Observation of $b \to d\gamma$ decays

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Belle Collaboration

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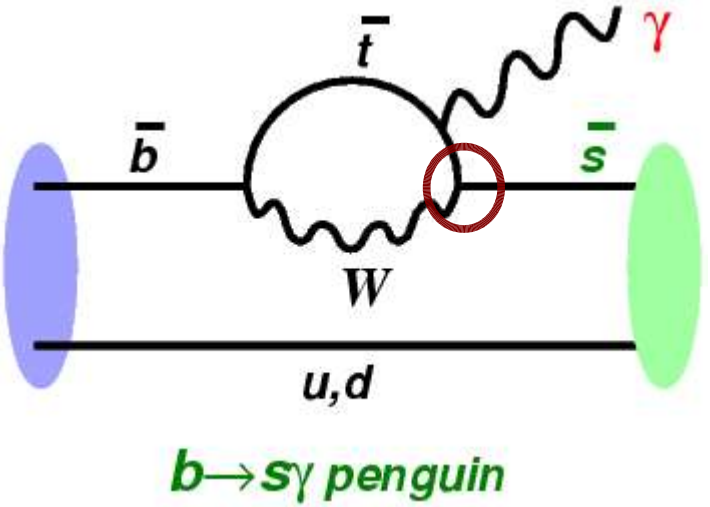
Radiative B decays: $b \to s\gamma$

Flavor-changing-neutral-current (FCNC) processes
- allowed in the Standard Model via penguin loop
- first observed by CLEO 12 years ago
- branching fraction $\sim 3.5 \times 10^{-4}$ (theory)



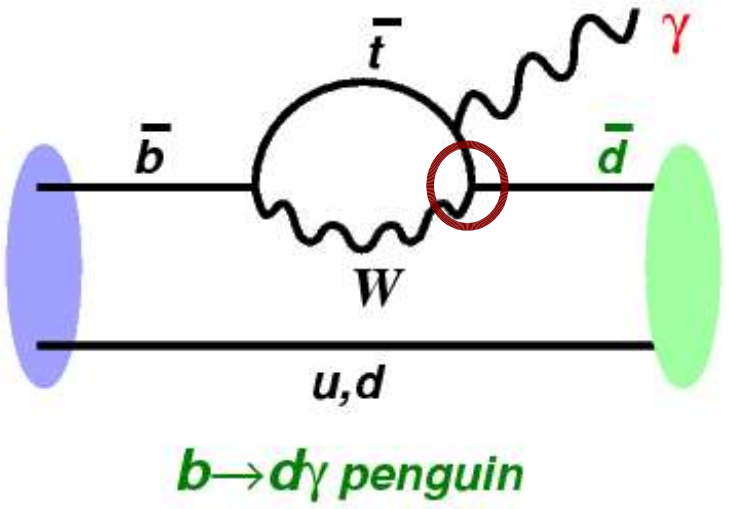
$b \to s\gamma$ penguin

$$\begin{vmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{vmatrix}$$

Radiative B decays: $b \to d\,\gamma$

- suppressed by $\left|V_{td}/V_{ts}\right|^2 (\sim 0.04)$ relative to $b \to s\,\gamma$
- branching fraction $\sim 10^{-6}$ (theory)
- $\dfrac{B \to \rho(\omega)\gamma}{B \to K^* \gamma}$ can be used to measure $\left|\dfrac{V_{td}}{V_{ts}}\right|$,

  complementary to B_s mixing $\left(\dfrac{\Delta M_d}{\Delta M_s}\right)$



$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

⇒ *Event Selection*

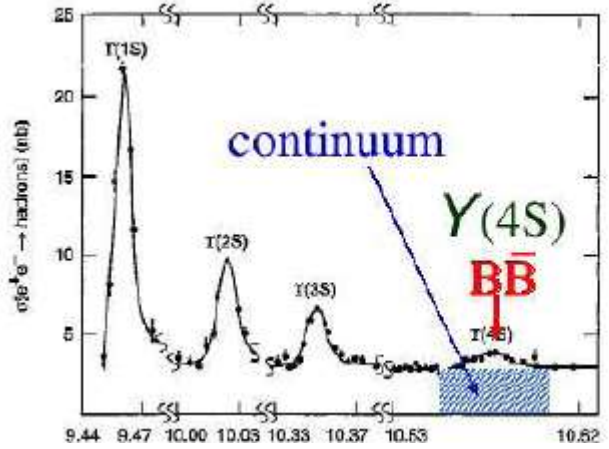
Event Selection

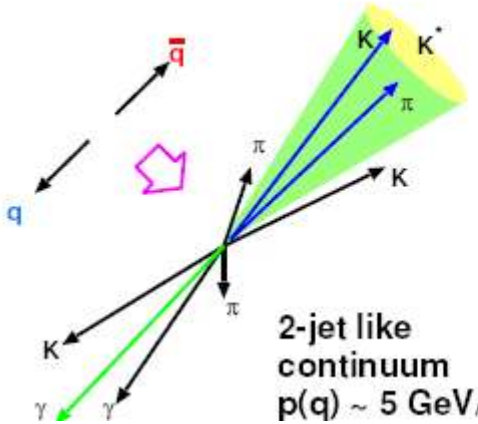
Photon selection	$1.8\,\text{GeV} < E^*_\gamma < 3.4\,\text{GeV}$ & $33^\circ < \theta_\gamma < 128^\circ$ Electromagnetic shower shape π^0 & η veto based on likelihood
Neutral pion selection $\pi^0 \to \gamma\gamma$	$E_\gamma > 50(100)\,\text{MeV}$ for barrel (endcap) $\cos\theta_{\gamma_1,\gamma_2} > 0.7$ $118\,\text{MeV} < M_{\gamma,\gamma} < 150\,\text{MeV}$
Reconstruction of ρ & ω $\rho^- \to \pi\pi$ $\omega \to \pi\pi\pi^0$	Tracks close to IP ($dr < 0.5\,\text{cm}$ & $\lvert dz\rvert < 3\,\text{cm}$) & tracks from K_s are removed $\frac{L_K}{L_K + L_\pi} < 0.15$ & $0.620\,\text{GeV} < M_\rho < 0.920$ GeV $\frac{L_K}{L_K + L_\pi} < 0.40$ & $0.752\,\text{GeV} < M_\omega < 0.812$ GeV
Reconstruction of B *Beam const. mass* *Energy difference*	$B \to \rho^- \gamma$, $\overline{B^0} \to \rho^0 \gamma$ & $\overline{B^0} \to \omega\gamma$ $5.2\,\text{GeV} < M_{\text{bc}} < 5.3\,\text{GeV}$, $M_{\text{bc}} = \sqrt{E^{*2}_{\text{beam}} - P^{*2}_B}$ $\lvert\Delta E\rvert < 0.5\,\text{GeV}$, $\Delta E = E^*_{\rho,\omega} + E^*_\gamma - E^*_B$

