DIRECT CP VIOLATION IN D DECAYS

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based on J. Brod, A. Kagan, JZ,1111.5000
see also A. Kagan, talk at FPCP11, May 2011

“Moriond 2012 EW session”, La Thuile, Italy Mar 6 2012
OUTLINE

• the topic of the talk
  \[ \Delta A_{CP} = A_{CP}(D \rightarrow K^+K^-) - A_{CP}(D \rightarrow \pi^+\pi^-) \]

• experiment (WA): \( \Delta A_{CP} = (-0.67 \pm 0.16)\% \)

• could it be New Physics?

• could it be Standard Model?

• could we have anticipated such a large value?

• how large is the SU(3) breaking in charm?
PRELIMINARIES
**SETTING UP THE STAGE**

- three classes of $D$ decays
  - Cabibbo allowed
    - example: $D^0 \rightarrow K^- \pi^+$
      \[
      A_T \sim V_{cs} V_{ud} \sim 1
      \]
  - singly Cabibbo suppressed (SCS)
    - example: $D^0 \rightarrow K^- K^+, D^0 \rightarrow \pi^- \pi^+$
      \[
      A_T \sim V_{cd} V_{ud}, V_{cs} V_{us} \sim \lambda
      \]
  - doubly Cabibbo suppressed
    - example: $D^0 \rightarrow \pi^- K^+$
      \[
      A_T \sim V_{cd} V_{us} \sim \lambda^2
      \]
DIRECT CPV

• focus on SCS $D$ decays in the SM

$$A_f(D \to f) = A_f^T [1 + r_f e^{i(\delta_f - \gamma)}],$$
$$\bar{A}_f(\bar{D} \to \bar{f}) = A_f^T [1 + r_f e^{i(\delta_f + \gamma)}],$$

• $A_f^T$ - tree ampl., $r_f$ - relative "penguin" contrib., $\delta_f$ - strong phase

• direct CP asymmetry

$$A_f^{\text{dir}} \equiv \frac{|A_f|^2 - |\bar{A}_f|^2}{|A_f|^2 + |\bar{A}_f|^2} = 2r_f \sin \gamma \sin \delta_f$$

• $\sin \gamma \sim 0.9$, so for $\delta_f \sim O(1)$

$$A_f^{\text{dir}} \sim 2r_f$$
CP VIOLATION IN CHARM

• in charm physics the first 2 gen. dominate
  • \( \Rightarrow \) CP conserving to a good approximation in the SM

• CPV is parametrically suppressed
  • in mixing it enters as \( \mathcal{O}(V_{cb}V_{ub}/V_{cs}V_{us}) \sim 10^{-3} \)
  • direct CPV in SCS as \( \mathcal{O}([V_{cb}V_{ub}/V_{cs}V_{us}]\alpha_s/\pi) \sim 10^{-4} \)

• is it possible that it is significantly larger?
Size of P/T needed

- expect. that $A_{KK}$ and $A_{\pi\pi}$ add up in $\Delta A_{CP}$
  - global exp. avers.
    - $A_{K^+K^-} = (-0.23 \pm 0.17)\%$
    - $A_{\pi^+\pi^-} = (0.20 \pm 0.22)\%$
  - for $O(1)$ strong phases then
    - $\Delta A_{CP} \sim 4r_f$
  - from experiment thus required
    - $r_f \sim 0.15\%$
  - naive estimate
    - $r_f \sim \mathcal{O}([V_{cb}V_{ub}/V_{cs}V_{us}]\alpha_s/\pi) \sim 0.01\%$
  - an order of magnitude enhancement over naive estimate required
COULD IT BE NEW PHYSICS?
NEW PHYSICS?

