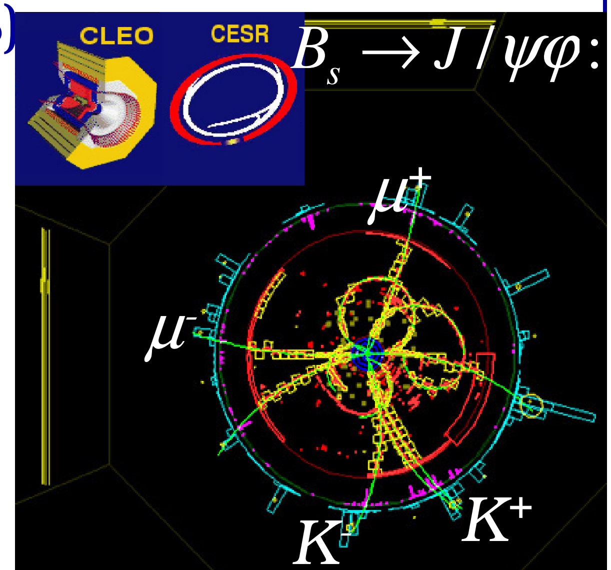
Υ(5S) Results from CLEO

Results from four CLEO Υ(5S) analyses:

- Exclusive B_s and B Reconstruction at the Υ(5S)
- Inclusive D_s and ϕ Production at the Υ(5S)



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on behalf of

the CLEO Collaboration

DPF-2006

References:

Exclusive measurements:

- "Observation of B_s Production at the Y(5S) Resonance", (CLEO collaboration) PRL **96**, 022002 (2006)
- "Measurements of the Exclusive Decays of the Y(5S) to B Meson Final States and Improved B_s^* Mass Measurement", (CLEO Collaboration) PRL **96,** 152001 (2006)

Inclusive Measurements:

- "Evidence for $B_s^{(*)}B_s^{(*)}$ Production at the Y(5S)", (CLEO collaboration) PRL **95,** 261801 (2005). [Includes a measurement of D_s production at the Y(5S)]
- "Measurement of $\mathcal{B}(Y(5S) \rightarrow B_s^{(*)}B_s^{(*)})$ Using ϕ Mesons", (CLEO Collaboration) hep-ex/0610035. Submitted to PRD. [Includes a measurement of ϕ production at the Y(5S)]

Υ(5S) Data Samples

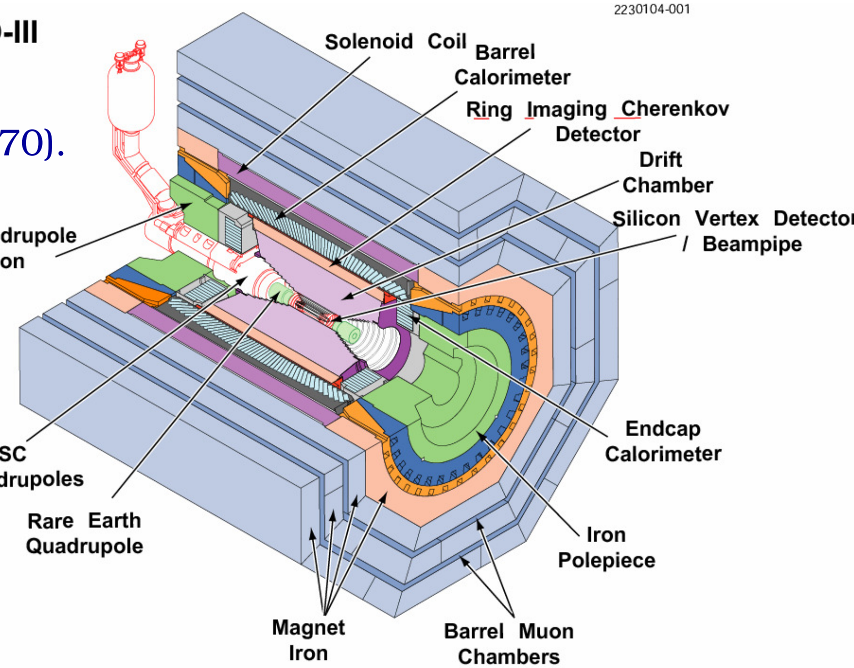
- CLEO I (1985): 0.12 fb^{-1}
- CLEO III (2003): 0.42 fb^{-1} — The topic of this talk
- BELLE (2005): 1.9 fb^{-1}
- BELLE (2006): ~20 fb^{-1}
- BABAR has not run at the Υ(5S)

[Note: E_{CM} are different by several MeV for different data sets]

CESR and CLEO

- The CLEO experiment is located at the Cornell Electron Storage Ring (CESR) operated in the region of the Upsilon resonances for over 20 years.
- In 2003, we started collecting data at the $\psi(3770)$. Before that, we took a short run at the Υ(5S).
- The CLEO detector was developed for *B* physics at the Υ(4S). The CLEO-III configuration:
  - ✓ B-field: 1.5 T
  - ✓ Gas (drift chamber): He and C_3H_8
  - ✓ Tracking: 93% of 4π, δP/P≈0.6% for a 1.0 GeV track
  - ✓ Hadron particle ID: RICH (80% of 4π) and dE/dx
  - ✓ E/M crystal calorimeter: 93% of 4π, δE/E ≈ 2.0% (4.0)% for a 1.0 GeV (100 MeV) photon
  - ✓ Muon prop. chambers at 3, 5 and 7 λ_I.

CLEO-III



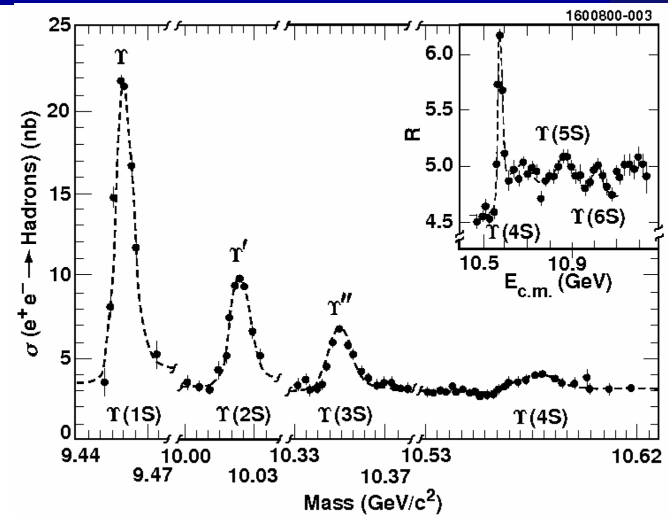
Introduction: B_s at the Y(5S) (1)

