Lepton flavour violation in D and B decays at Belle

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on behalf of

BELLE

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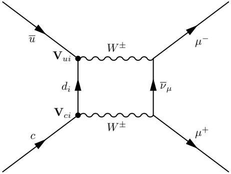
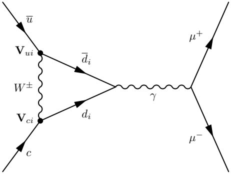
Contents

- Search for lepton-flavour violating $D^0 \to e^\pm \mu^\mp$
- Search for flavour-changing neutral current decays $D^0 \to \mu^+\mu^-, e^+e^-$

- Search for lepton-number violating decay $B^- \to D^+\ell^-\ell^-$

- FCNC decays are highly suppressed in SM (allowed at higher order)
- With long distance contributions $\mathcal{B} \sim 10^{-13}$
- LFV decays are forbidden in SM
- Certain NP scenarios can enhance $\mathcal{B}$ by many orders of magnitude
- Charm FCNC and LFV decays probe couplings of up-quark sector in contrast to B and K





Model	$\mathcal{B}(D^0 \to \mu^+\mu^-)$
Experiment	$\leq 4.3 \times 10^{-7}$ (CDF preliminary)
Standard Model (SD)	$\sim 10^{-18}$
Standard Model (LD)	$\sim$ several $\times 10^{-13}$
$Q = +2/3$ Vector-like Singlet	4.3×10^{-11}
$Q = -1/3$ Vector-like Singlet	1×10^{-11} $(m_S/500\ \text{GeV})^2$
$Q = -1/3$ Fourth Family	1×10^{-11} $(m_S/500\ \text{GeV})^2$
Z' Standard Model (LD)	$2.4 \times 10^{-12}/(M_{Z'}(\text{TeV}))^2$
Family Symmetry	0.7×10^{-18}
RPV-SUSY	4.8×10^{-9} $(300\ \text{GeV}/m_{\tilde{d}_k})^2$

E. Golowich, J. Hewett, S. Pakvasa, A. A. Petrov PRD79 114030 (2009)

- Except Family Symmetry all NP exceed the SM prediction

I. Dorsner, S. Fajfer, J. F. Kamenik, and N. Kosnik, PLB682 67 2009

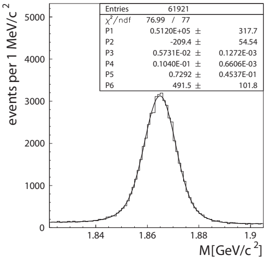
- Leptoquark explanation of $f_{D_s^+}$ discrepancy

$\mathcal{B}(D^0 \to \mu^+\mu^-) > 1.6 \times 10^{-7}$

Search for $D^0 \to \ell^+\ell^-$ - Method

- Search based on 659 fb^{-1} taken at $\Upsilon(4S)$ and 60 MeV below.
- To suppress background:
  - use high momentum $D^{*+} \to D^0\pi^+$ decays from $e^+e^- \to c\bar{c}$
- Measurement relative to well measured $D^0 \to \pi^+\pi^-$

$$\mathcal{B}(D^0 \to \ell^+\ell^-) = \frac{N_{\ell\ell}}{N_{\pi\pi}} \frac{\epsilon_{\pi\pi}}{\epsilon_{\ell\ell}} \mathcal{B}(D^0 \to \pi^+\pi^-)$$

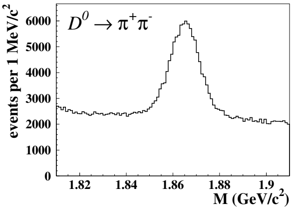


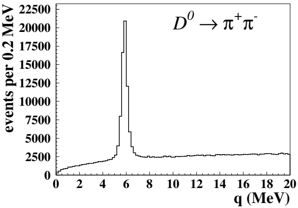
Normalisation channel (data)

