

# DIRECT CP VIOLATION IN D DECAYS

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based on J. Brod, A. Kagan, JZ,1111.5000  
J. Brod, Y. Grossman, A. Kagan, JZ, 1203.nnnn  
see also A. Kagan, talk at FPCP11, May 2011

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

# OUTLINE

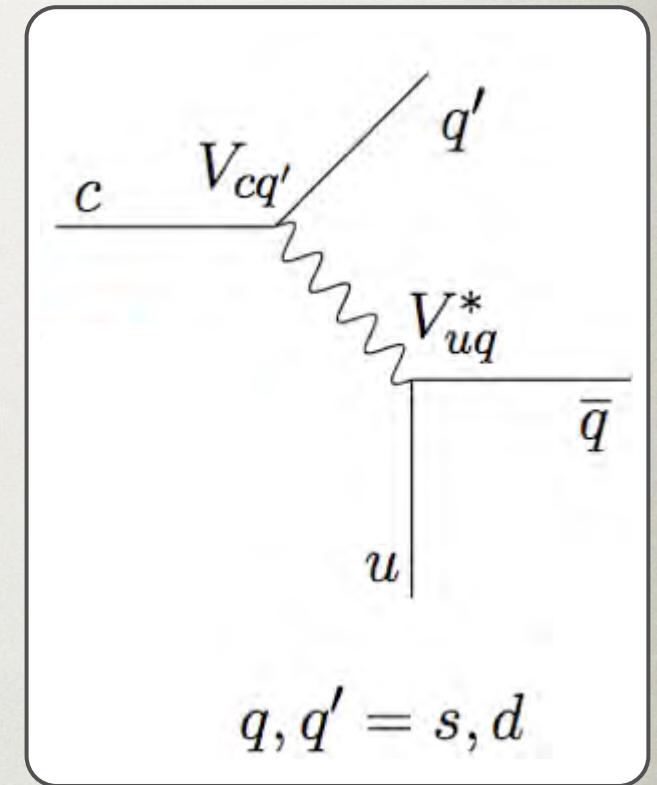
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- the topic of the talk  
$$\Delta A_{CP} = A_{CP}(D \rightarrow K^+K^-) - A_{CP}(D \rightarrow \pi^+\pi^-)$$
- experiment (WA):  $\Delta A_{CP} = (-0.67 \pm 0.16)\%$   
Di Canto, La Thuile 2012
- could it be New Physics?
- could it be Standard Model?
- 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

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

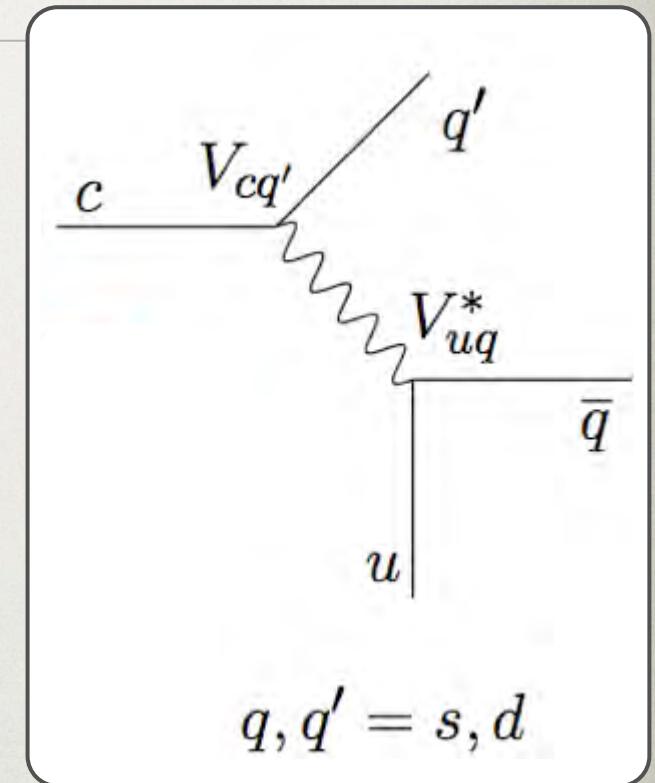
$$\bar{A}_{\bar{f}}(\bar{D} \rightarrow \bar{f}) = A_f^T [1 + r_f e^{i(\delta_f + \gamma)}],$$

- $A_f^T$  - tree ampl.,  $r_f$  - relative “penguin” contrib.,  $\delta_f$  - strong phase
- direct CP asymmetry

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

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

$$\mathcal{A}_f^{\text{dir}} \sim 2r_f$$



$$q, q' = s, d$$

# CP VIOLATION IN CHARM

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- 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

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- expect. that  $A_{KK}$  and  $A_{\pi\pi}$  add up in  $\Delta A_{CP}$

- global exp. avers.

$$\mathcal{A}_{K^+ K^-} = (-0.23 \pm 0.17)\% \quad \mathcal{A}_{\pi^+ \pi^-} = (0.20 \pm 0.22)\%$$

- for O(1) strong phases then

$$\Delta \mathcal{A}_{CP} \sim 4r_f$$

- 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?