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

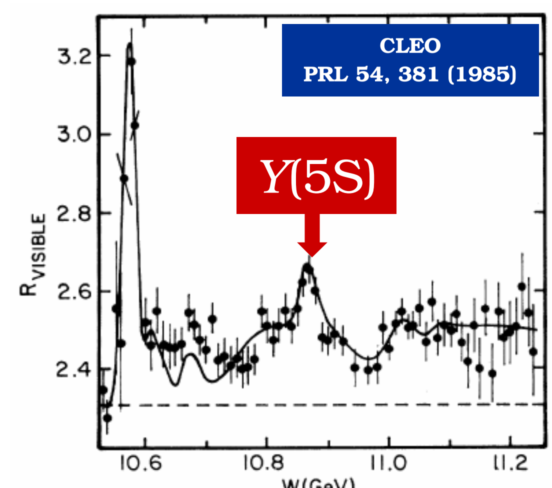
$$B\bar{B},\ B\bar{B}^*,\ B^*\bar{B}^*,\ B\bar{B}\pi,\ B\bar{B}^*\pi, B^*\bar{B}^*\pi, B\bar{B}\pi\pi$$

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

- *No* evidence for B_s production at the Y(5S) was found in 116 pb^{-1} collected in 1985.
- Knowledge of B_s production at the Y(5S) is important for evaluating the potential of B_s physics at a high luminosity e^+e^- collider (Super-B factory). Results from CLEO III studies of B_s production are the focus of this talk.

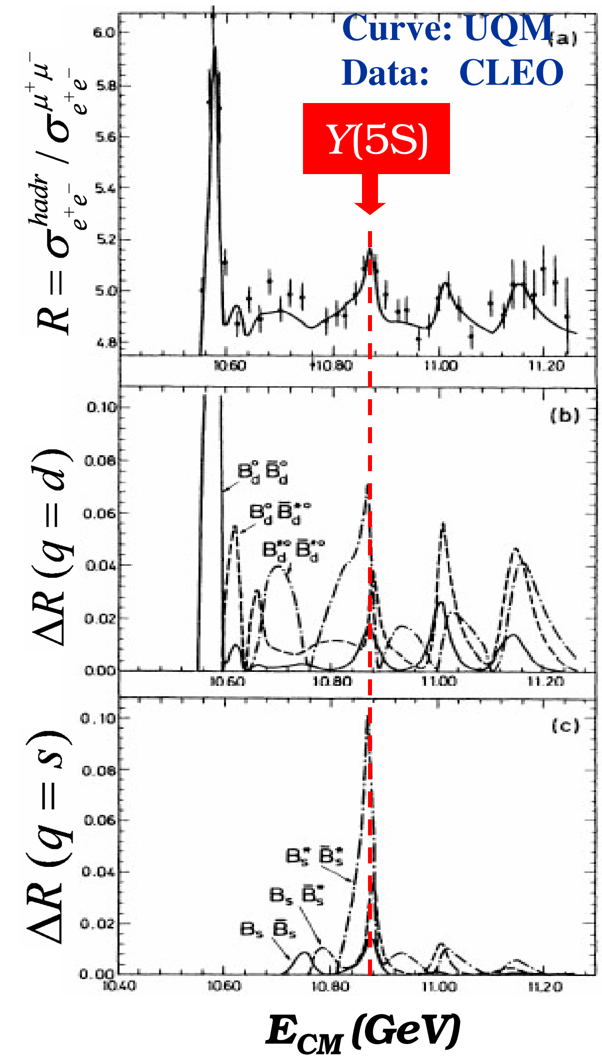


$M(Y(5S)) = (10.865 \pm 0.008)\ GeV$
$\Gamma_{total}(Y(5S)) = (110 \pm 13)\ MeV$



Introduction: B_s at the $\Upsilon(5S)$ (2)

- There are two papers that measure the hadronic cross section above the $\Upsilon(4S)$ resonance:
  - ✓ CLEO: PRL **54,** 381 (1985)
  - ✓ CUSB: PRL **54**, 377 (1985)
- The cross section above the $\Upsilon(4S)$ is described well by the Unitarized Quark Model (S.Ono *et al.*, Phys.Rev.D **34**, 186 (1986)).
- The UQ model predicts:
  - ✓ $\Upsilon(5S) \to B^*B^*$ or $B_s^*B_s^*$,
  - ✓ The B_s cross section is ≈ 1/3 of the $\Upsilon(5S)$ cross section.
  - ✓ $\sigma(e^+e^- \to \Upsilon(5S)) \approx 0.35$ nb
- Expect ≈150*K* of $\Upsilon(5S)$ decays in the CLEOIII 0.42 fb^{-1} data sample, 1/3 of that are $B_s^{(*)}B_s^{(*)}$ pairs.



Υ(5S) Cross Section Measurements

- Count hadronic events at the Υ(5S)
- Subtract the continuum using data taken below the Υ(4S)
  - ✓ Scale by ratios of luminosities and E_{cm}^2
  - ✓ Luminosity ratio is a significant source of systematic error since $\sigma(\Upsilon 5S) \sim 0.1\sigma(\text{continuum})$ and the continuum data are taken 300 MeV below the Υ(5S)
- Results:

$$\sigma[\Upsilon(5S)]=(0.301\pm0.002\pm0.039)\ \text{nb}$$

Ref: hep-ex/0610035

- Consistent with theoretical predictions

Exclusive $B_{(s)}$ Reconstruction at the Υ(5S)

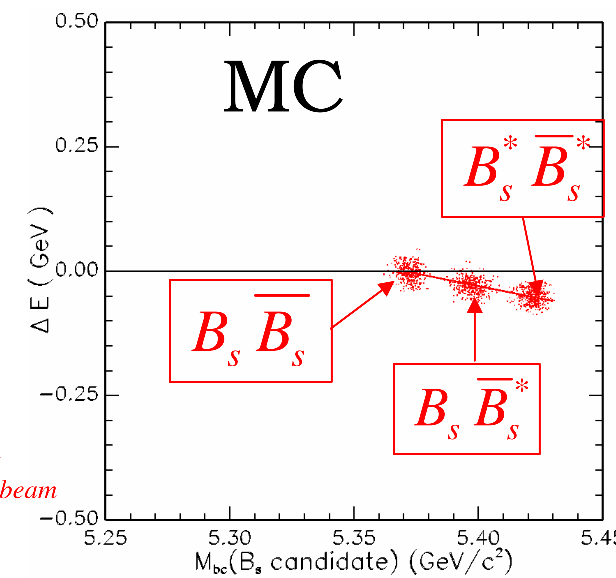
Overview of the Method (1)

