DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS

IB PHYSICS

LSN 7-3: THE STRUCTURE OF MATTER

Questions From Reading Activity?

Essential Idea:

- It is believed that all the matter around us is made up of fundamental particles called quarks and leptons. It is known that matter has a hierarchical structure with quarks making up nucleons, nucleons making up nuclei, nuclei and electrons making up atoms and atoms making up molecules. In this hierarchical structure, the smallest scale is seen for quarks and leptons (10^{-18} m).

Nature Of Science:

- Predictions: Our present understanding of matter is called the Standard Model, consisting of six quarks and six leptons. Quarks were postulated on a completely mathematical basis in order to explain patterns in properties of particles.

Nature Of Science:

- Collaboration: It was much later that large-scale collaborative experimentation led to the discovery of the predicted fundamental particles.

International-Mindedness:

- Research into particle physics requires ever-increasing funding, leading to debates in governments and international research organizations on the fair allocation of precious financial resources.

Theory Of Knowledge:

- Does the belief in the existence of fundamental particles mean that it is justifiable to see physics as being more important than other areas of knowledge?

Understandings:

- Quarks, leptons and their antiparticles
- Hadrons, baryons and mesons
- The conservation laws of charge, baryon number, lepton number and strangeness
- The nature and range of the strong nuclear force, weak nuclear force and electromagnetic force
- Exchange particles
- Feynman diagrams
- Confinement
- The Higgs boson

Applications And Skills:

- Describing the Rutherford-Geiger-Marsden experiment that led to the discovery of the nucleus
- Applying conservation laws in particle reactions
- Describing protons and neutrons in terms of quarks
- Comparing the interaction strengths of the fundamental forces, including gravity

Applications And Skills:

- Describing the mediation of the fundamental forces through exchange particles
- Sketching and interpreting simple Feynman diagrams
- Describing why free quarks are not observed

Guidance:

- A qualitative description of the standard model is required.

Data Booklet Reference:

Charge	Quarks			Baryon number
$\frac{2}{3}e$	u	c	t	$\frac{1}{3}$
$-\frac{1}{3}e$	d	s	b	$\frac{1}{3}$

All quarks have a strangeness number of 0 except the strange quark that has a strangeness number of –1

Charge	Leptons		
–1	e	μ	τ
0	υ_e	υ_μ	υ_τ

All leptons have a lepton number of 1 and antileptons have a lepton number of –1

Data Booklet Reference:

	Gravitational	Weak	Electromagnetic	Strong
Particles experiencing	All	Quarks, leptons	Charged	Quarks, gluons
Par ticles mediating	Graviton	W^+, W^-, Z^0	γ	Gluons

Utilization:

- An understanding of particle physics is needed to determine the final fate of the universe (see Physics option sub-topics D.3 and D.4).

Aims:

- Aim 1: the research that deals with the fundamental structure of matter is international in nature and is a challenging and stimulating adventure for those who take part
- Aim 4: particle physics involves the analysis and evaluation of very large amounts of data

Aims:

- Aim 6: students could investigate the scattering angle of alpha particles as a function of the aiming error, or the minimum distance of approach as a function of the initial kinetic energy of the alpha particle
- Aim 8: scientific and government organizations are asked if the funding for particle physics research could be spent on other research or social needs

Review: Models of the Atom

Review: Strong Nuclear Force

Standard Model

- Protons and neutrons in a concentrated nucleus
- Electrons in a cloud of quantized energy levels
- Photons released as electrons return from excited energy levels

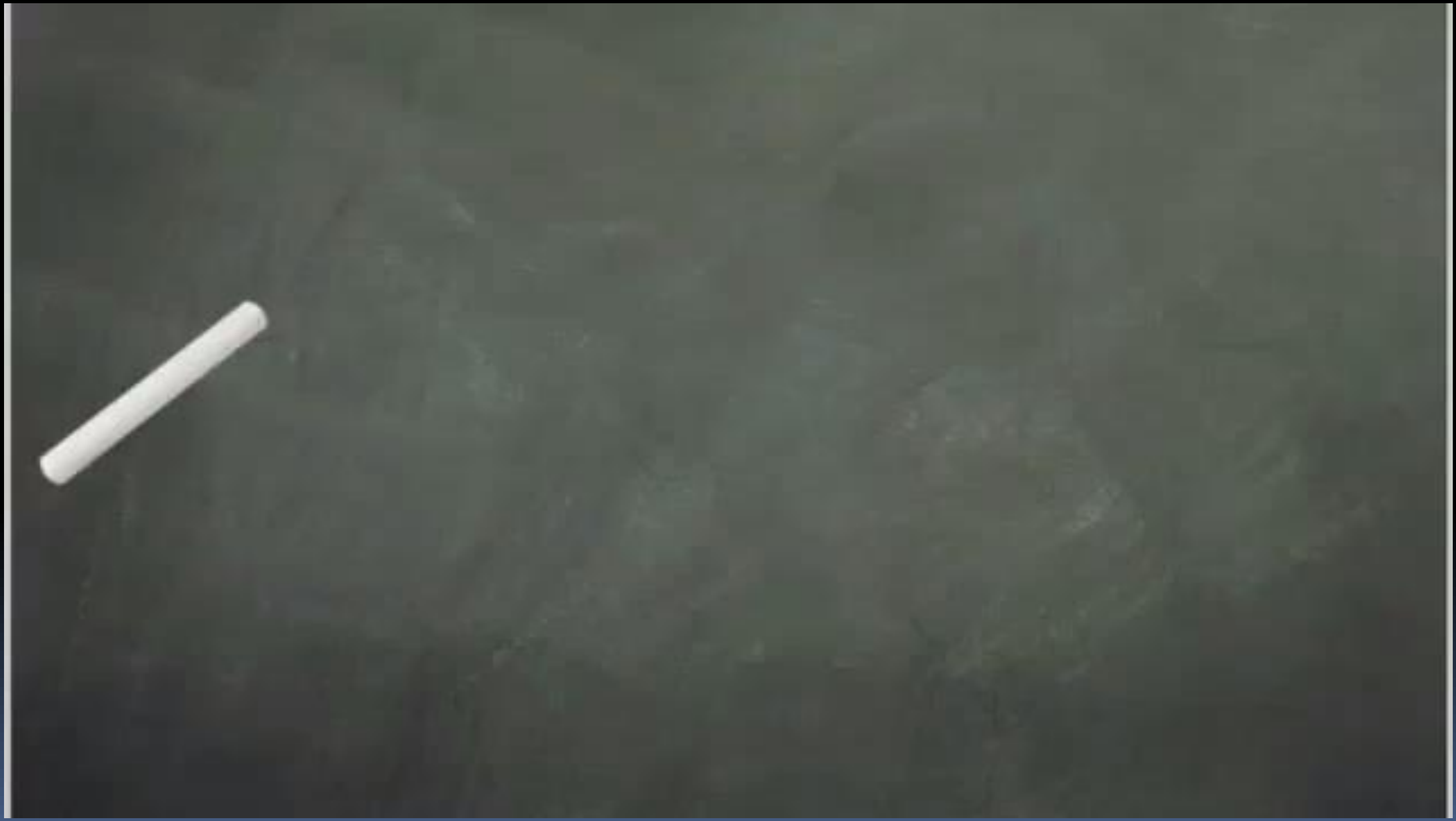
History of Discovery

- 1897 – electron
- 1905 - photon
- 1911 – nucleus
- 1920 – proton
- 1932 – neutron
- 1938 – nuclear fission

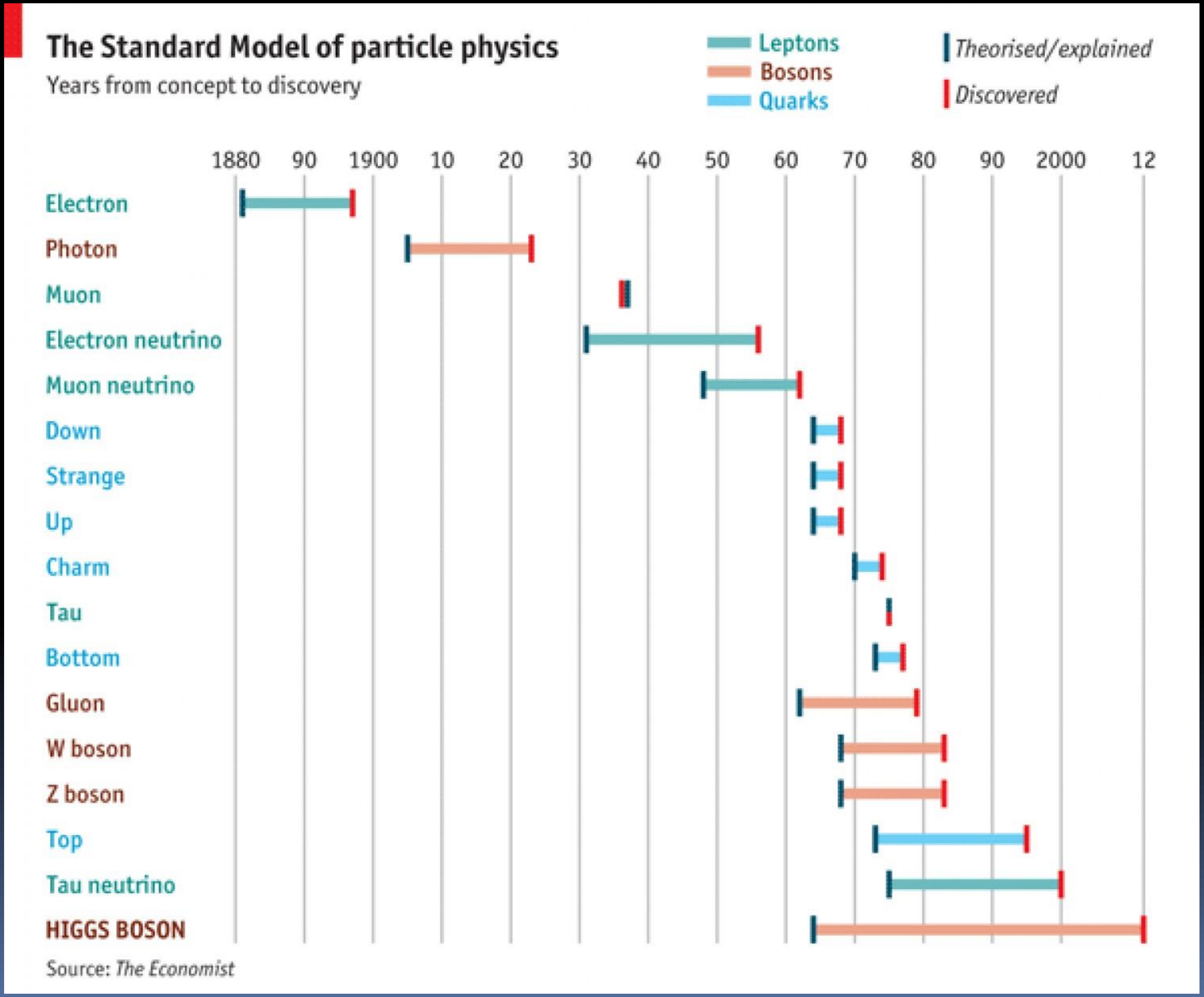
History of Discovery

- With particle accelerators and bubble chambers, hundreds of new particles were discovered in the 1950's and 1960's
  - Previously, they could not be detected due to short lifespans (unstable, rapid decay)
  - Making sense of it all was the biggest problem

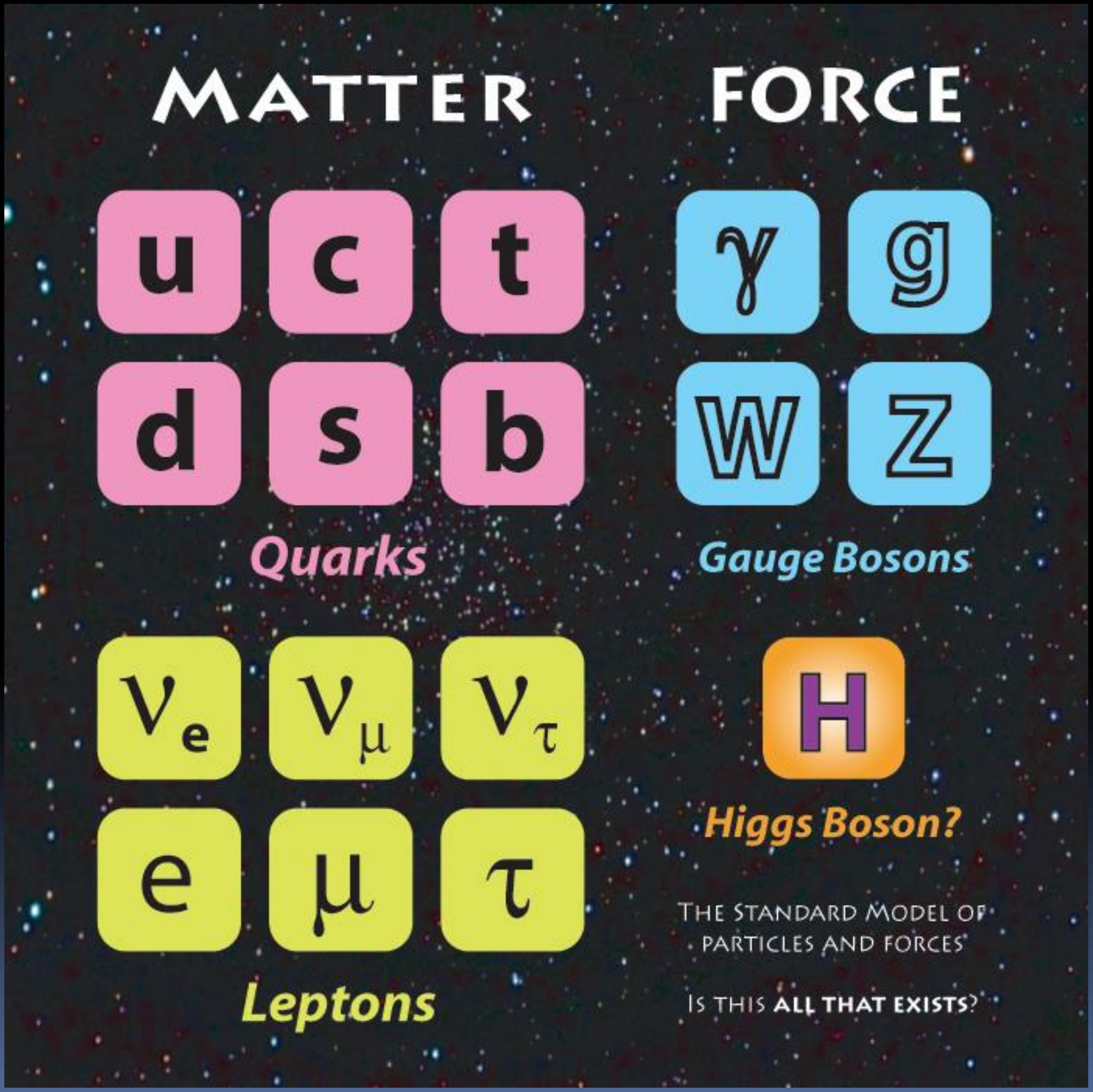
Large Hadron Collider (LHC)



