Evidence for the Bs Meson at the Y(5S) Resonance

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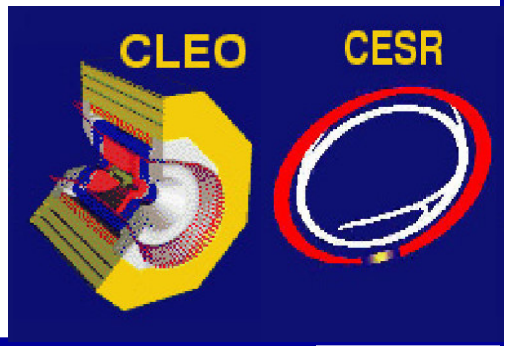
- Introduction
- The CLEO detector and Y(5S) data sample
- Analysis techniques:
  - ✓ Exclusive approach
  - ✓ Inclusive approach
- Summary



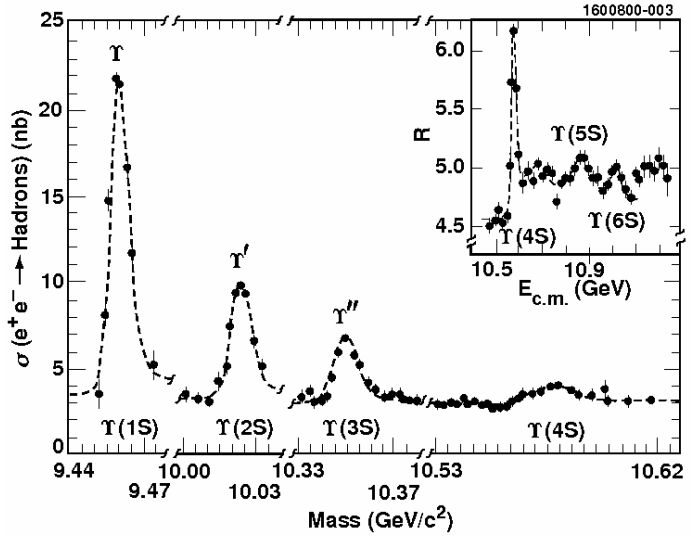
Introduction (1)

- The *Y(5S)* resonance was discovered by CLEO and CUSB collaborations operating at CESR in 1985.
- The *Y(5S)* resonance is massive enough to decay into the following channels:

$$B\bar{B},\ B\bar{B}^*,\ B^*\bar{B}^*,\ B\bar{B}\pi,\ B\bar{B}^*\pi, B^*\bar{B}^*\pi, B\bar{B}\pi\pi,$$

$$B_s\bar{B}_s,\ B_s\bar{B}_s^*,\ B_s^*\bar{B}_s^*$$

- *No* conclusive evidence for Bs production at the *Y(5S)* was found in 116/pb of data collected in 1985.
- Knowledge of Bs production at the *Y(5S)* is essential for assessing the potential of *Bs* physics at a high luminosity electron-positron collider.
- The three channels with *Bs* mesons are in the focus of two current CLEO studies.



$PDG-2004:$

$M_{Y(5S)} = (10.865 \pm 0.008)\ GeV$

$\Gamma = (110 \pm 13)\ MeV$

$M_{Bs} = (5.370 \pm 0.002)\ GeV$

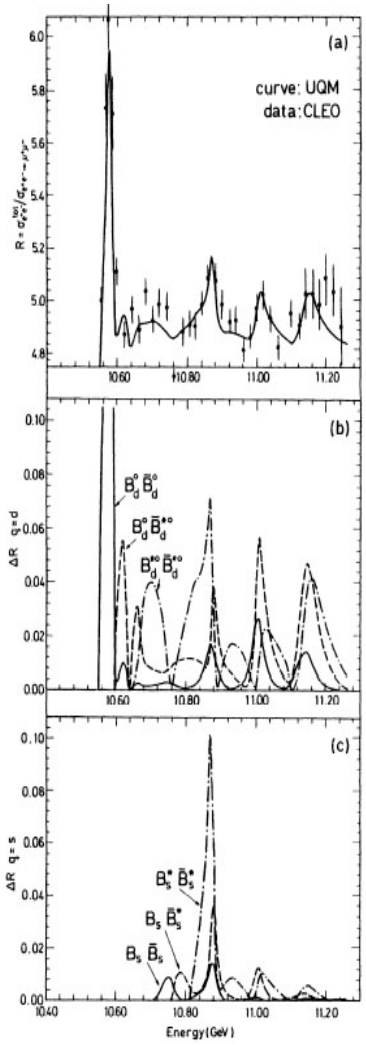
$M_{Bs^*} - M_{Bs} = (47.0 \pm 2.6)\ MeV$

