New Belle results on $B \to D^{**}\ell\nu$ decays.

Dmitri Liventsev[*]
(ITEP, Moscow)

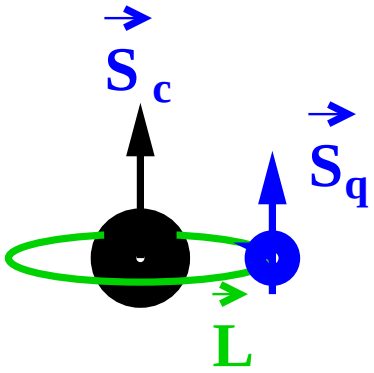
March 04, 2008

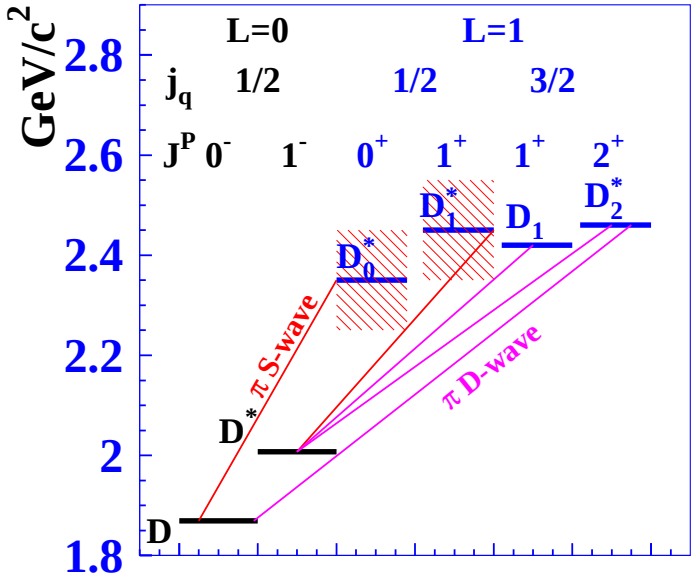
[*] e-mail:livent@itep.ru

D^{**} spectroscopy

- Spectroscopy
- Existing results
- Belle analysis
- Comparison
- Helicity
- Conclusions

D^{**} are P-wave excitations of D-mesons. HQET predicts four D^{**} mesons: two narrow and two wide. They were observed and studied (*e.g.* hep-ex/0307021, hep-ex/0611054).





HQET: Bigi *et al.* (arXiv:0708.1621)

$$j_q = \frac{3}{2}\left\{ \begin{array}{l} \mathcal{B}(B \to D_1 \ell\nu) = (0.40^{+0.12}_{-0.14})\% \\ \mathcal{B}(B \to D_2^* \ell\nu) = (0.6^{+0.3}_{-0.2})\% \end{array} \right. \quad large$$

$$j_q = \frac{1}{2}\left\{ \begin{array}{l} \mathcal{B}(B \to D_0^* \ell\nu) = (0.06 \pm 0.02)\% \\ \mathcal{B}(B \to D_1^{'} \ell\nu) = (0.06 \pm 0.02)\% \end{array} \right. \quad small$$

Existing results

- Spectroscopy
- Existing results
- Belle analysis
- Comparison
- Helicity
- Conclusions

Semileptonic B decays to narrow D_1 and D_2^* were studied by a number of experiments, mostly in $B \to D^* \pi^+ \ell\nu$ channel. Some assumptions were common:

$\mathcal{B}(b \to B) = 37.8 - 39.7\%$

$\mathcal{B}(D_1 \to D^* \pi^+) = 66.7\%$

$\mathcal{B}(D_2^* \to D^* \pi^+) = 20\%$

Exp.	Pub.	Environment	$\mathcal{B}(B \to D_1 \ell\nu)$	$\mathcal{B}(B \to D_2^* \ell\nu)$
ARGUS	1993	e^+e^- at $\Upsilon(4S)$	$\mathcal{B}(B \to D^{**} \ell\nu) = 2.7 \pm 0.7^\dagger$	
ALEPH	1996	e^+e^- at Z	0.74 ± 0.16	< 0.2
CLEO	1997	e^+e^- at $\Upsilon(4S)$	0.56 ± 0.16	< 0.8
OPAL	2002	e^+e^- at Z	1.05 ± 0.35	< 1.85
DELPHI	2005	e^+e^- at Z	0.33 ± 0.17	0.37 ± 0.17
DØ	2005	$p\bar{p}$ at 1.96 GeV	0.33 ± 0.06	0.44 ± 0.16