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- could it be NP?
- “reasonable” models of NP can do it
  - model independent NP ops. analysis  
[Isidori, Kamenik, Ligeti, Perez, 1111.4987](#)
  - supersymmetric examples  
[Grossman, Kagan, Nir, hep-ph/0609178](#)  
[Giudice, Isidori, Paradisi, 1201.6204](#)
  - tree level exchanges  
[Hochberg, Nir, 1112.5268](#)  
[Altmannshofer, Primulando, Yu, Yu, 1202.2866](#)

# SUSY?

- SUSY contribs. to QCD penguin particularly interesting

Grossman, Kagan, Nir, hep-ph/0609178

- LR mixing in squark matrices

$$Q_8 = \frac{m_c}{4\pi^2} \bar{u}_L \sigma_{\mu\nu} T^a g_s G_a^{\mu\nu} c_R$$

$$\frac{m_c}{m_W^2} \rightarrow \frac{v}{\tilde{m}^2}$$

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

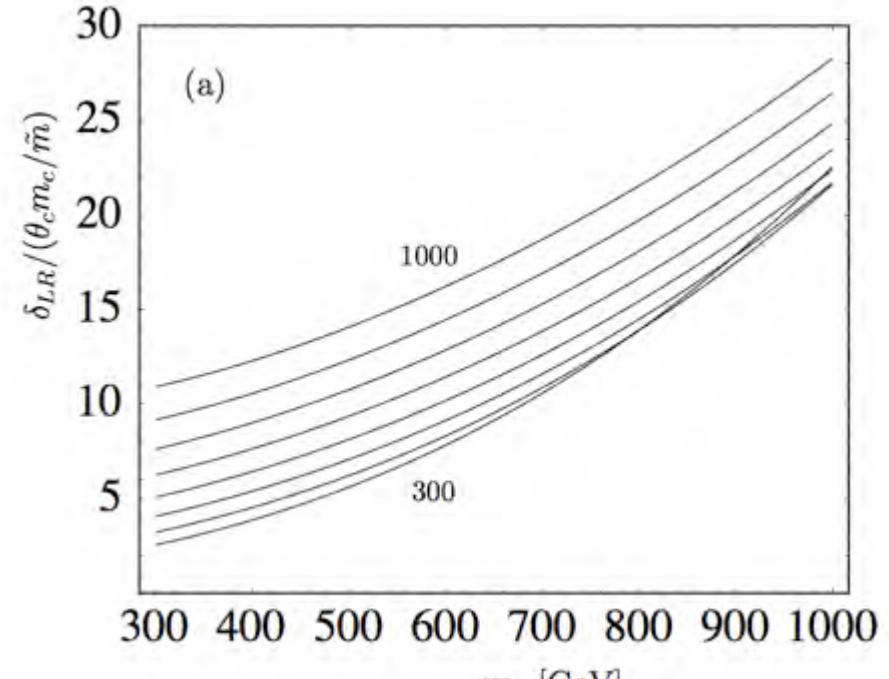
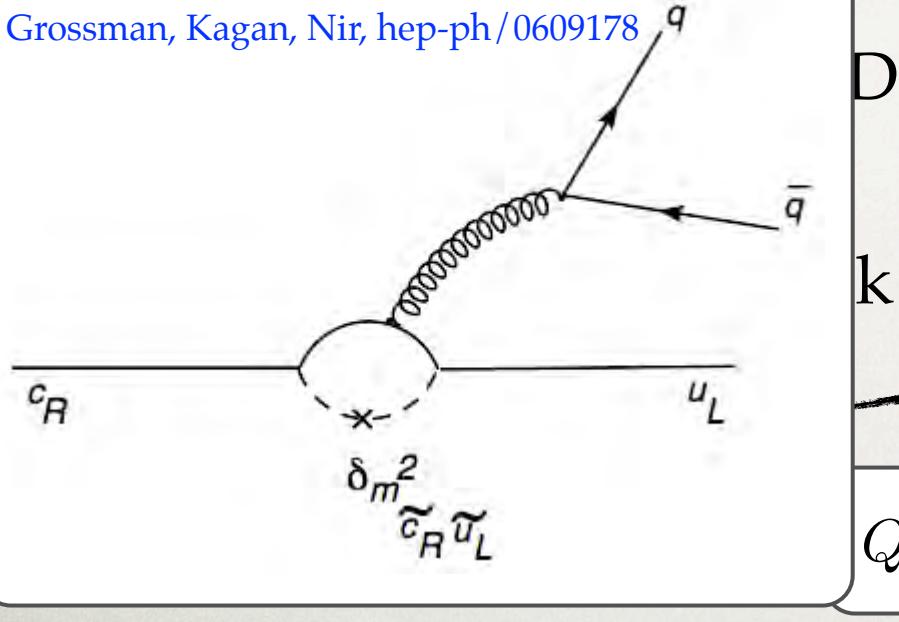
- for  $v \sim m_{susy}$  the op.  $Q_8$  is secretly dim=5
- $D$ - $Dbar$  mixing operators are dim=6

$$Q_2^{cu} = \bar{u}_R^\alpha c_L^\alpha \bar{u}_R^\beta c_L^\beta$$

- SUSY contributions are parametrically smaller

# SUSY?

Grossman, Kagan, Nir, hep-ph/0609178



Grossman, Kagan, Nir, hep-ph/0609178

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$$Q_2^{cu} = \bar{u}_R^\alpha c_L^\alpha \bar{u}_R^\beta c_L^\beta$$

- SUSY contributions are parametrically smaller

# NEW PHYSICS UPSHOT

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- it can be new physics
- but does it have to be?

