D^0-$\overline{D}^0$ Mixing/CP Violation at CDF

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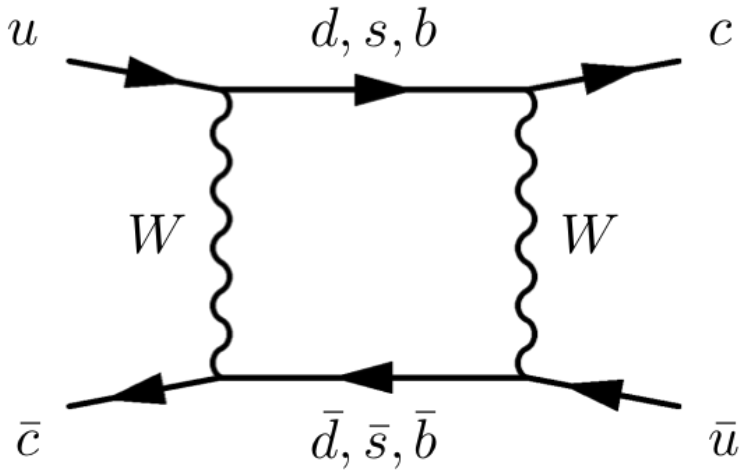
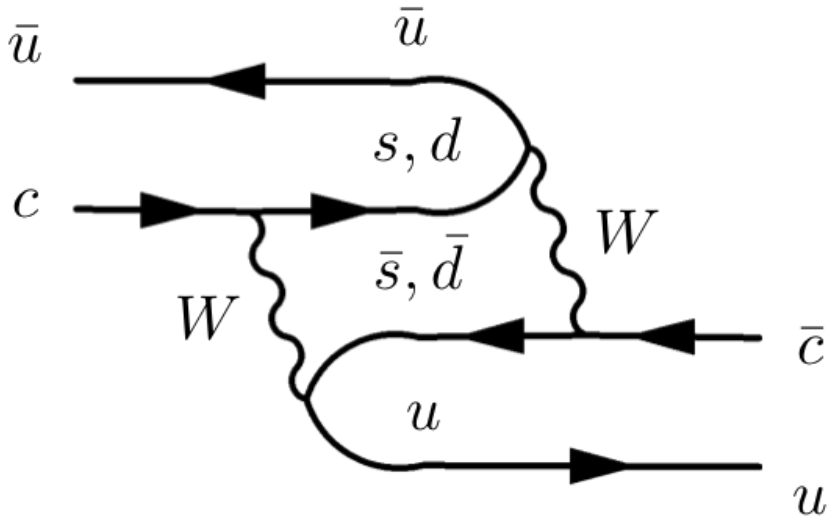
Introduction

D^0 mixing: expected small in the SM➔ very interesting
- D^0 is the only up type meson which shows mixing
- Discrepancies with SM ➔ New Physics

Short range processes
⇒ small amplitude
(m_b small, CKM suppression)



Long range processes
⇒ larger amplitude
(model dependent)

