Penguin Pollution in $D \to hh$ Decays

The CP eigenstates ππ and ρρ

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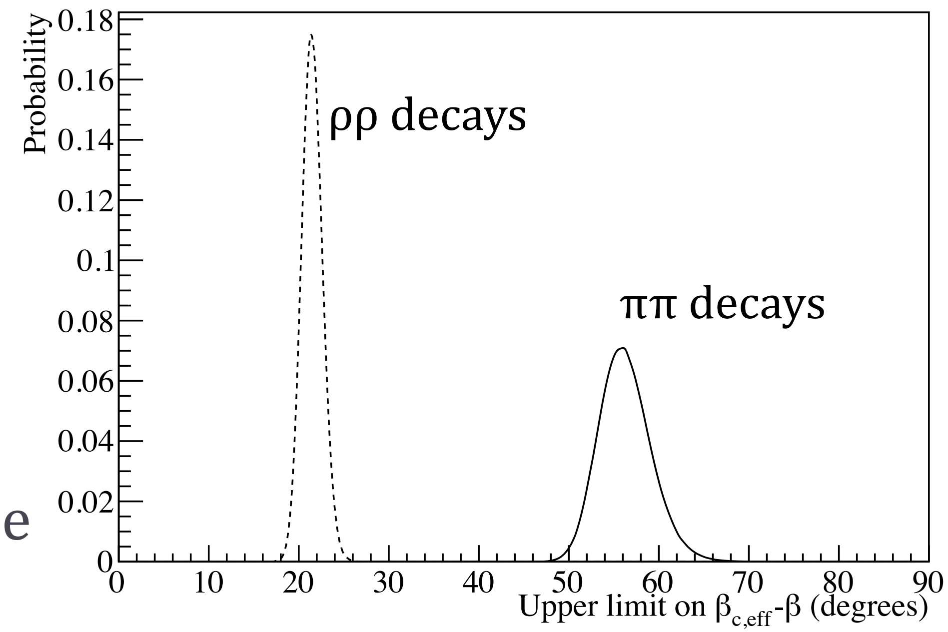
Grossman-Quinn Bound

- Simple upper limit (not optimal) to determine the penguin pollution in a given mode (for B decays).
  - Was used circa 2003, and has since been ignored as there are better methods on the market.

$$\sin^2(\beta_{c,\mathrm{eff}} - \beta_c) \leq \frac{\mathcal{B}^{00}}{\mathcal{B}^{+0}}$$

- Conclude from this penguins are larger in ππ than ρρ.

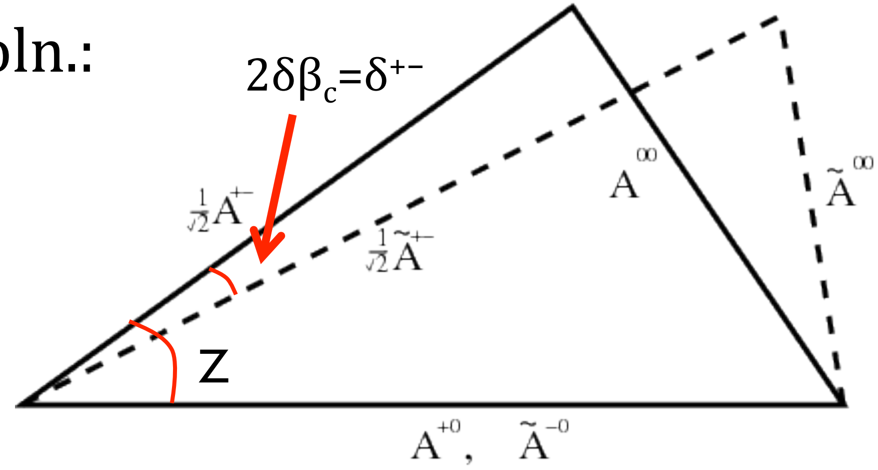
- This ignores long distance amplitudes.



