CP Violation at the B Factories

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Outline

- Introduction
- CP Violation in B decays
  - β
  - γ
  - α
- Global CKM fits
- Conclusions

Note:

- This topic too broad to cover completely
- Topic selection:

1. selected recent results (see parallel talks for more):
   - "*CP Violation in B decays at BaBar*" – A. Oyanguren Campos
   - "*CP Violation in tau and charm decays at BaBar*" – N. Neri
2. most important measurements (even if not so recent)

Introduction

- CP violation originally observed in the kaon system in the 1960s, but ~40 years passed without new discoveries of CP violation in other systems
- Main reason to construct the B factories: measurement of CP violation in the B meson system
- Many, many other types of measurements have been made at the B factories, but CPV was and remains the core of B factory physics
- CP violation closely connected with the CKM matrix...

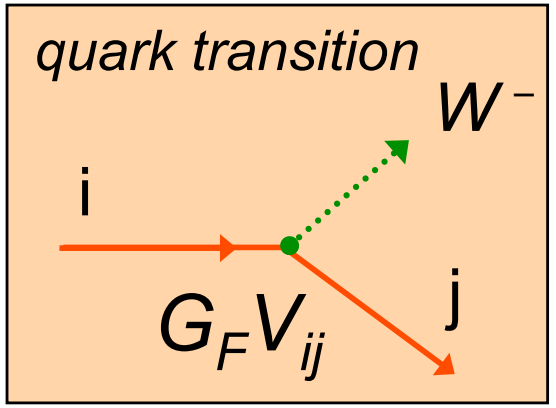
The CKM Matrix

- The CKM matrix connects the quark mass eigenstates to the weak interaction eigenstates → describes coupling strength of quarks to charged weak interaction

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- First suggested by M. Kobayashi and T. Maskawa in 1973 to explain CP violation in kaon mixing. Awarded Physics Nobel Prize (with Y. Nambu) in 2008. Extension of original idea posed by Nicola Cabibbo in 1963.

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



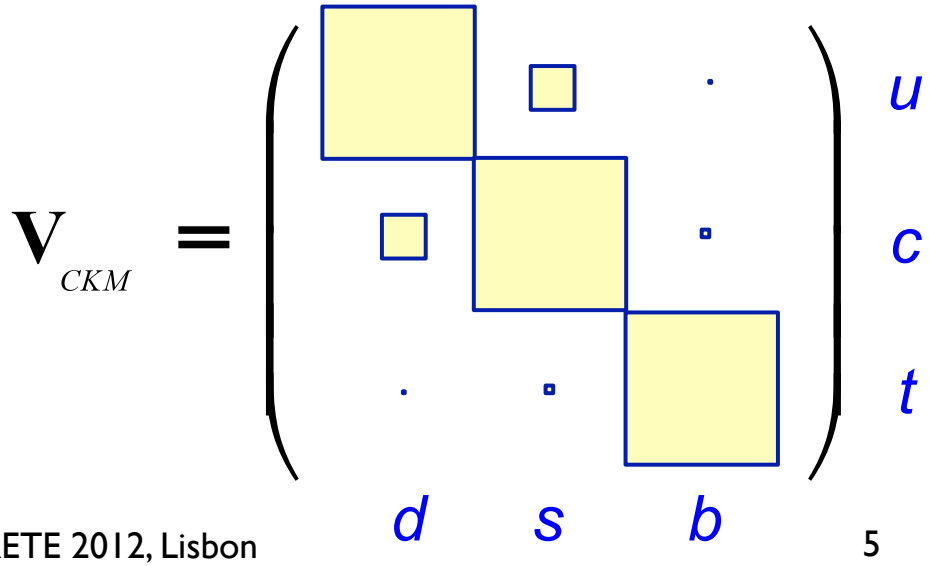
The CKM Matrix

- In Standard Model, 3x3 unitary matrix
  - values Vij not predicted in SM
  - V_{CKM} has 4 independent parameters
  - single complex phase leads to ***CP violation***

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

Wolfenstein parametrization

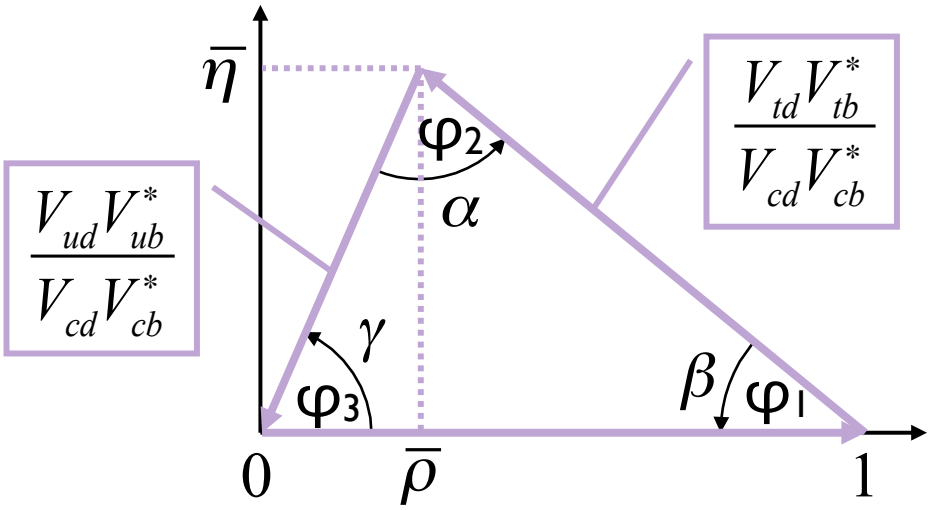
A, λ well measured
ρ, η poorly known
before B factories



area of square ∝ $|V_{ij}|^2$

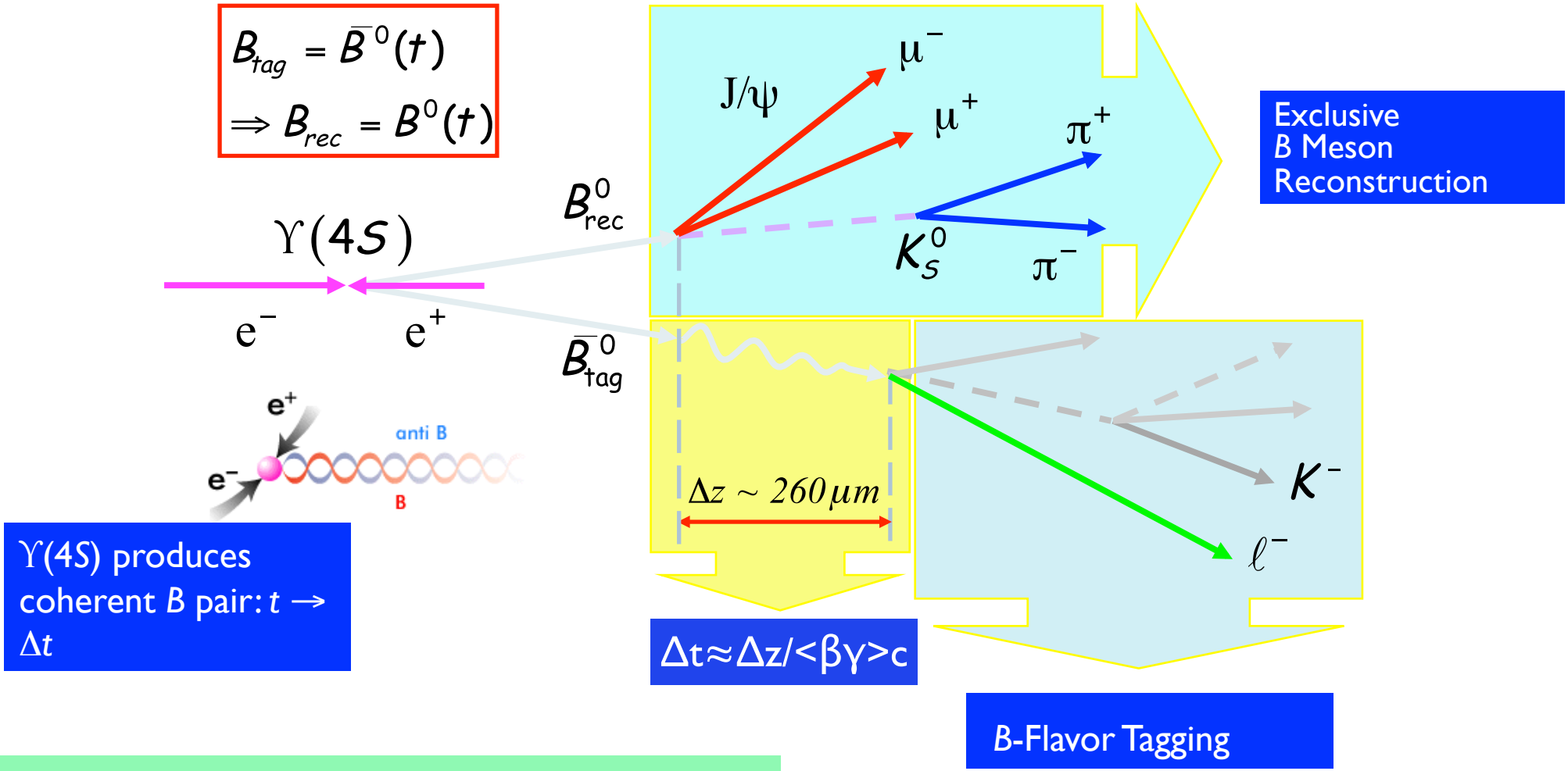
The Unitarity Triangle

- Unitarity of CKM implies $V^\dagger V = 1 \rightarrow$ 6 unitarity conditions
- Of particular interest: $\mathbf{V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0}$



- All sides ~ O(1) → possible to measure both sides and angles
  - Sides from semileptonic B decays, B mixing, rare B decays
  - Time-dependent CP asymmetries in B meson decays measure α, β and γ ($\varphi_2, \varphi_1, \varphi_3$)

Measuring time-dependent CP asymmetries

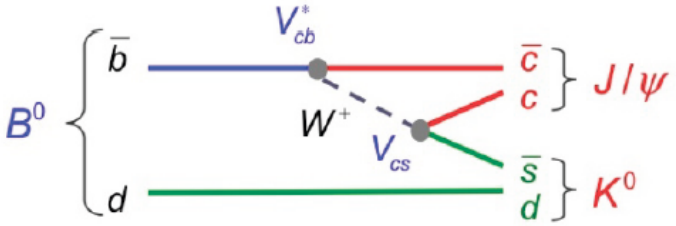


- Time-integrated asymmetries are zero
- $B^0_{rec} = B^0_{flav}$ → lifetime, mixing
- $B^0_{rec} = B^0_{CP}$ → CP violation

β, φ_1

sin 2β: time-dependent CP asymmetry in $b \to \bar{c}cs$

- Golden mode: only 1 amplitude contributes



- Measure CP asymmetry as function of time:

$$A_{CP}(t) = \frac{N(\bar{B}^0(t) \to f_{CP}) - N(B^0(t) \to f_{CP})}{N(\bar{B}^0(t) \to f_{CP}) + N(B^0(t) \to f_{CP})} = S_f \sin(\Delta m t) - C_f \cos(\Delta m t)$$

- For $B^0 \to J/\psi K_S$ we have the simple relation:

$$A_{CP}(t) = \sin 2\beta \sin \Delta m t$$

S_f

φ_1 from $B^0 \to (c\bar{c})K^0$

PRL 108, 171802 (2012)

- Based on full Belle dataset: 772 x 10^6 B$\bar{\text{B}}$ pairs
- Several final states included
- Yields from 2-D fit to

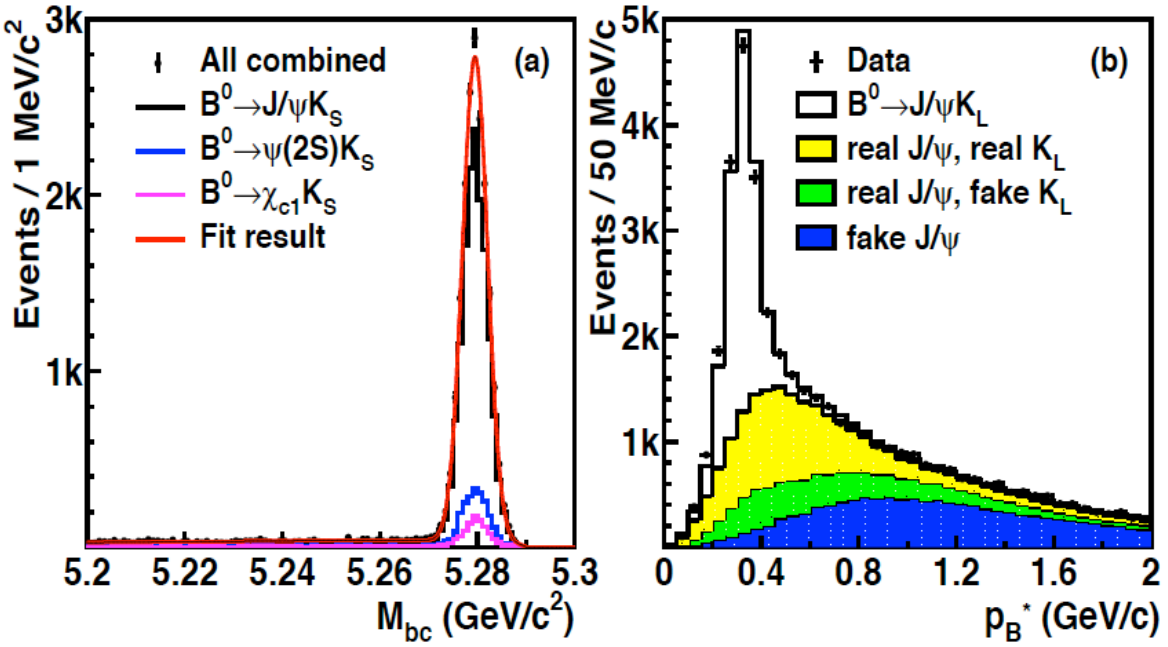
$$\Delta E \equiv E_B^* - E_{beam}^*$$

$$M_{\rm bc} \equiv \sqrt{(E_{beam}^*)^2 - (p_B^*)^2}$$

- For $B^0 \to J/\psi K_L$ mode, 1-D fit to p_B^*

Golden mode

mode	N_{sig}
$J/\psi K_S^0$	12649 ± 114
$\psi(2S)(l^+l^-)K_S^0$	904 ± 31
$\psi(2S)(J/\psi\pi^+\pi^-)K_S^0$	1067 ± 33
$\chi_{c1}K_S^0$	940 ± 33
$J/\psi K_L^0$	10040 ± 154



