Rare and forbidden charm decays

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University of Ljubljana
"Jožef Stefan" Institute

Introduction

$D_1^0 \to D^0\gamma$

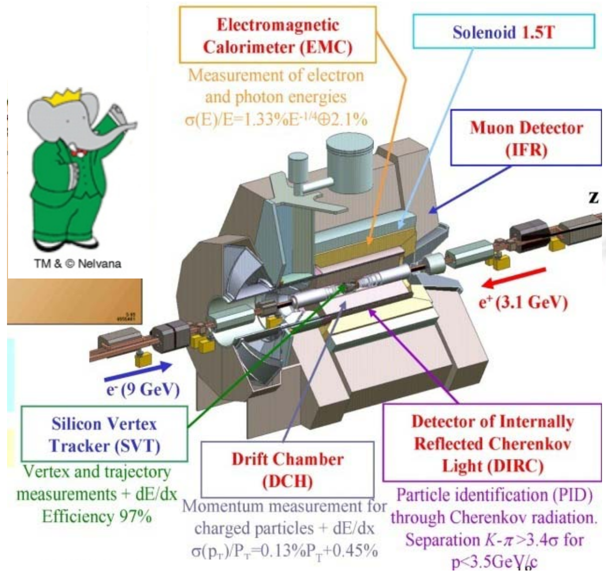
$D^0 \to \ell^+\ell^-$

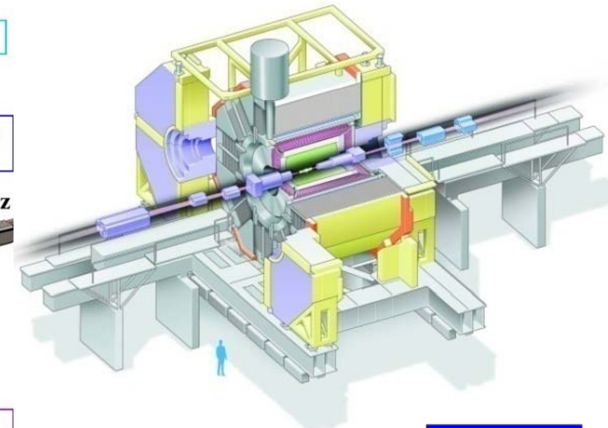
Charm 2010, IHEP,
Beijing, Oct 21 – 24, 2010

Introduction

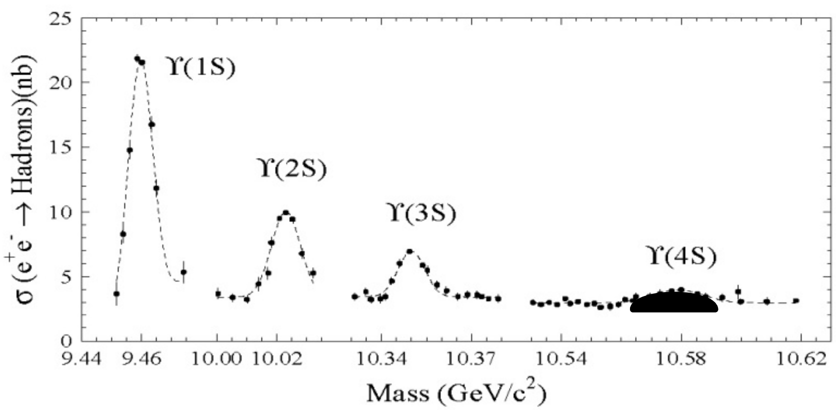
Experiments

B-Factories
BaBar @ PEPII
SLAC
Belle @ KEKB
KEK





on resonance production
$e^+e^- \to \Upsilon(4S) \to B^0\bar{B}^0, B^+B^-$
$\sigma(B\bar{B}) \approx 1.1$ nb ($\sim 10^9$ $B\bar{B}$ pairs)



Belle $\int\mathcal{L}dt \approx 1020$ fb^{-1}
BaBar $\int\mathcal{L}dt \approx 550$ fb^{-1}

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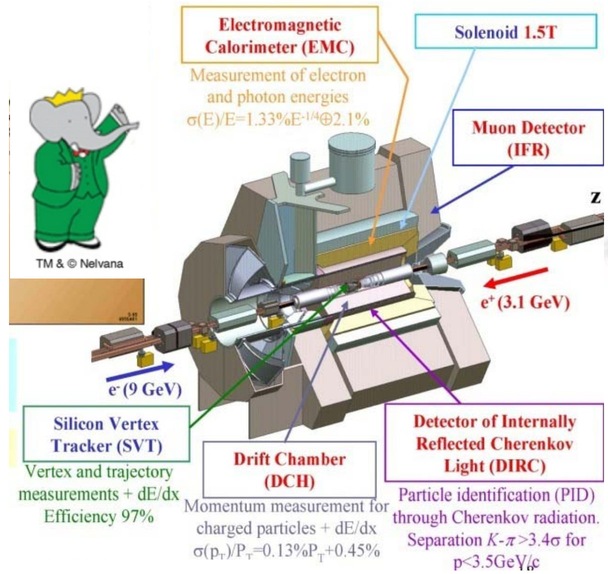

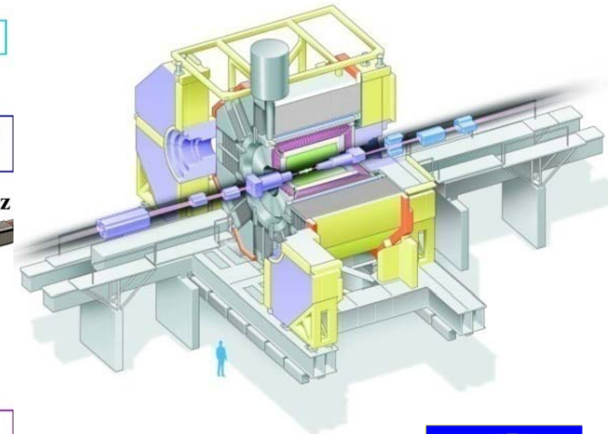

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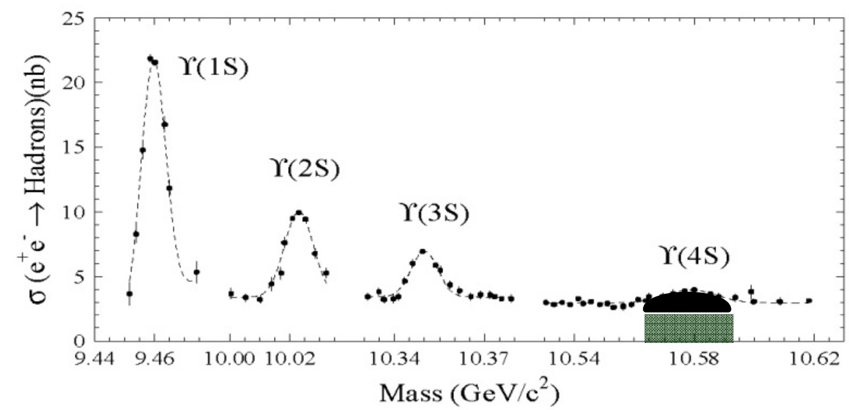
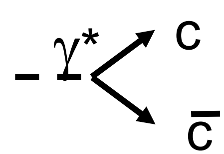


continuum production
$\sigma(c\bar{c}) \approx 1.3$ nb ($\sim 1.3\times10^9$ $X_c\bar{Y}_c$ pairs)
$N_{rec}(D^{*+} \to D^0\pi^+ \to K^-\pi^+\pi^+) \approx 2.5\times10^6$



