

# *Interazioni fondamentali*

## *note ed ignote*

*Progetto Art & Science*

Liceo Scientifico Augusto Righi

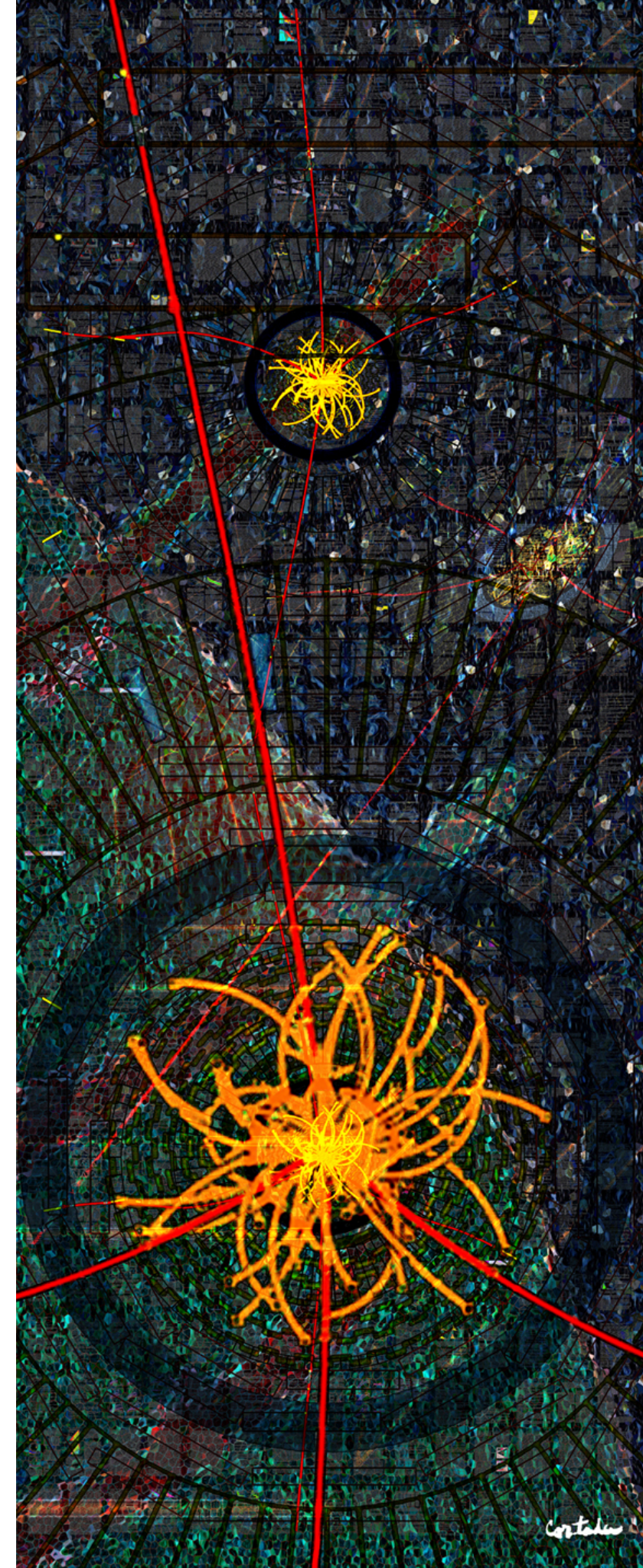
11 Feb 2019



**SAPIENZA**  
UNIVERSITÀ DI ROMA



Istituto Nazionale di Fisica Nucleare



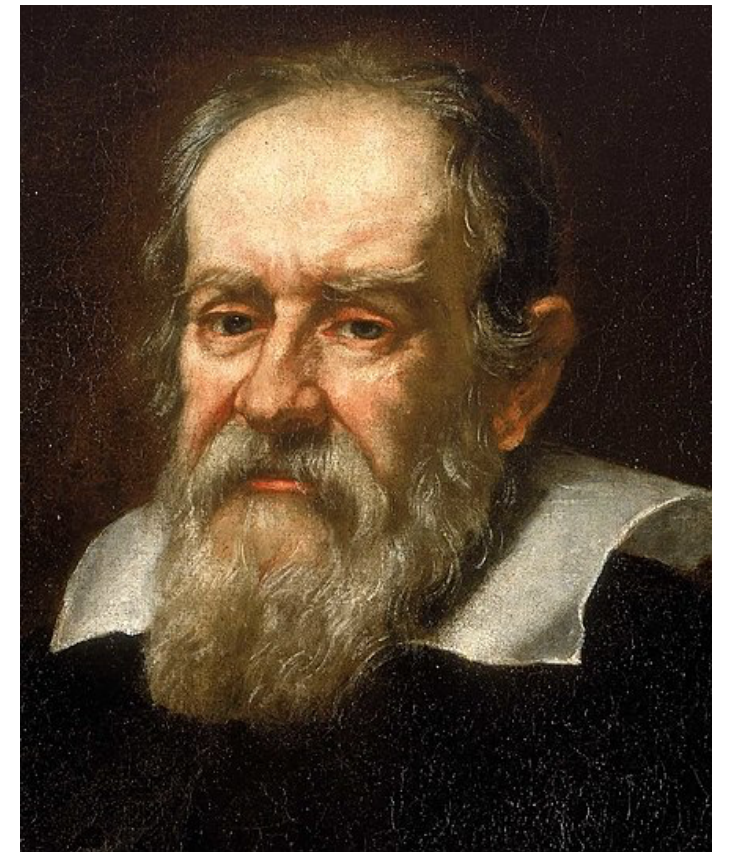
# Di Cosa parliamo oggi?

- ▷ Cosa intendiamo per Interazione?
  - Legame tra forza ed interazione
- ▷ Interazioni nella Fisica oggi
- ▷ Possono esserci nuovi tipi di Interazione?
  - Come possiamo cercarli?
- ▷ Esperimenti per verificare le teorie esistenti e cercare qualcosa di nuovo e esotico



# Fisica

- ▷ Studio della Natura e delle **interazioni** che governano i fenomeni
- ▷ Galileo fu artefice del metodo scientifico tuttora in uso oggi in tutti i campi scientifici
  - Osservare **fenomeni** in Natura con esperimenti
  - fare **ipotesi** sulle leggi che descrivono il fenomeno usando la matematica come il linguaggio (modello)
  - Fare **predizioni** quantitative
  - Verificare le predizioni con **esperimenti**
  - Se predizioni sono corrette il modello diventa una **teoria**
  - Cercare di **falsificare** la teoria con nuovi esperimenti sfruttando l'avanzamento tecnologico degli strumenti



Secolo XVI

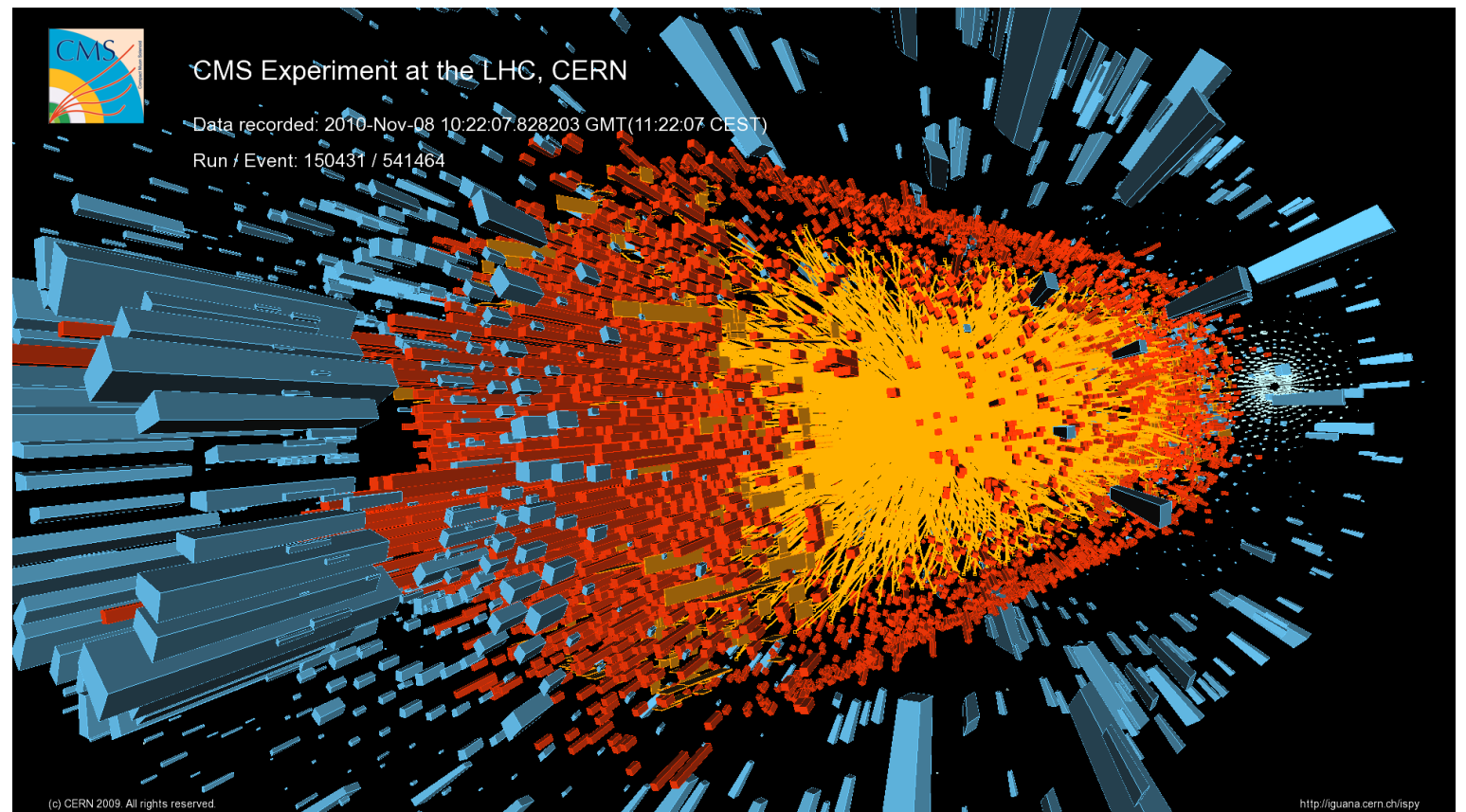
# Interazione

## interazione

/in·te·ra·zió·ne/

*sostantivo femminile*

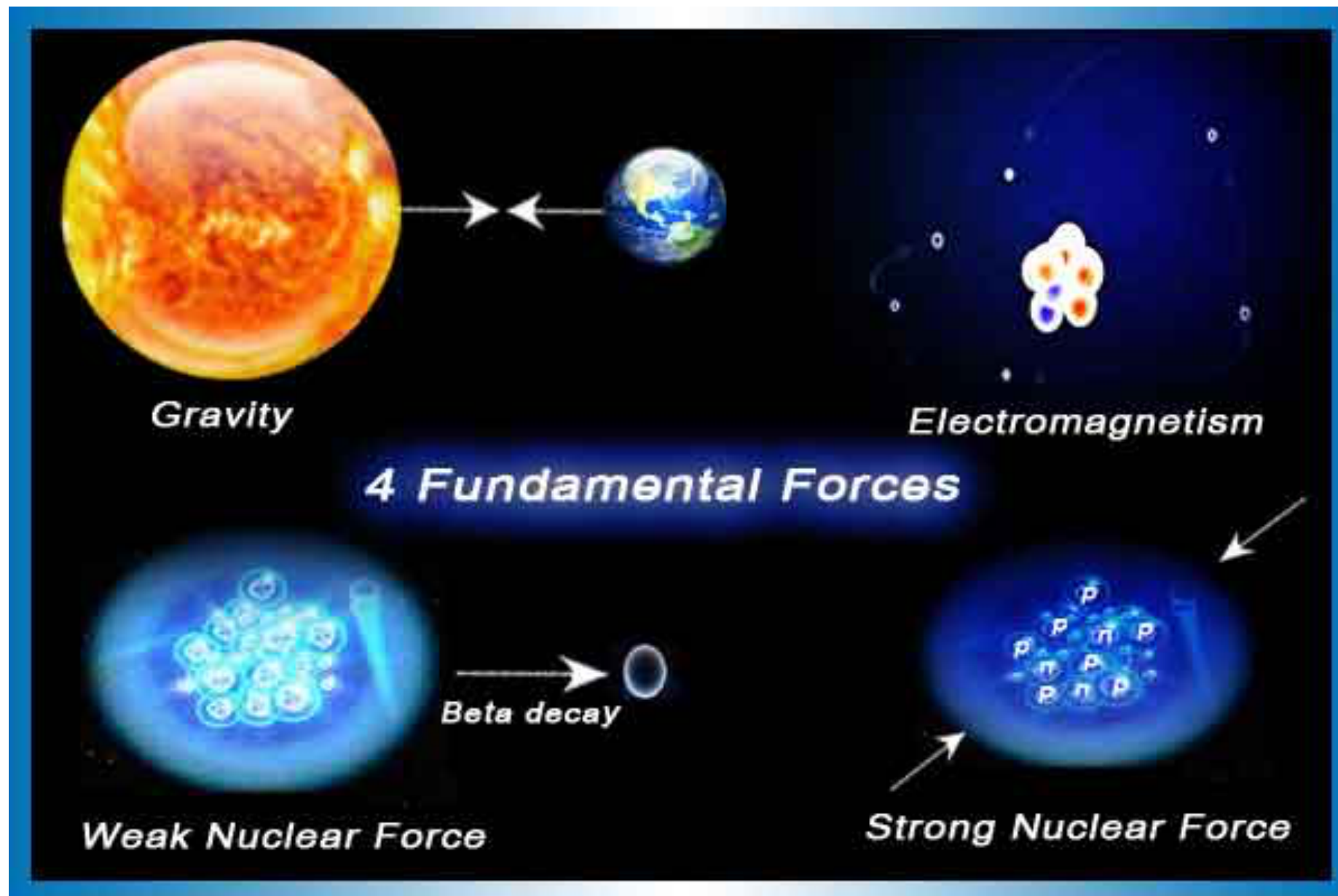
1. Reciproca influenza o azione e reazione di persone, fatti, fenomeni, sostanze.  
"i. farmacologica"
2. In fisica, ogni reciproca azione fra particelle, corpi o sistemi, che porta a una modifica del loro stato e della loro energia.





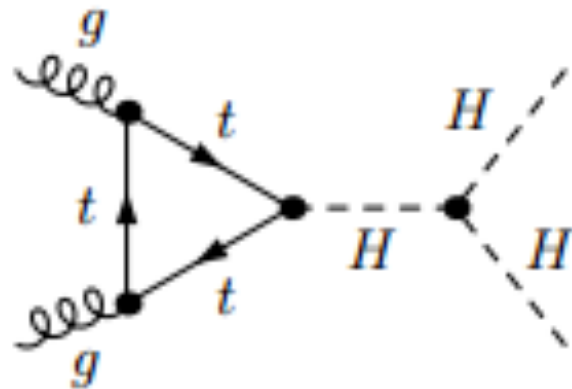
# Interazioni fondamentali

- ▷ Oggi ne conosciamo quattro tipi
  - Interazione Gravitazionale (1600)
  - Interazione Elettromagnetica (1800)
  - Interazione Debole (1900)
  - Interazione Forte (1900)



# Nuove Interazioni?

- ▷ Nel 2012 la scoperta del bosone di Higgs ha messo in luce un nuovo tipo di interazione tra i bosoni di Higgs



- ▷ Non sappiamo ancora come interagisca la Materia oscura
- ▷ Siamo anche alla costante ricerca di nuovi tipi di interazione



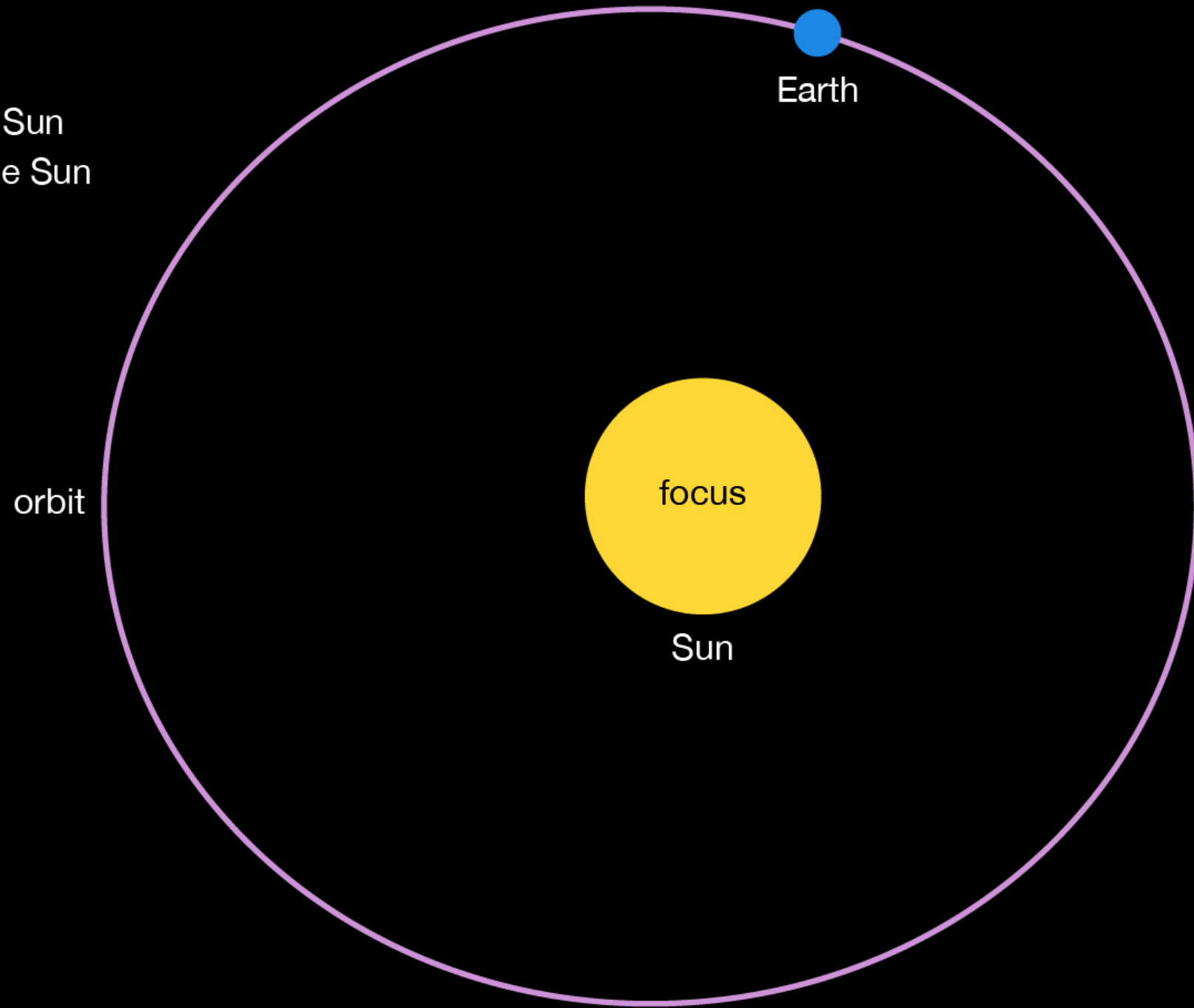
Gravita`

# I legge di Keplero

## Kepler's laws of planetary motion

### First law

All planets move about the Sun in elliptical orbits, having the Sun as one of the foci.



© Encyclopædia Britannica, Inc.

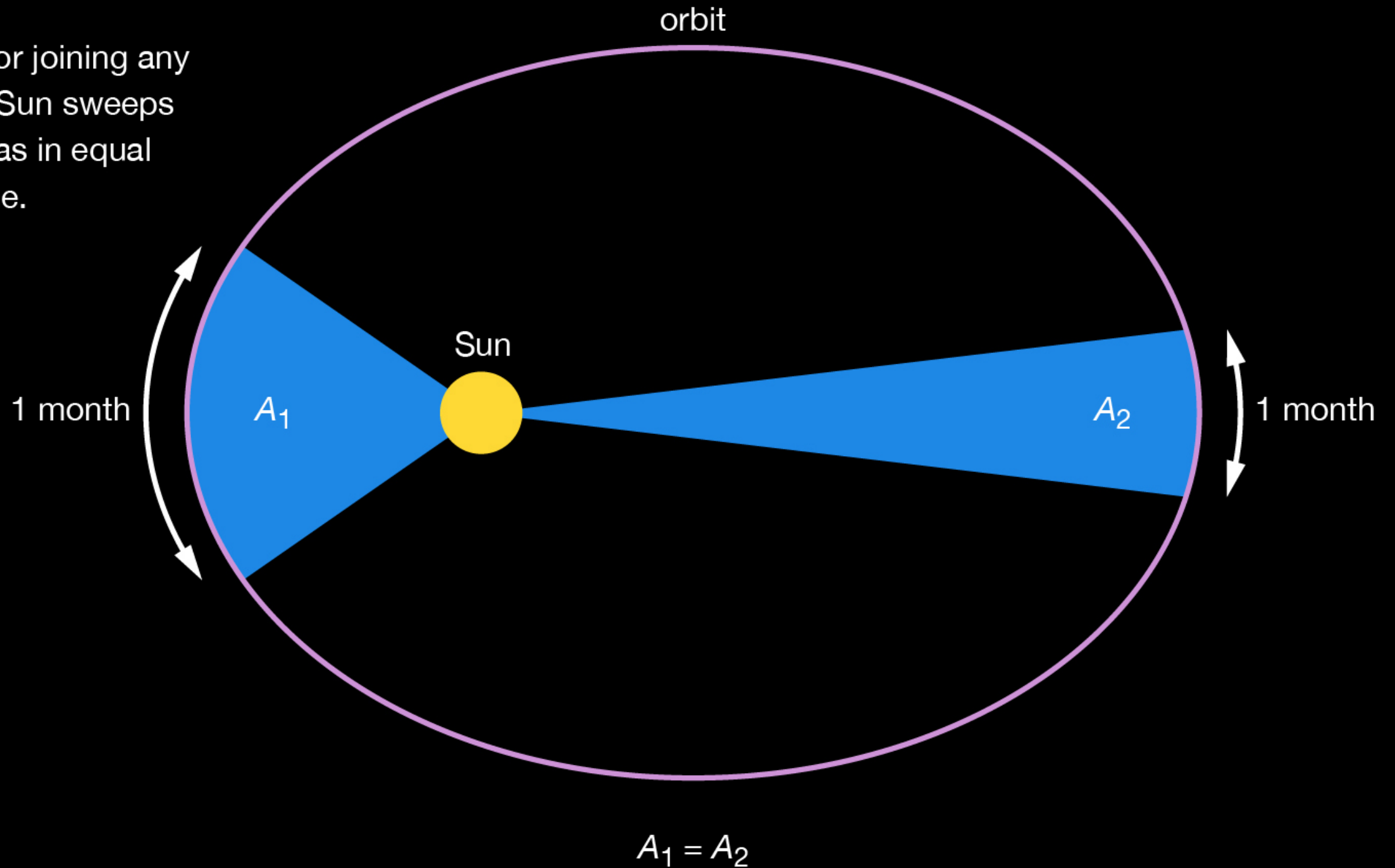


# Il legge di Keplero

## Kepler's laws of planetary motion

### Second law

A radius vector joining any planet to the Sun sweeps out equal areas in equal lengths of time.



# III legge di Keplero

## Kepler's laws of planetary motion

### Third law

The squares of the sidereal periods ( $P$ ) of the planets are directly proportional to the cubes of their mean distances ( $d$ ) from the Sun.

$$P \times P = k (d \times d \times d)$$

$$P^2 = kd^3$$

$$\frac{P^2}{d^3} = k$$

where  $k$  is a constant

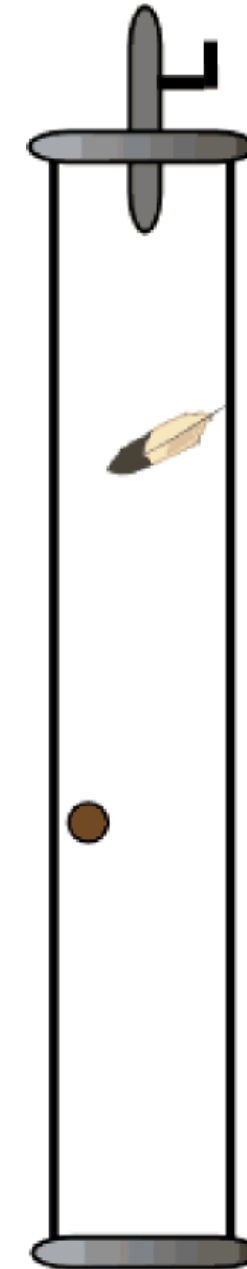
planet	period ( $P$ , year)	period squared	mean distance ( $d$ , AU)	mean distance cubed	$P^2/d^3$
Mercury	0.24	0.06	0.39	0.06	0.99
Venus	0.62	0.38	0.72	0.38	1.02
Earth	1.00	1.00	1.00	1.00	1.00
Mars	1.88	3.53	1.52	3.51	1.01
Jupiter	11.86	140.66	5.20	140.61	1.00
Saturn	29.46	867.89	9.58	879.22	0.99
Uranus	84.01	7057.68	19.20	7077.89	1.00
Neptune	164.80	27159.04	30.10	27270.90	1.00



# Esperimento di Galileo



Nell'aria



Nel vuoto





# La mela di Newton



Painting by Nasir



# Gravitazione

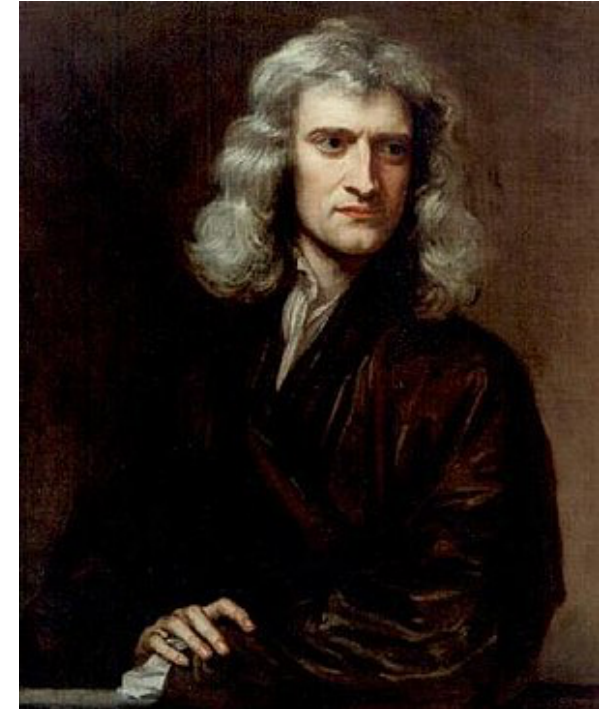
$$F = G \frac{m_1 m_2}{r^2}$$

$$G = 6.67 \times 10^{-11} \frac{Nm^2}{kg^2}$$

$$M_{terra} = 5972 \times 10^{24} kg$$

$$M_{sole} = 1989 \times 10^{30} kg$$

$$r = 150 \times 10^6 km$$



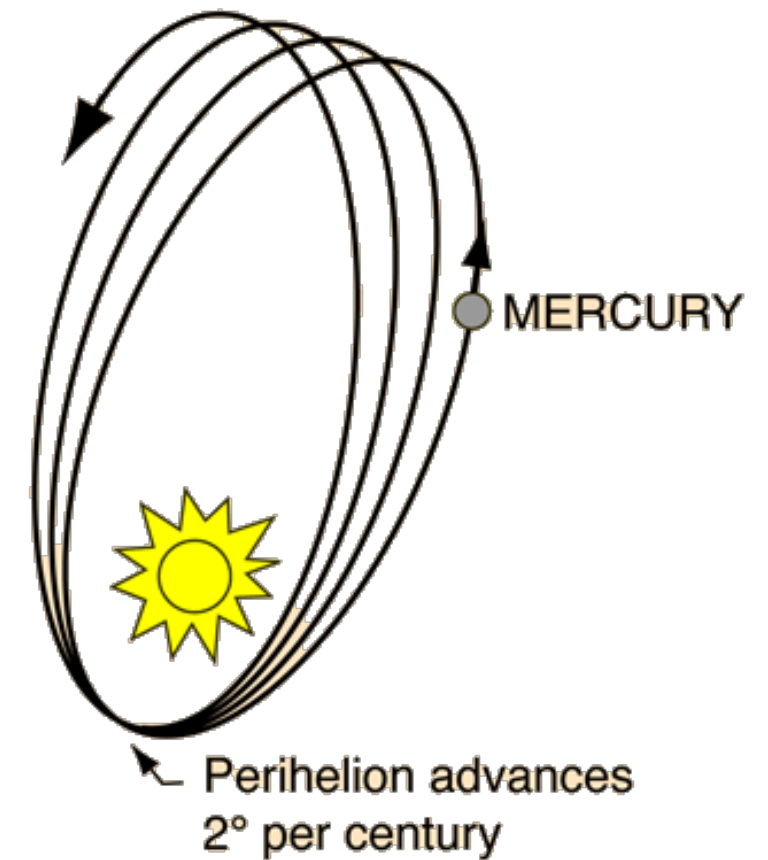
Secolo XVII

- ▷ La legge di gravitazione mette insieme la descrizione della caduta dei gravi sulla terra e il moto dei pianeti nel cielo
- ▷ Successo di Newton nel predire l'esistenza di Nettuno osservando il moto di Urano
  - Forze dei pianeti esistenti non era sufficienti per spiegare le modifiche all'orbita di Urano



# Relativita` Generale

- ▷ Discrepanze nell'orbita di Mercurio furono osservate verso la fine del 1800
  - Nessun nuovo pianeta tra Mercurio e il Sole
- ▷ Effetto fu spiegato nel 1915 da Einstein con la nascita della relativita` generale
- ▷ Presenza di massa modifica la struttura dello spazio tempo

