THE CASE FOR MEASURING GAMMA PRECISELY

Jure Zupan

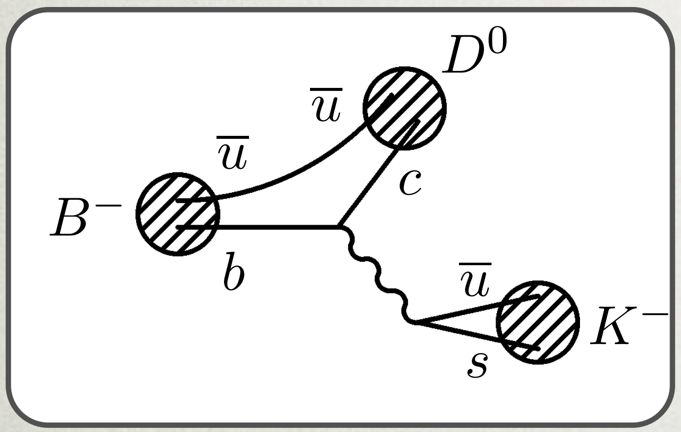
OUTLINE

- preliminaries
- new methods since CKM08
- how precise is precise enough?
  - th. error in γ extraction in the SM
  - "the ultimate test of MFV"

OBTAINING GAMMA

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

Gronau, Wyler, 1991; Gronau, London, 1990



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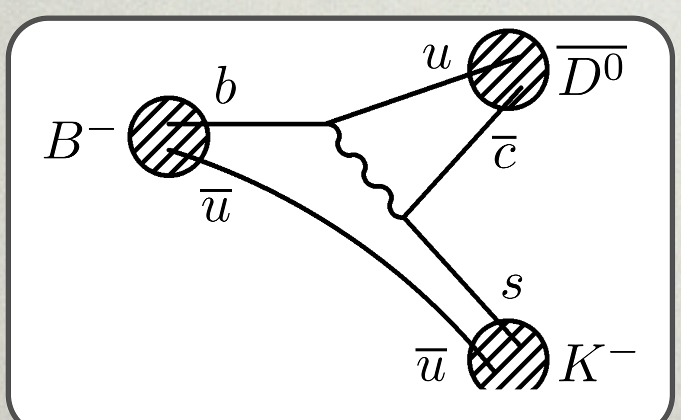