Age of Discovery



Elementary Particles



Introductory to Elementary Particle Physics

Quarks

- Quarks come in six different ***flavours***:
  - Those with electric charge ⅔e:
    - Up (u)
    - Charm (c)
    - Top (t) [also called Truth]
  - Those with electric charge –⅓e:
    - Down (d)
    - Strange (s)
    - Bottom (b) [also called Beauty]

Quarks

- ***Anti-particles***:
  - For every particle, there is an anti-particle
    - Neutrino, anti-neutrino
    - Electron, positron
  - Anti-particles are denoted by a bar over the symbol
    - Up
    - Top
    - Charm

$$u, \bar{u}$$

$$t, \bar{t}$$

$$c, \bar{c}$$

Quarks

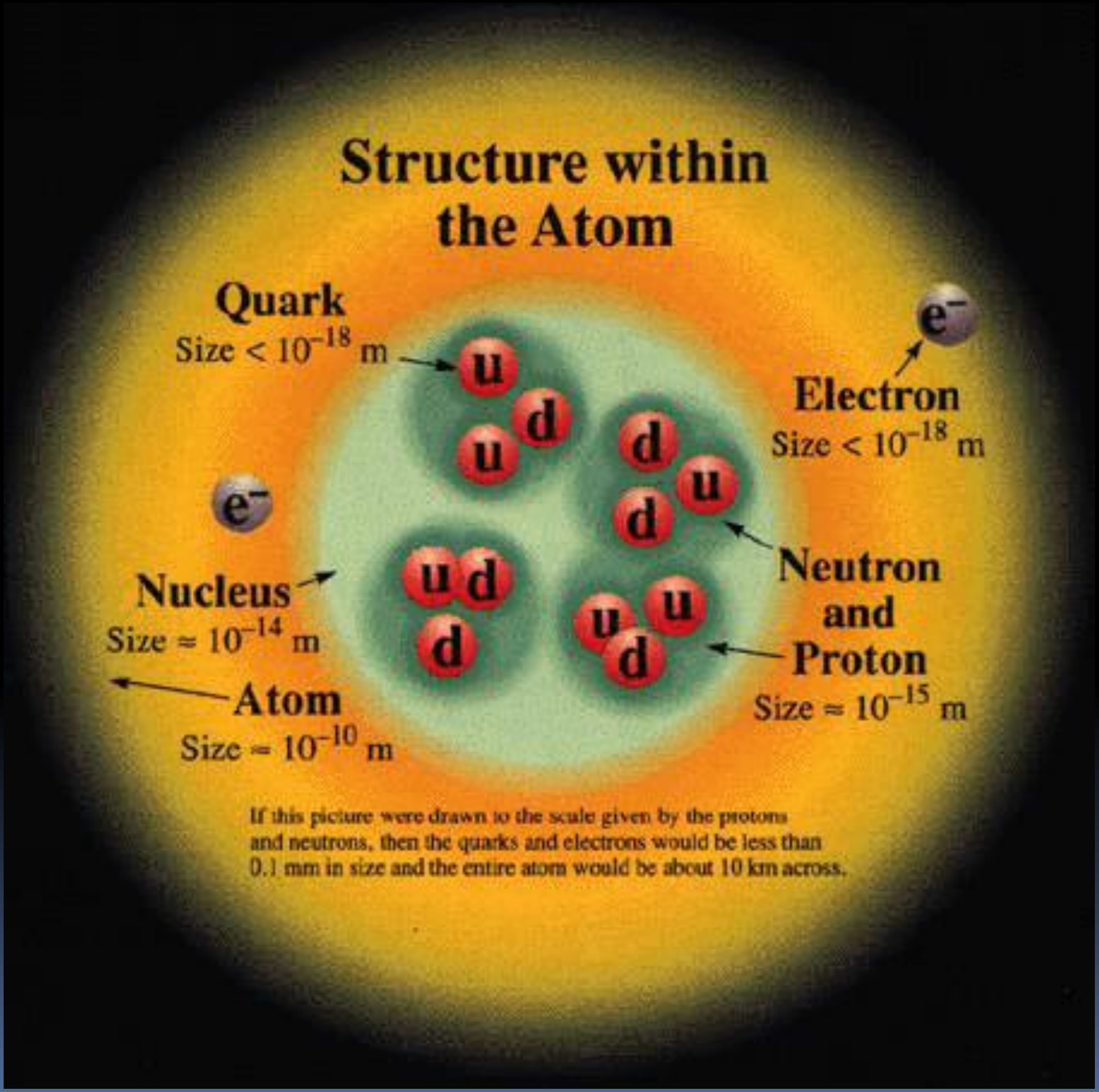
- Quarks combine in two ways to form ***hadrons***:
  - Three quarks combine to form ***baryons***:
    - Proton (uud)

$$Q_p = \left(+\frac{2}{3}e\right) + \left(+\frac{2}{3}e\right) + \left(-\frac{1}{3}e\right) = e$$

    - Neutron (udd)

$$Q_n = \left(+\frac{2}{3}e\right) + \left(-\frac{1}{3}e\right) + \left(-\frac{1}{3}e\right) = 0$$

Atomic Structure



Quarks

- Other baryons and their characteristics:

This quantum number is the isospin itself, I. Several values of I_3 occur for each value of I according to the rule:

$$I_3 = I, I-1, \ldots, -I$$

Conversely, for a group with the same isospin, I = maximum value of I_3.

Particle	Quarks	Mass	Q	Spin	P	I	I_3	Y	S
p	uud	938.3	+1	½	+1	½	+½	+1	0
n	udd	939.6	0	½	+1	½	–½	+1	0
Λ^0	uds	1116	0	½	+1	0	0	0	–1
Σ^+	uus	1189	+1	½	+1	1	+1	0	–1
Σ^0	uds	1192	0	½	+1	1	0	0	–1
Σ^-	dds	1197	–1	½	+1	1	–1	0	–1
Ξ^0	ssu	1315	0	½	+1	½	+½	–1	–2
Ξ^-	ssd	1321	–1	½	+1	½	–½	–1	–2

Quarks

- Quarks combine in two ways to form ***hadrons***:
  - A quark and anti-quark combine to form ***mesons***:
    - Pion (π^+ meson)
      - Up + Down anti-quark

$$\pi^+ = \left(u\bar{d}\right)$$

Quarks

- Another characteristic of Quarks is ***baryon number (B)***:
  - Quarks have a baryon number of +⅓
  - Anti-quarks have a baryon number of –⅓
  - To find the baryon number of a hadron, add the baryon numbers
    - Baryon

$$uct = \left(+\frac{1}{3}\right) + \left(+\frac{1}{3}\right) + \left(+\frac{1}{3}\right) = +1$$

    - Meson

$$u\bar{d} = \left(+\frac{1}{3}\right) + \left(-\frac{1}{3}\right) = 0$$

Quarks

- Another characteristic of Quarks is ***baryon number***:
  - All baryons have a baryon number of +1
  - All anti-baryons have a baryon number of -1
  - All mesons have a baryon number of 0
  - All other particles not made from quarks have a baryon number of 0

Quarks

- Quarks interact with:
  - Strong nuclear interaction
  - Weak nuclear interaction
  - Electromagnetic interaction

Quarks

- Conservation:
  - ***In all reactions, electric charge and baryon number are conserved***
  - ***The same values before and after the reaction***

$$\Delta^0 \rightarrow p + \pi^-$$

$$udd \rightarrow uud + d\bar{u}$$

$$\frac{2}{3}e - \frac{1}{3}e - \frac{1}{3}e \rightarrow$$

$$\left(\frac{2}{3}e + \frac{2}{3}e - \frac{1}{3}e\right) + \left(-\frac{1}{3}e - \frac{2}{3}e\right)$$

$$\frac{1}{3} + \frac{1}{3} + \frac{1}{3} \rightarrow \left(\frac{1}{3} + \frac{1}{3} + \frac{1}{3}\right) + \left(\frac{1}{3} - \frac{1}{3}\right)$$

Quarks

$$\Delta^0 \rightarrow p + \pi^-$$
$$udd \rightarrow uud + d\bar{u}$$
$$\Lambda^0 \rightarrow p + \pi^-$$
$$uds \rightarrow uud + d\bar{u}$$

- Time factor:
  - The two reactions look alike
  - The first takes 10^{-25} s
  - The second takes 10^{-10} s
- The shorter first decay involves a strong force interaction
- The longer second decay involves a weak force interaction

Quarks

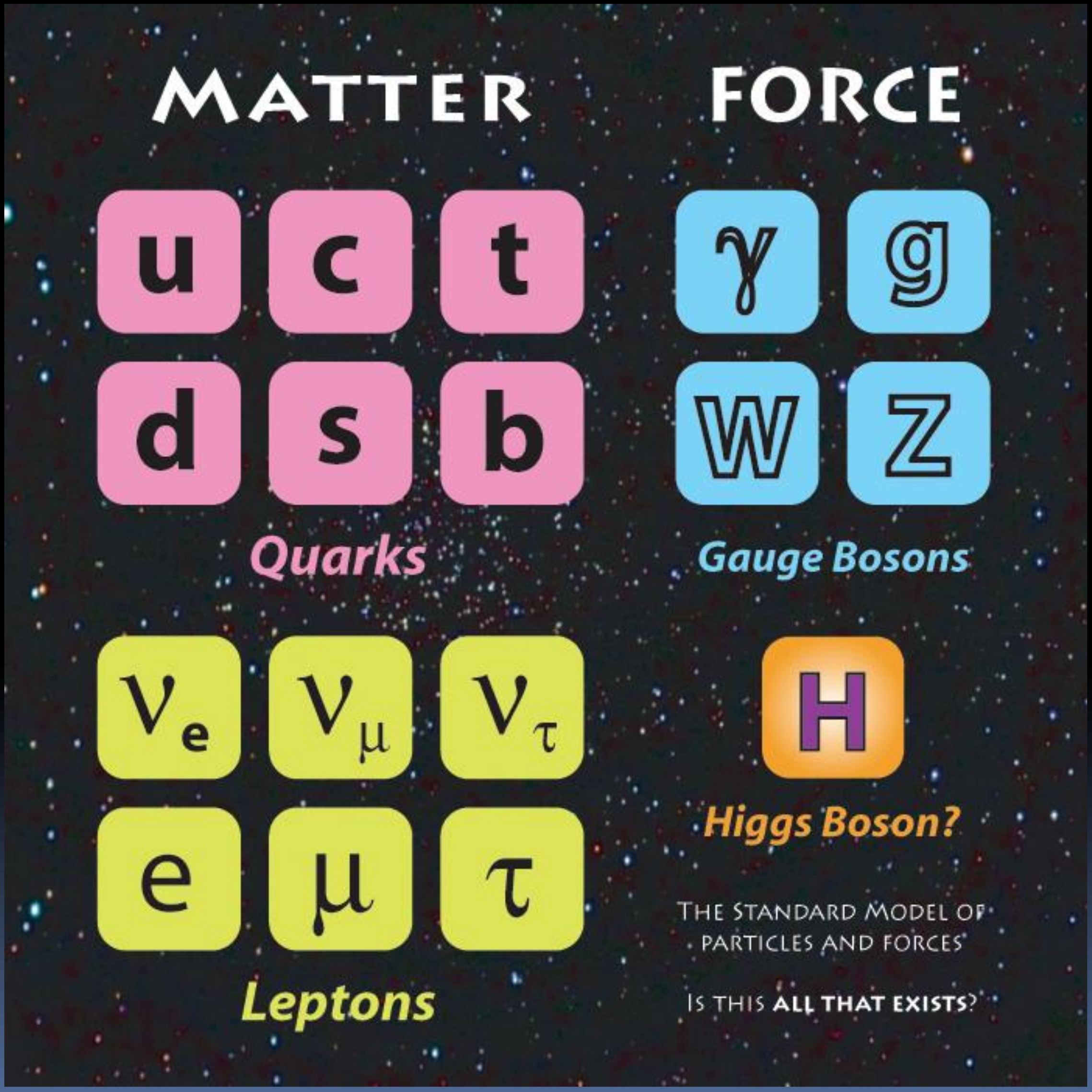
$$\Delta^0 \rightarrow p + \pi^-$$
$$udd \rightarrow uud + d\bar{u}$$
$$\Lambda^0 \rightarrow p + \pi^-$$
$$uds \rightarrow uud + d\bar{u}$$

- ***Strangeness (S)***:
  - Strange quarks have a strangeness of -1
  - Anti-strange quarks have a strangeness of +1
  - All other particles have a strangeness of 0
  - Strangeness is conserved in strong and electromagnetic interactions, but may be violated in weak interactions

Quarks

Quark / Antiquark	Symbol		Charge/*e*		Baryon number, B		Strangeness, S	
up	u	$\bar{u}$	+2/3	-2/3	1/3	-1/3	0	0
down	d	$\bar{d}$	-1/3	+1/3	1/3	-1/3	0	0
charm	c	$\bar{c}$	+2/3	-2/3	1/3	-1/3	0	0
strange	s	$\bar{s}$	-1/3	+1/3	1/3	-1/3	-1	1
top	t	$\bar{t}$	+2/3	-2/3	1/3	-1/3	0	0
bottom	b	$\bar{b}$	-1/3	+1/3	1/3	-1/3	0	0

Elementary Particles - Leptons



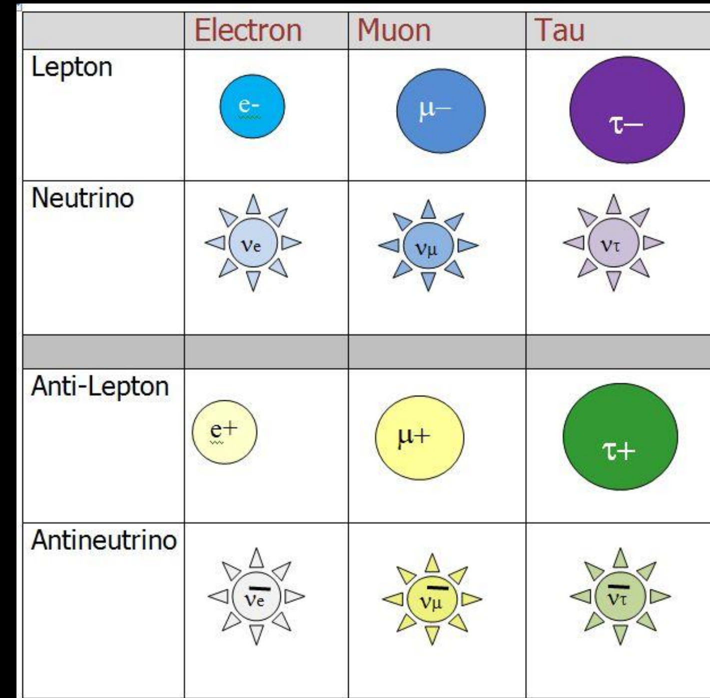
Leptons

- Six types of ***leptons***:
  - Electron, e^-
  - Electron neutrino, υ_e
  - Muon, μ^-
  - Muon neutrino, υ_μ
  - Tau, τ^-
  - Tau neutrino, υ_τ
- Each of these particles has its respective anti-particle

Leptons

	Electron	Muon	Tau
Lepton	e^-	μ^-	τ^-
Neutrino	ν_e	ν_μ	ν_τ
Anti-Lepton	e^+	μ^+	τ^+
Antineutrino	$\bar{\nu}_e$	$\bar{\nu}_\mu$	$\bar{\nu}_\tau$

