# Search for the Bs Meson in the Y(5S) Data via Exclusive Reconstruction

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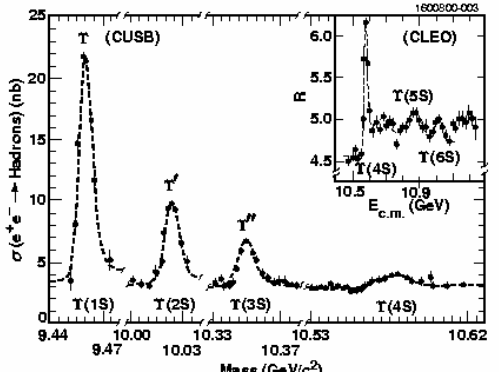
# Overview of the method

- *Y(5S)* can decay into a number of channels with ordinary *B* and *Bs* mesons:

$$B_d\overline{B_d},\quad B_d\overline{B_d^*},\quad B_d^*\overline{B_d^*},\quad B_s\overline{B_s},\quad B_s\overline{B_s^*},\quad B_s^*\overline{B_s^*},$$

$$B_d\overline{B_d}\pi,\ B^0B^+\pi,\quad B_d\overline{B_d^*}\pi,\ B_d\overline{B_d}\pi\pi$$



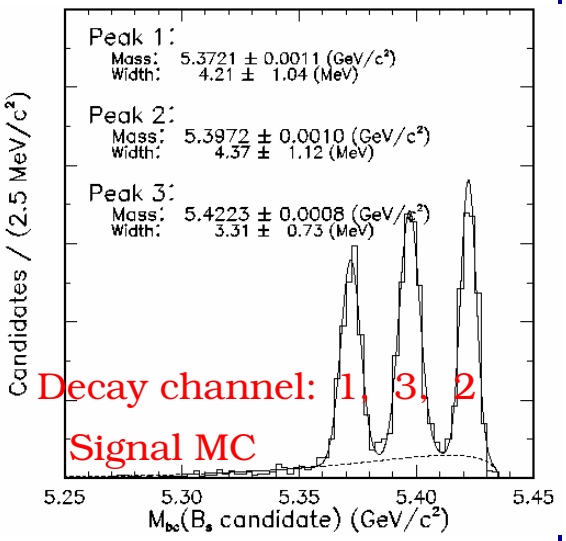

$$M_{Y(5S)} = (10.865 \pm 0.008)\ GeV/c^2$$

$$M_{Bs} = (5.370 \pm 0.002)\ GeV/c^2$$

$$M_{Bs^*} - M_{Bs} = (47.0 \pm 2.6)\ MeV/c^2$$

- The *B* reconstruction techniques used at *Y(4S)* are employed to reconstruct *Bs* from *Y(5S):*
  - ✓ $M_{bc} = \sqrt{E_{beam}^2 - P_{candidate}^2}$
  - ✓ $\Delta E = E_{beam} - E_{candidate}$ (Note the sign of ΔE)
  - ✓ The continuum ($e^+e^- \to q\bar{q}$) background suppression variables

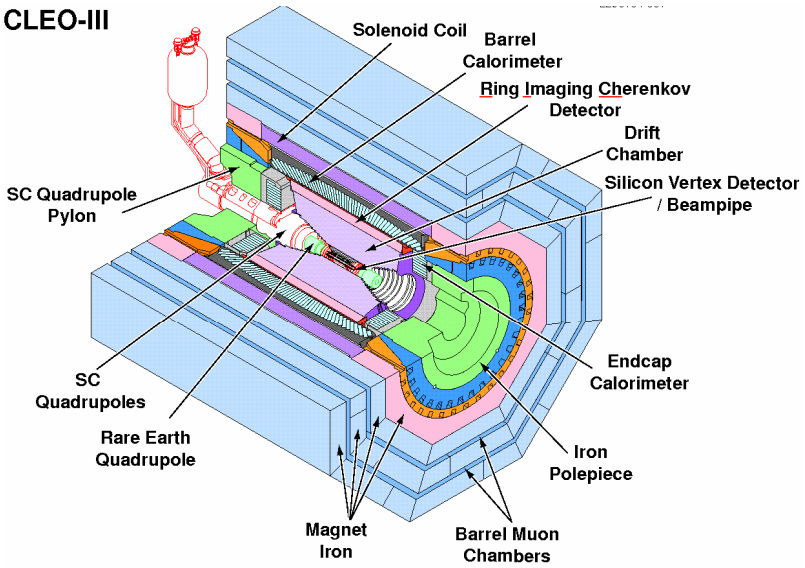
- Three decay channels of *Y(5S)* to *Bs* mesons are possible producing three peaks in *Mbc* :
  - ✓ Decay channel 1: $Y(5S) \to B_s\overline{B_s}$: $E_{B_s} = E_{beam}$
  - ✓ Decay channel 2: $Y(5S) \to B_s^*\overline{B_s^*}$: $E_{B_s^*} = E_{beam}$
  - ✓ Decay channel 3: $Y(5S) \to B_s B_s^*$ : $E_{B_s^*} > E_{beam}, E_{B_s} < E_{beam}$



