Evidence for B_s in $\Upsilon(5S)$ at CLEO and $\Upsilon(4S)$ Studies at BaBar

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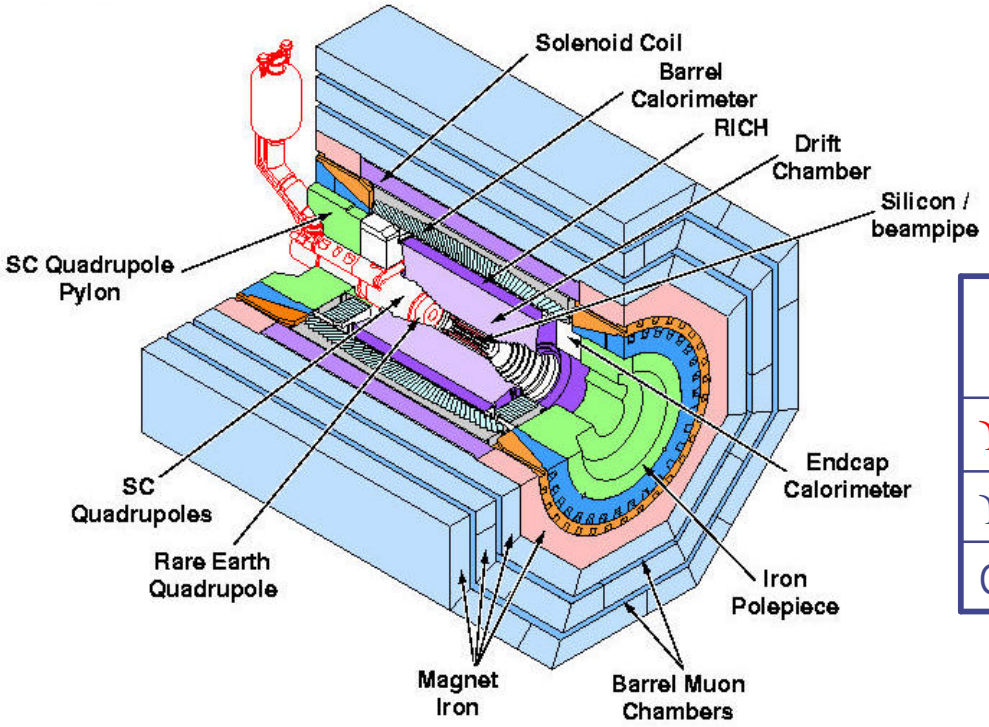
ICHEP'04 August 16-22, 2004, Beijing

Υ(5S) Study at CLEO

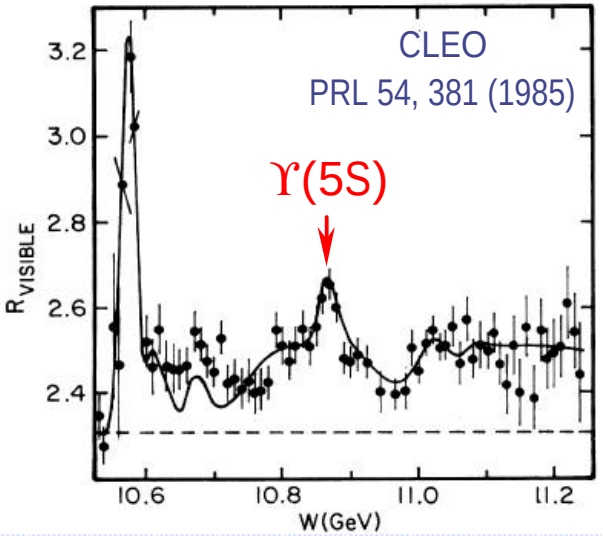
- CLEO studies B_s in both inclusive and exclusive modes.
- Data was taken with the CLEO III detector.



Data set	CM energy (GeV)	Integrated lumin (fb^{-1})
Υ(5S)	10.86	0.42
Υ(4S)	10.58	6.34
Continuum	10.54	2.32

A Brief Introduction of $\Upsilon(5S)$

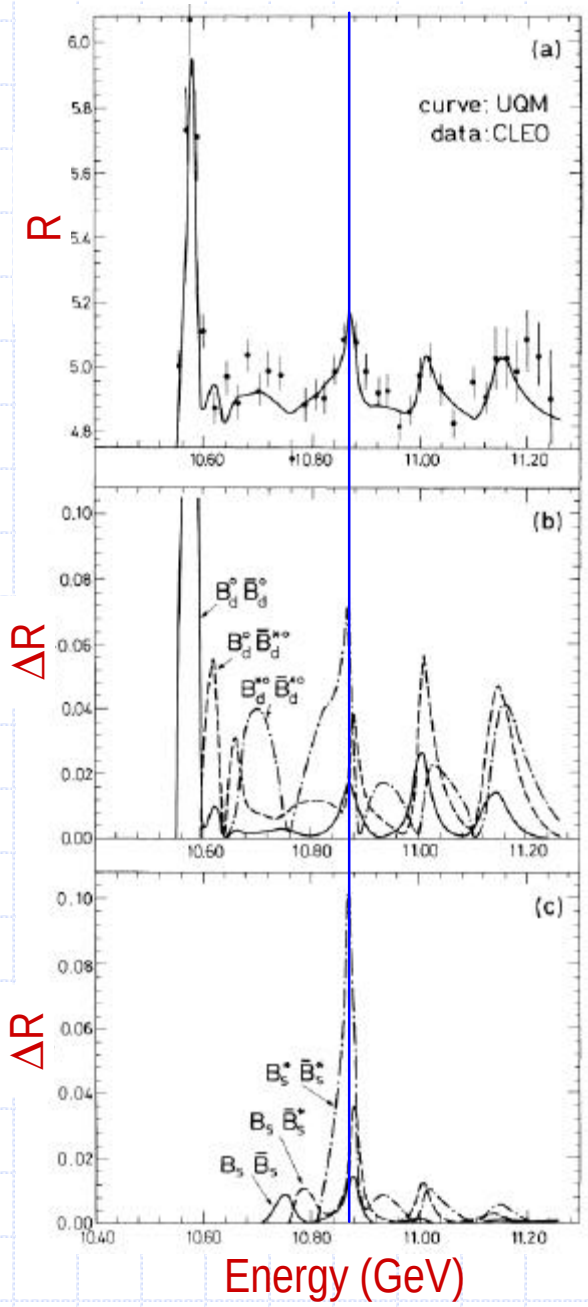
- CLEO & CUSB observed $\Upsilon(5S)$ in 1985.
  M = 10.865±0.008 GeV
  Γ = 110±13 MeV
  $\sigma(\Upsilon(5S))$~0.35 nb, ~1/10×σ(cont).
- The composition of the $\Upsilon(5S)$ needs to be investigated. In PDG only e^+e^- mode is quoted.