Leptons



- Chart is representative of size
- Neutrinos have been shown to have a very small non-zero mass
- Leptons interact with the *weak nuclear force*
- Those that have a charge (e^-, μ^-, τ^-) also interact with the *electromagnetic force*

Leptons

- ***Family lepton number (L):***
  - There is a quantum number for each lepton (L_e, L_μ, L_τ)
  - Most of the time it is just referred to as lepton number (L)
  - All leptons have L = +1
  - All anti-leptons have L = -1

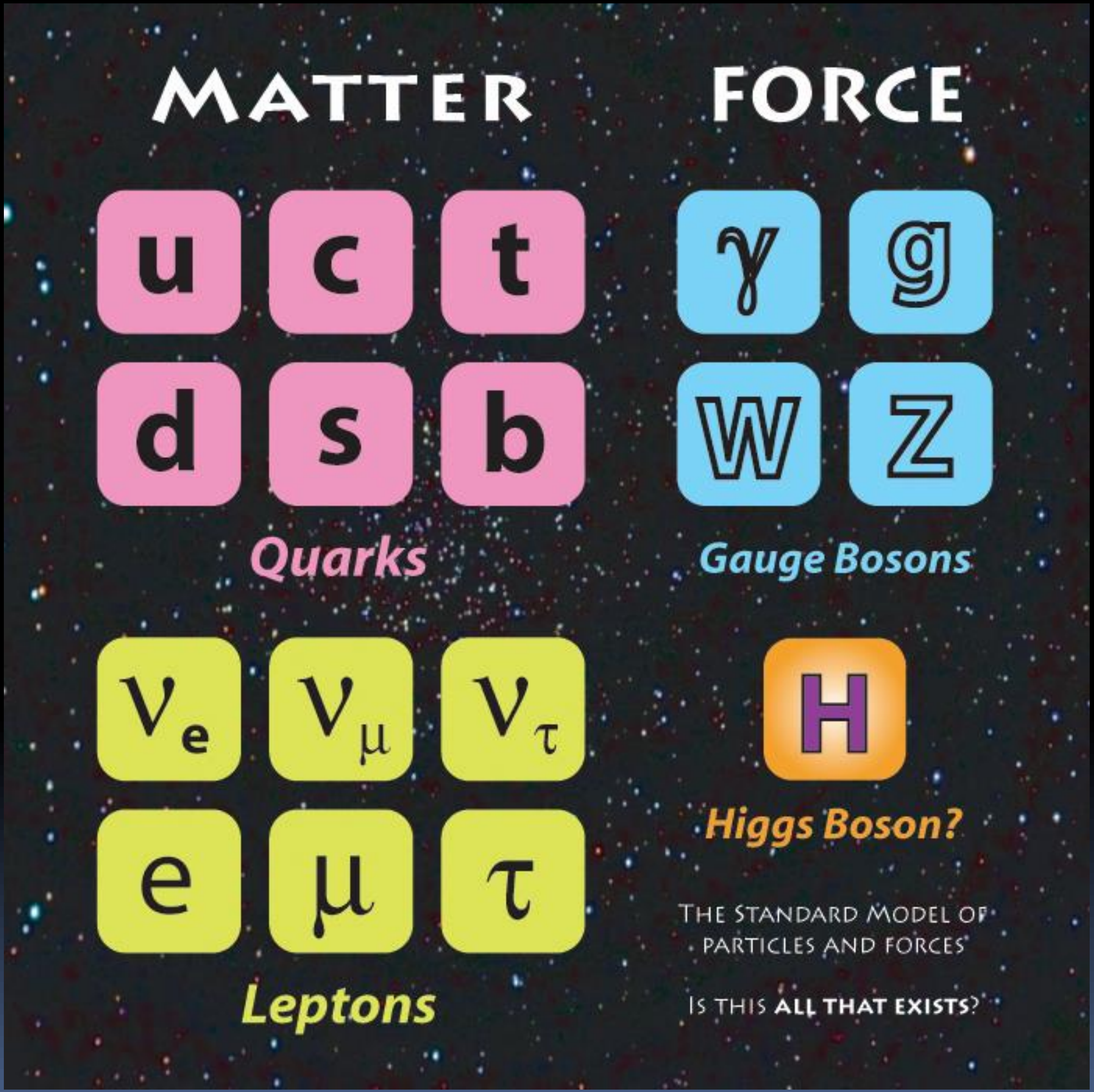
Leptons

- Charge:
  - Electron, e^- = -e
  - Electron neutrino, $\upsilon_e = 0$
  - Muon, μ^- = -e
  - Muon neutrino, $\upsilon_\mu = 0$
  - Tau, τ^- = -e
  - Tau neutrino, $\upsilon_\tau = 0$

Leptons

	12 Leptons			Charge	Lepton no.
Particles	e	μ	τ	-1e	+1
Antiparticles	$\underline{e}$	$\underline{\mu}$	$\underline{\tau}$	+1e	-1
Neutrinos	V_e	V_μ	V_τ	0e	+1
Antineutrinos	$\underline{V}_e$	$\underline{V}_\mu$	$\underline{V}_\tau$	0e	-1

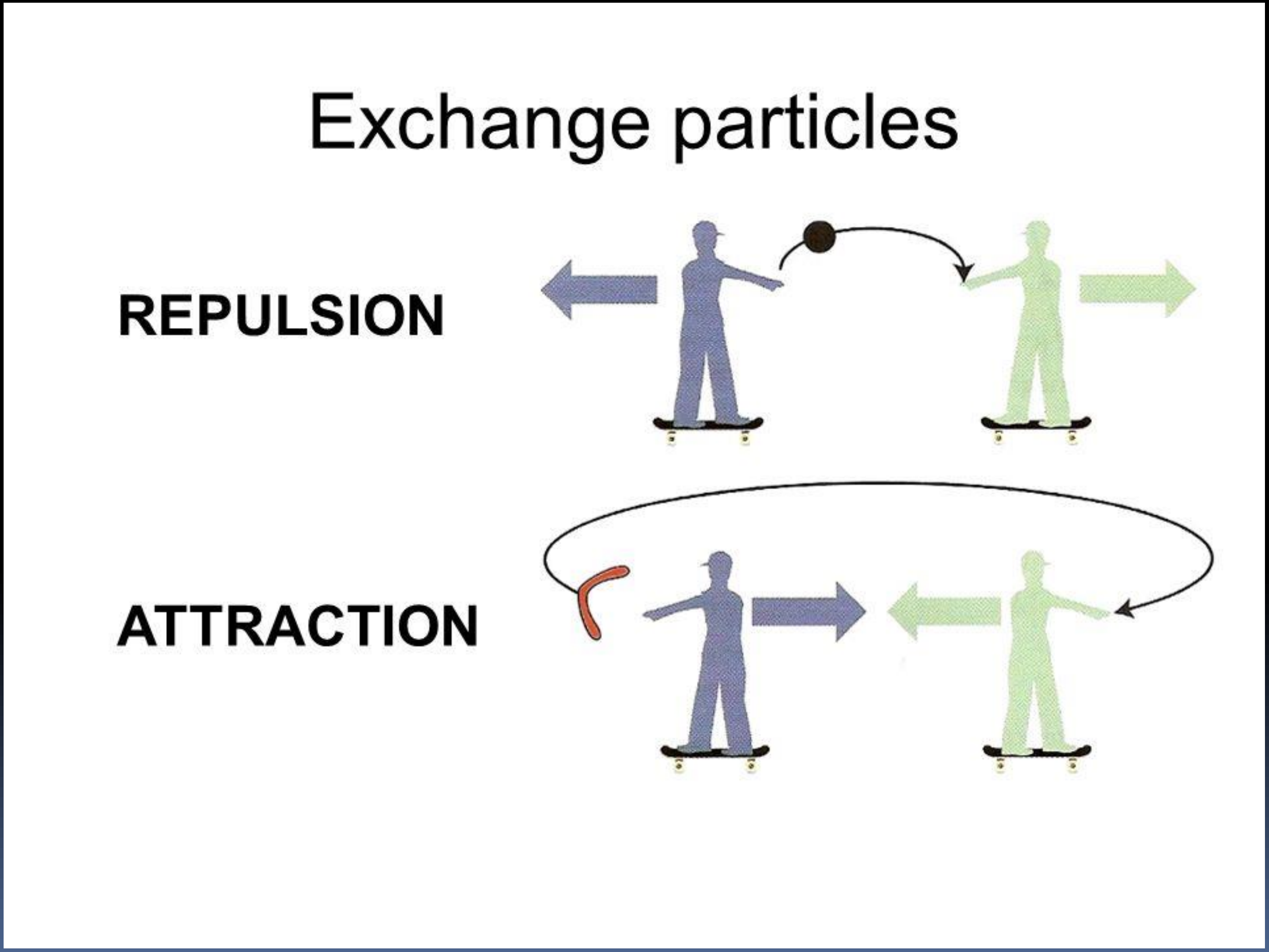
Elementary Particles – Exchange Particles



Exchange Particles

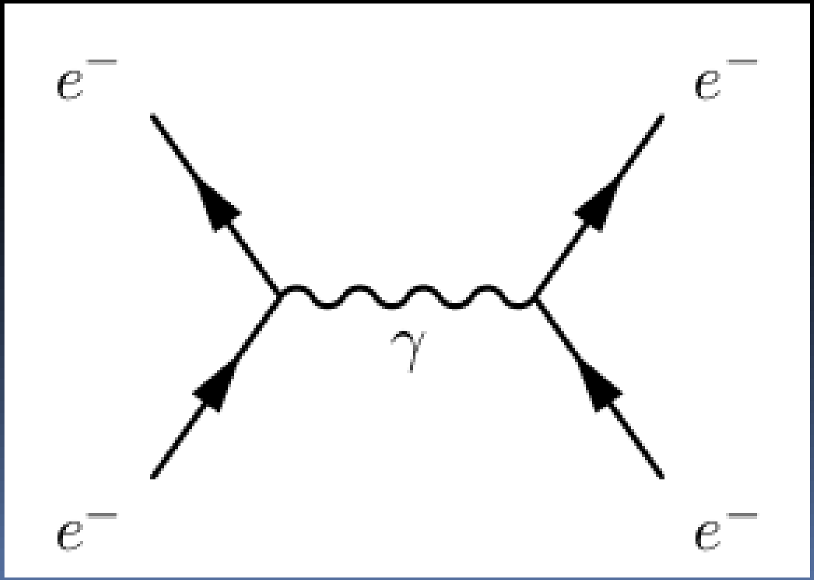
- Gravitational attraction and electrical attraction/repulsion classically explained by field strength
- Particle physics explains this force as an exchange of a particle using Newton’s Laws

Exchange Particles



Exchange Particles

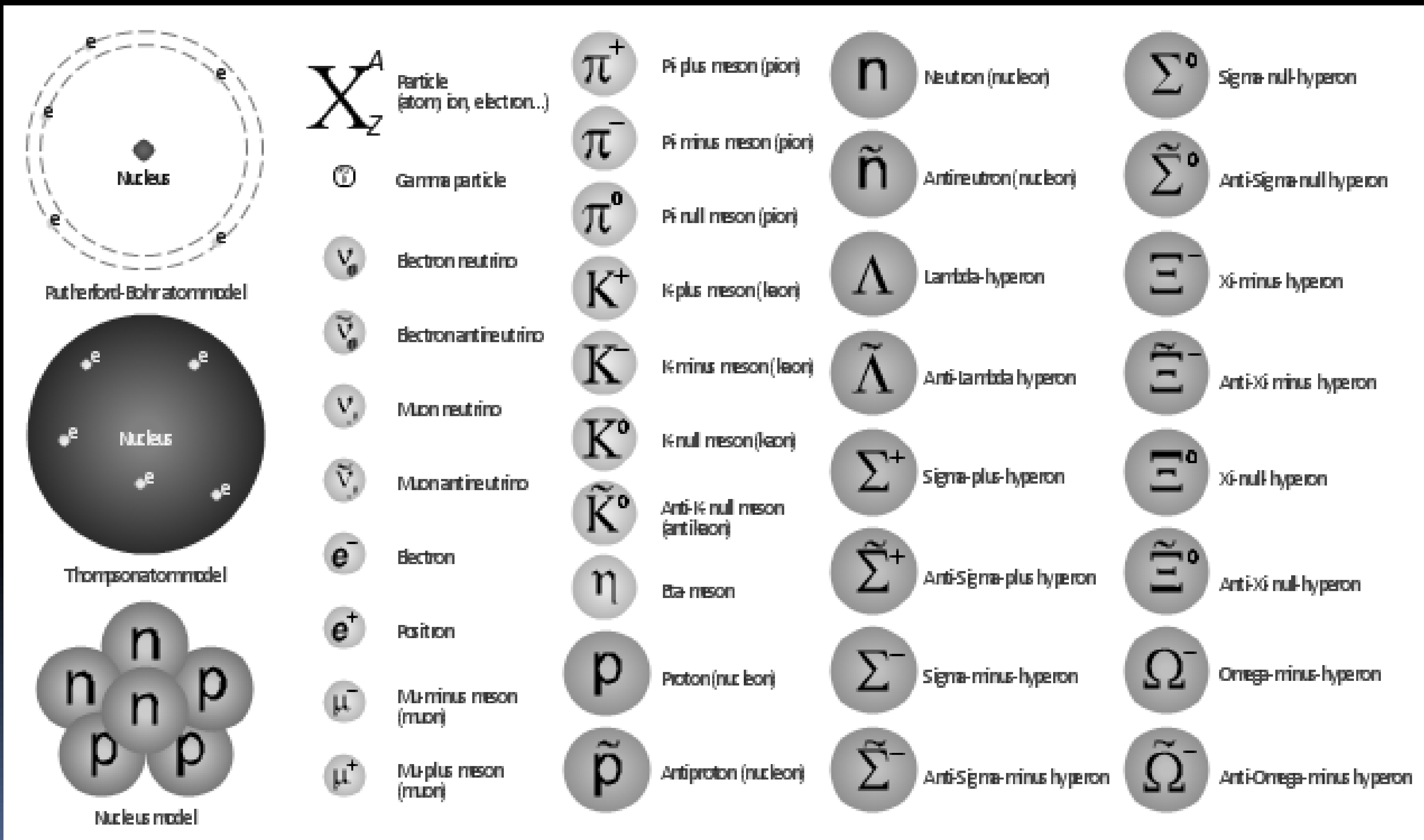
- In the case of the electromagnetic interaction, one electron emits a photon and the other absorbs it
- The photon carries momentum so the exchange exerts a force on each electron



Exchange Particles

force	boson	
	symbol	name
strong	g	*gluon*
electromagnetic	γ	*photon*
weak	W^+, W^-	*W bosons*
	Z°	*Z boson*

Particles Everywhere!



Halftime!