B-factory= charm factory

Belle $\int\mathcal{L}dt \approx 1020$ fb^{-1}
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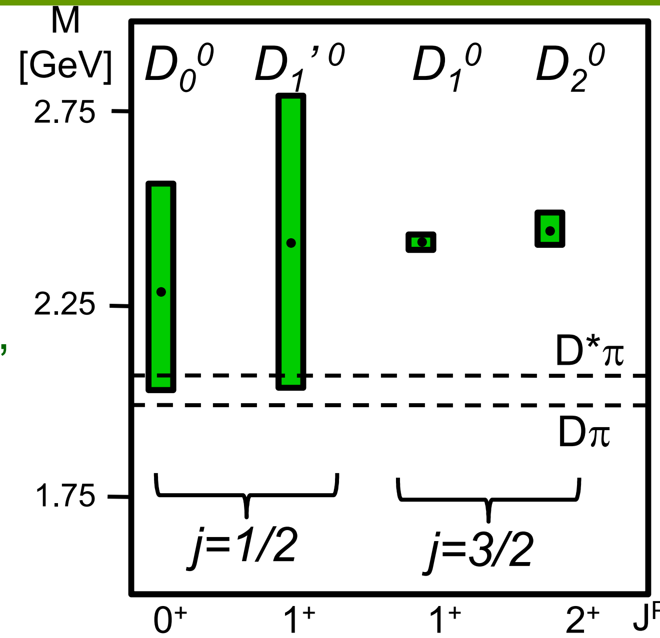
$D_1^0 \to D^0\gamma$

Motivation

- *1P → 1S* radiative transition
  - *L=1 D* mesons:
    - broad (*j=1/2*) doublet
      - $D_0^0 \to D\pi$, $D_1'^0 \to D^*\pi$
      - *S*-wave decays
    - narrow (*j=3/2*) doublet D_1^0, D_2^0
      - *D*-wave decays

L=1
D mesons,
*D***



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$D_0^0 \to D\pi$, $D_1'^0 \to D^*\pi$

S-wave decays

narrow (*j=3/2*) doublet D_1^0, D_2^0

D-wave decays

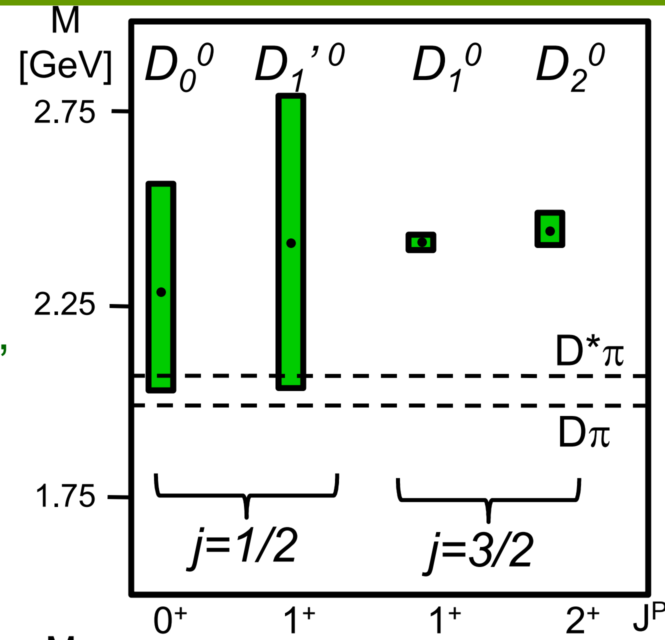
L=1 D_s mesons:

"broad" doublet

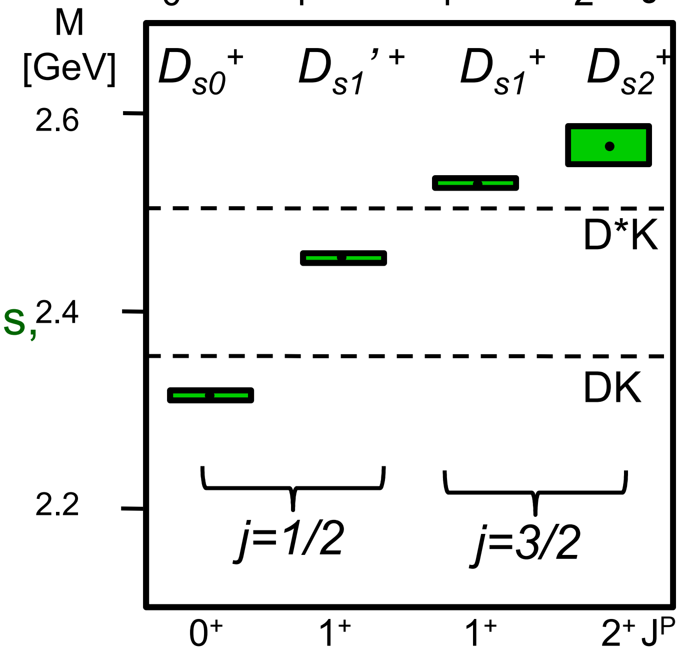
$D_{s0}^+ \not\to DK$, $D_{s1}'^+ \not\to D^*K$

narrow doublet D_{s1}^+, D_{s2}^+

L=1
D mesons,
*D***



L=1
D_s mesons,
D_s**



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L=1 D$_s$ mesons:

"broad" doublet

$D_{s0}^+ \not\to DK$, $D_{s1}'^+ \not\to D^*K$

narrow doublet D_{s1}^+, D_{s2}^+

exotic 4*q* states / convetional $q\bar{q}$ with corrections to *q* model/HQL ?

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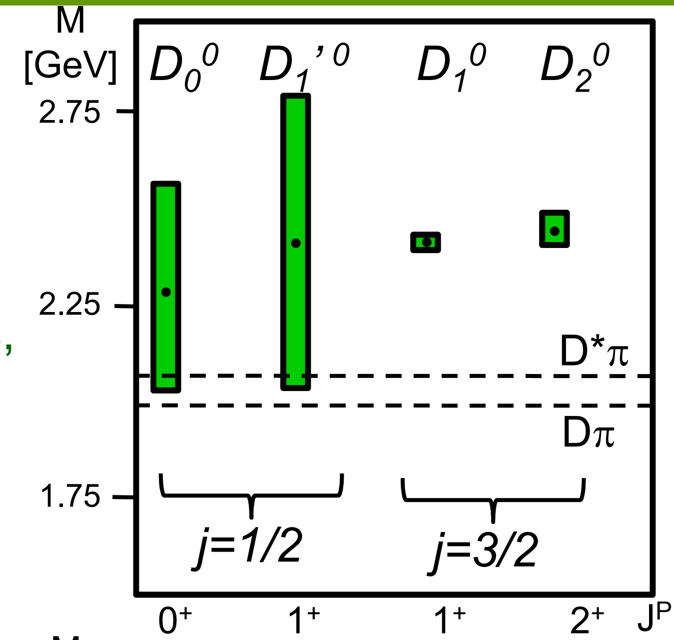
D mesons,
*D***



