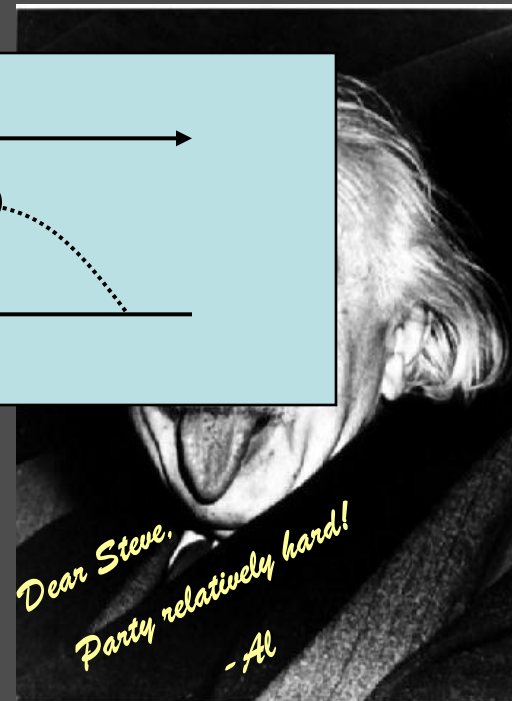
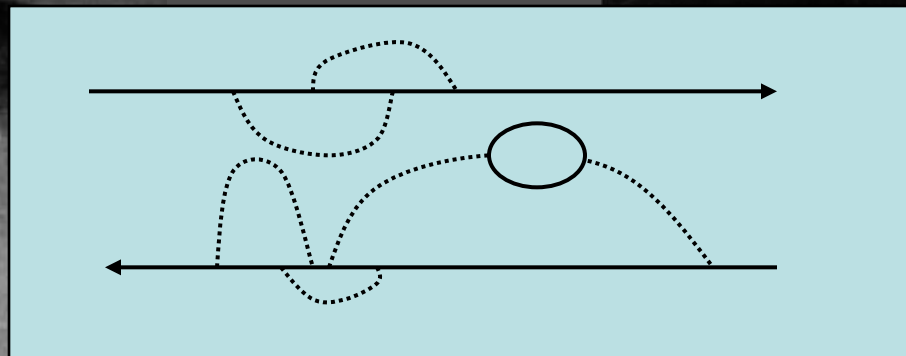
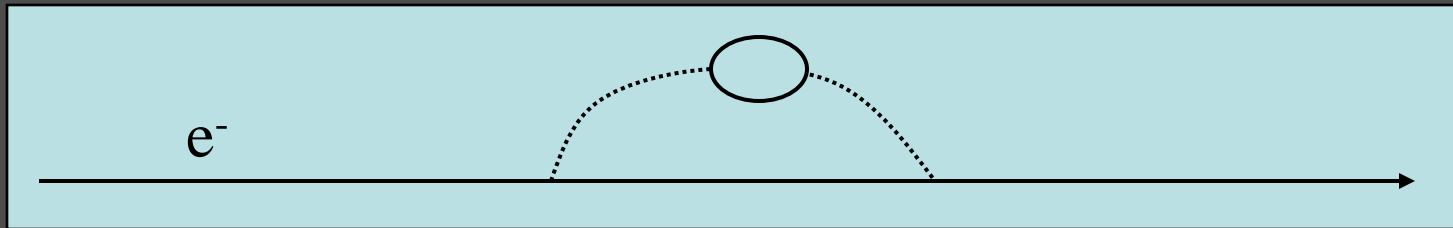


