Pauli blocking and SU(3) Breaking solve $K\pi$ puzzle

CP violation in $B^o \rightarrow K\pi$; not in $B^\pm \rightarrow K\pi$ decays

Direct CP violation observed in $B_d \rightarrow K^+\pi^-$ decays

$$A_{CP}(B_d \rightarrow K^+\pi^-) = -0.098 \pm 0.013$$

That CP violation is not seen in $B^\pm \rightarrow K\pi$ decays is a puzzle

$$A_{CP}(B^+ \rightarrow K^o_S\pi^+) = 0.009 \pm 0.029; \quad A_{CP}(B^+ \rightarrow K^+\pi^o) = 0.051 \pm 0.025$$

Spectator quark does not participate weak decay vertex

Changing spectator flavor should not make a difference

SU(3) breaking destroys relation between $B^\pm \rightarrow K\pi$ and $B^\pm \rightarrow \pi\pi$ decays

π^+, π^-, π^o degenerate members of isospin triplet with $I = 1; I_z = (1, 0, -1)$

K^+, K^- in V-spin triplet with $V = 1, V_z = \pm 1$ have no partner with $V = 1, V_z = 0$

The π^+ π^o state in a relative s-wave is a pure isospin eigenstate with $(I = 2, I_z = 1)$

No analogous strange two-particle state with $(V = 2, V_z = 1)$

Pauli blocking overlooked. B^+ tree diagram has two identical u quarks

Flavor symmetric $I = 1$ in relative s-wave must be color-spin antisymmetric

To combine with the uu pair to make the spin-zero color singlet final state.

Both uu diquark and $\bar{u}\bar{q}$ antidiquark antisymmetric in color-spin

Must be symmetric in flavor SU(3) and SU(2) subgroups V-spin or I-spin.

Each therefore symmetric V-spin or I-spin state with $V = 1$ or $I = 1$.

To decay into two pseudoscalar mesons in S wave

Final state must be even under general charge conjugation

$(V = 1, V_z = +1)$ diquark and $(V = 1, V_z = 0)$ antidiquark

Must be coupled symmetrically to $(V = 2, V_z = +1)$.

$(I = 1, I_z = +1)$ diquark and $(I = 1, I_z = 0)$ antidiquark

Must be coupled symmetrically to $(I = 2, I_z = +1)$.

This state is in the 27-dimensional representation of flavor SU(3).

Final $K^o\pi^+$ state has no $V = 2$ component; both K^o and π^+ have V=1/2.

Tree diagram for $K^o\pi^+$ decay must vanish and decay is pure penguin.

Final $K^+\pi^o$ state contains π^o; linear combination of $V = 0$ and $V = 1$ states with probability of $1/4$ for $V = 1$.

The component with $V = 0$ cannot combine with a $V = 1$ K^+ to make $V = 2$.

Only the $V = 1$ component can combine with a $V = 1$ to make $V = 2$.

$|\langle K^+\pi^o|V = 2; V_z = 1\rangle|^2 = \frac{1}{4}$

$|\langle K^+\pi^o|i; uu\bar{d}\bar{s}\rangle|^2 = \frac{1}{8}$

Serious Pauli blocking in $B^o \to K\pi$ decays,

A final $\pi^o\pi^+$ state $|f; \pi^o\pi^+\rangle$ is a pure $V = 2$ state

$\langle\pi^+\pi^o|i; uu\bar{d}\bar{u}\rangle = 1$

No Pauli blocking in $B^o \to \pi\pi$ decays,

Dependence on spectator flavor arises from

Pauli blocking by spectator quark of quark of same flavor emitted in weak vertex.

Pauli blocking explains

1. Observation of CP violation in $B^o \longrightarrow K\pi$ decays,

2. Absence of CP violation in $B^{\pm} \longrightarrow K\pi$ decays

3. New predictions agreeing with experiment.

Experimental observation and knowledge of penguin dominance for the decay imply

Must be interference between dominant penguin and smaller tree diagrams.

Tree diagrams must have both weak and strong phases different from those of penguin.

$K\pi$ final states contain:

A strange antiquark, a nonstrange antiquark and two nonstrange quarks.

Amplitudes where two nonstrange quarks have same flavor are Pauli suppressed.