# The CLEO detector and the data sample

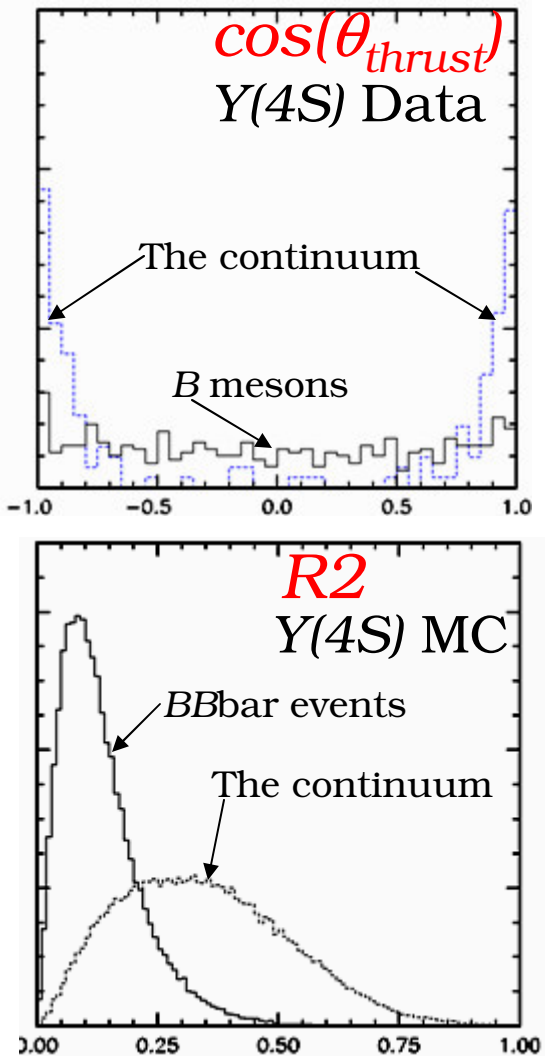
- Data sample of 0.46/fb collected with the CLEO III detector in February of 2003 is used in the search

- The *Y(5S)* cross section is ~0.35 nb sitting on ~3.0 nb of the continuum ($e^+e^- \to qq\text{bar}$):
  - ✓ Expect ~100*K* of *Bs* in 0.46/fb if $\sigma(e^+e^- \to Bs(*)Bs(*)) \sim 0.1$ nb
  - ✓ The amount of the continuum backgrond is larger compared to *Y(4S)*:
    - at *Y(4S)*: $\dfrac{\sigma(B\overline{B})}{\sigma(e^+e^- \to q\overline{q})} \sim 0.3$
    - at *Y(5S)*: $\dfrac{\sigma(B_s^{(*)}\overline{B_s^{(*)}})}{\sigma(e^+e^- \to q\overline{q})} \sim 0.03$



# Important variables for background suppression

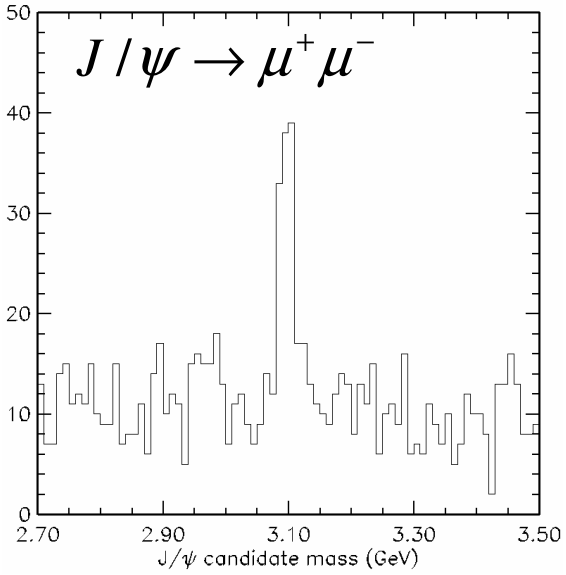
- $cos(\theta_{thrust})$ and $R2$:
  - ✓ $\theta_{thrust}$ is the angle between the thrust axis of the $Bs$ candidate and the thrust axis of the rest of the event
  - ✓ $R2 \equiv H_2/H_0$ – ratio of Fox-Wolfram moments of the event
- Cuts on lower shower energies used in the reconstruction of $\pi^0$, $\eta$ have a large impact on
  - ✓ the reconstruction efficiency
  - ✓ the level of background
- Mass window cuts for wide particles such as $\rho$, $K^*$.

