

Parçacık Fizikö

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CERN Türkiye Öğretmenleri Programı
Temmuz 2015

Parçacık Fizikinin Standard Modeli

fermion

boson

	mass	charge	spin																									
QUARKS	$\approx 2.3 \text{ MeV}/c^2$	$2/3$	$1/2$	u	up	$\approx 1.275 \text{ GeV}/c^2$	$2/3$	$1/2$	c	charm	$\approx 173.07 \text{ GeV}/c^2$	$2/3$	$1/2$	t	top	0	0	1	g	gluon	$\approx 126 \text{ GeV}/c^2$	0	0	0	H	Higgs boson		
	$\approx 4.8 \text{ MeV}/c^2$	$-1/3$	$1/2$	d	down	$\approx 95 \text{ MeV}/c^2$	$-1/3$	$1/2$	s	strange	$\approx 4.18 \text{ GeV}/c^2$	$-1/3$	$1/2$	b	bottom	0	0	1	γ	photon								
	$0.511 \text{ MeV}/c^2$	-1	$1/2$	e	electron	$105.7 \text{ MeV}/c^2$	-1	$1/2$	μ	muon	$1.777 \text{ GeV}/c^2$	-1	$1/2$	τ	tau	$91.2 \text{ GeV}/c^2$	0	1	Z	Z boson								
	$< 2.2 \text{ eV}/c^2$	0	$1/2$	ν_e	electron neutrino	$< 0.17 \text{ MeV}/c^2$	0	$1/2$	ν_μ	muon neutrino	$< 15.5 \text{ MeV}/c^2$	0	$1/2$	ν_τ	tau neutrino	$80.4 \text{ GeV}/c^2$	± 1	1	W	W boson								

QUARKS

LEPTONS

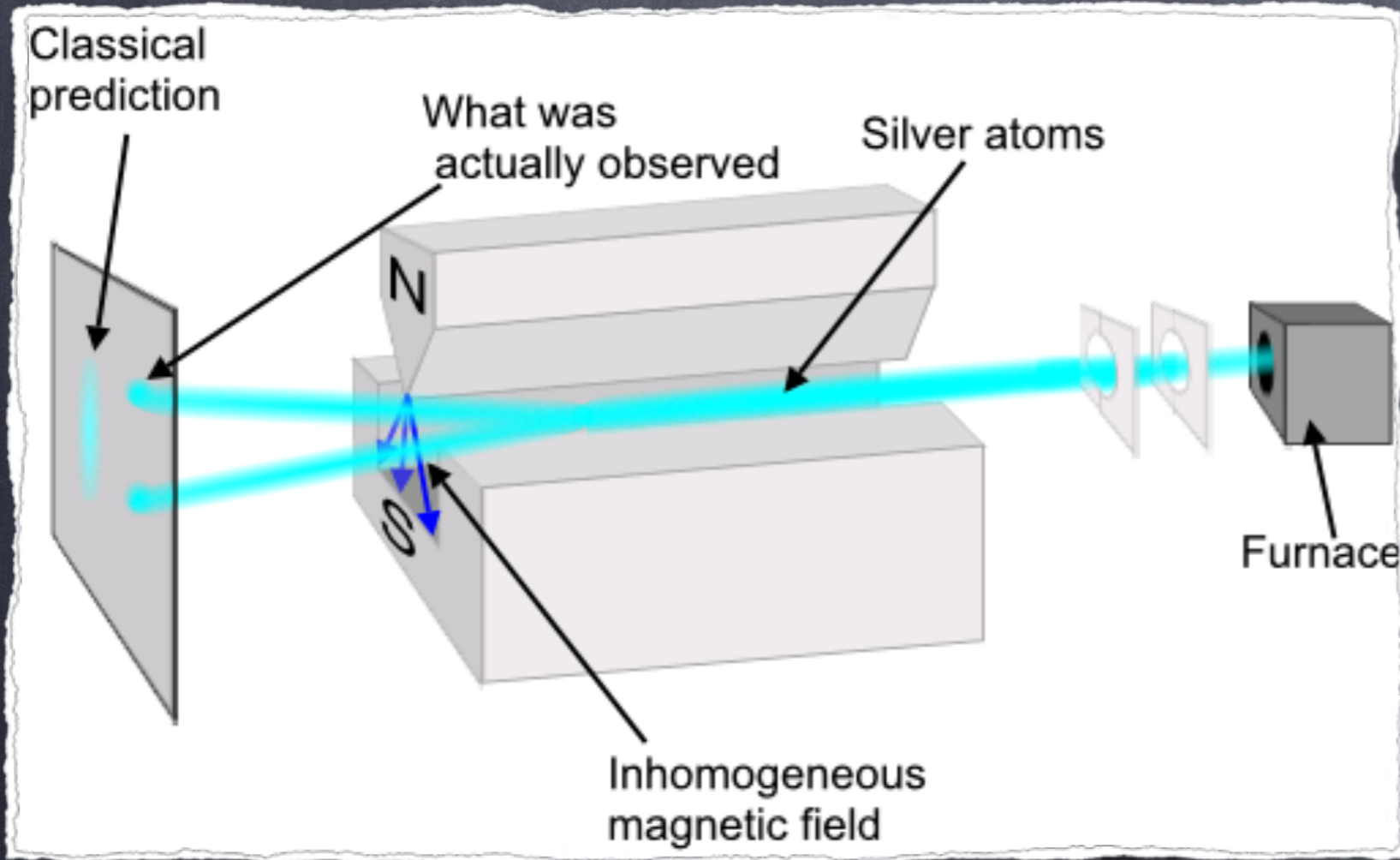
GAUGE BOSONS

Dönü

Spin/Dönü

- Bir parçacık özelliğidir (kütle, yük gibi..)
- içsel açısal momentum
- Dönü kuantum sayısı ile "parametrize" edilir
 - Dönü kuantum sayıları yarım (fermion) veya tam (bozon) sayı değerleri alabilirler
- Yüklü parçacıkların dönüsü manyetik moment ile ilişkilendirilir
- Dönünün yönü değişebilir ama büyüklüğü değişemez

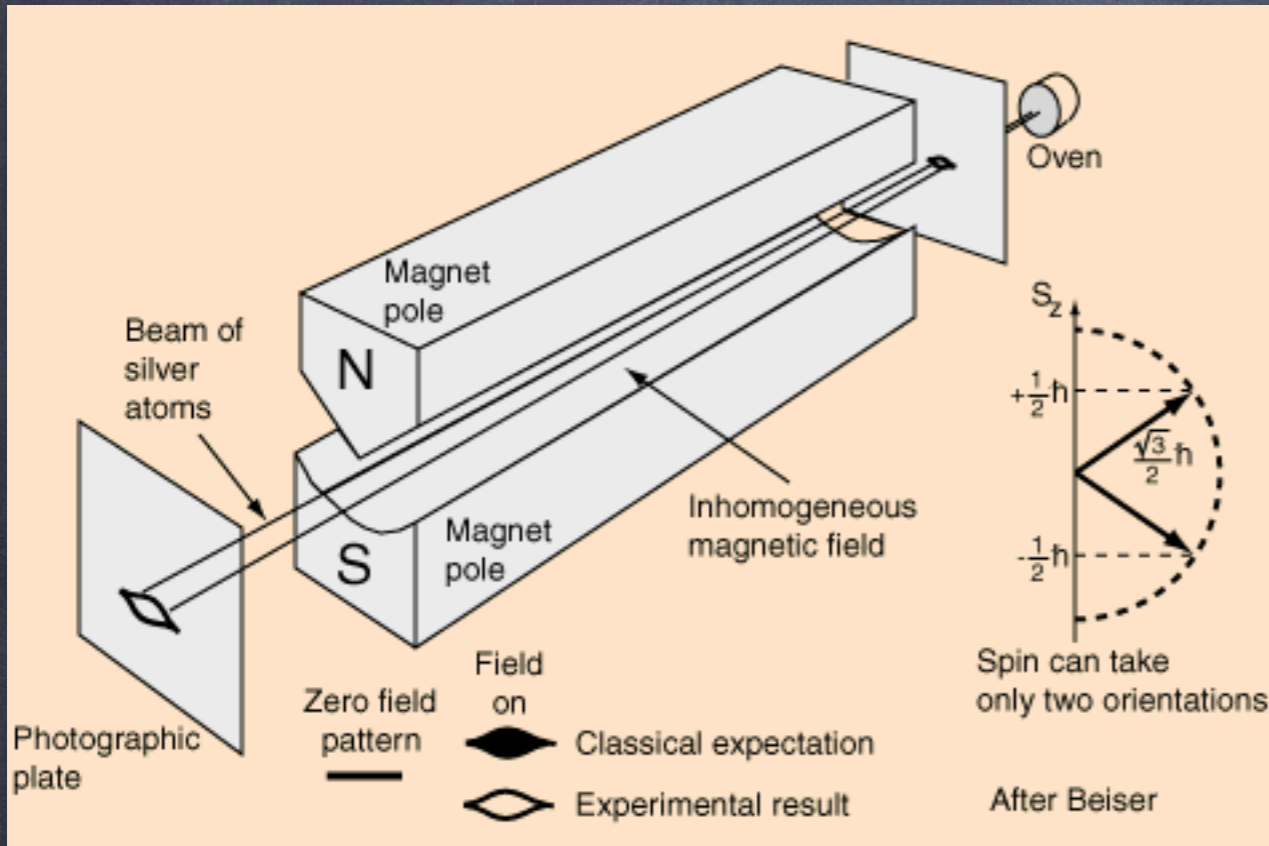
Stern-Gerlach Deneyi



- Otto Stern - Walther Gerlach (1922)
- Değişken manyetik alanda **sapma**

http://upload.wikimedia.org/wikipedia/commons/transcoded/9/9e/Quantum_spin_and_the_Stern-Gerlach_experiment.ogv/Quantum_spin_and_the_Stern-Gerlach_experiment.ogv.480p.webm

