Search for $D^0 \to \ell^+\ell^-$ decays and for CP violation in $D^+_{(s)} \to K^0_s\pi^+$ and $D^+_{(s)} \to K^0_s K^+$ at Belle

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on behalf of

BELLE

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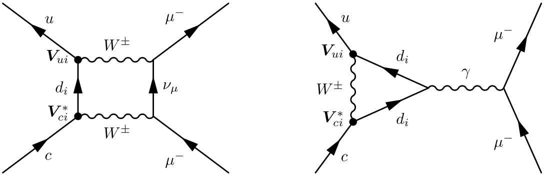
Contents

- Search for leptonic decays $D^0 \to \mu^+\mu^-,\ e^+e^-$ and $e^\pm\mu^\mp$
- Measurement of $\mathcal{B}\left(D^+_{(s)} \to K^0_s h^+\right)$ ratios
- Measurement of $A_{CP}^{D^+_{(s)} \to K^0_s h^+}$

- FCNC does not appear at tree level (but allowed in higher order)



- Certain new physics scenarios allows this process: new particle replacing W boson

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 $f_{D_s^+}$ anomaly

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

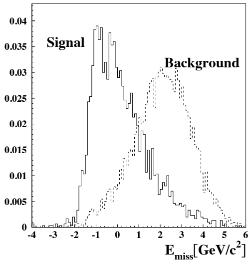
Data sample

- 659 fb^{-1} of data near or on the $\Upsilon(4S)$ resonance
- Normalisation channel $D^0 \to \pi^+\pi^-$

Event selection based upon

- $D^{*+} \to D^0\pi^+_{\text{slow}}$, $D^0 \to \ell^+\ell^-$
- Standard particle identification criteria
- Vertex fix for D^0 and IP constraint fit for D^{*+}
- $p^{D^{*+}}_{\text{cms}} > 2.5$ GeV$/c$ $\to$ reject D^0 from B mesons
- $M(\ell,\ell)$
- $q \equiv (M_{D^{*+}} - M - m_\pi)c^2$
- Missing energy of the event

Missing energy



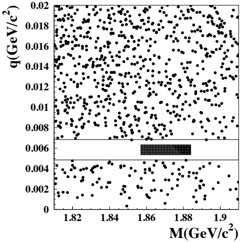
Optimisation

- FOM $\mathcal{F}_m = \epsilon_{\ell\ell}/N_{\text{UL}}$
- $\epsilon_{\ell\ell}$ is efficiency, N_{UL} is the Poisson average of Feldman-Cousins 90% confidence level upper limits if no signal determined from MC

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

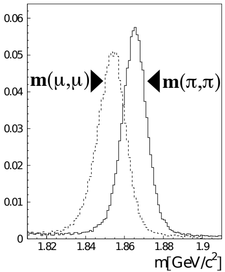
- Combinatorial background (flat)
  - estimation from 2D sideband M vs. q

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

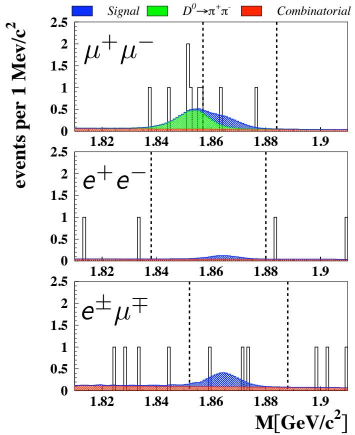


- Misidentification of $D^0 \to \pi^+\pi^-$ (peaking)
  - Shape $\to$ replacing the pion mass with the lepton mass in $D^0 \to \pi^+\pi^-$ decays
  - Weighting each event with misidentification probability measured on data
  - Resulting shape absolutely normalised

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



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



Channel	N_{sig}	N_{bkg}
$\mu^+\mu^-$	2	3.1±0.1
e^+e^-	0	1.7±0.2
$e^\pm\mu^\mp$	3	2.6±0.2

