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Direct CP asymmetries and charmless branching fractions with BABAR

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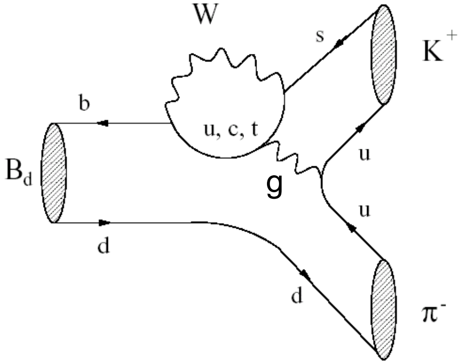
For the BABAR Collaboration

Overview

- Motivation: Direct CP Violation (CPV)
  New Physics sensitivity e.g. $X_S\gamma$, ϕK
  Penguins



- Event Selection Methods

- Results: Charmless decays, $K^*\gamma$, $D^0_{CP}K^-$

- Summary and outlook

Direct CP Violation

$$|A_f|^2 - |\overline{A}_{\overline{f}}|^2 \neq 0 \rightarrow$$ direct CPV

- **need interference between diagrams with different strong (δ_i) and weak phases (ϕ_i) :**

$$\rightarrow |A_f|^2 - |\overline{A}_{\overline{f}}|^2 = -2\sum_{i,j} A_i A_j \sin\left(\phi_i - \phi_j\right)\sin\left(\delta_i - \delta_j\right)$$

- **Direct CPV only seen in $K^0\overline{K}^0$; $\varepsilon' \sim$ few 10^{-6}**
- **theory predicts large asymmetries in $B^{+/0}$ (few to 80%)**

- **Diagrams from New Physics (e.g. SUSY) can modify SM asymmetries/branching fractions**

- **Experimentally - look for CP asymmetries:**

$$\boxed{A_{CP} = \frac{Br(\overline{B} \to \overline{f}) - Br(B \to f)}{Br(B \to f) + Br(\overline{B} \to \overline{f})}}$$

- **Neutral B – time dependent asymmetry**

direct CPV

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

$C\neq0$ ⟵ direct CPV; e.g. for $\rho\pi$, $\pi\pi$ …

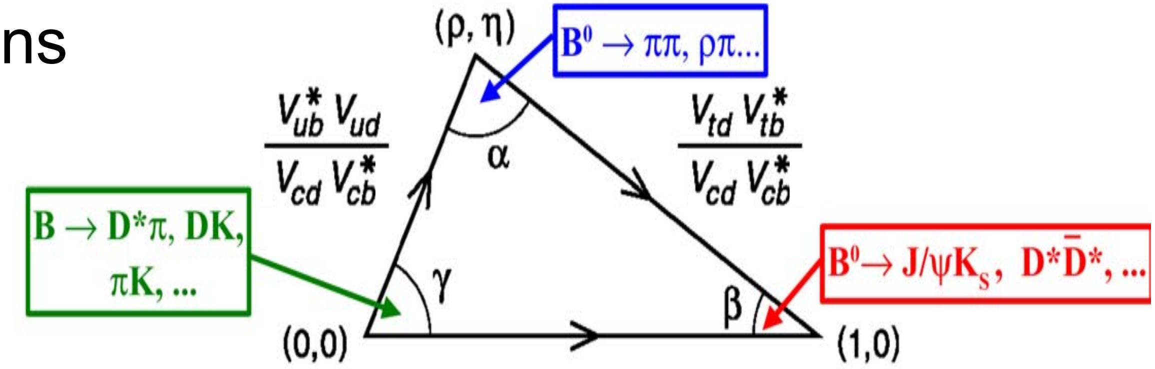
- **Charged B – time integrated asymmetry (no mixing); also used for some B^0 results (e.g. $K^0\pi^0$)**

Searching for direct CPV

- Large A_{CP} requires amplitudes of similar order
  - $b \rightarrow u$: suppressed tree: charmless decays
    - large predicted A_{CP}
  - $b \rightarrow s,d$: penguins: radiative decays
    - small predicted A_{CP}

- Understand penguins

- Access to α and γ



- Sensitive to New Physics effects via loops
  - minimal SUGRA: $B \rightarrow X_s\gamma$, ϕK^+, $K^0\pi^+$ …
  - R-parity Violating SUSY: ϕK_S …
  - SUSY searches – $K^*\gamma$

Experimental Issues

- small branching fractions
  - large continuum background (u,d,s,c)
  - other B background

- charge bias
  - detector: trigger, tracking; reconstruction
  - event selection, particle ID, analysis

- Proof of principle
  - A_{CP} in $J/\psi\pi$, $J/\psi K$ PRD **65** 091101 (2002)
  - $A_{J/\psi\pi} = 0.01 \pm 0.22 \pm 0.01$
  - $A_{J/\psi K} = 0.003 \pm 0.030 \pm 0.004$

small systematic error:

few per mille

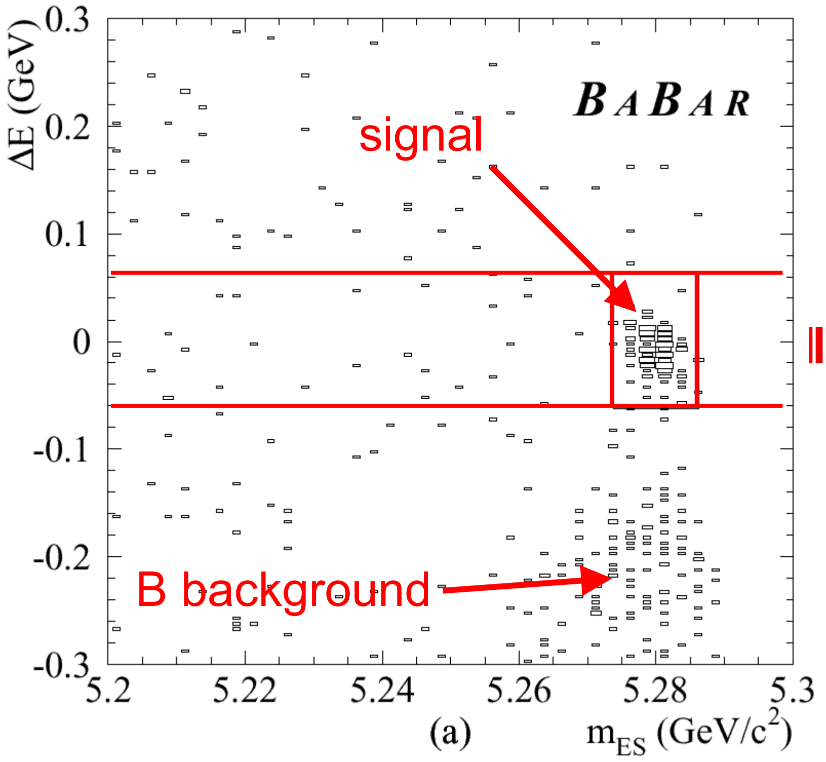
Event Selection Techniques

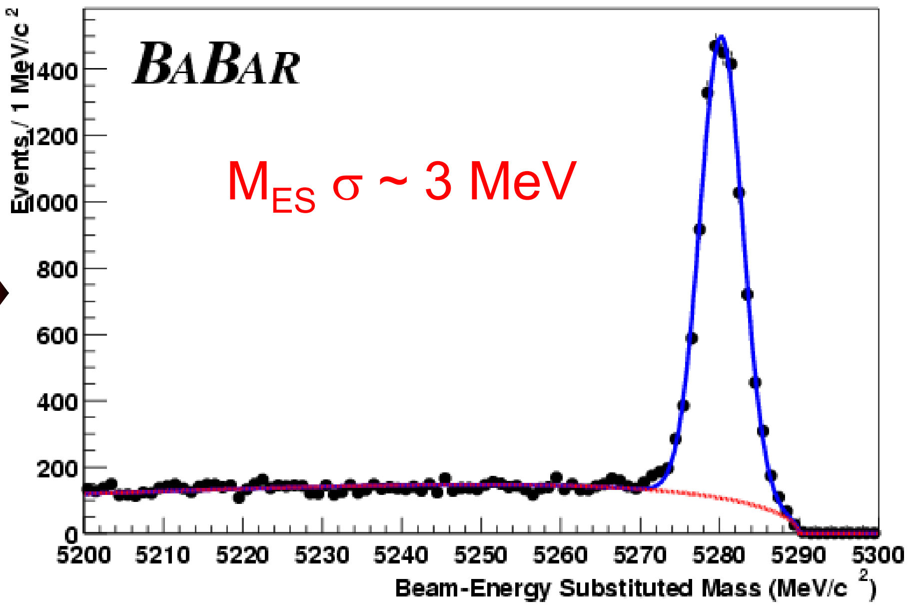
Use beam energy to constrain mass & energy

$$\Delta E = E_B - E^*_{beam}$$

$$m_{ES} = \sqrt{(E^*_{beam})^2 - P_B^2}$$

ΔE σ ~ 15-80 MeV; larger with neutrals

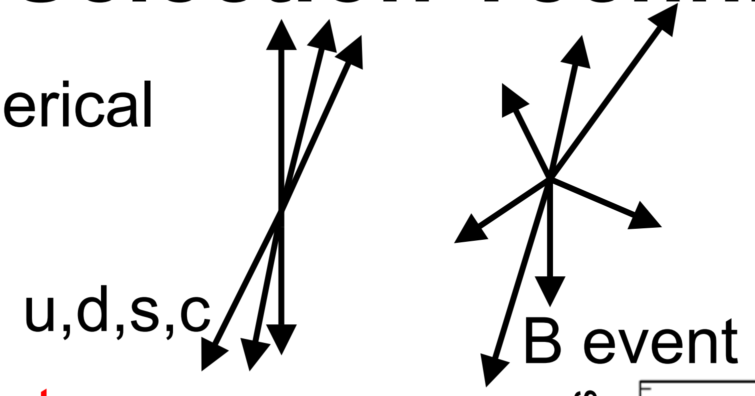




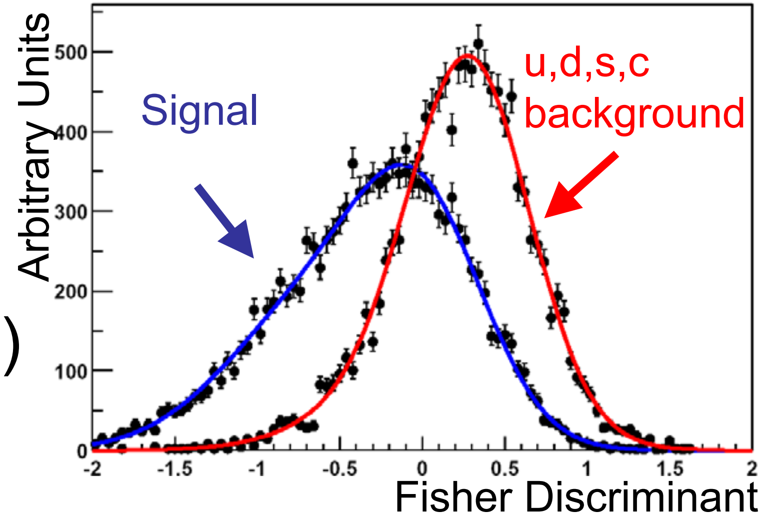
M_{ES} σ ~ 3 MeV

Event Selection Techniques

- B events are spherical
- u,d,s,c is jet-like



- Fisher Discriminants
- Thrust
- Sphericity
- Fox-Wolfram moments
- flavour-tagging (e, μ, K, slow π from other B)



