Les Recontres de Physique de La Vallee d'Aoste

La Thuile, Aosta Valley March 6-11, 2006

BaBar Measurements of $|V_{ub}|$ and γ

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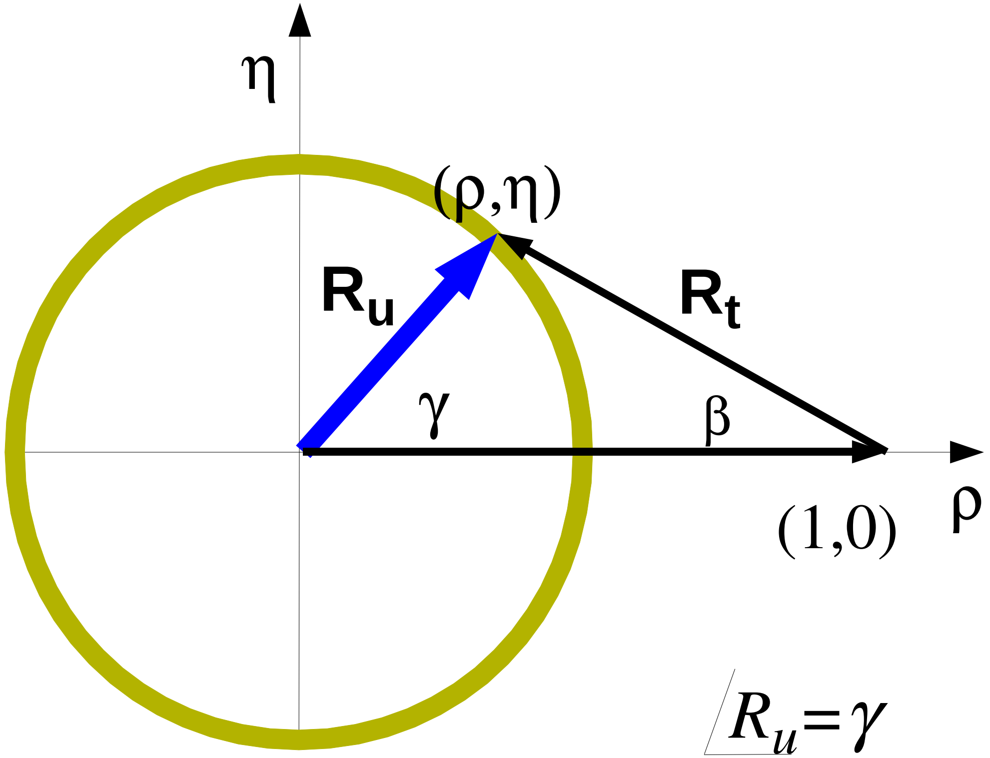
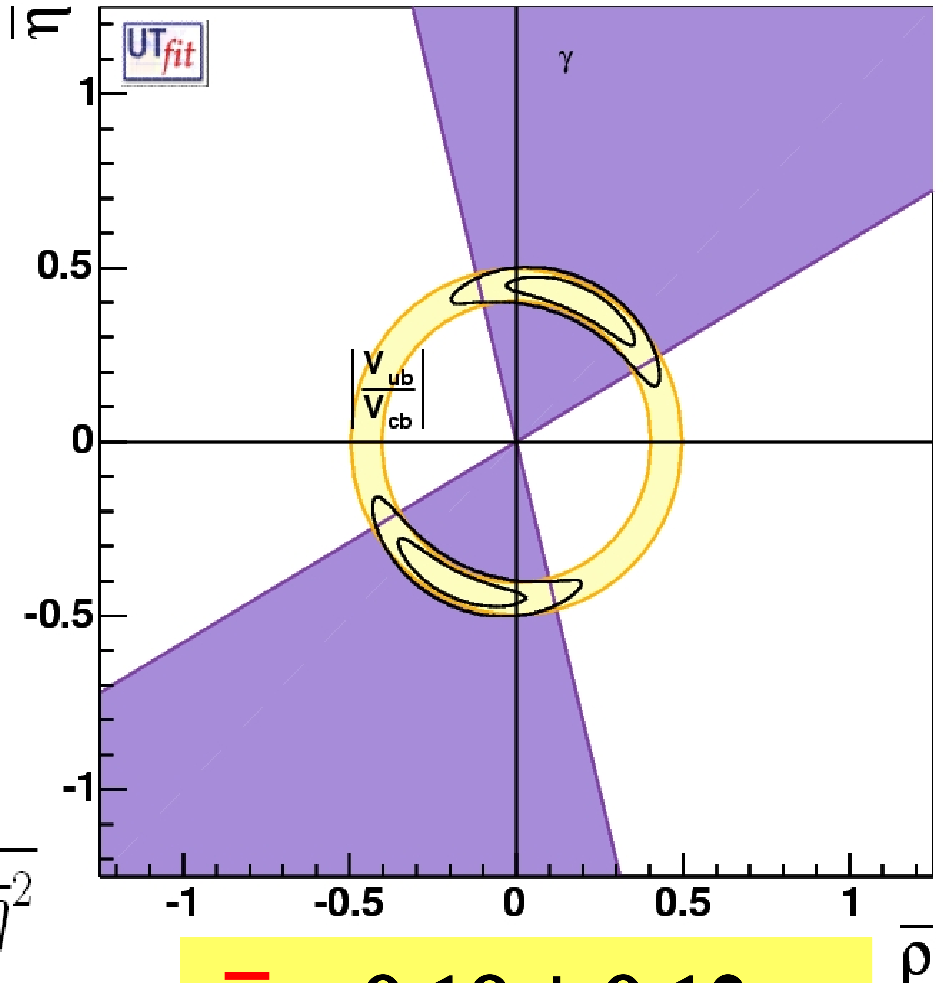
BaBar Collaboration

V_{ub} and the Unitarity Triangle

L.Silvestrini LP2005





$$|R_u| = \left|\frac{V_{ub}V_{ud}^*}{V_{cb}V_{cd}^*}\right| = \frac{1}{tan\theta_C}\left|\frac{V_{ub}}{V_{cb}}\right| = \sqrt{\bar{\rho}^2 + \bar{\eta}^2}$$

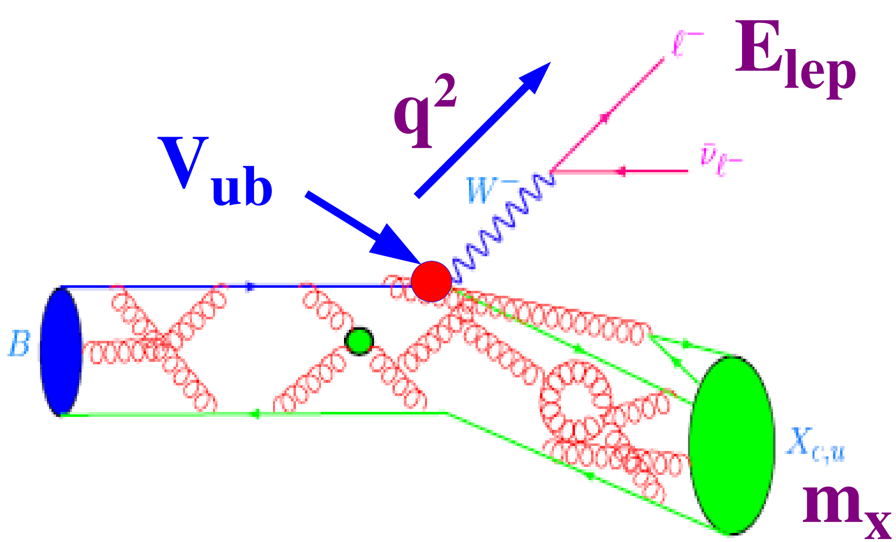
$$\bar{\rho} = 0.18 \pm 0.12$$
$$\bar{\eta} = 0.41 \pm 0.05$$

UTfit coll., hep-ph/0501199;
Botella et al., hep-ph/0502133

- **γ and $|V_{ub}|$ from tree level processes**
- **Any New Physics that does not occur at tree level, must satisfy this ($\bar{\rho}$,$\bar{\eta}$) constraint**

