

Outline

- Relativistic Kinematics
 - ▶ (4-momentum)² invariance, invariant mass
 - ▶ Hypothesis testing, production thresholds
 - ▶ Cross-sections, flux and luminosity, accelerators
 - ▶ Particle lifetime, decay length, width
- Classification of particles
 - ▶ Fermions and bosons
 - ▶ Leptons, hadrons, quarks
 - ▶ Mesons, baryons
- Quark Model
 - ▶ Meson and baryon multiplets
 - ▶ Isospin, strangeness, c, b, t quarks
- Particle Interactions
 - ▶ Virtual particles and range of forces
 - ▶ Strong and weak decays, conservation rules
 - ▶ Parity, charge conjugation, CP
 - ▶ Weak decays of quarks
 - ▶ Colour charge, QCD, gluons
 - ▶ Charmonium and upsilon systems
- Electroweak Interactions
 - ▶ Charged and neutral currents
 - ▶ W, Z, LEP experiments
 - ▶ Higgs and the future
- LHC Experiments
- Future - introduction to accelerator physics

Problem sheet for supervision classes (Peter Jones)
Attempt q1 from sheet 1 and q1 from sheet 2

Today

- Lecture 4 (11 slides/302) - static quark model
 - Particle discoveries before quark model proposed (1964)
 - Particle discoveries after 1964
 - Early proton synchrotrons
 - Discovery of the pion - Nature 159, 108-190 & 180, 450-458 (1947)
 - Discovery of strange particles - Nature 168, 864-867 (1949)
 - Williams Ch. 10.3; Perkins (3rd Ed.), pp. 146-160.

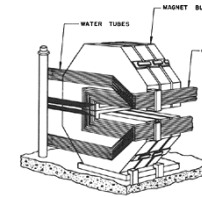
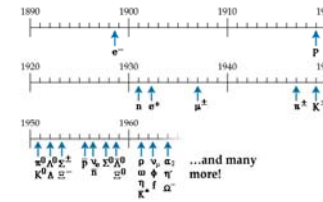
Previous Lecture

- Lecture 5 (4 slides/304) - synchrotron radiation, particle lifetime, width and classifications
 - lightsources.org - good starting point
 - Stanford Synchrotron Radiation Lightsource
 - Diamond Light Source
 - Perkins (3rd edition), pg. 32
 - Perkins (3rd edition), Appendix E (Fermi Golden Rule)
 - Synchrotron radiation in Particle Detector Briefbook

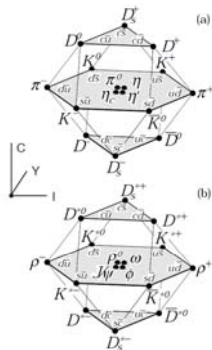
History - particle "explosion"



- Up to ~1950, only known particles are: p, n, ν_e , μ^- , e, K^+
- Revolutionised by Brookhaven "Cosmotron"
 - ▶ proton synchrotron
 - ▶ beam energy 3.3 GeV (by 1953)
- 288 C shaped magnets, 2k tonnes total (weak focussing)



(approximate) symmetries in flavour



- Ever increasing multitude of particles discovered in 1950-60's
- Complex mixture of mass, charge, spin, lifetimes, decay products
- Classification was the first step to understand underlying order - a la Mendeleev periodic table

Example of meson "multiplets" with four flavours

[<http://hepdata.cedar.ac.uk/lbl/2011/reviews/rpp2011-rev-quark-model.pdf>]
K. Nakamura *et al.*, JPC 37, 075021 (2010)

u, d meson groupings

$q\bar{q}$	S=0	S=1
$u\bar{d}$	$\pi^+(140)$	$\rho^+(770)$
$(u\bar{u} - d\bar{d})/\sqrt{2}$	$\pi^0(135)$	$\rho^0(770)$
$\bar{u}d$	$\pi^-(140)$	$\rho^-(770)$

- Meson triplet and singlet with u, d flavours
- (xxx) are masses in MeV - conventional

$(u\bar{u} + d\bar{d})/\sqrt{2}$	$\eta(548)$	$\omega(782)$
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Mesons: excited states

K. Nakamura *et al.*, JPG 37, 075021 (2010)

$n^{2s+1}L_J$	J^{PC}	$I=1$ $u\bar{d}, \bar{u}d, \frac{1}{\sqrt{2}}(d\bar{d} - u\bar{u})$	$I=\frac{1}{2}$ $u\bar{s}, d\bar{s}; \bar{d}s, -\bar{u}s$	$I=0$ f'	$I=0$ f
1^1S_0	0^{-+}	π	K	η	$\eta'(958)$
1^3S_1	1^{--}	$\rho(770)$	$K^*(892)$	$\phi(1020)$	$\omega(782)$
1^1P_1	1^{+-}	$b_1(1235)$	K_{1B}^+	$h_1(1380)$	$h_1(1170)$
1^3P_0	0^{++}	$a_0(1450)$	$K_0^*(1430)$	$f_0(1710)$	$f_0(1370)$
1^3P_1	1^{++}	$a_1(1260)$	K_{1A}^+	$f_1(1420)$	$f_1(1285)$
1^3P_2	2^{++}	$a_2(1320)$	$K_2^*(1430)$	$f_2'(1525)$	$f_2(1270)$
1^1D_2	2^{-+}	$\pi_2(1670)$	$K_2(1770)^{\dagger}$	$\eta_2(1870)$	$\eta_2(1645)$
1^3D_1	1^{--}	$\rho(1700)$	$K^*(1680)$		$\omega(1650)$
1^3D_2	2^{--}		$K_2(1820)$		
1^3D_3	3^{--}	$\rho_3(1690)$	$K_3^*(1780)$	$\phi_3(1850)$	$\omega_3(1670)$
1^3F_4	4^{++}	$a_4(2040)$	$K_4^*(2045)$		$f_4(2050)$
1^3G_5	5^{--}	$\rho_5(2350)$			

Strangeness: light meson nonets

$q\bar{q}$	$^1S_0, J=0$	$^3S_0, J=1$
$u\bar{d}$	$\pi^+(140)$	$\rho^+(770)$
$(u\bar{u} - d\bar{d})/\sqrt{2}$	$\pi^0(135)$	$\rho^0(770)$
$\bar{u}d$	$\pi^-(140)$	$\rho^-(770)$
$u\bar{s}$	$K^+(494)$	$K^{*+}(892)$
$d\bar{s}$	$K^0(498)$	$K^{*0}(896)$
$\bar{u}s$	$K^-(494)$	$K^{*-}(892)$
$\bar{d}s$	$\bar{K}^0(498)$	$\bar{K}^{*0}(896)$
$(u\bar{u} + d\bar{d})/\sqrt{2}$	$\eta(548)$	$\omega(782)$
$s\bar{s}$	$\eta'(958)$	$\phi(1020)$

- Meson nonets with u, d, s flavours
- Note η, η' are actually mixed $u\bar{u}, d\bar{d}, s\bar{s}$ states
- ω and ϕ also slight admixtures
- (xxx) are masses in MeV - conventional