

# Particles and forces

Particles

Forces

Interactions: coupling of forces to matter




Short history and new frontiers

Unification of forces




Summary

# Particles

## Leptons

	Electric Charge		Electric Charge	
Tau	-1		Tau Neutrino	0
Muon	-1		Muon Neutrino	0
Electron	-1		Electron Neutrino	0

## Quarks

	Electric Charge		Electric Charge	
Bottom	-1/3		Top	2/3
Strange	-1/3		Charm	2/3
Down	-1/3		Up	2/3

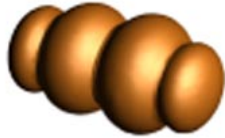
each quark: ●R, ●B, ●G 3 colors

*The particle drawings are simple artistic representations*

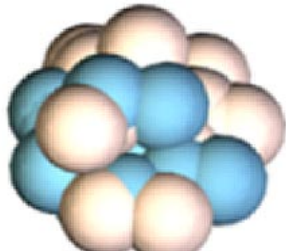
# Forces

## Strong

**Gluons (8)**



  
**Quarks**

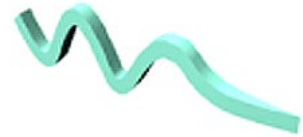


  
**Mesons**  
**Baryons**

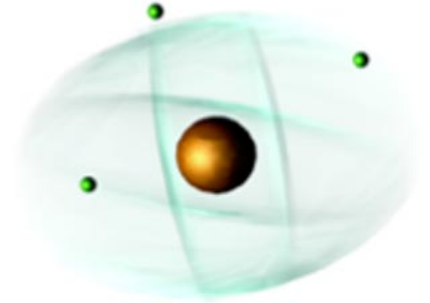