- An extension of B reconstruction technique used at the Υ(4S) is employed to reconstruct B_s mesons at the Υ(5S):
  - ✓ $M_{bc} = \sqrt{E_{beam}^2 - P_{candidate}^2}$
  - ✓ $\Delta E = E_{candidate} - E_{beam}$
  - ✓ Continuum background suppression variables (e.g., $R_2 = H_2/H_0$)
- Three decay channels of the Υ(5S) to B_s mesons are possible:
  - ✓ 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: $Y(5S) \to B_s \overline{B}_s^*$: $E_{B_s^*} > E_{beam}, E_{B_s} < E_{beam}$

<u>PDG–2004:</u>
$M_{Bs} = (5.370 \pm 0.002)\, GeV$
$M_{Bs^*} - M_{Bs} = (47.0 \pm 2.6)\, MeV$

<u>Assumption: $B(B_s^* \to B_s \gamma) = 100\%$</u>

<u>CDF–2005 (hep–ex/0508022):</u>
$M_{Bs} = (5.3660 \pm 0.0008\,(stat+sys))\, GeV$



Overview of the Method (2)

- The Υ(5S) can decay into a variety of states with ordinary B mesons:

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

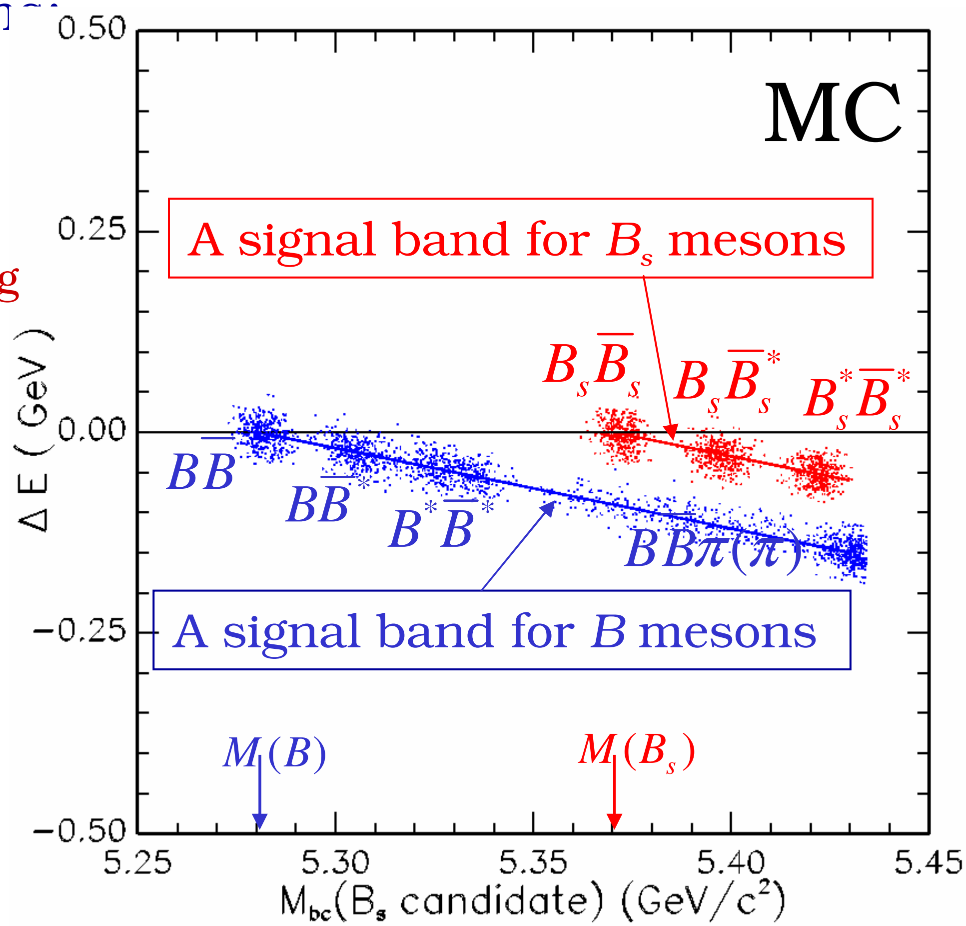
[The ON Υ(4S) data are used to model B bkg in the B_s analysis]

- Large background from the continuum ($e^+e^- \to qq$) :

✓ $\Upsilon(4S): \dfrac{\sigma(B\overline{B})}{\sigma(e^+e^- \to q\overline{q})} \sim 0.3$

✓ $\Upsilon(5S): \dfrac{\sigma(B_s^{(*)}\overline{B}_s^{(*)})}{\sigma(e^+e^- \to q\overline{q})} \sim 0.03$

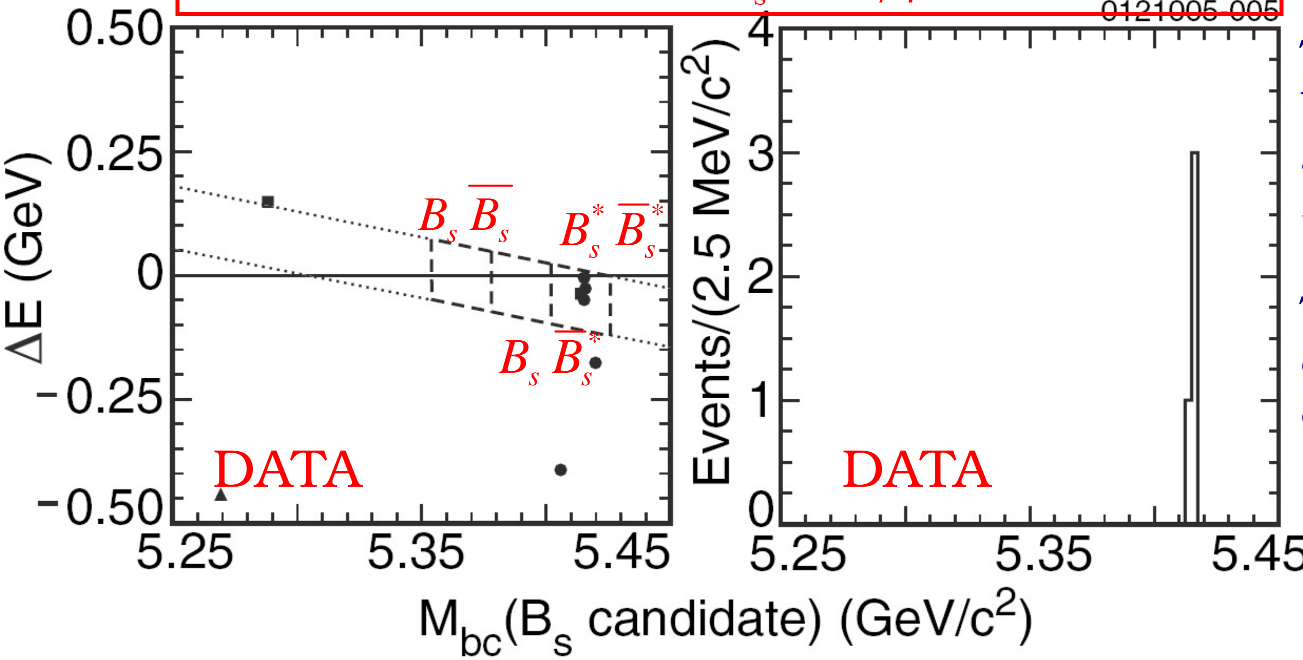
[The OFF Υ(4S) and Λ_b data are used to model the continuum bkg]