Stern-Gerlach Denevi



enerji

$$U = -\mu \cdot B = -\mu_B \frac{g}{2} B_z = \pm \mu_B B_z$$

$$\mu_z = \pm \frac{1}{2} g \mu_B$$

$$\mu_B = \frac{e\hbar}{2m_e}$$

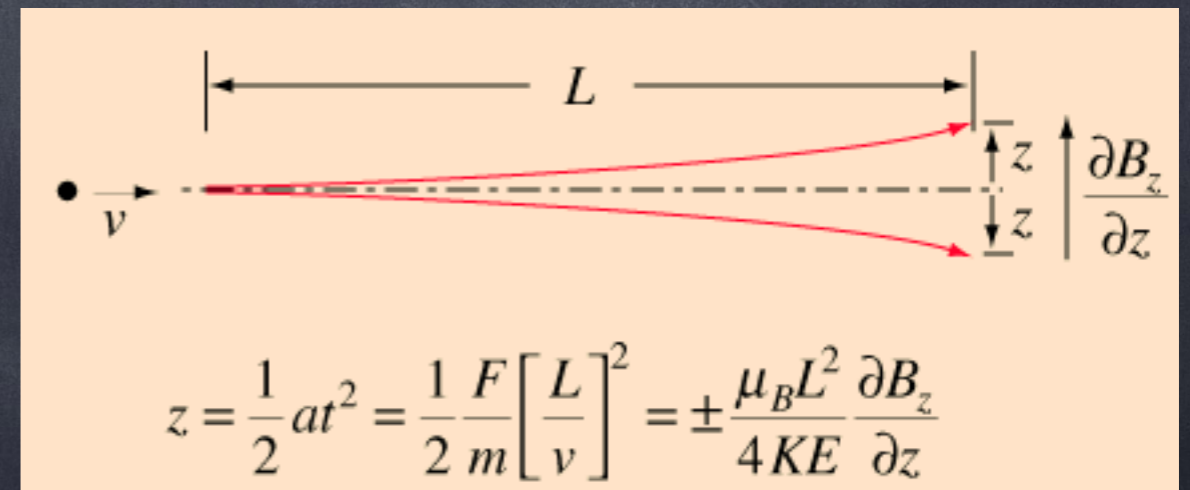
kuvvet

$$F_z = -\frac{\partial U}{\partial z} = \pm \mu_B \frac{\partial B_z}{\partial z}$$

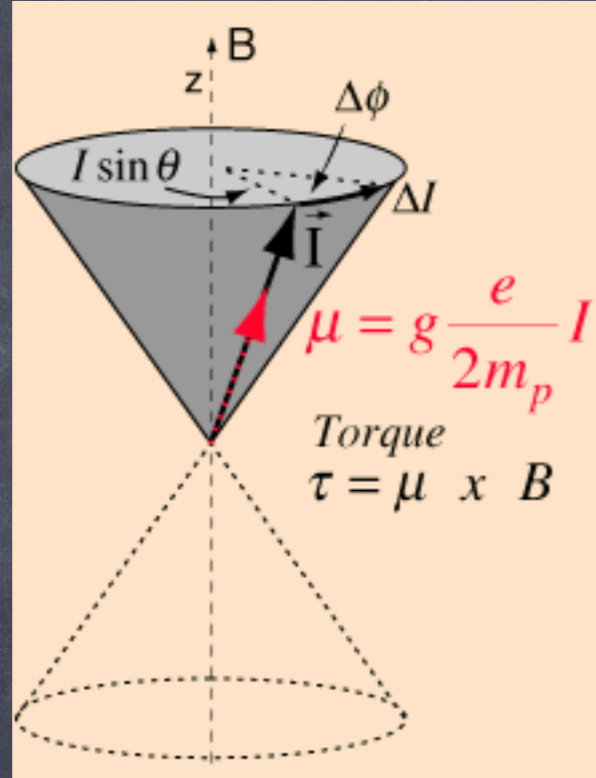
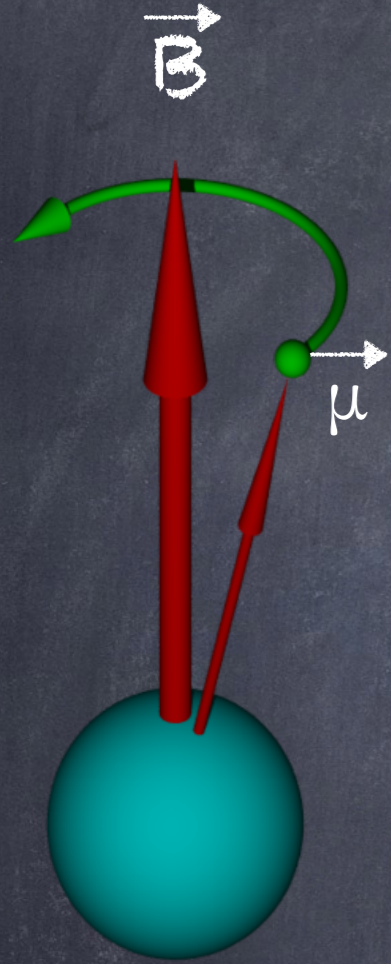
değişken manyetik alan

• Manyetik alan değişmeseydi ne olurdu?

Larmor Devrimi



Larmor Devrimi



μ = manyetik moment

B = manyetik alan

I = dönü

τ = dönme momenti

m = kütle

e = elektrik yükü

g = gyromagnetik oran

$$\tau = \frac{\Delta I}{\Delta t} = \frac{I \sin \theta \Delta \phi}{\Delta t} = |\mu B \sin \theta| = \frac{ge}{2m_p} IB \sin \theta$$

$$\omega_{Larmor} = \frac{d\phi}{dt} = \frac{ge}{2m_p} B$$

ω = devrimin açısal hızı

Dönü-İstatistik Kuramı

- Tam sayı-dönülü parçacıkların oluşturduğu bir sistemin dalga fonksiyonu parçacıklar yerdeğiştirirse de aynı değeri alır. Yerdeğiştirme karşısında dalga fonksiyonları aynı kalan parçacıklara bozon denir
- Yarım sayı-dönülü iki parçacığın oluşturduğu bir sistemin dalga fonksiyonu parçacıklar yerdeğiştirirse işaret değiştirir. Yerdeğiştirme karşısında dalga fonksiyonları işaret değiştiren parçacıklara fermion denir

Dalga fonksiyonu bir veya daha çok parçacıktan meydana gelen sistemin kuantum durumunu tanımlar, sistemle ilgili bütün bilgiyi içerir

Pauli dışlama ilkesi

- Hiçbir özdeş fermiyon aynı kuantum durumunda bulunamaz
- örneğin, birden fazla elektronu olan bir atomda elektronlar aynı kuantum sayılarını alamazlar. Aynı orbitalde olan elektronların bile dönüleri farklı olmak zorundadır

Bu ilkenin en önemli sonucu nedir?

- Kararlı madde oluşumu

Periodic Table of the Elements

1 H																	2 He	
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne	
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	
87 Fr	88 Ra	89 Ac	104 Unq	105 Unp	106 Unh	107 Uns	108 Uno	109 Une	110 Unn									
			58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu		
			90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr		

Kararlı madde oluşumu

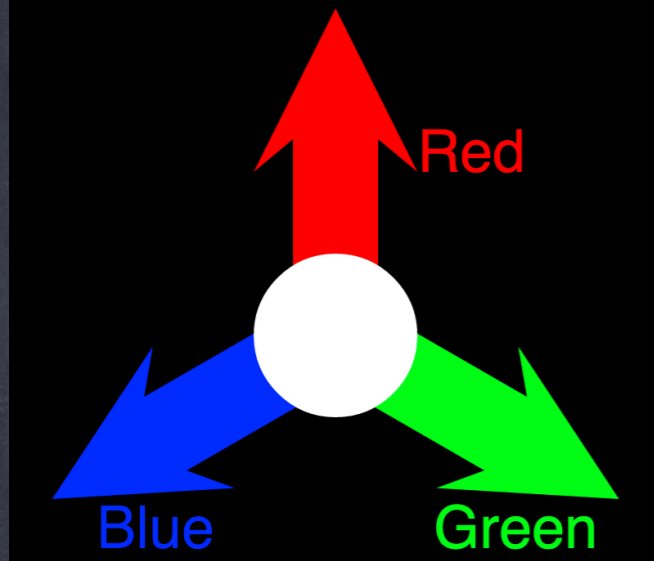
çevremizde
gördüğümüz
maddeyi 1. sütun
oluşturuyor

2. ve 3. sütun ne
yapıyor peki?
Onlar nerede?

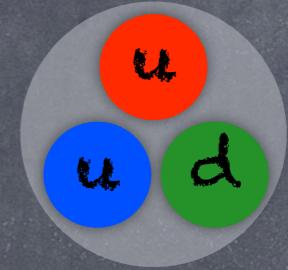
	mass =2.3 MeV/c ²	mass =1.275 GeV/c ²	mass =173.07 GeV/c ²	mass 0	mass =126 GeV/c ²
charge 2/3	2/3	2/3	2/3	0	0
spin 1/2	1/2	1/2	1/2	1	0
QUARKS	u up	c charm	t top	g gluon	H Higgs boson
	mass =4.8 MeV/c ²	mass =95 MeV/c ²	mass =4.18 GeV/c ²	mass 0	
charge -1/3	-1/3	-1/3	-1/3	0	
spin 1/2	1/2	1/2	1/2	1	
	d down	s strange	b bottom	γ photon	
	mass 0.511 MeV/c ²	mass =105.7 MeV/c ²	mass 1.777 GeV/c ²	mass 91.2 GeV/c ²	
charge -1	-1	-1	-1	0	
spin 1/2	1/2	1/2	1/2	1	
LEPTONS	e electron	μ muon	τ tau	Z Z boson	
	mass <2.2 eV/c ²	mass <0.17 MeV/c ²	mass <15.5 MeV/c ²	mass 80.4 GeV/c ²	
charge 0	0	0	0	±1	
spin 1/2	1/2	1/2	1/2	1	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
				GAUGE BOSONS	