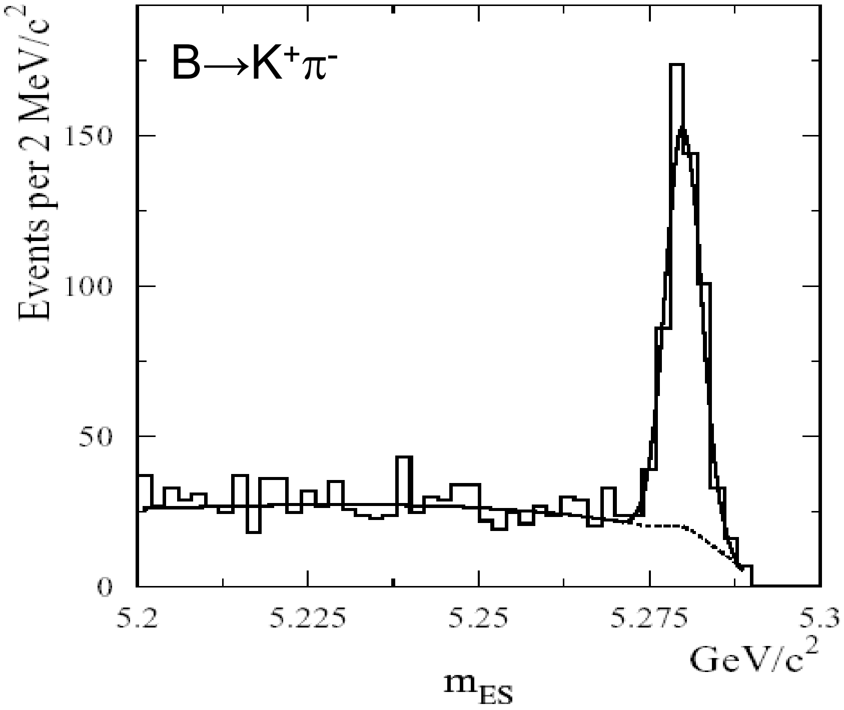
- Maximum Likelihood fits or cut based analysis
- off-resonance & *ΔE* sidebands are used to parameterise light quark background

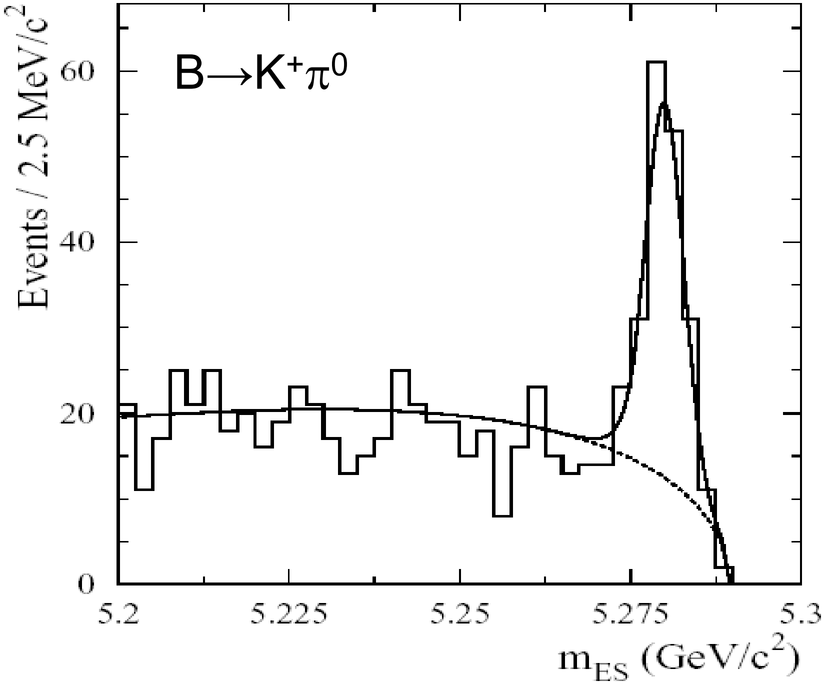
RESULTS

Two body decays

can measure

- α eg. $B\rightarrow\pi^+\pi^-$, $\pi^+\pi^0$, $\pi^0\pi^0$ **see Jim Olsen's talk**
- γ eg. $B\rightarrow K^+\pi^-$, $K^0\pi^+$ using Fleischer Mannel bound
- A_{CP} can be sizeable





Plots have an optimised cut on likelihood ratio

Preliminary

New results → $\sim 88\times10^{6}$ B pairs

$\sim 60\times10^{6}$ B pairs

Mode	N_{EVENTS}	Branching ratio ($\times 10^{-6}$)	A_{CP}
$B^0\to K^+\pi^-$	589 ± 30	$(17.9\pm0.9\pm0.6)$	$-0.102\pm0.050\pm0.016$
$B^+\to K^+\pi^0$	$239\pm22\pm6$	$(12.8\pm1.2\pm1.0)$	$-0.09\pm0.09\pm0.01$
$B^+\to \pi^+\pi^0$	$125^{+23}_{-21}\pm10$	$(5.5\pm1.0\pm0.6)$	$-0.03\pm0.18\pm0.02$
$B^0\to K^0\pi^0$	$86\pm13\pm3$	$(10.4\pm1.5\pm0.8)$	$0.03\pm0.36\pm0.09$
$B^0\to K^+K^-$	<15.9	<0.6 (90% C.L.)	-
$B^+\to K^+K^0$	<10	<1.3 (90% C.L.)	-
$B^+\to K^0\pi^+$	$172\pm17\pm9$	$(17.5\pm1.8\pm1.3)$	$-0.17\pm0.10\pm0.02$

5% ΔA_{CP}

hep-ex/0206053

All upper limits are @ 90% C.L.

