B Decays to Measure g

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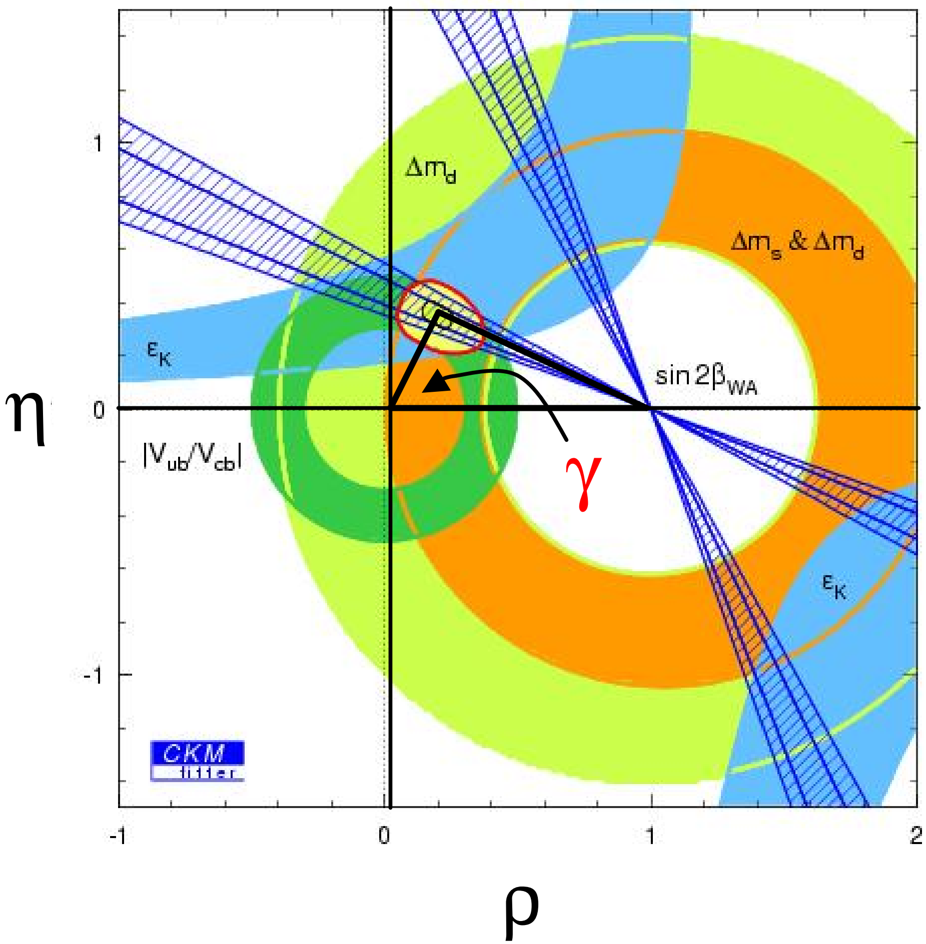
Background



- CP violation with $B^0 \to \psi K_S$ ($\sin 2\beta$) is well established
- Agrees with Standard Model
- Now we need to overconstrain the unitarity triangle to check consistency

- $\gamma = \arg(V_{ud} V_{ub}^{*} \,/\, V_{cd} V_{cb}^{*})$
- $\gamma = -\arg(V_{ub})$
  in standard phase convention

- Results from BaBar at PEP-II: $e^+e^- \to \Upsilon(4S) \to BB_{bar}$
- ~88 million BB_{bar} pairs

Many Methods – none are easy

- Amplitude relationships with $B^- \to D^0_{CP} K^-$ and friends
  - "Squashed" amplitude triangles:
    $BR(B^- \to \bar{D}^0 K^-) \ll BR(B^- \to D^0 K^-)$
  - Interference involving doubly Cabibbo suppressed D^0 decays

- $\sin(2\beta+\gamma)$ with $B^0 \to D^{(*)-} \pi^+, \rho^+, a_1^+, \ldots$
  - Cabibbo suppressed $B^0 \to D^{(*)+} \pi^-$
  - Use $B^0 \to D_s^{(*)} \pi$ and SU(3) to estimate $B^0 \to D^{(*)+} \pi^-$
  - Progress on both full and partial reconstruction techniques

- $B \to \pi\pi, K\pi, KK$
  - Several options with various theoretical trade-offs

