Rare B decays at BaBar

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La Thuile, March 3-9 2002

Introduction

- Previous BaBar results based on data taken in 1999-2000 (Run 1).
- Currently updating analyses with data taken in 2001 (Run 2).
- Some analyses are ready, some are unfortunately not ....

Outline

- General analyses techniques
- Radiative Penguins:
  - $B \longrightarrow K^* \gamma$
  - $B \longrightarrow \rho \gamma$
  - $B \longrightarrow K^{(*)} l^+ l^-$
- Conclusions

$m_{ES} - \Delta E$ plane

- $e^+e^- \longrightarrow \Upsilon(4S) \longrightarrow B\bar{B}$
- B mesons nearly at rest in the $\Upsilon(4S)$ rest frame: $p^* = 325$ MeV ($\beta\gamma = 0.55$).
- Beam energy is very well known.
- Define two new (largely uncorrelated) variables in the $\Upsilon(4S)$ rest frame.
- Energy substituted mass m_{ES}:

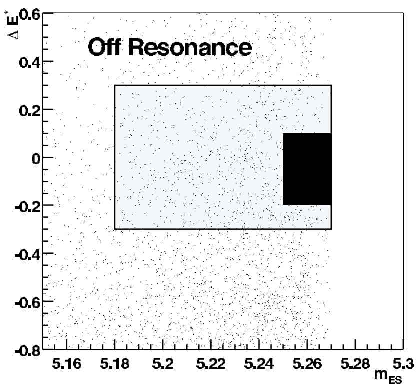
$$m_{ES} = \sqrt{E^{*\,2}_{Beam} - \vec{p}^{*\,2}_{B}} \qquad \sigma \approx 2.5 MeV$$

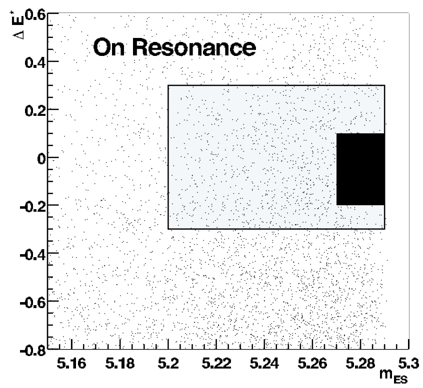
- Energy difference:

$$\Delta E = E^*_B - E^*_{Beam} \qquad \sigma \approx 20 - 40 MeV$$

Signal box

- Define signal box and (grand) sidebands in $m_{ES} - \Delta E$ plane.
- Blind analysis: Content of signal box unknown until all selection criteria are fixed.

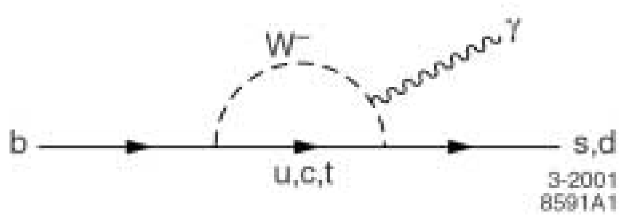




Fitting

- Cut-and-count analysis:
  - Use small signal box with well known efficiencies.
  - Optimize selection criteria wrt the signal box.
- Maximum likelihood fit:
  - Fit over a much larger region of the $\Delta E - m_{ES}$ plane.
  - Fit signal and (all) background components.
  - Higher efficiency / sensitivity, but more complicated PDFs (that are varied over a large region).
  - Use cut-and-count analysis as baseline.
- Selection criteria determined using background and signal MC, off resonance data and side band data.

$B \longrightarrow K^*\gamma$ and $\rho\,\gamma$: Theoretical Motivation



- Examples of radiative Penguin processes: $b \longrightarrow s, d \;\; \gamma$
- $B \longrightarrow K^*\gamma\ (\rho\gamma)$ is sensitive to V_{ts} (V_{td}).
- But also sensitive to new physics enhancing branching ratios and/or CP asymmetries (from $< 1\%$ up to 20% (Kagan & Neubert)).
- Use (Ali & Parkhomenko) ratio to cancel (long distance QCD) uncertainties (cf B_d and B_s mixing):

  $$\frac{Br(B \longrightarrow \rho\gamma)}{Br(B \longrightarrow K^*\gamma)} = (\tfrac{1}{2})(\frac{|V_{td}|}{|V_{ts}|})^2 \;\; \Omega_{(Phase\ space)} \;\; \zeta^2_{(Form\ Factors)}[1 + \Delta R]$$