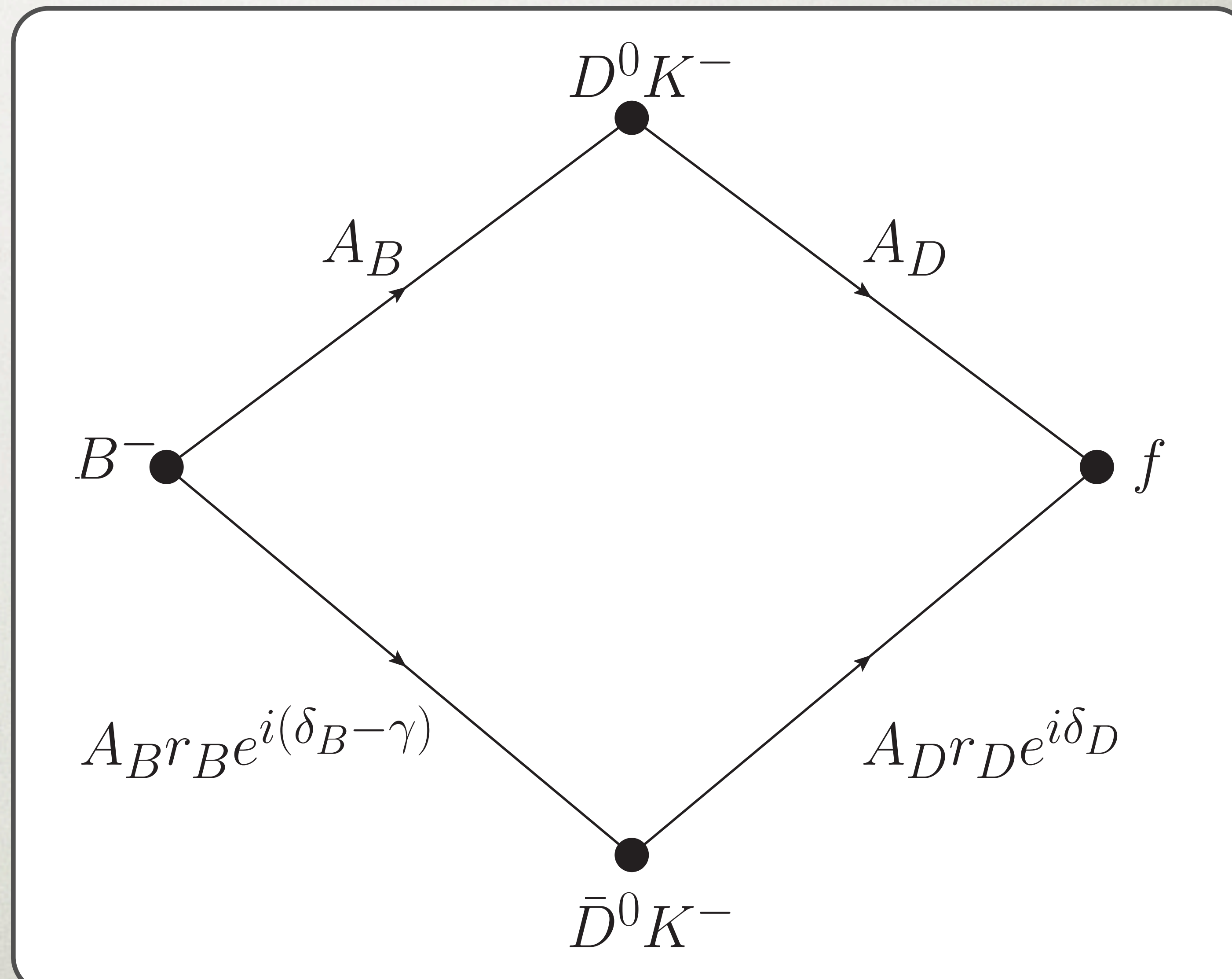

MANY FINAL STATE CHOICES

see also talks by Y. Horii, G. Marchiori, P. Squillacioti, M. Williams

- 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 decays (time dep., time-integr., self-tag)

