Particle discoveries; 1

Overview

- Discovery of fundamental particles in the last 100 years
- See how possibility of discovery goes hand in hand with available energy and technology

This lecture:

Resonances

Fundamental particles → 1970

Uncertainty principle

Heisenberg Uncertainty Relation:

$$\Delta E \Delta t = h/2\pi$$

In particle physics:

Δt = lifetime of particle (τ)

ΔE = width of particle

If particle at rest: $mc^2 = E$

$\Delta E \Rightarrow \Delta m$

(how well we know the mass)

Uncertainty principle

Resonances

- Resonances are excited states of mesons and baryons
- Most hadrons are resonances

resonance	$I(J^{PC})$
$\rho^0(769)$	$1(1^{--})$
$f_2^0\,(1275)$	$0(2^{++})$
$\rho^0(1700)$	$1(3^{--})$

e.g. excited π^0 states

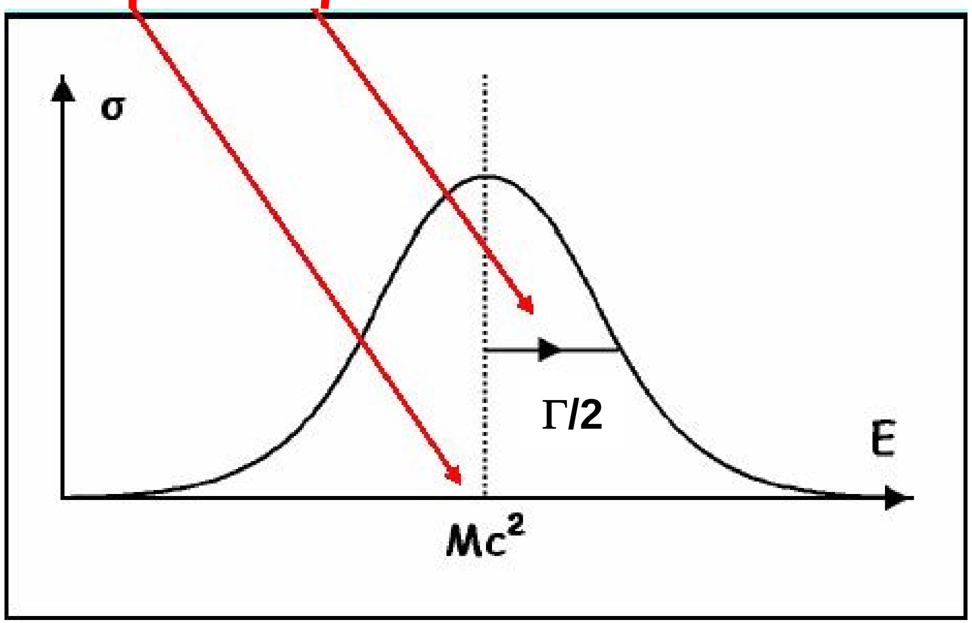
- Resonances decay by the strong force
  - Short lifetime (Δt small, ~10^{-23} s $\Rightarrow$ width large)
- Usually infer presence of resonance by reconstructing and combining decay products

Resonances

$$\sigma(E) \sim \frac{\Gamma^2}{(E - Mc^2)^2 + \Gamma^2/4}$$

Described by **Breit Wigner** formula

- Width $\Gamma = \Delta E \sim 1 / \tau$
- $\sigma(E)$ is cross-section for production at given E
- M is central mass of particle



