B decay and CP violation
CKM angles and sides

PIC 2008

Perugia,Italy

25-28 June, 2008

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For the B Factories

Outline

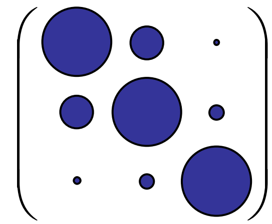
- The CKM matrix and Unitarity Triangle
- The BABAR and BELLE dectectors
- Side measurements
  - B_d and B_s mixing
  - V_{cb} inclusive & exclusive
  - V_{ub} inclusive & exclusive
  - *No time for Radiative decays !*
- CKM angle measurements
  - β / ϕ_1
  - α / ϕ_2
  - γ / ϕ_3

The CKM matrix

quark mixing matrix of charged current interactions

- **CKM matrix definition**:

$$\mathrm{L}_{W^\pm} = -\frac{g}{\sqrt{2}}\left(\overline{u_L} \quad \overline{c_L} \quad \overline{t_L}\right)\gamma^\mu \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}\begin{pmatrix} d_L \\ s_L \\ b_L \end{pmatrix} W_\mu^+ + h.c.$$



relative element sizes

  - Unitary matrix
  - 3 real parameters + ***1 complex phase*** ⟸ *Only source of ~~CP~~ in SM*

- **Wolfenstein parameterization**:

$$V_{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

$A\lambda^3(\rho - i\eta)$: $|V_{ub}|e^{-i\gamma}$

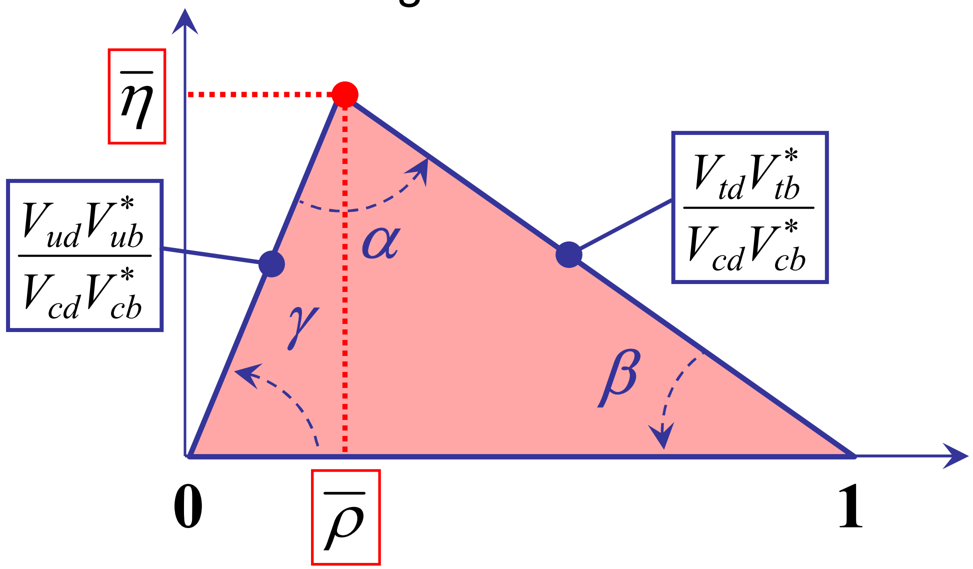
$A\lambda^3(1-\rho-i\eta)$: $|V_{td}|e^{-i\beta}$

  - the 4 parameters are $\lambda \approx 0.22$, $A \approx 0.83$, ρ and η.
  - matrix hierarchy reflected by development in power of λ.
  - in this representation CKM angles are carried by $V_{td}=|V_{td}|e^{-i\beta}$, $V_{ub}=|V_{ub}|e^{-i\gamma}$, with $\alpha=\pi-\beta-\gamma$

The Unitarity Triangle

- Unitary of V_{CKM} ➔ $V^{\dagger}_{CKM} V_{CKM} = 1$ ➔ $V_{ud}V^{*}_{ub} + V_{cd}V^{*}_{cb} + V_{td}V^{*}_{tb} = 0$
  - unitary triangle of *B* sector
  - all terms of the order λ^3 ➔ CPV angles sizeable

$\bar{\rho}$ and $\bar{\eta}$ are slight redefinition of ρ and η to provide a well defined expansion in λ of V_{CKM} and its unitarity of to all orders in λ.



Name of angles	
BELLE	**BABAR**
ϕ_1	β
ϕ_2	α
ϕ_3	γ

- **Sides of the triangles measurable by non *CP* violating processes**
  - eg : semileptonic *B* decays, $B^0\bar{B}^0$ mixing frequency
- **Angles measured with CP violating processes**
  - If α or β : $B^0\bar{B}^0$ mixing is needed ingredient to access the phase of V_{td}
  - If γ charged *B* decays can allow access as well

Three types of *CP* violation

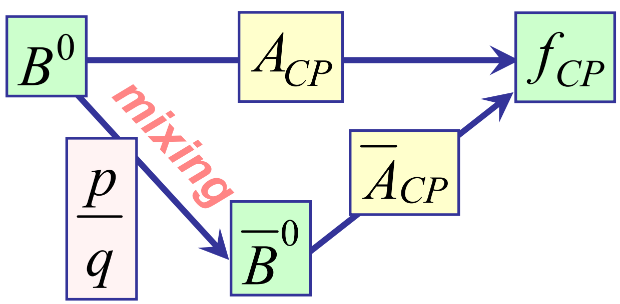
- ***CP* violation in decay ("direct" *CPV*):**
  - $\left|A(B\to f)\right| \neq \left|\bar{A}(\bar{B}\to \bar{f})\right|$
  - both charged or neutral *B*'s
    - *only possible CPV for B±'s*

- ***CP* violation in mixing:**
  - $\langle B^0 | \bar{B}^0 \rangle \neq \langle \bar{B}^0 | B^0 \rangle$

$$|B_L\rangle = p|B^0\rangle + q|\bar{B}^0\rangle$$
$$|B_H\rangle = p|B^0\rangle - q|\bar{B}^0\rangle$$

  - ($|p/q| \neq 1$)~10^{-3} in SM, approaching experimental limits

- ***CP* violation in interference between mixing and decay:**



$$\lambda_{f_{CP}} = \eta_{f_{CP}} \frac{p}{q} \frac{\bar{A}_{CP}}{A_{CP}}$$

Independent of phase convention

depend on final state ($\eta_{f_{CP}}$)

- Time dependent *CP* asymmetry:

$$A_{f_{CP}}(\Delta t) = \frac{N(B^0(\Delta t)\to f_{CP}) - N(\bar{B}^0(\Delta t)\to f_{CP})}{N(B^0(\Delta t)\to f_{CP}) + N(\bar{B}^0(\Delta t)\to f_{CP})}$$
$$= S_{f_{CP}}\cdot \sin\Delta m_{B^0}\Delta t - C_{f_{CP}}\cdot\cos\Delta m_{B^0}\Delta t$$

$$C_{f_{CP}} = \frac{1-|\lambda_{f_{CP}}|^2}{1+|\lambda_{f_{CP}}|^2} = -A_{f_{CP}}$$

if ≠ 0 : direct CPV

$$S_{f_{CP}} = \frac{2\,\mathrm{Im}\,\lambda_{f_{CP}}}{1+|\lambda_{f_{CP}}|^2}$$

I should make clear that :

At Δt = 0 the B meson is a pure B^0 or $\overline{B}^0$

It decays at Δt in a interference state

On an experimental point of view, the detector has to measure:

➔ B CP flavor (B^0 or $\overline{B}^0$) at Δt =0

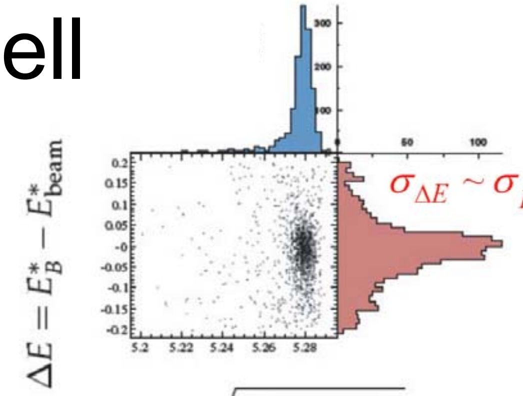
➔ The decay time Δt of the B meson

- Time dependent *CP* asymmetry:

$$A_{f_{CP}}(\Delta t) = \frac{N(B^0(\Delta t) \to f_{CP}) - N(\overline{B}^0(\Delta t) \to f_{CP})}{N(B^0(\Delta t) \to f_{CP}) + N(\overline{B}^0(\Delta t) \to f_{CP})}$$
$$= S_{f_{CP}} \cdot \sin \Delta m_{B^0} \Delta t - C_{f_{CP}} \cdot \cos \Delta m_{B^0} \Delta t$$

Time dependent measurements at B-factories in a nutshell

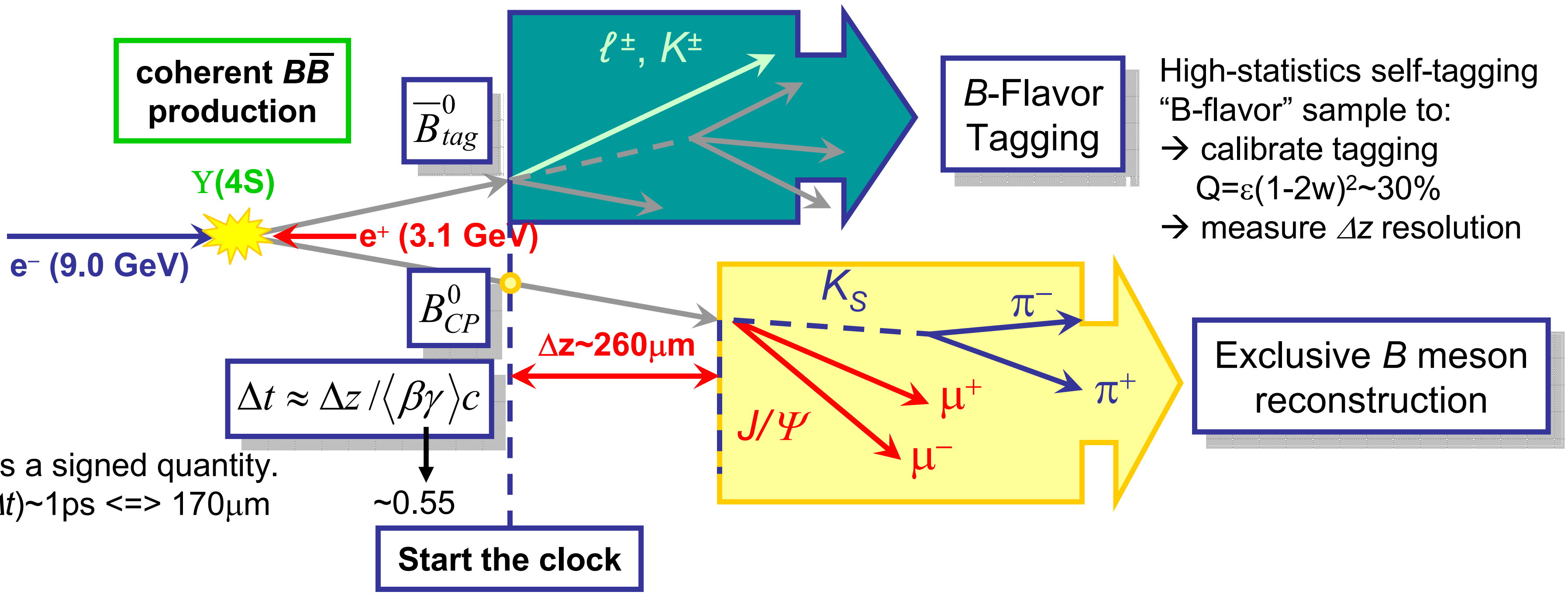
- reconstruct final (*CP* eigen)state
- measure distance between decay vertices
- determine B^0 tag flavor at decay time
- fit…



$\sigma_{\Delta E} \sim \sigma_{E_B^*} \approx 10 \div 50 MeV$

$m_{\text{ES}} = \sqrt{E_{\text{beam}}^{*} - p_B^{*2}}$

$\sigma_{m_{ES}} \sim \sigma_{beam} \sim 2.7 MeV$

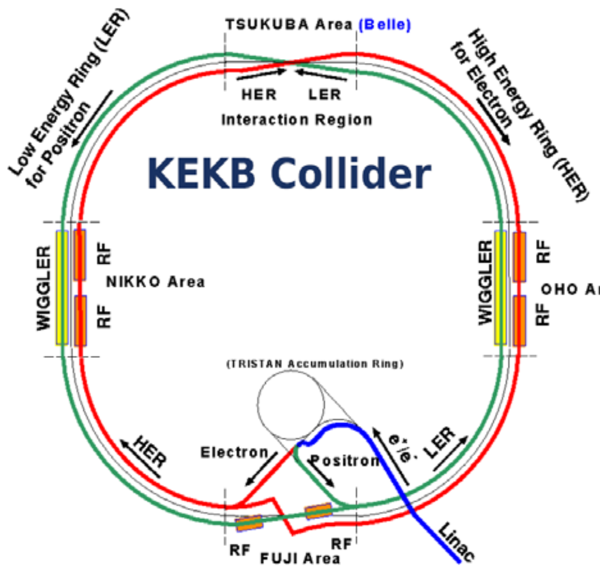


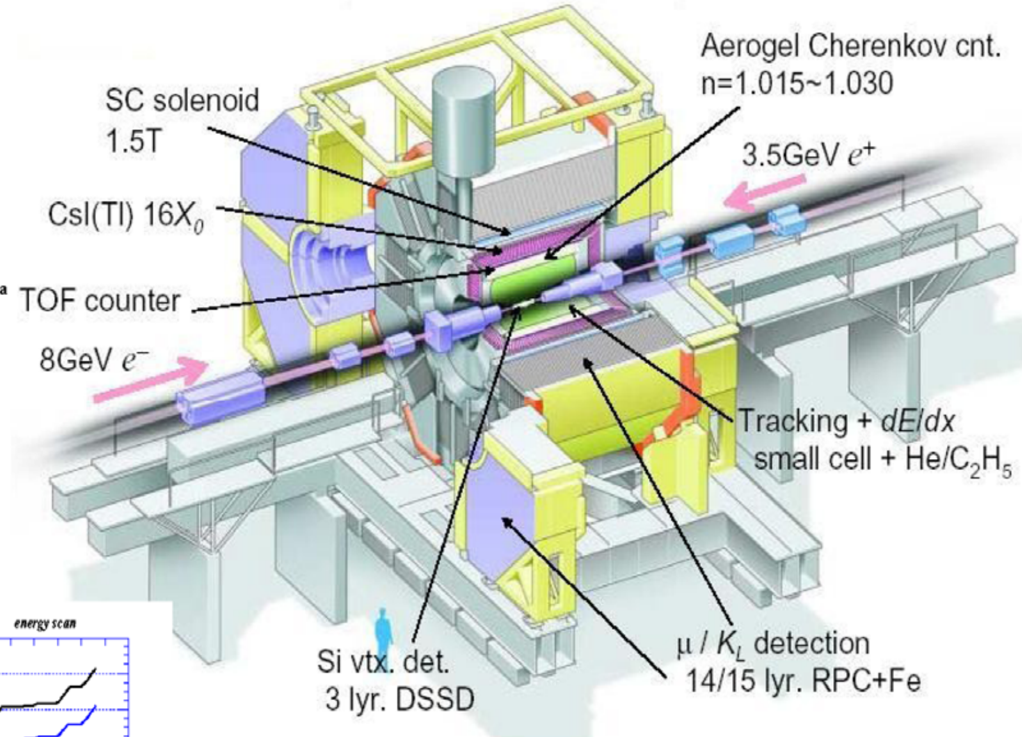
High-statistics self-tagging "B-flavor" sample to:
→ calibrate tagging
Q=ε(1-2w)²~30%
→ measure *Δz* resolution

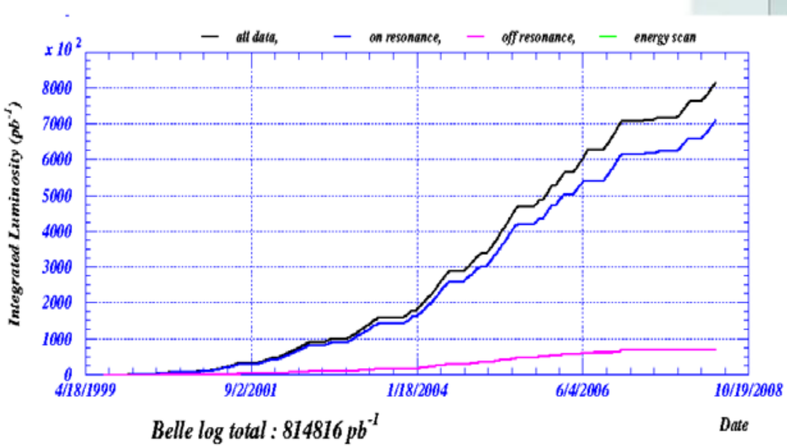
Δt is a signed quantity.
σ(*Δt*)~1ps <=> 170μm

The BABAR and BELLE detectors

The BELLE detector







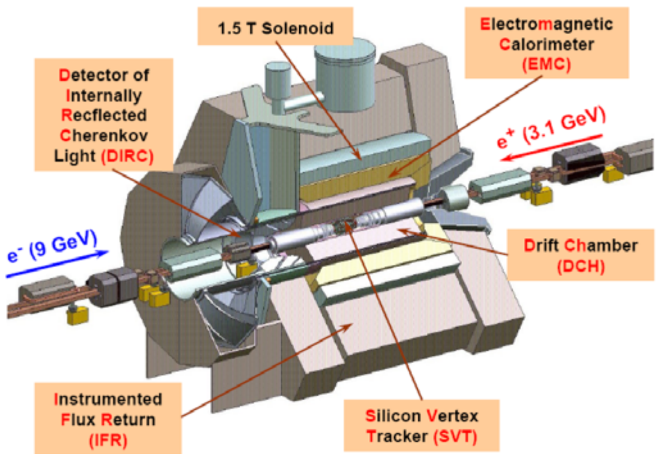
3.5 GeV e^+ & 8 GeV e^- beams

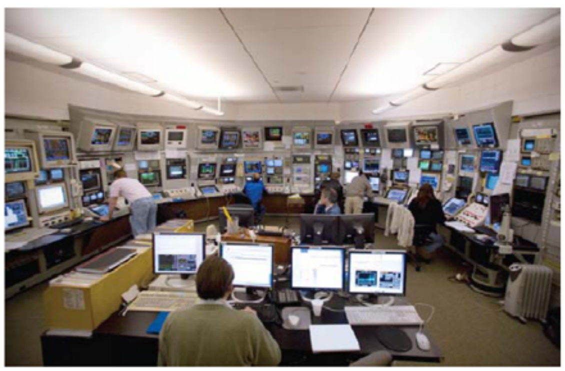
3 km circumference, 11 mrad crossing angle

L = 1.7 x 10^{34} $cm^{-2}s^{-1}$ (world record)

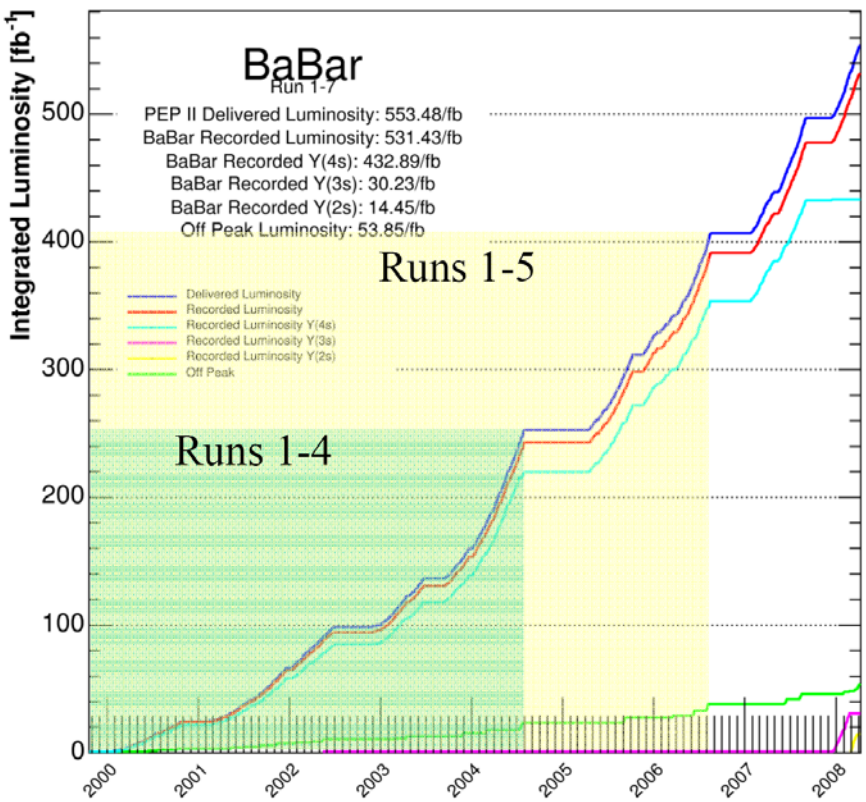
$\int L\,dt$ ~ 820 fb^{-1} @ $\Upsilon(4S)$+off(~10%)

