Aspen 2004 Winter Conference on Particle Physics

New results on CP violation from *BABAR*

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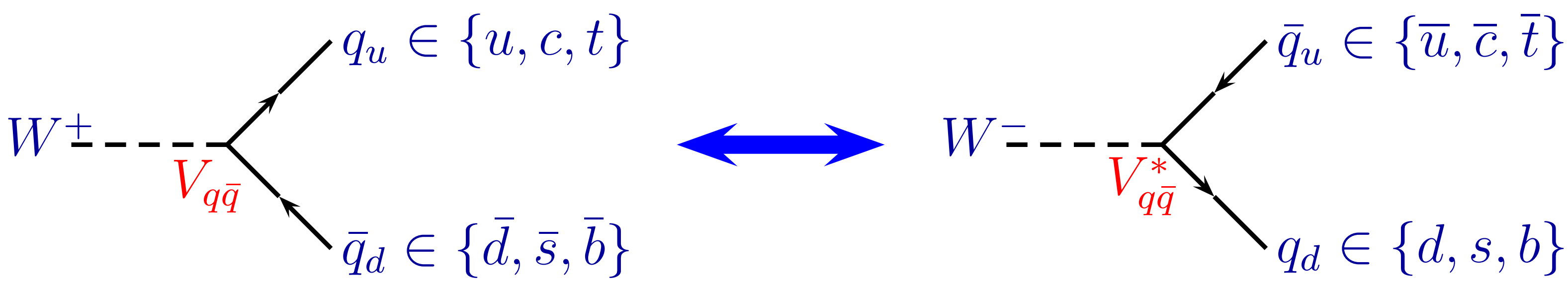
for the BABAR collaboration

Outline

- a quick reminder of CPV in the SM
- analysis technique
- results

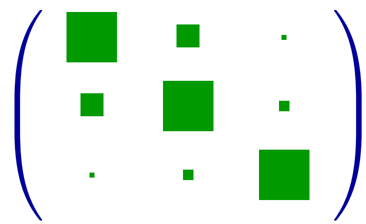
The CKM matrix

- quark sector: *weak eigenstates* $\neq$ *mass eigenstates*



- V is unitary with 4 independent 'physical' parameters
  $\longrightarrow$ one *complex* phase

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

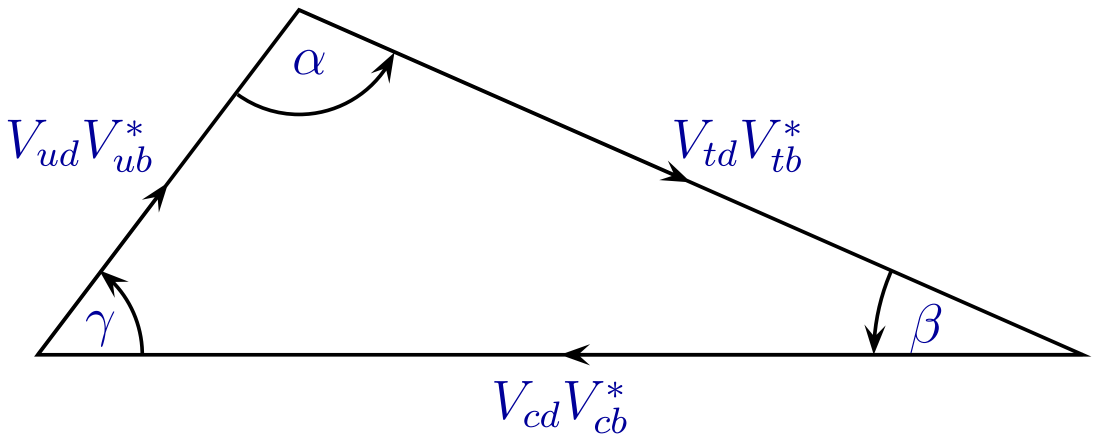


- Wolfenstein parameterization, $\lambda \approx 0.2$

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

The Unitary Triangle

- unitarity relations, *e.g.* $V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$



$$\alpha = \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right] \quad \beta = \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right] \quad \gamma = \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$$

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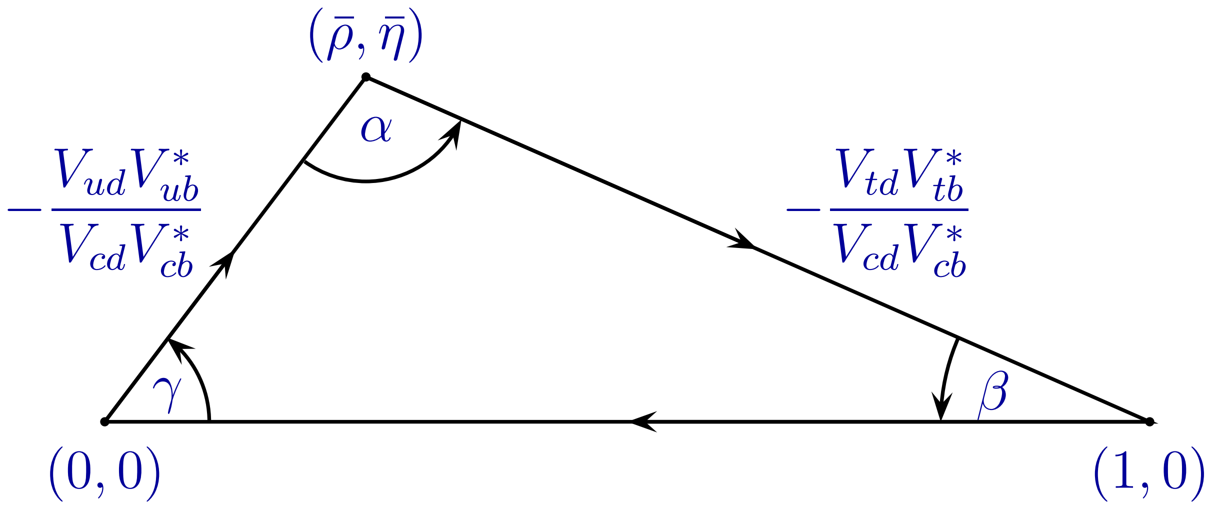

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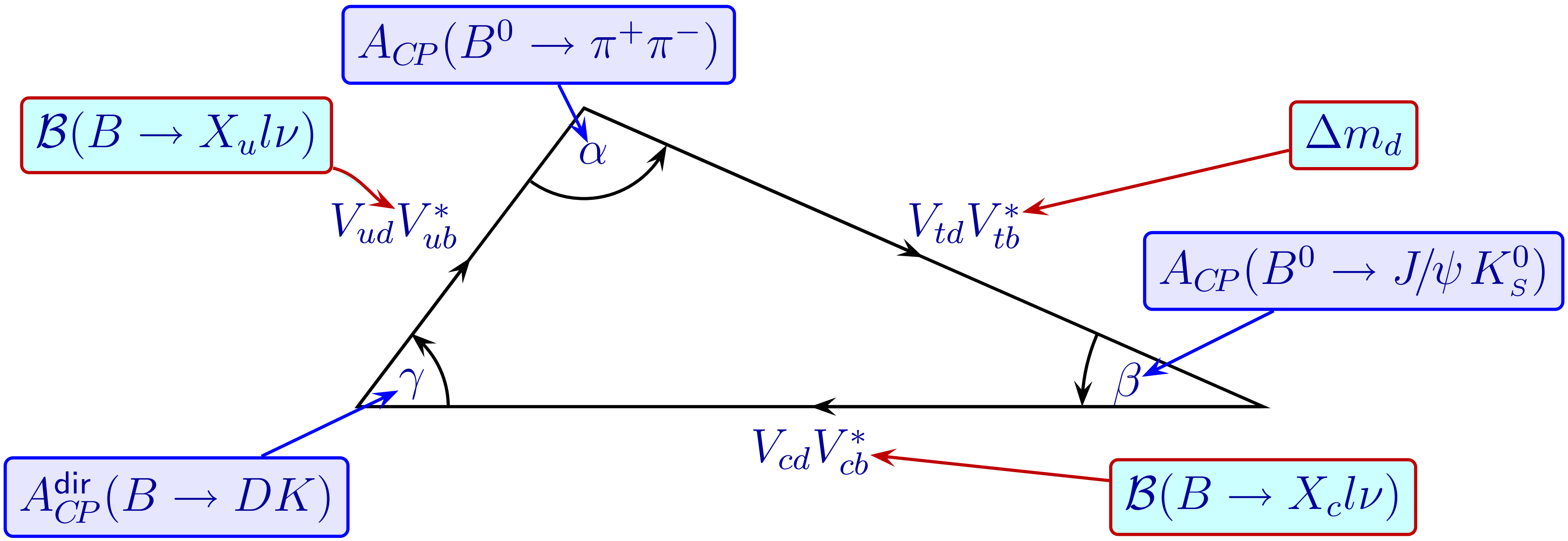

- standard model tests
  - measure consistency of 'unitary triangle' $\longrightarrow$ sides and angles
  - measure angles in more than one way $\longrightarrow$ *e.g.* tree versus penguin

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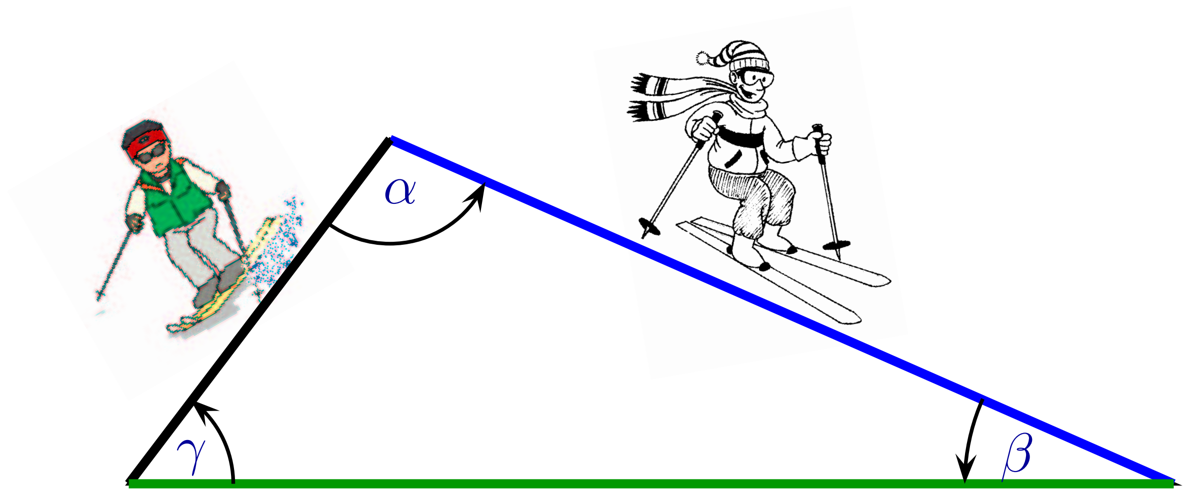