B_s modes with a J/ψ

- Search for very clean modes having very large S/B ratio: $B_s \to J/\psi\,\varphi$, $J/\psi\,\eta$ and $J/\psi\,\eta'$.
- The J/ψ is reconstructed in the $\mu\mu$ and ee channels. The following channels are used for other particles: $\varphi \to KK$, $\eta \to \gamma\gamma$, $\eta' \to \eta(\gamma\gamma)\pi^+\pi^-$.
- Expect to find few signal events, assuming branching fractions similar to those for B mesons. In the Υ(5S) data, we find:

4 events in the signal box for $\Upsilon(5S) \to B_s^* B_s^*$:
3 events in $B_s \to J/\psi\varphi$
1 event in $B_s \to J/\psi\eta'$



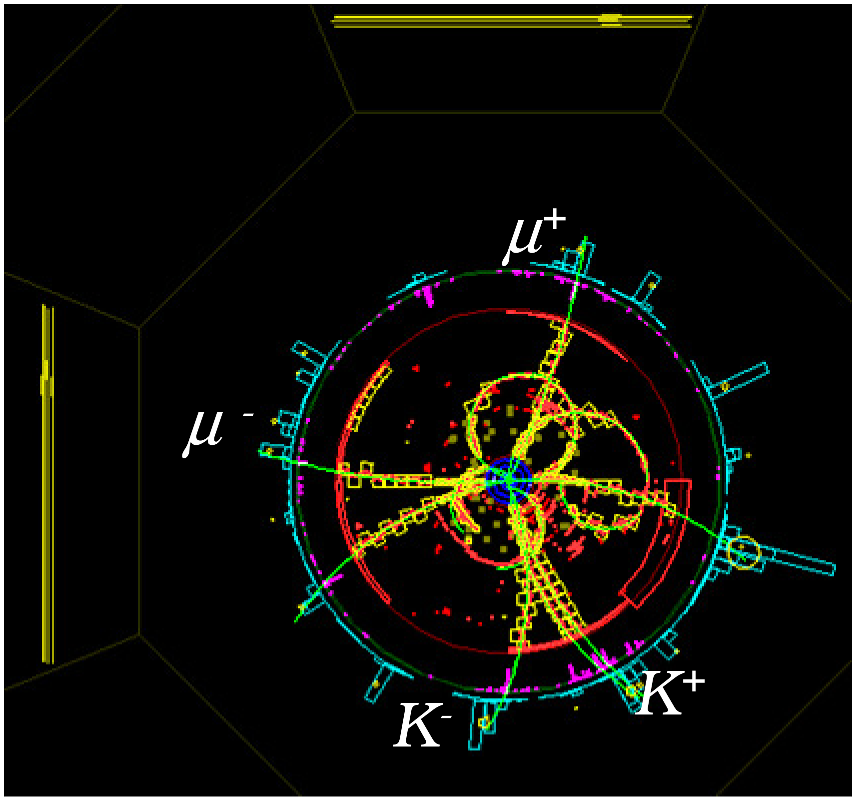
The level of non-B_s background is < 0.08 events at 68% CL in the $B_s^* B_s^*$ signal region.

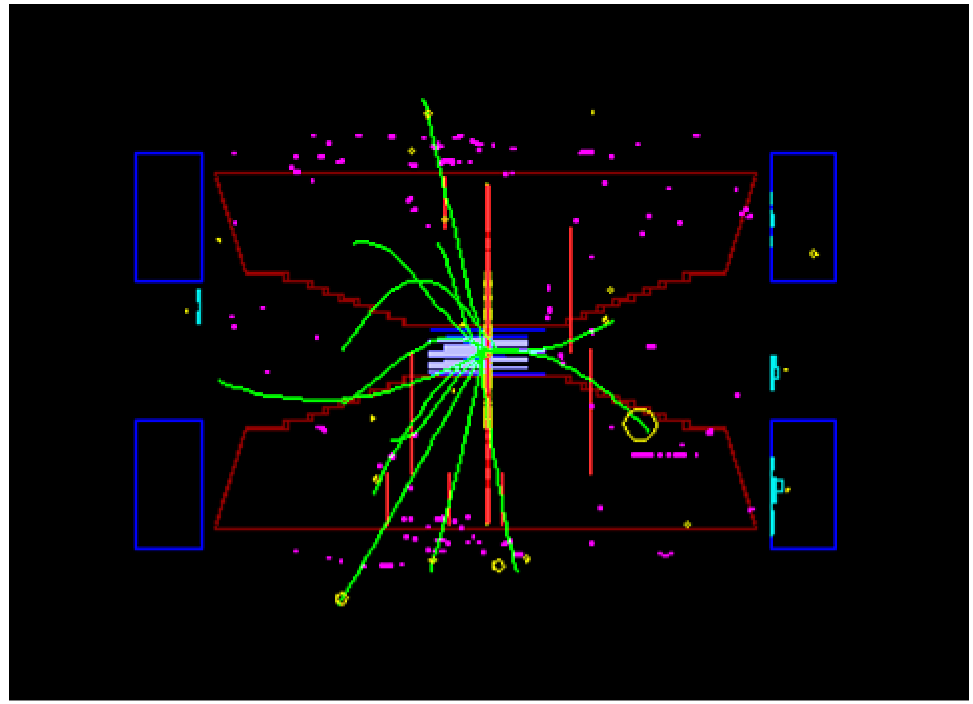
The probability for 0.08 events to fluctuate to 4 events or more is

$P_I < 1.6 \times 10^{-6}$

$M(B_s^*) =$
$5.4150 \pm 0.0018(\text{stat})$ (GeV)

A Signal Event





$$\Upsilon(5S) \to B_s^* \overline{B}_s^*, \quad B_s^* \to B_s \gamma \quad and$$
$$B_s \to J/\psi \phi, J/\psi \to \mu^+ \mu^-, \phi \to K^+ K^-$$