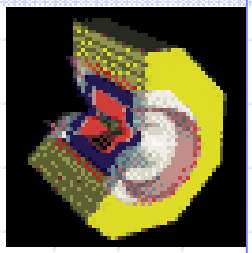
- Dominant hadronic decay modes:
  $(M_{\Upsilon(5S)}-2M_B=307MeV)$: $B\bar{B}$, $B\bar{B}^*$, $B^*\bar{B}^*$, $B\bar{B}p$, $B\bar{B}^*p$, $B^*\bar{B}^*p$, $B\bar{B}pp$ (& c.c.).
  $(M_{\Upsilon(5S)}-2M_{Bs}=126MeV)$: $B_s\bar{B}_s$, $B_s\bar{B}_s^*$, $B_s^*\bar{B}_s^*$.
- CUSB studied Doppler effect of photon in $B_{(s)}^* \rightarrow B_{(s)}^* \gamma$.
- CLEO studied: the shape of the lepton spectrum, inclusive particle yield and exclusive B_s reconstruction.
- With 116 pb^{-1} data there is no strong conclusion on B_s production.

Model Predictions

- The hadronic cross section in the Upsilon region is well described by the Unitarized Quark Model (UQM), which is a coupled channel model (ref: S. Ono *et al*, PRL55, 2938(1985)).
- The UQM predicts that the $B_s^{(*)}\bar{B}_s^{(*)}$ production ~ 1/3 of the total $\Upsilon(5S)$ cross section. And $\Upsilon(5S)$ decays are dominated by $B^*\bar{B}^*$ and $B_s^*\bar{B}_s^*$.
- Other models predict a smaller $\Upsilon(5S)\rightarrow B_s^*\bar{B}_s^*$ component.

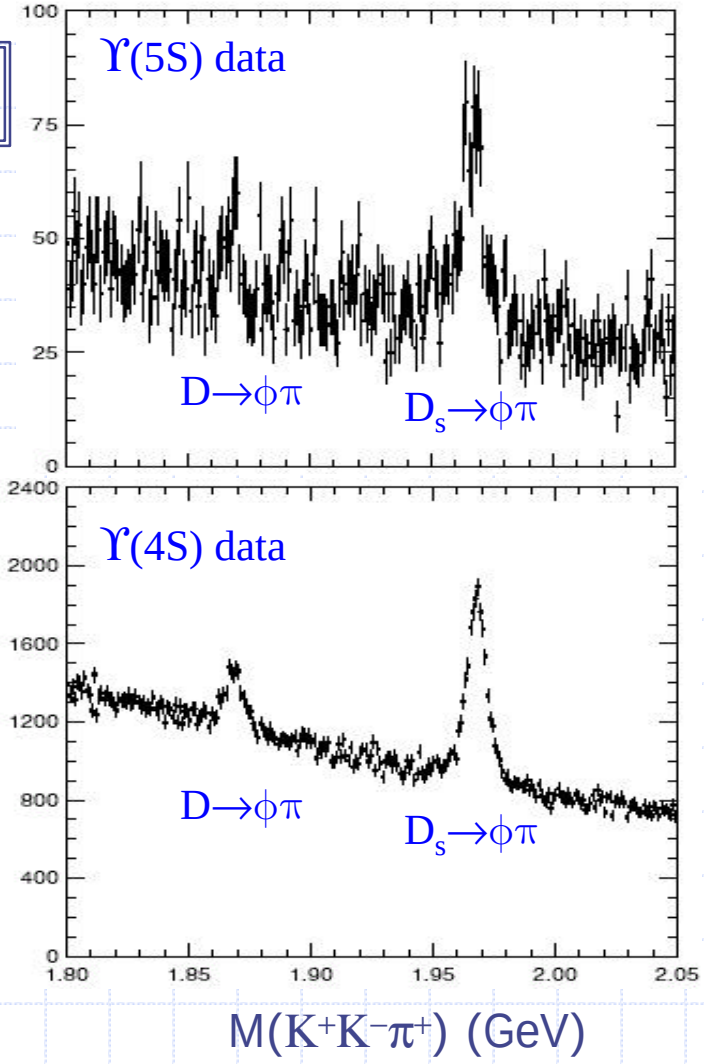


The Inclusive Channel



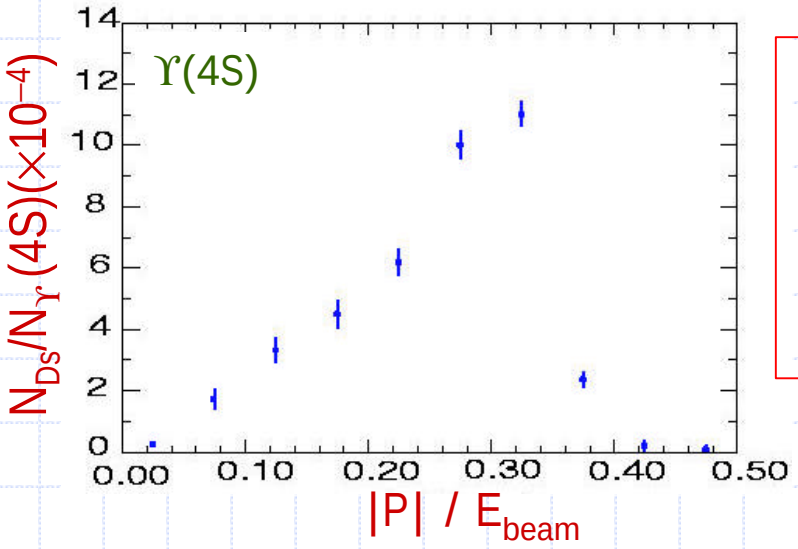
$$\overline{B}_{(s)} \rightarrow D_s^+ X,\ D_s^+ \rightarrow \phi\pi^+,\ \phi \rightarrow K^+K^-$$