• could it be NP?
• “reasonable” models of NP can do it
  • model independent NP ops. analysis
  • supersymmetric examples
  • tree level exchanges

Giudice, Isidori, Paradisi, 1201.6204
Hochberg, Nir, 1112.5268
Altmannshofer, Primulando, Yu, Yu, 1202.2866
• SUSY contribs. to QCD penguin particularly interesting

• LR mixing in squark matrices

\[ Q_8 = \frac{m_c}{4\pi^2} \bar{u}_L \sigma_{\mu\nu} T^a g_s G_\alpha^{\mu\nu} c_R \]

\[ Q_8 = \frac{1}{4\pi^2} (\bar{Q}_L H) \sigma_{\mu\nu} T^a g_s G_\alpha^{\mu\nu} c_R \]

• for \( v \sim m_{susy} \) the op. \( Q_8 \) is secretly dim=5

• \( D-Dbar \) mixing operators are dim=6

\[ Q_{2u}^{cu} = \bar{u}_R^\alpha c_L^\alpha \bar{u}_R^\beta c_L^\beta \]

• SUSY contributions are parametrically smaller


\( Q_8 = \frac{m_c}{m_W^2} \rightarrow \frac{v}{\tilde{m}^2} \)
• for $\nu \sim m_{\text{susy}}$ the op. $Q_8$ is secretly dim=5

• $D$-$D\bar{b}$ mixing operators are dim=6

\[
Q^{cu}_2 = \bar{u}_R^\alpha c_\alpha \bar{u}_R^\beta \bar{c}_L^\beta
\]

• SUSY contributions are parametrically smaller

NEW PHYSICS UPSHOT

• it can be new physics
• but does it have to be?
COULD IT BE STANDARD MODEL?
A REMINDER

• for $O(1)$ strong phases
  \[ \Delta A_{CP} \sim 4r_f \]

• size of P/T needed
  \[ r_f \sim 0.15\% \]

• naive estimate
  \[ r_f \sim \mathcal{O}(\frac{V_{cb}V_{ub}}{V_{cs}V_{us}}\alpha_s/\pi) \sim 0.01\% \]

• an order of magnitude enhancement over naive estimate required
THE STRATEGY

- is enhancement of $r_f$ in the SM possible?
- the strategy:
  - tree amplitudes from data
  - relate penguin amplitudes to tree amplitudes
  - try to estimate the ambiguity in doing this
QCD PENGUINS AT LEADING POWER

- as a start evaluate **leading power** penguin ampls. in QCD fact.
  - naive fact. + $O(\alpha_s)$ corrections
  - only a **rough** estimate of true value
- penguin to tree ratio
  \[ r_{LP} \equiv \left| \frac{A_P (\text{leading power})}{A_T (\text{exp})} \right| \]
  \[ r_{LP}^{K^+K^-} \approx (0.01 - 0.02)\%, \quad r_{\pi^+\pi^-}^{LP} \approx (0.015 - 0.03)\% \]
- assume O(1) phases, then \[ \Delta A_{CP} \sim 4r_f \]
- \[ \Delta A_{CP} (\text{leading power}) = O(0.05\% - 0.1\%) \]
- order of magnitude below the measurement
**POWER CORRECTIONS**

- from SU(3)$_F$ fits to branching ratios we learn:
  - $T_f = A_f[(1/m_c)^0] \sim E_f = A_f[(1/m_c)^1]$

- $1/m_c$ expansion broken
- will still use $N_c$ counting
- look at two particular $1/m_c$ contribs.

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Cheng, Chiang, 1001.0987, 1201.0785
Bhattacharya, Gronau, Rosner, 1201.2351
Pirtskhalava, Uttayarat, 1112.5451

Brod, Kagan, JZ, 1111.5000
PENGUIN CONTRACTIONS

- penguin contractions of tree op. $Q_1$
- in partonic picture: $P_{f,1}$ ($P_{f,2}$) $\leftrightarrow$ single gluon exchange between $d,s$ loop and spectator ($q\bar{q}$ pair)
- any number of gluons between external legs
- use one gluon exchange as rough estimate of hadronic effects, FSI, etc...
- the related $E_f$ hadronic matrix element from tree level $1/m_c$ amplitude (from data on $Br$)
- always make a choice that enhances the CP asymmetry

Brod, Kagan, JZ, 1111.5000
SUMMARY OF SM CONTRIBS.

