THEORY ISSUES IN MEASURING γ

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Introduction

γ from tree $B_{(s)}$ decays

γ from penguin $B_{(s)}$ decays

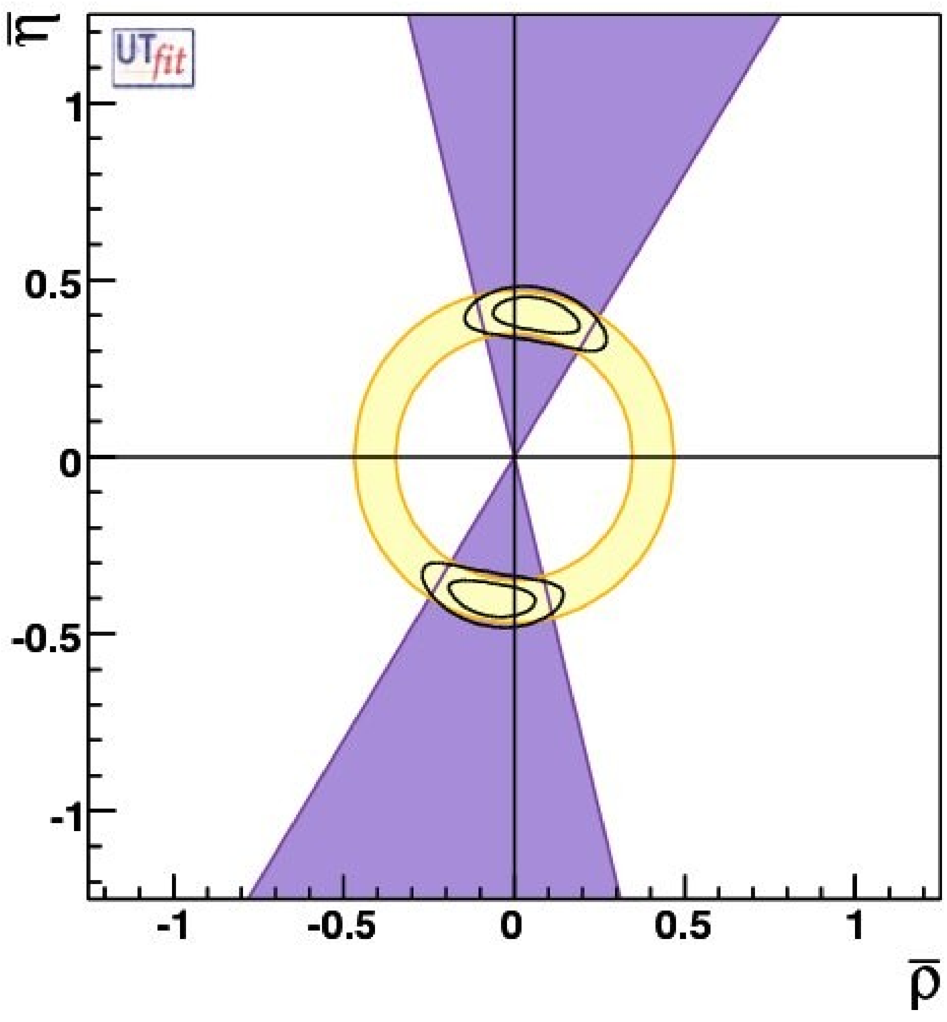
Extracting the tree from penguin B_s decays

Conclusions

INTRODUCTION - I

- The extraction of γ from tree-level decays is of fundamental importance for NP searches:
  - Fix ρ and η from tree-level V_{ub} and γ: insensitive to loop-mediated NP
  - Determine NP contributions to loop-mediated FCNC and CPV (meson mixing, penguin decays,...)
- Precision measurement of γ needed to fully exploit the constraining power of K and B mixing

INTRODUCTION - II



- Impressive achievement of B-factories: tree-level determination of the UT
- *Allows to constrain new CPV in K and B_d mixing at the 10% level*

INTRODUCTION - III

- The extraction of γ from penguin decays is sensitive to NP
- Some knowledge of hadronic parameters is necessary
- Several strategies based on hadronic models and/or flavour symmetries
- Quantifying hadronic uncertainties is the main issue

γ FROM TREE DECAYS

- Basic idea: use interference between $b \to c\bar{u}q$ and $b \to u\bar{c}q$ decays, with $q=d,s$.
- No penguins present: no loop-mediated NP
- Methods can be classified according to the charge of the decaying B meson and to the final state f in which the D meson is reconstructed

γ FROM TREE DECAYS - $B^{\pm}$

- Use interference between $B^{\pm} \to D_f K^{\pm}$ and $B^{\pm} \to \bar{D}_f K^{\pm}$, with f a common final state for D and $\bar{D}$
- Define $A(DK^{+})/A(\bar{D}K^{+}) = r_B e^{i(\delta B+\gamma)}$, with $r_B = 0.37\ |\bar{C}+A|/|T+C|$.
- Ratio of hadronic matrix elements difficult to estimate, expect $r_B \sim 0.1$.