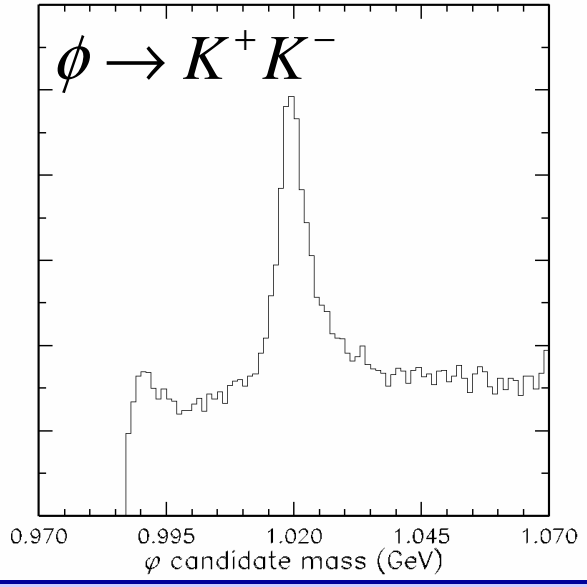


# APPROACH 1

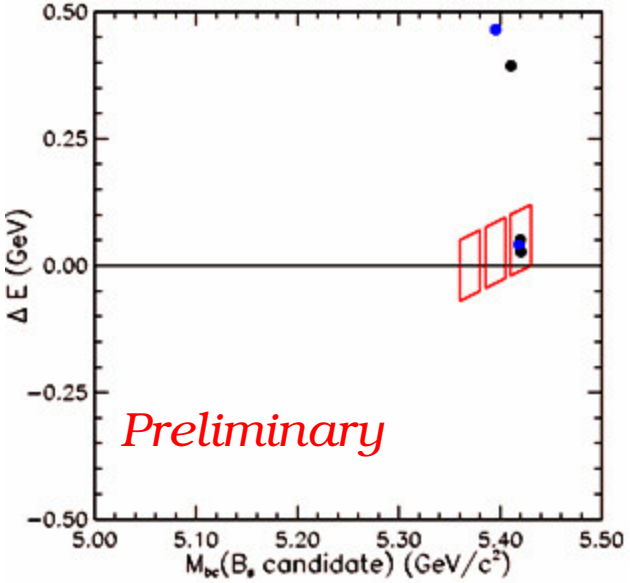
# "Gold plated" modes

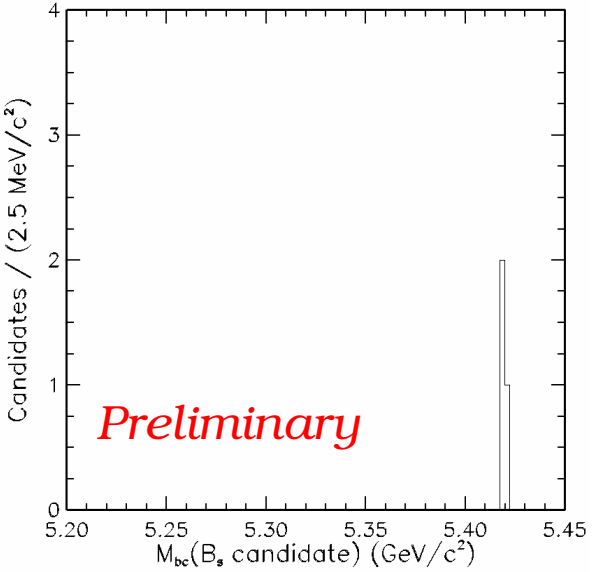
- Search for very clean modes having extremely high S/B ratio (unfortunately with small branching fractions).
- The best candidate mode is $Bs \to J/\psi\,\varphi$, analogous to $B^0 \to J/\psi\,K_s$. The search is made for $Bs \to J/\psi\,\eta$ and $Bs \to J/\psi\,\eta'$ as well.
- $J/\psi$ is reconstructed in $\mu\mu$ and $ee$ channels, the following clean channels are used for other particles: $\varphi \to KK$, $\eta \to \gamma\gamma$, $\eta' \to \eta\pi^+\pi^-$.
- Expect to find only a few signal counts, assuming branching fractions similar to those for ordinary $B$.