- individual power corrections could be enhanced by a factor of a few compared to leading power
- using $\Delta A_{CP} \sim 4r_f$ we obtain

$$\Delta A_{CP} \sim 0.3\% (P_{f,1}), \quad \Delta A_{CP} \sim 0.2\% (P_{f,2})$$

- the results are subject to large uncertainties
  - extraction of tree amplitude $E_f$ from data
  - use of $N_c$ counting
  - the modeling of $Q_1$ penguin contraction matrix elements.
- a cumulative uncertainty of a factor of a few is reasonable
- a SM origin for the LHCb measurement is possible
FURTHER INDICATION IN FAVOR OF SM

• long standing puzzle
  • $Br(D \to K^+K^-)=2.8 \ Br(D \to \pi^+\pi^-)$
  • should be the same in flavor SU(3) limit
• with large SM penguin a consistent picture
  • $Br$’s changed by $P_{break}=\varepsilon_{SU(3)}P\sim T$
• the fit to four $Br$ confirms $P_{break}\sim T$
• using $P\sim P_{break}/\varepsilon$ one predicts (for $\varepsilon=0.3$)
  
  $$r_f = \frac{|V_{cb}V_{ub}|}{|V_{cs}V_{us}|} \frac{P}{T} \sim \frac{|V_{cb}V_{ub}|}{|V_{cs}V_{us}|} \frac{1}{\epsilon} \sim 0.2\%$$

• exactly the required size for $\Delta A_{CP}$
**FURTHER INDICATION IN FAVOR OF SM**

\[
H_{\text{eff}}^{\Delta C=1} = \frac{G_F}{\sqrt{2}} \left( V_{cs}^* V_{us} \sum_{i=1,2} C_i (Q^s_i - Q^d_i) - V_{cb}^* V_{ub} \left[ \sum_{i=1,2} C_i (Q^d_i - Q^s_i) / 2 \right] + \sum_{i=1,2} C_i (Q^s_i + Q^d_i) / 2 + \sum_{i=3} C_i Q_i + C_{8g} Q_{8g} \right) + \text{h.c.,}
\]

- with large SM penguin and
- \( Br' \)'s changed by \( P_{\text{break}} = \frac{\left| V_{cb} V_{ub} \right|}{\left| V_{cs} V_{us} \right|} \cdot \frac{P}{T} \sim \frac{\left| V_{cb} V_{ub} \right|}{\left| V_{cs} V_{us} \right|} \cdot \frac{1}{\epsilon} \sim 0.2\% \)

- exactly the required size for \( \Delta A_{CP} \)
FURTHER INDICATION IN FAVOR OF SM

- long standing puzzle
  - $Br(D \to K^+K^-)=2.8 \ Br(D \to \pi^+\pi^-)$
  - should be the same in flavor SU(3) limit
- with large SM penguin a consistent picture
  - $Br$'s changed by $P_{\text{break}} = \varepsilon_{SU(3)} P \sim T$
  - the fit to four $Br$ confirms $P_{\text{break}}\sim T$
- using $P \sim P_{\text{break}}/\varepsilon$ one predicts (for $\varepsilon=0.3$)

$$rf = \frac{|V_{cb}V_{ub}|}{|V_{cs}V_{us}|} \frac{P}{T} \sim \frac{|V_{cb}V_{ub}|}{|V_{cs}V_{us}|} \frac{1}{\varepsilon} \sim 0.2\%$$

- exactly the required size for $\Delta A_{CP}$
long standing puzzle

\[ \text{Br}(D^{+} \rightarrow K^{+}K^{-}) = 2.8 \text{ Br}(D^{+} \rightarrow \pi^{+}\pi^{-}) \]

should be the same in flavor SU(3) limit

with large SM penguin a consistent picture

- Br’s changed by \( P_{\text{break}} = \varepsilon_{SU(3)} P \sim T \)
- the fit to four Br confirms \( P_{\text{break}} \sim T \)
- using \( P \sim P_{\text{break}}/\varepsilon \) one predicts (for \( \varepsilon = 0.3 \))

\[
rf = \frac{|V_{cb}V_{ub}|}{|V_{cs}V_{us}|} \frac{P}{T} \sim \frac{|V_{cb}V_{ub}|}{|V_{cs}V_{us}|} \frac{1}{\varepsilon} \sim 0.2\%
\]
- exactly the required size for \( \Delta A_{CP} \)
• long standing puzzle

\[ \text{Br}(D \to K^+K^-) = 2.8 \text{ Br}(D \to \pi^+\pi^-) \]

• should be the same in flavor SU(3) limit

\[ \text{Br}'s \text{ changed by } P_{\text{break}} = \varepsilon_{SU(3)} P \sim T \]