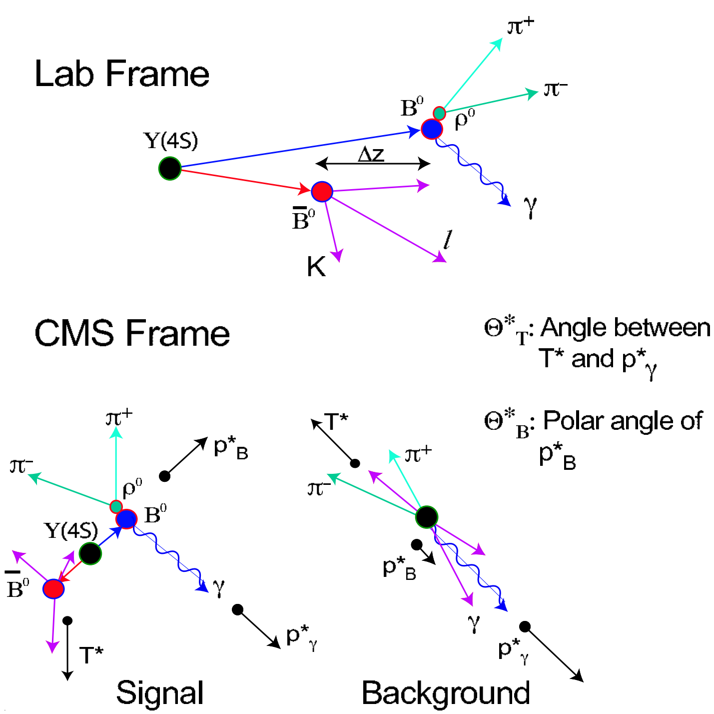
  where (1/2) is from isospin, $\zeta = 0.76 \pm 0.06$ (Z. Phys. C 63, 1994) and $\Delta R < 0.15$.
- Can extract $(\frac{|V_{td}|}{|V_{ts}|})^2$ with a theoretical uncertainty of 20%.

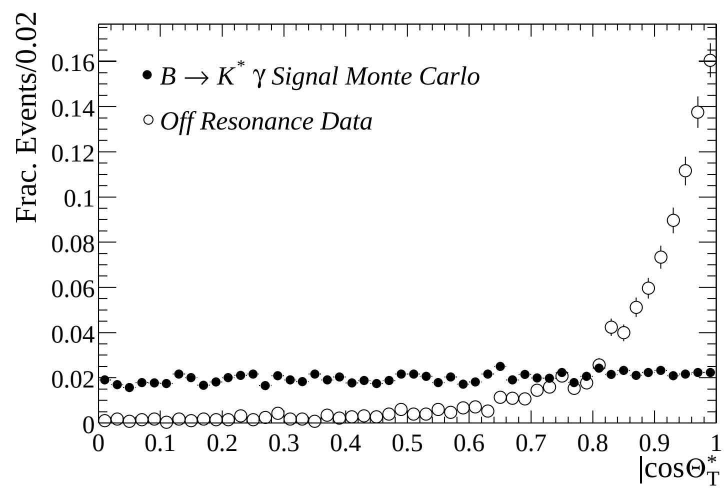
$B \longrightarrow K^* \gamma$: Reconstruction

- Based on run 1 data set: 20.7 fb^{-1} (2.6) on (off) resonance.
- K^* reconstruction modes:
  - $K^{*0} \longrightarrow K^+\pi^-$
  - $K^{*0} \longrightarrow K_s^0\pi^0$
  - $K^{*+} \longrightarrow K^+\pi^0$
  - $K^{*+} \longrightarrow K_s^0\pi^+$
- Require a high energy photon: $1.5 < E_\gamma < 4.5$ GeV
  $2.3 < E_\gamma^* < 2.85$ GeV
- Veto photons from π^0 and η.
- Require identified kaon in the DIRC: 87% efficient for the signal and reduces the combinatorial background by a factor 4.

$B \longrightarrow K^* \gamma$: Backgrounds

- Main background comes from continuum $q\bar{q}$ production with photon from ISR or π^0 and η decays. Other B backgrounds negligible.
- Use event topology to suppress jet like continuum background from isotropic $B\bar{B}$: thrust, B direction and K^* helicity.

