International Master Classes on Particle Physics

Francesco Maria Follega - 27/03/2024

INTERNATIONAL MASTERCLASSES

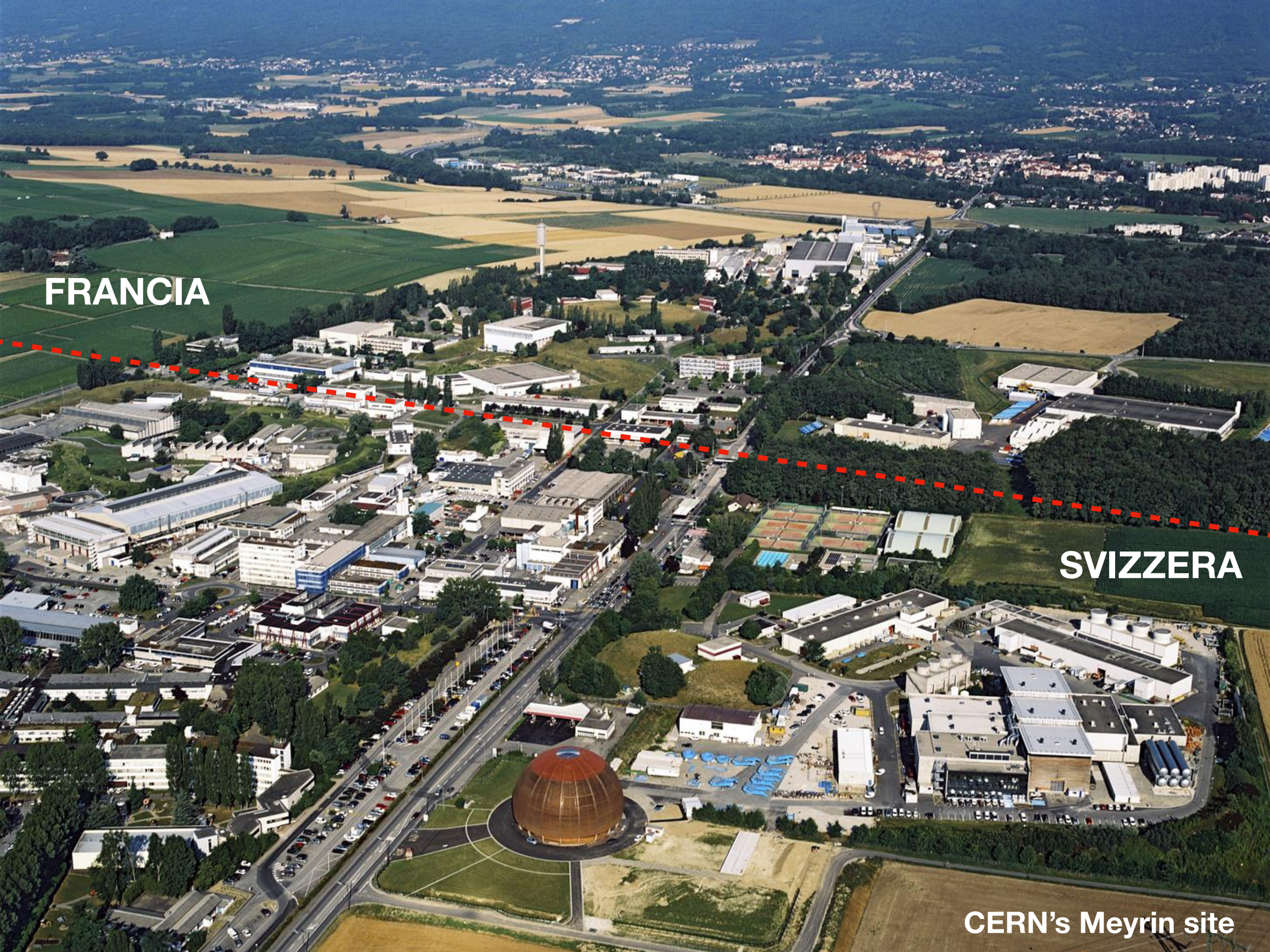
hands on particle physics

UNIVERSITÀ DI TRENTO

ATLAS EXPERIMENT

TIFPA

Trento Institute for Fundamental Physics and Applications


FRANCIA
SVIZZERA
CERN's Meyrin site

https://www.lhc-closer.es/taking_a_closer_look_at_lhc/1.lhc

CMS

LHCb

ALICE

ATLAS

https://www.lhc-closer.es/taking_a_closer_look_at_lhc/1.lhc

LHC
(2008-oggi)

CMS

>1600 magneti
@-271.3°C

27 km

LHCb

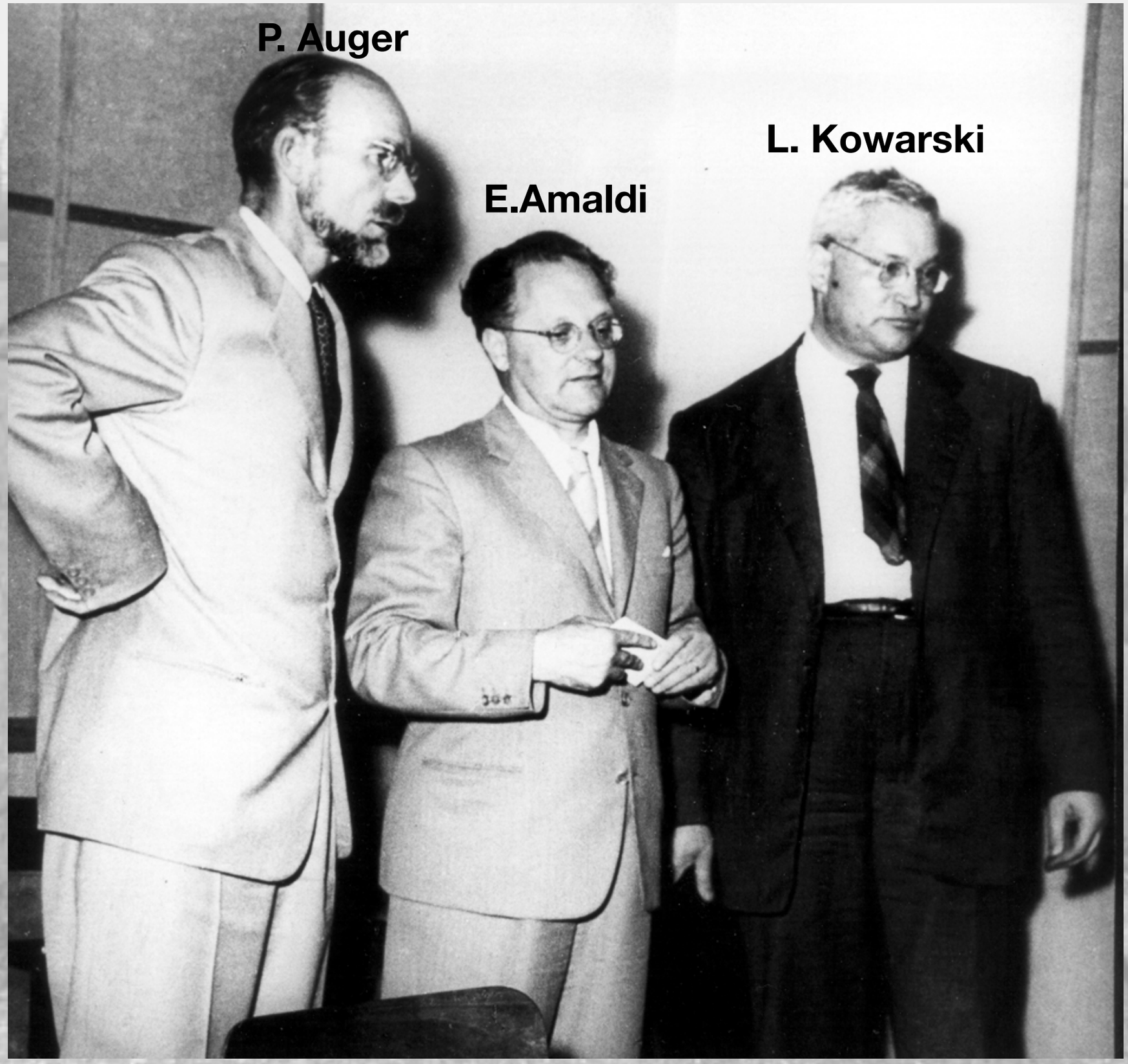
ALICE

ATLAS

The history of CERN - https://timeline.web.cern.ch/timeline-header/89

9 DICEMBRE 1949

Un gruppo di scienziati visionari immaginavano un laboratorio di fisica delle particelle (CERN)



The history of CERN - https://timeline.web.cern.ch/timeline-header/89

29 SETTEMBRE 1954

Nasce l'organizzazione europea per la ricerca nucleare (il CERN)

La sixième session du Conseil fut organisée à Paris du 29 juin au 1er juillet 1953. C'est à cette occasion que la Convention établissant l'Organisation fut signée, sous réserve de ratification, par douze Etats membres.

For the German Federal Republic — Pour la République Fédérale d'Allemagne

subject to ratification

For the Kingdom of Belgium — Pour le Royaume de Belgique

sous réserve de ratification

For the Kingdom of Denmark — Pour le Royaume de Danemark

sous réserve de ratification

For the French Republic — Pour la République Française

sous réserve de ratification

For the Kingdom of Greece — Pour le Royaume de Grèce

sous réserve de ratification

For Italy — Pour l'Italie

sous réserve de ratification

For the Kingdom of Norway — Pour le Royaume de Norvège

Subject to ratification

For the Kingdom of the Netherlands — Pour le Royaume des Pays-Bas

subject to ratification

For the United Kingdom of Great Britain and Northern Ireland — Pour le Royaume-Uni de la Grande-Bretagne et de l'Irlande du Nord

Subject to ratification

For the Kingdom of Sweden — Pour le Royaume de Suède

Subject to ratification

For the Confederation of Switzerland — Pour la Confédération Suisse

sous réserve de ratification

For the Federal People's Republic of Yugoslavia — Pour la République Fédérative Populaire de Yougoslavie

sous réserve de ratification

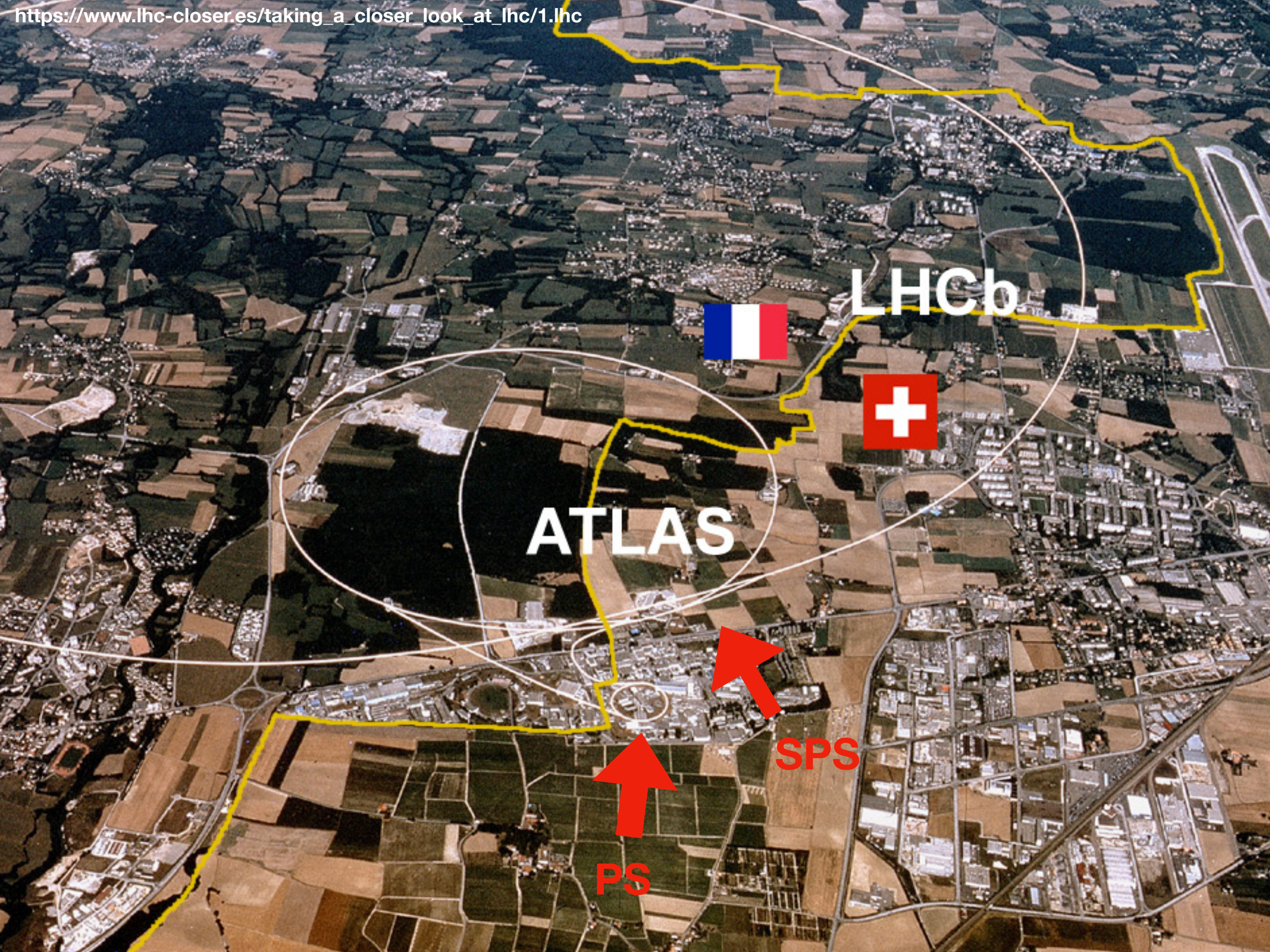
The Sixth Session of the CERN Council took place in Paris on 29 June—1 July 1953. It was here that the Convention establishing the Organization was signed, subject to ratification, by twelve States.

24 Novembre 1959
Viene acceso il Proton Synchrotron (PS) - 628 m

3 Maggio 1976
Viene completato il
Super Proton Synchrotron.
7 km di tunnel

The history of CERN - https://timeline.web.cern.ch/timeline-header/89

https://www.lhc-closer.es/taking_a_closer_look_at_lhc/1.lhc



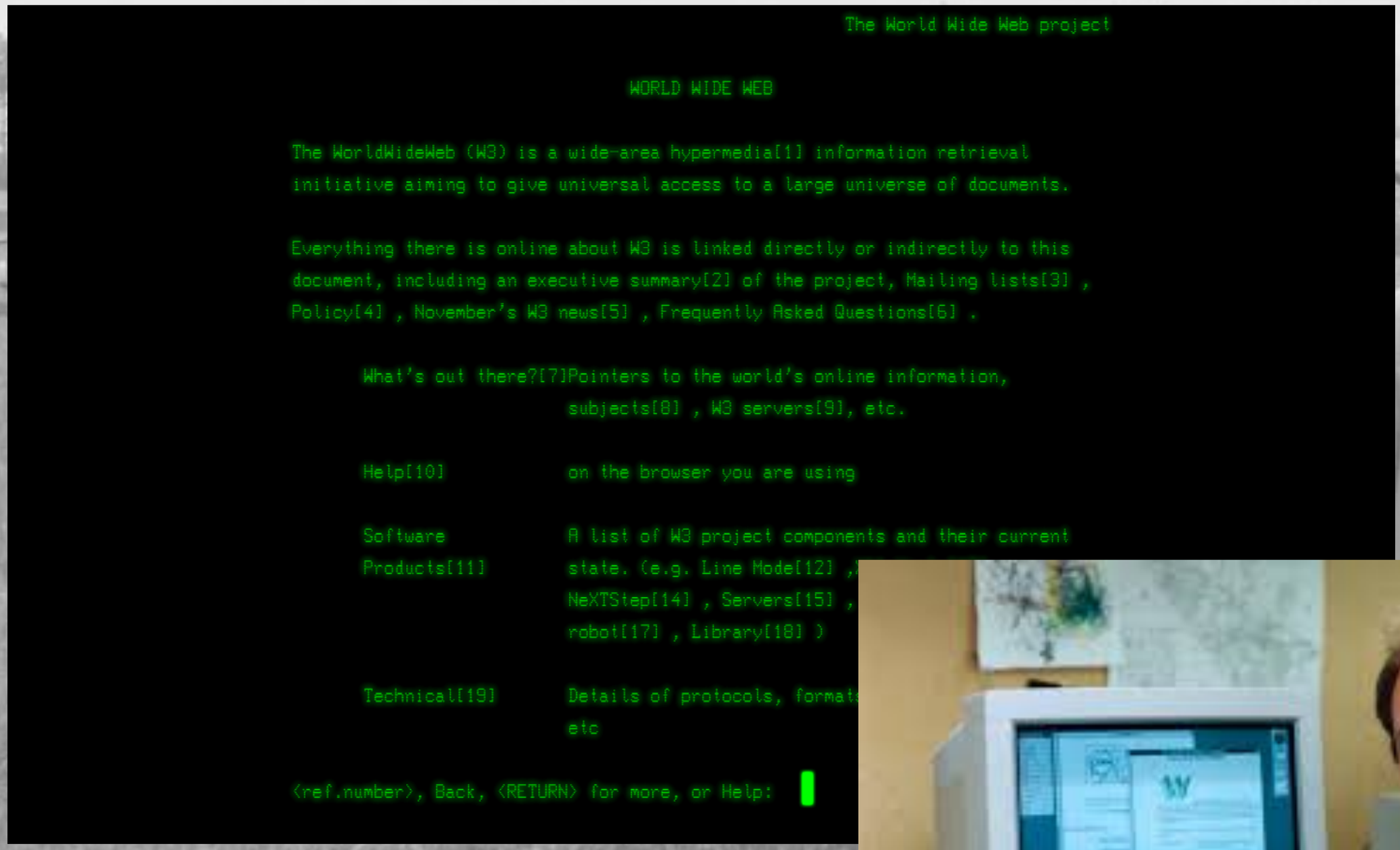
BENT STUMPLE INVENTA IL PRIMO TOUCH SCREEN 1973

Il primo touch screen capacitivo (e la tracker ball) vengono inventati da Bent Stumble per la control room di SPS

The history of CERN - https://timeline.web.cern.ch/timeline-header/89

Viene inventato il World Wide Web 1989

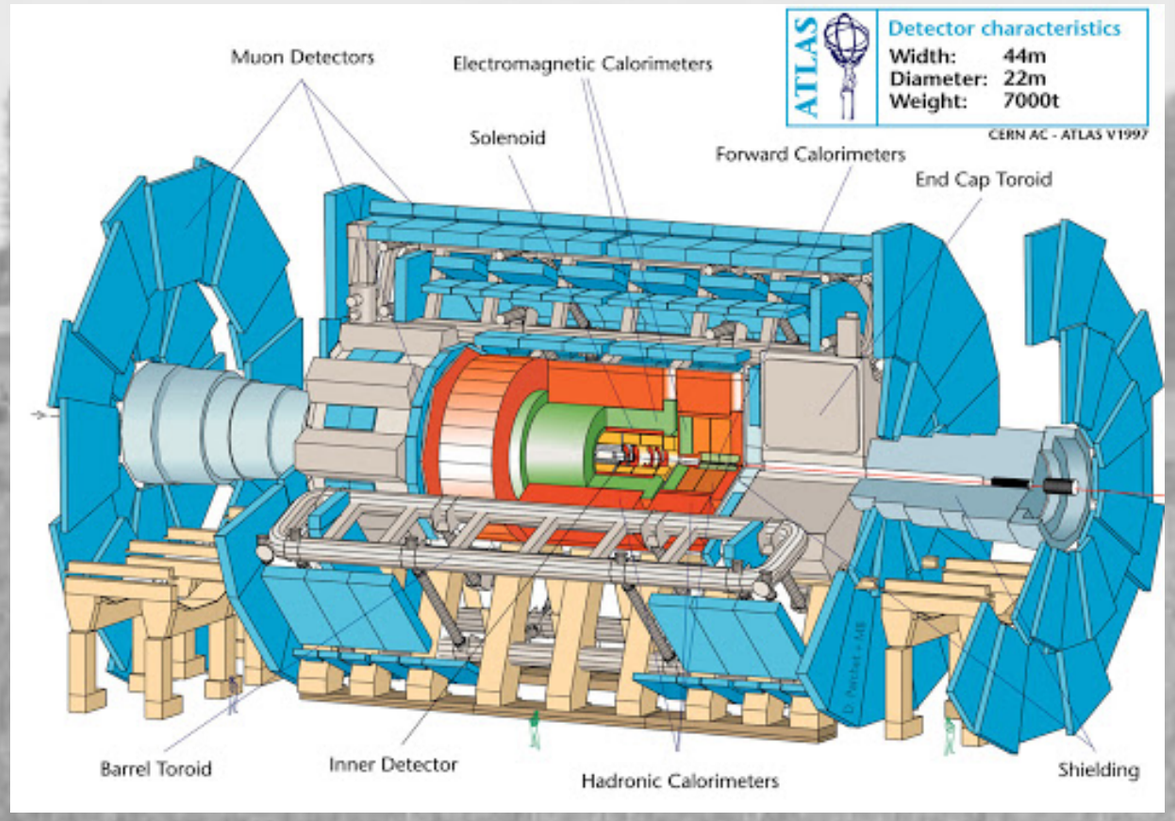
Il World Wide Web viene inventato dallo scienziato inglese Tim Berners-Lee che lavorava ad un sistema automatizzato per la condivisione delle informazioni al CERN

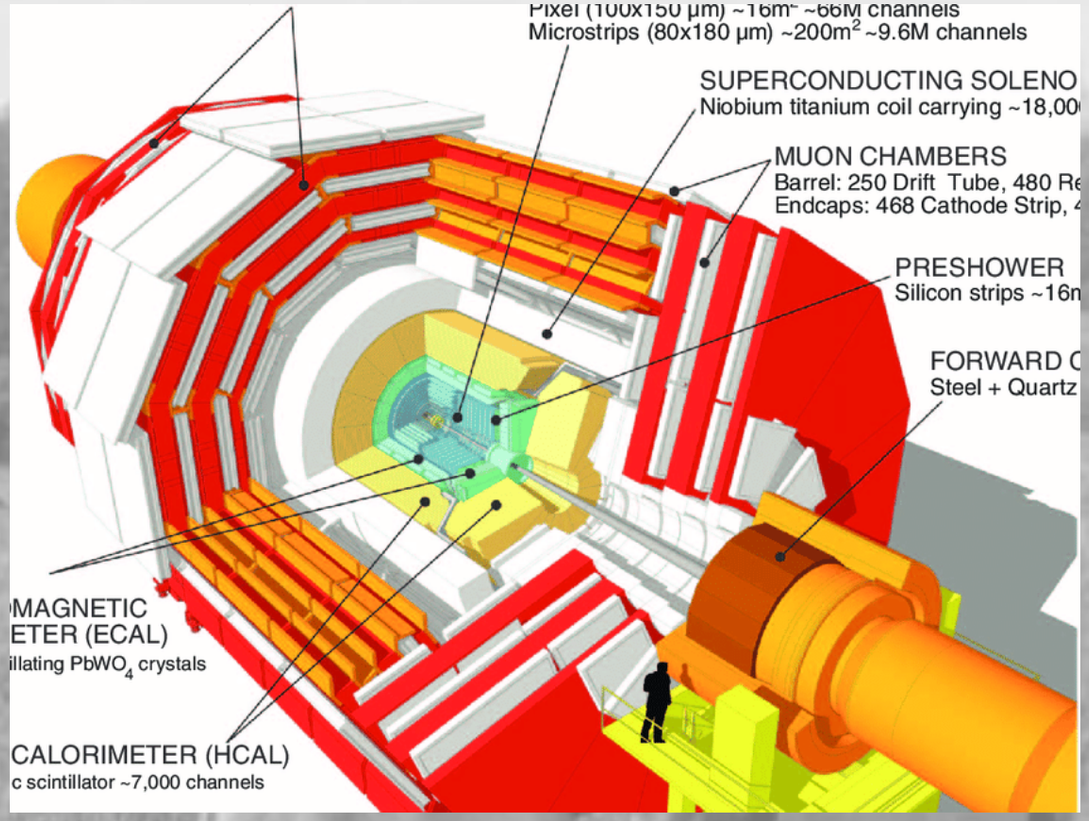


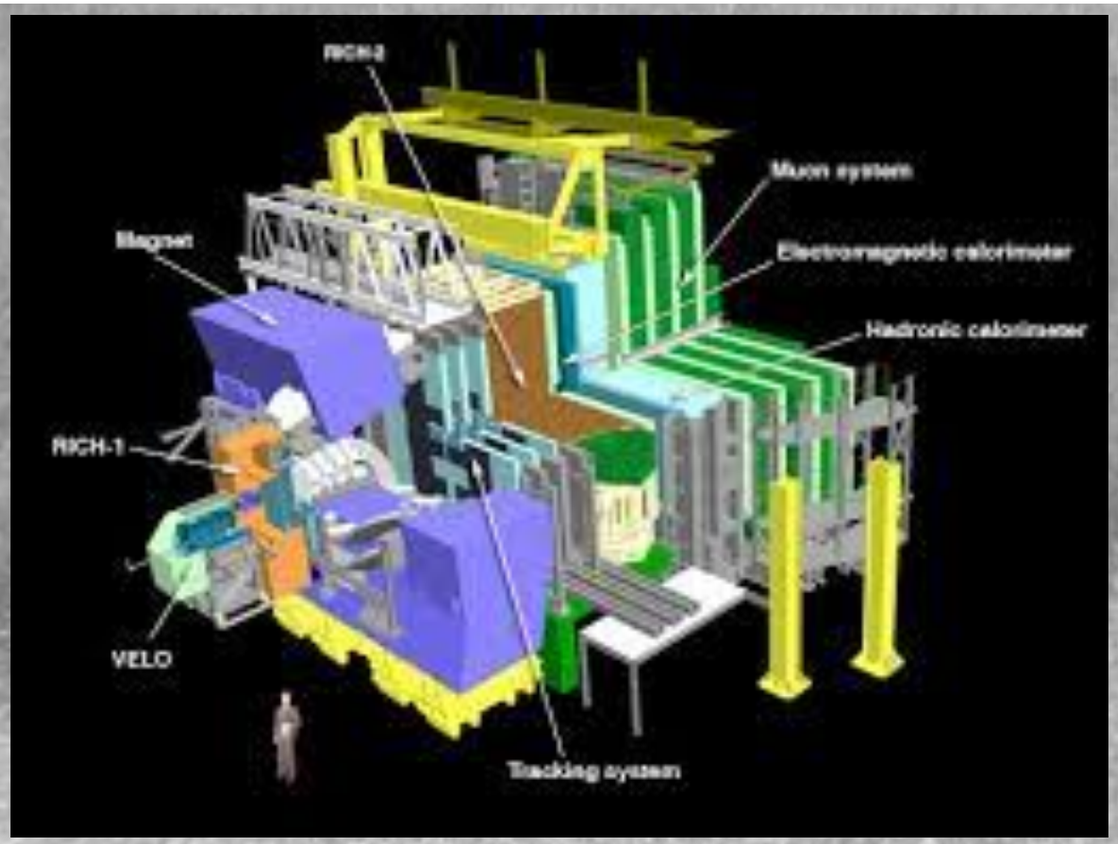
http://info.cern.ch/hypertext/WWW/TheProject.html

