Recent Results in Electroweak Penguin B Decays

Karsten Köneke

Massachusetts Institute of Technology

On behalf of the BABAR Collaboration

™ and © Nelvana, All Rights Reserved

PANIC05

October 27th 2005

Outline:

- $B \to X_s \gamma$ — *Branching fraction and photon spectrum*
- $B \to K^{(*)} l^+ l^-$ — *Branching fractions, CP asymmetries and more*
- $B^0 \to K^0_s \pi^0 \gamma$ — *Time-dependent CP –violating asymmetry*
- $B \to \rho/\omega \gamma$ — *Rare decay search*

Experiment:

Design Goal:

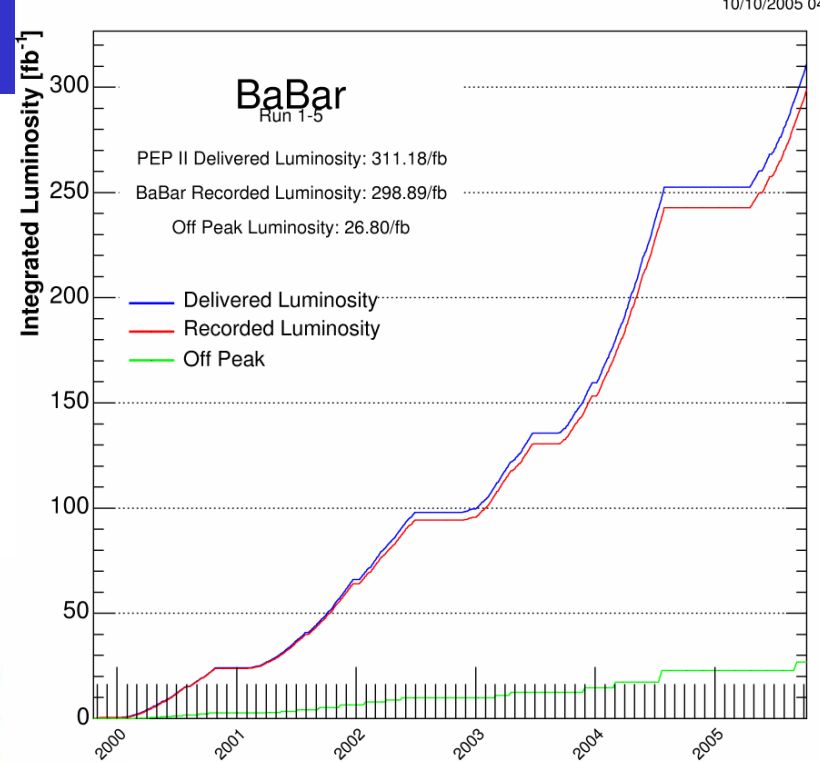
Study time dependent CP-violation in the B-meson system → Run asymmetric at Y(4S) resonance

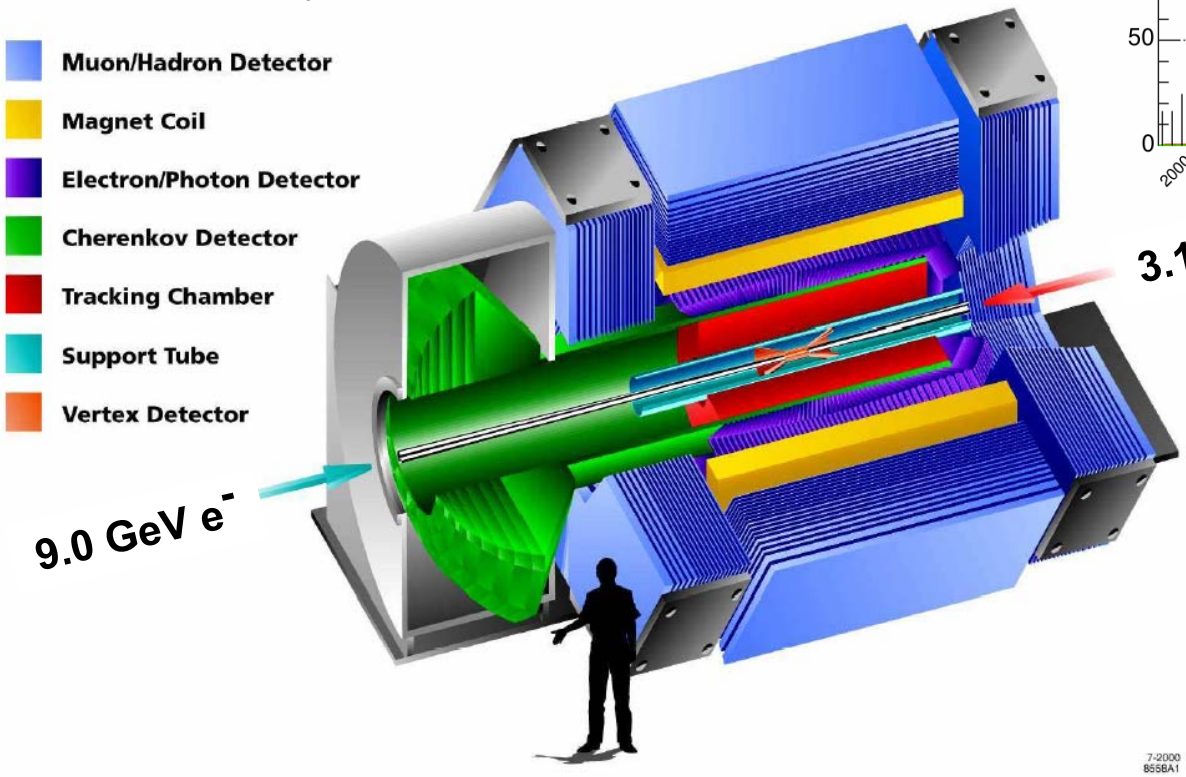
↳ $B\bar{B}$

PEP II:

Delivered Integrated Luminosity: 311.2 fb^{-1}

Peak Luminosity: 10.0×10^{33} $cm^{-2}s^{-1}$





BaBar:

Recorded Integrated Luminosity: 298.9 fb^{-1}

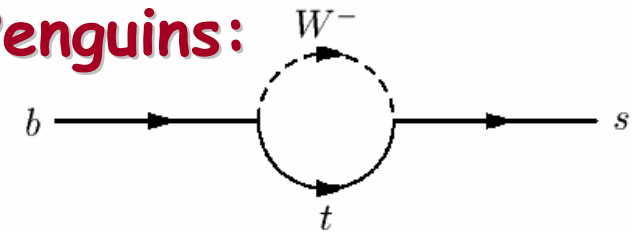
Asymmetric Detector

Exquisite Tracking and Particle ID performance, good calorimeter

Rare Decays - Motivation

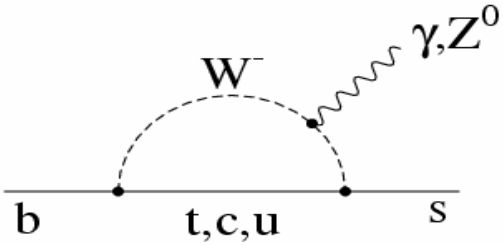
March of the Electroweak Penguins:

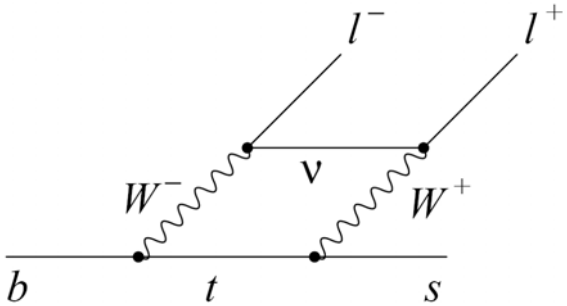
Penguin = One loop effective FCNC:



Focus of this talk:

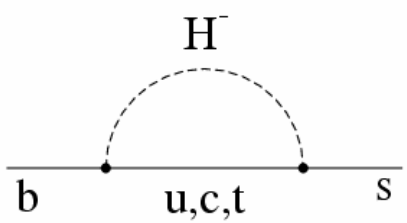
Decays where leading contribution is Penguin, thus BF ~ 10^{-4} – 10^{-7}

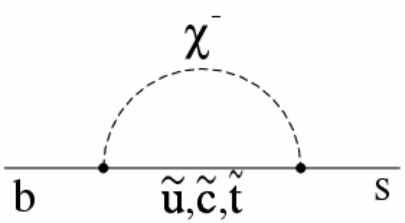


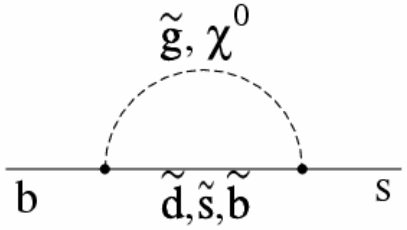


Search for New Physics:

New particles could appear in the loop and thus change branching fractions, CP-violating asymmetries, ratios of branching fractions,…







Experimental Techniques

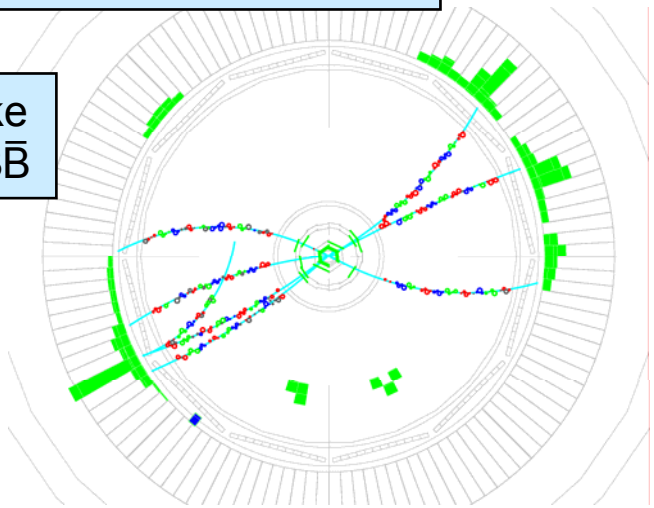
Reconstruction:

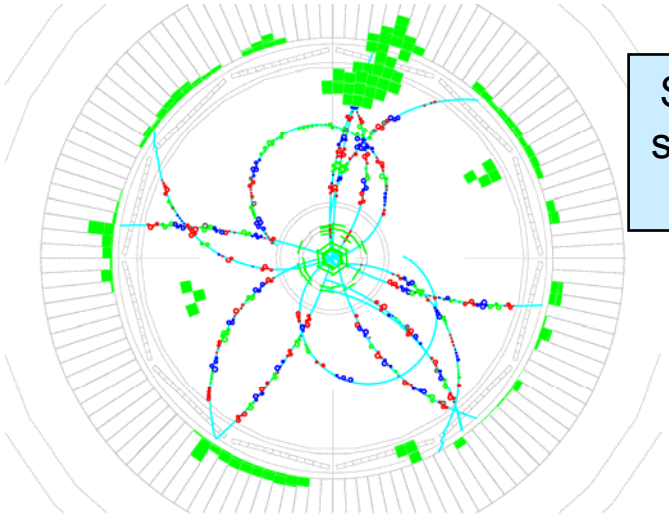
B-meson reconstruction: Use: $m_{ES} = \sqrt{\left(\frac{\sqrt{s}}{2}\right)^2 - \left|\vec{p}_B^{cm}\right|^2}$ and $\Delta E = E_B^{cm} - \sqrt{s}/2$

Background suppression:

Continuum ($e^+e^- \rightarrow$ light quark): Event shape variables and angular information

Jet-like non-$B\bar{B}$





Spherical symmetric $B\bar{B}$

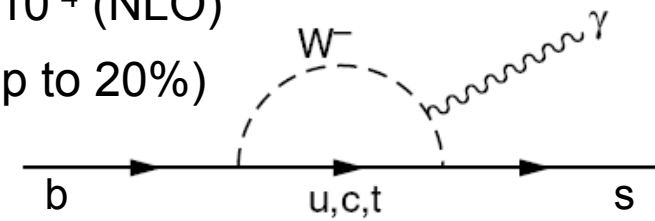
Unbinned (multidimensional) Maximum Likelihood Fit:

Components for signal, continuum background and $B\bar{B}$ background

New Physics:

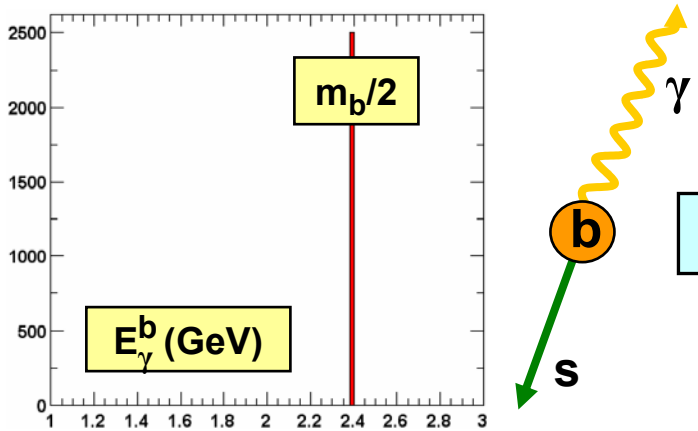
Standard Model expectations: $\mathcal{B}(B \to X_s \gamma) = (3.57 \pm 0.30) \times 10^{-4}$ (NLO)

$A_{CP}(B \to X_s \gamma) < 1\%$ (SUSY: up to 20%)

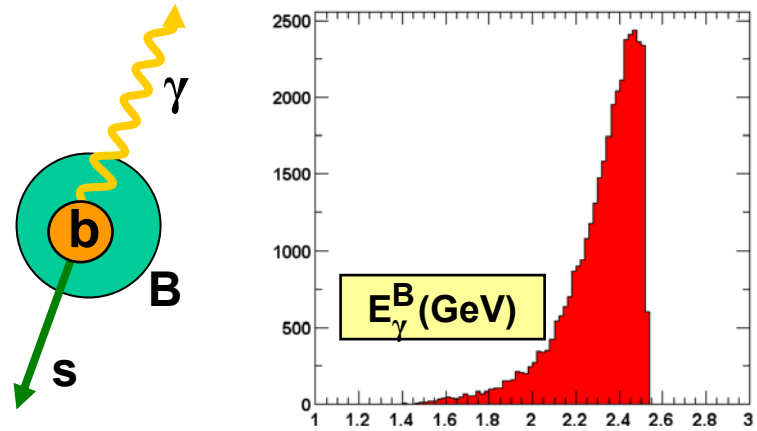


Photon Spectrum:

At the quark level: 2-body decay



b quark bound inside B meson:



Moments of Photon Energy Spectrum carry information:

1st moment: $\left\langle E_\gamma^B \right\rangle \approx \frac{m_b}{2}$ 2nd moment: $\left\langle \left(E_\gamma^B\right)^2 \right\rangle - \left\langle E_\gamma^B \right\rangle^2 \approx \mu_\pi^2 \approx E_{kin}^2(b)$

This information can be used to extract V_{cb} and V_{ub} from semileptonic $b \to c$ and $b \to u$ transitions

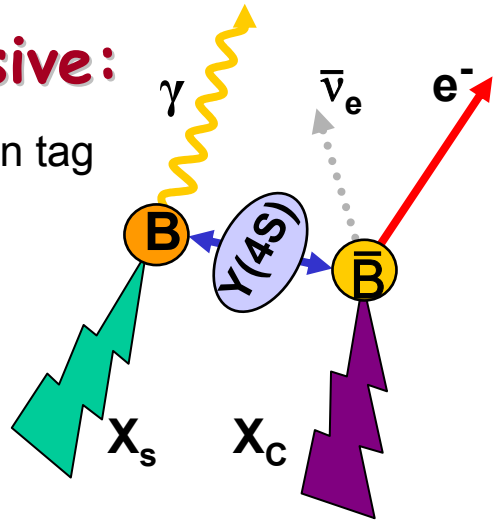
2 Approaches to fight this (logarithmic scale!):

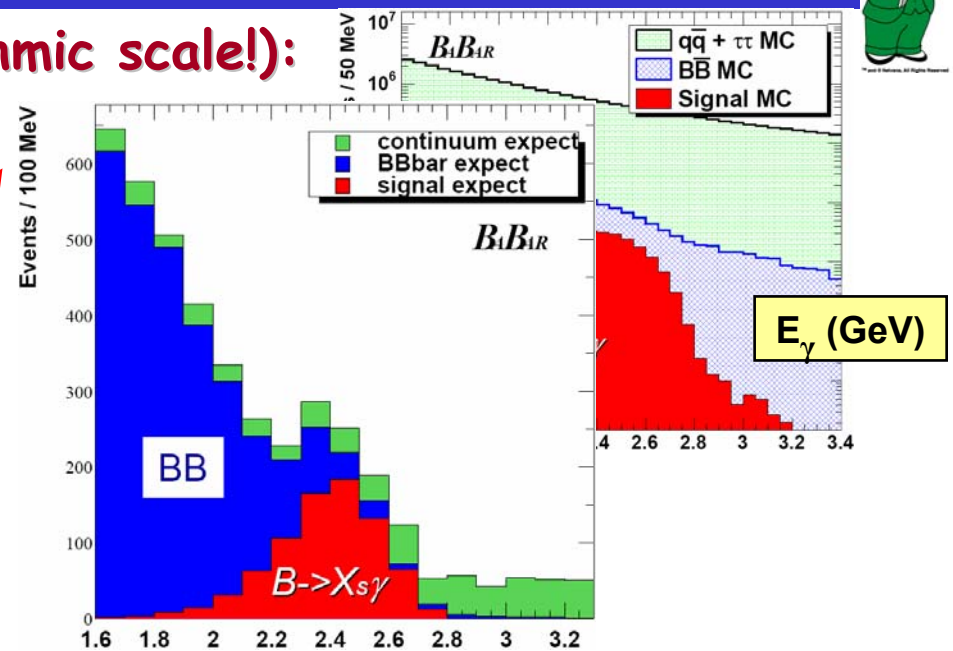
a) Fully Inclusive:

High momentum Lepton tag

$\mathcal{B}(B \to X\, l\, \nu) \sim 10\%$

Continuum subtraction using off-resonance data





$B\bar{B}$ background components calibrated by data

b) Sum of Exclusive Modes:

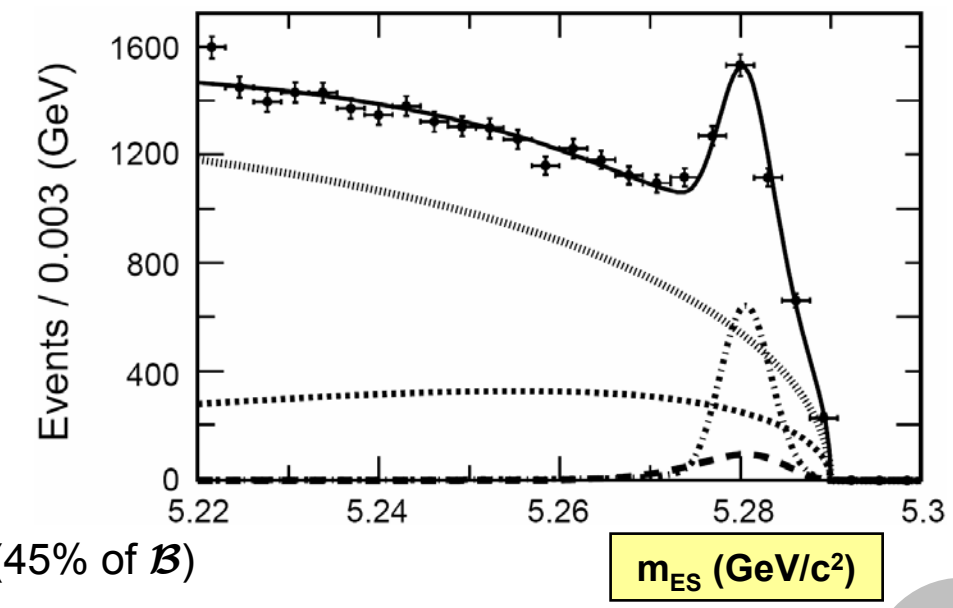
Reconstruct X_s system exclusively in 38 modes

(55% of $\mathcal{B}$) and infer $E_\gamma = \frac{m_B^2 - m_{X_s}^2}{2m_B}$

thus: very good energy resolution

Multicomponent fit in bins of hadronic Xs mass

Systematic uncertainty from missing final states (45% of $\mathcal{B}$)

