UNIVERSITY OF LIVERPOOL

THE ROYAL SOCIETY

Rare Charm Decays & $f(D_s)$

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BABAR™

What is Rare?

(A Definition)

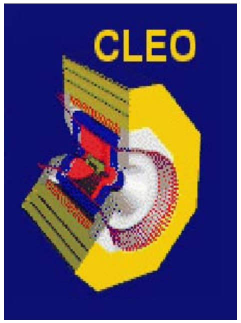
Suppressed or Forbidden by SM:

- Flavor Changing Neutral Currents
  - ($c \rightarrow u$)
- GIM suppressed:
  - $D^+ \rightarrow \pi^+ e^+ e^-$
  - $D \rightarrow X\gamma$
- Lepton Flavor Violation & Lepton Number Violation – If seen may indicate majorana nature of neutrino:
  - $D^+ \rightarrow \pi^- e^+ e^+$,
  - $D^+ \rightarrow \pi^+ e^+ \mu^-$
- Will not cover Radiative Decays, as the long distance contributions are not easily separated from short distance contributions

From: **Flavor Physics in the Quark Sector**:
hep-ph/0907.53862008:

- It is clear that due to the relatively little experimental progress in this area within the last decade and the large data sets from the flavor factories, that there is a several orders of magnitude in precision to be gained from re-reanalyzing these measurements with meaningful limits to be derived which may have the potential to constrain parameter space for many new physics models.

$D_{(s)}^+ \rightarrow hee$



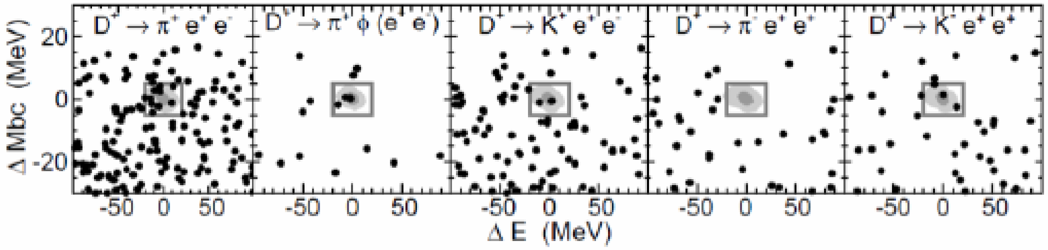


FIG. 1. Scatter plots of ΔM_{bc} vs ΔE. The two contours for each mode enclose regions determined with signal MC simulation to contain 50% and 85% of signal events, respectively. The signal region, defined by $(\Delta E, \Delta M_{bc}) = (\pm 20\,\mathrm{MeV}, \pm 5\,\mathrm{MeV})$, is shown as a box.

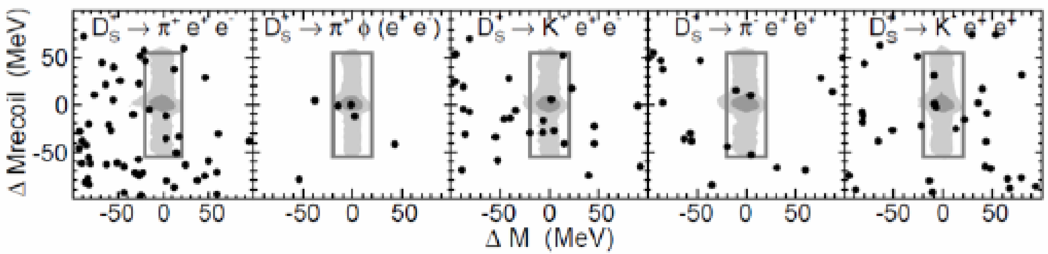


FIG. 2. Scatter plots of ΔM_{recoil} vs ΔM. The two contours for each mode enclose regions determined with signal MC simulation to contain 40% and 85% of signal events, respectively. The signal region, defined by $(\Delta M, \Delta M_{recoil}) = (\pm 20\,\mathrm{MeV}, \pm 55\,\mathrm{MeV})$, is shown as a box.

D^+
Ecm = 3.774 GeV
L = 818 pb^{-1}
N_{DD} = 2.4 x 10^6

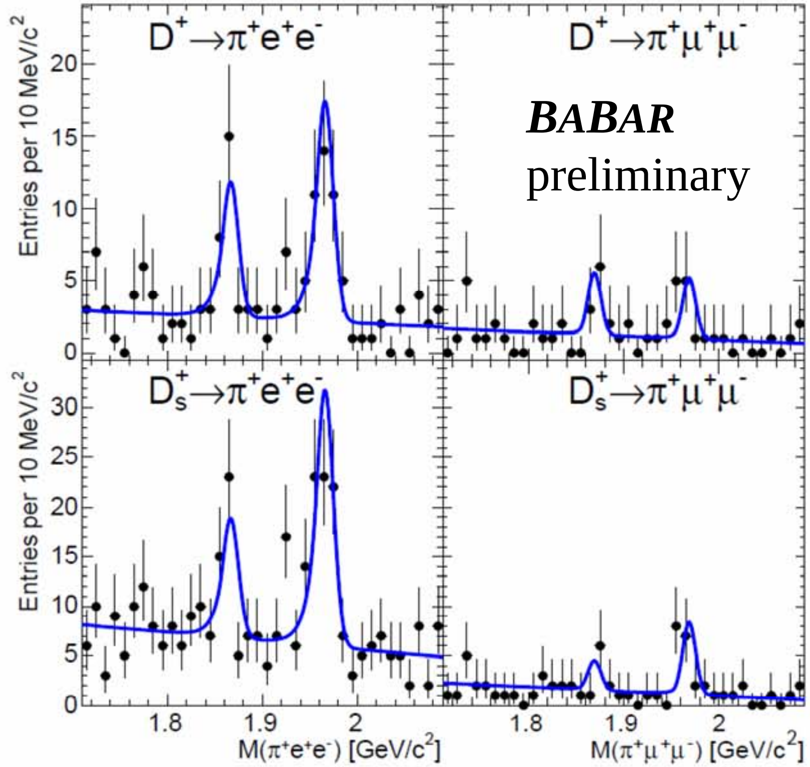
D_s^+
Ecm = 4.170 GeV
L = 602 pb^{-1}
N_{DsDs^*} = 0.6 x 10^6

Phys.Rev.D82:092007,2010.

Channel	N	ϵ (%)	N_{exp}	N_{obs}	$\mathcal{C}(N_{obs}\|N_{exp})$	$\mathcal{B}$
$D^+ \to \pi^+ e^+ e^-$	4.76×10^6	33.9	5.7	9	9.3	$< 5.9 \times 10^{-6}$
$D^+ \to \pi^- e^+ e^+$	4.76×10^6	43.5	1.3	0	2.3	$< 1.1 \times 10^{-6}$
$D^+ \to K^+ e^+ e^-$	4.76×10^6	23.1	4.9	2	3.2	$< 3.0 \times 10^{-6}$
$D^+ \to K^- e^+ e^+$	4.76×10^6	35.3	1.2	3	5.8	$< 3.5 \times 10^{-6}$
$D^+ \to \pi^+ \phi(e^+ e^-)$	4.76×10^6	46.2	0.3	4		$(1.7^{+1.4}_{-0.9} \pm 0.1) \times 10^{-6}$
					7.9	$< 3.7 \times 10^{-6}$
$D_s^+ \to \pi^+ e^+ e^-$	1.10×10^6	24.3	6.7	6	5.6	$< 2.2 \times 10^{-5}$
$D_s^+ \to \pi^- e^+ e^+$	1.10×10^6	33.4	2.2	4	6.2	$< 1.8 \times 10^{-5}$
$D_s^+ \to K^+ e^+ e^-$	1.10×10^6	17.3	3.0	7	9.3	$< 5.2 \times 10^{-5}$
$D_s^+ \to K^- e^+ e^+$	1.10×10^6	27.7	4.1	4	5.0	$< 1.7 \times 10^{-5}$
$D_s^+ \to \pi^+ \phi(e^+ e^-)$	1.10×10^6	33.9	0.7	3		$(0.6^{+0.8}_{-0.4} \pm 0.1) \times 10^{-5}$
					6.2	$< 1.8 \times 10^{-5}$

$X_c \to hll$ – Control Modes

- Before unblinding, checked procedure using ϕ resonance
  - Reverse l^+l^- mass cut:
    $0.995 < m(e^+e^-) < 1.030$ GeV/c^2
    $1.005 < m(\mu^+\mu^-) < 1.030$ GeV/c^2
- Significant signal seen in 3 of 4 modes
- Yield is about as expected
  - 1.5σ low in $D_s^+ \to \pi\phi$, $\phi \to e^+e^-$



Decay mode	Yield (events)	Efficiency (%)	Expected yield (events)
$D^+ \to \pi^+\phi_{e^+e^-}$	$21.8 \pm 5.8 \pm 1.5$	5.65	22.2 ± 1.1
$D^+ \to \pi^+\phi_{\mu^+\mu^-}$	$7.5 \pm 3.4 \pm 1.4$	1.11	4.5 ± 0.4
$D_s^+ \to \pi^+\phi_{e^+e^-}$	$62.8 \pm 9.9 \pm 3.0$	6.46	79 ± 3
$D_s^+ \to \pi^+\phi_{\mu^+\mu^-}$	$12.7 \pm 4.3 \pm 2.6$	1.07	13.1 ± 1.2

BABAR preliminary

$X_c \rightarrow hll$

Comparisons to Previous Limits

- Most channels improve upon previous limits
  - Many modes by more than order of magnitude
  - Dimuon modes have the worst limits (lowest efficiency)