• the fit to four Br confirms \( P_{\text{break}} \sim T \)

• using \( P \sim P_{\text{break}}/\varepsilon \) one predicts (for \( \varepsilon = 0.3 \))

\[ r_f = \left| \frac{V_{cb}V_{ub}}{V_{cs}V_{us}} \right| \frac{P}{T} \sim \left| \frac{V_{cb}V_{ub}}{V_{cs}V_{us}} \right| \frac{1}{\varepsilon} \sim 0.2\% \]

• exactly the required size for \( \Delta A_{CP} \)
• **Br**’s changed by $P_{\text{break}}=\varepsilon_{SU(3)}P \sim T$

• the fit to four $Br$ confirms $P_{\text{break}} \sim T$

• using $P \sim P_{\text{break}}/\varepsilon$ one predicts (for $\varepsilon=0.3$)

$$r_f = \frac{|V_{cb}V_{ub}|}{|V_{cs}V_{us}|} \frac{P}{T} \sim \frac{|V_{cb}V_{ub}|}{|V_{cs}V_{us}|} \frac{1}{\varepsilon} \sim 0.2\%$$

• exactly the required size for $\Delta A_{CP}$
NP or SM?
NP or SM?

- it could be NP or SM
- how to distinguish between the two?
- by building NP models
  - search for other signatures (collider or otherwise)
- also using just charm data
  - possible to write isospin sum rules that would be violated if NP
NP AND ISOSPIN

• the isospin of SM contributions
  • tree \((\bar{d}c)(\bar{u}d)\), so both \(\Delta I=3/2\) and \(\Delta I=1/2\) components
  • penguins \((\bar{u}c)(\bar{q}q)\) so purely \(\Delta I=1/2\)
• NP models can be grouped in two sets
  • if they contribute only to \(\Delta I=1/2\)
    • an example: LR contribs. to \(Q_{8g}\) from MSSM
  • models that also have \(\Delta I=3/2\) contributions
    • an example: single scalar explains \(A_{FB}(t \bar{t})\), but also \(\Delta A_{CP}\) from annih. op. \((\bar{u}c)(\bar{u}u)\)
• the second set of models can be tested for using charm data and isospin

Hochberg, Nir, 1112.5268
THE GENERAL IDEA

• in SM $\Delta I=3/2$ comes from tree operators (up to very small EWP)
  ● it carries no weak phase
• test if $\Delta I=3/2$ amplitude is CPV
  ● if it is $\Rightarrow$ found NP!
• will show only two examples
  ● more can be constructed for $D \to \pi\pi$, $\rho\pi, \rho\rho$, $D_s \to \pi K$ decays

D$\rightarrow$ππ and D$\rightarrow$qq

• the isospin decomposition

\[
\begin{align*}
A_{\pi^+\pi^-} &= -\sqrt{2}A_3 + \sqrt{2}A_1, \\
A_{\pi^0\pi^0} &= -2A_3 - A_1, \\
A_{\pi^+\pi^0} &= 3A_3,
\end{align*}
\]

• if $A_{CP}(\pi^+\pi^0)\neq0$, then $\Rightarrow \Delta I = 3/2$ NP

• exactly the same holds for $D\rightarrow\rho\rho$
NP test from $D \rightarrow \eta \pi$

- use $D \rightarrow \pi^+ \pi^- \pi^0$ Dalitz plot
  - measure magn. and phases of $D \rightarrow \rho \pi$
- construct isospin sum rule
  \[
  A_{\rho^+ \pi^-} + 2A_{\rho^0 \pi^0} + A_{\rho^- \pi^+} = -2\sqrt{3}A_3.
  \]
- construct the CP difference
  \[
  |A_{\rho^+ \pi^-} + 2A_{\rho^0 \pi^0} + A_{\rho^- \pi^+}|^2 - |\overline{A}_{\rho^+ \pi^-} + 2\overline{A}_{\rho^0 \pi^0} + \overline{A}_{\rho^- \pi^+}|^2
  \]
  - if nonzero then there is $\Delta I = 3/2$ NP
CONCLUSIONS

• $\Delta A_{CP}$ could be due to NP or SM
  ● showed additional indications from $Br$ that enhanced SM penguin