Hadronlar

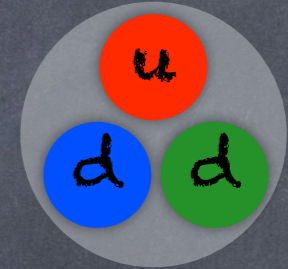
Baryon



baryonlar
3 kuarklı atomaltı
parçacıklar

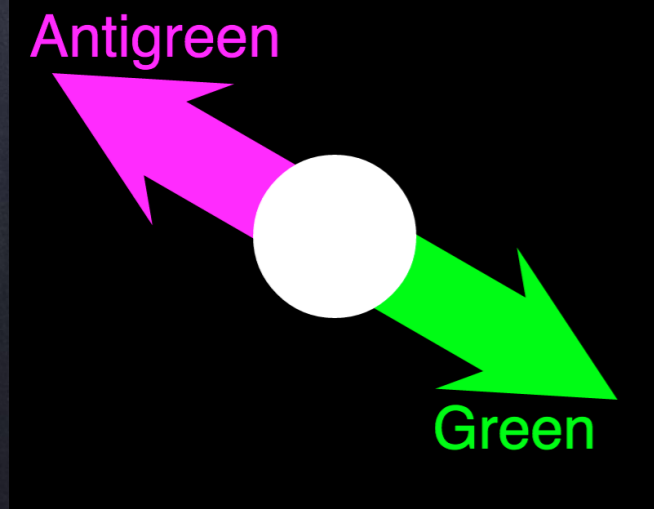


proton p



nötron n

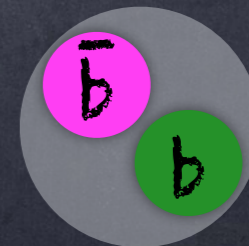
Meson



mesonlar
1 kuark ve 1 karşı-kuarklı
atomaltı parçacıklar

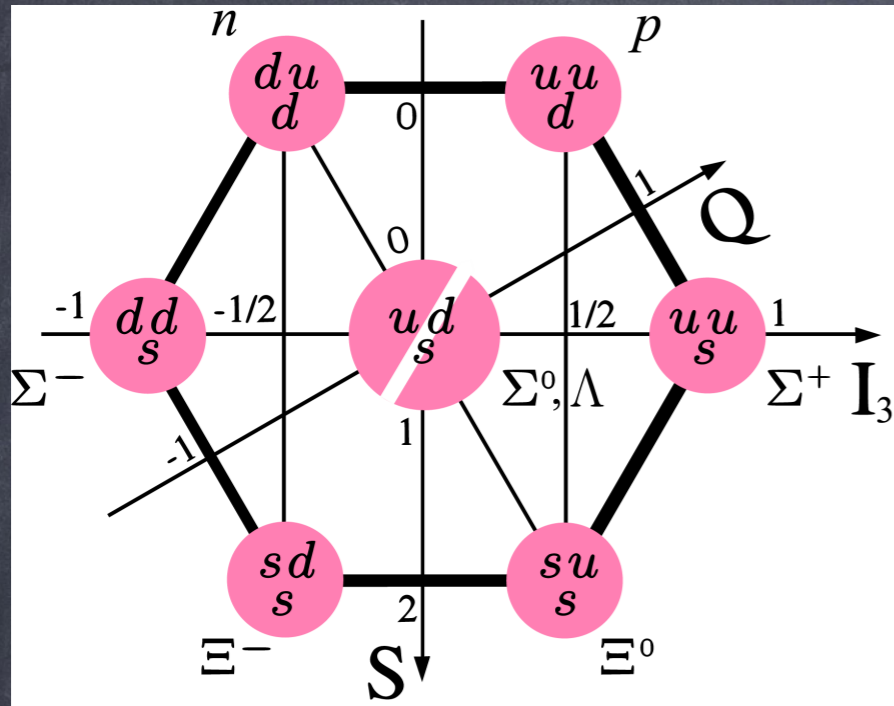


pion π^0



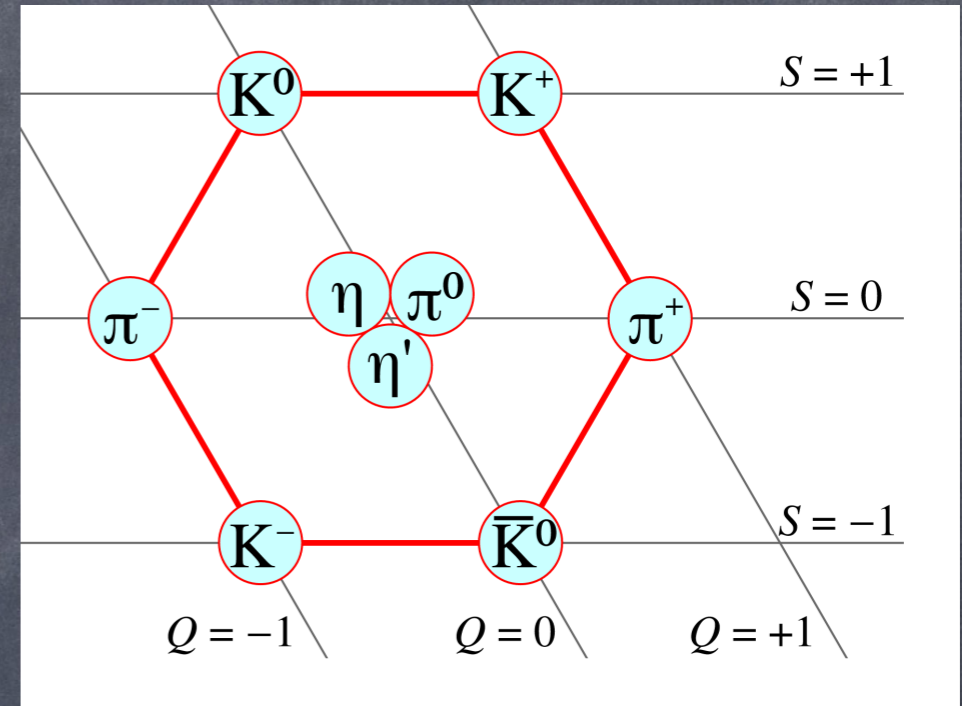
upsilon Υ

Baryonlar



u, d, s - kuarklı baryonlar

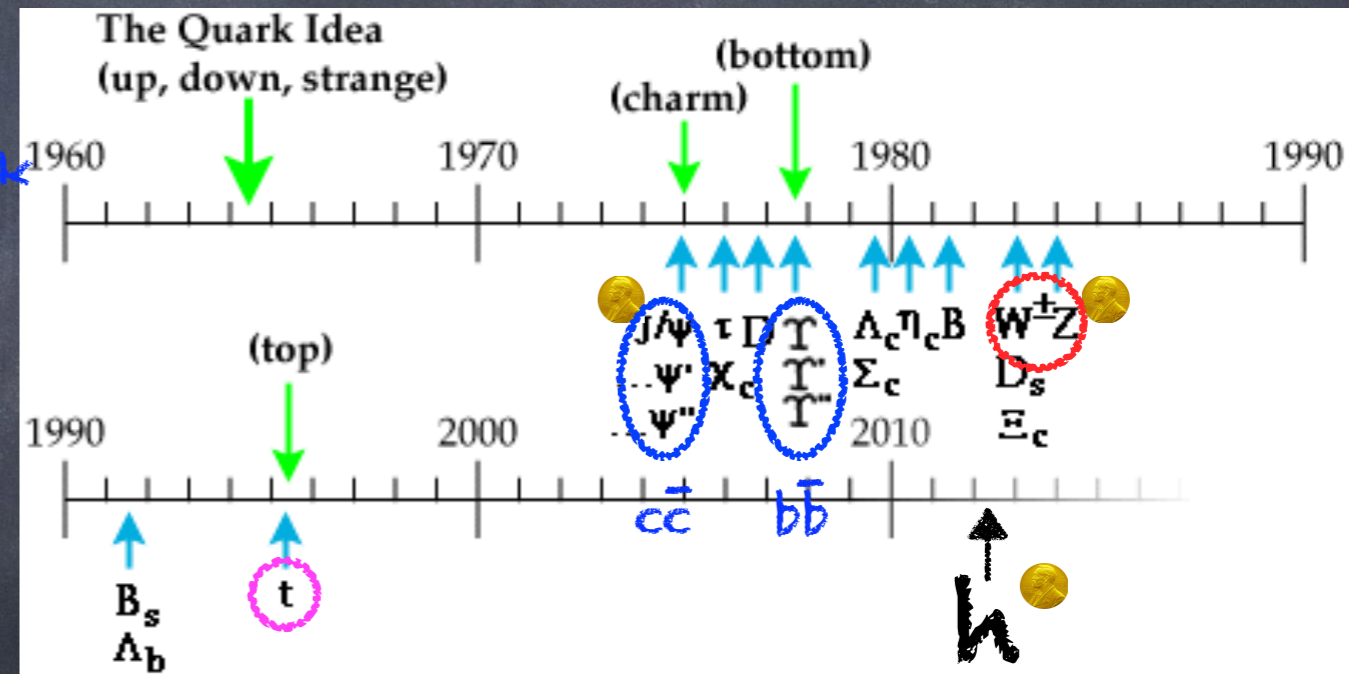
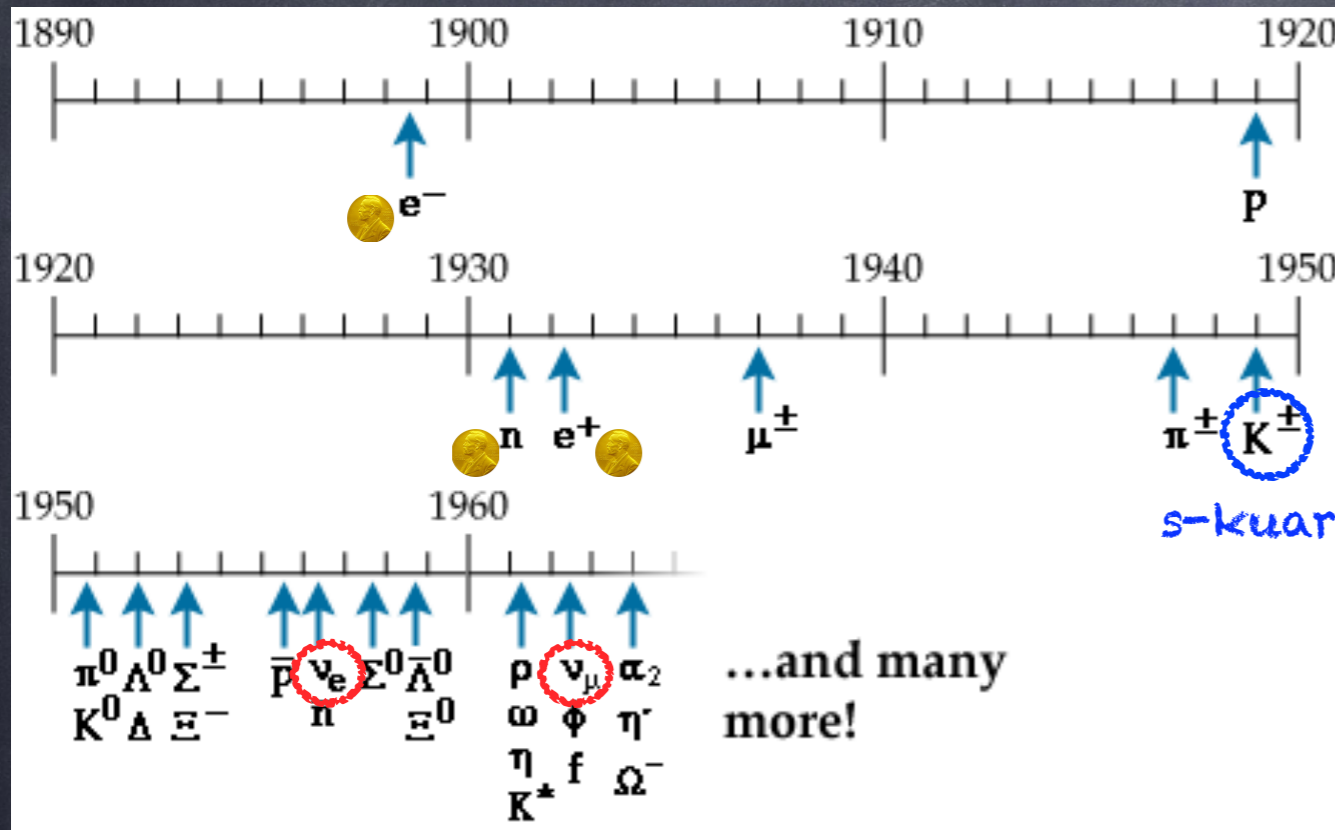
Mesonlar