Gronau-London Isospin Analysis

- More complicated general soln.:

$$\frac{1}{\sqrt{2}}A^{+-} = A^{+0} - A^{00},$$
$$\frac{1}{\sqrt{2}}\overline{A}^{-+} = \overline{A}^{-0} - \overline{A}^{00},$$

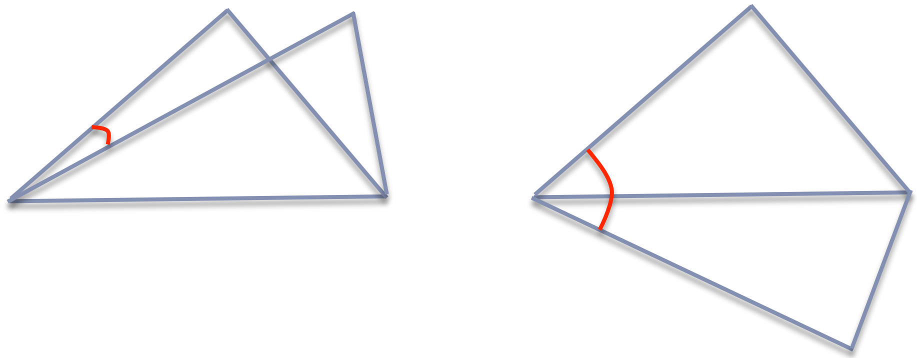


$$(A^{00})^2 = \frac{(A^{+-})^2}{2} + (A^{+0})^2 - \sqrt{2}A^{+-}A^{+0}\cos Z$$

- Bonus: Data available for ππ and 4π final states:
  - D^0 and $D^{\pm}$ lifetimes differ by a factor of 2.5.
  - Need to make assumption on resonant ρρ fraction in 4π state to compute $2\delta\beta_c$ for that system.
  - f_L only measured for $\rho^0\rho^0$
  - Remember to take the sqrt of the branching fractions.

Simple method

- Generate toy data, based on input branching fractions.
  - Correct +0 mode for lifetime difference in order to obtain numbers related to the amplitudes.
  - Assume CP asymmetries are zero when splitting amplitudes into A and A-bar.
  - Generate Ntoys, for each compute $2\delta\beta_c$
  - Note ambiguity in problem

