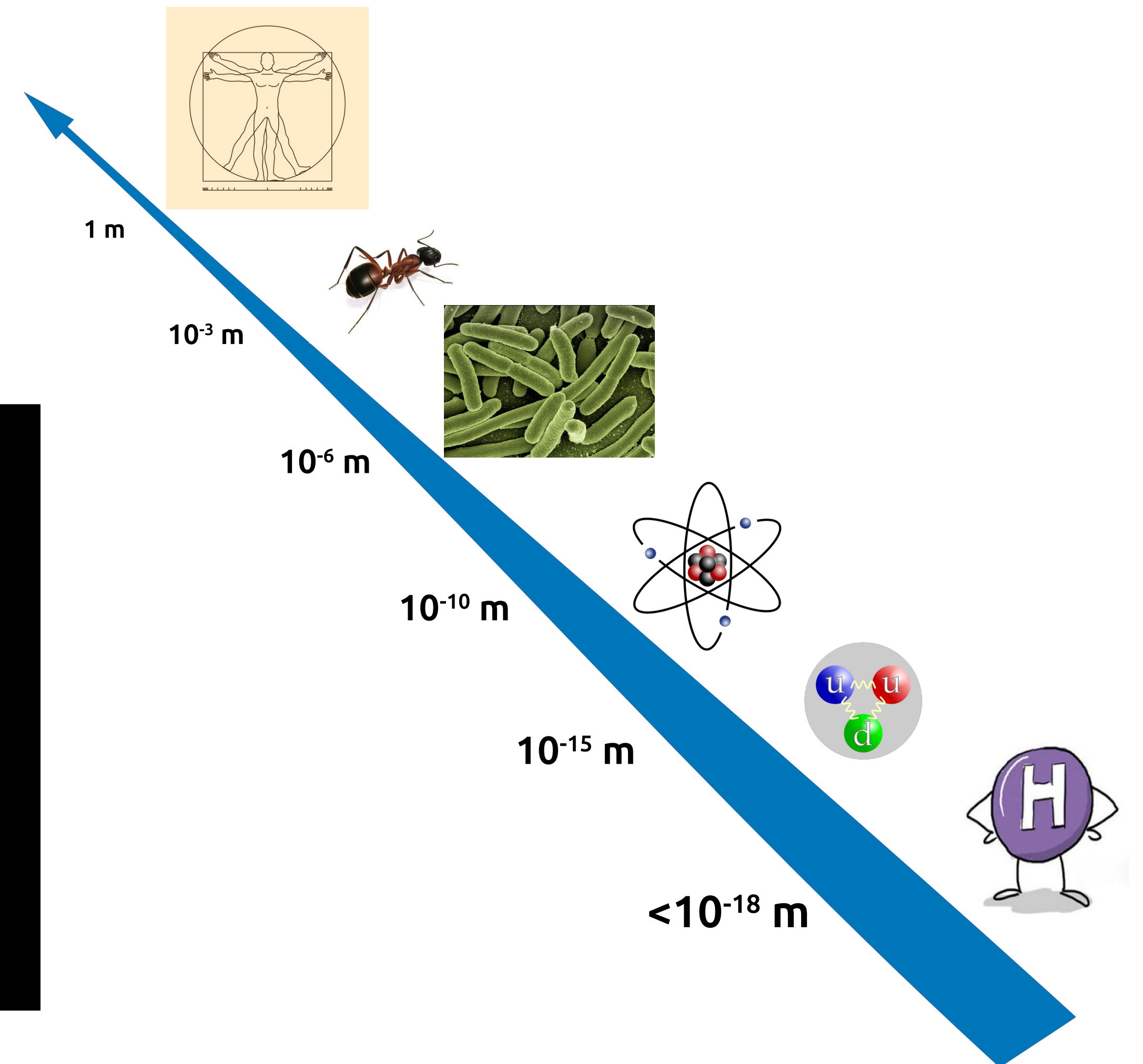
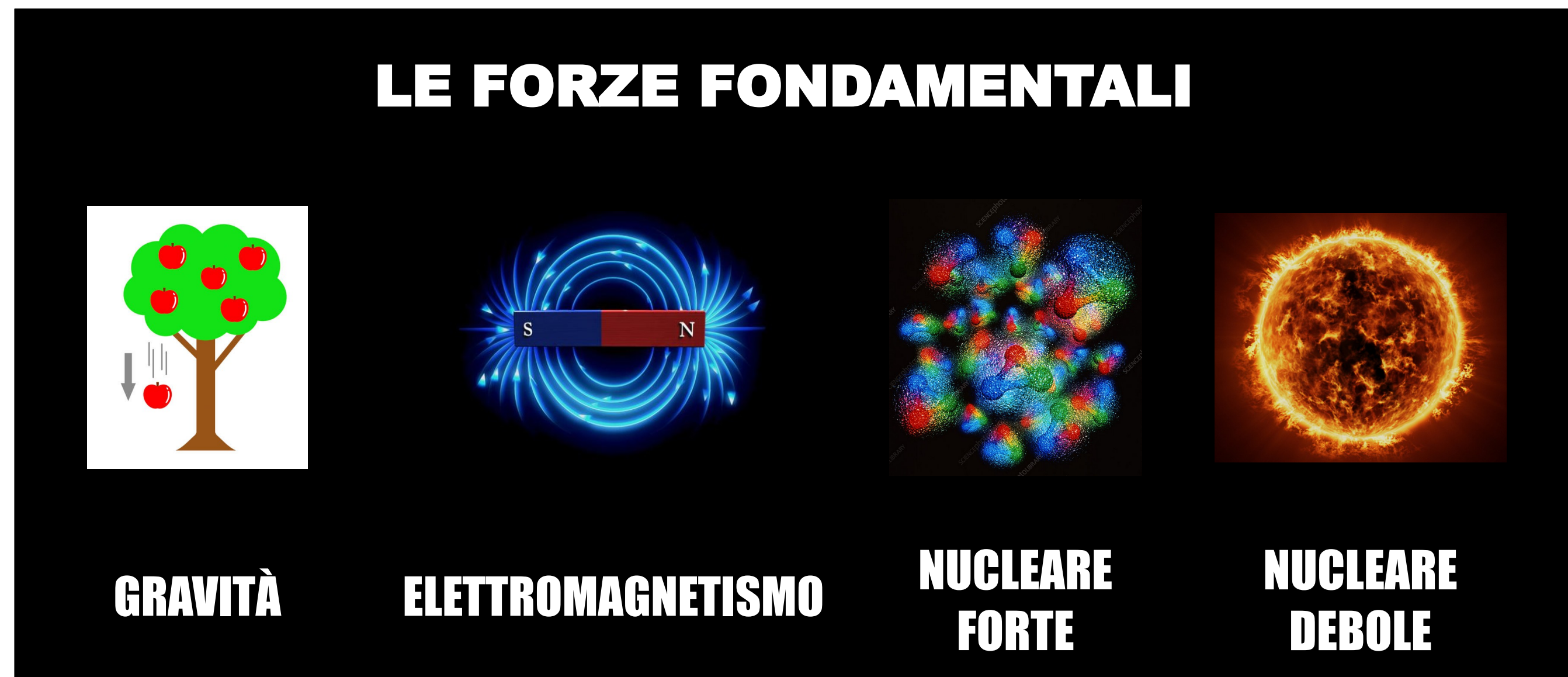


Progettare gli acceleratori del futuro

Leonardo Palombini

Una teoria del tutto?

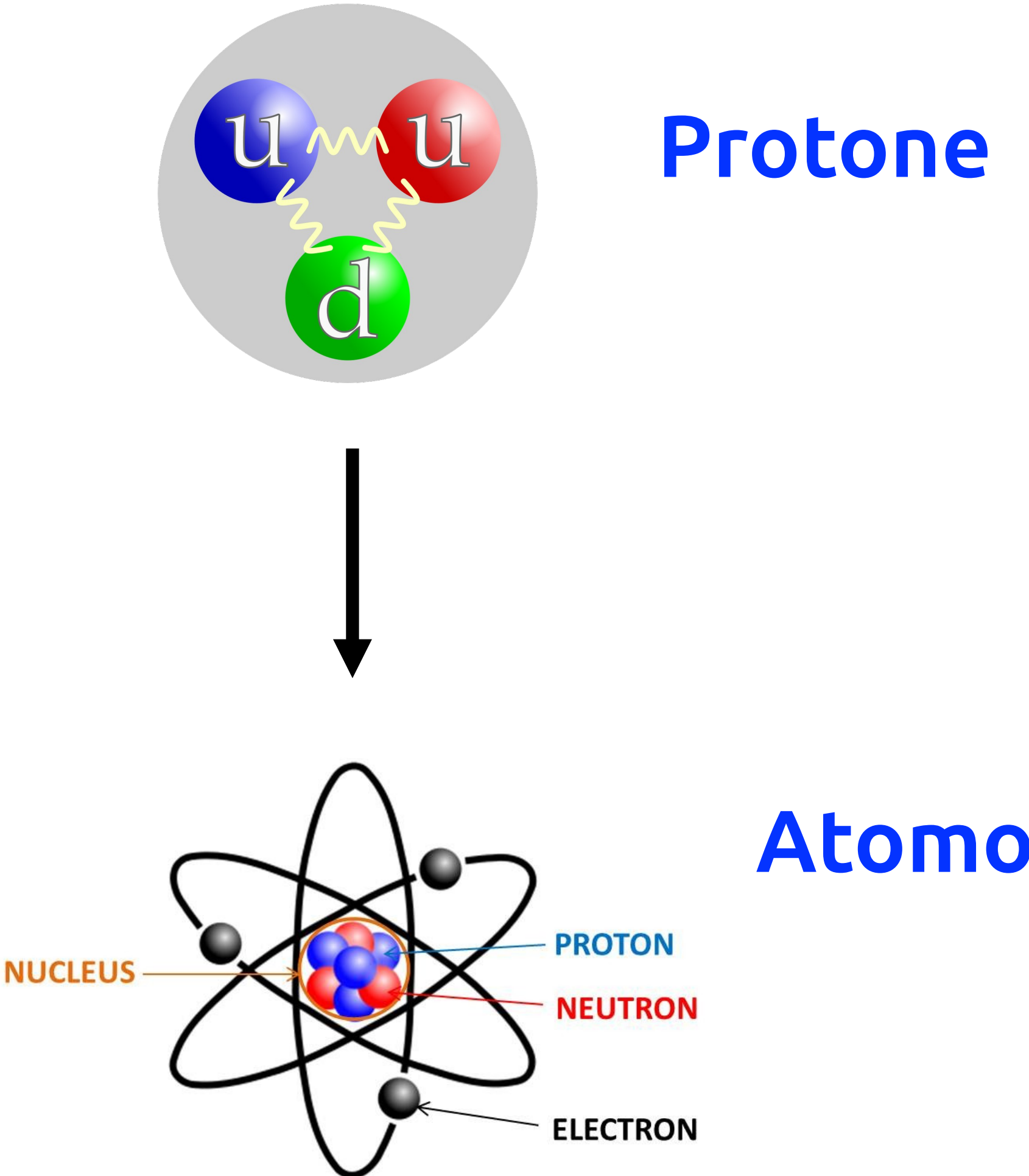
Scienziati e filosofi sognano da millenni una teoria che descriva da sola tutto l'Universo. Per cercarla, dobbiamo studiare i suoi più piccoli costituenti e le forze che li governano.



Le particelle elementari

Standard Model of Elementary Particles

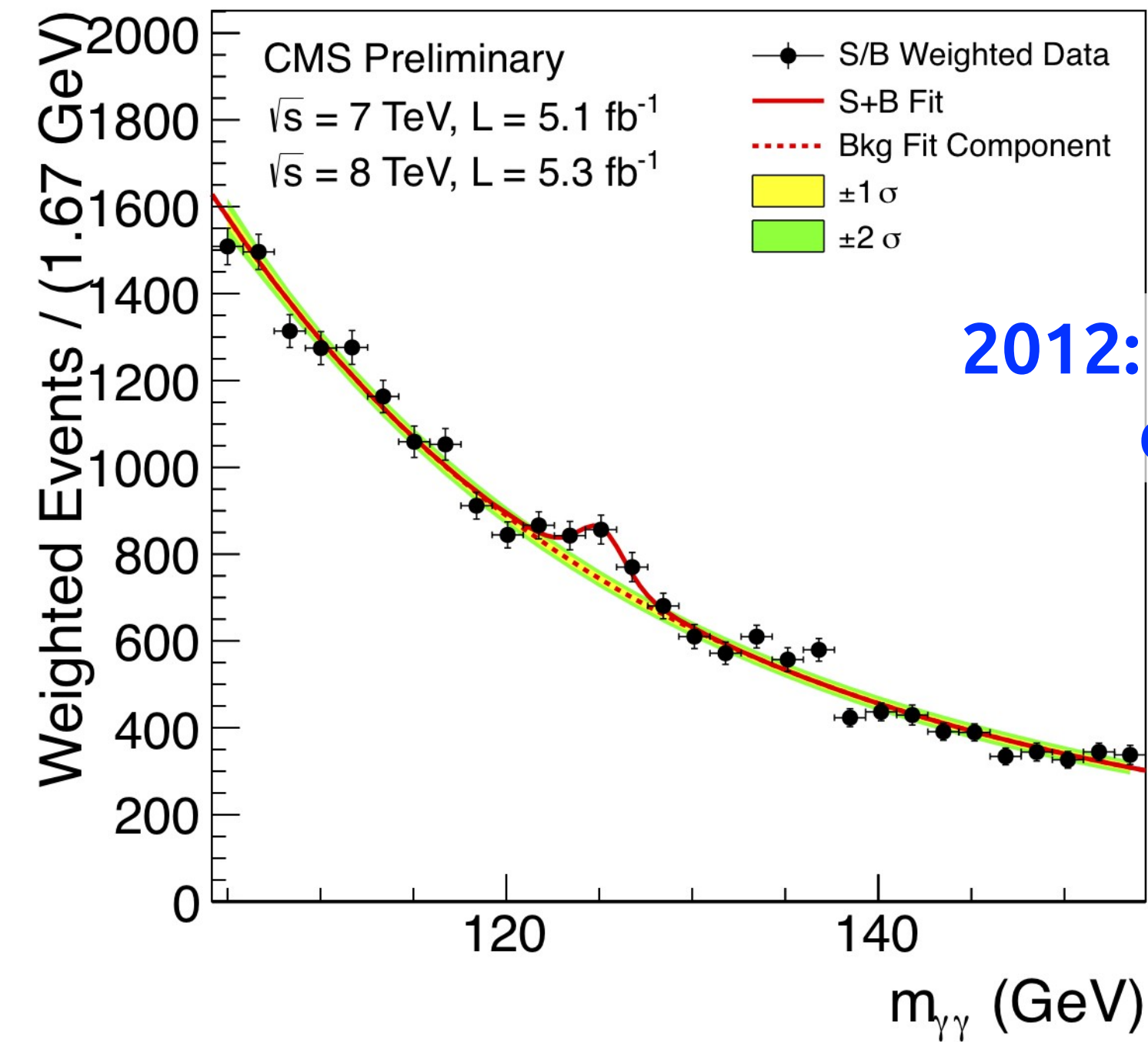
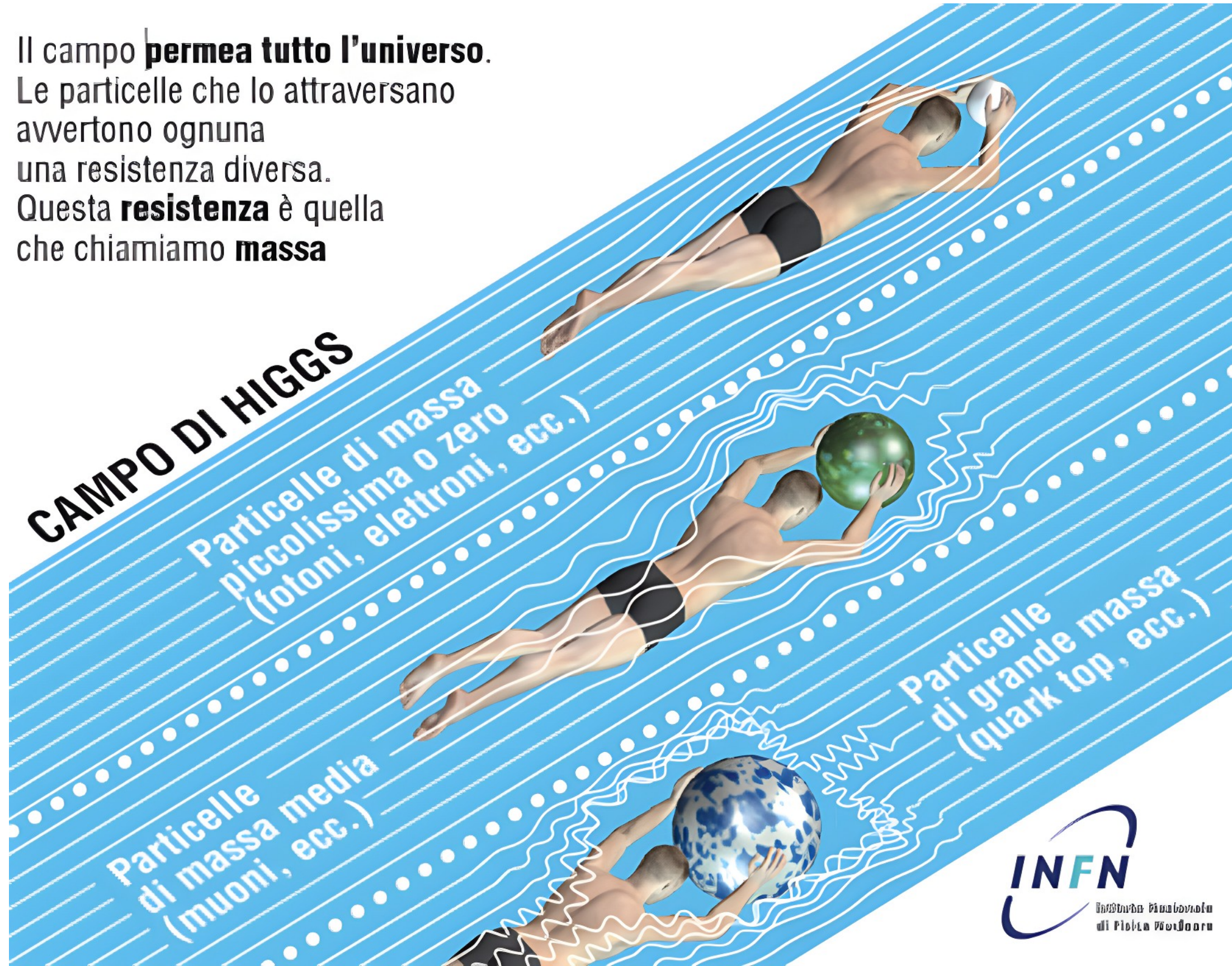
three generations of matter (fermions)			interactions / force carriers (bosons)	
	I	II	III	
mass	$\approx 2.16 \text{ MeV}/c^2$	$\approx 1.273 \text{ GeV}/c^2$	$\approx 172.57 \text{ GeV}/c^2$	$\approx 125.2 \text{ GeV}/c^2$
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0
QUARKS	u up	c charm	t top	g gluon
	d down	s strange	b bottom	γ photon
	e electron	μ muon	τ tau	Z Z boson
LEPTONS	$\approx 0.511 \text{ MeV}/c^2$	$\approx 105.66 \text{ MeV}/c^2$	$\approx 1.77693 \text{ GeV}/c^2$	$\approx 91.188 \text{ GeV}/c^2$
	-1	-1	-1	0
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	V_e electron neutrino	V_μ muon neutrino	V_τ tau neutrino	W W boson
	0	0	0	± 1
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1



https://it.wikipedia.org/wiki/Modello_standard

Una particella speciale: il bosone di Higgs

Il campo **permea tutto l'universo**.
Le particelle che lo attraversano
avvertono ognuna
una resistenza diversa.
Questa **resistenza** è quella
che chiamiamo **massa**

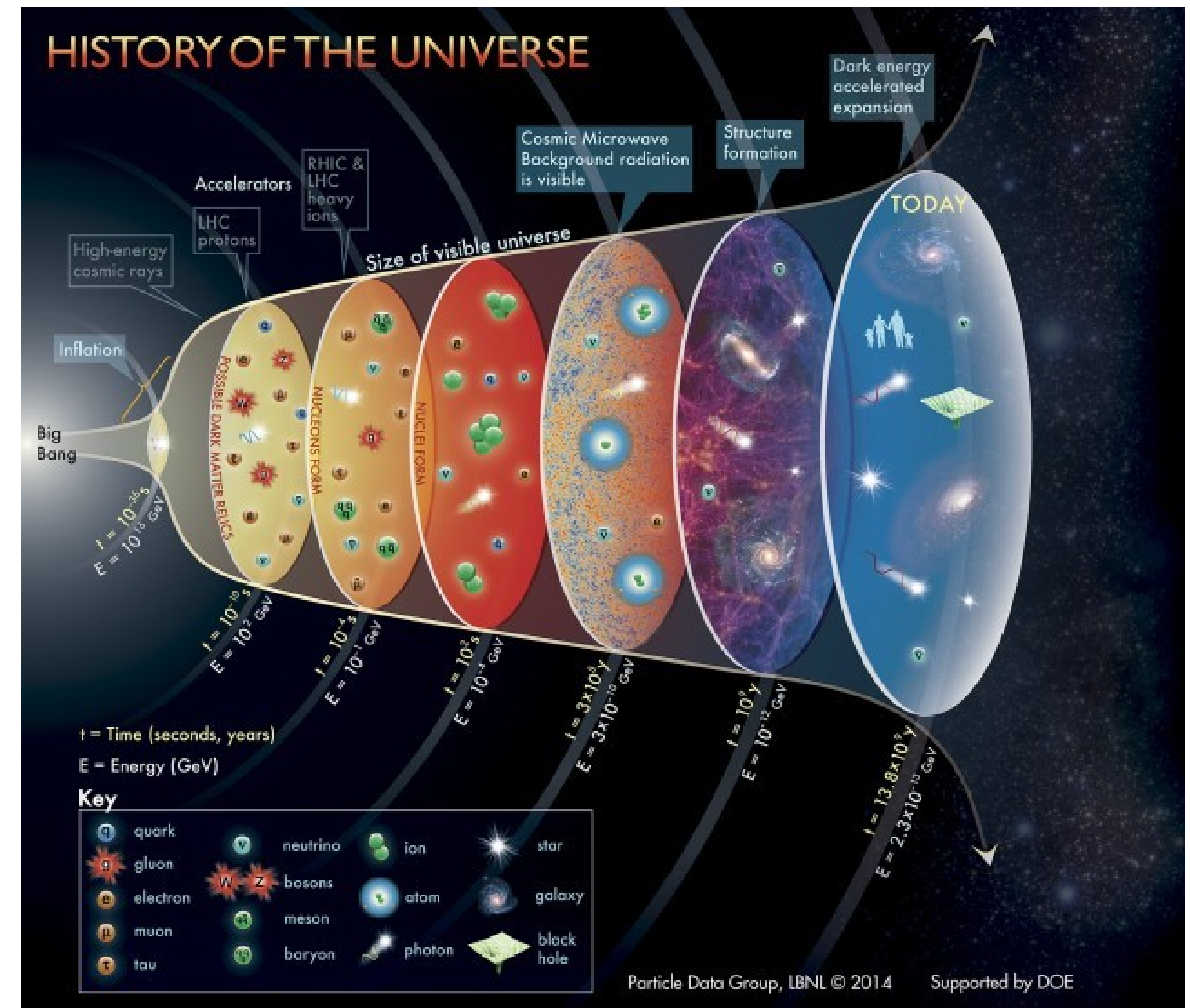
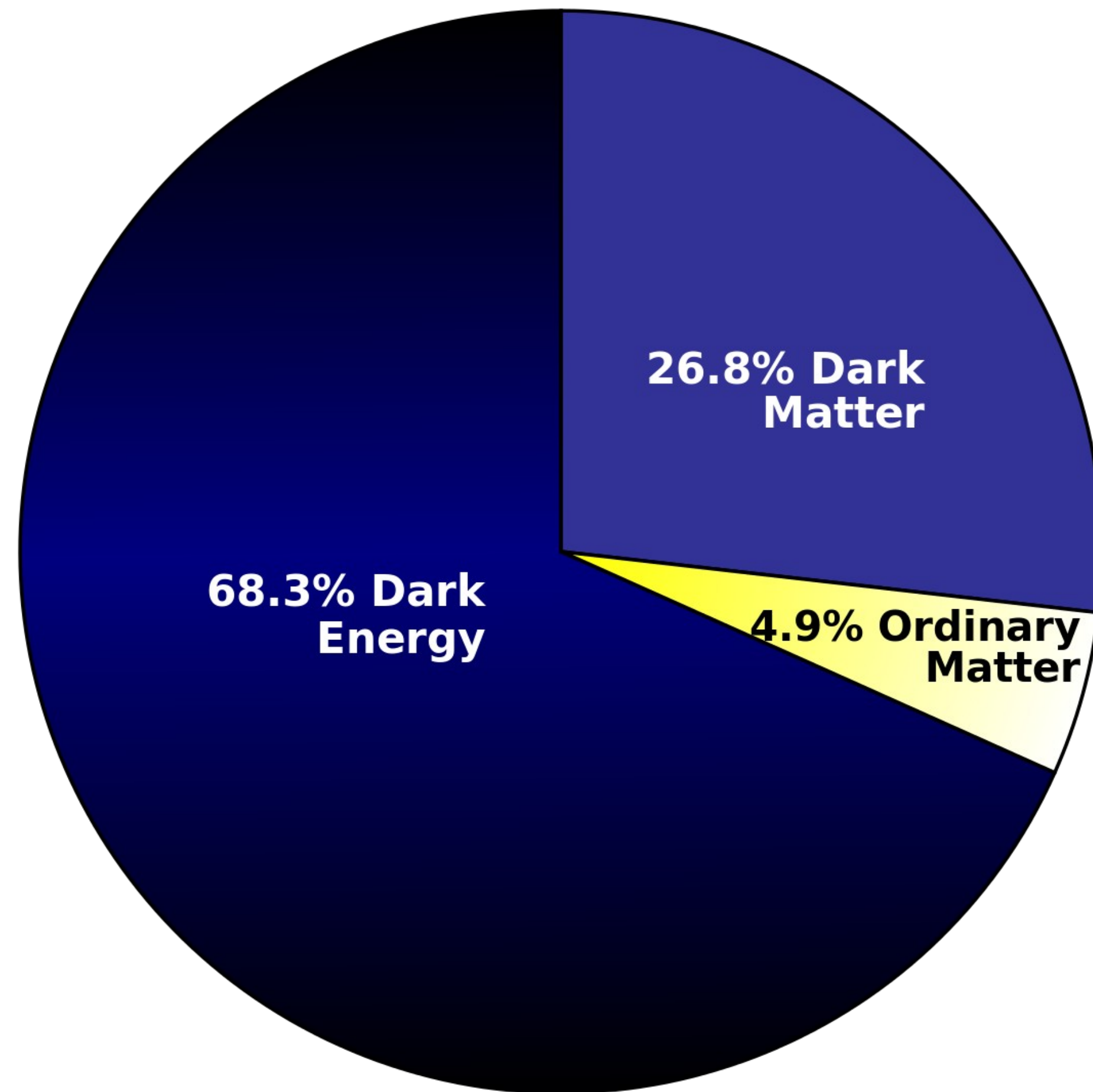