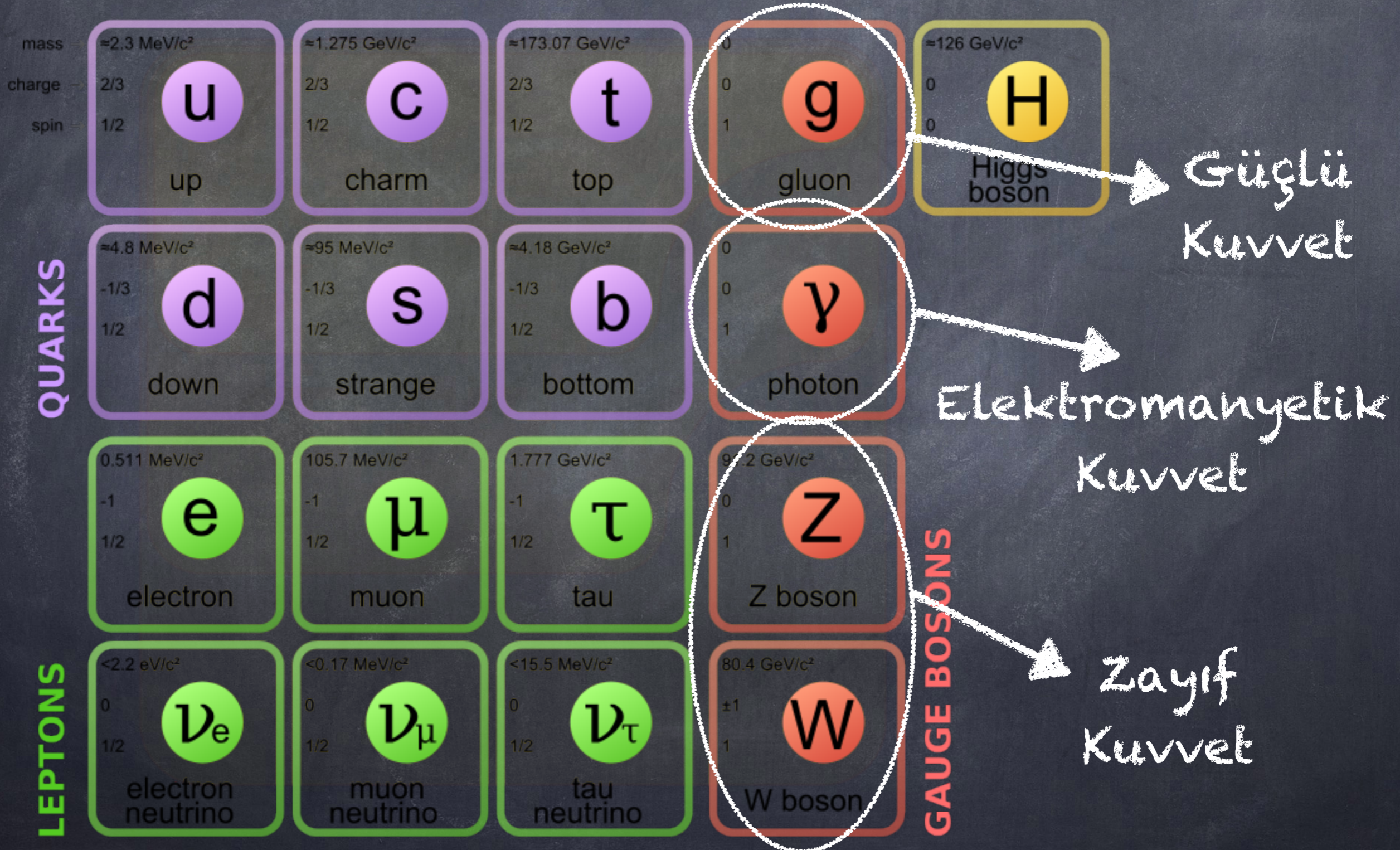
u, d, s - (karşı-)kuarklı mesonlar

Particle Data Group
<http://pdg.lbl.gov/>

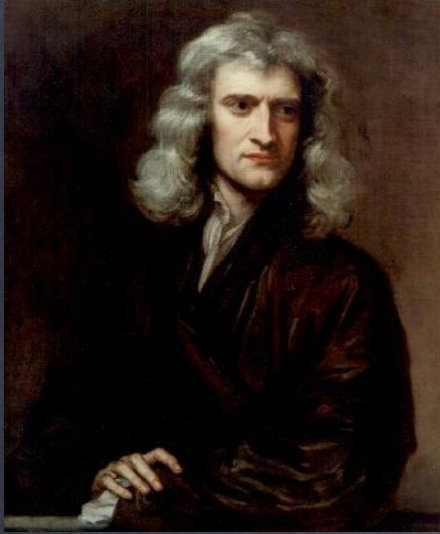
Bazı önemli keşifler



Kuvvetler

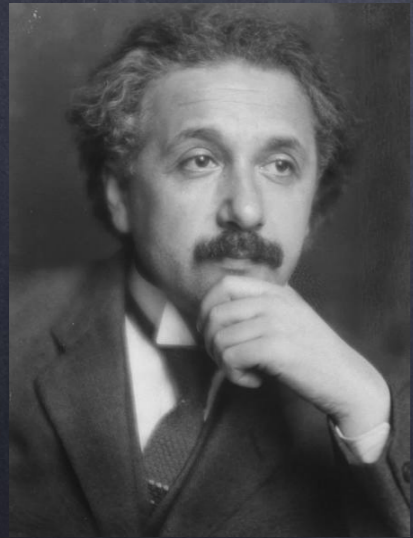
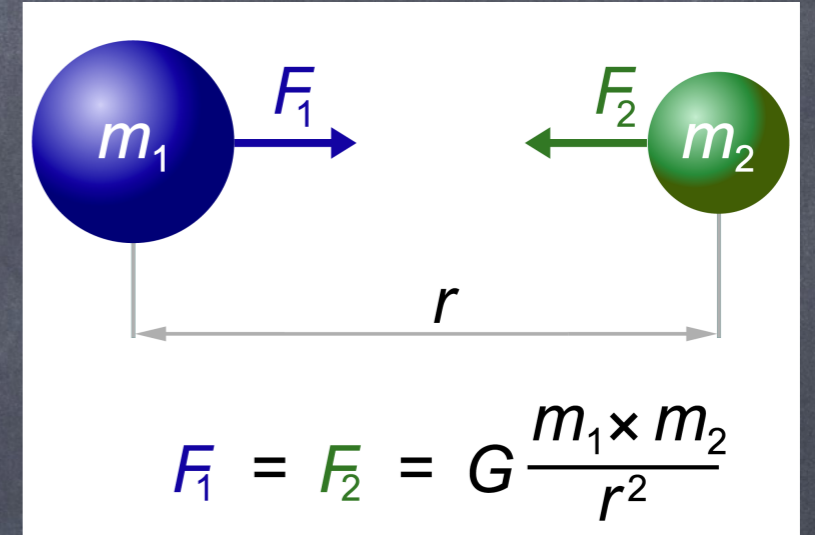


Kütle çekimi



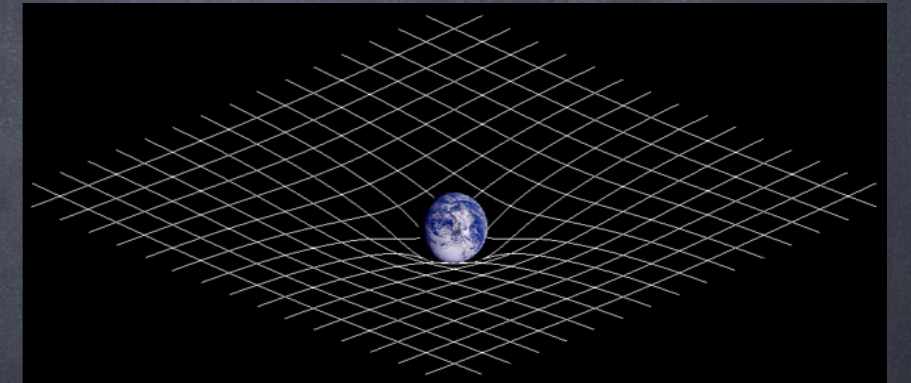
Klasik Mekanik

Isaac Newton



Genel Görelilik

Albert Einstein



$$G_{\mu\nu} + g_{\mu\nu} \Lambda = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Graviton?

- Kuramsal bir parçacık
- Madde ile etkileşim tesir kesiti çok küçük - gözlemlenmesi çok zor
- Eğer varsa,
 - Kütlesiz olmalı - Kütle çekiminin etkisi limitsiz
 - Dönüsü 2 olmalı - $T_{\mu\nu}$ Stres-Energy tensörü ikinci dereceden
- LIGO, VIRGO - Kütle çekimi dalgaları arayan deneyler