- Lsn 7-3A
  - Evolution of Standard and Particle Physics
  - Elementary particles
    - Quarks
    - Leptons
    - Exchange Particles
- Lsn 7-3B
  - Feynman Diagrams
  - Confinement
  - Higgs Boson

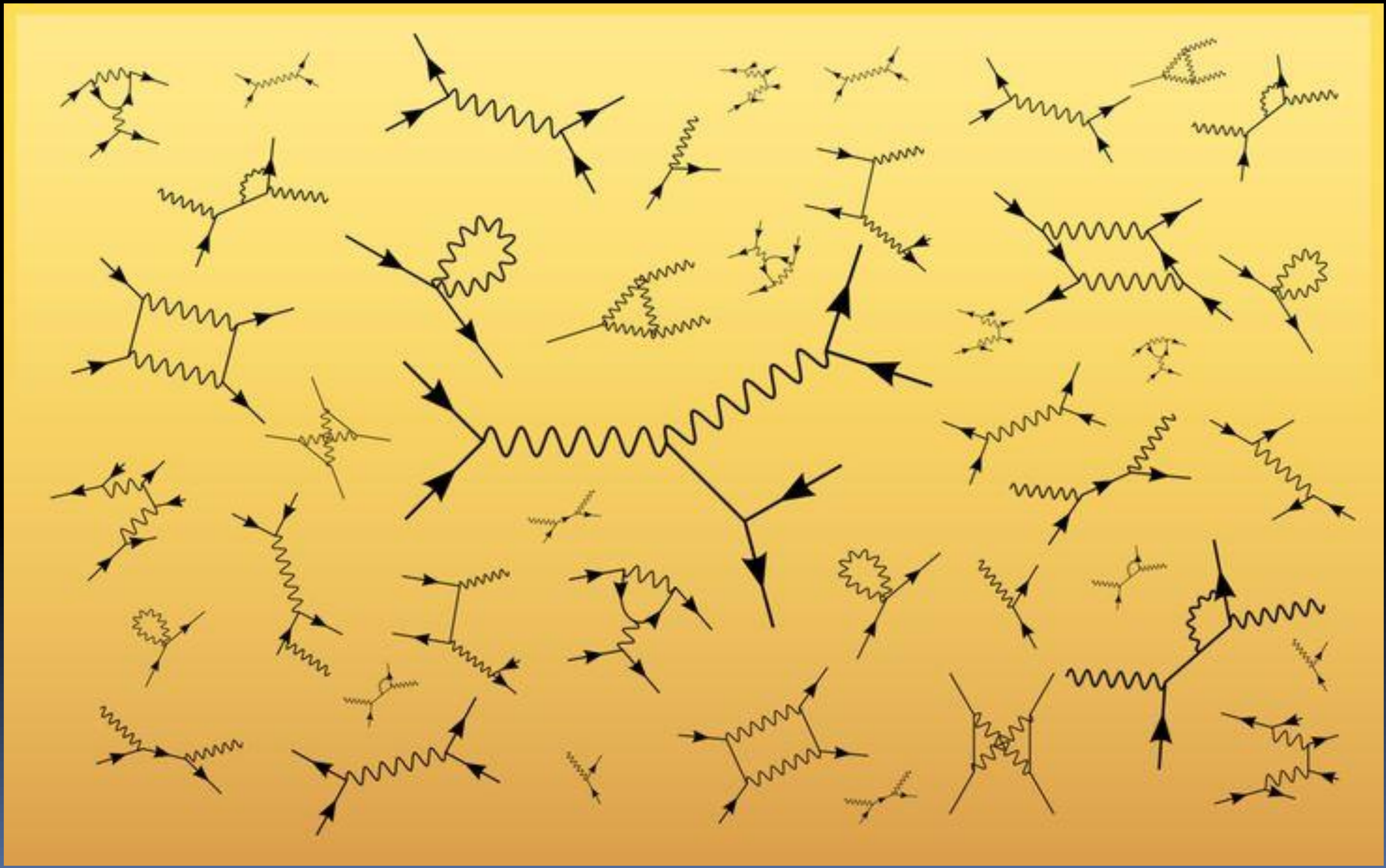
Halftime Homework

- Lsn 7-3A
  - #25-38
- Lsn 7-3B
  - #39-44

Halftime Homework

- Lsn 7-3A
  - #25-38
- Lsn 7-3B
  - #39-44

Feynman Diagrams



Feynman Diagrams

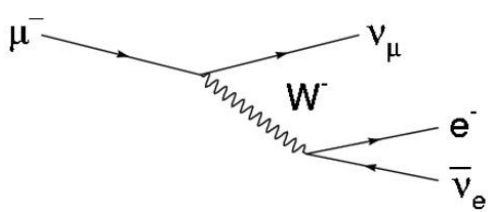
P780.02 Spring 2003 L3

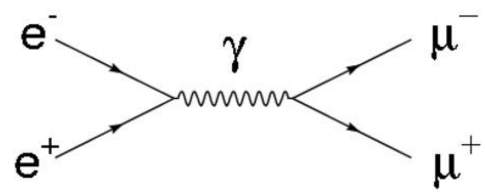
Feynman Diagrams

Richard Kass

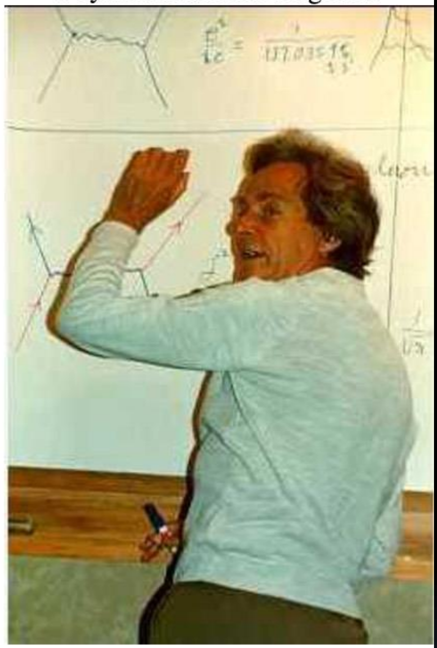
Feynman diagrams are pictorial representations of AMPLTUDES of particle reactions, i.e scatterings or decays. Use of Feynman diagrams can greatly reduce the amount of computation involved in calculating a rate or cross section of a physical process, e.g.

muon decay: $\mu^- \to e^- \bar{\nu}_e \nu_\mu$ or $e^+e^- \to \mu^+\mu^-$ scattering.





Feynman and his diagrams

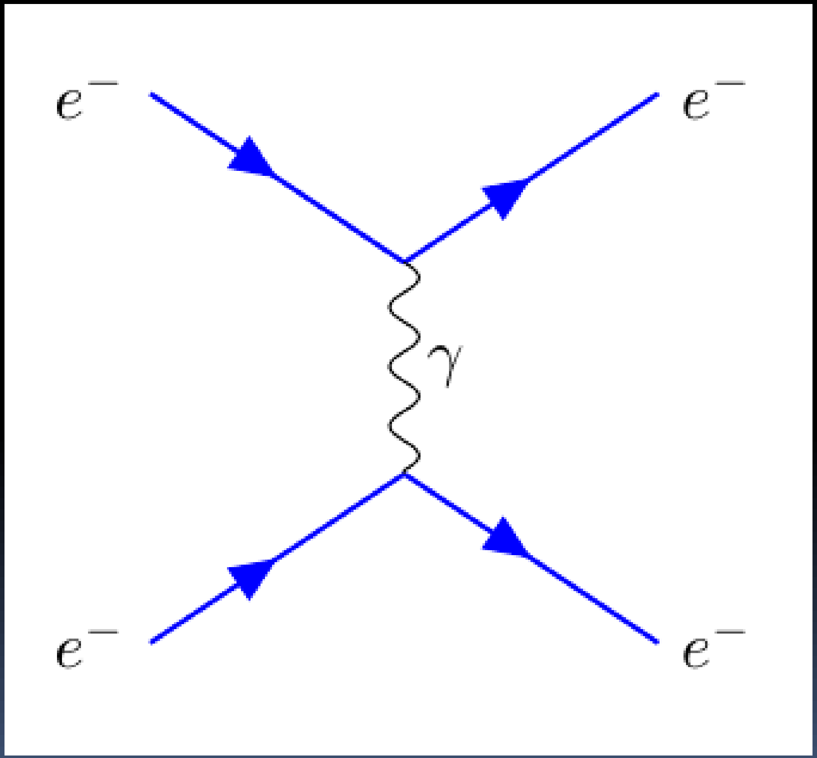


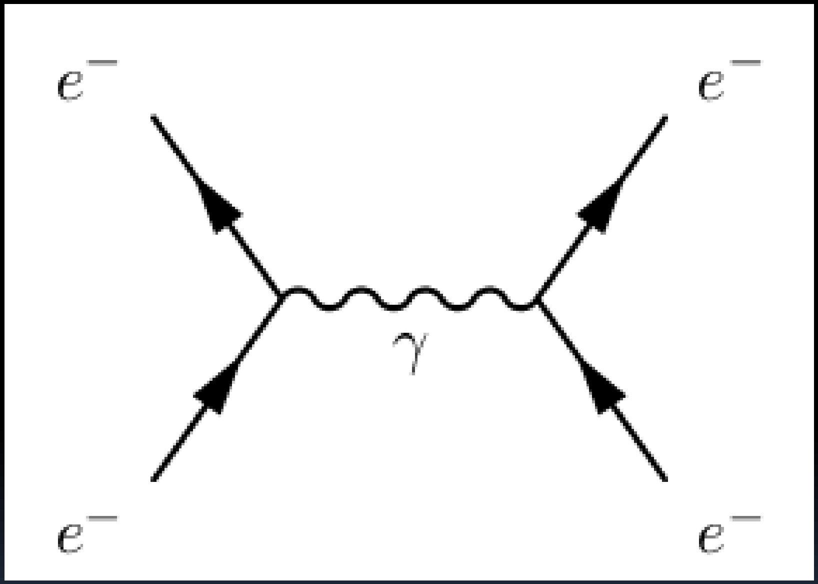
Like electrical circuit diagrams, every line in the diagram has a strict mathematical interpretation. Unfortunately the mathematical overhead necessary to do complete calculations with this technique is large and there is not enough time in this course to go through all the details. The details of Feynman diagrams are addressed in Advanced Quantum and/or 880.02. For a taste and summary of the rules look at Griffiths (e.g. sections 6.3, 6.6, and 7.5) or Relativistic Quantum Mechanics by Bjorken & Drell.

Feynman Diagrams

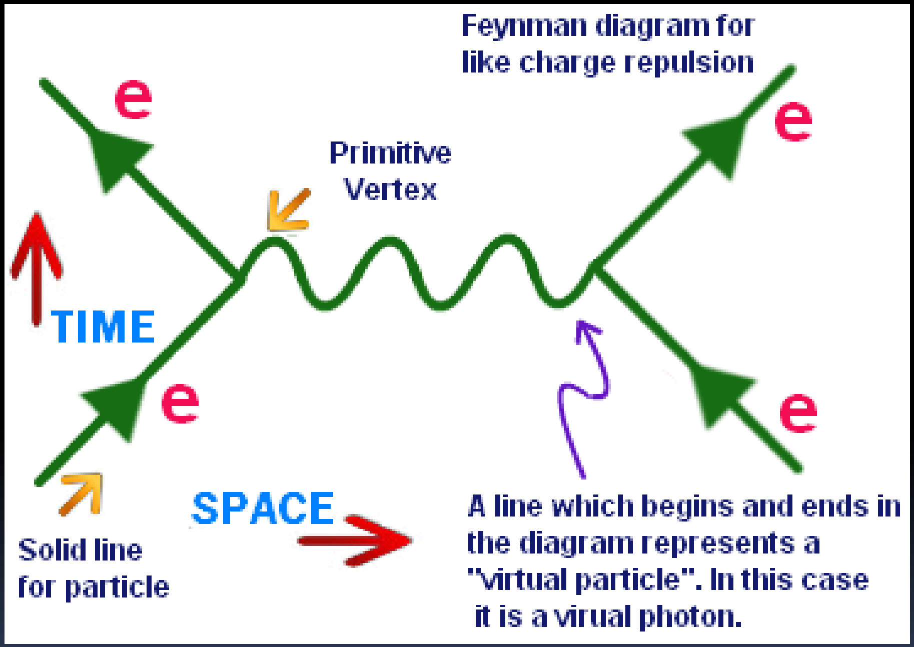
- Interactions between particles involve the exchange of particles
- Key is the interaction vertex
  - Two arrows and one wavy line
  - Time is along one axis, space on the other
  - Particles will have arrows in the opposite direction of antiparticles

