Charm and Tau Decays at Belle and BaBar

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On behalf of the
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XLIIIrd Rencontres de Moriond
Electroweak Interactions and Unified Theories
1 - 8 March, 2008

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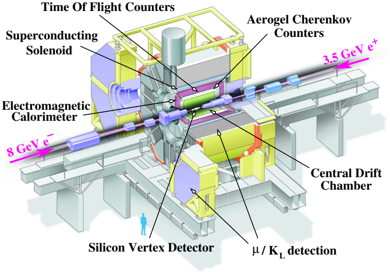
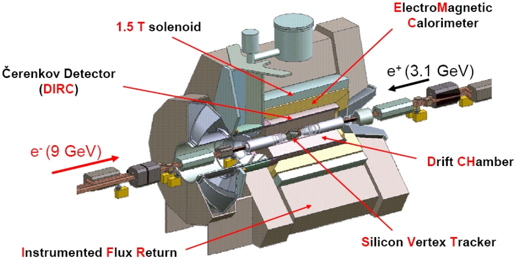
Experimental environment

Belle



BaBar



- large-solid-angle magnetic spectrometers, providing excellent tracking, vertexing and particle ID
- located at asymmetric energy $e^- e^+$ ($\sqrt{s} = \Upsilon(4S)$) colliders **KEKB**/**PEP-II**
- B–Factories are also Charm– and Tau–Factories

$e^+e^- \rightarrow$	$b\bar{b}$	$c\bar{c}$	$\tau^+\tau^-$
σ (nb)	1.05	1.30	0.94

	$N(B\bar{B})$	$N(X_c\bar{Y}_c)$	$N(\tau^+\tau^-)$
Belle	820 M	1000 M	700 M
BaBar	540 M	670 M	460 M

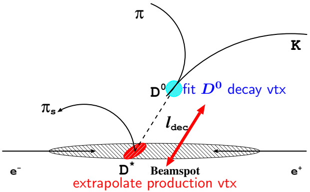
$D^0 - \bar{D}^0$ Mixing Measurements

Phenomenology:

- mass eigenstate $\neq$ flavor eigenstate
  - $|D_{1,2}>= p|D^0> \pm q|\bar{D}^0>, \; |p|^2 + |q|^2 = 1$
- time evolution of flavor eigenstate
  - $|D^0(t)>= \left[|D^0> cosh\left(\frac{ix+y}{2}t\right) + \frac{q}{p}|\bar{D}^0> sinh\left(\frac{ix+y}{2}t\right)\right] \times e^{-\frac{1}{2}(1+\frac{im}{\Gamma})t}$
- Mixing parameters **x** and **y**: in SM $|\mathbf{x}|, \; |\mathbf{y}| \leq \mathcal{O}(\mathbf{10^{-2}})$
  - $x = \frac{m_1 - m_2}{\Gamma}, \quad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}, \quad \Gamma = \frac{1}{2}(\Gamma_1 + \Gamma_2)$
  - GIM, CKM suppressed but enhanced by long-distance effects

Principle of Measurements:

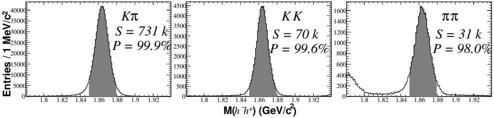
- $D^{*+} \to D^0 \pi_S^+$
  - background suppression
  - $D^0/\bar{D}^0$ flavor tagging with π_S^+
- Vertexing with beam point constraint
  - determines proper decay time $\mathbf{t} = \frac{\mathbf{l_{dec} m_{D^0}}}{\mathbf{p_{D^0}}}$ with uncertainty $\boldsymbol{\sigma}_\mathbf{t}$



Mixing in lifetime ratio of $D^0 \to K^+K^-, \pi^+\pi^-$ vs $D^0 \to K^-\pi^+$ at BaBar

Mixing parameters:

- $y_{CP} = \frac{\tau_{K\pi}}{\tau_{hh}} - 1 \xrightarrow[\text{conserv.}]{CP} y$
- $\Delta Y = \frac{\tau_{K\pi}}{<\tau_{hh}>} A_\Gamma;\ A_\Gamma = \frac{\tau^+_{hh} - \tau^-_{hh}}{\tau^+_{hh} + \tau^-_{hh}} \xrightarrow[\text{conserv.}]{CP} 0$



BaBar: $\mathcal{L} = 384\ \text{fb}^{-1}$; arXiv:0709.2715

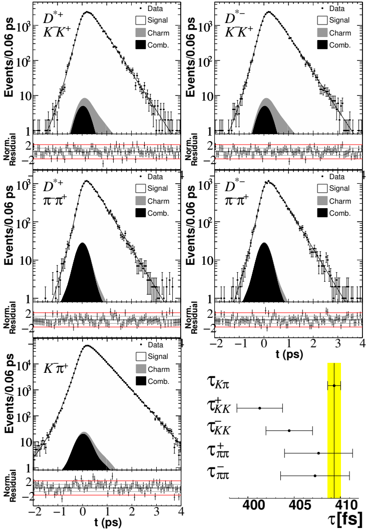
Sample	y_{CP}	ΔY
K^-K^+	$(1.60 \pm 0.46 \pm 0.17)\%$	$(-0.40 \pm 0.44 \pm 0.12)\%$
$\pi^-\pi^+$	$(0.46 \pm 0.65 \pm 0.25)\%$	$(\ \ 0.05 \pm 0.64 \pm 0.32)\%$
Combined	$(1.24 \pm 0.39 \pm 0.13)\%$	$(-0.26 \pm 0.36 \pm 0.08)\%$

No mixing excluded at 3σ.

Confirmation of **Belle**'s results PRL98,211803(2007)

	y_{CP}	A_Γ
Combined	$(1.31 \pm 0.32 \pm 0.25)\%$	$(0.01 \pm 0.30 \pm 0.15)\%$

Unbinned likelihood fit to (t, σ_t) to obtain τ_{hh}



Search for mixing in $D^0 \to K^{(*)-}\ell^+\nu_\ell$ decays at Belle

Mixing parameter:

- $< D^0|\bar{D}^0 > = \mathbf{R_M} \simeq \frac{\mathbf{x^2+y^2}}{\mathbf{2}} = \frac{\mathbf{N_{WS}}}{\mathbf{N_{RS}}}$

No mixing $\Rightarrow$ Right Sign (RS)

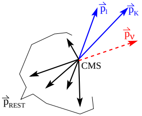
- $D^{*+} \to D^0\pi_s^+;\ D^0 \to K^-\ell^+\nu_\ell$

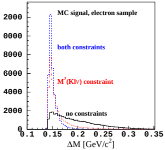
Mixing $\Rightarrow$ Wrong Sign (WS)

- $D^{*+} \to D^0\pi_s^+$
  $\hookrightarrow \bar{D}^0 \to K^+\ell^-\nu_\ell$

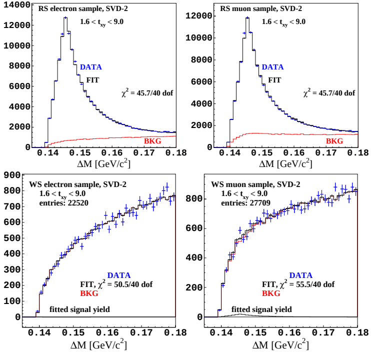
Neutrino reconstruction:

- $P_\nu = P_{\rm cms} - P_{K\ell} - P_{\rm rest}$
  - $M^2_{K\ell\nu} = m^2_{D^0}$ & $(P^*_\nu)^2 = 0$





ΔM = M(Kℓνπ$_s$) − M(Kℓν)



$\mathcal{L} = 492\ \text{fb}^{-1}$ arXiv:0802.2952 (sub. to PRD)