The tree diagram $\bar{b} \rightarrow \bar{s}u\bar{u}$ for $\bar{b}$ decay is

1. Pauli suppressed for B^+ decays with a spectator u quark
2. Not suppressed for B^o decays with a spectator d quark.

The presence of tree-penguin interference is indicated by

Finite value of an expression predicted to vanish in a pure penguin transition.

$\frac{\tau^o}{\tau^+} \cdot 2B(B^+ \rightarrow K^+\pi^o) - B(B^o \rightarrow K^+\pi^-) = (4.7 \pm 0.82) \cdot 10^-6$

This tree-penguin interference can produce CP violation in neutral B decays

Tree-penguin interference Pauli suppressed in charged decays.

Pauli-favored amplitudes $B_u \rightarrow \bar{s}du\bar{d}$ and $B_d \rightarrow \bar{s}du\bar{u}$ give new predictions. In units of 10^{-6},

$$B(B^o \rightarrow K^+\pi^-) - 2B(B^o \rightarrow K^o\pi^o) = (19.4 \pm 0.6) - 2 \cdot (9.4 \pm 0.6) = 0.6 \pm 1.3 \approx 0$$

$$2B(B^+ \rightarrow K^+\pi^o) - B(B^+ \rightarrow K^o\pi^+) = (25.8 \pm 1.2) - (23.1 \pm 1.0) = 2.7 \pm 1.6 \approx 0$$

Not predicted to vanish in treatments using color-favored and suppressed transitions.

Pauli-favored and suppressed classification depends only on the final state

Includes all final state interactions and all production diagrams.

Spectator quark does not participate in the weak interaction.

Pauli-favored transitions explain the dependence on spectator quark flavor

Color favored and suppressed tree diagrams ignore Pauli suppression

Differ in $B^\pm \rightarrow K\pi$ diagrams by interchange of two identical u quarks.

$B^o \rightarrow K^\pm\pi^\mp$ diagrams have no identical quark pairs.

Pauli blocking solves $K\pi$ puzzle

CP violation in $B^o \rightarrow K\pi$; not in $B^\pm \rightarrow K\pi$ decays

The $K-\pi$ Puzzle

A general theorem from CPT invariance shows that direct CP violation can occur only

Via interference between two amplitudes with different weak and different strong phases.

Holds for all contributions from new physics beyond standard model conserving CPT.

u-quark produced by tree diagram Pauli blocked by spectator u quark in B^+ decay

Tree diagram not affected by spectator d quark in neutral decays.

Difference in Pauli blocking suppresses tree contribution and CP violation in $B^\pm$ decays

In B^o decays tree-penguin interference allowed; Enables observation of CP violation

Puzzle resolved by calculation including Pauli principle

An approximate treatment of Pauli effects

Instead of standard treatment begin with Pauli constraints

Decay of $\bar{b}$ antiquark to a strange charmless final state

Described by vertex $\bar{b} \rightarrow \bar{s}n\bar{n}$ where $n\bar{n}$ denotes a nonstrange $u\bar{u}$ or $d\bar{d}$.

Transition from initial $\bar{b}$ antiquark and nonstrange spectator quark B meson state

To a strange charmless two-meson final state is written

$$|B_u\rangle = \bar{b}u \rightarrow \bar{s} \cdot \left[d\bar{d} + u\bar{u} + \xi \cdot u\bar{u}\right] u = \bar{s} \cdot \left[d\bar{d} + \kappa \cdot (1+\xi) u\bar{u}\right] u \approx \bar{s} \cdot du\bar{d}$$

$$|B_d\rangle = \bar{b}d \rightarrow \bar{s} \cdot \left[d\bar{d} + u\bar{u} + \xi \cdot u\bar{u}\right] d = \bar{s} \cdot \left[\kappa d\bar{d} + (1+\xi) \cdot ud\bar{u}\right] d \approx \bar{s} \cdot (1+\xi) \cdot ud\bar{u}$$

Final state first written as sum of isoscalar $q\bar{q}$ pair and $u\bar{u}$ pair

Together with strange antiquark and aspectator quark.

Analogous to conventional description as sum of penguin and tree contributions.

Parameter ξ generally considered small expresses ratio of tree to penguin contributions.

Parameter κ is Pauli factor expressing probability that two nonstrange quarks not in same color-spin state.

Pauli-favored states have $\kappa = 0$ and no quark pairs of the same flavor.