γ FROM TREE DECAYS - $B^{\pm}$

- GLW: use f $CP^{\pm}$ eigenstate, measure

$$R_{CP\pm} = \frac{\Gamma(B^+ \to D^0_{CP\pm} K^+) + \Gamma(B^- \to D^0_{CP\pm} K^-)}{\Gamma(B^+ \to D^0 K^+) + \Gamma(B^- \to \bar{D}^0 K^-)} = 1 + {r_B}^2 \pm 2 r_B \cos\gamma \cos\delta_B$$

$$A_{CP\pm} = \frac{\Gamma(B^+ \to D^0_{CP\pm} K^+) - \Gamma(B^- \to D^0_{CP\pm} K^-)}{\Gamma(B^+ \to D^0_{CP\pm} K^+) + \Gamma(B^- \to D^0_{CP\pm} K^-)} = \frac{\pm 2 r_B \sin\gamma \sin\delta_B}{R_{CP\pm}}$$

extract r_B and γ with a four-fold ambiguity

Gronau & Wiler 91; Gronau & London 91

- ADS: f non CP eigenstate. Define

Atwood, Dunietz & Soni 97, 01

$A(D\to f)/A(D\to \bar{f}) = r_D e^{i\delta D}$ and measure

$$R_{ADS} = \frac{\Gamma(B^+ \to \bar{f} K^+) + \Gamma(B^- \to f K^-)}{\Gamma(B^+ \to f K^+) + \Gamma(B^- \to \bar{f} K^-)} = r_D^2 + {r_B}^2 + 2 r_B r_D \cos\gamma \cos(\delta_B + \delta_D)$$

$$A_{ADS} = \frac{\Gamma(B^- \to f K^-) - \Gamma(B^+ \to \bar{f} K^+)}{\Gamma(B^- \to f K^-) + \Gamma(B^+ \to \bar{f} K^+)} = r_B r_D [\cos(\delta + \gamma) + \cos(\delta - \gamma)] / R_{ADS}.$$

γ FROM TREE DECAYS - $B^{\pm}$

- γ, r_B and δ_B are common to all final states f
- r_{Df} can be measured from D decays, so for each f add one unknown (δ_{Df}) and two observables (R_f and A_f)
- The same analysis can be repeated for D* or K*
- Add as many final states as possible!

γ FROM TREE DECAYS - $B^{\pm}$

- GGSZ: use Dalitz analysis of multi-body CP eigenstate final states (equivalent of measuring a continuum of final states)
- model-dependent approach: fit $A(D \to f)$ from the Dalitz plot
- model-independent approach: bin the Dalitz plot and determine the D decay strong phase from the B decay data. Need much more statistics and/or $D\bar{D}$ data.

Giri, Grossman, Soffer & Zupan 03

γ FROM TREE DECAYS - B_d

- Can use DK final states also for B_d decays
- Define $A(DK^0)/A(\bar{D}K^0)=r_{B0}e^{i(\delta B0+\gamma)}$, with $r_{B0}=0.37\ |\bar{C}|/|C|$ expected around $r_{B0}\sim0.4$
- If final state is self-tagging (e.g. $K^{*0} \to K^+\pi^-$) no B_d mixing
- If final state admits mixing (e.g. $B^0 \to D^- K^0 \pi^+$) need a time-dependent analysis, measure $2\beta + \gamma$