B_s modes with a $D_s^{(*)-}$

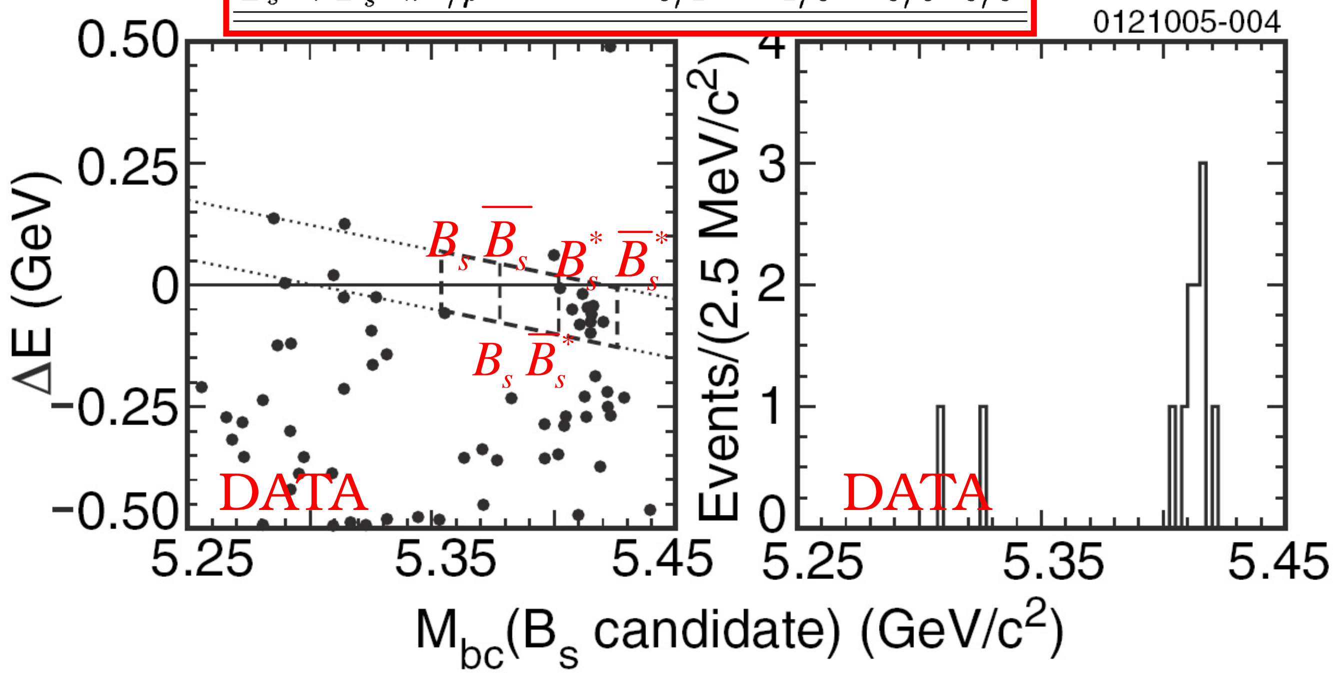
- $B_s \to D_s^{(*)}\ \pi/\rho$ with D_s modes given in the tables
- MC predicts that a total of 10-14 events can be reconstructed in these channels
- In the Υ(5S) data we find 10 signal candidates (including background):

$D_s^+ \to$	$K^+K_S^0$	$K^+\bar{K}^{0*}$	$\phi\pi^+$	$\phi\rho^+$
$\bar{B}_s \to D_s^+\pi^-/\rho^-$	0/0	1/1	1/3	1/1
$\bar{B}_s \to D_s^{*+}\pi^-/\rho^-$	0/1	1/0	0/0	0/0

B^0 branching fractions:

Decay Mode	$\mathcal{B}\times 10^{-3}$
$\bar{B}_s \to D_s\pi^-$	(2.8 ± 0.3)
$\bar{B}_s \to D_s\rho^-$	(7.7 ± 1.3)
$\bar{B}_s \to D_s^*\pi^-$	(2.8 ± 0.2)
$\bar{B}_s \to D_s^*\rho^-$	(6.8 ± 0.9)

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 level of background is < 1.8 events at 68% CL in the $B_s^*B_s^*$ signal region.

The probability for 1.8 events to fluctuate to 10 events or more is

$P_{II} < 1.9\times10^{-5}$

$M(B_s^*)$= 5.4129±0.0012(stat) (GeV)

Results for $B_s^{(*)}$ Production

- P_I and P_{II} are combined to obtain an overall probability for a background fluctuation [$P = (P_I P_{II})(1-\ln(P_I P_{II}))$]: $P < 8 \times 10^{-10}$ (>6σ).
- All signal events correspond to $B_s^* B_s^*$ production. We set the following limits (90% CL):

$$\frac{\sigma(e^+e^- \to B_s \overline{B}_s)}{\sigma(e^+e^- \to B_s^* \overline{B}_s^*)} < 0.16 \quad \text{and} \quad \frac{\sigma(e^+e^- \to B_s \overline{B}_s^*) + \sigma(e^+e^- \to B_s^* \overline{B}_s)}{\sigma(e^+e^- \to B_s^* \overline{B}_s^*)} < 0.16$$

- Relating B_s branching fractions to B branching fractions, we find:

$$\sigma(e^+e^- \to B_s^* \overline{B}_s^*) = [0.11^{+0.04}_{-0.03}(stat) \pm 0.02(syst)]\ nb$$

which is consistent with the theory (UQM): 1/3 of 0.30 - 0.35 nb of the total Y(5S) cross-section.

$$B(Y(5S) \to B_s^* \overline{B}_s^*) = [35^{+12}_{-11}(stat) \pm 10(syst)]\%$$

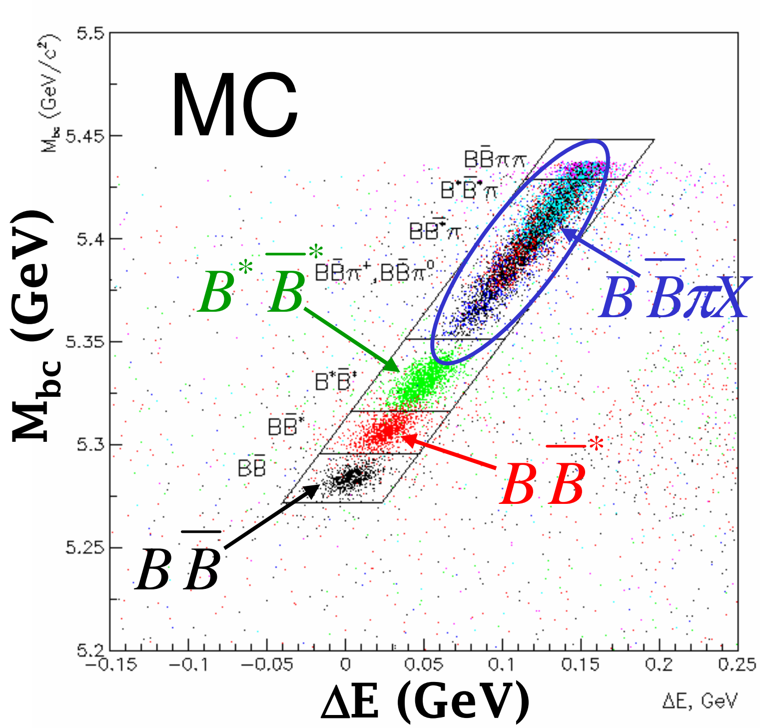
- The mass of the B_s^* meson is measured to be