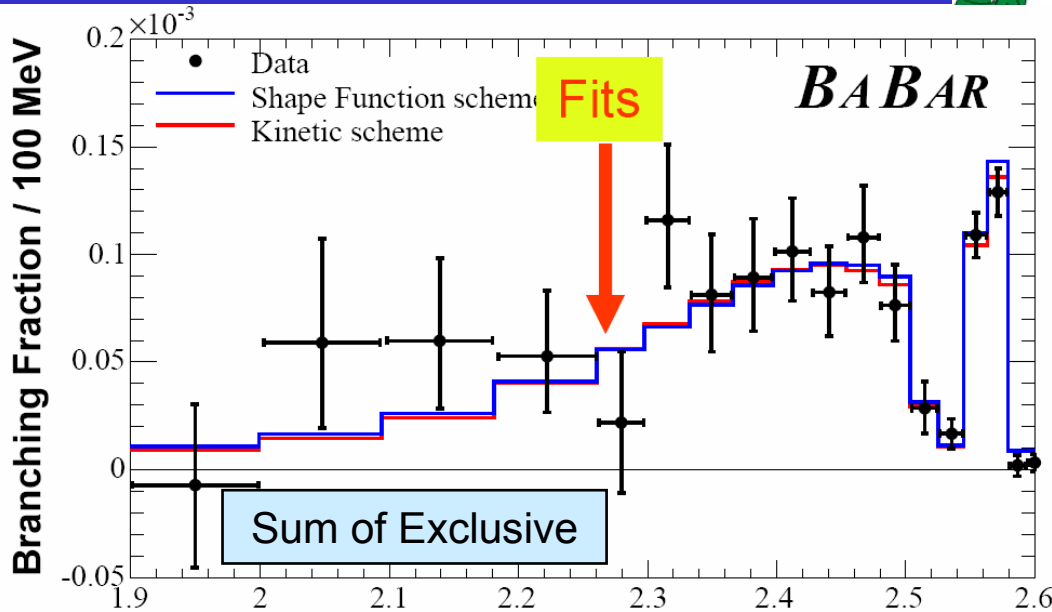


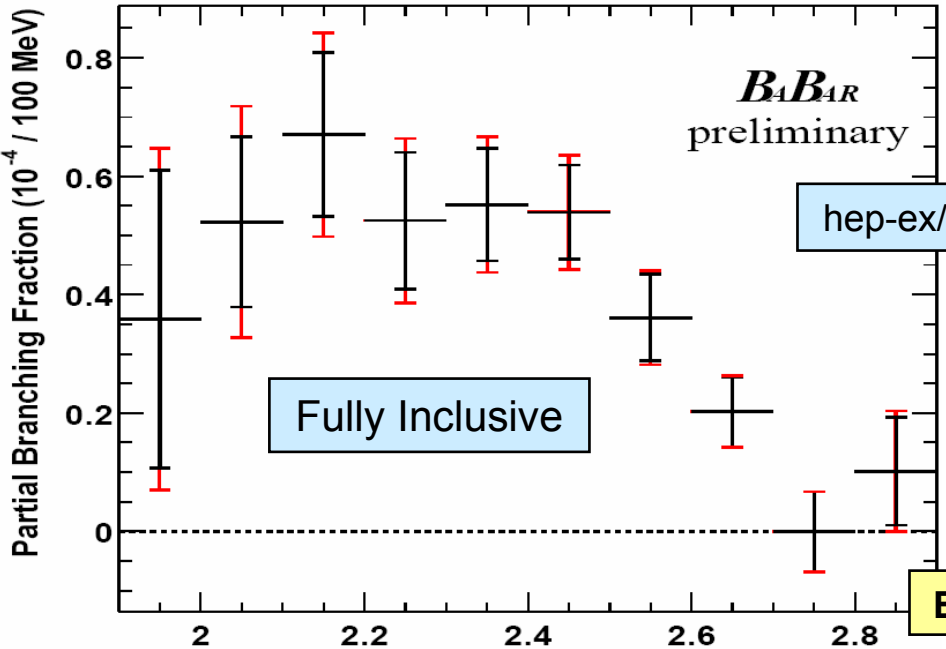
Photon Energy Spectrum:

B. Aubert *et al.* PRD **72,** 052004 (2005)

Resolution ~ 5 MeV

88.9 x 10^6 $B\bar{B}$ pairs





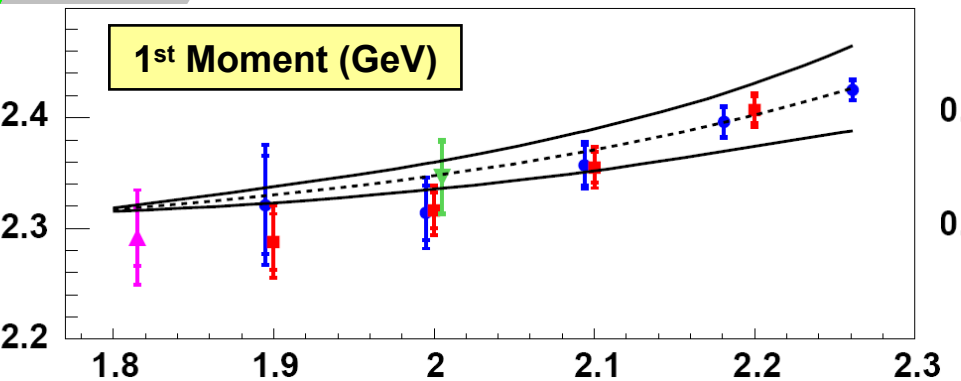
Resolution ~ 45 MeV due to calorimeter resolution

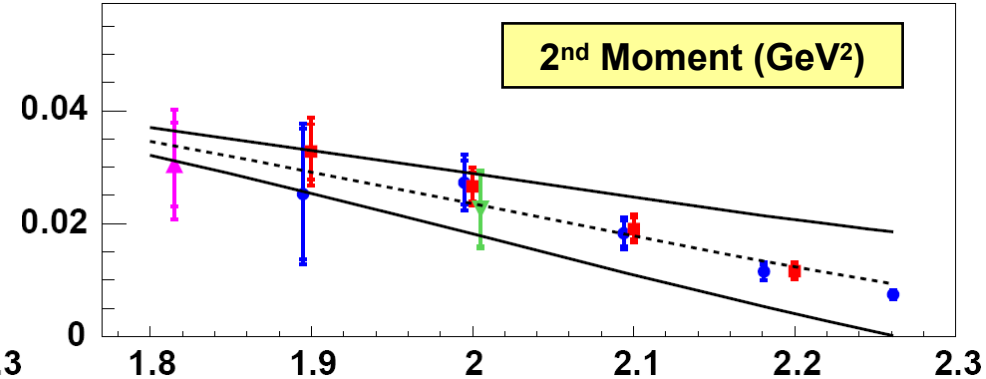
Inner error bar: statistical

Outer error bar: statistical + systematic

88.5 x 10^6 $B\bar{B}$ pairs

Moments: (Depending on minimum photon energy cut)





hep-ex/0507001

D. Benson, I.I. Bigi and N. Uraltsev Nucl. Phys. B **710**, 371-401 (2005)

- CLEO inclusive
- Belle inclusive untagged
- BaBar inclusive tagged (prel.)
- BaBar sum-of-exclusive
- Theory Central value
- Theory range

B. Aubert *et al.* PRD **72**, 052004 (2005)

Structure function describing Fermi motion of b quark is UNIVERSAL!

Branching Fraction and A_{CP}:

$\mathcal{B}(B \to X_s\gamma;\ E\gamma > 1.9\ \text{GeV}) = (3.67 \pm 0.29 \pm 0.34 \pm 0.29) \times 10^{-4}$ (prel.) — **Fully Inclusive**

$\mathcal{B}(B \to X_s\gamma;\ E\gamma > 1.9\ \text{GeV}) = (3.27 \pm 0.18\ ^{+0.55}_{-0.40}\ ^{+0.04}_{-0.09}) \times 10^{-4}$ — **Sum of Exclusive**

$\mathcal{B}(B \to X_s\gamma;\ E\gamma > 1.6\ \text{GeV}) = (3.25 \pm 0.19\ ^{+0.56}_{-0.41}\ ^{+0.04}_{-0.09}) \times 10^{-4}$ (extrapolated)

