Search for Rare B Decays

Using the L3 Detector

For the L3 Collaboration

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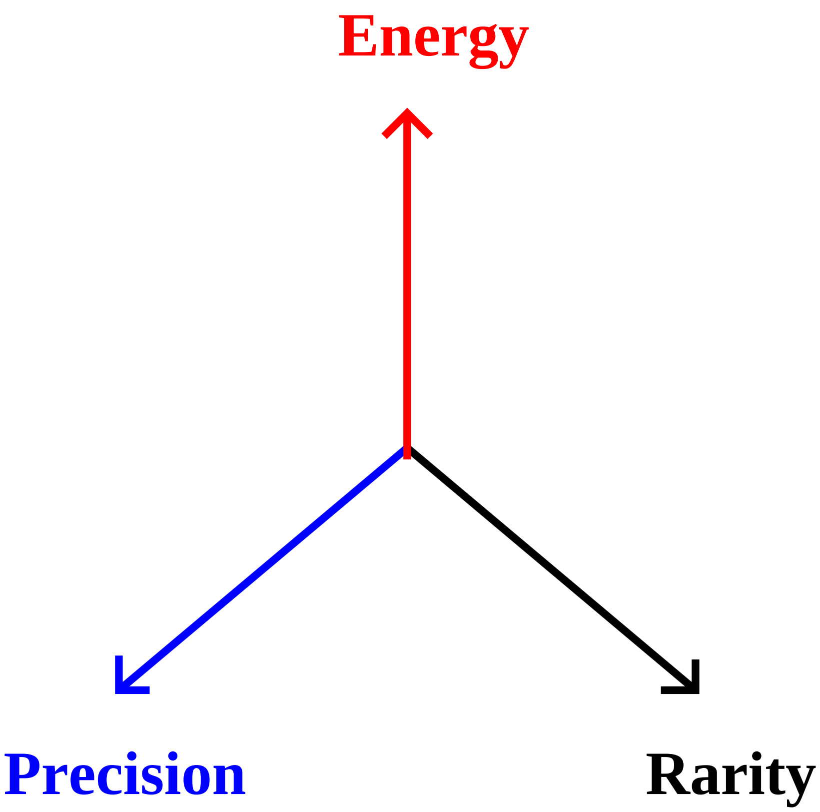
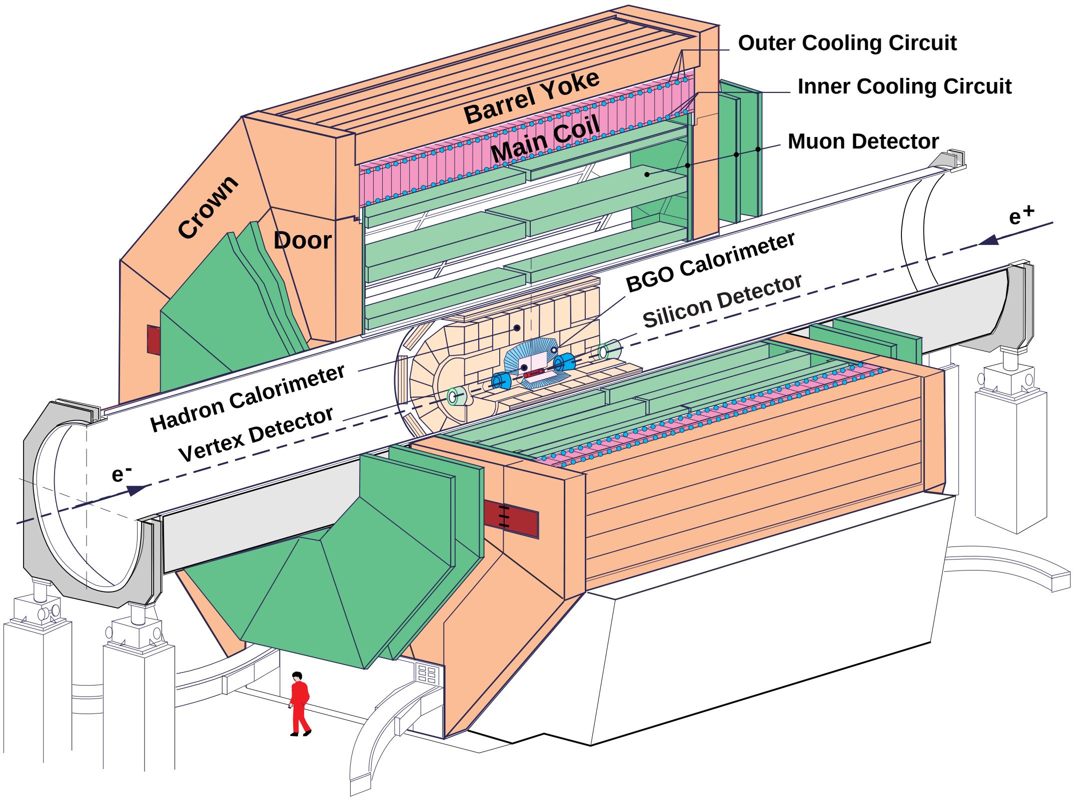
Outline

- Brief Introduction
- Detector
- Analysis
  - Inclusive radiative B decays
  - $B^0 \longrightarrow \eta\eta$
  - $B^0 \longrightarrow \pi^0\eta$
  - $B^0 \longrightarrow \pi^0\pi^0$
  - $B^0 \longrightarrow \gamma\gamma$
- Results
- Conclusions

Particle Physics Progress in three ways



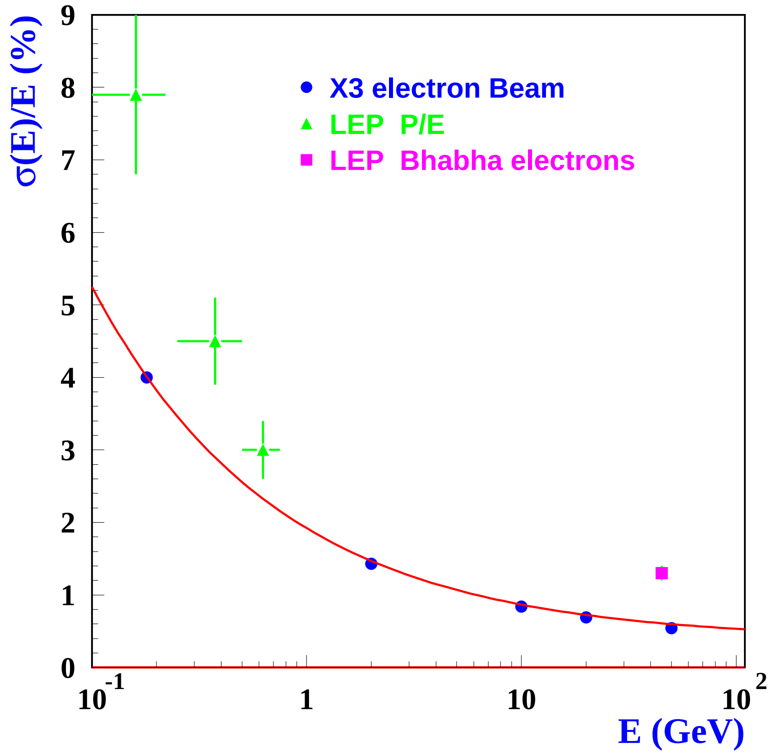
- Increase in Energy
  - Cross the threshold to observe New Phenomenon
- Precision Measurement
  - A challenge to Detector capability
  - Look for Virtual Effects of Higher order
- Rarity
  - One needs patience to collect enough statistics
  - Higher order effects show up in the rare Phenomena (like Penguins,etc..)
  - Virtual Reality