Fit of $m(\pi,\pi)$ distribution:
Double Gaussian + FSR tail + linear
$\sim 50 \times 10^3$ $D^0 \to \pi^+\pi^-$ decays

Search for $D^0 \to \ell^+\ell^-$ - Event selection

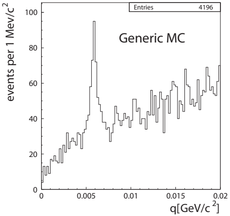
- Standard charged track and PID selection
- D^0 daughters fitted to common vertex (decay vertex)
- IP constrained fit of D^0 and π_{slow} to find D^0 production vertex
- $p_{\text{cms}}^{D^{*+}} > 2.5$ GeV/c to suppress bkg. (also rejects D^0 from B)
- Candidate D^0 mesons selected using two kinematic observables:
  - invariant mass of D^0 daughters: $1.81 < M < 1.91$ GeV/c^2
  - energy released in D^{*+} decay: $q < 20$ MeV



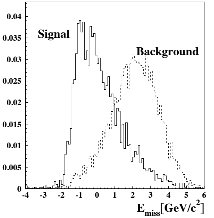


Search for $D^0 \to \ell^+\ell^-$ - Background

- Background in $D^0 \to \ell^+\ell^-$ according to generic MC simulation
  - 80% from semileptonic B decays
  - 10% from D^0 decays
  - 10% other sources



- Can be grouped into:
  1. smooth combinatorial background
  2. peaking background from mis-ID of $D^0 \to \pi^+\pi^-$

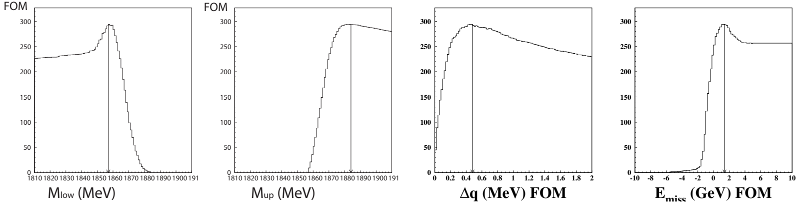


- To further suppress background:
  - requirements on signal region size in M and q
  - maximal allowed missing energy in the event E_{miss} to suppress bkg. from semileptonic B decays (undetected neutrinos!)

Search for $D^0 \to \ell^+\ell^-$ - Optimisation

- For optimisation we select:
  - signal region size (M_{low}, M_{up}, Δq)
  - maximal allowed E_{miss}
- Optimised to obtain the best upper limits
- Figure-of-merit: $\mathcal{F} = \epsilon_{\ell\ell}/N_{UL}$
  - $\epsilon_{\ell\ell}$ ... efficiency obtained from tuned signal MC
  - N_{UL} ... Poisson average of Feldman-Cousins 90% C.L. upper limits obtained with expected bkg. and no signal, using generic MC
- Each leptonic decay channel optimised separately

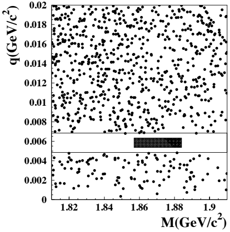
$D^0 \to \mu^+\mu^-$



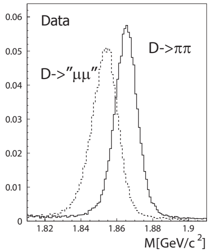
Search for $D^0 \to \ell^+\ell^-$ - Background estimation

To estimate background inside the signal region we rely (almost) exclusively on experimental data

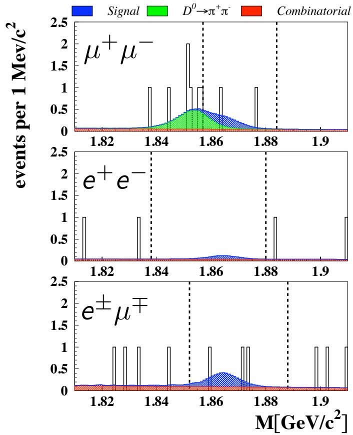
- Combinatorial background (smooth)
  - estimated from 2D sideband in M and q
  - shape: $f(M,q) \propto (1 - aM)\sqrt{q}$
  - parameter a determined from fit to MC sample