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  - measure consistency of 'unitary triangle' $\longrightarrow$ sides and angles
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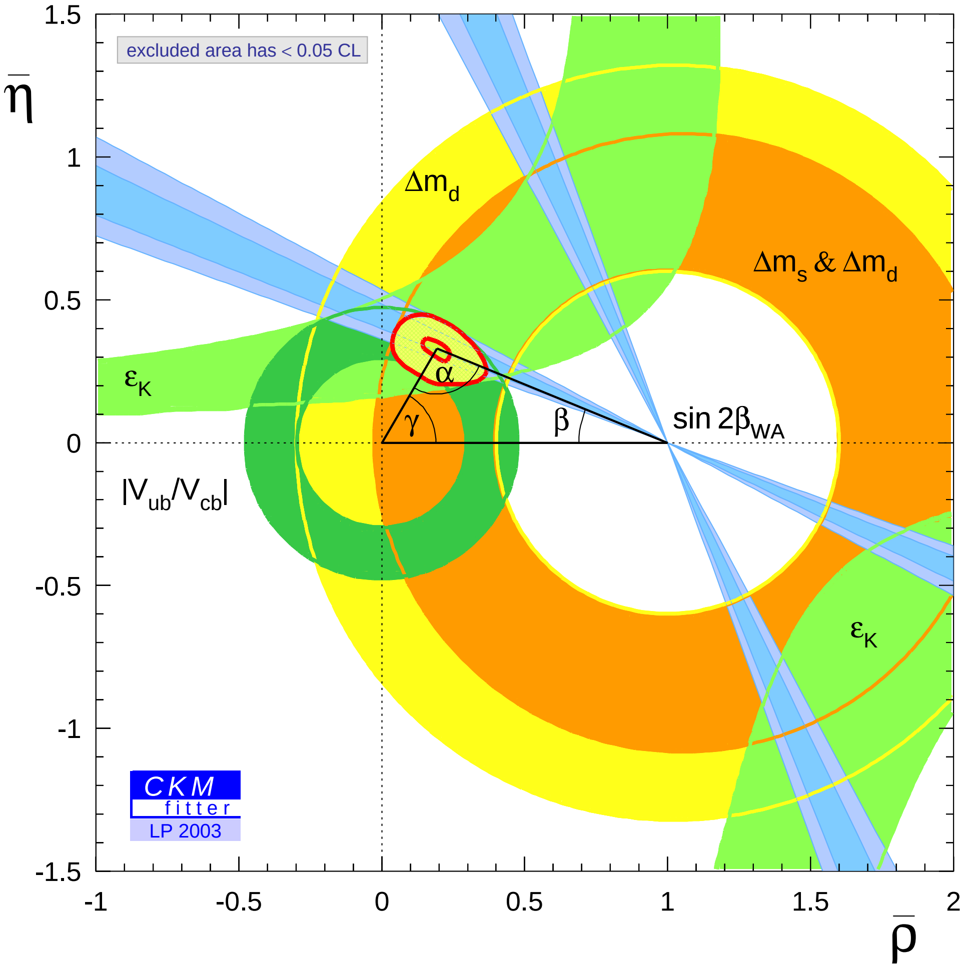
Where do we stand?



The first precision test of the CKM picture:

- using *only* Δm_d, Δm_s, $|V_{ub}/V_{cb}|$ and ε_K:

  $\sin(2\beta) \;=\; 0.676 \pm 0.090$

- time-dependent CP asymmetries in charmonium modes, *BABAR* on 82/fb:

$$\boxed{\sin(2\beta)_{\psi K^0_S} \;=\; 0.741 \pm 0.067^{\mathsf{stat}} \pm 0.034^{\mathsf{syst}}}$$

Excellent agreement!
So, what's next?

In this talk, the latest *BABAR* results for:

- $\sin(2\beta)$ from $\eta' K^0_S$, ϕK^0_S, $K^0_S\pi^0$
- $\sin(2\alpha)$ from $B \to \pi\pi$, $B \to \rho\pi$, $B \to \rho\rho$,
- $\sin(2\beta+\gamma)$ from $B^0 \to D^{(*)\mp}\pi^\pm$
- γ from $B^- \to DK$

Measuring CP violation in B decays

CPV in B decays is consequence of interfering amplitudes

Two types of measurements

1. Charge asymmetry: $$\boxed{A_f^{\text{ch}} \equiv \frac{N(B \to f) - N(\bar{B} \to \bar{f})}{N(B \to f) + N(\bar{B} \to \bar{f})}}$$

   ≥ 2 interfering amplitudes with both different weak and 'strong' phase

2. Time-dependent asymmetry: if B^0 and $\overline{B}^0$ have common final state f, interference through B^0-$\overline{B}^0$ *mixing*

$$\boxed{A(t) \equiv \frac{N(\overline{B}^0(t) \to f) - N(B^0(t) \to f)}{N(\overline{B}^0(t) \to f) + N(B^0(t) \to f)} = S_f \sin(\Delta m_d t) - C_f \cos(\Delta m_d t)}$$

For example, for $B^0 \to J/\psi K^0_S$: $S_{J/\psi K^0_S} = \sin 2\beta$ and $C_{J/\psi K^0_S} = 0$

Note, for asymmetry measurements of neutral Bs:

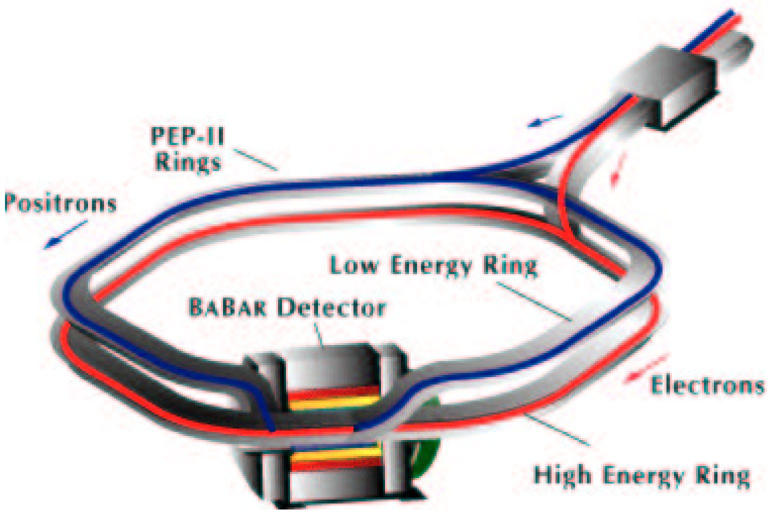
- need to *tag* the flavor of the $\overset{(-)}{B}{}^0$ at $t = 0$
- at $\Upsilon(4\mathrm{S})$, B^0 and $\overline{B}^0$ in coherent state:

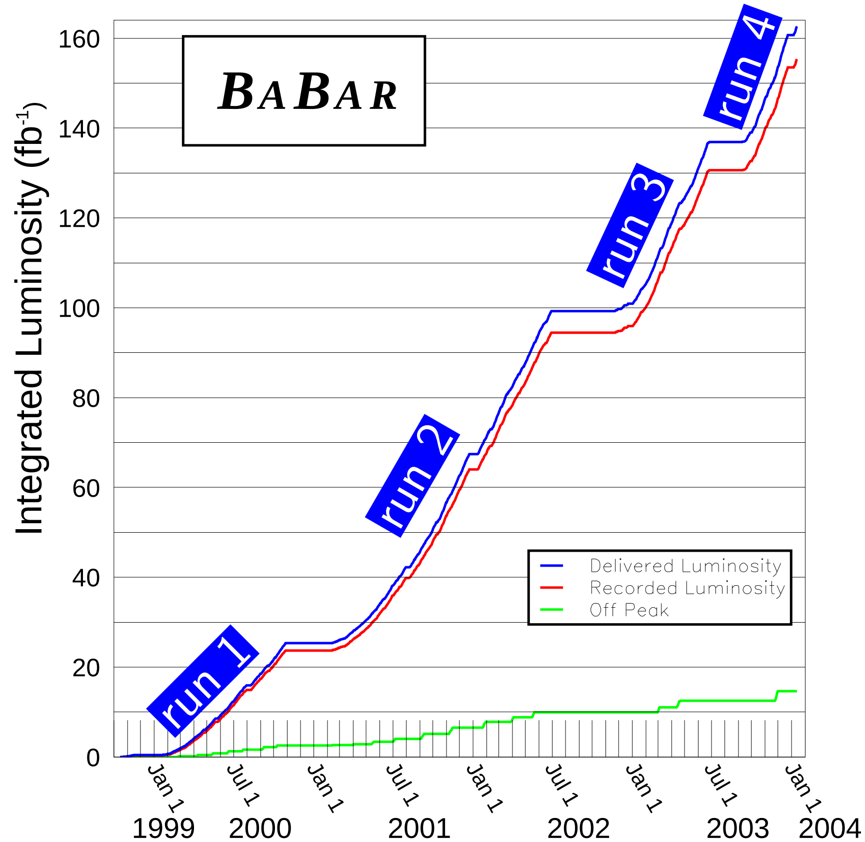
$$t \longrightarrow \Delta t \equiv t(B \to f) - t(\text{other}B)$$

The PEP-II storage ring

Asymmetric B-factory

- 9.0 GeV e^-/ 3.1 GeV e^+
- instantaneous luminosity:
  $L_{\text{peak}} \approx 7.3 \cdot 10^{33}\,\text{cm}^{-2}\,\text{s}^{-1}$
  $\longrightarrow \sim 9\ b\bar{b}$ per second !
- integrated luminosity (Jan 2004):
  $L_{\text{int}} \approx 160\,\text{fb}^{-1}$





Results based on

- run 1+2: $\sim 82\text{fb}^{-1}$
- run 1+2+3: $\sim 113\text{fb}^{-1}$

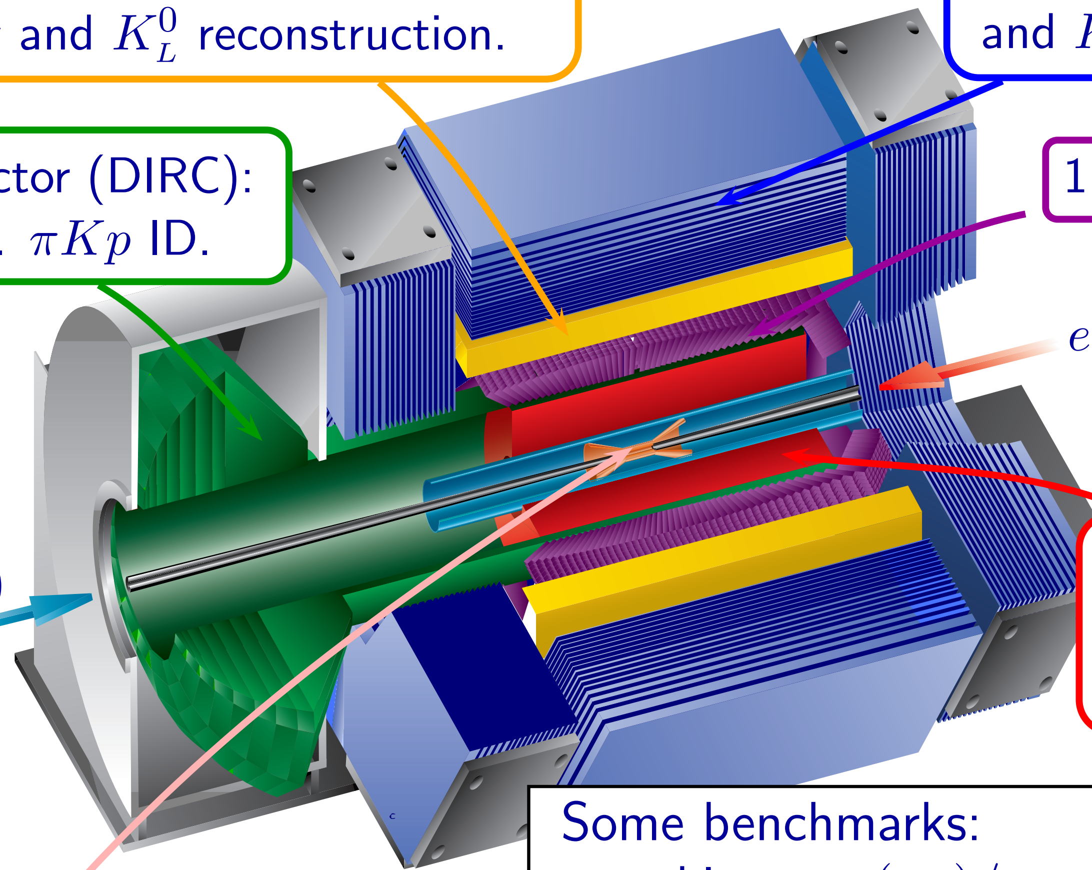
The BABAR Detector

EM calorimeter (EMC): CsI(Tl) crystals. $e^{\pm}$ ID, π^0, γ and K_L^0 reconstruction.

