Status and perspectives of measurements of V_{ub} and γ

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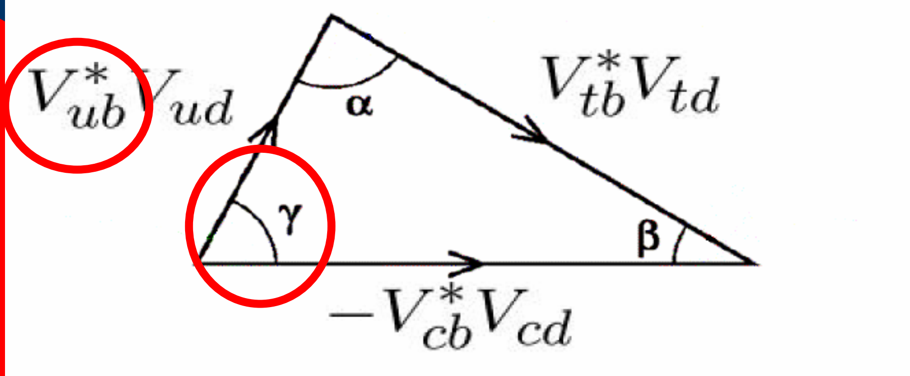
BaBar Collaboration

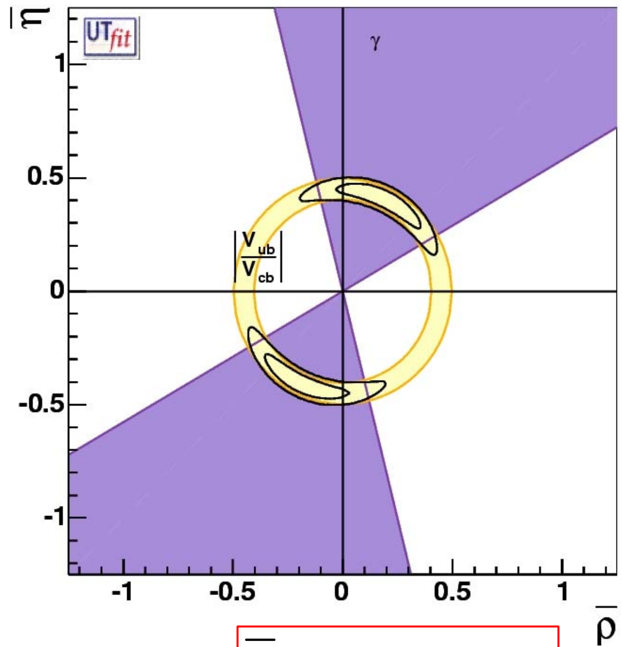
LHC Flavour Workshop
CERN – 7-10 nov 2005

The reference Unitarity Triangle

L.Silvestrini, LP'05



- γ and V_{ub} from pure tree level processes!
- Assumptions:
  - 3 generations only
  - No new physics at tree level
- Any new physics must satisfy this constraint



$\bar{\rho} = \pm 0.18 \pm 0.12$

$\bar{\eta} = \pm 0.41 \pm 0.05$

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

Mainly results from BaBar (Summer 2005)

V_{ub}, inclusive and exclusive

- Inclusive $B \to X_u \ell \nu$
  - large signal rate, large $X_c l\nu$ background
    - **Select limited region of phase space**
  - Total rate evaluates from OPE

$$\Gamma\left(\bar{B} \to X_u l \bar{\nu}\right) = \frac{G_F^2 m_b^5}{192\pi^3} |V_{ub}|^2 \times \left\{1 + O(\alpha_S) + O\left(\frac{1}{m_b^2}\right)\right\}$$

  - Non-perturbative contribution: Shape Function
    - determined experimentally from $b \to s\gamma$, $b \to cl\nu$

BNLP

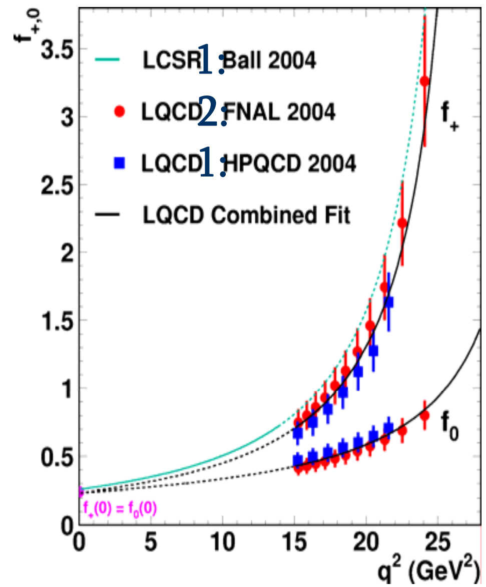
S.W. Bosch, B.O. Lange, M. Neubert, G. Paz, Nucl. Phys. B **669**, 355 (2004)
B.O. Lange, M. Neubert, G. Paz, hep-ph/0504071

BLL C.W. Bauer, Z. Ligeti, M. Luke, hep-ph/0111387

- Exclusive $B \to \pi \ell \nu, \rho \ell \nu$, etc.
  - Low signal rate, background rejection (kin. constraint)
  - FormFactors normalization (**V_{ub}**) : theory error
    FF shape (**acceptance**) affects exp'l uncert.

$$\frac{d\Gamma(B \to \pi \ell \nu)}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{ub}|^2 \, p_\pi^3 \left|f_+(q^2)\right|^2$$

Form Factor



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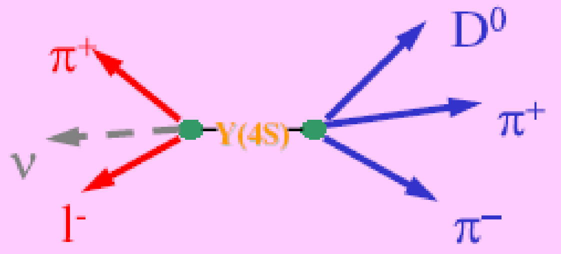
Measuring V_{ub}, experimental methods

- Tagging methods

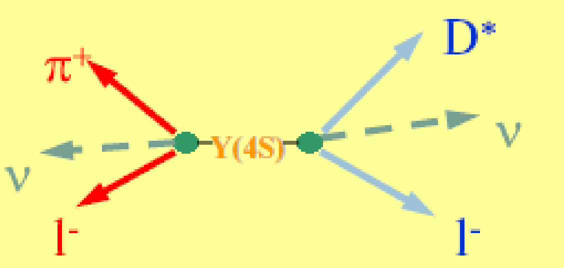


Hadronic Tag:

Fully reconstruct hadronic decay of one B:

$B \rightarrow D^{(*)} + (\pi^+, \pi^0, K^+, K^0)$ ≈ 1000 modes

$\rightarrow$ know kinematics of other B

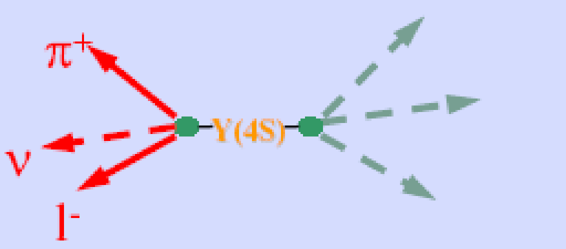


Semileptonic Tag:

Reconstruct $B \rightarrow D^{(*)} l \nu$ and study recoil

- Full reconstruction of $D^{(*)}$
- Partial reconstruction of D^* (only l, π_{soft})

Two ν $\rightarrow$ tag-B kinematics incomplete



No Tag:

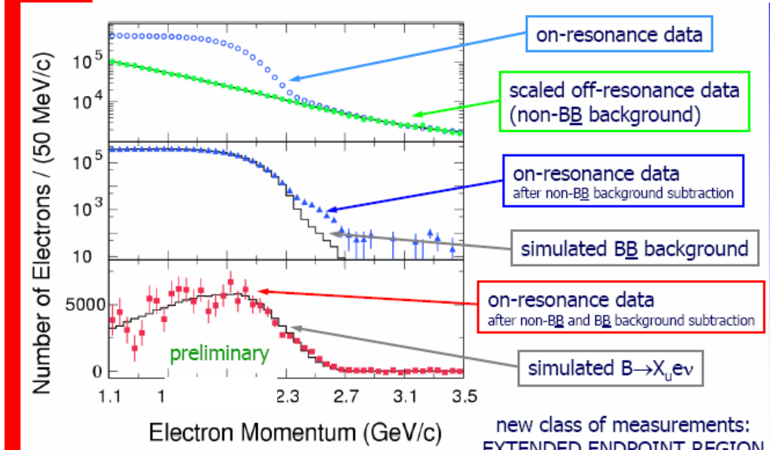
High statistics

High backgrounds and cross-feed

$\rightarrow$ Fully reconstruct signal side (ν reco.)

V_{ub}: inclusive analyses

$$|V_{ub}| = \sqrt{\frac{\Delta B}{\Delta\zeta \cdot \tau_B}}$$



new class of measurements: EXTENDED ENDPOINT REGION

Endpoint spectrum

$2.0 < E_e < 2.6$ GeV

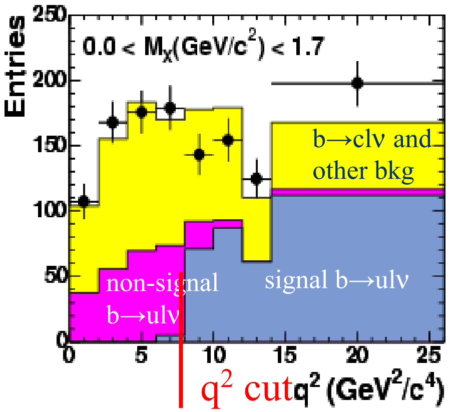
$$|V_{ub}| = (4.44 \pm 0.25_{exp} \, {}^{+0.42}_{-0.38}{}_{SF} \pm 0.22_{th\text{-}BLNP}) \times 10^{-3} \quad \sigma \sim 12\%$$

b →sγ, b →clv moments (BaBar) [O.Buchmuller and H.Flacher, hep-ph/0507253]

hep-ex/0509040

80 fb^{-1}

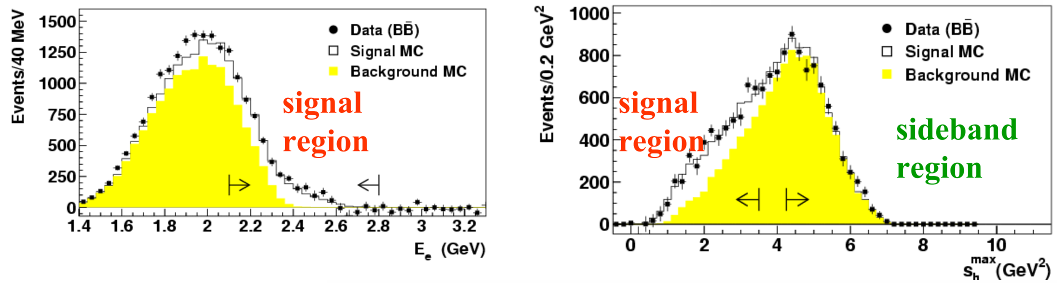
M_X vs q^2 : hadronic tag



hep-ex/0506036

81 fb^{-1}

Neutrino reconst.: E_l vs q^2



$\Delta BR(E_e^* > 2.0$ GeV, $s_h^{max} < 3.5$ GeV^2) =
$(3.54 \pm 0.33_{stat} \pm 0.34_{syst}) \times 10^{-4}$

$$|V_{ub}|_{BLL} = (4.82 \pm 0.26_{stat} \pm 0.25_{syst} \pm 0.46_{SF+theo}) \times 10^{-3} \quad \sigma \sim 12\%$$

$$|V_{ub}| = (3.95 \pm 0.26_{exp} \, {}^{+0.58}_{-0.42}{}_{HQ} \pm 0.25_{theo}) \times 10^{-3}$$

$$|V_{ub}|_{BLNP(BaBar\ b\to cl\nu)} = (4.65 \pm 0.24_{stat} \pm 0.24_{syst} \, {}^{+0.46}_{-0.36}{}_{SF} \pm 0.23_{th}) \times 10^{-3} \quad \sigma \sim 13\%$$

hep-ex/0507017 211 fb^{-1}

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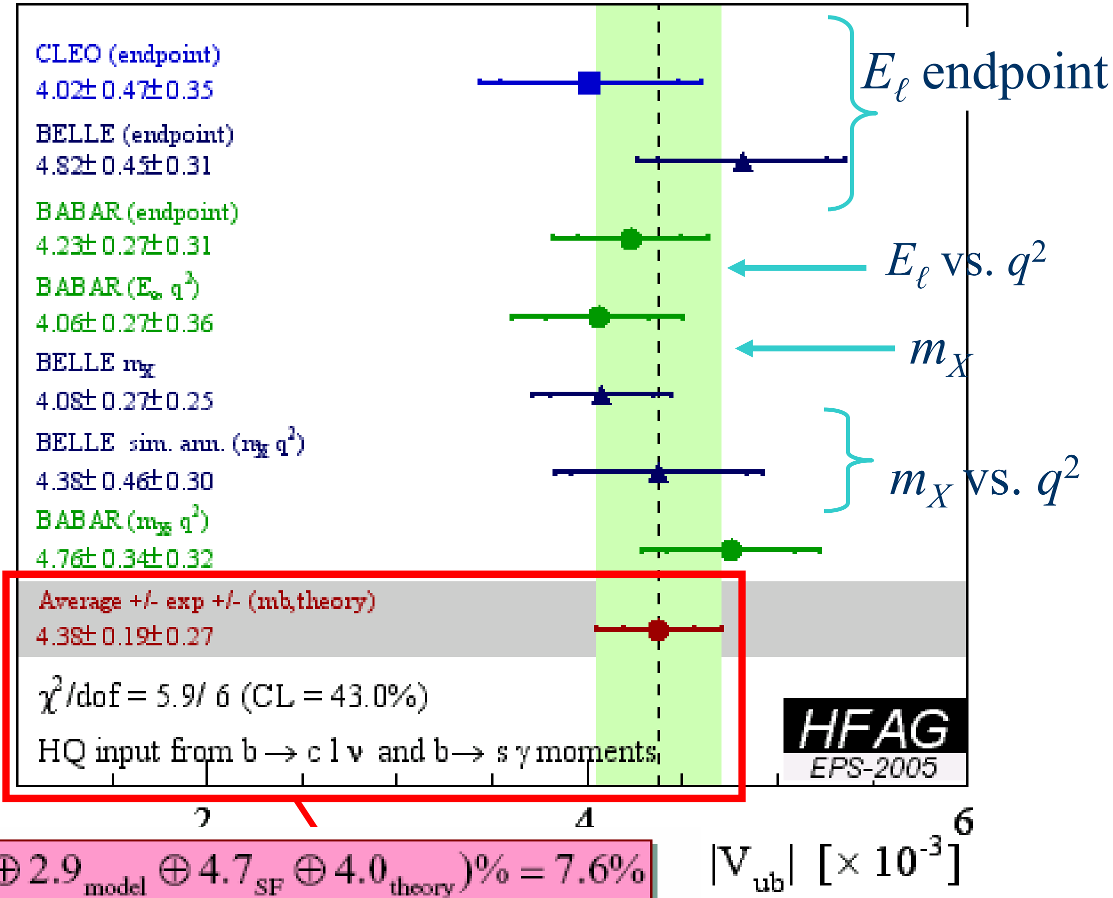
Results (and current limitations)