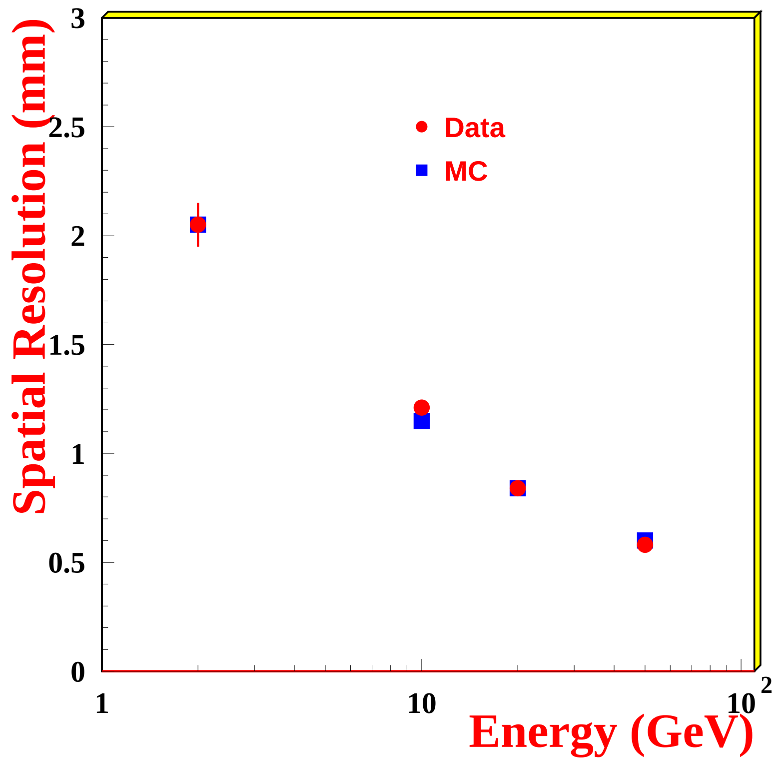


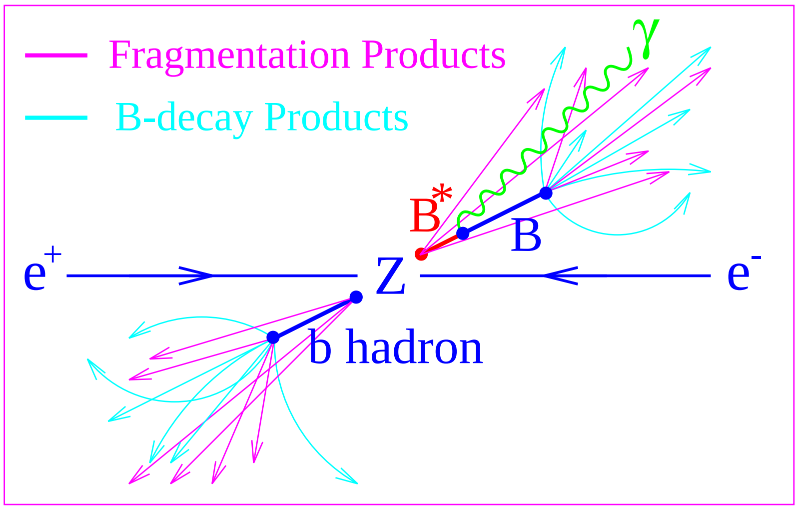
The L3 detector resolution is optimized for detecting electrons photons and muons

- Electromagnetic calorimeter: BGO Crystals

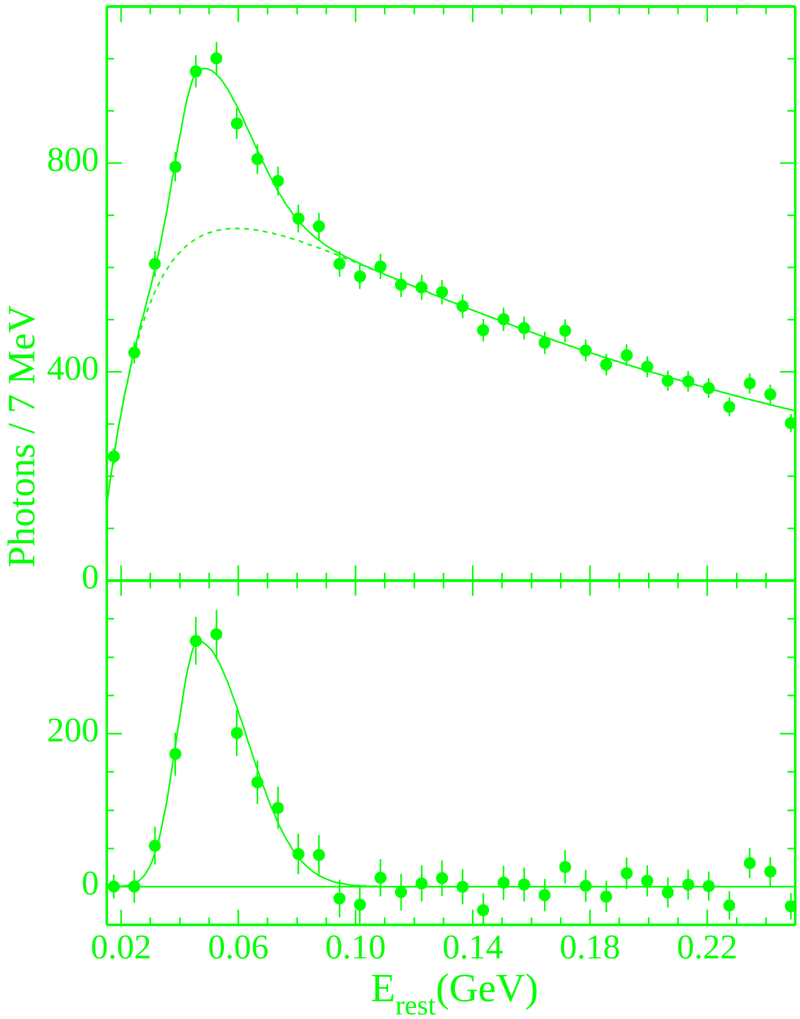
The BGO Detector







Fragmentation Products
B-decay Products
γ
B*
B
e+
Z
e-
b hadron



Photons / 7 MeV
800
400
0
200
0
0.02
0.06
0.10
0.14
0.18
0.22
E_rest(GeV)

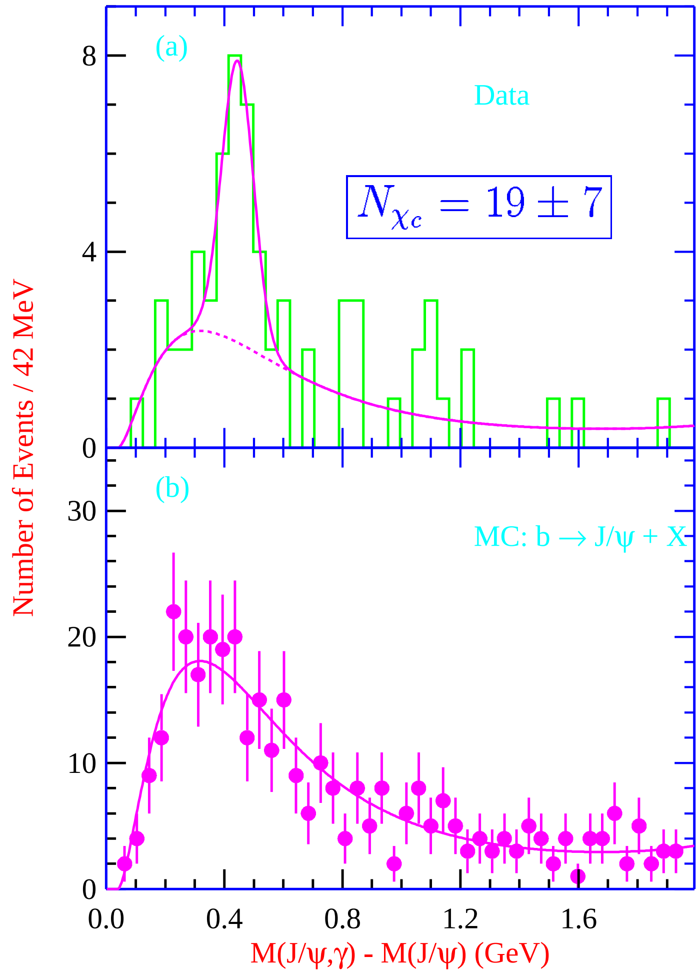
The BGO Detector

$e^+e^- \longrightarrow Z \longrightarrow b\bar{b} \longrightarrow B + X$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow \chi_c + X$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow J/\psi + \gamma$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow l^+l^-$



One gets

$$\mathrm{Br}(Z \rightarrow \chi_{c1} + X) = (0.75 \pm 0.29 \pm 0.06) \times 10^2$$

If χ_{c1} are produced only from B

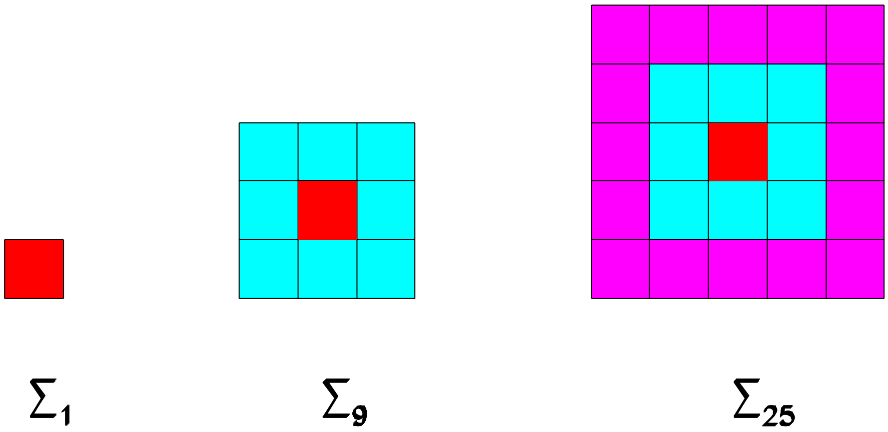
$$\mathrm{Br}(B \rightarrow \chi_{c1} + X) = (2.4 \pm 0.9 \pm 0.2) \times 10^{-2}$$

The BGO Detector

Transverse shape of the shower is used.
Identification depends on the environment, isolated photons, hadronic event, etc..

