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Compilation of $D^0 \to \overline{D}^0$ Mixing Predictions

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Abstract

We present a compilation of predictions for the amplitudes of $D^0 - \overline{D}^0$ mixing.

We are not aware of any exhaustive compilation of predictions for the amplitudes for $D^0 \to \overline{D}^0$. We have therefore found it helpful to compile, here, those predictions that we have found in a rudimentary search of the literature.

Our search has depended upon the `SLAC Spires` data base, available at the `URL`:

`http://www-spires.slac.stanford.edu/find/hep`.

We keep an annotated table of all of the references that we have found, hyperlinked where possible into both the `SLAC Spires` and `LANL xxx` data bases, at the URL:

`http://hep.ucsb.edu/people/hnn/wrongd/predictions/pred.html`.

For all predictions, it is useful to know how to convert between the two common standards for quoting the mixing amplitudes: x and y, or ΔM and $\Delta\Gamma$.

Denote the mean life of the D^0 as $\tau_{D^0} = 415 \pm 4$ fs[1], and the full width of the D^0 as $\Gamma_{D^0} = 1/\tau_{D^0}$. In the limit of CP conservation, $\Delta M = 2M_{12}$ and $\Delta\Gamma = \Gamma_{12}$, where M_{12} and $\Gamma_{12}/2$ are the mixing amplitudes through virtual and real intermediate states, respectively.

Then,

$$
\begin{aligned}
x &= \frac{\Delta M}{\Gamma_{D^0}} \\
&= \Delta M \tau_{D^0} \\
&= \left[\frac{c\tau_{D^0}}{\hbar c}\right] \times \Delta M \\
&= \left[\frac{2.998\times 10^{23}\mathrm{fm/s} \times 415\times 10^{-15}\mathrm{s}}{0.1973\,\mathrm{GeV\text{-}fm}}\right] \times \Delta M\ (\mathrm{GeV}) \\
&= [6.31\times 10^{11}] \times \Delta M\ (\mathrm{GeV}) \\
y &= \frac{\Delta\Gamma}{2\Gamma_{D^0}} \\
&= [3.15\times 10^{11}] \times \Delta\Gamma\ (\mathrm{GeV})
\end{aligned}
\tag{1}
$$

For Standard Model predictions, we have not made an effort to update author's limits for new values of the parameters that describe quark mixing (the CKM matrix elements), or the mass of the top, or any other, quark. We let the predictions of the authors stand as originally made.

Occasionally, new authors have revised the predictions of older authors. We simply include both predictions.

All non-Standard Model predictions concern x, the amplitude for mixing through virtual intermediate states (in units of one-half the mean D^0 decay rate). Most non-Standard Models contain numerous adjustable parameters; generally, we have tried to take values of the adjustable parameters that the authors themselves recommend.

Our compilation of predictions are summarized in Tables 1-2 and Fig. 1.

We assign a 'Reference Index' to each prediction that we include, and the first column of the Tables 1-2 is that Reference Index. Roughly, the reference index is assigned chronologically. The predictions are then plotted in Fig. 1, with the horizontal axis being this Reference Index.

Some papers contain multiple predictions. Usually we assign each prediction a new Reference Index. However, a family of predictions is usually assigned a range of predictions, and is plotted in Fig. 1 as a central value and an error bar, where the error bar construes the range, above a single Reference Index.

When mixing is measured with the decay of the D^0 to a particular hadronic final state $f_{\rm had}$, there is the possibility of a CP-conserving, *relative* strong phase δ between the amplitude for the decay $D^0 \to f_{\rm had}$, and that for $\overline{D}^0 \to f_{\rm had}$.

In the useful case of $f_{\rm had} = K^+\pi^-$, it has been argued[2] that δ is small. Although the strong phase δ_I, between the decay amplitudes for $\overline{D}^0 \to K^+\pi^-$ to specific isospin configurations of the $K^+\pi^-$ system, is known to be large, the *relative* strong phase δ between the *total* $\overline{D}^0 \to K^+\pi^-$ and $D^0 \to K^+\pi^-$ amplitudes is probably much smaller.

The presence of the relative strong phase δ causes mixing studies that use a specific hadronic final state to be, in effect, sensitive to a *rotated* set of mixing amplitudes:

$$\begin{aligned} y' &= y\cos\delta - x\sin\delta \\ x' &= x\cos\delta + y\sin\delta \end{aligned} \quad . \tag{2}$$

When δ is small, $y' \approx y$, and $x' \approx x$.

