Mixing Measurements and CP Violation Studies at CDF

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OUTLINE:

- Requirements for B Mixing and CP Violation measurements
- B Mixing Results achieved with Run I data
- B_S Mixing Prospects for Run II
- CP violation studies and expectation in Run II for
  - $\sin(2\beta)$
  - $\sin(2\alpha)$
  - $\sin(2\gamma)$ No detailed studies yet

Requirements for Mixing & CP violation measurements

- Time dependent mixing:

$$\mathcal{P}_{{B^0}_{d,s}(t) \to {\overline{B}^0}_{d,s}(t)} = \frac{e^{-t/\tau_{d,s}}}{2\tau_{d,s}} \left(1 - \cos\left(1 - \Delta m_{d,s} t\right)\right)$$

- Time dependent asymmetry:

$$A_{CP}(t) = \frac{N_{\overline{B}^0(t)} - N_{B^0(t)}}{N_{\overline{B}^0(t)} + N_{B^0(t)}} = \mathcal{A} \sin(\Delta m t)$$

$\mathcal{A} = \sin(2\zeta)$ $\zeta = \alpha, \beta, \gamma$

$\sin(2\beta) : {B^0}_d \to J/\Psi K_S, \sin(2\alpha) : {B^0}_d \to \pi^+\pi^-$

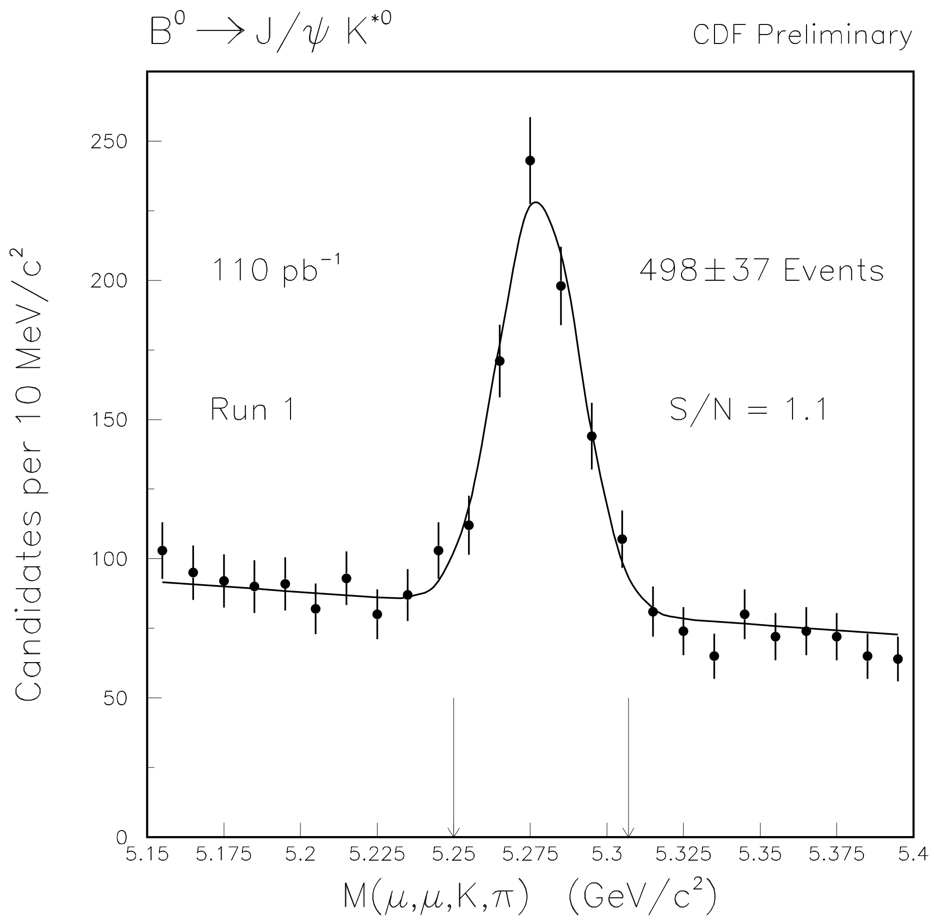
To perform a time dependent measurement we have to:

- reconstruct with enough statistics and good S/B the final CP eigenstate or tag the flavour at the decay time for mixing measurements ;
- reconstruct the decay time;
- tag the B^0 flavour at the production time.

