Extracting $\alpha = \varphi_2$ from charmless B-decays: status and perspectives

Introduction

$\pi^+\pi^-$: general framework

Constraints from BaBar & Belle
and the $K\pi/\pi\pi$ ratio

Other modes

Conclusion

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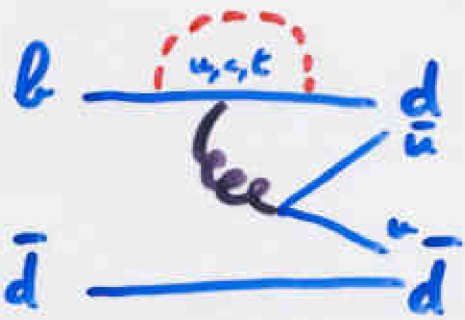
Penguin pollution

$V_{ub}V_{ud}^*$



$V_{ub}V_{ud}^*, V_{cb}V_{cd}^*, V_{tb}V_{td}^*$

short-distance suppression: $\frac{c_4}{c_1} \sim 0.04$

CKM enhancement: $\left|\frac{V_{td}V_{tb}}{V_{ud}V_{ub}}\right| \sim 3$

there may be long-distance contributions that could make sizable/large penguin contractions

for example large BR's are found for $B \to K\pi$ penguin-dominated modes compared to $B \to \pi\pi$ (CLEO, BaBar, Belle)

Many strategies to get α

Phenomenological approaches

- SU(2) isospin symmetry and $B \to \pi^\pm \pi^0, \pi^0 \pi^0$
  (Gronau - London)
- SU(3) and $B_{d,s} \to K\pi, K\bar{K}$
  (Silva - Wolfenstein, Gronau et al., Buras, Fleischer ...)

Theoretical approaches

- factorization à la BBNS
  $m_b \to \infty$ + $\mathcal{O}(\alpha_s)$ corrections
- pQCD approach
  ↳ E. Kou

⊕ theoretical input minimized

⊖ discrete ambiguities
experimentally challenging

⊕ more constraints
easier for experimentalists (just fit!)

⊖ need to control precisely the theoretical errors

Here:

1) back to basics: observables / parameters
2) what can we learn from BaBar and Belle first measurements
3) remarks on other modes

Observables

$$\Gamma\left(B^0(t)\to\pi^+\pi^-\right)=\mathcal{B}_{\pi^+\pi^-}\times$$
$$\times\left[1+a_{\mathrm{dir}}\cos\Delta m\,t-\sqrt{1-{a_{\mathrm{dir}}}^2}\,\sin 2\alpha_{\mathrm{eff}}\sin\Delta m\,t\right]$$

↪ Three observables

$\mathcal{B}_{\pi^+\pi^-}$	*CP*-averaged branching ratio, *CP*-conserving
a_{dir}	direct *CP*-violation, $a_{\mathrm{dir}}\xrightarrow{P\to0}0$
$\sin 2\alpha_{\mathrm{eff}}$	mixing-induced *CP*-violation $\sin 2\alpha_{\mathrm{eff}}\xrightarrow{P\to0}\sin 2\alpha$

Parameters

$$\begin{aligned} A &= V_{ud}V_{ub}^{*}M^{(u)} + V_{cd}V_{cb}^{*}M^{(c)} + V_{td}V_{tb}^{*}M^{(t)} \\ &= e^{-i\alpha}T + P \\ \overline{A} &= e^{+i\alpha}T + P \end{aligned}$$

T = tree + « u-penguin » − « c-penguin »

P = « t-penguin » − « c-penguin »

