Charming Penguins where do they come from? and how Dalitz plot can help?

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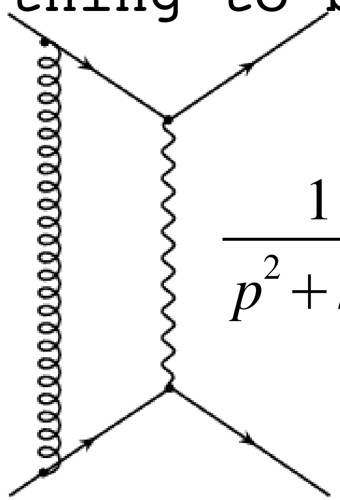
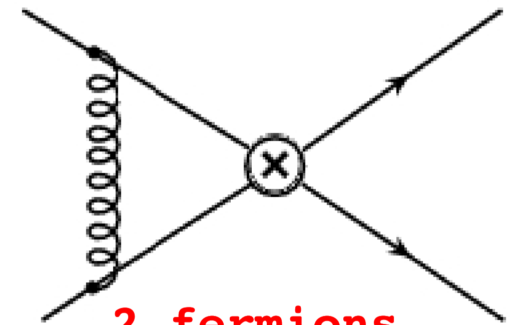
The OPE and decay amplitudes

Since m_b~4GeV and m_W~80GeV, weak interaction can be replaced by an effective local theory, contracting the W propagator to a point (similar thing to be done with t quark)

2 fermions
2 bosons
in the loop



$$\frac{1}{p^2+m_W^2} \Rightarrow 1+O\left(\frac{p^2}{m_W^2}\right)$$



2 fermions
1 boson in
the loop

This operation breaks the ultraviolet behavior of the theory.

$$\int \frac{d^4p}{p^6} \approx \int \frac{dp}{p^3} \rightarrow 0 \quad \Rightarrow \quad \int \frac{d^4p}{p^4} \approx \int \frac{dp}{p} \rightarrow \infty$$

To remove the ∞ after integrating out the heavy degrees of freedom we need to renormalize the theory, which introduces new operators and effective couplings, as a function of an unphysical regularization scale (μ).

Outline

How decay amplitudes are calculated

- Operator Product Expansion
- Effective Hamiltonian
- Contraction on initial and final state
- Renormalization Group Invariant combinations

The problem of non-perturbative effects

- ... in the most favorable case ($B^0 \to J/\psi K^0$)
- ... in the most confusing case ($b \to s$)

But Dalitz can help sometimes.

A practical example ($B \to K\pi\pi$)

- cancellation of hadronic effects
- a new bound on CKM matrix

The effective Hamiltonian

After the renormalization of the effective theory

$$\mathcal{H}_{\rm eff} = \frac{G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p \left(C_1\, Q_1^p + C_2\, Q_2^p + \sum_{i=3,\dots,10} C_i\, Q_i + C_{11}\, Q_{12} + C_{12}\, Q_{12} \right) + \text{h.c.}$$

Tree level operators

$$Q_1^p = (\bar{p}b)_{V-A}(\bar{s}p)_{V-A}\,, \qquad Q_2^p = (\bar{p}_i b_j)_{V-A}(\bar{s}_j p_i)_{V-A}\,,$$

Penguin operators

$$Q_3 = (\bar{s}b)_{V-A}\sum\nolimits_q (\bar{q}q)_{V-A}\,, \qquad Q_4 = (\bar{s}_i b_j)_{V-A}\sum\nolimits_q (\bar{q}_j q_i)_{V-A}\,,$$

$$Q_5 = (\bar{s}b)_{V-A}\sum\nolimits_q (\bar{q}q)_{V+A}\,, \qquad Q_6 = (\bar{s}_i b_j)_{V-A}\sum\nolimits_q (\bar{q}_j q_i)_{V+A}\,,$$

EW Penguin operators

$$Q_7 = (\bar{s}b)_{V-A}\sum\nolimits_q \tfrac{3}{2}e_q(\bar{q}q)_{V+A}\,, \qquad Q_8 = (\bar{s}_i b_j)_{V-A}\sum\nolimits_q \tfrac{3}{2}e_q(\bar{q}_j q_i)_{V+A}\,,$$

$$Q_9 = (\bar{s}b)_{V-A}\sum\nolimits_q \tfrac{3}{2}e_q(\bar{q}q)_{V-A}\,, \qquad Q_{10} = (\bar{s}_i b_j)_{V-A}\sum\nolimits_q \tfrac{3}{2}e_q(\bar{q}_j q_i)_{V-A}\,,$$

$$Q_{7\gamma} = \frac{-e}{8\pi^2}\, m_b\, \bar{s}\sigma_{\mu\nu}(1+\gamma_5)F^{\mu\nu} b\,, \qquad Q_{8g} = \frac{-g_s}{8\pi^2}\, m_b\, \bar{s}\sigma_{\mu\nu}(1+\gamma_5)G^{\mu\nu} b\,,$$