- Expect much more D_s in $\Upsilon(5S)$ decays than in $\Upsilon(4S)$ decays:
  - $B(\overline{B} \rightarrow D_s X)$ ~ (10.5±2.6)%
  - $B(\overline{B}_s \rightarrow D_s X)$ ~ 100%
- The $\Upsilon(5S)$, $\Upsilon(4S)$, and continuum data are analyzed to estimate contributions from different sources. In $\Upsilon(5S)$ and $\Upsilon(4S)$ samples ~20% of reconstructed D_s come from continuum.
- D_s yield is measured in different $x=|p|/E_{beam}$ intervals.
- Reconstruction efficiency ~30%.

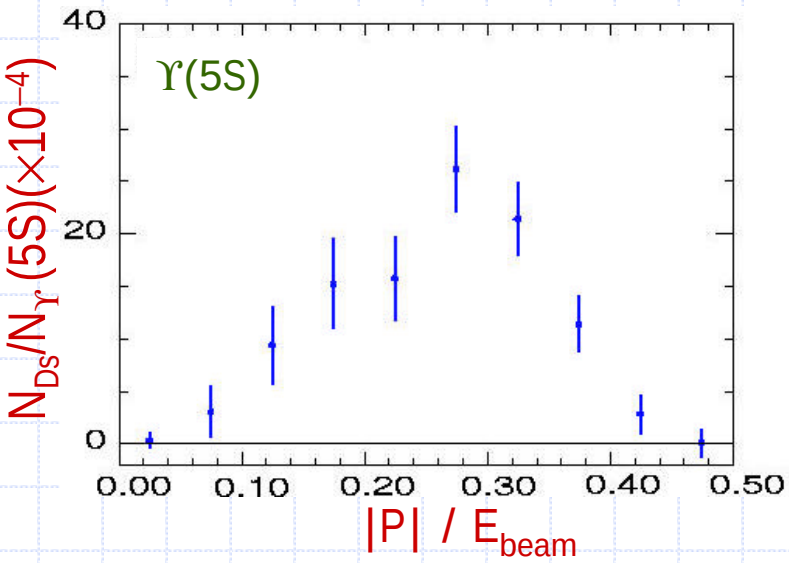


D_s Production in $\Upsilon(4S)$ & $\Upsilon(5S)$ Decays

Continuum subtraction and efficiency correction, no *B* correction in plots



Preliminary



$B\,(\Upsilon(4S)\to D_s X)$ = (22.3±0.7±5.7)%

$B\,(\overline{B}\to D_s X)$ = (11.1±0.4±2.9)%

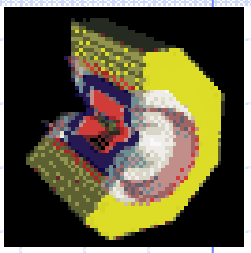
PDG (10.5±2.6)%

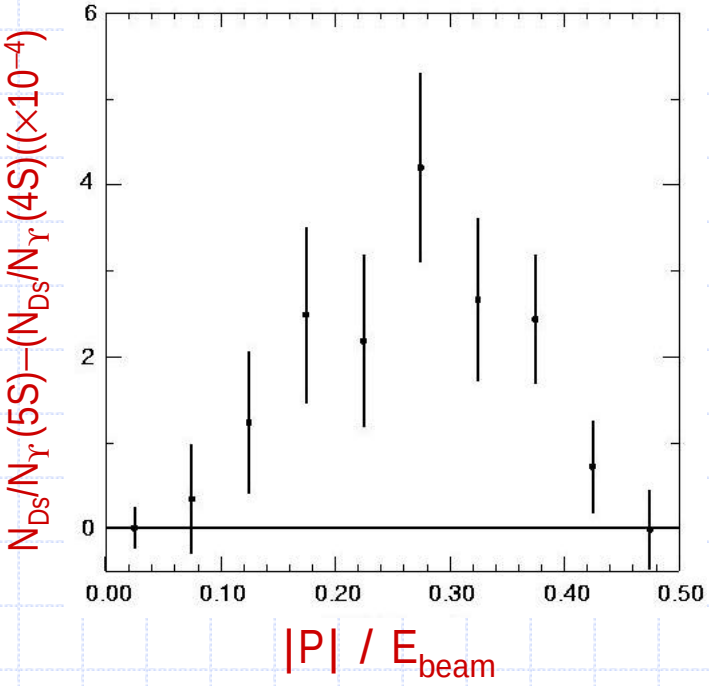
$B\,(\Upsilon(5S)\to D_s X)$ = (55.0±5.2±17.8)%

$B\,(\Upsilon(5S)\to D_s X)/B\,(\Upsilon(4S)\to D_s X)$=2.5±0.3±0.6

The systematic error is dominated by $B\,(D_s\to\phi\pi^+)$ and number of $\Upsilon(5S)$ events.

Evidence of B_s in $\Upsilon(5S)$ Decays





Significant excess of D_s at $\Upsilon(5S)$

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Evidence of B_s production at $\Upsilon(5S)$

B_s decay modes are analogous to the corresponding B decay modes. A model estimate gives

(ref: ICHEP04 ABS11-0778)

$$B(\overline{B}_s \to D_s X) = (92 \pm 11)\%.$$

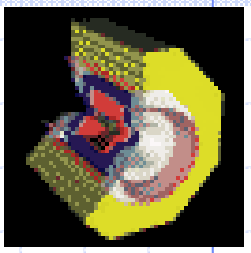
Knowing D_s production rate in $\Upsilon(5S)$, B, and B_s decays ➡

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

consistent with phenomenological predictions.