- Peaking background (mis-ID of $D^0 \to \pi^+\pi^-$)
  - estimated from reconstructed $D^0 \to \pi^+\pi^-$ by replacing pion mass with lepton mass and by weighting each event with mis-ID probability
  - mis-ID probabilities measured using $D^{*+} \to D^0\pi^+, D^0 \to K^-\pi^+$
  - resulting distribution normalised absolutely



Search for $D^0 \to \ell^+\ell^-$ - Results

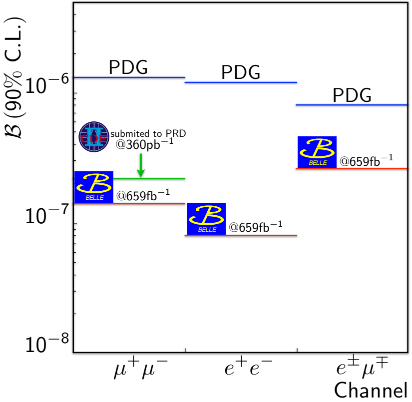


Channel	events	estimated bkg.
$\mu^+\mu^-$	2	3.1±0.1
e^+e^-	0	1.7±0.2
$e^\pm\mu^\mp$	3	2.6±0.2

90% C.L. upper limits with pole.f

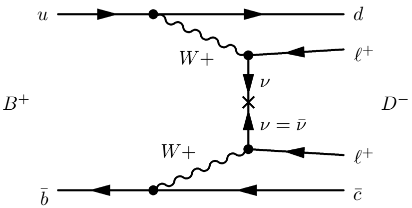
$$\mathcal{B}\left(D^0 \to \mu^+\mu^-\right) < 1.4 \times 10^{-7}$$
$$\mathcal{B}\left(D^0 \to e^+e^-\right) < 7.9 \times 10^{-8}$$
$$\mathcal{B}\left(D^0 \to e^\pm\mu^\mp\right) < 2.6 \times 10^{-7}$$

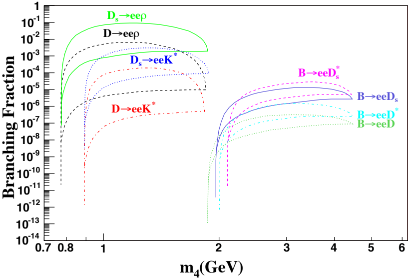
Lowest upper limit up to now



Search for $B^- \to D^+\ell^-\ell^-$ - Motivation

- Lepton-number violating decay forbidden in SM
- Possible in new physics scenarios: multi-Higgs-boson, leptoquarks, Majorana neutrinos, etc.
- In Majorana case up to $\mathcal{B} \sim 10^{-7}$ (M Zhang, G Wang, arXiv:1003.5570v2 [hep-ex])

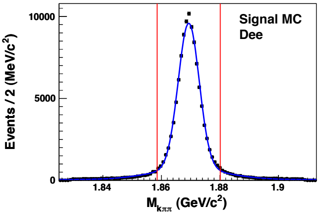


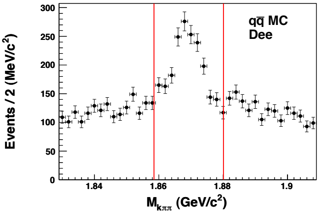


- CLEO studied $h^+\ell^-\ell^-$, $h = \pi, K^{(*)}, \rho$ in 2002 @9.2 fb^{-1}
- $B^- \to D^+\ell^-\ell^-$ is a CKM-favoured process in comparison to $h^+\ell^-\ell^-$
- $B^- \to D^+\ell^+\ell^-$ has never been searched for