(cromo)magnetic operators

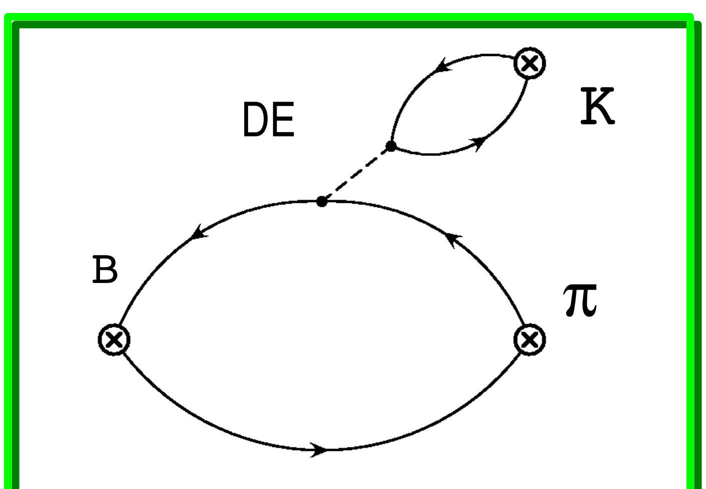
Contractions of the H_{eff}

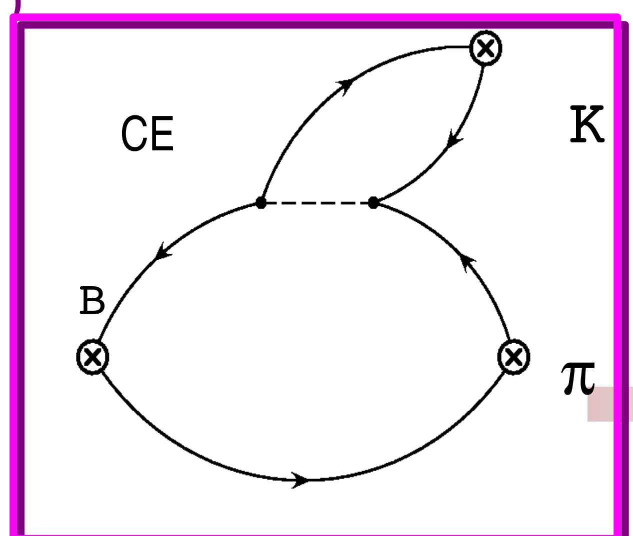
Contracting (by Wick theorem) the effective Hamiltonian on certain initial and final states

$$A(B^0 \to K^+\pi^-) = \langle K^+\pi^- | H_{eff} | B^0 \rangle = \sum_{i=1,10} C_i(\mu) \langle K^+\pi^- | Q_i(\mu) | B^0 \rangle$$

All the perturbative physics (scale > μ) in the Wilson coeff. $C_i(\mu)$. All the non-perturbative physics (scale < μ) in the matrix elements. The unphysical dependence on μ has to cancel out.

Every operator can produce several diagram topologies when contracted on the initial and final states. For example, the tree level operators can be contracted into tree level contractions: $\langle Q \rangle_{DE}(\mu)$ and $\langle Q \rangle_{CE}(\mu)$





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The RGI combinations

One can rearrange the contractions of various operators into Renormalization Group Invariant combinations, that represent the physical quantities defining the decay amplitude (**Buras & Silvestrini, hep-ph/9812392**). For example the tree level contributions T and C correspond to the RGI's E_1 and E_2

$$E_1 = C_1 \langle Q_1 \rangle_{DE} + C_2 \langle Q_2 \rangle_{CE} \qquad E_2 = C_1 \langle Q_1 \rangle_{CE} + C_2 \langle Q_2 \rangle_{DE}$$

Penguins are more complicated

$$\begin{aligned} P_1 &= C_1 \langle Q_1 \rangle^c_{CP} + C_2 \langle Q_2 \rangle^c_{DP} + \sum_{i=2}^{5} \Big(C_{2i-1} \langle Q_{2i-1} \rangle_{CE} + C_{2i} \langle Q_{2i} \rangle_{DE} \Big) \\ &+ \sum_{i=3}^{10} \Big(C_i \langle Q_i \rangle_{CP} + C_i \langle Q_i \rangle_{DP} \Big) + \sum_{i=2}^{5} \Big(C_{2i-1} \langle Q_{2i-1} \rangle_{CA} + C_{2i} \langle Q_{2i} \rangle_{DA} \Big) \end{aligned}$$

$$P_1^{\mathrm{GIM}} = C_1 \Big(\langle Q_1 \rangle^c_{CP} - \langle Q_1 \rangle^u_{CP} \Big) + C_2 \Big(\langle Q_2 \rangle^c_{DP} - \langle Q_2 \rangle^u_{DP} \Big)$$

Every RGI corresponds to a contraction of the $J_\mu J^\mu$ interaction term of the Standard Model (i.e. RGIs are the physical quantities)

The Decay Amplitude

The final formula is simplified and the dependence on μ is formally canceled out

CKM enhanced ($\sim \lambda^2$) — CKM suppressed ($\sim \lambda^4$)

$$A(B^0 \to K^+ \pi^-) = V_{ts} V_{tb}^* \times P_1 - V_{us} V_{ub}^* \times \{E_1 - P_1^{GIM}\}$$

Penguin (i.e. suppressed) RGI

Tree level (i.e. dominant) RGI

- We know **$C(\mu)$** from perturbative calculations
- We still **miss** a technique that calculates **matrix elements** without any dynamical assumption

