Semileptonic $b \to c$ Decays at Belle

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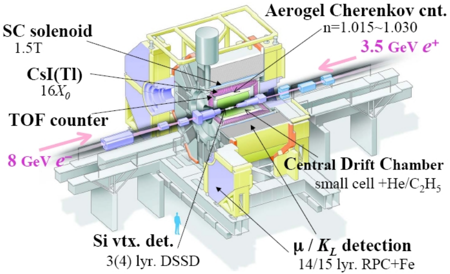
Institute for high energy physics
Austrian Academy of Sciences

on behalf of the Belle collaboration

EPS HEP 2009,
July 17, 2009

Greetings from Belle!

Belle and the KEK-B accelerator



New record, 2009/06/19!

$L^{peak} = 2.1 \times 10^{34} cm^{-2} s^{-1}$

Integrated luminosity, July 2009

- $\mathcal{L} \approx 950 \text{fb}^{-1}$

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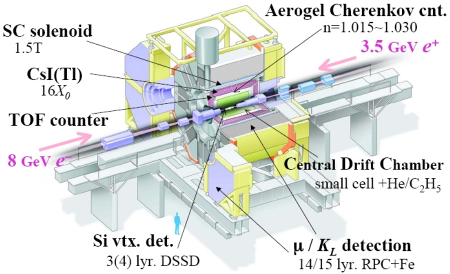

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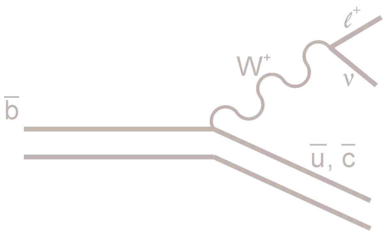
Precision measurements!

- Determine $\{|V_{ub}|, |V_{cb}|\}$



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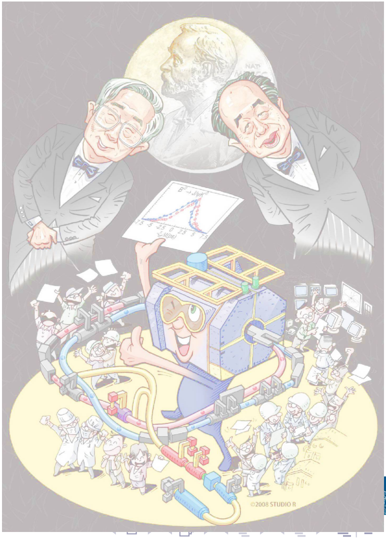
- Except ...



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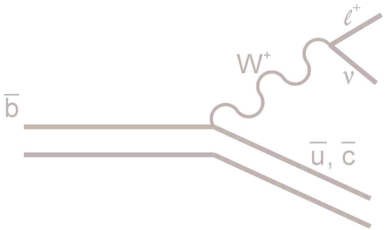

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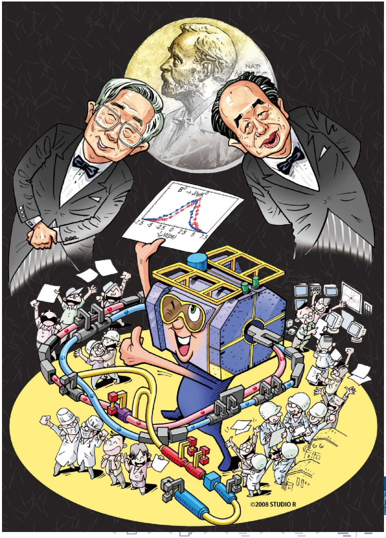

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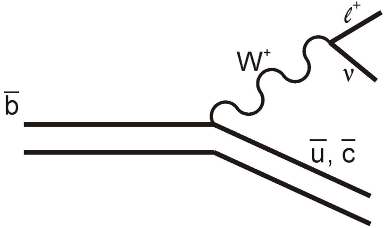

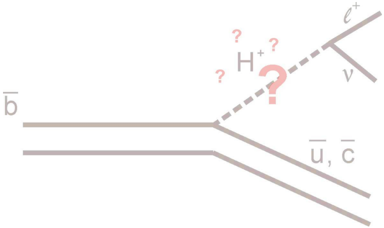

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- Precise measurements of $|V_{ub}|$ and $|V_{cb}|$ crucial to observe deviations from CKM mechanism

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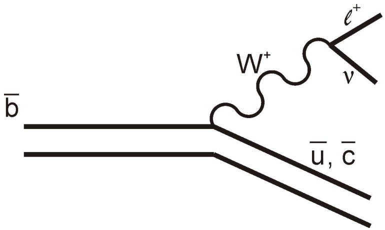

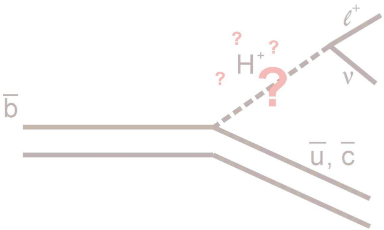

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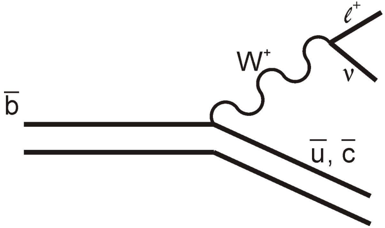

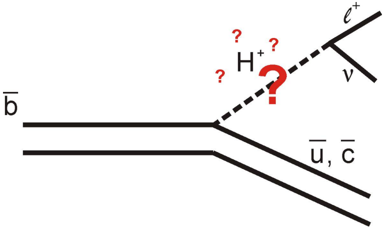

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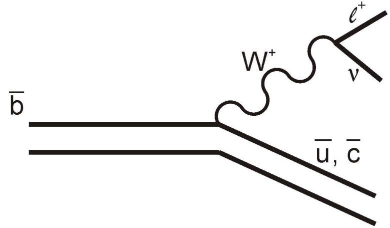

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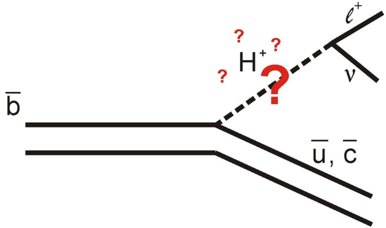

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日本
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Toky
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Tottori
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名古屋
Osaka
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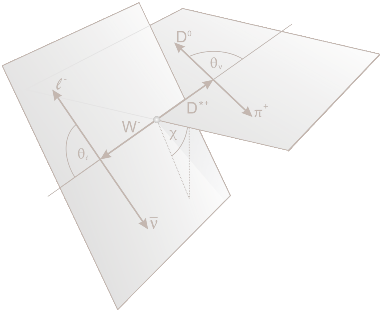
Measurement of the decays $B^0 \to D^{*-} \ell^+ \nu$ and $B^+ \to \bar{D}^{*0} \ell^+ \nu$ at Belle

Differential decay width

Kinematic variables

- $w = \frac{p_B^\mu \cdot p_{D^*,\mu}}{m_{B^0}\, m_{D^*}} = a + b\, q^2$
- $\cos\theta_\ell$, $\cos\theta_V$, χ



Differential decay width

$$\frac{d^4\Gamma(B \to D^* \ell^+ \nu_\ell)}{dw\, d(\cos\theta_\ell)\, d(\cos\theta_V)\, d\chi}$$

$$= \frac{6 m_B m_{D^*}^2}{8(4\pi)^4} \sqrt{w^2 - 1}(1 - 2wr + r^2) G_F^2 |V_{cb}|^2$$

$$\times \{(1 - \cos\theta_\ell)^2 \sin^2\theta_V H_+^2(w)$$

$$+ (1 + \cos\theta_\ell)^2 \sin^2\theta_V H_-^2(w)$$

$$+ 4 \sin^2\theta_\ell \cos^2\theta_V H_0^2(w)$$

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- Aside from masses etc. identical for B^0 and B^+

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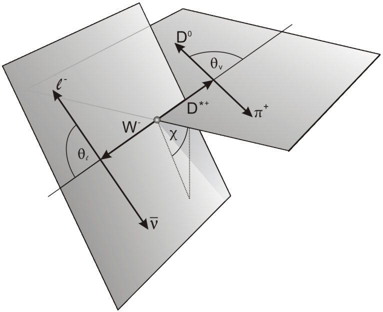

