CLEO Studies of $\Upsilon(5S)$
+ Search for the Λ_b Production Threshold

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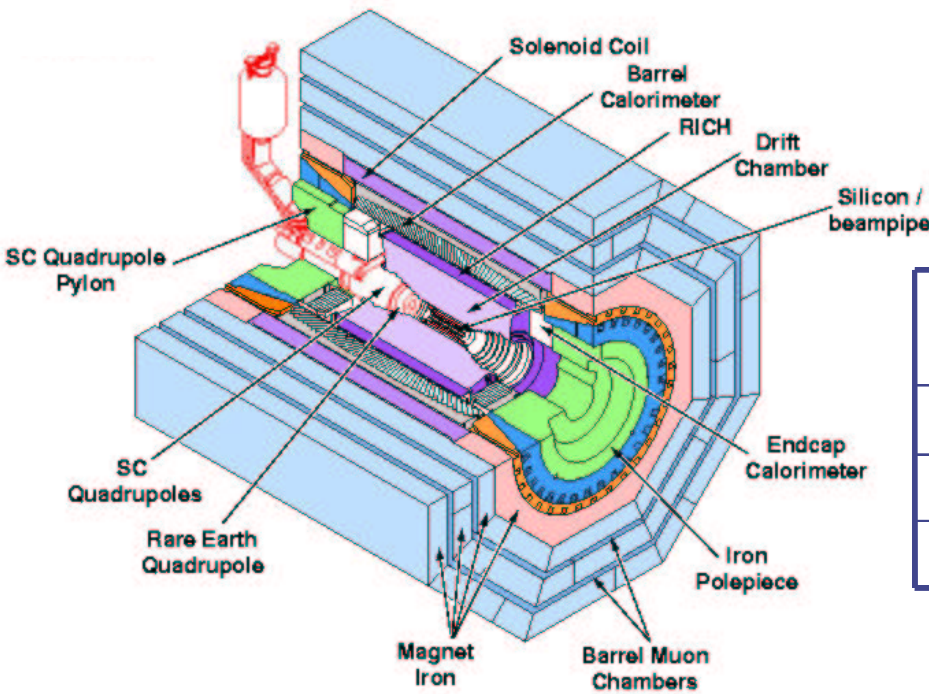
Outline

- Study of $B_s^{(*)}B_s^{(*)}$ Production at the Υ(5S)
- Evidence for Inclusive Production of $B_s^{(*)}$
- Exclusive Reconstruction of $B_s^{(*)}$
- Search for the Λ_b Production Threshold
- Conclusions

$\Upsilon(5S)$ 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})
$\Upsilon(5S)$	10.86	0.42
$\Upsilon(4S)$	10.58	6.34
Continuum	10.54	2.32

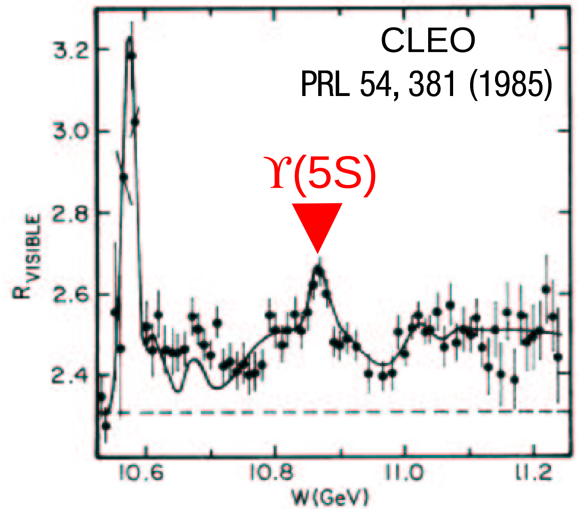
A Brief Introduction to ϒ(5S)

- CLEO & CUSB observed ϒ(5S) in 1985.

  M = 10.865±0.008 GeV

  Γ = 110±13 MeV

  σ(ϒ(5S)) ~ 0.35 nb ~ 0.1×σ(cont)



- Dominant hadronic decay modes:

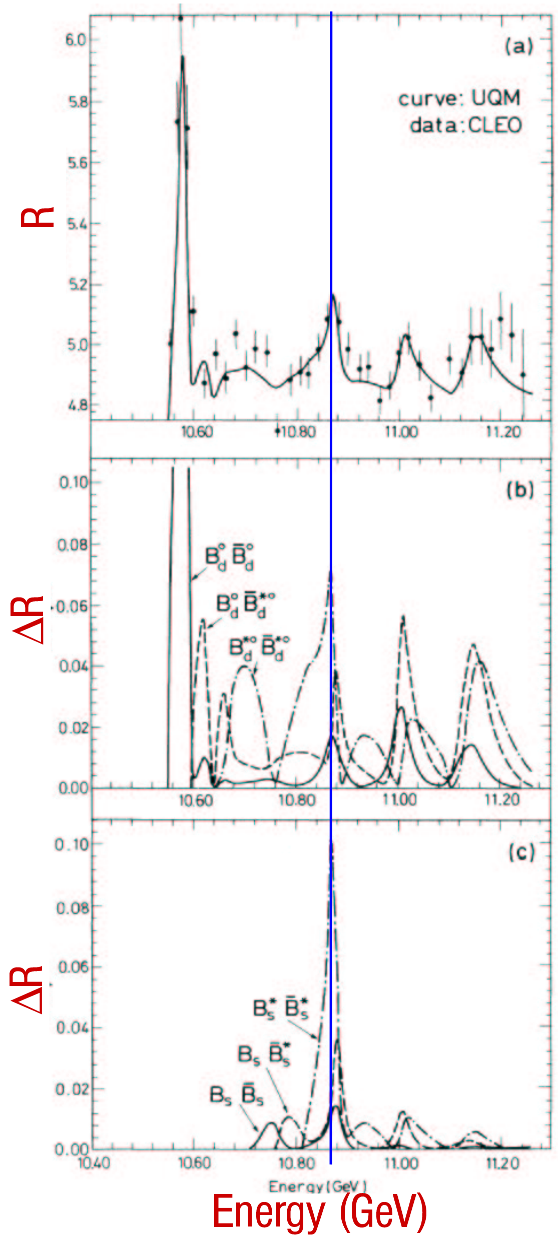
  ($M_{\Upsilon(5S)}-2M_B$=307MeV): $B\bar{B}$, $B\bar{B}^*$, $B^*\bar{B}^*$, $B\bar{B}\pi$, $B\bar{B}^*\pi$, $B^*\bar{B}^*\pi$, $B\bar{B}\pi\pi$ (& c.c.)

  ($M_{\Upsilon(5S)}-2M_{Bs}$=126MeV): B_sB_s, $B_sB_s^*$, $B_s^*B_s^*$.

- 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.
- Only 116 pb^{-1} of data --> no conclusive evidence of B_s production
- The composition of the ϒ(5S) needs to be investigated (PDG only quotes e^+e^- mode)

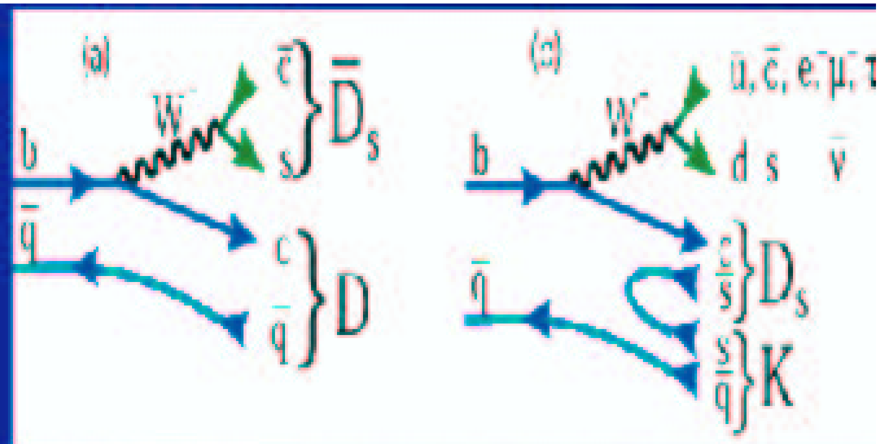
Model Predictions

- 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 $B_s^{(*)}B_s^{(*)}$ production ~ 1/3 of the total ϒ(5S) cross section. And ϒ(5S) decays are dominated by B*B* and $B_s^*B_s^*$.
- Other models predict a smaller $\Upsilon(5S)\rightarrow B_s^*B_s^*$ component.