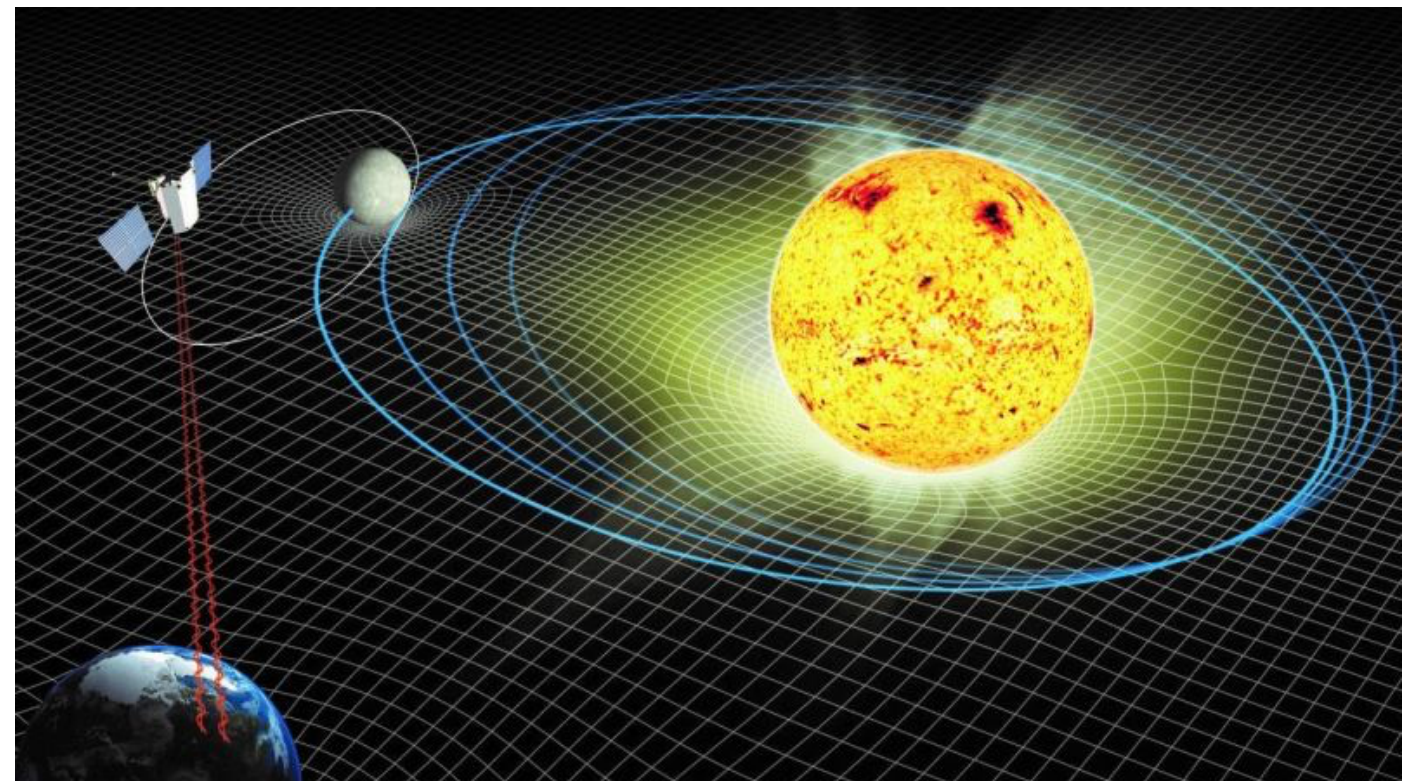


Curvature of space

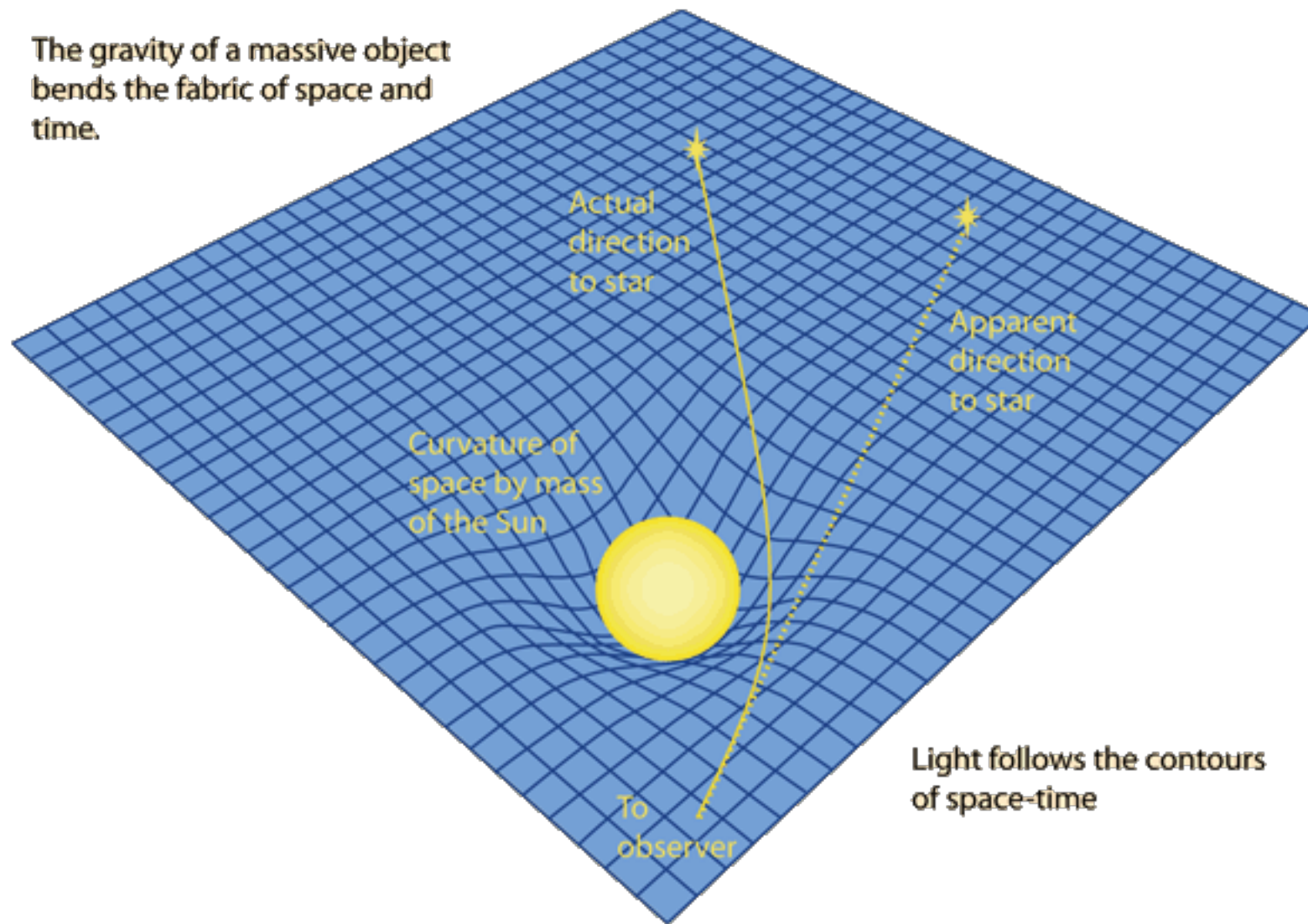
Distribution of mass/energy

$$G_{\alpha\beta} = \frac{8\pi G}{c^4} T_{\alpha\beta}$$

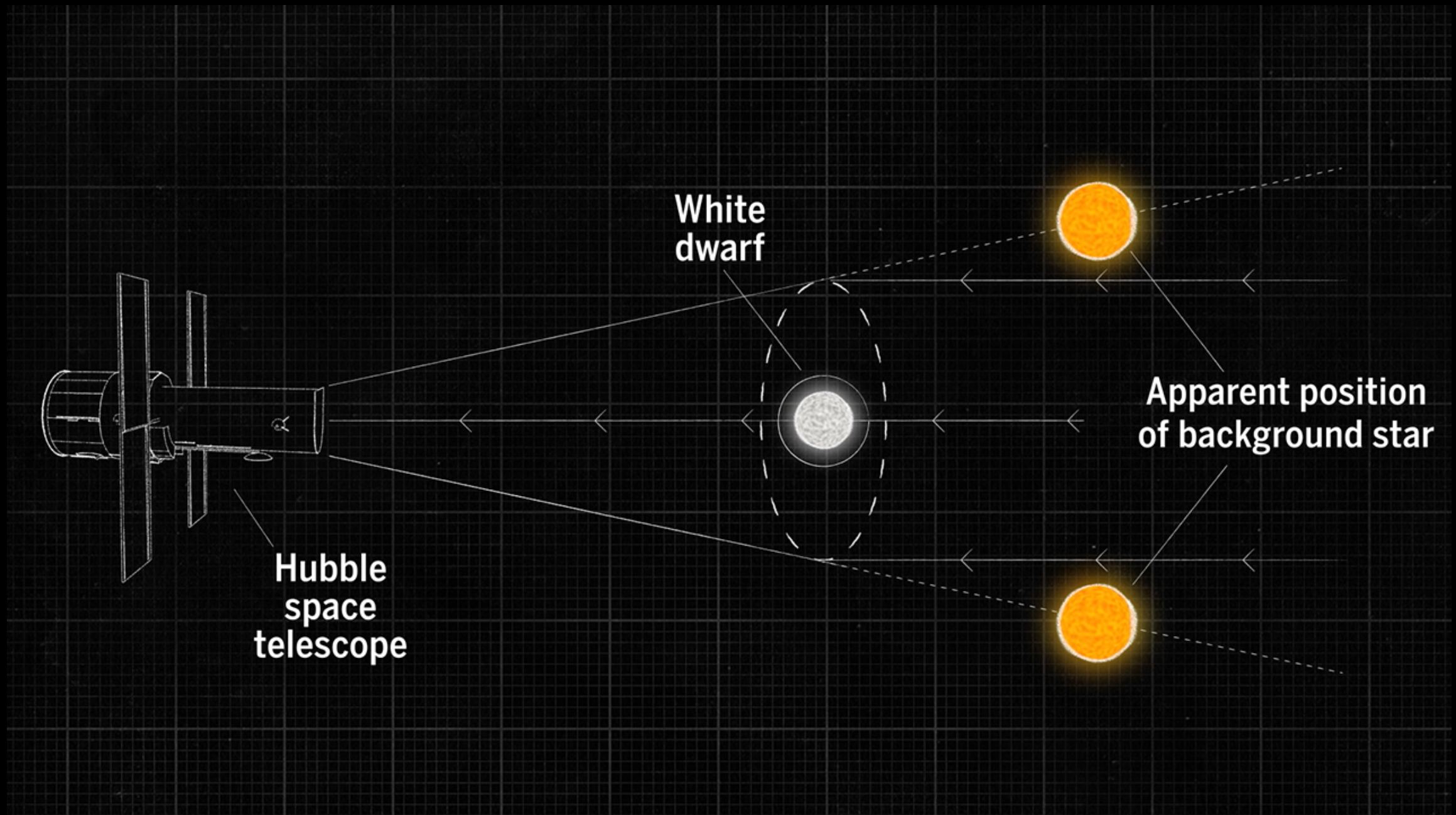
Some constants



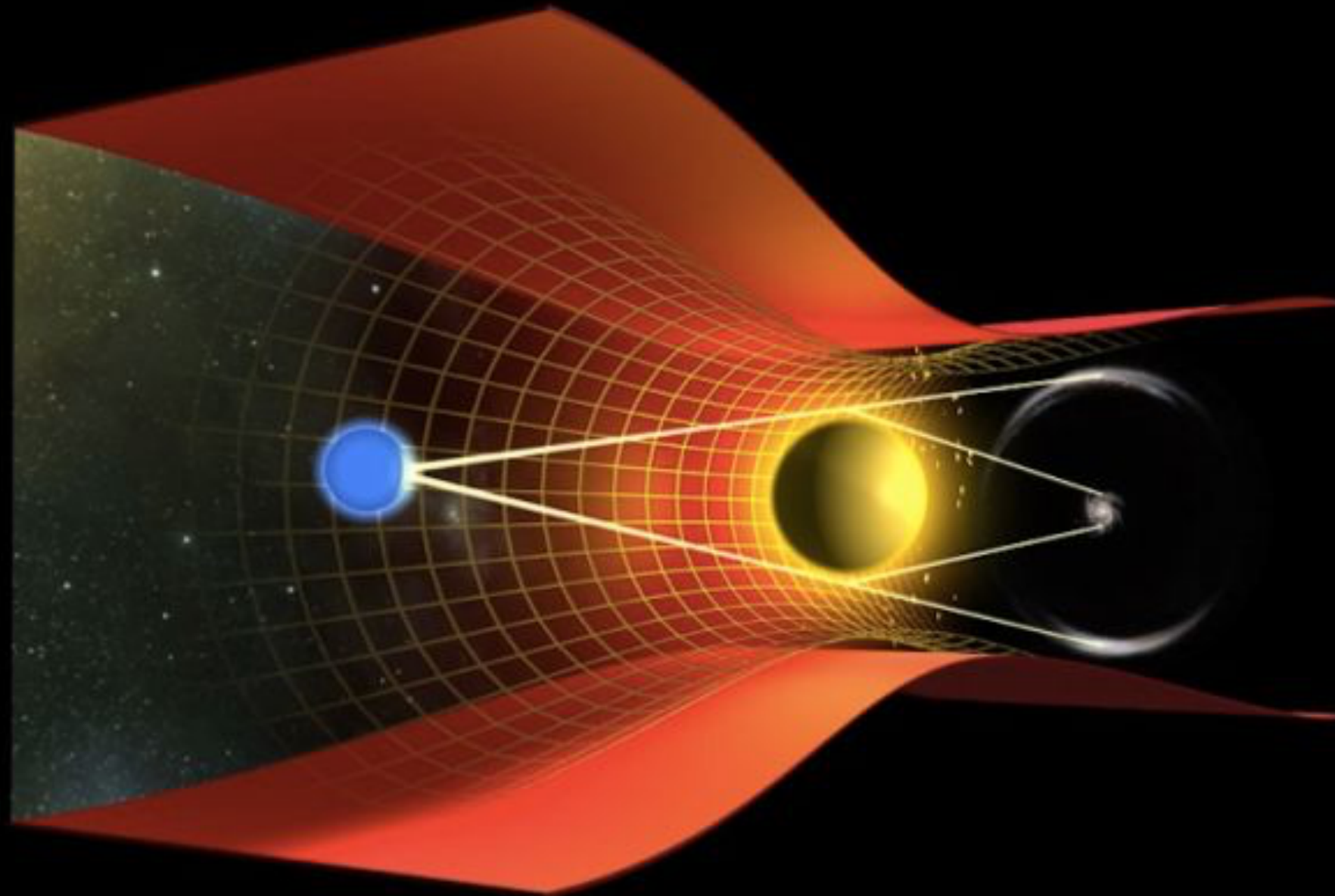
The gravity of a massive object bends the fabric of space and time.





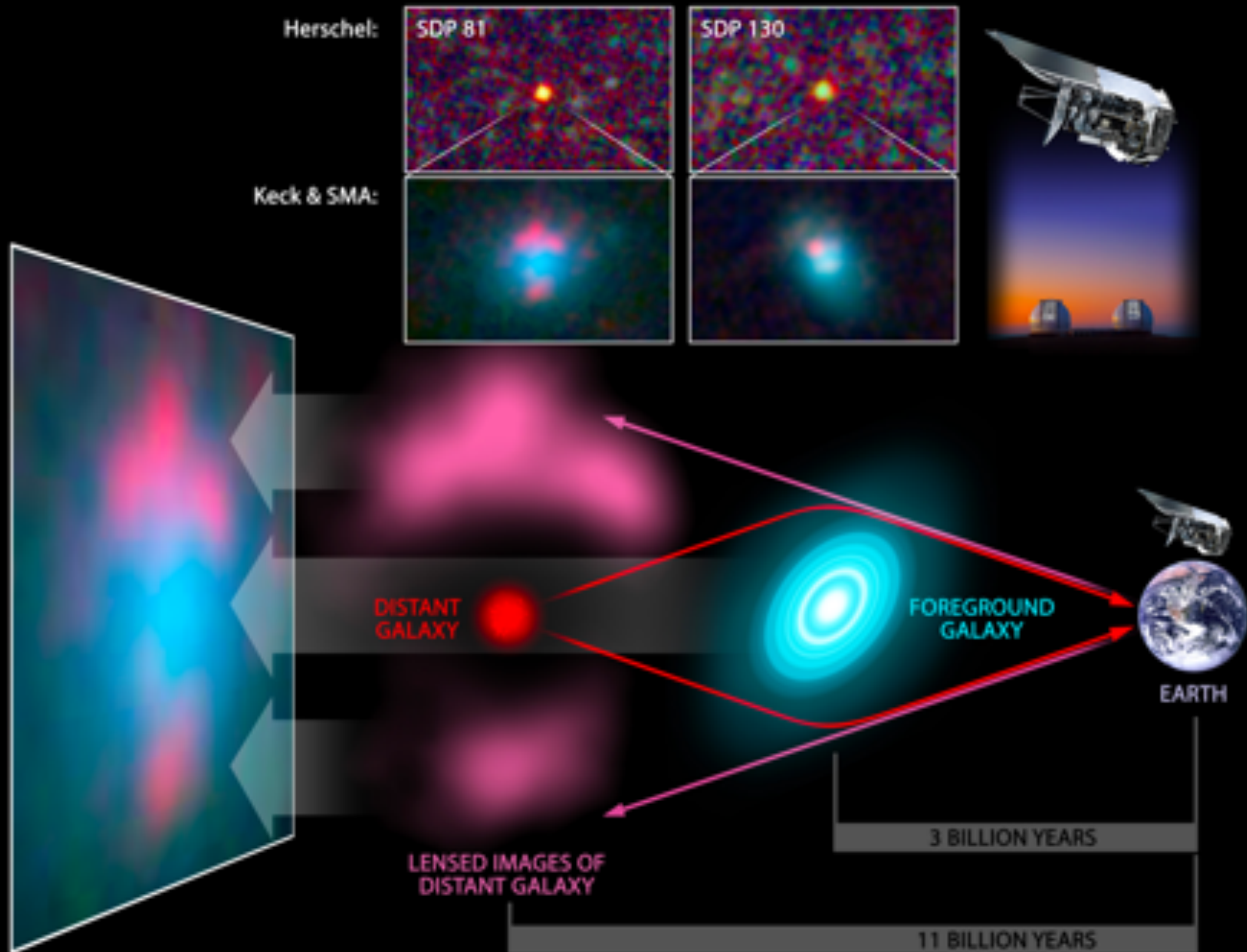


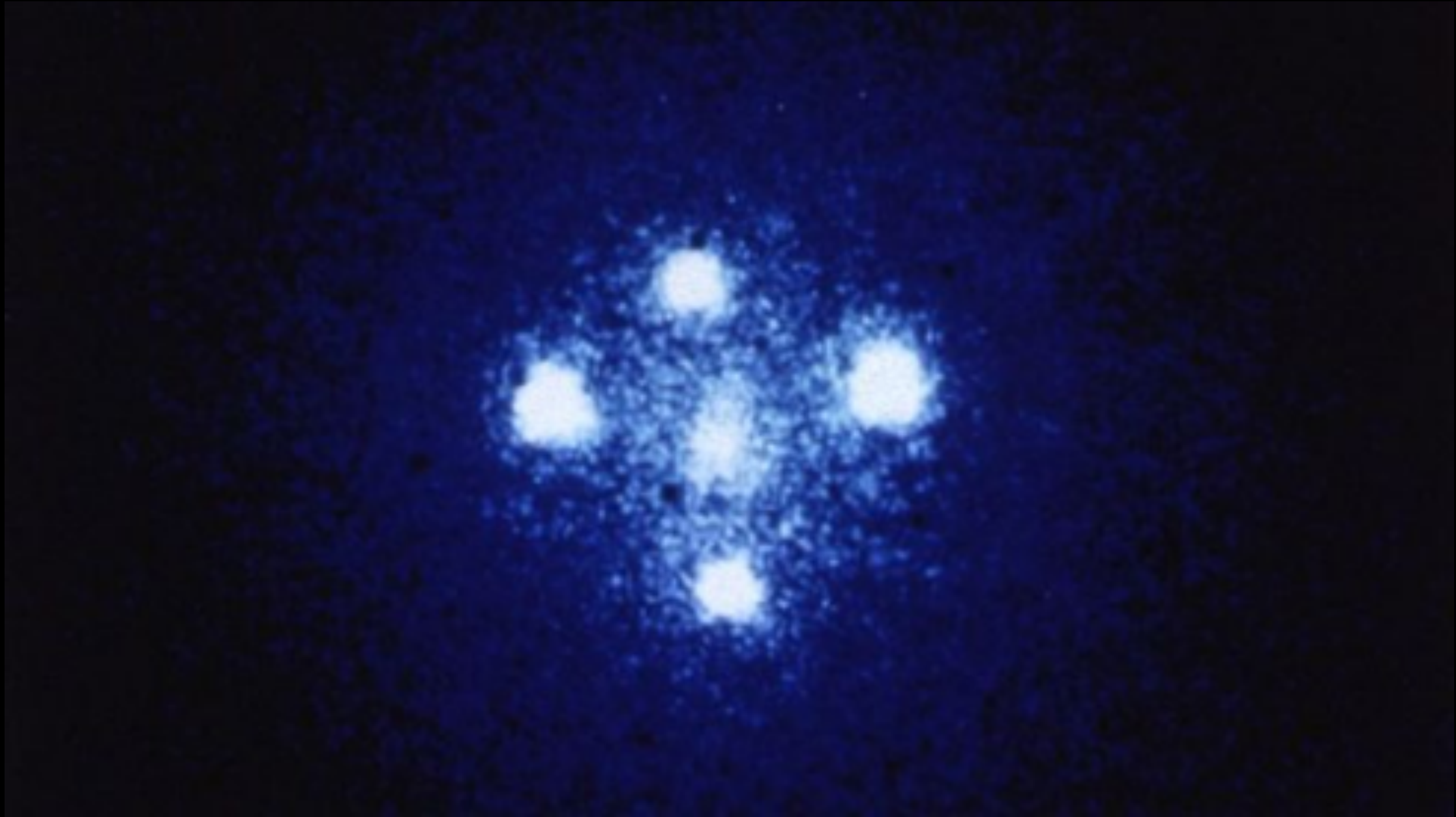
# Lente gravitazionale





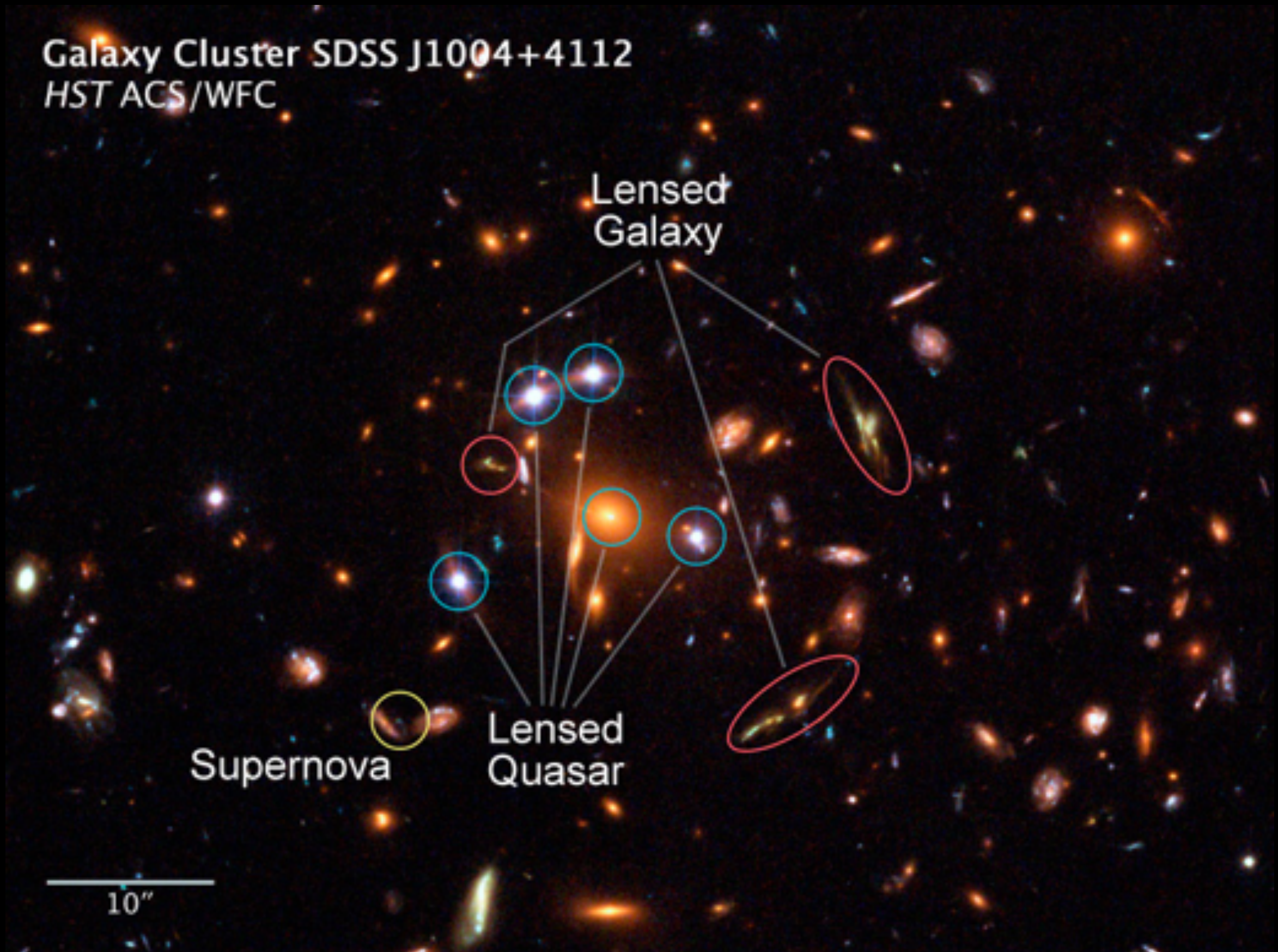
# Gravitational Lensing







# Gravitational Lensing

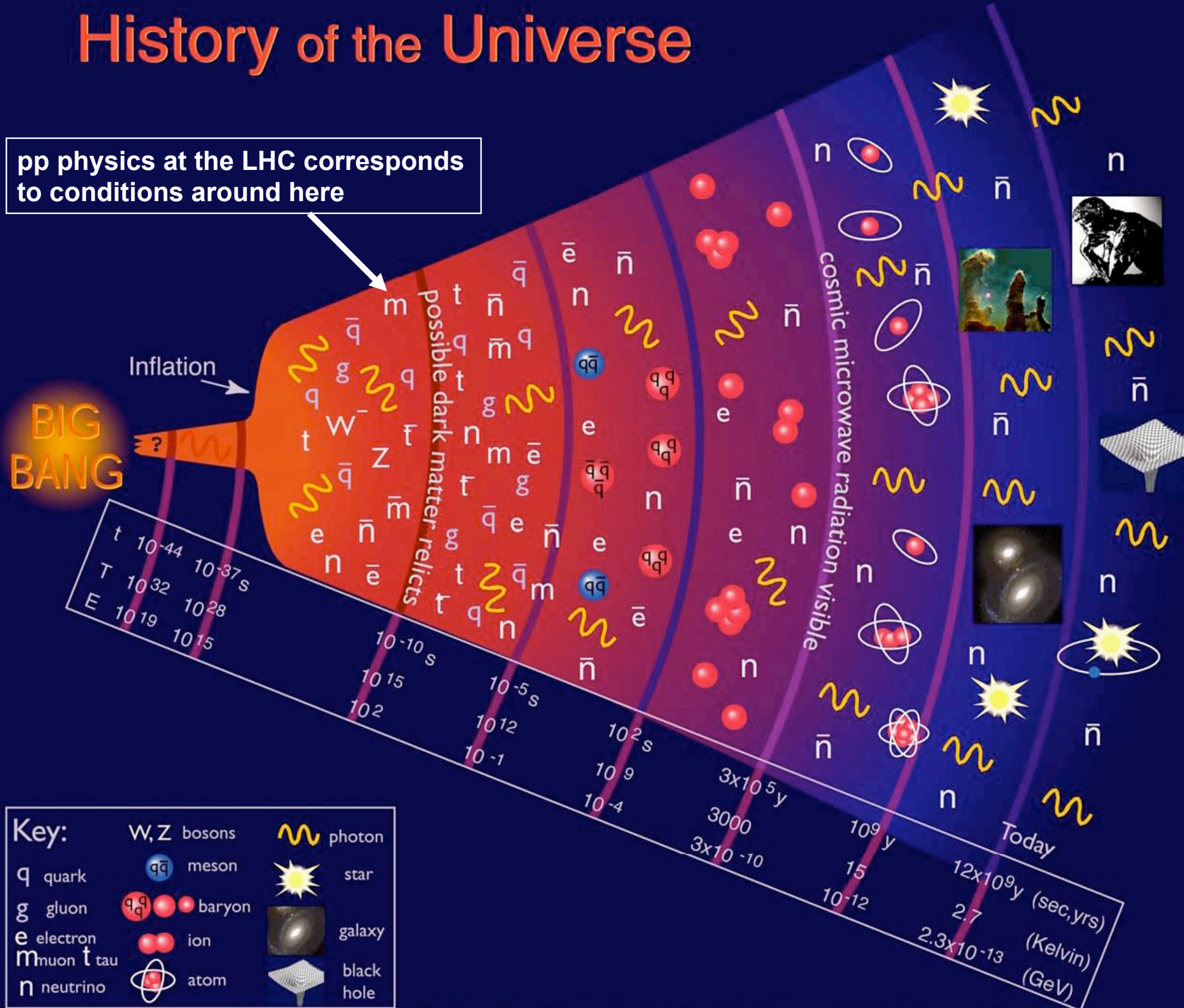


Dall'infinitamente grande  
all'infinitamente piccolo



# History of the Universe

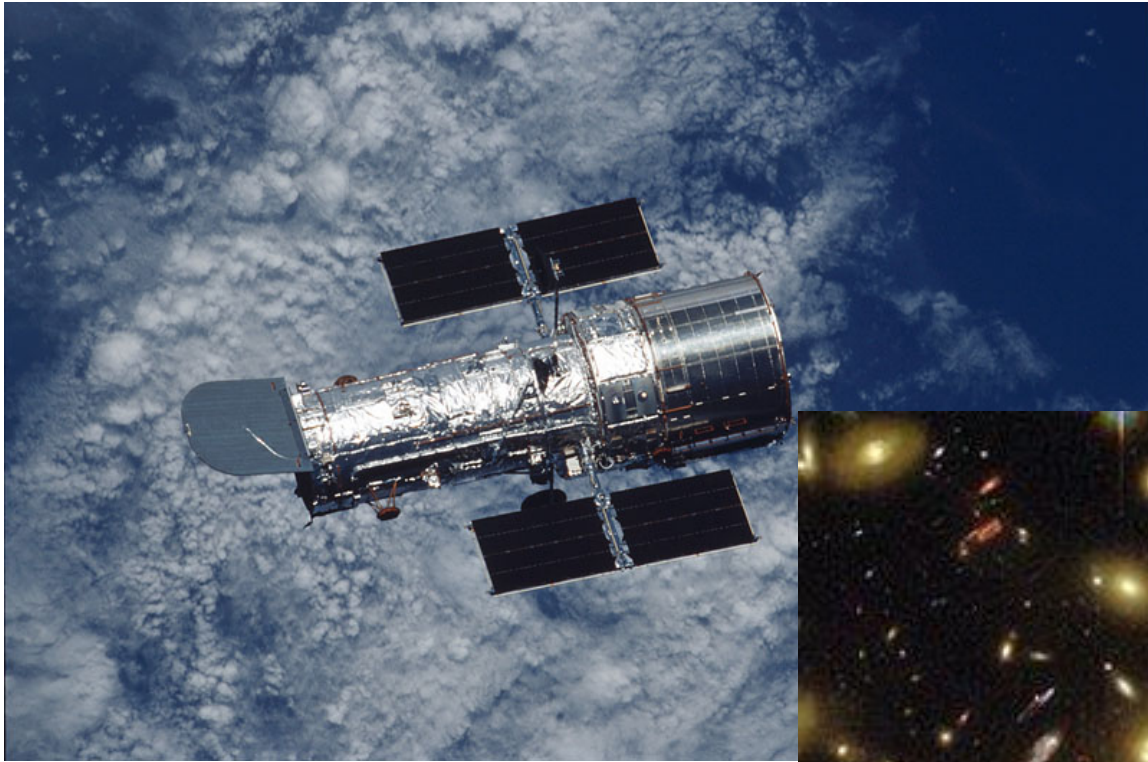
pp physics at the LHC corresponds to conditions around here



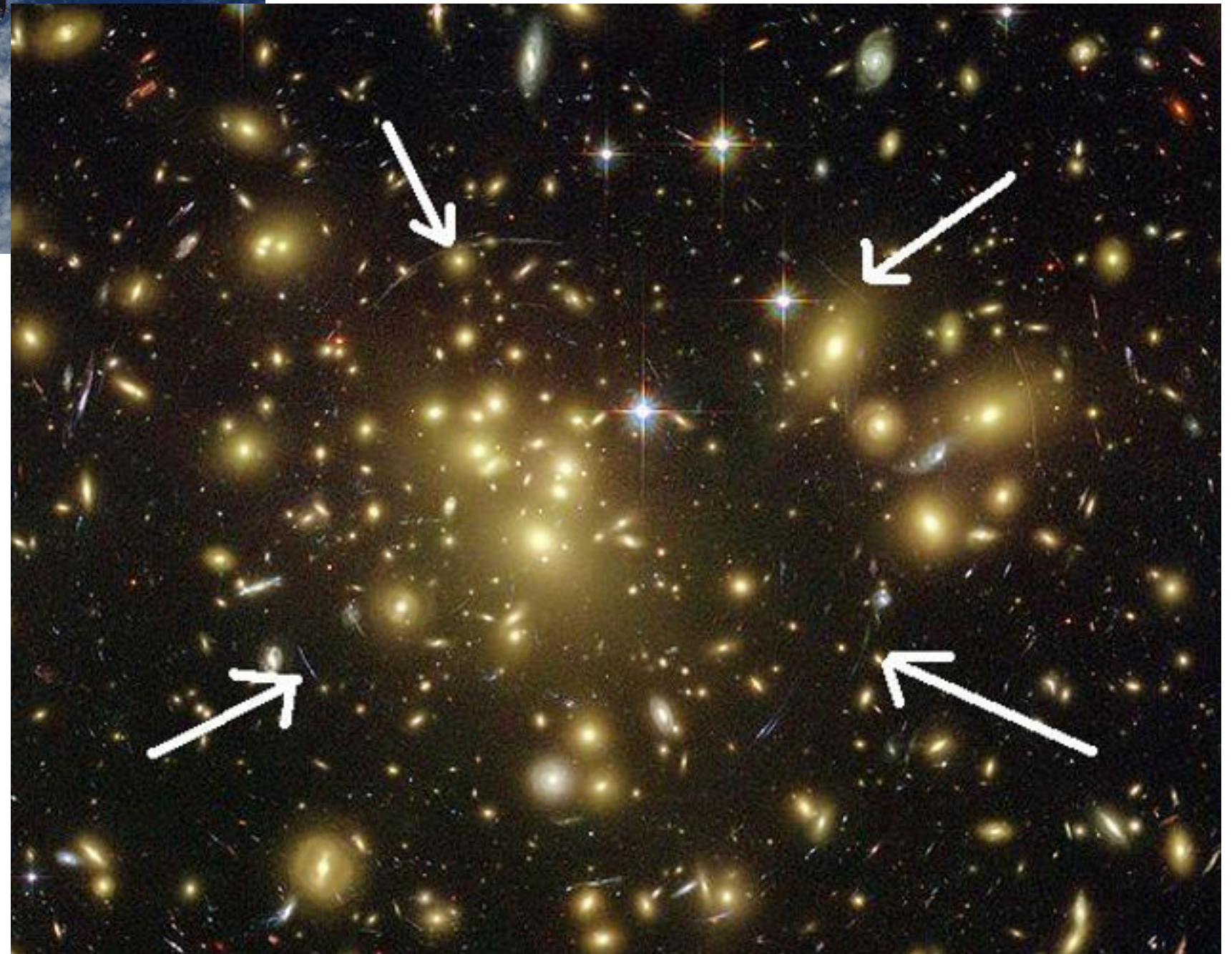
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF



# Dai telescopi...

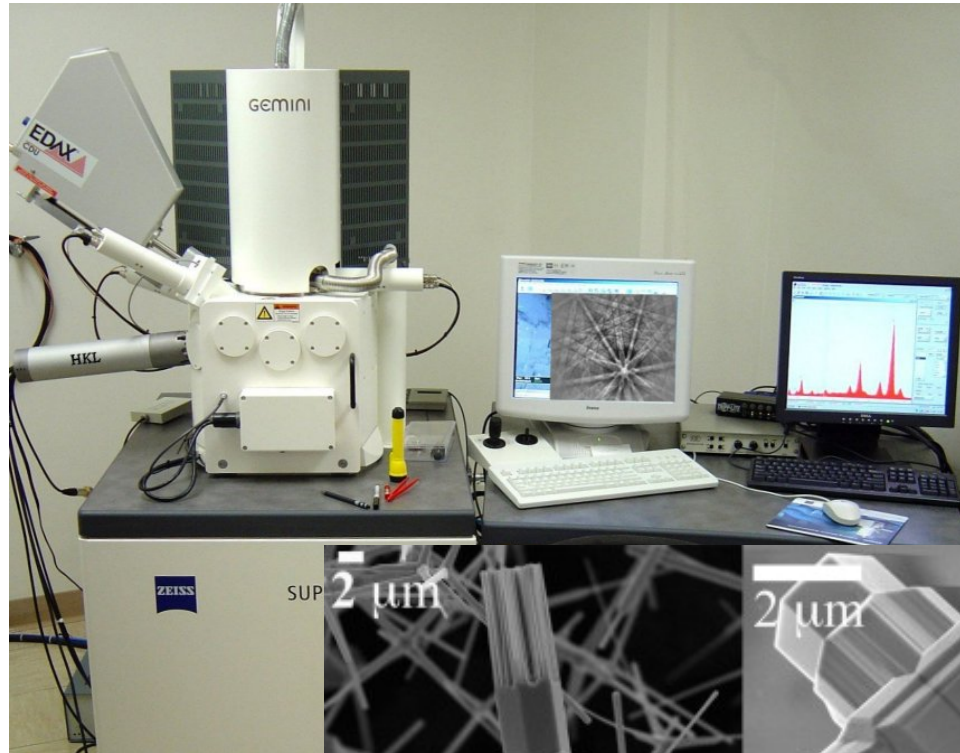


Gravita`

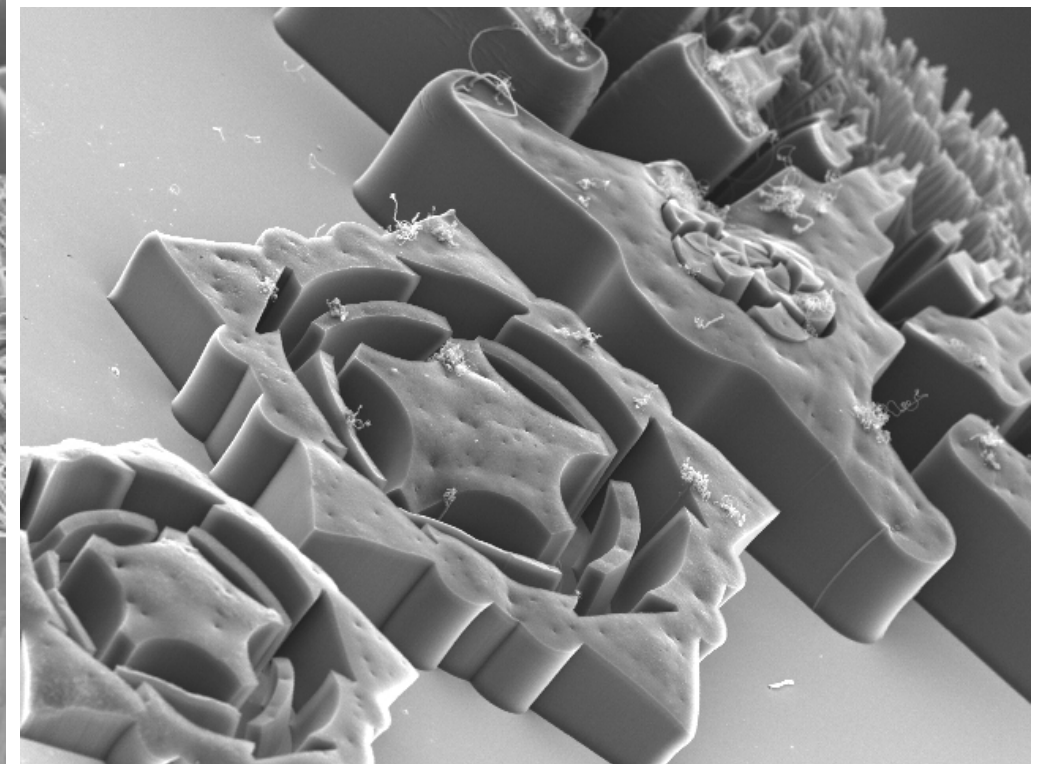
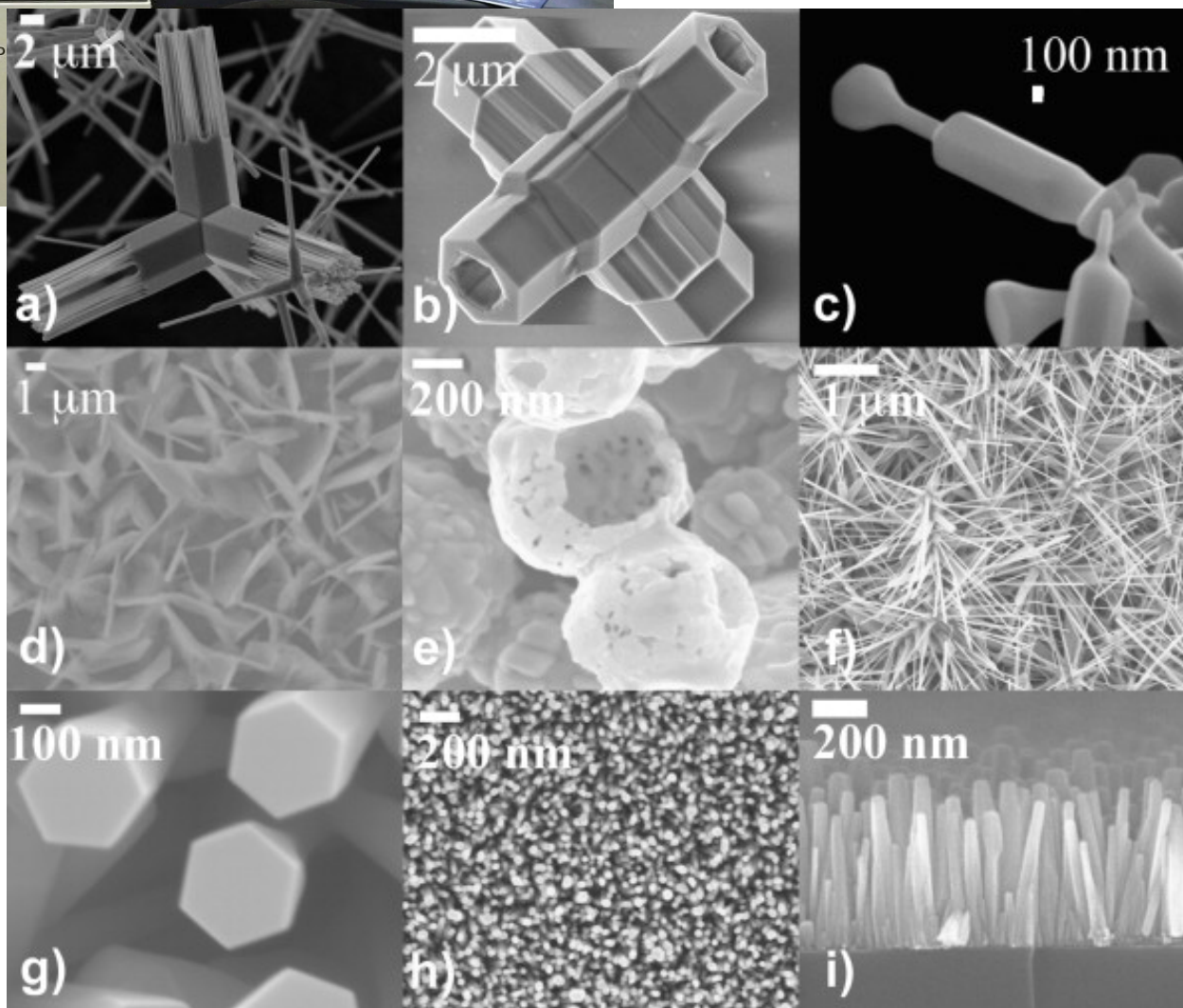




# ... ai microscopi...

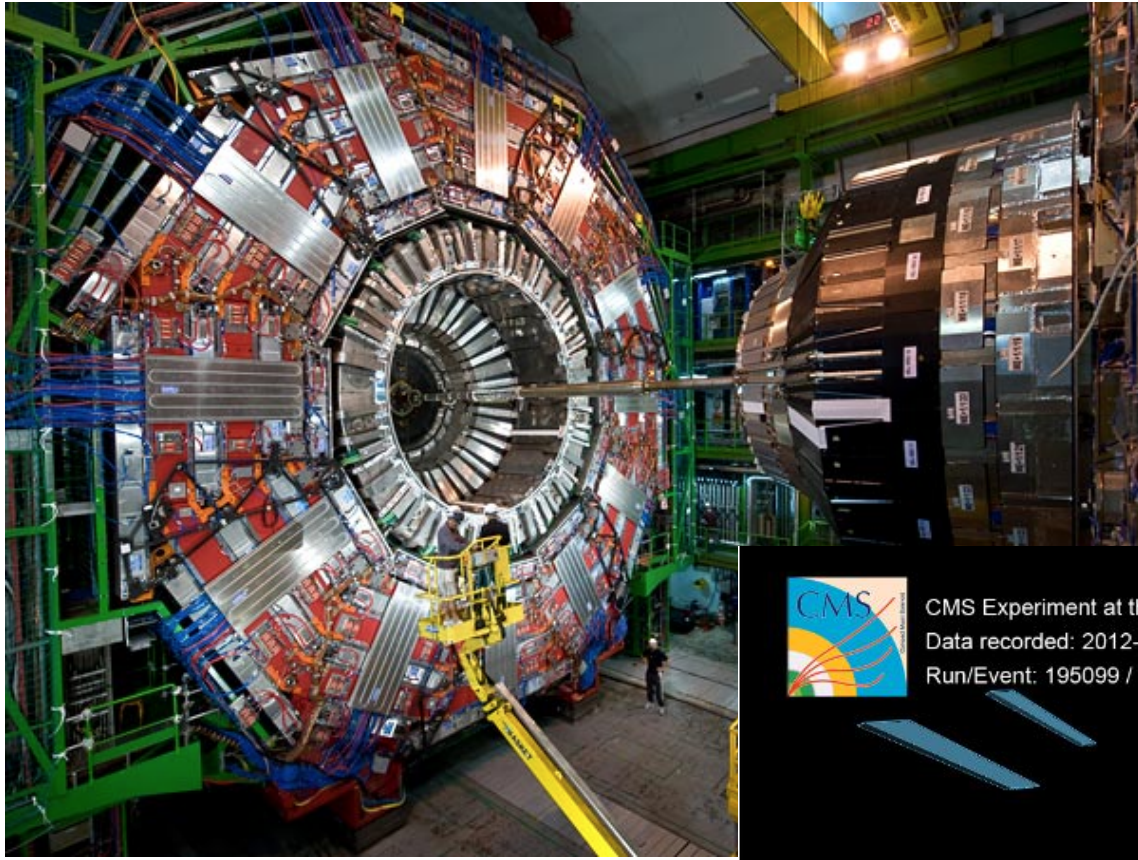


## Elettromagnetismo

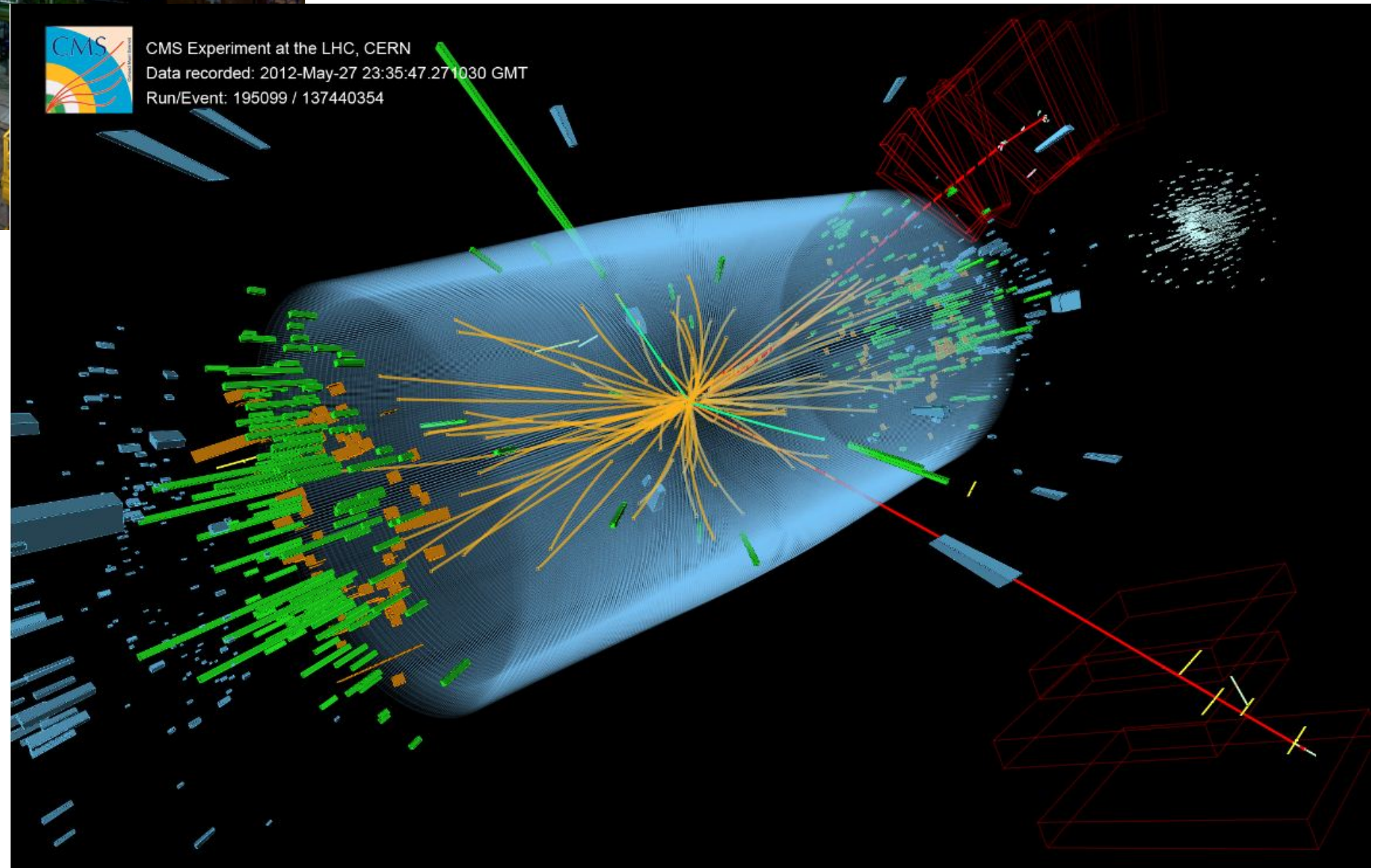




# ... a rivelatori di particelle

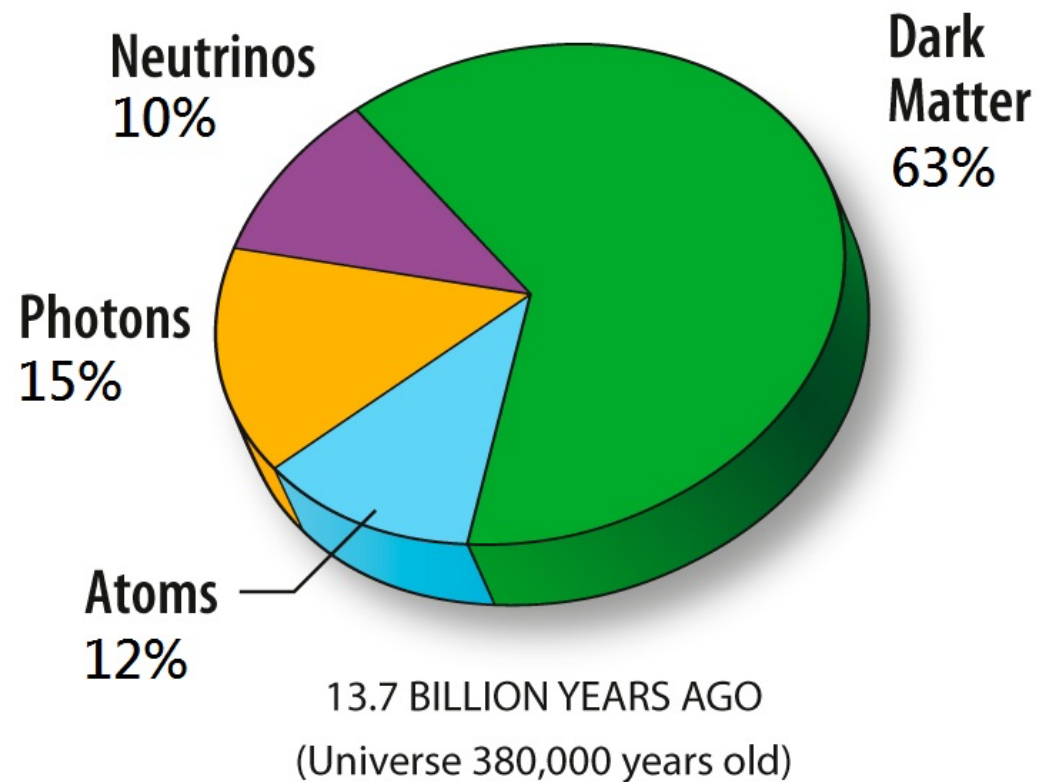
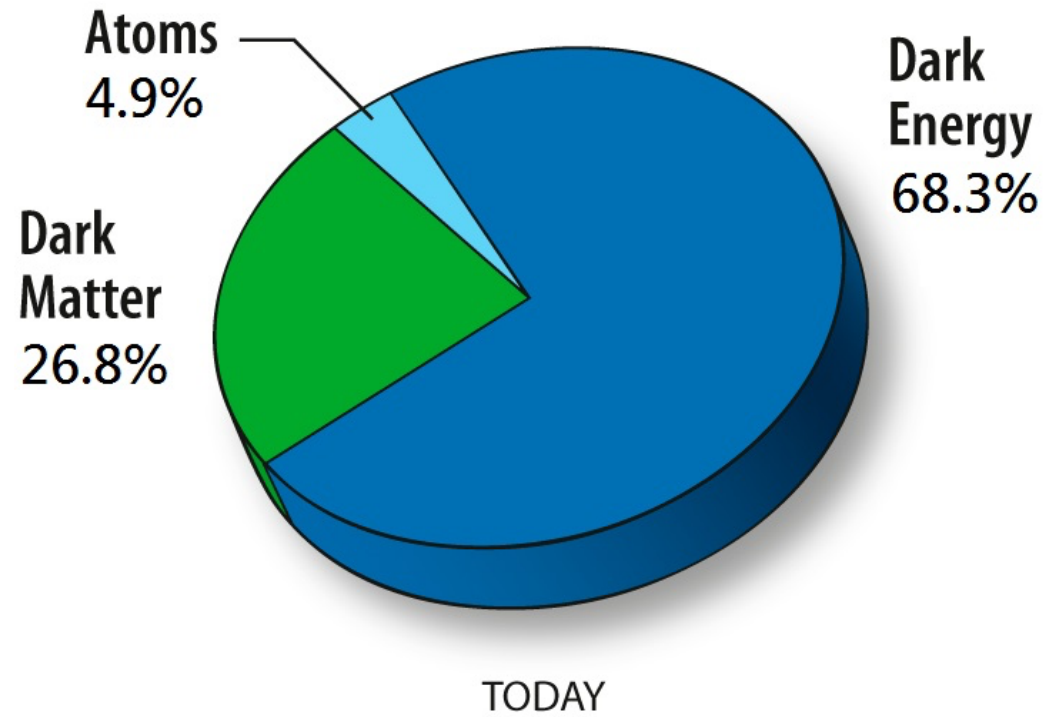


Interazioni forti ed elettrodeboli

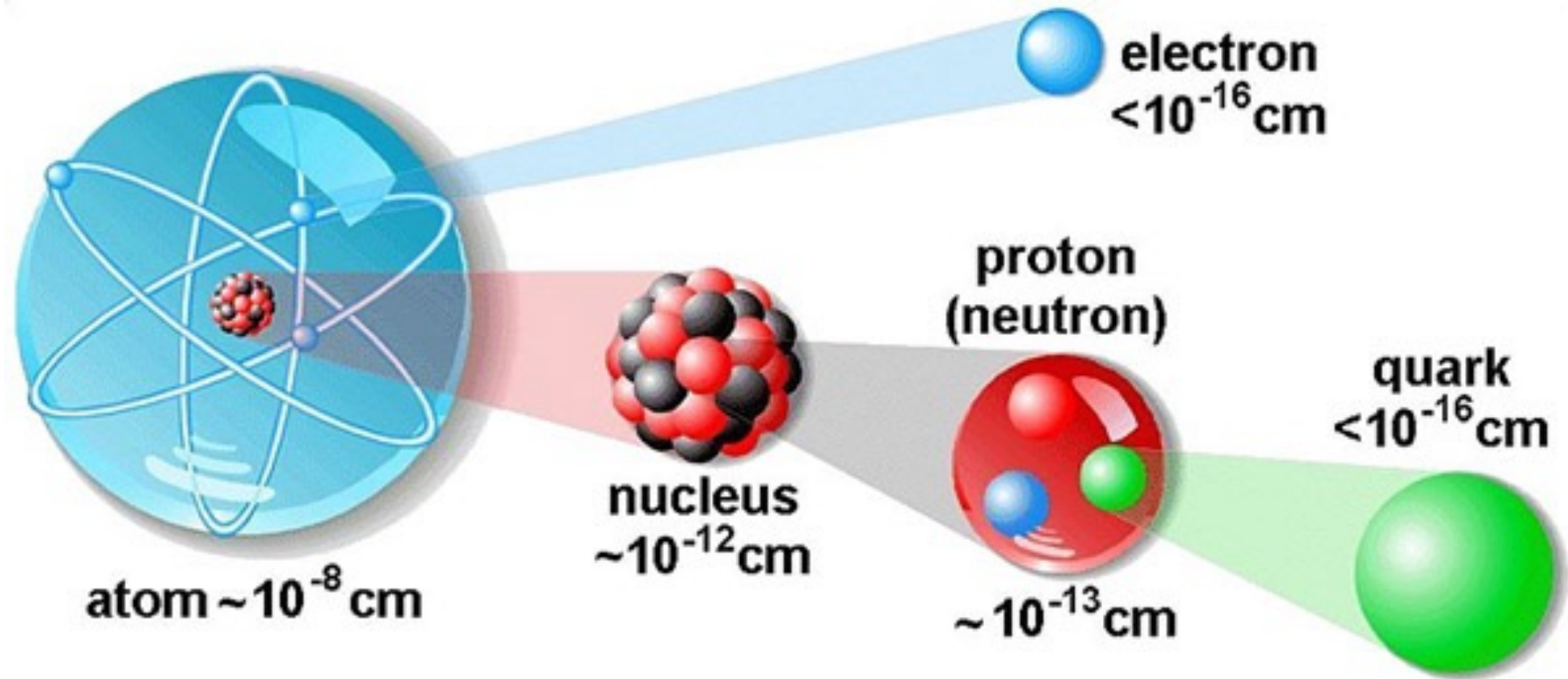




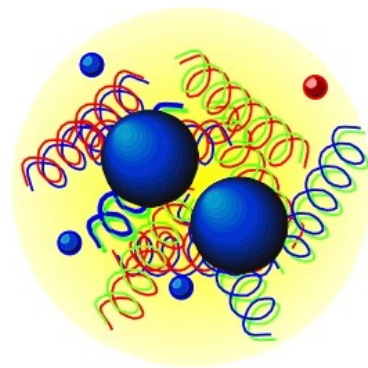
# Composizione dell'Universo



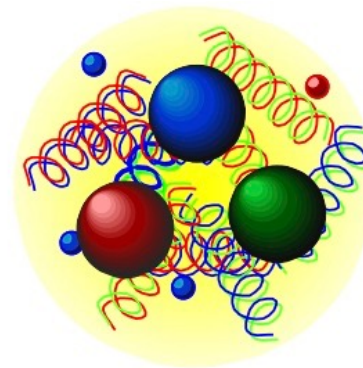
# Materia ordinaria



Mainly produced  
in laboratory



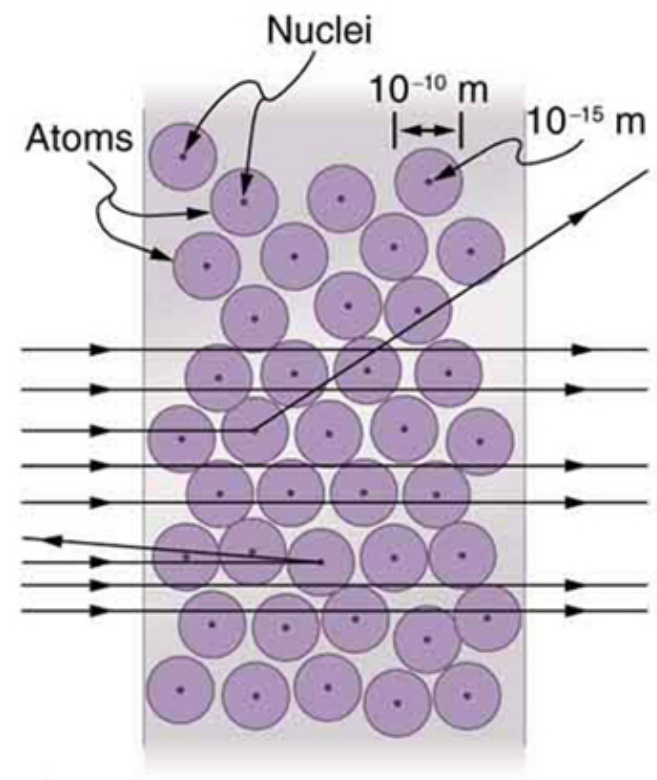
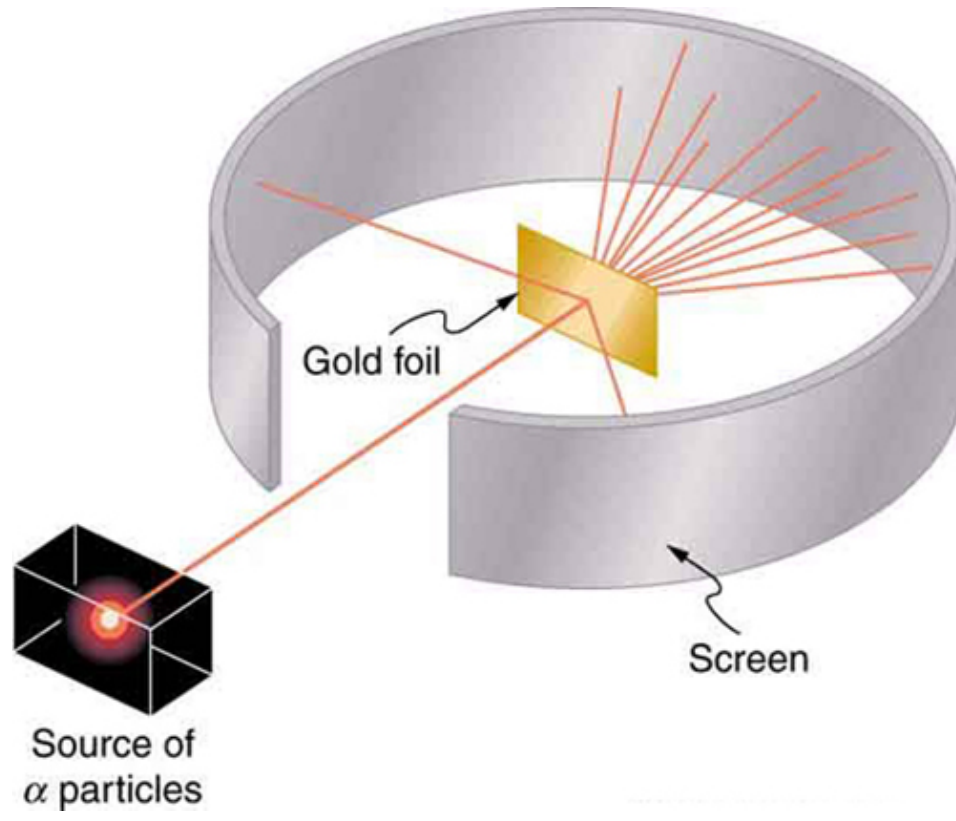
meson



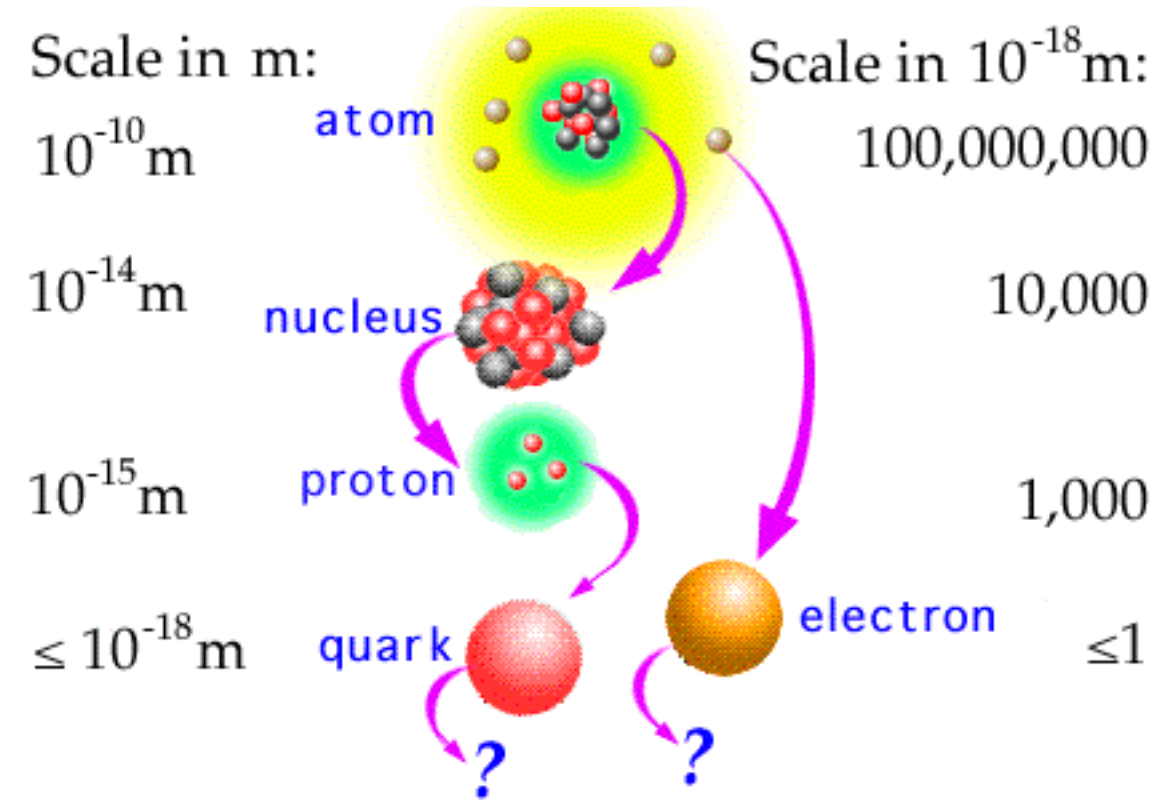
baryon

Ordinary matter

# Frontiera di Energia

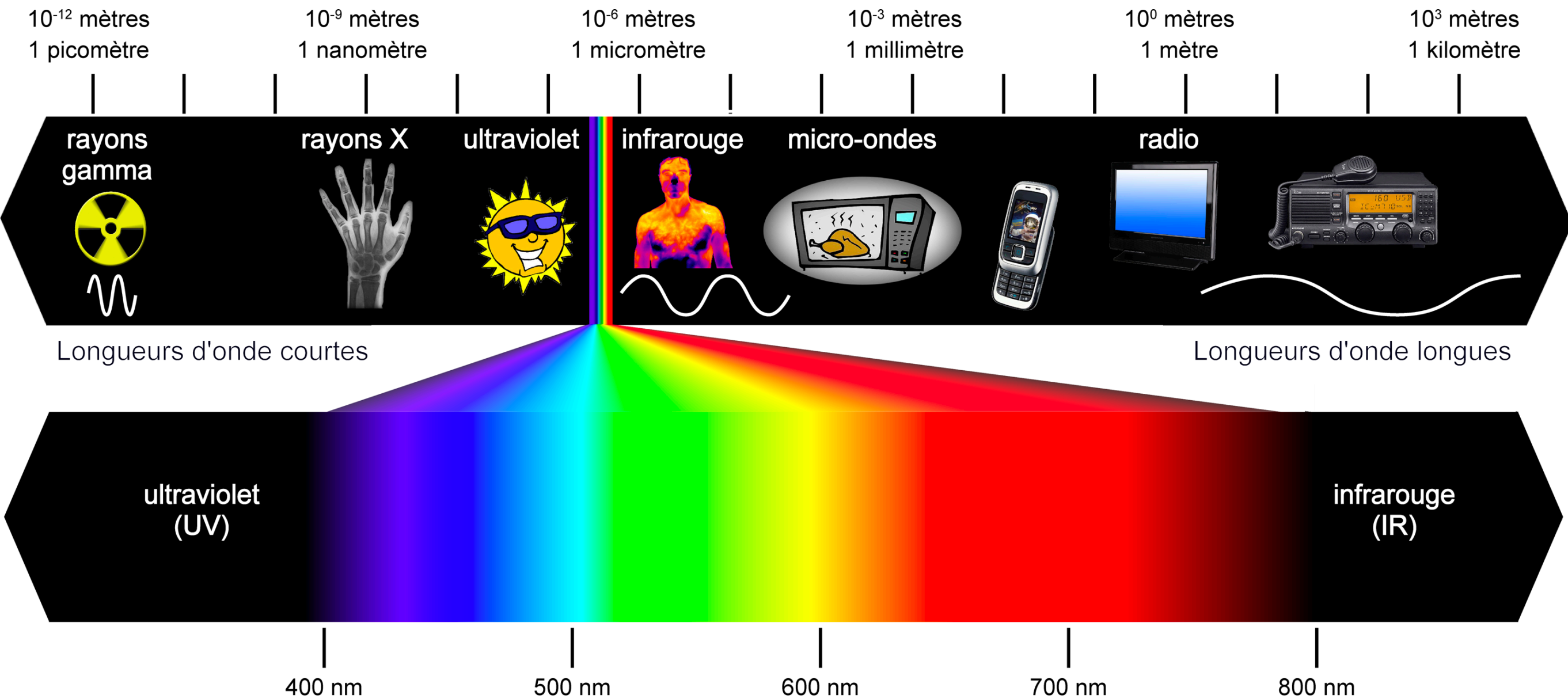


- ▷ Dualità onda-particella la chiave per esplorare la struttura della materia
- ▷ Energia più alta equivale a
  - lunghezza d'onda più piccola  $E \approx 1/\lambda$ 
    - risolvere costituenti più piccoli
  - temperature più alte  $E = kT$ 
    - ricreare condizioni simili al big bang