$CDF-2004:$

$M_{Bs} = (5.3660 \pm 0.0008(stat+sys))\ GeV$

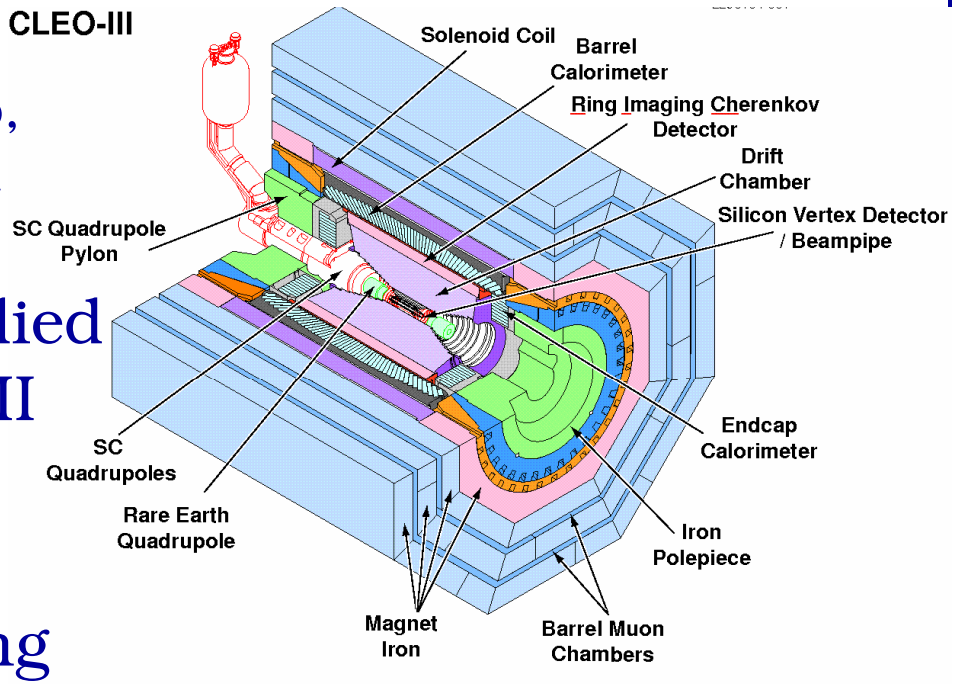
Introduction (2)

- Two papers exist that describe the hadronic cross section above the *Y(4S)* resonance:
  - ✓ CLEO: PRL **54,** 381 (1985)
  - ✓ CUSB: PRL **54**, 377 (1985)
- The cross section above the *Y(4S)* resonance is described reasonably well by Unitarized Quark Model (S.Ono et.al., Phys.Rev.D **34**, 186 (1986)). The model predicts:
  - ✓ $Y(5S) \rightarrow B^* B^*$ or $Bs^* Bs^*$,
  - ✓ The total Bs cross section of *Y(5S)* ~ 1/3.
  - ✓ $\sigma(e^+ e^- \rightarrow Y(5S))$ ~ 0.35 nb (compare this to the b-quark cross section in pp collisions)



The Data Sample and CLEOIII detector

- The *Y(5S)* Data sample: 0.42/fb collected with the CLEO III detector in 2003:
  - ✓ if $\sigma(e^+e^- \to Bs(*)Bs(*))$ ~ 0.1 nb, expect ~ 90*K* of *Bs* mesons in 0.42/fb
- The *BB* background is studied using the ON *Y(4S)* CLEO III data
- The continuum ($e^+ e^- \to qq$) background is studied using the OFF *Y(4S)* CLEO III data, taken 30 MeV below the *Y(4S)*



Experimental techniques

- Inclusive approach
  - ✓ Soft photon spectrum (from $B_{(s)}^{*}$)
  - ✓ Lepton spectra (dependent on $B_{(s)}$ masses)
  - ✓ Yields of particle with one or two s-quark
- Exclusive approach
  - ✓ $B_s \to J/\psi\, h \quad and \quad B_s \to D_s^{(*)}\pi^- / \rho^-$
  - ✓ $B_s \to D_s^{(*)} l^- \nu$
- This is work in progress. The ICHEP results will be shown.

EXCLUSIVE APPROACH

Overview of exclusive method

- The *B* reconstruction techniques used at the *Y(4S)* are employed to reconstruct the *Bs* meson at the *Y(5S)*:
  - ✓ $M_{bc} = \sqrt{E_{beam}^2 - P_{candidate}^2}$
  - ✓ $\Delta E = E_{beam} - E_{candidate}$ (Note the sign of ΔE)
  - ✓ The continuum ($e^+e^- \to qq\text{bar}$) background suppression variables
- Three decay channels of *Y(5S)* to *Bs* mesons are possible producing three peaks in *Mbc* :
  - ✓ Decay channel 1: $Y(5S) \to B_s \overline{B_s}: \quad E_{B_s} = E_{beam}$
  - ✓ Decay channel 2: $Y(5S) \to B_s^* \overline{B_s^*}: \quad E_{B_s^*} = E_{beam}$
  - ✓ Decay channel 3: $Y(5S) \to B_s B_s^*: E_{B_s^*} > E_{beam}, E_{B_s} < E_{beam}$

PDG–2004:

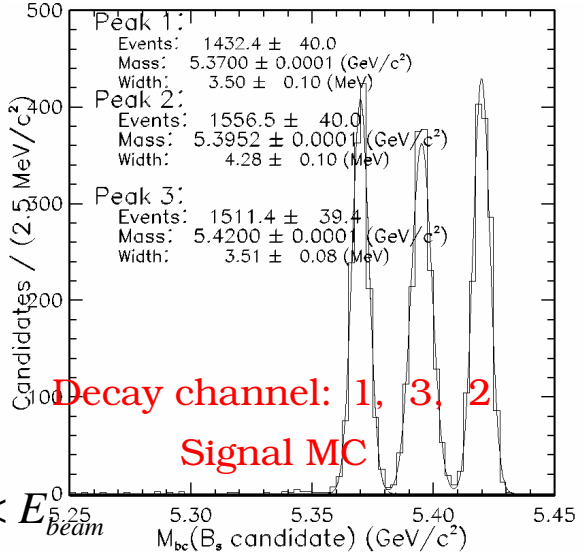
$M_{Bs} = (5.370 \pm 0.002)\, GeV$

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

Assumption $B(B_s^* \to B_s \gamma) = 100\%$

CDF–2004:

$M_{Bs} = (5.3660 \pm 0.0008\,(stat+sys))\, GeV$



Analysis backgrounds

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

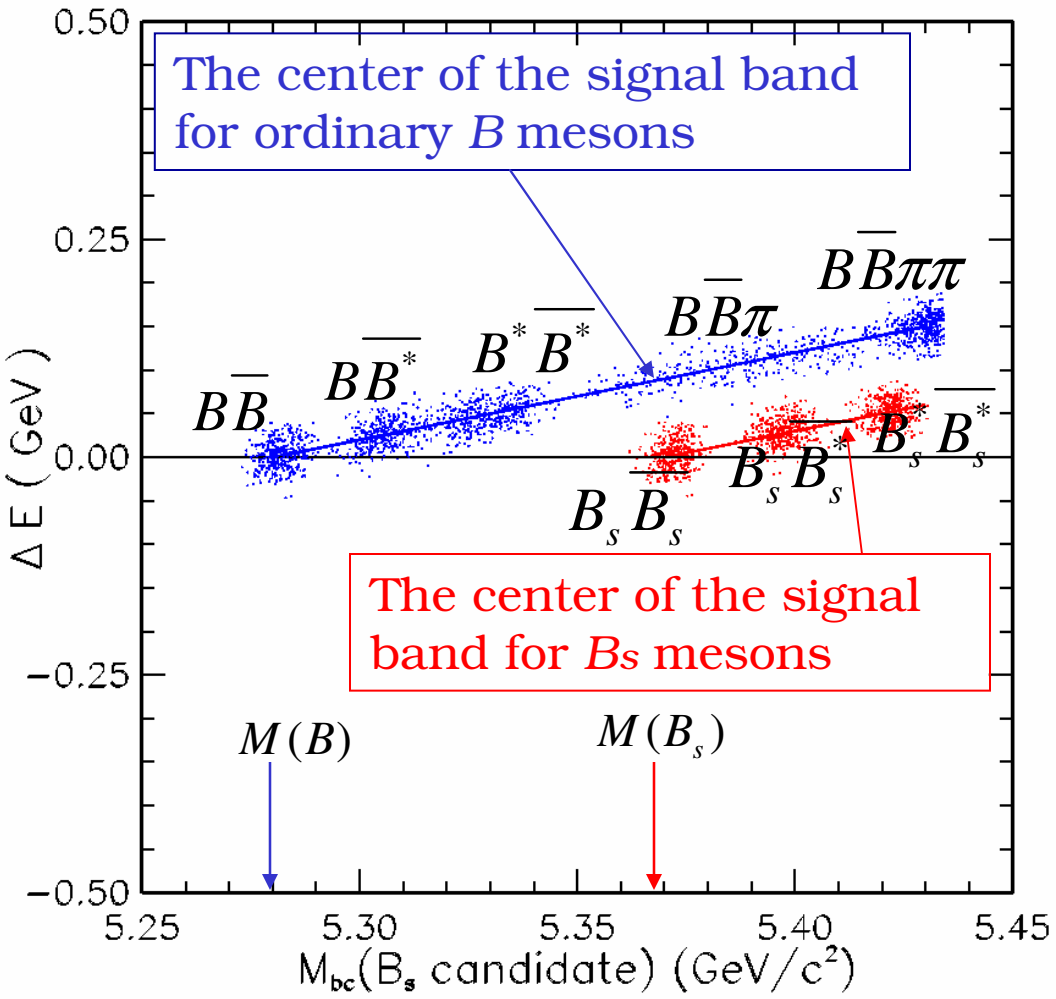
$$B\bar{B},\quad B\bar{B}^{*},\ B\bar{B}\pi,$$

$$B\bar{B}^{*}\pi, B^{*}\bar{B}^{*}\pi, B\bar{B}\pi\pi$$

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

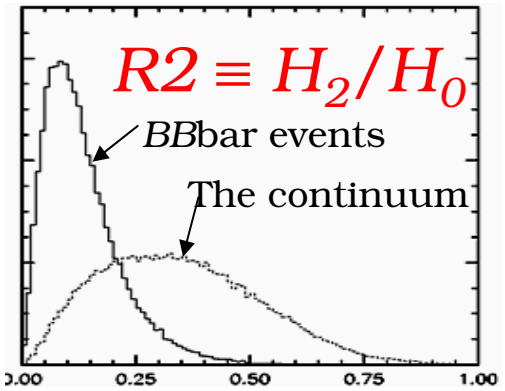
- The continuum ($e^{+}e^{-} \to q\bar{q}$bar) background is large:
  - ✓ $\dfrac{\sigma(B\bar{B})}{\sigma(e^{+}e^{-} \to q\bar{q})} \sim 0.3$
  - ✓ $\dfrac{\sigma(B_s^{(*)}\bar{B}_s^{(*)})}{\sigma(e^{+}e^{-} \to q\bar{q})} \sim 0.03$

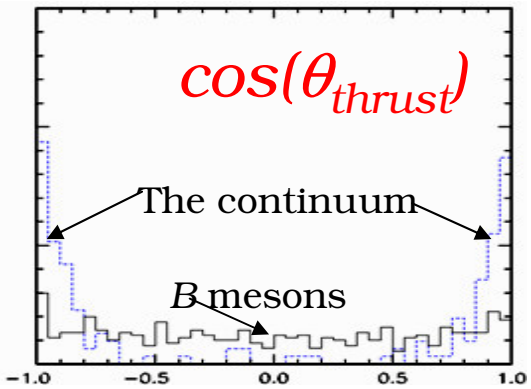
- *Bs* decay modes are poorly known.