Decay channels reconstruction

CDF has shown the capability of reconstructing with good signal to noise ratio and efficiency

$B \to \Psi K$ $\Psi = J/\Psi, \Psi(2s)$, $K = K^0_s, K^{*0}, K^0_s, K^{*+}$



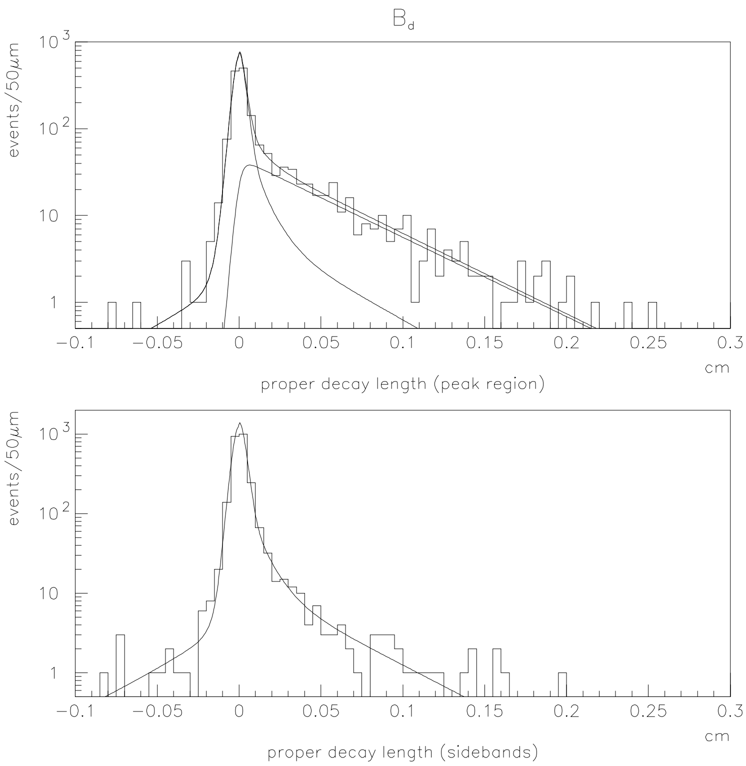
Decay time reconstruction

The experimental proper decay time resolution:

$$\frac{\sigma_t}{\tau} = \sqrt{\left(\frac{\Delta L}{\bar{L}}\right)^2 + \left(\frac{t}{\tau}\frac{\Delta p}{p}\right)^2} \qquad \bar{L} = \frac{\bar{p}}{m}c\tau$$

For fully reconstructed events $\frac{\Delta p}{p} \approx$ few %

The decay length resolution will be better than $\sim 50\mu m$ measured in the B^0 exclusive decays $B \Rightarrow J/\Psi + K$



Flavour tagging

CDF has developed several B tagging algorithm:

- Muons
- Electrons
- Same Side π (SST)
- Jet Charge

The figure of merit to compare these algorithms is ϵD^2

$$\epsilon = \frac{(N_R + N_W)}{N} \qquad D = \frac{(N_R - N_W)}{(N_R + N_W)}$$

$N_{R(W)}$ = Number of events with right(wrong) tag

Flavour Tagging

CDF extrapolates the tagging efficiencies and dilutions from Run I data

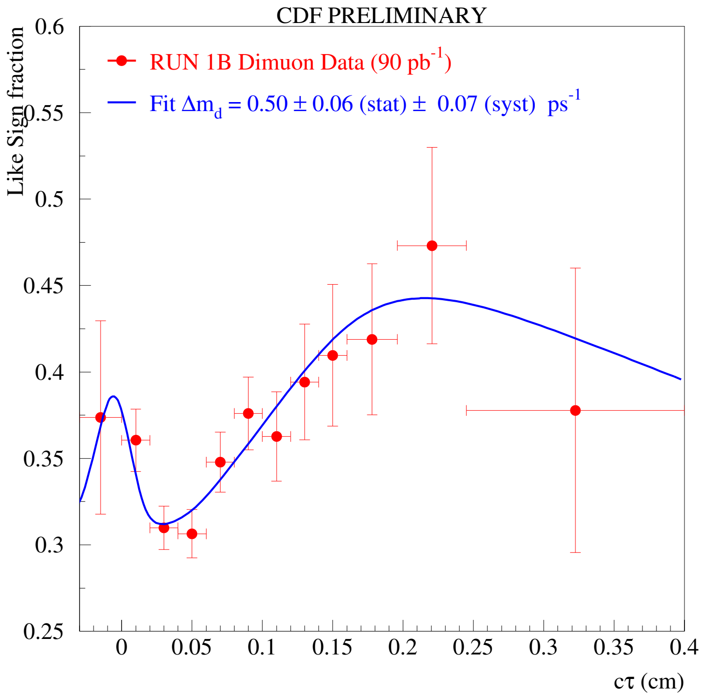
Tagging Method	ϵD^2 (%) measured Run I	ϵD^2 (%) expected Run II	Relevant Upgrade
Muons	0.6 ± 0.1	1.0	Ext. coverage
Electrons	0.3 ± 0.1	0.7	New Plug cal.
Same Side π	2.3 ± 0.4	3.0	New tracking
Jet charge	1.0 ± 0.4	3.0	New tracking
Opposite-side Kaon	–	3.0	
All combined	3.4*	6.0*	

* A correlation of $\sim 80\%$ is estimated.

Run I B_d Mixing Results

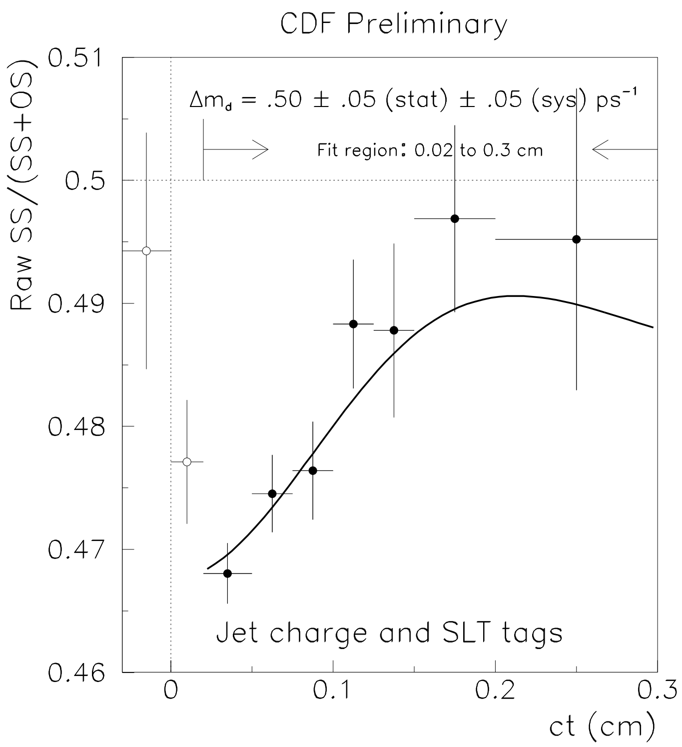
The B_d mixing frequency has been measured using different B decay mode and exploiting several tagging method.

- Lepton - Lepton Correlations
  1. Both $B_d \to \mu X$ (Pisa - Padova)
  2. $B_d \to eX$ and $B_d \to \mu X$ (Harvard)