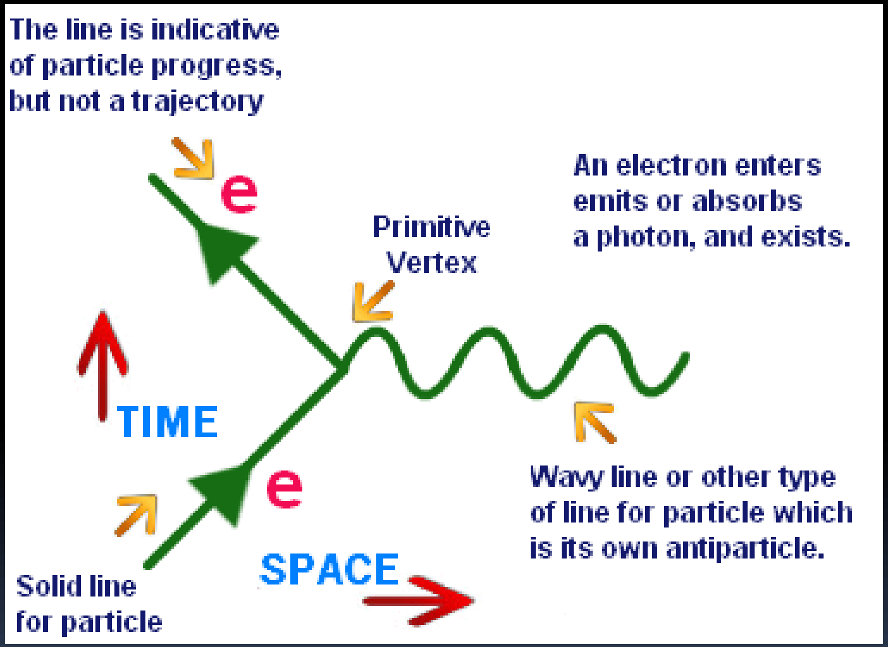
Feynman Diagrams





Feynman Diagrams

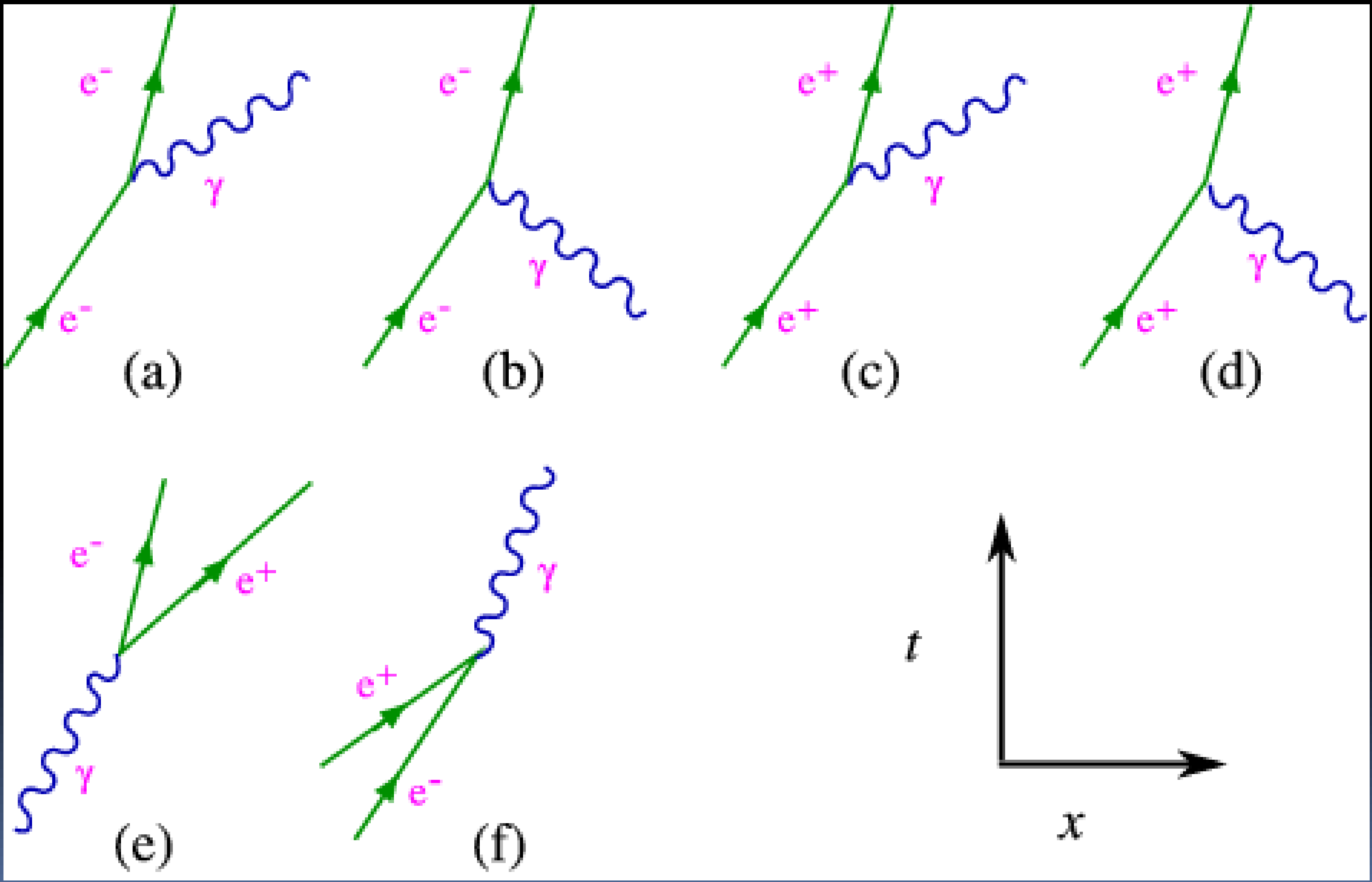




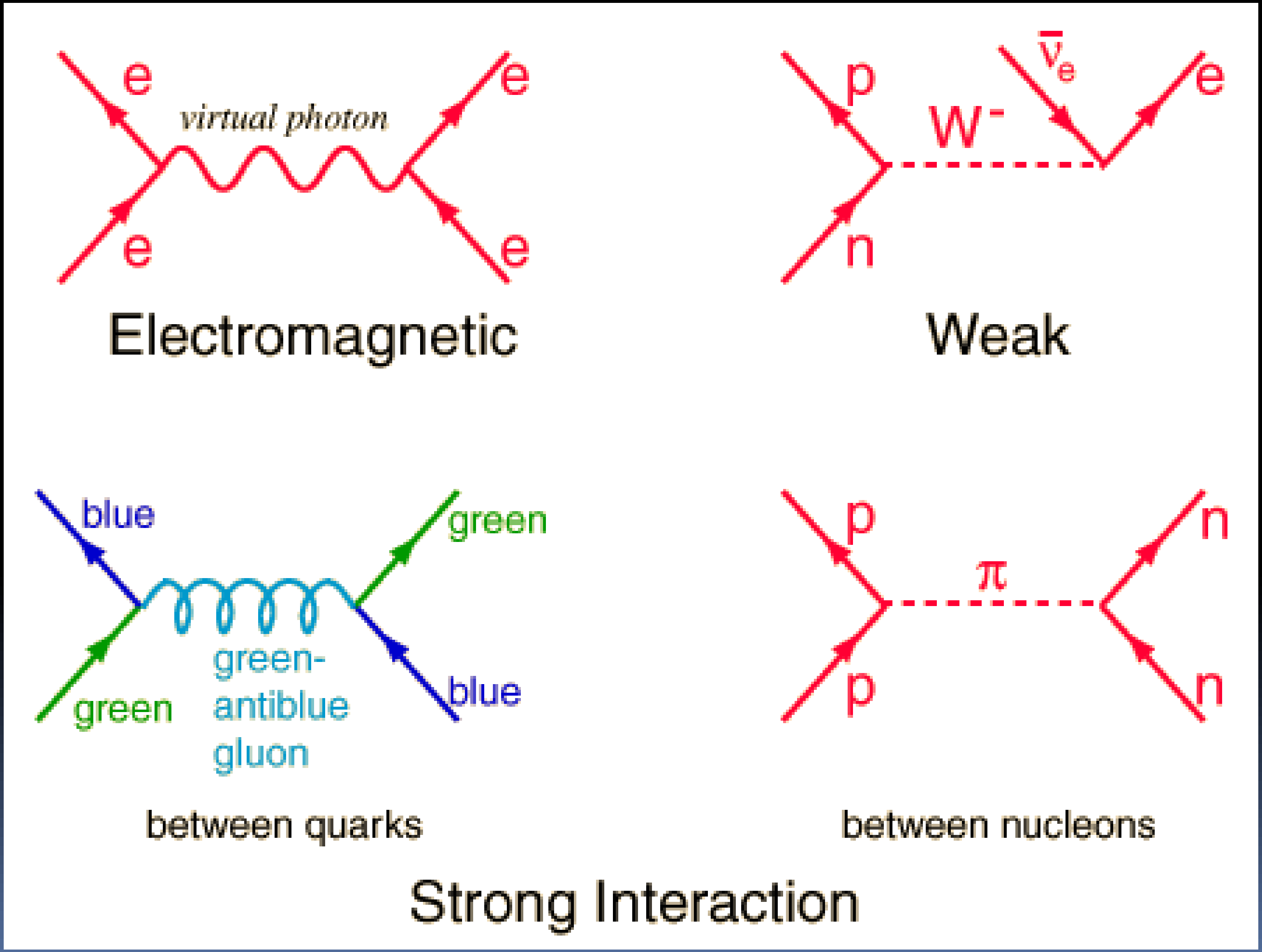
Feynman Diagrams

- Each line on the diagram corresponds to a precise mathematical expression
- Each expression contributes to the probability of the process occurring
- Precise rules for calculating probability from the diagram

Feynman Diagrams



Feynman Diagrams

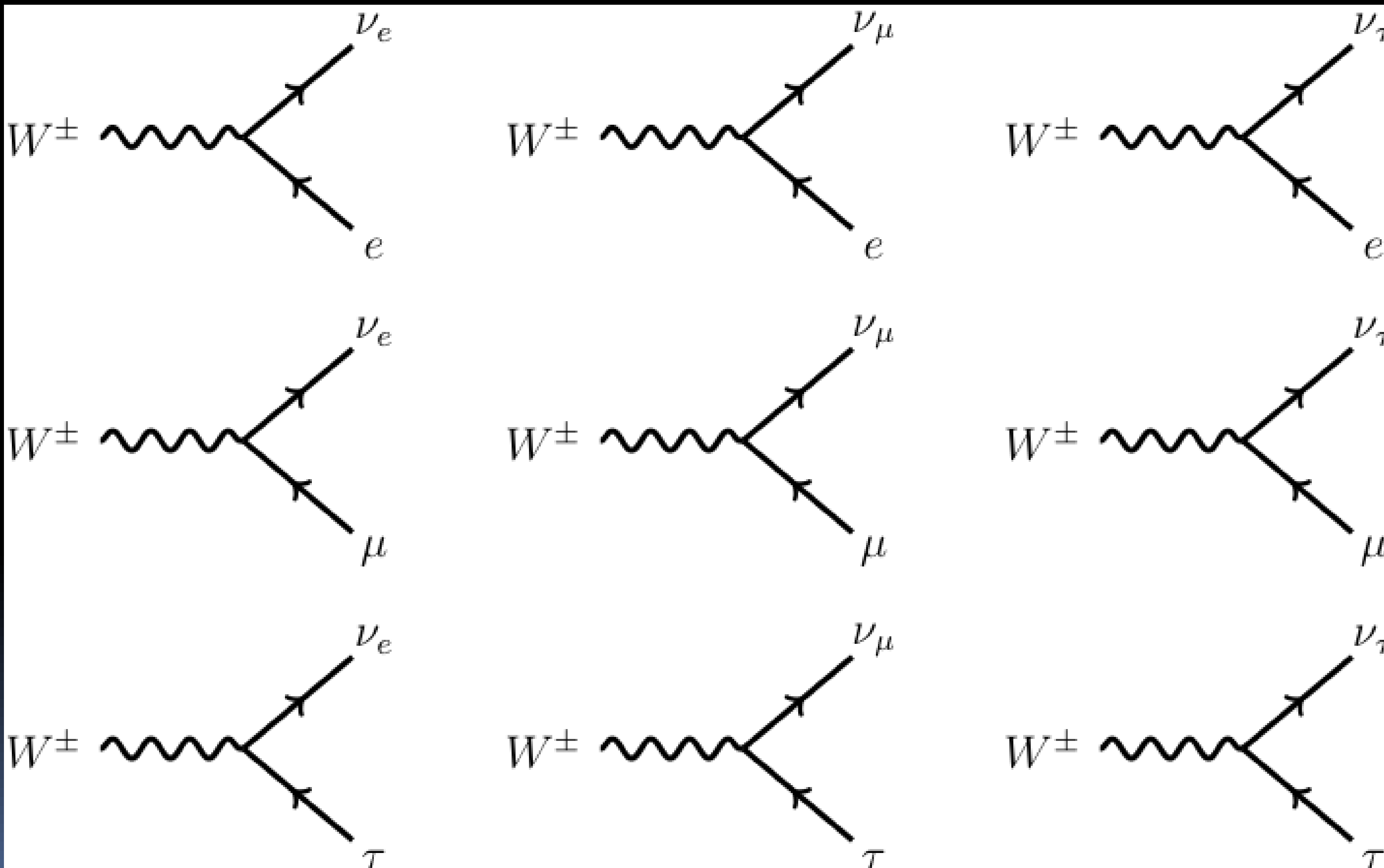


Feynman Diagrams

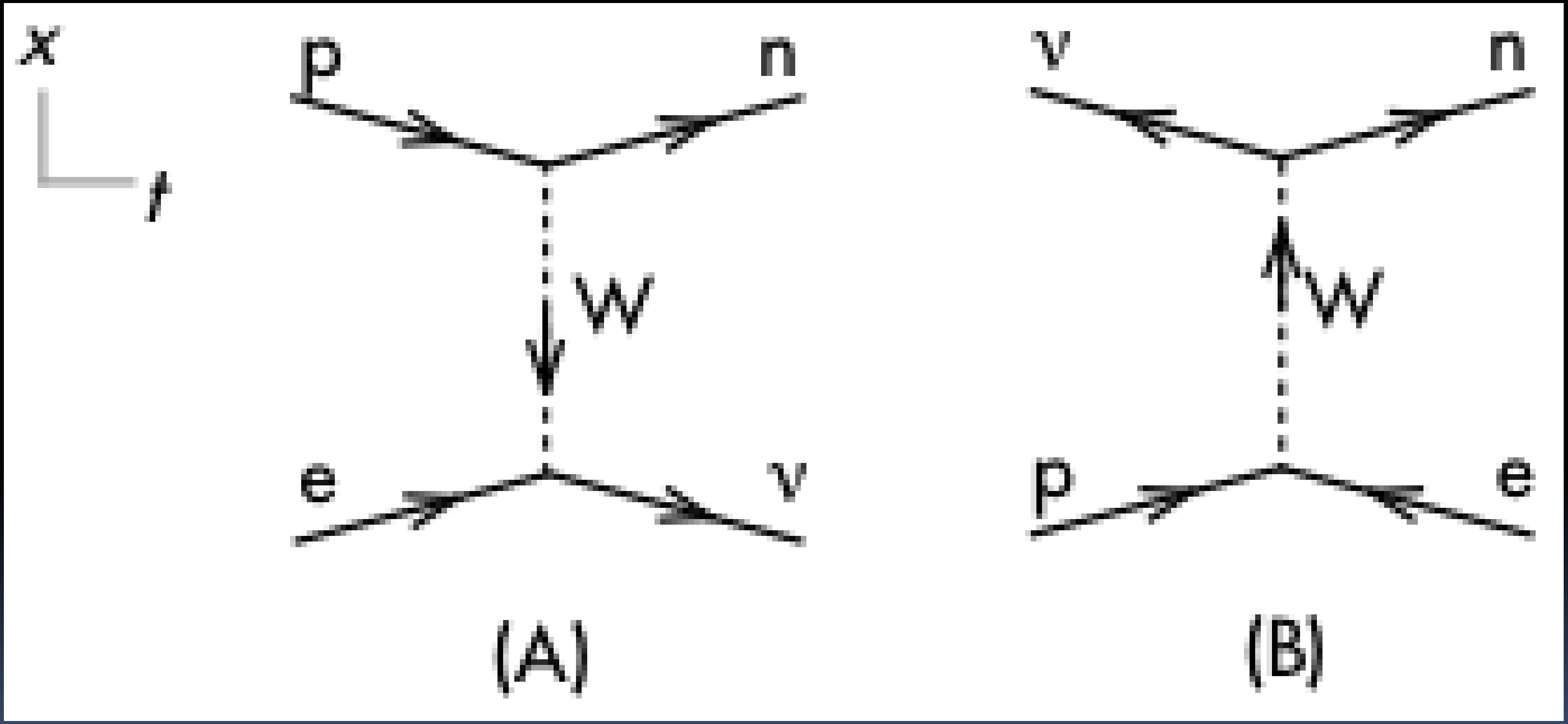
Fundamental Force Particles

Force	Particles Experiencing	Force Carrier Particle	Range	Relative Strength*
Gravity acts between objects with mass	all particles with mass	graviton (not yet observed)	infinity	much weaker
Weak Force governs particle decay	quarks and leptons	W^+, W^-, Z^0 (W and Z)	short range	
Electromagnetism acts between electrically charged particles	electrically charged	γ (photon)	infinity	
Strong Force** binds quarks together	quarks and gluons	g (gluon)	short range	much stronger