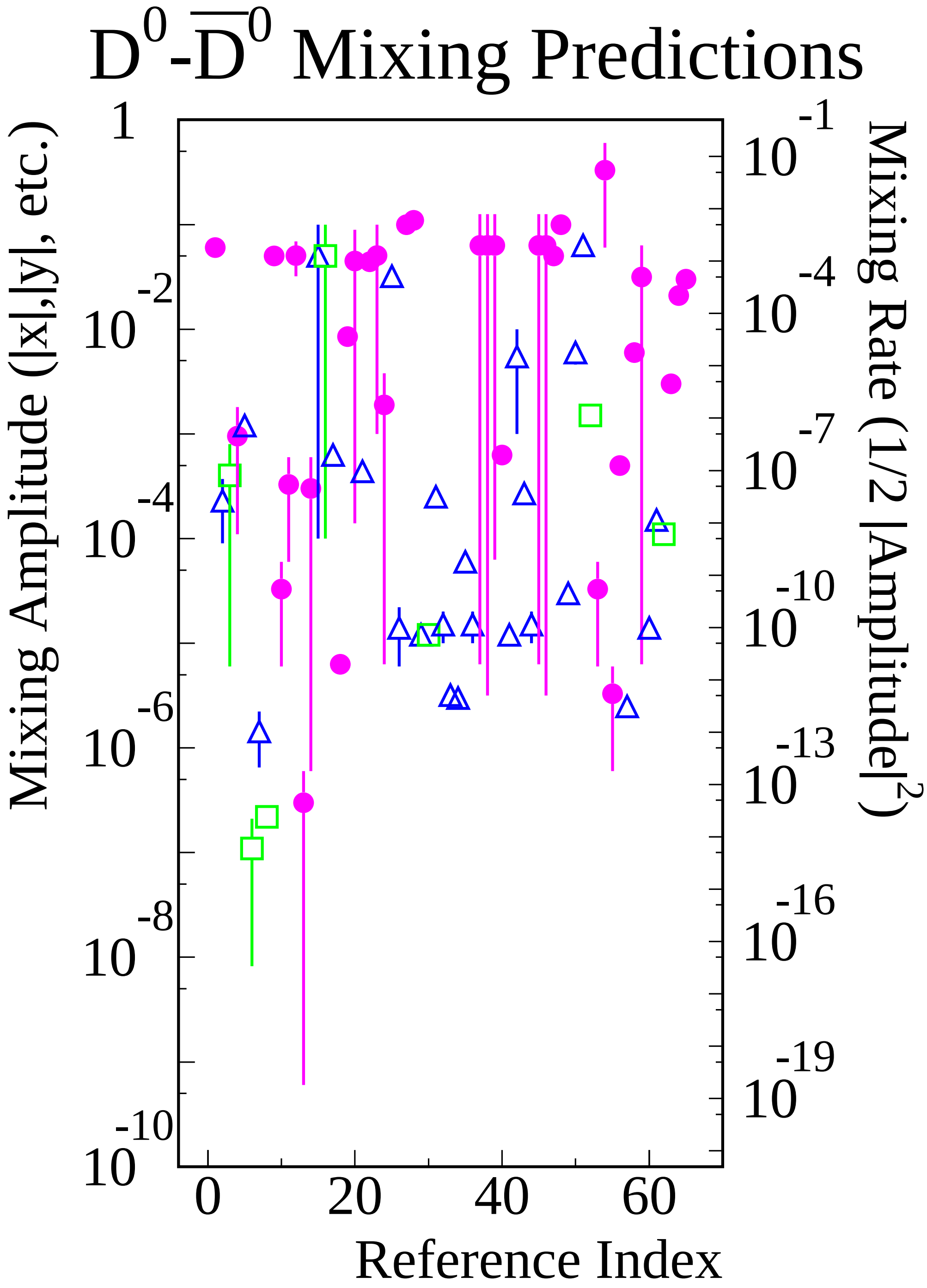

Figure 1: $D^0 - \overline{D}^0$ mixing predictions; the vertical direction, read off the left scale, is the mixing amplitude x, y, or, if the appropriate strong phase is negligible, x', y'. The right vertical scale is the equivalent mixing *rate*, which is either $(1/2)x^2$ or $(1/2)y^2$. The horizontal is the Reference Index, which is a number assigned to each prediction, and documented in Tables 1-2. The open triangles (blue) are Standard Model predictions for x, the open squares (green) are Standard Model predictions for y, and the solid circles (magenta) are non-Standard Models for x.

Table 1: Reference Indices from 1 to 40. The notation S stands for 'Standard Model' and the notation NS stands for 'non-Standard Model'. The notation '$\pm$' does not indicate a $1\,\sigma$ region, but an entire range of predictions, where unknowable parameters govern the variation.

