

# Radiative Penguin Decays of B Mesons: Measurements of $B \rightarrow K^*\gamma$ , $B \rightarrow K_2^*(1430)\gamma$ and Search for $B^0 \rightarrow \phi\gamma$

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for the *BABAR* Collaboration

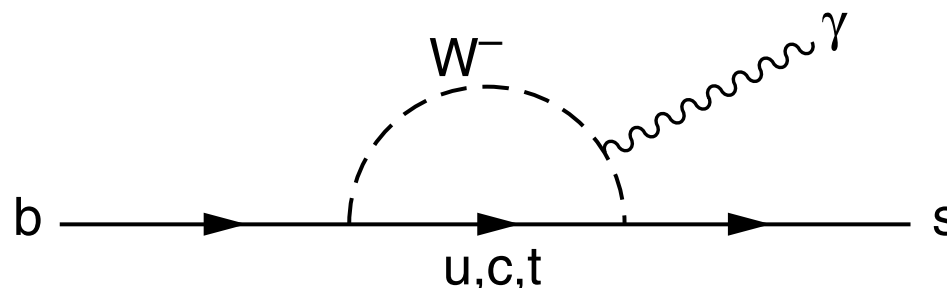
DPF 2004, Riverside, CA  
August 28, 2004

all results are preliminary



## Motivation — $K^*\gamma$ & $K_2^*(1430)\gamma$

- Decay mainly via one-loop  $b \rightarrow s\gamma$  electromagnetic penguins



- Non-SM virtual particles may change decay rate
- Non-perturbative hadronic effects complicate theoretical calculations  
→ measurements more accurate than predictions
- Theoretical uncertainties reduced in isospin asymmetry:

$$\Delta_{0-} = \frac{\Gamma(\bar{B}^0 \rightarrow \bar{K}^{*0}\gamma) - \Gamma(B^- \rightarrow K^{*-}\gamma)}{\Gamma(\bar{B}^0 \rightarrow \bar{K}^{*0}\gamma) + \Gamma(B^- \rightarrow K^{*-}\gamma)}$$

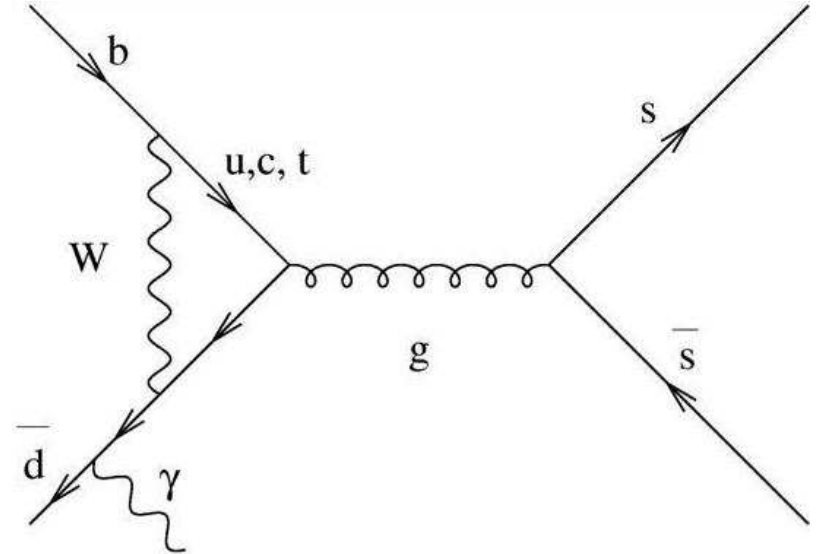
$$\text{Standard Model: } 6\% < \Delta_{0-} < 13\%$$

for measurements of direct & time-dependent CP asymmetries:  
see Patrick Spradlin's talk yesterday



# Motivation — $\phi\gamma$

- Penguin annihilation dominating
- Clean signature, but expected to be very rare



## Branching Fraction:

Standard-model prediction (QCD factorization):

Y.D. Yang, Eur.Phys.J. C36, 97 (2004)

$$\mathcal{B}(B^0 \rightarrow \phi\gamma) = 3.6 \times 10^{-12}$$

Supersymmetric models (R-parity violating):

Y.D. Yang, Eur.Phys.J. C36, 97 (2004)

$$\mathcal{B}(B^0 \rightarrow \phi\gamma) \sim 10^{-9} \text{ to } 10^{-8}$$

CLEO ( $9.2 \text{ fb}^{-1}$ ):

