B Quark Spectroscopy at LEP

OUTLINE

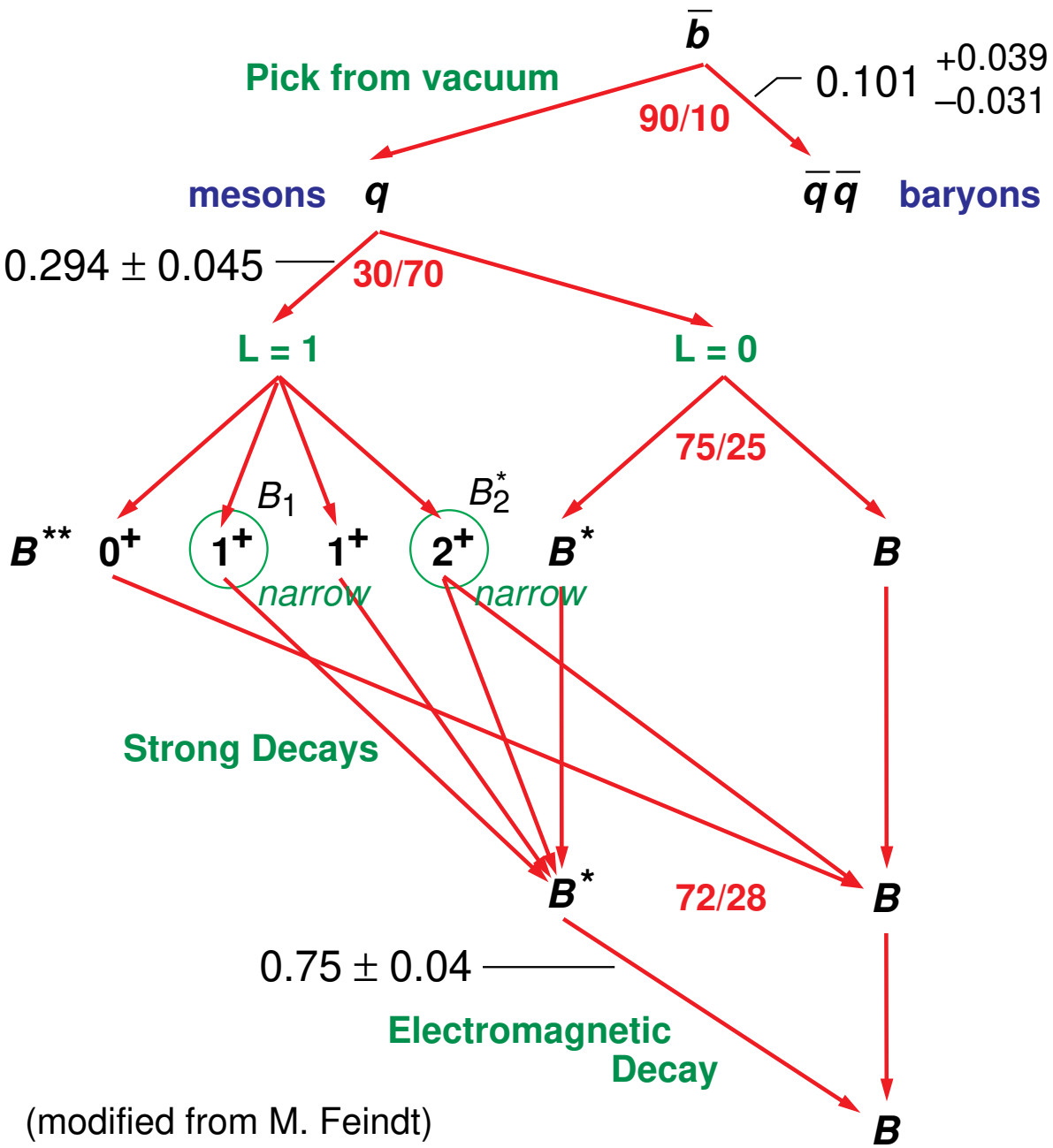
- **Tools**
- **Production Rates**
- ***B*** **Meson Spectroscopy:** $B^*, B^{**}, B', B_s^{**}, B_c$
- ***b*** **Baryon Spectroscopy:** $\Lambda_b, \Sigma_b, \Xi_b$

Acknowledgments: LEP 1 B Working Groups
of ALEPH, DELPHI, L3, OPAL

Rick Van Kooten
Indiana University/OPAL/D0 Run II

Workshop on B Physics at the Tevatron
Run II and Beyond
Production, Fragmentation, Spectroscopy Working Group
25 September 1999

B Spectroscopy

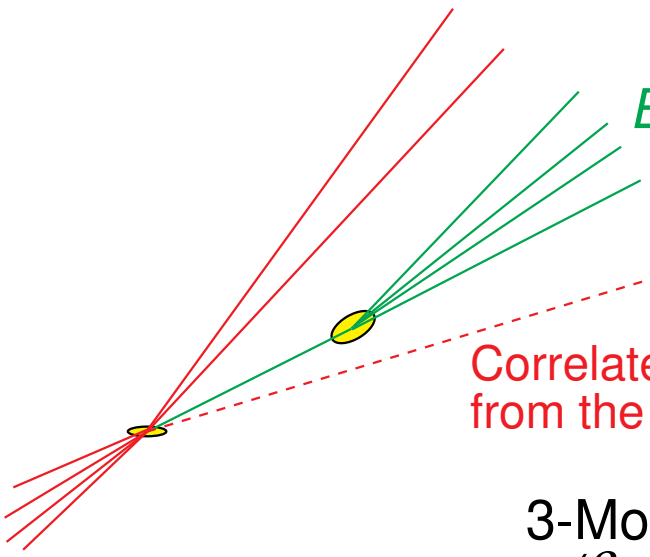


(modified from M. Feindt)

The Tools

Inclusive B tag

- vertex tag
- mass/multiplicity
- rapidity
- kinematics
- neural nets and variants



Correlate with something from the primary

3-Momentum of *B* ($\beta\gamma \sim 6$)

- e.g., corrected 2-body kinematics, known E_{cm}
- energy to ~7-10%
- angle to ~15 mrad in θ and ϕ

Charge of *B* (*b* quark)

- jet charge (of *B*-jet side or *B*-jet and opposite jet) and other variants

Production Fractions

f_{B^0}, f_{B^+}, f_{B_s}, f_{Λ_b} $\quad f_{B^0} + f_{B^+} + f_{B_s} + f_{\Lambda_b} = 1$

e.g. fraction of B_d^0 from b quark

But at LEP, we only measure the product:

e.g. $f_{B_s}\,\mathrm{Br}(B^0 \to X + \mathrm{tag})$ (tag usually semileptonic)

Measurement or theoretical estimate

$\oplus$ (for f_{B_s})

$$\bar{\chi} = f_{B_s}\chi_s + f_{B^0}\chi_d$$

0.5

Average Mixing (LEP/Tevatron)