COULD IT BE  
STANDARD MODEL?

# A REMINDER

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- for  $O(1)$  strong phases

$$\Delta\mathcal{A}_{CP} \sim 4r_f$$

- size of P/T needed

$$r_f \sim 0.15\%$$

- 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

# THE STRATEGY

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Brod, Kagan, JZ, 1111.5000

- 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

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- as a start evaluate leading power penguin ampls. in QCDfact.
  - naive fact.+  $O(\alpha_s)$  corrections
  - only a rough estimate of true value
- penguin to tree ratio

$$r^{\text{LP}} \equiv \left| \frac{A^P(\text{leading power})}{A^T(\text{exp})} \right|$$

$$r_{K^+ K^-}^{\text{LP}} \approx (0.01 - 0.02)\%, \quad r_{\pi^+ \pi^-}^{\text{LP}} \approx (0.015 - 0.03)\%$$

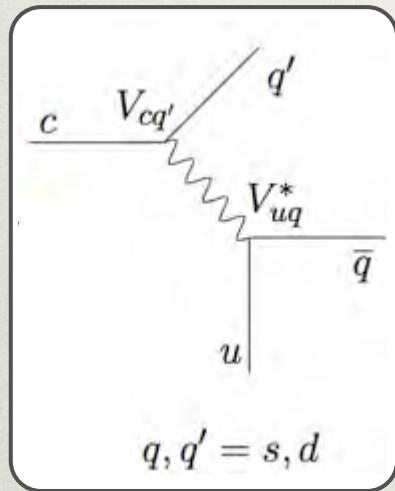
- assume  $O(1)$  phases, then  $\Delta A_{CP} \sim 4r_f$ 
$$\Delta A_{CP}(\text{leading power}) = O(0.05\% - 0.1\%)$$
- order of magnitude below the measurement

# POWER CORRECTIONS

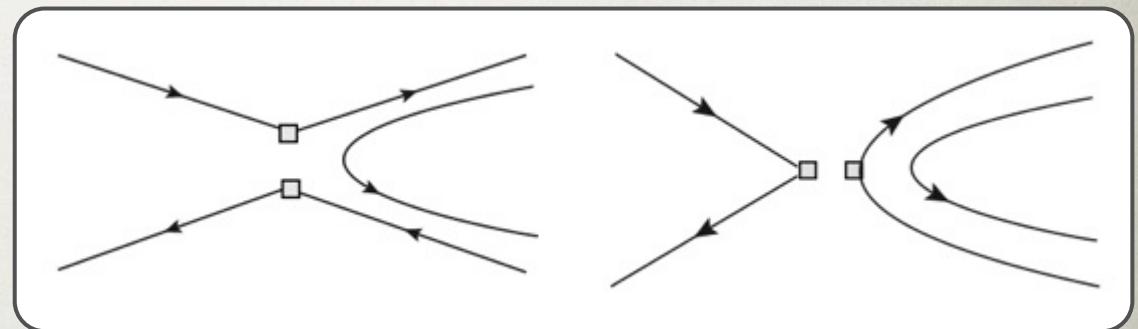
- from  $SU(3)_F$  fits to branching ratios we learn:

- $T_f = A_f[(1/m_c)^0] \sim E_f = A_f[(1/m_c)^1]$

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



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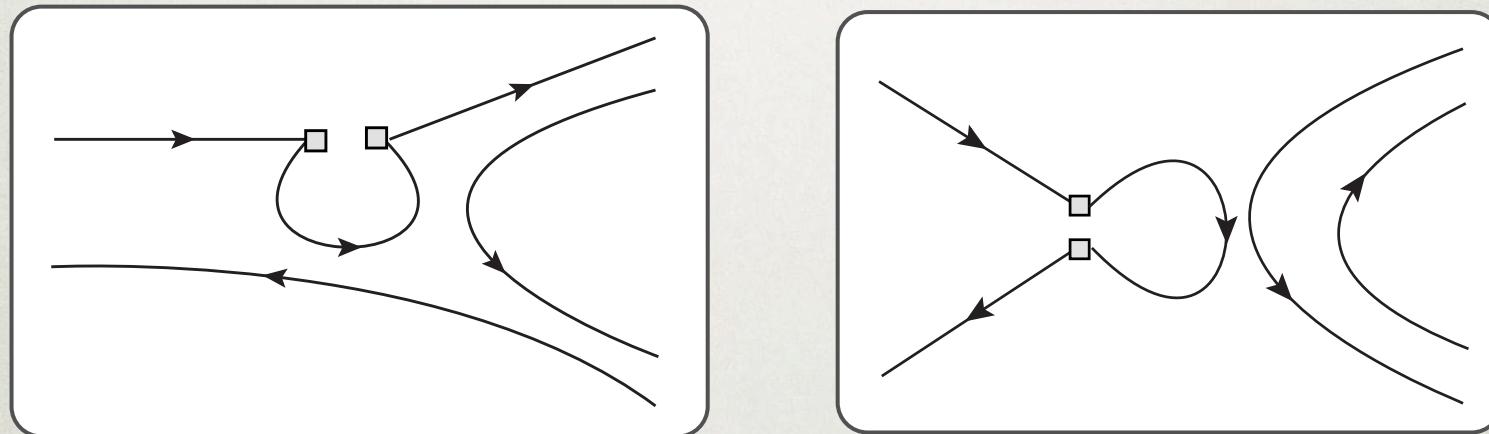
- $1/m_c$  expansion broken
- will still use  $N_c$  counting
- look at two particular  $1/m_c$  contribs.