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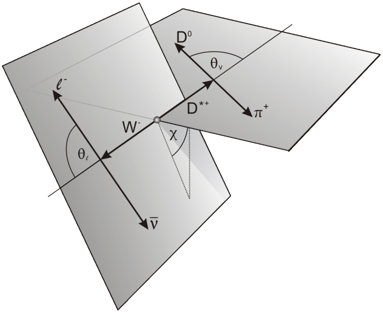

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Considered final states

- Only signal is reconstructed
- $\bar{B} \to D^* \ell^- \bar{\nu}_\ell$,
  - $D^* \to D^0 \pi_s$
    - $D^0 \to K^- \pi^+$
    - $D^0 \to K^- \pi^+ \pi^- \pi^+$

Results

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

Systematics

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

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

- Shown at ICHEP08
- $N_{signal} = 69,345 \pm 377$

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

- New preliminary result
- $N_{signal} = 27,106 \pm 367$

B^0 signal purity and background fractions

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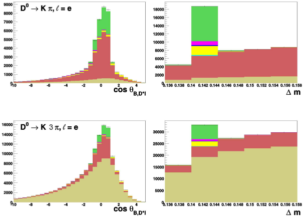
Investigation of B^+ background

Investigated using MC

- Fake D^0
- Combinatoric D^*
- Fake Lepton
- Uncorrelated
- $B \to D^{**} \ell \nu$, $B \to D^* X \ell \nu$
- Signal correlated

Off-resonance data

- Continuum: $q\bar{q}$ decays



Background fractions B^+

HMCMLL, TFractionFitter

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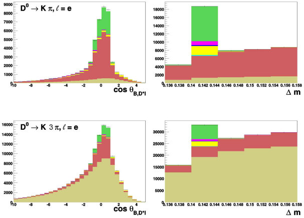

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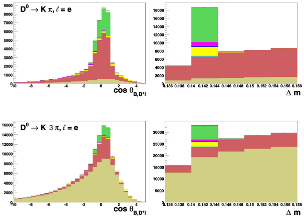

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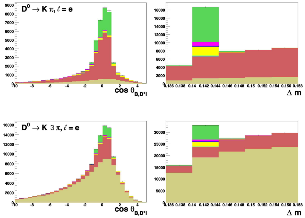

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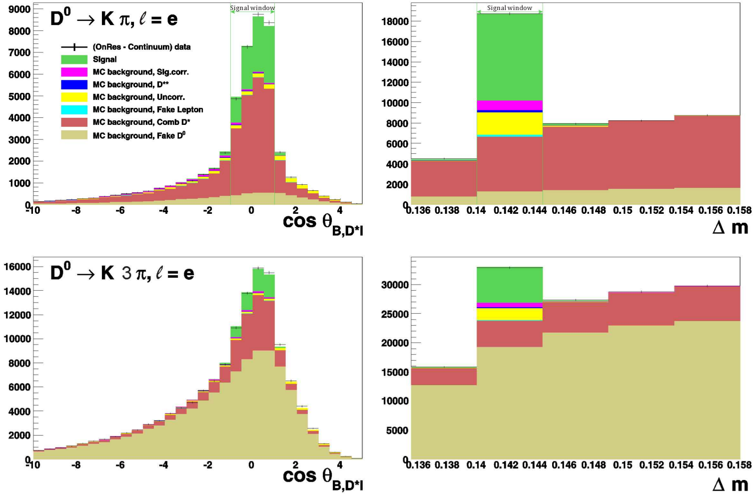
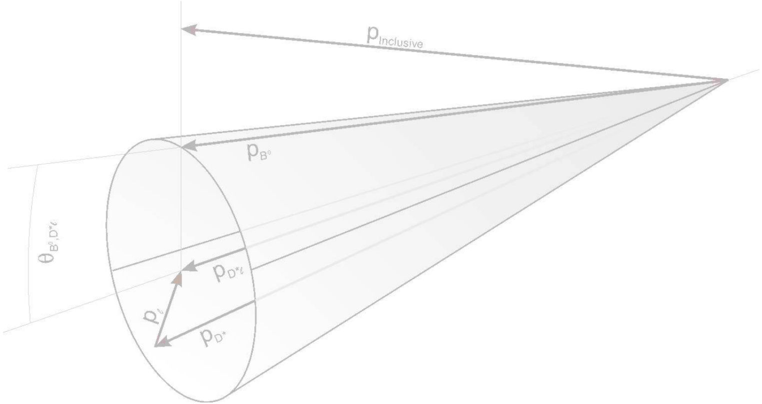
Plots of B^+ background - e channels



Reconstruction of the B rest frame



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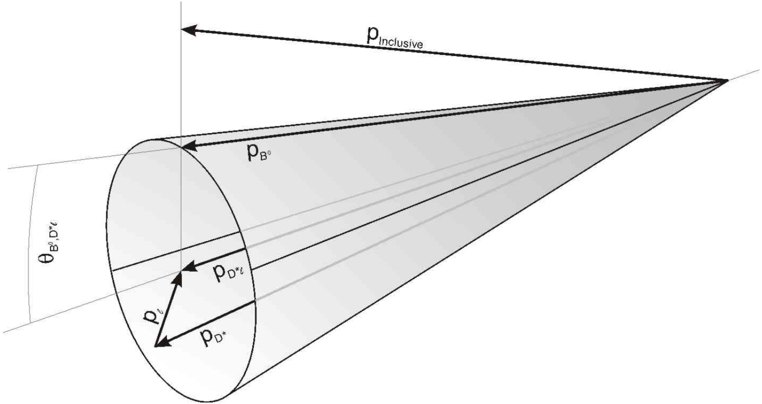

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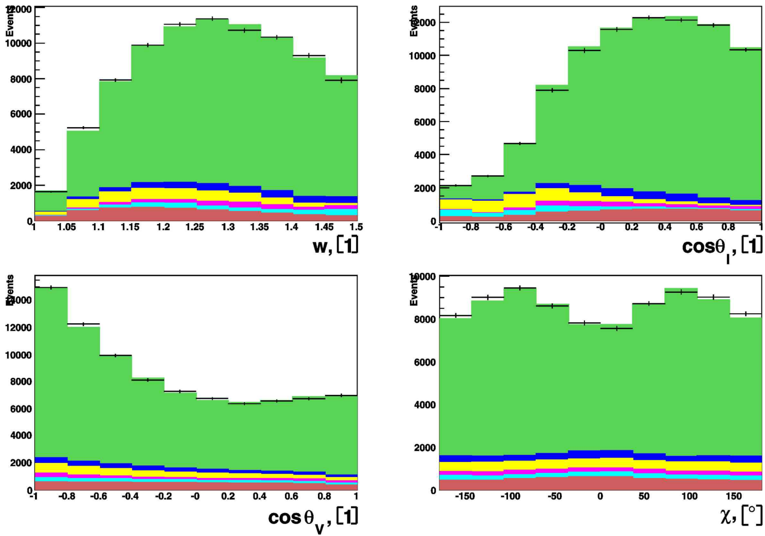
Plots of preliminary results - B^0



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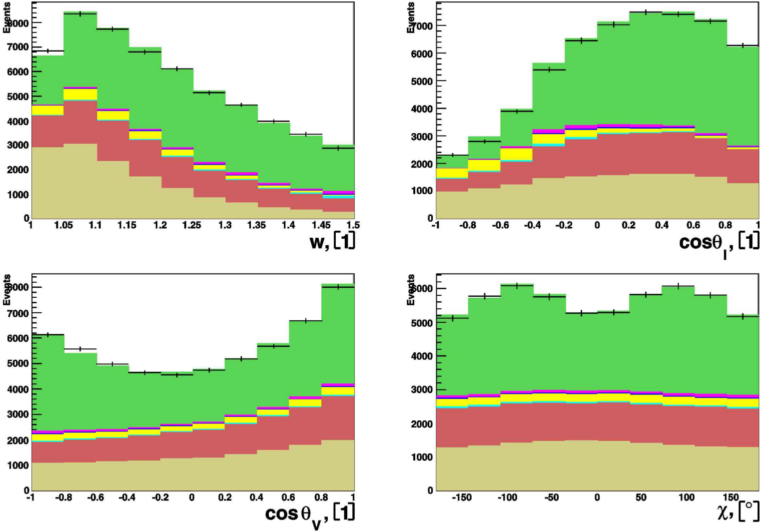


