

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

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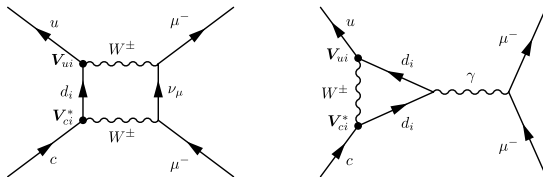
on behalf of



17<sup>th</sup> February, Lake Louise Winter Institute 2010

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

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

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, arXiv:0906.5585v2~[hep-ph]

- Leptoquarks

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

# Search for $D^0 \rightarrow \ell^+ \ell^-$ - Selection

## Data sample

- 659 fb<sup>-1</sup> of data near or on the  $\Upsilon(4S)$  resonance
- Normalisation channel  $D^0 \rightarrow \pi^+ \pi^-$

## Event selection based upon

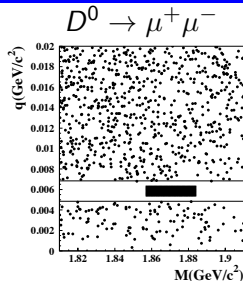
- $D^{*+} \rightarrow D^0 \pi_{\text{slow}}^+$ ,  $D^0 \rightarrow \ell^+ \ell^-$
- Standard particle identification criteria
- Vertex fix for  $D^0$  and IP constraint fit for  $D^{*+}$  mesons
- $p_{\text{cms}}^{D^{*+}} > 2.5 \text{ GeV}/c \rightarrow$  reject  $D^0$  from  $B$  mesons to reduce background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

## Optimisation

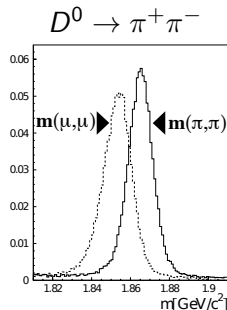
- FOM  $\mathcal{F}_m = \epsilon_{\ell\ell} / N_{\text{UL}}$
- $\epsilon_{\ell\ell}$  is efficiency,  $N_{\text{UL}}$  is the Poisson average of Feldman-Cousins 90% confidence level upper limits if no signal determined from MC

# Search for $D^0 \rightarrow \ell^+ \ell^-$ - Background determination $\mathcal{B}$

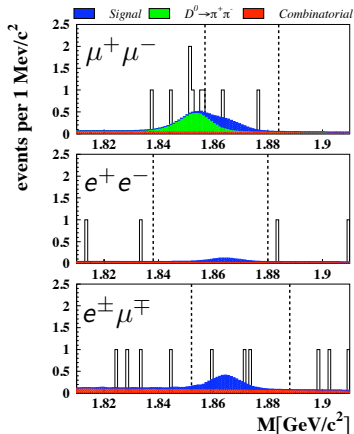
- Combinatorial background (flat)
  - estimation from 2D sideband  $M$  vs.  $q$



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



# Search for $D^0 \rightarrow \ell^+ \ell^-$ - Results



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

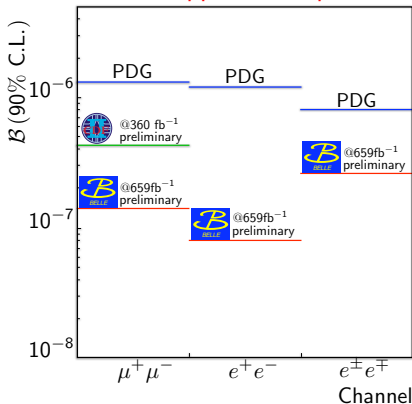
90% C.L. upper limits (preliminary)

