B-flavor Tagging Studies Using a $B \to \ell D^{(*)} X$ Sample.

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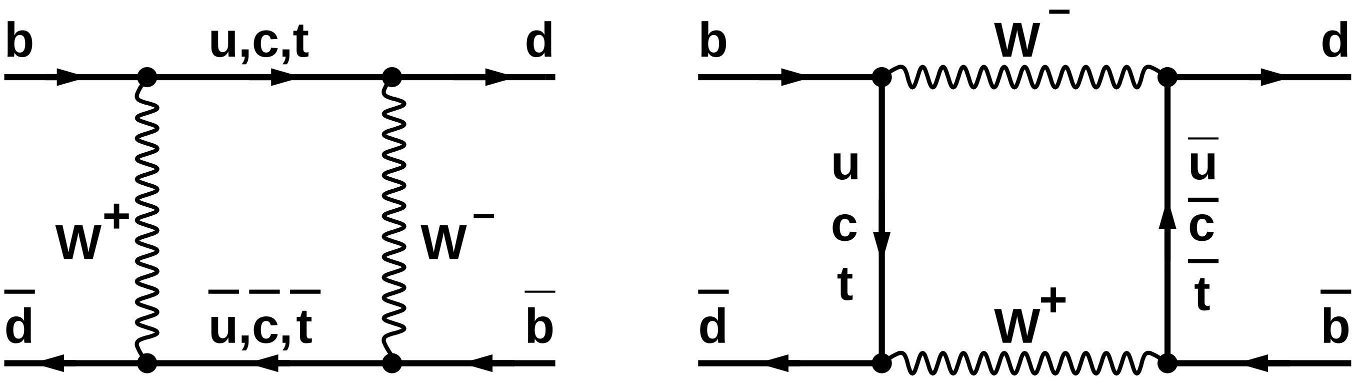
- Introduction to Tagging
- $\ell D^{(*)}$ Sample
- "Same Side" Tagging (SST)
- "Jet Charge" Tagging (JQT)
- Combination SST + JQT
- Conclusion

$B^0 \to \overline{B^0}$ mixing



Probability densities:

$$P(t)_{B^0 \to \overline{B^0}} = \frac{1}{2\tau} e^{-t/\tau} (1 - cos\Delta mt)$$

$$P(t)_{B^0 \to B^0} = \frac{1}{2\tau} e^{-t/\tau} (1 + cos\Delta mt)$$

Δm is a mass difference between mass eigenstates

Asymmetries and Dilutions

B^0-meson:

$$A_0(t)_{(true)} \equiv \frac{N(t)_{B^0 \to B^0} - N(t)_{B^0 \to \overline{B^0}}}{N(t)_{B^0 \to B^0} + N(t)_{B^0 \to \overline{B^0}}} = cos\Delta mt$$

$$A_0(t)_{(meas)} \equiv \frac{N_{RS}(t) - N_{WS}(t)}{N_{RS}(t) + N_{WS}(t)} = D_0 cos\Delta mt$$

where D_0 – tagging $dilution$ for B^0.

B^+-meson (as a cross-check):

