Search for $b \longrightarrow d\gamma$ process

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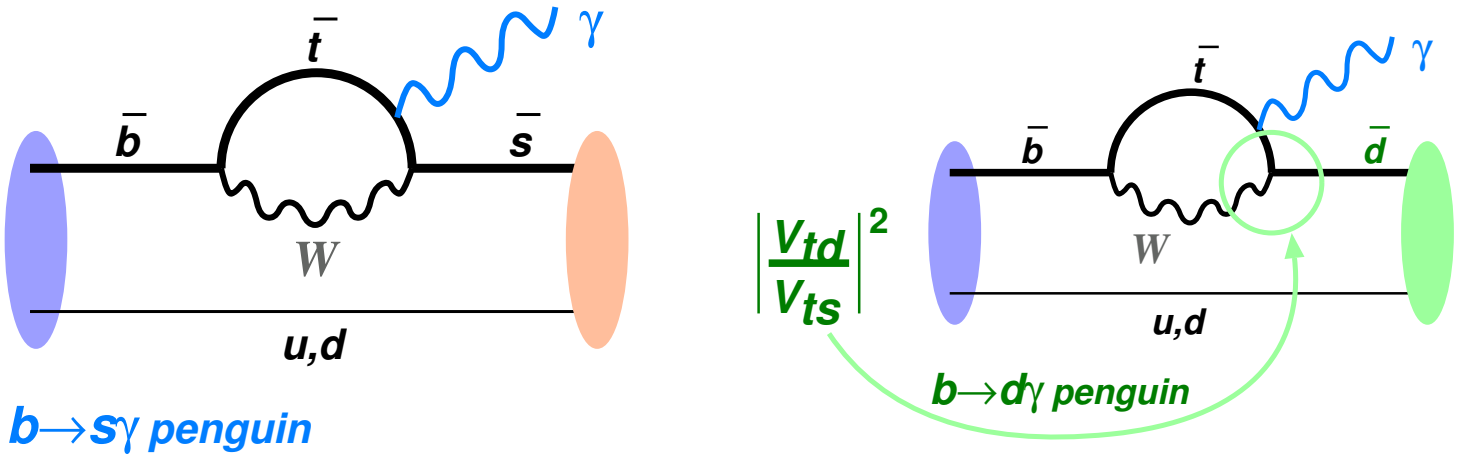
Meeting of The Division of Particles and Fields

of THE AMERICAN PHYSICAL SOCIETY

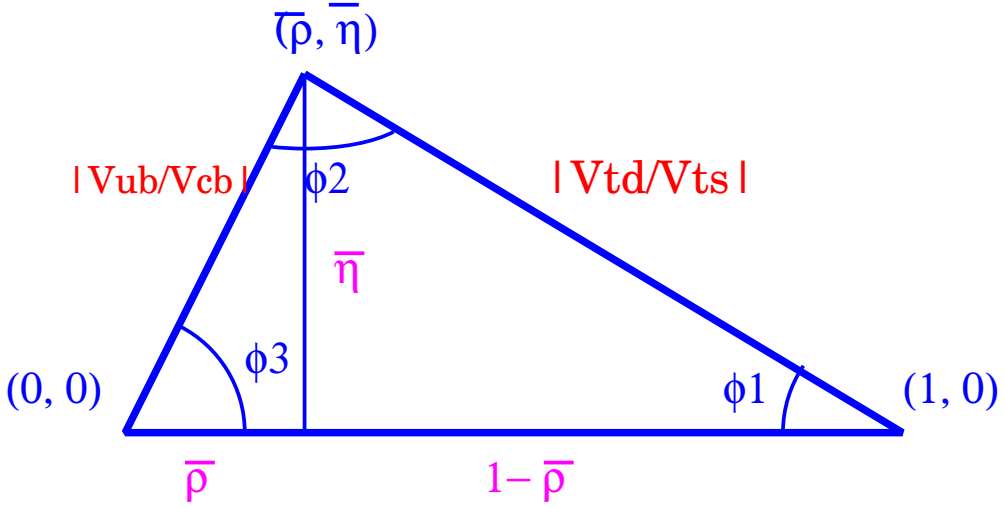
August 26-31, 2004

Introduction



- FCNC process $b \to d\gamma$ allowed via loop (penguin)
- suppressed in the Standard Model
  by $|V_{td}/V_{ts}|^2$ relative to $b \to s\gamma$
  - $\mathcal{B}(B \to \rho\gamma)$ and $\mathcal{B}(B \to \omega\gamma) \approx O(10^{-6})$
  - $\mathcal{B}(B \to \rho\gamma)/\mathcal{B}(B \to K^*\gamma)$ can measure $|V_{td}/V_{ts}|$, complementary to B_s mixing $(\Delta M_d/\Delta M_s)$
- large CP violation is predicted in $b \to d\gamma$
- $\mathcal{B}(B \to \rho\gamma)$ and $\mathcal{B}(B \to \omega\gamma)$ not seen experimentally

Introduction contd.



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

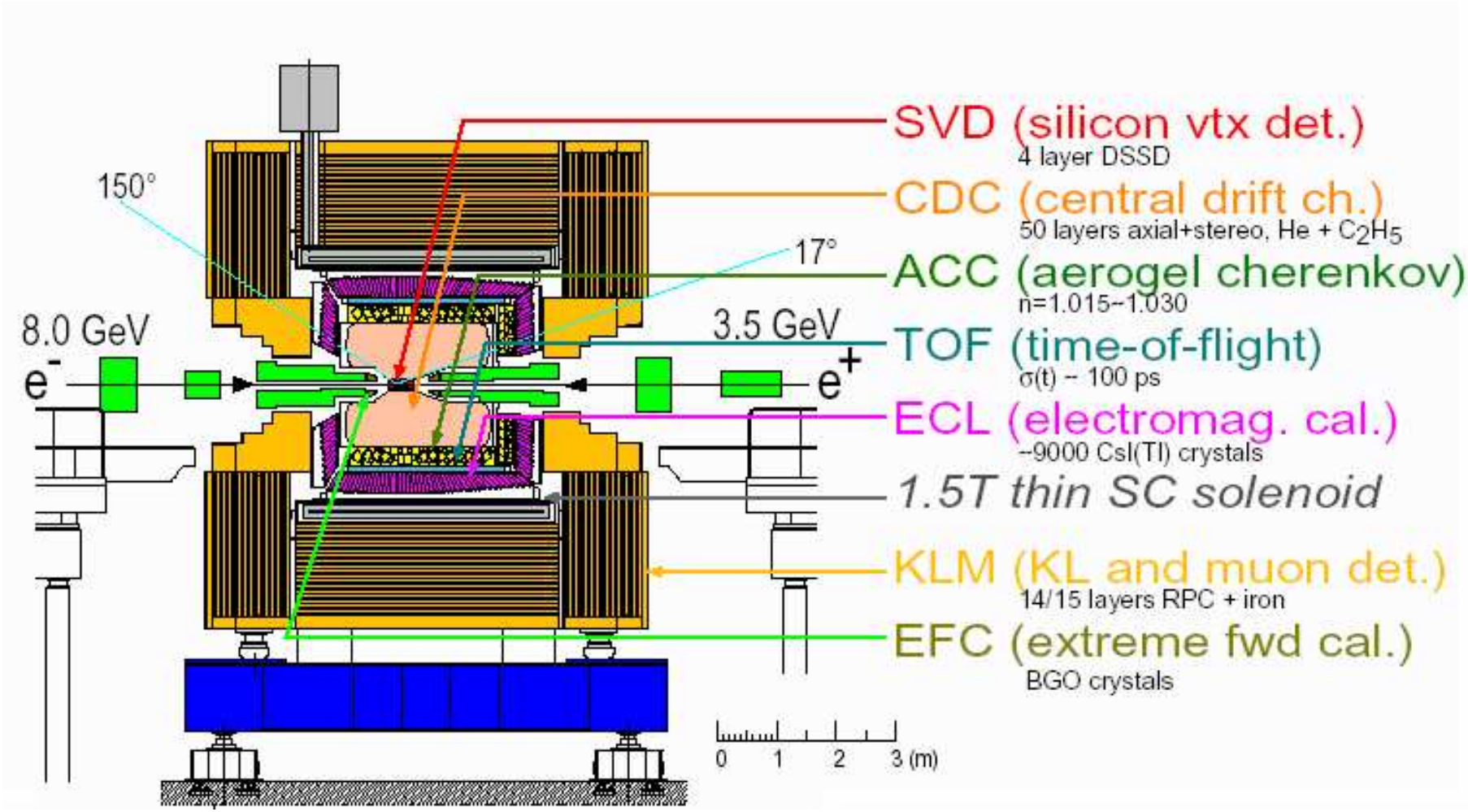
$$\frac{\tau_{B^+}}{\tau_{B^0}} = 1.086 \pm 0.017$$