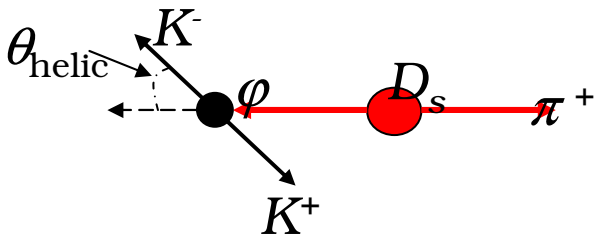


Important selection criteria

- $R2$ and $\cos(\theta_{thrust})$:
  - ✓ $R2 \equiv H_2/H_0$ – ratio of Fox-Wolfram moments of the event
  - ✓ θ_{thrust} is the angle between the thrust axis of the B_s candidate and the thrust axis of the rest of the event
- Mass window cuts for wide particles such as ρ, K^*.
- $\cos(\theta_{helicity})$ for the P → V(pp)P modes in the D_s reconstruction

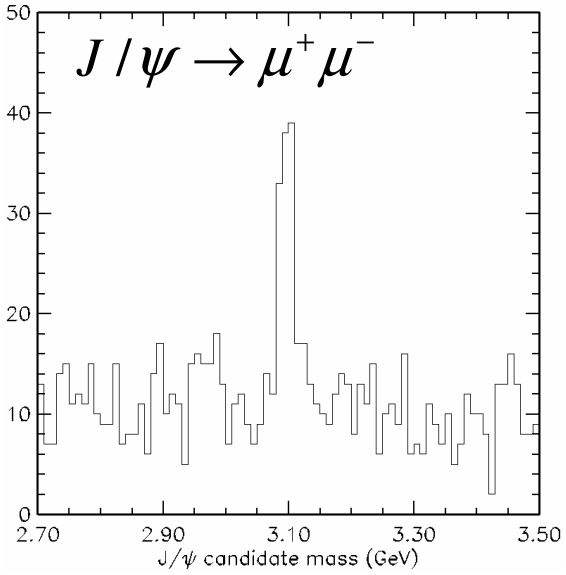


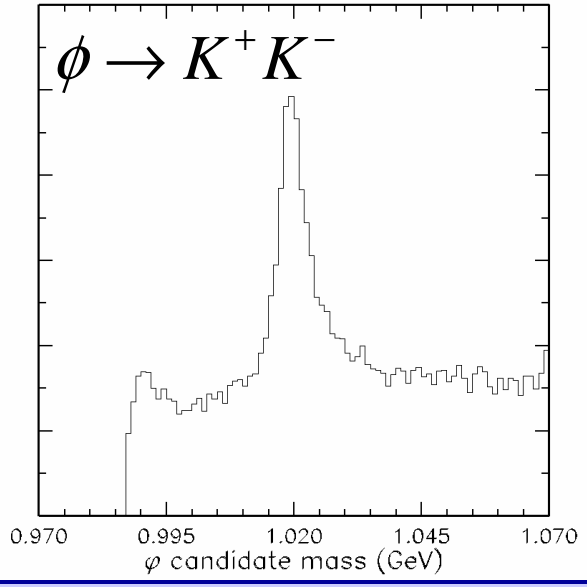




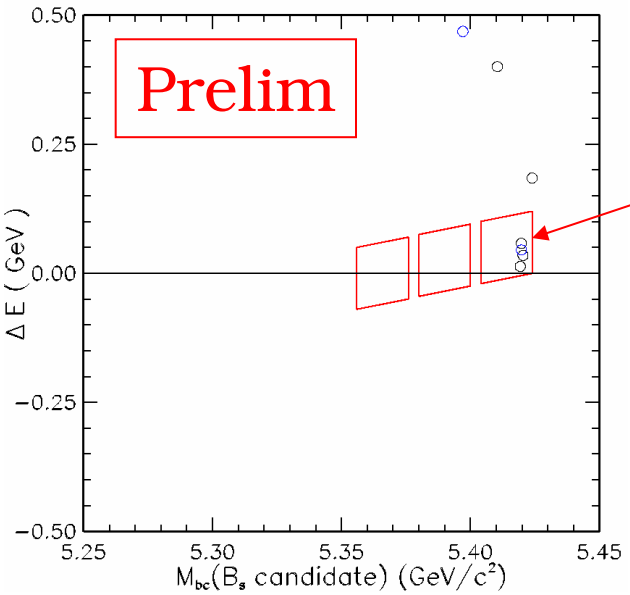
"Gold plated" modes

- 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/ψ 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.