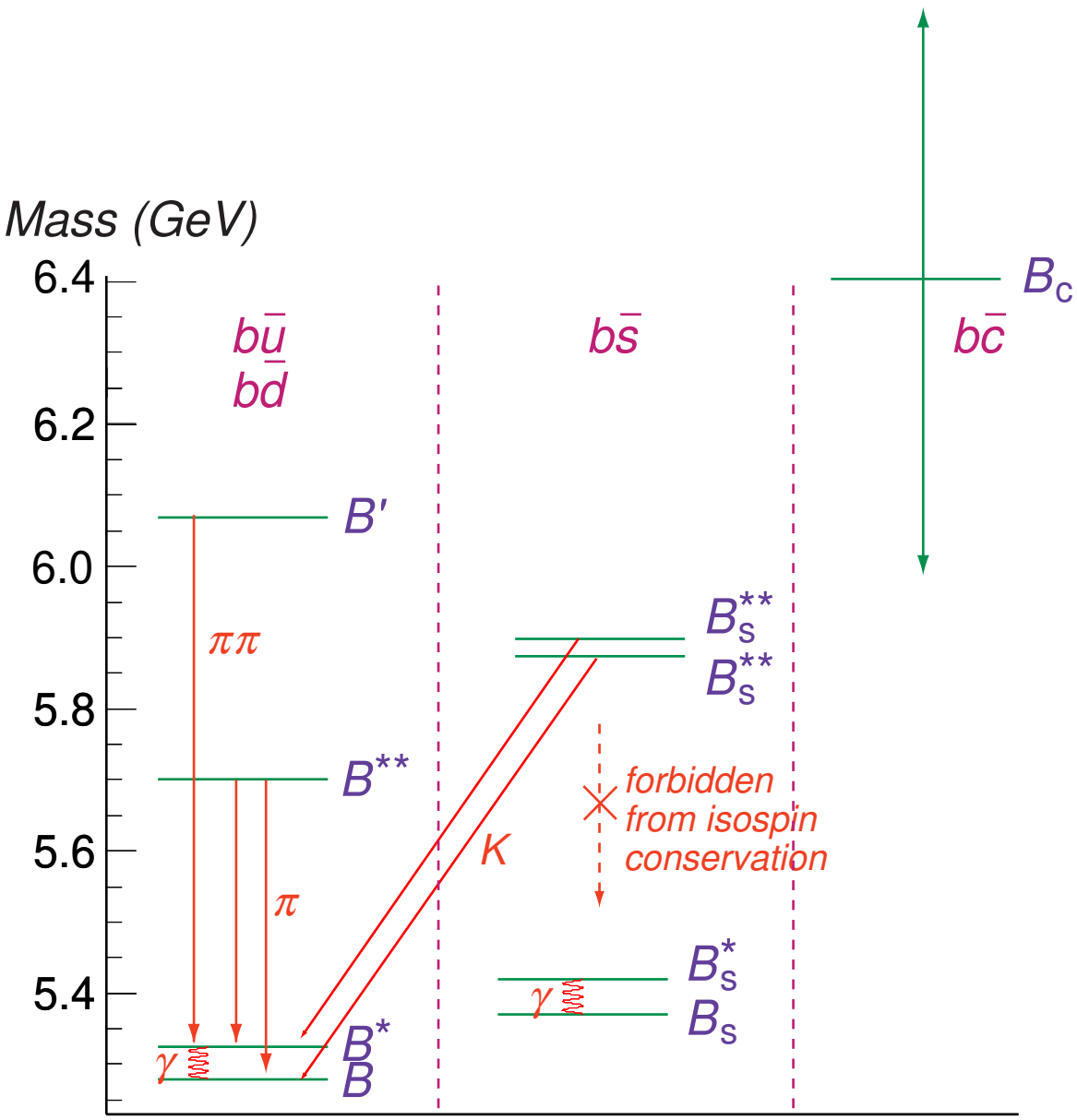
CLEO/ARGUS

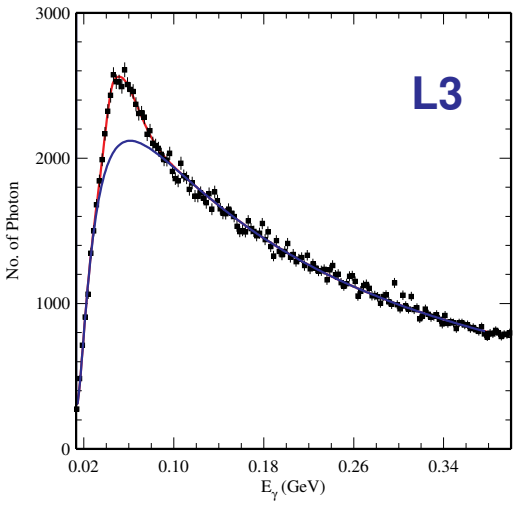
$\oplus$ unity constraint

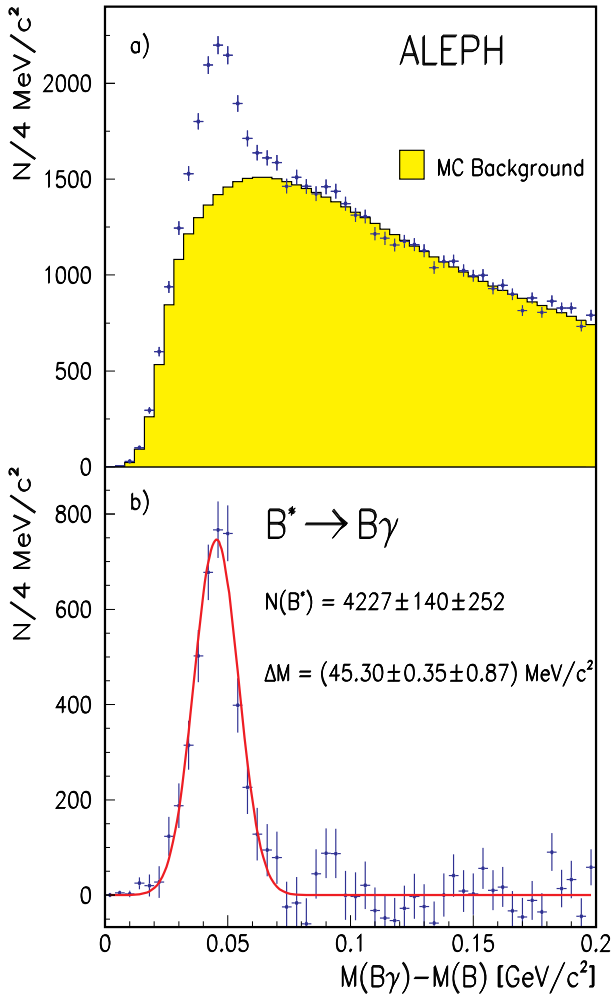
Plus, get $B(b \to X_b^0)$

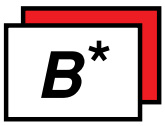
$B(b \to X_b^+)$ from b-hemisphere charge, for perfect charge assignment, X_b^+ is all B^+ then extract fractions

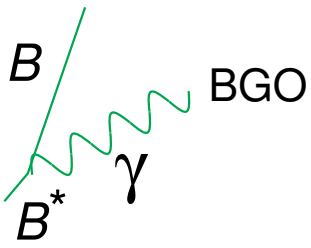
		c.f. CDF, Wendy Taylor
f_{B^0}, f_{B^+}	$0.397\ ^{+0.018}_{-0.022}$	0.375 ± 0.023
f_{B_s}	$0.105\ ^{+0.018}_{-0.017}$	0.160 ± 0.040
f_{Λ_b}	$0.101\ ^{+0.039}_{-0.031}$	0.090 ± 0.029

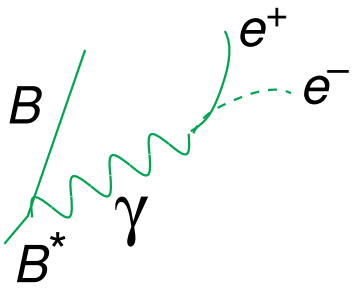

Mass (GeV)
6.4
6.2
6.0
5.8
5.6
5.4
$b\bar{u}$
$b\bar{d}$
$b\bar{s}$
$b\bar{c}$
B_c
B'
$\pi\pi$
B^{**}
π
γ
B^*
B
K
B_s^{**}
B_s^{**}
forbidden
from isospin
conservation
γ
B_s^*
B_s