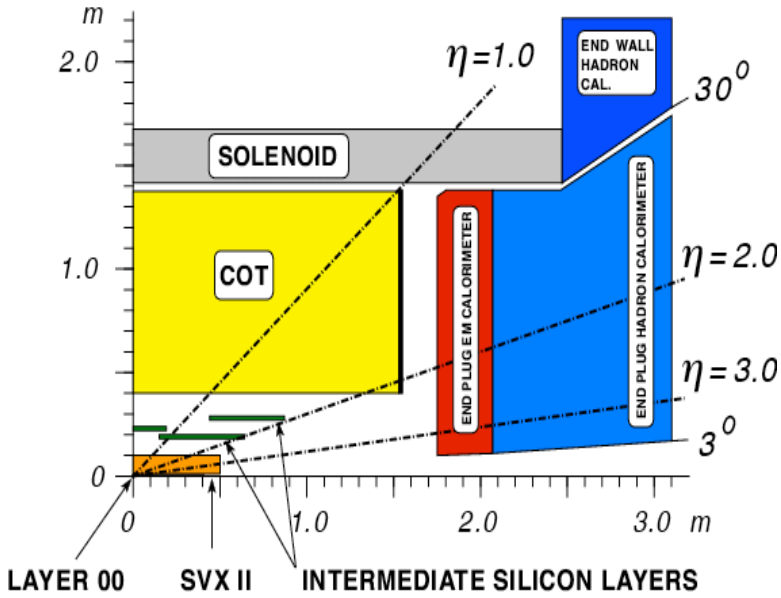


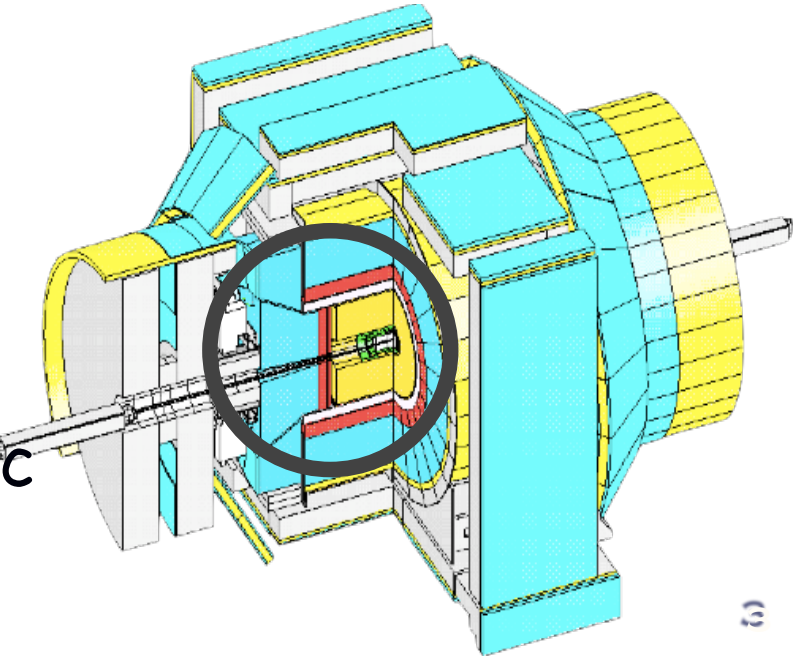
Important CDF features

- Central Drift chamber in B field
  - $\sigma(p_T)/p_T^2 \sim 0.1\%$ GeV/c^{-1}
    (excellent tracking/mass res)
  - dE/dx measurement

- Silicon Vertex detector
  - I.P. resolution 35 um @2 GeV/c

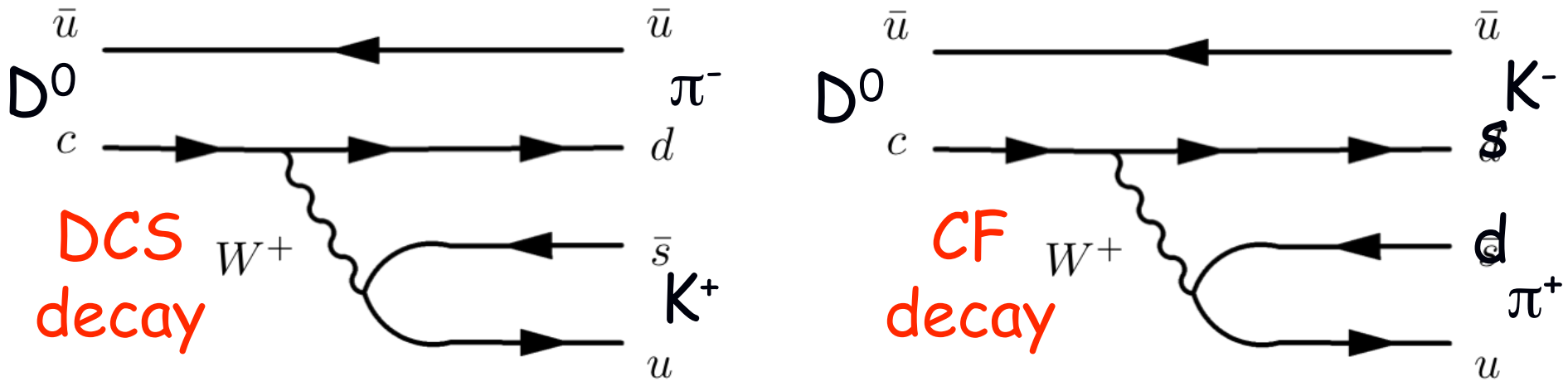
- Hadronic B/D triggers
  3D tracks in the COT, p_T>2 GeV/c
  2D tracks in COT+SVX, p_T>2 GeV/c
  Offline quality I.P. measurement





Measurement Technique

- Measure R(t) = Wrong Sign/Right Sign in $D^0 \to K^-\pi^+$ decay



- WS also due to $D^0 \to \overline{D^0} \to K^+\pi^-$ (D^0 mixing + CF decay)
- If no CP violation and small mixing (x,y << 1):

$$R(t/\tau) = R_D + \sqrt{R_D}\, y' \times (t/\tau) + 1/4 \times (x'^2 + y'^2) \times (t/\tau)^2$$

CDF-II: PRD-RC 74,031109 (2006) (time ind. meas.)