Kuvvetler

	<p>mass $\approx 2.3 \text{ MeV}/c^2$</p> <p>charge $2/3$</p> <p>spin $1/2$</p> <p>u</p> <p>up</p>	<p>mass $\approx 1.275 \text{ GeV}/c^2$</p> <p>charge $2/3$</p> <p>spin $1/2$</p> <p>c</p> <p>charm</p>	<p>mass $\approx 173.07 \text{ GeV}/c^2$</p> <p>charge $2/3$</p> <p>spin $1/2$</p> <p>t</p> <p>top</p>	<p>mass 0</p> <p>charge 0</p> <p>spin 1</p> <p>g</p> <p>gluon</p>	<p>mass $\approx 126 \text{ GeV}/c^2$</p> <p>charge 0</p> <p>spin 0</p> <p>H</p> <p>Higgs boson</p>
QUARKS	<p>mass $\approx 4.8 \text{ MeV}/c^2$</p> <p>charge $-1/3$</p> <p>spin $1/2$</p> <p>d</p> <p>down</p>	<p>mass $\approx 95 \text{ MeV}/c^2$</p> <p>charge $-1/3$</p> <p>spin $1/2$</p> <p>s</p> <p>strange</p>	<p>mass $\approx 4.18 \text{ GeV}/c^2$</p> <p>charge $-1/3$</p> <p>spin $1/2$</p> <p>b</p> <p>bottom</p>	<p>mass 0</p> <p>charge 0</p> <p>spin 1</p> <p>γ</p> <p>photon</p>	
	<p>mass $0.511 \text{ MeV}/c^2$</p> <p>charge -1</p> <p>spin $1/2$</p> <p>e</p> <p>electron</p>	<p>mass $105.7 \text{ MeV}/c^2$</p> <p>charge -1</p> <p>spin $1/2$</p> <p>μ</p> <p>muon</p>	<p>mass $1.777 \text{ GeV}/c^2$</p> <p>charge -1</p> <p>spin $1/2$</p> <p>τ</p> <p>tau</p>	<p>mass $91.2 \text{ GeV}/c^2$</p> <p>charge 0</p> <p>spin 1</p> <p>Z</p> <p>Z boson</p>	<p>Elektromanyetik Kuvvet</p>
	LEPTONS	<p>mass $< 2.2 \text{ eV}/c^2$</p> <p>charge 0</p> <p>spin $1/2$</p> <p>ν_e</p> <p>electron neutrino</p>	<p>mass $< 0.17 \text{ MeV}/c^2$</p> <p>charge 0</p> <p>spin $1/2$</p> <p>ν_μ</p> <p>muon neutrino</p>	<p>mass $< 15.5 \text{ MeV}/c^2$</p> <p>charge 0</p> <p>spin $1/2$</p> <p>ν_τ</p> <p>tau neutrino</p>	

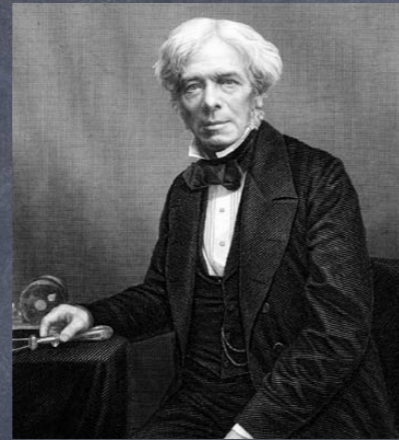
Elektromanyetik Kuvvet



Gauss



Ampere



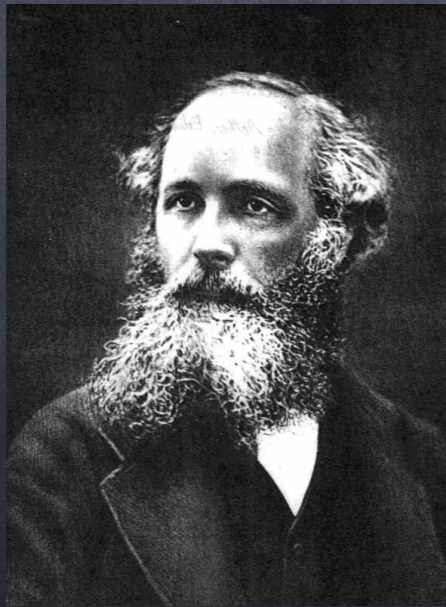
Faraday

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{B} = \mu_0 \left(\mathbf{J} + \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right)$$



James Clerk Maxwell

E elektrik alan

B manyetik alan

J akım yoğunluğu

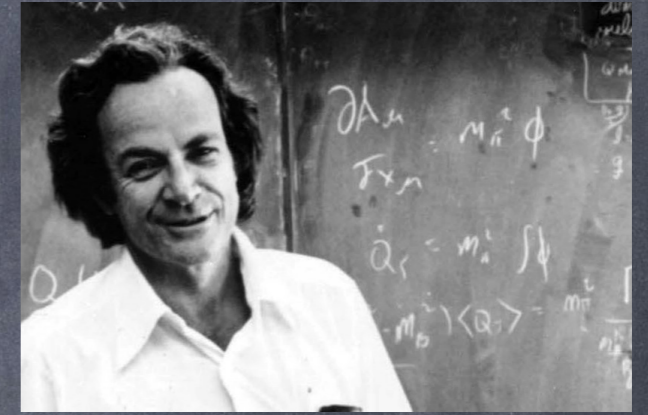
ρ yük yoğunluğu

ϵ_0 elektriksel geçirgenlik

μ_0 manyetik geçirimsizlik

Kuantum Elektrodinamiği

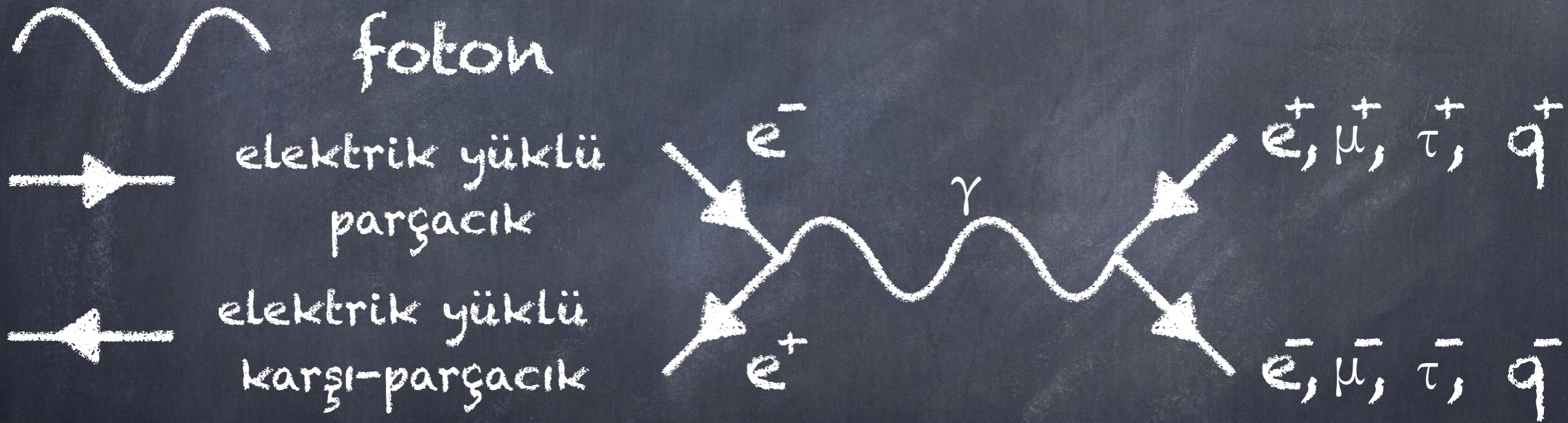
- Elektrik yükü taşıyan bütün parçacıkların foton aracılığıyla nasıl etkileştiğini açıklar
- Kuantum mekaniği ile özel göreliliği birleştirmiştir



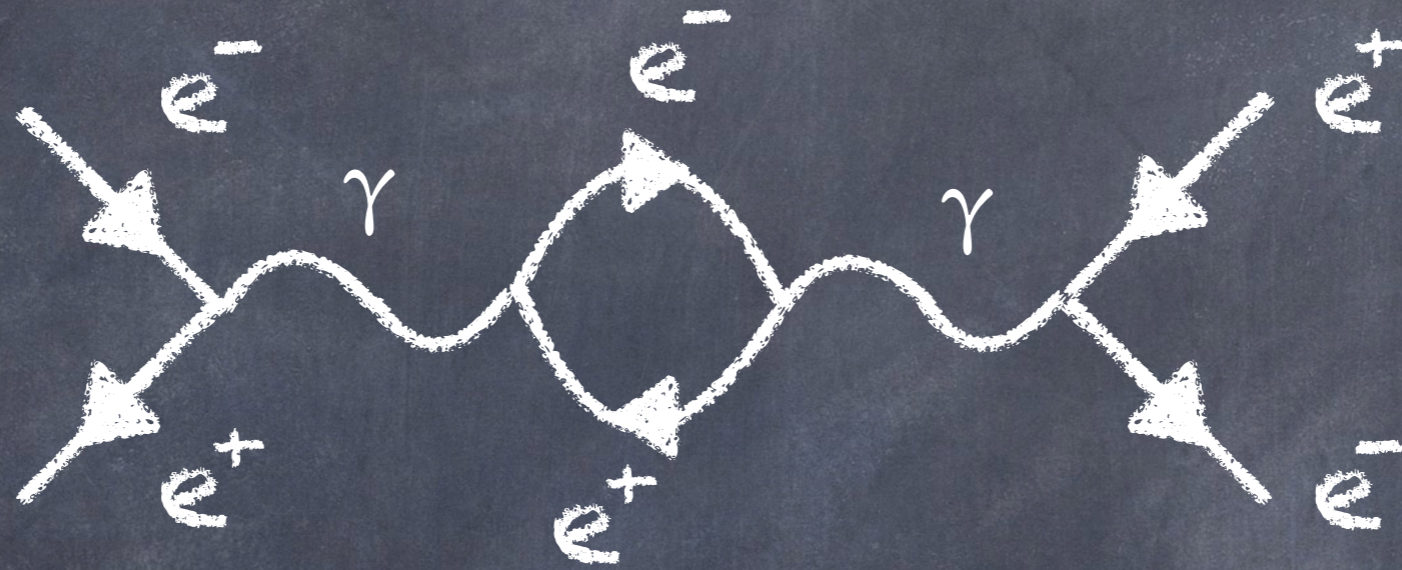
Richard
Feynman

Kuantum Elektrodinamiği

Feynman diyagramları



Kuantum Elektrodinamiği



- KED pertürbatif bir kuramdır

$$A = c^0 A_0 + c^1 A_1 + c^2 A_2 + \dots$$

- KED'in etkisi limitsiz - foton kütlelessiz

Kuvvetler

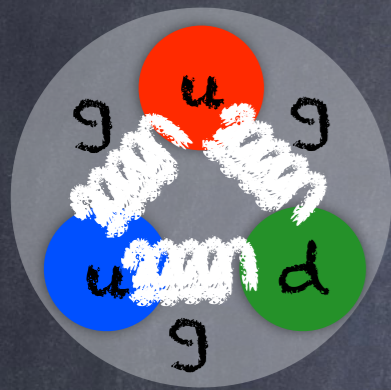
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QUARKS	<p>mass $\approx 4.8 \text{ MeV}/c^2$</p> <p>charge $-1/3$</p> <p>spin $1/2$</p> <p>d</p> <p>down</p>	<p>mass $\approx 95 \text{ MeV}/c^2$</p> <p>charge $-1/3$</p> <p>spin $1/2$</p> <p>s</p> <p>strange</p>	<p>mass $\approx 4.18 \text{ GeV}/c^2$</p> <p>charge $-1/3$</p> <p>spin $1/2$</p> <p>b</p> <p>bottom</p>	<p>mass 0</p> <p>charge 0</p> <p>spin 1</p> <p>γ</p> <p>photon</p>		
	<p>mass $0.511 \text{ MeV}/c^2$</p> <p>charge -1</p> <p>spin $1/2$</p> <p>e</p> <p>electron</p>	<p>mass $105.7 \text{ MeV}/c^2$</p> <p>charge -1</p> <p>spin $1/2$</p> <p>μ</p> <p>muon</p>	<p>mass $1.777 \text{ GeV}/c^2$</p> <p>charge -1</p> <p>spin $1/2$</p> <p>τ</p> <p>tau</p>	<p>mass $91.2 \text{ GeV}/c^2$</p> <p>charge 0</p> <p>spin 1</p> <p>Z</p> <p>Z boson</p>	GAUGE BOSONS	
	LEPTONS	<p>mass $< 2.2 \text{ eV}/c^2$</p> <p>charge 0</p> <p>spin $1/2$</p> <p>ν_e</p> <p>electron neutrino</p>	<p>mass $< 0.17 \text{ MeV}/c^2$</p> <p>charge 0</p> <p>spin $1/2$</p> <p>ν_μ</p> <p>muon neutrino</p>	<p>mass $< 15.5 \text{ MeV}/c^2$</p> <p>charge 0</p> <p>spin $1/2$</p> <p>ν_τ</p> <p>tau neutrino</p>		<p>mass $80.4 \text{ GeV}/c^2$</p> <p>charge ± 1</p> <p>spin 1</p> <p>W</p> <p>W boson</p>