Kayser & London 00; Atwood & Soni 03; Fleischer 03; Gronau et al. 04

γ FROM TREE DECAYS - B_s

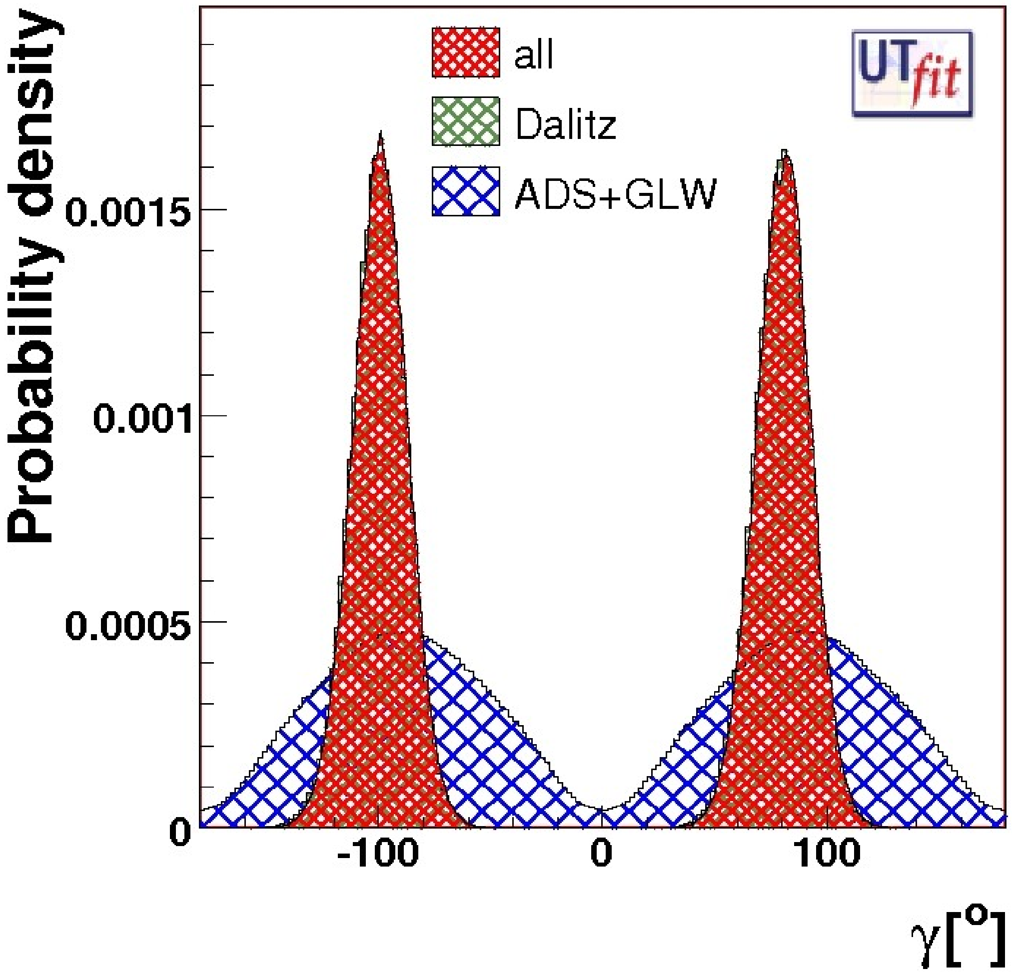
- A time-dependent analysis of $B_s \to D_s^{\pm} K^{\pm}$ gives access to $\phi_s + \gamma$

Dunietz & Sachs 88; Aleksan, Dunietz & Kaiser 92; Dunietz 98

- Combining this with the measurement of the B_s mixing phase ϕ_s one can extract γ
- There is however an eightfold ambiguity (fourfold if $\Delta\Gamma_s$ effects are observable)
- The ambiguity can be resolved using SU(3) related $B_d \to D^{\pm}\pi^{\pm}$ decays

Fleischer 03

γ FROM TREE DECAYS TODAY



- Combining all results gives

$$\gamma = (80 \pm 13)^\circ$$

$$r_B = 0.10 \pm 0.02$$

$$r_B^* = 0.09 \pm 0.04$$

- Theory error is (and will remain in the future) negligible

γ FROM PENGUIN DECAYS

- Idea: extract γ using the interference of tree (V_{ub}) and penguin (V_{tb}) amplitudes
- Sensitive to NP contributions to penguins
- Need some control of hadronic matrix elements
- The main issue is the determination of hadronic uncertainties: theoretical errors are dominant in this case