$|V_{ub}|$

Inclusive Semileptonic B-decays



- **Full Γ(b→ulν) Rate:** Operator Product Expantion (OPE) allows to extract $|V_{ub}|$ with 5% error

$$|V_{ub}| = 0.00424 \left(\frac{\mathcal{B}(B \to X_u l\nu)}{0.002} \frac{1.61\,\mathrm{ps}}{\tau_b} \right)^{1/2} \times (1.0 \pm 0.028_{pert+nonpert} \pm 0.039_{m_b}).$$

- **Apply cuts to reduce b→c background: OEP fails**
  - Measure partial branching fraction *ΔBr*:

$$\Gamma(b \to u\ell\bar{\nu}) = \frac{1}{f_u} \cdot \frac{\Delta Br}{\tau_B}$$

  - Acceptance f_u sensitive to Fermi motion of b-quark in meson B (needs non perturbative QCD computation)

b→u have smaller m_X

→ larger E_{lep}&q^2

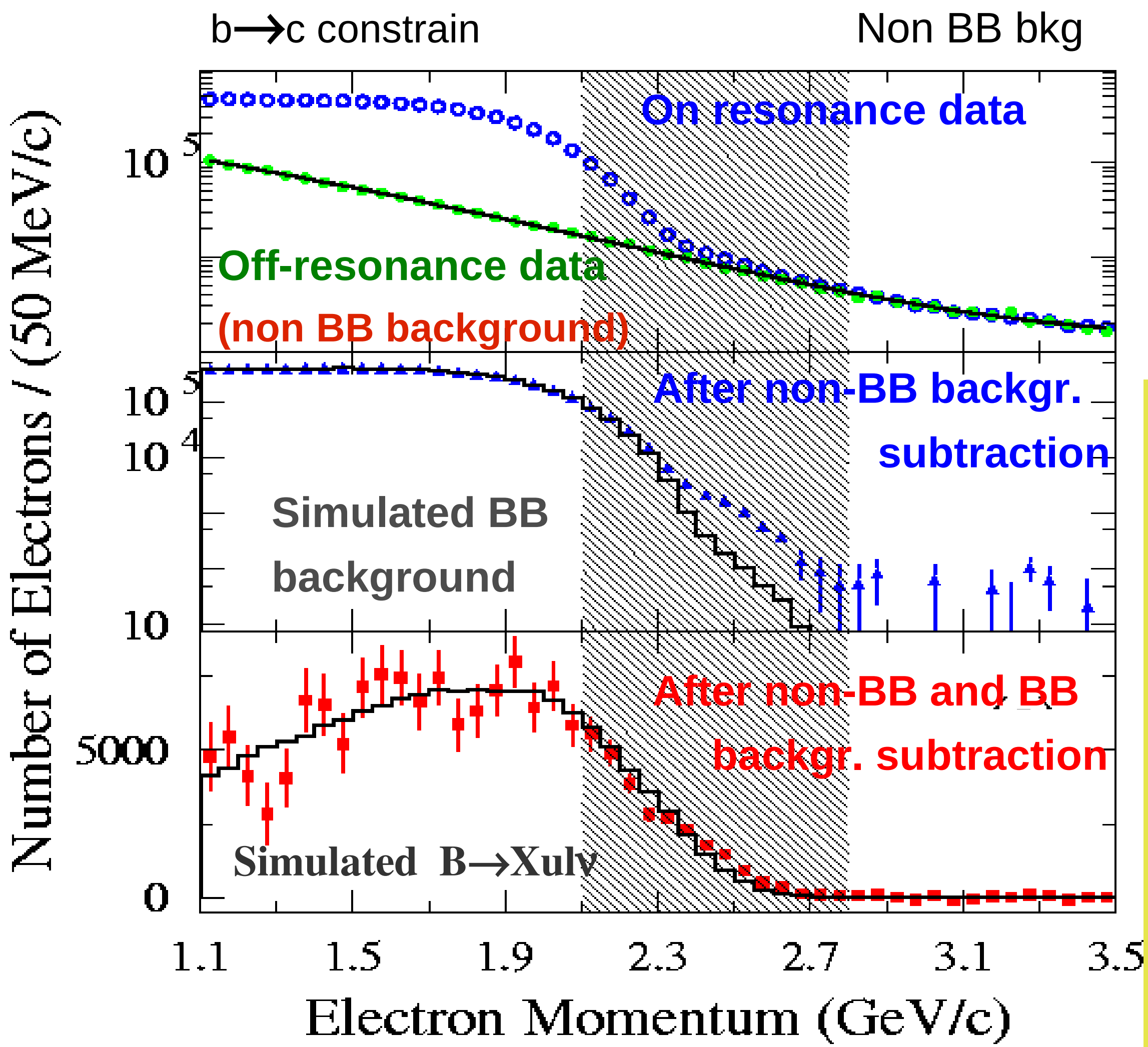
Cut on these variables to Maximize Phase Space

  - The b-quark motion is parameterized by the **shape function** f(k+)
    - universal function for B mesons, can be extracted from data: b→ sγ or b→ clν

$|V_{ub}|$: E_e spectrum near end-point

- **Historically first method to look for $b \to u$ (CLEO '89): $E_{lep} > 2.3$ GeV ($f_u = 8\%$)**
- **Present knowledge of $b \to c$ allows us to lower the E_{lep}**
  - Much smaller theoretical uncertainties

- **Babar >2.0GeV (f_u=25%)**
- **Belle >1.9GeV (f_u=30%)**



Typical requirements:

- missing momentum
- event shape

Hep-ex/0509040, PRD73(012006)

S/N~1/10, ε~40%

88 M BB

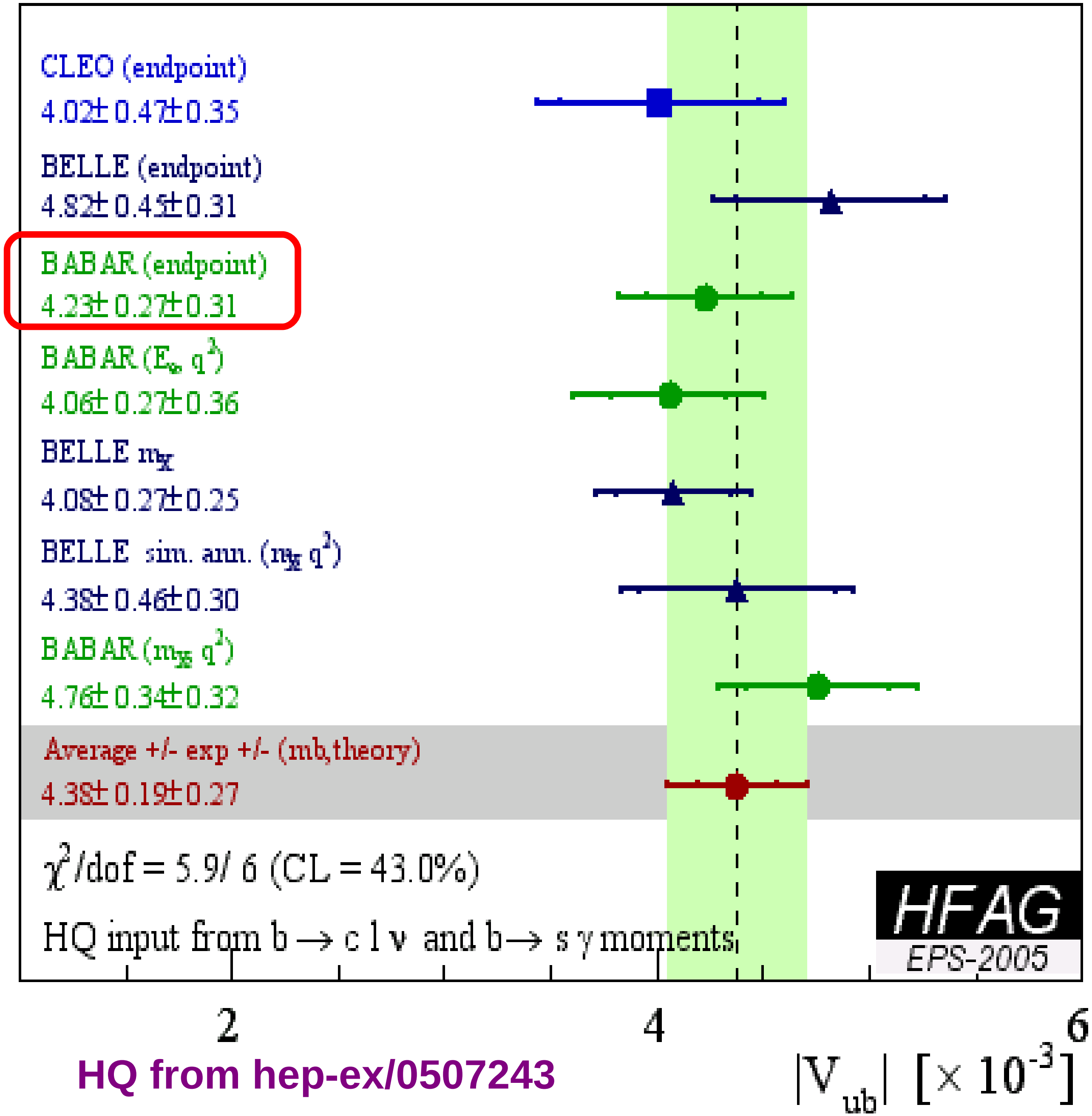
$$\Delta Br = (0.572 \pm 0.041_{stat} \pm 0.065_{syst}) \times 10^{-3}$$

