CKM GAMMA FROM TREE DECAYS

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TAKE HOME MESSAGE

- γ from $B \to DK$ 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

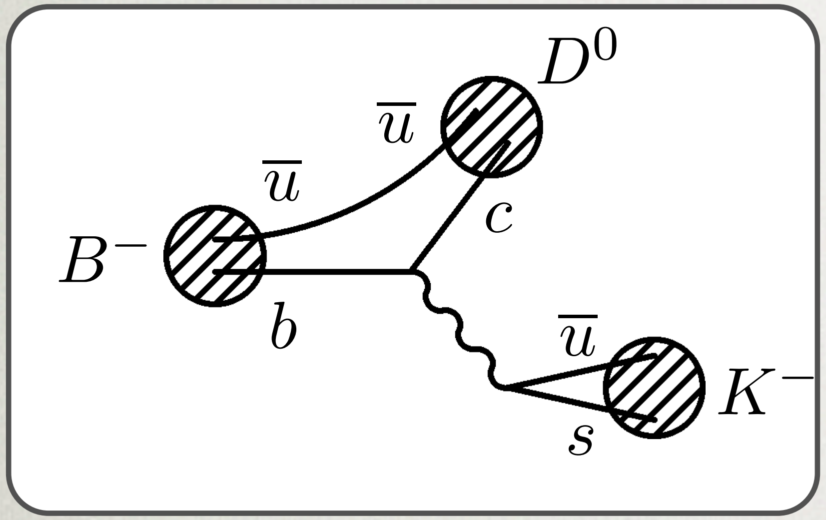
Pirjol, JZ, to appear

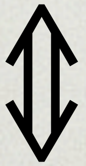
- "the ultimate test of (MFV) NP"