Instrumented flux return (IFR): RPCs with iron. $\mu^{\pm}$ and K_L^0 ID.

Cherenkov detector (DIRC): 144 quartz bars. $\pi K p$ ID.

1.5 T Magnet



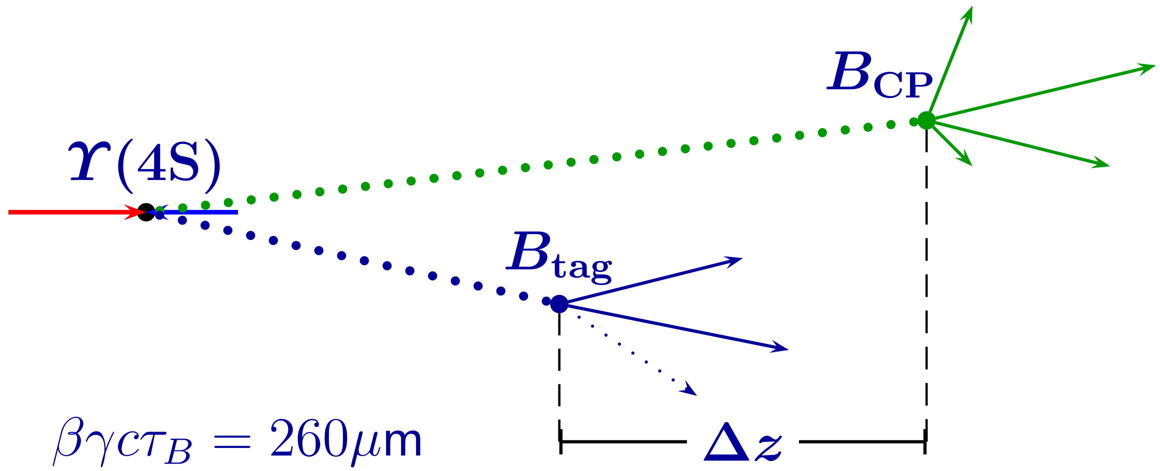
Drift chamber (DCH): 40 layers in 10 superlayers, He-Isobutane (80:20).

Silicon vertex detector (SVT): 5 layers double-sided Si.

Some benchmarks:

tracking:	$\sigma(p_\perp)/p_\perp \; = \; 0.45\% \; + \; 0.13\% p_\perp$
DIRC:	K/π sep. $> 3.5\sigma$ for $p < 3.5$ GeV
EMC:	$\sigma(E)/E = 1.9\% \oplus 2.3\% E^{-\frac{1}{4}}$

Δt reconstruction and flavour tagging



$$\Delta t \approx \Delta z/\beta\gamma\gamma_B c$$

1. Exclusive reconstruction of $B_{\rm CP}$

- typical z_{CP} resolution: $60\ \mu$m

2. Inclusive reconstruction of $B_{\rm tag}$

- all remaining tracks
  - reconstruct K_S^0 and Λ^0
  - remove conversions
- typical $z_{\rm tag}$ resolution: $180\ \mu$m
- typical Δt resolution: 0.7 ps

3. Flavour tagging

- use decay products of $B_{\rm tag}$
- combine PID and momentum info
- neural network technique
- different tagging 'catagories'
- tagging performance

  $\sum_i \varepsilon_i(1-2\omega_i)^2 \ = \ 28\%$

  ($\varepsilon_i \equiv$ efficiency, $\omega_i \equiv$ mistag rate)

Selecting B events: Kinematic variables

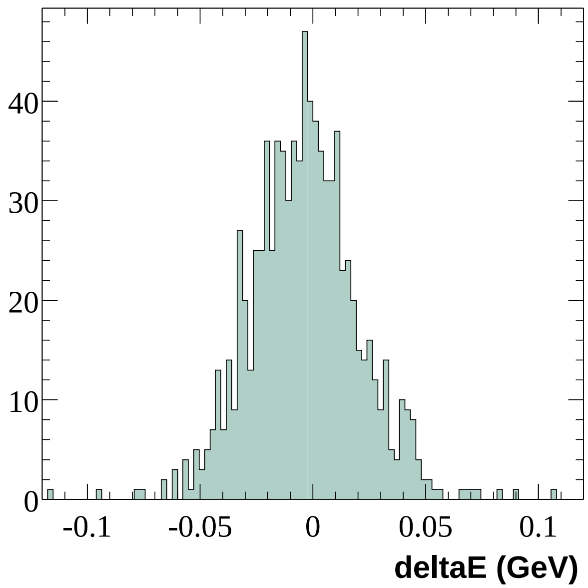
Two kinematic constraints in $\Upsilon(4S)$ rest frame:

"B energy"

$$\boxed{\Delta E \;=\; E^*_B - \tfrac{1}{2}\sqrt{s}}$$

typical resolution 20-50 MeV
(dominated by particle momenta)

example: $B^0 \to D^{*-}\pi^+$

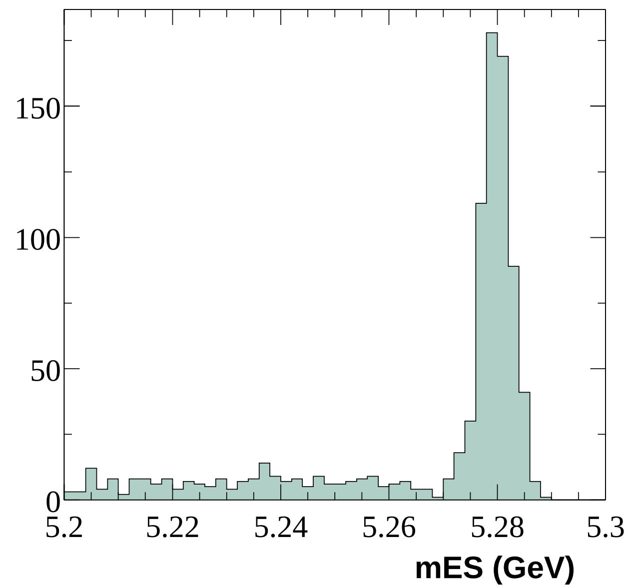


"beam energy substituted mass"

$$\boxed{m_{\mathrm{ES}} \;=\; \sqrt{\tfrac{1}{4}s - p^{*2}_B}}$$

typical resolution 2.6 MeV
(dominated by spread in $\sqrt{s}$)

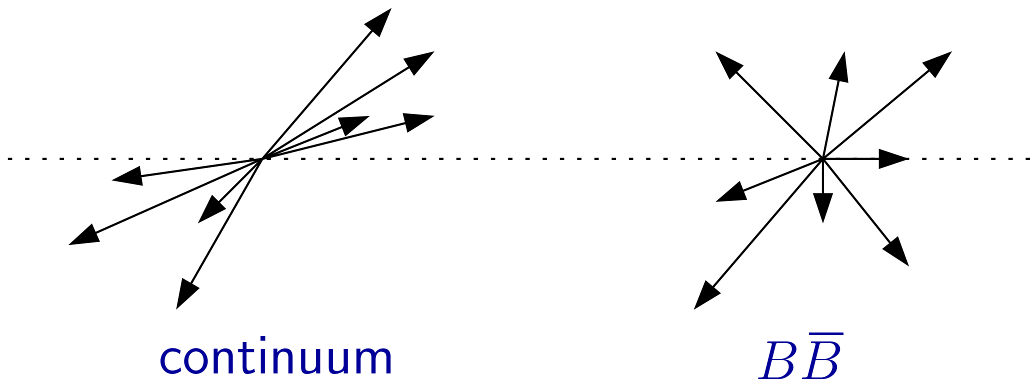
example: $B^0 \to D^{*-}\pi^+$



Continuum suppression: Event shape

Continuum is main background for rare B decays

Suppress with event shape:

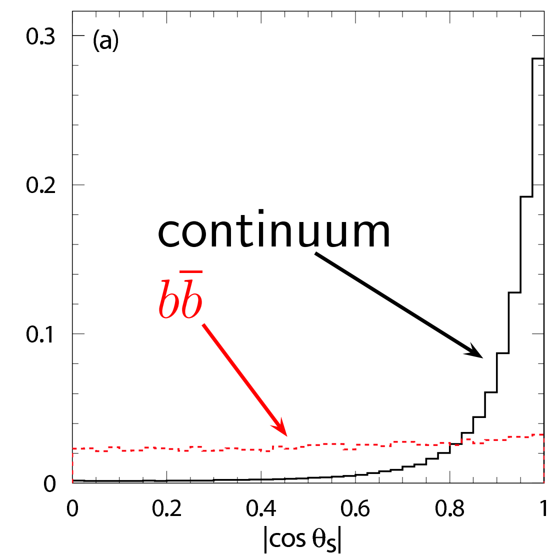


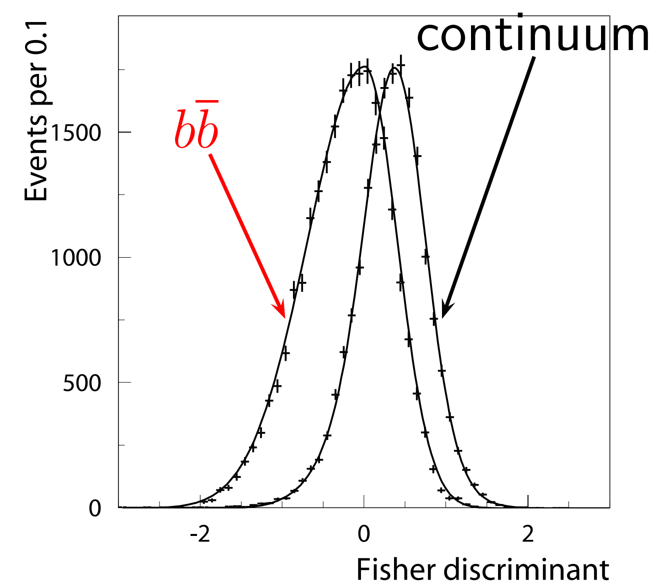
Observables

- sphericity angle: $\angle(\,p_B,$ thrust axis rest of event$)$
- Legendre moments of energy flow about p_B

$\longrightarrow$ usually combined in Fisher discriminant

cos(sphericity angle)