Search for $B^- \to D^+\ell^-\ell^-$ - Event selection

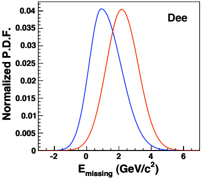
- Search based on 710 fb^{-1}
- Standard charged track and PID selection
- Use $K^-\pi^+\pi^+$ to construct D^+
- Require $\Delta M_{K^-\pi^+\pi^+} < 0.044$ GeV/c^2
- Lepton requirement:
  - $p_e > 0.395$GeV/c, $p_\mu > 0.69$ GeV/c
  - $E_{\ell\ell} > 1.3$ GeV/c^2
- Combine D^+ candidate and two highest energy same charge leptons
- Require window $(M_{bc}, \Delta E)$:
  - $M_{bc} = \sqrt{E_{beam}^2 - p_B^2}$
  - $\Delta E = E_B - E_{beam}$

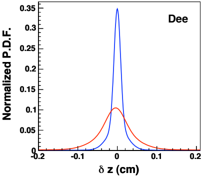


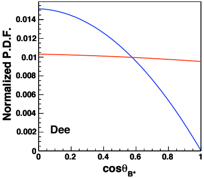


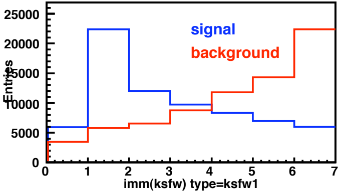
To suppress backgrounds, we use background and signal PDFs of the following variables:

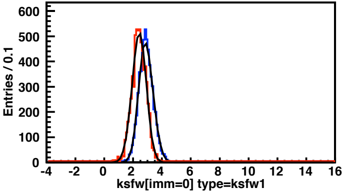
- Missing energy $E_{\text{miss}} = 2E_{\text{beam}} - \sum E$
- Distance between helix parameter z of two leptons (δz)
- B flight direction $\cos\theta_{B^*} = \frac{\vec{p}_z^B}{|\vec{p}^B|}$
- Fisher discriminant of Fox-Wolfram moments ($D_{\mathcal{KSFV}}$) in bins of missing mass square:



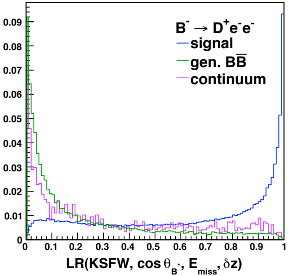


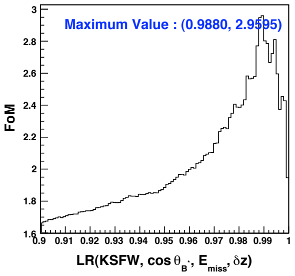






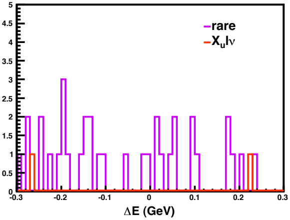
- From PDFs $\to$ likelihood ratio $\mathcal{R}$
- $b \to c$ decays and $e^+e^- \to q\overline{q}$, ($q = u, d, s, c$) contribute to background
- Using FoM $= N_{\text{sig}}/\sqrt{N_{\text{bkg}}}$ determine $\mathcal{R}$ cut
- Use counting method to evaluate signal yield
- Signal region defined in $(M_{\text{bc}}, \Delta E)$:
  - $5.27 < M_{bc} < 5.29$ GeV/c^2
  - $-0.055(-0.035) < \Delta E < 0.035$ GeV

