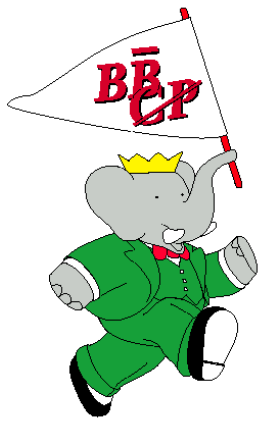
Direct CP Violation & Radiative Decays



Henry Band
U. of Wisconsin

Representing the BaBar Collaboration

June19, 2002

Direct CP Violation

- Possible CP violation in B system
  - CP Violation in Mixing
  - CP Violation in decay
  - CP Violation in mixing and decay

$$A_{CP} = \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)}$$

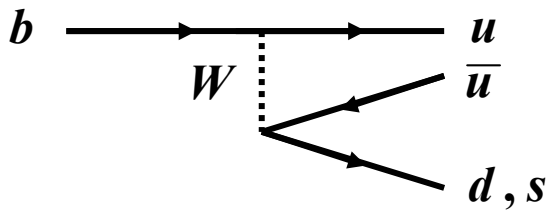
- Direct CPV may be observed in B^+ or B^0 modes
  - Observed in the K^o decays
  - Requires interference between tree and penguin amplitudes with different phases ($\Delta\phi$ weak, $\Delta\delta$ strong)

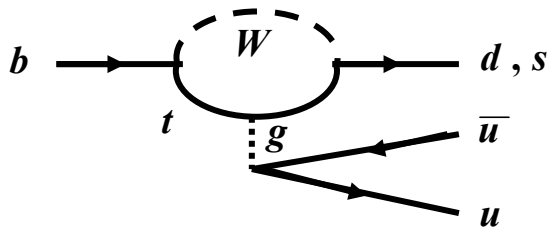
$$A_{CP} = \frac{2|P||T|\sin\Delta\phi\sin\Delta\delta}{|P|^2 + |T|^2 + 2|P||T|\cos\Delta\phi\cos\Delta\delta}$$

  - Examples: $B \to \pi K$, $\eta' K$, ($\pi\pi$, $\omega\pi$)
  - $\Delta\varphi$ is $\gamma = \arg[-V_{ud}V_{ub}^{*}/V_{cd}V_{cb}^{*}]$, ($\alpha = \arg[-V_{td}V_{tb}^{*}/V_{ud}V_{ub}]$,)
  - Complicated by strong phases
  - In certain models A_{CP} ~10%

Direct CP Violation II

- Strategy
  - Study decay diagrams with comparable tree and penguin rates





  - Charmless B decays
    - $b \to u$ (CKM-suppressed Tree $|V_{ub}/V_{cb}|^2 \approx 0.006$) (T)
    - $b \to s,d$ (Penguins, induced FCNC) (P)

$B \to \pi^+\pi^-$, $B \to K^+\pi^-$, K^+K^-

$B \to \pi^0\pi^0$, $\pi^+\pi^0$. K^0K^0, ..

$B \to \rho\pi$, $\pi\pi\pi$, $K^*\pi$,$K\pi\pi$, $KK\pi$

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

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

Direct CP Violation III

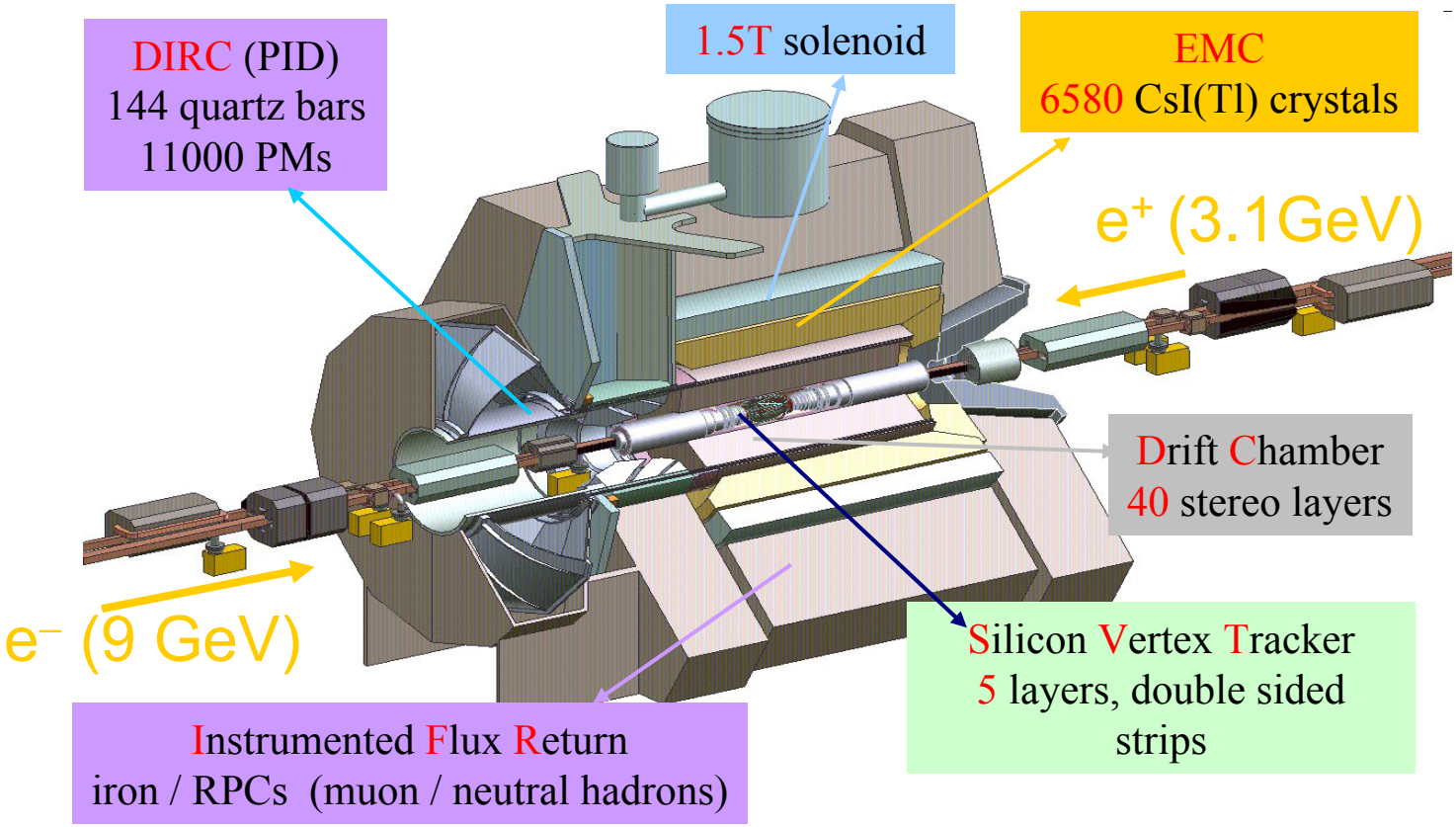
- Another approach
  - Study modes with only penguin modes
    - Sensitive to "new" physics (charged Higgs, SUSY) appearing in the loops
- Reminder
  - Direct CPV measurements previously presented
  - In SM $|\lambda_{CP}| = 1$, however, new physics may interfere

    allow λ to float in $B \to J/\Psi\ K^s$, $\Psi(2S)\ K^s$, $X_{C1}\ K^s$

    $$|\lambda_{CP}| = 0.093 \pm 0.06 \pm 0.02$$ **hep-ex/0203007**
  - In analysis of $B^0 \to \pi^+\pi^-$, $K^+\pi^-$, K^+K^-
    - $\mathbf{A_{K\pi^+}} = -0.05 \pm 0.06 \pm 0.01$ **hep-ex/0205082**