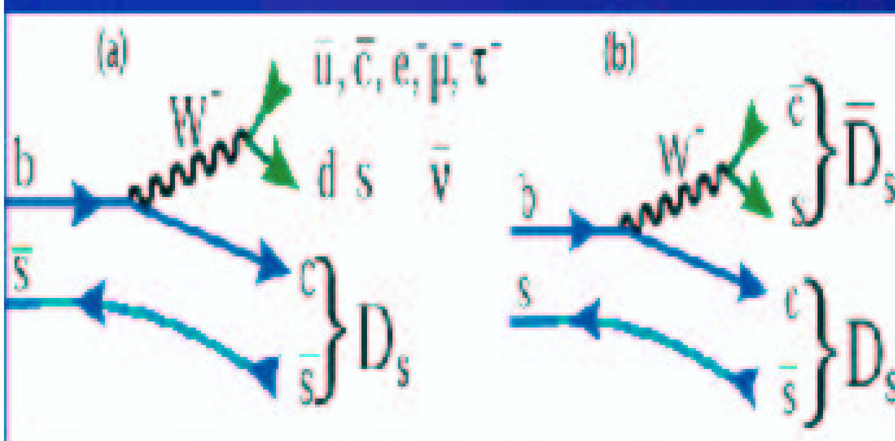
The Inclusive Channel

In the simple spectator model the B_s decays into the D_s nearly all the time. Since the $B(B \to D_s X)$ has already been measured to be $(10.5 \pm 2.6 \pm 2.5)\%$,



Dominant Decay Diagrams for a B meson into D_s meson

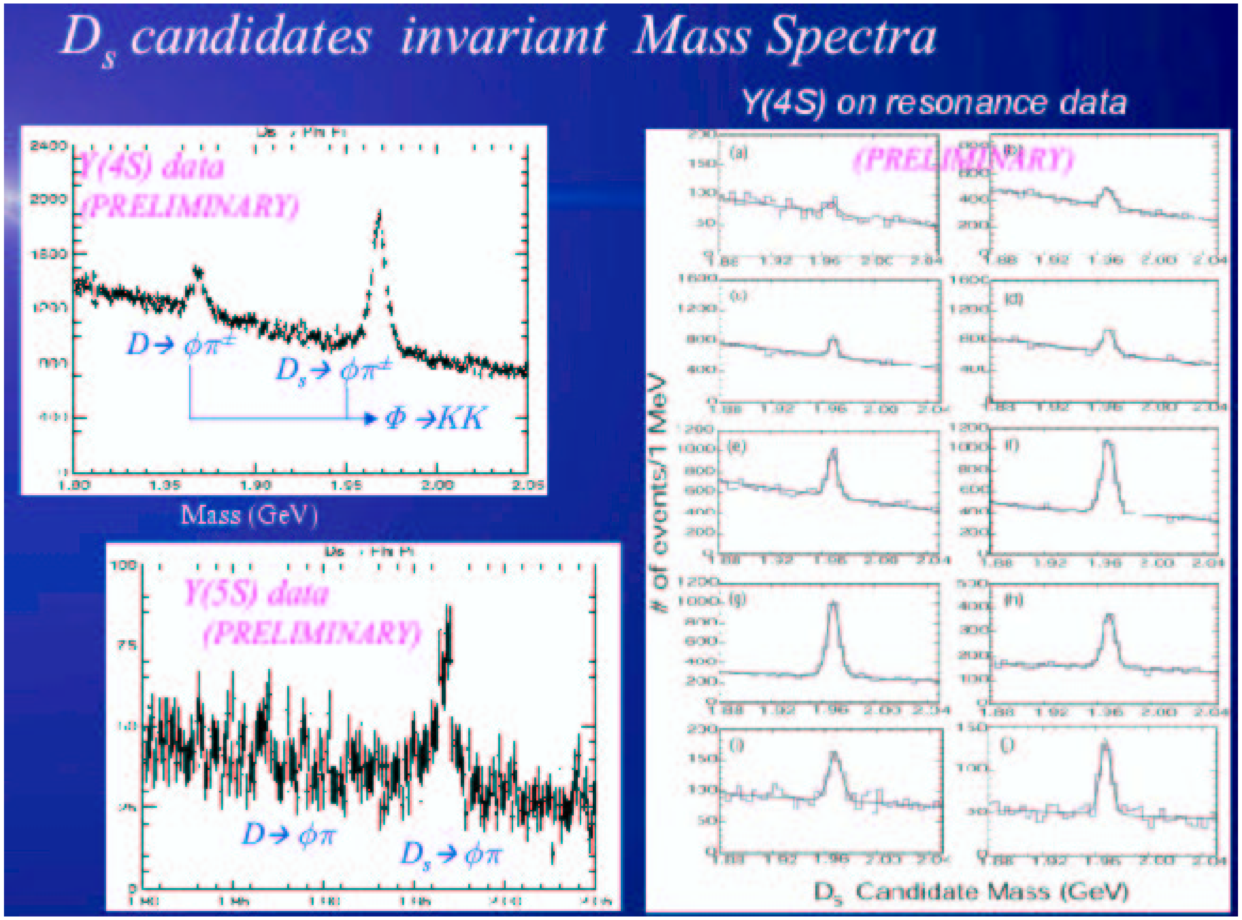
B_s



we expect a large difference between the D_s yields at the Y(5S) and the Y(4S) that can lead to an estimate of the size of the $B_s^{(*)}\bar{B}_s^{(*)}$ component at the Y(5S).

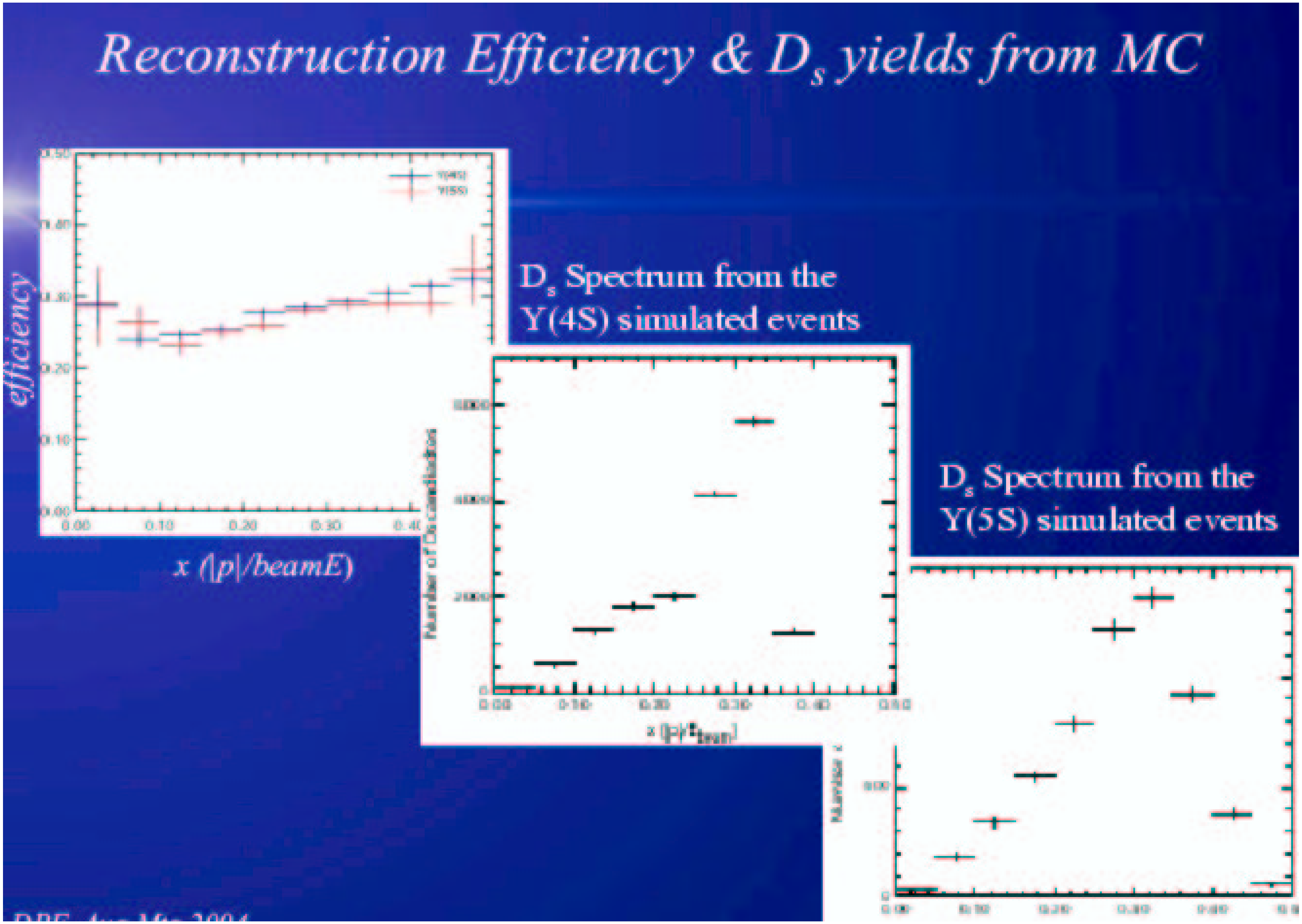
The Inclusive Channel

- **Expect more D_s in Υ(5S) decays than in Υ(4S) decays:**
- **$\mathcal{B}(B \to D_s X) \sim (10.5 \pm 2.6)\%$**
- **$\mathcal{B}(B_s \to D_s X) \sim 100\%$**
- Υ(5S), Υ(4S), and continuum data are analyzed to estimate contributions from different sources. In Υ(5S) and Υ(4S) samples ~20% of reconstructed D_s come from continuum