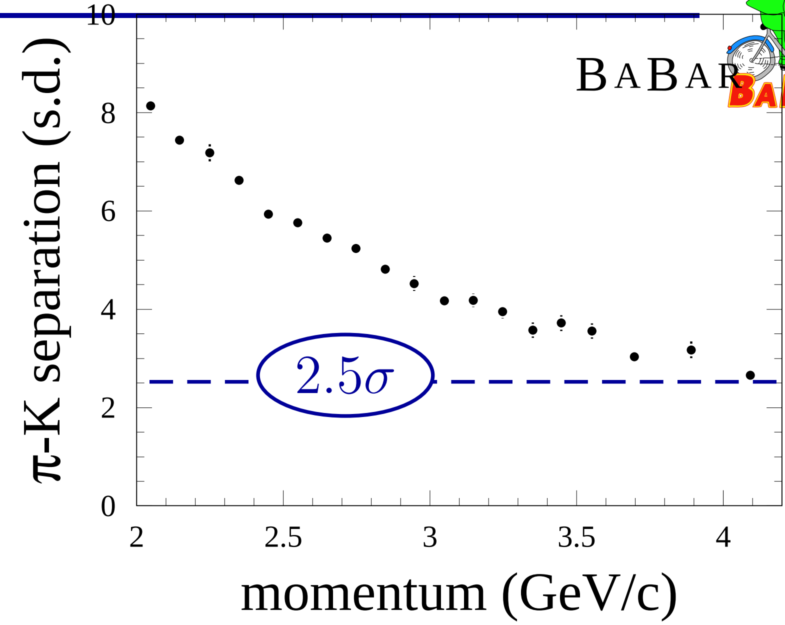




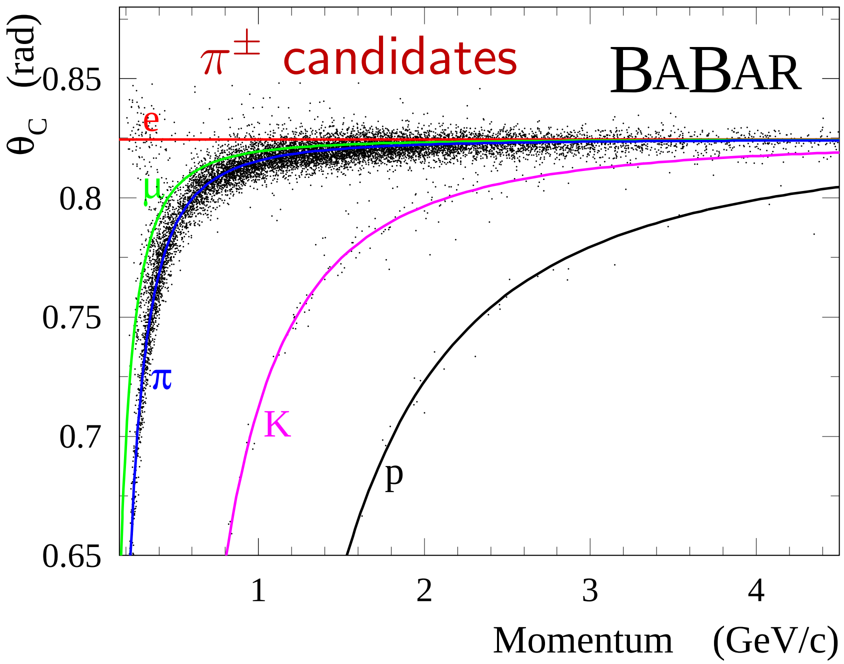
Particle ID

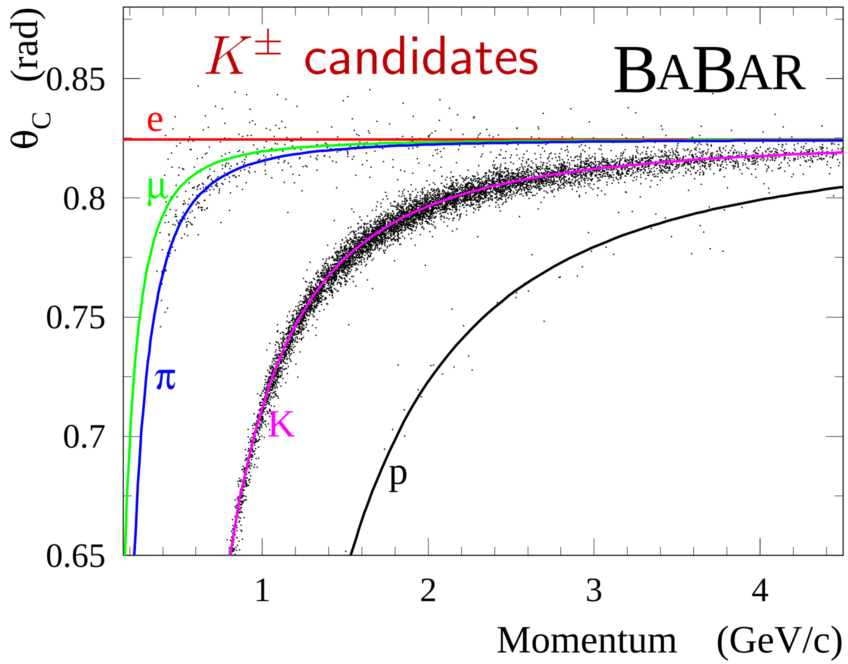
Combine information from

- DCH $\mathrm{d}E/\mathrm{d}x$
- EMC cluster energy and shape
- IFR track segments
- **DIRC cherenkov angle θ_C**



DIRC θ_c for $\pi^{\pm}$ and $K^{\pm}$ from
$D^{*+} \to D^0\pi^+ \to (K^-\pi^+)\pi^+$





Analysis strategy

General scheme:

Observables
- kinematics
- event shape
- particle ID, B tagging
- vertex info, Δt

loose cuts $\longrightarrow$ keep side-bands!

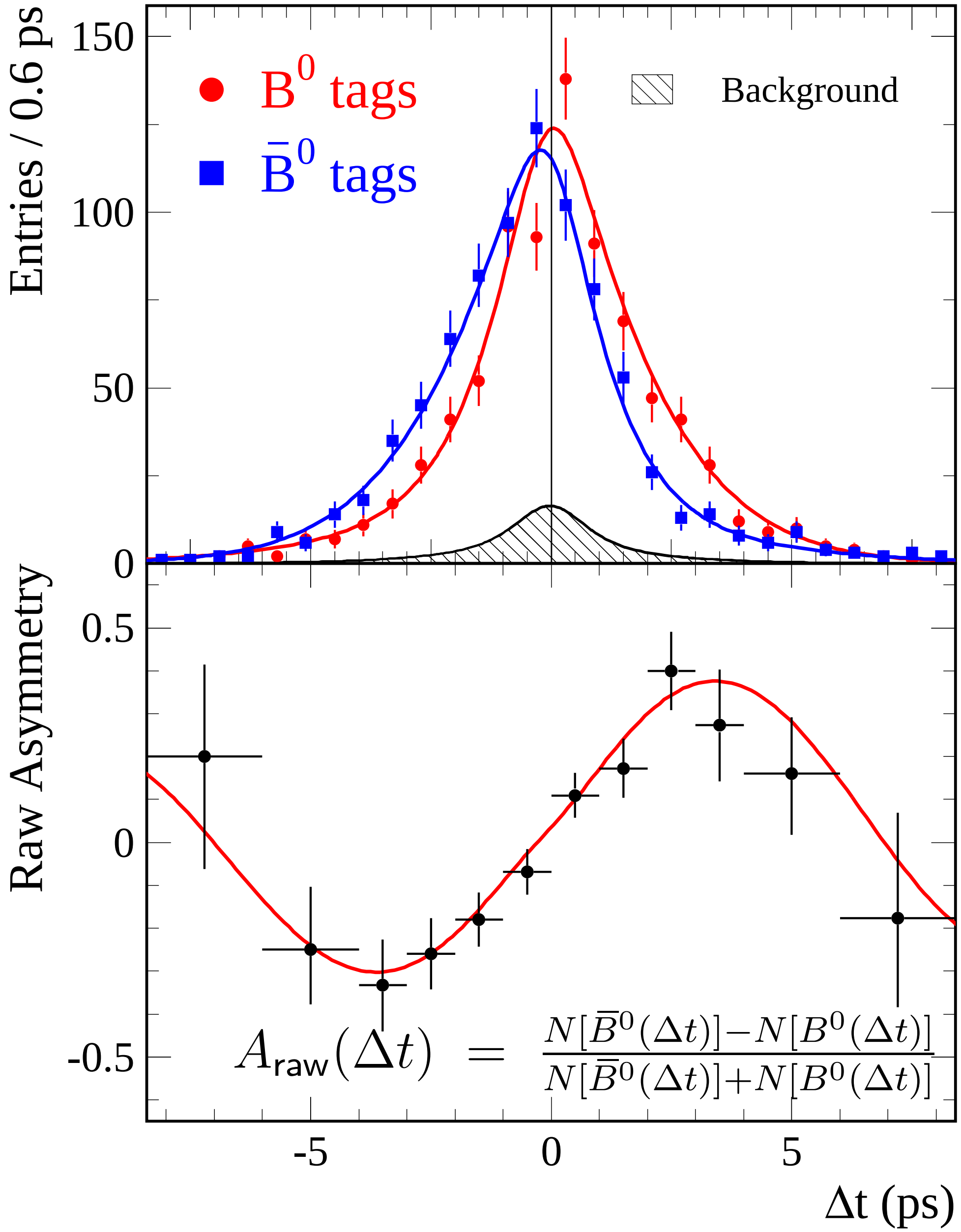
Model
- n signal $+$ m background components
- signal PDFs from MC or control sample
- background PDFs from data

Extract from maximum likelihood fit
- signal yields
- S and C
- background shapes and yields
- ...

The details depend on the analysis ...

The golden mode: time-dependent CPV in $B^0 \to J/\psi\, K^0_S$

Δt distribution



- 1683 ± 43 candidates from 82 fb^{-1}
- neglecting detector resolution:

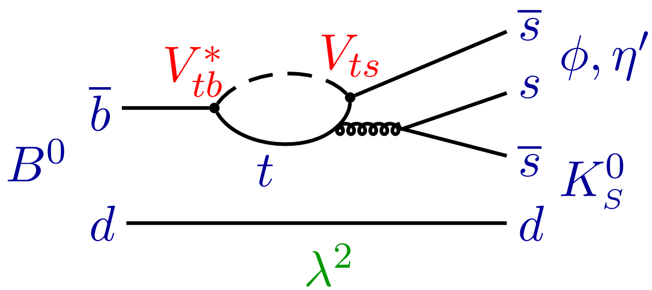
$$N_{B^0}(t) \propto e^{-|\Delta t|/\tau} \times [1 + S_f \sin(\Delta m_d \Delta t) - C_f \cos(\Delta m_d \Delta t)]$$

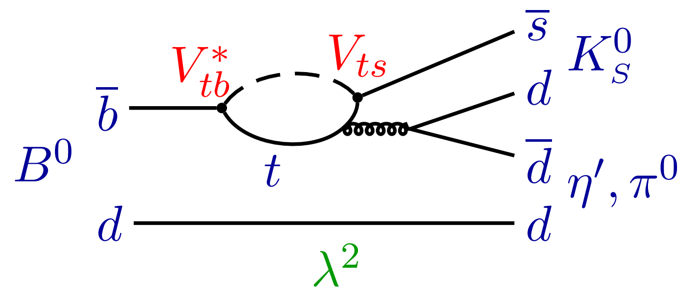
$$N_{\overline{B}^0}(t) \propto e^{-|\Delta t|/\tau} \times [1 - S_f \sin(\Delta m_d \Delta t) + C_f \cos(\Delta m_d \Delta t)]$$

$$A_{\text{raw}}(\Delta t) \approx (1 - 2\omega) \times [S_f \sin(\Delta m_d \Delta t) - C_f \cos(\Delta m_d \Delta t)]$$

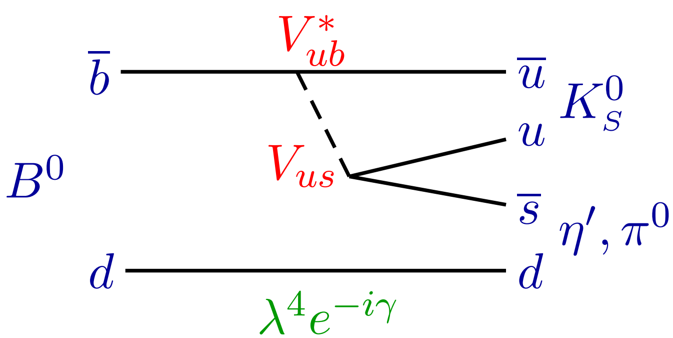
Measuring $\sin(2\beta)$ *in penguins*

- $B^0 \to \phi K^0_S$, $B^0 \to \eta' K^0_S$ and $B^0 \to \pi^0 K^0_S$ dominated by $b \to s$ penguin