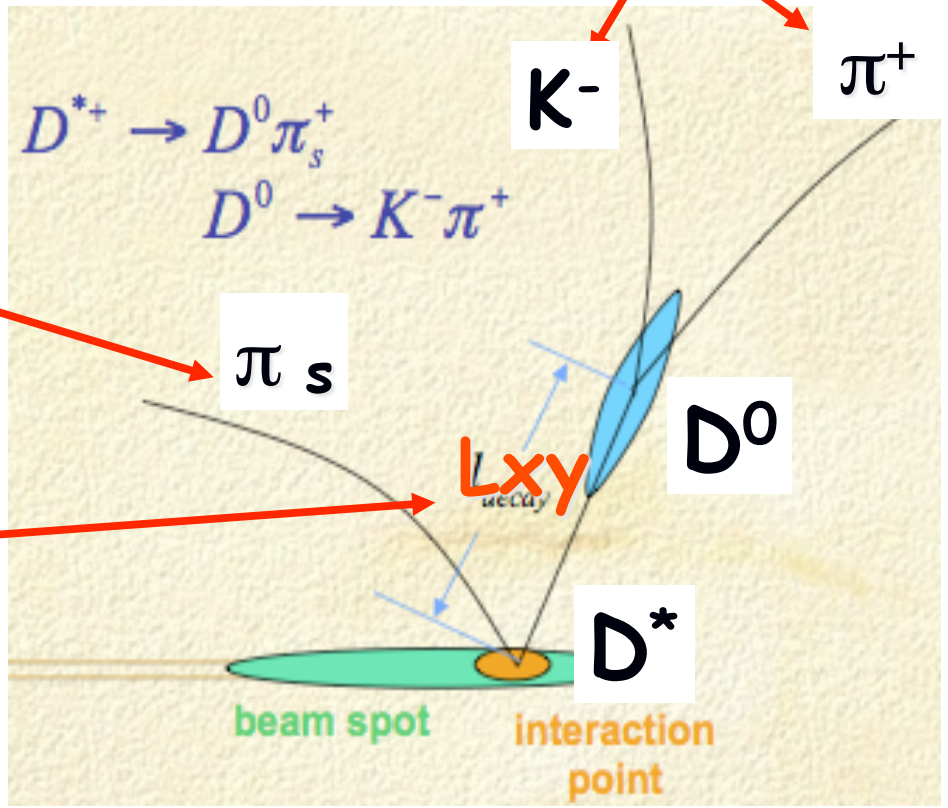
Measurement Technique

1) Measure proper decay time
2) Identify charm @production
3) Identify charm @decay

Kπ final state tags charm @decay

π_s tags charm @production

Lxy measures decay time



Data Sample

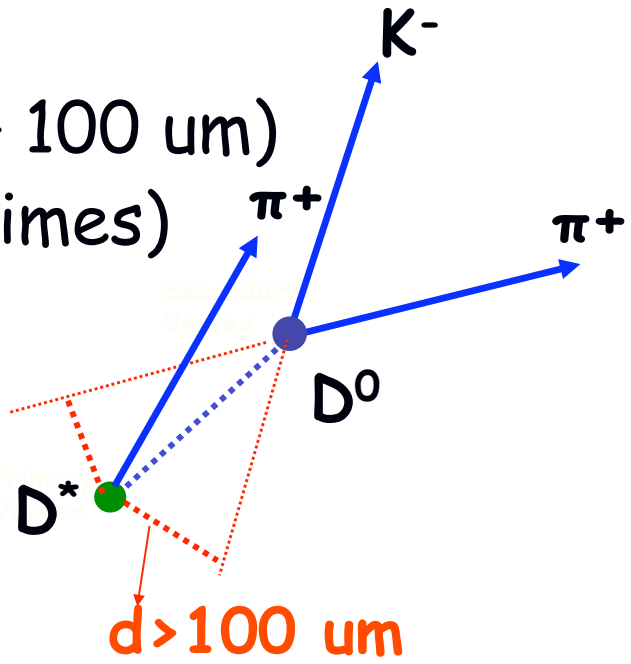
$\int L \approx 1.5\ fb^{-1}$ CDF data (Feb 2002 – Jan 2007)

Hadronic Trigger requires

- 2 Tracks from a displaced vertex (d > 100 um)
  (good acceptance for >0.5 - 10 D^0 lifetimes)

Offline reconstruction requires

- 2 Trigger tracks form $D^0 \rightarrow K\pi$
- Add soft track to form $D^{*+} \rightarrow \pi_s^+ D^0$



Extract RS & WS signals

WS signal blinded during cut optimization

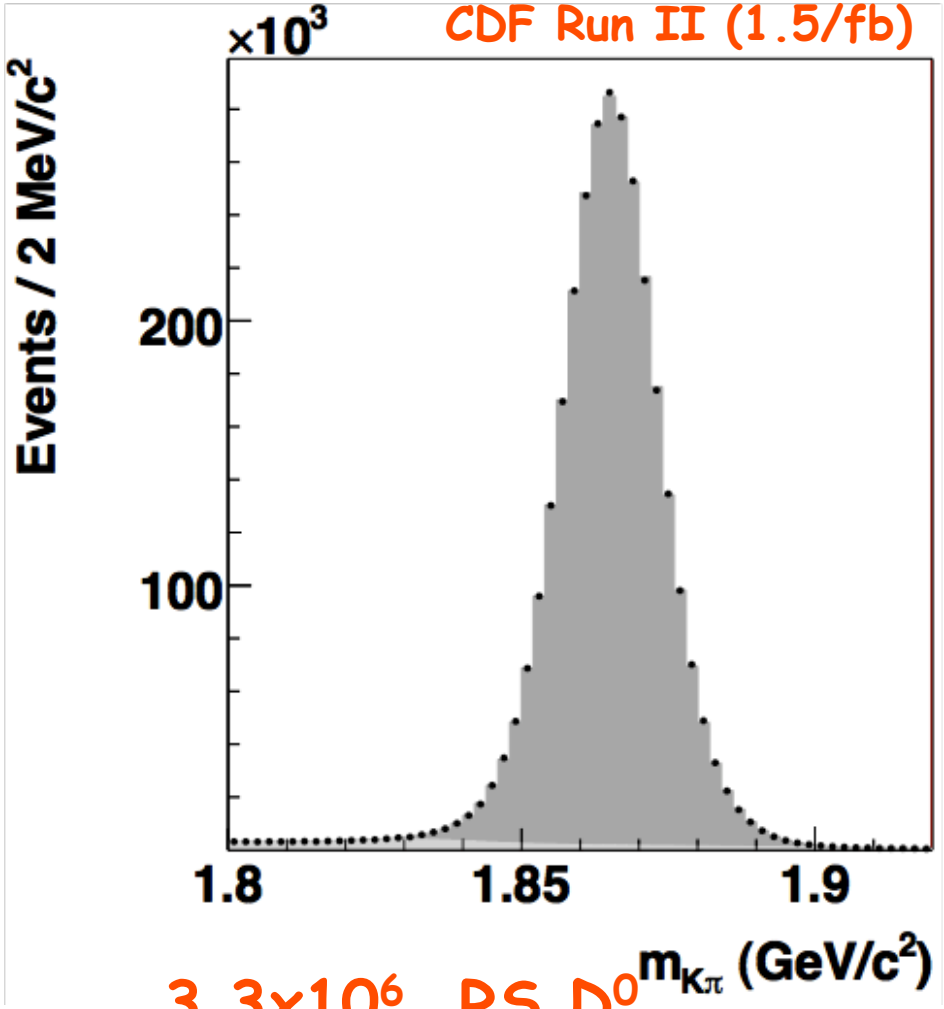
- scaled RS signal acts as substitute (WS=0.004xRS)