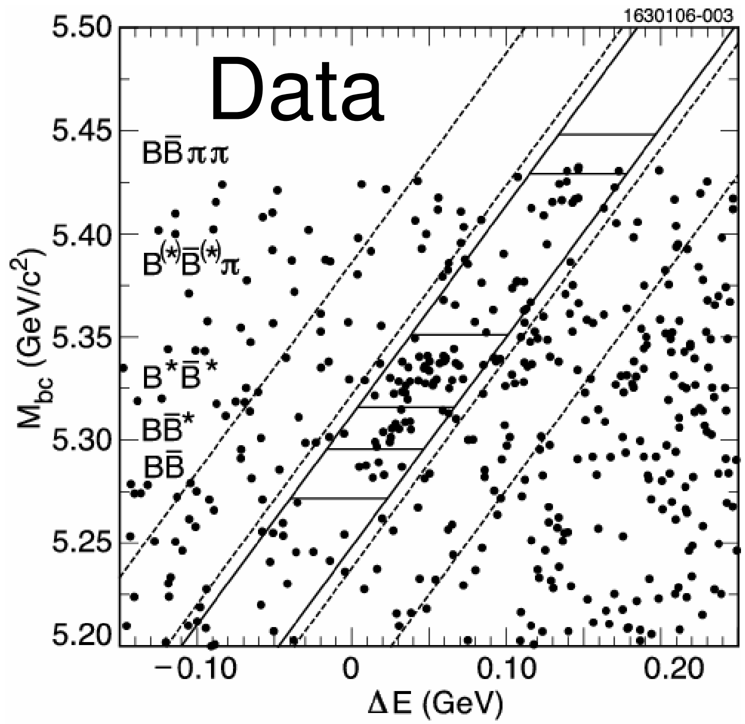
$$M(B_s^*) = [5.414 \pm 0.001(stat) \pm 0.003(syst)]\ GeV$$

[for more information see: PRL **96**, 022002 (2006)]

B modes with J/ψ and $D^{(*)}$

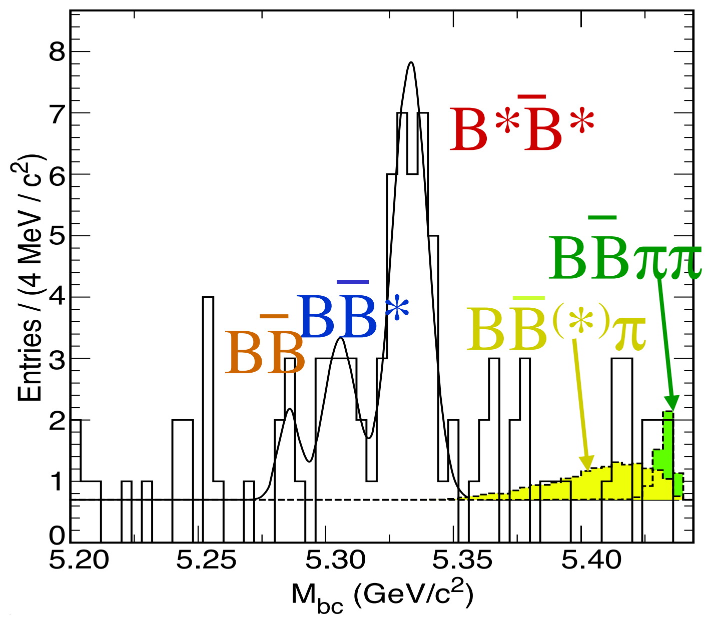
- Modes $B \to D^{(*)}\pi/\rho$ and $B \to J/\psi K^{(*)}$ (in total 25 modes):

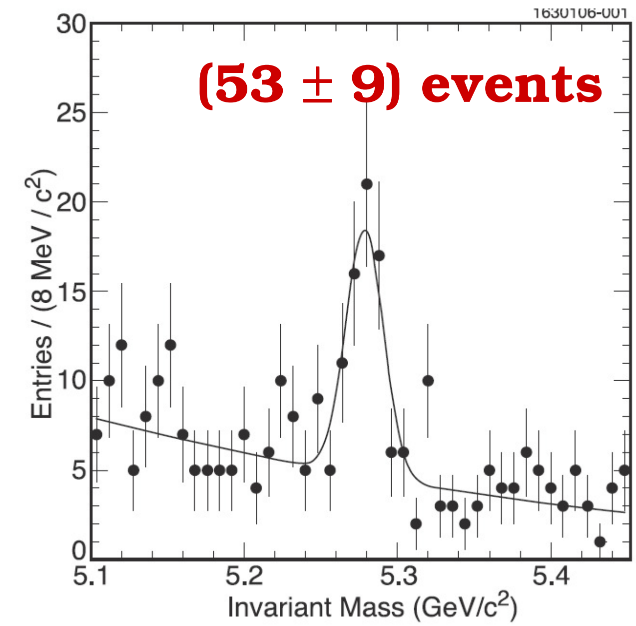




Note the non-standard definition of ΔE in these plots (should have the opposite sign)

Results for $B^{(*)}$ Production





- B^*B^* is again dominant (consistent with models):
  - ✓σ(B*B*)/σ(BBX) = (74±15±8)%
  - ✓σ(BB*)/σ(BBX) = (24±9±3)%
  - ✓σ(BB)/σ(BBX) < 22% at 90% CL
- $M(B_s^*) = [5.4117 \pm 0.0016(stat) \pm 0.0006(syst)]\ GeV$

[for more information see: PRL **96**, 152001 (2006)]

$\sigma(e^+e^- \to B\overline{B}X) = [0.177 \pm 0.030(stat) \pm 0.016(syst)]\ nb$

In combination with

$\sigma(e^+e^- \to B_s^*\overline{B}_s^*) = [0.11^{+0.04}_{-0.03}(stat) \pm 0.02(syst)]\ nb$

gives

$\sigma(e^+e^- \to B_{(s)}^{(*)}\overline{B}_{(s)}^{(*)}X) = [0.29 \pm 0.04]\ nb$

consistent with theory and exper.