The most commonly used estimators :

$$\rho_{BGO} = \Sigma_9 / \Sigma_{25}$$

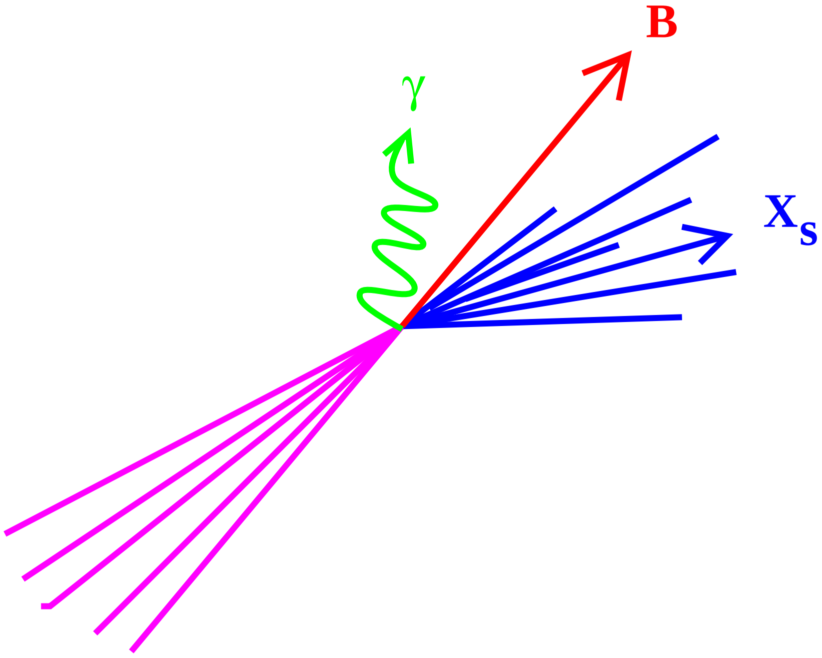


ρ_{BGO} should be about 1 for electromagnetic showers

$$\chi^2_{BGO} = \sum_{i=1}^{9} \left(\frac{F_i - F_i^{TB}}{\sigma_i^{TB}} \right)^2 \qquad (1)$$

where F_i is the fraction of energy deposited in the crystal i (i = 1, 9), ${F_i}^{TB}$ and ${\sigma_i}^{TB}$ are the fraction and the width of the fraction of energy deposited, as determined from the test beam.

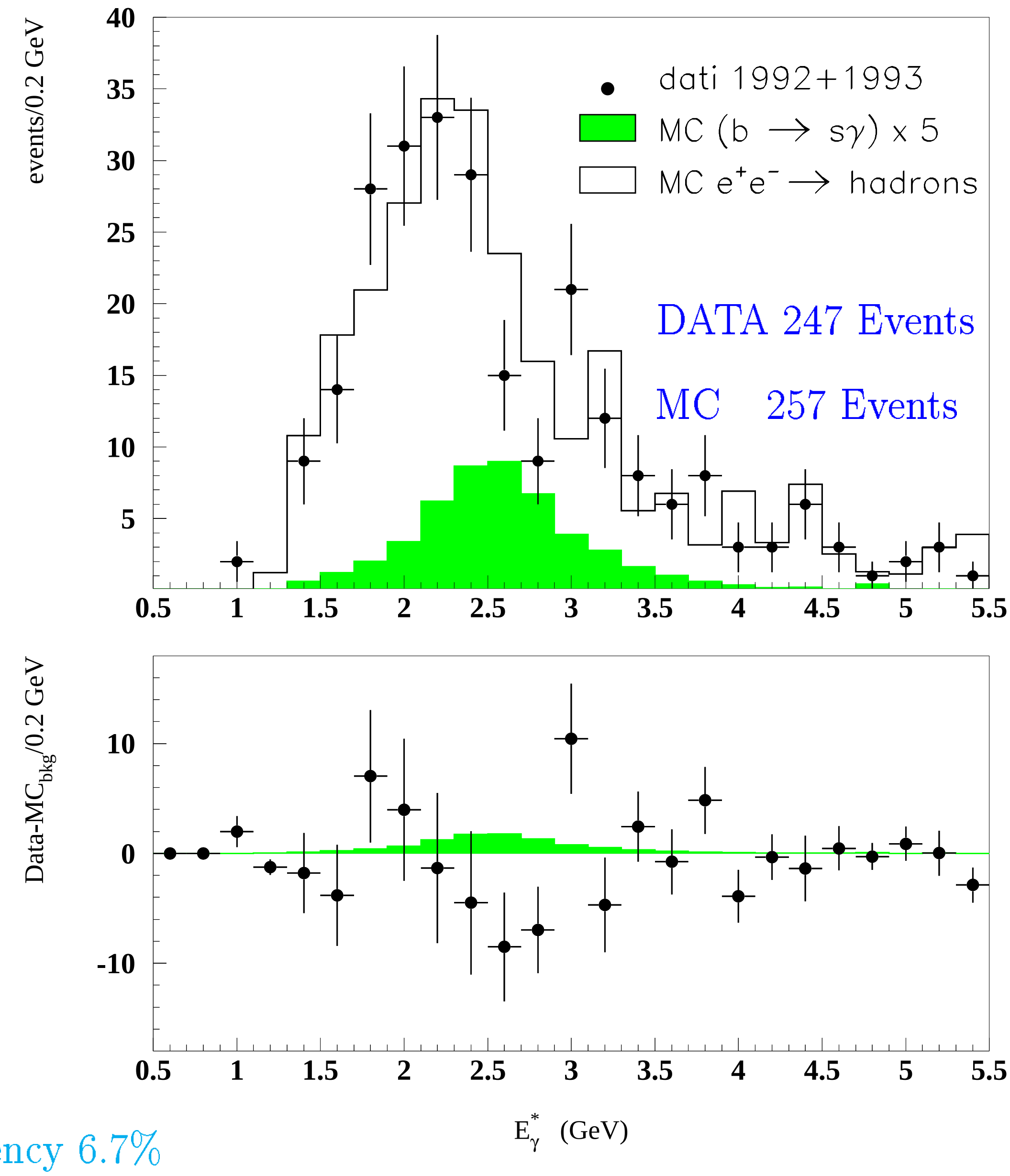
Inclusive Radiative B Decay



- b Events are tagged with two independent methods
  - b -lifetime based on Impact Parameters
  - Event Shape Variables
- Invaraint Mass of a system is reconstructed independent of X_s
- γ is searched with $E_\gamma > 10$ GeV
- Jet Axis Kinematics
- The signal is identified by requiring the mass of B to be compatible with that of b hadron
- $E^\star_\gamma$ Spectrum in the B rest frame.
  - Energetic π^0 faking $\gamma \approx 52\%$ Contribution
  - Final State Radiation $\approx 31\%$

Inclusive Radiative B Decay

- 1.3 Million $Z \to q\bar{q}$



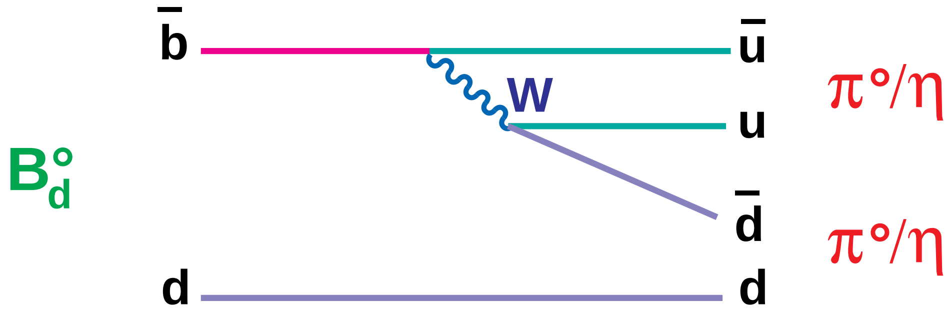
- Efficiency 6.7%

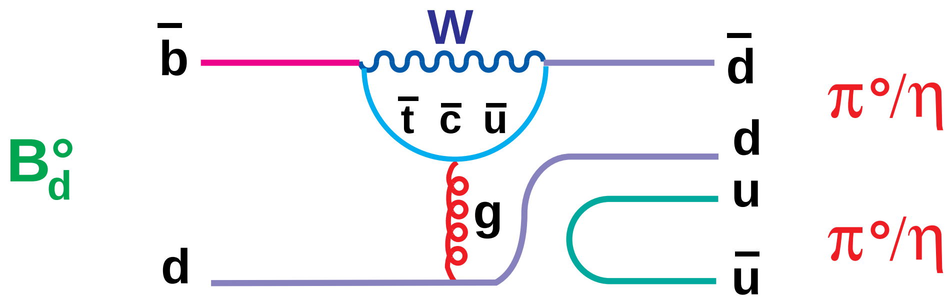
$$\boxed{Br(B \to X_s + \gamma) < 8.4 \times 10^{-4} \quad 90\%\ \text{C.L.}}$$

- Result include 20% preliminary estimation of Systematics
- An Upper Limit close to CLEO is expected by the end of LEP I