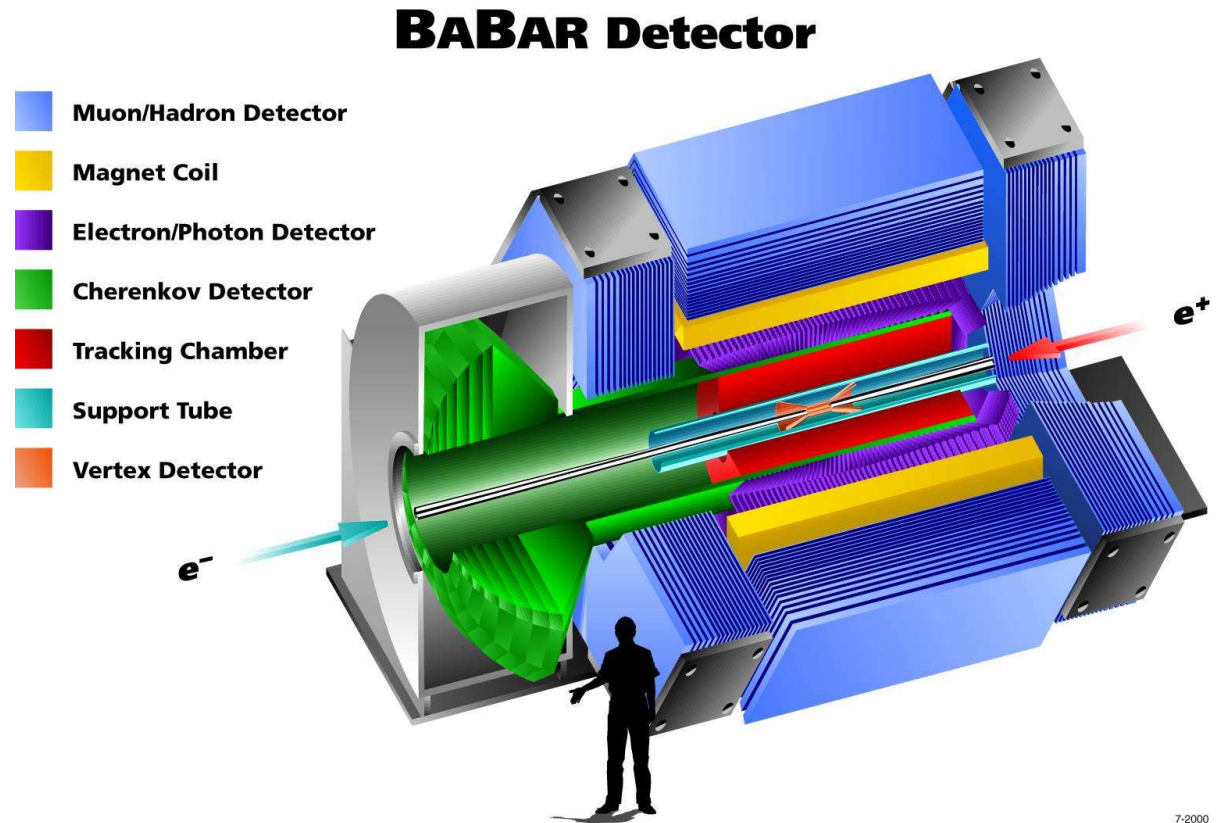
$$\mathcal{B}(B^0 \rightarrow \phi\gamma) < 33 \times 10^{-7} \text{ @ } 90\% \text{ C.L.}$$



# Our Data

## BABAR Detector

- part of asymmetric  $B$  Factory (Stanford Linear Accelerator Center)
- $B\bar{B}$  pair production on  $\Upsilon(4S)$  resonance
- Analyses presented here use
  - $88 \times 10^6$   $B\bar{B}$  events ( $81.9 \text{ fb}^{-1}$ ) for  $K^*\gamma$  &  $K_2^*(1430)\gamma$
  - $124 \times 10^6$   $B\bar{B}$  events ( $113.1 \text{ fb}^{-1}$ ) for  $\phi\gamma$
- Three independent analyses, but some overlap in methods



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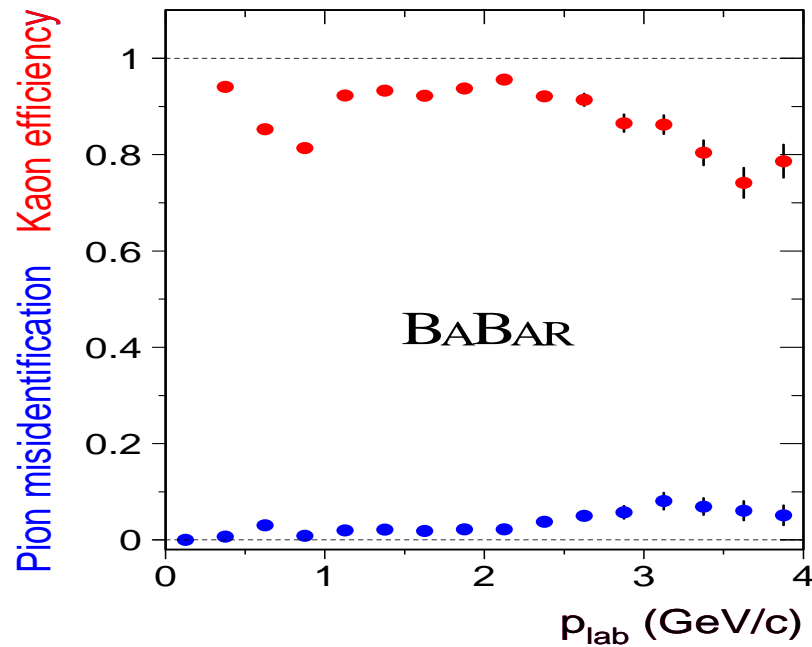
# Analysis Overview

## Hard Photon Selection

- $E_{\text{CMS}}$  → 1.5 to 3.5 GeV / 1.8 to 2.75 GeV
- Calorimeter acceptance → excluding edges of calorimeter
- Isolation → no track/photon close-by
- Shower shape → consistent with photon
- $\pi^0/\eta$  veto →  $\gamma$  not part of possible  $\pi^0$  or  $\eta$