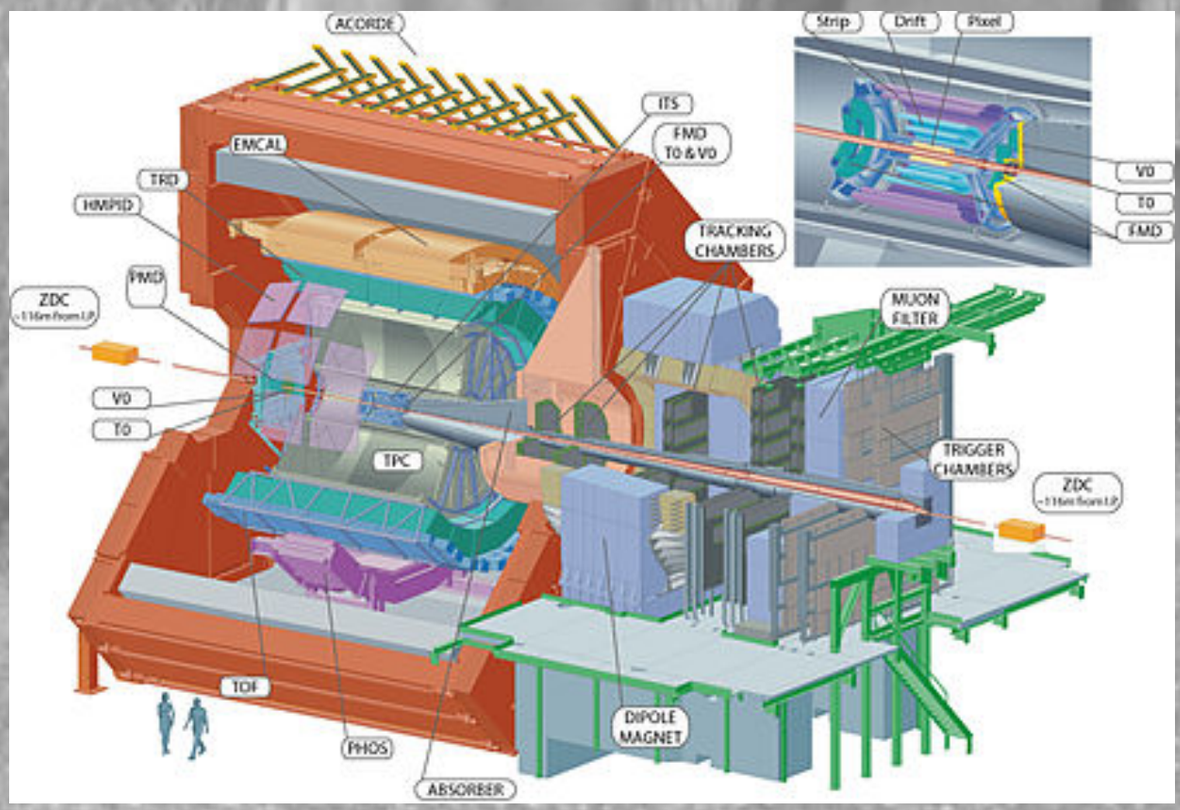
The history of CERN - https://timeline.web.cern.ch/timeline-header/89

1997-1998
ATLAS, CMS, ALICE e LHCb vengono approvati









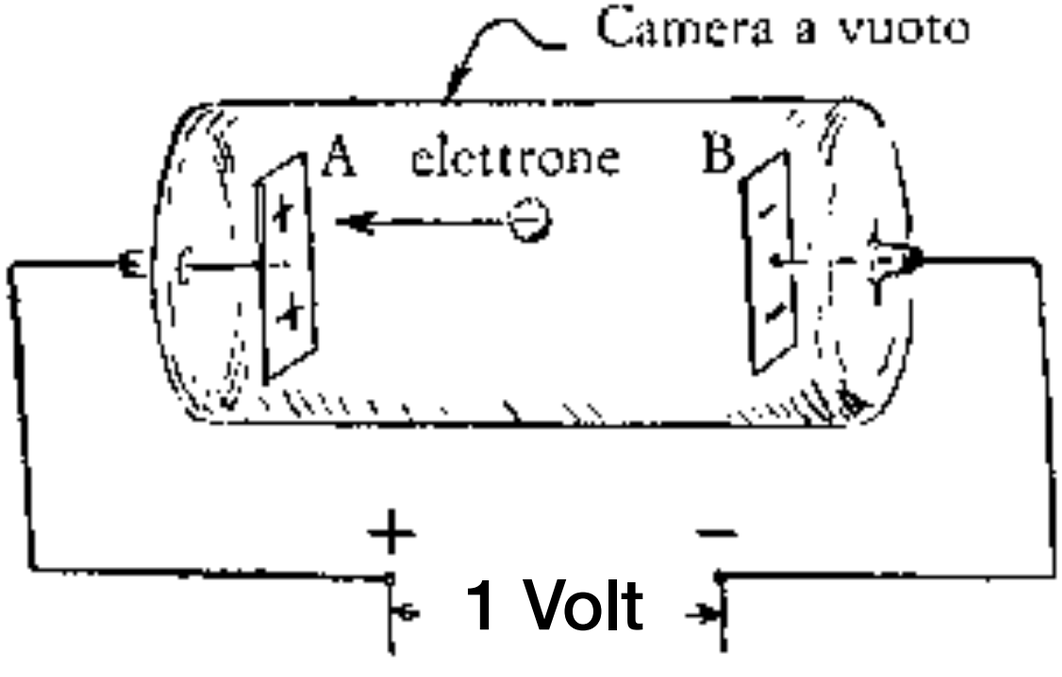
2 Novembre 2000
Inizia la costruzione del Large Hadron Collider (LHC)

https://home.cern/science/accelerators/large-hadron-collider

Come funziona LHC?

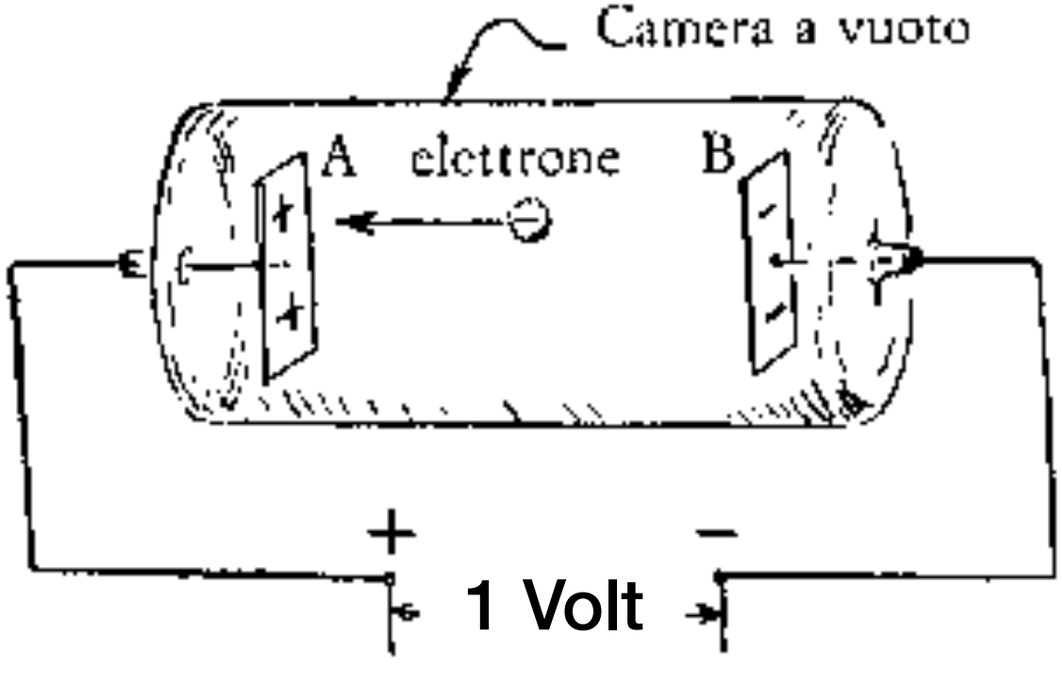
http://phdcomics.com/

Unità di misura dell'energia



$$1\ eV = e \cdot 1\ V = 1{,}602 \cdot 10^{-19}\ C \cdot 1\ V = 1{,}602 \cdot 10^{-19} J$$

Unità di misura dell'energia



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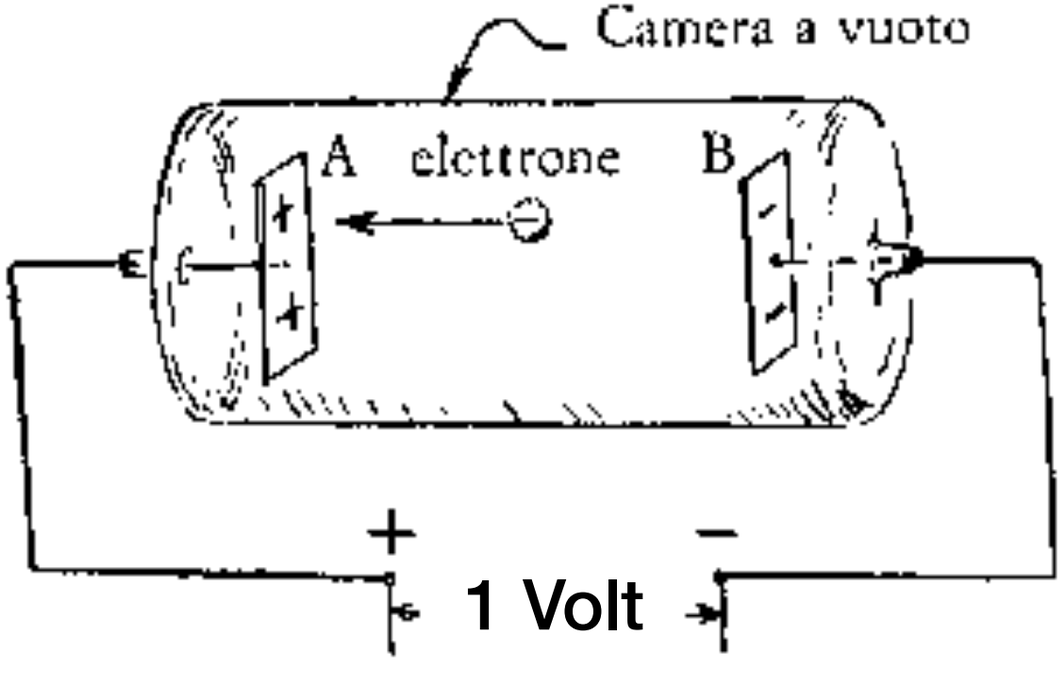

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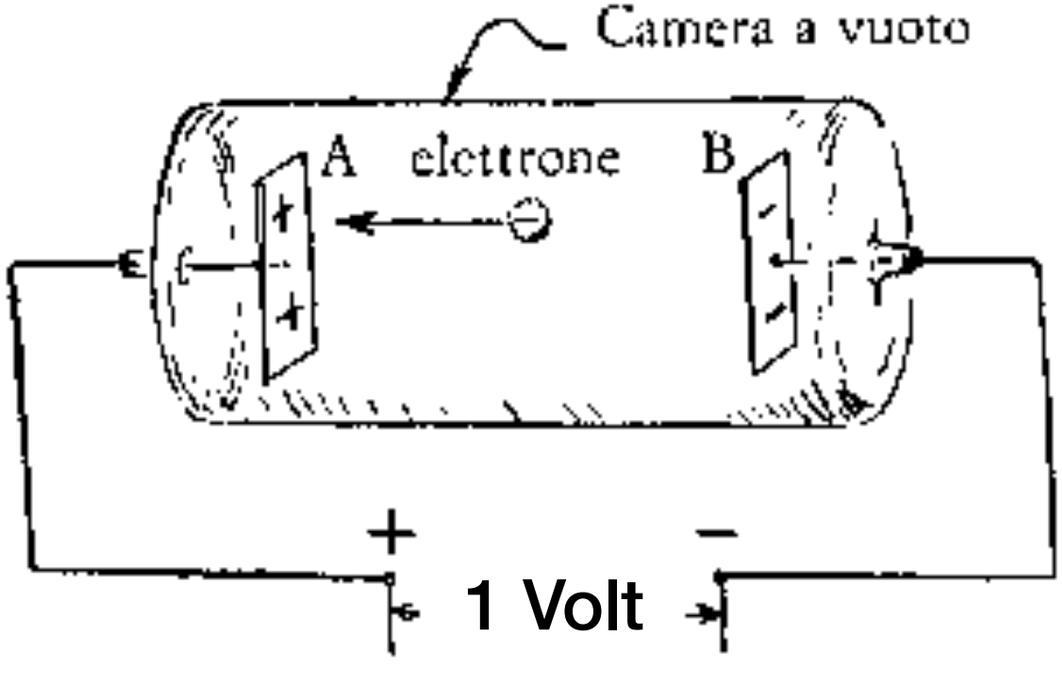
$$1\ eV/c^2 = 1.6 \times 10^{-19} C\ V/(3 \times 10^8\ m/s)^2 = 1.78 \times 10^{-20} \times 10^{-16}\ J/(m2/s2) = 1.78 \times 10^{-36}\ Kg$$

Unità di misura dell'energia



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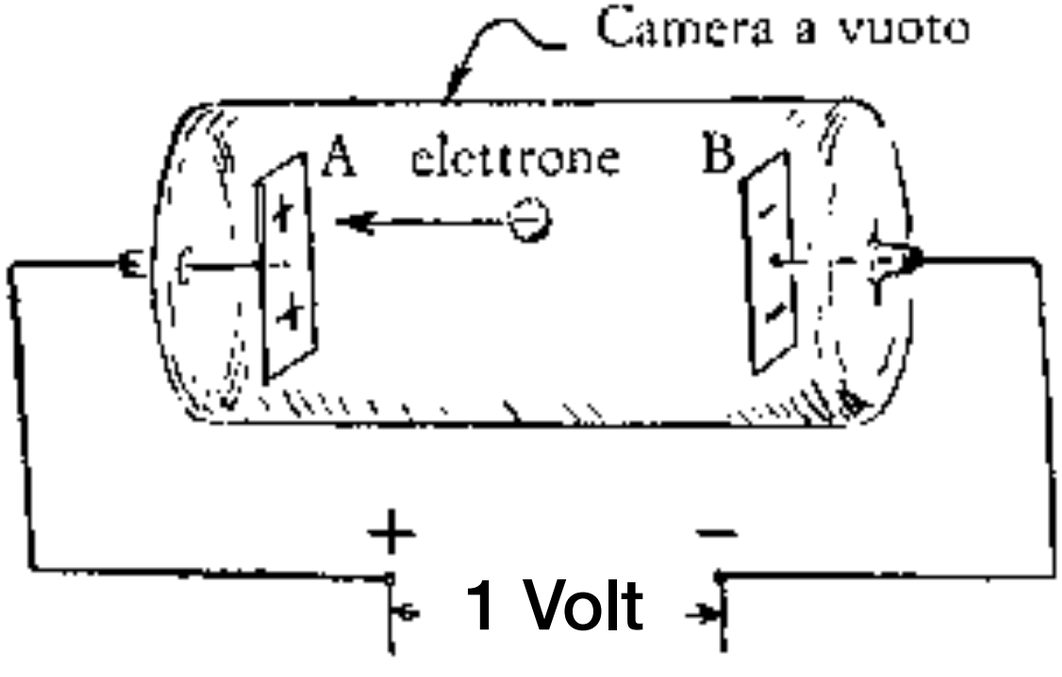

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$$1\ KeV = 1000\ eV$$

$$1\ MeV = 1.000.000\ eV$$

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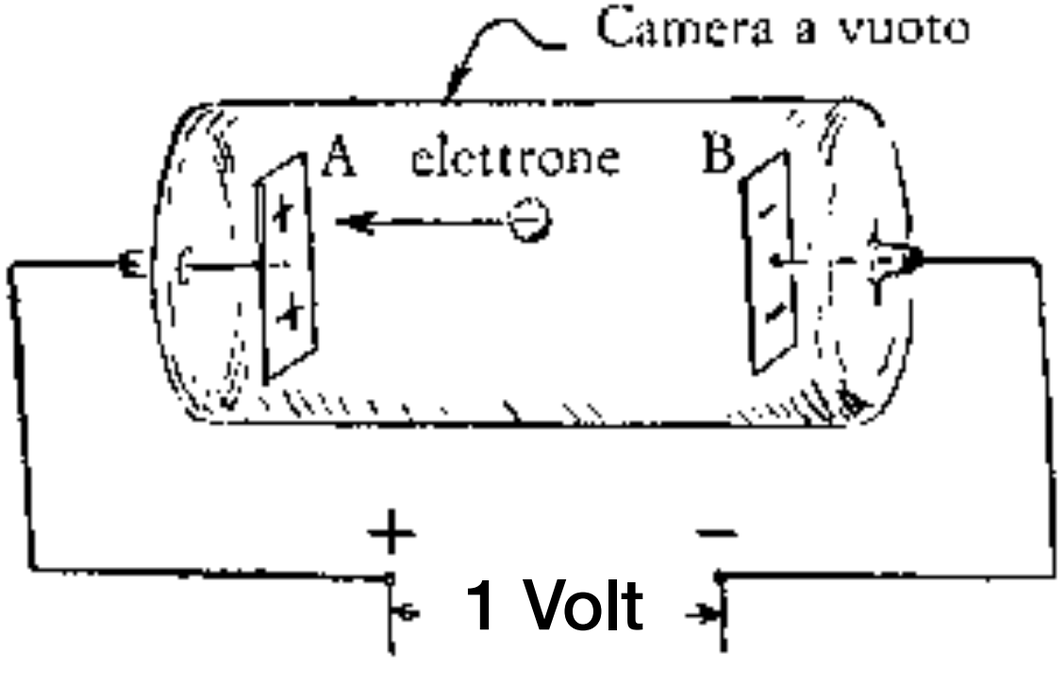

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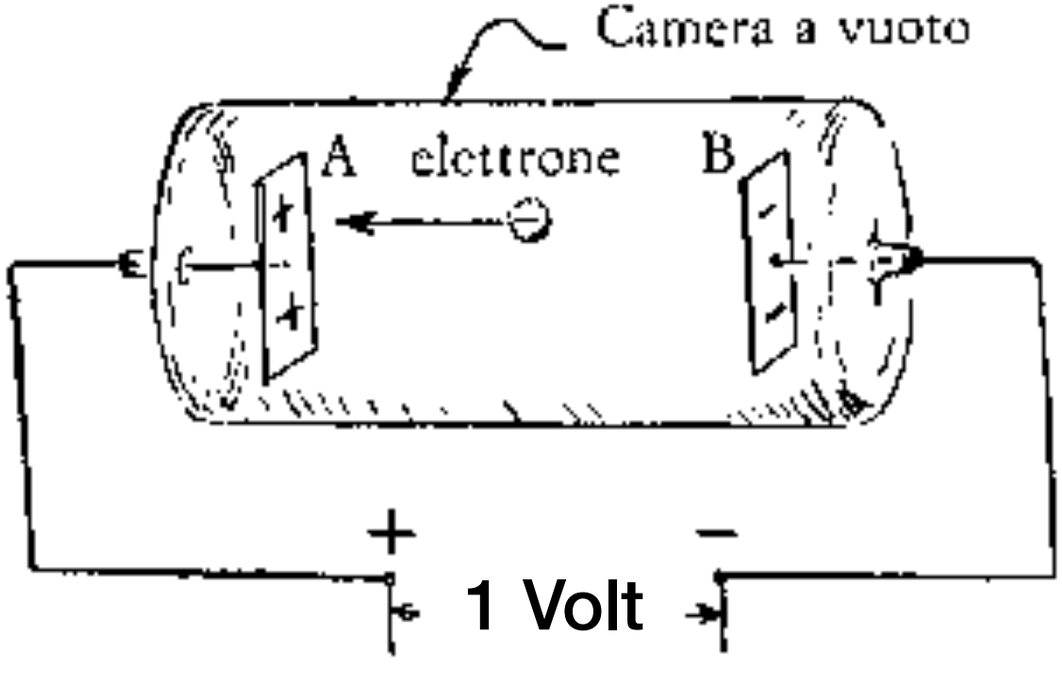

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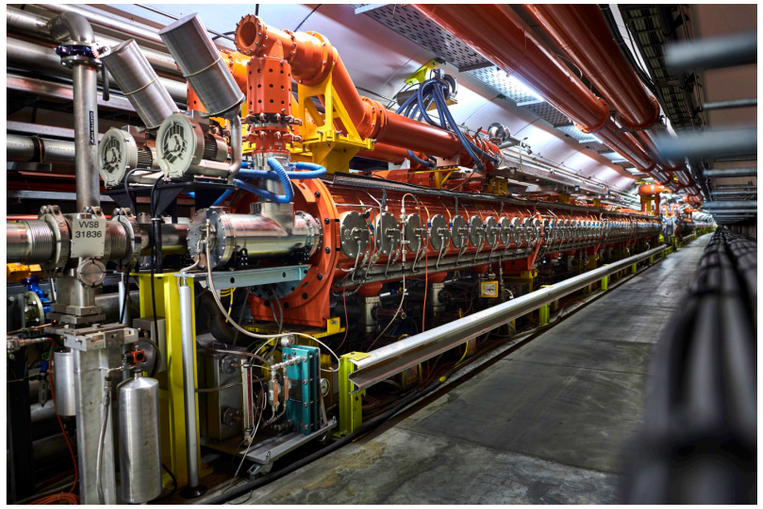
$$1\ KeV = 1000\ eV$$

