Update to Proposal P-909: Physics Performance of the CDF II Detector with An Inner Silicon Layer and A Time of Flight Detector

The CDF Collaboration

Submitted to the Fermilab Director and PAC

Presented by Joseph Kroll
University of Pennsylvania

15 January 1999

PAC Questions from October 1998

In response to Proposal P-909, the PAC asked about our sensitivity to B_s^0-$\bar{B}_s^0$ flavor oscillations:

1. The collaboration should report on what trigger was assumed for the mixing studies, how its efficiency was estimated, and the reliability of these estimates in the face of real-life conditions such as noise and multiple interactions per crossing.

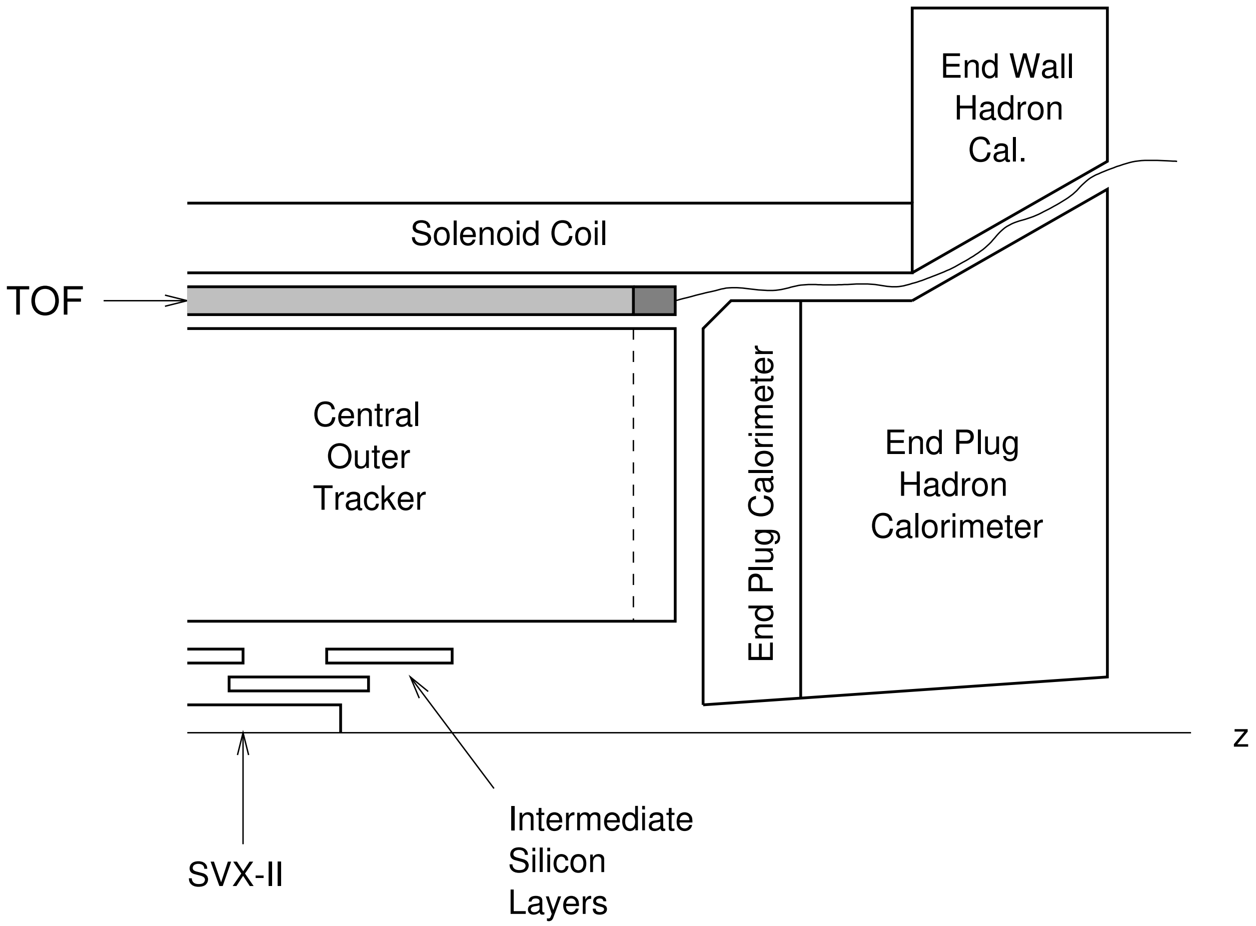
2. The collaboration should justify their use of the DELPHI signal to background given the very different B momentum spectrum and event environments at the Tevatron and LEP.

3. The collaboration should provide studies of the benefits of the TOF for suppressing background, including $B_s^0 \to D_s^- \pi^+$ and $B_s^0 \to D_s^- \pi^+ \pi^- \pi^+$ mass plots.

4. In all studies, the collaboration should specify the luminosity assumed and should provide the results for the baseline detector and for the detector upgraded with L00 and the TOF separately and together.

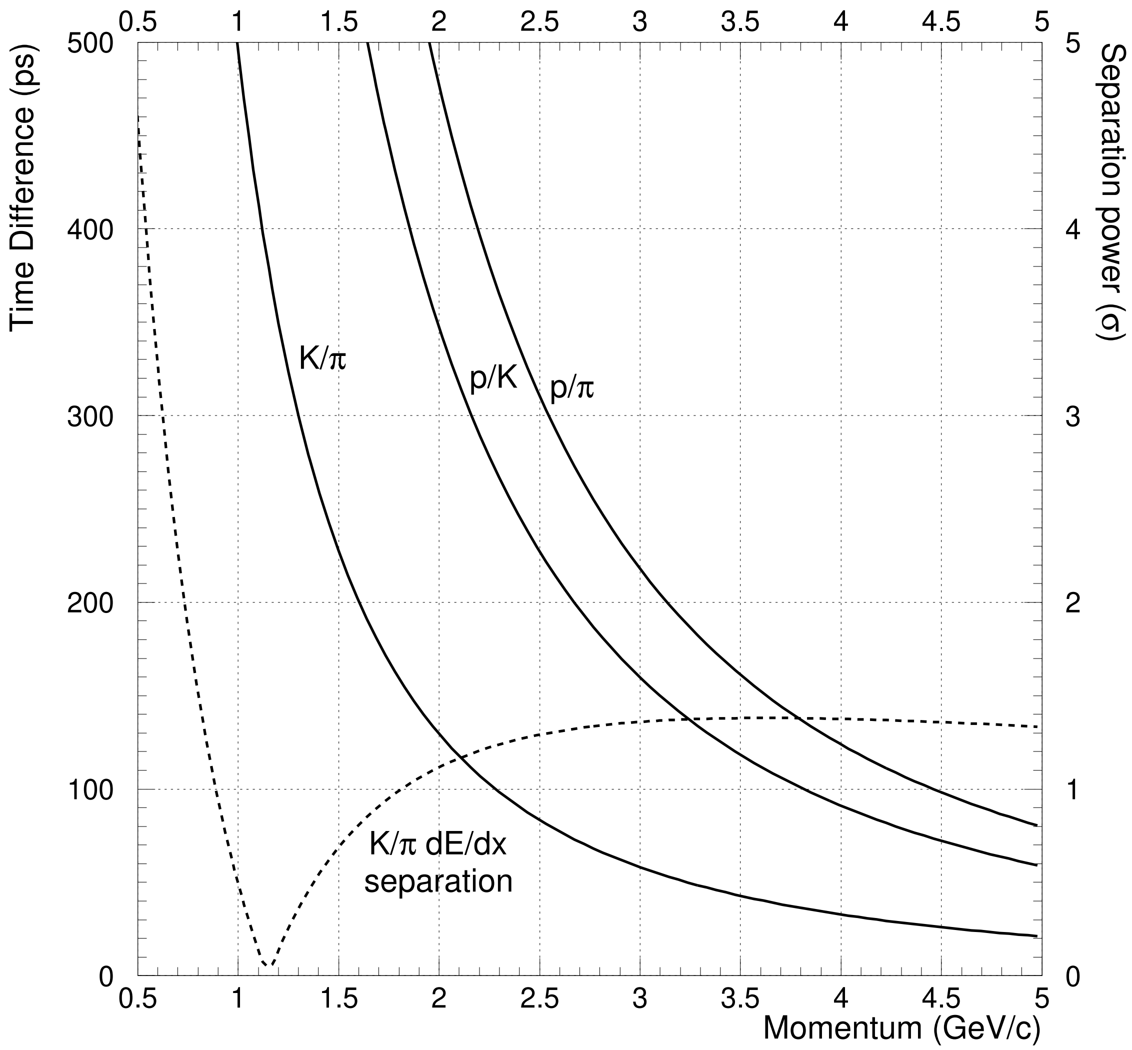
5. In addition, the committee recommends that the collaboration begin to develop a detailed Monte Carlo simulation of B decays, as this tool will be essential as CDF pursues B physics.

A Time-of-Flight Detector for CDF



- 216 scintillator bars located just outside COT
  - 3m long
  - cross-section $\approx 4 \times 4\text{cm}^2$
  - read out on both ends with fine-mesh PMTs
- Expected time-of-flight resolution: 100ps
- Primary purpose: kaon identification for B hadron flavor determination

Particle Identification with TOF



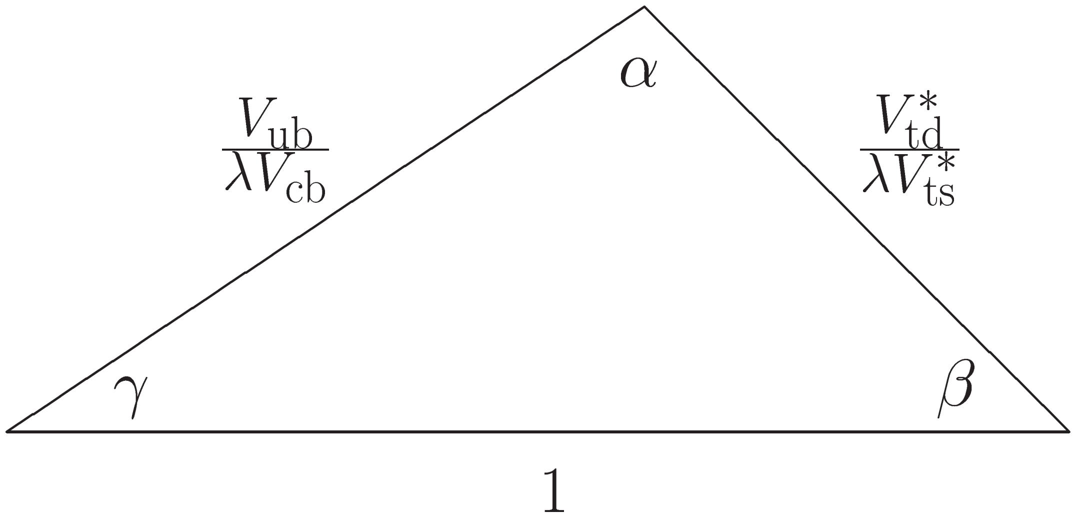
With 100ps resolution: 2σ separation of

- K and π for $p < 1.6$ GeV$/c$
- p and K for $p < 2.7$ GeV$/c$
- p and π for $p < 3.2$ GeV$/c$

TOF and dE/dx are complementary

Future Analysis in B Physics

Goal of B physics in next decade:



First test of Unitarity may be a combination of:

1. $\sin(2\beta)$ from $B^0/\bar{B}^0 \to J/\psi K^0_{\rm S}$
2. $|V^*_{\rm td}/\lambda V^*_{\rm ts}|$ from $B^0 \leftrightarrow \bar{B}^0$ and $B^0_s \leftrightarrow \bar{B}^0_s$ flavor oscillations

CDF is in the unique position to do both

Run II B Physics at CDF

- Precise Measurement of $|V_{\rm td}/V_{\rm ts}|$
  - (†) $B_s^0 - \bar{B}_s^0$ flavor oscillations (also $\Delta\Gamma_s/\Gamma_s$)
  - Radiative decays:
    e. g. $B_s^0 \to K^{*0}\gamma$ vs. $B_s^0 \to \phi\gamma$ (†)
- Observe CP Violation in $B^0/\bar{B}^0 \to J/\psi K_{\rm S}^0$
  Precise measurement of $\sin(2\beta)$
- Observe CP Violation in $B^0/\bar{B}^0 \to \pi^+\pi^-$
  Precise measurement of asymmetry (related to $\sin(2\alpha)$)
- (†) Search for large CP Violation in $B_s^0/\bar{B}_s^0 \to J/\psi\phi$
  Unambiguous signal of physics beyond SM
- Reconstruction of decay modes related to angle γ:
  $B_s^0 \to D_s^{\pm}K^{\mp}$(†) and $B^+ \to \bar{D}^0K^+$
- Observe $B^+ \to \mu^+\mu^-K^+$, $B^0 \to \mu^+\mu^-K^{*0}$,
  $B_s^0 \to \mu^+\mu^-\phi$ (†)
- (†) Study B_c^+ meson and b baryons

