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Charmed Mesons

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Introduction

- Properties of the charm quark
- The early predictions of the charm quark
- The necessity of the charm quark in the GIM mechanism
- The discovery of charm-containing particles
- Discovery of the D-meson

The Charm Quark

- 4th quark to be discovered after the *u, d* and *s*.
- 1968 experiment showed protons/neutrons had substructure
- Experimentally discovered in 1974.
- Same charge as an up quark but higher mass.

Name of particle	Up (*u*)	Down (*d*)	Strange (*s*)	Charm (*c*)
Year of discovery	1968	1968	1968	1974
Approximate Mass (MeV/c^2)	2.3	4.8	95	1275
Charge (e)	+2/3	-1/3	-1/3	+2/3

Bjorken and Glashow Prediction - 1964

- Noticed symmetry in leptons but not in quarks.

- Postulated a 4th quark to allow symmetry in quarks - charm.

Lepton	Quarks
Electron	Up (*u*)
Electron neutrino	Down (*d*)
Muon	Strange (*s*)
Muon neutrino	?

GIM Mechanism - 1970

- Flavour changing neutral currents (FCNCs) are highly suppressed.
- Cabibbo angle (θ_c) was introduced for quark mixing for s→u in kaon decays.
- Showed that an up quark couples to a linear combination of strange and down quarks.

$$\begin{pmatrix} u \\ d' \end{pmatrix} = \begin{pmatrix} u \\ d\cos\theta_c + s\sin\theta_c \end{pmatrix}$$

GIM Mechanism - 1970

- The last term suggests that a neutral current can change flavour with $\Delta s=1$.

- With 3 quarks the FCNC could be possible - doesn't make sense.

$$u\bar{u} + \left(d\bar{d}\cos\theta_c{}^2 + s\bar{s}\sin\theta_c{}^2\right) + \left(s\bar{d} + s\bar{d}\right)\sin\theta_c\cos\theta_c$$

GIM Mechanism - 1970

- Glashow, Iliopoulos and Maiani (GIM) suggested the need for a second doublet including the charm quark.

$$\begin{pmatrix} c \\ s' \end{pmatrix} = \begin{pmatrix} c \\ s\cos\theta_c - d\sin\theta_c \end{pmatrix}$$

- This caused a cancellation of second order terms, making FCNC highly suppressed.

$$u\bar{u} + \left(d\bar{d}\cos\theta_c{}^2 + s\bar{s}\sin\theta_c{}^2\right) + \cancel{\left(s\bar{d} + s\bar{d}\right)\sin\theta_c\cos\theta_c} + c\bar{c}$$
$$+ \left(d\bar{d}\sin\theta_c{}^2 + s\bar{s}\cos\theta_c{}^2\right) - \cancel{\left(s\bar{d} + s\bar{d}\right)\sin\theta_c\cos\theta_c}$$

GIM Mechanism - 1970

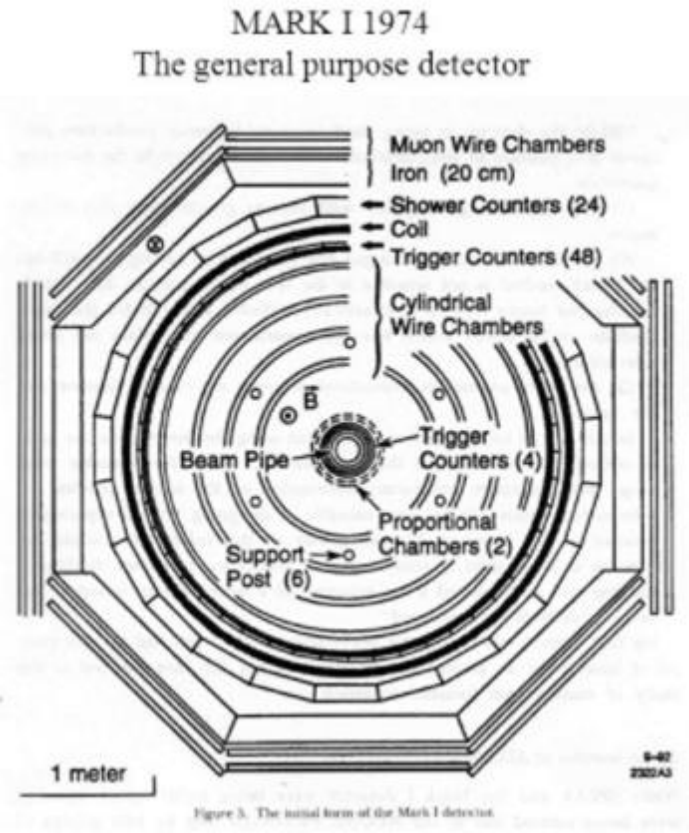
- Decay of neutral kaon was observed to occur at a much slower rate than predicted using the knowledge of 3 quarks.
- By introducing a 4th quark, charm, the two diagrams cancel each other assuming the mass of the charm and up quarks are the same.
- GIM mechanism showed that the charm quark was necessary in the quark model.