# Distributions in the data for channels with $J/\psi \to \mu^+\mu^-$



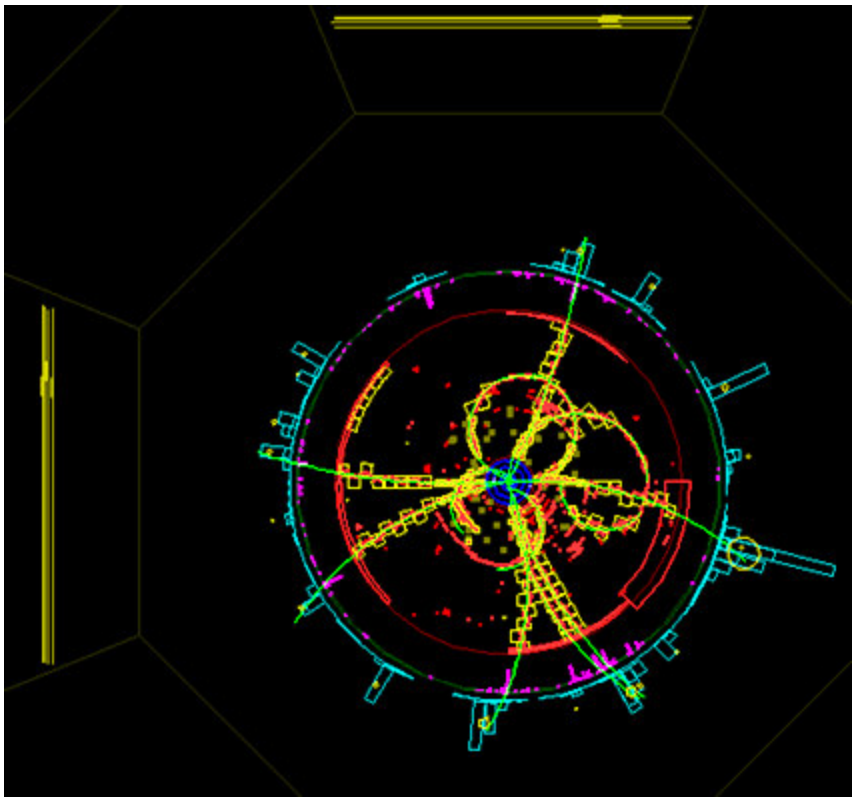



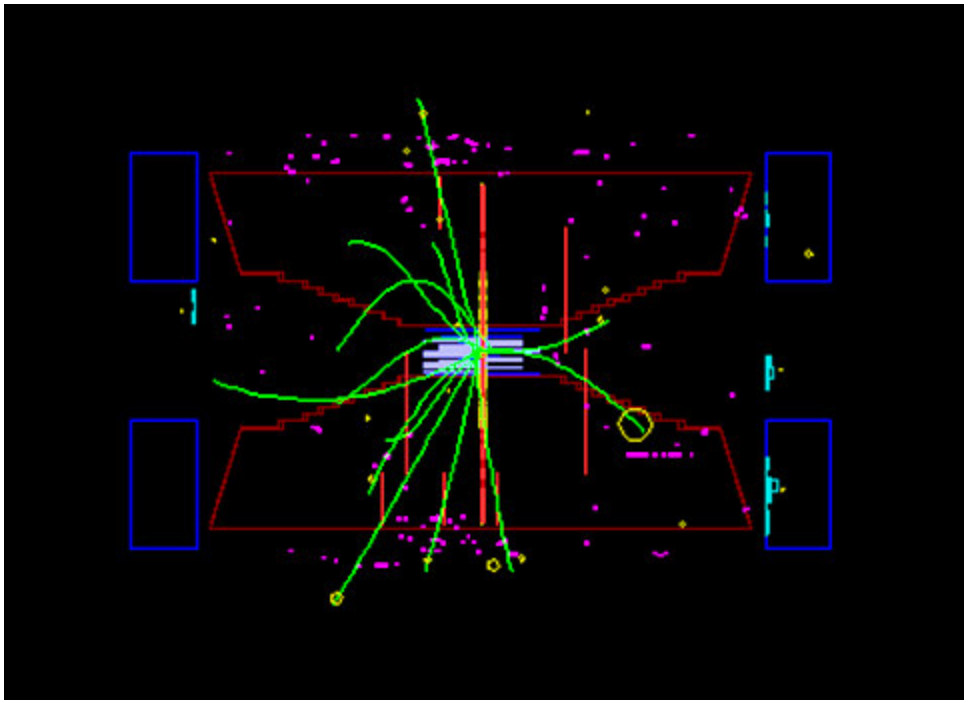

3 counts in the signal box for *Y(5S)* → *Bs* Bs*bar*:
2 counts in $Bs \to J/\psi\varphi$ (in black),
1 count in $Bs \to J/\psi\eta'$ (in blue).

This is a compelling evidence for the presence of *Bs* in the *Y(5S)* data as the background level is VERY small.

Expect ~ 2 - 3 MeV statistical uncertainty on the $Bs^*$ - *Bs* mass difference from these three events. The beam energy scale is being studied for this measurement. More events would be very helpful.

# One of the signal events





$$Y(5S) \to B_s^* \overline{B_s^*}, with$$

$$B_s \to J/\psi\phi, J/\psi \to \mu^+\mu^-, \phi \to K^+K^-$$

# Distributions in the data for channels with $J/\psi \to e^+e^-$

- All plots are empty. No signal candidates are observed.
- Studies are ongoing.

# APPROACH 2

# Modes used in reconstruction

- Modes for *Bs*:

**BRs are from the corresponding BRs for $B^0$**

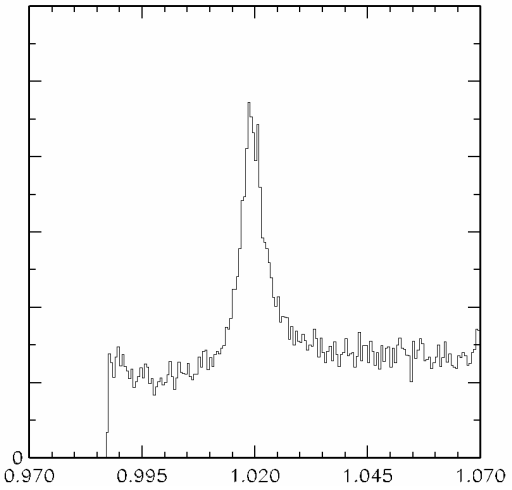
| Decay Mode | $\mathcal{B} \times 10^{-3}$ |
|---|---|
| $\bar{B}_s \to D_s\pi^-$ | $(3.0 \pm 0.4)$ |
| $\bar{B}_s \to D_s\rho^-$ | $(7.8 \pm 1.4)$ |
| $\bar{B}_s \to D_s a_1^-$ | $(6.0 \pm 3.3)$ |
| $\bar{B}_s \to D_s^*\pi^-$ | $(2.8 \pm 0.2)$ |
| $\bar{B}_s \to D_s^*\rho^-$ | $(7.3 \pm 1.5)$ |
| $\bar{B}_s \to D_s^* a_1^-$ | $(10.3 \pm 2.7)$ |