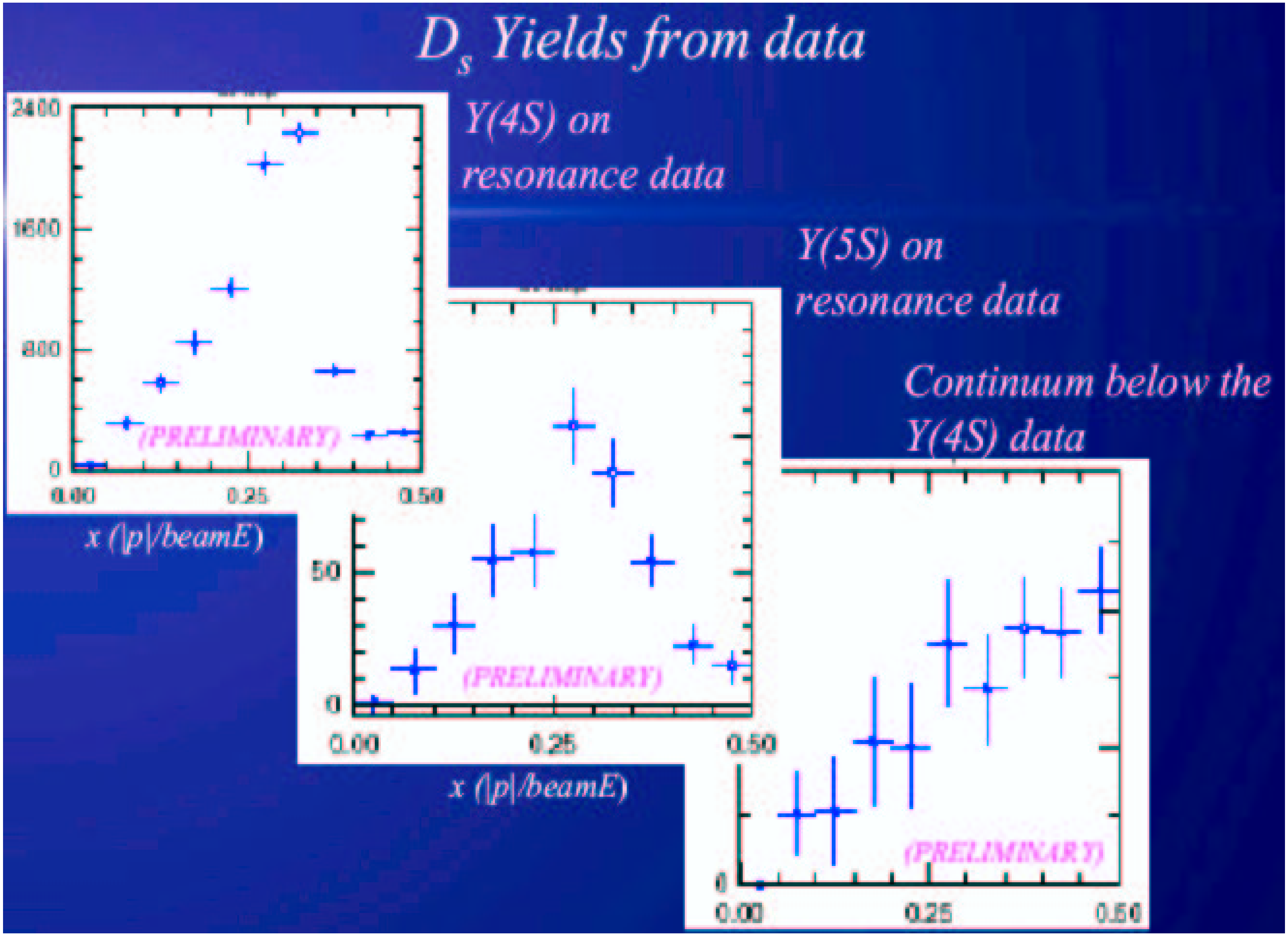


- D_s yield is measured in different $x = |p|/E_{beam}$ intervals
- Reconstruction efficiency ~30%

The Inclusive Channel: MC

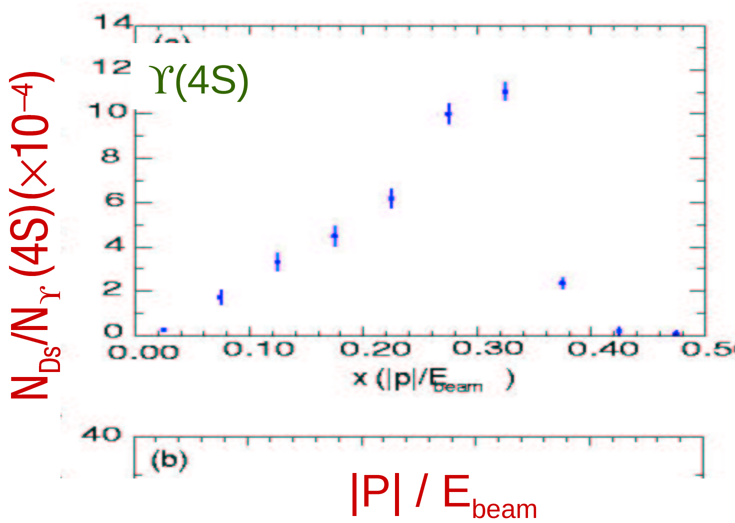


The Inclusive Channel: Data

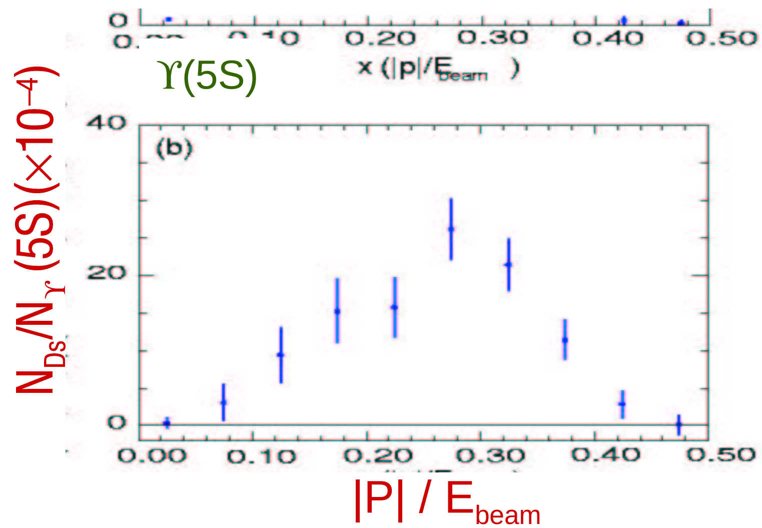


D_s Production in Υ(4S) & Υ(5S) Decay

Continuum subtraction and efficiency correction, no $\mathcal{B}$ correction in plots



Preliminary



$\mathcal{B}(\Upsilon(4S)\to D_sX)$ = (22.3±0.7±5.7)%

$\mathcal{B}(\bar{B}\to D_sX)$ = (11.1±0.4±2.9)%

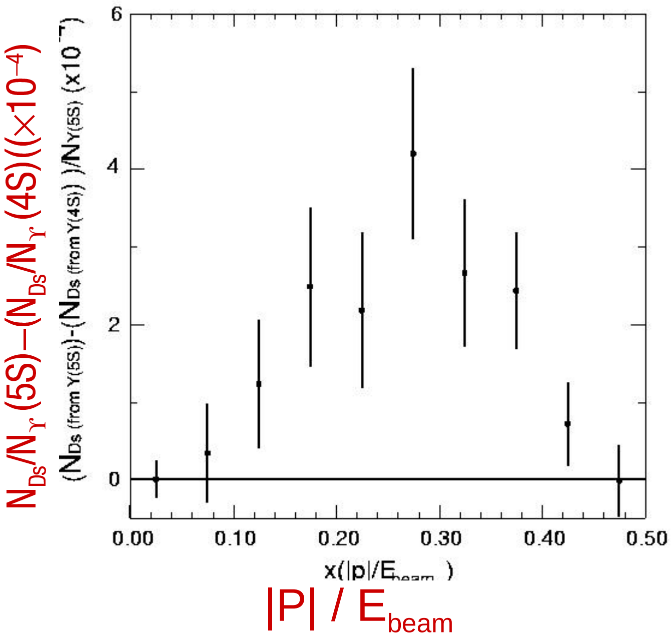
PDG (10.5±2.6)%

$\mathcal{B}(\Upsilon(5S)\to D_sX)$ = (55.0±5.2±17.8)%

$\mathcal{B}(\Upsilon(5S)\to D_sX)/\mathcal{B}(\Upsilon(4S)\to D_sX)$=2.5±0.3±0.6

Systematic error dominated by $\mathcal{B}(D_s\to \phi\pi)$ and number of Υ(5S) events.