Discovery of J/ψ Particle - 1974

- The ψ particle - discovered by Burton Richter et al. at SLAC.
- The J particle - discovered by Samuel Ting et al. at BNL.
- Both credited with the discovery and awards the Nobel Prize in physics in 1976.
- First particle discovered with charm, but charm was hidden.

Mark I – 1973-1977

- Discovered ψ Particle and D-meson.
- Was the first 4π steradian detector. Foundation for all modern detectors.
- There was already some hints of evidence for charm in literature, e.g. cosmic rays
- Could estimate charmed meson mass due to the rise in e^+e^- annihilation cross section.

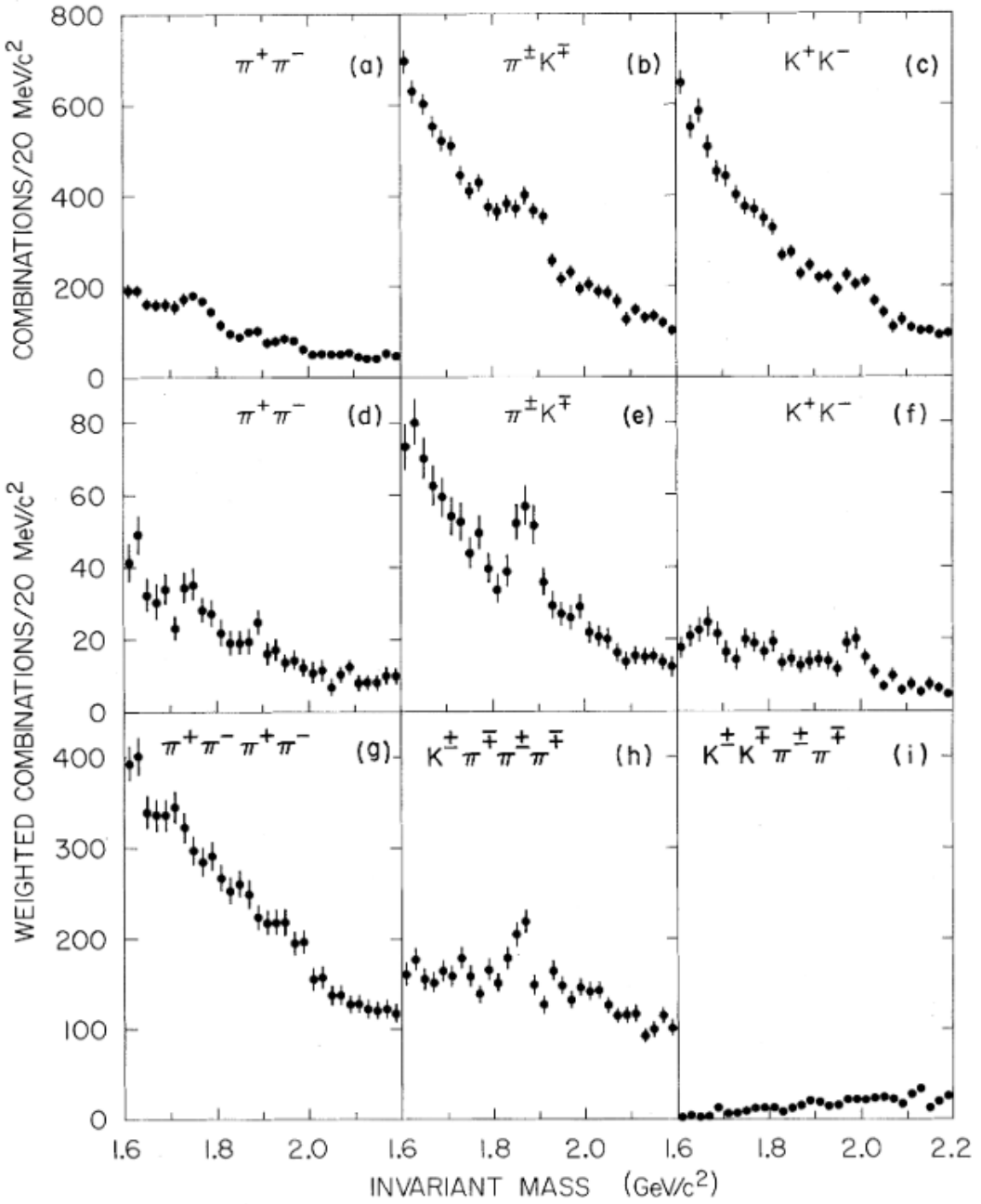


D-Mesons - 1976

- D mesons first particle discovered to carry explicit charm
- As D mesons were pair produced, with a particle of equal or greater mass, this indicated the existence of another quantum number
- Decays via weak interaction, proven by decay width and parity violation

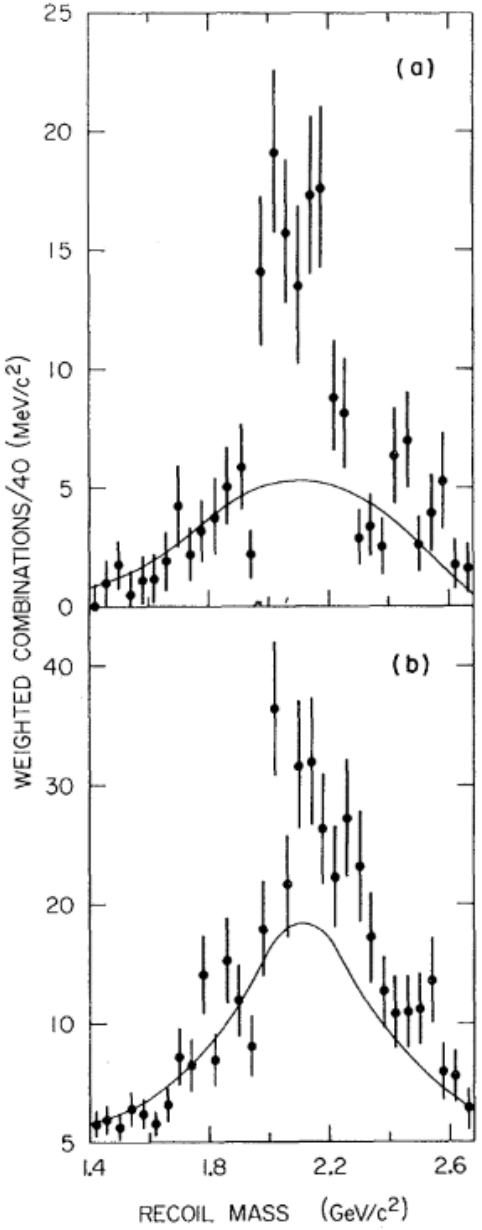
D-Mesons → SLAC

- Mark 1 eventually isolated decays like $D^0 \to K^- \pi^+$ and $D^0 \to K^- \pi^- \pi^+ \pi^+$
- Invariant-mass spectra seen in graphs.
- Weighted results using time of flight data.
- Peaks seen at 1.87GeV/c^2 and 1.86GeV/c^2.