- Modes for *Ds(*)*:

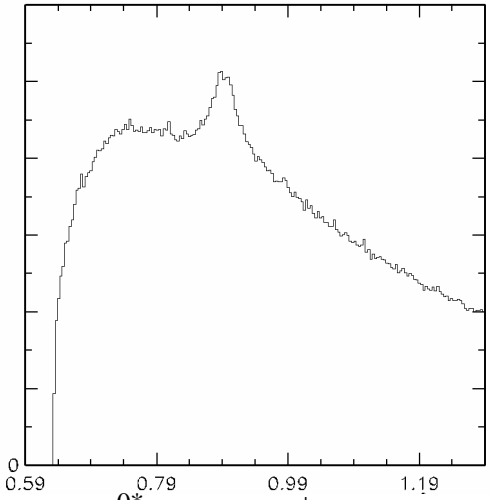
| Decay Mode | $\mathcal{B}$ (%) |
|---|---|
| $D_s \to K^+\bar{K}^0$ | $(3.6 \pm 1.1)$ |
| $D_s \to K^+K^{*0}(892)$ | $(3.3 \pm 0.9)$ |
| $D_s \to \phi\pi^+$ | $(3.9 \pm 0.9)$ |
| $D_s \to \phi\rho^+$ | $(6.7 \pm 2.3)$ |
| $D_s \to \eta\pi^+$ | $(1.7 \pm 0.5)$ |
| $D_s \to \eta\rho^+$ | $(10.8 \pm 3.1)$ |
| $D_s \to \eta'\pi^+$ | $(3.9 \pm 1.0)$ |
| $D_s \to \eta'\rho^+$ | $(10.1 \pm 2.8)$ |
| $D_s^* \to D_s\gamma$ | $(94.2 \pm 2.5)$ |

- Optimistic estimates of the number of *Bs* mesons that can be reconstructed in two body decays of *Bs* → *Ds(*)* $\pi/\rho$ (assuming the branching fraction from the corresponding decays of $B^0$) give around 50 events. Given large background levels, the background suppression criteria reduce the yield.

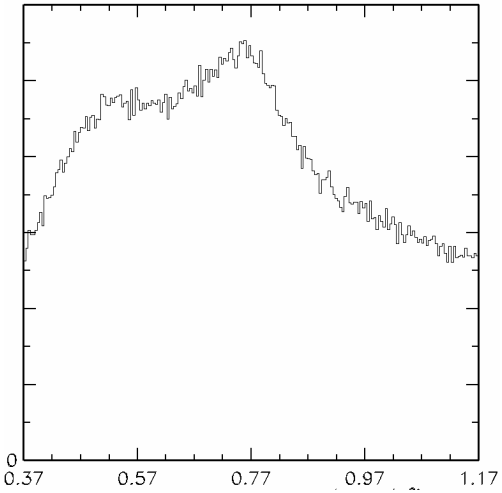
# Representative plots in the $D_s$ reconstruction



