Excited b states

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Introduction
Current Experimental Situation
New DELPHI Analyses on $B^{**}_{u,d}$, B^{**}_{s}, $\Sigma_b^{(*)}$
Summary & Conclusions

(Results are preliminary!)

Introduction

l	j_q	J^P	state	dom.decay mode	
0	$\frac{1}{2}$	0^-	B		
		1^-	B*	$B\gamma$	
1	$\frac{1}{2}$	0^+	B_0^*	$B\pi$	(s-wave)
		1^+	B_1^*	$B^*\pi$	(s-wave)
1	$\frac{3}{2}$	1^+	B_1	$B^*\pi$	(d-wave)
		2^+	B_2^*	$B^{(*)}\pi$	(d-wave)

broad

narrow

HQET: Heavy quark as static colour source; light degrees of freedom decoupled from heavy quark spin

$$\vec{s}_q \oplus \vec{l} \to \vec{j}_q ; \quad \vec{s}_Q \oplus \vec{j}_q \to \vec{J}$$

➔ $\vec{s}_Q$ and $\vec{j}_q$ separately conserved
➔ Grouping into doublets of j_q (degenerate for $m_Q \to \infty$)
➔ Similar for charm and bottom

- B_0^*, B_1^*, B_1, B_2^* commonly labeled as B^{**} (or B_J^* in PDG)
- Mass hierarchy: $M_{1/2} > M_{3/2}$? ('Spin-Orbit Inversion')
- Also other decay modes to $B^{(*)}\pi\pi$ final states allowed

Similar for B_s^{**}, but decays $B_s^{**} \to B_s^{(*)}\pi$ forbidden by I-spin conservation
➔ dominant decay mode expected to be $B_s^{**} \to B^{(*)}K$ if above threshold

Summary of B^{**} Results

- Inclusive Analyses from all LEP Collaborations
- Exclusive Analysis from ALEPH
- Semi-exclusive Analysis from CDF $(B \to D^{(*)} l X)$

Different assumptions used to extract mass and yield!

	$M(\mathrm{B}^{**})[MeV]$	$\sigma_{B^{**}_{u,d}}/\sigma_b$
OPAL incl.	5712 ± 11	0.22 ± 0.05
DELPHI incl.	$5734 \pm 5 \pm 17$	$0.26 \pm 0.02 \pm 0.05$
ALEPH incl.	$5734 \pm 3 \pm 16$	$0.14 \pm 0.01 \pm 0.03$
L3 incl.	B_2^* : $5768 \pm 5 \pm 6$	$0.32 \pm 0.03 \pm 0.06$
CDF semi-excl.	B_1 : 5710 ± 20	$0.22 \pm 0.05 \pm 0.02$
ALEPH excl.	B_2^* : $5739^{+8\ +6}_{-11-4}$	$0.25 \pm 0.07^{+0.05}_{-0.04}$

Some numbers recomputed using updated values e.g. for fractions and to use a similar set of assumptions!!

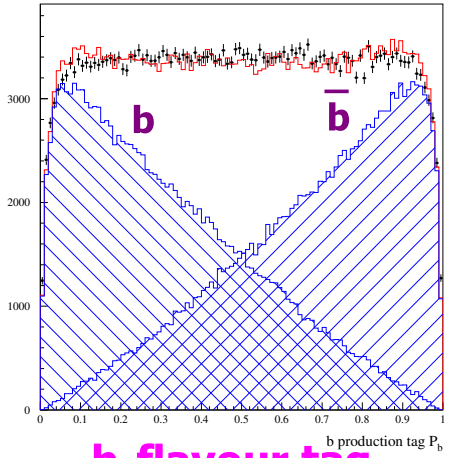
- Masses in reasonable agreement; some disagreement for production rates (systematics from BG modelling dominating for inclusive analyses)
- Composition of signal not clearly resolved
- Mass hierarchy not resolved unambiguously

Furthermore from OPAL: $BR(B^{**} \to B^{*}\pi(X)) = 0.85\ ^{+0.26}_{-0.27}(stat.)\ \pm 0.12\,(syst.)$ FINAL!