## Hadron Selection

- require strict particle ID
- apply appropriate cuts on mass and other quantities



# Analysis Overview (cont.)

## Continuum Background Rejection

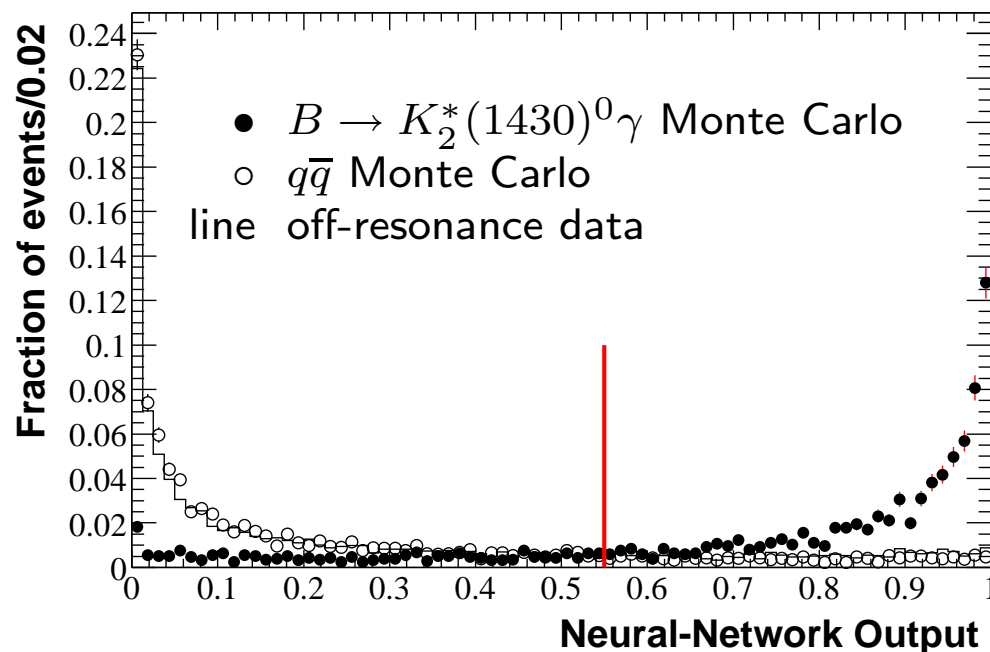
$q\bar{q}$  (u,d,s,c)

- hard  $\gamma$  from initial-state radiation and  $\pi^0$  and  $\eta$  decays
- more jet-like than  $B\bar{B}$

### Neural Network

(details depend on analysis)

- event shape variables
- flavor information
- helicity angle
  - angle of  $K^\pm$  or  $K_S^0$  in CM system of  $K^*$  w.r.t.  $K^*$  flight direction



## $B\bar{B}$ Background

Input from Monte Carlo (generic and specific modes)



# Analysis Overview (cont.)

## Kinematic Variables of $B$

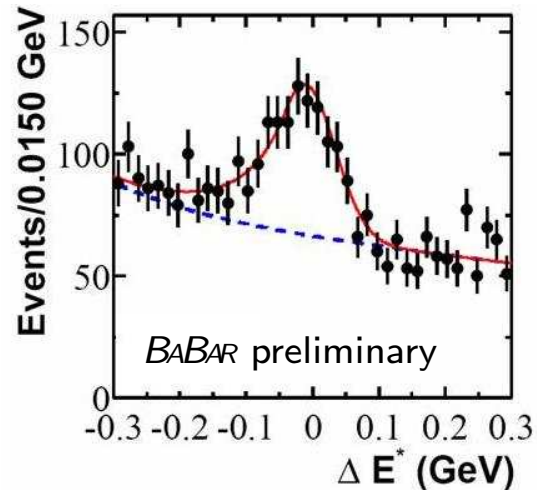
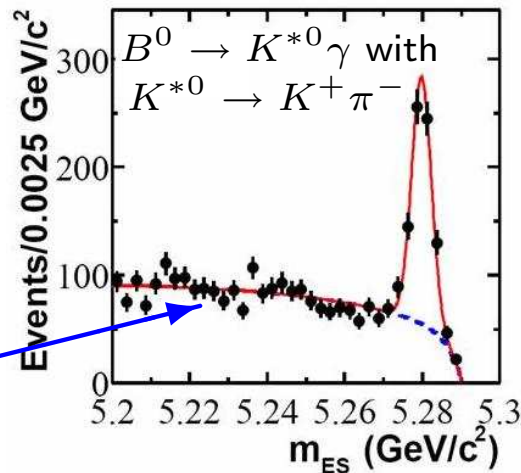
(quantities with \* in CM frame)

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

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

signal peaks at  
 $m_B = 5.28 \text{ GeV}/c^2$

combinatoric bkgd  
described by  
ARGUS function



signal peaks  
at 0 GeV

## Extraction of Signal

Two methods:

- Maximum Likelihood Fit ( $K^* \gamma$  and  $K_2^*(1430)^0 \gamma$ )
- Count events in  $m_{ES} - \Delta E^*$  signal region ( $\phi \gamma$ )