Reference Index	**Cita-tion**	**Ampli-tude**	**S/NS**	**Value**	**Comment**
1	[3]	x	NS	6×10^{-2}	Family Symmetry
2	[4]	x	S	$(0.9\pm3.7)\times10^{-4}$	Short Distance
3	[4]	y	S	$-(0.06-8.0)\times10^{-4}$	Short Distance
4	[4]	x	NS	$(0.11\pm1.8)\times10^{-3}$	Higgs Doublet
5	[5]	x	S	1.2×10^{-3}	Short Distance
6	[5]	y	S	$(0.082-2.1)\times10^{-7}$	Short Distance
7	[6]	x	S	$(1.44\pm0.79)\times10^{-6}$	Short Distance
8	[6]	y	S	2.2×10^{-7}	Short Distance
9	[7]	x	NS	5×10^{-2}	Higgs Doublet
10	[7]	x	NS	$(0.6-6.0)\times10^{-5}$	L-R Symmetry
11	[7]	x	NS	$(0.6-6.0)\times10^{-4}$	Broken L-R Symmetry
12	[7]	x	NS	$(5.05\pm1.85)\times10^{-2}$	Kane-Thun Model
13	[7]	x	NS	$(0.06-60)\times10^{-8}$	SUSY
14	[7]	x	NS	$(0.06-60)\times10^{-5}$	SUSY - large CKM
15	[8]	x	S	$(0.01-10)\times10^{-2}$	Long Distance
16	[8]	y	S	$(0.01-10)\times10^{-2}$	Long Distance
17	[9]	x	S	6.3×10^{-4}	Long Distance
18	[10]	x	NS	6.3×10^{-6}	L-R Sym., 10 TeV Higgs
19	[10]	x	NS	8.5×10^{-3}	FCNC, at K^0 bound
20	[12]	x	NS	$(0.15-90)\times10^{-3}$	Superstring-inspired E_6
21	[13]	x	S	4.4×10^{-4}	Short Distance
22	[13]	x	NS	4.4×10^{-2}	Higgs Doublets, $m_H=1$ TeV
23	[14]	x	NS	$(0.1-10)\times10^{-2}$	Fourth Generation
24	[15]	x	NS	$(0.06-40)\times10^{-4}$	FCNC, seesaw limit
25	[16]	x	S	3.2×10^{-2}	Long Distance
26	[17]	x	S	$(1.4\pm0.8)\times10^{-5}$	HQET
27	[18]	x	NS	≈ 0.1	(s)/quark mass matrix align.
28	[19]	x	NS	0.11	Flavor Changing Scalar Int.
29	[20]	x	S	1.2×10^{-5}	Short Distance
30	[20]	y	S	1.2×10^{-5}	Short Distance
31	[20]	x	S	2.5×10^{-4}	Dispersive
32	[20]	x	S	$(1.5\pm0.5)\times10^{-5}$	HQET
33	[21]	x	S	3.2×10^{-6}	Short Distance
34	[22]	x	S	3.0×10^{-6}	Short Distance
35	[22]	x	S	6.0×10^{-5}	Dispersive
36	[22]	x	S	$(1.5\pm0.5)\times10^{-5}$	HQET
37	[22]	x	NS	$(0.006-120)\times10^{-3}$	4^{th} Generation
38	[22]	x	NS	$(0.004-120)\times10^{-3}$	Higgs Doublet
39	[22]	x	NS	$(0.06-120)\times10^{-3}$	Flavor-Changing Higgs
40	[23]	x	NS	6.3×10^{-4}	Isosinglet Quarks

Table 2: Reference Indices from 41 to 65. The notation S stands for 'Standard Model' and the notation NS stands for 'non-Standard Model'. The notation '$\pm$' does not indicate a $1\,\sigma$ region, but an entire range of predictions, where unknowable parameters govern the variation.

Reference Index	**Citation**	**Amplitude**	**S/NS**	**Value**	**Comment**
41	[24]	x	S	5.8×10^{-5}	Short Distance
42	[24]	x	S	$(1-10)\times10^{-3}$	Long Distance
43	[24]	x	S	2.7×10^{-4}	Dispersive
44	[24]	x	S	$(1.5\pm0.5)\times10^{-5}$	HQET
45	[24]	x	NS	$(0.06-120)\times10^{-3}$	$4^{\rm th}$ Generation
46	[24]	x	NS	$(0.04-120)\times10^{-3}$	Higgs Doublet
47	[24]	x	NS	5×10^{-2}	Tree Level FCNC
48	[24]	x	NS	0.1	SUSY
49	[25]	x	S	3×10^{-5}	Short Distance
50	[25]	x	S	$(6.0\pm1.4)\times10^{-3}$	Broken SU(3), Octet
51	[25]	x	S	6×10^{-2}	Upper Limit
52	[26]	y	S	1.5×10^{-3}	Phenomenological B. R.'s
53	[27]	x	NS	$(0.6-6)\times10^{-5}$	Higgs Doublet
54	[27]	x	NS	$(0.6-6)\times10^{-1}$	Higgs Doublet
55	[27]	x	NS	$(0.6-6)\times10^{-6}$	Higgs Doublet
56	[28]	x	NS	5×10^{-4}	SUSY
57	[29]	x	S	2.5×10^{-6}	Dipenguin
58	[30]	x	NS	6×10^{-4}	Neutral Scalar Subquarks
59	[31]	x	NS	$(0.06-600)\times10^{-4}$	Singlet Quarks
60	[32]	x	S	1.4×10^{-5}	$\mathrm{U(4)_L\times U(4)_R}$ Chiral
61	[33]	x	S	1.5×10^{-4}	Long Dist. - Resonances
62	[33]	y	S	1.1×10^{-4}	Long Dist. - Resonances
63	[34]	x	NS	3×10^{-3}	FCNC Dualized SM
64	[35]	x	NS	2.1×10^{-2}	SUSY Broken by Flavor
65	[36]	x	NS	3.0×10^{-2}	Flavor Changing from Higgs

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