TAKE HOME MESSAGE

• $\gamma$ from $B \rightarrow DK$ is theoretically extremely clean
• it is an interesting observable to measure precisely
OUTLINE

• brief outline of the $B \to DK$ methods
• what is the ultimate theory error?
  • electroweak corrections
• “the ultimate test of (MFV) NP”

Pirjol, JZ, to appear
OBTAINING GAMMA

• use interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$

MANY FINAL STATE CHOICES

- possible choices for final state $f$ in $D$ decay
  - CP- eigenstate (e.g. $K_S \pi^0$)  
  - flavor state (e.g. $K^+\pi^-$)  
    Atwood, Dunietz, Soni (1997)
  - singly Cabibbo suppressed (e.g. $K^*+K^-$)  
  - many-body final state (e.g. $K_S \pi^+\pi^-$)  
    Poluektov et al. [Belle] (2004)
- other extensions:
  - many body $B$ final states: $B^+ \rightarrow DK^+\pi^0$, $B^0 \rightarrow D\pi^-K^+$  
  - use $D^{0*}$ in addition to $D^0$  
    Bondar, Gershon (2004)
  - use self tagging $D^{0**}$, $D^2$  
  - neutral $B_d$, $B_s$ decays (time dep., time-integr., self-tag)  

see also talk by Stefania Ricciardi
WHY THE METHODS WORK

• many methods: GLW, ADS, Dalitz,…

• one has \( \sim N_D N_B \) measurements, but \( \sim N_D + N_B \) unknowns
  
  - \( \Rightarrow \) can determine \( \gamma \)

• does it make sense to split into “methods”?
  
  - we are really interested in \( \gamma \)

    - combined analysis wins

• “only” benefit of splitting: compare diff. \( \gamma \)

  - check for NP or systematics
WHY MEASURE GAMMA?
WHY MEASURE GAMMA?

- now (= in the age of LHCb and upcoming SFF)
  - theoretically clean extraction of the CKM weak phase
  - standard candle of the CKM
- unlikely there is NP in $\gamma$ (at present precision)
  - search for NP by comparing to other observables
  - can test for consistency in $\gamma$ extraction in $B \rightarrow D K$ itself
TEST FOR NP IN DECAY AMPLITUDES

• extraction of $\gamma$ has a built in test for presence of extra NP in decay ampl.

$$A(B^- \to f_D K^-) \propto r_D e^{i\delta_D} + r_B e^{i\delta_B - \gamma} + r'_B e^{i\delta_B' - \gamma'}$$

$$A(B^+ \to f_D K^+) \propto r_D e^{i\delta_D} + r_B e^{i\delta_B + \gamma} + r'_B e^{i\delta_B' + \gamma'}$$

• thus for $B^+$ and $B^-$ different $r_B$

$$r_{B^+} \to |r_B e^{i\delta_B + \gamma} + r'_B e^{i\delta_B' + \gamma'}|; \quad r_{B^-} \to |r_B e^{i\delta_B - \gamma} + r'_B e^{i\delta_B' - \gamma'}|$$
TEST OF DIRECT CPV NP IN B→DK

• there is NP in B→DK amplitude if

\[ r_{B^-} \neq r_{B^+} \]

• Belle and Babar already measure this

\[ x_\pm = r_B \cos(\gamma \pm \delta_B) \]
\[ y_\pm = \pm r_B \sin(\gamma \pm \delta_B) \]

• even, if \( x_+^2 + y_+^2 = x_-^2 + y_-^2 \) still possible that \( \gamma \) is shifted
IN THE (FAR) FUTURE

• another test: $\gamma$ from $B^\pm \rightarrow DK^\pm$, $B^\pm \rightarrow DK^{*\pm}$, $B^\pm \rightarrow D^*K^\pm$, $B^0 \rightarrow DK^0$, ... all need to coincide!

• NP with contributions of different chirality could for instance give different shifts in $\gamma$

• since the extraction of gamma theoretically clean

• can be used to search for high scale NP when a lot of statistics

• next: what is the scale we could in principle probe?