φ_1 from $B^0 \to (c\bar{c})K^0$

PRL 108, 171802 (2012)

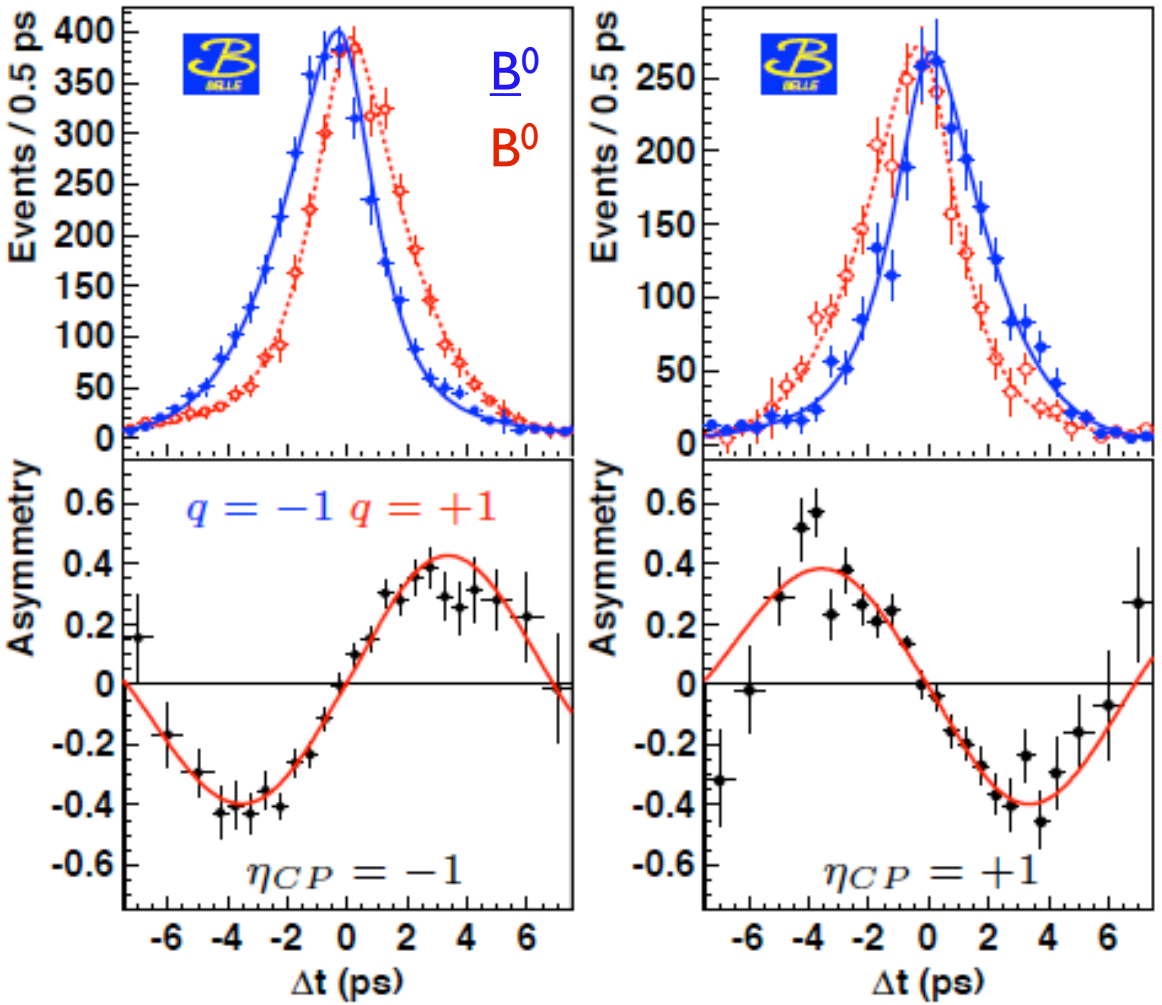
- World's most precise measurement:

$$\sin 2\phi_1 = 0.667 \pm 0.023 \pm 0.012$$

- No evidence for direct CP violation:

$$\mathcal{A}_{CP} = 0.006 \pm 0.016 \pm 0.012$$

Note: A_{CP} = -C_f (previously defined)

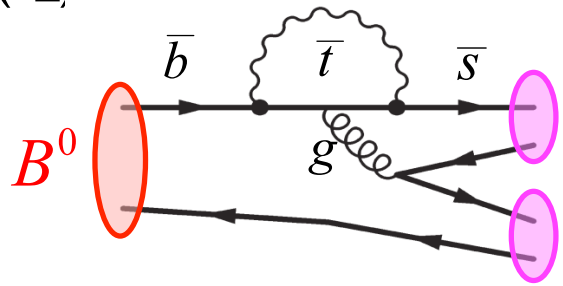


BaBar result:

$$S_f = 0.687 \pm 0.028 \pm 0.012$$
$$C_f = 0.024 \pm 0.020 \pm 0.016$$

sin 2β from b→s(qq̄) penguins

- In SM, penguin decay amplitude is dominant with same weak phase as b→s(cc̄) amplitude



- Suppressed b→s(qq) diagrams contribute (~0.01 - 0.1) to S, yielding:

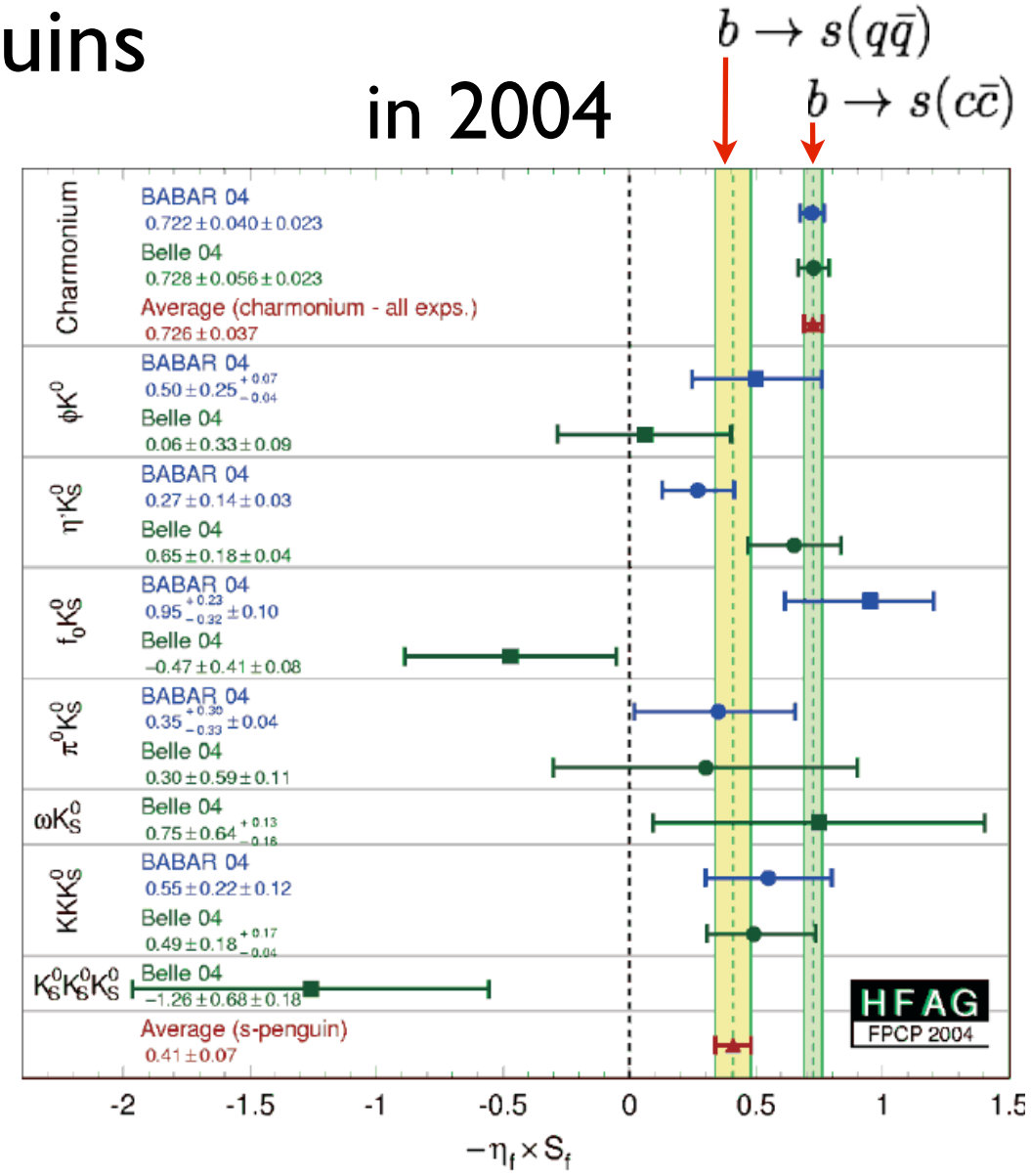
$$S_{sc\bar{c}} = S_{sq\bar{q}} + \Delta S_{SM} = -\eta_{CP} \sin 2\beta$$

- New Physics can give additional contributions to $S_{sq\bar{q}}$
- Definitions:

$$\Delta S = S_{sc\bar{c}} - S_{sq\bar{q}}$$

$$\sin 2\beta_{\text{eff}} = -\eta_{CP} S_{sq\bar{q}}$$

in 2004



Possible tension among s(qq) and s(cc) measurements

sin 2β from b→s(qq̄) penguins

- Much better agreement now. New sin 2β HFAG world averages:

$$c\bar{c}s : 0.68 \pm 0.02$$

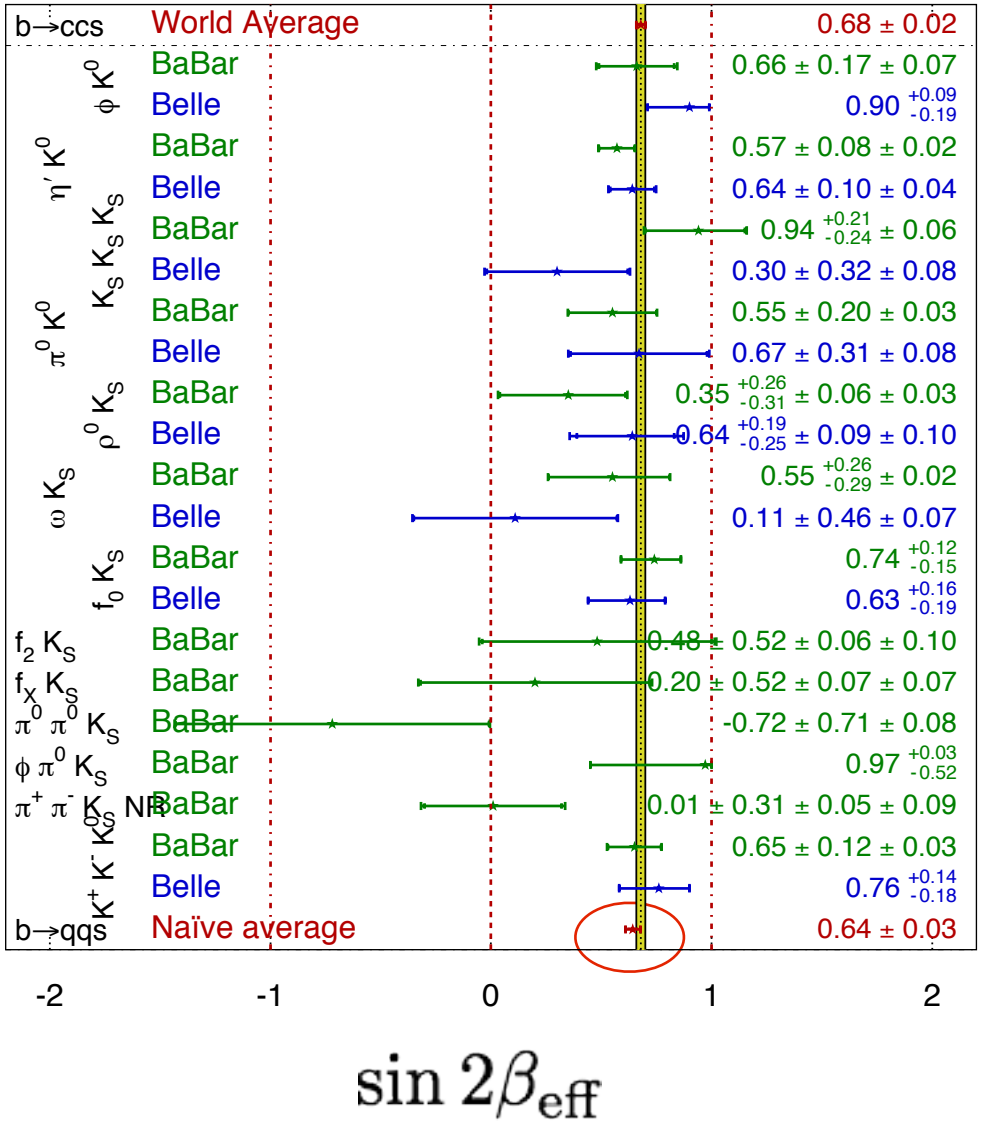
$$q\bar{q}s : 0.64 \pm 0.04$$ ←(naive average!)