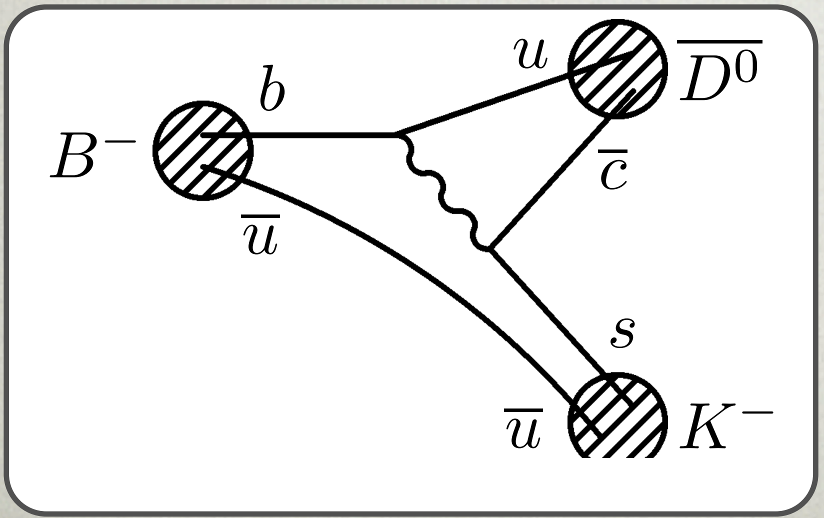
OBTAINING GAMMA

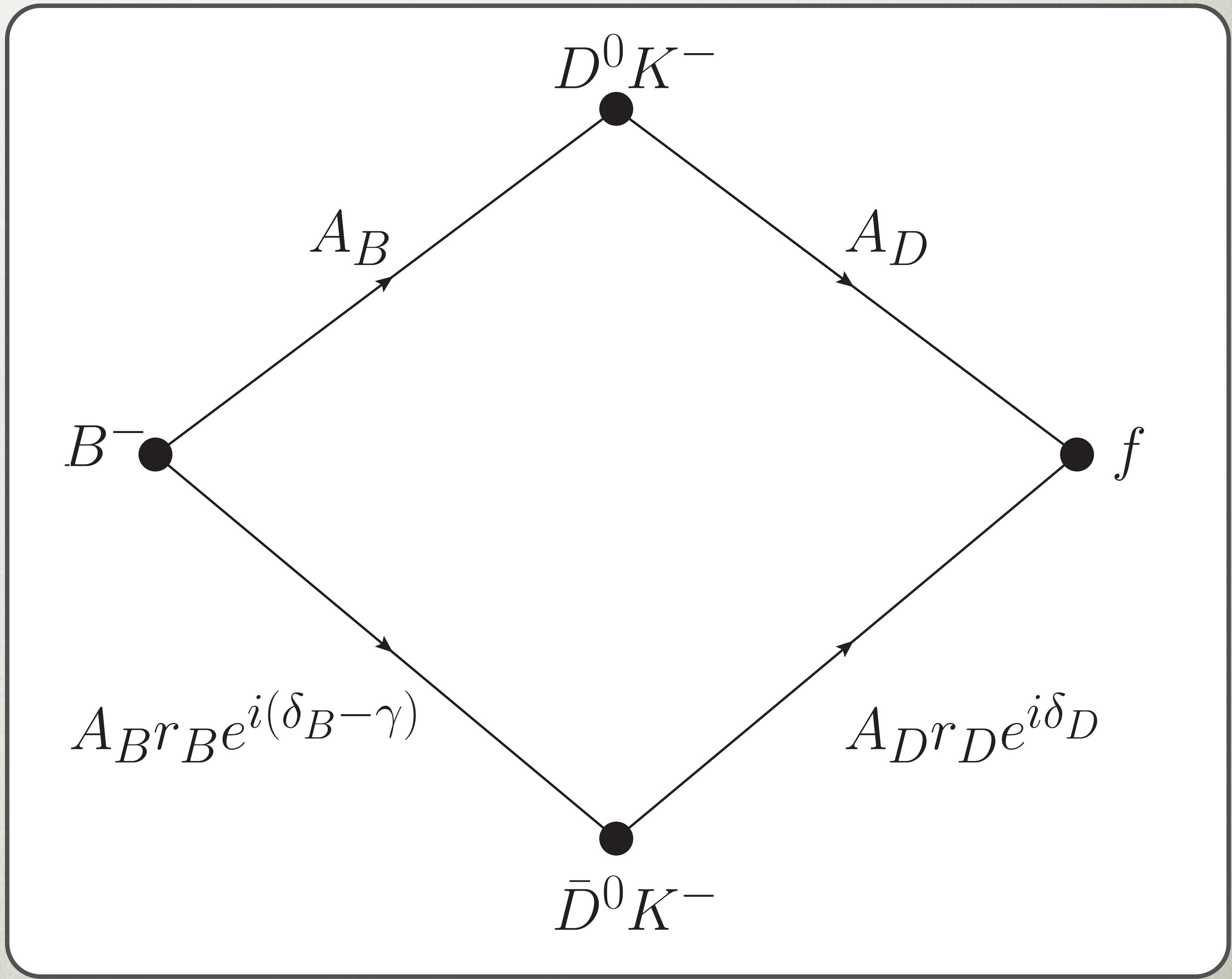
- use interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$

Gronau, Wyler, 1991; Gronau, London, 1990









MANY FINAL STATE CHOICES

see also talk by Stefania Ricciardi

- possible choices for final state f in D decay
  - CP- eigenstate (e.g. $K_S\pi^0$) Gronau, London, Wyler (1990,1991)
  - flavor state (e.g. $K^+\pi^-$) Atwood, Dunietz, Soni (1997)
  - singly Cabibbo suppressed (e.g. $K^{*+}K^-$) Grossman, Ligeti, Soffer (2002)
  - many-body final state (e.g. $K_S\,\pi^+\pi^-$) Giri, Grossman, Soffer, JZ (2003) Poluektov et al. [Belle] (2004)
- other extensions:
  - many body B final states: $B^+ \to DK^+\pi^0$, $B^0 \to D\pi^-K^+$ Aleksan, Petersen, Soffer (2002), Gershon (2008), Gershon, Poluektov (2009)
  - use D^{0*} in addition to D^0 Bondar, Gershon (2004)
  - use self tagging D^{0**} , $D_2{}^{*-}$ Sinha (2004) Gershon (2008)
  - neutral B_d, B_s decays (time dep., time-integr., self-tag) Aleksan, Dunietz, Kayser (1992), Kayser, London (2000), Atwood Soni (2003), Fleischer (2003), Gronau et al (2004)