Inclusive D_s and ϕ Measurements at the $Y(5S)$

Overview of the Inclusive Method

- The method relies on the fact that D_s (and ϕ) mesons are produced more copiously in B_s decays compared to B decays.

$$f_s = B(\Upsilon(5S) \to B_s^{(*)} \overline{B_s^{(*)}})$$

$$B(\Upsilon(5S) \to D_s X) = 2 f_s B(B_s \to D_s X) + (1 - f_s) B(\Upsilon(4S) \to D_s X)$$

measure — $B(\Upsilon(5S) \to D_s X)$

Model dependent estimate:
$B(B_s \to D_s X)$ = (92 ± 11) %
[$B(B_s \to \phi X)$ = (15 ± 3) %]

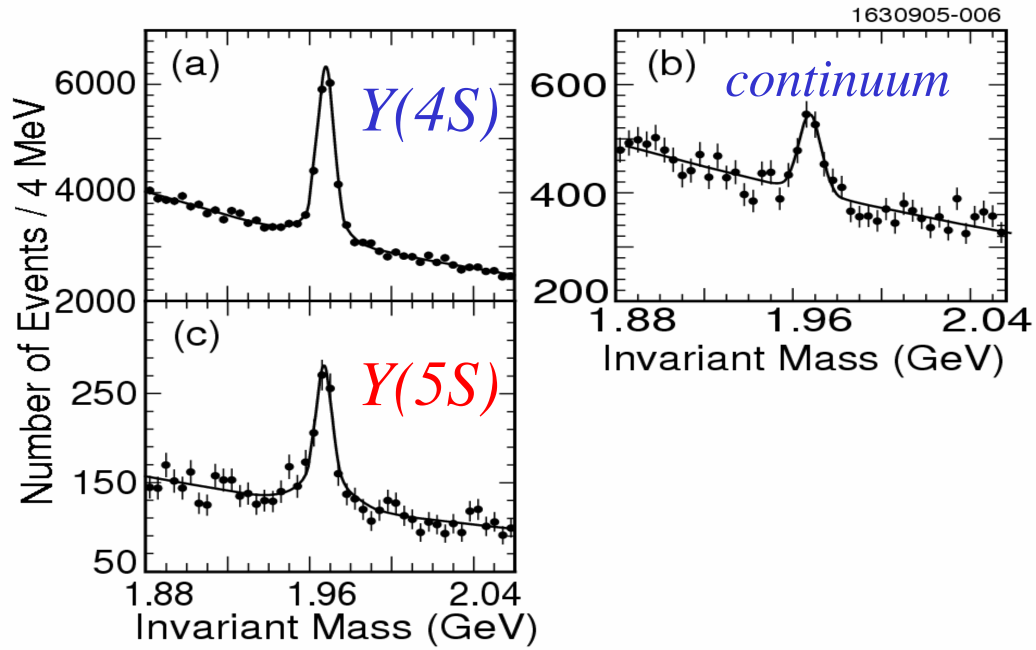
measure — $B(\Upsilon(4S) \to D_s X)$

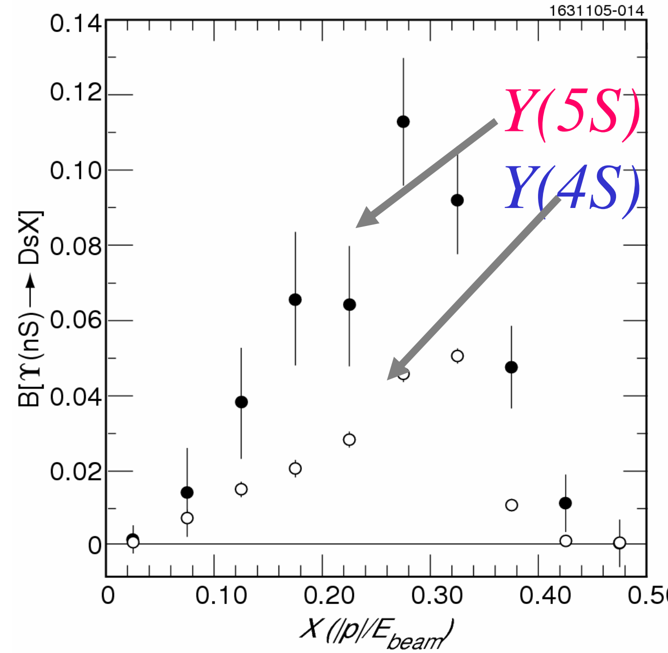
Main Analysis Steps:

- Measure D_s yields ($D_s \to \varphi\pi^+$, $\varphi \to K^+K^-$) in bins of $x = |P_{Ds}| / E_{beam}$ in the continuum, $\Upsilon(4S)$ and $\Upsilon(5S)$ data.
- Measure $\mathcal{B}(\Upsilon(4S) \to D_s X)$ and $\mathcal{B}(\Upsilon(5S) \to D_s X)$ by subtracting properly scaled and normalized continuum yields from the $\Upsilon(4S)$ and $\Upsilon(5S)$ yields
- Extract f_s according to the equation above and account for systematic errors.

Results of the Inclusive D_s Method

- CLEO inclusive D_S yields for $x < 0.5$ and $R_2<0.25$





$$f_S = B(Y(5S) \to B_s^{(*)}\overline{B}_s^{(*)}) = (16.8 \pm 2.6(stat)^{+6.7}_{-3.4}(syst))\%$$