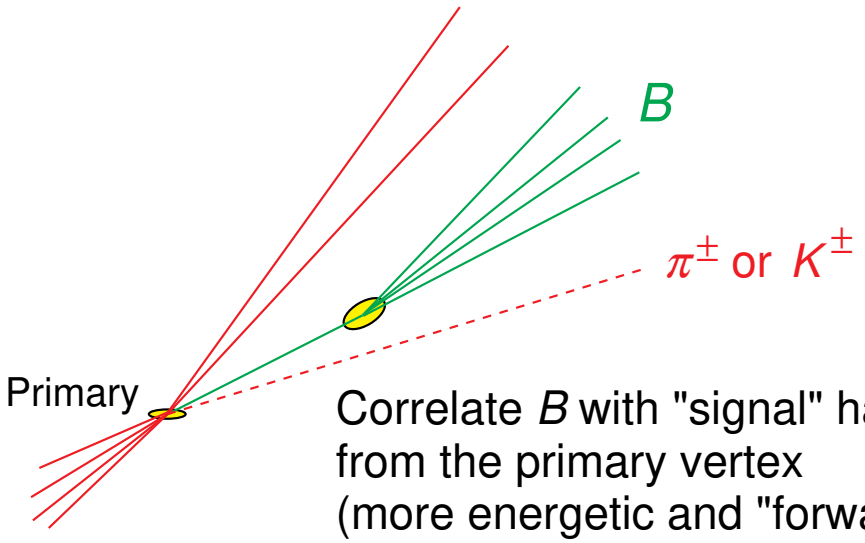
Spin counting:

$$\frac{V}{V+P} = \frac{3}{4}$$

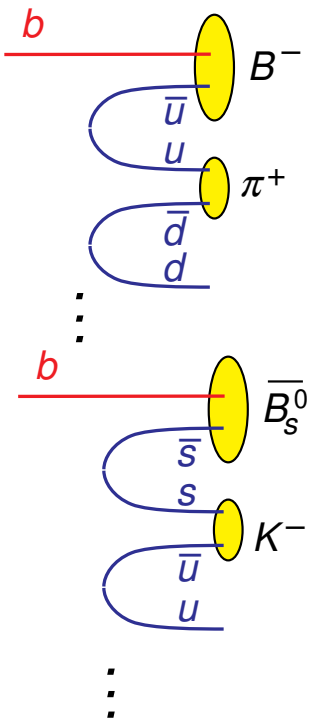
Combined measurements (all 4 LEP Collab.)

$$\frac{\sigma_{B^*}}{\sigma_{B^*}+\sigma_B} = 0.75 \pm 0.04$$

B^{**}

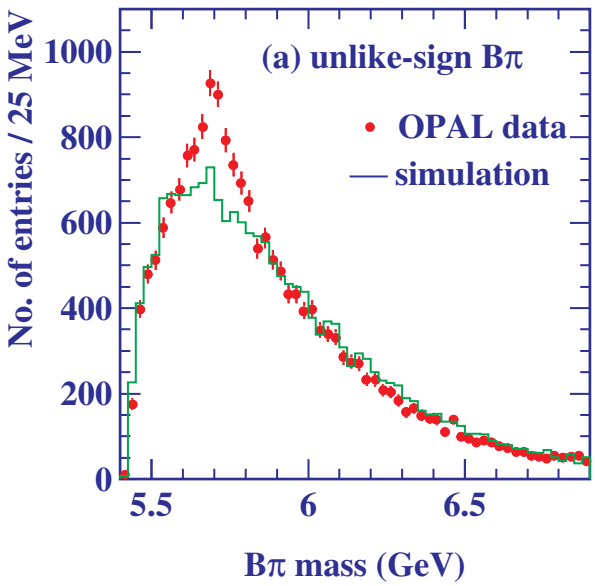


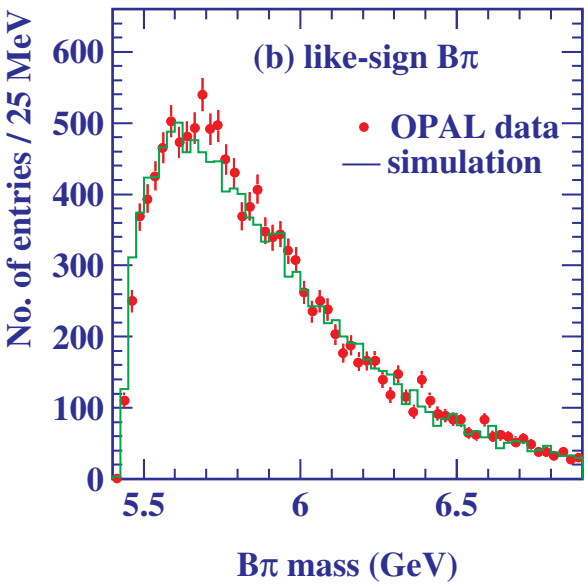
Correlate B with "signal" hadron from the primary vertex (more energetic and "forward" than other fragmentation tracks)

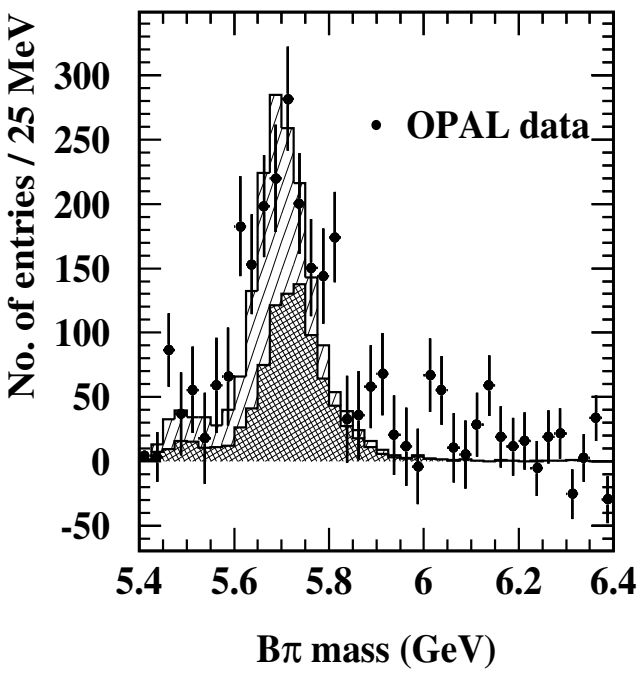


- $B^{**}_{u,d} \Rightarrow \pi^{\pm}$
- $B^{**}_{s} \Rightarrow K^{\pm}$

Right Sign	Wrong Sign
$B^-\pi^+, B^+\pi^-$	$B^+\pi^+, B^-\pi^-$
$\overline{B}^0\pi^-, B^0\pi^+$	$\overline{B}^0\pi^+, B^0\pi^-$