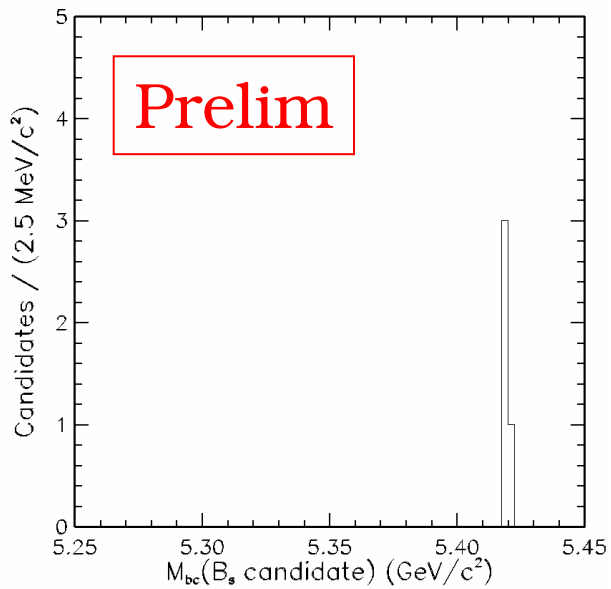




Distributions in the Data



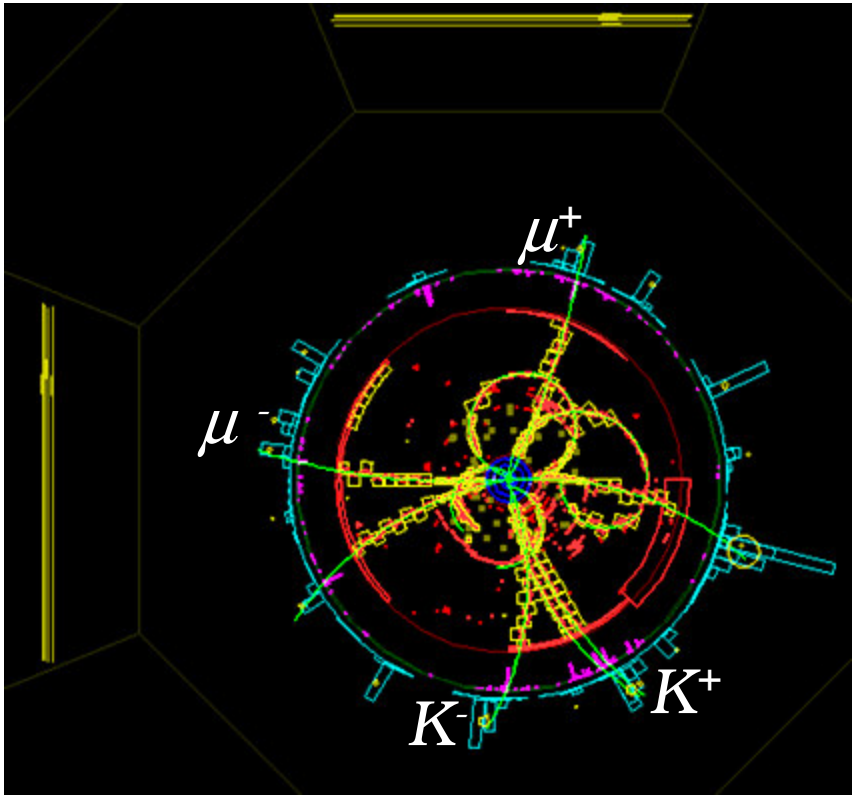
The boxes show the signal regions assuming the CDF Bs mass.

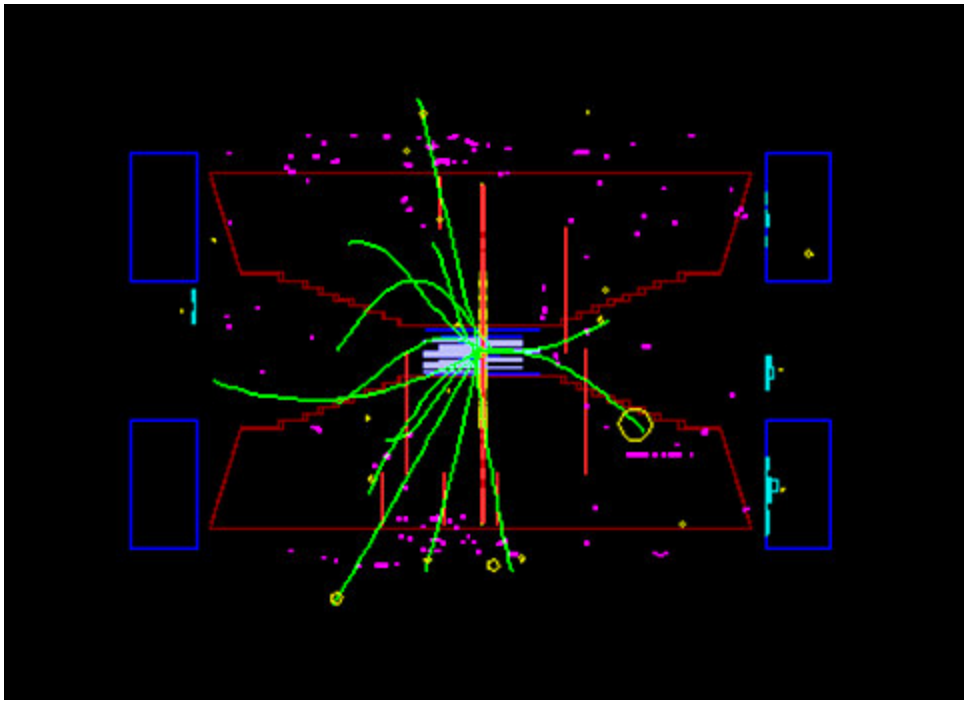


4 counts in the signal box for $Y(5S) \rightarrow Bs^{*} Bs^{*}$:
3 counts in $Bs \rightarrow J/\psi\varphi$ (in black),
1 count in $Bs \rightarrow J/\psi\eta'$ (in blue).
This is a compelling evidence for the presence of the *Bs* in the *Y(5S)* data as the background level is estimated to be less than 0.1 event (prelim).

The beam energy scale is being studied for the Bs^{*} mass measurement.

One of the signal events





$$Y(5S) \to B_s^* \overline{B_s^*}, \quad B_s^* \to B_s \gamma \quad and$$

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

Reconstruction of $Bs \to Ds(*)\ \pi / \rho$

- 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 ± 0.4)
$\bar{B}_s \to D_s \rho^-$	(7.8 ± 1.4)
$\bar{B}_s \to D_s^* \pi^-$	(2.8 ± 0.2)
$\bar{B}_s \to D_s^* \rho^-$	(7.3 ± 1.5)