• how clean? what is the theory error?
THEORY ERRORS ON EXTRACTING GAMMA
THEORY ERRORS

• assume SM
• several sources that can induce a shift in $\gamma$
• most can be avoided
  • with more statistics
    • example: Dalitz plot theory error
  • by modifying equations
    • example: errors from $D - \bar{D}$ mixing
• remain: errors from electroweak corrections
$D - \bar{D}$ MIXING

• in SM $D - \bar{D}$ mixing is CP conserving $\Rightarrow$ the effect is small
• if $D$ decay info. is from flavor tagged $D$ (i.e. from $D^* \rightarrow D \pi$)
  • then only important changes are in the interf. term
  • change in relative phase: $\delta_f \rightarrow \langle \delta_f \rangle$
  • dilutes the interference: $\ldots \rightarrow \ldots \times e^{-\varepsilon}$
• the effect on $\gamma$ is $\varepsilon \sim O(x_D^2/r_f^2, y_D^2/r_f^2)$
  • applies e.g. to GLW, ADS
  • even for doubly Cabibbo supp. $D$ decays the shift $\Delta \gamma < 1^\circ$
• in model indep. Dalitz analysis no changes needed, if everything from $B \rightarrow DK$
  • one already fits for both $\langle \delta_f \rangle$ and $\varepsilon$ by fitting for $c_i, s_i$

Grossman, Soffer, JZ, 2005
$D - \bar{D}$  **MIXING**

- the effect potentially larger, if $D$ decay info from CLEO ($\psi(3770) \rightarrow D\bar{D}$)
- the change since time integr. interv.: $t \in (-\infty, \infty)$
  - the shift in $\gamma$ is now linear in $x_D, y_D$
  - but still small: $\Delta \gamma \leq 2.9^\circ$ ($\leq 0.2^\circ$, if $|A_D|^2$ info. comes from $D^* \rightarrow D \pi$)
- most importantly: $D - \bar{D}$ mixing effects can be incl. exactly if $x_D, y_D$ precisely measured
OTHER ERRORS

• for $\gamma$ from (untagged) $B_s \rightarrow D\phi$ the inclusion of $\Delta \Gamma_s$ depen. important
  • $\Delta \Gamma_s$ needs to be well measured

• QED radiative corrections
  • CP conserv., in principle no effect on $\gamma$

• the remaining (SM) theory error from
  • higher electroweak corrections

Gronau, Grossman, Soffer, Surujon, JZ, 2007
IRREDUCIBLE THEORY
ERROR ON GAMMA

• irreduc. theory error in SM introduced by ew. corrections that change CKM structure
  • if only vertex corrections no effect on $\gamma$ extr.
  • no effect from $Z$ exchange
  • there is effect from box diagrams

\[ \bar{u} \rightarrow \bar{u} b c W \quad \leftrightarrow \quad \bar{u} \rightarrow \bar{u} b s W \]

Pirjol, JZ, to appear
IRREDUCIBLE THEORY
ERROR ON GAMMA

- the shift on $\gamma$ due to the box diagram
- dominant contrib. effectively due to $t$ and $b$ in the loop
- $b \rightarrow us\bar{c}$:
  - tree level $\sim V_{ub}V_{cs}^*$
  - box diagram $\sim (V_{tb}V_{ts}^*)(V_{ub}V_{cb}^*)$
  - same week phase, does not induce $\delta\gamma$
- $b \rightarrow cs\bar{u}$:
  - tree level $\sim V_{cb}V_{us}^*$
  - box diagram $\sim (V_{tb}V_{ts}^*)(V_{cb}V_{ub}^*)$
  - different week phase $\Rightarrow \delta\gamma \neq 0$
IRREDUCEIBLE THEORY ERROR ON GAMMA

• we estimate it in two ways
• integrate both $t$ and $b$ at the same time
  • local operator, but large logs
• resum $\log(m_b/m_W)$ but also nonlocal contribs
  • keep only local ones
• the precision suffices for our purposes

• irreducible theory error on $\gamma$ is
  $\delta\gamma/\gamma < O(10^{-6})$
  • most likely even $\delta\gamma/\gamma \lesssim O(10^{-7})$
ULTIMATE TEST OF MFV