• to test NP interpretation
  ● through models and direct searches
  ● isospin sum rules in charm decays
BACKUP SLIDES
**TREE AMPLITUDES**

- tree ampl. in SU(3) diagrammatic notation

\[
A^T(\pi^+\pi^-) = V_{cd}^* V_{ud} (T_{\pi\pi} + E_{\pi\pi})
\]
\[
A^T(K^+K^-) = V_{cs}^* V_{us} (T_{KK} + E_{KK})
\]

- \(T_f\) is the “tree” ampl. (in naive fact. \(T_{\pi\pi} \propto f_\pi F^{D\rightarrow\pi}\))

- \(E_f\) is the “W-exchange” ampl.
  - annihilation topology amplitude
  - formally \(1/m_c\) suppressed
THE PENGUIN AMPLITUDES

• tree amplitudes a relative sign due to CKMs

\[ A^T(\pi^+\pi^-) = V_{cd}^* V_{ud} (T_{\pi\pi} + E_{\pi\pi}) \]
\[ A^T(K^+K^-) = V_{cs}^* V_{us} (T_{KK} + E_{KK}) \]

• penguin amplitudes carry the weak phase

\[ A^P(K^+K^-) = -V_{cb}^* V_{ub} P_{KK}, \quad A^P(\pi^+\pi^-) = -V_{cb}^* V_{ub} P_{\pi\pi} \]

• it is \(-\gamma(\text{for } \pi\pi), \pi - \gamma(\text{for } KK)\)

• we thus expect (up to flavor SU(3) breaking)

\[ \text{sign}(A_{K^+K^-}) = -\text{sign}(A_{\pi^+\pi^-}) \]
\[ |A_{K^+K^-}| \sim |A_{\pi^+\pi^-}| \]
QCD Penguin Power Corrections

- we estimate the size just for a subset of $1/m_c$ suppressed amplitudes
- penguin annihilation topology
  - two examples

\[ P_{f,1} = \frac{G_F}{\sqrt{2}} V_{cb} V_{ub}^* C_6 \times \langle f \mid -2 (\bar{u}u)_{S+P} \otimes^A (\bar{u}c)_{S-P} \mid D^0 \rangle \]

\[ P_{f,2} = \frac{G_F}{\sqrt{2}} V_{cb} V_{ub}^* 2 (C_4 + C_6) \times \langle f \mid (\bar{q}_\alpha q_\beta)_{V\pm A} \otimes^A (\bar{u}_\beta c_\alpha)_{V-A} \mid D^0 \rangle \]
ESTIMATING PENGUIN POWER CORRECTIONS

- matrix elements for $P_{f,1}, P_{f,2}$ we estimate from "W-exchange" annihilation amplitudes

$$E_f = \pm \frac{G_F}{\sqrt{2}} C_1 \sin \theta_c \langle f | (\bar{s}_\alpha s_\beta - \bar{d}_\alpha d_\beta)_{V-A} \otimes A (\bar{u}_\beta c_\alpha)_{V-A} | D \rangle + C_2 \text{ term}$$

- expect

$$\frac{\langle f | (\bar{u}u)_{S+P} \otimes A (\bar{u}c)_{S-P} | D^0 \rangle}{\langle f | (\bar{s}_\alpha s_\beta - \bar{d}_\alpha d_\beta)_{V-A} \otimes A (\bar{u}_\beta c_\alpha)_{V-A} | D \rangle} = O(N_c)$$

$$\frac{\langle f | (\bar{u}_\alpha u_\beta)_{V+A} \otimes A (\bar{u}_\beta c_\alpha)_{V-A} | D^0 \rangle}{\langle f | (\bar{s}_\alpha s_\beta - \bar{d}_\alpha d_\beta)_{V-A} \otimes A (\bar{u}_\beta c_\alpha)_{V-A} | D \rangle} = O(1)$$