- if $V_{ts}V^*_{tb}$ amplitude dominates: $\boxed{S = \sin(2\beta) \text{ and } C = 0}$
- bound on $V_{us}V^*_{ub}$ ('tree') contribution



	'naive' T/P	flavour symmetry $\lvert -\eta_f S_f - \sin 2\beta \rvert$
ϕK^0_S	< 0.05 [1]	< 0.3 [3]
$\eta' K^0_S$	~ 0.02 [2]	< 0.4 [3]
$\pi^0 K^0_S$	~ 0.04 [2]	< 0.2 [4]

- SU(3) bounds improve with better measurements of rare decays, *e.g.*

$$\text{bound on } \Delta\sin(2\beta)_{K^0_S\pi^0} \propto \sqrt{\frac{\mathcal{B}(B^0 \to K^+K^-)}{\mathcal{B}(B^0 \to \pi^0\pi^0)}}$$

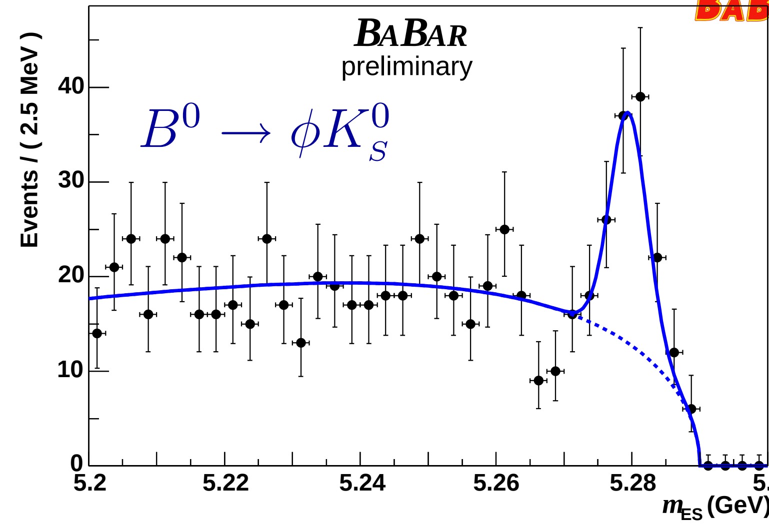
[1] Y.Grossman, G.Isidori, M.Worah, PRD58,057504 (1998).
[2] D.London and A.Soni, PLB 407,61-65 (1997).
[3] Y.Grossman, Z.Ligeti, Y.Nir, H.Quinn, PRD68,015004 (2003).
[4] M.Gronau, Y.Grossman, J.Rosner, PLB579,331-339 (2004).

$B^0 \to \phi K^0_S$ (prel.) and $B^+ \to \phi K^+$ (hep-ex/0309025)

- reconstructed mode:
  $\phi \to K^+K^-$, $K^0_S \to \pi^+\pi^-$

- number of signal events:

	82/fb	110/fb
$N(\phi K^0_S)$	50 ± 9	70 ± 9
$N(\phi K^+)$	173 ± 15	

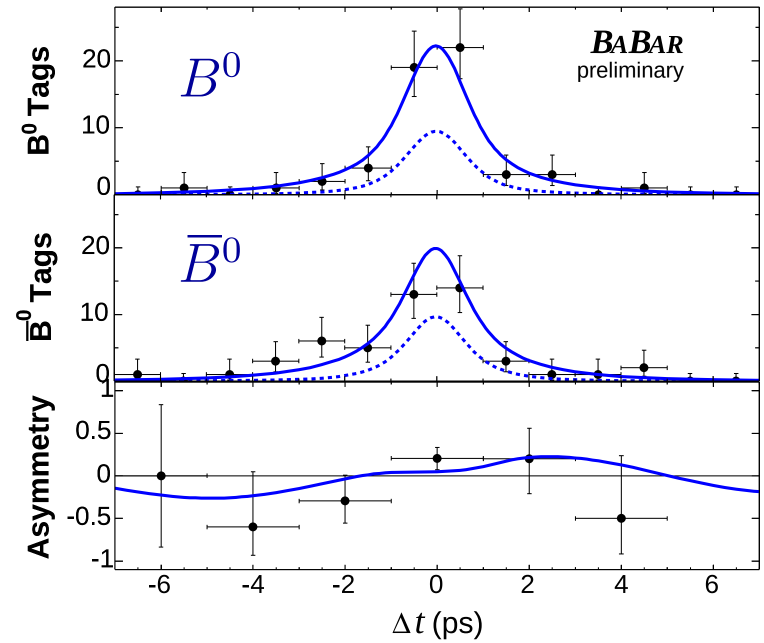


- Branching fractions (82/fb, hep/ex 0309025)

$$\mathcal{B}(B^0 \to \phi K^0_S) = (8.5^{+1.5}_{-1.3} \pm 0.5^{\mathsf{syst}}) \cdot 10^{-6}$$
$$\mathcal{B}(B^+ \to \phi K^+) = (10.0^{+0.9}_{-0.8} \pm 0.5^{\mathsf{syst}}) \cdot 10^{-6}$$

- Measured asymmetry:

$$S_{\phi K^0_S} = 0.45 \pm 0.43^{\mathsf{stat}} \pm 0.07^{\mathsf{syst}} \text{ (prel.)}$$
$$C_{\phi K^0_S} = -0.38 \pm 0.37^{\mathsf{stat}} \pm 0.12^{\mathsf{syst}} \text{ (prel.)}$$
$$A^{\mathsf{ch}}_{\phi K^+} = 0.04 \pm 0.09^{\mathsf{stat}} \pm 0.01^{\mathsf{syst}}$$



$B^0 \to \eta' K_S^0$ *and* $B^+ \to \eta' K^+$ *(PRL91;161801(2003))*

- reconstructed modes: $\eta' \to \eta\pi^+\pi^-$, $\eta' \to \rho^0\gamma$, $\eta \to 2\gamma$, $\rho^0 \to \pi^+\pi^-$, $K_S^0 \to \pi^+\pi^-$

- number of signal events in 82/fb:

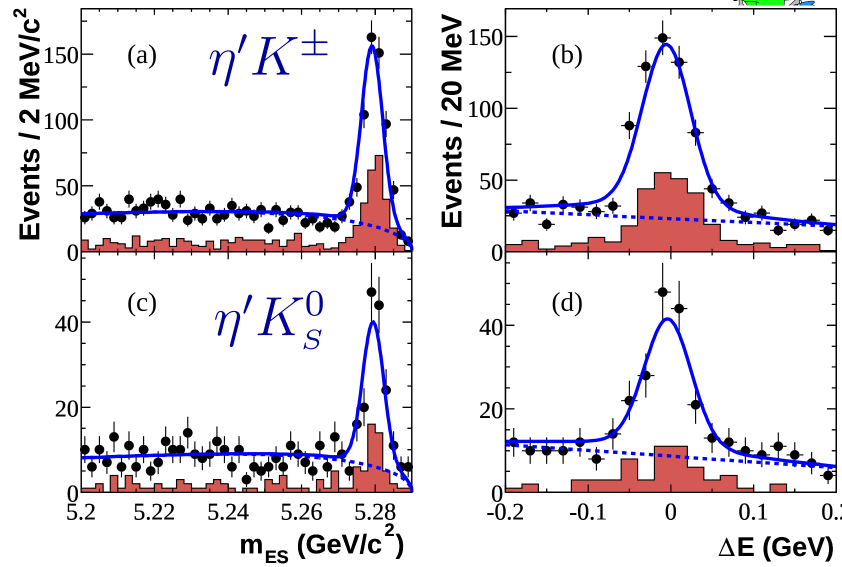
$$N(B^0 \to \eta' K_S^0) = 203 \pm 19$$
$$N(B^+ \to \eta' K^+) = 782 \pm 36$$

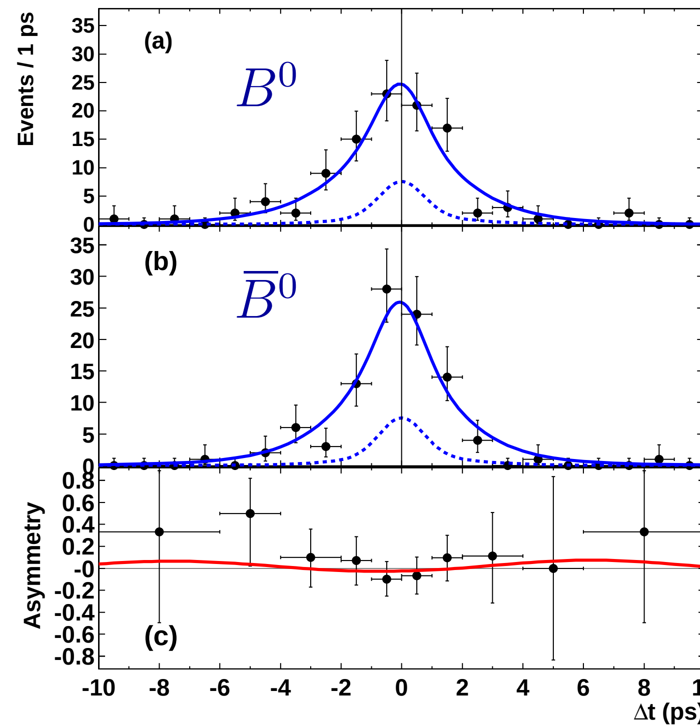
- measured branching fractions (times 10^6):

$$\mathcal{B}(B^0 \to \eta' K_S^0) = 60.6 \pm 5.6^{\text{stat}} \pm 4.6^{\text{syst}}$$
$$\mathcal{B}(B^+ \to \eta' K^+) = 76.9 \pm 3.4^{\text{stat}} \pm 4.4^{\text{syst}}$$

- measured asymmetry:

$$S_{\eta' K_S^0} = 0.02 \pm 0.34^{\text{stat}} \pm 0.03^{\text{syst}}$$
$$C_{\eta' K_S^0} = 0.10 \pm 0.22^{\text{stat}} \pm 0.04^{\text{syst}}$$
$$A^{\text{ch}}_{\eta' K^+} = 0.037 \pm 0.045^{\text{stat}} \pm 0.011^{\text{syst}}$$





$B^0 \to K_S^0\pi^0$ *and* $B^+ \to K_S^0\pi^+$ *(preliminary)*

- reconstructed mode:
  $\pi^0 \to \gamma\gamma$, $K_S^0 \to \pi^+\pi^-$

- number of signal events:

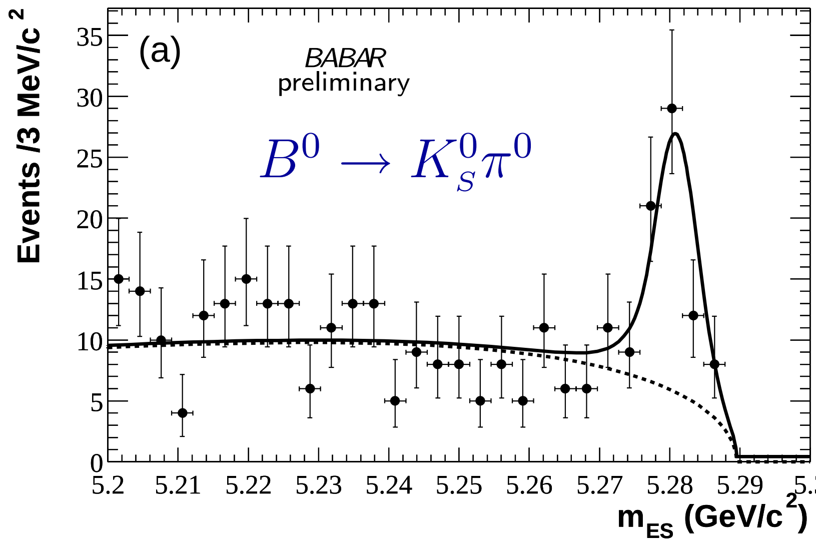
	82/fb	113/fb
$N(K_S^0\pi^0)$	86 ± 13	122 ± 16
$N(K_S^0\pi^+)$	255 ± 20	