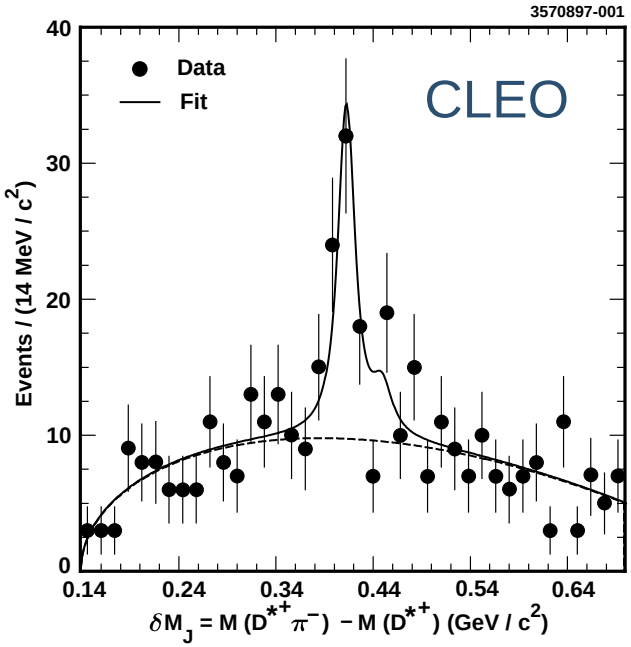
DELPHI: $\mathcal{B}(B \to D_1^* \ell\nu) = (1.25 \pm 0.37)\%$

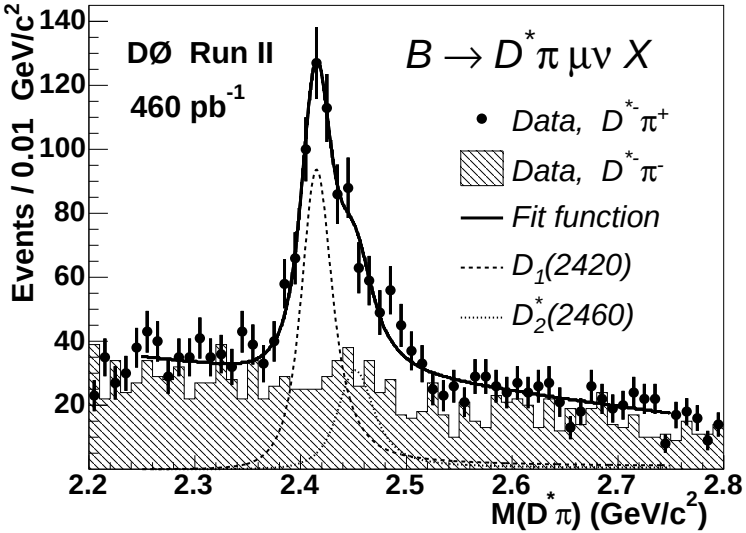
$\mathcal{B}(B \to D_0^* \ell\nu) = (0.42 \pm 0.40)\%$