- different reduced matrix elements under SU(3)
  - order of magnitude estimate

- use $T_f \sim E_f$ to get for power corrections

$$r_{f,1} = \left| \frac{A_{f,1}^P}{A_{f}^T} \right| \sim 2N_c |V_{cb}V_{ub}C_6^{\text{eff}}|/(C_1 \sin \theta_c),$$

$$r_{f,2} = \left| \frac{A_{f,2}^P}{A_{f}^T} \right| \sim 2|V_{cb}V_{ub}(C_4^{\text{eff}} + C_6^{\text{eff}})|/(C_1 \sin \theta_c)$$
**ESTIMATING PENGUIN POWER CORRECTIONS**

- can define effective Wilson coefficient that depends on gluon’s virtuality

\[
C_{6(4)}^{\text{eff}} \left( \mu, \frac{q^2}{m_c^2} \right) = C_{6(4)}(\mu) + C_1(\mu) \frac{\alpha_s(\mu)}{2\pi} \left( \frac{1}{6} + \frac{1}{3} \log \left( \frac{m_c}{\mu} \right) - \frac{1}{8} G \left[ \frac{m_s^2}{m_c^2}, \frac{m_d^2}{m_c^2}, \frac{q^2}{m_c^2} \right] \right)
\]

- can **roughly estimate** penguin contraction contribs. through approximations
  - partonic $G$ func. as estimator of hadronic effects, FSI, etc...
  - evaluate $G$ func. at particular $q^2$ (and vary it)
  - the related $E_f$ hadronic matrix element from tree level $1/m_c$ amplitude (from data on $Br$)
the estimate for $r_{f,1}$, $r_{f,2}$ depends on $q^2$

- vary it in $[0,m_c^2]$, choose $m_s=0.3$, $m_d=0.1$
- $\mu=1$ GeV, $m_c$, $m_D$, top-to-bottom
- dashed curve $G=0$, shows relative importance of penguin contraction contributions
• Giudice et al. identify two viable scenarios

• disoriented $A$ terms

\[(\delta_{ij}^q)_{LR} \sim \frac{A \theta_{ij}^q m_{q_j}}{\tilde{m}}\quad q = u, d ,\]

\[\text{Im} (\delta_{12}^u)_{LR} \approx \frac{\text{Im}(A) \theta_{12} m_c}{\tilde{m}} \approx \left( \frac{\text{Im}(A)}{3} \right) \left( \frac{\theta_{12}}{0.3} \right) \left( \frac{\text{TeV}}{\tilde{m}} \right) 0.5 \times 10^{-3}\]

• FV only in trilinears

\[|\Delta a_{CP}^{\text{SUSY}}| \approx 0.6\% \left( \frac{|\text{Im} (\delta_{12}^u)_{LR}|}{10^{-3}} \right) \left( \frac{\text{TeV}}{\tilde{m}} \right)\]

• split families

\[(\delta_{12}^u)^{\text{eff}}_{RL} = (\delta_{13}^u)_{RR} (\delta_{33}^u)_{RL} (\delta_{32}^u)_{LL} , \quad (\delta_{12}^u)^{\text{eff}}_{LR} = (\delta_{13}^u)_{LL} (\delta_{33}^u)_{RL} (\delta_{32}^u)_{RR} \]
OTHER EXAMPLES

• SUSY: typically some tuning needed for EDMs
• other examples for $Q_8$ oper.
  • FCNC in $Z$, higgs $Q_8$ at 1-loop
  • same EDM challenge as SUSY
• tree level exchanges
  • if vectors ($Z$, $Z'$, $G'$) safest if FV in coupl. to $u_R, c_R$
  • typically still problems with $D$-$D\bar{D}$ mixing
• scalars - two viable examples
  • 2HDM with MFV (but very large $\tan\beta$)
  • gives only $A_{CP}(K^+K^-)$
  • scalar doublet that can simultaneously explain $A_{FB}^{HF}$

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D DECAYS IN SM

• effective weak Hamiltonian
  • run down to $\mu \sim \mu_c$

$$H_{\text{eff}}^{D=1} = \frac{G_F}{\sqrt{2}} \left[ \sum_{p=d,s} V_{cp}^* V_{up} \left( C_1 Q_1^p + C_2 Q_2^p \right) - V_{cb}^* V_{ub} \sum_{i=3}^6 C_i(\mu) Q_i(\mu) + C_{8g} Q_{8g} \right] + \text{H.c.}$$

