Physics 661

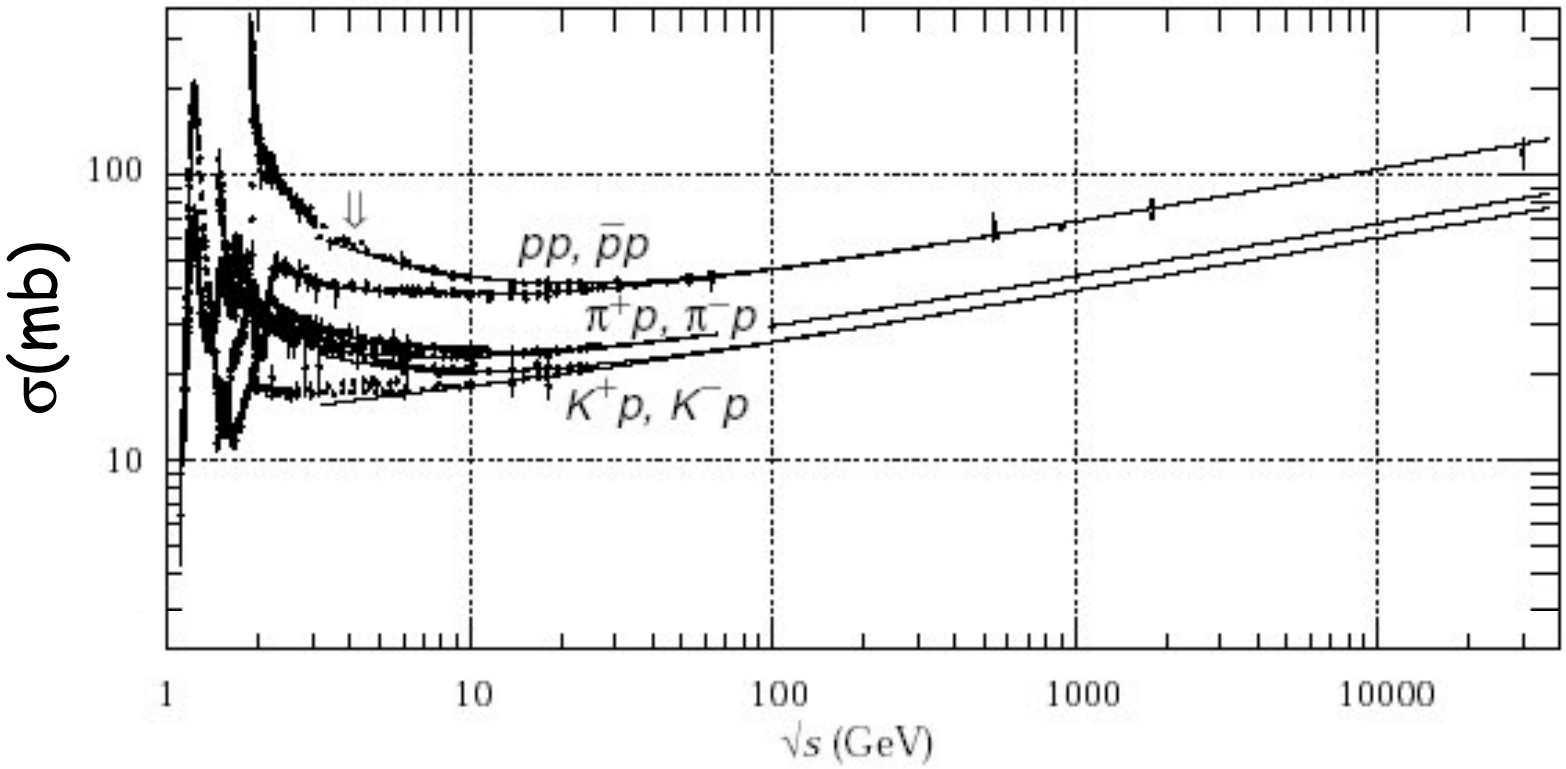
Particle Physics Phenomenology

November 26, 2003

Quarks in Hadrons

- Charm and beauty ✓
- Quarkonium ✓
- Baryon decuplet ✓
- Quark spin and color ✓
- Baryon octet ✓
- Pseudoscalar mesons ✓
- Vector mesons ✓
- Other tests of the quark model
- Mass relations and hyperfine splitting
- EM mass differences and isospin symmetry
- Baryon magnetic moments
- Heavy quark mesons
- The top quarks