# $K^*\gamma$ & $K_2^*(1430)\gamma$ — Signal Selection

- Reconstruction

4 modes for  $K^*\gamma$ :

$$\begin{array}{ll} B^0 \rightarrow K^{*0}\gamma & \text{with } K^{*0} \rightarrow K^+\pi^- \text{ or } K_S^0(\pi^+\pi^-)\pi^0 \\ B^+ \rightarrow K^{*+}\gamma & \text{with } K^{*+} \rightarrow K^+\pi^0 \text{ or } K_S^0(\pi^+\pi^-)\pi^+ \end{array}$$

3 modes for  $K_2^*(1430)\gamma$ :

$$\begin{array}{ll} B^0 \rightarrow K_2^*(1430)^0\gamma & \text{with } K_2^*(1430)^0 \rightarrow K^+\pi^- \\ B^+ \rightarrow K_2^*(1430)^+\gamma & \text{with } K_2^*(1430)^+ \rightarrow K^+\pi^0 \text{ or } K_S^0(\pi^+\pi^-)\pi^+ \end{array}$$

- $K^*$  and  $K_2^*(1430)$  Candidate:

- Tight particle identification on tracks
- Invariant mass cuts
- Vertex cuts



## $K^*\gamma$ & $K_2^*(1430)\gamma$ — Continuum Background

- Major background
- Reduced through Neural Network Cuts
- Described by
  - ARGUS function in  $m_{ES}$
  - 1<sup>st</sup>-order polynomial in  $\Delta E^*$

## $K^*\gamma$ & $K_2^*(1430)\gamma$ — $B\bar{B}$ Background

- Smaller, mainly from other  $B \rightarrow X_s\gamma$   
→ may peak in  $m_{ES}$  &  $\Delta E^*$  where signal peaks
- For  $K_2^*(1430)$  also contribution from:
  - $K^*(1410)$
  - non-resonant  $B \rightarrow K\pi\gamma$   
⇒ discriminate three modes by helicity angle
- PDF determined from generic  $B\bar{B}$  and exclusive Monte Carlo