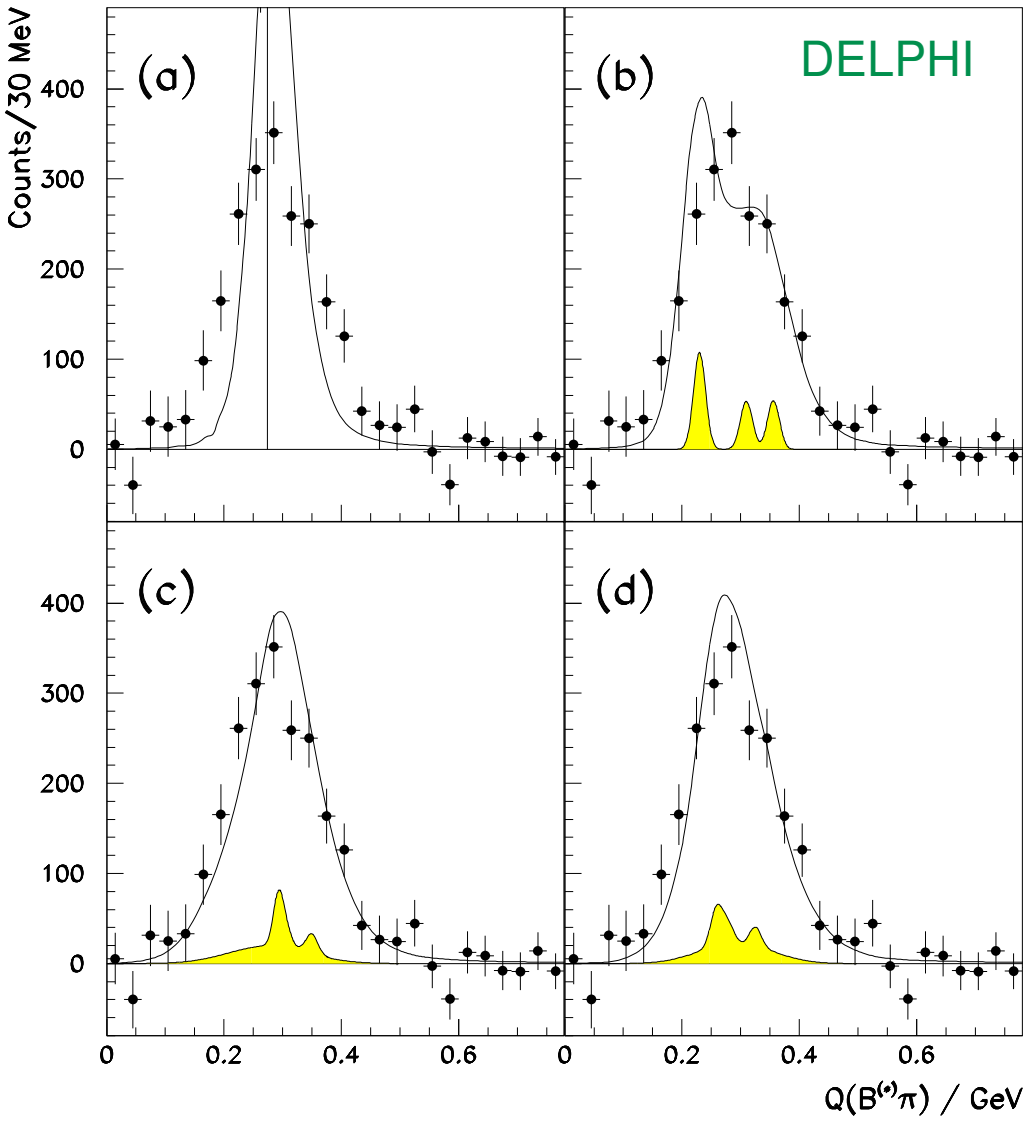






Fit to excess with modified HQET model of Eichten, Hill, Quigg ('93)

	B_1	B_2^*
Mass (GeV)	5.725	5.737
Width (GeV)	0.020	0.025
Br($B^+\pi^-$)	0.000	0.300
Br($B^{*+}\pi^-$)	0.533	0.300
Br($B^+\rho^-$)	0.100	0.007
Br($B^{*+}\pi^-$)	0.033	0.060



Comparison of background-subtracted Q-value distribution compared with various models. Shaded area model prior to resolution effects.

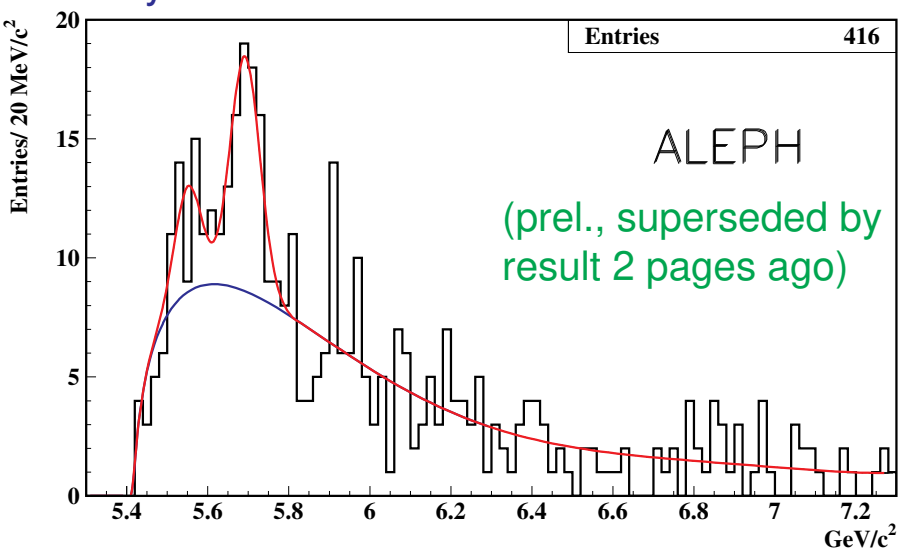
(a) Delta function with detector resolution

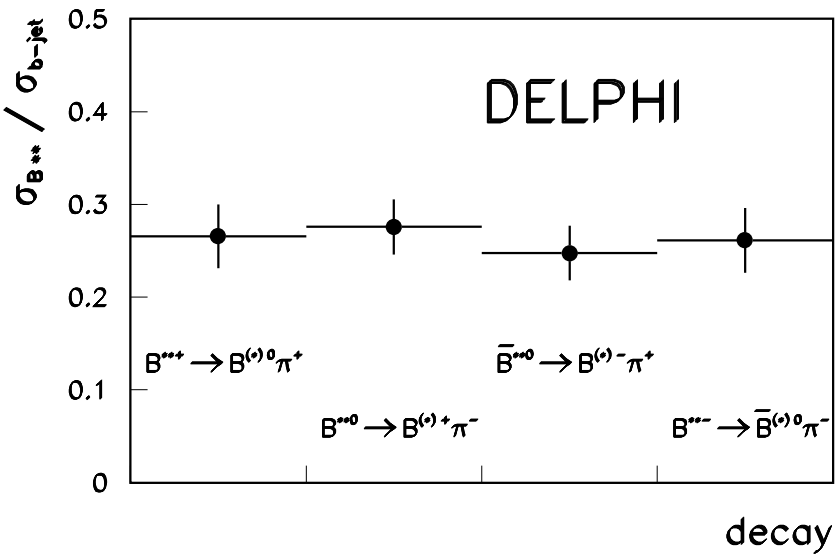
(b) Two narrow resonances, one to $B\pi$, other to $B\pi$ and $B^*\pi$