- Improved value from cc̄s has come down (0.72 → 0.68)

- Several new and updated measurements have moved qq̄s value up

in 2012

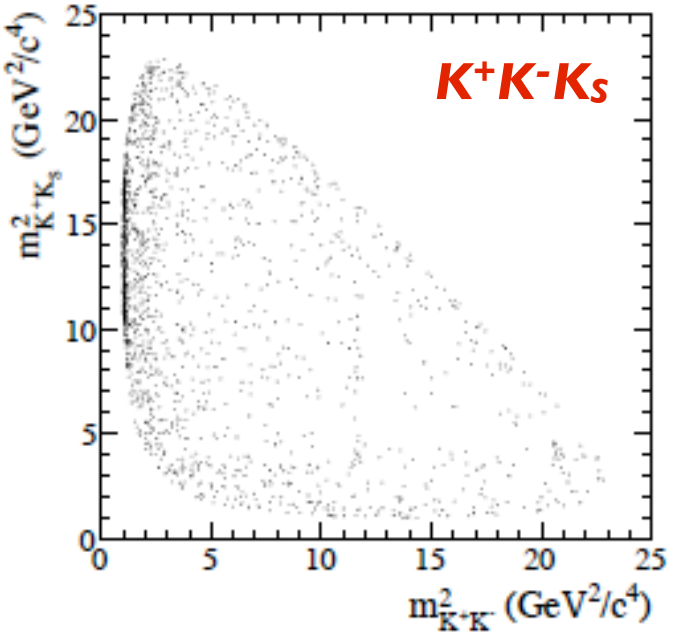
$\sin(2\beta^{\rm eff}) \equiv \sin(2\phi_1^{\rm eff})$ HFAG Moriond 2012 PRELIMINARY



sin 2β: $B^0 \to K^+K^-K_S$

PRD 85, 112010 (2012)

- Time-dependent asymmetry measurement
- Final state is a superposition of many resonant contributions
  - includes $B^0 \to \varphi K_S$ (small theoretical uncertainty)
- Perform combined Dalitz plot analysis to separate different CP eigenstates: $K^+K^-K^+$, $K^+K^-K_S$, $K^+K_SK_S$



Dalitz plot model

$A \sim \Sigma\, c_i\, F(m^2_{13}, m^2_{23})$ B decays

$\bar{A} \sim \Sigma\, \bar{c}_i\, F(m^2_{13}, m^2_{23})$ $\bar{B}$ decays

complex e.g. Breit-Wigner

$$\frac{d\Gamma}{ds_{12}\,ds_{23}\,d\Delta t} = \frac{1}{(2\pi)^3}\frac{1}{32 m^3_{B^0}}\frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}$$
$$\times[|\mathcal{A}|^2 + |\bar{\mathcal{A}}|^2 - Q(1-2w)(|\mathcal{A}|^2 - |\bar{\mathcal{A}}|^2)$$
$$\times \cos\Delta m_d \Delta t + Q(1-2w)$$
$$\times 2\,\mathrm{Im}[e^{-2i\beta}\,\bar{\mathcal{A}}\,\mathcal{A}^*]\sin\Delta m_d \Delta t],$$

sin 2β: $B^0 \to K^+K^-K_S$ results

PRD 85, 112010 (2012)

- N_{sig} = 1579±46 (18% purity)

$$BF = (25.4 \pm 0.9 \pm 0.8) \times 10^{-6}$$

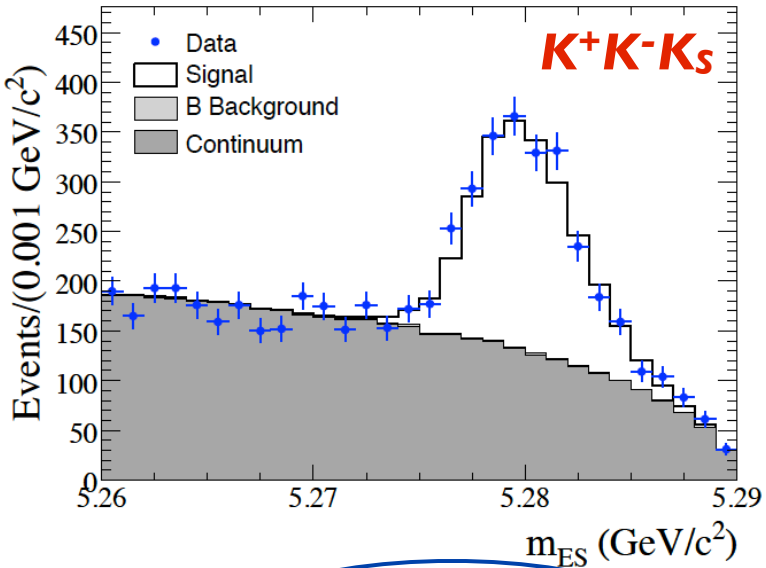
[excludes χ_{c0}K]

$$\beta_{\rm eff}(\phi K_s) = (21 \pm 6 \pm 2)^\circ$$

most precise

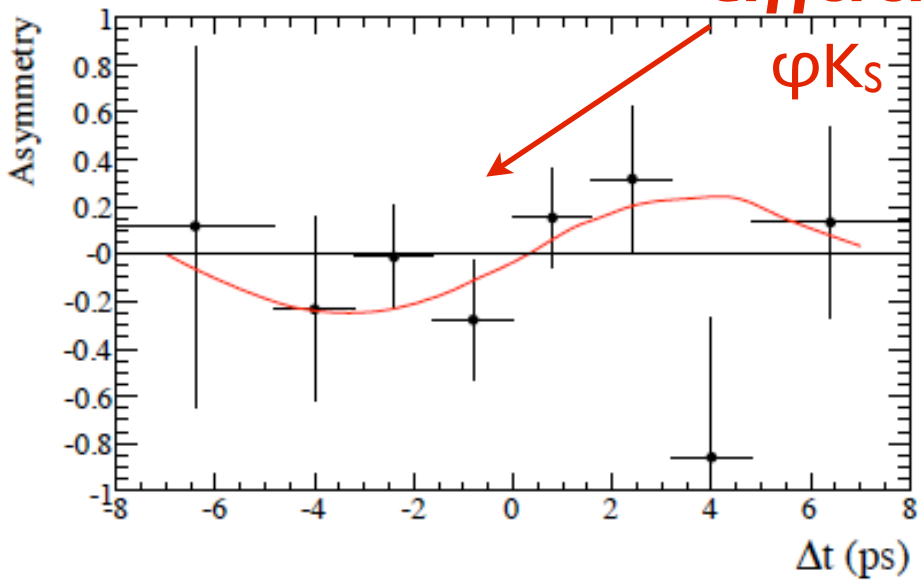
$$\beta_{\rm eff}(f_0 K_s) = (18 \pm 6 \pm 4)^\circ$$

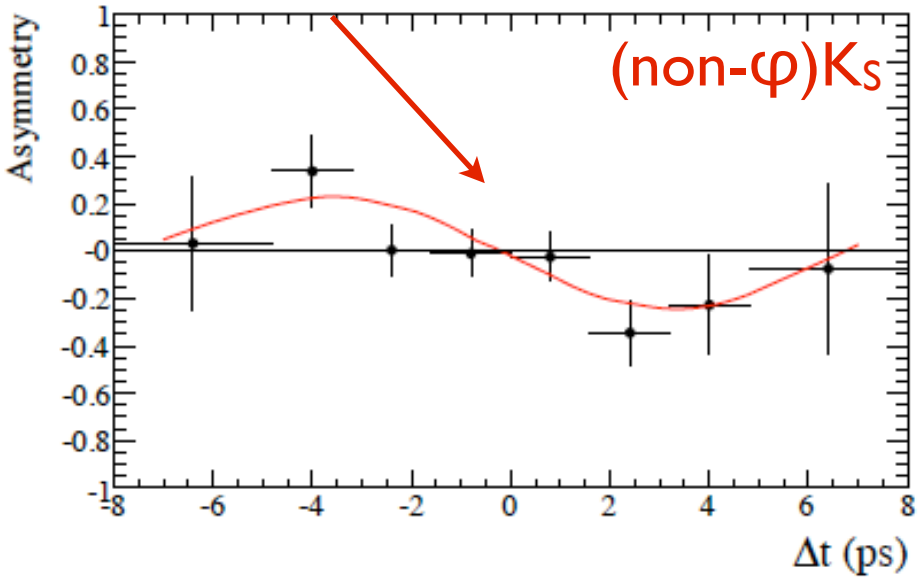
$$\beta_{\rm eff}(\text{non}-\phi, \text{non}-f_0) = (20.3 \pm 4.3 \pm 1.2)^\circ$$



90-$\beta_{\rm eff}$ excluded at 4.8σ (J/ψK_S ambiguity)

different CP content





γ, φ_3

Methods to measure γ using B→DK decays

- GGSZ (Dalitz plot method):
  - D^0 mesons reconstructed in 3-body decays $K_S\pi^+\pi^-$, $K_SK^+K^-$, $\pi^+\pi^-\pi^0$, etc. and Dalitz plot fitted to disentangle different CP-eigenstate contributions
- GLW:
  - D^0 mesons reconstructed in two-body CP eigenstates K^+K^-, $\pi^+\pi^-$ (CP-even), $K_S\pi^0$,$K_S\omega$ (CP-odd)
- ADS:
  - D^0 mesons reconstructed in doubly Cabibbo suppressed decays $K^+\pi^-$, $K^+\pi^-\pi^0$, ...

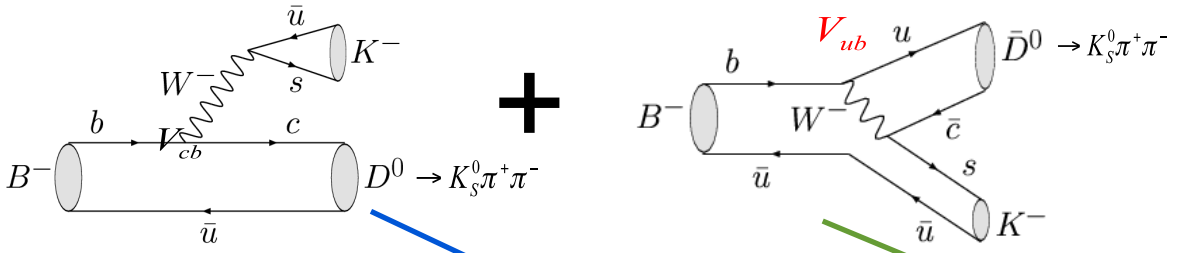
← not today

- Exploit several B decays: $D^0K^\pm$, $D^{*0}K^\pm$, $D^0K^{*\pm}$. They depend on different hadronic factors (r_b,δ_b).
- Combine results from all methods to obtain most precise determination of γ

GGSZ (Dalitz) method

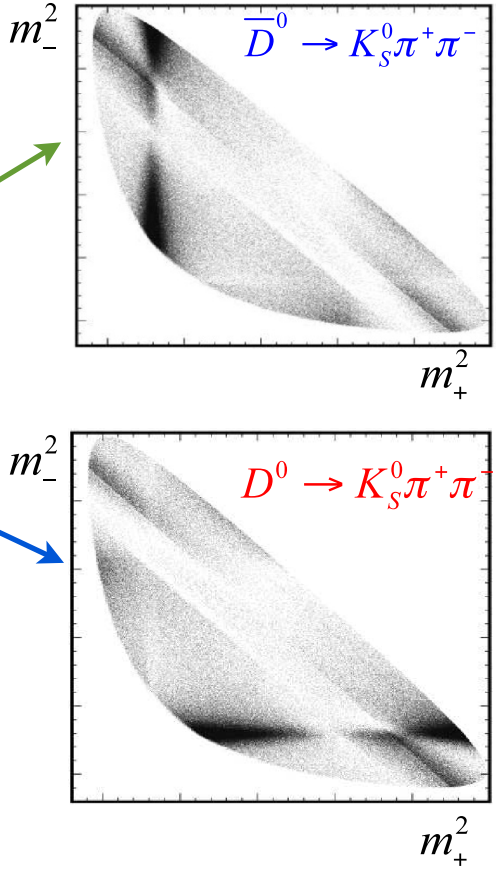
D. Atwood et al., PRL78, 3257 (1997);
A. Giri et al., PRD68, 054018 (2003)

- Interference between two amplitudes varies with position in Dalitz plot



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

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



- $A_D(m_-^2,m_+^2)$ determined from Dalitz plot analysis on high-statistics samples of tagged D^0 and $\underline{D}^0$ decays
- B^+ and B^- yields determined as fcn of Dalitz plot position
- Unknowns: γ, r_B and δ_B. In cartesian coordinates:

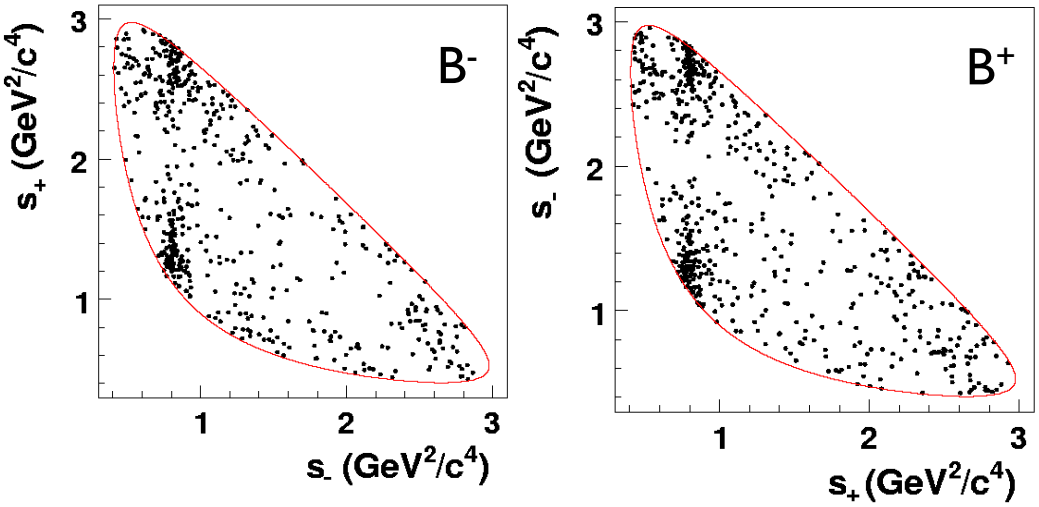
Gaussian-distributed variables

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

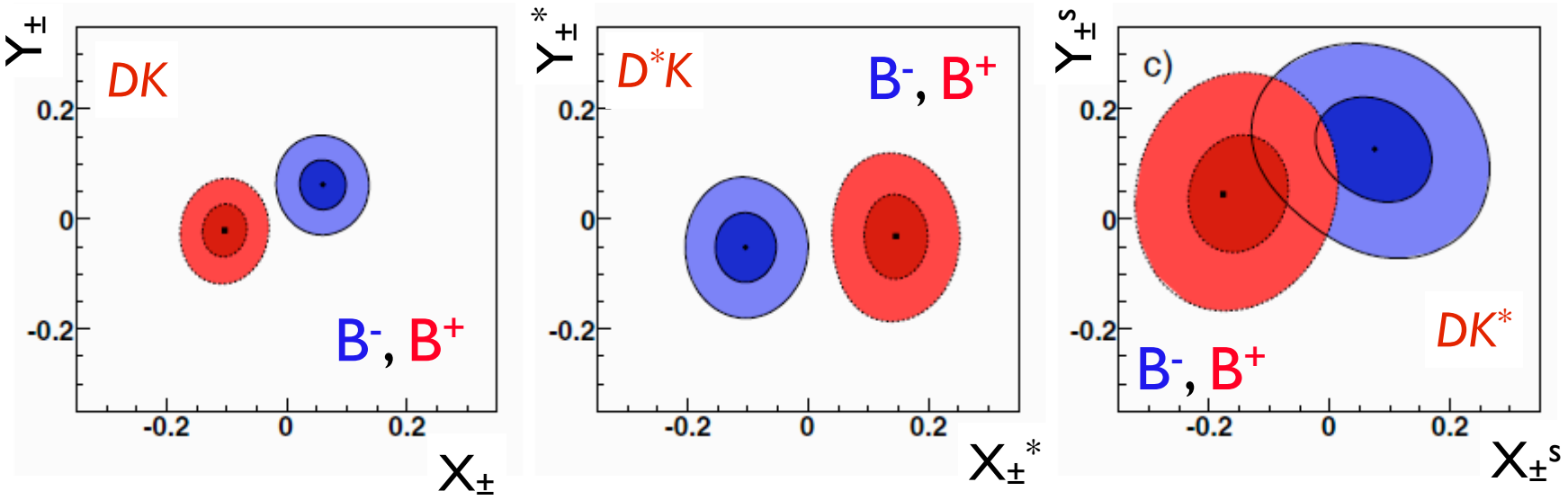
$$z_\pm \equiv x_\pm + iy_\pm$$

GGSZ results: Babar PRL 105, 121801 (2010)

- Isobar Dalitz plot model



		Real part (%)	Imaginary part (%)
DK	z_-	$6.0 \pm 3.9 \pm 0.7 \pm 0.6$	$6.2 \pm 4.5 \pm 0.4 \pm 0.6$
	z_+	$-10.3 \pm 3.7 \pm 0.6 \pm 0.7$	$-2.1 \pm 4.8 \pm 0.4 \pm 0.9$
D^*K	z^*_-	$-10.4 \pm 5.1 \pm 1.9 \pm 0.2$	$-5.2 \pm 6.3 \pm 0.9 \pm 0.7$
	z^*_+	$14.7 \pm 5.3 \pm 1.7 \pm 0.3$	$-3.2 \pm 7.7 \pm 0.8 \pm 0.6$
DK^*	z_{s-}	$7.5 \pm 9.6 \pm 2.9 \pm 0.7$	$12.7 \pm 9.5 \pm 2.7 \pm 0.6$
	z_{s+}	$-15.1 \pm 8.3 \pm 2.9 \pm 0.6$	$4.5 \pm 10.6 \pm 3.6 \pm 0.8$



GGSZ results: Belle

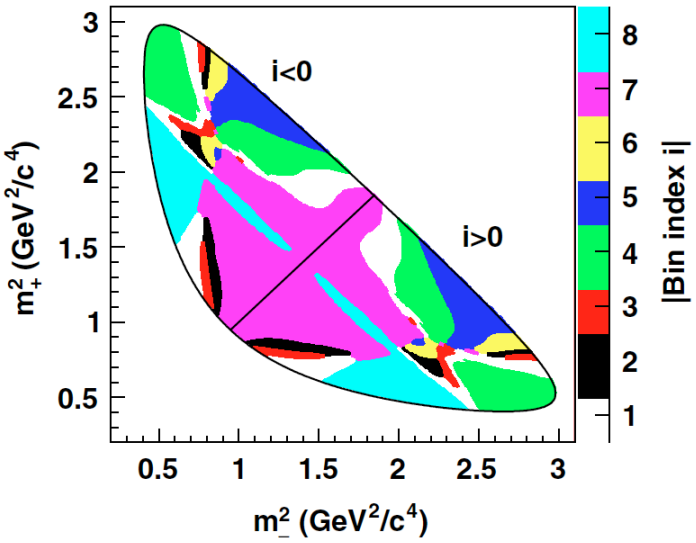
PRD 85, 11204 (2012)

Bondar, PoluetkovEPJ C55, 51(2008)

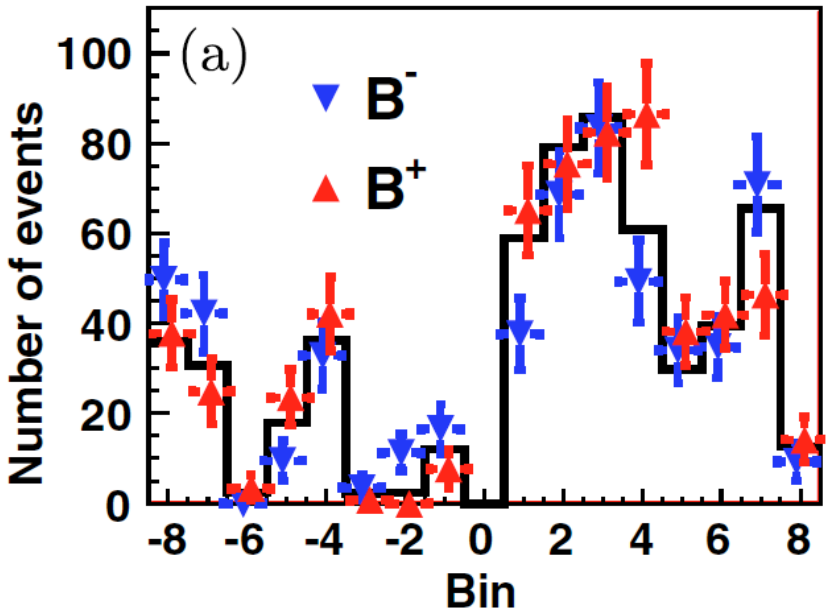
- Model-independent technique: avoid Dalitz plot model error by symmetrically binning the Dalitz plane
- Expected number of events in each bin, i:

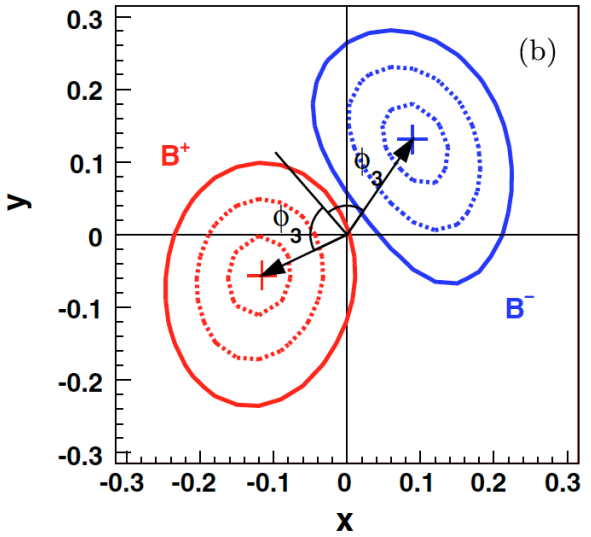
$$N_i^{\pm} = hK_i + r_B^2 K_{-i} + 2\sqrt{K_i K_{-i}}(x_{\pm}c_i + y_{\pm}s_i)$$

  - K_i # events in bin i from flavour-tagged sample $D^{*\pm} \to D\pi^{\pm}$
  - c_i and s_i related to strong phase in bin i: obtained from CLEO threshold data



Signal yield in Dalitz bins





$$\gamma = (77.3\ ^{+15.1}_{-14.9} \pm 4.1 \pm 4.3)^\circ$$

$$r_B = 0.145 \pm 0.030 \pm 0.010 \pm 0.011$$

$$\delta_B = (129.9 \pm 15.0 \pm 3.8 \pm 4.7)^\circ$$

GLW Method

M. Gronau, D. London, D. Wyler, PLB253,483 (1991); PLB 265, 172 (1991)

- Measure D^0 into CP-eigenstates: K^+K^-, $\pi^+\pi^-$ (CP+) and $K_S\pi^0$, $K_S\omega$ and $K_S\varphi$ (CP-)
- Observables:

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

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

4 observables (3 independent); 3 unknowns

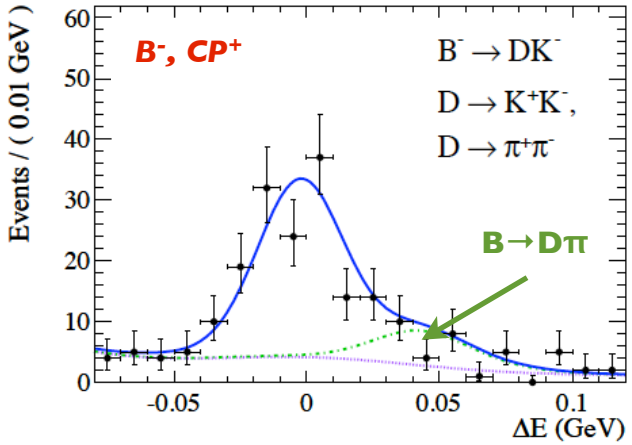
- GLW in cartesian coordinates:

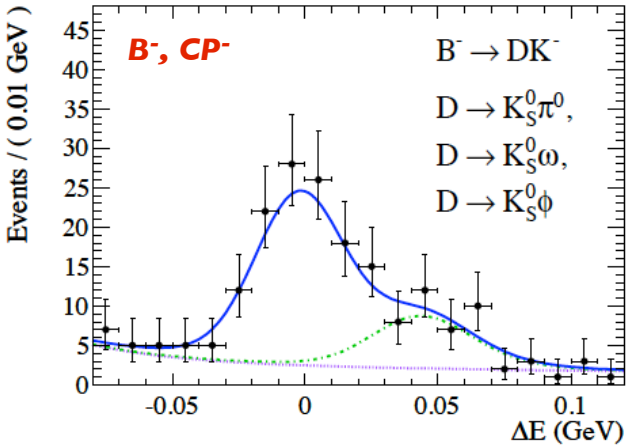
$$A^{(*)}_{CP\pm} = \pm \frac{x^{(*)}_- - x^{(*)}_+}{1 + |z^{(*)}|^2 \pm (x^{(*)}_- + x^{(*)}_+)}, \qquad R^{(*)}_{CP\pm} = 1 + |z^{(*)}|^2 \pm (x^{(*)}_- + x^{(*)}_+)$$

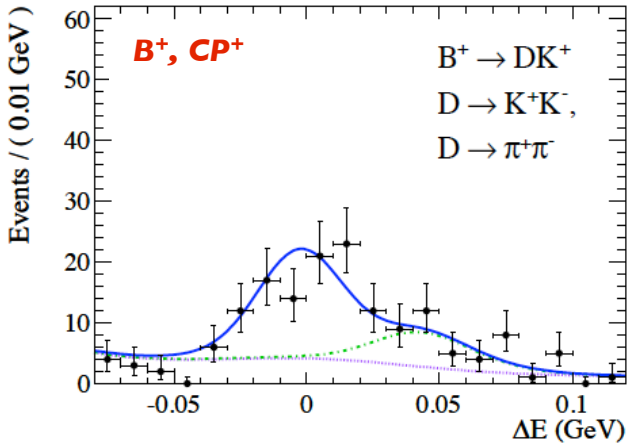
- GLW method not sensitive to $y_\pm$

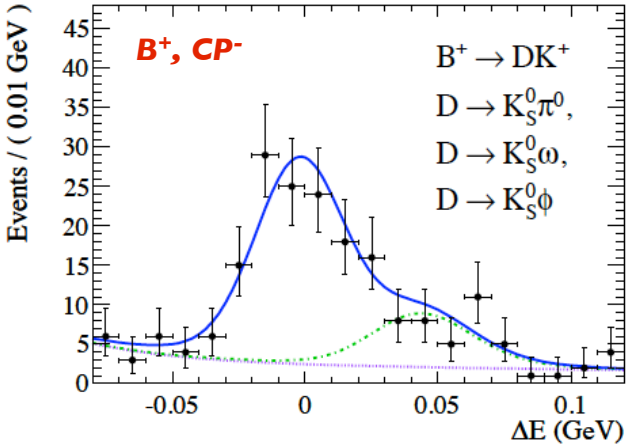
Babar: GLW results with B→DK

PRD 82 072004 (2010)