Decay mode	BF UL (10^{-6}) 90% CL	Previous	Experiment
$D^+ \to \pi^+ e^+ e^-$	1.1	5.9	CLEO-c
$D^+ \to \pi^+ \mu^+ \mu^-$	6.5	3.9	D0
$D^+ \to \pi^+ e^+ \mu^-$	2.9	34	E791
$D^+ \to \pi^+ \mu^+ e^-$	3.6	34	E791
$D_s^+ \to \pi^+ e^+ e^-$	13	22	CLEO-c
$D_s^+ \to \pi^+ \mu^+ \mu^-$	43	26	FOCUS
$D_s^+ \to \pi^+ e^+ \mu^-$	12	610	E791
$D_s^+ \to \pi^+ \mu^+ e^-$	20	610	E791
$D^+ \to K^+ e^+ e^-$	1.0	3.0	CLEO-c
$D^+ \to K^+ \mu^+ \mu^-$	4.3	9.2	FOCUS
$D^+ \to K^+ e^+ \mu^-$	1.2	68	E791
$D^+ \to K^+ \mu^+ e^-$	2.8	68	E791
$D_s^+ \to K^+ e^+ e^-$	3.7	52	CLEO-c
$D_s^+ \to K^+ \mu^+ \mu^-$	21	36	FOCUS
$D_s^+ \to K^+ e^+ \mu^-$	14	630	E791
$D_s^+ \to K^+ \mu^+ e^-$	9.7	630	E791
$\Lambda_c^+ \to p e^+ e^-$	5.5	340	E653
$\Lambda_c^+ \to p \mu^+ \mu^-$	44		
$\Lambda_c^+ \to p e^+ \mu^-$	9.9		
$\Lambda_c^+ \to p \mu^+ e^-$	19		

Decay mode	BF UL (10^{-6}) 90% CL	Previous	Experiment
$D^+ \to \pi^- e^+ e^+$	1.9	1.1	CLEO-c
$D^+ \to \pi^- \mu^+ \mu^+$	2.0	4.8	FOCUS
$D^+ \to \pi^- \mu^+ e^+$	2.0	50	E791
$D_s^+ \to \pi^- e^+ e^+$	4.1	18	CLEO-c
$D_s^+ \to \pi^- \mu^+ \mu^+$	14	29	FOCUS
$D_s^+ \to \pi^- \mu^+ e^+$	8.4	730	E791
$D^+ \to K^- e^+ e^+$	0.9	3.5	CLEO-c
$D^+ \to K^- \mu^+ \mu^+$	10	13	FOCUS
$D^+ \to K^- \mu^+ e^+$	1.9	130	E687
$D_s^+ \to K^- e^+ e^+$	5.2	17	CLEO-c
$D_s^+ \to K^- \mu^+ \mu^+$	13	13	FOCUS
$D_s^+ \to K^- \mu^+ e^+$	6.1	680	E791
$\Lambda_c^+ \to \overline{p} e^+ e^+$	2.7		
$\Lambda_c^+ \to \overline{p} \mu^+ \mu^+$	9.4		
$\Lambda_c^+ \to \overline{p} \mu^+ e^+$	16		

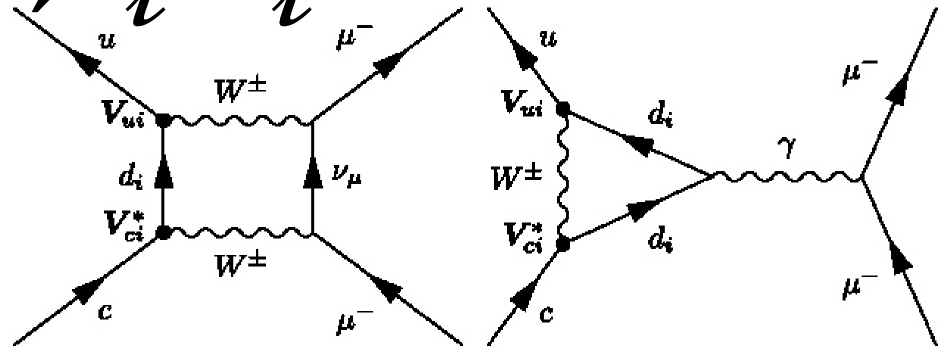
BABAR
preliminary

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

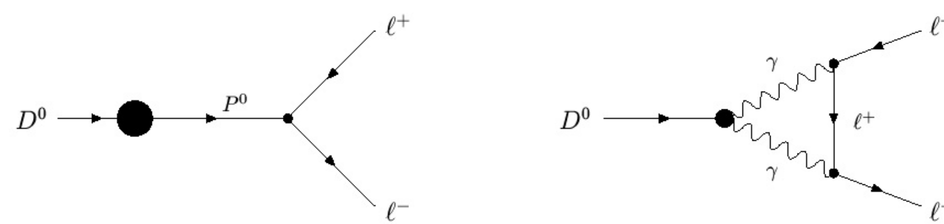
Motivation

FCNC of *D* mesons

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



short distance, $\mathrm{B}\sim 10^{-18}$



long distance, $\mathrm{B}\sim$few 10^{-13}

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

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

example $\not{R}$ SUSY:
$\mathrm{B}(D^0 \to \mu^+\mu^-)\sim 4\cdot 10^{-6}$
$\mathrm{B}(D^0 \to e^+e^-)\sim 10^{-10}$
$\mathrm{B}(D^0 \to e^+\mu^-)\sim 10^{-6}$

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

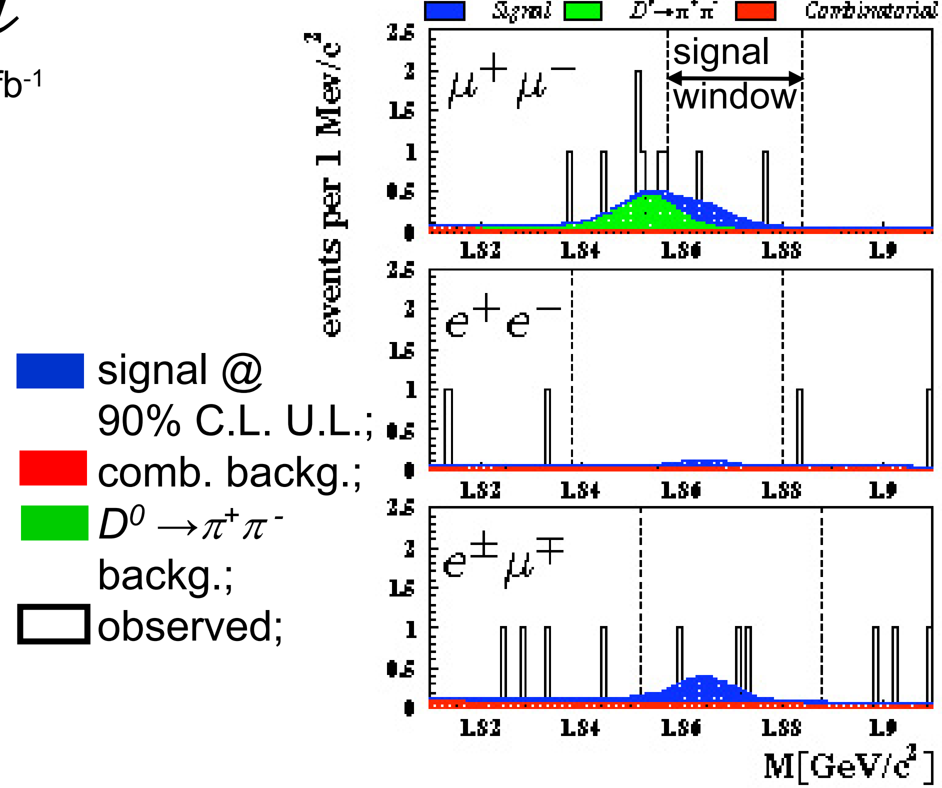
Belle, PRD81, 091102 (2010), 660 fb^{-1}

Results

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

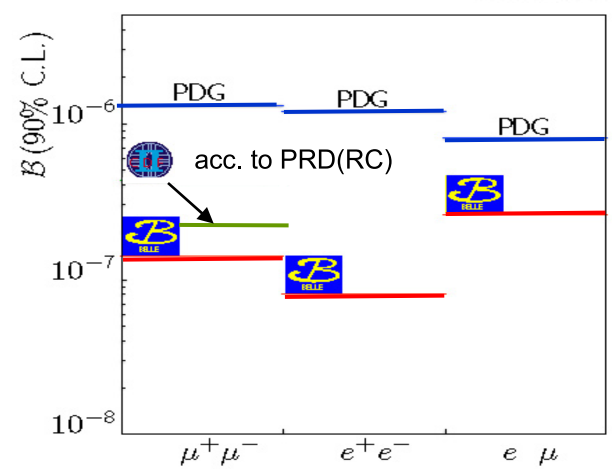
channel	$D^0 \rightarrow \mu\mu$	$D^0 \rightarrow ee$	$D^0 \rightarrow e\mu$
N	2	0	3
N_{bg}^{exp}	3.1±0.1	1.7±0.2	2.6±0.2

