The term "charm" first introduced by

James Bjorken and Shelly Glashow in 1964.

Motivation: The search for models of integrally charged constituents of hadrons.

Reintroduced in 1970 by Glashow, John Iliopoulos and Luciano Maiani

Motivation: Suppression of strangeness changing neutral currents

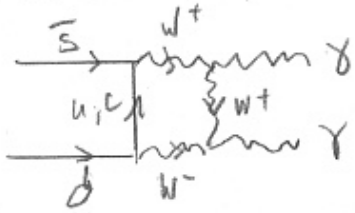
Cabibbo theory: $\mathcal{A}(u \to d + W^+) \propto \cos(\theta_c), \quad \mathcal{A}(u \to s + W^+) \propto \sin(\theta_c)$

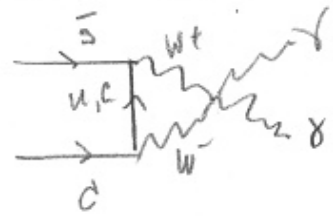
$$\mathcal{A}(K \to \mu^+\mu^-) \sim \int d^4p \frac{1}{(p^2 - m_u^2)(m_W^2 - p^2)^2} \sim \frac{1}{m_W^2}$$

without charm

$\to (m_c^2 - m_u^2)/m_W^4$ with charm

FermiLab 1973-4: MK to Ben Lee: Why $K \to \gamma\gamma$ not suppressed by GIM?

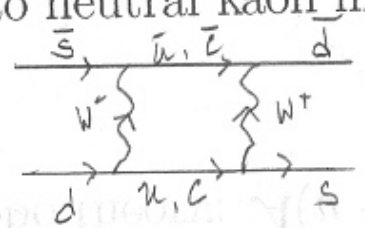


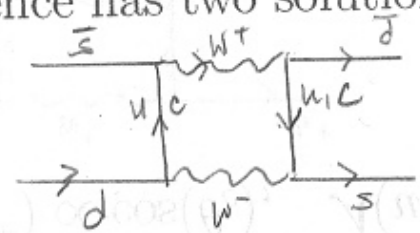


$\sim \ln(m_q^2/m_W^2)$ wthout charm $\to \ln(m_u^2/m_c^2)$ with charm

We undertook systematic study of rare neutral K decays. Found

- $K \to \gamma\gamma$ rate $\Rightarrow m_u \ll m_c$
- $K \to 2\mu$ rate $\Rightarrow m_c - m_u < 9$ GeV
- Fit to neutral kaon mass difference has two solutions:





$m_c \approx m_u \approx 1$ GeV, or $m_u \ll m_c \approx 1.5$ GeV

Total: $m_u \ll m_c \approx 1.5$

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Frightening answer: experimentalists looking for charm in hadron collisions told us nothing there at such low masses.

Abstract of paper $m_c \leq 5$ GeV. Husband "You don't find 5; you find 1.5".

Jon Rosner had been studying strong interactions of charmed particles.

Joined forces $\Rightarrow$ GLR "Search for Charm" QCD in its infancy

Used tools of the time:

- parton model to estimate charm production in ν-nucleon collisions
- apparent violation of empirical selection rules;

e.g. $\Delta S = -\Delta Q$ for hadrons in semi-leptonic strange particle decay

= signature for charm production:

$\nu + d \to \mu^- + c, \quad c \to s + u + \bar{(d)}$

- "Zweig rule": $\Gamma_{\phi_i} \propto M_{\phi_i}^{-1}, \quad \phi =$ spin 1 resonance

to estimate width ≈ 2 MeV of lightest $c\bar{c}$ triplet bound state.

Hints for charm:

- Brookhaven 1970: Lederman group observed a bump near 3.5 GeV in $\mu^+\mu^-$ invariant mass

Abstract: " no resonant structure"

- 1971: emulsion event that could be interpreted $D^+(\bar{d}, c) \to \pi^+\pi^0$

- CERN 1974: Rubbia group 2 "dimuon" events

$\nu + N \to \mu^- + c + X, \quad c \to \mu^+ + s$

- CEA Cambridge 1973 & CERN 1974: unexpected rise in cross section $E_{cm} > 3$ GeV

- Samios group finds bubble chamber event that could be production & decay of charmed baryon

GLR calculated production and decay rates of charmed particles

preprint appeared August 1974

"November revolution"

Brookhaven (Ting) & SLAC (Richter) announce spin-1 resonance

"J,ψ" at ≈ 3 GeV

Lightest $c\bar{c}$ bound state?

Alternative hypotheses

- "naked" color e.g. blue up quark + anti green anti-up quark
- new gauge boson Z'

CERN debate

John Ellis + MKG (charm) vs Paul Matthews (naked color)

vs Alexander Dolgov (Z')

1975: DeRujula, Georgi and Glashow: more precise predictions of charmed baryon masses as quarks in Coulomb-like chromagnetic field

1974: Appelquist & Politzer: More precise prediction (narrower) for triplet width based on "charmonium" analysis.

Charm coupling orthogonal to up coupling in charged currents:

$\mathcal{A}(c \to d + W^+) \propto \sin(\theta_c), \quad \mathcal{A}(d \to s + W^+) \propto \cos(\theta_c)$

Prediction: Lots of K's in final state in $e^+e^- \to$ hadrons

Not seen.

CERN cafeteria: "When are you going to stop believing in charm"

Lederman at IRS srudying $pp \to \bar{m}^+\mu^- + X$:

"We looked just below and just above 3 GeV"

MKG: "Why don't you look at 3 GeV?"

Answer: "Too many events" ???

Comment to Rosner: "The ship is sinking"

June 1976: Call from Ben Lee: "Charm is found"

SLAC: Goldberger et al.

$e^+e^- \to K^\pm + \pi^\mp + \pi^0$