Search for $B^0 \to \eta\eta / \eta\pi^0 / \pi^0\pi^0$

The final state contains mixing of $u\bar{u}, d\bar{d}$





- Theoretical and Experimental Status

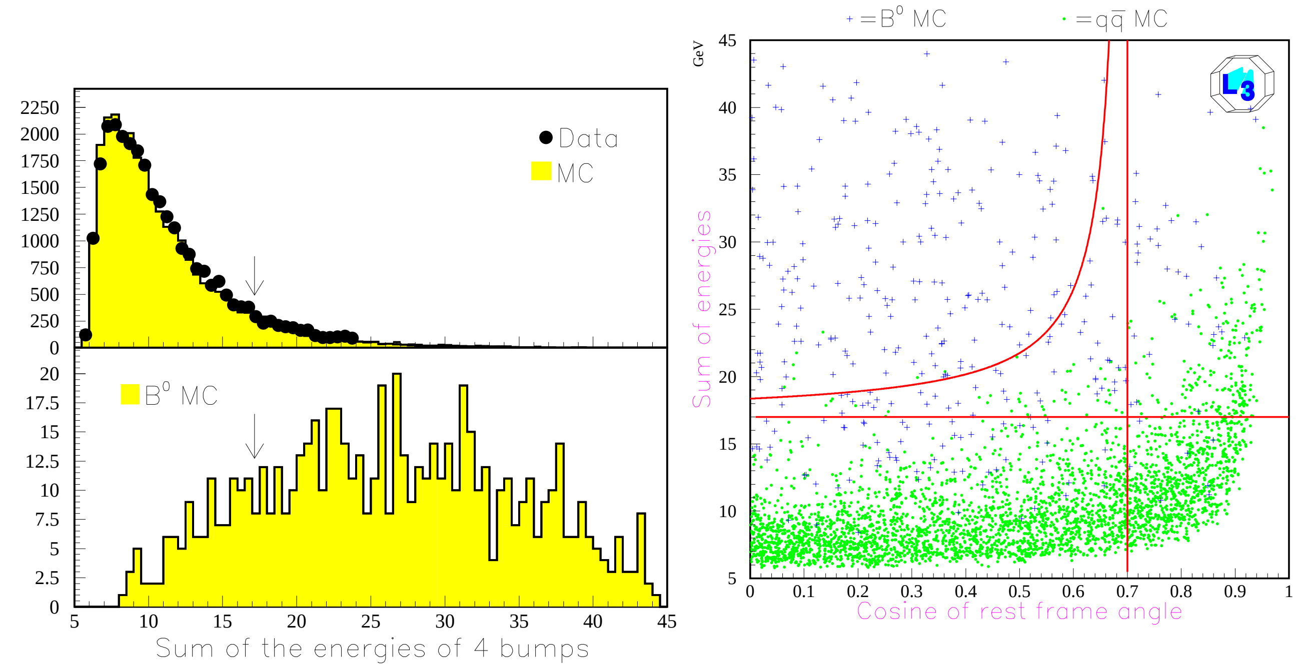
			Penguins	Experimental
$B^0 \to \eta\eta$	2.7×10^{-6}	$(6 \pm 3) \times 10^{-8}$	1.4×10^{-5}	No
$B^0 \to \pi^0\eta$			4.1×10^{-6}	1.8×10^{-3}
$B^0 \to \pi^0\pi^0$	2.6×10^{-6}	$(6 \pm 3) \times 10^{-7}$	1.0×10^{-6}	0.9×10^{-5}

- The major contribution may arise for "Gluonic Peguins"
- There are no calculations beyond the SM

$B^0 \to \eta\eta \to \gamma\gamma\gamma\gamma$

- Electromagnetic Clusters as Photons
- Combine pairs of Bumps, each having η Invariant Mass in 3σ (17 MeV)
- Total Invariant Mass of the final bumps

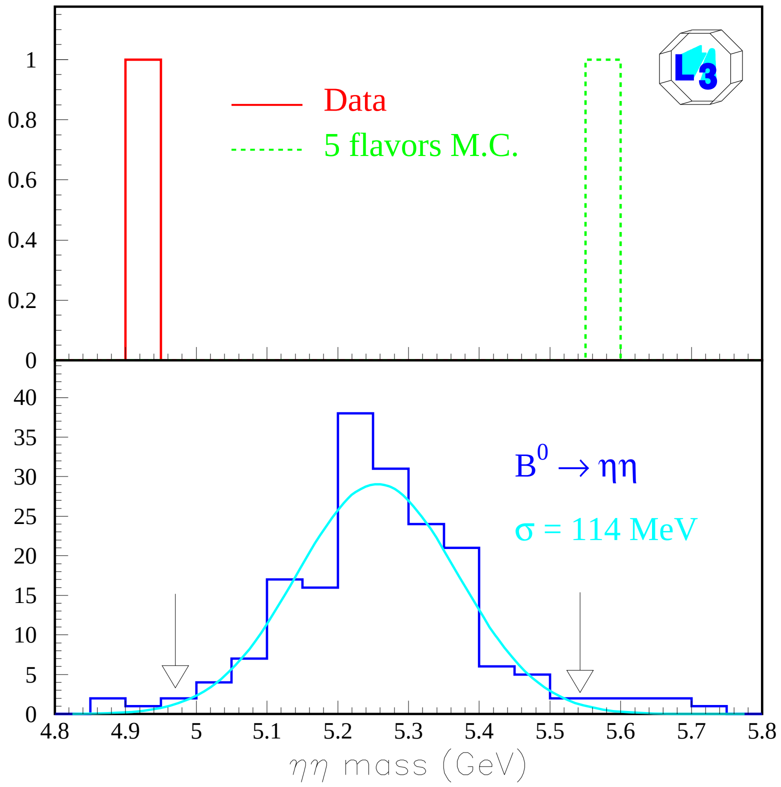
Due to the hard fragmentation, the energy carried by the two η's form B^0 decay is large.



- Reduce the Background
  - $\mathrm{Cos}\theta_{\eta B^0}$
  - $\mathrm{Cos}\theta_{\eta B^0}$ vs E_{Total}

$B^0 \to \eta\eta \to \gamma\gamma\gamma\gamma$

- 91 + 92 Hadronic Events $\approx$ 1 Million
- Five Flavour $q\bar{q}$ Events



The Non Observation of any event can be translated to an Upper Limit.

- $\epsilon_{B^0 \to \eta\eta} = 3.5\%$

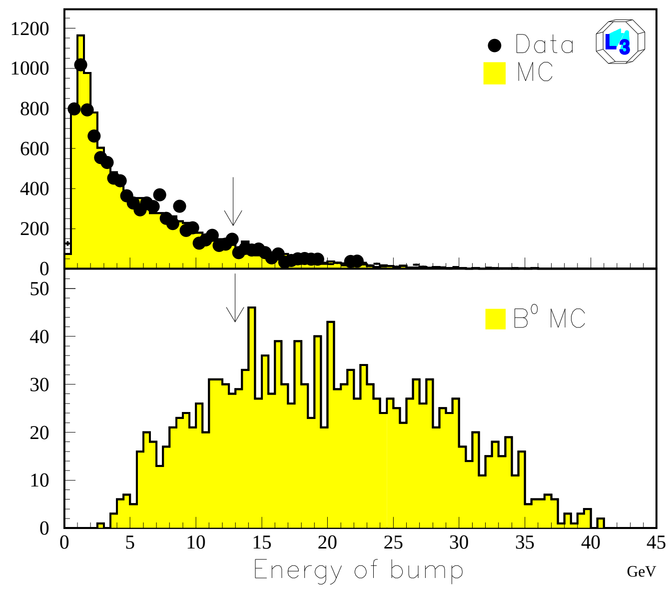
$$Br(B^0 \to \eta\eta) < \frac{N_{Observed}}{N_h \times 2 \times R_{b\bar{b}} \times f_{b \to d} \times Br(\eta \to \gamma\gamma)^2 \times \epsilon_{B^0 \to \eta\eta}}$$