# Spettro Elettromagnetico

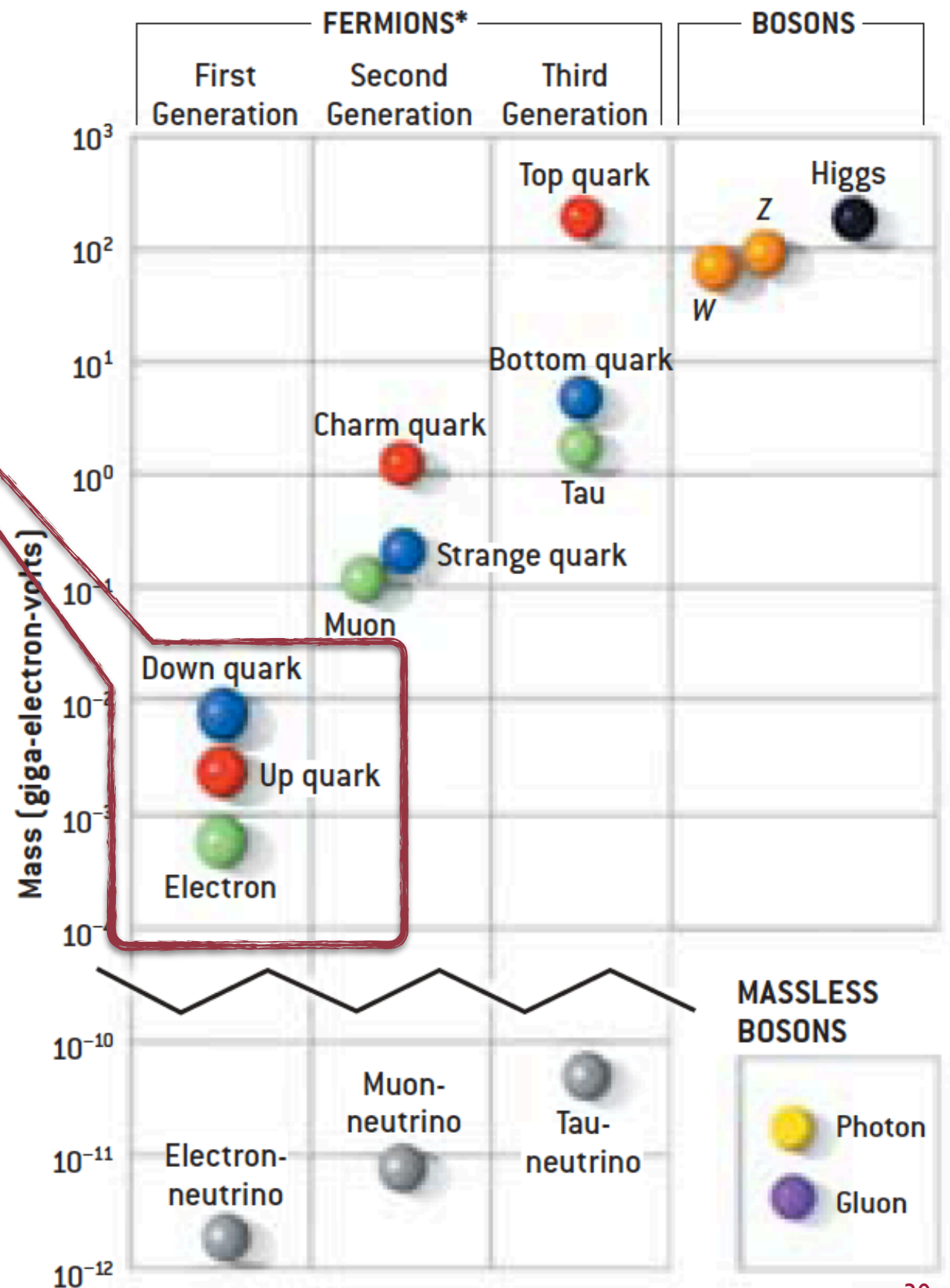


# Materia

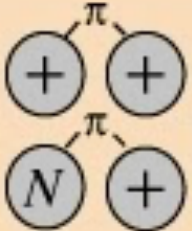
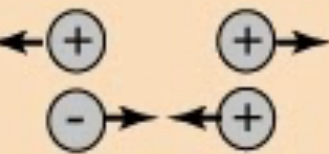
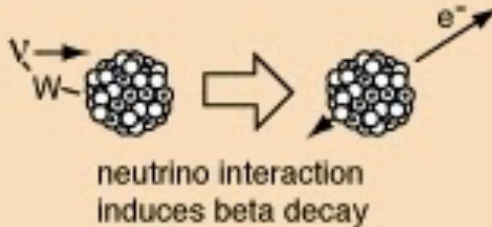
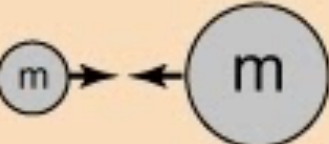
- ▷ Almost all visible matter composed of
  - up and down quarks
  - electrons
- ▷ All particles produced in laboratories and in universe made of elementary fermions
  - 3 families of leptons
  - 3 families of quarks

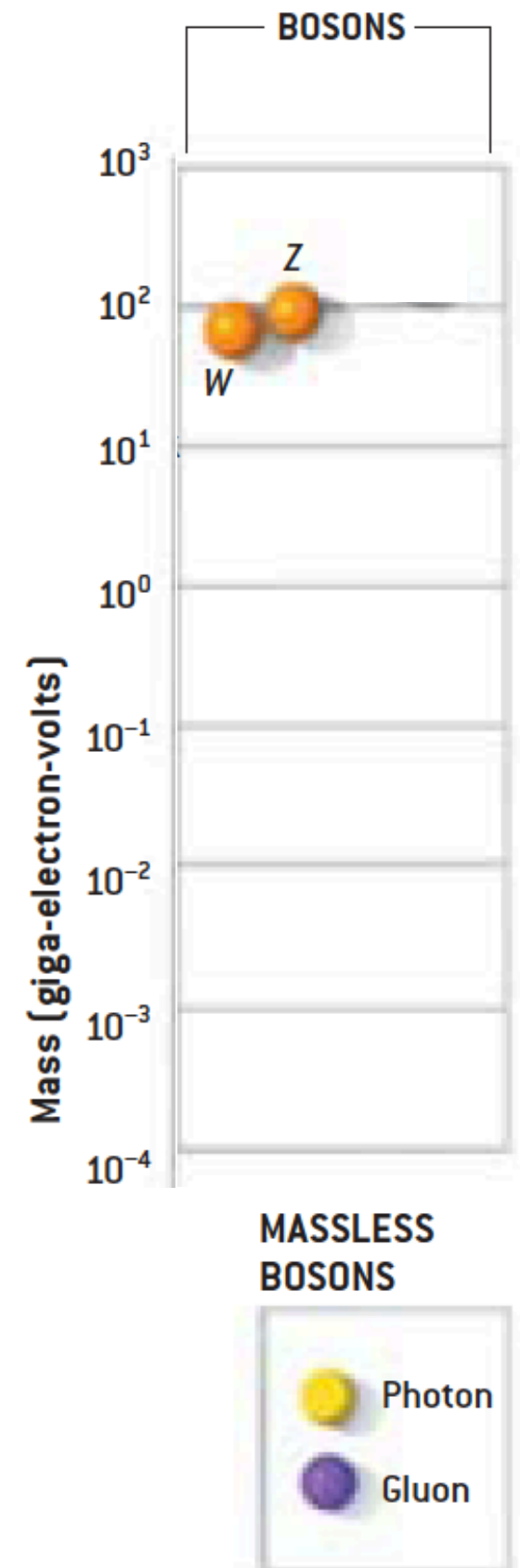
$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ joule}$$

$$E = mc^2$$



# Fundamental Forces

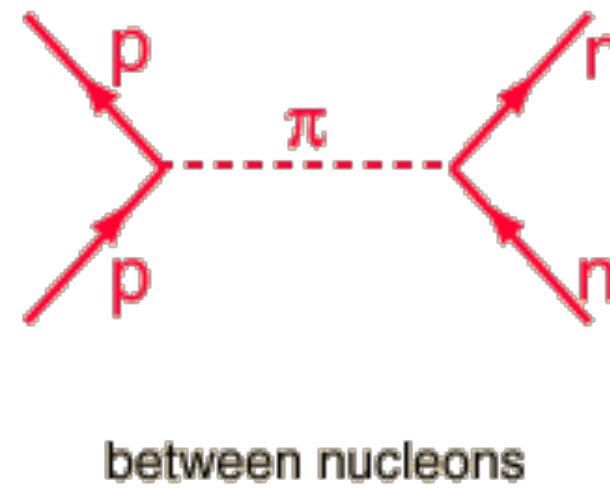
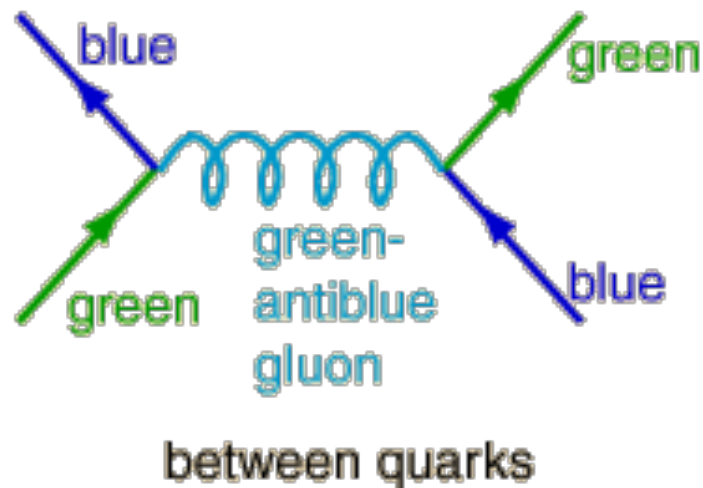
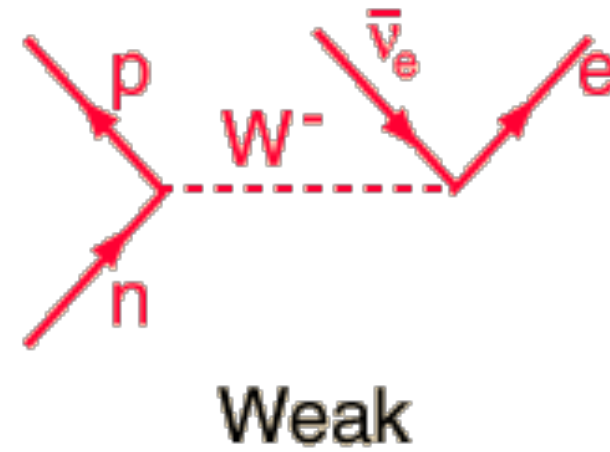
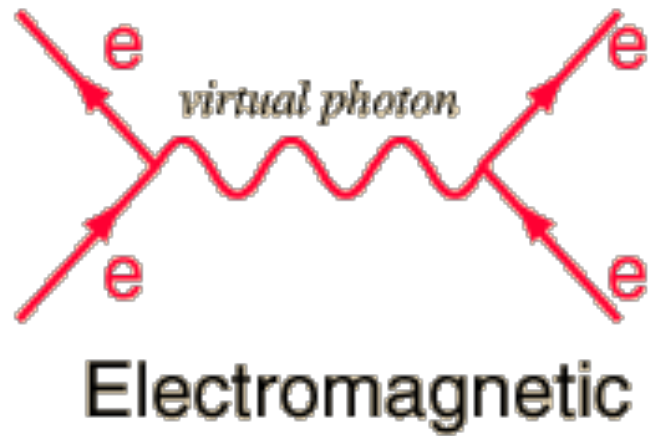
<b>Strong</b>		Force which holds nucleus together	Strength <b>1</b>	Range (m) $10^{-15}$ (diameter of a medium sized nucleus)	Particle gluons, $\pi$ (nucleons)
<b>Electro-magnetic</b>			Strength $\frac{1}{137}$	Range (m) Infinite	Particle photon mass = 0 spin = 1
<b>Weak</b>		neutrino interaction induces beta decay	Strength $10^{-6}$	Range (m) $10^{-18}$ (0.1% of the diameter of a proton)	Particle Intermediate vector bosons $W^+$ , $W^-$ , $Z_0$ , mass > 80 GeV spin = 1
<b>Gravity</b>			Strength $6 \times 10^{-39}$	Range (m) Infinite	Particle graviton ? mass = 0 spin = 2



- ▷ Nella fisica moderna le interazioni sono mediate da scambio di particelle
- ▷ Le particelle si possono propagare al massimo alla velocità della luce

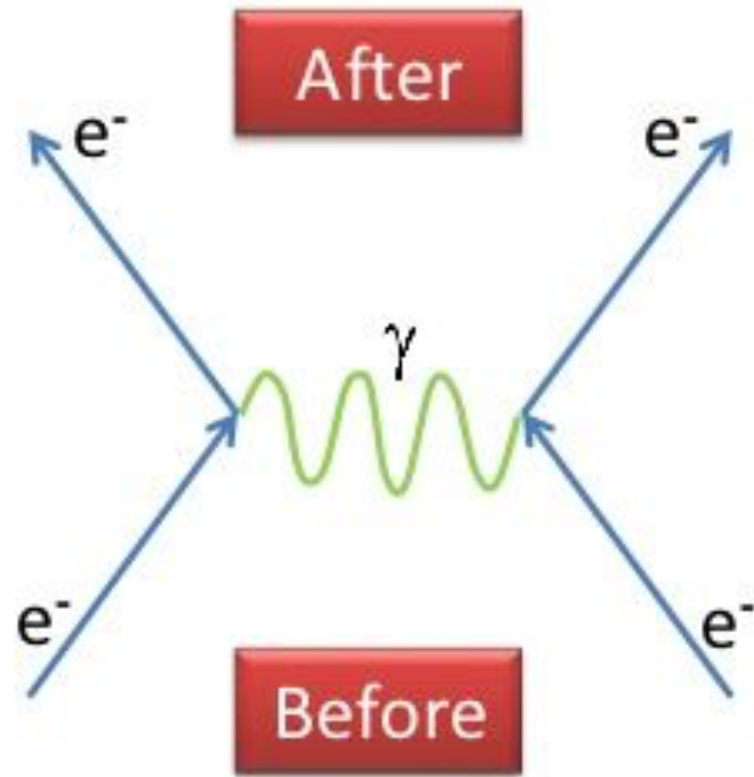


# Interazione mediata da particelle

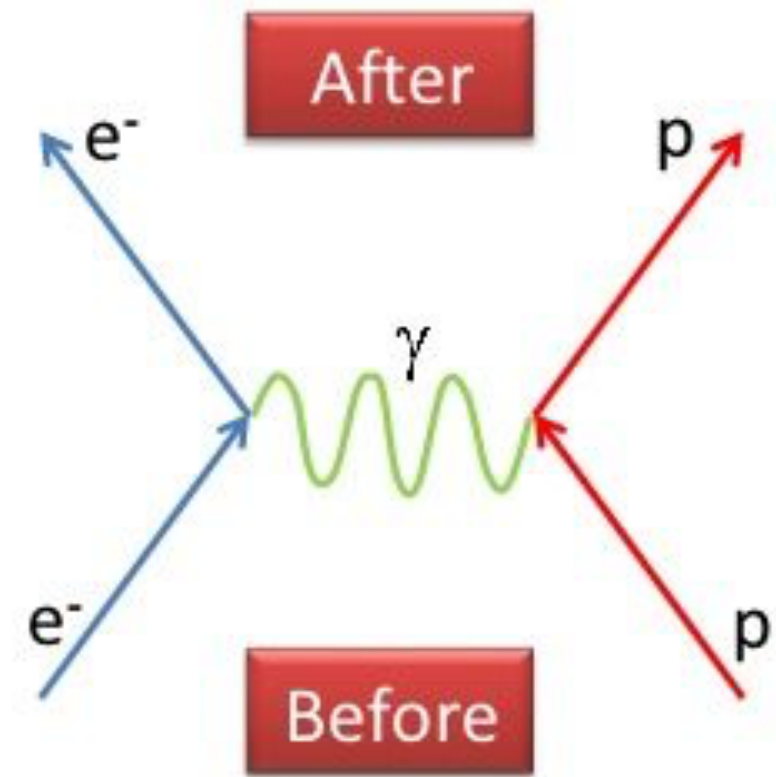


Strong Interaction

# Interazione elettromagnetica

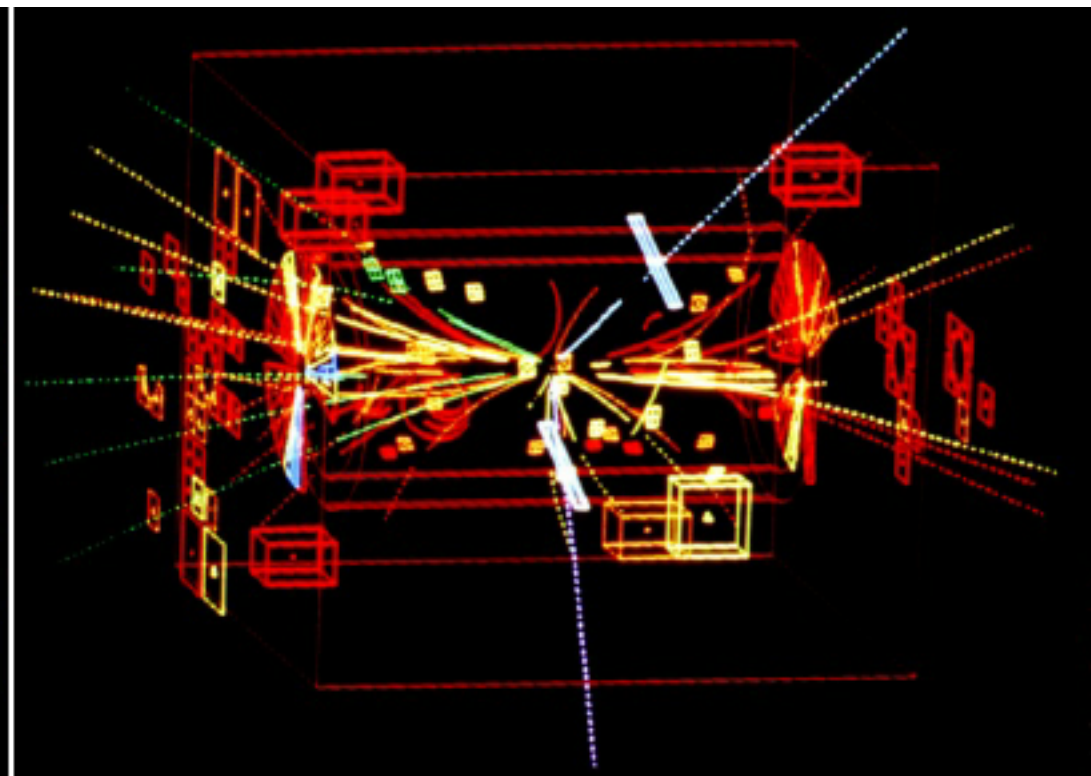
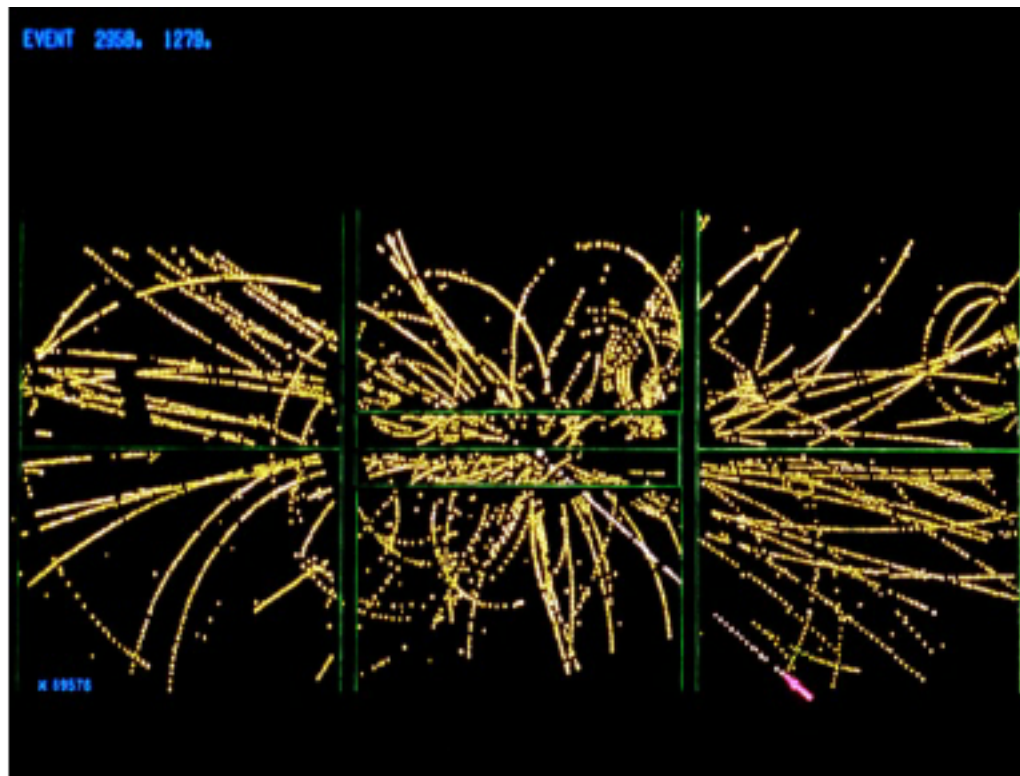
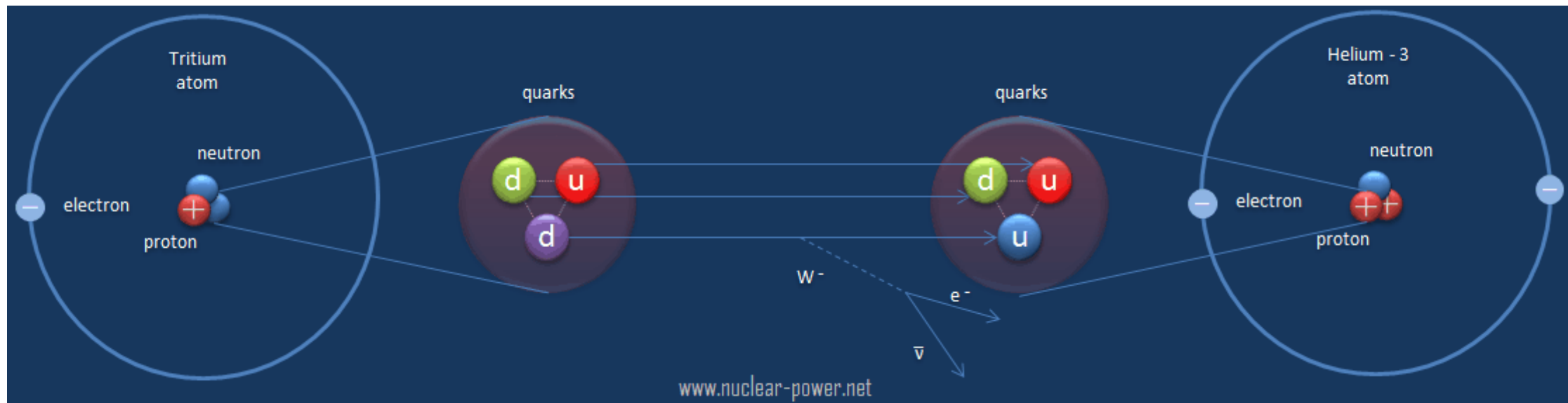


electron – electron repulsion



electron – proton attraction

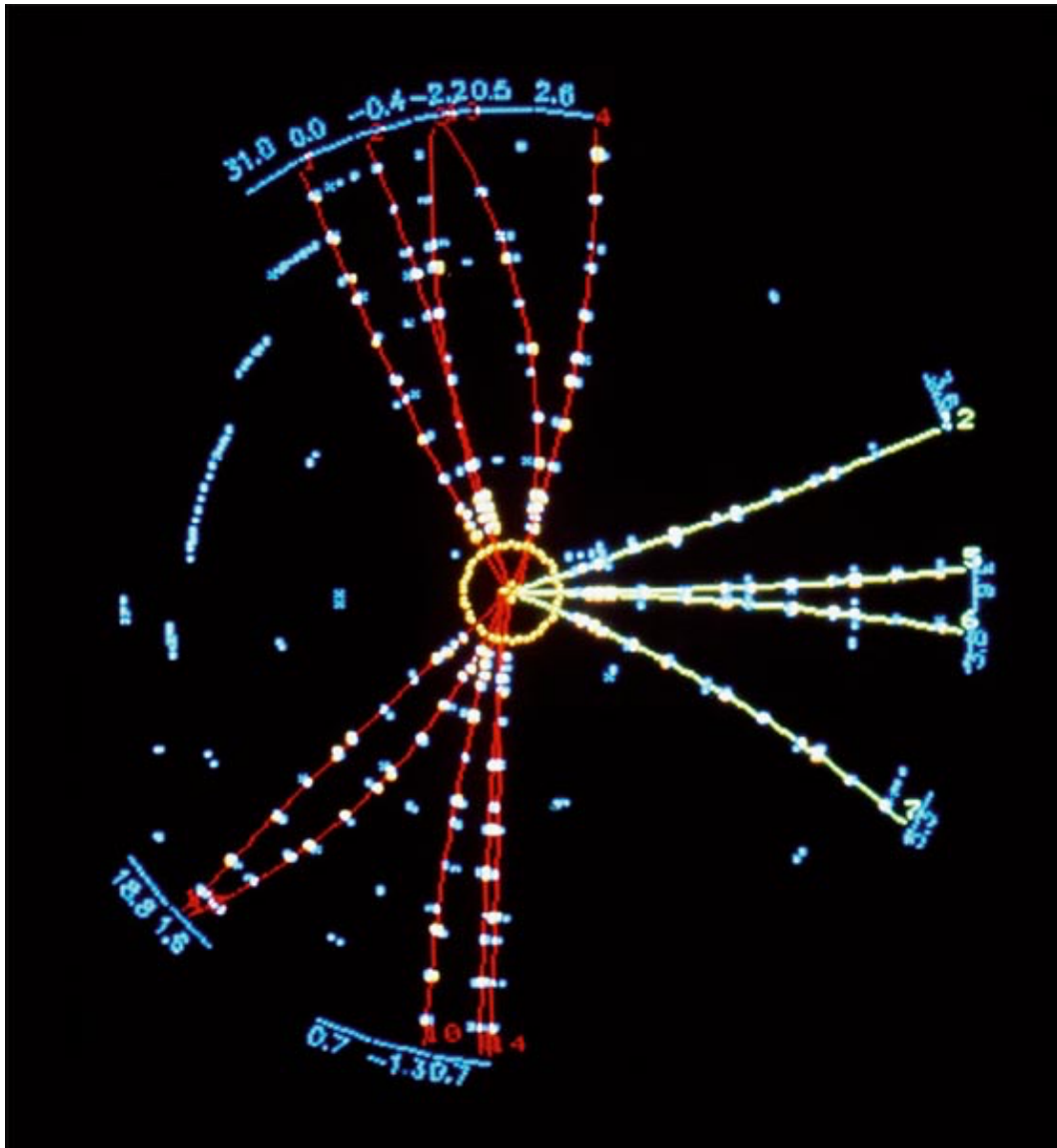
# Interazione debole



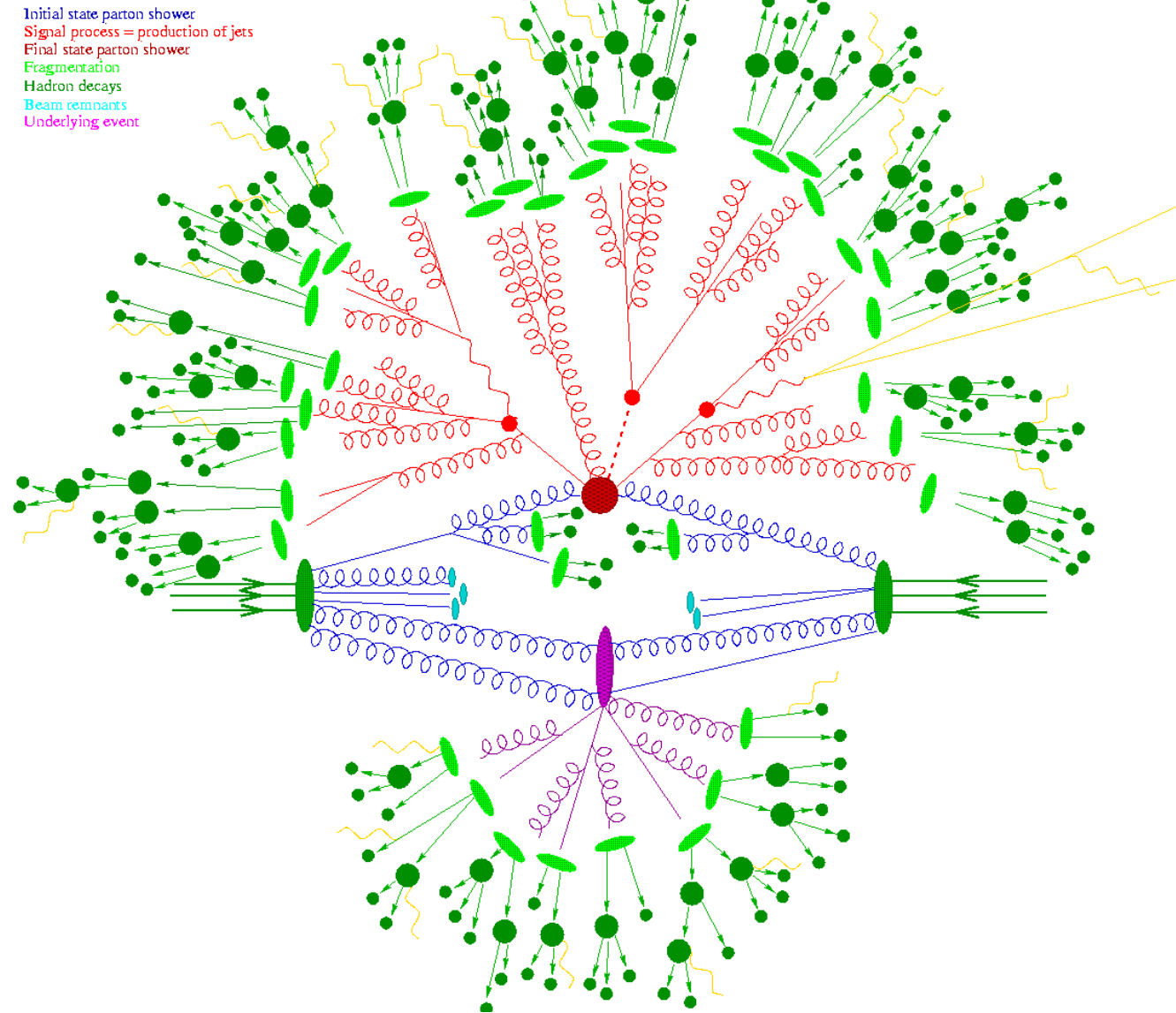
- ▷ Bosoni W e Z scoperti nel 1983 al CERN
  - premio nobel per la fisica nel 1984



# Interazione forte



Sketch of a proton–proton collision at high energies



▷ gluons furono scoperti nel 1979

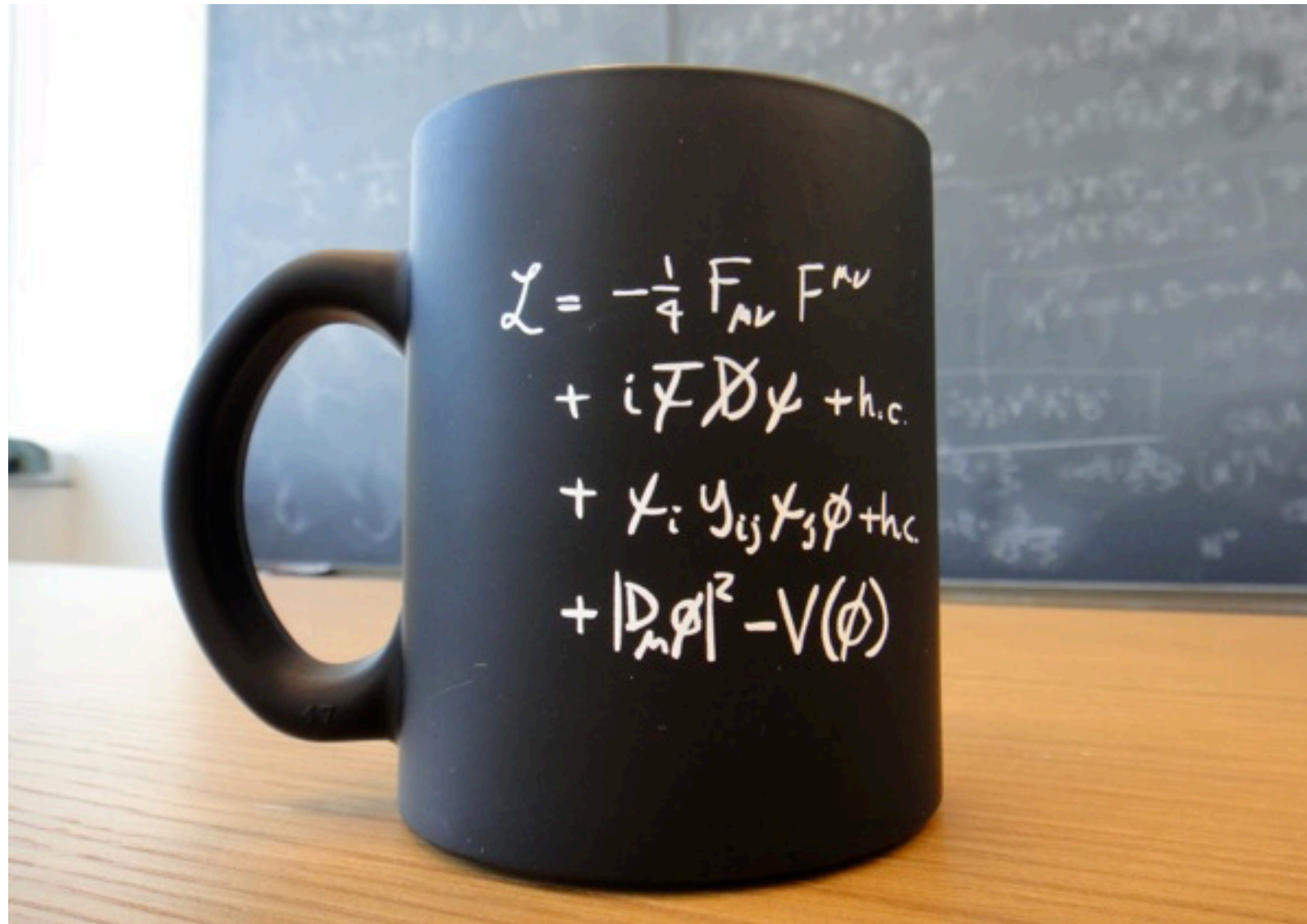
– ci sono 8 tipi o colori diversi di loro che mediano quark di 3 colori diversi