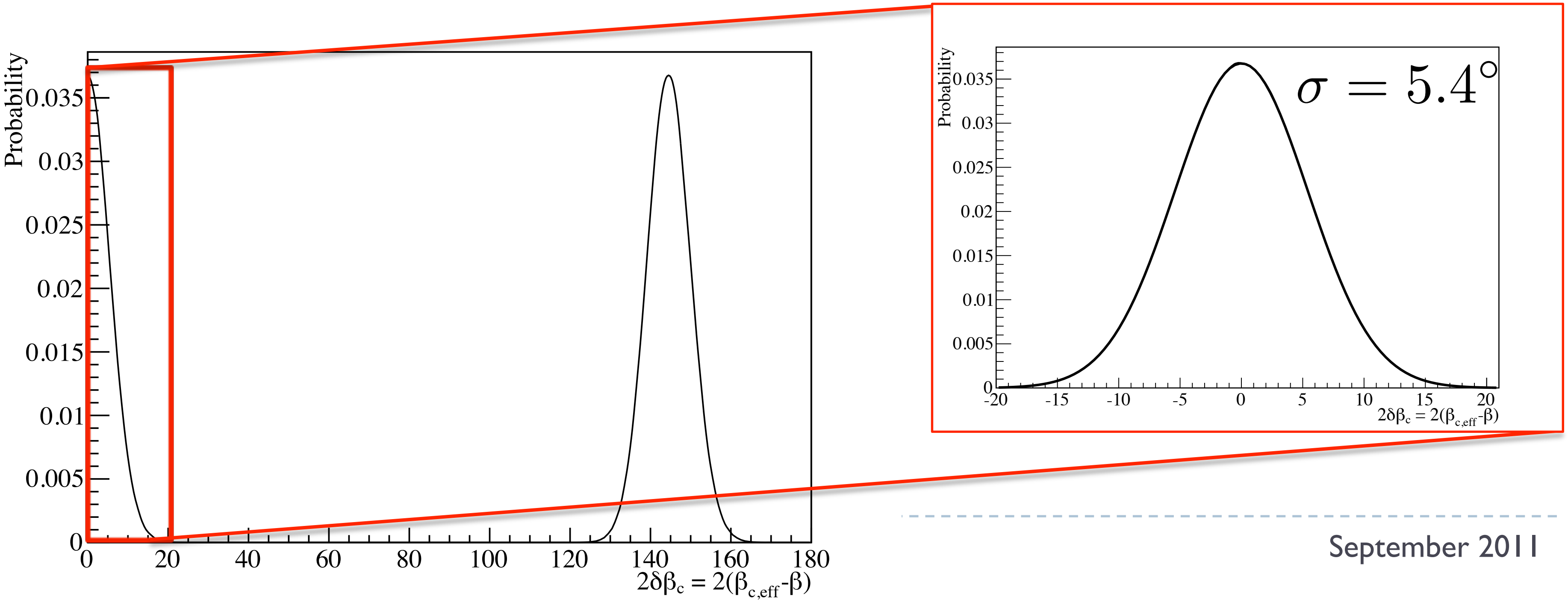


We get 2 solutions for the penguin pollution angle (this is in addition to the 4 solutions when trying to convert the phase of λ into a β_c measurement.

$D \to \pi\pi$

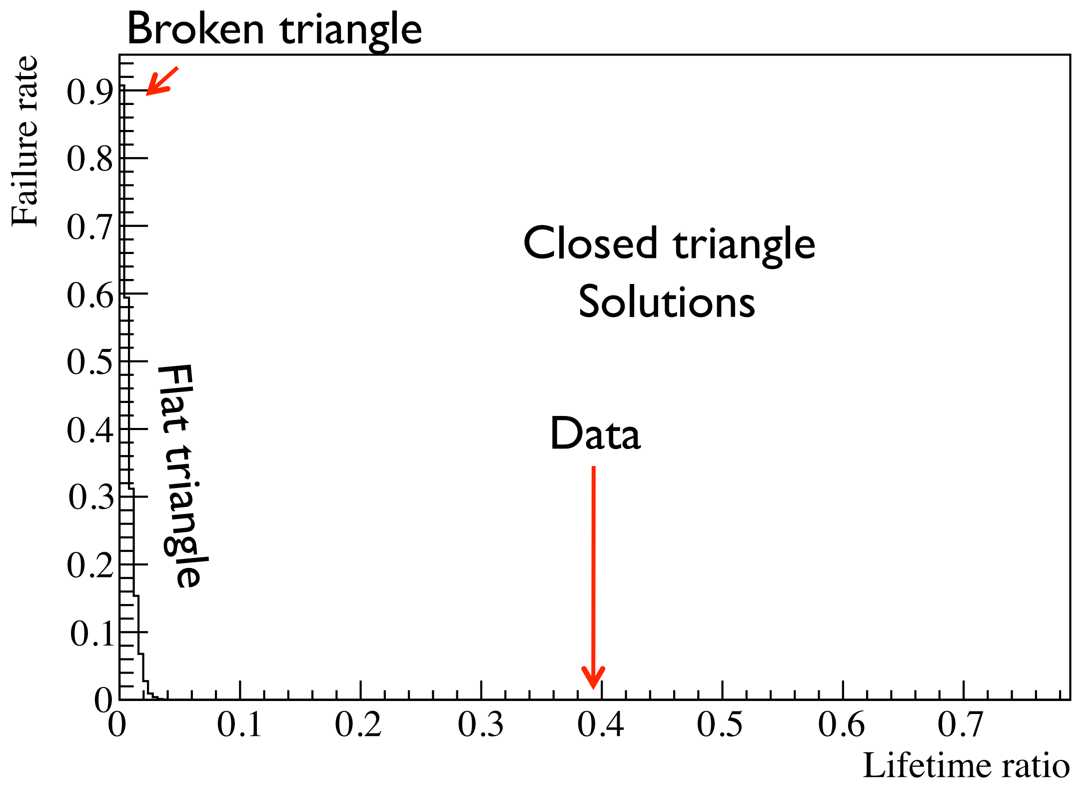
- Experimental inputs available, in terms of branching fractions.
  - In the SM asymmetries are ~0.
  - Assume A_{CP}=0 for all modes.
- The Isospin analysis gives:

Parameter	Measured Value
$\mathcal{B}(D^0 \to \pi^+\pi^-)$ $(\times 10^{-3})$	1.400 ± 0.026
$\mathcal{B}(D^\pm \to \pi^+\pi^0)$ $(\times 10^{-3})$	1.19 ± 0.06
$\mathcal{B}(D^0 \to \pi^0\pi^0)$ $(\times 10^{-3})$	0.80 ± 0.05



$D \to \pi\pi$

- Failure rate as a function of the lifetime ratio: i.e. how flat are the Isospin triangles?



The lifetime ratio is varied to see if the result is sensitive to this (it tells us about the shape of the triangle).

One expects that any physically correct solution is insensitive, and there is no motivation for this test.

- So the data look fine, and the triangles are closed.

Conclusions: $D \rightarrow \pi\pi$

- The current data (includes unpublished $\pi^0\pi^0$ result from BaBar) work well.
  - 2 solutions for δ^{+-} as expected: one at 0° and one at 100°.
  - Uncertainty from penguins 5.4° on $2\delta\beta_c$, so ~2.7° on β_c.

- What do long distance amplitudes do to this?
  - Need a theorist to do some work here (or to have published on this area in the literature).

- The Grossman-Quinn bound (neglecting the LD contribution) indicates that penguin pollution is large in these decays compared to $\rho\rho$.
  - This indicates the two possible solutions 0, and 100°, and we can't learn anything else beyond this.

$D \longrightarrow \rho\rho$

- But the ρρ scenario is more complicated.

Parameter	Measured Value
$\mathcal{B}(D^0 \to \rho^+\rho^-)$ $(\times 10^{-3})$	$10.0 \pm 0.9\dagger$
$\mathcal{B}(D^\pm \to \rho^+\rho^0)$ $(\times 10^{-3})$	$11.3 \pm 0.8\dagger$
$\mathcal{B}(D^0 \to \rho^0\rho^0)$ $(\times 10^{-3})$	1.82 ± 0.13
$f_L(D^0 \to \rho^+\rho^-)$ $(\times 10^{-3})$	$0.83\star$ (Ref. [3])
$f_L(D^\pm \to \rho^+\rho^0)$ $(\times 10^{-3})$	$0.83\star$ (Ref. [3])
$f_L(D^0 \to \rho^0\rho^0)$ $(\times 10^{-3})$	0.69 ± 0.08

The good news:
•Our prediction of f_L for these modes is in agreement with the data available for the 00 mode.