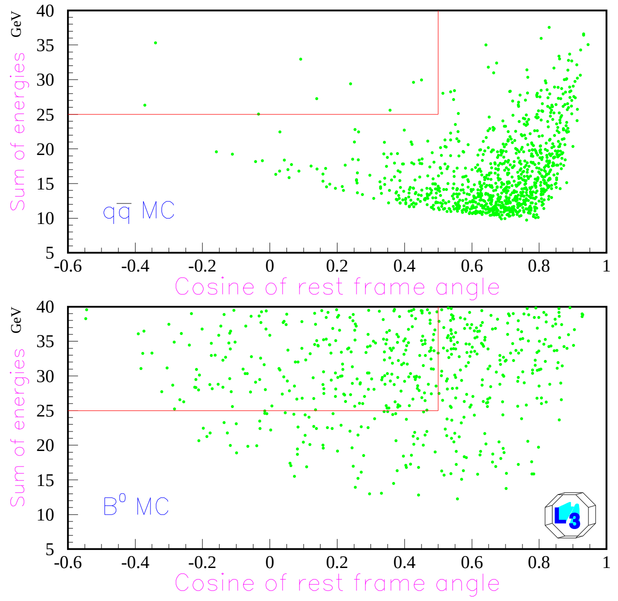
- $N_{Observed} = 2.3$
- $R_{b\bar{b}} = 0.222 \pm 0.007$
- $f_{b \to d} = 39.5\%$

$$\boxed{Br(B^0 \to \eta\eta) < 2.7 \times 10^{-3} \quad 90\%\ C.L.}$$

$B^0 \rightarrow \pi^0\eta \rightarrow \text{bump} + \gamma\gamma$

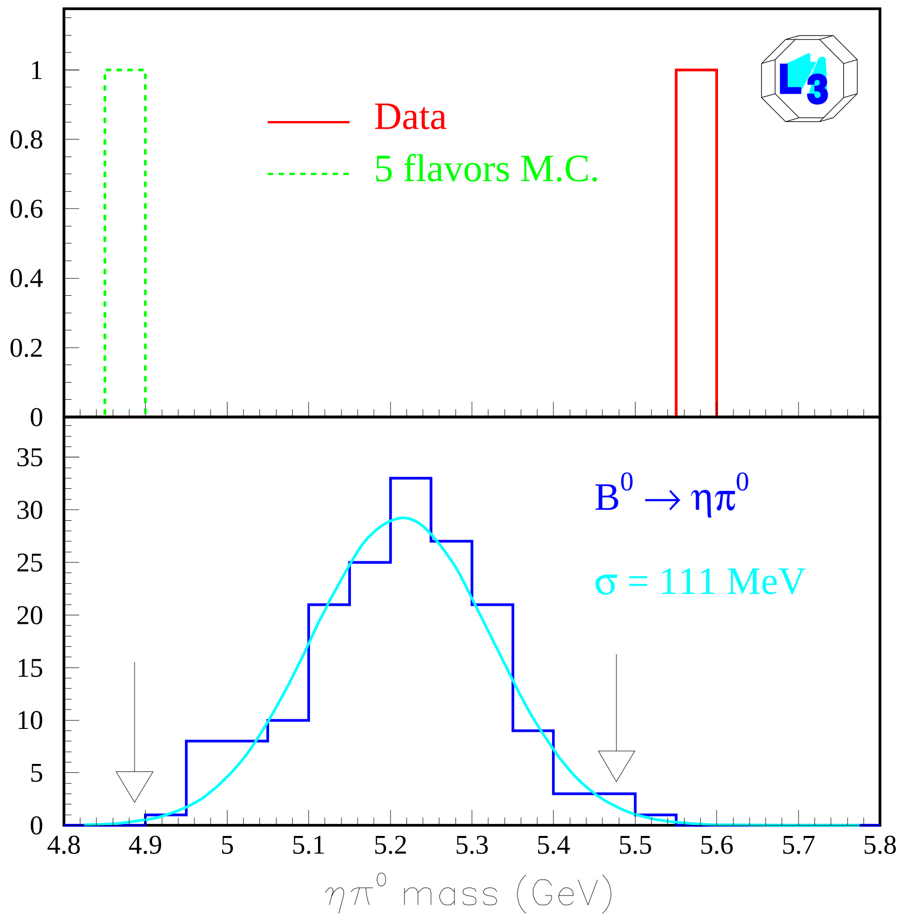
- Energetic $Br(\pi^0 \rightarrow \gamma\gamma)$ deposits its energy like that of Single Bump
- MC studies show, 38% times two photons from π^0 go in the same bump
- We search for three bumps, two bumps with η Invariant mass in 3σ and the third bump corresponding to high energetic π^0
- Kinematical Cuts: To reject the Background
  - $\mathrm{Cos}\theta_{B^0\mathrm{Bump}}$
  - $\mathrm{Cos}\theta_{B^0\mathrm{Bump}}$ vs E_{Total}





$B^0 \rightarrow \pi^0\eta \rightarrow \text{bump} + \gamma\gamma$

- 91 + 92 Hadronic Events $\approx$ 1 Million
- Five Flavour $q\bar{q}$ Events



- $\epsilon_{B^0 \rightarrow \pi^0\eta} = 3.5\%$

The Non Observation of any event can be translated to an Upper Limit

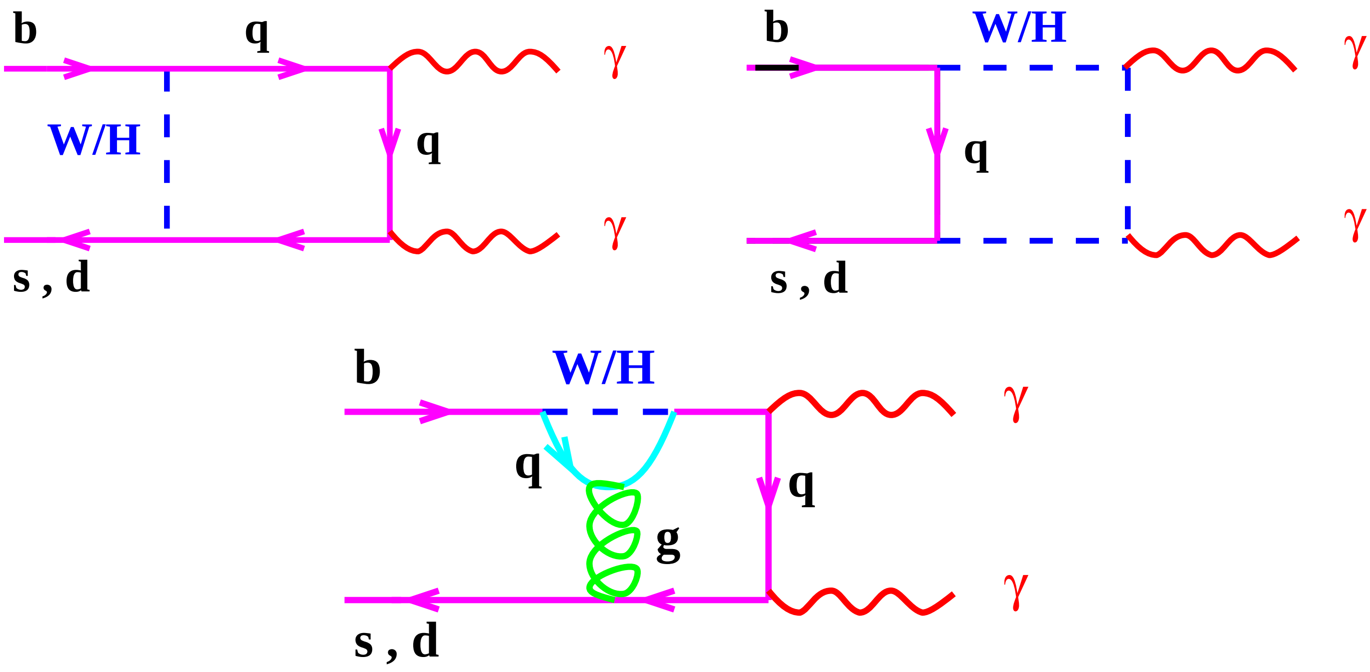
$$\boxed{Br(B^0 \rightarrow \pi^0\eta) < 1.1 \times 10^{-3} \quad 90\% \text{ C.L.}}$$

This Limit is better than earlier measurement by ARGUS

Search for $B^0 \to \gamma\gamma$

- SM $\approx 10^{-7}$

- Within the Minimal Extension of SM $Br(B^0 \to \gamma\gamma)$ is enhanced by two to three orders of magnitude compared to SM



- Main Contribution is from Charged Higgs $H^{\pm}$ in the Higgs Doublet Model (2HDM)