Evidence for B_s at the $\Upsilon(5S)$



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

$$\mathcal{B}(B_s \rightarrow D_s X) = (92 \pm 11)\%.$$

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

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

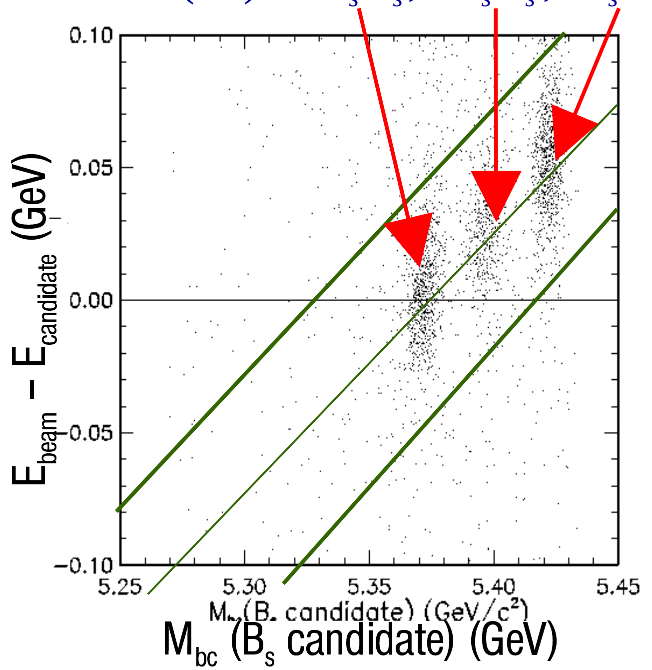
consistent with phenomenological predictions.

Preliminary

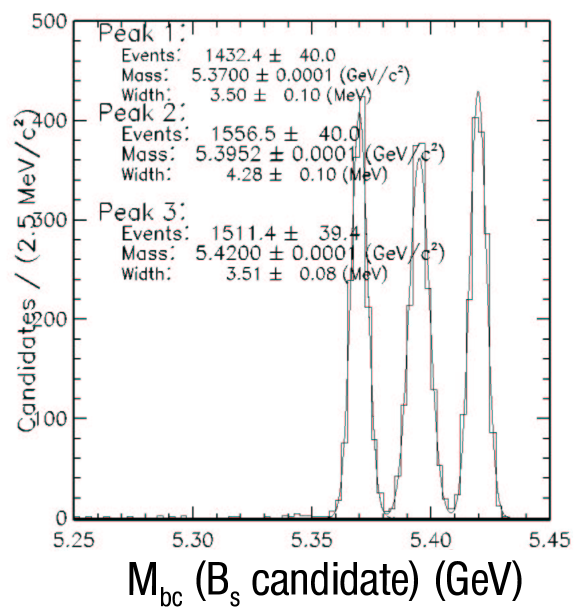
Exclusive B_s Reconstruction

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

$\Upsilon(5S) \to B_s \overline{B}_s, \quad B_s \overline{B}_s^*, \quad B_s^* \overline{B}_s^*$ $\quad \mathcal{B}(B_s^* \to B_s \gamma) \sim 100\%$



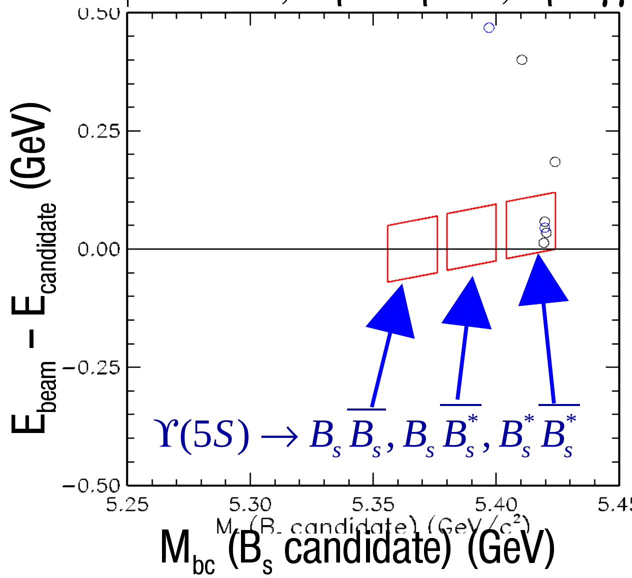
MC



Exclusive B_s Signals at the $\Upsilon(5S)$

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

$\phi \to K^+K^-$, $\eta' \to \eta\pi^+\pi^-$, $\eta \to \gamma\gamma$

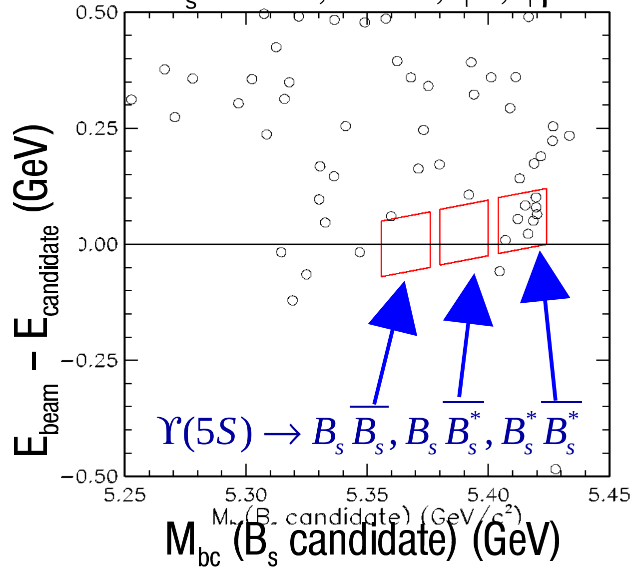


$N_{signal} = 4$, $N_{bkg} \leq 0.1$

Preliminary

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

$D_s \to K^+K^0$, K^+K^{*0}, $\phi\pi$, $\phi\rho$



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

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

Results on B_s Preliminary

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

CLEO III: Search for Λ_b Production in e^+e^- Collisions Near Threshold

- Motivation.
- Search techniques for Λ_b
  - Measure σ_{bb}
  - Look for "bumps"
  - Find characteristics of Λ_b decay
    - Correlated protons, leptons, Λ
- Measurement of R in scan range.
- Summary

Motivation

- Λ_b is the lightest *b* -flavored baryon (*b u d*)
- Recently CDF presented new, improved measurements of Λ_b

$$M(\Lambda_b) = (5620.4 \pm 1.6 \pm 1.2)\ \text{MeV}$$

- No measurements exist on the direct production of Λ_b in e^+e^- annihilation

Data Sample and MC

Energy Region: from 5.575 GeV to 5.691 GeV with 3 MeV increment.