⇒ ***Background suppression***

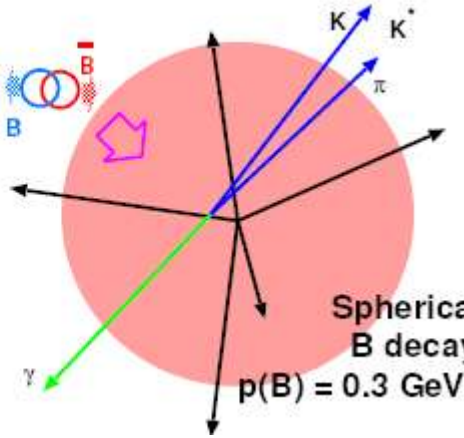
Background Suppression

1. Continuum background: $e^+e^- \to q\bar{q}, q = u, d, s, c$



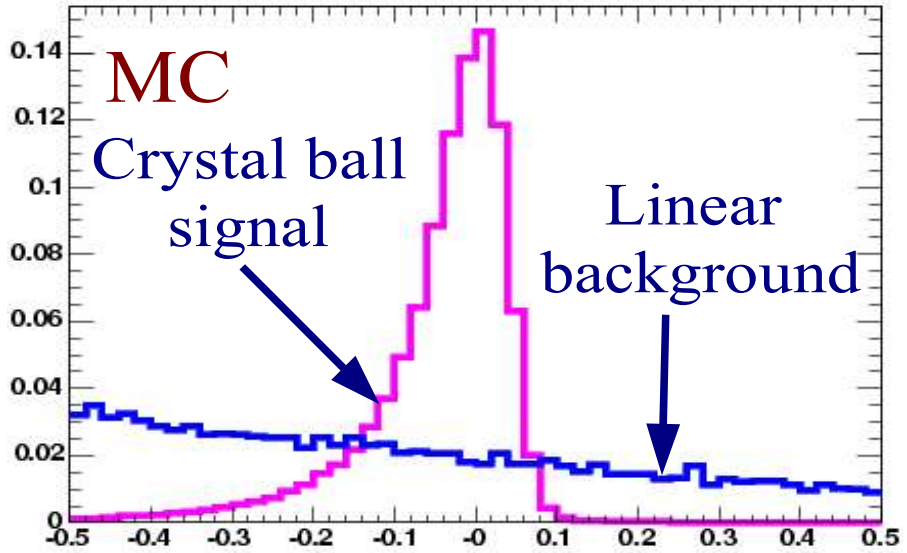


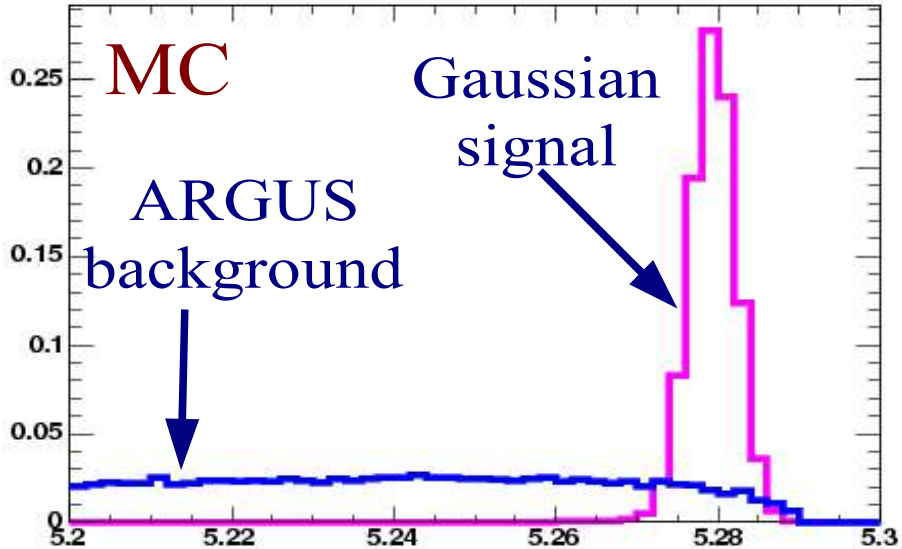
2-jet like
continuum
p(q) ~ 5 GeV/c



Spherical
B decays
p(B) = 0.3 GeV/c

Signal and continuum background shapes:

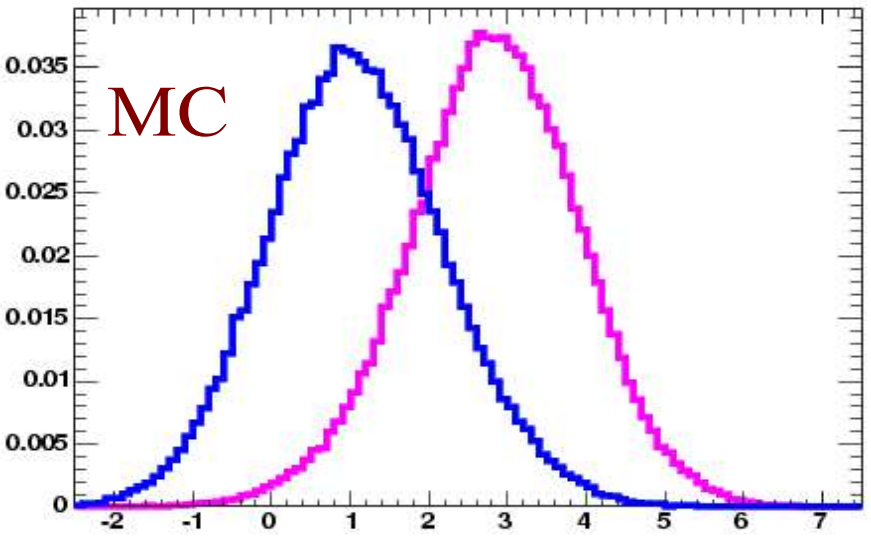


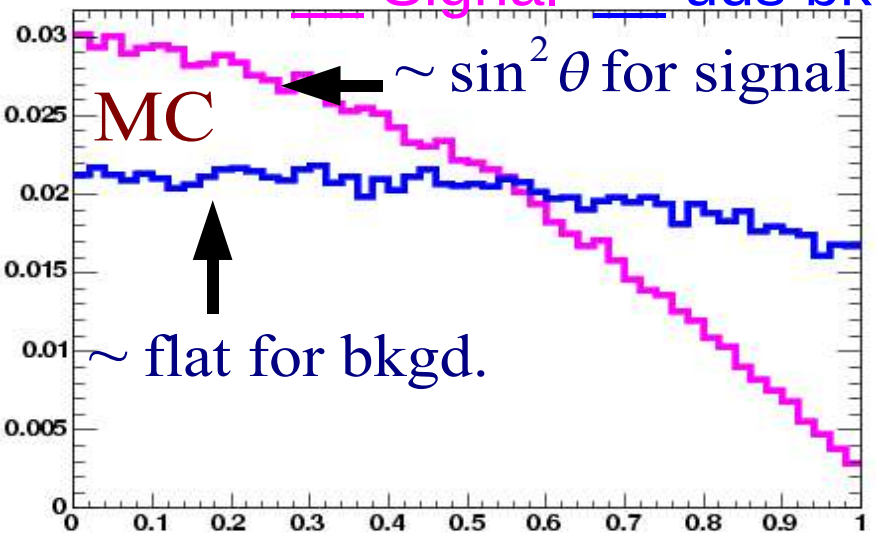


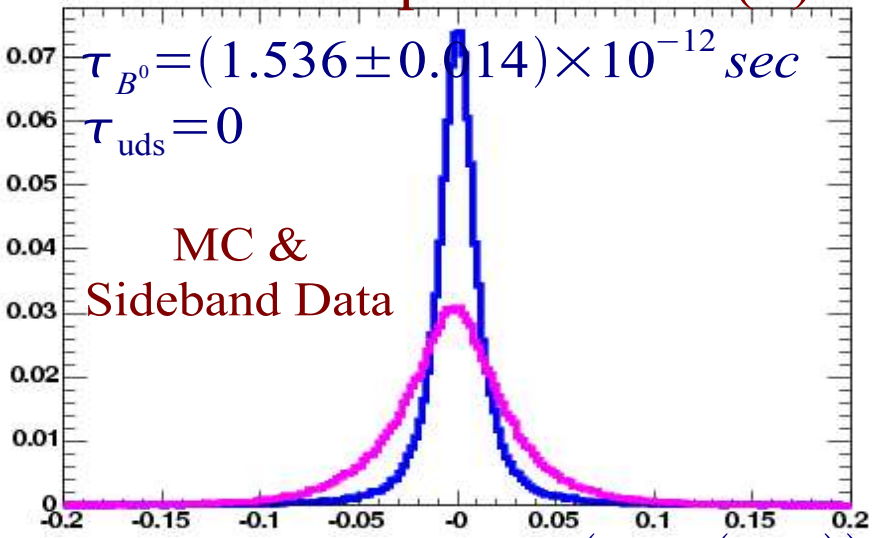
__ Signal __ continuum background

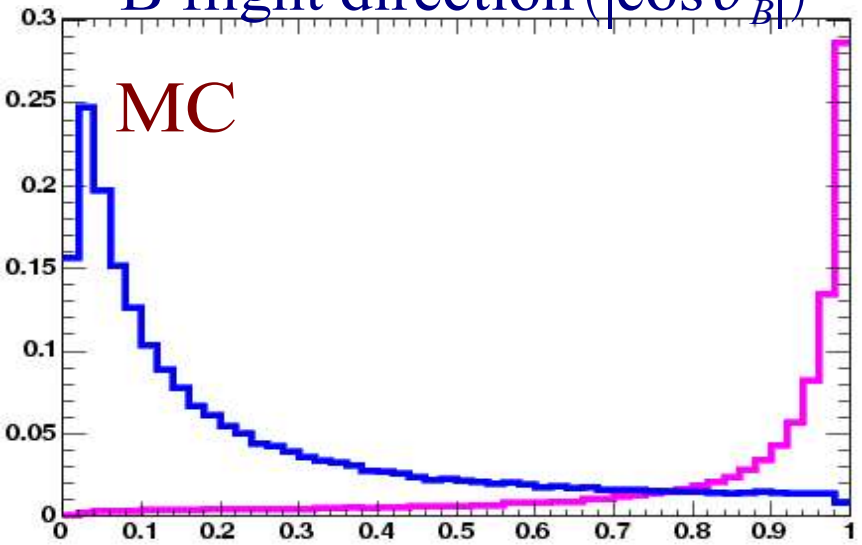
Background Suppression contd.

Continuum suppression





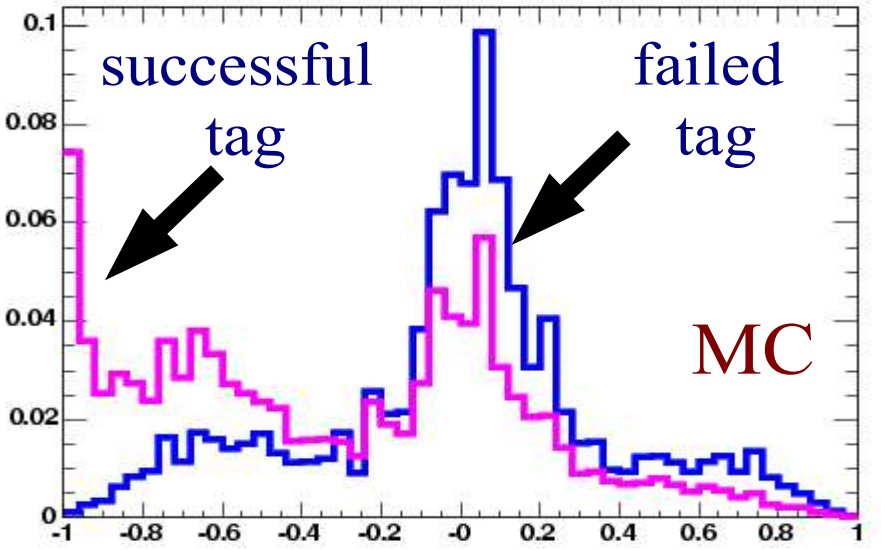




Background Suppression contd.

Additional discrimination from Quality of B flavor tag (r)

* successful-tag $\Rightarrow$ peak at $r = \pm 1$
* failed-tag $\Rightarrow$ peak at $r = 0$

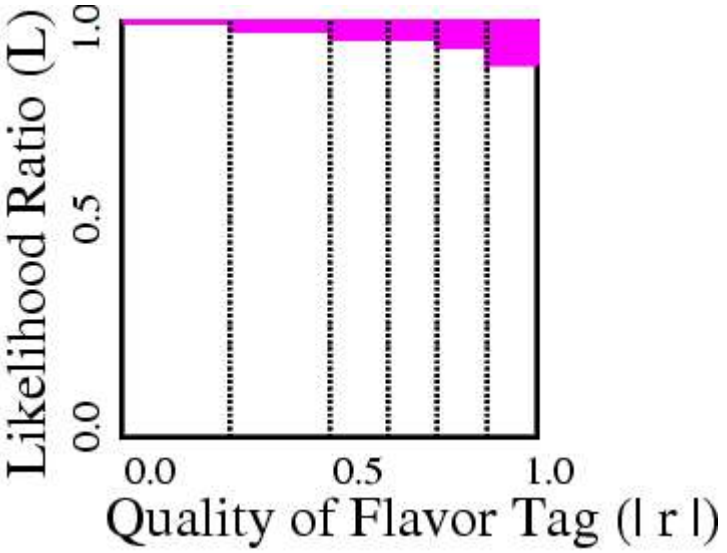


Quality of B Flavor Tag (r)

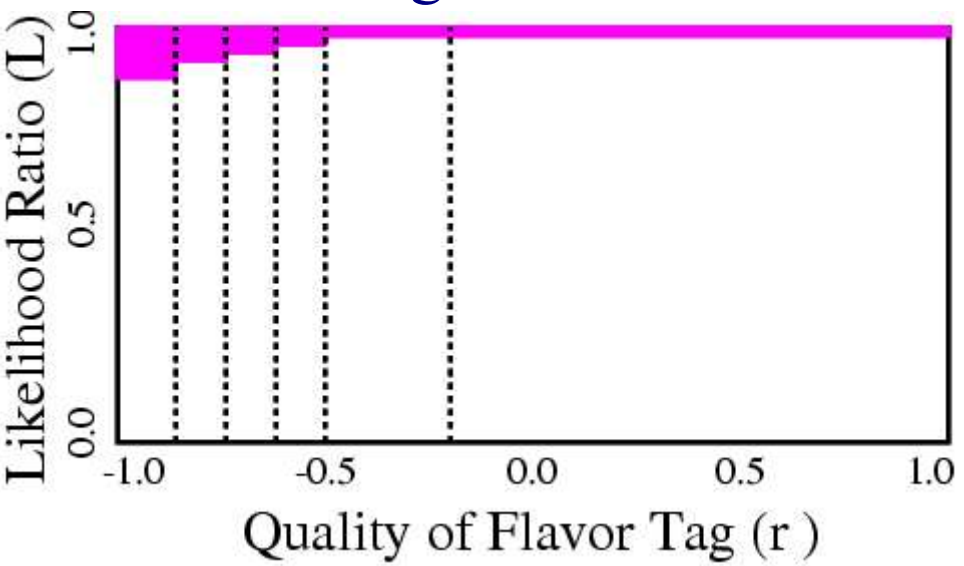
__ Signal __ uds bkgd.