The BABAR detector

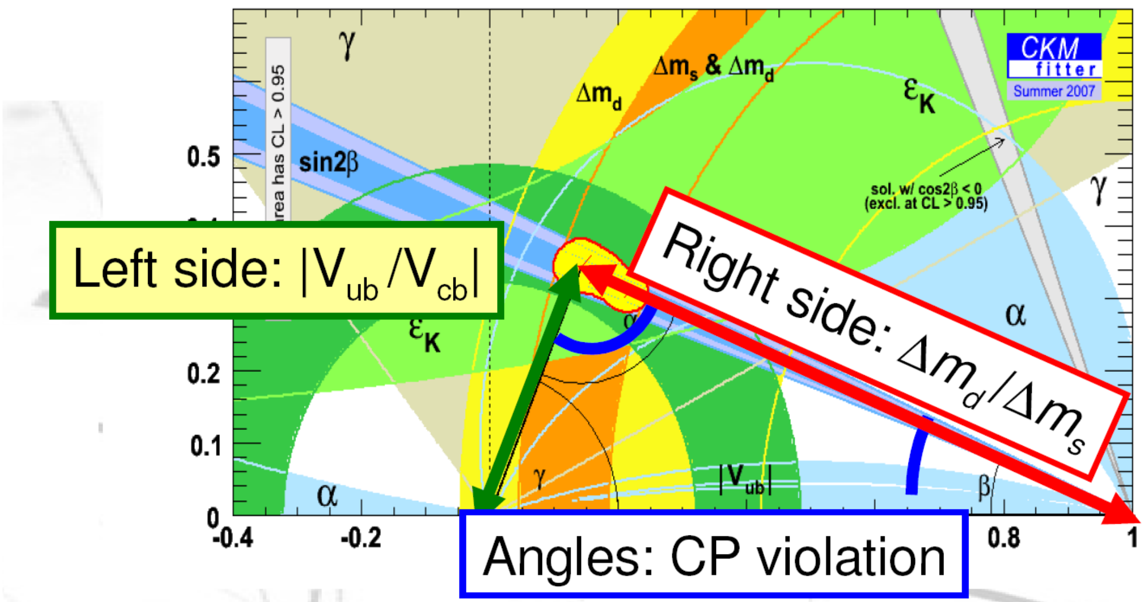




Final collisions 12:43pm, Monday 7 Apr 2008



Side measurements



$|V_{td}|/|V_{ts}|$ from $\Delta m_s/\Delta m_d$

- B_d and B_s oscillation frequency controlled by mass difference:

$$\Delta m_q = \frac{G_F^2 m_W^2 \eta S(x_t^2)}{6\pi^2} m_{B_q} f_{B_q}^2 B_{B_q} \,|V_{tq}^* V_{tb}|^2$$

- Form factor and B-parameters from Lattice calculations known to ~15% ➔ uncertainty on V_{td}

- Ratio better controlled (hep-lat/0510113):

$$\xi^2 = \frac{f_d^2 B_d}{f_s^2 B_s} = 1.210 \,^{+0.047}_{-0.035} \quad (\sigma \sim 4\%)$$

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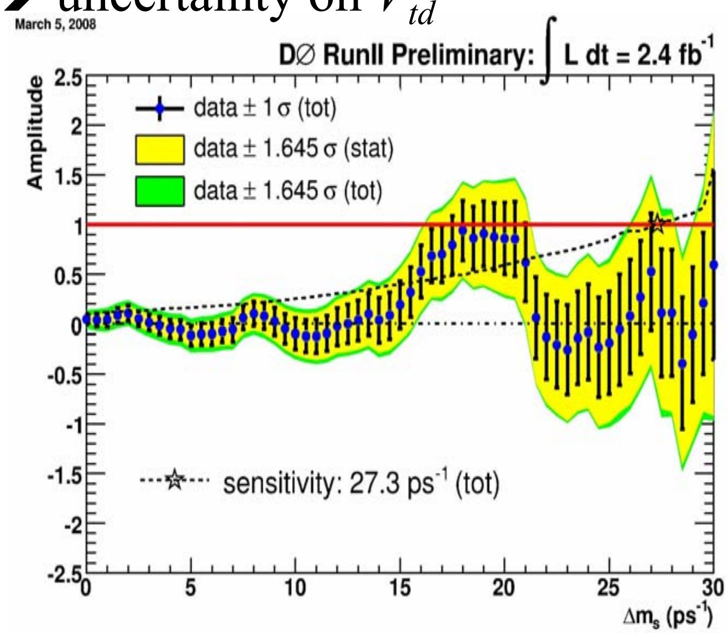

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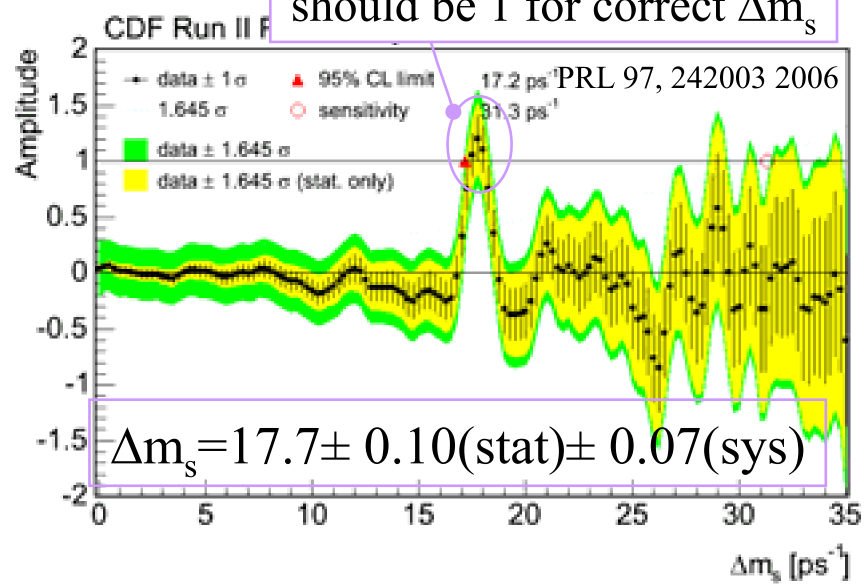
- Performed "amplitude scan":

$$L_{sig}^t = \frac{1}{\tau} e^{-t/\tau}\left(1 \pm A \cdot D \cdot \cos(\Delta M \cdot t)\right)$$

should be 1 for correct Δm_s



PRL 97, 242003 2006

$\Delta m_s = 17.7 \pm 0.10(\text{stat}) \pm 0.07(\text{sys})$

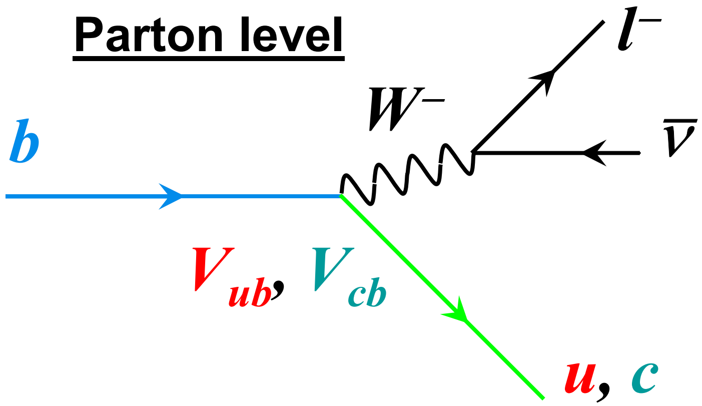
$|V_{td}|/|V_{ts}|$ from $\Delta m_s/\Delta m_d$

- Together with Δm_d=0.505±0.005 (PDG) and $m(B_d)/m(B_s)$=0.98320 (PDG):

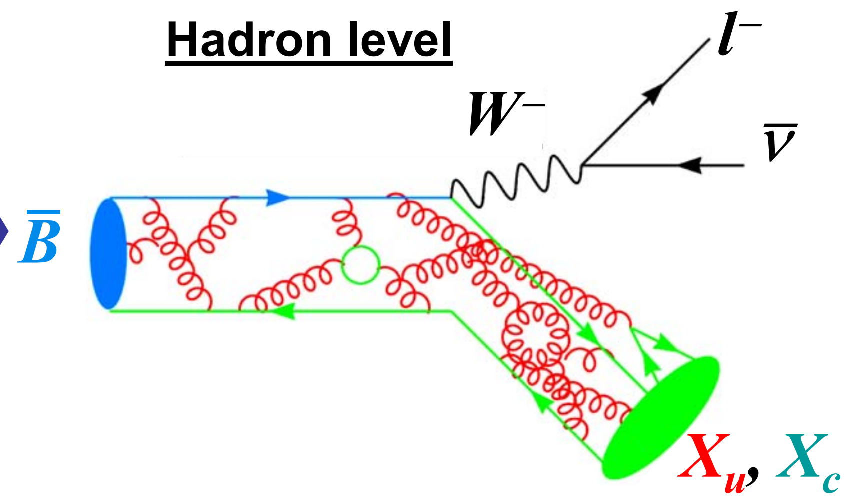
$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.2060 \pm 0.0007\,(\exp)^{+0.0081}_{-0.0060}\,(\mathrm{theo})$$

Semileptonic decays
from partons to hadrons

Parton level



Hadron level



- Quark decay is a tree level, short distance process.
- Decay properties depend directly on $|V_{c(u)b}|$ and m_b in perturbative regime (α_s^n expansion).

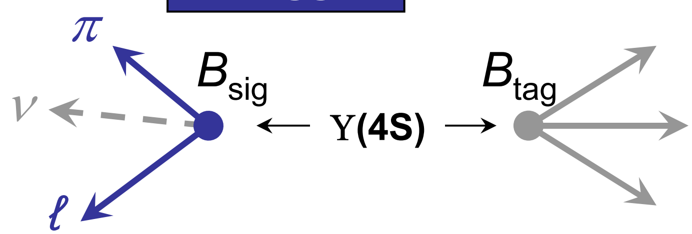
- But quarks are bound by soft gluons…
- ***Non-perturbative*** long distance interactions of *b* quark with light quarks complicate the situation.

- **Two different approaches are used**:
  - Inclusive : extrapolate by theory phase space measured to the full phase space
  - Exclusive : needs prediction of form factor by theory

Experimental methods

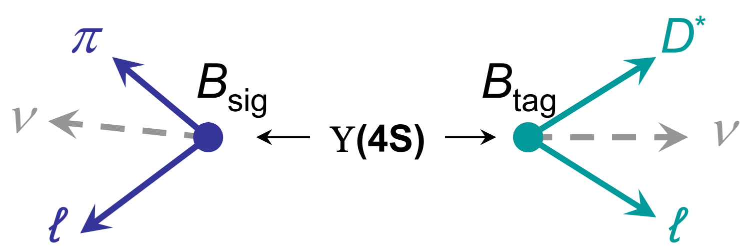
- Exclusive or inclusive reconstruction are used on the signal side
- In addition, on the other *B* ("tag") side:

Untagged



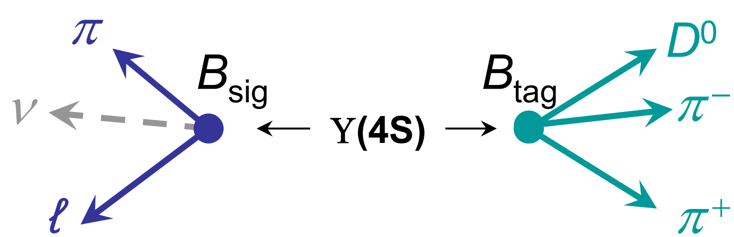
- Only signal reconstruction
- High statistics
- Sensitive to background simulation

Semileptonic tag

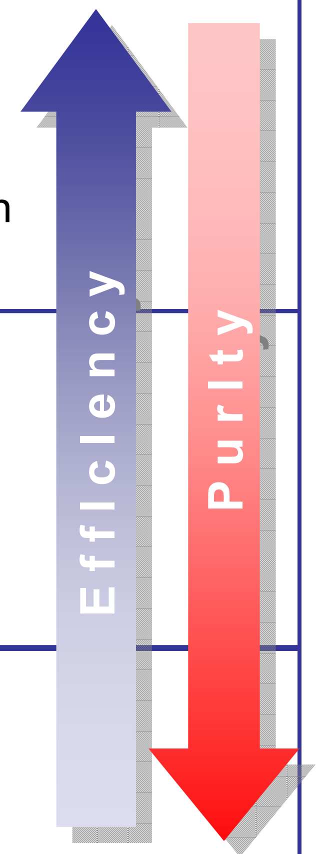


- Reconstruct $B \to D^{(*)} \ell \nu$
- 2ν : incomplete kinematics

Hadronic tag



- Reconstruct $B \to D^{(*)} Y$ ($Y = \pi, K$)
- Several decay modes
- Complete kinematics, charge and flavor known



Coping with non-perturbative interactions in V_{cb} extraction (inclusive analysis)

- Total decay rate:

$$\Gamma\left(B \to X_{c(u)} l\nu\right) = \frac{G_F^2 m_b^5}{192\pi^3}\left|V_{c(u)b}\right|^2 \left[\left[1 + A_{EW}\right] A_{\text{pert.}} A_{\text{non pert.}}\right]$$

free quark decay

α_s^k expansion

$(1/m_b)^n$ expansion

- Non perturbative parameters ***need to be measured***
  - they depend on the expansion, which depends on the m_b definition
- Can be extracted from ***the moments of lepton energy and hadronic mass spectra: (integration)***

$$\left\langle E_l^n \right\rangle_{E>E_{cut}} = \frac{1}{\Gamma_{c(u)}} \int \left(E_l - \left\langle E_l \right\rangle\right)^n \frac{d\Gamma_{c(u)}}{dE_l} dE_l$$

$$\left\langle m_X \right\rangle_{E>E_{cut}} = \frac{1}{\Gamma_{c(u)}} \int m_X^n \frac{d\Gamma_{c(u)}}{dm_X} dm_X$$

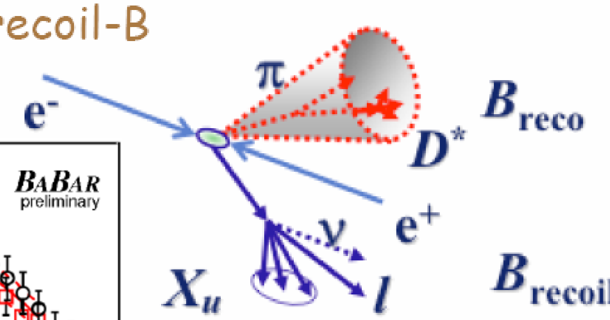
Calculations are available in "**kinetic**" (Benson & *al.*, Nucl. Phys. B665:367) and "**1S**" (Bauer & *al.*, PRD **70**, 094017 (2004)) schemes.
They are based on Heavy Quark Expansion (HQE) and Operator Product Expansion (OPE).

- More than 60 measured moments available from DELPHI, CLEO, BABAR, BELLE, CDF

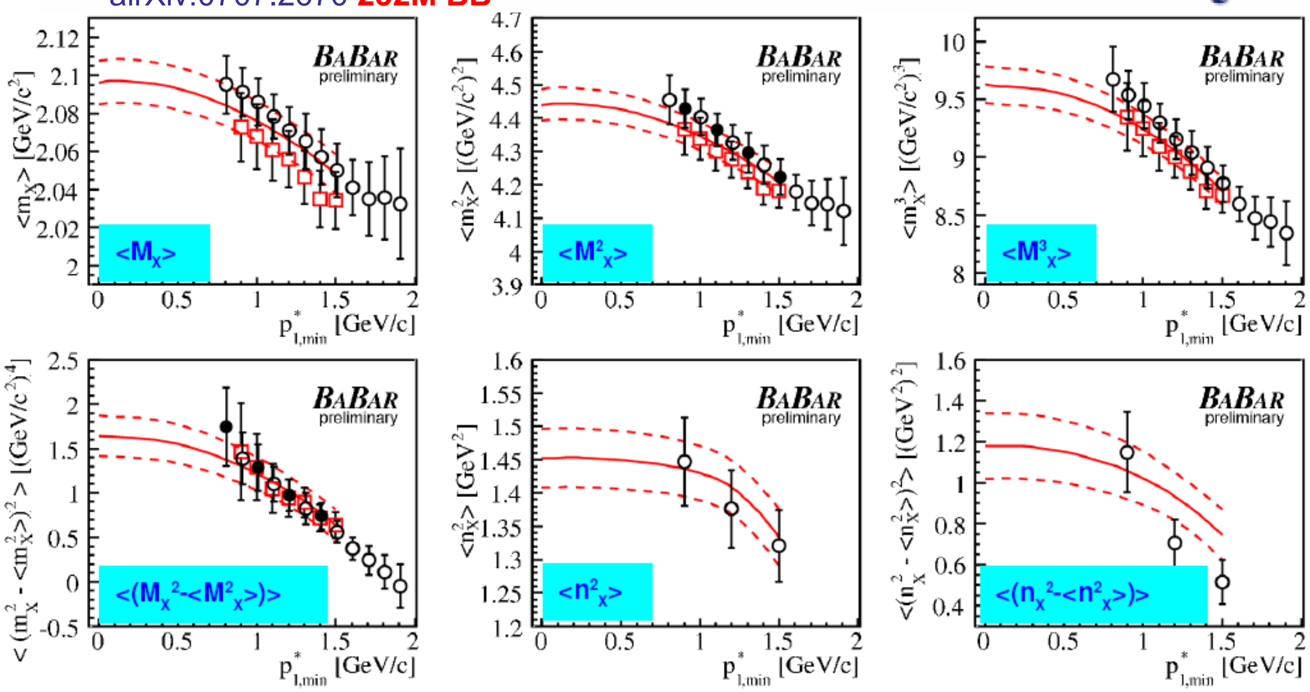
Moments in semileptonic decays

fully-reconstructed B meson B flavor and momentum known.

rest of the event contains one "recoil" lepton in the recoil-B



airXiv:0707.2670 **232M BB**



$\langle m_X^n \rangle$ new

$\langle m_X^n \rangle$ old

$n_x = m_x^2 c^4 - 2\tilde{\Lambda} E_x + \tilde{\Lambda}$

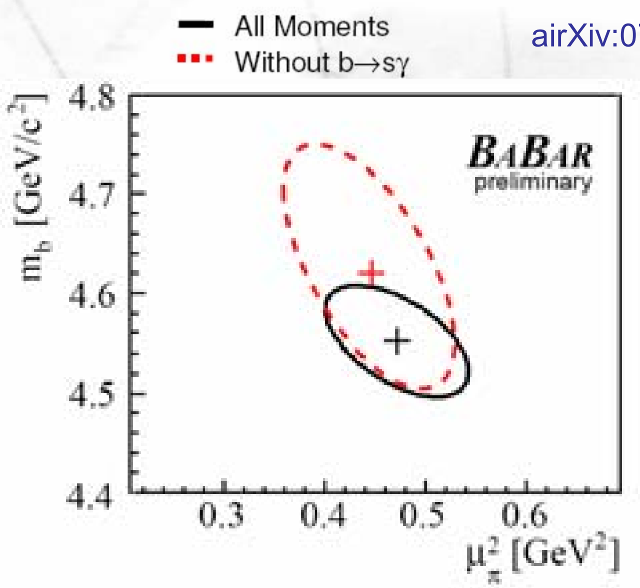
($\tilde{\Lambda}$=0.65 GeV)

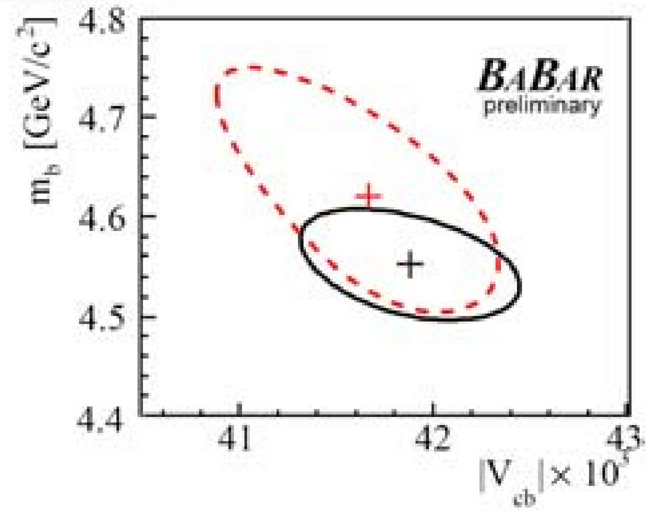
Fit moments of these distribution to get V_{cb} and HQ parameters

Global OPE fit – Kinetic Scheme

airXiv:0707.2670 **232M BB**

- 27 input moments:
  - 8 mass moments (this analysis)
  - 13 E_l moments (Phys. Rev. D69 111104 (2004))
  - 6 E_γ moments (Phys. Rev. D 72, 052004 (2005), Phys. Rev. Lett. 97 171803 (2006))
- Further input: τ_B
- 8 fit parameters:
  - $|V_{cb}|$, m_b, m_c, $\mathcal{B}_{sl}$
  - 4 HQE parameters





- Fit results:

$|V_{cb}| = (41.88 \pm 0.44_{exp} \pm 0.35_{theo} \pm 0.59_{\Gamma SL})10^{-3}$ (1.9% total error)

$m_b = (4.55 \pm 0.038_{exp} \pm 0.040_{theo})$ GeV (1.2% total error)

$m_c = (1.070 \pm 0.038_{exp} \pm 0.040_{theo})$ GeV

$\mathcal{B}_{SL} = (10.597 \pm 0.171_{exp} \pm 0.053_{theo})$ %

Non-perturbative params:

$m^2_\pi = (0.471 \pm 0.034_{exp} \pm 0.062_{theo})$ GeV²

$m^2_G = (0.330 \pm 0.042_{exp} \pm 0.043_{theo})$ GeV²

$\rho^3_D = (0.220 \pm 0.021_{exp} \pm 0.042_{theo})$GeV³

$\rho^3_{LS} = -(0.159 \pm 0.081_{exp} \pm 0.050_{theo})$GeV³

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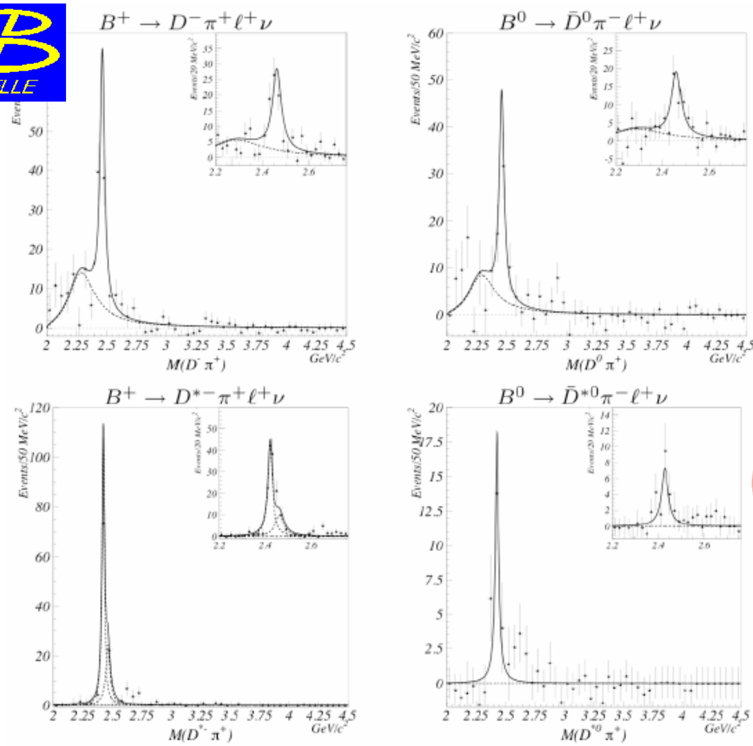
BR measurements of B→D**lν

- Measurement to control D** background in V_{cb} analyses:



HQET predicts the rate of broad D^*_0 ~10 times smaller than narrow D^*_2

Belle measure comparable branchings fractions

$\mathcal{B}(\text{mode}) \equiv \mathcal{B}(B \to D^{**}\ell\nu) \times \mathcal{B}(D^{**} \to D^{(*)}\pi^+)$

$D\pi$ invariant mass study

Mode	Yield	$\mathcal{B}$, %	Signif.
$B^+ \to D_0^{*0}\ell^+\nu$	102 ± 19	$0.24 \pm 0.04 \pm 0.06$	5.4
$B^+ \to \bar{D}_2^{*0}\ell^+\nu$	94 ± 13	$0.22 \pm 0.03 \pm 0.04$	8.0
$B^0 \to D_0^{*-}\ell^+\nu$	61 ± 22	$0.20 \pm 0.07 \pm 0.05$	2.6
$B^0 \to D_2^{*-}\ell^+\nu$	68 ± 13	$0.22 \pm 0.04 \pm 0.04$	5.5

$D^*\pi$ invariant mass study

Mode	Yield	$\mathcal{B}$, %	Signif.
$B^+ \to \bar{D}_1^{\prime 0}\ell^+\nu$	-5 ± 11	< 0.07 @ 90% C.L.	
$B^+ \to \bar{D}_1^0\ell^+\nu$	81 ± 13	$0.42 \pm 0.07 \pm 0.07$	6.7
$B^+ \to \bar{D}_2^{*0}\ell^+\nu$	35 ± 11	$0.18 \pm 0.06 \pm 0.03$	3.2
$B^0 \to D_1^{\prime -}\ell^+\nu$	4 ± 8	< 0.5 @ 90% C.L.	
$B^0 \to D_1^-\ell^+\nu$	20 ± 7	$0.54 \pm 0.19 \pm 0.09$	2.9
$B^0 \to D_2^{*-}\ell^+\nu$	1 ± 6	< 0.3 @ 90% C.L.	

arXiv:0711.3252

BF($B^- \to D_1^0 l\nu$) = 0.42 ± 0.04 ± 0.04 %
BF($B^- \to D_1^{\prime 0} l\nu$) = 0.47 ± 0.06 ± 0.06%
BF($B^- \to D_2^{*0} l\nu$) = 0.29 ± 0.05 ± 0.03%
BF($B^- \to D_0^{*0} l\nu$) = 0.52 ± 0.07 ± 0.06%

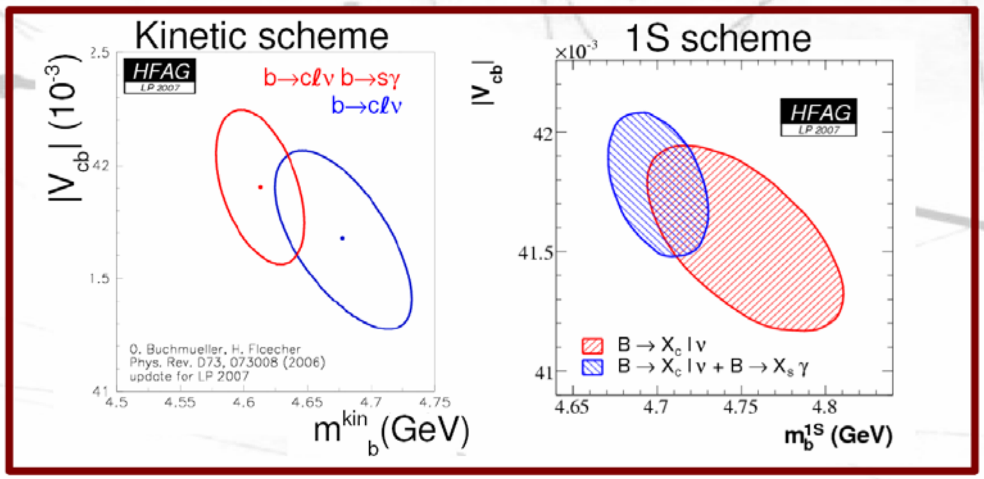
PRL 100, 151802 (2008)

BABAR confirms large BR for D_0^*, and finds large BR for D_1' (6σ difference will BELLE !)

V_{cb} and HQE parameters

- More results from global fits in the kinetic and 1S schemes are available. Recent averages performed by the HFAG
- A pattern is present: results with $b \to c\ell\nu$ and $b \to s\gamma$ moments differ from results with $b \to c\ell\nu$ moments only (except in hep-ex/0611047, but larger errors).
- HFAG results for Lepton Photon:

	m_b (GeV) $b \to c\ell\nu$ $b \to s\gamma$	m_b (GeV) $b \to c\ell\nu$
Kinetic scheme	4.613 ± 0.035	4.677 ± 0.053
1S scheme	4.701 ± 0.030	4.751 ± 0.058



- Large uncertainties due to the ansatz and missing terms

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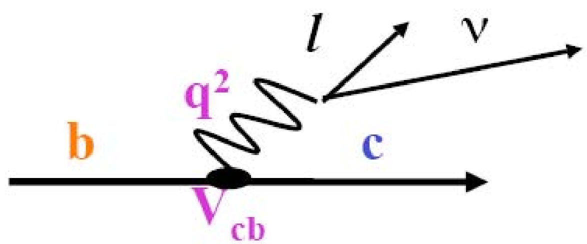
- Different values of m_b impact the determination of $|V_{ub}|$ from inclusive decays

V_{cb} exclusive $B^- \to D^{*0} e^- \nu$

$B^- \to D^{*0} e^- \nu;\ D^* \to \pi^0 D^0$

$$\frac{d\Gamma(B \to D^* l\nu)}{dw} = K(w)\mathcal{F}^2(w)|V_{cb}|^2$$



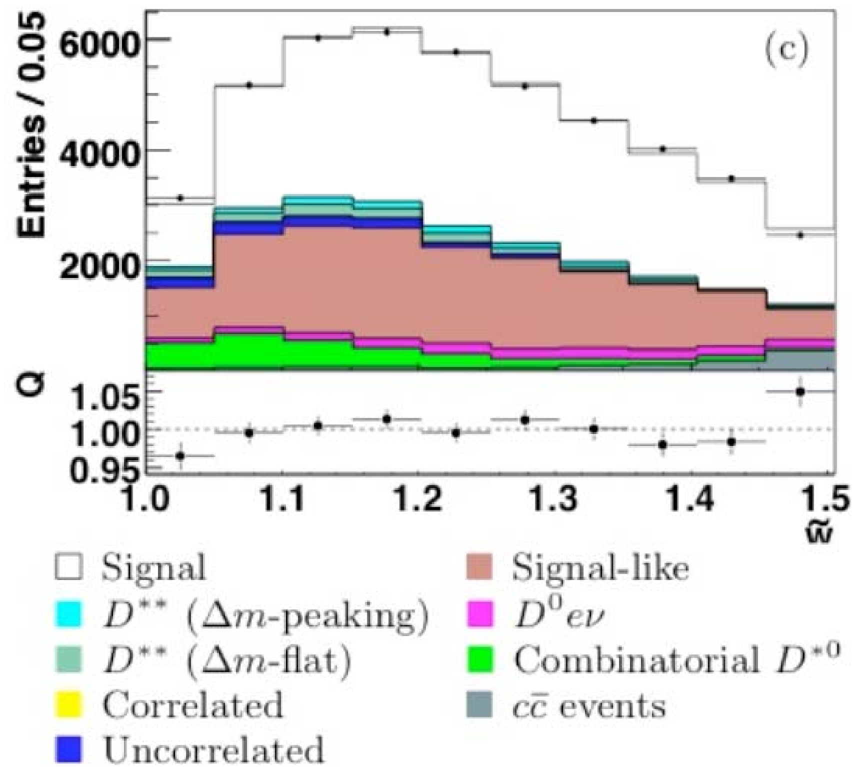
$$w = \frac{m_B^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$$

$$F(1) \cdot |V_{cb}| = (35.9 \pm 0.6 \pm 1.4) \cdot 10^{-3}\ ,$$

$$\rho^2_{A_1} = 1.16 \pm 0.06 \pm 0.08\ ,$$

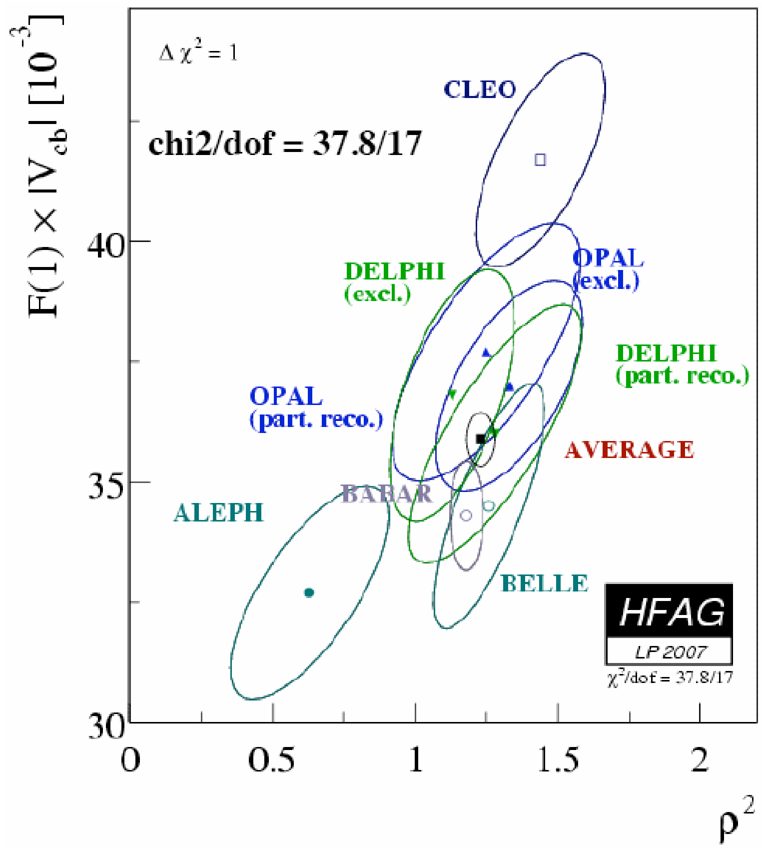
$$\mathcal{B}(B^- \to D^{*0} e^- \overline{\nu}_e) = (5.56 \pm 0.08 \pm 0.41)\%\ .$$

PRL **100** 231803 (2008) **226M BB**



Main physics background $B \to D^{**} l\nu$

F(1)|V_{cb}|



$\mathcal{F}(1)|V_{cb}|=(35.9\pm0.6)10^{-3}$ $\rho_A^2=1.23\pm0.05$

From F(1)=0.919±0.033:

$|V_{cb}|=(39.1\pm0.65\pm1.4)10^{-3}$

error is dominated by the lattice calculation

$B\rightarrow D^0 l\,\nu$ has a small theoretical error but it's more difficult experimentally and very few measurement

HFAG average uses R_1, R_2 from BaBar

this decrease $\mathcal{F}(1)|V_{cb}|$

PRL **77**, 032002 (2007)
79fb^{-1}+9.6fb^{-1} offpeak

V_{ub} from inclusive semileptonic decays

$$\Gamma(\bar{B} \to X_u \ell \bar{\nu}) = \frac{G_F^2 |V_{ub}|^2 m_b^5}{192\pi^3} \left[1 + \mathcal{O}(\alpha_s) + \mathcal{O}(1/m_b^2) + H.C. \right]$$

O.P.E.
~5% uncertainty

free quark decay — perturbative correction — non perturbative correction

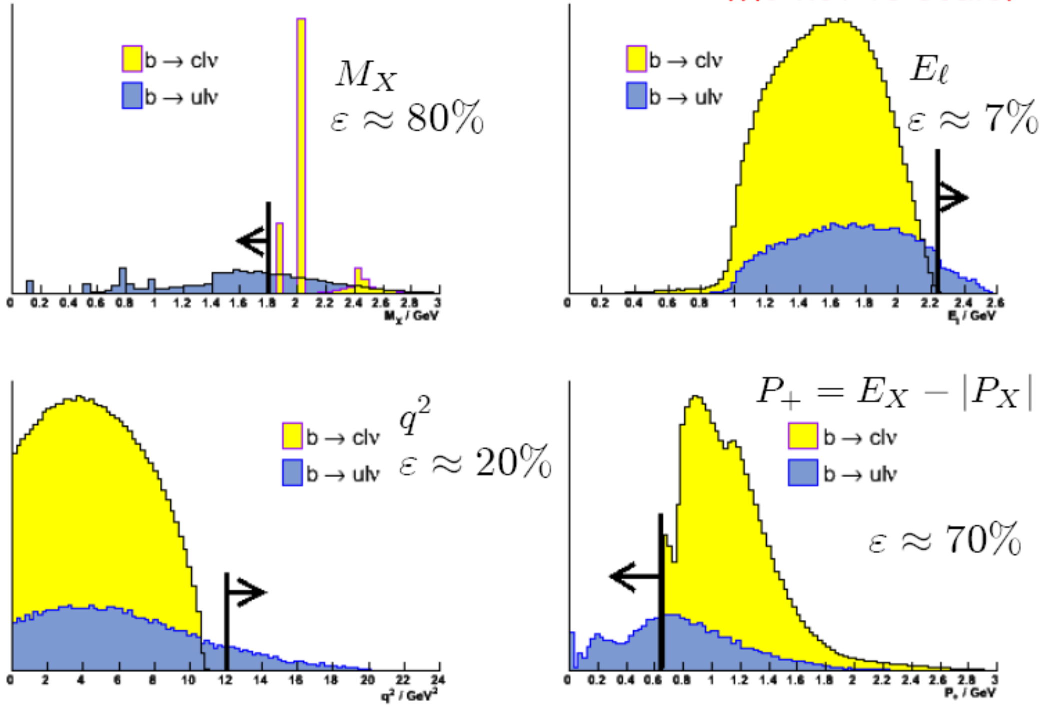
$$\frac{\Gamma_u}{\Gamma_c} \approx \frac{1}{50}$$

$m_u \ll m_c$ different kinematics

phase space cuts
to exclude $b \to c$ transition

this breaks the OPE convergence

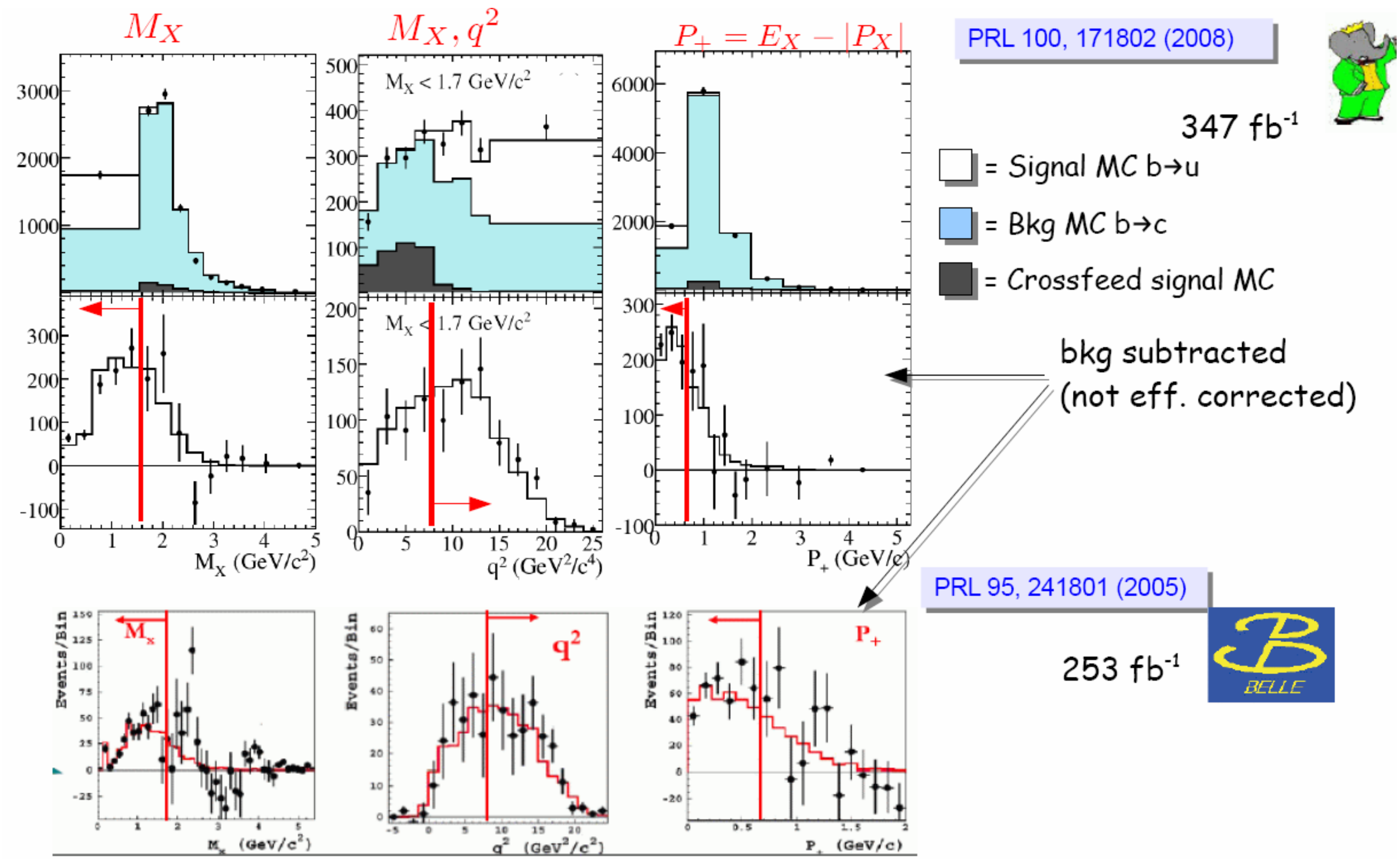
MC not to scale!



theoretical acceptances
are sensitive to b quark
motion (Fermi motion)
parametrized by Shape Function

(Leading) Shape Function
can be measured by E_γ
spectrum in $B \to X_s \gamma$ decays

Inclusive V_{ub} with hadronic tag



Hadronic tag: results

Kinematic region	N	$\Delta\mathcal{B}$ ($B\to X_u l\nu$) 10^{-3} (stat. syst. theo.)	$\lvert V_{ub}\rvert$ 10^{-3} (stat. syst. theo.)	theoretical framework
$m_X < 1.55$ GeV/c^2	803 ± 60	1.18 ± 0.09 ± 0.07 ± 0.01	4.27 ± 0.16 ± 0.13 ± 0.30 4.56 ± 0.17 ± 0.14 ± 0.32	BLNP DGE
$P_+ < 0.66$ GeV/c	633 ± 63	0.95 ± 0.10 ± 0.08 ± 0.01	3.88 ± 0.19 ± 0.16 ± 0.28 3.99 ± 0.20 ± 0.16 ± 0.24	BLNP DGE
$m_X < 1.7$ GeV/c^2 $q^2 > 8$ GeV^2/c^4	562 ± 55	0.81 ± 0.08 ± 0.07 ± 0.02	4.57 ± 0.22 ± 0.19 ± 0.30 4.64 ± 0.23 ± 0.19 ± 0.25 4.93 ± 0.24 ± 0.20 ± 0.36	BLNP DGE BLL

Largest uncertainty: theoretical error 6-7.5%

How predictive is theory?