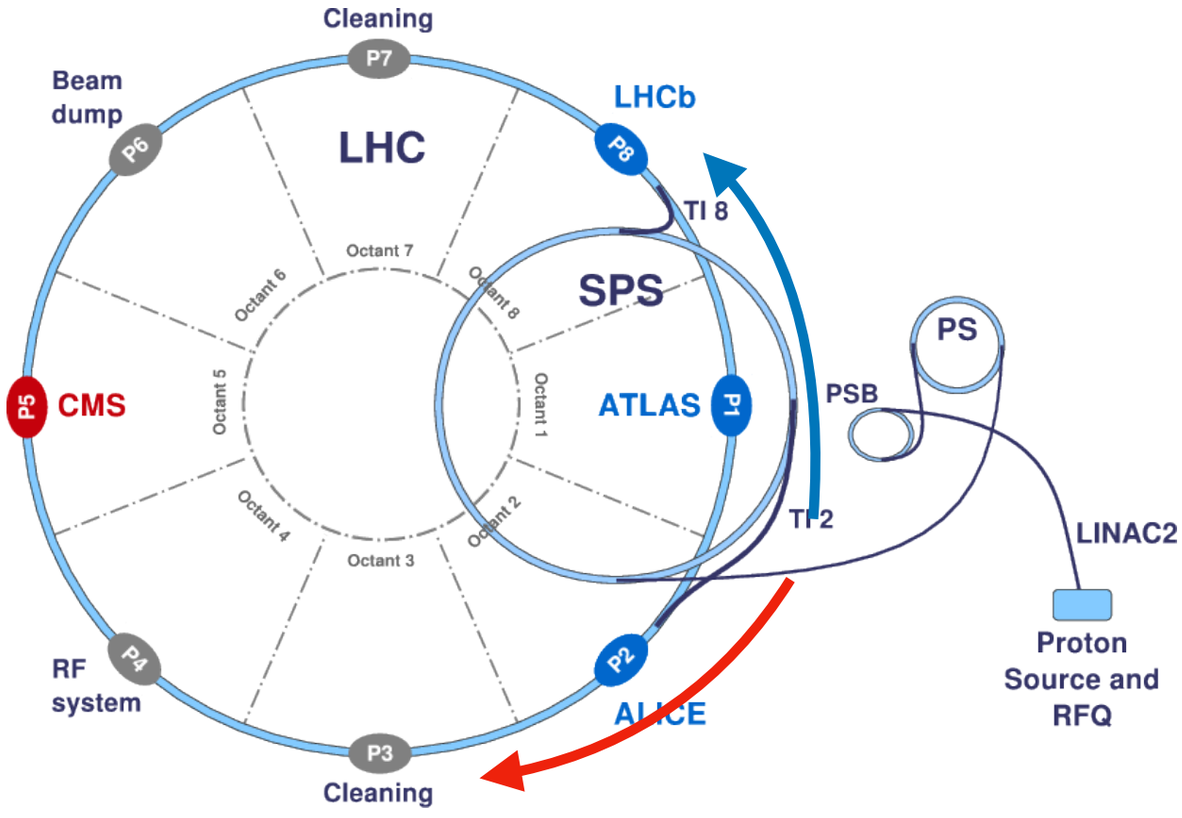
$$1\ MeV = 1.000.000\ eV$$

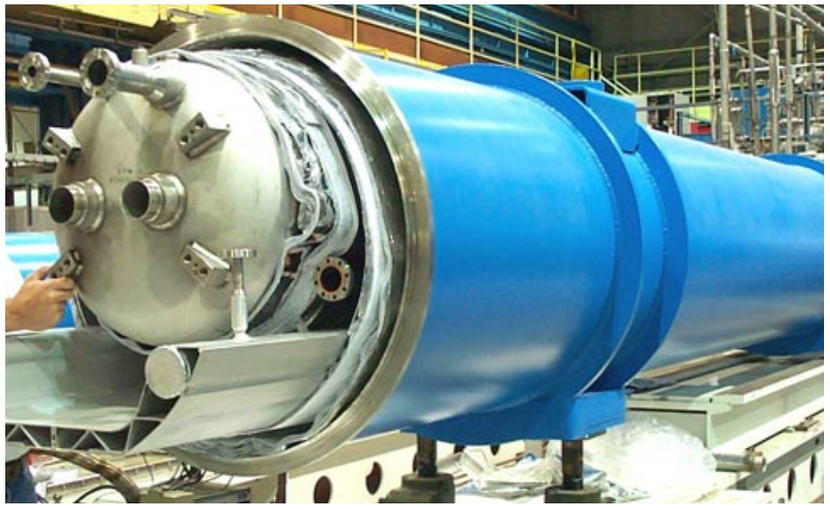
$$1\ GeV = 1.000.000.000\ eV$$

$$1\ TeV = 1.000.000.000.000\ eV$$



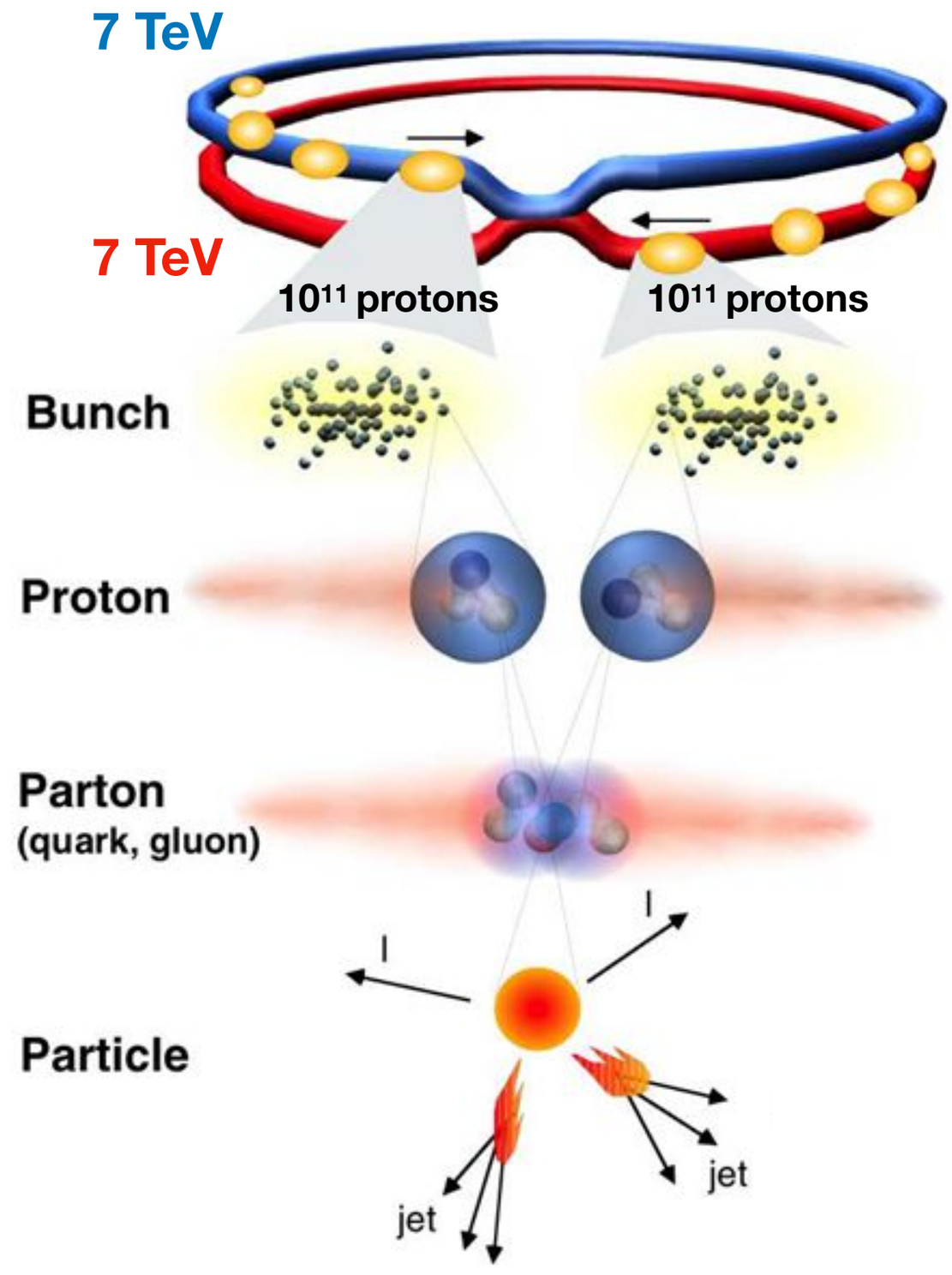
Cavità RF

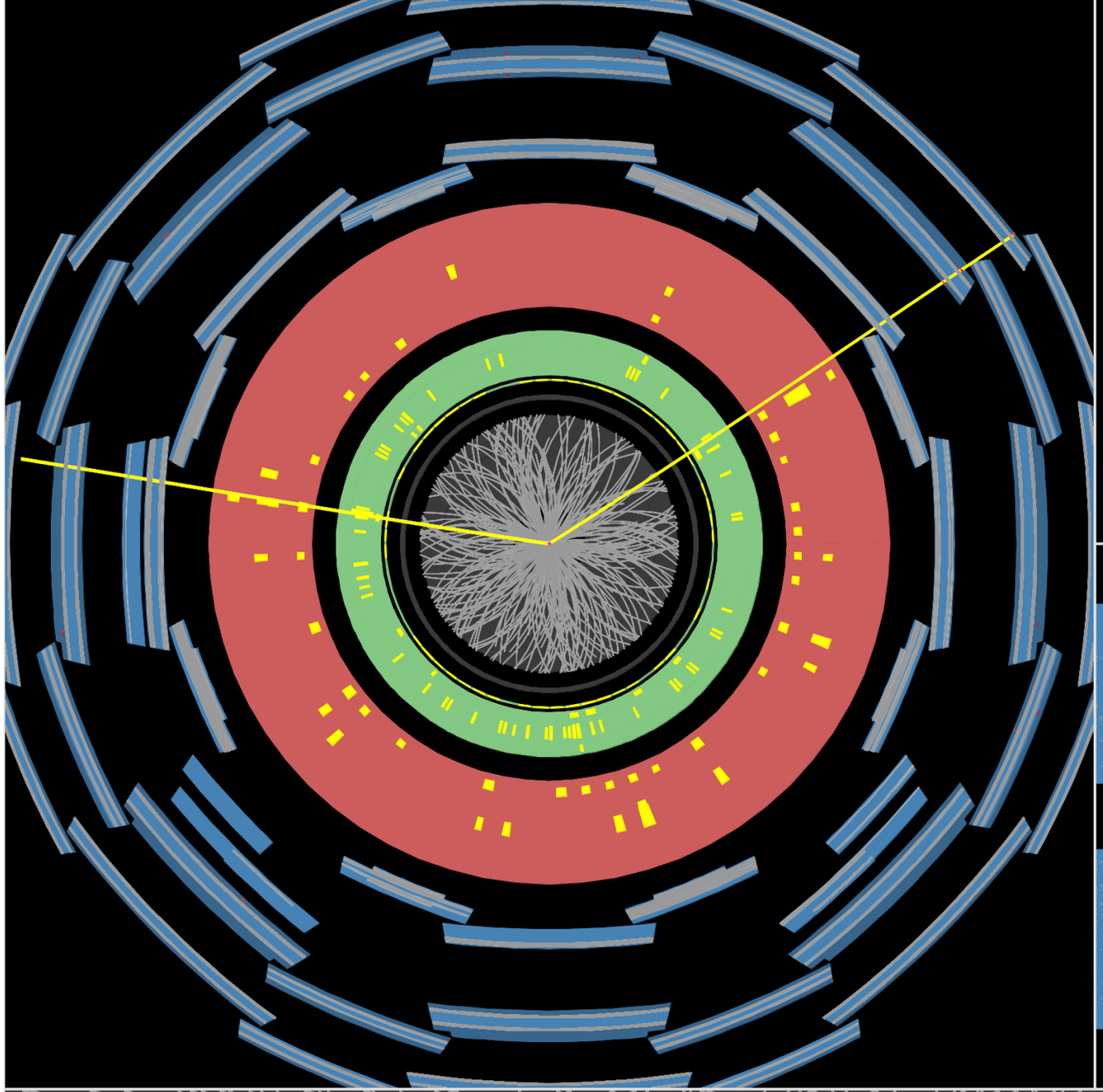




Magneti superconduttori

Collisione dei bunch ogni 25 ns!

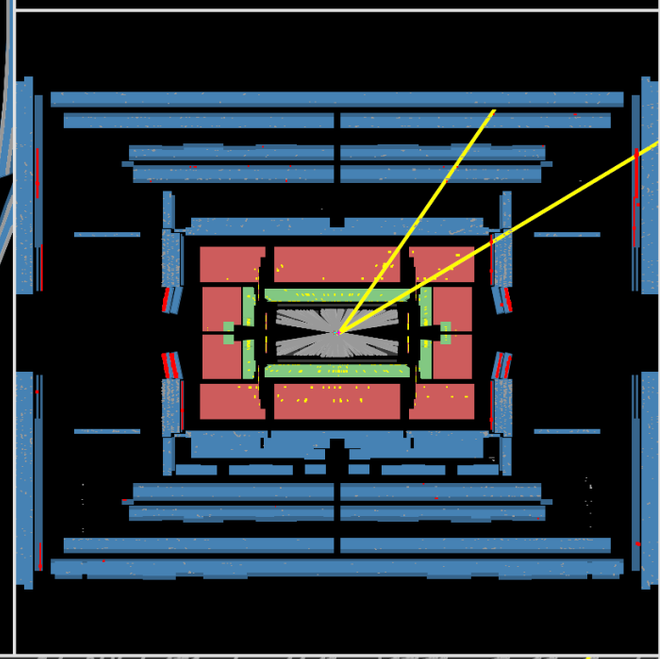




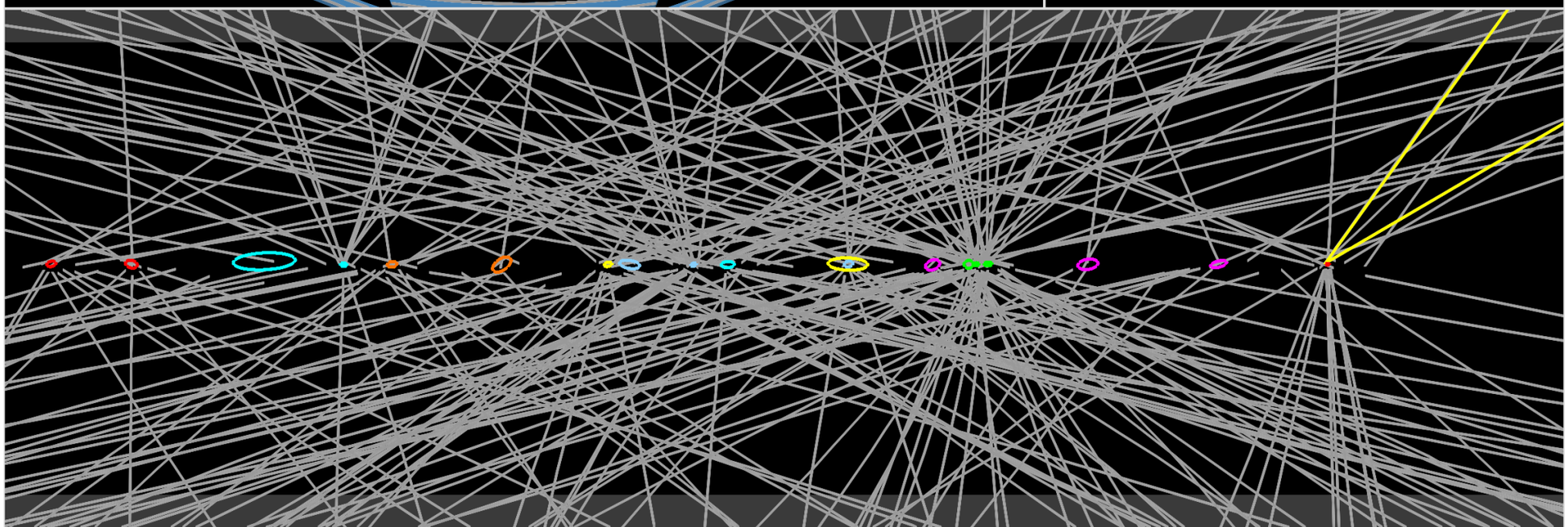
ATLAS EXPERIMENT

Run Number: 189280, Event Number: 1705325

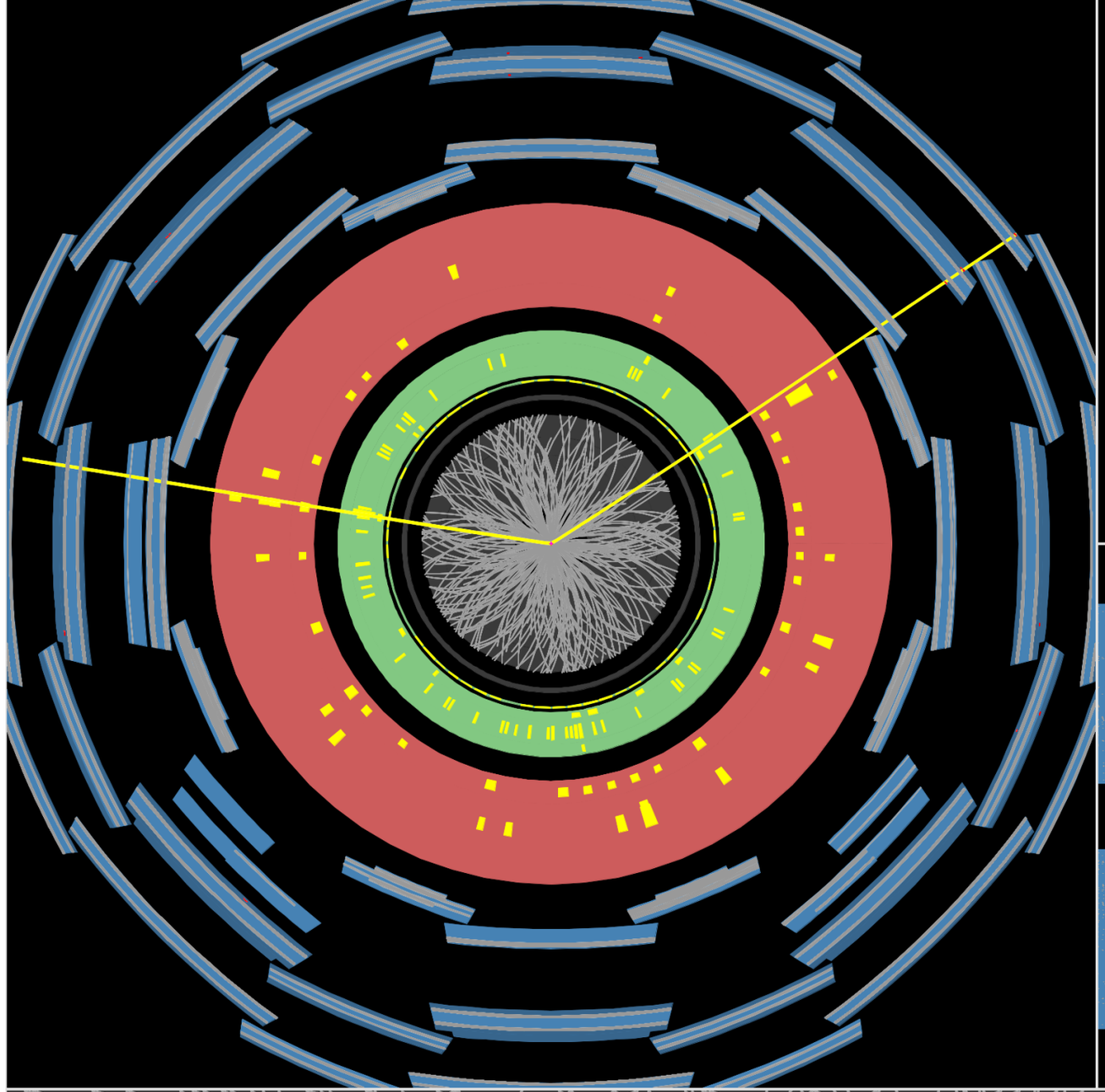
Date: 2011-09-14 02:47:14 CEST



LHC



LHC



ATLAS EXPERIMENT

Run Number: 189280, Event Number: 1705325

Date: 2011-09-14 02:47:14 CEST

99.99999% degli eventi vengono scartati!

(da 1000000000 ev/s-> 200 ev/s)

LHC

LHC

Prima accensione di LHC - 10/09/2008

https://home.cern/science/accelerators/large-hadron-collider

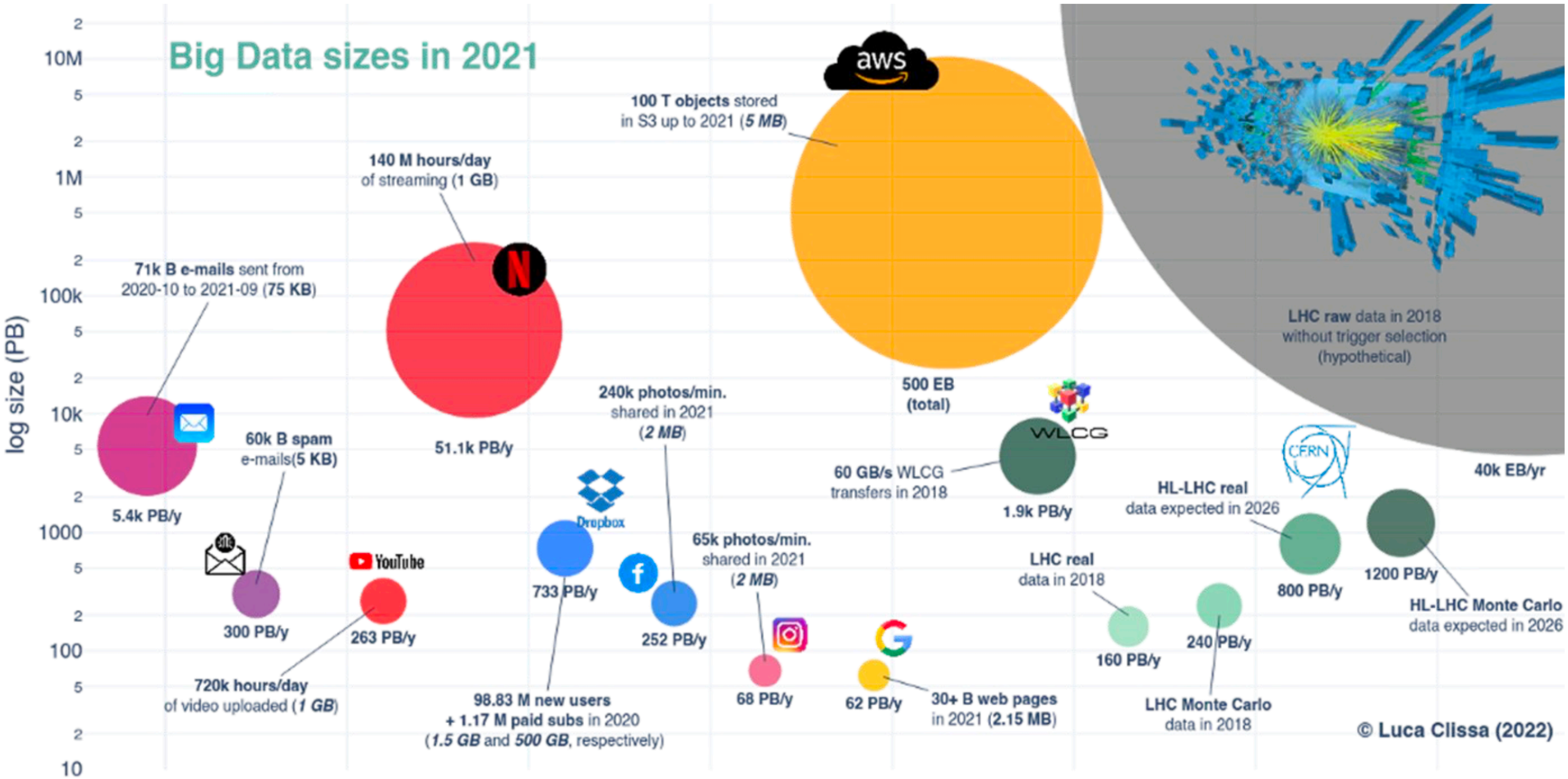
LHC batte il record di energia raggiunta dei protoni (1.18 TeV) - 30/11/2009

https://home.cern/science/accelerators/large-hadron-collider

LHC control room in un giorno tranquillo…

https://home.cern/science/accelerators/large-hadron-collider

LHC and Big Data



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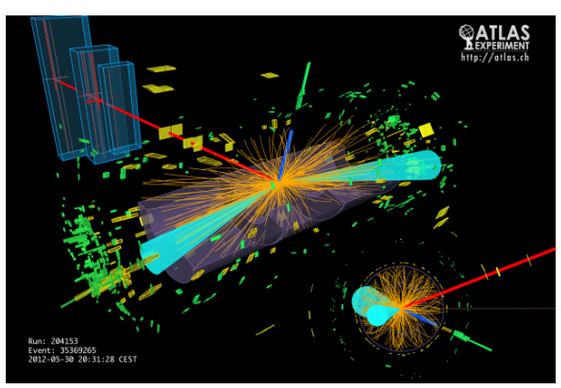
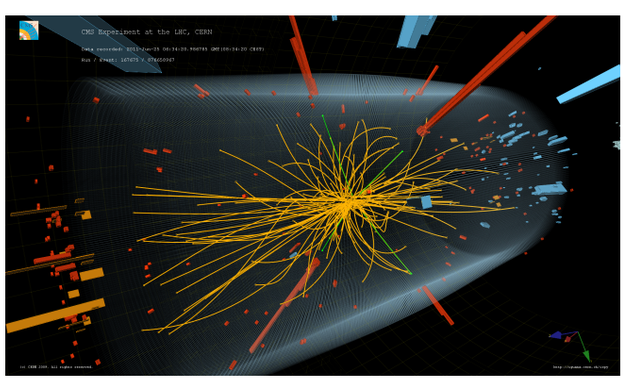
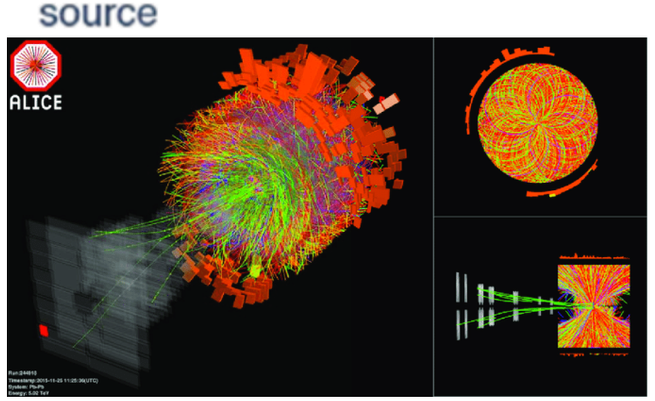
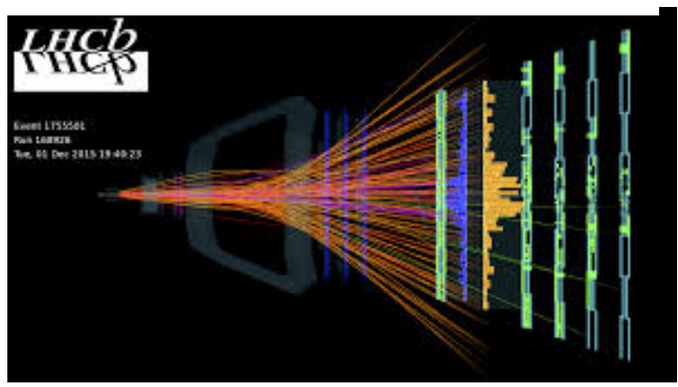
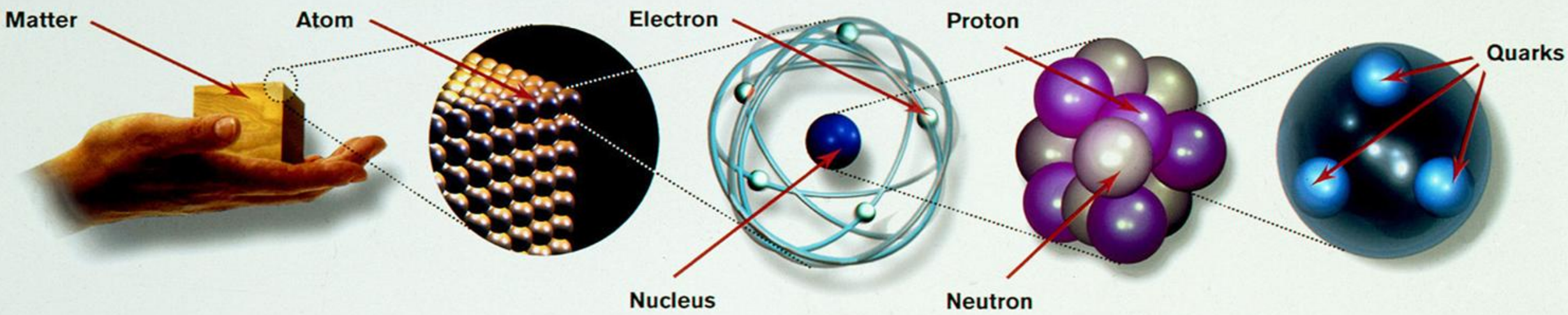








Matter constituents



Matter particles
All ordinary particles belong to this group

These particles existed just after the Big Bang. Now they are found only in cosmic rays and accelerators

LEPTONS

FIRST FAMILY	**Electron** Responsible for electricity and chemical reactions; it has a charge of -1	**Electron neutrino** Particle with no electric charge, and possibly no mass; billions fly through your body every second
SECOND FAMILY	**Muon** A heavier relative of the electron; it lives for two-millionths of a second	**Muon neutrino** Created along with muons when some particles decay
THIRD FAMILY	**Tau** Heavier still; it is extremely unstable. It was discovered in 1975	**Tau neutrino** not yet discovered but believed to exist