Güçlü Kuvvet

Kuantum Renk Dinamiđi

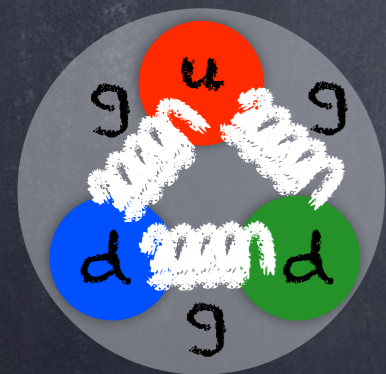
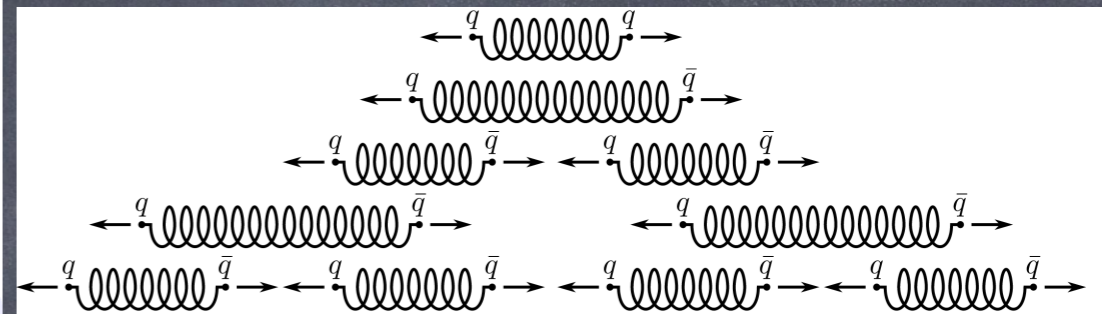
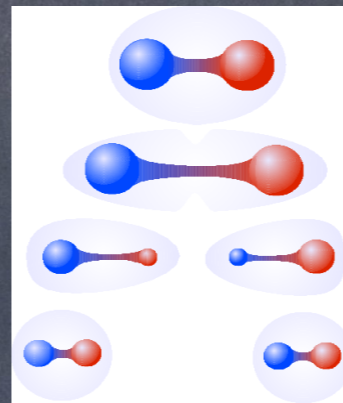
- Hadronların kendi içlerinde ve birbirleriyle olan etkileşimini açıklar
- Renk yükü taşıyan parçacıklar, kuarklar, arası bu etkileşim gluonlar tarafından yayılır
- Etkileşim kısa-menzillidir (10^{-15} m)
- Renk yükü

Kuantum Renk Dinamiği



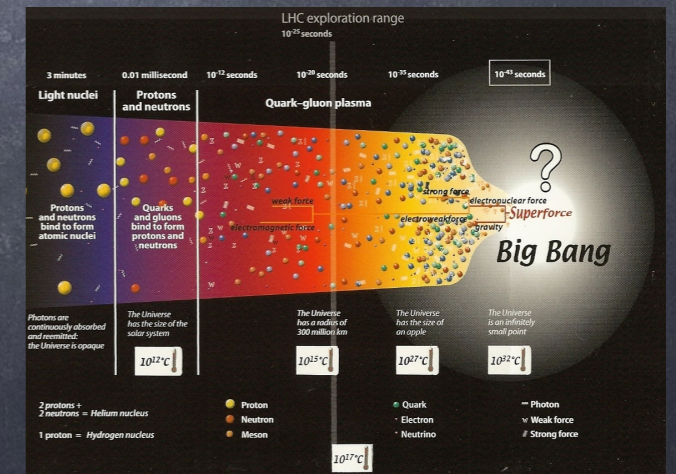
proton

Renk hapsi
Kütle

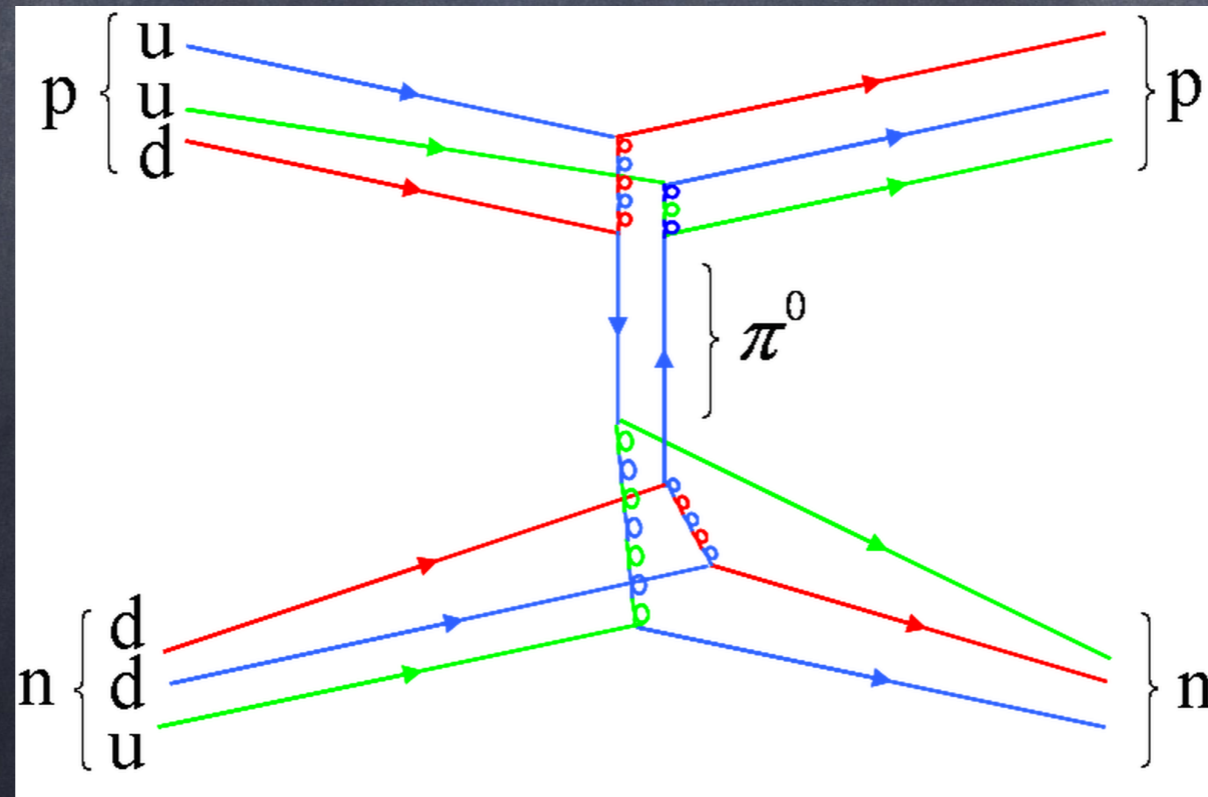
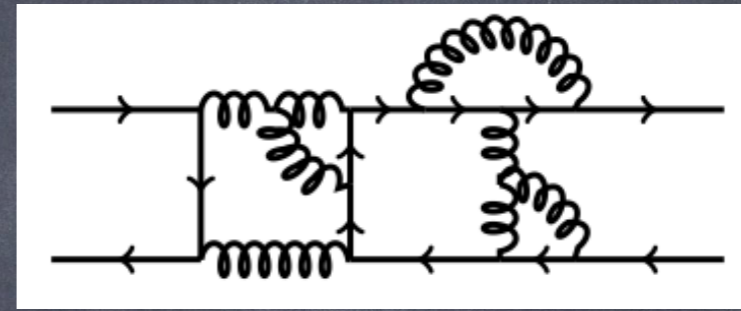
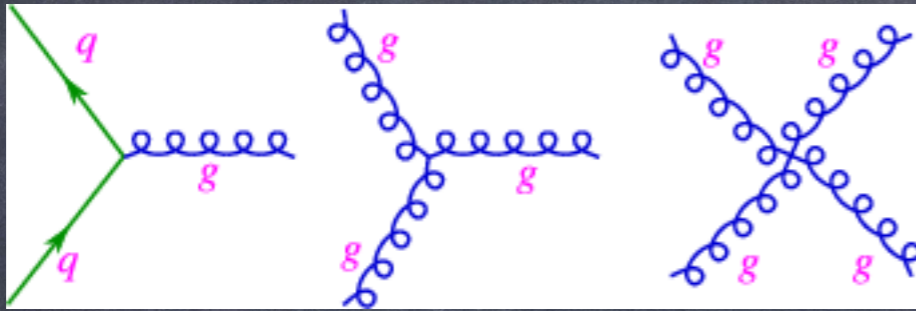