↪ four real parameters

CP-conserving: $|T|$, $|P|$, $\delta = \arg(PT^{*})$
CP-violating: α

Exact equations

$$\cos(2\alpha - 2\alpha_{\rm eff}) = \frac{1}{\sqrt{1 - a_{\rm dir}{}^2}} \left[1 - \left(1 - \sqrt{1 - a_{\rm dir}{}^2} \cos 2\alpha_{\rm eff} \right) \left| \frac{P}{T} \right|^2 \right]$$

$$|P|^2 = \frac{\mathcal{B}_{\pi^+\pi^-}}{1 - \cos 2\alpha} \left[1 - \sqrt{1 - a_{\rm dir}{}^2} \cos(2\alpha - 2\alpha_{\rm eff}) \right]$$

$$|T|^2 = \frac{\mathcal{B}_{\pi^+\pi^-}}{1 - \cos 2\alpha} \left[1 - \sqrt{1 - a_{\rm dir}{}^2} \cos 2\alpha_{\rm eff} \right]$$

$$\tan\delta = \frac{a_{\rm dir} \, \tan\alpha}{1 - \sqrt{1 - a_{\rm dir}{}^2} \left[\cos 2\alpha_{\rm eff} + \tan\alpha \sin 2\alpha_{\rm eff} \right]}$$

Bounding the error $|2\alpha - 2\alpha_{\rm eff}|$

$$|2\alpha - 2\alpha_{\rm eff}| \;\leq\; \arccos\left[\frac{1}{\sqrt{1-a_{\rm dir}^2}}\left(1 - 2\frac{\mathcal{B}_{\pi^0\pi^0}}{\mathcal{B}_{\pi^\pm\pi^0}}\right)\right]$$

SU(2) (Grossman-Quinn)

$$|2\alpha - 2\alpha_{\rm eff}| \;\leq\; \arccos\left[\frac{1}{\sqrt{1-a_{\rm dir}^2}}\left(1 - 2\lambda^2\,\frac{\mathcal{B}_{K^\pm\pi^\mp}}{\mathcal{B}_{\pi^+\pi^-}}\right)\right]$$

SU(3) + ...

this SU(3) bound comes from

$$\left|P(\pi^+\pi^-)\right| = \left|P_{(K^+\pi^-)}\right| \times \lambda \sin\gamma/\sin\alpha$$

that is

- SU(3) flavor symmetry

- neglect of OZI-suppressed annihilation penguin diagrams

$\simeq 0$

$$\leq$$

dominant (factorizable) $\cancel{SU(3)}$ correction

$$P_{\pi\pi} = \frac{f_\pi}{f_K} P_{K\pi} \times \lambda \sin\gamma / \sin\alpha$$

↳ the bound in the strict SU(3) limit is a conservative one!

order of magnitude w.r. to dominant penguin

$$\frac{\Lambda_{QCD}}{m_B} \times \frac{a_3 \text{ or } a_5}{a_4 \text{ or } a_6} \sim 2-4\,\%$$

difficult to find a model in which
this bound is violated!

Constraints from BaBar and Belle data

$S_{\pi\pi} = \sqrt{1 - a_{dir}^2}\ \sin 2\alpha_{eff} \qquad C_{\pi\pi} = a_{dir}$

BaBar

$S_{\pi\pi} = -0.01 \pm 0.37 \pm 0.07 \qquad C_{\pi\pi} = -0.02 \pm 0.29 \pm 0.07$

Belle

$S_{\pi\pi} = -1.21^{+0.38\,+0.16}_{-0.27\,-0.13} \qquad C_{\pi\pi} = -0.94^{+0.31}_{-0.25} \pm 0.09$