Same selection for RS and WS (same kinematics)

Events have decay times from 0.75-10 D^0 lifetimes

-Trigger acceptance is low for shorter decay times

-Few events at long decay time (exponential decay)



3.3×10^6 RS D^0
(time integrated)

Analysis Overview

What we need to measure

$$R(t/\tau) = R_D + \sqrt{R_D}\, y' \times (t/\tau) + 1/4 \times (x'^2 + y'^2) \times (t/\tau)^2$$

20 decay time bins	Fit R(t) to determine mixing parameters
Divide events into RS and WS	Ratio R for each time bin
Two $d_0(D^0)$ bins: $\leq 60\ \mu m$, $>60\ \mu m$	Prompt or from B-decay (wrong decay time)
60 bins Δm $(D^* - D^0 - \pi)$	D^* or not D^*
$K\pi$ mass distribution	D^0 or not D^0

m(Kπ) spectrum

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Divide events into RS and WS	Ratio R for each time bin
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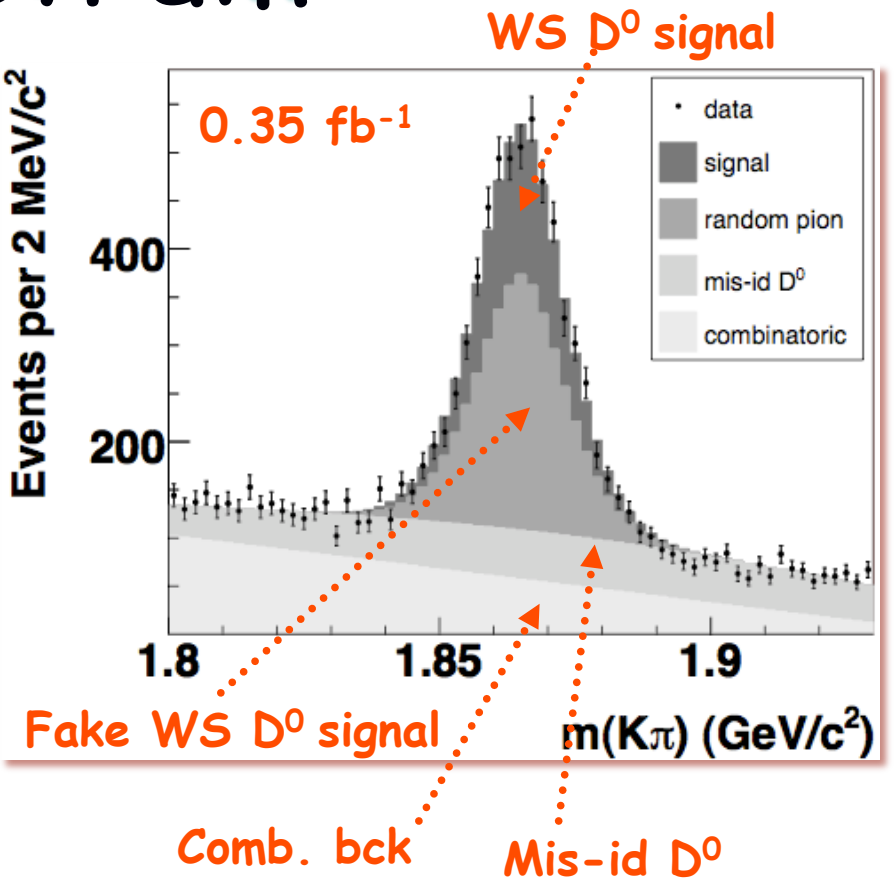
Kπ mass distribution	D^0 or not D^0