HFAG results are rescaled to common HQE inputs:
m_b=4.60±0.04 GeV,
μ_π^2=0.20±0.04 GeV^2

- Limited by uncertainties on SF paramaters (m_b)
  - Improve inputs from $b \to c l \nu$ and $b \to s\gamma$
  - Improve SF evaluation
- Weak annihilation
  - Should be small (2%)
  - Can be checked with B^0/B^+ comparison



$$\Delta V_{ub}/V_{ub} = (3.3_{expt} \oplus 2.9_{model} \oplus 4.7_{SF} \oplus 4.0_{theory})\% = 7.6\%$$

$$|V_{ub}|_{WAvg} = (4.38 \pm \underbrace{0.19}_{expt} \pm \underbrace{0.27}_{m_b,\ theory}) \times 10^{-3}$$

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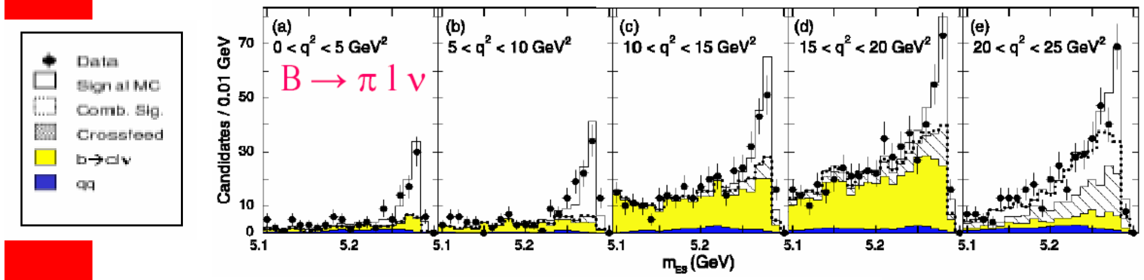
V_{ub}: exclusive, $B\to\pi l\nu,\rho l\nu$

Untagged

Binning in q^2



$B(B^0\to\pi^-\ell^+\nu)=$
$(1.38\pm0.10_{stat}\pm0.18_{syst}\pm0.08_{FF})\times10^{-4}$

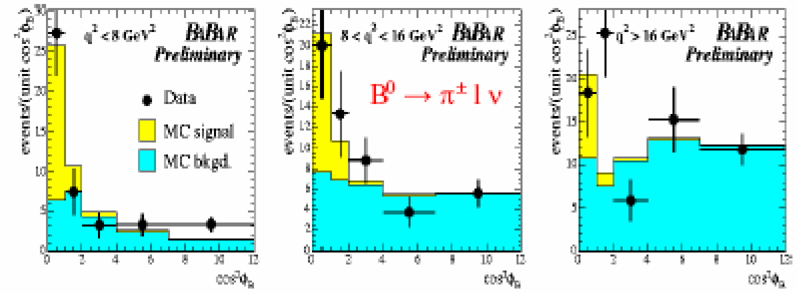
$B(B^0\to\rho^-\ell^+\nu)=$
$(2.14\pm0.21_{stat}\pm0.53_{syst}\pm0.28_{FF})\times10^{-4}$

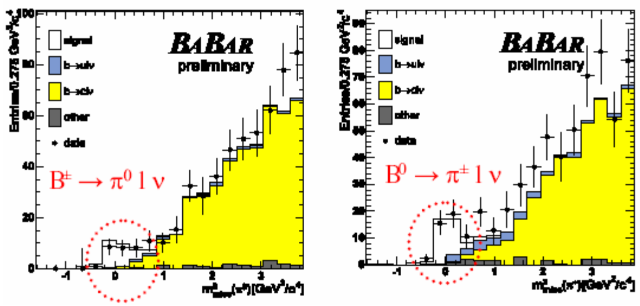
hep-ex/0506064 211 fb^{-1}

Semileptonic tag

No phase space cut
Coarse q^2 binning

$$B(B^0\to\pi^-\ell^+\nu)=(1.03\pm0.25_{stat}\pm0.13_{syst})\times10^{-4}$$
$$B(B^+\to\pi^0\ell^+\nu)=(1.80\pm0.37_{stat}\pm0.23_{syst})\times10^{-4}$$



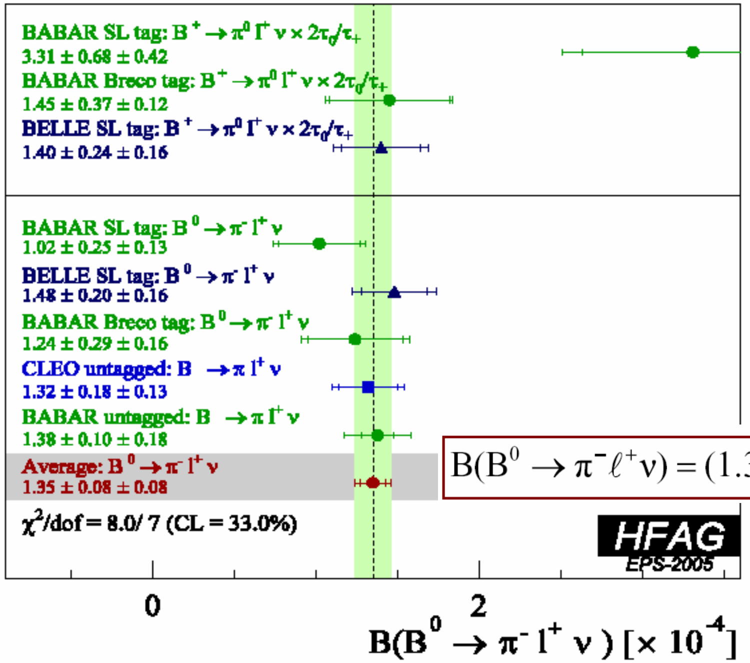


Hadronic tag

Low background, no phase space cut!!!
Low signal rate
More channels in progress:

$B\to\rho\ell\nu$, $B\to\omega\ell\nu$, $B\to\eta\ell\nu$, $B\to\eta'\ell\nu$, $B\to a_0\ell\nu$

