

# Mixing in Heavy Mesons

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UCSB PhD

→  $D^0 - \bar{D}^0$

hep-ex/0001060  
PRL 84, 5038 (2000)

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Cornell PhD

→  $B^0 - \bar{B}^0$

hep-ex/0005013

Osaka

July, 2000

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UCSB/CLEO

# Mass

NEW PHYSICS?

CP conserv.



$t$  in units of  $\tau_D$

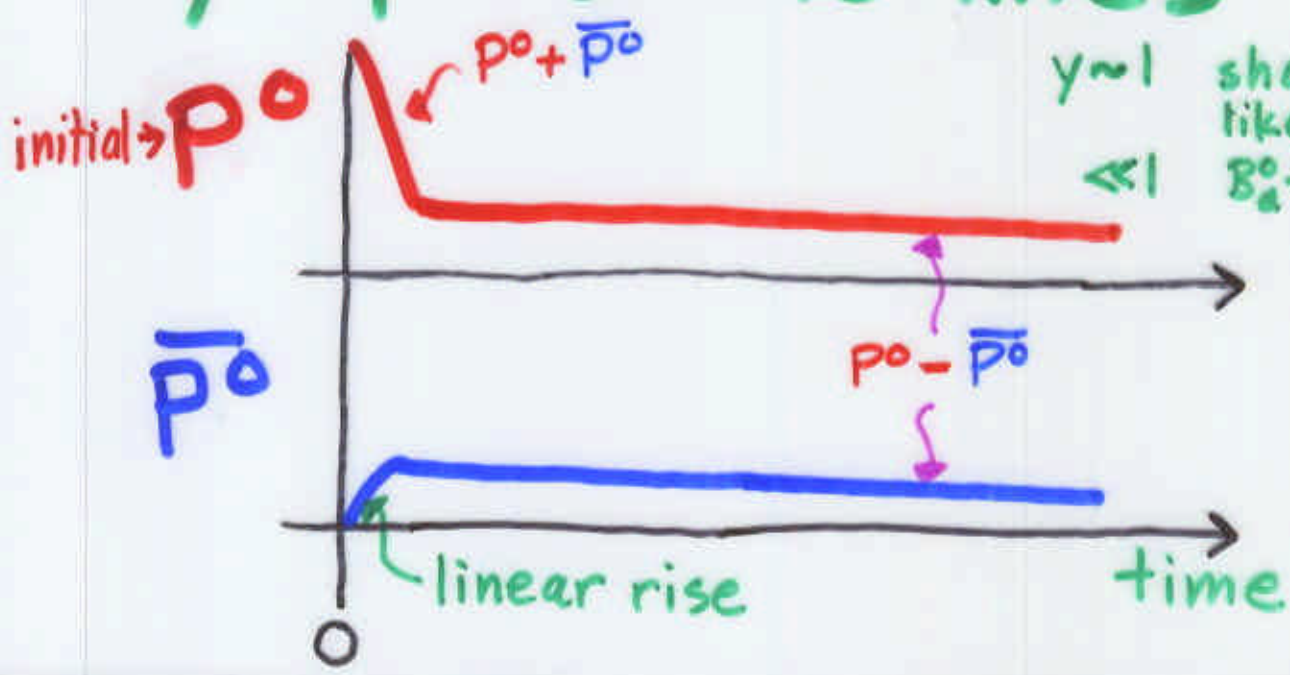
$$\frac{\partial}{\partial t} \begin{Bmatrix} e^+ [D^0] \\ [D^0] \end{Bmatrix} = -\frac{i}{2} \begin{bmatrix} 0 & ix+y \\ ix+y & 0 \end{bmatrix} \begin{Bmatrix} D^0 \\ \bar{D}^0 \end{Bmatrix}$$