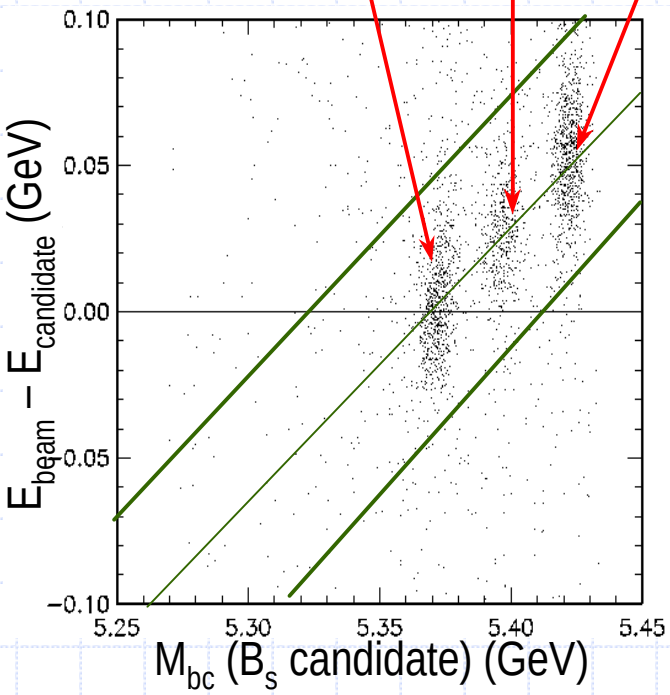
Preliminary

Exclusive B_s Reconstruction

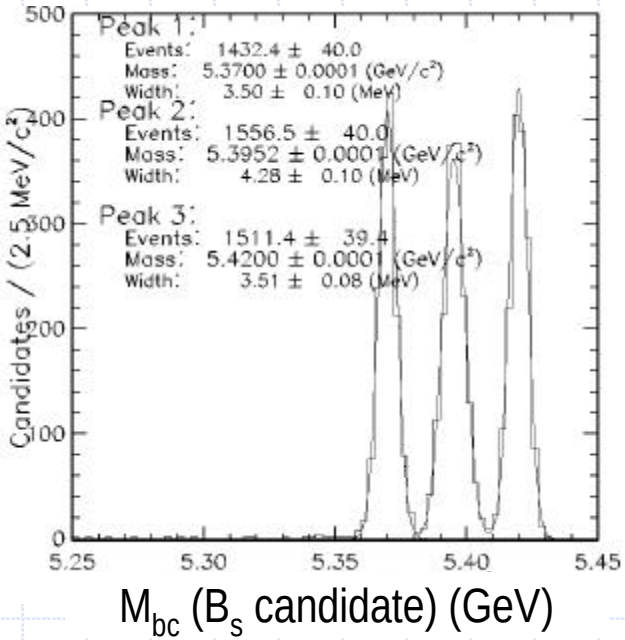


- The B reconstruction techniques used at $\Upsilon(4S)$ are employed to reconstruct B_s from $\Upsilon(5S)$: $M_{bc} = \sqrt{E_{beam}^2 - P_{candidate}^2}$, $\Delta E = E_{beam} - E_{candidate}$
- Three sources of B_s produce three distinct distributions.

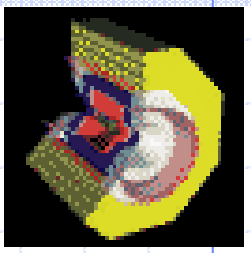
$\Upsilon(5S) \to B_s\overline{B_s}$, $B_s\overline{B_s^*}$, $B_s^*\overline{B_s^*}$ B ($B_s^* \to B_s\gamma$) ~100%



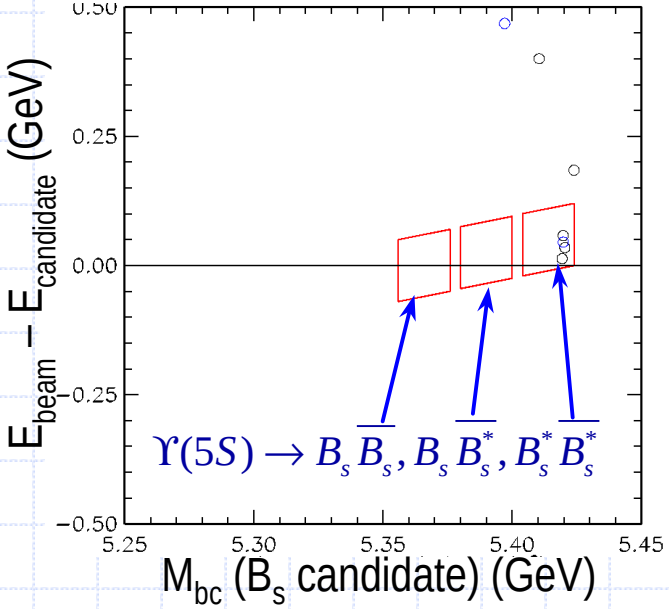
MC



Exclusive B_s Signals At $\Upsilon(5S)$

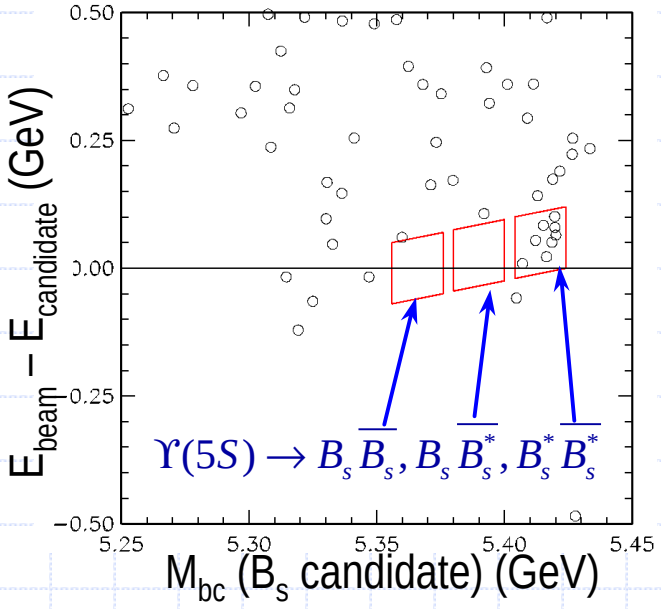


$B_s \to J/\psi\,\phi/\eta'/\eta$, $J/\psi \to \mu^+\mu^-, e^+e^-$
$\phi \to K^+K^-$, $\eta' \to \eta\,\pi^+\pi^-$, $\eta \to \gamma\gamma$