The Most favorable case

$$A(B^0 \to J/\psi K^0) = \underbrace{-V_{cs} V_{cb}^* \times (E_2 - P_2)}_{\sim \lambda^2} + \underbrace{V_{us} V_{ub}^* \times (P_2^{GIM} - P_2)}_{\sim \lambda^4}$$

- $B^0 \to J/\psi K^0$ is considered the cleanest mode to measure $\sin 2\beta$
- Hadronic corrections coming from CKM suppressed terms are expected to be small
- Trying to fit them from data implies effects $O(1)$ on S (no sensitivity from the BR)
- One can use $B^0 \to J/\psi \pi^0$ to obtain the bound on the hadronic parameters of $B^0 \to J/\psi K^0$

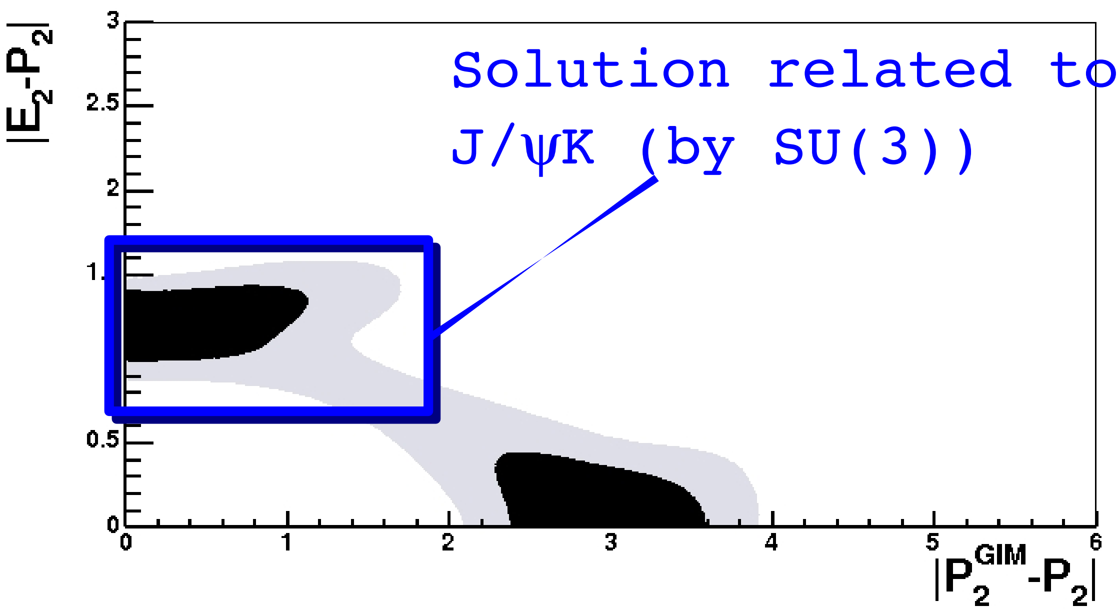
$$A(B^0 \to J/\psi \pi^0) = \underbrace{-V_{cd} V_{cb}^* \times (E_2 - P_2)}_{\sim \lambda^3} + \underbrace{V_{ud} V_{ub}^* \times (P_2^{GIM} - P_2)}_{\sim \lambda^3}$$

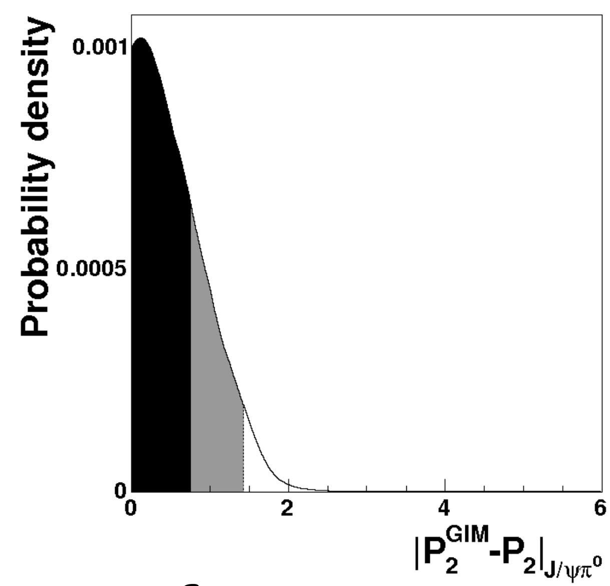
using the experimental informations (BR, S and C) as input

CPS hep-ph/0507290

Range of Corrections from J/ψπ

$\mathrm{BR}^{\mathrm{th}} \times 10^5$	2.2 ± 0.4	$\mathrm{BR}^{\mathrm{exp}} \times 10^5$	2.2 ± 0.4	$\mathcal{C}_{\mathrm{CP}}^{\mathrm{th}}$	0.09 ± 0.19
$\mathcal{C}_{\mathrm{CP}}^{\mathrm{exp}}$	0.12 ± 0.24	$\mathcal{S}_{\mathrm{CP}}^{\mathrm{th}}$	-0.47 ± 0.30	$\mathcal{S}_{\mathrm{CP}}^{\mathrm{exp}}$	-0.40 ± 0.33
$\lvert E_2 - P_2 \rvert$	1.22 ± 0.15 0.15 ± 0.15	$\lvert P_2^{\mathrm{GIM}} - P_2 \rvert$	0.43 ± 0.43 2.87 ± 0.43	δ_P	$(-24 \pm 41)^\circ$ $(-146 \pm 50)^\circ$





