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

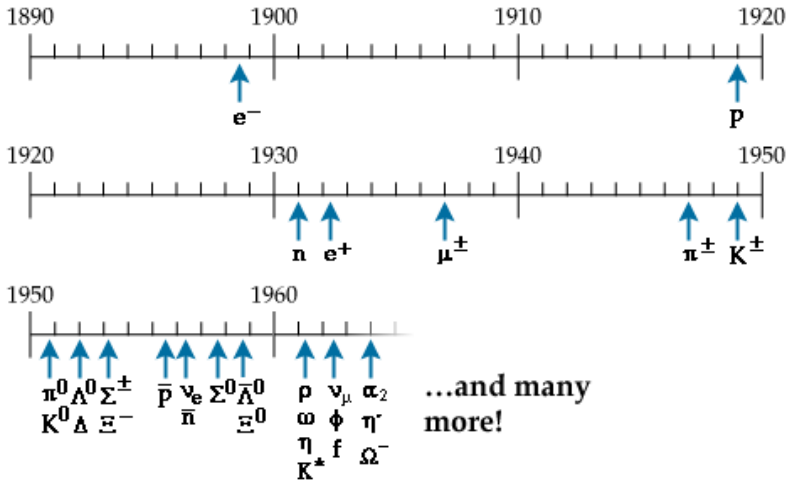
Please see web page for specific references to textbooks and brief reviews from PDG.

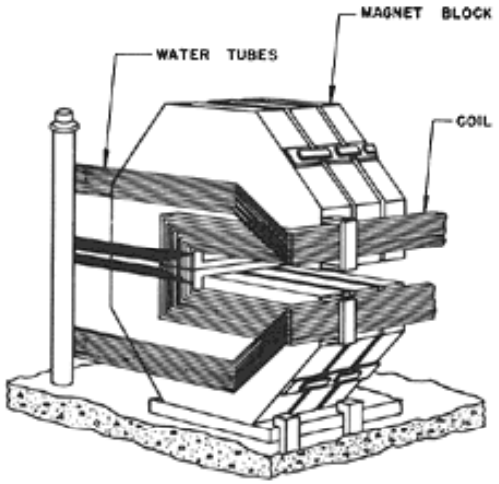
Problem sheet for tutorial classes (with Peter Jones) to appear tomorrow

Reminder: **no lecture on Monday 30 Jan.**
To be re-arranged later in term as required.

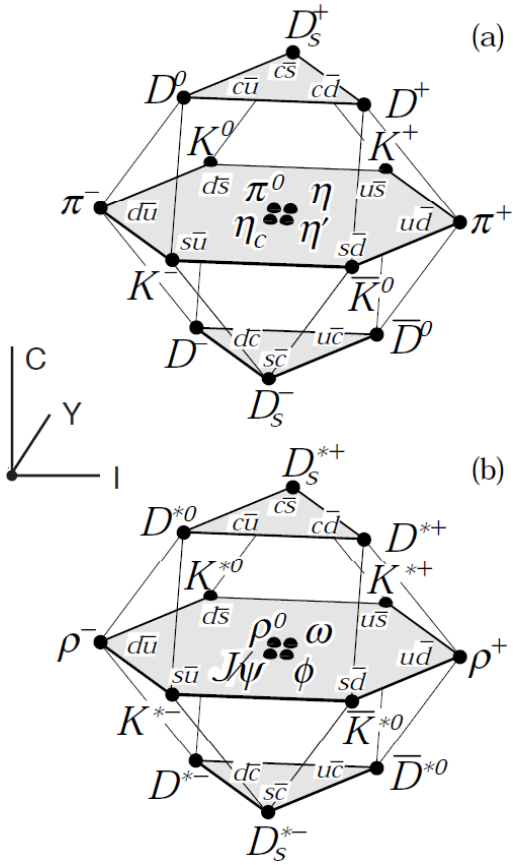
History - particle "explosion"

- 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.*, JPG **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

$(u\bar{u}-d\bar{d})/\sqrt{2}$	$\eta(548)$	$\omega(782)$

Mesons: excited states

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

$n\,^{2s+1}\ell_J$	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^{+-}	$b_1(1235)$	$K_{1B}{}^\dagger$	$h_1(1380)$	$h_1(1170)$
$1\,^3P_0$	0^{++}	$a_0(1450)$	$K_0^*(1430)$	$f_0(1710)$	$f_0(1370)$
$1\,^3P_1$	1^{++}	$a_1(1260)$	$K_{1A}{}^\dagger$	$f_1(1420)$	$f_1(1285)$
$1\,^3P_2$	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