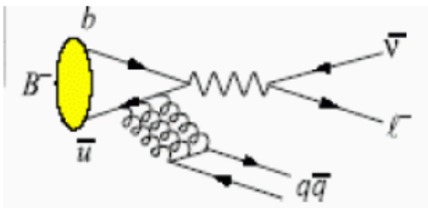
Φ_1/Φ_2	Data ($\Delta\mathcal{B}$)	Γ_{thy} (BLNP)	double ratio $\Gamma_{thy}/\Delta\mathcal{B}$
$M_X/M_x, q^2$	1.46 ± 0.13	1.67 ± 0.05	1.14 ± 0.11
P_+/M_X	0.81 ± 0.07	0.98 ± 0.03	1.21 ± 0.11
$P_+/M_X, q^2$	1.18 ± 0.14	1.63 ± 0.05	1.38 ± 0.17

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(\bar{B}\to X_u\ell\bar{\nu})}{\tau_B\cdot\Gamma_{thy}}}$$

$$\frac{\Delta\mathcal{B}(\Phi_1)}{\Delta\mathcal{B}(\Phi_2)} = \frac{\Gamma_{thy}(\Phi_1)}{\Gamma_{thy}(\Phi_2)}$$

Weak Annhilation

arXiv: 0708.1753



- introduces differences between B^0 and B^+ decays

347 fb^{-1}

- small contribution: 3% of the total decay rate

. But would sit in the high q^2 region, where V_{ub} meas. is performed.

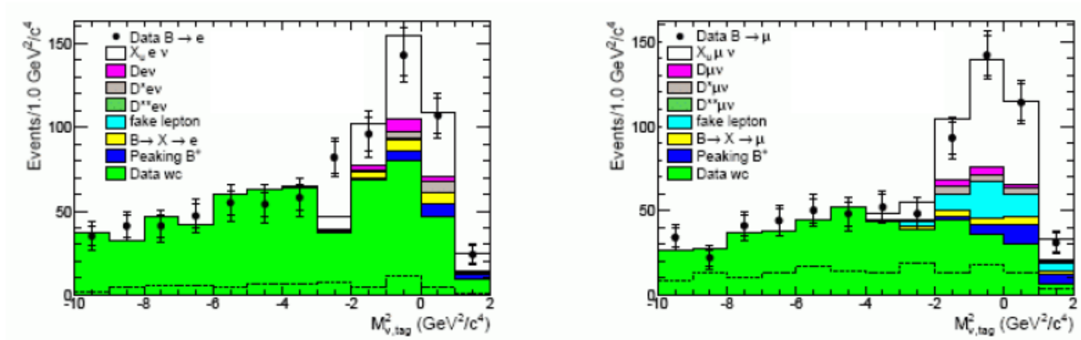
- compare B^0 partial rate to the charge averaged rate in region where WA contribution is greater (high q^2 and large p_l)

- Study charmless semileptonic decays on recoil of partial reconstructed $B^0 \rightarrow D^{*+} l^- \nu$

- neutrino mass $m_\nu^2 = (P_B - P_{D^*} - P_\ell)^2$

131.1 ± 36.9 172.0 ± 32.2

$$A^{+/0} = \frac{\Delta\Gamma^+ - \Delta\Gamma^0}{\Delta\Gamma^+ + \Delta\Gamma^0}$$



Δp	$\Delta\mathcal{B}(B) \cdot 10^4$[8]	$\Delta\mathcal{B}(B^0) \cdot 10^4$	$A^{+/0}$
$2.2 - 2.6\,\mathrm{GeV}/c$	$2.31 \pm 0.10 \pm 0.18$	$2.62 \pm 0.33 \pm 0.16$	$-0.17 \pm 0.15 \pm 0.11$
$2.3 - 2.6\,\mathrm{GeV}/c$	$1.46 \pm 0.06 \pm 0.10$	$1.30 \pm 0.21 \pm 0.07$	$0.08 \pm 0.15 \pm 0.08$
$2.4 - 2.6\,\mathrm{GeV}/c$	$0.75 \pm 0.04 \pm 0.06$	$0.76 \pm 0.15 \pm 0.05$	$-0.05 \pm 0.20 \pm 0.10$

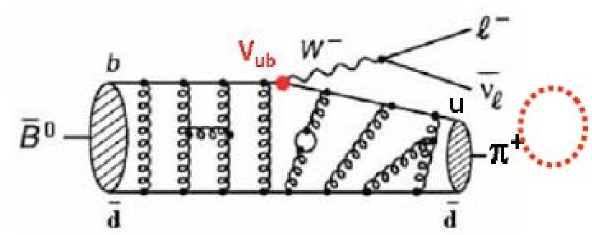
A. Petrella HQ&L 2008

No evidence of weak annihilation

$\Gamma_{wa}/\Gamma_{b\rightarrow ul\nu} < 8\%$ @90% CL

consistent with CLEO q^2 studies
PRL 96, 121801 (2006)

V_{ub} measurement with exclusive decays



Experimentally clean

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

Currently only $B \to \pi l \nu$ for $|V_{ub}|$ - one dominant form factor (q^2 shape and normalization needed)

- Form factor calculations from various methods:
  - "unquenched" lattice QCD (HPQCD, Fermilab, ...)
  - Light-Cone Sum Rules (Ball & Zwicky, ...)
  - quark models (ISGW2, ...)

FF dominates |Vub| error

ISGW2 quark-model incompatible (Prob<0.06%).

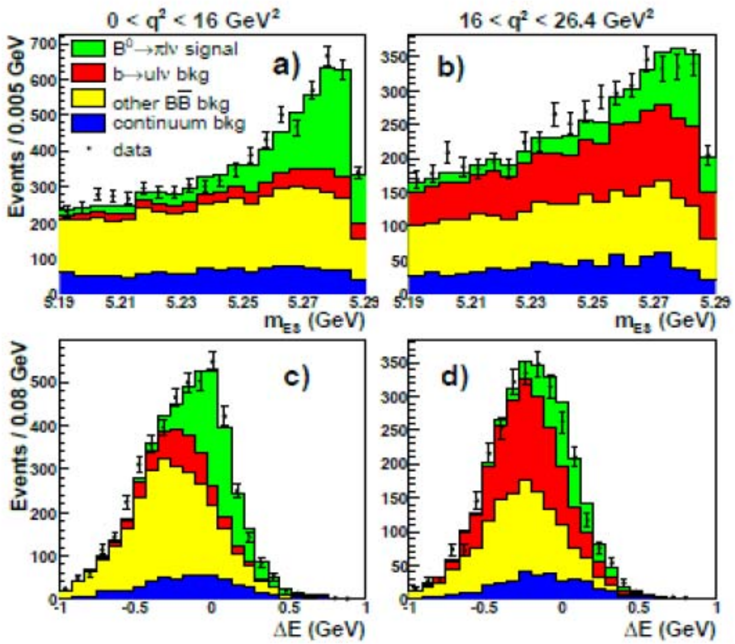
E. Barberio 30

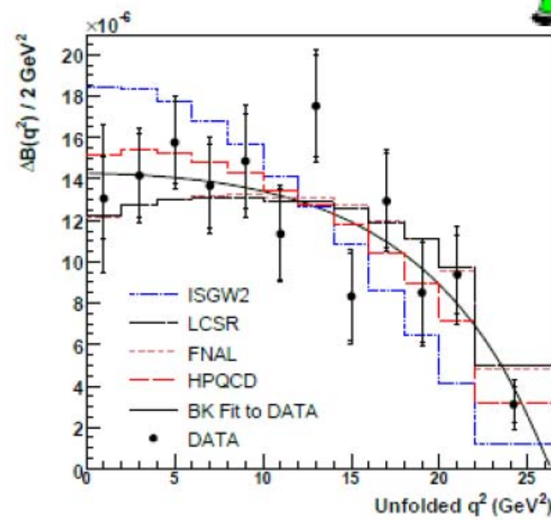
V_{ub} measurement with exclusive decays

$B \to \pi l \nu$: untagged method

BaBar 227MBB

Loose neutrino reconstruction



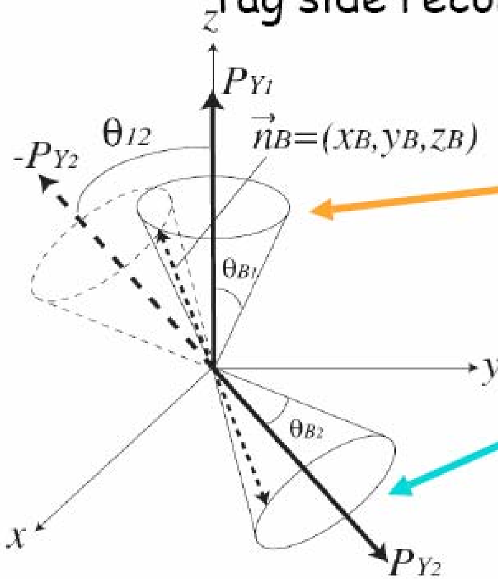


	q^2 (GeV^2)	$\Delta\zeta$ (ps^{-1})	$\|V_{ub}\|$ (10^{-3})
HPQCD [3]	> 16	1.46 ± 0.35	$4.1 \pm 0.2 \pm 0.2\,^{+0.6}_{-0.4}$
FNAL [4]	> 16	1.83 ± 0.50	$3.7 \pm 0.2 \pm 0.2\,^{+0.6}_{-0.4}$
LCSR [5]	< 16	5.44 ± 1.43	$3.6 \pm 0.1 \pm 0.1\,^{+0.6}_{-0.4}$
ISGW2 [6]	0–26.4	9.6 ± 4.8	$3.2 \pm 0.1 \pm 0.1\,^{+1.3}_{-0.6}$

Phys. Rev. Lett. 98:091801 (2007)

Exclusive ρ and π decay, with $D^*l\nu$ tag

Tag side reconstruction

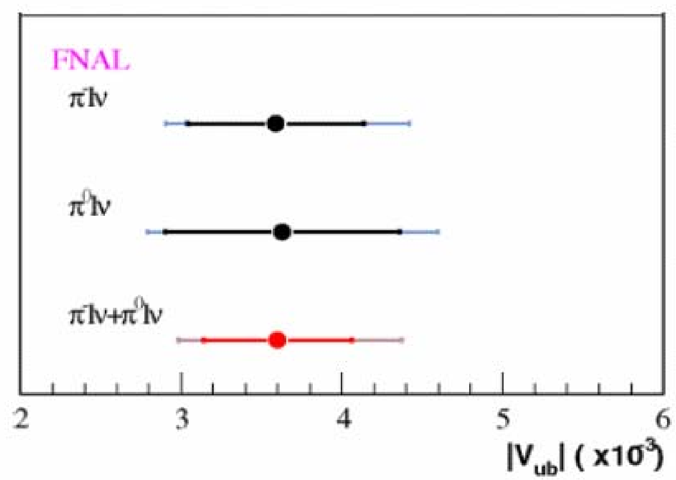


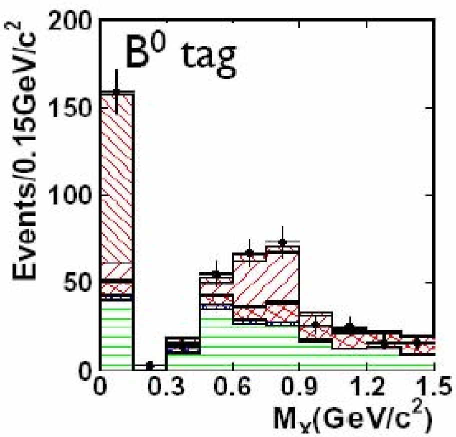
$B^0_{tag} \to D^{*+}l^-\bar{\nu}/D^+l^-\bar{\nu}$
$B^-_{tag} \to D^{*0}l^-\bar{\nu}/D^0l^-\bar{\nu}$

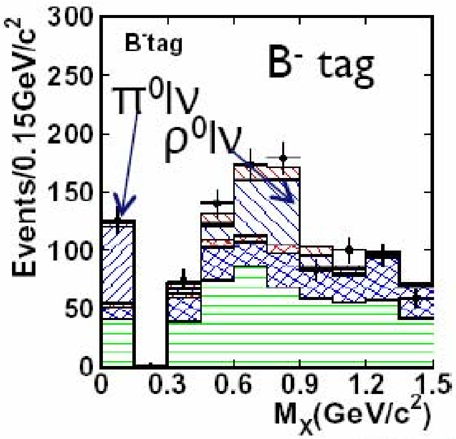
Signal
$B^0_{sig} \to \pi^-l^+\nu$ / $\pi^-\pi^0l^+\nu$ → ρ^-
$B^+_{sig} \to \pi^0l^+\nu$ / $\pi^+\pi^-l^+\nu$ → ρ^0

253 fb^{-1}
(275M BB pairs)

Full q^2 region

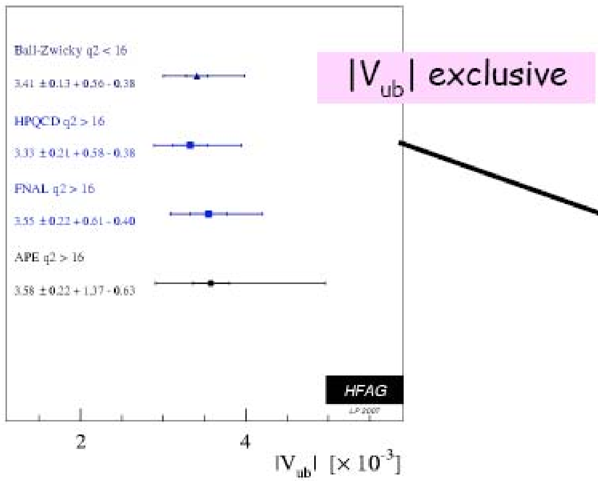


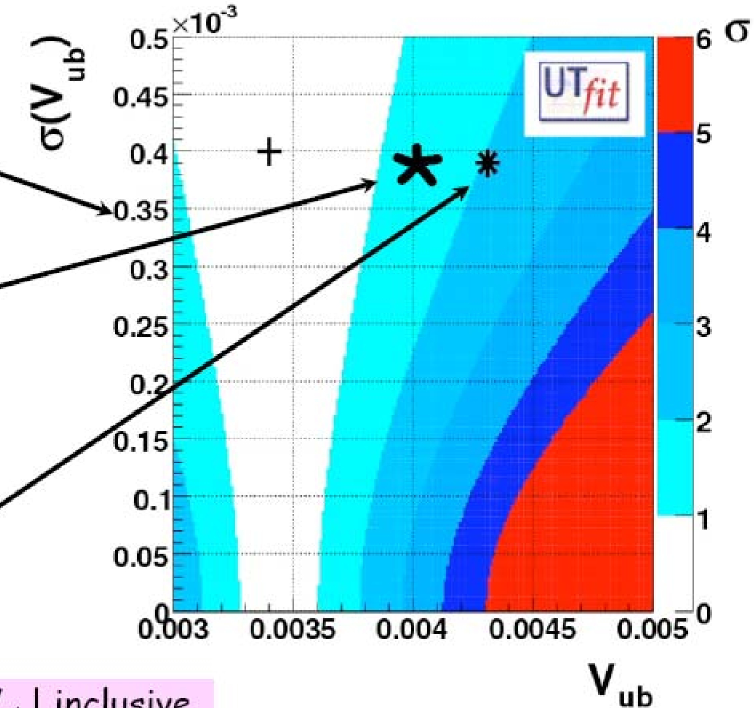


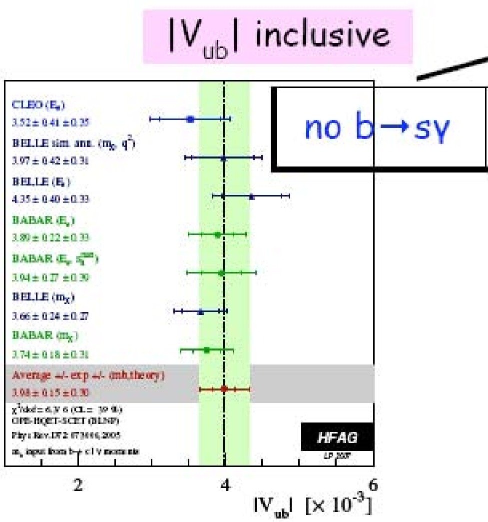


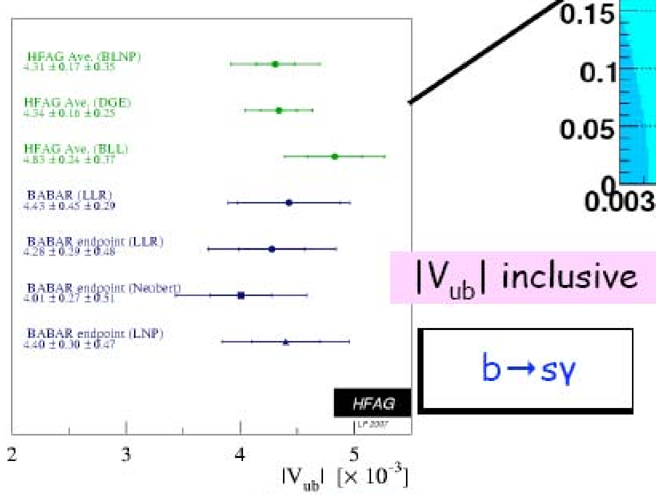
$|V_{ub}|$: inclusive vs exclusive

Most probable value of V_{ub} from measurements of other CKM parameters



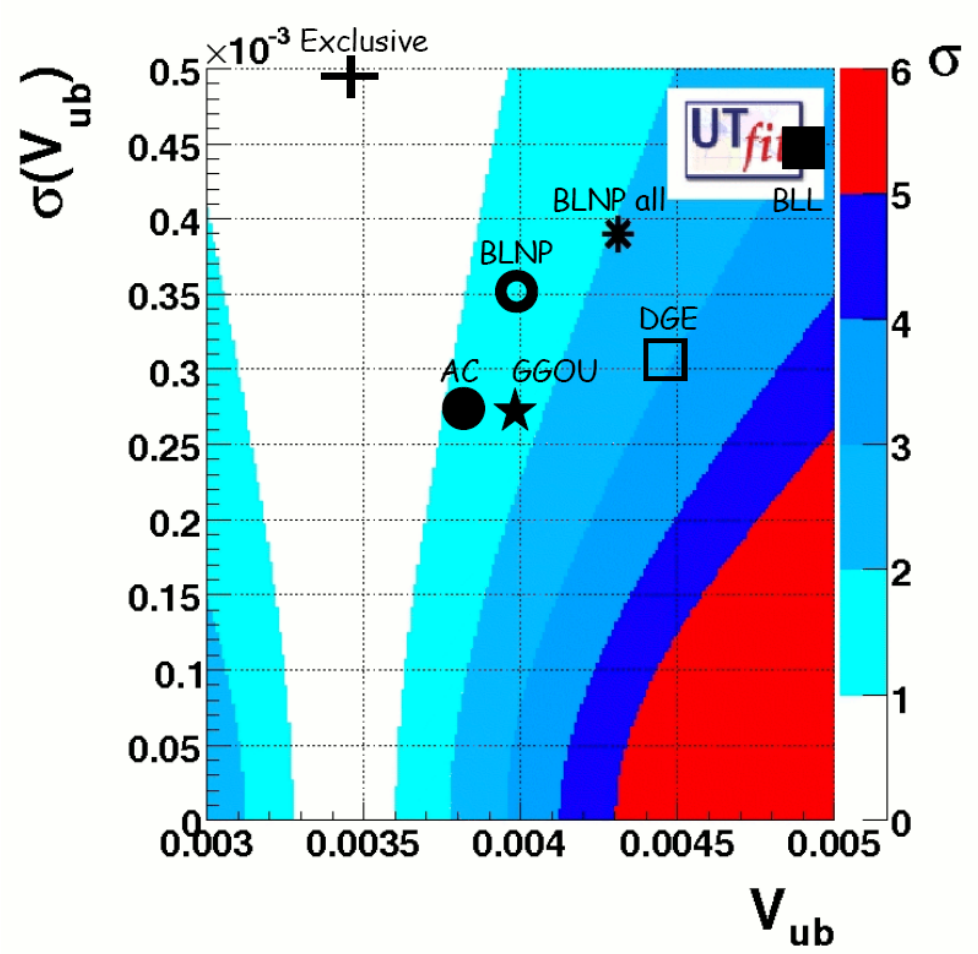






E. Barberio

V_{ub} : inclusive versus exclusive

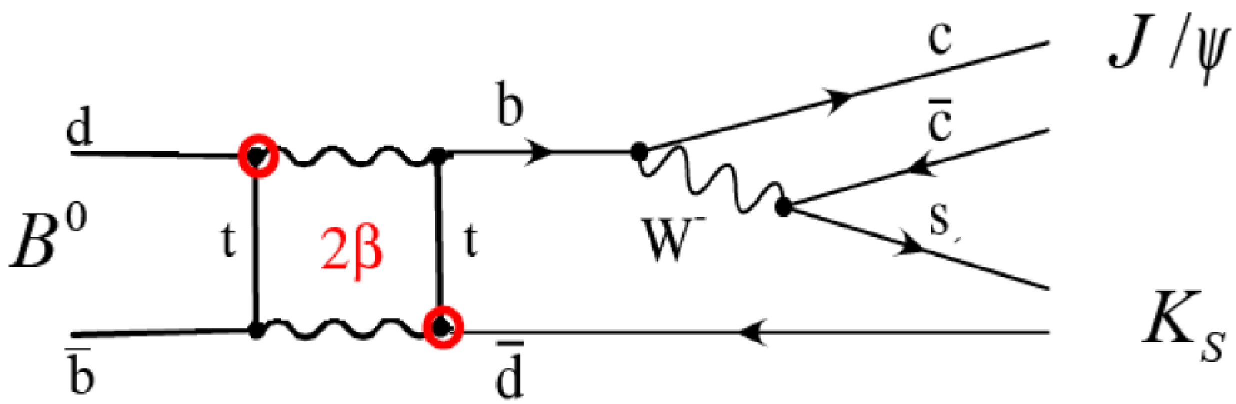


- small "tension" with exclusive for some calculations
- measurements still dominated by theory great effort to improve: measurements can help as well
- error on $|V_{ub}|$~ 9%; expected to push down to 5%