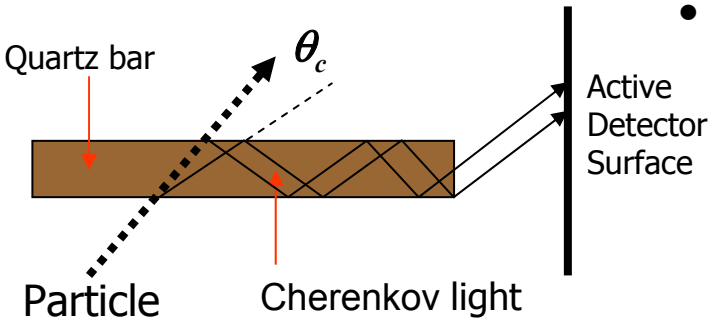
BaBar Detector

Pep-II delivers boosted $e^+e^- \rightarrow \Upsilon(4s) \rightarrow B\bar{B}$, $\beta\gamma = 0.55$



Particle Identification (DIRC)

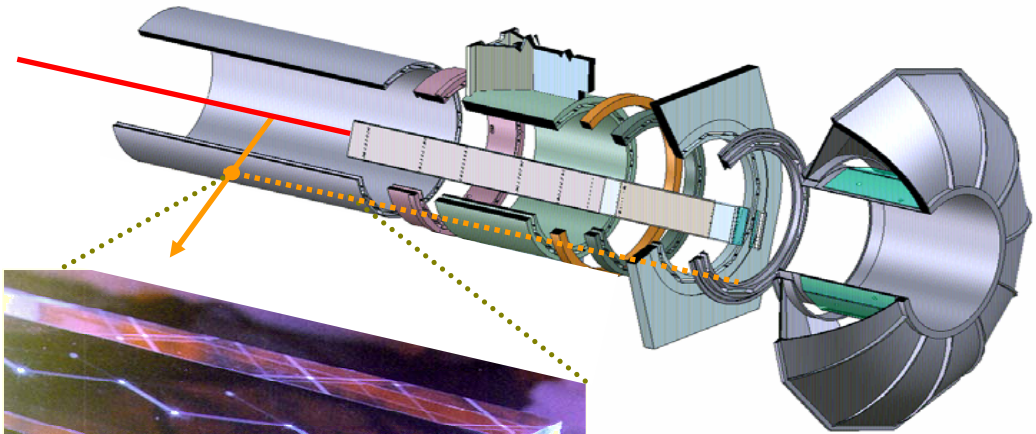
(Detector of Internally Reflected Cherenkov Light)

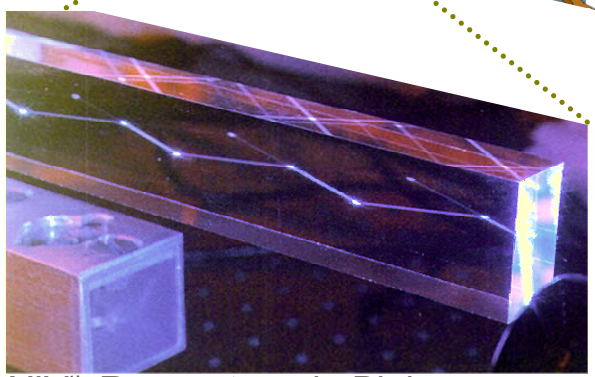


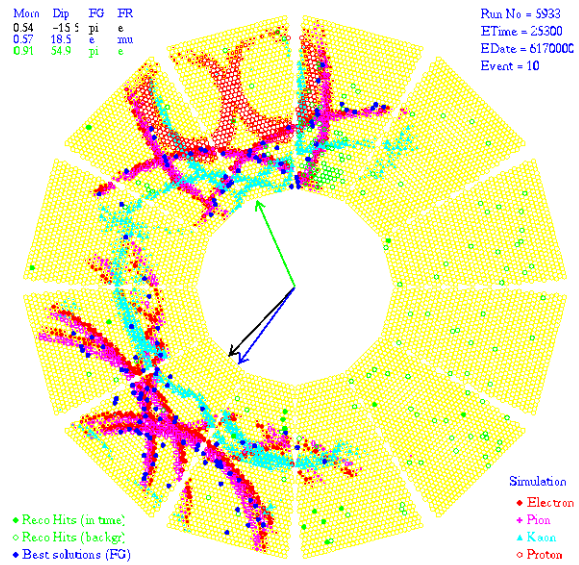
- Measure Angle of Cherenkov Cone in quartz

$$\cos\theta_c = 1/n\beta, \; p = m\beta\gamma$$

  - Transmitted by internal reflection
  - Detected by PMTs







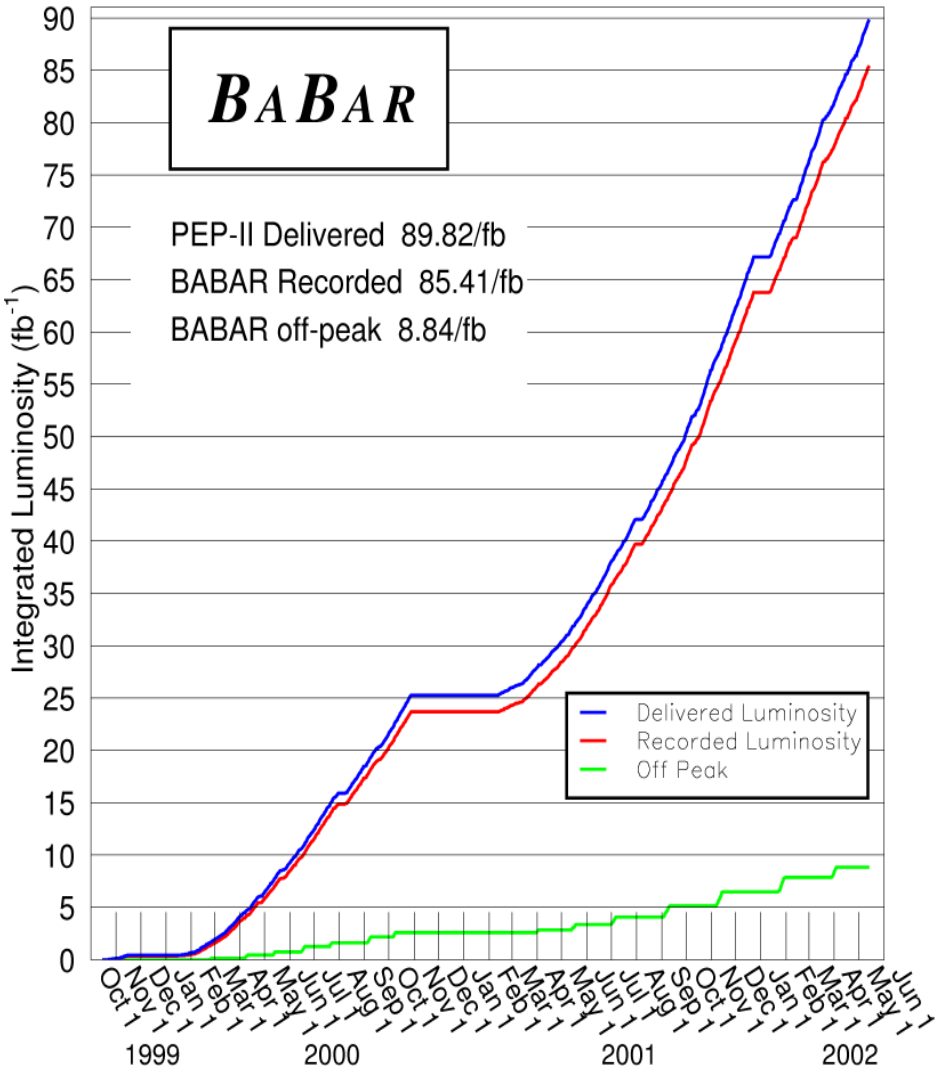
PEP-II Performance

- PEP-II and BaBar records:
  - Luminosity: 4.60 x $10^{33}cm^{-2}s^{-1}$
  - Recorded Lumi/8hr: 105 pb^{-1}
  - Recorded Lumi/24h: 303 pb^{-1}
  - Recorded Lumi/week: 1.8 fb^{-1}
- Most results based on 55.6/fb recorded between Jan. 2000 and Dec. 2001