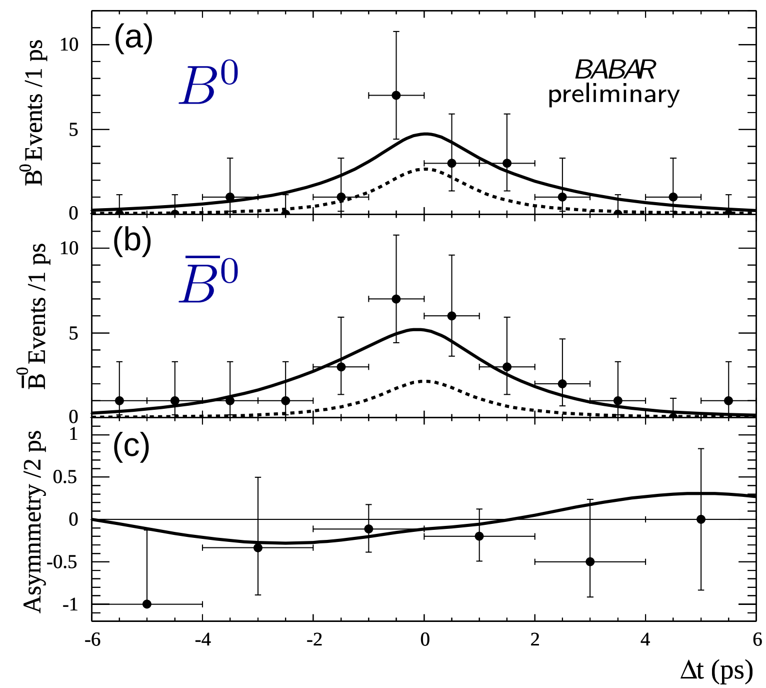
- Branching fractions times 10^6 (in 82/fb)

$$\mathcal{B}(B^0 \to K_S^0\pi^0) = 11.4 \pm 1.7^{\mathsf{stat}} \pm 0.8^{\mathsf{syst}}$$
$$\mathcal{B}(B^+ \to K_S^0\pi^+) = 22.3 \pm 1.7^{\mathsf{stat}} \pm 1.1^{\mathsf{syst}}$$

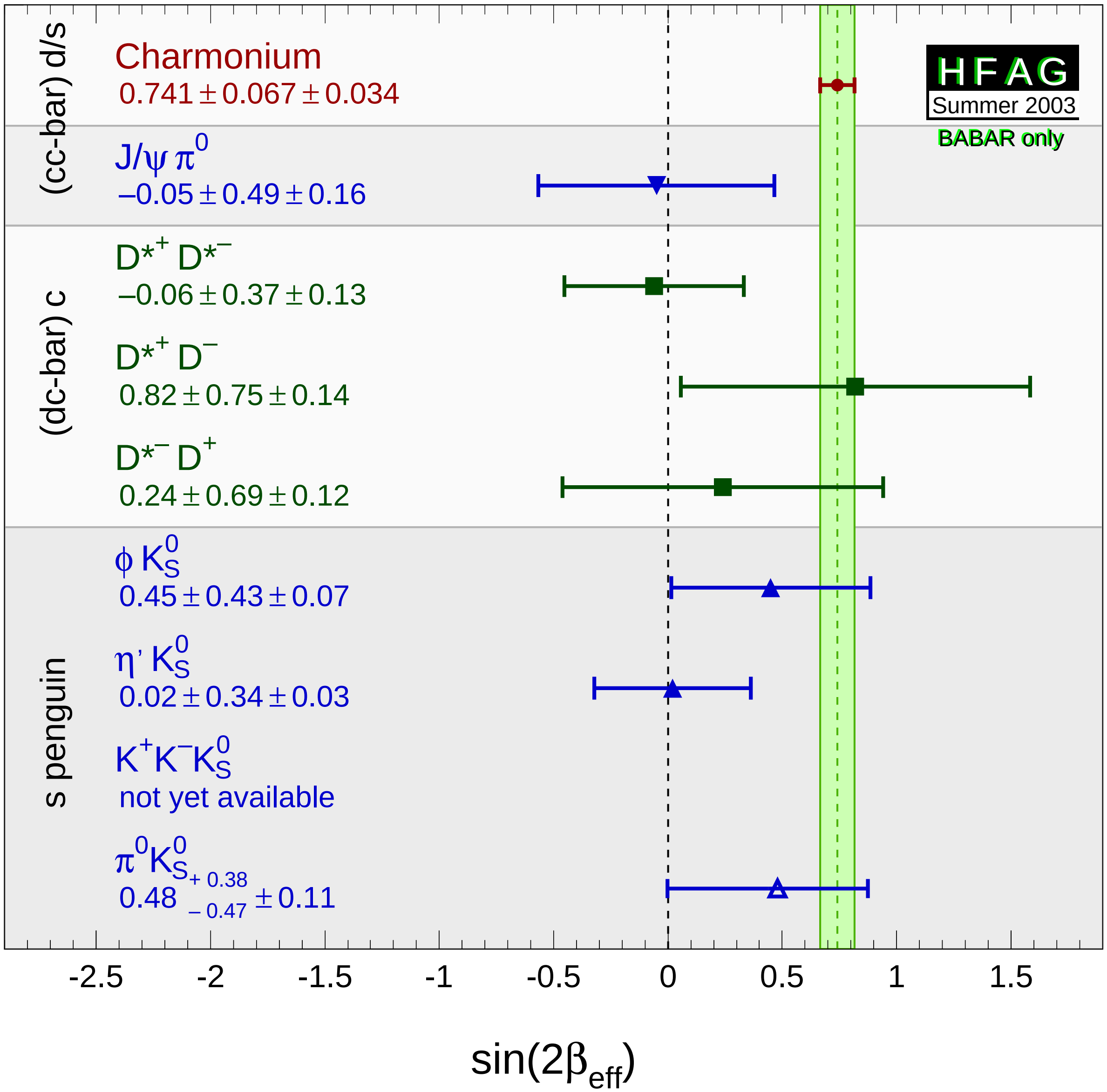
- Measured asymmetry:

$$S_{K_S^0\pi^0} = 0.48^{+0.38}_{-0.47} \pm 0.11^{\mathsf{syst}}$$
$$C_{K_S^0\pi^0} = 0.40^{+0.27}_{-0.28} \pm 0.10^{\mathsf{syst}}$$
$$A^{\mathsf{ch}}_{K_S^0\pi^+} = -0.05 \pm 0.08^{\mathsf{stat}} \pm 0.01^{\mathsf{syst}}$$





The BABAR picture of $\sin 2\beta$



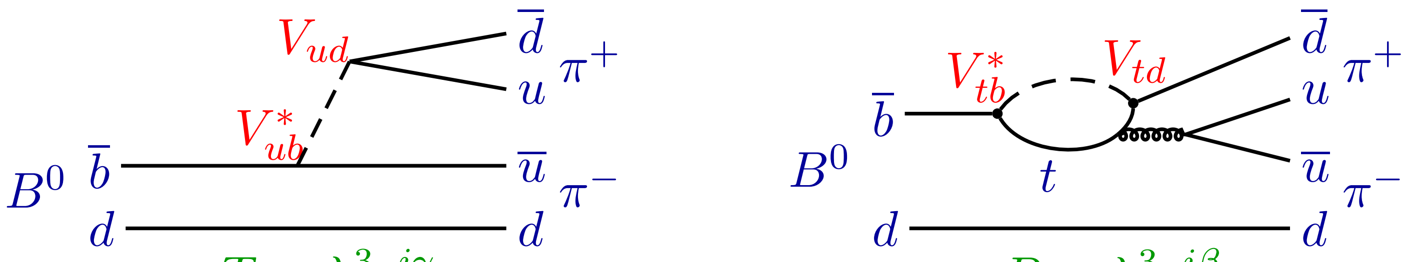
$b \to s$ penguin average:

$\sin(2\beta) \;=\; 0.27 \pm 0.22$

No smoking guns yet . . .

Measuring α

- $B \to \pi^+\pi^-$ is decay to CP eigenstate with $b \to u\bar{u}d$ tree

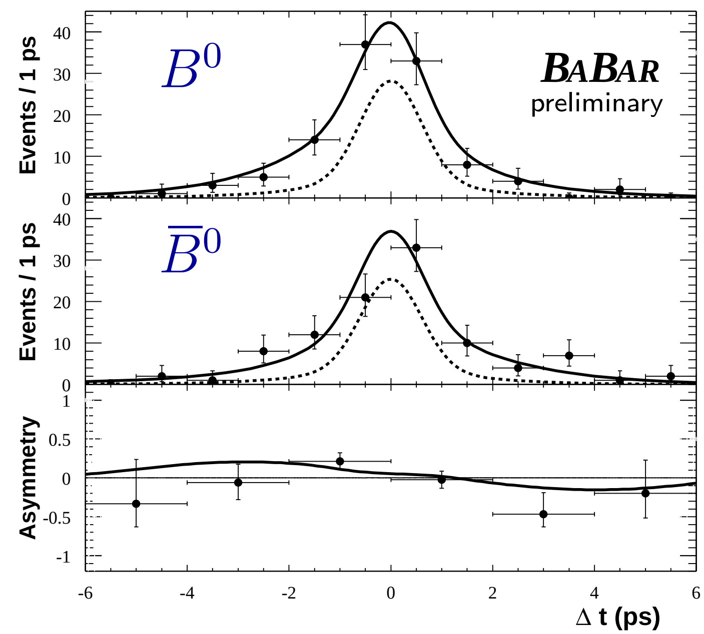


$T \sim \lambda^3 e^{i\gamma}$ $\quad$ $P \sim \lambda^3 e^{i\beta}$

- if only $b \to u\bar{u}d$ amplitude contributes: $\boxed{S = \sin 2\alpha,\ C = 0}$

- *BABAR* measurement on 113/fb (preliminary)

$$\boxed{\begin{array}{rcl} N_{\pi^+\pi^-} & = & 266 \pm 24 \\ S_{\pi^+\pi^-} & = & -0.40 \pm 0.22^{\text{stat}} \pm 0.03^{\text{syst}} \\ C_{\pi^+\pi^-} & = & -0.19 \pm 0.19^{\text{stat}} \pm 0.05^{\text{syst}} \end{array}}$$