HQE fits $b \to s\gamma$ and $b \to cl\nu$ + Calculations by Bosh *et al.* (**BLNP**): **hep-ph/0402094, 0504071**

$$|V_{ub}| = (4.44 \pm 0.25_{exp} {}^{+0.42}_{-0.38}{}_{SF} \pm 0.22_{th}) \times 10^{-3}$$

Limited by uncertainties on SF parameters

Results on inclusive $|V_{ub}|$



HQ from hep-ex/0507243

acceptance from BLNP

- **Uncertainty on SF parameters: 4.7%**
  - δm_b ~ 40MeV
- **Other theory uncertainties: 4%**
  - Subleading SF, Weak annihilation (can be constrained experimentally)
- **Experimental uncertainties: 4.4%**
  - Statistics: 2%
  - Detector systematics: 2.6%
  - Background modeling: 2%
  - Signal modeling: 2.2%

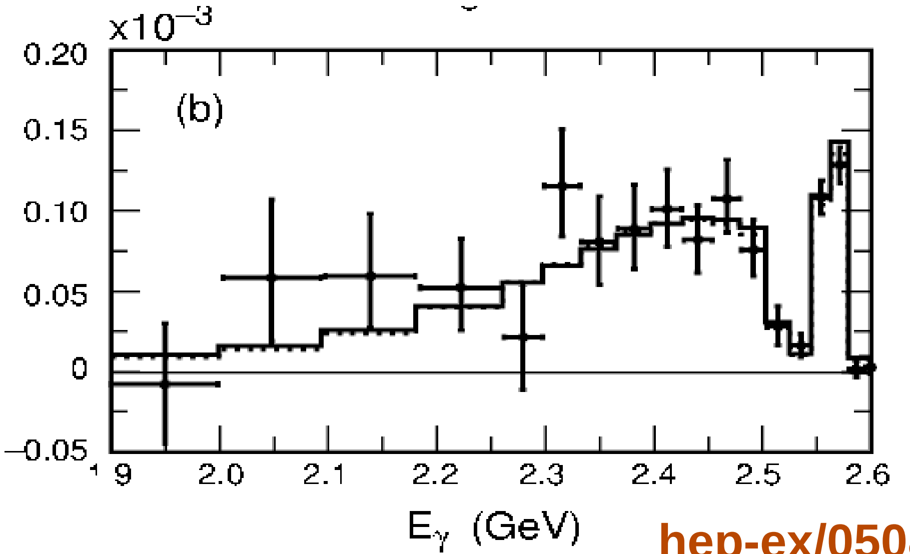
World average Summer 2005

$|V_{ub}|=(4.38 \pm 0.19 \pm 0.27)\text{x}10^{-3}$

σ=7.6%

$|V_{ub}|$: without shape functions

- **Approach based on Leibovich et.al method (LLR): hep-ph/0005124,0105066**
  - f(k+) same in $B \rightarrow X\gamma$ and in $B \rightarrow X_u l\nu$ decays: **use directly the γ spectrum!**



hep-ex/0508004

  - **Combine measurable endpoint in γ spectra with partial rate $b \rightarrow u$ below hadronic mass (m_x^{cut})**

$$\frac{|V_{ub}|}{|V_{ts}|} = \left\{ \frac{6\alpha(1+H^{\gamma}_{mix})C_7(m_b)^2\delta\Gamma(c)}{\pi[I_0(c)+I_+(c)]} \right\}^{\frac{1}{2}}$$

$$I_0(c) = \int_{1-\frac{\sqrt{c}}{2}}^{1} du\, \frac{d\Gamma^{\gamma}}{du}\, i_0(u)$$

$$I_+(c) = \int_{1-\frac{\sqrt{c}}{2}}^{1} du\, \frac{d\Gamma^{\gamma}}{du}\, i_+(u)$$

$$u = 2E_{\gamma}/m_B \qquad c=(m_x^{cut}/m_B)^2$$

$\delta\Gamma(c)$ is the partial $b \rightarrow u$ rate

Functions $i_{0,+}(u)$ Weight Functions

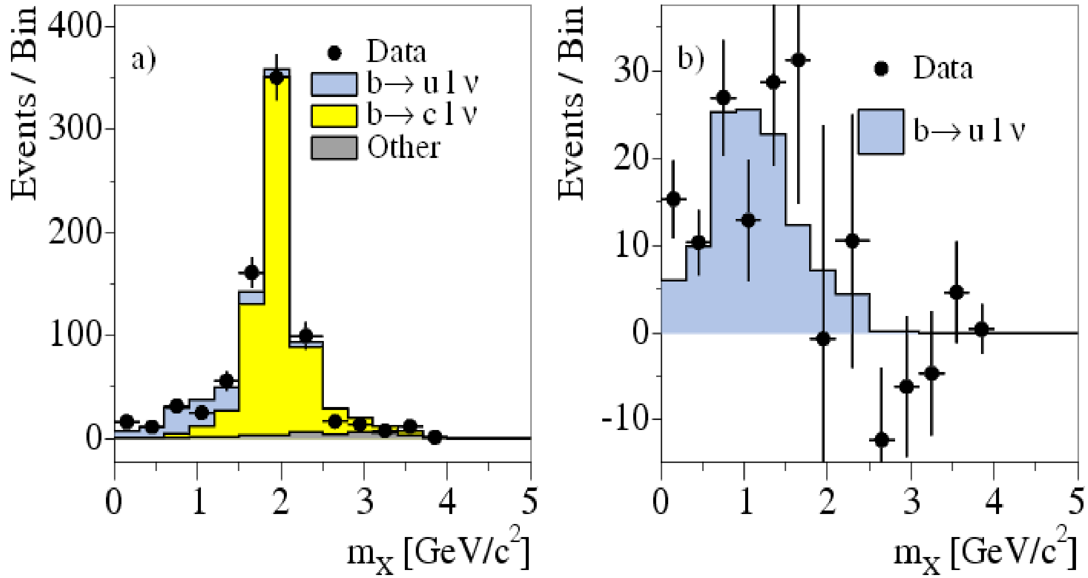
Non perturbative uncertainties of order **$(\Lambda m_B/m_b m_x^{cut})^2$**