2012: scoperta del bosone di Higgs ad LHC



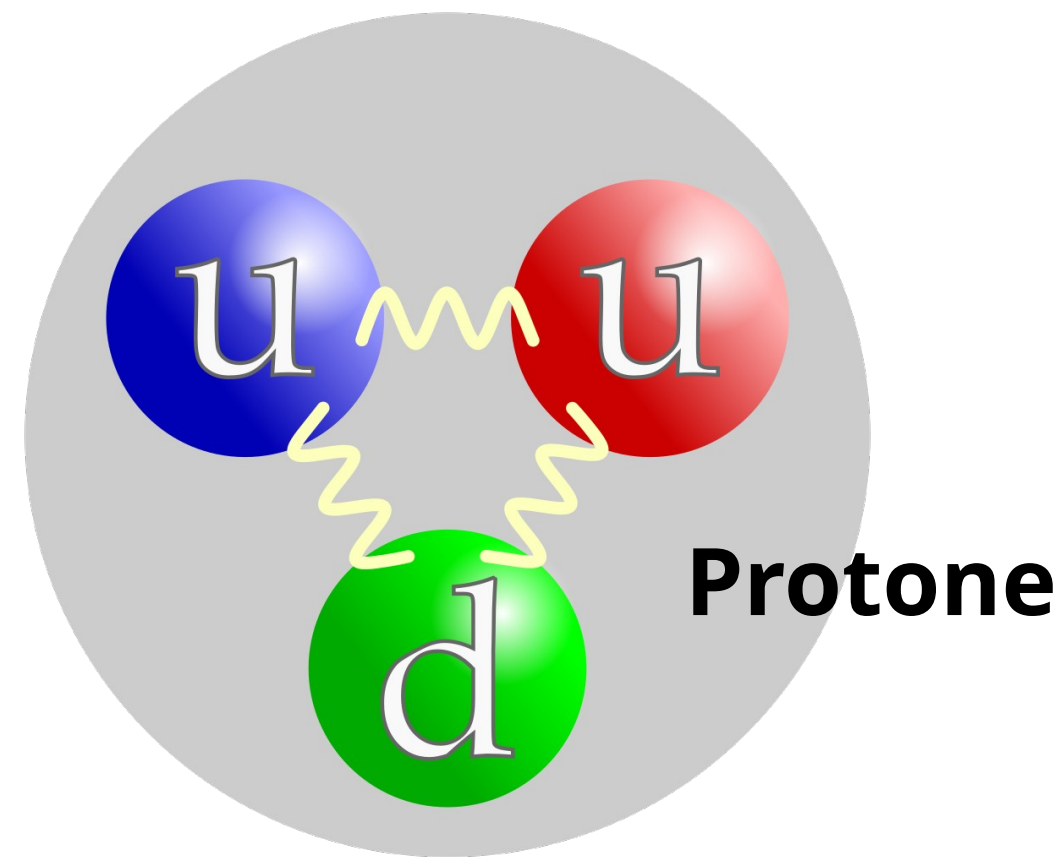
2012: Premio Nobel a P. Higgs e F. Englert

Quanto conosciamo del nostro Universo?



Perché accelerare (e collidere) particelle?

Come un microscopio:
struttura delle particelle



Condizioni simili alle prime
fasi dell'Universo



Produzione di particelle
sconosciute

$$E=mc^2$$

E tante applicazioni mediche e
tecnologiche!

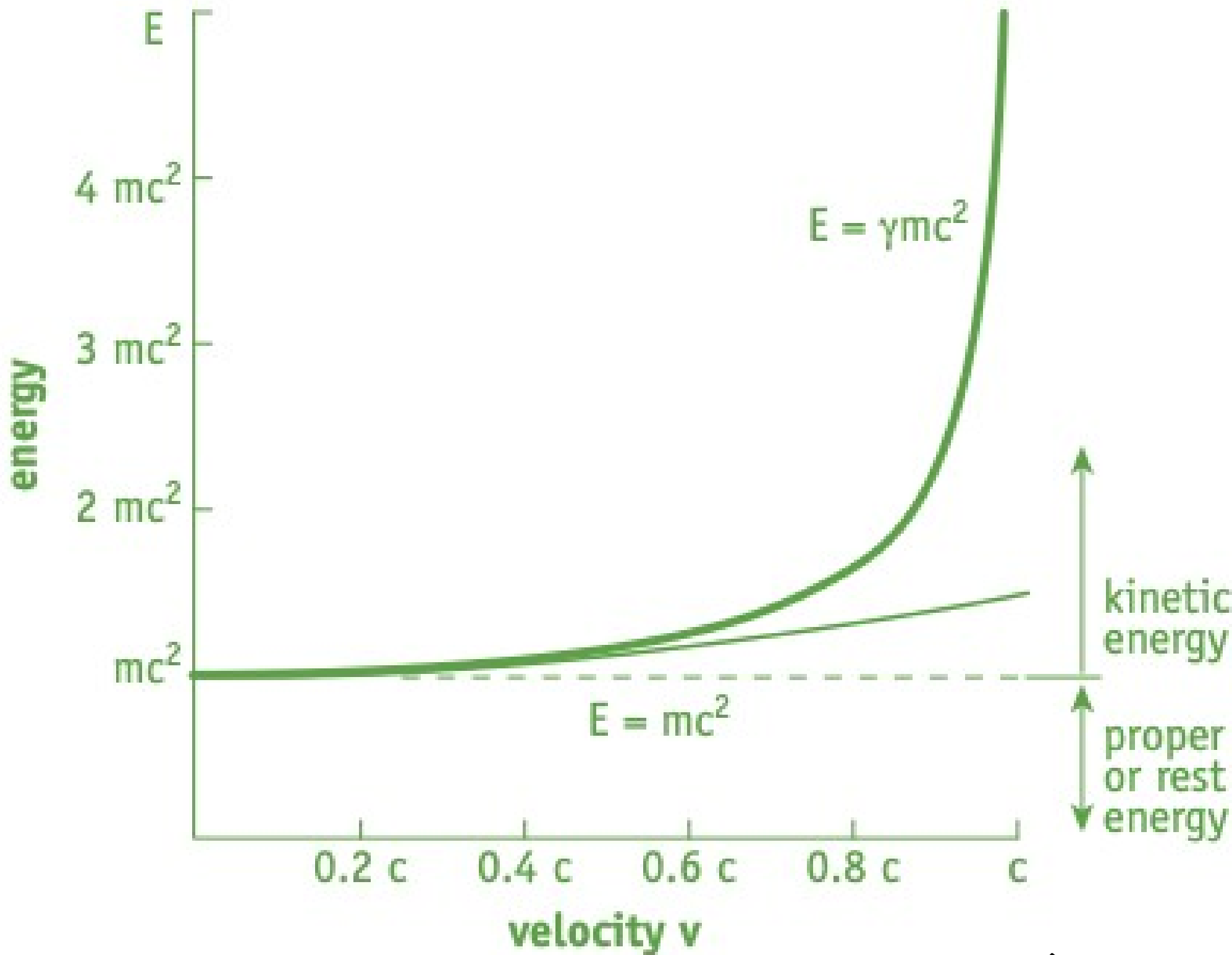
Scala di energie

Relatività: la velocità della luce non può essere superata

Scala di unità naturali

1 elettronvolt (eV) = 1.6×10^{-19} Joule

1 TeV = 1000 GeV = 10^6 MeV = 10^{12} eV



Kinetic energy of a proton (K)	Speed (%c)	Accelerator
50 MeV	31.4	Linac 2
1.4 GeV	91.6	PS Booster
25 GeV	99.93	PS
450 GeV	99.9998	SPS
7 TeV	99.9999991	LHC

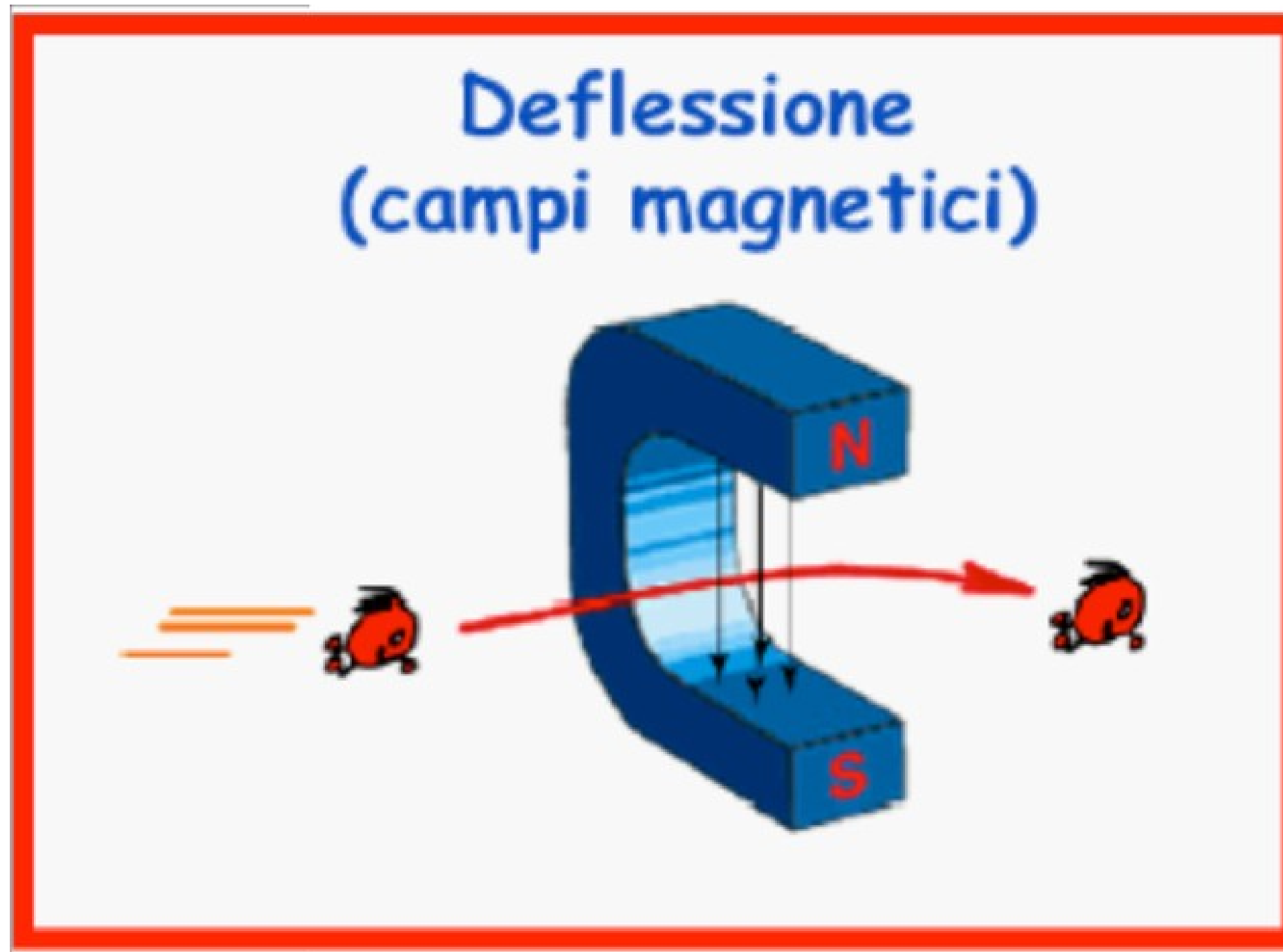
Relationship between kinetic energy and speed of a proton in the CERN machines. The rest mass of the proton is $0.938 \text{ GeV}/c^2$

<https://home.cern>

energia fascio protoni a 7 TeV = energia motocicletta di 150 Kg a 150 Km/h

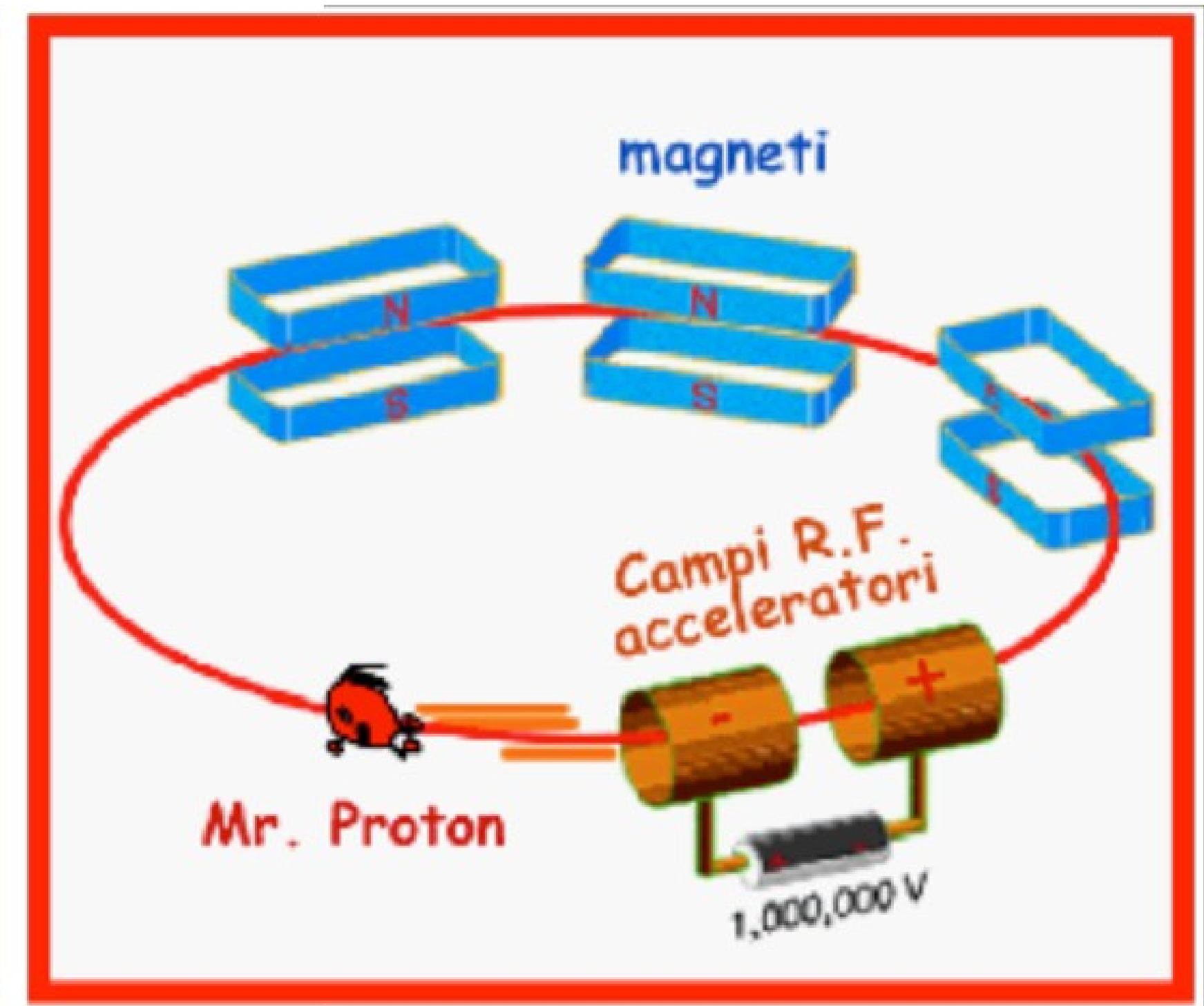


Come si costruisce un acceleratore?



$$\vec{F} = q (\vec{v} \times \vec{B})$$

Forza magnetica

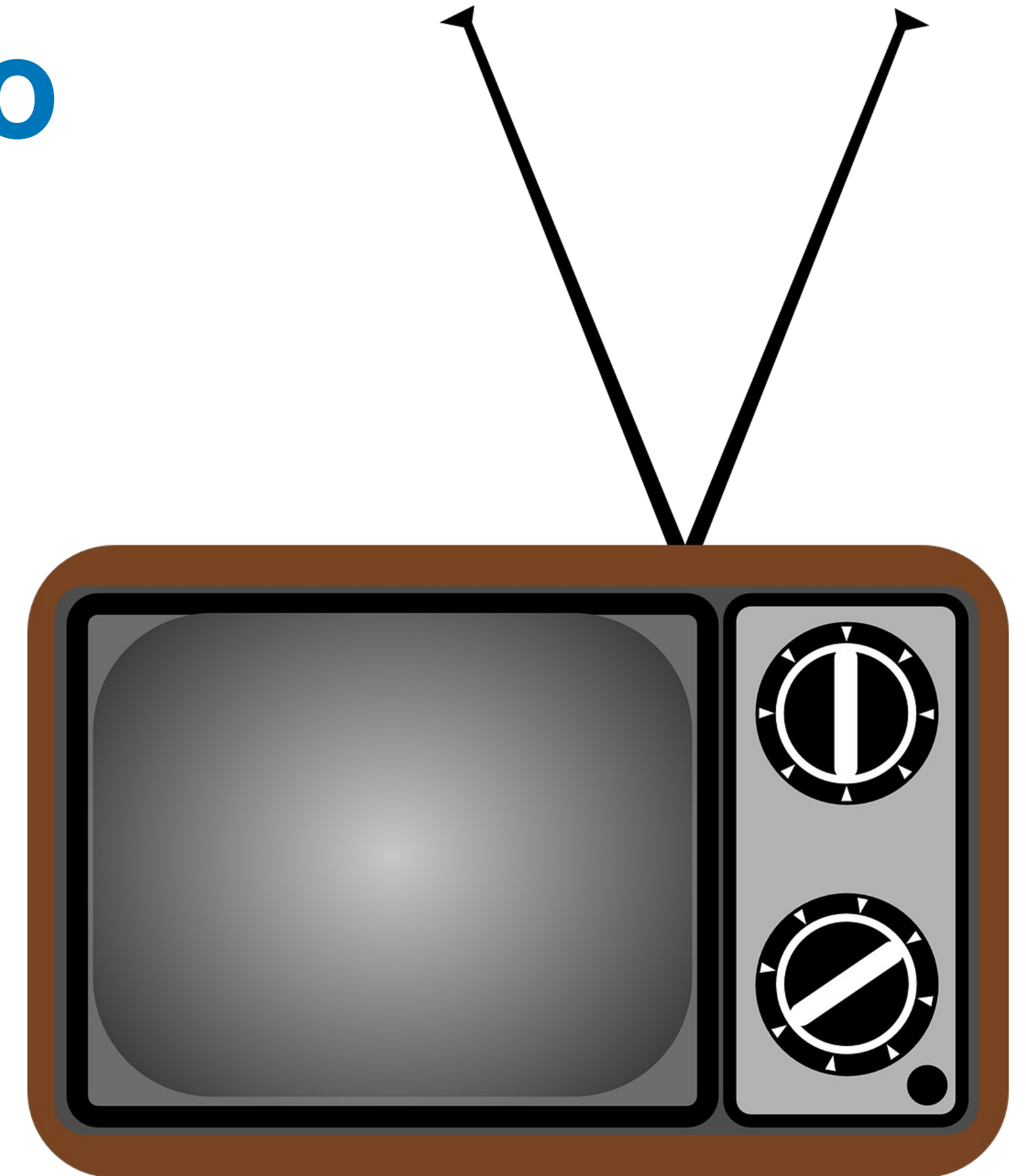
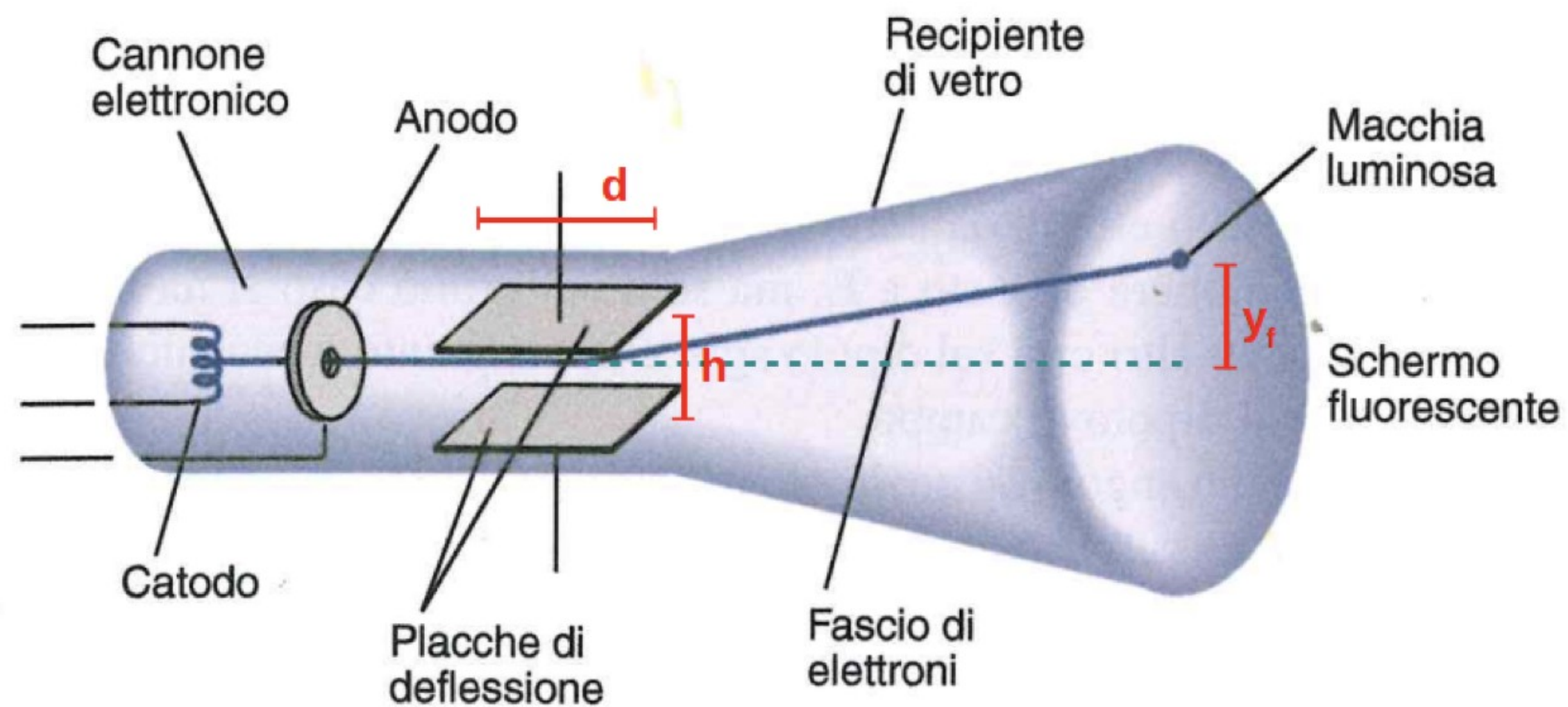


$$\vec{F} = q \vec{E}$$

Forza elettrica

Tubo catodico

Un acceleratore molto comune
qualche anno fa

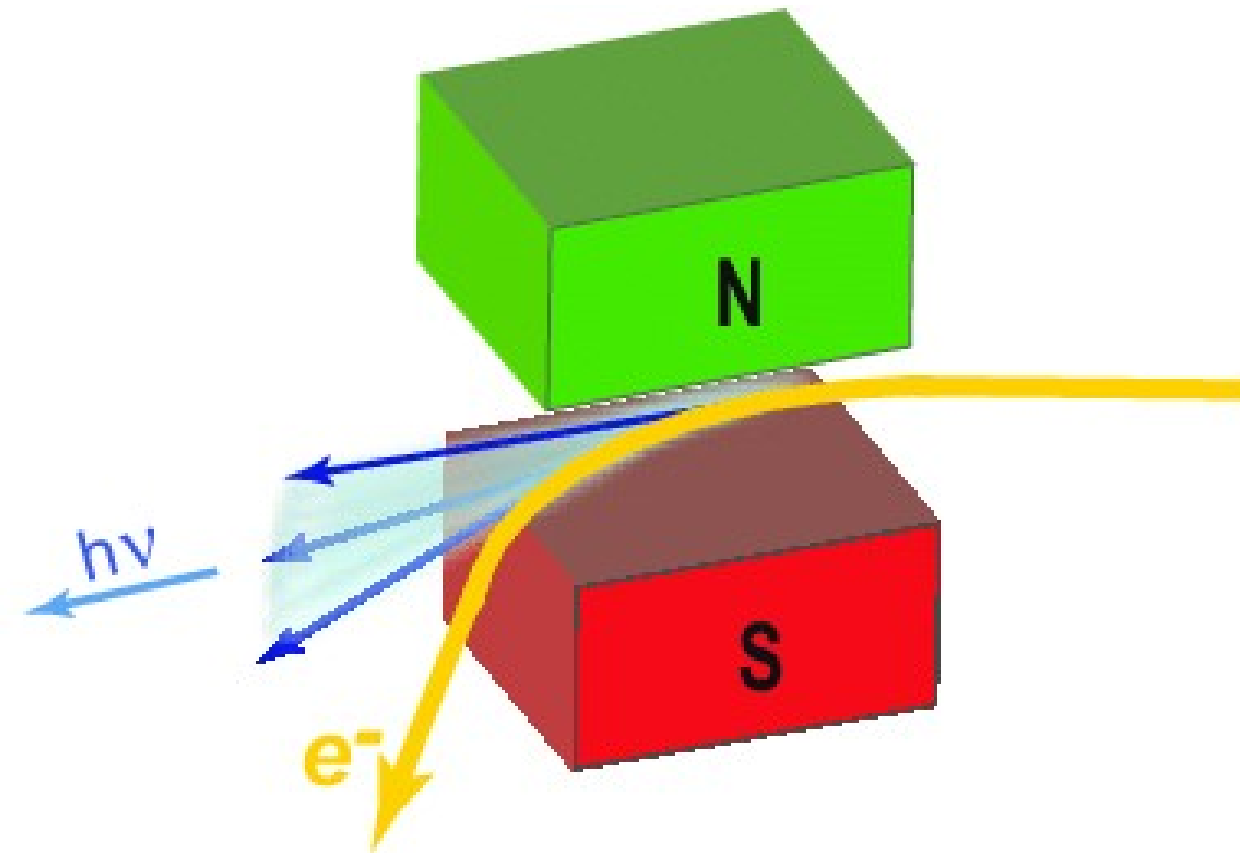


Accelerazione e deflessione tramite campi elettrici
(elettrodi a tensione)