Background Suppression contd.

Neutral modes



Charged modes



Neutral modes ⇒ cut in |r|-L

Charged modes ⇒ cut in r-L

Multidimensional scan to uniquely determine the best $S/\sqrt{B}$

	$\rho^- \gamma$	$\rho^0 \gamma$	$\omega \gamma$
ϵ_{sig}	38%	45%	32%
ϵ_{uds}	4%	8%	3%

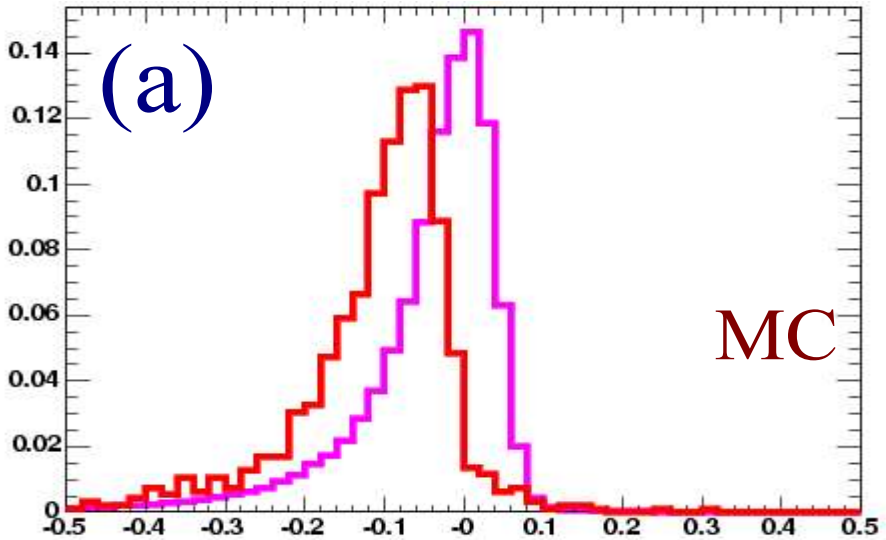
~95 % of continuum background is rejected

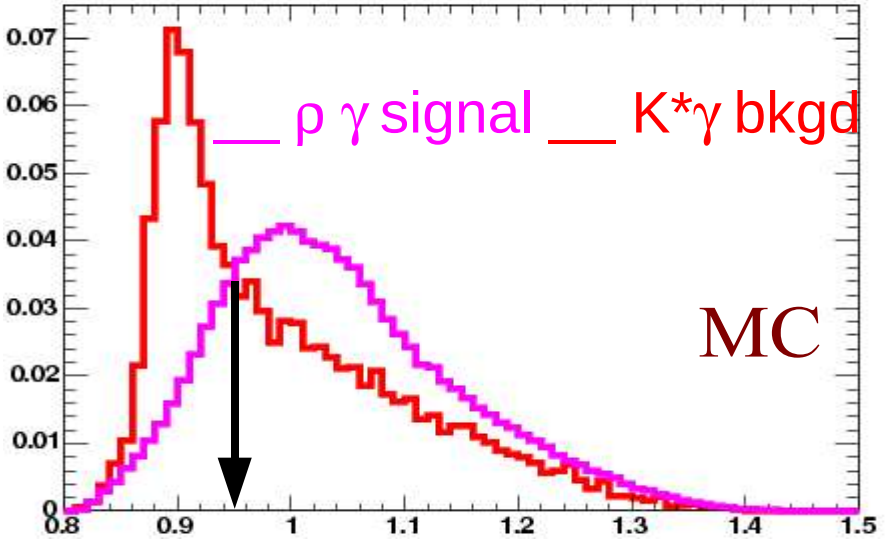
Background Suppression contd.

2. Backgrounds from $B\bar{B}$

(a) K/π misidentification $\Rightarrow B \to K^* \gamma$ background

* $K^* \gamma$ veto: $M_{K\pi}$ optimized for $\frac{S}{\sqrt{B}}$





	$\rho^- \gamma$	$\rho^0 \gamma$
ϵ_{sig}	87%	63%
$\epsilon_{K^* \gamma}$	36%	20%

Background Suppression contd.

2. **Background from $B\bar{B}$**

(b) asymmetric $\pi^0(\eta)$ decay (with missing soft photon)

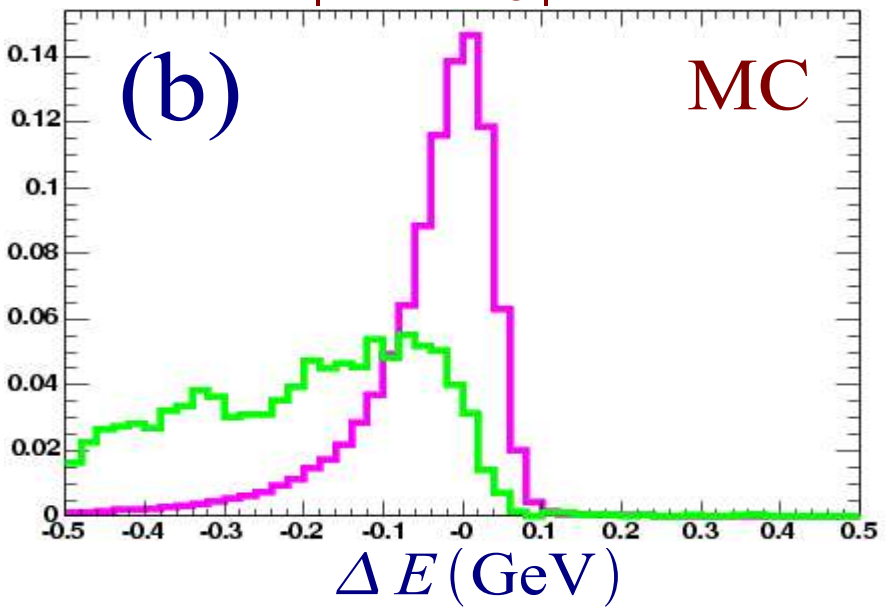
$\Rightarrow B\to\rho(\omega)\pi^0$ & $B\to\rho(\omega)\eta$ background

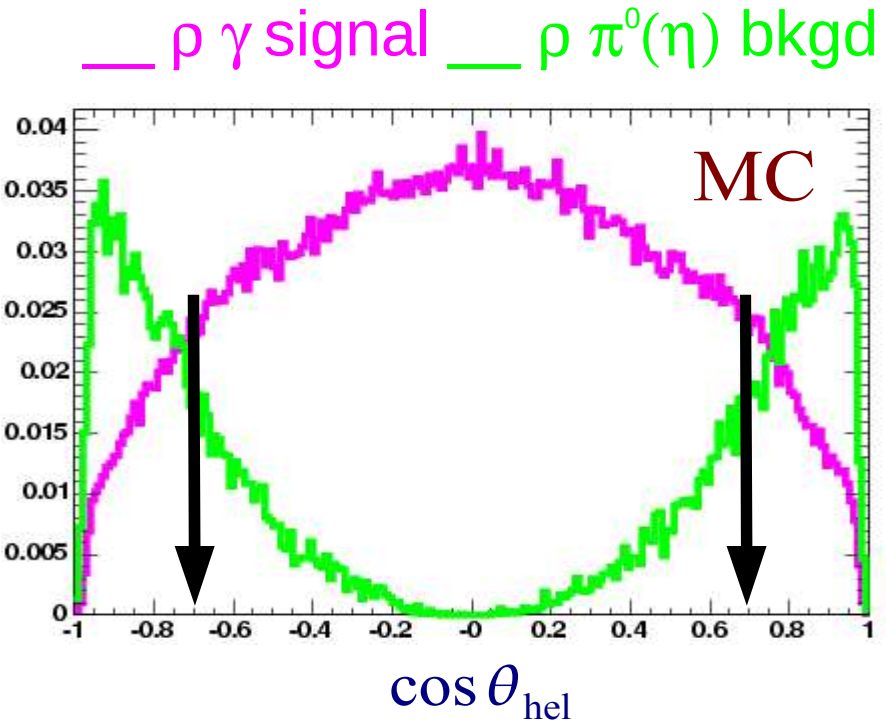
* $\cos\theta_{\rm hel}$ optimized for $\frac{S}{\sqrt{B}}$