Preliminary

$\bar{B}_s \to D_s^{(*)}\,\pi^-/\rho^-$, $D_s^* \to D_s\gamma$
$D_s \to K^+K^0$, K^+K^{*0}, $\phi\pi^+$, $\phi\rho^+$

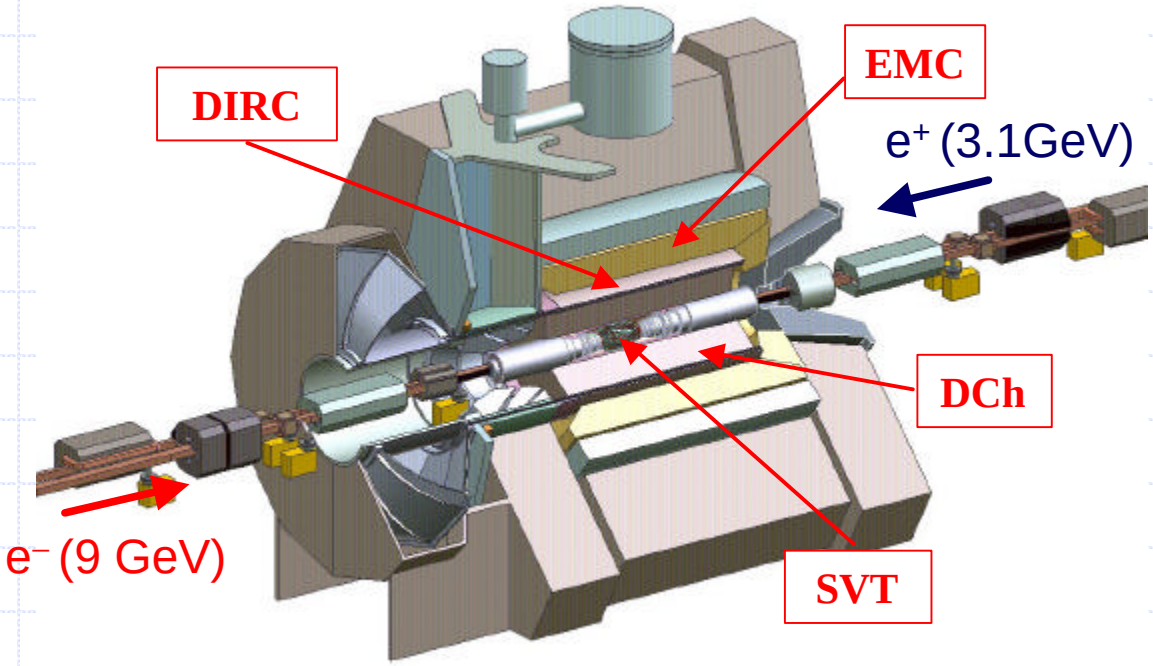


$N_{signal} = 4$, $N_{bkg} \le 0.1$

$N_{signal} = 8$, $N_{bkg} \le 1$

$\Upsilon(5S)$ decay to $B_s^{(*)}\bar{B}_s^{(*)}$ is dominated by $B_s^*\bar{B}_s^*$ mode.

$\Upsilon(4S)$ Studies at BaBar



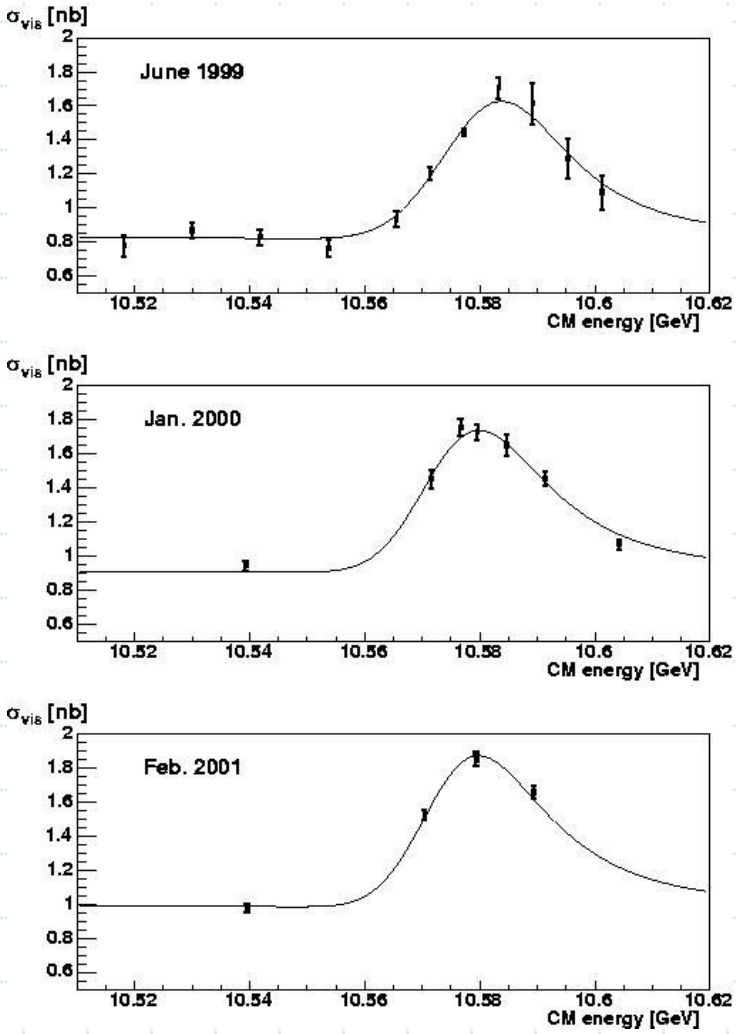
- Three $\Upsilon(4S)$ scans and one $\Upsilon(3S)$ scan are used in the measurement of the $\Upsilon(4S)$ resonance parameters.
- 81.7 fb^{-1} $\Upsilon(4S)$ data are used in the measurement of $\mathcal{B}(\Upsilon(4S)\rightarrow B^0\overline{B}^0)$.