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



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

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



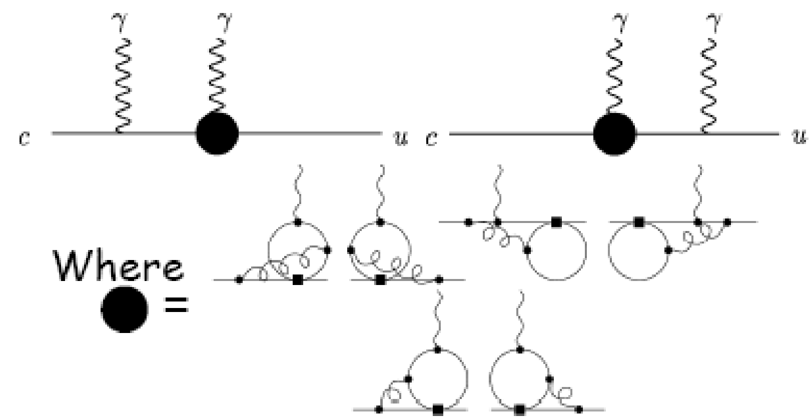
$D^0 \rightarrow \gamma\gamma$

- FCNC Decay
  - Forbidden at the tree-level
  - 1-loop GIM suppressed

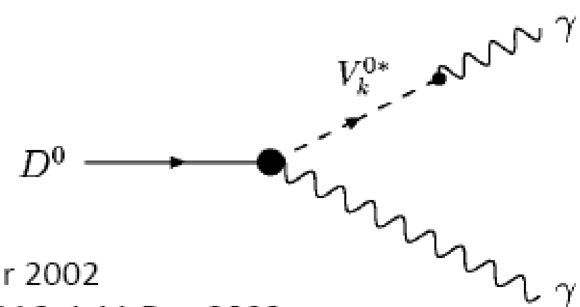
- Dominated by long distance effects [1]
  - Short-range (2-loop dominate):
    $B(D^0 \to \gamma\gamma) \approx 3 \times 10^{-11}$
  - Long-range (VMD contribution dominates):
    $B(D^0 \to \gamma\gamma) \approx 3.5 \times 10^{-8}$

- However, possible 10^2 enhancement from new physics (gluino-exchange of MSSM) [2]
- Within the range of BaBar sensitivity.
- Excellent (but difficult) mode to search for new physics

Short Distance

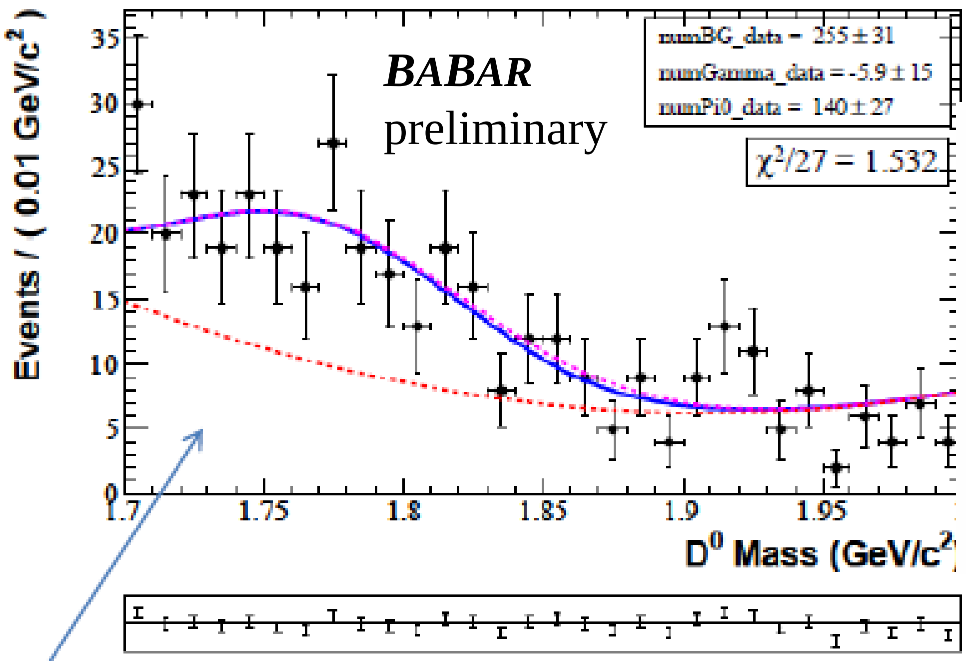


Long Distance



[1] Burdman et al. hep-ph/0112235v2 1 Mar 2002
[2] S. Prelovsek and D. Wyler, hep-ph/0012116v1 11 Dec 2000

$D^0 \to \gamma\gamma$



Systematics

Systematic	$\sigma(D^0 \to \gamma\gamma)$ (%)	$\sigma(D^0 \to \pi^0\pi^0)$ (%)
Tracking (K_S^0) and Vertexing	0.96	0.96
Photon Reconstruction	0.60	3.00
π^0 Veto	1.80	-
D^{*+} Fragmentation	0.02	0.03
Signal Shape	*	0.20
Background Shape	*	0.80
Cut selection	*	2.50
$D^0 \to K_s^0\pi^0$ Signal Shape	0.53	0.17
$D^0 \to K_s^0\pi^0$ Background Shape	0.01	0.63
$D^0 \to K_s^0\pi^0$ Cut selection	0.76	0.76
Total Systematic Effect	*	4.23

[*] Near-zero relative errors are ill-defined and is accounted for using toy MC simulation

- $D^0 \to \gamma\gamma$
  - $B(D^0 \to \gamma\gamma) < 2.51 \times 10^{-6}$
  - About factor of 10 improvement on previous CLEO measurement

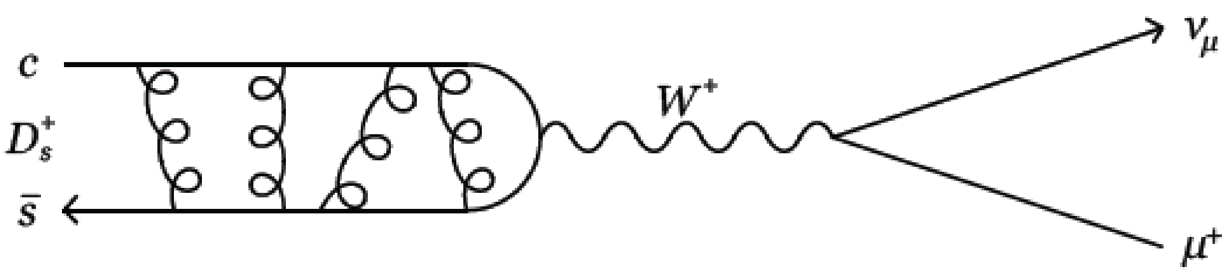
State of flux

- searching for FCNC, LFV, or LNV modes in the charm sector is a relatively inviting place to investigate new physics in the SM.
- Similar arguments hold for rare decays in the K and B sector. However, the charm system is unique in that it couples an up-type quark to new physics.
- more recently measurements are starting to confine the allowed parameter space of R-parity violating super-symmetric models.

$f(D_s)$

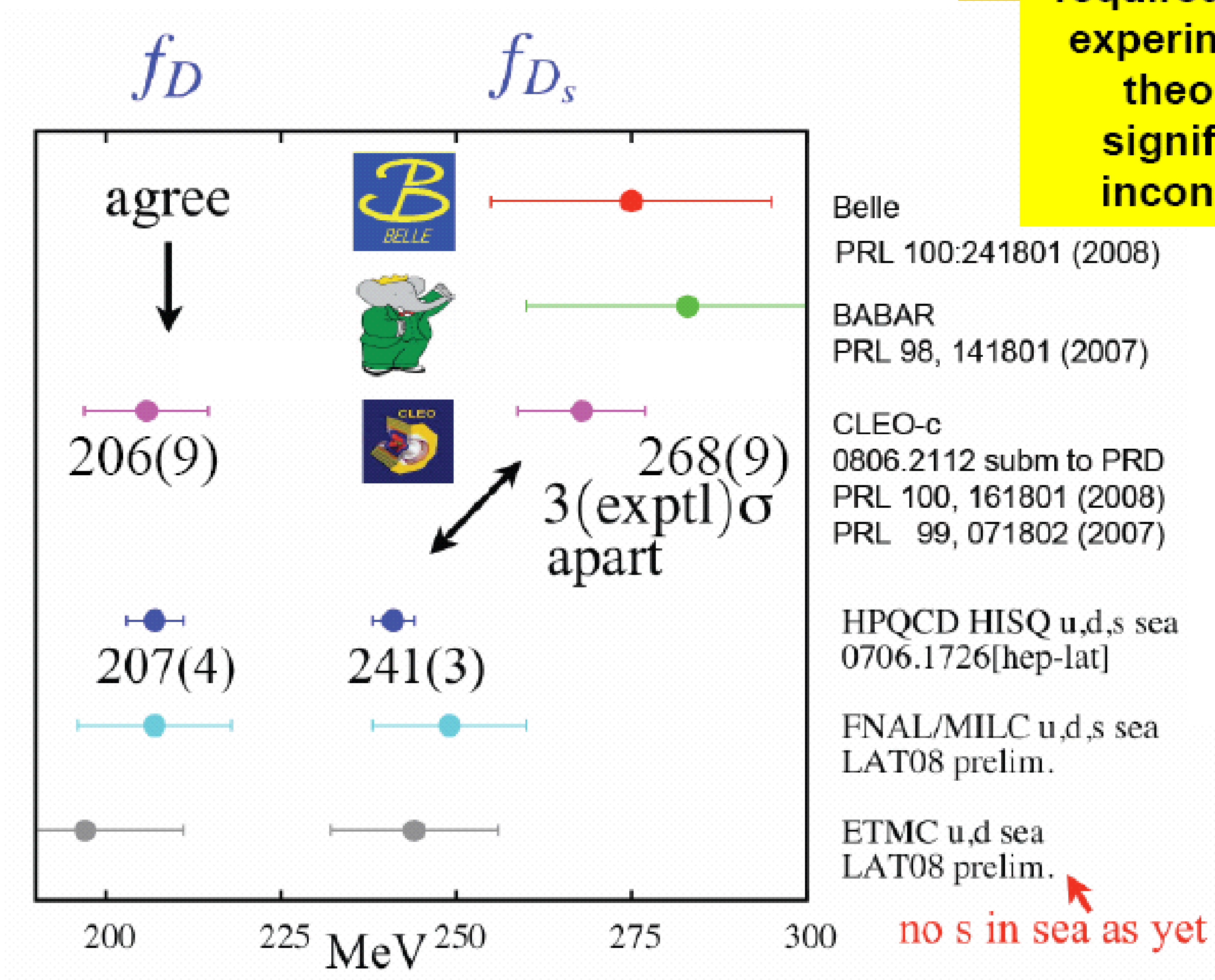
- In the standard model the leptonic decays of the D_s meson provide a clean way to measure the decay constant f_{Ds}:

$$B(D_s \to l\upsilon) = \frac{\Gamma(D_s \to l\upsilon)}{\Gamma(D_s \to all)} = \frac{G_F^2}{8\pi}|V_{cs}|^2 f_{D_s}^2 M_{D_s}^3 \left(\frac{m_l}{M_{D_s}}\right)^2 \left(1 - \frac{m_l^2}{M_{D_s}^2}\right)^2$$



From CKM08

More data required to see if experiment and theory are significantly inconsistent



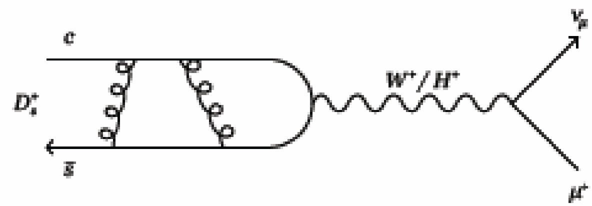
Many Averages, eg:

Previously 3.8 σ disagreement.

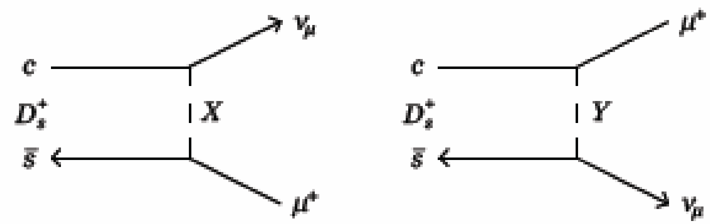
Phys.Rev.Lett.100:241802,2008.

& Many Explanations:

- This discrepancy could be the result of new physics:
  - Charged Higgs boson



  - Leptoquarks



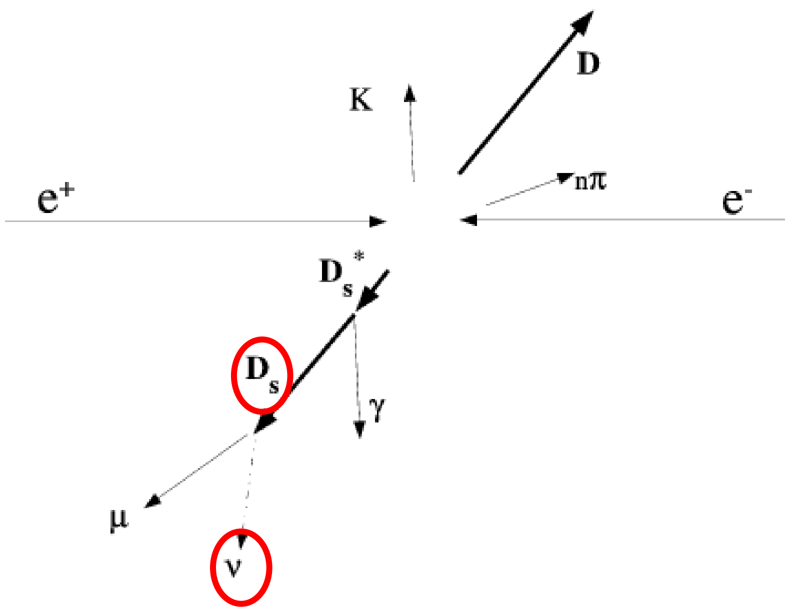
[Phys. Rev. D RC **82**, 091103 (2010)]

f(D_s) Analysis Strategy

Event reconstruction :

$$e^+e^- \rightarrow c\,\bar{c} \rightarrow D\,K\,X\,D_s^{*-} \rightarrow D\,K\,X\,\gamma\,\ell^-\,\bar{\nu}$$

$$\quad\quad\quad\quad\quad\quad\quad\quad\quad \llcorner D_s^-\,\gamma$$



X = reconstructed pions

- A normalization sample is created by D_s Tagging using the recoil mass:

$$m_{Ds}^2 = [p_{e+} + p_{e-} - (p_D + p_K + p_X + p_\gamma)]^2$$

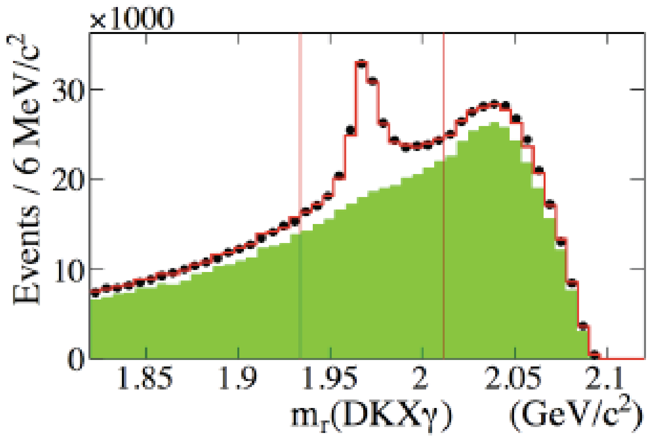
- $D_s^- \rightarrow \mu^-\nu$, $e^-\nu$ events can be can be detected by calculating the mass of the neutrino:

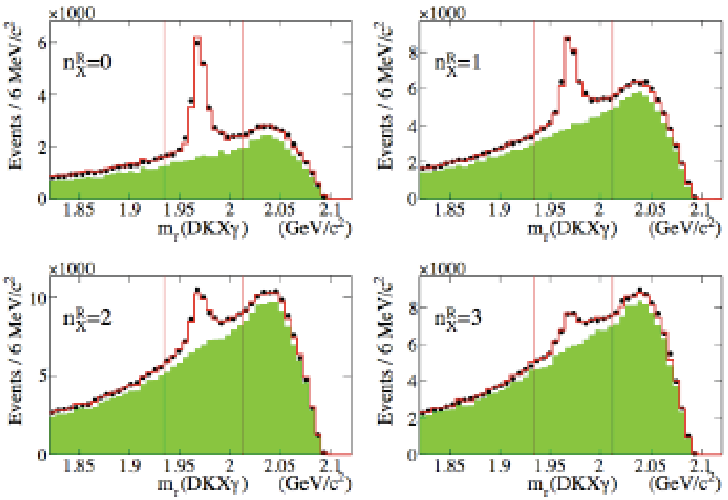
$$m_\nu^2 = [p_{e+} + p_{e-} - (p_D + p_K + p_X + p_\gamma + p_\ell)]^2$$

- $D_s^- \rightarrow \tau^-\nu$ events are counted using the distribution of extra energy in the EMC which should peak towards 0.

$f(D_s)$ The Denominator

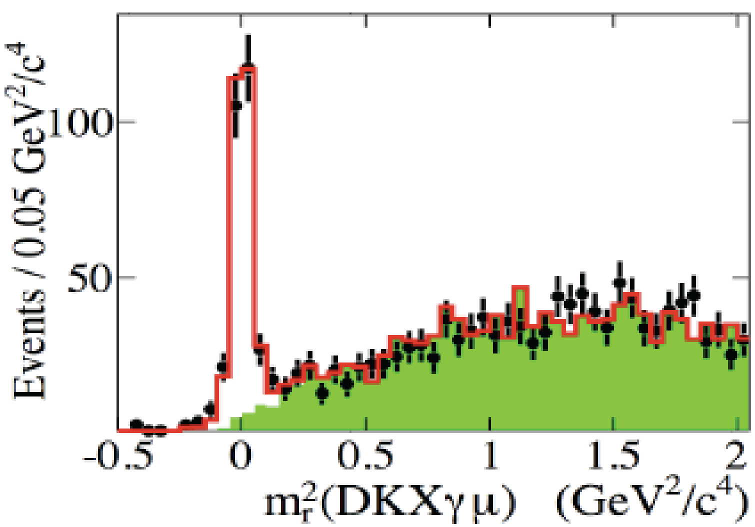
- The yield of Ds mesons is determined using a 2-D fit to:
  - Mass recoiling against the DKX γ system
  - n_X^R, the reconstructed number of pions in the fragmentation system.
- We obtain $n(D_s) = 67{,}200 \pm 1500$.





$D_s \rightarrow \mu\upsilon$ reconstruction

- **A muon** candidate is identified, using standard particle identification techniques.
- The mass of the D_s candidate is constrained to the mass provided by the Particle Data Group.
- We require $E_{Extra} < 1$ GeV.
- A kinematic fit to the whole event is performed.
- A binned maximum likelihood fit to the mass squared recoiling against the DKX $\gamma\ \mu$ system, m_m^2, is performed.