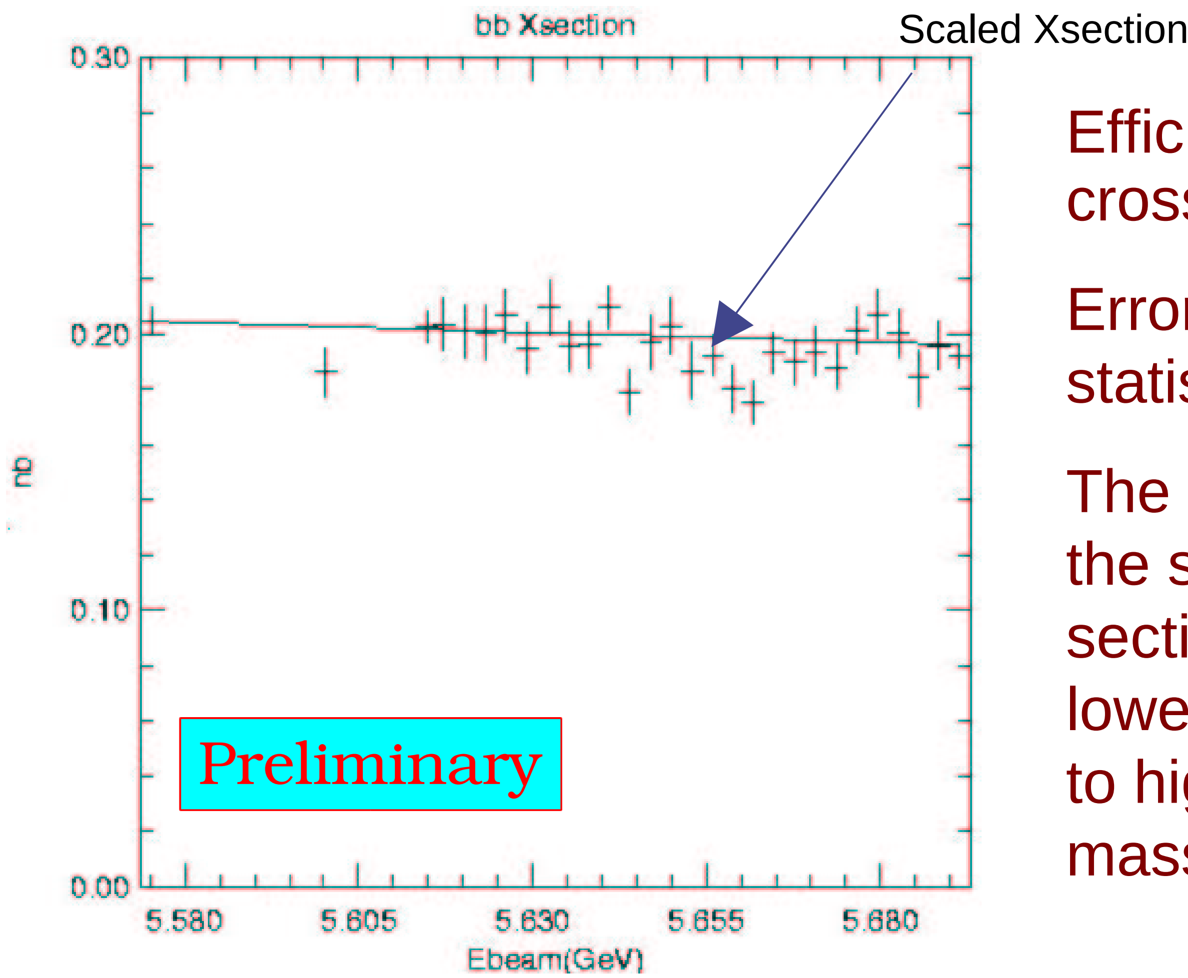
Total Luminosity 710 pb^{-1}.

We used CLEO III $\Upsilon(4S)$ data to cross check the performance of our methods.

We used $\Upsilon(4S)$ CLEO MC farms.

For higher energy region we created MC using Jetset 7.4 with default parameters.

bb Cross Section Near Threshold



Efficiency corrected cross section

Error bars are statistical only

The line represents the scaled cross section from the lower energy region to higher by center mass energy

Particle selection

Proton : Good track,

dE/dX and RICH

Electron : Good track,

dE/dX, RICH, E/p

Muon : Good track,

Muon Chamber hits

$\Lambda \to p\pi^-$

Efficiencies

	#p /event (%)
Off 4S	$4.96 \pm 0.02 \pm 0.10$
Λ_b (MC)	$46.1 \pm 0.1 \pm 4.6$
bb(MC)	$8.23 \pm 0.21 \pm 0.16$
4qq(MC)	$4.3 \pm 0.2 \pm 0.09$

	#Λ /event (%)
Λ_b (MC)	$12.1 \pm 0.9 \pm 0.24$
5qq(MC)	$1.16 \pm 0.03 \pm 0.02$

Errors for *b* and Λ_b type of event selection

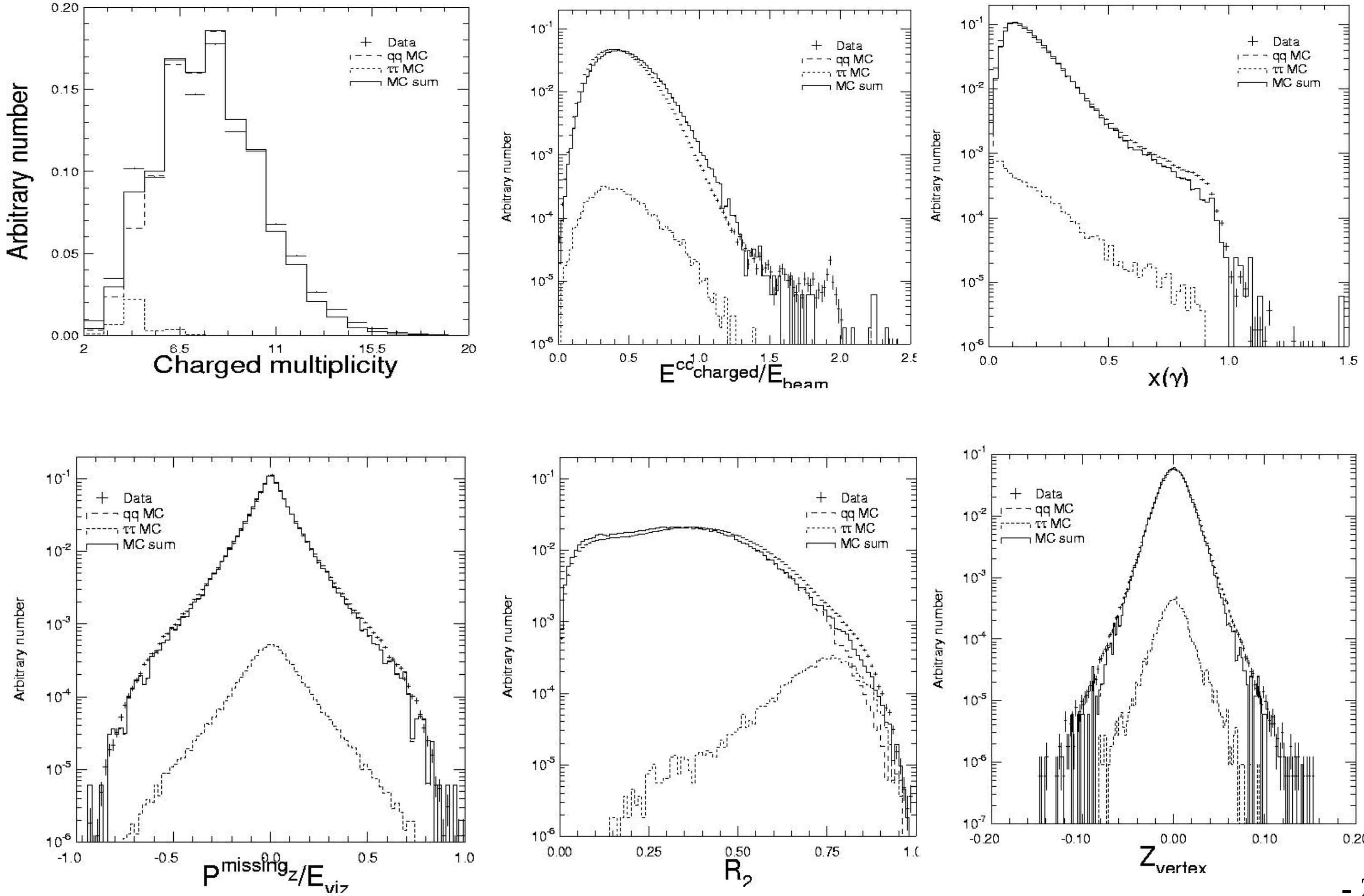
- Luminosity 2%
- Statistical from 0.1 to 2 %
- Systematic on hadron selection efficiency 2 %
- Systematic

$\mathcal{B}(\Lambda_b \rightarrow p + \text{anything}) = (50 \pm 17)\ \%$ (PDG)