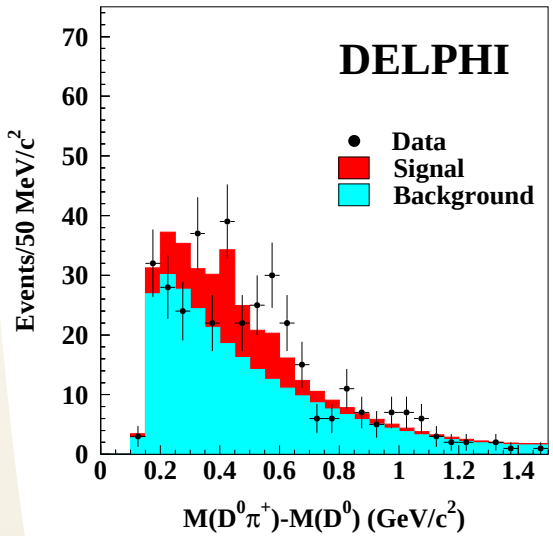
$^\dagger D^{**}$ is "not D, D^*" here

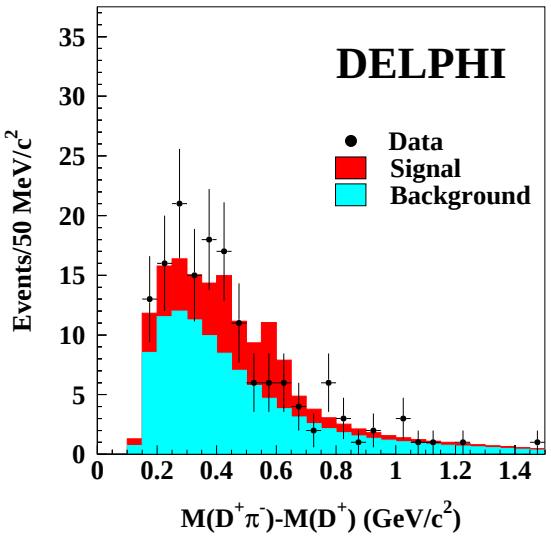
Existing results: Figures

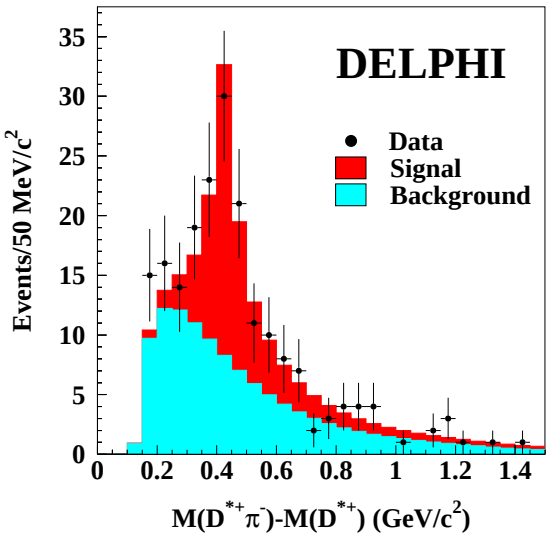
- Spectroscopy
- Existing results
- Belle analysis
- Comparison
- Helicity
- Conclusions





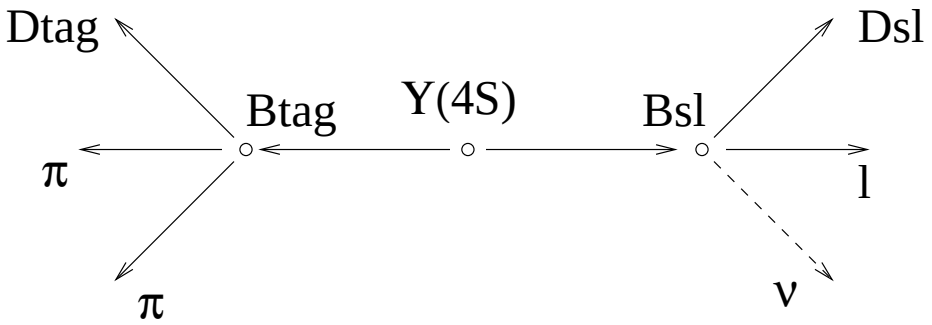






Belle analysis: method

- Spectroscopy
- Existing results
- Belle analysis
- Comparison
- Helicity
- Conclusions



