

## Particles and Interactions

- Particles
  - ▶ Fermions and bosons
  - ▶ Mesons and baryons
  - ▶ Energy, mass and momentum
- Interactions
  - ▶ Cross-section in  $e^+e^-$  and "R"
- Mass versus Range
- de Broglie wavelength
- Vacuum polarization
- Running coupling constants
- Unification of forces

## Summary

### ■ From PDG

BOSONS						FERMIONS					
Unified Electroweak spin = 1			Strong (color) spin = 1			Leptons spin = 1/2			Quarks spin = 1/2		
Name	Mass GeV/c <sup>2</sup>	Electric charge	Name	Mass GeV/c <sup>2</sup>	Electric charge	Flavor	Mass GeV/c <sup>2</sup>	Electric charge	Flavor	Approx. Mass GeV/c <sup>2</sup>	Electric charge
$\gamma$ photon	0	0	$g$ gluon	0	0	$\nu_e$ electron neutrino	$<1 \times 10^{-8}$	0	$u$ up	0.003	2/3
$W^-$	80.4	-1				$e^-$ electron	0.000511	-1	$d$ down	0.006	-1/3
$W^+$	80.4	+1				$\nu_\mu$ muon neutrino	$<0.0002$	0	$c$ charm	1.3	2/3
$Z^0$	91.187	0				$\mu^-$ muon	0.106	-1	$s$ strange	0.1	-1/3
						$\nu_\tau$ tau neutrino	$<0.02$	0	$t$ top	175	2/3
						$\tau^-$ tau	1.7771	-1	$b$ bottom	4.3	-1/3

PROPERTIES OF THE INTERACTIONS					
Property	Gravitational	Weak (Electroweak)	Electromagnetic	Fundamental Strong	Residual Strong
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)	$W^+$ $W^-$ $Z^0$	$\gamma$	Gluons	Mesons
Strength relative to electromagnetism for two u quarks at:	$10^{-41}$	0.8	1	25	Not applicable to quarks
for two protons in nucleus	$10^{-41}$	$10^{-4}$	1	60	Not applicable to hadrons
	$10^{-36}$	$10^{-7}$	1		20

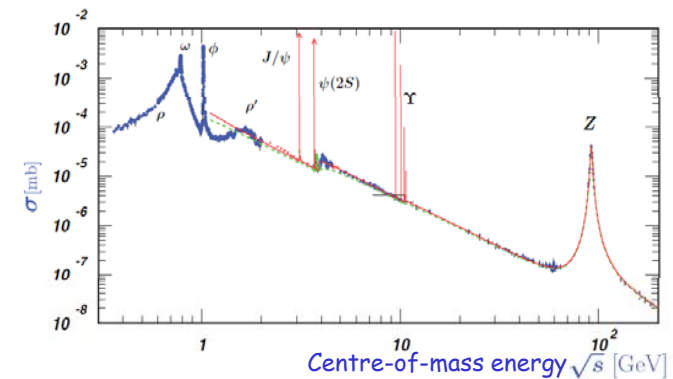
To name but a few... see "PDG" (online) for details

Mesons $q\bar{q}$					
Mesons are bosonic hadrons. There are about 140 types of mesons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c <sup>2</sup>	Spin
$\pi^+$	pion	$u\bar{d}$	+1	0.140	0
$K^-$	kaon	$s\bar{u}$	-1	0.494	0
$\rho^+$	rho	$u\bar{d}$	+1	0.770	1
$B^0$	B-zero	$d\bar{b}$	0	5.279	0
$\eta_c$	eta-c	$c\bar{c}$	0	2.980	0

<http://pdg.lbl.gov/>

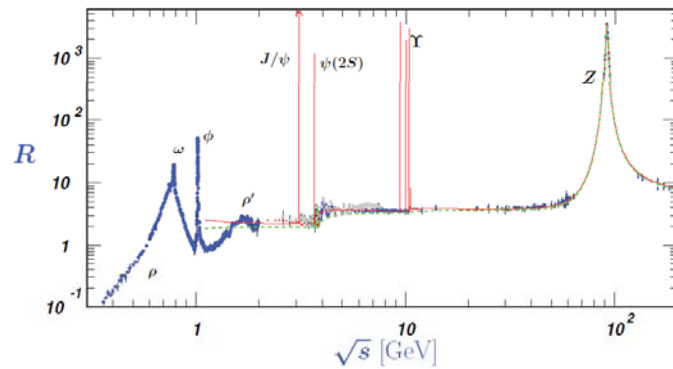
Baryons $qqq$ and Antibaryons $\bar{q}\bar{q}\bar{q}$					
Baryons are fermionic hadrons. There are about 120 types of baryons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c <sup>2</sup>	Spin
$p$	proton	$uud$	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	-1	0.938	1/2
$n$	neutron	$udd$	0	0.940	1/2
$\Lambda$	lambda	$uds$	0	1.116	1/2
$\Omega^-$	omega	$sss$	-1	1.672	3/2

### cross-section ( $e^+e^- \rightarrow \text{hadrons}$ )



<http://pdg.lbl.gov/2008/reviews/hadronicrpp.pdf>

cross-section ratio:  $(e^+e^- \rightarrow \text{hadrons}) / (e^+e^- \rightarrow \mu^+\mu^-)$



<http://pdg.lbl.gov/2008/reviews/hadronicrpp.pdf>

Data: E.M. coupling "constant",  $\alpha_{\text{EM}}$

XXVI Physics in Collision, Búzios, Rio de Janeiro, 6-9 July 2006

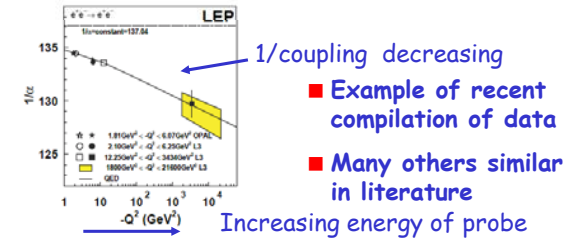


Figure 6: Summary of LEP results on the measurement of the running of the electromagnetic coupling. The band represents the L3 measurement at high  $Q^2$ . The full symbols represent the OPAL and the L3 measurements at low and intermediate  $Q^2$ . The open symbols are the reference values to which the measurement are anchored, as discussed in the last section of the text. The solid line shows the QED predictions of Reference [5].