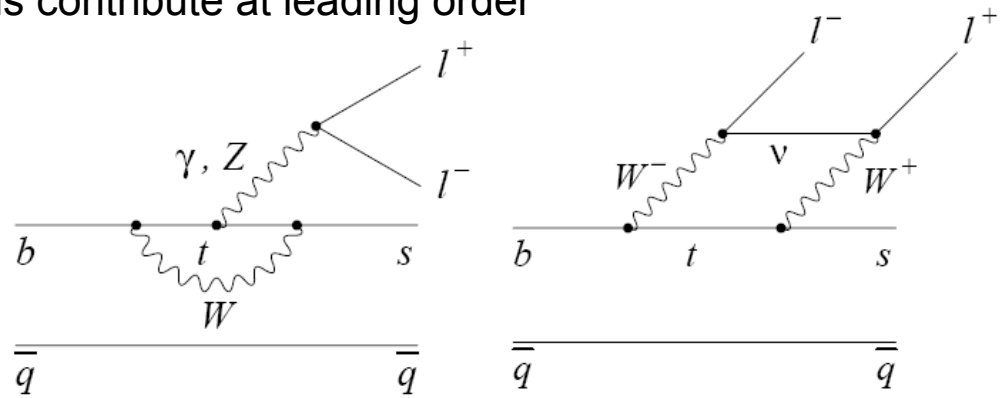
$A_{CP}(B \to X_{(s+d)}\gamma) = -0.110 \pm 0.115 \pm 0.017$ (prel.) — **Fully Inclusive**

$A_{CP}(B \to X_s\gamma) = 0.025 \pm 0.050 \pm 0.015$ — **Sum of Exclusive**

B. Aubert *et al.* PRL **93**, 021804 (2004)

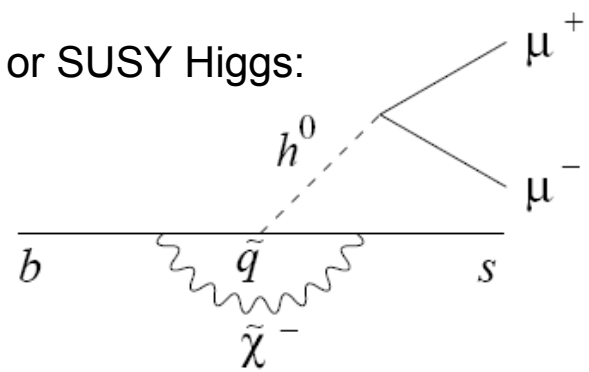
Very low branching fraction but rich phenomenology:

Two additional diagrams contribute at leading order



new possibilities for New Physics to enter, e.g. Gaugino loops or SUSY Higgs:

For example:
G. Hiller and F. Kruger,
PRD **69,** 074020 (2004)



couples stronger to heavier particles, enhances:

$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)} \mu^+ \mu^-)}{\mathcal{B}(B \to K^{(*)} e^+ e^-)}$$

A_{CP} in SM < 1% but new physics at electroweak scale could enhance it to $\mathcal{O}(1)$

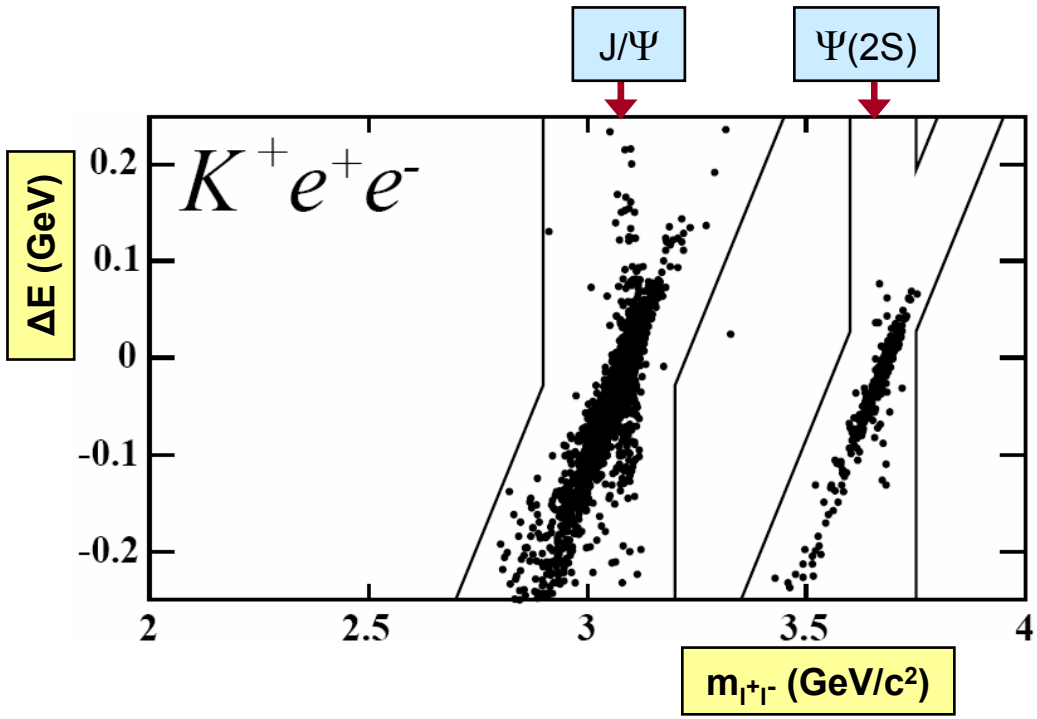
Reconstruction:

Only charged final state particles:

two leptons (e^+e^-, $\mu^+\mu^-$), a kaon ($K^\pm$ or K^0_s with $K^0_s \to \pi^+\pi^-$) and for K* modes a $\pi^\pm$

Charmonium veto:

Veto l^+l^- coming from J/Ψ or Ψ(2S)



Fit:

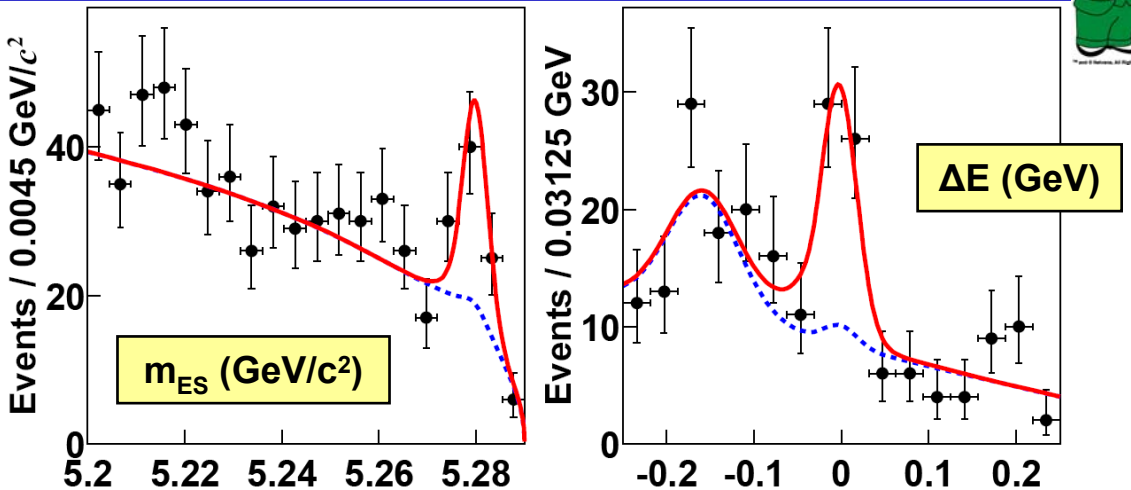
m_{ES} and ΔE (for K* mode additionally $m_{K\pi}$)