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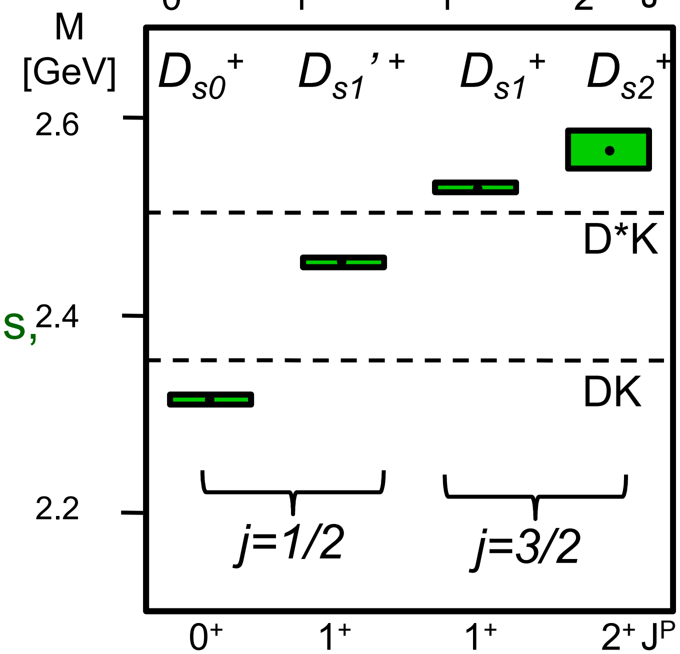

$D_1^0 \to D^0\gamma$

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1P → *1S* radiative transition

use (not measured yet) *D*** radiative transitions as probes of internal structure; test the HQL, mixing between 1^+ states;

$$\frac{\Gamma(D_1 \to {}^3S_1 + \gamma)}{\Gamma(D_1 \to {}^1S_0 + \gamma)} = \frac{\omega_t^3 |\langle r \rangle_t|^2}{\omega_s^3 |\langle r \rangle_s|^2} \frac{\sin^2\theta}{\cos^2\theta}$$

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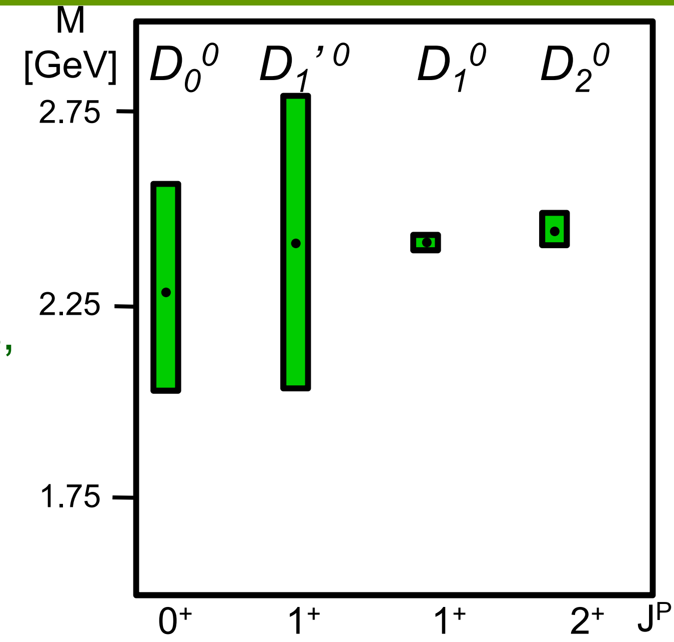

S. Godfrey, PRD72, 054029 (2005)

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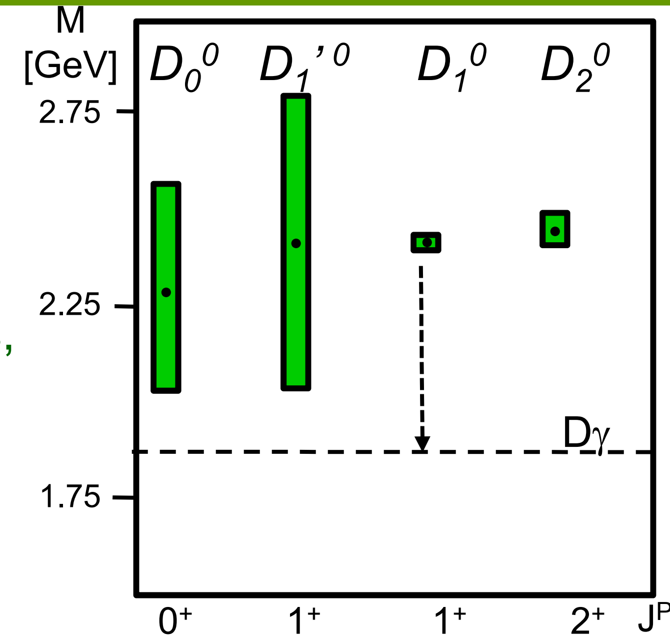
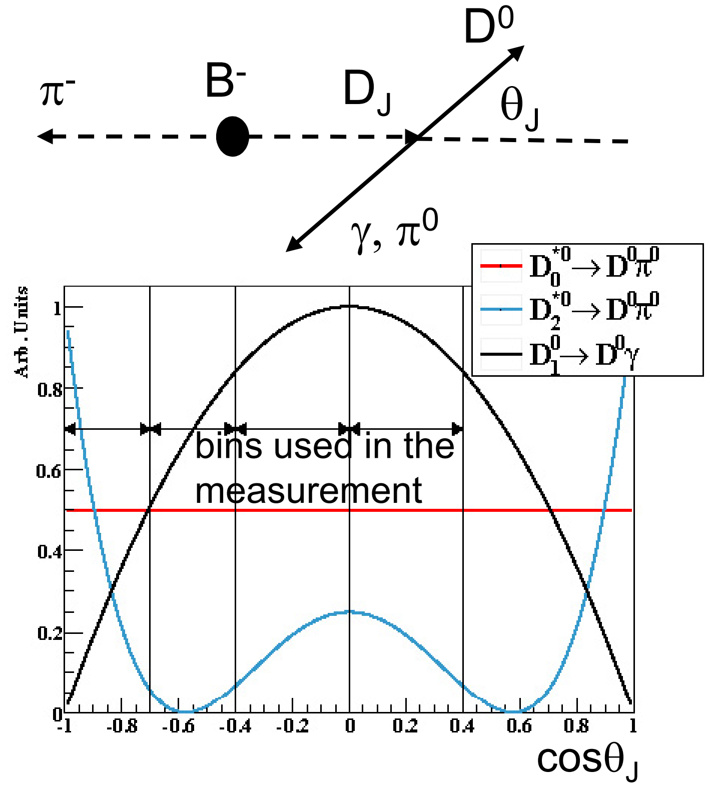


obvious 1st choice:
$D_1^0 \to \gamma D^0$ ($\pi^0 D^0$ forbidden)

Method

Belle, 605 fb^{-1}, preliminary



*D*** from *B* decays

$B^- \to D_1^0\pi^- \to (D^0\gamma)\pi^- \to (K^-\pi^+\gamma)\,\pi^-$

background from $B^- \to D^{**0}\pi^- \to (D^0\pi^0)\pi^-$
(D_0^0/D_2^0)

different helicity angle;