many refs.; see also talks by A. Rubin, Y. Onuki, V. Gligorov

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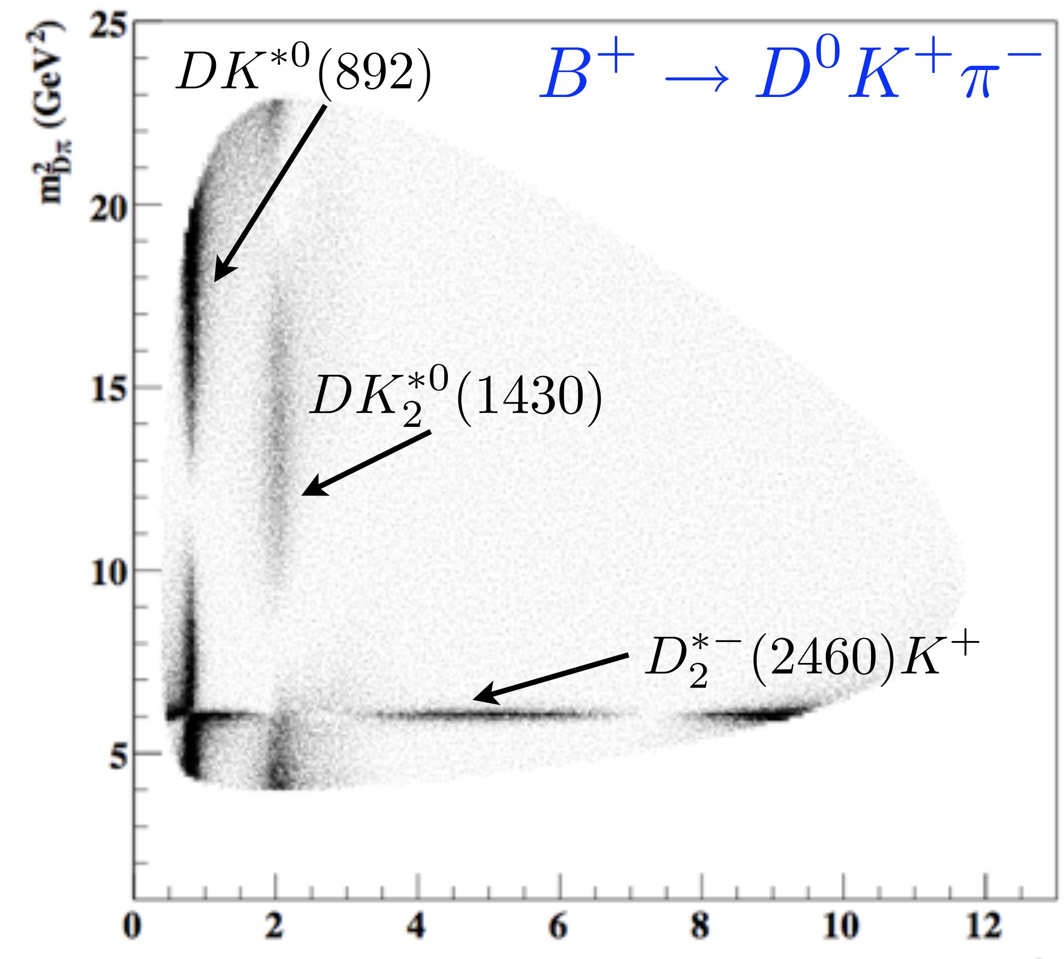
NEW METHOD(S) SINCE CKM2008

- 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

NEW METHOD(S): $B^0 \to DK^+\pi^-$

see also talk by M. Williams

- compared to quasi-two-body $B^0 \to DK^{*0}$

  Gershon, Williams, 0909.1495

  - at least 50% better sensitivity to γ
- 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

TO COMBINE OR NOT TO COMBINE

- many methods: GLW, ADS, Dalitz,…
- we are really interested in γ
- does it make sense to split into “methods”?
- one has $\sim N_D N_B$ measurements, but $\sim N_D + N_B$ unknowns
  - combined analysis wins
- only benefits of splitting: compare diff. γ
  - check for NP or systematics

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 CP NP IN B→DK

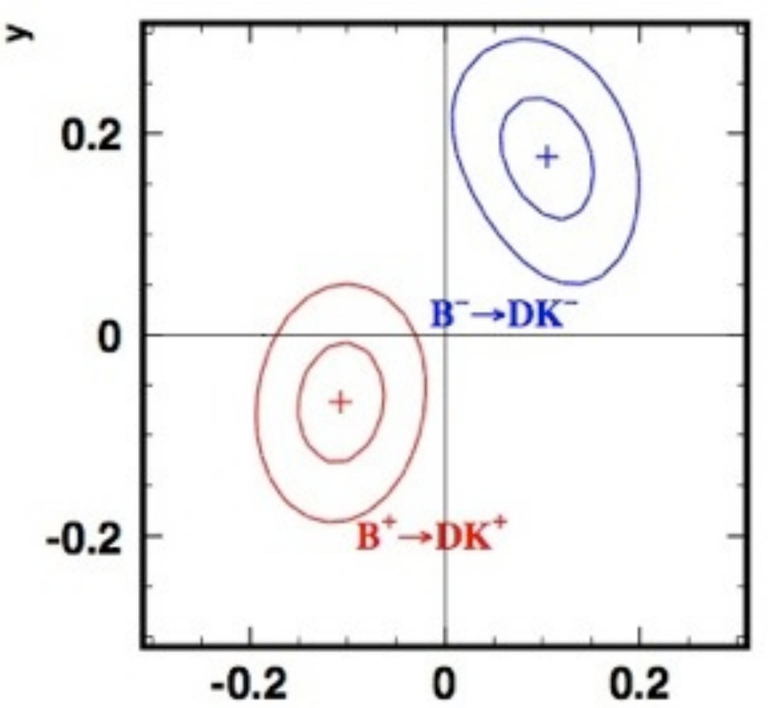
- there is NP in B→DK amplitude if

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

- 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 γ is shifted



Belle, 0803.3375

- 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!