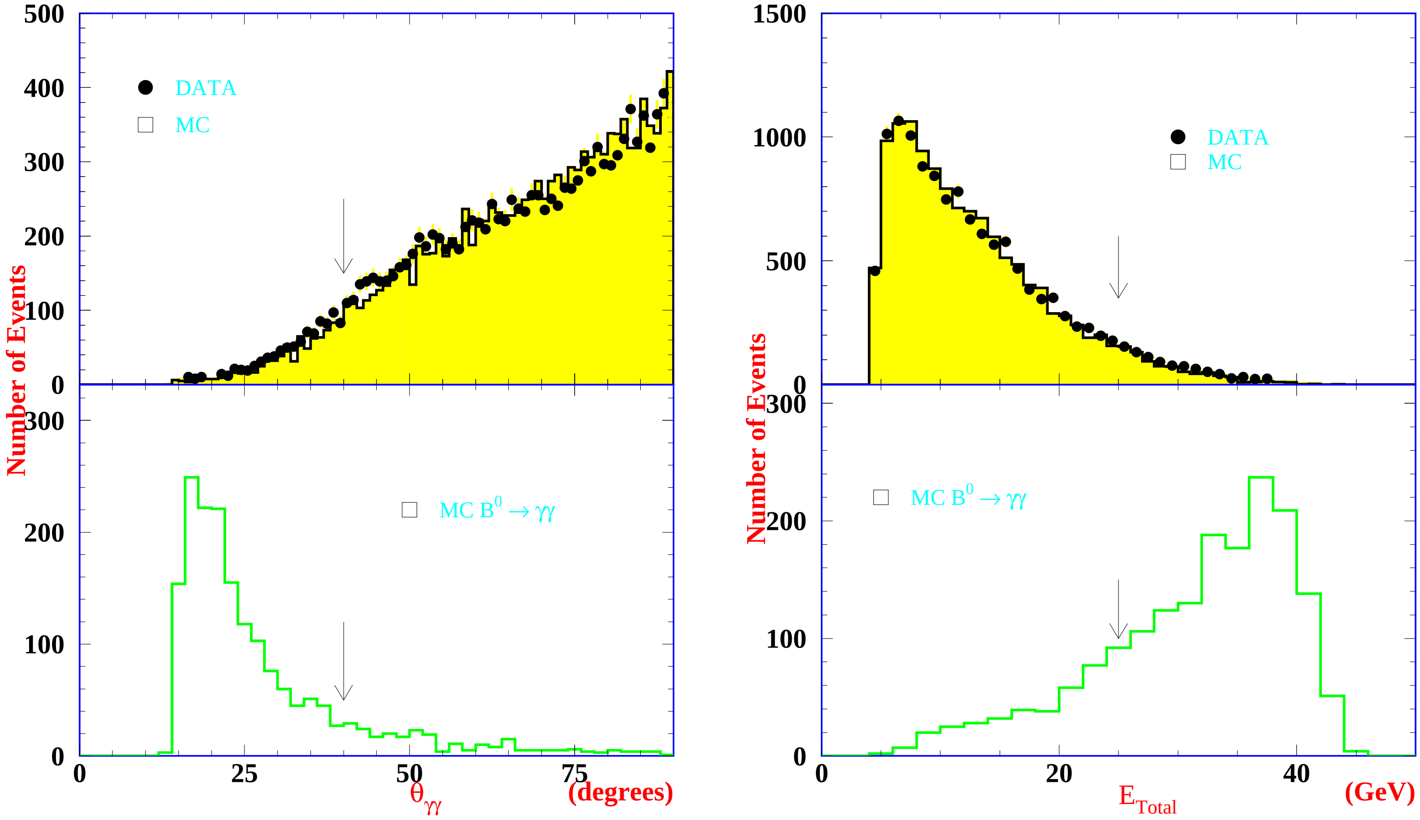
- $Br(B^0_s \to \gamma\gamma) > Br(B^0_d \to \gamma\gamma)$, $|V_{ts}| >> |V_{td}|$

- These decays are more sensitive to the NEW PHYSICS beyond SM and thus are more Promising

- There are no reliable Theoretical Calculations Available

Search for $B^0 \rightarrow \gamma\gamma$

- Analysis is performed on 1991 - 1994 Data
  - $\approx$ 3 Million Hadronic Events
- $E_\gamma > 2$ GeV
- $\theta_{\gamma\gamma} < 40^\circ$
- $E_{Total} > 25$ GeV

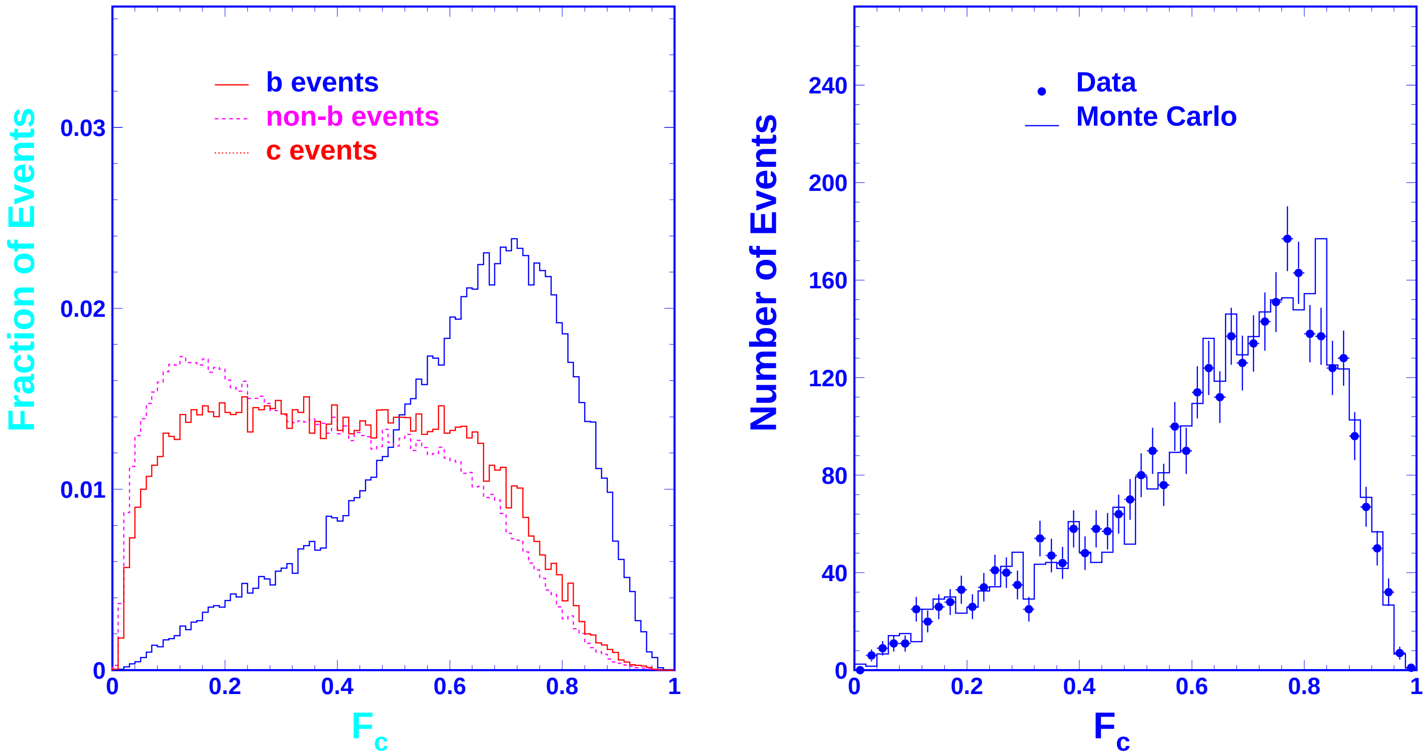


- To identify $b\bar{b}$ events we use Neural Network based on Event Shape Variables.

Search for $B^0 \to \gamma\gamma$

Classifier Response for the MC Test Sample of 200,000 $q\bar{q}$ events

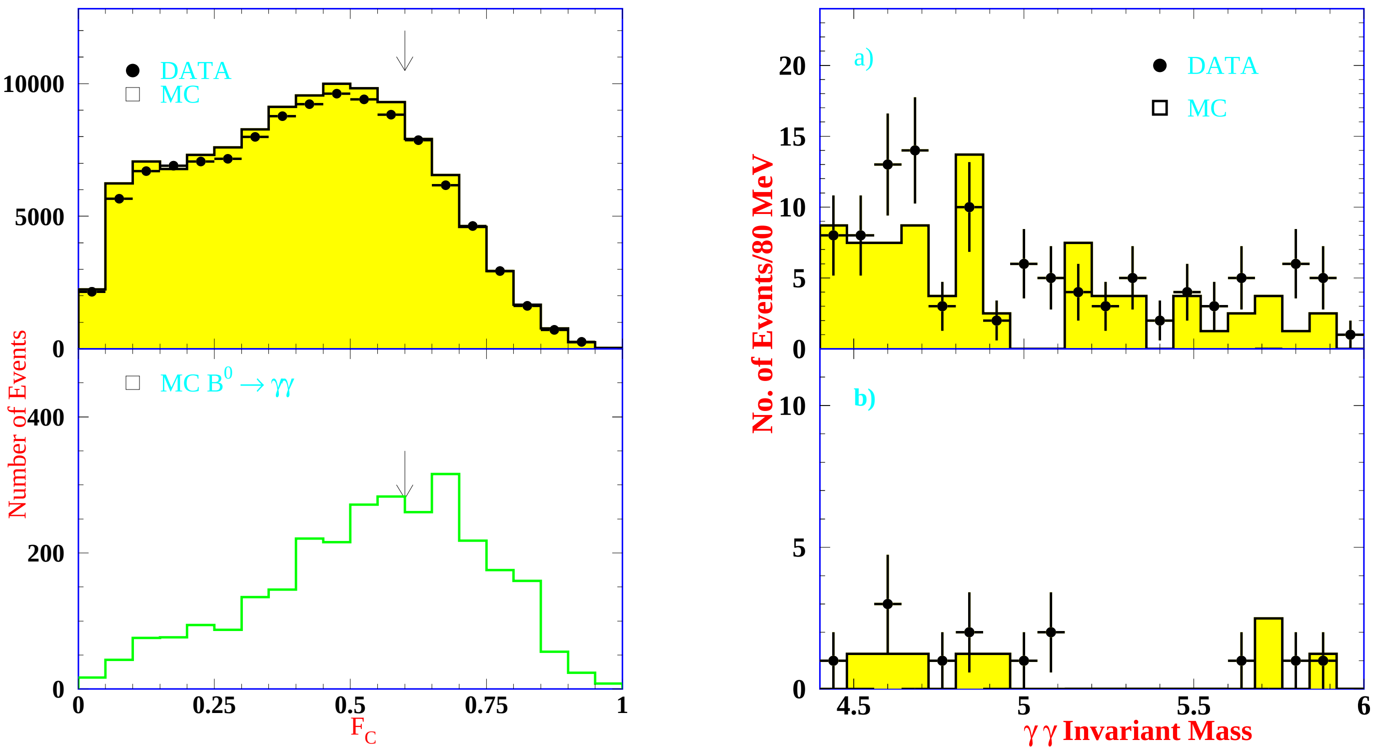
- b events are populated in the region of Large F_c
- Cutting at Large Value of F_c
- $\approx$ 60% Efficiency for $\approx$ 35% Purity