Pion-nucleon cross-sections

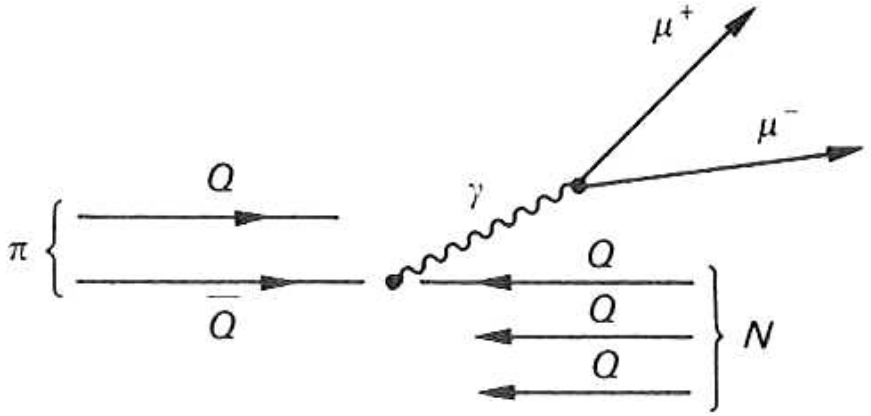


$\sigma(\pi p) = 2/3\ \sigma(pp)$

Additive quark model

Lepton Pair Production on Isoscalar Targets

- Drell-Yan production



$\sigma(\pi^- C \to \mu^+\mu^- + \ldots) \sim 18\ Q_u^2 = 18(4/9)$

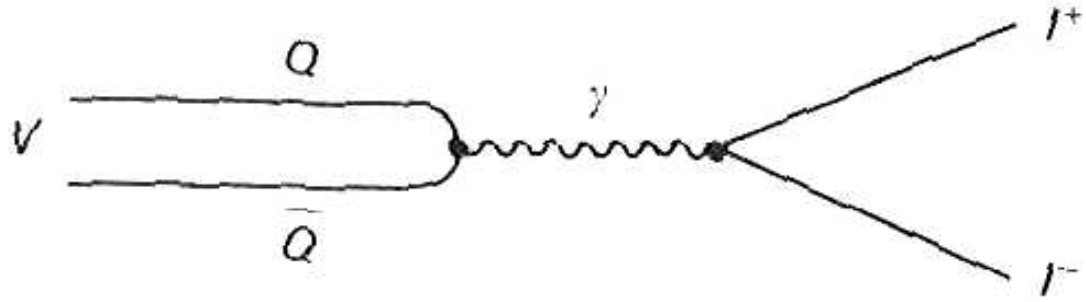
$\sigma(\pi^+ C \to \mu^+\mu^- + \ldots) \sim 18\ Q_d^2 = 18(1/9)$

since $\pi^- = \bar{u}d$

$\pi^+ = \bar{d}u$

$C = 18u + 18d$

Vector Meson Decay to Leptons



Meson	Quark wavefunction	$\lvert\Sigma a_i Q_i\rvert^2$	$\Gamma_{e^+e^-}$, keV	$\Gamma_{e^+e^-}/\lvert\Sigma a_i Q_i\rvert^2$
ρ	$\frac{1}{\sqrt{2}}(u\bar{u}-d\bar{d})$	$\frac{1}{2}$	6.8 ± 0.3	13.6 ± 0.6
ω	$\frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d})$	$\frac{1}{18}$	0.60 ± 0.02	10.8 ± 0.4
ϕ	$s\bar{s}$	$\frac{1}{9}$	1.37 ± 0.05	12.3 ± 0.5
ψ	$c\bar{c}$	$\frac{4}{9}$	5.3 ± 0.4	11.9 ± 0.9
Υ	$b\bar{b}$	$\frac{1}{9}$	1.32 ± 0.05	11.9 ± 0.5