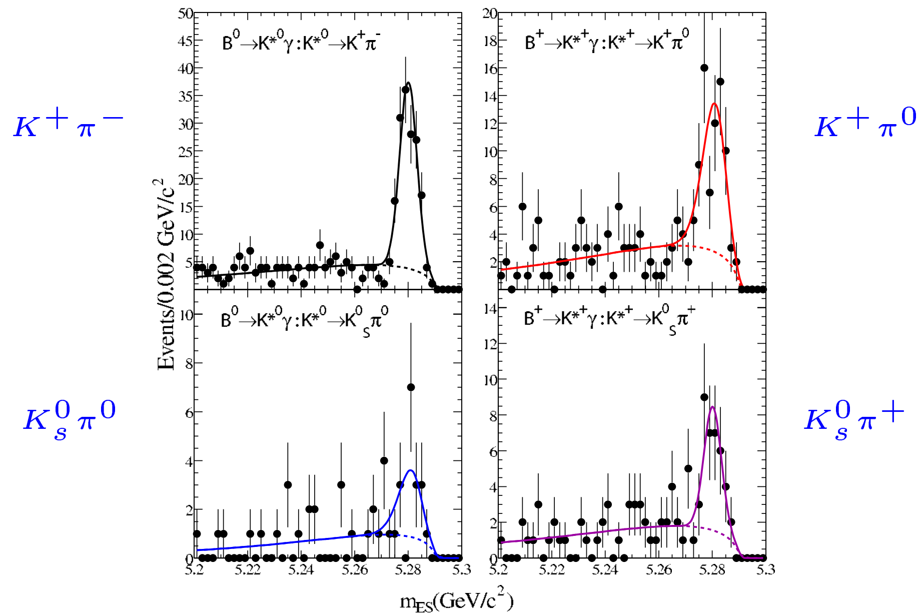




$B \longrightarrow K^* \gamma$: ΔE^*

- Require: -200 (-225) MeV $< \Delta E^* <$ 100 (125) MeV
- (Single) photon candidate rescaled to $\Delta E^* = 0$:
  - Removes tail in m_{ES} resolution.
  - Improves the resolution from 2.7 (2.9) MeV to 2.5 (2.6) MeV for B^0 and B^+ respectively.
- Signal yields obtained from fitting m_{ES} distributions.

$B \longrightarrow K^* \gamma$: **Results**



Mode	Efficiency	Nbr signal events	Br $(B \longrightarrow K^*\gamma) \times 10^{-5}$
$K^+\pi^-$	14.0%	135.7 ± 13.3	$4.24 \pm 0.41 \pm 0.22$
$K_s^0\pi^0$	1.4%	14.8 ± 5.6	$4.10 \pm 1.71 \pm 0.42$
$K^+\pi^0$	3.9%	28.1 ± 6.6	$3.01 \pm 0.76 \pm 0.21$
$K_s^0\pi^+$	4.3%	57.6 ± 10.4	$5.52 \pm 1.07 \pm 0.38$

$B \longrightarrow K^* \gamma$: **Combined results**

- Combined results (to appear in PRL):

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

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

- Define CP-violating asymmetries A_{CP}:

$$A_{CP} = \frac{\Gamma(\bar{B} \to \bar{K}^*\gamma) - \Gamma(B \to K^*\gamma)}{\Gamma(\bar{B} \to \bar{K}^*\gamma) + \Gamma(B \to K^*\gamma)}$$

- We obtain at 90% C.L.:

$$-0.170 < A_{CP}(B \to K^*\gamma) < 0.082$$

- This analysis is currently being updated with Run 2 data.

$B \longrightarrow \rho\, \gamma$: Current situation

- Experimentally the mode has not been seen!
- Current situation:

	$Br(B^0 \longrightarrow \rho^0 \gamma)$	$Br(B^+ \longrightarrow \rho^+ \gamma)$
Ali and Parkhomenko	$(0.49 \pm 0.21) \times 10^{-6}$	$(0.85 \pm 0.40) \times 10^{-6}$
Bosh and Buchalla	$0.76^{+0.26}_{-0.23} \times 10^{-6}$	$1.53^{+0.53}_{-0.46} \times 10^{-6}$
CLEO	$< 1.7 \times 10^{-5}$	$< 1.3 \times 10^{-5}$
BELLE	$< 0.99 \times 10^{-5}$	$< 1.06 \times 10^{-5}$

$B \longrightarrow \rho\,\gamma$: Preliminaries

- Based on Run 1 and Run 2 data set: 56 (6.3) fb^{-1} on (off) resonance
- Decay modes: $\rho^0 \longrightarrow \pi^+\pi^-$ and $\rho^+ \longrightarrow \pi^+\pi^0$.
- Analysis similar to $K^*\gamma$, but:
  - Smaller branching fraction (x50) and wider resonance (x3).
  - Less help from Particle IDentification to suppress combinatorial background (continuum pions).
  - $K^*\gamma$ with kaon misidentified as a pion has similar kinematics and will be a background. A new pion selector (80%) has been introduced specifically to reduce the $K^*\gamma$ background to $\sim 1\%$.
  - Unobserved mode $B^+ \longrightarrow \rho^+\pi^0$ will be a significant systematic uncertainty for the $\rho^+\gamma$ mode.
- Blind analysis.

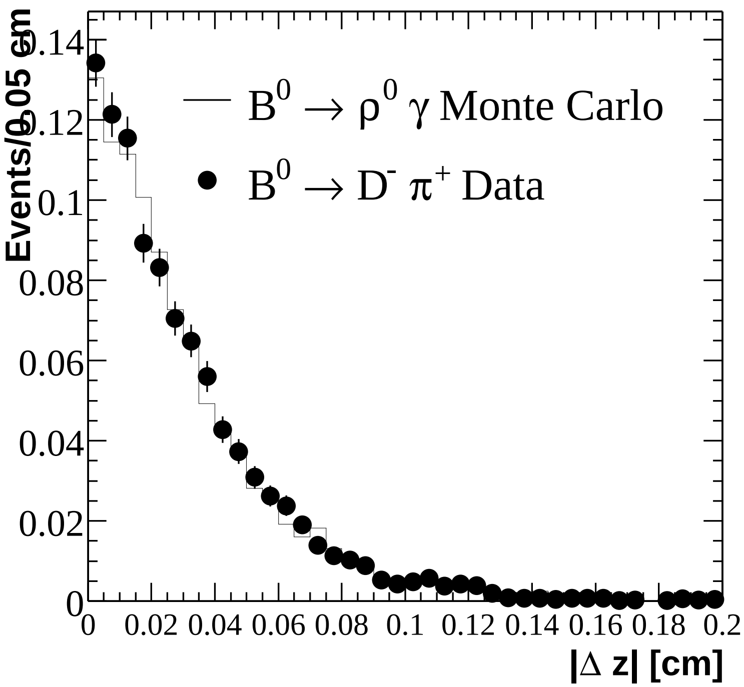
$B \longrightarrow \rho\,\gamma$: Background suppression