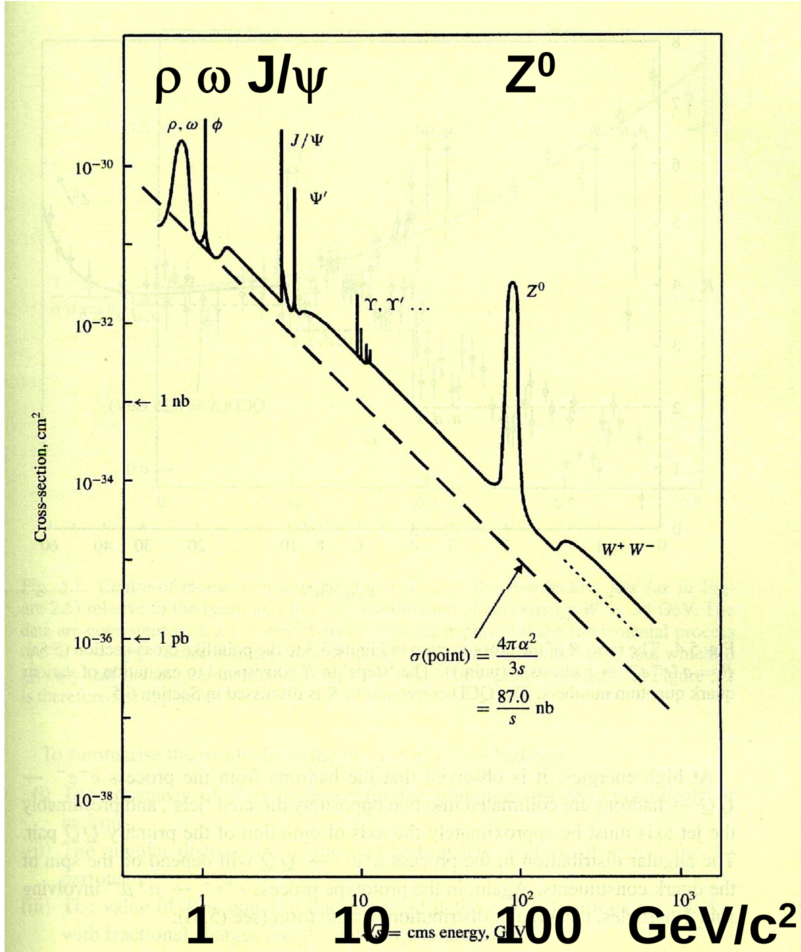
Section 5.3, Martin & Shaw

Resonances

Identified by looking for:

- invariant mass “bumps”
- increases in production cross-section with rising CM energy

We will see examples in history of particle discovery



Overview

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This lecture:

Resonances

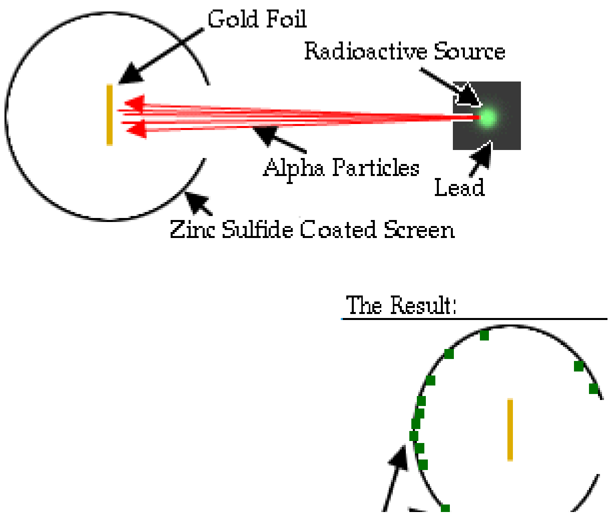
Fundamental particles $\rightarrow$ 1970

Proton & neutron

Protons:

1919 Rutherford;

Realised that nucleus contained small positively charged scattering centres

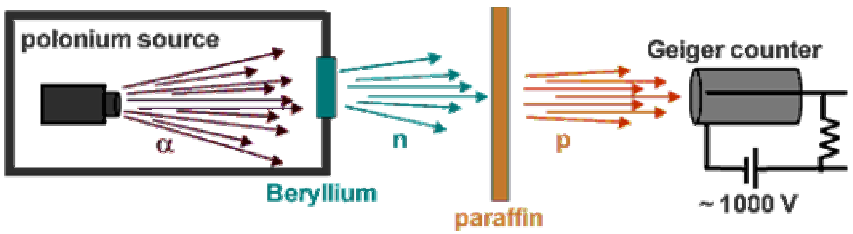


Neutrons:

1931 Chadwick:

Bombarded Be foil with α particles: neutral particles produced.