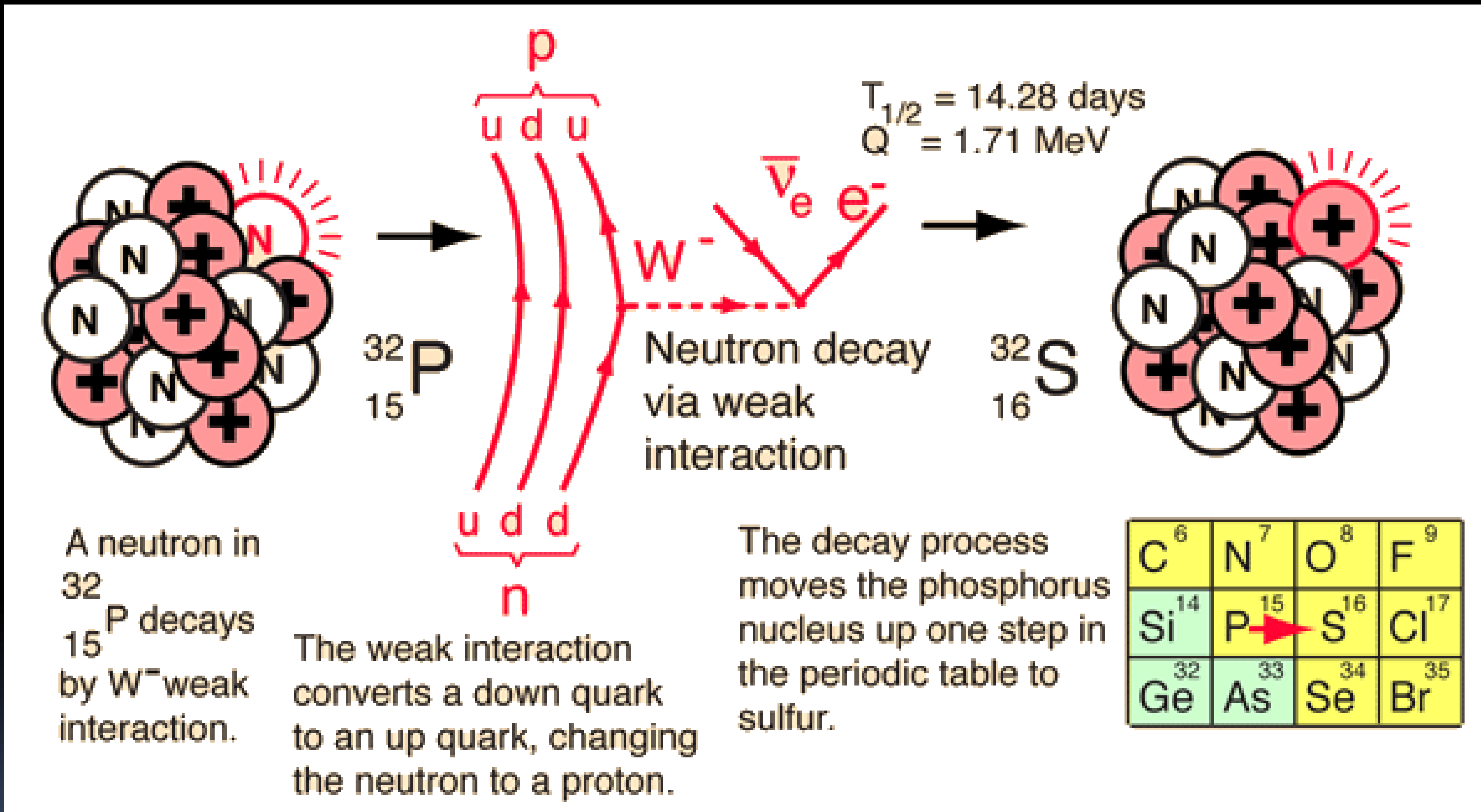
Feynman Diagrams – Weak Interaction



Feynman Diagrams – Weak Interaction

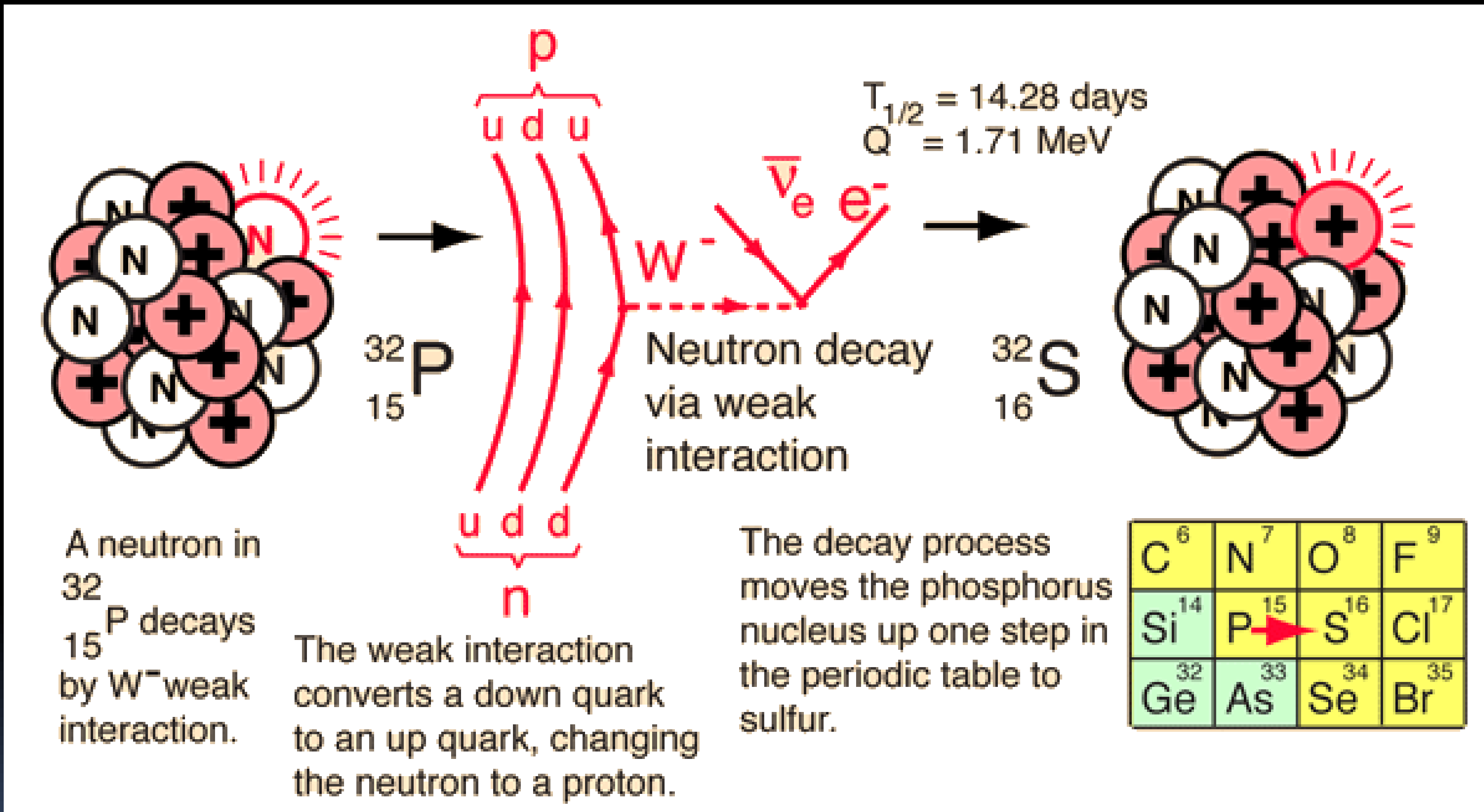


Feynman Diagrams – Weak Interaction



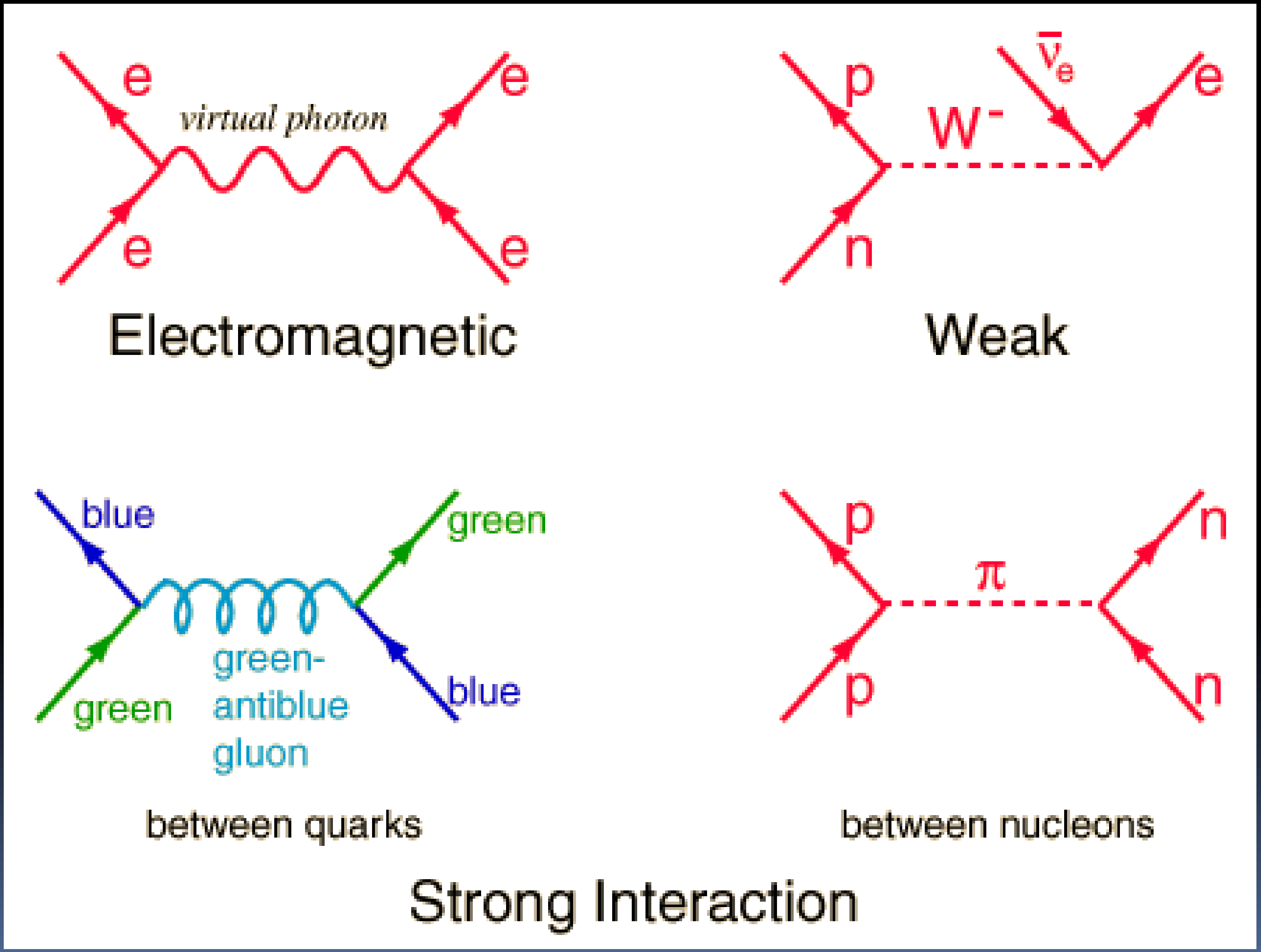
What type of decay is this?

Feynman Diagrams – Weak Interaction

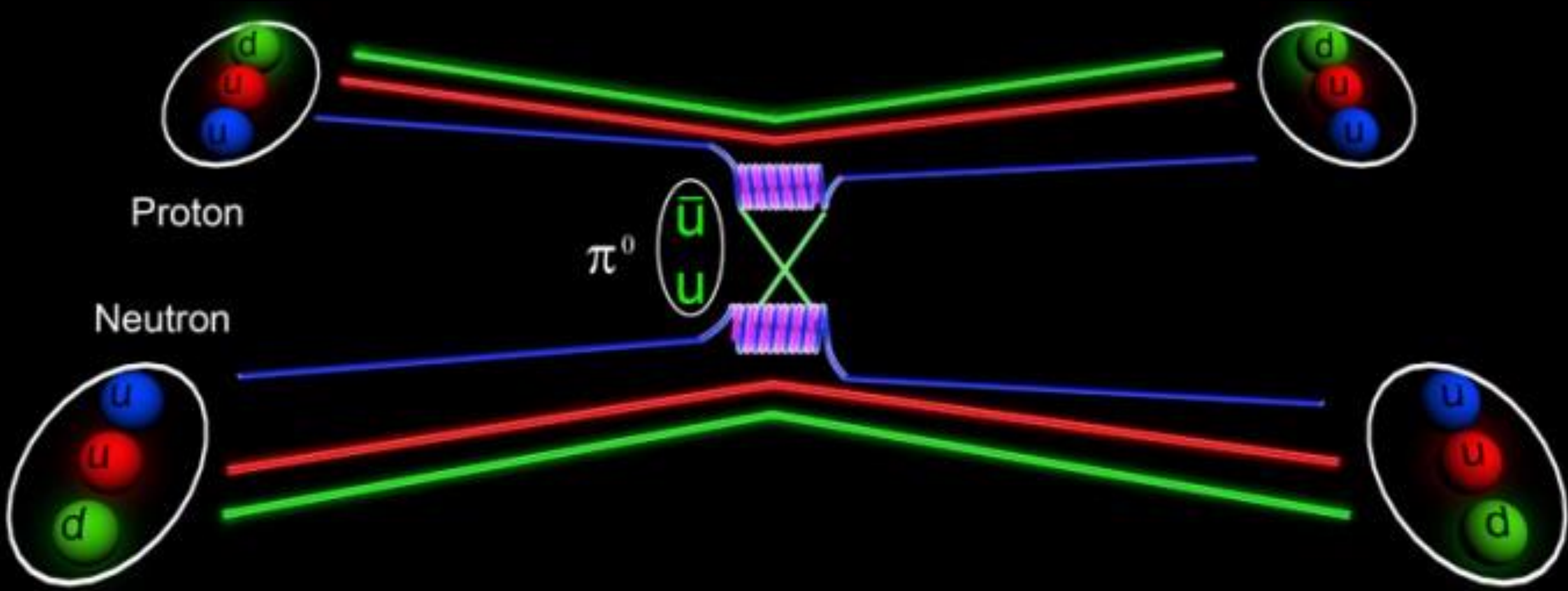


Beta Decay!