$$A_{+(true)} \equiv 1$$

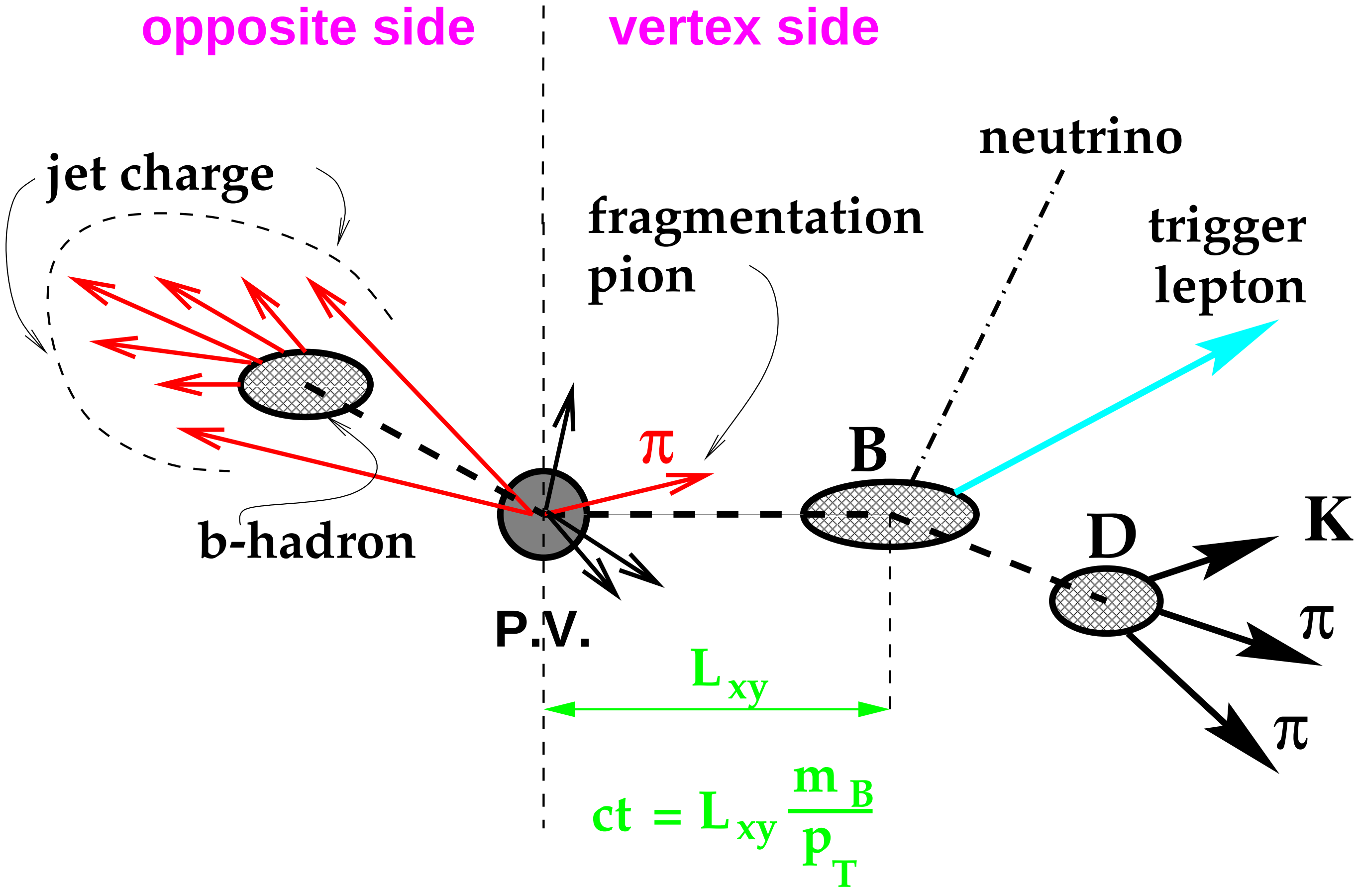
$$A_{+(meas)} \equiv \frac{N_{RS} - N_{WS}}{N_{RS} + N_{WS}} = D_+$$

where D_+ – tagging $dilution$ for B^+.

B-flavor Tagging:

To tag event we need:

1. b-quark flavor at birth (SST, Jet Charge)
2. b-quark flavor at decay (trigger lepton)
3. Proper time of B-meson life ($L_{xy} \Longrightarrow ct$)

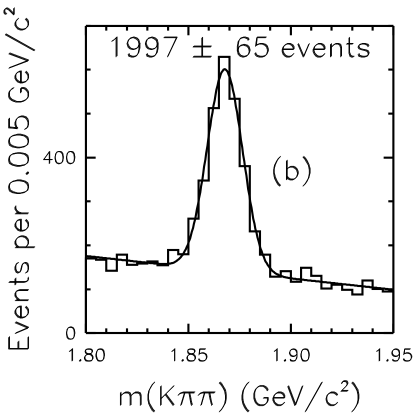


Goal – study tagging techniques (for Δm_s, CP, ...)

Δm_d – just gauge for taggers

The $B \to \ell D^{(*)}$ Sample

Five signatures were used†:



$$B^0 \to \nu\ell^+ D^- \ , \ D^- \to K^+\pi^-\pi^-$$

$$B^0 \to \nu\ell^+ D^{*-}, \ D^{*-} \to \overline{D^0}\pi_*^-, \ \overline{D^0} \to K^+\pi^-$$

$$B^0 \to \nu\ell^+ D^{*-}, \ D^{*-} \to \overline{D^0}\pi_*^-, \ \overline{D^0} \to K^+\pi^-\pi^-\pi^+$$

$$B^0 \to \nu\ell^+ D^{*-}, \ D^{*-} \to \overline{D^0}\pi_*^-, \ \overline{D^0} \to K^+\pi^-\pi^0$$

$$B^+ \to \nu\ell^+ \overline{D^0} \ , \ \overline{D^0} \to K^+\pi^-$$

Almost 10,000 B-mesons in sample

†CDF SST Δm_d analysis in Phys. Rev., **D59**, 032001, (1999)