The fundamental nature of forces: virtual particles

$$\Delta E \Delta t \approx h \quad \text{Heisenberg}$$

$$E = mc^2 \quad \text{Einstein}$$

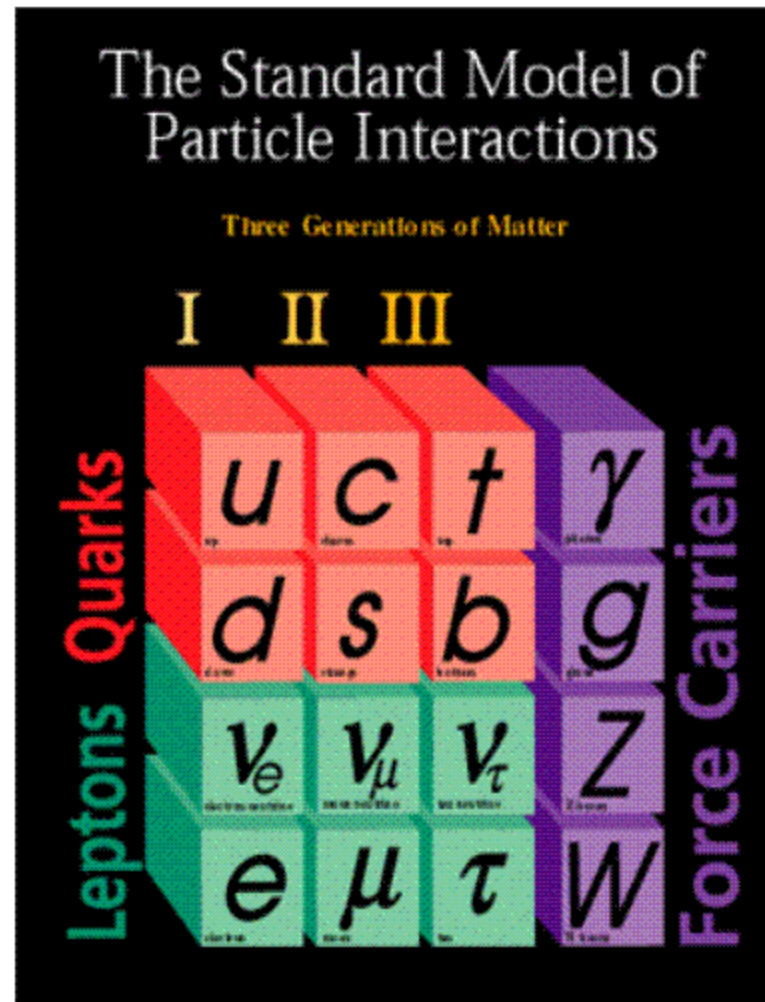


QUANTUM Field Theory \rightarrow Exchange force



<i>Force</i>	<i>Source</i>	<i>Range</i>	<i>Strength</i>
<i>Gravitation</i>	mass	infinite	10^{-39}
<i>Electromagnetism</i>	Electric charge	infinite	10^{-2}
<i>Strong nuclear</i>	Color charge	10^{-15} m	1
<i>Weak nuclear</i>	Weak charge	10^{-18} m	10^{-5}

The "Fundamental" particles



Anti matter

$e^- \sim e^+$ Positron
Anti-electron

$e^- \cup e^+ \longrightarrow \gamma\gamma$

All particles have antiparticles

Why is universe made of matter rather than antimatter?

We don't know why this is true ... yet.

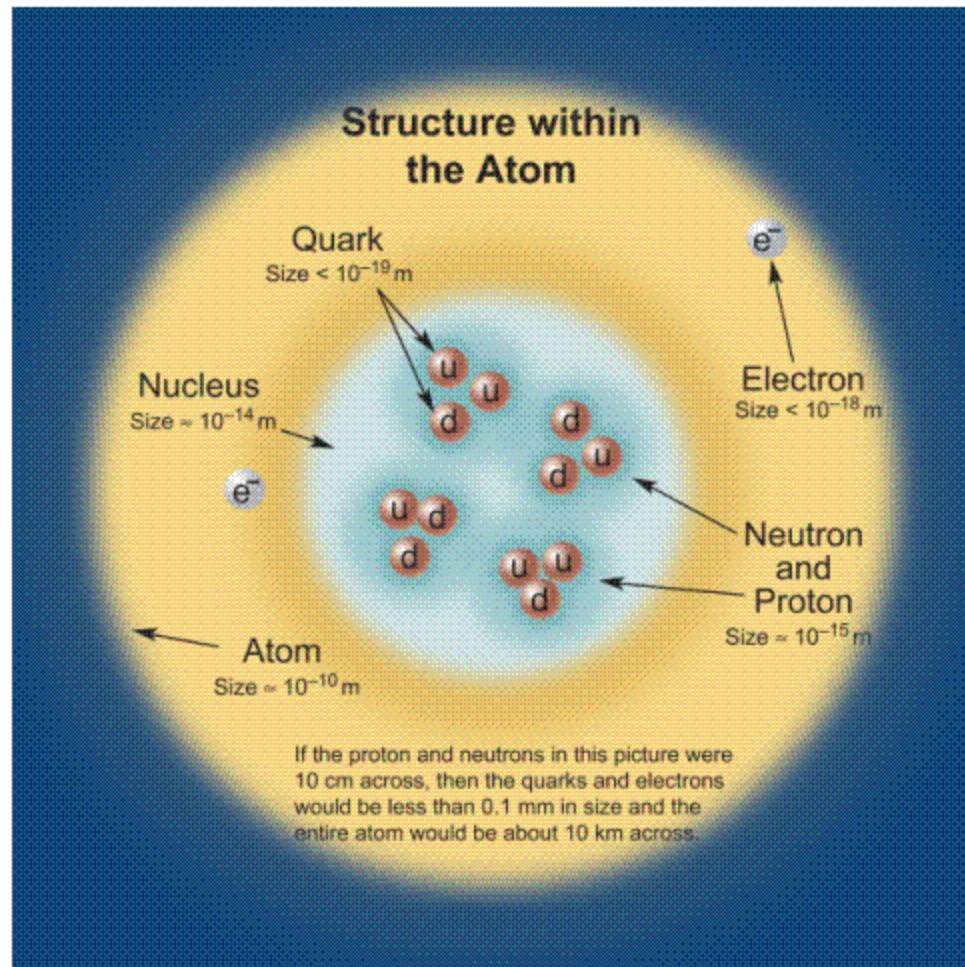
Active area of study ... believe it is probably due to a basic matter-antimatter asymmetry in one of the forces of nature.

→ Standard Model of Particle Physics

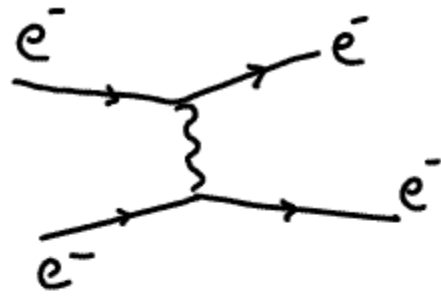
<http://particleadventure.org/>

<http://hepwww.rl.ac.uk/Pub/Phil/ppintro/ppintro.html>

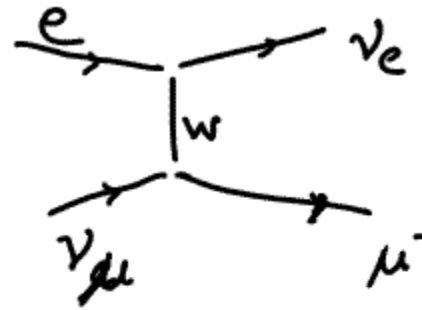
Decent
online sources
of
information
- please read



$$\Delta E \Delta T \approx \hbar$$



Electromagnetism



Weak interaction



Strong force

BOSONS

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

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.39	-1
W^+	80.39	+1
W bosons		
Z^0	91.188	0
Z boson		

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at {	10^{-18} m	0.8	1	25
	3×10^{-17} m	10^{-41}	1	60

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

Baryons are fermionic hadrons.