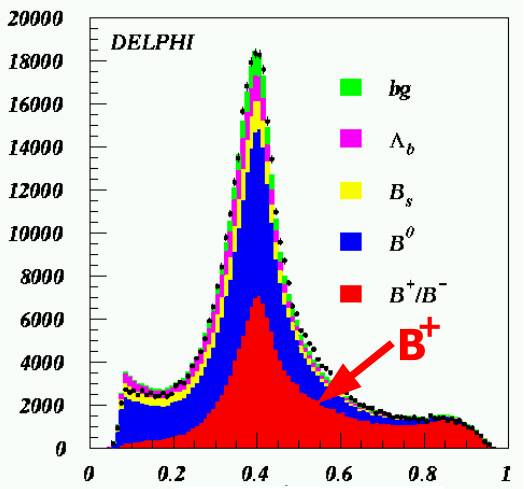
(Charm: narrow D^{**} clearly identified and first observation of broad state from CLEO & DELPHI)

Motivation for new DELPHI analyses

- **Larger data samples** using full LEP I statistics
- Complete reprocessing **of data**, esp. with strongly **improved tracking algorithms** and particle identification
- **Improved analysis techniques** e.g.:
  - → better inclusive B-reconstruction
  - → improved flavour- and charge tags
- **Control samples**: MC description of background known to be problematic in old analyses!
  - → **reduce model dependence** by using **purer samples**, control samples and/or **fitting BG on the data itself**
- Try to **answer** some of the **open questions**:
  - → composition of the signals
  - → mass hierarchy
  - → production rates
- **Clarification** of situation for some (unpublished) earlier results which have neither been **confirmed** nor **disproved**



b-flavour tag



B+ network

Outline of 2 analysis lines

Common to both analyses:

- ★Reconstruct weakly decaying B meson using inclusive techniques
- ★Select pion or kaon from primary vertex and suppress fragment. BG
- ★Quantity analysed: **Q value:**

$$Q = m\left(B^{(*)}\pi/K\right) - m\left(B^{(*)}\right) - m\left(\pi/K\right)$$

- ★Use correlations between $Q_{\pi/K}$ ⇔ **b-flavour** and $Q_{\pi/K}$ ⇔ Q_B to define
  - i) B_d^{**}/B_u^{**} samples
  - ii) signal enriched/depleted samples

$$B_d^{**}(\bar{b}\,d) \rightarrow B^+\,\pi^- \qquad \rightarrow B^0\,\pi^0$$

$$B_u^{**}(\bar{b}\,u) \rightarrow B^0\,\pi^+ \qquad \rightarrow B^+\,\pi^0$$

'Soft' Analysis:

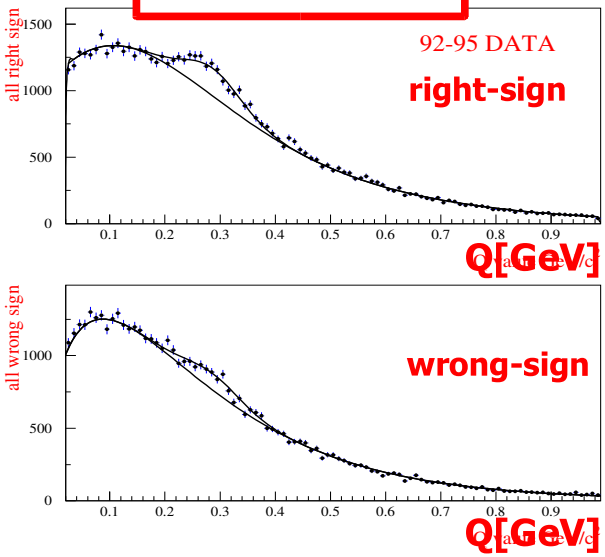
- ➢using relative soft cuts designed to produce similar background shapes in the signal enriched/depleted samples
- ➢reduce dependence on MC model strongly by extracting the background shape from the data itself by simultaneous fit to signal enriched/depleted samples

Neural Network Analysis:

- ➢optimise performance and purity by use of dedicated Neural Networks for B-momentum reconstruction, charge- and flavour tags, PV/SV assignment, signal enrichment .....

The $B^{**}_{u,d}$ Analyses

$B_d^{**} \to B^+ \pi^-$

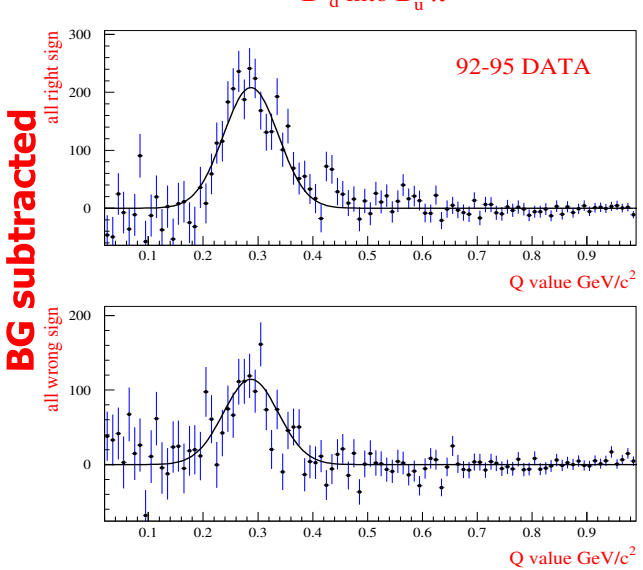


'Soft' Analysis:

Simultaneous fit to wrong-sign and right-sign sample including background shape

Width of single Gaussian for signal compatible with resolution

- ➔ **suggests interpretation as narrow states**
- ➔ **low mass splitting within doublet and only small contribution from $B_2 \to B\pi$ prefered**



Compatible results for B_d^{**} and B_u^{**} .

$$Q = 289 \pm 4\ (stat.) \pm 12\ (syst.)\ MeV$$

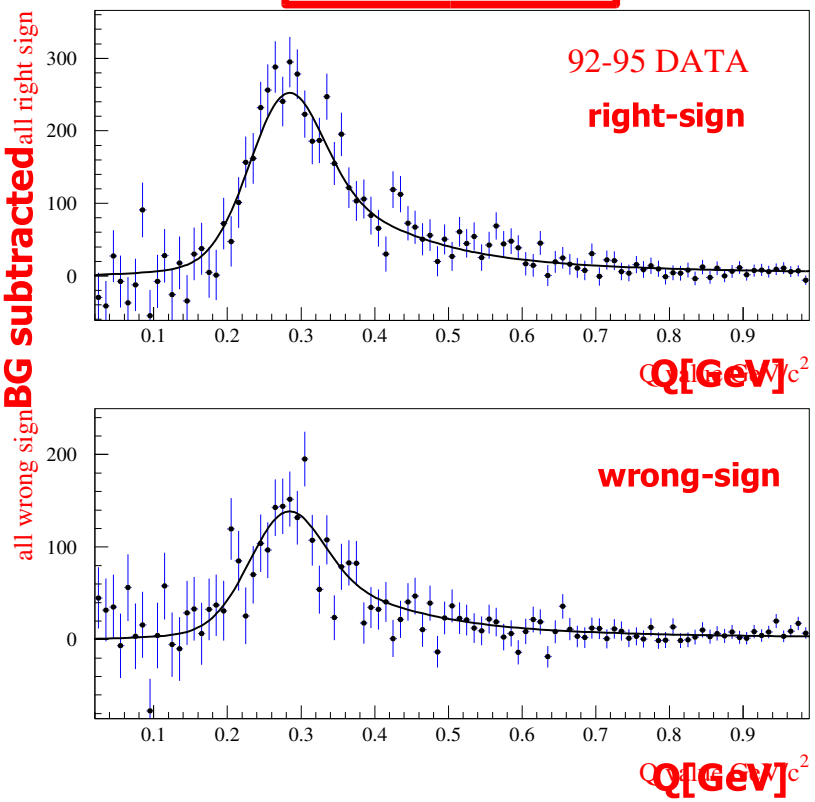
$$\sigma = 47 \pm 3\ (stat.) \pm 5\ (syst.)\ MeV$$

$$\frac{\sigma(B_d^{**}) + \sigma(B_u^{**})}{\sigma_b} = 0.098 \pm 0.007 \pm 0.012$$

≈**Rate of narrow states only!**

Search for broad states

$B_d^{**} \to B^+ \pi^-$



'Soft' Analysis:

Add 2 additional parameters for mass dependent Breit-Wigner: Q and Γ .
Fix parameters for Gaussian to those of previous fit.
Fix relative contribution of broad:narrow states to 1:1 (state counting) or 1:2 (spin counting).

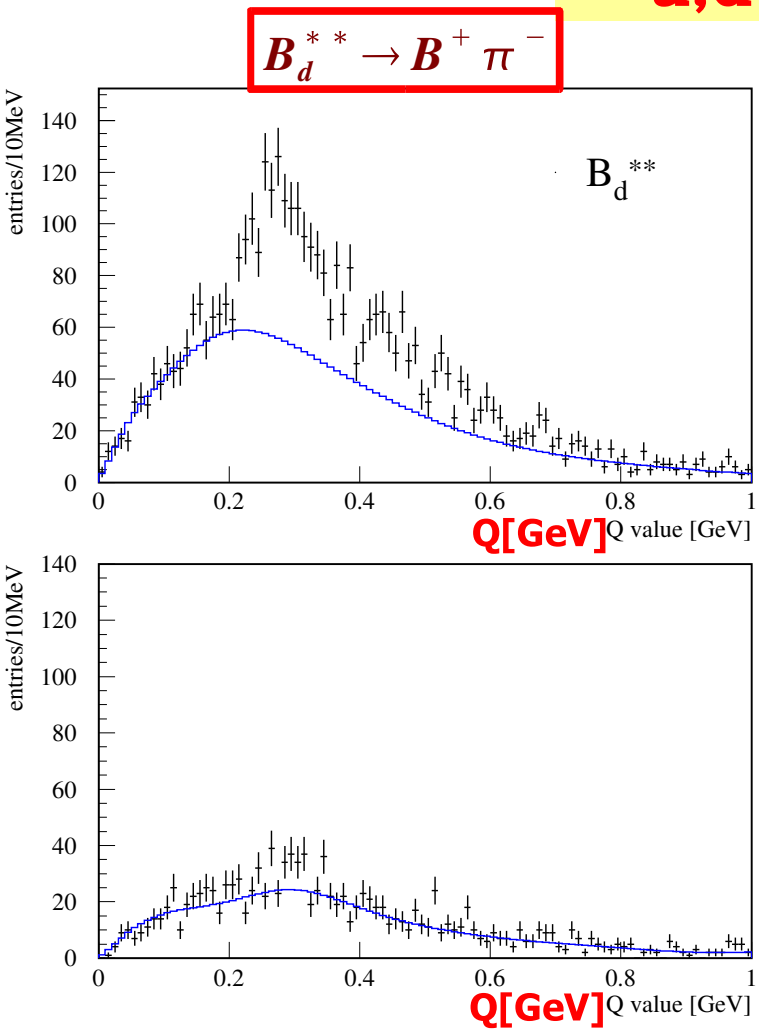
➔ A broad component with Q-value $\approx$ 100 MeV above the Gaussian and $\Gamma \approx 250\,MeV$ significantly improves the fit quality!

Broad D^{**} states:

CLEO: $D_1^{0\,*}(1/2)$: $m = 2461^{+41}_{-34} \pm 10 \pm 32\ MeV$ $\quad \Gamma = 290^{+101}_{-79} \pm 26 \pm 36\ MeV$

DELPHI: $D_1^{*}(1/2)$: $m = 2470 \pm 28 \pm 46\ MeV$ $\quad \Gamma = 160 \pm 66 \pm 40\ MeV$

$B^{**}_{u,d}$ Analyses II



'NN' Analysis:

- **Working at much higher purity**
- **Narrow component roughly compatible with resolution (probably mainly consisting of narrow states)**

  Q-value and width in agreement with 'soft' analysis

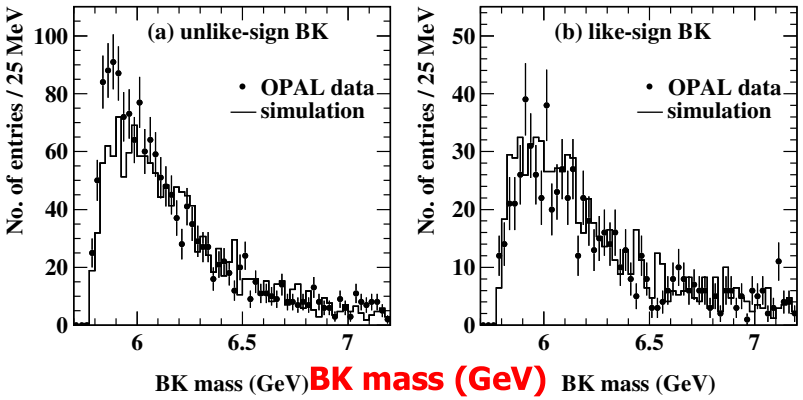
- **This component alone is not enough to give a good description of the signal!**
  - ➔ **additional contributions needed, preferably at higher masses**

➔ Results seem to favour models predicting 'Spin-Orbit-Inversion'

No final conclusion yet!

More tests of different models have to be performed!

Reminder: Status of B_s^{**}



OPAL: Excess in the right-sign $B^{(*)}K$ spectrum at $m = 5853 \pm 15\,MeV\ (Q \approx 80\,MeV)$.

$$\frac{\sigma(B_s^{**}) \cdot BR(B_s^{**} \to B^{(*)}K)}{\sigma_b} = 0.021 \pm 0.004 \pm 0.005 \quad (\approx 3\sigma)$$

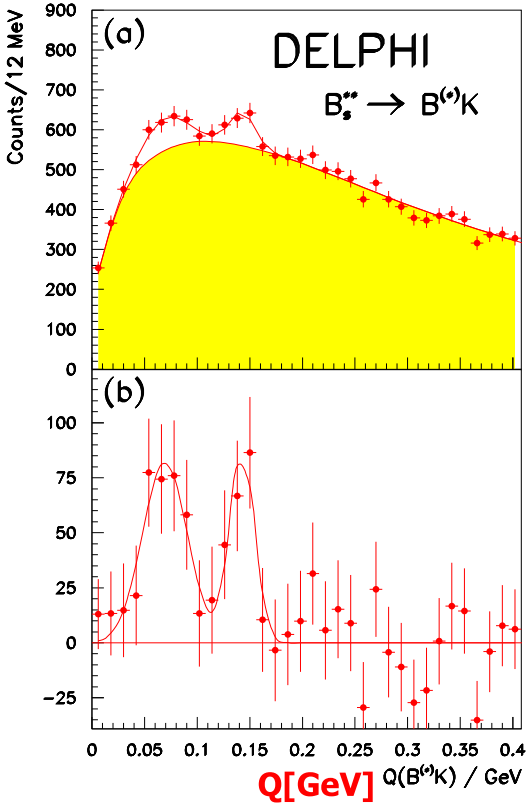
DELPHI (Brussels 95, unpublished):

Evidence for 2 narrow resonances in the $B^{(*)}K$ spectrum at $Q = 70\,MeV$ and $Q = 142\,MeV$ interpreted as $B_{s1} \to B^* K$ and $B_{s2}^* \to BK$.

Production rates:

$$\frac{\sigma(B_{s1}) \cdot BR(B_{s1} \to B^* K)}{\sigma_b} = 0.021 \pm 0.005 \pm 0.007 \quad (\approx 2.5\sigma)$$

$$\frac{\sigma(B_{s2}^*) \cdot BR(B_{s2}^* \to BK)}{\sigma_b} = 0.016 \pm 0.005 \pm 0.007 \quad (\approx 2\sigma)$$

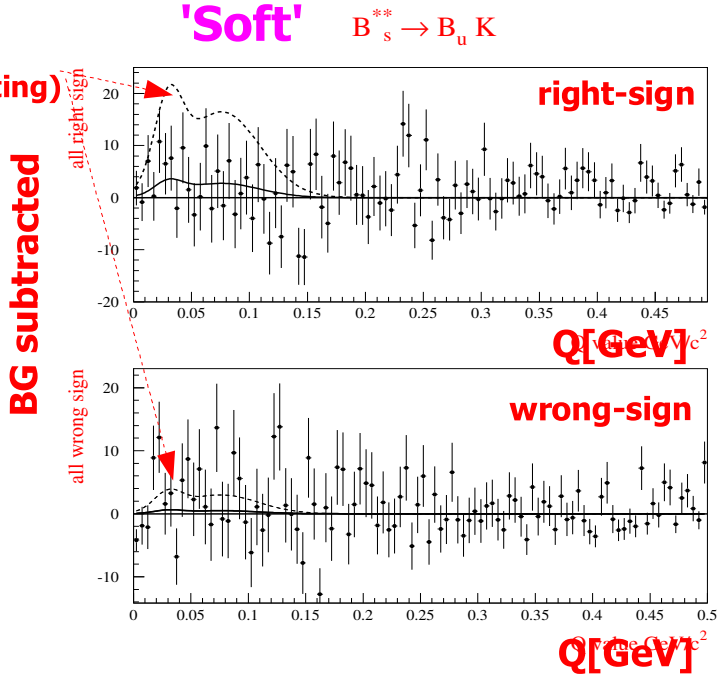


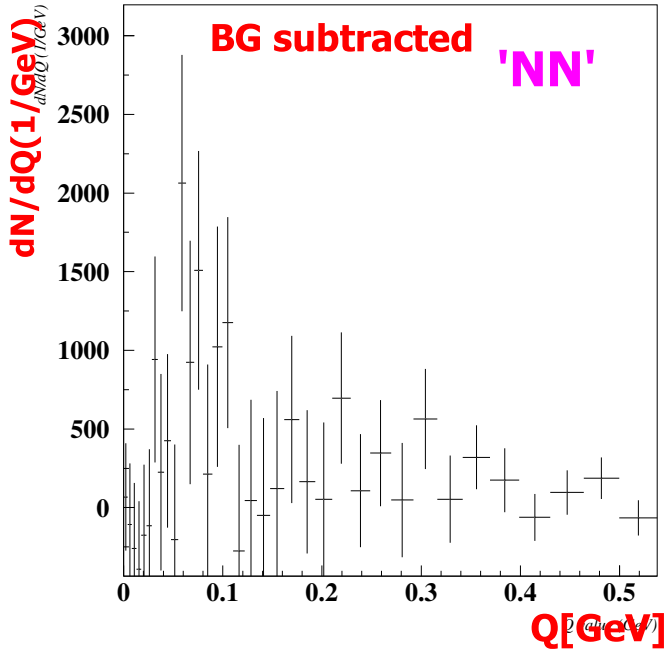
➔ 3.7% per b-jet (≈30-35% relative to $\bar{b}s$) in narrow states!

Results on B_s^{**} from new analyses

Replace pion with kaon; charge- and flavour correlation more powerful!

Eichten et al.
(12 MeV splitting)



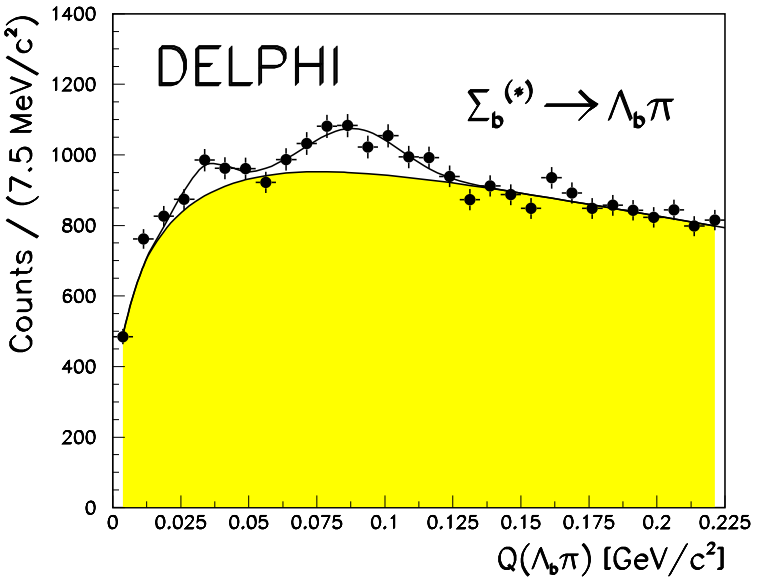


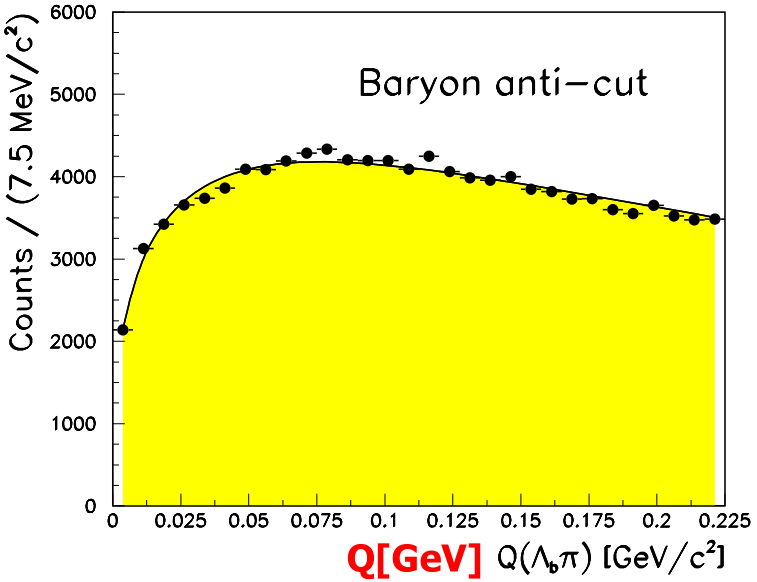
Upper limit on production rate of narrow resonances up to Q=150 Mev:

$$\frac{\sigma\left(B_s^{**}\right)}{\sigma_b} < 0.015 @ 95\ \%\ \mathrm{CL}$$

➔ **Measured production rates of OPAL and DELPHI not confirmed!**

Reminder: Status of $\Sigma_b^{(*)}$





Spectroscopy of light b-baryons (bqq; q=u,d) with l=0:

$S_{qq}=0 \rightarrow \Lambda_b$ $\qquad$ $S_{qq}=1$: $J=1/2 \rightarrow \Sigma_b$

$J=3/2 \rightarrow \Sigma_b^*$

DELPHI (Brussels 95, unpublished):

Evidence for 2 narrow resonances in the $\Lambda_b \pi$ spectrum at $Q=33\,MeV$ and $Q=89\,MeV$ interpreted as Σ_b and Σ_b^*.

Corresponding production rate:

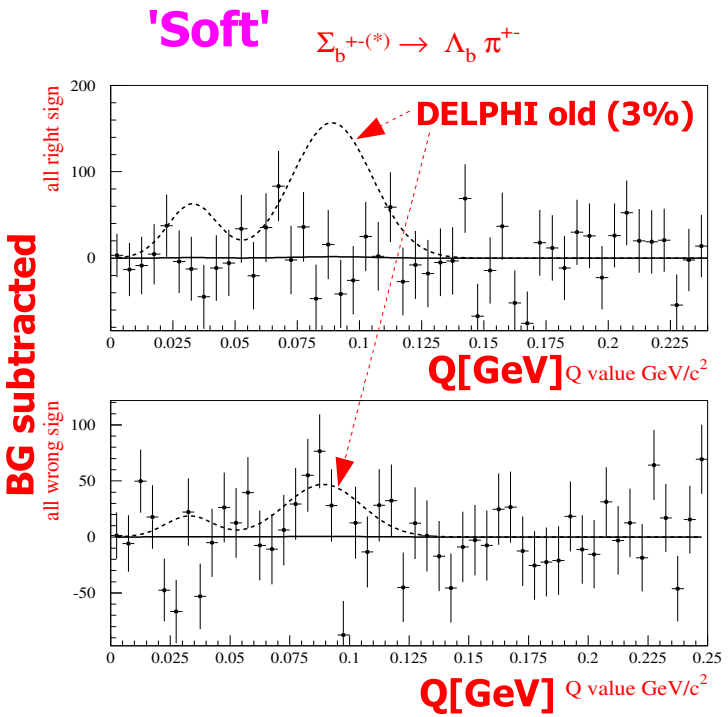
$$\frac{\sigma\left(\Sigma_b+\Sigma_b^*\right)}{\sigma_b}=0.048\pm0.006\pm0.015 \quad (\approx 3\sigma)$$

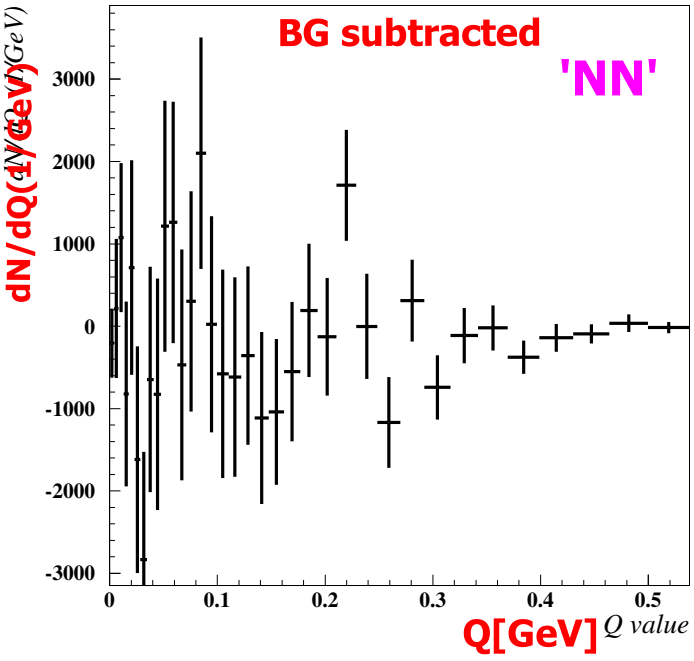
➔ **≈50% of light b-baryons (bqq with q=u,d) produced as Σ_b or Σ_b^*.**

➔ **Mass difference bigger than expected (from $\Sigma_c - \Sigma_c^*$).**

Results on $\Sigma_b^{(*)}$ from new analyses

Replace inclusive B-meson with Λ_b . rs/ws sample more difficult!





Upper limit on production rate for narrow resonance up to Q=150 MeV:

$$\frac{\sigma\left(\Sigma_b^{(*)}\right)}{\sigma_b} < 0.015 @ 95\%\ \text{CL}$$

➔ **Results of old DELPHI analysis not confirmed!**

Summary and Conclusions

- DELPHI performed new analyses on excited b states using highly improved analysis techniques increasing the purity and reducing the dependence on the background modelling

- The production rate of of a component compatible with detector resolution -suggesting the interpretation as stemming from narrow $B^{**}_{u,d}$ states only- has been measured in the 'soft' analysis to be:

$$\frac{\sigma(B^{**}_{u,d})_{narrow}}{\sigma_b} = 0.098 \pm 0.007 \pm 0.012$$

- Data suggest the presence of broad states with an indication for 'Spin-Orbit-Inversion'

- For B^{**}_s and $\Sigma_b^{(*)}$ upper limits on the production rates have been obtained:

$$\sigma(B^{**}_s)/\sigma_b < 0.015\ , \quad \sigma(\Sigma_b^{(*)})/\sigma_b < 0.015\ @\ 95\%\ CL$$

- Still open questions:
  Final answer from TEVATRON in exclusive modes?