THEORY ERRORS ON EXTRACTING GAMMA

THEORY ERRORS

- how precise is precise enough?
  - how precisely will we know γ after the end of LHCb, SFF? see talk A. Poluektov
  - is there any benefit in making things more precise?
- will assume SM
  - errors from $D-\bar{D}$ mixing
  - errors from electroweak corrections
- long look in the future, if we have infinite statistics, “the limits of our knowledge”

$D-\bar{D}$ 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 ($\psi(3770) \to D\bar{D}$)

on important charm inputs see talks by S. Ricciardi, P. Spradlin

- 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

Gronau, Grossman, Soffer, Surujon, JZ, 2007

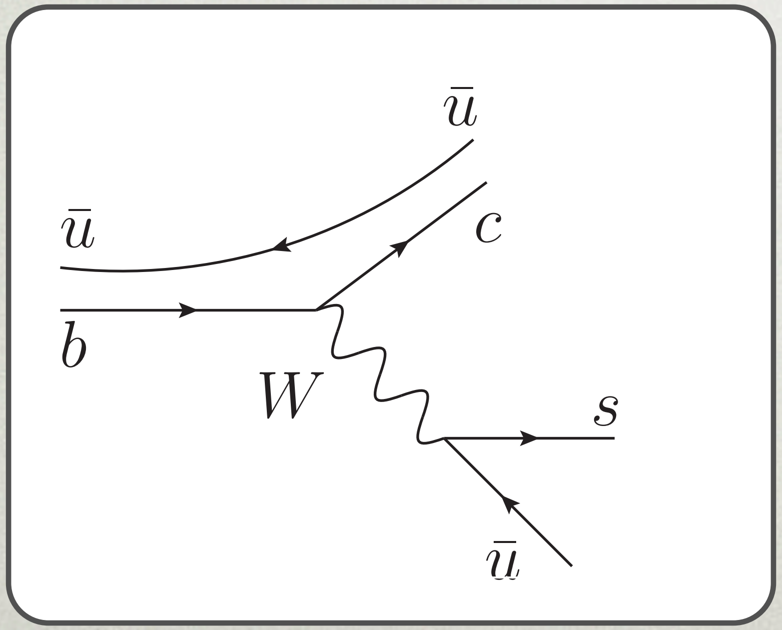
  - $\Delta\Gamma_s$ needs to be well measured

- the remaining (SM) theory error is coming from

  - higher electroweak corrections

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 γ extr.
  - no effect from Z exchange
  - there is effect from box diagrams



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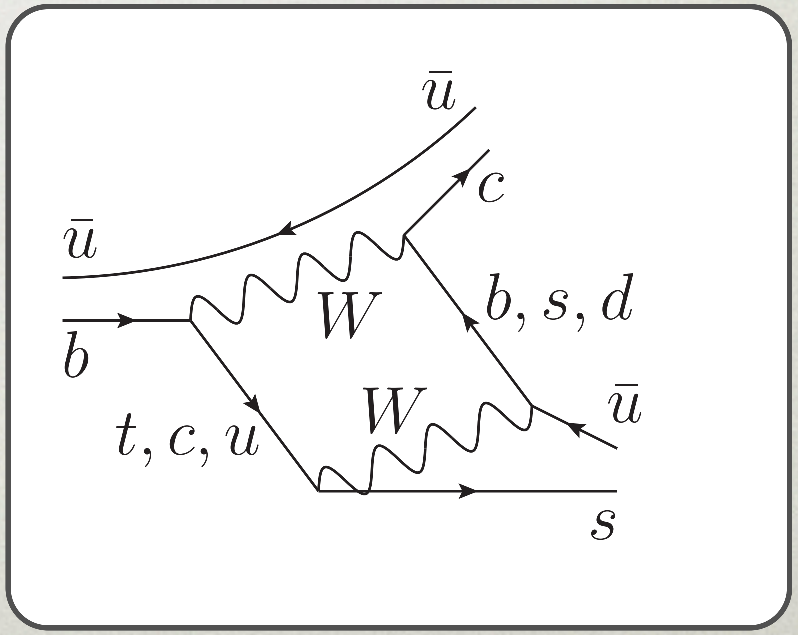