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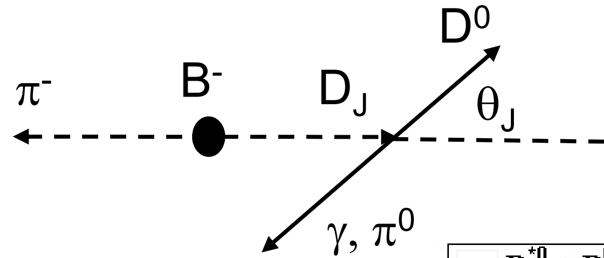

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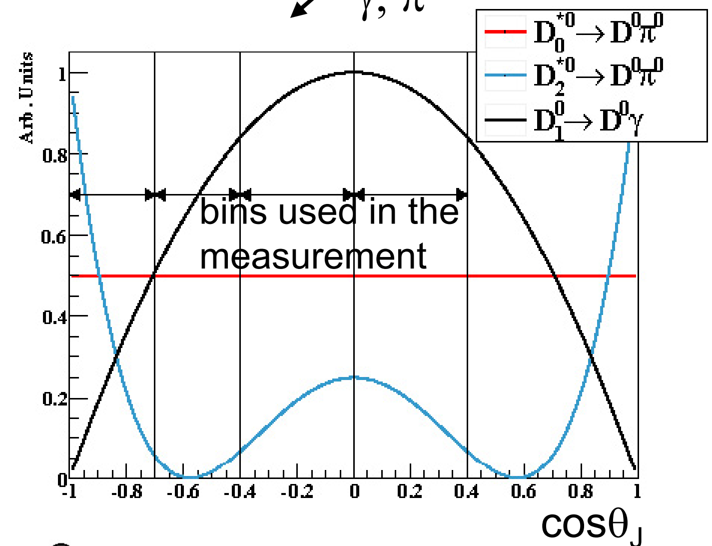
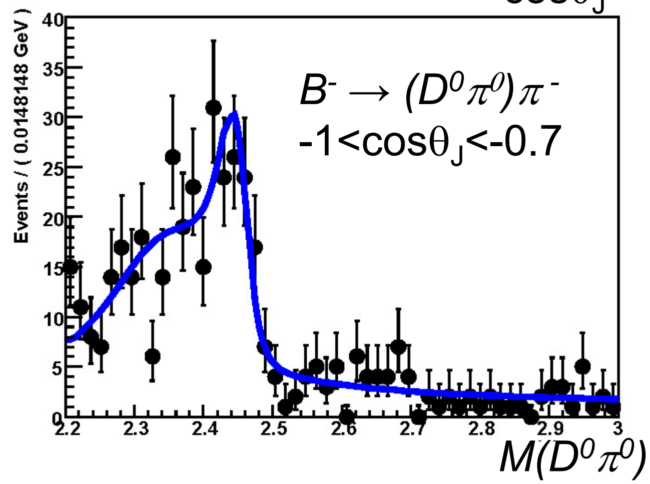


simultaneous fit in bins of $\cos\theta_J$:
$M(D^0\pi^0)$ for $B^- \to (D^0\pi^0)\pi^-$ decays;



MC: feed-down shape & relative ε
for $D^0\pi^0$ reconstr. as $D^0\gamma$

MC using results on D_0^0/D_2^0 properties
from Belle, PRD69, 112002 (2004) 60 fb^{-1}

Method

Belle, 605 fb^{-1}, preliminary

D^{**} from B decays

$B^- \rightarrow D_1^0 \pi^- \rightarrow (D^0\gamma)\pi^- \rightarrow (K^-\pi^+\gamma)\,\pi^-$

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$M(D^0\gamma)$ for $B^- \rightarrow (D^0\gamma)\pi^-$ decays;
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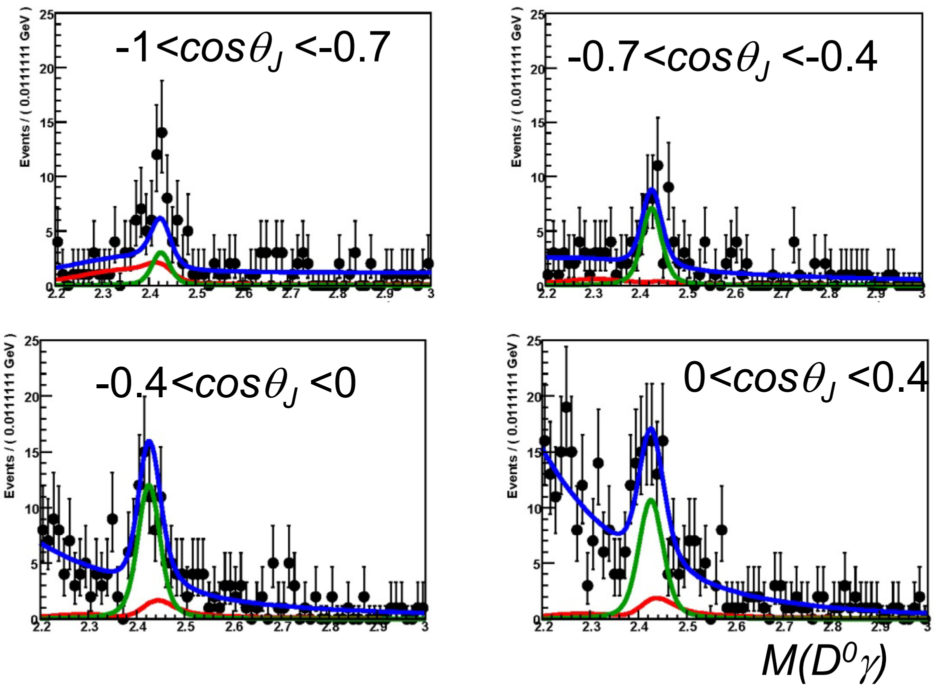

— sum
— signal
— feed-down

$D_1^0 \to D^0\gamma$

Belle, 605 fb^{-1}, preliminary

Result (first observation)

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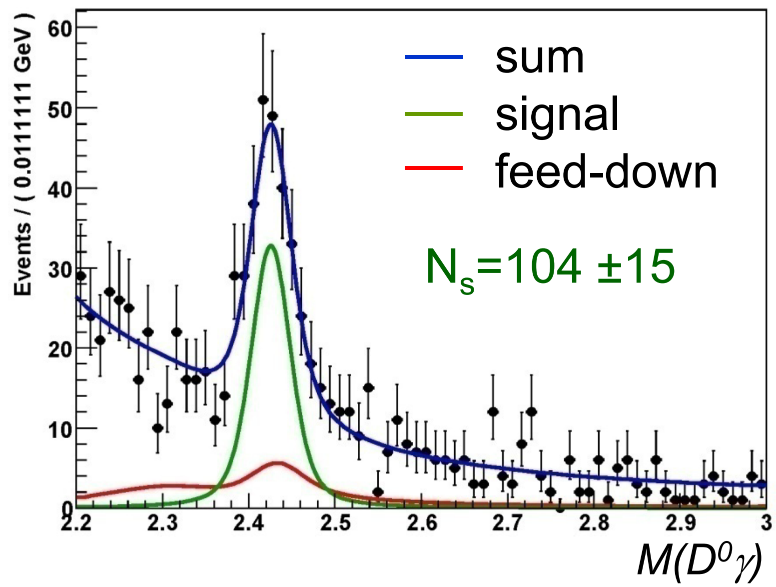
Belle, 605 fb^{-1}, preliminary