WHY THE METHODS WORK

- many methods: GLW, ADS, Dalitz,…
- one has ~$N_D N_B$ measurements, but ~N_D+N_B unknowns
  - ⇒ can determine γ
- does it make sense to split into "methods"?
  - we are really interested in γ
  - combined analysis wins
- "only" benefit of splitting: compare diff. γ
  - 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 γ (at present precision)
  - search for NP by comparing to other observables
  - can test for consistency in γ extraction in $B \to DK$ itself

TEST FOR NP IN DECAY AMPLITUDES

- extraction of γ has a built in test for presence of extra NP in decay ampl.

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

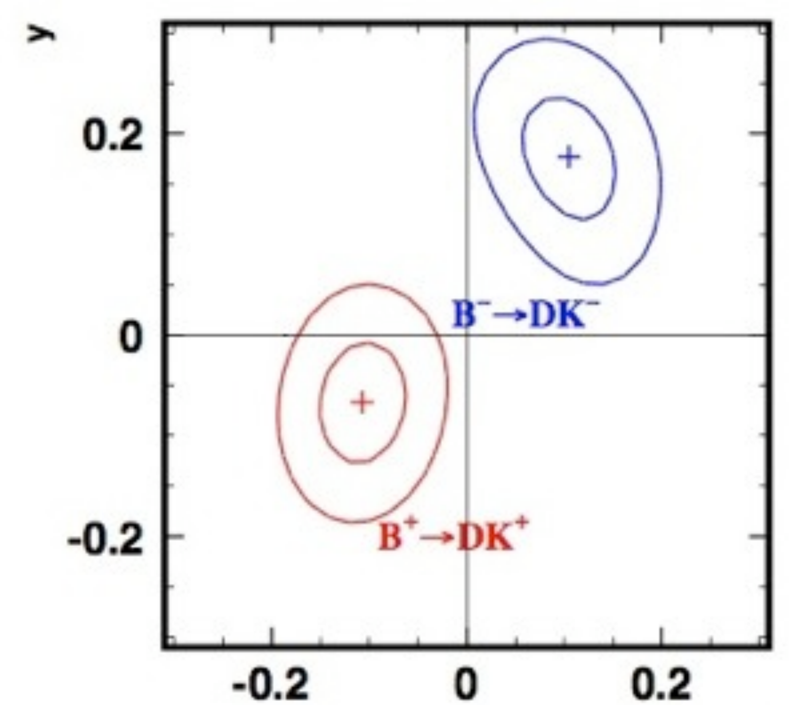
- thus for B^+ and B^- different r_B

$$r_{B^+} \to |r_B e^{i\delta_B + \gamma} + r'_B e^{i\delta'_B + \gamma'}|; \; r_{B^-} \to |r_B e^{i\delta_B - \gamma} + r'_B e^{i\delta'_B - \gamma'}|$$

TEST OF DIRECT CPV NP IN B→DK

- there is NP in B→DK amplitude if

$$r_{B^-} \neq r_{B^+}$$



Belle, 0803.3375

- 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 γ is shifted

IN THE (FAR) FUTURE

- another test: γ from $B^{\pm} \to DK^{\pm}$, $B^{\pm} \to DK^{*\pm}$, $B^{\pm} \to D^{*}K^{\pm}$,$B^{0} \to DK^{0}$,... all need to coincide!
  - NP with contributions of different chirality could for instance give different shifts in γ
- 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 γ
- most can be avoided
  - with more statistics
    - example: Dalitz plot theory error
  - by modifiying 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 ⇒ the effect is small
- if D decay info. is from flavor tagged D (i.e. from $D^* \to D\,\pi$)
  - then only important changes are in the interf. term
    - change in relative phase: $\delta_f \to \langle\delta_f\rangle$ Grossman, Soffer, JZ, 2005
    - dilutes the interference: $\ldots \to \ldots \times e^{-\varepsilon}$
- the effect on γ is $\varepsilon \sim \mathcal{O}(x_D^2/r_f^2, y_D^2/r_f^2)$
  - 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 $B \to DK$
  - one already fits for both $\langle\delta_f\rangle$ and ε by fitting for c_i, s_i