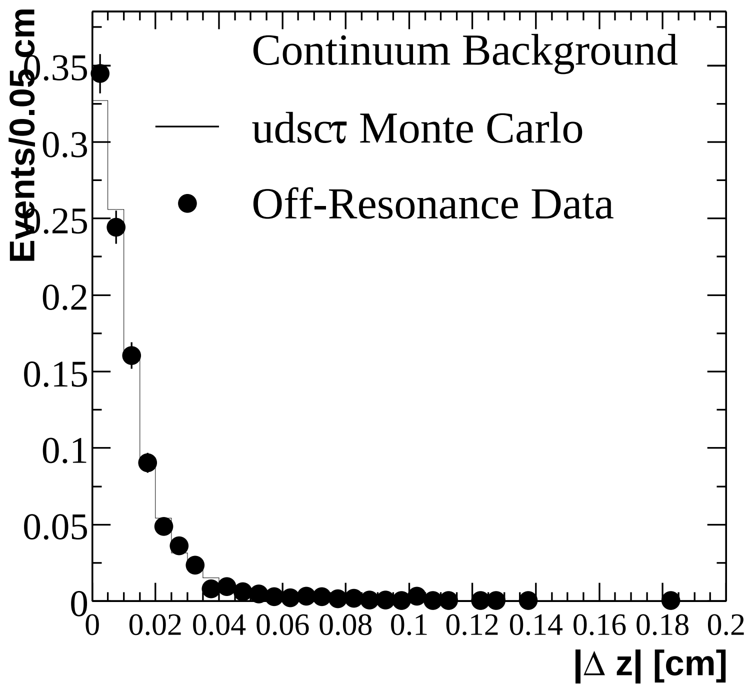
- Continuum suppression:
  - Vertex separation between $\rho^0\gamma$ candidate and the rest of the event.
  - Net flavour production in the rest of the event.
  - Event shape variables: thrust, polar angle, helicity, Fox-Wolfram $R^{'}2$.
  - 18 energy cones around the photon.
  - Combined into a neural net.
  - Reduces backgrounds / improves sensitivity by up to a factor two.
  - Net trained on continuum background, but also efficient for rejecting combinatorial $B\bar{B}$ background.
  - Working on improving the net flavour production separation and also vertex separation for $\rho^+\gamma$ mode.