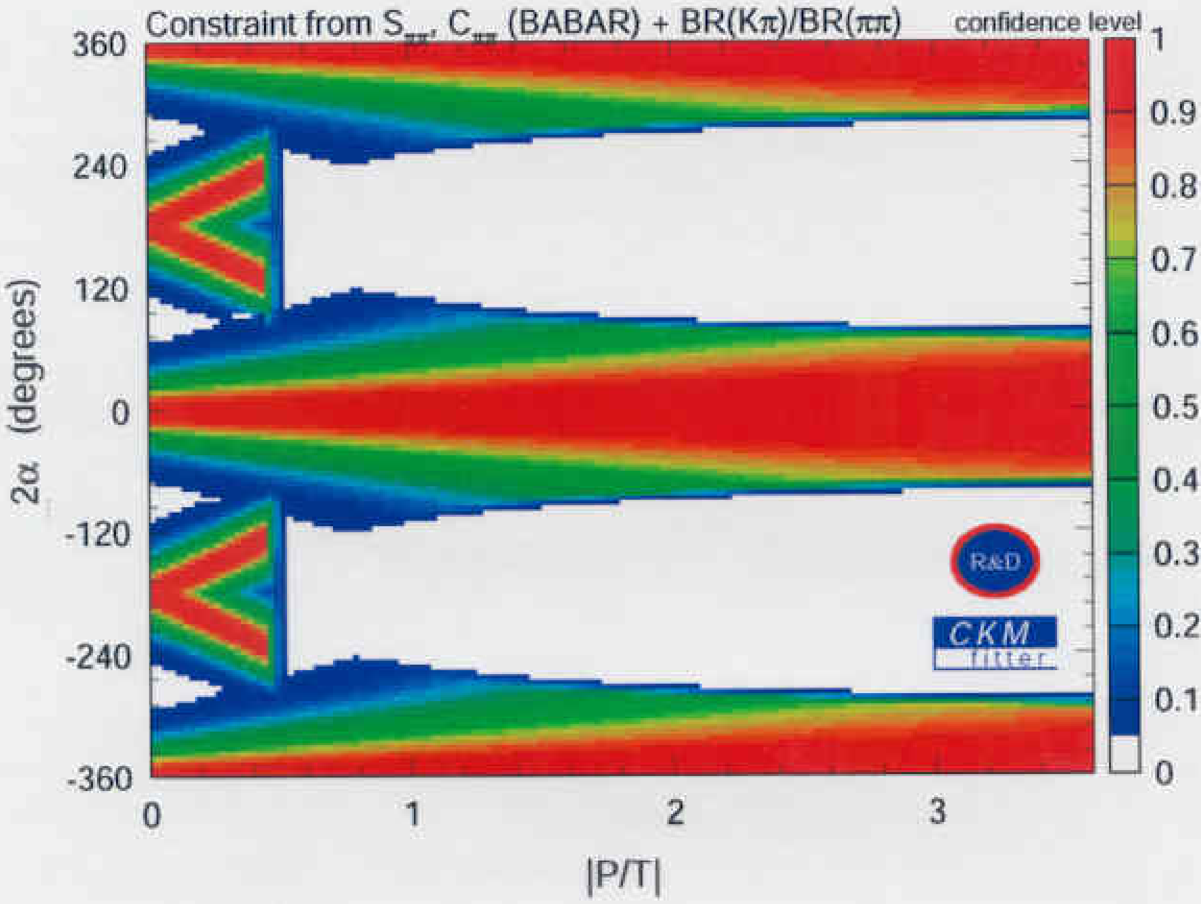
what can we learn from these data and the SU(3) bound?