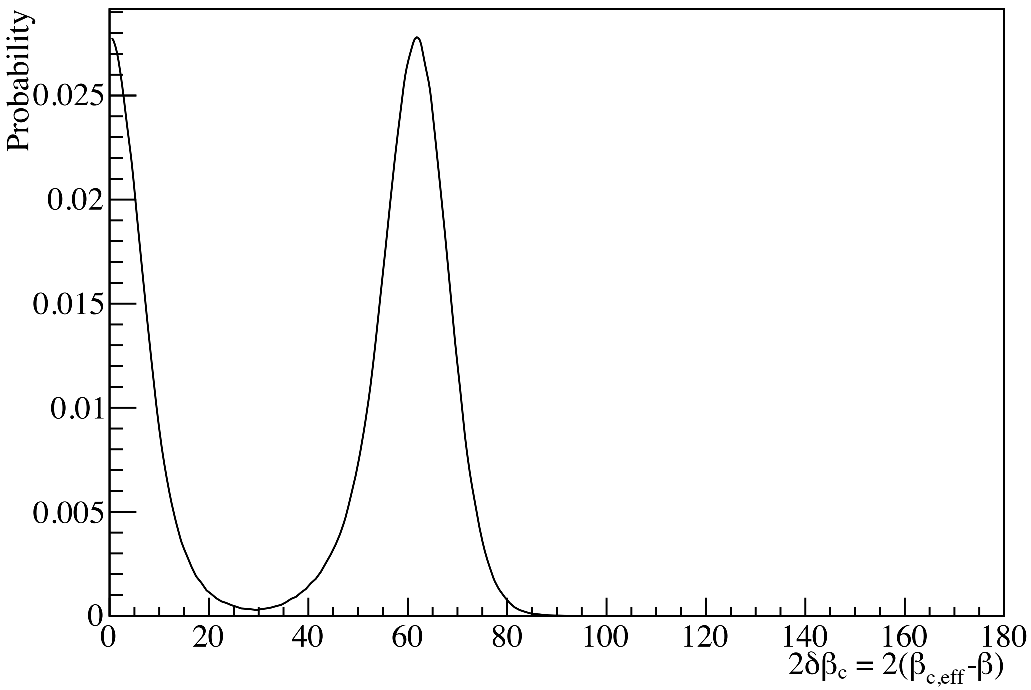
The bad news:
•PDG reports 4π final states for +− and +0 final states.

•Assume these are dominated by ρρ (but don't know if this is true, and need to review the measurements to see what has been done wrt fit models and interference).

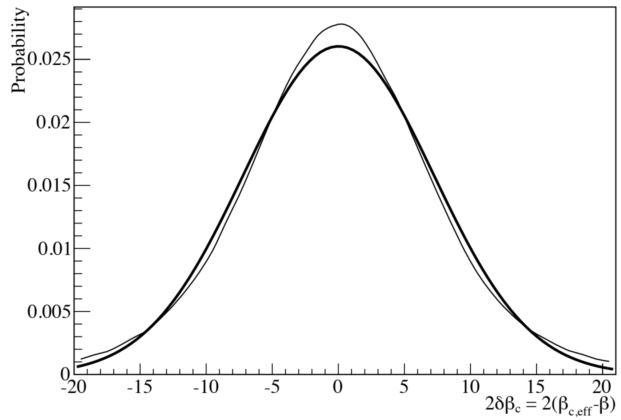
•Consequently f_L is not measured: but we predicted this in our last paper, so use ~0.83.

$D \to \rho\rho$

- The two broad peaks observed for these modes, assuming completely resonant sample.
  - Note 3% of toys fail here.
  - uncertainty for central peak σ=9.3°.