$B \longrightarrow \rho\,\gamma$: Δz

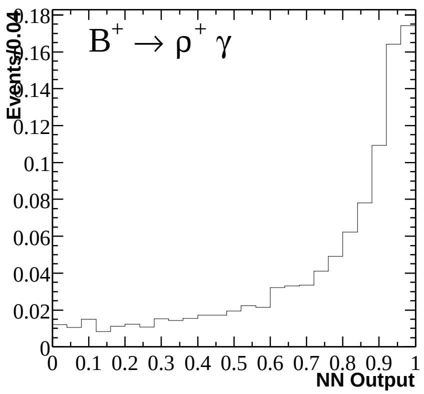
ΔZ Signal

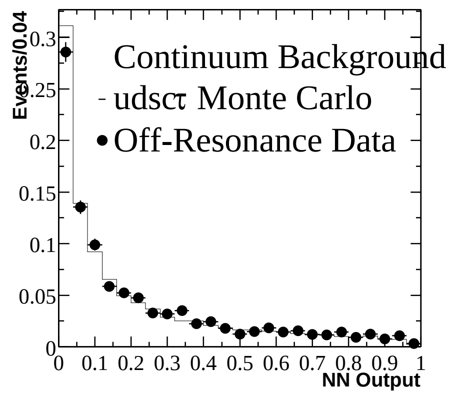
ΔZ Background

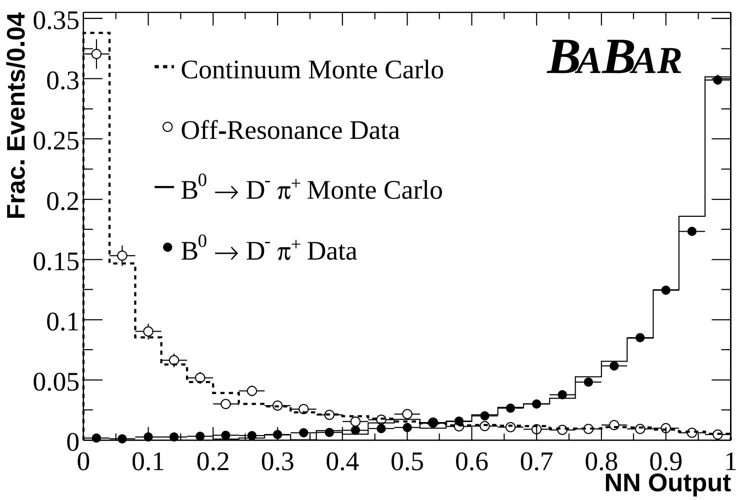


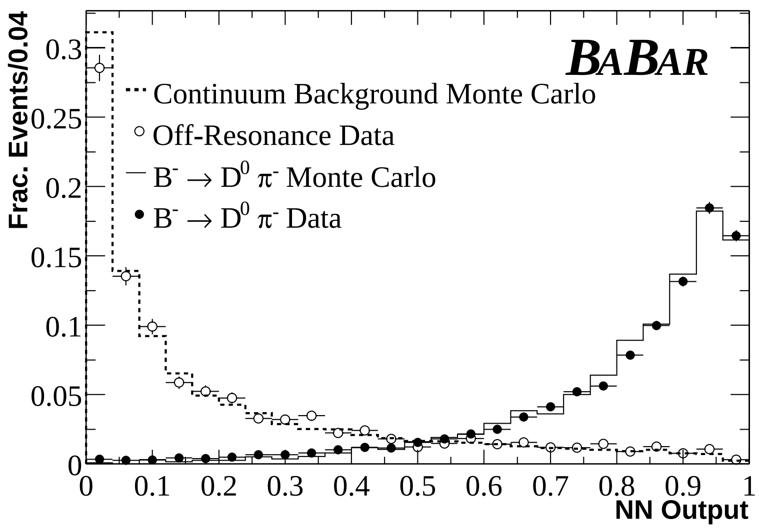


$B \longrightarrow \rho\,\gamma$: Neural Net output









$B \longrightarrow \rho\,\gamma$: Cuts and Fit

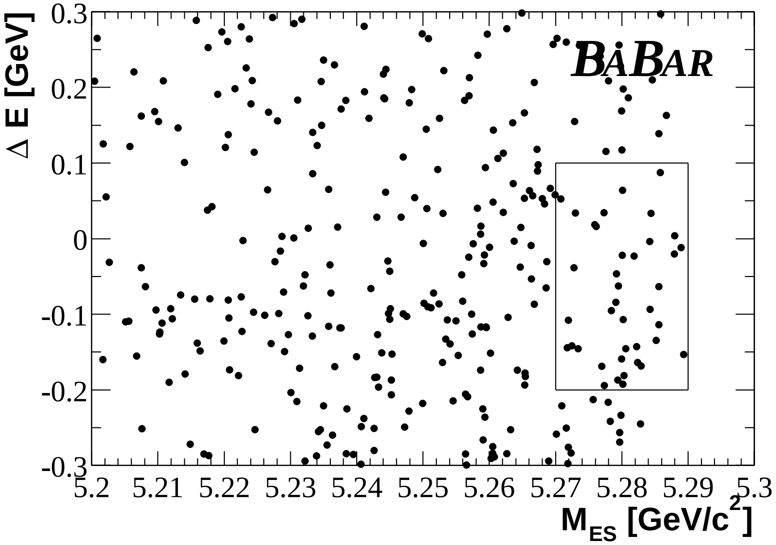
- Multiple candidates: Use ΔE^* and $p_{\rho,CMS}$ to select the best candidate - 2.8% of signal candidates are wrongly selected.
- Subsequent helicity angle cut still useful to reject $B^+ \longrightarrow \rho^+\pi^0$ ($sin^2\theta$ vs. $cos^2\theta$ - reduces background by a factor 2 with a 10% signal loss).
- (Single) photon energy rescaling symmetrizes and improves m_{ES} resolution by 1 MeV to 2.5 MeV.
- Fit:
  - Cut on neural net output to reduce continuum and $B\bar{B}$ combinatorial background.
  - Then do a Maximum Likelihood fit with m_{ES}, ΔE^* and M_ρ.
  - Only fit $B \longrightarrow \rho\gamma$ signal and continuum background.
  - Estimate B background effects with Toy MC study.

$B \longrightarrow \rho\,\gamma$: Efficiencies and Fit bias

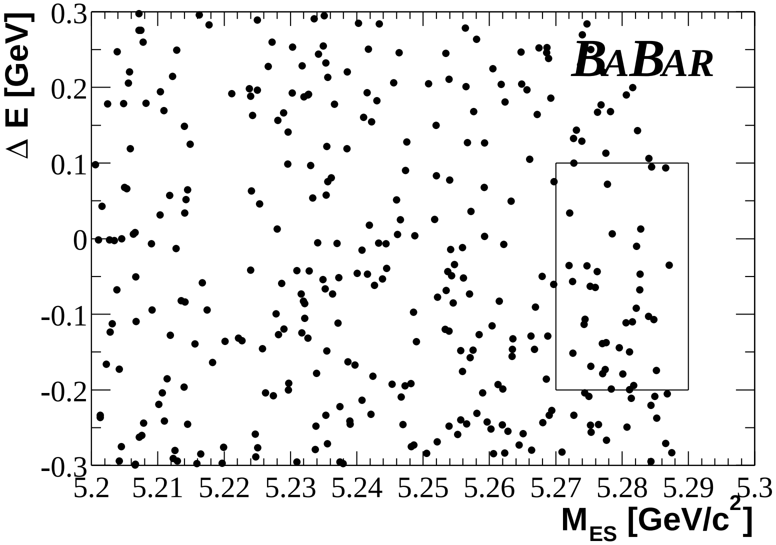
- Signal efficiencies:
  - $\rho^0\gamma$: 11.7%
  - $\rho^+\gamma$: 9.3%
- Fit region: -300 $< \Delta E^* <$ 300 MeV   5.2 $< m_{ES} <$ 5.29 GeV
- Signal PDFs fixed to $K^*\gamma$ values while floated for the continuum background (except ρ resonant fraction).
- B decay background effect on signal yield:
  - Systematic shift when B background is ignored in the fit.
  - $\rho^0\gamma$: 0.5 ± 0.5 events.
  - $\rho^+\gamma$: 2.5 ± 2.5 events.