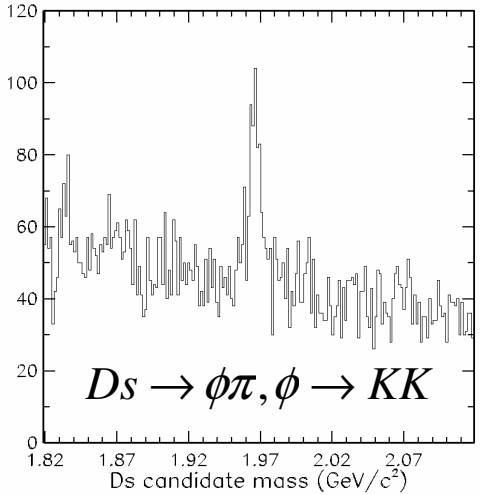

$M(\phi \to K^+K^-)\ (GeV/c^2)$

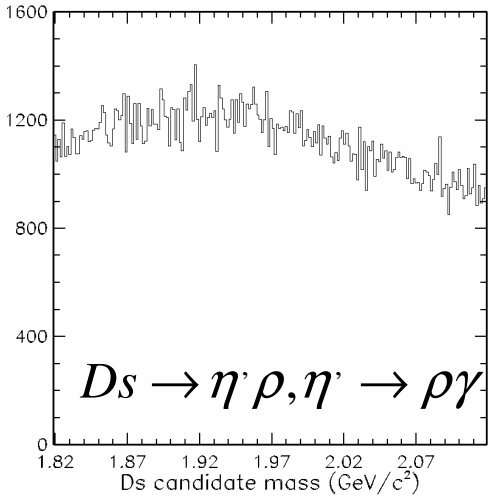



$M(K^{0*} \to K^-\pi^+)\ (GeV/c^2)$



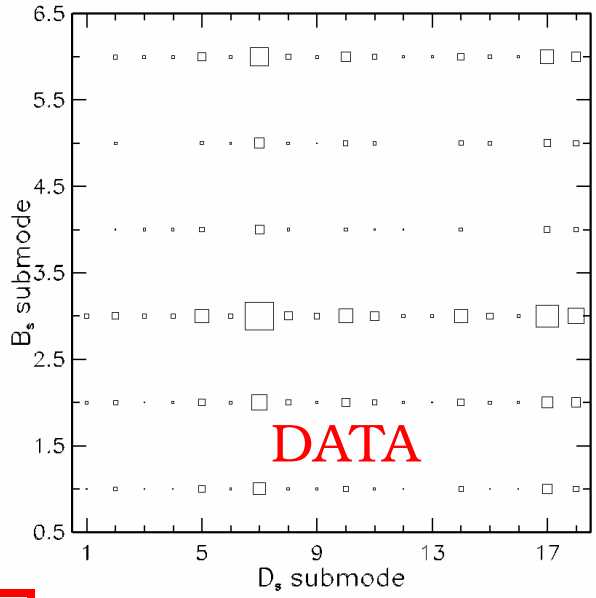

$M(\rho^+ \to \pi^+\pi^0)\ (GeV/c^2)$



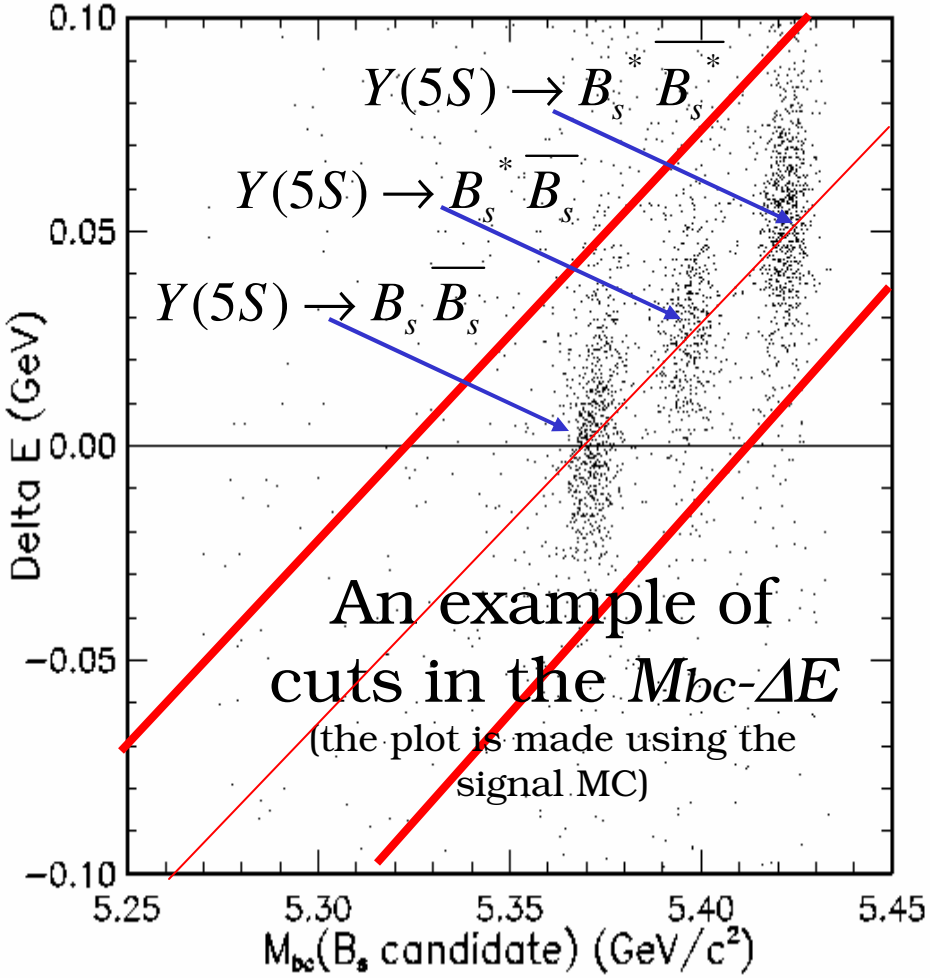
# Optimization

- Optimization of the analysis is sought in the space of
  - ✓ *Ds* and *Bs* modes
  - ✓ background suppression variables
- The plot on the right show background levels for each decay sequence we are considering:
  - ✓ 17 decay sequences of *Ds* (the X axis)
  - ✓ 6 decay sequences of *Bs* to final states with *Ds* (the Y axis)
  - ✓ Total number of distinct decay sequences is 102
  - ✓ Relative background levels and S/B ratio can be two orders of magnitude different for different decay sequences
- Criteria on the background suppression variables are varied in the reconstruction depending on the $S^2/(S+B)$ ratio.