QUARKS

Up Has an electric charge of plus two-thirds; protons contain two, neutrons contain one	**Down** Has an electric charge of minus one-third; protons contain one, neutrons contain two
Charm A heavier relative of the up; found in 1974	**Strange** A heavier relative of the down; found in 1964
Top Heavier still	**Bottom** Heavier still; measuring bottom quarks is an important test of electroweak theory

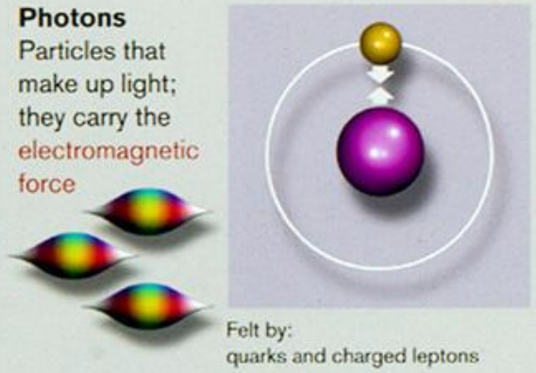
Force particles
These particles transmit the four fundamental forces of nature although gravitons have so far not been discovered

Gluons
Carriers of the strong force between quarks

Felt by: quarks

The explosive release of nuclear energy is the result of the strong force

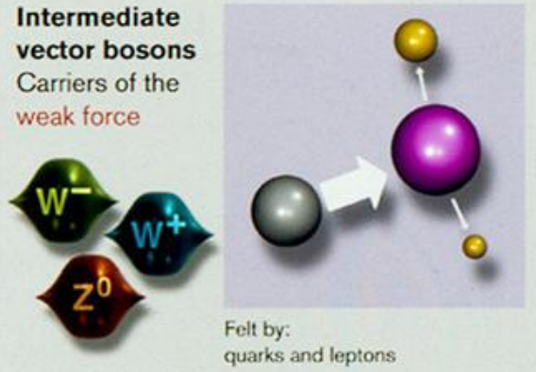
Photons
Particles that make up light; they carry the electromagnetic force



Felt by: quarks and charged leptons

Electricity, magnetism and chemistry are all the results of electro-magnetic force

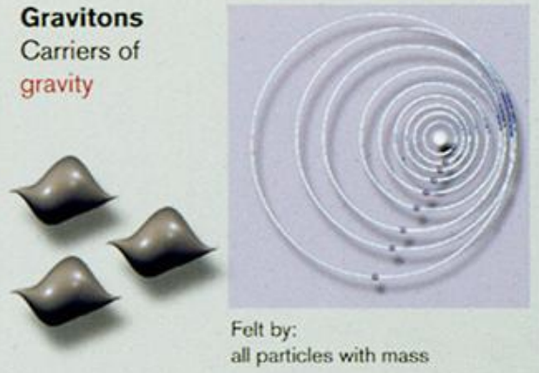
Intermediate vector bosons
Carriers of the weak force



Felt by: quarks and leptons

Some forms of radio-activity are the result of the weak force

Gravitons
Carriers of gravity

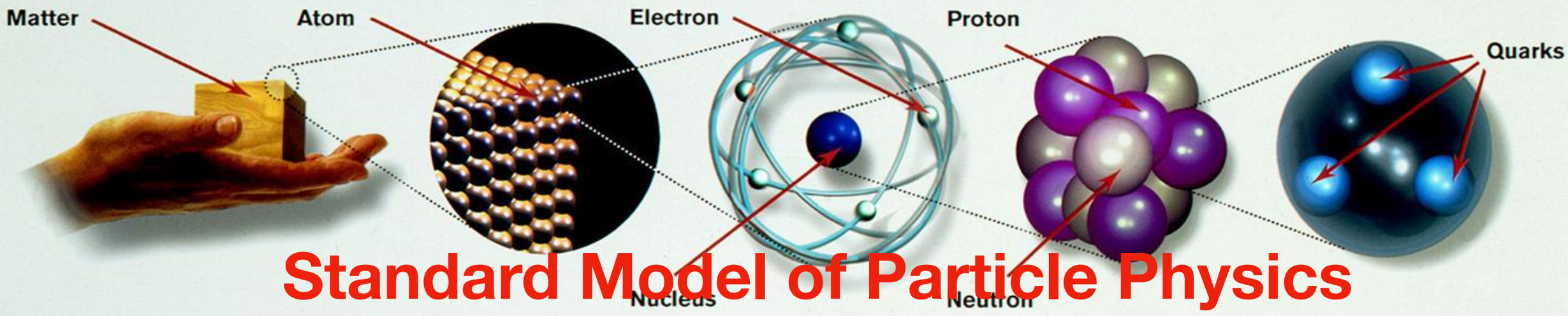


Felt by: all particles with mass

All the weight we experience is the result of the gravitational force

GRAPHICS: PETER CROWTHER

Matter constituents



Standard Model of Particle Physics

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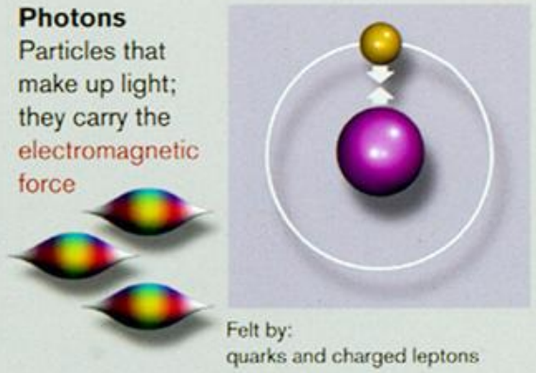

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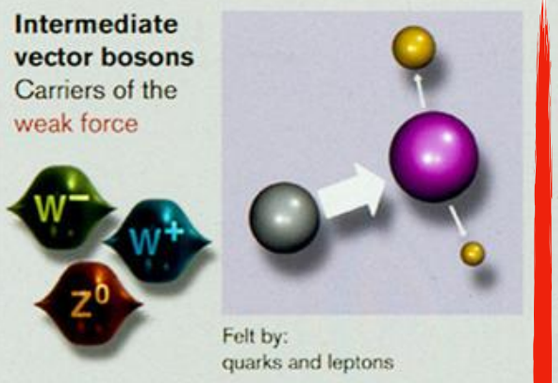
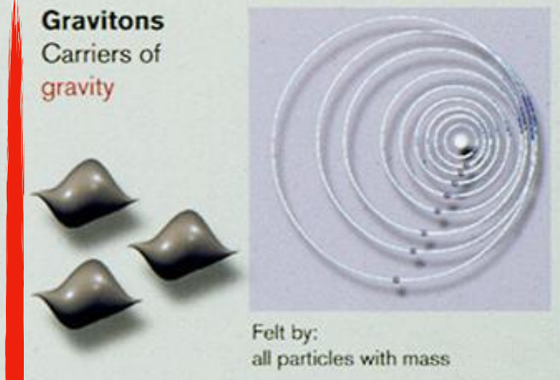


Felt by: quarks and leptons

Some forms of radio-activity are the result of the weak force

Gravitons
Carriers of gravity

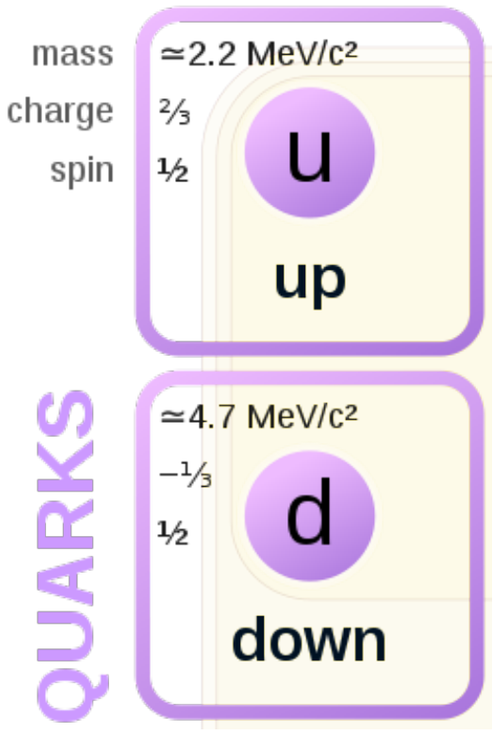


Felt by: all particles with mass

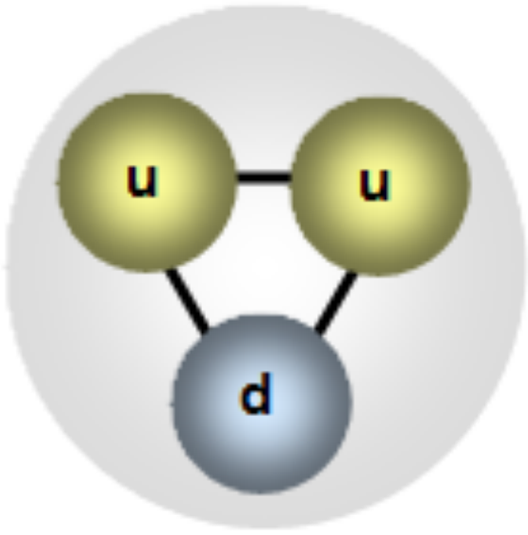
All the weight we experience is the result of the gravitational force

GRAPHICS: PETER CROWTHER

Standard Model of Elementary Particles

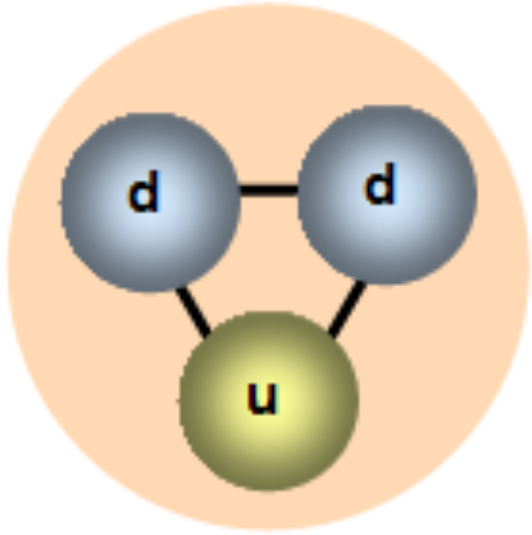


938,27 MeV/c²



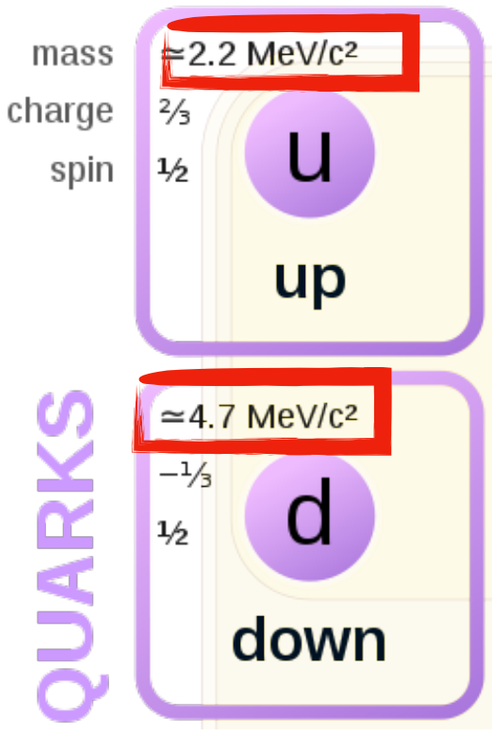
proton

939,57 MeV/c²

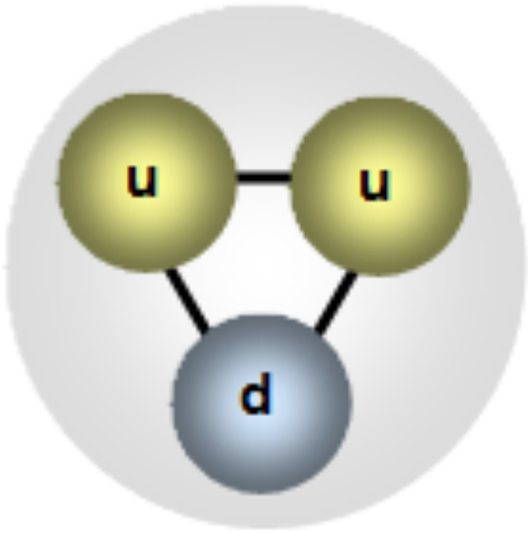


neutron

Standard Model of Elementary Particles

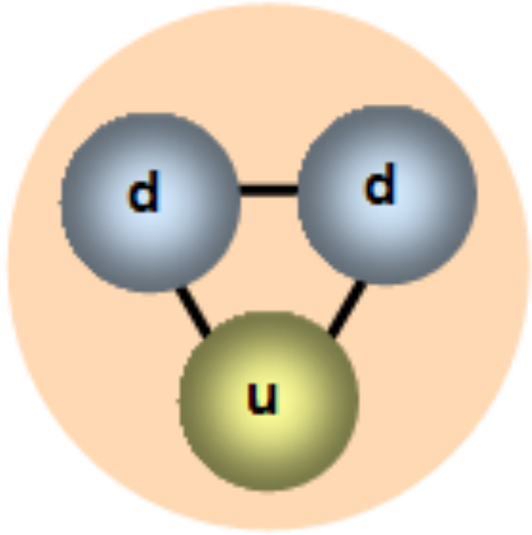


938,27 MeV/c²



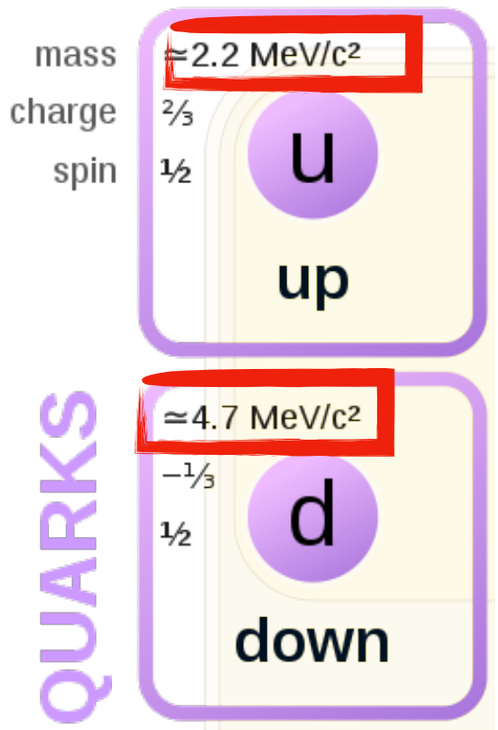
proton

939,57 MeV/c²

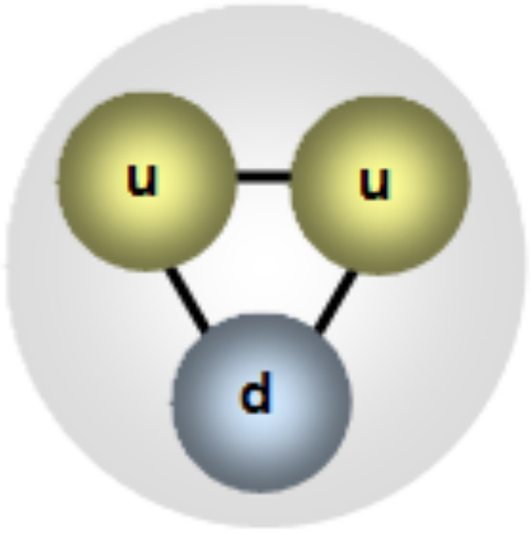


neutron

Standard Model of Elementary Particles

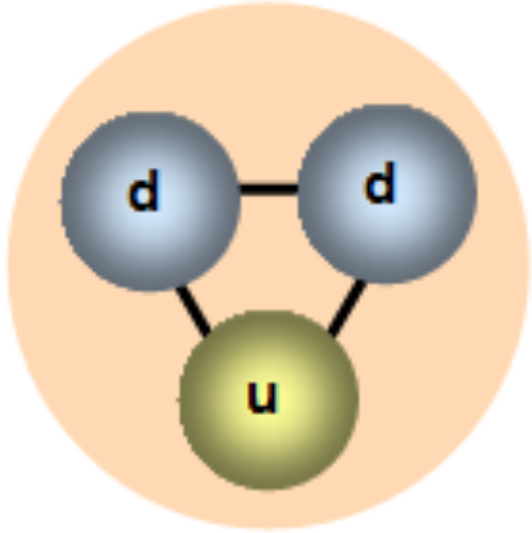


938,27 MeV/c²

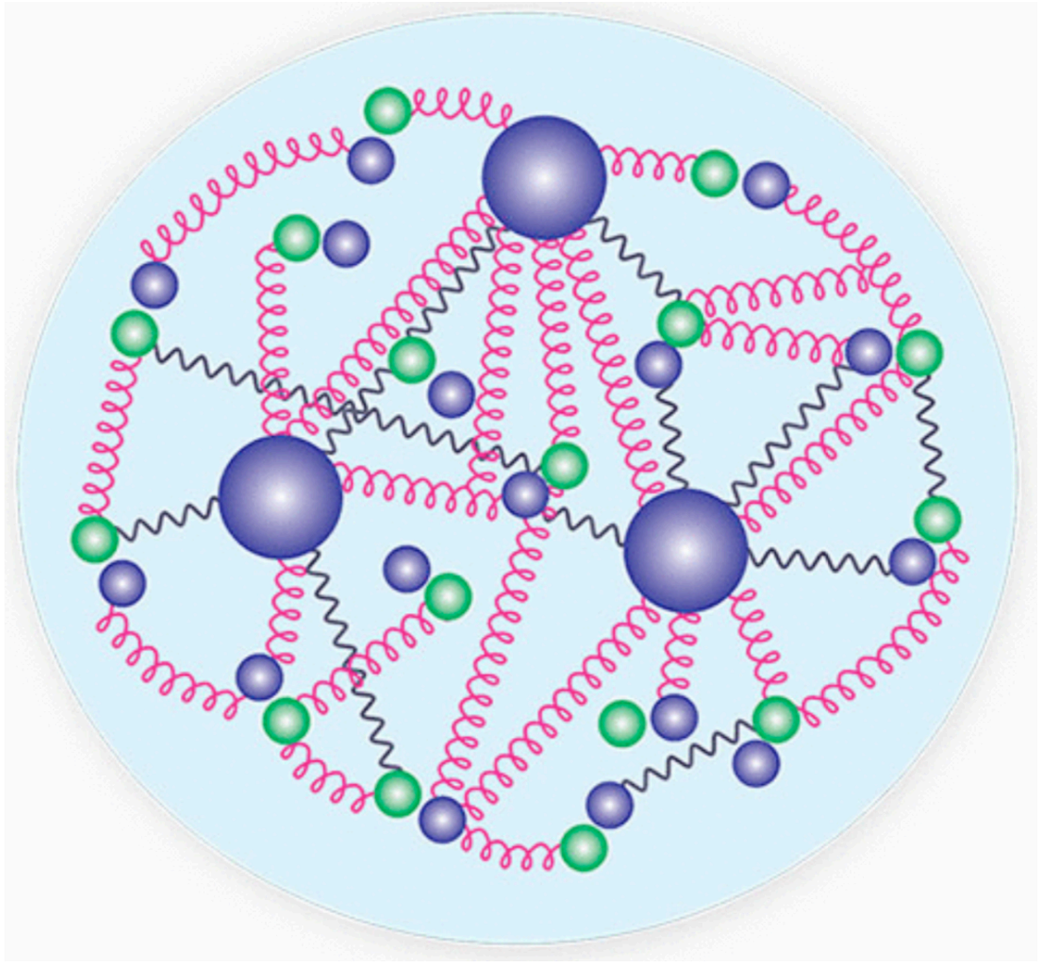


proton

939,57 MeV/c²

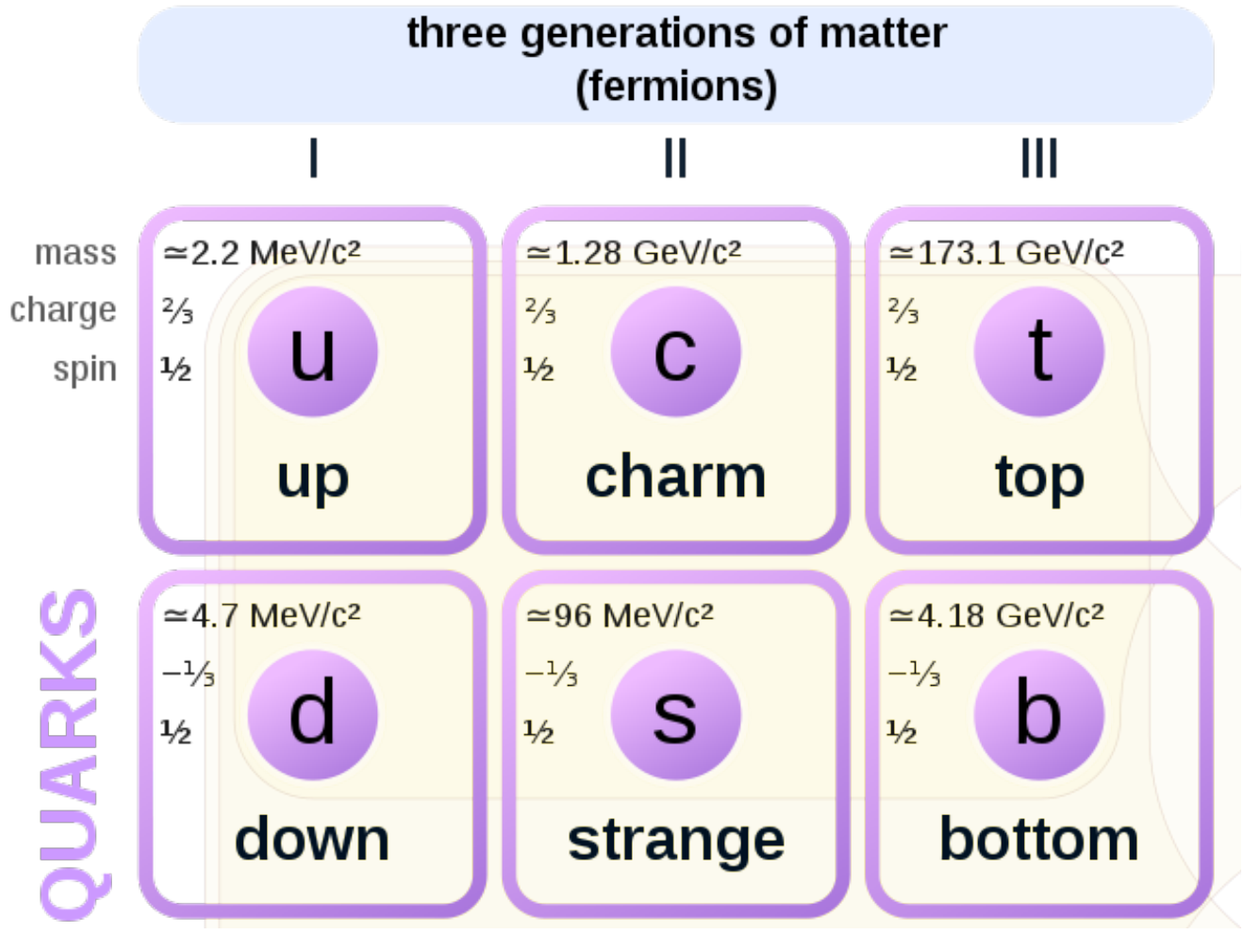


neutron



Gluoni!