Run I B_d Mixing Results

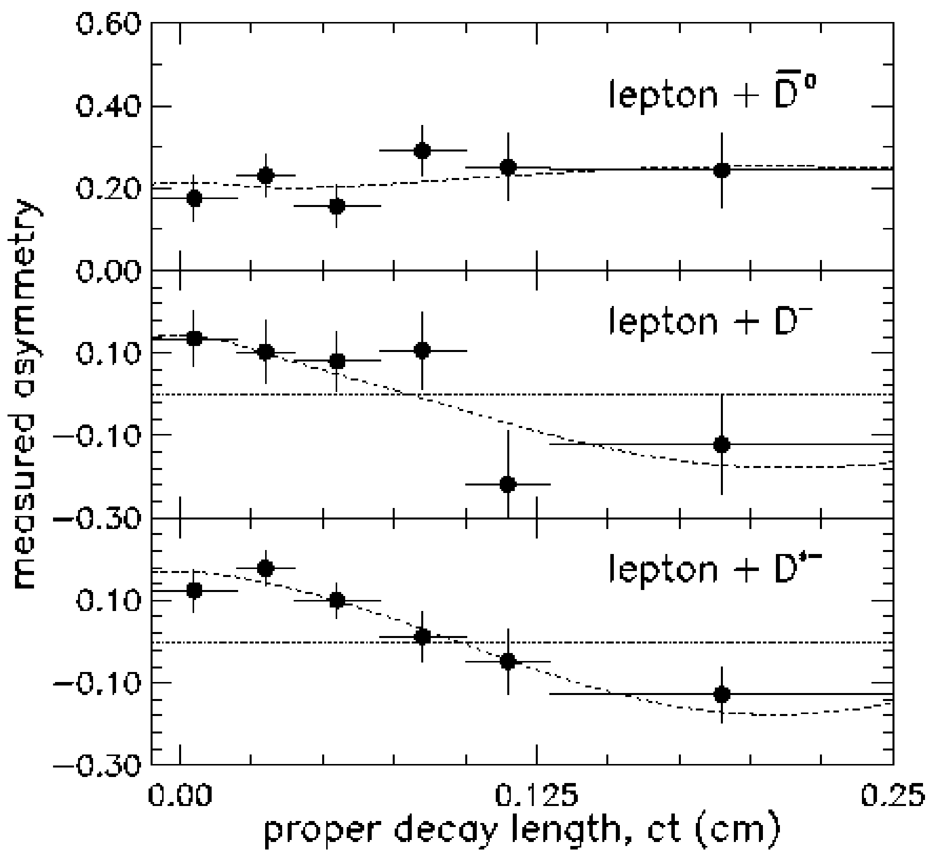
- Lepton +Charm - Lepton Correlation (Tsukuba, Pennsylvania)
  $B_d \Rightarrow l^- D^{*+} X$ and lepton for the other B
  $$\Delta m_d = 0.512^{+0.095}_{-0.093}(stat.)^{+0.031}_{-0.038}(syst.)\ ps^{-1}$$
- Lepton - Jet charge/Lepton Correlation (Pennsylvania, Berkeley)