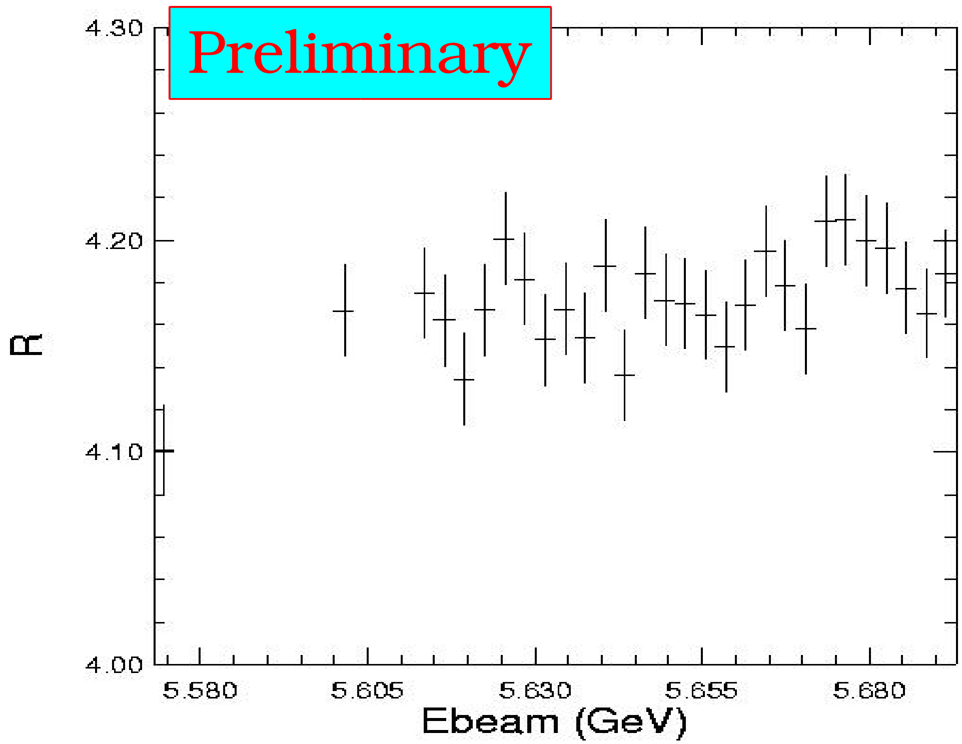
Reconstruction efficiency = 46.1 ± 4.6 %

--> 20% relative error overall on Λ_b efficiency

Some of the Variables used in the Selection

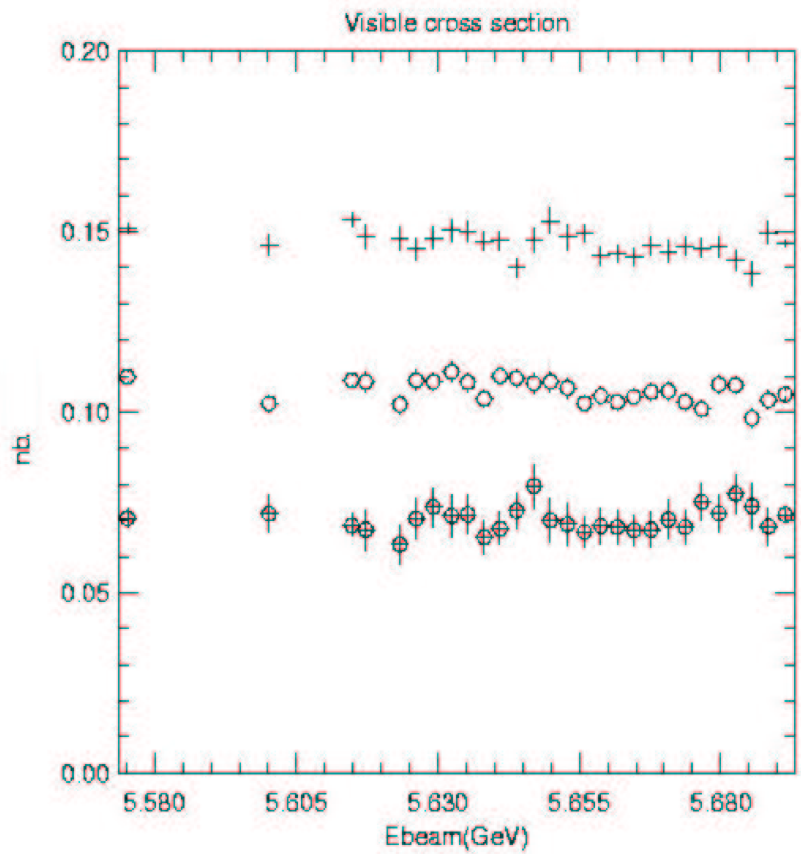


R in the scan range

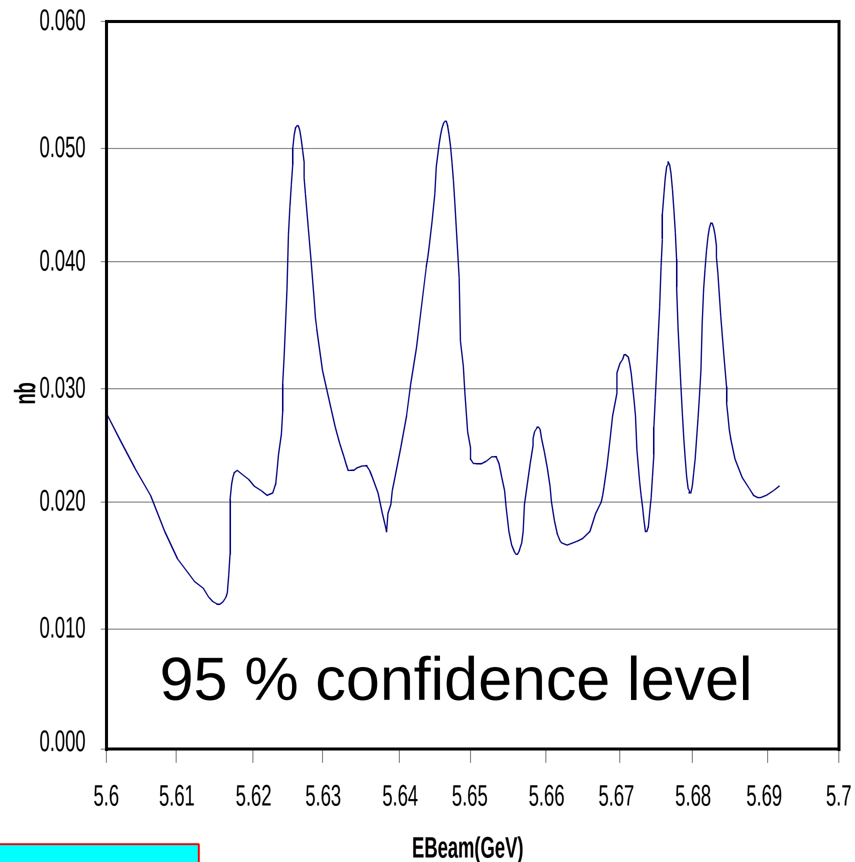


Near Λ_b threshold, $R = 4.17 \pm 0.02 \pm 0.15$

Proton Yields



Upper limit for Λ_b cross section

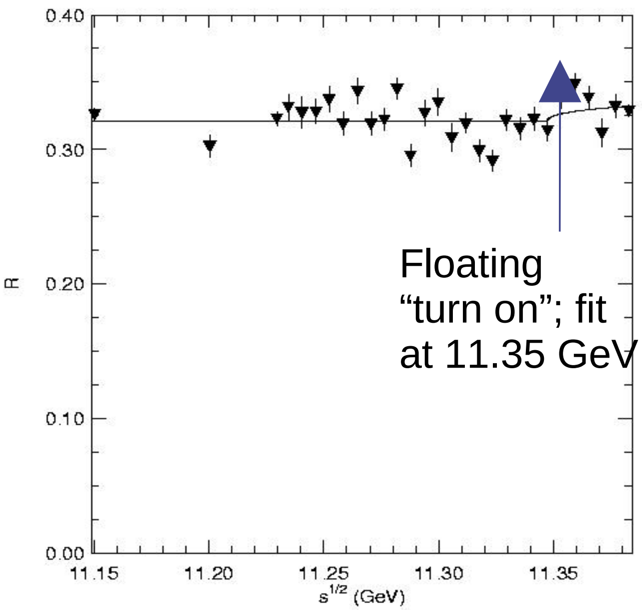


Preliminary

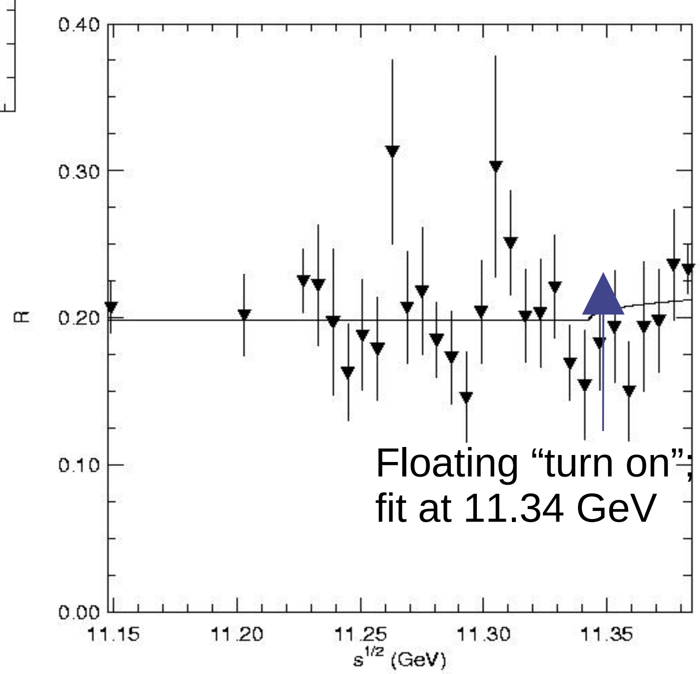
Attempts at Fitting the Λ_b Pair Production Threshold

