Introduction	$B ightarrow D^* \ell^+ u_\ell$	$B \rightarrow D^{(*)} \tau^+ \nu_{\ell}$	Inclusive tag	Hadronic tag	Summary
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Semileptonic $b \rightarrow c$ Decays at Belle

Wolfgang Dungel

Institute for high energy physics Austrian Academy of Sciences

on behalf of the Belle collaboration

EPS HEP 2009, July 17, 2009





EPS09 - Semileptonic $b \rightarrow c$ Decays at Belle



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 $\begin{array}{ccc} B \to D^* \ell^+ \nu_{\ell} & B \to D^{(*)} \tau^+ \nu_{\ell} \\ \text{occocccccc} \end{array}$

Inclusive tag

Summary

Greetings from Belle!





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Introduction 0000	$B \to D^* \ell^+ \nu_\ell$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00

Belle and the KEK-B accelerator



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Introduction ○●○○	$B \to D^* \ell^+ \nu_\ell$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00

Belle and the KEK-B accelerator



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Belle and the KEK-B accelerator





Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \end{array}$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00
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Semileptonic $b \rightarrow c$ transitions at *B* factories





Introduction	$\begin{array}{c} B \rightarrow D^* \ell^+ \nu_\ell \\ \circ \end{array}$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00
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• Determine $\{|V_{ub}|, |V_{cb}|\}$ • What to do with $B\bar{B}$ data?

• Except ... 🙂



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- New physics can introduce additional terms
- Precise measurements of |V_{ub}| and |V_{cb}| crucial to observe deviations from CKM mechanism





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Semileptonic $b \rightarrow c$ transitions at *B* factories



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Introduction	$B ightarrow D^* \ell^+ u_\ell$ 000000000	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00





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Introduction	$B ightarrow D^* \ell^+ u_\ell$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary
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Measurement of the decays $B^0 \to D^{*-}\ell^+\nu$ and $B^+ \to \overline{D}^{*0}\ell^+\nu$ at Belle



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Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \bullet \circ \circ$	$B ightarrow {\cal D}^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00
Differer	ntial decay	width			

Kinematic variables

•
$$w = \frac{p_B^{\mu} \cdot p_{D^*, \mu}}{m_{B^0} m_{D^*}} = a + b q^2$$

• $\cos \theta_{\ell} \cos \theta_{V} \propto$



Differential decay width

Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \bullet \circ \circ \circ \circ \circ \circ \circ \circ \end{array}$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00
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Differential decay width

Kinematic variables

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$$w = \frac{p_B^{\mu} \cdot p_{D^*,\mu}}{m_{P^0} m_{D^*}} = a + b q^2$$

• $\cos \theta_{\ell}, \cos \theta_{V}, \chi$



Differential decay width

Aside from masses etc. identical for B⁰ and B⁺

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Introduction	$B \to D^* \ell^+ \nu_\ell$	$B ightarrow D^{(*)} au^+ u_{\ell}$	Inclusive tag	Hadronic tag	Summary
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Differential decay width

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Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \bullet \bullet \circ \circ \circ \circ \circ \circ \end{array}$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00
Conside • Only • $\overline{B} \rightarrow$ •	red final st signal is re $D^*\ell^-ar u_\ell,$ $D^* o D^0\pi_s$	ates constructed	$B^0 \rightarrow D^{*-}$ • Showr	$\ell^+ \nu$ n at ICHEP08	3
	• $D^0 \rightarrow K$ • $D^0 \rightarrow K$		• N_{signal} $B^+ o ar D^{*0}$	$= 69,345 \pm \ell^+ \nu$	377
• $\mathcal{F}_1 V$ • Form	/ _{cb} n factor para	ameters	 New p N_{signal} 	reliminary re = 27,106 ±	sult 367
● B ⁰ a syste	nd <i>B</i> + show ematic unce	v different π_s ertainty			actions

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BELLE

ntroduction	$B \to D^* \ell^+ \nu_\ell$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00
	dered final st				
• 0	nly signal is re	constructed			
• B	$ ightarrow D^* \ell^- \bar{ u}_\ell,$ $ ho D^* ightarrow D^0 \pi_2$		 Shown 	n at ICHEP08	
			• N _{signal}	$=$ 69, 345 \pm	377
Resul	ts		New p	reliminary re	sult
• F	1 V _{cb} orm factor para	ameters	• N _{signal}	= 27,106 ±	367
Syste	matics				
• B ⁽ sy	⁰ and <i>B</i> ⁺ show vstematic unce	v different π_s rtainty			actions

ntroduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \circ \bullet \circ \circ \circ \circ \circ \circ \end{array}$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00
Consid	dered final st	ates			
● Or ● Ē	hly signal is re $ ightarrow D^* \ell^- \overline{\nu}_\ell,$ $ ho D^* ightarrow D^0 \pi_s$ $ ho D^0 ightarrow K$ $ ho D^0 ightarrow K$	constructed $^{-\pi^+}_{-\pi^+\pi^-\pi^+}$	$B^0 \rightarrow D^{*-}$ • Shown • N_{signal}	$\ell^+ \nu$ at ICHEP08 = 69,345 ±	3 377
			$B^+ ightarrow ar{D}^{*0}$		
Result	S		New p	reliminary re	sult
 \$\mathcal{F}_1\$ Fo 	<i>V_{cb}</i> rm factor para	ameters	• N _{signal}	= 27, 106 ±	367
D 0	and Rt show	u difforont -			



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ntroduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \bullet \bullet \circ \circ \circ \circ \circ \circ \end{array}$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00
Consi	dered final st	ates			
• Oi • B	nly signal is re $\rightarrow D^* \ell^- \bar{\nu}_\ell,$ • $D^* \rightarrow D^0 \pi_s$ • $D^0 \rightarrow K$ • $D^0 \rightarrow K$	constructed $\pi^{-}\pi^{+}$ $\pi^{+}\pi^{-}\pi^{+}$	$B^0 \rightarrow D^{*-}$ • Shown • N_{signal}	ℓ ⁺ ν n at ICHEP08 = 69,345 ±	3 377
Result	ts		New p	reliminary re	sult
 <i>F</i>1 Fc 	_I V _{cb} orm factor para	ameters	• N _{signal}	= 27,106 ±	367
Syster	matics				
• B ⁰	and B ⁺ show	v different π_s			



systematic uncertainty

ntroduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \circ \bullet \circ \circ \circ \circ \circ \circ \circ \end{array}$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summar 00
Consid Or B	dered final st hly signal is re $\rightarrow D^* \ell^- \bar{\nu}_\ell,$	ates constructed	$B^0 \rightarrow D^{*-}$ • Shown	^{ℓ+} ν at ICHEP08	3
	• $D^* \rightarrow D^0 \pi_s$ • $D^0 \rightarrow K$ • $D^0 \rightarrow K$	$^{-}\pi^{+}$ $^{-}\pi^{+}\pi^{-}\pi^{+}$	• N _{signal}	$= 69,345 \pm$	377
_			$B^+ ightarrow ar{D}^{*0}$	$\ell^+ u$	
Result	S		New p	reliminary re	sult
• <i>F</i> ₁	$ V_{cb} $		N _{signal}	$=$ 27, 106 \pm	367

- $\mathcal{F}_1 | V_{cb} |$
- Form factor parameters

Systematics

• B^0 and B^+ show different π_s systematic uncertainty

- B⁰ signal purity and background fractions
- B^+ signal purity and background fractions

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Introduction	$B \to D^* \ell^+ \nu_\ell$	$B ightarrow {\it D}^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary
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Investigated using MC

- Fake D⁰
- Combinatoric D*
- Fake Lepton
- Uncorrelated
- $B \rightarrow D^{**}\ell\nu, B \rightarrow D^*X\ell\nu$
- Signal correlated

Off-resonance data • Continuum: *q̄q* decays



HMCMLL, TFractionFitter

- Determine norm of MC components from fit to data
- Use 2D distribution $\cos \theta_{B^0, D^* \ell}$ vs. Δm



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Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \circ \circ \circ \bullet \circ \circ \circ \circ \end{array}$	$B ightarrow {\cal D}^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00
Plots of	B ⁺ backo	round - <i>e</i> ch	nannels		