- Use High P_T Muon Tagged sample from MC and DATA ($\approx$ 80% purity of b)
- No information from Muon, except the tag
- MC reproduces DATA well
- Classifier F_c Response for this sample is like all other $b\bar{b}$ events

Search for $B^0 \to \gamma\gamma$

Classifier F_c Response



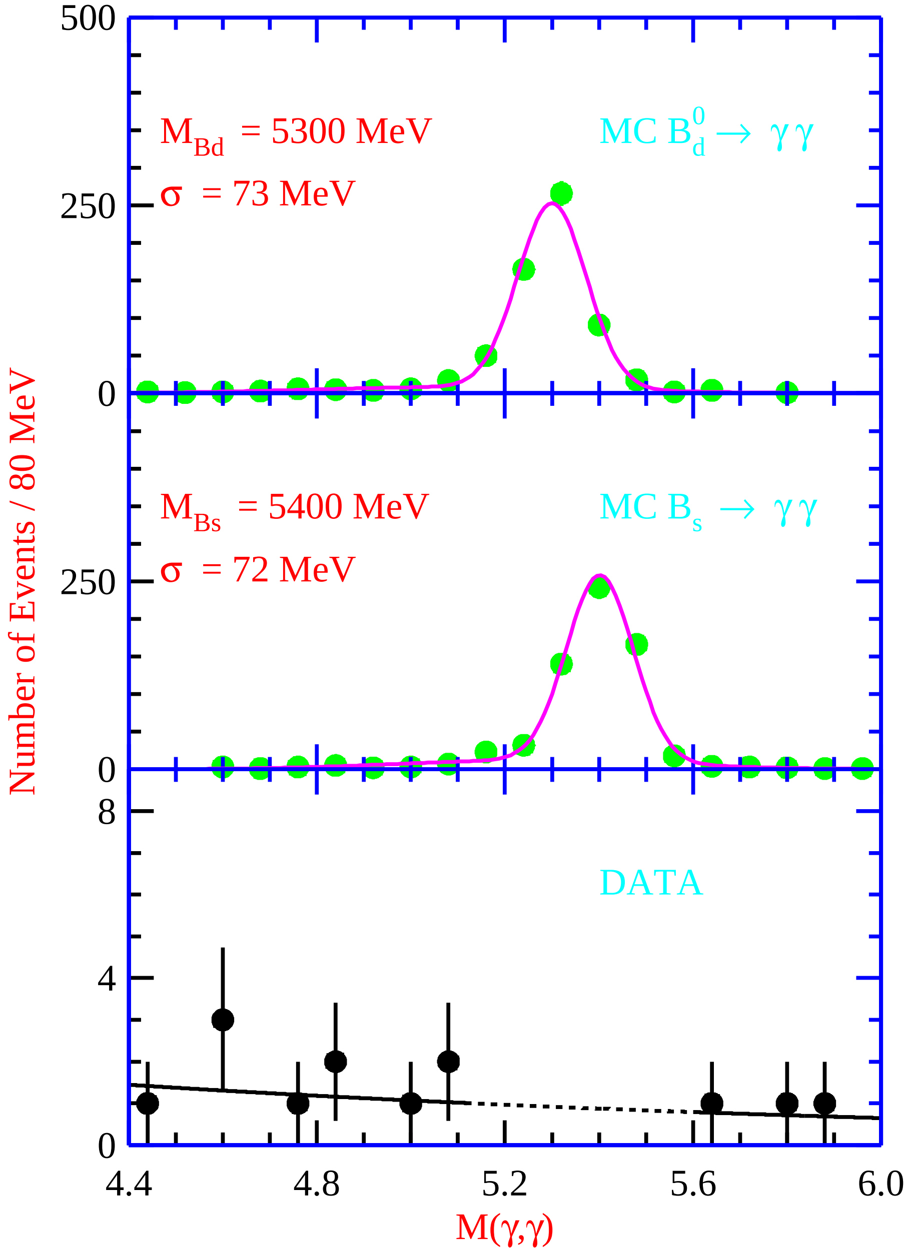
Classifier F_c Response for $B^0 \to \gamma\gamma$ is like all other $b\bar{b}$ events

To Calculate the Upper Limit

$$P(\mu) = \prod_{i=1}^{n} \frac{e^{-\mu_i}\mu_i^{N_i}}{N_i!}$$

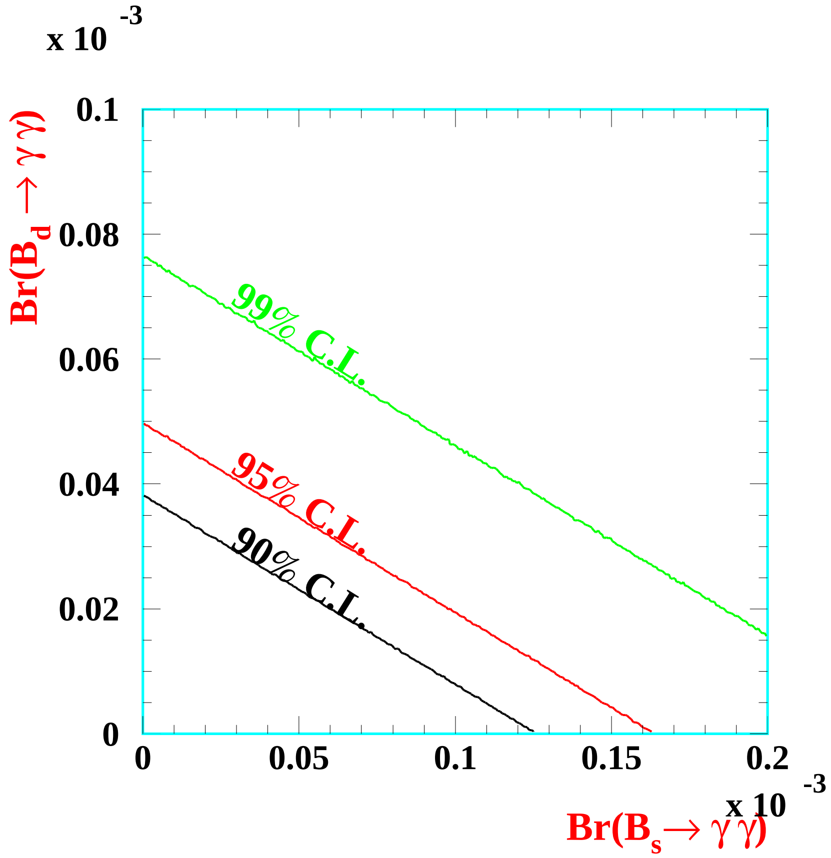
- $\mu = \mu_s + \mu_b$
- N is the Number of Data events / bin
  - $\mu_s(Br) = \mu_{s1}(\mathrm{Br}(B_d^0 \to \gamma\gamma)) + \mu_{s2}(\mathrm{Br}(B_s^0 \to \gamma\gamma))$
  - $\mu_{sj} = \mathrm{Br}(B^0 \to \gamma\gamma) \times N_h \times 2 \times R_{b\bar{b}} \times f_{b\to d,s} \times \epsilon_{B^0\to\gamma\gamma} \times$Gaussian Dist.
- Systematics on the Efficiency and $R_{b\bar{b}}$ has been taken into account