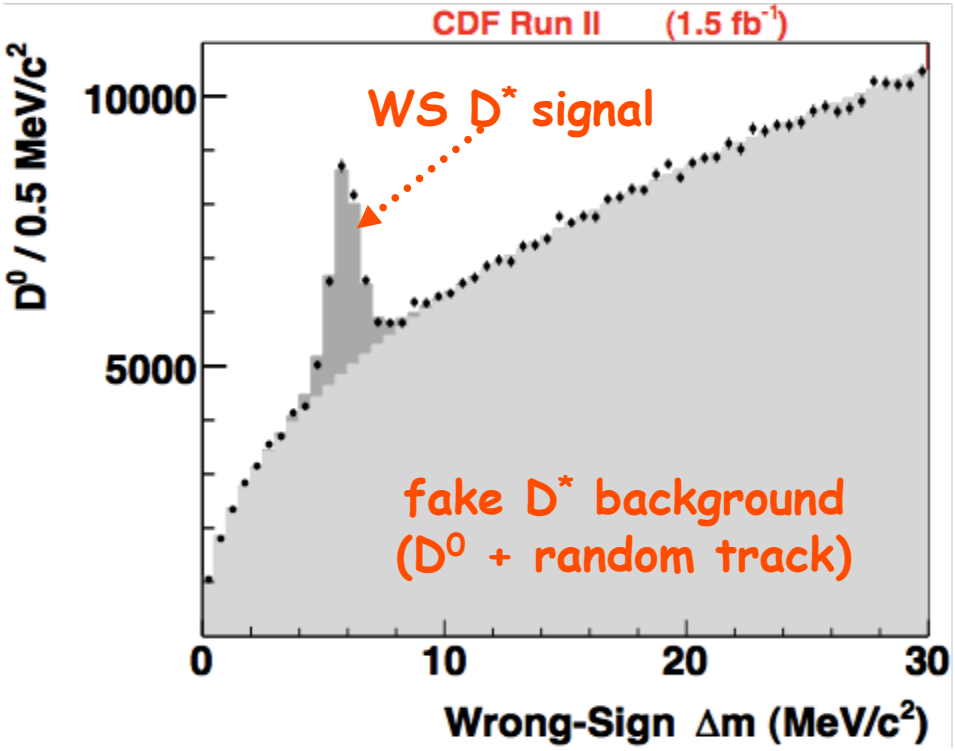


Fit for D^0 yields

- Single signal shape used for all fits
- Parameters for background independent for all fits
- Typical χ^2/dof for these fits = 1.0

m(D*)-m(D⁰)-m(π) spectrum

20 decay time bins	Fit R(t) to determine mixing parameters
Divide events into RS and WS	Ratio R for each time bin
Two d_0 bins: ≤ 60 μm, >60 μm	Prompt or from B-decay
60 bins Δm (D* - D⁰ - π)	D* or not D*
Kπ mass distribution	D⁰ or not D⁰



Fit for D* yield

- Same signal shape for all fits
- Background shape is time independent
- Independent parameters for signal and background amplitudes