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Introduction	$B \to D^* \ell^+ \nu_\ell$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary
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Reconstruction of the *B* rest frame



D*l reconstruction yields 1D space of B candidates
Combined with inclusive sum of remaining event: "best B"



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Plots of preliminary results - B^0



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Introduction	$B \to D^* \ell^+ \nu_\ell$	$B \rightarrow D^{(*)} \tau^+ \nu_\ell$	Inclusive tag	Hadronic tag	Summary
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Plots of preliminary results - B^+



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Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \circ \circ \circ \circ \circ \circ \bullet \circ \end{array}$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00
Prelimina	ary results				

	$B^0 ightarrow D^{*-} \ell u$	$B^+ ightarrow ar{D}^{*0} \ell u$
ρ^2	$1.293 \pm 0.045 \pm 0.029$	$1.376 \pm 0.074 \pm 0.056$
<i>R</i> ₁ (1)	$1.495 \pm 0.050 \pm 0.062$	$1.620 \pm 0.091 \pm 0.092$
<i>R</i> ₂ (1)	$0.844 \pm 0.034 \pm 0.019$	$0.805 \pm 0.064 \pm 0.036$
$R_{K3\pi/K\pi}$	$\textbf{2.153} \pm \textbf{0.011}$	2.072 ± 0.023
${\cal B}(B o D^* \ell^+ u_\ell)$	$(4.42\pm 0.03\pm 0.25)\%$	$(4.84\pm 0.04\pm 0.56)\%$
$\mathcal{F}(1) \left V_{cb} ight imes 10^3$	$34.4\pm0.2\pm1.0$	$35.0\pm0.4\pm2.2$
$\chi^2/n.d.f.$	138.8/155	187.8/155
P_{χ^2}	82.0%	3.7%





Explicit test of the parametrization - $B^+ \rightarrow \bar{D}^{*0} \ell \nu$

- Result of discussions with theoreticians in Karlsruhe
- Extract shapes of longitudinal and transversal helicity amplitudes from a 2D fit
- Good agreement with parametrized result



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Introduction	$B ightarrow D^* \ell^+ u_\ell$	$B ightarrow {\cal D}^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary
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Observation of $B^0 \rightarrow D^{*-} \tau^+ \nu_{\tau}$ Decay at Belle

PRL 99, 191807 (2007)



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Observation of $B^0 \rightarrow D^{*-} \tau^+ \nu_{\tau}$

Signal reconstruction

• Three signal cascades are considered

•
$$B^0 \rightarrow D^{*-} \tau^+ \nu$$

• $\tau^+ \rightarrow e^+ \nu \nu$
• $D^{*-} \rightarrow D^0 \pi^-$
• $D^0 \rightarrow K \pi$

•
$$B^0 \rightarrow D^{*-} \tau^+ \nu$$

• $\tau^+ \rightarrow e^+ \nu \nu$
• $D^{*-} \rightarrow D^0 \pi^-$
• $D^0 \rightarrow K \pi \pi^0$

$$B^{0} \rightarrow D^{*-}\tau^{+}\nu$$

$$\bullet D^{*-} \rightarrow D^{0}\pi^{-}$$

$$\bullet D^{0} \rightarrow K\pi$$
Introduction	$B ightarrow D^* \ell^+ u_\ell$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary
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 $\begin{array}{ccc} \text{Introduction} & B \to D^* \ell^+ \nu_\ell & B \to D^{(*)} \tau^+ \nu_\ell & \begin{array}{ccc} \text{Inclusive tag} & \text{Hadronic tag} & \text{Summary} \\ \bullet \bullet \bullet \bullet & \bullet & \bullet \end{array} \end{array}$

Observation of $B^0 \rightarrow D^{*-} \tau^+ \nu_{\tau}$

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• $\tau^+ \rightarrow e^+ \nu \nu$
• $D^{*-} \rightarrow D^0 \pi^-$
• $D^0 \rightarrow K \pi \pi^0$

$$B^{D} \rightarrow D^{*-}\tau^{+}\nu$$

$$T^{+} \rightarrow \pi^{+}\nu$$

$$D^{*-} \rightarrow D^{0}\pi^{-}$$

$$D^{0} \rightarrow K\pi$$

 $\begin{array}{ccc} \text{Introduction} & B \to D^* \ell^+ \nu_\ell & B \to D^{(*)} \tau^+ \nu_\ell & \begin{array}{ccc} \text{Inclusive tag} & \text{Hadronic tag} & \text{Summary} \\ \bullet \bullet \bullet \bullet & \bullet & \bullet \end{array} \end{array}$

Observation of $B^0 \rightarrow D^{*-} \tau^+ \nu_{\tau}$

Signal reconstruction

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Introduction	$\begin{array}{c} B \rightarrow D^* \ell^+ \nu_\ell \\ \circ $	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00
Full reco	onstruction	า			

Inclusive *B*_{tag} reconstruction

- All tracks remaining after signal reconstruction $\Rightarrow B_{tag}$
- No selection of specific *B*_{tag} channel
- Quality cuts similar to normal full reconstruction

•
$$\Delta E = E_{tag} - E_{beam}$$

•
$$m_{bc}=\sqrt{E_{beam}^2-ec{p}_{tag}^2}$$

• Total event charge, small residual energy, ...





Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \end{array}$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00
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Signal reconstruction???

• What about full reconstruction?



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Full rec	constructio	n						
Inclu	sive B _{tag} reco	onstruction						
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• (Quality cuts si	milar to normal	full reconstru	uction				
	• $\Delta E = E_{tag}$	- E _{beam}						

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• Total event charge, small residual energy, ...



• What about full reconstruction?

"Inverted procedure"

Reconstruct second B after signal

Introduction	$B ightarrow D^*\ell^+ u_\ell$ 000000000	$B ightarrow {\it D}^{(*)} au^+ u_\ell$	Inclusive tag ○○●○	Hadronic tag	Summary 00
Full rec	constructio	n			
Inclu	sive <i>B_{tag}</i> rec	onstruction			
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	No selection o	f specific B _{tag} c	hannel		

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Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \end{array}$	$B ightarrow {\cal D}^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00

Full reconstruction

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Results					

- Excess of events seen
- Extraction via unbinned maximum likelyhood fit to M_{tag}

Simultaneous fit to all channels, signal yield: N = 60⁺¹²₋₁₁
 B(B⁰ → D^{*−}τ⁺ν) = 2.02^{+0.40}_{-0.37}(stat) ± 0.37(syst)%



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 B(B⁰ → D^{*−}τ⁺ν) = 2.02^{+0.40}_{-0.37}(stat) ± 0.37(syst)%



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Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \end{array}$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag ○○○●	Hadronic tag	Summary 00
Results					

- Excess of events seen
- Extraction via unbinned maximum likelyhood fit to M_{tag}
- Simultaneous fit to all channels, signal yield: N = 60⁺¹²₋₁₁
 B(B⁰ → D^{*−}τ⁺ν) = 2.02^{+0.40}_{-0.37}(stat) ± 0.37(syst)%



Introduction	$B ightarrow D^*\ell^+ u_\ell$ 000000000	$B ightarrow {\cal D}^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag ●০০০	Summary 00

$B \rightarrow D^{(*)} \tau^+ \nu_\ell$ at Belle - hadronic tag



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000	C

 $B \rightarrow D^{(*)} \tau^+ \nu_{\ell}$

Inclusive tag

Hadronic tag 0000

Summary

Investigation of $B \rightarrow D^{(*)} \tau^+ \nu_{\ell}$

- B_{tag} from hadronic modes
 - $B^+ \rightarrow D^0 \tau^+ \nu$ • $B^+ \rightarrow D^{*0} \tau^+ \nu$ • $B^0 \rightarrow D^- \tau^+ \nu$
 - $B^0 \rightarrow D^{*-} \tau^+ \nu$

• $\tau \rightarrow \ell \nu \nu$

- $B \rightarrow D^{(*)} \ell \nu$
- Suppression via \vec{p}_{ℓ} cut
- Contribution still sizeable