$B \longrightarrow \rho\,\gamma$: Results

$B^0 \longrightarrow \rho^0\gamma$



$B^+ \longrightarrow \rho^+\gamma$



$B \longrightarrow \rho\,\gamma$: Results

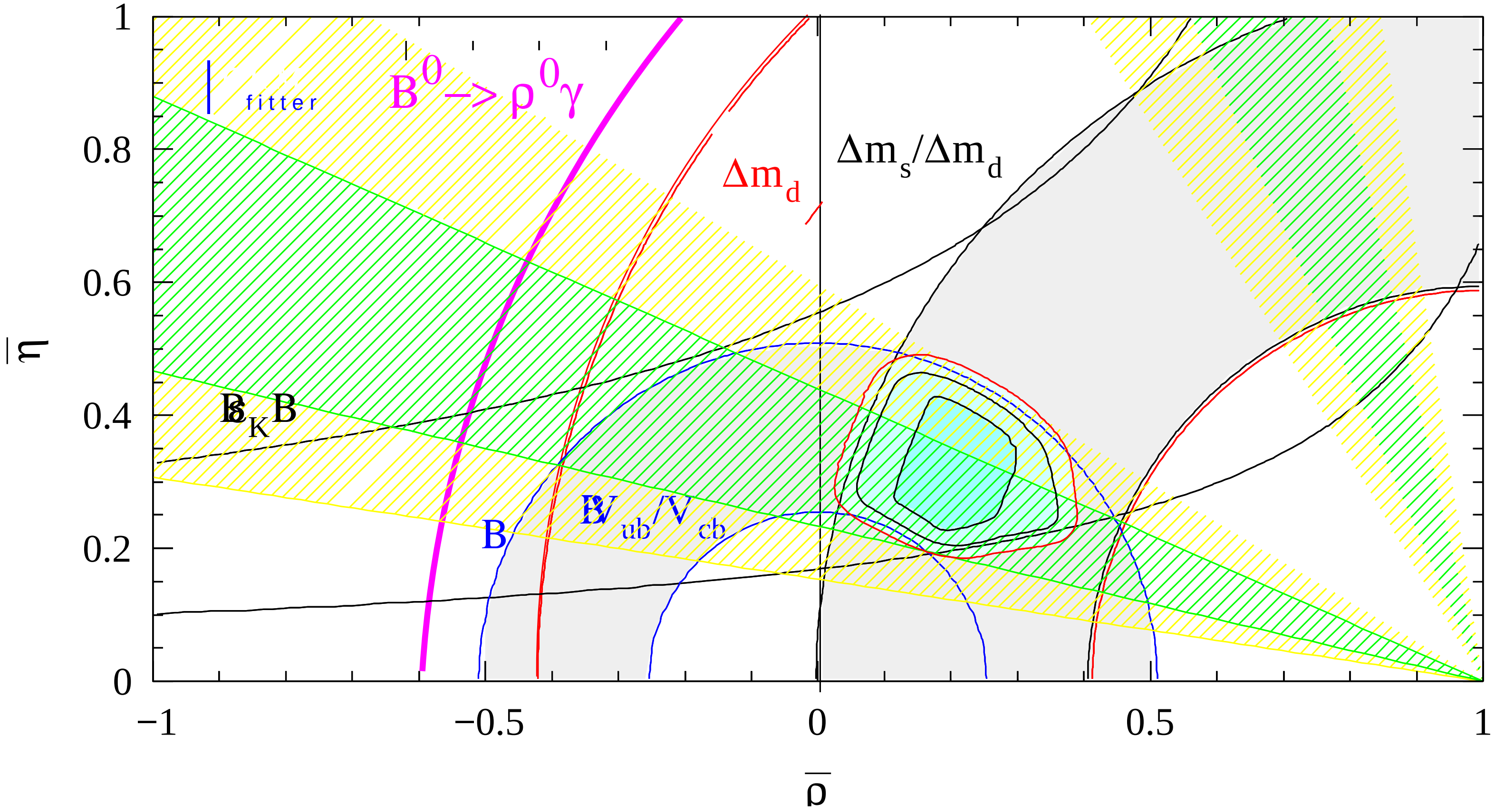
- Results from the fit:
  - $\rho^0\gamma$: 3.1 ± 4.2 signal events
  - $\rho^+\gamma$: 4.6 ± 5.8 signal events
- Upper limits:
  - We do not subtract B background bias to calculate upper limits.
  - Include 15% systematics (10% from ρ resonant fraction).