# $K^*\gamma$ — Maximum Likelihood Fit

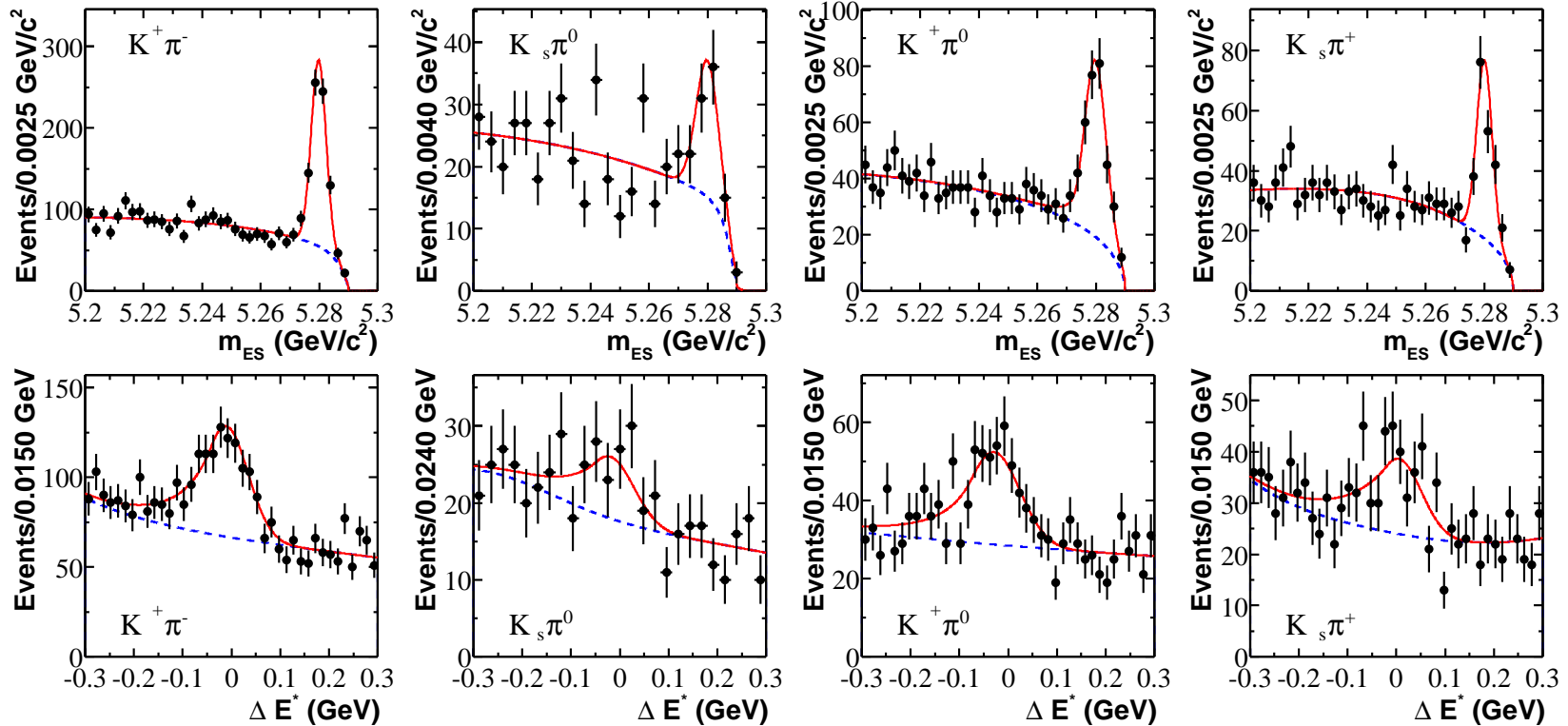
2-D fit:  $m_{ES}, \Delta E^*$

all plots: *BABAR* preliminary

points: data

red line: full fit

blue line: background component



signal yield  
from fit

$K^+\pi^-$   
 $583 \pm 30$

$K_S^0\pi^0$   
 $62 \pm 15$

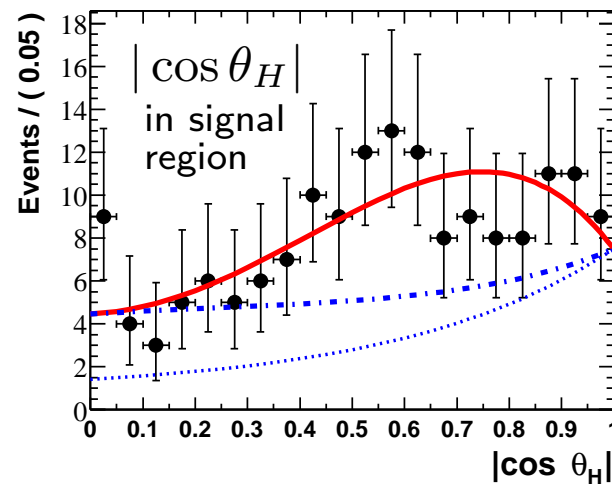
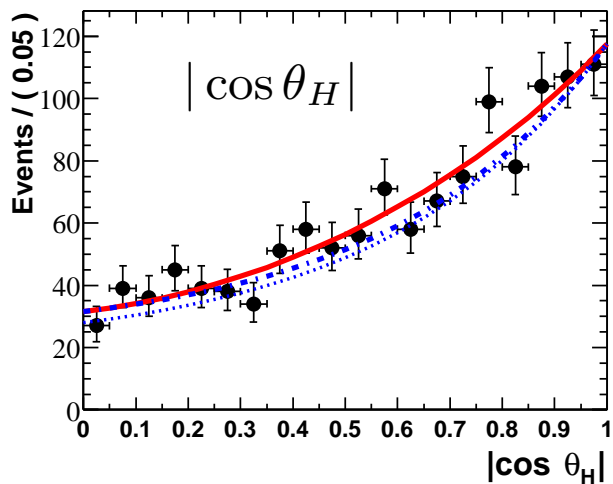
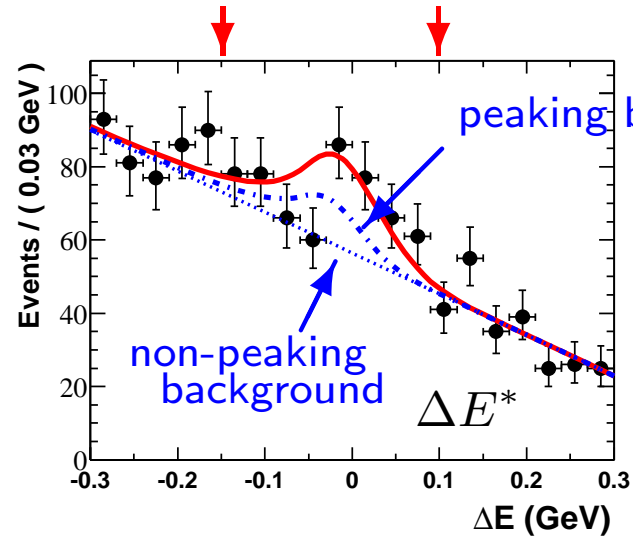
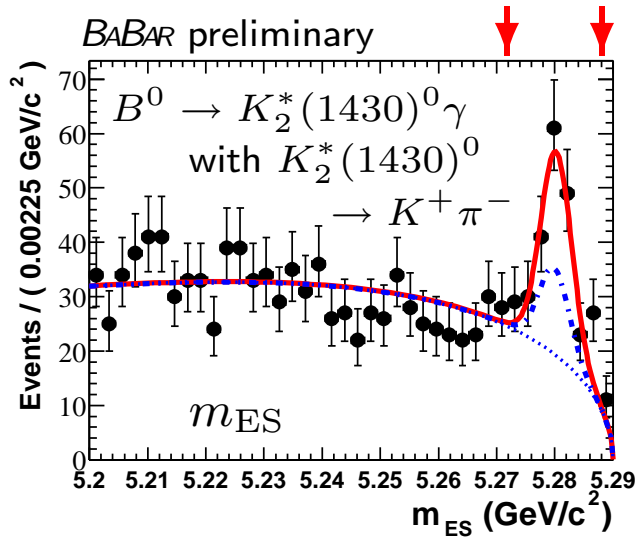
$K^+\pi^0$   
 $251 \pm 23$

$K_S^0\pi^+$   
 $157 \pm 16$  events



# $K_2^*(1430)\gamma$ — Maximum Likelihood Fit

3-D fit:  $m_{ES}$ ,  $\Delta E^*$ , helicity angle



signal yield & signal significance:

$K^+ \pi^-$   
 $69 \pm 14$  events ( $5.8\sigma$ )

$K_S^0 \pi^+$   
 $29 \pm 10$  events ( $3.3\sigma$ )

$K^+ \pi^0$   
 $20 \pm 9$  events ( $2.6\sigma$ )

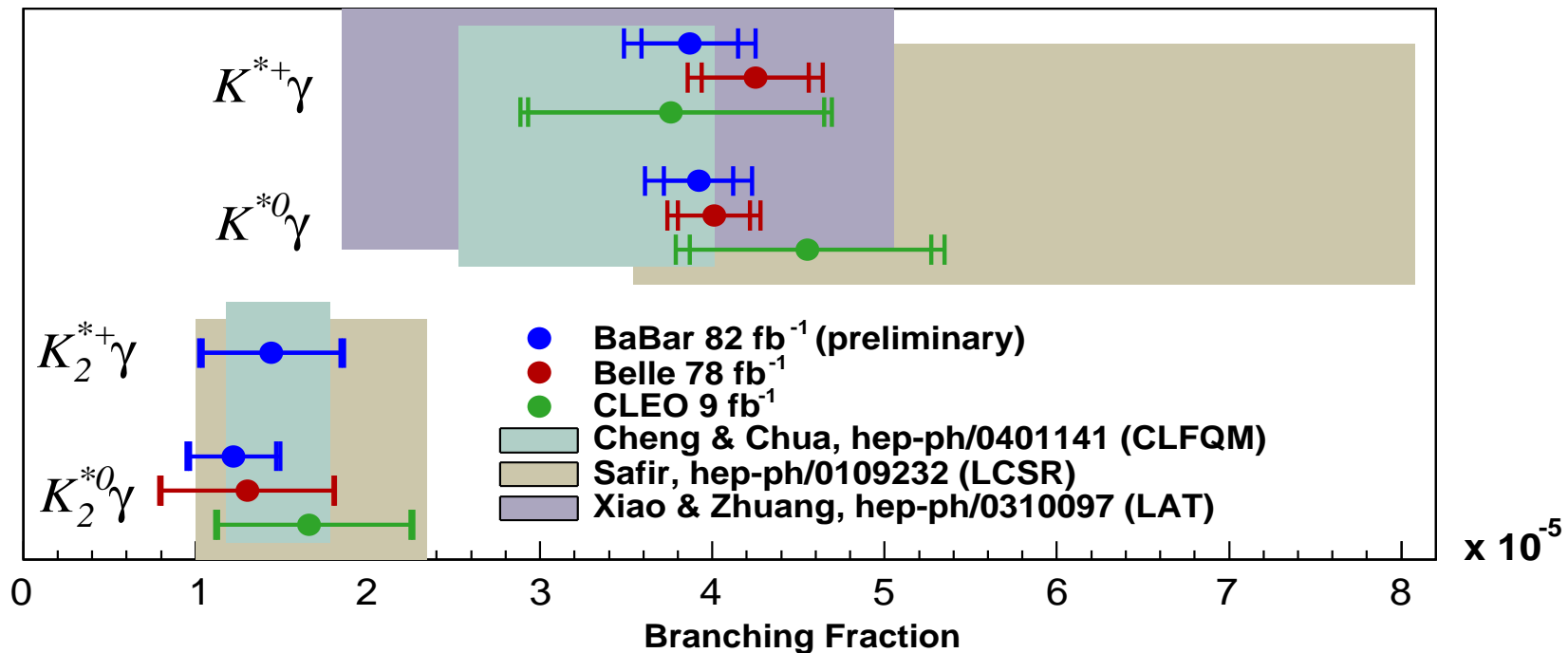


# $K^*\gamma$ & $K_2^*(1430)\gamma$ — Branching Fractions

$$\begin{aligned} \mathcal{B}(B^0 \rightarrow K^{*0}\gamma) &= (3.92 \pm 0.20 \pm 0.24) \times 10^{-5} && \text{major syst. error:} \\ \mathcal{B}(B^+ \rightarrow K^{*+}\gamma) &= (3.87 \pm 0.28 \pm 0.26) \times 10^{-5} && \text{photon efficiency} \\ \mathcal{B}(B^0 \rightarrow K_2^{*0}(1430)\gamma) &= (1.22 \pm 0.25 \pm 0.11) \times 10^{-5} \\ \mathcal{B}(B^+ \rightarrow K_2^{*+}(1430)\gamma) &= (1.44 \pm 0.40 \pm 0.13) \times 10^{-5} \end{aligned}$$