(c) Model of Eichten et al., broad resonances shifted down by 50 MeV

(d) Two narrow and two broad states, no large mass split

Fully reconstructed B's - two B^{**} states discernable



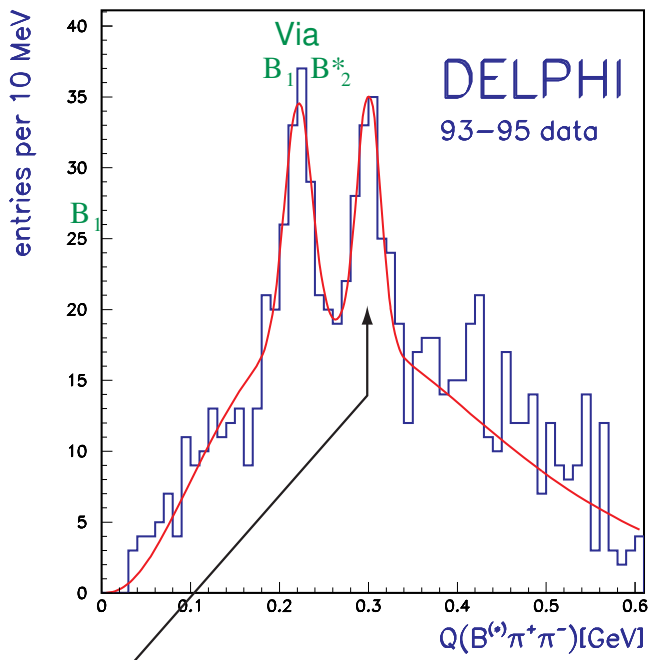


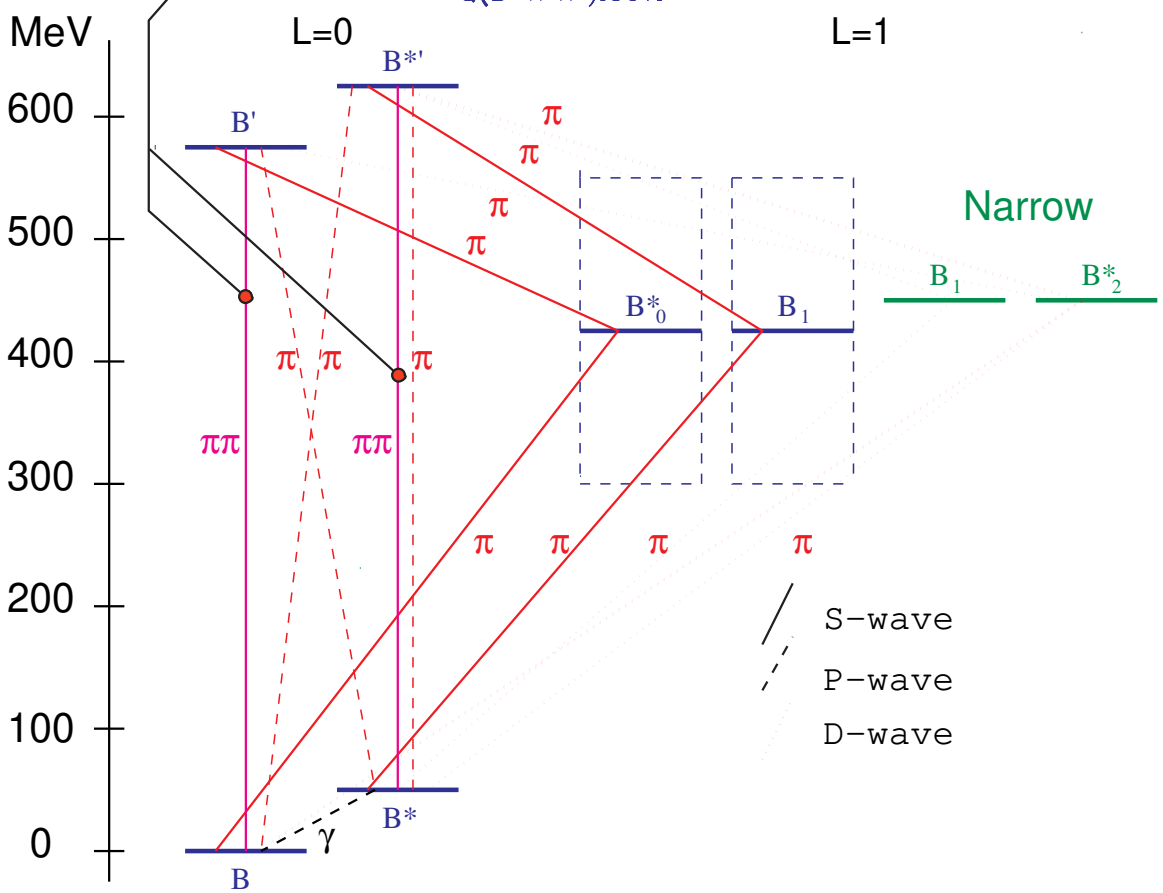
$$\frac{\mathrm{Br}(b \to B^{**}_{u,d})}{\mathrm{Br}(b \to B_{u,d})} = (29.4 \pm 4.5)\%$$

ALEPH, DELPHI, OPAL, my average

Radially Excited States

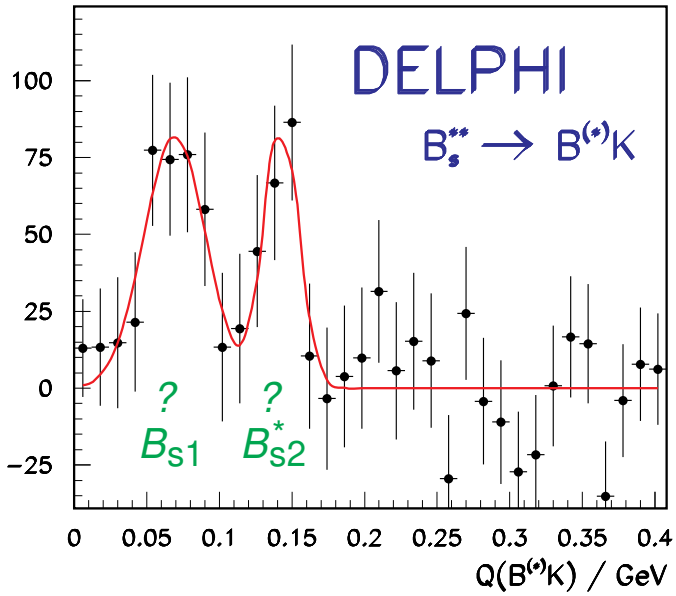
Needs confirmation!

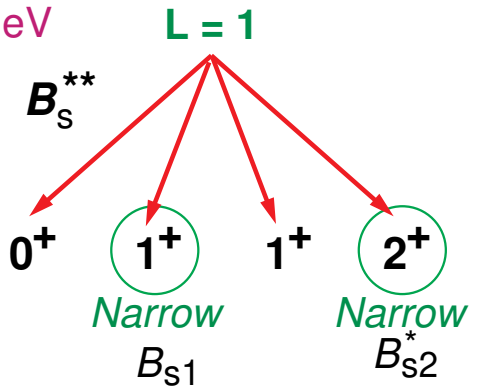




B_s^{**} — K Correlations

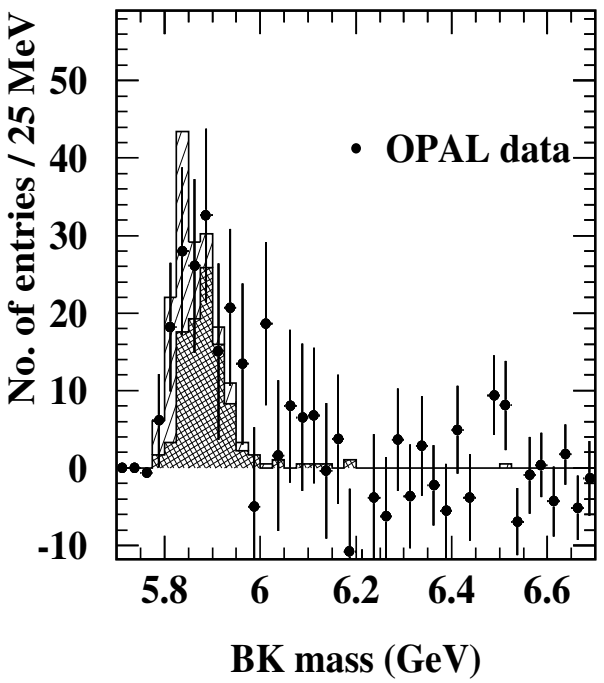
Masses: 5888 ± 4 ± 8 and 5914 ± 4 ± 8 MeV