- Signal $B_{\rm sl}$ is reconstructed as $D^{(*)}(\pi)\ell$; the rest of the event is reconstructed as a tagging $B_{\rm tag}$ as $D^{(*)}\rho^+$, $D^{(*)}{\rm n}\pi$ (${\rm n} \leq 6$); recoil mass, i.e., neutrino mass, is calculated:

$$M_\nu^2 = (P_{\rm beam} - P_{B_{\rm tag}} - P_{B_{\rm sl}})^2$$

- Backgrounds are subtracted using data: by $\Delta E \equiv E_{\rm tag} - E_{\rm beam}$ and $M(D_{\rm sl})$ sidebands and $D^{(*)}\pi h^+$ analysis (lepton fakes); feed-down ($B \to D^*(\pi)\ell\nu$ reconstructed as $B \to D(\pi)\ell\nu$ with lost neutral) is subtracted using MC;
- Branching ratios are calculated relative to the normalization modes $B \to D\ell\nu$ to cancel out the $B_{\rm tag}$ reconstruction efficiency.

Belle analysis: M_ν^2 distributions

- Spectroscopy
- Existing results
- Belle analysis
- Comparison
- Helicity
- Conclusions

$\mathcal{L} \sim 605\text{fb}^{-1}$

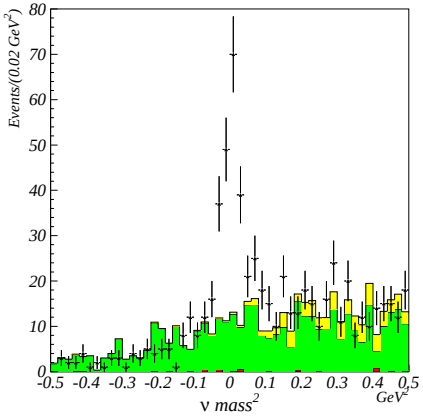
$\Delta E + M(D) - \Delta E, M(D)$ sidebands are shown in green

Lepton fakes are shown in red

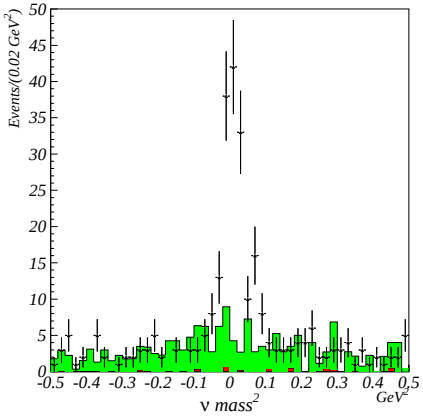
Feed-down from $B \to D^* \pi \ell \nu$
taken from MC
and normalized to data
is shown in yellow