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

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

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

Lowest upper limit up to now



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

- Measuring the ratio  $R(D_{(s)}^+) = \text{SCS}/\text{CF}$  decays

Mode	PDG 2008	CLEO 2009 <sup>†</sup>
$\mathcal{B}(D^+ \rightarrow K_s K^+)/\mathcal{B}(D^+ \rightarrow K_s \pi^+)$	$0.189 \pm 0.016 \pm 0.007$	$0.199 \pm 0.007$
$\mathcal{B}(D_s^+ \rightarrow K_s \pi^+)/\mathcal{B}(D_s^+ \rightarrow K_s K^+)$	$0.082 \pm 0.009 \pm 0.002$	$0.085 \pm 0.007$

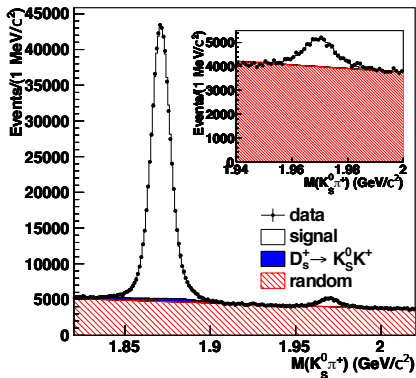
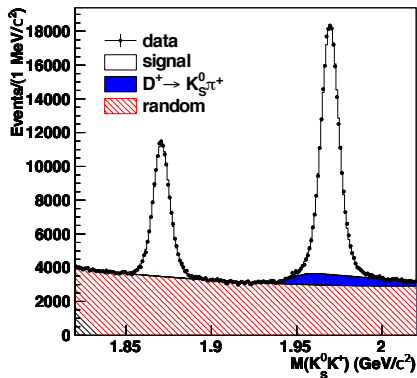
<sup>†</sup> Decuded from CLEO arXiv:0906.3198v1~[hep-ex]

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

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

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

# Study of $D_{(s)}^+ \rightarrow K_s h^+$ - ratio measurement



Decay modes	Yields	$\epsilon$ (%)
$D^+ \rightarrow K_s^0 K^+$	$100855 \pm 561$	$12.59 \pm 0.01$
$D_s^+ \rightarrow K_s^0 K^+$	$204093 \pm 768$	$13.53 \pm 0.01$
$D^+ \rightarrow K_s^0 \pi^+$	$566285 \pm 1162$	$14.19 \pm 0.01$
$D_s^+ \rightarrow K_s^0 \pi^+$	$17583 \pm 481$	$15.35 \pm 0.01$

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

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

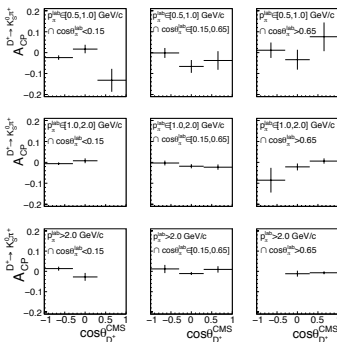
Most precise measurement up to now

Belle PRD80 111101 2009



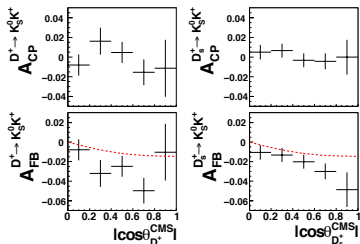
# Study of $D_{(s)}^+ \rightarrow K_S^0 h^+ - A_{CP}$

- Instead of  $A_{CP}^{X^+ \rightarrow K_S^0 h^+}$  we measure  $A_{rec}^{X^+ \rightarrow K_S^0 h^+} = \frac{N_{rec}^{X^+ \rightarrow K_S^0 h^+} - N_{rec}^{X^- \rightarrow K_S^0 h^-}}{N_{rec}^{X^+ \rightarrow K_S^0 h^+} + N_{rec}^{X^- \rightarrow K_S^0 h^-}}$
- Since  $K_S$  reconstructed from  $\pi^+ \pi^-$  no difference in reconstruction asymmetry, thus  $A_{rec}^{X^+ \rightarrow K_S^0 h^+} \approx A_{CP}^{X^+ \rightarrow K_S^0 h^+} + A_{FB}^{X^+} + A_{\epsilon}^{h^+}$ ; ( $A \ll 1$ )
- subtraction performed in bins of  $p_{lab}^{h^+}$ ,  $\cos \theta_h^{lab}$ ,  $\cos \theta_{D_{(s)}^+}^{CMS}$
- The  $K_S \pi^+$  case:
  - measuring  $A_{FB}^{D_s^+} + A_{\epsilon}^{\pi^+}$  from CF decays  $D_s^+ \rightarrow \phi \pi^+$
  - by subtracting  $A_{FB}^{D_s^+} + A_{\epsilon}^{\pi^+}$  obtaining  $A_{CP}$