 $B \rightarrow D^* \ell^+ \nu_{\ell}$

 $B \rightarrow D^{(*)} \tau^+ \nu_{\ell}$

Inclusive tag

Hadronic tag 0000

Summary

Investigation of $B \rightarrow D^{(*)} \tau^+ \nu_{\ell}$

Analysis strategy

• B_{tag} from hadronic modes signal:

•
$$B^+ \rightarrow D^0 \tau^+ \nu$$

• $B^+ \rightarrow D^{*0} \tau^+ \nu$
• $B^0 \rightarrow D^- \tau^+ \nu$
• $B^0 \rightarrow D^{*-} \tau^+ \nu$

• $\tau \rightarrow \ell \nu \nu$

•
$$B \rightarrow D^{(*)} \ell \nu$$

- Suppression via \vec{p}_{ℓ} cut
- Contribution still sizeable





 $B \rightarrow D^* \ell^+ \nu_{\ell}$

 $B \rightarrow D^{(*)} \tau^+ \nu_{\ell}$

Inclusive tag

Hadronic tag 0000

Summary

Investigation of $B \rightarrow D^{(*)} \tau^+ \nu_{\ell}$

Analysis strategy

- B_{tag} from hadronic modes
- signal:

•
$$B^+ \rightarrow D^0 \tau^+ \nu$$

• $B^+ \rightarrow D^{*0} \tau^+ \nu$
• $B^0 \rightarrow D^- \tau^+ \nu$

•
$$B^0 \rightarrow D^{*-} \tau^+ \nu$$

• $\tau \rightarrow \ell \nu \nu$

Main Background

•
$$B \rightarrow D^{(*)} \ell \nu$$

- Suppression via \vec{p}_{ℓ} cut
- Contribution still sizeable





 $B \rightarrow D^* \ell^+ \nu_{\ell}$

 $B \rightarrow D^{(*)} \tau^+ \nu_{\ell}$

Inclusive tag

Hadronic tag 0000

Summary

Investigation of $B \rightarrow D^{(*)} \tau^+ \nu_{\ell}$

Analysis strategy

- B_{tag} from hadronic modes
- signal:

•
$$B^+ \rightarrow D^0 \tau^+ \nu$$

• $B^+ \rightarrow D^{*0} \tau^+ \nu$
• $B^0 \rightarrow D^- \tau^+ \nu$

•
$$B^0 \rightarrow D^{*-} \tau^+ \nu$$

• $\tau \rightarrow \ell \nu \nu$

Main Background

•
$$B \rightarrow D^{(*)} \ell \nu$$

- Suppression via \vec{p}_{ℓ} cut
- Contribution still sizeable





Introduction	$B ightarrow D^* \ell^+ u_\ell$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary 00
Signal e	extraction				

- These distributions are sensitive to signal
- Ideal signal event: No unmatched energy in ECL!
- $B \rightarrow D^{(*)} \ell \nu$ events give peak at $M_{mis}^2 = 0$





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Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \end{array}$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag ○○●○	Summary 00
Signal ex	xtraction				

2D fit to M_{mis}^2 vs. E_{ECL} distribution

- These distributions are sensitive to signal
- Ideal signal event: No unmatched energy in ECL!
- $B \rightarrow D^{(*)} \ell \nu$ events give peak at $M_{mis}^2 = 0$





Introduction	$B ightarrow D^* \ell^+ u_\ell$ 000000000	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	H o	adronic tag oo●	Summary 00
Fit resu	lts					
					Stat. s	
 B(B⁺) B(B⁺) B(B⁰) B(B⁰) 	$\rightarrow \overline{D}^{0}\tau^{+}\nu) = 1.5$ $\rightarrow \overline{D}^{*0}\tau^{+}\nu) = 3.0$ $\rightarrow D^{-}\tau^{+}\nu) = 1.0$ $\rightarrow D^{*-}\tau^{+}\nu) = 2.0$	$\begin{array}{l} 1 + 0.41 \\ - 0.39 \\ (stat) + 0.19 \\ 04 - 0.66 \\ (stat) + 0.40 \\ - 0.66 \\ (stat) + 0.41 \\ - 0.41 \\ (stat) + 0.11 \\ - 0.11 \\ (stat) + 0.31 \\ - 0.22 \\ \end{array}$	$(syst) \pm 0.15(norm)\%$ $(syst) \pm 0.22(norm)$ $(syst) \pm 0.10(norm)\%$ $(syst) \pm 0.10(norm)$		 3.8a 3.9a 2.6a 4.7a 	
Data s	sample)4.5fb ⁻¹		First evidence So charged	, <i>В</i> -	$^+ ightarrow D^0 au^-$ igas?	+ _ν !

Deviation from Standard model predictions

• $B^+ \rightarrow \bar{D}^0 \tau^+ \nu$: 1.6 $\sigma, B^0 \rightarrow D^- \tau^+ \nu$: 0.5 σ

Measurements agree with the SM within the errors



Introduction	$B ightarrow D^* \ell^+ u_\ell$ 000000000	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag 000●	Summary 00
Fit resu	ults				
Obtaine	d branching	ratios		Stat. s	ign.
● B(B ⁺	$\bar{D} \to \bar{D}^0 au^+ u) = 1.5^{-1}$	$1^{+0.41}_{-0.39}(stat)^{+0.24}_{-0.19}(sy$	$st) \pm 0.15(norm)^{\circ}$	% • 3.80	τ

• $\mathcal{B}(B^+ \to \bar{D}^{*0}\tau^+\nu) = 3.04^{+0.69}_{-0.66}(stat)^{+0.40}_{-0.47}(syst) \pm 0.22(norm)\%$

• $\mathcal{B}(B^0 \to D^- \tau^+ \nu) = 1.01^{+0.46}_{-0.41}(stat)^{+0.13}_{-0.11}(syst) \pm 0.10(norm)\%$

• $\mathcal{B}(B^0 \to D^{*-}\tau^+\nu) = 2.56^{+0.75}_{-0.66}(stat)^{+0.31}_{-0.22}(syst) \pm 0.10(norm)\%$



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EPS09 - Semileptonic $b \rightarrow c$ Decays at Belle

nan

3.9σ

2.6σ • 4.7σ

Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \end{array}$	$B ightarrow {\cal D}^{(*)} au^+ u_\ell$	Inclusive tag	Hadro	onic tag	Summary 00	
Fit resu	lts						
Obtained	d branching	ratios			Stat. si		
● <i>B</i> (<i>B</i> ⁺	$ ightarrow ar{D}^0 au^+ u) =$ 1.51	$^{+0.41}_{-0.39}(stat)^{+0.24}_{-0.19}(sy)$	$st) \pm 0.15(norm)^{o}$	%	3.8c		
● B(B ⁺	$ ightarrow ar{D}^{*0} au^+ u) =$ 3.0	$4^{+0.69}_{-0.66}(stat)^{+0.40}_{-0.47}(s_{-0.47})^{+0.40}$	yst) \pm 0.22(norm))%	3.9d		
$\mathbf{P}(\mathbf{P})$	$(D^{-} - +) = 1.0$	+0.46 (atat) $+0.13$ (a)	$(at) \perp 0.10(norm)$	0/	2.60		

• $\mathcal{B}(B^0 \to D^- \tau^+ \nu) = 1.01^{+0.46}_{-0.41}(stat)^{+0.13}_{-0.11}(syst) \pm 0.10(norm)\%$

•
$$\mathcal{B}(B^0 \to D^{*-}\tau^+\nu) = 2.56^{+0.75}_{-0.66}(stat)^{+0.31}_{-0.22}(syst) \pm 0.10(norm)\%$$

● 604.5fb⁻¹

• First evidence,
$$B^+ \rightarrow D^0 \tau^+ \nu!$$

So charged Higgs?