From Standard Model [A. Ali *et al.*, hep-ph/0405075]

- $\mathcal{B}(B \to (\rho,\omega)\gamma) = (1.38 \pm 0.42) \times 10^{-6}$
- $\frac{\mathcal{B}(B\to(\rho,\omega)\gamma)}{\mathcal{B}(B\to K^*\gamma)} = 0.033 \pm 0.010$
- $0.16 \leq |V_{td}/V_{ts}| \leq 0.29$ @ 68% CL

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

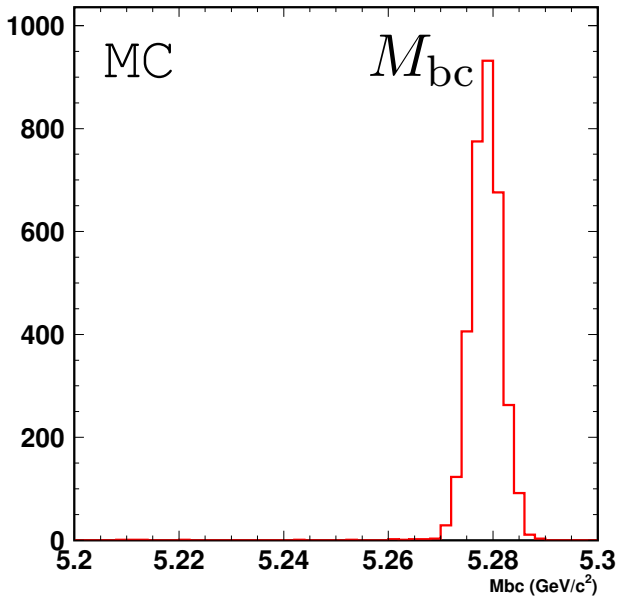
Belle Detector

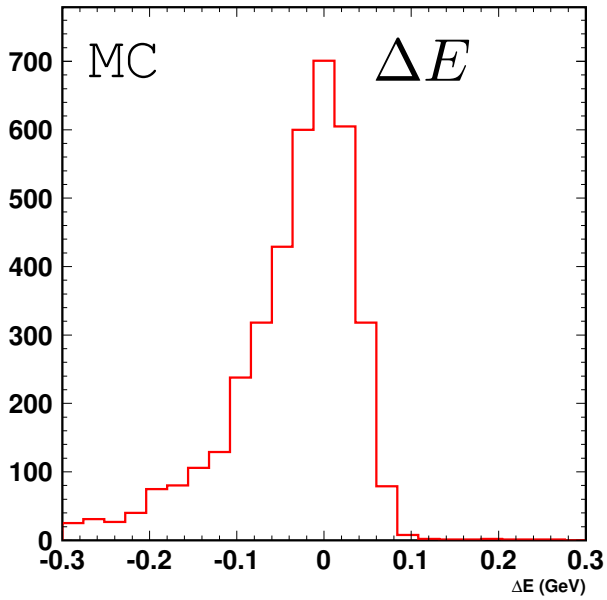


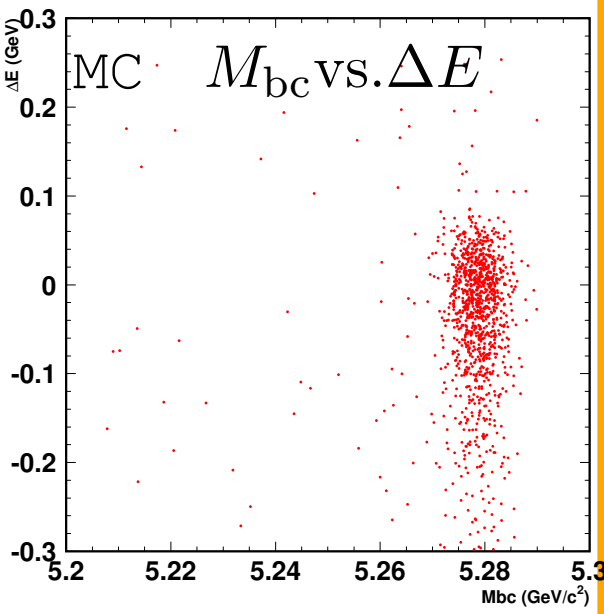
Data Sample and Selection criteria

- Data Sample
  - $253\,\mathrm{fb}^{-1}$ On Resonance Data $\equiv 274 \times 10^6 B\overline{B}$ pairs
    - $140\,\mathrm{fb}^{-1}$ On Resonance Data with SVD1
    - $113\,\mathrm{fb}^{-1}$ On Resonance Data with SVD2
  - $28\,\mathrm{fb}^{-1}$ Off Resonance Data ($60\,\mathrm{MeV}$ below $\Upsilon(4S)$)
- Photon Selection
  - isolated photons with $1.8\,\mathrm{GeV} < E^*_\gamma < 3.4\,\mathrm{GeV}$
  - electro-magnetic shower shape
  - photons from Barrel ECL only ($33^\circ < \theta^{lab}_\gamma < 128^\circ$)
  - veto photons from π^0 and η
- Reconstruction of $\rho \to \pi\pi$ and $\omega \to \pi\pi\pi^0$
  - veto charged tracks from K_S
  - $\rho : \mathcal{L}_K/(\mathcal{L}_K + \mathcal{L}_\pi) < 0.15, \quad 0.620\,\mathrm{GeV}/c^2 < M_\rho < 0.920\,\mathrm{GeV}/c^2$
  - $\omega : \mathcal{L}_K/(\mathcal{L}_K + \mathcal{L}_\pi) < 0.20, \quad 0.752\,\mathrm{GeV}/c^2 < M_\omega < 0.812\,\mathrm{GeV}/c^2$

B meson kinematic variables







$$M_{\rm bc} = \sqrt{(E^*_{\rm beam})^2 - |\overrightarrow{p^*_B}|^2}, \quad \Delta E = E^*_B - E^*_{\rm beam}$$

$$\overrightarrow{p^*_B} = \overrightarrow{p^*_\rho} + \left(E^*_{\rm beam} - E^*_\rho\right)\widehat{p^*_\gamma}$$

Fit region:

- $M_{\rm bc} > 5.2\,{\rm GeV}/c^2$
- $-0.3\,{\rm GeV} < \Delta E < 0.3\,{\rm GeV}$

Background Suppression

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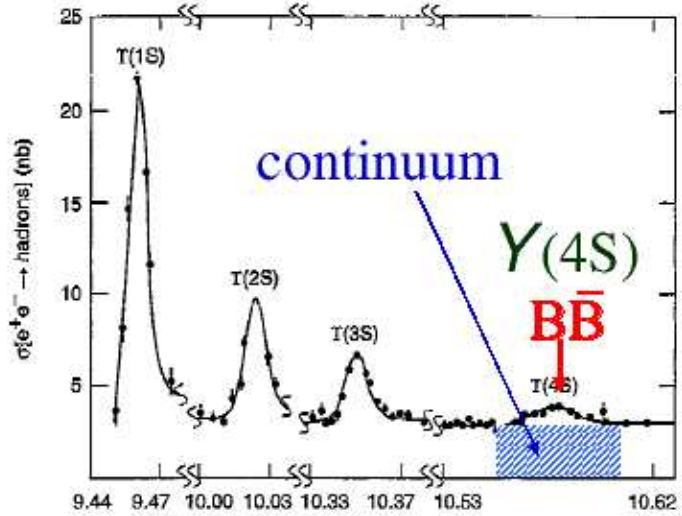
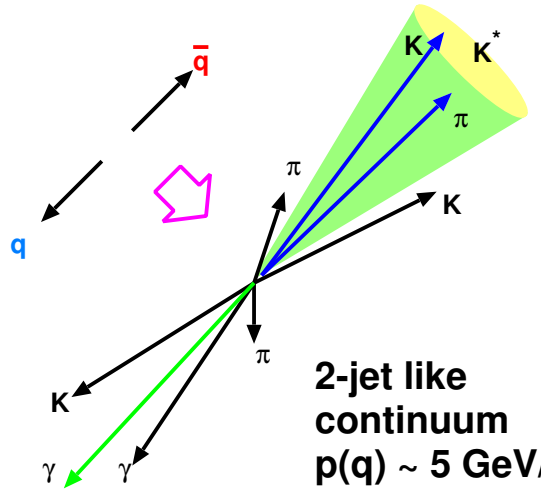
Background Taxonomy:

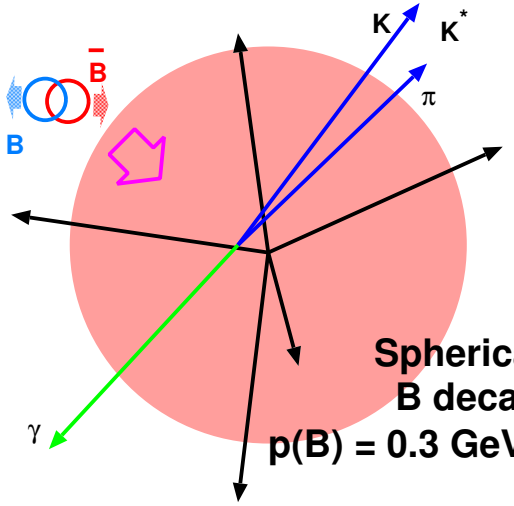
1. Continuum events ($e^+e^- \to q\overline{q}$)
2. $B \to K^*\gamma$
3. $B \to X_s\gamma$ where $X_s = K + n\pi$ and $M_{X_s} > 1.15\,\mathrm{GeV}/c^2$
4. $B \to V\pi^0$ and $B \to V\eta$
5. Rare B background other than $B \to V\pi^0$ and $B \to V\eta$

1. Continuum Suppression





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



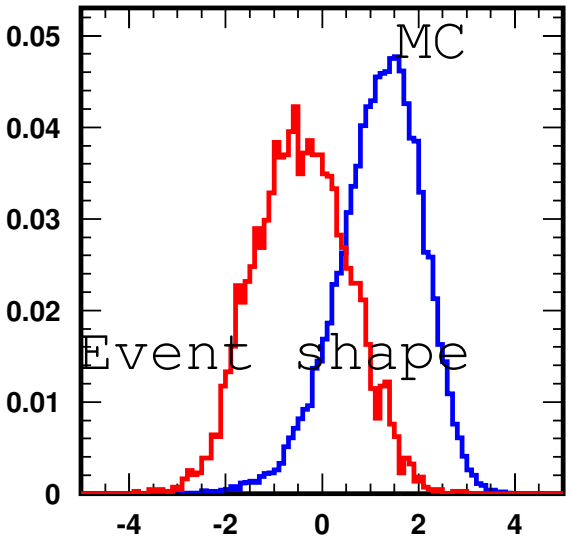
Spherical
B decays
p(B) = 0.3 GeV/c

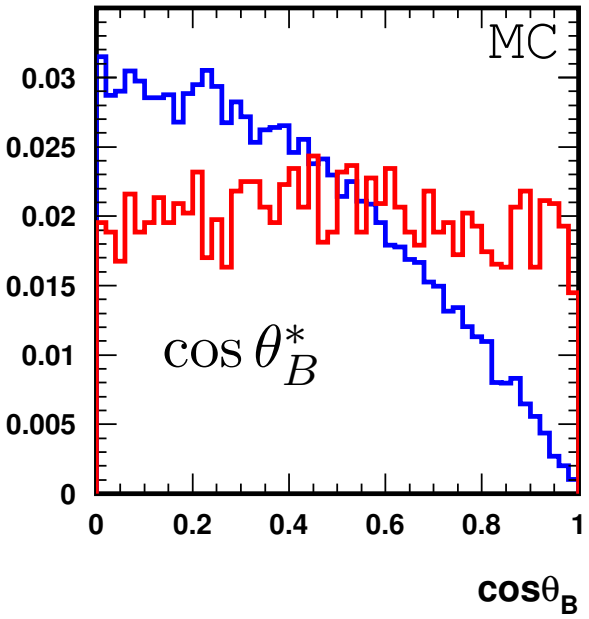
For continuum suppression we use

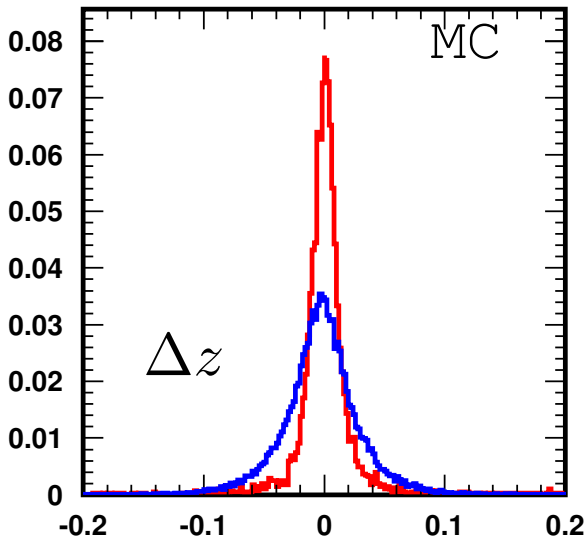
- Fisher discriminant of event shape variables
- B decay angle in CM frame
- Distance between B and $\bar{B}$ vertices along Z-axis
- Quality of B flavor tag

Continuum Suppression, contd.

Plots: Signal, Continuum

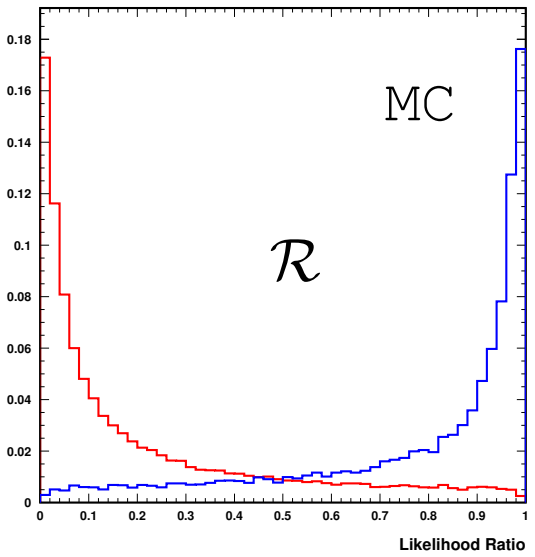






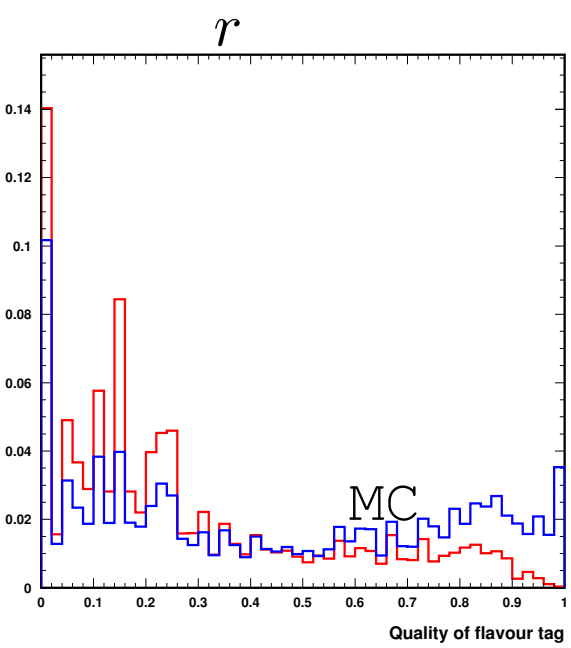
Likelihood Ratio:

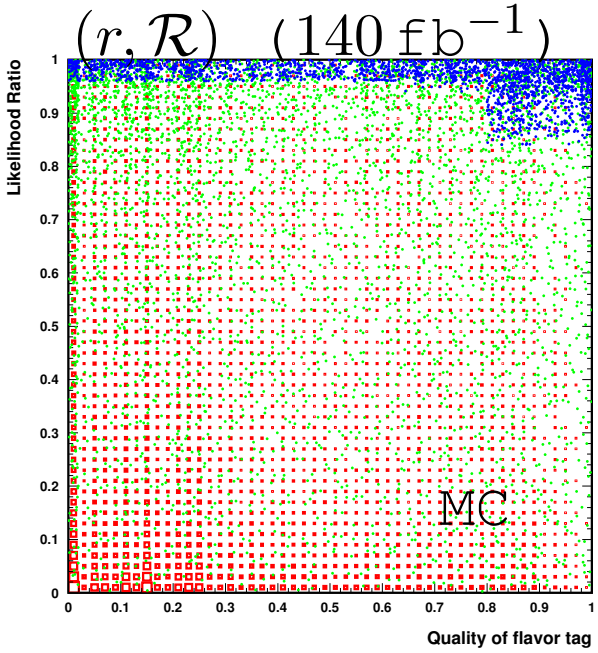
- $\mathcal{R} = \mathcal{R}(F, \cos\theta^*_B, \Delta z)$
- $\mathcal{R} = \mathcal{R}(F, \cos\theta^*_B)$
  if vertexing fails ($\sim 15\%$)

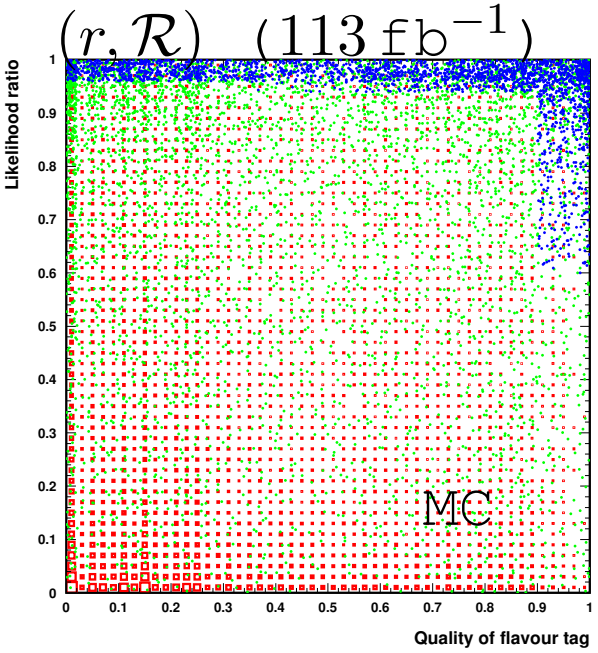


Continuum Suppression, contd.

