Experimental Tests of CPT with B Decays

Rob Gardner
Indiana University

- Outline:
  - Why study CPT symmetry with B Decays?
  - Quantities sensitive to CPT symmetry violation
  - Current bounds from B Decays
  - Aside: CPT in charm decay
  - Conclusions

Why Search for CPT Violations in B Decays?

- CPT is preserved by local, relativistic, point-like particle theories (such as the standard model)

- Violations could result from fundamental theories

string theory

$\Downarrow$

spontaneous breaking of Lorentz symmetry and CPT Kostelecky,Potting ‘91

$\Downarrow$

Standard Model extensions
Kostelecky, Potting ‘95
Colladay, Kostelecky ‘97 ‘98

$\Downarrow$

experimental tests

Experimental Tests

- Tests in QED
  - Penning traps
  - Spectroscopy of hydrogen/antihydrogen

- Neutral Meson sensitivities
  - K decay: $$\frac{\left|M_{K^0} - M_{\overline{K}^0}\right|}{M_{K^0}} \leq 10^{-18}$$
  - B decay: $$\frac{\left|M_{B^0} - M_{\overline{B}^0}\right|}{M_{B^0}} \leq 10^{-16}$$
  - D decay: (?)

CP Violation in B Decay

- Physical states given by:

$$|B_1\rangle \propto (1+\varepsilon_b+\delta_b)|B^0\rangle + (1-\varepsilon_b-\delta_b)|\overline{B}^0\rangle$$

$$|B_1\rangle \propto (1+\varepsilon_b-\delta_b)|B^0\rangle - (1-\varepsilon_b+\delta_b)|\overline{B}^0\rangle$$

where ε_b, δ_b are small complex parameters describing CP violation

$$\varepsilon_b \propto -i(\Lambda_{12}-\Lambda_{21})$$

T violated
CPT preserved

$$\delta_b \propto -i(\Lambda_{11}-\Lambda_{22})$$

CPT violated
T preserved

note: in SM, $\delta = 0$

δ in SM Extension

- It is a derivable quantity
- Depends on a single coupling of the form:

$$-a_\mu^q \bar{q}\gamma^\mu q$$

q valence quark field

a_μ^q spacetime constant,

but depends on quark flavor

- Thus δ can be different for K,B,D
- Also, Lorentz symmetry is broken, so δ depends on boost and orientation of meson 4-velocity relative to frame in which couplings are specified

Semileptonic B Decay Rates

- Time dependent decay probabilities

$$B_d^0 \to B_d^0 : \quad \frac{e^{-t/\tau}}{\tau} \cdot \frac{1 + \cos \Delta m_d t - 4 \operatorname{Im} \delta_B \sin \Delta m_d t}{2k}$$

$$B_d^0 \to \overline{B}_d^0 : \quad \frac{e^{-t/\tau}}{\tau} \cdot \frac{1 - \cos \Delta m_d t}{2} \cdot \frac{1 - 4 \operatorname{Re} \varepsilon_B}{k}$$

$$\overline{B}_d^0 \to \overline{B}_d^0 : \quad \frac{e^{-t/\tau}}{\tau} \cdot \frac{1 + \cos \Delta m_d t + 4 \operatorname{Im} \delta_B \sin \Delta m_d t}{2k}$$

$$\overline{B}_d^0 \to B_d^0 : \quad \frac{e^{-t/\tau}}{\tau} \cdot \frac{1 - \cos \Delta m_d t}{2} \cdot \frac{1 + 4 \operatorname{Re} \varepsilon_B}{k}$$

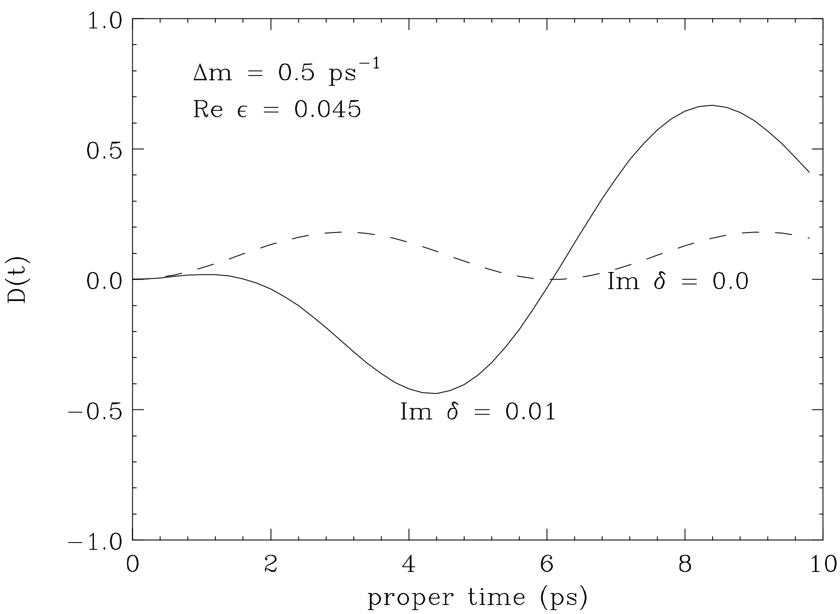
- mass difference Δm_d determines oscillation frequency

Difference in time dependent asymmetries

- A key quantity sensitive to CP and CPT violating parameters is the difference in decay rate asymmetries:

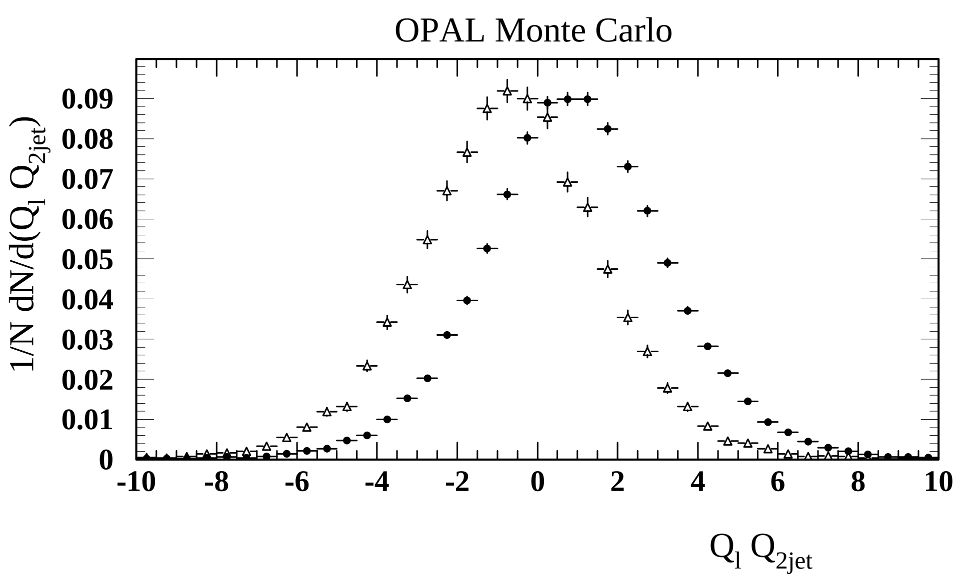
$$D(t) = \frac{\Gamma(\overline{B} \to \overline{f}) - \Gamma(\overline{B} \to f)}{\Gamma(\overline{B} \to \overline{f}) - \Gamma(\overline{B} \to f)} - \frac{\Gamma(B \to f) - \Gamma(B \to \overline{f})}{\Gamma(B \to f) + \Gamma(B \to \overline{f})}$$

$$\approx -\mathrm{Re}\,\varepsilon_B \cdot (1 - \cos \Delta m_d t) + 4\,\mathrm{Im}\,\delta_B \sin \Delta m_d t$$



CPT Limits on B Decay from LEP

- OPAL first to try this out with inclusive leptons. Q_l tags flavor at decay
- b-hadron flavor at production using a jet charge technique incorporating information from both same-side and away-side jets: Q_{2jet}
- Product $Q_l\, Q_{2jet}$ estimates mix or not

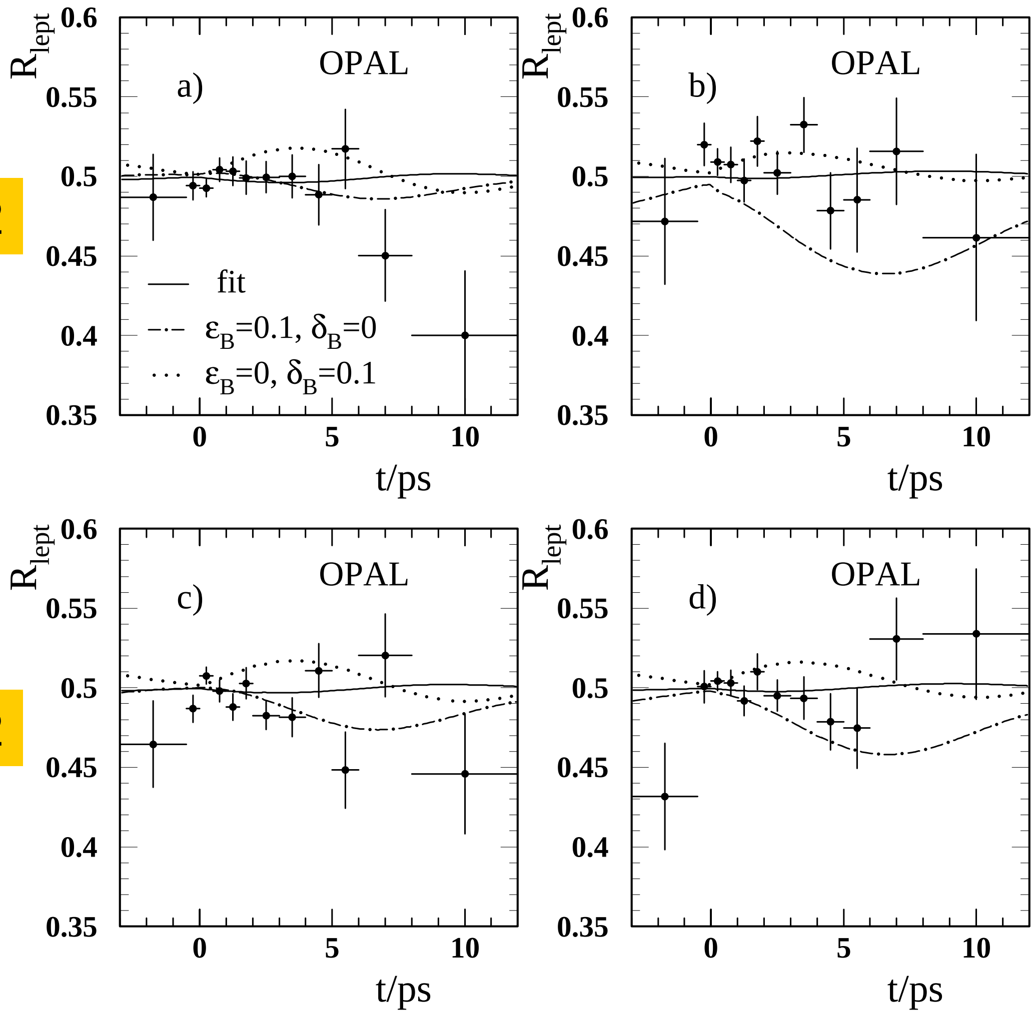


B Decay CPT limit (OPAL)

$Q_l\, Q_{2jet} > 0$ $Q_l\, Q_{2jet} < 0$

$|Q_{2jet}| > 2$

$|Q_{2jet}| < 2$

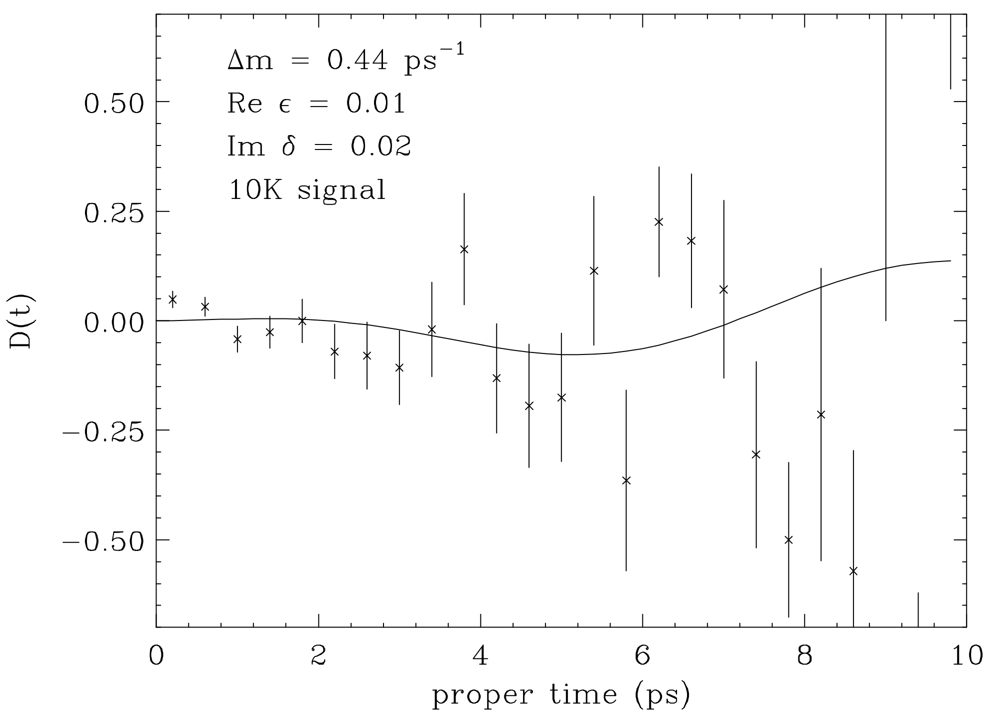


- Fit result: $\mathrm{Re}\,\varepsilon_B = -0.006 \pm 0.010 \pm 0.006$

  $\mathrm{Im}\,\delta_B = -0.020 \pm 0.016 \pm 0.006$

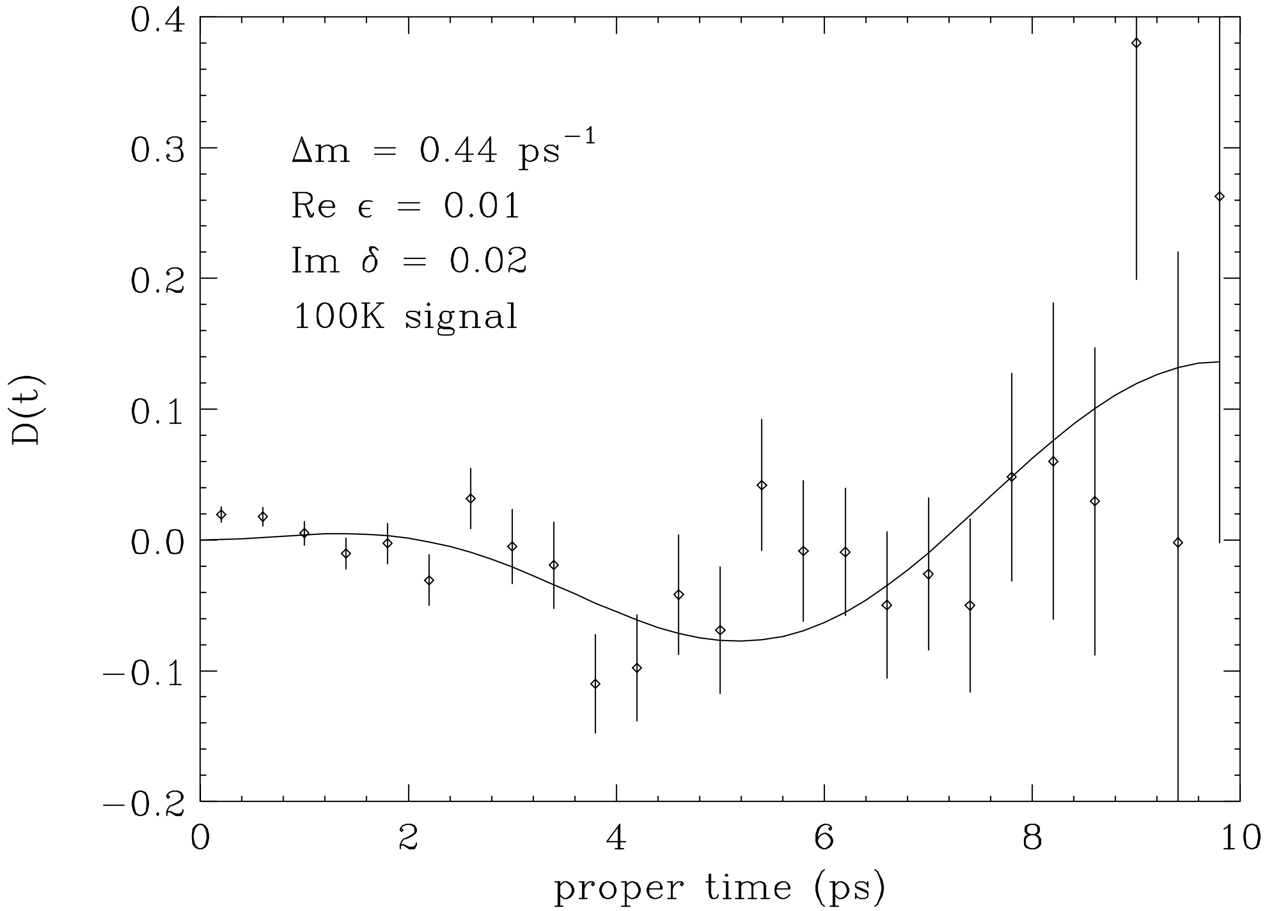
Testing CPT with BTeV

- Consider:
  - 10,000 “effective” reconstructed semileptonic B decays
  - proper time resolution of 50 fs
  - use a jet charge technique which yields a mistag probability of 25%
- Result:



Testing CPT with BTeV

- Same, but with 100K semileptonic decays

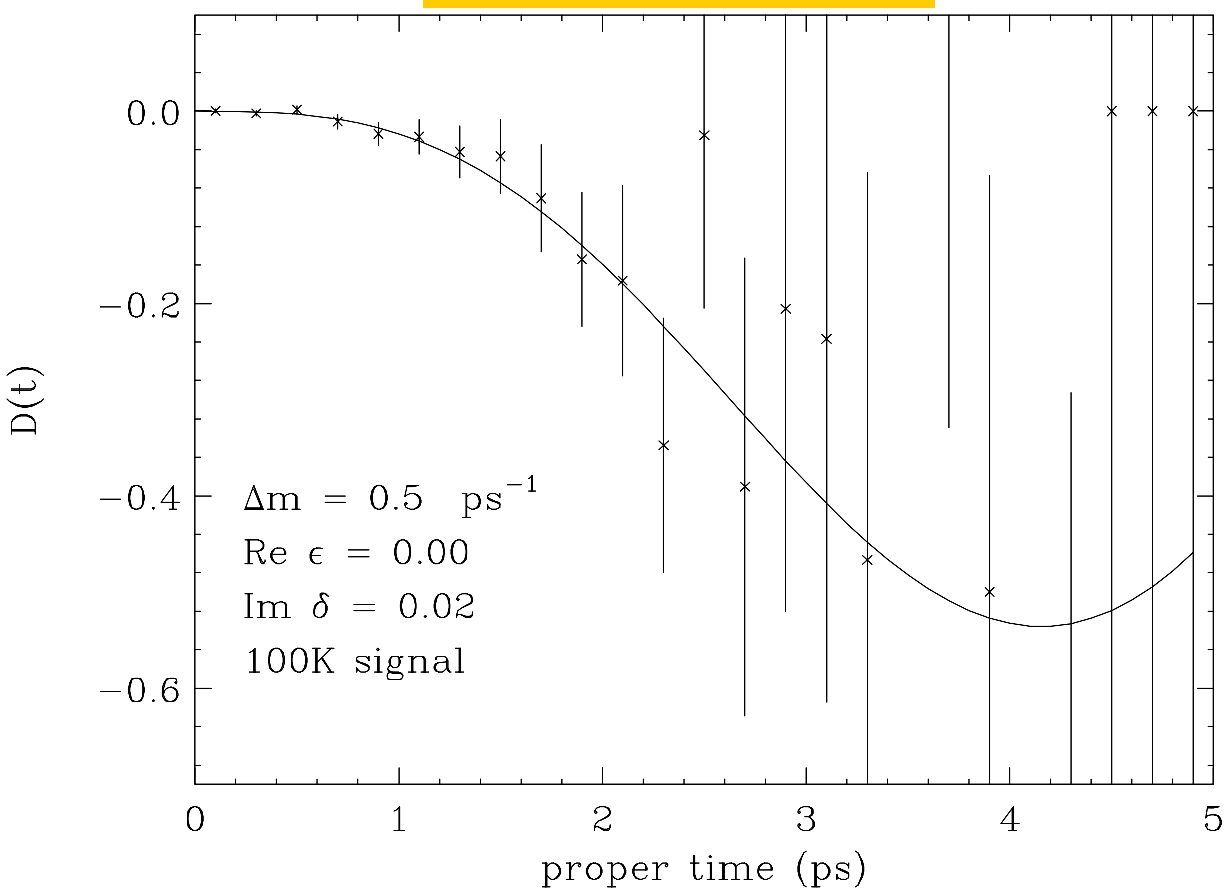


Aside: CPT in Charm Decay

- D* is an excellent production tag

$$D^{*+} \rightarrow D^0\pi^+ \quad \text{Soft } \pi^+ \text{ tags initial state}$$
$$\downarrow$$
$$D^0 \rightarrow K^-\pi^+ \quad \text{(right sign)}$$
$$D^0 \rightarrow K^+\pi^- \quad \text{(wrong sign)}$$

eg: 2% mistag prob:



Conclusions

- Fundamental theories in which Lorentz symmetry is spontaneously broken result in spontaneous CPT breaking.

- SM extensions incorporating string theory have been developed and can be tested experimentally.

- CPT symmetry tests at LEP using B decays have been surprisingly sensitive $\sim 10^{-16}$

- Data from Run II and beyond should significantly improve these constraints. This should be pursued along with other CP, mixing studies.