Not γ; prob. of interaction too large



Detection ability dependant on probing power (particle energy)

Electron,muon,neutrinos

Electron: **J.J. Thomson 1897**

Cathode tubes

(nb. Also xrays →γ)

Muon: **Cosmic rays 1937**

Very penetrating. 200 electron mass particle in cosmic rays

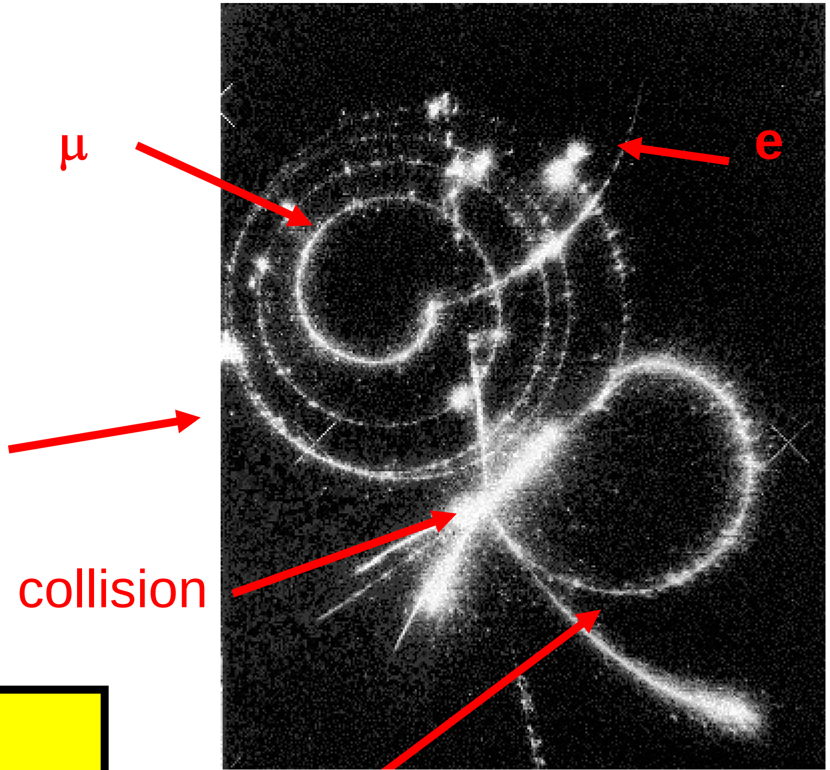
No strong interactions

Neutrinos : **Reines and Cowan 1956**

Nuclear reactor produces anti-neutrinos

Interact with proton detector : $\nu_e + p \rightarrow e^+ + n$

$e^+ + e^- \rightarrow \gamma$ **(detect** γ **with scintillator)**



More energetic probes ….
More massive particles found

Mesons

Pions: cosmic rays 1946

$\pi^+ \rightarrow \mu^+ + \nu\mu$

$\mu^+ \rightarrow e^+ + \nu e + \nu\mu$

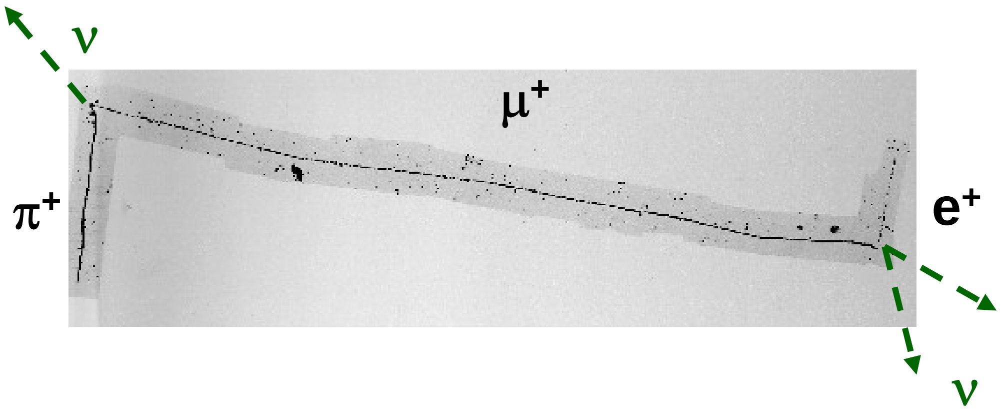
Kaons: cosmic rays

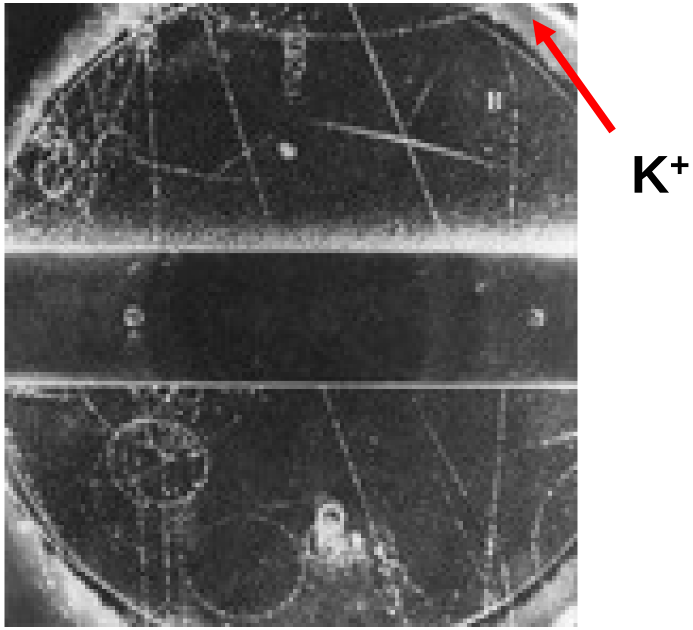
1944 K^+, 1947 K^0

Interact weakly;
"strangely" long lifetime
cf. charged pions

Advent of colliders;

Loads of mesons and
baryons!





$n\ ^{2S+1}L_J$	J^{PC}	$u\bar{d}, u\bar{u}, d\bar{d}$ $I=1$	$u\bar{u}, d\bar{d}, s\bar{s}$ $I=0$	$c\bar{c}$ $I=0$	$b\bar{b}$ $I=0$	$\bar{s}u, \bar{s}d$ $I=1/2$	$c\bar{u}, c\bar{d}$ $I=1/2$	$c\bar{s}$ $I=0$	$\bar{b}u, \bar{b}d$ $I=1/2$	$\bar{b}s$ $I=$