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

Brod, Kagan, JZ, 1111.5000



- 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

# SUMMARY OF SM CONTRIBS.

Brod, Kagan, JZ, 1111.5000

- 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 J. Brod, Y. Grossman, A. Kagan, JZ, 1203.nnnn
  - $Br(D \rightarrow K^+ K^-) = 2.8 Br(D \rightarrow \pi^+ \pi^-)$
  - should be the same in flavor SU(3) limit
- with large SM penguin a consistent picture
  - $Br$ 's changed by  $P_{break} = \epsilon_{SU(3)} P \sim T$
  - the fit to four  $Br$  confirms  $P_{break} \sim T$
- using  $P \sim P_{break}/\epsilon$  one predicts (for  $\epsilon=0.3$ )

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

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

# FURTHER INDICATION IN FAVOR OF SM

$$H_{\text{eff}}^{\Delta C=1} = \frac{G_F}{\sqrt{2}} \left( V_{cs}^* V_{us} \sum_{i=1,2} C_i (Q_i^s - Q_i^d) - V_{cb}^* V_{ub} \left[ \sum_{i=1,2} C_i (Q_i^d - Q_i^s) / 2 \right] \right) + \text{h.c.}$$

$$+ \sum_{i=1,2} C_i (Q_i^s + Q_i^d) / 2 + \sum_{i=3}^6 C_i Q_i + C_{8g} Q_{8g} \right) + \text{h.c.},$$

- with large SM penguins in a
- $Br$ 's change  $\rightarrow P_{break}$

$$T_{KK} = T_{KK}^s + P_{KK}^{T,s} - P_{KK}^{T,d},$$

$$T_{\pi\pi} = -T_{\pi\pi}^d + P_{\pi\pi}^{T,s} - P_{\pi\pi}^{T,d},$$

$$A_f^P = -V_{cb}^* V_{ub} (P_f + [P_f^{T,s} + P_f^{T,d}] / 2 + [P_f^{E,s} + P_f^{E,d}] / 2)$$

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

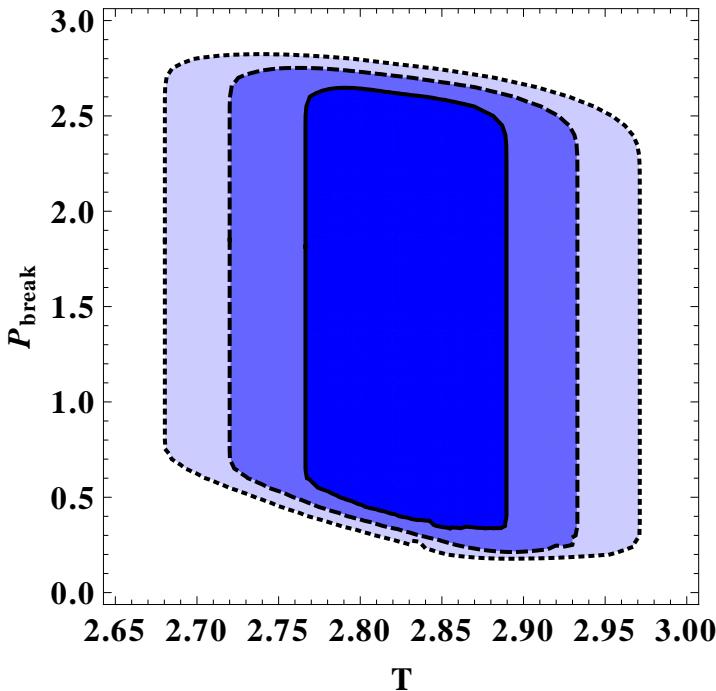
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# R INDICATION IN VOR OF SM