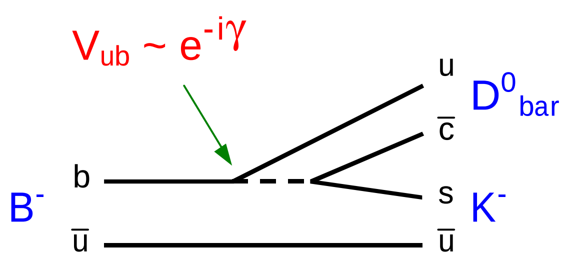
$B^{\pm}$ ® D^0_{CP} $K^{\pm}$ and friends

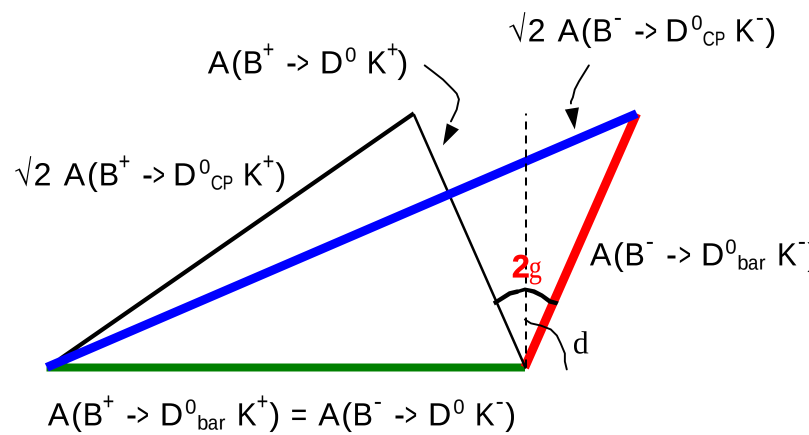
- $D^0_{CP} = (D^0 \pm D^0_{bar}) / \sqrt{2}$: CP even or odd decays, e.g. K^+K^-
- Measure sides of amplitude triangles to determine γ
  - $\sqrt{2}\, A(B^- \to D^0_{CP}K^-) = A(B^- \to D^0K^-) \pm A(B^- \to D^0_{bar}K^-)$
  - $\sqrt{2}\, A(B^- \to D^0_{CP}K^-) = A(B^- \to D^0K^-) \pm |A(B^- \to D^0_{bar}K^-)|\, e^{-i\gamma}e^{i\delta}$

  strong phase (arrow to $e^{i\delta}$)

  weak phase (arrow to $e^{-i\gamma}$)

- Sensitivity to γ depends on $r = |A(B^- \to D^0_{bar}K^-)| / |A(B^- \to D^0K^-)|$





B^- ® D^0 K^-

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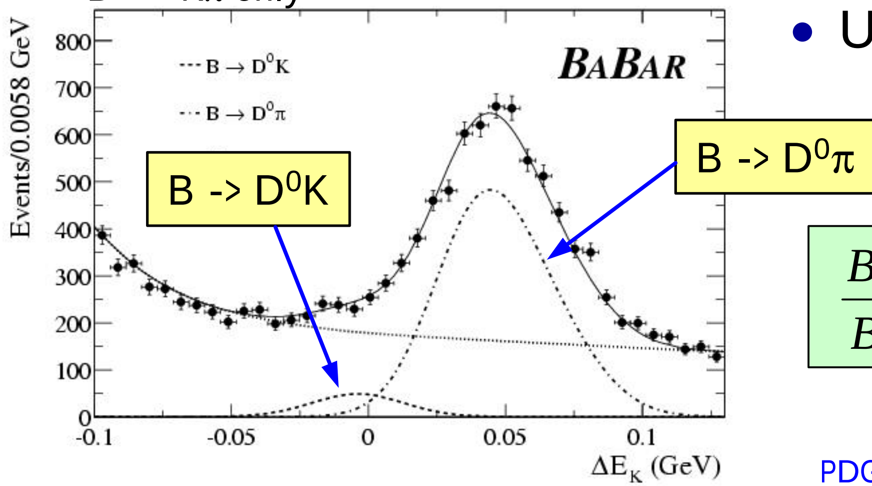
D^0 -> $K\pi$ only