$$Br(B^0 \longrightarrow \rho^0\gamma) < 1.5 \times 10^{-6} \text{ at 90\% C.L.}$$
$$Br(B^+ \longrightarrow \rho^+\gamma) < 2.8 \times 10^{-6} \text{ at 90\% C.L.}$$

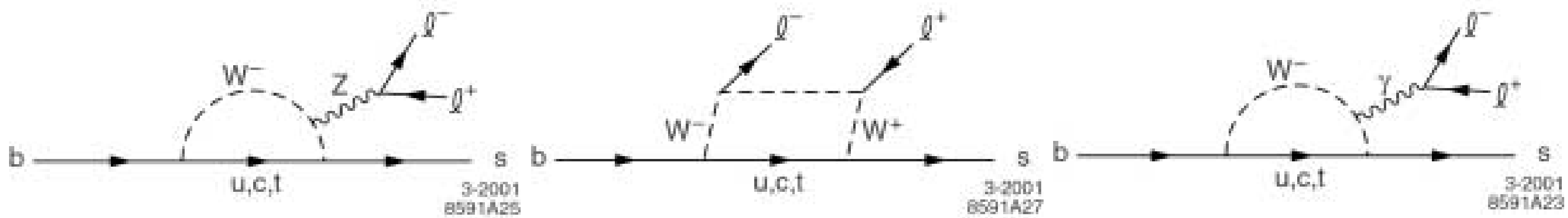
- Close to theoretical predictions.

$B \longrightarrow \rho\,\gamma$: CKM

For illustrative purposes only - No theoretical errors!



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



- ElectroMagnetic and Z penguins and WW box diagram contributions.
- EM penguin seen in $B \longrightarrow K^*\gamma$.
- SM calculations have large uncertainties because of strong interactions (form factors).
- Expected to be at the 0.57-2.3 $\times 10^{-6}$ level (A. Ali et al.)
- Sensitive to new physics.

$B \longrightarrow K^{(*)}\, l^+l^-$: Modes

- Based on Run 1 data set.
- Modes:
  - $B^+ \longrightarrow K^+l^+l^-$
  - $B^0 \longrightarrow K_s^0 l^+l^-$
  - $B^+ \longrightarrow K^{*+}l^+l^-$
  - $B^0 \longrightarrow K^{*0}l^+l^-$

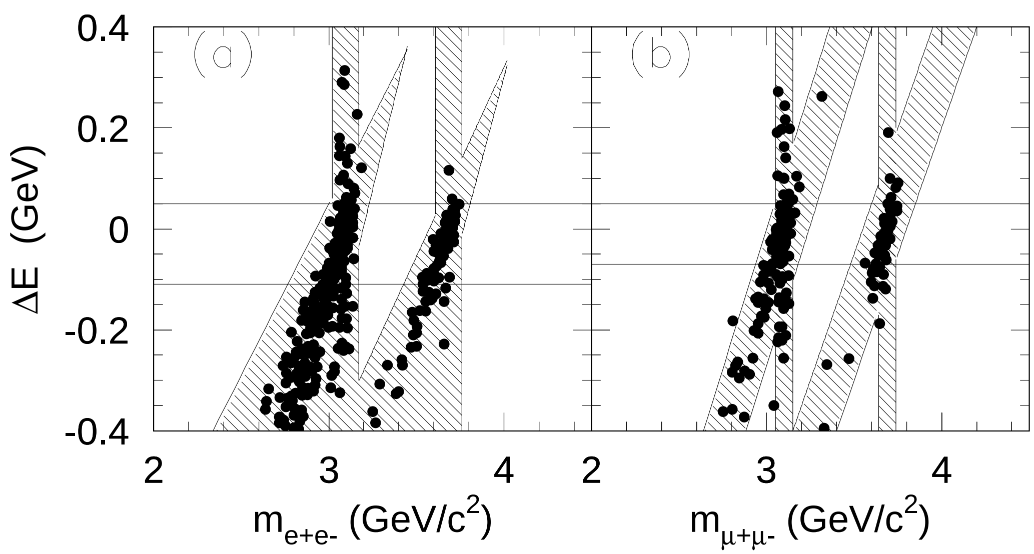
  where $l = e, \mu$, and $K^{*0} \longrightarrow K^+\pi^-$ and $K^{*+} \longrightarrow K_s^0\pi^+$.
- Signal estimated with an unbinned Maximum Likelihood fit in the $m_{ES} - \Delta E$ plane.
- Blind analysis.