Include peaking background component

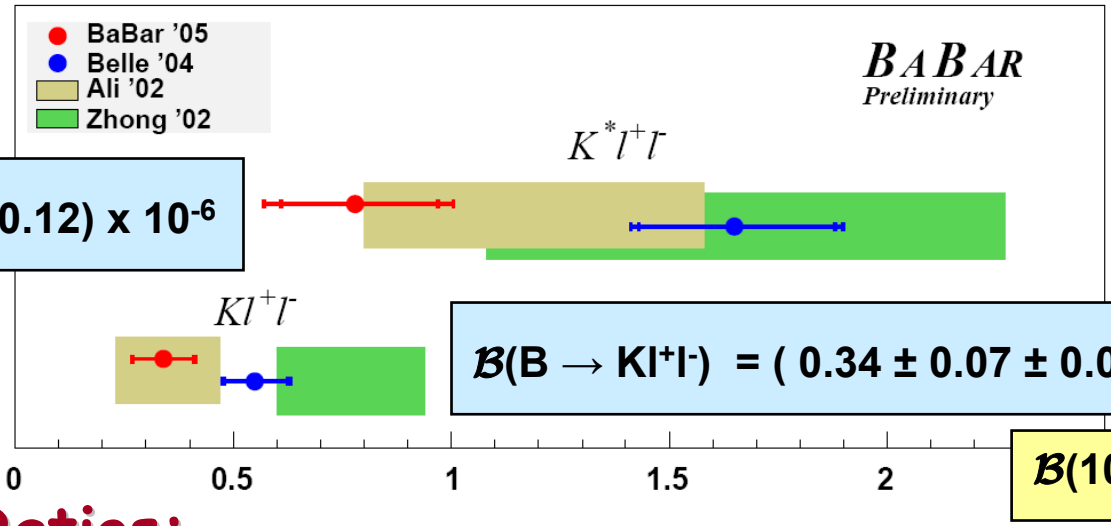
Fit Result for Kl^+l^-

hep-ex/0507005

229 x 10^6 $B\bar{B}$ pairs



All Results



$\mathcal{B}(B \to K^* l^+ l^-) = (0.78^{+0.19}_{-0.17} \pm 0.12) \times 10^{-6}$

$\mathcal{B}(B \to K l^+ l^-) = (0.34 \pm 0.07 \pm 0.03) \times 10^{-6}$

All consistent with the SM!

Asymmetries and Ratios:

$A_{CP}(B \to K^* l^+ l^-) = -0.03 \pm 0.23 \pm 0.12$

$A_{CP}(B^+ \to K^+ l^+ l^-) = 0.08 \pm 0.22 \pm 0.11$

$R_{K^*} = 0.93 \pm 0.46 \pm 0.06$ (SM: 0.75)

$R_K = 1.06 \pm 0.48 \pm 0.05$ (SM: 1.00)

Naively a CP eigenstate!

Interference between decay with and without B^0-$\bar{B}^0$ mixing!

The time evolution of $B^0 \to K^{*0} \gamma$ is governed by:

B^0 mixing frequency

Time difference between known B^0 flavor time and decay time

$$\mathcal{P}_\pm(\Delta t) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B} \times \left[1 \pm S_{K^{*0}\gamma} \sin(\Delta m_d \Delta t) \mp C_{K^{*0}\gamma} \cos(\Delta m_d \Delta t)\right]$$

B^0 lifetime

~ direct CP violation, close to 0 in SM

Naively expect $S_{K^{*0}\gamma} \approx \sin(2\beta)$

But: Due to photon polarization: Interference is suppressed by $\frac{m_s}{m_b}$

Thus, time-dependent CP-violating asymmetry is expected to be small:

D. Atwood, M. Gronau and A. Soni, PRL **79,** 185 (1997)

$$\left|S_{K^{*0}\gamma}\right| \approx \left|-2\frac{m_s}{m_b}\sin 2\beta\right| < 0.1$$

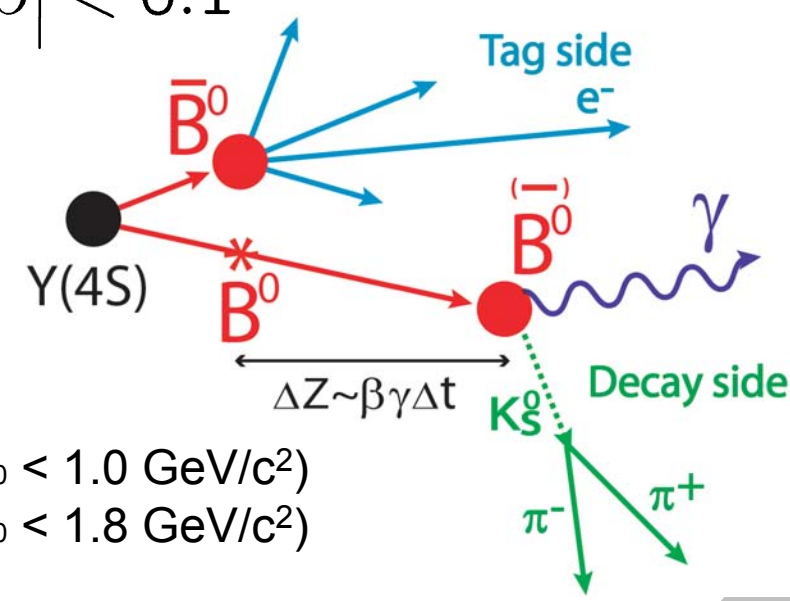
B. Grinstein *et al.*, PRD **71,** 011504 (2005)

Flavor Tagging:

Determine the flavor (B^0 or $\bar{B}^0$) of the "other B"

in the event, the B_{tag}, by looking at its decay products.

Calculate Δt from measured Δz

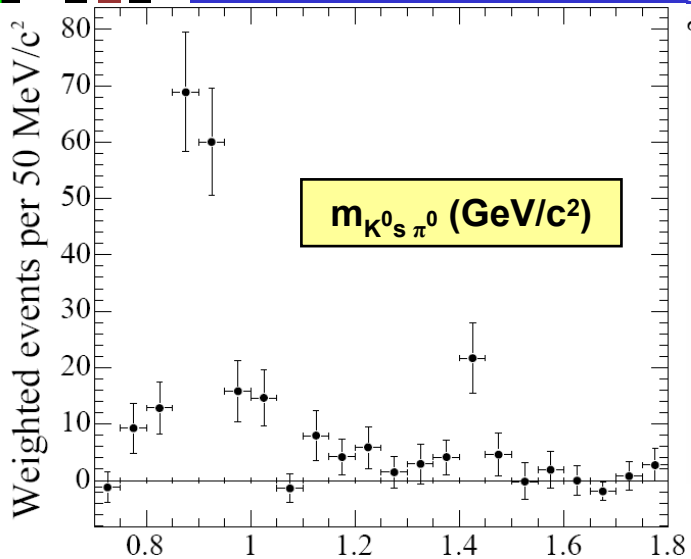


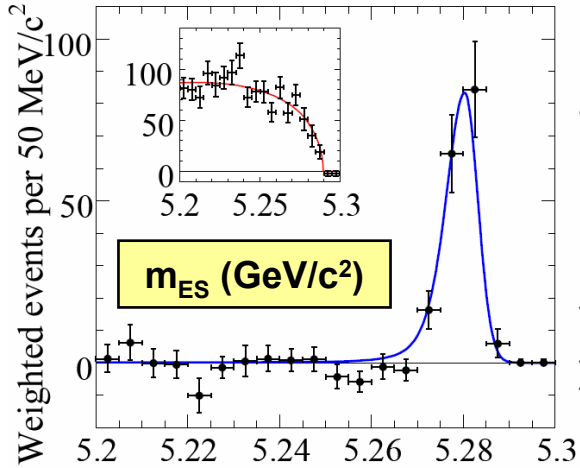
Reconstruction:

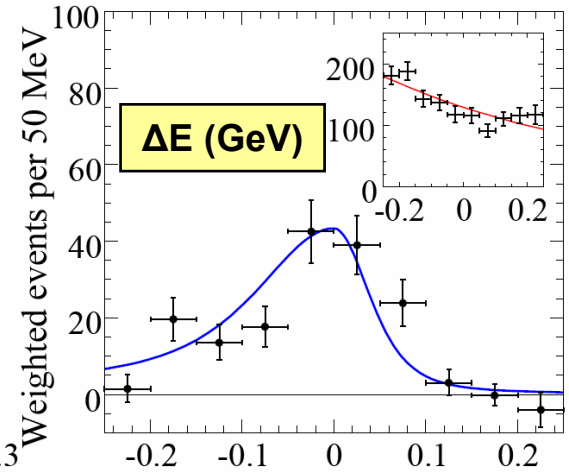
K* region ($0.8 < m_{K^0_s\pi^0} < 1.0$ GeV/c²)

non-K* region ($1.1 < m_{K^0_s\pi^0} < 1.8$ GeV/c²)

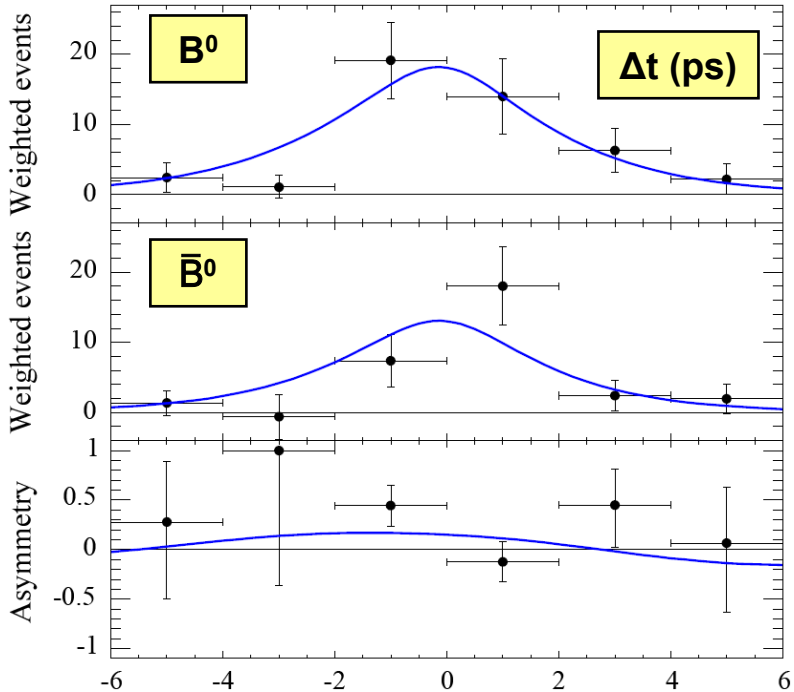
$B^0 \to K^0_s \pi^0 \gamma$







232 x 10^6 $B\bar{B}$ pairs



K* region:

$$S_{K^{*0}\gamma} = -0.21 \pm 0.40 \pm 0.05$$

$$C_{K^{*0}\gamma} = -0.40 \pm 0.23 \pm 0.03$$

B. Aubert *et al.* PRD **72,** 051103 (R) (hep-ex/0507038)

Non-K* region:

$$S_{K^0_S \pi^0 \gamma} = 0.9 \pm 1.0 \pm 0.2$$

$$C_{K^0_S \pi^0 \gamma} = -1.0 \pm 0.5 \pm 0.2$$

$B \to \rho/\omega\,\gamma$

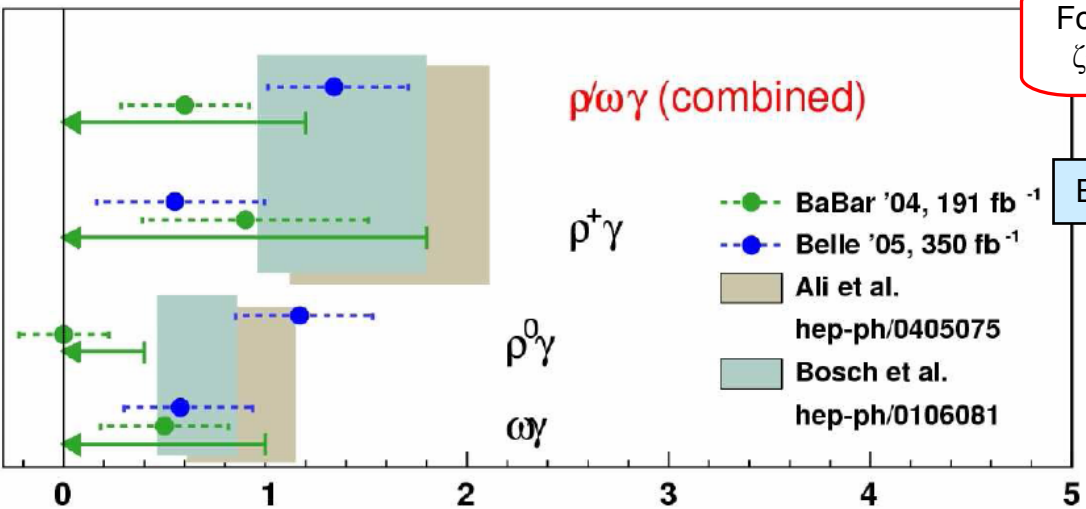
Sensitive to far side of Unitarity Triangle:

$$\frac{\mathcal{B}[B \to (\rho/\omega)\gamma]}{\mathcal{B}(B \to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m_\rho^2/M_B^2}{1 - m_{K^*}^2/M_B^2}\right)^3 \zeta^2\,[1 + \Delta R]$$