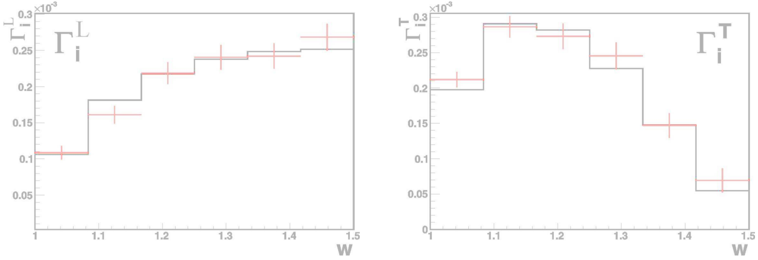
Preliminary results

	$B^0 \to D^{*-} \ell \nu$	$B^+ \to \bar{D}^{*0} \ell \nu$
ρ^2	$1.293 \pm 0.045 \pm 0.029$	$1.376 \pm 0.074 \pm 0.056$
$R_1(1)$	$1.495 \pm 0.050 \pm 0.062$	$1.620 \pm 0.091 \pm 0.092$
$R_2(1)$	$0.844 \pm 0.034 \pm 0.019$	$0.805 \pm 0.064 \pm 0.036$
$R_{K3\pi/K\pi}$	2.153 ± 0.011	2.072 ± 0.023
$\mathcal{B}(B \to D^* \ell^+ \nu_\ell)$	$(4.42 \pm 0.03 \pm 0.25)\%$	$(4.84 \pm 0.04 \pm 0.56)\%$
$\mathcal{F}(1)\,\lvert V_{cb}\rvert \times 10^3$	$34.4 \pm 0.2 \pm 1.0$	$35.0 \pm 0.4 \pm 2.2$
$\chi^2/\text{n.d.f.}$	$138.8/155$	$187.8/155$
P_{χ^2}	82.0%	3.7%

Subsamples - B^0 | Systematic error - B^0 | Correlations - B^0
Subsamples - B^+ | Systematic error - B^+ | Correlations - B^+

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

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



(The statistical error is shown in these plots)

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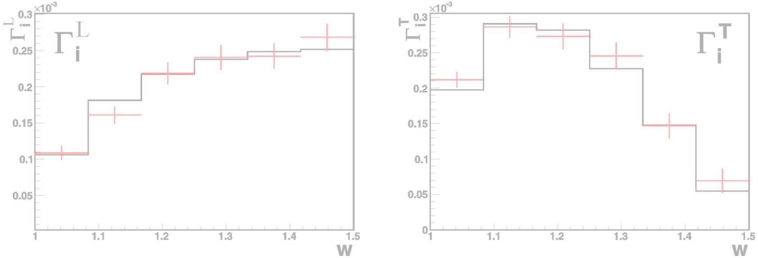

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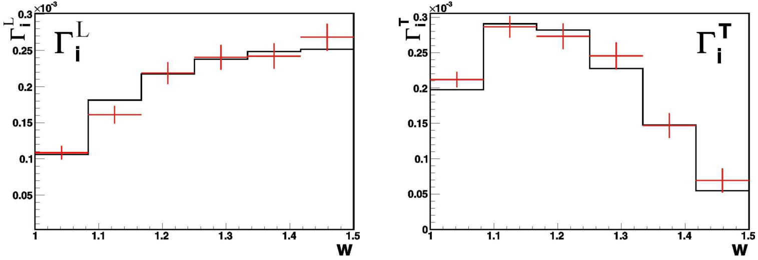

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Observation of $B^0 \to D^{*-} \tau^+ \nu_\tau$ Decay at Belle

PRL 99, 191807 (2007)

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

Signal reconstruction

- Three signal cascades are considered

- $B^0 \to D^{*-} \tau^+ \nu$
  - $\tau^+ \to e^+ \nu \nu$
  - $D^{*-} \to D^0 \pi^-$
    - $D^0 \to K \pi$

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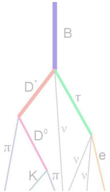

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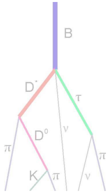

Observation of $B^0 \to D^{*-} \tau^+ \nu_\tau$

Signal reconstruction

- Three signal cascades are considered

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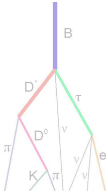

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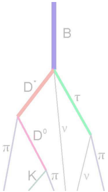

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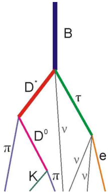

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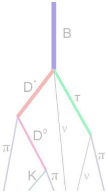

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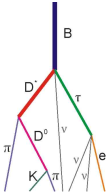

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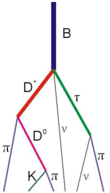

Full reconstruction

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
  - $\Delta E = E_{tag} - E_{beam}$
  - $m_{bc} = \sqrt{E_{beam}^2 - \vec{p}_{tag}^2}$
  - Total event charge, small residual energy, ...

Signal reconstruction???

- What about full reconstruction?

"Inverted procedure"

- Reconstruct second B after signal

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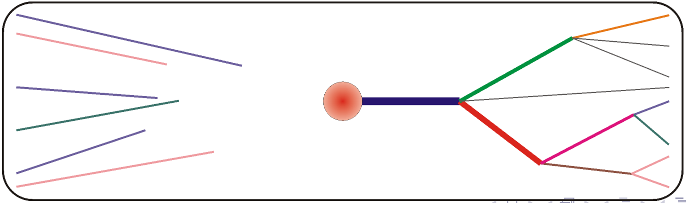

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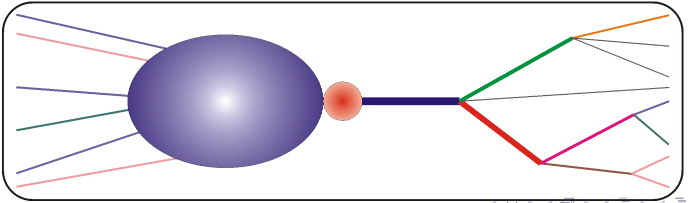

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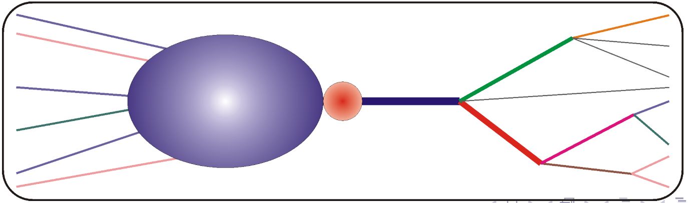

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- Excess of events seen
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- Simultaneous fit to all channels, signal yield: $N = 60^{+12}_{-11}$
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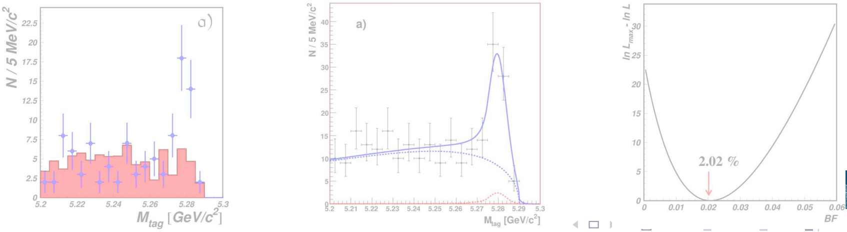

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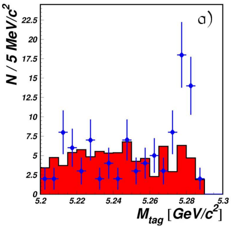