Measurement of $\Upsilon(4S)$ Parameters

- The current mass and width of $\Upsilon(4S)$ are with large uncertainty. It can be improved.
- The $\Upsilon(4S)$ resonance parameters can be determined by measuring the energy dependence of the cross section $\sigma_{b\bar{b}}$ and fitting to a line-shape function.
  - Relativistic Breit-Wigner function.

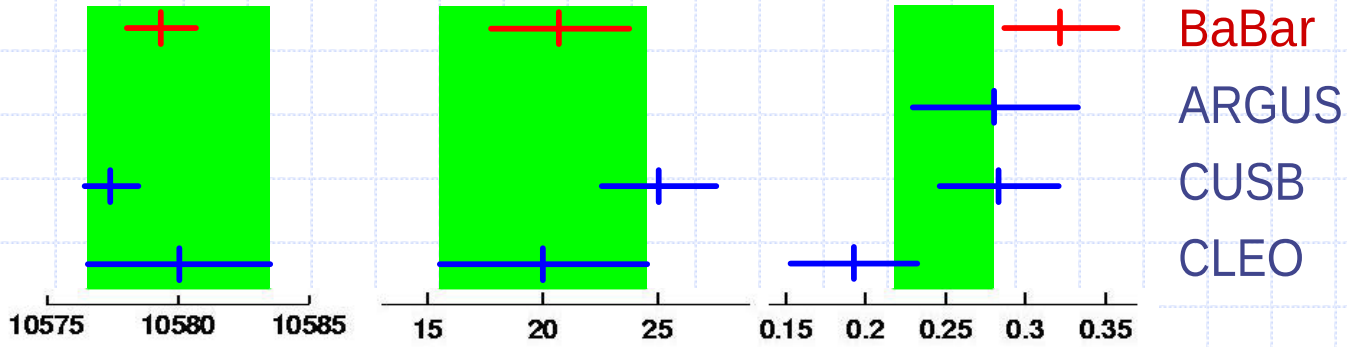
$$s_0(s) = 12p \frac{\Gamma_{ee}^0 \Gamma_{tot}(s)}{\left(s - M^2\right)^2 + M^2 \Gamma_{tot}^2(s)}$$

  - Radiation correction.
  - Beam energy spread correction.
- The $\Upsilon(3S)$ scan is used to measure energy spread and calibrate energy.
- Large sample of data around $\Upsilon(4S)$ peak is used to determine the peak cross-section.



The $\Upsilon(4S)$ Parameters

(For details of BaBar measurement see: B. Aubert, *et al*., hep-ex/0405025)



	Mass (MeV)	Γ_{tot} (MeV)	Γ_{ee} (keV)
BaBar	10579.3 ± 0.4 ± 1.2	20.7 ± 1.6 ± 2.5	0.321 ± 0.017 ± 0.029
ARGUS	—	—	0.28 ± 0.05 ± 0.01
CUSB	(*10577.4 ± 1.0*)	(*25 ± 2.5*)	0.283 ± 0.037
CLEO	10580.0 ± 3.5	20 ± 2 ± 4	0.192 ± 0.007 ± 0.038
PDG	10580.0 ± 3.5	20 ± 2 ± 4	0.248 ± 0.031

Measurement of $B(\Upsilon(4S)\to B^0\bar{B}^0)$

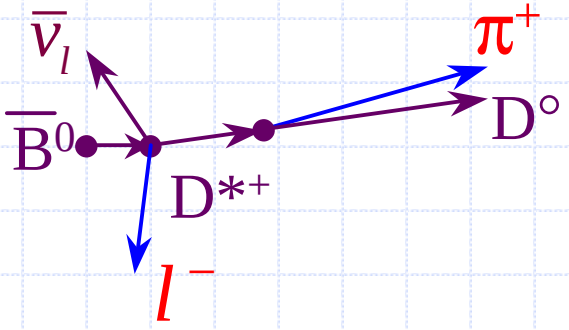
- Status of $R^{+/0} \equiv f_{+-}/f_{00} \equiv B(\Upsilon(4S)\to B^+B^-) / B(\Upsilon(4S)\to B^0\bar{B}^0)$:
  - Theoretical predications range from 1.03 to 1.25.
  - Current PDG value (1.029±0.054±0.045) consistent with unity.
  - Precise measurement will re-normalize many B decay branching fractions, and contribute to our understanding of isospin violation.
- BaBar uses single and double tag $\bar{B}^0 \to D^{*+} l \bar{\nu}_l$ events to measure f_{00}.

$$N_s = 2N_{B\bar{B}} f_{00} e_s B(\bar{B}^0 \to D^{*+} l \bar{\nu}_l),$$

$$N_d = N_{B\bar{B}} f_{00} e_d \left[B(\bar{B}^0 \to D^{*+} l \bar{\nu}_l)\right]^2.$$

$$\Rightarrow \quad f_{00} = \frac{N_s^2}{4 N_d N_{B\bar{B}}} \times \frac{e_d}{e_s^2} \quad = 1$$

- Only slow π^+ (60MeV < P < 200MeV) and l^- (1.5GeV < P < 2.5 GeV) detected.