$1\ ^1S_0$	0^{-+}	π	η, η'	η_c		K	D	D_s	B	B_s
$1\ ^3S_1$	1^{--}	ρ	ω, ϕ	$J/\psi(1S)$	$\Upsilon(1S)$	$K^*(892)$	$D^*(2010)$	D_s^*	B^*	B_s^*
$1\ ^1P_1$	1^{+-}	$b_1(1235)$	$h_1(1170), h_1(1380)$	$h_c(1P)$		K_{1B}†	$D_1(2420)$	$D_{s1}(2536)$		
$1\ ^3P_0$	0^{++}	$a_0(1450)^*$	$f_0(1370)^*, f_0(1710)^*$	$\chi_{c0}(1P)$	$\chi_{b0}(1P)$	$K_0^*(1430)$				
$1\ ^3P_1$	1^{++}	$a_1(1260)$	$f_1(1285), f_1(1420)$	$\chi_{c1}(1P)$	$\chi_{b1}(1P)$	K_{1A}†				
$1\ ^3P_2$	2^{++}	$a_2(1320)$	$f_2(1270), f_2'(1525)$	$\chi_{c2}(1P)$	$\chi_{b2}(1P)$	$K_2^*(1430)$	$D_2^*(2460)$			
$1\ ^1D_2$	2^{-+}	$\pi_2(1670)$	$\eta_2(1645), \eta_2(1870)$			$K_2(1770)$				
$1\ ^3D_1$	1^{--}	$\rho(1700)$	$\omega(1650)$	$\psi(3770)$		$K^*(1680)$‡				
$1\ ^3D_2$	2^{--}					$K_2(1820)$				
$1\ ^3D_3$	3^{--}	$\rho_3(1690)$	$\omega_3(1670), \phi_3(1850)$			$K_3^*(1780)$				
$1\ ^3F_4$	4^{++}	$a_4(2040)$	$f_4(2050), f_4(2220)$			$K_4^*(2045)$				
$2\ ^1S_0$	0^{-+}	$\pi(1300)$	$\eta(1295), \eta(1440)$	$\eta_c(2S)$		$K(1460)$				
$2\ ^3S_1$	1^{--}	$\rho(1450)$	$\omega(1420), \phi(1680)$	$\psi(2S)$	$\Upsilon(2S)$	$K^*(1410)$‡				
$2\ ^3P_2$	2^{++}		$f_2(1810), f_2(2010)$		$\chi_{b2}(2P)$	$K_2^*(1980)$				
$3\ ^1S_0$	0^{-+}	$\pi(1800)$	$\eta(1760)$			$K(1830)$				