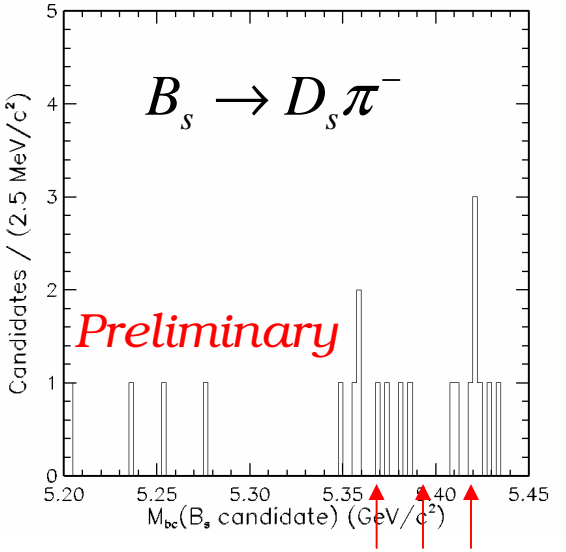


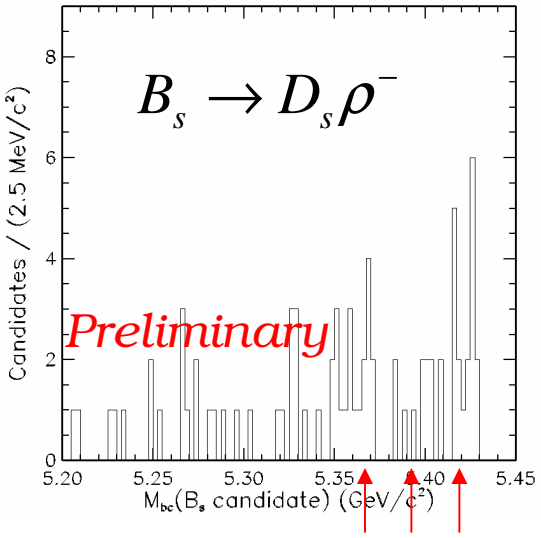
# The signal band in the *Mbc-ΔE* plane for *Bs* candidates

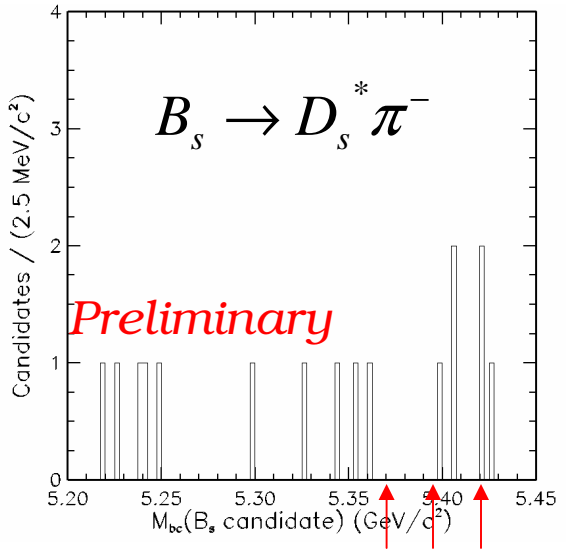
- Candidates within a diagonal band in the *Mbc-ΔE* plane are accepted.
- If there are two or more candidates, choose the one closest to the center of the band in *ΔE* .
- The above is done first for *Ds* modes with larger S/B ratios and after that for other noisier modes