# Standard Model of Elementary Particles

		three generations of matter (fermions)			interactions / force carriers (bosons)	
		I	II	III		
QUARKS	mass	$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$	0	$\approx 125.09 \text{ GeV}/c^2$
	charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0	0
	spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0
		<b>u</b> up	<b>c</b> charm	<b>t</b> top	<b>g</b> gluon	<b>H</b> higgs
		<b>d</b> down	<b>s</b> strange	<b>b</b> bottom	<b><math>\gamma</math></b> photon	
		<b>e</b> electron	<b><math>\mu</math></b> muon	<b><math>\tau</math></b> tau	<b>Z</b> Z boson	
LEPTONS		$< 2.2 \text{ eV}/c^2$	$< 1.7 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$\approx 80.39 \text{ GeV}/c^2$	
		0	0	0	$\pm 1$	
		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
		<b><math>\nu_e</math></b> electron neutrino	<b><math>\nu_\mu</math></b> muon neutrino	<b><math>\nu_\tau</math></b> tau neutrino	<b>W</b> W boson	
					GAUGE BOSONS VECTOR BOSONS	
					SCALAR BOSONS	



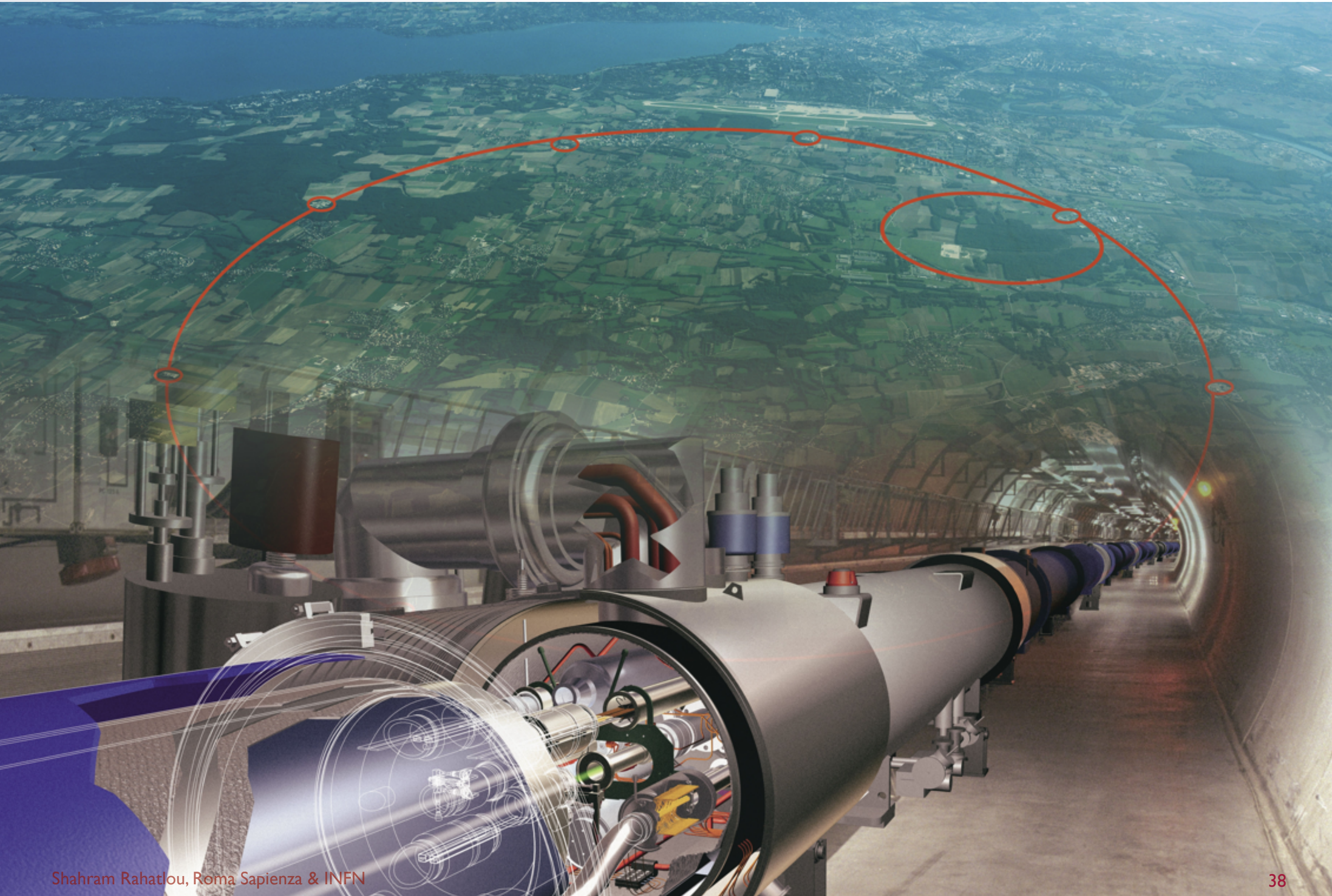
# Modello Standard



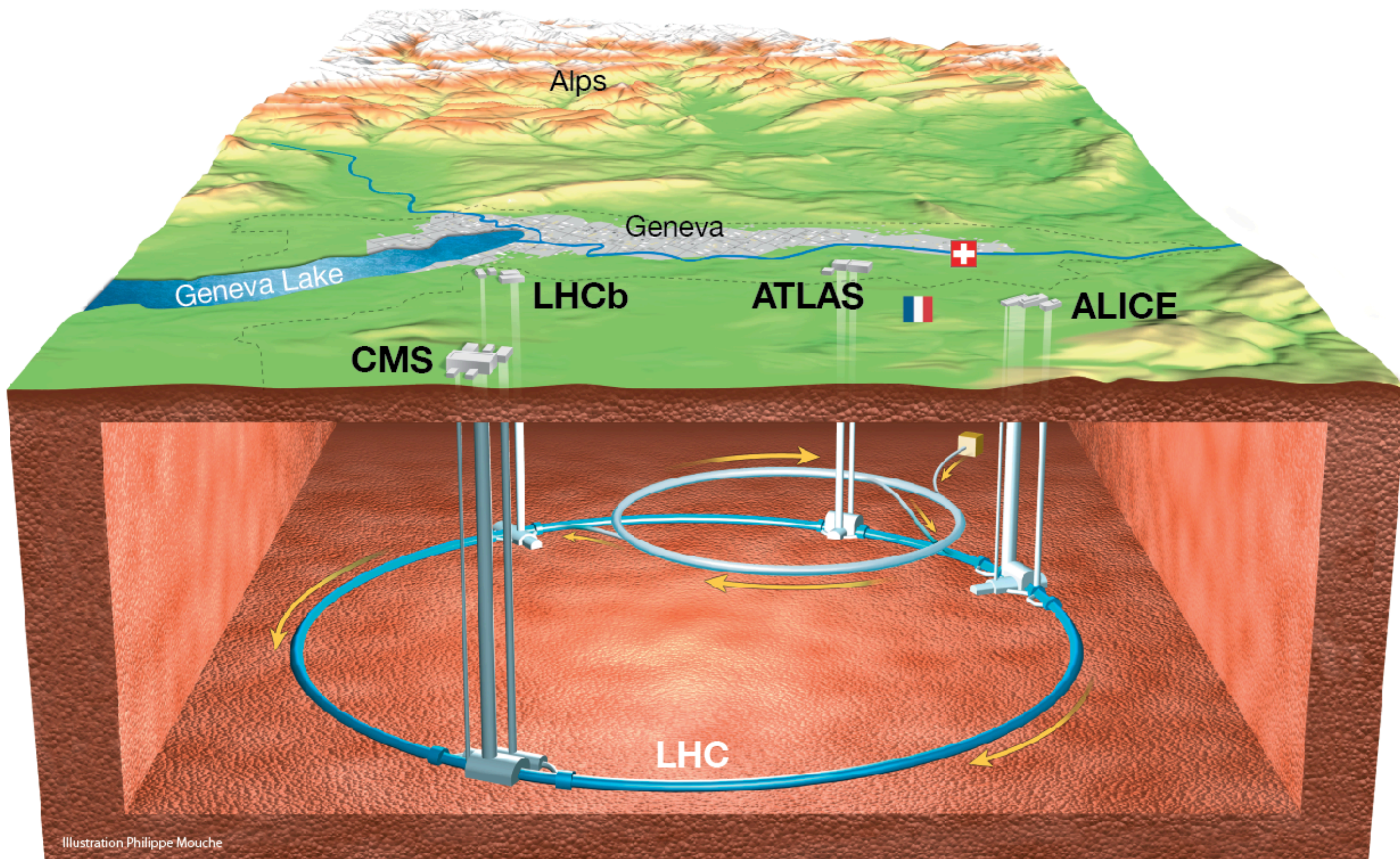
Descrive le interazioni elettromagnetiche, deboli e forti che governano tutti i fenomeni osservati



# Studio di interazioni con Large Hadron Collider







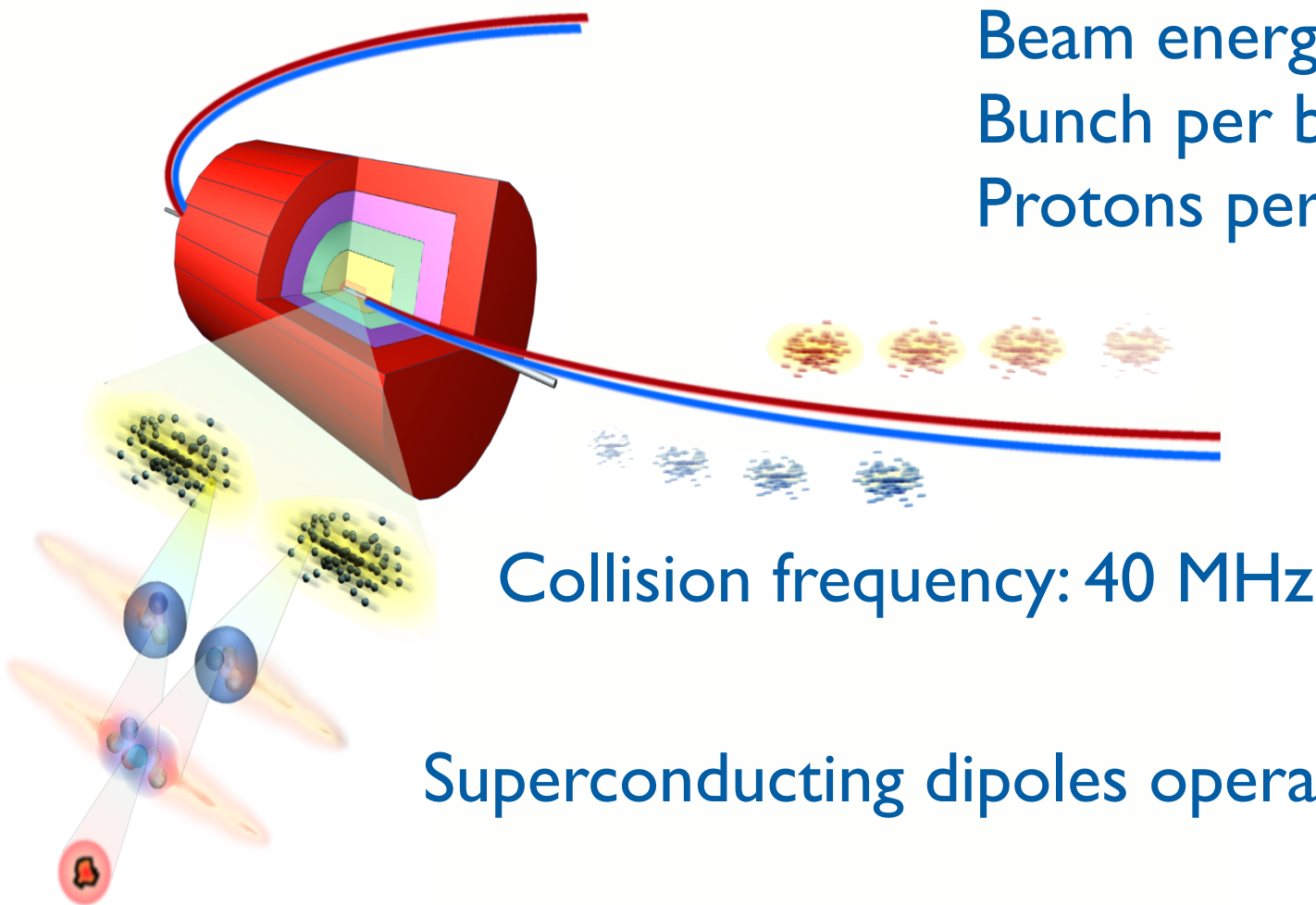


# Four Experiments at LHC





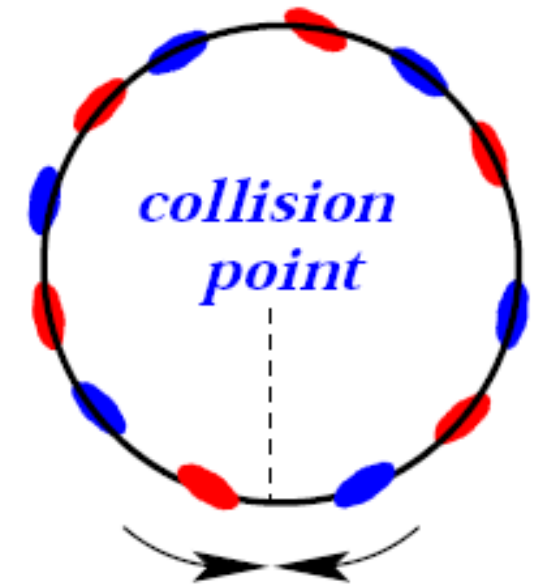
# Facts About LHC



Beam energy: 7 TeV  
Bunch per beam: 2835  
Protons per beam:  $10^{11}$

Collision frequency: 40 MHz

Superconducting dipoles operated at 1.9 K



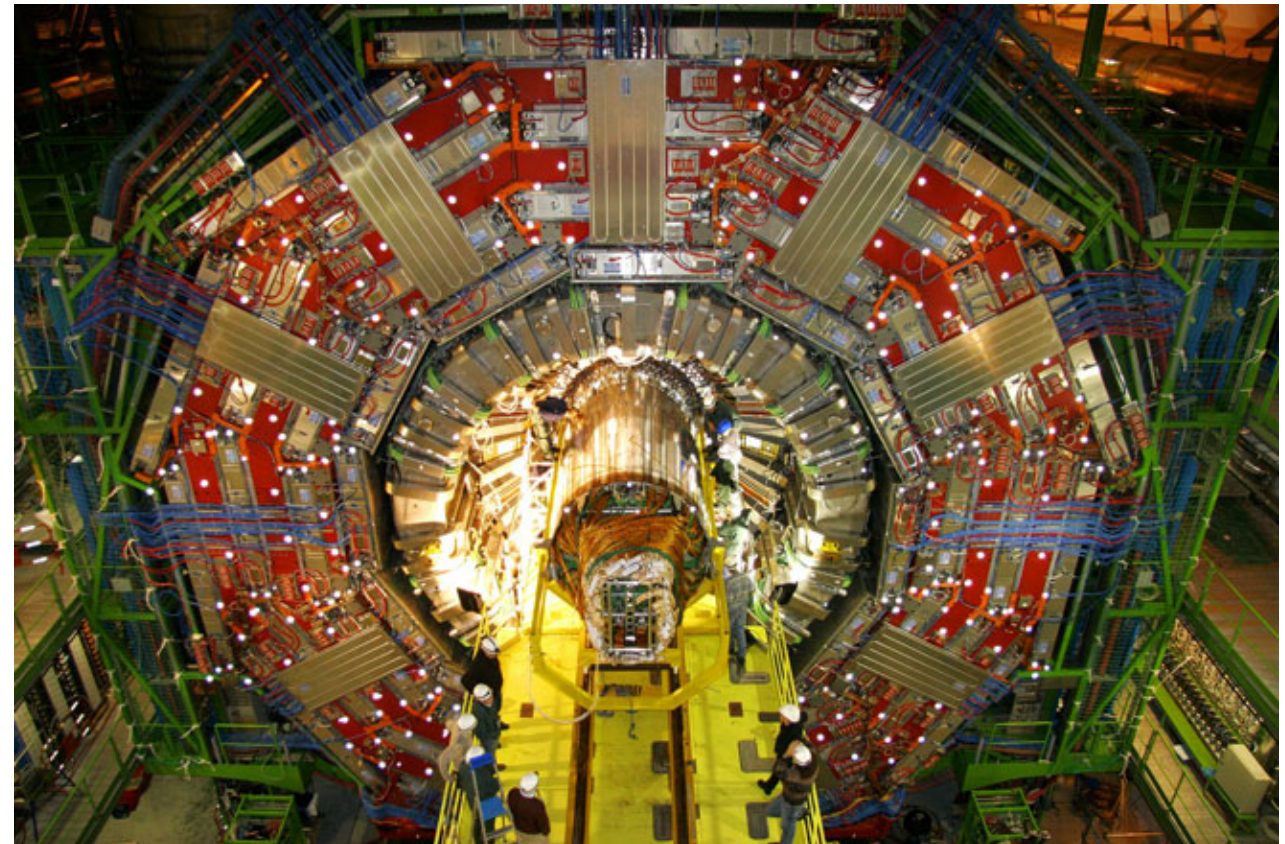
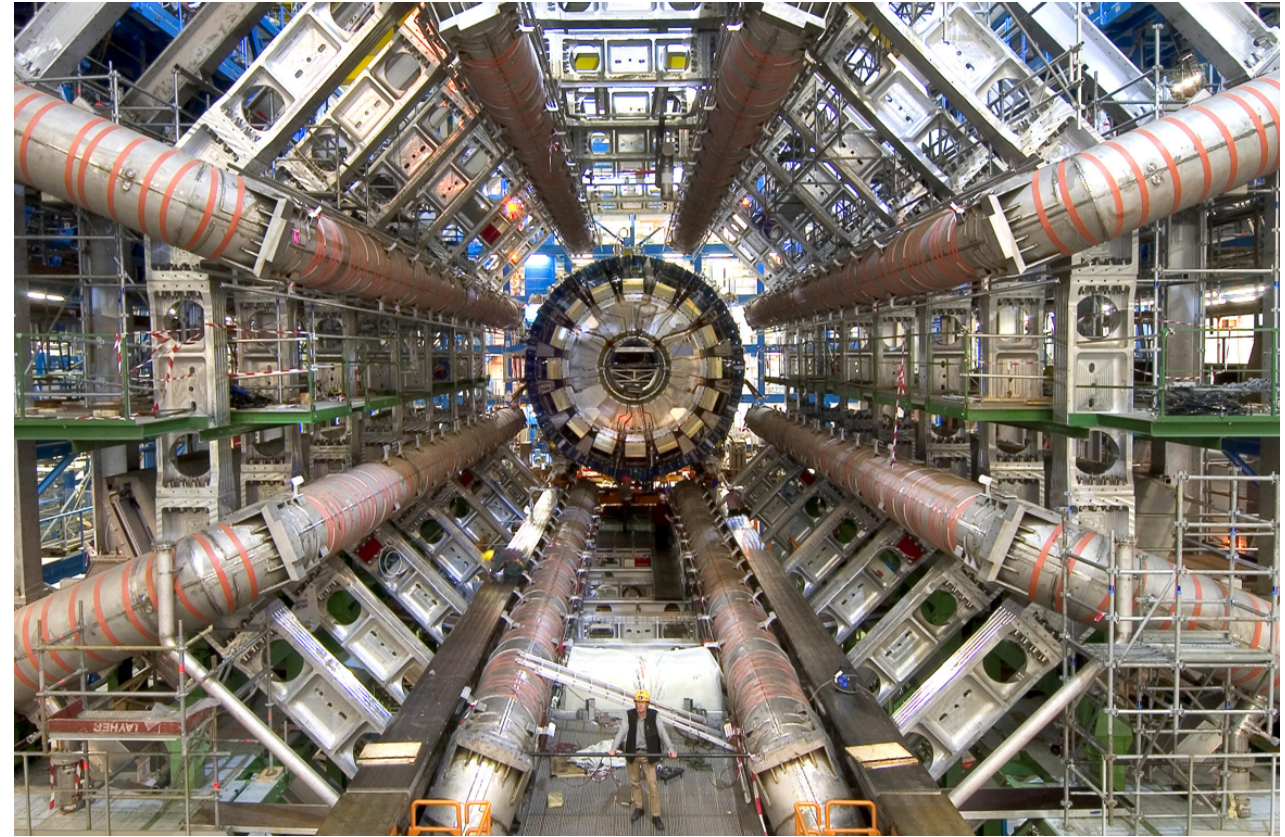
- ▷ Energy stored in LHC magnets when operating at 14 TeV: 10.4 GJ
  - Enough to melt 12 tons of Copper!
  - The kinetic energy of an A380 at 700 km/hour
- ▷ Kinetic energy of 1 proton bunch: 129 kJ
- ▷ Kinetic energy of beam: 362 MJ





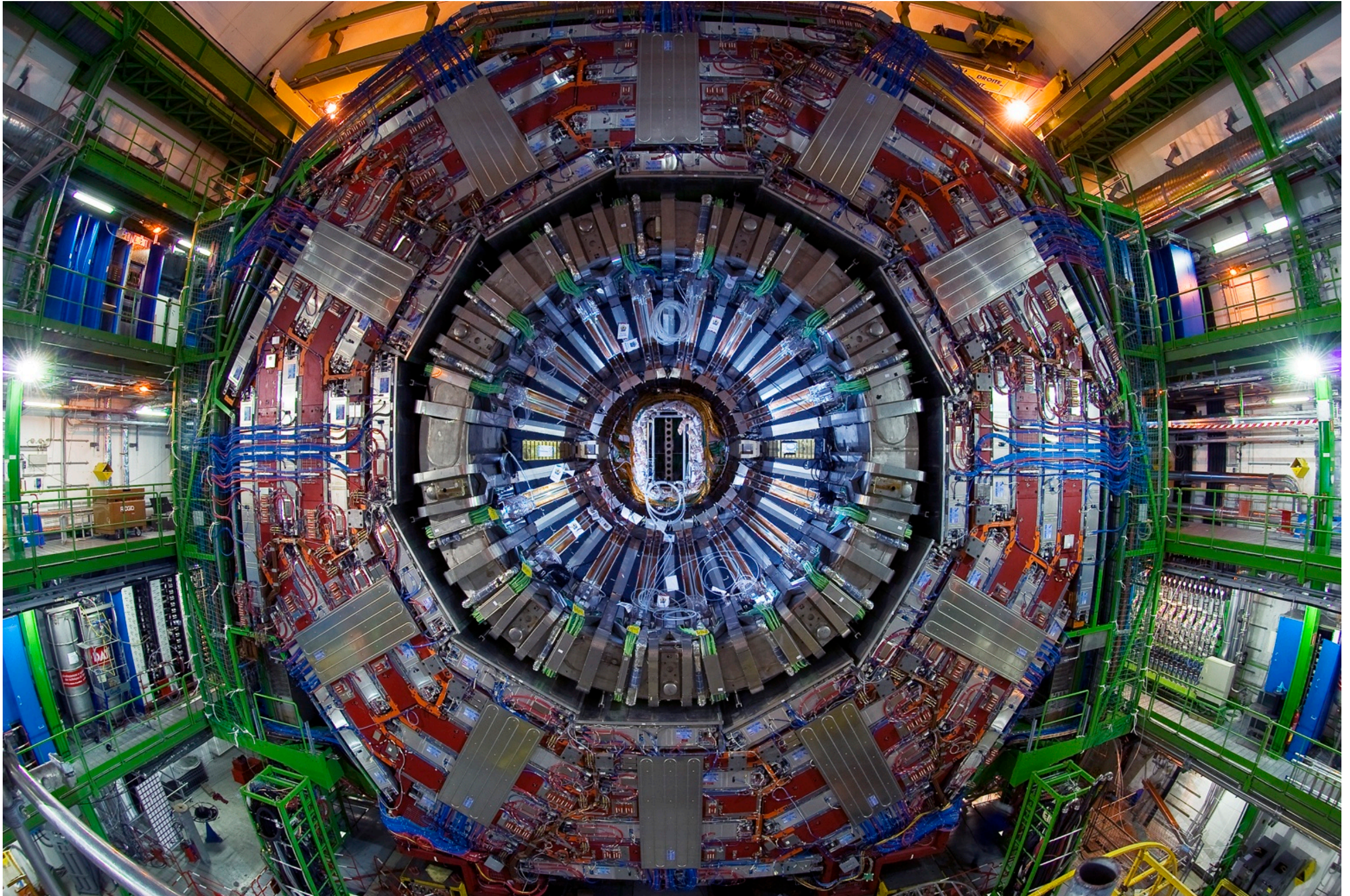
# Gigantic Digital Camera

- ▷ Very heavy digital camera
  - 40 million pictures per second
  - Almost 100 million pixels
  - 3D pictures
- ▷  $>100'000$  of CPUs used to quickly filter data
  - 10'000 pictures selected each second
- ▷ Only 1000 pictures stored on disk
  - pictures selected within 100 ms
- ▷ 22 million GigaByte of data each year ( $>1$  million DVD)
  - Data hosted and analyzed at computing centers worldwide
    - Sapienza Roma is part of the network



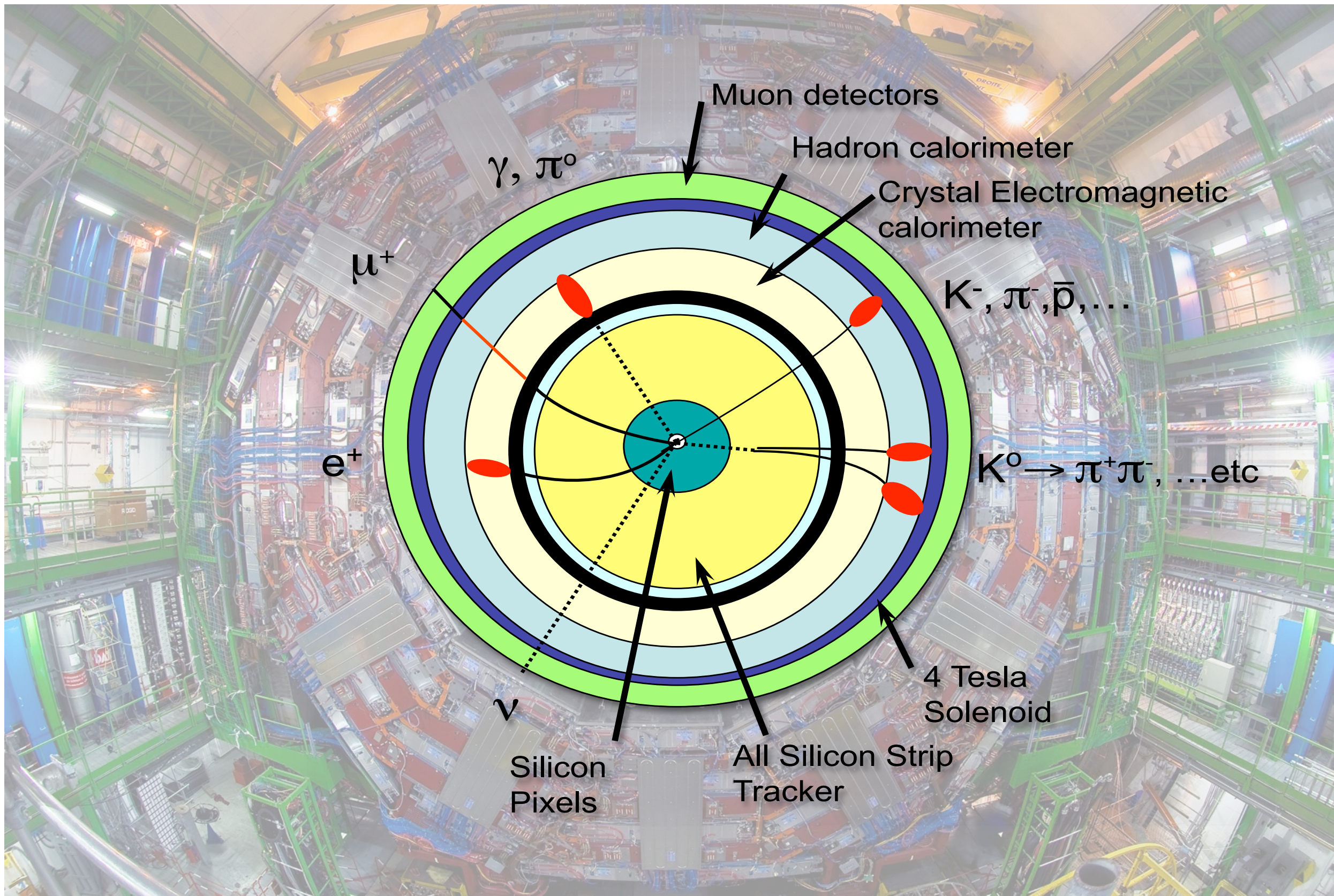


# Compact Muon Solenoid



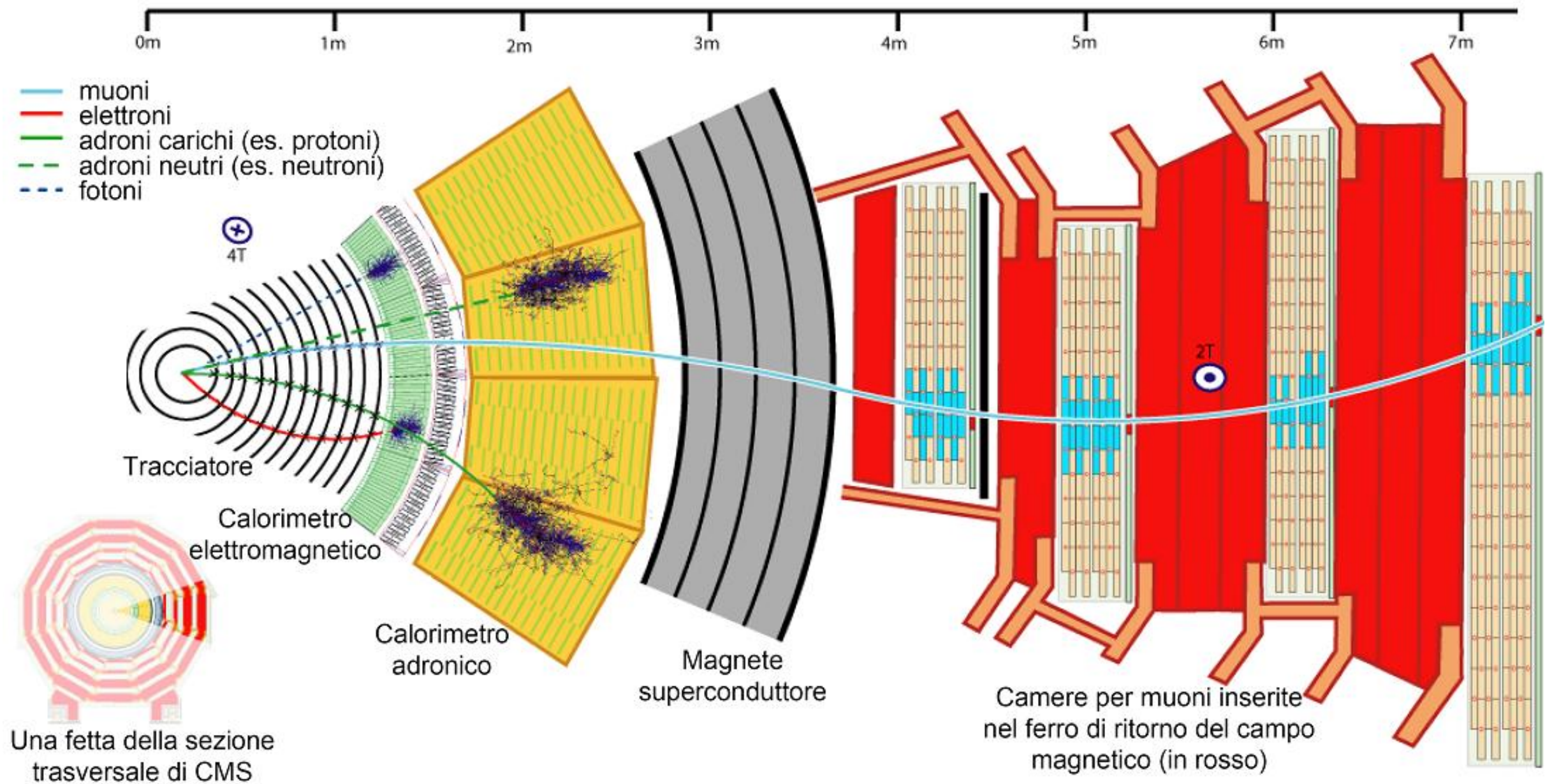


# Compact Muon Solenoid



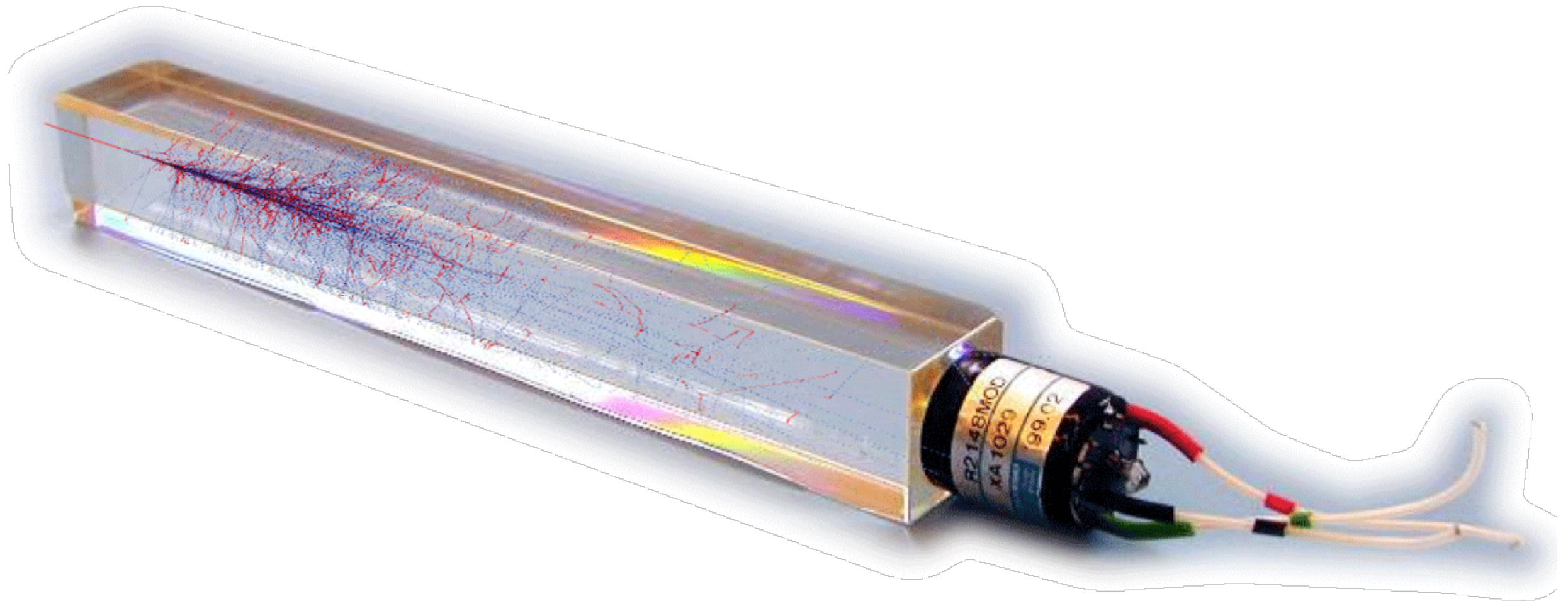


# Particle Detection and Identification



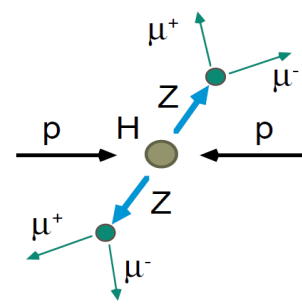
- ▷ Detectors record signals from charged particles and photons
- ▷ Simple kinematics with **momentum** and **energy**
- ▷ Energy and momentum **conservation** used to discriminate signal and background