all preliminary

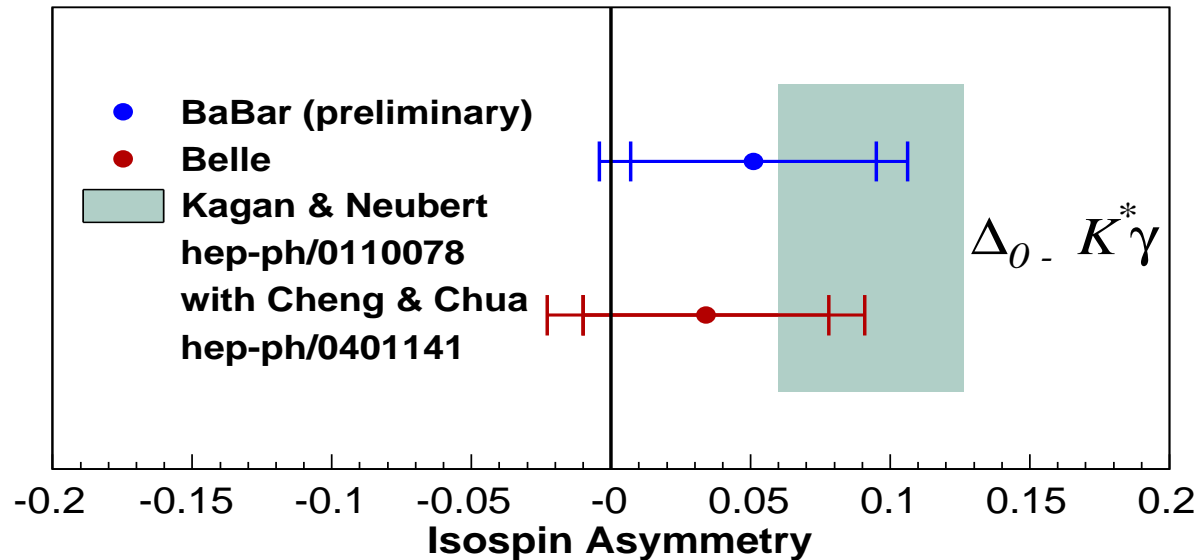
1<sup>st</sup> error statistical, 2<sup>nd</sup> systematic



# $K^*\gamma$ — Isospin Asymmetry

$$\Delta_{0-} = \frac{\Gamma(\bar{B}^0 \rightarrow \bar{K}^{*0}\gamma) - \Gamma(B^- \rightarrow K^{*-}\gamma)}{\Gamma(\bar{B}^0 \rightarrow \bar{K}^{*0}\gamma) + \Gamma(B^- \rightarrow K^{*-}\gamma)}$$

Our result:  $\Delta_{0-} = 0.050 \pm 0.045$  (stat)  $\pm 0.028$  (syst)  $\pm 0.024$  ( $R^{+/0}$ )  
 $-0.046 < \Delta_{0-} < 0.146$  @90% C.L. **all preliminary**  
 $\implies$  consistent with SM prediction



## $\phi\gamma$ — Signal Selection

- Reconstruction:  $B^0 \rightarrow \phi\gamma$  with  $\phi \rightarrow K^+K^-$
- $\phi$  Candidate:  
Kaon ID on both tracks, invariant mass cut
- Signal Region:  
 $5.27 \text{ GeV}/c^2 < m_{\text{ES}} < 5.29 \text{ GeV}/c^2 \quad -0.2 \text{ GeV} < \Delta E^* < 0.1 \text{ GeV}$

## $\phi\gamma$ — Background

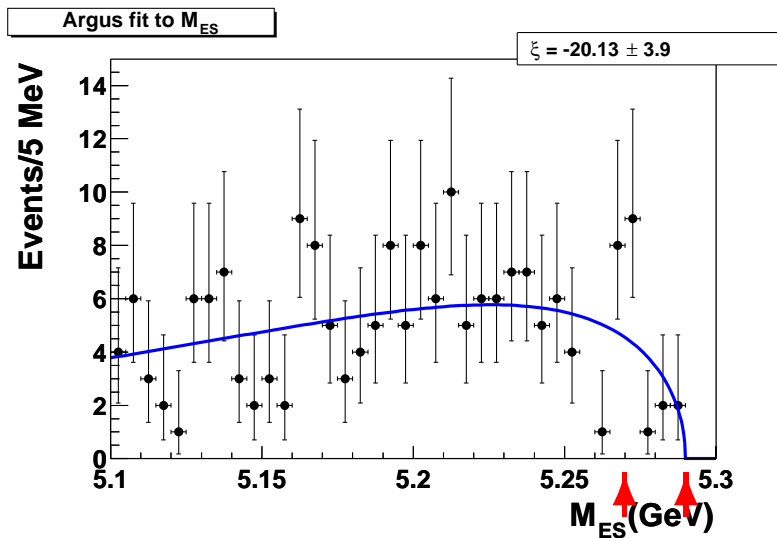
- $B\bar{B}$  Background  
from generic MC and  $\phi\pi^0$  &  $\phi\eta$  MC (assuming  $\mathcal{B} = 10^{-7}$ )  
 $\implies$  expecting  $0.09 \pm 0.05$  events
- Continuum Background
  - Main background
  - $\phi$  mass cuts and neural network (both optimized on MC)