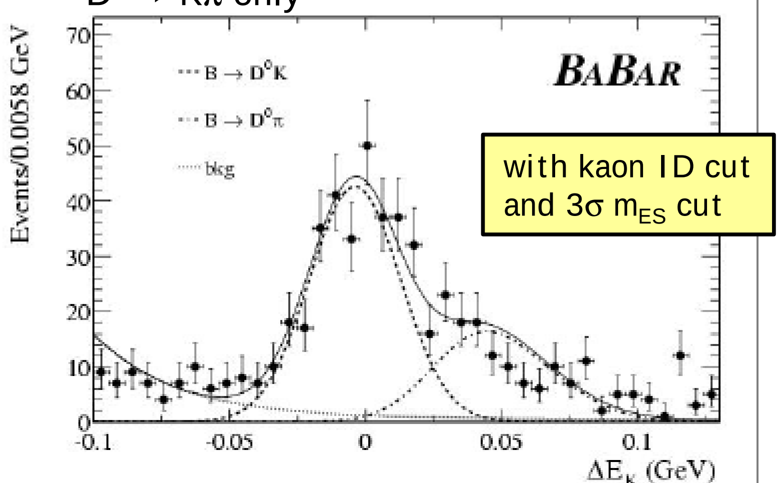
- Use $D^0 \to K^-\pi^+, K^-\pi^+\pi^-\pi^+, K^-\pi^+\pi^0$

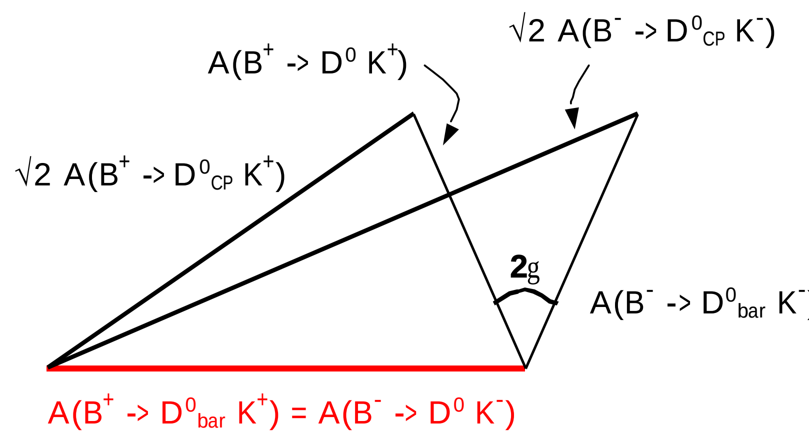
$$\frac{BF(B^- \to D^0 K^-)}{BF(B^- \to D^0 p^-)} = (8.31 \pm 0.35 \pm 0.20)\%$$

(81M BB_{bar} pairs; 75 fb^{-1})

PDG: $BF(B^- \to D^0\pi^-) = (5.3\pm0.5)\times10^{-3}$

D^0 -> $K\pi$ only





$B^{\pm}$ ® D^0_{CP} $K^{\pm}$

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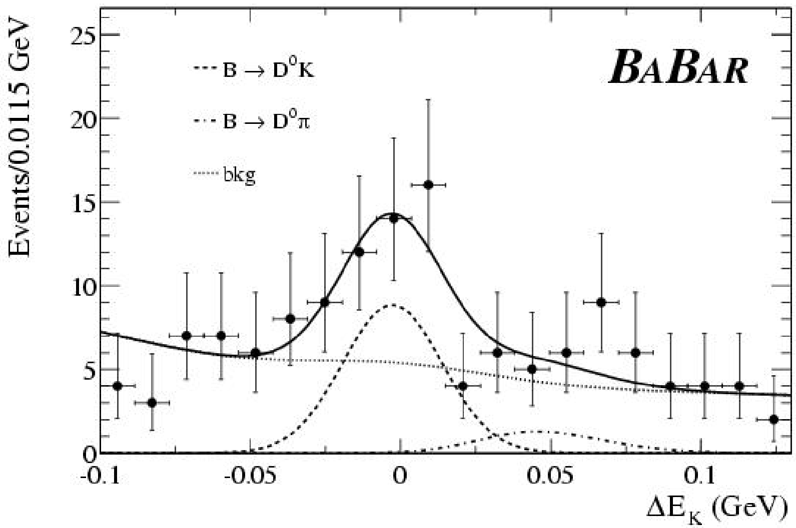
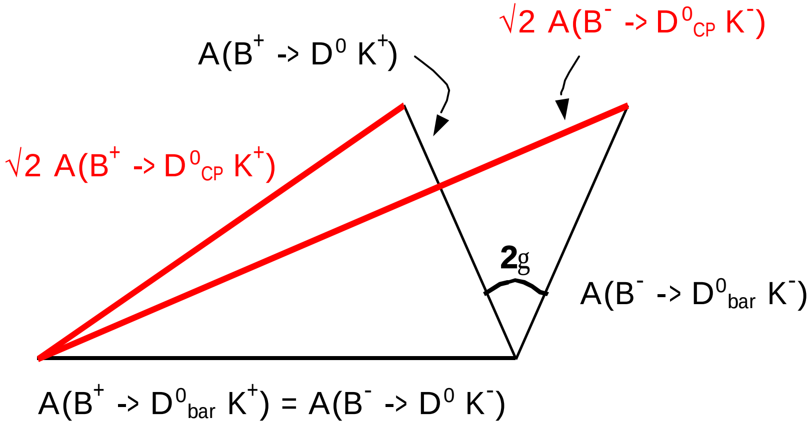
- $B^{\pm} \rightarrow D^0[K^+K^-]$ $K^{\pm}$
  - 36.8 ± 8.4 ± 4.0 signal events
- $B^{\pm} \rightarrow D^0[\pi^+\pi^-]$ $K^{\pm}$
  - Upcoming
  - backgrounds from B -> ππK