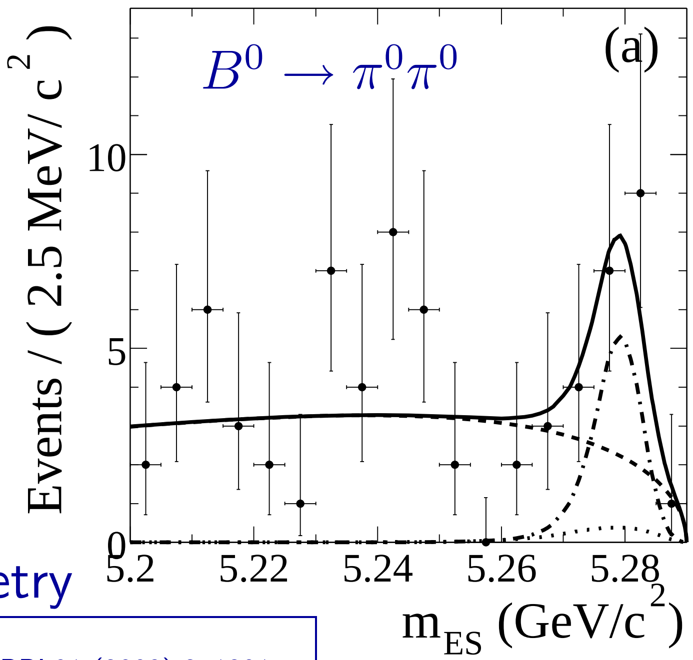


- but ... large **penguin effects**: $P/T \sim 0.3$
  - Gronau & London: extract '$\alpha_{\text{eff}} - \alpha$' from isospin analysis of tagged $B \to \pi\pi$ rates
  - in lack of statistics: use Grossman-Quinn bound

$$\boxed{\sin^2(\alpha_{\text{eff}} - \alpha) \leq \frac{\mathcal{B}(B^0 \to \pi^0\pi^0) + \mathcal{B}(\overline{B}^0 \to \pi^0\pi^0)}{\mathcal{B}(B^+ \to \pi^+\pi^0) + \mathcal{B}(B^- \to \pi^-\pi^0)}}$$

$B^0 \to \pi^0\pi^0$ *and the Grossman-Quinn bound*

- search for $B^0 \to \pi^0\pi^0$
  - small branching fraction: $\sim 10^{-6}$
  - large background from continuum
  - some background from $B^+ \to \rho^+\pi^0$



- last summer, in 113/fb: first signal!

$$\boxed{N_{\pi^0\,\pi^0} \;=\; 46 \pm 13^{\text{stat}} \pm 3^{\text{syst}} \qquad \Longrightarrow \mathbf{4.2\sigma}}$$

- all $\pi\pi$ branching fractions (times 10^6) and asymmetry

$\mathcal{B}(B^0 \to \pi^0\pi^0)$	$=$	$2.1 \pm 0.6^{\text{stat}} \pm 0.3^{\text{syst}}$	PRL91 (2003) 241801
$\mathcal{B}(B^0 \to \pi^+\pi^-)$	$=$	$4.7 \pm 0.6^{\text{stat}} \pm 0.2^{\text{syst}}$	PRL89 (2002) 281802
$\mathcal{B}(B^\pm \to \pi^\pm\pi^0)$	$=$	$5.5\,^{+1.0}_{-0.9}{}^{\text{stat}} \pm 0.6^{\text{syst}}$	PRL91 (2003) 0218011
$A^{\text{ch}}_{\pi^\pm\pi^0}$	$=$	$-0.03\,^{+0.18}_{-0.17}{}^{\text{stat}} \pm 0.02^{\text{syst}}$	PRL91 (2003) 0218011

- Grossman-Quinn bound using world average

$$|\alpha_{\text{eff}} - \alpha|_{\pi\pi} < 47^o \text{ at } 90\%\text{ CL}$$

- not a very useful bound . . . full isospin analysis required ☹

Measuring α *in* $B^0 \to \rho^+\rho^-$

- vector-vector final state (mixed CP) $\longrightarrow$ requires angular analysis

- luckily, nature helps: entirely longitudinally polarized!

$$f_L(B^0 \to \rho^+\rho^-) = (98\ ^{+2}_{-8}\,\text{stat} \pm 3^{\text{syst}})\% \qquad \text{preliminary, hep-ex/0311017}$$
$$f_L(B^+ \to \rho^+\rho^0) = (97\ ^{+3}_{-7}\,\text{stat} \pm 4^{\text{syst}})\% \qquad \text{PRL91 (2003) 171802}$$

$\longrightarrow$ $\rho^+\rho^-$ is a CP-even state with same formalism as $\pi^+\pi^-$

- branching fractions in 82/fb (times 10^6)

$$\mathcal{B}(B^0 \to \rho^0\rho^0) < 2.1 \text{ (90\% CL)} \qquad \text{PRL91 (2003) 171802}$$
$$\mathcal{B}(B^\pm \to \rho^\pm\rho^0) = 22.5\ ^{+5.7}_{-5.4}\,\text{stat} \pm 5.8^{\text{syst}} \qquad \text{PRL91 (2003) 171802}$$
$$\mathcal{B}(B^0 \to \rho^+\rho^-) = 25\ ^{+7}_{-6}\,\text{stat}\ ^{+5}_{-6}\,\text{syst} \qquad \text{preliminary, hep-ex/0311017}$$

- Grossman-Quinn bound using WA and assuming 100% polarization

$$\boxed{|\alpha_{\text{eff}} - \alpha|_{\rho_L\rho_L} < 17^o \text{ (90\% CL)}}$$

- much better than for $\pi\pi$ and could still improve!

- time-dependent $\rho^+\rho^-$ results will follow soon ...

α *from* $B^0 \to \rho^+\pi^-$

- $B^0 \to \rho^\pm\pi^\mp$ not a CP eigenstate
  - more observables: separate $A(\Delta t)$ for $B^0 \to \rho^+\pi^-$ and for $B^0 \to \rho^-\pi^+$ $\longrightarrow C,\ S,\ \Delta C,\ \Delta S$
  - more unknowns: need to extract CP conserving phase difference δ

$$S \pm \Delta S \;=\; \sqrt{1-(C\pm\Delta C)^2}\ \sin(2\alpha^{\pm}_{\mathsf{eff}} \pm \delta)$$

- branching fractions using 82/fb (in units 10^{-6})

$\mathcal{B}(B^0 \to \rho^\pm\pi^\mp)$	$=$	$22.6 \pm 1.8^{\mathsf{stat}} \pm 2.2^{\mathsf{syst}}$	PRL91(2003)201802
$\mathcal{B}(B^+ \to \rho^+\pi^0)$	$=$	$10.9 \pm 1.9^{\mathsf{stat}} \pm 1.9^{\mathsf{syst}}$	hep-ex/0311049 (subm. to PRL)
$\mathcal{B}(B^+ \to \rho^0\pi^+)$	$=$	$9.5 \pm 1.1^{\mathsf{stat}} \pm 0.8^{\mathsf{syst}}$	hep-ex/0311049
$\mathcal{B}(B^0 \to \rho^0\pi^0)$	$<$	2.9 at 90% CL	hep-ex/0311049

- direct CP asymmetries using 82/fb

$A^{\mathsf{ch}}_{\rho^\pm\pi^\mp}$	$=$	$-0.18 \pm 0.08^{\mathsf{stat}} \pm 0.03^{\mathsf{syst}}$	PRL91(2003)201802
$A^{\mathsf{ch}}_{\rho^+\pi^0}$	$=$	$0.24 \pm 0.16^{\mathsf{stat}} \pm 0.06^{\mathsf{syst}}$	hep-ex/0311049 (subm. to PRL)
$A^{\mathsf{ch}}_{\rho^0\pi^+}$	$=$	$-0.19 \pm 0.11^{\mathsf{stat}} \pm 0.02^{\mathsf{syst}}$	hep-ex/0311049

a 2σ effect for $A^{\mathsf{ch}}_{\rho^\pm\pi^\mp}$?

$B^0 \to \rho^\pm\pi^\mp$ *(continued)*

- time-dependent asymmetry of $B^0 \to \rho^\pm\pi^\mp$ (PRL91(2003)201802)

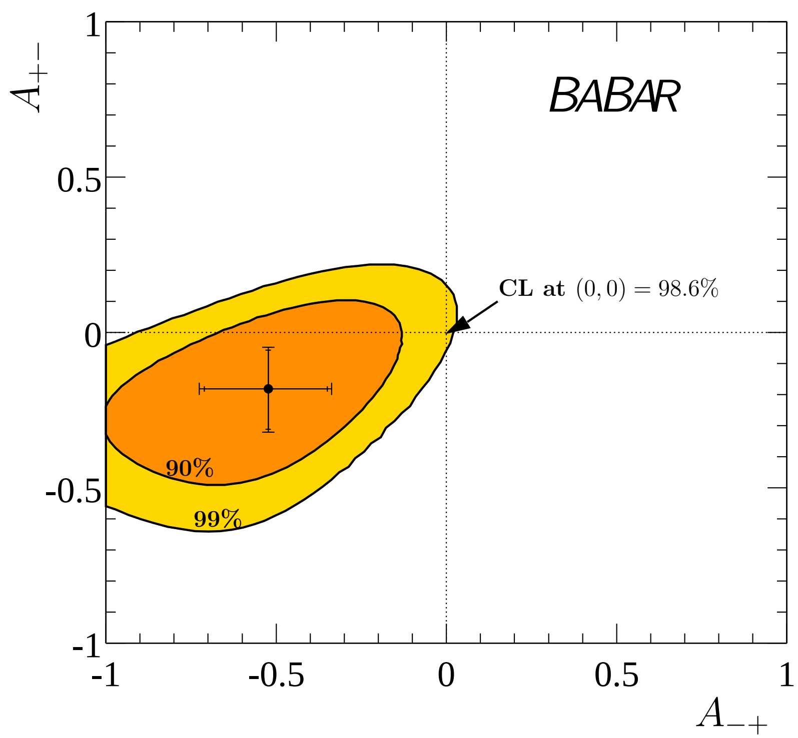
$$\boxed{\begin{array}{lcl} C_{\rho^+\pi^-} & = & 0.36 \pm 0.18^{\text{stat}} \pm 0.04^{\text{syst}} \\ S_{\rho^+\pi^-} & = & 0.19 \pm 0.24^{\text{stat}} \pm 0.03^{\text{syst}} \\ \Delta C_{\rho^+\pi^-} & = & 0.28\ {}^{+0.18}_{-0.19}{}^{\text{ stat}} \pm 0.04^{\text{syst}} \\ \Delta S_{\rho^+\pi^-} & = & 0.15 \pm 0.25^{\text{stat}} \pm 0.03^{\text{syst}} \end{array}}$$

$\longrightarrow$ another 2σ effect for C ?

- recasting $(A, C, \Delta C)$ in a more familiar form:

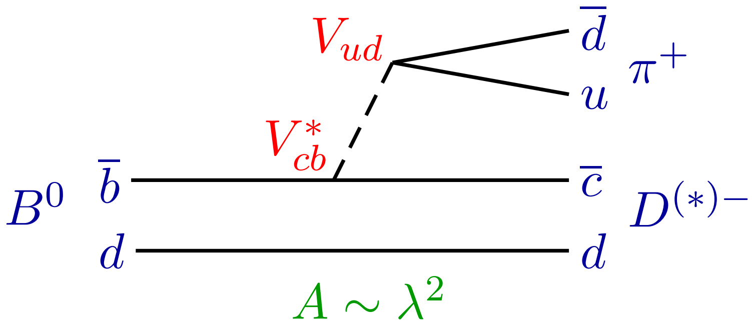
$$A_{-+} \equiv \frac{N(\overline{B}^0 \to \rho^+\pi^-) - N(B^0 \to \rho^-\pi^+)}{N(\overline{B}^0 \to \rho^+\pi^-) + N(B^0 \to \rho^-\pi^+)}$$

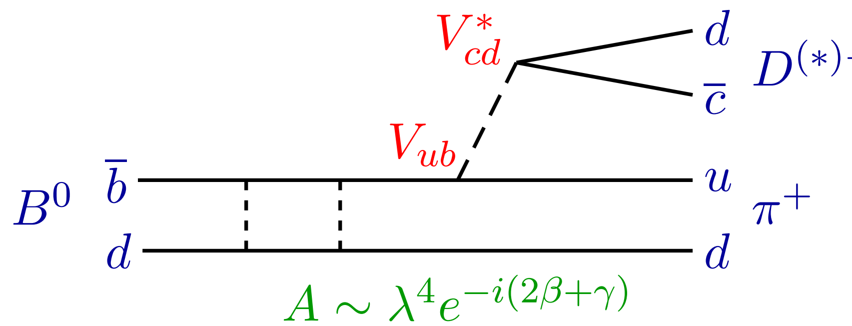
$$A_{+-} \equiv \frac{N(\overline{B}^0 \to \rho^-\pi^+) - N(B^0 \to \rho^+\pi^-)}{N(\overline{B}^0 \to \rho^-\pi^+) + N(B^0 \to \rho^+\pi^-)}$$



- a 2.5σ hint for direct CPV in $B^0 \to \rho^\pm\pi^\mp$!