We approximate Pauli blocking by setting $\kappa = 0$

In this approximation u quark emitted in weak interaction cannot enter same state as u spectator quark.

The CP violation is proportional to ξ. In some approximation we can write

$$\xi \approx V_{bu} V_{bc}$$

When $\kappa = 0$ the final state in neutral decays depends upon ξ while final state in charged decays is independent of ξ. This solves one puzzle by suppressing the tree contribution and CP violation in charged B decay while allowing it in neutral decays.

This suppression is lost in conventional treatments which consider color-favored and color-suppressed tree amplitudes as independent without considering Pauli suppression.

The ud pair in the final states must be isoscalar by the generalized Pauli principle.

The final states must then be pure isospin eigenstates with $I = 1/2$.

In the standard treatments the $I = 3/2$ component is not suppressed, except in pure penguin transitions

Experiment confirms treatment of Pauli effects

New experimental data confirm this $I = 3/2$ suppression

Also provide evidence against a pure penguin transition.

We combine our Pauli analysis with the color favored and suppressed analysis

Conventional analysis expresses four $B \to K\pi$ amplitudes in terms of three.

P, T and S denote penguin and color favored and color suppressed tree amplitudes

$$A[K^o\pi^+] = P; \quad A[K^+\pi^-] = T + P$$

$$A[K^o\pi^o] = \frac{1}{\sqrt{2}}[S - P]; \quad A[K^+\pi^o] = \frac{1}{\sqrt{2}}[T + S + P]$$

When the interference terms are taken only to first order,

$$|A[K^o\pi^+]|^2 = |\vec{P}|^2; \quad |A[K^+\pi^-]|^2 = |\vec{P}|^2 + 2\vec{P}\cdot\vec{T}$$

$$2\cdot|A[K^o\pi^o]|^2 = |\vec{P}|^2 - \vec{P}\cdot\vec{S}; \quad 2\cdot|A[K^+\pi^o]|^2 = |\vec{P}|^2 + 2\vec{P}\cdot(\vec{T} + \vec{S})$$

Four experimental branching ratios overdetermine P, T and S

Three different independent differences between these branching ratios eliminate P

$$\Delta(K^o\pi^+) \equiv |A[K^o\pi^+]|^2 - |A[K^+\pi^-]|^2 \approx -2\vec{P}\cdot\vec{T}$$

$$\Delta(K^+\pi^o) \equiv 2|A[K^+\pi^o]|^2 - |A[K^+\pi^-]|^2 \approx 2\vec{P}\cdot\vec{S}$$

$$\Delta(K^o\pi^o) \equiv 2|A[K^o\pi^o]|^2 - |A[K^+\pi^-]|^2 \approx -2\vec{P}\cdot(\vec{T}+\vec{S})$$

where the appoximate equalities hold to first order in the T and S amplitudes.

With available experimental branching ratio data corrected for the lifetime ratio Isospins of individual branching ratios for B^o and B^+ decays agree with pure I=1/2 amplitude predicted by a penguin diagram.

$$\frac{\tau^o}{\tau^+}\cdot B(B^+ \to K^o\pi^+) - B(B^o \to K^+\pi^-) = 2.2 \pm 1.1 \propto -\vec{P}\cdot\vec{T} \approx 0$$

$$2B(B^o \to K^o\pi^o) - B(B^o \to K^+\pi^-) = -0.6 \pm 1.3 \propto -\vec{P}\cdot(\vec{T}+\vec{S}) \approx 0$$

Pure penguin relation between B^+ and B^o decays disagrees with experiment.

$$\frac{\tau^o}{\tau^+}\cdot 2B(B^+ \to K^+\pi^o) - B(B^o \to K^+\pi^-) = 4.7 \pm 0.82 \propto \vec{P}\cdot\vec{S}$$

Significant difference between experimental values of these expressions is not expected in the conventional analyzes.

All vanish in the case of a pure penguin transition.

That two still vanish while the other is finite seems to indicate a surprising cancelation and motivates a search for a theoretical explanation.

They confirm the $I = 3/2$ suppression in neutral decays suggested by the Pauli-blocking approximation..

The LHS is just the $I = 3/2$ contribution to neutral decays.

In this approximation the $I = 3/2$ contribution to neutral decays vanishes.

The relation shows that the $B \to K\pi$ transition is not a pure penguin. It gives a finite experimental value for an expression which vanishes in a pure penguin transition.