• how high NP scales can we probe using $\gamma$ from $B \rightarrow DK$?
• assuming MFV: can probe $\Lambda \sim 10^2 \text{TeV}$
• assume gen. FV: can probe $\Lambda \sim 10^3 \text{TeV}$
• this is far future of course
  • $O(10^{18})$ $B\bar{B}$ pairs needed
# SOME NUMBERS FOR FUN

<table>
<thead>
<tr>
<th>PROBE</th>
<th>$\Lambda_{\text{NP}}$ for (N)MFV NP</th>
<th>$\Lambda_{\text{NP}}$ for gen. FV NP</th>
<th>No. of $BB$ pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$ from $B\rightarrow DK$</td>
<td>$\Lambda \sim O(10^2 \text{ TeV})$</td>
<td>$\Lambda \sim O(10^3 \text{ TeV})$</td>
<td>$\sim 10^{18}$</td>
</tr>
<tr>
<td>$B\rightarrow \tau\nu$ 1)</td>
<td>$\Lambda \sim O(\text{TeV})$</td>
<td>$\Lambda \sim O(30 \text{ TeV})$</td>
<td>$\sim 10^{13}$</td>
</tr>
<tr>
<td>$b \rightarrow ssd\bar{d}$</td>
<td>$\Lambda \sim O(\text{TeV})$</td>
<td>$\Lambda \sim O(10^3 \text{ TeV})$</td>
<td>$\sim 10^{15}$</td>
</tr>
<tr>
<td>$\beta$ from $B\rightarrow J/\psi K_S$ 2)</td>
<td>$\Lambda \sim O(50 \text{ TeV})$</td>
<td>$\Lambda \sim O(200 \text{ TeV})$</td>
<td>$\sim 10^{12}$</td>
</tr>
<tr>
<td>$K$-$K$ mixing 3)</td>
<td>$\Lambda &gt; 0.4 \text{TeV}(6 \text{TeV})$</td>
<td>$\Lambda &gt; 10^3 \text{TeV}(10^4 \text{TeV})$</td>
<td>now</td>
</tr>
</tbody>
</table>

1) assuming no err. on $f_B$, so that ultimate th. error just from ew. corr.
2) assuming pert. error estimates $\delta\beta/\beta \sim 0.1\%$
3) bounds for Re$C_1$ (Im $C_1$) from UTfitter 0707.0636
CONCLUSIONS

• $\gamma$ extraction from $B \to DK$ is theoretically clean
  • irreducible theory error on $\gamma$ is below $\delta\gamma/\gamma < 10^{-6}$
• measuring $\gamma$ is important
  • standard candle of the SM
  • search for NP
BACKUP SLIDES
SOME SPECIFIC IDEAS FOR LHCB

- a "method": a subset of final states allowing for extr. of $\gamma$
- multibody $B^0 \rightarrow DK^+\pi^-$
  - contains flavor specific $D^*_2 (2460) \rightarrow \bar{D}^0 \pi^-$
  - interf. with other resonances (e.g. $B^0 \rightarrow DK^*$) gives $\gamma$
- many choices for $D \rightarrow f$ still
- equivalent of GLW does not need CP-odd $D \rightarrow K_S \pi^0$ decays (that is difficult for LHCb)


Gershon, Williams, 0909.1495
MORE ON

\[ B^0 \rightarrow D K^+ \pi^- \]

- compared to quasi-two-body \( B^0 \rightarrow D K^{*0} \)
- at least 50% better sensitivity to \( \gamma \)
- extension of model indep. method possible
- double Dalitz plot analysis \( B^0 \rightarrow D K^+ \pi^- \)
  \[ \rightarrow (K_S \pi^+ \pi^-)_{D} K^+ \pi^- \]
- \( B^0 \rightarrow D K^+ \pi^- \) Dalitz still poorly known
- estimates using reasonable models: 20 annual yields of LHCb \( \Rightarrow O(1^\circ) \) error

Gershon, Williams, 0909.1495
Gershon, Poluektov, 0910.5437