nötron

Asimptotik özgürlük



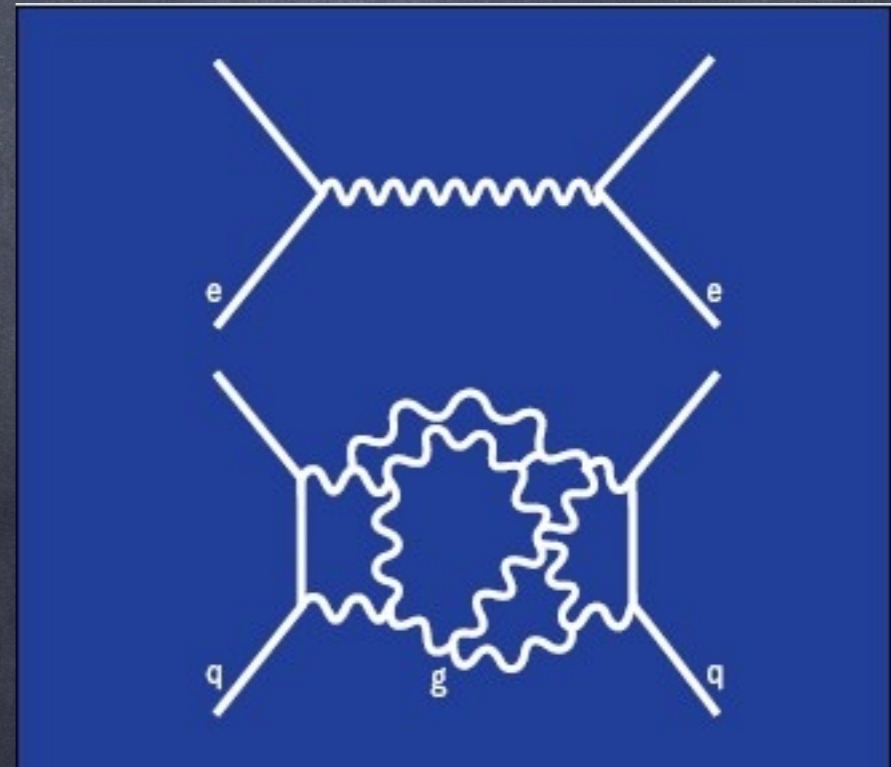
Kuantum Renk Dinamiği



Kuantum Renk Dinamiği

- KED'in taşıyıcısı foton elektrik yükü taşımaz
- KRD'nin taşıyıcısı gluon renk yükü taşır

Gluonlar kendileri ile de etkileşir



Kuvvetler

	<p>mass $\approx 2.3 \text{ MeV}/c^2$</p> <p>charge $2/3$</p> <p>spin $1/2$</p> <p>u</p> <p>up</p>	<p>mass $\approx 1.275 \text{ GeV}/c^2$</p> <p>charge $2/3$</p> <p>spin $1/2$</p> <p>c</p> <p>charm</p>	<p>mass $\approx 173.07 \text{ GeV}/c^2$</p> <p>charge $2/3$</p> <p>spin $1/2$</p> <p>t</p> <p>top</p>	<p>mass 0</p> <p>charge 0</p> <p>spin 1</p> <p>g</p> <p>gluon</p>	<p>mass $\approx 126 \text{ GeV}/c^2$</p> <p>charge 0</p> <p>spin 0</p> <p>H</p> <p>Higgs boson</p>		
QUARKS	<p>mass $\approx 4.8 \text{ MeV}/c^2$</p> <p>charge $-1/3$</p> <p>spin $1/2$</p> <p>d</p> <p>down</p>	<p>mass $\approx 95 \text{ MeV}/c^2$</p> <p>charge $-1/3$</p> <p>spin $1/2$</p> <p>s</p> <p>strange</p>	<p>mass $\approx 4.18 \text{ GeV}/c^2$</p> <p>charge $-1/3$</p> <p>spin $1/2$</p> <p>b</p> <p>bottom</p>	<p>mass 0</p> <p>charge 0</p> <p>spin 1</p> <p>γ</p> <p>photon</p>			
LEPTONS	<p>mass $0.511 \text{ MeV}/c^2$</p> <p>charge -1</p> <p>spin $1/2$</p> <p>e</p> <p>electron</p>	<p>mass $105.7 \text{ MeV}/c^2$</p> <p>charge -1</p> <p>spin $1/2$</p> <p>μ</p> <p>muon</p>	<p>mass $1.777 \text{ GeV}/c^2$</p> <p>charge -1</p> <p>spin $1/2$</p> <p>τ</p> <p>tau</p>	<p>mass $91.2 \text{ GeV}/c^2$</p> <p>charge 0</p> <p>spin 1</p> <p>Z</p> <p>Z boson</p>	GAUGE BOSONS		
	<p>mass $< 2.2 \text{ eV}/c^2$</p> <p>charge 0</p> <p>spin $1/2$</p> <p>ν_e</p> <p>electron neutrino</p>	<p>mass $< 0.17 \text{ MeV}/c^2$</p> <p>charge 0</p> <p>spin $1/2$</p> <p>ν_μ</p> <p>muon neutrino</p>	<p>mass $< 15.5 \text{ MeV}/c^2$</p> <p>charge 0</p> <p>spin $1/2$</p> <p>ν_τ</p> <p>tau neutrino</p>	<p>mass $80.4 \text{ GeV}/c^2$</p> <p>charge ± 1</p> <p>spin 1</p> <p>W</p> <p>W boson</p>			

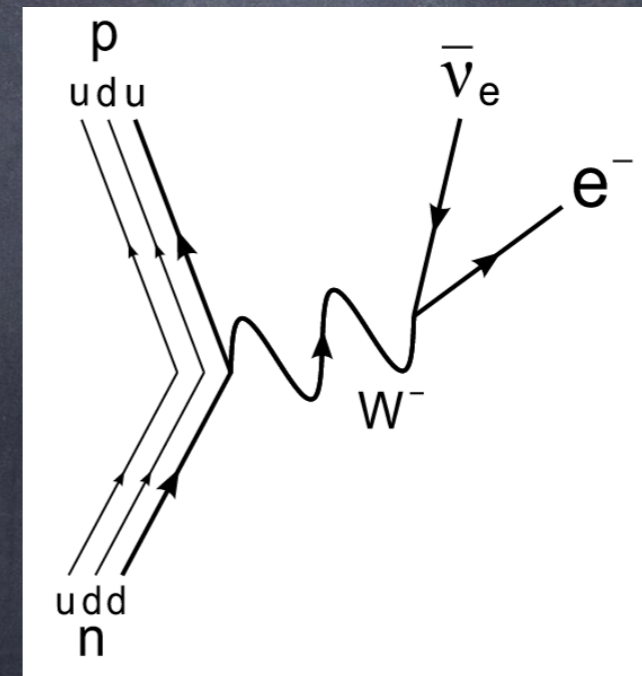
Zayıf Kuvvet

Kuantum Geçiş Dinamiği

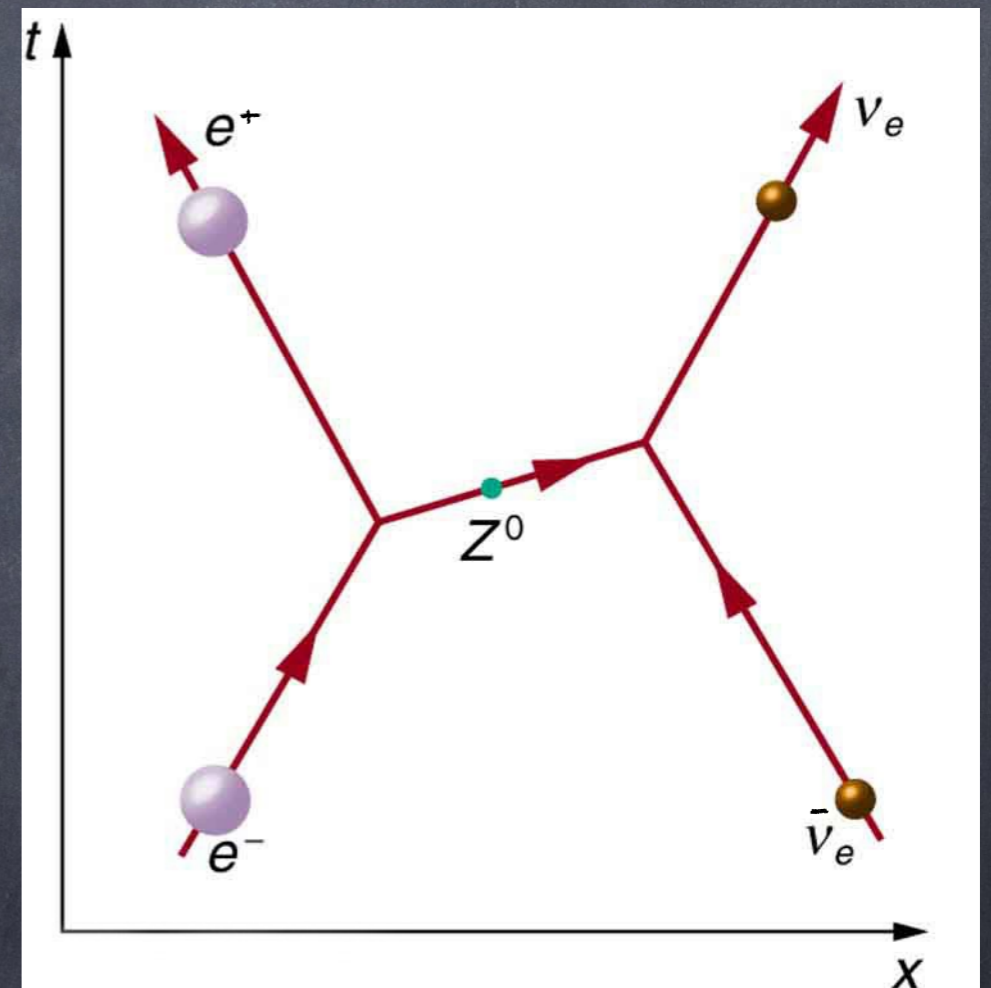
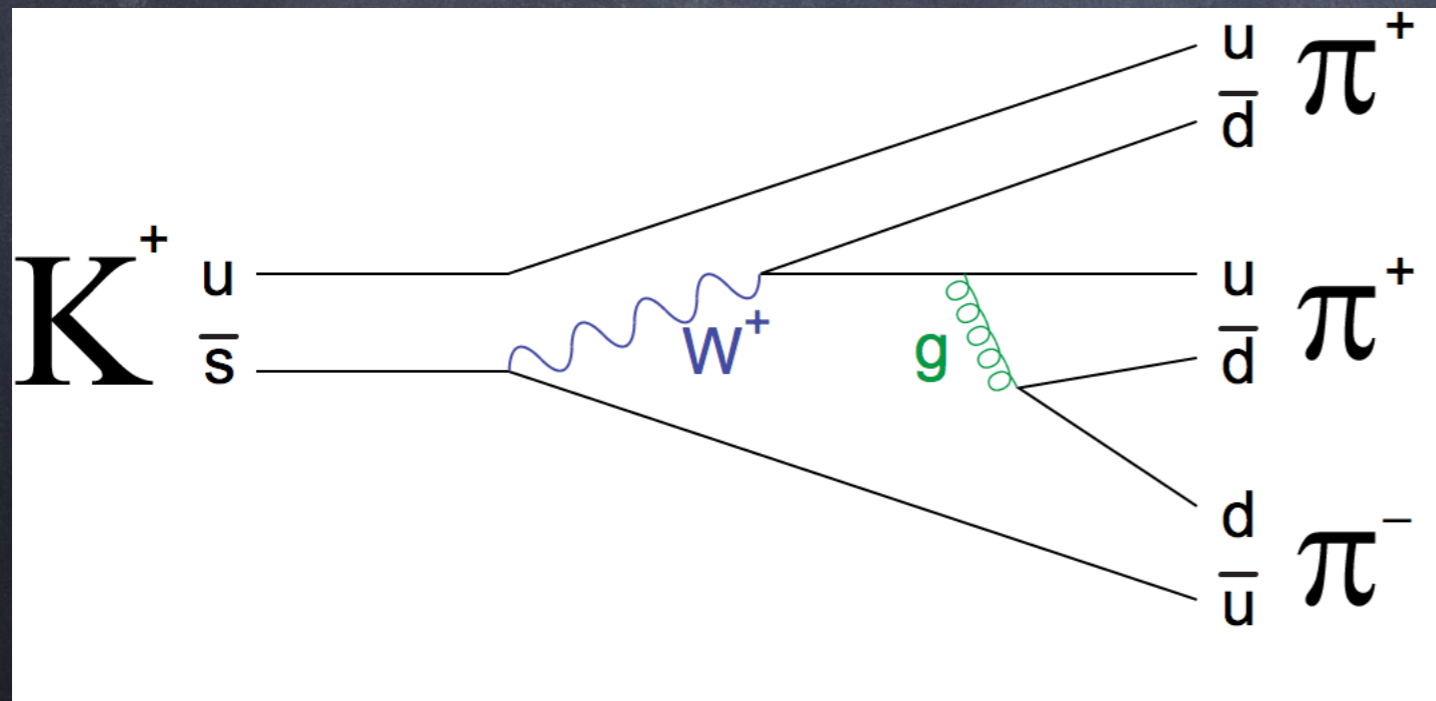
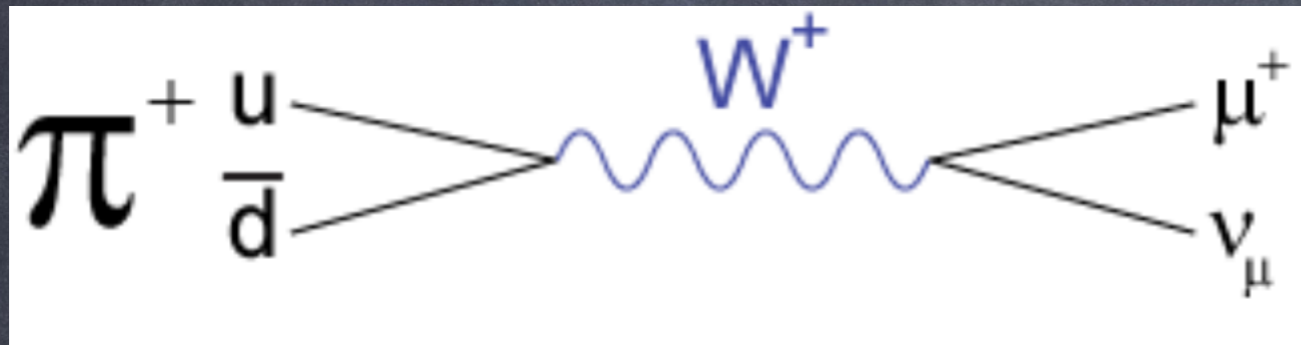
- Kuarkların geçişlerini KÇD ile değiştirir
- Etkileşim kısa-men-zillidir (10^{-18} m)
- Taşıyıcı parçacıkları kütle sahibidir