must study time evolution to distinguish NEW PHYSICS  
 $X$  from  $Y$

# Types of Mixing

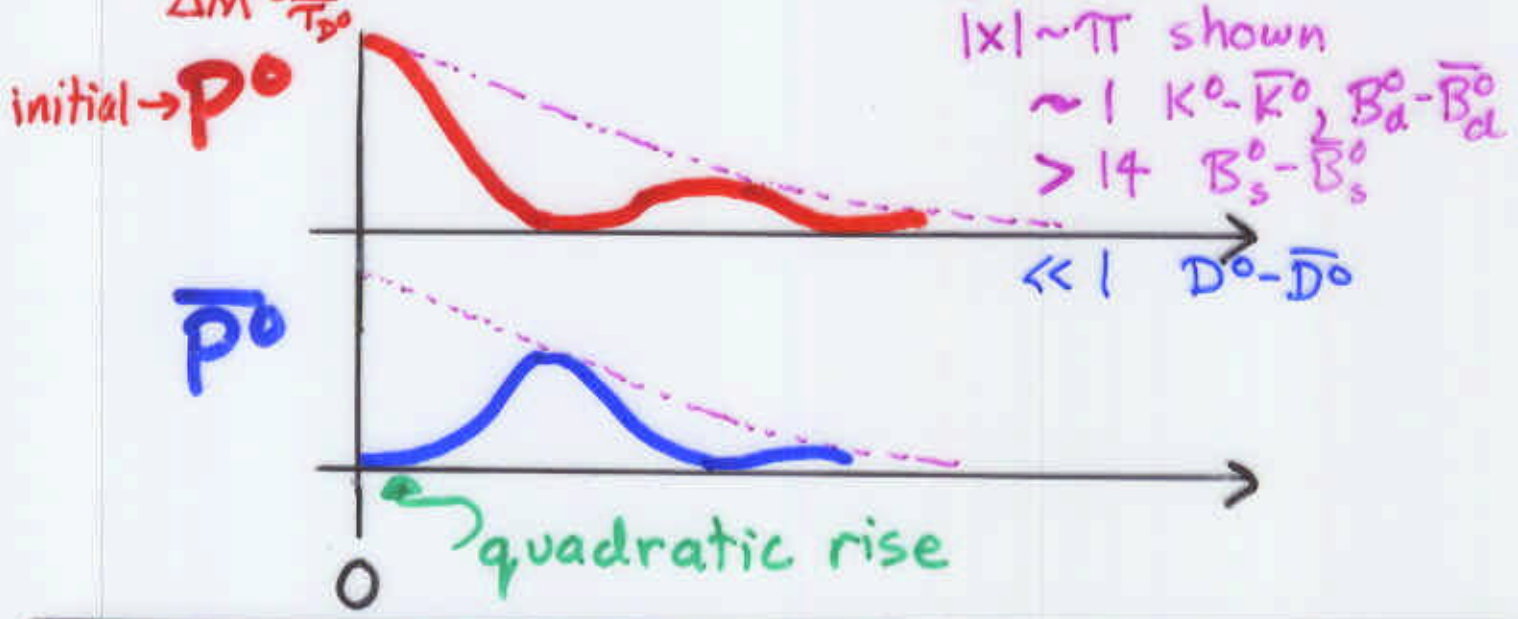
•  $y$  splits lifetimes

$$\Delta\Gamma \sim \frac{2y}{\tau_{D^0}}$$



•  $x$  splits masses, causes oscillations

$$\Delta M \sim \frac{x}{\tau_{D^0}}$$



1998 PDG:



$|y| \lesssim 0.12$   
 $|x| \lesssim 0.12$

95%  
C.L.