puzzle

J. Brod, Y. Grossman, A. Kagan, JZ, 1203.nnnn

$$=2.8 \ Br(D \rightarrow \pi^+ \pi^-)$$

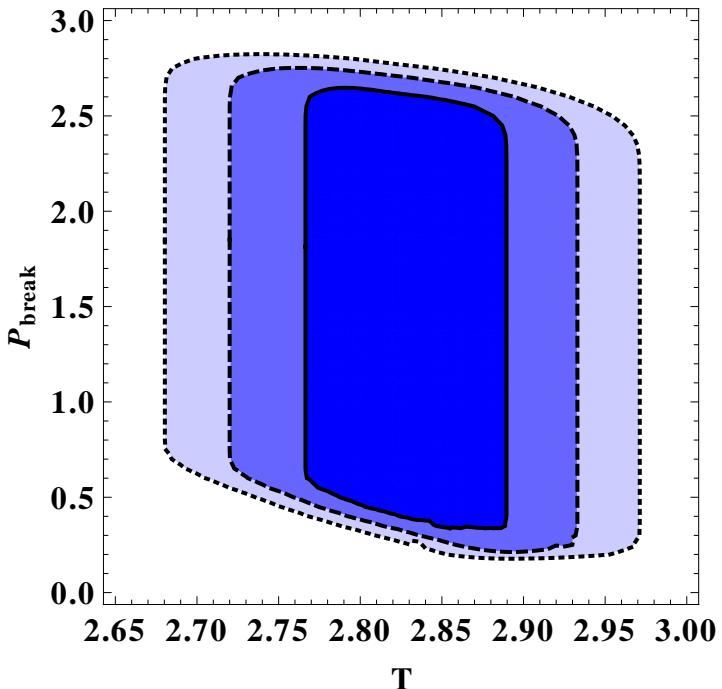
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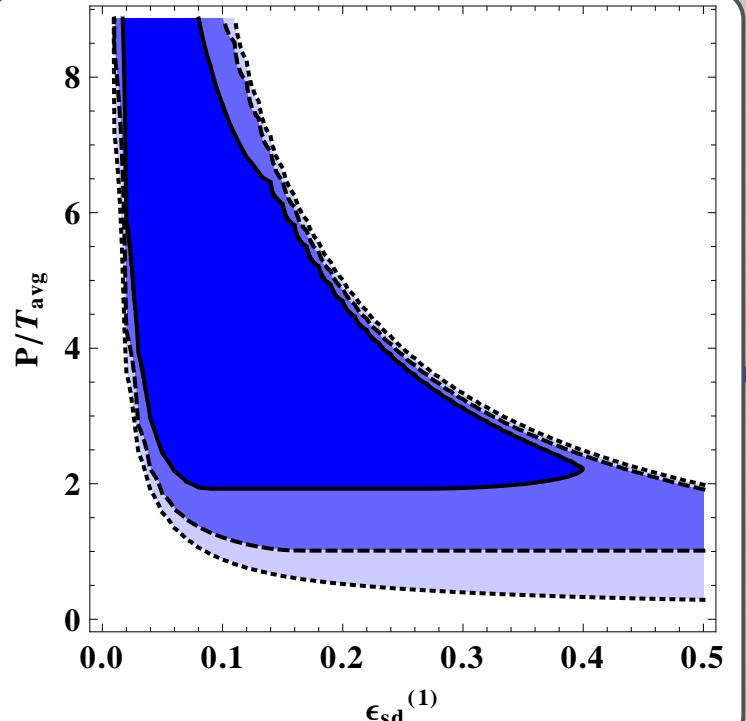
# R INDICATOR VOR OF S