Magneti

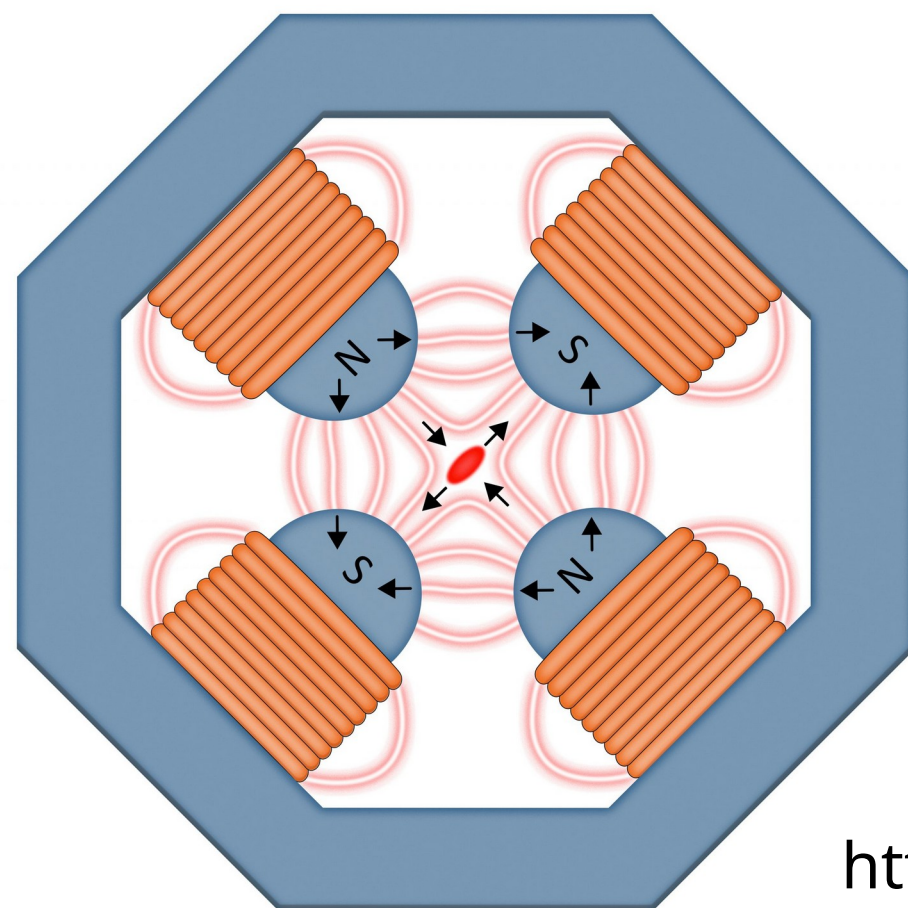
Dipolo magnetico: deflessione

Solo per le
particelle leggere
(elettroni):
emissione di fotoni
durante la
deflessione



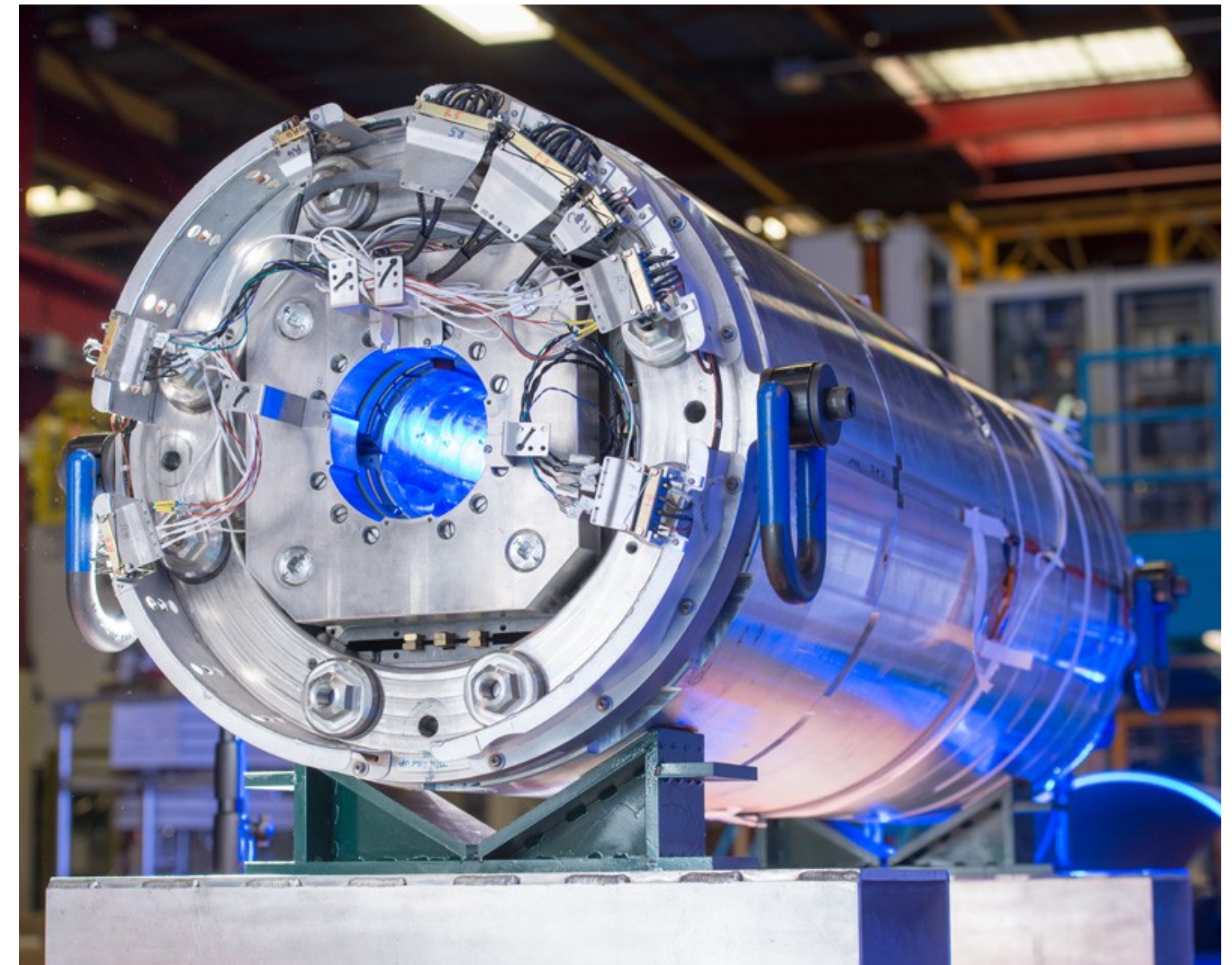
O. Travnikova: Structure and Dynamics of Core-Excited Species, 2008

Quadrupolo magnetico: focalizzazione



<https://news.fnal.gov>

Magnete per l'aggiornamento del Large Hadron Collider



$B = 8.3$ Tesla $\rightarrow$ più di 100'000 volte il campo magnetico terrestre

Tre principali tipi di acceleratori

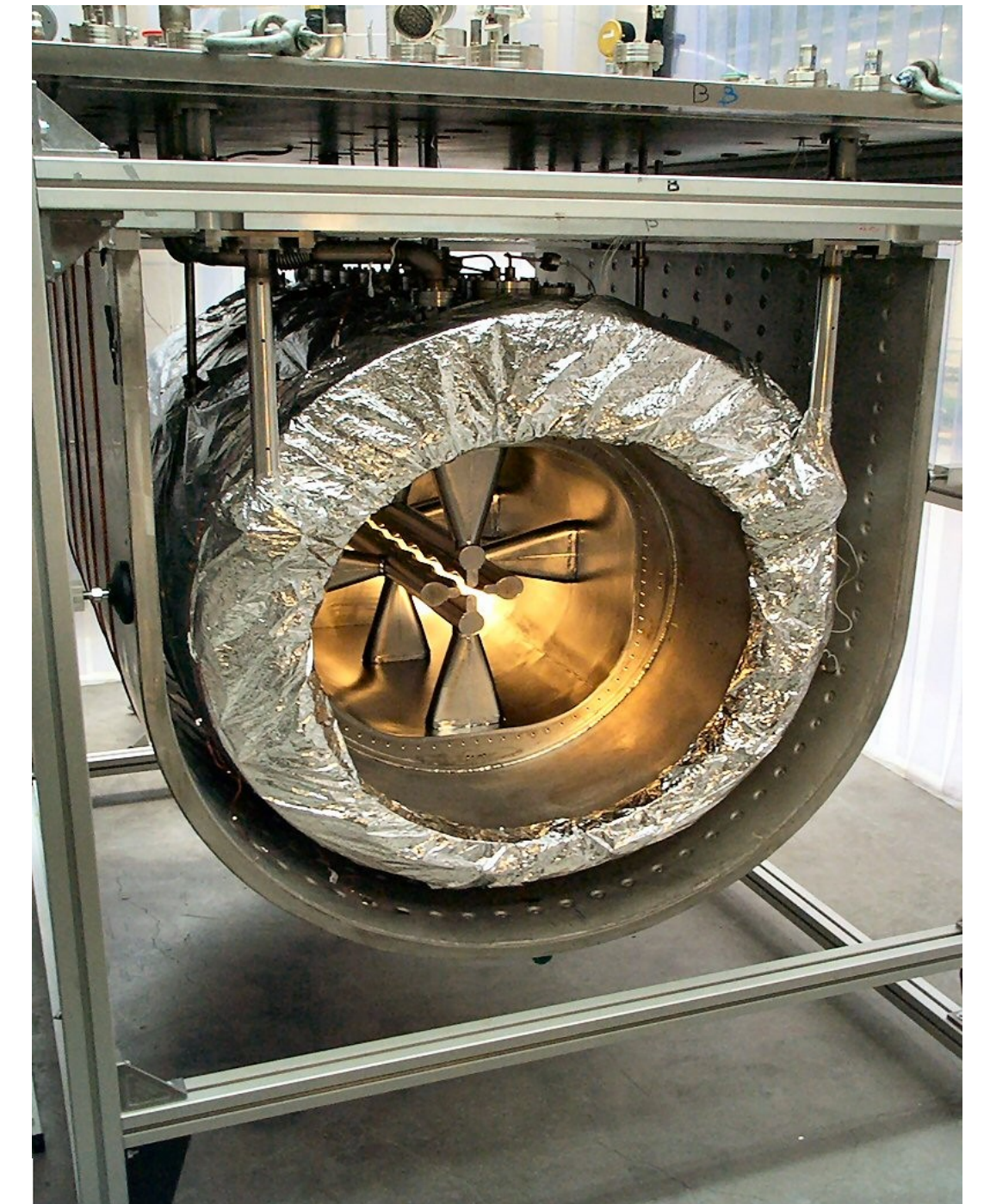
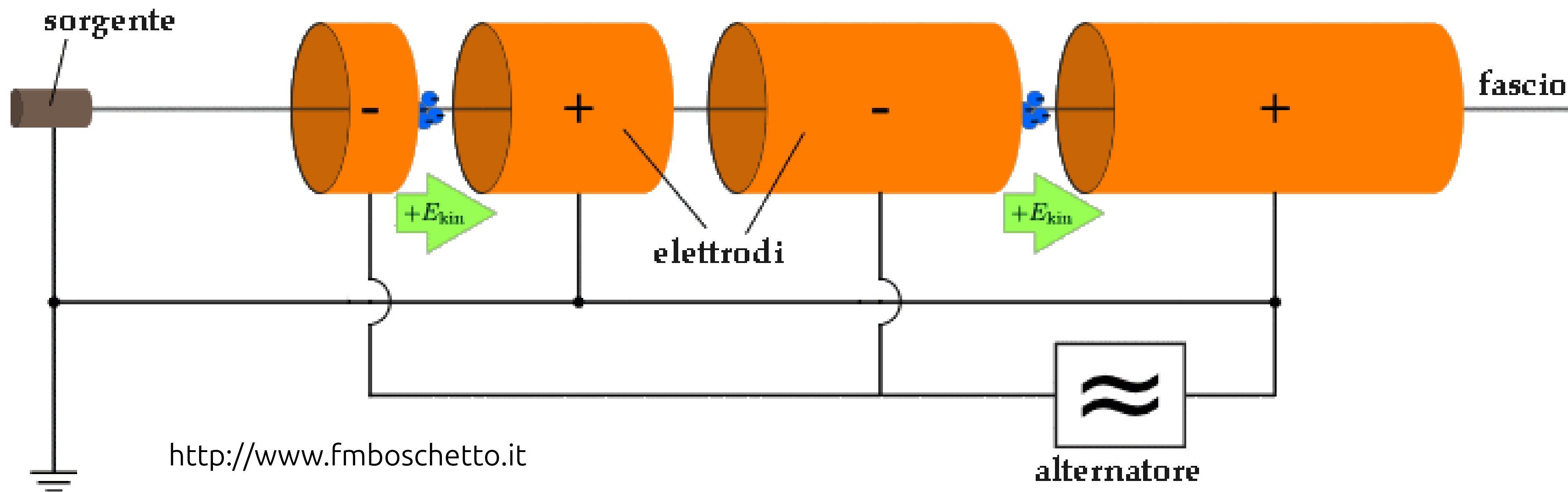
Lineari