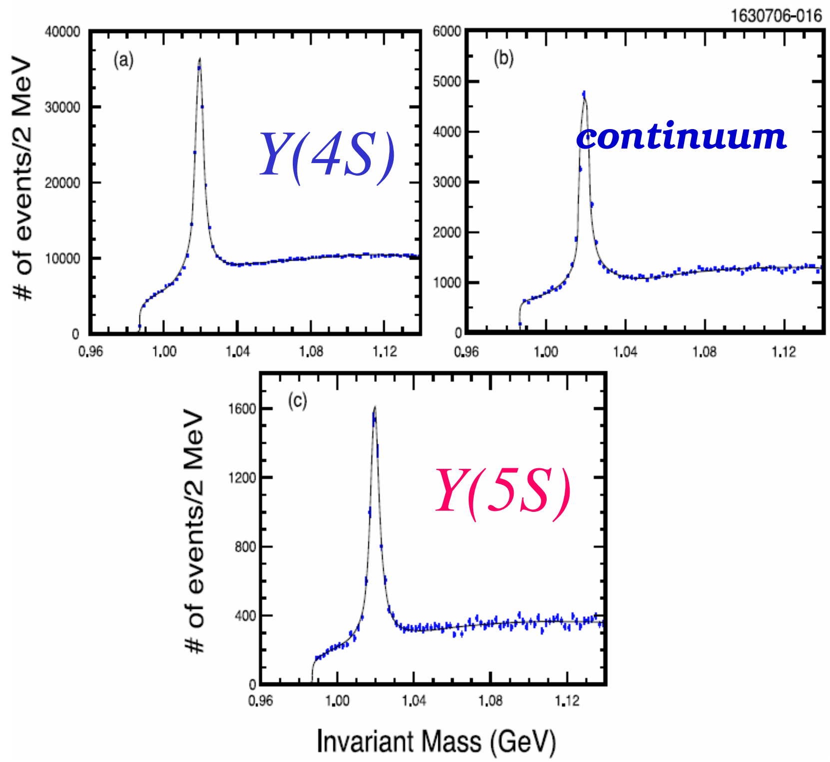
The largest sources of the systematic uncertainty are

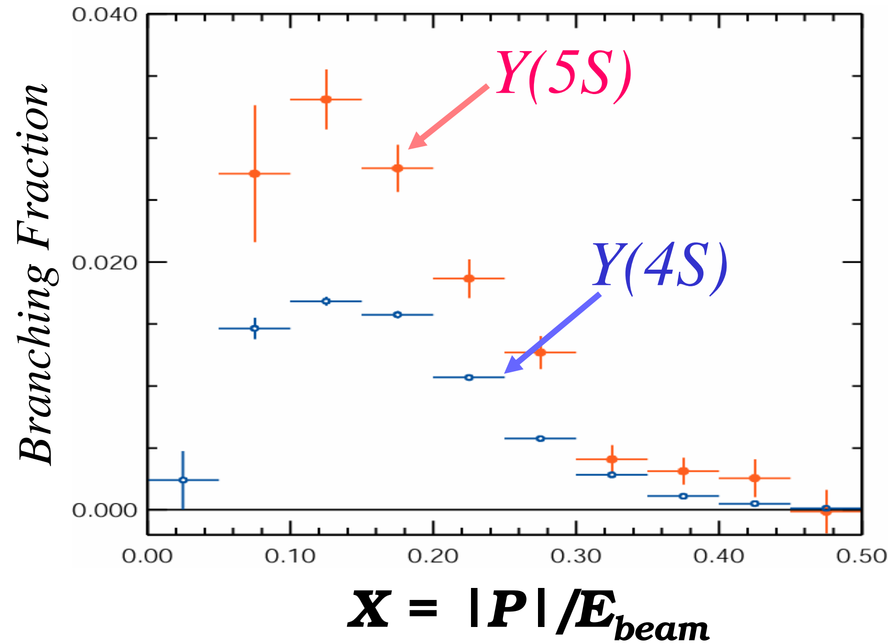
- ✓ the uncertainty associated with **the luminosity measurements**
- ✓ the uncertainty in $\mathcal{B}(D_s \to \varphi\pi)$.

[for more information see: PRL **95**, 261801 (2005)]

Results of the inclusive ϕ method

- CLEO inclusive ϕ yields for $x < 0.5$ and $R_2 < 0.25$





$$f_S = B(Y(5S) \to B_s^{(*)}\overline{B}_s^{(*)}) = (24.6 \pm 2.9(stat)^{+11.0}_{-5.3}(syst))\%$$

[for more information see: hep-ex/0610035

Summary and Conclusions

Using 0.42 fb^{-1} of data at the Υ(5S) resonance, we obtain the following results:

- ❑ First observation of B_S production at the $Υ$(5S):
  - ✓ $\sigma(e^+e^- \to B_s^*\overline{B}_s^*) = [0.11^{+0.04}_{-0.03}(stat) \pm 0.02(syst)]\ nb$; $B(Υ(5S) \to B_s^*\overline{B}_s^*) = [35^{+12}_{-11}(stat) \pm 10(syst)]\%$
  - ✓ and limits: $\frac{\sigma(e^+e^- \to B_sB_s)}{\sigma(e^+e^- \to B_s^*\overline{B}_s^*)} < 0.16$ and $\frac{\sigma(e^+e^- \to B_s\overline{B}_s^*) + \sigma(e^+e^- \to B_s^*\overline{B}_s)}{\sigma(e^+e^- \to B_s^*\overline{B}_s^*)} < 0.16$
- ❑ First study of B production at the $Υ$(5S):
  - ✓ $\sigma(e^+e^- \to B\overline{B}X) = [0.177 \pm 0.030(stat) \pm 0.016(syst)]\ nb$; $B(Υ(5S) \to B_s\overline{B}_sX) = [41 \pm 10(stat) \pm 9(syst)]\%$
  - ✓ $\sigma(B^*B^*) : \sigma(BB^*) : \sigma(BB) \cong 3:1:<1$
- ❑ Determination of $M(B_s^*) = (5411.7 \pm 1.6 \pm 0.6)\ MeV$
- ❑ Estimates of B_s production using inclusive measurements of D_s and ϕ production at the $Υ$(5S) (model dependent):
  - ✓ D_s production: $B(Υ(5S) \to B_s\overline{B}_sX) = [17 \pm 3(stat)^{+7}_{-3}(syst)]\%$
  - ✓ ϕ production: $B(Υ(5S) \to B_s\overline{B}_sX) = [25 \pm 3(stat)^{+11}_{-5}(syst)]\%$
- ❑ Belle (using the 1.9 fb^{-1} sample) confirms CLEO results

The $Υ$(5S) resonance is a significant source of B_s mesons for a high luminosity e^+e^- collider

Additional Slides

Model estimate of $\mathcal{B}(B_S \to \phi X)$

- Use CLEO-c inclusive yields (hep-ex/0610008) for

$$\mathcal{B}(D^o \to \phi X) = (1.0 \pm 0.10 \pm 0.10)\%$$
$$\mathcal{B}(D^+ \to \phi X) = (1.0 \pm 0.10 \pm 0.20)\%$$
$$\mathcal{B}(D_S \to \phi X) = (15.1 \pm 2.1 \pm 1.5)\%$$

- Demonstrate that majority of ϕ mesons arise from $B \to D \phi$ and $B \to D_S \to \phi$.

- Predict $\mathcal{B}(B_S \to \phi X) = (14.9 \pm 2.9)\%$

- Consult hep-ex/0610035 for details