puzzle

$$=2.8 \ Br(D \rightarrow \pi^+ \pi^-)$$

e same in flavor

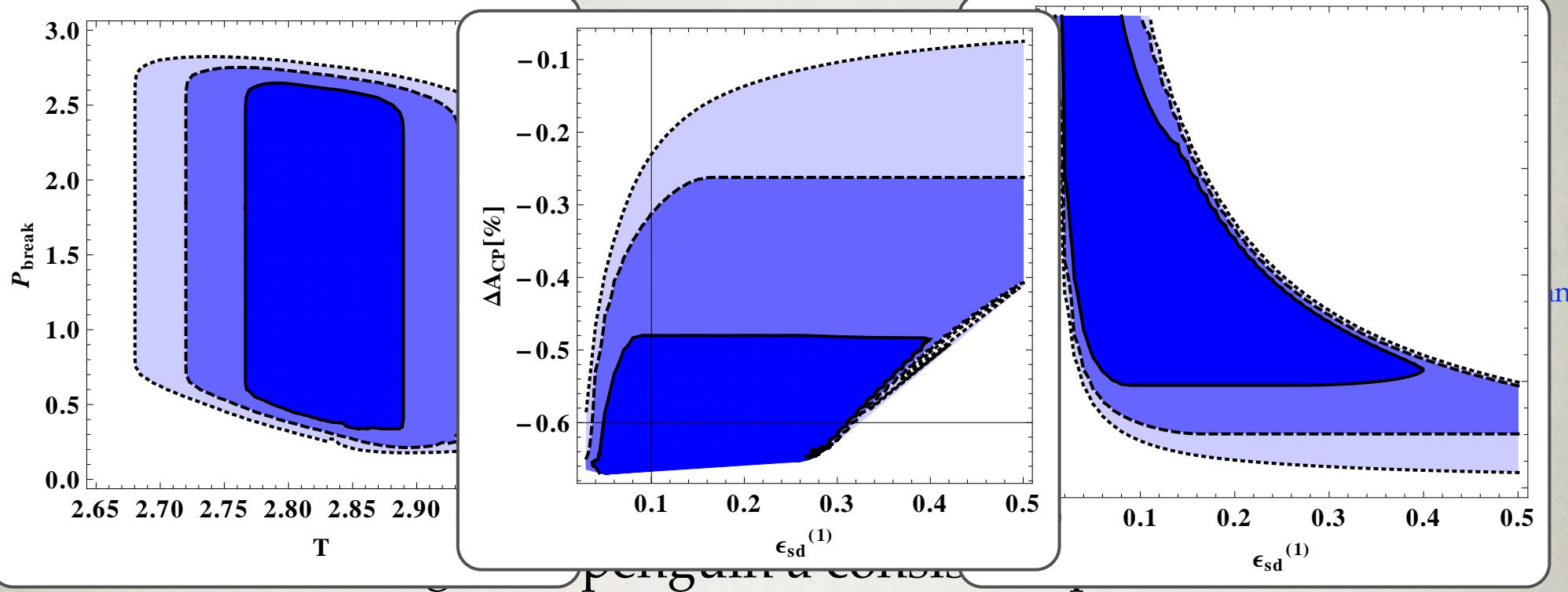
penguin a consis



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- exactly the required size for  $\Delta A_{\text{CP}}$

# 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  $\sim (\bar{d}c)(\bar{u}d)$ , so both  $\Delta I=3/2$  and  $\Delta I=1/2$  components
  - penguins  $\sim (\bar{u}c)(\bar{q}q)$  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.  $(\bar{u}c)(\bar{u}u)$  Hochberg, Nir, 1112.5268
- the second set of models can be tested for using charm data and isospin

# THE GENERAL IDEA

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Y. Grossman, A. Kagan, JZ, work in progress

- 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  $D \rightarrow \pi\pi$ ,  
 $\rho\pi, \rho\rho, D_s \rightarrow \pi K$  decays

# $D \rightarrow \pi\pi$ AND $D \rightarrow \eta\eta$

---

- the isospin decomposition

$$A_{\pi^+\pi^-} = -\sqrt{2}\mathcal{A}_3 + \sqrt{2}\mathcal{A}_1,$$

$$A_{\pi^0\pi^0} = -2\mathcal{A}_3 - \mathcal{A}_1,$$

$$A_{\pi^+\pi^0} = 3\mathcal{A}_3,$$

- if  $A_{CP}(\pi^+\pi^0) \neq 0$ , then  $\Rightarrow \Delta I=3/2$  NP
- exactly the same holds for  $D \rightarrow \rho\rho$

# NP TEST FROM $D \rightarrow Q\pi$

---

- use  $D \rightarrow \pi^+ \pi^- \pi^0$  Dalitz plot
  - measure magn. and phases of  $D \rightarrow \rho \pi$
- construct isospin sum rule

$$A_{\rho^+ \pi^-} + 2A_{\rho^0 \pi^0} + A_{\rho^- \pi^+} = -2\sqrt{3}\mathcal{A}_3.$$

- construct the CP difference

$$|A_{\rho^+ \pi^-} + 2A_{\rho^0 \pi^0} + A_{\rho^- \pi^+}|^2 - |\bar{A}_{\rho^+ \pi^-} + 2\bar{A}_{\rho^0 \pi^0} + \bar{A}_{\rho^- \pi^+}|^2$$

- 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

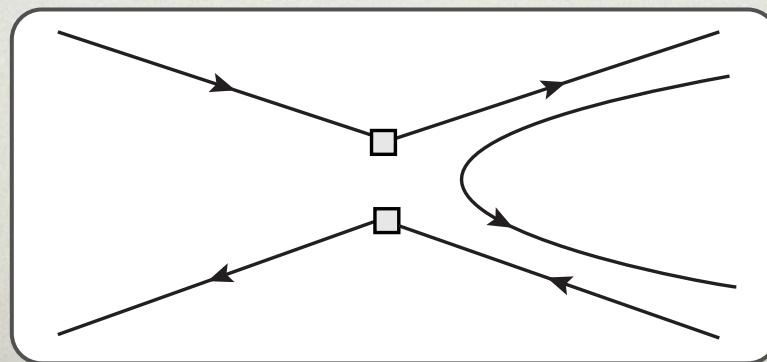
# TREE AMPLITUDES

- 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

$$A^T(\pi^+\pi^-) = V_{cd}^* V_{ud} (T_{\pi\pi} + E_{\pi\pi})$$

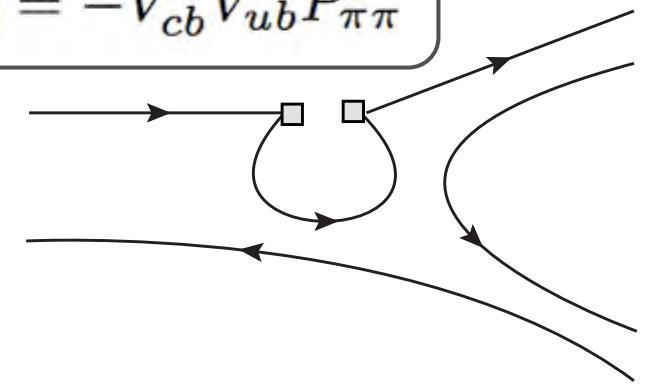
$$A^T(K^+K^-) = V_{cs}^* V_{us} (T_{KK} + E_{KK})$$