Run I B_d Mixing Results

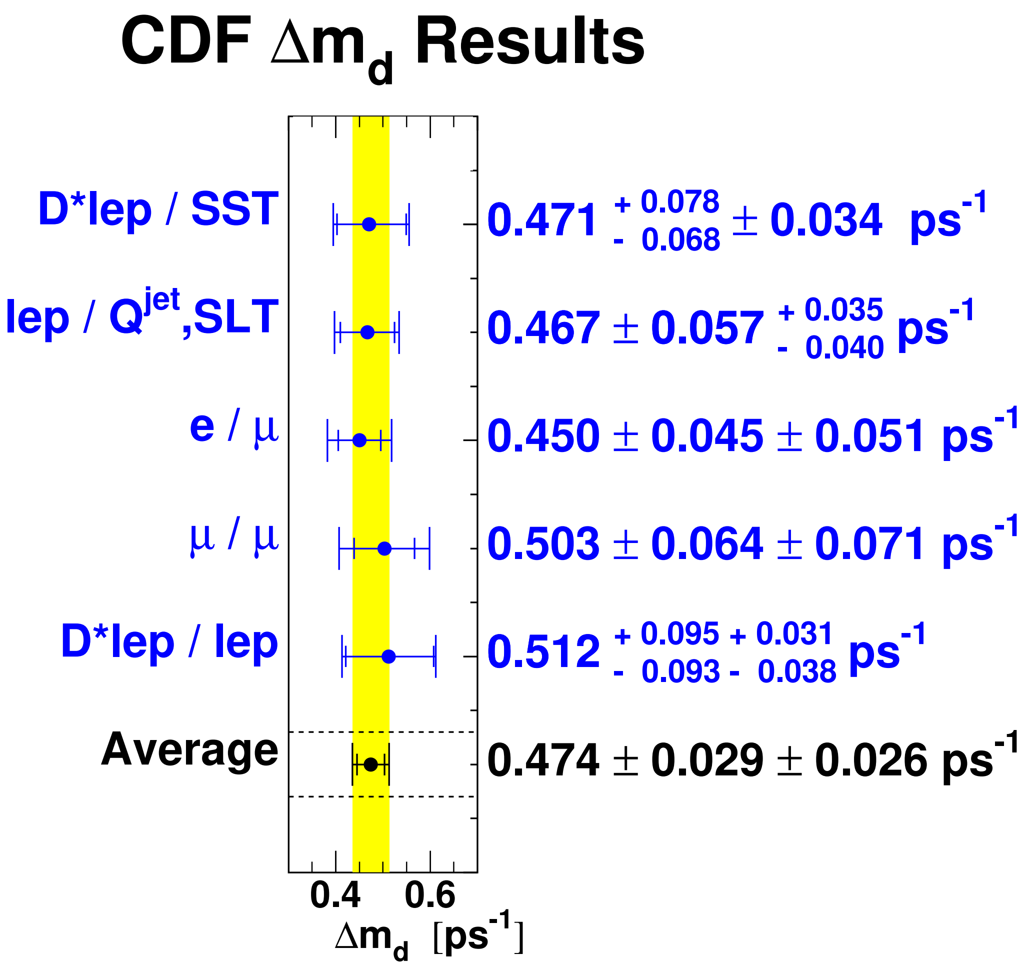
- Lepton+Charm - Soft π Correlations (MIT)