$|V_{ub}|$: without shape functions

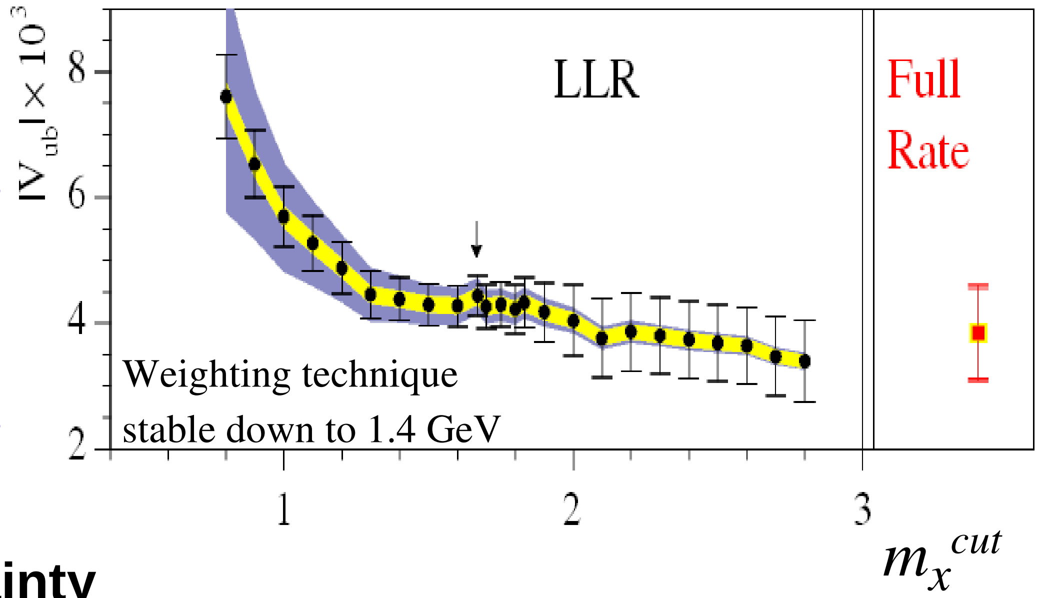
New

hep-ex/0601046

88x10^6 BB



- **Fully reconstructed B recoil analysis:**
  - Clear sample & kinematics known
  - Signal extracted from fit to m_X
- **Use the full hadronic mass spectra**
  - Extract $|V_{ub}|$ from OPE
  - $|V_{ub}|=(3.84\pm0.70_{stat}\pm0.30_{syst}\pm0.10_{th})\times10^{-3}$
- **LLR, best error $m_X<1.67$ GeV/c^2**
  - $|V_{ub}|=(4.43\pm0.38_{stat}\pm0.25_{syst}\pm0.29_{th})\times10^{-3}$



Uncertainty from SF ⟶ statistical uncertainty

smaller uncertainty from m_b and SF models

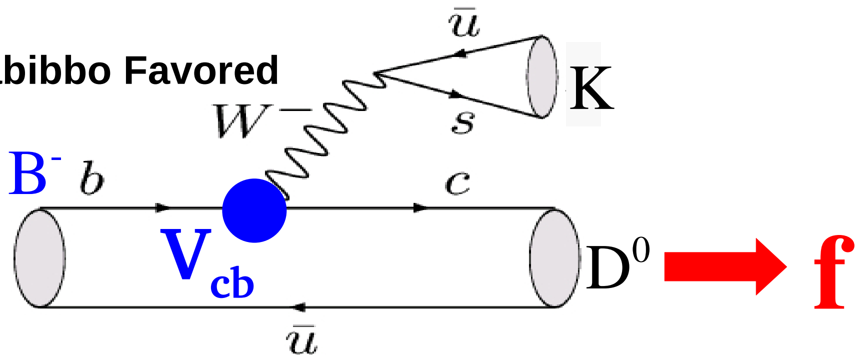
Not yet included in HFAG

γ

Measurement of γ with $B^\pm \to D^{(*)}K^{(*)\pm}$

- Exploiting the **interference** among $b \to u\bar{c}s$ and $b \to c\bar{u}s$ decay amplitude in charged B
- No Time Dependent analysis required

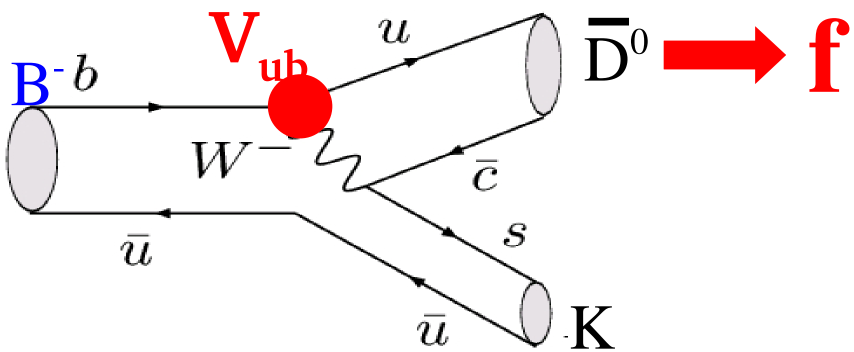
Cabibbo Favored



$a = A(B^- \to D^0K^-) \sim \lambda^3$

δ relative strong phase unknown

(Cabibbo & color) Suppressed



$A(B^- \to \bar{D}^0K^-) \sim a\, r_B\, \lambda^3\, e^{i(\delta - \gamma)}$

f D final state common to D^0 and $\bar{D}^0$

- -Three body $K_S\pi\pi$ (GGSZ)
- - CP eigenstate (GLW)
- - Double Cabibbo Suppressed mode (ADS)

Not covered in this talk

Size of CP asymmetry

$$r_B = \frac{|A(B^+ \to D^0K^+)|}{|A(B^+ \to \bar{D}^0K^+)|} \approx \frac{|V_{ub}||V_{cs}|}{|V_{cb}||V_{us}|} \cdot f_{COL} \approx 0.10$$

Depends on the B decay mode

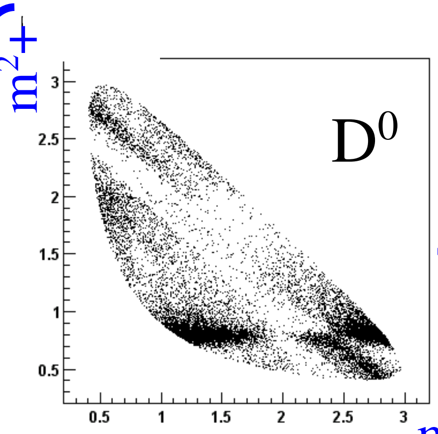
Large r_B, larger interference, better γ exp. precision

From Dalitz analysis: $B^{\pm} \to D^{(*)}K^{\pm}$ with $D^0(K_S\pi\pi)$

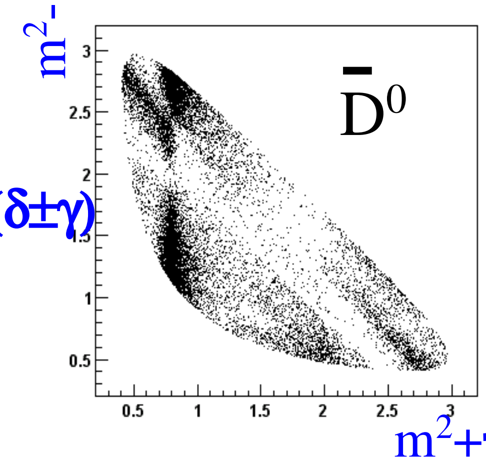
Giri-**G**rossman-**S**offer-**Z**upan:PRD68 054018 (2003)

f$=K_S\pi\pi$ 3-body final state accessible through many different decays: **Dalitz Analysis**

$A^{\pm}=\Big($



$+ r_B e^{i(\delta\pm\gamma)}$



$\Big)^2$

fit to the interference pattern between D^0 and $\bar{D}^0$

$$(x_{\pm}, y_{\pm})^{(*)} \equiv (\mathrm{Re}, \mathrm{Im})\{r_B^{(*)} e^{i(\delta_B^{(*)} \pm \gamma)}\}$$

Converted in γ, $\delta_B^{(*)}$ $r_B^{(*)}$

(γ with a 2-fold ambiguity)