# Interazione elettromagnetica

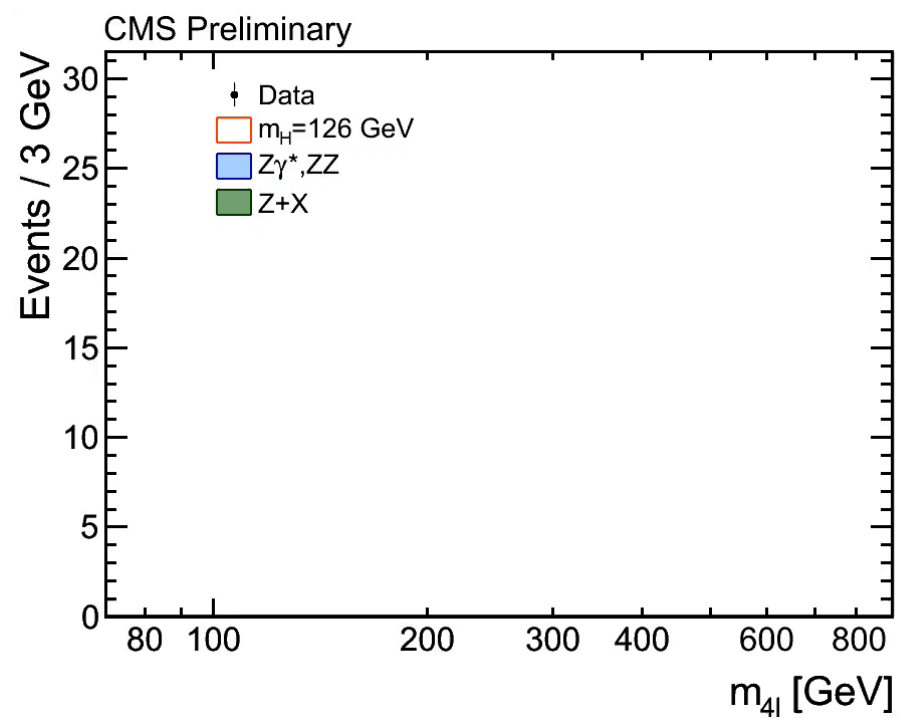
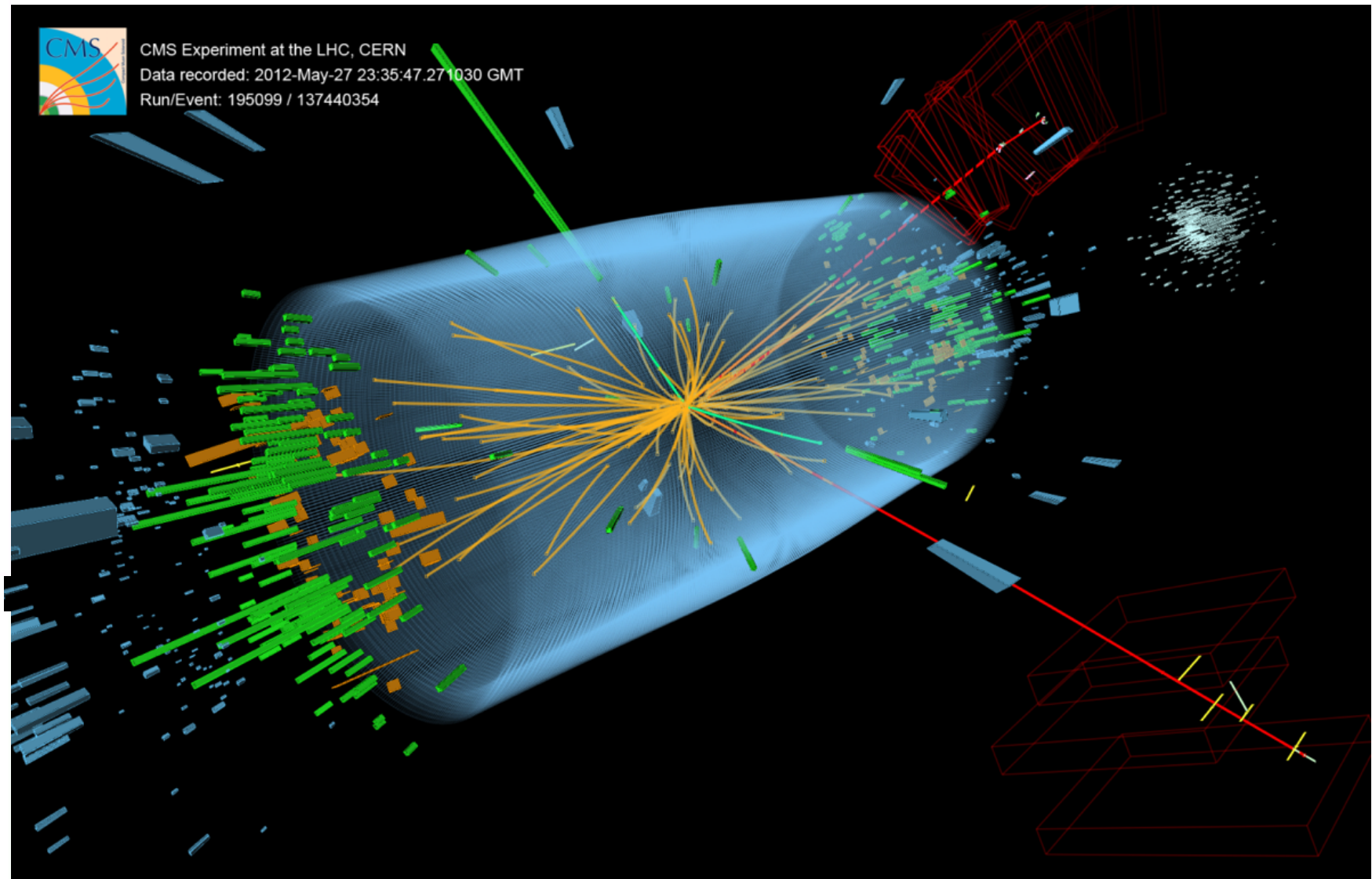
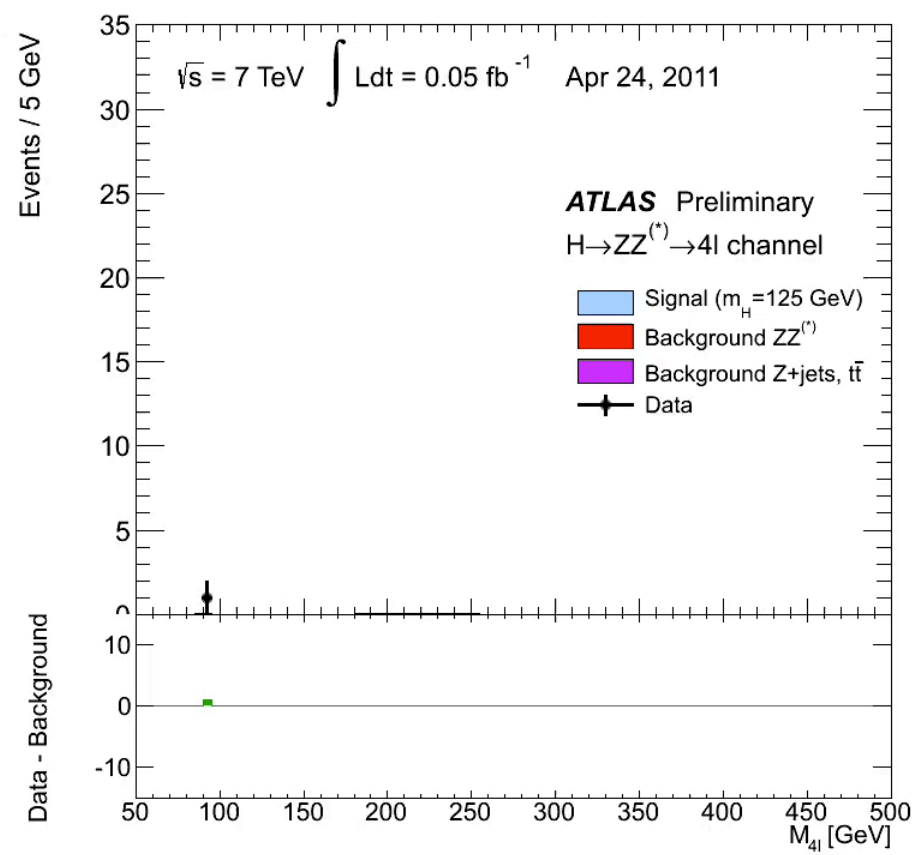




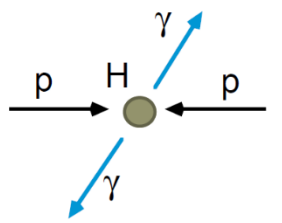
# Higgs decay to ZZ (leptons)



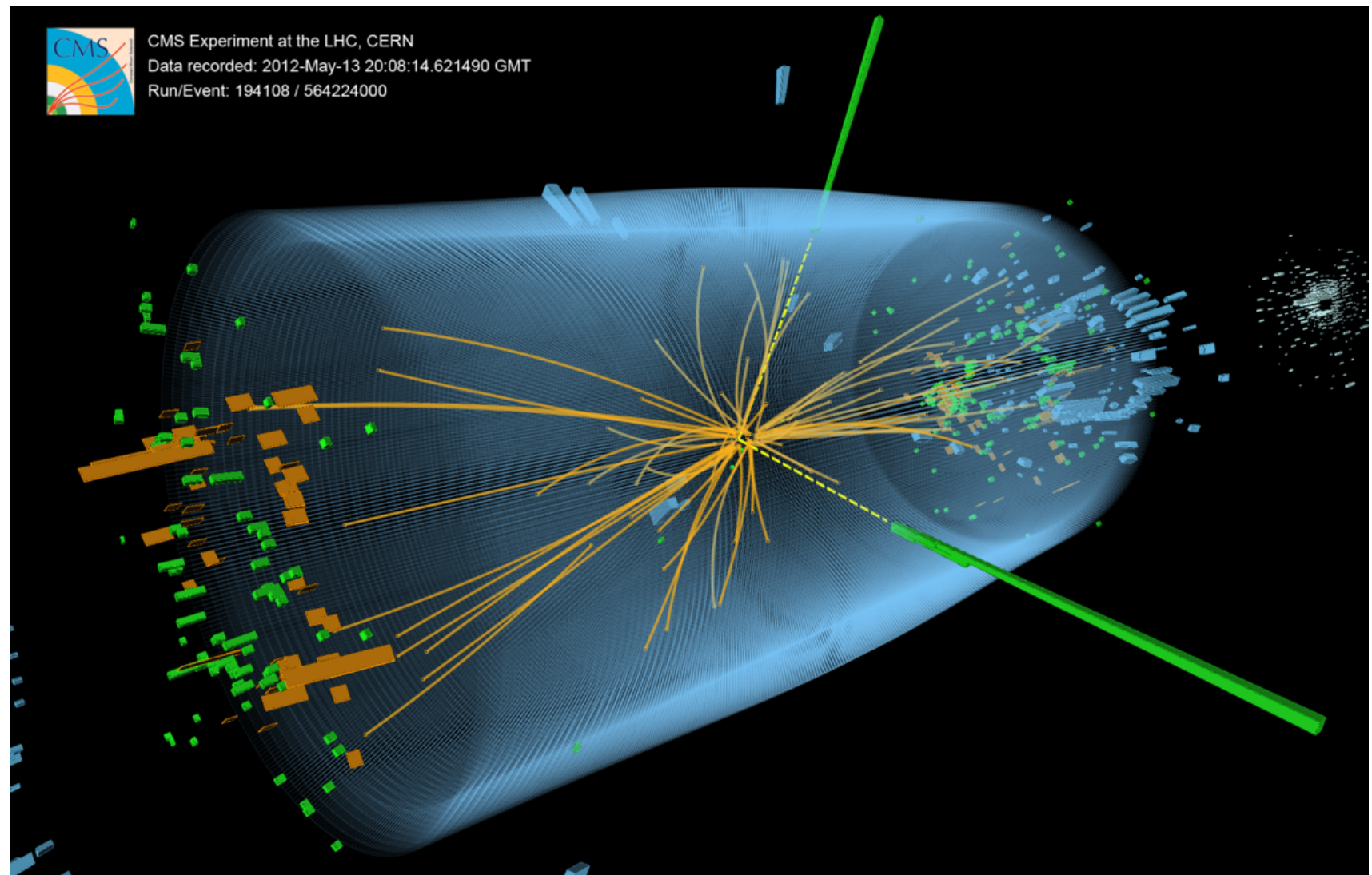
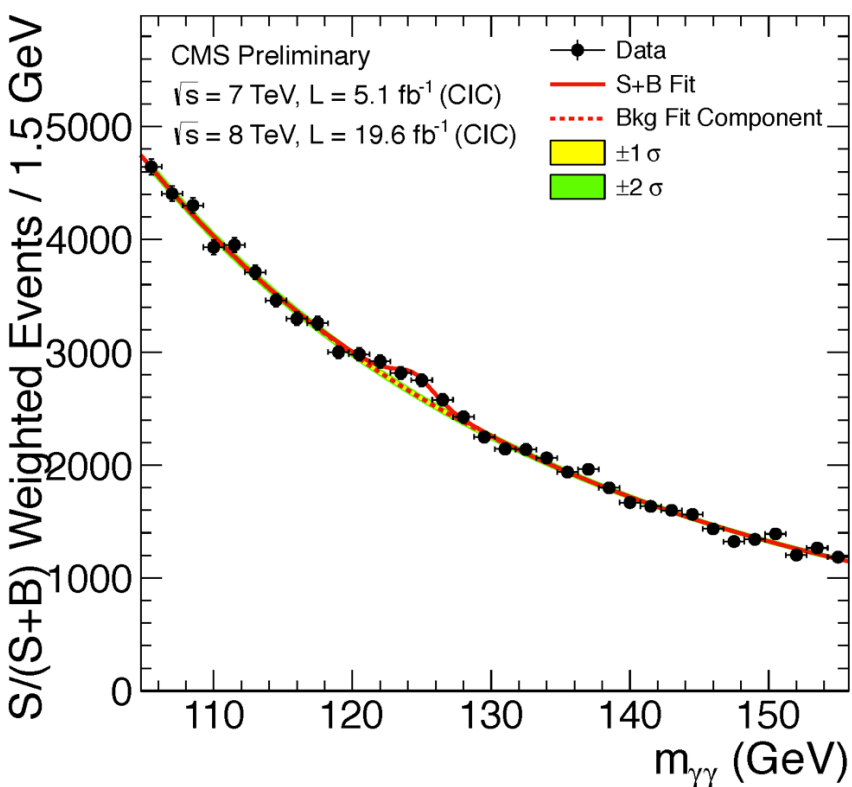
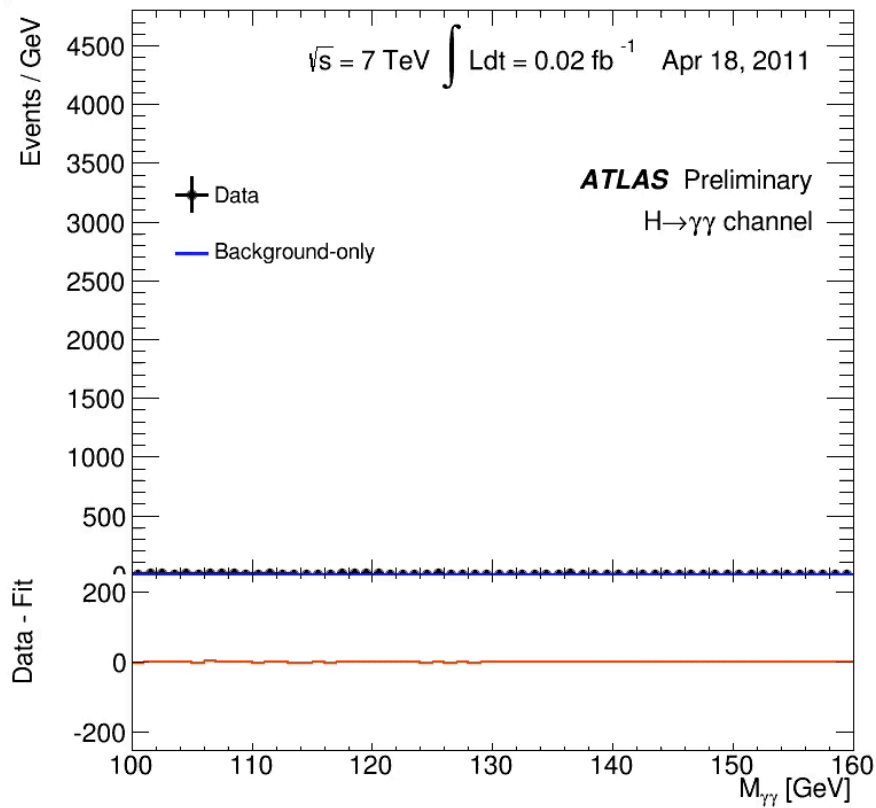
$$mass = \sqrt{\vec{p}_1^2 + \vec{p}_2^2 + \vec{p}_3^2 + \vec{p}_4^2}$$



# Higgs decay to Photons



$$mass = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1 - \cos \theta_{12})}$$



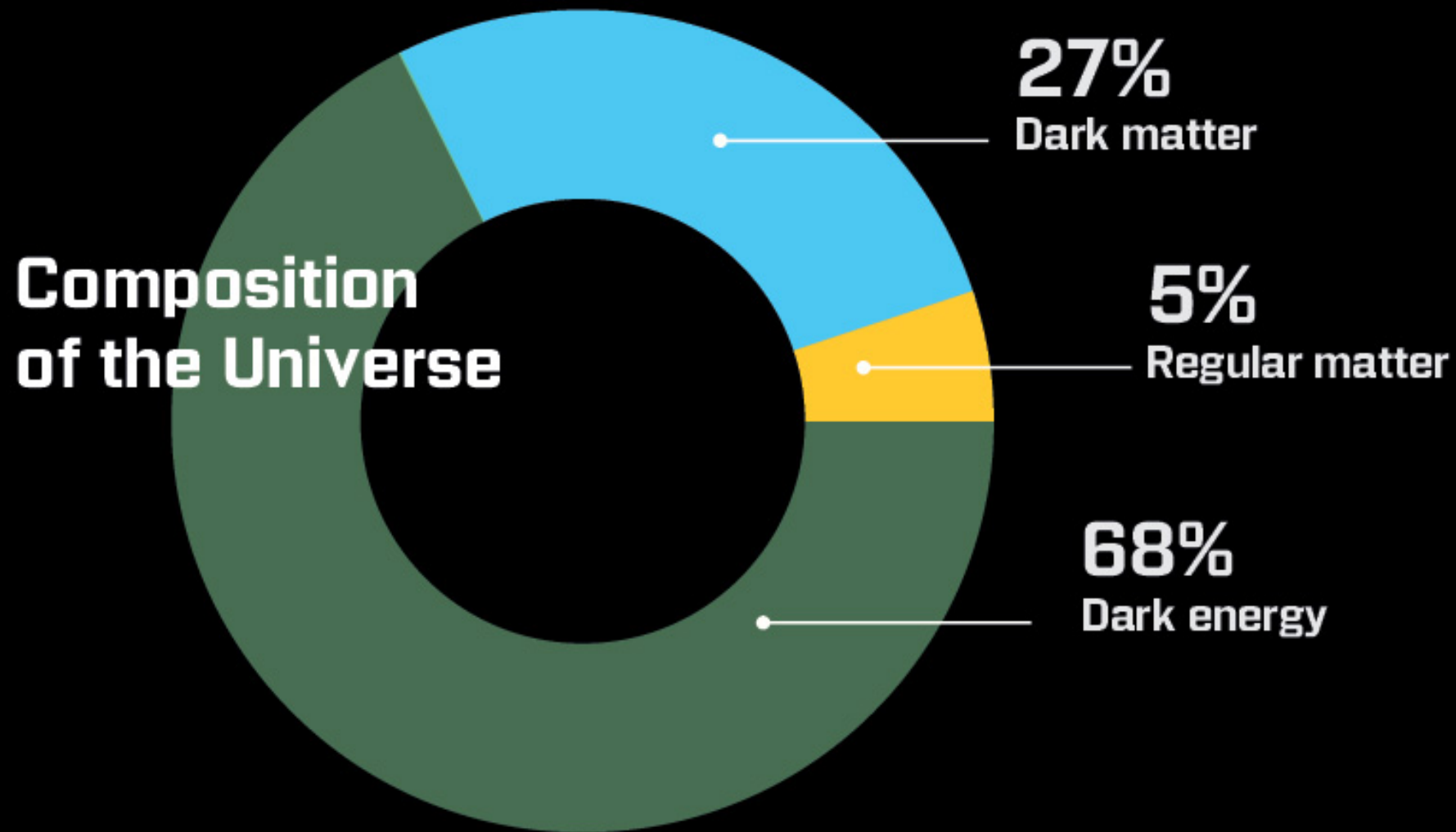




Dark

Matter

# UNIVERSE COMPOSITION



- Strong astrophysical evidence for the existence of dark matter
  - Evidence from bullet cluster, gravitational lensing, rotation curves
  - Dark Matter 5 times more abundant than baryons
  - Contributes  $\sim 1/4$  of the total energy budget!



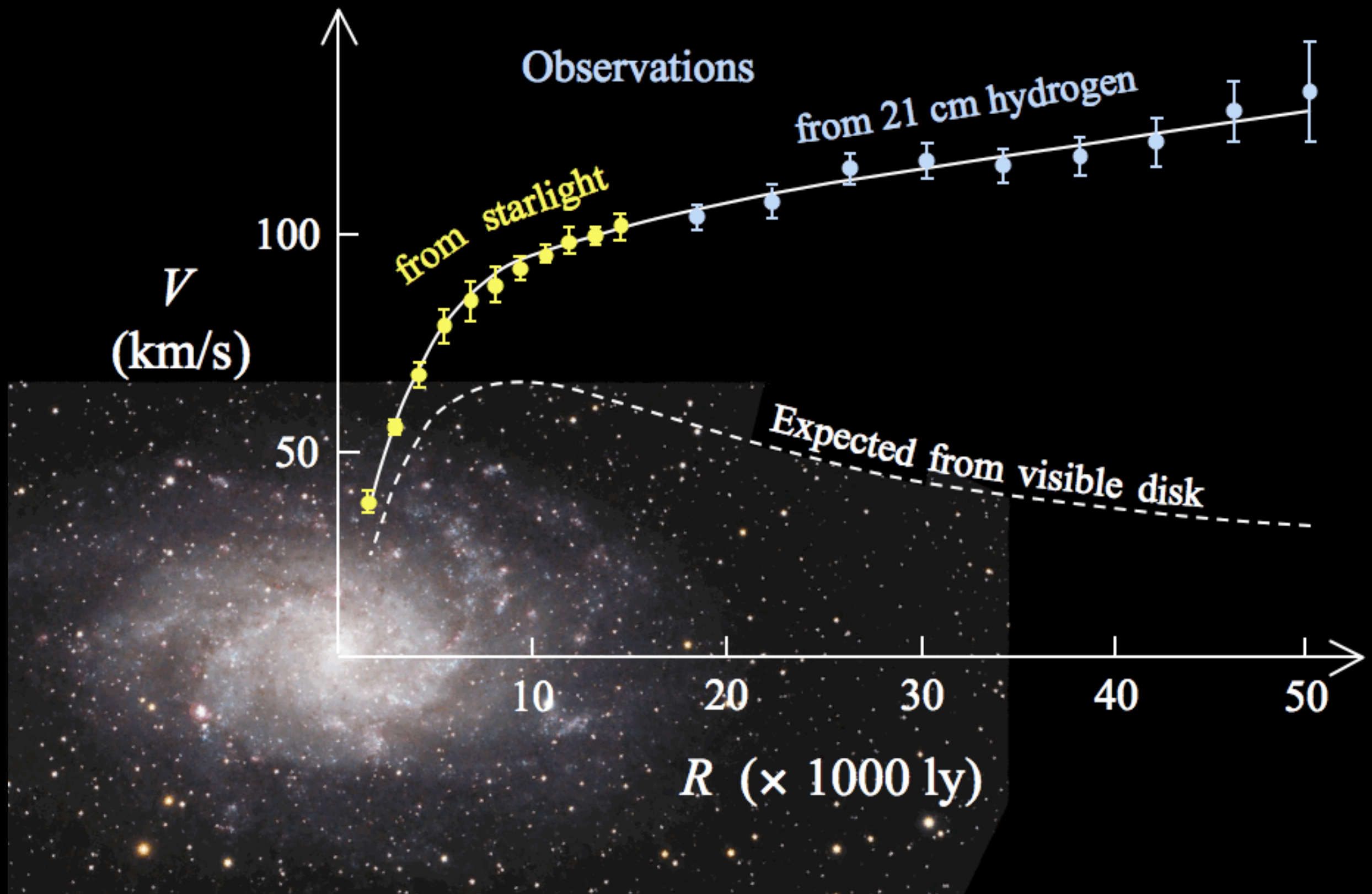
# First Indications of Dark Matter

In 1933, Fritz Zwicky calculated the mass of the Coma cluster using galaxies on the outer edge, and came up with a number 400 times larger than expected.

Now we know 90% of its mass due to Dark Matter



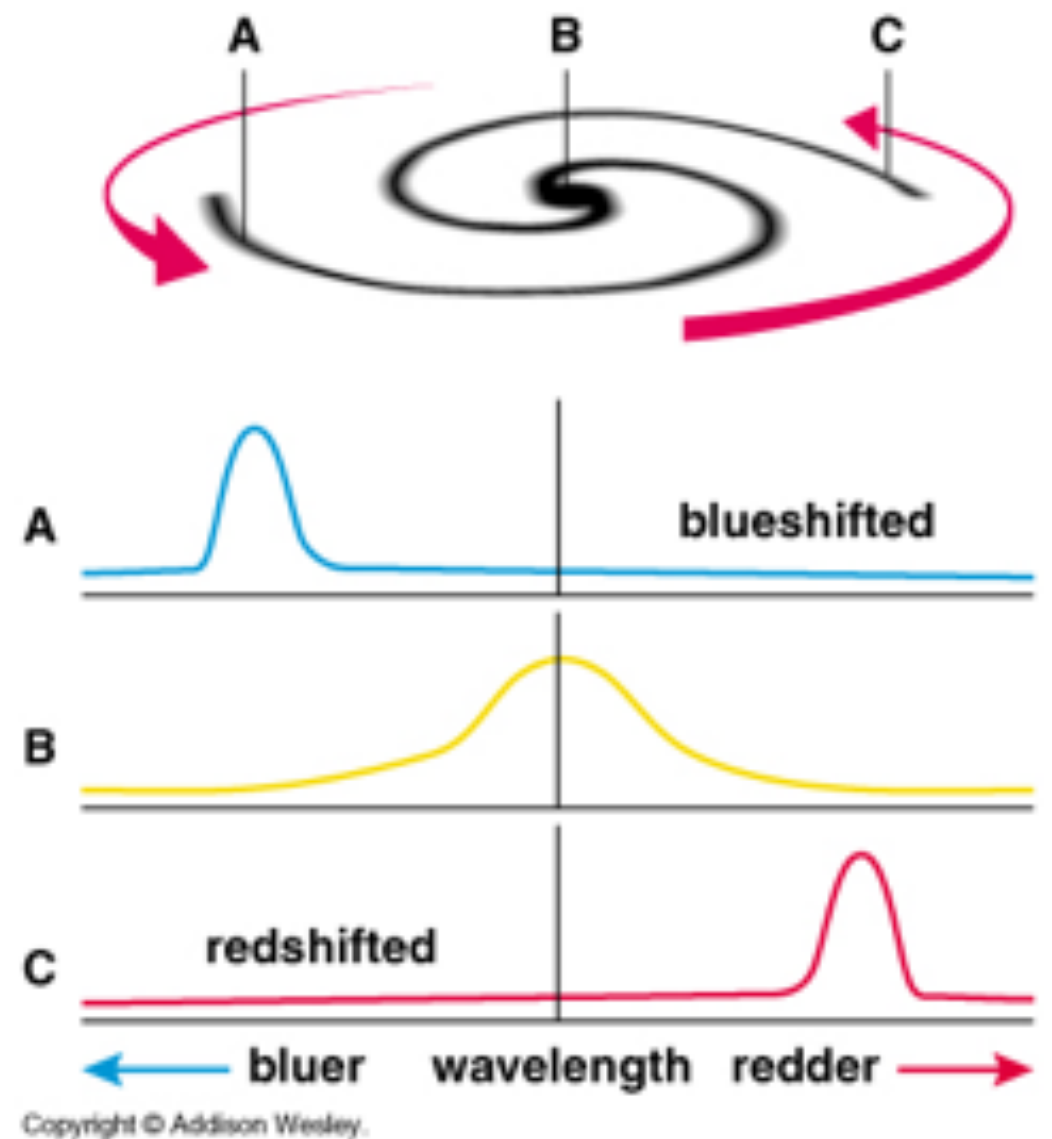
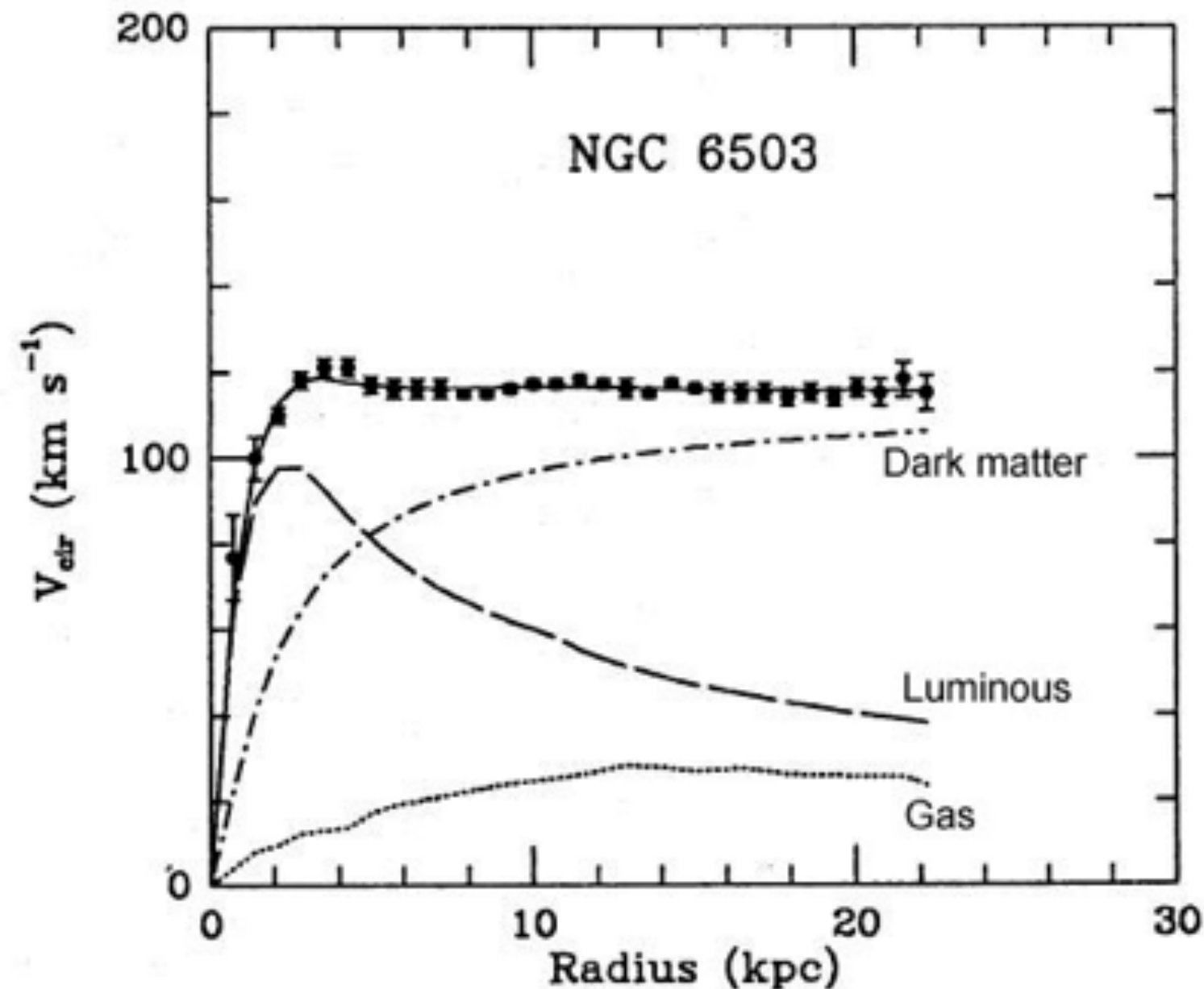
# Galaxy Rotation