Plots: Signal, Continuum

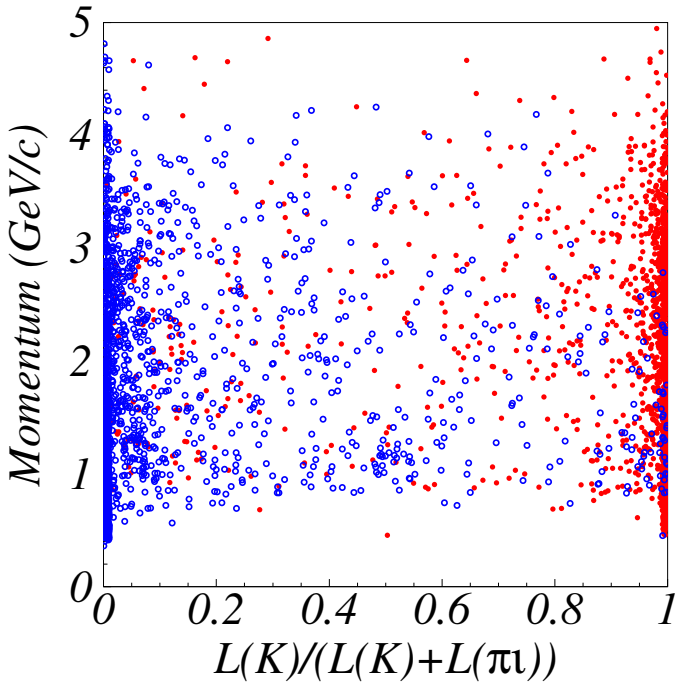






- r: Quality of flavor tag
  - $r = \pm 1$: correctly identified $B\overline{B}$
  - $r = 0$: flavor tagging fails
- Select polygon in $(r, \mathcal{R})$:
  - optimized to maximize $S/\sqrt{S+B}$
  - two different selected regions: different Δz resolutions for the two data sets

2. $B \to K^*\gamma$ background



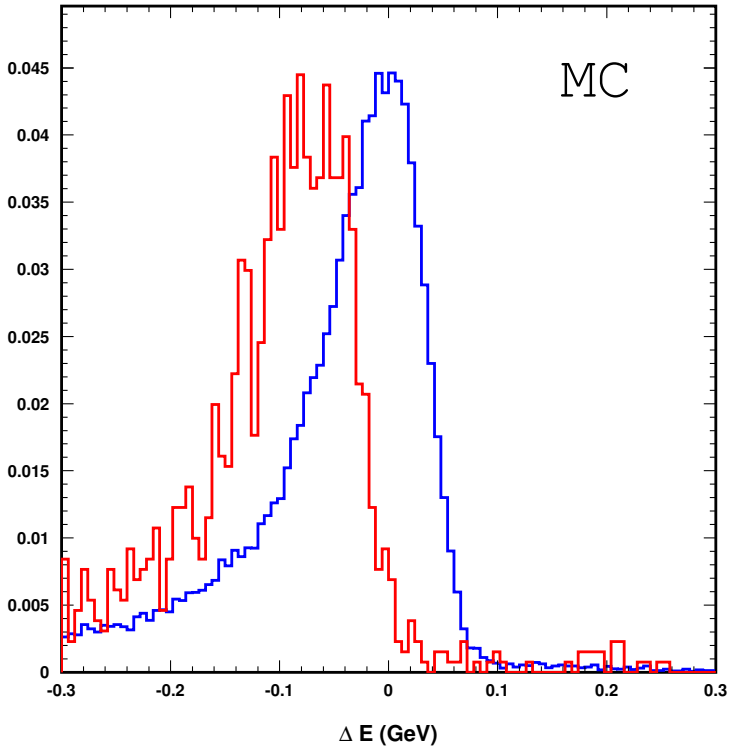
- $\mathcal{L}_K/(\mathcal{L}_K + \mathcal{L}_\pi) < 0.15$
  - π efficiency $\sim 89\%$
  - K/π fake $\sim 10\%$

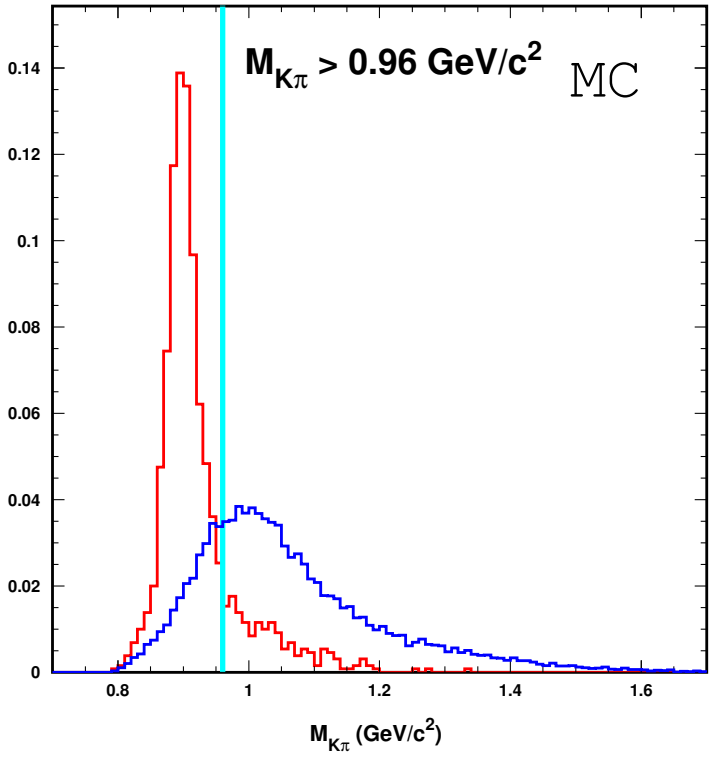
- Particle Identification:
  - Aerogel Cherenkov Counter (ACC)
  - dE/dx from Central Drift Chamber (CDC)
  - Time-of-flight (TOF)
- K/π misidentification $\Rightarrow B \to K^*\gamma$ background