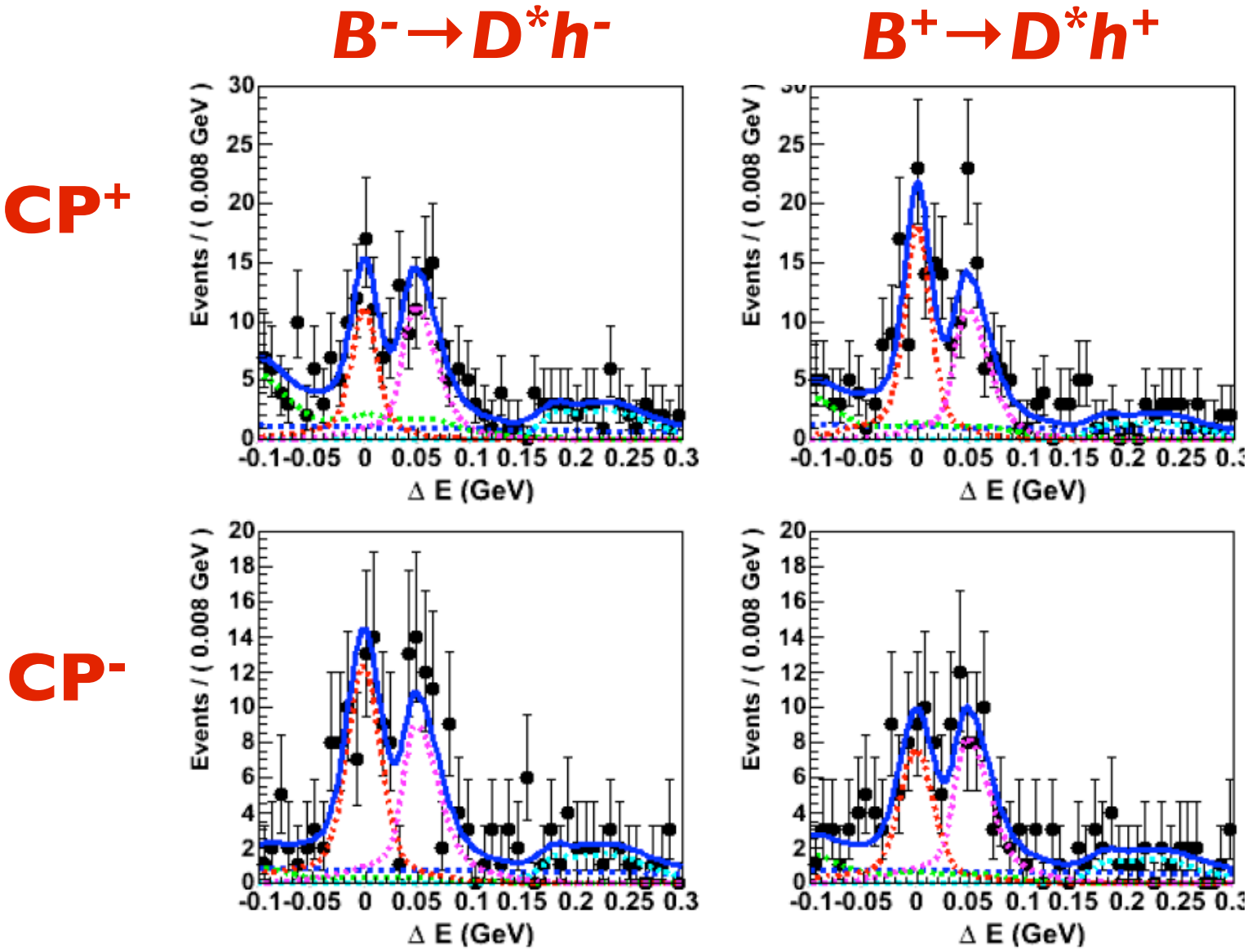
Event yields

D^0 mode	$N(B^\pm \to DK^\pm)$
K^+K^-	367 ± 27
$\pi^+\pi^-$	110 ± 9
$K^0_S\pi^0$	338 ± 24
$K^0_S\omega$	116 ± 9
$K^0_S\phi$	52 ± 4
$K^-\pi^+$	3361 ± 82

$$
\begin{aligned}
A_{CP+} &= 0.25 \pm 0.06(\text{stat}) \pm 0.02(\text{syst}) \\
A_{CP-} &= -0.09 \pm 0.07(\text{stat}) \pm 0.02(\text{syst}) \\
R_{CP+} &= 1.18 \pm 0.09(\text{stat}) \pm 0.05(\text{syst}) \\
R_{CP-} &= 1.07 \pm 0.08(\text{stat}) \pm 0.04(\text{syst})
\end{aligned}
$$

Belle: GLW results with $B \to D^* K$

preliminary



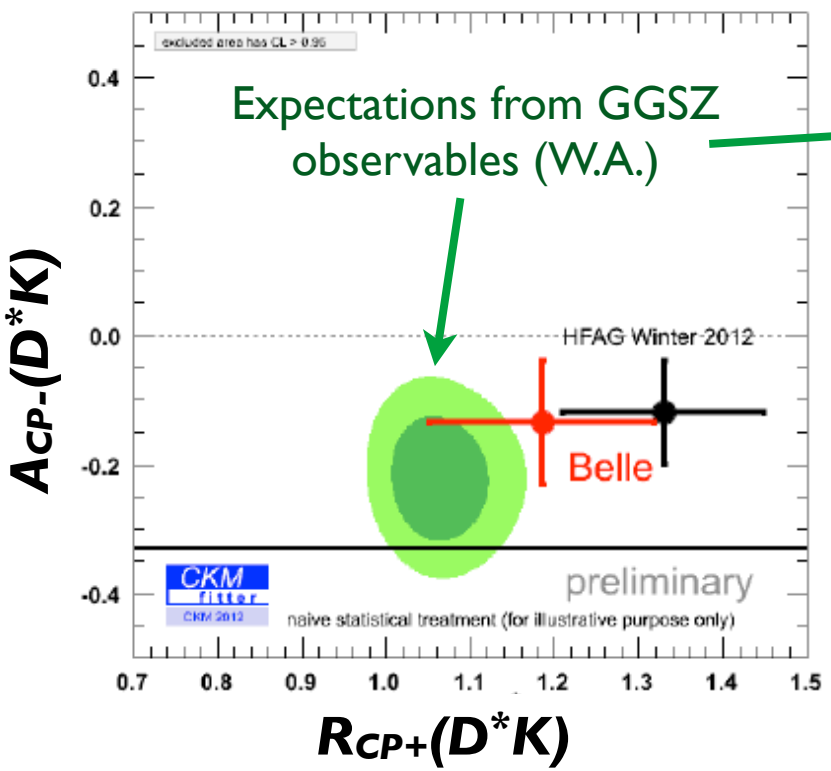
Belle: GLW results with $B \to D^*K$

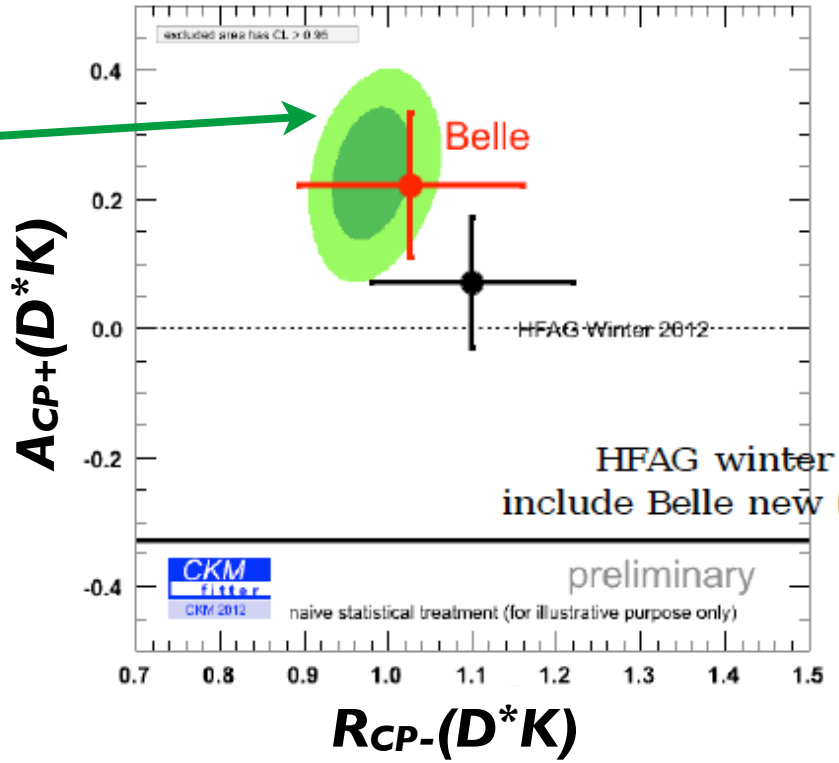
preliminary

$$R_{CP+} = 1.19 \pm 0.13 \pm 0.03$$
$$R_{CP-} = 1.03 \pm 0.13 \pm 0.03$$
$$A_{CP+} = -0.14 \pm 0.10 \pm 0.01$$
$$A_{CP-} = +0.22 \pm 0.11 \pm 0.01$$