V_{ub}: exclusive results



$$B(B^0 \to \pi^- \ell^+ \nu) = (1.35 \pm 0.08 \ \pm 0.08\ ) \times 10^{-4}$$

Full q^2 range
FNAL LQCD

hadronic tag

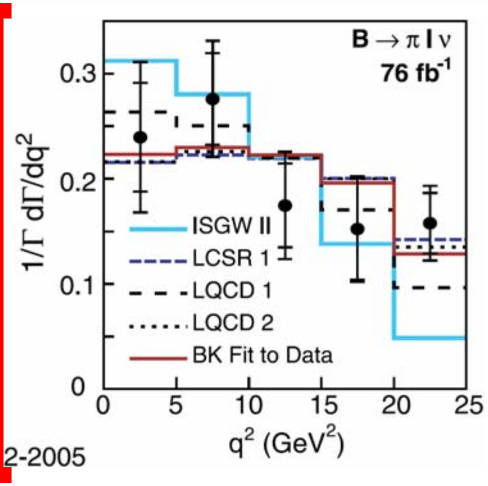
$$|V_{ub}| = (3.7 \pm 0.3_{stat} \pm 0.2_{syst}\ {}^{+0.8}_{-0.5 FF(LQCD)}) \times 10^{-3}$$

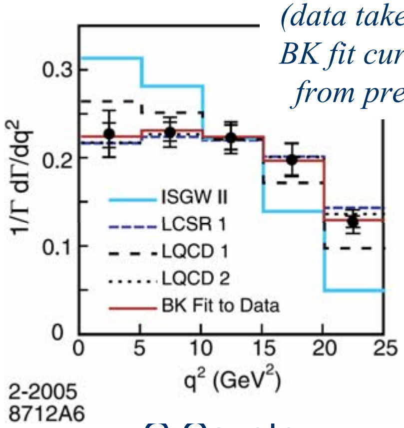
semileptonic tag

$$|V_{ub}| = (3.3 \pm 0.4_{stat} \pm 0.2_{syst}\ {}^{+0.8}_{-0.4 FF(LQCD)}) \times 10^{-3}$$

untagged

$$|V_{ub}| = (3.82 \pm 0.14_{stat} \pm 0.24_{syst} \pm 0.11_{FF}\ {}^{+0.88}_{-0.52 LQCD}) \times 10^{-3}$$





Projection to 1 ab^{-1}

(data taken to be on BK fit curve from present measurement).

In the high q^2 region alone, branching fraction at (6-7)% , or (3-3.5)% on $|V_{ub}|$.
Lattice expect to reach 6%

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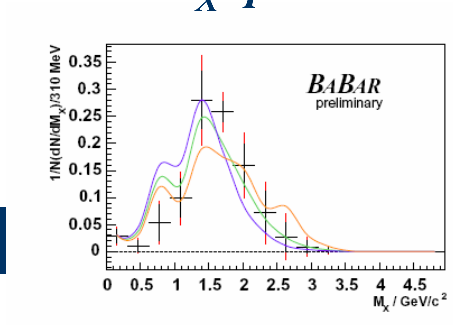
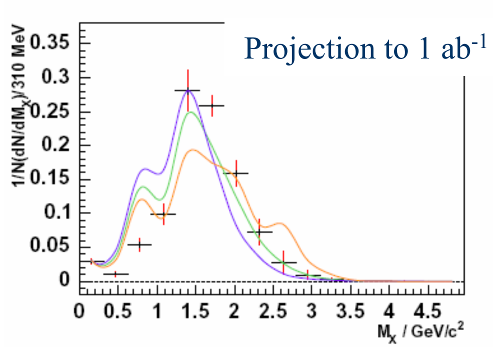
V_{ub} : outlook

250 $fb^{-1} \rightarrow$ 500 fb^{-1}

M_X spectrum





Inclusive

technique	$\Delta\|V_{ub}\| / \|V_{ub}\|$ (%)	
	Statistical	experimental systematics
$E_l > 2.0$ GeV	$2 \rightarrow 1$	3
E_l vs. q^2	$3 \rightarrow 2$	4
M_X vs. q^2	$5 \rightarrow 3$	5

Combination of larger dataset and confidence in theory (subleading SF): 5-7%

Exclusive

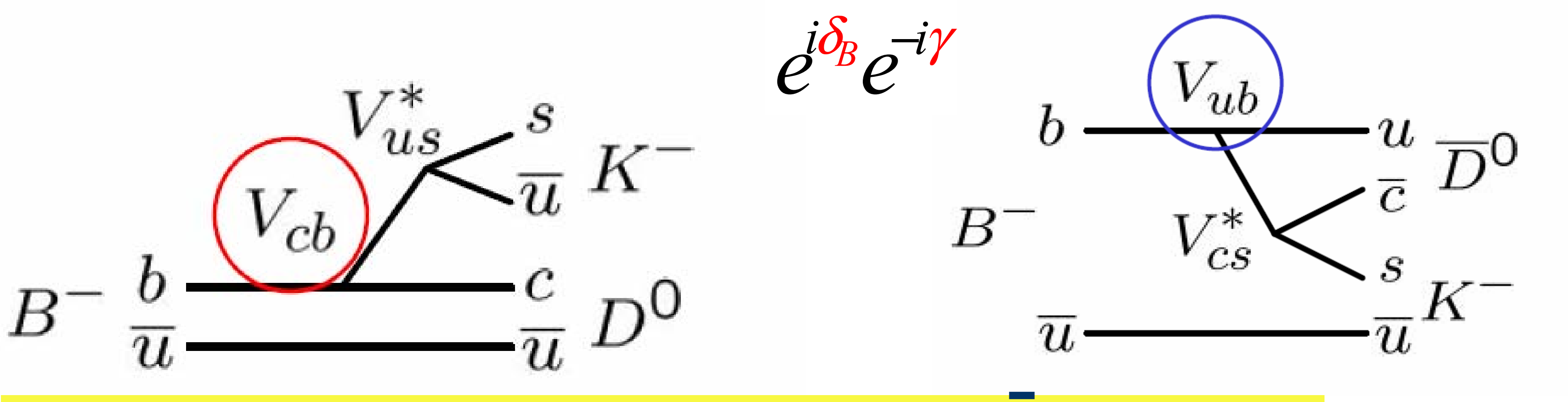
	210 fb-1 σ_{exp}(%)	1000 fb-1 σ_{exp}(%)
hadronic tag	17	9
semileptonic tag	13	9
ν reconstruction	9	8

Need help from theory: Uncertainty on $|V_{ub}|$ dominated by theory error! **(~15%)**

- Reliable error estimate for ρlν FF → needed for π and ρ BF and $|V_{ub}|$
- Progress in LQCD for **πlν** : theory error 6-7% ?
  (Lubicz, Lattice04; Bernard CKMWS 05)

Big improvements possible
total error ~ 9%

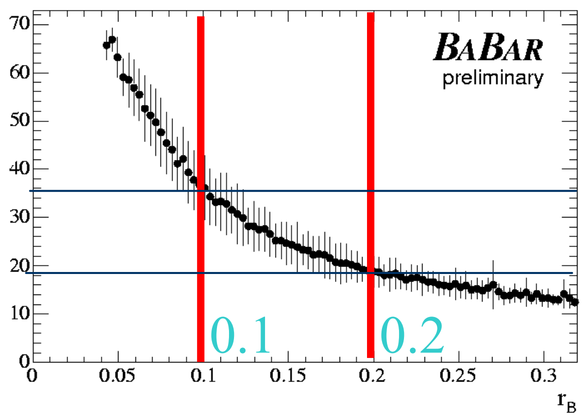
γ from direct CP violation



Interference when D final state common to both $\overline{D}^0$ and D^0

Relative size (r_B) of B decay amplitudes

$$r_B = \left| \frac{A(b \to u)}{A(b \to c)} \right|$$



Larger r_B, larger interference, **better γ** experimental precision

Gronau & London, PLB 253, 483 (1991),
Gronau & Wyler, PLB 265, 172 (1991)].