$$\Delta m_d = 0.471^{+0.078}_{-0.068}(stat.) \pm 0.034(syst.)\ ps^{-1}$$



$$\epsilon = 70\% \quad D^2 = 18\% \Rightarrow \epsilon D^2 = 2.3\%$$

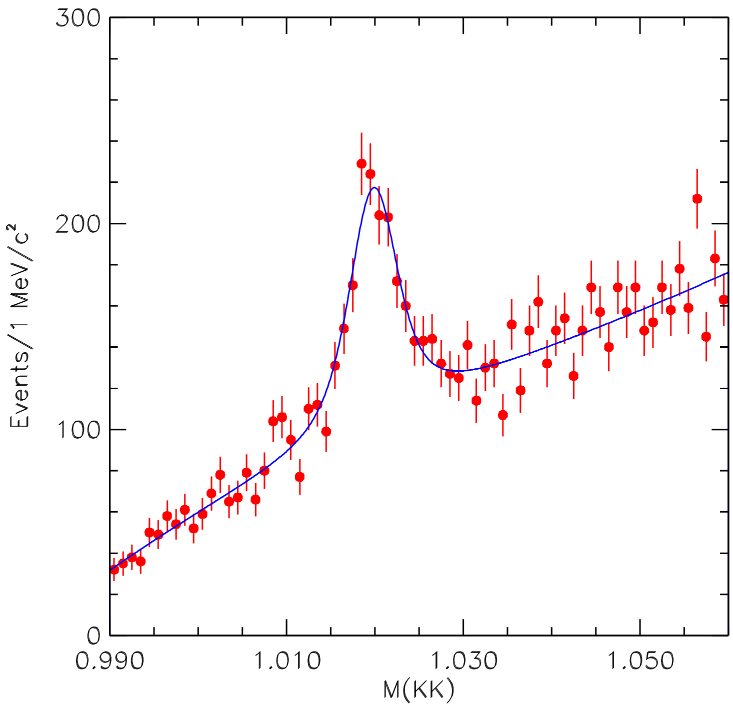
Run I B_d Mixing Results



LEP experiments combined all together $\Delta m_d = 0.466$

Run I B_S Mixing Results

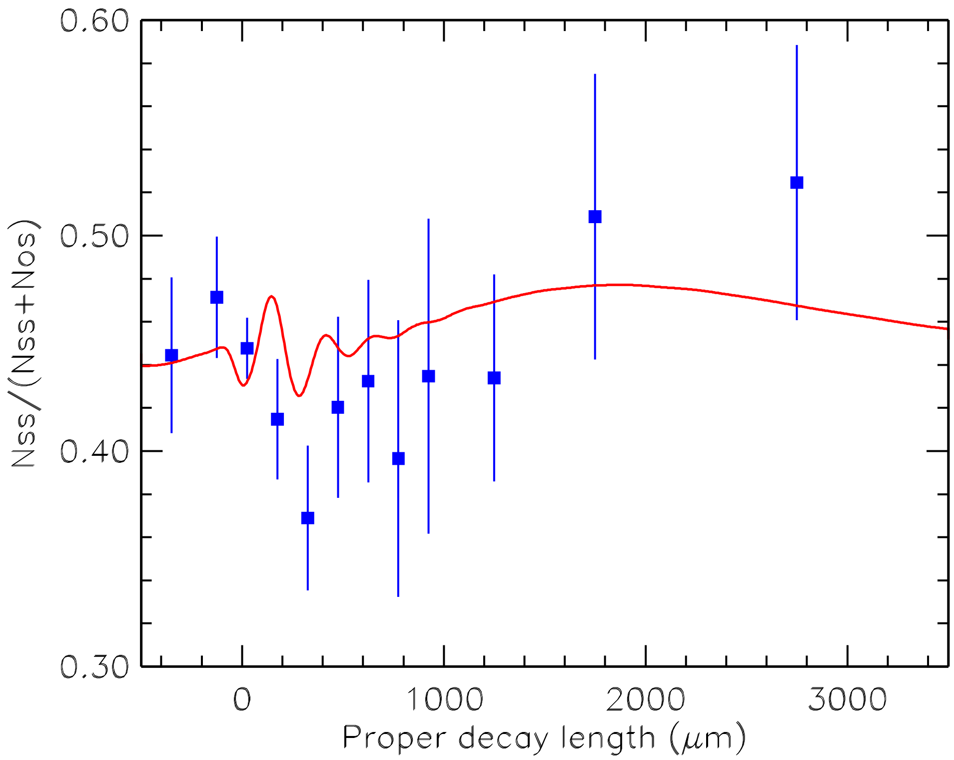
- Decay channel reconstructed: $B_S \Rightarrow D_S^- l^+ \nu$
  Starting point: $\phi \Rightarrow K^+K^-$; ϕ + h to have D_S vertex
- Flavour tagging : leptons e μ Mistag Rate, R = 0.30
- Fitting the K^+K^- invariant mass $N_s = 1068 \pm 70$ with $S/B = 1/2$
- Sample composition: B_S : 61% B^0 : 24.5% B^+ : 14.5%



Run I B_S Mixing Results

Fitting the data with the amplitude fit method we get:

$$X_S > 8.7 \text{ (stat.)} \qquad X_S > 8.2 \text{ (stat.+sys.)}$$



B_S Mixing Prospects for Run II

$\Rightarrow B_S \Rightarrow l^+ D_S^- \nu$ with $D_S^- \Rightarrow \phi + h^-, \mu^-$ or KK,
440 events in Single Lepton Run I are expected to be increased by factors:

$\times$ 20	more integrated statistics
$\times$ 2	larger SVX coverage
$\times$ 2	lower lepton threshold

$$440 \times 20 \times 2 \times 2 = 35,200 \text{ events}$$

In the conservative assumption $\epsilon D^2 = 5.4\%$

$D = 0.4 \rightarrow \epsilon = 0.33 \qquad 35,200 \times 0.33 = 11,616$

We expect $\sim 10,000$ tagged B_S in the semileptonic decay channel from which we obtain the limit:

$$X_S = 22$$

B_S Mixing Prospects for Run II

We can also:

- use the highmass dilepton trigger events
- Exploiting the SVT ditracks Trigger

The idea is that the 2 highest P_t tracks in the decay chain $B_S \to D^+{}_S\pi^-$ or $B_S \to D^+{}_S\pi^-\pi^+\pi^-$ pass the trigger based on impact parameter.
From MC study we expect ~ 1600 fully recontructed and tagged $B_S \to X_S \approx 20$ can be measured.