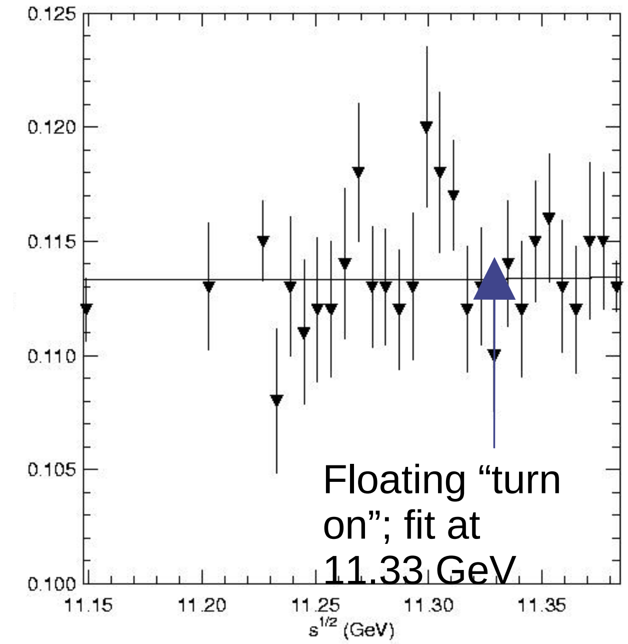
Preliminary

R_{Λ}



R_{bb}





R_{proton}

Λ_b Search Summary

- 95% CL upper limits for Λ_b production in e^+e^- annihilation at c.m. energies up to 10.39 GeV are between 20 and 50 pb
- Near Λ_b threshold, $R = 4.17 \pm 0.15$
- Further study of systematic errors is in progress
- There is no obvious "Λ_b Factory"!

CONCLUSION

- **CLEOIII explored the region at and above the $\Upsilon(5S)$, up to the limit of CESR's reach**
- **Found evidence for $B_s^{(*)}$ pair production at the $\Upsilon(5S)$, in both inclusive and exclusive channels**
- **Measured R and lepton, proton, Λ yields above $\Upsilon(5S)$, up to E(c.m.) ~ 11.4 GeV**
- **No clear evidence for onset of Λ_b production; set upper limits**

Backup Slides

Efficiencies and fake rates

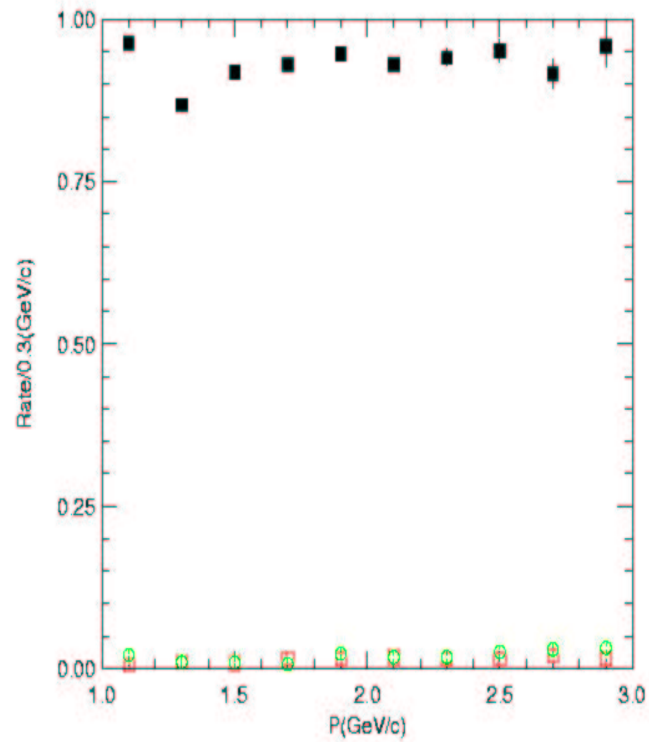
	$(\#\bar{p}>0)$/event (%)
Λ_b (MC)	$31.8 \pm 0.1 \pm 6.7$
5qq(MC)	$2.88 \pm 0.06 \pm 0.16$

$\varepsilon(\Lambda) = 0.164 \pm 0.009 \pm 0.010$

Momentum dependent efficiency for proton(black),

kaon fake proton rate(green),

pion fake proton rate(red).



Partial and total Br ($\Upsilon(5S, 4S) \longrightarrow D_sX$) vs x

(PRELIMINARY)

$\Upsilon(4s)$

$x(\frac{\|p\|}{Ebeam})$	D_s yields	$\epsilon(\%)$	$\frac{\Delta B}{\Delta x}(\%)$
0 - 0.05	44 ± 16	28.9	0.1 ± 0.1
0.05-0.10	261 ± 51	23.9	1.0 ± 0.3
0.10-0.15	525 ± 68	24.7	1.9 ± 0.5
0.15-0.20	732 ± 77	25.4	2.5 ± 0.7
0.20-0.25	1097 ± 78	27.7	3.5 ± 0.9
0.25-0.30	1838 ± 80	28.6	5.6 ± 1.4
0.30-0.35	2079 ± 75	29.4	6.2 ± 1.6
0.35-0.40	457 ± 55	30.4	1.3 ± 0.4
0.40-0.45	34 ± 43	31.4	0.1 ± 0.1
0.45-0.50	13 ± 40	32.4	0.0 ± 0.1

$\Upsilon(5s)$

$x(\frac{\|p\|}{Ebeam})$	D_s yields	$\epsilon(\%)$	$\frac{\Delta B}{\Delta x}(\%)$
0 - 0.05	1 ± 3	28.9	0.1 ± 0.1
0.05-0.10	9.7 ± 8.3	23.9	1.8 ± 1.6
0.10-0.15	26.7 ± 10.7	24.7	4.7 ± 2.2
0.15-0.20	47.2 ± 13.3	25.4	8.0 ± 3.0
0.20-0.25	50.7 ± 13.0	27.7	7.9 ± 2.8
0.25-0.30	92.0 ± 14.3	28.6	13.9 ± 4.1
0.30-0.35	76.9 ± 12.4	29.4	11.3 ± 3.4
0.35-0.40	41.0 ± 9.7	30.4	5.8 ± 2.0
0.40-0.45	10.1 ± 7.0	31.4	1.4 ± 1.0
0.45-0.50	0.1 ± 6.0	32.4	0.0 ± 0.8

$BR(\Upsilon(4S) \to D_sX) = (22.3 \pm 0.7 \pm 5.7)\%$

$BR(B \to D_sX) = (11.1 \pm 0.4 \pm 2.9)\%$

PDG $\longrightarrow$ $(10.5 \pm 2.6 \pm 2.5)\%$

$BR(\Upsilon(5S) \to D_sX)$
$= (55.0 \pm 5.2 \pm 17.8)\%$

Conclusions

We report a preliminary measurement of the following Inclusive Production Rates:

- ✓ $BR(\Upsilon(4S) \to D_s X) \,.\, BR(D_s \to \phi\pi) = (8.0 \pm 0.3 \pm 0.4).10^{-3}\%$
- ✓ $BR(\Upsilon(5S) \to D_s X) \,.\, BR(D_s \to \phi\pi) = (20 \pm 2 \pm 4).10^{-3}\%$

Hence:

- ✓ $BR(\Upsilon(5S) \to D_s X) / BR(\Upsilon(4S) \to D_s X) = 2.5 \pm 0.3 \pm 0.6$