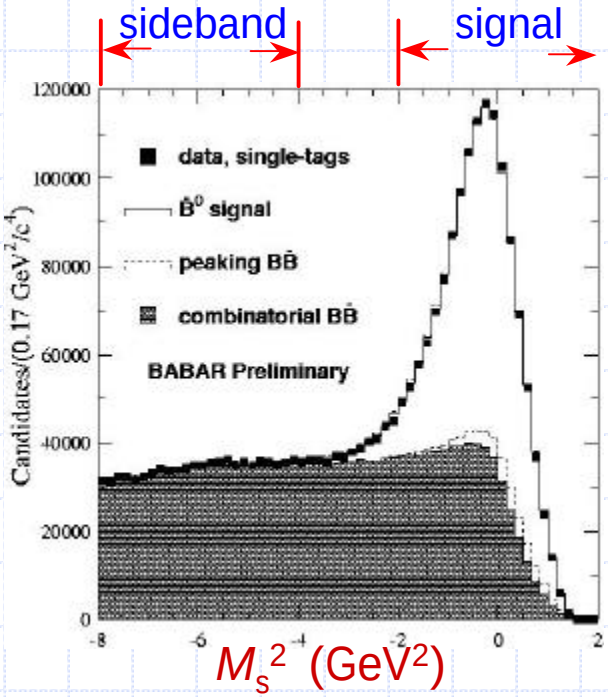


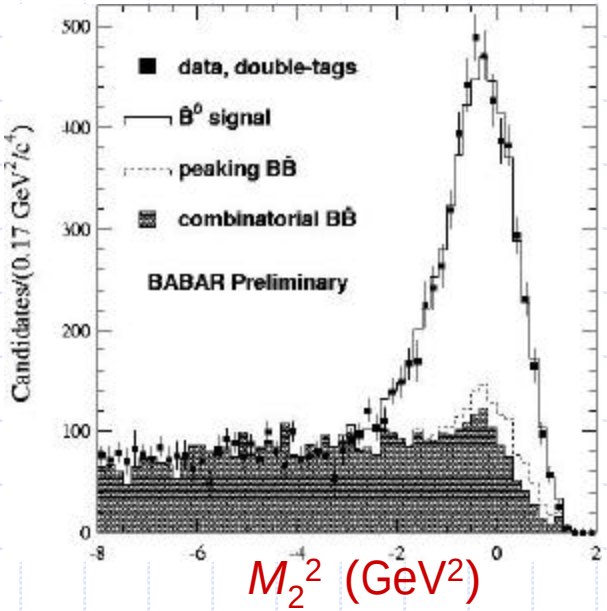
$$\vec{P}_{D^*} = (c_1 P_p + c_2)\frac{\vec{P}_p}{P_p},$$

$$M^2 \equiv (E_{beam} - E_{D^*} - E_l)^2 - (\vec{P}_{D^*} + \vec{P}_l)^2.$$

Event Samples

- PDF of Signal, combinatorial and peaking $B\bar{B}$ bkg are determined from MC simulation. The continuum bkg are subtracted using continuum data.
- Double tag sample contains extra bkg from combinatorial and peaking $B\bar{B}$ in selecting the first one. These are subtracted using sideband.





The Measurement of f_{00}

Source	M_s^2	M_2^2
Combinatorial $B\overline{B}$	558090 ± 760	1520 ± 40
Peaking $B\overline{B}$	68170 ± 260	300 ± 20
Signal	786300 ± 2000	3560 ± 80
Continuum	238500 ± 1300	160 ± 40
M_1^2-combinatorial	—	180 ± 20
M_1^2-peaking	—	60 ± 10
χ^2/d.o.f.	41/56	48/56
Confidence level	93%	77%

$$f_{00} = 0.486 \pm 0.010 \pm 0.009$$

The measurement is independent on B (decay chain), reconstruction efficiency, τ_{B+}/τ_{B0}, or assumption of isospin symmetry.

(ref: B. Aubert, *et al.*, hep-ex/0408022)

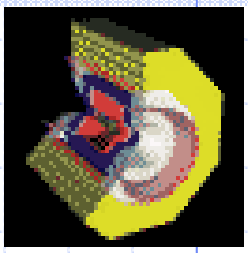
Summary

- CLEO studied B_s in both inclusive and exclusive modes. They found evidence for $B_s^{(*)}\overline{B}_s^{(*)}$ production at the $\Upsilon(5S)$, dominated by $B_s^*\overline{B}_s^*$ mode.
  - $\mathcal{B}(\Upsilon(4S)\to D_sX) = (22.3\pm0.7\pm5.7)\%$
  - $\mathcal{B}(\overline{B}\to D_sX) = (11.1\pm0.4\pm2.9)\%$
  - $\mathcal{B}(\Upsilon(5S)\to D_sX) = (55.0\pm5.2\pm17.8)\%$
  - $\mathcal{B}(\Upsilon(5S)\to D_sX)/\mathcal{B}(\Upsilon(4S)\to D_sX) = 2.5\pm0.3\pm0.6$
  - $\mathcal{B}(\Upsilon(5S)\to B_s^{(*)}\overline{B}_s^{(*)}) = (21\pm3\pm9)\%$, model dependent

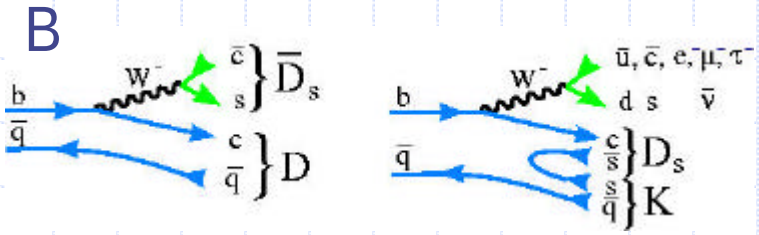
  Preliminary
- The BaBar had measured $\Upsilon(4S)$ parameters:
  - $M = (10579.3\pm0.4\pm1.2)$ MeV,
  - $\Gamma_{tot} = (20.7\pm1.6\pm2.5)$ MeV,
  - $\Gamma_{ee} = (0.321\pm0.017\pm0.029)$ keV.
- The BaBar measured $\mathcal{B}(\Upsilon(4S)\to B^0\overline{B}^0) = 0.486\pm0.010\pm0.009$.