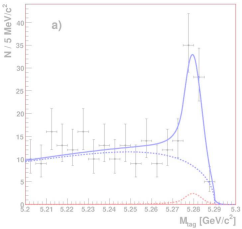

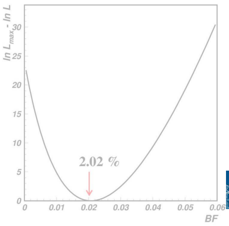

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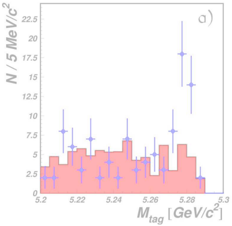

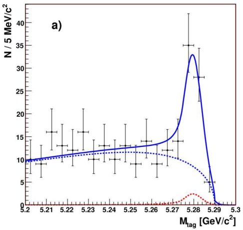

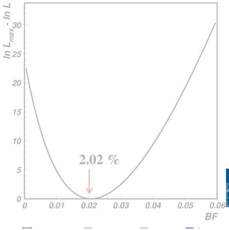

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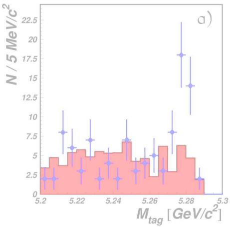

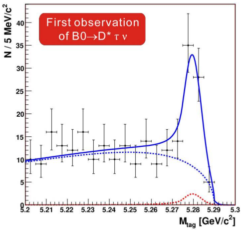

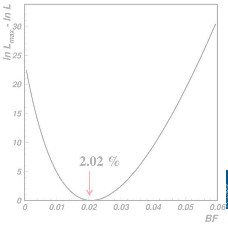

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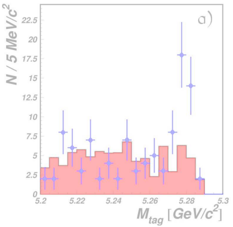

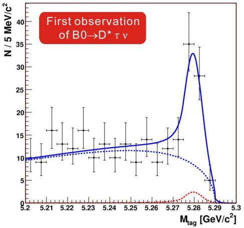

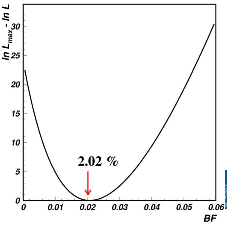

$B \to D^{(*)} \tau^+ \nu_\ell$ at Belle - hadronic tag

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

Analysis strategy

- B_{tag} from hadronic modes
- signal:
  - $B^+ \to D^0 \tau^+ \nu$
  - $B^+ \to D^{*0} \tau^+ \nu$
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- $\tau \to \ell \nu \nu$

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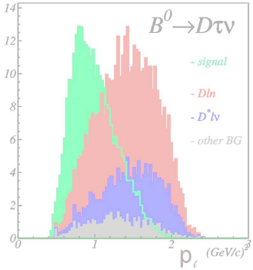
Main Background

- $B \to D^{(*)} \ell \nu$

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



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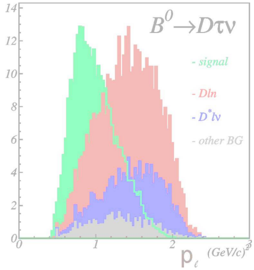

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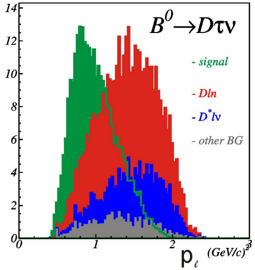

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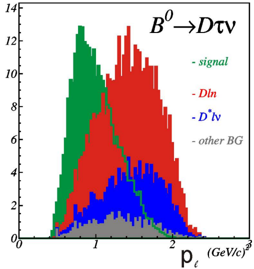

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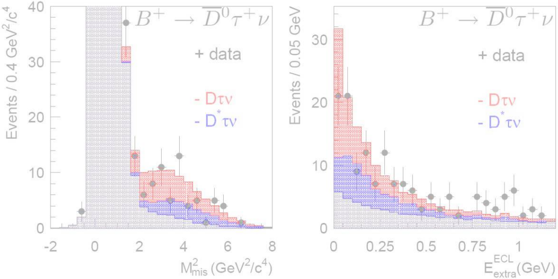
2D fit to M^2_{mis} vs. E_{ECL} distribution

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



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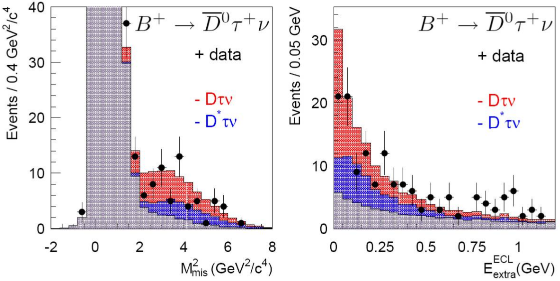

Fit results

Obtained branching ratios

- $\mathcal{B}(B^+ \to \bar{D}^0 \tau^+ \nu) = 1.51^{+0.41}_{-0.39}(stat)^{+0.24}_{-0.19}(syst) \pm 0.15(norm)\%$
- $\mathcal{B}(B^+ \to \bar{D}^{*0} \tau^+ \nu) = 3.04^{+0.69}_{-0.66}(stat)^{+0.40}_{-0.47}(syst) \pm 0.22(norm)\%$
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Stat. sign.

- 3.8σ
- 3.9σ
- 2.6σ
- 4.7σ

Data sample

- 604.5fb^{-1}

- First evidence, $B^+ \to D^0 \tau^+ \nu$!

- So .... charged Higgs?

Deviation from Standard model predictions

- $B^+ \to \bar{D}^0 \tau^+ \nu$: 1.6σ, $B^0 \to D^- \tau^+ \nu$: 0.5σ
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- $\mathcal{B}(B^+ \to \bar{D}^{*0} \tau^+ \nu) = 3.04^{+0.69}_{-0.66}(stat)^{+0.40}_{-0.47}(syst) \pm 0.22(norm)\%$
- $\mathcal{B}(B^0 \to D^- \tau^+ \nu) = 1.01^{+0.46}_{-0.41}(stat)^{+0.13}_{-0.11}(syst) \pm 0.10(norm)\%$
- $\mathcal{B}(B^0 \to D^{*-} \tau^+ \nu) = 2.56^{+0.75}_{-0.66}(stat)^{+0.31}_{-0.22}(syst) \pm 0.10(norm)\%$

Stat. sign.

- 3.8σ
- 3.9σ
- 2.6σ
- 4.7σ

Data sample

- $604.5 \mathrm{fb}^{-1}$

- First evidence, $B^+ \to D^0 \tau^+ \nu$!

- So .... charged Higgs?

Deviation from Standard model predictions

- $B^+ \to \bar{D}^0 \tau^+ \nu$: 1.6σ, $B^0 \to D^- \tau^+ \nu$: 0.5σ
- Measurements agree with the SM within the errors

$B^0 \to D^{*-} \ell^+ \nu$ and $B^+ \to \bar{D}^{*0} \ell^+ \nu$ at Belle

	B^0	B^+
ρ^2	$1.293 \pm 0.045 \pm 0.029$	$1.376 \pm 0.074 \pm 0.056$
$R_1(1)$	$1.495 \pm 0.050 \pm 0.062$	$1.620 \pm 0.091 \pm 0.092$
$R_2(1)$	$0.844 \pm 0.034 \pm 0.019$	$0.805 \pm 0.064 \pm 0.036$
$\mathcal{F}(1)\,\lvert V_{cb}\rvert \times 10^3$	$34.4 \pm 0.2 \pm 1.0$	$35.0 \pm 0.4 \pm 2.2$

Observation of $B^0 \to D^{*-} \tau^+ \nu_\tau$ Decay at Belle

- Similar, new measurement of B^+ almost ready

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

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Thanks for your attention!