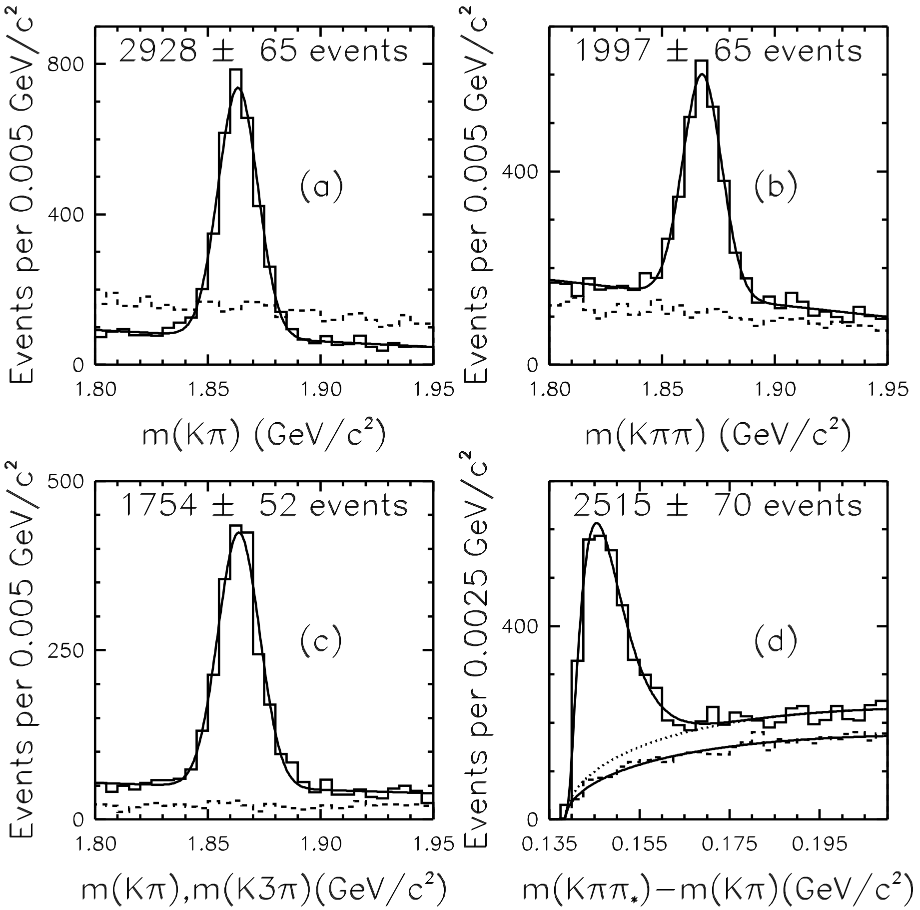
The mass distributions†:

$B^{+} \to \nu l^{+} \overline{D^{0}}$

$\quad \hookrightarrow K^{+} \pi^{-}$

$B^{0} \to \nu l^{+} D^{-}$

$\quad \hookrightarrow K^{+} \pi^{-} \pi^{-}$



$B^{0} \text{—} \nu l^{+} D^{*-}$

$\quad \hookrightarrow \overline{D^{0}} \pi^{-}_{*}$

$\qquad \hookrightarrow K^{+} \pi^{-} \pi^{-} \pi^{+}$

$B^{0} \to \nu l^{+} D^{*-}$

$\quad \hookrightarrow \overline{D^{0}} \pi^{-}_{*}$

$\qquad \hookrightarrow K^{+} \pi^{-}$

$B^{0} \to \nu l^{+} D^{*-}$

$\quad \hookrightarrow \overline{D^{0}} \pi^{-}_{*}$

$\qquad \hookrightarrow K^{+} \pi^{-} \pi^{0}$

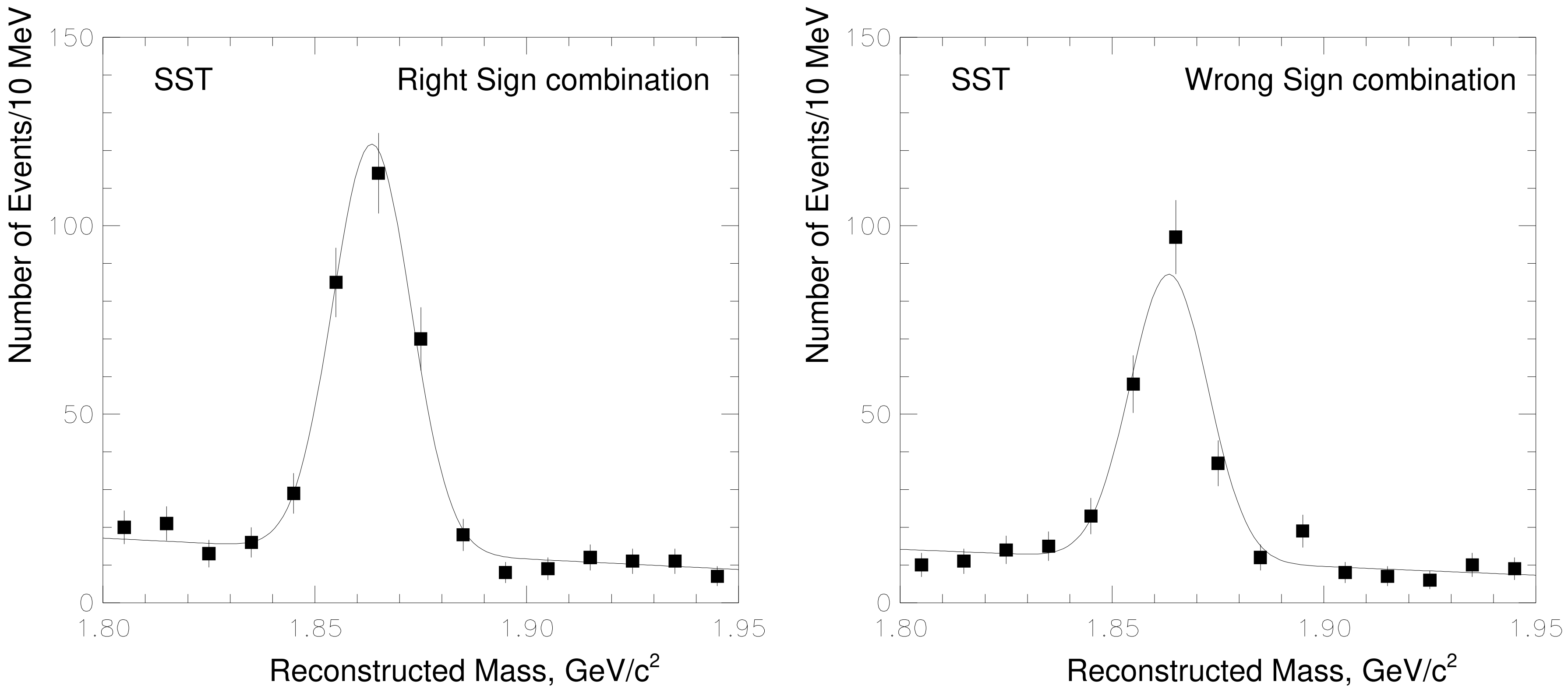
†CDF SST Δm_d analysis in Phys. Rev. D, **D59**, 032001, (1999)

Mass fit for SST

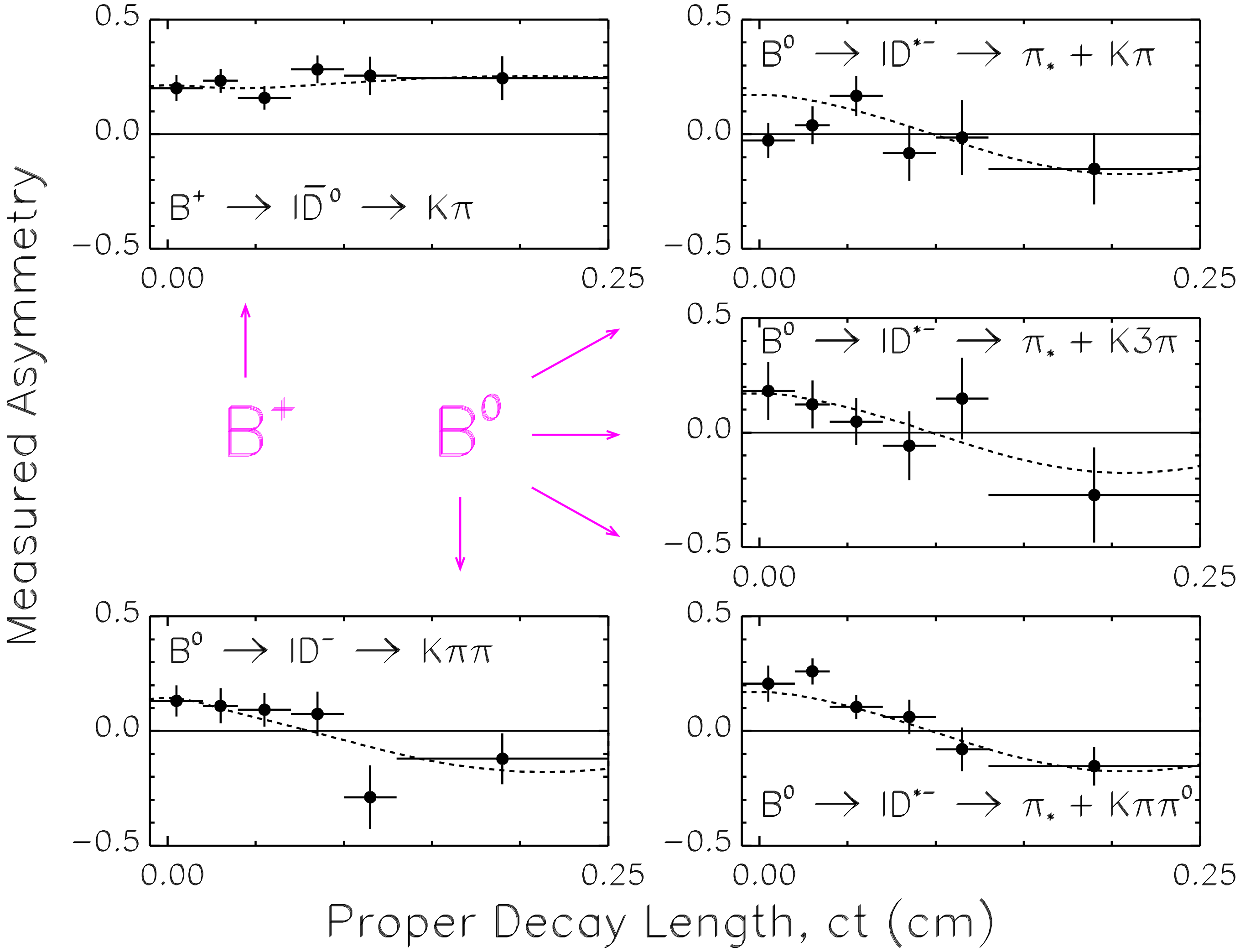
Signature: $B^+ \to \nu\ell^+\overline{D^0}$, $\overline{D^0} \to K^+\pi^-$