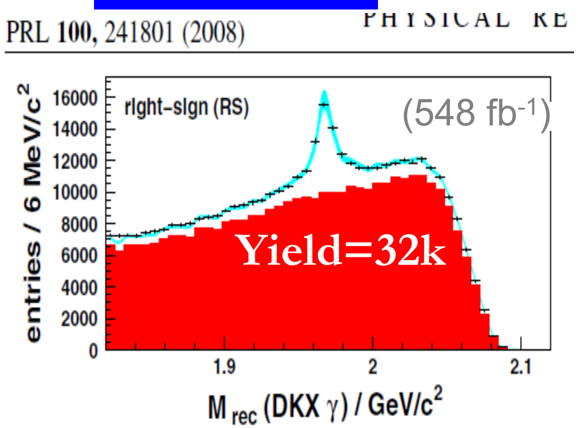


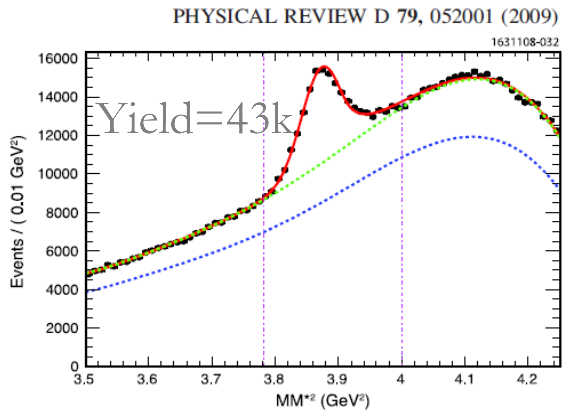
We obtain events 274 ± 17, which yields $B(D_s \rightarrow \mu\ \nu) = (6.02 \pm 0.37 \pm 0.33) \times 10^{-3}$

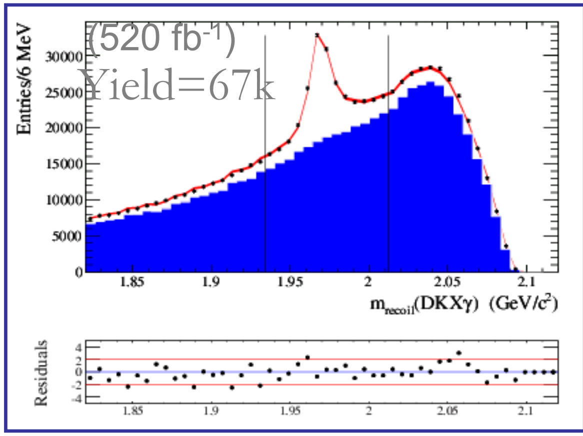
[Phys. Rev. D RC **82**, 091103 (2010)]

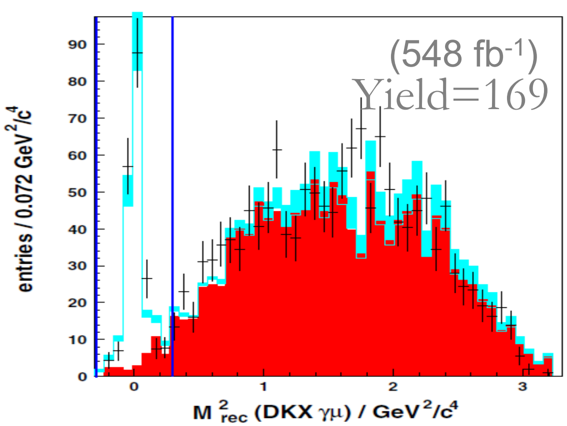
Comparison to CLEOc and BELLE

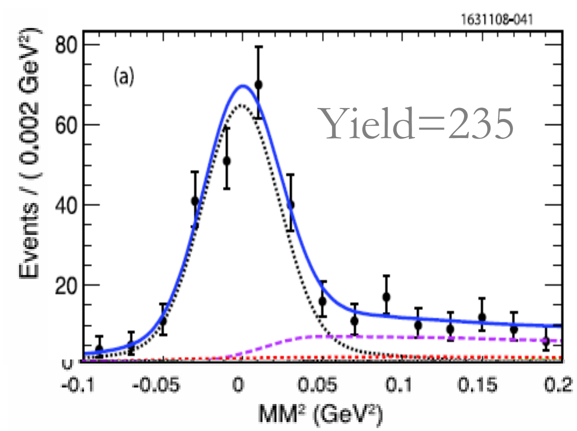
[Phys. Rev. D RC **82**, 091103 (2010)]

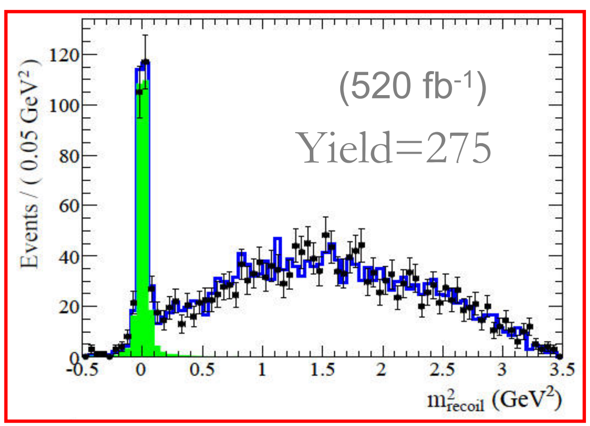












[Phys. Rev. D RC **82**, 091103 (2010)]

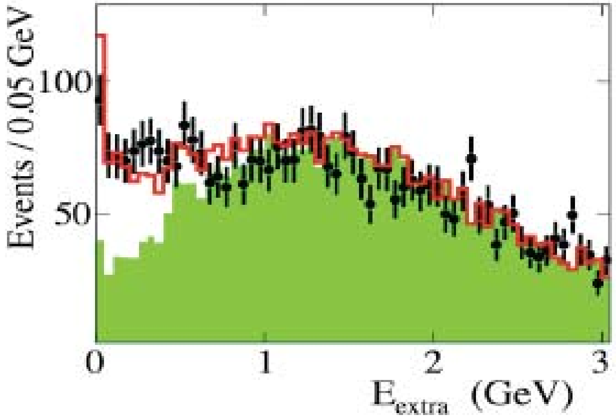
$D_s \to \tau\ \nu$ reconstruction

$\tau \to \pi\nu$ impossible due to backgrounds

- We measure the final states
  - $\tau \to e\nu\ \nu$
  - $\tau \to \mu\ \nu\ \nu$ first measurement since LEP
- Particle identification procedure remains the same as for $D_s \to e\nu$ and $D_s \to \mu\ \nu$ as appropriate.
- For $D_s \to \tau\ \nu$; $\tau \to \mu\ \nu\ \nu$ we require $m_m^2 > 0.3$ GeV^{2}c^{-4} to remove backgrounds from $D_s \to \mu\ \nu$ events.
- For $D_s \to \tau\ \nu$ decays we perform a binned maximum likelihood fit to E_{Extra}.

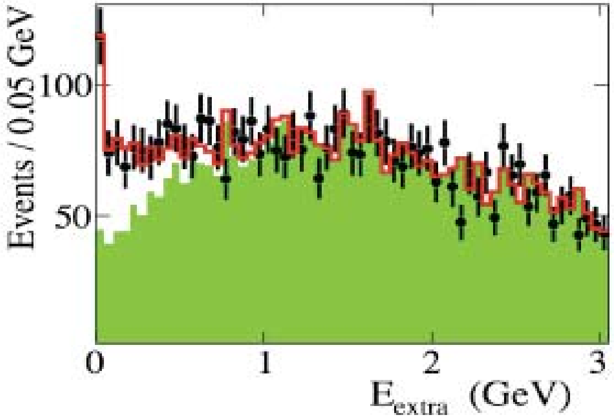
[Phys. Rev. D RC **82**, 091103 (2010)]

$D_s \rightarrow \tau\ \nu$ reconstruction



Left: $\tau \rightarrow e\,\nu\ \nu$

Right: $\tau \rightarrow \mu\ \nu\ \nu$



Mode	Yield	Branching fraction
$D_s \rightarrow \tau\ \nu$; $\tau \rightarrow e\,\nu\ \nu$	408 ± 42	$(4.91 \pm 0.50 \pm 0.66) \times 10^{-2}$
$D_s \rightarrow \tau\ \nu$; $\tau \rightarrow \mu\ \nu\ \nu$	340 ± 32	$(5.07 \pm 0.48 \pm 0.54) \times 10^{-2}$
Combined		$(5.00 \pm 0.35 \pm 0.49) \times 10^{-2}$

[Phys. Rev. D RC **82**, 091103 (2010)]

- Due to the nature of the reconstruction, most of the systematic uncertainties cancel out exactly
- Remaining dominant systematic uncertainties arise from signal and background models

- Values for f_{Ds} are obtained using the formula:

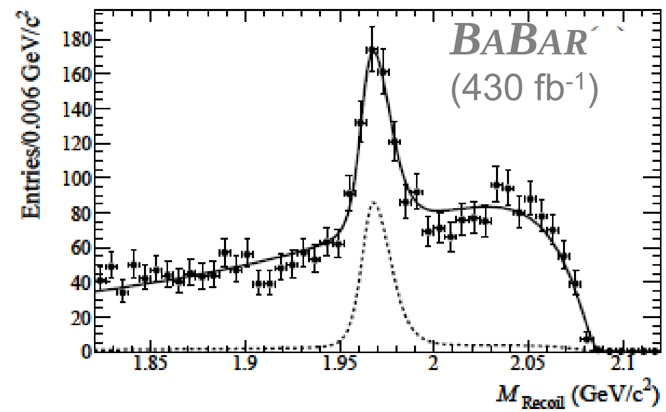
$$f_{D_s^+} = \frac{1}{G_F m_\ell \left(1 - \frac{m_\ell^2}{M_{D_s^+}^2}\right) |V_{cs}|} \sqrt{\frac{8\pi B(D_s^+ \to \ell\nu)}{M_{D_s^+} \tau_{D_s^+}}}$$