**Nuclei**

## Electromagnetic

**Photon**



**Atoms**  
**Light**  
**Chemistry**  
**Electronics**



## Gravitational

**Graviton ?**

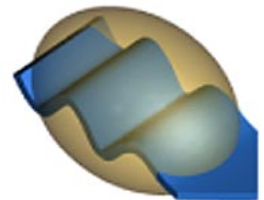


**Solar system**  
**Galaxies**  
**Black holes**

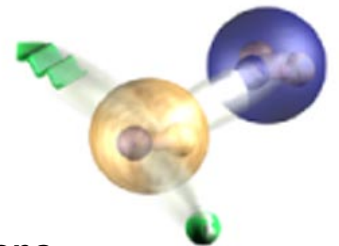


## Weak

**Bosons (W,Z)**



**Neutron decay**  
**Beta radioactivity**  
**Neutrino interactions**  
**Burning of the sun**

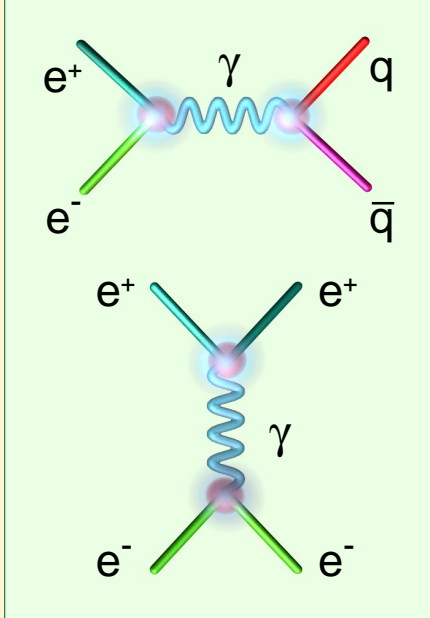


*The particle drawings are simple artistic representations*

# Interactions: coupling of forces to matter

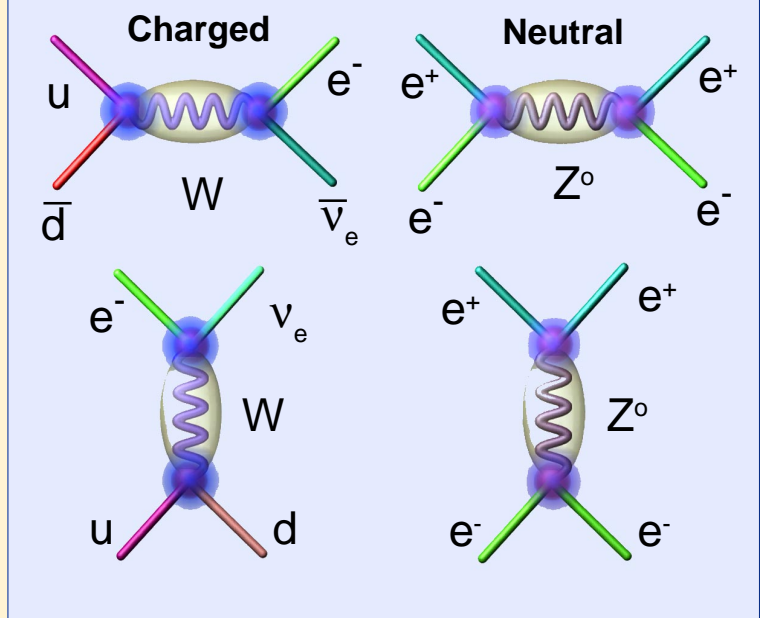
## Electroweak

### Electromagnetic



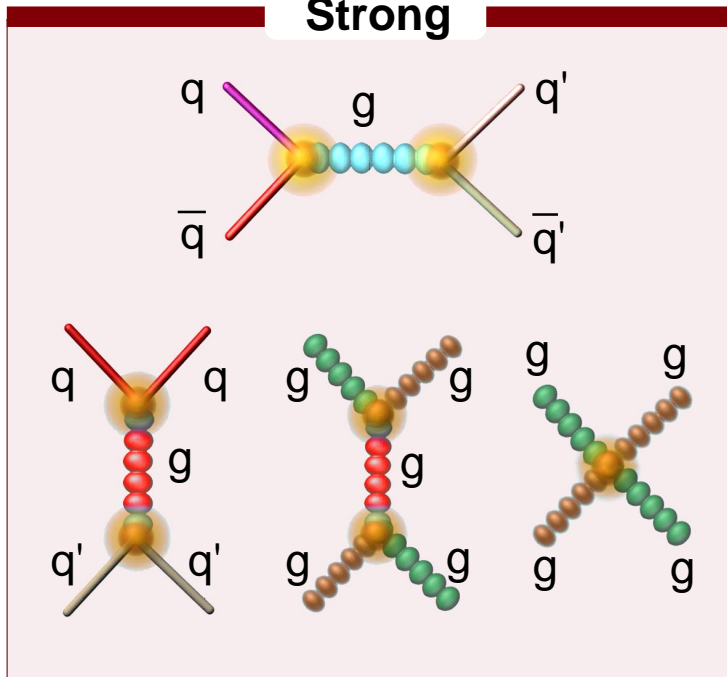
Range  $\infty$ , relative strength  $\leq 10^{-2}$

### Weak



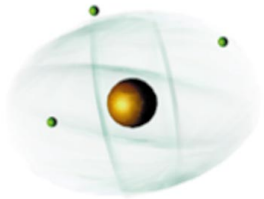
Range  $\sim 10^{-18}$  m, relative strength  $10^{-14}$