CKM angle measurements

Measurement of β

- The measurement of β is to "collect" the phase of the B^0B^0 mixing:



$$A(\Delta t) = S_{f_{CP}} \sin(\Delta m_d \Delta t) - C_{f_{CP}} \cos(\Delta m_d \Delta t)$$

$$\lambda_{f_{CP}} = \frac{q}{p}\frac{\overline{A}}{A} = \eta_{f_{CP}} e^{-i2\beta}$$

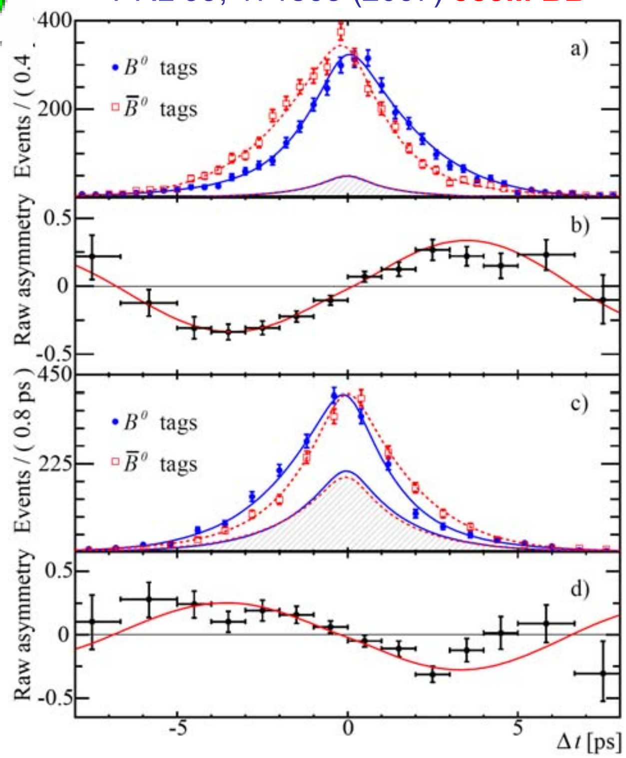
$$|\lambda_{f_{CP}}| = 1, C_{f_{CP}} = 0 \quad S_{f_{CP}} = -\eta_{f_{CP}} \sin 2\beta$$

Uncertainty ~1%

sin(2β) in b→cc̄s decays : "golden modes"

$B^0 \rightarrow J/\psi K_S, J/\psi K^{*0}, \psi(2S)K_S, J/\psi K_L, \eta_C K_S, \chi_{C1} K_S$

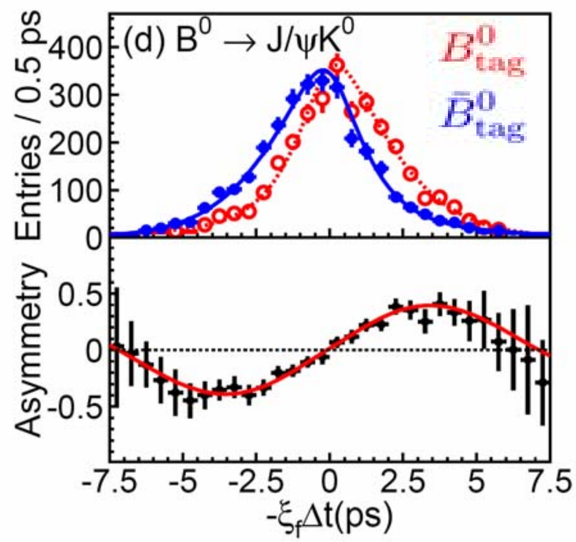
PRL **99**, 171803 (2007) **383M BB**



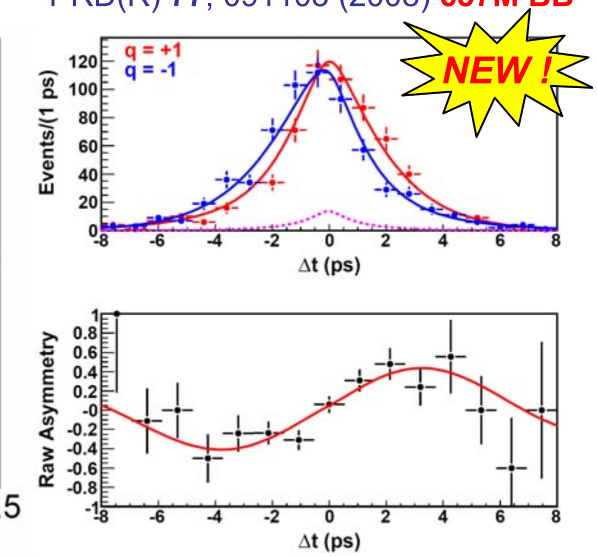
sin2β = 0.714 ± 0.032 ± 0.018
|λ| = 0.952 ± 0.022 ± 0.017

$B^0 \rightarrow J/\Psi K_S, J/\Psi K_L$ $B^0 \rightarrow \Psi(2S) K_S$

PRL **98**, 031802 (2007) **535 BB**



PRD(R) **77**, 091103 (2008) **657M BB**



sin2ϕ_1 = +0.642 ± 0.031 ± 0.017
A = -0.018 ± 0.021 ± 0.014

S = +0.72 ± 0.09 ± 0.03
A = +0.04 ± 0.07 ± 0.05

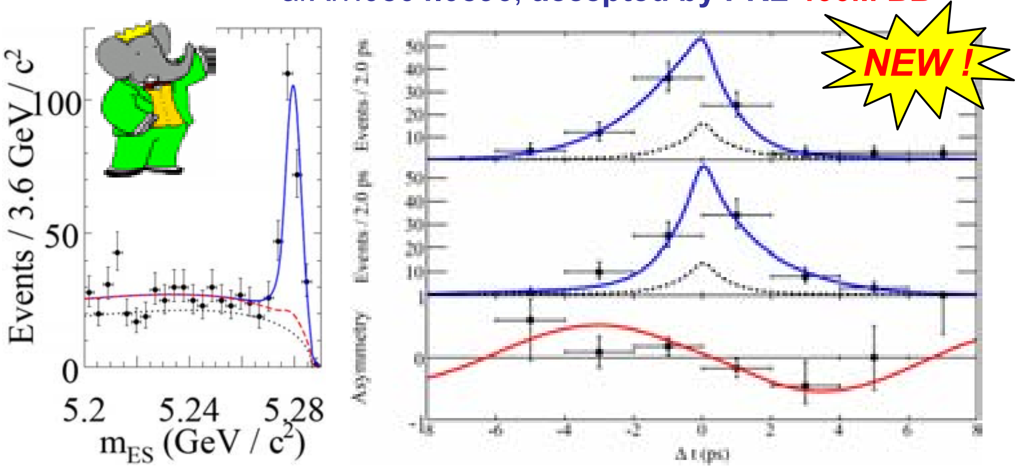
New BELLE average
sin2β = +0.650 ± 0.029 ± 0.018
A = -0.019 ± 0.020 ± 0.015

b→cc̄d decays : $B^0 \rightarrow J/\Psi\pi^0$

- Penguins with different phases could contribute
- If not, SM predicts S=-sin2β, C=0
- Can constrain penguin pollution in $J/\Psi K^0$, by SU(3)

(see PRL **95**, 221804 (2005) : uncertainties may be larger than considered)

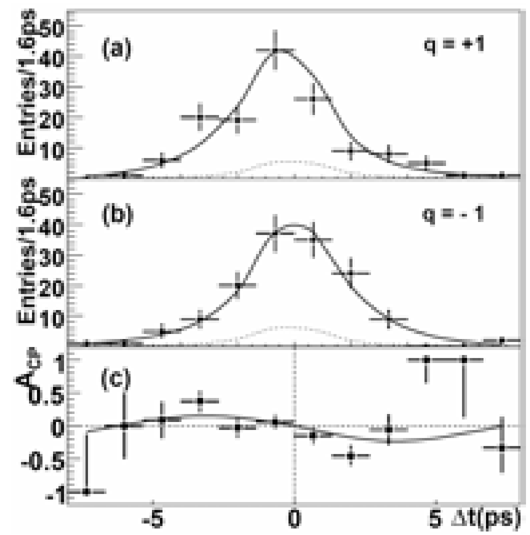
arXiv:**0804.0896**, **accepted by PRL** **466M BB**



S = –1.23 ± 0.21 ± 0.04
C = –0.20 ± 0.19 ± 0.03
BF = (1.69 ± 0.14 ± 0.07)*10^{-5}

4σ evidence for CPV !

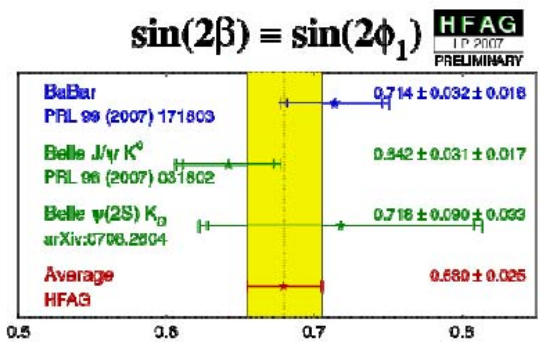
PRD(RC) **77**, 071101 (2008) **535M BB**

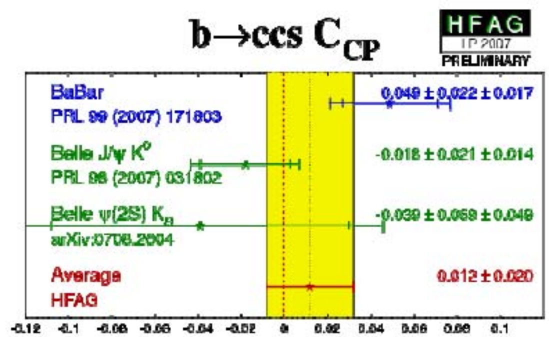


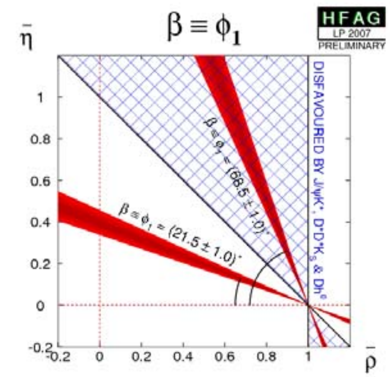
S = –0.65 ± 0.21 ± 0.05
C = –0.08 ± 0.16 ± 0.05

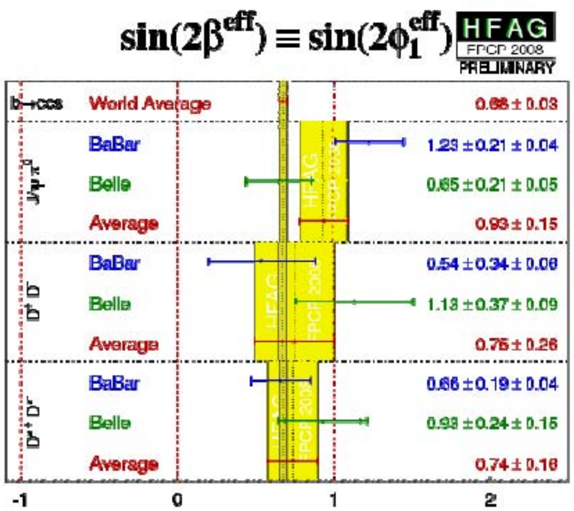
S is 2.4σ from 0

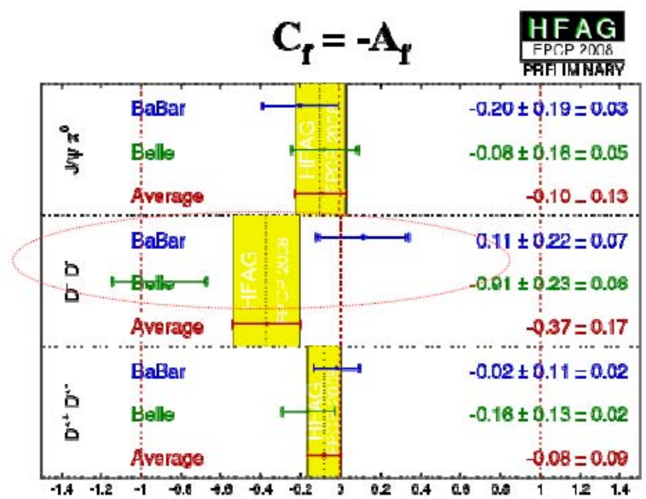
sin2β from b→cc̄s, cc̄d decays: summary







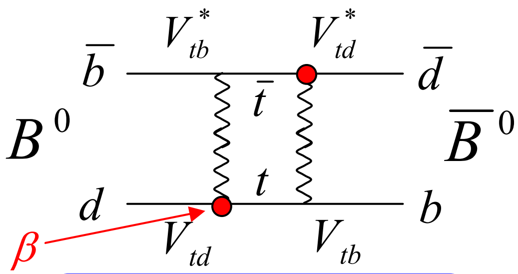




BEACH 2008, 22-28 June, 2008 F. Martínez-Vidal , Unitarity Triangle angles at BaBar 26

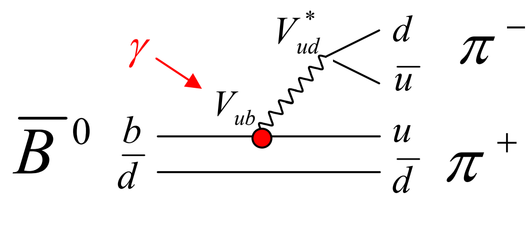
Measuring α : penguin pollution

$B^0\overline{B}^0$ mixing



$q/p \propto V_{tb}^* V_{td} / V_{tb} V_{td}^*$

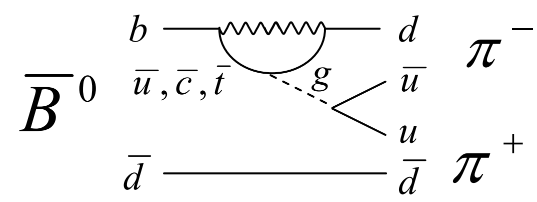
Tree decay



$A \propto V_{ud}^* V_{ub}$

⊕

Penguin decay



$A \approx V_{td}^* V_{tb}$

|P/T|~30-60% in $\pi^+\pi^-$

$$A(\Delta t) = S_{f_{CP}} \sin(\Delta m_d \Delta t) - C_{f_{CP}} \cos(\Delta m_d \Delta t)$$

$$\lambda_{f_{CP}} = \frac{q}{p}\frac{\overline{A}}{A} = \eta_{f_{CP}} e^{-i2\beta} e^{-i2\gamma} = \eta_{f_{CP}} e^{i2\alpha}$$
$$S_{f_{CP}} = -\eta_{f_{CP}} \sin 2\alpha$$
$$C_{f_{CP}} = 0$$

penguin pollution ⇒

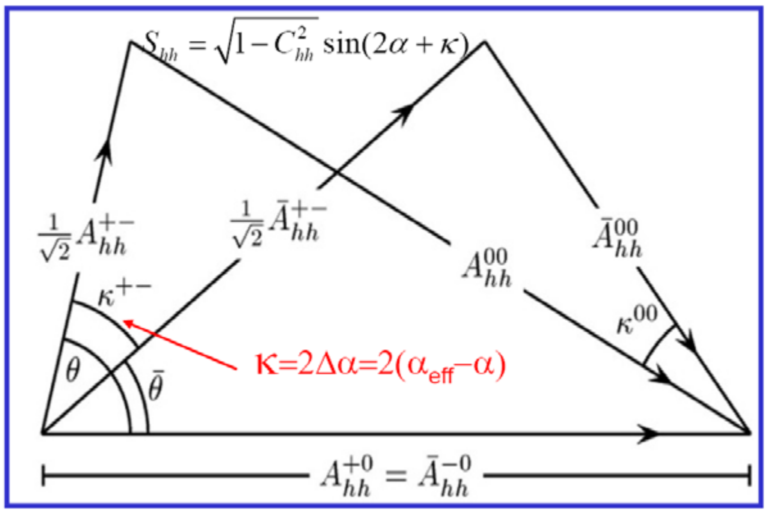
$$\lambda_{f_{CP}} = \eta_{f_{CP}} e^{i2\alpha} \frac{T + P e^{+i\gamma} e^{i\delta}}{T + P e^{-i\gamma} e^{i\delta}} = \eta_{f_{CP}} \left|\lambda_{f_{CP}}\right| e^{i2\alpha_{eff}}$$
$$S_{f_{CP}} = \eta_{f_{CP}} \sqrt{1 - C_{f_{CP}}^2} \sin 2\alpha_{eff}$$
$$C_{f_{CP}} \propto \sin\delta, \quad \delta = \delta_P - \delta_T \text{ strong phase diff.}$$

How to obtain α from α_{eff}? ➔ need additional information

Coping with penguins

- **Gronau & London analysis**:
  - According to SU(2):
    - Tree amplitude is I=0 and I=2
    - Gluonic penguin is pure I=0
    - $B^+ \to h^+h^0$ is pure I=2 (neglecting EW penguins) so : $A^{+0} = \overline{A}^{-0}$
  - Decay amplitudes are related by:

$$A^{+0} = \frac{1}{\sqrt{2}} A^{+-} + A^{00};\ \overline{A}^{-0} = \frac{1}{\sqrt{2}} \overline{A}^{+-} + \overline{A}^{00}$$



  - Allows estimation of penguin-induced shift in α:

$$\kappa^{+-} = 2(\alpha_{eff} - \alpha)$$

    - But 4-fold ambiguity

$$\kappa^{+-} = \pm(\theta \pm \overline{\theta})$$

    - And 2-fold ambiguity in 2α
  - Measurement of 6 amplitudes needed, on 6 tagged samples
    - time dependent analyses needed for B^0 amplitudes.

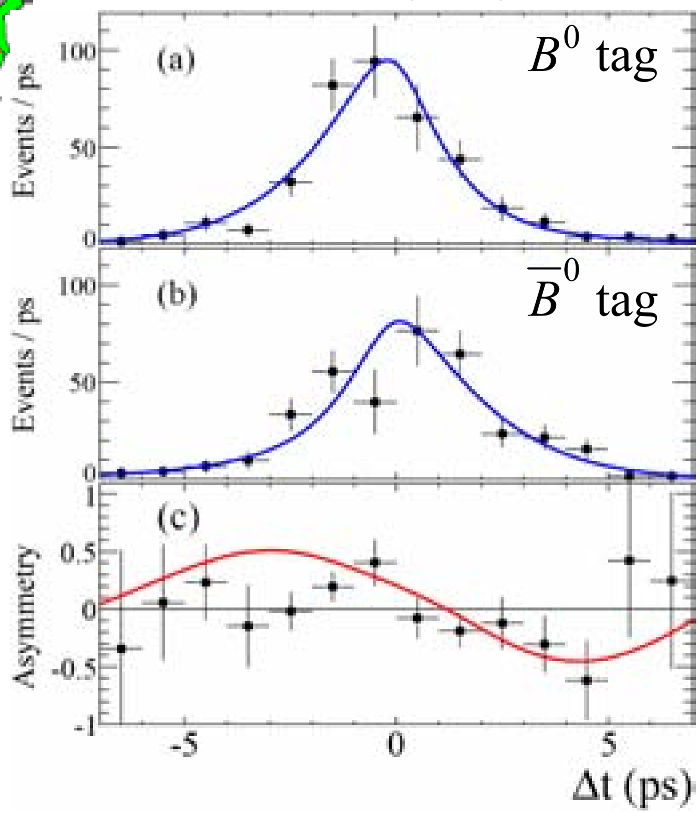
- **Grossman/Quinn bound**:

$$\sin^2(\alpha_{eff} - \alpha) \leq \frac{BF(B \to h^0h^0)}{BF(B^{\pm} \to h^{\pm}h^0)}$$

  - don't need to tag B flavor
  - useful if $BF(B \to h^0h^0)$ is small

CP asymmetries in $B^0 \to \pi^+\pi^-$

PRL **99**, 021603 (2007) **383M BB**

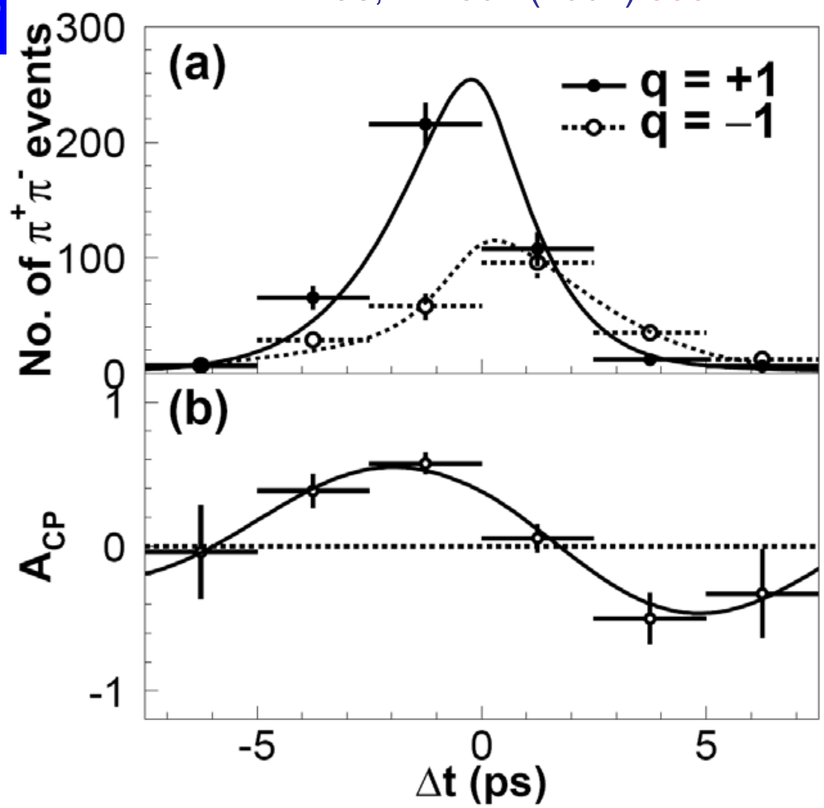


1139 ± 49 signal events

S_{+-} = -0.60 ± 0.11 ± 0.03 (5.1σ)

C_{+-} = -0.21 ± 0.09 ± 0.02 (2.2σ)

PRL **98**, 211801 (2007) **535M BB**



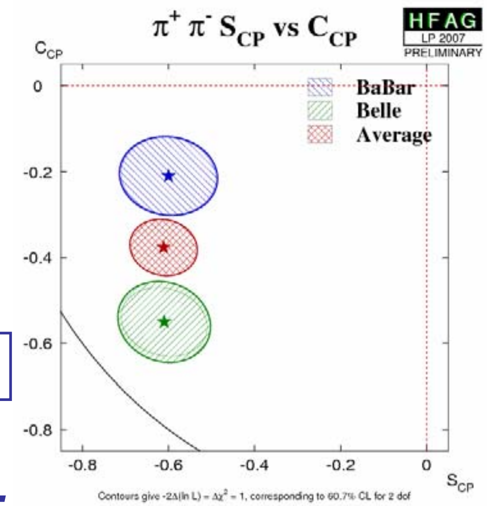
1464 ± 65 signal events

S_{+-} = -0.61 ± 0.10 ± 0.04 (5.3σ)

C_{+-} = -0.55 ± 0.08 ± 0.05 (5.5σ)

α from $B\to\pi\pi$

- CPV well established in $B^0\to\pi^+\pi^-$
  - still some 2.1σ difference in direct CPV between BABAR and BELLE

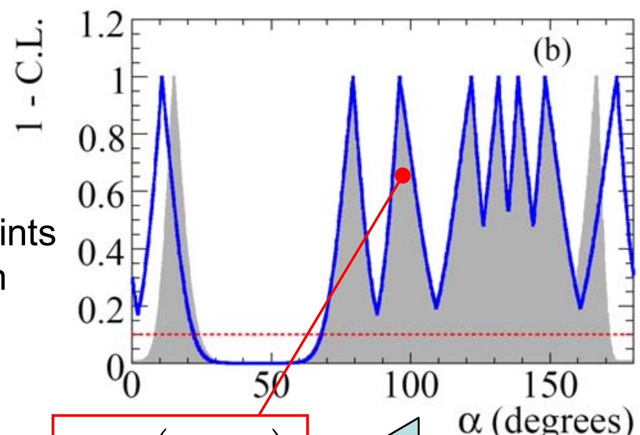


$\pi^0\pi^0$ time dependent asymmetry !