Result (first observation)

sum over $cos\theta_J$ bins



$D_1^0 \to D^0\gamma$

Belle, 605 fb^{-1}, preliminary

Result (first observation)

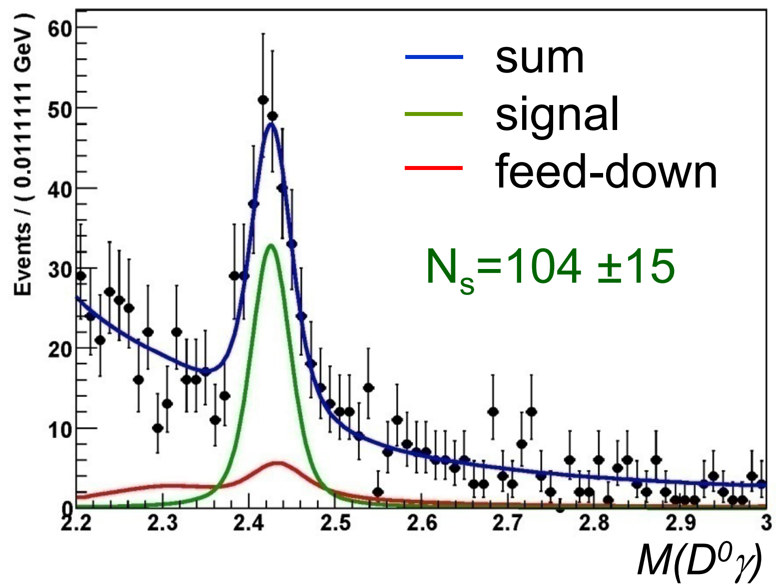
$$\mathcal{B}(B^- \to D_1^0\pi^-)\mathcal{B}(D_1^0 \to D^0\gamma) = (5.0 \pm 0.5 \pm 1.5)\cdot 10^{-5}$$

using $\mathcal{B}(B^- \to D_1^0\pi^-)=(1.5\pm0.6)\cdot 10^{-3}$ from PDG

$\Rightarrow$

$$\mathcal{B}(D_1^0 \to D^0\gamma) = (3.3 \pm 1.7)\%$$

sum over $\cos\theta_J$ bins



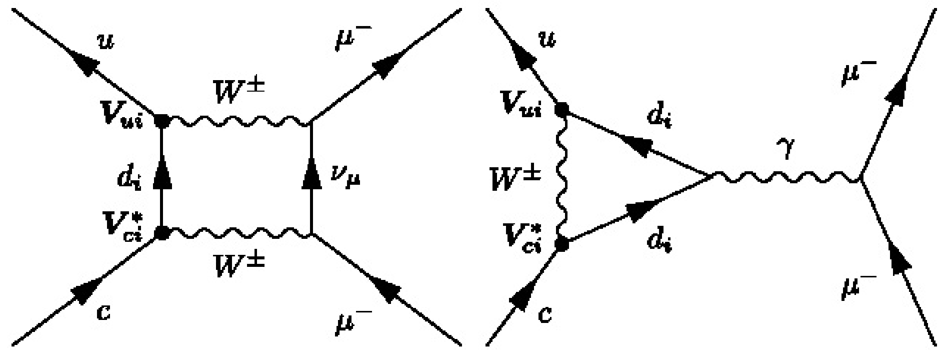
Initial state	Final state	Width (keV)	BR
D_1^0	$D^{*0}\gamma$	85	4.2×10^{-3}
	$D^0\gamma$	574	2.8×10^{-2}

S. Godfrey, PRD72, 054029 (2005)

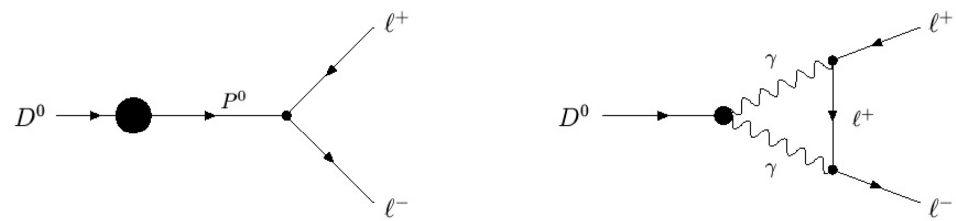
$D^0 \to \ell^+\ell^-$

Motivation

FCNC of *D* mesons
- FCNC of uplike (*c*) quarks;
- ⇒ complementary constraints to *B* (and *K*) rare decays;



short distance, $\mathcal{B}$~10^{-18}



long distance, $\mathcal{B}$~few 10^{-13}

G. Burdman et al., PRD66, 014009 (2002)

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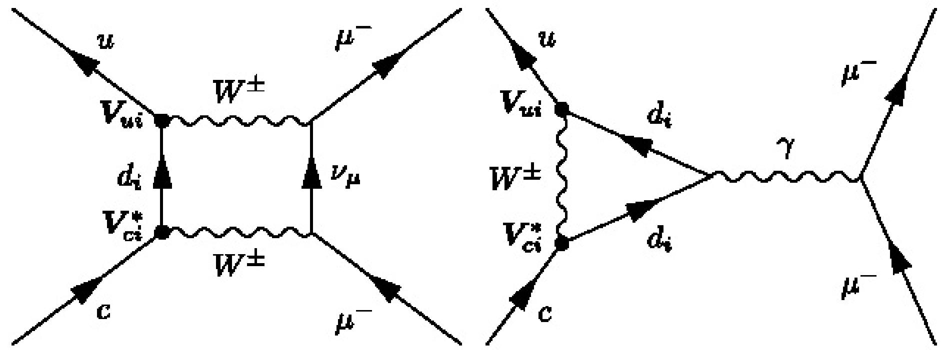

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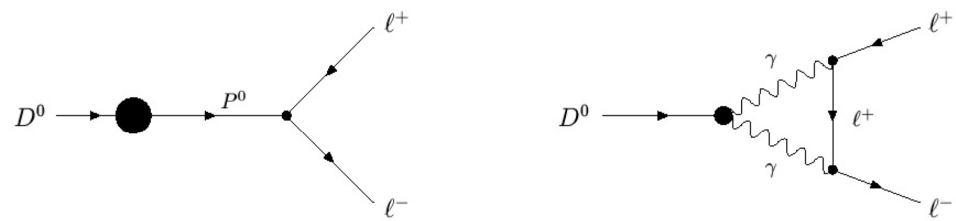

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NP: enhancement of
$\mathcal{B}(D^0 \to \mu^+\mu^-)$, $\mathcal{B}(D^0 \to e^+e^-)$,
by orders of magnitude;
possibility of LFV $\mathcal{B}(D^0 \to e^+\mu^-)$;

example $\not{R}$ SUSY:
$\mathcal{B}(D^0 \to \mu^+\mu^-)$~$4\cdot10^{-6}$
$\mathcal{B}(D^0 \to e^+e^-)$~$10^{-10}$
$\mathcal{B}(D^0 \to e^+\mu^-)$~$10^{-6}$