$B \longrightarrow K^{(*)}\, l^+ l^-$: Background suppression

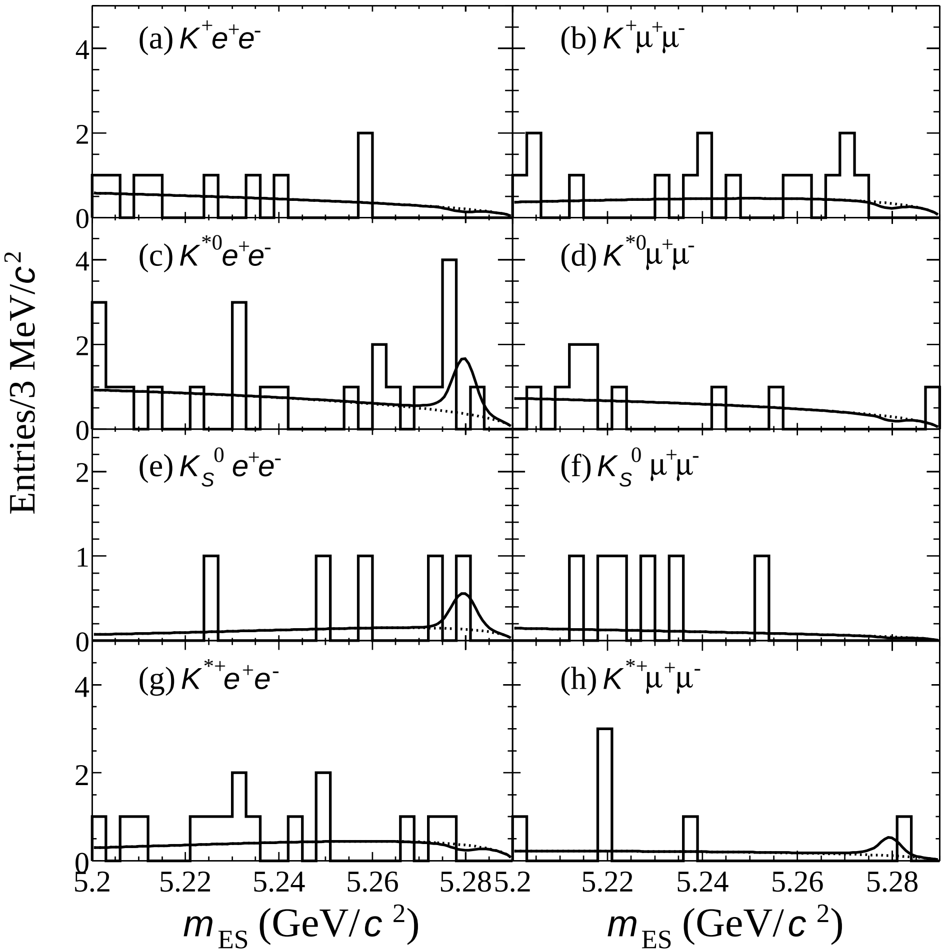
- Combinatorial background from $B\bar{B}$: Likelihood ratios
  - Vertex probabilities
  - Dilepton separation
  - Missing energy
- Continuum background: Fisher discriminant
  - Event topology variables
  - m_{Kl} to discriminate against semileptonic D decays

$B \longrightarrow K^{(*)} \, l^+ l^-$: Peaking Backgrounds

- Peaking background from:
  - $B \longrightarrow J/\psi K^*$ where $J/\psi \rightarrow l^+ l^-$
  - $B \longrightarrow \psi(2S) K^*$ where $\psi(2S) \rightarrow l^+ l^-$
- Veto in the $\Delta E - m_{l^+ l^-}$ plane
- $K - \mu$ reassignment veto



$B \longrightarrow K^{(*)} l^+ l^-$: Results



$B \longrightarrow K^{(*)}\, l^+ l^-$: Results

- Efficiencies range from 5.8% ($K^{*+}\mu^+\mu^-$) to 17.5% ($K^+e^+e^-$).
- Upper limits including systematics (submitted to PRL):

$$Br(B \longrightarrow K l^+ l^-) \quad < \quad 0.50 \times 10^{-6} \text{ at 90\% C.L.}$$
$$Br(B \longrightarrow K^* l^+ l^-) \quad < \quad 2.9 \times 10^{-6} \text{ at 90\% C.L.}$$

- Close to theoretical prediction!
- Currently being updated with Run 2 data.

Conclusions

- First results on $B \longrightarrow \rho\gamma$ based on full Run 1 and Run 2 data set:

$$Br(B^0 \longrightarrow \rho^0\gamma) < 1.5 \times 10^{-6} \text{ at 90\% C.L.}$$
$$Br(B^+ \longrightarrow \rho^+\gamma) < 2.8 \times 10^{-6} \text{ at 90\% C.L.}$$

- Close to SM predictions with:

$$Br(B \longrightarrow Kl^+l^-) < 0.50 \times 10^{-6} \text{ at 90\% C.L.}$$
$$Br(B \longrightarrow K^*l^+l^-) < 2.9 \times 10^{-6} \text{ at 90\% C.L.}$$

- BaBar is busy updating Run 1 based results with Run 2 data.
- Will soon have new results on: $B \longrightarrow K^{(*)}l^+l^-$, h^+h^-, $K^*\gamma$ .....
- New analyses coming along: $B \longrightarrow \omega\gamma$, $\pi^0\pi^0$ .....
- We are on our way to $100\ fb^{-1}$ by the summer.