Semileptonic $b \to c$ Decays at Belle

Wolfgang Dungel

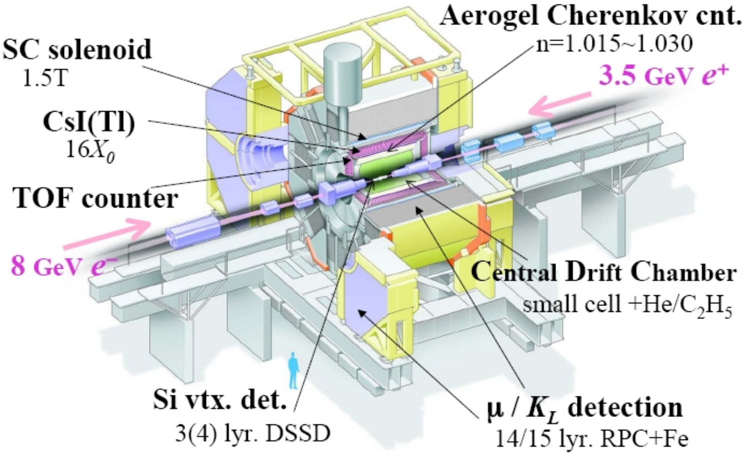
Institute for high energy physics
Austrian Academy of Sciences

on behalf of the Belle collaboration

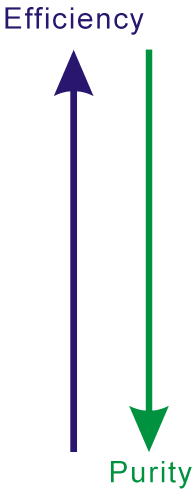
EPS HEP 2009,
July 17, 2009

The Belle Collaboration

The Belle Detector



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

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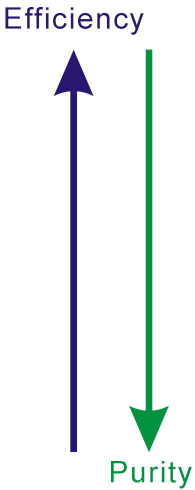

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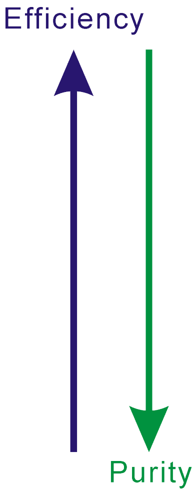

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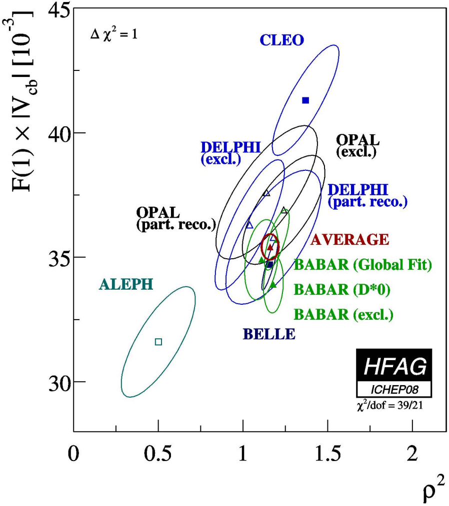
Nobel prize 2008

HFAG average, Summer 2008



HQET and parametrization

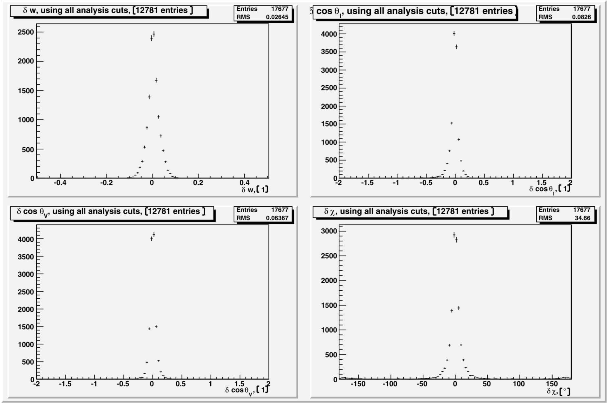
Helicity amplitudes

- $H_\pm = f_\pm(w)\,h_{A_1}(w)\,\left(1 \mp \sqrt{\frac{w-1}{w+1}}R_1(w)\right)$
- $H_0 = f_0(w)\,h_{A_1}(w)\,\left(1 + \frac{w-1}{1-\frac{m_{D^*}}{m_B}}\left(1 - R_2(w)\right)\right)$

Parametrization by CLN

- $h_{A_1}(w) = h_{A_1}(1)\,(1-8\rho^2 z+(53\rho^2-15)z^2-(231\rho^2-91)z^3)$
  $z = \frac{\sqrt{w+1}-\sqrt{2}}{\sqrt{w+1}+\sqrt{2}}$
- $R_1(w) = R_1(1) - 0.12(w-1) + 0.05(w-1)^2$
- $R_2(w) = R_2(1) + 0.11(w-1) - 0.06(w-1)^2$

Resolutions in kinematic variables



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

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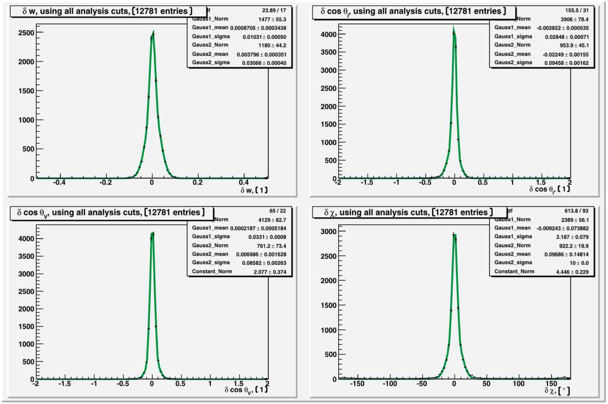

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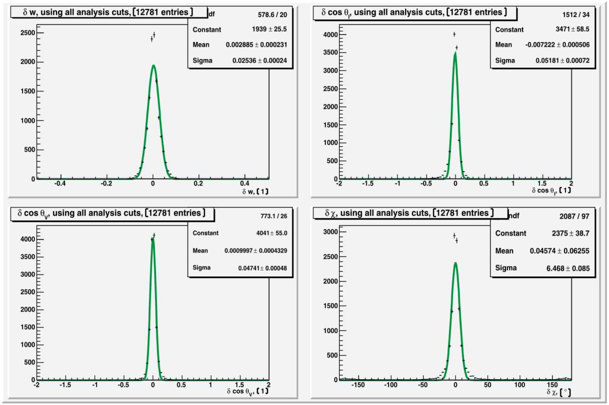
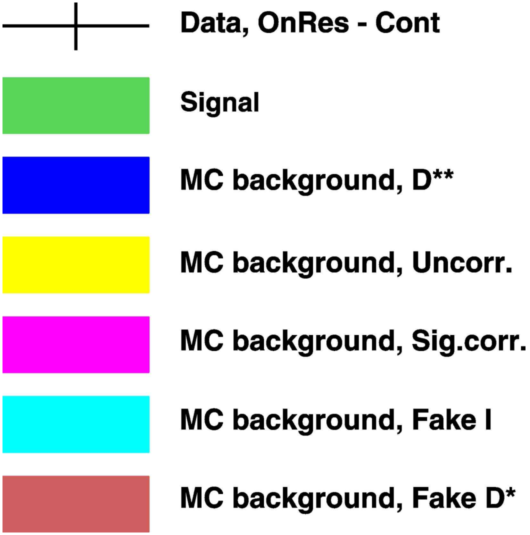


- For easier comparison: Gaussian assumption
- $\delta_{\mathrm{w}} = 0.025$, $\delta_{\cos\theta_\ell} = 0.052$, $\delta_{\cos\theta_V} = 0.047$, $\delta_\chi = 6.47^\circ$

