Excited B,D Mesons at OPAL

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for the  Collaboration

Outline

Part I: B Spectroscopy at OPAL: B^{**}

Part II: D Spectroscopy at OPAL: $D^{*\prime}$

Introduction: HQET

Mutual interaction of quarks dominated by QCD
$\rightarrow$ precise predictions only for special cases

Among them: systems of one heavy quark and one light quark.

Heavy Quark Effective Theory

Much easier formalism in the limit $\mathrm{m_Q} \rightarrow \infty$:
$\rightarrow$ system approximated as light quark moving in static potential of heavy quark.
Additional symmetries occur that simplify calculation of this potential.

Corrections to $\mathrm{m_Q} \rightarrow \infty$ case are applied via $1/\mathrm{m_Q}$ expansion.

$\rightarrow$ Prediction of bound state properties
(mass, width, decay modes)

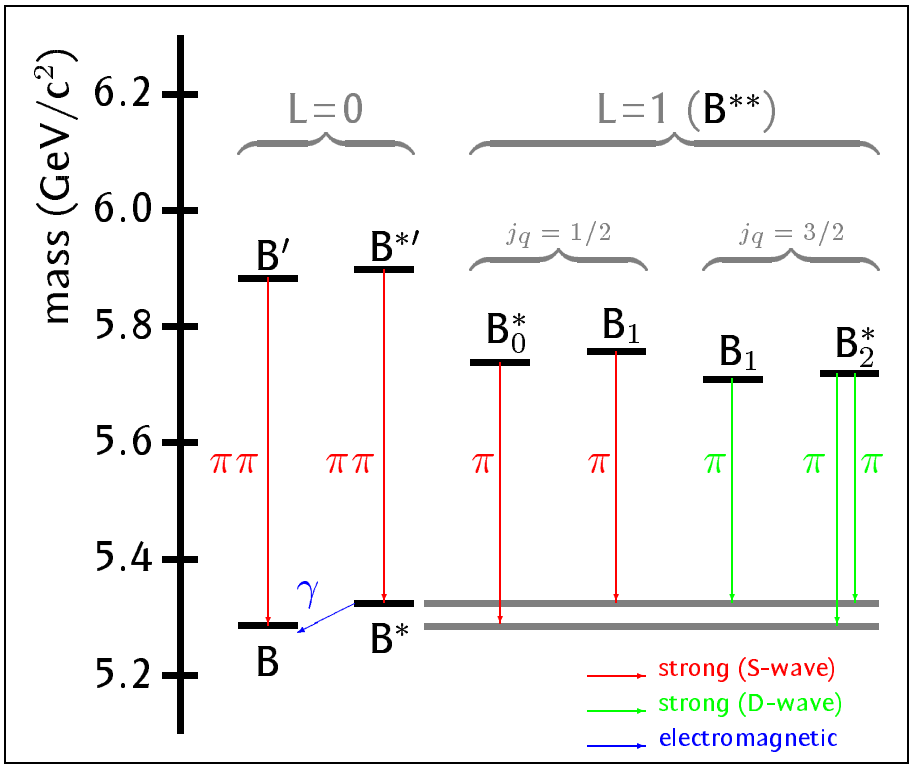
HQET-Predictions: B Spectrum

Calculation of Ebert, Faustov, Galkin (Phys.Rev. D57 (1998) 5663):

Relativistic treatment of light quark,

heavy quark expansion to first order in $1/m_Q$.

Predictions for $B_{u,d}$ spectrum: (B_s similarly)



Experimental accessibility: B ,B^* - very good
B^{**} - partially (see this talk)
B',$B^{*\prime}$ - not seen at OPAL

Orbital B Excitations: B^{**}

HQET predictions for orbitally excited B states (B^{**}):

state	mass $[GeV/c^2]$	width $[GeV/c^2]$	decay mode
B_0^*	5.738	≈0.1-1.0	$B\pi$
$B_1(1/2)$	5.757	≈0.1-1.3	$B^*\pi$
$B_1(3/2)$	5.719	0.021	$B^*\pi$
B_2^*	5.733	0.025	$B^*\pi$, $B\pi$

Separation of these states is difficult:

- Overlap in mass
- Two different decay modes:

$$B^{**} \to B^* \pi \hookrightarrow B\gamma \quad \text{and} \quad B^{**} \to B\pi$$

Only difference: γ in $B^{**} \to B\gamma\pi$

But: Photon reconstruction is difficult experimentally

→ Decay modes undistinguishable

→ Bad B^{**} mass resolution

→ Insufficient separation of different B^{**} states (e.g. B_0^* and $B_1(1/2)$)

New attempt by OPAL to overcome these problems!

B^{**} Reconstruction

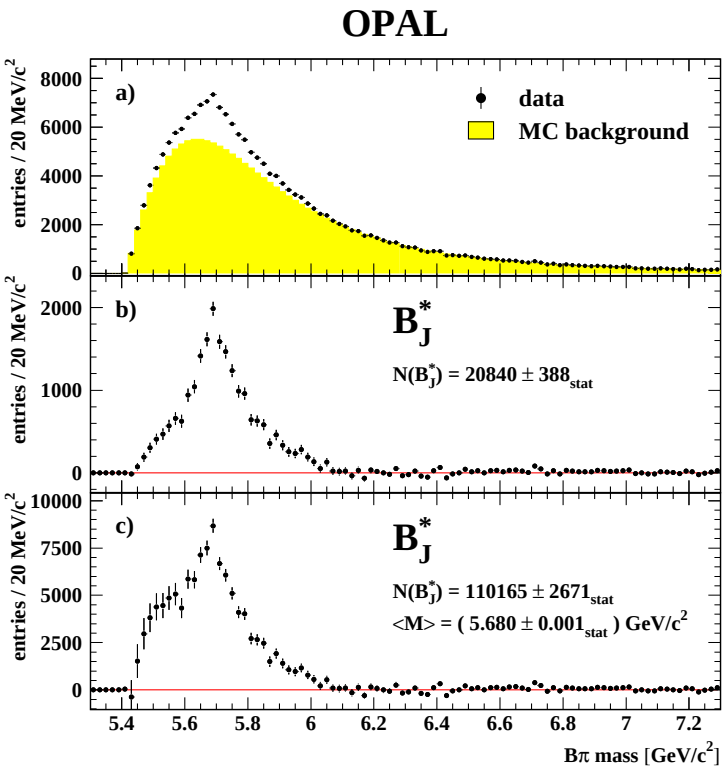
- tag B events
  by looking for decay vertices, high p_t leptons, jet shapes
- inclusive B reconstruction
  using all tracks with suitable kinematic properties
- Look for $B^{**} \rightarrow B\pi + X$ decays
  (X= additional photons, pions, ...)

$B\pi$ mass distribution

(all B^{**} candidates)

background subtracted

efficiency corrected signal
(efficiency is mass-dependent)



This distribution includes both $B^{**} \rightarrow B\pi$ and $B^{**} \rightarrow B^*\pi \rightarrow B\gamma\pi$ final states

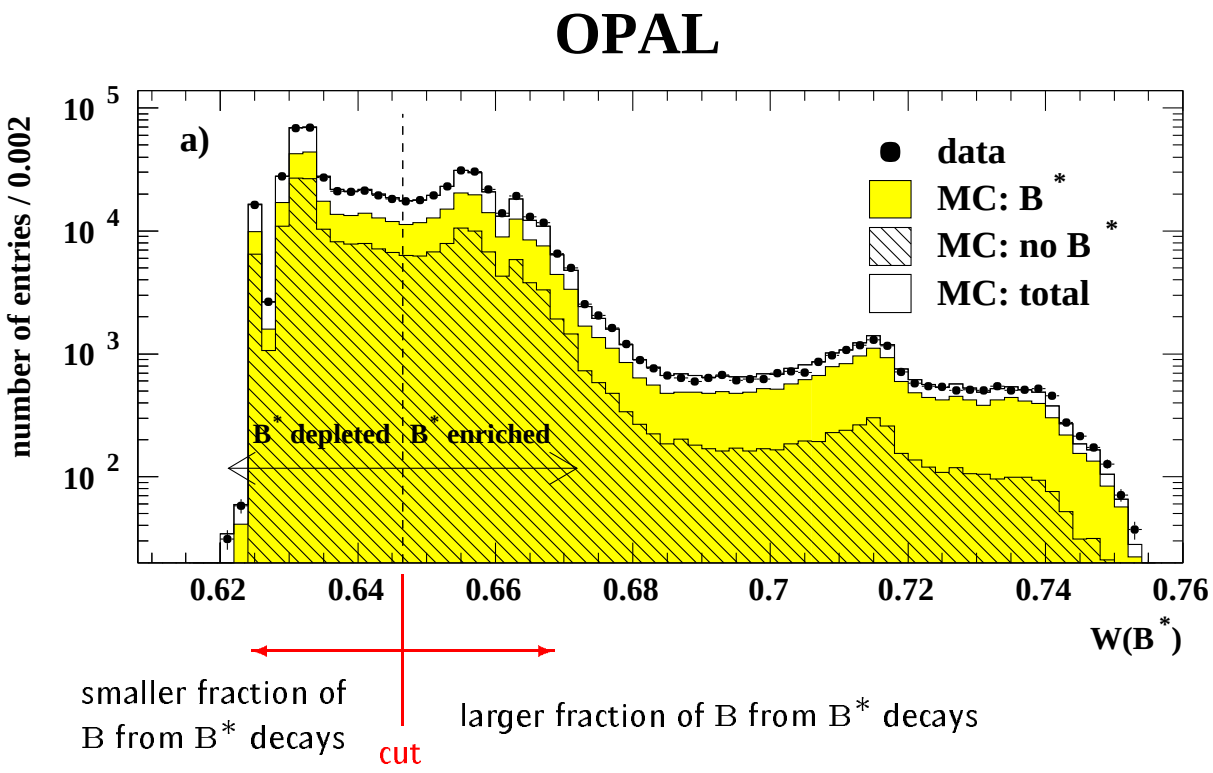
Separation of $B\gamma\pi$ and $B\pi$ Final States I

Do NOT explicitly reconstruct the γ

Instead:

- Search for good γ candidates in event
- Calculate probability that B in $B\pi$ candidate comes from B^* decay (using $B\gamma$ mass, γ energy, ...)

Distribution of this B^* weight:



Use photons only as tag, not in reconstruction!

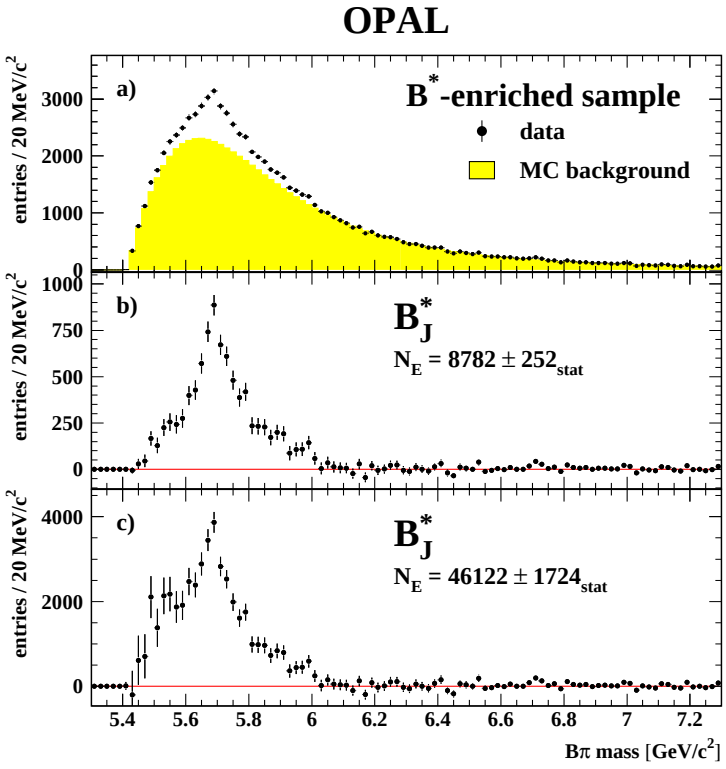
Separation of $B\gamma\pi$ and $B\pi$ Final States II

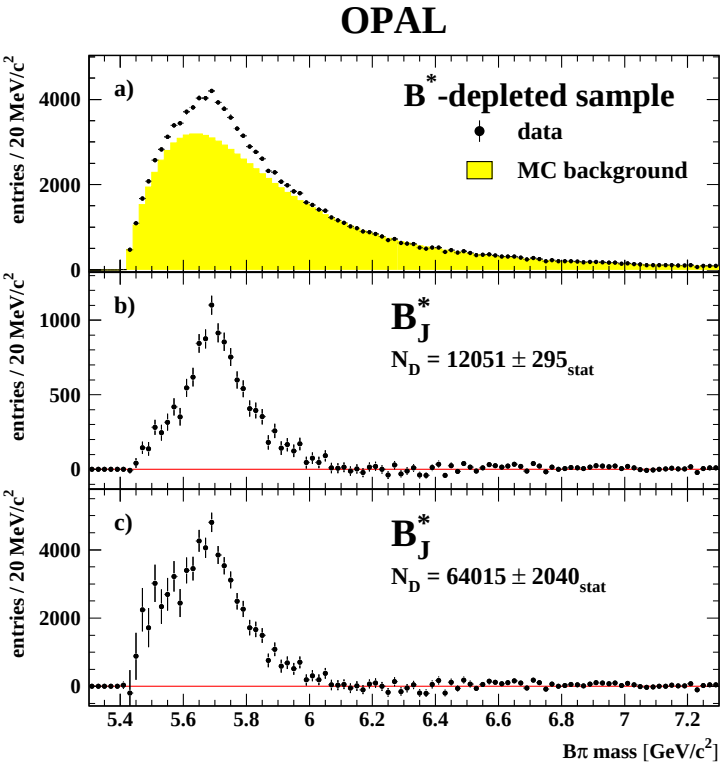
Cut on B^* weight

→ One sample enriched in $B^{**} \to B^*\pi \to B\gamma\pi$ decays,
second sample enriched in direct $B^{**} \to B\pi$ decays

"B^* -enriched" $B\pi$ sample,
enriched in
$B_1(1/2)$, $B_1(3/2)$, $B_2^* \to B^*\pi \to B\gamma\pi$;
depleted from
B_0^*, $B_2^* \to B\pi$.

"B^* -depleted" $B\pi$ sample,
enriched in
B_0^*, $B_2^* \to B\pi$;
depleted from
$B_1(1/2)$, $B_1(3/2)$, $B_2^* \to B^*\pi \to B\gamma\pi$.





$\mathrm{BR}(\mathrm{B}^{**} \to \mathrm{B}^{*}\pi + \mathrm{X})$

Evaluate number of B^{**} in
- $\mathrm{B}^{**} \to \mathrm{B}\pi$ enriched sample
- $\mathrm{B}^{**} \to \mathrm{B}^{*}\pi \to \mathrm{B}\gamma\pi$ enriched sample

$\to$ model-independent measurement of B^{**} branching ratio into $\mathrm{B}^{*}\pi + \mathrm{X}$ (i.e. $\mathrm{B}\gamma\pi + \mathrm{X}$):

$$\mathrm{BR}(\mathrm{B}^{**} \to \mathrm{B}^{*}\pi + \mathrm{X}) = 0.85^{+0.26}_{-0.27}(\mathrm{stat.}) \pm 0.12(\mathrm{syst.})$$

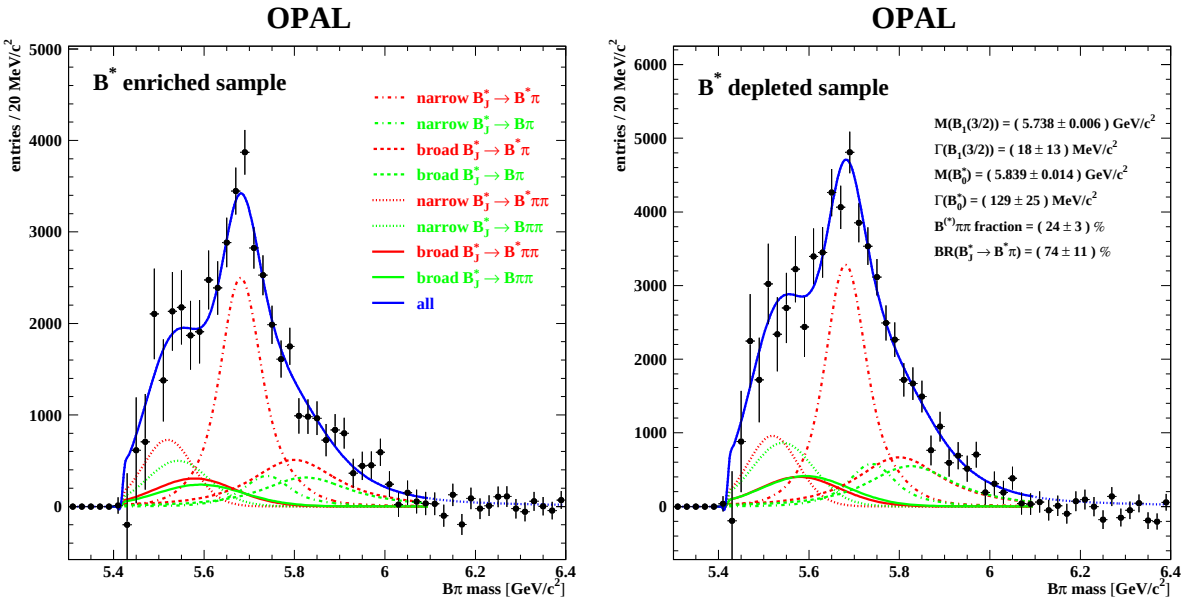
averaged over all four B^{**} states.

This is the first measurement of this quantity.
Compatible with predictions
and measured B^{**} and B^{*} production rates.

Dominant systematic uncertainties:
- background (composition, sideband range)
- electromagnetic calorimeter efficiency
- B^{**} decay helicity distribution
- B^{*} probability cut

Further Information about Individual B^{**} States

Simultaneous fit to $B\pi$ mass distributions from B^*-enriched/-depleted samples in HQET framework:



Difficult fit - not all results stable

$$M(B_1(3/2)) = (5.738^{+0.005}_{-0.006} \pm 0.007)\,\mathrm{GeV/c^2}$$

$$\Gamma(B_1(3/2)) = (18^{+15+29}_{-13-23})\,\mathrm{MeV/c^2}$$

$$BR(B^{**} \to B^*\pi) = 0.74^{+0.12+0.21}_{-0.10-0.15}$$

Caution:
large systematic uncertainties!

→ Some details of B^{**} spectrum are resolved

But: different ALEPH and L3 fit results for broad B^{**} masses, radial excitations and di-pion transitions

→ more effort needed to sort this out

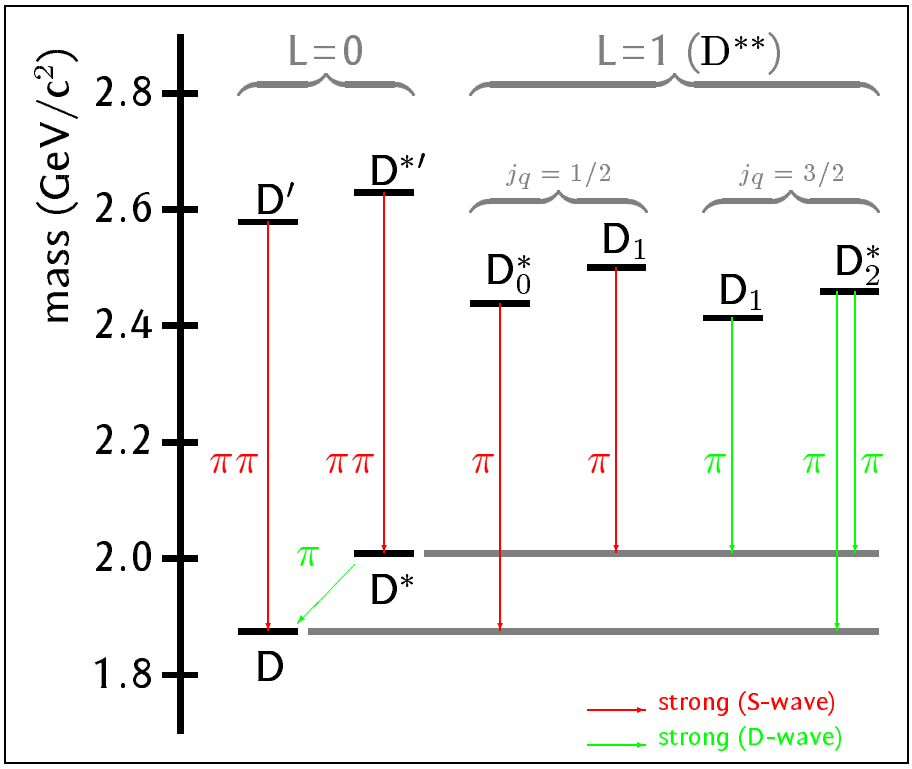
D Mesons

Calculation of Ebert, Faustov, Galkin (Phys.Rev. D57 (1998) 5663):

Relativistic treatment of light quark,

heavy quark expansion to first order in $1/m_Q$.

Predictions for $D_{u,d}$ spectrum: (D_s similarly)



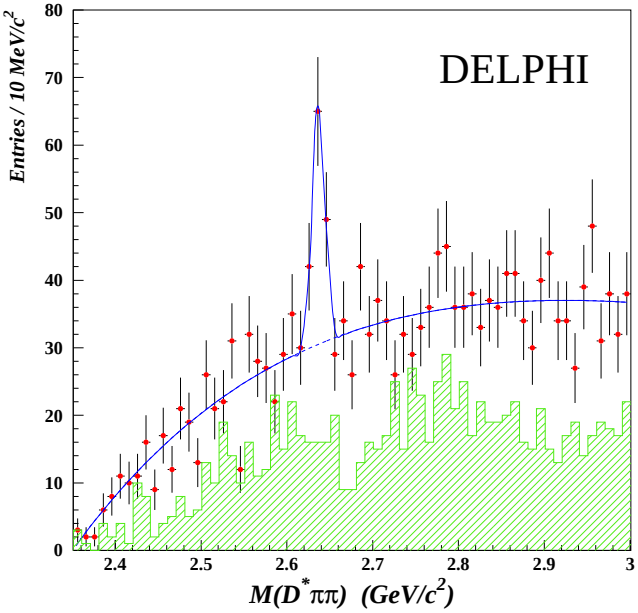
Experimental accessibility: $D, D^{*\pm}$ - very good

D^{**} - partially (narrow states)

$D', D^{*\prime}$ - partially (see this talk)

$D^{*\prime}$: How it started

DELPHI collaboration saw narrow resonance at $2637 \pm 2(\text{stat.}) \pm 6(\text{syst.})$ MeV/c^2, very close to predicted $D^{*\prime}$ mass (2629 MeV/c^2).



Phys. Lett. **B426** (1998) 231.

This was unexpected: narrow (< 15 MeV/c^2) resonance despite S-wave decay!

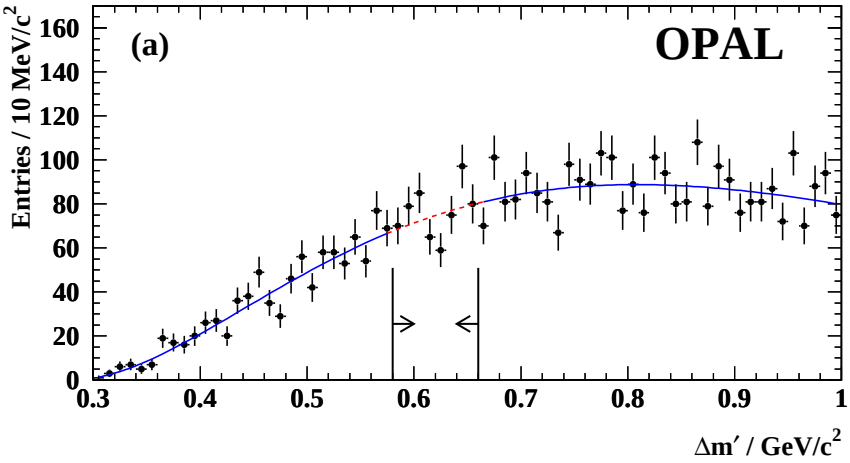
Decay chains investigated by DELPHI:

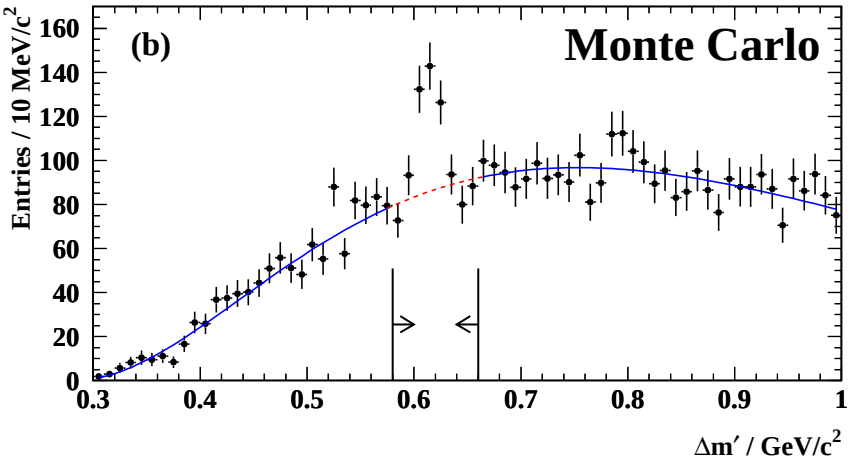
$$D^{*\prime +} \to D^{*+}\pi^-\pi^+$$
$$\hookrightarrow D^0\pi^+$$
$$\hookrightarrow K^-\pi^+$$
$$\hookrightarrow K^-\pi^+\pi^+\pi^-$$

blue part also used in OPAL analysis

OPAL $D^{*\prime}$ Selection Result

$D^{*\prime\pm} \to D^{*\pm}\pi^+\pi^-$ reconstruction:
Combine $D^{*\pm}$ candidates with two extra pions,
impose simple energy/vertex topology cuts





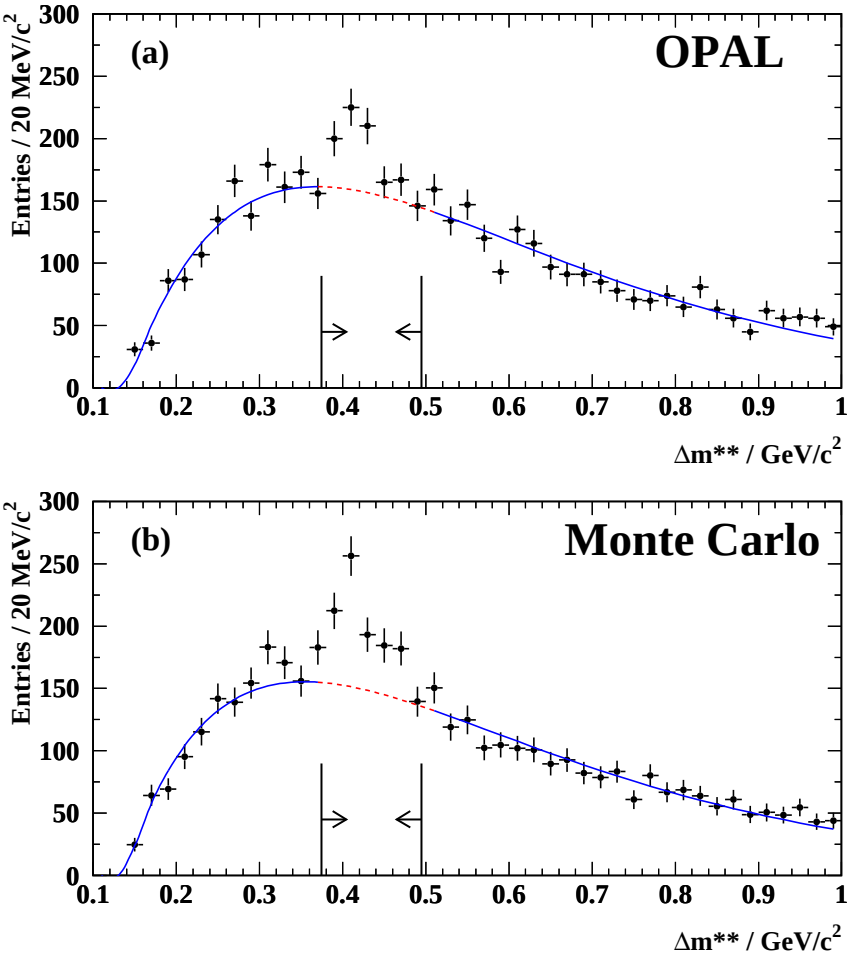
No excess seen in OPAL data.

14 ± 28 candidates observed, where 145 have been expected from Monte Carlo tuned to DELPHI measurement

D^{**0} Cross-check

Cross-check $D^{*\prime +} \to D^{*+}\pi^-\pi^+$
by looking at $D^{**0} \to D^{*+}\pi^-$:

Find narrow orbital excitations
in analysis similar to $D^{*\prime}$ reconstruction



OPAL $\mathrm{D}^{*\prime}$ Production Rate Limits

95% C.L. limit on narrow $\mathrm{D}^{*\prime}$ production in Z decays:

$$f(\mathrm{Z} \to \mathrm{D}^{*\prime\pm}(2629)) \times \mathrm{Br}(\mathrm{D}^{*\prime+} \to \mathrm{D}^{*+}\pi^+\pi^-) < 3.1 \times 10^{-3}$$

DELPHI (no official DELPHI result): $(8.8 \pm 1.9(\text{stat.})) \times 10^{-3}$

Looking at charm and bottom enriched samples separately:

$$f(\mathrm{c} \to \mathrm{D}^{*\prime+}(2629)) \times \mathrm{Br}(\mathrm{D}^{*\prime+} \to \mathrm{D}^{*+}\pi^+\pi^-) < 0.9 \times 10^{-2}$$

$$f(\mathrm{b} \to \mathrm{D}^{*\prime+}(2629)) \times \mathrm{Br}(\mathrm{D}^{*\prime+} \to \mathrm{D}^{*+}\pi^+\pi^-) < 2.4 \times 10^{-2}$$

No subsample shows any sign of a narrow resonance

Ratio of $\mathrm{D}^{*\prime+} \to \mathrm{D}^{*+}\pi^+\pi^-$ over $\mathrm{D}^{**0} \to \mathrm{D}^{*+}\pi^-$:

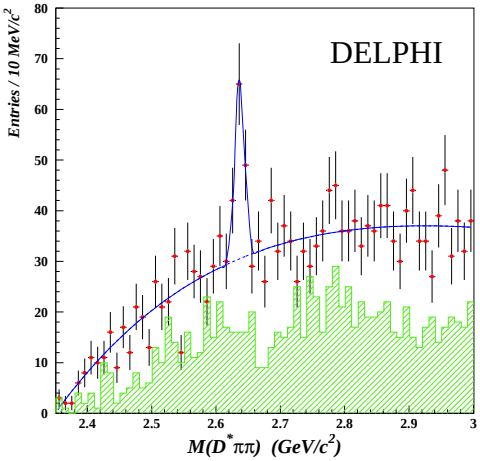
$R < 0.22$ (95% C.L.)

DELPHI: $R = 0.49 \pm 0.18(\text{stat.}) \pm 0.10(\text{syst.})$

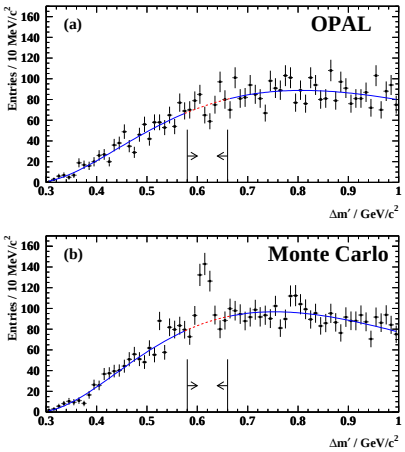
Overview of $D^{*\prime}$ Measurements

	relative prod. rate R		$f(c \to D^{*\prime +}) \times Br(D^{*\prime +} \to D^{*+}\pi^+\pi^-)$	
	95% C.L.	90% C.L.	simple (95% C.L.)	conservative (95% C.L.)
DELPHI	$0.49 \pm 0.18 \pm 0.10$			
OPAL	< 0.22	< 0.17	$< 0.78 \times 10^{-2}$	$< 0.9 \times 10^{-2}$
CLEO ($c\bar{c}$)		< 0.16		
ZEUS ($c\bar{c}$)			$< 0.7 \times 10^{-2}$	

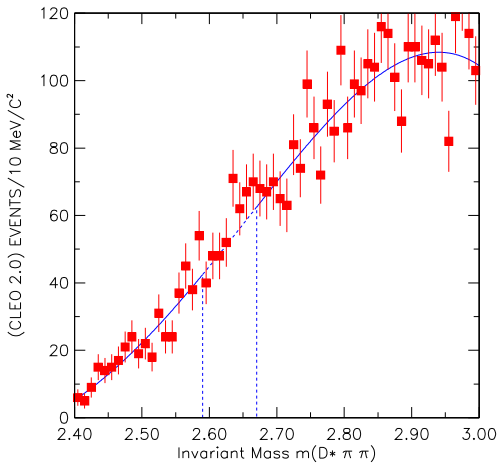
DELPHI, Phys. Lett. **B426** (1998) 231



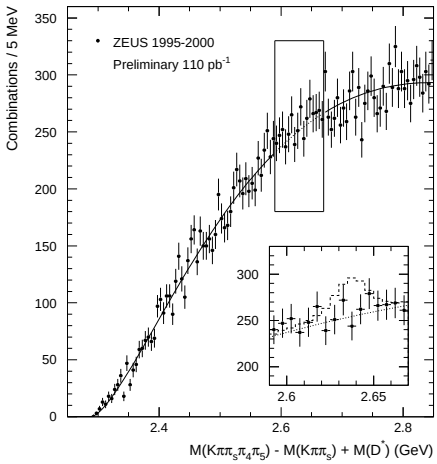
OPAL, accepted by Eur Phys J **C**



CLEO prelim., hep-ex/9901008



ZEUS prelim., ICHEP 2000, Abstract 854



Summary

Years after progression to LEP2, and even after the LEP shutdown, heavy flavour spectroscopy with LEP1 data is still an active field in the OPAL collaboration. Recent results include:

- Investigation of the Decay of Orbitally-Excited B Mesons and First Measurement of the Branching Ratio BR($\mathrm{B}^{**} \to \mathrm{B}^{*}\pi + \mathrm{X}$):
  $\mathrm{BR}(\mathrm{B}^{**} \to \mathrm{B}^{*}\pi + \mathrm{X}) = 0.85^{+0.26}_{-0.27}(\mathrm{stat.}) \pm 0.12(\mathrm{syst.})$
  Partial insight has been gained into the substructure of the B^{**} peak.

  EPS2001 Abstract No. 22; Submitted to Eur Phys J

- A Search for a Radial Excitation of the $\mathrm{D}^{*\pm}$ Meson: A production limit of
  $f(\mathrm{Z} \to \mathrm{D}^{*\prime\pm}(2629)) \times \mathrm{Br}(\mathrm{D}^{*\prime +} \to \mathrm{D}^{*+}\pi^{+}\pi^{-})$
  $< 3.1 \times 10^{-3}$ (95% C.L.) has been obtained.
  This is in disagreement with the DELPHI measurement, but supported by other results.

  EPS2001 Abstract No. 11; Accepted by Eur Phys J