Residual $B \to K^*\gamma$ background

After particle ID

Plots: Signal, $B \to K^*\gamma$

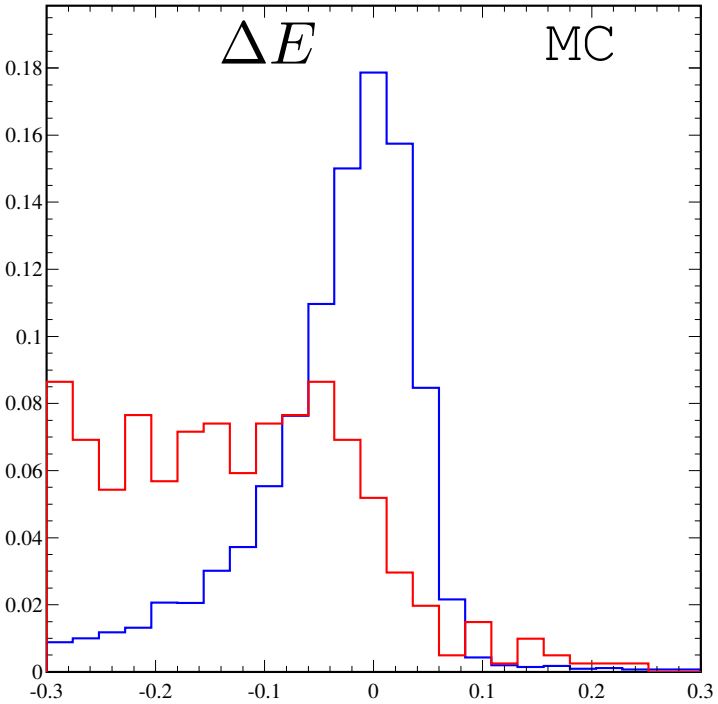


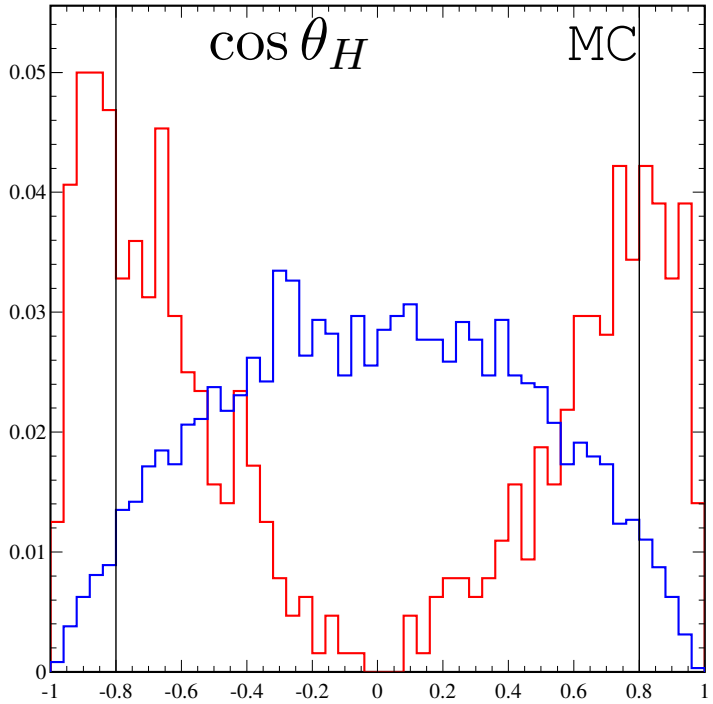


- $M_{K\pi}$ to reduce remaining $B \to K^*\gamma$
  - $M_{K\pi} > 0.96\,\mathrm{GeV}/c^2$ for $B^0 \to \rho^0\gamma$
  - $M_{K\pi} > 0.92\,\mathrm{GeV}/c^2$ for $B^+ \to \rho^+\gamma$
- Remaining $B \to K^*\gamma$ is fixed from DATA

4. $B \to V\pi^0$ and $B \to V\eta$ background

Plots: Signal, $B \to V\pi^0$ $(B \to V\eta)$





- Due to asymmetric decay of $\pi^0 \to \gamma\gamma$ $(\eta \to \gamma\gamma)$: less energetic γ is missed.
- Helicity angle follows
  - $\cos^2\theta$ for $B \to V\pi^0$ $(B \to V\eta)$
  - $\sin^2\theta$ for $B \to V\gamma$
- $|\cos\theta_H| < 0.8$ (0.6) for $B \to (\rho^0, \omega)\gamma$ $(B^+ \to \rho^+\gamma)$

Fit Method

- 2D extended unbinned maximum likelihood fit
- Simultaneous fit for two data sets
- Simultaneous fit of 5 modes $B \to (\rho^0, \rho^+, \omega, K^{*0}, K^{*+})\gamma$ using isospin relation

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

$$= \frac{\tau_{B^+}}{\tau_{B^0}} \cdot 2\mathcal{B}(B^0 \to \omega\gamma)$$

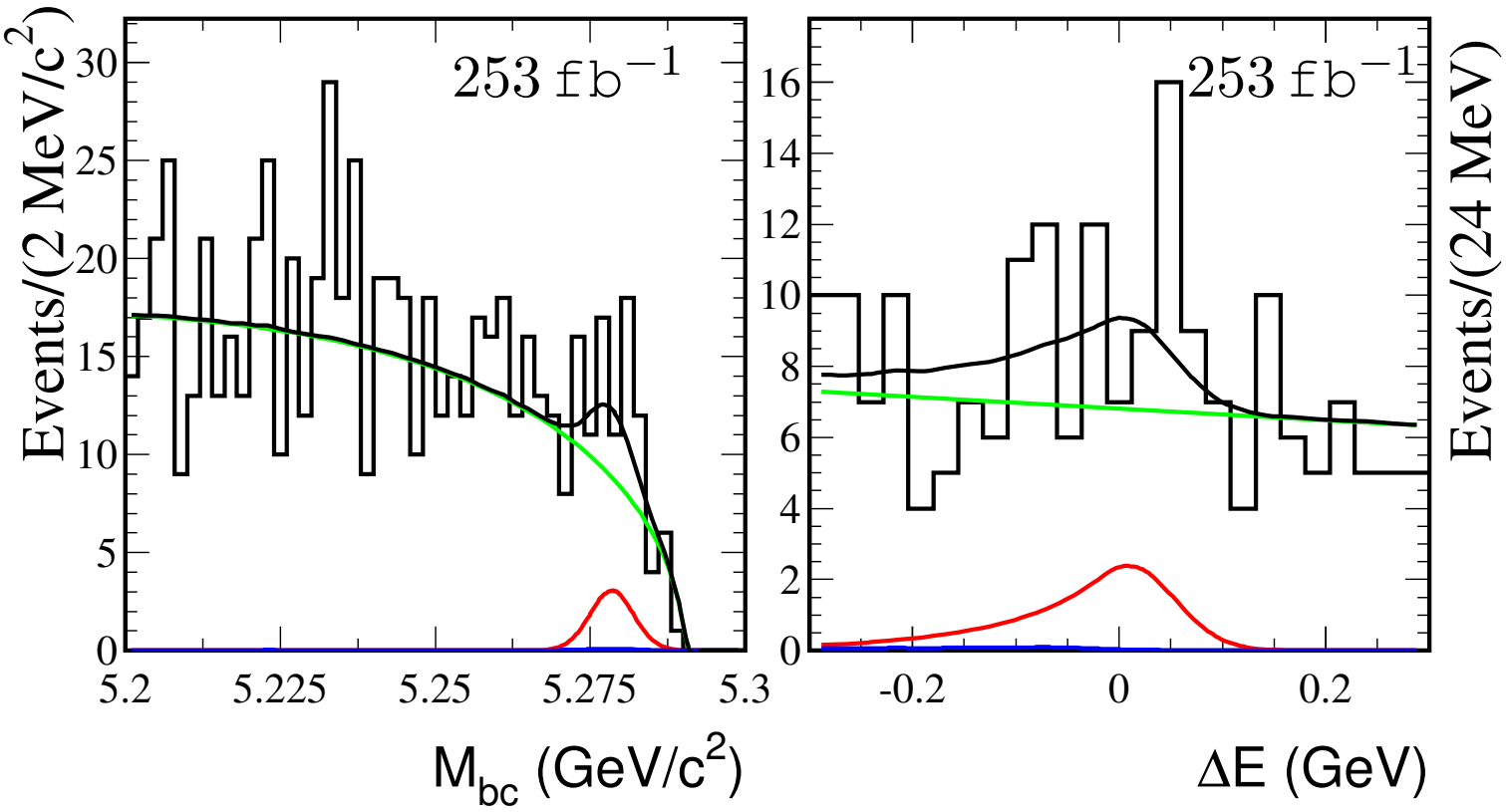
  - free parameters:
    - $\mathcal{B}(B \to (\rho,\omega)\gamma)$ $(\frac{\mathcal{B}(B\to(\rho,\omega)\gamma)}{\mathcal{B}(B\to K^*\gamma)})$
    - $\mathcal{B}(B \to K^*\gamma)$
    - Continuum yields
    - Continuum ΔE shapes
- PDFs($M_{\rm bc}$ x ΔE) used in fitting
  - Signal: Gaussian x Crystal Ball Line shape
  - Continuum background: ARGUS x Linear
  - $B\overline{B}$ background: two dimensional histograms [$B \to K^*\gamma$, $B \to X_s\gamma$, $B \to V\pi^0 (B \to V\eta)$ and Rare B except $B \to V\pi^0 (B \to V\eta)$]

Simultaneous fit results

- $\mathcal{B}(B \to (\rho,\omega)\gamma) = (0.72^{+0.43+0.28}_{-0.39-0.27}) \times 10^{-6}$
- Significance $= 1.9\sigma$ incl. systematic error
- $\mathcal{B}(B \to (\rho,\omega)\gamma) < 1.4 \times 10^{-6}$ @ 90% CL (incl syst. error)