Combined results from

$$D^{*0} \to D^0\pi^0, D^0\gamma$$



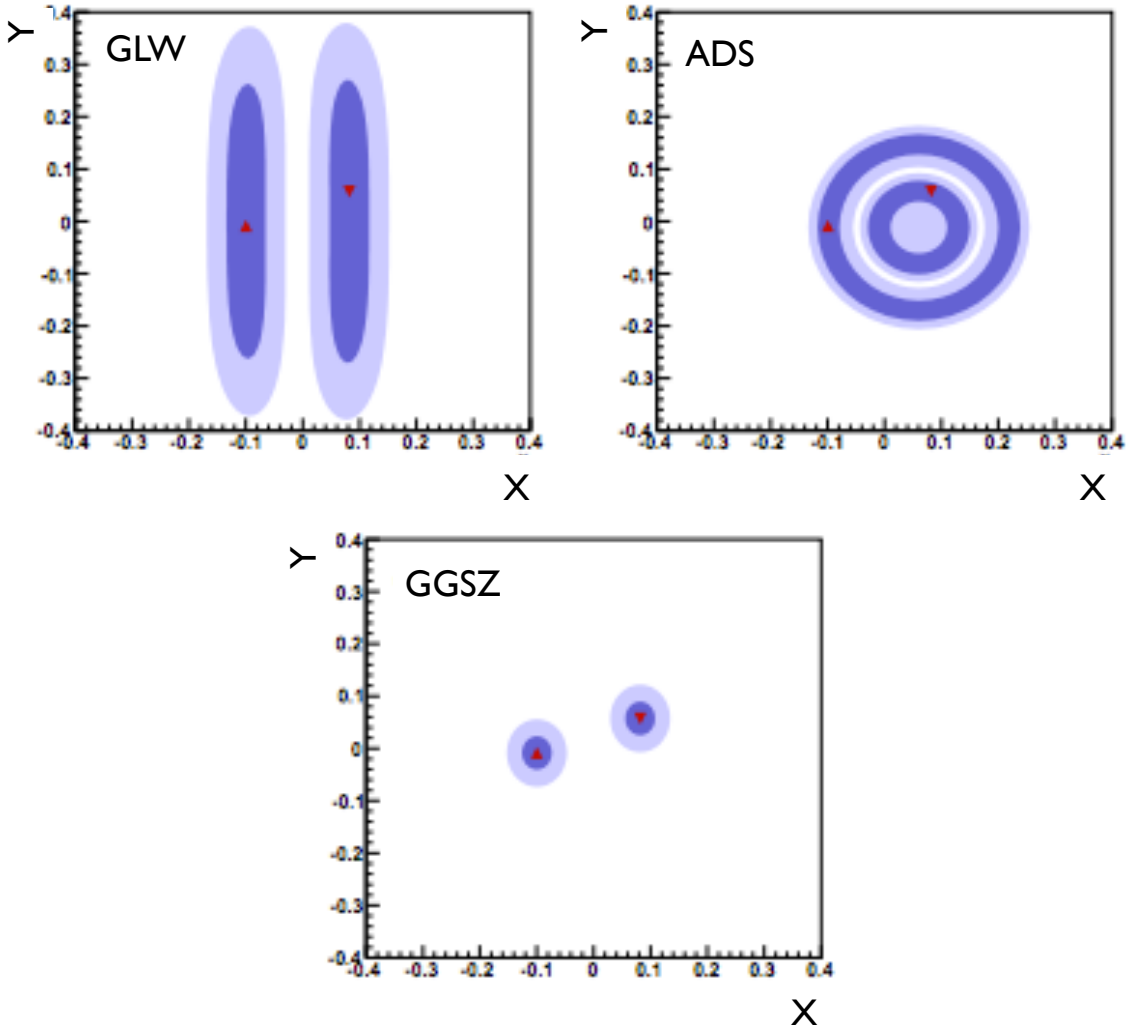


HFAG winter 2012 doesn't include Belle new (GLW D^*K) results

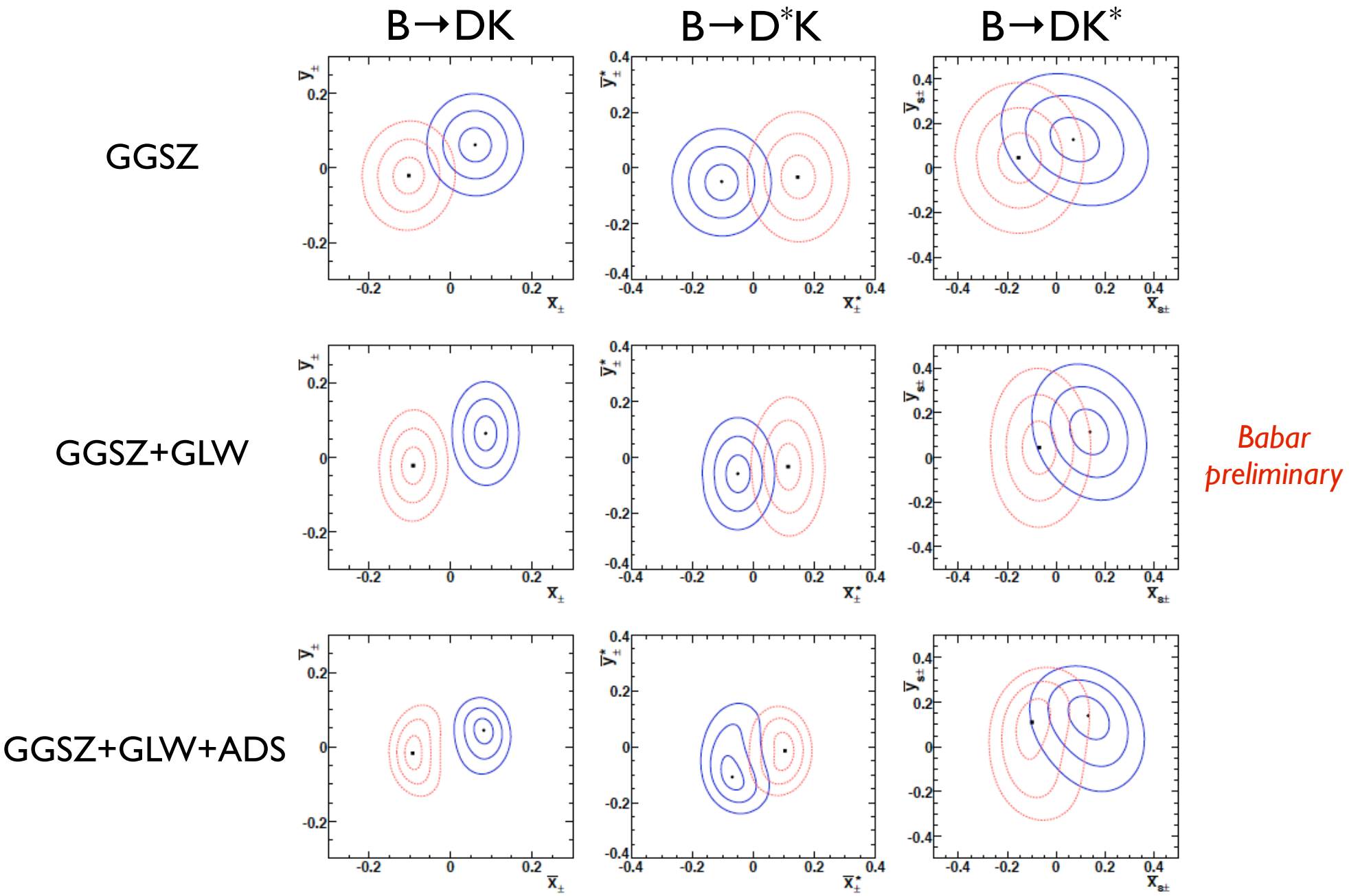
Combining γ results

- Express GLW and ADS results in cartesian coordinates
- Parametrize likelihood shapes (Gaussian) w/ syst. errors
- Maximize global LH → product of partial PDFs
  - 18 fit parameters
  - 39 input observables
- Finally, transform to polar coordinates: $\{\gamma, r_b, \delta_b\}$

Constraints from different methods



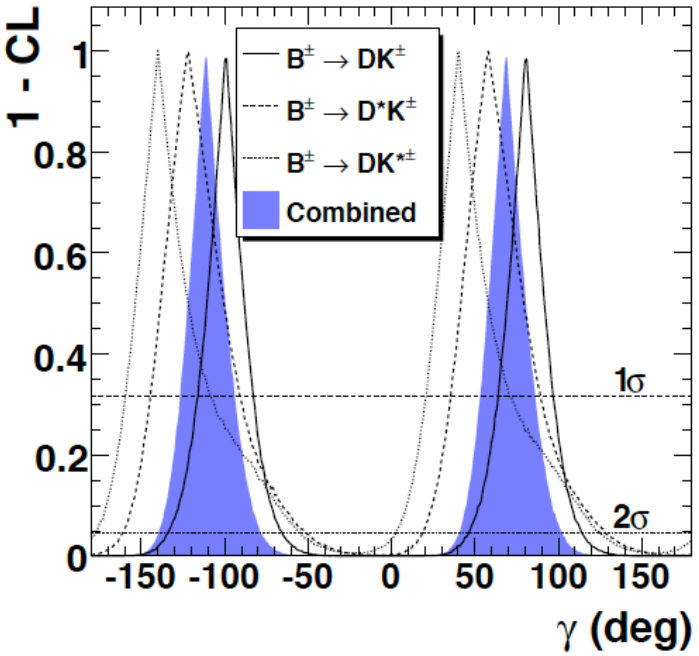
Combination of cartesian coordinates



γ combined

BaBar

Parameter	68.3% C.L.		95.5% C.L.	
	Combination	GGSZ	Combination	GGSZ
γ (°)	69^{+17}_{-16}	68^{+15}_{-14}	[41, 102]	[39, 98]
r_B (%)	$9.2^{+1.3}_{-1.2}$	9.6 ± 2.9	[6.0, 12.6]	[3.7, 15.5]
r_B^* (%)	$10.6^{+1.9}_{-3.6}$	$13.3^{+4.2}_{-3.9}$	[3.0, 14.7]	[4.9, 21.5]
κr_s (%)	$14.3^{+4.8}_{-4.9}$	$14.9^{+6.6}_{-6.2}$	[3.3, 25.1]	< 28.0
δ_B (°)	105^{+16}_{-17}	119^{+19}_{-20}	[72, 139]	[75, 157]
δ_B^* (°)	-66^{+21}_{-31}	-82 ± 21	$[-132, -26]$	$[-124, -38]$
δ_s (°)	101 ± 43	111 ± 32	[32, 166]	[42, 178]



Belle

GGSZ

$\gamma = [82\ ^{+18}_{-23}]^\circ$

GGSZ+ADS

$\gamma = [70\ ^{+37}_{-24}]^\circ$

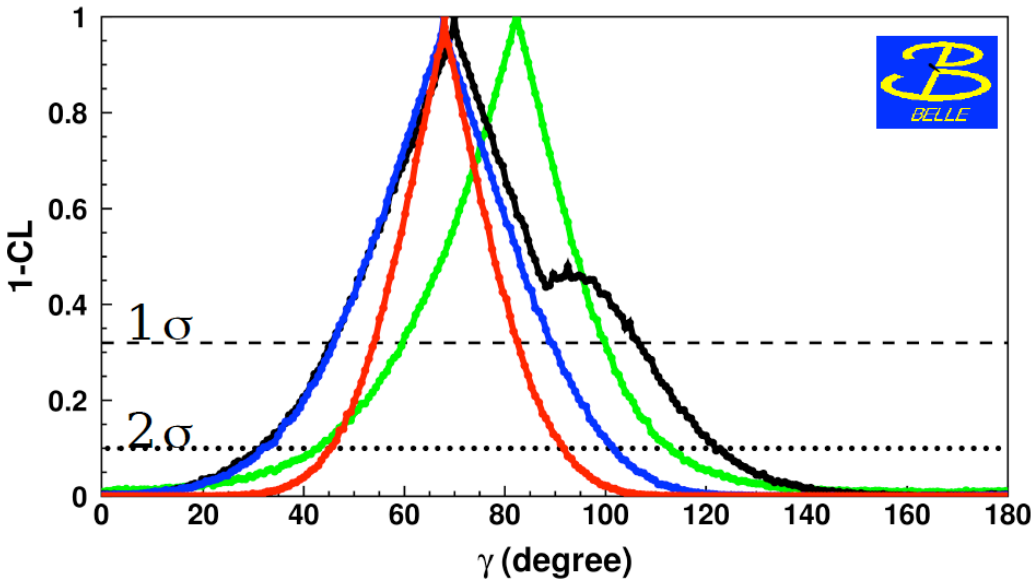
GGSZ+ADS+δ_D

$\gamma = [68 \pm 22]^\circ$

GGSZ+ADS+GLW+δ_D

$\gamma = [68\ ^{+15}_{-14}]^\circ$

$(2\sigma = ^{+28^\circ}_{-27})$



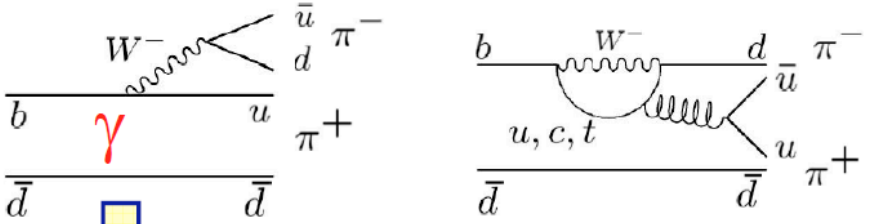
α, φ_2

α from B→ππ

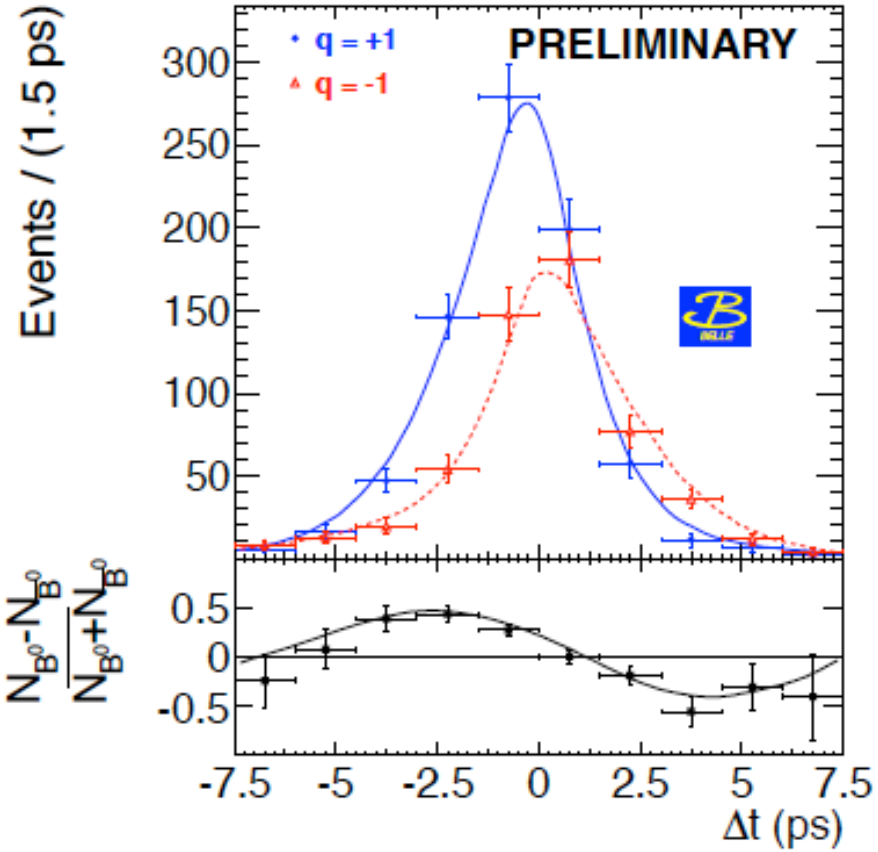
- Measure α_{eff} with via time-dependent CP asymmetry of $B^0 \to \pi^+\pi^-$
- Use isospin analysis to determine α
  - measure all B→ππ rates

Two sizeable amplitudes (P/T ~ 0.3) :

b → u "tree" b → d "penguin"