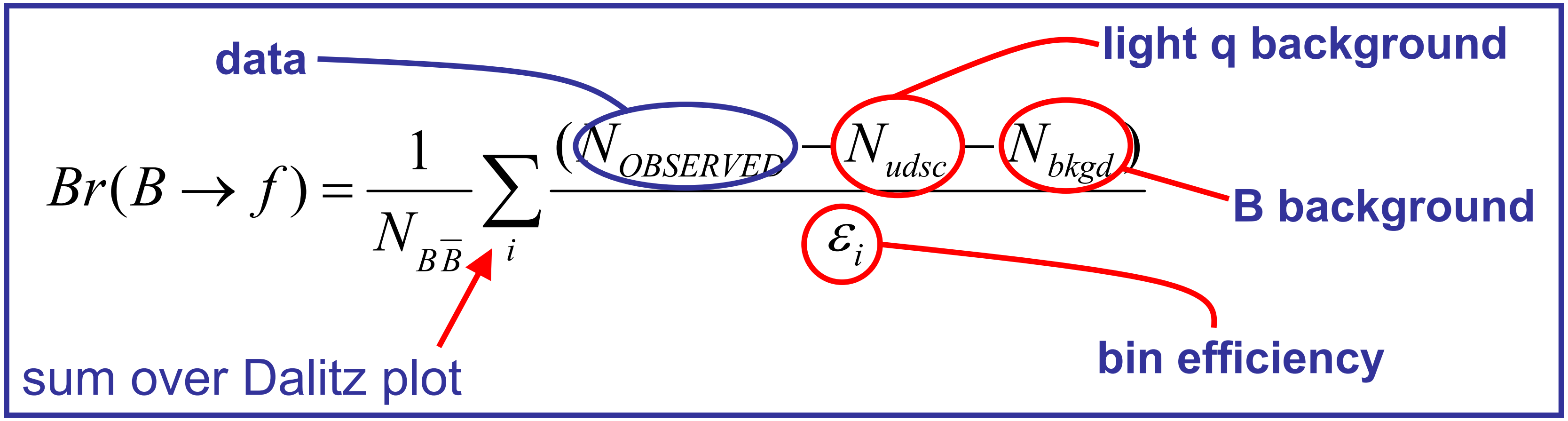
$B \rightarrow hhh$, $h=\pi$, K

Motivation

- measure γ using a full Dalitz plot
- look for direct CPV in charge asymmetry

Method

- cut based analysis across the Dalitz plot for branching ratio:



data

light q background

$$Br(B \to f) = \frac{1}{N_{B\bar{B}}} \sum_i \frac{(N_{OBSERVED} - N_{udsc} - N_{bkgd})}{\varepsilon_i}$$