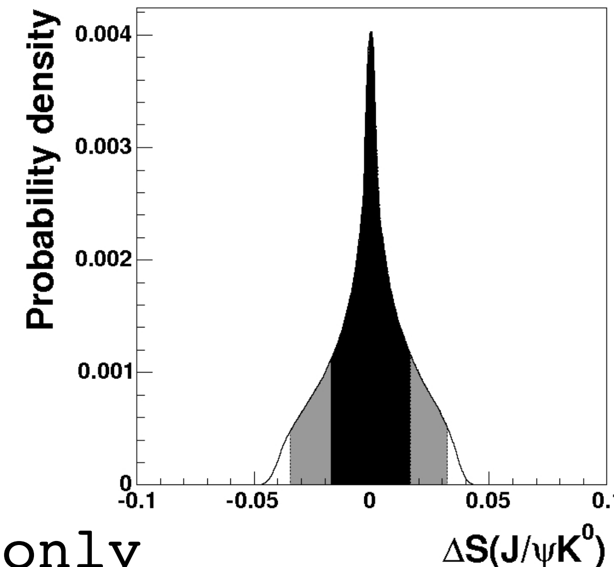
We can use SU(3) to **determine the range** of CKM suppressed contributions in J/ψ K. This assumption is **weaker than** fixing the value of the parameter with **SU(3)**

Consequences on J/ψ K

One can then obtain model independent (i.e. no factorization assumption) determination on the theoretical error on sin2β

$BR^{th} \times 10^5$	8.5 ± 0.5	$BR^{exp} \times 10^5$	8.5 ± 0.5	$\mathcal{C}_{CP}^{th}$	0.00 ± 0.02
$\mathcal{C}_{CP}^{exp}$	-0.01 ± 0.04	$\mathcal{S}_{CP}^{out}$	0.73 ± 0.05	$\mathcal{S}_{CP}^{in}$	0.73 ± 0.04
$\lvert E_2 - P_2 \rvert$	1.44 ± 0.05				

$\Delta S = 0.000 \pm 0.017$



The Lesson:

- CKM suppressed contributions are relevant for CP asymmetries
- They are not crucial for a fit to BR only
- They cannot be bound without additional assumptions
- Flavor symmetries can be used to bound the order of magnitude (going further requires to control symmetry breaking effects)

The Most confusing case

Charming Penguin $\sim \lambda^2$ $\quad V_{us} V_{ub}^* \sim \lambda^4$

$$A(B^0 \to K^+ \pi^-) = V_{ts} V_{tb}^* \times P_1 - V_{us} V_{ub}^* \times \{E_1 - P_1^{GIM}\}$$

$$\sqrt{2} \cdot A(B^0 \to K^0 \pi^0) = -V_{ts} V_{tb}^* \times P_1 - V_{us} V_{ub}^* \times \{E_2 + P_1^{GIM}\}$$

$$\sqrt{2} \cdot A(B^+ \to K^+ \pi^0) = V_{ts} V_{tb}^* \times P_1 - V_{us} V_{ub}^* \times \{E_1 + E_2 + A_1 - P_1^{GIM}\}$$

$$A(B^+ \to K^0 \pi^+) = -V_{ts} V_{tb}^* \times P_1 + V_{us} V_{ub}^* \times \{A_1 - P_1^{GIM}\}$$

- Charming Penguin is doubly Cabibbo enhanced
- Amplitudes less sensitive to the other Λ_{QCD}/m_b terms
- $B^0 \to K^0\pi^0$ is penguin dominated: **S** coefficient sensitive to **New Physics**
- We can use $B \to \pi\pi$ to guess the order of magnitude of suppressed terms

Range of Corrections from ππ

Charming Penguin $\sim \lambda^3$

$V_{ud} V_{ub}^{*} \sim \lambda^3$

$$A(B^0 \to \pi^+ \pi^-) = V_{td} V_{tb}^{*} \times P_1 - V_{ud} V_{ub}^{*} \times \{E_1 + A_2 - P_1^{GIM}\}$$

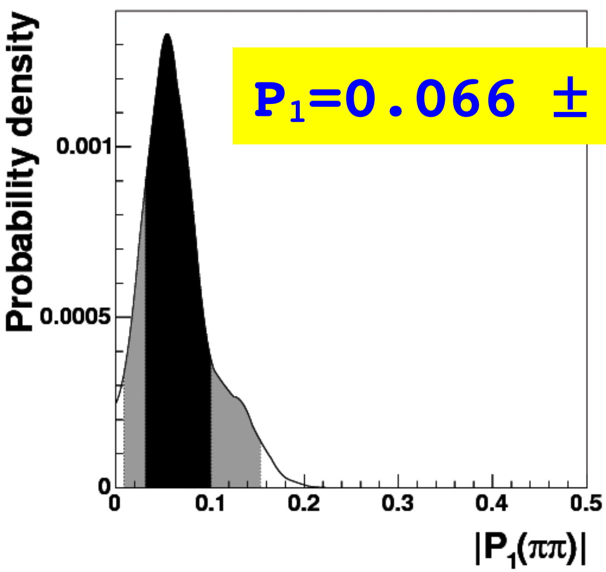
$$\sqrt{2} \cdot A(B^+ \to \pi^+ \pi^0) = - V_{ud} V_{ub}^{*} \times \{E_1 + E_2\}$$

$$\sqrt{2} \cdot A(B^0 \to \pi^0 \pi^0) = -V_{td} V_{tb}^{*} \times P_1 - V_{ud} V_{ub}^{*} \times \{E_2 - A_2 + P_1^{GIM}\}$$