Ciclotroni

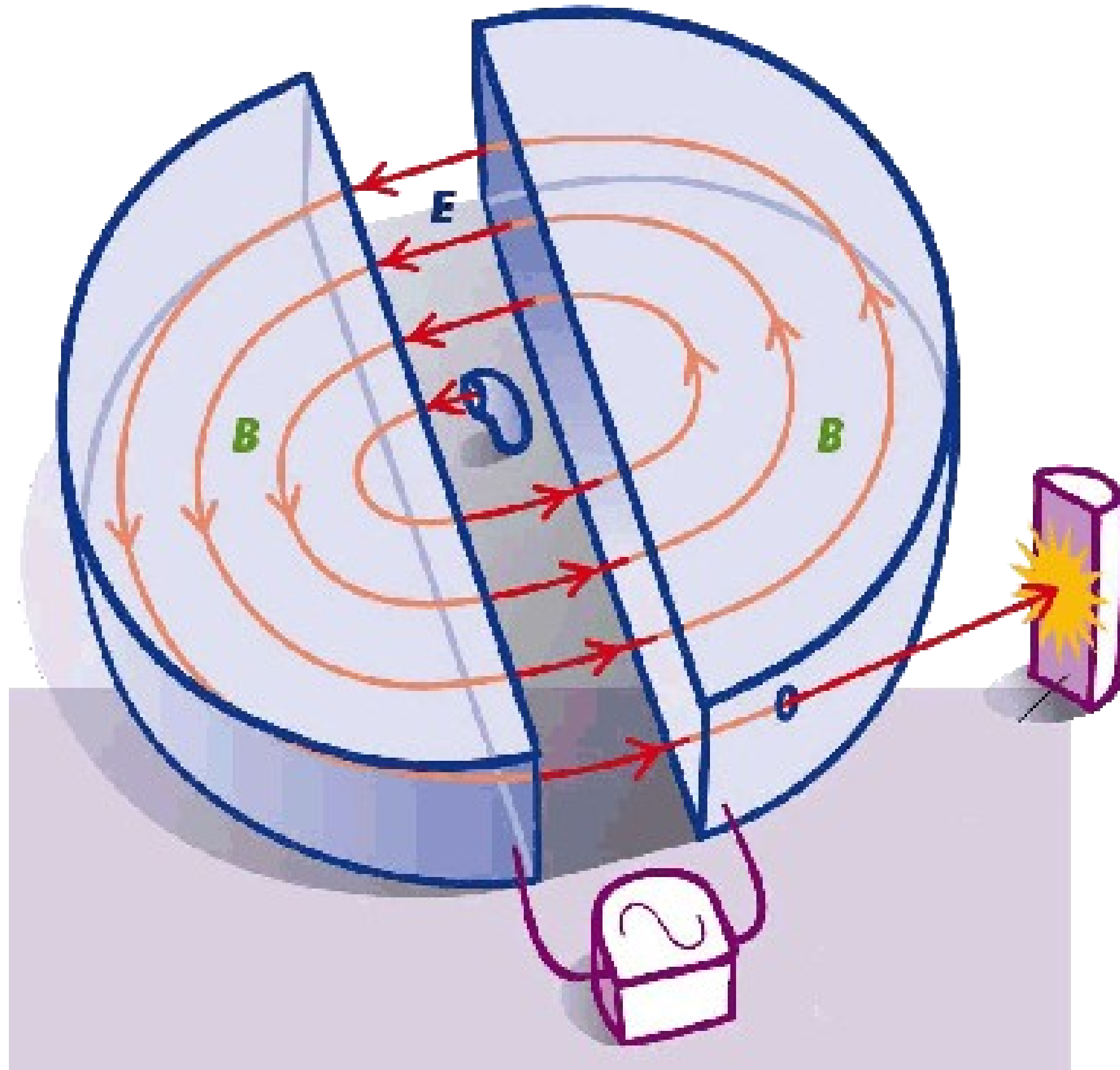
Sincrotroni

Acceleratori lineari

Cavità risonante dell'acceleratore lineare ALPI
ai Laboratori di Legnaro



Ciclotroni



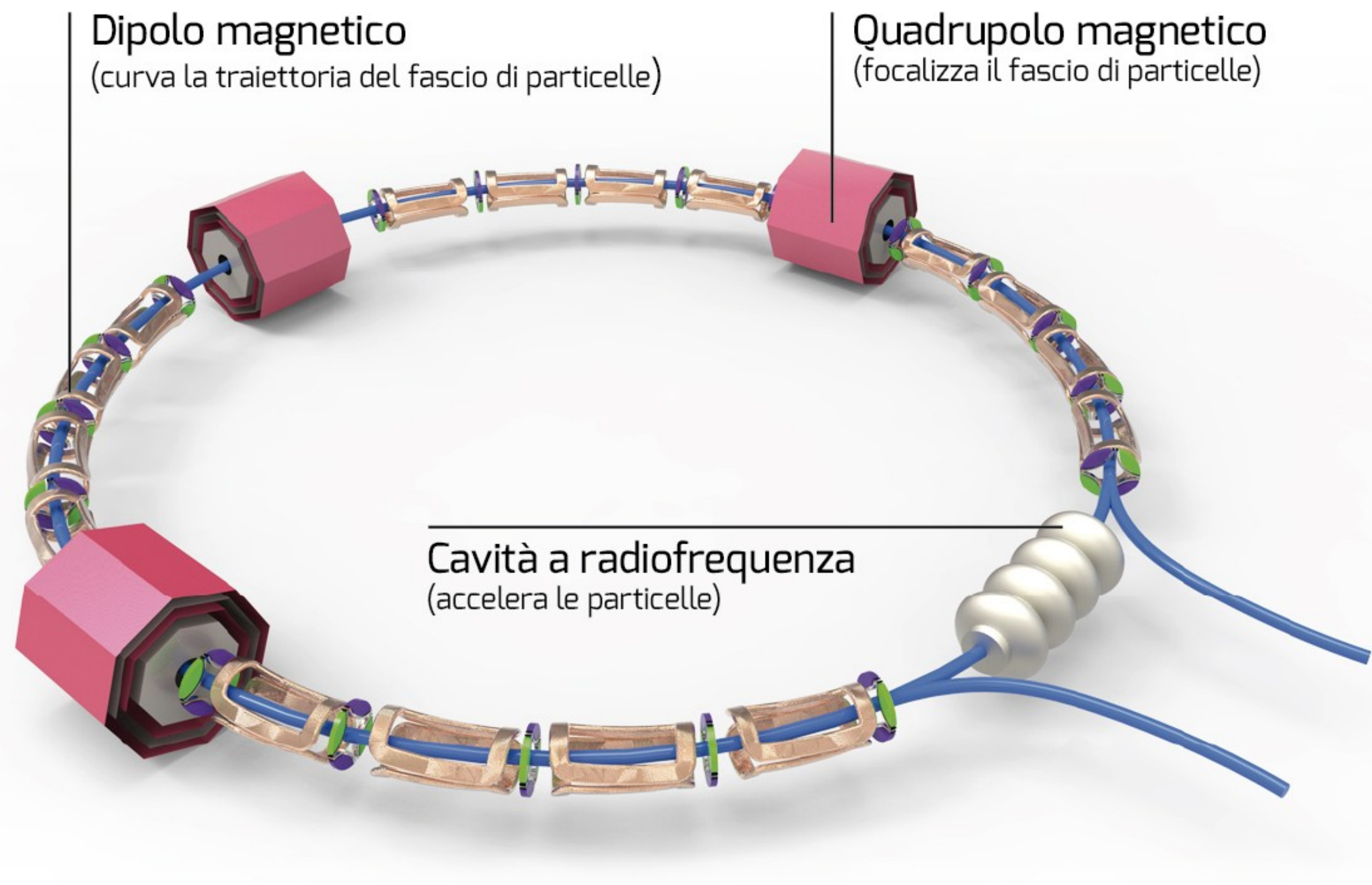
<http://www.fmboschetto.it>

Ciclotrone SPES ai Laboratori di Legnaro



Sincrotroni

$$R = \frac{m(t)v(t)}{qB(t)}$$

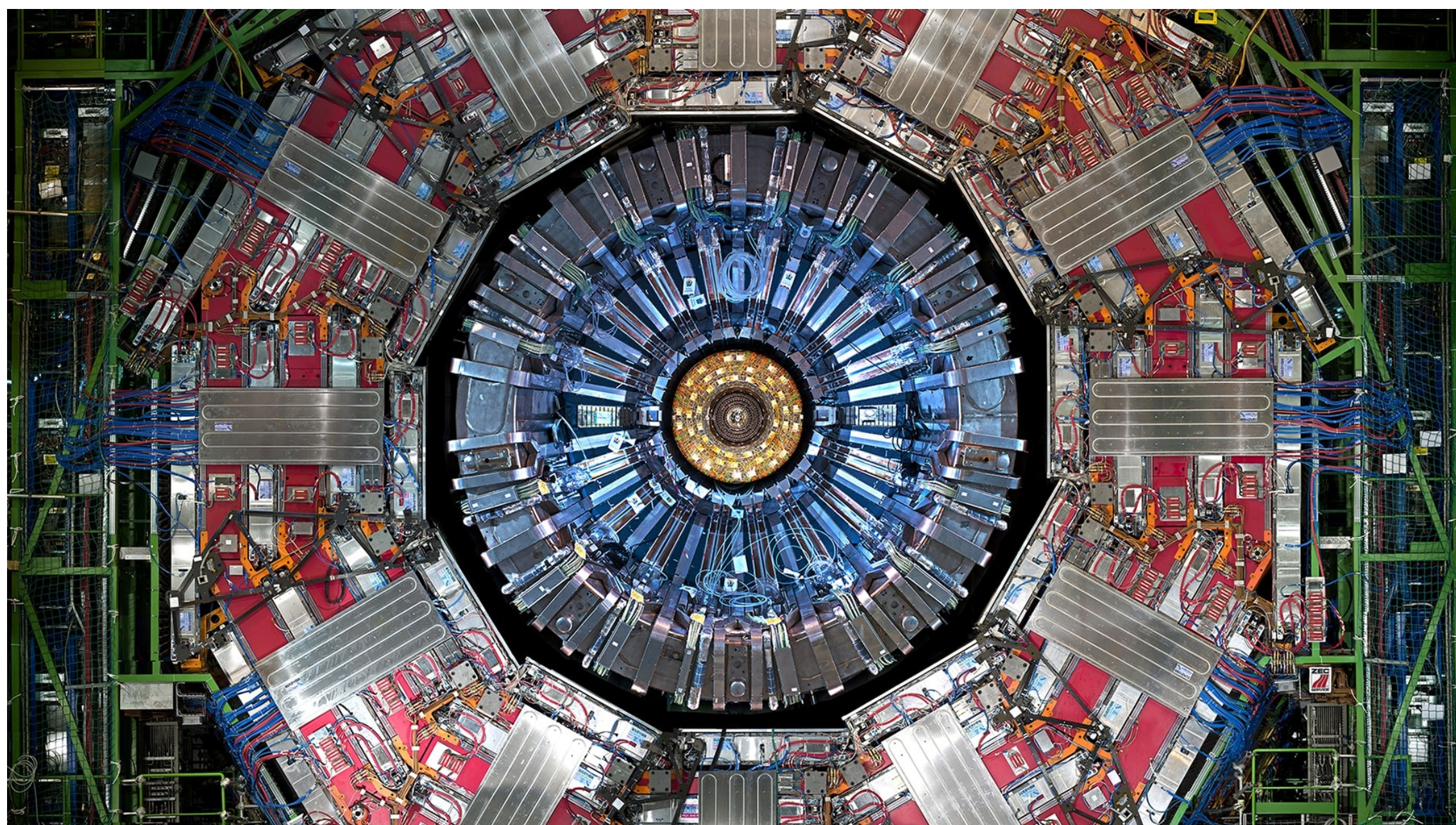


Sincrotrone Elettra a Trieste

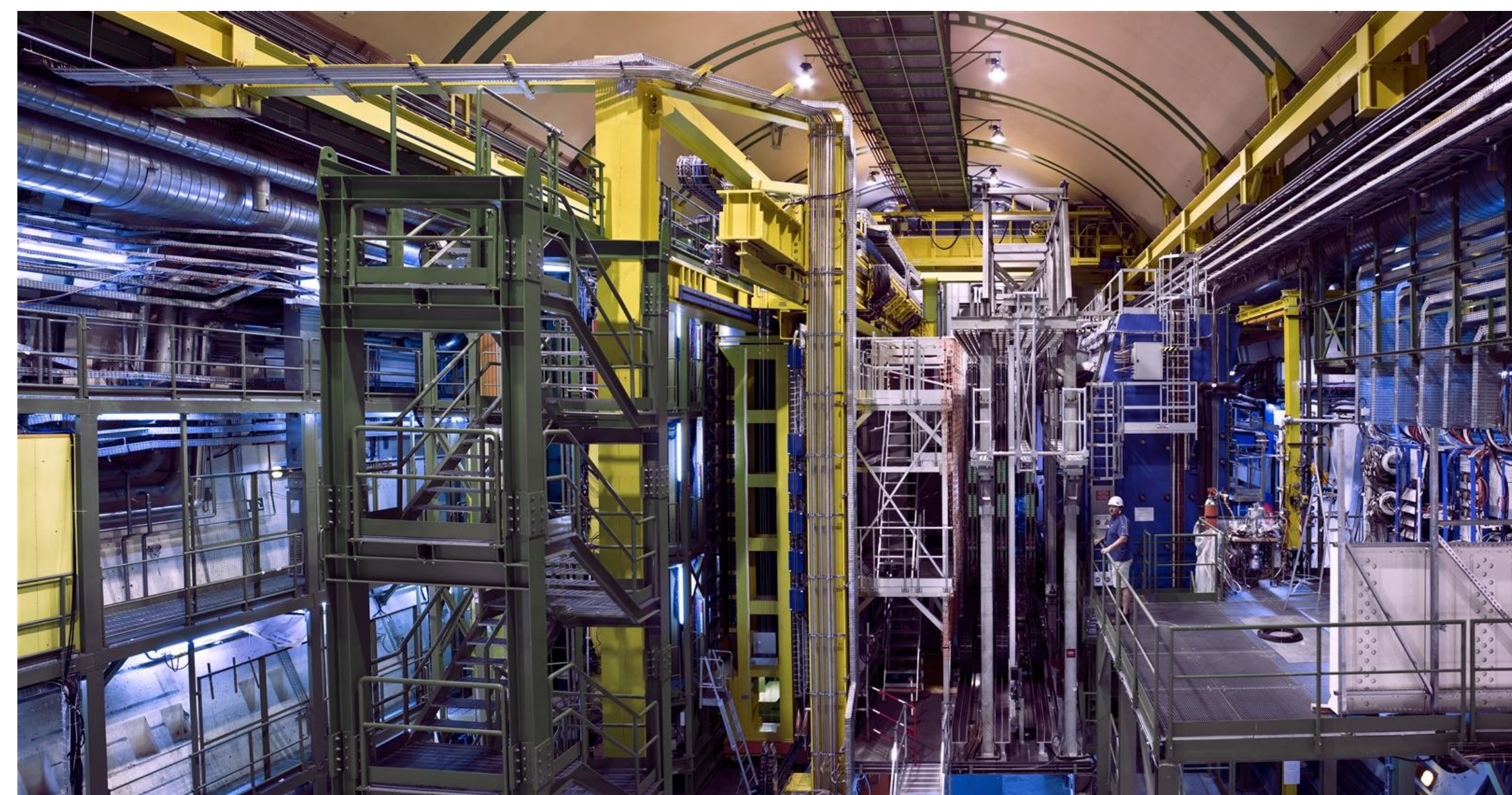


I nostri “occhi” nelle collisioni

Rivelatore CMS ad LHC

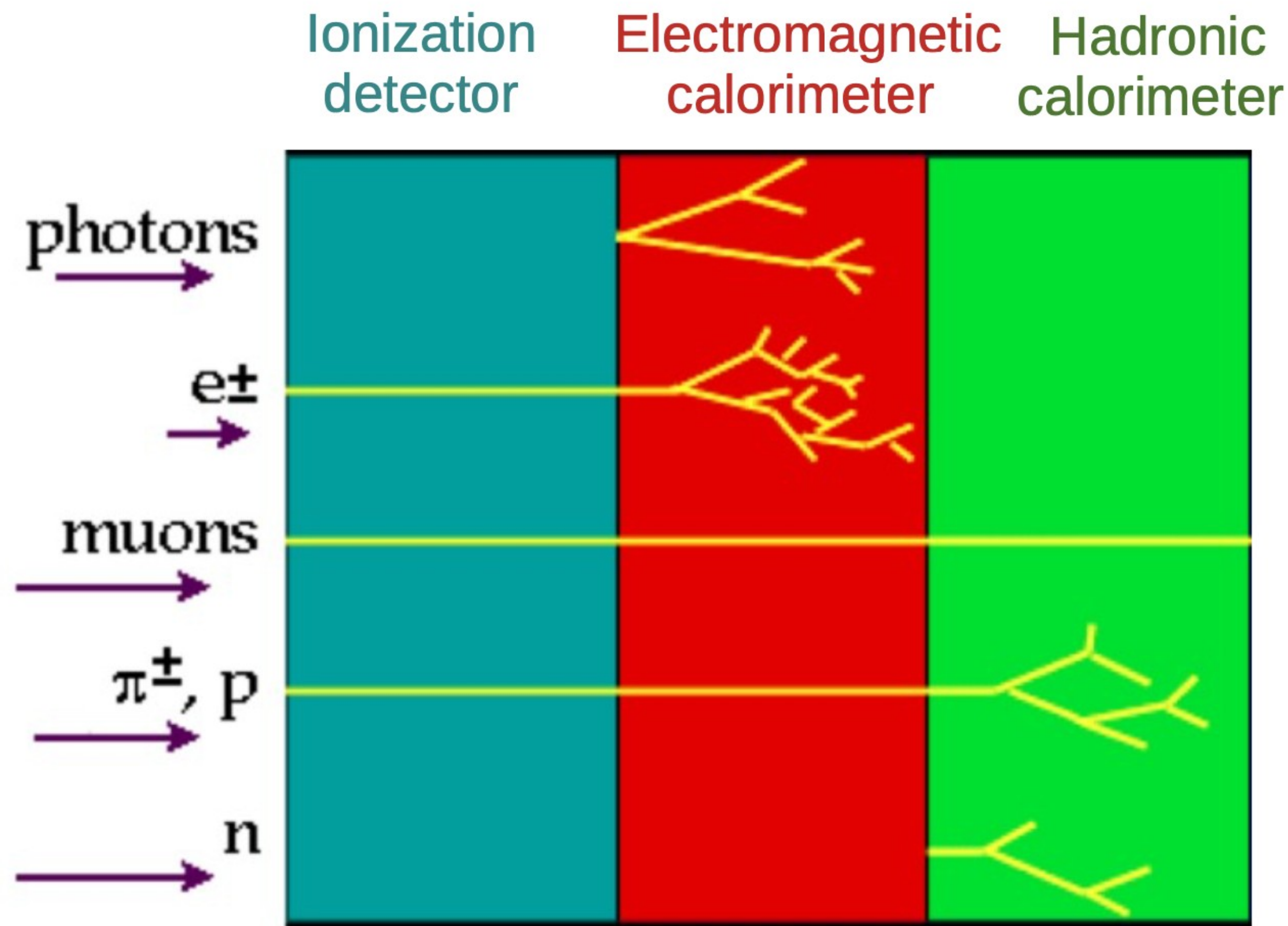


Rivelatore LHCb ad LHC

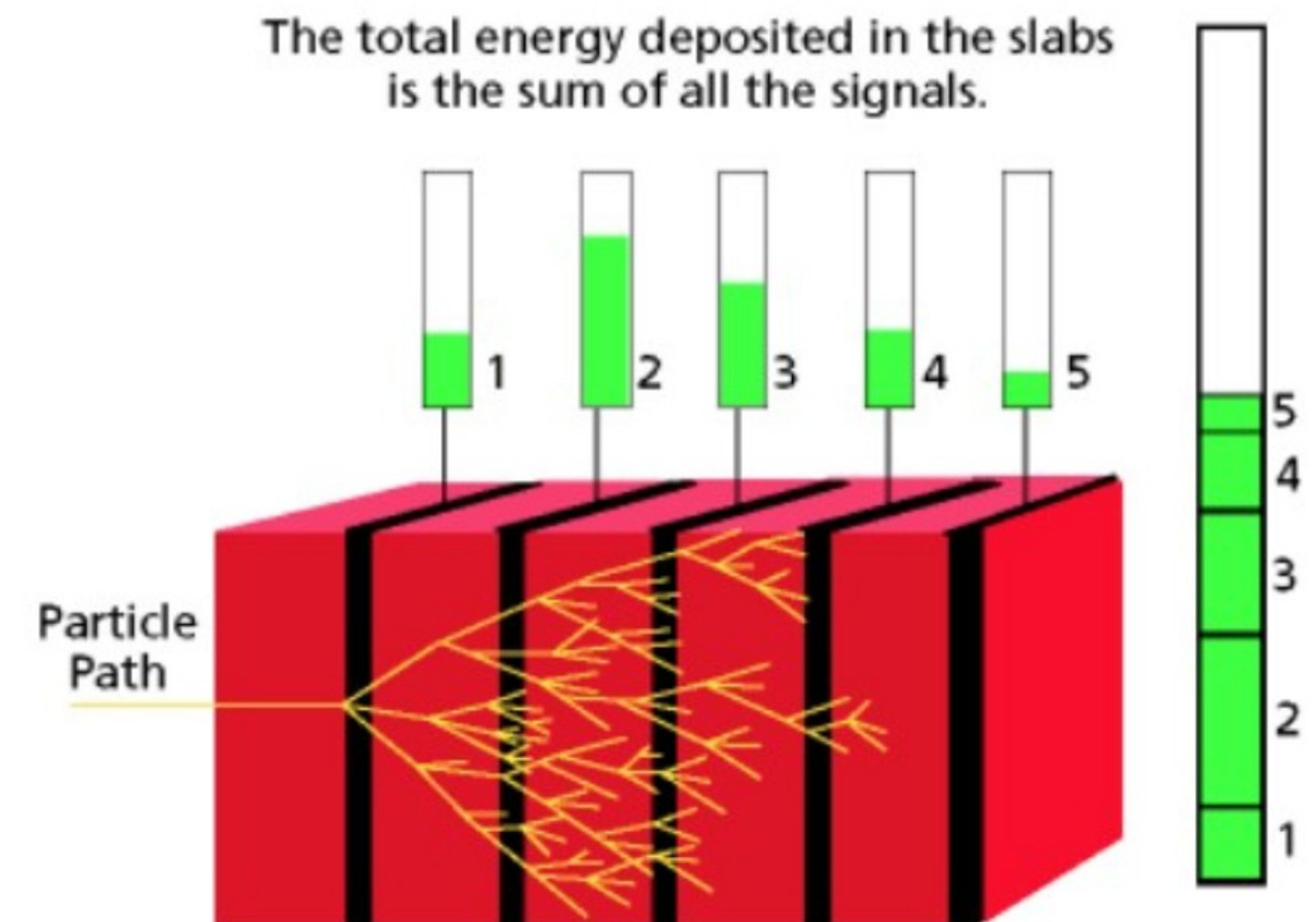


I nostri “occhi” nelle collisioni

Identificare le particelle prodotte nella collisione



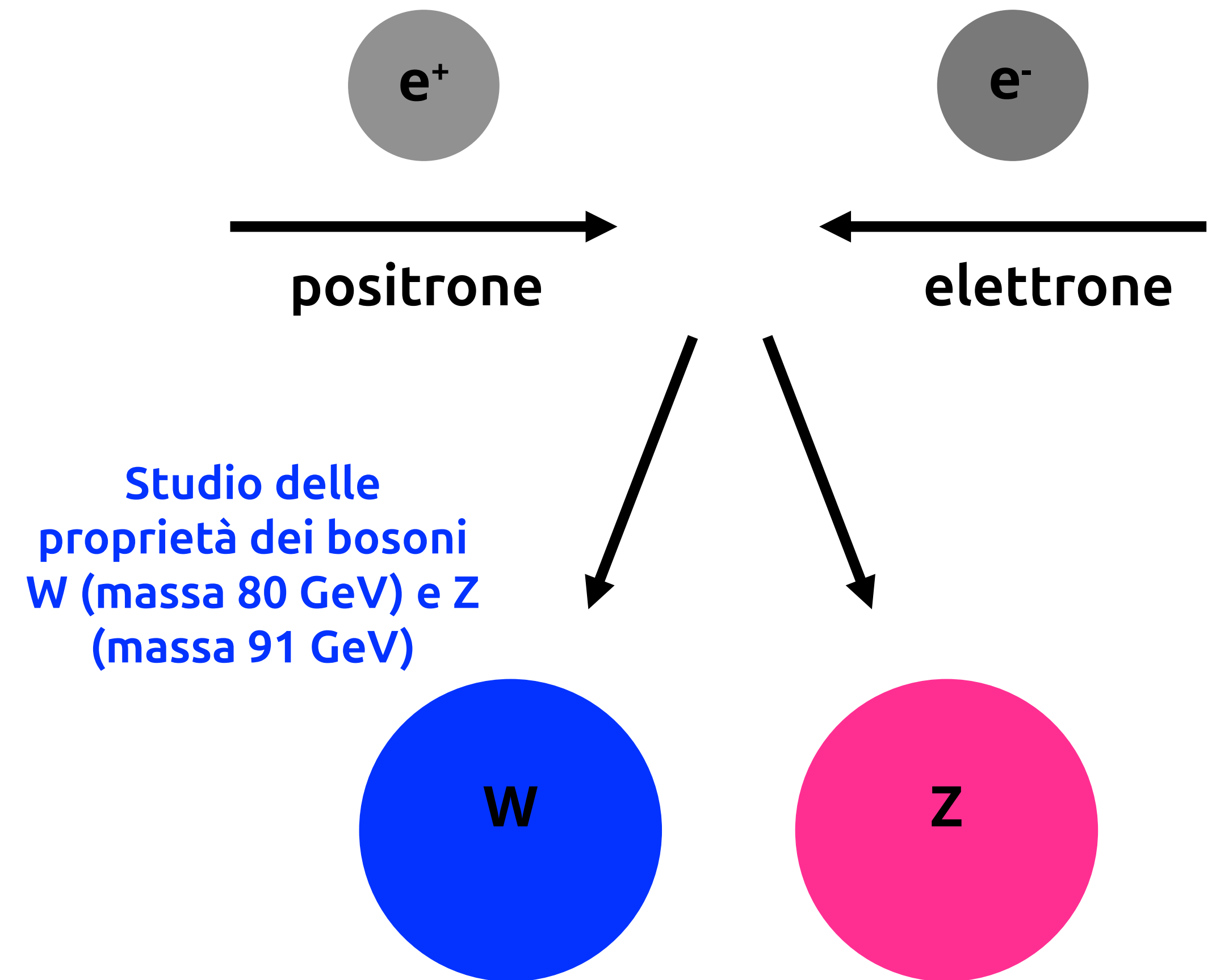
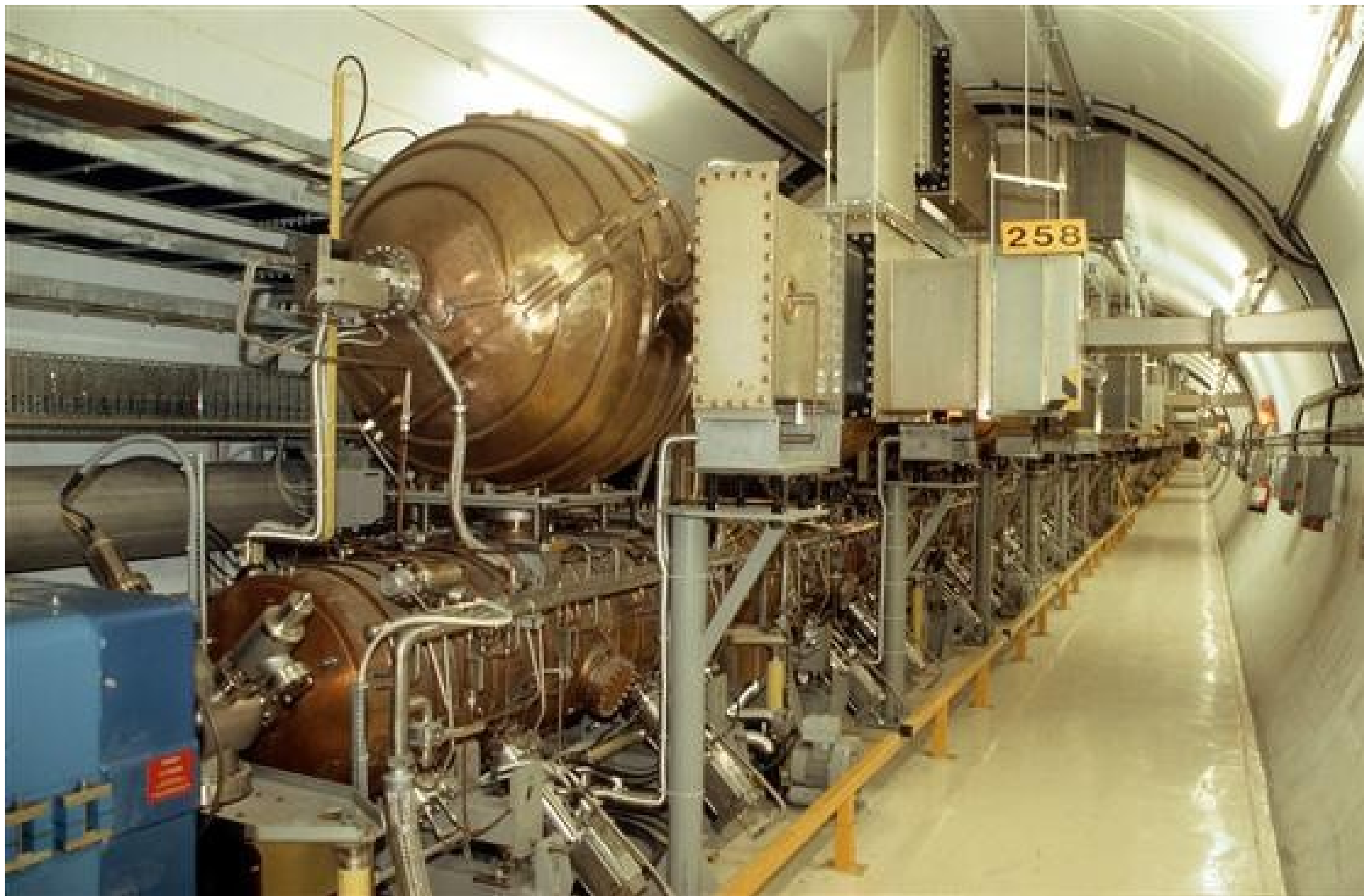
Misurare la loro energia



Quali particelle sappiamo accelerare?

Large Electron-Positron collider (LEP), CERN 1989-2000

Energia dei fasci fino a 104.5 GeV



Quali particelle sappiamo accelerare?

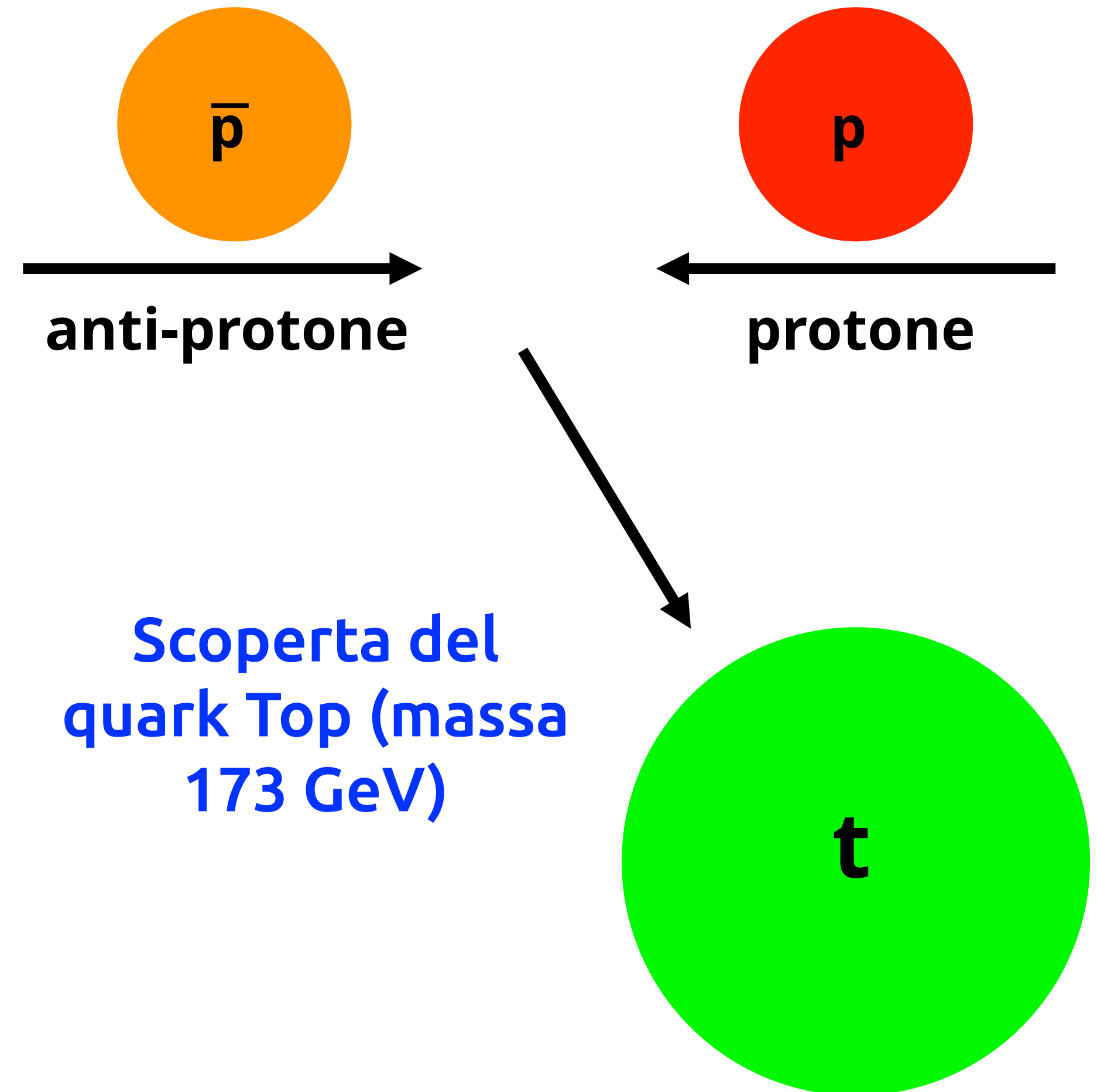
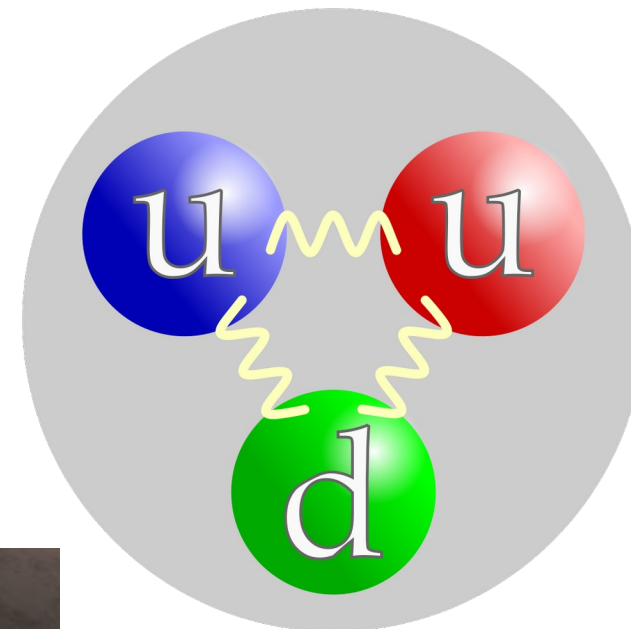
Tevatron, Fermilab-Chicago 1983-2011
Energia delle collisioni fino a 1.96 TeV