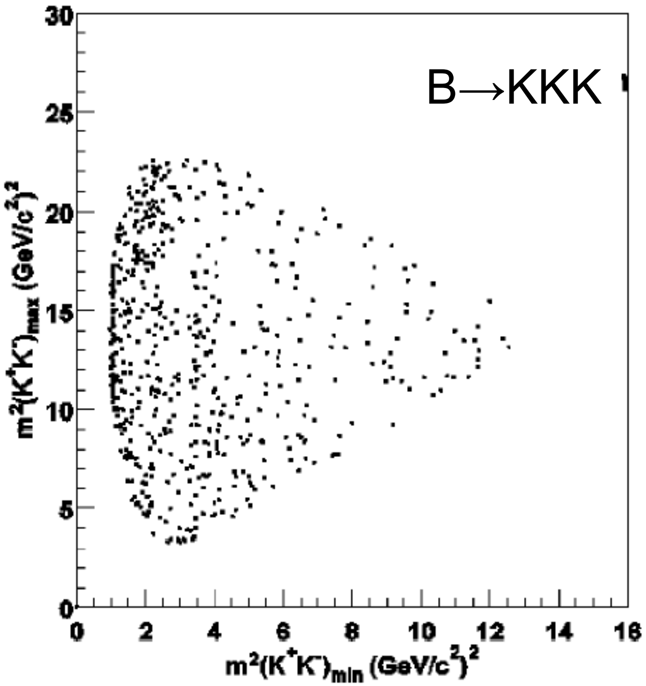
B background

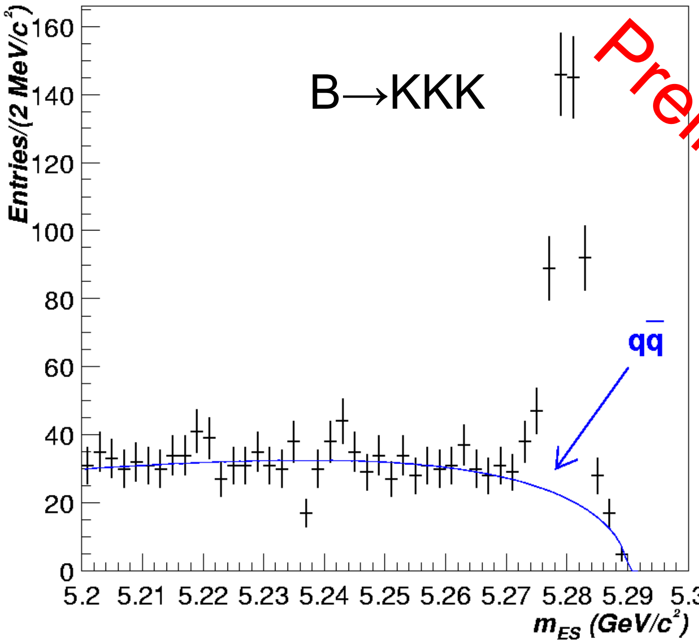
sum over Dalitz plot

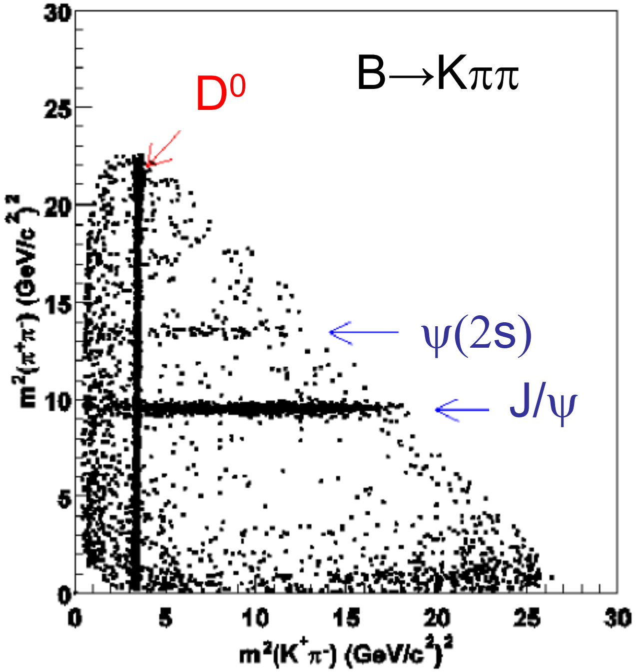
bin efficiency

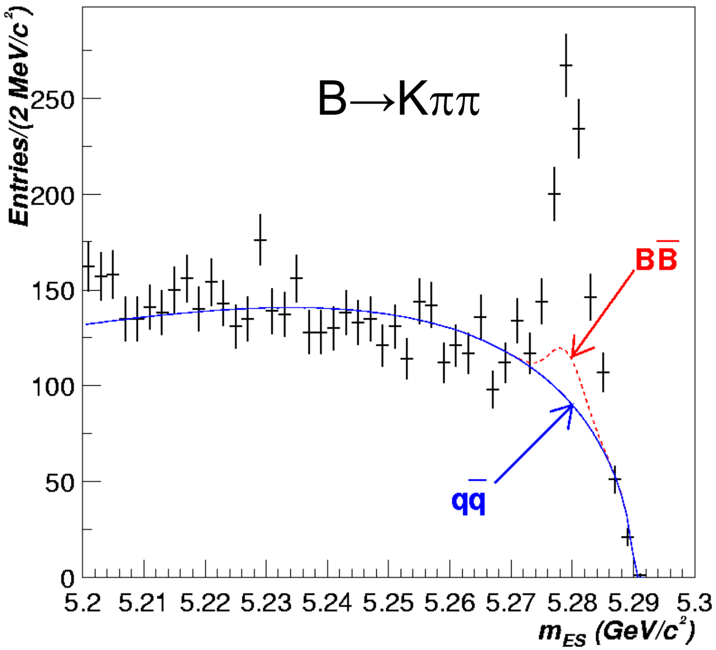
- B backgrounds: J/ψK, Dπ/DK, X-feed; D→$\pi\pi$, Kπ, KK
  - subtract open charm from J/ψ, $\psi_{(2s)}$ and D^0
- measure $Br(B^- \rightarrow D^0\pi^-)$ as a cross check

Preliminary









56.2×10^{6} B pairs

Branching fractions measured across the Dalitz plot

$$Br(B^{\pm}\rightarrow K^{\pm}\pi^{\mp}\pi^{\pm})=(59.2\pm4.7\pm4.9)\times10^{-6}$$

$$Br(B^{\pm}\rightarrow K^{\pm}K^{\mp}K^{\pm})=(34.7\pm2.0\pm1.8)\times10^{-6}$$

$$Br(B^{\pm}\rightarrow \pi^{\pm}\pi^{\mp}\pi^{\pm})<15\times10^{-6}\quad \text{(90\% C.L.)}$$

$$Br(B^{\pm}\rightarrow K^{\pm}K^{\mp}\pi^{\pm})<7\times10^{-6}\quad \text{(90\% C.L.)}$$

- Main systematic uncertainties
  - PID 3 ~ 6%
  - tracking 2.4%

Preliminary

$B \to \eta' K^{(*)}$, ωK, ωπ±

- $B \to \eta' K^{(*)}$, suppressed tree; A_{CP} 4~30% (theory) sensitive to γ
- B→ωK, ωπ±, penguin; A_{CP} ~6% (theory) sensitive to α,γ