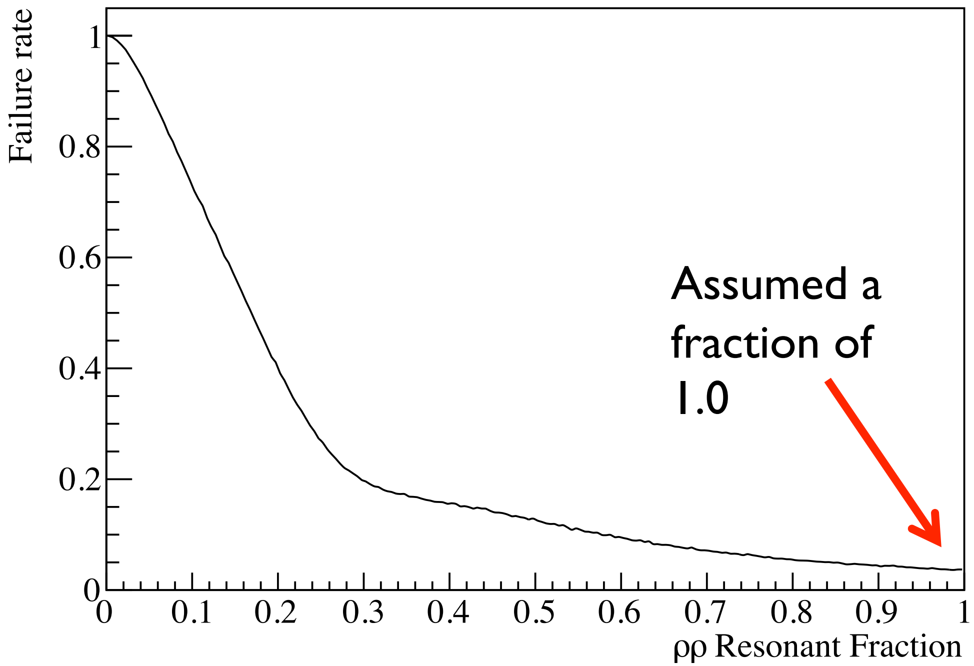


The central peak for this case is slightly non-Gaussian (the result of failed unphysical toy experiments)



$D \rightarrow \rho\rho$

- The Isospin analysis fails in 3% of the cases:
  - For this case we have a natural parameter to tune: the resonant fraction of ρρ events.
  - The fit failure rate is minimised at a fraction of 1.0.