$D-\bar{D}$ MIXING

Bondar, Poluektov, Vorobiev, 1004.2350

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

OTHER ERRORS

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

Gronau, Grossman, Soffer, Surujon, JZ, 2007

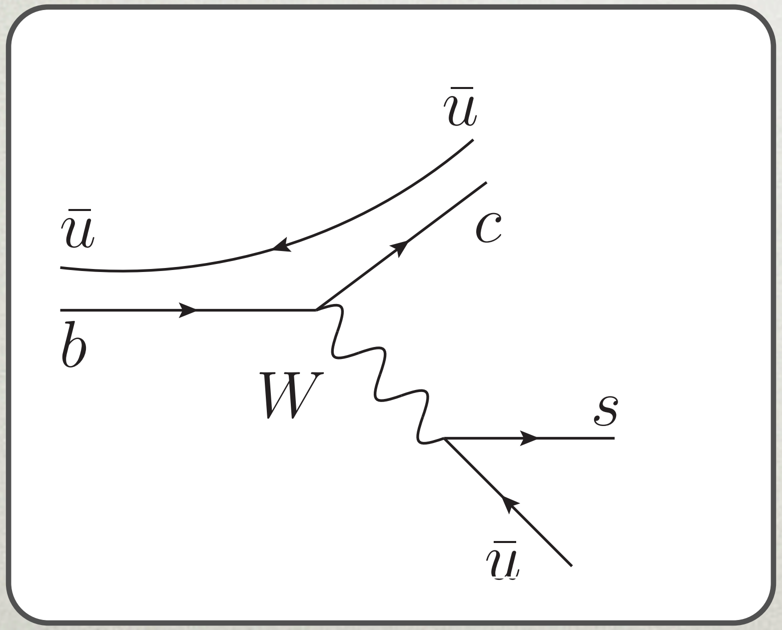
- QED radiative corrections
  - CP conserv., in principle no effect on γ
- the remaining (SM) theory error from
  - higher electroweak corrections

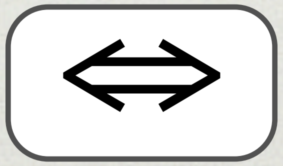
IRREDUCIBLE THEORY ERROR ON GAMMA

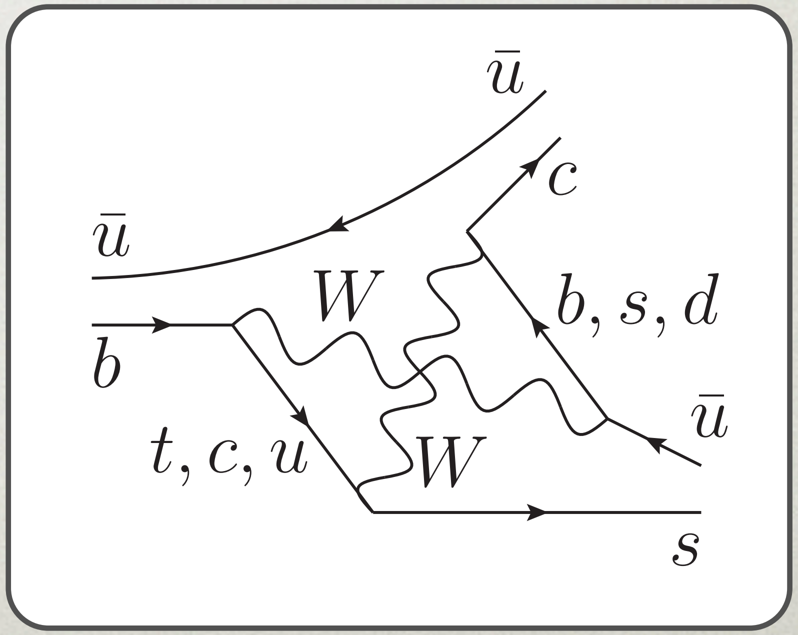
- irreduc. theory error in SM introduced by ew. corrections that change CKM structure

Pirjol, JZ, to appear

- if only vertex corrections no effect on γ extr.
- no effect from Z exchange
- there is effect from box diagrams