Results with 227 million BB

Combining: DK + D*K + DK*

DK $r_b=0.12\pm0.08\pm0.03\pm0.04$

D*K $r_{b*}=0.17\pm0.10\pm0.03\pm0.03$

DK* $r_s < 0.19$ @ 90% CL

PRL95 (2005) & hep-ex/0507101

$$\gamma = (67 \pm 28_{stat} \pm 13_{syst} \pm 11_{Dalitz})^{\circ}$$

Golden Mode for γ

GLW method: B →D[CP-Eigenstate]K

$CP^{+} = \pi^{+}\pi^{-}\ K^{+}K^{-}$

$CP^{-} = K_s\pi^0\ \ K_s\phi\ \ K_s\omega$

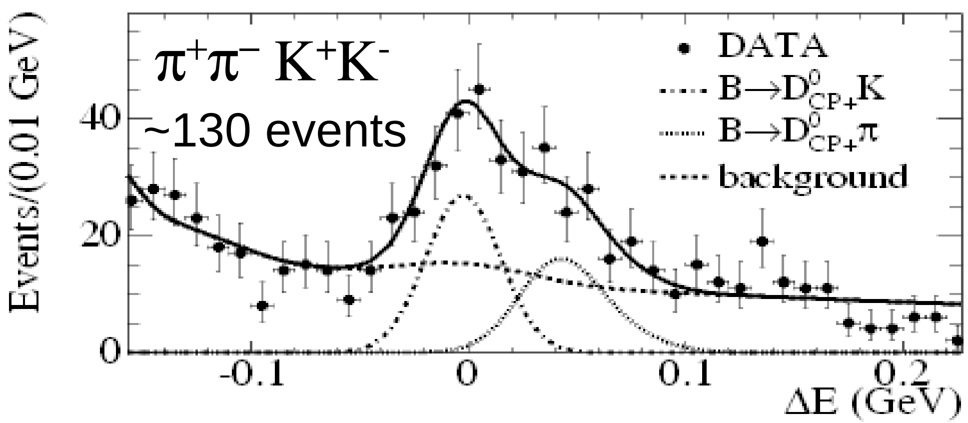
Gronau-**L**ondon-**W**yler: PLB253, 483 PLB265,172(1991)

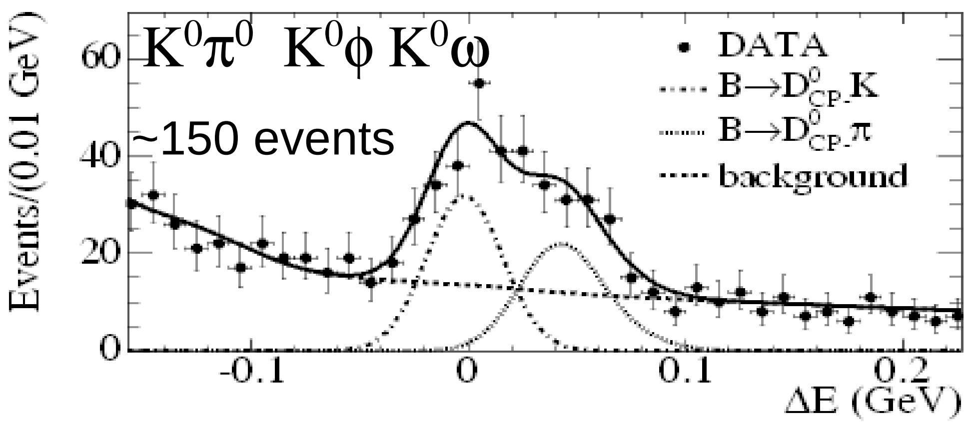
Select CP-even and CP-odd final state

- Theoretically clean but
- 8-fold ambiguity
- 3 ind. observables
- 3 unknown: r_B, δ_B, γ

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

$$R_{CP\pm} \equiv \frac{\Gamma(B^- \to D_\pm K^-) + \Gamma(B^+ \to D_\pm K^+)}{[\Gamma(B^- \to D^0 K^-) + \Gamma(B^+ \to \bar{D}^0 K^+)]/2} = 1 + r_B^2 \pm 2\, r_B \cos(\delta_B)\cos(\gamma)$$





New

hep-ex/0512067

232 million of BB

D^0 mode	R_{CP}	A_{CP}
$CP+$	$0.90 \pm 0.12 \pm 0.04$	$0.35 \pm 0.13 \pm 0.04$
$CP-$	$0.86 \pm 0.10 \pm 0.05$	$-0.06 \pm 0.13 \pm 0.04$

CP observables expressed in $x_\pm$ to allow a direct comparison with Dalitz results

$$x_+ = -0.082 \pm 0.053(\text{stat}) \pm 0.018(\text{syst}),$$
$$x_- = +0.102 \pm 0.062(\text{stat}) \pm 0.022(\text{syst}),$$
$$r^2 = -0.12 \pm 0.08(\text{stat}) \pm 0.03(\text{syst}).$$

- results on $x_\pm$ consistent with Dalitz analysis both in central value and in error