- $M_Z = 90 \text{ GeV}/c^2$

- $M_W = 81 \text{ GeV}/c^2$

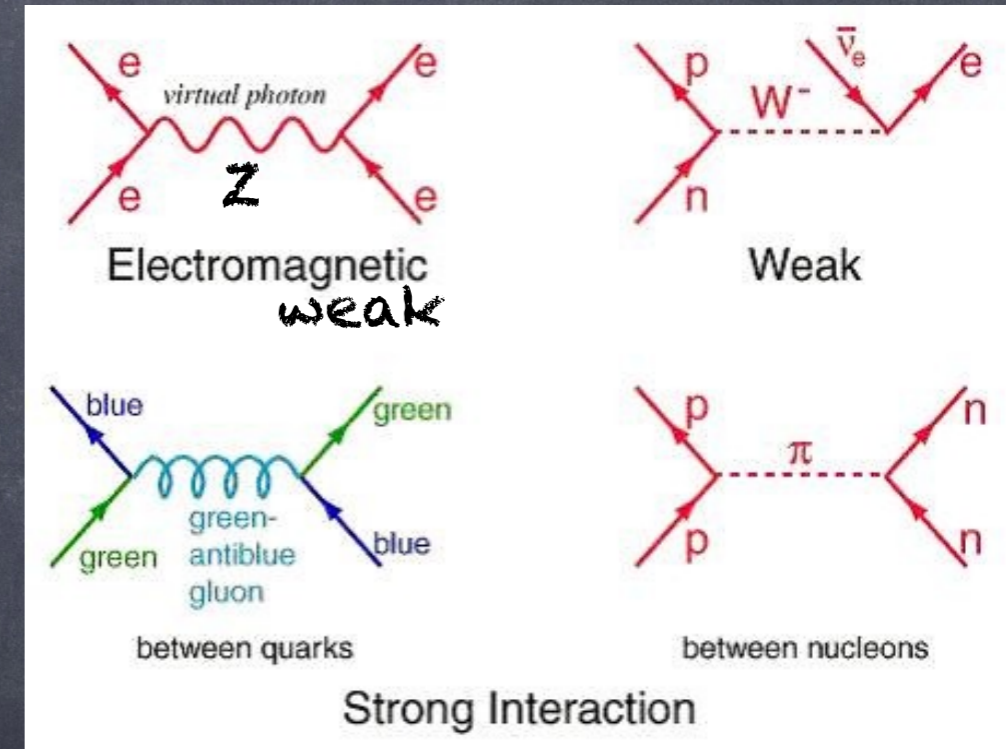
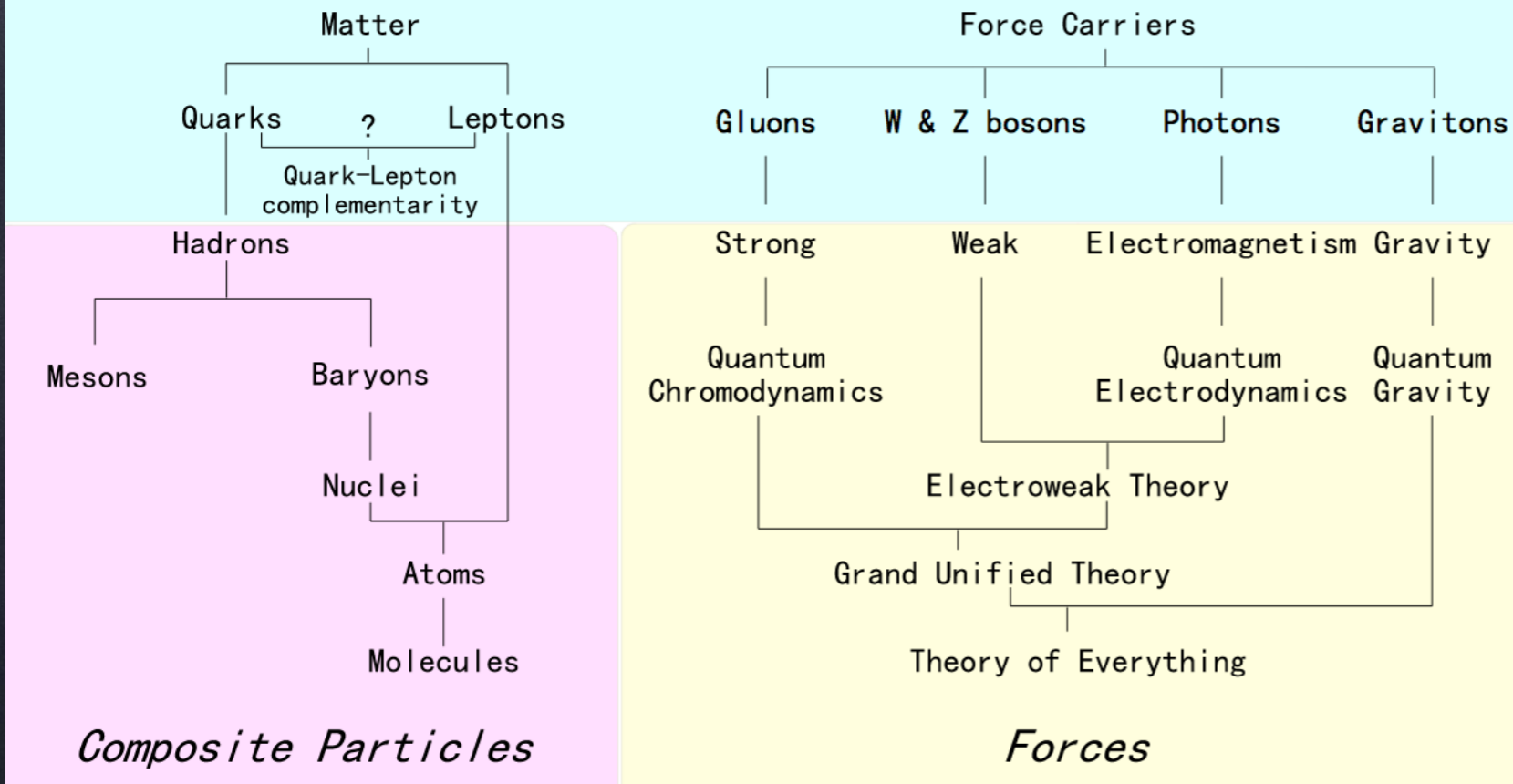


Kuantum Geçmi Dinamigi



Parçacıklar ve Kuvvetler

Elementary Particles



Yedekler

Genel Görelilik

Einstein Alan Denklemleri

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu} R + g_{\mu\nu}\Lambda = \frac{8\pi G}{c^4}T_{\mu\nu}$$

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu}$$

$R_{\mu\nu}$ Ricci eğrilik tensörü

$g_{\mu\nu}$ Metrik Tensör

R Skalar eğrilik

Λ Kosmolojik sabit

G Newton'un kütle çekimi sabiti

c Işık hızı

$T_{\mu\nu}$ Stres-Enerji Tensörü

Einstein tensörü

$$G_{\mu\nu} + g_{\mu\nu}\Lambda = \frac{8\pi G}{c^4}T_{\mu\nu}$$