First ct bin $(-0.01cm < ct < 0.02cm)$

$$\Longrightarrow \textbf{Asymmetry} = \frac{N_{RS}-N_{WS}}{N_{RS}+N_{WS}} = 0.175 \pm 0.055$$



Same Side Tagging



Δm_d (ps^{-1})	$0.471^{+0.084}_{-0.075}$
D_0 (%)	$18.1^{+3.6}_{-3.1}$
D_+ (%)	$26.7^{+3.9}_{-3.4}$
ϵ (%)	72.7 ± 0.5

Phys. Rev., **D59**, 032001, (1999)

Jet Charge Tagging

Momentum-average jet charge†

$$Q_{jet} = \frac{\Sigma q_i (\vec{p_i} \cdot \hat{a})^\kappa}{\Sigma (\vec{p_i} \cdot \hat{a})^\kappa}$$

where

- q_i is the charge of the track,
- $\hat{a}$ is the unit vector along the jet axis,
- $\vec{p_i}$ is particle's momentum,
- κ is a factor tuning sensitivity to different parts of the momentum spectrum ($\kappa = 1$ was chosen).

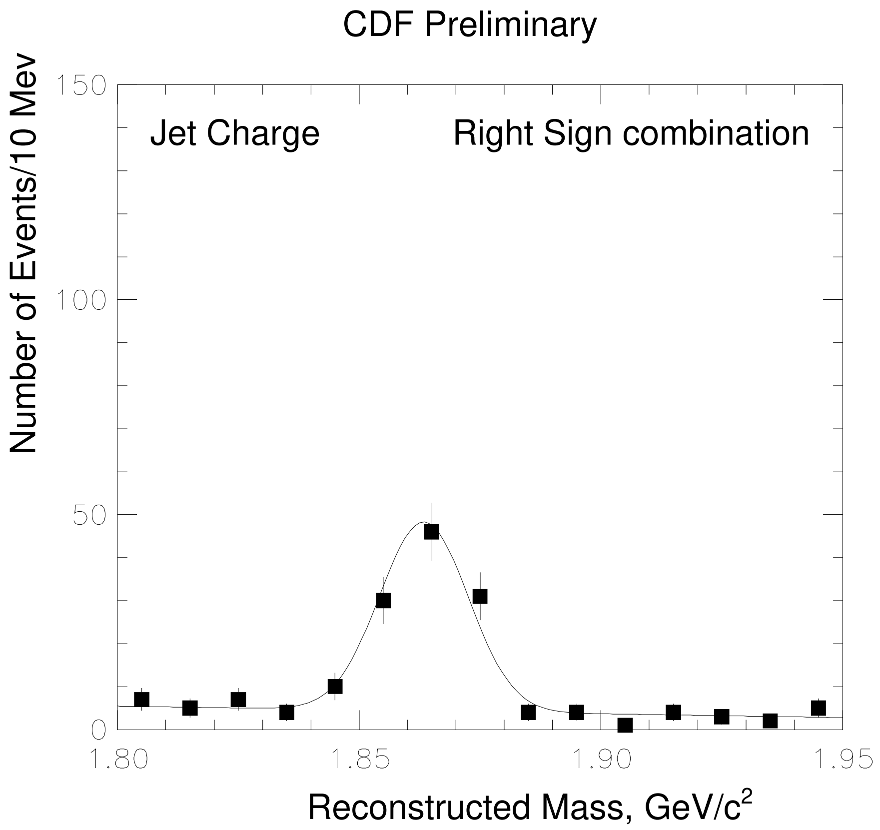
†FERMILAB-PUB-99/019-E, Submitted to Phys. Rev. D. (CDF inclusive lepton sample)