Combined results on γ

Dalitz: $x_\pm$ & $y_\pm$

GLW: $x_\pm$ from R_{CP} and A_{CP}

ADS: with current statistics, limit on r_B

$\gamma_{Dalitz} = (67 \pm 33)^\circ$

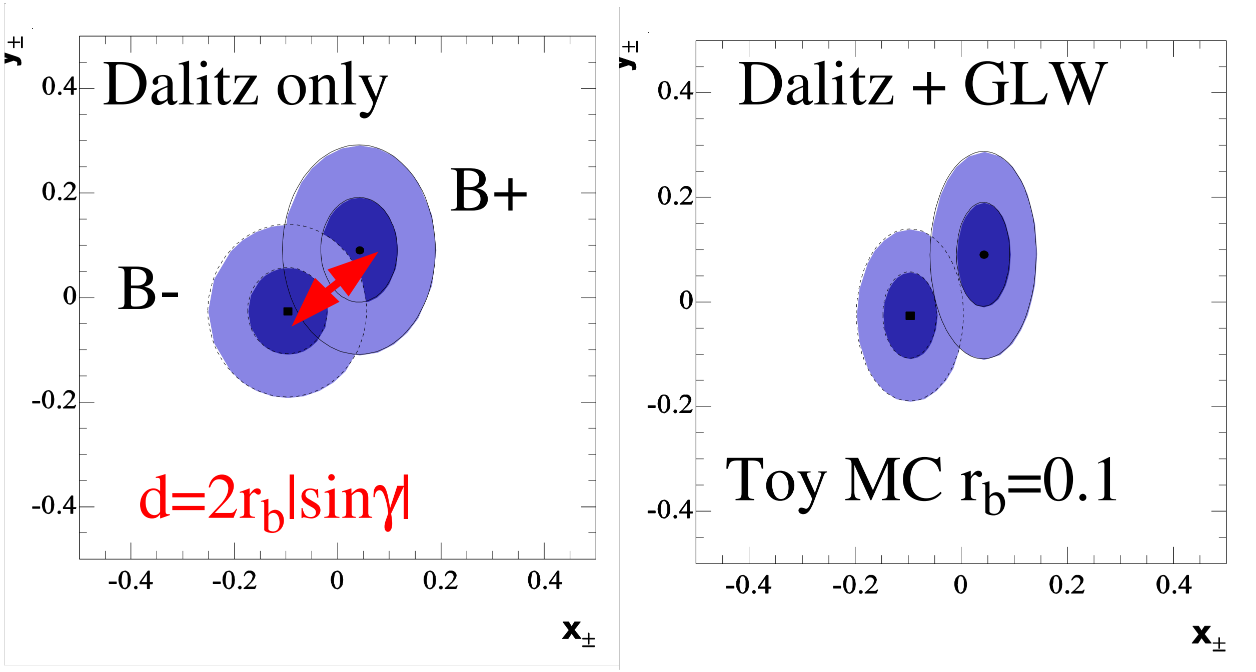
$\gamma_{All} = (72 \pm 30)^\circ$

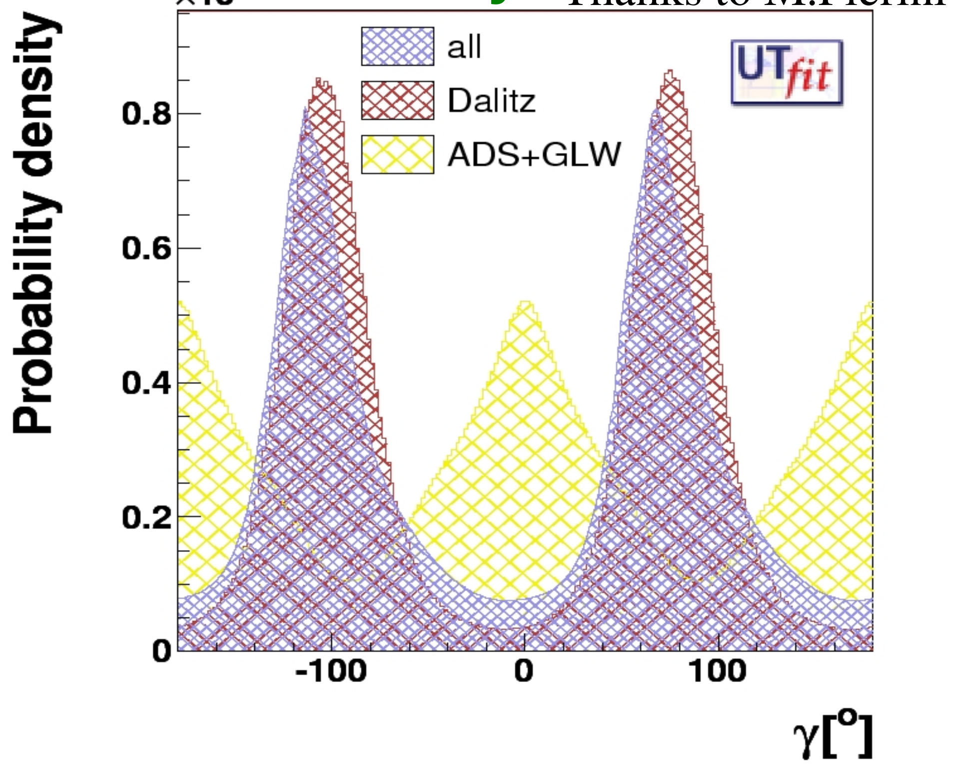
UTfit results

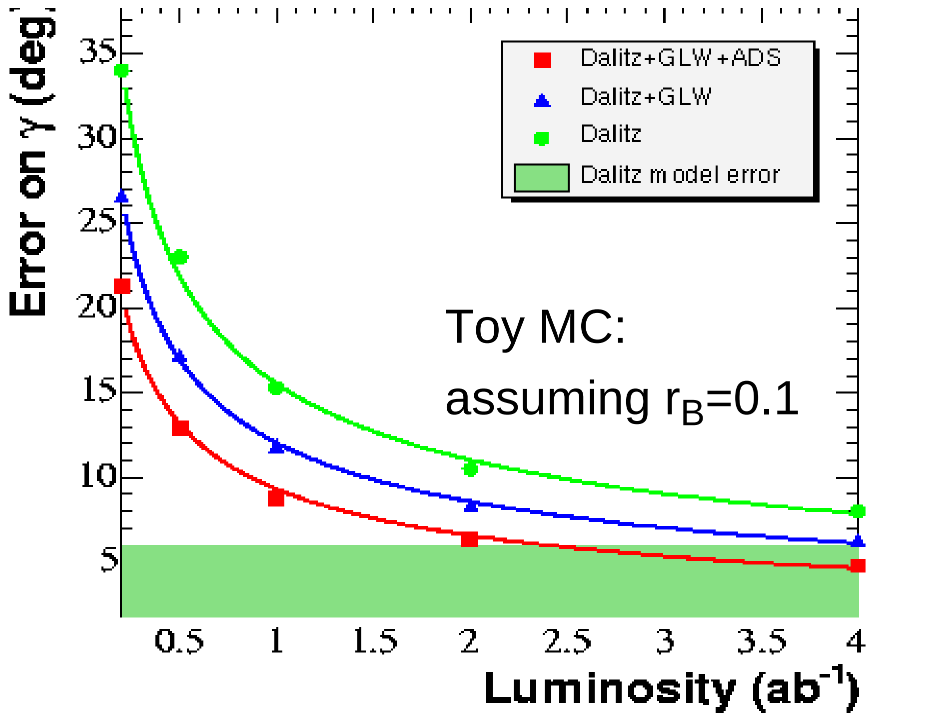
SM fits predicts $\gamma=(58\pm7)^\circ$

Small r_B from GLW -> Small improvement on $\sigma(\gamma)$

More statistics is needed!





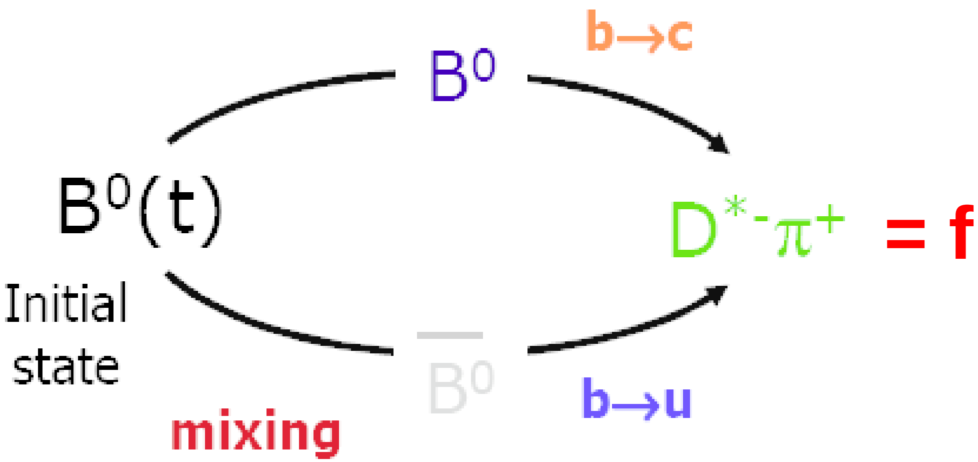


Different path

towards γ …

Measurement of sin(2β+γ) from B^0

- **Exploit mixing (2β) and interference between b→c and b→u transitions (γ) in Time Dependent Analysis like $B^0(t)\rightarrow D(*)\pi(\rho)$**



Sensitivity depends on

r=|A(b→ u)/A(b→c)|

Different possible final state **f**

hep-ex/0602049 & PRD71,112003(2005)

- **f** = D(*)π(ρ) → Large BR but r~0.02 small asymmetry — **|sin(2β+γ)|>0.4 @90%CL** — Not covered in this talk

- **f** = D(*)K(*)0
- **f** = $D(*)a_{0(2)}$
- **f** = DKπ

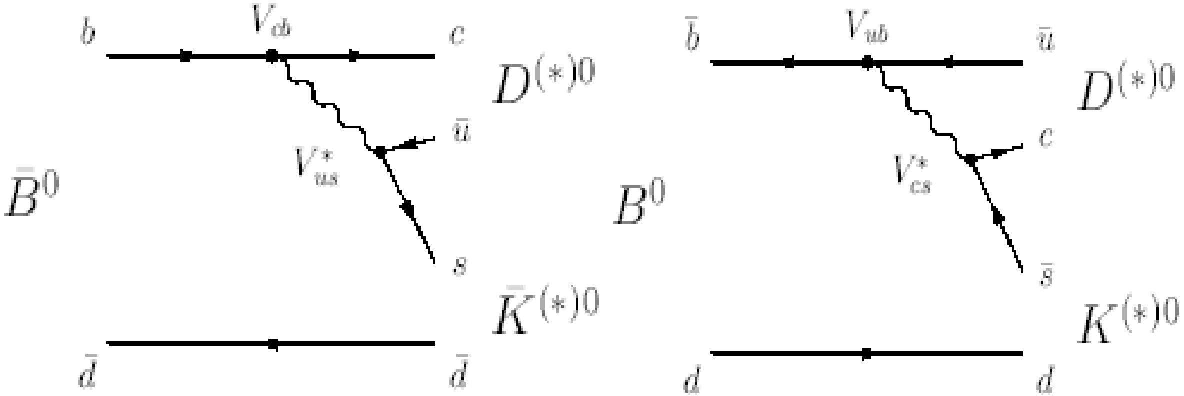
→ Small BR, but expected r~O(1)
Large asymmetry