(†) Unique to Tevatron

B Flavor Tagging with TOF

Determine if B meson contained a b or $\bar{b}$ at production

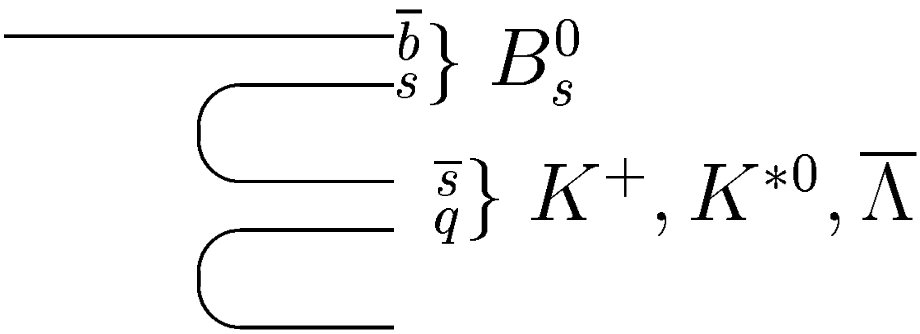
TOF used for two methods of flavor tagging

1. Opposite-side Kaon tagging:

   $B^0 \rightarrow K^+$ *but*

   $\bar{B}^0 \rightarrow K^-$

2. Same-side Kaon Tagging

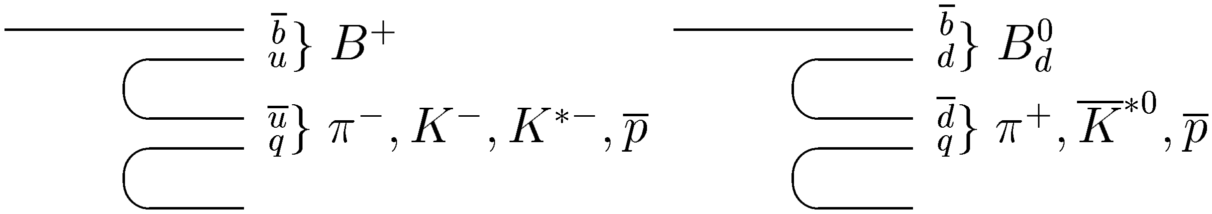


Quantify flavor tag performance with ϵD^2:

- ϵ = tag efficiency
- D = tag dilution: $D = 1 - 2w$
  where w = mistag probability

At hadron collider $\epsilon D^2 = 1\%$ is respectable

Same-side Flavor Tag in CDF Data



SST used for two published analyses from Run 1 data:

The CDF Collaboration, F. Abe *et al.*,

1. *Measurement of the* B^0_d-$\bar{B}^0_d$ *Oscillation Frequency Using* π-B *Charge-Flavor Correlations in* $p\bar{p}$ *collisions at* $\sqrt{s} = 1.8$ *TeV*, Phys. Rev. Lett. **80**, 2057 (1998);

   Measurement of the B^0_d-$\bar{B}^0_d$ *Oscillation Frequency and Study of Same Side Flavor Tagging of* B *Mesons in* $p\bar{p}$ *Collisions*, Phys. Rev. D **59**, 032001 (1999).

2. *Measurement of the* CP*-Violation Parameter* $\sin(2\beta)$ *in* $B^0_d/\bar{B}^0_d \to J/\psi K^0_S$ *Decays*, Phys. Rev. Lett. **81**, 5513 (1998).

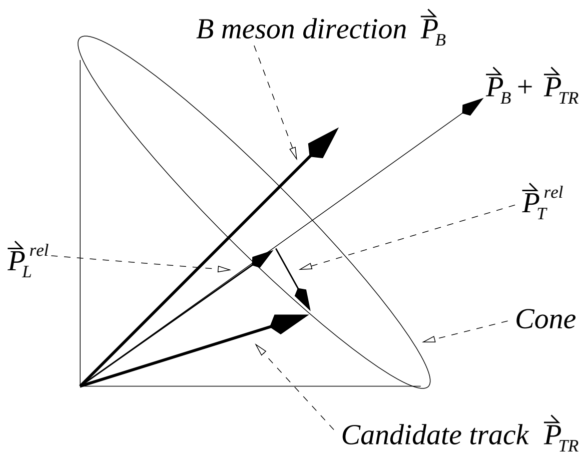
Flavor tagging ϵD^2 measured in data:

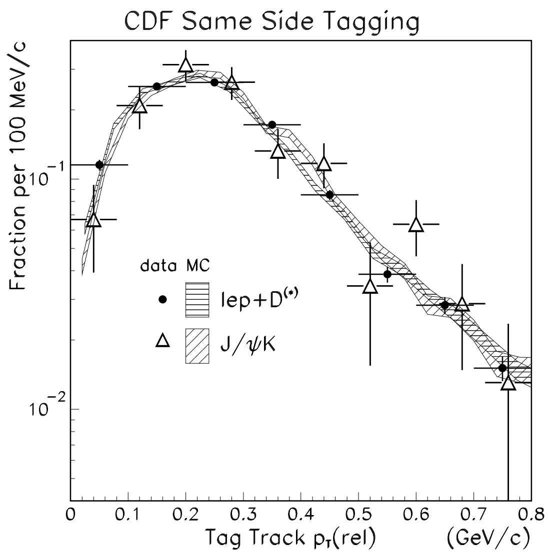
$$
\begin{array}{rcll}
\epsilon D^2_+ & = & 5.2 \pm 1.2^{+0.9}_{-0.6}\% & (B^+ \to \ell^+ \nu \bar{D}^0) \\
\epsilon D^2_0 & = & 2.4 \pm 0.7^{+0.6}_{-0.4}\% & (B^0 \to \ell^+ \nu D^{(*)-}) \\
\epsilon D^2_0 & = & 1.66 \pm 0.18 \pm 0.13\% & (B^0/\bar{B}^0 \to J/\psi K^0_{\mathrm{S}})
\end{array}
$$

SST: Data vs. PYTHIA

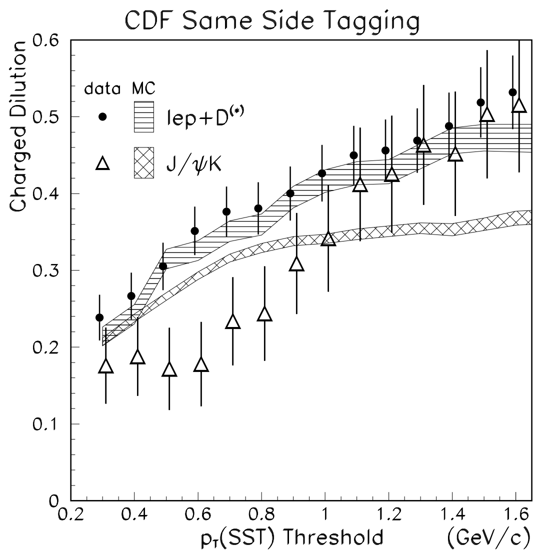
Tuned PYTHIA Monte Carlo reproduces SST in data

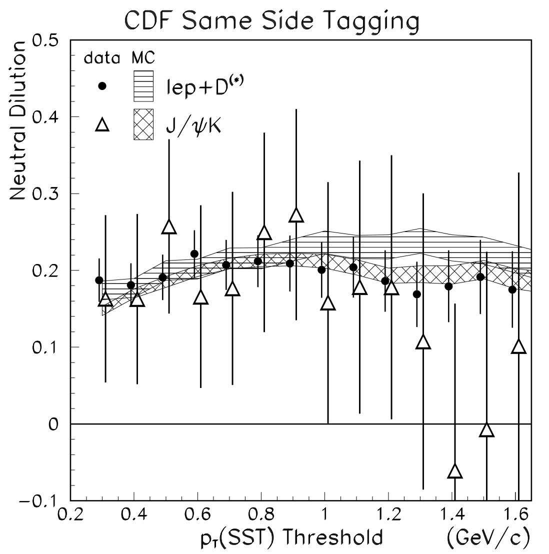
Multiplicity Distributions





Dilutions

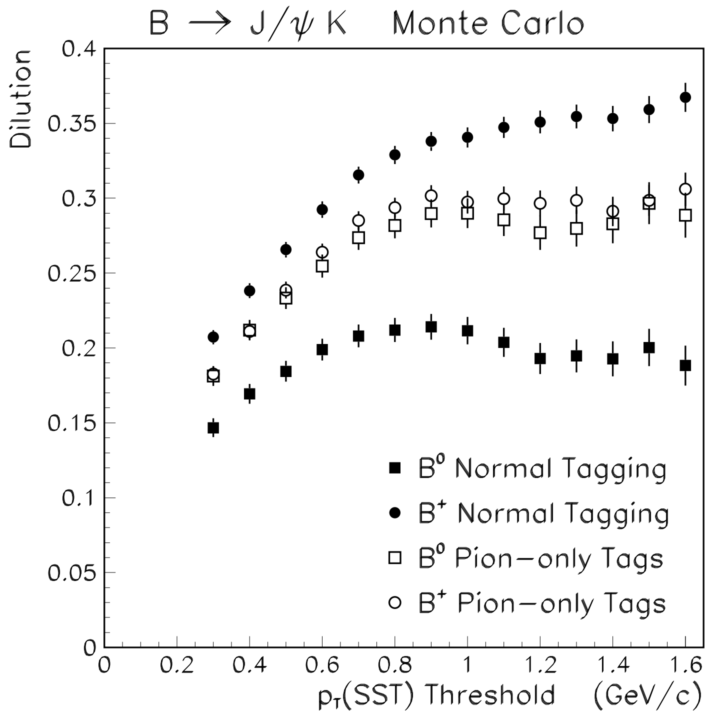




Expected Flavor Tagging in Run II B_d^0

TOF provides opposite-side K tag

TOF improves same-side π tag (K veto)



$B^0/\bar{B}^0 \to J/\psi K_S^0$		
	without TOF	with TOF
Same-Side (pion) Tag	1.4	1.9
Soft Lepton Tag (μ)	1.0	1.0
Soft Lepton Tag (e)	0.7	0.7
Jet Charge	3.0	3.0
Opposite-Side Kaon Tag	—	2.4
Total	6.1%	9.0%

Expected Flavor Tagging in Run II B_s^0

$B_s^0 \to D_s^- \pi^+$		
	without TOF	with TOF
Same-Side (Kaon) Tag	1.0	4.2
Soft Lepton Tag (μ)	1.0	1.0
Soft Lepton Tag (e)	0.7	0.7
Jet Charge	3.0	3.0
Opposite-Side Kaon Tag	—	2.4
Total	5.7%	11.3%

$B_s^0/\bar{B}_s^0 \to J/\psi\phi$		
	without TOF	with TOF
Same-Side (Kaon) Tag	0.2	2.6
Soft Lepton Tag (μ)	1.0	1.0
Soft Lepton Tag (e)	0.7	0.7
Jet Charge	3.0	3.0
Opposite-Side Kaon Tag	—	2.4
Total	4.9%	9.7%

Measuring $B_s^0 - \bar{B}_s^0$ Oscillations

Measure oscillation frequency $\Delta m_s = \frac{x_s}{\tau(B_s^0)}$
Requires:

- Proper decay time t (Layer 00)
- Flavor at production: B_s^0 $(\bar{b}s)$ or $\bar{B}_s^0$ $(b\bar{s})$ (TOF)
- Flavor at Decay (unambiguous for decay modes here)

Also: B_s^0 signal with adequate signal-to-noise (TOF)

$$\frac{N_{\text{unmixed}}(t) - N_{\text{mix}}(t)}{N_{\text{unmixed}}(t) + N_{\text{mix}}(t)} = D \cdot \cos\left(\frac{x_s}{\tau(B_s^0)} t\right)$$

Flavor tag Dilution: $D = 2 \cdot \mathcal{P} - 1$

Proper time reconstruction:

$$t = m(B) \cdot \frac{L}{p}$$

Uncertainty δt on t:

$$(\delta t)^2 = \left(\frac{m(B)}{p}\delta L\right)^2 \oplus \left(t \cdot \frac{\delta p}{p}\right)^2$$