Standard Model of Elementary Particles



Standard Mo rticles

three

I

mass ≃2.2 MeV

charge ⅔

spin ½

QUARKS

u

d

c

s

t

b

Standard Model of Elementary Particles

three generations of matter
(fermions)

	I	II	III
mass	≃2.2 MeV/c²	≃1.28 GeV/c²	≃173.1 GeV/c²
charge	⅔	⅔	⅔
spin	½	½	½
	u up	c charm	t top
QUARKS	≃4.7 MeV/c²	≃96 MeV/c²	≃4.18 GeV/c²
	−⅓	−⅓	−⅓
	½	½	½
	d down	s strange	b bottom

Richter e Ting (1974)

J/Ψ

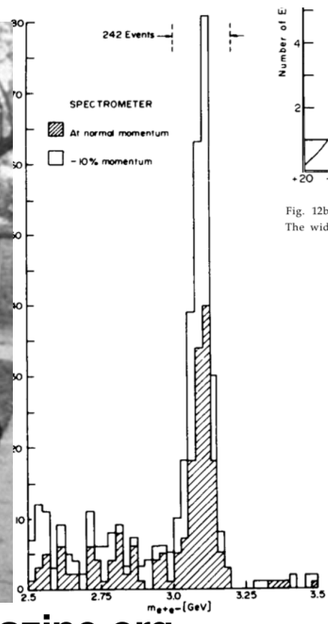
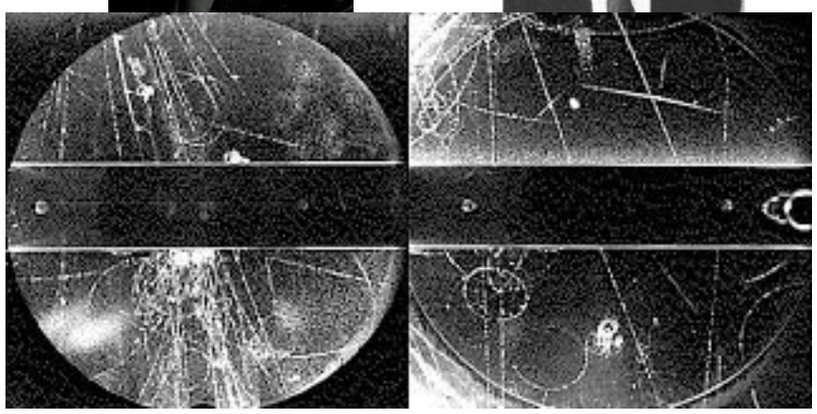


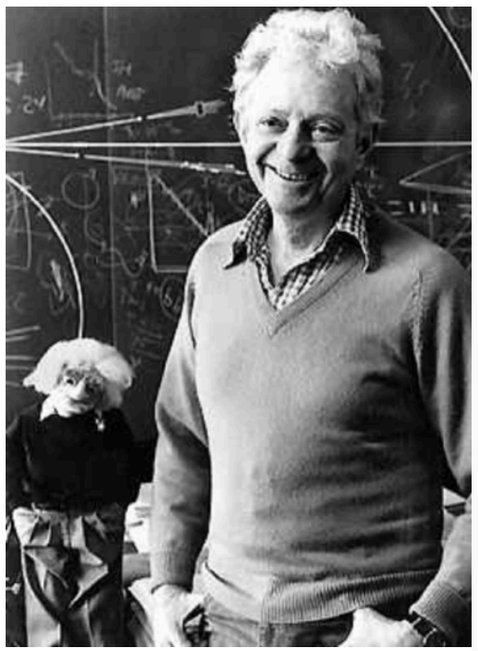
Fig. 12b
The wid

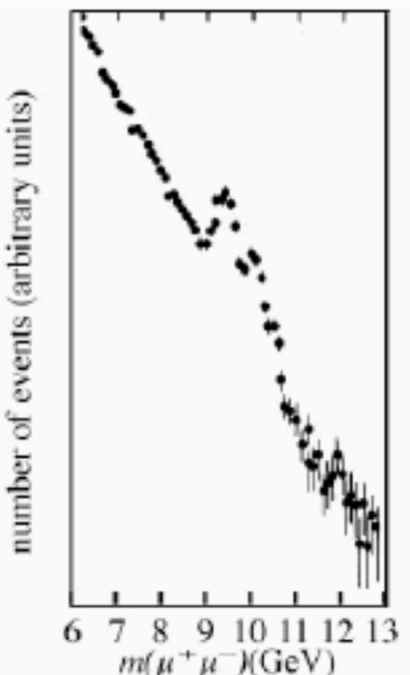
https://www.symmetrymagazine.org

Rochester e Butler (1947)

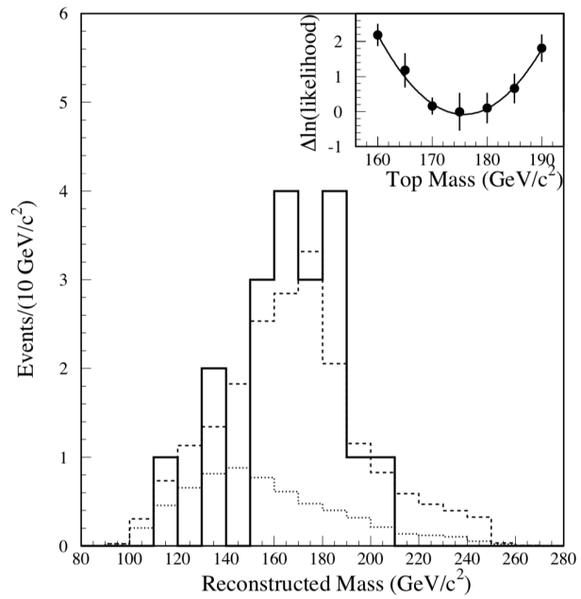


Lederman (1977)



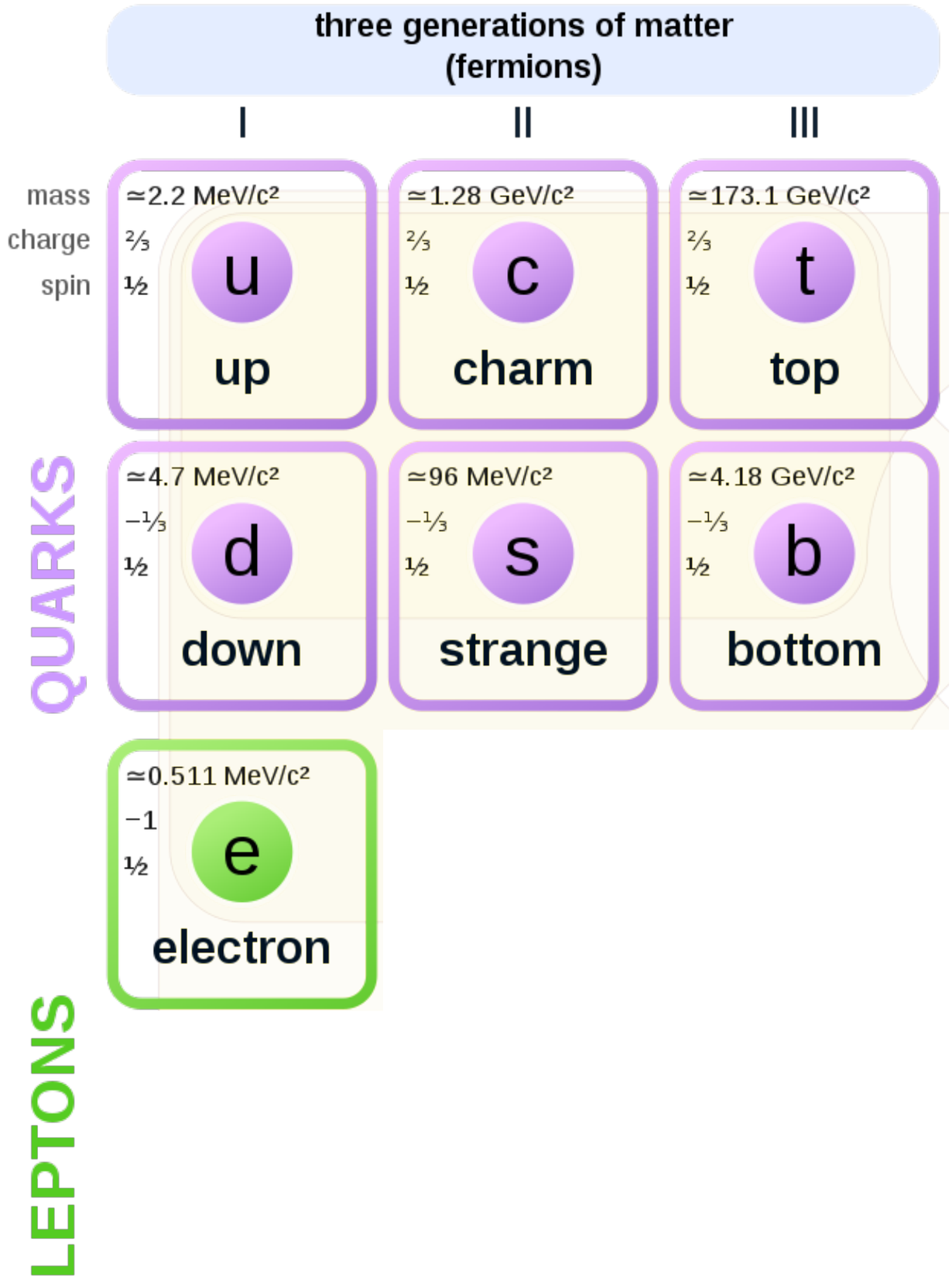


CDF e D0(1995)

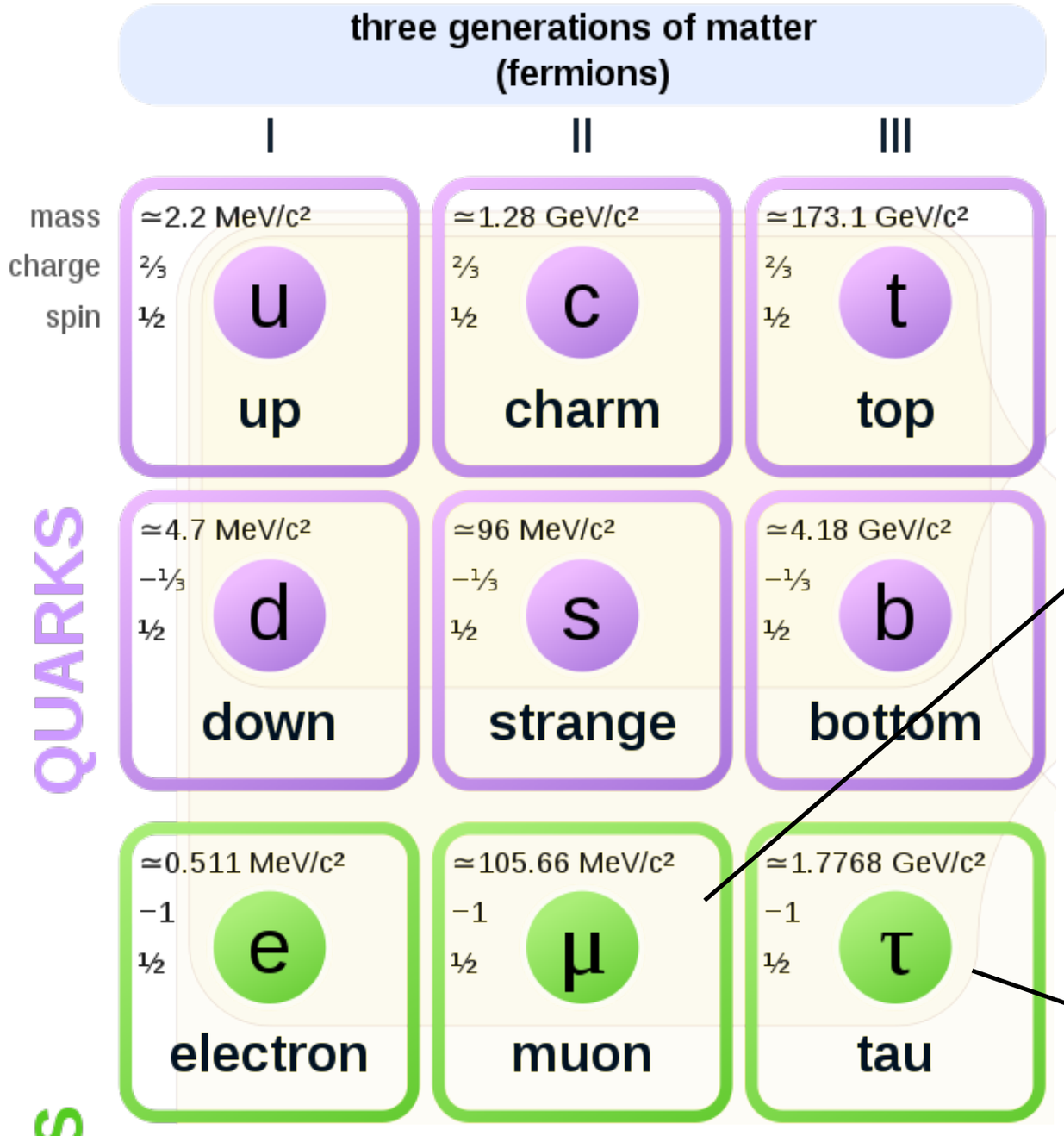


https://arxiv.org/abs/hep-ex/9503002

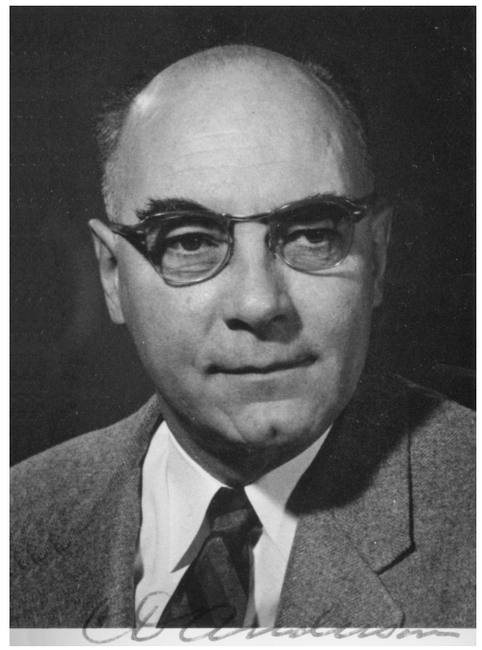
Standard Model of Elementary Particles



Standard Model of Elementary Particles

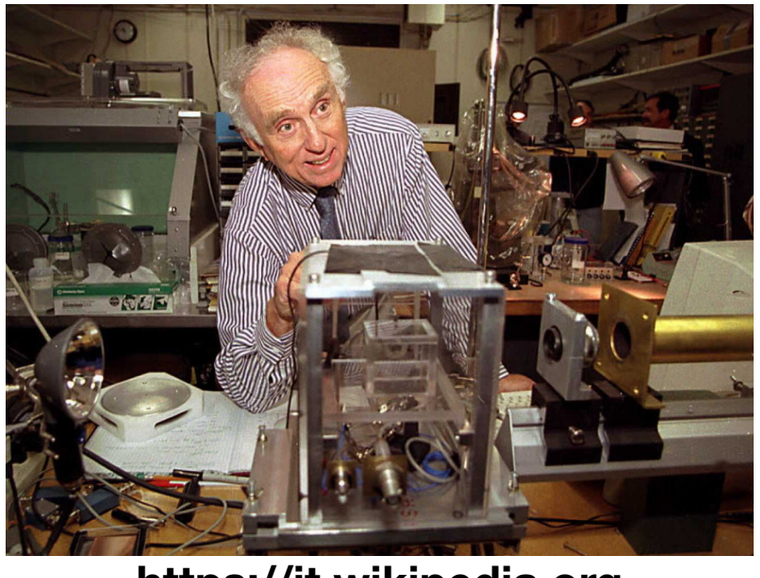


Carl Andreson (1936)



https://it.wikipedia.org

Martin Lewis Perl at SLAC (1977)



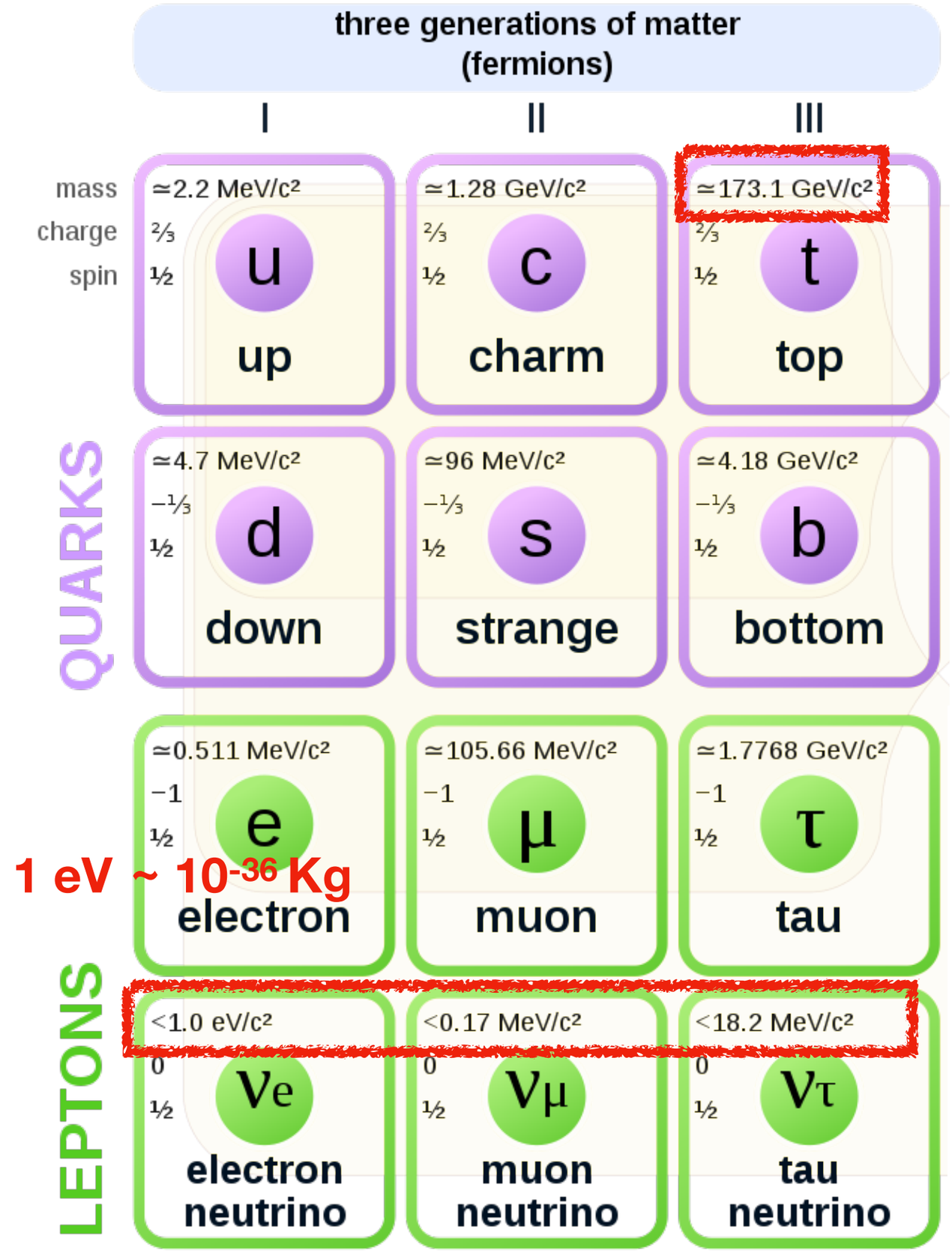
https://it.wikipedia.org

Standard Model of Elementary Particles

three generations of matter (fermions)

	I	II	III
mass	≃2.2 MeV/c²	≃1.28 GeV/c²	≃173.1 GeV/c²
charge	⅔	⅔	⅔
spin	½	½	½
QUARKS	u up	c charm	t top
	≃4.7 MeV/c²	≃96 MeV/c²	≃4.18 GeV/c²
	−⅓	−⅓	−⅓
	½	½	½
	d down	s strange	b bottom
LEPTONS	≃0.511 MeV/c²	≃105.66 MeV/c²	≃1.7768 GeV/c²
	−1	−1	−1
	½	½	½
	e electron	μ muon	τ tau
	<1.0 eV/c²	<0.17 MeV/c²	<18.2 MeV/c²
	0	0	0
	½	½	½
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino

Standard Model of Elementary Particles



Standard Model of Elementary Particles

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charge	⅔	⅔	⅔
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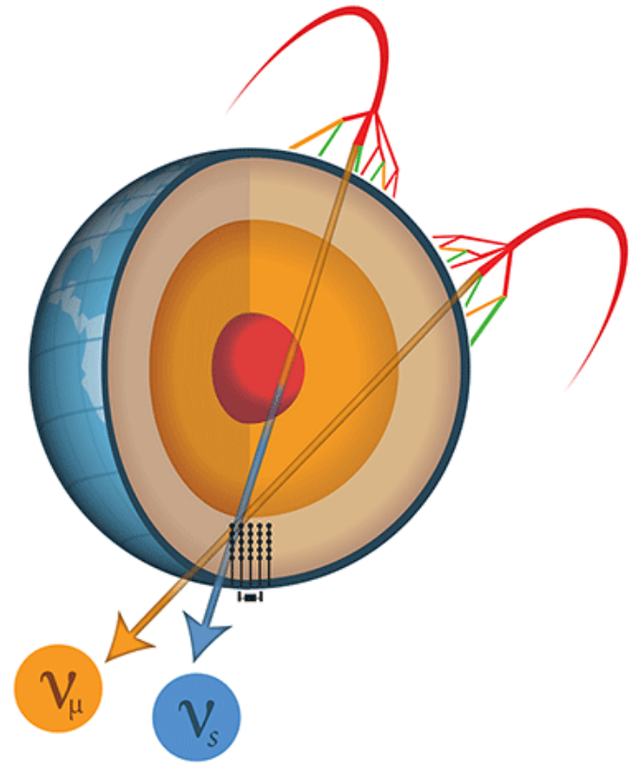
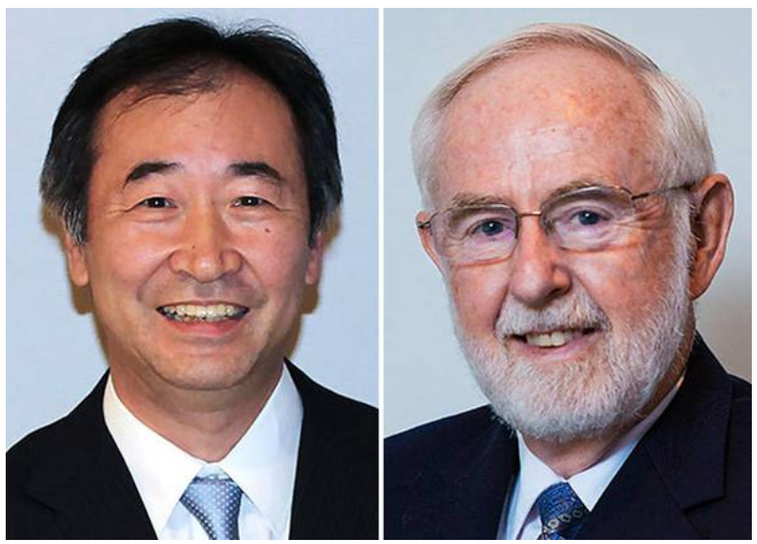
QUARKS	u up	c charm	t top
	≃4.7 MeV/c²	≃96 MeV/c²	≃4.18 GeV/c²
	−⅓	−⅓	−⅓
	½	½	½
	d down	s strange	b bottom
	≃0.511 MeV/c²	≃105.66 MeV/c²	≃1.7768 GeV/c²
	−1	−1	−1
	½	½	½
LEPTONS	e electron	μ muon	τ tau
	<1.0 eV/c²	<0.17 MeV/c²	<18.2 MeV/c²
	0	0	0
	½	½	½
	νe electron neutrino	νμ muon neutrino	ντ tau neutrino

1 eV ~ 10^{-36} Kg

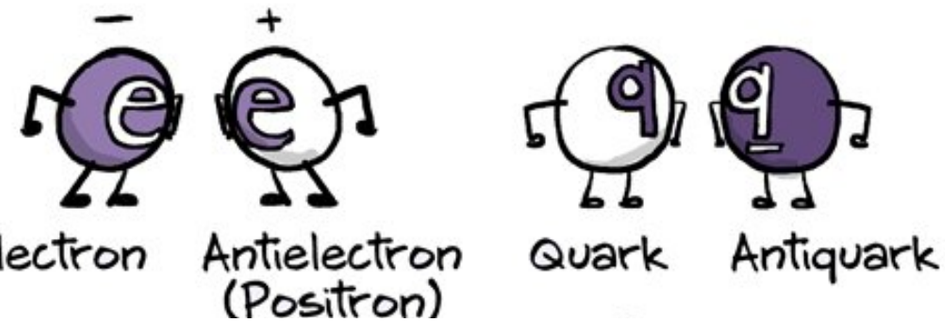
Oscillazioni del neutrino (BSM)



Takaaki Kajita e Arthur McDonald



Particles are Political



Stessa massa

Carica opposta

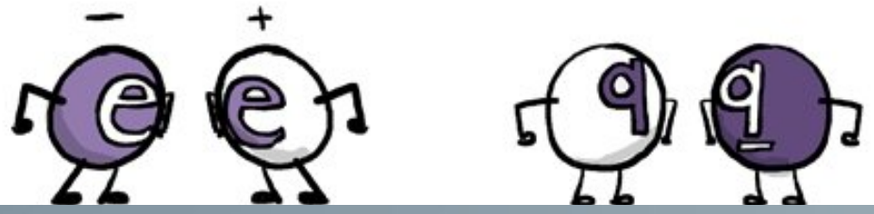
Particelle

mass	≃2.2 MeV/c²	≃1.28 GeV/c²	≃173.1 GeV/c²
charge	⅔	⅔	⅔
spin	½	½	½
	u up	c charm	t top
QUARKS	≃4.7 MeV/c² −⅓ ½ d down	≃96 MeV/c² −⅓ ½ s strange	≃4.18 GeV/c² −⅓ ½ b bottom
LEPTONS	≃0.511 MeV/c² −1 ½ e electron	≃105.66 MeV/c² −1 ½ μ muon	≃1.7768 GeV/c² −1 ½ τ tau
	<2.2 eV/c² 0 ½ ν_e electron neutrino	<0.17 MeV/c² 0 ½ ν_μ muon neutrino	<18.2 MeV/c² 0 ½ ν_τ tau neutrino

Anti-particelle

	≃2.2 MeV/c²	≃1.28 GeV/c²	≃173.1 GeV/c²
	−⅔	−⅔	−⅔
	½	½	½
	$\bar{u}$ antiup	$\bar{c}$ anticharm	$\bar{t}$ antitop
	≃4.7 MeV/c² ⅓ ½ $\bar{d}$ antidown	≃96 MeV/c² ⅓ ½ $\bar{s}$ antistrange	≃4.18 GeV/c² ⅓ ½ $\bar{b}$ antibottom
	≃0.511 MeV/c² 1 ½ e^+ positron	≃105.66 MeV/c² 1 ½ $\bar{\mu}$ antimuon	≃1.7768 GeV/c² 1 ½ $\bar{\tau}$ antitau
	<2.2 eV/c² 0 ½ $\bar{\nu}_e$ electron antineutrino	<0.17 MeV/c² 0 ½ $\bar{\nu}_\mu$ muon antineutrino	<18.2 MeV/c² 0 ½ $\bar{\nu}_\tau$ tau antineutrino