Analyzed ~230x10^6 BB

sin(2β+γ) with $B^0 \to D^{(*)0}K^{(*)0}$

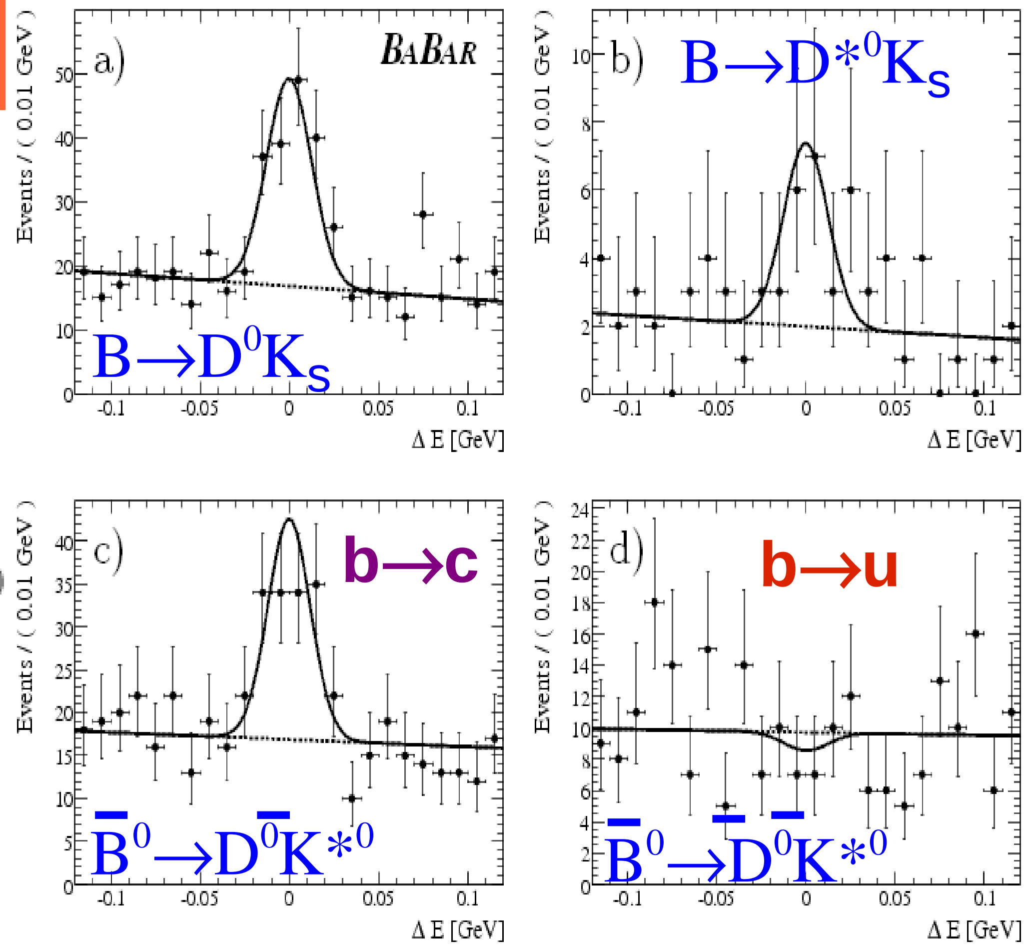
New

PRL78,3257(1997)
PRD61,116013(2001)



- Both diagrams color suppressed: expected large asymmetry
- Time dependent measurement with $K^0 \to K_S$
- r_B from self-tagged final states $K^{*0} \to K^- \pi^+$

$$\mathcal{B}(B \to D^0 \overline{K}^0) = (5.3 \pm 0.7 \pm 0.3) \times 10^{-5}$$
$$\mathcal{B}(B \to D^{*0} \overline{K}^0) = (3.6 \pm 1.2 \pm 0.3) \times 10^{-5}$$
$$\mathcal{B}(\overline{B}^0 \to D^0 \overline{K}^{*0}) = (4.0 \pm 0.7 \pm 0.3) \times 10^{-5}$$
$$\mathcal{B}(\overline{B}^0 \to \overline{D}^0 \overline{K}^{*0}) = (0.0 \pm 0.5 \pm 0.3) \times 10^{-5}$$



No evidence of b→u mode

$Br(B^0 \to D^0 K^{*0}) < 1.1 \times 10^{-5}$ @90%CL

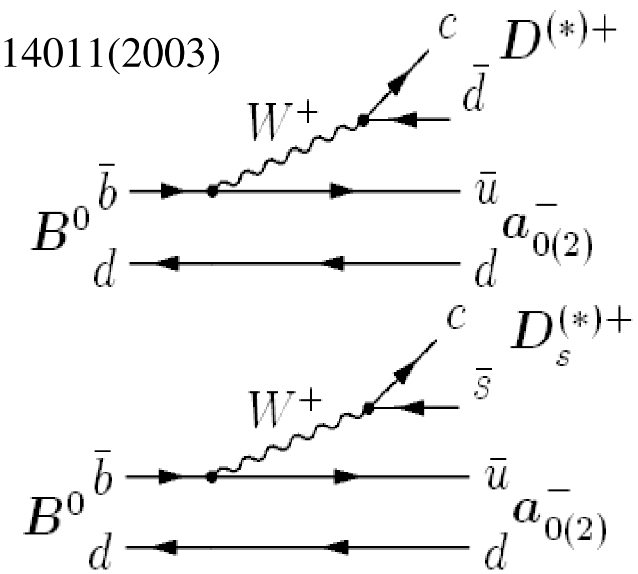
$r_B < 0.40$ @ 90%CL

r_B smaller than theoretical expectation (~0.4) not useful to measure γ value yet

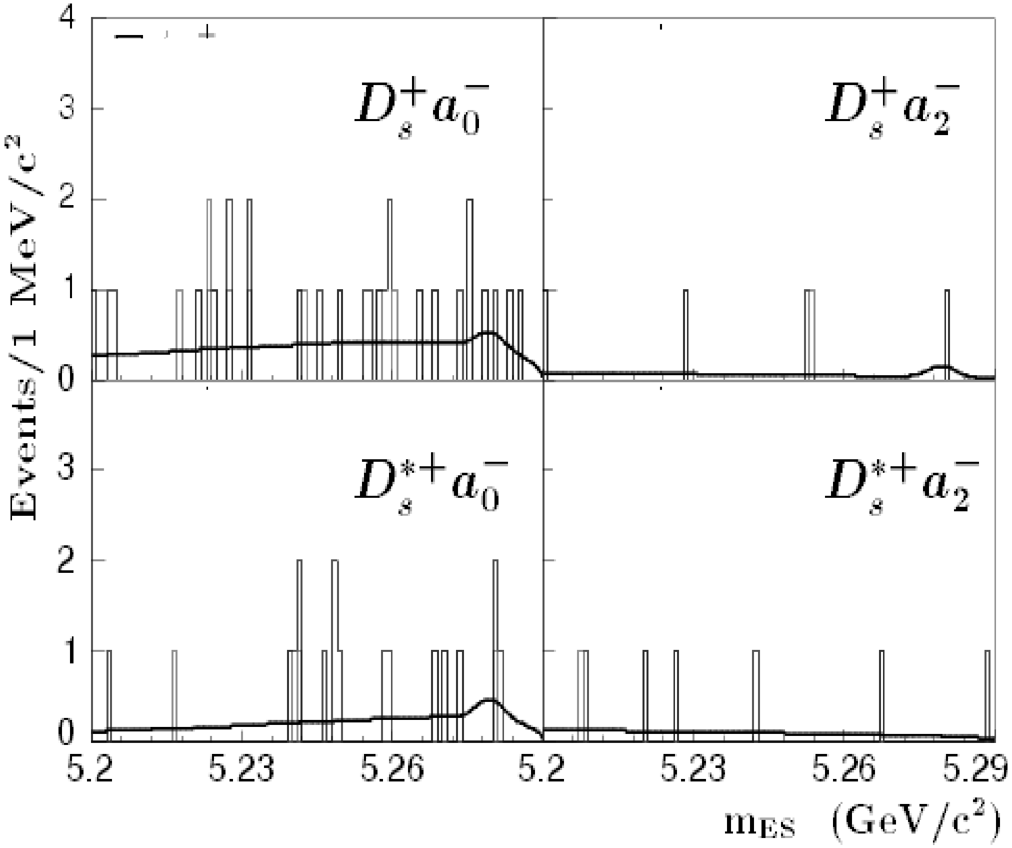
sin(2β+γ) with $B^0 \to D^{(*)+} a_{0(2)}^-$: Search for $B^0 \to D_s^{(*)+} a_{0(2)}^-$

- **CKM-favored is suppressed:**
  - $b \to c$ and $b \to u$ same magnitude: **expected large r_B**

PLB517,125(2001),PRD67,014011(2003)



- **$B^0 \to D_s^{(*)+} a_{0(2)}^-$** hep-ex/0512031
  - Constrain (assuming SU(3)) the $b \to u$ process