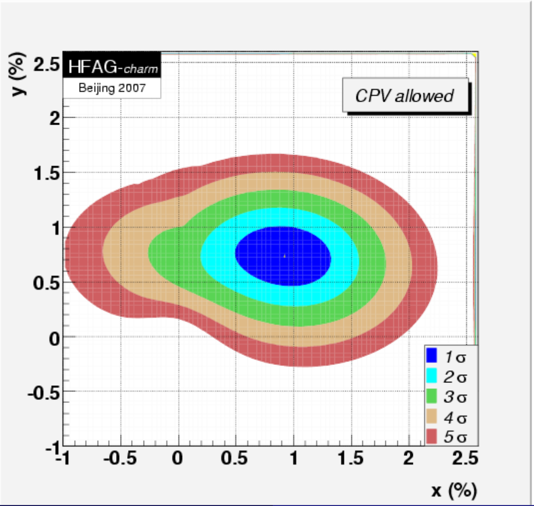
R_M	$=$	$(1.3 \pm 2.2 \pm 2.0) \times 10^{-4}$
R_M	$<$	6.1×10^{-4} @ 90% C.L.
R_M	$=$	$(1.7 \pm 3.9) \times 10^{-4}$ (HFAG)

Update of PRD 72, 071101 (2005)
and including μ sample.

Current status of $D^0 - \bar{D}^0$ Mixing

The world average (HFAG) on x and y determined with χ^2 fit to the results of all $D^0 - \bar{D}^0$ mixing measurements for CPV allowed case (8 independent parameters):

http://www.slac.stanford.edu/xorg/hfag/charm/index.html



$$x = (0.97^{+0.27}_{-0.29})\%$$

$$y = (0.78^{+0.18}_{-0.19})\%$$

Consistent with the high end of SM expectations.

CP Violation in D^0 Decays

CP Violation:

- time-integrated asymmetry: $A_{CP} = \frac{\Gamma(D^0 \to f) - \Gamma(\bar{D}^0 \to \bar{f})}{\Gamma(D^0 \to f) + \Gamma(\bar{D}^0 \to \bar{f})}$
  - in decays (only in singly Cabbibo suppressed decays)
  - in mixing
  - in interference between mixing and decay
- for $f = K^- K^+, \pi^- \pi^+$: $A_{CP} \sim \mathcal{O}(10^{-5} - 10^{-4})$ PRD51,3478(1995); RNCIB,26N7,11(2003)
- for $f = \pi^- \pi^+ \pi^0$: $A_{CP} \sim \mathcal{O}(10^{-3})$ hep-ph/0703132v2; PRD75,036008(2007)

Principle of measurements:

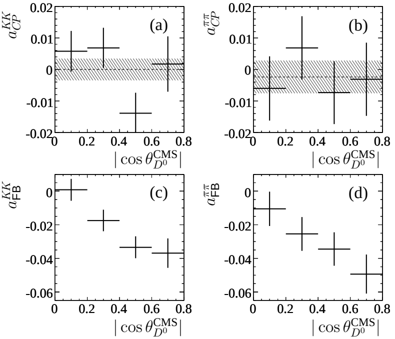
- $D^{*+} \to D^0 \pi_S^+$
- $N_{D^0}^{\mathrm{reco}} = N_{D^{*+}}^{\mathrm{prod}} \cdot \mathcal{B}(D^{*+} \to D^0 \pi^+) \cdot \mathcal{B}(D^0 \to f) \cdot \varepsilon_f \cdot \varepsilon_{\pi_S^+}$
  - Contributions to measured asymmetry: $\mathbf{A}^{\mathrm{meas}} = \mathbf{A_{FB}} + \mathbf{A_{CP}} + \mathbf{A}_{\epsilon}^{\pi_S}$
    - $\mathbf{A_{FB}}$: production asymmetry (anti-symmetric function of $cos\theta^*$)
    - $\mathbf{A_{CP}}$: CP asymmetry
    - $\mathbf{A}_{\epsilon}^{\pi_S}$: asymmetry in π_S^+/π_S^- reconstruction efficiency (measured and corrected for using tagged and untagged $D^0 \to K^- \pi^+$ decays)

Search for CPV in $D^0 \to K^+K^-, \pi^+\pi^-$ at BaBar and Belle

$$A^{\rm reco}_{\rm corr}(cos\theta^*) = \frac{N(D^0) - N(\bar{D}^0)}{N(D^0) + N(\bar{D}^0)} = A^{D^{*+}}_{FB} + A^{hh}_{CP}$$

- $A_{CP} = \frac{A^{\rm reco}_{\rm corr}(cos\theta^*) + A^{\rm reco}_{\rm corr}(-cos\theta^*)}{2}$
- $A_{FB} = \frac{A^{\rm reco}_{\rm corr}(cos\theta^*) - A^{\rm reco}_{\rm corr}(-cos\theta^*)}{2}$

BaBar

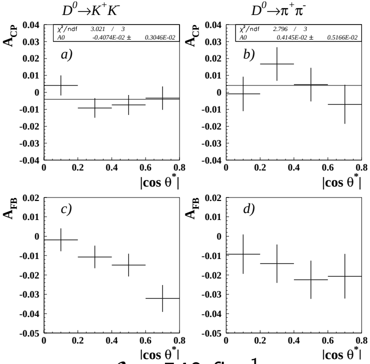


$\mathcal{L} = 386$ fb^{-1}

$$A^{KK}_{CP} = (\ \ 0.00 \pm 0.34(\mathrm{stat}) \pm 0.13(\mathrm{syst}))\%$$
$$A^{\pi\pi}_{CP} = (-0.24 \pm 0.52(\mathrm{stat}) \pm 0.22(\mathrm{syst}))\%$$

PRL 100, 061803 (2008)

Belle Preliminary

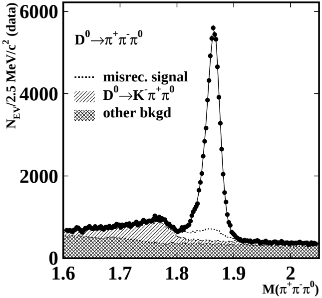


$\mathcal{L} = 540$ fb^{-1}

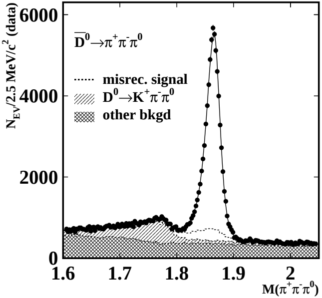
$$A^{KK}_{CP} = (-0.41 \pm 0.30(\mathrm{stat}) \pm 0.11(\mathrm{syst}))\%$$
$$A^{\pi\pi}_{CP} = (+0.41 \pm 0.52(\mathrm{stat}) \pm 0.12(\mathrm{syst}))\%$$

CPV in decay, integrated over time and Dalitz space

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



$\bar{D}^0 \to \pi^+\pi^-\pi^0$



Efficiency corrected signal yields:

$$S_{D^0} = (1154.7 \pm 6.7) \times 10^3$$

$$S_{\bar{D}^0} = (1144.7 \pm 6.6) \times 10^3$$

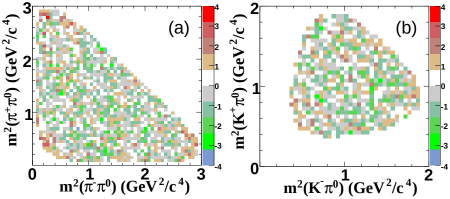
$\mathcal{L} = 532\ \text{fb}^{-1}$

arXiv:0801.2439 (subm. to PLB)

$$\frac{\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)}{\mathcal{B}(D^0 \to K^-\pi^+\pi^0)} = (10.12 \pm 0.04 \pm 0.18)\%$$

$$A_{CP} = \frac{S_{D^0} - S_{\bar{D}^0}}{S_{D^0} + S_{\bar{D}^0}} = (0.43 \pm 0.41 \pm 1.23)\%$$

$\pi^+\pi^-\pi^0$ $\quad$ $K^+K^-\pi^0$



Normalized residuals.