These are a few of the many types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
\bar{p}	antiproton	$\bar{u}\bar{u}\bar{d}$	-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

Other particles

999

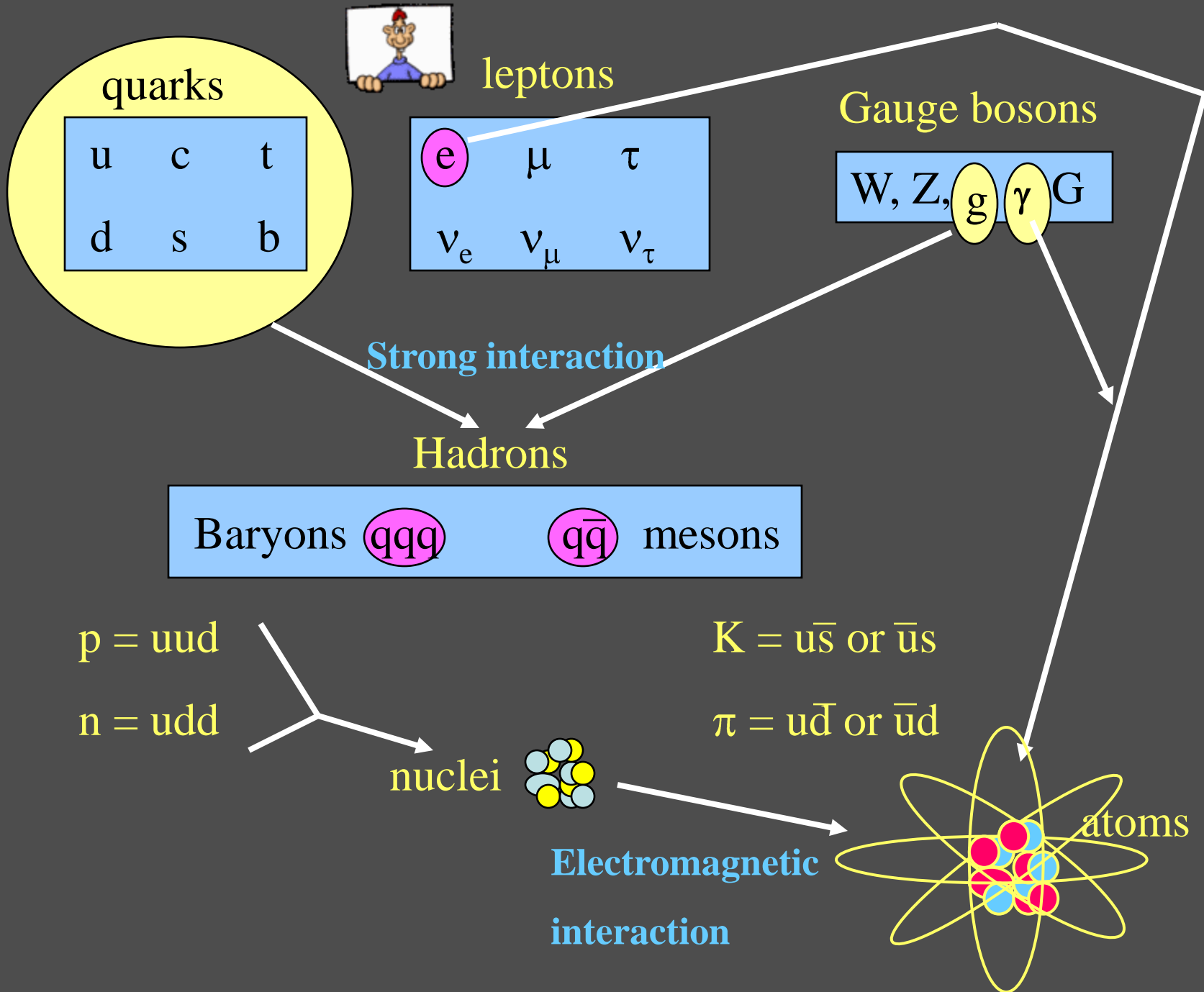
Mesons $q\bar{q}$

Mesons are bosonic hadrons

These are a few of the many types of mesons.