G. Burdman et al., PRD66, 014009 (2002)

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

Method

Belle, PRD81, 091102 (2010), 660 fb^{-1}

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

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

tagged $D^{*+} \to D^0\pi_s^-$;
blind optimization of

$M(\ell\ell)$, $q=M(\ell\ell\pi_s)-M(\ell\ell)-m_\pi$, E_{miss},

$F.O.M. = \varepsilon_{\ell\ell}/N_{UL}$

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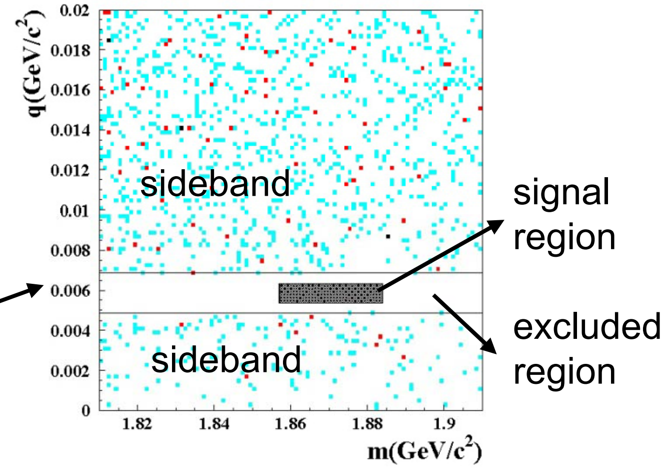
comb. backgr. from q sideband,
linear in M, $\sqrt{q}$;



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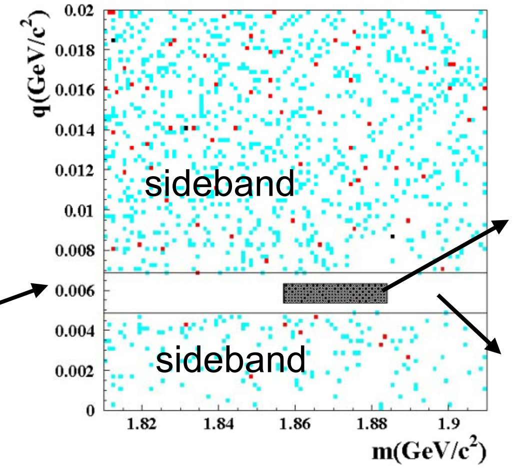
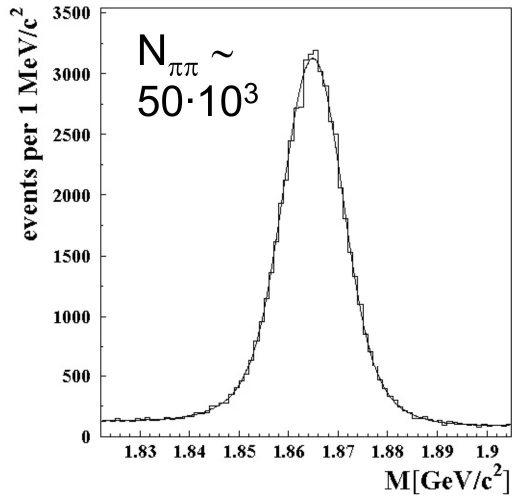


$D^0 \to \pi^+\pi^-$ control sample:
same kinematic selection (except M);
normalization;
misid. background ($\pi \to \mu$), using
measured misid. probabilities $\mathcal{W}(p,\cos\theta)$

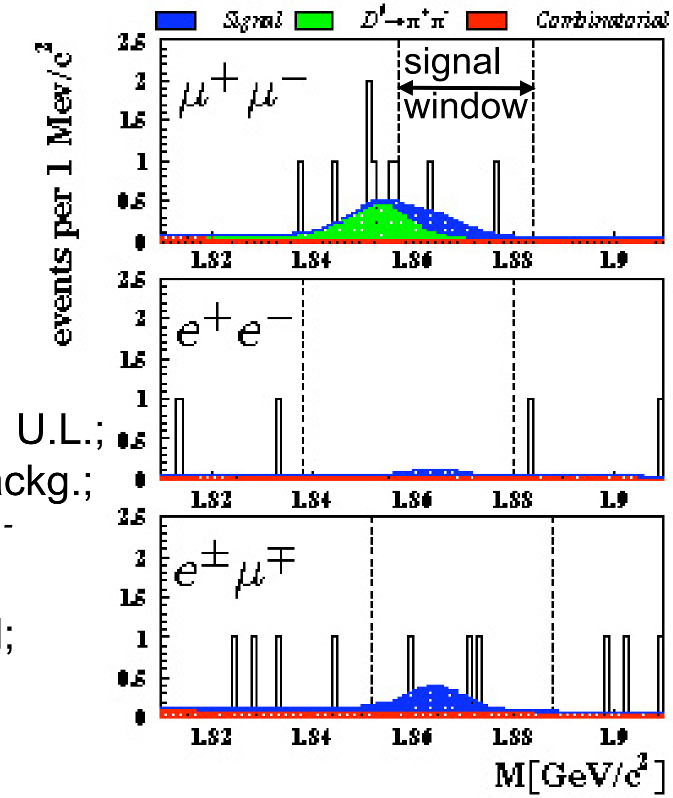


Results

Belle, PRD81, 091102 (2010), 660 fb^{-1}

$D^0 \to \ell^+\ell^-$ yield

signal @ 90% C.L. U.L.;
comb. backg.;
$D^0 \to \pi^+\pi^-$ backg.;
observed;



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$D^0 \to \ell^+\ell^-$ yield

channel	$D^0 \to \mu\mu$	$D^0 \to ee$	$D^0 \to e\mu$
N	2	0	3
N_{bg}^{exp}	3.1±0.1	1.7±0.2	2.6±0.2

U.L.'s calculated from N and N_{bg}^{exp} including systematic uncertainties (negligible)

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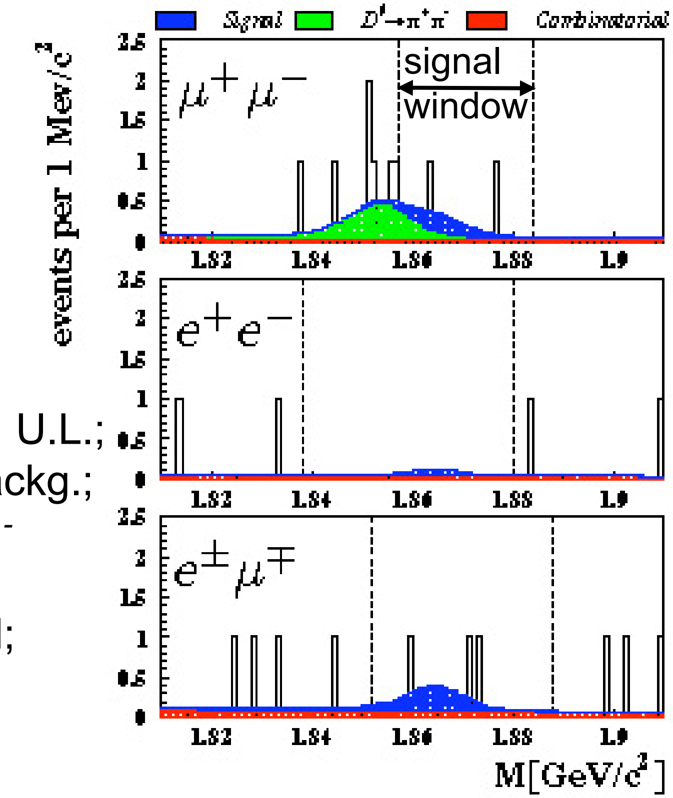