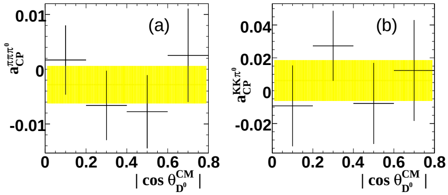
Method I: Search for differences in Dalitz plots between D^0 and $\bar{D}^0$

$$\Delta = (N_{\bar{D}^0} - RN_{D^0})/\sqrt{\sigma^2_{N_{\bar{D}^0}} + R^2\sigma^2_{N_{D^0}}}$$

$$\chi^2/\nu = (\sum_{DP} \Delta^2)/\nu = \begin{cases} 1.020 & \pi^+\pi^-\pi^0 \\ 1.056 & K^+K^-\pi^0 \end{cases}$$

One Sided Gaussian CL for consistency with no CPV: 32.8%($\pi^+\pi^-\pi^0$) **and** 16.6%($K^+K^-\pi^0$)

$\pi^+\pi^-\pi^0$ $\quad$ $K^+K^-\pi^0$



Method II: Look for a phase space integrated asymmetry

$$A^{\rm reco}_{\rm corr}(cos\theta^*) = \frac{N(D^0) - N(\bar{D}^0)}{N(D^0) + N(\bar{D}^0)}$$

$$A^{\pi\pi\pi}_{CP} = (-0.31 \pm 0.41({\rm stat}) \pm 0.17({\rm syst}))\%$$
$$A^{KK\pi}_{CP} = (+1.00 \pm 1.67({\rm stat}) \pm 0.25({\rm syst}))\%$$

$\mathcal{L} = 385\ \mathrm{fb}^{-1}$ $\quad$ arXiv:0802.4035

Leptonic $D_s^+ \to \mu^+\nu_\mu$ decays at Belle

Similar techniques are used to calculate b and c decay constants in lattice QCD:

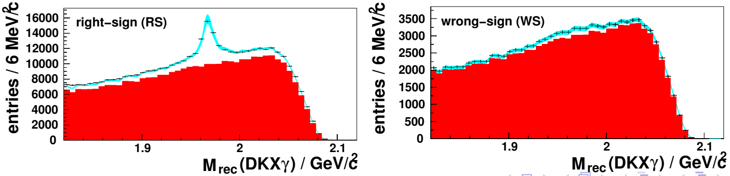
- often these calculations are needed to interpret ex. results on B decays
- decays of charmed hadrons used to test predictions for analogous quantities

$\mathcal{B}(D_s \to \tau\nu_\tau)$: $\mathcal{B}(D_s \to \mu\nu_\mu)$: $\mathcal{B}(D_s \to e\nu_e)$= 10: 1: 10^{-5}, $\mathcal{B}(\tau \to h\nu_\tau) \sim 0.11$

Principle of Measurement:

- Full Reconstruction Recoil Method
  - fully reconstructed $e^+e^- \to D_s^* D^{\pm,0} K^{\pm,0} X$, $X = n\pi$ and up to one γ
  - *tag/signal side*
    - *tag:* $D \to K n\pi$ $(n = 1, 2, 3)$ and K
    - *signal:* $D_s^* \to D_s\gamma$ (reconstructed in the recoil against **DKX**)

$\mathbf{32100 \pm 1490}$ reconstructed inclusive $\mathbf{D_s}$ decays ($\mathcal{L} = 548\ \mathrm{fb}^{-1}$)



Measurement of $\mathcal{B}(D_s \to \mu\nu_\mu)$ at Belle

Within the sample of D_s-tags:

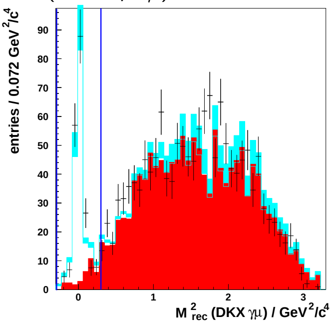
- require only one more track in event, identified as a muon
- use $D_s \to e\nu_e$ sample for background shape determination

Absolute $\mathcal{B}$ measurement $(\mathcal{L} = 548 \text{ fb}^{-1})$

$$\mathcal{B}(D_s \to \mu\nu_\mu) = [6.44 \pm 0.76(\text{stat}) \pm 0.57(\text{syst})] \cdot 10^{-3}$$

$$\mathbf{f_{D_s} = 275 \pm 16(stat) \pm 12(syst)} \text{ MeV}$$

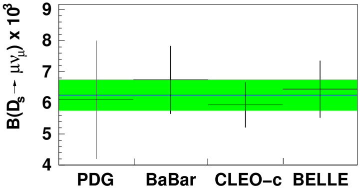
$N(D_s \to \mu\nu_\mu) = 169 \pm 16 \pm 8$



W.A. vs. LQCD prediction:

$$f_{D_s}^{exp} = 271 \pm 11 \text{ MeV}$$
$$f_{D_s}^{LQCD} = 241 \pm 3 \text{ MeV}$$

$\Longrightarrow$ **2.6σ discrepancy**



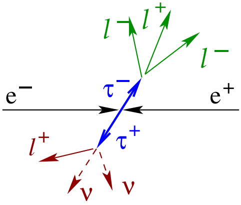
LQCD=PRL100,062002(2008), BaBar=PRL98,141801(2007), CLEO-c=PRL99,071802(2007)

Search for Lepton Flavor Violating Decays

Predictions:

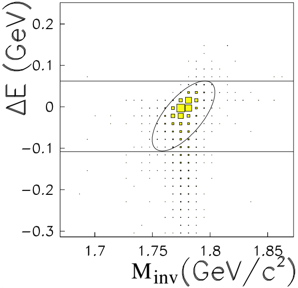
Model	$\mathcal{B}(\tau \to \ell\ell\ell)$
SM + ℓ mix.	10^{-14}
mSUGRA + seesaw	10^{-9}
SUSY + SO(10)	10^{-10}
SM + heavy ν_R^M	10^{-10}
Non-universal Z'	10^{-8}
SUSY + Higgs	10^{-7}

$$\mathcal{B}(\tau \to \ell V^0) \sim 10^{-8} - 10^{-7}$$



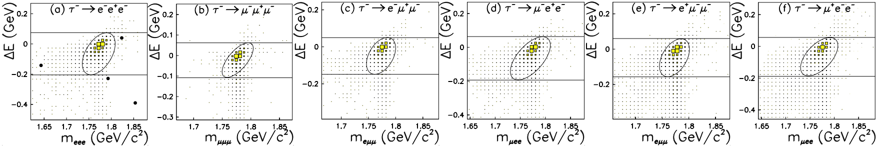
Principle of measurement:

- tag one τ by its 1-prong decay ($\mathcal{B}_{1-\mathrm{prong}} \sim 85\%$)
- the other τ is searched for in LVF decay
- suppress background from: $\tau\tau$, low multiplicity $q\bar{q}$ events ($q = u, d, s, c$), Bhabha and $\mu\mu$
- determine signal/background yield on the M_{inv} vs. ΔE plane:
  - $M_{\mathrm{inv}} \simeq m_\tau$, $\Delta E = E_{\mathrm{LVF}} - E_{beam} \simeq 0$

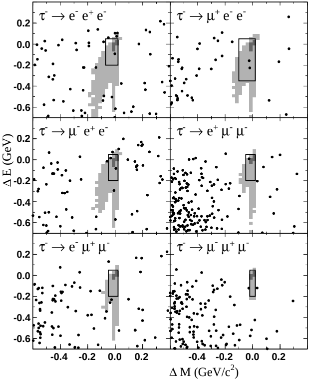


Search for $\tau \to \ell\ell\ell$ ($\ell = e, \mu$) Decays at Belle and BaBar

Belle arXiv:0711.2189



BaBar PRL99,251803(2007)