Time integrated asymmetry

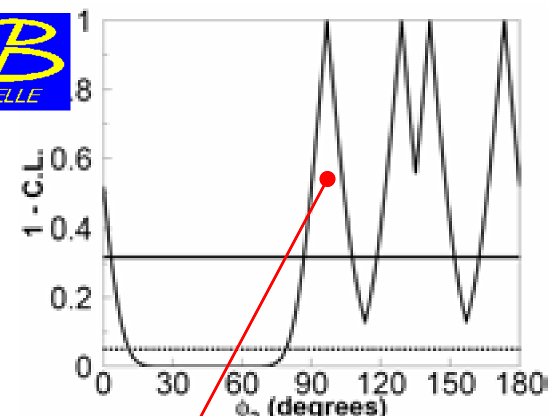
- Isospin analysis to extract α
  - use/measure S_{+-}, C_{+-}, ~~S_{00}~~, C_{00}, BF_{+-}, BF_{00}

PRD **76**, 091102 (2007) **383M BB**



SU(3) constraints on penguin from $B_s\to K^+K^-$

PRL **98**, 211801 (2007) **535M BB**



$\alpha = \left(96^{+11}_{-6}\right)^\circ$

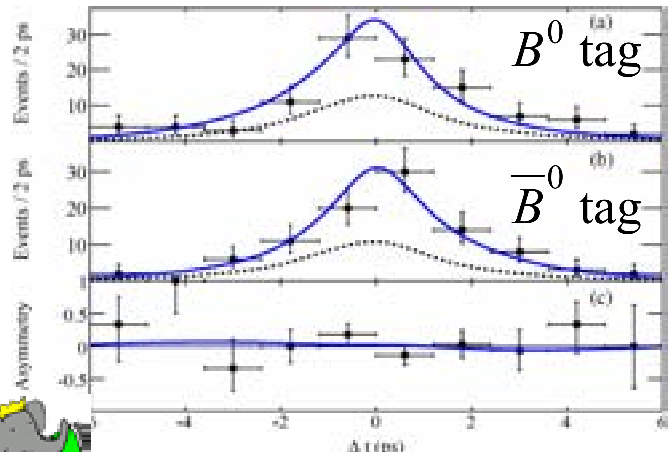
SM compatible solutions

$\alpha = \left(96 \pm 11\right)^\circ$

CP asymmetries in $B^0 \to \rho^+\rho^-$

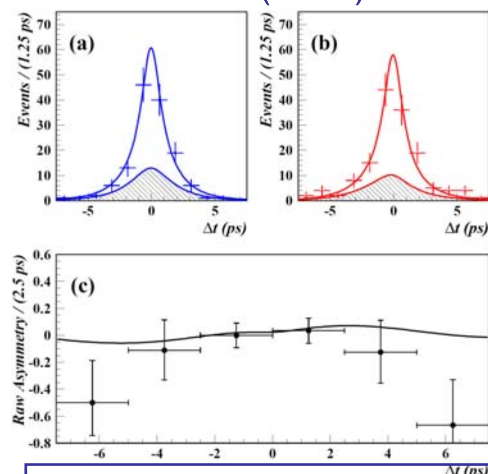
- Vector Vector final state
  - but almost pure *CP* even (f_L~1)
- Large BF, small penguin pollution
- Experimentally challenging
  - up to $2\pi_0$ in final state
  - ρ is wide

PRD **76** 052007 (2007) **383M BB**

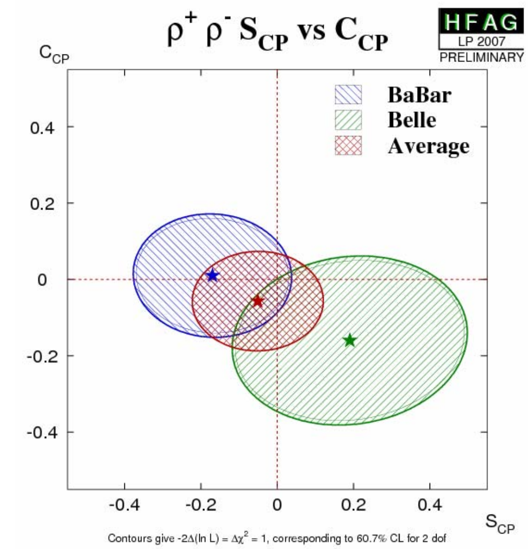


$$BF^{+-} = (25.5 \pm 2.1^{+3.6}_{-3.9}) \times 10^{-6}$$
$$f_L^{+-} = 0.992 \pm 0.024^{+0.026}_{-0.013}$$
$$C_L^{+-} = +0.01 \pm 0.15 \pm 0.06$$
$$S_L^{+-} = -0.17 \pm 0.20^{+0.05}_{-0.06}$$

PRL **96** 171801 (2006) **265M BB**
PRD **76** 011104 (2007) **535M BB**



$$BF^{+-} = (22.8 \pm 3.8^{+2.3}_{-2.6}) \times 10^{-6}$$
$$f_L^{+-} = 0.941^{+0.034}_{-0.040} \pm 0.30$$
$$C_L^{+-} = -0.16 \pm 0.21 \pm 0.08$$
$$S_L^{+-} = +0.19 \pm 0.30 \pm 0.08$$

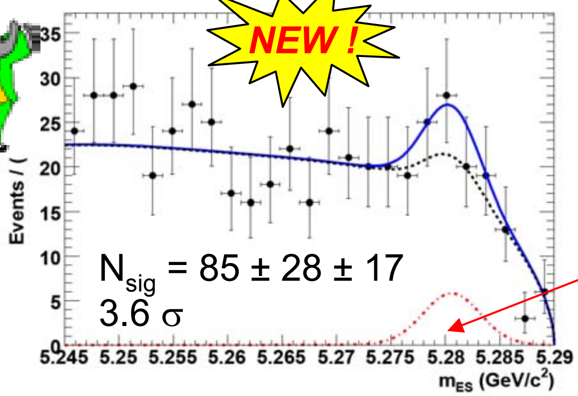


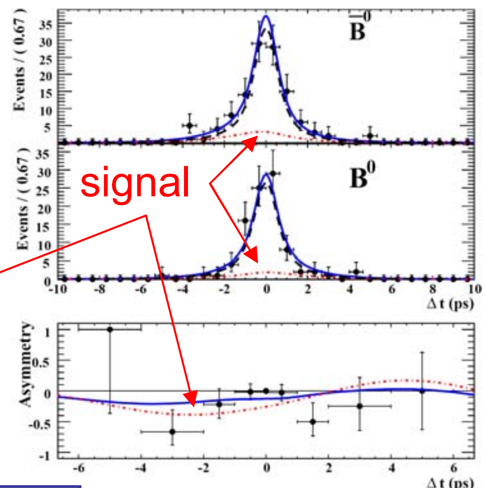
World average:
S_{+-}=–0.05 ± 0.17
C_{+-}=–0.06 ± 0.13

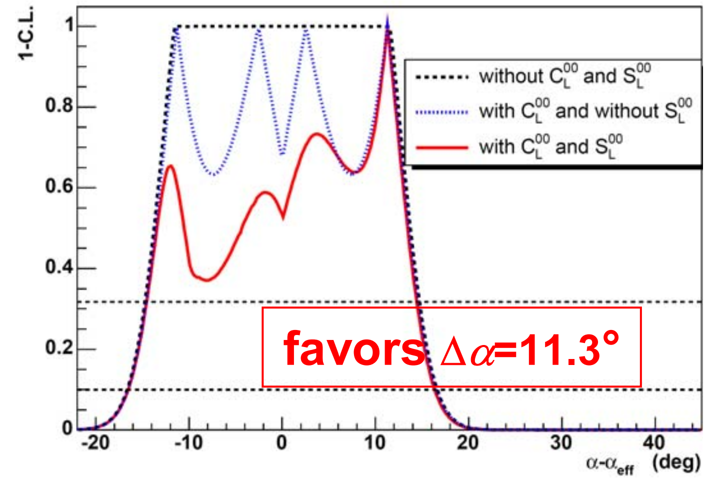
$B^0 \to \rho^0 \rho^0$ and isospin analysis

- First measurement of time dependent asymmetries in $\rho^0 \rho^0$
  - in contrast with $\pi^0\pi^0$, $\rho^0\rho^0$ vertex can be reconstructed ➔ TD possible
  - allows measurement of S_L^{00} ➔ full isospin analysis

NEW !







Preliminary !

arXiv:0708.1630 **427M BB**

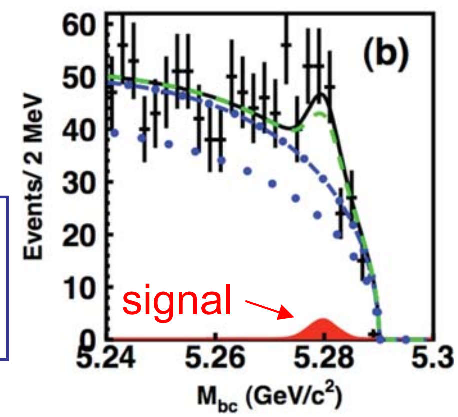
$$BF^{00} = (0.84 \pm 0.29 \pm 0.17) \times 10^{-6}$$
$$f_L^{00} = 0.70 \pm 0.14 \pm 0.05$$
$$C_L^{00} = +0.4 \pm 0.9 \pm 0.2$$
$$S_L^{00} = +0.5 \pm 0.9 \pm 0.2$$

BF^{00} low ➔ penguin small

LaThuile, Italy **657M BB**

NEW !

$$BF^{00} = (0.4 \pm 0.4 \pm 0.2) \times 10^{-6}$$
$$< 1.0 \times 10^{-6} \text{ @ } 90\% \text{ CL}$$

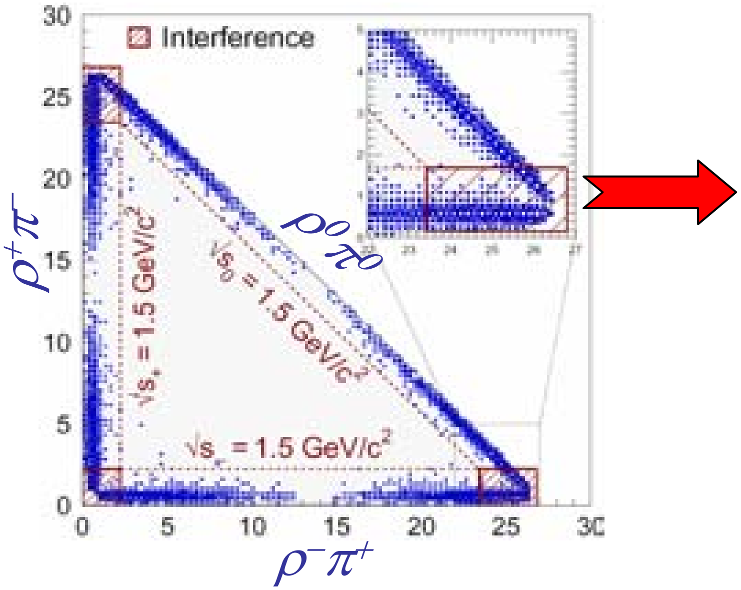


Dalitz analysis of $B^0 \rightarrow (\rho\pi)^0 \rightarrow \pi^+\pi^-\pi^0$

- Dominant $B^0 \rightarrow \rho^+\pi^-$ is not a **CP eigenstate**
- 5 amplitudes involved : $B^0 \rightarrow \rho^+\pi^-$, $\rho^-\pi^+$, $\rho^0\pi^0$ and $B^+ \rightarrow \rho^+\pi^0$, $\rho^0\pi^+$
  - ➔ Isospin pentagon !
- Better approach ➔ TD Dalitz analysis assuming isospin symmetry:

$$A(B^0 \rightarrow \pi^+\pi^-\pi^0) = f_+ A(\rho^+\pi^-) + f_- A(\rho^-\pi^+) + f_0 A(\rho^0\pi^0)$$
$$\overline{A}(\overline{B}^0 \rightarrow \pi^+\pi^-\pi^0) = f_+ \overline{A}(\rho^+\pi^-) + f_- \overline{A}(\rho^-\pi^+) + f_0 \overline{A}(\rho^0\pi^0)$$

A. Snyder and H. Quinn, PRD **48**, 2139 (1993)



Interferences at equal masses provides information on **strong phases** between resonances

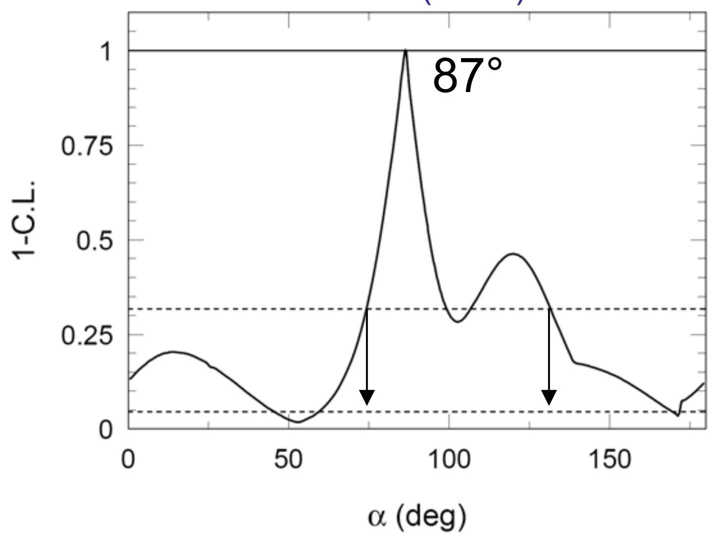
Dalitz analysis of $B^0 \to (\rho\pi)^0 \to \pi^+\pi^-\pi^0$

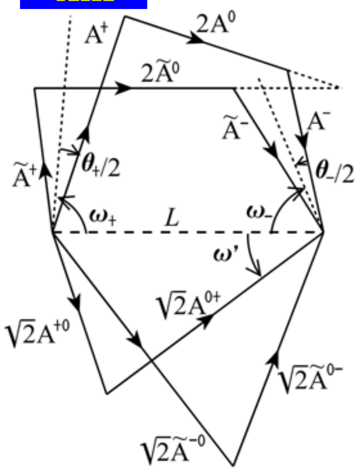
PRD **76** 012004 (2007) **375M BB**

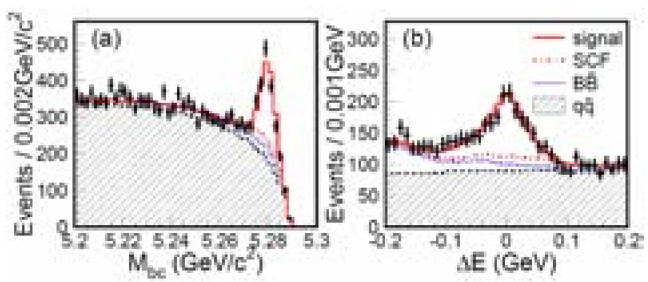
2067 ± 86 signal events

$$\alpha = \left(87^{+45}_{-13}\right)^{\circ}$$

(+ mirror solution at α +180°)

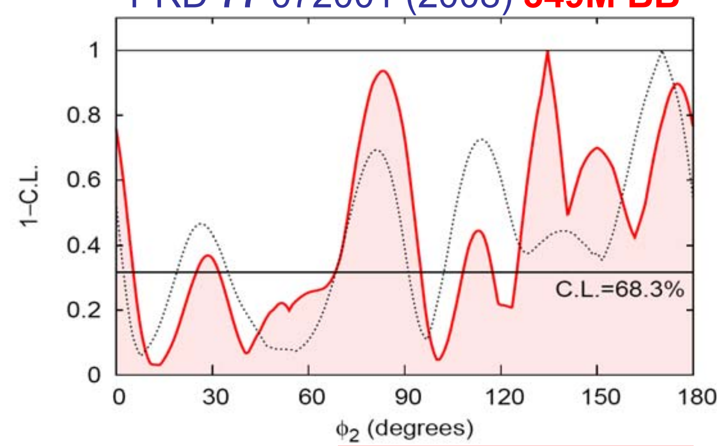






68 < α < 95° at 68% CL

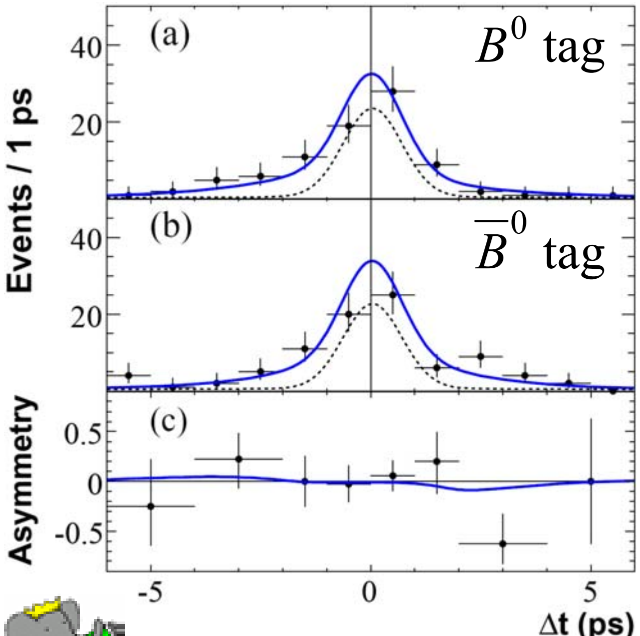
PRD **77** 072001 (2008) **349M BB**



Dalitz

Dalitz+pentagon

$B^0 \to a_1 \pi$



PRD **98** 181803 (2007) **384M BB**

$$\alpha_{eff}^{a_1\pi} = (78.6 \pm 7.3)^\circ$$

- Decay $B^0 \to a_1\pi$ has same quark diagram than $B \to \pi\pi, \rho\pi, \ldots$
  - and is similar to $B \to \rho\pi$: not a CP eigenstate, quasi-2 body approach
- High branching fraction:

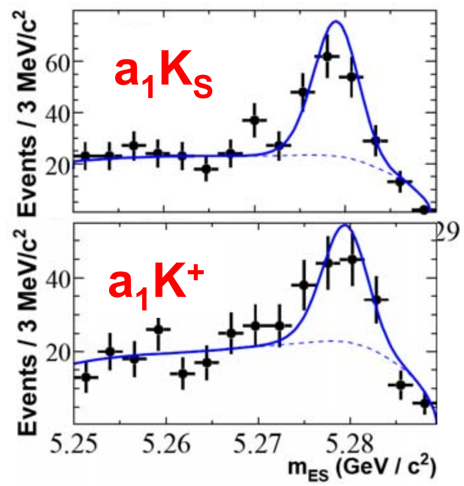
  BR=$(33.2 \pm 3.2 \pm 3.2)\times10^{-6}$