In the following analysis we use
events from $|M_\nu^2| < 0.1\,\text{GeV}^2$

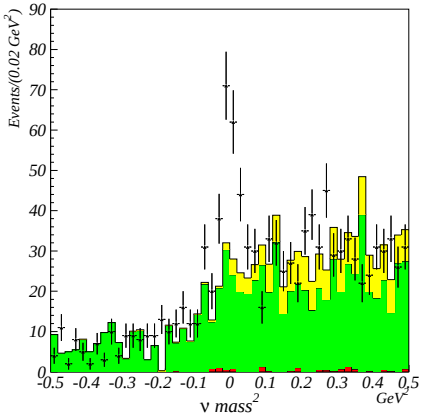
$B^+ \to D^- \pi^+ \ell^+ \nu$



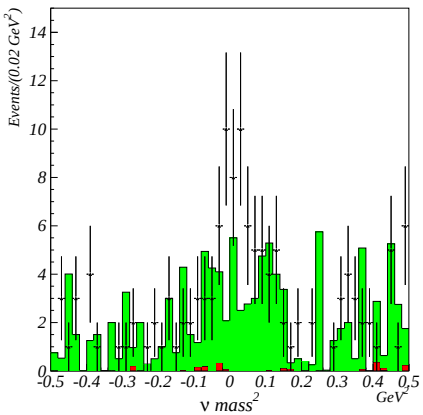
$B^+ \to D^{*-} \pi^+ \ell^+ \nu$



$B^0 \to \bar{D}^0 \pi^- \ell^+ \nu$

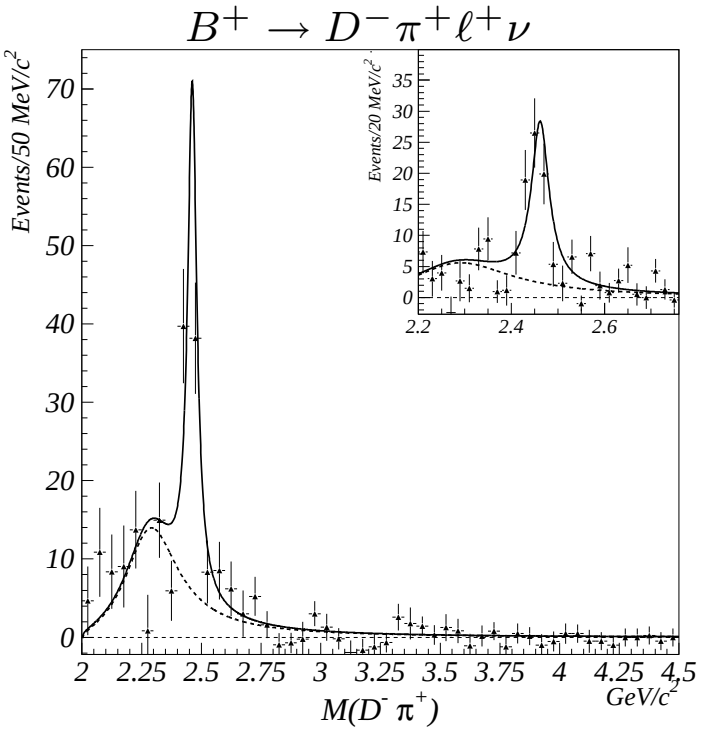


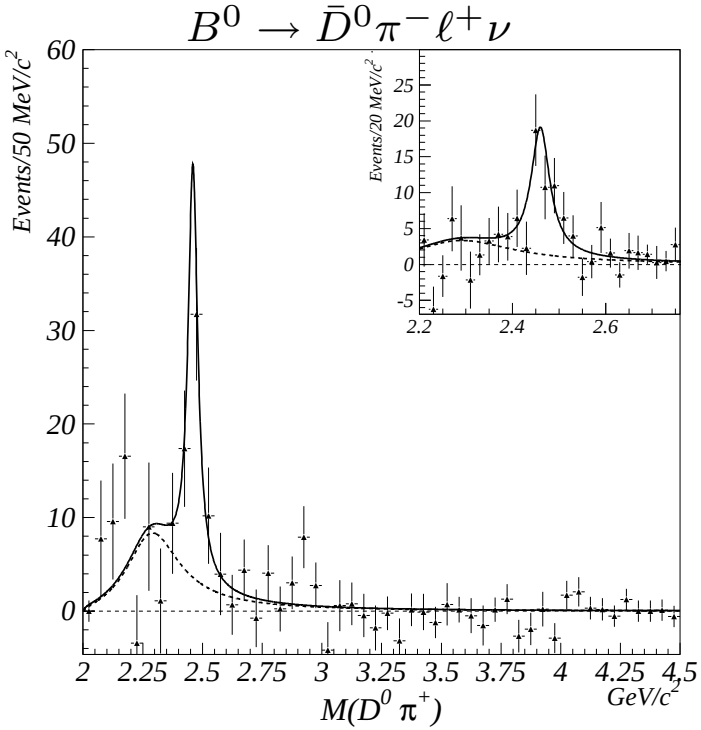
$B^0 \to \bar{D}^{*0} \pi^- \ell^+ \nu$



Belle analysis: $D\pi$ invariant mass

- Spectroscopy
- Existing results
- Belle analysis
- Comparison
- Helicity
- Conclusions





$|M_\nu^2| < 0.1\,\mathrm{GeV}^2$

Backgrounds are subtracted

$D\pi$ invariant mass is fitted with sum of Breit-Wigner functions and nonresonant part (Goity-Roberts models):