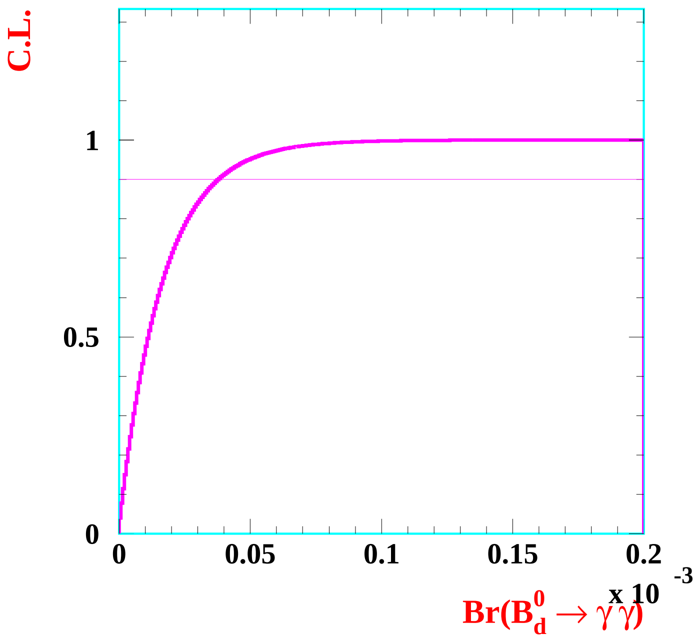
Search for $B^0 \to \gamma\gamma$

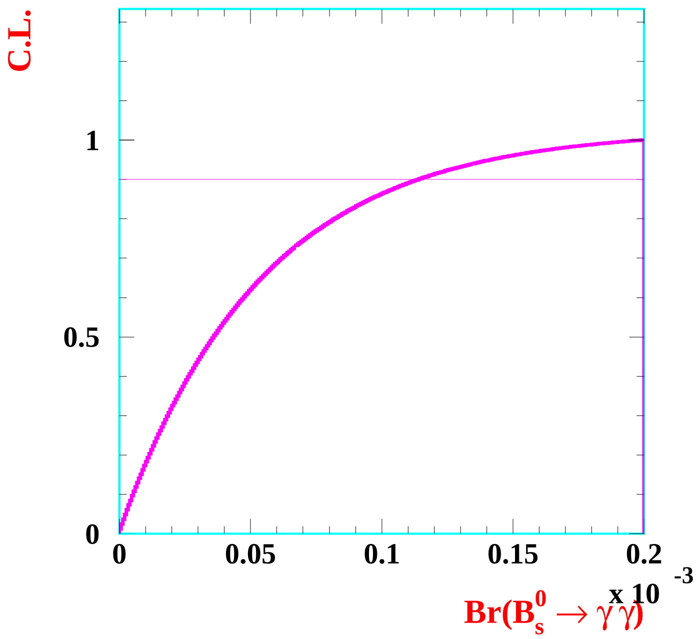


- $\epsilon_{B^0 \to \gamma\gamma} = 11.8 \pm 0.8\%$
- Overlapping region of B_d^0 and B_s^0 are taken into account while calculating the limit

Search for $B^0 \to \gamma\gamma$







$\mathrm{Br}(B_d^0 \to \gamma\gamma) < 3.8 \times 10^{-5}$ 90% C.L.

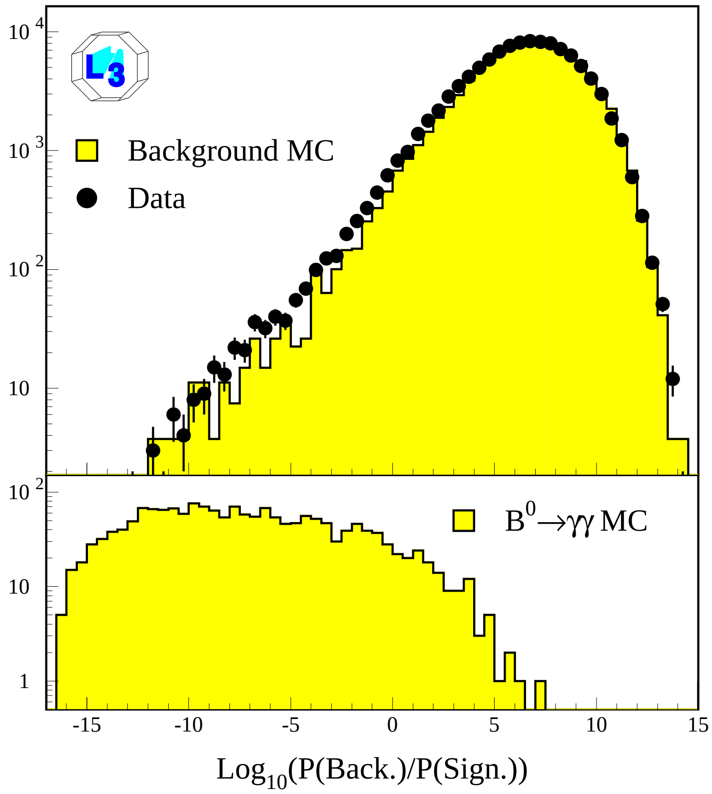
$\mathrm{Br}(B_s^0 \to \gamma\gamma) < 11.4 \times 10^{-5}$ 90% C.L.

Search for $B^0 \to \gamma\gamma$

- Complementary Analysis
- Based on Kinematic Variables
- Build Probablities to be Signal/ Background from the X_i variables

$$P = \prod_{i}^{n} P_i^{\mathrm{Back/Signal}}(X_i)$$

- Random Construction of Signal/Background samples used for Training/Analysis



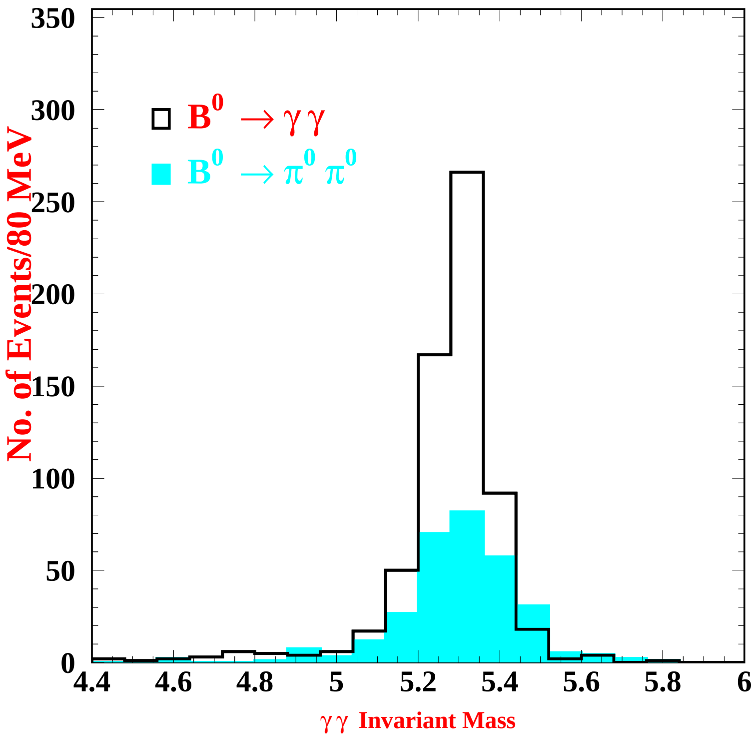
Compatible Results

Search for $B^0 \to \pi^0\pi^0$

Energetic π^0 faking γ

Since Energetic π^0's can fake single γ.

The Possiblity of $B^0 \to \pi^0\pi^0$ faking $B^0 \to \gamma\gamma$ is also considered



$\epsilon_{B^0 \to \pi^0\pi^0} = 5\%$

This is a factor two smaller compared to $B^0 \to \gamma\gamma$

Other fake combinations like

$B^0 \to \eta\eta$

$B^0 \to \pi^0\eta$

These are found to be Negligible

$$\boxed{Br(B^0 \to \pi^0\pi^0) < 8.7 \times 10^{-5} \quad 90\%\ C.L.}$$

Results

We have searched following for Rare B decays

- $\mathrm{Br}(\mathrm{B} \rightarrow \mathrm{X_s} + \gamma) < 8.4 \times 10^{-4}$ 90% C.L.
- $\mathrm{Br}(\mathrm{B}^0 \rightarrow \eta\eta) < 2.7 \times 10^{-3}$ 90% C.L.
- $\mathrm{Br}(\mathrm{B}^0 \rightarrow \pi^0\eta) < 1.1 \times 10^{-3}$ 90% C.L.
- $\mathrm{Br}(\mathrm{B}^0 \rightarrow \pi^0\pi^0) < 8.7 \times 10^{-5}$ 90% C.L.
- $\mathrm{Br}(\mathrm{B}^0_\mathrm{d} \rightarrow \gamma\gamma) < 3.8 \times 10^{-5}$ 90% C.L.
- $\mathrm{Br}(\mathrm{B}^0_\mathrm{s} \rightarrow \gamma\gamma) < 11.4 \times 10^{-5}$ 90% C.L.

Conclusions

- Large data sample will allow us to get better results on Rare B decays

- Measurements on the Hadronic Decays provides information on the relative importance of the Penguins and Spectator Amplitudes.

- $B^0 \rightarrow \gamma\gamma$, Provide constraints on the Standard Model parameters $|V_{ts}|$ and $|V_{td}|$.

$$\frac{Br(B_d^0 \rightarrow \gamma\gamma)}{Br(B_s^0 \rightarrow \gamma\gamma)} \approx \frac{|V_{td}|^2}{|V_{ts}|^2} \frac{f(B_d)^2}{f(B_s)^2}$$

- Complementary to Mixing Method

$$\frac{\Delta m_s}{\Delta m_d} \approx \frac{|V_{ts}|^2}{|V_{td}|^2}$$

- Look for NEW PHYSICS beyond Standard Model.

$\boxed{\text{Virtual Reality is Virtually Real}}$