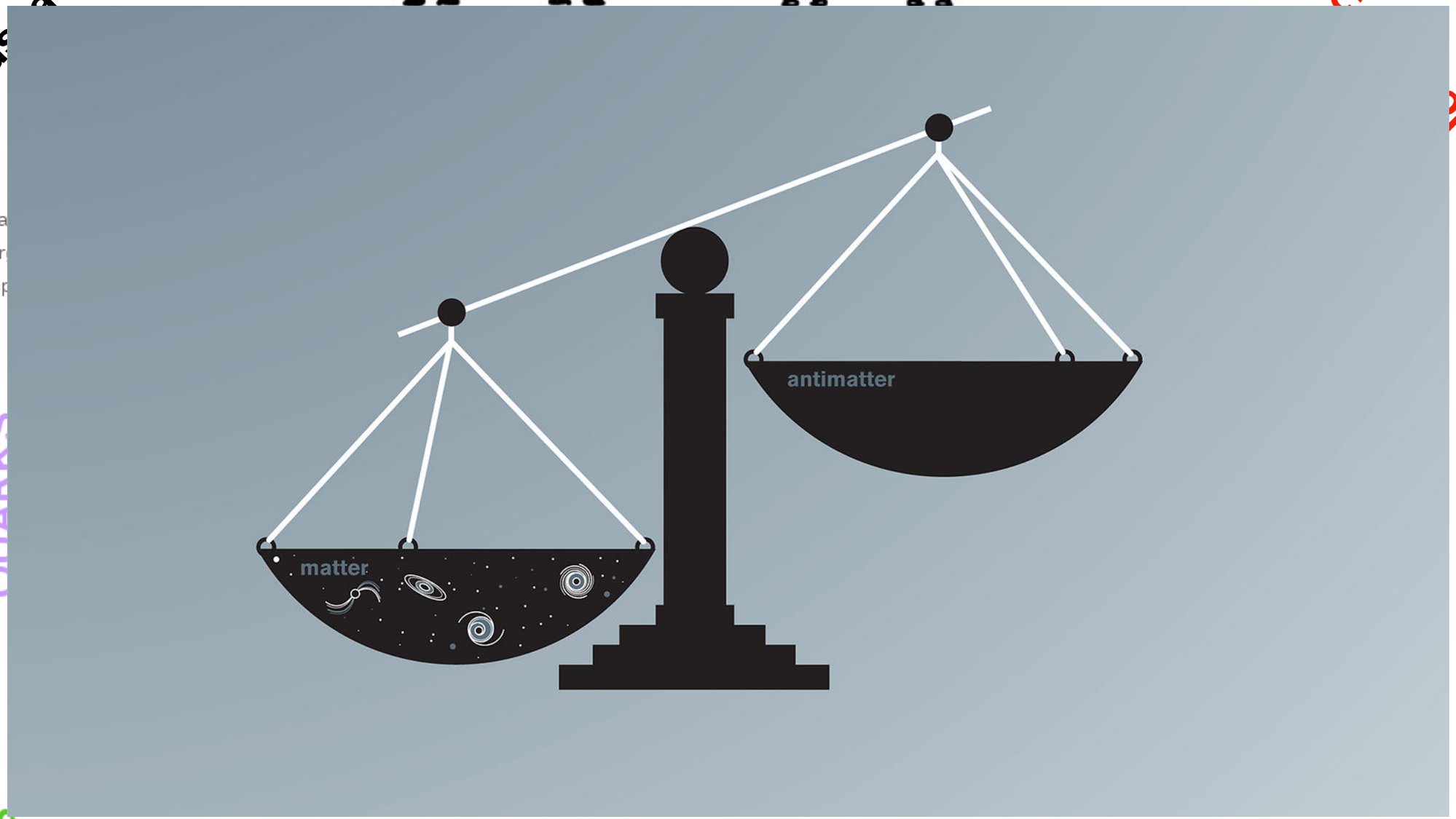
Particles are Political



Stessa mas

Cari

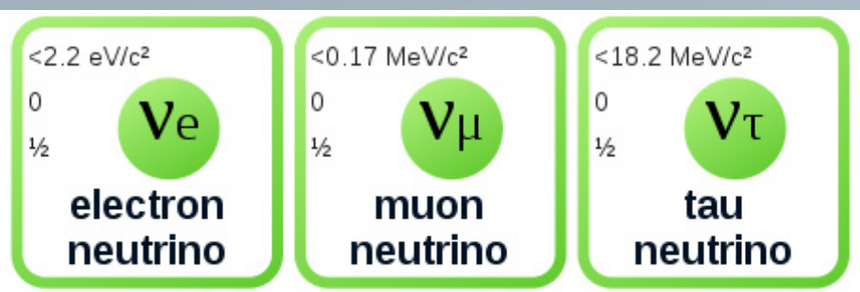
opposta

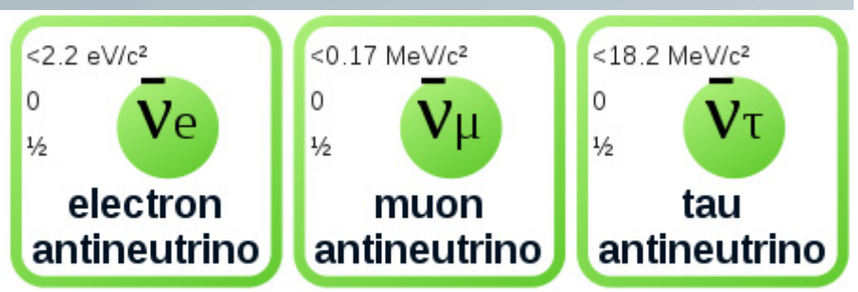


ma
char
sp

QUARKS

LEPTONS





Standard Model of Elementary Particles

three generations of matter (fermions) | interactions / force carriers (bosons)

	I	II	III	
mass	≃2.2 MeV/c²	≃1.28 GeV/c²	≃173.1 GeV/c²	0
charge	⅔	⅔	⅔	0
spin	½	½	½	1
QUARKS	u up	c charm	t top	g gluon
	≃4.7 MeV/c²	≃96 MeV/c²	≃4.18 GeV/c²	0
	−⅓	−⅓	−⅓	0
	½	½	½	1
	d down	s strange	b bottom	γ photon
LEPTONS	≃0.511 MeV/c²	≃105.66 MeV/c²	≃1.7768 GeV/c²	≃91.19 GeV/c²
	−1	−1	−1	0
	½	½	½	1
	e electron	μ muon	τ tau	Z Z boson
	<1.0 eV/c²	<0.17 MeV/c²	<18.2 MeV/c²	≃80.39 GeV/c²
	0	0	0	±1
	½	½	½	1
	νe electron neutrino	νμ muon neutrino	ντ tau neutrino	W W boson

Carlo Rubbia (1983) @ CERN

https://it.wikipedia.org

Standard Model of Elementary Particles

three generations of matter (fermions) | interactions / force carriers (bosons)

	I	II	III	
mass	≃2.2 MeV/c²	≃1.28 GeV/c²	≃173.1 GeV/c²	0
charge	⅔	⅔	⅔	0
spin	½	½	½	1
QUARKS	u up	c charm	t top	g gluon
QUARKS	≃4.7 MeV/c², −⅓, ½, d down	≃96 MeV/c², −⅓, ½, s strange	≃4.18 GeV/c², −⅓, ½, b bottom	0, 0, 1, γ photon
LEPTONS	≃0.511 MeV/c², −1, ½, e electron	≃105.66 MeV/c², −1, ½, μ muon	≃1.7768 GeV/c², −1, ½, τ tau	≃91.19 GeV/c², 0, 1, Z Z boson
LEPTONS	<1.0 eV/c², 0, ½, νe electron neutrino	<0.17 MeV/c², 0, ½, νμ muon neutrino	<18.2 MeV/c², 0, ½, ντ tau neutrino	±1, 1, W W boson

$m_Z = 91.2\ \text{GeV}/c^2$

Standard Model of Elementary Particles

three generations of matter (fermions) | interactions / force carriers (bosons)

$m_H = 125\ \mathrm{GeV/c^2}$

	I	II	III		
mass	≃2.2 MeV/c²	≃1.28 GeV/c²	≃173.1 GeV/c²	0	≃124.97 GeV/c²
charge	⅔	⅔	⅔	0	0
spin	½	½	½	1	0
	u up	c charm	t top	g gluon	H higgs
	≃4.7 MeV/c²	≃96 MeV/c²	≃4.18 GeV/c²	0	
	−⅓	−⅓	−⅓	0	
	½	½	½	1	
	d down	s strange	b bottom	γ photon	
	≃0.511 MeV/c²	≃105.66 MeV/c²	≃1.7768 GeV/c²	≃91.19 GeV/c²	
	−1	−1	−1	0	
	½	½	½	1	
	e electron	μ muon	τ tau	Z Z boson	
	<1.0 eV/c²	<0.17 MeV/c²	<18.2 MeV/c²	≃80.39 GeV/c²	
	0	0	0	±1	
	½	½	½	1	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	

QUARKS

LEPTONS

BOSONS

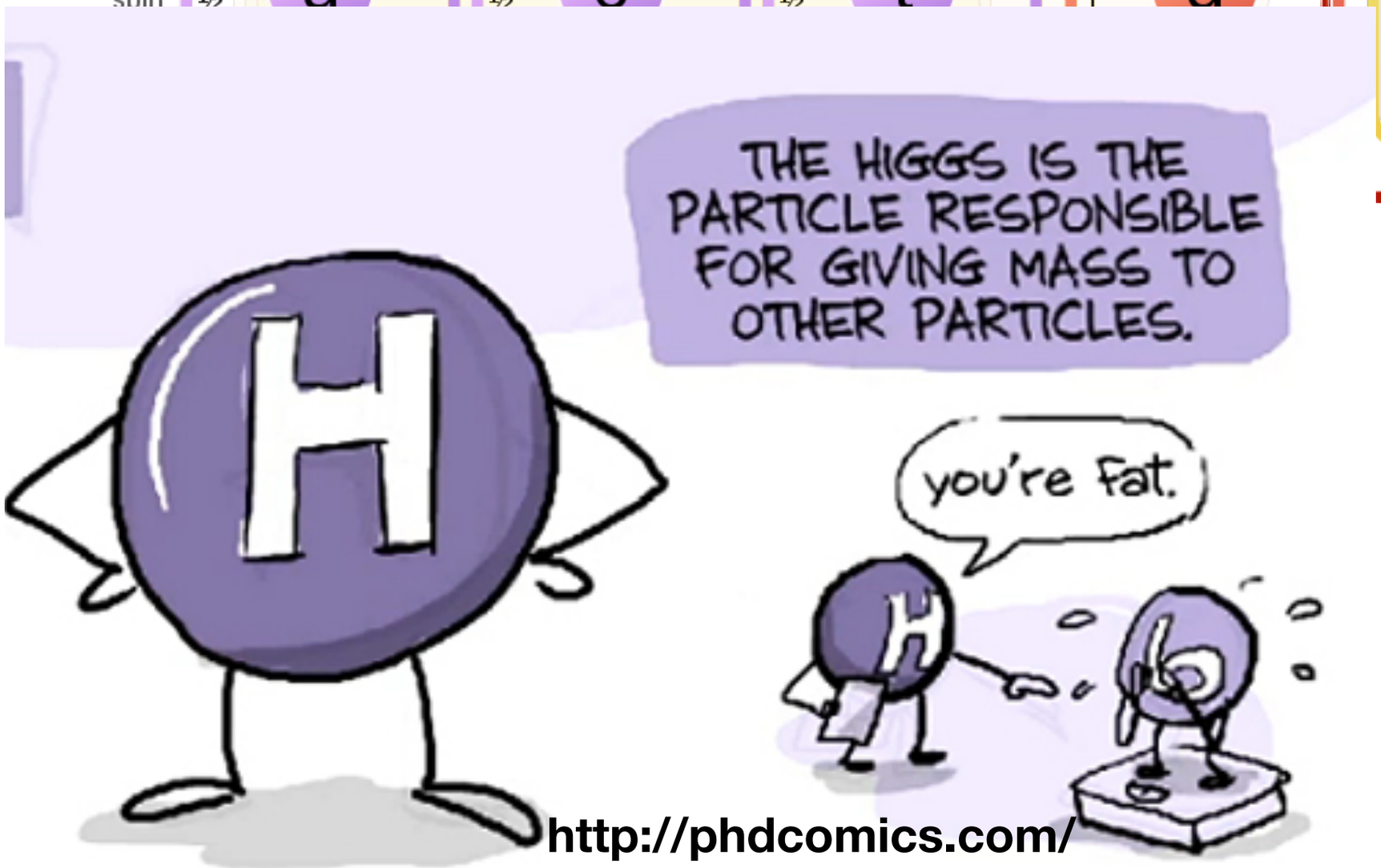
BOSONS

Standard Model of Elementary Particles

three generations of matter (fermions) | interactions / force carriers (bosons)

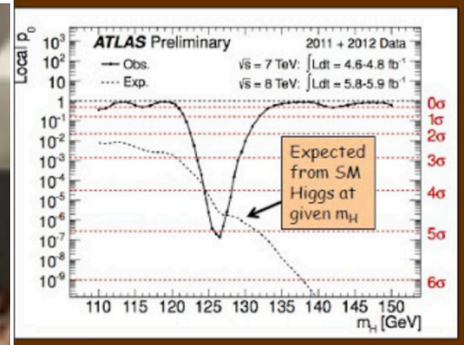
$m_H = 125\ \mathrm{GeV/c^2}$

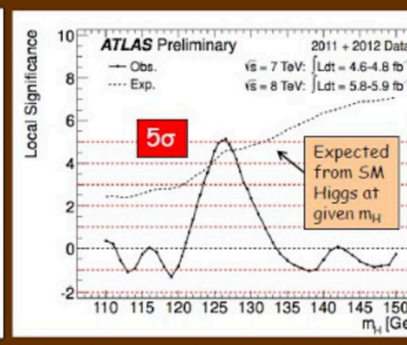
	I	II	III		
mass	≃2.2 MeV/c²	≃1.28 GeV/c²	≃173.1 GeV/c²	0	≃124.97 GeV/c²
charge	⅔	⅔	⅔	0	0
spin	½	½	½	1	0
	u	c	t	g	H
	up	charm	top	gluon	higgs
LEPTONS	electron neutrino	muon neutrino	tau neutrino	W boson	BOSONS



http://phdcomics.com/

Combined results: the excess





Maximum excess observed at	m_H = 126.5 GeV
Local significance (including energy-scale systematics)	5.0 σ
Probability of background up-fluctuation	3 x 10^{-7}
Expected from SM Higgs m_H=126.5	4.6 σ

Global significance: 4.1-4.3 σ (for LEE over 110-600 or 110-150 GeV)

https://www.focus.it/scienza/scienze/fabiola-gianotti-confermata-direttrice-del-cern

https://www.lhc-closer.es/taking_a_closer_look_at_lhc/1.lhc

LHC
(2008-oggi)

CMS

>1600 magneti
@-271.3°C

27 km

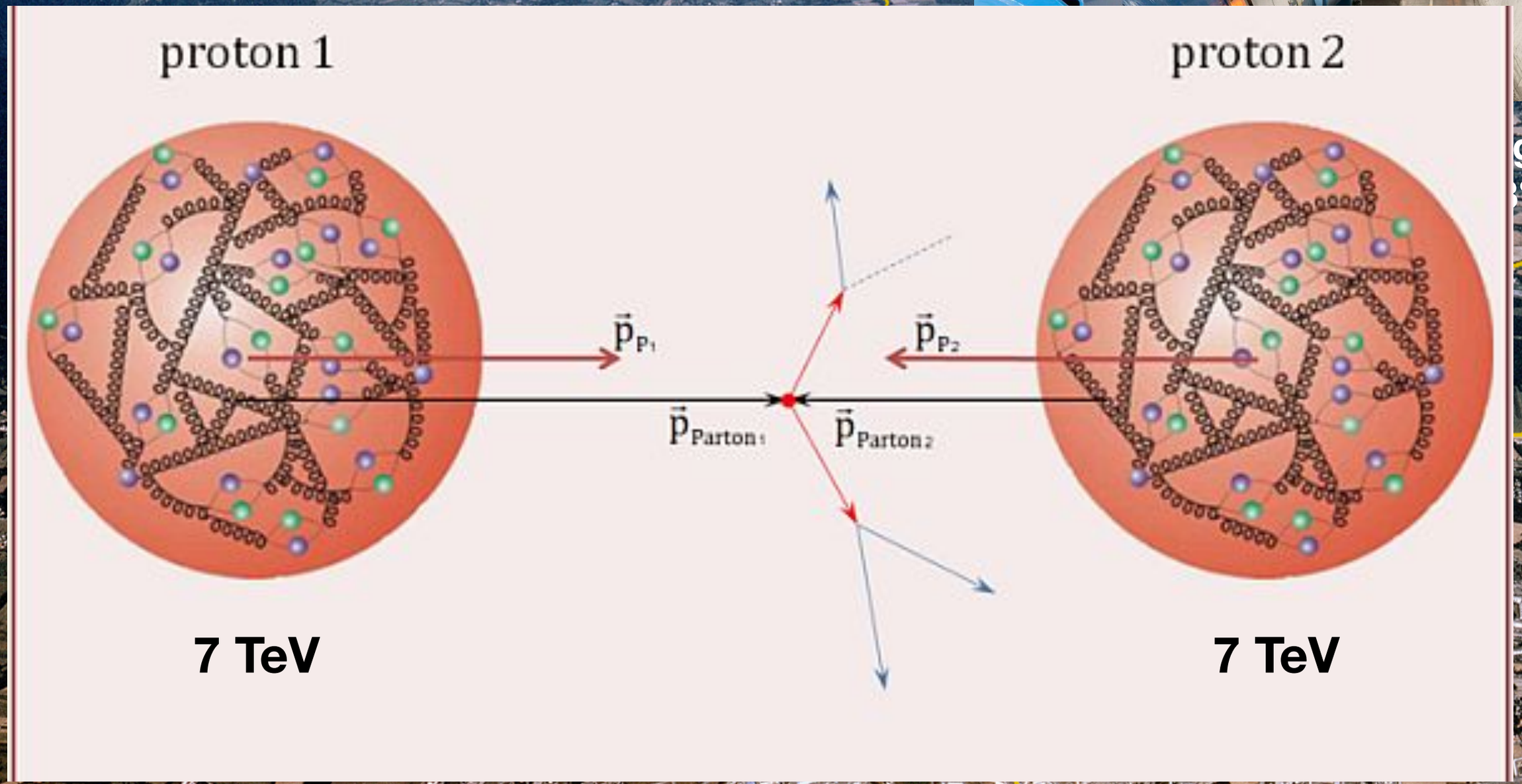
LHCb

ALICE

ATLAS

https://www.lhc-closer.es/taking_a_closer_look_at_lhc/1.lhc

LHC
(2008-oggi)