Color scheme



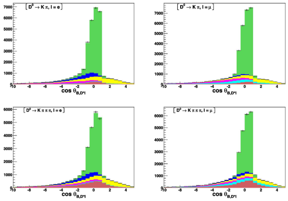
Background investigation

Investigated using MC

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

Off-resonance data

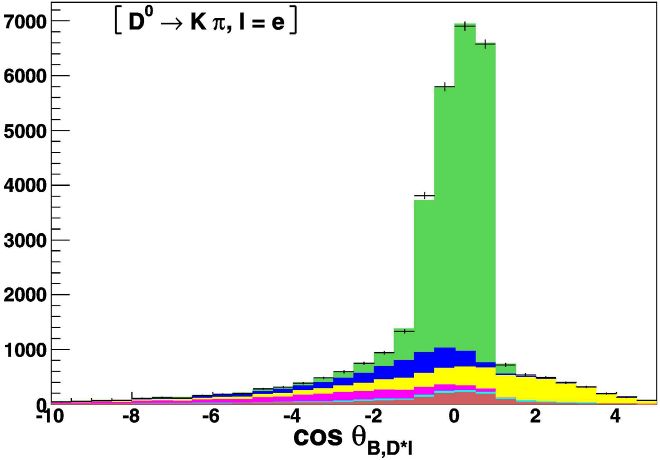
- Continuum: $q\bar{q}$ decays



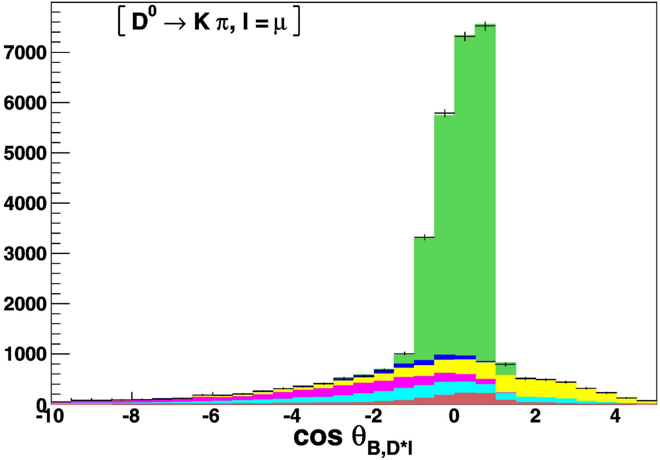
HMCMLL, TFractionFitter

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

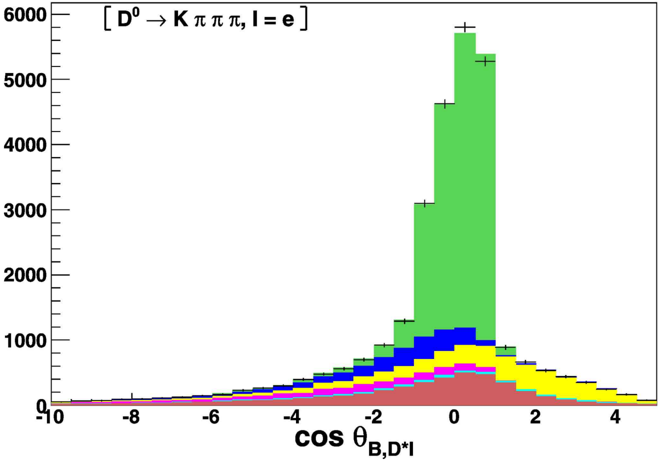
TFractionFitter result - $K\pi$, e sample



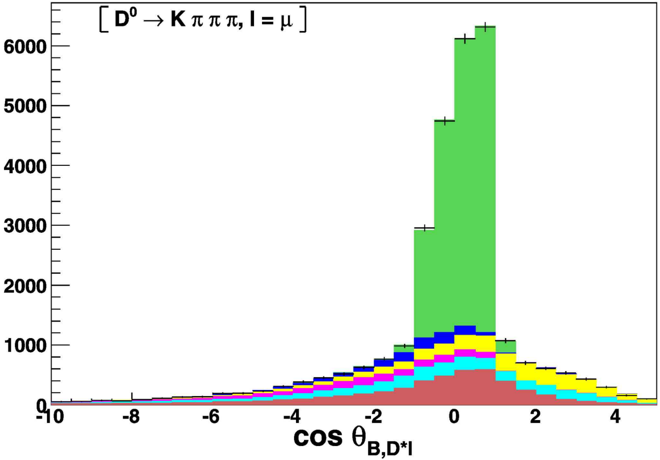
TFractionFitter result - $K\pi$, μ sample



TFractionFitter result - $K3\pi$, e sample



TFractionFitter result - $K3\pi$, μ sample



Background and signal purity

Fractions of the components

sample	$K\pi$, e	$K\pi$, μ	$K3\pi$, e	$K3\pi$, μ
signal	$(80.95 \pm 1.06)\%$	$(80.92 \pm 0.98)\%$	$(73.17 \pm 1.71)\%$	$(72.22 \pm 1.46)\%$
D^{**}	$(4.73 \pm 0.87)\%$	$(1.24 \pm 0.85)\%$	$(5.21 \pm 1.18)\%$	$(2.85 \pm 1.10)\%$
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

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

- 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: $p_{ij} = p_i p_j \to \mathrm{Cov}_{ij} \equiv 0$
- Perfect anti-correlation: $n_{ij} = 0 \to \mathrm{Cov}_{ij} < 0$
- Positive correlation: $p_{ij} > p_i p_j \to \mathrm{Cov}_{ij} > 0$

Results for all subsamples

Fit results for all subsamples and the total sample

sample	$K\pi$, e	$K\pi$, μ	$K3\pi$, e
ρ^2	$1.329 \pm 0.072 \pm 0.017$	$1.221 \pm 0.075 \pm 0.046$	$1.238 \pm 0.133 \pm 0.053$
$R_1(1)$	$1.455 \pm 0.077 \pm 0.046$	$1.608 \pm 0.087 \pm 0.099$	$1.085 \pm 0.125 \pm 0.044$
$R_2(1)$	$0.782 \pm 0.055 \pm 0.014$	$0.853 \pm 0.055 \pm 0.027$	$0.980 \pm 0.087 \pm 0.027$
$R_{K3\pi/K\pi}$	2.153 (fixed)	2.153 (fixed)	2.153 (fixed)
$\mathcal{B}(B^0)$	$4.43 \pm 0.03 \pm 0.25$	$4.41 \pm 0.03 \pm 0.26$	$4.42 \pm 0.04 \pm 0.25$
$\mathcal{F}(1)\|V_{cb}\|$	$34.3 \pm 0.4 \pm 1.0$	$33.5 \pm 0.4 \pm 1.0$	$35.6 \pm 0.8 \pm 1.3$
$\chi^2/\mathrm{n.d.f.}$	$29.2/36$	$37.4/36$	$19.2/36$
P_{χ^2}	78.2%	40.4%	99.0%

sample	$K3\pi$, μ		total sample
ρ^2	$1.436 \pm 0.121 \pm 0.062$		$1.293 \pm 0.045 \pm 0.029$
$R_1(1)$	$1.643 \pm 0.163 \pm 0.112$		$1.495 \pm 0.050 \pm 0.062$
$R_2(1)$	$0.842 \pm 0.105 \pm 0.038$		$0.844 \pm 0.034 \pm 0.019$
$R_{K3\pi/K\pi}$	2.153 (fixed)		2.153 ± 0.011
$\mathcal{B}(B^0)$	$4.47 \pm 0.04 \pm 0.26$		$4.42 \pm 0.03 \pm 0.25$
$\mathcal{F}(1)\|V_{cb}\|$	$35.6 \pm 0.7 \pm 1.3$		$34.4 \pm 0.2 \pm 1.0$
$\chi^2/\mathrm{n.d.f.}$	$17.9/36$		$138.8/155$
P_{χ^2}	99.5%		82.0%

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Preliminary systematic error

	ρ^2	$R_1(1)$	$R_2(1)$	$\mathcal{B}(B^0)$	$\mathcal{F}(1)\,\lvert V_{cb}\rvert$
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
$\mathcal{B}\left(D^0\right)$	-	-	-	0.081	0.31
$\mathcal{B}\left(D^*\right)$	-	-	-	0.033	0.13
B^0 life time	-	-	-	0.026	0.10
$N_{B\bar{B}}$	-	-	-	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

Parameters	Correlations				
	Global	ρ^2	$R_1(1)$	$R_2(1)$	$R_{K3\pi/K\pi}$
$\mathcal{F}(1)\,\lvert V_{cb}\rvert$	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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Color scheme

- (OnRes - Continuum) data
- Signal
- MC background, Sig.corr.
- MC background, D**
- MC background, Uncorr.
- MC background, Fake Lepton
- MC background, Comb D*
- MC background, Fake D^0