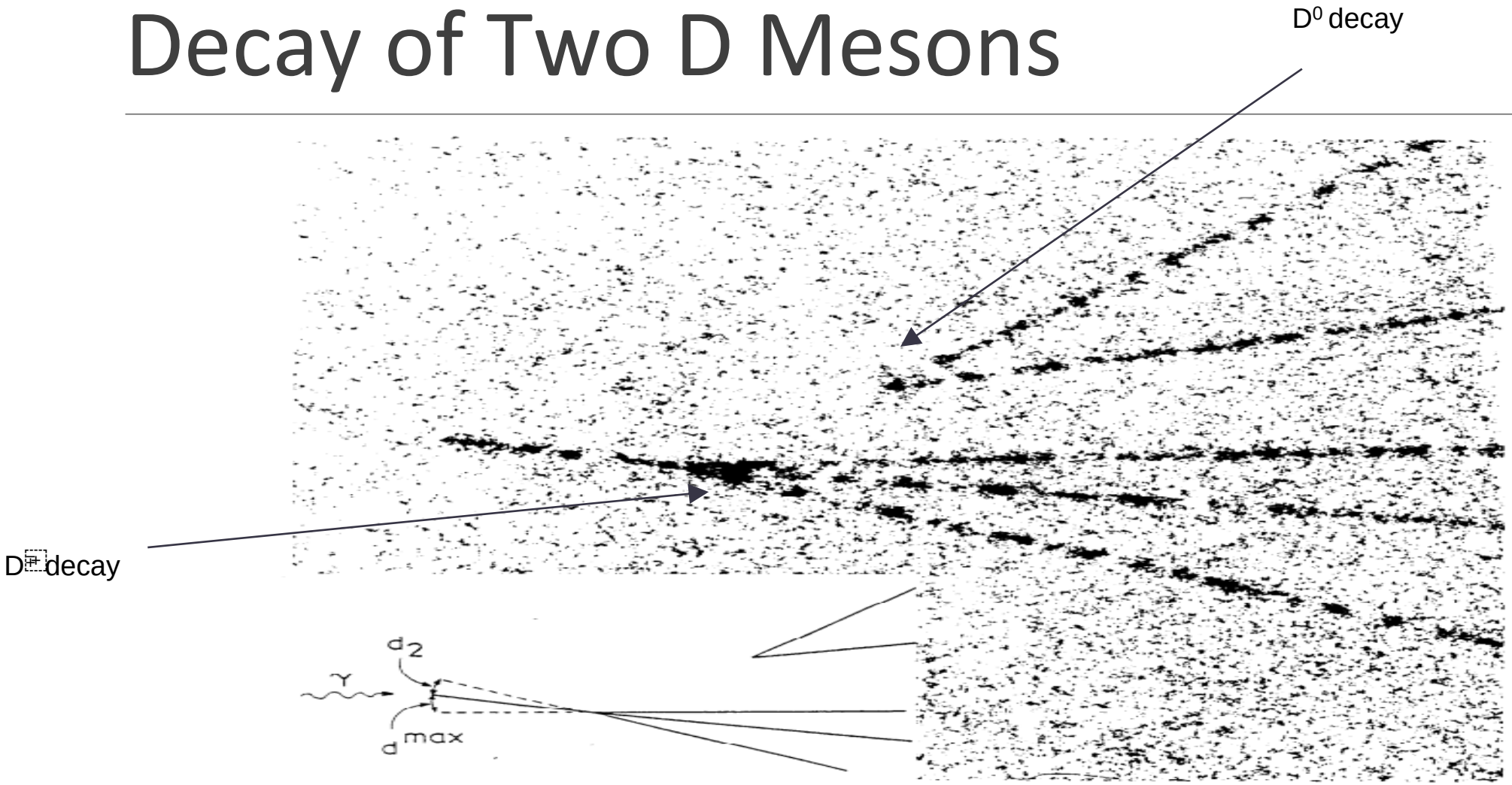


D-mesons - 1976

- The recoil-mass spectrum suggests that the unknown neutral particle is produced in a pair from a threshold energy more than or equal to 3.7GeV.
- The two decay modes are of the same object - the upper graph being $K^- \pi^+$ and the lower being the decay into $K^-\pi^+\pi^+\pi^-$.
- Unknown particle had mass of 1865 ± 15 MeV/c^2 – the mass of the neutral D-meson



Decay of Two D Mesons



D-Mesons - 1976

Particle	Antiparticle	Quark composition	Approximate Mass (MeV/c^2)	Approximate Lifetime (s)
D^+	D^-	$c\bar{d}$	1870	1.0×10^{-12}
D^0	$\overline{D}^0$	$c\bar{u}$	1860	4.0×10^{-13}
D_s^+	D_s^-	$c\bar{s}$	1970	5.0×10^{-13}
D^{*+}	D^{*-}	$c\bar{d}$	2010	6.8×10^{-21}
D^{*0}	$\overline{D}^{*0}$	$c\bar{u}$	2010	$>3.1 \times 10^{-22}$

Timeline

1964 - Bjorken and Glashow predicted the existence of the charm quark.

1970 - GIM mechanism was proposed which relied on the necessity of the charmed quark.

1974 - J/ψ particle discovered by SLAC confirmed the existence of the charmed quark.

1976 - D meson discovery at SLAC. Strange D-meson D_s followed.

Conclusion

- Advanced understanding of strong force by studying spectrum of *cc* mesons.
- Advanced understanding of weak force due to long decay chain of D-meson
- Initiated a race to find as many new particles as possible, thus greatly advancing particle physics as a whole.

References

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