# *B* mixing prospects at DØ – Run-IIa

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- The DØ: Detector & Trigger
- Experimental Issues
- Mixing Studies

# Fermilab & Run-IIa: The Upgraded Tevatron

$p$ (1 TeV) → ← $\bar{p}$ (1 TeV)

**Challenging Running Conditions** — Compared with RunI (1992-96)

- Luminosity: $2\times10^{32}$ cm$^{-2}$ s$^{-1}$ — ($\times$10 increase)
- Bunch crossing time: 396 ns — ($\times$10 decrease)

132 ns or 7 MHz in RunII-b

**$1.1\times10^{31}$ cm$^{-2}$ s$^{-1}$ this month, 8 pb$^{-1}$ /22 pb$^{-1}$ in total**

**What's new at DØ:**

- New subdetectors (silicon tracker, fiber tracker, solenoid, preshowers)
- Improved muon system
- Enhanced trigger system
- Extra shielding around beamlines



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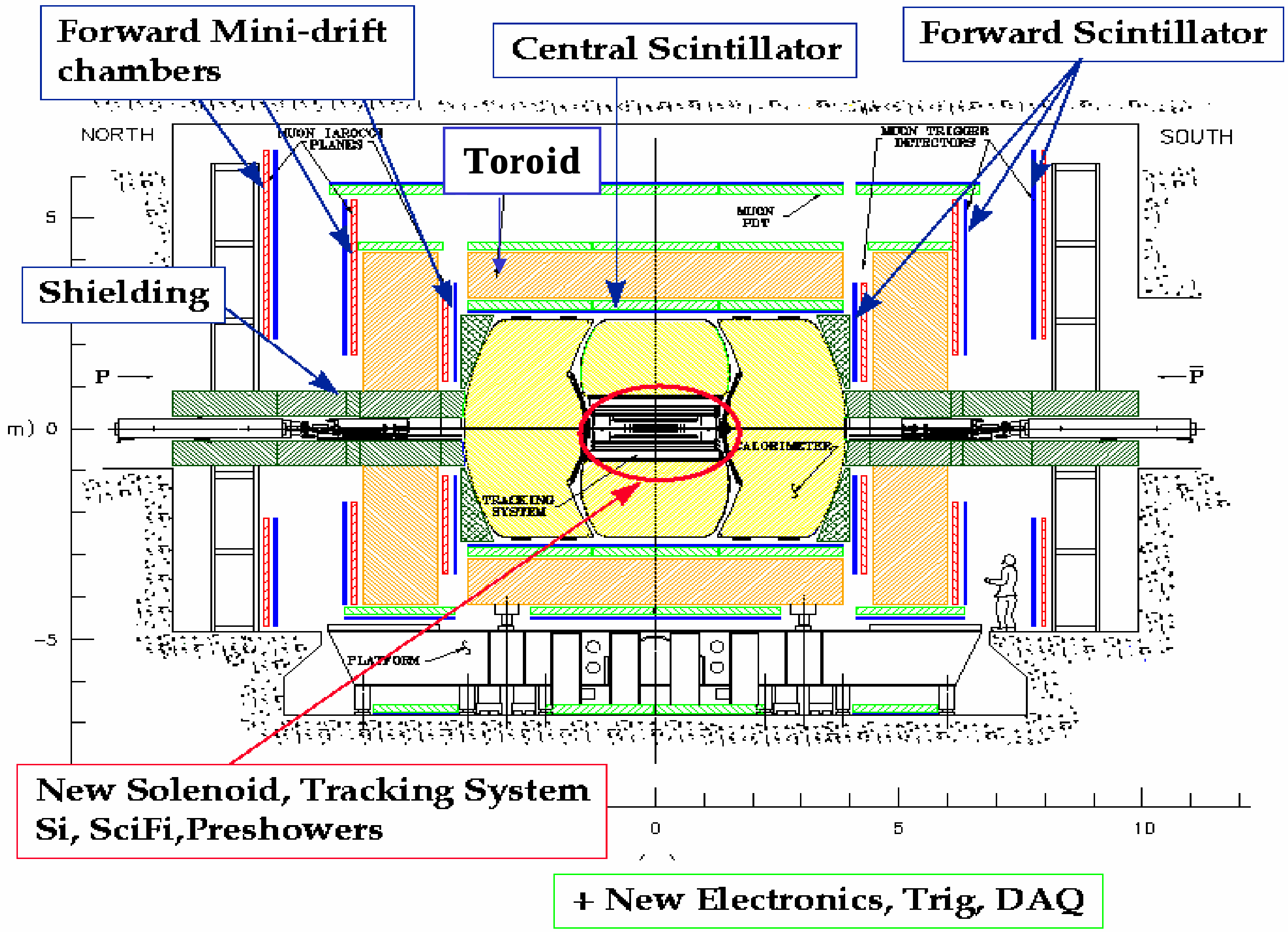
# DØ: The Upgraded Detector