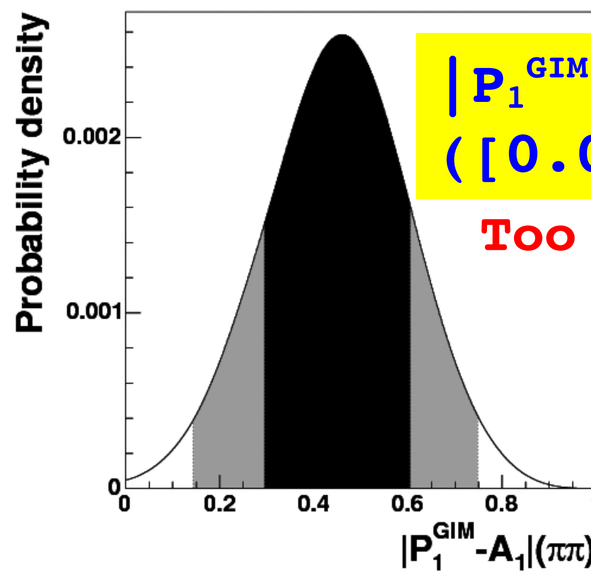
- We can use 3 BR and 2 A_{CP} measurements, together with $S_{\pi\pi}$
- We take E_1 and E_2 and the perturbative part of the penguins from QCD factorization
- We have to fit for 2 complex parameters (P_1 and $A_2 - P_1^{GIM}$)

Fit to $B \to \pi\pi$

Channel	$BR^{th} \times 10^6$	$BR^{exp} \times 10^6$	$\mathcal{A}_{CP}^{th}$	$\mathcal{A}_{CP}^{exp}$	$\mathcal{S}^{th}$	$\mathcal{S}^{exp}$
$\pi^+\pi^-$	5.5 ± 0.4	5.4 ± 0.4	0.33 ± 0.11	0.37 ± 0.10	-0.54 ± 0.12	-0.50 ± 0.12
$\pi^+\pi^0$	5.7 ± 0.6	5.8 ± 0.6	0	0.01 ± 0.06	-	-
$\pi^0\pi^0$	1.42 ± 0.29	1.45 ± 0.29	0.07 ± 0.24	0.28 ± 0.39	-	-



$P_1 = 0.066 \pm 0.035$



$|P_1^{GIM} - A_1| = 0.45 \pm 0.15$ ([0.08,0.90] at 95%)

Too large to be Λ_{QCD}/m_b. Problems with factorization?

- **Values are given in units of E_1**
- We will use [0.0,0.90] for the $K\pi$ fit (to be conservative)