- 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  $-\gamma$  (for  $\pi\pi$ ),  $\pi - \gamma$  (for  $KK$ )
- we thus expect (up to flavor SU(3) breaking)

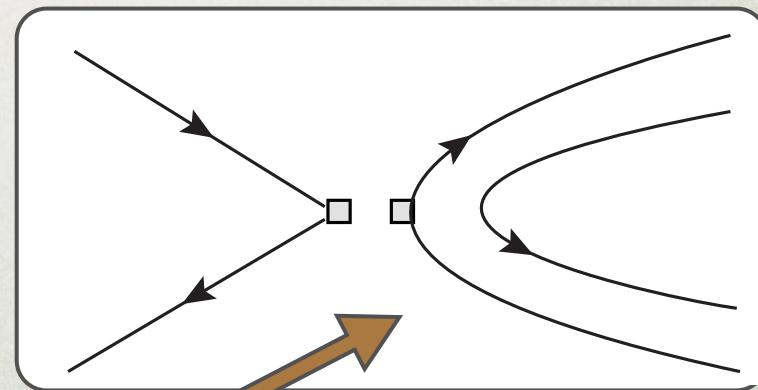
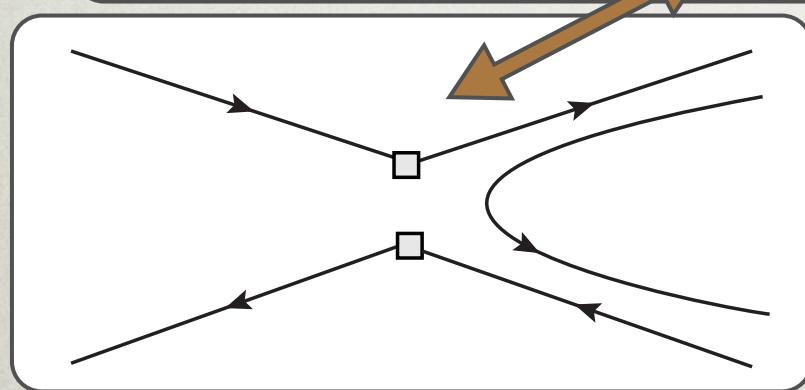
$$\begin{aligned} \text{sign}(\mathcal{A}_{K^+K^-}) &= -\text{sign}(\mathcal{A}_{\pi^+\pi^-}) \\ |\mathcal{A}_{K^+K^-}| &\sim |\mathcal{A}_{\pi^+\pi^-}| \end{aligned}$$



# QCD PENGUIN POWER CORRECTIONS

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

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



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

# 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

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

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

- different reduced matrix elements under SU(3)

- order of magnitude estimate

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

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

$$r_{f,2} \equiv \left| \frac{A_{f,2}^P}{A_f^T} \right| \sim 2 |V_{cb} V_{ub} (C_4^{\text{eff}} + C_6^{\text{eff}})| / (C_1 \sin \theta_c)$$

# ESTIMATING PENGUIN POWER CORRECTIONS

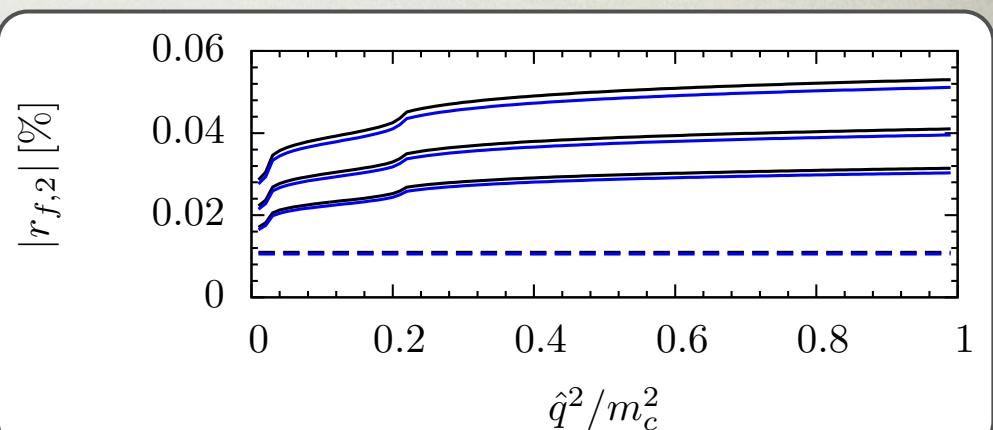
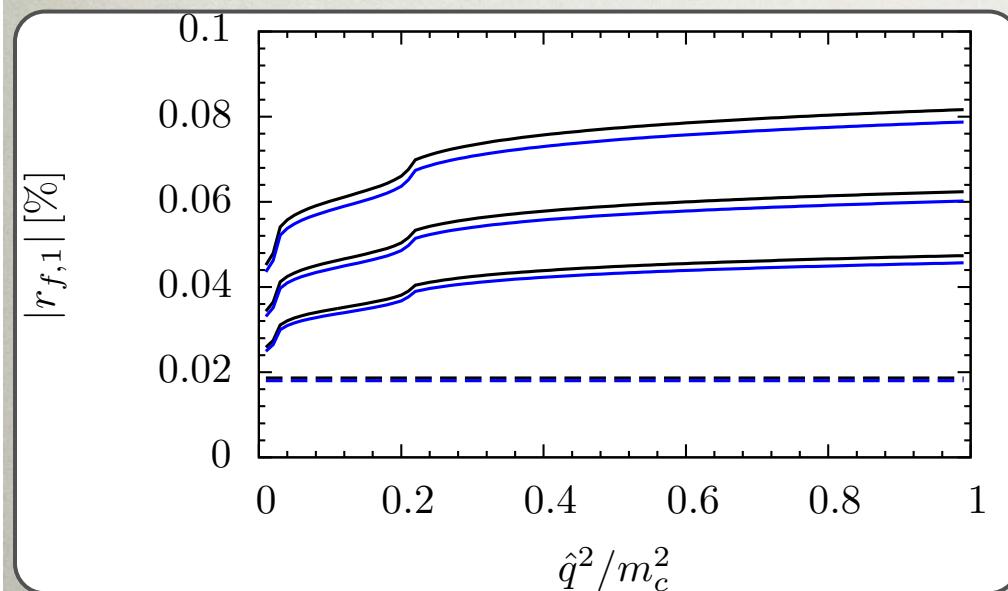
- can define effective Wilson coefficient that depends on gluon's virtuality