$sin(2\beta+\gamma)$ *from* $B^0 \to D^{(*)\mp}\pi^{\pm}$





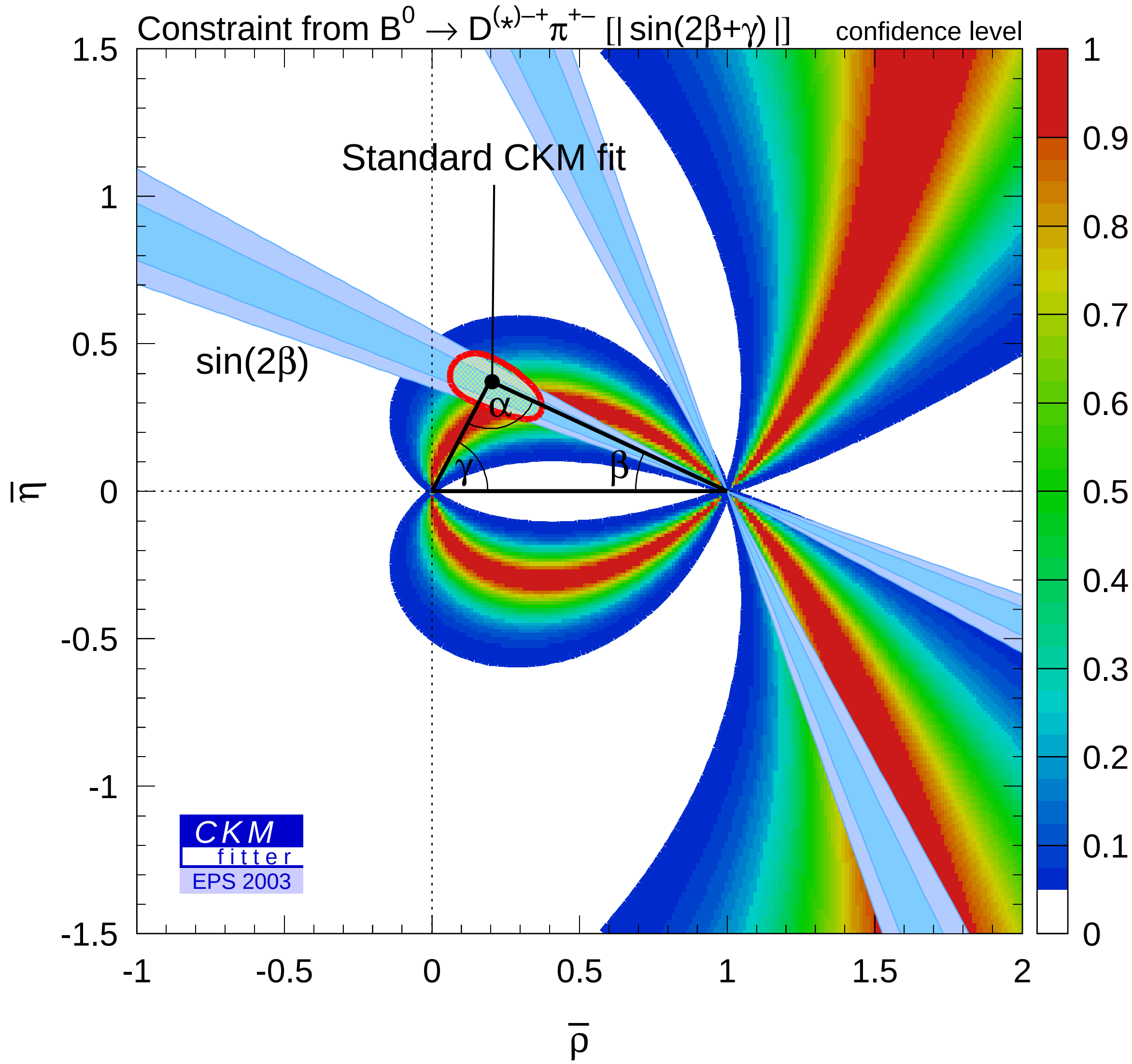
- final state not CP eigenstate $\longrightarrow$
  extract strong phase from $A_{D^-\pi^+}(t)$ *and* $A_{D^+\pi^-}(t)$
- one amplitude suppressed by factor $r \approx 0.02$
  - asymmetry small
  - must estimate $r \longrightarrow$: use $B^0 \to D_s^{*+}\pi^-$ and SU(3)

- Two *BABAR* analyses (run 1 + 2, 88M bbar)
  - from partial reconstruction of $B^0 \to D^{*\mp}\pi^{\pm}$

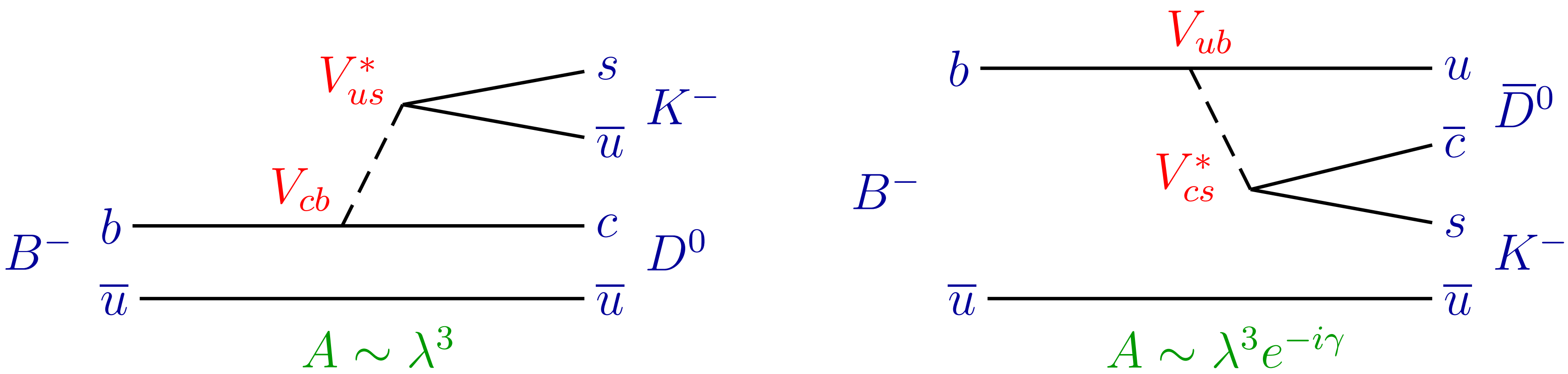
    $|\sin(2\beta+\gamma)| > 0.87$ at 68% CL, > 0.56 at 95% CL   hep-ex/0310037 (subm. to PRL)

  - from exclusive reconstruction of $B^0 \to D^{*\mp}\pi^{\pm}$ and $B^0 \to D^{\mp}\pi^{\pm}$

    $|\sin(2\beta+\gamma)| > 0.69$ at 68% CL   hep-ex/0309017 (subm. to PRL)


Constraint from $B^0 \to D^{(*)-+}\pi^{+-}$ [| sin(2β+γ) |]
confidence level
Standard CKM fit
sin(2β)
α
γ
β
$\bar{\eta}$
$\bar{\rho}$
1.5
1
0.5
0
-0.5
-1
-1.5
-1
-0.5
0
0.5
1
1.5
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
CKM fitter
EPS 2003

γ *from* $B^- \to D^{(*)0} K^{(*)-}$



- interfere for final states common to D^0 and $\overline{D}^0$
- relative weak phase γ, relative size
  $r_b \equiv |A(B^- \to \overline{D}^0 K^-)/A(B^- \to D^0 K^-)| \approx 0.1 - 0.4$
- the larger r_b, the more interference

- different strategies, among others
  - Gronau, London, Wyler [1,2]: use $D^0 \!\to$ CP eigenstates
    $\longrightarrow$ large yields, small asymmetries
  - Atwood, Dunietz, Soni [3]: equalize interfering amplitudes,
    e.g. $B^- \to K^-[K^+\pi^-]_{D^0}$ and $B^- \to K^-[K^+\pi^-]_{\overline{D}^0}$
    $\longrightarrow$ small yields, large asymmetries

[1] M. Gronau and D. London, PLB253, 483 (1991).
[2] M. Gronau and D. Wyler, PLB265, 172 (1991).
[3] D. Atwood, I. Dunietz and A. Soni, PRL78, 3257 (1997).

γ: *Gronau, London, Wyler method*

- use D^0 decays to CP eigenstates

  CP even : $D^0_{CP+} = (D^0 + \overline{D}^0)/\sqrt{2} \;\; \rightarrow \pi^+\pi^-, K^+K^-$

  CP odd : $D^0_{CP-} = (D^0 - \overline{D}^0)/\sqrt{2} \;\; \rightarrow K^0_S\pi^0, K^0_S\phi, \ldots$

- extract γ by measuring the four ratios

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

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

  (δ_b is the strong phase difference)

- *BABAR* measurement on 82/fb (hep-ex/0311032, submitted to PRL)

$$\boxed{\begin{array}{lcl} A_{CP+} & = & 0.07 \pm 0.17 \pm 0.06 \\ \left.\begin{array}{l} R(K/\pi)_{CP+} \\ R(K/\pi) \end{array}\right. & \begin{array}{c} = \\ = \end{array} & \left.\begin{array}{l} (0.0831 \pm 0.0035^{\mathsf{stat}} \pm 0.0020^{\mathsf{syst}}) \\ (0.088 \pm 0.016^{\mathsf{stat}} \pm 0.005^{\mathsf{syst}}) \end{array}\right\} R_{CP+} \approx 1.06{\pm}0.21 \end{array}}$$

- results for CP odd final states are coming

- current statistical uncertainties too large for useful bound on γ
  $\longrightarrow$ need to use all the '$(*)$' modes as well

Summary

The *BABAR* experiment is in great shape ...

- $\sin 2\beta$
  - measurements for $B^0 \to \phi K_S^0$ and $B^0 \to K_S^0 \pi^0$

$\longrightarrow$ *is there evidence for physics beyond the SM in $b \to s$ penguin?*

- $\sin 2\alpha$
  - update of $B^0 \to \pi^+\pi^-$, observation of $B^0 \to \pi^0\pi^0$
  - polarization of $B^0 \to \rho^+\rho^-$, hint for direct CPV in $B^0 \to \rho^\pm\pi^\mp$

$\longrightarrow$ *is $B^0 \to \rho^+\rho^-$ the golden mode for measuring α?*

- γ
  - $\sin(2\beta + \gamma)$ in $B^0 \to D^{(*)\pm}\pi^\mp$
  - γ in $B^- \to DK$

$\longrightarrow$ *is γ more accessible than we thought?*

... the key to answering these questions is more data!

Backup slides

Gamma: projections for GWL+ADS

- projection for 500 fb^{-1}
- input parameters:

$$\boxed{\gamma = 75^o,\ \delta_b = 30^o,\ \delta_d = 15^o}$$

- scenarios:
  - GWL alone
  - GWL + ADS($K\pi$)
  - GWL + ADS($K\pi$) + δ_d from CLEO-c
- The value of r_b makes all the difference .