B^0 mode	n_{sig}	$\mathcal{B}\ [10^{-5}(10^{-7})]$	U.L. $[10^{-5}]$
$D_s^+ a_0^-$	$0.9^{+2.2}_{-1.7}$	$0.6^{+1.4}_{-1.1} \pm 0.1\ \ (2.6^{+6.6}_{-5.1} \pm 0.5)$	1.9 (0.09)
$D_s^+ a_2^-$	$0.6^{+1.0}_{-0.6}$	$6.4^{+10.4}_{-5.7} \pm 1.5\ \ (4.5^{+7.3}_{-4.0} \pm 0.8)$	19 (0.13)
$D_s^{*+} a_0^-$	$1.5^{+2.3}_{-1.8}$	$1.4^{+2.1}_{-1.6} \pm 0.3\ \ (6.5^{+10.1}_{-7.8} \pm 1.2)$	3.6 (0.17)
$D_s^{*+} a_2^-$	–	– (–)	20 (0.13)

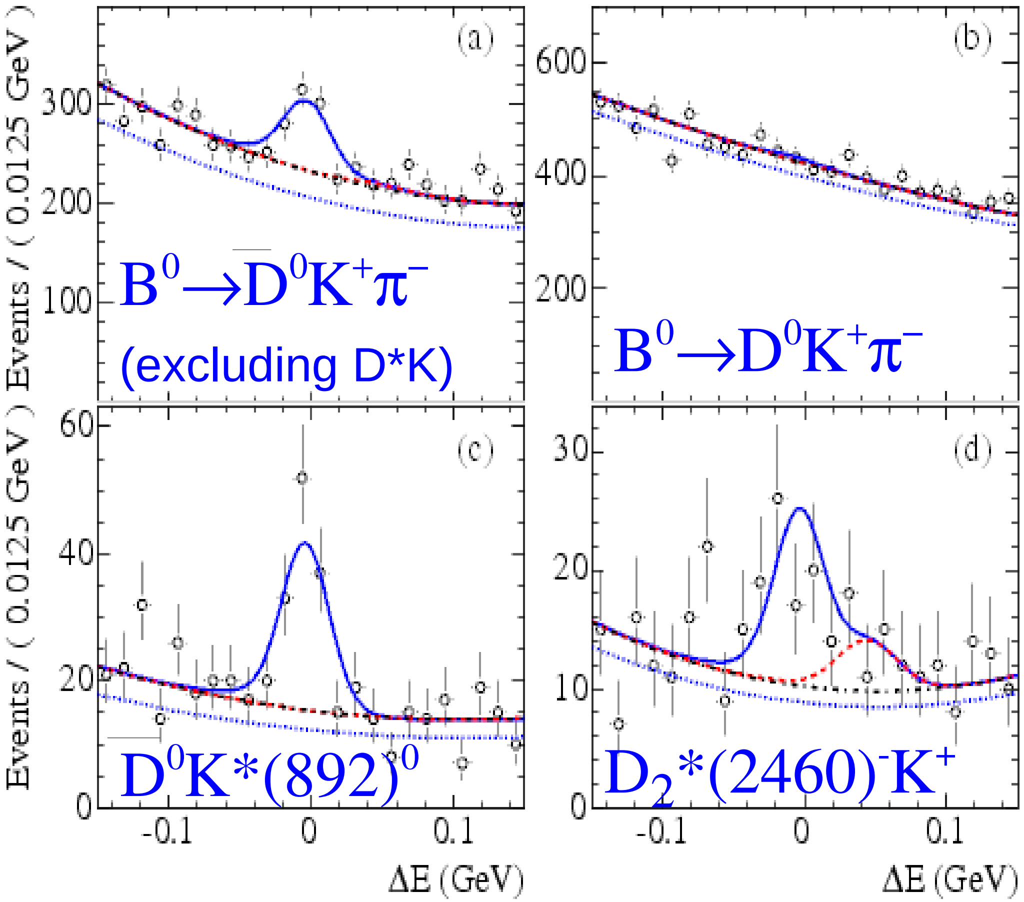
Lower than expected from theory:

- **UL suggests BR($B^0 \to D^{(*)+} a_{0(2)}^-$) too low to extract γ with present B-factories**
- **Revisit $B \to a_0 X$ transitions and Form-Factors**
- **Limit of the factorization for this decays?**

$B^0 \to D^0/\overline{D}^0 K^+\pi^-$

- **Principle similar to GLW: CP eigenstate isospin analysis to extract γ**
  - **CKM suppressed $b \to ucs$ include color-allowed diagrams**
    - Expected large rate and large CP violation
  - **Dalitz analysis allow to resolve δ, reduce ambiguity to 2-fold**

R.Aleksan et.al
PRD67,096002(2003)
PLB557,198(2003)



PRL96, 011803(2006) *New*

$$\mathcal{B}(B^0 \to \overline{D}^0 K^+\pi^-) = (88 \pm 15 \pm 9) \times 10^{-6}$$

$$\mathcal{B}(B^0 \to \overline{D}^0 K^*(892)^0) \cdot \mathcal{B}(K^*(892)^0 \to K^+\pi^-) = (38 \pm 6 \pm 4) \times 10^{-6}$$

$$\mathcal{B}(B^0 \to D_2^*(2460)^- K^+) \cdot \mathcal{B}(D_2^*(2460)^- \to \overline{D}^0\pi^-) = (18.3 \pm 4.0 \pm 3.1) \times 10^{-6}$$

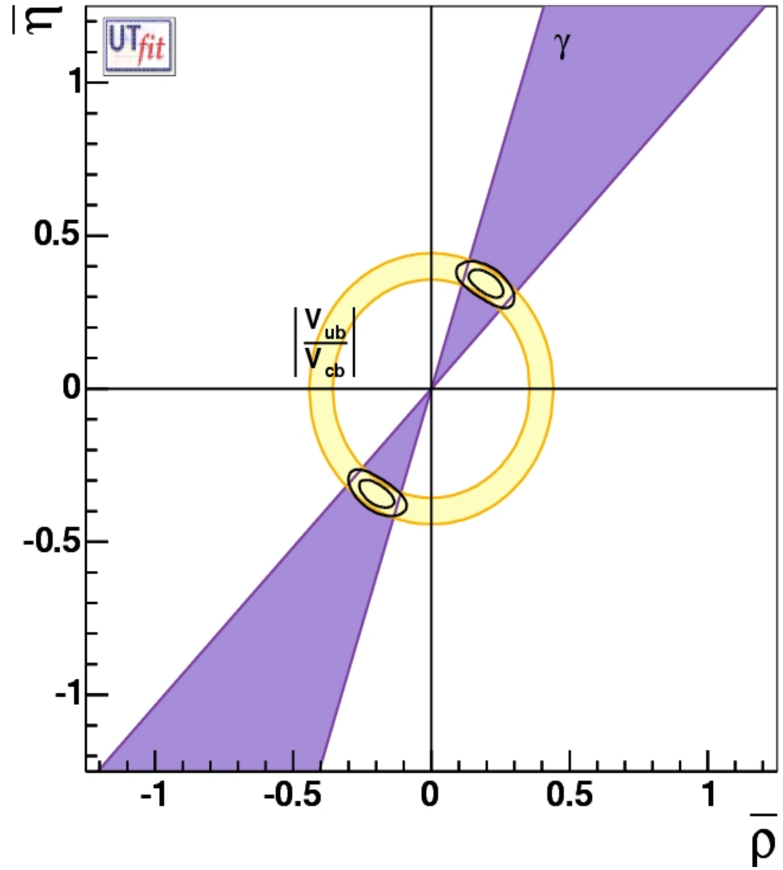
$BR(B^0 \to D^0 K^+\pi^-) < 19 \times 10^{-6}$ 90%CL

- **No significant CKM-suppressed component**
- **CP violation effects smaller than expected**
- **Not useful for γ extraction yet**

Conclusions

- **Many different and independent techniques to extract $|V_{ub}|$ and γ**
- **The shape function is one of most relevant systematic uncertainty on $|V_{ub}|$**
  - **First $|V_{ub}|$ extraction with reduced shape function dependence!**

2008



- **Dalitz gives the best sensitivity to γ:**
  - **GLW methods can improves the γ extraction: more modes and statistics is needed**
  - **Many other alternative methods have been evaluated:**
    - Less promising than theoretical expectation