Deviation from Standard model predictions

• $B^+ \rightarrow \bar{D}^0 \tau^+ \nu$: 1.6 $\sigma, B^0 \rightarrow D^- \tau^+ \nu$: 0.5 σ

• Measurements agree with the SM within the errors

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EPS09 - Semileptonic $b \rightarrow c$ Decays at Belle

• 4.7σ

Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \text{ooooooooo} \end{array}$	$B o D^{(*)} au^+ u_\ell$	Inclusive tag	Hadro 000●	nic tag	Summary 00
Fit resul	ts					
Obtained	l branching r	atios			Stat. si	
 B(B⁺) B(B⁺) 	$egin{array}{lll} ightarrow ar{D}^0 au^+ u) = 1.51 \ ightarrow ar{D}^{*0} au^+ u) = 3.04 \end{array}$	$^{+0.41}_{-0.39}(stat)^{+0.24}_{-0.19}(sys)$ $4^{+0.69}_{-0.66}(stat)^{+0.40}_{-0.47}(sys)$	$(st)\pm 0.15(\mathit{norm})$	%)%	3.8σ3.9σ	





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EPS09 - Semileptonic $b \rightarrow c$ Decays at Belle

• 4.7σ

Int oc	roduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \end{array}$	$B ightarrow {\cal D}^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag ○○○●	Summary 00
F	it resu	lts				
(Obtained	d branching	ratios		Stat.	
	 B(B⁺) B(B⁺) 	$egin{array}{lll} ightarrow ar{D}^0 au^+ u) = 1.51 \ ightarrow ar{D}^{*0} au^+ u) = 3.0 \end{array}$	$^{+0.41}_{-0.39}(stat)^{+0.24}_{-0.19}(sy)$ $4^{+0.69}_{-0.66}(stat)^{+0.40}_{-0.47}(sy)$	$(st)\pm 0.15(\mathit{norm})$	% • 3)% • 3	

• $\mathcal{B}(B^0 \to D^- \tau^+ \nu) = 1.01^{+0.46}_{-0.41}(stat)^{+0.13}_{-0.11}(syst) \pm 0.10(norm)\%$

• $\mathcal{B}(B^0 \to D^{*-}\tau^+\nu) = 2.56^{+0.75}_{-0.66}(stat)^{+0.31}_{-0.22}(syst) \pm 0.10(norm)\%$

Data sample • 604.5fb⁻¹



So charged Higgs?

Deviation from Standard model predictions

• $B^+ \rightarrow \bar{D}^0 \tau^+ \nu$: 1.6 $\sigma, B^0 \rightarrow D^- \tau^+ \nu$: 0.5 σ

• Measurements agree with the SM within the errors



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EPS09 - Semileptonic $b \rightarrow c$ Decays at Belle

4.7σ

Introduction 0000	$B ightarrow D^* \ell^+ u_\ell$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Ha	adronic tag ⊃O●	Summary 00	
Fit resu	lts						
Obtained	d branching	ratios			Stat. s		
● <i>B</i> (<i>B</i> ⁺	$ ightarrow ar{D}^0 au^+ u) = 1.5^{-1}$	$ ^{+0.41}_{-0.39}(stat)^{+0.24}_{-0.19}(sy$	$st) \pm 0.15(norm)^{t}$	%	3.8d		
● <i>B</i> (<i>B</i> ⁺	$ ightarrow ar{D}^{*0} au^+ u) = 3.0$	$04^{+0.69}_{-0.66}(stat)^{+0.40}_{-0.47}(s$	yst) \pm 0.22(norm)%	3.9a		
B(B ⁰ -	$\rightarrow D^- \tau^+ \nu) = 1.0$	$1^{+0.46}_{-0.41}(stat)^{+0.13}_{-0.44}(sv$	$(st) \pm 0.10(norm)$	%	2.6a		

•
$$\mathcal{B}(B^0 \to D^{*-}\tau^+\nu) = 2.56^{+0.75}_{-0.66}(stat)^{+0.31}_{-0.22}(syst) \pm 0.10(norm)\%$$



• 4.7σ

Introduction	$B ightarrow D^* \ell^+ u_\ell$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summary ●O





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Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \circ \circ \circ \circ \circ \circ \circ \circ \end{array}$	$B ightarrow {\it D}^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summa ●○
			at Belle		
		0^3 34.4 ± 0.2 ± 1.0		.4 ± 2.2	

• Similar, new measurement of B⁺ almost ready

 $B
ightarrow D^{(*)} au^+
u_\ell$ - hadronic tag

$$\begin{split} \mathcal{B}(B^+ \to \bar{D}^0 \tau^+ \nu) &= 1.51^{+0.41}_{-0.39}(\textit{stat})^{+0.24}_{-0.19}(\textit{syst}) \pm 0.15(\textit{norm})\% \\ \mathcal{B}(B^+ \to \bar{D}^{*0} \tau^+ \nu) &= 3.04^{+0.69}_{-0.66}(\textit{stat})^{+0.40}_{-0.47}(\textit{syst}) \pm 0.22(\textit{norm})\% \\ \mathcal{B}(B^0 \to D^- \tau^+ \nu) &= 1.01^{+0.46}_{-0.44}(\textit{stat})^{+0.13}_{-0.11}(\textit{syst}) \pm 0.10(\textit{norm})\% \\ \mathcal{B}(B^0 \to D^{*-} \tau^+ \nu) &= 2.56^{+0.75}_{-0.66}(\textit{stat})^{+0.31}_{-0.22}(\textit{syst}) \pm 0.10(\textit{norm})\% \end{split}$$



Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \circ \circ \circ \circ \circ \circ \circ \circ \end{array}$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summar ●○
B ⁰	$ ightarrow {\it D}^{*-} \ell^+ u$ an	id $B^+ o ar{D}^{*0} \ell^+$ i	ν at Belle		
		B ⁰	B ⁺		
	ρ^2	$1.293 \pm 0.045 \pm 0.045$.029 1.376 ± 0.07	74 ± 0.056	
	<i>R</i> ₁ (1)	$1.495 \pm 0.050 \pm 0.050$.062 1.620 ± 0.09	01 ± 0.092	
	<i>R</i> ₂ (1)	$0.844 \pm 0.034 \pm 0.034$.019 0.805 ± 0.06	64 ± 0.036	
	$\mathcal{F}(1) V_{cb} >$	$< 10^3$ 34.4 \pm 0.2 \pm 1.0	0 35.0 ± 0.4	4 ± 2.2	

Similar, new measurement of B⁺ almost ready

 $B
ightarrow D^{(*)} au^+
u_\ell$ - hadronic tag

$$\begin{split} \mathcal{B}(B^+ \to \bar{D}^0 \tau^+ \nu) &= 1.51^{+0.41}_{-0.39}(\textit{stat})^{+0.24}_{-0.19}(\textit{syst}) \pm 0.15(\textit{norm})\% \\ \mathcal{B}(B^+ \to \bar{D}^{*0} \tau^+ \nu) &= 3.04^{+0.69}_{-0.66}(\textit{stat})^{+0.40}_{-0.47}(\textit{syst}) \pm 0.22(\textit{norm})\% \\ \mathcal{B}(B^0 \to D^- \tau^+ \nu) &= 1.01^{+0.46}_{-0.44}(\textit{stat})^{+0.13}_{-0.11}(\textit{syst}) \pm 0.10(\textit{norm})\% \\ \mathcal{B}(B^0 \to D^{*-} \tau^+ \nu) &= 2.56^{+0.75}_{-0.66}(\textit{stat})^{+0.31}_{-0.22}(\textit{syst}) \pm 0.10(\textit{norm})\% \end{split}$$



Introduction	$\begin{array}{c} B \to D^* \ell^+ \nu_\ell \\ \circ \end{array}$	$B ightarrow D^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag	Summar ●○
B ⁰ -	$ ightarrow {\it D}^{*-} \ell^+ u$ and	$B^+ o ar{D}^{*0} \ell^+ u$	at Belle		
		B ⁰	B-	+	
	ρ^2	1.293 ± 0.045 ± 0.02	$1.376 \pm 0.0^{\circ}$	74 ± 0.056	
	<i>R</i> ₁ (1)	$1.495 \pm 0.050 \pm 0.06$	1.620 ± 0.09	91 \pm 0.092	
	<i>R</i> ₂ (1)	$0.844 \pm 0.034 \pm 0.01$	9 0.805 ± 0.0	64 ± 0.036	
	$\mathcal{F}(1) V_{cb} imes T$	10 ³ 34.4 \pm 0.2 \pm 1.0	35.0 ± 0.	.4 ± 2.2	