$B^- \to \rho^- \gamma : |\cos\theta_{\rm hel}| < 0.75$

$\overline{B^0} \to \rho^0 \gamma : |\cos\theta_{\rm hel}| < 0.70$

$\overline{B^0} \to \omega \gamma : |\cos\theta_{\rm hel}| < 0.80$





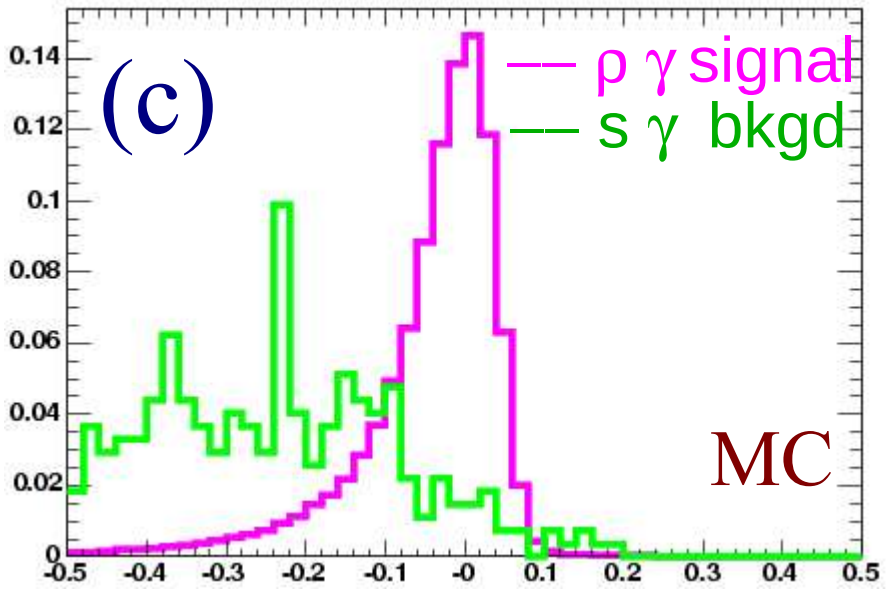
Background Suppression contd.

2. **Background from $B\bar{B}$**

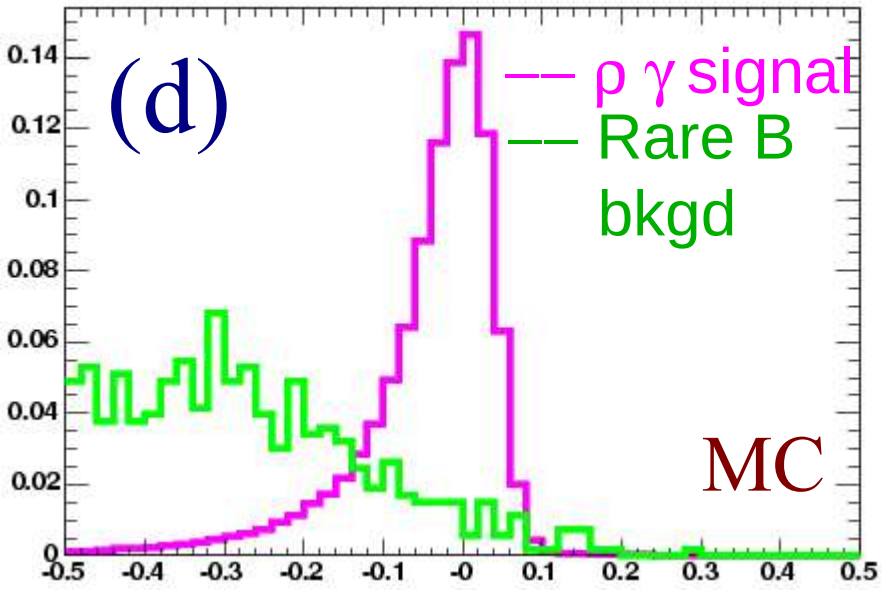
(c) $b \to s\gamma$ background other than $B \to K^* \gamma$

(d) Charmless rare B background other than

$B \to \rho(\omega)\pi^0$ & $B \to \rho(\omega)\eta$



$\Delta E(\mathrm{GeV})$



$\Delta E(\mathrm{GeV})$

⇒ ***Signal extraction***

Signal Extraction

2D Fit $(M_{bc}, \Delta E)$: Unbinned extended maximum likelihood fit

1. Shapes of Signal & Background

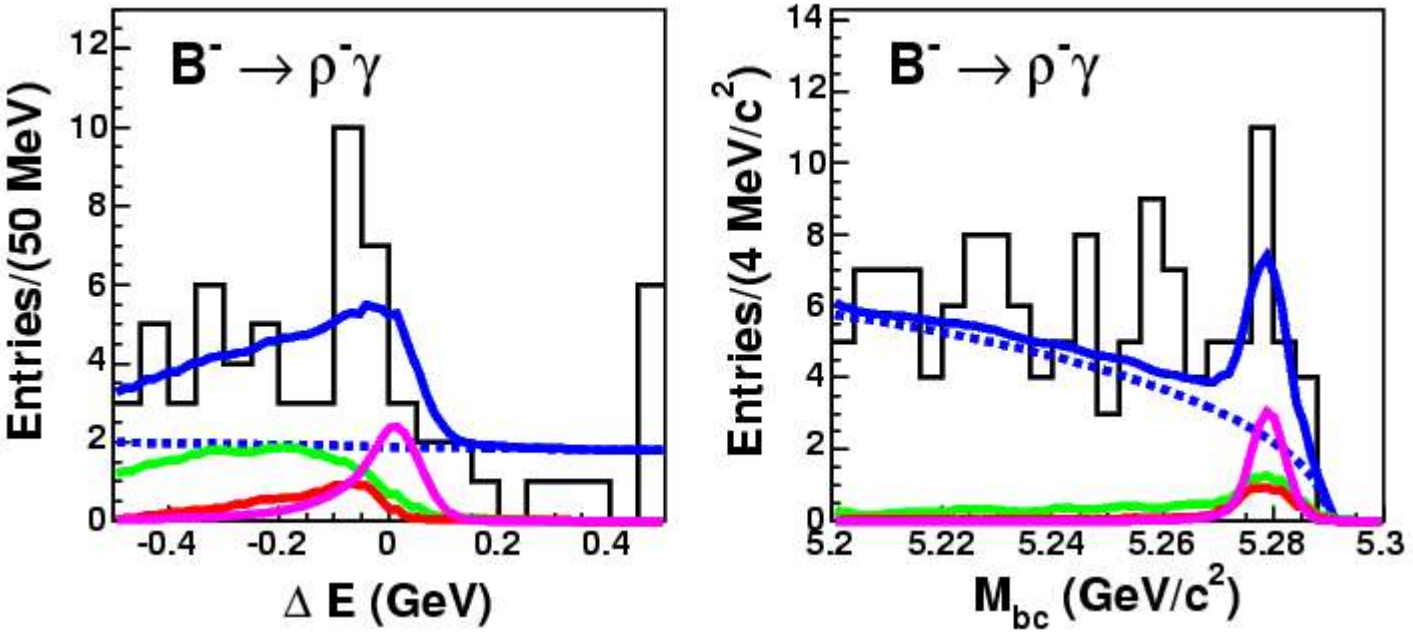
	$M_{\rm bc}$	ΔE
$B\to\rho^-(\omega)\gamma$	*CrystalBall*	*CrystalBall*
$B\to\rho^0\gamma$	*Gaussian*	*CrystalBall*
Continuum	ARGUS	Linear

