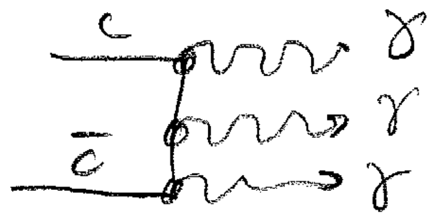
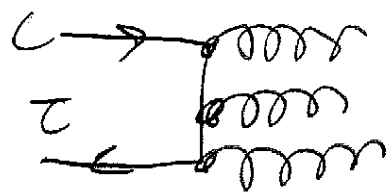
(B) Annihilation :

Produce 1γ, EM DECAY ... <u>3</u> γ



But ... n (<u>gluons</u>) <u>have</u> <u>same</u>
C as n (photons)

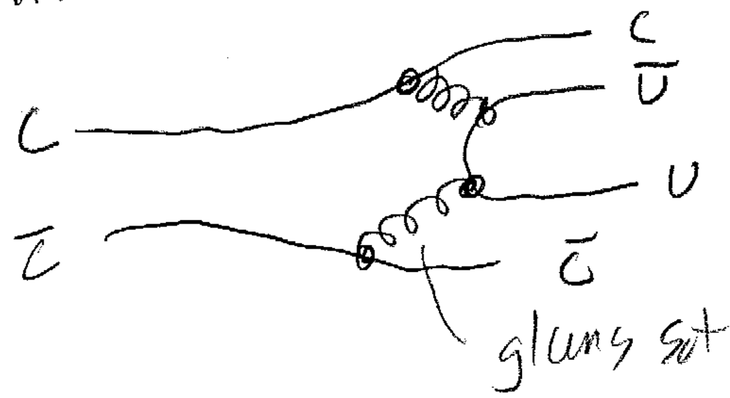


possible, but way slower than naive guessed.

"OZI" suppression

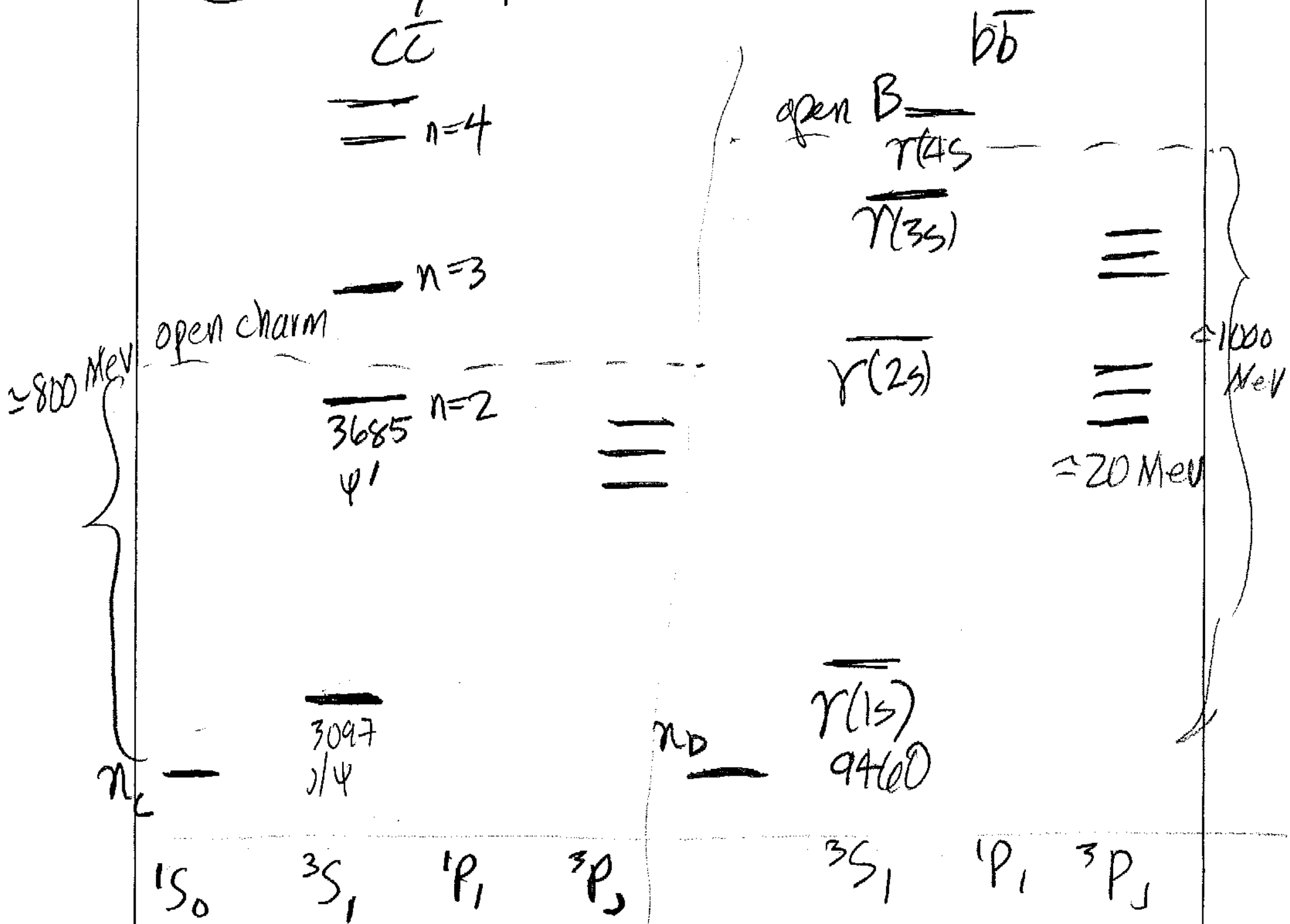
"hard" gluons, energetic.
α_s <u>smaller</u>