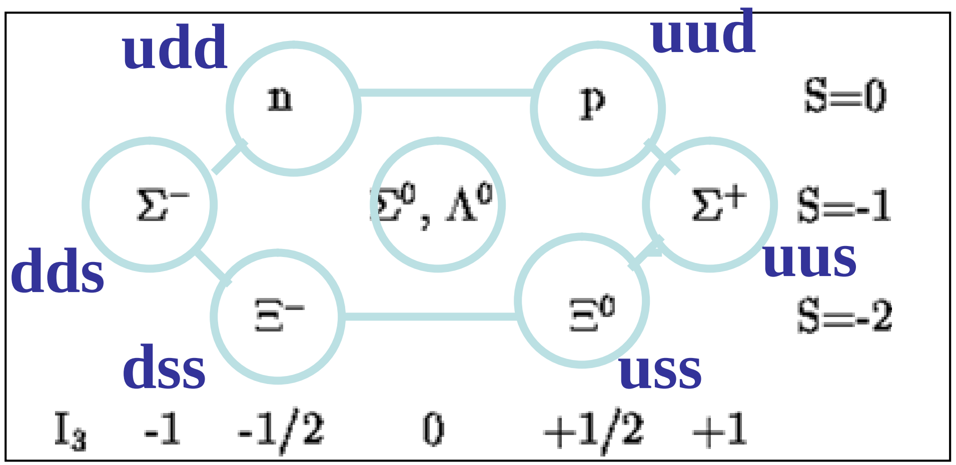
Arrrghh!!!

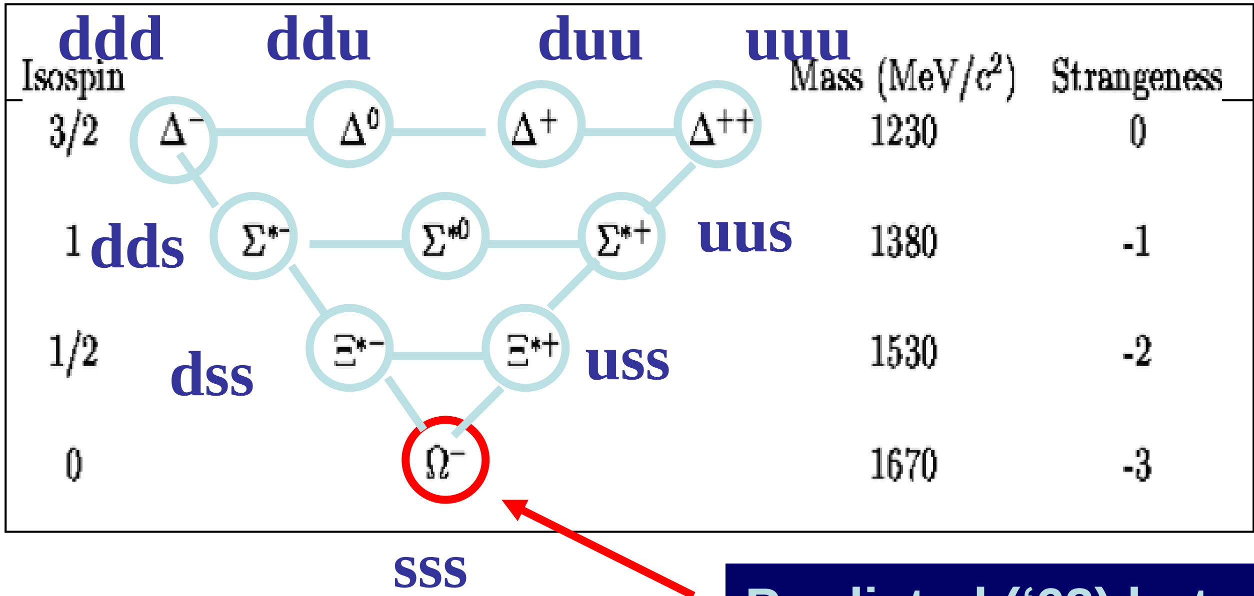
Too many fundamental particles …..