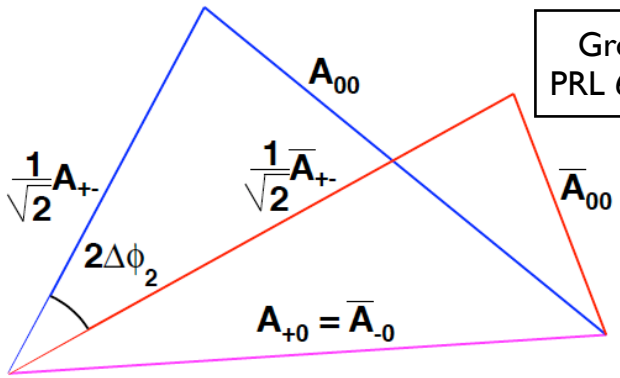


$$\underbrace{e^{+i2\beta}}_{\text{mixing}}\underbrace{e^{+i2\gamma}}_{\text{decay}} = e^{-2i\alpha}$$



$$S_{\pi\pi} \propto \sin 2\alpha_{eff} = \sin 2(\alpha + \delta)$$

Gronau, London
PRL 65, 3381 (1990)



$$S_{CP}^{\pi^+\pi^-} = -0.636 \pm 0.082 \pm 0.027$$

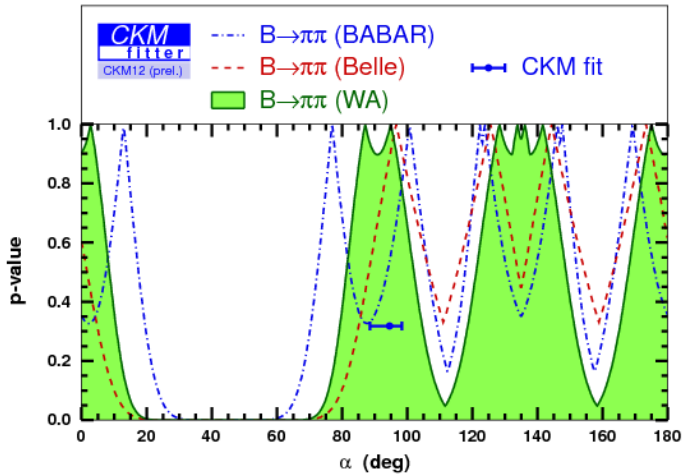
$$\mathcal{A}_{CP}^{\pi^+\pi^-} = +0.328 \pm 0.061 \pm 0.027$$

BELLE

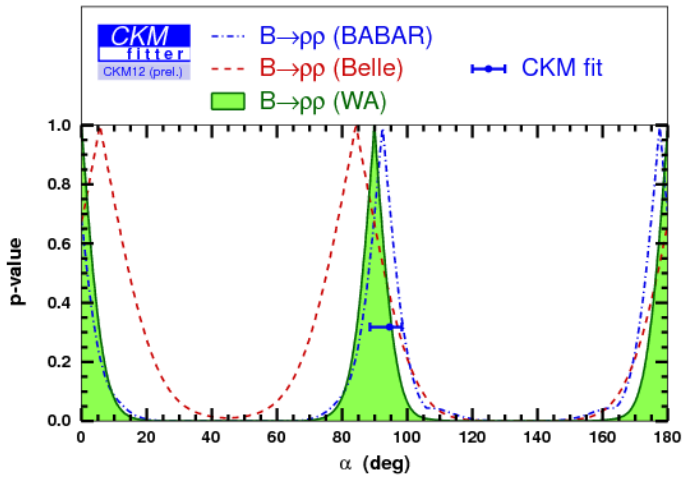
Combined α results

- Other penguin modes provide constraints on α, especially B→ρρ

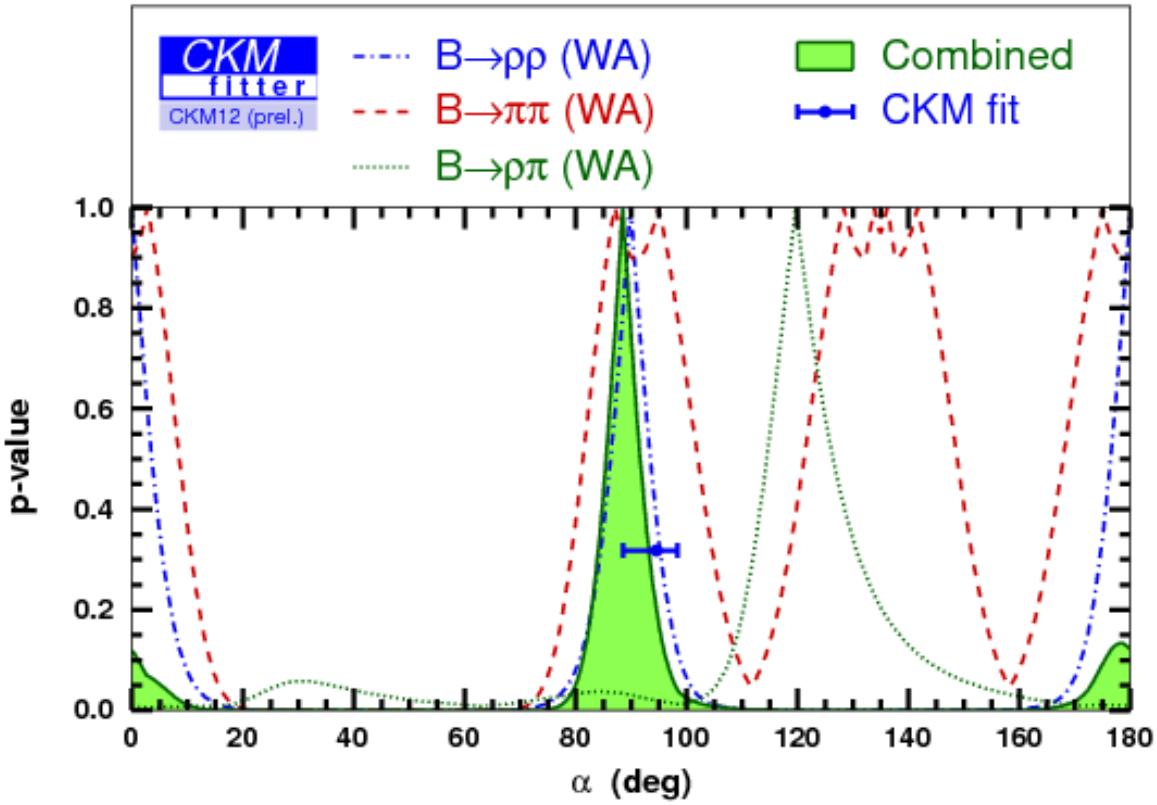
B→ππ



B→ρρ



Combined

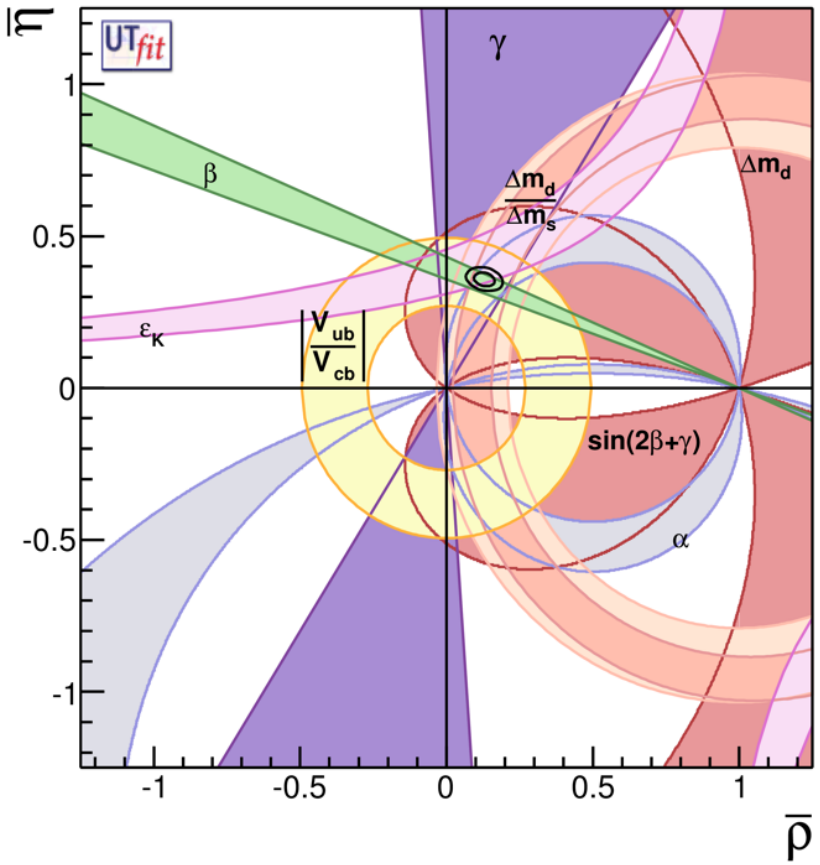


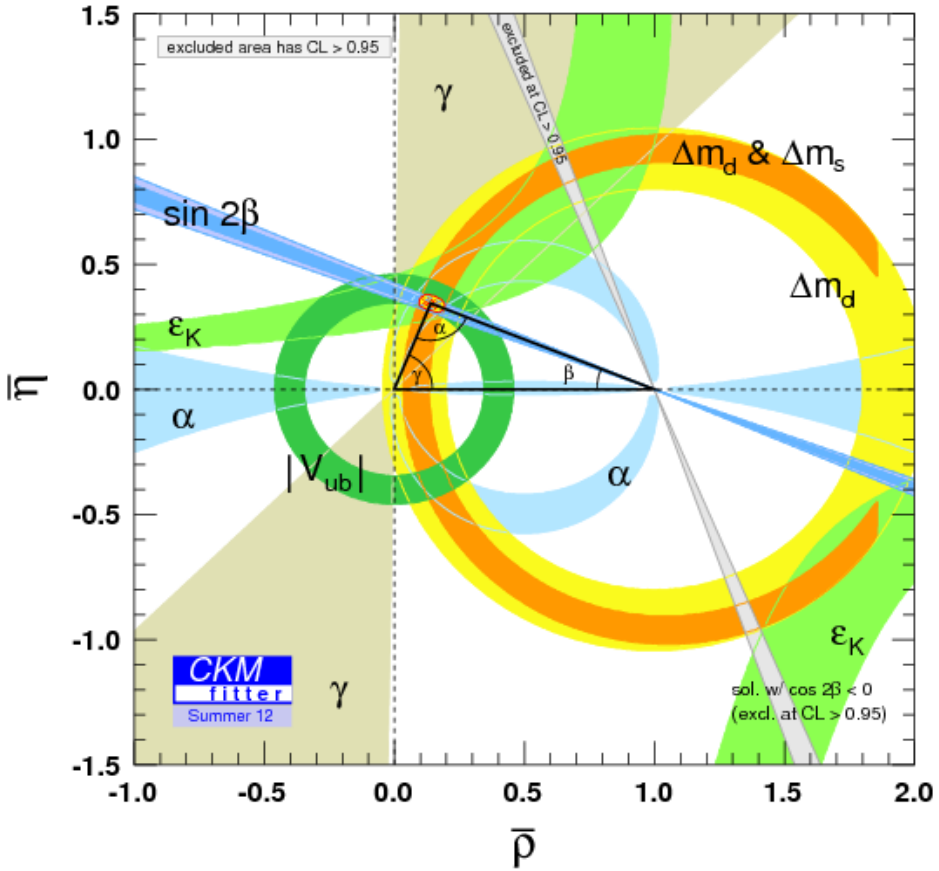
$$\alpha = (88.7^{+4.6}_{-4.2})^{\circ}$$ *(CKMFitter)*

Global CKM results

Global CKM fits

- B factory goals included over-constraining CKM matrix with many measurements
- CKMFitter [ckmfitter.in2p3.fr] and UTFit [www.utfit.org] both perform global fits, combining many flavour inputs to constrain the CKM matrix





Numerical results

- ***Experimental values for the 3 angles***
- Tabulated by UTFit and HFAG groups
- Uncertainties symmetrized for presentation

	Measured value
β [°]	(21.5 or 68.5) ± 0.8
α [°]	91.4 ± 6.1
γ [°]	(-103.8 or 75.5) ± 10.5

- ***Global CKM fits***
- Many flavour-related measurements used, including from hadron colliders and kaon experiments
- Assumes UT paradigm, hence $\alpha + \beta + \gamma = 180°$

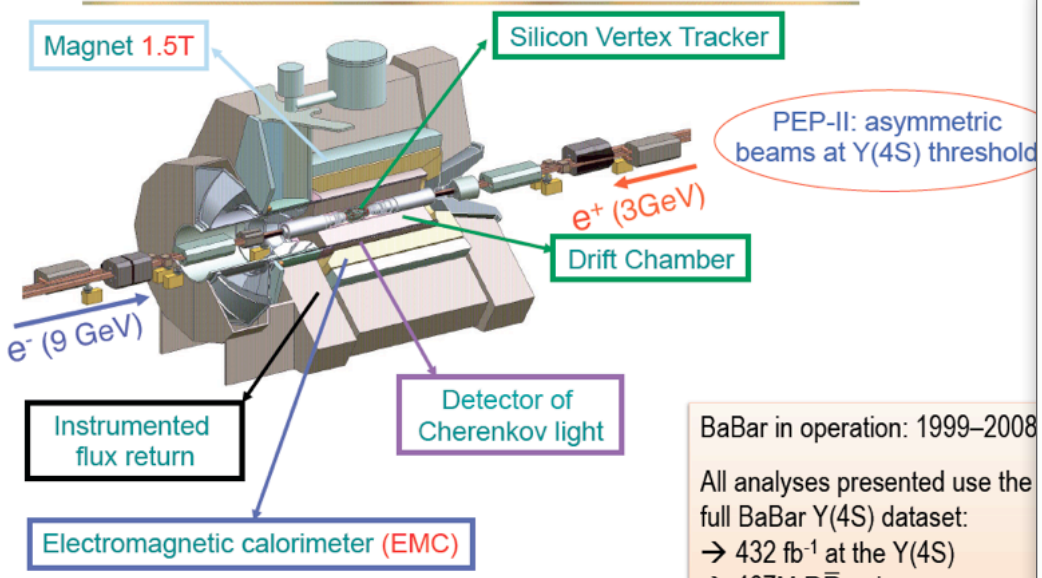
	CKMFitter	UTFit
β [°]	21.73 ± 0.76	22.28 ± 0.92
α [°]	90.5 ± 4.2	89.1 ± 3.0
γ [°]	67.7 ± 4.2	68.5 ± 3.1
$\underline{\rho}$	0.140 ± 0.027	0.139 ± 0.021
$\underline{\eta}$	0.343 ± 0.015	0.352 ± 0.016