  PRL **97**, 051802 (2006)

  BR=$(29.8 \pm 3.2 \pm 4.6)\times10^{-6}$

  hep-ex 0706.3279

- SU(3) related modes ($\pi \leftrightarrow K$, $a_1 \leftrightarrow K_1$) to constrain α-$\alpha_{\rm eff}$:
  - $B \to a_1 K$: PRL **100**, 051802 (2008)
  - $B \to K_1 \pi$: ongoing

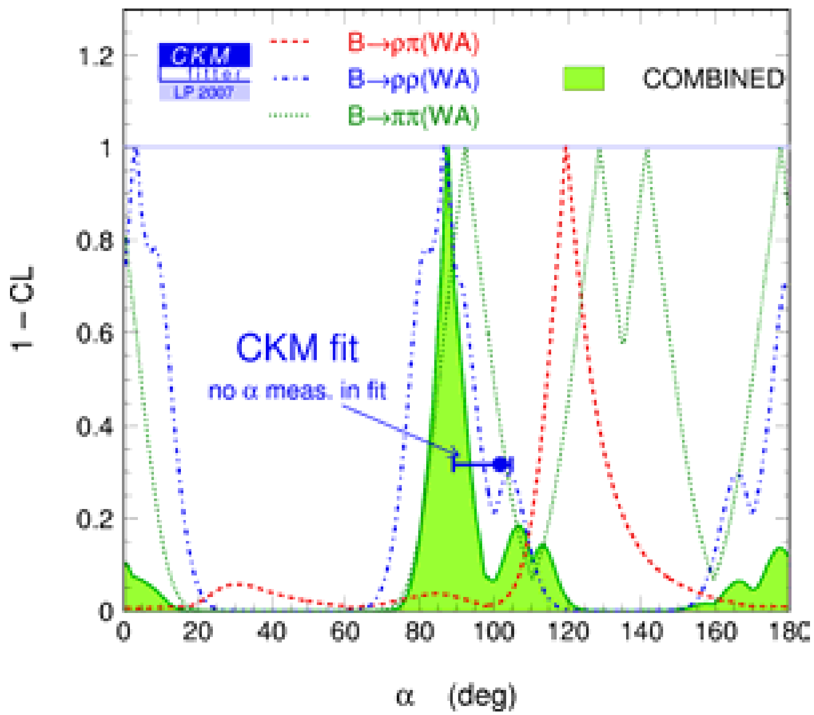


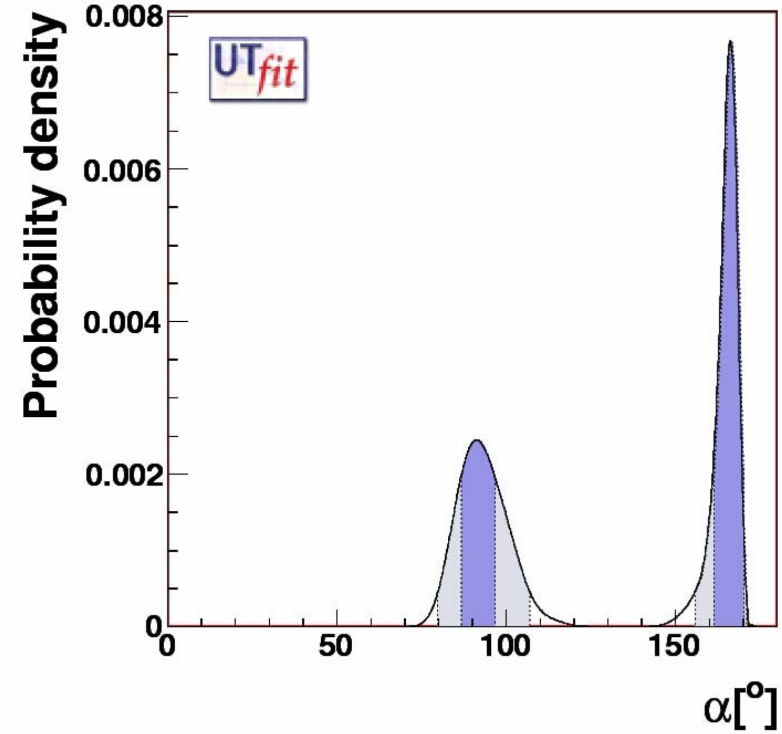
BF($B^0 \to a_1^- K^+$) = $(16.3 \pm 2.9 \pm 2.3)\times10^{-6}$

BF($B^0 \to a_1^- K^0$) = $(34.9 \pm 5.0 \pm 4.4)\times10^{-6}$

Combined constraints on α

- Frequentist versus Bayesian treatment of constraints





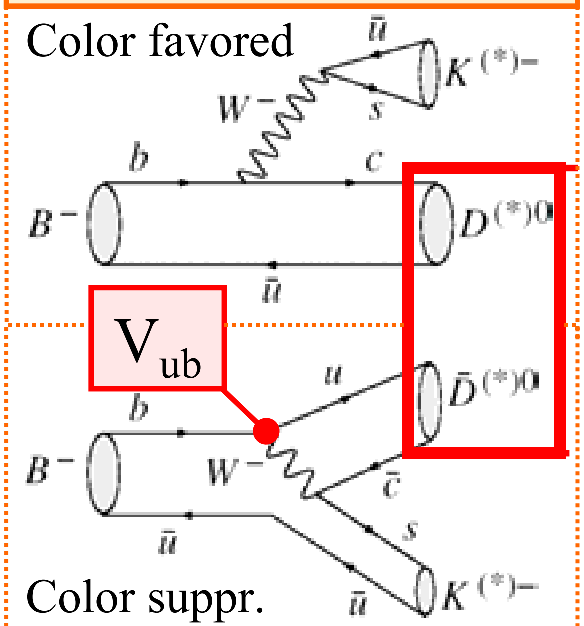
1 σ interval for α [82.2 ; 93.7]°

- Excluded regions are common.
- Situation should clarify with more data.

Measurement of γ: methods overview

- Measure relative phase (γ) between $b \to c\bar{u}s$ and $b \to u\bar{c}s$ decay processes
- **For final states common to D^0 and $\bar{D}^0$ $\Rightarrow$ interferences $\Rightarrow$ γ accessible**

$A \sim \lambda^3$



$A \sim \lambda^3 r_B^{(*)} e^{-i\gamma} e^{i\delta}$

Theoretically clean: no penguin contributions.

Three methods

GLW D^0 CP modes	ADS DCSD mode	GGSZ Dalitz
K^+K^-, $\pi^+\pi^-$ [CP^+] $K_S\pi^0$, $K_S\omega$, $K_S\phi$ [CP^-]	$K^+\pi^-$ $D^0 \to K^+\pi^-$ suppr. $\bar{D}^0 \to K^+\pi^-$ fav.	$K_S\pi^+\pi^-$ $K_SK^+K^-$ $\pi^0\pi^+\pi^-$

- δ = relative (unknown) strong phase
- γ = weak phase
- $r_B^{(*)}$ = (critical) ratio of suppr./fav. amplitudes:

$$r_B^{(*)} \equiv \left| \frac{A(B^- \to \bar{D}^{(*)0} K^-)}{A(B^- \to D^{(*)0} K^-)} \right| \sim 0.1 - 0.2$$

Updated $B^+ \to D^* K^+$ and $B^+ \to DK$ GLW

- Based on triangle relations of amplitudes

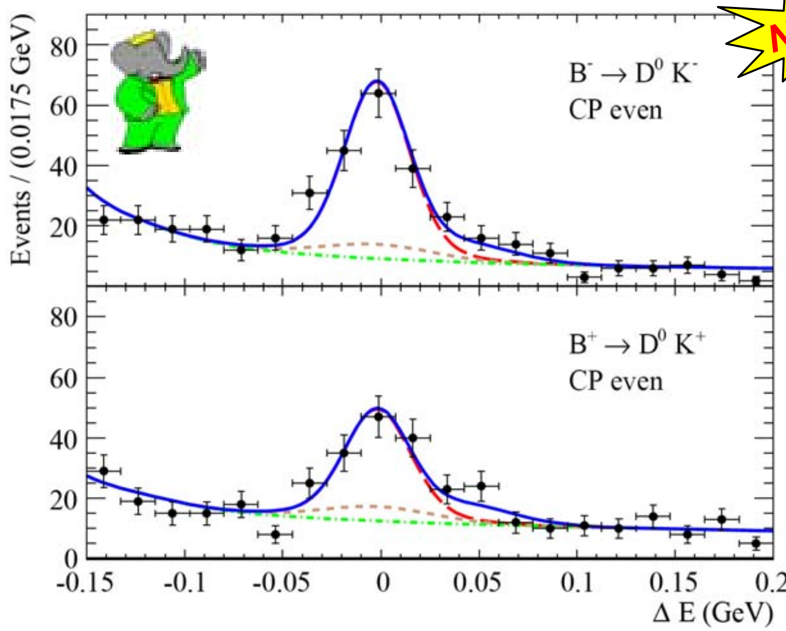
8-fold ambiguity on γ

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

$$A_{CP+}R_{CP+} = -A_{CP-}R_{CP-}$$

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

2.8σ from no CPV



NEW !

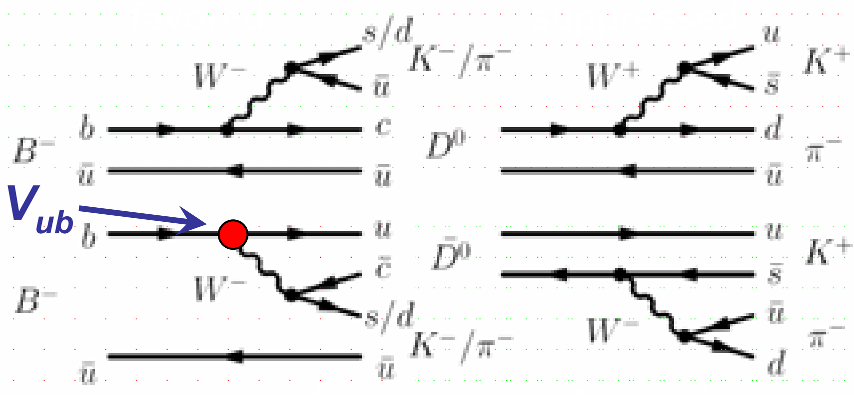
	$B^+ \to DK^+$	$B^+ \to D^* K^+$
A_{CP+}	+0.27 ± 0.09 ± 0.04	-0.11 ± 0.09 ± 0.01
A_{CP-}	-0.09 ± 0.09 ± 0.02	+0.06 ± 0.10 ± 0.02
R_{CP+}	1.06 ± 0.10 ± 0.05	1.31 ± 0.13 ± 0.04
R_{CP-}	1.03 ± 0.10 ± 0.05	1.10 ± 0.12 ± 0.04

arXiv:0802.4052 **383M BB**
accepted by PRD

preliminary **383M BB**
(hot topic FPCP 08)

Results consistent with γ=(67.6±4.0)° from SM fit

Updated $B^+ \to DK^+$ ADS

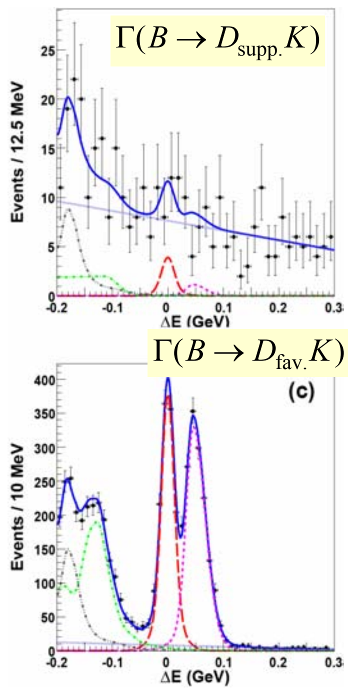


r_D=0.0578 ± 0.0008

$$R_{ADS} \equiv \frac{\Gamma(B \to D_{\text{supp.}}K)}{\Gamma(B \to D_{\text{fav.}}K)} = r_D^2 + r_B^2 + 2 r_B r_D \cos\gamma \cos\delta$$

$$A_{ADS} \equiv \frac{\Gamma(B^- \to D_{\text{supp.}}K^-) - \Gamma(B^+ \to D_{\text{supp.}}K^+)}{\Gamma(B^- \to D_{\text{supp.}}K^-) - \Gamma(B^+ \to D_{\text{supp.}}K^+)}$$
$$= 2 r_B r_D \sin\gamma \sin\delta / R_{ADS}$$

$\delta = \delta_B + \delta_D$: relative strong phases for B and D decays



arXiv:**0804.2063**, **submitted to PRD(RC)** **657M BB**

No significant signal observed in the suppressed mode:

BF($B \to D_{supp.}K$) < 2.8 10^{-7} @ 90% CL

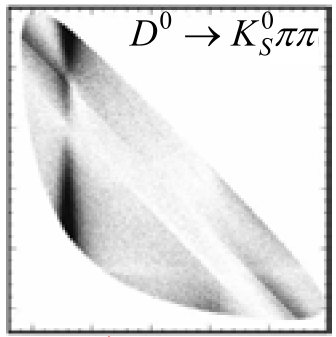
r_B<0.19 @ 90% CL

$B^+ \to D^{(*)}K^+$ Dalitz

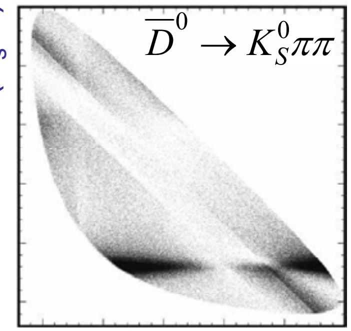
Giri *et al.* PRD **68**, 054018 (2003)
Bondar, PRD **70**, 072003 (2004)

- The idea in pictures:

$A(B^-)=|A(B\to D^0K)|\times$



$+r_B e^{i\delta_B} e^{-i\gamma}$



$+D^0\to K_sKK$, $\pi^0\pi\pi$

$$A_-(m_-^2,m_+^2)=\left|A(B^-\to D^0K^-)\right|\left[A_D(m_-^2,m_+^2)+r_Be^{i\delta_B}e^{-i\gamma}A_D(m_+^2,m_-^2)\right]$$

$$A_+(m_-^2,m_+^2)=\left|A(B^+\to \overline{D}^0K^+)\right|\left[A_D(m_+^2,m_-^2)+r_Be^{i\delta_B}e^{+i\gamma}A_D(m_-^2,m_+^2)\right]$$

$m_\pm^2 = m^2(K_S^0\pi^\pm), m^2(K_S^0K^\pm), m^2(\pi^0\pi^\pm)$

change of sign

- Extract γ, r_B, δ_B using cartesian coordinates $x_\pm$ and $y_\pm$

$$\Gamma_\pm(m_-^2,m_+^2)\propto\left|A_{D^\pm}\right|^2+r_B^2\left|A_{D^\mp}\right|^2+2\eta\left\{x_\pm\Re e\left[A_{D^\pm}A_{D^\mp}^*\right]+y_\pm\Im m\left[A_{D^\pm}A_{D^\mp}^*\right]\right\}$$

$x_\pm = \kappa r_B\cos(\delta_B\pm\gamma)$
$y_\pm = \kappa r_B\sin(\delta_B\pm\gamma)$

  - makes likelihood Gaussian and unbiased

κ account for natural width of K^*
η accounts for parities $D^{*0}\to D^0\gamma$ wrt $D^0\pi^0$

- Two-fold ambiguity $(\delta_B,\gamma)\to(\delta_B+\pi,\gamma+\pi)$

Dalitz plot analysis of $D^0/\bar{D}^0$ decays

- Extract $D^0/\bar{D}^0$ decay amplitudes from high statistics samples of $D^{*+}\to D^0\pi^+$, tagging D^0 flavor with pion charge

NEW !

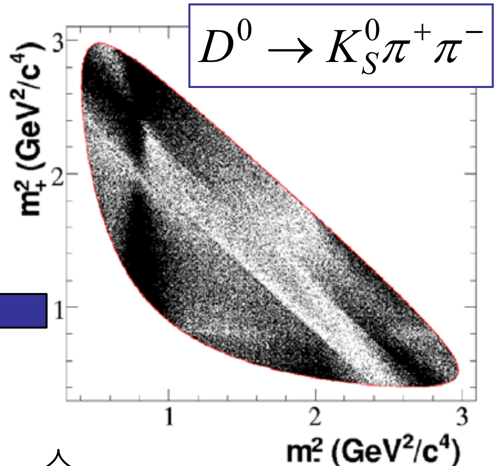
arXiv:0802.4052 **383M BB**

accepted by PRD

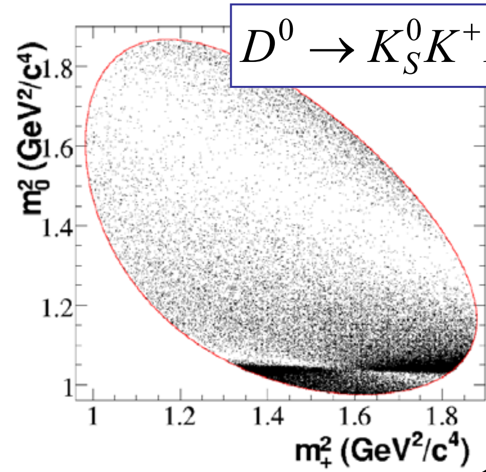
parameterization

$K^*(892)^{\pm}, K_0^*(1430)^{\pm},$
$K_2^*(1430)^{\pm}, K^*(1680)^{-},$
$\rho(770), \omega(782), f_2(1270),$
K–matrix for $\pi\pi$ S–wave
and running phase,
non–resonant for
$K\pi$ S–wave

$D^0 \to K_S^0\pi^+\pi^-$



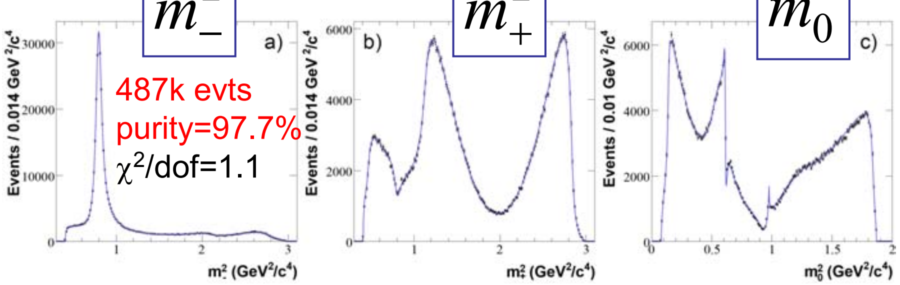
$D^0 \to K_S^0 K^+ K^-$



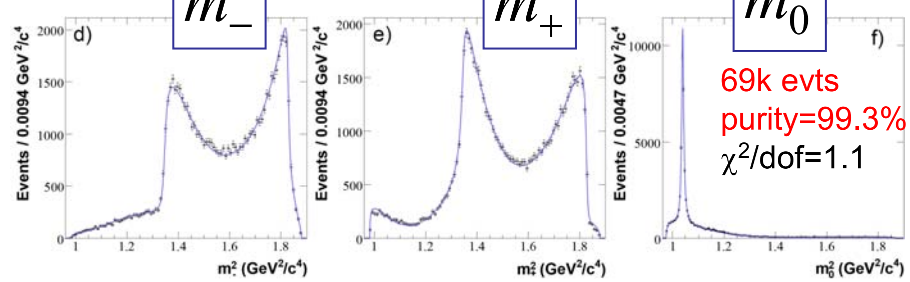
parameterization

$a_0(980)^0, \phi(1020),$
$f_0(1370), f_2(1270),$
$a_0(980)^{\pm}, a_0(1450)^0$
$, a_0(1450)^+$