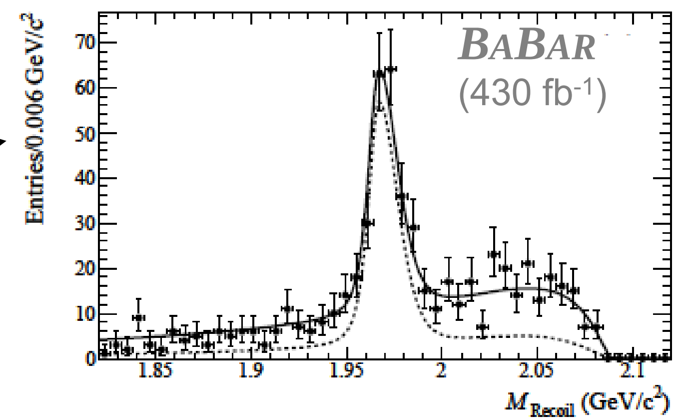
Decay mode	B(Ds→l ν)	f_{Ds}
$D_s \to \mu\ \nu$	$(6.02 \pm 0.37 \pm 0.33) \times 10^{-3}$	$(265.7 \pm 8.4 \pm 7.9)$ MeV
$D_s \to \tau\ \nu$; $\tau \to e\ \nu\ \nu$	$(4.91 \pm 0.50 \pm 0.66) \times 10^{-2}$	$(247 \pm 13 \pm 17)$ MeV
$D_s \to \tau\ \nu$; $\tau \to \mu\ \nu\ \nu$	$(5.07 \pm 0.48 \pm 0.54) \times 10^{-2}$	$(243 \pm 12 \pm 14)$ MeV
Combined		$(258.6 \pm 6.4 \pm 7.5)$ MeV

Relative Measurement of $D_s^- \rightarrow \tau^- \bar{\nu}$ using $D_s^- \rightarrow K_s K^-$

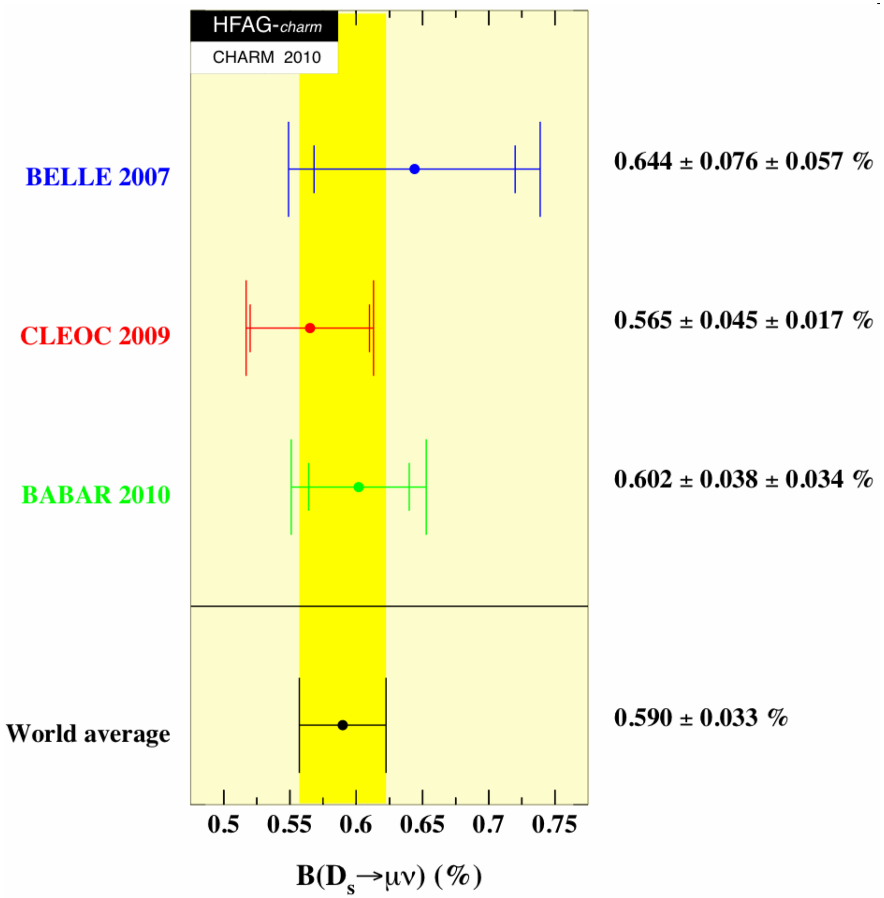
[arXiv: 1003.3063]

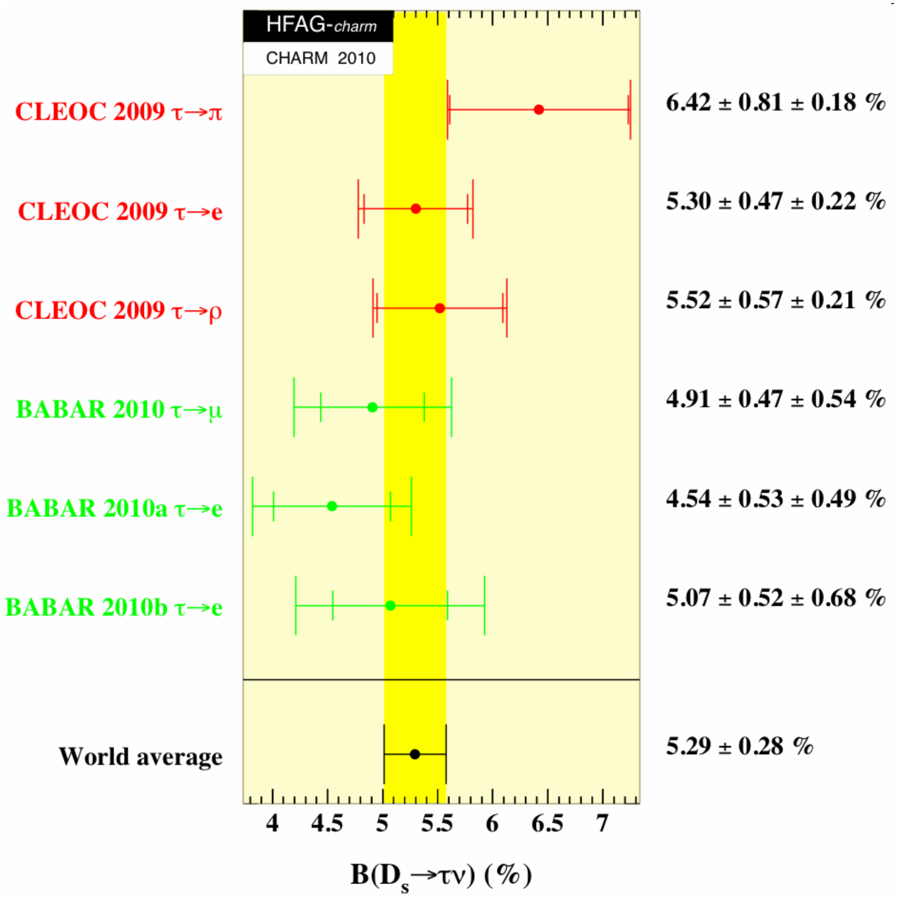
- Reconstruct recoil mass against $DKX\gamma$ to tag D_s events
- Require an additional electron tagging $\tau^- \rightarrow e^- \nu \nu$
- Peaking backgrounds remaining are estimated.
- Similarly, create separate sample which is tagged as $D_s^- \rightarrow K_s K^-$
- Signal yields: 448±36 for $D_s \rightarrow \tau\nu$ and 333 ± 28 for $K_s K$.