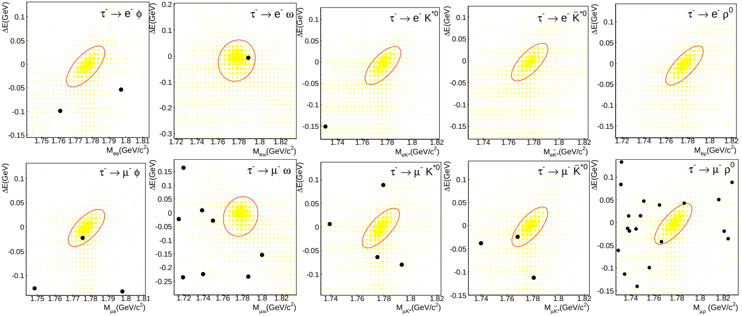
Belle $\mathcal{B}^{90}_{\mathrm{UL}}(\times 10^{-8})$	Mode	BaBar $\mathcal{B}^{90}_{\mathrm{UL}}(\times 10^{-8})$
3.6	$\tau^- \to e^- e^+ e^-$	4.3
3.2	$\tau^- \to \mu^- \mu^+ \mu^-$	5.3
4.1	$\tau^- \to e^- \mu^+ \mu^-$	3.7
2.7	$\tau^- \to \mu^- e^+ e^-$	8.0
2.3	$\tau^- \to e^+ \mu^- \mu^-$	5.6
2.0	$\tau^- \to \mu^+ e^- e^-$	5.8
535	$\mathcal{L}$ (fb^{-1})	376

Improvement of UL by factors of 5 to 10.

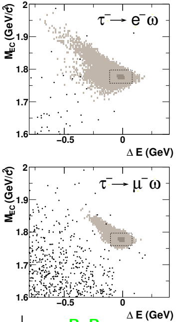
Already restricting the parameter space of models beyond SM.

Search for $\tau \to \ell V^0$ decays at Belle and BaBar

Belle arXiv:0801.2475



BaBar arXiv:0801.2475



Belle $\mathcal{B}_{90}(\times 10^{-8})$	Mode	BaBar $\mathcal{B}_{90}(\times 10^{-8})$
7.3	$\tau^- \to e^- \phi$	–
18	$\tau^- \to e^- \omega$	11
7.8	$\tau^- \to e^- K^{*0}$	–
7.7	$\tau^- \to e^- \bar{K}^{*0}$	–
6.3	$\tau^- \to e^- \rho^0$	–
543	$\mathcal{L}$ (fb^{-1})	384

Belle $\mathcal{B}^{90}_{\mathrm{UL}}(\times 10^{-8})$	Mode	BaBar $\mathcal{B}^{90}_{\mathrm{UL}}(\times 10^{-8})$
13	$\tau^- \to \mu^- \phi$	–
8.9	$\tau^- \to \mu^- \omega$	10
5.9	$\tau^- \to \mu^- K^{*0}$	–
10	$\tau^- \to \mu^- \bar{K}^{*0}$	–
6.8	$\tau^- \to \mu^- \rho^0$	–
543	$\mathcal{L}$ (fb^{-1})	384

First search for the $\tau^- \to \ell^- \omega$ mode and 3–10 times more restrictive UL for other modes than previous measurements.

Conclusions

Charm Physics:

- precision measurements of mixing parameters, e.g.

  $\hookrightarrow$ $\mathbf{y_{CP} = (1.132 \pm 0.266)\%}$ (HFAG world average)

  $\hookrightarrow$ consistent with SM expectations, providing strong constraints for new physics models

- focusing on precise measurements of x and search for CP Violation

  $\hookrightarrow$ **New Physics**

- discrepancy between Latice QCD calculation and experiments in D_s decay constant

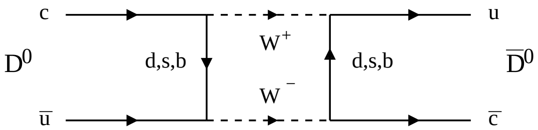
Tau Physics:

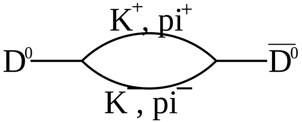
- upper limits on $\mathcal{B}$ for LFV decays are approaching the 10^{-8} level

  $\hookrightarrow$ restricting the parameter space of many models beyond SM

Backup slides

$D^0 - \bar{D}^0$ Mixing Phenomenology





Short distance:

$$< \overline{D}^0 | H_{\rm w}^{\Delta C=2} | D^0 > = \frac{G_F^2}{4\pi^2} V_{cs}^* V_{cd}^* V_{ud} V_{us} \frac{(m_s^2 - m_d^2)^2}{m_c^2} < \overline{D}^0 | \bar{u}\gamma^\mu (1-\gamma_5) c \bar{u} \gamma_\mu (1-\gamma_5) c | D^0 >$$

- $|V_{cb}^* V_{ub}| \ll |V_{cs}^* V_{us}|,\ |V_{cd}^* V_{ud}|$
- main contribution from d and s quarks
- $m_d \sim m_s \Rightarrow$ mixing small

$$|x| \sim \mathcal{O}(10^{-5})$$

Ann.Rev.Nucl.Sci. 53, 431 (2003)

Long distance:

- absorptive part (real intermediate states) $\Rightarrow y$
- dispersive part (off-shell intermediate states) $\Rightarrow x$

$$|x| \sim \mathcal{O}(10^{-2})$$
$$|y| \sim \mathcal{O}(10^{-2})$$

Nucl. Phys. B592, 92 (2001); PRD69, 114021 (2004)

$D^0 - \bar{D}^0$ mixing is rare process in SM $\Rightarrow$ possible contributions from NP

$D^0 \to K^-K^+, \pi^-\pi^+$ backup

Fitting procedure:

- 3 categories:
  - signal:
    $PDF_{sig} \propto e^{-t/\tau} \otimes R(t, t_0, \sigma_t)$, $R(t, t_0, \sigma_t) = \sum_{n=1,3} G(t, t_0, s_n \sigma_t^n)$
    - resolution function offset t_0 (due to detector misalignment) is common for all three modes
    - up to an overall scale factor in the width, the resolution function parameters are shared among all three modes
  - combinatorial background:
    $PDF_{comb.} \propto$ Gaussian + Gaussian with a power law tail
    - shape parameters determined for each mode individually using the m and Δm sidebands
    - means are free parameters of the fit
    - the amount is determined using MC samples scaled to the luminosity of data sample
  - mis-reconstructed charm events ($D^0 \to K^- l^+ \nu$, $D^0 \to K^- \pi^+ \pi^0$)
    $PDF_{charm} \propto e^{-t/\tau'} \otimes G(t, \mu', \sigma')$
    - shape and normalization determined using MC samples
    - crosschecked by comparing the data and MC events in m and Δm sidebands

$D^0 \to K^-K^+, \pi^-\pi^+$ backup

Systematics:

- most systematic errors related to the signal are expected to cancel in the lifetimes ratio

Systematic	$\sigma_{y_{CP}}$ (%)			$\sigma_{\Delta Y}$ (%)		
	K^-K^+	$\pi^-\pi^+$	Av.	K^-K^+	$\pi^-\pi^+$	Av.
Signal model	0.130	0.059	0.085	0.072	0.265	0.062
Charm bkg.	0.062	0.037	0.043	0.001	0.002	0.001
Combinatoric bkg.	0.019	0.142	0.045	0.001	0.005	0.002
Selection criteria	0.068	0.178	0.046	0.083	0.172	0.011
Detector model	0.064	0.080	0.064	0.054	0.040	0.054
Quadrature sum	0.172	0.251	0.132	0.122	0.318	0.083