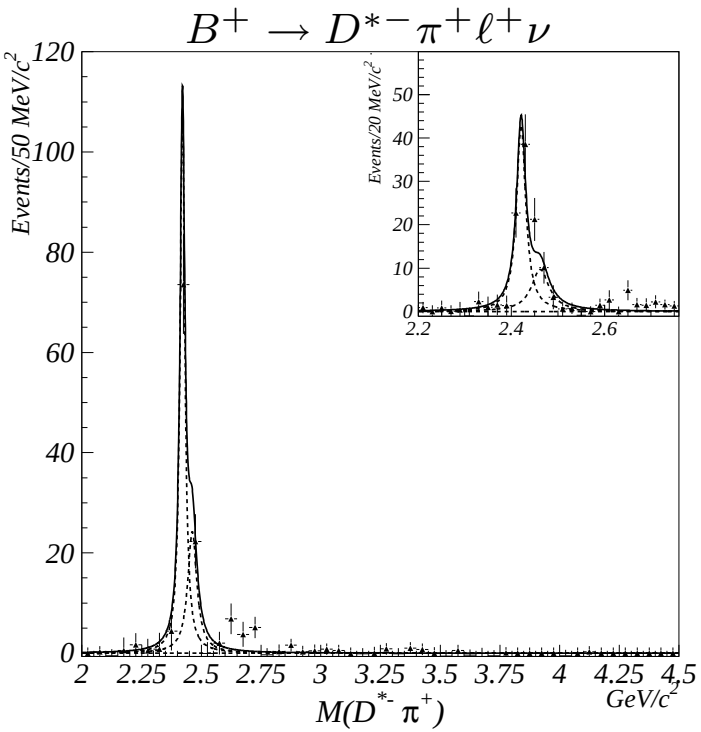
$D_0^* + D_2^* + nonres$

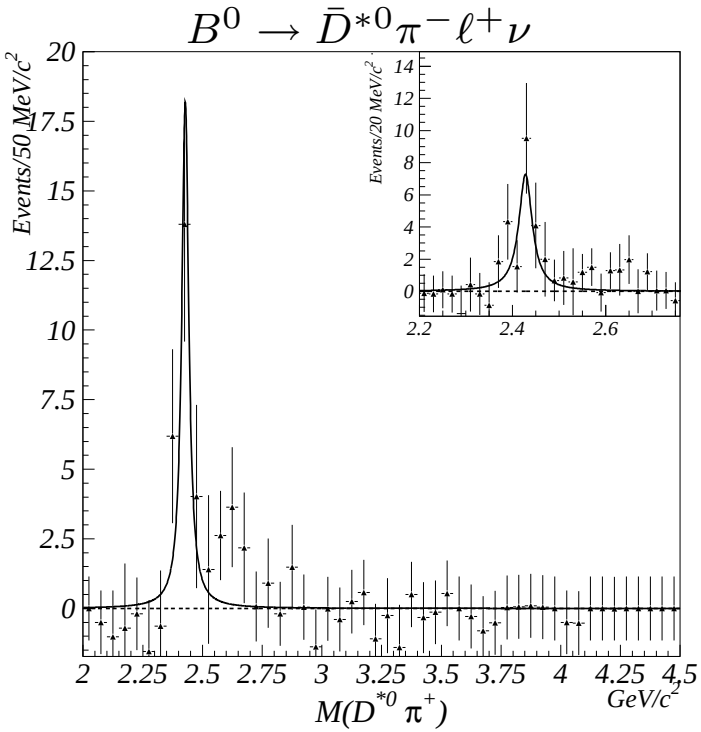
D^{**} masses and widths are fixed

Broad D_0^* contribution is large

Belle analysis: $D^*\pi$ invariant mass

- Spectroscopy
- Existing results
- Belle analysis
- Comparison
- Helicity
- Conclusions





$|M_\nu^2| < 0.1\mathrm{GeV}^2$

Backgrounds are subtracted

$D\pi$ invariant mass is fitted with sum of Breit-Wigner functions and nonresonant part (Goity-Roberts models):