B_s^0 Measurements from Run I

Largest samples of semileptonic and hadronic B_s^0 decays

- $B_s^0 \rightarrow D_s^- \ell^+ \nu_\ell X$ with

  $D_s^- \rightarrow \phi \pi^-$

  $D_s^- \rightarrow K^{*0}(892) K^-$

  $D_s^- \rightarrow K_S^0 K^-$

  $D_s^- \rightarrow \phi \ell^- \bar{\nu}_\ell X$

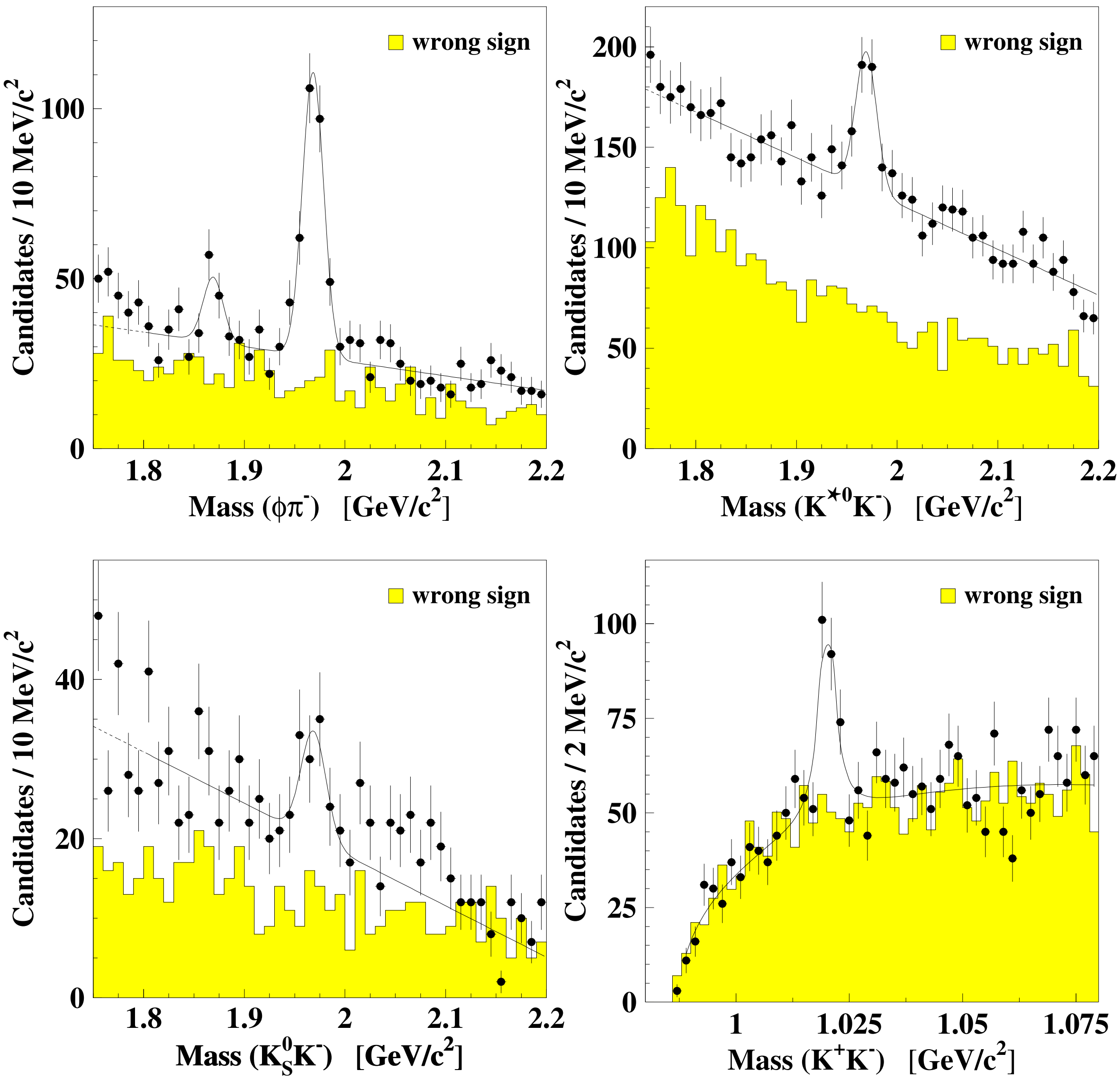
- $B_s^0 \rightarrow J/\psi \phi$

Physics results:

- World's most precise single measurement of $\tau(B_s^0)$
- Limit on $\Delta\Gamma_s / \langle \Gamma_s \rangle$
- $\Delta m_s > 5.8 \text{ ps}^{-1}$
- CP composition of $B_s^0 \rightarrow J/\psi \phi$ (transversity)
- Fragmentation fraction f_s in $p\bar{p}$ collisions

$\tau(B_s^0)$ and $\Delta\Gamma_s/\Gamma_s$ using $B_s^0 \to D_s^- \ell^+ \nu_\ell X$

F. Abe *et al.*, Phys. Rev. D **59**, 032004 (1999)



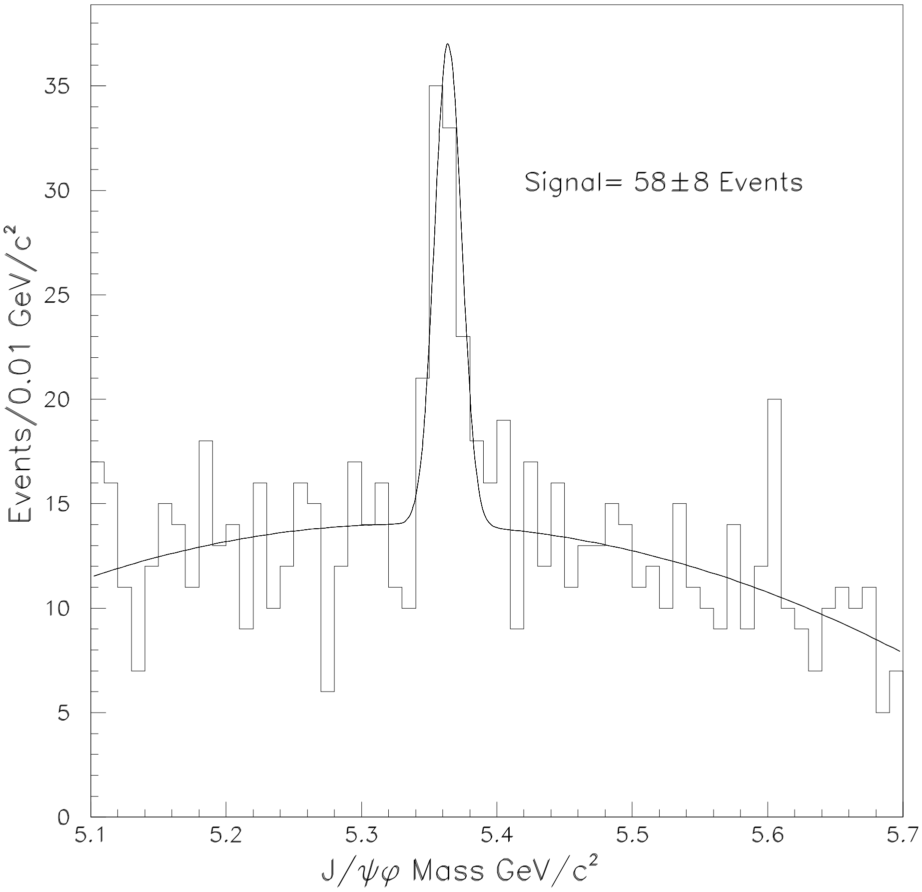
$$\tau(B_s^0) = 1.36 \pm 0.09^{+0.06}_{-0.05}\ \mathrm{ps}$$

$$\Delta\Gamma_s/\Gamma_s < 0.83 \text{ at } 95\% \text{ C.L.}$$

$\tau(B_s^0)$ from $B_s^0 \to J/\psi\phi$

F. Abe *et al.*, Phys. Rev. Lett. **77**, 1945 (1996).

$$\tau(B_s^0) = 1.34^{+0.23}_{-0.19} \pm 0.05 \text{ ps}$$

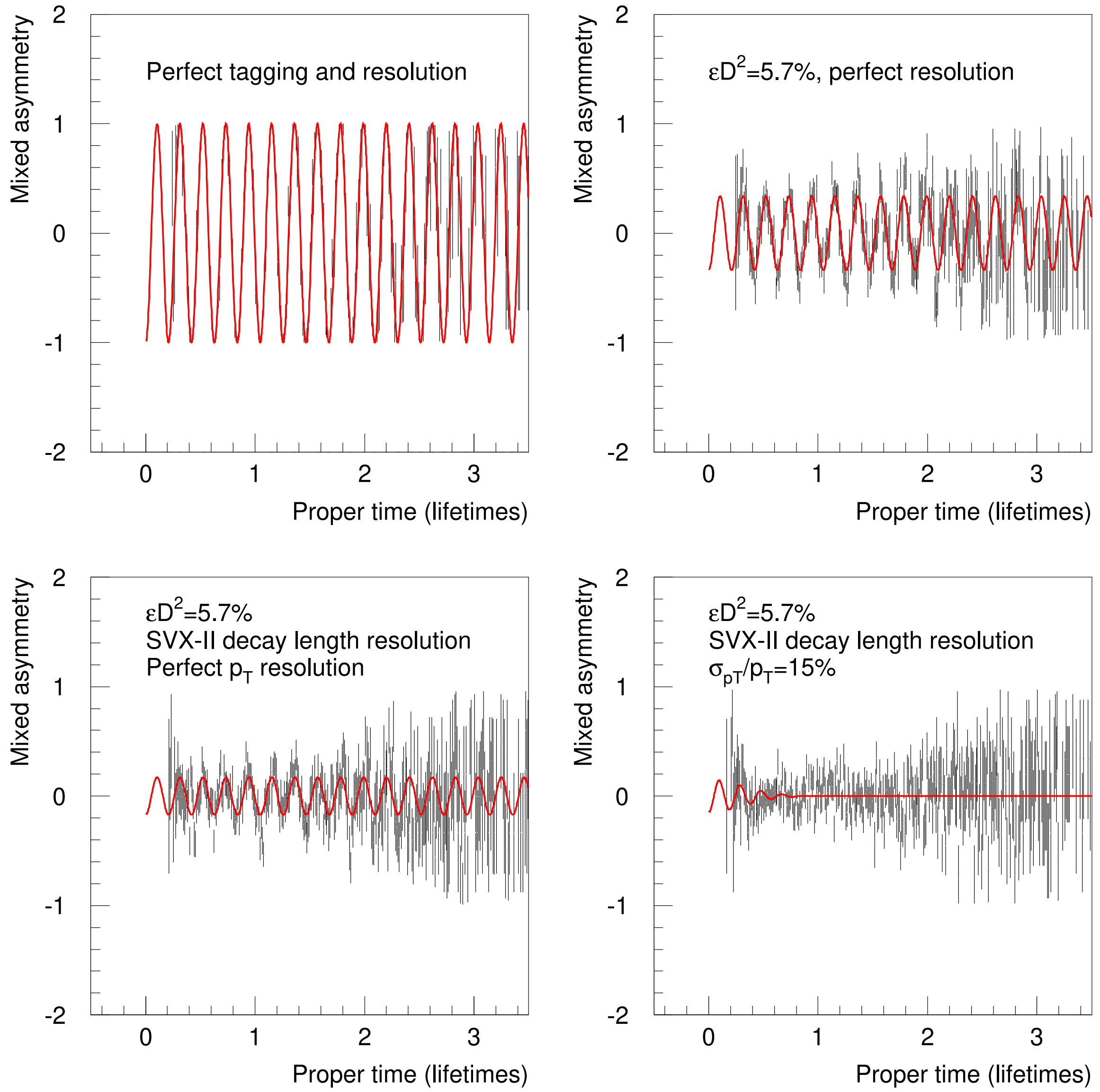


Also:

CP-odd composition: $|A_\perp|^2 = 0.126^{+0.121}_{-0.093} \pm 0.028$

Illustration of $B_s^0 - \bar{B}_s^0$ Oscillations

Example: $x_s = 30$



Conclusion:

To go beyond current limit
need *fully* reconstructed B_s^0

B_s^0 Hadronic Modes

We study the following modes:

- $B_s^0 \to D_s^- \pi^+$ (BF=$0.30 \pm 0.04\%$ from B^0 mode)
- $B_s^0 \to D_s^- \pi^+ \pi^- \pi^+$ (BF=$0.80 \pm 0.25\%$ from B^0 mode)

For the D_s^- we use

- $D_s^- \to \phi \pi^-$ (BF=$3.6 \pm 0.9\%$), $\phi \to K^+ K^-$
- $D_s^- \to K^{*0}(892) K^-$ (BF=$3.3 \pm 0.9\%$), $K^{*0} \to K^+ \pi^-$

For comparison, we also include

- $B_s^0 \to D_s^{*-} \pi^+$ (BF=$0.28 \pm 0.02\%$ from B^0 mode)
- $B^0 \to \pi^+ \pi^-$ BF=10^{-5} (assumption)

Acceptance normalized to CDF measurement:
$\sigma(p\bar{p} \to B^0 X, p_T > 6 \text{ GeV}/c, |y| < 1) = 2.39 \pm 0.54\ \mu\text{b}$

$f_s = \frac{\sigma(p\bar{p} \to B_s^0 X)}{\sigma(p\bar{p} \to B^0 X)} = 0.26 \pm 0.05$ (LEP)

Acceptance modeled with single b Monte Carlo based on NDE next-to-leading order calculation.