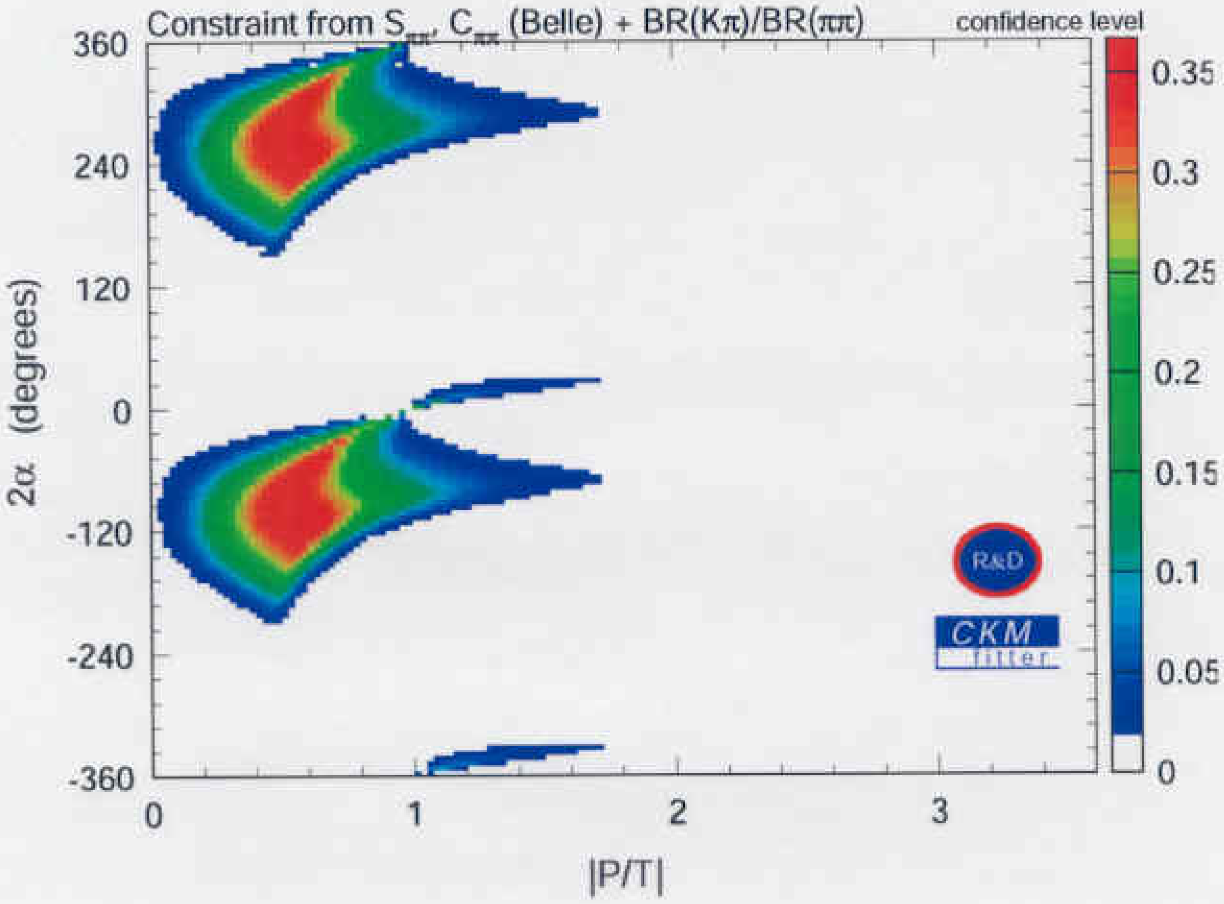
↳ CKM fitter