Background investigation

Investigated using MC

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- Combinatoric D^*
- Fake Lepton
- Uncorrelated
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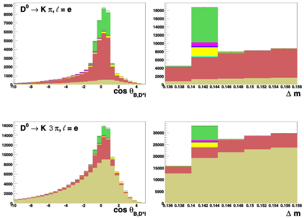
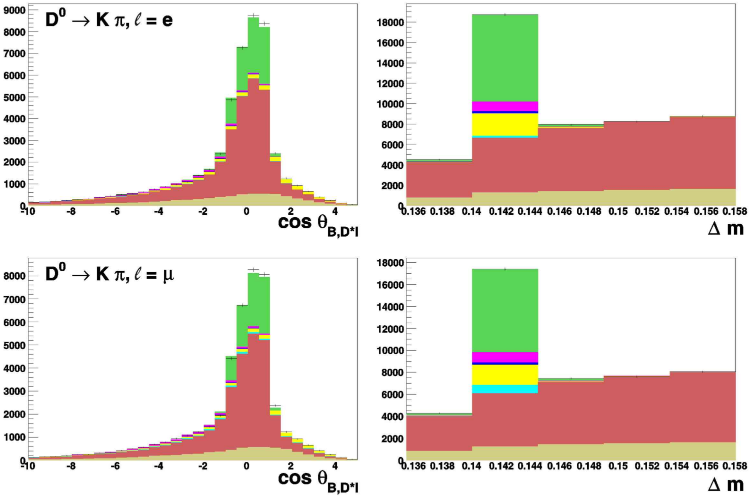
- Continuum: $q\bar{q}$ decays



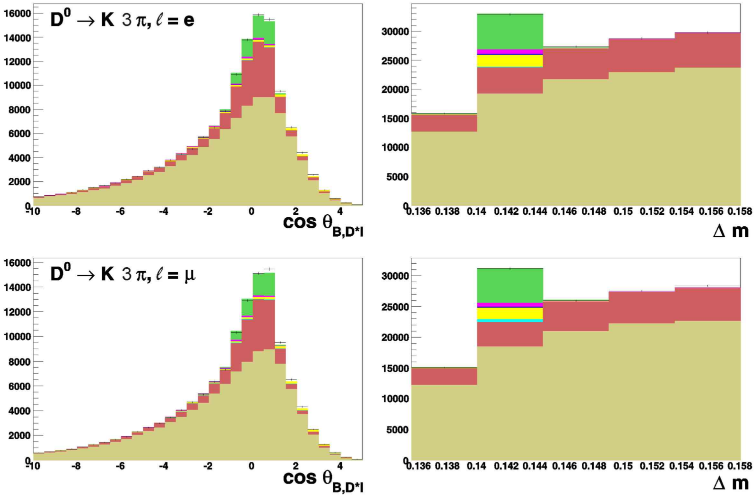
HMCMLL, TFractionFitter

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

Plot of TFractionFitter result - $D^0 \to K\pi$ modes



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



Background and signal purity

Fractions of the components

	$K\pi$, e	$K\pi$, μ	$K3\pi$, e	$K3\pi$, μ
Raw yield	13035	12262	16989	16350
Signal events	8133 ± 205	7447 ± 201	5987 ± 229	5539 ± 222
Signal	$(62.39 \pm 1.57)\%$	$(60.73 \pm 1.64)\%$	$(35.24 \pm 1.35)\%$	$(33.88 \pm 1.36)\%$
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	$(2.91 \pm 0.25)\%$	$(3.12 \pm 0.23)\%$	$(38.53 \pm 0.50)\%$	$(39.45 \pm 0.51)\%$
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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Results for all subsamples

	$D^0 \to K\pi, \ell = e$	$D^0 \to K\pi, \ell = \mu$	$D^0 \to K3\pi, \ell = e$
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
$\mathcal{B}(B^+ \to \bar{D}^{*0}\ell^+\nu_\ell)$	$4.91 \pm 0.05 \pm 0.58$	$4.77 \pm 0.05 \pm 0.57$	$4.83 \pm 0.07 \pm 0.57$
$\mathcal{F}(1)\|V_{cb}\| \times 10^3$	$34.3 \pm 0.6 \pm 2.2$	$35.0 \pm 0.6 \pm 2.3$	$36.5 \pm 1.0 \pm 2.4$
χ^2/ndf.	48.3 / 36	40.6 / 36	39.6 / 36
P_{χ^2}	8.3 %	27.5 %	31.3 %

	$D^0 \to K3\pi, \ell = \mu$		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
$\mathcal{B}(B^+ \to \bar{D}^{*0}\ell^+\nu_\ell)$	$4.83 \pm 0.07 \pm 0.58$		$4.84 \pm 0.04 \pm 0.57$
$\mathcal{F}(1)\|V_{cb}\| \times 10^3$	$34.8 \pm 1.0 \pm 2.3$		$35.0 \pm 0.4 \pm 2.2$
χ^2/ndf.	44.2 / 36		187.8 / 155
P_{χ^2}	16.3 %		3.7 %

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Breakdown of the preliminary systematic error

	ρ^2	$R_1(1)$	$R_2(1)$	$\mathcal{F}(1)\lvert V_{cb}\rvert \times 10^3$	$\mathcal{B}(B^+ \to \bar{D}^{*0}\ell^+\nu_\ell)$
Value	1.376	1.620	0.805	34.98	4.841
Statistical Error	0.074	0.091	0.064	0.37	0.044
π^0_s & 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	
$\mathcal{B}(D^0 \to K\pi)$				0.32	0.089
$\mathcal{B}(D^{*0} \to D^0\pi^0)$				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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Correlations

Correlations between the fit parameters

- Table shows statistical/systematic/total correlation coefficients

	$\mathcal{F}(1)\lvert V_{cb}\rvert$	ρ^2	$R_1(1)$	$R_2(1)$
$\mathcal{F}(1)\lvert V_{cb}\rvert$	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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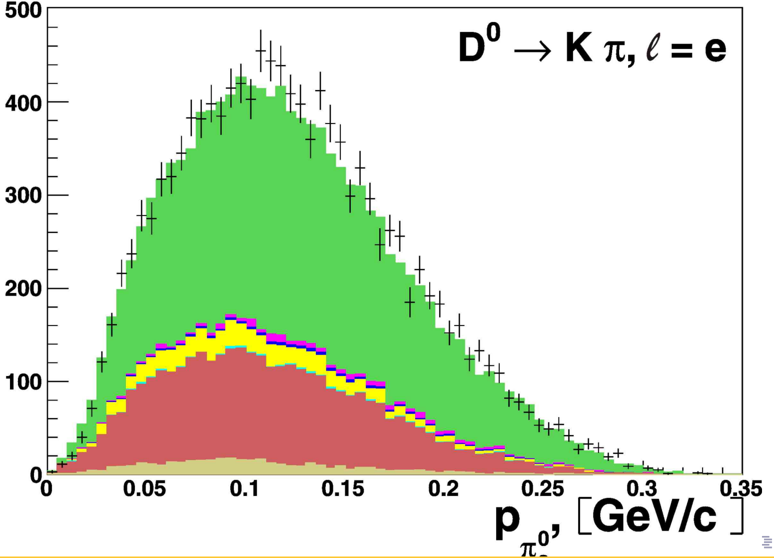
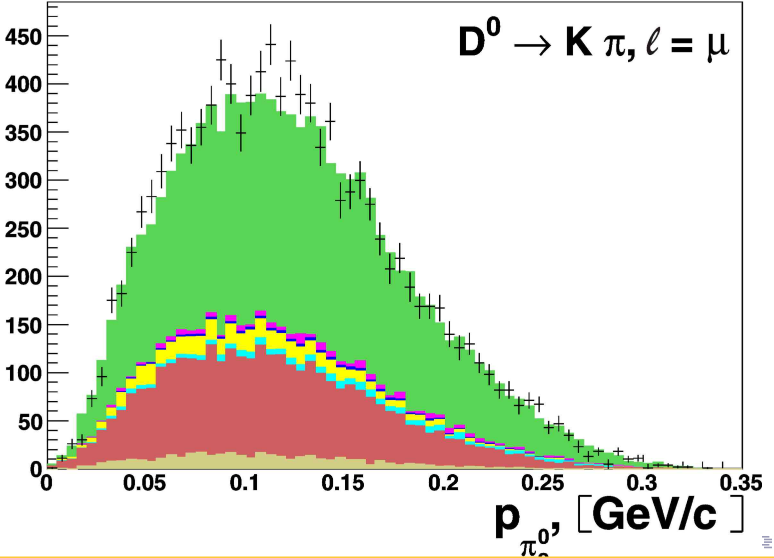
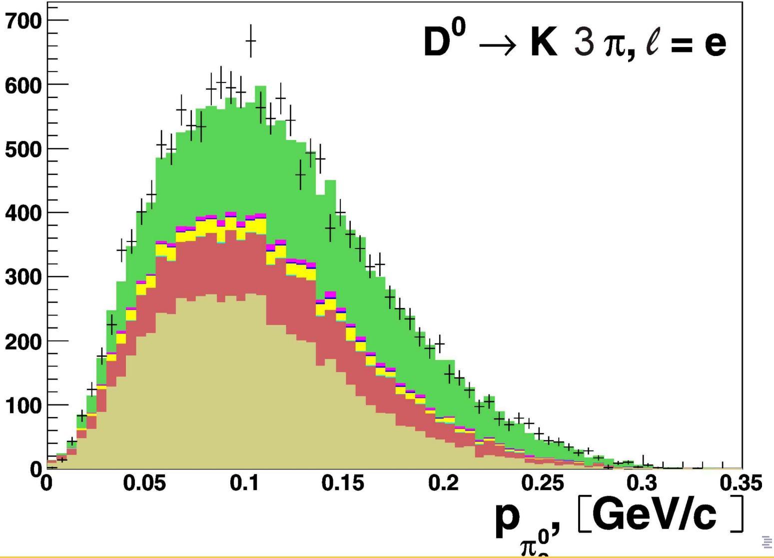
$p_{\pi_s^0}$ distribution - $K\pi$, e channel