Gronau London Wyler method

D decays into CP eigenstate

Theoretically clean, but with 8-fold ambiguity

Select CP-even and CP-odd final states

$$D^0_{CP\pm} \equiv (D^0 \pm \overline{D}^0)/\sqrt{2}$$

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

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

3 observables, 3 unknowns

$$CP = +1 \quad \pi^+\pi^-, K^+K^-$$

$$CP = -1 \quad K^0_S\pi^0, K^0_S\phi, K^0_S\omega, K^0_S\eta, K^0_S\eta'$$

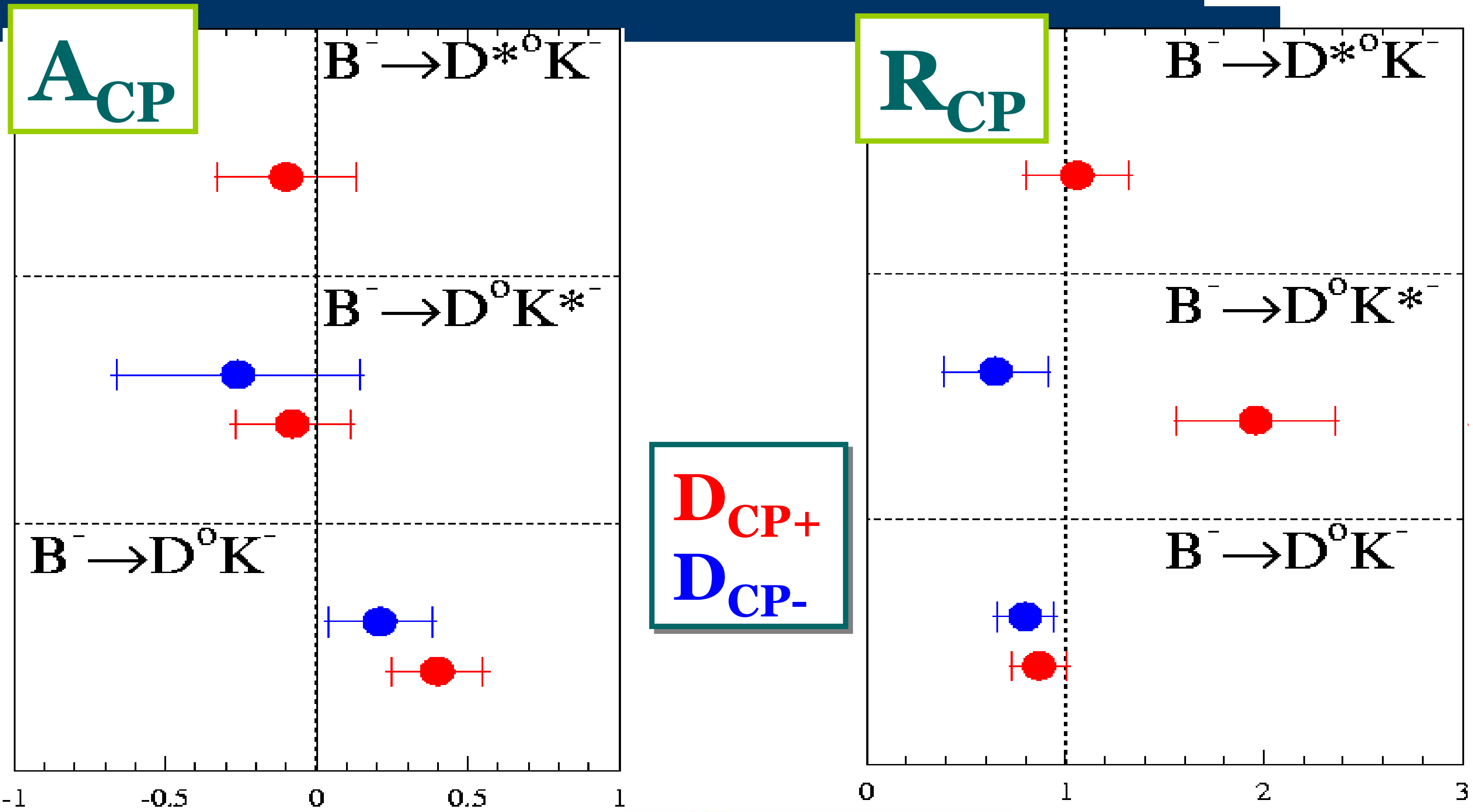
Experimentally

- Normalize to D^0 decay into flavour state ($K^-\pi^+$)
- CP modes: small D^0 branching ratio

GLW results

PRD71,031102(2005)

Systematic uncertainties hardly visible !



$$\frac{R_{CP+} + R_{CP-}}{2} = 1 + r_B^2$$

$\Rightarrow (r_B)^2\ (D^0K^-) = -0.17 \pm 0.16$

$\Rightarrow (rs_B)^2\ (D^0K^{*-}) = 0.30 \pm 0.25$

Atwood, Dunietz, & Soni, PRL 78, 3257 (1997), PRD 63, 036005 (2001)

Atwood Dunietz Soni method

D decay into flavor state

favored: $B^- \to D^0 K^-$ suppressed: $D^0 \to K^+\pi^-$

suppressed: $B^- \to \overline{D}^0 K^-$ favored: $\overline{D}^0 \to K^+\pi^-$

δ_B δ_D $\to [K^+\pi^-]_D K^-$

Count B candidates with opposite sign kaons

$$R_{ADS} = \frac{Br([K^+\pi^-]K^-) + Br([K^-\pi^+]K^+)}{Br([K^-\pi^+]K^-) + Br([K^+\pi^-]K^+)} = r_D^2 + r_B^2 + 2r_B r_D \cos(\delta_D + \delta_B)\cos\gamma$$

$$A_{ADS} = \frac{Br([K^+\pi^-]K^-) - Br([K^-\pi^+]K^+)}{Br([K^+\pi^-]K^-) + Br([K^-\pi^+]K^+)} = 2r_B r_D \sin(\delta_D + \delta_B)\sin\gamma / R_{ADS}$$

Input: $r_D = \frac{|A(D^0 \to K^+\pi^-)|}{|A(D^0 \to K^-\pi^+)|} = 0.060 \pm 0.003$