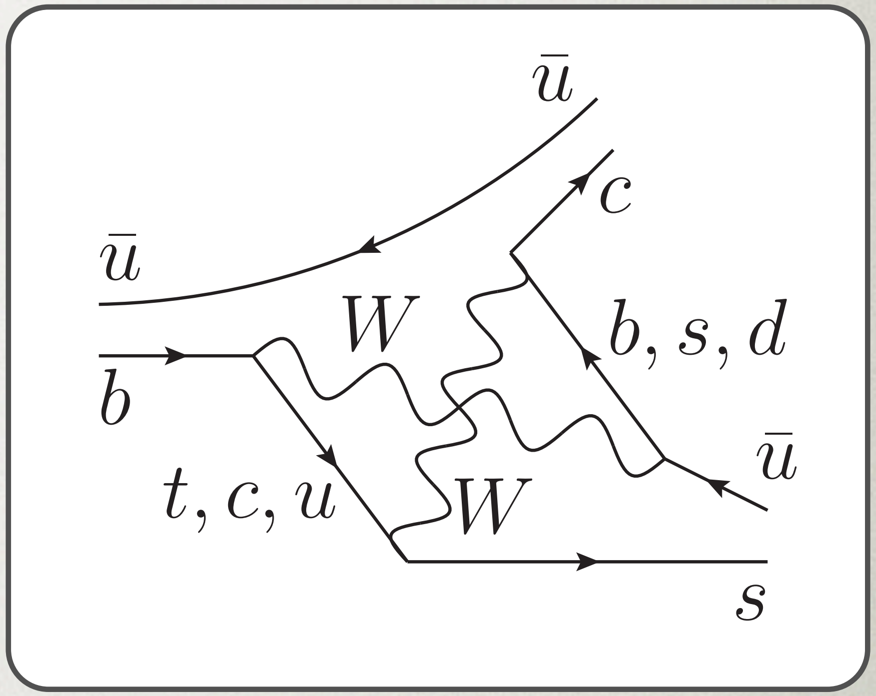






IRREDUCIBLE THEORY ERROR ON GAMMA

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



IRREDUCIBLE THEORY ERROR ON GAMMA

Pirjol, JZ, to appear

- 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 γ 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 γ from $B\to DK$?
- assuming MFV: can probe $\Lambda \sim 10^2 TeV$
- assume gen. FV: can probe $\Lambda \sim 10^3 TeV$
- this is far future of course
  - $O(10^{18})$ $B\bar{B}$ pairs needed

SOME NUMBERS FOR FUN

JZ, 1101.0134

PROBE	Λ_{NP} for (N)MFV NP	Λ_{NP} for gen. FV NP	No. of *BB* pairs
γ from $B \to DK$	$\Lambda \sim O(10^2\ \text{TeV})$	$\Lambda \sim O(10^3\ \text{TeV})$	$\sim 10^{18}$
$B \to \tau\nu$ 1)	$\Lambda \sim O(\text{TeV})$	$\Lambda \sim O(30\ \text{TeV})$	$\sim 10^{13}$
$b \to ss\bar{d}$	$\Lambda \sim O(\text{TeV})$	$\Lambda \sim O(10^3\ \text{TeV})$	$\sim 10^{15}$
β from $B \to J/\psi K_S$ 2)	$\Lambda \sim O(50\ \text{TeV})$	$\Lambda \sim O(200\ \text{TeV})$	$\sim 10^{12}$
K-*K* mixing 3)	$\Lambda > 0.4\text{TeV}(6\text{TeV})$	$\Lambda > 10^3\text{TeV}(10^4\text{TeV})$	now

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 ReC_1 (Im C_1) from UTfitter 0707.0636