# Galactic Rotation

- ▷ Starting in 1970's, first measurements of velocity curve of edge-on spiral galaxies
- ▷ Velocity found to be flat, consistent with  $\sim 10x$  as much "dark" mass for more than one galaxy



# Galactic Rotation Velocity

▷ For a star of mass  $m$  at distance  $r$  from center of the galaxy

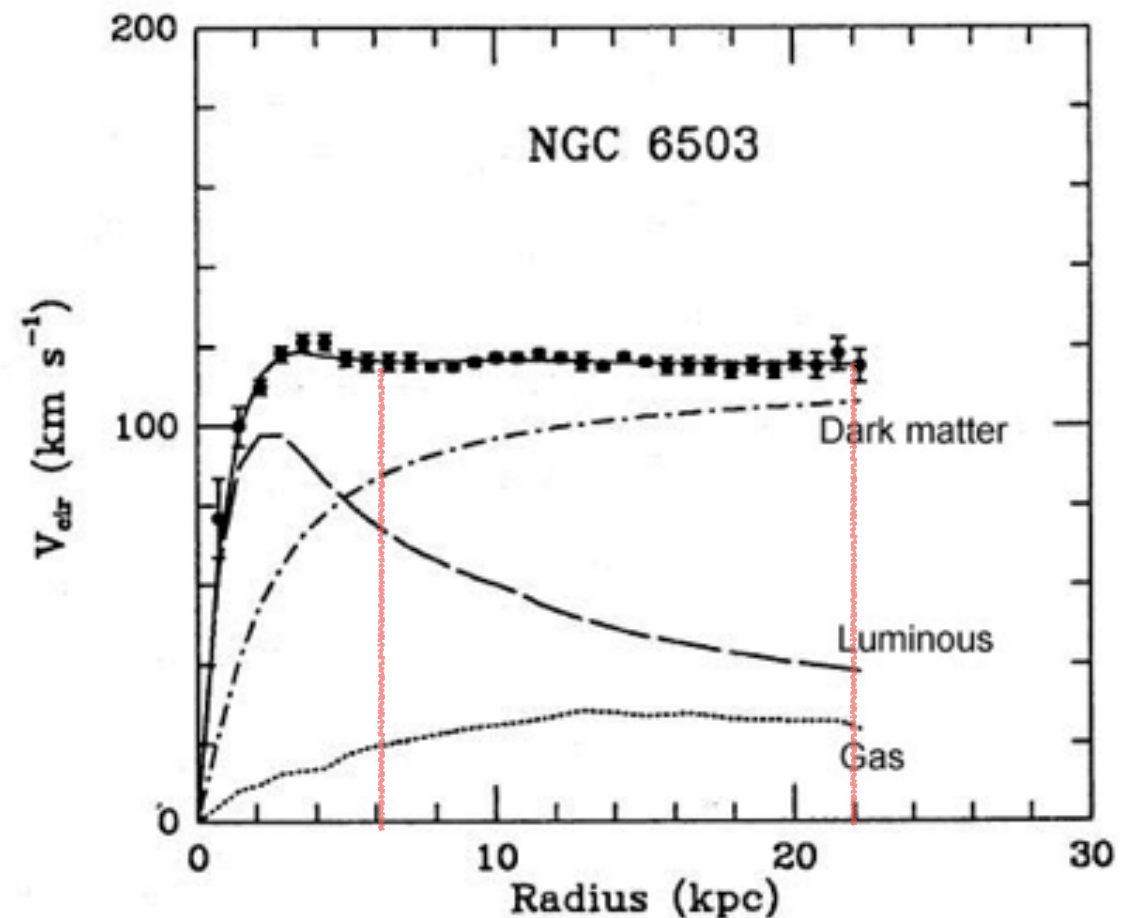
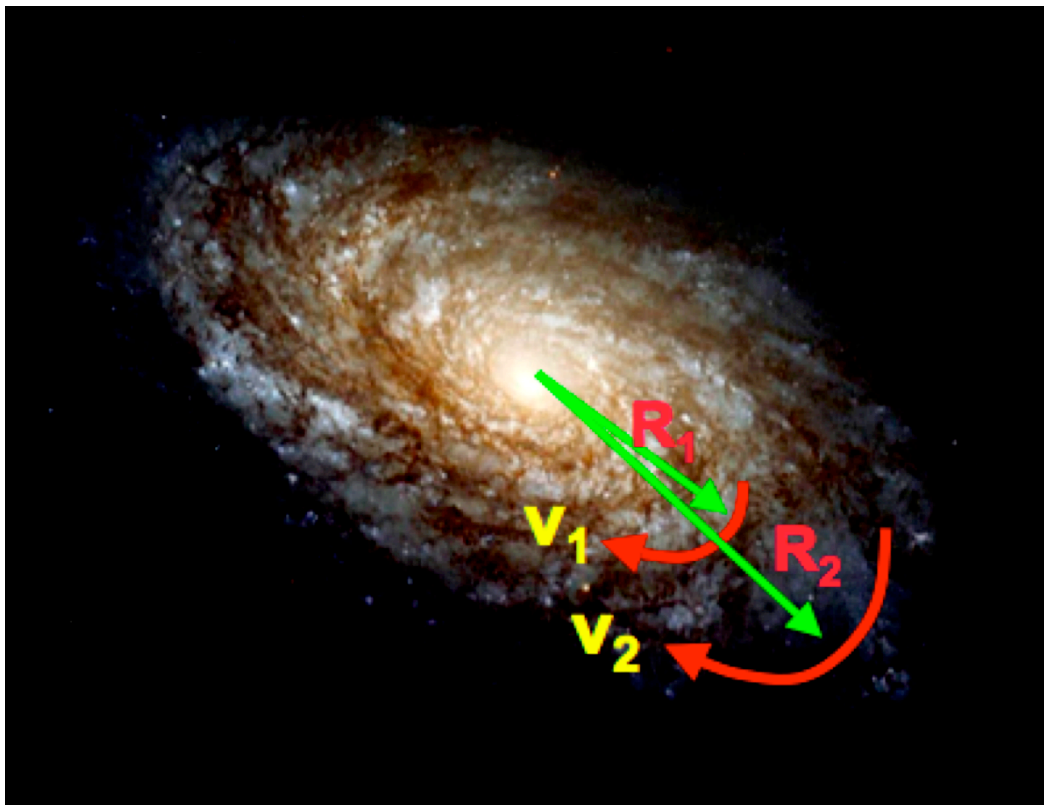
$$\frac{mv^2(r)}{r} = \frac{mM(r)G}{r^2}$$

▷ Galaxy mass mainly within core radius of  $R_0$

$$M(r) = \begin{cases} \rho r^3 & r < R_0 \\ \rho R_0^3 & r \geq R_0 \end{cases}$$

▷ Galaxy rotation velocity

$$v(r) = \begin{cases} \propto r & r < R_0 \\ \propto r^{-1/2} & r \geq R_0 \end{cases}$$



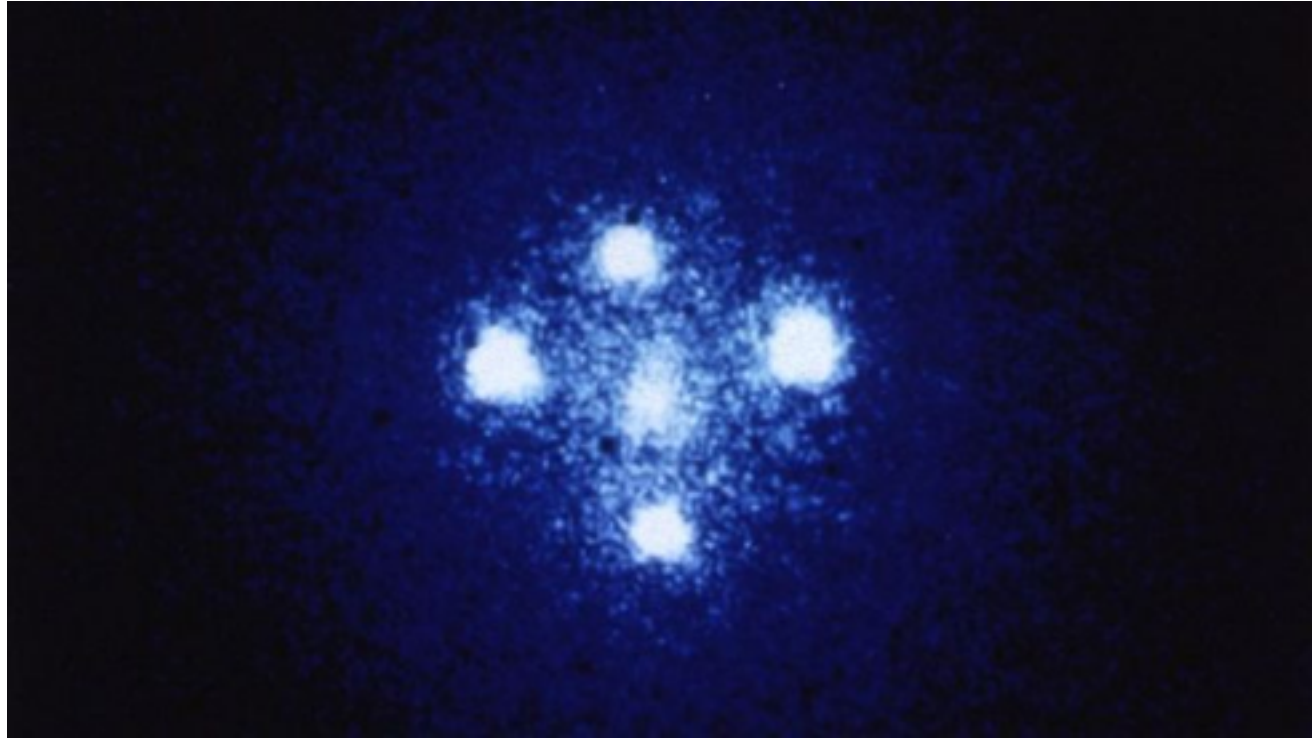
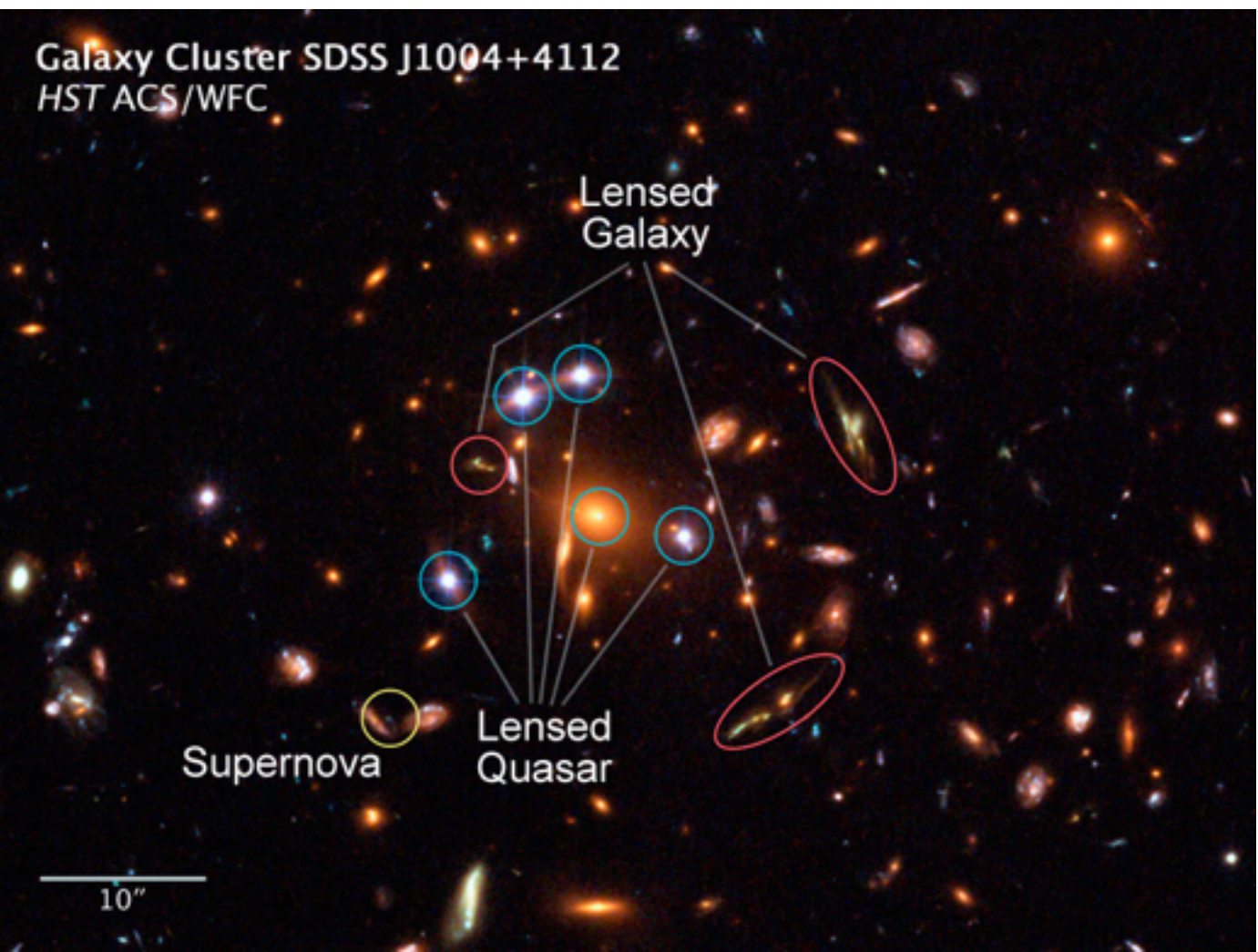
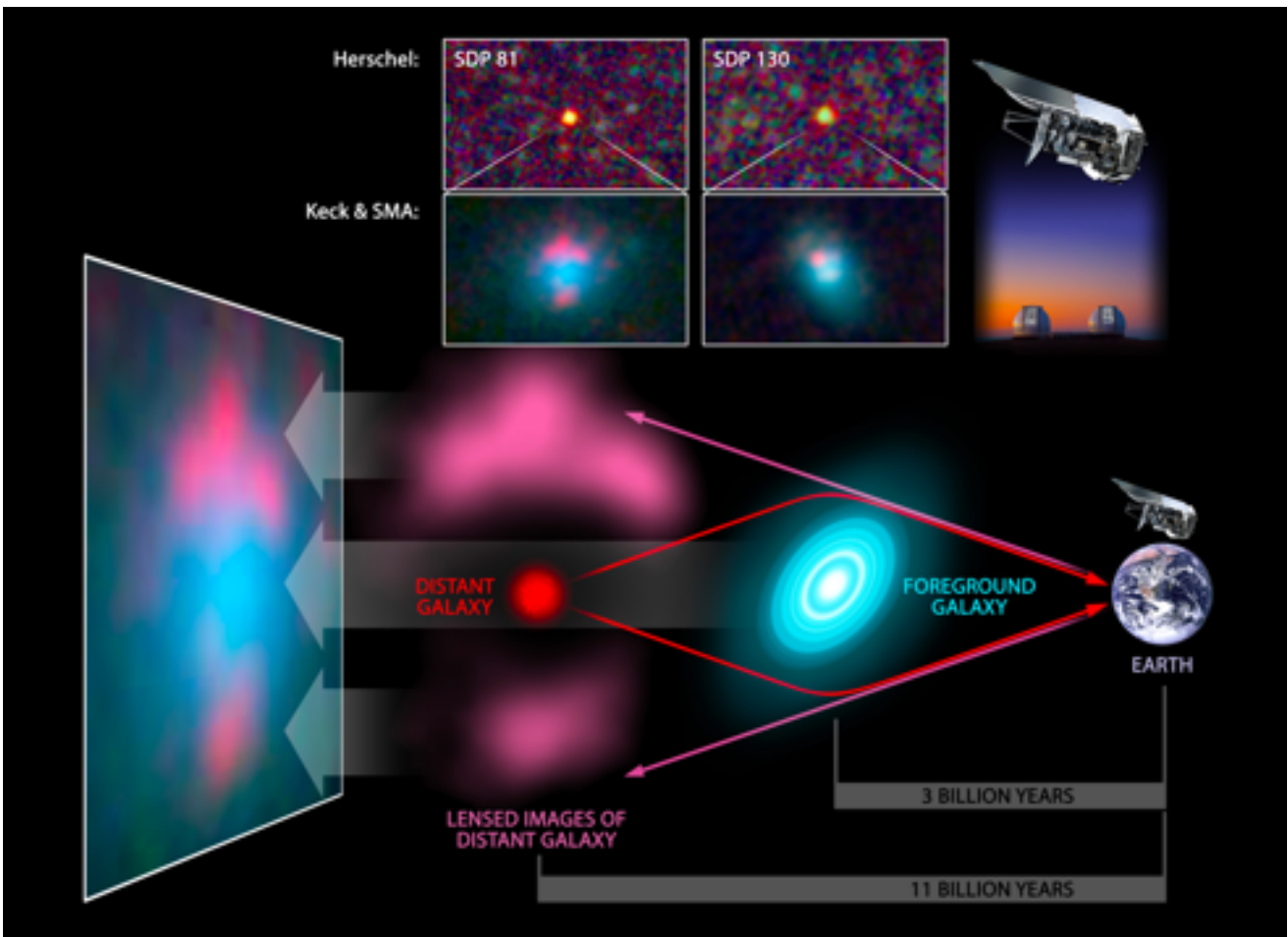


# Dark Matter Halo



# Gravitational Lensing

- ▷ visible mass not sufficient to explain observed lensing effects





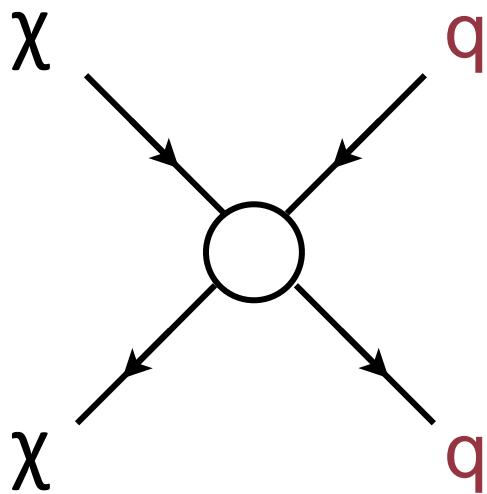
# Bullet Cluster



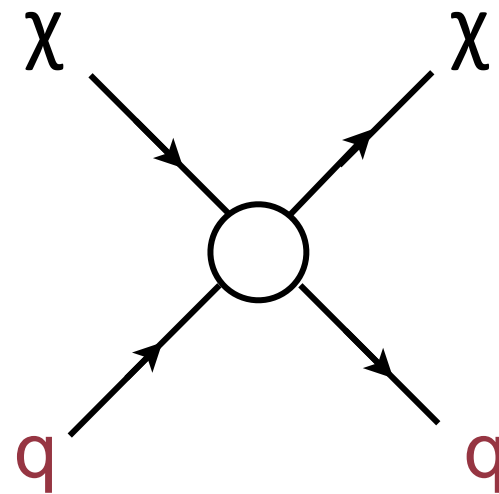
- Collision of galaxies in bullet cluster
  - lensing of background objects suggest at least 10x more Dark matter than visible mass

# Interazione di Materia Oscura

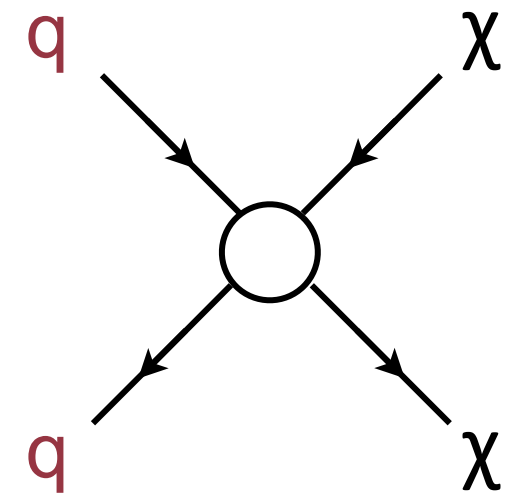
- ▷ Non sappiamo ancora come interagisce con la materia ordinaria
- ▷ Il tipo di interazione determina la quantità di materia oscura oggi nel nostro universo



*Indirect Detection*



*Direct Detection*

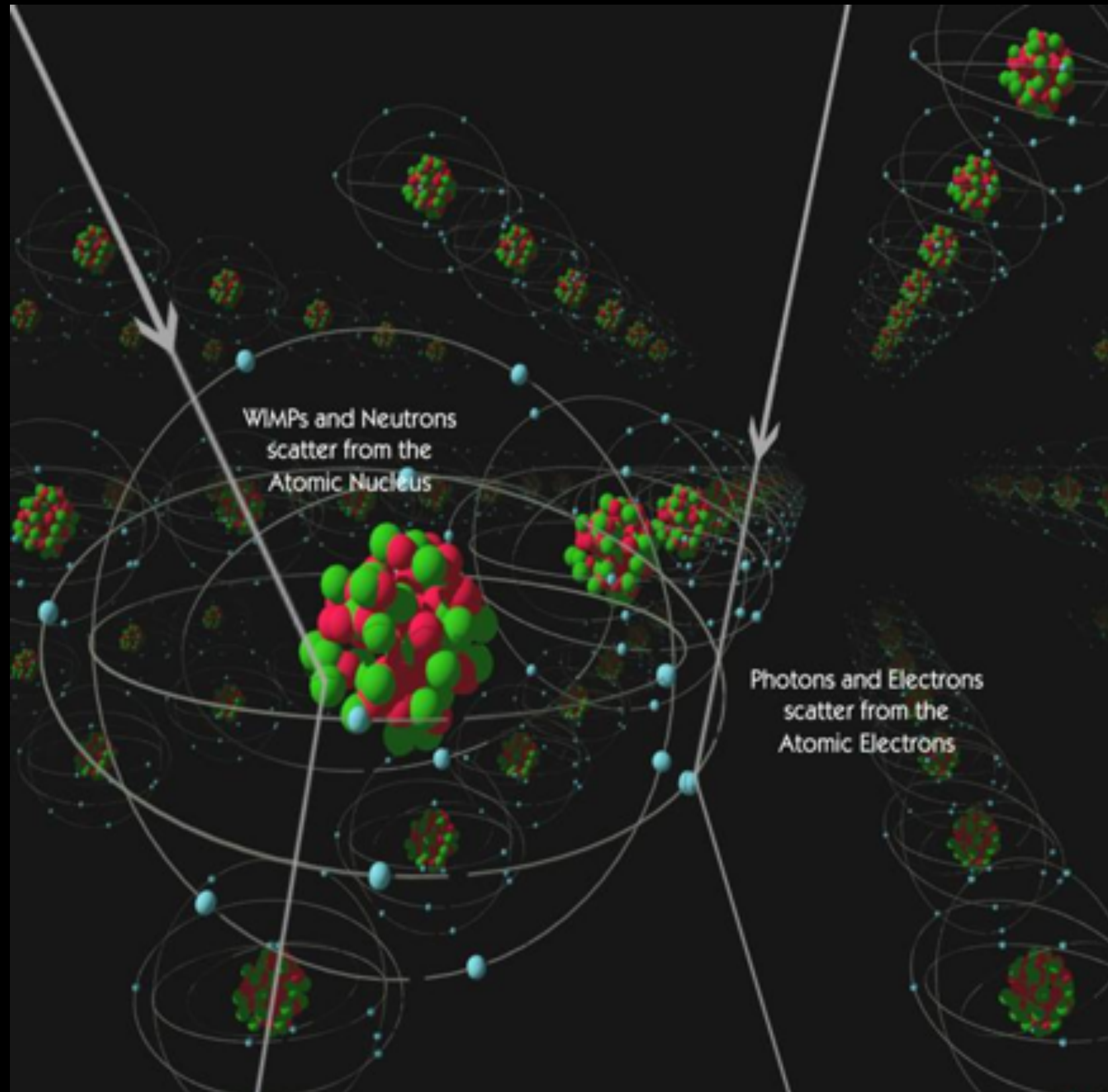


*Production at Colliders*

- ▷ Metodi sperimentali diversi per ciascun modo di rivelazione

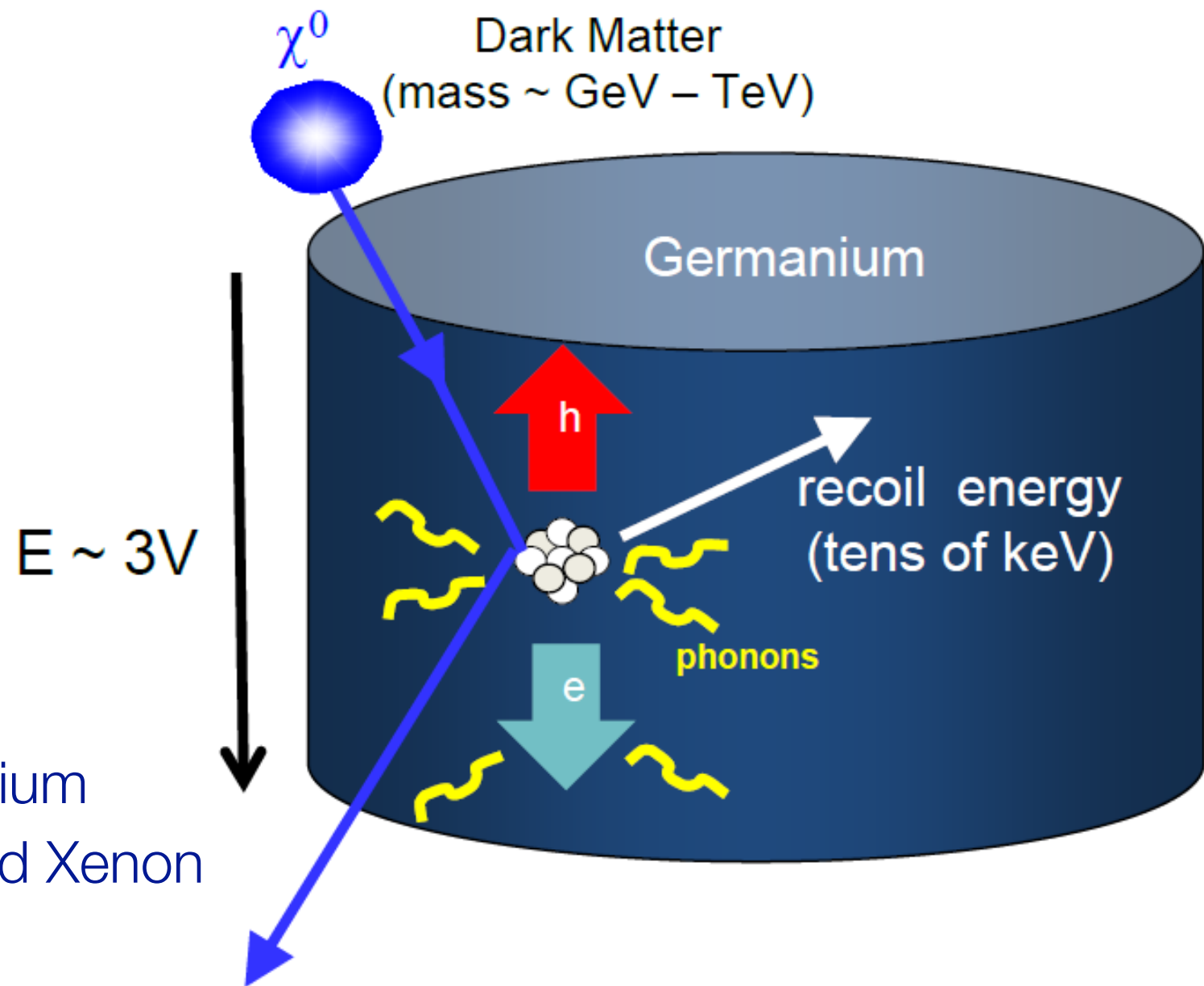
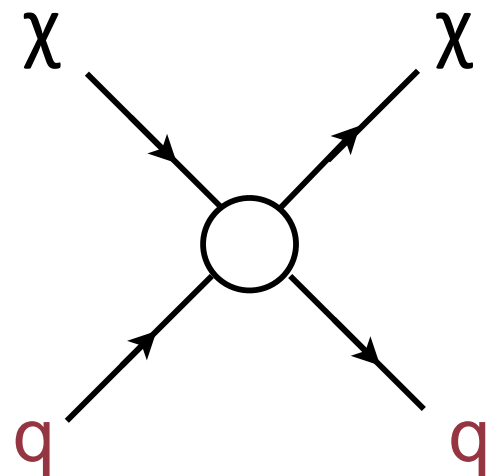


# Metodo diretto (Direct Detection)



# Rivelazione diretta dell'urto

- ▷ Observe recoil of dark matter from nucleus
  - Extremely sensitive, extremely difficult... extremely successful!
  - Limited by threshold effects, energy scale, backgrounds

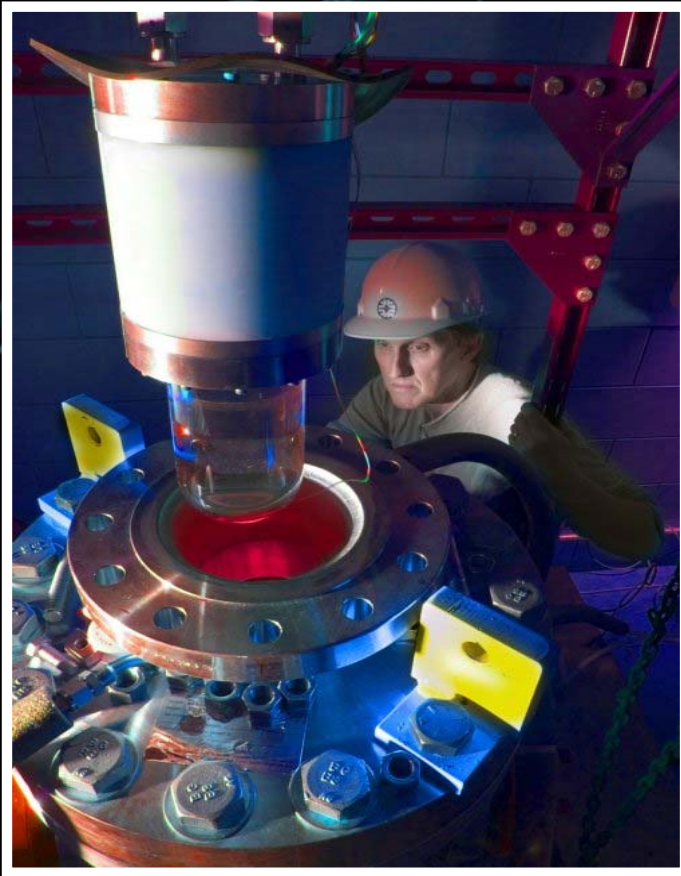


- Detection techniques
  - Heat, vibration: silicon, Germanium
  - Light: NaI, CsI, Liquid Argon and Xenon
  - Charge: Germanium, silicon, Gas and liquid Ar and Xe