Mass Relations and Hyperfine Splitting

Baryon and mass (MeV)	Quark composition (n denotes u or d)	$\Delta E/K$	Predicted mass, MeV
$N(939)$	$3n$	$-3/m_n^2$	939
$\Lambda(1116)$	$2n, 1s$	$-3/m_n^2$	1114
$\Sigma(1193)$	$2n, 1s$	$1/m_n^2 - 4/(m_n m_s)$	1179
$\Xi(1318)$	$1n, 2s$	$1/m_n^2 - 4/(m_n m_s)$	1327
$\Delta(1232)$	$3n$	$3/m_n^2$	1239
$\Sigma(1384)$	$2n, 1s$	$1/m_n^2 + 2/(m_n m_s)$	1381
$\Xi(1533)$	$1n, 2s$	$1/m_s^2 + 2/(m_n m_s)$	1529
$\Omega(1672)$	$3s$	$3/m_s^2$	1682

$$\Delta E(Q\overline{Q}) = 8\pi\alpha_s |\psi(0)|^2 \sigma_i \cdot \sigma_j / 9 m_i m_j = 2K \sigma_i \cdot \sigma_j / m_i m_j$$
$$\Delta E(QQ) = 4\pi\alpha_s |\psi(0)|^2 \sigma_i \cdot \sigma_j / 9 m_i m_j = K \sigma_i \cdot \sigma_j / m_i m_j$$

Electromagnetic Mass Differences and Isospin Symmetry

$$M(\text{hadron}) = M_{\text{bare}} + \Delta M_{EM}$$

M_{bare} = constituents plus S.I.

Expect the ΔM_{EM} for multiplet to be same for like charge particles:

$$\Delta M(p) = \Delta M(\Sigma^+)$$

$$\Delta M(\Sigma^-) = \Delta M(\Xi^-)$$

$$\Delta M(\Xi^0) = \Delta M(n)$$

With bare masses:

$$M(p) + M(\Sigma^-) + M(\Xi^0) = M(\Sigma^+) + M(\Xi^-) + M(n)$$

$$M_d - M_u = 2 \text{ MeV}$$

Magnetic Moments of Baryons

- Magnetic moments of the nucleons
  - proton 2.793 nuclear magnetons
  - neutron - 1.913 nuclear magnetons
  - [nuclear magneton = $e\hbar/(2Mc)$]

- Recall the proton wave function:

$$(2u\uparrow u\uparrow d\downarrow + 2d\downarrow u\uparrow u\uparrow + 2u\uparrow d\downarrow u\uparrow - u\downarrow d\uparrow u\uparrow - u\uparrow u\downarrow d\uparrow - u\downarrow u\uparrow d\uparrow - d\uparrow u\downarrow u\uparrow - u\uparrow d\uparrow u\downarrow - d\uparrow u\uparrow u\downarrow) / \sqrt{18}$$

Magnetic Moments of Baryons

proton: $(2u\uparrow u\uparrow d\downarrow + 2d\downarrow u\uparrow u\uparrow + 2u\uparrow d\downarrow u\uparrow$
$- u\downarrow d\uparrow u\uparrow - u\uparrow u\downarrow d\uparrow - u\downarrow u\uparrow d\uparrow$
$- d\uparrow u\downarrow u\uparrow - u\uparrow d\uparrow u\downarrow - d\uparrow u\uparrow u\downarrow) / \sqrt{18}$

$\mu_p = 12/18\ (2\mu_u - \mu_d) + 6/18\ (\mu_d)$
$= 4/3\ \mu_u - 1/3\ \mu_d$
$\mu_n = 4/3\ \mu_d - 1/3\ \mu_u$