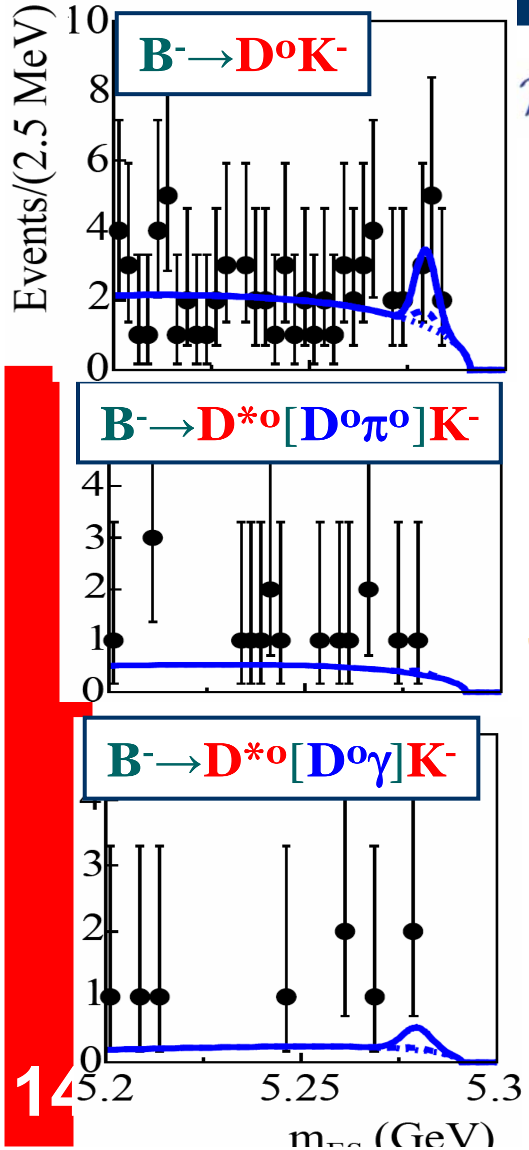
Phys.Rev.Lett.91:171801,2003

D decay strong phase δ_D unknown

ADS: results

hep-ex/0504047

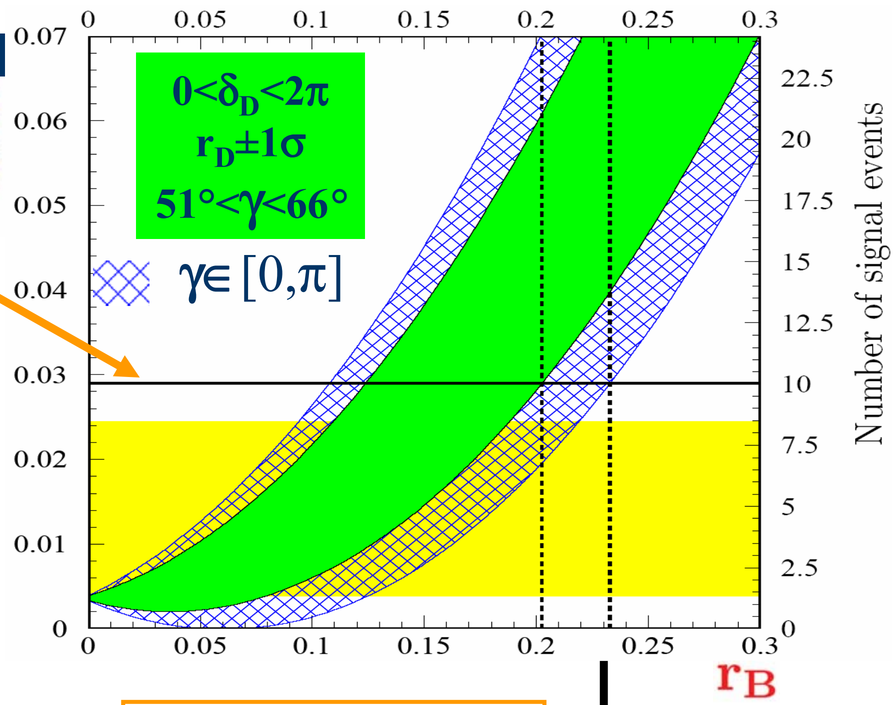
232×10^6 $\bar{B}B$



$\mathcal{R}_{ADS}^{K\pi} < 0.029$ *

*@ 90%CL

No DCS signal ...



r_B<0.23 @ 90% CL

$\mathcal{R}_{ADS}^{K\pi,D\pi^0} < 0.023$ *

$\mathcal{R}_{ADS}^{K\pi,D\gamma} < 0.045$ *

Bondar & Gershon PRD70,091503(2004)

$\Rightarrow D^{*0}\rightarrow D^0\pi^0/D^0\gamma$

$\neq$ in δ_{D^*} by π

$$\frac{\mathcal{R}_{ADS}^{K\pi,D\pi^0} + \mathcal{R}_{ADS}^{K\pi,D\gamma}}{2} - r_D^2 = r_B^{*\,2}$$

$(r^*_B)^2 < (0.16)^2$ @ 90% CL

(Bayesian $r^{*2}_B>0$ & uniform, $\forall\,\gamma$ and $\delta_D{}^*$)

Giri, Grossman, Soffer, & Zupan, PRD 68, 054018 (2003),
Bondar (Belle), PRD 70, 072003 (2004)

If we knew the charm phase shift δ_D?

$B^- \to D^{(*)0} K^-$ $D^0(K_S\pi\pi)$ Dalitz analysis

Amplitude for $B^-/B^+ \to$ "D^0" K^-/K^+

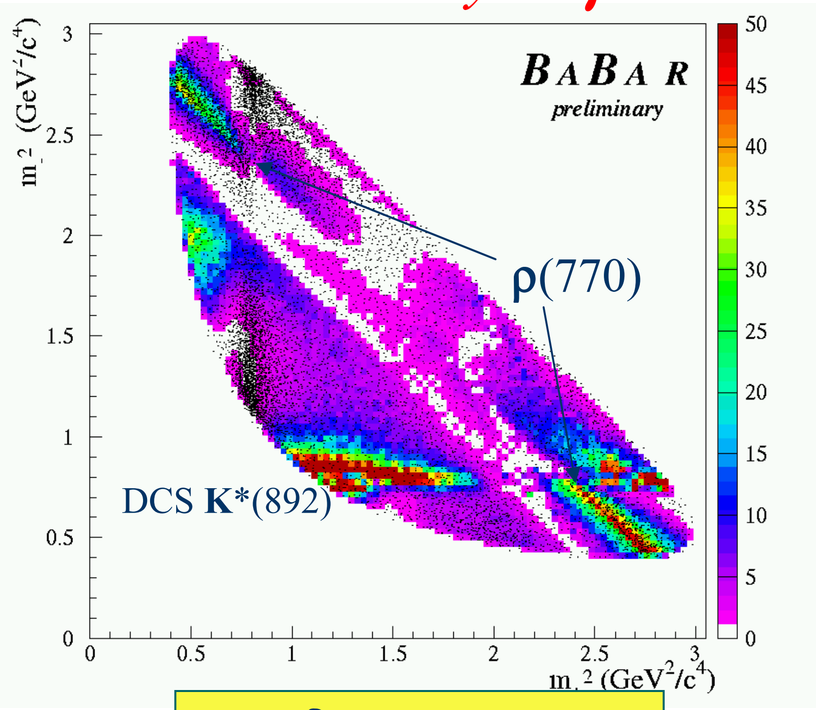
$$M_-(m_-^2, m_+^2) = \mathbf{f}(m_-^2, m_+^2) + r_B e^{i(\delta_B - \gamma)}\ \mathbf{f}(m_+^2, m_-^2)$$

$$M_+(m_-^2, m_+^2) = \mathbf{f}(m_+^2, m_-^2) + r_B e^{i(\delta_B + \gamma)}\ \mathbf{f}(m_-^2, m_+^2)$$

$$m_-^2 = M(K_S^0\pi^-)^2$$

$$m_+^2 = M(K_S^0\pi^+)^2$$

Sensitivity to γ



γ=75, δ=180, r_B=0.125

Isobar model for f(m^2_+, m^2_-) can fix phase variation δ_D across Dalitz plot.