Assume 2 fb^{-1} integrated luminosity

CDF Run II Trigger

Three Level Architecture (like Run I)
"Deadtimeless" (pipelined)

Level 1

- Simple objects (same as Run I)
  e.g., EM cal. cluster
  track stub in μ chamber
- New: tracks (XFT) for $p_T > 1.5$ GeV/c
  $\delta p_T / p_T^2 = 0.015\ (\mathrm{GeV}/c)^{-1}$
  $\delta\phi_6 = 0.0015$ rad
- Output: 50 KHz

Level 2

- Limited Event reconstruction with Alpha (like Run I)
- New: Silicon information available (SVT)
  trigger on impact parameter and displaced vertex
- Output: 300 Hz

Level 3

- Full event reconstruction on PC farm (LINUX)
- Output: 75 Hz

All-Hadronic B Decay Trigger

Level 1:

Inclusive p_T spectrum in $p\bar{p} \to h^{\pm}X \propto p_t^{-8}$

p_T spectrum from $p\bar{p} \to b\bar{b}X$ harder

- Require two stiff tracks ($i.e.$, $p_T > p_{T,\min}$)
- remove back-to-back combinations ($\Delta\phi < \Delta\phi_{\max}$)
- require opposite charge

Level 2:

B hadrons have relatively long lifetime ($\tau \sim 1.5\text{ps}$)

SVT provides impact parameter information
(and improved helix parameters)

Alpha can combine tracks to form vertices
($i.e.$, limited event reconstruction)

- Require two tracks with large impact parameter d_0
- Vertex tracks - require positive decay length
- tighten azimuthal requirements ($\Delta\phi$)

Hadronic B Trigger (continued)

Consider 3 operating scenarios

Scenario	T_{bunch} (ns)	$\mathcal{L}$ $\times 10^{32}$ cm^{-2}s^{-1}	$\langle N_{p\bar{p}} \rangle$
A	396	0.7	2
B	132	2.0	2
C	396	1.7	5

and 2 trigger selections

1. **two-body decays**
   optimized on $B^0 \to \pi^+\pi^-$
2. **multi-body decays**
   optimized on $B_s^0 \to D_s^-\pi^+, D_s^-\pi^+\pi^-\pi^+$

The hadronic B trigger is the "or" of these two selections

Level 1 Selection and Rates

Level 1 selection

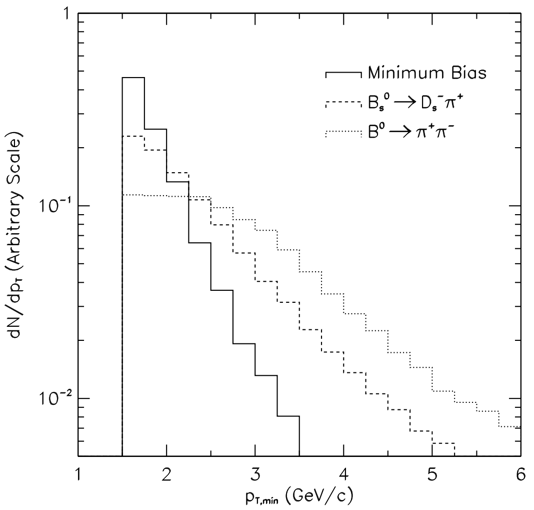
Scenario	$p_{T,\mathrm{min}}$ GeV/c	$(\Sigma p_T)_{\mathrm{min}}$ GeV/c	$\Delta\phi_{6,\mathrm{max}}$
A	2.00	5.5	135°
B	2.25	6.0	135°
C	2.50	6.5	135°

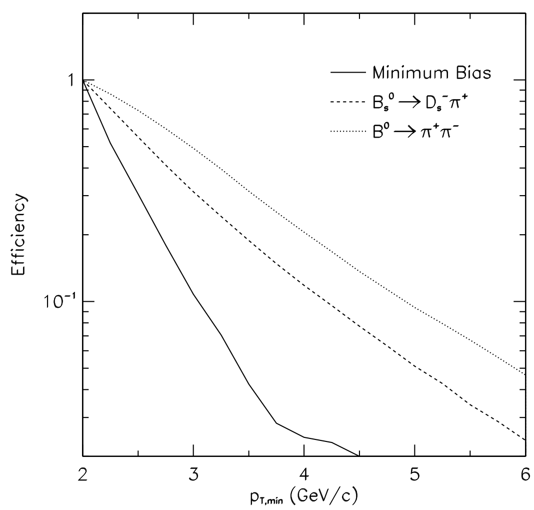
Predicted Level 1 rates

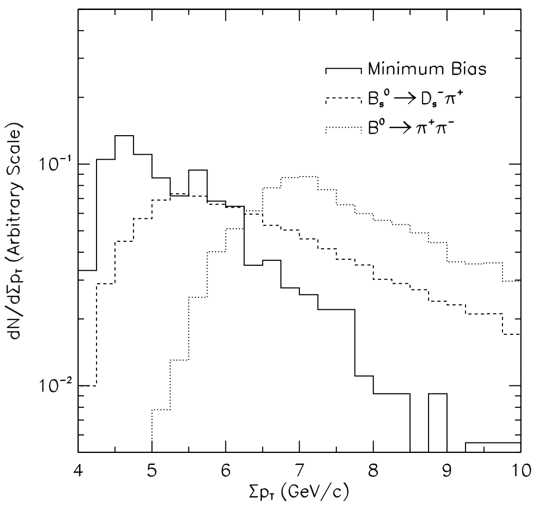
Scenario	Two-track cross section (μb)	Two-track rate (kHz)
A	252 ± 18	18
B	152 ± 14	30
C	163 ± 16	28

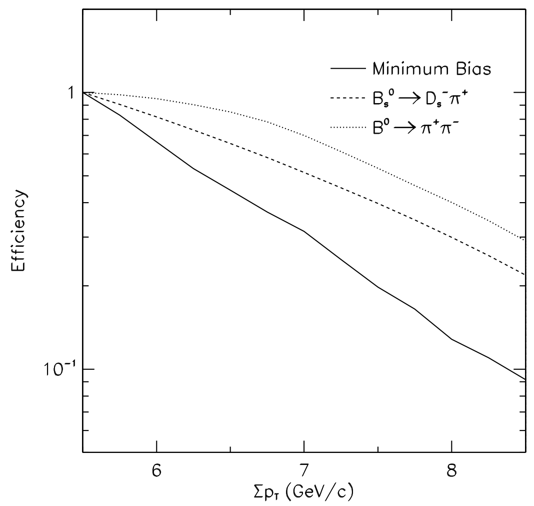
- **Uses Run I minimum bias data**
  provides realistic hit distributions
  used as input to COT and XFT simulations
- **Within Level 1 bandwidth (50 kHz)**

Level 1 Selection Criteria









Level 2 Selection and Rates

Level 2 selections

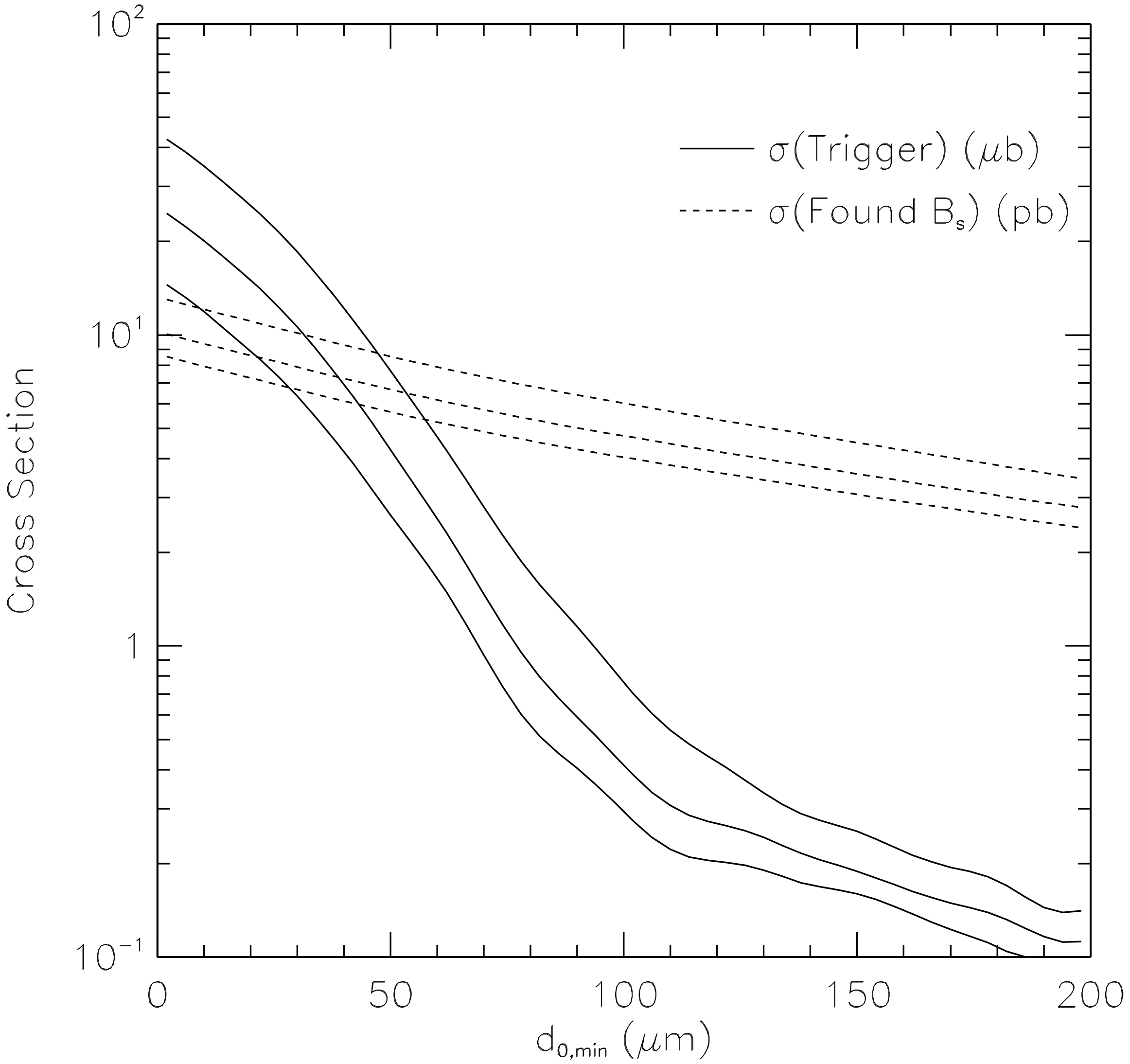
Multi-body ($B_s^0 \to D_s^- \pi^+$)	Two-body ($B^0 \to \pi^+ \pi^-$)
$120\ \mu\text{m} < \lvert d_0 \rvert < 1$ mm	$100\ \mu\text{m} < \lvert d_0 \rvert < 1$ mm
$2^\circ < \Delta\phi_0 < 90^\circ$	$20^\circ < \Delta\phi_0 < 135^\circ$
$p_T \cdot X_v > 0$	$P_T \cdot X_v > 0$
—	$d_B < 140\,\mu$m

Predicted Level 2 rates (nb)

Scenario	Multi-body selection	Two-body selection	Combined selections	Level 2 Rate (Hz)
A	394 $\pm$105	360 $\pm$100	560 $\pm$125	39
B	280 $\pm$89	196 $\pm$74	336 $\pm$97	67
C	196 $\pm$74	84 $\pm$48	224 $\pm$79	38

- **Can predict using Run I data**
  (special two CFT track trigger)
  use hits from Run I Si det. SVX$'$
  SVX II and SVX$'$ have similar geometry
  SVT uses $r\phi$ information only
- **Within Level 2 bandwidth (300 Hz)**

Level 2 Selection Criteria



Predicted Signal Rates (2 fb^{-1})

Signal Cross-sections (pb)

Mode	A	B	C
$B_s^0 \to D_s^- \pi^+$	5.3	4.2	3.6
$B_s^0 \to D_s^- \pi^+ \pi^- \pi^+$	6.4	5.2	4.1
$B_s^0 \to D_s^{*-} \pi^+$	4.7	3.7	2.9
$B^0 \to \pi^+ \pi^-$	7.6	5.9	4.2

Signal Sizes

Mode	A	B	C
$B_s^0 \to D_s^- \pi^+$	10600	8400	7200
$B_s^0 \to D_s^- \pi^+ \pi^- \pi^+$	12800	10400	8100
$B_s^0 \to D_s^{*-} \pi^+$	9400	7400	5800
$B^0 \to \pi^+ \pi^-$	15200	11800	8400

- **Correlated uncertainty on B_s^0 rates $= 40\%$**
  (due to cross-section, BF's, and f_s)
- **Use $D_s^- \pi^+, D_s^- \pi^+ \pi^- \pi^+$ only for x_s reach**
- **Vary total from 5000 to 30000**

Signal to Background: Introduction

Large sample of all-hadronic B decays

Question: Can we extract them from the enormous combinatorial background?