$\mu_u = -\ 2\ \mu_d$

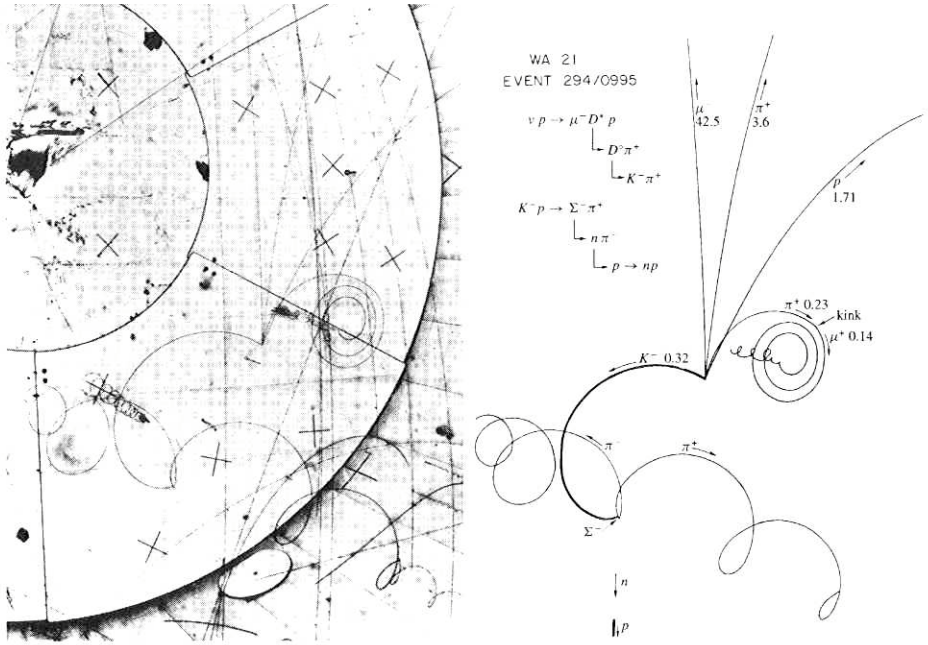
$\mu_p = 4/3\ \mu_u - 1/3(-1/2\ \mu_u) = 3/2\ \mu_u$
$\mu_n = 4/3(-1/2\ \mu_u) - 1/3\ \mu_u = -\ \mu_u = -2/3\ \mu_p$

Magnetic Moments of Baryons

Baryon	Magnetic moment in quark model	Predicted, n.m.	Observed, n.m.
p	$\frac{4}{3}\mu_u - \frac{1}{3}\mu_d$	$+2.79$	$+2.793$
n	$\frac{4}{3}\mu_d - \frac{1}{3}\mu_u$	-1.86	-1.913
Λ	μ_s	-0.61	-0.614 ± 0.005
Σ^+	$\frac{4}{3}\mu_u - \frac{1}{3}\mu_s$	$+2.68$	$+2.46 \pm 0.01$
Σ^-	$\frac{4}{3}\mu_d - \frac{1}{3}\mu_s$	-1.04	-1.16 ± 0.03
Ξ^0	$\frac{4}{3}\mu_s - \frac{1}{3}\mu_u$	-1.44	-1.25 ± 0.014
Ξ^-	$\frac{4}{3}\mu_s - \frac{1}{3}\mu_d$	-0.51	-0.65 ± 0.01
Ω^-	$3\mu_s$	-1.84	-2.02 ± 0.05

m_n (= m_u = m_d) = 336 MeV
m_s = 509 MeV

Mesons Built of Light and Heavy Quarks



Heavy quark mass	Triplet–singlet difference	Product
$M_c \simeq 1.86$ GeV	$M_{D^*} - M_D = 0.14$ GeV	$M_c(M_{D^*} - M_D) = 0.26$ GeV
$M_b \simeq 5.28$ GeV	$M_{B^*} - M_B = 0.046$ GeV	$M_b(M_{B^*} - M_B) = 0.24$ GeV

~ 1/M (color magnetic int.)

independent of M

Top Quark

- First observed in 1995 at Fermilab
- M = 175 GeV
- $p\bar{p} \rightarrow t\,\bar{t} + X$ (1/10^{10} collisions)

  $\rightarrow W^+ b\, W^- \bar{b}$