$B\bar{B}$ background	$M_{\rm bc}-\Delta E$
$B\to K^*\gamma$	2D Histogram
$B\to(\rho^-,\rho^0,\omega)\pi^0$ & $B\to(\rho^-,\rho^0,\omega)\eta$	2D Histogram
$B\to X_s\gamma$	2D Histogram
Charmless Rare B	2D Histogram

2. Floated parameters:
   * Shape parameters of continuum background
   * Signal and continnum background yields

⇒ Results with 386 M $B\bar{B}$ events

Fit results: $B \to \rho^- \gamma$ 386 M $B\overline{B}$



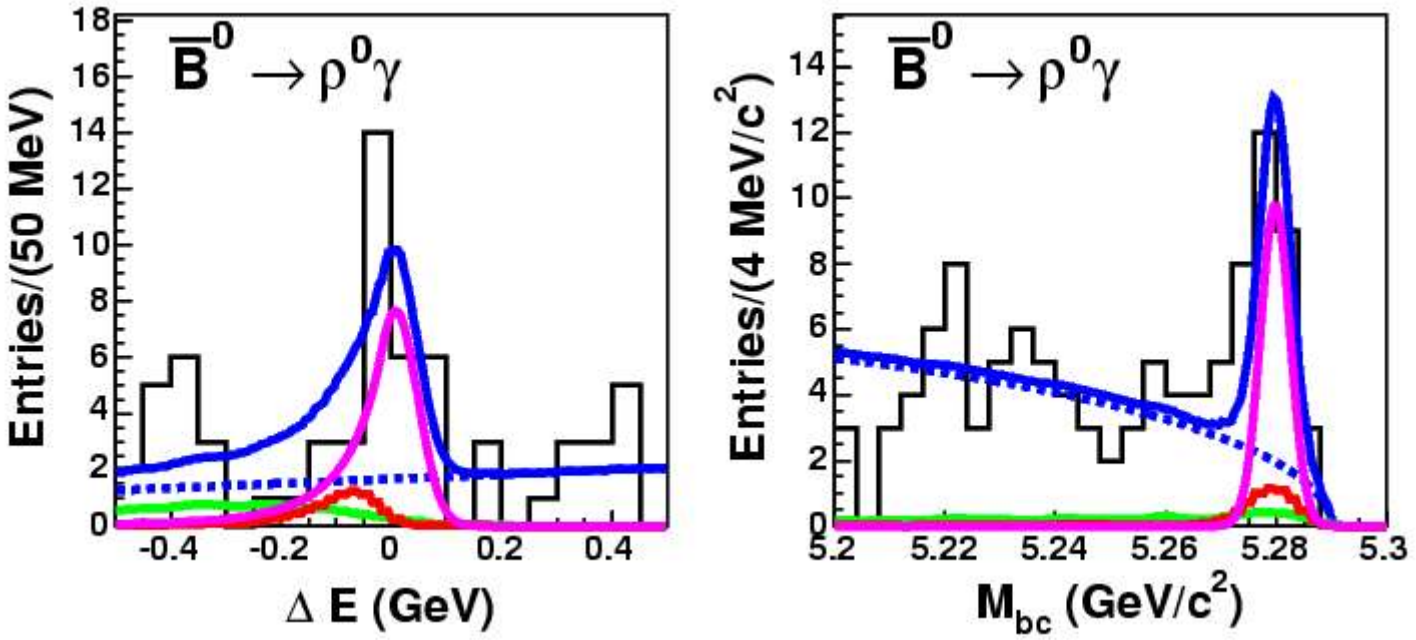
$$\text{Signal Yield} = 8.1^{+6.4}_{-5.5}(\text{stat.})^{+1.8}_{-1.6}(\text{syst.})$$

$$\text{Significance} = 1.5\sigma(\text{incl. syst.})$$

$$B(B \to \rho^- \gamma) = (0.55^{+0.43}_{-0.37}(\text{stat.})^{+0.12}_{-0.11}(\text{syst.})) \times 10^{-6}$$

— ρ γ -- continuum background — K*γ — remaining B background

Fit results: $\overline{B^0} \to \rho^0 \gamma$ 386 M $B\overline{B}$



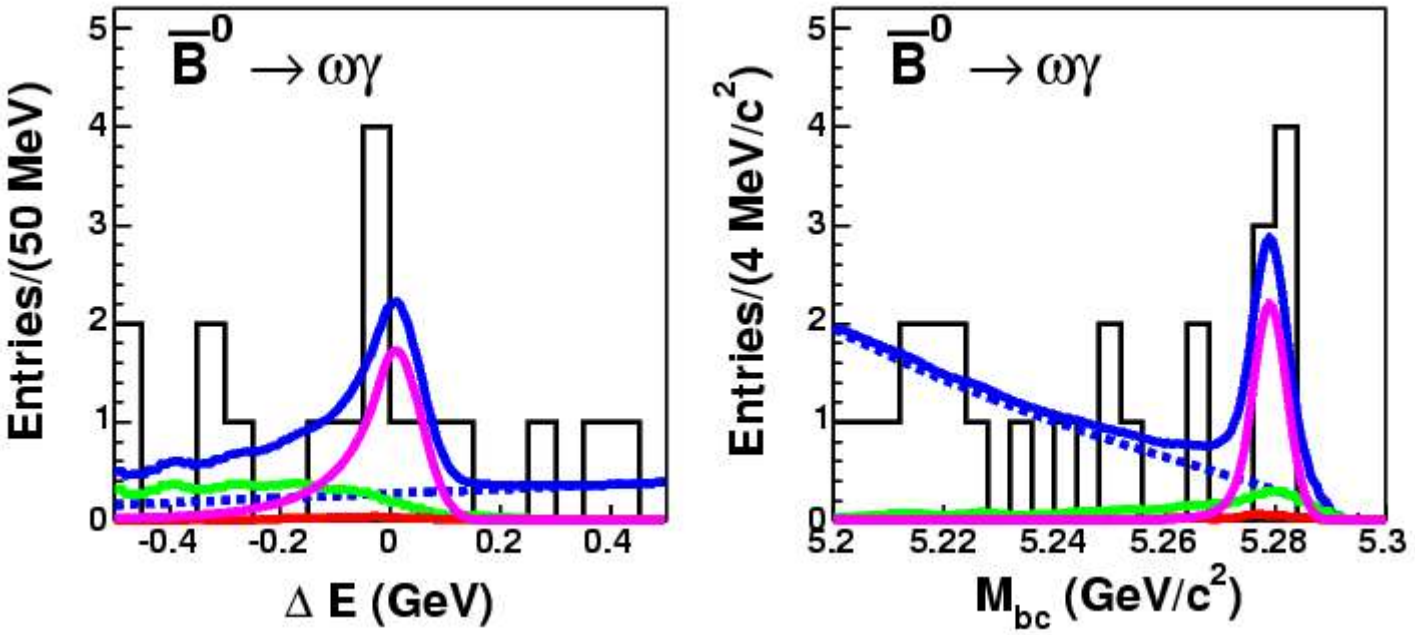
$$\text{Signal Yield} = 20.8^{+6.2}_{-5.5}(\text{stat.})^{+1.2}_{-1.4}(\text{syst.})$$

$$\text{Significance} = 5.1\,\sigma\,(\text{incl. syst.})$$

$$B(\overline{B^0} \to \rho^0\gamma) = (1.17^{+0.35}_{-0.31}(\text{stat.})^{+0.09}_{-0.08}(\text{syst.}))\times 10^{-6}$$