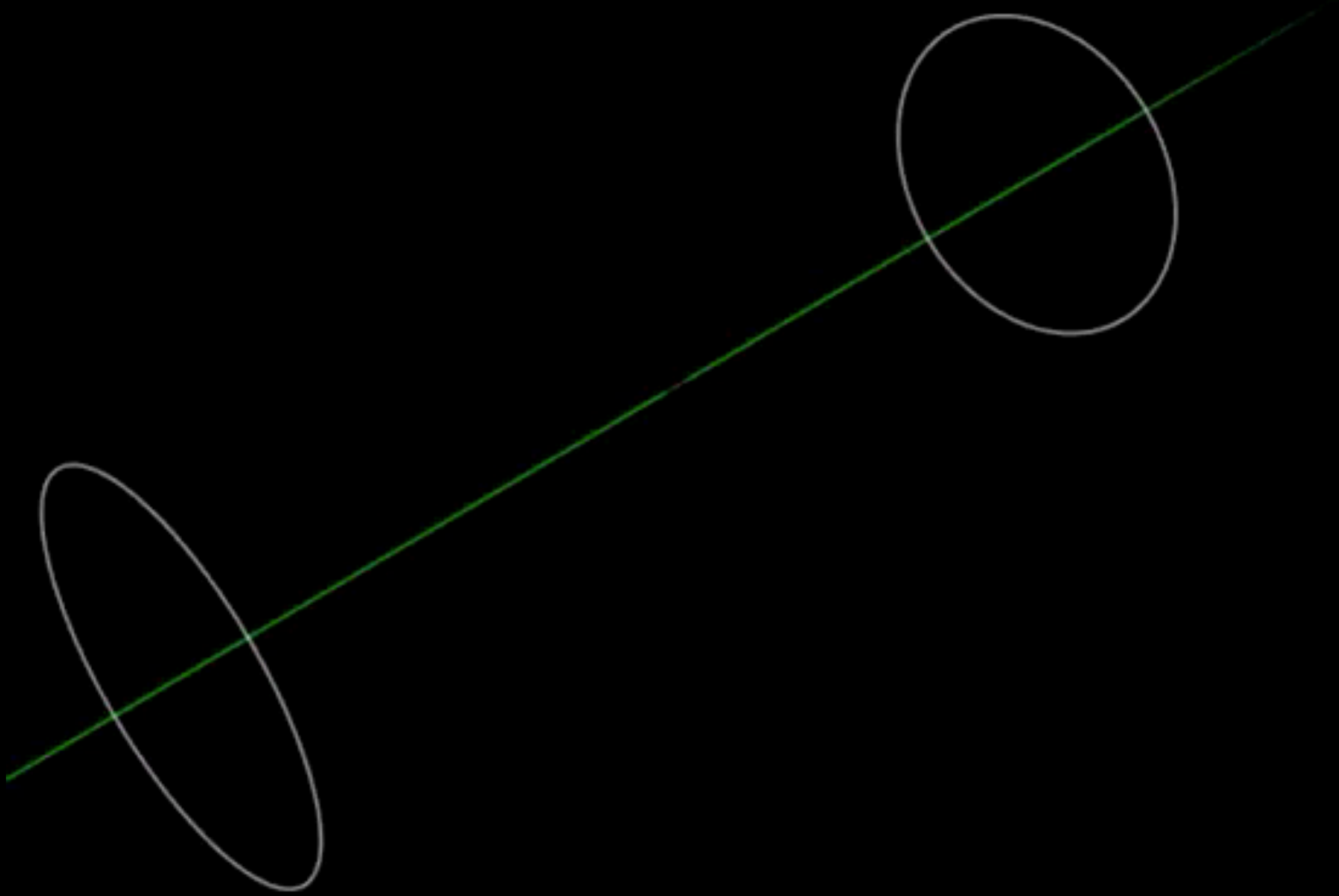
7 TeV

7 TeV

gneti
°C

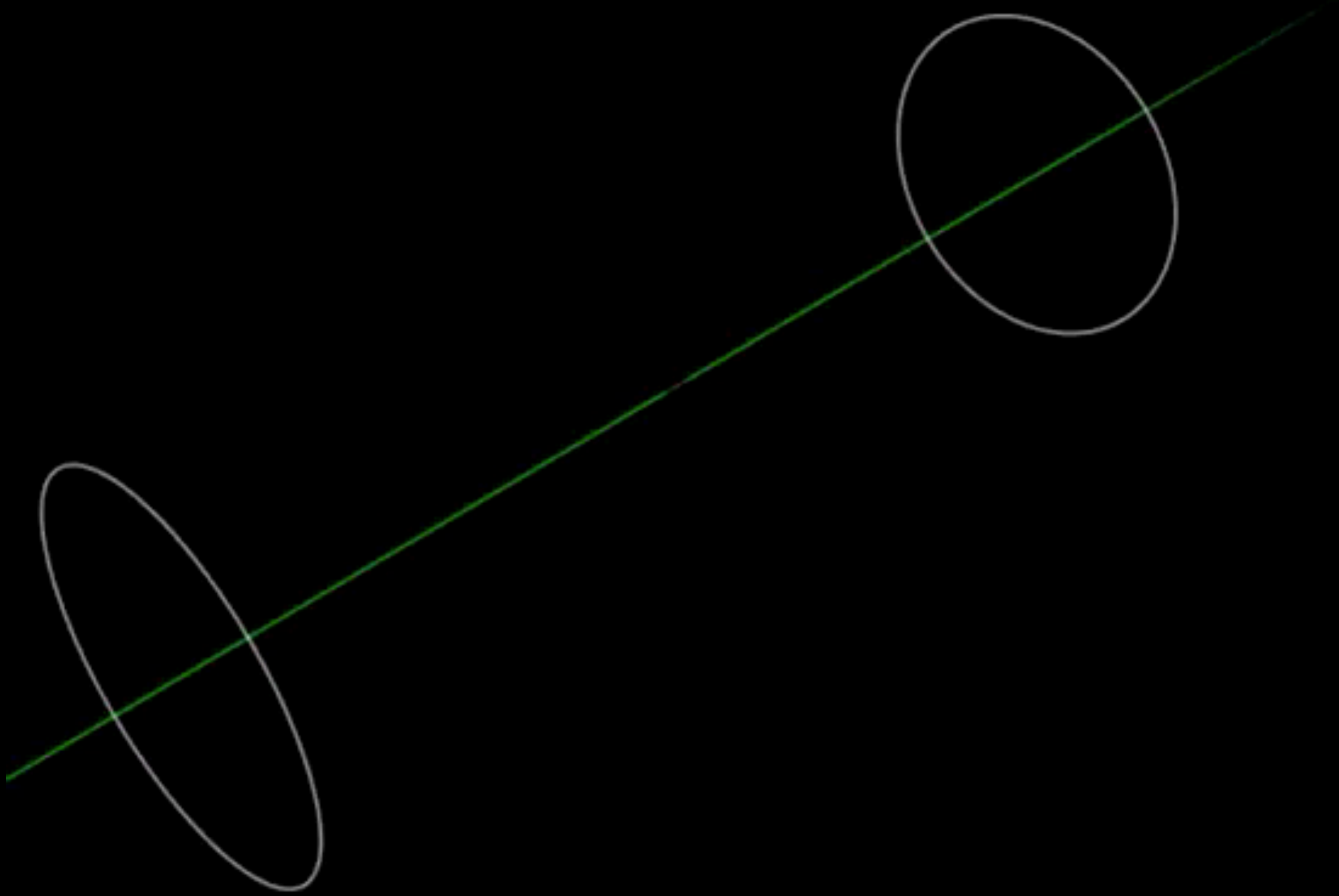
Time: 0.0 ns

Phi: 0.798954



Time: 0.0 ns

Phi: 0.798954



Time: 0.0 ns

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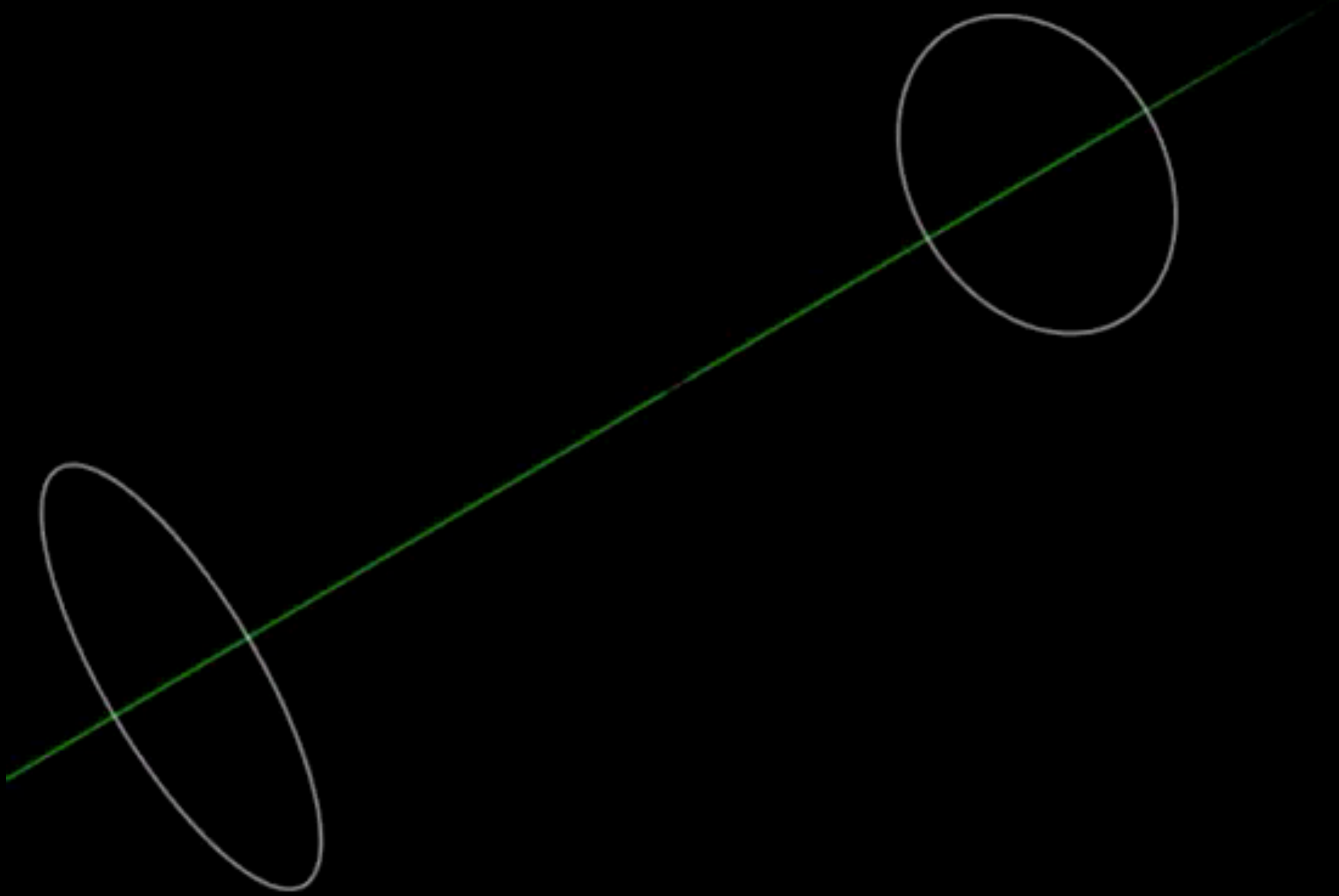
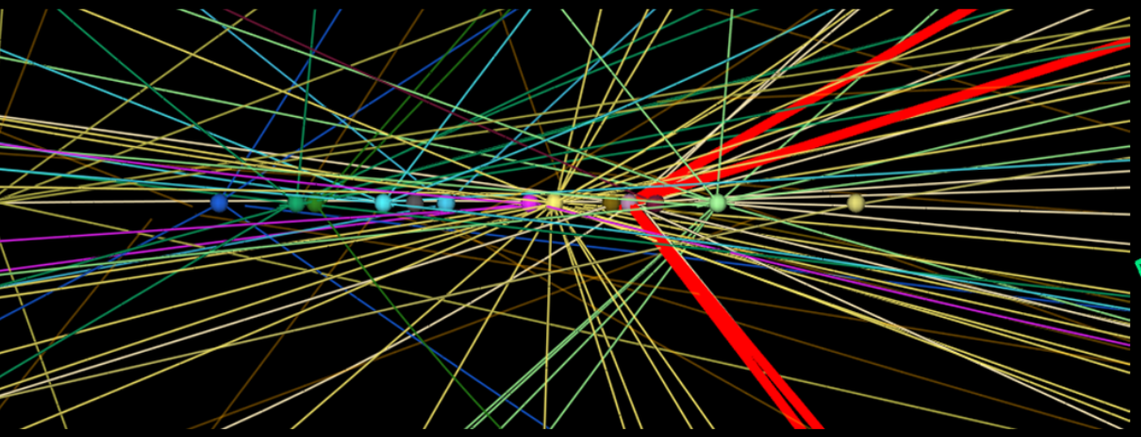
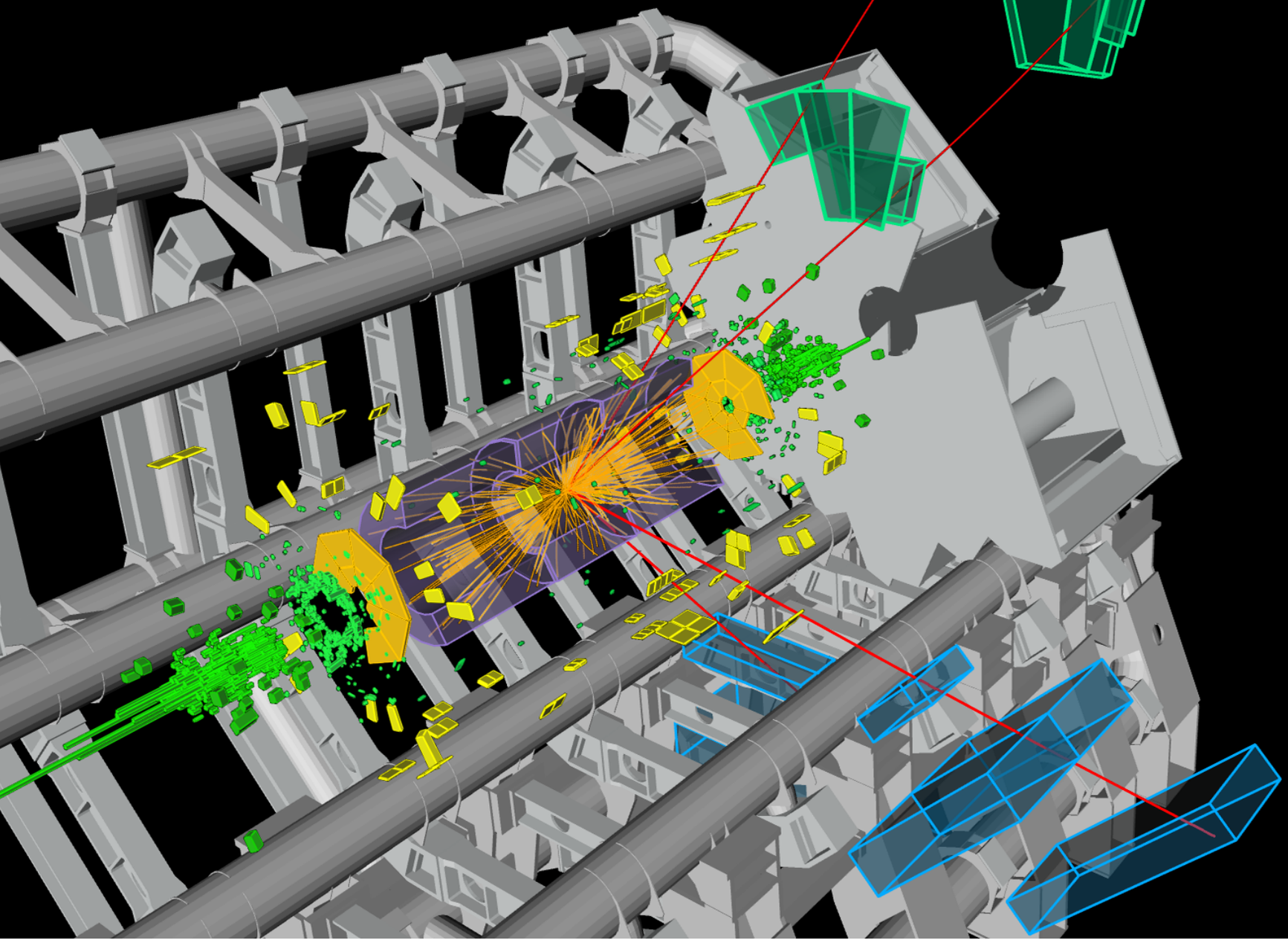
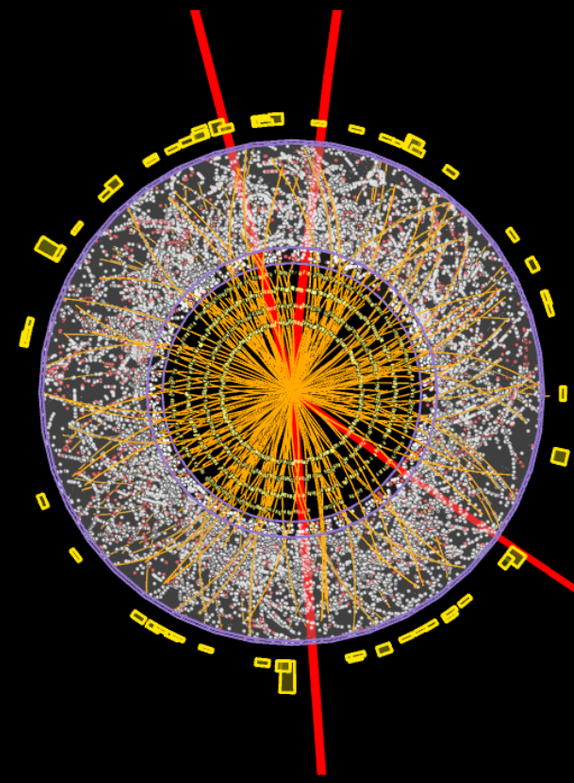








ATLAS EXPERIMENT
http://atlas.ch

Run: 204769
Event: 71902630
Date: 2012-06-10
Time: 13:24:31 CEST

Per quanto vivono le particelle?

TABLE 32–2 Particles (selected)†

Category	Forces involved	Particle name	Symbol	Anti-particle	Spin	Mass (MeV/c^2)	B	L_e	L_μ	L_τ	S	Mean life (s)	Principal Decay Modes
							[antiparticles have opposite sign]						
Fundamental													
Gauge bosons (force carriers)	str	Gluons	g	Self	1	0	0	0	0	0	0	Stable	
	em	Photon	γ	Self	1	0	0	0	0	0	0	Stable	
	w, em	W	W^+	W^-	1	80.385×10^3	0	0	0	0	0	3×10^{-25}	$e\nu_e$, $\mu\nu_\mu$, $\tau\nu_\tau$, hadrons
	w	Z	Z^0	Self	1	91.19×10^3	0	0	0	0	0	3×10^{-25}	e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, hadrons
Higgs boson	w, str	Higgs	H^0	Self	0	125×10^3	0	0	0	0	0	1.6×10^{-22}	$b\bar{b}$, Z^0Z^0, W^+W^-, $g\bar{g}$, $\tau\bar{\tau}$, $\gamma\gamma$
Leptons	w, em‡	Electron	e^-	e^+	$\frac{1}{2}$	0.511	0	+1	0	0	0	Stable	
		Neutrino (e)	ν_e	$\bar{\nu}_e$	$\frac{1}{2}$	0 ($<0.14\ eV/c^2$)‡	0	+1	0	0	0	Stable	
		Muon	μ^-	μ^+	$\frac{1}{2}$	105.7	0	0	+1	0	0	2.20×10^{-6}	$e^-\bar{\nu}_e\nu_\mu$
		Neutrino (μ)	ν_μ	$\bar{\nu}_\mu$	$\frac{1}{2}$	0 ($<0.14\ eV/c^2$)‡	0	0	+1	0	0	Stable	
		Tau	τ^-	τ^+	$\frac{1}{2}$	1777	0	0	0	+1	0	2.91×10^{-13}	$\mu^-\bar{\nu}_\mu\nu_\tau$, $e^-\bar{\nu}_e\nu_\tau$, hadrons $+\nu_\tau$
		Neutrino (τ)	ν_τ	$\bar{\nu}_\tau$	$\frac{1}{2}$	0 ($<0.14\ eV/c^2$)‡	0	0	0	+1	0	Stable	
Quarks	w, em, str	(see Table 32–3)											
Hadrons (composite), selected													
Mesons (quark–antiquark)	str, em, w	Pion	π^+	π^-	0	139.6	0	0	0	0	0	2.60×10^{-8}	$\mu^+\nu_\mu$
			π^0	Self	0	135.0	0	0	0	0	0	0.85×10^{-16}	2γ
		Kaon	K^+	K^-	0	493.7	0	0	0	0	+1	1.24×10^{-8}	$\mu^+\nu_\mu$, $\pi^+\pi^0$
			K^0_S	$\overline{K}^0_S$	0	497.6	0	0	0	0	+1	0.895×10^{-10}	$\pi^+\pi^-$, $2\pi^0$
			K^0_L	$\overline{K}^0_L$	0	497.6	0	0	0	0	+1	5.12×10^{-8}	$\pi^\pm e^\mp \overline{\nu}_e$, $\pi^\pm \mu^\mp \overline{\nu}_\mu$, 3π
		Eta	η^0	Self	0	547.9	0	0	0	0	0	5.1×10^{-19}	2γ, $3\pi^0$, $\pi^+\pi^-\pi^0$
		Rho	ρ^0	Self	1	775	0	0	0	0	0	4.4×10^{-24}	$\pi^+\pi^-$, $2\pi^0$
			ρ^+	ρ^-	1	775	0	0	0	0	0	4.4×10^{-24}	$\pi^+\pi^0$
		and others											
Baryons (3 quarks)	str, em, w	Proton	p	$\bar{p}$	$\frac{1}{2}$	938.3	+1	0	0	0	0	Stable	
		Neutron	n	$\bar{n}$	$\frac{1}{2}$	939.6	+1	0	0	0	0	882	$pe^-\bar{\nu}_e$
		Lambda	Λ^0	$\overline{\Lambda}^0$	$\frac{1}{2}$	1115.7	+1	0	0	0	−1	2.63×10^{-10}	$p\pi^-$, $n\pi^0$
		Sigma	Σ^+	$\overline{\Sigma}^-$	$\frac{1}{2}$	1189.4	+1	0	0	0	−1	0.80×10^{-10}	$p\pi^0$, $n\pi^+$
			Σ^0	$\overline{\Sigma}^0$	$\frac{1}{2}$	1192.6	+1	0	0	0	−1	7.4×10^{-20}	$\Lambda^0\gamma$
			Σ^-	$\overline{\Sigma}^+$	$\frac{1}{2}$	1197.4	+1	0	0	0	−1	1.48×10^{-10}	$n\pi^-$
		Xi	Ξ^0	$\overline{\Xi}^0$	$\frac{1}{2}$	1314.9	+1	0	0	0	−2	2.90×10^{-10}	$\Lambda^0\pi^0$
			Ξ^-	$\overline{\Xi}^+$	$\frac{1}{2}$	1321.7	+1	0	0	0	−2	1.64×10^{-10}	$\Lambda^0\pi^-$
		Omega	Ω^-	Ω^+	$\frac{3}{2}$	1672.5	+1	0	0	0	−3	0.82×10^{-10}	$\Xi^0\pi^-$, Λ^0K^-, $\Xi^-\pi^0$
		and others											

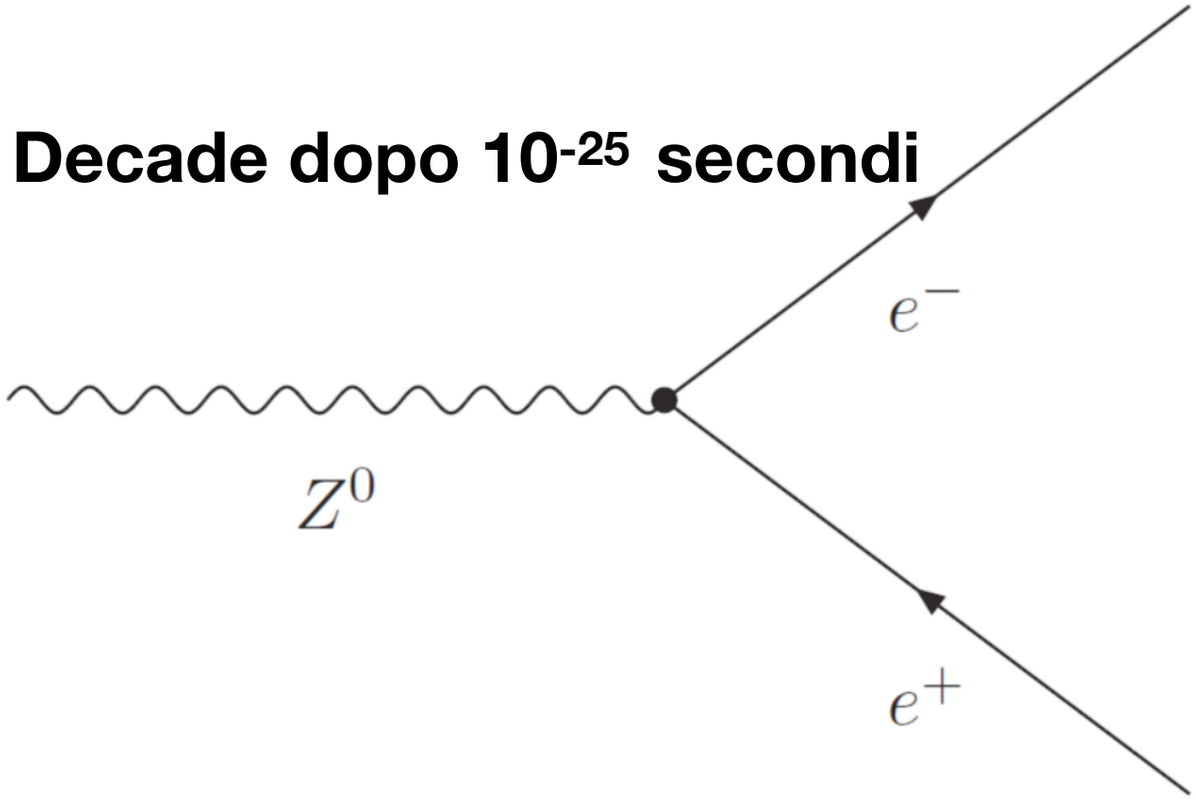
Per quanto vivono le particelle?

TABLE 32–2 Particles (selected)†

Category	Forces involved	Particle name	Symbol	Anti-particle	Spin	Mass (MeV/c^2)	B	L_e	L_μ	L_τ	S	Mean life (s)	Principal Decay Modes
[antiparticles have opposite sign]													
Fundamental													
Gauge bosons (force carriers)	str	Gluons	g	Self	1	0	0	0	0	0	0	Stable	
	em	Photon	γ	Self	1	0	0	0	0	0	0	Stable	
	w, em	W	W^+	W^-	1	80.385×10^3	0	0	0	0	0	3×10^{-25}	$e\nu_e$, $\mu\nu_\mu$, $\tau\nu_\tau$, hadrons
	w	Z	Z^0	Self	1	91.19×10^3	0	0	0	0	0	3×10^{-25}	e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, hadrons
Higgs boson	w, str	Higgs	H^0	Self	0	125×10^3	0	0	0	0	0	1.6×10^{-22}	$b\bar{b}$, Z^0Z^0, W^+W^-, $g\bar{g}$, $\tau\bar{\tau}$, $\gamma\gamma$
Leptons	w, em‡	Electron	e^-	e^+	$\frac{1}{2}$	0.511	0	+1	0	0	0	Stable	
		Neutrino (e)	ν_e	$\bar{\nu}_e$	$\frac{1}{2}$	0 (<0.14 eV/c^2)‡	0	+1	0	0	0	Stable	
		Muon	μ^-	μ^+	$\frac{1}{2}$	105.7	0	0	+1	0	0	2.20×10^{-6}	$e^-\bar{\nu}_e\nu_\mu$
		Neutrino (μ)	ν_μ	$\bar{\nu}_\mu$	$\frac{1}{2}$	0 (<0.14 eV/c^2)‡	0	0	+1	0	0	Stable	
		Tau	τ^-	τ^+	$\frac{1}{2}$	1777	0	0	0	+1	0	2.91×10^{-13}	$\mu^-\bar{\nu}_\mu\nu_\tau$, $e^-\bar{\nu}_e\nu_\tau$, hadrons $+\nu_\tau$
		Neutrino (τ)	ν_τ	$\bar{\nu}_\tau$	$\frac{1}{2}$	0 (<0.14 eV/c^2)‡	0	0	0	+1	0	Stable	
Quarks	w, em, str	(see Table 32–3)											
Hadrons (composite), selected													
Mesons (quark–antiquark)	str, em, w	Pion	π^+	π^-	0	139.6	0	0	0	0	0	2.60×10^{-8}	$\mu^+\nu_\mu$
			π^0	Self	0	135.0	0	0	0	0	0	0.85×10^{-16}	2γ
		Kaon	K^+	K^-	0	493.7	0	0	0	0	+1	1.24×10^{-8}	$\mu^+\nu_\mu$, $\pi^+\pi^0$
			K^0_S	$\overline{K}^0_S$	0	497.6	0	0	0	0	+1	0.895×10^{-10}	$\pi^+\pi^-$, $2\pi^0$
			K^0_L	$\overline{K}^0_L$	0	497.6	0	0	0	0	+1	5.12×10^{-8}	$\pi^\pm e^\mp \overset{(-)}{\nu}_e$, $\pi^\pm \mu^\mp \overset{(-)}{\nu}_\mu$, 3π
		Eta	η^0	Self	0	547.9	0	0	0	0	0	5.1×10^{-19}	2γ, $3\pi^0$, $\pi^+\pi^-\pi^0$
		Rho	ρ^0	Self	1	775	0	0	0	0	0	4.4×10^{-24}	$\pi^+\pi^-$, $2\pi^0$
			ρ^+	ρ^-	1	775	0	0	0	0	0	4.4×10^{-24}	$\pi^+\pi^0$
		and others											
Baryons (3 quarks)	str, em, w	Proton	p	$\bar{p}$	$\frac{1}{2}$	938.3	+1	0	0	0	0	Stable	
		Neutron	n	$\bar{n}$	$\frac{1}{2}$	939.6	+1	0	0	0	0	882	$pe^-\bar{\nu}_e$
		Lambda	Λ^0	$\overline{\Lambda}^0$	$\frac{1}{2}$	1115.7	+1	0	0	0	−1	2.63×10^{-10}	$p\pi^-$, $n\pi^0$
		Sigma	Σ^+	$\overline{\Sigma}^-$	$\frac{1}{2}$	1189.4	+1	0	0	0	−1	0.80×10^{-10}	$p\pi^0$, $n\pi^+$
			Σ^0	$\overline{\Sigma}^0$	$\frac{1}{2}$	1192.6	+1	0	0	0	−1	7.4×10^{-20}	$\Lambda^0\gamma$
			Σ^-	$\overline{\Sigma}^+$	$\frac{1}{2}$	1197.4	+1	0	0	0	−1	1.48×10^{-10}	$n\pi^-$
		Xi	Ξ^0	$\overline{\Xi}^0$	$\frac{1}{2}$	1314.9	+1	0	0	0	−2	2.90×10^{-10}	$\Lambda^0\pi^0$
			Ξ^-	$\overline{\Xi}^+$	$\frac{1}{2}$	1321.7	+1	0	0	0	−2	1.64×10^{-10}	$\Lambda^0\pi^-$
		Omega	Ω^-	Ω^+	$\frac{3}{2}$	1672.5	+1	0	0	0	−3	0.82×10^{-10}	$\Xi^0\pi^-$, Λ^0K^-, $\Xi^-\pi^0$
		and others											

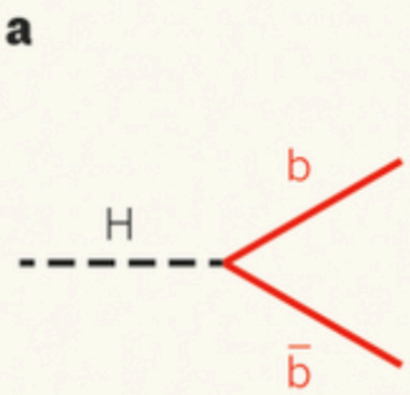
Modi di decadimento del bosone Z

Decade dopo 10^{-25} secondi



hadronic	leptonic	
	visible	invisible
$Z^\circ \to q\bar{q}$	$Z^\circ \to e^+e^-$	$Z^\circ \to \nu\bar{\nu}$
	$Z^\circ \to \mu^+\mu^-$	
	$Z^\circ \to \tau^+\tau^-$	

Modi di decadimento del bosone H



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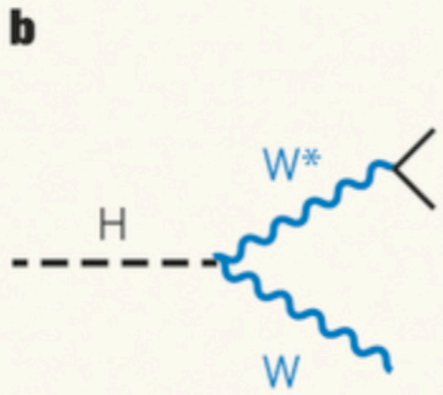

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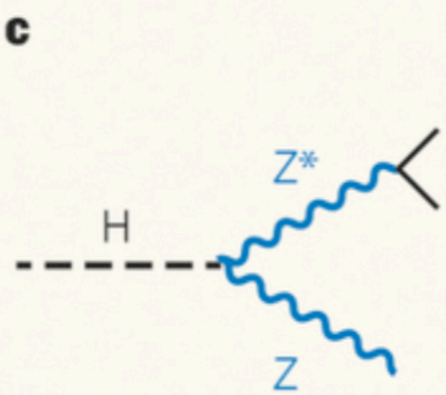
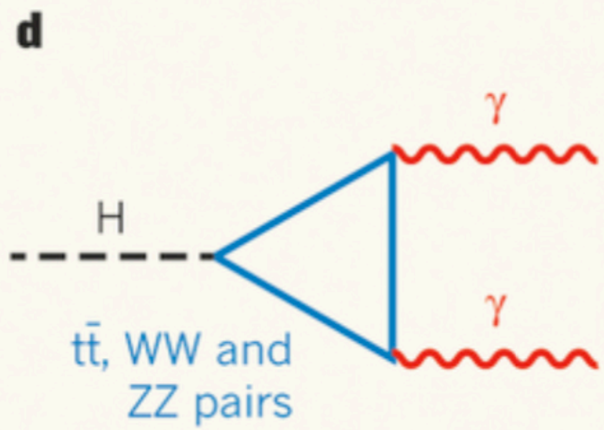


