

# Outline

- Relativistic Kinematics
  - ▶ (4-momentum)<sup>2</sup> 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.

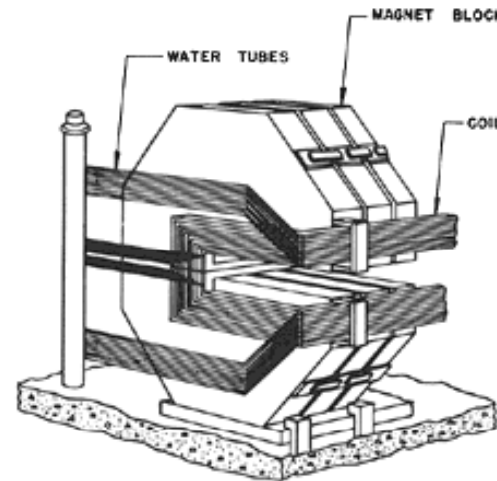
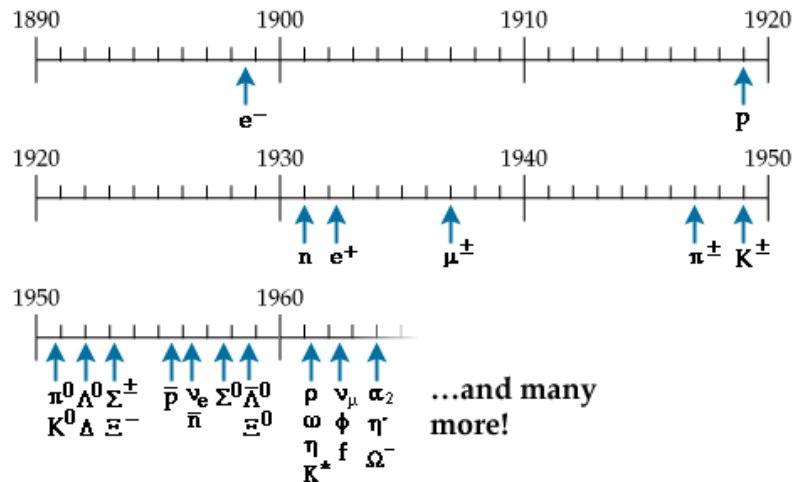
Problem sheet for tutorial classes (with Peter Jones) to appear tomorrow

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

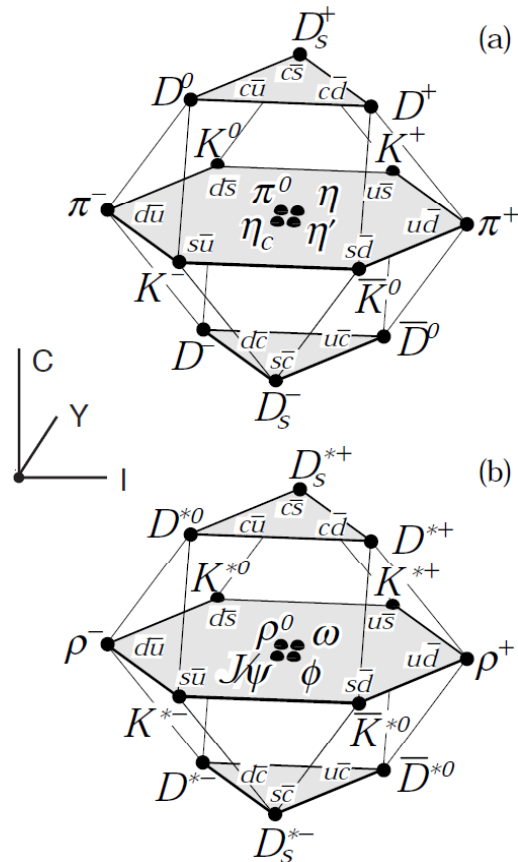
# History - particle "explosion"



- Up to ~1950, only known particles are:  $p$ ,  $n$ ,  $\nu_e$ ,  $\mu^-$ ,  $e$ ,  $K^+$
- 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

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

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

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

# 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  $\eta, \eta'$  are actually mixed  $u\bar{u}, d\bar{d}, s\bar{s}$  states
- $\omega$  and  $\phi$  also slight admixtures
- (xxx) are masses in MeV - conventional