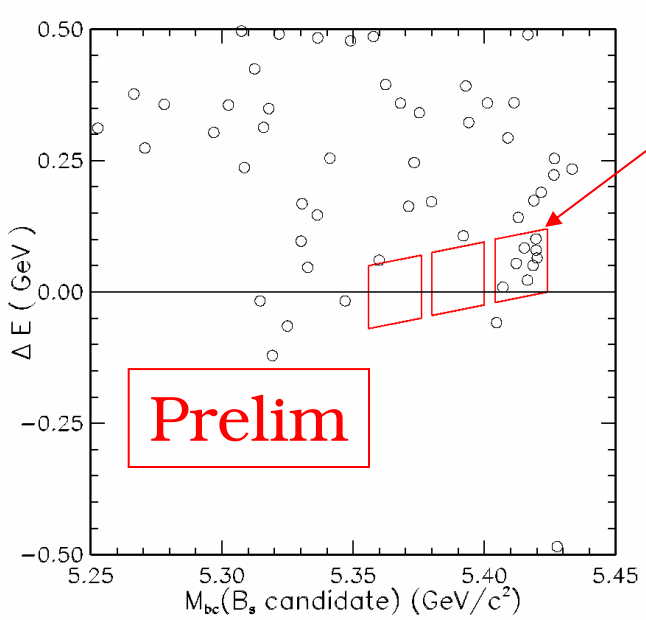
- Modes for *Ds(*)*:

Decay Mode	$\mathcal{B}$ (%)
$D_s \to K^+ \bar{K}^0$	(3.6 ± 1.1)
$D_s \to K^+ K^{*0}(892)$	(3.3 ± 0.9)
$D_s \to \phi \pi^+$	(3.6 ± 0.9)
$D_s \to \phi \rho^+$	(6.7 ± 2.3)
$D_s^* \to D_s \gamma$	(94.2 ± 2.5)

- The choice of $Bs \to Ds(*)\ \pi/\rho$ and the four "clean" *Ds* modes listed above is motivated by the difficulty of background modeling.

- Monte Carlo simulation using the branching fraction above predicts a total of 9 events can be reconstructed in these channels, subject to statistical fluctuations.

Distributions in the Y(5S) data



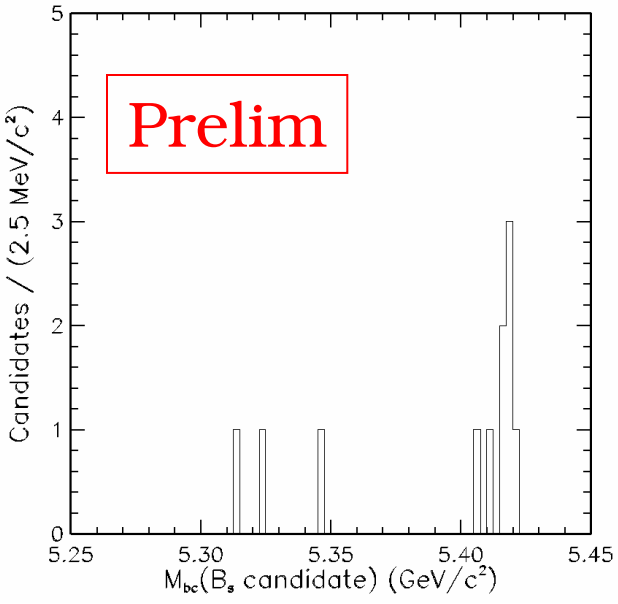
The boxes show the signal regions assuming the CDF Bs mass.

$B_s \to D_s\pi^- :$ 2 *events*

$B_s \to D_s\rho^- :$ 4 *events*

$B_s \to D_s^*\pi^- :$ 1 *event*

$B_s \to D_s^*\rho^- :$ 1 *event*



We find 8 events in the same upper signal box and estimate that the level of background is approx. 1.0 event (or less, prelim). Therefore, we have established an evidence for the *Bs* meson in the $Ds^{(*)}\,\pi/\rho$ modes as well

The beam energy scale is being studied for the Bs^* mass measurement.

Summary for Exclusive Reconstructrion

- We have shown evidence for the *Bs* meson in the CLEO *Y(5S)* data using exclusive reconstruction in two different types of *Bs* decay modes.
- The *Y(5S)* resonance favors decays to $Bs^{*}Bs^{*}$ over those to *BsBs* or $BsBs^{*}$, which is consistent with model predictions.
- We intend to add the semileptonic modes $Bs \to Ds^{(*)}\, l\, \nu$ in order to improve measurement of the total *Bs* production rate at the *Y(5S)* energy.
- Expect the results for
  - ✓ $\sigma(B_s\overline{B_s})/\sigma(B_s^{*}\overline{B_s^{*}})$ *and* $\sigma(B_s^{*}\overline{B_s} + B_s\overline{B_s^{*}})/\sigma(B_s^{*}\overline{B_s^{*}})$
  - ✓ the mass of Bs^{*}
  - ✓ and, possibly, the total *Bs* production rate at *Y(5S)* energy

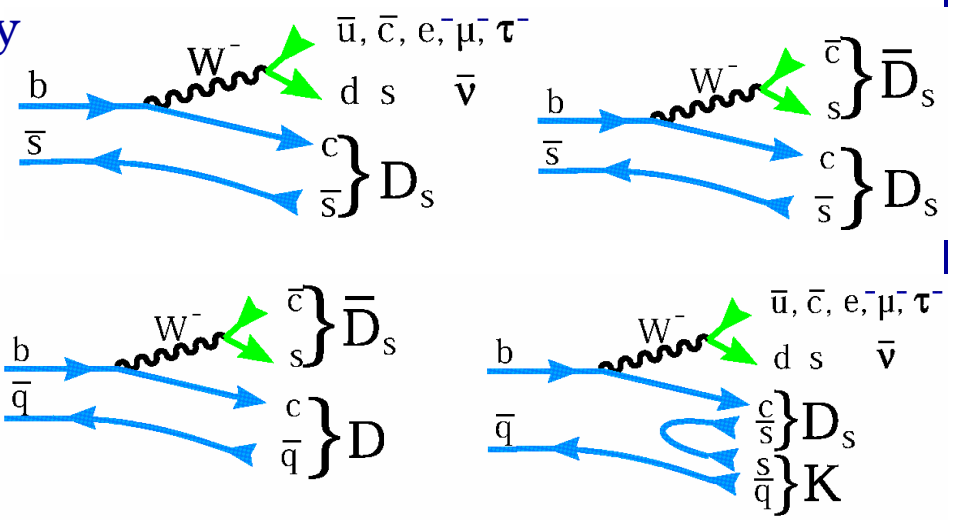
  from this approach to be available in early spring 2005.