<https://www.fnal.gov>

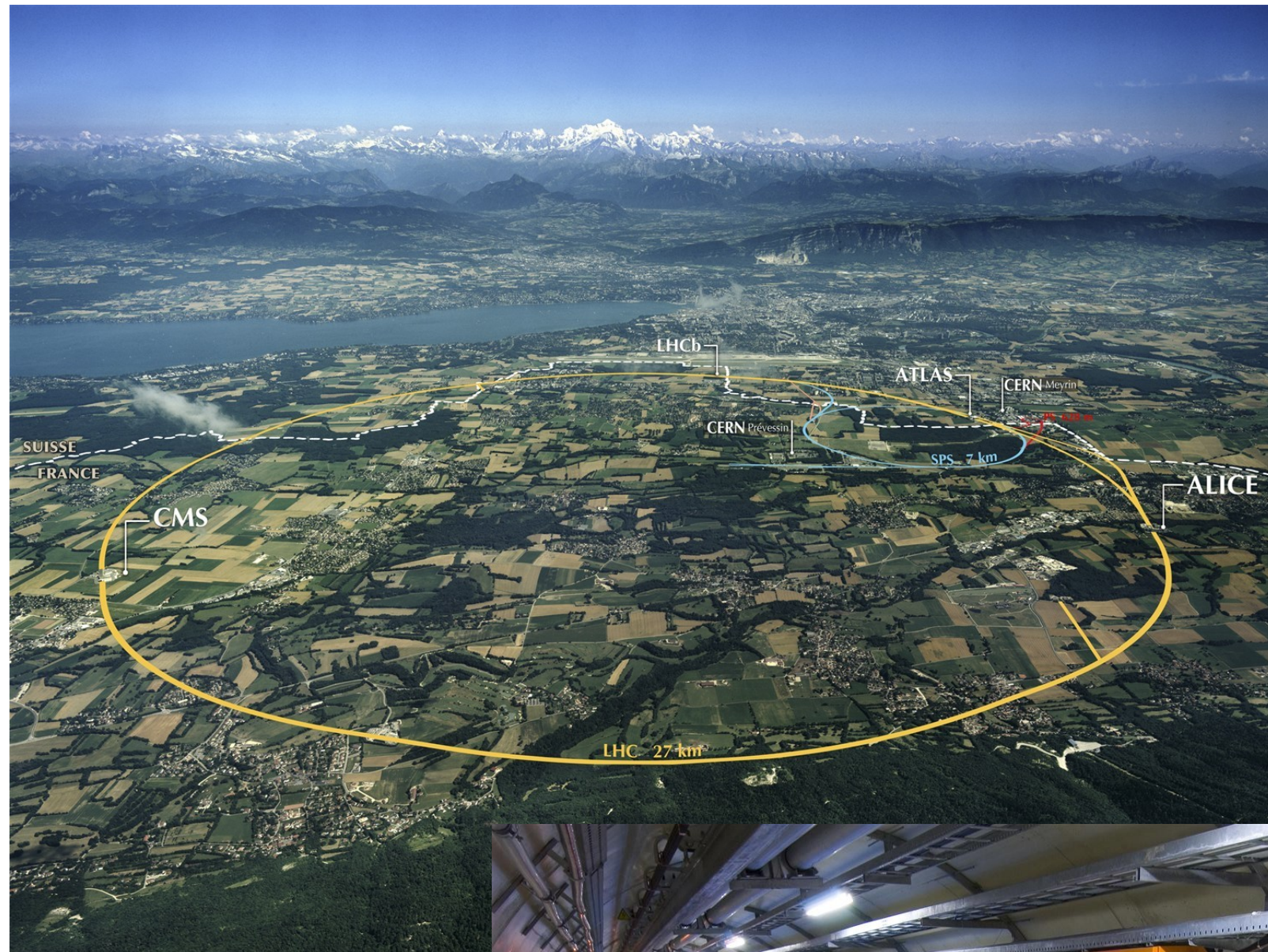


Energia divisa tra i
costituenti del
protone/antiprotone

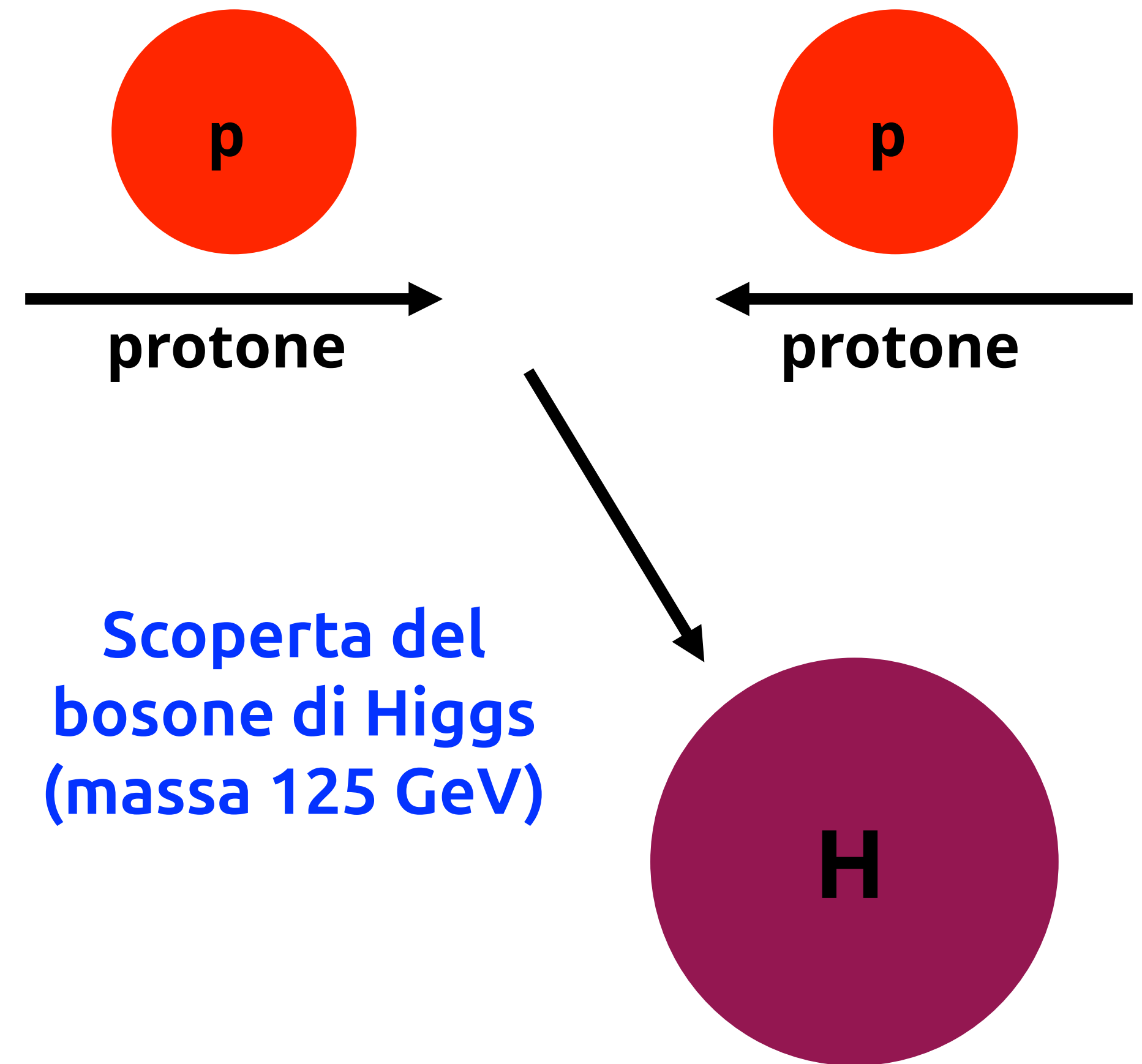
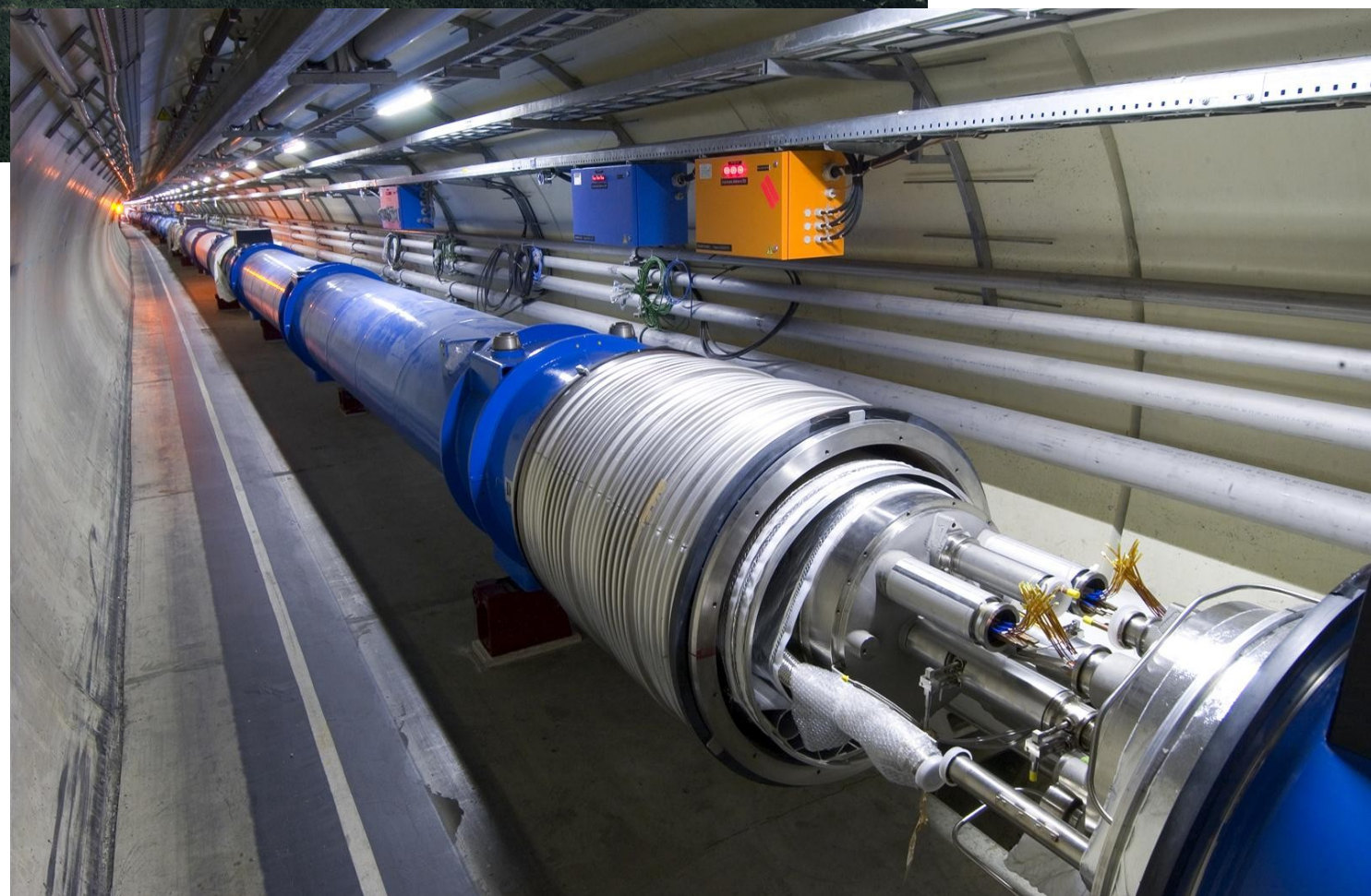


Quali particelle sappiamo accelerare?

LHC, CERN 2010-oggi
Energia delle collisioni fino a 14 TeV

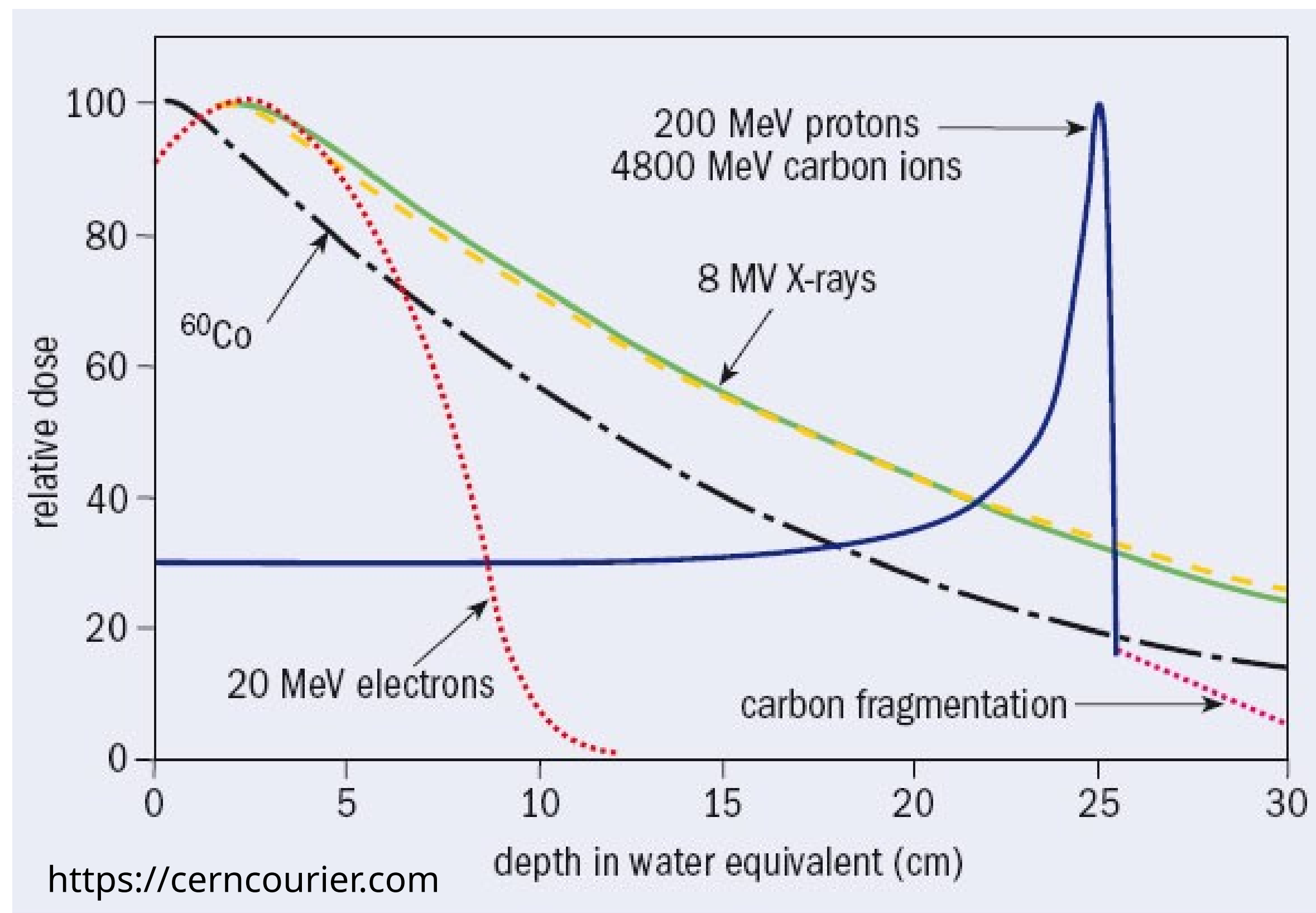


**Possibilità di
accelerare gli ioni!**



Applicazioni nella Fisica Medica

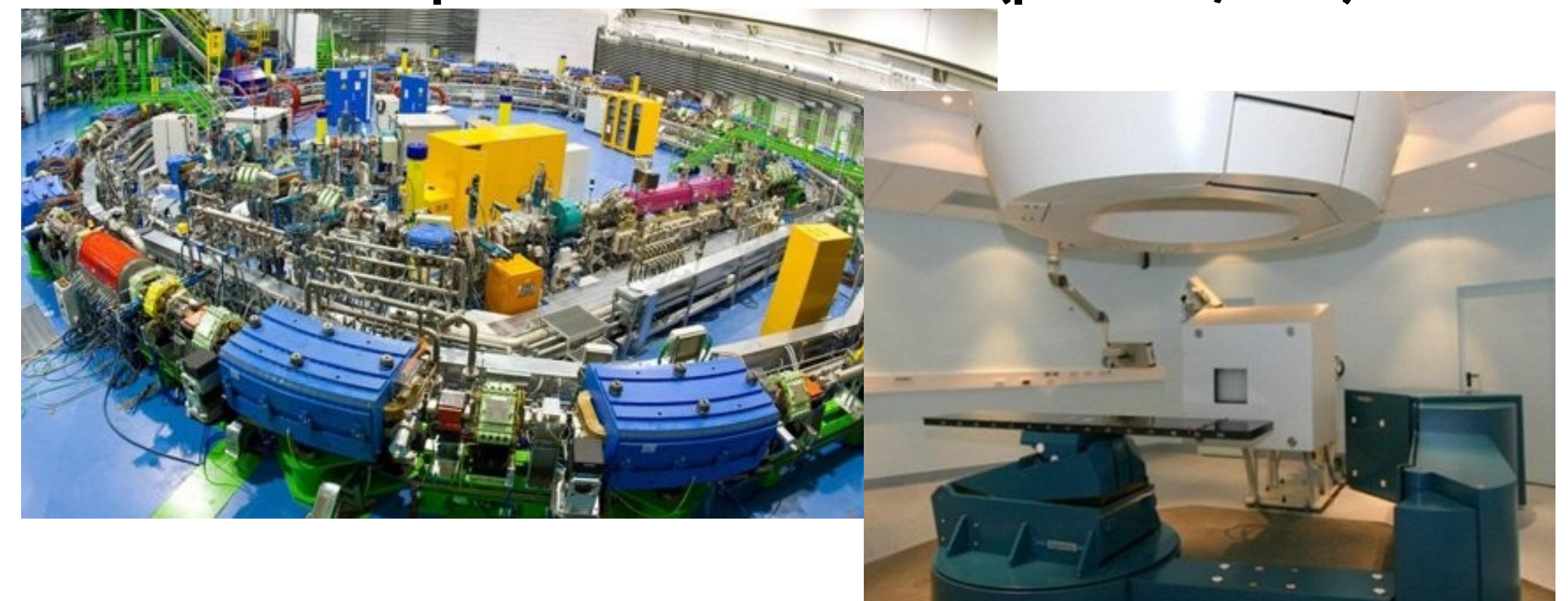
Dose: $D = \frac{E_d}{m}$ E_d : energia assorbita da una massa m . 1Gy=1 J/Kg



Radioterapia convenzionale (elettroni, fotoni)

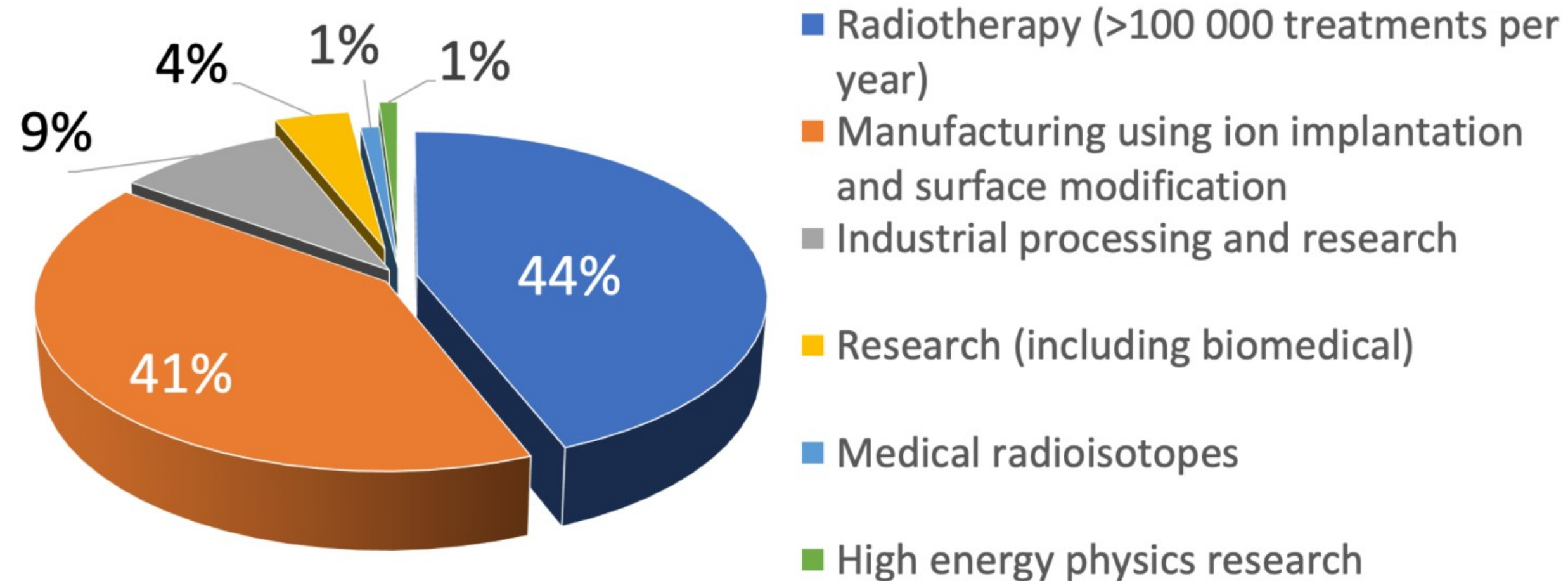


Adroterapia al CNAO di Pavia (protoni, ioni)



E molto altro

Uses and applications of particle accelerators

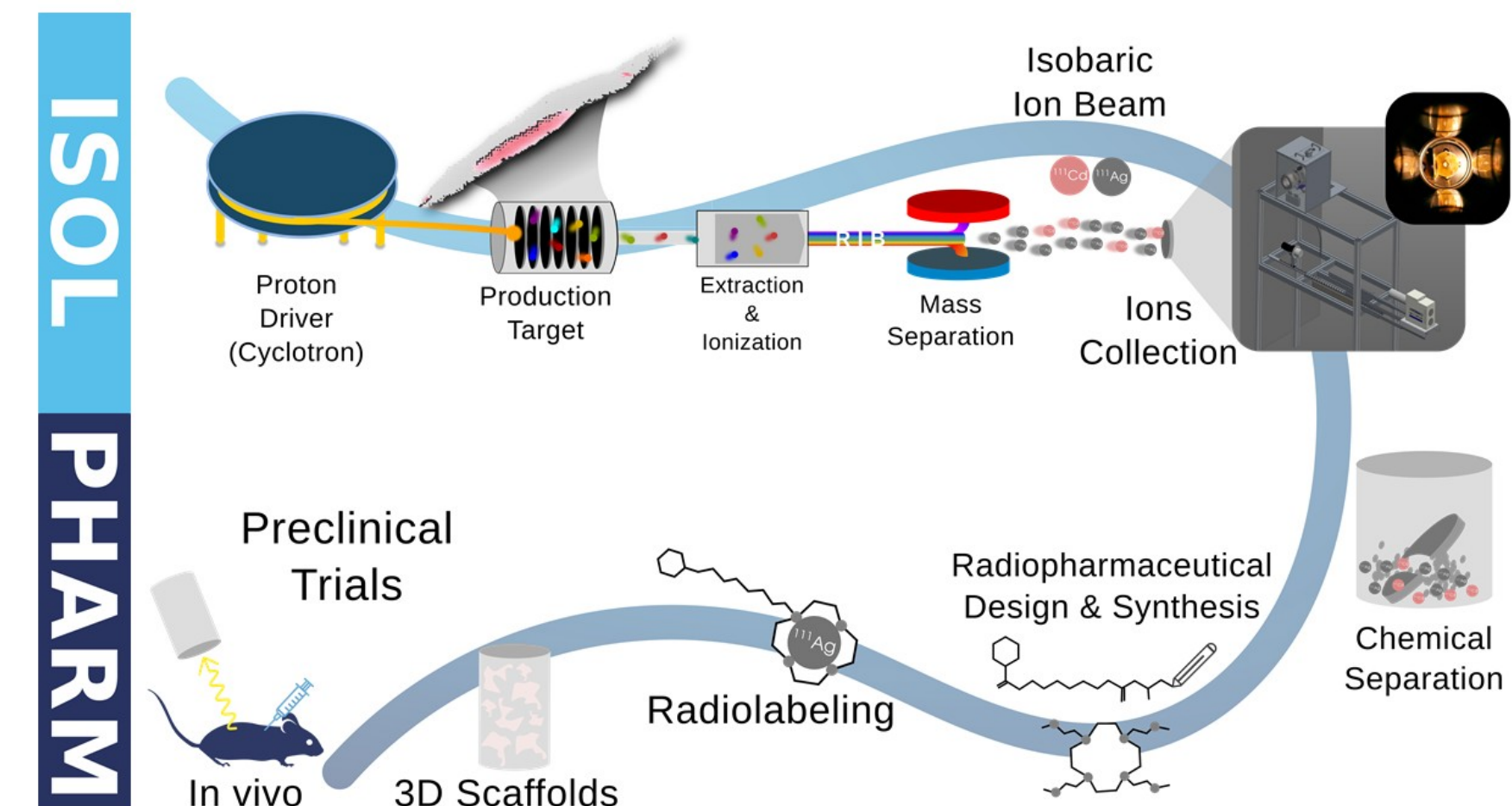
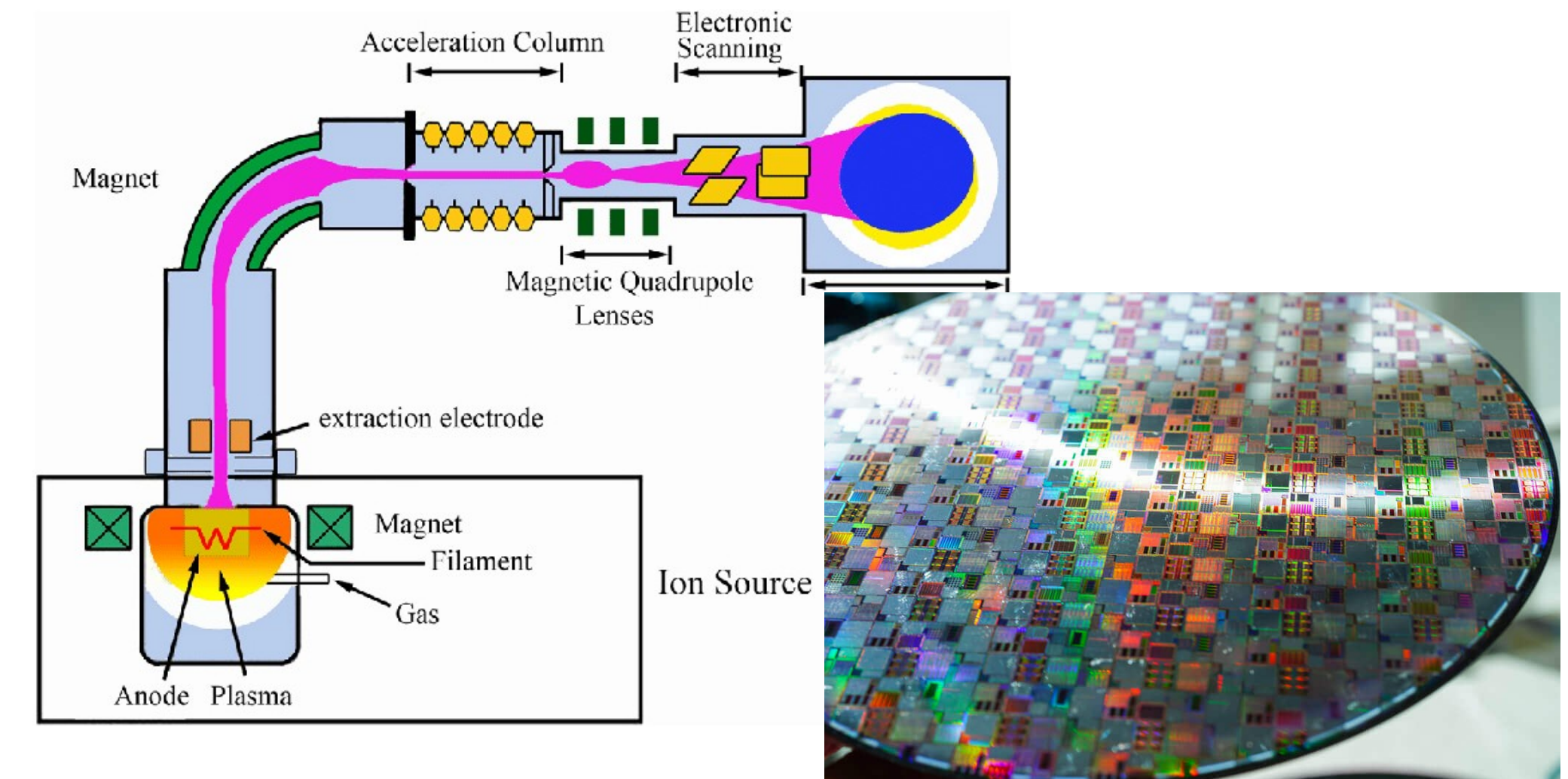


La fisica delle particelle è solo l'1%!

Radioisotopi a uso medico

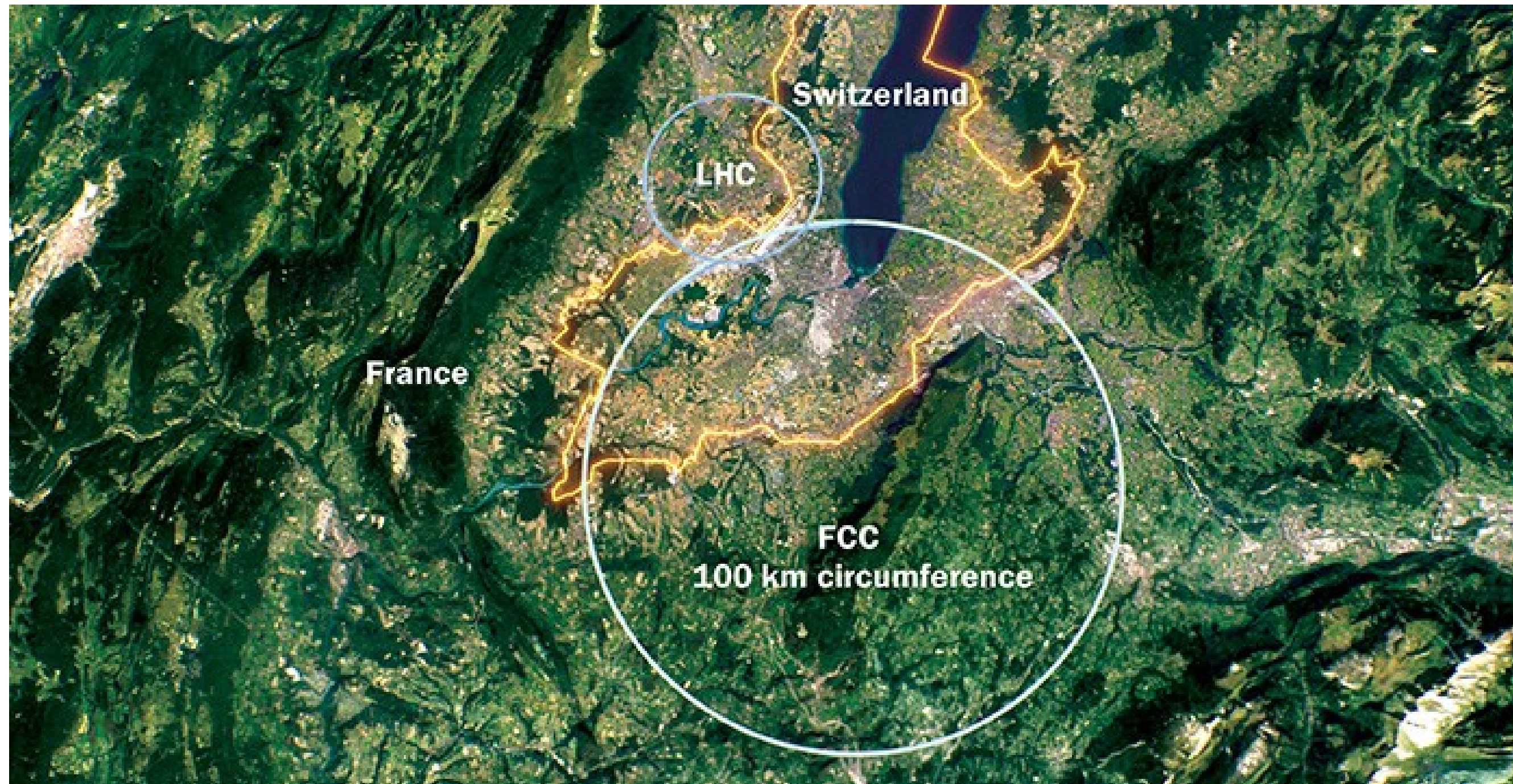
Inl.infn.it
scienceinschool.org
10.1063/5.0021322

Produzione chip silicio

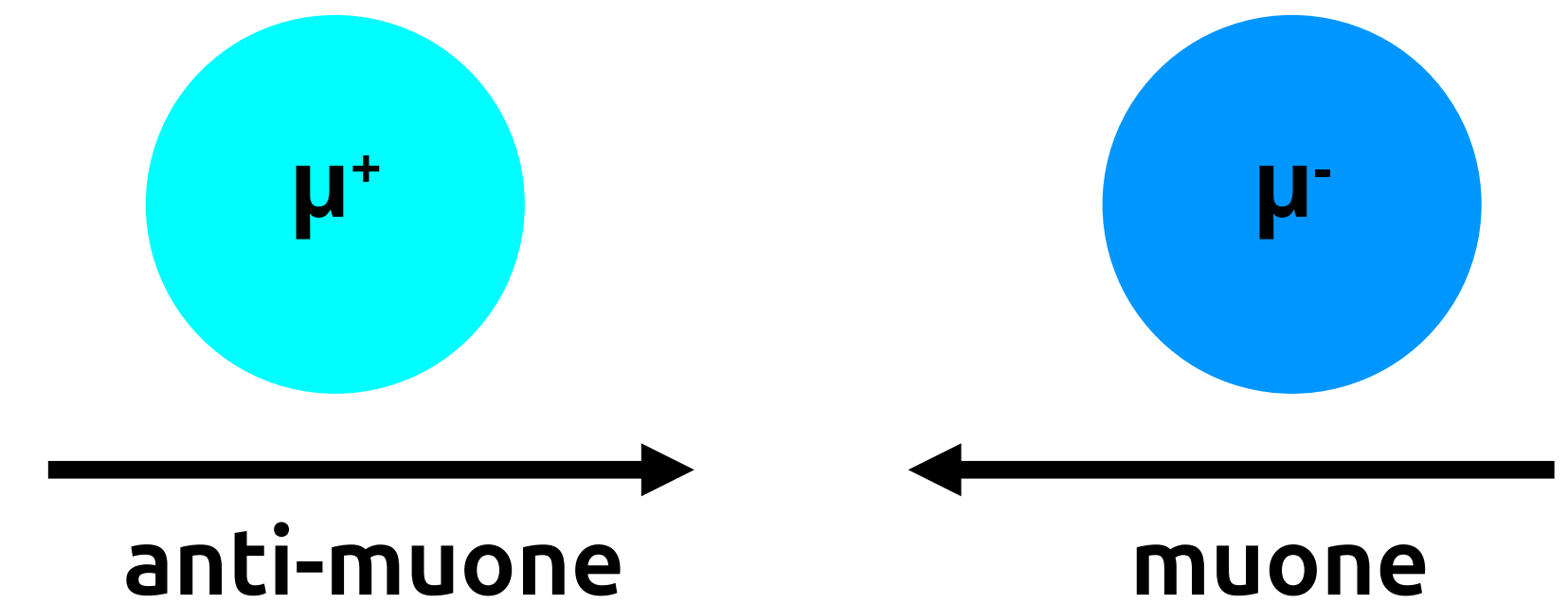


What next?

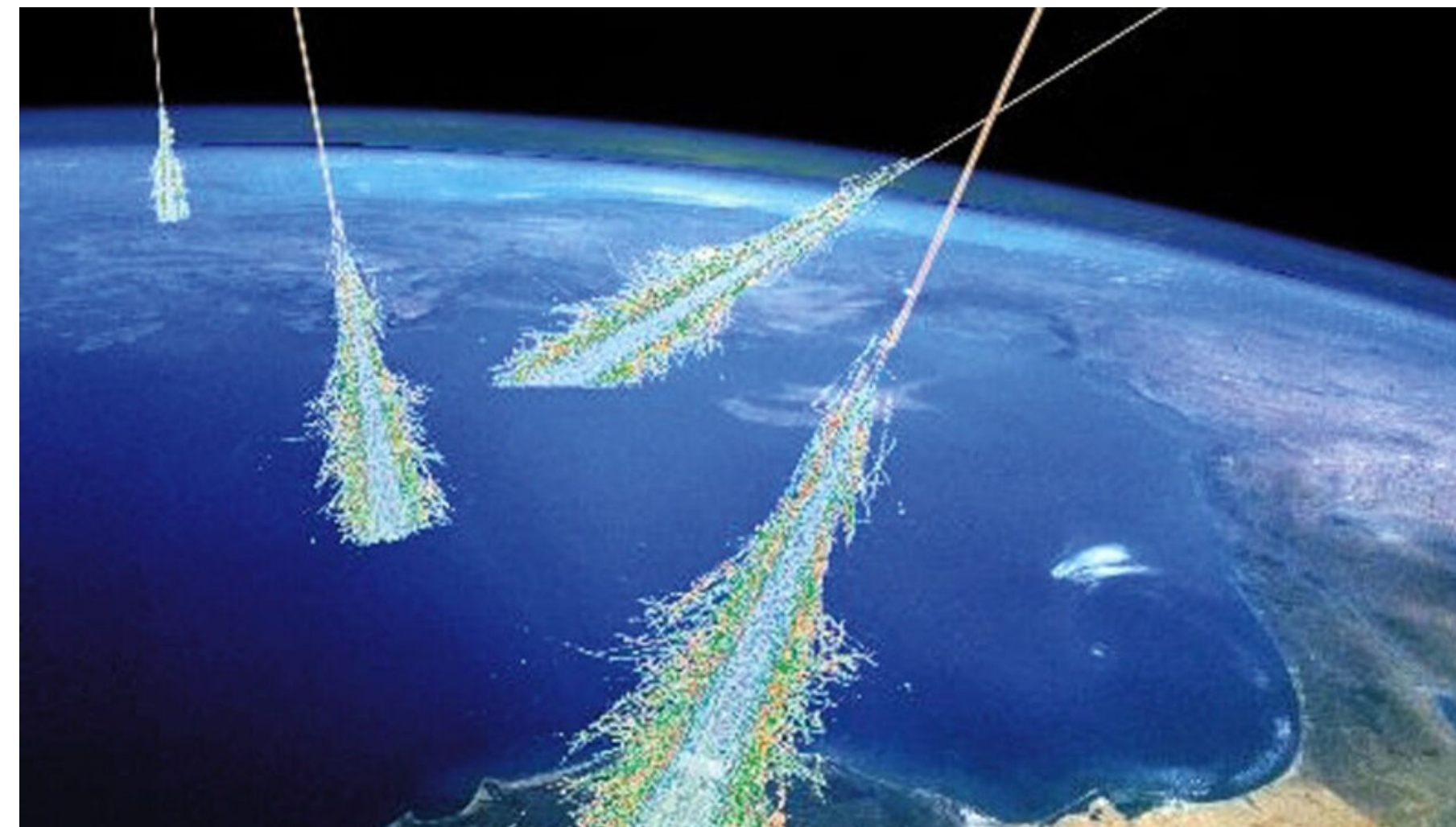
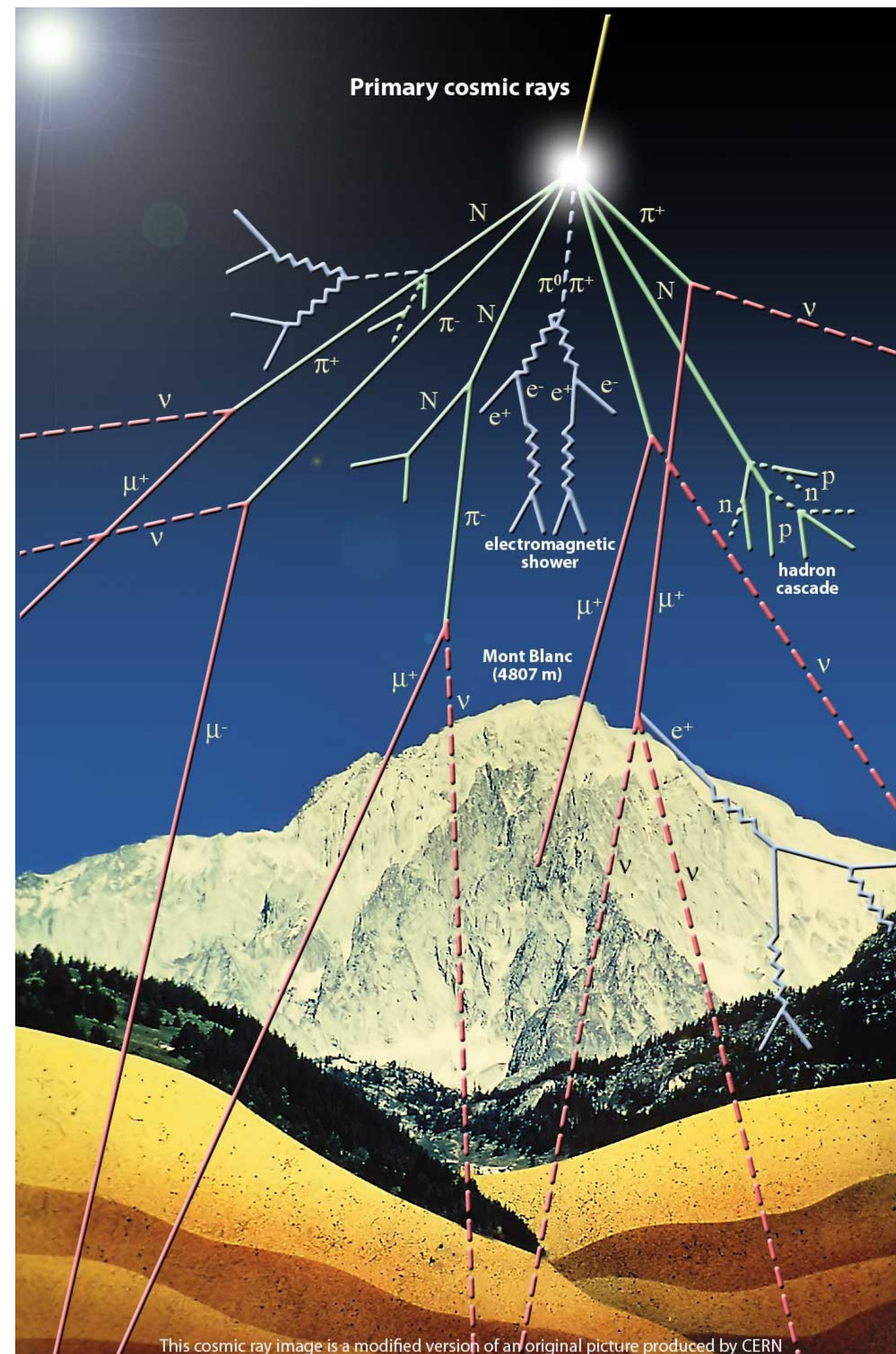
Future Circular Collider: collisioni (elettrone-positrone o protone-protone) fino a energie di 100 TeV



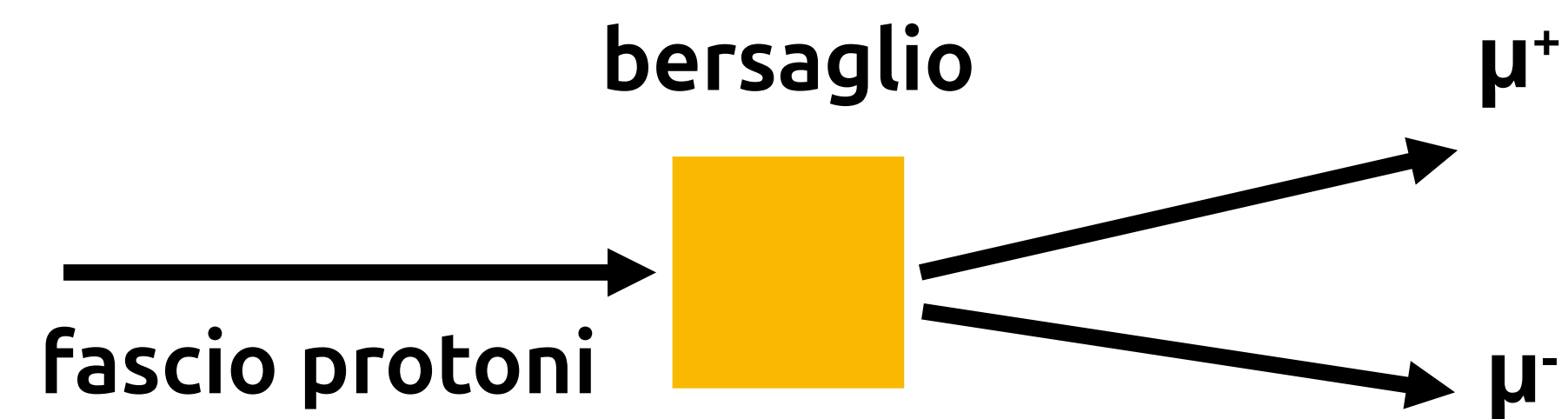
Oppure particelle mai accelerate prima



Dove si trovano i muoni in natura?

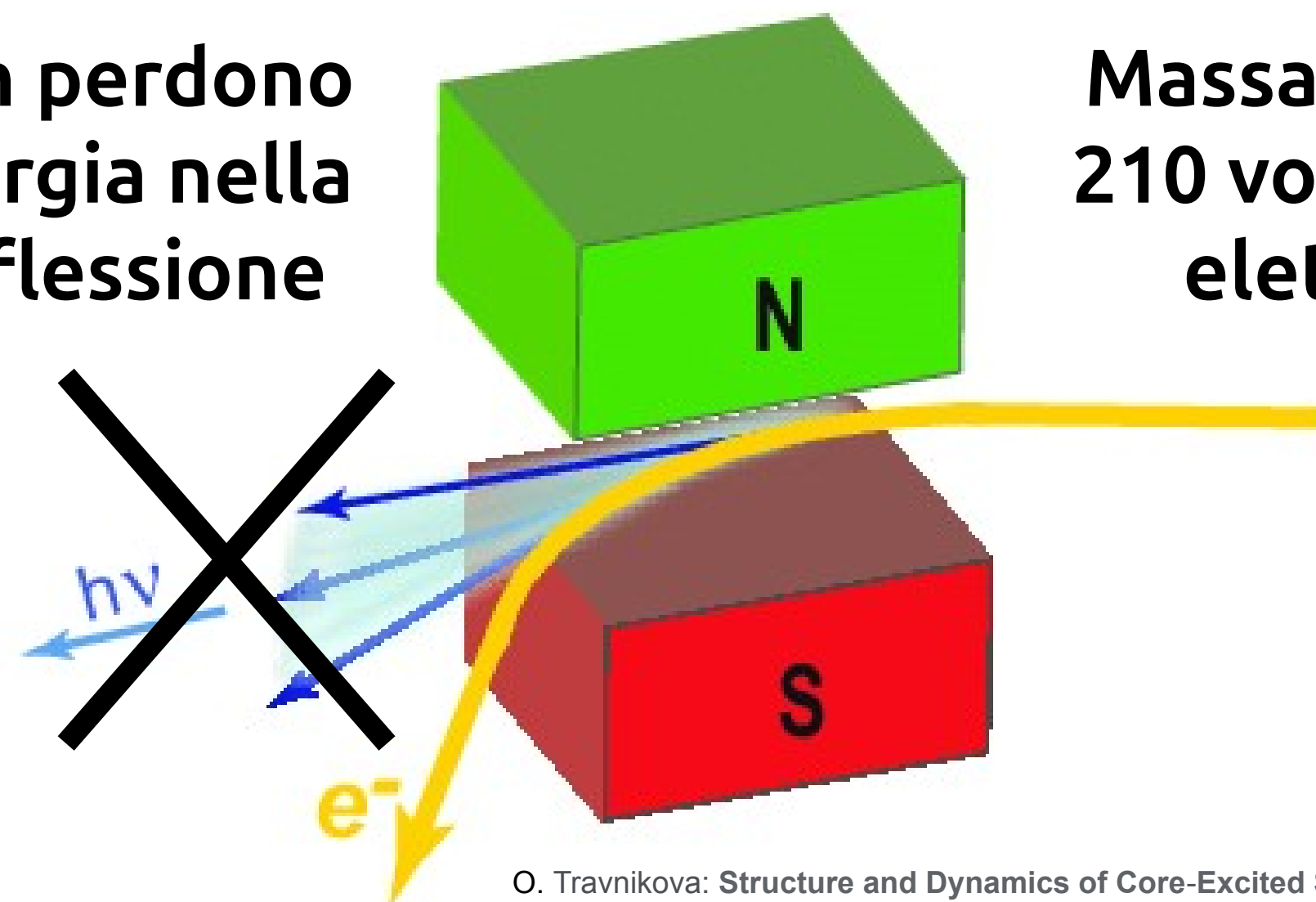


**I muoni sono estremamente rari
sulla Terra!**



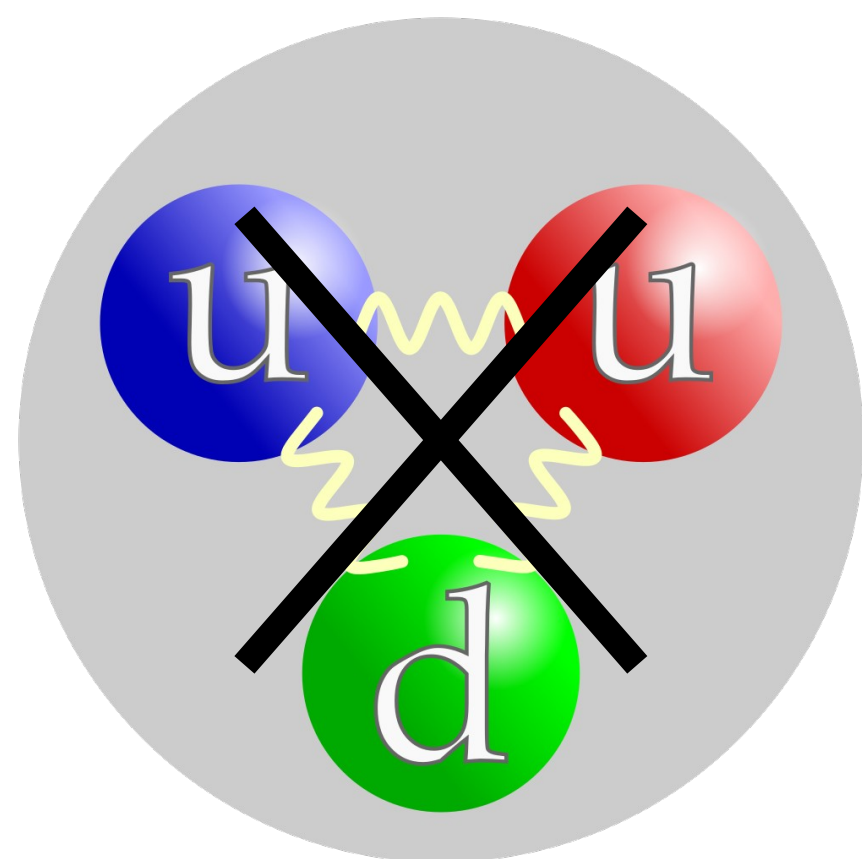
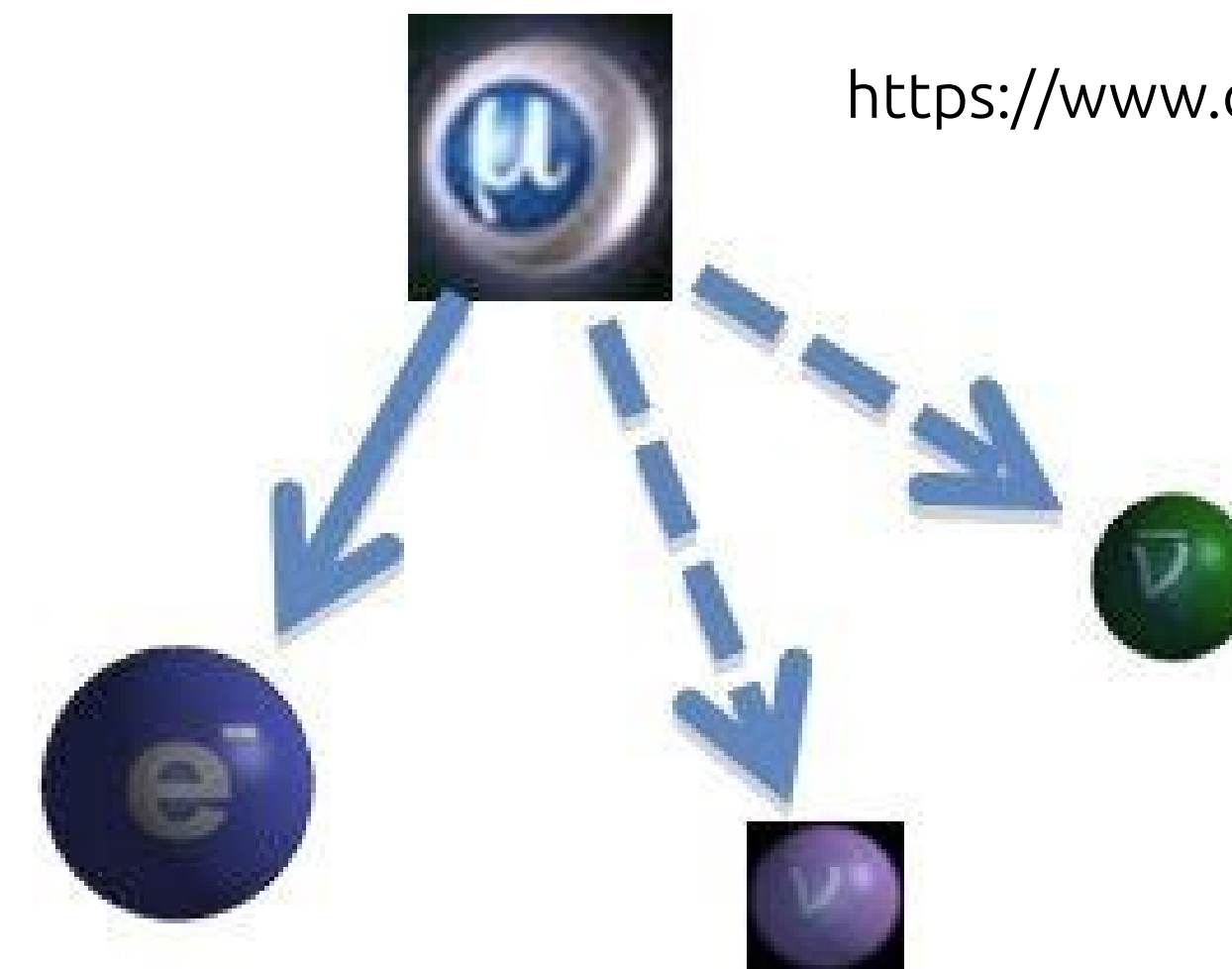
Accelerare i muoni