$$N_{B\bar{B}} = (60.2 \pm 0.7)x10^6$$

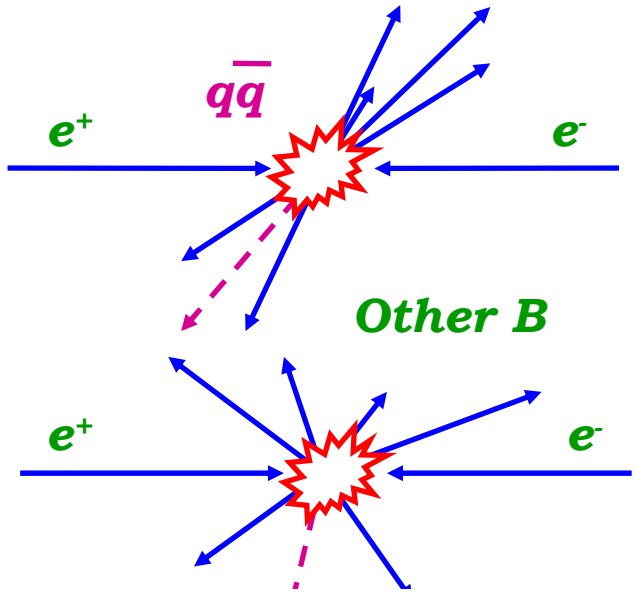
Some results for 2000 data only

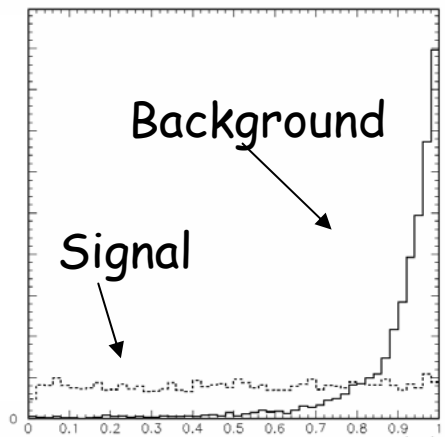
$$N_{B\bar{B}} = (22.7 \pm 0.7)x10^6$$



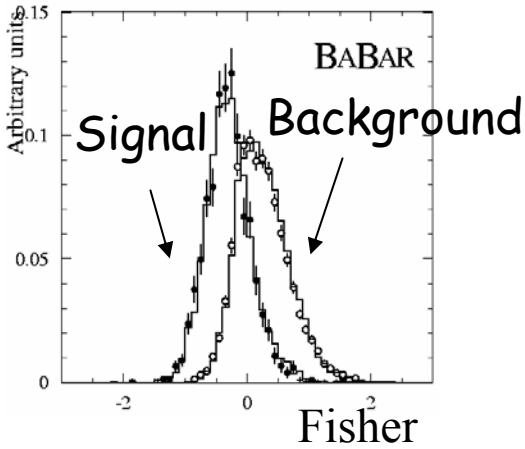
Charmless 2-body Analysis

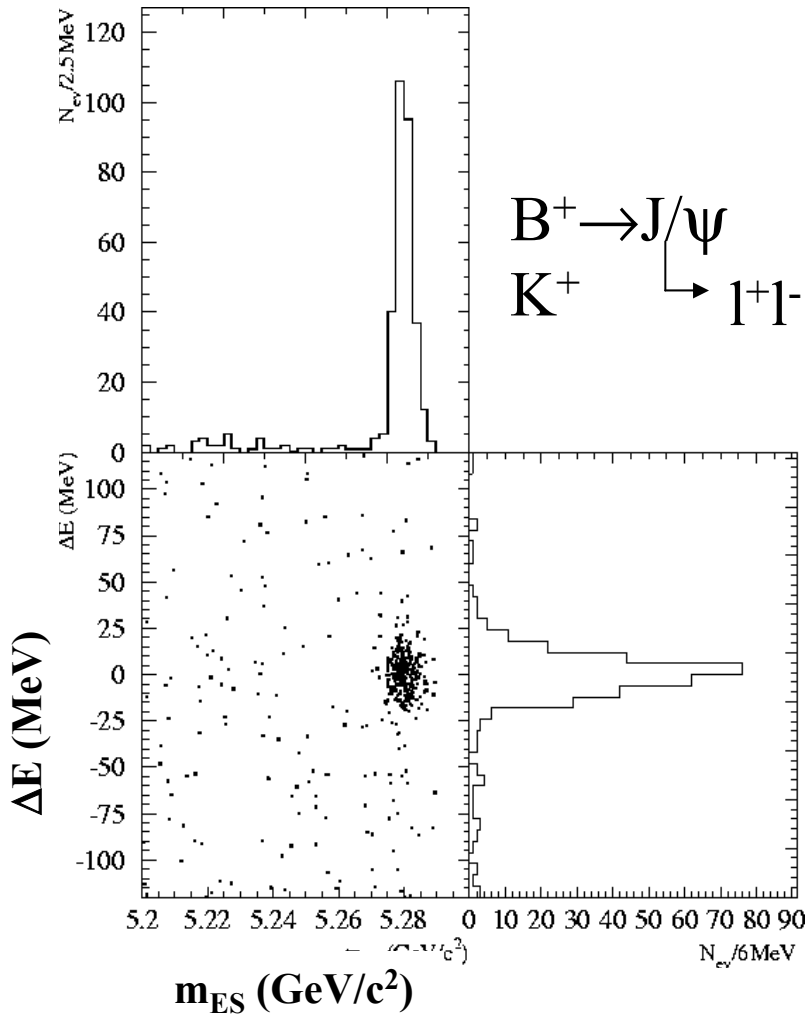
- $B^+ \rightarrow \pi^+\pi^0$, $K^+\pi^0$, $K^0_s\pi^+$, $K^+K^0_s$
  - High p B daughters (tracks and light resonances) $1.7<p<4.3$ GeV/c^2
  - Backgrounds dominated by qq continuum
    - B background from b→c tend to lower momenta
    - Use B kinematics and event shape variables to discriminate between signal and background
  - Reconstruct π^0 and Ks from $\gamma\gamma$ and $\pi\pi$ pairs within 3 σ of nominal mass
  - Combine with charged tracks to form B candidates
  - Calculate the thrust direction of the remaining tracks in the event relative to the B. Cut $\cos\theta_T < .9$ (.8)





B Meson Kinematics





Combine other shape variables into a Fisher Discriminant

- B meson energy given by the CM beam energy
- Compare with measured candidate energy

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

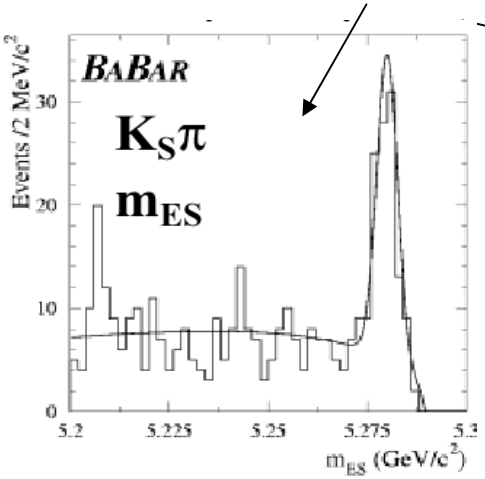
- Substitute in invariant mass

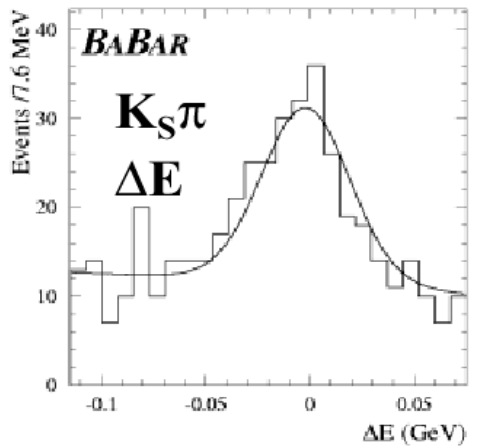
$$m_{\text{ES}} = \sqrt{E_{\text{beam}}^{*2} - p_B^{*2}}$$

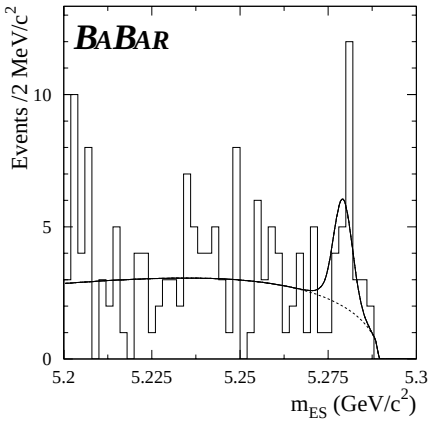
$B^+ \rightarrow \pi^+\pi^0,\ K^+\pi^0,\ K^0_s\pi^+$

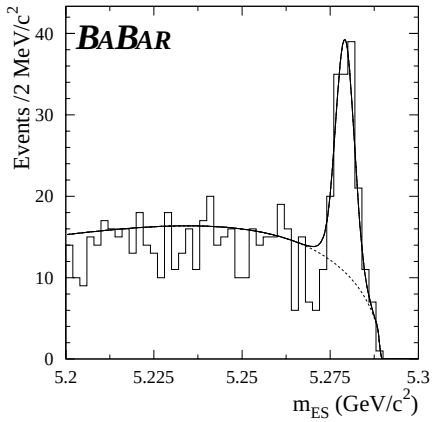
Projection of the maximum likelihood fits in m_{ES} and ΔE

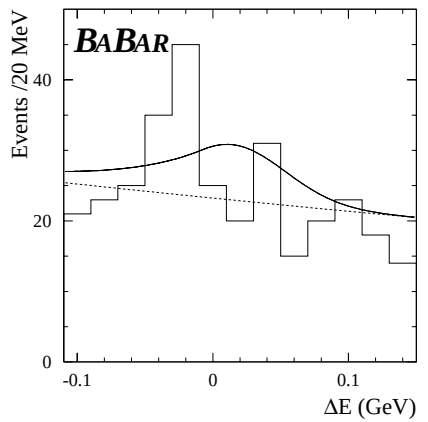
$B^+ \rightarrow \pi^+\pi^0$ $B^+ \rightarrow K^+\pi^0$











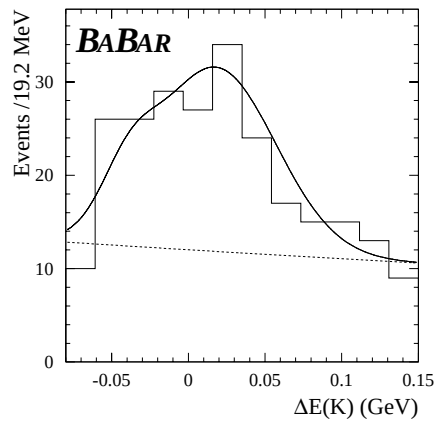


Figure 1: Distributions of m_{ES} and ΔE for $\pi^+\pi^0$ events (left) and $K^+\pi^0$ events (right) a additional requirements on likelihood ratios. Solid curves represent projections of the maxim

Charmless 2-body Analysis II

- Estimate signal with a maximum likelihood fit using m_{ES}, ΔE, F, θ_C , separately for π^0 and K^o

Preliminary

From MC

	yield	efficiency	$\mathcal{B}(10^{-6})$
$K^0\pi$	$N_{K_S\pi} = 171.8^{+17.3}_{-16.7} \pm 9.2$	$16.3 \pm 0.8\%$	$17.5^{+1.8}_{-1.7} \pm 1.3$
K^0K	$N_{K_SK} = -5.6^{+2.8}_{-5.5} \pm 2.5$	$16.2 \pm 0.8\%$	$(-0.6^{+0.6}_{-0.7} \pm 0.3) < 1.3$
$\pi\pi^0$	$N_{\pi\pi^0} = 62^{+17+10}_{-16-11}$	$25.3 \pm 1.7\%$	$4.1^{+1.1+0.8}_{-1.0-0.7}$
$K\pi^0$	$N_{K\pi^0} = 149^{+17+8}_{-17-7}$	$22.3 \pm 1.5\%$	$11.1^{+1.3}_{-1.2} \pm 1.0$

$$A(K_s^0\pi^+) = -0.17 \pm 0.10 \pm 0.02$$

$$Belle - A(K_s^0\pi^+) = 0.46 \pm 0.15 \pm 0.02$$

$$A(K^+\pi^0) = 0.00 \pm 0.11 \pm 0.02$$

A_{CP} Summary

Preliminary

hep-ex/0205082

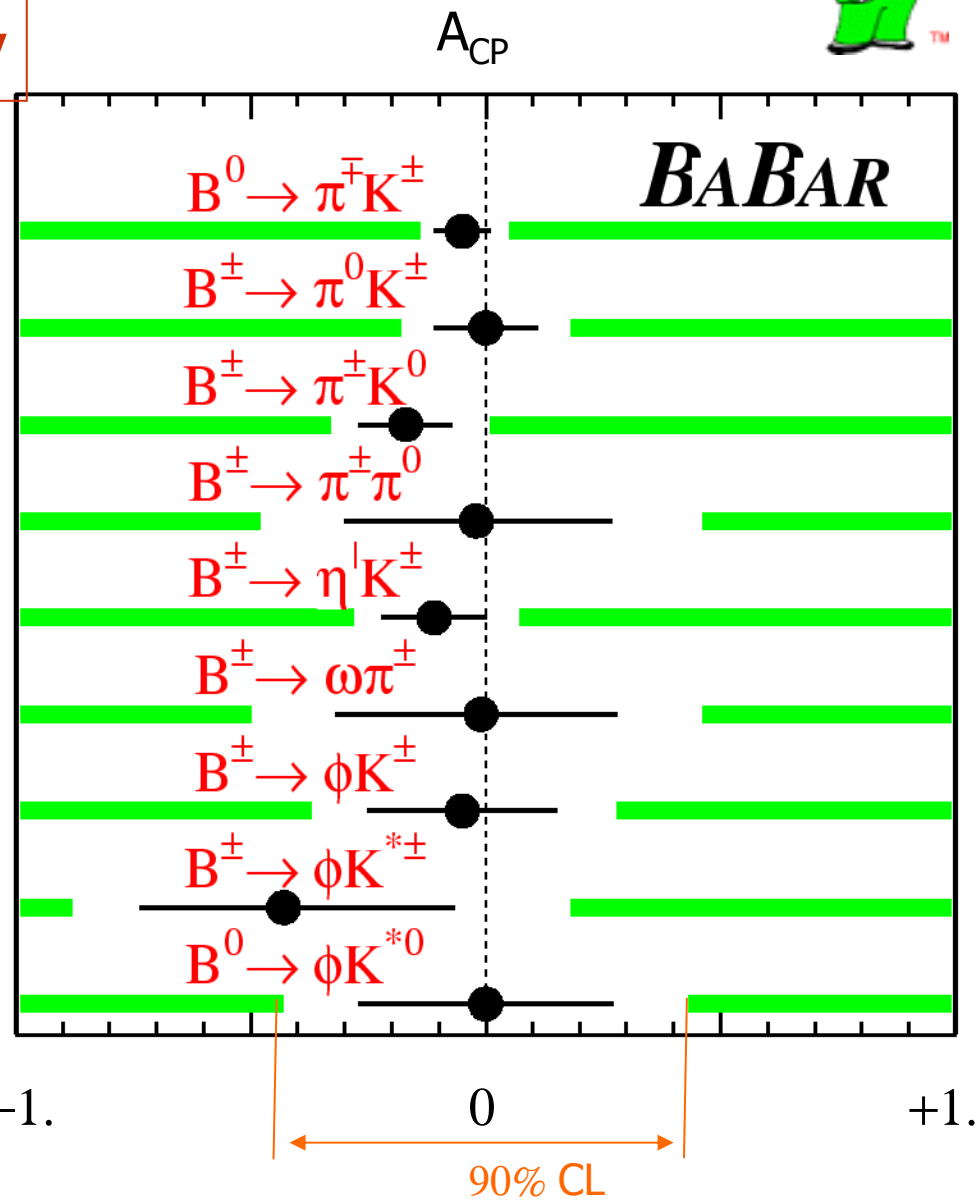
Updates results in

PRL **87** p. 151802(2001)

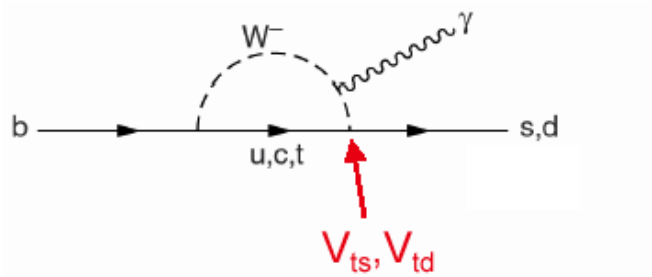
hep-ex/0105061

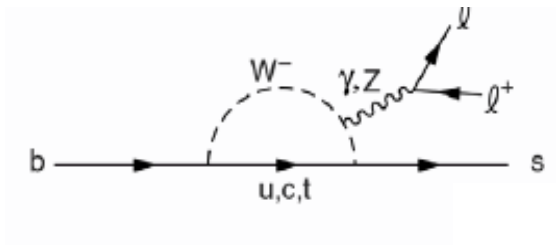
PRD 65 p. 051101(2002),

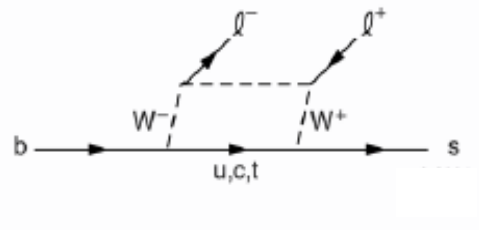
hep-ex/0109006



Radiative penguins







- b → sγ is effective FCNC transition in SM via "penguin" loop diagrams
  - Dominated by virtual t quark contribution
  - Sensitive to new heavy non-SM particles
    - Potentially large A_{CP}
- b → sγ inclusive (ICHEP)
- **B** → $K^*\gamma$
- B →ρ γ

$$\frac{B(B \to \rho\gamma)}{B(B \to K^*\gamma)} \approx \left|\frac{V_{td}}{V_{ts}}\right|^2$$

- **Expected branching fractions**
  - **B(B→ $K^*\gamma$)= 5x10^{-5}** (CLEO)
  - **B(B→ργ)= .5-.8x10^{-6}**
  - **B(B→K $l^+ l^-$) ~(0.5) x10^{-6}**
  - **B(B→K* $l^+ l^-$) ~(2) x10^{-6}**

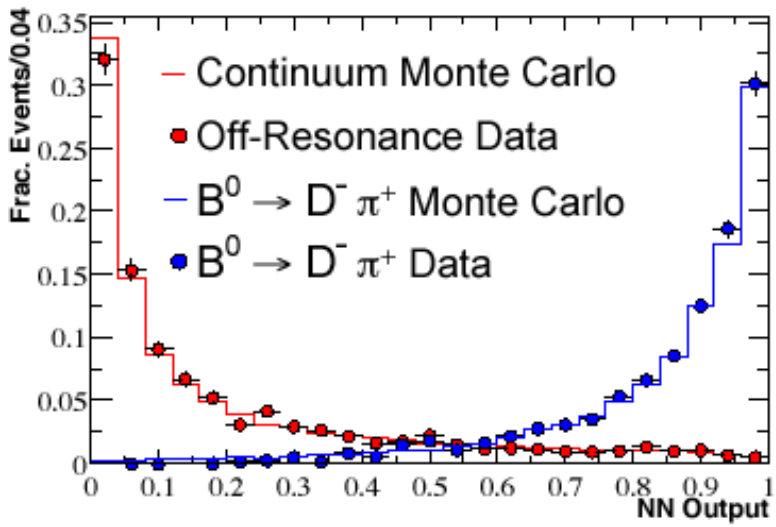
B -> K* γ , ργ analysis

- Both modes require isolated, energetic γ
  - $1.5 < E_{lab} < 4.5$
  - $-0.74 < \cos\theta < 0.93$
  - Veto π^0, η with $m_{\gamma\gamma}$ mass cut and lateral shower profiles
- Reconstruct ρ^0 , ρ^+, K^{*0}, K^{*+}
- Combine with γ to form B

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

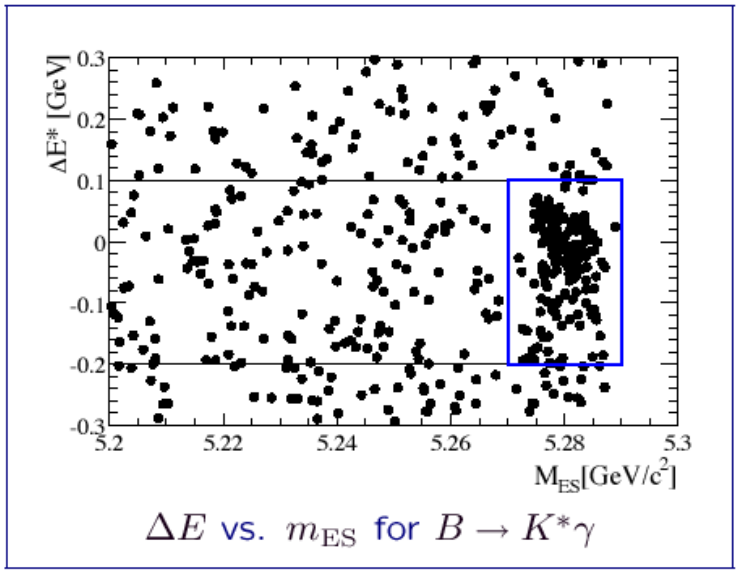
$$m_{\text{ES}} = \sqrt{E_{\text{beam}}^{*2} - p_B^{*2}}$$