# Study of $D_{(s)}^+ \rightarrow K_S h^+ - A_{CP}$

- The  $K_S K^+$  case:
- measuring  $A_{FB}^{D_s^+}$  and  $A_{\epsilon}^{\pi^+}$  from CF decays  
 $D_s^+ \rightarrow \phi \pi^+$  and  $D^0 \rightarrow K^- \pi^+$
- by subtraction obtaining  $A_{\epsilon}^{K^+}$
- measuring  $A_{CP}^{K_S^0 K^+} = A_{rec}^{K_S^0 K^+} - A_{\epsilon}^{K^+}$  in bins of  $\cos \theta_{D_{(s)}^+}^{CMS}$  to extract  $A_{FB}$  and  $A_{CP}$
- $A_{CP}^{K_S^0 K^+} = [A_{rec}^{K_S^0 K^+}(\cos \theta_{D_{(s)}^+}^{CMS}) + A_{rec}^{K_S^0 K^+}(-\cos \theta_{D_{(s)}^+}^{CMS})]/2$
- $A_{FB}^{K_S^0 K^+} = [A_{rec}^{K_S^0 K^+}(\cos \theta_{D_{(s)}^+}^{CMS}) - A_{rec}^{K_S^0 K^+}(-\cos \theta_{D_{(s)}^+}^{CMS})]/2$



Channel	$A_{CP}$ (%)
$D^+ \rightarrow K_S^0 \pi^+$	$-0.71 \pm 0.19 \pm 0.20^\dagger$
$D_s^+ \rightarrow K_S^0 \pi^+$	$+5.45 \pm 2.50 \pm 0.33$
$D^+ \rightarrow K_S^0 K^+$	$-0.16 \pm 0.58 \pm 0.25$
$D_s^+ \rightarrow K_S^0 K^+$	$+0.12 \pm 0.36 \pm 0.22$

$^\dagger$  -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]

Search for leptonic decays of  $D^0$

- No signal observed
- New best upper limits achieved (preliminary)
- Leptoquark scenario ruled out

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

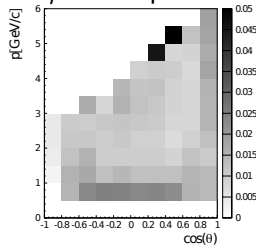
- Measurement of SCS to CF decay rate ratios
  - Most precise ratio measurements up to now
- Search for CP violation - no evidence
  - No evidence found
  - Most stringent constraint on CP violation in these modes

# Backup

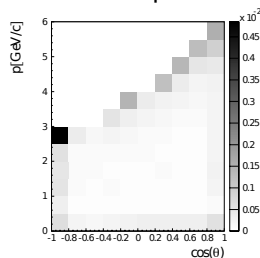
# Search for $D^0 \rightarrow \ell^+ \ell^-$ - Background determination $\mathcal{B}$

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

$\pi \rightarrow \mu$  misid probability



$\pi \rightarrow e$  misid probability



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



## Selection criteria

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

## Optimisation

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

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

- differences in interactions of  $K^0$  and  $\bar{K}^0$  mesons in material
- mesons interact with material near IP
- produces an asymmetry originating from difference in strong interactions of  $K^0$  and  $\bar{K}^0$
- differences between  $K^0$  and  $\bar{K}^0$  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  $K^0/\bar{K}^0$ -material effects  $\approx 0.06\%$