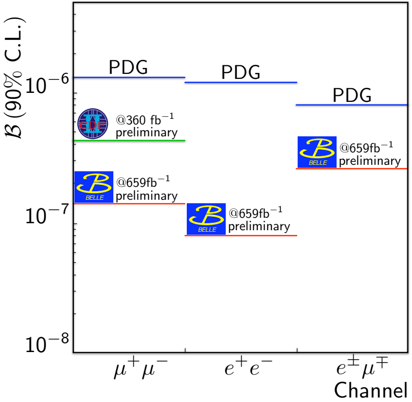
90% C.L. upper limits (preliminary)

$$\mathcal{B}\left(D^0 \to \mu^+\mu^-\right) < 1.4 \times 10^{-7}$$

$$\mathcal{B}\left(D^0 \to e^+e^-\right) < 7.9 \times 10^{-8}$$

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

Lowest upper limit up to now



Study of $D^+_{(s)} \to K_s h^+$

- Measuring the ratio $R(D^+_{(s)})$ =SCS/CF decays

Mode	PDG 2008	CLEO 2009[†]
$\mathcal{B}(D^+ \to K_s K^+)/\mathcal{B}(D^+ \to K_s \pi^+)$	$0.189 \pm 0.016 \pm 0.007$	0.199 ± 0.007
$\mathcal{B}(D^+_s \to K_s \pi^+)/\mathcal{B}(D^+_s \to K_s K^+)$	$0.082 \pm 0.009 \pm 0.002$	0.085 ± 0.007

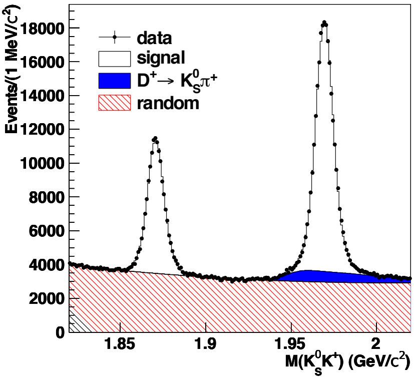
[†] Deduced from CLEO arXiv:0906.3198v1~[hep-ex]

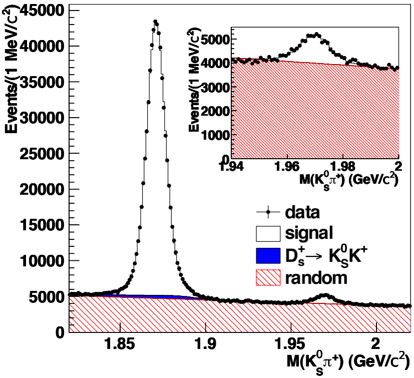
- It may give us better understanding on flavour SU(3) symmetry with other measurements
- Measuring $A_{CP}^{D^+_{(s)} \to K^0_s h^+}$, in SM for SCS at level $\mathcal{O}(0.1\%)$

Channel	$A_{CP}[\%]$ PDG 2008	$A_{CP}[\%]$ CLEO 2009
$D^+ \to K_s \pi^+$	-0.9 ± 0.9	$-1.3 \pm 0.7 \pm 0.3$
$D^+ \to K_s K^+$	7 ± 6	$-0.2 \pm 1.5 \pm 0.9$
$D^+_s \to K_s \pi^+$	27 ± 11	$-16.3 \pm 7.3 \pm 0.3$
$D^+_s \to K_s K^+$	4.9 ± 2.3	$-4.7 \pm 1.8 \pm 0.9$

- The goal is to improve $R(D^+_s)$ ratio measurements and A_{CP} accuracy

Study of $D^+_{(s)} \to K_s h^+$ - ratio measurement





Decay modes	Yields	ϵ (%)
$D^+ \to K^0_s K^+$	100855± 561	12.59±0.01
$D^+_s \to K^0_s K^+$	204093± 768	13.53±0.01
$D^+ \to K^0_s \pi^+$	566285±1162	14.19±0.01
$D^+_s \to K^0_s \pi^+$	17583± 481	15.35±0.01