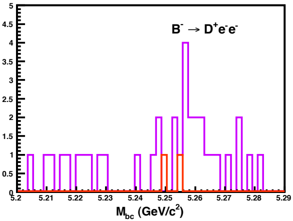




Search for $B^- \to D^+\ell^-\ell^-$ - Background estimation

20 × data statistics





- Background from $b \to c$ and $e^+e^- \to q\overline{q}$
- Background form rare decays:
  - hadronic $b \to s,\ u,\ d$
  - semileptonic $b \to u\ell\nu$
  - both contributions negligible
- Topologically similar background:
  - $B^+ \to J/\psi K^+\pi^+\pi^+$ lepton ID inefficiency and lepton misID
  - $B^+ \to D^-h^+h'^+$ lepton misID
- No significant background peaking
- Background in signal region estimated from $(M_{\rm bc}, \Delta E)$ sideband:
  - $5.20 < M_{bc} < 5.29$ GeV/c^2
  - $-0.3 < \Delta E < 0.3$ GeV

Search for $B^- \to D^+\ell^-\ell^-$ - Calculating $\mathcal{B}$

- Branching fraction determined

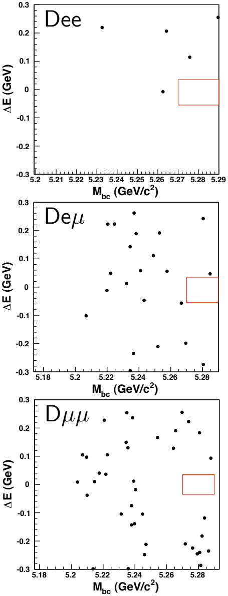
$$\mathcal{B} < \frac{N_{\rm UL}}{\text{eff.}\times\mathcal{B}(D^+\to K^-\pi^+\pi^+)\times N_{B\overline{B}}}$$

- Upper limit $N_{\rm UL}$ calculated using program pole by Conrad (PRD 67 012002 2003)
- extension of Feldman-Cousins method by inclusion of systematic errors

Systematics

Source Unit	Dee	$De\mu$ %	$D\mu\mu$
MC signal efficiency	1.1	1.1	0.9
Tracking efficiency	5.2	5.2	5.2
$K^\pm\pi^\pm$ ID	1.3	1.4	1.4
Lepton ID	3.0	3.4	3.5
M_{bc} and ΔE shape	1	5	1
D^+ mass shape	0.2	0.2	0.2
$N(B\overline{B})$	1.4	1.4	1.4
$\mathcal{B}\left(D^+\to K^-\pi^+\pi^+\right)$	2.7	2.7	2.7
LR cut	5	5	5
Sum in quadrature	8.6	10.1	8.8

Search for $B^- \to D^+\ell^-\ell^-$ - Preliminary results



Channel	events	estimated background
$D^+e^-e^-$	0	0.2 ± 0.1
$D^+e^-\mu^-$	0	0.8 ± 0.3
$D^+\mu^-\mu^-$	0	1.4 ± 0.4

No signal observed

Calculated 90% C.L. upper limits (preliminary)

$$\mathcal{B}\left(B^- \to D^+e^-e^-\right) < 2.7 \times 10^{-6}$$

$$\mathcal{B}\left(B^- \to D^+e^-\mu^-\right) < 1.9 \times 10^{-6}$$

$$\mathcal{B}\left(B^- \to D^+\mu^-\mu^-\right) < 1.1 \times 10^{-6}$$

First measurement

Summary

Search for leptonic decays of D^0 (PRD81 091102 2010)

- Found no evidence of these decays.
- Set new upper limits on branching fractions for these decays $\mathcal{O}(10^{-7})$
- Our results can further constrain the size of certain NP parameters
- The upper limit for $D^0 \to \mu^+\mu^-$ (1.4×10^{-7}) strongly disfavours a leptoquark contribution as the explanation for the f_{D_s} discrepancy (PLB682 67 2009)

Search for LNV decay $B^- \to D^+\ell^-\ell^-$ (Preliminary result)

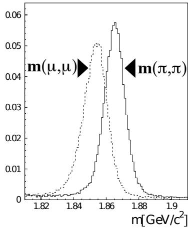
- First measurement
- No signal observed
- Obtained upper limit $\mathcal{O}(10^{-6})$