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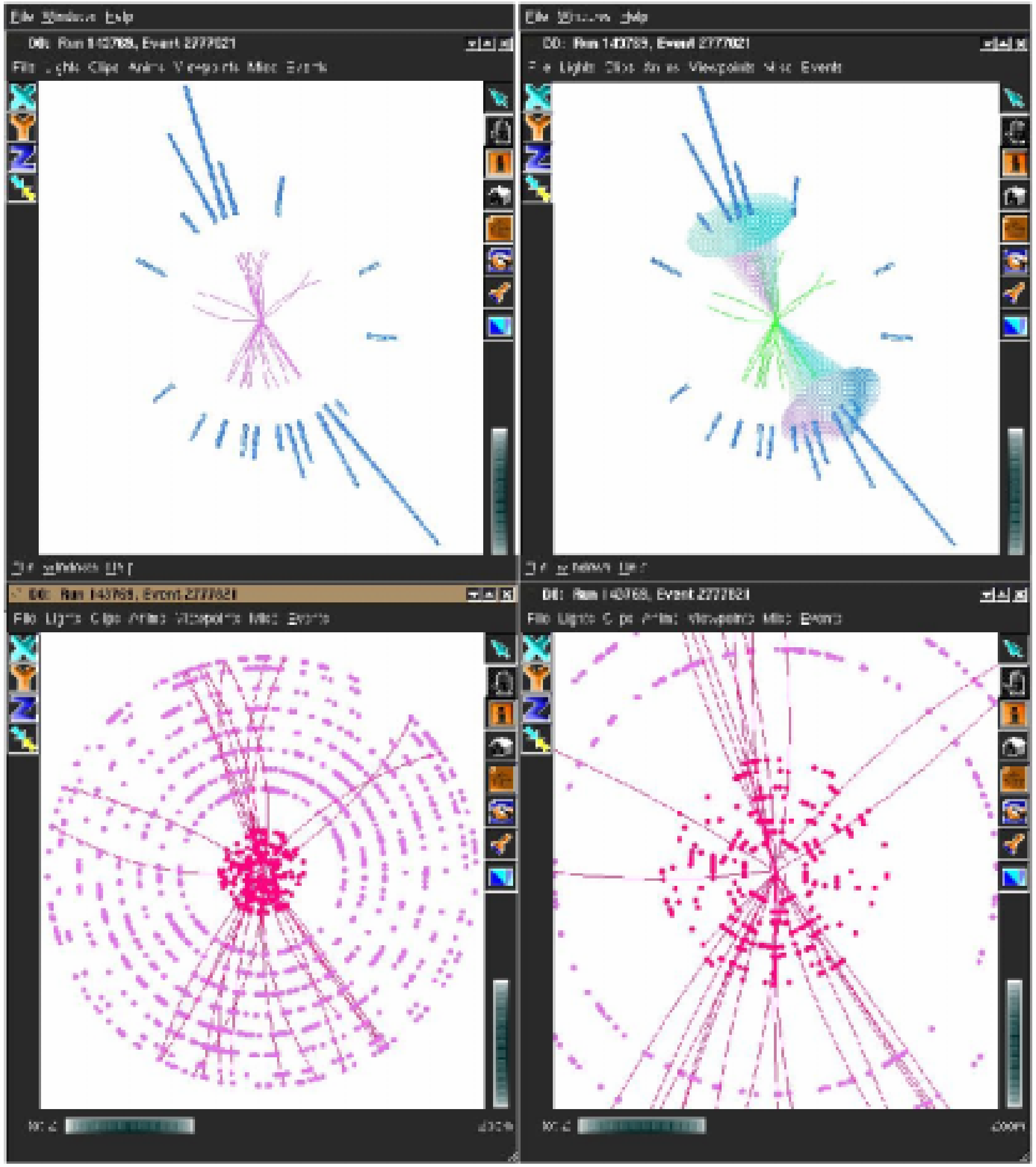
# Exercising the detector…