$R(D^+) = 0.1899 \pm 0.0011 \pm 0.0022$

$R(D^+_s) = 0.0803 \pm 0.0024 \pm 0.0019$

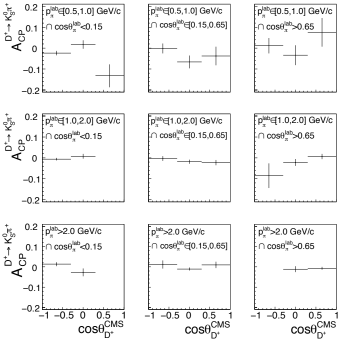
Most precise mesurement up to now

Belle PRD80 111101 2009

Study of $D_{(s)}^{+} \to K_s h^{+}$ - A_{CP}

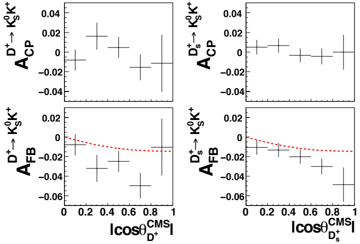
- We measure $A_{\mathrm{rec}}^{X^+\to K_S^0 h^+} = \frac{N_{\mathrm{rec}}^{X^+\to K_S^0 h^+} - N_{\mathrm{rec}}^{X^-\to K_S^0 h^-}}{N_{\mathrm{rec}}^{X^+\to K_S^0 h^+} + N_{\mathrm{rec}}^{X^-\to K_S^0 h^-}}$
- Since K_s reconstructed from $\pi^+\pi^-$ no difference in reconstruction asymmetry, thus $A_{\mathrm{rec}}^{X^+\to K_S^0 h^+} \approx A_{\mathrm{CP}}^{X^+\to K_S^0 h^+} + A_{\mathrm{FB}}^{X^+} + A_{\epsilon}^{h^+}$; $(A \ll 1)$
- subtraction performed in bins of $p_{\mathrm{lab}}^{h^+}$, $\cos\theta_h^{\mathrm{lab}}$, $\cos\theta_{D_{(s)}^+}^{\mathrm{CMS}}$

- The $K_s\pi^+$ case:
  - mesuring $A_{\mathrm{FB}}^{D_s^+} + A_{\epsilon}^{\pi^+}$ from CF decays $D_s^+ \to \phi\pi^+$
  - A_{FB} due to $\gamma^* - Z^0$ interference in $e^+e^- \to c\bar{c}$
  - by subtracting $A_{\mathrm{FB}}^{D_s^+} + A_{\epsilon}^{\pi^+}$ obtaining A_{CP}



Study of $D^+_{(s)} \to K_s h^+$ - A_{CP}

- The $K_s K^+$ case:
- mesuring $A_{FB}^{D_s^+}$ and $A_\epsilon^{K^+}$ from CF decays $D_s^+ \to \phi\pi^+$ and $D^0 \to K^-\pi^+$
- by subtraction obtaining $A_\epsilon^{K^+}$
- measuring $A^{K_S^0 K^+_{\text{corr}}} = A_{\text{rec}}^{K_S^0 K^+} - A_\epsilon^{K^+}$ in bins of $\cos\theta^{\text{CMS}}_{D^+_{(s)}}$ to extract A_{FB} and A_{CP}



- $$A_{CP}^{K_S^0 K^+} = [A_{\text{rec}}^{K_S^0 K^+_{\text{corr}}}(\cos\theta^{\text{CMS}}_{D^+_{(s)}}) + A_{\text{rec}}^{K_S^0 K^+_{\text{corr}}}(-\cos\theta^{\text{CMS}}_{D^+_{(s)}})]/2$$
$$A_{FB}^{K_S^0 K^+} = [A_{\text{rec}}^{K_S^0 K^+_{\text{corr}}}(\cos\theta^{\text{CMS}}_{D^+_{(s)}}) - A_{\text{rec}}^{K_S^0 K^+_{\text{corr}}}(-\cos\theta^{\text{CMS}}_{D^+_{(s)}})]/2$$