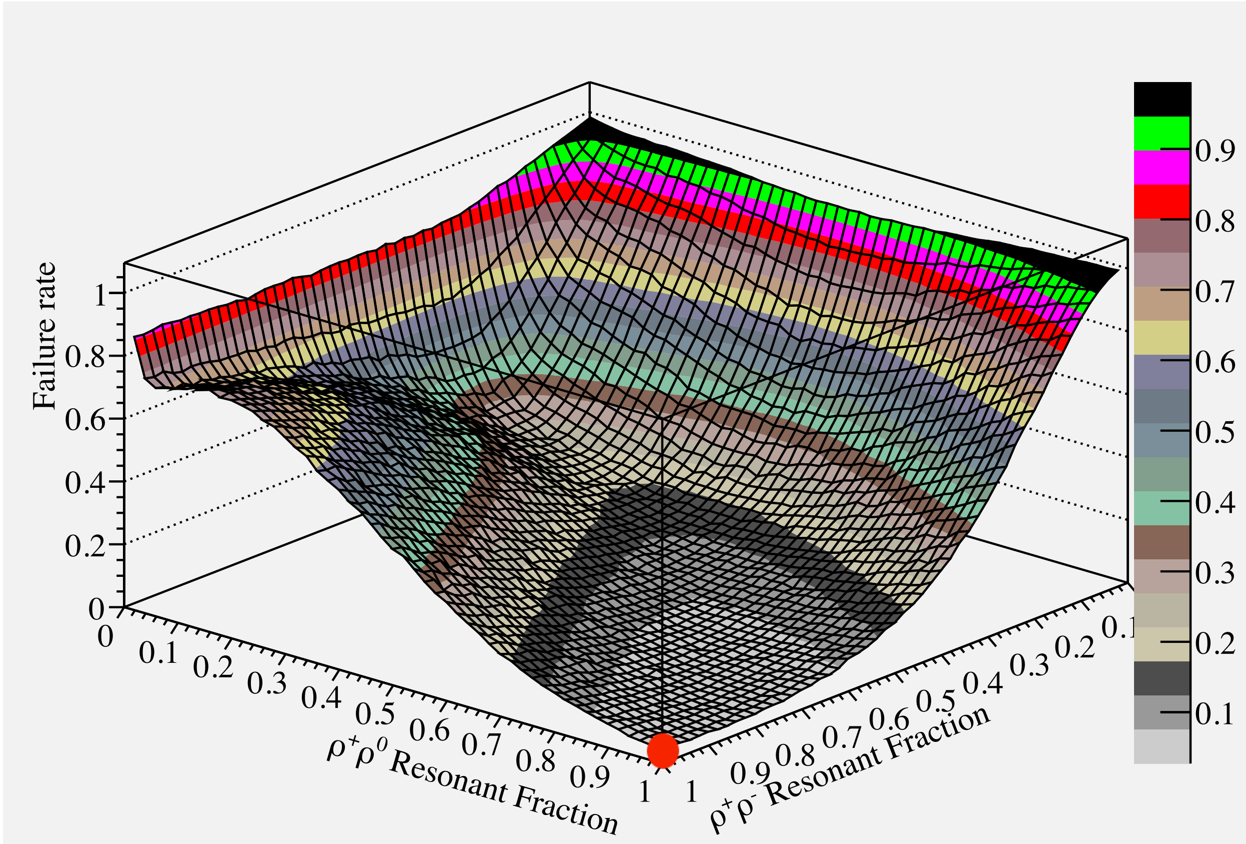


Of course the +− and +0 resonant fractions should be different, and we think this plot is telling us that they probably are quite different.

The issue of LD effects may also be relevant here.

$D \to \rho\rho$

- A 2D look at the resonant fraction plane does not shed much light...



Assumed fraction gives the most stable result.

Conclude that we need more (better) data to understand if we can rely on these modes.

Conclusion: $D \to \rho\rho$

- Isospin analysis is akin to guess work given current data.
  - Measurements only sufficient for the $\rho^0\rho^0$ mode.
  - Need to improve knowledge of $\rho^+\rho^0$ and $\rho^+\rho^-$ before we can draw solid conclusions on the viability of a $\rho\rho$ Isospin analysis.
  - The Grossman-Quinn bound (ignoring LD amplitudes) would indicate that penguins are smaller in $\rho\rho$ than $\pi\pi$ decays.
    - This is backed up by noting that the two solutions obtained for $\rho\rho$ are closer together than for $\pi\pi$.
- Also need to understand if the long distance amplitudes are relevant.
- Note: The different penguin contributions are important, this means that one can start resolving ambiguities in β_c using time-dependent results from $\pi\pi$ and $\rho\rho$ decays.
  - Adding in the $\pi\pi\pi^0$ DP result will probably improve the situation further. c.f. the B decay situation with the measurement of α.

Ultimate limits…

- Consider only the branching fraction systematic uncertainties here:

Now:

Parameter	Measured Value	
$\mathcal{B}(D^0 \to \pi^+\pi^-)$ $(\times 10^{-3})$	1.400 ± 0.026	(1.9%)
$\mathcal{B}(D^\pm \to \pi^+\pi^0)$ $(\times 10^{-3})$	1.19 ± 0.06	(5.0)%
$\mathcal{B}(D^0 \to \pi^0\pi^0)$ $(\times 10^{-3})$	0.80 ± 0.05	(6.3)%

Parameter	Measured Value	
$\mathcal{B}(D^0 \to \rho^+\rho^-)$ $(\times 10^{-3})$	$10.0 \pm 0.9\dagger$	(9.0%)
$\mathcal{B}(D^\pm \to \rho^+\rho^0)$ $(\times 10^{-3})$	$11.3 \pm 0.8\dagger$	(7.1)%
$\mathcal{B}(D^0 \to \rho^0\rho^0)$ $(\times 10^{-3})$	1.82 ± 0.13	(7.1)%
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Ultimate (?):

Just consider detection efficiency systematic uncertainties assuming we can do as well as BaBar.

- 0.8% per track → +− mode limited to ~1.2%
- 3% per π^0 → +0 mode limited to ~3.1%
- 3% per π^0 → 00 mode limited to 6%

Will SuperB do better than this?

Ultimately we can make marginal improvements for ππ. But the ρρ modes need to be studied properly before concluding.