Feynman Diagrams – Strong Interaction

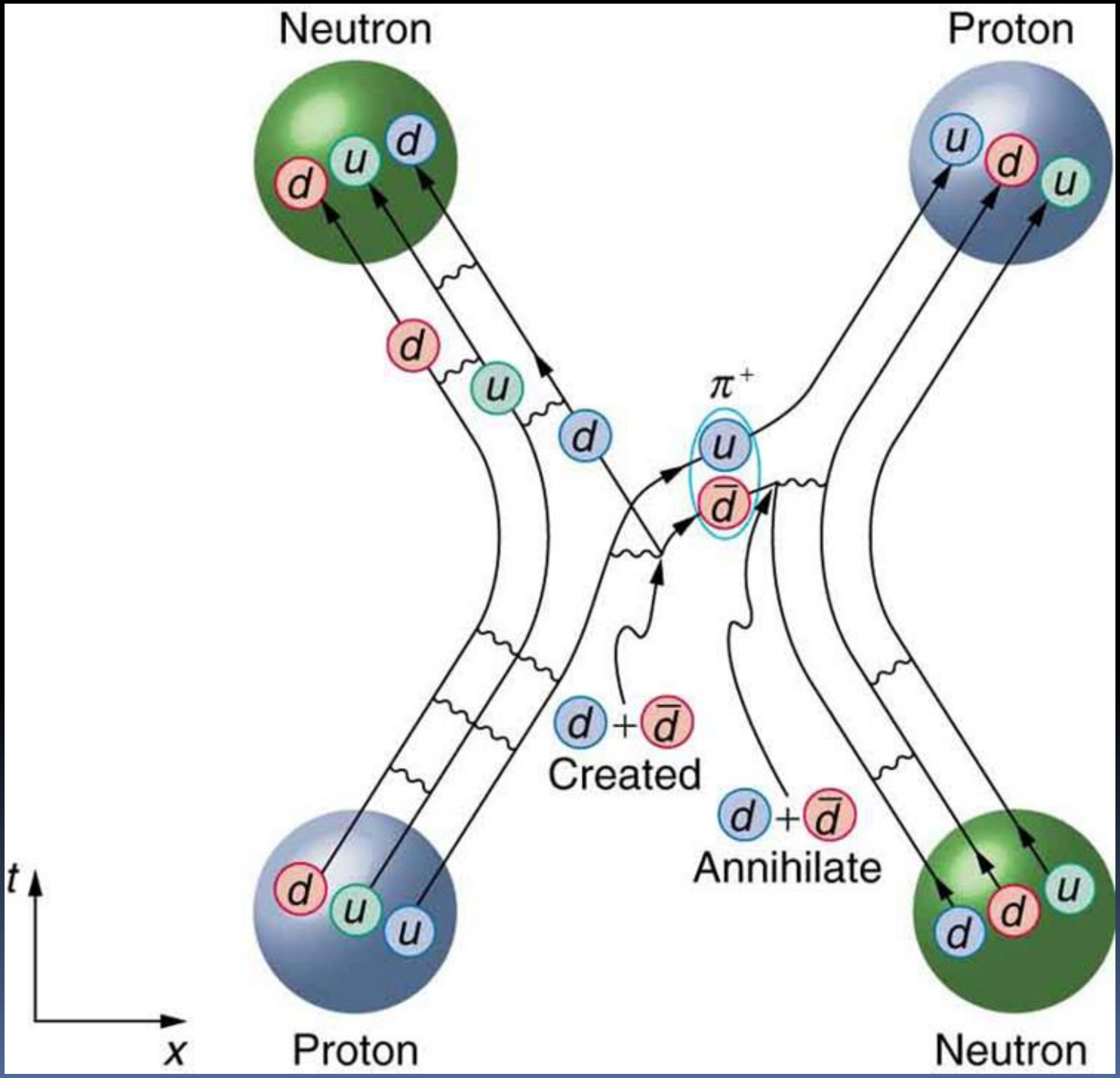


Feynman Diagrams – Strong Interaction



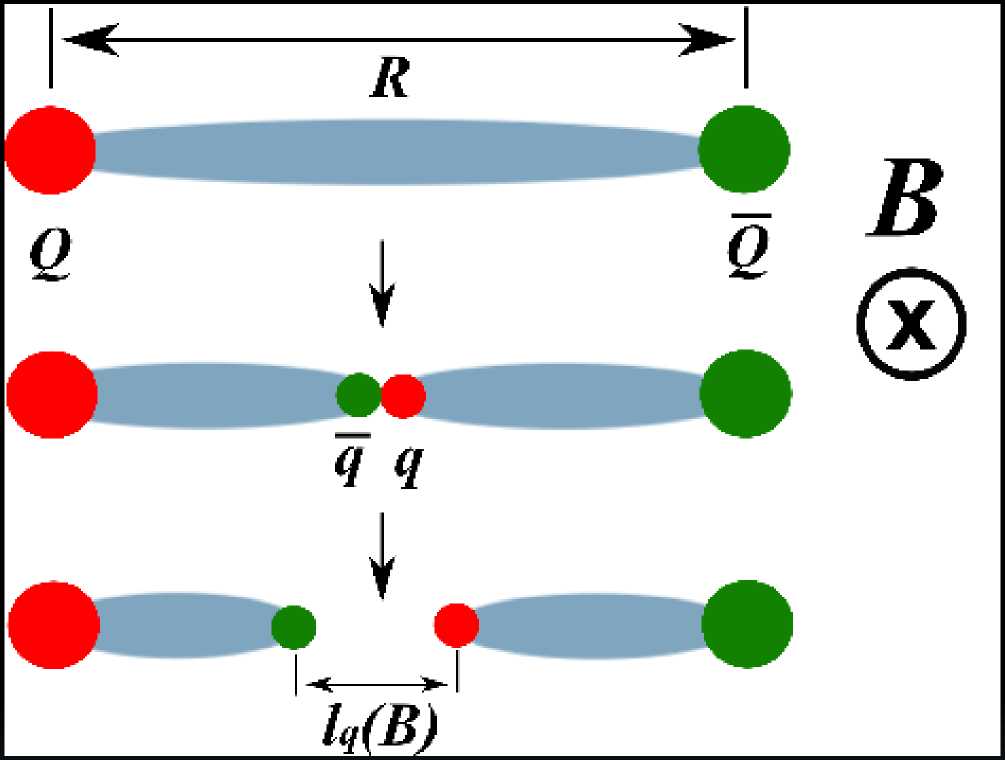
A Feynman diagram showing an example of the kind of interaction that binds neutrons and protons together inside the nucleus. The nuclear force, a residual effect of the strong force between quarks is transmitted by the exchange of a quark-antiquark pair, known as a meson (in this case a pi zero meson).

Feynman Diagrams – Strong Interaction



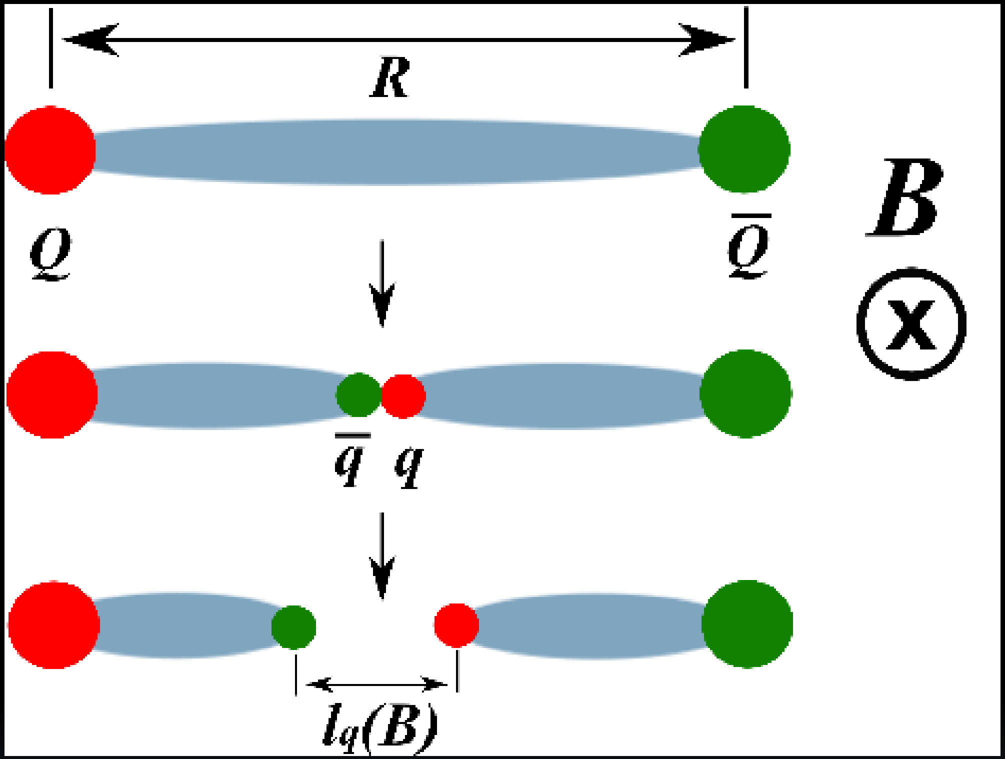
Quark Confinement

- Different from CAS detention, but analogous
- ***The force between a quark-anti-quark pair is the same regardless of the separation***
- It takes a continuous amount of energy to move them apart



Quark Confinement

- If you were theoretically able to supply enough force to separate them, that energy would create a new pairing
- ***It is not possible to observe isolated quarks***

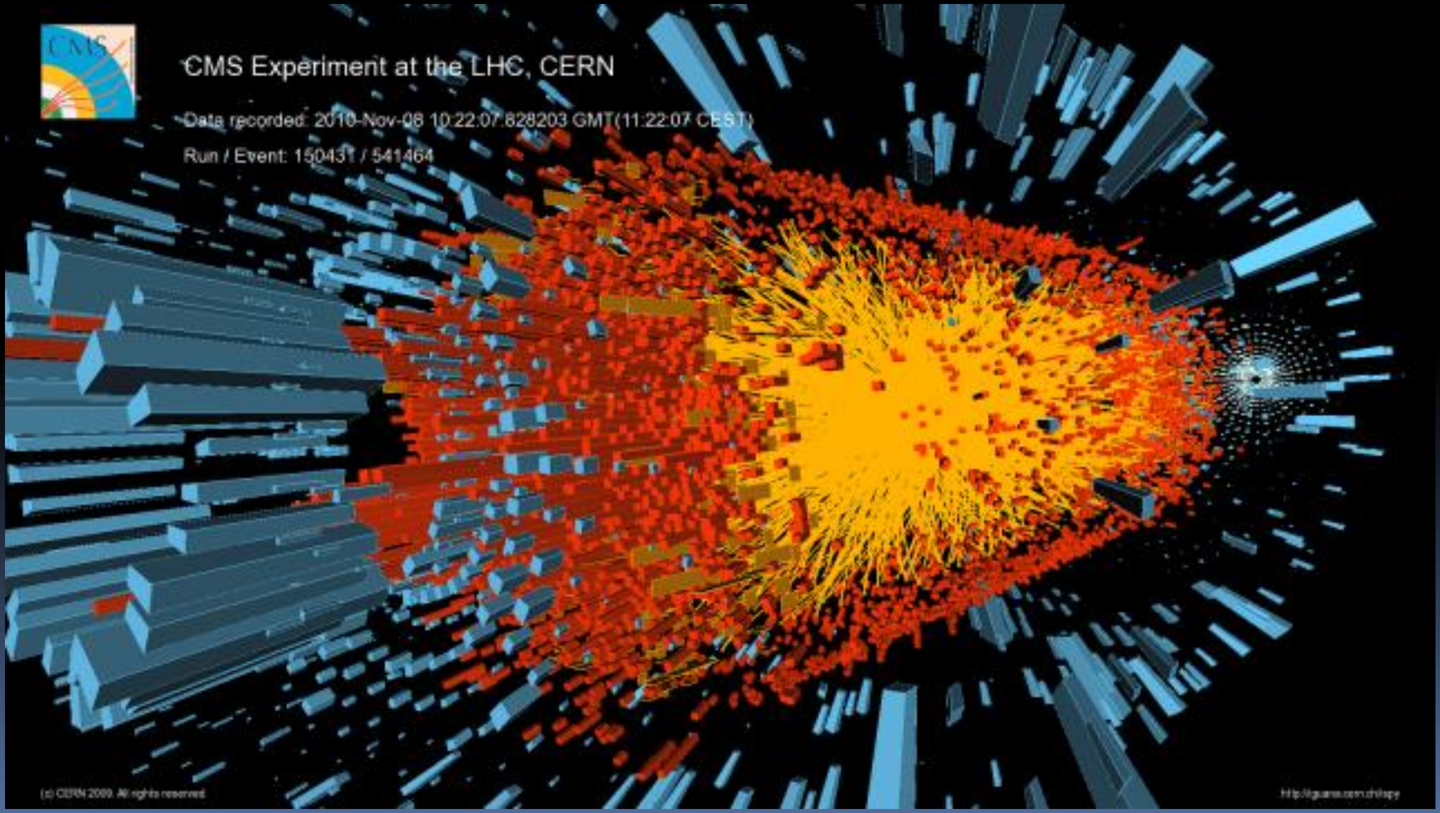


Higgs Particle

- All aspects of the Standard Model have been proved experimentally – except one
- The missing link has been the one that holds it all together – the Higgs Boson
- How do elementary particles acquire mass and why do they have the mass that they do?
- The Standard Model is based on mathematical symmetry and that symmetry did not allow for the existence of mass

Higgs Particle

- The Higgs particle was finally discovered in 2012
- Higgs particle is the quantum (unit or packet) of the Higgs field



Higgs Particle

- Illustration:
  - If you apply a force to an object in space, it accelerates
  - If you apply the same force to an object in water, the acceleration is less
  - To get the same acceleration, you must apply more force
  - This gives the appearance of greater mass, "The force produced less acceleration so the mass must be greater

$$F = ma$$

$$m = \frac{F}{a}$$

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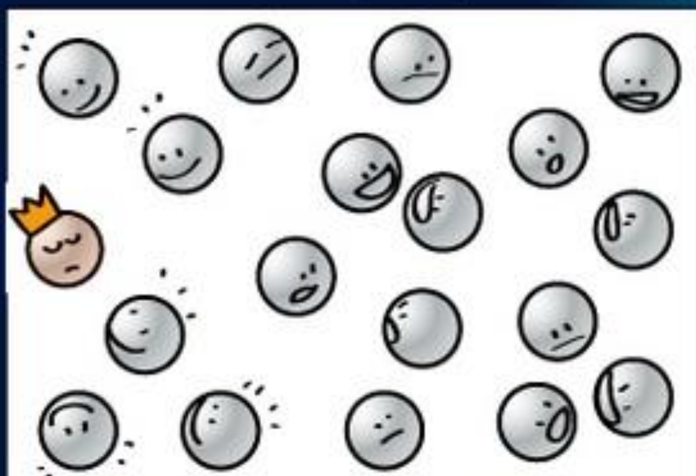
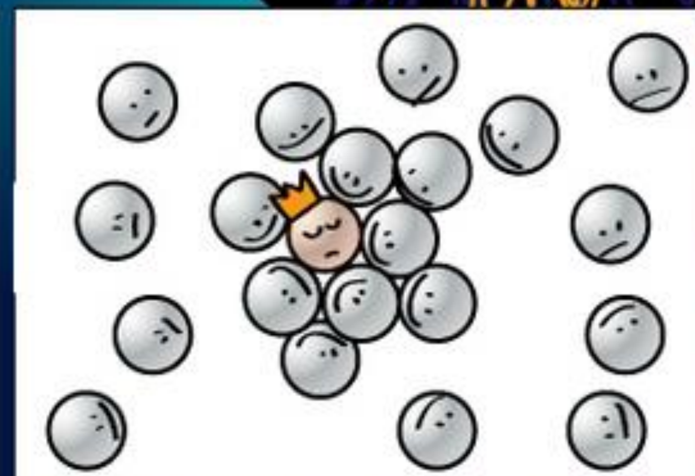
What is a Higgs Boson?

The elusive Higgs boson, if found, would complete the Standard Model of physics. It is thought that matter obtains mass by interacting with the Higgs field. If Higgs did not exist, according to the model, everything in the universe would be massless.