WHEN KINEMATICALLY ALLOWED,

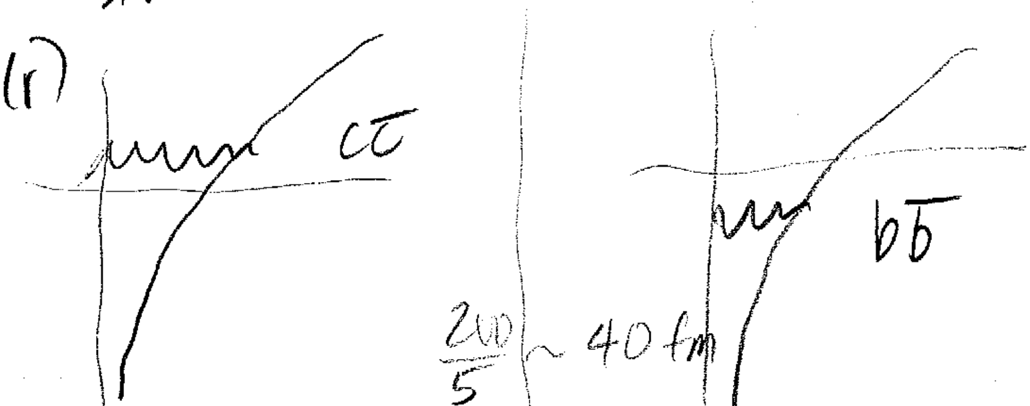


dominates.

(C) Heavy quark neutral mesons



well studied.



$$\frac{200}{5} \sim 40\ \text{fm}$$

$$\frac{\hbar}{mc} \sim \frac{\hbar c}{mc^2} = \frac{200\ \text{MeV}}{1200\ \text{MeV}} \simeq \frac{1}{10}\ \text{fm}$$

$$\frac{200}{4300} \simeq \frac{1}{40}\ \text{fm}$$

Chapter 6 – Feynman Calculus

NR Quantum Mechanics ... mainly "static" or "eigenstate" properties

R QFT: also rates of $\boxed{\text{change}}$

Types of change:

Decay of unstable particles...

E real valued

$$\left\{ \begin{array}{l} i\hbar \frac{\partial \psi_E}{\partial t} = \left(-\hbar^2 \nabla^2 + V(x)\right)\psi_E = \underbrace{E\psi_E}_{\text{eigenstate}} \\ \psi_E(t) = \psi_E(0)\, e^{\frac{E}{i\hbar}t} \end{array} \right.$$

but want $|\psi_E(t)|^2 = |\psi_E(0)|^2 e^{-t/\tau}$

$$\frac{Et}{i\hbar} \to \left(\frac{E}{i\hbar} - \frac{1}{2\tau}\right)t$$

$$\to \frac{1}{i\hbar}\left(E - \frac{i\hbar}{2\tau}\right)t$$

$$= \frac{1}{i\hbar}\left(E - i\frac{\gamma}{2}\right) \qquad \frac{\gamma}{2} = \frac{\hbar}{2\tau}$$

$$\gamma = \hbar/\tau$$

Imaginary value of energy $\leftrightarrow$ Non Hermitian $\leftrightarrow$ Decaying State

Another way:

Lifetime in rest frame of particle

Any one particle will decay at a random time ... but if you start with $N(0)$ $(\gg 1)$ define decay rate Γ $\left(= \frac{\gamma}{\hbar}\right)$ through equation ...

change in N $\rightarrow$ $$dN(t) = -\underbrace{[N(t)\ \underset{\substack{\uparrow \\ \text{dimensionality: 1/time, rate}}}{\Gamma}]}_{\text{no time is special}}\ \underbrace{dt}_{\text{time interval}}$$

$$\frac{dN}{N} = -\Gamma\, dt$$

$$\ln N = -\Gamma t + \text{constant}$$

$$N = e^{\text{constant}}\, e^{-\Gamma t}$$

$$N(0) = e^{\text{constant}} \cdot \underline{1}$$

$$\boxed{N(t) = N(0)\, e^{-\Gamma t}}$$

key point: $N(t)$ is # that survive.

probability of surviving $$P(t) = \frac{N(t)}{N(0)} = e^{-\Gamma t} \propto |\psi(t)|^2$$

One particle has a variety of ways to decay, usually.

	BR
$\pi^+ \to \mu^+ \nu_\mu$	99.9877%
$\mu^+ \nu_\mu \gamma$	$2 \cdot 10^{-4}$
$e^+ \nu_e$	$1.23 \cdot 10^{-4}$
$e^+ \nu_e \gamma$	$1.6 \cdot 10^{-7}$
$e^+ \nu_e \pi^0$	$1.04 \cdot 10^{-8}$
$e^+ \nu_e e^+ e^-$	$3 \cdot 10^{-9}$
$K^+ \to \mu^+ \nu_\mu$	63.5%
$\pi^+ \pi^0$	20.7%
$\pi^+ \pi^- \pi^-$	5.6%
$\pi^+ \pi^0 \pi^0$	1.8%

(lots more)

Partial Rate

$$\text{Particle} \xrightarrow{\Gamma_1} \text{Final State 1}$$

$$\text{Particle} \xrightarrow{\Gamma_2} \text{Final State 2}$$

$$\text{Particle} \xrightarrow{\Gamma_3} \text{Final State 3}$$

$$\Gamma = \Gamma_1 + \Gamma_2 + \ldots = \sum_i \Gamma_i$$

↑

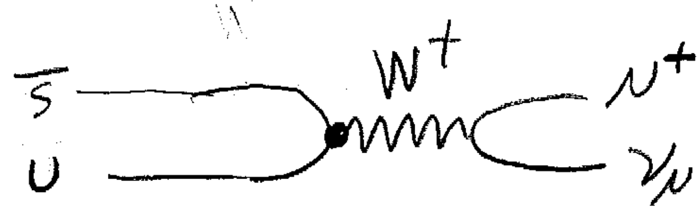
Overall Decay Rate of Particle
"intrinsic property"

branching ratio $B_i = \dfrac{\Gamma_i}{\Gamma}$

<u>Feynman</u>: Focus, in general, on one final state, WHY?

<u>K^+ decay</u>: <u>overall</u> decay amplitude

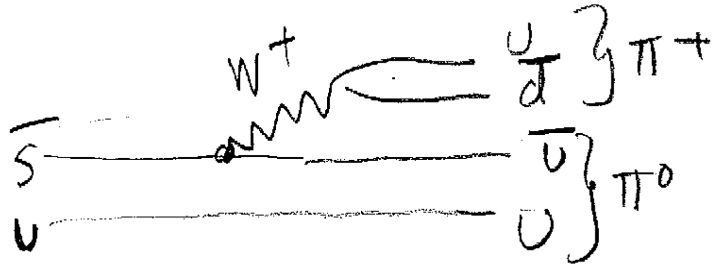
=



(symbol for a transition amplitude)

A_1

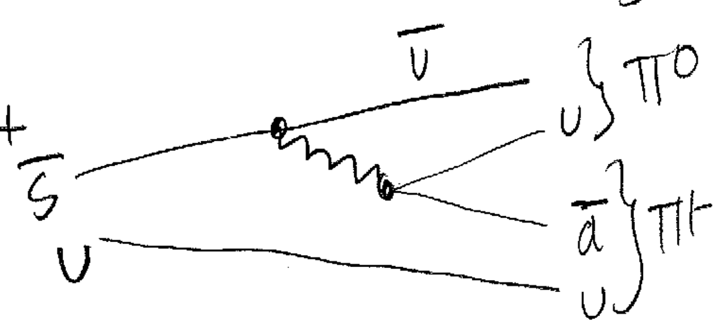
+



A_2

<u>distinguishable!</u>

+



A_2'

indistinguishable from A_2!