2.6%

Decade dopo 10^{-22} secondi



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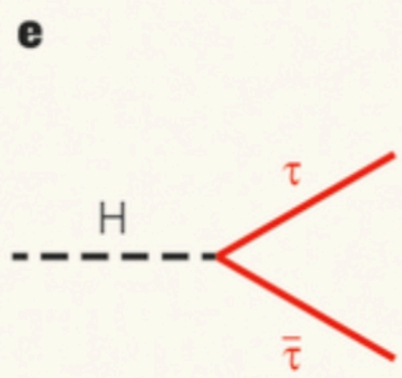
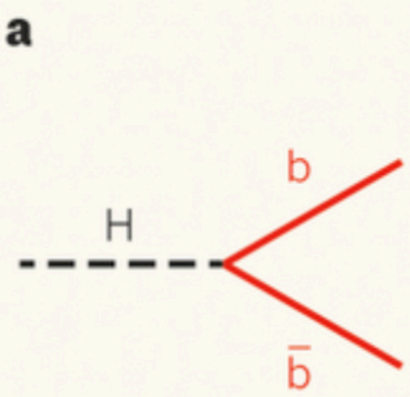
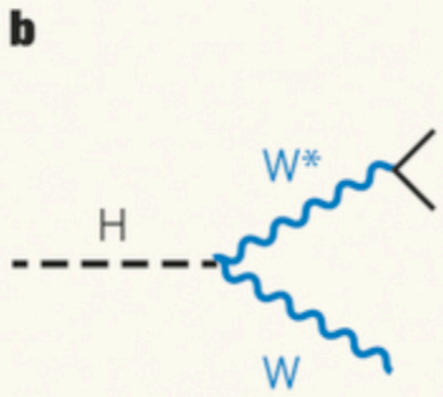


6.3%

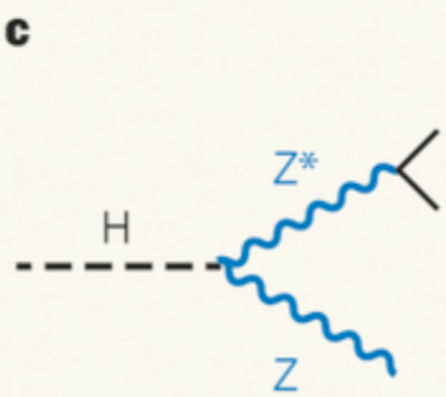
Modi di decadimento del bosone H



57.7%

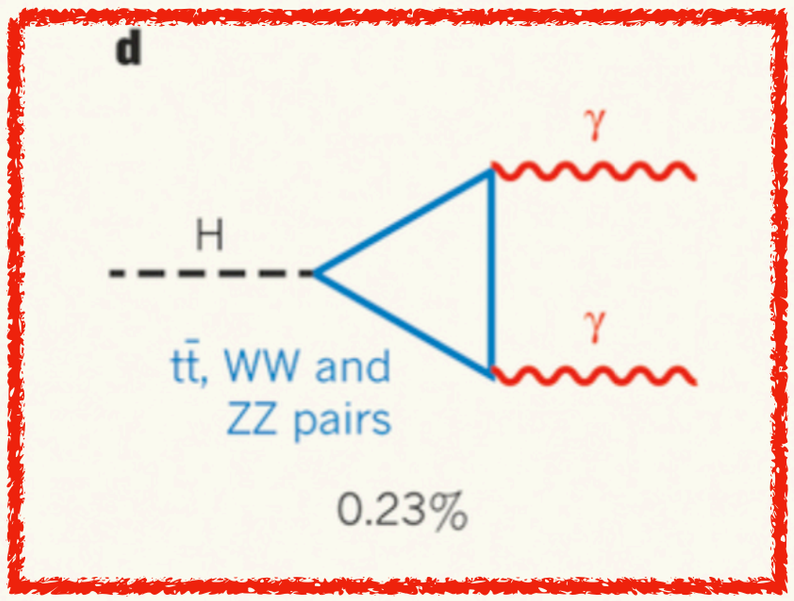


21.5%



2.6%

Decade dopo 10^{-22} secondi



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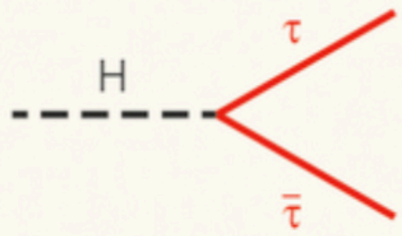
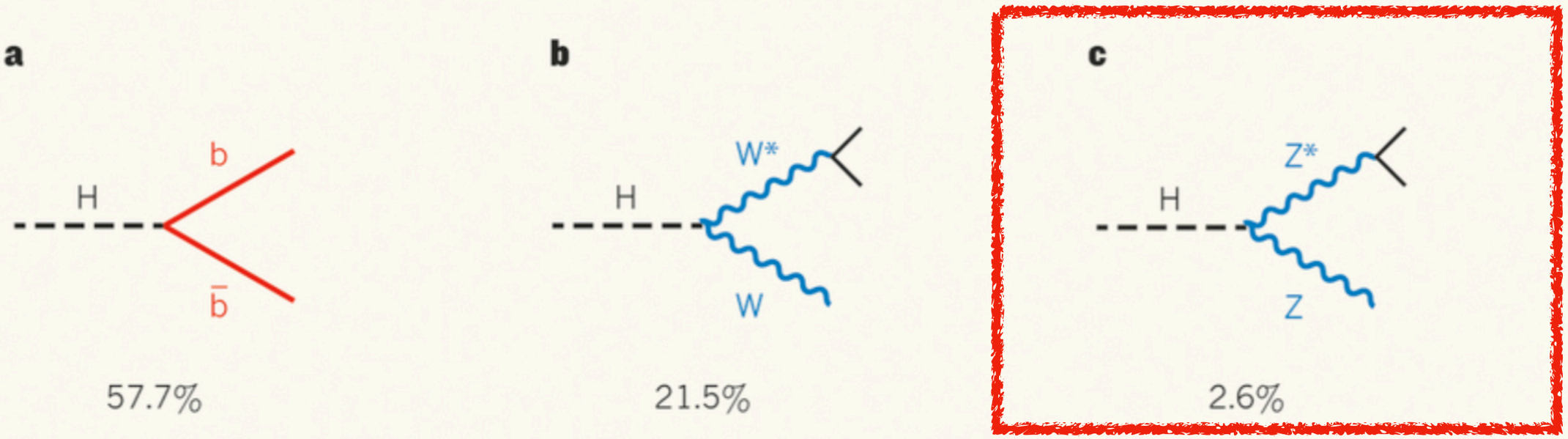
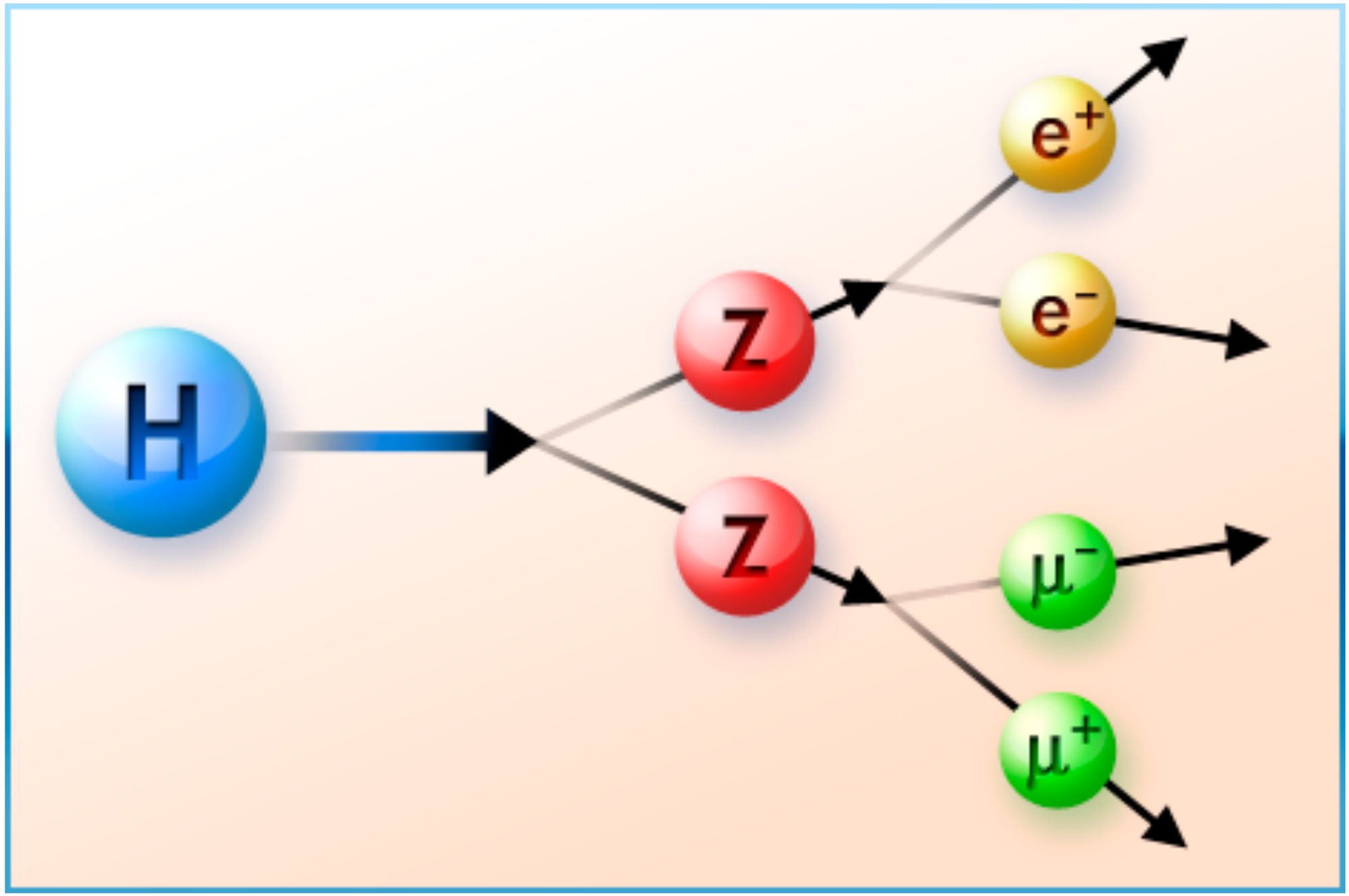


6.3%

Modi di decadimento del bosone H

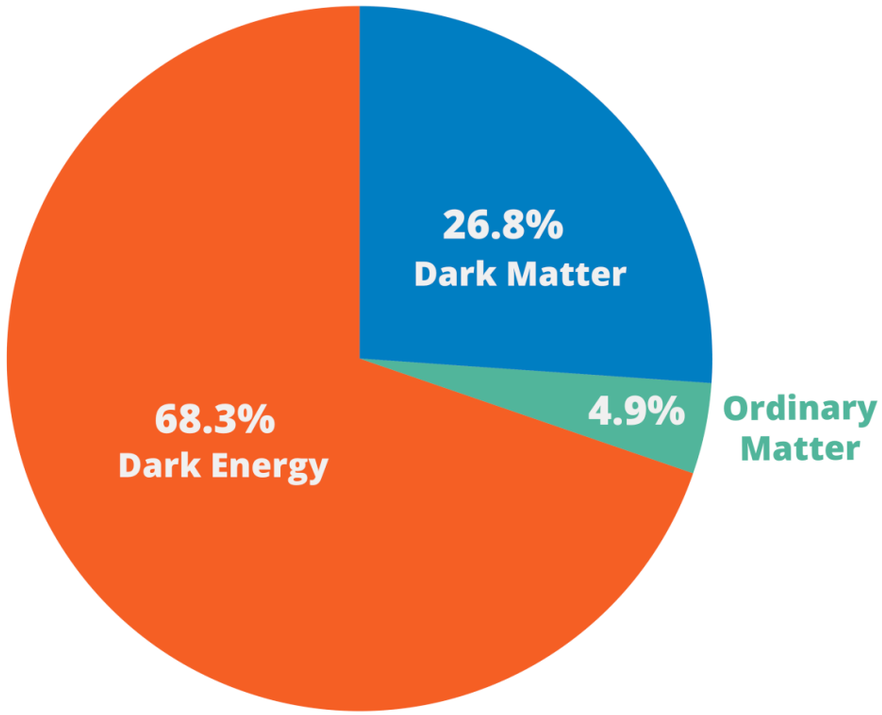


Modi di decadimento del bosone H



C’è ancora tanto da fare…

https://en.wikipedia.org/wiki/List_of_unsolved_problems_in_physics



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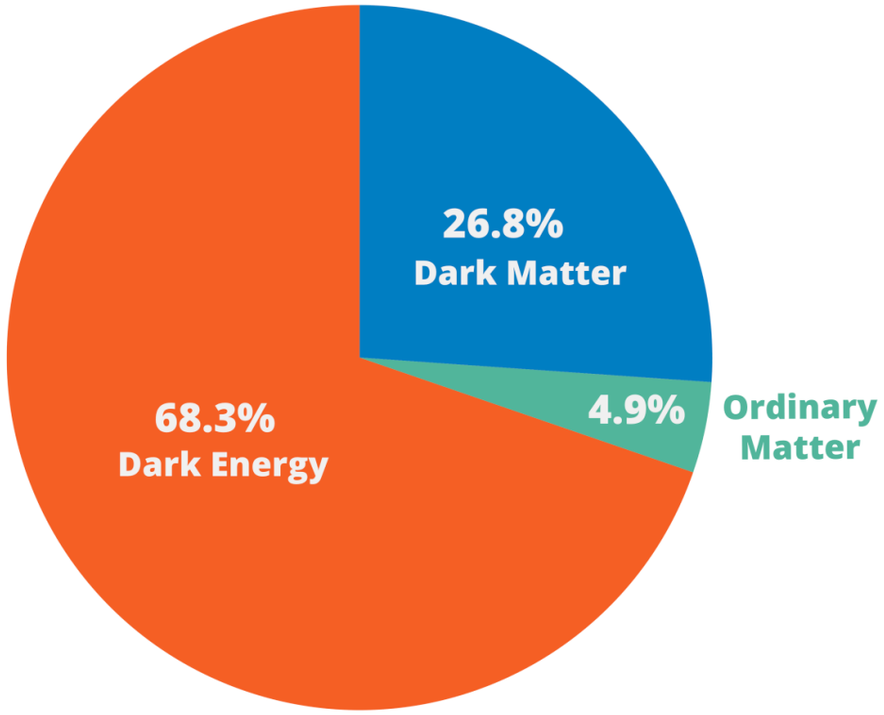

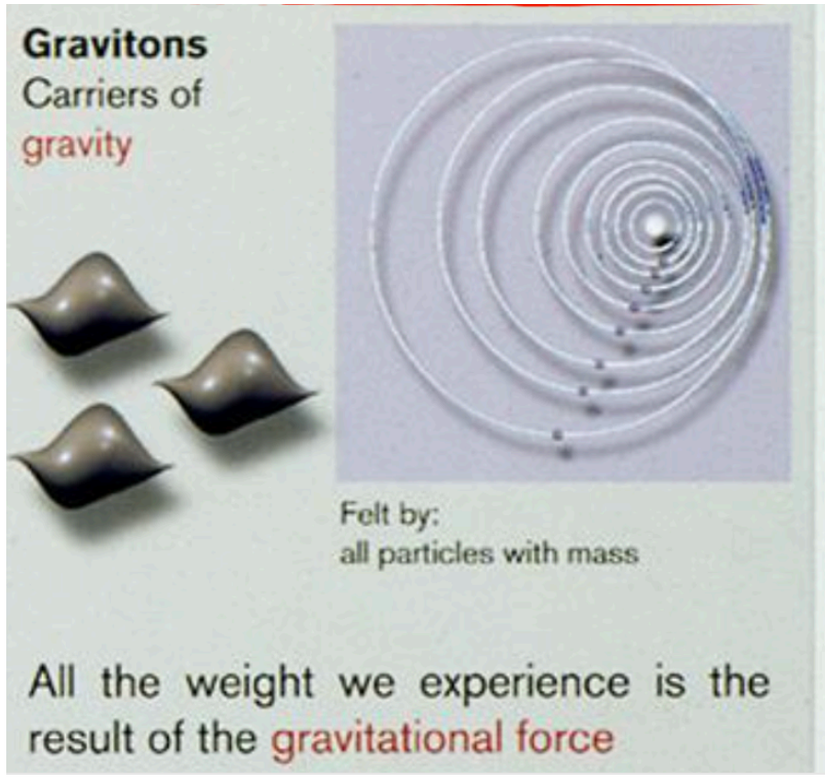

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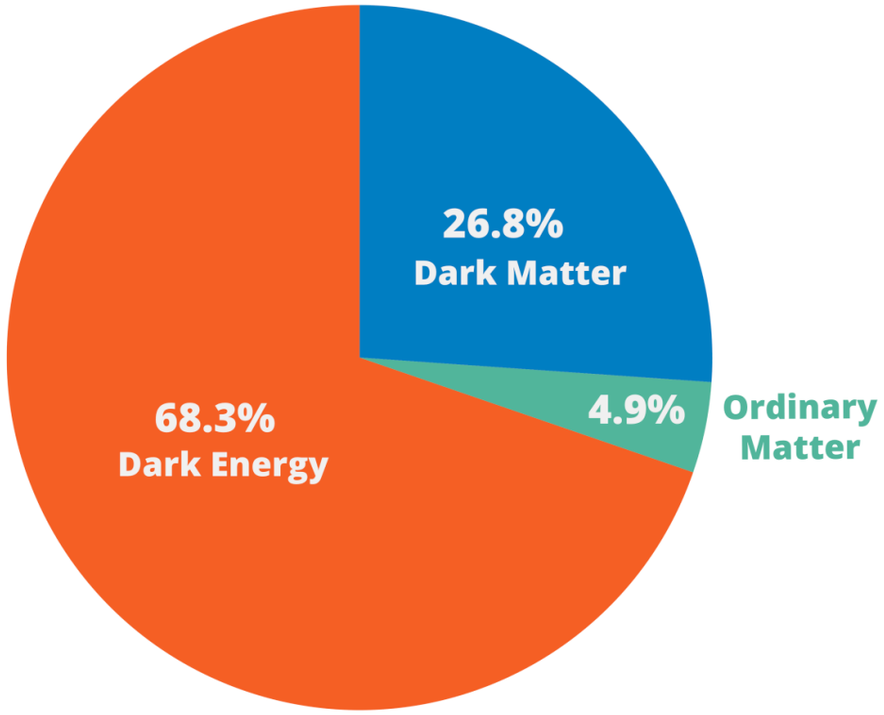

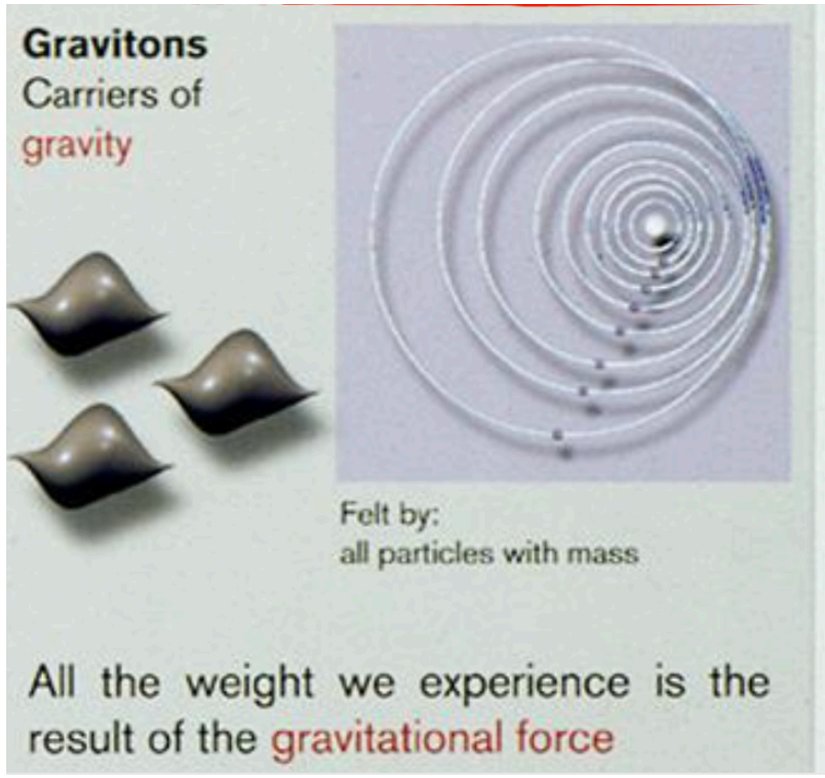

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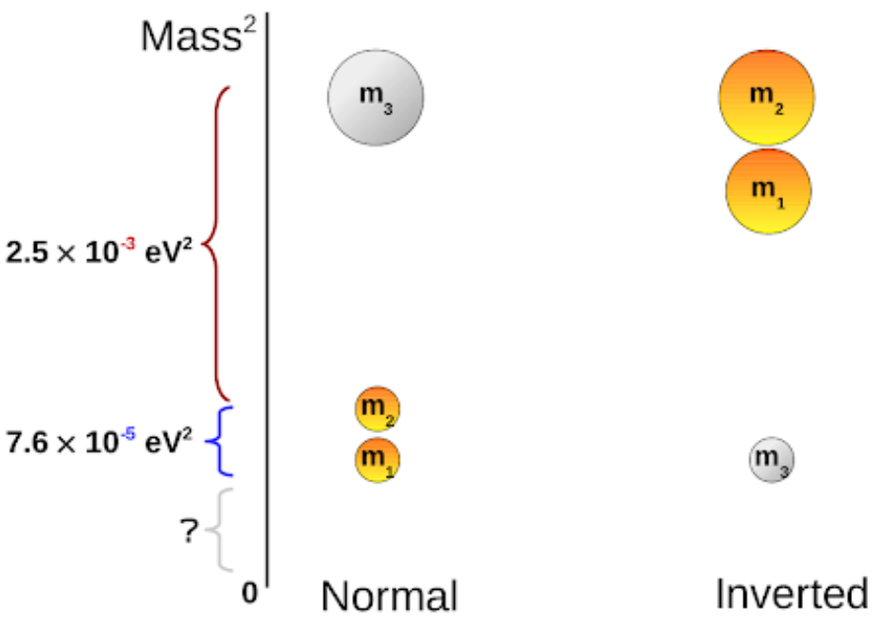

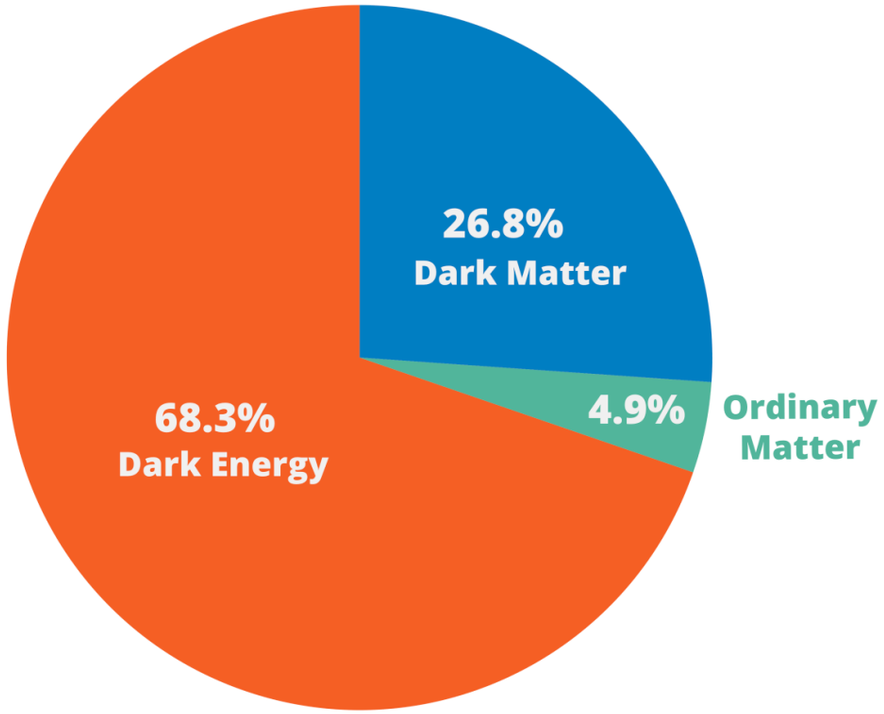

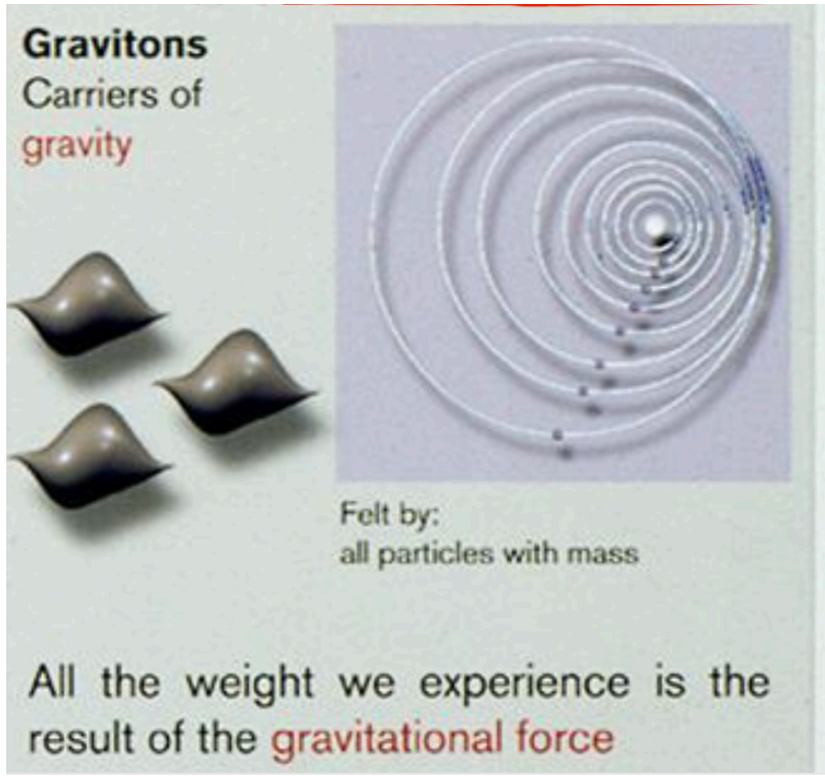

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