$\sim 60 \times 10^{6}\, B\ \ pairs$

preliminary

$Br(B^{\pm} \to \eta' K^{+}) = (67 \pm 5 \pm 5) \times 10^{-6}$

$Br(B^{0} \to \eta' K^{0}) = (46 \pm 6 \pm 4) \times 10^{-6}$

$Br(B^{0} \to \eta' K^{*0}) < 13 \times 10^{-6}$

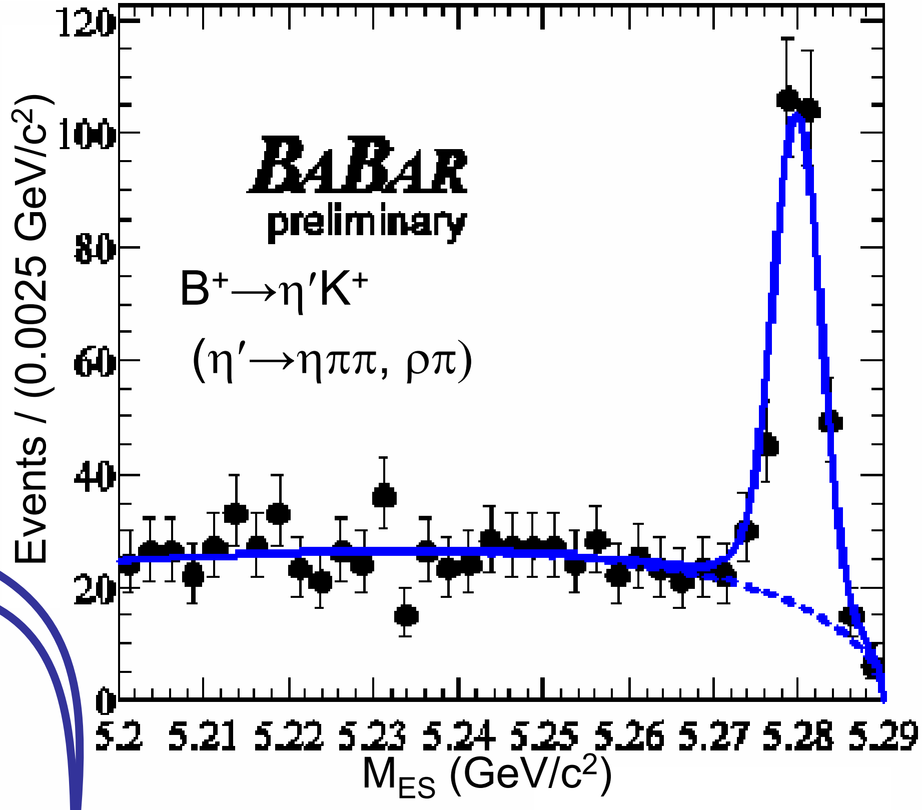
$\sim 22.7 \times 10^{6}\, B\ \ pairs$

$Br(B^{0} \to \omega\pi^{\pm}) = (6.6^{+2.1}_{-1.8} \pm 0.7) \times 10^{-6}$

$\sim 22.7 \times 10^{6}\, B\ \ pairs$

$A_{CP}(B^{\pm} \to \eta' K^{+}) = -0.11 \pm 0.11 \pm 0.02$

$A_{CP}(B^{\pm} \to \omega\pi^{+}) = -0.01^{+0.29}_{-0.31} \pm 0.03$



PRD **65** (2002) 051101

Preliminary

$B^0 \to \omega K^0$

~60×10^6 B pairs

First Observation!

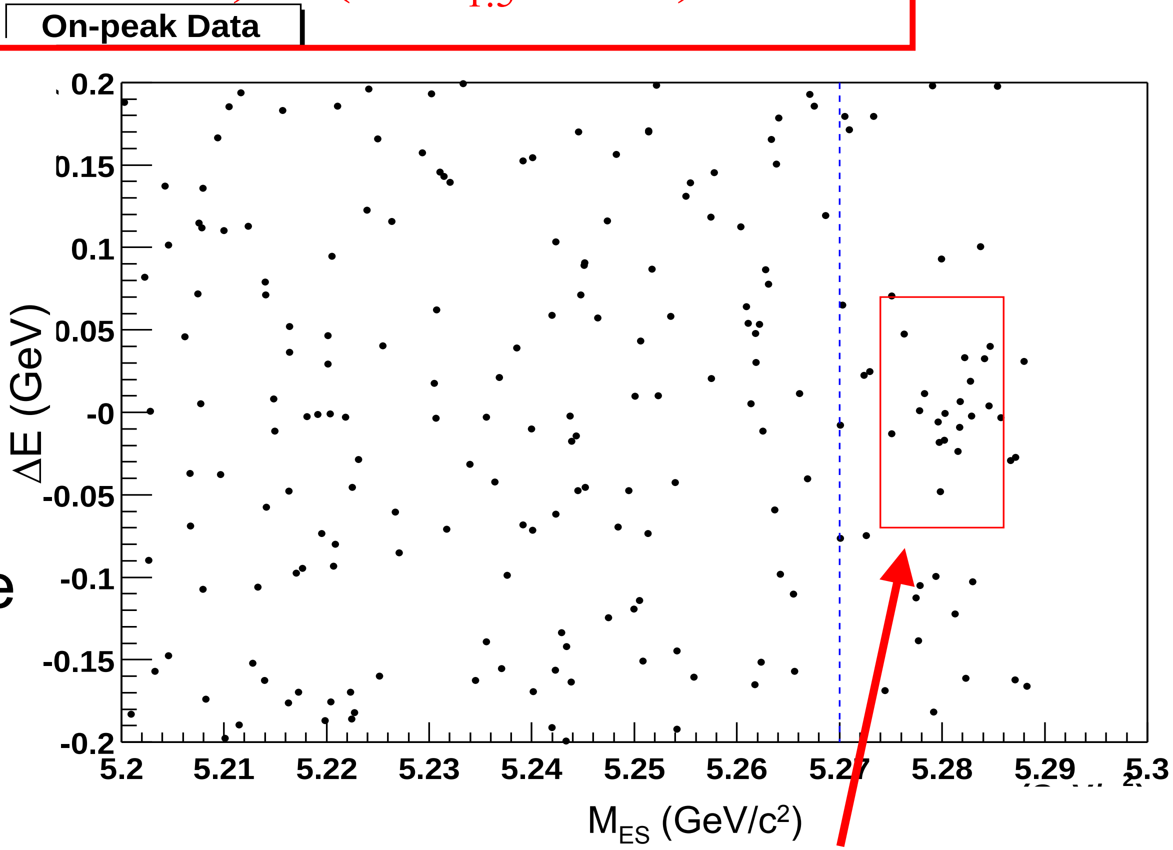
6.6 σ significance (statistical)

Signal yield = $26.6^{+7.7}_{-6.6}$ events

$$Br(B^0 \to \omega K^0) = (5.9^{+1.7}_{-1.5} \pm 0.9) \times 10^{-6}$$

- penguin
- sensitive to α, γ
- expect small A_{CP}

- ML fit
- dominant systematic uncertainty:
  - background shape
  - neutral eff
  - tracking



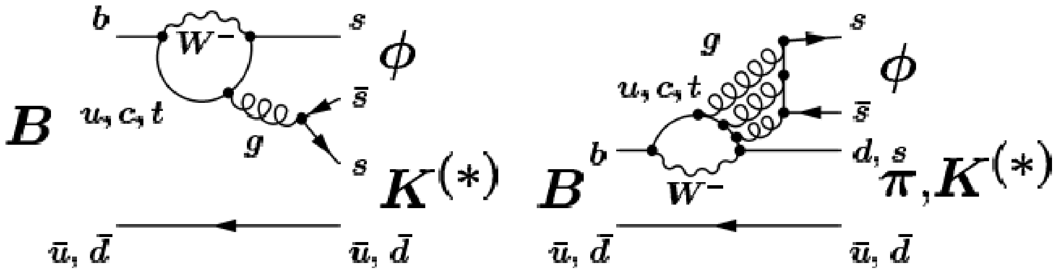
Signal region

$B\to\phi K^{(*)}$, $\phi\pi$

Motivation:

- A_{CP} ~2% in SM
- New Physics
  (A_{CP} up to 30%)
- sin2β if no new physics

see Doug Wright's talk



PRD **65** (2002) 051101

$\sim 22.7\times10^{6}\,B\ \ pairs$

$A_{CP}(B^{\pm}\to\varphi K^{\pm})=-0.05\pm0.20\pm0.03$

$A_{CP}(B^{\pm}\to\varphi K^{*\pm})=-0.43^{+0.36}_{-0.30}\pm0.06$

$A_{CP}(B^{0}\to\varphi K^{*0})=0.00\pm0.27\pm0.03$

$\sim 22.7\times10^{6}\,B\ \ pairs$

PRL **87** 151801 (2001)

$Br(B^{\pm}\to\varphi K^{*\pm})=(9.7\pm^{+4.2}_{-3.4}\pm1.7)\times10^{-6}$

$Br(B^{0}\to\varphi K^{*0})=(8.6^{+2.8}_{-2.4}\pm1.1)\times10^{-6}$

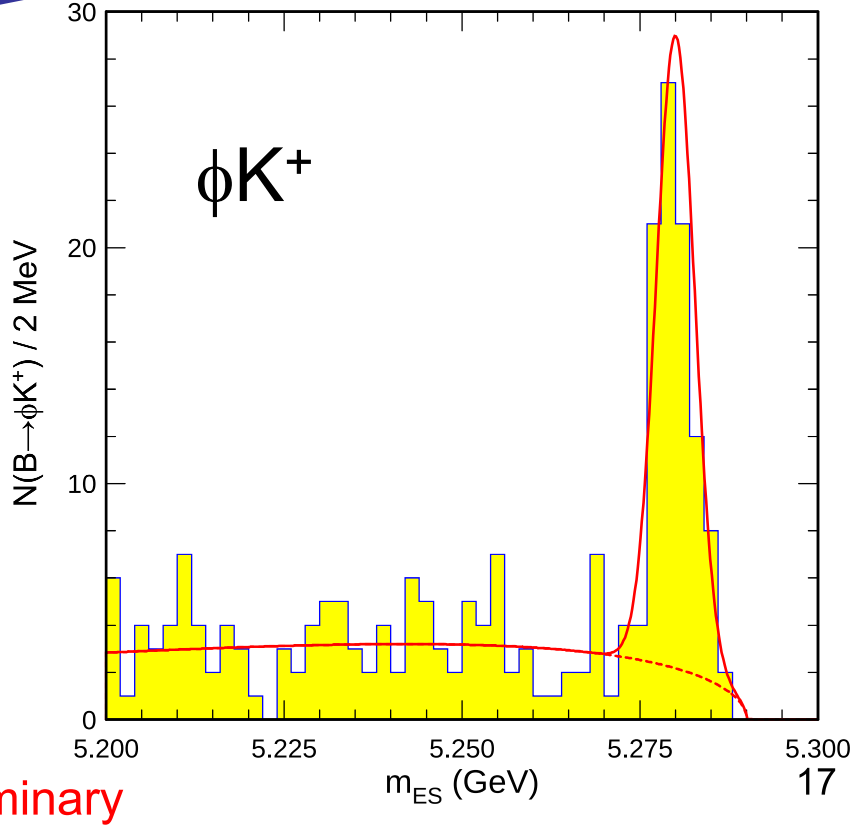
$\sim 60\times10^{6}\,B\ \ pairs$

$Br(B^{\pm}\to\varphi K^{\pm})=(9.2\pm1.0\pm0.8)\times10^{-6}$

$Br(B^{0}\to\varphi K^{0}_{S})=(8.7^{+1.7}_{-1.5}\pm0.9)\times10^{-6}$

$Br(B^{\pm}\to\varphi\pi^{\pm})<0.56\times10^{-6}(90\%\ \ C.L.)$

preliminary



see Erich Varnes' talk

$B^- \to D^0_{(CP)} K^-$

- A_{CP} may be large
- access to γ

$$A(B^+ \to \overline{D}^0 K^+) = |\overline{A}|\, e^{i\delta_1} \quad (V_{cb}^* V_{us})$$

$$A(B^+ \to D^0 K^+) = |A|\, e^{i\delta_2} e^{i\gamma} \quad (V_{ub}^* V_{cs})$$

D° reconstructed:

- in Kπ, Kππ°, Kπππ
- in **K⁺K⁻** (CP=+1 eigenstate)

$$R \equiv \frac{Br(B^- \to D^0 K^-)}{Br(B^- \to D^0 \pi^-)} = (8.31 \pm 0.35 \pm 0.20)\%$$

$$A_{CP} \equiv \frac{Br(B^- \to D^0_{CP} K^-) - Br(B^+ \to D^0_{CP} K^+)}{Br(B^- \to D^0_{CP} K^-) + Br(B^+ \to D^0_{CP} K^+)} = 0.17 \pm 0.23^{+0.09}_{-0.07}$$

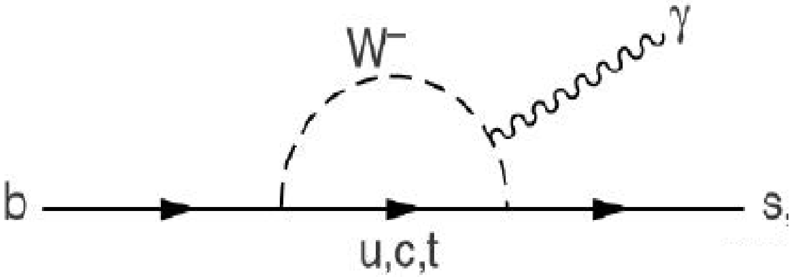
Preliminary

$B \to K^*\gamma$

~22.7×10^6 B pairs

Phys Rev Lett **88** 101805 (2002)