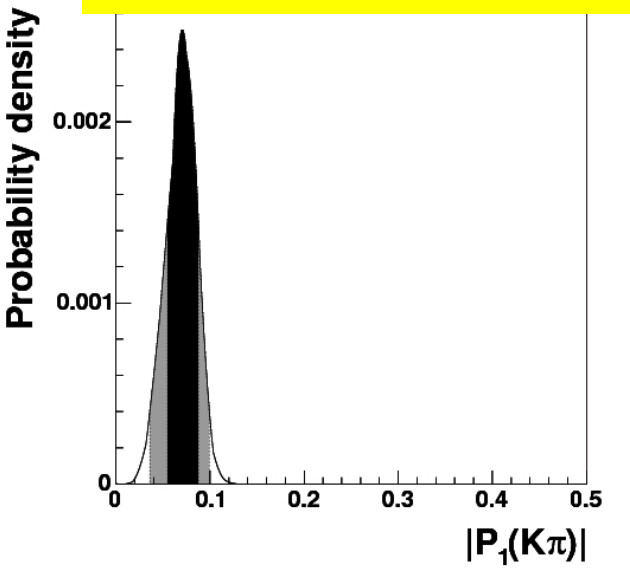
Preliminary

Fit to B→Kπ

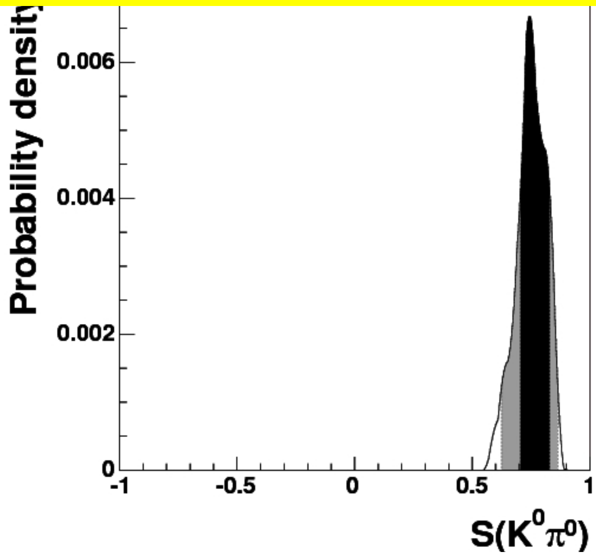
Channel	$BR^{th} \times 10^6$	$BR^{exp} \times 10^6$	$\mathcal{A}_{CP}^{th}$	$\mathcal{A}_{CP}^{exp}$
$K^+\pi^-$	20.1 ± 0.6	19.7 ± 0.7	-0.107 ± 0.018	-0.115 ± 0.018
$K^+\pi^0$	12.9 ± 0.5	12.2 ± 0.8	0.00 ± 0.04	0.04 ± 0.04
$K^0\pi^+$	24.9 ± 1.0	25.3 ± 1.4	0.00 ± 0.04	-0.02 ± 0.02
$K^0\pi^0$	9.9 ± 0.4	11.5 ± 1.0	-0.09 ± 0.06	0.02 ± 0.13

Including the radiative corrections, the discrepancy in the BR is gone. **No more Kπ puzzle!!!!**

$P_1 = 0.071 \pm 0.016$



$\Delta S(K^0\pi^0) = 0.08 \pm 0.06$



Prediction in the Standard Model (exp error on sin2β not included)

Dalitz can help sometimes: an example of how measuring directly amplitudes avoids problems

CPS, hep-ph/0601233

B→K*π Decay Amplitudes

Charming Penguin ~ λ^2 $V_{us}V_{ub}^* \sim \lambda^4$

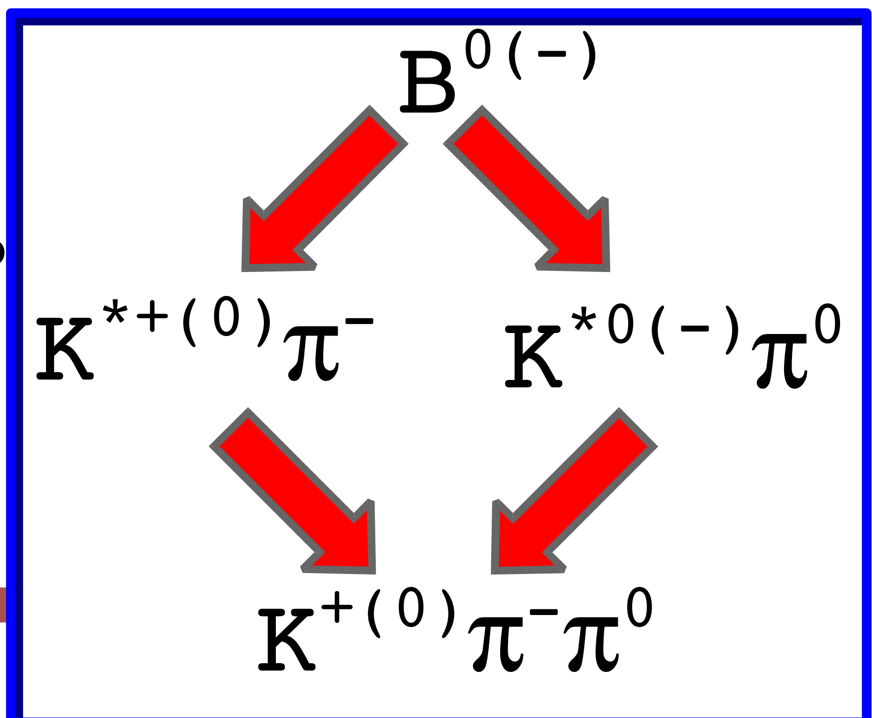
$$A(B^0 \to K^{*+}\pi^-) = V_{ts}V_{tb}^* \times P_1 - V_{us}V_{ub}^* \times \{E_1 - P_1^{GIM}\}$$

$$\sqrt{2}\cdot A(B^0 \to K^{*0}\pi^0) = -V_{ts}V_{tb}^* \times P_1 - V_{us}V_{ub}^* \times \{E_2 + P_1^{GIM}\}$$

$$\sqrt{2}\cdot A(B^+ \to K^{*+}\pi^0) = V_{ts}V_{tb}^* \times P_1 - V_{us}V_{ub}^* \times \{E_1 + E_2 + A_1 - P_1^{GIM}\}$$

$$A(B^+ \to K^{*0}\pi^+) = -V_{ts}V_{tb}^* \times P_1 + V_{us}V_{ub}^* \times \{A_1 - P_1^{GIM}\}$$

- Formally equivalent to B→Kπ decays
- The values of RGI parameters are in principle different respect to Kπ, but equal among K*π (SU(2))
- But we can access abs and arg of the amplitudes through the interference in Dalitz Plots



A new bound on CKM Matrix

It is possible to experimentally access $\Delta I=3/2$ amplitude

from $K^+\pi^-\pi^0$ Dalitz plot

$$A^0 = A(K^{*+}\pi^-) + \sqrt{2}A(K^{0+}\pi^0) = -V_{ub}^* V_{us}(E_1+E_2)$$

$$A^+ = A(K^{*+}\pi^0) + \sqrt{2}A(K^{0+}\pi^+) = -V_{ub}^* V_{us}(E_1+E_2)$$

from $K^0\pi^+\pi^0$ Dalitz plot

Assuming (***for the moment***) no EW Penguins, the ratio of these quantities and their CP conjugated measure γ