All modes combined

Signal, $B\overline{B}$ background, Continuum background



Simultaneous fit results

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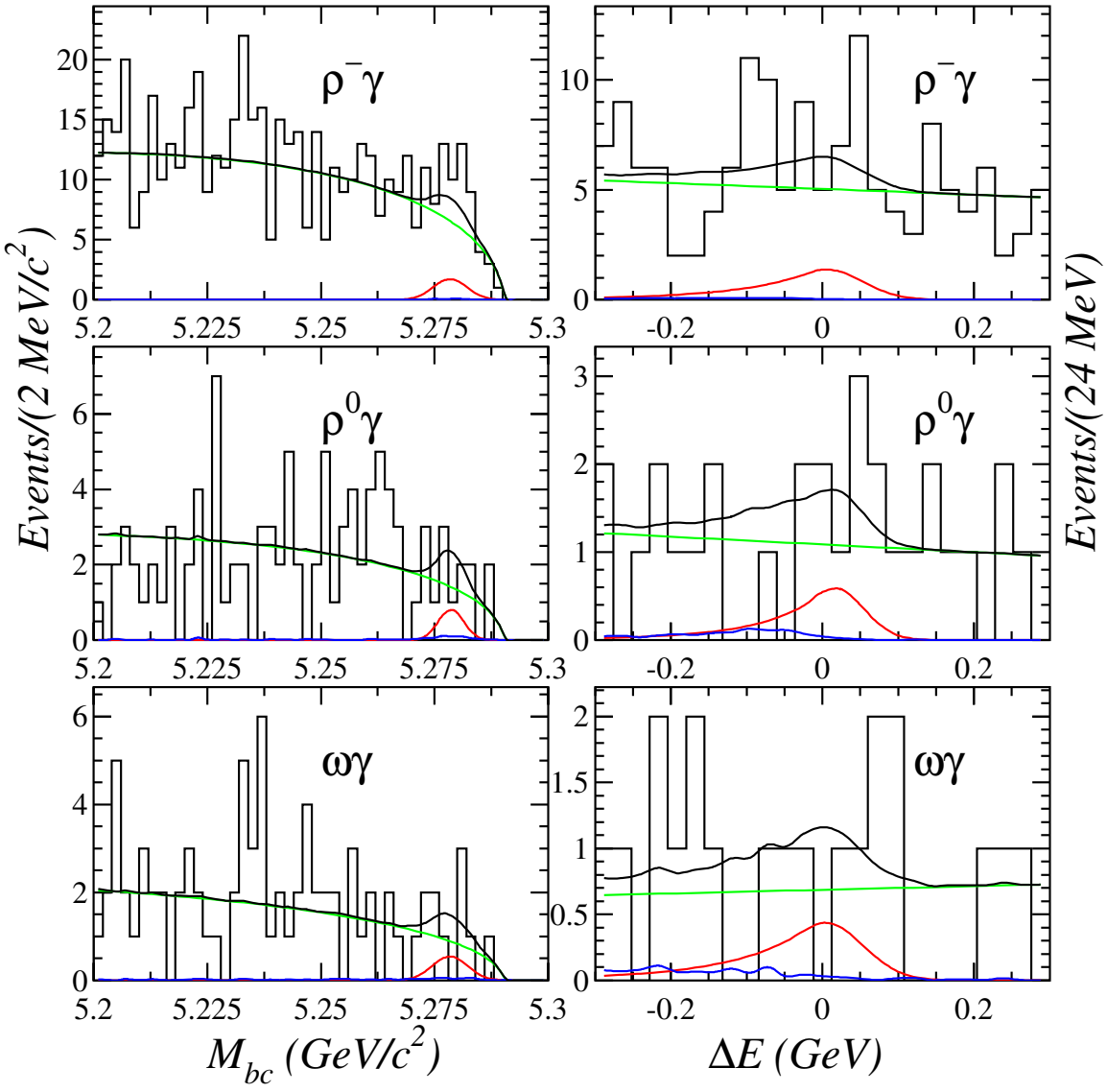
$253\,\mathrm{fb}^{-1}$



Mode	UL @ 90% CL
$B^+ \to \rho^+\gamma$	2.2×10^{-6}
$B^0 \to \rho^0\gamma$	0.8×10^{-6}
$B^0 \to \omega\gamma$	0.8×10^{-6}

Extraction of $|V_{td}/V_{ts}|$

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

- $S_\rho = 1$ is the isospin weight for ρ^+
- m_ρ, m_{K^*} and m_B are the masses of the ρ^+, K^*, and B
- $\zeta = 0.85 \pm 0.10$ is the ratio of HQET/LEET form factors
- $\Delta R = 0.1 \pm 0.1$ is the $SU(3)$ breaking effect
- $\frac{\mathcal{B}(B\to(\rho,\omega)\gamma)}{\mathcal{B}(B\to K^*\gamma)} < 0.035$ @ 90% CL
- $|V_{td}/V_{ts}| < 0.21$ @ 90% CL (incl. syst. error)

Summary

Results with $253\,\mathrm{fb}^{-1}$

- Combined $\mathcal{B}(B \to (\rho,\omega)\gamma) = (0.72^{+0.43+0.28}_{-0.39-0.27}) \times 10^{-6}$
- 1.9σ significance
- Upper Limits @ 90% CL (incl. syst. error)
  - $\mathcal{B}(B \to (\rho,\omega)\gamma) < 1.4 \times 10^{-6}$
  - $\mathcal{B}(B^+ \to \rho^+\gamma) < 2.2 \times 10^{-6}$
  - $\mathcal{B}(B^0 \to \rho^0\gamma) < 0.8 \times 10^{-6}$
  - $\mathcal{B}(B \to \omega\gamma) < 0.8 \times 10^{-6}$
  - $\frac{\mathcal{B}(B\to(\rho,\omega)\gamma)}{\mathcal{B}(B\to K^*\gamma)} < 0.035$
  - $|V_{td}/V_{ts}| < 0.21$

Next summer results with $\sim 400 - 500\,\mathrm{fb}^{-1}$
and may be

RETURN OF THE PENGUINS

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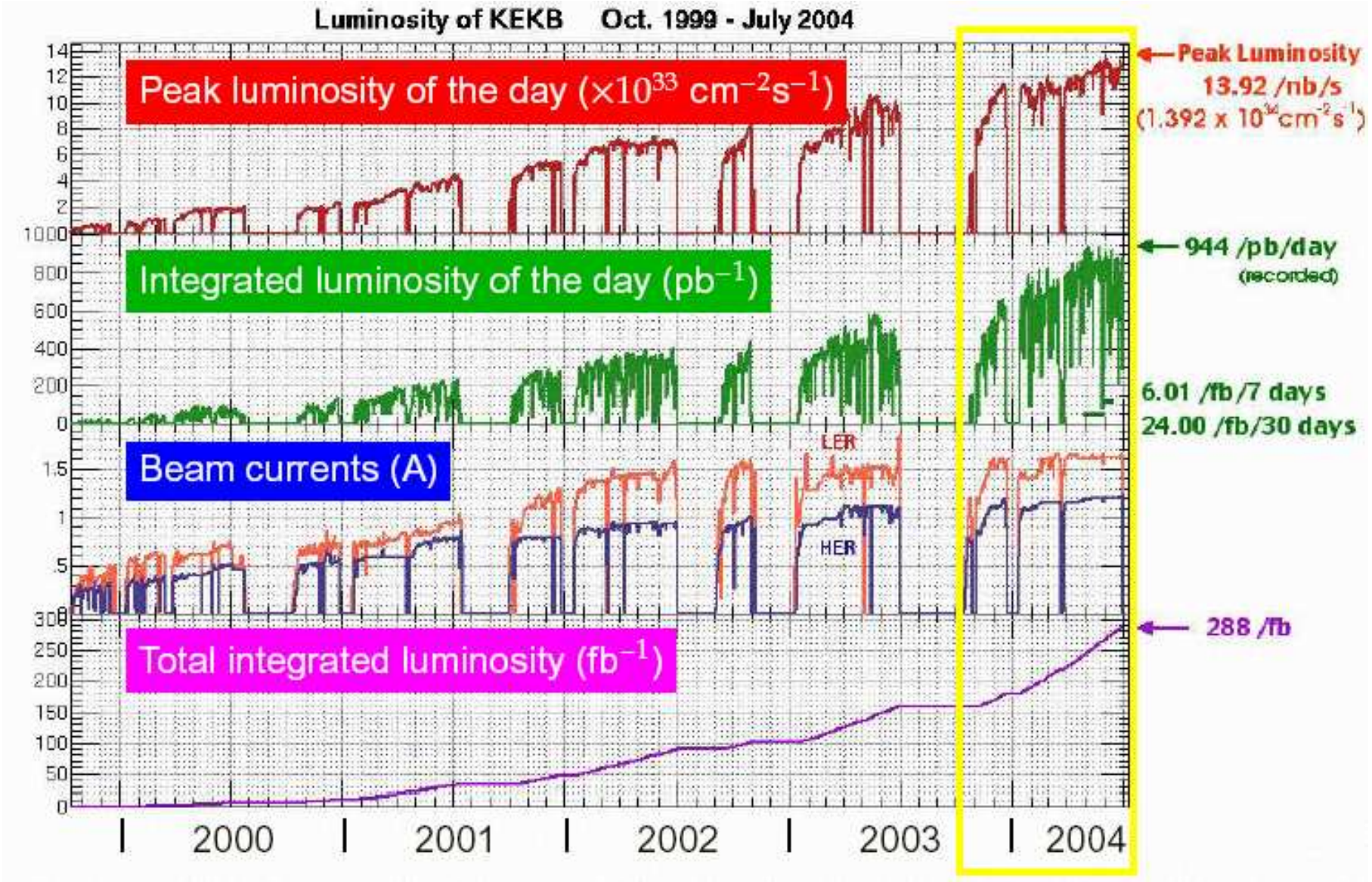
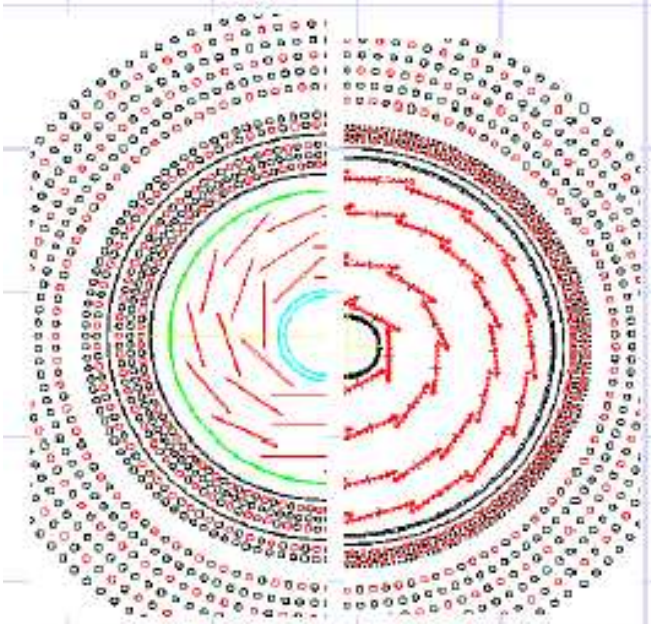
The End