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

- 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  $Br$ )

# ORDER OF MAGNITUDE ESTIMATE FOR P/T

- the estimate for  $r_{f,1}, r_{f,2}$  depends on  $q^2$ 
  - vary it in  $[0, m_c^2]$ , choose  $m_s=0.3, m_d=0.1$
  - $\mu=1 \text{ GeV}, m_c, m_D$ , top-to-bottom
  - dashed curve  $G=0$ , shows relative importance of penguin contraction contributions



# SUSY

- Giudice et al. identify two viable scenarios
  - disoriented  $A$  terms

[Giudice, Isidori, Paradisi, 1201.6204](#)

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

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

- 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

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

# OTHER EXAMPLES

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- SUSY: typically some tuning needed for EDMs
- other examples for  $Q_8$  oper.

[Giudice, Isidori, Paradisi, 1201.6204](#)

- FCNC in  $Z$ , higgs  $Q_8$  at 1-loop
- same EDM challenge as SUSY
- tree level exchanges

[Altmannshofer, Primulando, Yu, Yu, 1202.2866](#)

- if vectors ( $Z, Z', G'$ ) safest if FV in coupl. to  $u_R, c_R$ 
  - typically still problems with  $D$ - $\bar{D}$  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  $A_{FB}^{t\bar{t}}$

[Hochberg, Nir, 1112.5268](#)

# D DECAYS IN SM

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

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

- “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

$$Q_3 = (\bar{u}c)_{V-A} \sum_q (\bar{q}q)_{V-A}$$

$$Q_4 = (\bar{u}_\alpha c_\beta)_{V-A} \sum_q (\bar{q}_\beta q_\alpha)_{V-A}$$

$$Q_5 = (\bar{u}c)_{V-A} \sum_q (\bar{q}q)_{V+A}$$

$$Q_6 = (\bar{u}_\alpha c_\beta)_{V-A} \sum_q (\bar{q}_\beta q_\alpha)_{V+A}$$

$$Q_{8g} = -\frac{g_s}{8\pi^2} m_c \bar{u} \sigma_{\mu\nu} (1 + \gamma_5) G^{\mu\nu} c$$

# FURTHER TESTS

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- 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

$$\begin{aligned} & \frac{1}{\sqrt{2}} A_{\pi^+ \pi^-} + A_{\pi^0 \pi^0} - \frac{1}{\sqrt{2}} \bar{A}_{\pi^+ \pi^-} - \bar{A}_{\pi^0 \pi^0} \\ &= 3(\mathcal{A}_3 - \bar{\mathcal{A}}_3). \end{aligned}$$

- r.h.s nonzero only if CPV  $\Delta I = 3/2$  NP

# NP TEST FROM $D \rightarrow Q\pi$

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- 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

$$\begin{aligned} A_{\rho^+ \pi^-} + A_{\rho^- \pi^+} + 2A_{\rho^0 \pi^0} - \\ (\bar{A}_{\rho^+ \pi^-} + \bar{A}_{\rho^- \pi^+} + 2\bar{A}_{\rho^0 \pi^0}) = \\ \dots (\mathcal{A}_3 - \bar{\mathcal{A}}_3). \end{aligned}$$

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

# TEST USING $D_s$ DECAYS

- isospin sum-rule

$$\sqrt{2}A(D_s^+ \rightarrow \pi^0 K^{*+}) + A(D_s^+ \rightarrow \pi^+ K^{*0}) = 3\mathcal{A}_3.$$

- 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