- Decays to B_s and B_s^* via π forbidden

Mass: 5884 ± 15 MeV

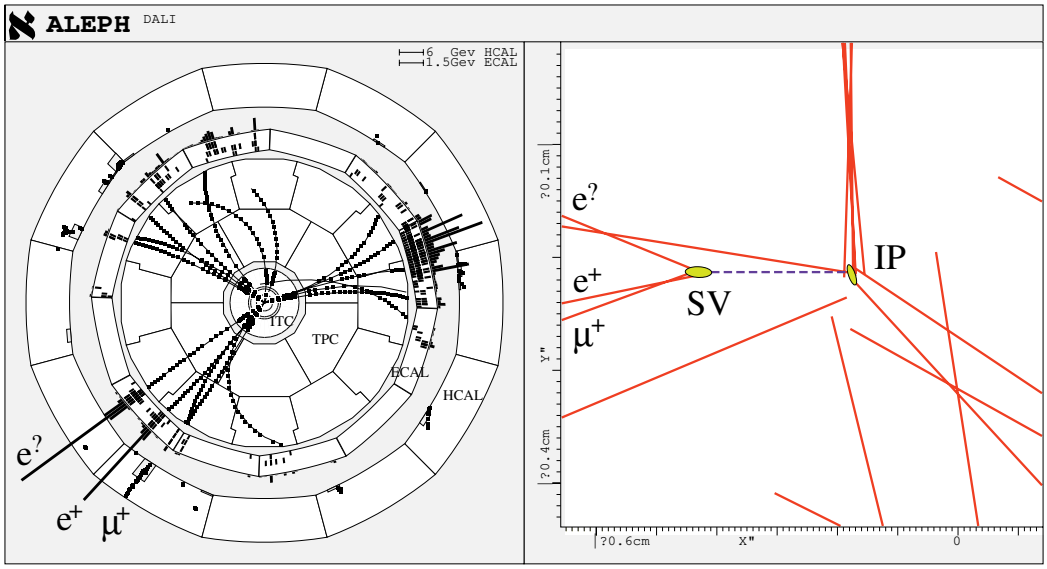


Fit to excess with modified HQET model of Eichten, Hill, Quigg ('93)

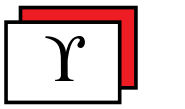
	B_{s1}	B_{s2}^*
Mass (GeV)	5.874	5.886
Width (GeV)	0.001	0.001
Br(B^+K^-)	0.000	0.300
Br($B^{*+}K^-$)	0.500	0.200

B_c

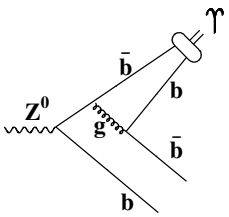
- LEP has limits and a handful of clean reconstructed decays
  (CDF with dominant mass measurement of $6.40 \pm 0.39 \pm 0.13$ GeV)



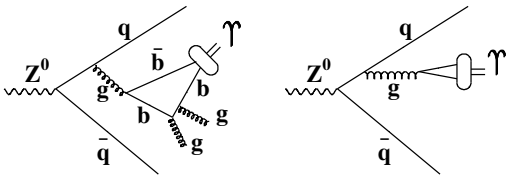
- e.g. DELPHI, two candidates:
  masses of 6.341 ± 0.027 GeV and 6.119 ± 0.022 GeV (i.e., "significantly different, suggesting that at least one of them is not a B_c meson")
- OPAL weighted average mass of two candidates 6.32 ± 0.06 GeV



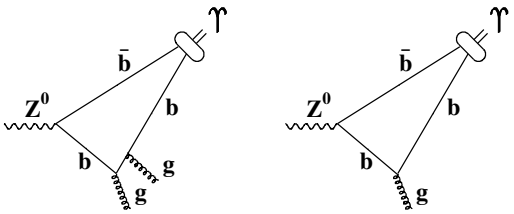
colour-singlet **colour-octet**



b-quark fragmentation



gluon fragmentation



gluon radiation

Baryon Landscape

$\Lambda_b^0 = [\,(ud)_0 b\,]_{1/2}$ $M = 5624 \pm 9$ MeV

$\Sigma_b^0 = [\,(ud)_1 b\,]_{1/2}$ $\Sigma_b^0 \to \Lambda_b^0 \gamma$

$\Sigma_b^+ = [\,(uu)_1 b\,]_{1/2}$ $\Delta M = 191 \pm 2$ MeV

$\Sigma_b^{*+} = [\,(uu)_1 b\,]_{3/2}$ $\Delta M = 216 \pm 4$ MeV

(DELPHI, prelim. in 1995!)

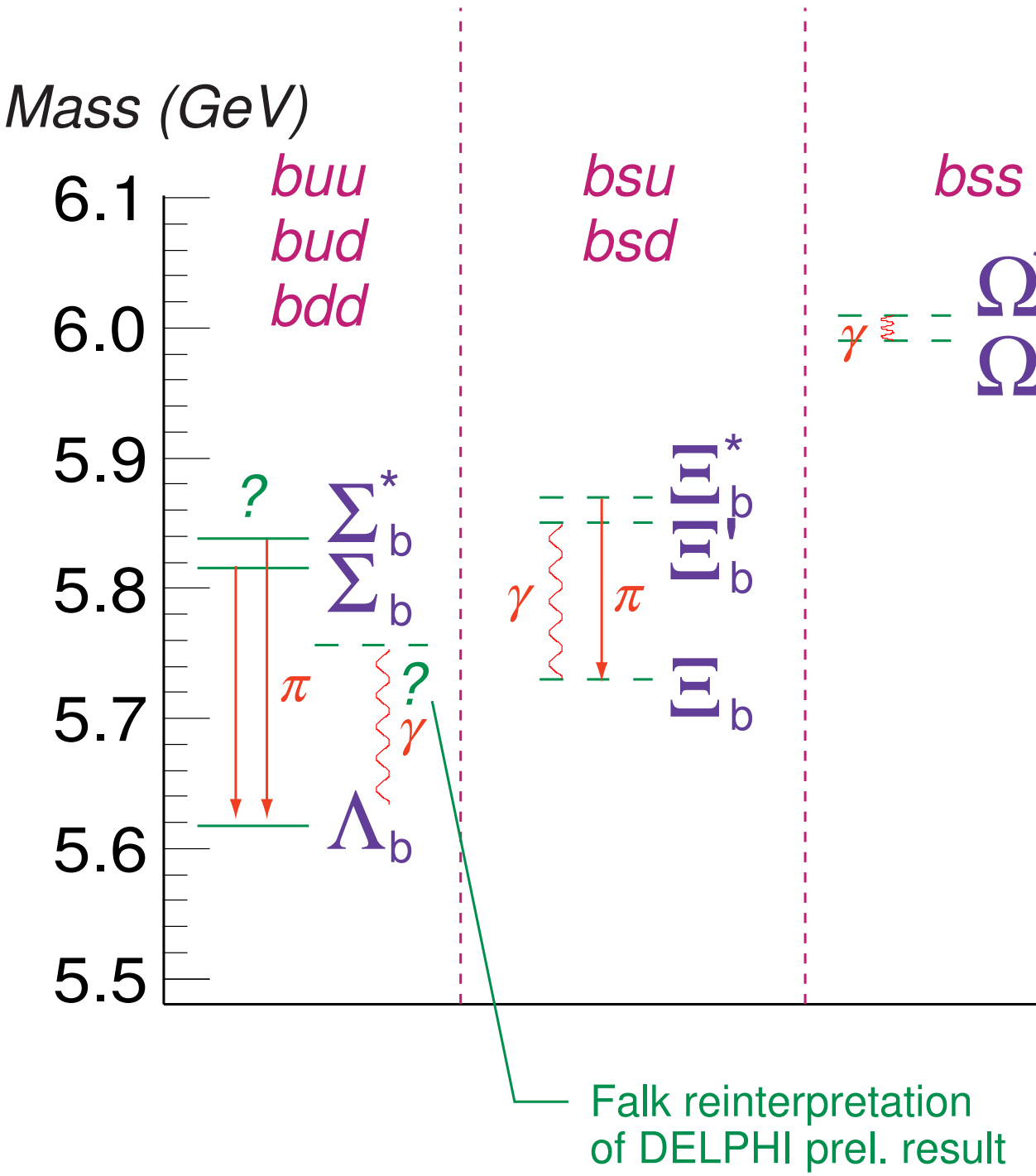
$\Sigma_b^{(*)+} \to \Lambda_b^0 \pi^+$

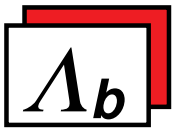
$\Xi_b^0 = [\,(us)_1 b\,]_{1/2}$

$\Xi_b^- = [\,(ds)_1 b\,]_{1/2}$

"Seen"