We use Run I data to study these backgrounds

- No all-hadronic B trigger $\Longrightarrow$ use inclusive e & μ
- Inclusive leptons $\sim 40\%$ $b\bar{b}$ from $b \to \ell$
  remainder is $c\bar{c}$ and fake ℓ ($e.g.$, $\gamma \to e^+e^-$)

Two sources of combinatoric background

1. Heavy flavor ($b\bar{b}$ and $c\bar{c}$)
   have true lifetime and displaced tracks.

   Can predict with Monte Carlo, but use data

   Opposite ℓ is unbiased B decay

   Look for signal, study background from $b\bar{b}$

2. Light quark and gluon production (generic QCD)
   Mismeasured tracks or K, Λ or $\gamma \to e^+e^-$.

   Cannot predict with Monte Carlo, must use data

   Opposite identified $\gamma \to e^+e^-$

   study background from generic QCD

Generic QCD versus $b\bar{b}$

What fraction of triggered events are $b\bar{b}$?

Predict rate with Monte Carlo normalized
to CDF measured B cross-section

Compare to rate in Run I data (scenario A)

	data rate	$b\bar{b}$ Monte Carlo	$b\bar{b}$ fraction
Level 1	$(252 \pm 18)\mu$b	(720 ± 20)nb	0.3%
Level 2	(394 ± 105)nb	(81 ± 4)nb	24%

After Level 2 Multi-body B trigger is $\sim \frac{1}{4}\ b\bar{b}$

Similar to purity in inclusive ℓ and J/Ψ samples
Found clean $B \to D\ell\nu$ and $B \to J/\psi K$

Conclusion:

Background from Generic QCD manageable

Generic Jets and Top b Tag

Top quark discovery:

b identification using lifetime drastically reduces generic QCD jet background

Applied to jet-triggered data $\Longrightarrow$
80% of jets with positive lifetime ($c\tau$) are $b\bar{b}$ and $c\bar{c}$

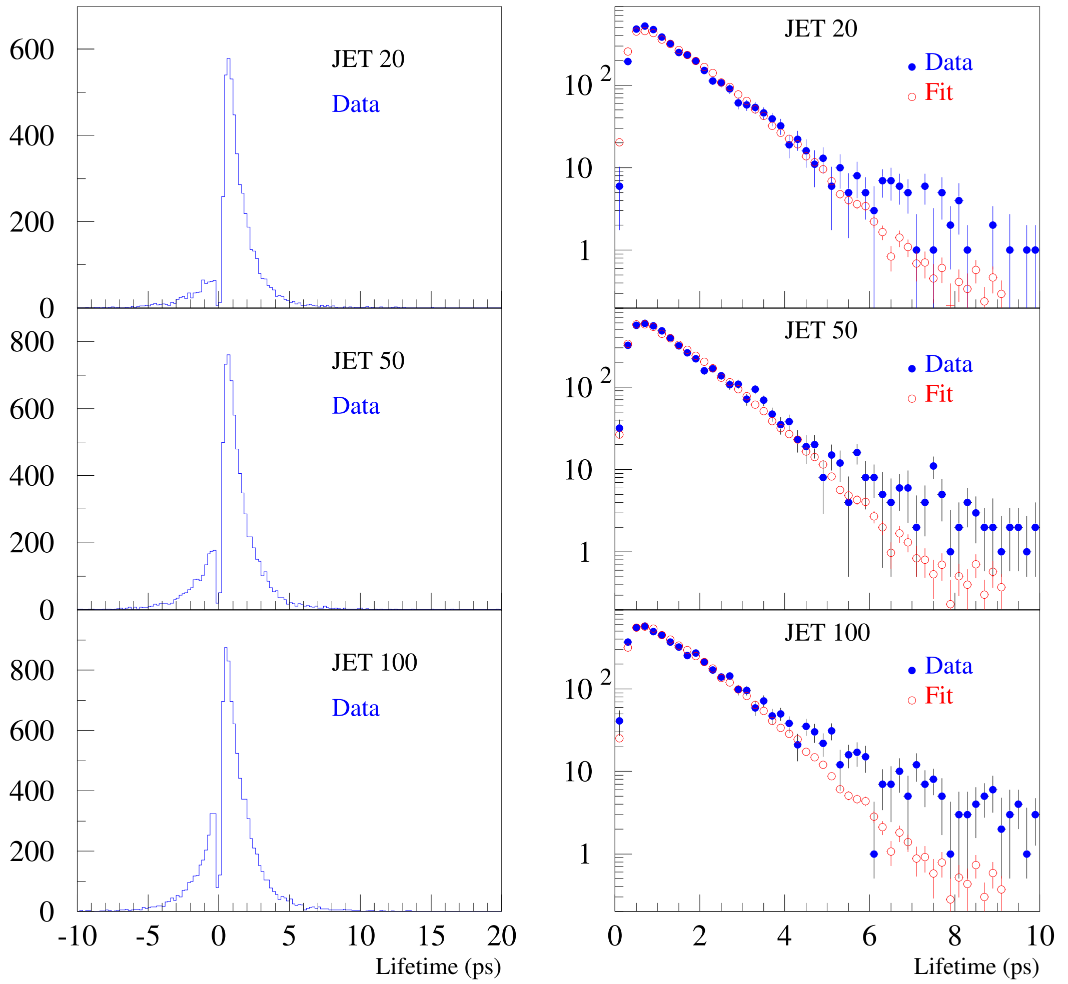


Figure 9: $c\tau$ distributions of SECVTX tags before and after mistag subtraction in all QCD data.

Background from $b\bar{b}$

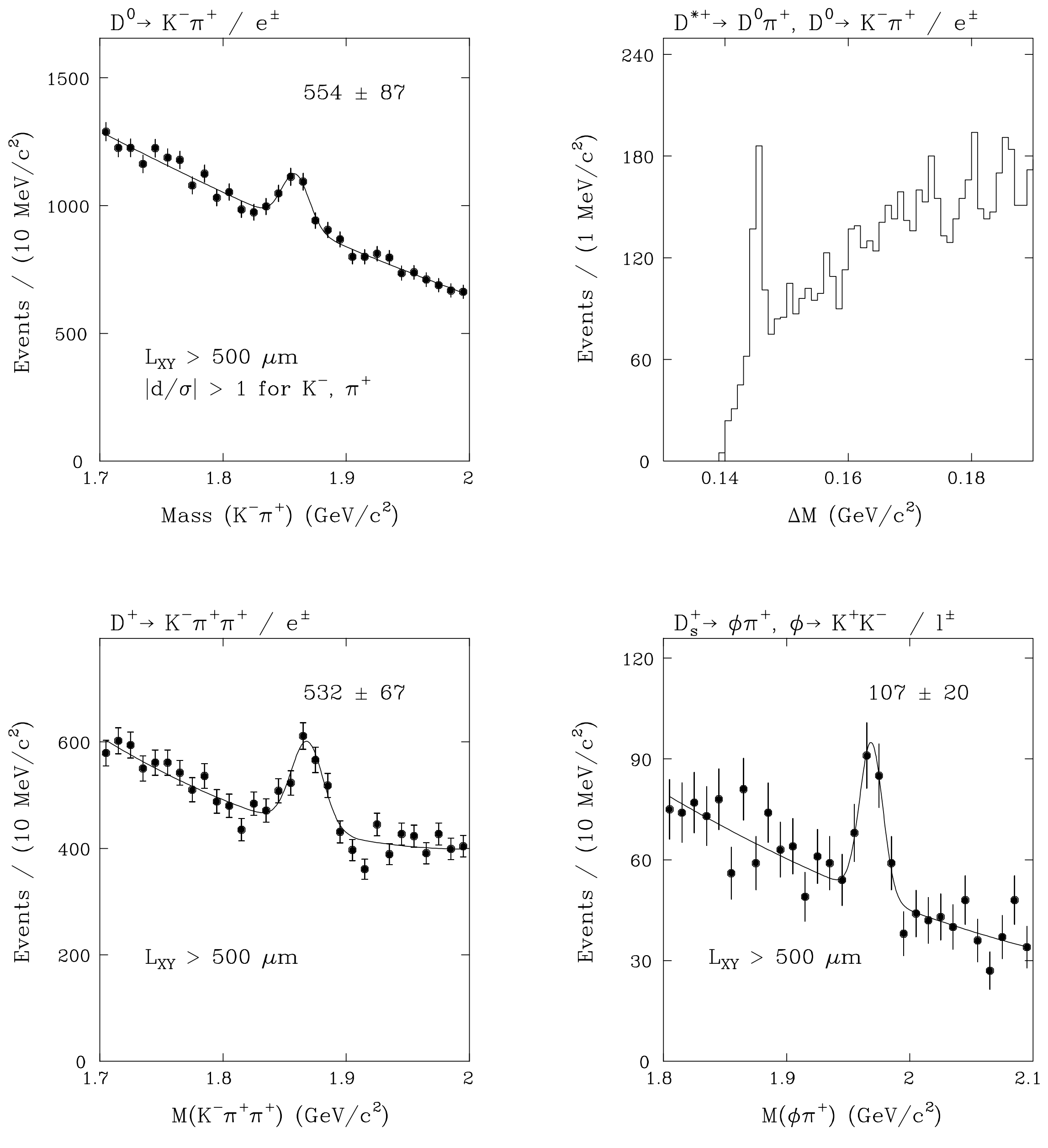
Search for the following decay modes:

- $B \to D\pi, D\pi\pi\pi$;
- where $D = D^0, D^{*+}, D^+, D_s^+$

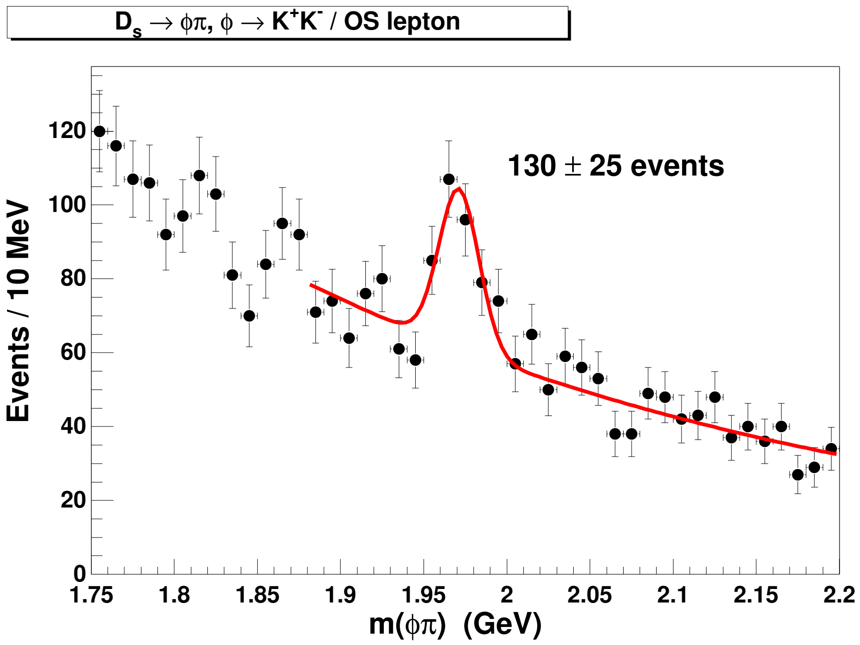
Start by looking for D opposite ℓ

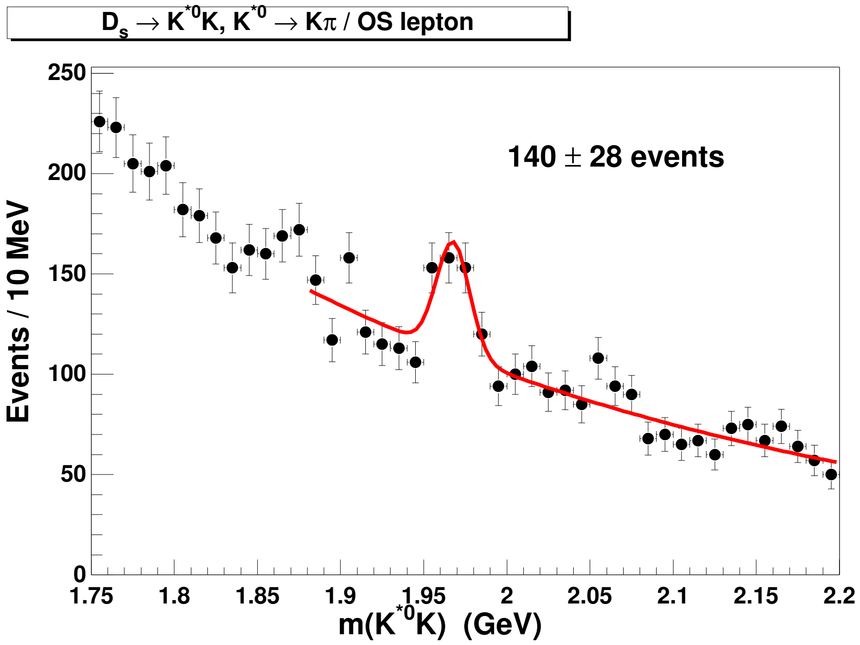
- $D^0 \to K^-\pi^+$;
- $D^{*+} \to D^0\pi^+$, D^0 reconstructed as above;
- $D^+ \to K^-\pi^+\pi^+$;
- $D_s^+ \to \phi\pi^+$, with $\phi \to K^+K^-$;