**Tracks in SMT, CFT matching with CAL cells**

*no, this is not a typical event…*



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# $b$ Physics at Tevatron

- **Lots of $B$'s!**

$(B_d, B_s, B_c, \Lambda_b, \ldots)$

**A $b\bar{b}$ pair can give any combination of mesons & baryons!**

$$\sigma(p\bar{p} \to b\bar{b}) = 150\ \mu\text{b}\ @2\ \text{TeV}$$

$$\sigma(e^+e^- \to Z^0 \to b\bar{b}) = 7\ \text{nb}$$

$$\sigma(e^+e^- \to \Upsilon(4S) \to b\bar{b}) = 1\ \text{nb}$$

- **Lots of background!**

***Need good triggers***

- high/medium $P_T$: $\ell$ or $\ell\ell$
- secondary vertices/impact parameters (L2/L3)

**since Run-I**

**Run-II "feature": use to lower $P_T$ threshold**

**# of interactions/crossing**

| **bunch Xing** | $b\bar{b}$ | **Total** |
|---|---|---|
| 396 ns | 0.008 | 6.0 |
| 132 ns | 0.003 | 2.0 |



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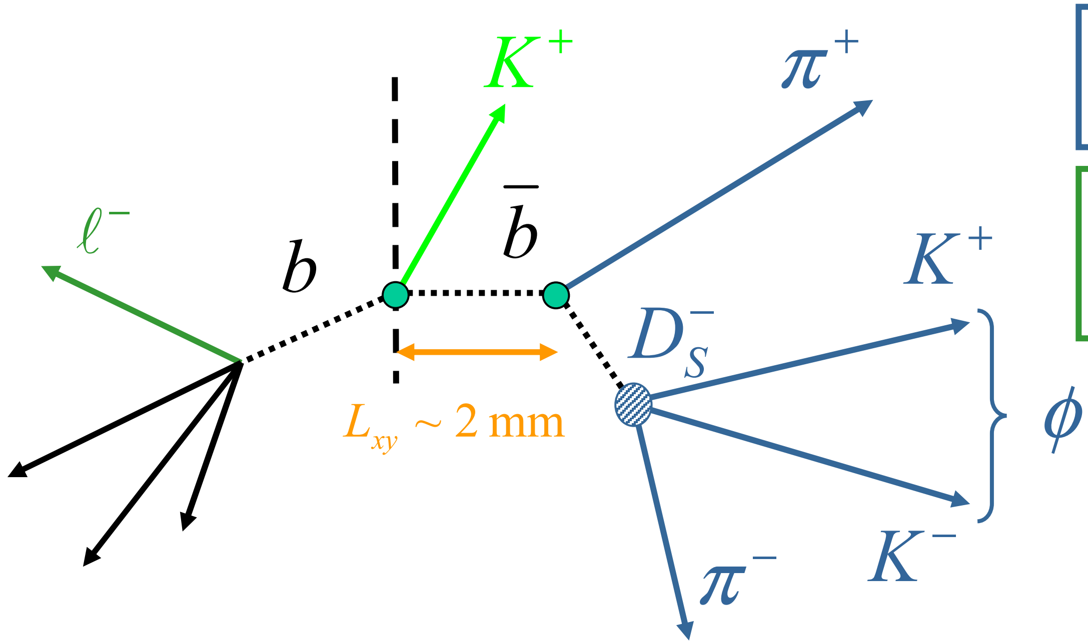
# $B$ mixing: The Measurement




**"flavor at final state": Full/Partial reconstruction**

**"flavor at *t=0*": Opposite Side Tag or Same Side Tag: hadronization**

**Vertexing: Need**

- **primary & secondary vertices**
- **$P_T$ measurement**

**Not needed in a $e^+e^-$ B factory!**

**"Tag quality":**

$$\varepsilon_{\text{eff}} \equiv \varepsilon\,\underbrace{(1-2w)}_{\text{Dilution: D}}{}^2$$