- ργ analysis
- Use DIRC info to reject K's
- Several shape parameters are combined in a Neural Net
  - $\cos\theta_{\text{Thrust}}$, $\cos\theta_{\text{Helicity}}$, $\cos\theta_B$, Energy cones, Δz, R_2
  - Checked on $B^0 \rightarrow D^- p^+$

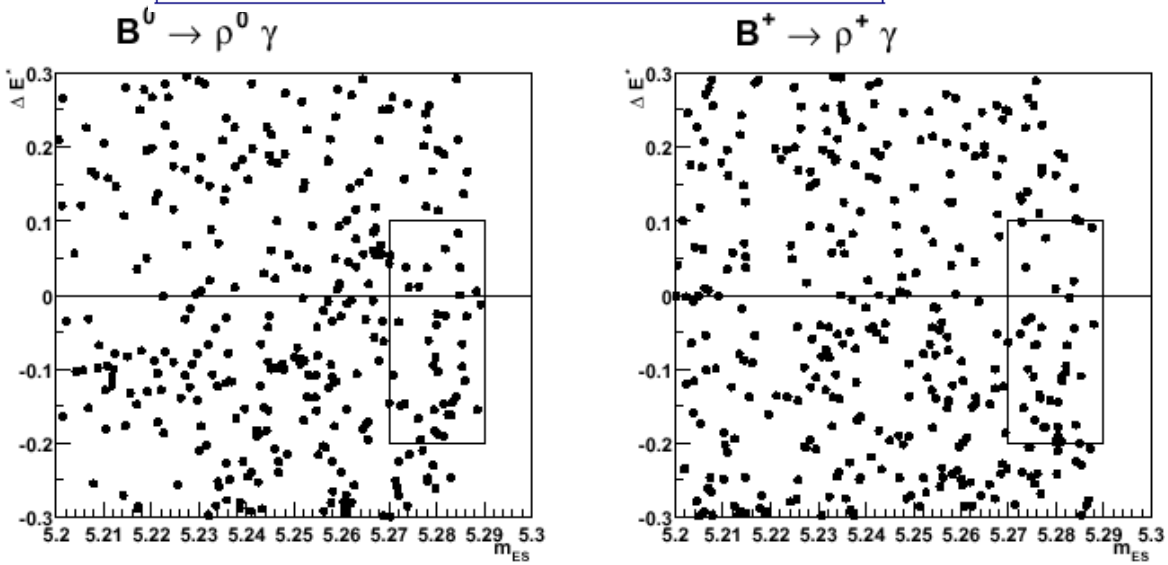


B –> K*γ , ργ analysis

K^* Cut on $-0.20 < \Delta E < 0.10$ GeV. Fit m_{ES}

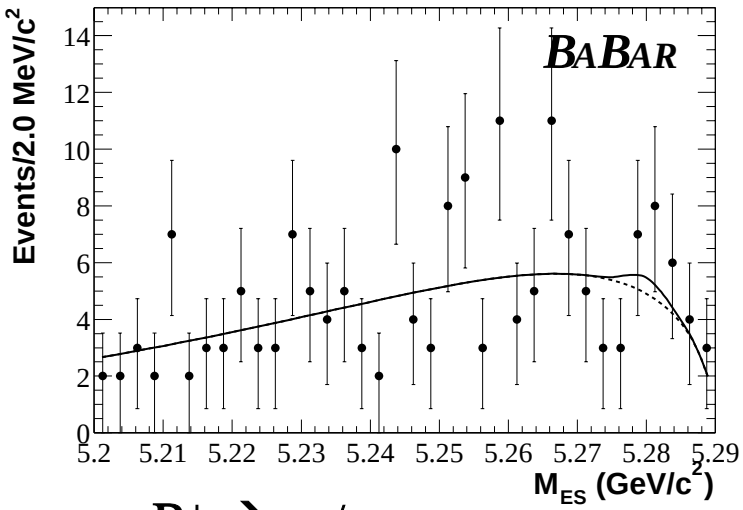


ργ Signal obtained by Maximum likelihood fit using m_{ES} , ΔE, mρ after NN cut.