• "tree" operator
  $$Q_1^p = (\bar{p}c)_{V-A} (\bar{u}p)_{V-A} \quad Q_2^p = (\bar{p}\alpha c_\beta)_{V-A} (\bar{u}_\beta p_\alpha)_{V-A}$$

• "penguin" operators
  $$Q_3 = (\bar{u}c)_{V-A} \sum_q (\bar{q}q)_{V-A} \quad Q_4 = (\bar{u}_\alpha c_\beta)_{V-A} \sum_q (\bar{q}_\beta q_\alpha)_{V-A}$$
  $$Q_5 = (\bar{u}c)_{V-A} \sum_q (\bar{q}q)_{V+A} \quad Q_6 = (\bar{u}_\alpha c_\beta)_{V-A} \sum_q (\bar{q}_\beta q_\alpha)_{V+A}$$
  $$Q_{8g} = -\frac{g_s}{8\pi^2} m_c \bar{u} \sigma_{\mu\nu} (1 + \gamma_5) G^{\mu\nu} c$$
FURTHER TESTS

- let us assume that $A_{CP}(\pi^+\pi^0)=0$
- if $\Delta A_{CP}$ due to $\Delta I=3/2$ NP then this sum is zero
  \[ |A_{\pi^+\pi^-}|^2 - |\bar{A}_{\pi^+\pi^-}|^2 + |A_{\pi^0\pi^0}|^2 - |\bar{A}_{\pi^0\pi^0}|^2 \]
- if nonzero $\Delta A_{CP}$ (also) due to $\Delta I=1/2$
- could be SM or NP
- caveat: the inference only goes one way
- the sum could be zero also for purely $\Delta I=1/2$
  and a particular choice of strong phases
FURTHER TESTS

- another test possible using \( D(t) \rightarrow \pi^{+}\pi^{-} \)
- needs \( D(t) \rightarrow \pi^{0}\pi^{0} \) or info from charm factor. on phases
- construct the isospin sum (and its CP conjugate)

\[
\frac{1}{\sqrt{2}} A_{\pi^{+}\pi^{-}} + A_{\pi^{0}\pi^{0}} + A_{\pi^{+}\pi^{0}} = A_{\text{break}}
\]

- note: cannot use triangle construction from rates as in \( B \) physics due to isospin breaking
- the isospin breaking \( A_{\text{break}} \) is CP conserving
  - it cancels in the sum rule

\[
\frac{1}{\sqrt{2}} A_{\pi^{+}\pi^{-}} + A_{\pi^{0}\pi^{0}} - \frac{1}{\sqrt{2}} \bar{A}_{\pi^{+}\pi^{-}} - \bar{A}_{\pi^{0}\pi^{0}} = 3(A_{3} - \bar{A}_{3})
\]
- r.h.s nonzero \textit{only} if CPV \( \Delta I = 3/2 \) NP
NP test from $D \rightarrow 0\pi$

- no strong phase needed if time dependent Dalitz plot is measured
- from $D(t) \rightarrow \pi^+\pi^-\pi^0$ all amplitudes (and phases) measured can construct

\[
A_{\rho^+\pi^-} + A_{\rho^-\pi^+} + 2A_{\rho^0\pi^0} - \\
(\bar{A}_{\rho^+\pi^-} + \bar{A}_{\rho^-\pi^+} + 2\bar{A}_{\rho^0\pi^0}) = \\
....(A_3 - \bar{A}_3).
\]

- l.h.s. is nonzero for CPV $\Delta I = 3/2$ NP
TEST USING $D_s$ DECAYS

- isospin sum-rule

$$\sqrt{2}A(D_s^+ \rightarrow \pi^0 K^{*+}) + A(D_s^+ \rightarrow \pi^+ K^{*0}) = 3A_3.$$  

- the relative phase can be measured in $D_s^+ \rightarrow K_S\pi^+\pi^0$ Dalitz plot

- if the following sum rule nonzero

$$|\sqrt{2}A(D_s^+ \rightarrow \pi^0 K^{*+}) + A(D_s^+ \rightarrow \pi^+ K^{*0})|^2 - |\sqrt{2}A(D_s^- \rightarrow \pi^0 K^{*-}) + A(D_s^- \rightarrow \pi^- \overline{K}^{*0})|^2 \neq 0$$

- then there is $\Delta I = 3/2$ NP