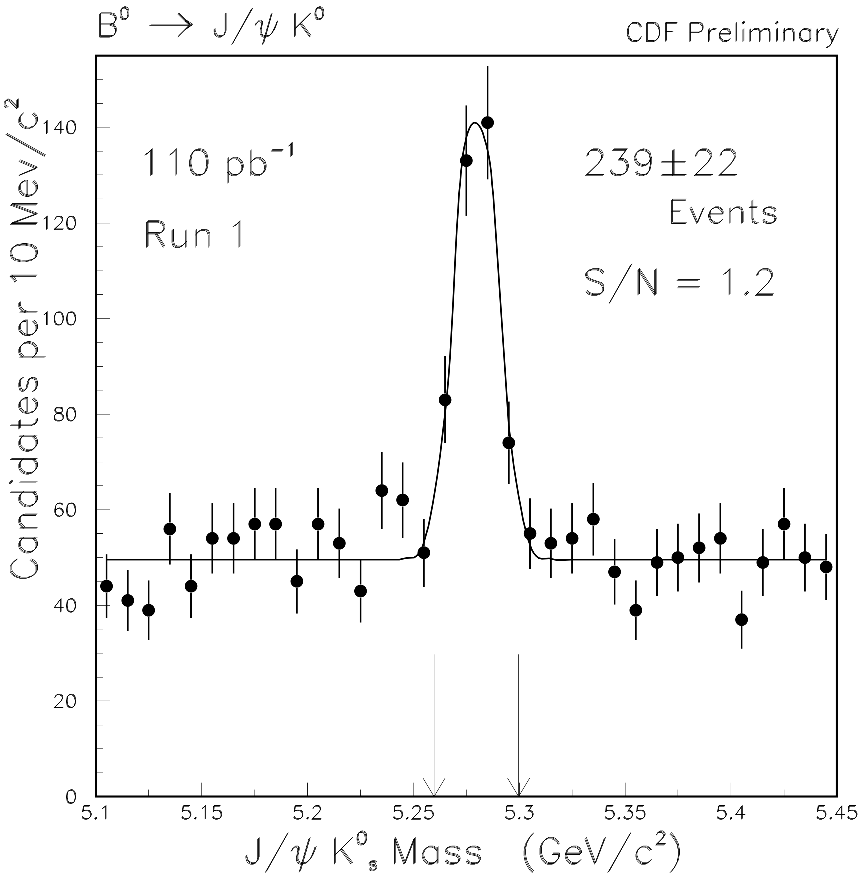
If $X_S > 20$ CDF II may be able to measure it via the lifetime difference. Model dependence $\sim 20\%$

$$\frac{\Delta\Gamma_{B_S}}{\Delta m_{B_S}} \sim \frac{m_b^2}{m_t^2}\frac{\eta_{qcd}^{\Delta\Gamma_{B_S}}}{\eta_{qcd}^{\Delta m_{B_S}}}$$

It has been calculated that for $X_S \sim 15$ a 7% difference in lifetime is expected. The CDF sensitivity on $\Delta\Gamma \sim 3\%$

CP violation studies:
$\sin(2\beta)$

CDF has already collected the world's largest sample of $B_S \Rightarrow J\psi K$



After Same Side tagging we measure:

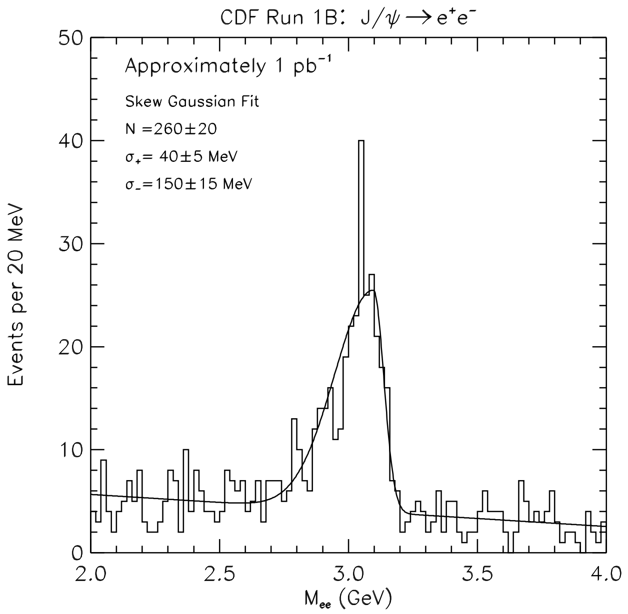
$$\sin(2\beta) = 1.69^{+0.97+0.41}_{-1.01-0.34}$$

CP violation studies:
$\sin(2\beta)$

In Run II the number of $B^0 \Rightarrow J/\Psi K^0{}_S$ should be increased by factors:

$\times 20$	integrated Luminosity of $2fb^{-1}$
$\times 2$	lower muon trigger threshold and
$\times 1.5$	inclusion $J/\Psi \Rightarrow e^+e^-$

Scaling the 240 events from Run I, we expect $\sim 10,000$ events or $\sim 15,000$ if we include the $J/\Psi \Rightarrow e^+e^-$ trigger.



CP violation studies:
$\sin(2\beta)$

The error on the integrated asymmetry:

$$\delta\left(\sin\left(2\beta\right)\right) \approx \frac{1+x_d^2}{x_d}\frac{1}{\sqrt{\epsilon D^2 N}}\sqrt{\frac{S+B}{S}}$$

Scenario	ϵD^2 (%)	$N\left(J/\Psi K_S^0\right)$	$\delta\left(\sin\left(2\beta\right)\right)$
μ trigger measured tags	3.4	10,000	0.14
$\mu + e$ trigger impr. SST+l+Q	6.0	15,000	0.09
$\mu + e$ trigger impr. SST+l+Q time dep. anal.	6.0	15,000	0.05

Studies done on Run I data showed that by fitting the time dependent asymmetry we have an improuvement of **1.8**

CP violation studies: $\sin(2\alpha)$

The branching ratio $B \Rightarrow \pi^{+}\pi^{-} \sim 10^{-5}$

Main problems:

- trigger
- background
- theoretical uncertainties

We think we are solving the first with this plan:

- **Level 1:** 2 oppositely-charged tracks with $P_{t1} > 2$ GeV, $P_{t2} > 3$ GeV and $30^{o} < \Delta\Phi < 160^{o}$.
  Rate: $\sim$ 20 KHz @$10^{32} cm^{-2} s^{-1}$
- **Level 2:** use SVT processor to determine the track impact parameter, d $100\mu m < d < 1mm$.
  Rate: $\sim$ 20 Hz @$10^{32} cm^{-2} s^{-1}$
- **Level 3:** Full event information available.
  Rate:$\sim$ 1 Hz

With this requirements we expect $\sim 32,000$ events in 2 fb^{-1}

CP violation studies:
$\sin(2\alpha)$

To get ride of background we plan to use:

- Good detector resolution in momemtum ($\sim$ 20 Mev)
- dE/dx and TOF (up to $\sim$ 2 GeV)

The error on the integrated asymmetry $\sigma_{\mathcal{A}}$

$$\sigma_{\mathcal{A}} \approx \frac{1+x_d^2}{x_d} \frac{1}{\sqrt{\epsilon D^2 N}} \sqrt{1+\frac{B}{S}}$$

Assuming SVT trigger + isolation cuts we have:

20,000 events

$\epsilon D^2 = 6\%$ as in the $J/\Psi {K^0}_S$ case

$\frac{S}{B} \sim \frac{1}{8}$ for all tagging methods

$$\sigma_{\mathcal{A}} = 0.18$$

We expect further improvements by fitting the time dependent asymmetry