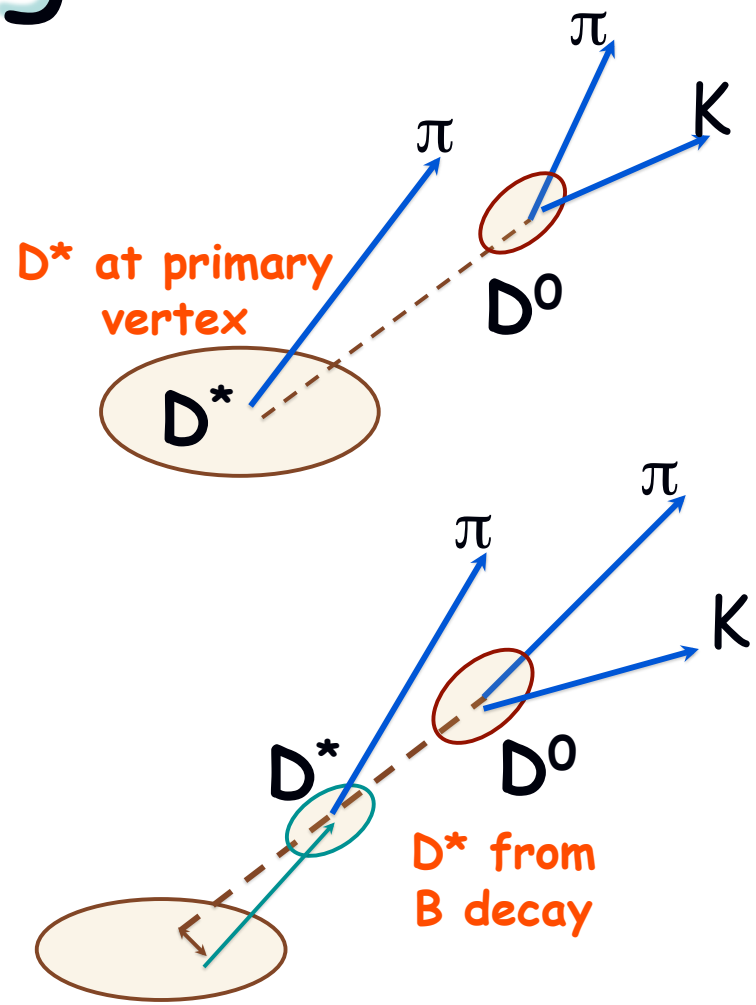
B-Decay Background

D* produced from B-decays has the wrong proper decay time

- decay length is measured from the primary vertex

Extrapolate the D^0 towards the primary vertex

- D* produced at a secondary vertex has a larger $d_0(D^0)$ value



D* impact parameter

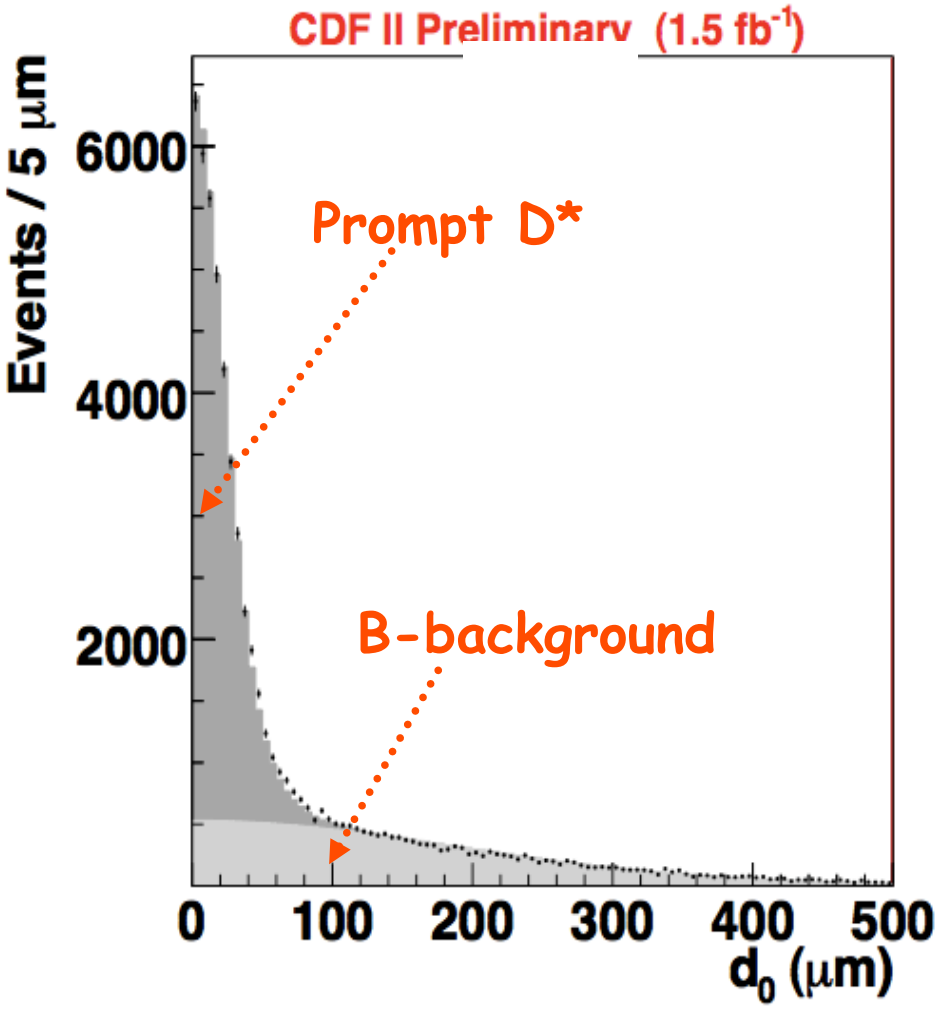
Prompt D*: narrow d0 distribution
(time independent)

D* from B: wide d0 distribution
(width increases with decay time)

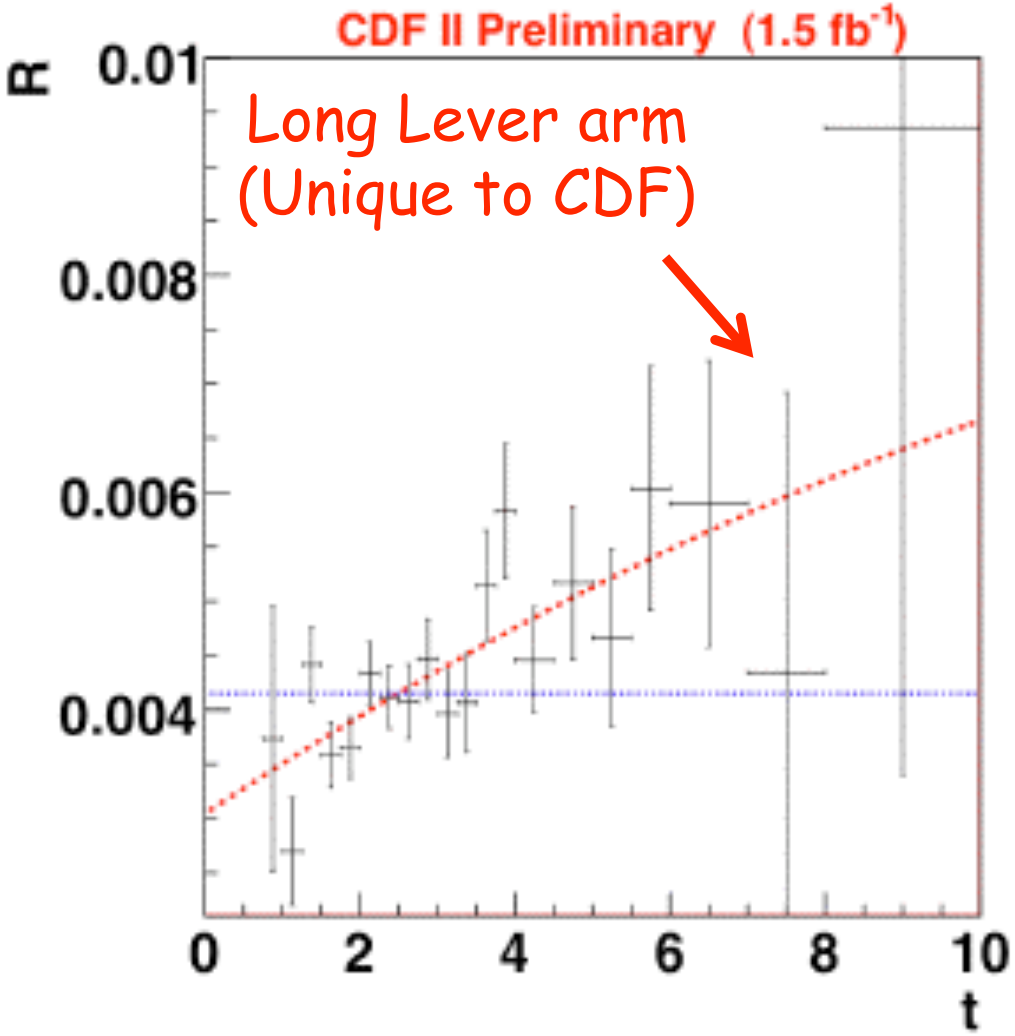
Fit distribution using RS signal
(RS width same as WS)