- $A_{cp} \leq 1\%$ in SM.
- SUSY can enhance to ~20%

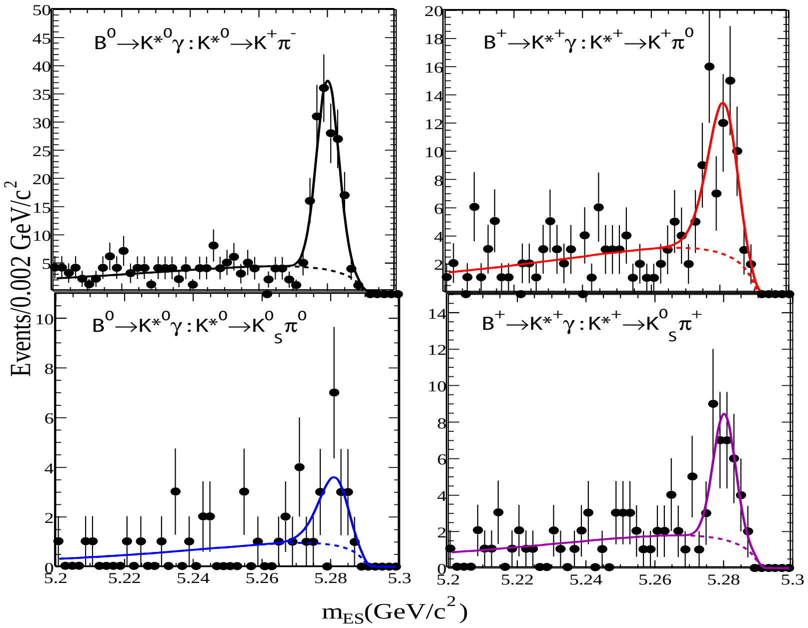


Reconstruct

$$K^* \to K^+\pi^-, K^+\pi^0, K_s\pi^0, K_s\pi^+$$

$$Br(B^0 \to K^*\gamma) = (4.23 \pm 0.40 \pm 0.22) \times 10^{-5}$$

$$Br(B^+ \to K^{*+}\gamma) = (3.83 \pm 0.62 \pm 0.22) \times 10^{-5}$$



$A_{CP}(B \to K^*\gamma) = -0.044 \pm 0.076 \pm 0.012$

[-0.170, 0.082] (90% C.L.)

Other results: see talk on α

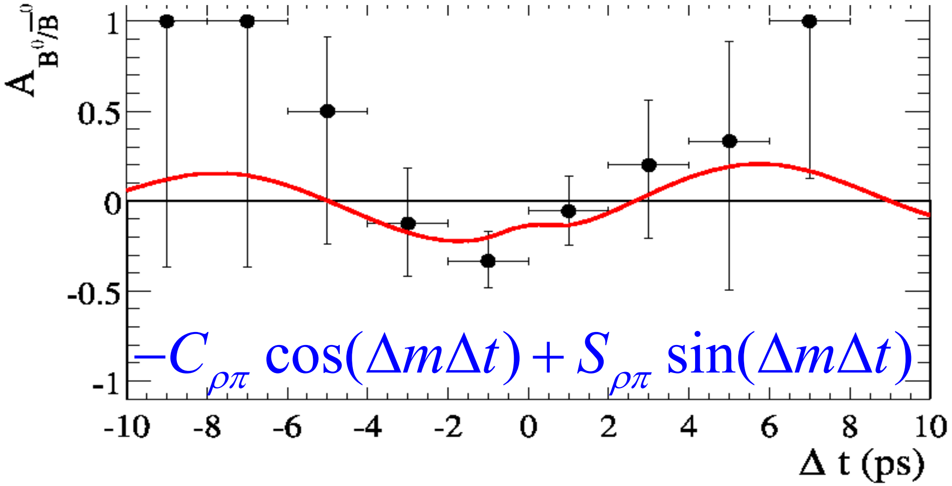
~88×10^6 B pairs

$B^0 \to \rho\pi,\ B^0 \to \rho K$

$$A_{CP}^{\rho K} = 0.19 \pm 0.14 \pm 0.11$$
$$A_{CP}^{\rho\pi} = -0.22 \pm 0.08 \pm 0.07$$
$$C_{\rho\pi} = 0.45^{+0.18}_{-0.19} \pm 0.09$$
$$S_{\rho\pi} = 0.16 \pm 0.25 \pm 0.07$$

$$\Delta C_{\rho\pi} = 0.38^{+0.19}_{-0.20} \pm 0.11$$
$$\Delta S_{\rho\pi} = 0.15 \pm 0.25 \pm 0.05$$

Factorization predicts 0.4



$B \to \pi\pi$

α via isospin analysis and direct CPV from time evolution of $B \to \pi^+\pi^-$

$$C_{\pi\pi} = -0.30 \pm 0.25 \pm 0.03$$
$$S_{\pi\pi} = 0.02 \pm 0.34 \pm 0.03$$

$Br(B^0 \to \pi^+\pi^-) = (4.6 \pm 0.6 \pm 0.2) \times 10^{-6}$
$Br(B^+ \to \pi^+\pi^0) = (5.5 \pm 1.0 \pm 0.6) \times 10^{-6}$
$Br(B^0 \to \pi^0\pi^0) < 3.6\ 10^{-6}$

Preliminary

Summary and outlook

- First CP results from $B^0 \to \rho\pi$
- Branching fractions and A_{CP}

  measured in many decays
- A_{CP} precision achieved 5~20%
- No direct CPV signal yet …
- watch for future updates