Only two-fold ambiguity in γ extraction

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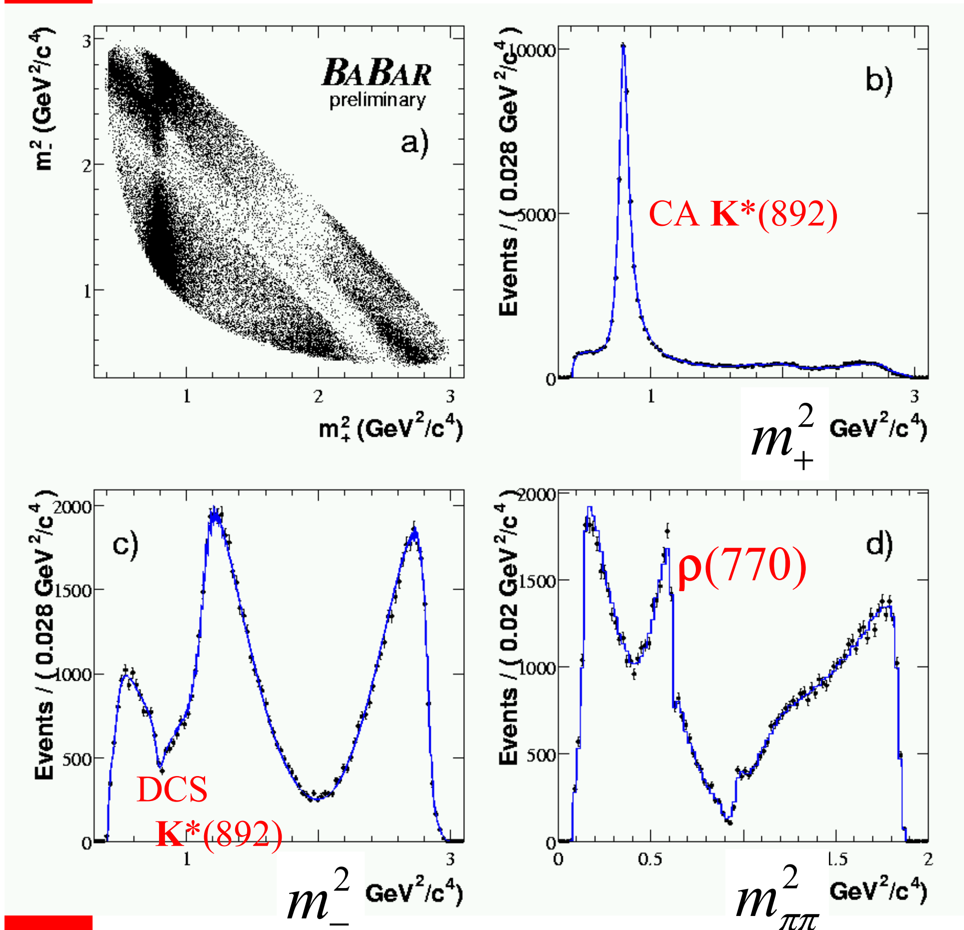
Determined on $D^* \to D^0\pi$ sample

$\overline{D}^0(K_S\pi^+\pi^-)$ Dalitz model



D^0 decay model ≡ **coherent sum** of **Breit-Wigner** (BW) **amplitudes** (quasi 2 body terms).

13 distinct resonances (**3** WS DCS) + **1 NR term**. This isobar model is **not so good for ππ S waves** ⇒ need controversial **σ(500) / σ'(1000)** to describe reasonably well the data.

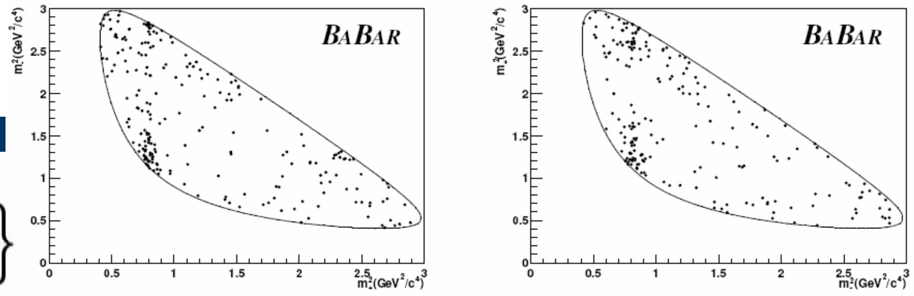
Better description of quasi 2-body terms: BW + ππ S-waves with K-matrix formalism

Anisovich & Saratev
Eur. Phys. J A16, 229 (2003)

No D-mixing, No CP violation in D decays

γ from Dalitz

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



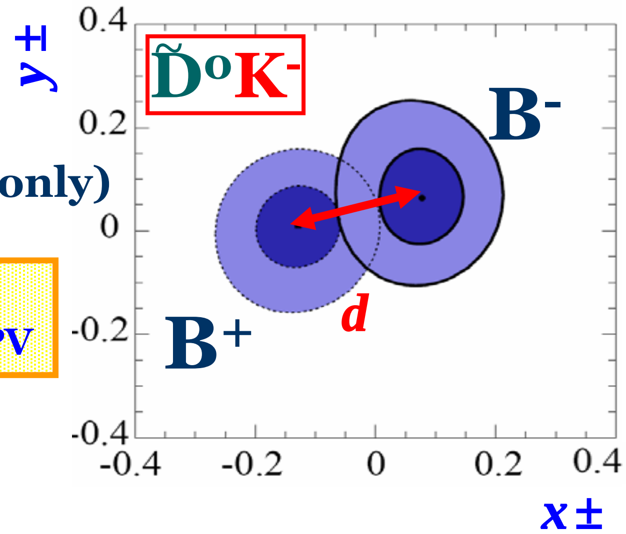
2D

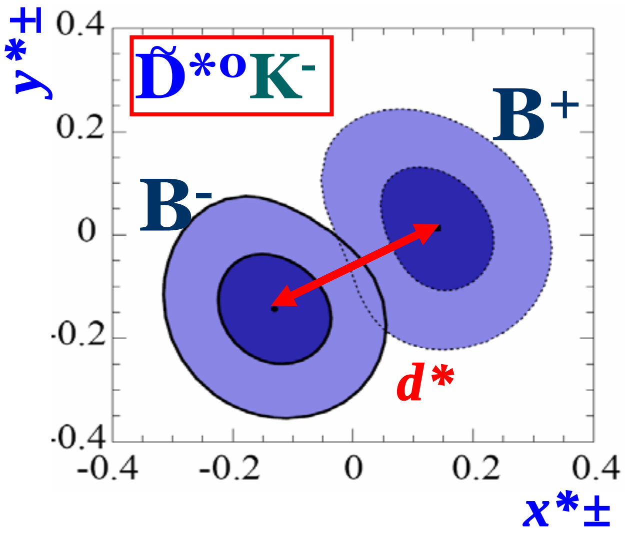
2 σ CL

1 σ CL (stat. only)