γ FROM $B \to K\pi$

- Quark level transition is $b \to s\, q\, \bar{q}$ (q=u,d)
- $V_{ub}V_{us}^*$ contribution is doubly Cabibbo suppressed w.r.t. $V_{tb}V_{ts}$: interference effects expected at the level of 10% or smaller
- Six independent hadronic matrix elements $\Rightarrow$ 11 real hadronic parameters + γ
- 9 observables, 2 quadrangular isospin relations $\Rightarrow$ need some theory input

γ FROM $B \to K\pi$ - II

- Most popular approaches: neglect of some contributions (annihilations, electroweak penguins, ...) and/or $B \to \pi\pi$ plus flavour symmetries

  Fleischer 96; Fleischer & Mannel 98; Fleischer 99; Atwood & Soni 98; Gronau & Rosner 98, 02; Neubert & Rosner 98; Neubert 99; Buras & Fleischer 99, 00;Kim, Oh & Yoon 07; ...

- Theoretical error can only be guessed: no way to check it on data

- Cannot conclude from vanishing CP asymmetries that one amplitude dominates: can be just due to vanishing strong phases

γ FROM $B_s \to KK$ and $B \to \pi\pi$

- Using SU(3) can combine $B_s \to KK$ and $B \to \pi\pi$ to obtain a determination of γ

Fleischer 99; Fleischer & Matias 02 London, Matias & Virto 05; Baek, London, Matias & Virto 06; ...

- The same considerations on hadronic uncertainties apply here: to estimate the theory error need to quantify the amount of SU(3) (U-spin) breaking

γ FROM $B_s \to K^*\pi$

- Idea: isolate tree decay amplitude using a Dalitz plot analysis and extract its phase
- Quark level transition is $b \to d\,\bar{q}\,q$ (q=u,d)
  - tree contribution ($V_{ub}\,V_{ud}^*$) is not Cabibbo suppressed w.r.t. $V_{tb}V_{td}^*$
  - electroweak penguins are negligible
- Analogous to the extraction of α from $B_d \to \rho\pi$ decays

Ciuchini, Pierini & L.S. 06;
Gronau, Pirjol, Soni & Zupan 06, 07

γ FROM $B_s \to K^*\pi$ - II

- Extract γ using the following amplitude isospin relations:

$$A_s = A(B_s \to K^{*-}\pi^+) + \sqrt{2}\,A(B_s \to \bar{K}^{*0}\pi^0) = -V_{ub}^* V_{ud}(E_1 + E_2)$$
$$\bar{A}_s = A(\bar{B}_s \to K^{*+}\pi^-) + \sqrt{2}\,A(\bar{B}_s \to K^{*0}\pi^0) = -V_{ub} V_{ud}^*(E_1 + E_2)$$

$$R_s = \frac{\bar{A}_s}{A_s} = \frac{V_{ub} V_{us}^*}{V_{ub}^* V_{us}} = e^{-2i\gamma}$$

- $A(B_s \to K^{*-}\pi^+)$ and $A(B_s \to \bar{K}^{*0}\pi^0)$ can be extracted from $B_s \to K^-\pi^+\pi^0$ Dalitz plot, and the conjugate amplitudes from $\bar{B}_s \to K^+\pi^-\pi^0$

γ FROM $B_s \to K^*\pi$ - III

- To obtain the relative phase of the $B_s \to K^- \pi^+\pi^0$ and $\bar{B}_s \to K^+\pi^-\pi^0$ Dalitz plots, use the $B_s \to K_S\, \pi^+ \pi^-$ Dalitz plot, exploiting interference of $K^{*+}\pi^-$ and $K^{*-}\pi^+$ with $\rho^0 K_S$ and other $\pi^+ \pi^-$ resonances.
- At hadron colliders, the sensitivity is given by the Re $\lambda\, \Delta\Gamma_s/\Gamma_s$ term in the time-integrated rate ($\lambda = q/p\ \bar{A}/A$). Of course, a time-dependent analysis would also help.

CONCLUSIONS

- The extraction of γ from tree-level amplitudes plays a crucial role in looking for NP in the flavour sector
- Theory uncertainties are negligible in tree-level decays
- Tree-level amplitudes can be successfully isolated in $B_s \to K^* \pi$ decays – same procedure as in $B_d \to \rho\pi$

CONCLUSIONS - II

- The extraction of γ from the interference of tree and penguin amplitudes looks much more problematic
- Some theoretical input needed to reduce the number of unknown hadronic parameters
- Theoretical uncertainties very difficult to estimate, cannot be verified using data
- Use penguin channels to look for NP in penguin amplitudes, taking γ as input!