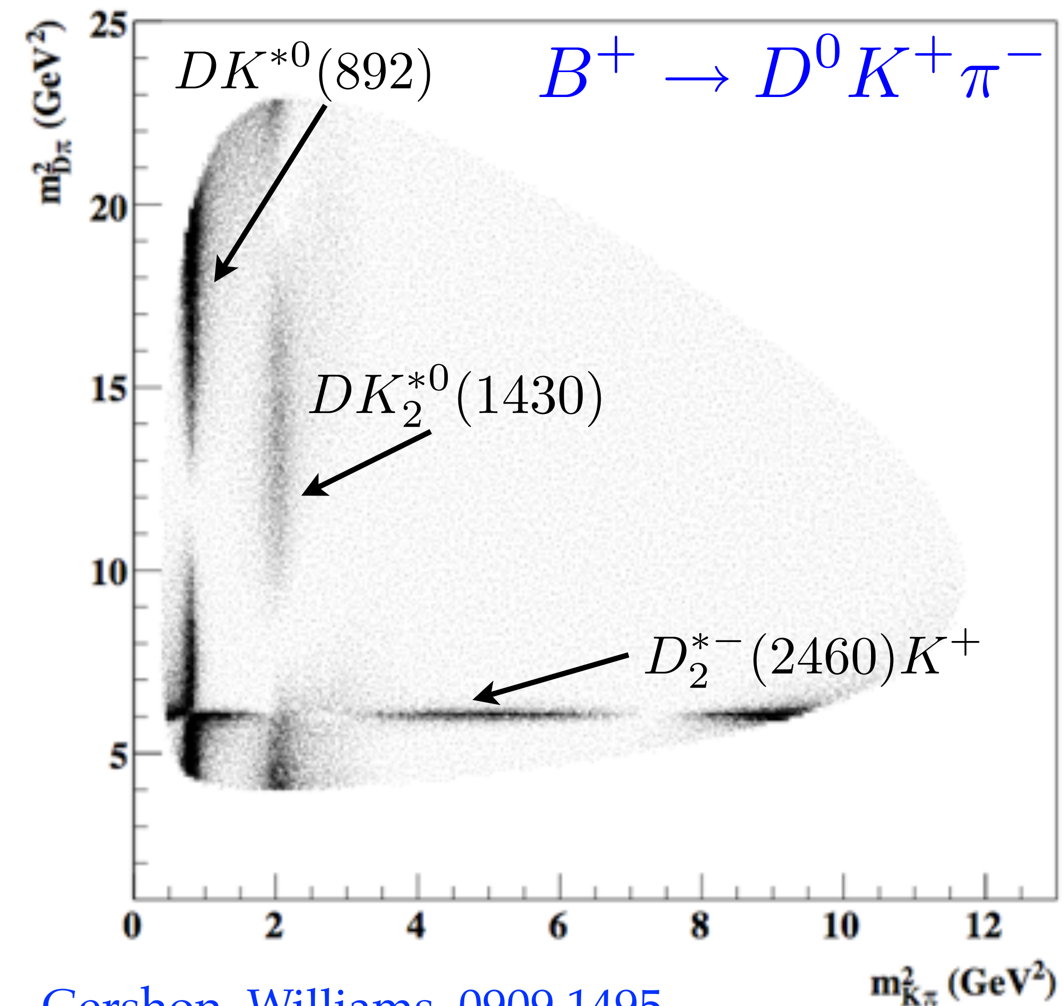
CONCLUSIONS

- γ extraction from $B \to DK$ is theoretically clean
  - irreducible theory error on γ is below $\delta\gamma/\gamma < 10^{-6}$
- measuring γ 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 γ
- multibody $B^0 \to DK^+\pi^-$ Gershon (2008) Gershon, Williams (2009)
  - contains flavor specific $D_2^{*-}(2460) \to \bar{D}^0\pi^-$
  - interf. with other resonances (e.g. $B^0 \to DK^{*0}$) gives γ
  - many choices for $D \to f$ still
  - equivalent of GLW does not need CP-odd $D \to K_S\pi^0$ decays (that is difficult for LHCb)



Gershon, Williams, 0909.1495

MORE ON $B^0 \to DK^+\pi^-$

- compared to quasi-two-body $B^0 \to DK^{*0}$
  - at least 50% better sensitivity to γ — Gershon, Williams, 0909.1495
- extension of model indep. method possible
  - double Dalitz plot analysis $B^0 \to DK^+\pi^-$ $\to (K_S\, \pi^+\, \pi^-)_D K^+\pi^-$ — Gershon, Poluektov, 0910.5437
  - $B^0 \to DK^+\pi^-$ Dalitz still poorly known
  - estimates using reasonable models: 20 annual yields of LHCb $\Rightarrow O(1^\circ)$ error