Non perdono
energia nella
deflessione



Massa muone =
210 volte massa
elettrone

O. Travnikova: Structure and Dynamics of Core-Excited Species, 2008



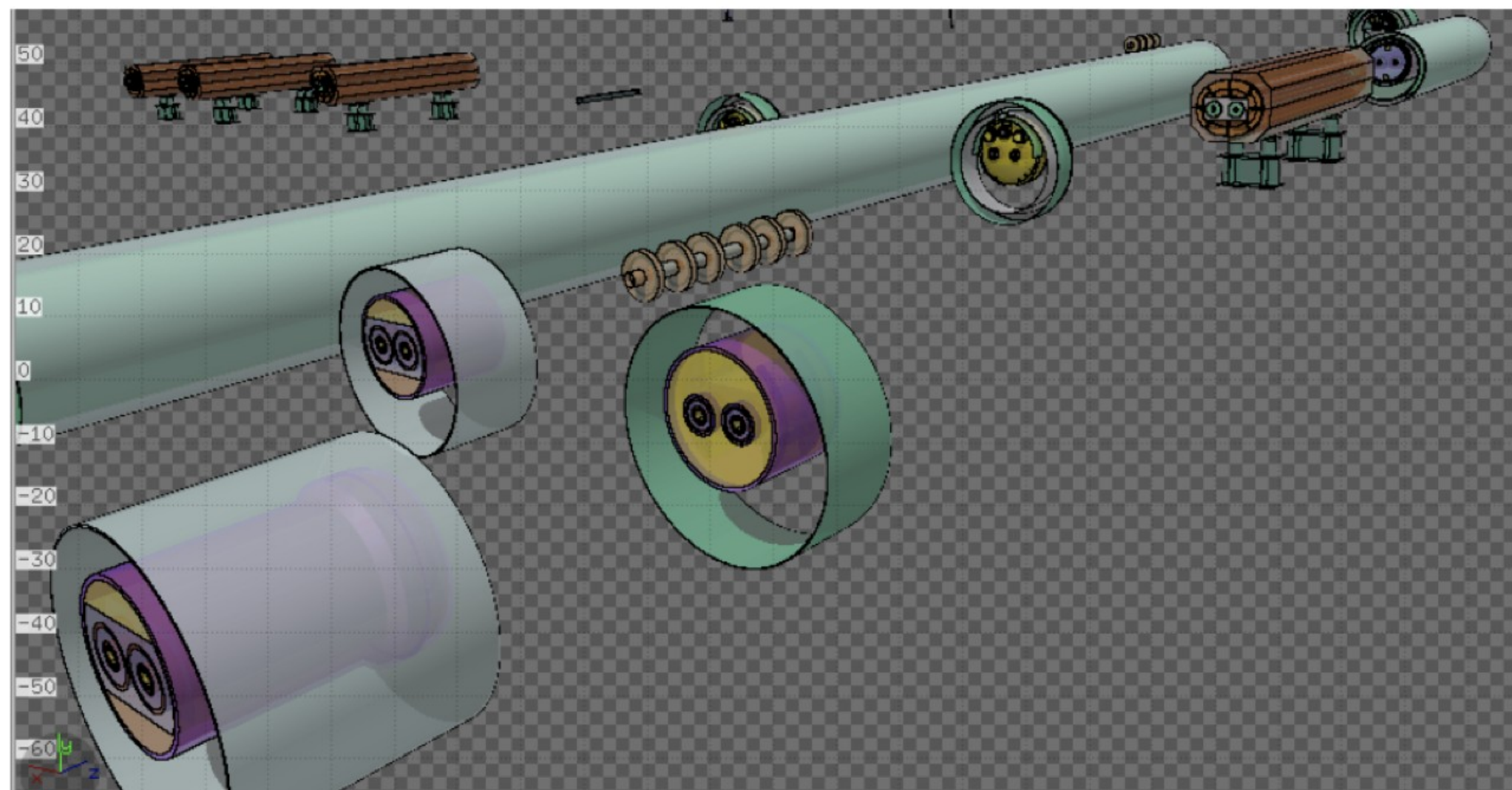
Non sono costituiti da
altre particelle: tutta
l'energia è disponibile
per la collisione!

Purtroppo decadono velocemente...
**Devono essere accelerati in circa 0.000001
secondi**

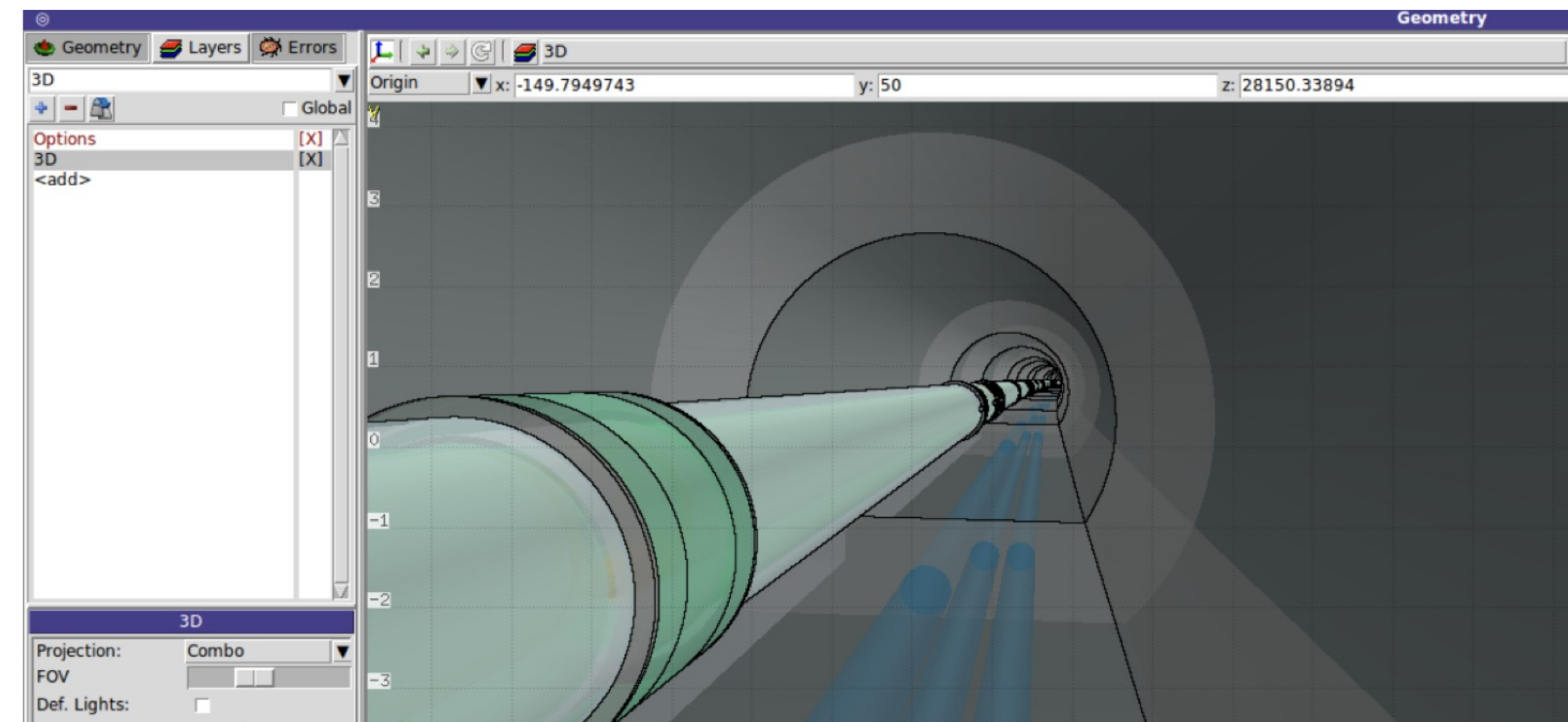
Progettare un Muon Collider

Esistono dei software che permettono di simulare gli acceleratori

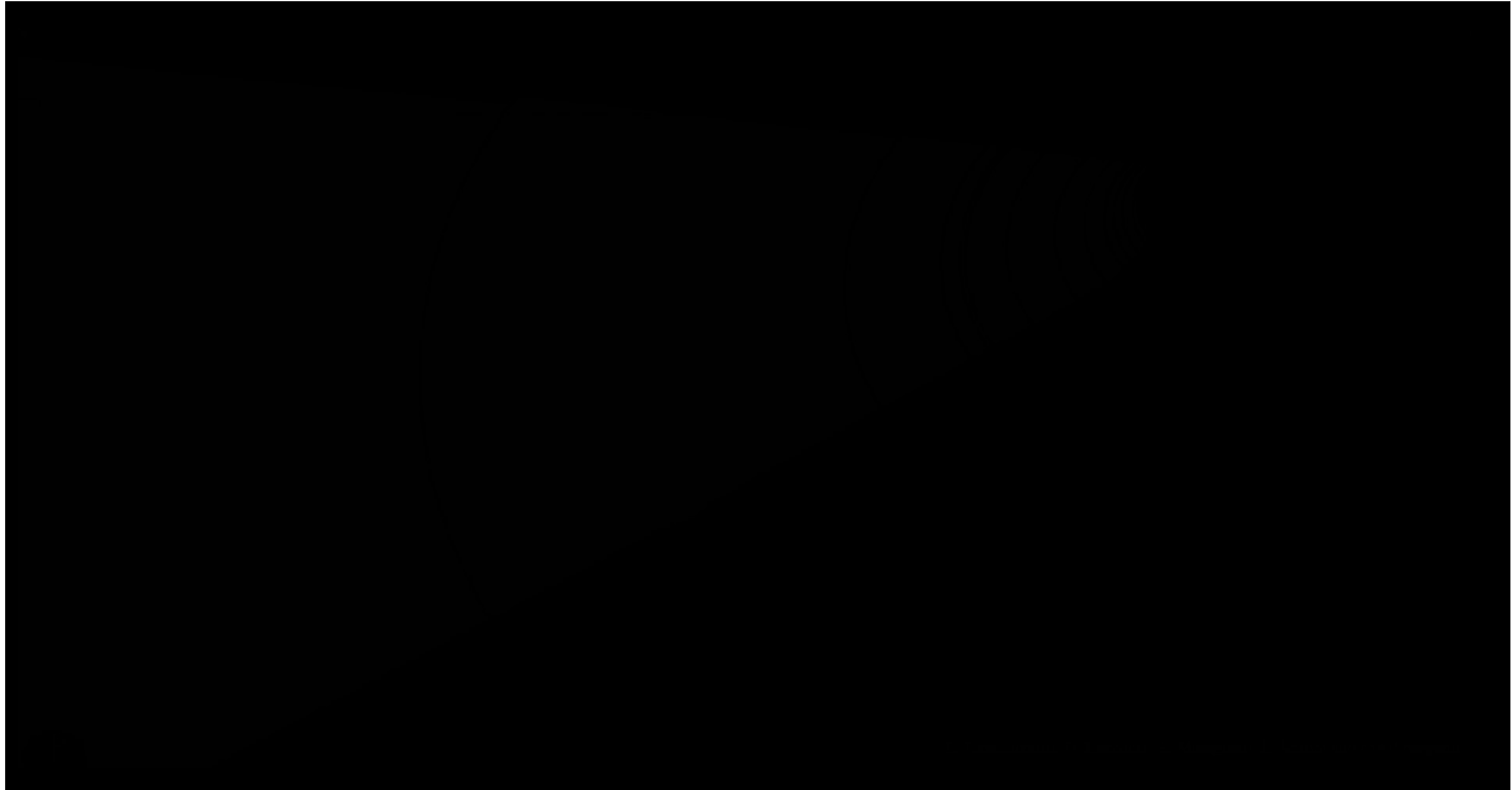
Si scelgono i vari componenti



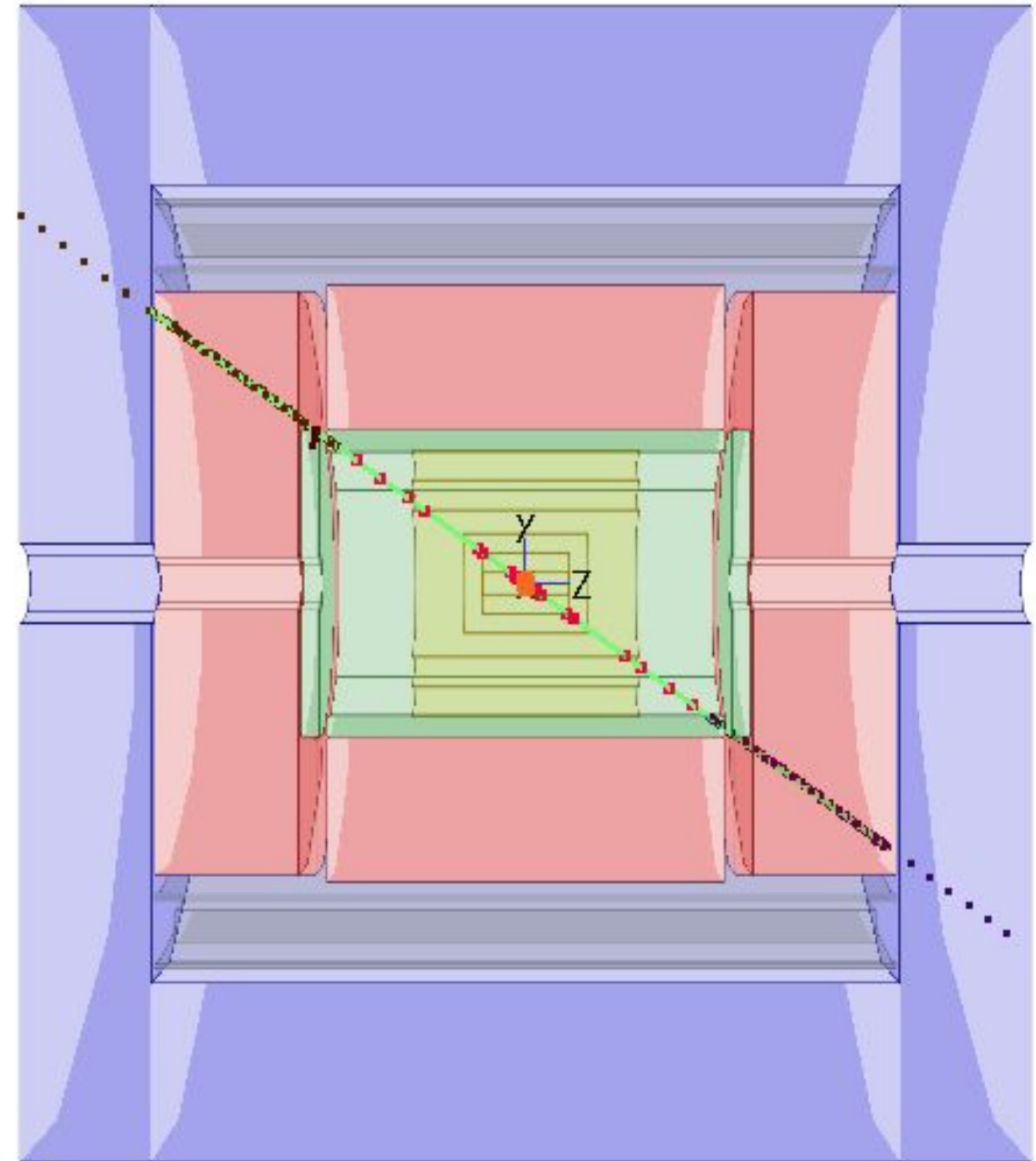
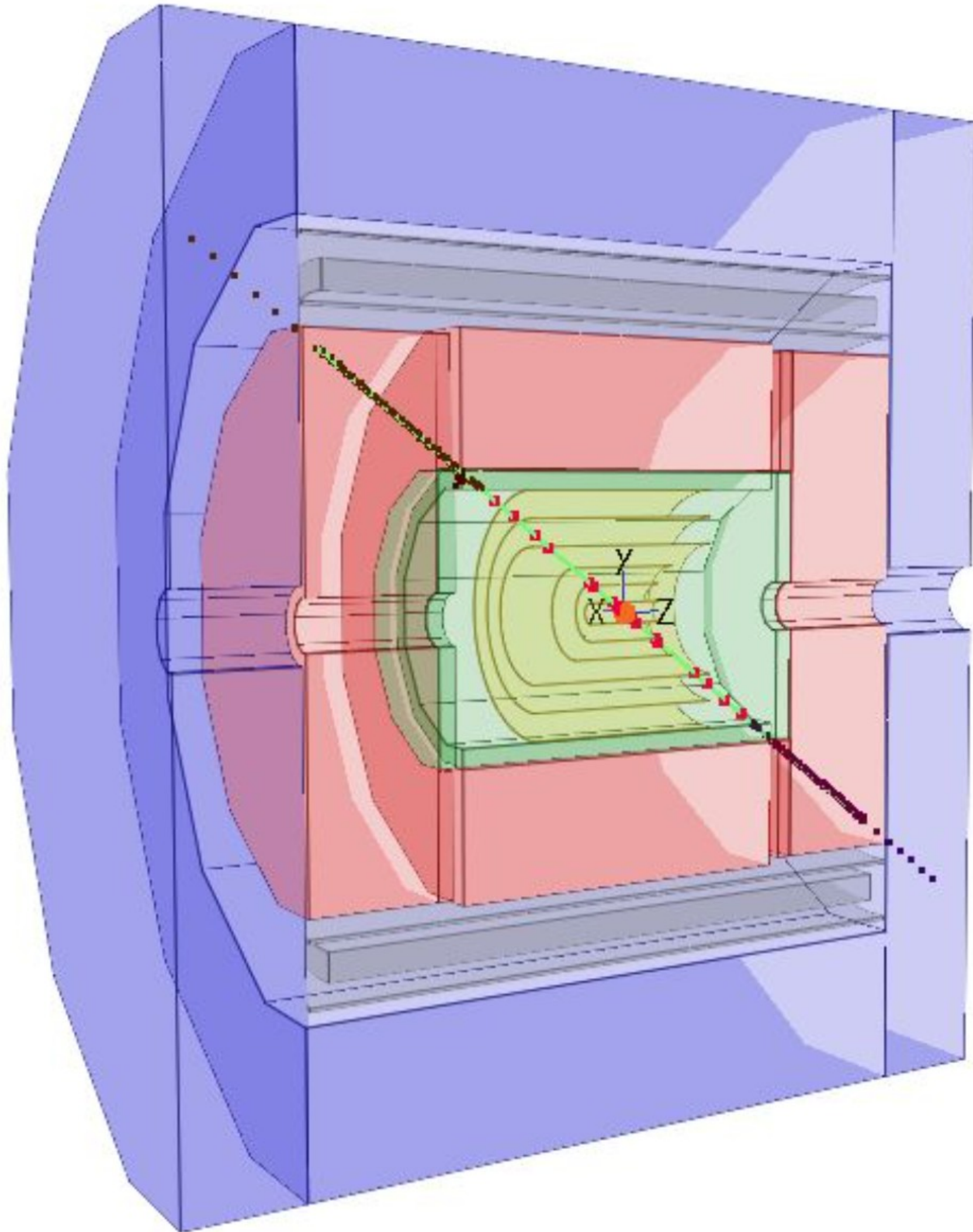
Si assembla l'acceleratore



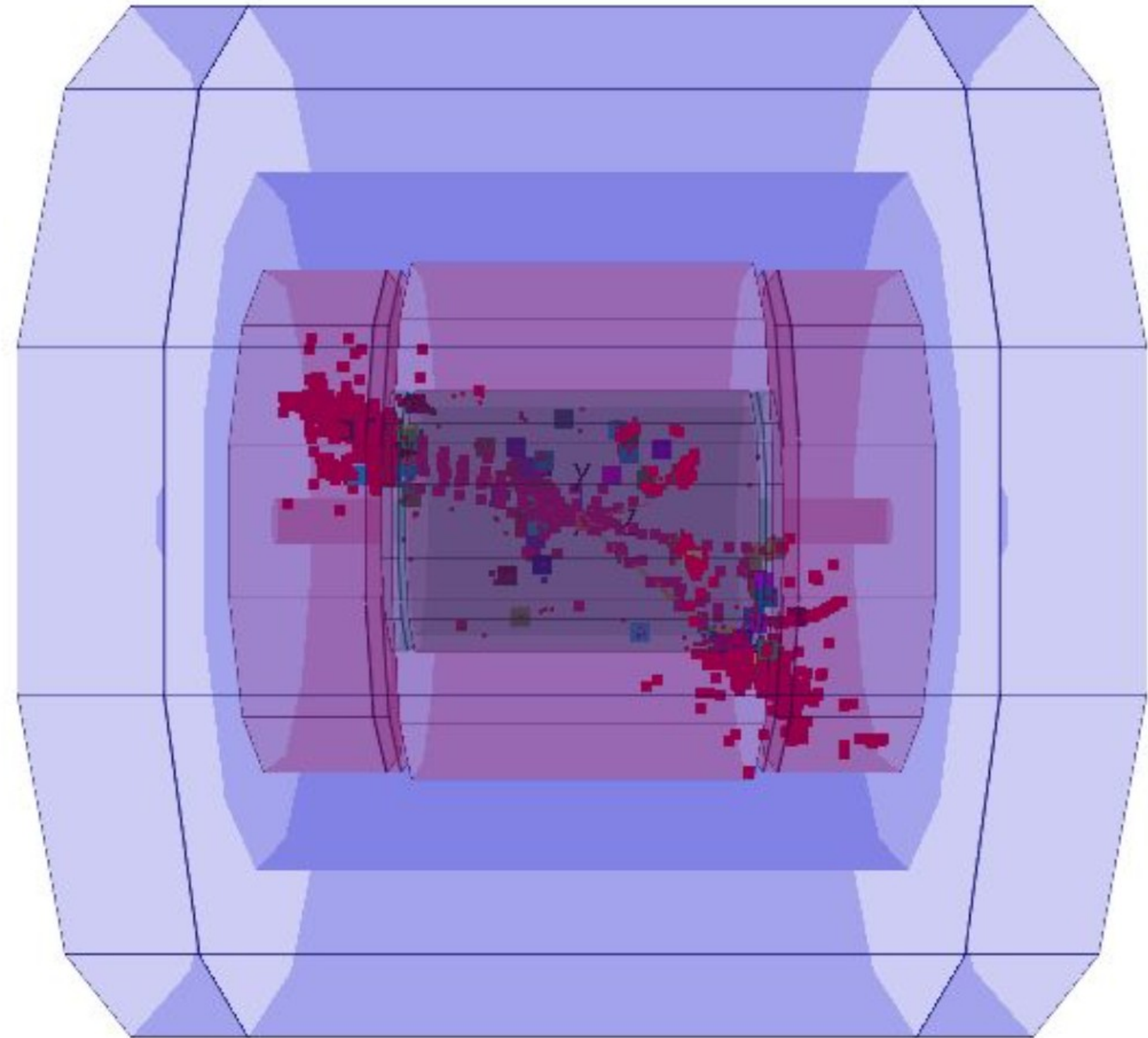
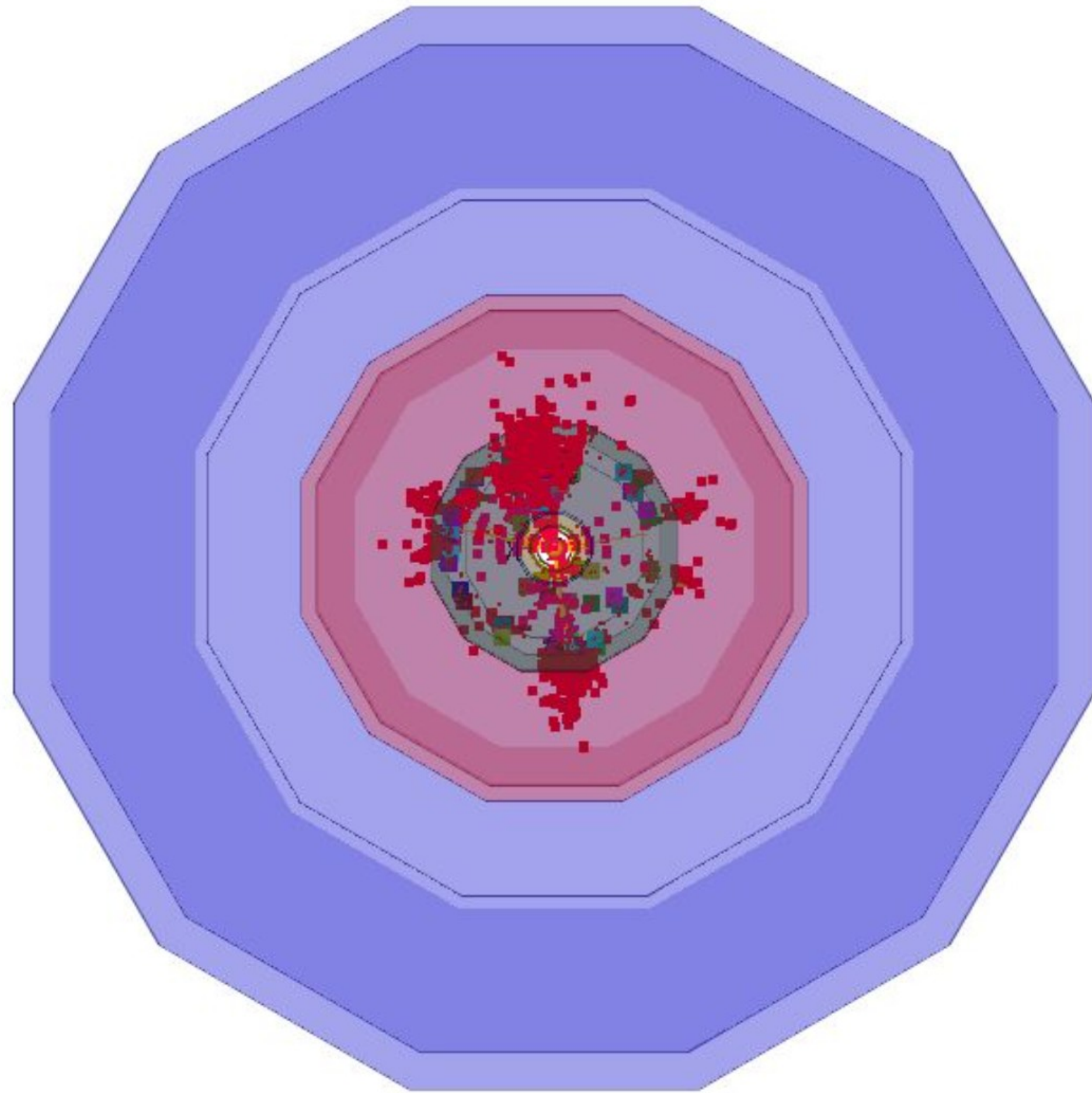
Dentro alla simulazione: il viaggio del muone



Collisioni elastiche



Due bosoni di Higgs?