• Similar, new measurement of *B*⁺ almost ready

 $m{B}
ightarrow m{D}^{(*)} au^+
u_\ell$ - hadronic tag

$$\begin{split} &\mathcal{B}(B^+ \to \bar{D}^0 \tau^+ \nu) = \quad 1.51^{+0.41}_{-0.19}(\textit{stat}) {}^{+0.24}_{-0.19}(\textit{syst}) \pm 0.15(\textit{norm})\% \\ &\mathcal{B}(B^+ \to \bar{D}^{*0} \tau^+ \nu) = \quad 3.04^{+0.69}_{-0.66}(\textit{stat}) {}^{+0.40}_{-0.47}(\textit{syst}) \pm 0.22(\textit{norm})\% \\ &\mathcal{B}(B^0 \to D^- \tau^+ \nu) = \quad 1.01^{+0.46}_{-0.44}(\textit{stat}) {}^{+0.13}_{-0.11}(\textit{syst}) \pm 0.10(\textit{norm})\% \\ &\mathcal{B}(B^0 \to D^{*-} \tau^+ \nu) = \quad 2.55^{+0.75}_{-0.65}(\textit{stat}) {}^{+0.32}_{-0.27}(\textit{syst}) \pm 0.10(\textit{norm})\% \end{split}$$



Introduction B 0000 0		В — 000	$\rightarrow D^* \ell^+ \nu_{\ell}$	В	$\to D^{(*)} \tau^+ \nu_\ell$	Inclusive tag	Hadronic tag	Summar ●○
	$B^0 ightarrow$	→ D *-	$\ell^+ u$ and	<i>B</i> +	$ ightarrow ar{D}^{*0} \ell^+ u$ a	t Belle		
		=			B ⁰	B	+	
		_	ρ ²		$1.293 \pm 0.045 \pm 0.029$	1.376 ± 0.0	0.056	
			<i>R</i> ₁ (1)		$1.495 \pm 0.050 \pm 0.062$	1.620 ± 0.0	91 \pm 0.092	
			R ₂ (1)		$0.844 \pm 0.034 \pm 0.019$	0.805 ± 0.0	064 ± 0.036	
		_	$\mathcal{F}(1) V_{cb} \times 1$	0 ³	$34.4\pm0.2\pm1.0$	35.0 ± 0	.4 ± 2.2	

• Similar, new measurement of *B*⁺ almost ready

 $B \to D^{(*)}\tau^{+}\nu_{\ell} \text{ - hadronic tag}$ $B \to D^{(*)}\tau^{+}\nu_{\ell} \text{ - hadronic tag}$ $B(B^{+} \to \bar{D}^{0}\tau^{+}\nu) = 1.51^{+0.41}_{-0.39}(\text{stat})^{+0.24}_{-0.19}(\text{syst}) \pm 0.15(\text{norm})\%$ $B(B^{+} \to \bar{D}^{*0}\tau^{+}\nu) = 3.04^{+0.66}_{-0.66}(\text{stat})^{+0.40}_{-0.41}(\text{syst}) \pm 0.22(\text{norm})\%$ $B(B^{0} \to D^{-}\tau^{+}\nu) = 1.01^{+0.46}_{-0.41}(\text{stat})^{+0.13}_{-0.11}(\text{syst}) \pm 0.10(\text{norm})\%$ $B(B^{0} \to D^{*-}\tau^{+}\nu) = 2.56^{+0.75}_{-0.66}(\text{stat})^{+0.31}_{-0.22}(\text{syst}) \pm 0.10(\text{norm})\%$

Introduction	$B ightarrow D^* \ell^+ u_\ell$	$B ightarrow {\cal D}^{(*)} au^+ u_\ell$	Inclusive tag	Hadronic tag
0000	00000000		0000	0000

Thanks for your attention!





Summary

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Semileptonic $b \rightarrow c$ Decays at Belle

Wolfgang Dungel

Institute for high energy physics Austrian Academy of Sciences

on behalf of the Belle collaboration

EPS HEP 2009, July 17, 2009





COACHE Austrian Academy of Sciences

Appendix 00000

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

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

Title 0

The Belle Collaboration





Appendix

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

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

Hadronic Tag

Title o

The Belle Detector



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Appendix 00000	$B^0 ightarrow D^{*-} \ell^+ u$	$B^+ ightarrow D^{*0} \ell^+ u$	Hadronic Tag O	Title ○
Tags at B	elle			



- Only signal reconstructed
- High efficiency

- Good statistics, clean events
- Kinematics not fully determined

- Kinematics fully determined
- Low statistics



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<mark>Appendix</mark> ୦୦୦●୦	$B^0 \to D^{*-} \ell^+ \nu$	$B^+ ightarrow D^{*0} \ell^+ u$	Hadronic Tag o	Title ○
Tags at E	Belle			



Untagged

- Only signal reconstructed
- High efficiency

Semileptonic tag

- Good statistics, clean events
- Kinematics not fully determined

Full reconstruction tag

- Kinematics fully determined
- Low statistics



4 日

Appendix ୦୦୦●୦	$B^0 ightarrow D^{*-} \ell^+ u$	$B^+ ightarrow D^{*0} \ell^+ u$	Hadronic Tag o	Title ○
Tags at	Belle			



Untagged

- Only signal reconstructed
- High efficiency

Semileptonic tag

- Good statistics, clean events
- Kinematics not fully determined

Full reconstruction tag

- Kinematics fully determined
- Low statistics

ヨト イヨト ヨヨ わへの

$B^0 \rightarrow D^{*-} \ell^+ \nu$

 $B^+ \rightarrow D^{*0} \ell^+ \nu$

200

Nobel prize 2008

2008年ノーベル物理学賞受賞!小林益川理論とは?

クォークとは何ですか?



0 反映子とは何ですか?

CF対称性の現れ」とは何ですか?

① 小林台川理論とは何ですか?

2 どうしてクォークから種類必要なのですか? P. ROFRANDSTLEVEL, 2 105 4 88574, 2011

sore-

持ちに待った実験結果! B ファクトリーによる検証 CP 対称性の破れはどのように測定したので すか?

どうして小林益川理論が正しいとわかった

に合わせる数字が描したさらなまでも数目し、多単数字の (F) 細の多単現したころによって、単葉2000 (B) 日ちって、よう













小林雄川環論は森羅万象を説明できるんで

大人数の研究グループの中で、個性を発揮 するチャンスはありますか?

うなナキンスにおりますが ス市は広都市市場外展し、まさに入りませんしてかり上げられた。 等に、あられたしたくだくとくから前にただしたとしてい、「市田 いどうシママネスのシリ、などに開始になった。他に 市台になったまでするため、人にため着した時代で 時台になられるとしてい、ませていたからの美術に行いたか。



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

Hadronic Tag

Title

HFAG average, Summer 2008







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

HQET and parametrization

Helicity amplitudes

•
$$H_{\pm} = f_{\pm}(w) h_{A_1}(w) \left(1 \mp \sqrt{\frac{w-1}{w+1}} R_1(w)\right)$$

• $H_0 = f_0(w) h_{A_1}(w) \left(1 + \frac{w-1}{1 - \frac{m_{D^*}}{m_B}} \left(1 - R_2(w)\right)\right)$

Parametrization by CLN

•
$$h_{A_1}(w) = h_{A_1}(1) (1 - 8\rho^2 z + (53\rho^2 - 15)z^2 - (231\rho^2 - 91)z^3)$$

 $z = \frac{\sqrt{w+1} - \sqrt{2}}{\sqrt{w+1} + \sqrt{2}}$
• $R_1(w) = R_1(1) - 0.12(w - 1) + 0.05(w - 1)^2$
• $R_2(w) = R_2(1) + 0.11(w - 1) = 0.06(w - 1)^2$

•
$$R_2(w) = R_2(1) + 0.11(w-1) - 0.06(w-1)$$

$B^0 \rightarrow D^{*-} \ell^+ \nu$ $B^+ \rightarrow D^{*0} \ell^+ \nu$ 00000000000000