The "cocktail party" analogy



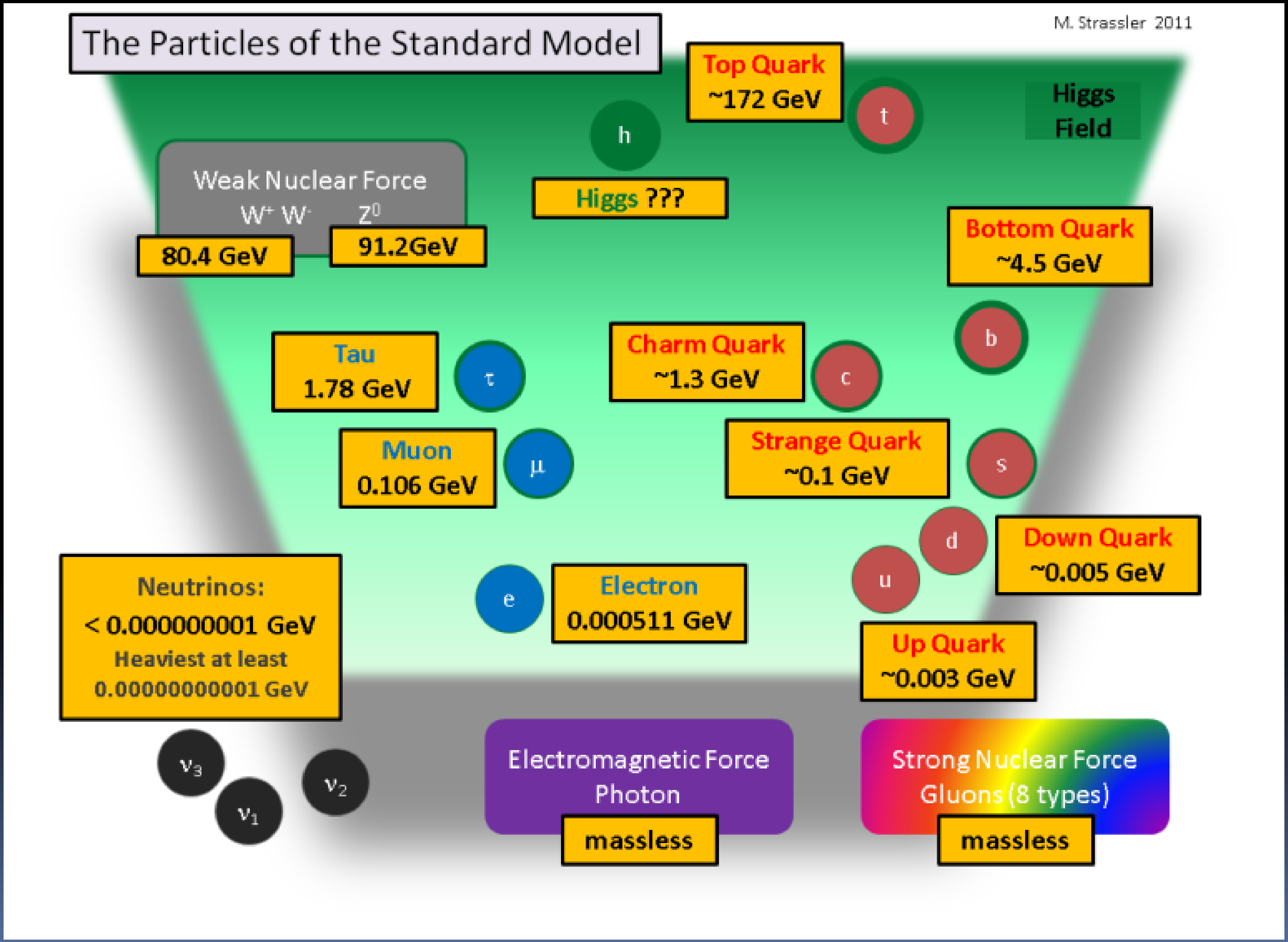
Imagine a party where guests are evenly spaced around the room. The room of guests represents the Higgs field, which is everywhere in the universe. Suddenly a celebrity enters. Guests notice the celebrity and rush in closer to be near her, forming a tight knot.



As the celebrity passes through the room, the concentrated clump of guests surrounding her gives the group additional momentum. The clump is harder to stop than one guest alone would be, and so we can say that the clump has acquired mass.

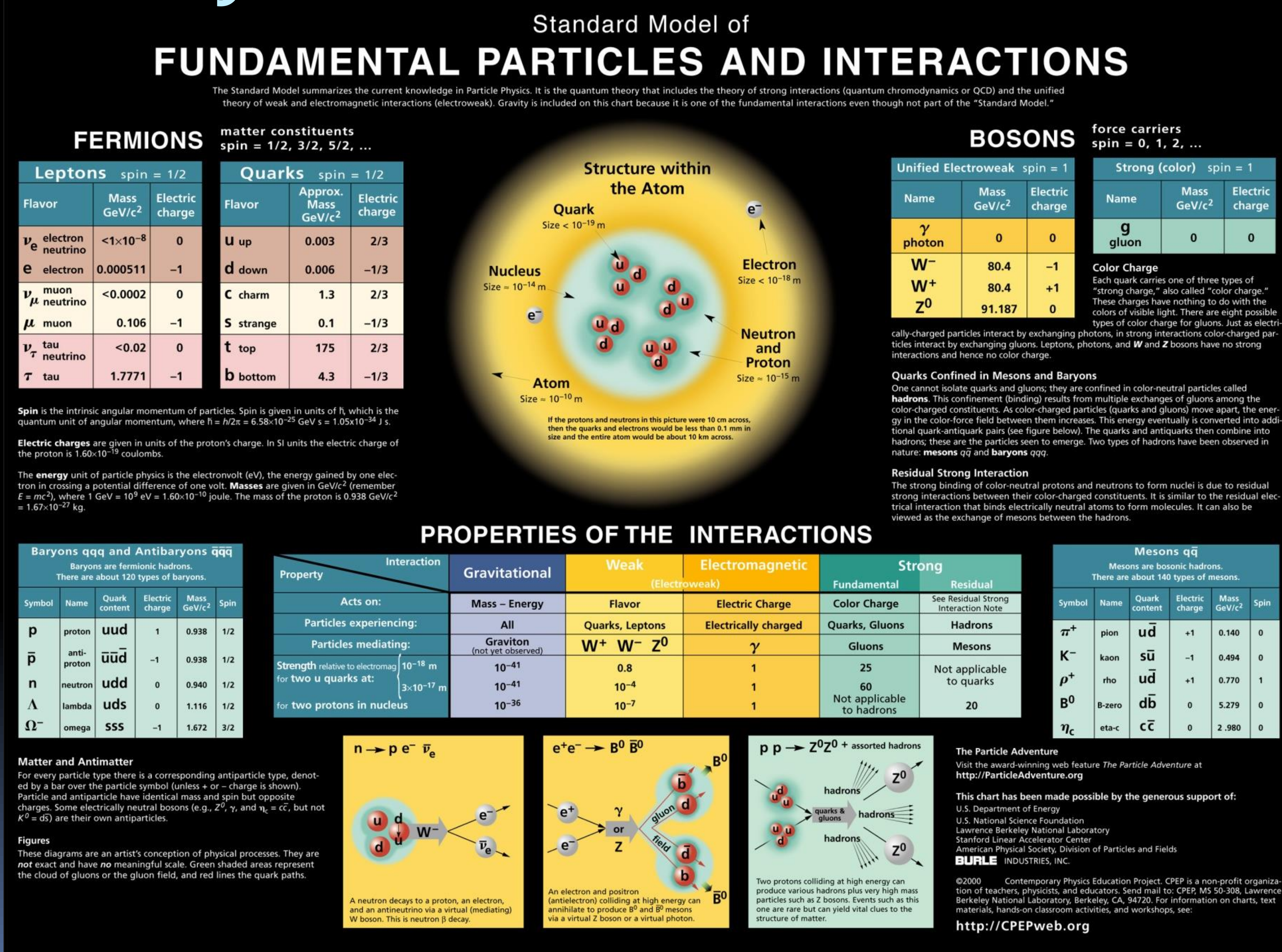
SOURCE: CERN

Standard Model and Higgs Field



AND SO, . . .

Summary



Standard Model of

FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor	Mass GeV/c²	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	–1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	–1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	–1

Quarks spin = 1/2

Flavor	Approx. Mass GeV/c²	Electric charge
u up	0.003	2/3
d down	0.006	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	175	2/3
b bottom	4.3	–1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of ħ, which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s $= 1.05\times10^{-34}$ J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$), where 1 GeV $= 10^9$ eV $= 1.60\times10^{-10}$ joule. The mass of the proton is 0.938 GeV/c^2 $= 1.67\times10^{-27}$ kg.

Structure within the Atom

Quark Size $< 10^{-19}$ m

Nucleus Size $\approx 10^{-14}$ m

Electron Size $< 10^{-18}$ m

Neutron and Proton Size $\approx 10^{-15}$ m

Atom Size $\approx 10^{-10}$ m

If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

BOSONS force carriers spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c²	Electric charge
γ photon	0	0
W^-	80.4	–1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c²	Electric charge
g gluon	0	0

Color Charge

Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically-charged particles interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and ***W*** and ***Z*** bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons

One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** $q\bar{q}$ and **baryons** qqq.

Residual Strong Interaction

The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
Strength relative to electromag for two u quarks at: 3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons. There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c²	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	–1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	–1	1.672	3/2

Mesons $q\bar{q}$

Mesons are bosonic hadrons. There are about 140 types of mesons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c²	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	–1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

Matter and Antimatter

For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or – charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and $\eta_c = c\bar{c}$, but not $K^0 = d\bar{s}$) are their own antiparticles.

Figures

These diagrams are an artist's conception of physical processes. They are ***not*** exact and have ***no*** meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.

$n \to p\, e^-\, \bar{\nu}_e$

A neutron decays to a proton, an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β decay.

$e^+e^- \to B^0\, \bar{B}^0$

An electron and positron (antielectron) colliding at high energy can annihilate to produce B^0 and $\bar{B}^0$ mesons via a virtual Z boson or a virtual photon.

$p\,p \to Z^0Z^0$ + assorted hadrons

Two protons colliding at high energy can produce various hadrons plus very high mass particles such as Z bosons. Events such as this one are rare but can yield vital clues to the structure of matter.

The Particle Adventure

Visit the award-winning web feature *The Particle Adventure* at **http://ParticleAdventure.org**

This chart has been made possible by the generous support of:

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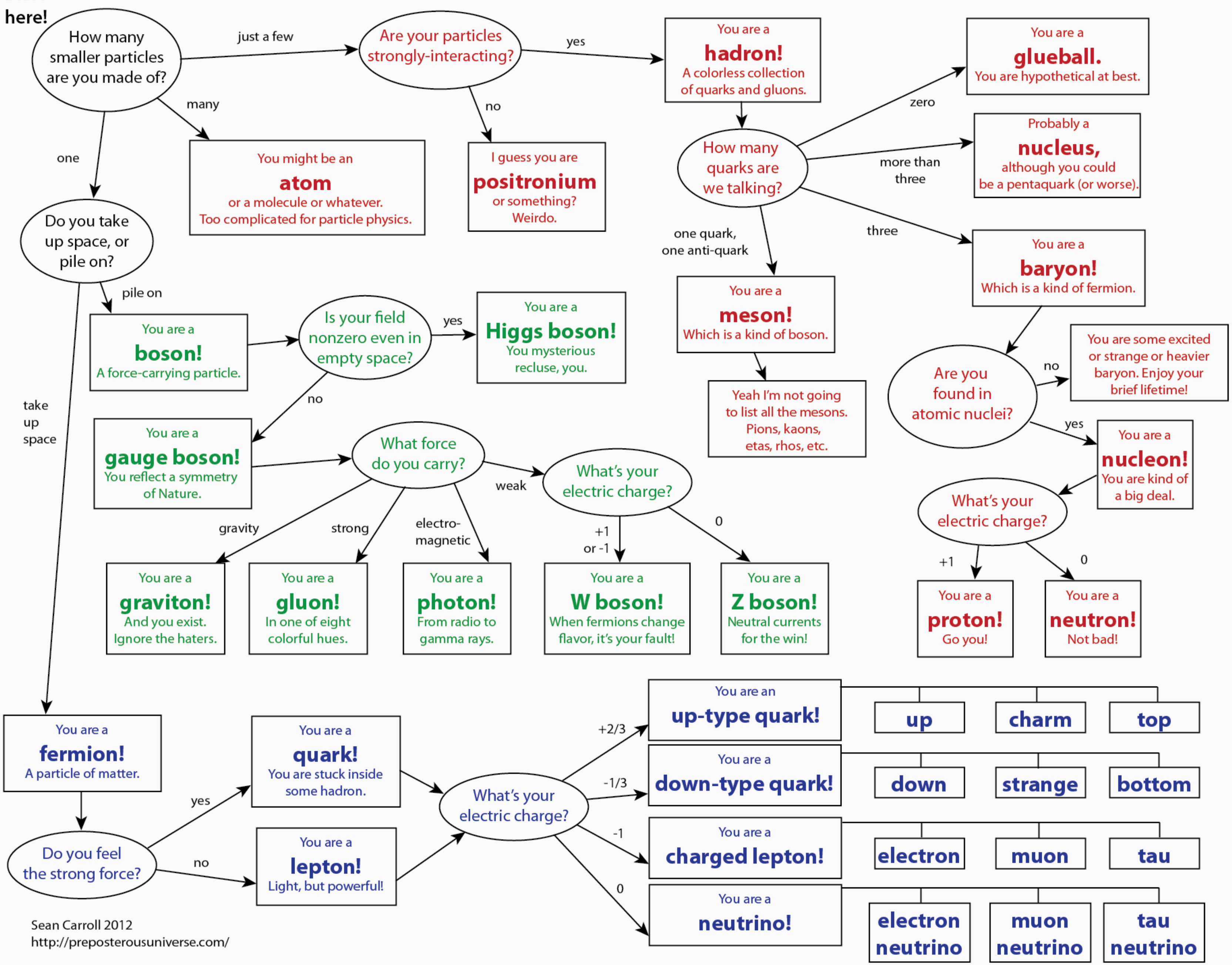
Stanford Linear Accelerator Center
American Physical Society, Division of Particles and Fields
BURLE INDUSTRIES, INC.

What Particle Are You?

(Standard Model particles only! Dark matter and other exotica not welcome.)

Color code:
elementary fermions
elementary bosons
composite particles



Understandings:

- Quarks, leptons and their antiparticles
- Hadrons, baryons and mesons
- The conservation laws of charge, baryon number, lepton number and strangeness
- The nature and range of the strong nuclear force, weak nuclear force and electromagnetic force
- Exchange particles
- Feynman diagrams
- Confinement
- The Higgs boson

Applications And Skills:

- Describing the Rutherford-Geiger-Marsden experiment that led to the discovery of the nucleus
- Applying conservation laws in particle reactions
- Describing protons and neutrons in terms of quarks
- Comparing the interaction strengths of the fundamental forces, including gravity

Applications And Skills:

- Describing the mediation of the fundamental forces through exchange particles
- Sketching and interpreting simple Feynman diagrams
- Describing why free quarks are not observed

Data Booklet Reference:

Charge	Quarks			Baryon number
$\frac{2}{3}e$	u	c	t	$\frac{1}{3}$
$-\frac{1}{3}e$	d	s	b	$\frac{1}{3}$
All quarks have a strangeness number of 0 except the strange quark that has a strangeness number of –1				

Charge	Leptons		
–1	e	μ	τ
0	υ_e	υ_μ	υ_τ
All leptons have a lepton number of 1 and antileptons have a lepton number of –1			

Data Booklet Reference:

	Gravitational	Weak	Electromagnetic	Strong
Particles experiencing	All	Quarks, leptons	Charged	Quarks, gluons
Par ticles mediating	Graviton	W^+, W^-, Z^0	γ	Gluons

Utilization:

- An understanding of particle physics is needed to determine the final fate of the universe (see Physics option sub-topics D.3 and D.4).

Essential Idea:

- It is believed that all the matter around us is made up of fundamental particles called quarks and leptons. It is known that matter has a hierarchical structure with quarks making up nucleons, nucleons making up nuclei, nuclei and electrons making up atoms and atoms making up molecules. In this hierarchical structure, the smallest scale is seen for quarks and leptons (10^{-18}m).

QUESTIONS?

Homework

7-3A - #25-38

7-3B - #39-44