Tecnologie basate sui muoni sono già realtà

Tomografia Muonica

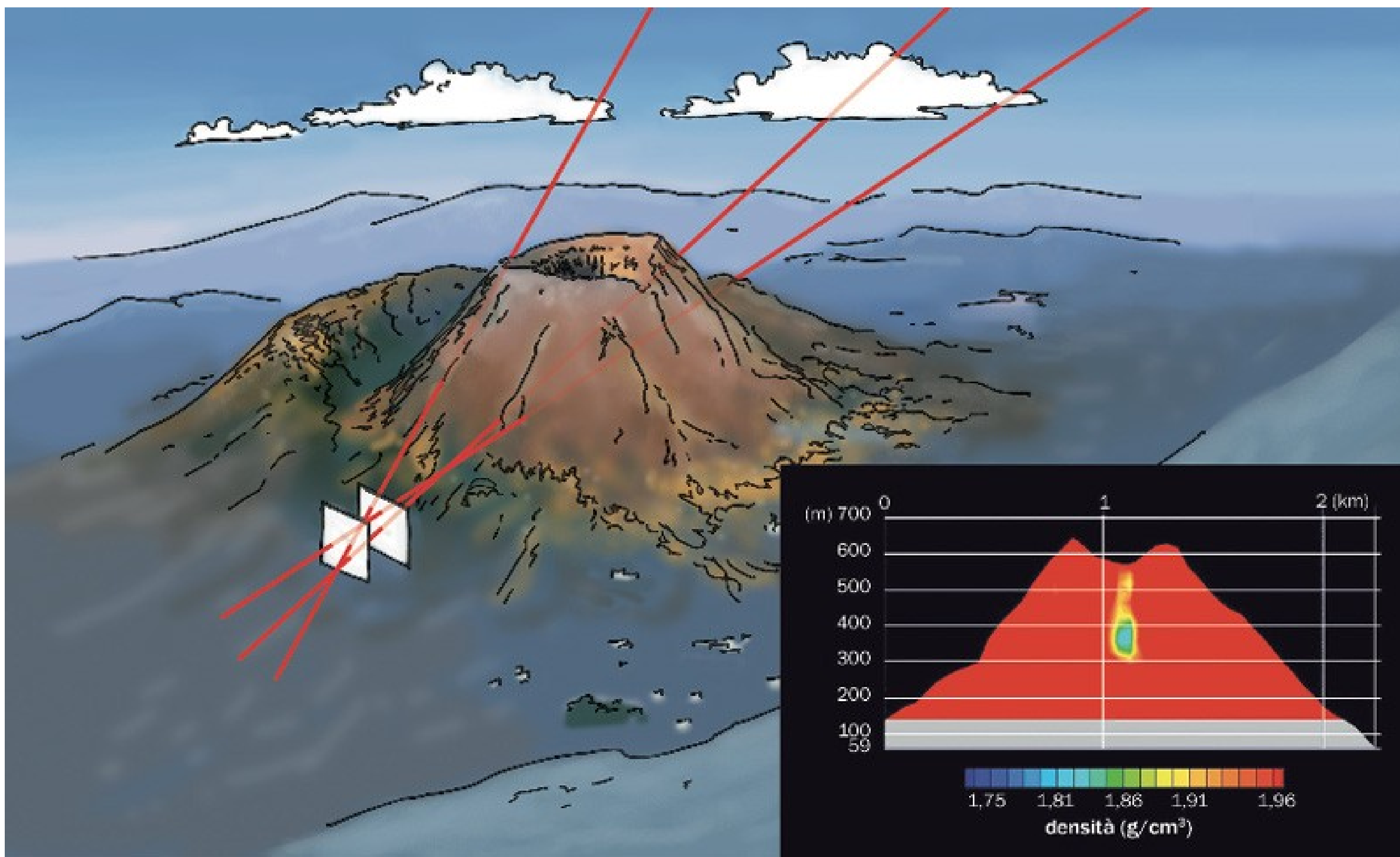
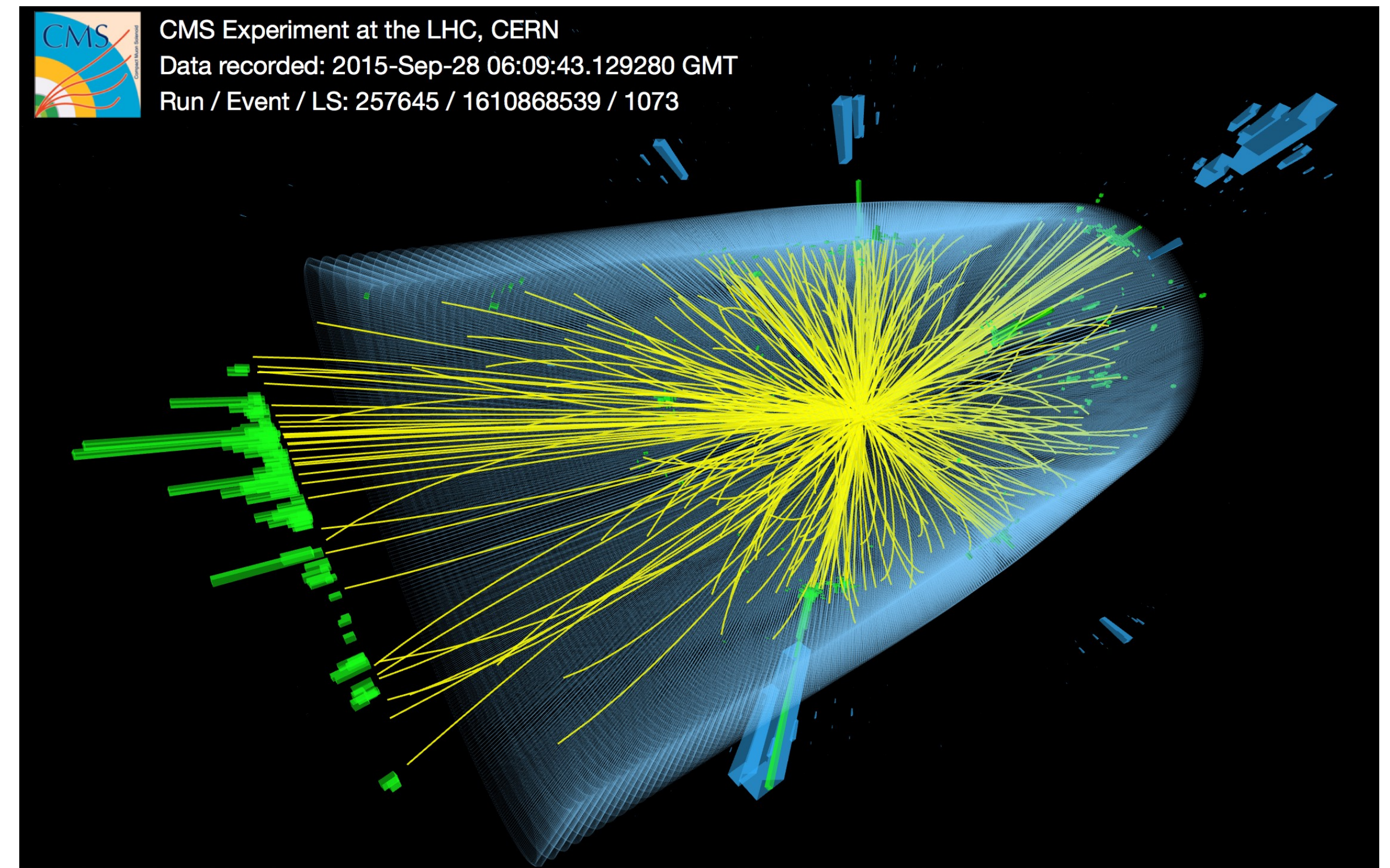
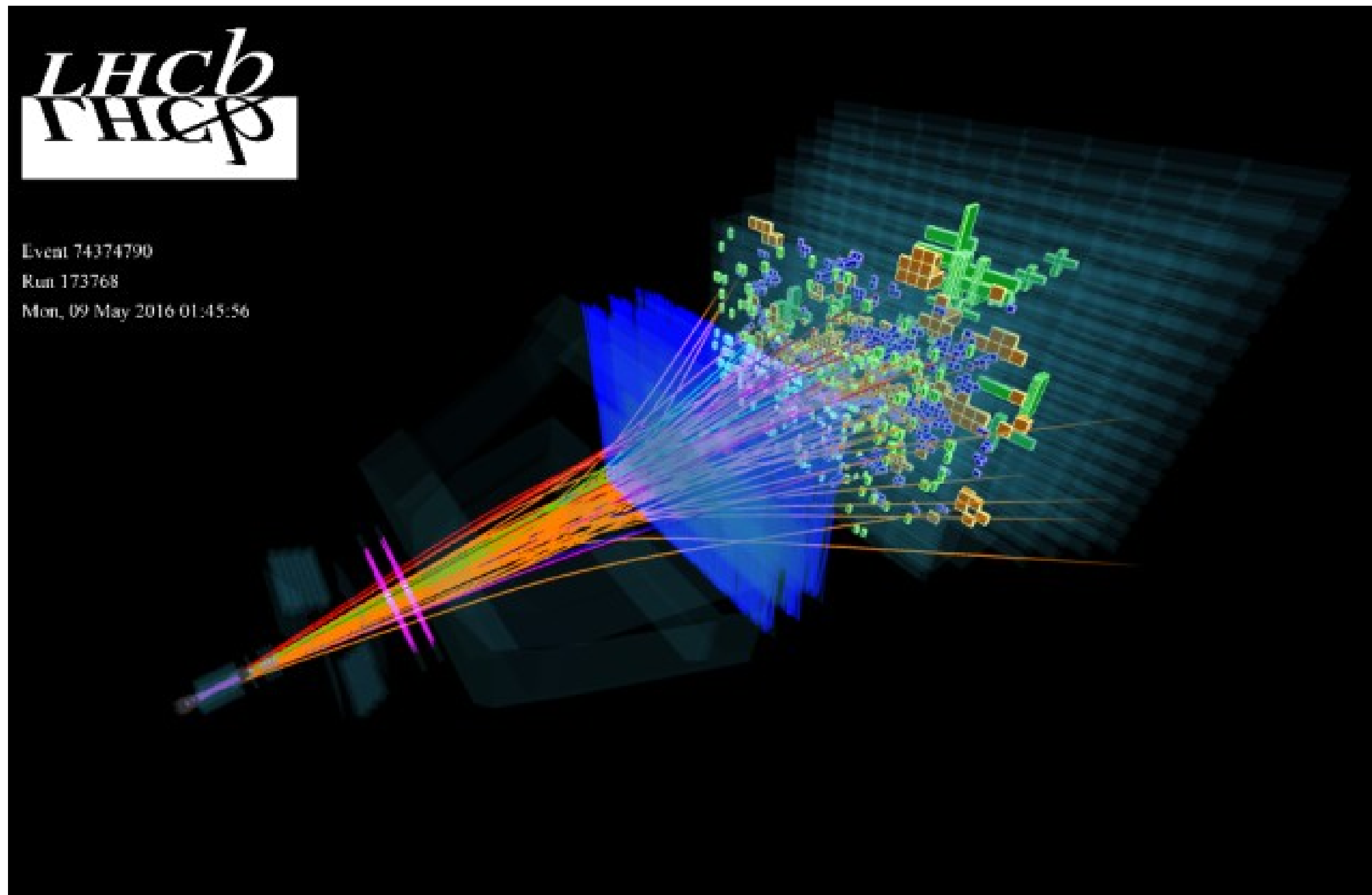


Immagine 3D del reattore di Fukushima



Ma si guarda comunque al presente mentre si costruisce il futuro

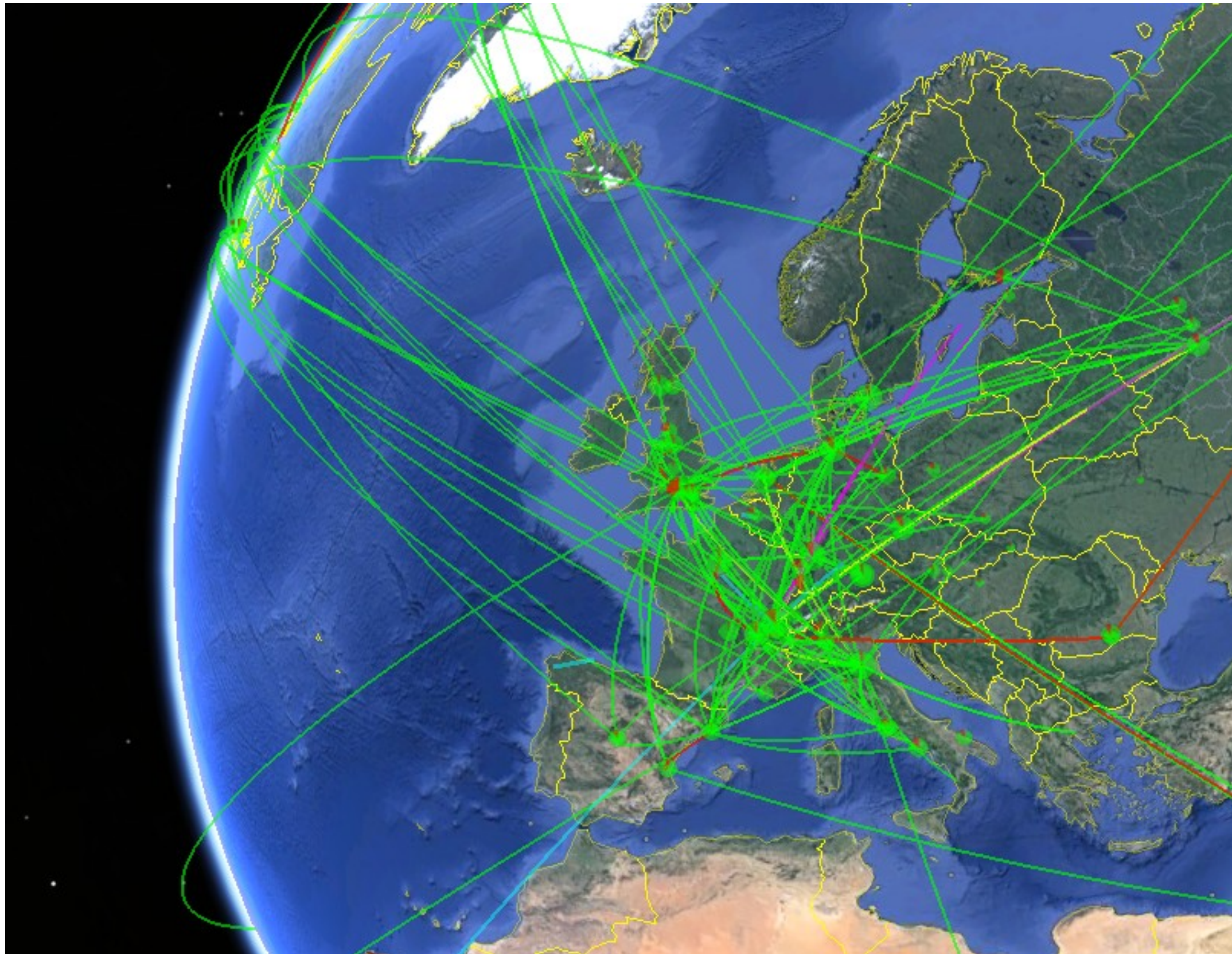
Tanti dati da analizzare ad LHC ... e nuovi dati stanno per arrivare!



The background features abstract, overlapping geometric shapes in various shades of blue (from light sky blue to a deeper cerulean) and white. These shapes are arranged in a dynamic, layered fashion, creating a sense of depth and movement. The overall aesthetic is clean and modern.

Grazie per l'attenzione!

Calcolo agli acceleratori

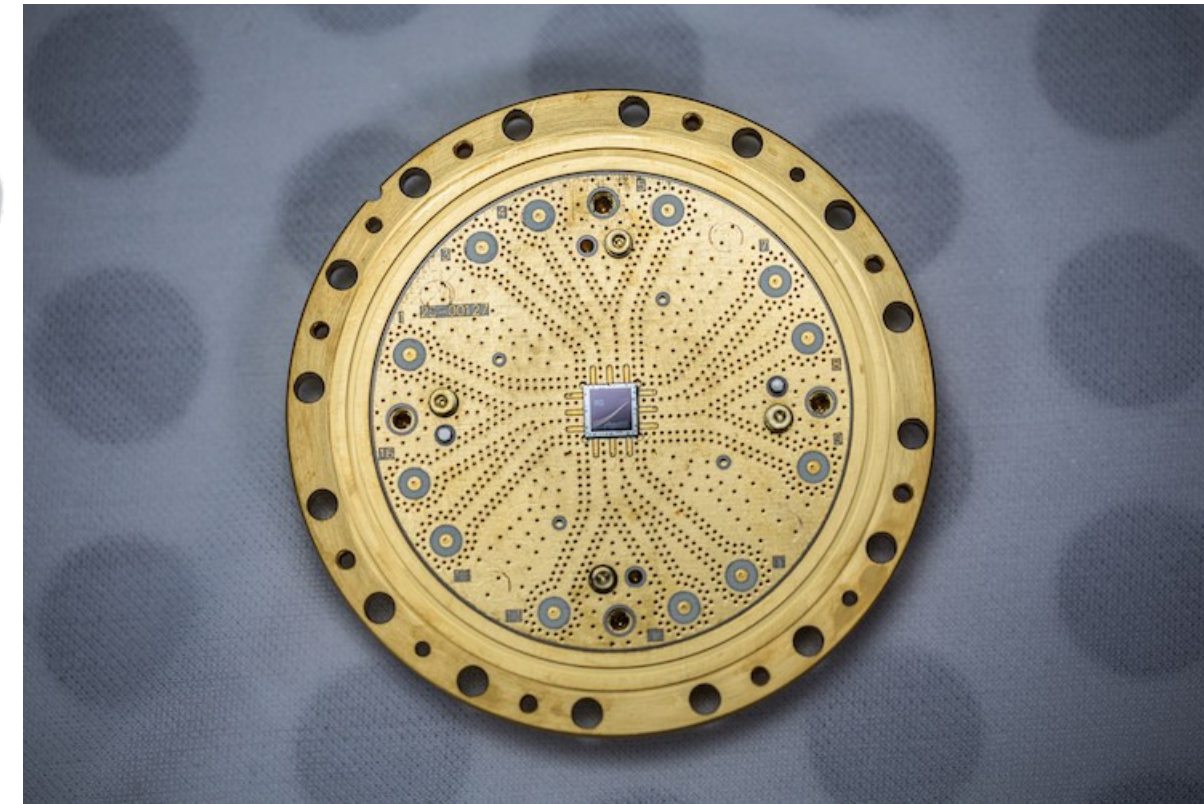
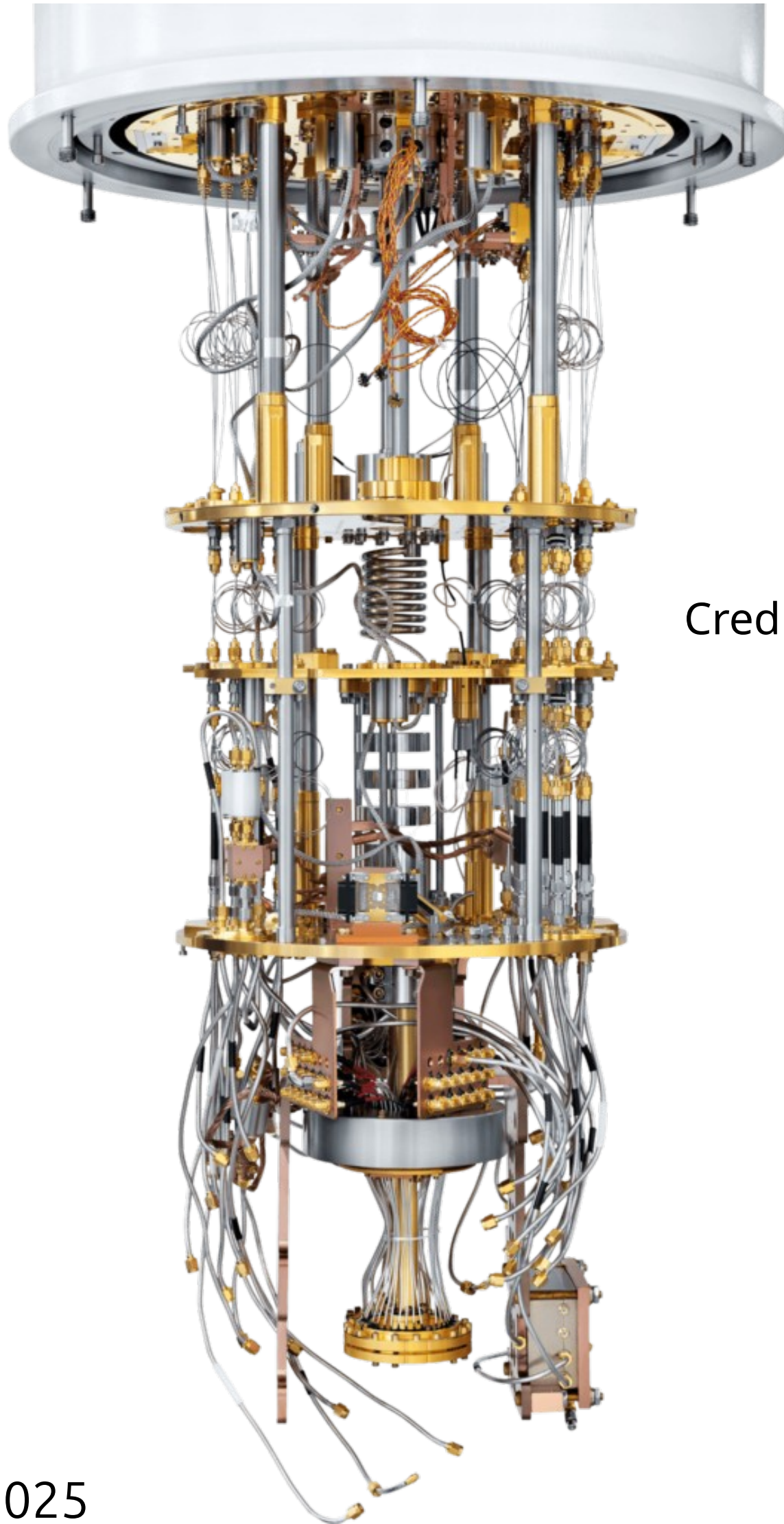


<https://home.cern/resources/faqs/facts-and-figures-about-lhc>

The CERN Data Centre stores more than 30 petabytes of data per year from the LHC experiments, enough to fill about 1.2 million Blu-ray discs, i.e. 250 years of HD video.

**Worldwide LHC Computing Grid:
Circa 1.4M processori, distribuiti in 170 siti di 42 paesi
Trasferimento medio di 60 GB/s**

Computer Quantistici



Credits: Rigetti Computing

L'enorme quantità di dati ci spinge ad usare tecniche di calcolo innovative