Resolutions in kinematic variables



- Resolutions are approximately double gaussians
- Almost identical for B^0 and B^+



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Resolutions in kinematic variables



- Resolutions are approximately double gaussians
- Almost identical for B^0 and B^+



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$B^{0} \rightarrow D^{*-} \ell^{+} \nu$

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

Resolutions in kinematic variables



- For easier comparison: Gaussian assumption
- $\delta_{\rm w} = 0.025, \, \delta_{\cos \theta_{\ell}} = 0.052, \, \delta_{\cos \theta_{V}} = 0.047, \, \delta_{\chi} = 6.47^{\circ}$



Appendix 00000	$B^{0} \rightarrow D^{*-} \ell^{+} \nu$	$\begin{array}{ccc} B^+ \rightarrow D^{*0} \ell^+ \nu \\ \circ \circ$	Hadronic Tag O	Title ○
Color sche	eme			
		Data, OnRes - Cont		
		Signal		
		MC background, D**		
		MC background, Unc	corr.	
		MC background, Sig.	.corr.	
		MC background, Fak	e I	
		MC background, Fak	e D*	
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$B^{0} \rightarrow D^{*-} \ell^{+} \nu$

Background investigation

Investigated using MC

- Fake D*
- Fake Lepton
- Uncorrelated
- $B \rightarrow D^{**}\ell\nu, B \rightarrow D^*X\ell\nu$
- Signal correlated

Off-resonance data

• Continuum: qq decays



HMCMLL, TFractionFitter

- Determine norm of MC components from fit to data
- Use one dimensional distribution cos θ_{B⁰,D^{*}ℓ}



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

Hadronic Tag

Title

TFractionFitter result - $K\pi$, *e* sample



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

Hadronic Tag

Title o

TFractionFitter result - $K\pi$, μ sample



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

Hadronic Tag

Title

TFractionFitter result - $K3\pi$, *e* sample



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

Hadronic Tag

Title o

TFractionFitter result - $K3\pi$, μ sample



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

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

Hadronic Tag

Title

Background and signal purity

Fractions of the components

sample	Кπ, е	$K\pi, \mu$	КЗπ, е	$K3\pi, \mu$
signal	(80.95 ± 1.06)%	$(80.92 \pm 0.98)\%$	(73.17 ± 1.71)%	$(72.22 \pm 1.46)\%$
D**	(4.73 ± 0.87)%	$(1.24 \pm 0.85)\%$	$(5.21 \pm 1.18)\%$	$(2.85 \pm 1.10)\%$
uncorrelated	$(5.36 \pm 0.27)\%$	$(4.38 \pm 0.29)\%$	$(5.42 \pm 0.58)\%$	$(4.17 \pm 0.54)\%$
correlated	$(1.69 \pm 0.26)\%$	$(2.42 \pm 0.28)\%$	$(2.04 \pm 0.69)\%$	$(2.25 \pm 0.59)\%$
fake ℓ	0.68 % (fixed)	3.62% (fixed)	0.72% (fixed)	4.04% (fixed)
fake D*	2.96% (fixed)	2.91% (fixed)	$(8.78 \pm 2.63)\%$	$(9.63 \pm 2.15)\%$
continuum	3.62% (fixed)	4.51% (fixed)	4.81% (fixed)	4.87% (fixed)

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Covariances between bins of the marginal distributions

Covariances

$$\operatorname{Cov}_{ij} = \operatorname{Cov}(n_i, n_j) = N \cdot (p_{ij} - p_i p_j), \forall i \neq j$$

- N: Total number of events
- n_{ij}: Bin content of the bin (i, j) of 2d histogram
- *n_k*: Bin content of the bin *k* of a 1d histogram
- $p_x = \frac{n_x}{N}$

Special cases

- Independent variables: $p_{ij} = p_i p_j \rightarrow \text{Cov}_{ij} \equiv 0$
- Perfect anti-correlation: $n_{ij} = 0 \rightarrow Cov_{ij} < 0$
- Positive correlation: $p_{ij} > p_i p_j \rightarrow \text{Cov}_{ij} > 0$

$B^0 \rightarrow D^{*-} \ell^+ \nu$ $B^+ \rightarrow D^{*0} \ell^+ \nu$

Results for all subsamples

Fit results for all subsamples and the total sample

sample	Кπ, е	$K\pi,\mu$	К3π, е
ρ^2	$1.329 \pm 0.072 \pm 0.017$	$1.221 \pm 0.075 \pm 0.046$	$1.238 \pm 0.133 \pm 0.053$
<i>R</i> ₁ (1)	$1.455 \pm 0.077 \pm 0.046$	$1.608 \pm 0.087 \pm 0.099$	$1.085 \pm 0.125 \pm 0.044$
R ₂ (1)	$0.782 \pm 0.055 \pm 0.014$	$0.853 \pm 0.055 \pm 0.027$	$0.980 \pm 0.087 \pm 0.027$
$R_{K3\pi/K\pi}$	2.153 (fixed)	2.153 (fixed)	2.153 (fixed)
$\mathcal{B}(B^0)$	$4.43 \pm 0.03 \pm 0.25$	$4.41 \pm 0.03 \pm 0.26$	$4.42 \pm 0.04 \pm 0.25$
$\mathcal{F}(1) V_{cb} $	$34.3 \pm 0.4 \pm 1.0$	$33.5 \pm 0.4 \pm 1.0$	$35.6\pm0.8\pm1.3$
$\chi^2/n.d.f.$	29.2/36	37.4/36	19.2/36
P_{χ^2}	78.2%	40.4%	99.0%
sample	$K3\pi, \mu$		total sample
ρ^2	$1.436 \pm 0.121 \pm 0.062$		$1.293 \pm 0.045 \pm 0.029$
<i>R</i> ₁ (1)	$1.643 \pm 0.163 \pm 0.112$		$1.495 \pm 0.050 \pm 0.062$
R ₂ (1)	$0.842 \pm 0.105 \pm 0.038$		$0.844 \pm 0.034 \pm 0.019$
$R_{K3\pi/K\pi}$	2.153 (fixed)		$\textbf{2.153} \pm \textbf{0.011}$
$\mathcal{B}(B^0)$	$4.47 \pm 0.04 \pm 0.26$		$4.42 \pm 0.03 \pm 0.25$
$\mathcal{F}(1) V_{cb} $	$35.6 \pm 0.7 \pm 1.3$		$34.4\pm0.2\pm1.0$
$\chi^2/n.d.f.$	17.9/36		138.8/155
P_{χ^2}	99.5%		82.0%



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Preliminary systematic error

	ρ^2	$R_{1}(1)$	$R_{2}(1)$	$\mathcal{B}(B^0)$	$\mathcal{F}(1) V_{cb} $
Stat. error	0.050	0.060	0.043	0.030	0.22
D**	0.015	0.038	0.011	0.051	0.25
Uncorr.	0.009	0.028	0.002	0.003	0.04
Sig.corr.	0.003	0.003	0.007	0.028	0.14
Fake ℓ	0.020	0.037	0.009	0.002	0.04
Fake D*	0.012	0.011	0.009	0.034	0.33
Continuum	0.003	0.008	0.000	0.001	0.02
Trk., det.eff.	-	-	-	0.221	0.86
$\mathcal{B}(D^0)$	-	-	-	0.081	0.31
$\mathcal{B}(D^*)$	-	-	-	0.033	0.13
B ⁰ life time	-	-	-	0.026	0.10
N _{BB}	-	-	-	0.036	0.14
$f_{+-}/f_{0\bar{0}}$	0.003	0.011	0.005	0.001	0.04
Syst. error	0.029	0.062	0.019	0.251	1.04



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Correlations

Correlations between the fit parameters

	Correlations						
Parameters	Global	ρ^2	$R_{1}(1)$	$R_{2}(1)$	$R_{K3\pi/K\pi}$		
$\mathcal{F}(1) V_{cb} $	0.99168	0.635	-0.285	-0.220	0.011		
ρ^2	0.99732		0.388	-0.870	0.040		
$R_{1}(1)$	0.95366			-0.511	0.001		
$R_{2}(1)$	0.99342				0.002		
$R_{K3\pi/K\pi}$	0.41362						