$d \equiv 2\, r_B |\sin\gamma| \neq 0$

⇒ *size* of direct CPV



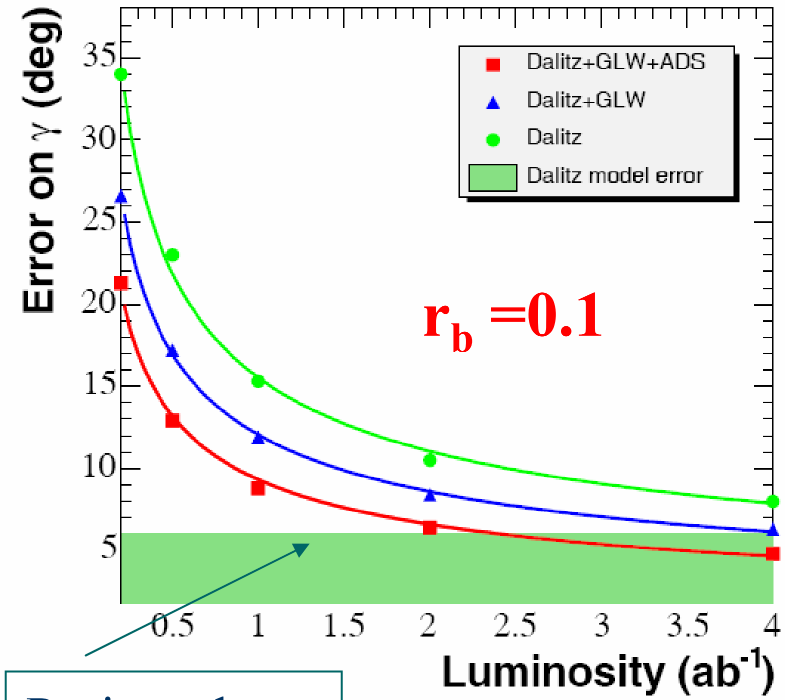


$\gamma = [67° \pm 28°_{(stat.)} \pm 13°_{(syst.\ exp.)} \pm 11°_{(Dalitz\ model^*)}]$

*evaluated removing ππ S-wave

3° for **K-matrix / BW difference**

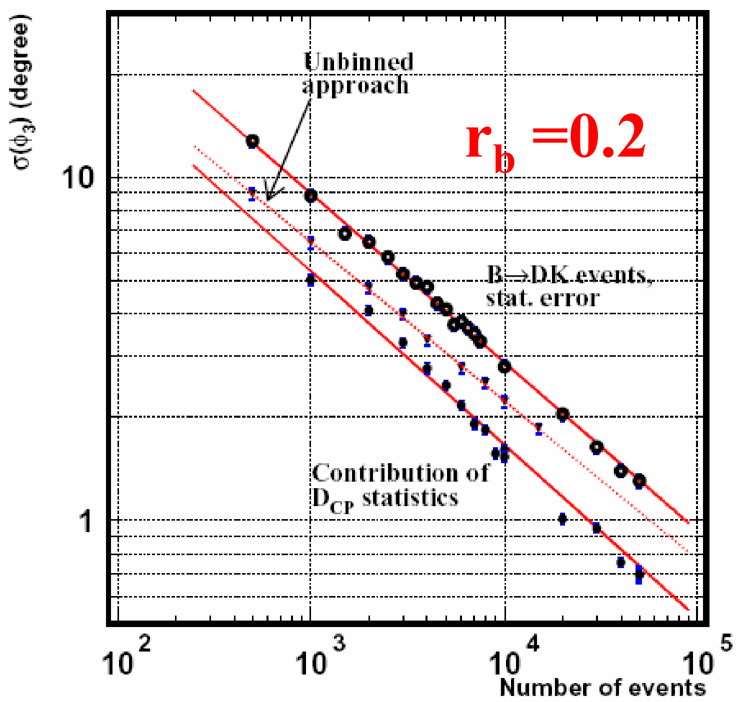
Projected γ uncertainty



Projected sys error due to D^0 Dalitz plot

Model independent approach

A.Bondar and A.Poluetkov, hep-ph/0510246



Charm and (super)B-factory interplay

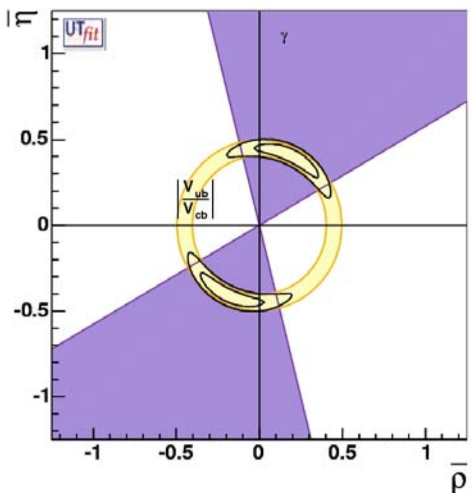
Summary

- Many different and independent techniques to constrain V_{ub} and γ

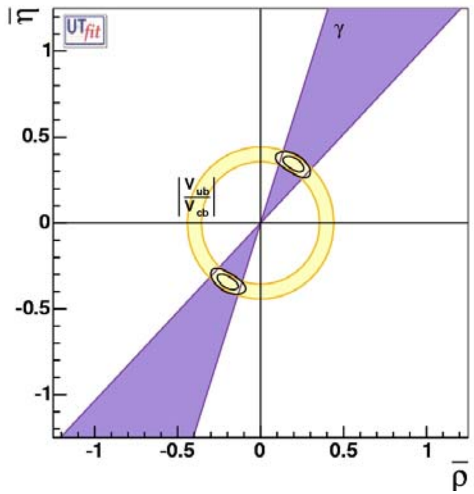
– By 2008 1 ab^{-1}/B-factory

- **V_{ub}** inclusive: 5-6%
- **V_{ub}** exclusive : dominated by theoretical error
  total error 8% (?)
- γ
  - Dalitz technique most promising
    - r_b critical parameter for sensitivity
    - Dalitz model limit at 5° ?
    - More stat for model indep.
  - Including more modes/techniques adds to $1/\sqrt{N}$ improvements

2005



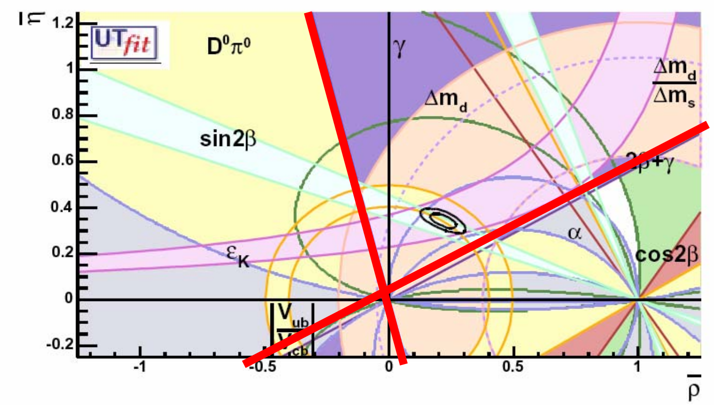
2008



Backup slides

UT in 2008

2005



2008