Mixing Limits of the Strange B^0 Meson

Jamie E. Hegarty
Advised by Phil Gutierrez
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Mixing Limits: Outline

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Background & Motivation

Standard Model Quarks

- ★ **Quarks** come in 6 flavors, and 3 "flavor doublets", as do their antiquarks:

Chg:	Quarks		
+2/3	[redacted]	c	t
-1/3	[redacted]	s	b

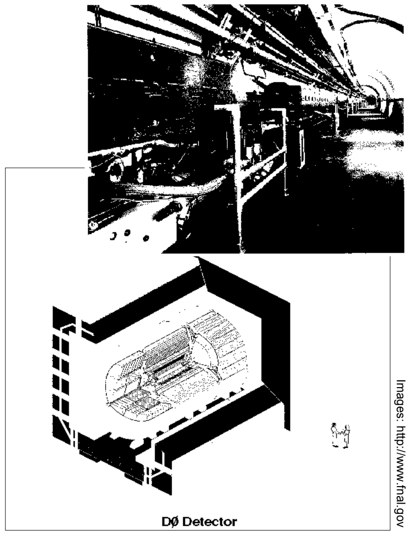
← CHARGE CONJUGATION →

Chg:	Antiquarks		
-2/3	[redacted]	cbar	tbar
+1/3	[redacted]	sbar	bbar

- ★ **Hadrons** are composites of 2 or 3 quarks
- ★ **Mesons** are hadrons which contain quark-antiquark (q,qbar) pairs.
- ★ The **B^0 meson** contains (bbar,d).
- ★ The **strange B^0** (B_s) contains (bbar,s).

B_s Production & Detection

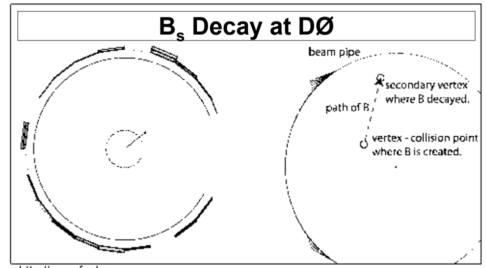
- ★ Our B_s currently produced at the Tevatron (Fermilab), detected at DØ.
- ★ DØ only detects ***stable long-lived, charged*** particles (e, μ, p, etc.)
- ★ B_s not detected directly - must be reconstructed from tracks of other particles
- ★ TeV is a *hadron* collider (not designed for B physics), so reconstruction is ***messy***



Images: http://www.fnal.gov

B_s Decay & Mixing

B_s Decay at DØ



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- ★ Lifetime of B_s must be *Reconstructed*

⇒ inherent error in lifetime measurement

(vertex not always well-defined)

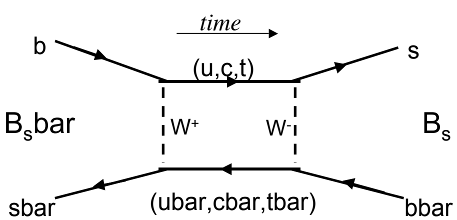
- ★ B_s and $B_s$bar are ***Uncharged***
- ★ Exist in ***superposition*** of 2 mass/CP eigenstates (differ by Δm_s)
- ★ Δm_s ***small*** (~10 μeV … m_B~100 MeV)
- ★ B_s may transition to $B_s$bar or v.v. [mixing]
- ★ "***mixing" may occur before decay***

B_s Mass Eigenstates

$$B_S^0 = \tfrac{1}{\sqrt{2}}\left|B_{S,1}^0\right\rangle + \tfrac{1}{\sqrt{2}}\left|B_{S,2}^0\right\rangle$$

$$\overline{B}_S^0 = \tfrac{1}{\sqrt{2}}\left|B_{S,1}^0\right\rangle - \tfrac{1}{\sqrt{2}}\left|B_{S,2}^0\right\rangle$$

The B_s Mixing Process



- ★ B_s transforms into $B_s$bar via exchange of virtual W's between quarks
- ★ *Weak, flavor-changing interaction*
- ★ Dominated by top quark
- ★ Statistical Frequency of Mixing determined by difference in mass.

⇒ *Measurement of mixing frequency allows measurement of Δm*

$$\frac{U-M}{U+M} = \cos(\Delta m \cdot t_p)$$

Ultimate Goal: Set a Limit on Measurement of Δm

Simulating Mixing Events

"Toy" Monte Carlo Production

Simulating Mixing Events

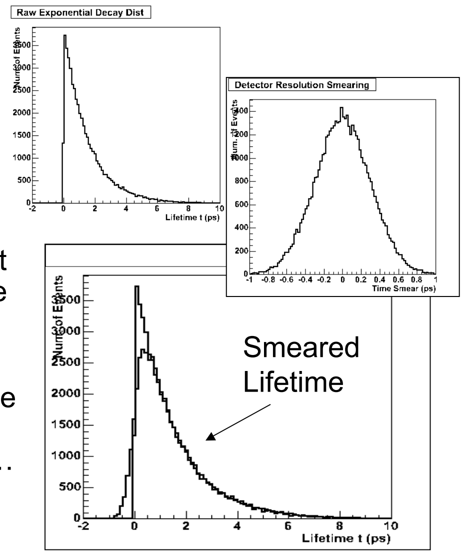
★ Lifetime t_p Randomly Selected from Raw Exp. Decay Dist. $e^{-t/\tau}$

τ is the mean B_s lifetime:

$\tau = 1.5 * 10^{-12}$ s

★ t_p is "smeared" to Account for Time-Resolution of the Detector

⇒ Random "smearing" Value Selected from Gaussian (centered at 0, width σ_t)… added to t_p



Simulating Mixing Events

★ Lifetime t_p smeared again to account for (unmeasured) neutrinos in primary decay

$$B_s \rightarrow D_s^- + \mu^+ + \nu_\mu$$

✷ Higher momentum (longer t_p) B_s decay to higher momentum ν_μ

⇒ This smearing is ***lifetime-dependent*** ($\sigma = t_p \sigma_n$)

★ Random Value Selected from Gaussian (cent. at 0, width $t_p \sigma_n$) … added to t_p

Simulating Mixing Events

★ <u>Tagging</u>: Separating B_s from B_s*bar*

$U(t_p)$ = "Unmixed" (B_s or B_s*bar* remained intact)
$M(t_p)$ = "Mixed" (B_s became B_s*bar*, or v.v.)

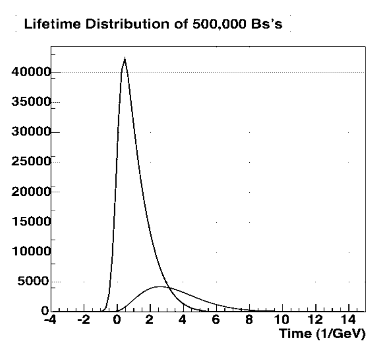
★ *U, M* related by:

$$\frac{U - M}{U + M} = \cos(\Delta m \cdot t_p)$$

★ Random Number Selected from a flat dist. $-1 \leq n \leq 1$

$n < \cos(\Delta m\, t_p) \rightarrow$ Unmixed

$n > \cos(\Delta m\, t_p) \rightarrow$ Mixed



Simulating Mixing Events

★ <u>Mistagging</u>: Tagging B_s as B_s*bar* or v.v.

★ With mistag rate α :

$$N_u(t_p) = (1-\alpha)U(t_p) + \alpha M(t_p)$$
$$N_m(t_p) = (1-\alpha)M(t_p) + \alpha U(t_p)$$

$$\frac{N_u - N_m}{N_u + N_m} = (1-2\alpha)\cos(\Delta m \cdot t_p)$$

⇒ Mistagging affects only the ***<u>amplitude</u>*** of the cosine.

(1-2α) is called "Dilution"

Analysis & Calculations

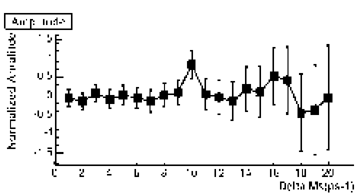
Determining Sensitivity of a Dilution Measurement to Changes in Other Parameters

Fitting to the Simulated Data

- ★ A long, complicated function *f(t)* was used
  - ✷ ***<u>5 parameters</u>*** (!): `tag`, $\sigma_{t\text{-}fit}$, Δm_{fit}, τ_{fit}, α_{fit}
- ★ Unbinned Likelihood Amplitude Fitting:
  - ✷ [unbinned] MC lifetime data compared event-by-event (rather than being histogrammed first)
  - ✷ [likelihood] Each value of t_p in the MC compared to distribution $f(t_p)$ to determine likelihood that t_p was selected from *f(t)*
  - ✷ [amplitude] All parameters *except* α_{fit} held fixed during the fit

⇒ ***only fit for Dilution (D=1-2α)***

Analysis: Dilution Comparison

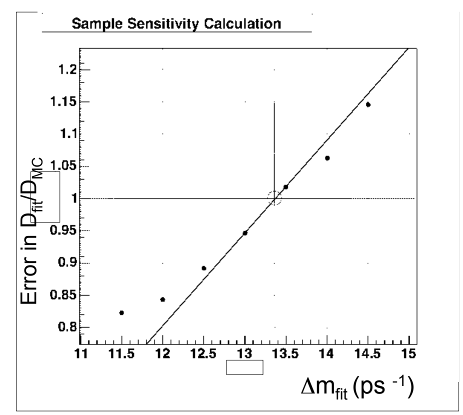


If error in D_{fit} ≥ 1, true Δm cannot be determined!

- ★ Each fit done ~20 times, varying Δm_{fit} each time.
- ★ Resulting Values of $D_{fit}=(1-2\alpha_{fit})$ divided by D_{MC} (dilution in the MC), then plotted against Δm_{fit}
- ★ D_{fit}/D_{MC} peaks to 1 when $\Delta m_{fit} = \Delta m_{MC}$
- ★ Errors in D_{fit} greater for larger Δm_{fit}

Sensitivity Calculation

- ★ <u>Goal</u>: Find Δm_{fit} for which error in D_{fit} is ≥ 1 … *regardless of true Δm*
- ★ Δm_{MC} set very high (>1eV, or 1000 ps^{-1}) so no peak occurs
- ★ *Error* in D_{fit}/D_{MC} plot vs. Δm_{fit}
- ★ Δm_{fit} where error = 1: Sensitivity of D to these MC/fit conditions
- ★ Correct D (and Δm) would only be measurable below the Sensitivity value.



(Preliminary)
Results & Conclusions

Sensitivity Results

★ Sensitivity Calculated for:
- ✷ ± 20% variation in σ_t (detector time resolution)
- ✷ ± 20% variation in D (dilution)

Fit/MC	0.08	0.10	0.12
0.08	22.07	23.56	-
0.10	17.66	17.74	17.88
0.12	-	15.74	15.00

Fit/MC	0.128	0.160	0.192
0.128	16.35	16.35	-
0.160	17.75	17.74	17.75
0.192	-	18.90	18.91

- ✷ No neutrino smearing used here (σ_n = 0)
- ✷ Fit values for D are "initial" values

To-Do & Preliminary Conclusions

★ Up Next:
- ✷ Sensitivity for ± 20% variation in σ_n
- ✷ Add background noise
- ✷ Repeat all this with Full DØ-MC

★ Potential Problems:
- ✷ ***Fit function becomes extremely difficult (non-analytical?) with σ_n included!***
- ✷ Signal-to-Noise ratio unknown.
- ✷ We might be entirely forgetting something.

★ Conclusions:
- ✷ This method works great … up to a point
- ✷ *Either σ_n will need to be "ignored" in fitting, or another method must be used.*

References & Acknowledgements

★ References

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- ✷ Perkins, Donald H., *Introduction to High Energy Physics*, 4th ed., Cambridge UP, 2000
- ✷ *"CP Violation in B Meson Decay: FAQ"*, http://www.physics.uc.edu/~kayk/cpviol/CP_A0.html, 09/30/04
- ✷ Griffiths, David, *Introduction to Elementary Particles*

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- ✷ Phil Gutierrez (advisor)
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★ Images:
- ✷ B-event: http://quarknet.fnal.gov/run2/b_lifetime2.shtml
- ✷ DØ cutaway: http://www-d0.fnal.gov/public/detector/picures.html