m_-^2 m_+^2 m_0^2

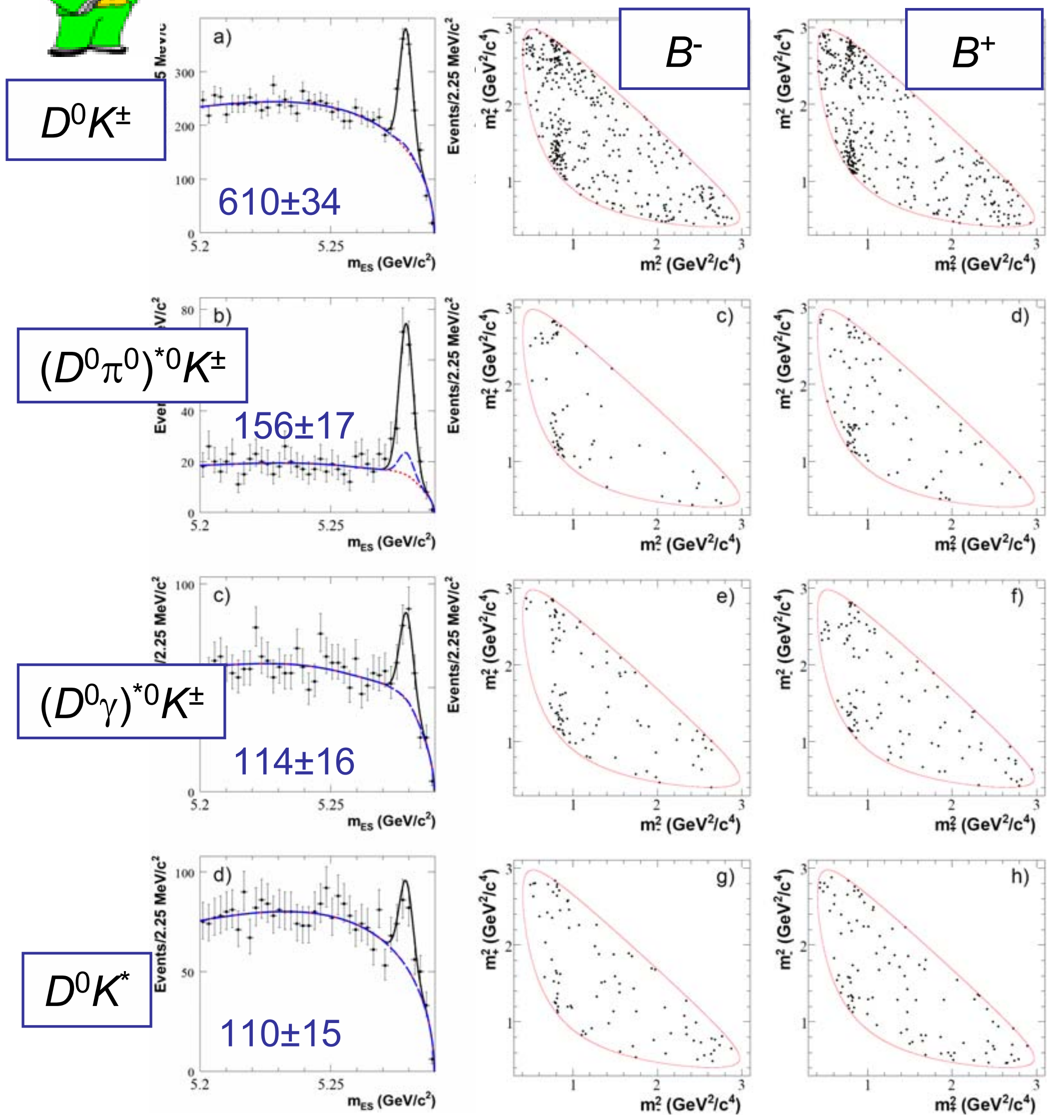


m_-^2 m_+^2 m_0^2

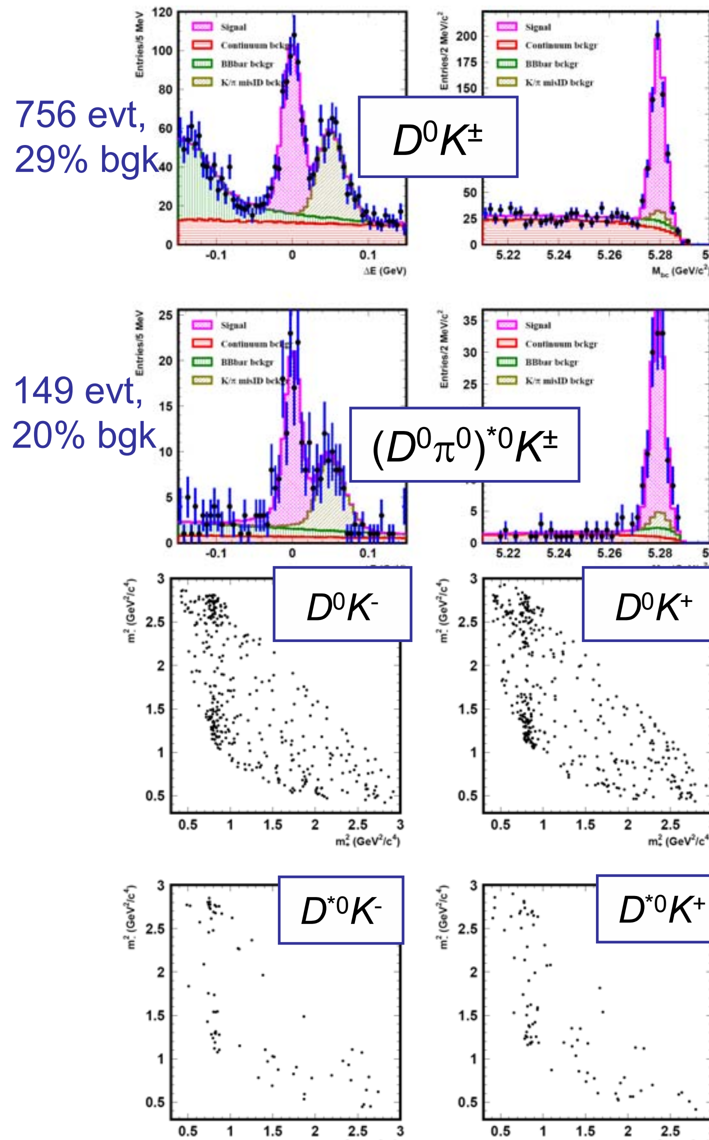


$D \rightarrow K_S \pi\pi$ Selected samples

($D \rightarrow KKK$ from BABAR not shown)

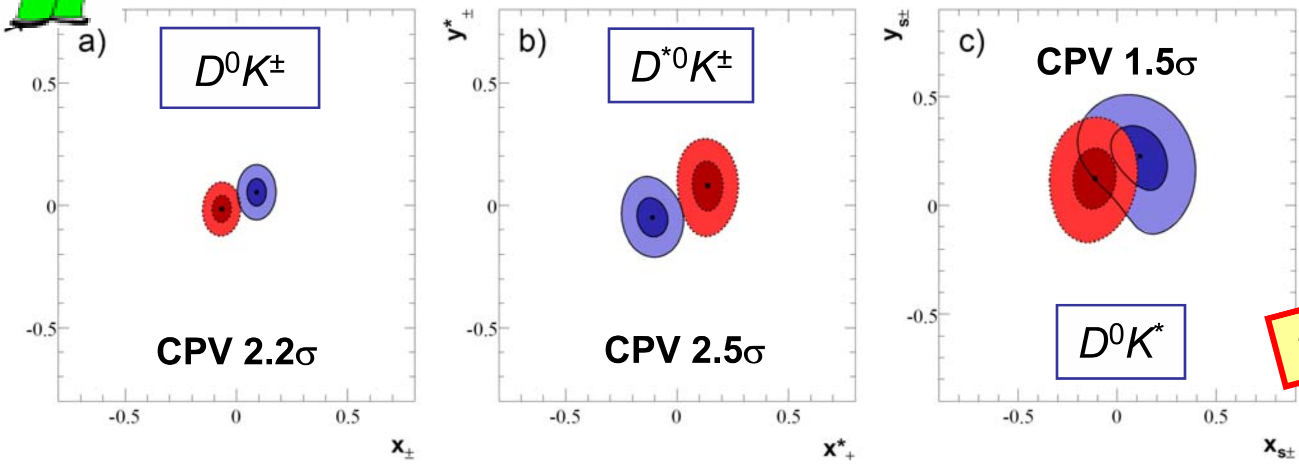


arXiv:0802.4052 383M BB *accepted by PRD*



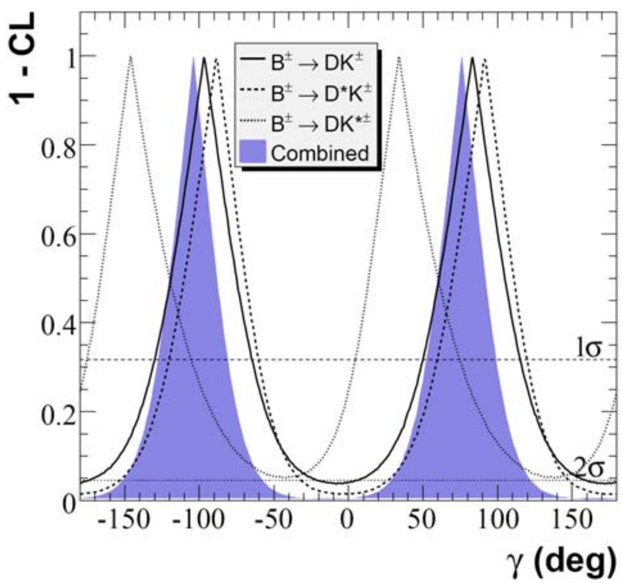
arXiv:0803.3375v1 657M BB

BABAR Dalitz results



d(B^+,B^-) = $2r_b|\sin\gamma|$:
size of direct CPV

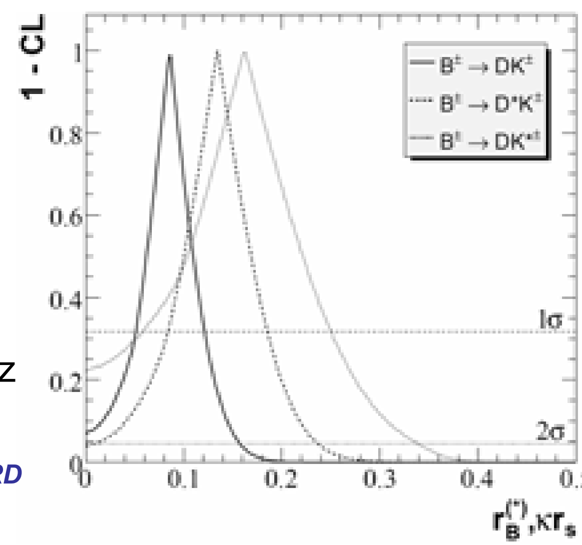
3σ evidence for direct CPV



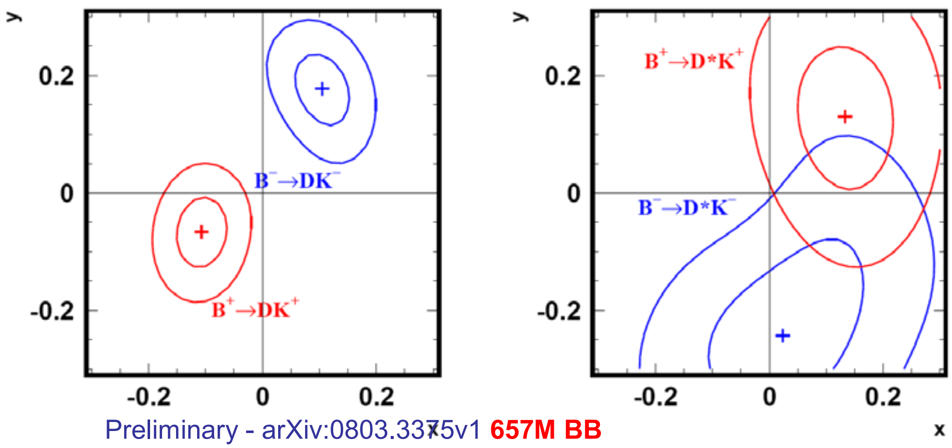
$$r_B(DK) = 0.086 \pm 0.035$$
$$r_B(D^*K) = 0.135 \pm 0.051$$
$$kr_s(DK^*) = 0.163^{+0.088}_{-0.105}$$
$$\gamma = \left(76^{+23}_{-24}\right)^\circ$$

includes 5°exp. and 5° Dalitz

arXiv:0802.4052 **383M BB** ***accepted by PRD***



BELLE Dalitz results



Preliminary - arXiv:0803.3375v1 **657M BB**

3.5 σ evidence for direct CPV

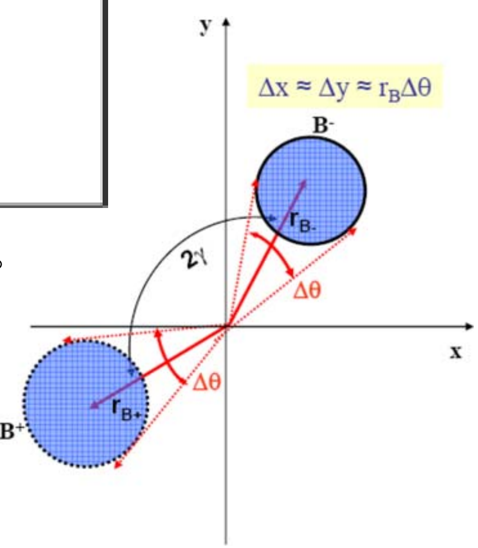
Parameter	1σ interval	2σ interval	Systematic error	Model uncertainty
ϕ_3	$76^\circ\ ^{+12^\circ}_{-13^\circ}$	$49^\circ < \phi_3 < 99^\circ$	4°	9°
r_{DK}	0.16 ± 0.04	$0.08 < r_{DK} < 0.24$	0.01	0.05
r_{D^*K}	0.21 ± 0.08	$0.05 < r_{D^*K} < 0.39$	0.02	0.05
δ_{DK}	$136^\circ\ ^{+14^\circ}_{-16^\circ}$	$100^\circ < \delta_{DK} < 163^\circ$	4°	23°
δ_{D^*K}	$343^\circ\ ^{+20^\circ}_{-22^\circ}$	$293^\circ < \delta_{DK} < 389^\circ$	4°	23°

- Comparison BABAR/BELLE
  - BELLE uncertainties are significantly smaller than BABAR ones
  - despite the (x,y) observables have comparable errors
  - this is the "r_B" effect

$$\gamma = \left(76^{+22}_{-23} \pm 5 \pm 5\right)^\circ$$

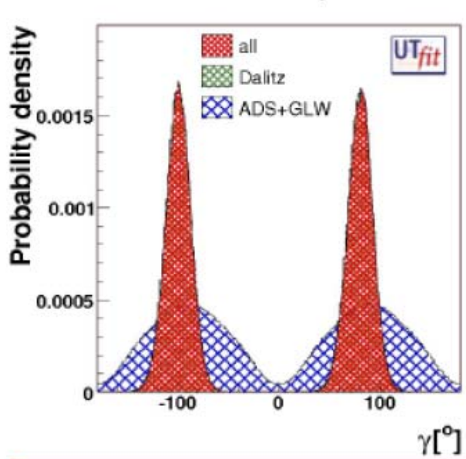
$$r_B(DK) = 0.086 \pm 0.035$$

$$r_B(D^*K) = 0.135 \pm 0.051$$

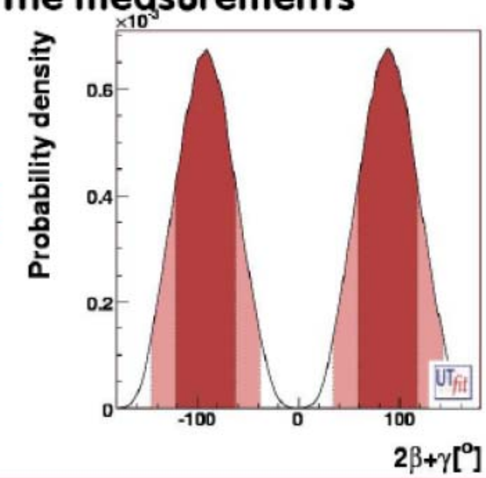


Combined constraints on γ

Babar + Belle, from the combination of all the measurements

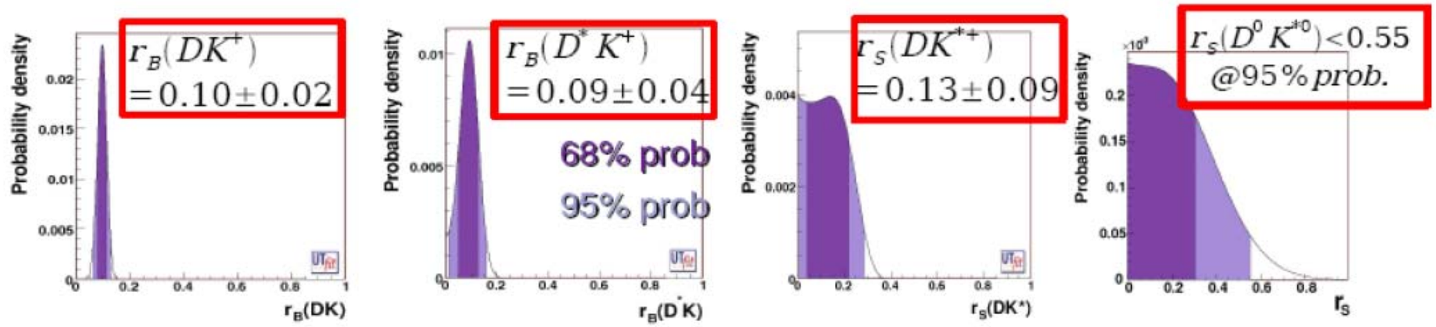


WOLRD AVERAGE (all new measurements here presented are included)



$\gamma/\phi_3 = (80 \pm 13)^o (mod.180^o)$

$2\beta + \gamma = (88 \pm 29)^o (mod.180^o)$



$r_B(DK^+) = 0.10 \pm 0.02$

$r_B(D^* K^+) = 0.09 \pm 0.04$

$r_S(DK^{*+}) = 0.13 \pm 0.09$

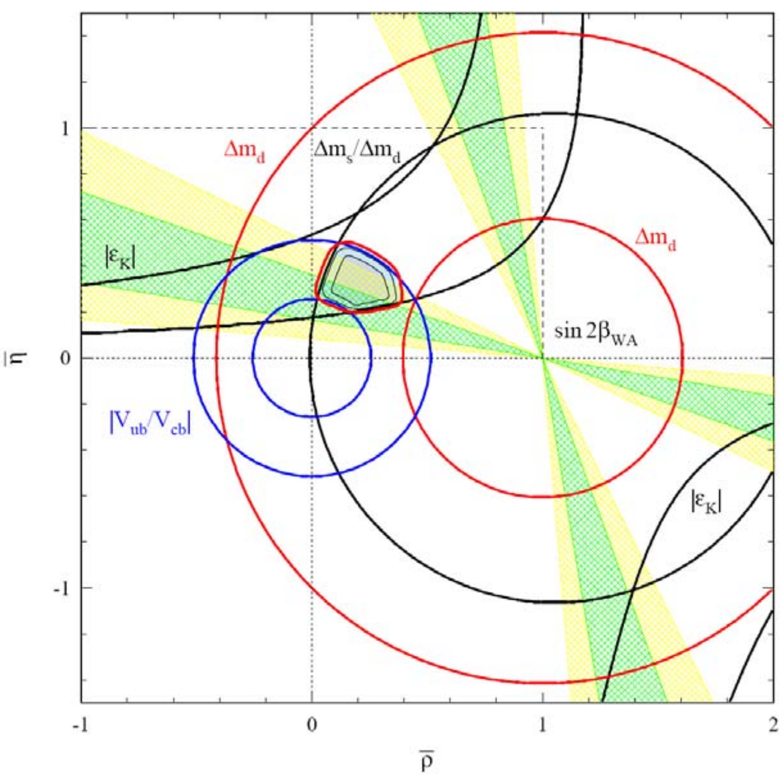
$r_S(D^0 K^{*0}) < 0.55$ @95% prob.

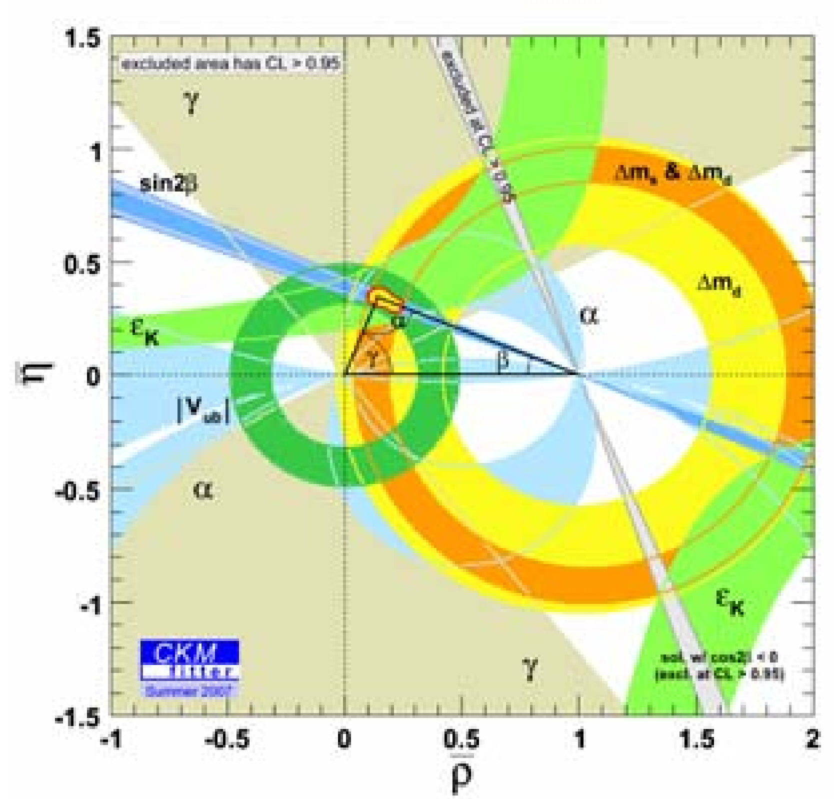
BEACH 2008, 22-28 June, 2008 F. Martínez-Vidal , Unitarity Triangle angles at BaBar 30

Conclusion

- Remarkable success of B factories
  - succeeded beyond expectation, with eg, measurement of γ
- BABAR has now finished its data taking
  - leaving BELLE alone in the “race”…
  - but still many analyses to do or update on the full data sample
- CKM UT is constrained by measurements based on both by CP conserving and CP violating
  - the picture is consistent with the SM !
- Measurement of semileptonic decays become more precise as the experimental techniques are improving and the theoretical computation of parameters.
- The measurement of β is a precision measurement, reaching accuracy of SM calculations
- The angle a will ultimately be limited by penguin pollution
  - still more new channels being added
- The measurement of γ is reaching the 13° precision

2001… and now


Δm_d
Δm_s/Δm_d
Δm_d
|ε_K|
sin 2β_WA
|V_ub/V_cb|
|ε_K|
ρ̄
η̄


excluded area has CL > 0.95
excluded at CL > 0.95
γ
sin2β
Δm_s & Δm_d
Δm_d
α
ε_K
|V_ub|
α
ε_K
γ
CKM fitter
Summer 2007
ρ̄
η̄