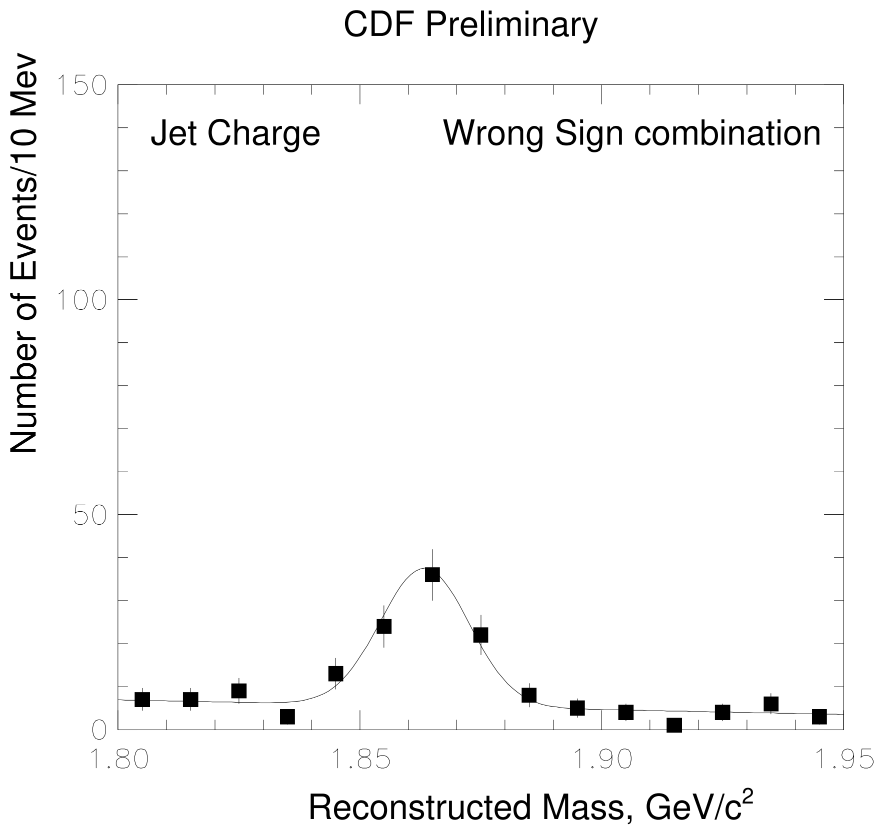
Mass fit for Jet Charge

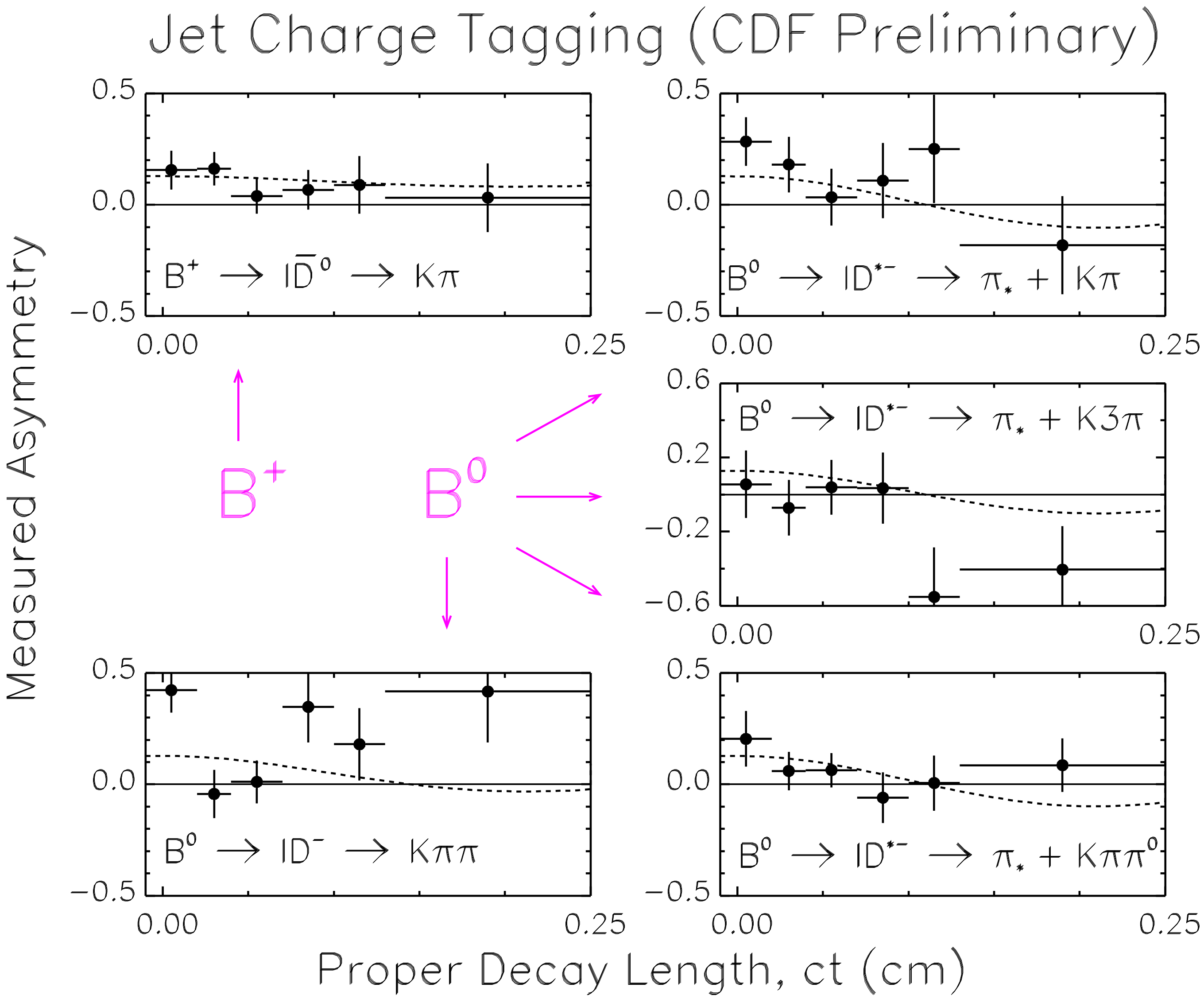
Signature: $B^+ \to \nu l^+ \overline{D^0}$, $\overline{D^0} \to K^+\pi^-$