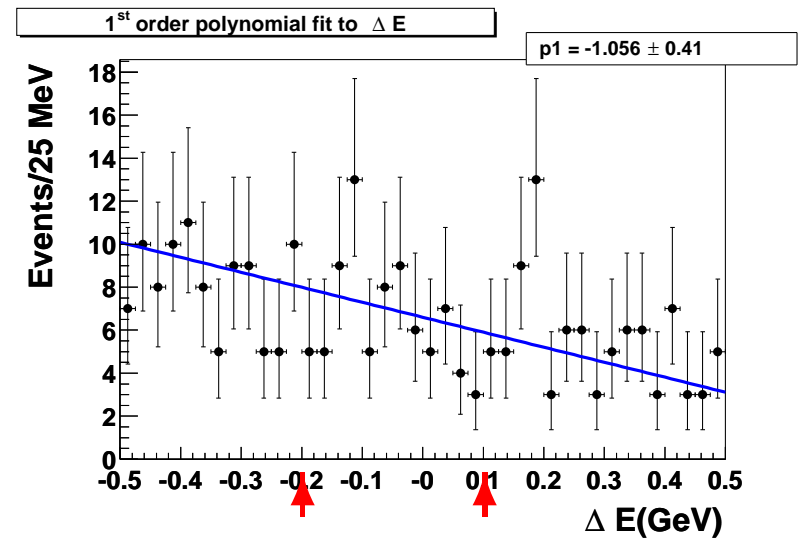
# $\phi\gamma$ — $q\bar{q}$ Background Estimate from Real Data

Fit in sidebands and extrapolate into signal box

ARGUS function for  $m_{ES}$   
sideband data + fit



1<sup>st</sup>-order polynomial for  $\Delta E^*$   
all data + fit to sideband



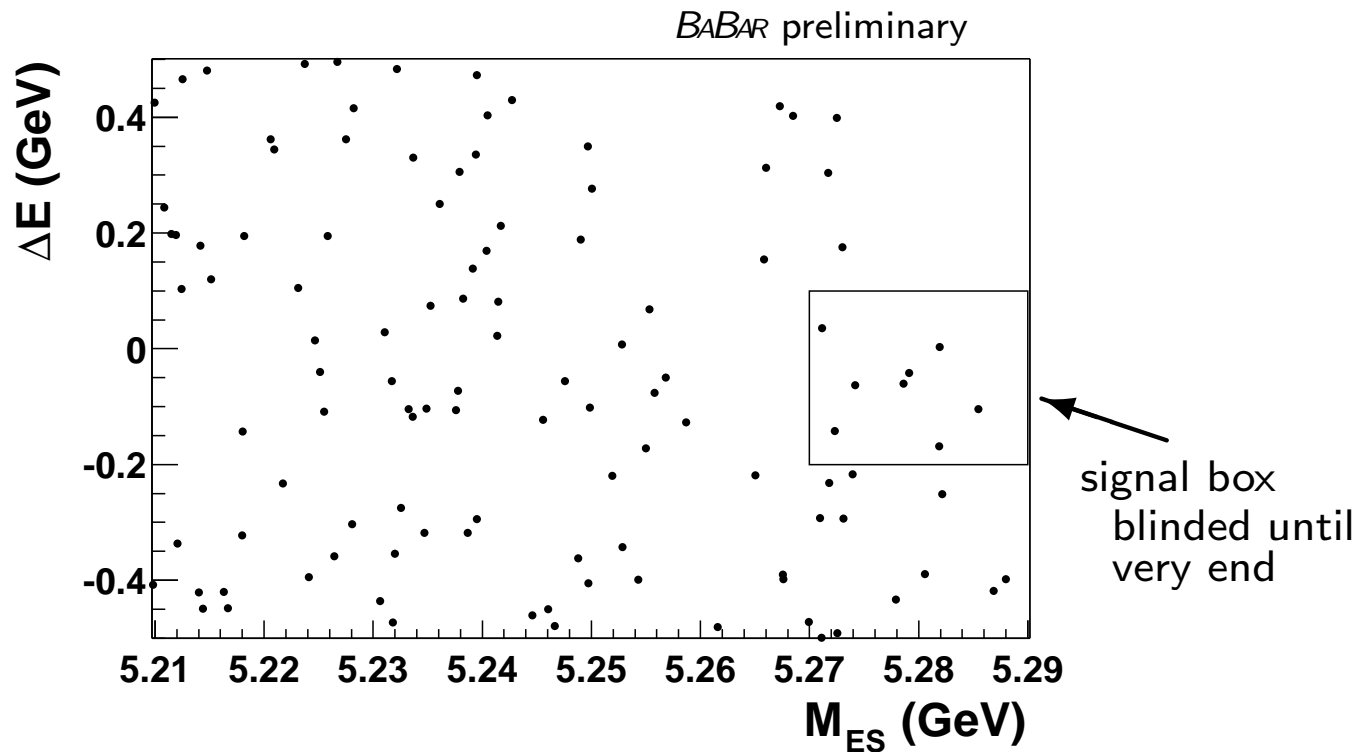
Estimated # events in signal region:  $6 \pm 1$

$q\bar{q}$  Monte Carlo in signal region:  $5 \pm 1$  (same procedure)



# $\phi\gamma$ Result

- 8 events in signal box



- No evidence for signal
- Upper limit (90% C.L.) is  $9.4 \times 10^{-7}$  (preliminary)



# Summary

$$B \rightarrow K^* \gamma \text{ \& \ } K_2^*(1430) \gamma$$

- Branching fractions and isospin asymmetry measured with higher statistics
- Results consistent with Standard Model calculations & other experiments

hep-ex/0407003  
submitted to PRL

hep-ex/0308021  
to be submitted to PRD

$$B^0 \rightarrow \phi \gamma$$

- Upper limit on branching fraction:  $9.4 \times 10^{-7}$  at 90% C.L.
- Marked improvement over CLEO's limit
- Lack of signal is consistent with Standard Model