**Dilution: D**

# Experimental sensitivity

**Statistical significance:**

$$S(\Delta m, \sigma_t) = \sqrt{\frac{\varepsilon N}{2}} \sqrt{\frac{S}{S+B}} (1-2w) \times e^{-(\Delta m\, \sigma_t)^2/2}$$

**difficult measurement for larger Δm**

**Proper time resolution:**

$$\sigma_t \sim \frac{m_B}{\langle p \rangle} \sigma_L \oplus \frac{t}{p} \sigma_p$$

**relevant for partial reconstructed *B*'s**

**main contribution to proper time error**

For $B_S^0 \to D_S^- \pi^+$ :

$\sigma_L \sim 44\ \mu\text{m}$

$\sigma_t \sim 32\ \mu\text{m}/c\ (100\ \text{fs})$

$p_T > 3\ \text{GeV}/c\ \&\ |\eta| < 2$

$L/\sigma_L > 1.5$

**Remember:**

$\eta \equiv -\log(\tan \vartheta/2)$

$\eta \in [-2, 2] \Leftrightarrow \vartheta \in [15°, 165°]$



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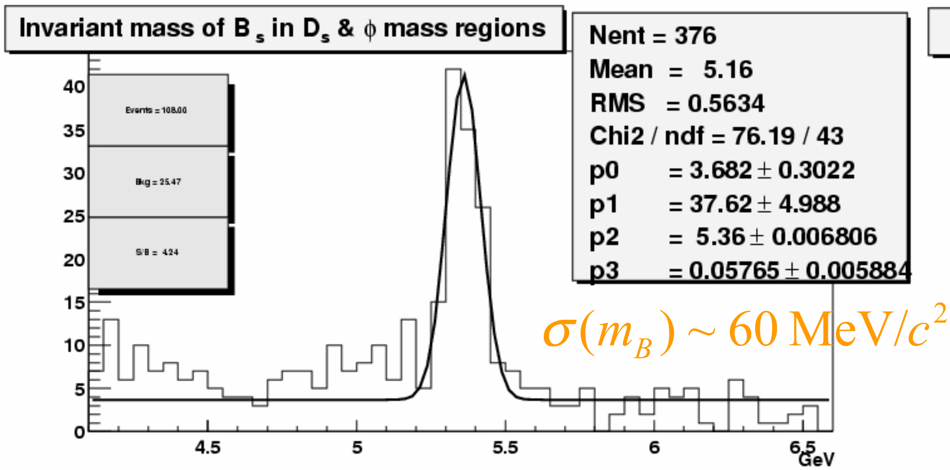