### Strong



Range  $\sim 10^{-15}$  m, relative strength = 1

# Short history and new frontiers



$$\lambda = h / p$$

$10^{-10}$  m

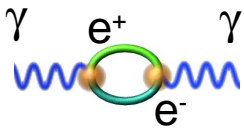
$\leq 10$  eV

$$T \approx t^{-1/2}$$

$> 300000$  Y

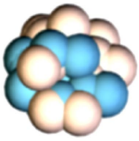
**1900....**

**Quantum Mechanics  
Atomic Physics**



**1940-50**

**Quantum Electro Dynamics**



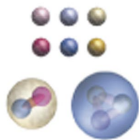
$10^{-15}$  m

MeV - GeV

$\approx 3$  min

**1950-65**

**Nuclei, Hadrons  
Symmetries  
Field theories**



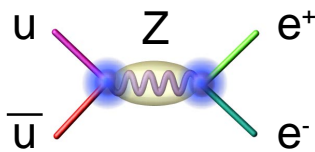
$10^{-16}$  m

$\gg$  GeV

$\approx 10^{-6}$  sec

**1965-75**

**Quarks  
Gauge theories**



$10^{-18}$  m

$\approx 100$  GeV

$\approx 10^{-10}$  sec

**SPS,  $p\bar{p}$  1970-83**

**ElectroWeak Unification,  
QCD**

6 Leptons	$\nu_e$	$\nu_\mu$	$\nu_\tau$
	e	$\mu$	$\tau$
6 Quarks	u	c	t
	d	s	b
3 "Colors" each quark			
	R	G	B

**LEP 1990**

**3 families**

**Tevatron 1994**

**Top quark**

**Origin of masses  
The next step...**

$10^{-19}$  m

$\approx 10^3$  GeV

$\approx 10^{-12}$  sec

**LHC 2005**

**Higgs ? Supersymmetry ?**

**Proton Decay ?**

$10^{-32}$  m

$\approx 10^{16}$  GeV

$\approx 10^{-32}$  sec

**Underground Labs**

**GRAND Unified  
Theories ?**

**The Origin of the  
Universe**

$10^{-35}$  m

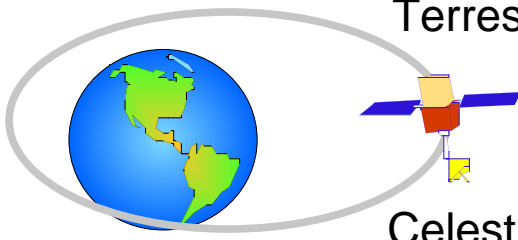
$\approx 10^{19}$  GeV  
(Planck scale)

$\approx 10^{-43}$  sec

??

**Quantum Gravity?  
Superstrings ?**

# Unification of forces

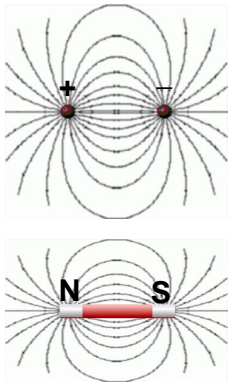


Terrestrial mechanics

Celestial mechanics

## Universal Gravitation

Inertial vs. Gravitational mass  
(I. Newton, 1687 )

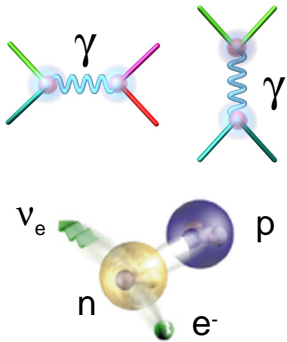


Electricity

Magnetism

## Electromagnetism

Electromagnetic waves (photon)  
(J.C. Maxwell, 1860 )