IRREDUCIBLE THEORY ERROR ON GAMMA

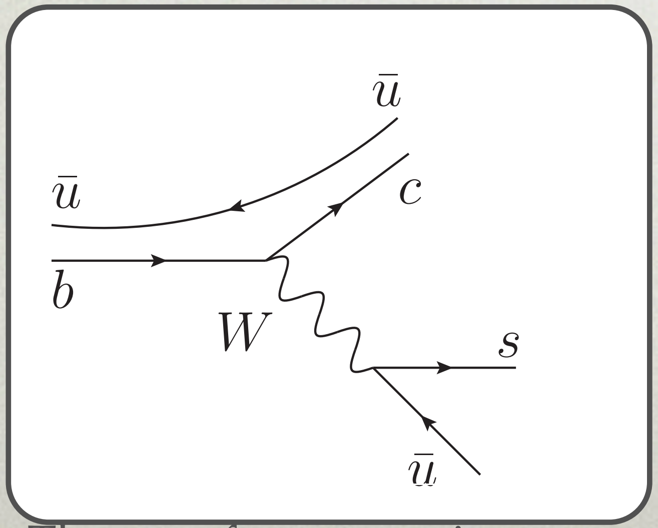
- shift in γ only ops. with different weak phase than LO
  - for $(\bar{c}b)_L(\bar{s}u)_L$ need w.ph., leading corr.

$$\sim \frac{g^2}{16\pi^2} V_{cb} V_{cs}^* V_{ub}^* V_{cb} \frac{m_b^2}{m_W^2} \left[A_B / (V_{cb} V_{us}^*) \right] \sim \frac{g^2}{16\pi^2} \lambda^4 \frac{m_b^2}{m_W^2} A_B$$

  - for $(\bar{u}b)_L(\bar{s}c)_L$ need w.ph. diff. from γ

$$\sim \frac{g^2}{16\pi^2} V_{cb} V_{cs}^* V_{cs}^* V_{us} \frac{m_c^2}{m_W^2} \left[A_B / (V_{cb} V_{us}^*) \right] \sim \frac{g^2}{16\pi^2} \frac{m_c^2}{m_W^2} A_B$$

- contribs. with interm t power supp.



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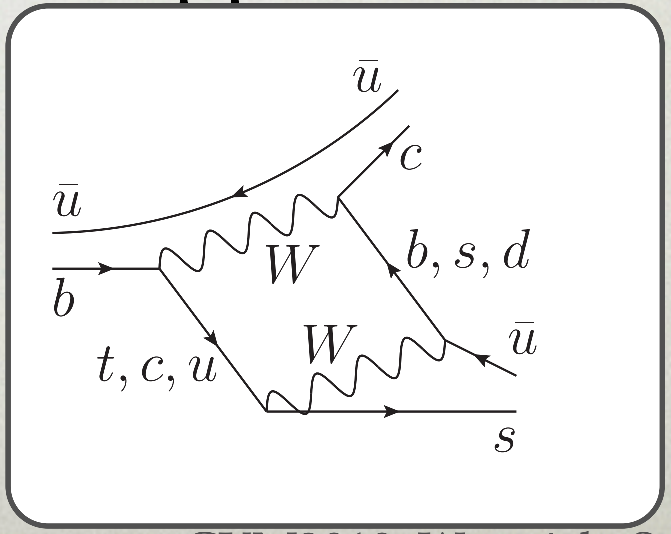

- irreducible theory error on γ is $\delta\gamma/\gamma \sim O(10^{-6})$

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

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

- reviewed new methods for γ extraction from $B \to DK$
- shown that the irreducible theory error on γ is $\delta\gamma/\gamma \sim O(10^{-6})$

BACKUP SLIDES