$D_1^* + D_1 + D_2^* + nonres$

D^{**} masses and widths are fixed

No broad D_1^*

Belle analysis: results

- Spectroscopy
- Existing results
- Belle analysis
- Comparison
- Helicity
- Conclusions

$$\mathcal{B}(\text{mode}) \equiv \mathcal{B}(B \to D^{**}\ell\nu) \times \mathcal{B}(D^{**} \to D^{(*)}\pi^+)$$

$D\pi$ invariant mass study

Mode	Yield	$\mathcal{B}$, %	Signif.
$B^+ \to \bar{D}_0^{*0}\ell^+\nu$	102 ± 19	$0.24 \pm 0.04 \pm 0.06$	5.4
$B^+ \to \bar{D}_2^{*0}\ell^+\nu$	94 ± 13	$0.22 \pm 0.03 \pm 0.04$	8.0
$B^0 \to D_0^{*-}\ell^+\nu$	61 ± 22	$0.20 \pm 0.07 \pm 0.05$	2.6
$B^0 \to D_2^{*-}\ell^+\nu$	68 ± 13	$0.22 \pm 0.04 \pm 0.04$	5.5

$D^*\pi$ invariant mass study

Mode	Yield	$\mathcal{B}$, %	Signif.
$B^+ \to \bar{D}_1^{*0}\ell^+\nu$	-5 ± 11	< 0.07 @ 90% C.L.	
$B^+ \to \bar{D}_1^{0}\ell^+\nu$	81 ± 13	$0.42 \pm 0.07 \pm 0.07$	6.7
$B^+ \to \bar{D}_2^{*0}\ell^+\nu$	35 ± 11	$0.18 \pm 0.06 \pm 0.03$	3.2
$B^0 \to D_1^{*-}\ell^+\nu$	4 ± 8	< 0.5 @ 90% C.L.	
$B^0 \to D_1^{-}\ell^+\nu$	20 ± 7	$0.54 \pm 0.19 \pm 0.09$	2.9
$B^0 \to D_2^{*-}\ell^+\nu$	1 ± 6	< 0.3 @ 90% C.L.	

Comparison

- Spectroscopy
- Existing results
- Belle analysis
- Comparison
- Helicity
- Conclusions

$\mathcal{B}(D_1 \to D^*\pi^+) = 66.7\%$
$\mathcal{B}(D_2^* \to D^*\pi^+) = 20\%$

Exp.	$\mathcal{B}(B \to D_1\ell\nu)$	$\mathcal{B}(B \to D_2^*\ell\nu)$
ALEPH	0.74 ± 0.16	< 0.2
CLEO	0.56 ± 0.16	< 0.8
OPAL	1.05 ± 0.35	< 1.85
DELPHI	0.33 ± 0.17	0.37 ± 0.17
DØ	0.33 ± 0.06	0.44 ± 0.16
Belle	0.65 ± 0.11	0.47 ± 0.09 (from $D\pi^+$) 0.9 ± 0.3 (from $D^*\pi^+$)

DELPHI: $\mathcal{B}(B \to D_1^*\ell\nu) = (1.25 \pm 0.37)\%$
$\mathcal{B}(B \to D_0^*\ell\nu) = (0.42 \pm 0.40)\%$

Belle: $< 0.11\%$
$(0.35 \pm 0.05)\%$

D^{**} helicity distribution

- Spectroscopy
- Existing results
- Belle analysis
- Comparison
- Helicity
- Conclusions

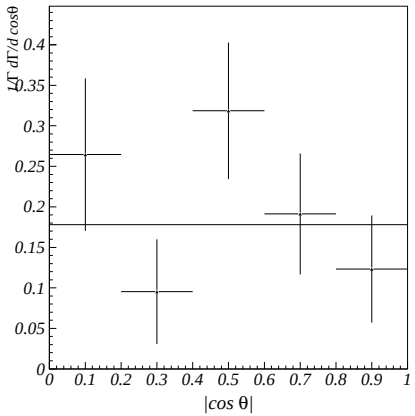
$D\pi$ invariant mass is fitted in bins of helicity