— ρ γ -- continuum background — K*γ — remaining B background

Fit results: $\overline{B^0} \to \omega\gamma$ 386 M $B\overline{B}$



$$\text{Signal Yield} = 8.9^{+3.5}_{-2.7}(\text{stat.})^{+0.7}_{-0.8}(\text{syst.})$$

$$\text{Significance} = 2.6\,\sigma\,(\text{incl. syst.})$$

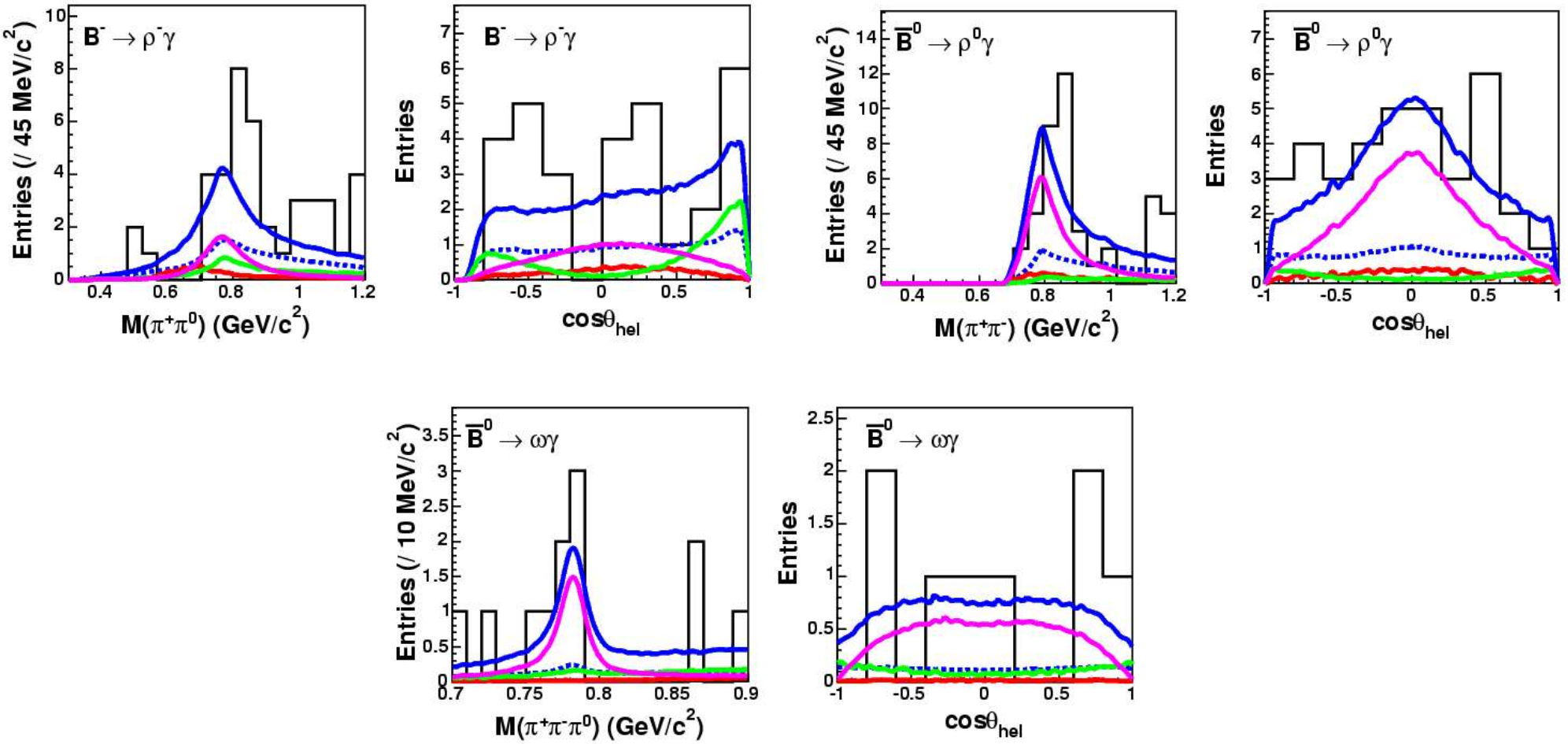
$$B(\overline{B^0} \to \omega\gamma) = (0.58^{+0.35}_{-0.27}(\text{stat.})^{+0.07}_{-0.08}(\text{syst.})) \times 10^{-6}$$

— ρ γ -- continuum background — K*γ — remaining B background

Mass & Helicity Plots

Results from fit are superimposed on Mass and Helicity plots

$M_{\pi\pi}$ & $\cos\theta_{\rm hel}$ deformed by $M_{K\pi}$ ($K^*\gamma$ veto variable)