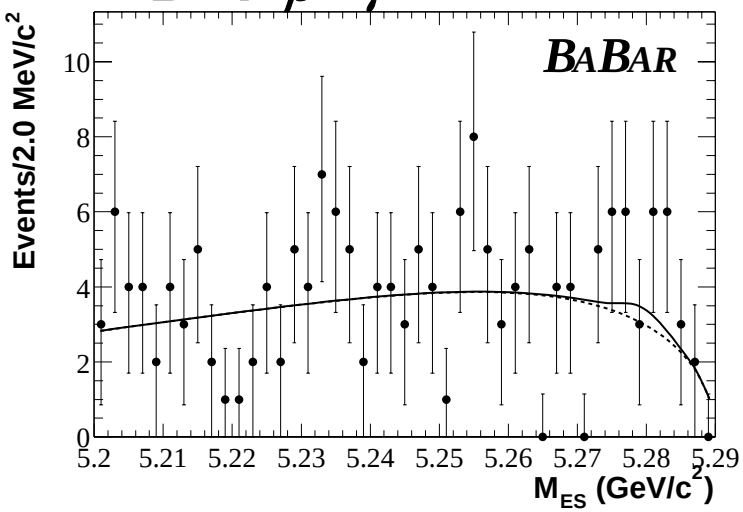


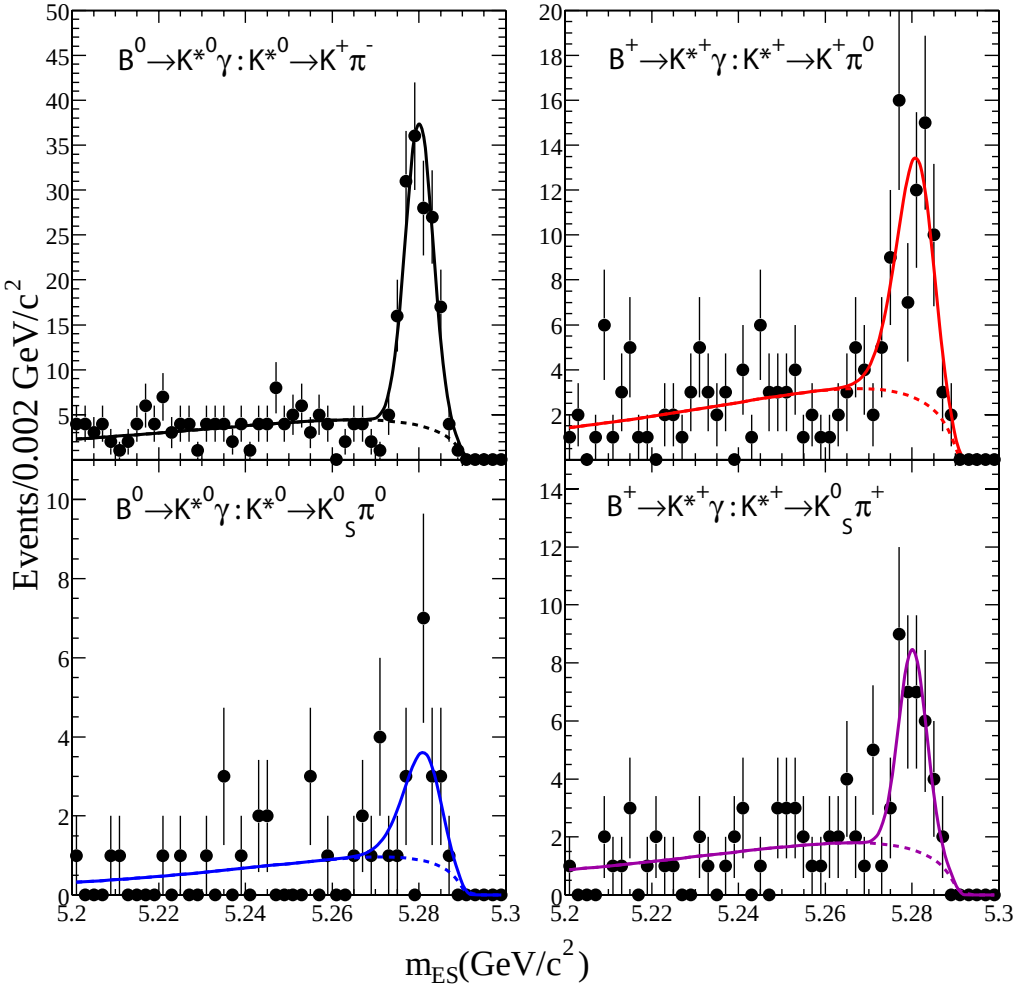
Projected yields

$B^0 \to \rho^0 \gamma$



$B^+ \to \rho^+ \gamma$





B -> K* γ , ργ results

- $\mathcal{B}[B^0 \to K^{*0}\gamma] = [4.23 \pm 0.40 \pm 0.22] \times 10^{-5}$
- $\mathcal{B}[B^+ \to K^{*+}\gamma] = [3.83 \pm 0.62 \pm 0.22] \times 10^{-5}$
- $A_{CP} = -0.044 \pm 0.076 \pm 0.012,\ [-0.170 < A_{CP} < 0.082]\ 90\%$ CL

22.7 10^6 BB

hep-ex/0110065

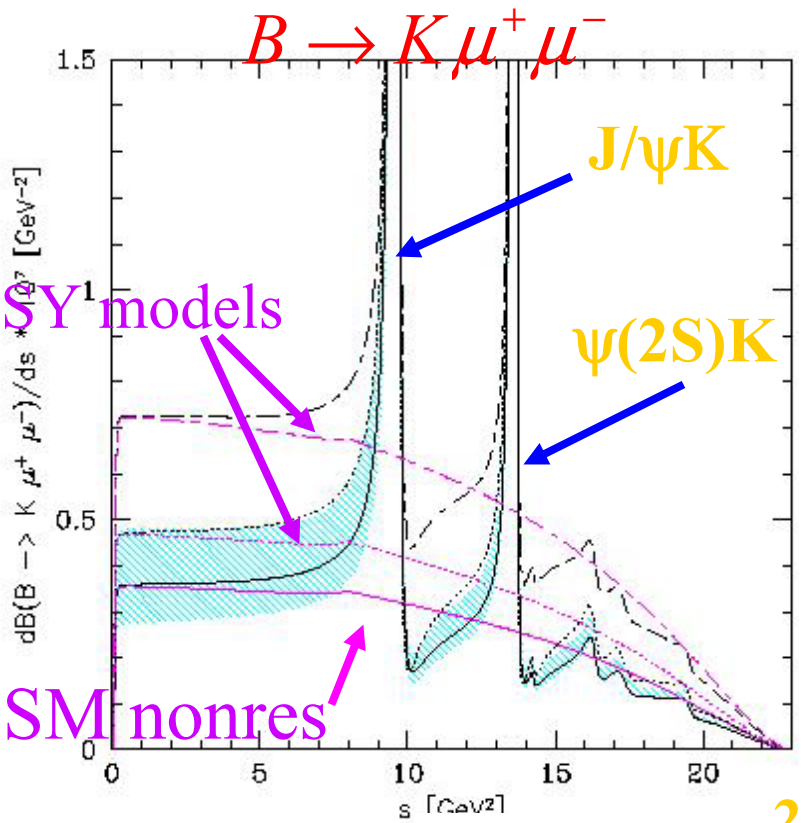
No significant signal for $B \to \rho\gamma$ 62.2 10^6 BB

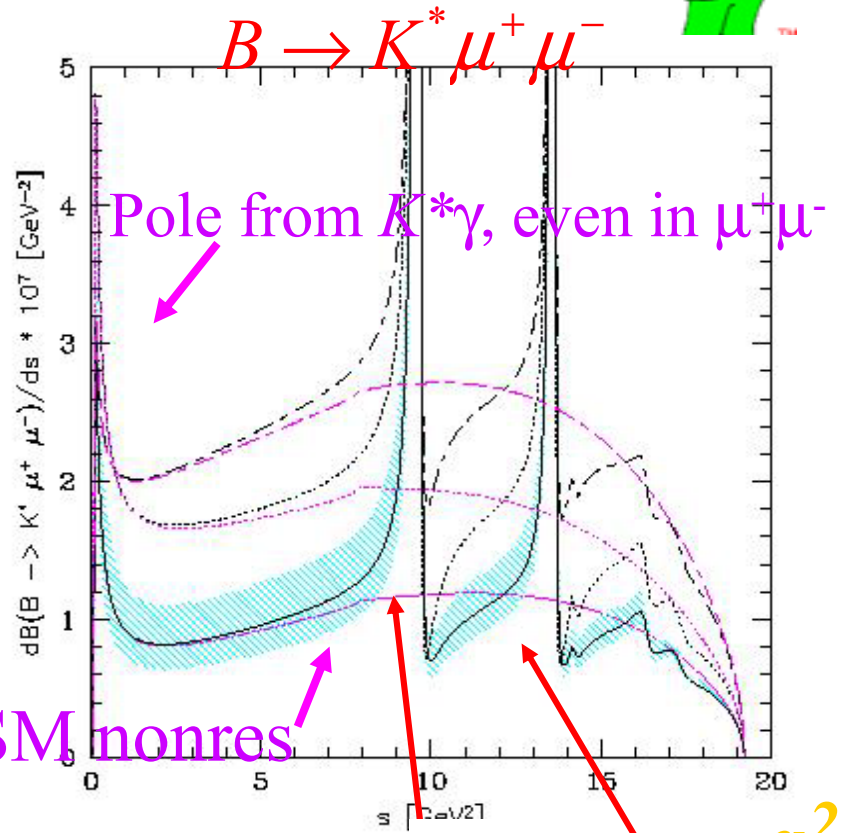
Preliminary 90% Confidence Level Limits:

$\mathcal{B}[B^0 \to \rho^0\gamma] < 1.5 \times 10^{-6}$, $\mathcal{B}[B^+ \to \rho^+\gamma] < 2.8 \times 10^{-6}$

Combined limit $BR[B \to \rho\gamma] < 2.3 \times 10^{-6}$, $\frac{\mathcal{B}(B \to \rho\gamma)}{\mathcal{B}(B \to K^*\gamma)} < 0.06$