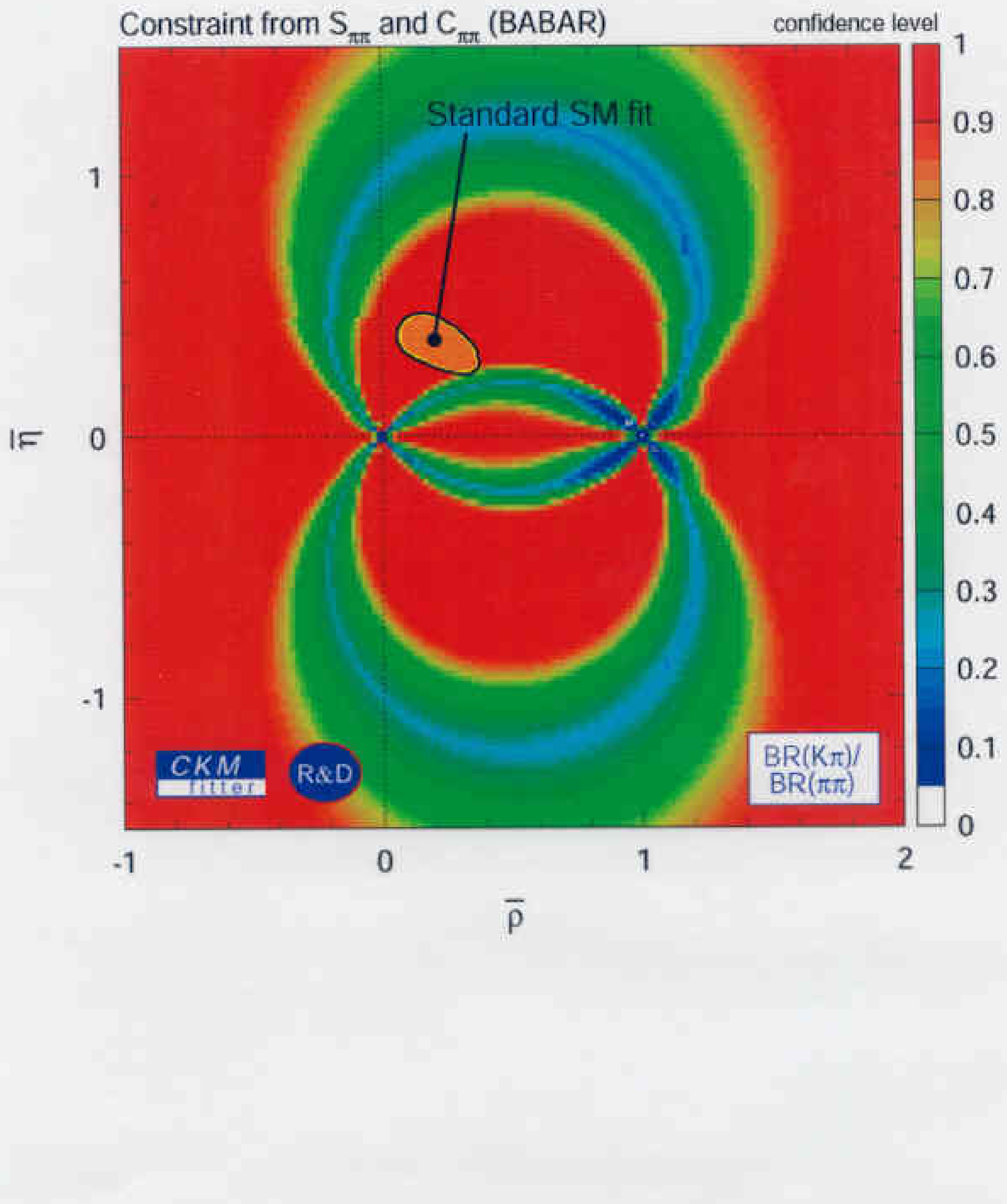
a fit program based on a frequentist approach