Concluding remarks

- Measurements of CP violation have been at the core of the B-factories' physics programs since their inception
- A large number of independent measurements have yielded very good measurements of the Unitarity Triangle
- The CKM mechanism for CP violation in the Standard Model has been essentially verified by these measurements
- Additional CPV measurements all rolling in from LHCb and many more will come from future flavour experiments

Backup slides

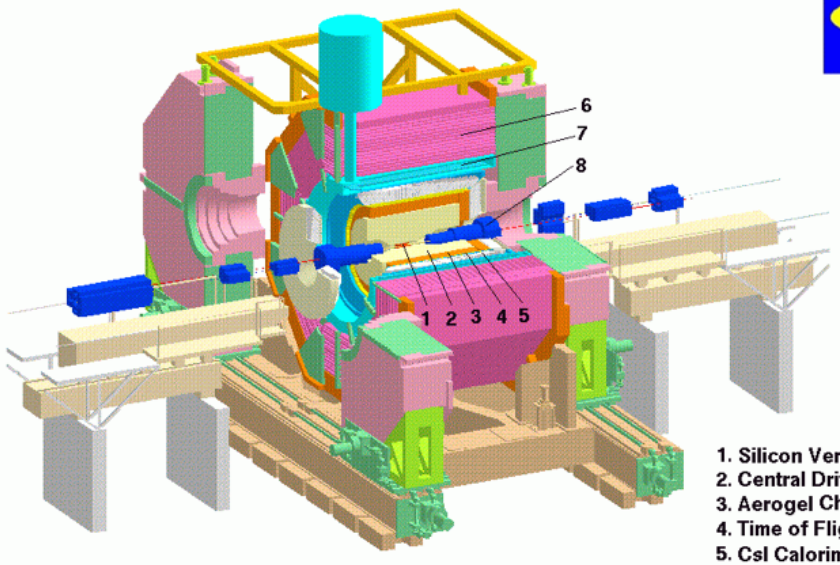
The BaBar detector and dataset



BaBar in operation: 1999–2008

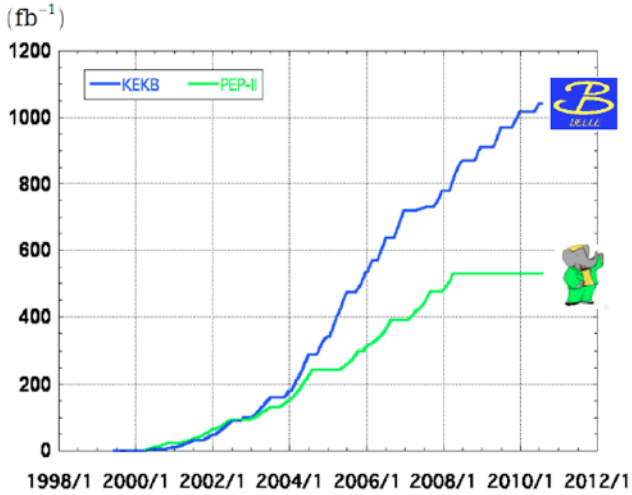
All analyses presented use the full BaBar Y(4S) dataset:
→ 432 fb^{-1} at the Y(4S)
→ 467M B$\bar{B}$ pairs

BELLE Detector



1. Silicon Vertex Detector
2. Central Drift Chamber
3. Aerogel Cherenkov Counter
4. Time of Flight Counter
5. CsI Calorimeter
6. KLM Detector
7. Superconducting Solenoid
8. Superconducting Final Focussing System

Integrated luminosity of B factories



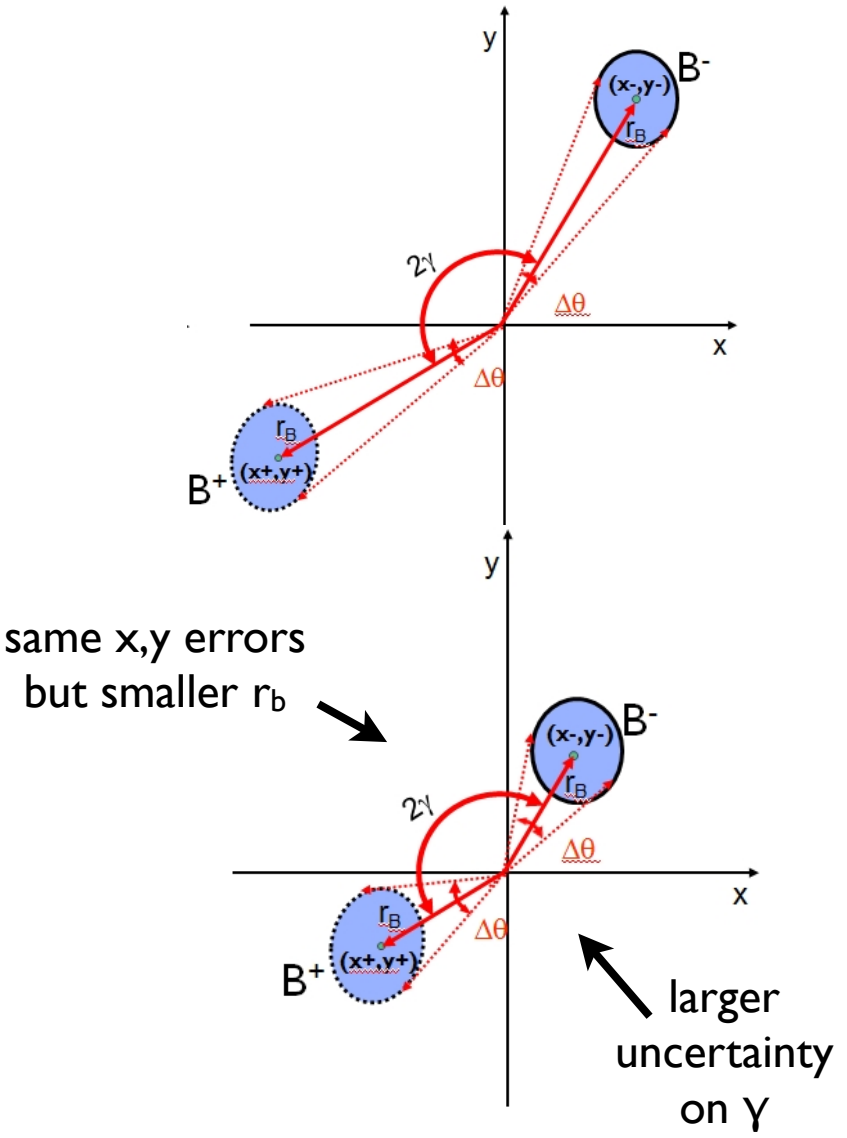
> 1 ab^{-1}
On resonance:
Υ(5S): 121 fb^{-1}
Υ(4S): 711 fb^{-1} 772M B$\bar{B}$
Υ(3S): 3 fb^{-1}
Υ(2S): 25 fb^{-1}
Υ(1S): 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
Υ(4S): 433 fb^{-1} 470M B$\bar{B}$
Υ(3S): 30 fb^{-1}
Υ(2S): 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

In total, more than 1G B$\bar{B}$ pairs are recorded at B-factories and used to measure angles.

Dependence of γ uncertainty on r_b

- Statistical uncertainty on γ scales approximately as $1/r_b$
- Babar γ combination procedure leads to slight reduction of r_b, compared to GGSZ value
- Combination doesn't improve γ uncertainty (for Babar)



ADS method

D. Atwood, I. Dunietz, A. Soni, PRL 78, 3357 (1997)

- Exploit suppressed D^0 decays: $D^0 \to K^+\pi^-, K^+\pi^-\pi^0, K^+\pi^-\pi^+\pi^-$

favoured **suppressed**

$$B^+ \to D^{(*)0}K^{(*)+} \quad + \quad D^0 \to f$$

suppressed **favoured**

$$B^+ \to \bar{D}^{(*)0}K^{(*)+} \quad + \quad \bar{D}^0 \to f$$

Identical final state
O(1) interference

- ADS observables:

$$R_\pm^{(*)} \equiv \frac{\Gamma(B^\pm \to [K^\mp\pi^\pm]_D^{(*)}K^\pm)}{\Gamma(B^\pm \to [K^\pm\pi^\mp]_D^{(*)}K^\pm)}$$

$$R_\pm^{(*)} = {r_{B^\pm}^{(*)}}^2 + r_D^2 + 2(\lambda)r_D\left[x_\pm^{(*)}\cos\delta_D - y_\pm^{(*)}\sin\delta_D\right]$$

where:

$$r_D = \left|\frac{A(\bar{D}^0 \to f)}{A(D^0 \to f)}\right| \quad \text{and} \quad \delta_D = \arg\left[\frac{A(\bar{D}^0 \to f)}{A(D^0 \to f)}\right]$$

$$r_D(K^+\pi^-) = 0.06$$

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suppressed **favoured**

$$B^+ \to \bar{D}^{(*)0}K^{(*)+} \quad + \quad \bar{D}^0 \to f$$

Identical final state
O(1) interference

- ADS observables:

$$\mathcal{R}_{DK} \equiv \frac{\mathcal{B}([K^+\pi^-]_D K^-) + \mathcal{B}([K^-\pi^+]_D K^+)}{\mathcal{B}([K^-\pi^+]_D K^-) + \mathcal{B}([K^+\pi^-]_D K^+)}$$

$$\mathcal{A}_{DK} \equiv \frac{\mathcal{B}([K^+\pi^-]_D K^-) - \mathcal{B}([K^-\pi^+]_D K^+)}{\mathcal{B}([K^+\pi^-]_D K^-) + \mathcal{B}([K^-\pi^+]_D K^+)}$$

$$\mathcal{R}_{DK} = r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D)\cos\phi_3$$

$$\mathcal{A}_{DK} = 2r_B r_D \sin(\delta_B + \delta_D)\sin\phi_3/\mathcal{R}_{DK},$$

where:

$$r_D = \left|\frac{A(\bar{D}^0 \to f)}{A(D^0 \to f)}\right| \quad \text{and} \quad \delta_D = \arg\left[\frac{A(\bar{D}^0 \to f)}{A(D^0 \to f)}\right]$$

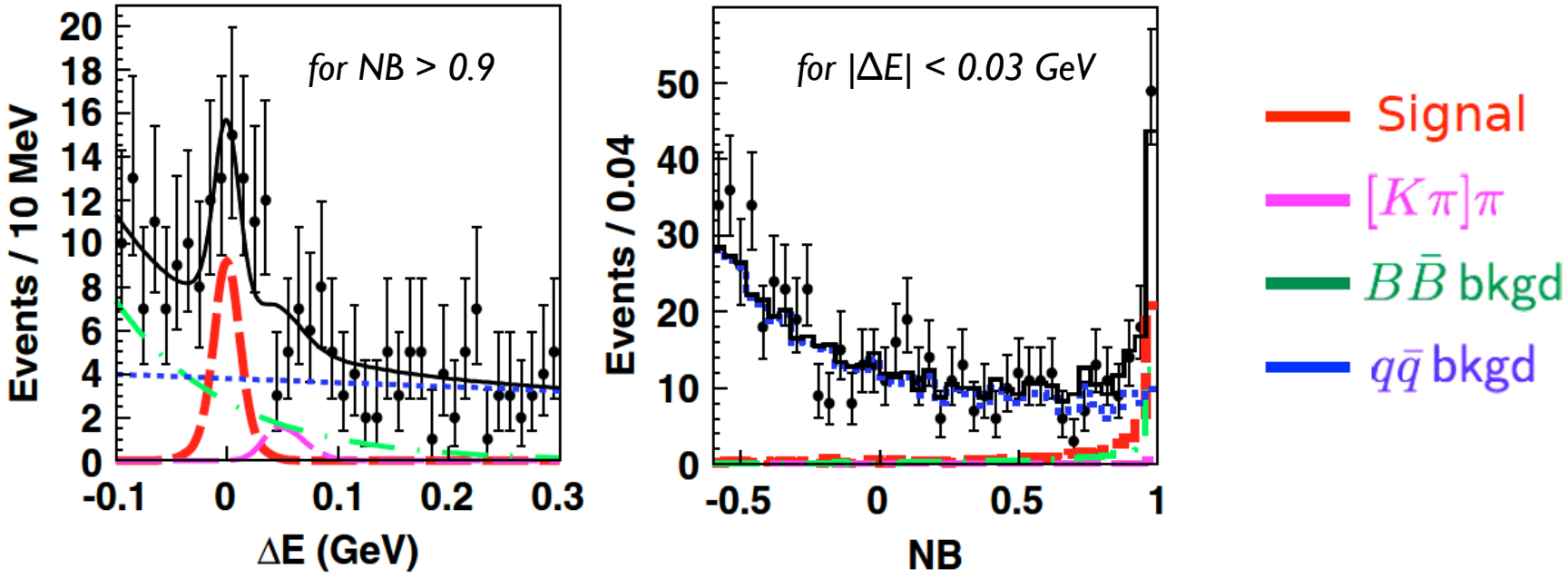
$$r_D(K^+\pi^-) = 0.06$$

ADS: Belle results on $B^- \to [K^+\pi^-]_D K^-$

PRL 106, 231803 (2011)

- Use neural net selector (NB) to reduce large continuum background – 10 input variables
- Simultaneous Fit to ΔE and neural net distributions
- Statistical significance of 4.1σ, including systematics

$$56.0^{+15.1}_{-14.2} \text{ events}$$

$$R_{DK} = (1.63^{+0.44\,+0.07}_{-0.41\,-0.13}) \times 10^{-2}$$

$$A_{DK} = -0.39^{+0.26\,+0.04}_{-0.28\,-0.03}$$