Same argument applies to higher K* resonances

$$R^0 = \frac{\overline{A}^0}{A^0} = \frac{V_{ub} V_{us}^*}{V_{ub}^* V_{us}} = e^{-2i\gamma} = \frac{A^-}{A^+} = R^{\mp}$$

Experimental Problems (I)

Since the final states are self-tagging, relative phase between B and $\overline{B}$ Dalitz plots is not measurable (i.e. there are two arbitrary phases).

- **For $K^+\pi^-\pi^0$**
  - Fix the two arbitrary phases such that $A(K^{*+}\pi^-)$ and $A(K^{*-}\pi^+)$ have the same phase
  - Measure the relative phase in the CP eigenstate Dalitz plot $B\to K^0\pi^+\pi^-$, where the two process indirectly interfere

In this way we get

$$R^0 = e^{-2i\gamma + Arg(A(K^{*+}\pi^-)) - Arg(A(K^{*-}\pi^+))}$$

and the **error on CKM** has two sources but it is **½ the error on R (!!!)**

Experimental Problems (II)

- **For $K^0\pi^-\pi^0$**
  - **Clean (but less powerful?):** one can use SU(2) relation

$$A(K^{*+}\pi^-)+\sqrt{2}A(K^{*0}\pi^0)=A^+=A(K^{*+}\pi^0)+\sqrt{2}A(K^{*0}\pi^+)$$

in this way the sensitivity to CKM terms is lost to indirectly determine the strong phase. But we still have the other K* resonances.

  - **Model dependent method:** since $K^{*0+}\pi^+$ is penguin dominated, one can write

$$Arg(A(K^{*0}\pi^+))=\beta_s+Arg(1+\frac{V^*_{ub}V_{us}}{V^*_{tb}V_{ts}}\Delta_+e^{i\delta_+})$$

where $\Delta_+=(A_1-P_1^{GIM})/P_1$ is $O(1)$ correction, the ratio of CKM terms is $O(\lambda^2)$, β_s is the B_s mixing phase and the dependence on $\bar{\rho}$ and $\bar{\eta}$ is known

Inclusion of EW Penguins

EW penguins are suppressed $\sim\alpha_{em}$ respect to strong penguins but they are enhanced by λ^{-2} respect to $\Delta I=3/2$ amplitude They provide an O(1) correction. We use

$$Q_9=\frac{3}{2}\left(Q_1^{suu}-Q_1^{scc}\right)+3Q_1^{scc}-\frac{1}{2}Q_3^s \quad ; \quad Q_{10}=\frac{3}{2}\left(Q_2^{suu}-Q_2^{scc}\right)+3Q_2^{scc}-\frac{1}{2}Q_4^s$$

to write

Q_7 and Q_8 neglected
$|C_{7,8}| \ll |C_{9,10}|$

$$H_{eff}\propto\left(V_{ub}^*V_{us}C_1-\frac{3}{2}V_{tb}^*V_{ts}C_9\right)\left(Q_1^{suu}-Q_1^{scc}\right)+\left(V_{ub}^*V_{us}C_2-\frac{3}{2}V_{tb}^*V_{ts}C_{10}\right)\left(Q_2^{suu}-Q_2^{scc}\right)-V_{tb}^*V_{ts}H_{peng}^{\Delta I=1/2}$$

R becomes
$$R^0 = R^{\mp} = e^{-2i\gamma+Arg\left(1+\kappa_{EW}\right)}$$

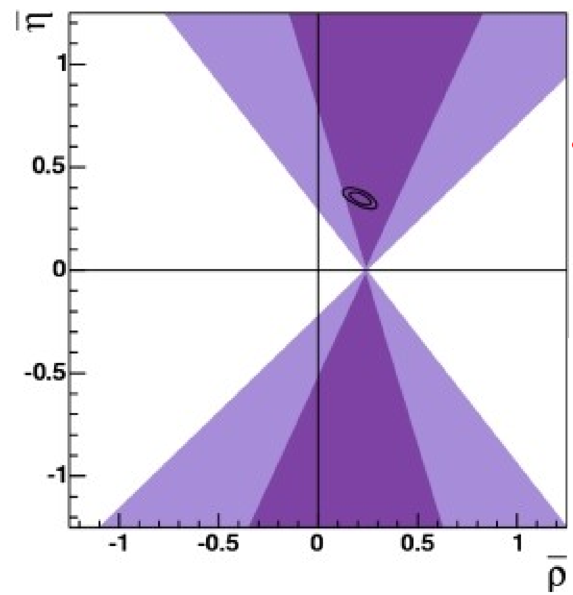
where
$$\kappa_{EW}=-\frac{3}{2}\frac{C_9+C_{10}}{C_1+C_2}\frac{V_{tb}^*V_{ts}}{V_{ub}^*V_{us}}=\frac{3}{2}\frac{C_9+C_{10}}{C_1+C_2}\left(1+\frac{\left(1-\lambda^2/2\right)^2}{\lambda^2\left(\bar{\rho}+i\bar{\eta}\right)}\right)$$