$\Omega_b^- = [\,(ss)_1 b\,]_{1/2}$

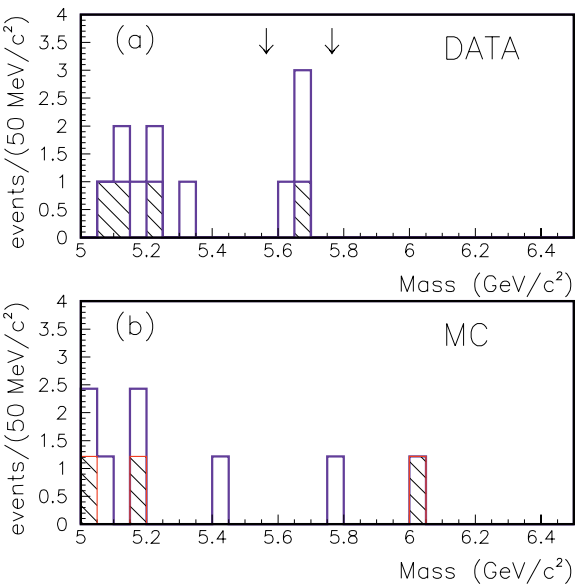

Mass (GeV)
6.1
6.0
5.9
5.8
5.7
5.6
5.5
buu
bud
bdd
bsu
bsd
bss
?
Σ_b^*
Σ_b
π
?
γ
Λ_b
γ
π
Ξ_b^*
Ξ_b'
Ξ_b
γ
Ω
Ω
Falk reinterpretation
of DELPHI prel. result

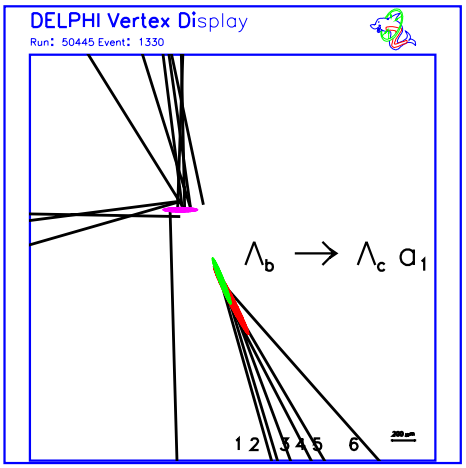


Firmly established, large samples through
Λ – lepton correlations, but
very few exclusive reconstructions

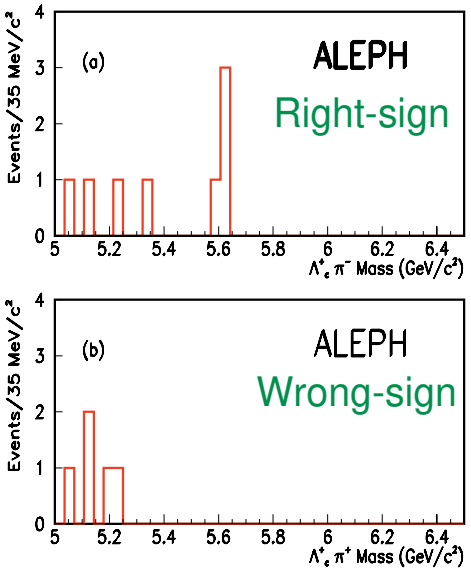
Mass:

$\Lambda_b \rightarrow \Lambda_c \pi$



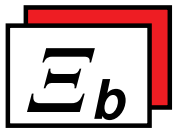


Mass: 5668 ± 16 ± 8 MeV

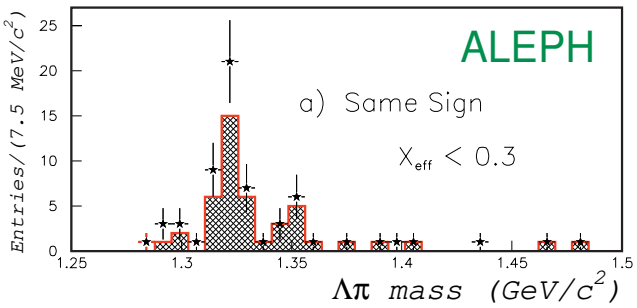


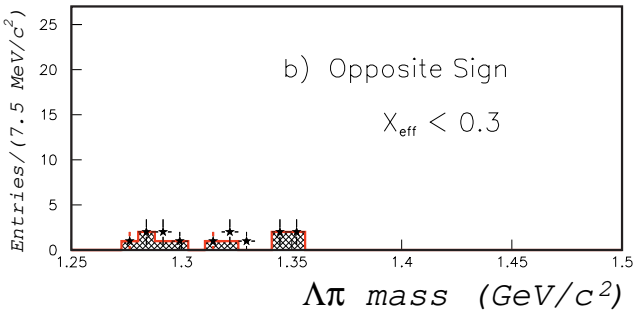
Mass: 5614 ± 21 ± 4 MeV

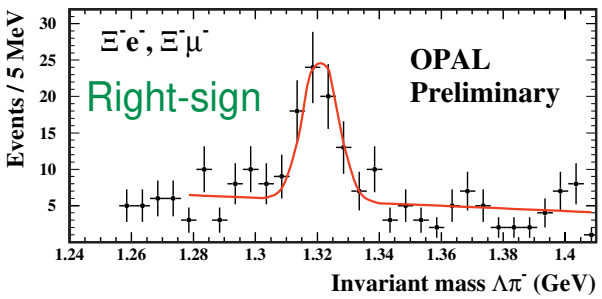
World Average Mass:
5624 ± 9 MeV dominated by CDF: Tevatron the future of exclusive *b* reconstruction

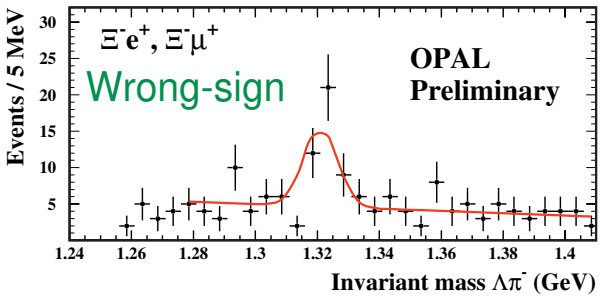


Weakly decaying, some evidence for existence through Ξ – lepton correlations, no mass measurement though!