KEKB Performance



SVD1($140\ \mathbf{fb}^{-1}$) - SVD2($113\ \mathbf{fb}^{-1}$)



SVD1 SVD2

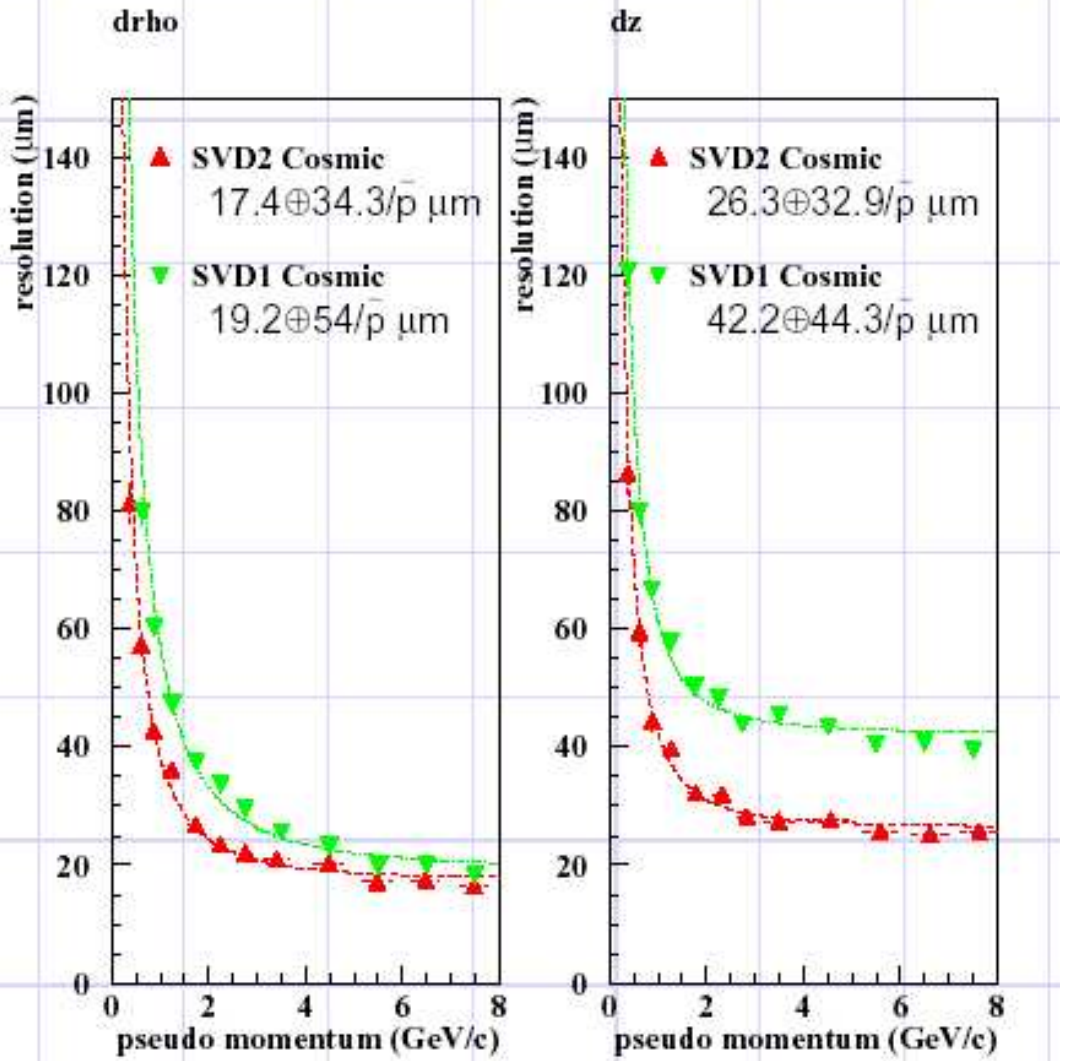
3-layer 4-layer

2 cm ← beampipe → 1.5 cm

23–139° ← θ → 17–150°

1 Mrad >20 Mrad

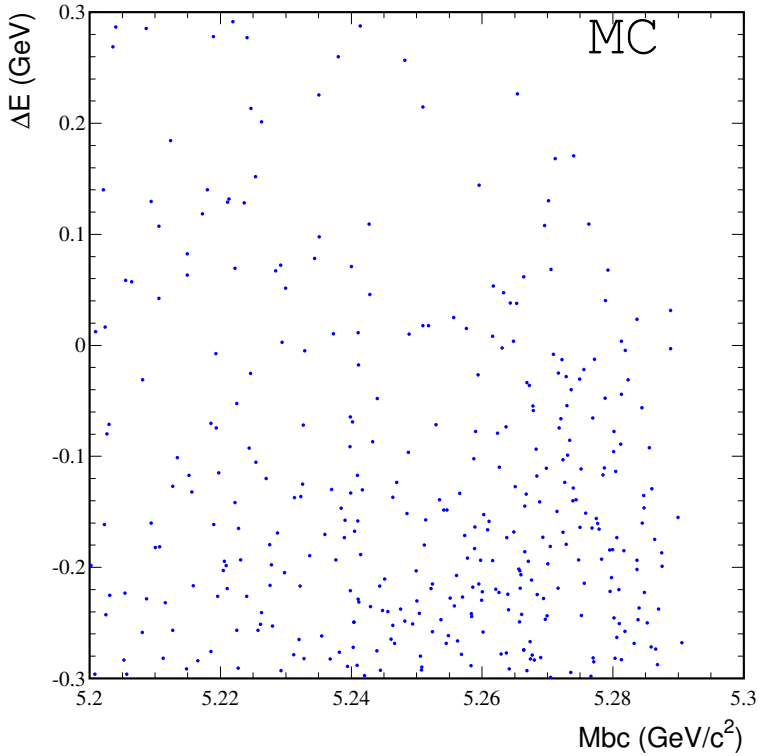
Better detector!

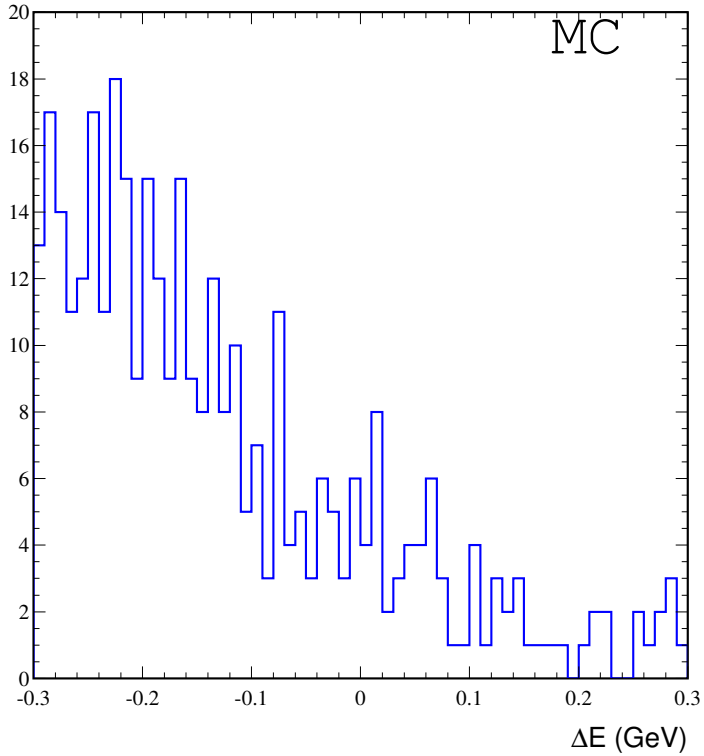


Impact parameter resolutions

[Y. Ushiroda, Nucl. Instr. and Meth. A**511**(2003) 6]