D Signals Opposite Leptons



See $D_s^- \to \phi\pi^-$, and $K^{*0}K^-$

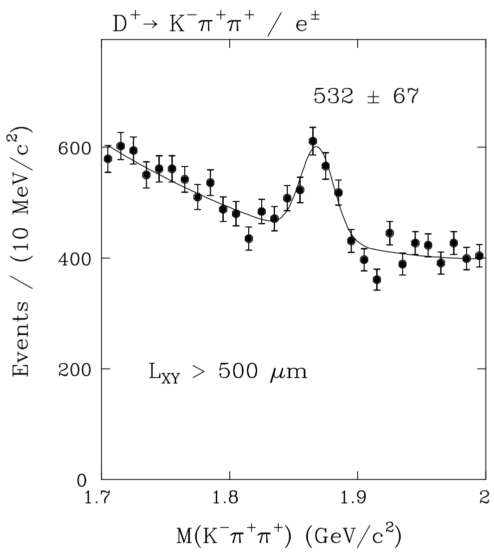




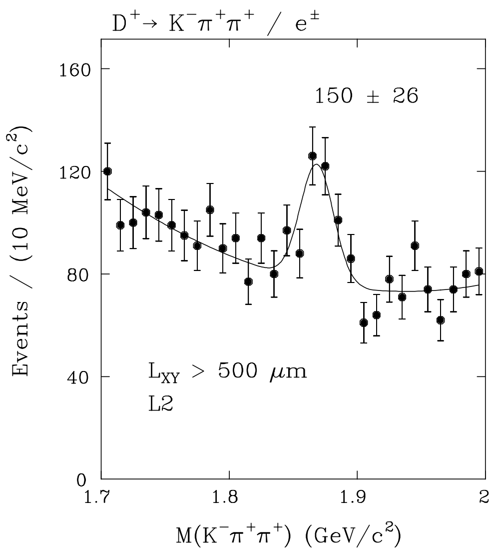
Focus on D^+

$D^+ \to K^-\pi^+\pi^+$ like $D_s^+ \to \phi\pi^+, \phi \to K^+K^-$
(Three-prong vertex)

No Run II trigger



Run II Level 1 & Level 2

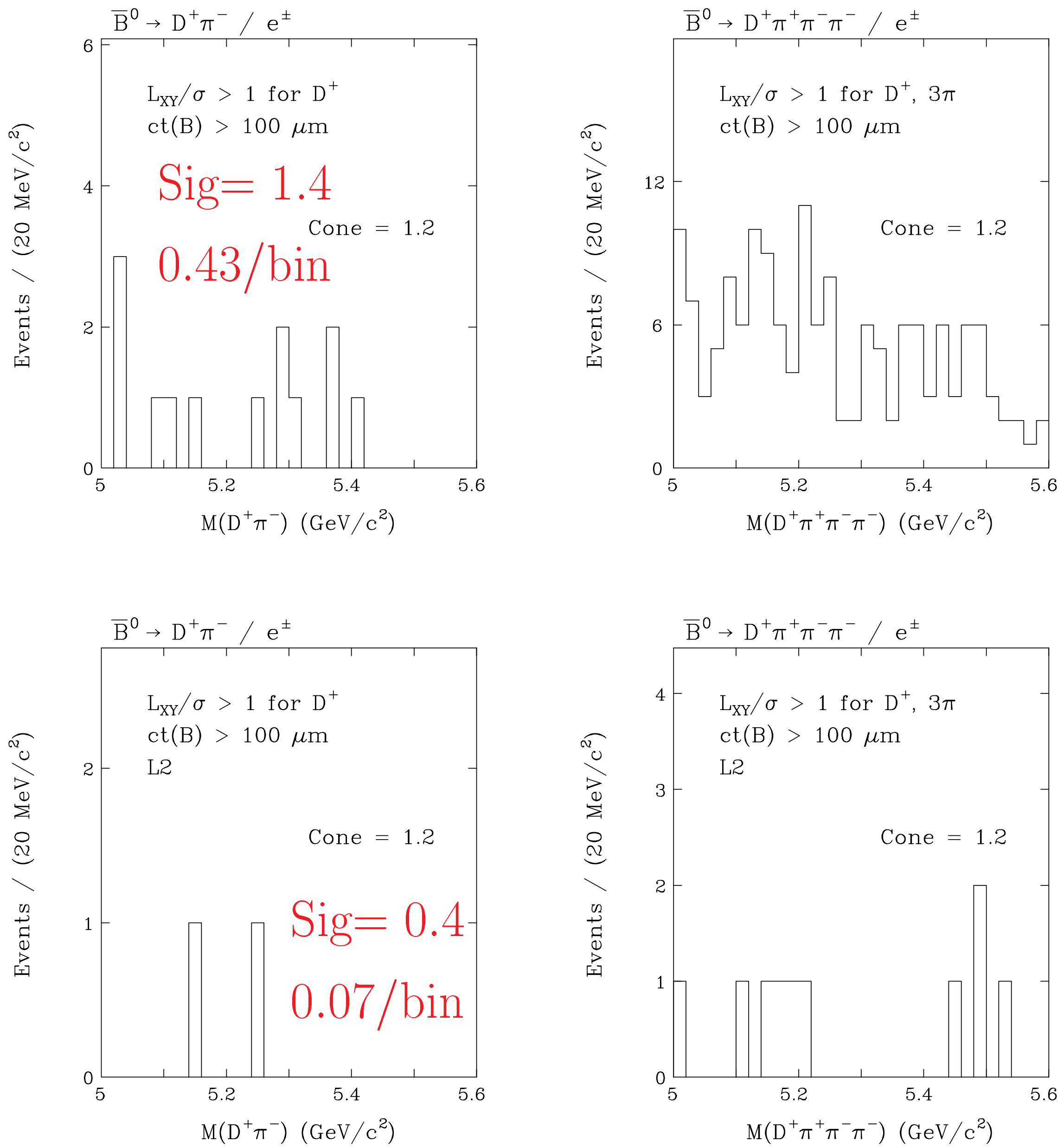


Run II trigger requirements
improve D^+ signal to noise

Combine D^+ signals with π^- or $\pi^-\pi^+\pi^-$

$\Longrightarrow$

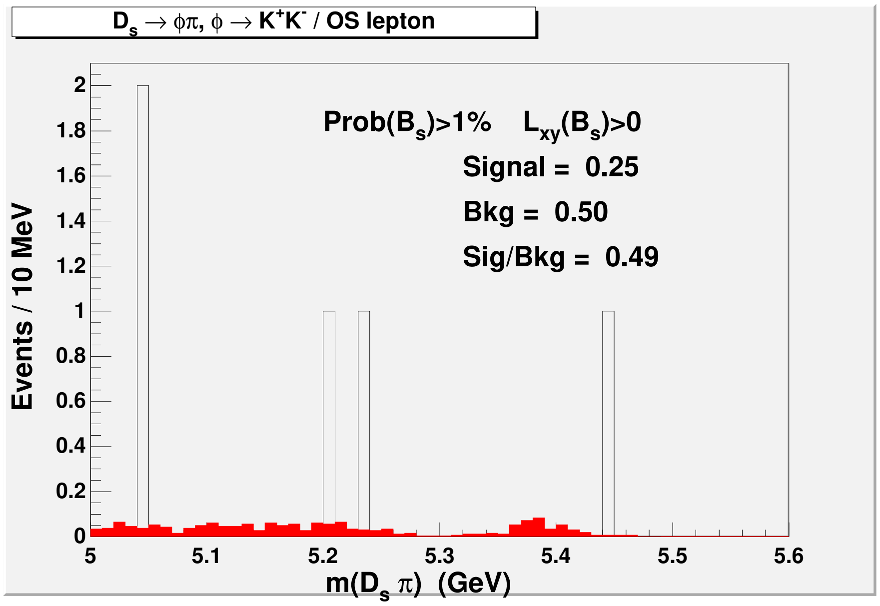
$\bar{B}^0 \to D^+\pi^-, D^+\pi^-\pi^+\pi^-$



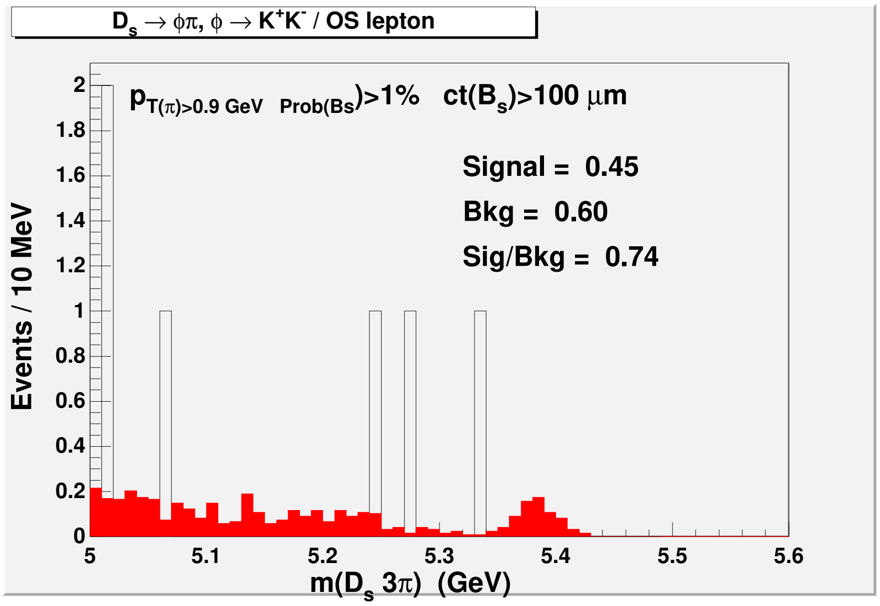
$\bar{B}^0 \to D^+\pi^-$	Expected Signal	Background/20 MeV/c^2	S:N
no trigger selection	1.4	0.43	**3:1**
Run II trigger	0.4	0.07	**6:1**

Background in $B_s^0 \to D_s^- \pi^+, D_s^- \pi^+ \pi^- \pi^+$

$B_s^0 \to D_s^- \pi^+$



$B_s^0 \to D_s^- \pi^+ \pi^- \pi^+$



Conclusions: Signal to Noise

Combinatoric background expected from

1. Heavy Flavor
2. Generic QCD

Heavy Flavor: D signals found opposite ℓ

- Combined with π^+ and $\pi^+\pi^-\pi^+$
- No B signal seen (not expected)
- observed background $\Longrightarrow$ S:N better than 1:1 especially after Run II trigger

Generic QCD:

- Monte Carlo: $b\bar{b}$ fraction significant after Level 2
- No D signals opposite $\gamma \rightarrow e^+e^-$
- Combinatorics in $\gamma \rightarrow e^+e^- \Longrightarrow$ Generic QCD similar to Heavy Flavor
- Should be better in Run II, SVX II is 3-D