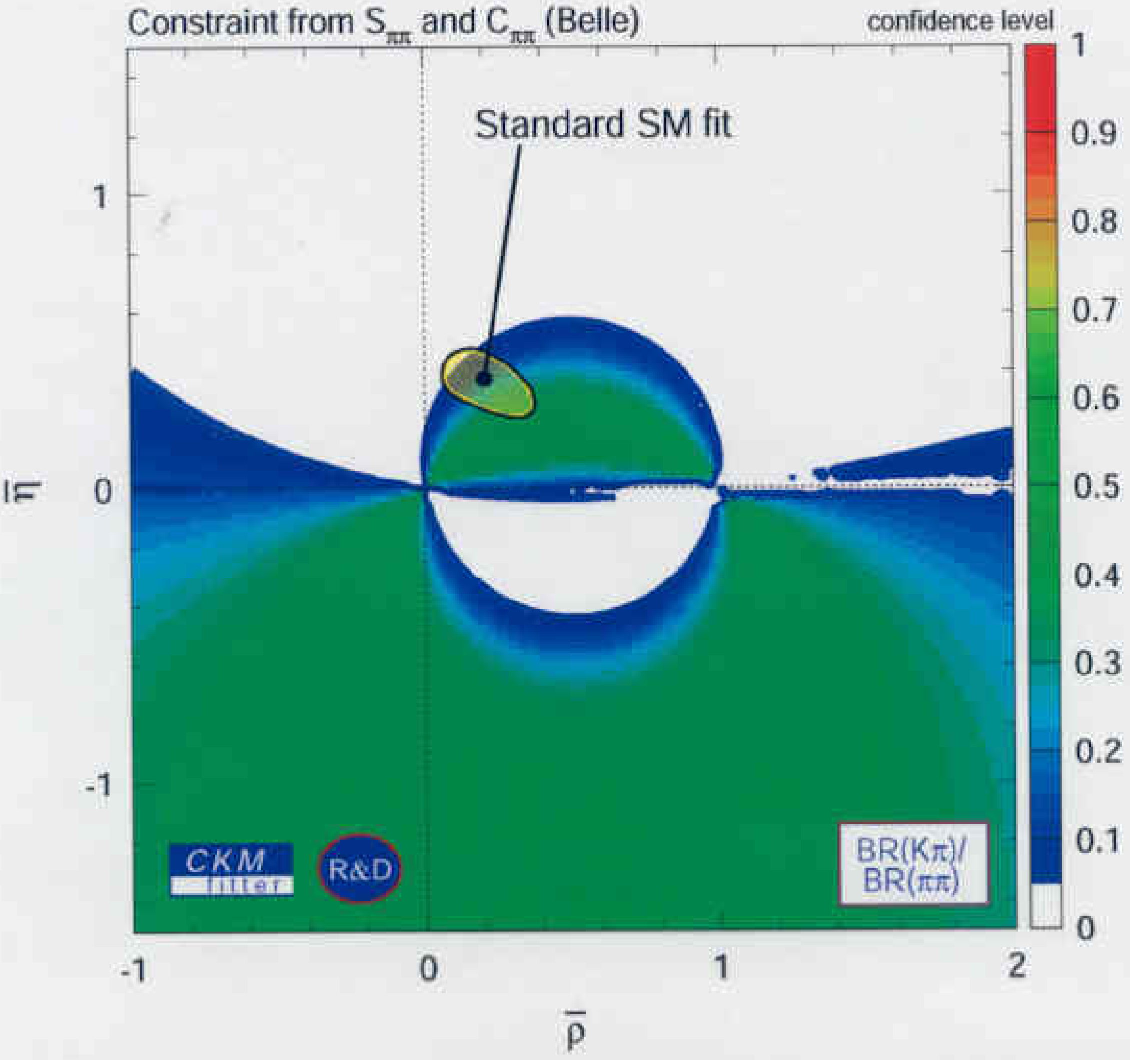
see A. Höcker
H. Lacker
S. Laplace
F. Le Diberder
J. Ocariz