Quark Model

Express particles as combinations of **u,d,s type quarks** → patterns

“Quarks”; “Three quarks for Muster Mark”





Predicted (‘62) but not seen

Discovery of Ω$^-$(sss) baryon

1964:

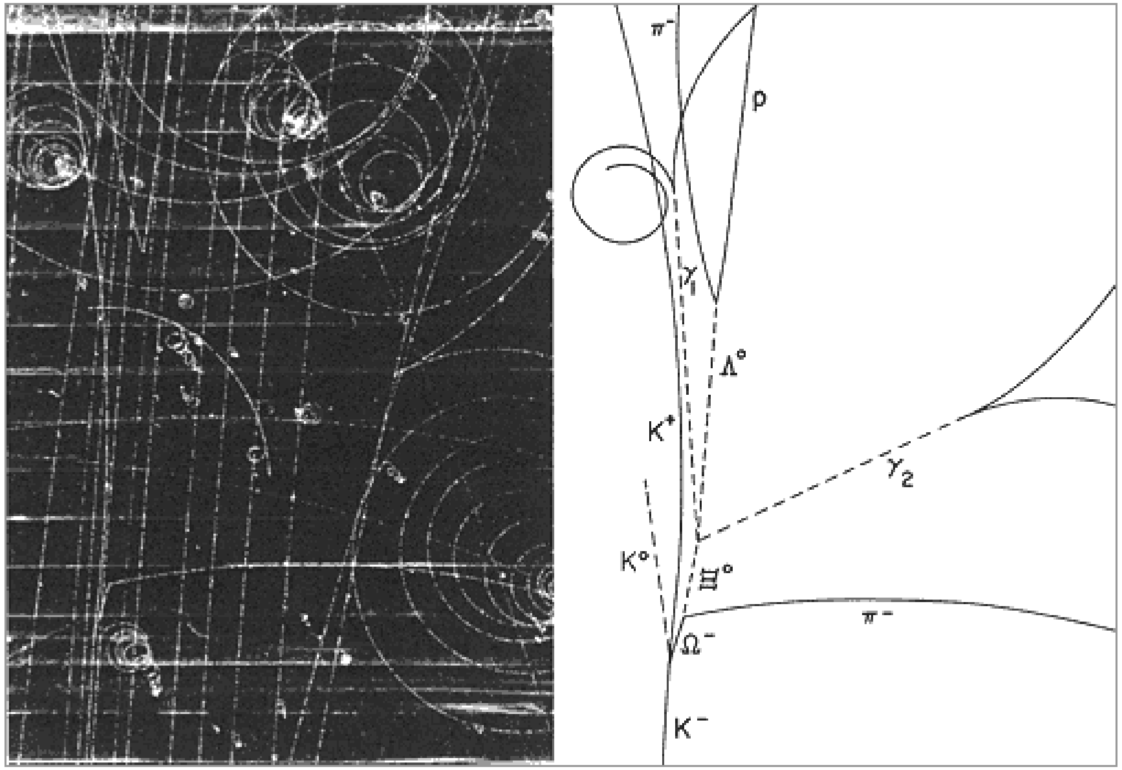
Brookhaven, bubble chamber experiment

Kaon beam incident on proton target

-We worked out before how energetic the kaon beam must be to create an omega;

-In fact kaon beam is 5 GeV

Discovery confirmed multiplet and quark models of particles



$K^- + p \rightarrow \Omega^- + K^0_s + K^+$

$\Omega^- \rightarrow \Xi^0 + \pi^-$

Review

- Concept of resonances
  - Semi-bound excited hadron states
  - Strong force $\Rightarrow$ short lifetime $\Rightarrow$ measureable width
  - Detect from reconstructing decays; characteristic mass, shape from Breit Wigner
- Particle history
  - p,n,e,μ,ν,mesons $\rightarrow$ Ω^-

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