Backup

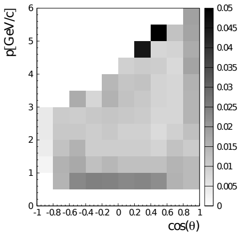
Search for $D^0 \to \ell^+\ell^-$ - Background determination

- Misidentification of $D^0 \to \pi^+\pi^-$ (peaking)
  - Shape $\to$ replacing the pion mass with the lepton mass in $D^0 \to \pi^+\pi^-$ decays
  - Weighting each event with misidentification probability measured on data
  - Misidentification probabilities measured in data with $D^0 \to K^-\pi^+$, in bins of particle momentum p and cosine of polar angle θ
  - Resulting shape absolutely normalised

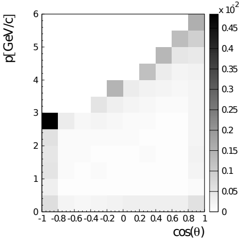
$D^0 \to \pi^+\pi^-$



$\pi \to \mu$ misid probability

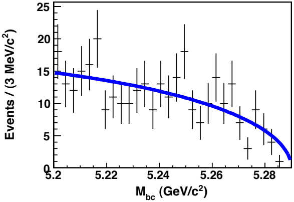


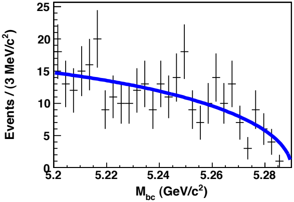
$\pi \to e$ misid probability



$20 \times$ data statistics

$B^+ \to J/\psi K^+\pi^+\pi^+$

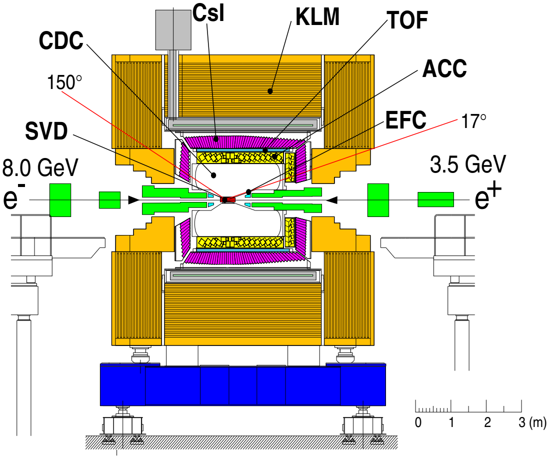




The analysis has considered:

- Flat background form $b \to c$ and $e^+e^- \to q\bar{q}$
- Non-peaking background form rare decays:
  - hadronic $b \to s,\ u,\ d$
  - semileptonic $b \to u\ell\nu$
  - both contributions negligible
- Peking background:
  - $B^+ \to J/\psi K^+\pi^+\pi^+$ lepton ID inefficiency and lepton misID
  - $B^+ \to D^- h^+ h'^+$ lepton misID
  - both contributions non-peaking

Spectrometer BELLE



- B=1.5 T
- Tracking system:
  - Silicon Vertex Detector (SVD)
  - Central Drift Chamber (CDC)
- Particle identification :
  - CDC(dE/dx)
  - Aerogel Čerenkov Counter (ACC),
  - Time Of Flight (TOF)
  - Electromagnetic calorimeter (ECL)
  - Detector K_L and μ (KLM)

Experiment Belle

- KEK, Tsukuba, Japan
- KEKB: asymmetric e^+e^- collider at the energy of the resonance $\Upsilon(4S) = 10.56$ GeV$/c^2$ $(e^+(3.5GeV) \rightarrow\leftarrow e^-(7GeV))$
- Luminosity: $\mathrm{d}N/\mathrm{d}t = \mathcal{L}\sigma$, $\mathcal{L} = 2.1 \cdot 10^{34}/cm^2/s$
- Integrated luminosity: $\int \mathcal{L}dt = 1000 fb^{-1}$