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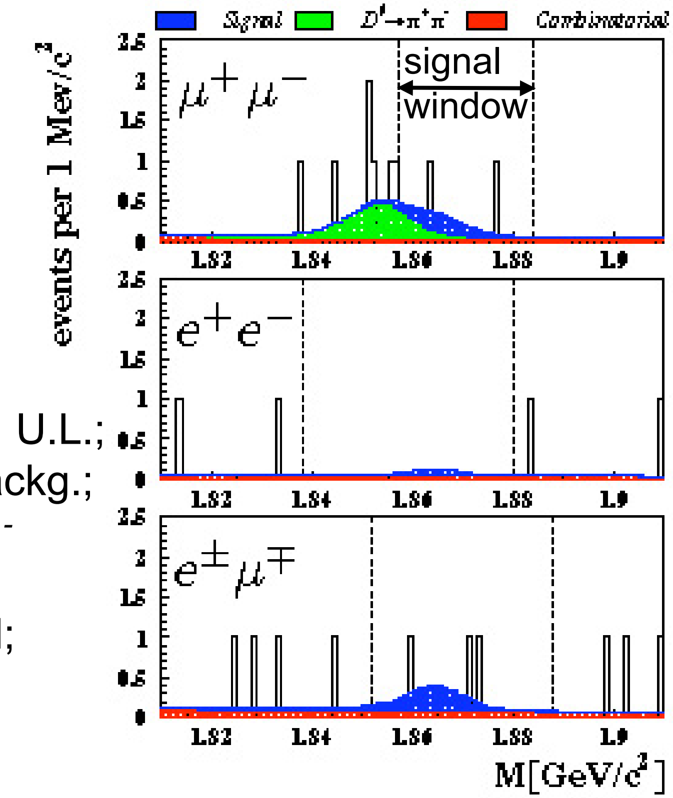

signal @ 90% C.L. U.L.;
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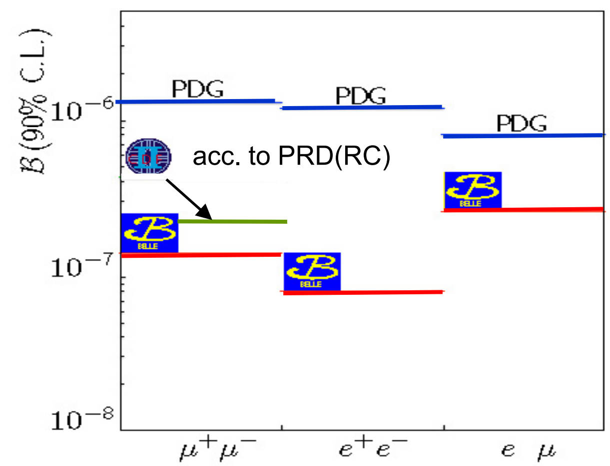
U.L.'s @ 90% C.L.

$$\mathcal{B}(D^0 \to \mu^+\mu^-) < 1.4\cdot 10^{-7}$$
$$\mathcal{B}(D^0 \to e^+e^-) < 0.8\cdot 10^{-7}$$
$$\mathcal{B}(D^0 \to e^\pm\mu^\mp) < 2.6\cdot 10^{-7}$$



Results

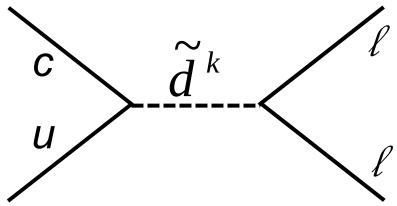
Constraints on NP

$\not{R}$ SUSY:

$$\mathcal{B}^{\not{R}}(D^0 \to \mu\mu) \propto \frac{\tilde{\lambda}'_{22k}\tilde{\lambda}'_{21k}}{m^4_{\tilde{d}^k}}$$

G. Burdman et al., PRD66, 014009 (2002)

constraints on $\not{R}$ couplings;



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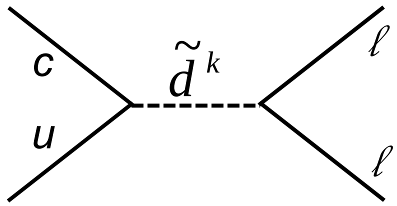

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(genuine, coupling to ℓq;

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I. Dorsner et al., PLB682, 67 (2009)

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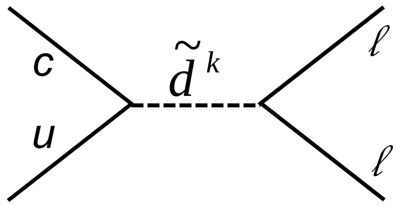

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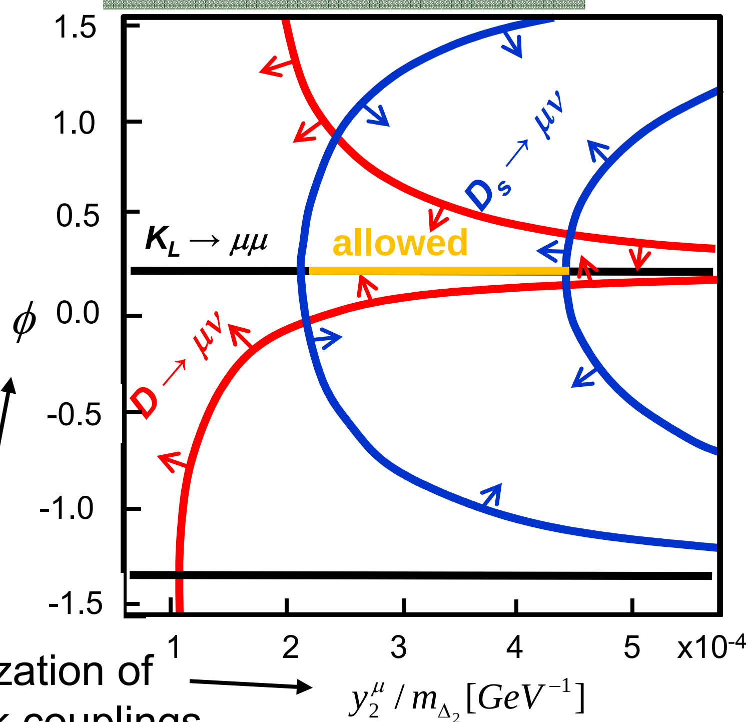
$\mathcal{B}(D^0 \to \mu\mu) < 1.4 \cdot 10^{-7}$

$\mathcal{B}(D_s \to \mu\nu) = (0.590 \pm 0.033)\%$

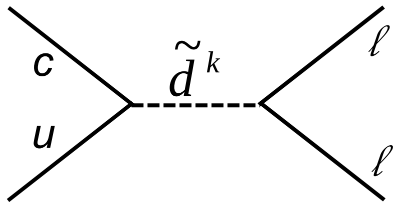
$f_{Ds}(LQCD) = (248.0 \pm 2.5)$ MeV

J. Kamenik, private comm.



parametrization of leptoquark couplings

Results



Constraints on NP

$\not{R}$ SUSY:

$$\mathcal{B}^{\not{R}}(D^0 \to \mu\mu) \propto \frac{\tilde{\lambda}'_{22k}\tilde{\lambda}'_{21k}}{m^4_{\tilde{d}^k}}$$

G. Burdman et al., PRD66, 014009 (2002)

constraints on $\not{R}$ couplings;

leptoquarks:

(genuine, coupling to ℓq;

contribute to $D_{(s)} \to \mu\nu$, $D^0 \to \mu\mu$)

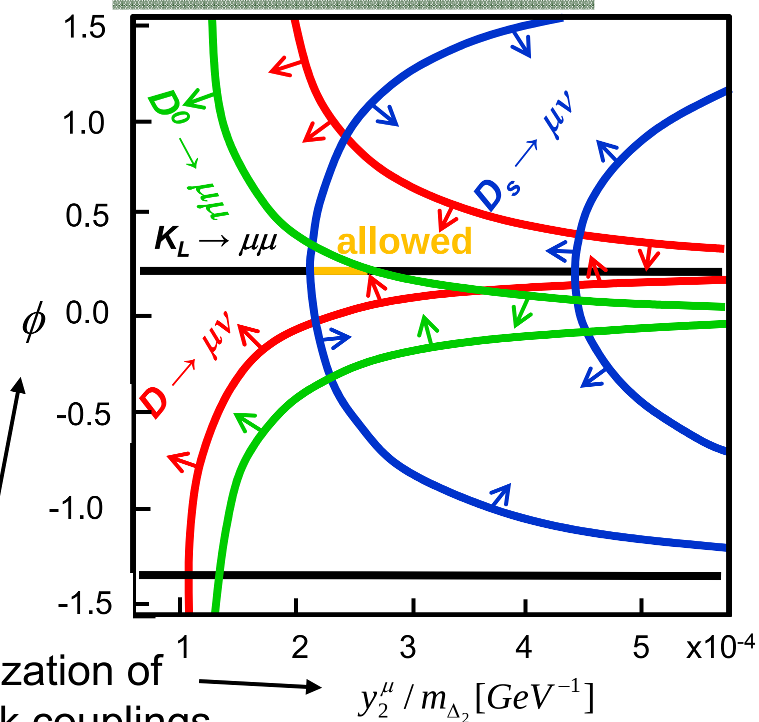
I. Dorsner et al., PLB682, 67 (2009)

$\mathcal{B}(D^0 \to \mu\mu) < 1.4 \cdot 10^{-7}$

$\mathcal{B}(D_s \to \mu\nu) = (0.590 \pm 0.033)\%$

$f_{Ds}(LQCD) = (248.0 \pm 2.5)$ MeV

J. Kamenik, private comm.



parametrization of leptoquark couplings

Summary

- B-factories active also in rare charm decays
- *1P* → *1S* charm meson radiative transition measured for the first time
- best UL's on $D^0 \to \ell^+\ell^-$
- FCNC of charm:
  complementary constraints to rare *B* decays

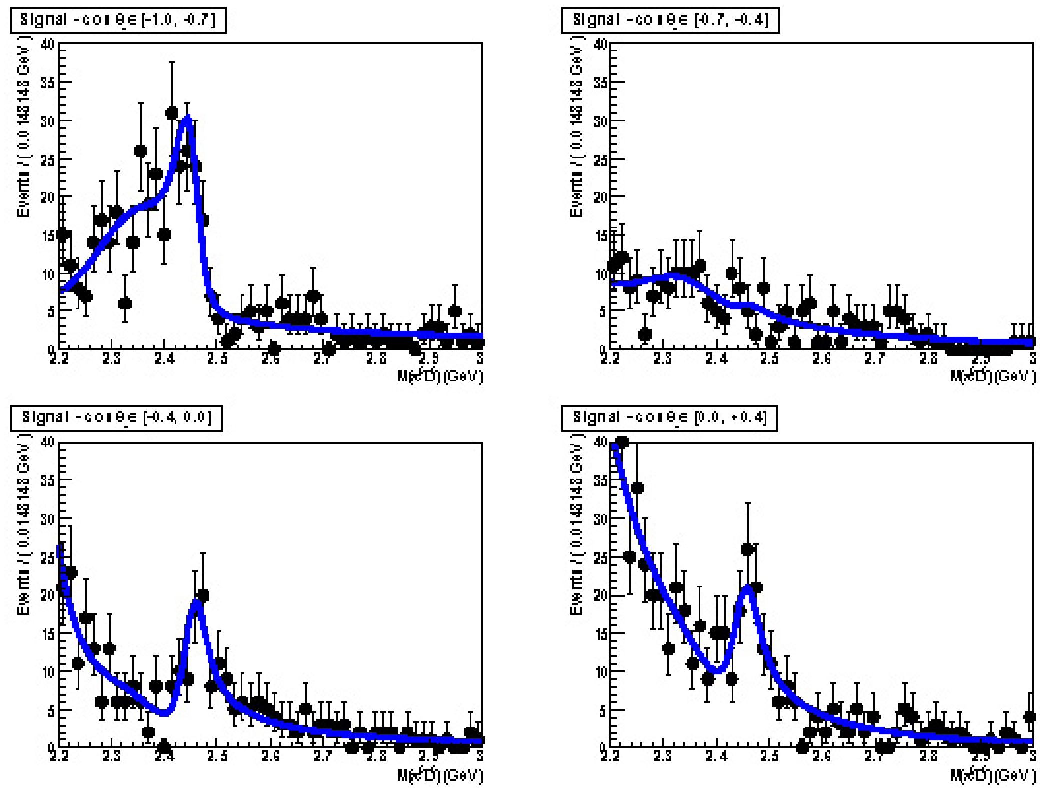
Additional info

*D*** from *B* decays

$B^- \to D_1^0\pi^- \to (D^0\gamma)\pi^-$
$\to (K^-\pi^+\gamma)\,\pi^-$

background from
$B^- \to D^{**0}\pi^- \to (D^0\pi^0)\pi^-$
(D_0^0/D_2^0)
different helicity angle;

simultaneous fit in bins of $\cos\theta_J$:
$M(D^0\pi^0)$ for $B^- \to (D^0\pi^0)\pi^-$ decays



Additional info

Normalization $D^0 \to \pi^+\pi^-$
tagged $D^{*+} \to D^0\pi_s^-$;

$$f \equiv \frac{1}{N_{\pi\pi}} \frac{\epsilon_{\pi\pi}}{\epsilon_{\ell\ell}} \mathcal{B}\left(D^0 \to \pi^+\pi^-\right)$$

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

	$D^0 \to \mu^+\mu^-$	$D^0 \to e^+e^-$	$D^0 \to e^\pm\mu^\mp$
N_{bkg}	3.1 ± 0.1	1.7 ± 0.2	2.6 ± 0.2
N	2	0	3
$\epsilon_{\ell\ell}[\%]$	7.02 ± 0.34	5.27 ± 0.32	6.24 ± 0.27
$\epsilon_{\pi\pi}[\%]$	12.42 ± 0.10	10.74 ± 0.09	11.22 ± 0.09
$f[10^{-8}]$	$4.84(1 \pm 5.3\%)$	$6.47(1 \pm 6.4\%)$	$5.48(1 \pm 4.8\%)$
UL $[10^{-7}]$	1.4	0.79	2.6

F.O.M.= $\varepsilon_{\ell\ell} / N_{UL}$
background estimated from tuned MC (6x data)

UL's

Channel.	n	b	U.L.
$\mu^+\mu^-$	2	3.1 ± 0.1	2.98
e^+e^-	0	1.7 ± 0.2	1.22
$e^\pm\mu^\mp$	3	2.6 ± 0.2	4.83

FC w/o syst.

2.97