$B^{\pm}$ ® D^0_{CP} $K^{\pm}$ and friends

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- Direct CP asymmetry from D^0_{CP} states:

strong phase

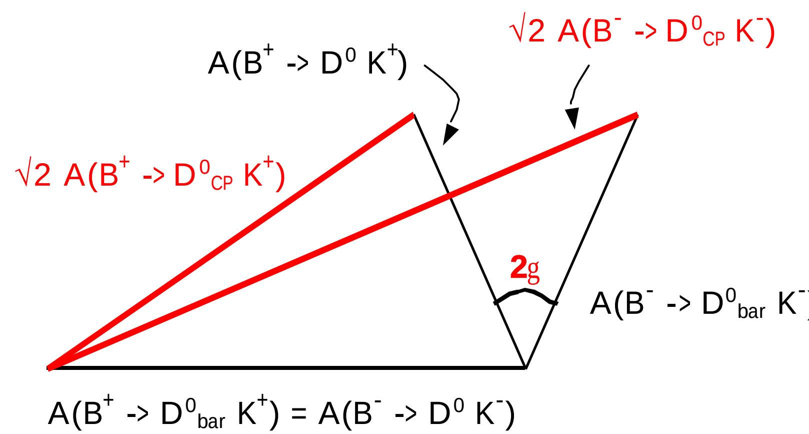
weak phase

$$A_{CP} = \frac{BF(B^- \to D^0_{CP}K^-) - BF(B^+ \to D^0_{CP}K^+)}{BF(B^- \to D^0_{CP}K^-) + BF(B^+ \to D^0_{CP}K^+)} = \frac{\pm 2r \sin d \sin g}{1 \pm 2r \cos d \cos g + r^2}$$

$$r \equiv \frac{|A(B^- \to \overline{D}^0 K^-)|}{|A(B^- \to D^0 K^-)|} \sim 0.2$$

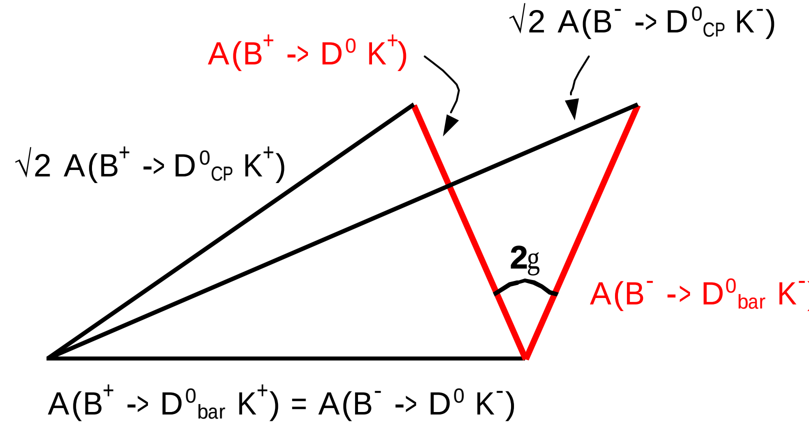
$A_{CP} = 0.17 \pm 0.23 +0.09/-0.07$

(81M BB_{bar} pairs; 75 fb^{-1})