θ is an angle between
- π in D^{**} rest frame
- and D^{**} boost vector

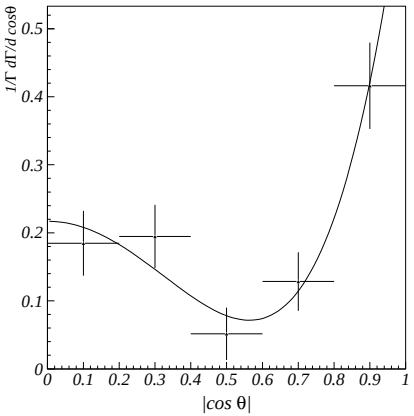
Helicity distributions for
- D_0^* and D_2^* are fitted with $J = 0$ ($\chi^2/ndf = 6.0/4$)
- and $J = 2$ ($\chi^2/ndf = 2.0/3$)

D_2^* is dominated by the $s_z = 0$

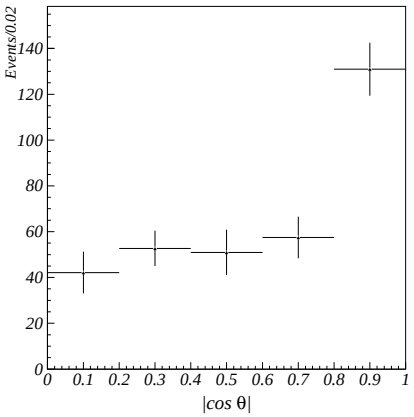
$D_0^* \to D\pi^+$



$D_2^* \to D\pi^+$



Background



Conclusions

- Spectroscopy
- Existing results
- Belle analysis
- Comparison
- Helicity
- Conclusions

- $B \to D^{**}\ell\nu$ were studied with fully reconstructed B tags;
- $B \to D_2^*\ell\nu$, $D_2^* \to D\pi$ decay was observed and measured for the first time, its properties were studied;
- A large branching ratio for $B \to D_0^*\ell\nu$ was observed in a fit assuming only D_0^* and D_2^* contributions. This contradicts HQET predictions. However, we do not observe a wide D_1^* in the $D^*\pi$ mode, which should be of the same order. Other possible contributions (D_v^*)?
- arXiv:0711.3252, submitted to PRD.

Backup slide: w-distribution

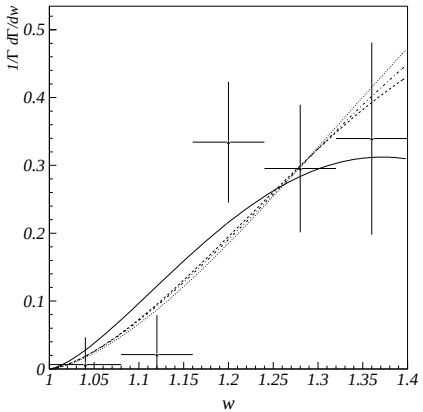
- Spectroscopy
- Existing results
- Belle analysis
- Comparison
- Helicity
- Conclusions

$D\pi$ invariant mass is fitted in bins of w

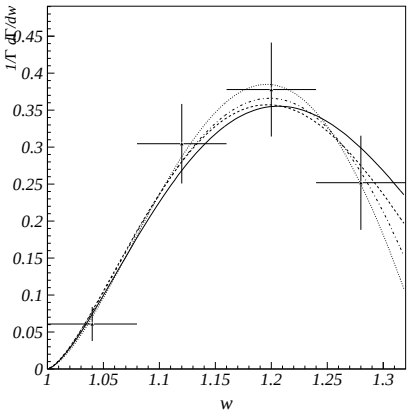
$$w \equiv v_B \cdot v_{D^{**}}$$

$$= \frac{M_B^2 + M_{D^{**}}^2 - q^2}{2 M_B M_{D^{**}}}$$

$D_0^* \to D\pi^+$



$D_2^* \to D\pi^+$



Four models:

one from Yaouanc *et al* (hep-ph/9706265)

three from Leibovich *et al* (hep-ph/9705467)

Background