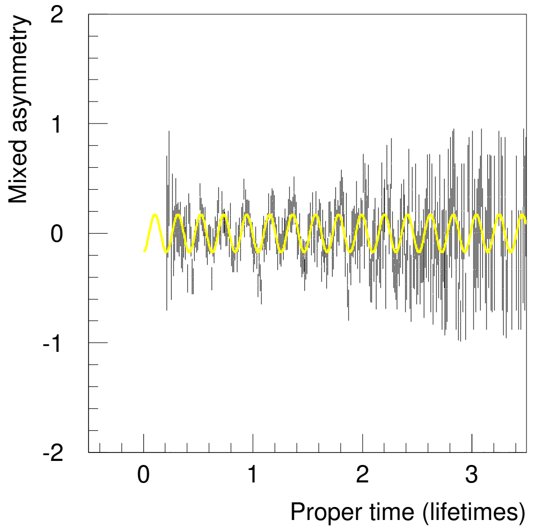
Conclusion:

Varying S:N from 1:2 $\rightarrow$ 2:1 reasonable

(Worse S:N does not compromise x_s reach)

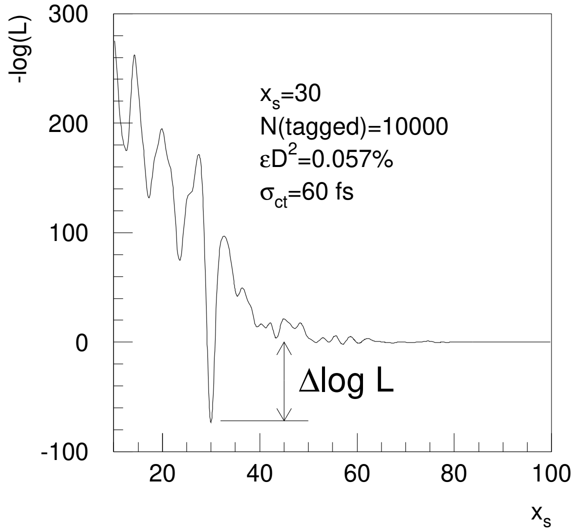
B_s^0 Mixing Analysis

$$A_{\text{mixed}}(t) = \frac{N_{\text{unmixed}}(t) - N_{\text{mixed}}(t)}{N_{\text{unmixed}}(t) + N_{\text{mixed}}(t)}$$



$$\text{Fit to} \quad a(t) = A \cos x_s t/\tau$$

Minimize $-\log \mathcal{L}$ with respect to x_s:



Define significance in terms of depth of the minimum.

B_s^0 Mixing Analysis

Significance:

$$\text{Sig} = \sqrt{2\Delta \log \mathcal{L}}$$

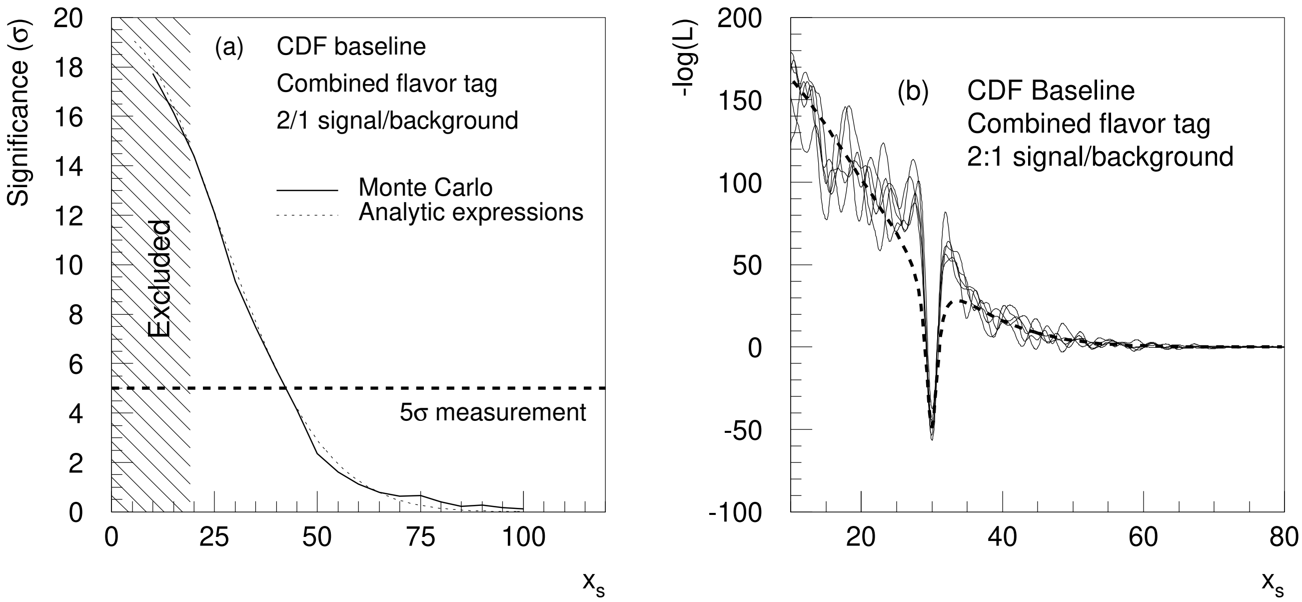
5-sigma x_s *reach*:

$$\text{Maximum } x_s \text{ with } \text{Sig}(x_s) > 5.$$

Estimate reach using:

- Monte Carlo
- Analytic formula:

$$\text{Sig}(x_s) = \sqrt{\frac{N\epsilon D^2}{2}} e^{-(x_s\sigma_{ct}/\tau)^2/2} \sqrt{\frac{S}{1+S}}$$

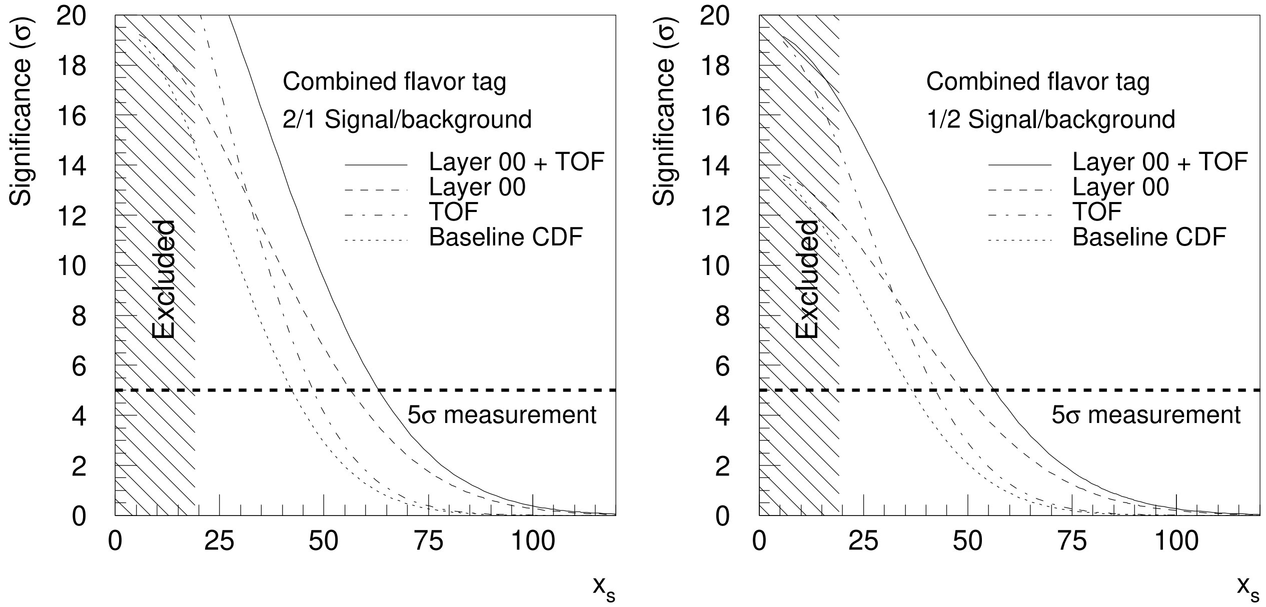


B_s^0 Mixing Analysis

Assumptions:

- Number of untagged decays: $N = 5,000 \to 30,000$
- Neglect p_T resolution ($\sigma_{p_T}/p_T \sim 0.4\%$)
- $$\epsilon D^2 = \begin{cases} 5.7\% & \text{Without TOF} \\ 11.3\% & \text{With TOF} \end{cases}$$
- $$\sigma_{ct} = \begin{cases} 60\text{ fs} & \text{Without Layer 00} \\ 45\text{ fs} & \text{With Layer 00} \end{cases}$$
- Signal-to-background ratio: $S = 1/2 \to 2/1$
- B_s^0 lifetime, $\tau = 1.54$ ps
- Background (no asymmetry) lifetime $= B_s^0$ lifetime.

Estimated x_s Reach



TOF + Layer 00 could extend x_s reach by ~ 20

TOF & Layer 00 are complementary

- TOF important for $x_s \leq 30$
- Layer 00 important for $x_s \geq 40$

Both provide insurance that we can cover this physics in case our current best estimates are overly optimistic

Estimated x_s Reach

x_s reach for different signal yields

$N(B_s^0)$	S/B=2:1				S/B=1:2			
	Baseline	TOF	L00	TOF+L00	Baseline	TOF	L00	TOF+L00
5,000	30	36	40	49	21	30	27	39
10,000	37	42	49	56	30	36	40	49
20,000	42	47	56	63	37	42	49	56
30,000	45	50	61	67	40	45	53	60

Minimum S:N required for 5σ observation

$N(B_s^0)$	$x_s = 30$				$x_s = 40$			
	Baseline	TOF	L00	TOF+L00	Baseline	TOF	L00	TOF+L00
5,000	2.20	0.53	0.61	0.24	—	—	2.20	0.53
10,000	0.52	0.21	0.23	0.11	—	1.01	0.52	0.21
20,000	0.21	0.10	0.10	0.05	0.99	0.34	0.21	0.10
30,000	0.13	0.06	0.07	0.03	0.50	0.20	0.13	0.06

Answers to Questions

1. The collaboration should report on what trigger was assumed for the mixing studies, how its efficiency was estimated, and the reliability of these estimates in the face of real-life conditions such as noise and multiple interactions per crossing.

   The trigger is an all-hadronic B Decay trigger that uses tracks at Level 1 and impact parameter at Level 2. We have estimated the rate of this trigger using data collected during Run I of the Tevatron, which takes into account noise and multiple interactions. These are the most reliable estimates we can make, until we get Run II data. The signal yields are estimated using Monte Carlo with the B hadron production cross-section normalized to the CDF measurement. We include a ±50% uncertainty on the signal rates in the estimates of our reach for x_s.

2. The collaboration should justify their use of the DELPHI signal to background given the very different B momentum spectrum and event environments at the Tevatron and LEP.

   We are no longer relying on results from the LEP experiments to justify our expected signal to background. Instead, we have looked at our own Run I data. This study is still in progress, but preliminary indications indicate that our assumed range of signal to background of 1:2 to 2:1 is reasonable. The committee has been provided with enough information to determine our reach for x_s *for a more pessimistic value of signal to background, as well. Results on signal to background from Run I data are a pessimistic estimate of the signal to background since the Run I silicon detector only provides two-dimensional measurements in the plane transverse to the beamline, but SVX II will provide a three-dimensional space point. This could have a significant impact, particularly for two-body modes such as* $B^0 \to \pi^+\pi^-$.

3. The collaboration should provide studies of the benefits of the TOF for suppressing background, including $B_s^0 \to D_s^-\pi^+$ and $B_s^0 \to D_s^-\pi^+\pi^-\pi^+$ mass plots.

We have begun these studies, but have not reported on them here. We illustrated the potential with two examples of using dE/dx in our Run I data. TOF provides significantly better separation that dE/dx in a part of the momentum range important for reconstructed B hadrons, so we believe it will have an impact.

4. In all studies, the collaboration should specify the luminosity assumed and should provide the results for the baseline detector and for the detector upgraded with L00 and the TOF separately and together.

   The studies presented here are for $2fb^{-1}$ of data. The sensitivity to B_s^0 flavor oscillations has been presented separately for all four configurations: (1) baseline detector, (2) baseline with TOF, (3) baseline with Layer 00, and (4) baseline with TOF and Layer 00.

5. The committee would like the results of these studies in January.

   We tried to provide as much new information as possible.

6. In addition, the committee recommends that the collaboration begin to develop a detailed Monte Carlo simulation of B decays, as this tool will be essential as CDF pursues B physics.

   We agree with this recommendation and we are working on the most efficient means to generate a large sample of inclusive B hadron decays with a detailed simulation of the Run II detector that can be used, in particular, to study details of the tracking performance.