INCLUSIVE APPROACH

More information is available in arXiv:hep-ex/0408070

Overview of the inclusive method

- The *Ds* meson is expected to be produced in *Bs* decays more copiously than in B decays (PDG):
  - ✓ $\mathcal{B}(Bs \to Ds\, X) = (94 \pm 30)\%$
  - ✓ $\mathcal{B}(B \to Ds\, X) = (10.5 \pm 2.6)\%$



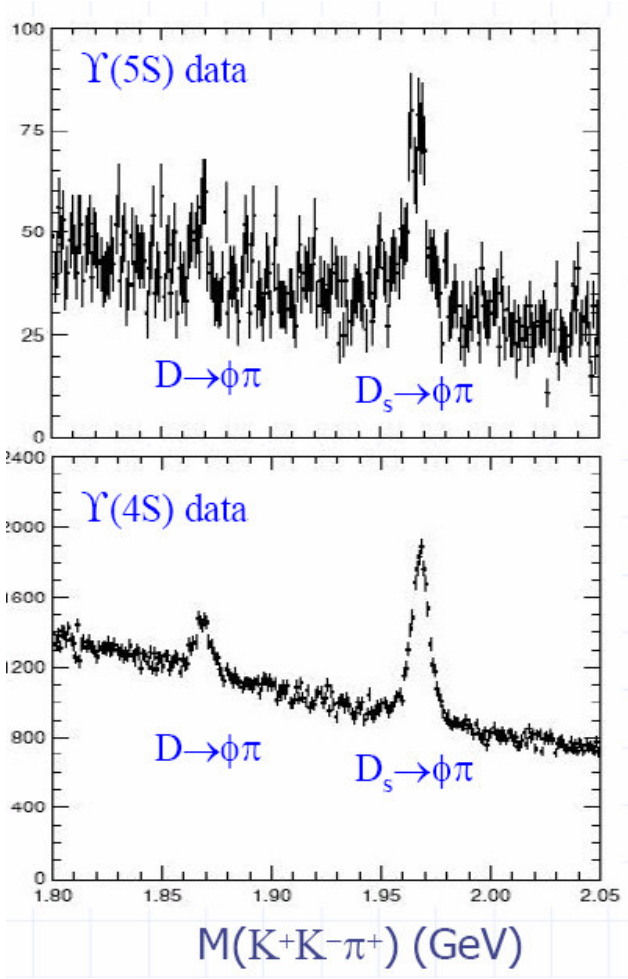
Inclusive analysis steps:

- Measure Ds yields in bins of x = $|P_{Ds}|/E_{beam}$ in the continuum, *Y(4S)* and *Y(5S)* data.
- Measure $\mathcal{B}(Y(4S) \to DsX)$ and $\mathcal{B}(Y(5S) \to DsX)$ by subtracting properly scaled and normalized continuum yields from the Y(4S) and Y(5S) yields.
- Extract $\mathcal{B}(Y(5S) \to Bs^{(*)}\, Bs^{(*)})$ from the measured $\mathcal{B}(Y(4S) \to DsX)$ and $\mathcal{B}(Y(5S) \to DsX)$.

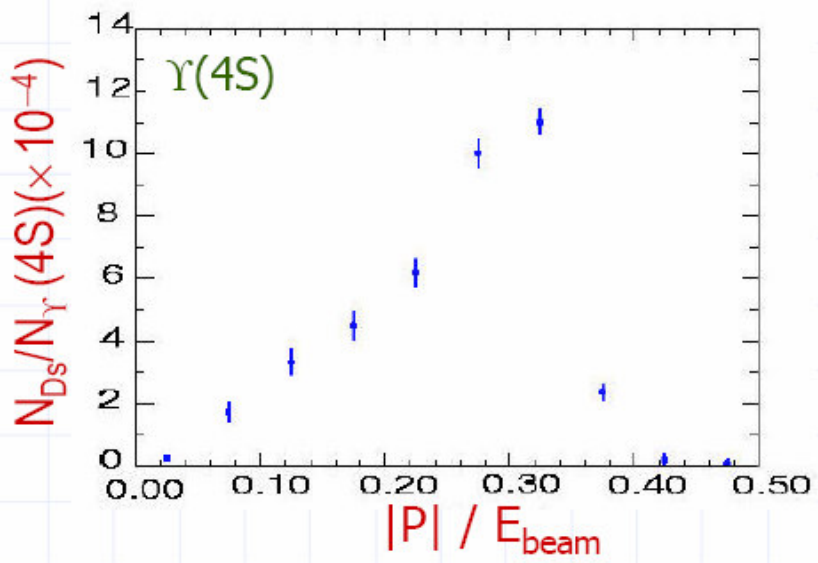
$Ds \rightarrow \varphi\, \pi^+$ inclusive reconstruction