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Appendix 00000	$B^0 ightarrow D^{*-} \ell^+ u$	$\begin{array}{c} B^+ \to D^{*0} \ell^+ \nu \\ \bullet \circ \circ$	Hadronic Tag o	Title ⊙
Color sch	eme			
+	— (OnRes	s - Continuu	m) data	
	MC bad	ckground, Si ckaround. D	ig.corr. **	
	MC ba	ckground, U	ncorr.	
	MC ba	ckground, Fa	ake Leptor	ו
	MC ba	ckground, C	omb D*	
	MC ba	ckground, Fa		

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

Background investigation

Investigated using MC

- Fake D⁰
- Combinatoric D*
- Fake Lepton
- Uncorrelated
- $B \rightarrow D^{**}\ell\nu, B \rightarrow D^*X\ell\nu$
- Signal correlated

Off-resonance data

• Continuum: qq decays



HMCMLL, TFractionFitter

- Determine norm of MC components from fit to data
- Use 2D distribution $\cos \theta_{B^0, D^* \ell}$ vs. Δm







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Plot of TFractionFitter result - $D^0 \rightarrow K3\pi$ modes



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$B^0 \rightarrow D^{*-} \ell^+ \nu$ $B^+ \rightarrow D^{*0} \ell^+ \nu$

Background and signal purity

Fractions of the components

	Кπ, е	$K\pi, \mu$	К3π, е	$K3\pi, \mu$
Raw yield	13035	12262	16989	16350
Signal events	8133 ± 205	7447 ± 201	5987 ± 229	5539 ± 222
Signal	(62.39 ± 1.57)%	(60.73 ± 1.64)%	(35.24 ± 1.35)%	(33.88 ± 1.36)%
Signal correlated	$(1.27 \pm 0.31)\%$	$(1.46 \pm 0.32)\%$	$(1.16 \pm 0.26)\%$	$(1.34 \pm 0.31)\%$
D**	$(0.77 \pm 0.98)\%$	$(0.73 \pm 0.98)\%$	$(0.39 \pm 0.50)\%$	$(0.36 \pm 0.47)\%$
Uncorrelated	$(4.97 \pm 0.54)\%$	$(4.25 \pm 0.45)\%$	$(3.48 \pm 0.41)\%$	$(3.30 \pm 0.38)\%$
Fake ℓ	$(0.31 \pm 0.10)\%$	$(1.94 \pm 0.59)\%$	$(0.18 \pm 0.06)\%$	$(0.95 \pm 0.29)\%$
Combinatoric D*0	$(24.76 \pm 0.51)\%$	$(24.30 \pm 0.48)\%$	$(16.35 \pm 0.69)\%$	$(15.19 \pm 0.67)\%$
Fake D ⁰	(2.91 ± 0.25)%	$(3.12 \pm 0.23)\%$	$(38.53 \pm 0.50)\%$	$(39.45 \pm 0.51)\%$
Continuum	$(2.63 \pm 0.43)\%$	$(3.46 \pm 0.51)\%$	$(4.68 \pm 0.50)\%$	$(6.14 \pm 0.56)\%$

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

Results for all subsamples

	$D^0 o K\pi, \ell = e$	$D^0 \to K\pi, \ell = \mu$	$D^0 ightarrow K3\pi, \ell = e$
ρ^2	$1.199 \pm 0.125 \pm 0.051$	$1.370 \pm 0.129 \pm 0.057$	$1.723 \pm 0.162 \pm 0.062$
R ₁ (1)	$1.507 \pm 0.135 \pm 0.095$	$1.568 \pm 0.158 \pm 0.089$	$1.840 \pm 0.271 \pm 0.110$
R ₂ (1)	$0.868 \pm 0.093 \pm 0.036$	$0.839 \pm 0.110 \pm 0.032$	$0.585 \pm 0.198 \pm 0.049$
$R_{K3\pi/K\pi}$	2.072	2.072	2.072
$\mathcal{B}(B^+ \to \bar{D}^{*0}\ell^+ \nu_\ell)$	$4.91 \pm 0.05 \pm 0.58$	$4.77 \pm 0.05 \pm 0.57$	$4.83 \pm 0.07 \pm 0.57$
$\mathcal{F}(1) V_{cb} \times 10^3$	$34.3\pm0.6\pm2.2$	$35.0 \pm 0.6 \pm 2.3$	$36.5 \pm 1.0 \pm 2.4$
$\chi^2/\text{ndf.}$	48.3 / 36	40.6 / 36	39.6 / 36
P_{χ^2}	8.3 %	27.5 %	31.3 %
	$D^0 \rightarrow K3\pi, \ell = \mu$		Fit to total sample
ρ^2	$1.434 \pm 0.209 \pm 0.086$		$1.376 \pm 0.074 \pm 0.056$
R ₁ (1)	$1.813 \pm 0.273 \pm 0.107$		$1.620 \pm 0.091 \pm 0.093$
R ₂ (1)	$0.764 \pm 0.191 \pm 0.052$		$0.805 \pm 0.064 \pm 0.037$
$R_{K3\pi/K\pi}$	2.072		2.072 ± 0.023
$\mathcal{B}(B^{+'} \rightarrow \bar{D}^{*0}\ell^+ \nu_{\ell})$	$4.83 \pm 0.07 \pm 0.58$		$4.84 \pm 0.04 \pm 0.57$
$\mathcal{F}(1) V_{cb} imes 10^3$	$34.8\pm1.0\pm2.3$		$35.0\pm0.4\pm2.2$
$\chi^2/\text{ndf.}$	44.2 / 36		187.8 / 155
P_{χ^2}	16.3 %		3.7 %



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$B^0 \rightarrow D^{*-} \ell^+ \nu$ $B^+ \rightarrow D^{*0} \ell^+ \nu$

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Breakdown of the preliminary systematic error

	ρ^2	<i>R</i> ₁ (1)	<i>R</i> ₂ (1)	$\mathcal{F}(1) V_{cb} imes 10^3$	${\cal B}(B^+ o ar D^{*0} \ell^+ u_\ell)$
Value	1.376	1.620	0.805	34.98	4.841
Statistical Error	0.074	0.091	0.064	0.37	0.044
π_s^0 & tracking	0.027	0.025	0.012	1.97	0.491
LeptonID	0.012	0.024	0.011	0.39	0.096
Norm - Signal Corr.	0.007	0.002	0.007	0.13	0.038
Norm - D**	0.005	0.023	0.002	0.04	0.041
Norm - Uncorr	0.014	0.074	0.025	0.28	0.023
Norm - Fake ℓ	0.017	0.028	0.010	0.05	0.024
Norm - Comb D ^{*0}	0.008	0.014	0.008	0.11	0.028
Norm - Fake D ⁰	0.009	0.014	0.007	0.06	0.020
Norm - Continuum	0.004	0.005	0.001	0.00	0.003
Shape - Uncorr	0.014	0.003	0.005	0.10	
Shape - Comb D* ⁰	0.027	0.005	0.008	0.21	
Shape - Fake D ⁰	0.024	0.003	0.008	0.17	
${\cal B}(D^0 o K \pi)$				0.32	0.089
${\cal B}(D^{*0} ightarrow D^0 \pi^0)$				0.82	0.227
B^+ life time				0.12	0.033
$N(\Upsilon(4S))$				0.14	0.040
f_{+-}/f_{00}	0.003	0.006	0.003	0.15	0.043



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Appendix 00000	$B^0 \to D^{*-} \ell^+ \nu$	$B^+ \to D^{*0} \ell^+ \nu$	Hadronic Tag O	Title ○
Correla	tions			

Correlations between the fit parameters

• Table shows statistical/systematic/total correlation coefficients

	$\mathcal{F}(1) V_{cb} $	ρ^2	R ₁ (1)	R ₂ (1)
$\mathcal{F}(1) V_{cb} $	1.000	0.455/0.399/0.295	-0.222 /-0.219/-0.179	-0.054/-0.024/-0.019
ρ^2		1.000	0.648/ 0.413/ 0.540	-0.889/-0.751/-0.841
R ₁ (1)			1.000	-0.749/-0.873/-0.763
$R_{2}(1)$				1.000