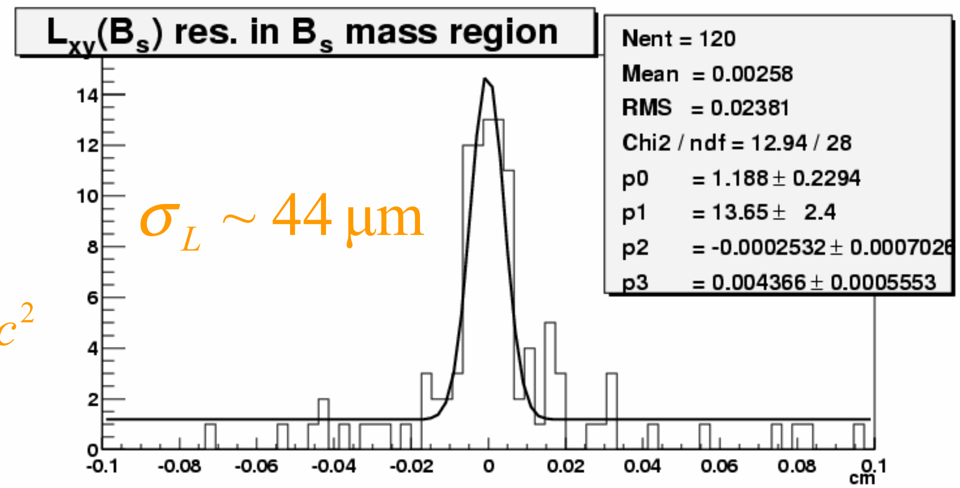
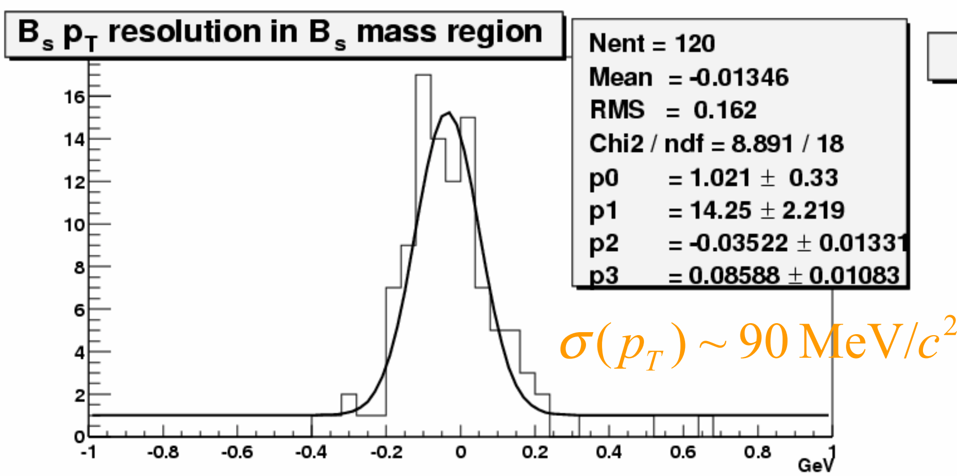
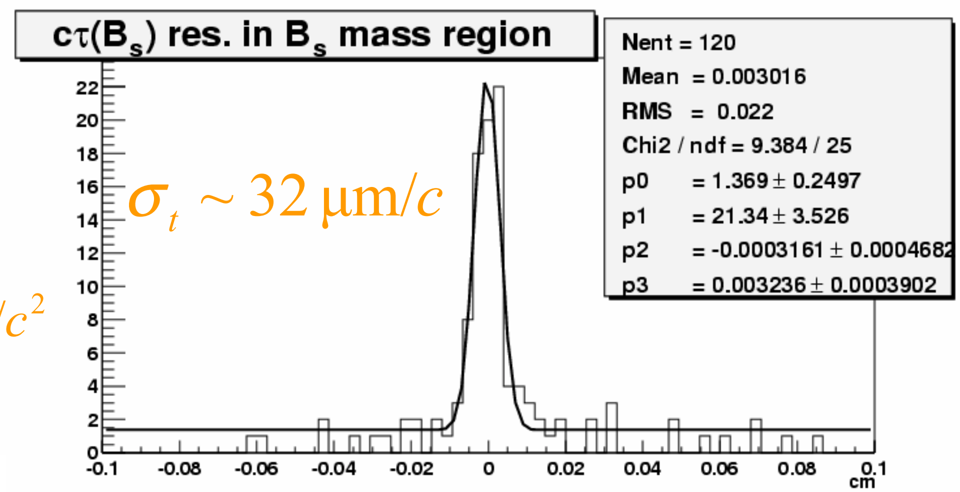
# GEANT: $B_s \rightarrow D_s \pi$



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# tagging power: $\varepsilon D^2$

$b \to \ell^- X$

$$Q_j = \frac{\sum q_i \vec{p}_i \cdot \hat{a}}{\sum \vec{p}_i \cdot \hat{a}}$$

$b \to c \to K^- X$

| Method | Mode | D0 | CDF | CDF @RunI | Comment |
|---|---|---|---|---|---|
| soft lepton (OS) | both | 3.1 | 1.7 | 1.7 | better e, μ coverage |
| Jet charge (OS) | both | 4.7 | 3.0 | 3.0 | forward tracking |
| fragment. $\pi$ (SS) | $B_d$ | 2.0 | 1.9 | 1.4 | – |
| fragment. $K$ (SS) | $B_s$ | – | 4.2 | 1.0 | no K-ID |
| cascade $K$ (OS) | both | – | 2.4 | 2.4 | no K-ID |