Get fraction of distribution
with d_0<60 μm and d_0 > 60 μm

Calculate number of prompt D*
in each time bin



WS/RS Fit results



Best Fit Parameters

$R_D = (3.04 \pm 0.55) \times 10^{-3}$

$y' = (8.54 \pm 7.55) \times 10^{-3}$

$x'^2 = (-0.12 \pm 0.35) \times 10^{-3}$

$chi^2 = 19.2$ for 17 dof

No mixing fit

$R_D = (4.15 \pm 0.10) \times 10^{-3}$

$x'^2 = y' = 0$

$chi^2 = 36.8$ for 19 dof

Note: Parameters heavily correlated

$$R(t/\tau) = R_D + \sqrt{R_D}\, y' \times (t/\tau) + 1/4 \times (x'^2 + y'^2) \times (t/\tau)^2$$

Uncertainties

Quoted uncertainties are statistical + systematic

Most parameters for the background shapes and amplitudes are determined by the fits of the data, associated syst. uncertainties already included in the uncertainty on the RS and WS signal yields.

We added additional systematic effects that were not part of the fit procedure (bck. shape in the Δm distribution)

Detector geometric acceptance, trigger efficiency, particle id, time resolution have negligible effect on the WS/RS ratio (compared to current uncertainties)

Probability Contours

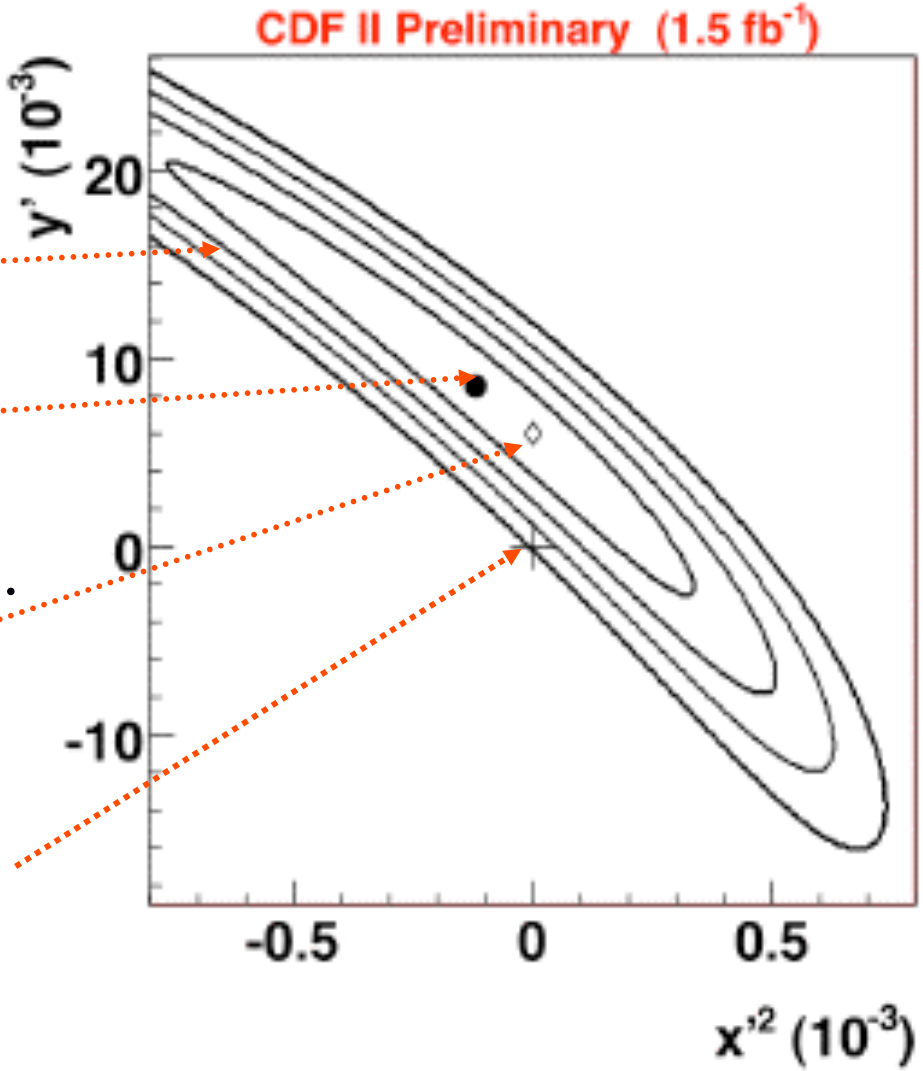
Bayesian probability intervals equivalent to 1-4σ