$f(D_s)$ Comparison to Other experiments

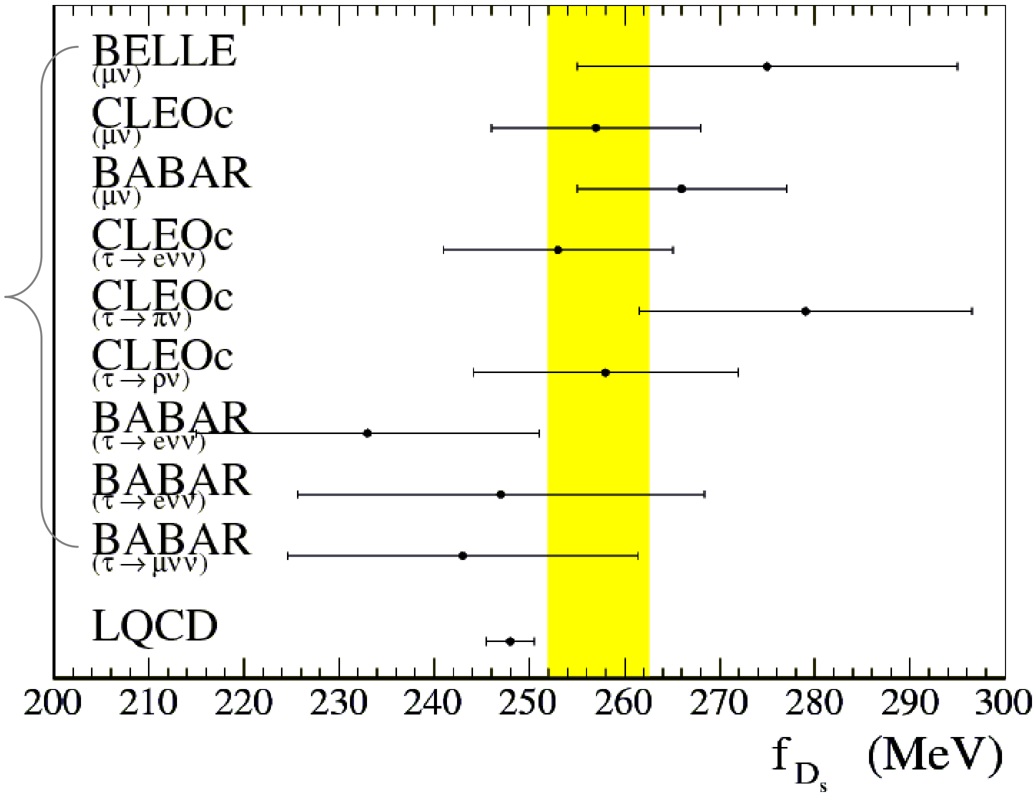


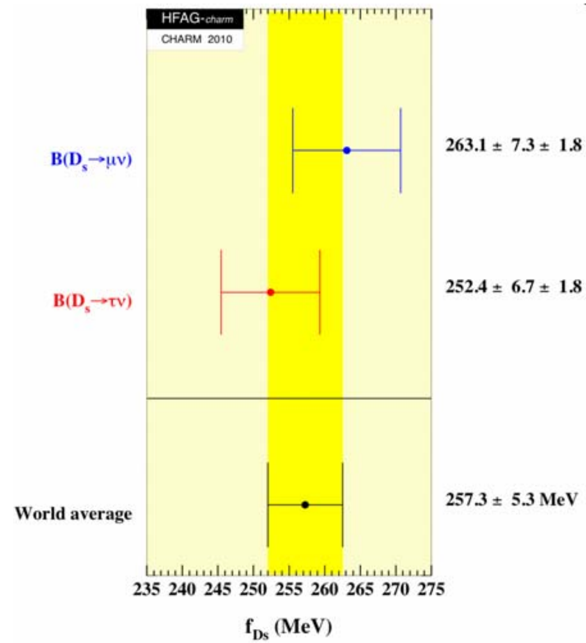


Theory vs. Experiment (new LQCD calculation)

Experiment

Theory





LQCD value changed with their new energy scale calibration.

[PRD 82, 114504 (2010)]

HFAG(2011) = 257.3 +- 5.3

LQCD(2010) = 248.0 +- 2.5

$\Delta = 1.6\ \sigma$

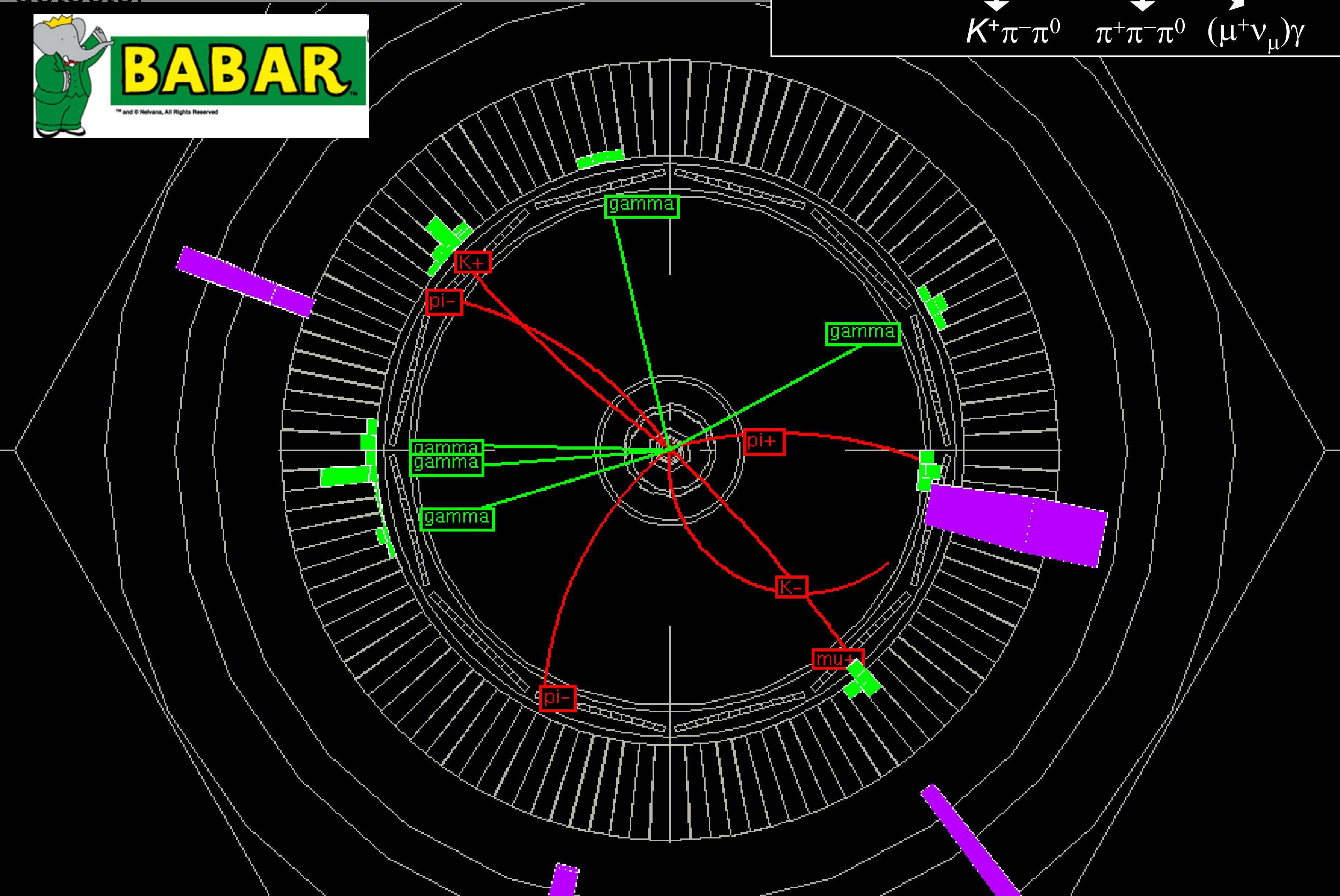
Summary

- Recent results on Rare decays have been presented
  - Improved upper limits
  - Starting to eat into the parameter space of new physics
  - Many results have not been updated in over a decade (E791, FOCUS, etc…)
  - Existing Data sets from Flavor Factories could provide much insight on Rare Decays
- *BABAR's* recent absolute measurements use a D_s-tagging technique (similar to the technique *BELLE* used) which reduces the systematic uncertainties. These measurements significantly improved the uncertainty on the world average value of $f(D_s)$
- The current difference between theory and experiment for $f(D_s)$ is only about 1.6σ after the shift upwards in the new LQCD calculations.
  - A real difference would indicate contributions from Non-SM particles contributing in the decays.

A simulated signal event in the BABAR detector

$$c\bar{c} \to D^0 K^- X D_s^{*+}$$

$D^0 \to K^+\pi^-\pi^0$, $X \to \pi^+\pi^-\pi^0$, $D_s^{*+} \to (\mu^+\nu_\mu)\gamma$

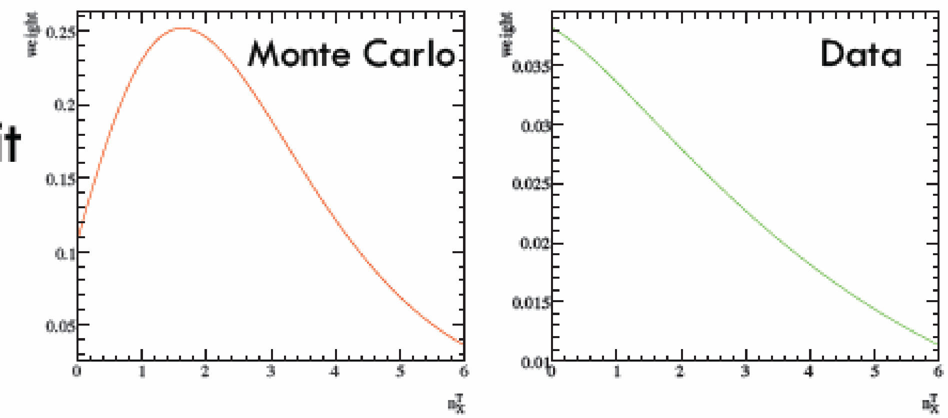


$f(D_s)$ n_X^T unfolding

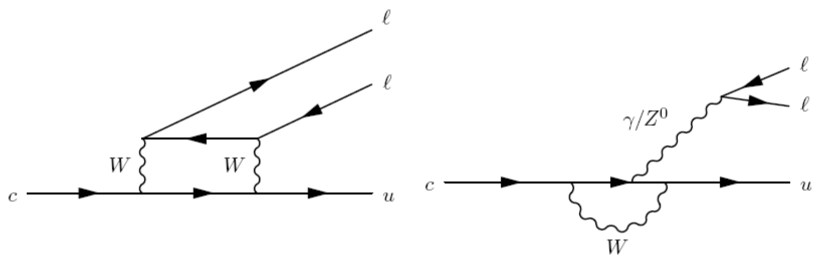
- While the 2-D fit is being performed the n_X^T distribution is unfolded.
- A weights model for each value of n_X^T=j is constructed:

$$w_j^{RS} = \frac{(j-\alpha)^\beta e^{-\gamma j}}{\sum_{k=0}^{6}(k-\alpha)^\beta e^{-\gamma k}}$$

- This weights model accounts for data-Monte Carlo differences
- The parameters are floated in the 2-D fit
- Efficiencies are calculated after n_X^T unfolding.