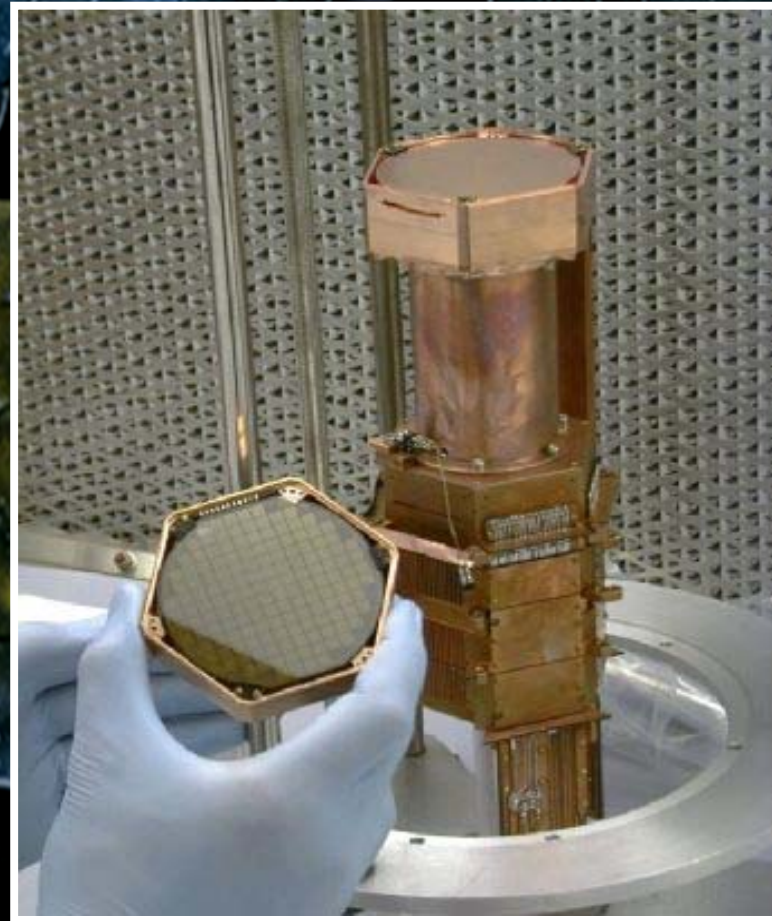


# Direct Detection

COUPP



CDMS



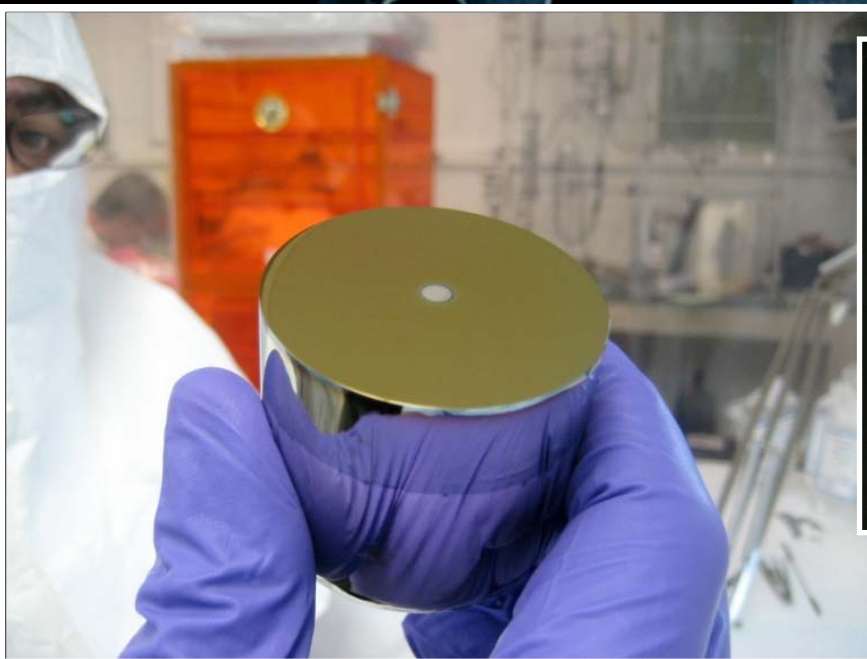
CRESST



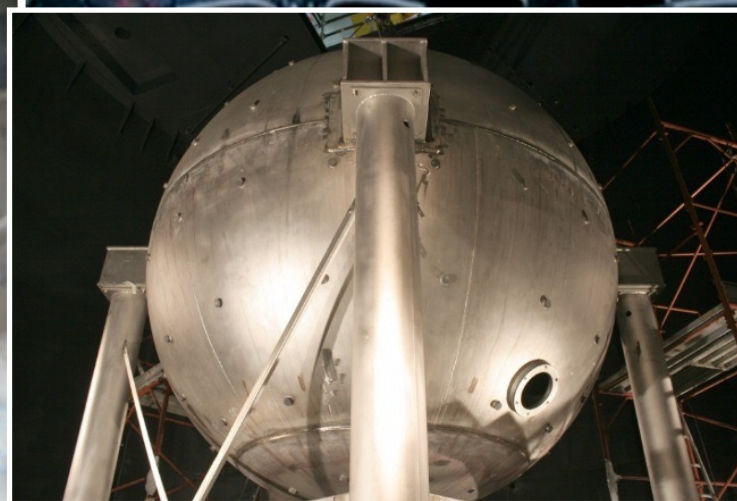
DAMA



CoGeNT



Darkside

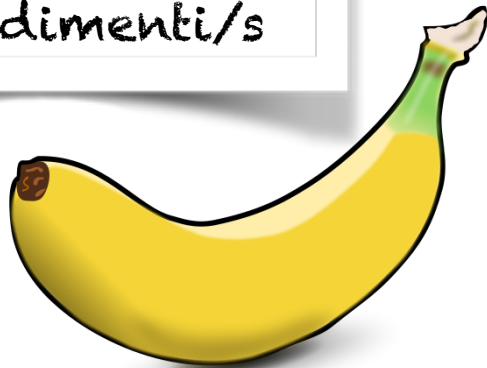




# Fondo naturale dovuto a radioattività

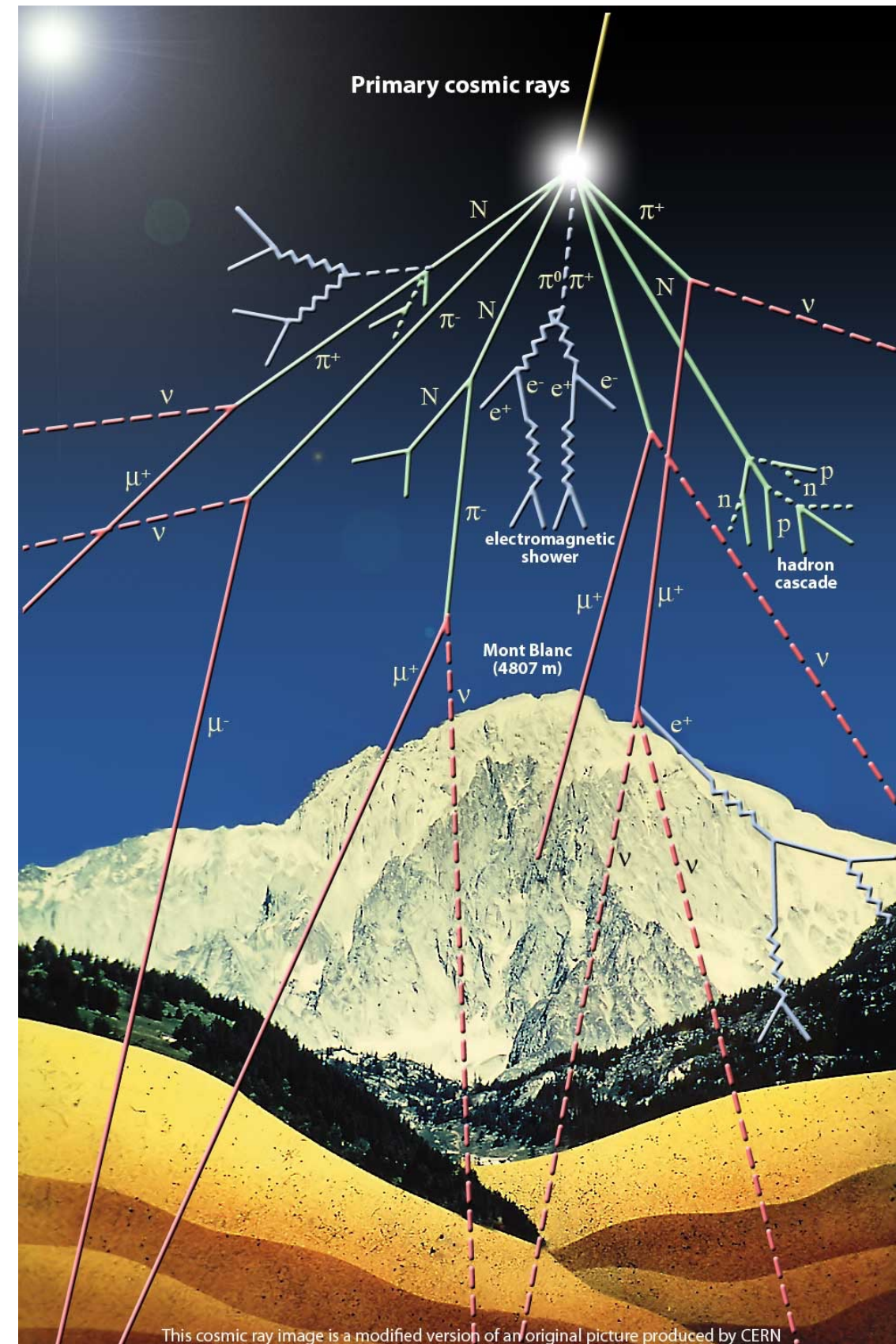
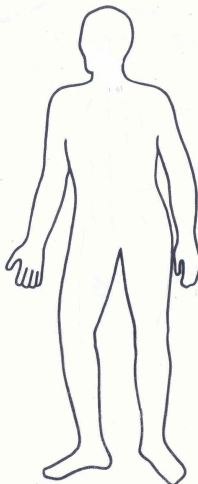
- ▷ Rare process subject to two major background
- ▷ Cosmic rays producing showers in the atmosphere
- ▷ Natural radioactivity!

15 decadimenti/s



1 decadimento/s  
per grammo

CORPO UMANO





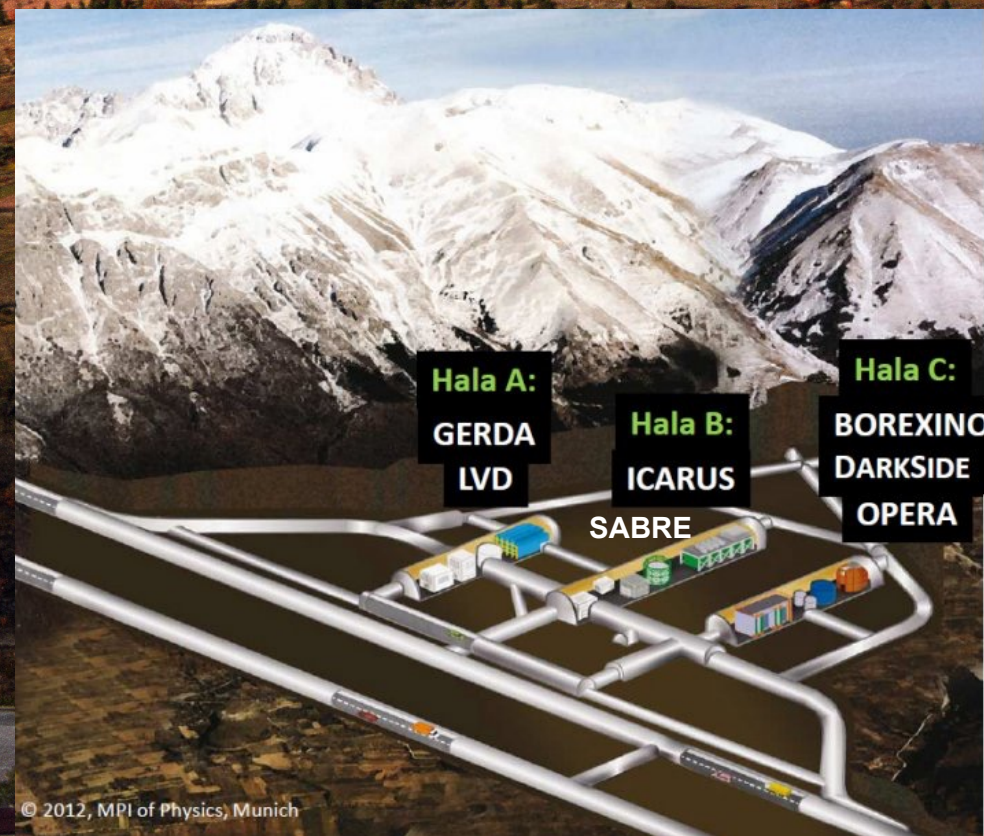
# LABORATORI NAZIONALI DEL GRAN SASSO

1400 m di roccia  
sovrastante

Superficie: 17 800 m<sup>2</sup>

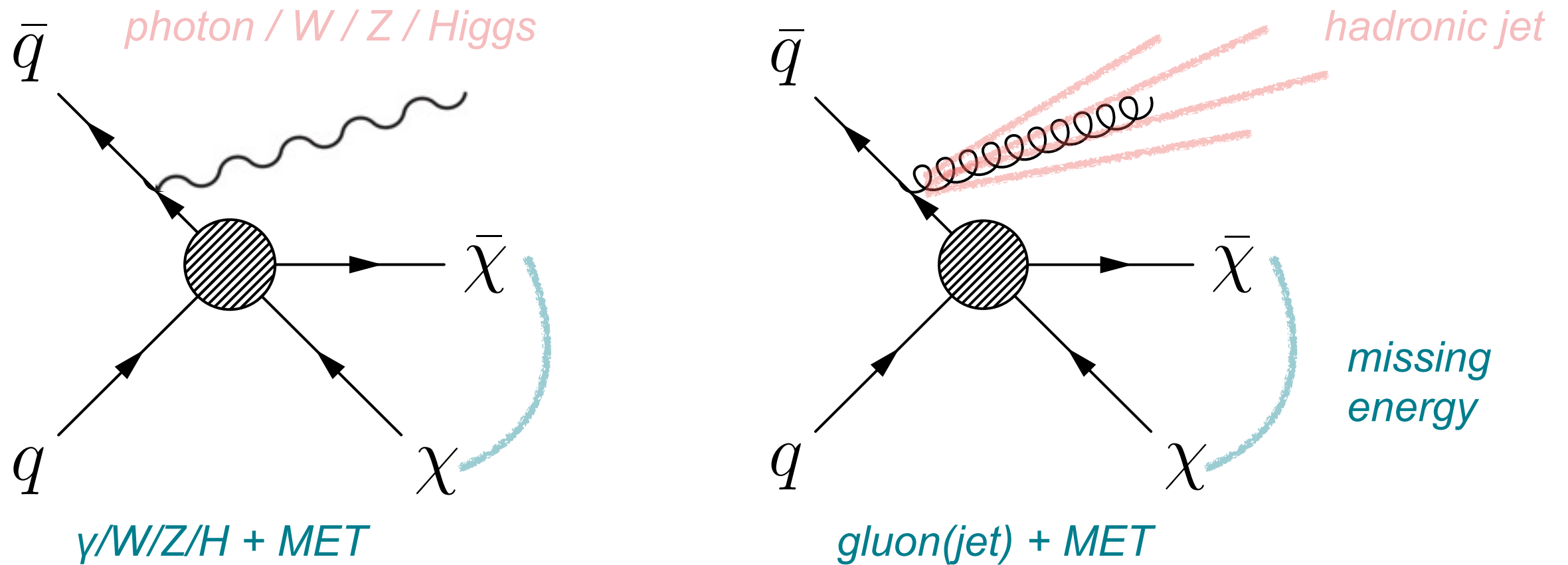
Volume: 180 000 m<sup>3</sup>

Riduzione di un milione di  
volte del flusso di muoni





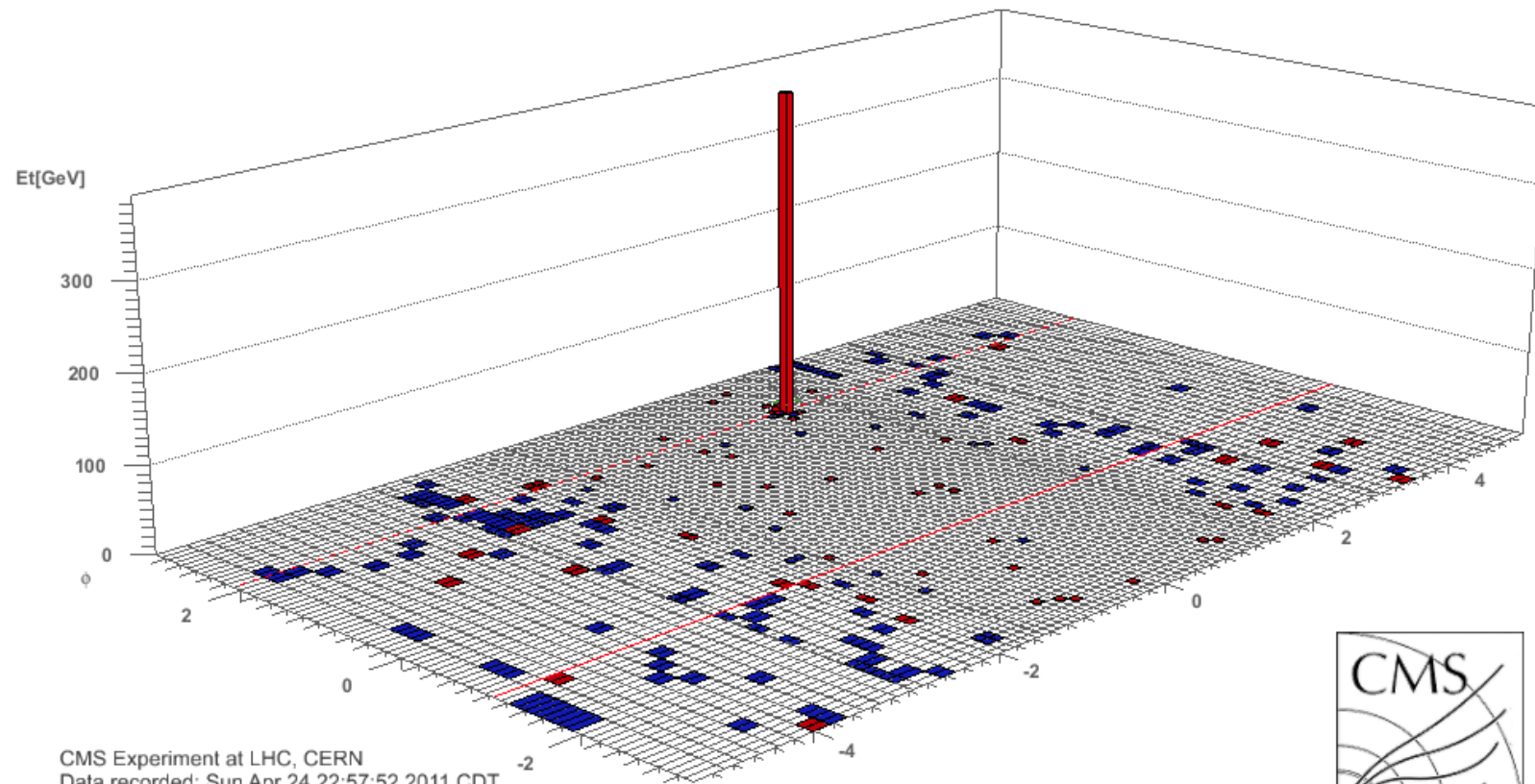
# Produzione di Materia Oscura a LHC



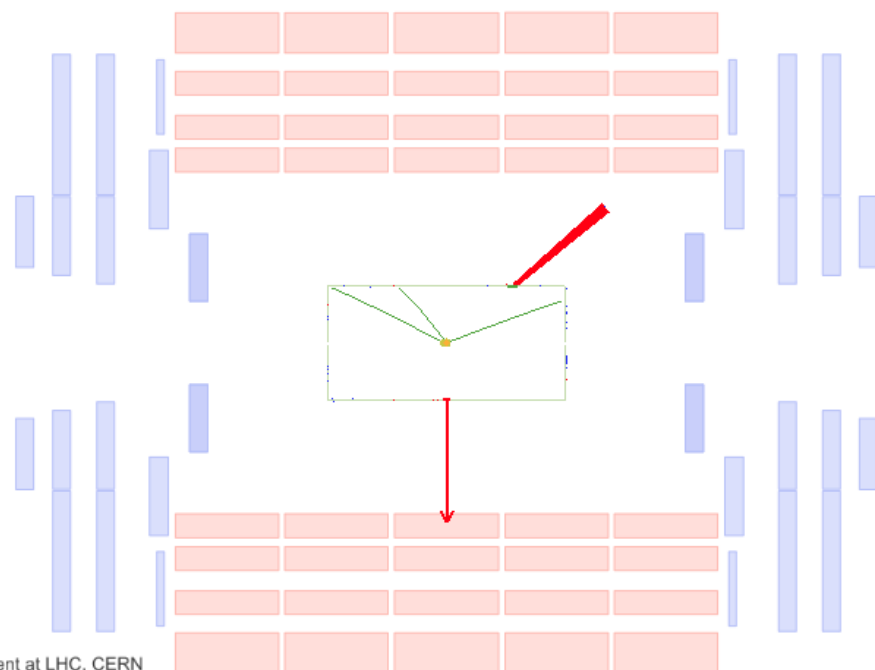
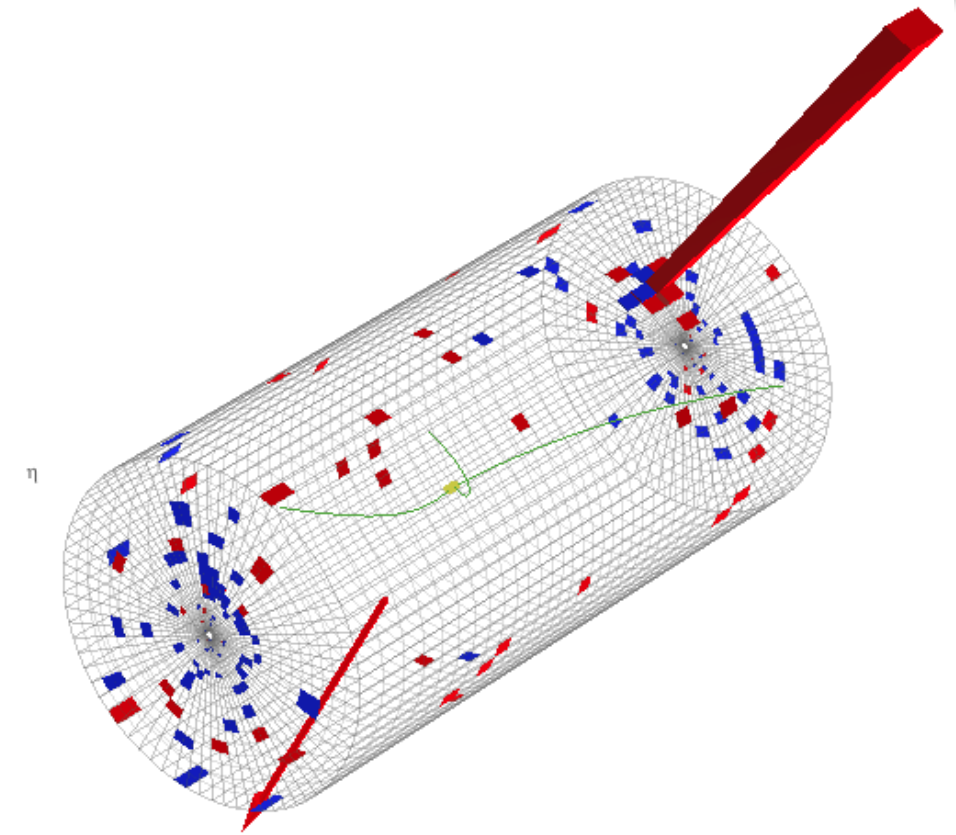
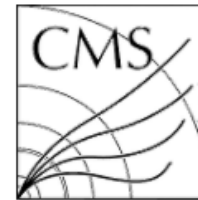
- ▷ Photons and gluons can be radiated by initial partons
- ▷ Presence of high energy photon, W, Z or gluons *in addition* to large missing transverse energy
- ▷ Gluon radiation at higher rate than photon
  - strong interaction vs. electromagnetic



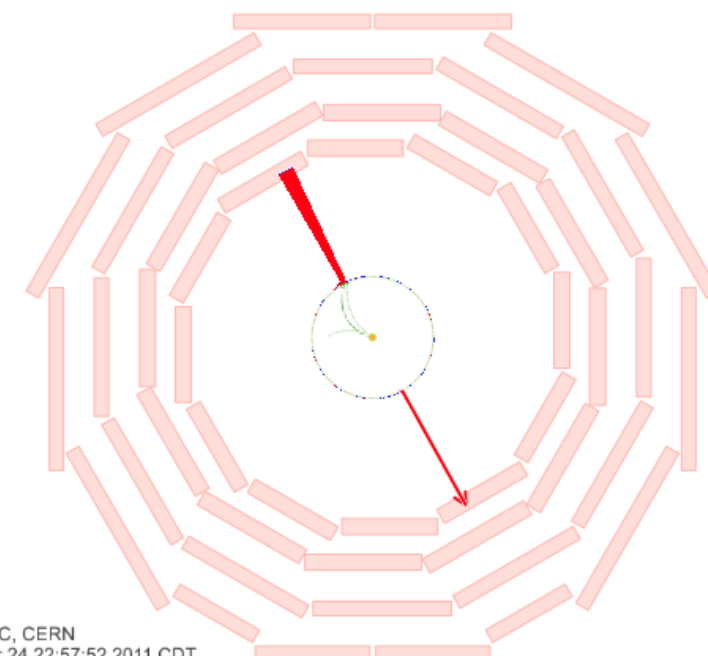
# MONOPHOTON EVENT



CMS Experiment at LHC, CERN  
Data recorded: Sun Apr 24 22:57:52 2011 CDT  
Run/Event: 163374 / 314736281  
Lumi section: 604



CMS Experiment at LHC, CERN  
Data recorded: Sun Apr 24 22:57:52 2011 CDT  
Run/Event: 163374 / 314736281  
Lumi section: 604

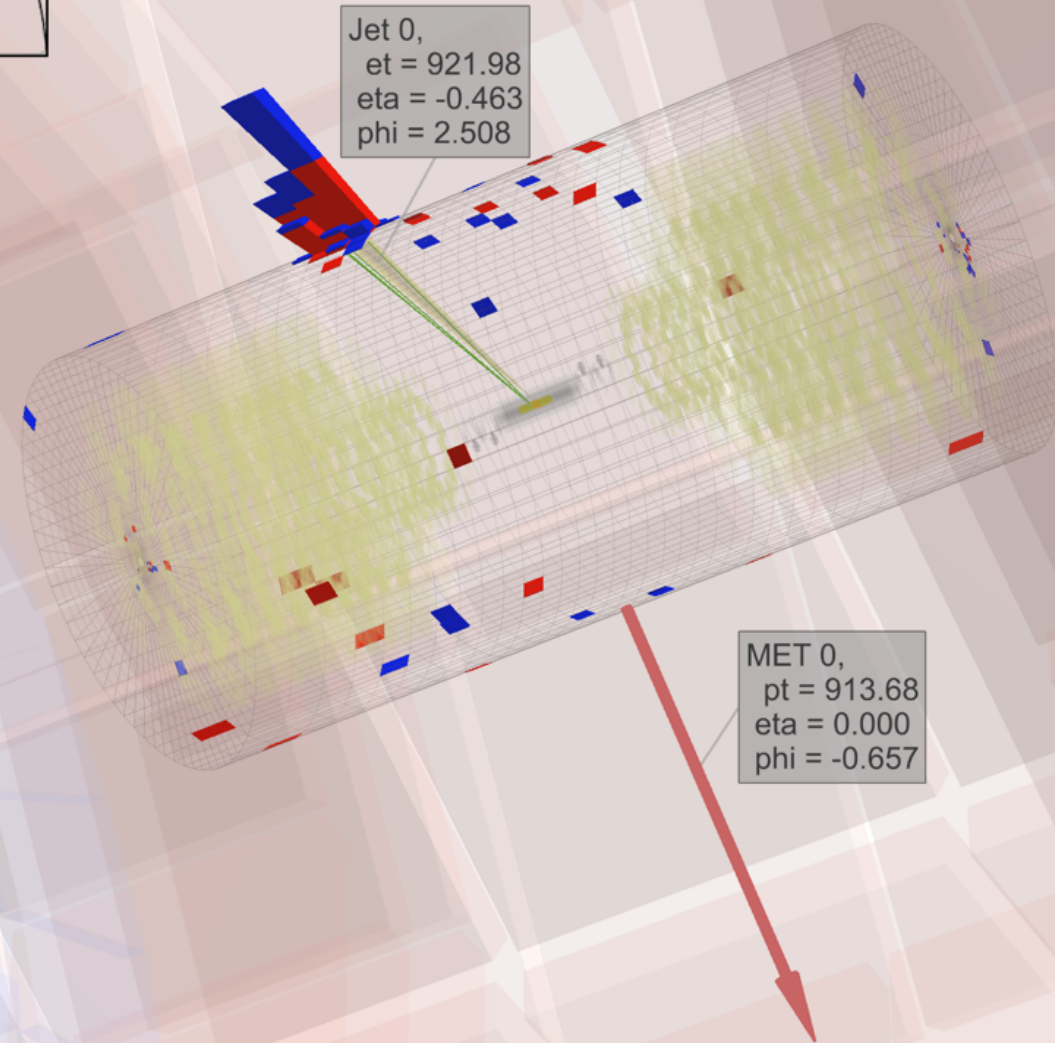


CMS Experiment at LHC, CERN  
Data recorded: Sun Apr 24 22:57:52 2011 CDT  
Run/Event: 163374 / 314736281  
Lumi section: 604

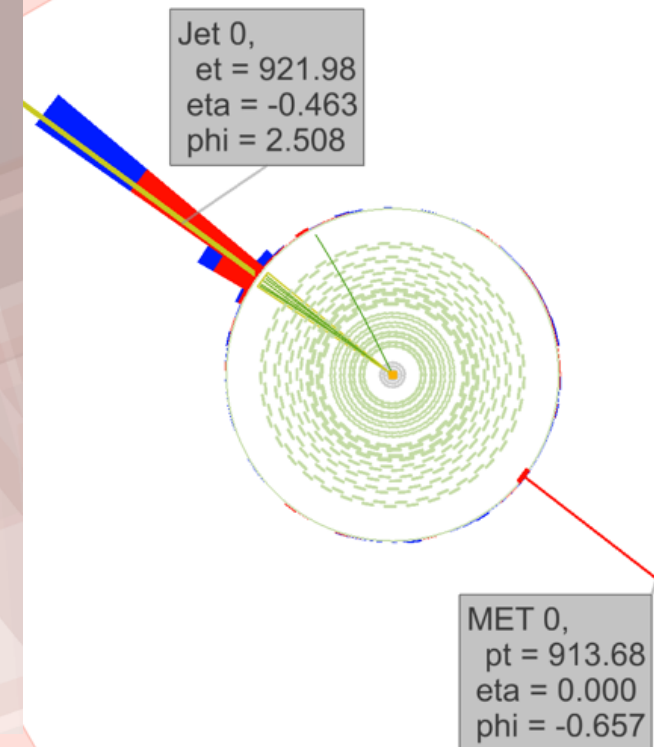
# MONOJET EVENT



CMS Experiment at LHC, CERN  
Data recorded: Fri Oct 5 20:41:32 2012 CEST  
Run/Event: 204553 / 26729384  
Lumi section: 31

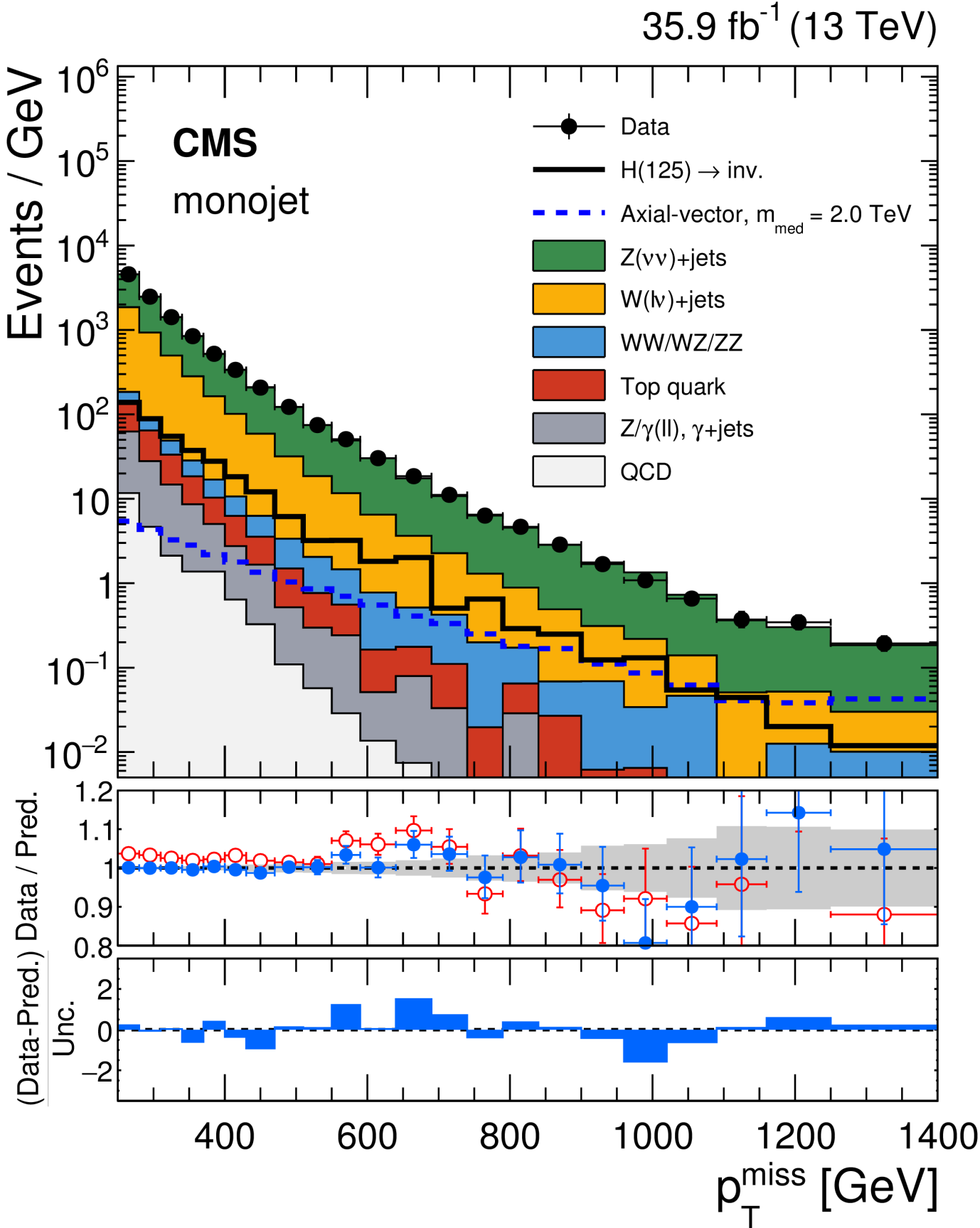


CMS Experiment at LHC, CERN  
Data recorded: Fri Oct 5 20:41:32 2012 CEST  
Run/Event: 204553 / 26729384  
Lumi section: 31





# Ancora nessun eccesso di eventi



# Sommario

- ▷ Studio delle interazioni fondamentali e` cominciato nell'antichita` e ha fatto grandi passi in avanti negli ultimi 2 secoli
- ▷ Oggi stiamo studiando un nuovo tipo di interazione tra bosoni di Higgs
- ▷ Molti esperimenti in corso per scoprire la natura e l'interazione della materia oscura
- ▷ A cosa serve studiare queste interazioni?
  - Relativita` generale alla base del funzionamento del GPS
  - Microonde alla base della telecomunicazione
  - Meccanica quantistica nei semiconduttori alla base dell'elettronica
  - Laser e fisica nucleare hanno permesso grandi passi in avanti in Medicina
- ▷ Interazioni fondamentali sono alla base dei piu` grandi avanzamenti tecnologici nella nostra societa`
- ▷ ***Sarete voi a dirci come usare l'interazione dei bosoni di Higgs o della materia oscura***