Physics Conclusions

We hope that this supplement to proposal P-909 will help the PAC arrive at the conclusion that both TOF and Layer 00 are powerful additions to the CDF detector, particularly in the study of B physics. The precise measurement of B_s^0 flavor oscillations is a cornerstone of the test of unitarity of the CKM Matrix that is unique to hadron colliders and SLD in the near future. We have demonstrated that TOF and Layer 00 are complementary detectors for the measurement of x_s. The TOF system makes the most significant improvement at lower x_s (< 30). The Layer 00 upgrade is more important at high x_s (> 40). Although we have presented plausible arguments based on our best knowledge that we expect high yields in the number of B_s^0 events, lower yields are quite possible. Both these upgrades are more powerful if the event yield is low (5000 events).

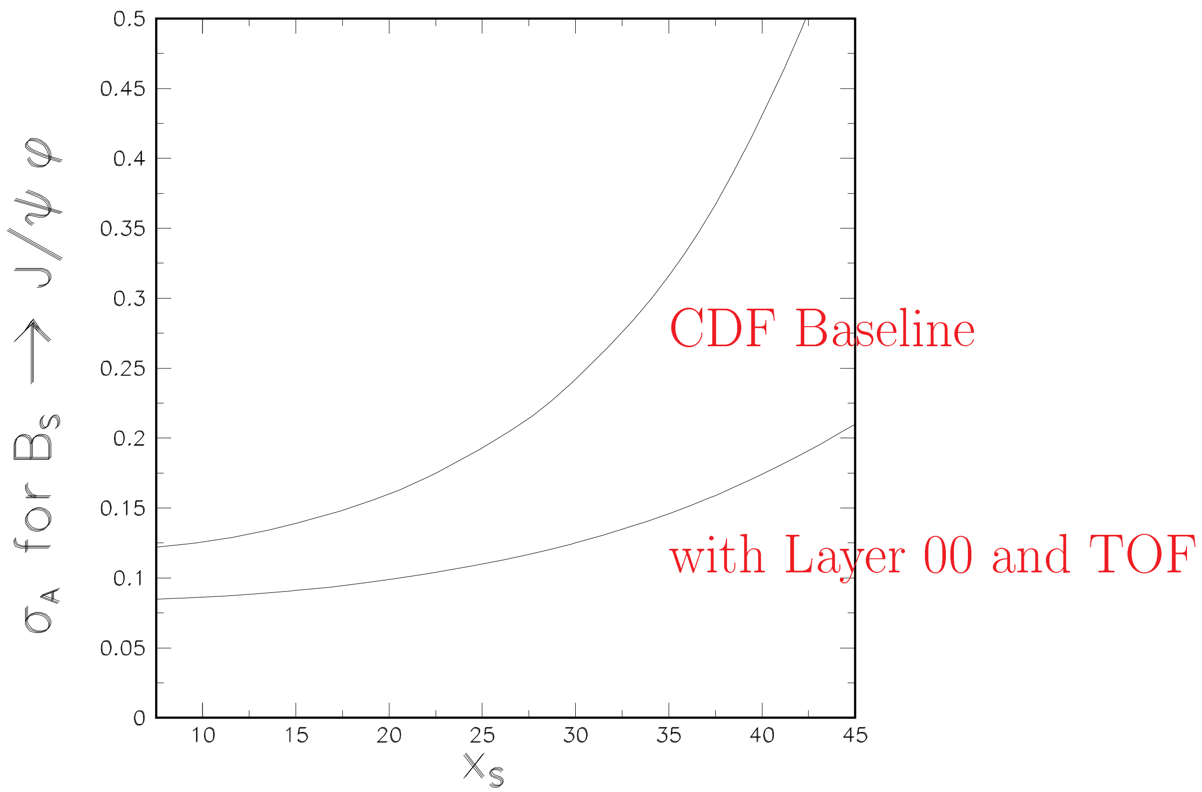
Observing B_s^0 flavor oscillations would be the beginning of a plethora of important measurements in the B_s^0 system, including measurements of CP asymmetries in B_s^0 decays. The impact of TOF on b flavor tagging and the improvement from Layer 00 on proper decay time resolution could be even more important for these measurements.

The studies presented in this report should help convince the PAC that CDF has designed a practical trigger to collect very large samples of hadronic B decays, allowing us to take advantage of the enormous B production cross section at the Tevatron. All other experiments devoted to the study of B physics have realized that particle identification is crucial and have made major investments in detectors that will provide excellent particle identification capabilities. CDF will need particle identification as well to extract the most physics from our large samples of B hadron decays. Time-of-flight is the most economical and the only practical means for us to augment our particle identification capabilities for Run II.

We emphasize that both TOF and Layer 00 have many more applications that we have not explored in the detailed studies presented in this Report. Better vertex resolution and event-by-event particle identification are crucial for extending the physics reach of an already very powerful baseline CDF-II detector.

CP **Violation in** $B_s^0/\bar{B}_s^0 \to J/\psi\phi$

- Small in the Standard Model
  Significant asymmetry unambiguous sign of new physics
- Expected signal: 6000 $B_s^0/\bar{B}_s^0 \to J/\psi\phi$
- Requires measurement of x_s
- Expected combined ϵD^2 for this sample: $\epsilon D^2 = 9.7\%$



History of TOF Project

Feb. 94	J. Peoples calls for proposals for B experiments
	B. Kephart and N. Lockyer design TOF system for CDF
Nov. 94	CDF forms internal review committee to review TOF
Mar. 95	CDF Collaboration approves TOF
Apr. 95	TOF Proposal submitted to PAC
Jun. 95	Director provides R&D funds to carry out test in B0 during Run 1c
Fall 95	successful installation and test of 20 bar prototype in B0
Fall 95	pions, kaons, and protons identified with the prototype system
Feb. 97	Lehmann review approves CDF baseline upgrade
Summer 98	Internal CDF review of additional "beyond the baseline" detectors
Aug. 98	TOF approved again by Collaboration
Oct. 98	TOF presented to PAC

Five years since TOF conceived

Present design similar to original concept

20 Bar Prototype Test: Goals

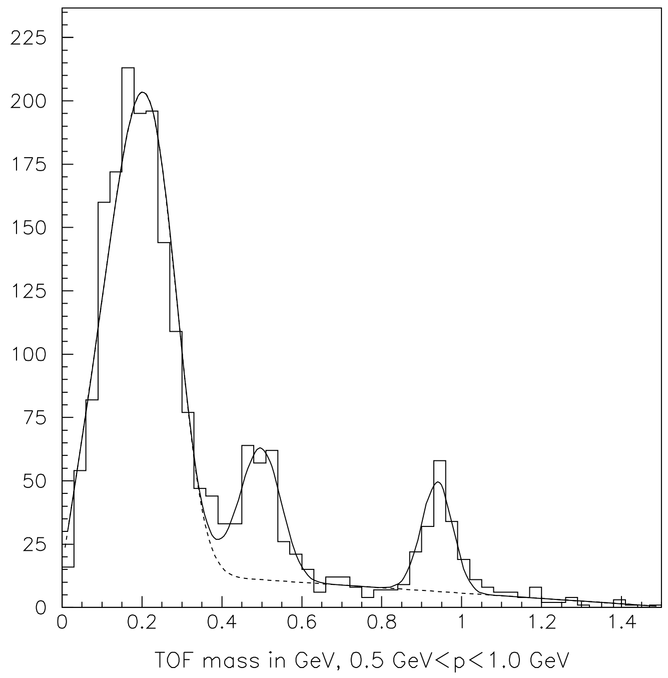
Jun. 95 R&D funds approved to spend on TOF prototype test in CDF

Aug. 95 Removed part of CDT, installed 20 1.3m scintillator bars with 16-stage PMTs

Goals of the test:

- Study occupancy
- See if albedo a problem
- determine if t_0 a problem
- Learn about installation of large number of bars and PMTs

Particle ID not a goal: Nevertheless $\Longrightarrow$



20 Bar Prototype Test: Results

Results from the test

- Occupancy not a problem
- possible to determine event t_0 even with 5% of system
- 16-stage PMTs had inadequate gain
  $\Longrightarrow$ go to 19-stage PMTs
- Cabling and connections were problematic
  (small time window to assemble system)
  $\Longrightarrow$ new PMT mounting scheme

Resolution in PMTs varied from 160ps to 250ps
Extrapolated resolution of best tubes = 110ps

- Average walk correction
- small number of tracks for event t_0 determination

The Time-of-Flight Project (1)

- Scintillator:
  - 216 bars of Bicron BC408
    2.8m long, $\approx 4 \times 4\text{cm}^2$ trapezoidal cross-section
  - Decommissioned CLEO TOF will provide
    half our scintillator
- Photomultiplier tubes:
  - Hamamatsu R5946M, 19 stage, 1.5in diameter
    fine mesh PMT for operation in 1.4T Field
  - Same scintillator and similar PMTs (2in)
    for TOF at BELLE
- Mechanical support:
  - Mounting scheme design well advanced
    (see model)
  - Can install PMTs after bars in detector

The Time-of-Flight Project (2)

- Electronics:
  - Exploit existing calorimeter design (simplifies integration into DAQ)
  - Production ADMEM with CAFE (QIE) for charge
  - Modified ADMEM with TOFFEE for time
  - Need system for stable clock distribution
  - LV for electronics and HV for PMTs
  - Cables
- Calibration and Monitoring:
  - Laser system with optical fibers for in situ testing
- Software:
  - Data reconstruction
  - Detector simulation (almost complete)
  - Detector calibration for physics

Installation, Assembly, and Schedule

Goal:

Install TOF in time for data taking in April 2000, *but* cause as little interference as possible with baseline

Crucial Components:

- Scintillator and Mechanical Support
- Photomultiplier Tubes
- Electronics

Working Assumption:

Scintillator will be installed before Run II begins

Mechanical design allows easy insertion of PMTs after installation of scintillator in cryostat

This staged-design has the *least* impact on the baseline detector

Scintillator and Mechanical Support

- Once Central Detector in collision hall
  no clearance to install 3m bars (end plugs)
- Bars will be inserted into aluminum support blocks
  3 bars for one unit (see model)
- TOF bar assembly supported by solenoid cryostat
- TOF can be assembled before/after COT inserted,
  much easier to assemble before COT is cabled.
- COT installed and ready for cabling by 9/2/99
  $\Longrightarrow$ scintillator installed by this date.

Scintillator Delivery Time

CLEO TOF will provide $\frac{1}{2}$ of scintillator
(64 bars 5cm $\times$ 10cm $\times$ 2.8m = 128 CDF bars)

- CLEO removes scintillator in April 1999
  Needs to be machined
- Have 5 bars in hand
  attenuation length looks good
  currently developing machining (FNAL & industry)

Order remaining scintillator from Bicron
2 months for first bars
3 months for complete delivery of 100 bars

Preparation (wrapping, testing,
insertion into support structure)
will take place in parallel with delivery
$\Longrightarrow$ bars ready for insertion soon after delivery

Order from Bicron in February
Scintillator ready for installation
by August 1999

Cables

Ready to install by 9/2/99 to minimize interference with cabling of COT, ISL, and SVX II.

Slots already reserved for TOF in 30° crack

Currently investigating signal, LV, and HV cable, and optical fiber

Should be ordered as soon as possible

Phototubes

Mechanical mount allows installation of PMTs
after scintillator is installed in cryostat

Want to install as many PMTs as possible before 9/2/99
If possible, assemble PMTs and scintillator
before installation to allow testing.

32 PMTs located behind COT mounts
much easier if available at same time
as installation of scintillator
$\Longrightarrow$ **order 40 PMTs as soon as possible (Korea)**

Phototube Delivery

Delivery time:

We have ordered two R5946-MOD
and paid for tooling of entire order

Receive these tubes in early February.

Once these are tested and approved (early March)
Ready to order remaining 448 tubes

- 2.5 months for the first 100
- 3.5 months for the additional 348

i.e. **6 months** total for delivery

If ordered in March, last tubes by September 1999
(February 2000 last opportunity to install tubes)

Urgent: 40 tubes before COT installed

Testing:

Test PMTs at Hamamatsu, Tsukuba, and FNAL
Tests (Spain) in 1.4T possible at FNAL and Trieste

Testing and assembly of tubes in parallel to delivery
$\Longrightarrow$ assembly complete shortly after last tube arrives

Electronics

Base and preamp:

Based on design from 20 bar test

Must be available when PMTs inserted

Front-end electronics

Not critical path, can be installed after scintillator and PMTs installed.

Does not interfere with baseline detector

Use Calorimeter FE electronics (ADMEM and CAFE)

Slots in VME crates on detector already reserved for TOF

TOFFEE development at Penn underway
R&D funding needs to continue

Summary:

We are ready to go as soon as we are approved

Most pressing needs for funds upon approval:

- Order scintillator from Bicron
  Obtain CLEO scintillator
  and start machining
- Order 40 PMTs for installation
  with Scintillator (COT mount)
- Exercise option to add 24 ADMEMS
  to imminent production order
  Delay will cost substantial extra funds
- Mechanical mounts
- Cables