Electromagnetism

Weak force

## Electroweak

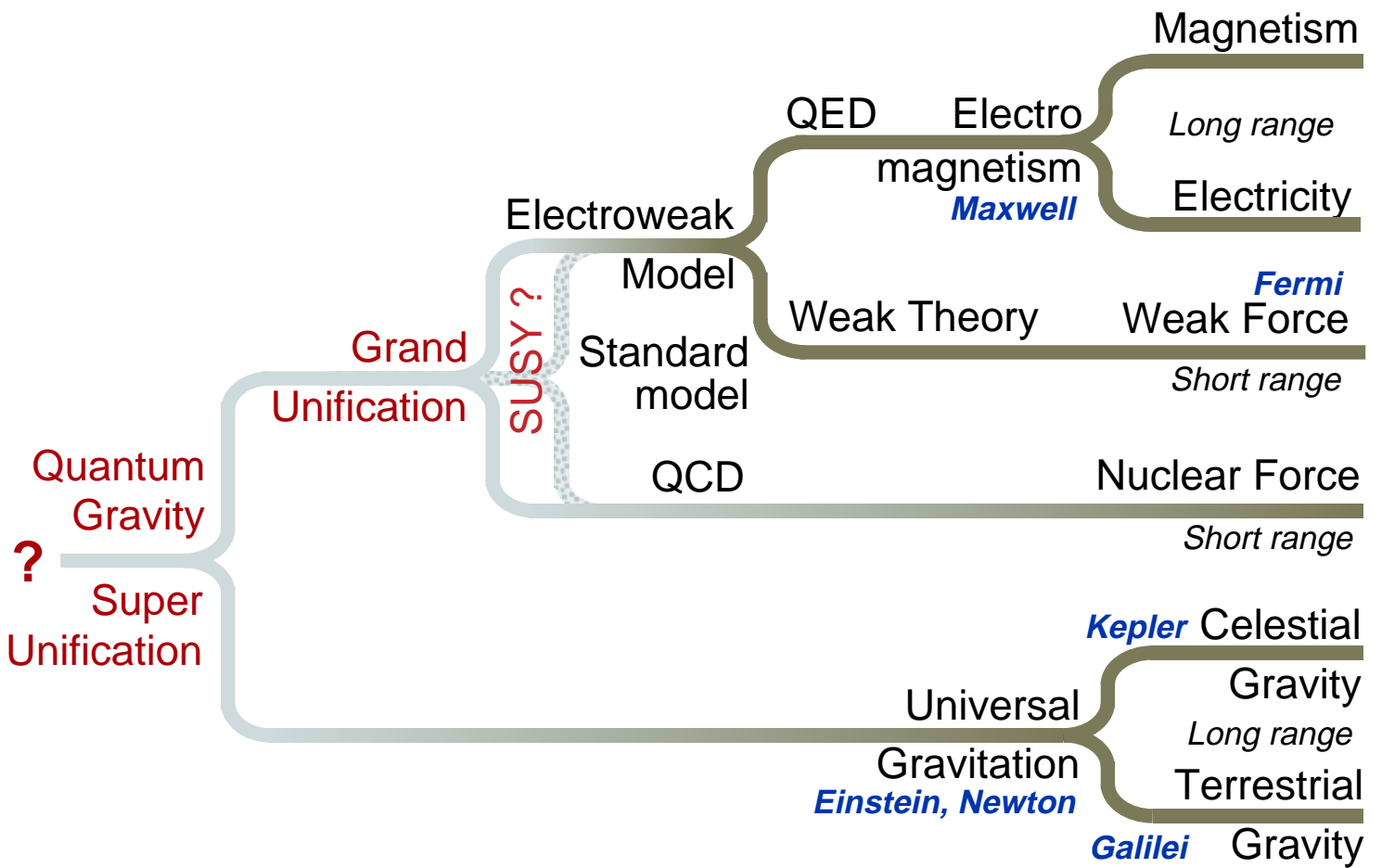
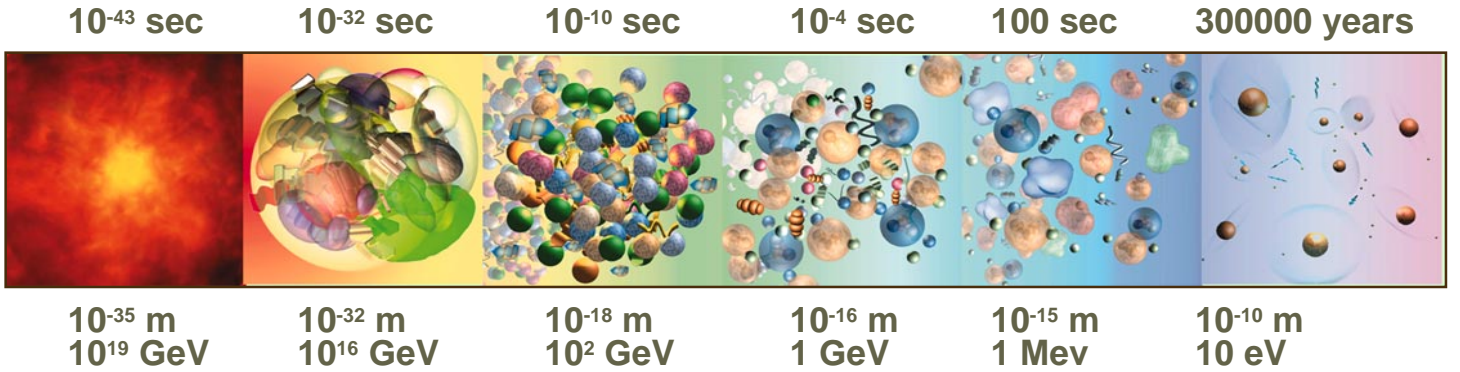
Intermediate bosons W, Z  
(1970-83 )

?

Probing shorter distances  
reveals  
deeper regularities

**UNIFIED DESCRIPTIONS**

# Summary



## Theories:

STRINGS?

RELATIVISTIC/QUANTUM

CLASSICAL