$D^0 \to K^-\ell^+\nu_\ell$ backup

Wrong Sign (mixed events; no DCS decays):

- $|x|, |y| \ll 1$ and negligible CPV:
  - time-dependent mixing probability

$$\mathcal{P}(D^0 \to \bar{D}^0 \to K^+\ell^-\bar{\nu}_\ell) \propto R_M t^2 e^{-t/\tau} \qquad R_M \approx \frac{x^2+y^2}{2}$$

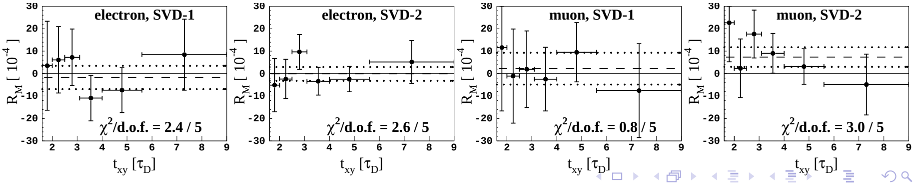
Right Sign:

$$\mathcal{P}(D^0 \to K^-\ell^+\bar{\nu}_\ell) \propto e^{-t/\tau}$$

$<t>$ for bkg. and RS $<$ $<t>$ for mixed signal

$\Downarrow$

Evaluate R_M in six bins in t on the interval $[1.6 \cdot \tau_{D^0}, 9 \cdot \tau_{D^0}]$



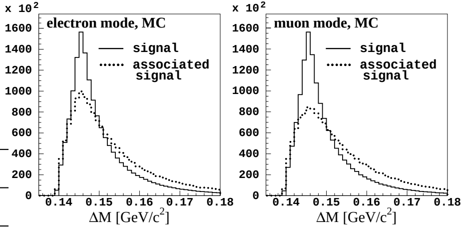
$D^0 \to K^-\ell^+\nu_\ell$ backup

Associated signal:

- $D^0 \to K^-\pi^0\ell^+\nu$
- $D^0 \to K^{*-}\ell^+\nu_\ell,\ K^{*-} \to K^-\pi^0$
- $D^0 \to \pi^-\ell^+\nu_\ell$
- $D^0 \to \rho^-\ell^+\nu_\ell,\ \rho^- \to \pi^-\pi^0$
- $D^0 \to K^{*-}\ell^+\nu_\ell,\ K^{*-} \to \overline{K}^0\pi^-$

	assoc. sig. [%]		sig. from B decays [%]	
	all t_{xy}	1.6 — 9.0	all t_{xy}	1.6 — 9.0
e	16.58±0.05	17.7±0.1	1.20±0.01	1.18±0.03
μ	11.54±0.04	12.3±0.1	1.07±0.01	1.04±0.03

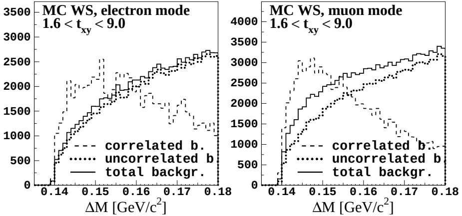
Associated signal



Background:

- Correlated (5%(15%) in $e(\mu)$ WS sample)
  - $K^\pm$ candidate or/and $\ell^\pm$ candidate originate from the same decay chain as $\pi_s^\pm$
  - described using MC
- Uncorrelated
  - described using event mixing on data sample

Background



$D^0 \to K^- \ell^+ \nu_\ell$ backup

Systematics:

	source	e-1	e-2	μ-1	μ-2
1	fitting histo. statistics	± 1.54	± 0.91	± 2.64	± 1.81
2	WS correlated bkg.	± 0.37	$^{+0.39}_{-0.38}$	$^{+2.98}_{-2.89}$	$^{+3.05}_{-2.97}$
3	WS uncorrelated bkg.	$^{+1.30}_{-1.88}$	$^{+1.70}_{-1.85}$	$^{+2.58}_{-2.82}$	$^{+1.57}_{-3.20}$
4	imperfect t_{xy}	± 0.05	± 0.02	± 0.01	$^{+0.25}_{-0.33}$
5	associated signal	$^{+0.01}_{-0.00}$	± 0.00	$^{+0.09}_{-0.10}$	± 0.02
6	RS correlated bkg.	± 0.00	± 0.00	± 0.01	± 0.04
	total systematic	$^{+2.05}_{-2.46}$	$^{+1.97}_{-2.10}$	$^{+4.75}_{-4.83}$	$^{+3.89}_{-4.74}$
	statistical + systematic	$^{+5.58}_{-5.74}$	$^{+3.66}_{-3.73}$	$^{+8.53}_{-8.57}$	$^{+5.86}_{-6.45}$

CPV backup

Number of reconstructed decays:

$$N^{reco} = N^{prod}_{D^{*+}} \cdot \mathcal{B}(D^{*+} \to D^0\pi^+) \cdot \mathcal{B}(D^0 \to h^+h^-) \cdot \epsilon_{hh} \cdot \epsilon_\pi$$

- Contributions to asymmetry in N^{reco}:
  - production (A_{FB})
  - branching fractions (A_{CP})
  - efficiencies (A_ϵ)
- If asymmetries are small ($A_{FB}, A_{CP}, A_\epsilon \ll 1$) it is easy to see, that the asymmetry in N^{reco} is:

$$A^{reco} = A^{D^{*+}}_{FB} + A^{D^0\pi}_{CP} + A^{hh}_{CP} + A^{hh}_\epsilon + A^\pi_\epsilon$$

- Some are zero: $A^{D^0\pi}_{CP} = 0$ (strong decay), $A^{hh}_\epsilon = 0$ (same final state)

CPV backup

- Production asymmetry (A_{FB}) is due to interference in $e^+e^- \to c\bar{c}$ (mediated by virtual γ or Z^0)
  - anti-symmetric function of $\cos\theta^*$ (follows from CP conservation)

$$A_{FB}(\cos\theta^*) = -A_{FB}(-\cos\theta^*)$$

- Measured asymmetry:

$$A^{reco} = A_{FB}^{D^{*+}}(\cos\theta^*) + A_{CP}^{hh} + A_{\epsilon}^{\pi}(\theta, p)$$

- Asymmetry in π_{slow} efficiency $A_{\epsilon}^{\pi}(\theta, p)$ can be measured in $D^0 \to K^-\pi^+$ by using tagged and untagged decays
- Corrected asymmetry

$$A_{corr}^{reco} = A^{reco} - A_{\epsilon}^{\pi}(\theta, p)$$

$$A_{corr}^{reco}(\cos\theta^*) = A_{FB}^{D^{*+}}(\cos\theta^*) + A_{CP}^{KK}$$

CPV backup

Number of reconstructed tagged and untagged $D^0 \to K^-\pi^+$ decays:

$$N^{\mathrm{untag}} = N^{\mathrm{prod}}_{D^0} \cdot \mathcal{B}(D^0 \to K^-\pi^+) \cdot \epsilon_{K\pi}$$
$$N^{\mathrm{tag}} = N^{\mathrm{prod}}_{D^{*+}} \cdot \mathcal{B}(D^{*+} \to D^0\pi^+_S) \cdot \mathcal{B}(D^0 \to K^-\pi^+) \cdot \epsilon_{K\pi} \cdot \epsilon_\pi$$

Measured asymmetry:

$$A^{\mathrm{untag}} = A^{D^0}_{FB} + A^{K\pi}_{CP} + A^{K\pi}_{\epsilon}$$
$$A^{\mathrm{tag}} = A^{D^0}_{FB} + A^{K\pi}_{CP} + A^{K\pi}_{\epsilon} + A^{\pi}_{\epsilon}$$

Assuming $A^{D^0}_{FB} = A^{D^{*+}}_{FB}$:

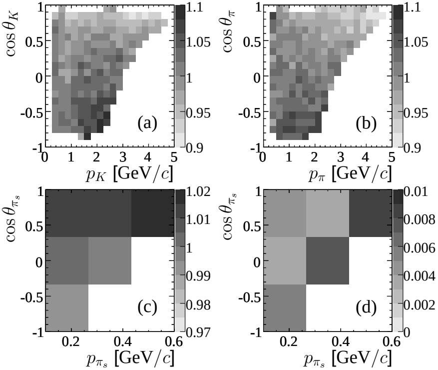
$$A^{\pi}_{\epsilon} = A^{\mathrm{tag}} - A^{\mathrm{untag}}$$

$A^{K\pi}_{\epsilon}$ and A^{π}_{ϵ} are functions of corresponding phase spaces.