B^{-} ® D^{0}_{bar} K^{-}

- Hard: $BR(B^- \to D^0_{bar} K^-) \ll BR(B^- \to D^0 K^-)$
- Interference from doubly Cabibbo suppressed D^0 decays:
  - B^- -> $D^0_{bar} K^-$ (small)
    --> $K^+\pi^-$ (big)
  - B^- -> $D^0 K^-$ (big)
    --> $K^+\pi^-$ (small)
- Plan:
  - Measure B^- -> $D^0_{(bar)}$ K^-
    w/ D^0_{bar} -> $K^+\pi^-$, $K^+\pi^-\pi^+\pi^-$, $K^+\pi^-\pi^0$
  - Measure Multiple D^0_{CP} modes
  - See Gronau, hep-ph/0211282



$B^{\pm} \rightarrow D^0_{CP} K^{\pm}$ Summary

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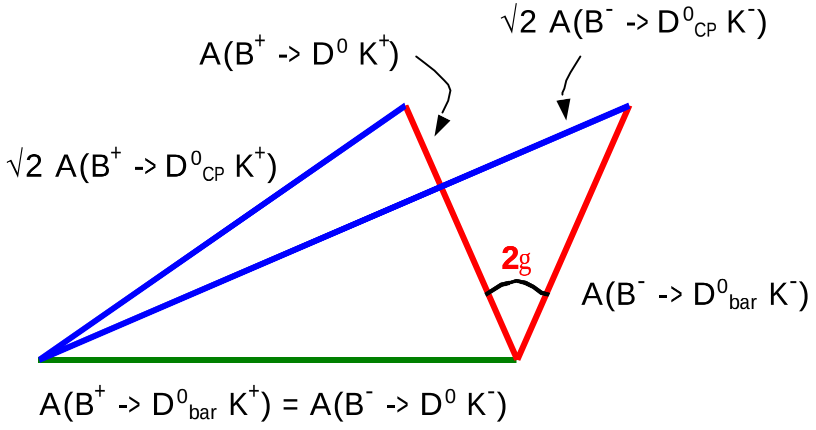
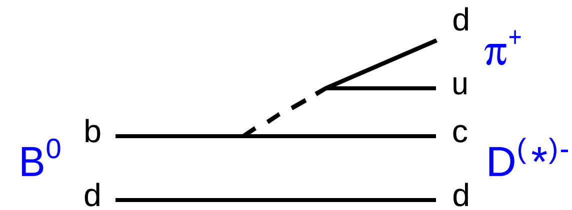
- $B^- \to D^0 K^-$ measured (81M BB_{bar} pairs; 75 fb^{-1})
  - $R(B \to D^0K/D^0\pi) = (8.31 \pm 0.35 \pm 0.20)\%$
- $D^0_{CP} \to K^+K^-$: initial results available
  - Direct Asymmetry: $A_{CP} = 0.17 \pm 0.23 +0.09/-0.07$
  - More modes (e.g. $D^0_{CP} \to \pi\pi$) in progress
  - More data coming too...
- Cabibbo suppressed modes in progress...



sin(2b + g) with B^0 ® D$^{(*)}$p

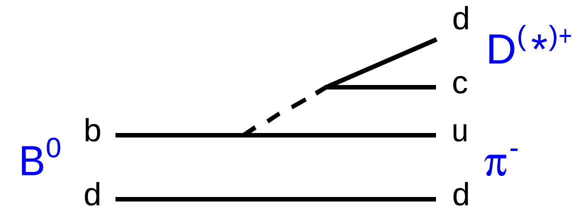
- Both $D^{(*)+}\pi^-$ and $D^{(*)-}\pi^+$ from B^0 and B^0_{bar}
  - Interference -> CP violation
  - B^0 B^0_{bar} mixing : $e^{-i2\beta}$
  - b -> u : $V_{ub} \sim e^{-i\gamma}$