Rare Decays



relatively little experimental progress in this area within the last decade

Figure 1: Standard model short-distance contributions to the $c \to u\ell^+\ell^-$ transition.

90% confidence limits on Flavor-changing neutral current, (FCNC), lepton family-number (LFV) violating, or lepton-number (LV) violating decay modes of the D^+ (left) and the D_s^+ (right) [285].

Process	Decay type	Upper limit	Reference
$\pi^+ e^+e^-$	FCNC	$< 7.4 \times 10^{-6}$	[851]
$\pi^+ \mu^+\mu^-$	FCNC	$< 3.9 \times 10^{-6}$	[852]
$\rho^+\mu^+\mu^-$	FCNC	$< 5.6 \times 10^{-4}$	[853]
$K^+ e^+e^-$	N/A [a]	$< 6.2 \times 10^{-6}$	[851]
$K^+ \mu^+\mu^-$	N/A [a]	$< 9.2 \times 10^{-6}$	[854]
$\pi^+ e^\pm \mu^\mp$	LFV	$< 3.4 \times 10^{-5}$	[855]
$K^+ e^\pm \mu^\mp$	LFV	$< 6.8 \times 10^{-5}$	[855]
$\pi^- e^+ e^+$	LV	$< 3.6 \times 10^{-6}$	[851]
$\pi^- \mu^+ \mu^+$	LV	$< 4.8 \times 10^{-6}$	[854]
$\pi^- e^+ \mu^+$	LV	$< 5.0 \times 10^{-5}$	[855]
$\rho^-\mu^+ \mu^+$	LV	$< 5.6 \times 10^{-4}$	[853]
$K^- e^+ e^+$	LV	$< 4.5 \times 10^{-6}$	[851]
$K^- \mu^+ \mu^+$	LV	$< 1.3 \times 10^{-5}$	[854]
$K^- e^+ \mu^+$	LV	$< 1.3 \times 10^{-4}$	[856]
$K^{*-} \mu^+ \mu^+$	LV	$< 8.5 \times 10^{-4}$	[853]

[a] These modes are not a useful test for FCNC, because both quarks must change flavor.

Process	Decay type	Upper limit	Reference
$\pi^+ e^+e^-$	N/A [a]	$< 2.7 \times 10^{-4}$	[855]
$\pi^+ \mu^+\mu^-$	N/A [a]	$< 2.6 \times 10^{-5}$	[854]
$K^+ e^+e^-$	FCNC	$< 1.6 \times 10^{-3}$	[855]
$K^+ \mu^+\mu^-$	FCNC	$< 3.6 \times 10^{-5}$	[854]
$K^{*-} \mu^+\mu^-$	FCNC	$< 1.4 \times 10^{-3}$	[853]
$\pi^+ e^\pm \mu^\mp$	LFV	$< 6.1 \times 10^{-4}$	[855]
$K^+ e^\pm \mu^\mp$	LFV	$< 6.3 \times 10^{-4}$	[855]
$\pi^- e^+ e^+$	LV	$< 6.[illegible] \times 10^{-4}$	[855]
$\pi^- \mu^+ \mu^+$	LV	$< 2.9 \times 10^{-5}$	[854]
$\pi^- e^+ \mu^+$	LV	$< 7.3 \times 10^{-4}$	[855]
$K^- e^+ e^+$	LV	$< 6.3 \times 10^{-4}$	[855]
$K^- \mu^+ \mu^+$	LV	$< 1.3 \times 10^{-5}$	[854]
$K^- e^+ \mu^+$	LV	$< 6.8 \times 10^{-4}$	[855]
$K^{*-} \mu^+ \mu^+$	LV	$< 1.4 \times 10^{-3}$	[853]

Flavor Physics in the Quark Sector:
hep-ph/0907.5386

90% confidence limits on flavor-changing neutral current (FCNC), lepton family-number (LFV) violating, or lepton-number (LV) violating decay modes of the D^0 [285].

Process	Decay type	Upper limit	Reference
$\gamma\gamma$	FCNC	$< 2.7 \times 10^{-5}$	[857]
e^+e^-	FCNC	$< 1.2 \times 10^{-6}$	[858]
$\mu^+\mu^-$	FCNC	$< 1.3 \times 10^{-6}$	[858]
$\pi^0 e^+e^-$	FCNC	$< 4.5 \times 10^{-5}$	[859]
$\pi^0 \mu^+\mu^-$	FCNC	$< 1.8 \times 10^{-4}$	[853]
ηe^+e^-	FCNC	$< 1.1 \times 10^{-4}$	[859]
$\eta\mu^+\mu^-$	FCNC	$< 5.3 \times 10^{-4}$	[859]
$\pi^+\pi^- e^+e^-$	FCNC	$< 3.73 \times 10^{-4}$	[860]
$\rho^0 e^+e^-$	FCNC	$< 1.0 \times 10^{-4}$	[859]
$\pi^+\pi^- \mu^+\mu^-$	FCNC	$< 3.0 \times 10^{-5}$	[860]
$\rho^0 \mu^+\mu^-$	FCNC	$< 2.2 \times 10^{-5}$	[860]
ωe^+e^-	FCNC	$< 1.8 \times 10^{-4}$	[859]
$\omega\mu^+\mu^-$	FCNC	$< 8.3 \times 10^{-4}$	[859]
$K^+K^- e^+e^-$	FCNC	$< 3.15 \times 10^{-4}$	[860]
ϕe^+e^-	FCNC	$< 5.2 \times 10^{-5}$	[859]
$K^+K^- \mu^+\mu^-$	FCNC	$< 3.3 \times 10^{-5}$	[860]
$\phi\mu^+\mu^-$	FCNC	$< 3.1 \times 10^{-5}$	[860]
$\overline{K}^0 e^+e^-$	N/A [a]	$< 1.1 \times 10^{-4}$	[859]
$\overline{K}^0 \mu^+\mu^-$	N/A [a]	$< 2.6 \times 10^{-4}$	[853]
$K^- \pi^+ e^+e^-$	FCNC	$< 3.85 \times 10^{-4}$	[860]
$\overline{K}^{*0} e^+e^-$	N/A [a]	$< 4.7 \times 10^{-5}$	[860]
$K^+ \pi^+ \mu^+\mu^-$	FCNC	$< 3.59 \times 10^{-4}$	[860]

Process	Decay type	Upper limit	Reference
$\overline{K}^{*0} \mu^+\mu^-$	N/A [a]	$< 2.4 \times 10^{-5}$	[860]
$\pi^+\pi^- \pi^0 \mu^+\mu^-$	FCNC	$< 8.1 \times 10^{-4}$	[853]
$e^\pm \mu^\mp$	LFV	$< 8.1 \times 10^{-7}$	[858]
$\pi^0 e^\pm \mu^\mp$	LFV	$< 8.6 \times 10^{-5}$	[859]
$\eta e^\pm \mu^\mp$	LFV	$< 1.0 \times 10^{-4}$	[859]
$\pi^+\pi^- e^\pm \mu^\mp$	LFV	$< 1.5 \times 10^{-5}$	[860]
$\rho^0 e^\pm \mu^\mp$	LFV	$< 4.9 \times 10^{-5}$	[859]
$\omega e^\pm \mu^\mp$	LFV	$< 1.2 \times 10^{-4}$	[859]
$K^-K^+ e^\pm \mu^\mp$	LFV	$< 1.8 \times 10^{-4}$	[860]
$\phi e^\pm \mu^\mp$	LFV	$< 3.4 \times 10^{-5}$	[859]
$\overline{K}^0 e^\pm \mu^\mp$	LFV	$< 1.0 \times 10^{-4}$	[859]
$K^- \pi^+ e^\pm \mu^\mp$	LFV	$< 5.53 \times 10^{-4}$	[859]
$\overline{K}^{*0} e^\pm \mu^\mp$	LFV	$< 8.3 \times 10^{-5}$	[860]
$\pi^- \pi^- e^+ e^+ + c.c$	LV	$< 1.12 \times 10^{-4}$	[860]
$\pi^- \pi^- \mu^+ \mu^+ + c.c$	LV	$< 2.9 \times 10^{-5}$	[860]
$K^- \pi^- e^+ e^+ + c.c$	LV	$< 2.06 \times 10^{-4}$	[860]
$K^- \pi^- \mu^+ \mu^+ + c.c$	LV	$< 3.9 \times 10^{-4}$	[860]
$K^- K^- e^+ e^+ + c.c$	LV	$< 1.52 \times 10^{-4}$	[860]
$K^- K^- \mu^+ \mu^+ + c.c$	LV	$< 9.4 \times 10^{-5}$	[860]
$\pi^- \pi^- e^+ \mu^+ + c.c$	LV	$< 7.9 \times 10^{-5}$	[860]
$K^- \pi^- e^+ \mu^+ + c.c$	LV	$< 2.18 \times 10^{-4}$	[860]
$K^- K^- e^+ \mu^+ + c.c$	LV	$< 5.7 \times 10^{-5}$	[860]

[a] These modes are not a useful test for FCNC, because both quarks must change flavor.

D→hll

arXiv:hep-ex/0607051

Anything more updated?