A. Ali and A. Y. Parkhomenko Eur. Phys. J. C **23,** 89 (2002)
A. Ali *et al.* PLB **595,** 323 (2004)

Form factor ratio $\zeta^2 \approx 0.85 \pm 0.1$

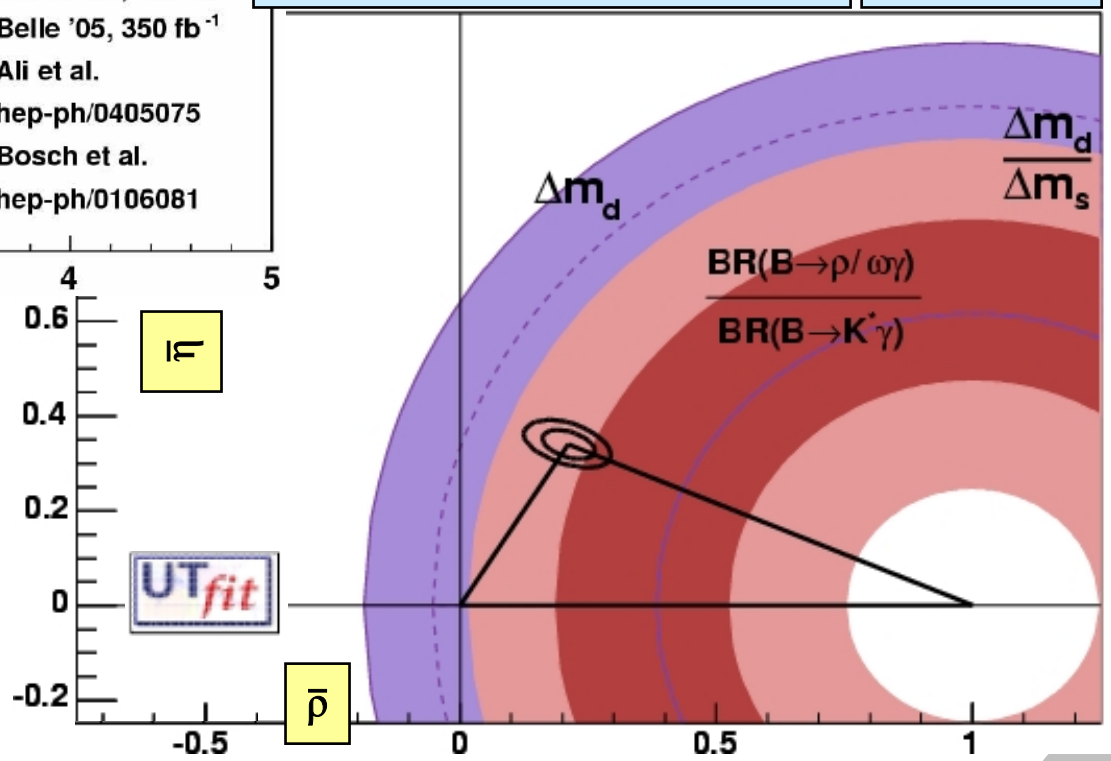
Difference in dynamics (such as W annihilation) $\Delta R \approx 0.1 \pm 0.1$



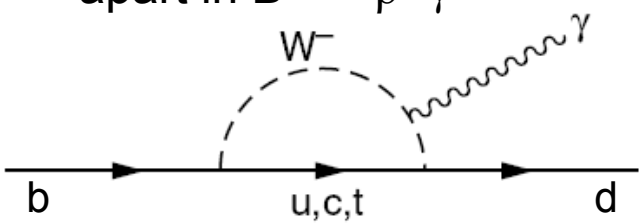
Branching Fraction (10^{-6})

B. Aubert *et al.* PRL **94,** 011801 (2005)

221 x 10^6 $B\bar{B}$ pairs



Babar and Belle are 2.7σ apart in $B^0 \to \rho^0\,\gamma$



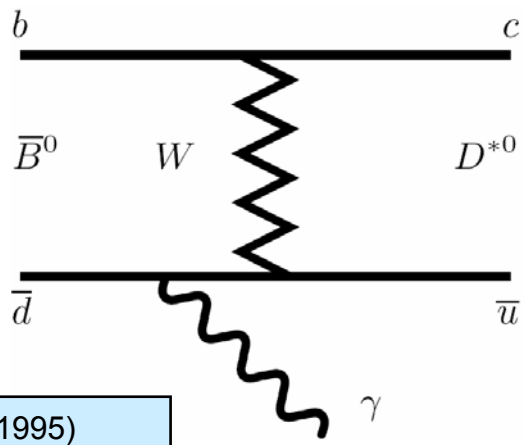
Motivation:

W exchange diagram is dominant:

→ study long-distance QCD, i.e. test factorization ansatz

→ may help to understand other decays better, e.g. $B^0 \to \rho^0\gamma$

Theory predictions for branching fraction: ~ 1-2 x 10^{-6}



H. Y. Cheng *et al.* PRD **51,** 1199 (1995)
R. R. Mendel and P. Sitarski, PRD **36,** 953 (1987)

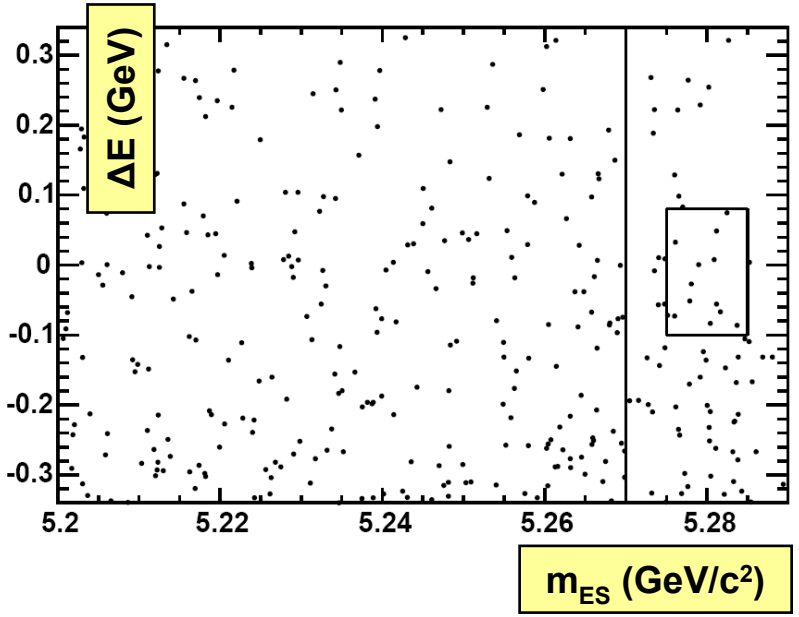
Method:

Reconstruct D^{*0} in six decay modes:

$D^{*0} \to D^0 (\pi^0, \gamma)$ with: $D^0 \to (K^- \pi^+,\ K^- \pi^+ \pi^0,\ K^- \pi^+ \pi^+ \pi^-)$

Plot events in $\Delta E - m_{ES}$ plane

Expected background events in signal box: 9.4 ± 1.7



Result:

(based on 87.8 x 10^6 $B\bar{B}$ pairs)

Observed events in signal box: 13

$$\mathcal{B}(\bar{B}^0 \to D^{*0}\gamma) < 2.5 \times 10^{-5} \text{ @ } 90\% \text{ C.L.}$$

B. Aubert *et al.* PRD-RC **72,** 051106 (2005)

Conclusion

- $B \rightarrow X_s \gamma$

Branching fraction and photon spectrum

New measurement of photon energy spectrum and its moments, thus, precise knowledge of b-quark mass and kinetic energy. Branching fractions and A_{CP} in good agreement with SM. Good constraints on physics beyond the Standard Model.

- $B \rightarrow K^{(*)} l^+ l^-$

Branching fractions, CP asymmetries and more

Rarest decay so far measured by BaBar! Rich system.

- $B^0 \rightarrow K^0_s \pi^0 \gamma$

Time-dependent CP –violating asymmetry

Very interesting approach, but statistical limited.

- $B \rightarrow \rho/\omega \gamma$

Rare decay search

No significant signal seen, 2.7 sigma disagreement with Belle, let's wait for the Belle speaker at the end of this session…

All these measurements are statistically limited…

Stay tuned as Babar continues taking data!!!