Backup Slides

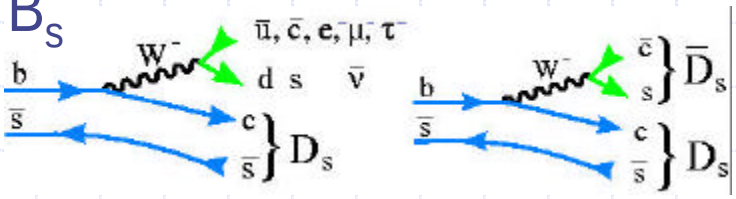
MC Expectation & Feynman Diagram

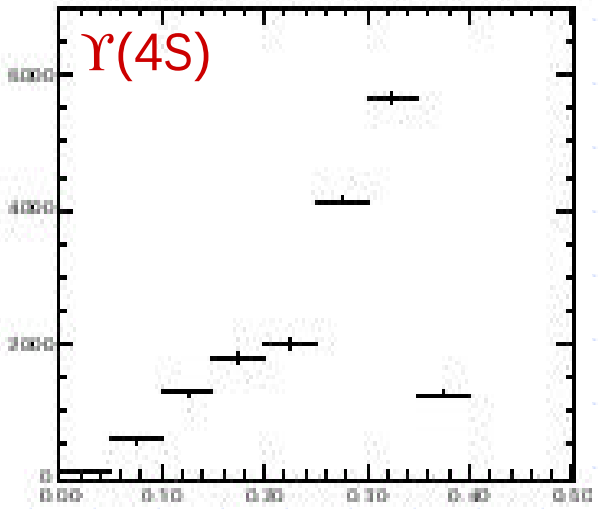


B

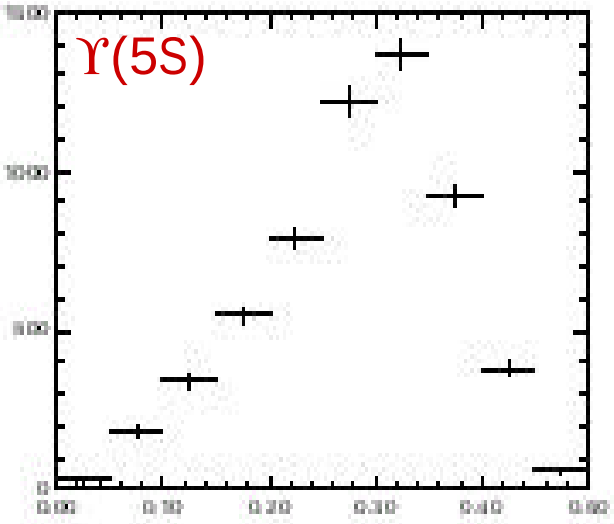


B_s

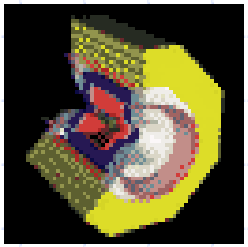




$|P_{Ds}| / E_{beam}$



$|P_{Ds}| / E_{beam}$



B_s Exclusive Modes

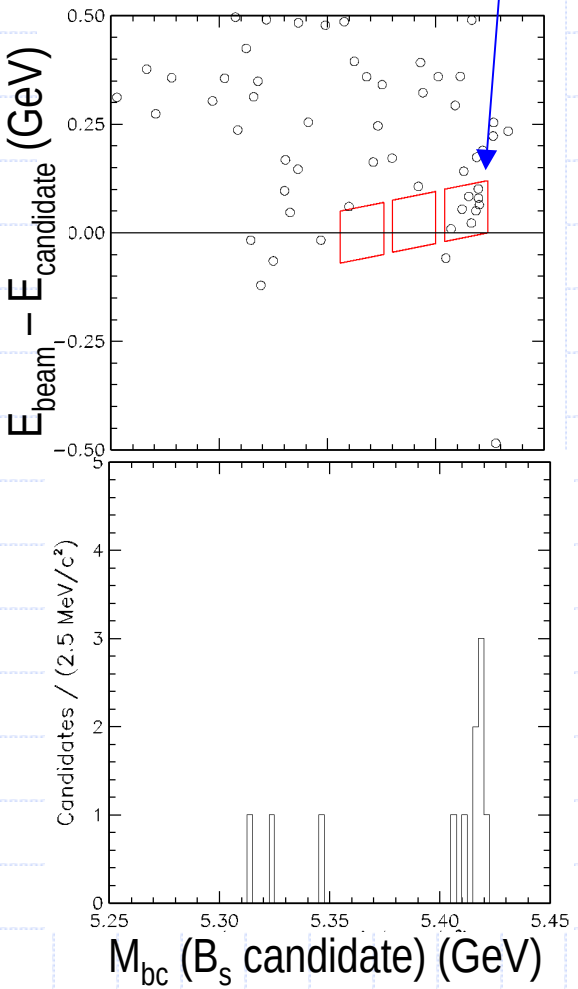
$\Upsilon(5S) \to B_s \overline{B_s}, \quad B_s \overline{B_s^*}, \quad B_s^* \overline{B_s^*}$

B_s decays estimated from B decays.

Decay Mode	$B \times 10^{-3}$	Events
$B_s \to D_s \pi^-$	3.0±0.4	2
$B_s \to D_s \rho^-$	7.8±1.4	4
$B_s \to D_s^* \pi^-$	2.8±0.2	1
$B_s \to D_s^* \rho^-$	7.3±1.5	1

$Ds^{(*)}$ decays

Decay Mode	$B \times 10^{-3}$
$D_s \to K^+ K^0$	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



$\Upsilon(4S)$ Parameter Systematic Errors

TABLE I: Summary of systematic uncertainties

	$\delta\Gamma_{\rm tot}$ (MeV)	$\delta\Gamma_{ee}$ (keV)	$\delta B_{ee} \times 10^2$	δM (MeV/c^2)
model uncertainty	1.4	0.017	0.03	0.1
systematic bias by single data point	2.0	0.022	0.04	0.3
uncertainty of energy spread	0.5	0.0024	0.03	< 0.1
uncertainty of peak cross section	< 0.1	0.006	0.03	< 0.1
long term drift of energy scale	-	-	-	1.0
error on $M_{\Upsilon(4S)}$	-	-	-	0.5
total error	2.5	0.029	0.07	1.2

Systematic Error for f_{00}

$$f_{00} = 0.486 \pm 0.010 \pm 0.009$$

Source	$\delta(f_{00})$
$\mathcal{M}_{\mathrm{ES}}^2$-combinatorial	0.0005
$\mathcal{M}_{\mathrm{ES}}^2$-peaking	0.0005
Same charged events	0.0025
Peaking background	0.004
B-meson counting	0.0055
$\Upsilon(4S) \to$ non-$B\overline{B}$	0.0025
Efficiency correlation	0.004
Monte Carlo statistics	0.002
Total	0.009