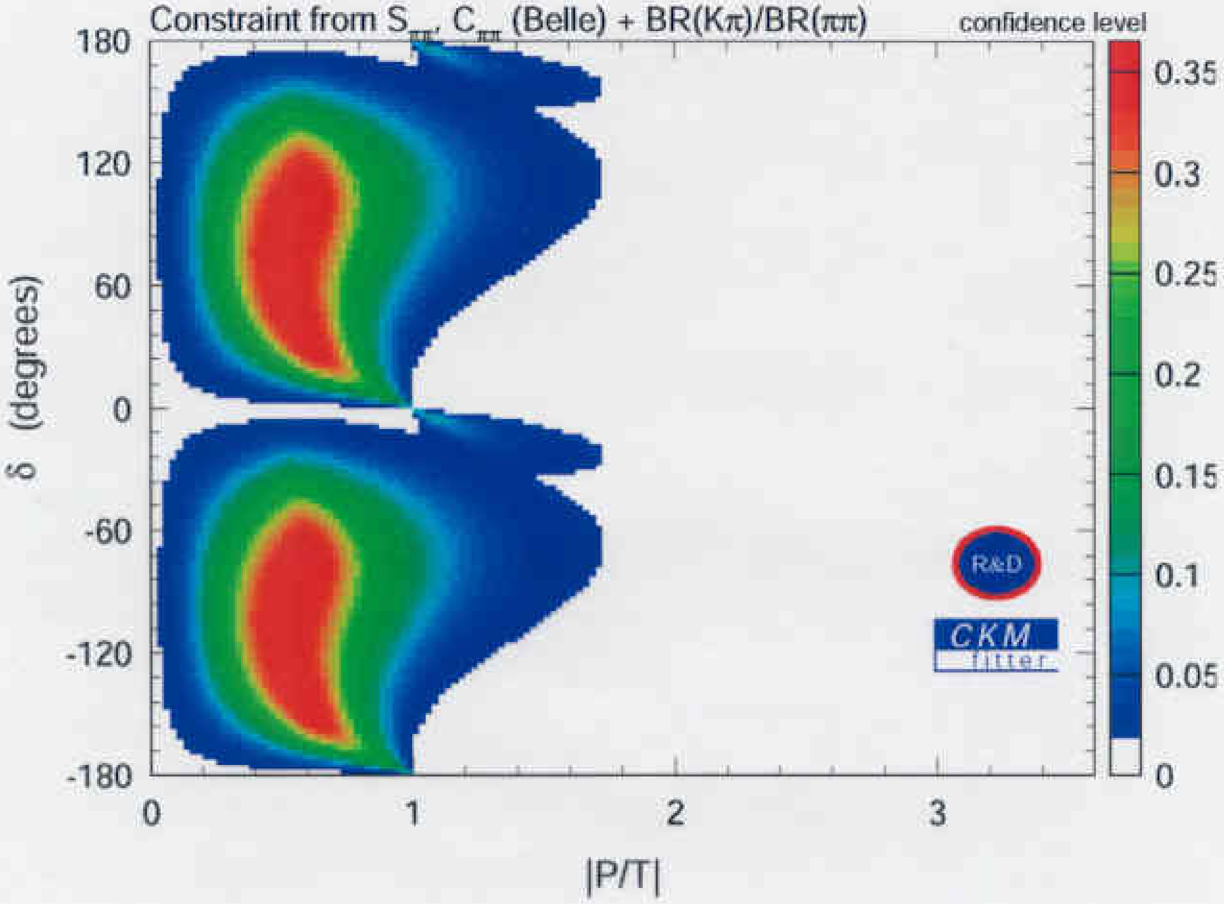
http://ckmfitter.in2p3.fr


Constraint from $S_{\pi\pi}$, $C_{\pi\pi}$ (BABAR) + BR(Kπ)/BR(ππ)
confidence level
2α (degrees)
360
240
120
0
-120
-240
-360
|P/T|
0
1
2
3
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
R&D
CKM
fitter


Constraint from $S_{\pi\pi}$, $C_{\pi\pi}$ (Belle) + BR(Kπ)/BR($\pi\pi$)
confidence level
360
240
120
0
-120
-240
-360
2α (degrees)
0
1
2
3
|P/T|
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
R&D
CKM
fitter


Constraint from $S_{\pi\pi}$ and $C_{\pi\pi}$ (BABAR)
confidence level
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Standard SM fit
$\bar{\eta}$
1
0
-1
-1
0
1
2
$\bar{\rho}$
CKM fitter
R&D
BR(Kπ)/
BR(ππ)


Constraint from $S_{\pi\pi}$ and $C_{\pi\pi}$ (Belle)
confidence level
Standard SM fit
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
$\bar{\eta}$
1
0
-1
-1
0
1
2
$\bar{\rho}$
CKM fitter
R&D
BR(Kπ)/
BR(ππ)


Constraint from S_ππ, C_ππ (Belle) + BR(Kπ)/BR(ππ)
confidence level
180
120
60
0
-60
-120
-180
δ (degrees)
0
1
2
3
|P/T|
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
R&D
CKM
fitter

Other modes

- $B \to \rho\pi \to \pi^+\pi^-\pi^0$ resonant decay
  (Snyder-Quinn)

  ⊕ a lot of information thanks to $\rho^+/\rho^-/\rho^0$ interference effects
  → α without discrete ambiguities
  penguin pollution

  ⊖ experimentally very challenging
  need to understand higher resonance and non-resonant contributions

- $B \to a_0\pi \to \eta\pi^+\pi^-$ resonant decay
  (Dighe-Kim, Shelkov-Laplace)

  ⊖ would need $\eta\pi^0\pi^0$ to disentangle penguins
  dominant transition is $(B \to a_0)\,\pi$,
  $(B \to \pi)\,a_0$ is suppressed:

$$\begin{tikzcd} B^0 \arrow[r] \arrow[d, dashed] & a_0^- \; \pi^+ \\ \overline{B}^0 \arrow[ur] & \end{tikzcd}$$

interference effects are negligible

Conclusion

- getting α with a really controlled theo./exp. error still is an open problem
- large direct $\cancel{CP}$ in $B \to \pi^+\pi^-$ would really help (the worst case being large real penguins)
- ultimately, and hopefully, a well defined consistent theoretical framework could be used as a base for global fits (BBNS or pQCD?)
- other modes may require several years of data taking