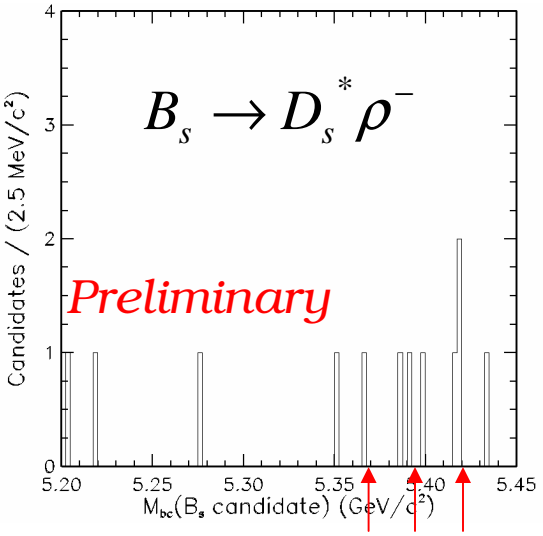


# $M_{bc}(Bs)$ in the data for submodes



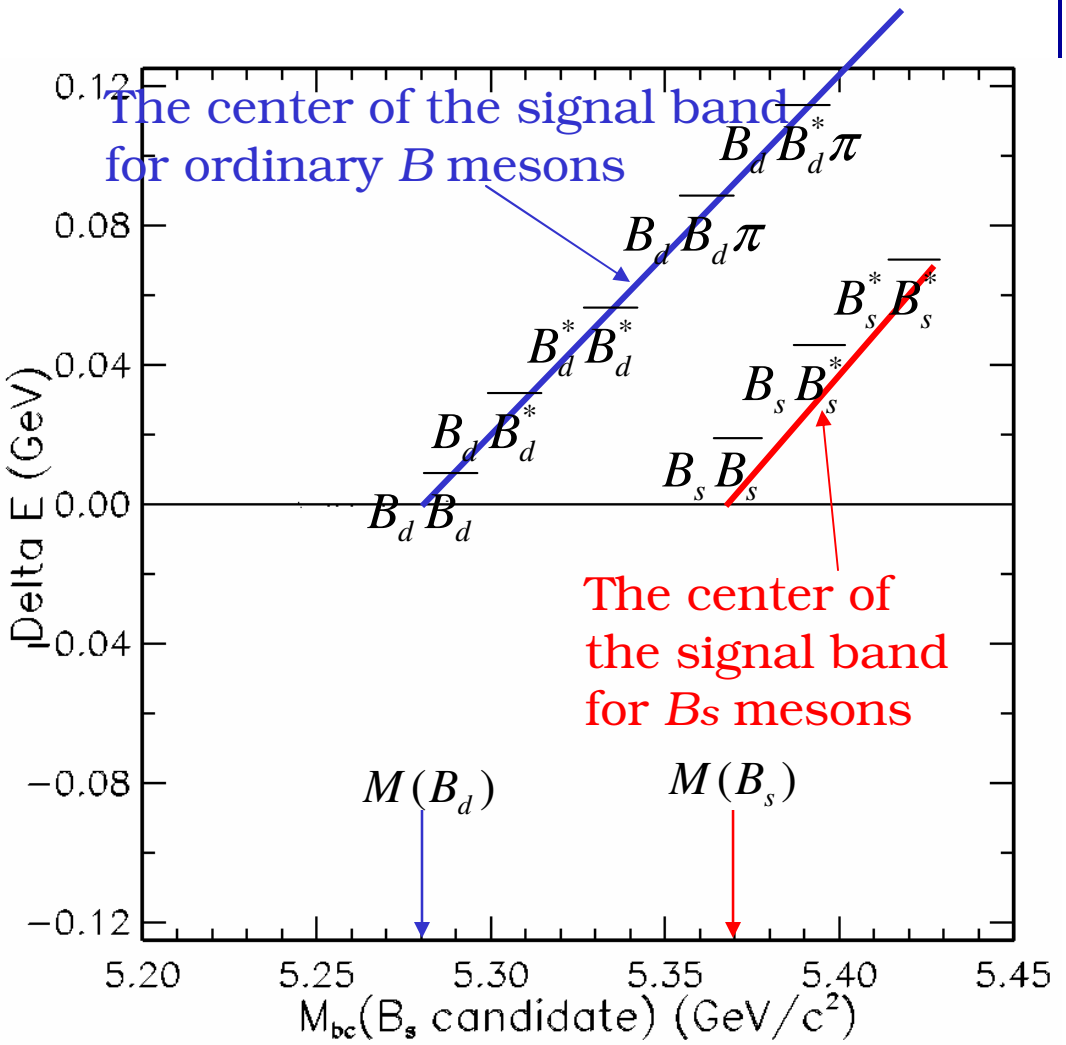
# A few words about backgrounds

- *Y(5S)* cay decay into a variety of states with ordinary *B* mesons

$$B_d\overline{B}_d,\quad B_d\overline{B}_d^*,\ B_d\overline{B}_d\pi,$$
$$B_d\overline{B}_d^*\pi, B_d^*\overline{B}_d^*\pi, B_d\overline{B}_d\pi\pi$$

- These decays are a source of background in the search as shown in the plot

- The continuum ($e^+e^- \to q\bar{q}$) background is being studied using the OFF/ON *Y(4S)* data and the data collected above the *Y(5S)* resonance.



# Summary and Outlook

- We have presented two approaches in our search for the $B_s$ meson in the CLEO $\Upsilon(5S)$ data
- Both approaches are promising and will be pursued further:
  - ✓ Approach 1:
    - Other (clean) modes with charmonium will be considered
    - An estimate of background level for the observed events is being made in order to calculate the signal significance
    - A measurement of the mass difference of $B_s^*$ and $B_s$ will be made
  - ✓ Approach 2:
    - Further optimization will be sought
    - The background studies will be continued
    - Exclusive reconstruction of $\Upsilon(5S) \rightarrow BBX$ will be attempted
- The search already provides very strong direct evidence for the presence of the $B_s$ meson in the $\Upsilon(5S)$ data.

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# Distributions for $B_u$'s and $B_d$'s

- Ordinary $B$ mesons have large boosts in the lab frame. This complicates their "clean" reconstruction. Typical $M_{bc}$ distributions for the decay modes of $\Upsilon(5S)$ without pions (the upper cut on $\Delta E$ is at 100MeV) in the final state we obtain are shown in the these plots: