Mixing Limits of the Strange B^0 Meson

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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	u	c	t
-1/3	d	s	b

CHARGE ⟷ CONJUGATION

Chg:	Antiquarks		
-2/3	ubar	cbar	tbar
+1/3	dbar	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

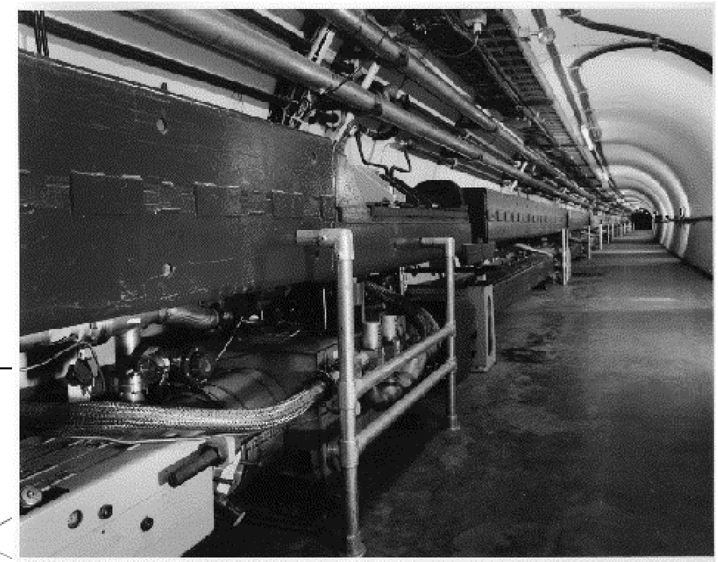
- ★ Our B_s currently produced at the Tevatron (Fermilab), detected at DØ.

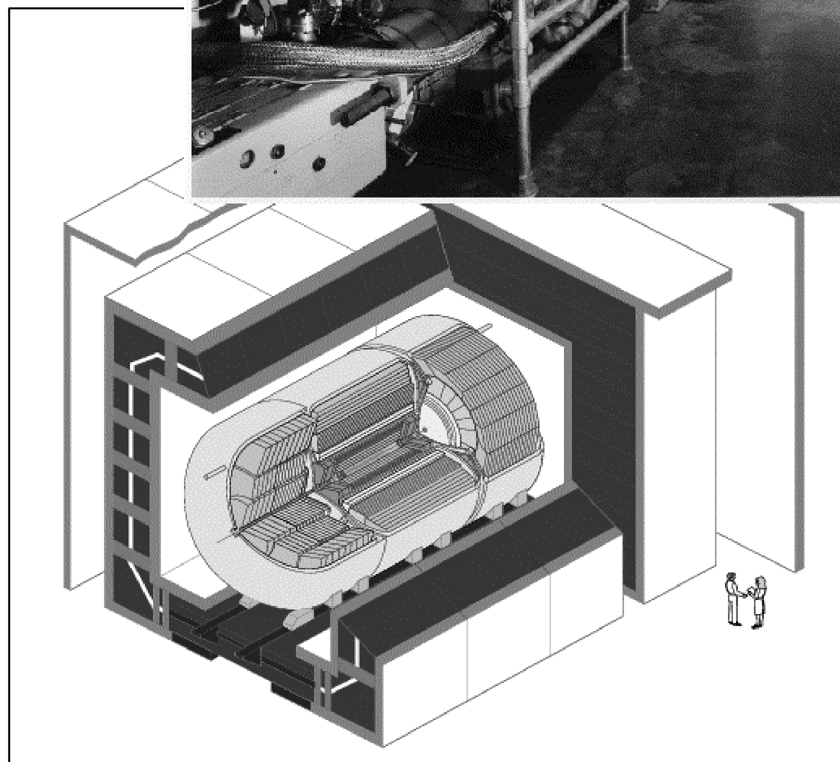
- ★ DØ only detects ***stable long-lived***, ***charged*** particles

  (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***



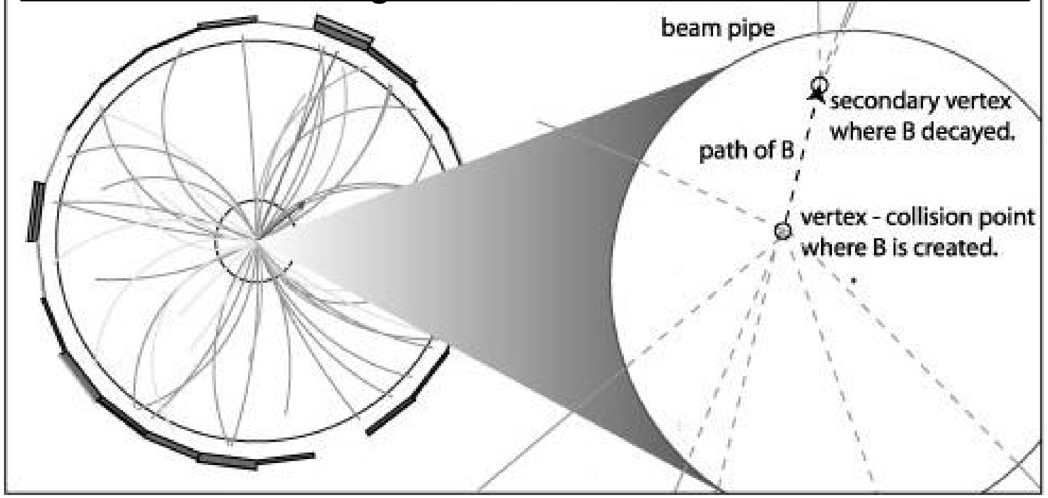


DØ Detector

Images: http://www.fnal.gov

B_s Decay & Mixing

B_s Decay at DØ



http://www.fnal.gov

- ★ 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)

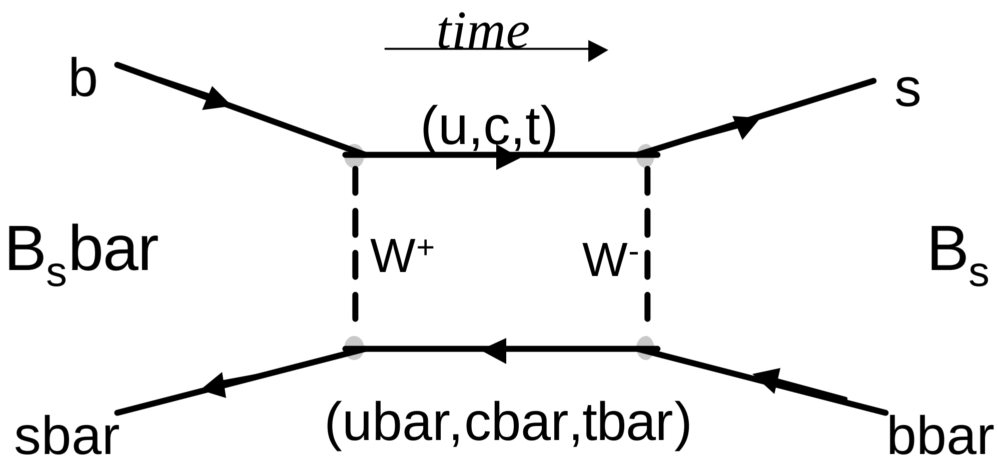
- ★ B_s may transition to $B_s$bar or v.v. [mixing]
- ★ "***mixing" may occur before decay***

B_s Mass Eigenstates

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

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

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 Dm*

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

<u>Ultimate Goal</u>: Set a Limit on Measurement of Δm

Simulating Mixing Events

“Toy” Monte Carlo Production

Simulating Mixing Events

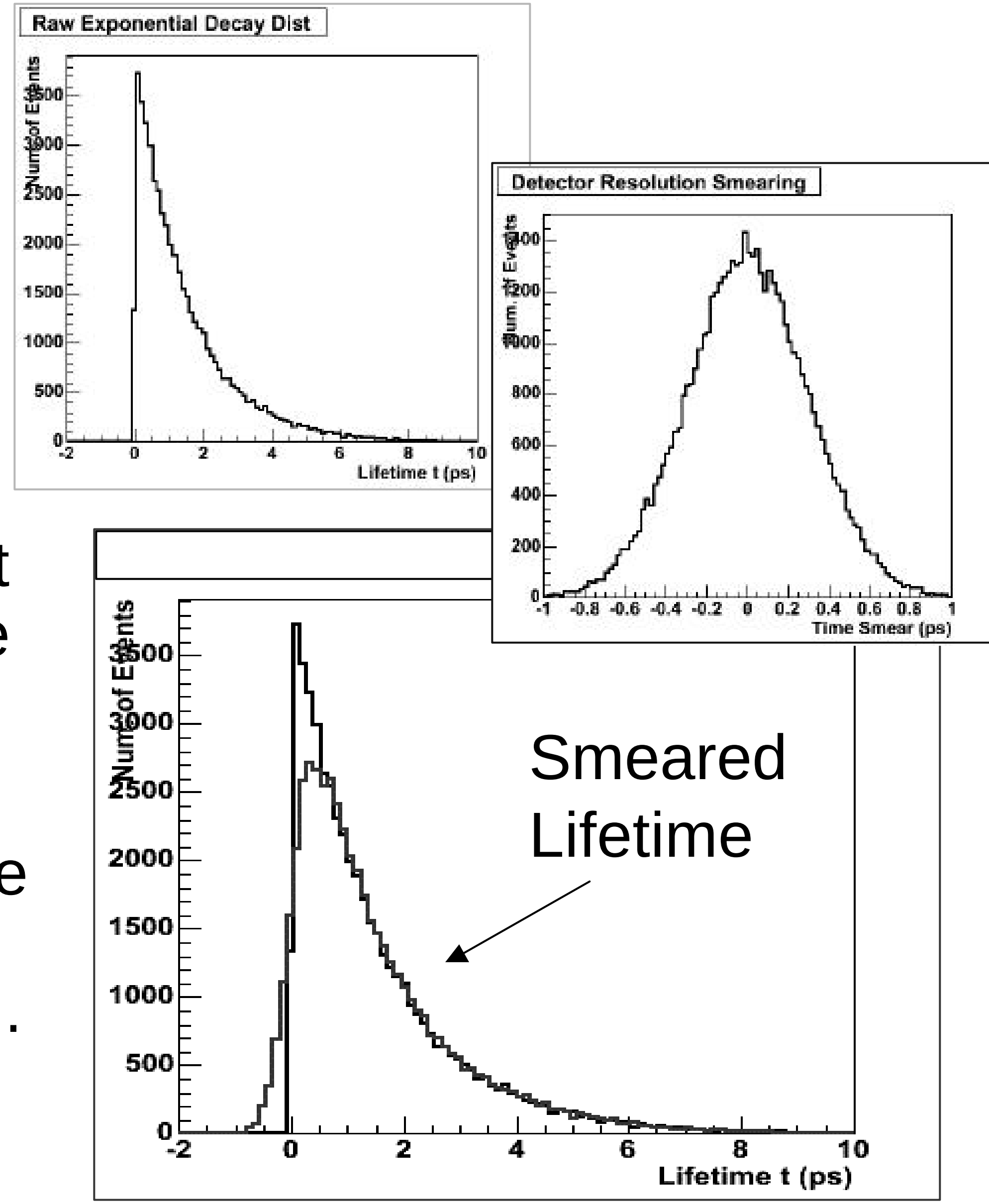
★ Lifetime t_p Randomly Selected from Raw Exp. Decay Dist. $e^{-t/t}$

t is the mean B_s lifetime:

$t = 1.5 * 10^{-12}$ s

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

⇒ Random “smearing” Value Selected from Gaussian (centered at 0, width s_t)… added to t_p



Simulating Mixing Events

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

$$B_s \text{ ® } D_s^- + m^+ + n_m$$

  - ✷ Higher momentum (longer t_p) B_s decay to higher momentum n_m

⇒ This smearing is ***lifetime-dependent*** ($s = t_p s_n$)

- ★ Random Value Selected from Gaussian
  (cent. at 0, width $t_p s_n$) … 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.)

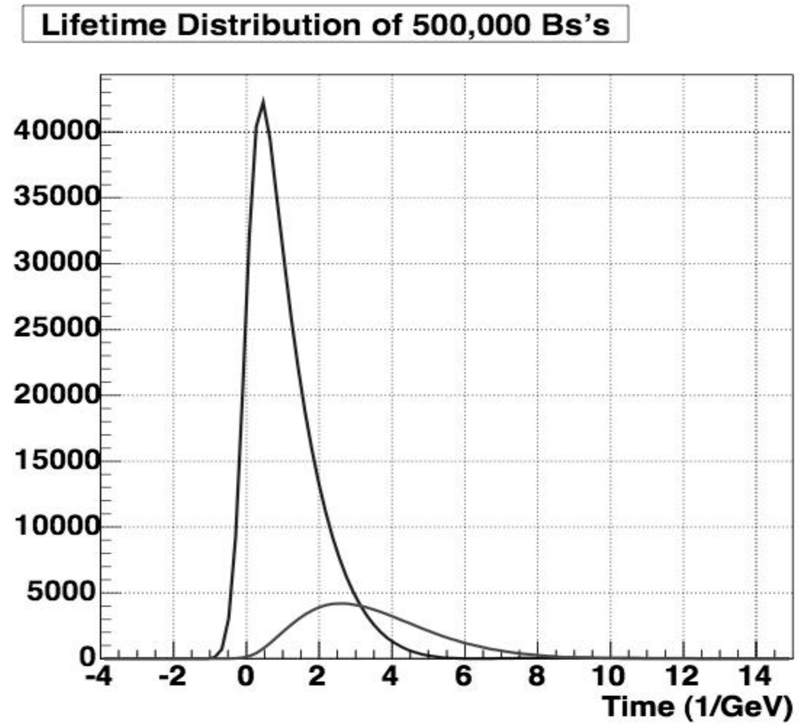
★ *U, M* related by:

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

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

$n < \cos(Dm\ t_p) \rightarrow$ Unmixed

$n > \cos(Dm\ t_p) \rightarrow$ Mixed



Simulating Mixing Events

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

★ With mistag rate a :

$$N_u(t_p) = (1-a)U(t_p) + aM(t_p)$$

$$N_m(t_p) = (1-a)M(t_p) + aU(t_p)$$

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

$\Rightarrow$ Mistagging affects only the ***<u>amplitude</u>*** of the cosine.

(1-2a) is called "Dilution"

Analysis & Calculations

Determining Sensitivity of a
Dilution Measurement to Changes
in Other Parameters

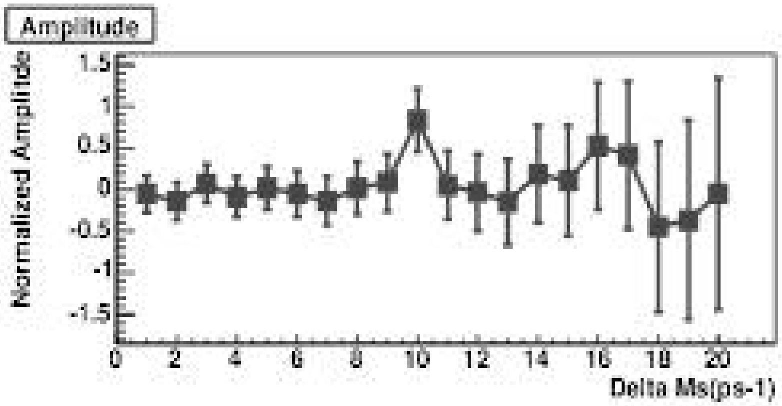
Fitting to the Simulated Data

- ★ 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

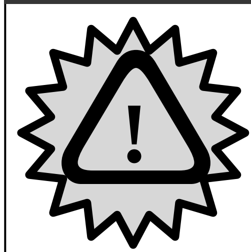
$\Rightarrow$ ***only fit for Dilution (D=1-2*** a***)***

Analysis: Dilution Comparison



- ★ Each fit done ~20 times, varying Δm_{fit} each time.
- ★ Resulting Values of $D_{fit}=(1-2a_{fit})$ 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}

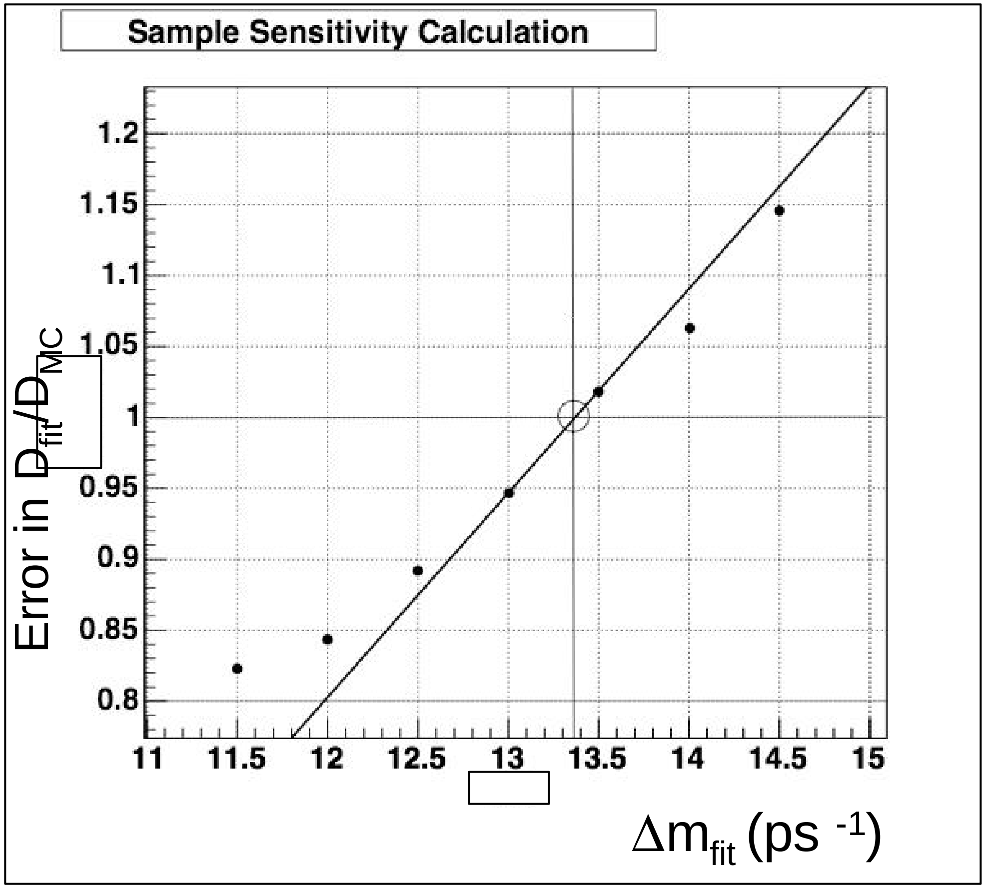
W A R N I N G !



If error in $D_{fit} \geq 1$, true Δm cannot be determined!

Sensitivity Calculation

- ★ <u>Goal</u>: Find Δm_{fit} for which error in D_{fit} is ≥ 1 … *regardless of true Dm*
- ★ 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.



Results & Conclusions

Sensitivity Results

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

Sens of D to ±20% var. in σ_t (ps^{-1})			
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

Sens of D to ±20% var. in D (ps^{-1})			
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 ($\sigma_n = 0$)
  - Fit values for D are “initial” values

Sensitivity Results

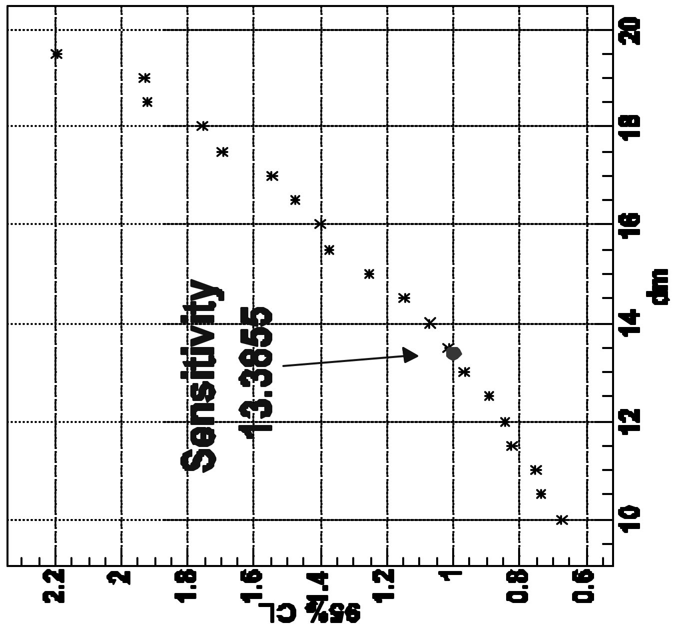
- ★ Sensitivity Calculated for:
  - ✷ ± 20% variation in σ_n (time-dependent resolution)
  - ✷ σ_n couldn't be explicity included in fitting

s_n ignored:
included in MC but not in fit

Avg:
MC values binned, bin-weighted average σ used in fit

Eff s at t:
actual smearing value calc'd at each t during fit

Sens of D to ±20% var. in σ_n (ps^{-1})			
Fit/MC	0.130	0.163	0.196
s_n ignored	17.799	17.783	17.808
Avg ($s_{n,}$ s_t)	6.473	5.840	5.162
Eff s at t	-	13.386	-



Conclusions

- Up Next (possibly):
  - Add background noise
  - Repeat all this with Full DØ-MC
  - Check sensitivity values with another method

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

- Conclusions:
  - This method works great … up to a point
  - Sensitivity values lowest (worst) when smearing is averaged, highest (best) for underestimating σ_t or overestimating D

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*

★ Acknowledgements

- Phil Gutierrez (advisor)
- Peter Williams (theory guru)

★ Images:

- B-event: http://quarknet.fnal.gov/run2/b_lifetime2.shtml
- DØ cutaway: http://www-d0.fnal.gov/public/detector/picures.html