CPV in $D^0 \to K^-K^+, \pi^-\pi^+$ decays backup (BaBar)

Determination of soft pion π_s asymmetry:

- using tagged and untagged $D^0 \to K^-\pi^+$ decays



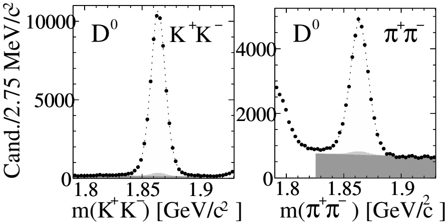
$\Longrightarrow$ $K\pi$ efficiency-map obtained from the non-tagged D^0 daughters

$\hookrightarrow$ weight D^0 candidates in the π_s tagged $K\pi$ sample (eliminating asym. due to $D^0/\bar{D}^0$ daughters)

$\Longrightarrow$ $K\pi$ relative π_s efficiency-map (left) with uncertainty (right)

$\hookrightarrow$ weight D^0 yields to correct for tagging asymmetry

CPV in $D^0 \to K^-K^+, \pi^-\pi^+$ decays backup (BaBar)



The signal yields are determined by the $2D$ (m vs. Δm) fits:

Final state	Raw yields D^0			Raw yields $\bar{D}^0$			Post-correction yields: Corr. used	Post-correction yields: D^0	Post-correction yields: $\bar{D}^0$
$K\pi$	3,363,000	$\pm$	6,000	3,368,000	$\pm$	6,000	none	—	—
$K\pi\pi_s$	705,100	$\pm$	1,000	703,500	$\pm$	1,000	$K\pi$ map	633, 300	630, 100
$KK\pi_s$	65,730	$\pm$	340	63,740	$\pm$	330	π_s map	65, 210	63, 490
$\pi\pi\pi_s$	32,210	$\pm$	310	31,930	$\pm$	310	π_s map	31, 900	31, 760

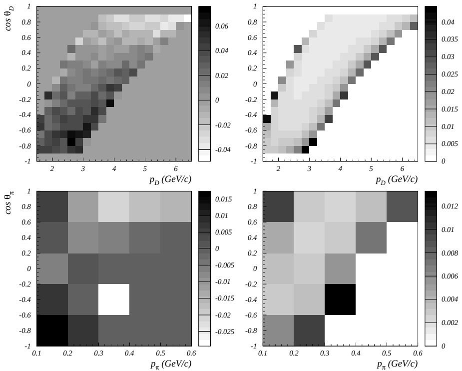
Systematics:

Category	Δa_{CP}^{KK}	$\Delta a_{CP}^{\pi\pi}$
2-Dim. PDF shapes	$\pm 0.04\%$	$\pm 0.05\%$
π_s correction	$\pm 0.08\%$	$\pm 0.08\%$
a_{CP} extraction	$\pm 0.09\%$	$\pm 0.20\%$
Quadrature sum	$\pm 0.13\%$	$\pm 0.22\%$

CPV in $D^0 \to K^-K^+, \pi^-\pi^+$ decays backup (Belle)

Determination of soft pion π_s asymmetry:

- using tagged and untagged $D^0 \to K^-\pi^+$ decays



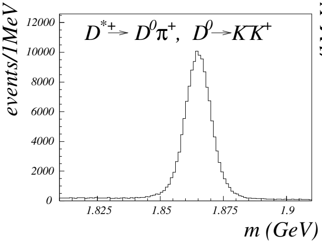
$\Longrightarrow$ asymmetry map of the untagged $K\pi$ sample (left) with uncertainty (right)

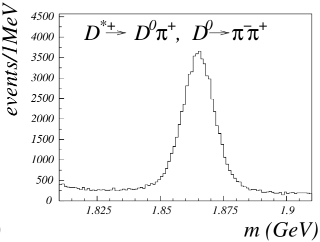
$\hookrightarrow$ weight D^0 candidates in the π_s tagged $K\pi$ sample

$\Longrightarrow$ asymmetry map of the slow pion efficiency (left) with uncertainty (right)

$\hookrightarrow$ weight D^0 yields to correct for tagging asymmetry

CPV in $D^0 \to K^-K^+, \pi^-\pi^+$ decays backup (Belle)





The signal counting was performed by the mass-sideband subtraction.

Systematics:

Signal counting

	KK	$\pi\pi$
Signal shape diff.	0.02%	0.04%
Sideband position	0.01%	0.03%
Random π_{slow} bkg.	0.03%	0.03%
Total	0.04%	0.06%

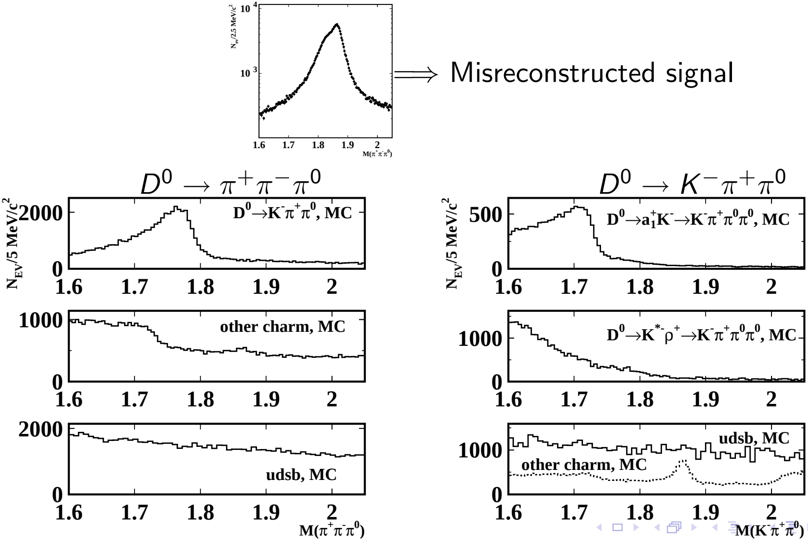
π_S eff. correction

	KK	$\pi\pi$
Statistics of $K\pi$	0.09%	0.09%
Binning	0.03%	0.02%
Min. num. events/bin	0.04%	0.03%
Total	0.10%	0.10%

A_{CP} extraction

	KK	$\pi\pi$
Binning	0.03%	0.03%
SVD1/2	0.03%	0.00%
Total	0.04%	0.03%

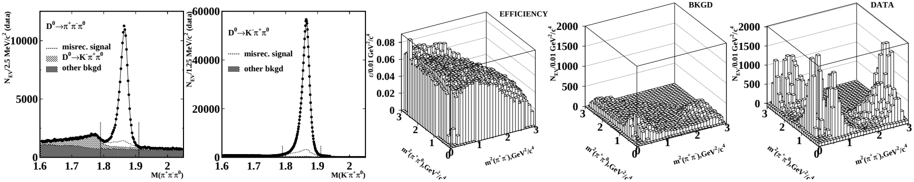
Background sources:



$\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$ backup (Belle)

Signal Yields:

- The shape parameters of the signal and background contributions are fixed to the values obtained on MC sample (signal peak position and *scale* parameter of the widths are free parameters)



- after the signal/background normalizations are obtained the $M^2(h\pi)$ vs. $M^2(\pi\pi^0)$ Dalitz histograms are filled with events from the signal region for data and simulated background

$$S = \frac{D^i - N_{\text{misrec}} S^i_{\text{misrec}} - N_{udsb} B_{udsb} - N_{\text{misid}} B^i_{misid} - N_c B^i_c}{\epsilon^i}$$

$\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$ backup (Belle)

Systematics:

Source	Error, %	Source	Error, %
PID corrections	0.91	**Selection criteria:**	
MC statistics	0.30	K_S veto	0.50
Fit($D^0 \to \pi^+\pi^-\pi^0$)	0.61	$p_{\rm cms}(D^*)$	0.77
Fit($D^0 \to K^-\pi^+\pi^0$)	0.30	$M(K^-\pi^+\pi^0/3\pi)$	0.36
$D^0 \to \pi^+\pi^-\pi^0$ backgr. model	0.48	ΔM	0.30
Binning	0.54	E_γ	0.40
MC misreconstruction	0.10	$M(\pi^0)$	0.20
Tracking	0.01	$p_{\rm lab}(\pi^0)$	0.16
Total			**1.79**

Comparison:

Group	$N_{\rm ev}, 10^3$	$\frac{\mathcal{B}(D^0\to\pi^+\pi^-\pi^0)}{\mathcal{B}(D^0\to K^-\pi^+\pi^0)}$	$\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0), 10^{-3}$
Belle	123.19 ± 0.49	$0.1012 \pm 0.0004 \pm 0.0018$	$13.66 \pm 0.05 \pm 0.24 \pm 0.61$
BaBar	60.43 ± 0.34	$0.1059 \pm 0.0006 \pm 0.0013$	$14.30 \pm 0.08 \pm 0.18 \pm 0.64$
CLEO	10.83 ± 0.16	—	$13.14 \pm 0.19 \pm 0.46 \pm 0.24$

CPV in $D^0 \to \pi^+\pi^-\pi^0$ decays backup (Belle)

π_s reconstruction efficiency correction:

- The charge-dependent data/MC PID corrections for π_s were obtained using independent $D^* \to D^0(K_S^0\pi^0)\pi_s$ data and MC samples

Forward-backward asymmetry (A_{fb}):

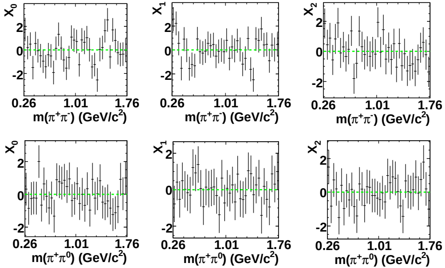
- data sample of $D^0 \to K^+K^-, \pi^+\pi^-$ decay events used to calculate $A_{fb}(cos(\theta))$

Systematics:

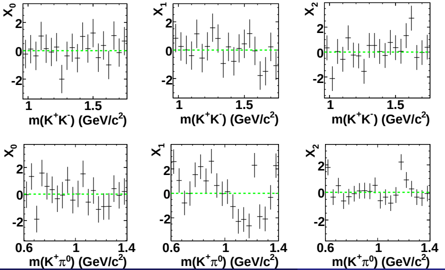
Source	MC stat.	Tracking	Fit	K_S veto	PID	Binning	A_{fb}	Total
σ, %	0.24	1.01	0.58	0.23	0.15	0.05	0.15	1.23

CPV in $D^0 \to \pi^+\pi^-\pi^0$, $K^+K^-\pi^0$ backup (BaBar)

$\pi^+\pi^-\pi^0$



$K^+K^-\pi^0$



Method III: Look for differences in angular moments of the D^0 and $\bar{D}^0$ intensity distributions

Angular moment $\equiv$ efficiency corrected invariant mass distribution of events weighted by spherical harmonics $\mathbf{Y_l^0(\theta_H) = \sqrt{1/2\pi}P_l(\cos\theta_H)}$

Normalized residuals:

$$X_l = (\bar{P}_l - RP_l)/\sqrt{\sigma^2_{\bar{P}_l} + R^2\sigma^2_{P_l}}$$

Obtained one sided Gaussian CL for consistency with no CPV:

- 28.2% for $\pi^+\pi^-$
- 28.4% for $\pi^+\pi^0$
- 63.1% for K^+K^-
- 23.8% for $K^+\pi^0$

CPV in $D^0 \to \pi^+\pi^-\pi^0$, $K^+K^-\pi^0$ backup (BaBar)

State	f_r (%)	Δa_r (%)	$\Delta\phi_r$ (°)	Δf_r (%)
$\rho^+(770)$	68	-3.2±1.7±0.8	-0.8±1.0±1.0	-1.6±1.1±0.4
$\rho^0(770)$	26	2.1±0.9±0.5	0.8±1.0±0.4	1.6±1.4±0.6
$\rho^-(770)$	35	2.0±1.1±0.8	-0.6±0.9±0.4	0.7±1.1±0.5
$\rho^+(1450)$	0.1	2±11±8	-30±25±9	0.0±0.1±0.1
$\rho^0(1450)$	0.3	13±8±6	-1±14±3	0.1±0.2±0.1
$\rho^-(1450)$	1.8	-3±6±5	8±7±3	-0.2±0.3±0.1
$\rho^+(1700)$	4	19±27±9	9±7±3	0.4±1.0±0.4
$\rho^0(1700)$	5	-31±20±12	-7±6±2	-1.3±0.8±0.3
$\rho^-(1700)$	3	-3±14±11	-3±8±3	-0.5±0.6±0.3
$f_0(980)$	0.2	0.0±0.1±0.2	-3±7±4	0.0±0.1±0.1
$f_0(1370)$	0.4	-0.3±1.3±1.2	7±14±5	-0.2±0.1±0.1
$f_0(1500)$	0.4	0.4±1.1±0.7	-1±12±1	0.0±0.1±0.1
$f_0(1710)$	0.3	-3±3±2	-25±13±11	0.0±0.1±0.1
$f_2(1270)$	1.3	8±4±5	2±5±2	0.1±0.1±0.1
$\sigma(400)$	0.8	-0.3±0.7±2.0	-4±7±3	-0.1±0.1±0.1
Nonres	0.8	12±7±8	11±9±4	0.2±0.3±0.2

State	f_r (%)	Δa_r (%)	$\Delta\phi_r$ (°)	Δf_r (%)
$K^*(892)^+$	45	2±3±2	10±12±3	0.8±1.1±0.4
$K^*(1410)^+$	4	101±65±37	1±21±6	1.7±1.8±0.6
$K^+\pi^0(S)$	16	-130±64±51	-9±10±6	-2.3±4.7±1.0
$\phi(1020)$	19	-1±2±1	-10±20±5	-0.4±0.8±0.2
$f_0(980)$	7	14±16±6	-12±25±8	0.4±2.6±0.2
$\left[a_0(980)^0\right]$	[6]	[19±16±6]	[-7±16±8]	[0.6±1.9±0.2]
$f_2'(1525)$	0.1	-38±74±8	6±36±12	0.0±0.1±0.3
$K^*(892)^-$	16	1±3±1	-7±4±2	1.7±1.3±0.4
$K^*(1410)^-$	5	133±93±68	-23±13±9	1.7±2.8±0.7
$K^-\pi^0(S)$	3	8±68±36	32±39±14	0.4±2.4±0.5

Method IV:

Measure amplitudes and phases of resonances in D^0 and $\bar{D}^0$ independently

Dalitz plot amplitude:

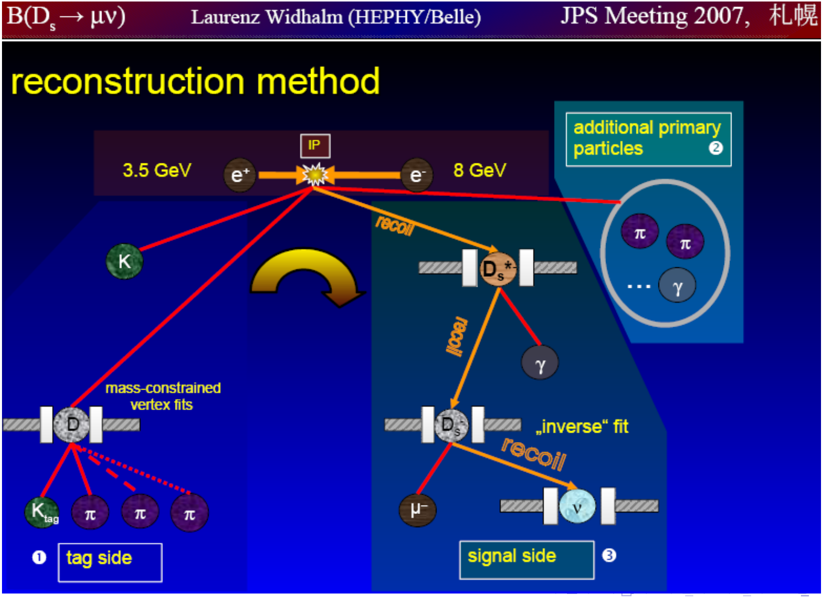
$$\mathcal{A} = \sum_r a_r e^{i\phi_r} A_r(s_+, s_-)$$

PRD76,011102(2007), PRL99,251801(2007)

$$\Delta a_r = a_r^{\bar{D}^0} - a_r^{D^0}$$
$$\Delta\phi_r = \phi_r^{\bar{D}^0} - \phi_r^{D^0}$$
$$\Delta f_r = f_r^{\bar{D}^0} - f_r^{D^0}$$

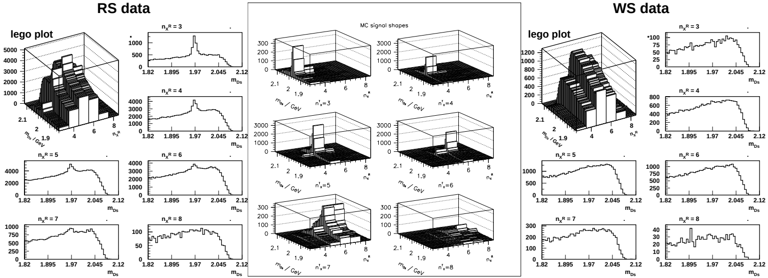
The CP asymmetry in any amplitude, relative to that of the whole decay, is no larger than a few percent.

$D_s \to \mu\nu_\mu$ reconstruction method backup



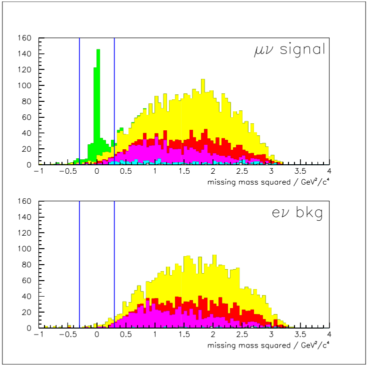
Signal yield extraction:

- signal shapes and efficiency depend on number of prompt particles (n_X) in $e^+e^- \to D_s^* DKX$ reactions
- Problem: MC doesn't reproduce the n_X distribution obtained on the data sample and $n_X^{rec} \leq n_X^{true}$
- Solution: number of D_s-tags as a function of n_X^{true} in data is extracted from 2D histograms in n_X^{rec} and $M_{rec}(DKX\gamma)$ using MC signal shapes for different values of n_X^{true} and WS sample for background shapes



$D_s \to \mu\nu_\mu$ backup

Background in $D_s \to \mu\nu_\mu$:



- signal
- non-D_s
- semileptonic D_s
- $\tau\nu$
- hadronic

Systematics:

- data/MC background samples (**4.5%**)
- signal MC distribution (**6.4%**)
- μ tracking and identification eff. (**2.8%**)
- difference in relative rates of individual D_s decays between data and MC (**3.0%**)

Predictions:

Model	REF.	$\mathcal{B}(\tau \to \ell\ell\ell)$
SM + ℓ mix.	PRD 16,1444(1977); PRD 45,1908(1980); EPJ C8,513(1999)	10^{-14}
mSUGRA + seesaw	EPJ C14,319(2002); PRD 66,115013(2002)	10^{-9}
SUSY + SO(10)	NPB 649,189(2003); PRD 68,033012(2003)	10^{-10}
SM + heavy ν_R^M	PRD66,034008(2002)	10^{-10}
Non-universal Z'	PLB 547,252(2002)	10^{-8}
SUSY + Higgs	PLB 549,159(2002); PLB 566,217(2003)	10^{-7}

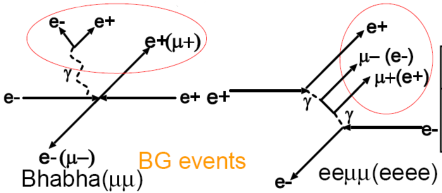
$\mathcal{B}(\tau \to \ell V^0) \sim 10^{-8} - 10^{-7}$: PRD 62,030610(2000); NPB 701,3(2004); PRD 74,035010(2006)

LVF in $\tau \to \ell\ell\ell$ decays backup

LVF τ decays at B-factories:

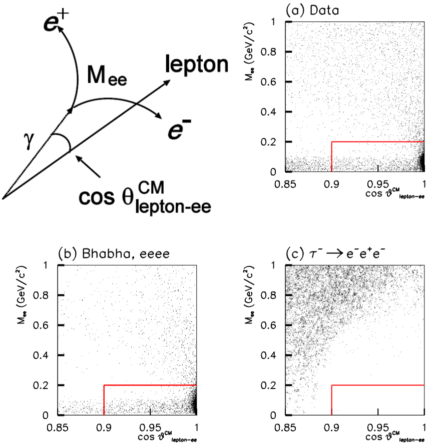
- clean environment
  - jet like events ($B\bar{B}$ background rejection through event shape variables)
- signal LVF decay is neutrinoless
  - no missing momentum

Main types of background:

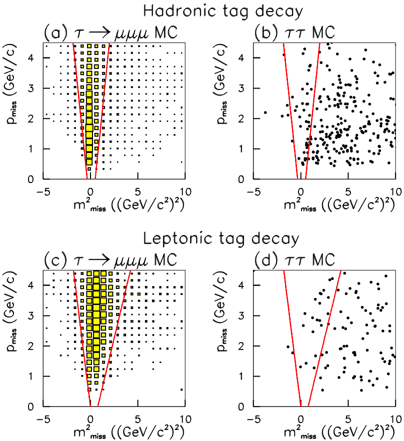


$\tau^- \to$ Mode	$\mu^-\mu^+\mu^-$	$e^-e^+e^-$	$\mu^-e^+e^-$ $e^-\mu^+\mu^-$	$\mu^+e^-e^-$ $e^+\mu^-\mu^-$
Dominant Background	$\tau\tau$ continuum $\mu\mu\mu\mu$	Bhabha $eeee$ $\tau\tau$	$ee\mu\mu$ $\tau\tau$ $\mu\mu$	$\tau\tau$ continuum

γ-conversion suppression:



$\tau^+\tau^-$ and $q\bar{q}$ background suppression:



LVF in $\tau \to \ell V^0$ decays backup