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$B^0 \rightarrow D^{*-} \ell^+ \nu$

 $B^+ \rightarrow D^{*0} \ell^+ \nu$ 00000000000000

$p_{\pi_s^0}$ distribution - $K\pi$, *e* channel



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

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

Hadronic Tag

Title ○

$p_{\pi_s^0}$ distribution - $K\pi, \mu$ channel



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

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

Hadronic Tag

Title o

$p_{\pi_s^0}$ distribution - $K3\pi$, *e* channel



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

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

Hadronic Tag

Title o

$p_{\pi_s^0}$ distribution - $K3\pi, \mu$ channel



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$B^0 ightarrow D^*^- \ell^+ u$	$B^+ ightarrow D^{*0} \ell^+ u$	Hadronic Tag
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Check of Γ_L

Appendix 00000

	$D^0 o K\pi, \ell = e$	$D^0 \to K\pi, \ell = \mu$
$\Gamma^{00}, w \in (1, \frac{13}{12})$	$(1.025\pm0.119\pm0.120){\times}10^{-4}$	$(1.176\pm0.146\pm0.137){ imes}10^{-4}$
$\Gamma^{00}, w \in (\frac{13}{12}, \frac{7}{6})$	$(1.544 \pm 0.165 \pm 0.176) imes 10^{-4}$	(1.689 \pm 0.177 \pm 0.192)×10 ⁻⁴
$\Gamma^{00}, w \in (\frac{7}{6}, \frac{15}{12})$	(2.238 \pm 0.213 \pm 0.237) $ imes$ 10 $^{-4}$	(2.121 \pm 0.216 \pm 0.238)×10^{-4}
$\Gamma^{00}, w \in (\frac{15}{12}, \frac{8}{6})$	(2.677 \pm 0.244 \pm 0.268)×10^{-4}	(2.059 \pm 0.240 \pm 0.228)×10^{-4}
$\Gamma^{00}, w \in (\frac{8}{6}, \frac{17}{12})$	(2.406 \pm 0.235 \pm 0.256) $ imes$ 10 $^{-4}$	(2.426 \pm 0.263 \pm 0.263) $ imes$ 10 $^{-4}$
$\Gamma^{00}, w \in (\frac{17}{12}, 1.5)$	(2.907 \pm 0.250 \pm 0.301) $\times 10^{-4}$	(2.384 \pm 0.273 \pm 0.278) $\times 10^{-4}$

	fit to total sample	central value of parametrized fit
$\Gamma^{00}, w \in (1, \frac{13}{12})$	$(1.087\pm 0.092\pm 0.123){\times}10^{-4}$	1.062×10^{-4}
$\Gamma^{00}, w \in (\frac{13}{12}, \frac{7}{6})$	(1.611 \pm 0.121 \pm 0.179)×10 ⁻⁴	1.812×10^{-4}
$\Gamma^{00}, w \in (\frac{7}{6}, \frac{15}{12})$	(2.186 \pm 0.151 \pm 0.238)×10^{-4}	2.175×10^{-4}
$\Gamma^{00}, w \in (\frac{15}{12}, \frac{8}{6})$	(2.406 \pm 0.172 \pm 0.262)×10 ⁻⁴	2.379×10^{-4}
$\Gamma^{00}, w \in (\frac{8}{6}, \frac{17}{12})$	(2.421 \pm 0.175 \pm 0.258)×10^{-4}	2.483 ×10 ⁻⁴
$\Gamma^{00}, w \in (\frac{17}{12}, 1.5)$	$(2.683\pm 0.186\pm 0.298){\times}10^{-4}$	2.514×10^{-4}

Title

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$B^0 ightarrow D^{*-} \ell^+ u$	$B^+ ightarrow D^{st 0} \ell^+ u$	Hadronic Tag
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Check of Γ_T

Appendix 00000

	$D^0 o K \pi.\ell = e$	$D^0 \to K \pi.\ell = \mu$
$\Gamma^{T}, w \in (1, \frac{13}{12})$	$(2.267\pm 0.153\pm 0.264)\!\times\!10^{-4}$	(1.939 \pm 0.152 \pm 0.228)×10^{-4}
$\Gamma^{T}, w \in (\frac{13}{12}, \frac{7}{6})$	$(2.695 \pm 0.214 \pm 0.307) imes 10^{-4}$	(3.015 \pm 0.216 \pm 0.348) $ imes$ 10 $^{-4}$
$\Gamma^{T}, w \in (\frac{7}{6}, \frac{15}{12})$	(2.786 \pm 0.253 \pm 0.310) $ imes$ 10 $^{-4}$	(2.678 \pm 0.261 \pm 0.299)×10 ⁻⁴
$\Gamma^{T}, w \in (\frac{15}{12}, \frac{8}{6})$	(2.298 \pm 0.249 \pm 0.246) $ imes$ 10 $^{-4}$	(2.673 \pm 0.295 \pm 0.290)×10^{-4}
$\Gamma^{T}, w \in (\frac{8}{6}, \frac{17}{12})$	$(1.557 \pm 0.242 \pm 0.162) imes 10^{-4}$	(1.369 \pm 0.250 \pm 0.144)×10^{-4}
$\Gamma^{T}, w \in (\frac{17}{12}, 1.5)$	(0.588 \pm 0.205 \pm 0.056) $\times 10^{-4}$	(0.862 \pm 0.284 \pm 0.099)×10^{-4}

	fit to total sample	central value of parametrized fit
$\Gamma^{T}, w \in (1, \frac{13}{12})$	$(2.117\pm0.108\pm0.248){\times}10^{-4}$	1.975×10^{-4}
$\Gamma^{T}, w \in (\frac{13}{12}, \frac{7}{6})$	(2.865 \pm 0.152 \pm 0.327)×10 ⁻⁴	2.908×10^{-4}
$\Gamma^{T}, w \in (\frac{7}{6}, \frac{15}{12})$	(2.732 \pm 0.181 \pm 0.303)×10 ⁻⁴	2.819×10^{-4}
$\Gamma^{T}, w \in (\frac{15}{12}, \frac{8}{6})$	(2.454 \pm 0.191 \pm 0.263)×10 ⁻⁴	2.276 ×10 ⁻⁴
$\Gamma^{T}, w \in (\frac{8}{6}, \frac{17}{12})$	(1.468 \pm 0.174 \pm 0.154)×10 ⁻⁴	1.478×10^{-4}
$\Gamma^{T}, w \in (\frac{17}{12}, 1.5)$	$(0.693\pm0.170\pm0.070){ imes}10^{-4}$	0.547×10^{-4}

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Systematics

Source	$ar{D}^0 au^+ u$ [%]	$\bar{D}^{*0}\tau^+\nu[\%]$	$\bar{D}^-\tau^+\nu [\%]$	$ar{D}^{*-} au^+ u$ [%]
M_{mix}^2 shape	+9.10/-7.89	+9.86/-10.7	+6.39/-5.78	+5.80/-6.12
E_{extra}^{ECL} shape	+10.6/-7.58	+7.01/-9.73	+9.03/-7.27	+9.84/-4.97
$D^{**}\ell u$	+0.35/-0.41	+0.75/-0.02	+4.50/-2.56	+0.58/-0.28
$D \leftrightarrow D^*$ cross feed	+7.05/-6.86	+5.12/-5.34	+5.77/-6.01	+3.48/-3.37
${\cal B}(au o \ell u u)$	±0.3	±0.3	±0.3	±0.3
Total	+15.7/-12.9	+13.2/-15.4	+13.3/-11.4	+12.0/-8.58



Semileptonic $b \rightarrow c$ Decays at Belle

Wolfgang Dungel

Institute for high energy physics Austrian Academy of Sciences

on behalf of the Belle collaboration

EPS HEP 2009, July 17, 2009





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EPS09 - Semileptonic $b \rightarrow c$ Decays at Belle

COACU Austrian Academy of Sciences