Bound on CKM from Arg(R^0)

BaBar, hep-ex/0408073

A measurement of $B^0 \to K^+\pi^-\pi^0$ Dalitz exists, which determines both K* and K*(1430) and provides Arg(R0) with an error of 18°. We do not have $\overline{K}^0\pi\pi$ Dalitz plot yet, so the relative phase of B and $\overline{B}$ cannot be fixed

We can assume **a perfect agreement to SM and ...**

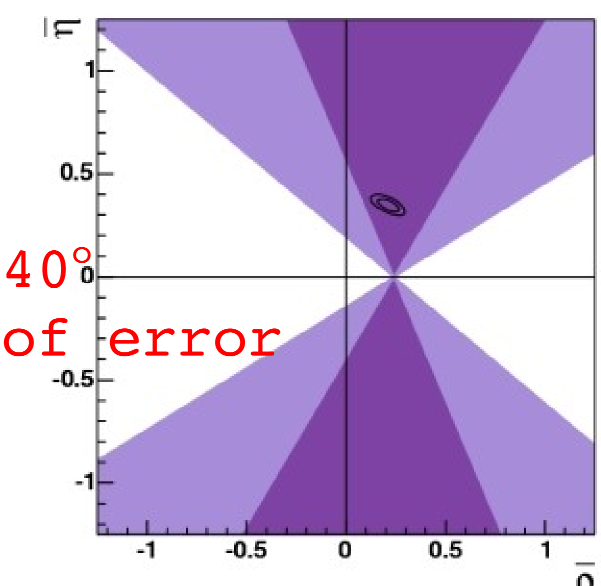


...20° of error

crossing point

$$\overline{\rho_0} = -\frac{3}{2}\,\frac{C_9 + C_{10}}{C_1 + C_2 + C_9 + C_{10}}\,\frac{(1-\lambda^2/2)^2}{\lambda^2}$$

The precision is already comparable to γ from DK



...40° of error

Possible improvements

- fitting directly for R (cancellation of systematics)
- using all BaBar & Belle current data
- adding charged modes

What New Physics can do

(assuming that NP does not enters at tree-level)

NP can affect the Coefficients of EW penguins

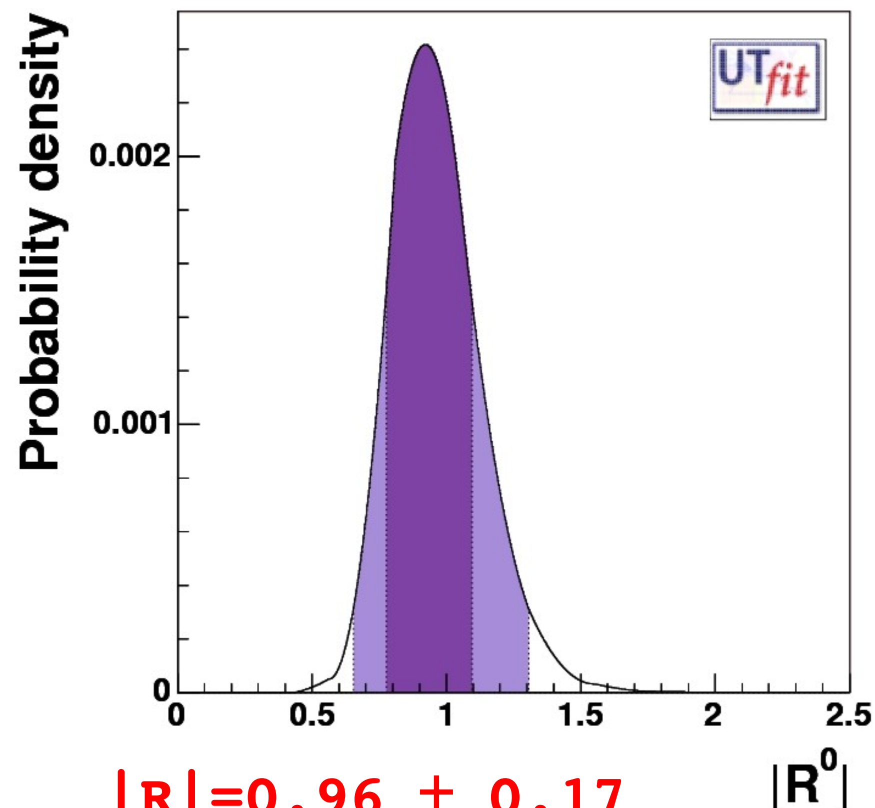
The analysis of R^0 is unchanged, but NP will modify the value of the phase

NP can modify the hierarchy between EW and strong penguins (respecting $C_{7,8} \ll C_{9,10}$)

The phase of κ_{EW} will change, breaking the relation between Arg(R) and $\bar{\rho}$, $\bar{\eta}$

NP can modify the hierarchy among EW penguins ($C_{7,8} \sim C_{9,10}$)

the new $\Delta I=3/2$ operators will break the relation between R and $\bar{\rho}$, $\bar{\eta}$. In particular, $|R| \neq 1$ is expected



$|R| = 0.96 \pm 0.17$