  (brace joining the last two items:) in standard phase convention



Cabibbo Favored

- Large difference in branching fractions:
  - $BF_{favored}(B^0 \rightarrow D^{(*)-}\pi^+) \sim 3\times10^{-3}$
  - $BF_{suppressed}(B^0 \rightarrow D^{(*)+}\pi^-) \sim 10^{-6}$
  - Small CP violating effect expected (2%)



Cabibbo Suppressed

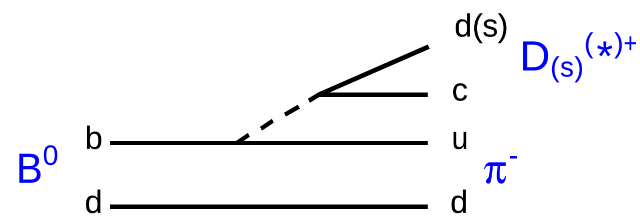
- Measure one weak phase ($2\beta+\gamma$) and a strong phase (δ) for each mode

sin(2b + g) : B^0 ® $D_s^{(*)}$p

hep-ex/0207053

too small to measure w/ current data

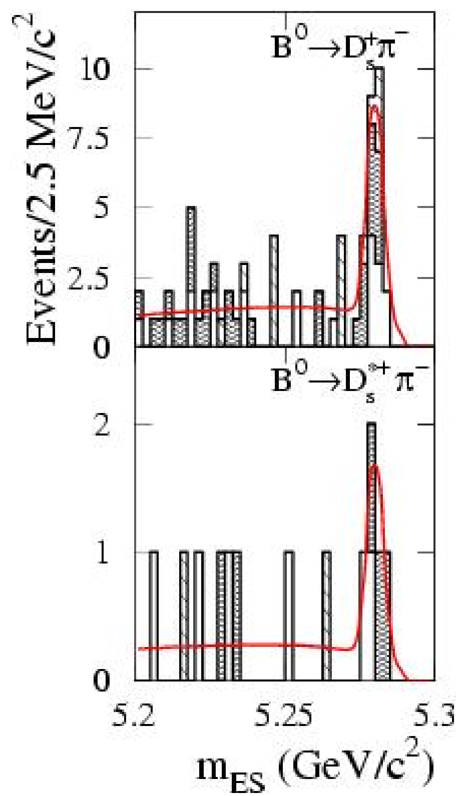
- $|\lambda^{(*)}| = \dfrac{|A(\bar{B}^0 \to D^{(*)-}\pi^+)|}{|A(B^0 \to D^{(*)-}\pi^+)|} \sim 0.02$



- Use $B^0 \to D_s^{(*)+}\pi^-$ to estimate $|A(B^0 \to D^{(*)+}\pi^-)|$ via SU(3) symmetry
  - Introduces theoretical uncertainty

- $B^0 \to D_s^+\pi^-$
  - Use $D_s^+ \to \phi\pi^+$, K_sK^+, $\bar{K}^*K^+$
  - 21.4 ± 5.1 signal events
  - $BF(B^0 \to D_s^+\pi^-) = (3.2 \pm 0.9 \pm 1.0) \times 10^{-5}$
  - 84M $B\bar{B}$ pairs; 78 fb^{-1}

- $BF(B^0 \to D_s^{*+}\pi^-) < 4.1 \times 10^{-5}$ [90% CL]



sin(2b + g) : Fully reconstructed B⁰ ® D(*)p

- Fully reconstruct both Dπ and D*π
- Time evolution for each state *f*

$$f_{\pm}(\Delta t) = \frac{e^{-|\Delta t|/t}}{4t}[1 \mp C_f \cos(\Delta m_d \Delta t) \mp S_f \sin(\Delta m_d \Delta t)]$$