First ct bin $(-0.01cm < ct < 0.02cm)$

$$\Longrightarrow \textbf{Asymmetry} = \frac{N_{RS}-N_{WS}}{N_{RS}+N_{WS}} = 0.156 \pm 0.087$$







Variable	Fit result
Δm_d (ps^{-1})	$0.463^{+0.414}_{-0.166}$
D_{jqt} (%)	$12.8^{+4.6}_{-2.8}$
ϵ (%)	33.2 ± 0.6

The procedure

Calculate time-dependent asymmetries for each decay signature:

1. Divide data into 6 ct bins
2. Divide data in each ct bin into Right Sign and Wrong Sign events
3. Fit data with Gaussian (signal) and linear function (background)

   $\Longrightarrow$ N_{RS} and N_{WS}

   $\Longrightarrow$ Asymmetries for each ct bin

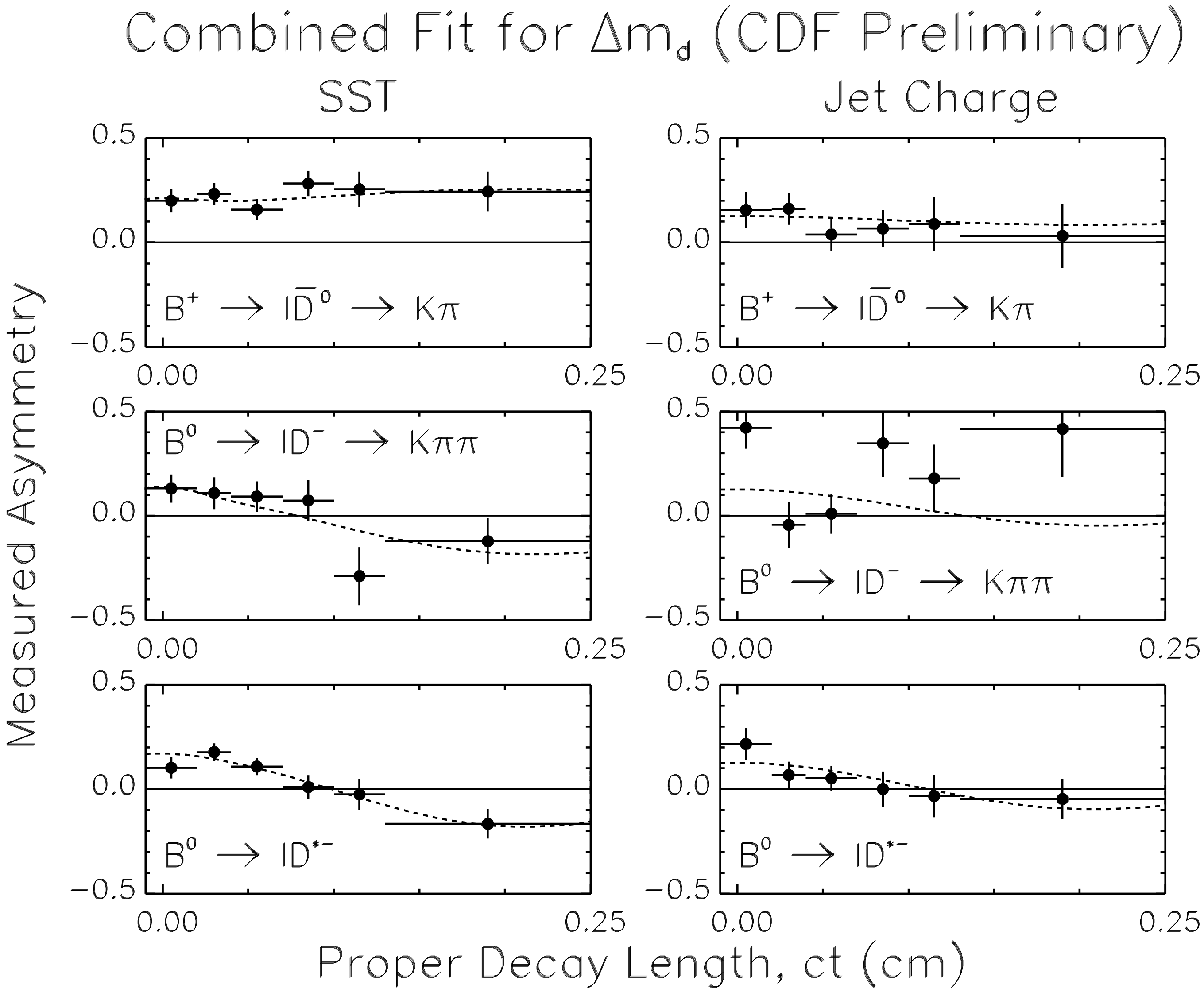
$$A(t)_{(meas)} = \frac{N_{RS} - N_{WS}}{N_{RS} + N_{WS}}$$

4. Fit asymmetries simultaneously with sample composition parameters, F:

$$\chi^2 = \sum \left(\frac{A_{(meas)} - A_{(pred)}}{\sigma_A} \right)^2 + \sum \left(\frac{F_{(meas)} - F_{(pred)}}{\sigma_F} \right)^2$$

“Combined” chi squared

$$\chi^2 = \sum_{\substack{SST,\\JQT}} \left(\frac{A_{(meas)} - A_{(pred)}}{\sigma_A}\right)^2 + \sum \left(\frac{F_{(meas)} - F_{(pred)}}{\sigma_F}\right)^2$$



Variable	Fit result
Δm_d (ps^{-1})	$0.463^{+0.075}_{-0.066}$
D_0 (%)	$18.4^{+3.6}_{-3.1}$
D_+ (%)	$27.0^{+3.8}_{-3.4}$
D_{jqt} (%)	12.7 ± 2.7

Variable	SST	JQT	SST + JQT
$\boldsymbol{\Delta m_d}$, **ps**$^{-1}$	$\mathbf{0.471}^{+0.084}_{-0.075}$	$\mathbf{0.463}^{+0.414}_{-0.166}$	$\mathbf{0.463}^{+0.075}_{-0.066}$
D_{B^0} (%)	$18.1^{+3.6}_{-3.1}$	n/a	$18.4^{+3.6}_{-3.1}$
D_{B^+} (%)	$26.7^{+3.9}_{-3.4}$	n/a	$26.9^{+3.8}_{-3.4}$
D_{jqt} (%)	n/a	$12.8^{+4.6}_{-2.8}$	12.7 ± 2.7
χ^2/DoF	26.5/30	39.3/33	63.8/59
ϵ (%)	72.7 ± 0.5	33.2 ± 0.6	-
ϵD^2 (%) *	$2.4^{+1.0}_{-0.8}$	$0.6^{+0.4}_{-0.2}$	$3.0^{+1.0}_{-0.9}$
$\sigma_{\Delta m_d}\sqrt{\epsilon D^2}$	$+1.3\ _{-1.2}$	$+3.1\ _{-1.2}$	$+1.3\ _{-1.1}$

$$^{*}\sigma_{\Delta m_d} \sim \frac{1}{\sqrt{N\epsilon D^2}}$$

Summary:

Our studies of Same Side and Jet Charge taggers show consistency:

- Combined fit behave as expected
- $\sigma_{\Delta m_d}$ scales like $\frac{1}{\sqrt{\epsilon D^2}}$

ℓD sample is useful for studying tagging ...

In Future:

- To tag with combined tagger on event-by-event basis rather than just fit asymmetries
- To use other algorithms for Jet Charge Tagging
- To use another method - Soft Lepton Tagging (SLT)