Channel	A_{CP} (%)
$D^+ \to K_S^0\pi^+$	$-0.71\pm0.19\pm0.20^\dagger$
$D_s^+ \to K_S^0\pi^+$	$+5.45\pm2.50\pm0.33$
$D^+ \to K_S^0 K^+$	$-0.16\pm0.58\pm0.25$
$D_s^+ \to K_S^0 K^+$	$+0.12\pm0.36\pm0.22$

† -0.332% expected from K^0 mixing

No evidence for CP violation

Most stringent constraint up to now

Submitted to PRL
Belle arXiv:1001.3202v1∼[hep-ex]

Summary

Search for leptonic decays of D^0

- No signal observed
- New best upper limits achieved (preliminary)
- Explanation of $f_{D_s^+}$ anomaly with leptoquarks ruled out (PLB682 67 2009)

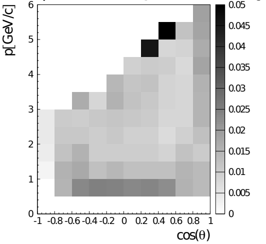
Study of $D_{(s)}^+ \to K_s h^+$

- Measurement of SCS to CF decay rate ratios (PRD80 111101 2009)
  - Most precise ratio measurements up to now
- Search for CP violation (arXiv:1001.3202v1∼[hep-ex])
  - No evidence found
  - Most stringent constraint on CP violation in these modes

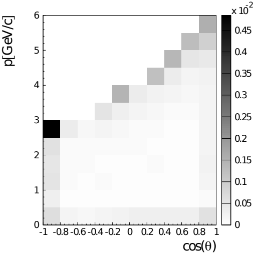
Backup

- Combinatorial background (flat)
  - estimation from 2D sideband M vs. q
  - parametrising with $a(1 - bM)\sqrt{q}$
  - a and b fixed on generic MC
- 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

$\pi \to \mu$ misid probability



$\pi \to e$ misid probability



$D_{(s)}^{+} \to K_s h^{+}$

Selection criteria

- Standard particle identification criteria
- Vertex for $D_{(s)}^{+}$
- p_{CMS} and $\frac{p_{CMS}}{\sqrt{\left(\frac{E_{CMS}}{2}\right)^2 - M^2}}$
- $\Delta M(K_s) < 18\ \mathrm{MeV}/c^2$

Optimisation

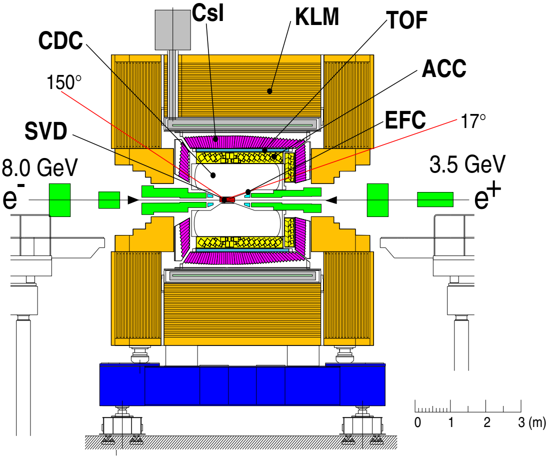
- after standard selection criteria
- analyzing off-resonance data to optimizes the signal significance.
- use only on-resonance sample for measurements $\to$ blind analysis
- using FOM $\mathcal{F} = \frac{N_{sig}}{\sigma_{sig}}$ to optimise

$$asymp \equiv \frac{|p_{K_s} - p_h|}{|p_{K_s} + p_h|}$$

$D^+_{(s)} \to K_s h^+$ - $K^0\overline{K}^0$ systematics

- differences in interactions of K^0 and $\overline{K}^0$ mesons in material
- mesons interact with material near IP
- produces an asymmetry originating from difference in strong interactions of K^0 and $\overline{K}^0$
- differences between K^0 and $\overline{K}^0$ interactions $\approx$ difference K^+ and K^-
- calculate the probability of K^0 and $\bar{K}^0$-nucleons interactions using the known K^+ and K^- cross sections
- take into account time evolution of neutral kaons.
- uncertainty in CP asymmetry due to $K^0/\overline{K}^0$-material effects $\approx 0.06\%$

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