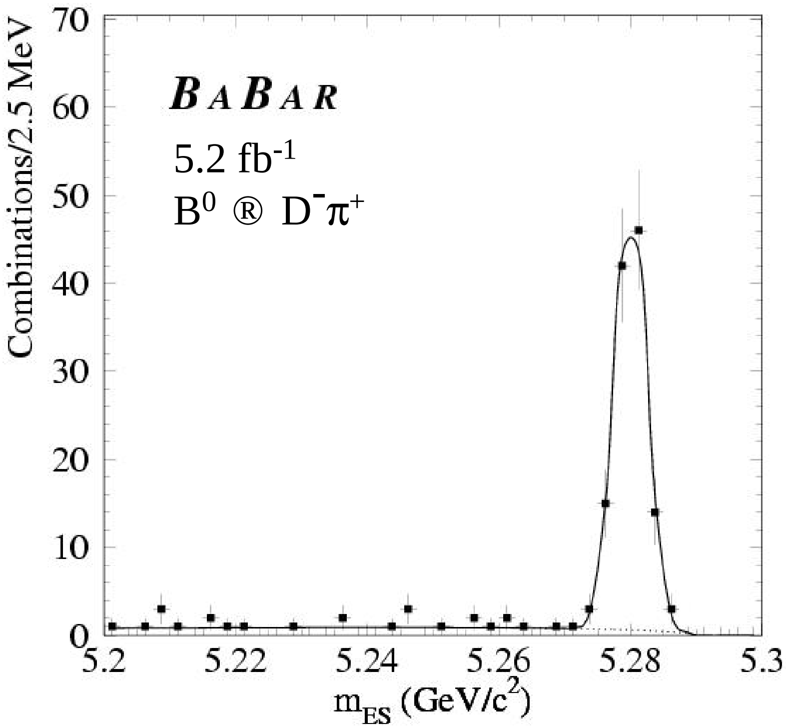
$$C_f = \frac{1-|l_f|^2}{1+|l_f|^2} \qquad S_f = \frac{-2\,\mathrm{Im}\, l_f}{1+|l_f|^2} \qquad l_f = \frac{q}{p}\frac{\overline{A}_f}{A_f}$$

- Four λ's include one weak phase (2β+γ) and two strong phases ($\delta^{(*)}$)

$\arg(\lambda_{D^+\pi^-}) = -(2\beta+\gamma+\delta)$ $\qquad$ $\arg(\lambda_{D^{*+}\pi^-}) = -(2\beta+\gamma+\delta^*)$

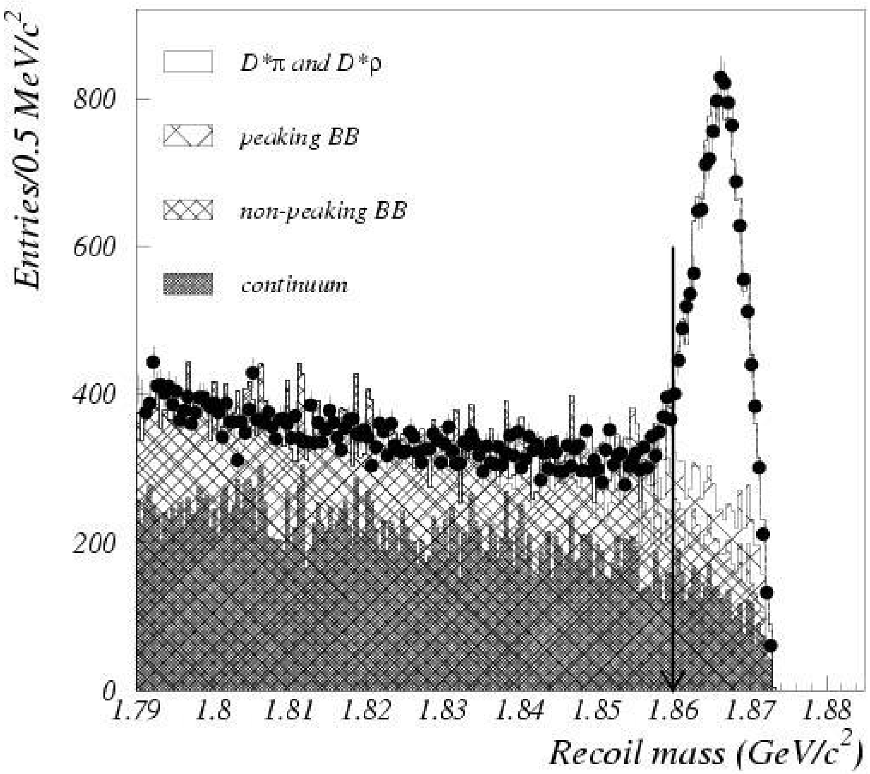
$\arg(\lambda_{D^-\pi^+}) = -(2\beta+\gamma-\delta)$ $\qquad$ $\arg(\lambda_{D^{*-}\pi^+}) = -(2\beta+\gamma-\delta^*)$