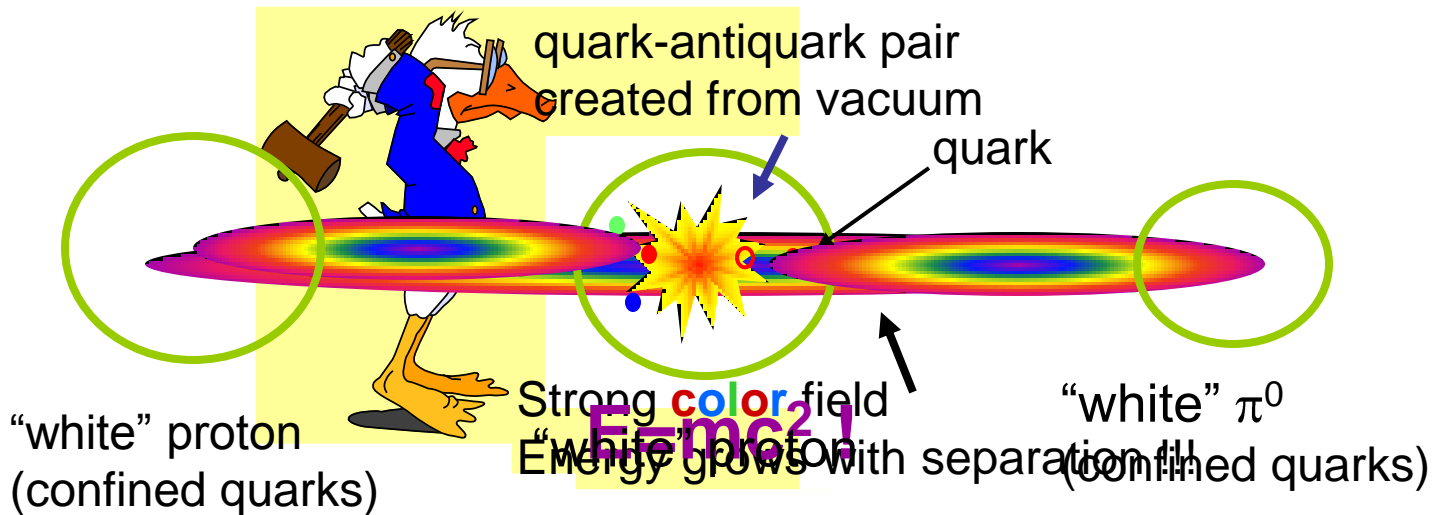
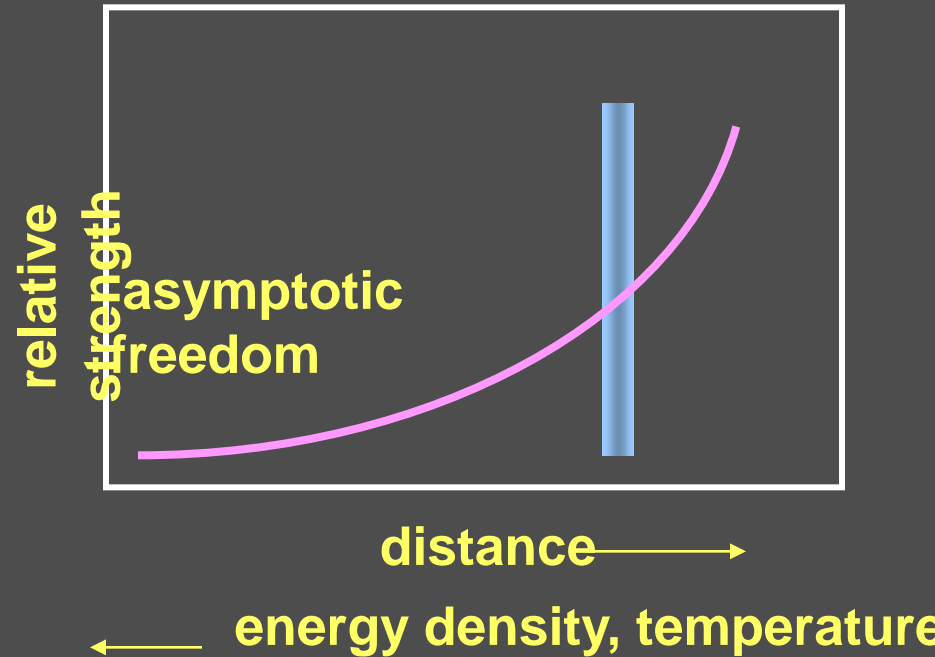
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	-1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.776	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2.980	0