$B \to K^{(*)} \ell^+\ell^-$ Decay rate vs. q^2 in the SM and SUSY





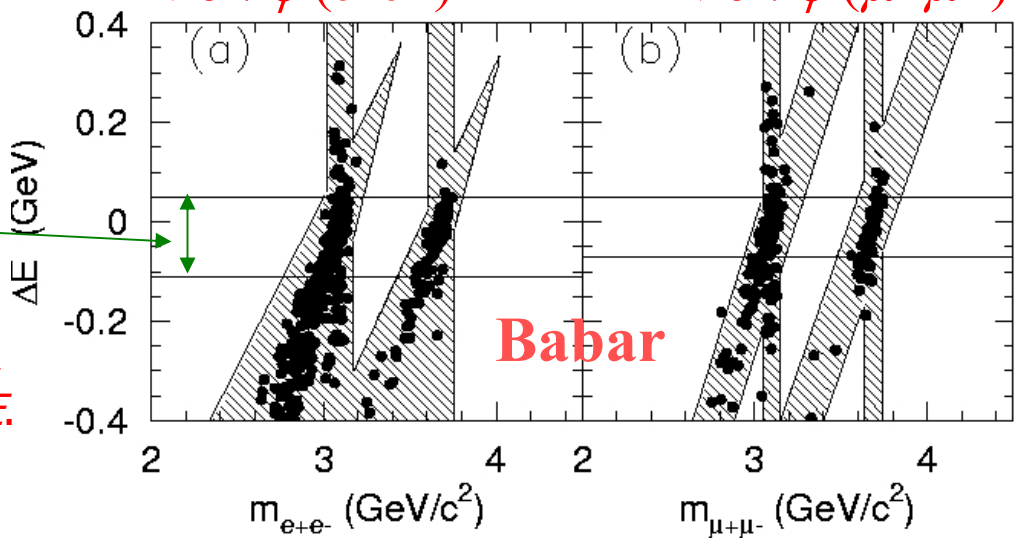
- Solid line+blue bands: SM range (±35%); Ali *et al.* form factors
- Dotted line: SUGRA model ($R_7 = -1.2$, $R_9 = 1.03$, $R_{10} = 1$; $R_i = C_i/C_i^{\rm SM}$)
- Long-short dashed line: SUSY model ($R_7 = -0.83$, $R_9 = 0.92$, $R_{10} = 1.61$)

B → K l^+l^-, $K^* l^+l^-$ analysis

- Exclusively reconstruct $K^{(*)} l^+ l^-$
  - $K^{*+} \to K_s^0 \pi^+$, $K^{*0} \to K^+ \pi^-$, $l = e, \mu$
- Reject candidates consistent with $B \to K^{(*)} J/\psi(\to l^+ l^-)$
- Veto potentially peaking backgrounds
  - $B \to D(\to K\pi)\pi$ with PID misid errors

Inverting the veto allows B→J/Ψ K samples to be used for signal efficiency studies

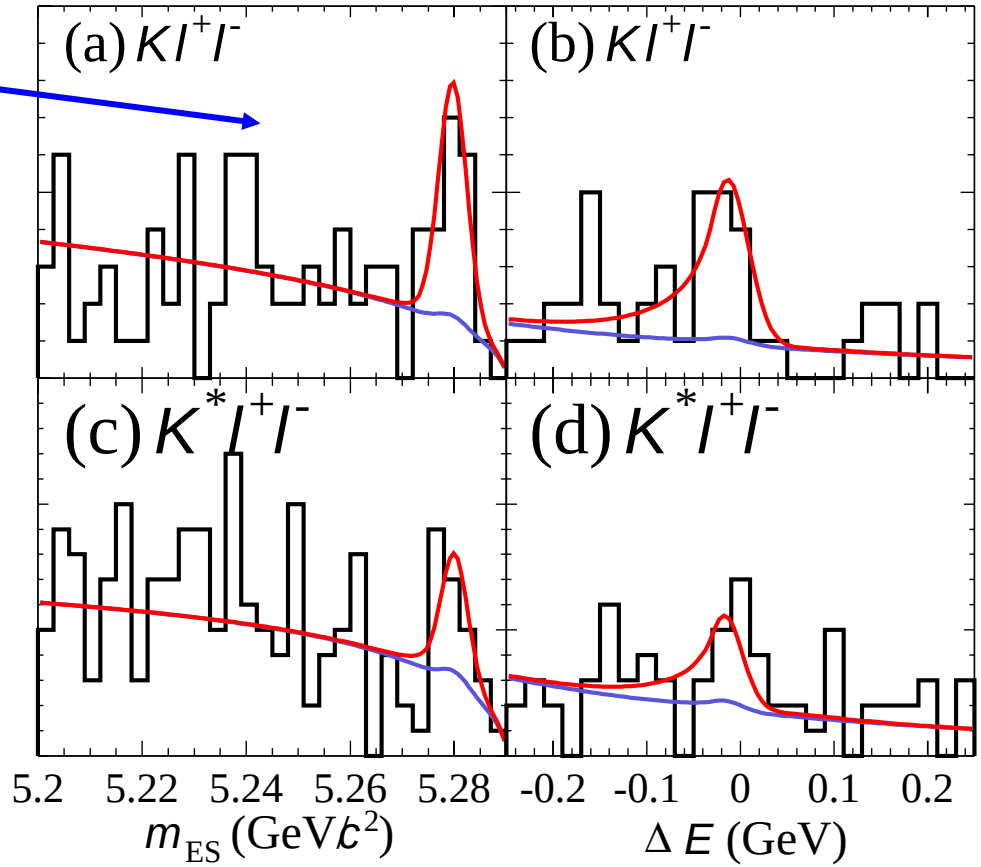
$B \to J/\psi(e^+e^-)K^{*0}$ $B \to J/\psi(\mu^+\mu^-)K^{*0}$



•$J/\psi \to l^+l^-$ *radiate* or are *mismeasured*, the event shifts in both $m(\psi)$ and in ΔE.

Search for B→ K l^+ l^- and B→ K* l^+ l^-

Combining channels, the M_{ES} and ΔE projections of the fit



Previous limit from 23 10^6 BB

B(B→K l^+ l^-) <0.5 x10^{-6}

B(B→K*l^+ l^-) <2.9 x10^{-6}

New Results

$$B(B \to Kl^+l^-) = (0.84^{+0.30+0.10}_{-0.24-0.18}) \times 10^{-6}$$

$$B(B \to K^* l^+l^-) = (1.89^{+0.84}_{-0.72} \pm 0.31) \times 10^{-6}$$

Quote K * as limit

B(B→ K* l^+ l^-) < 3.5 x10^{-6}

@ 90% CL

Assumed B(K*ee)/B(K*$\mu\mu$) = 1.2

Summary

- No significant signal of direct CP violation has been seen
  - Systematic errors are small
- BaBar's result on $K^0\pi^+$ $A_{CP} = -0.17 \pm 0.10 \pm 0.02$

  inconsistent with Belle at 3.3 sigma level
- Now observe
  - **B→ K l^+ l^-**
  - **B→ $\pi^+ \pi^0$**

  Improved upper limits

  B→ K^+K^0

  B→ K* l^+ l^-

  B→ $\rho\,\gamma$
- Study of rare modes just starting
- BaBar hopes to collect 500 fb -1 in ~4 years
  - ~* 10 the reported events
- With continued analysis improvements may observe Direct CP Violation