Solid point = best fit

Open diamond = highest prob.

Phys. allowed point ($x'^2>0$)

Cross = no-mixing ($y'=x'^2=0$)



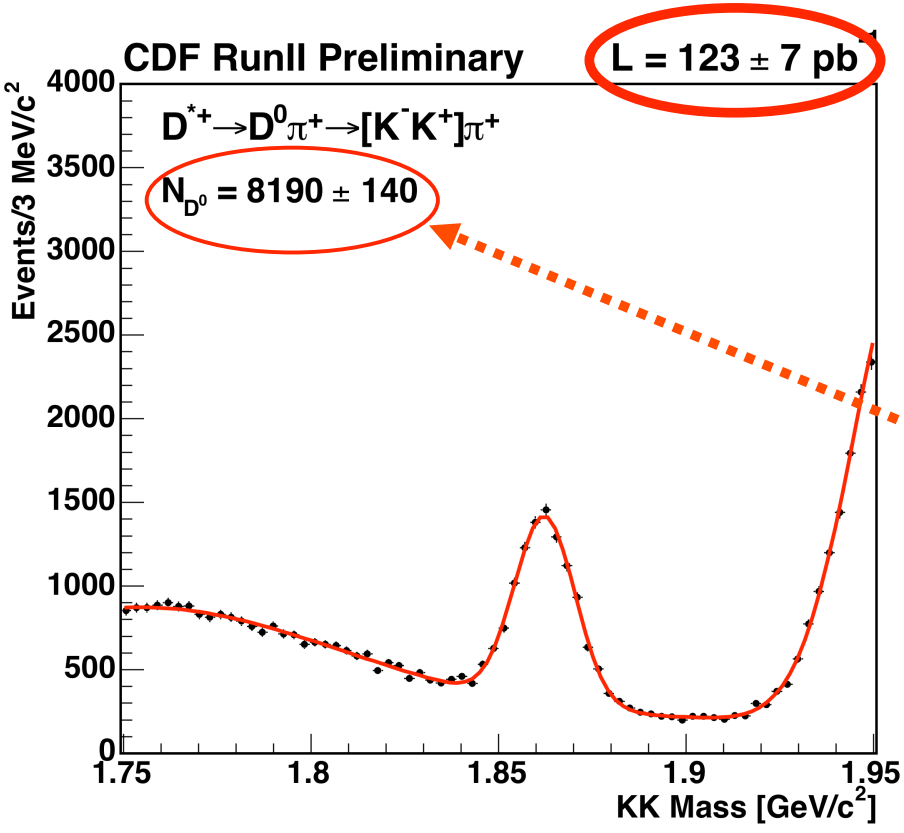
No-mixing excluded at 3.8 Gaussian standard deviations level

CDF results in context

	Data	N_{WS}	$x'^2 \times 10^{-3}$	$y' \times 10^{-3}$	Signif
Belle	400 fb^{-1}	4024	0.18±0.23	0.6±4.0	2.0
BaBar	384 fb^{-1}	4030	0.22±0.37	9.7±5.4	3.9
CDF	1.5 fb^{-1}	12700	-0.12±0.35	8.5±7.6	3.8

CDF has already ~2x data for analysis,
will be ~4x in 2009
Meas. improves with $1/\sqrt{N}$

Prospects for CP violation



$A_{CP}(D^0 \to KK) = (2.0 \pm 1.2 \pm 0.6) \times 10^{-2}$

$A_{CP}(D^0 \to \pi\pi) = (1.0 \pm 1.3 \pm 0.6) \times 10^{-2}$

Expect x40 data by 2009

➔ $\pm 0.2 \times 10^{-2}$ stat. error

(PRL 94, 122001, 2005)

	Data	N(KK)	A_{CP} (x10^{-2})
Belle	540 fb-1	120 K	-0.43±0.30±0.11
BaBar	386 fb-1	130 K	0.00±0.34±0.13

Conclusions

CDF confirmed the evidence for charm mixing seen by BaBar with time dep. $D^0 \to K^+\pi^-$, $K^-\pi^+$ analysis

- No-mixing excluded @3.8σ , PRL 100, 121802 (2008)

CDF future prospects

- Improve the existing analysis (>2x data already available)
- Perform also lifetime/CP analysis in $D^0 \to KK/\pi\pi$ (we expect a very precise CP measurement)