Using $BR(D_s \to \phi\pi) = (3.6 \pm 0.9)\%$, *we measure:*

- ✓ $BR(\Upsilon(4S) \to D_s X) = (22.3 \pm 0.7 \pm 5.7)\%$
- ✓ $BR(\Upsilon(5S) \to D_s X) = (55.0 \pm 5.2 \pm 17.8)\%$
- ✓ $BR(B \to D_s X) = (11.1 \pm 0.4 \pm 2.9)\%$

And using $BR(B_s \to D_s X) = (92 \pm 11)\%$, *we report a preliminary model dependent estimate of the ratio of* $B_s^{(*)}\bar{B}_s^{(*)}$ *to the total* $b\bar{b}$ *quark pair production at the* $\Upsilon(5S)$ *energy:*

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

Systematic Errors

- *Are dominated by:*

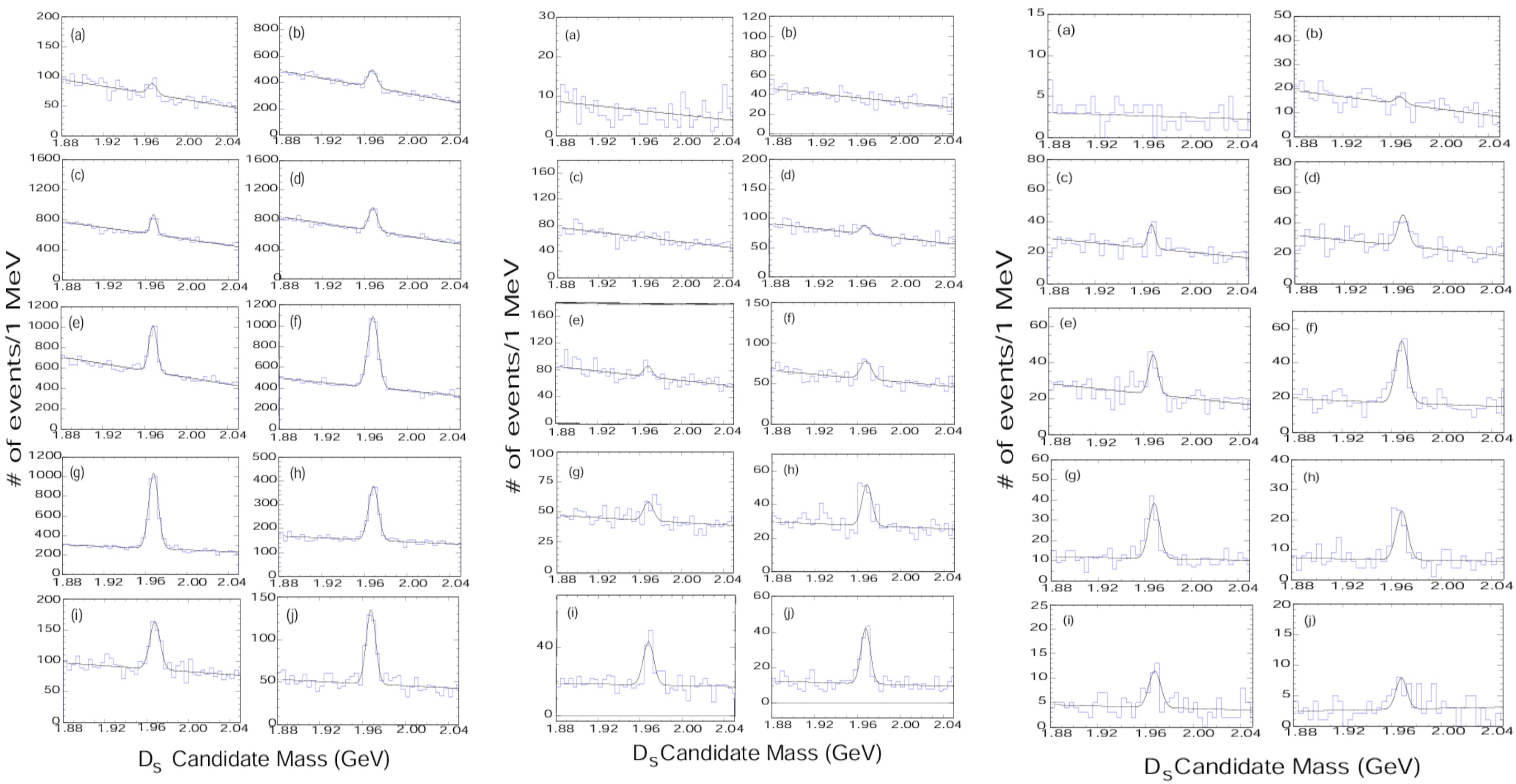
  - *the 25% error on the absolute $D_s \longrightarrow \phi\pi$*
  - *the 1% relative error on S_1 and 1.7% on S_2 scale factors.*
  - *the 12% on our estimate of $B(B_s \longrightarrow D_s X)$.*

- *And have components from:*

  - *the 4.1% component from the D_s detection efficiency.*

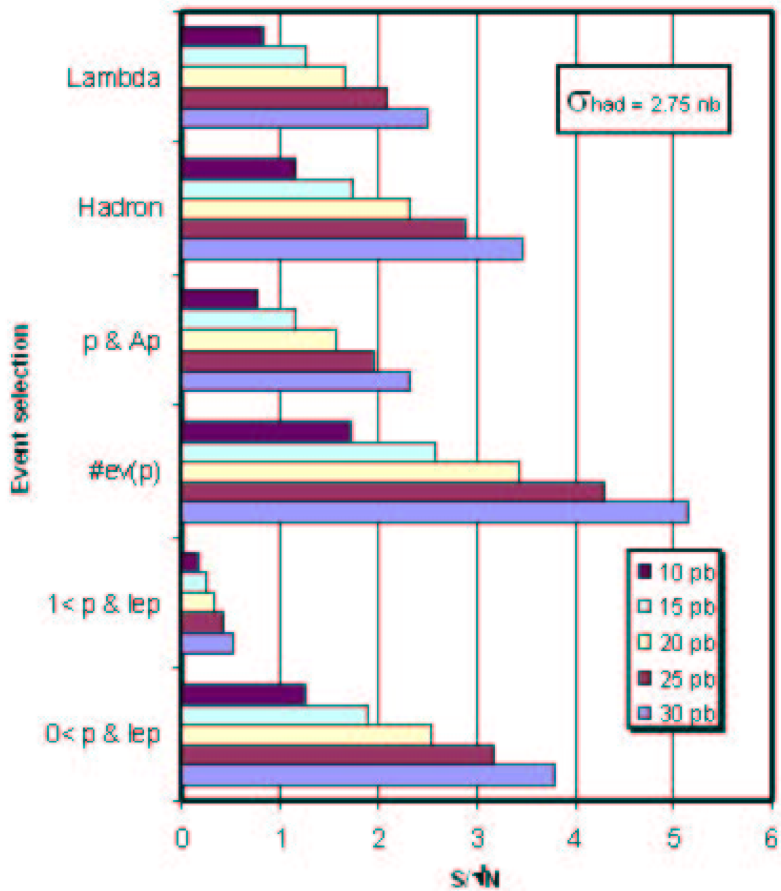
- *Because of the large relative error on the luminosity measurement, we did a second measurement of the scale factors used for continuum subtraction. We used the data to measure the ratio of the number of tracks with $0.5 < x < 0.8$. The difference between the two values gave an estimate of the systematic error.*

- *Ongoing work to improve the systematic errors…*



# of events/1 MeV
D_S Candidate Mass (GeV)
# of events/1 MeV
D_S Candidate Mass (GeV)
# of events/1 MeV
D_S Candidate Mass (GeV)

Signal to background ratio estimation



- The cross section of a five flavor background assumed to be 2.75 nb.
- For the typical statistics of hadronic events per scan bin - get signal to background ratio for the giving cross section of the Λ_b pair production.

Data sets and MC

Energy region: beam energy from 5.575 GeV to 5.691 GeV.
Scan in 3 MeV increments between 5.613 Gev to 5.691 GeV.

Total Luminosity 710 pb^{-1}.

Used Y(4S) and Y(1S) data to check the analysis methods.

Used 4S and 1S data generated by CLEO MC farms.

For higher energy region we created MC using Jetset 7.3 with default parameters.

Data sets and MC (cont.)

For the signal MC we used the generic Λ_b decay table. But we rescaled the semileptonic branching fraction to $(B^0 \to Xl\nu)$ $\tau(\Lambda_b)/\tau\ (B^0)$.

For higher energy five-flavor continuum MC, events were generated separately for “light" four-flavor continuum (*c, s, u, d*) and *bb* continuum events and then added in the expected 10:1 ratio.