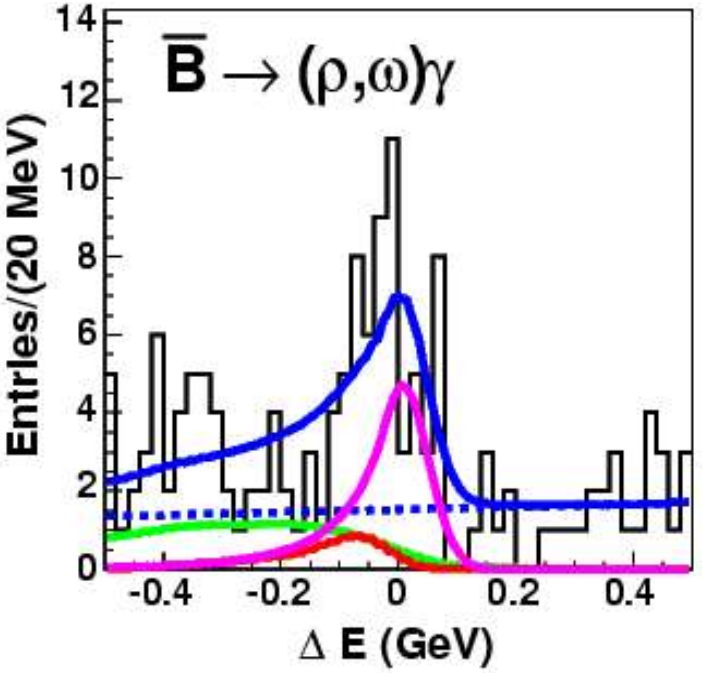


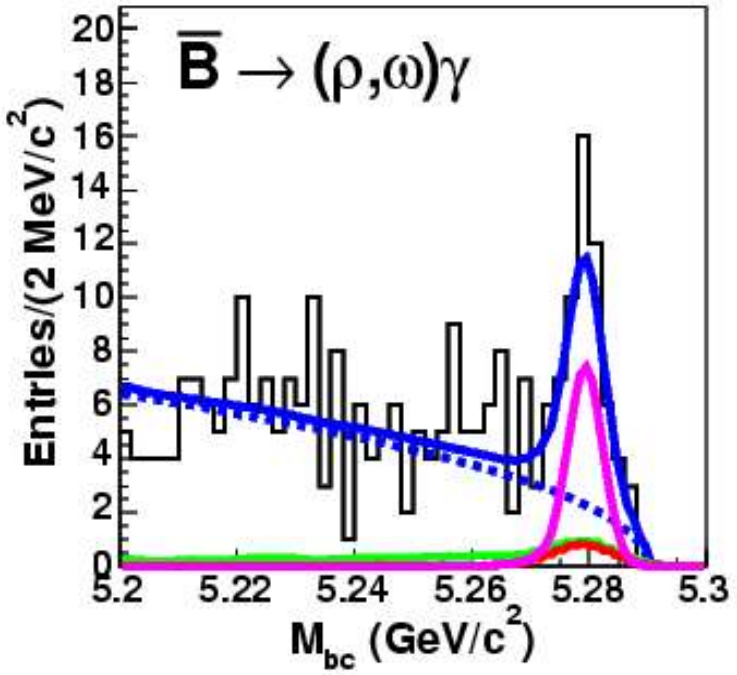
— ρ γ -- continuum background — K*γ — remaining B background

Combined fit: $\overline{B} \to (\rho, \omega)\gamma$ 386 M $B\overline{B}$

$$B(\overline{B} \to (\rho, \omega)\gamma) \equiv B(B^- \to \rho^- \gamma) = 2 \times \frac{\tau_{B^+}}{\tau_{B^0}} B(\overline{B^0} \to \rho^0 \gamma) = 2 \times \frac{\tau_{B^+}}{\tau_{B^0}} B(\overline{B^0} \to \omega \gamma)$$

using $\frac{\tau_{B^+}}{\tau_{B^0}} = 1.076 \pm 0.008$





$$B(B \to (\rho, \omega)\gamma) = \left(1.34^{+0.34}_{-0.31}(\text{stat.})^{+0.14}_{-0.10}(\text{syst.})\right) \times 10^{-6}$$

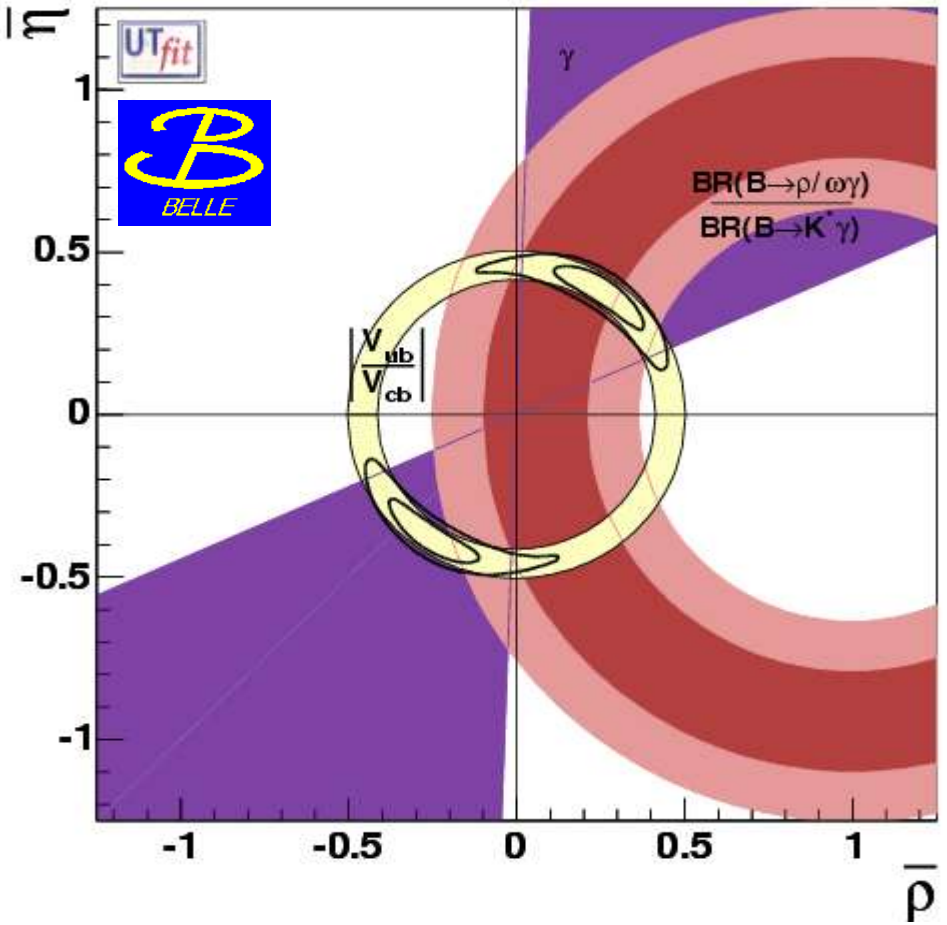
$$\text{Significance} = 5.5\,\sigma\,(\text{incl. syst.})$$

Extraction of $\left|V_{td}/V_{ts}\right|$

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

Form factor ratio $\zeta=0.85\pm0.10$

SU(3)-breaking effect $\Delta R=0.1\pm0.1$



$$\frac{B(B\to(\rho,\omega)\gamma)}{B(B\to K^{*}\gamma)}=0.032\pm0.008^{+0.003}_{-0.002}$$

$$\mathbf{0.143<\left|\frac{V_{td}}{V_{ts}}\right|<0.260}$$

(95 % C.L. interval)

$$\mathbf{\left|\frac{V_{td}}{V_{ts}}\right|=0.200\,^{+0.026}_{-0.025}(expt.)\,^{+0.038}_{-0.029}(theo.)}$$

Summary

Belle observes $b \to d\gamma$ with 5.5σ significance

$$B(B \to (\rho,\omega)\gamma) = (1.34^{+0.34\,+0.14}_{-0.31\,-0.10}) \times 10^{-6}$$

$$B(B^- \to \rho^-\gamma) = (0.55^{+0.43\,+0.12}_{-0.37\,-0.11}) \times 10^{-6}$$

$$B(\overline{B^0} \to \rho^0\gamma) = (1.17^{+0.35\,+0.09}_{-0.31\,-0.08}) \times 10^{-6}$$

$$B(\overline{B^0} \to \omega\gamma) = (0.58^{+0.35\,+0.07}_{-0.27\,-0.08}) \times 10^{-6}$$

and determines

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.200^{+0.026}_{-0.025}(\text{expt.})^{+0.038}_{-0.029}(\text{theo.})$$

Thanks

References

1. Belle Collaboration, K. Abe *et al*, hep-ex/0507036
2. Belle Collaboration, K. Abe *et al*, hep-ex/0506079
3. Belle Collaboration, D. Mohapatra *et al*, *PRD*72,011101(*R*)(2005)
4. BaBar Collaborartion, B. Aubert *et al*, *PRL*92,111801(2004)
5. LP05 Talk, Francesco Forti, CKM parameters and rare B decays
6. Susy2005, Shohei Nishida, Recent Results from Belle
7. EPS2005, Deb Mohapatra, Observation of $b\to d\gamma$ and search for $\overline{B^0}\to\gamma\gamma$

and references therein...