(B) **Annihilation**

Produce 1\(\chi\), EM DECAY \(\rightarrow 3\chi\)

\[
\begin{array}{c}
\text{\(c\)} \\
\text{\(\gamma\)} \\
\text{\(c\)}
\end{array}
\]

But \(n\) (gluons) have same \(c\) as \(n\) (photons)

\[
\begin{array}{c}
\text{\(c\)} \\
\text{\(\gamma\)} \\
\text{\(c\)}
\end{array}
\]

Possible, but way lower than naive guess. "OZI" suppression "hard" gluons, energetic as smaller

When kinematically allowed, 

\[
\begin{array}{c}
\text{\(c\)} \\
\text{\(\gamma\)} \\
\text{\(c\)}
\end{array}
\]

gluons set dominates.
Chapter 6 - Feynman Calculus

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

R QFT: also rates of change

Types of change:

Decay of unstable particles...

\[ i\hbar \frac{\partial \Psi_E}{\partial t} = \left( -\hbar^2 \frac{\partial^2}{\partial x^2} + V(x) \right) \Psi_E = E \Psi_E \]

\[ \Psi_E(t) = \Psi_E(0) e^{\frac{E}{i\hbar} t} \]

but want \[ |\Psi_E(t)|^2 = |\Psi_E(0)|^2 e^{\frac{-1}{2}\hbar \gamma t} \]

\[ \frac{E}{i\hbar} \to \left( \frac{E}{i\hbar} - \frac{1}{2\hbar} \right) + \]

\[ \to \frac{1}{i\hbar} \left( E - \frac{i\hbar}{2\hbar} \right) + \]

\[ = \frac{1}{i\hbar} \left( E - \frac{\hbar}{2\hbar} \right) \]

Imaginary value of energy

\[ \Rightarrow \text{Non Hermitian Decaying State} \]
Another way:

Lifetime in rest frame of particle

Any one particle will decay at a random time... but if you start with \( N(0) \rightarrow 1 \) define decay rate \( \Gamma = \frac{\sigma}{\hbar} \) through equation...

\[
\frac{dN}{N} = -\Gamma dt
\]

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

\[
N = e^{\text{constant} - \Gamma t}
\]

\[
N(0) = e^{\text{constant}} \cdot 1
\]

\[
N(t) = N(0) e^{-\Gamma t}
\]

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

probability of surviving \( P(t) = \frac{N(t)}{N(0)} = e^{-\Gamma t} \cdot A \left| \Psi(t) \right|^2 \)
One particle has a variety of ways to decay, usually:

\[ \pi^+ \rightarrow \mu^+ \nu_\mu \]
\[ \mu^+ \nu_\mu \gamma \]
\[ e^+ \nu_e \gamma \]
\[ e^+ \nu_e \pi^0 \]
\[ e^+ \nu_e e^+ e^- \]

\[ \frac{\text{BR}}{99.9877\%} \]
\[ 2 \cdot 10^{-4} \]
\[ 1.23 \cdot 10^{-4} \]
\[ 1.6 \cdot 10^{-7} \]
\[ 1.04 \cdot 10^{-8} \]
\[ 3 \cdot 10^{-9} \]

\[ K^+ \rightarrow \mu^+ \nu_\mu \]
\[ \pi^+ \pi^0 \]
\[ \pi^+ \pi^- \pi^- \]
\[ \pi^+ \pi^0 \pi^0 \]

\[ (\text{lots more}) \]

Partial Rate

\[ \pi^+ \rightarrow \text{Final State 1} \]
\[ \pi^- \rightarrow \text{Final State 2} \]
\[ \pi^0 \rightarrow \text{Final State 3} \]
\[ \Pi = \Pi_1 + \Pi_2 + \ldots = \sum \Pi_i \]

**Overall branching ratio**

\[ B_i = \frac{\Pi_i}{\Pi} \]

*Particle intrinsic property*

**Feynman:** Focus, in general, on one final state. Why?

**K^+ decay:** overall decay amplitude

\[ \begin{array}{c}
\text{symbol for a transition amplitude} \\
A_1 \\
\end{array} \]

\[ \frac{s}{u} \]

\[ W^+ \]

\[ \begin{array}{c}
\text{distinguishable} \\
A_2 \\
\end{array} \]

\[ \frac{s}{u} \]

\[ \frac{u}{d} \]

\[ \frac{u}{d} \]

\[ \frac{u}{d} \]

\[ \frac{u}{d} \]

\[ \frac{u}{d} \]

\[ \frac{u}{d} \]

\[ \frac{u}{d} \]