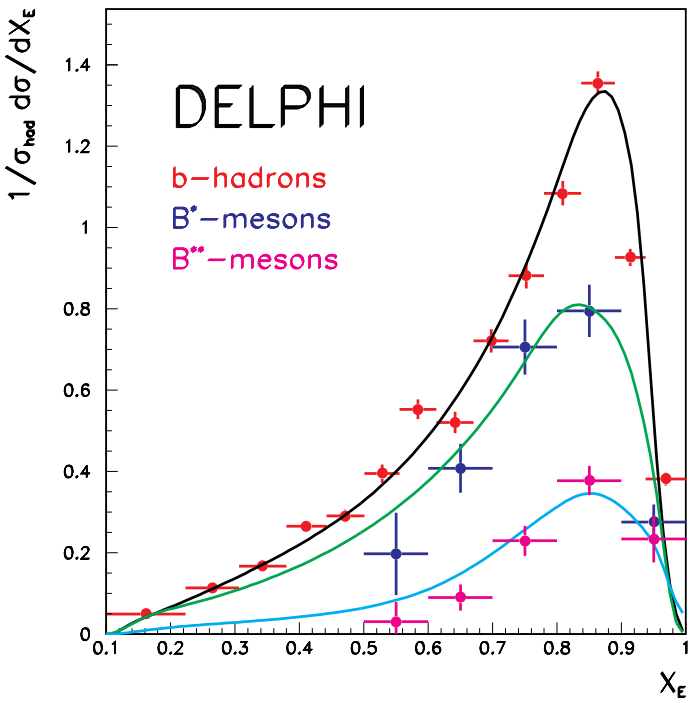
- Excess found to be sensitive to MC background assumptions from semileptonic Λ_b and *B* meson decays, only limits set

Summary

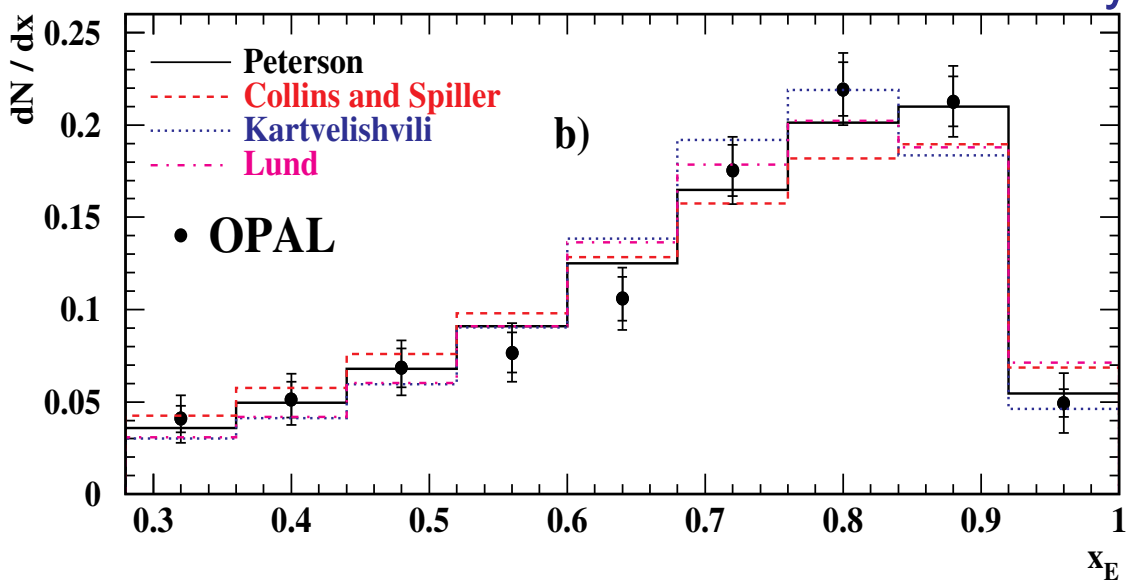
- Still many more nuggets in the data (but the presence of LEP2 data doesn't help!!)
- LEP statistically limited on necessary exclusive decays to further advance *B* spectroscopy
- Tevatron Run II poised to make significant contributions (particularly for heavier *B* meson and *b* baryon states not produced at the *B* factories)

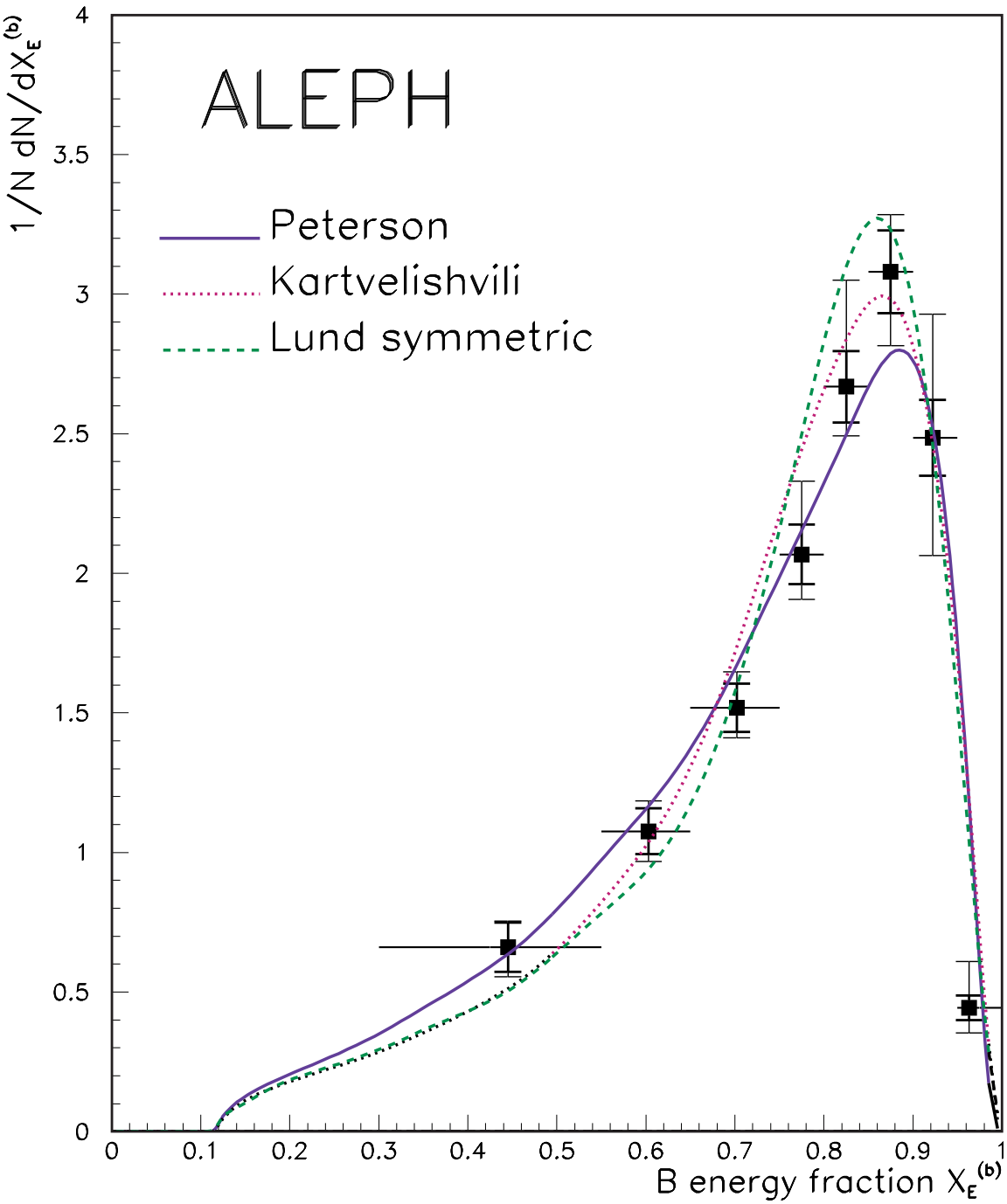
  ⇒ Why we are here!
- However, spectroscopy pushes the capabilities of detectors...

Fragmentation



$B^{0,\pm}$ mesons only




ALEPH
Peterson
Kartvelishvili
Lund symmetric
1/N dN/dX_E^(b)
B energy fraction X_E^(b)
0
0.5
1
1.5
2
2.5
3
3.5
4
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1