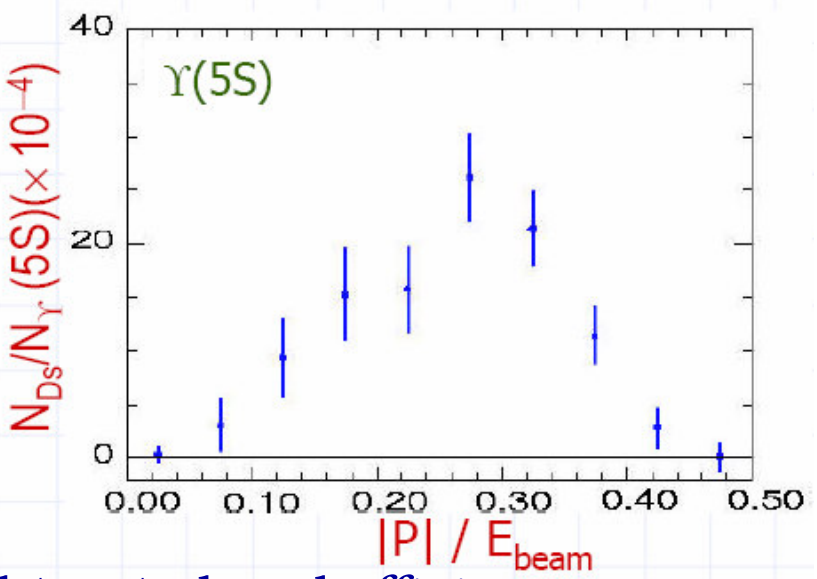
- The decay sequence $Ds \rightarrow \varphi\, \pi^+$, $\varphi \rightarrow K^+K^-$ is used.
- The reconstruction efficiency is ~30% and it is independent of the beam energy for the three data sets.
- The plots show raw *Ds* yields in the *Y(5S)* and *Y(4S)* data.
- The raw *Ds* yields are corrected for the contribution from the continuum. The continuum data are scaled in the following way:

$$S = \frac{L}{L_{cont}} \cdot \left(\frac{E_{cont}}{E} \right)^2$$



Ds spectra at Y(4S) and Y(5S)





- The plots show the continuum subtracted and efficiency corrected *Ds* yields at the Y(4S) and Y(5S). *No* Ds branching fraction correction was applied to be above plots.
- Using $B(Ds \to \varphi\pi)$ = (3.6±0.9)%, CLEO finds:

$$B(Y(4S) \to D_s X) = (22.3 \pm 0.7 \pm 5.7)\%$$

$$B(Y(5S) \to D_s X) = (55.0 \pm 5.2 \pm 17.8)\%$$

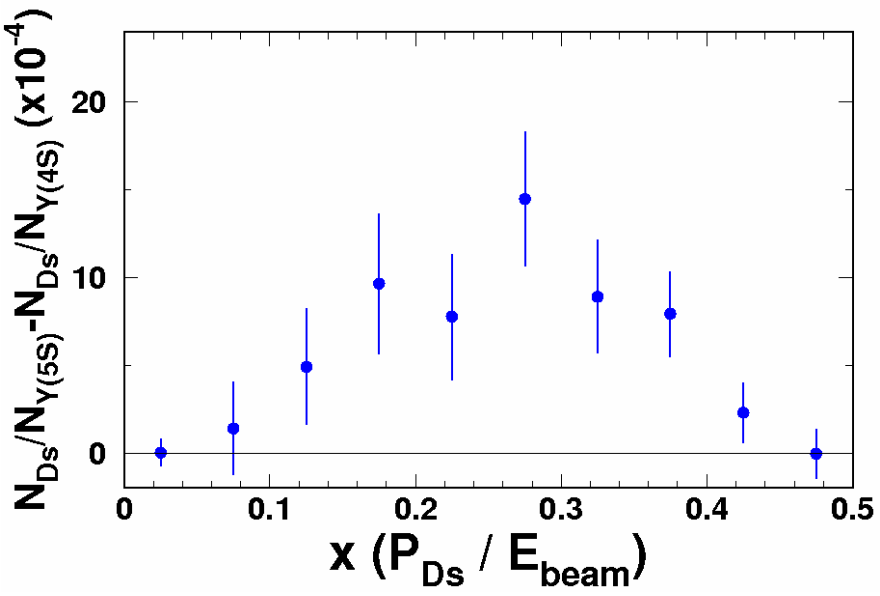
$$B(Y(5S) \to D_s X) / B(Y(4S) \to D_s X) = 2.5 \pm 0.3 \pm 0.6$$

$$\textit{This work}: \; B(B \to D_s X) = (11.1 \pm 0.4 \pm 2.9)\%$$

$$PDG: \; B(B \to D_s X) = (10.5 \pm 2.6 \pm 2.5)\%$$

Results for the inclusive method

- The plot shows an excess in the *Ds* production at the *Y(5S)* over that at the *Y(4S)*. The excess is interpreted as an evidence for *Bs* at the *Y(5S)*.
- From $\mathcal{B}(Y(4S)\to DsX)$ and $\mathcal{B}(Y(5S)\to DsX)$, CLEO makes a model dependent estimate:



$$B(Y(5S)\to B_s^{(*)}\overline{B_s^{(*)}}) = (21\pm 3(stat)\pm 9(sys))\%$$

The largest contributors to the systematic error are

- ✓ the uncertainty associated with the continuum subtraction
- ✓ the error from the uncertainty in $\mathcal{B}(Ds\to\varphi\pi)$.

Expect improvements in the systematic error

Summary and outlook

- Evidence for the *Bs* meson at the Y(5S) resonance is found in both exclusive and inclusive approaches
- It is found that
  - ✓ $B(Y(5S) \to B_s^{(*)}\overline{B_s^{(*)}}) = (21 \pm 3(stat) \pm 9(sys))\%$
  - ✓ The *Y(5S)* decays predominantly to Bs^*Bs^* rather than to *BsBs* or $BsBs^*$.
- All results are preliminary
- Further studies are ongoing. Expect finalized results in the near future (spring, 05).