999



Quantum Chromodynamics QCD

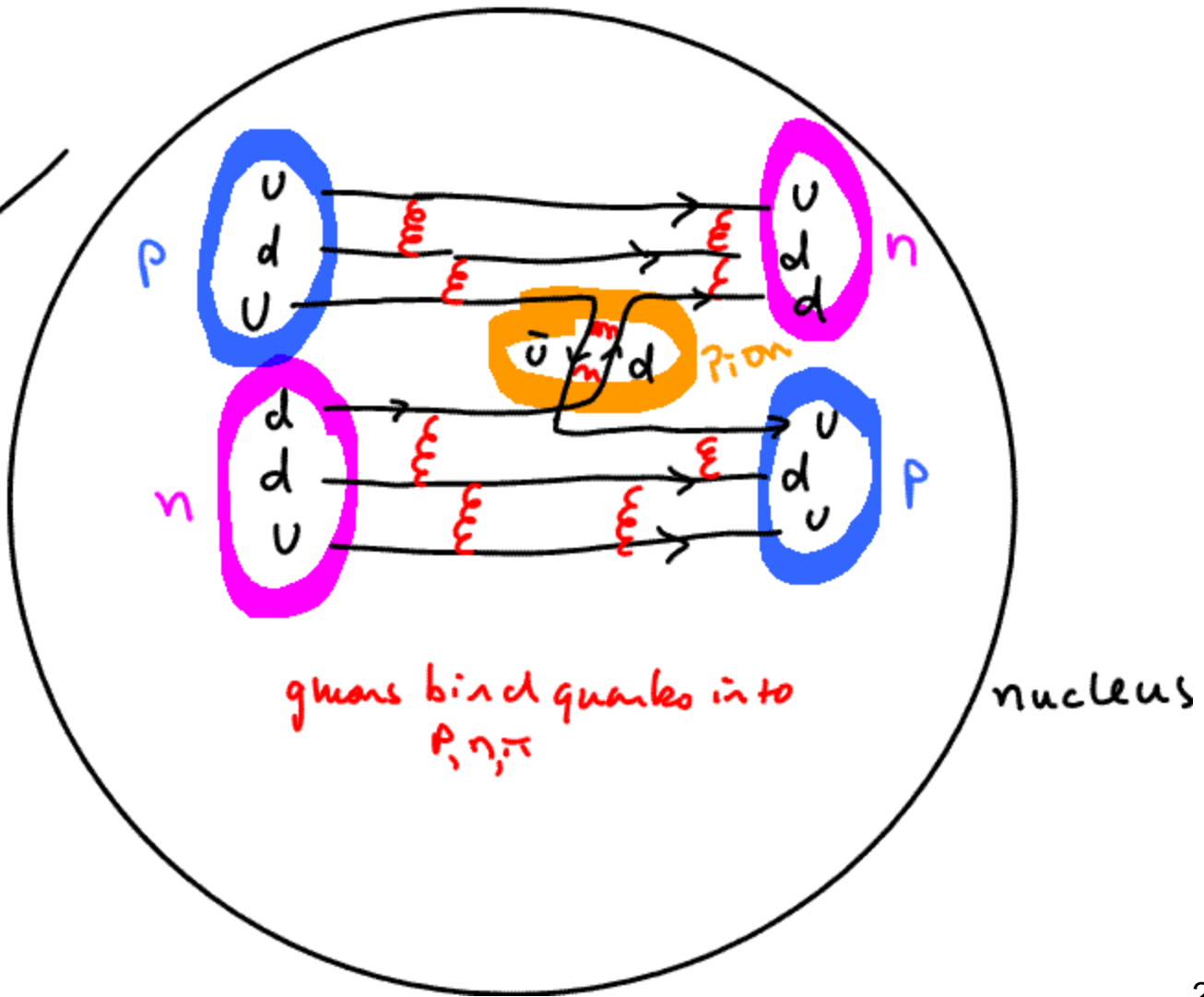
Why bare quarks have never been observed.