*tag quality calculated with* $J/\psi \to \ell\ell$ *trigger sample*

- **different tagging methods → different systematic errors**
- **consistency checks between methods & experiments**



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# $\Delta m_s$ measurements

| Mode | Trigger | Initial Tag | Final Tag | # of reco. events | $\Delta m_s$ reach |
|---|---|---|---|---|---|
| $B_S^0 \to D_S^- \ell^+ \nu X$<br>$D_S^- \to \phi \pi^- \to K^+ K^- \pi^-$ | $\ell\ell$ | Soft lepton (OS) | lepton from $B_s$ | ~ 40k | < 20 ps$^{-1}$ |
| *Large statistics, missed ν carries momentum: affects $t^*_B$ resolution* | | | | | |
| $B_S^0 \to D_S^- \pi^+, D_S^- \pi^+\pi^-\pi^+$<br>$D_S^- \to \phi \pi^- \to K^+ K^- \pi^-$ | $\ell$ | Soft lepton (OS) | Sign of $D_s$ | 500-1200 | < 22 ps$^{-1}$ |
| *Small statistics, good vertex resolution* | | | | | |
| $B_S^0 \to J/\psi K^*, K^* \to K^+ \pi^-$<br>$J/\psi \to e^+e^-, \mu^+\mu^-$ | $\ell\ell$ | All | Sign of $K^+$ | 400-1000 | < 22 ps$^{-1}$ |
| *Small statistics, good vertex resolution, compare fitted mass of $K^+\pi^{?}$, $K^{?}\pi^+$* | | | | | |

**Notes:**

- **Additional modes $D_s \to K^{*0} K^-$ , $J/\psi \to e^+e^-$ not explored yet**
- **Older MC studies, do not include forward detector**
- **Studies with new tracking & vertexing underway**

$\eta > 1 \Leftrightarrow \vartheta < 40°$

$\eta < -1 \Leftrightarrow \vartheta > 140°$



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# Sources of uncertainty

- **Branching ratios for $B_s$ decays: poorly measured**
- **Efficiency for reconstruction, trigger: based on MC studies**
- **New triggers, tagging: need to study bias**



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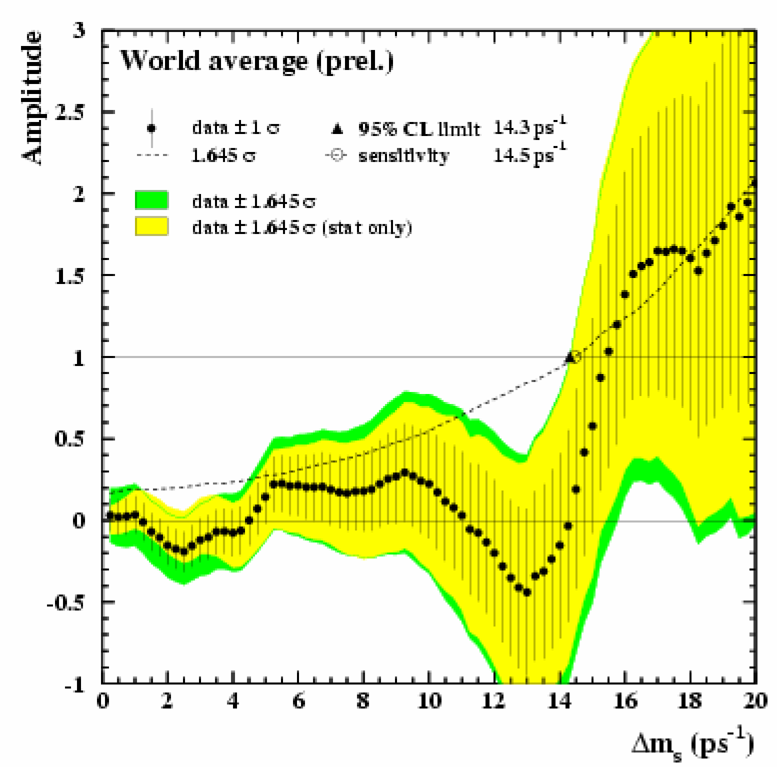
# $\Delta m_s$ fit: Amplitude Method