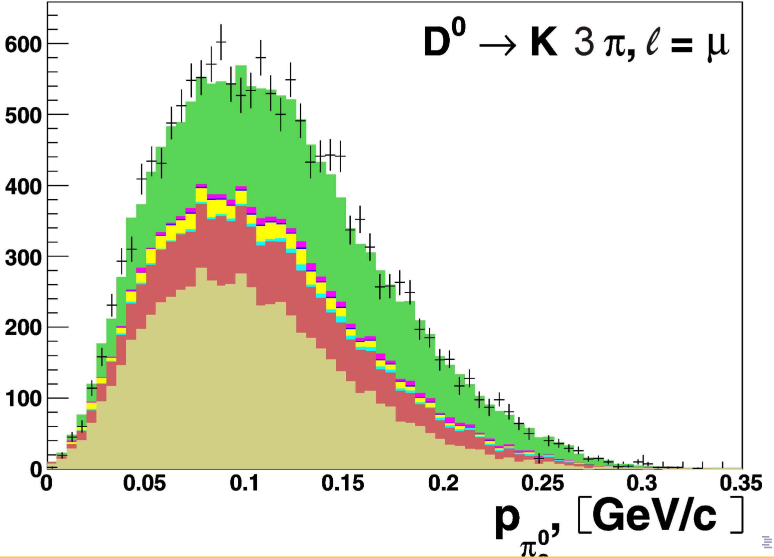
$p_{\pi^0_s}$ distribution - $K\pi, \mu$ channel



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



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



Check of Γ_L

	$D^0 \to K\pi, \ell = e$	$D^0 \to K\pi, \ell = \mu$
$\Gamma^{00}, w \in (1, \frac{13}{12})$	$(1.025 \pm 0.119 \pm 0.120) \times 10^{-4}$	$(1.176 \pm 0.146 \pm 0.137) \times 10^{-4}$
$\Gamma^{00}, w \in (\frac{13}{12}, \frac{7}{6})$	$(1.544 \pm 0.165 \pm 0.176) \times 10^{-4}$	$(1.689 \pm 0.177 \pm 0.192) \times 10^{-4}$
$\Gamma^{00}, w \in (\frac{7}{6}, \frac{15}{12})$	$(2.238 \pm 0.213 \pm 0.237) \times 10^{-4}$	$(2.121 \pm 0.216 \pm 0.238) \times 10^{-4}$
$\Gamma^{00}, w \in (\frac{15}{12}, \frac{8}{6})$	$(2.677 \pm 0.244 \pm 0.268) \times 10^{-4}$	$(2.059 \pm 0.240 \pm 0.228) \times 10^{-4}$
$\Gamma^{00}, w \in (\frac{8}{6}, \frac{17}{12})$	$(2.406 \pm 0.235 \pm 0.256) \times 10^{-4}$	$(2.426 \pm 0.263 \pm 0.263) \times 10^{-4}$
$\Gamma^{00}, w \in (\frac{17}{12}, 1.5)$	$(2.907 \pm 0.250 \pm 0.301) \times 10^{-4}$	$(2.384 \pm 0.273 \pm 0.278) \times 10^{-4}$

	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}
$\Gamma^{00}, w \in (\frac{13}{12}, \frac{7}{6})$	$(1.611 \pm 0.121 \pm 0.179) \times 10^{-4}$	1.812×10^{-4}
$\Gamma^{00}, w \in (\frac{7}{6}, \frac{15}{12})$	$(2.186 \pm 0.151 \pm 0.238) \times 10^{-4}$	2.175×10^{-4}
$\Gamma^{00}, w \in (\frac{15}{12}, \frac{8}{6})$	$(2.406 \pm 0.172 \pm 0.262) \times 10^{-4}$	2.379×10^{-4}
$\Gamma^{00}, w \in (\frac{8}{6}, \frac{17}{12})$	$(2.421 \pm 0.175 \pm 0.258) \times 10^{-4}$	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}

Check of Γ_T

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

	fit to total sample	central value of parametrized fit
$\Gamma^T, w \in (1, \frac{13}{12})$	$(2.117 \pm 0.108 \pm 0.248)\times 10^{-4}$	1.975×10^{-4}
$\Gamma^T, w \in (\frac{13}{12}, \frac{7}{6})$	$(2.865 \pm 0.152 \pm 0.327)\times 10^{-4}$	2.908×10^{-4}
$\Gamma^T, w \in (\frac{7}{6}, \frac{15}{12})$	$(2.732 \pm 0.181 \pm 0.303)\times 10^{-4}$	2.819×10^{-4}
$\Gamma^T, w \in (\frac{15}{12}, \frac{8}{6})$	$(2.454 \pm 0.191 \pm 0.263)\times 10^{-4}$	2.276×10^{-4}
$\Gamma^T, w \in (\frac{8}{6}, \frac{17}{12})$	$(1.468 \pm 0.174 \pm 0.154)\times 10^{-4}$	1.478×10^{-4}
$\Gamma^T, w \in (\frac{17}{12}, 1.5)$	$(0.693 \pm 0.170 \pm 0.070)\times 10^{-4}$	0.547×10^{-4}

Systematics

Source	$\bar{D}^0\tau^+\nu$[%]	$\bar{D}^{*0}\tau^+\nu$[%]	$\bar{D}^-\tau^+\nu$[%]	$\bar{D}^{*-}\tau^+\nu$[%]
M^2_{mix} shape	+9.10/-7.89	+9.86/-10.7	+6.39/-5.78	+5.80/-6.12
E^{ECL}_{extra} shape	+10.6/-7.58	+7.01/-9.73	+9.03/-7.27	+9.84/-4.97
$D^{**}\ell\nu$	+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
$\mathcal{B}(\tau \to \ell\nu\nu)$	$\pm$0.3	$\pm$0.3	$\pm$0.3	$\pm$0.3
Total	+15.7/-12.9	+13.2/-15.4	+13.3/-11.4	+12.0/-8.58

Semileptonic $b \to c$ Decays at Belle

Wolfgang Dungel

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on behalf of the Belle collaboration

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