Thanks to Mike Lisa (OSU) for parts of this

nucleon-nucleon force - exchange of π (pion)

fine point for completeness



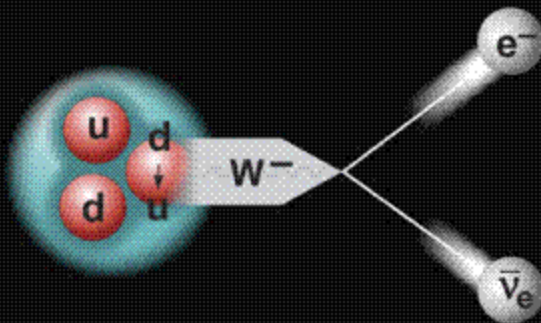
quarks bind quarks into p, n, π

Example

Particle Processes

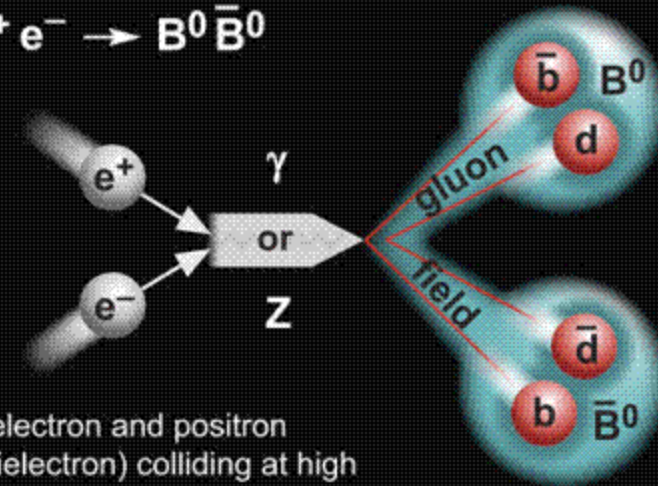
These diagrams are an artist's conception. Blue-green shaded areas represent the cloud of gluons.

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



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

$$e^+ e^- \rightarrow B^0 \bar{B}^0$$



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

The Vacuum



-R. Kolb

e^+e^-
 e^+e^-

e^+e^-
 e^+e^-

$q\bar{q}$ e^+e^- $q\bar{q}$
Much ado about NOTHING:
 $q\bar{q}$ $q\bar{q}$ $q\bar{q}$ $q\bar{q}$ e^+e^-
Nothing is something $q\bar{q}$ $q\bar{q}$
Nothing has energy e^+e^- e^+e^- e^+e^-
Nothing interacts with something $q\bar{q}$ $q\bar{q}$
 $q\bar{q}$ $q\bar{q}$ e^+e^- $q\bar{q}$
 $q\bar{q}$ $q\bar{q}$ $q\bar{q}$ $q\bar{q}$