**Fit to**

$$\frac{\Gamma_S}{2} e^{(-\Gamma_S t)} \times [1 \pm A \cos(\Delta m_S\ t)]$$

**Moser & Roussarie NIM A 384 (1997)**




- **"Bump" at 17 ps$^{-1}$**
- **SM gives: 20 < $x_S$ < 31 (13 ps$^{-1}$ < $\Delta m_s$ < 21 ps$^{-1}$)**

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# $\Delta\Gamma_s$ Phenomenology

- **SM : *CP* violation in $B_s$ mixing small**

$$\Gamma(B_S^{\text{short}}) - \Gamma(B_S^{\text{long}}) \equiv \Delta\Gamma_S \approx \Delta\Gamma_{CP} \equiv \Gamma(B_S^{\text{CP even}}) - \Gamma(B_S^{\text{CP odd}})$$

$$\Delta\Gamma_S = \Delta\Gamma_{CP} \cos\phi$$

→ ***CPV* phase in mixing**

**($\varphi_{SM} \sim 0$)**

- **New physics: large CP violation; affects only $\Delta\Gamma_s$**

$$a_{CP}(B_S \to J/\psi\, \phi) \propto \sin\phi$$

→ **determine *CPV* phase**



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# $\Delta\Gamma_s$ measurements

## From lifetime of $B_s$ candidates:

**1. *CP* eigenstate sample: sensitivity ~** $\Delta\Gamma_S \cdot \cos\varphi = \Delta\Gamma_{CP} \cdot \cos^2\varphi$

$"B_S \to J/\psi\,\phi"$

**CDF-RunI: (77 ± 19) % *CP*-even**

**easy trigger: ~20k reconstructed events**

- **admixture of *CP*-even and *CP*-odd states**
- **angular analysis is needed**
- **the $\Delta\Gamma_s$ error depends on the admixture**



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# $\ldots \Delta\Gamma_s$ measurements

## …From lifetime of $B_s$ candidates:

**2. *CP* eigenstate + (50%-even, 50%-odd) sample:**

$$\Delta\Gamma_S = 2\cos\phi \times \left[\Gamma(B_S^{\text{CP even}}) - \Gamma(B_S^{\text{CP 50:50}})\right]$$

$$"B_S \to J/\psi\,\Phi"$$

$$B_S \to D_S\,\pi$$

**~ 1000 events**

**3. *CP* eigenstate sample:**

$$B_S \to D_s^+ D_s^- \qquad CP\text{-even}$$

**<u>But:</u> not straightforward: overlaps with ~ 4x copious**

$$B_S \to D_s^{*+} D_s^{*-} \qquad \text{(unknown) admixture of } CP\text{-even } \& \; CP\text{-odd}$$



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# $\Delta\Gamma_s$ - Expected sensitivity

$$\sigma(\Delta\Gamma_S / \Gamma_S) \sim 0.04 - 0.07$$

**All modes combined**

**Phenomenology**

$$\frac{|\Delta\Gamma_S|}{\Gamma_S} \sim 10 - 20\% \ \ (\mathrm{SM})$$

**keep in mind: we need >5σ for discovery**



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# What about $\Delta m_d$ ?

- **Many modes (semileptonic, hadronic, dileptons, …);**

  **~ same methodology**

- **More $B_d$'s than $B_s$'s:** $\frac{f_d}{f_s} \approx 4$

- **Easier than $\Delta m_s$ in principle (slower oscillation)**

- ***But:*** **focus has been on $\Delta m_s$ ; use $\Delta m_d$ to prove tagging & vertexing, come back to this later**



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# Status of DØ

- **Data collection:**
  - **global DAQ most of the time**
  - **10% of time devoted to detector commissioning**
- **Silicon Detector: operating with 80% of system (95% in 2 weeks)**
- **Fiber Tracker: all axial boards, 20% of stereo in place**
- **Calorimeter: running smoothly**
- **Muon Detectors: running smoothly**
- **Trigger:**
  - **L1: running with electrons, jets, muons and dimuons**
  - **L2: commissioning muons, cal; filtering within month**
  - **L3: filtering with jet & EM; output: 30 Hz**
- **Working on improving tracking efficiency**

**Lots of data and hard work are ahead of us!**



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