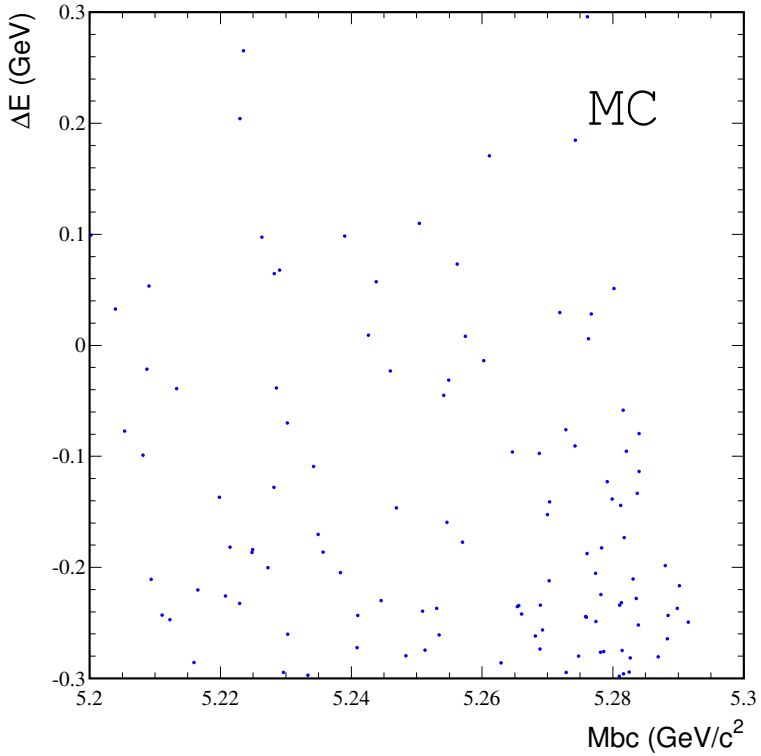
3. $b \to s\gamma$ background

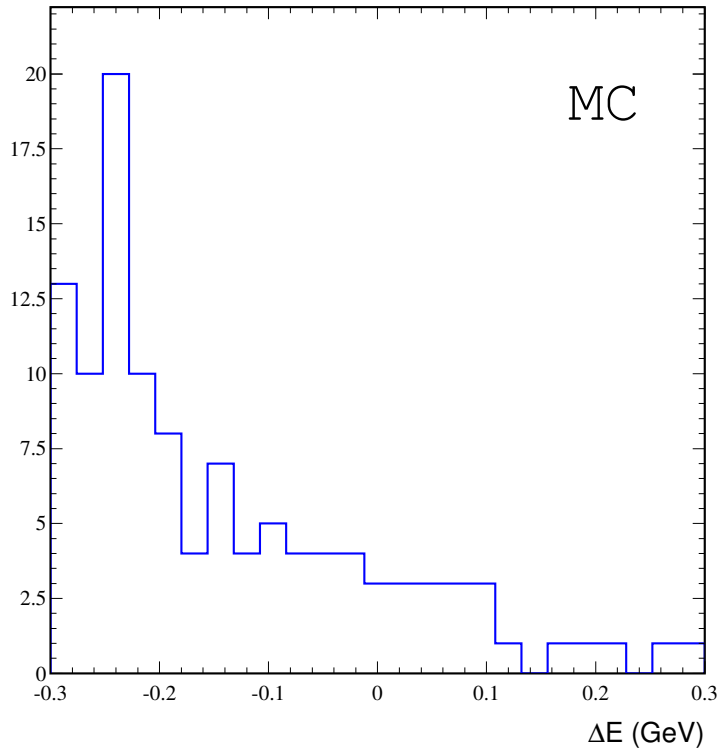




- Backgrounds from higher $X_s(K + n\pi)$ resonances
- Used $B \to X_s\gamma$ MC to study this background

5. Rare B background





- Rare B bkgd other than $B \to (\rho, \omega)\pi^0$ and $B \to (\rho, \omega)\eta$

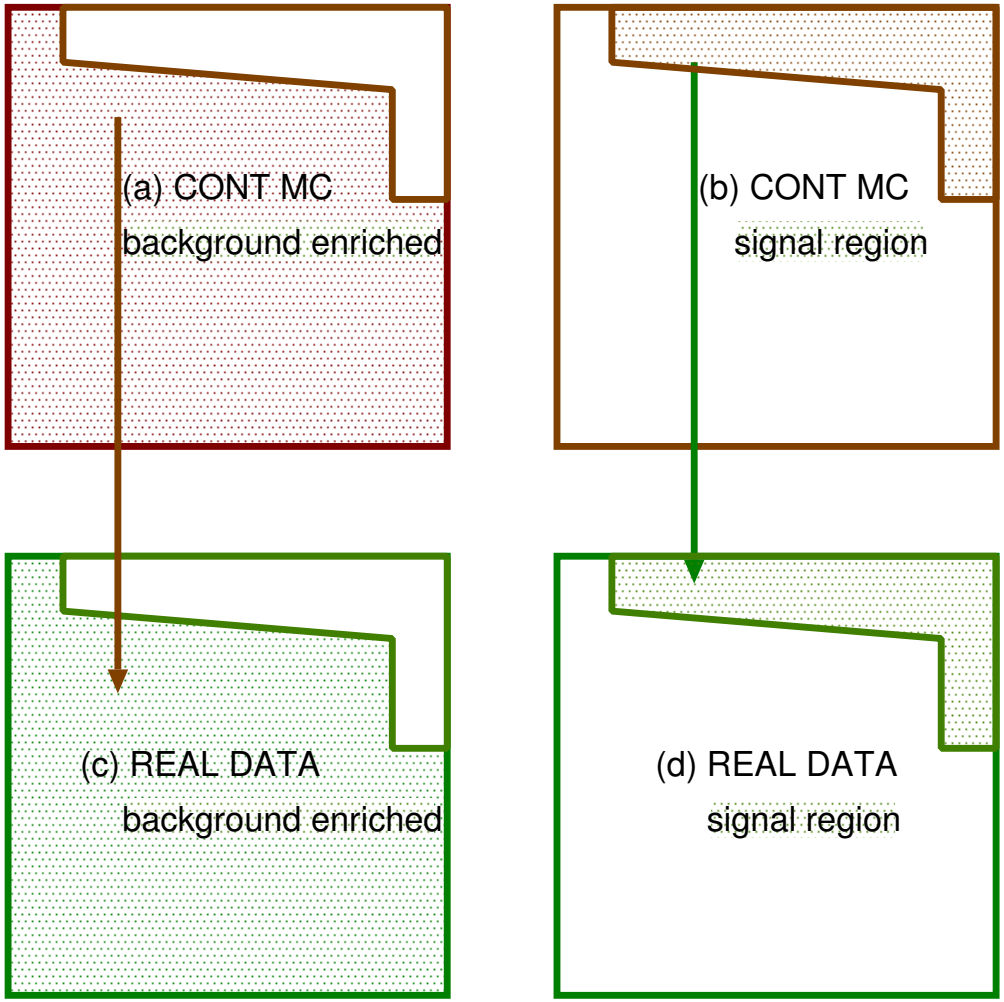
Group similar $B\overline{B}$ backgrounds together

Group	Group Members
GR-A	Dominant exclusive $B \to K^*\gamma$ modes
GR-B	$B \to X_s\gamma$ and remaining exclusive $B \to K^*\gamma$ modes
GR-C	$B \to V\pi^0$ + $B \to V\eta$ modes
GR-D	(Rare B - ($B \to V\pi^0$ + $B \to V\eta$))

- P.d.f without applying a cut on 2D likelihood ratio
- P.d.fs are 2D histograms.
- Normalization are fixed to calculated values from MC or. DATA

Group	$B^0 \to \rho^0\gamma$	$B^+ \to \rho^+\gamma$	$B \to \omega\gamma$
	(SVD1, SVD2)	(SVD1, SVD2)	(SVD1, SVD2)
GR-A	$1.47, 1.44$	$6.51, 6.51$	$0.38, 0.22$
GR-B	$2.86, 2.72$	$8.61, 7.30$	$5.30, 4.33$
GR-C	$0.91, 0.83$	$3.05, 2.58$	$1.07, 0.76$
GR-D	$1.48, 1.44$	$1.17, 1.04$	$2.22, 1.34$

ARGUS Shape modeling



- `efact(d) = efact(b) + efact(c) - efact(a)`
- `efact(x) is obtained from 1D fit of` $M_{\rm bc}$