sin(2b + g) : Fully reconstructed B^0 ® $D^{(*)}$p



- We have thousands of fully reconstructed B^0 -> $D\pi$ and B^0 -> $D^*\pi$
- The $\sin(2\beta+\gamma)$ fitter is being studied
- The results aren’t unblinded yet
- m_{ES} from B^0 -> $D^-\pi^+$ with 5.2 fb^{-1}
  - very clean signal
  - now we have almost 20x more data

sin(2b + g) : Partially reconstructed B⁰ ® D*p



20.3 fb^{-1} : only a fraction of the current data, but shows approximate S/B

- Another method:
  Partial D* reconstruction
  - Reconstruct low momentum π in D* -> Dπ, but not rest of D
  - More signal events, but also more background
  - N(tagged) > 40 000 events in full dataset

sin(2b + g) : Partially reconstructed B^0 ® D*p

- Unreconstructed D daughters could affect tag side vertex position measurement
- Validate partial reco. method with a lifetime measurement
  - $\tau(B^0) = (1.510 \pm 0.040 \pm 0.041)$ ps (with 20.7 fb^{-1})
  - cf PDG $\tau(B^0) = (1.548 + 0.032)$ ps
  - hep-ex/0212012 submitted to PRD
- Proceeding with $\sin(2\beta+\gamma)$ fit, results not unblinded yet…

B^0 ® pp, Kp, KK

- Amplitude relationships with B -> ππ, Kπ, KK may also measure or constrain γ
- Theoretical interpretation is complicated:
  - Penguins
  - Rescattering contributions
  - SU(3) symmetry breaking
  - etc.
  - For a recent brief review, see Fleischer, hep-ph/0207324

- For now we'll quote branching fractions (BF) and Asymmetries (A) and let you plug the numbers into your favorite theory…

B^0 ® pp, Kp, KK

hep-ex/0207055
hex-ex/0207065
hex-ex/0207063
hep-ex/0206053

Mode	BF x 10^{-6}	A
$B^0 \to \pi^0\pi^0$	< 3.6 [90% CL]	
$B^0 \to \pi^+\pi^-$	$4.7 \pm 0.6 \pm 0.2$	S= 0.02 ± 0.34 ; C= -0.30 ± 0.25
$B^0 \to K^0\pi^0$	$10.4 \pm 1.5 \pm 0.8$	$0.03 \pm 0.36 \pm 0.09$
$B^0 \to K^+\pi^-$	$17.9 \pm 0.9 \pm 0.7$	$-0.102 \pm 0.050 \pm 0.016$
$B^0 \to K^+K^-$	< 0.6 [90% CL]	
$B+ \to \pi^+\pi^0$	$5.5\,^{+1.0}_{-0.9} \pm 0.6$	$-0.03\,^{+0.18}_{-0.17} \pm 0.02$
$B^+ \to K^+\pi^0$	$12.8\,^{+1.2}_{-1.1} \pm 1.0$	$-0.09 \pm 0.09 \pm 0.01$
$B^+ \to K^0\pi^+$	$17.5\,^{+1.8}_{-1.7} \pm 1.3$	$-0.17 \pm 0.10 \pm 0.02$
$B^+ \to K^+K^0_{bar}$	< 1.3 [90% CL]	

(81 fb^{-1} except $K^0\pi^+$, $K^+K^0_{bar}$: 54 fb^{-1})

Many More Modes

- Exploring many other modes which could measure γ or $2\beta+\gamma$:
  - $B \to D^{(*)}K^{(*)}$
  - $B \to D^{(*)}K_S$
  - $B \to D\ K_S\ \pi$
  - $B \to D^{(*)}\ K^{(*)}\ \pi$
  - Dalitz analysis of $B \to \pi\pi\pi$
  - etc.

Outlook

- The Good News: We're making progress
  - $B^- \to D^0_{CP} K^-$
    - Several sides of amplitude triangles measured
    - $A_{CP} = 0.17 \pm 0.23 +0.09/-0.07$
  - $\sin(2\beta+\gamma)$ with $B^0 \to D^{(*)}\pi$
    - Decay modes reconstructed
    - Lifetime measurement checks method
    - $\sin(2\beta+\gamma)$ fit results in progress
  - $B^0 \to \pi\pi, K\pi, KK$
    - Many branching fractions measured
    - Need theoretical input for interpretation
- Final story will likely involve:
  - B factory measurements of many decay modes
  - Hadronic accelerator results with B_s decays
  - Theoretical input