# D<sup>0</sup> Mixing Benchmarks

$$\frac{|y|}{|x|} = \overset{\sim 0.05}{\tan^2 \theta_c} \times \overset{10^{-6} \Rightarrow 1}{\text{GIM Suppression Factor}}$$

in Standard Model

Non-Standard:

$$|x| \sim 0.01$$

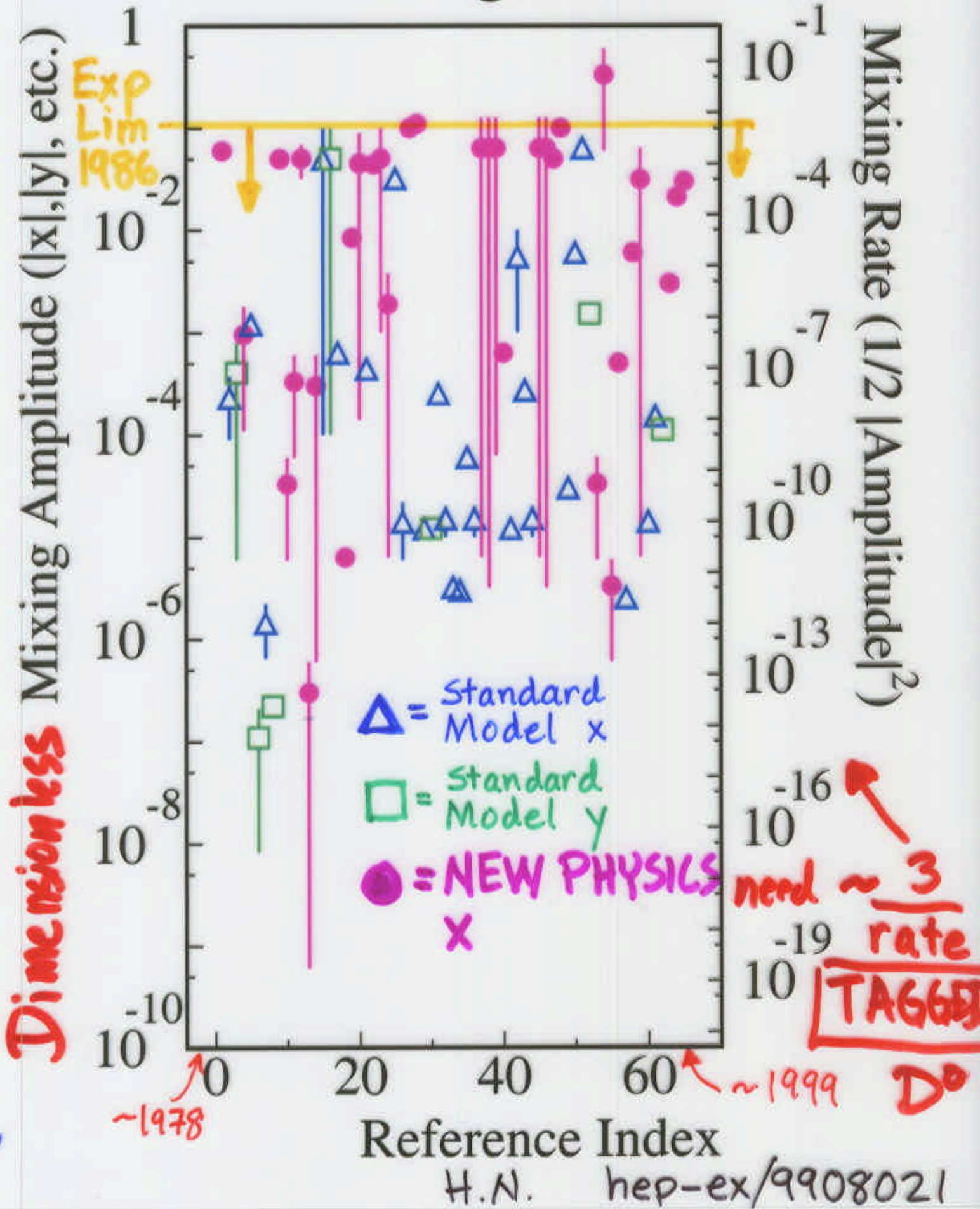
more sensitive than  
K<sup>0</sup>- $\bar{K}^0$  to new physics

Proofs of New Physics

$$|x| \gg |y|$$

CP Violation:  $\frac{\text{Im}(x)}{|x|}$  large

# D<sup>0</sup>- $\bar{D}^0$ Mixing Predictions

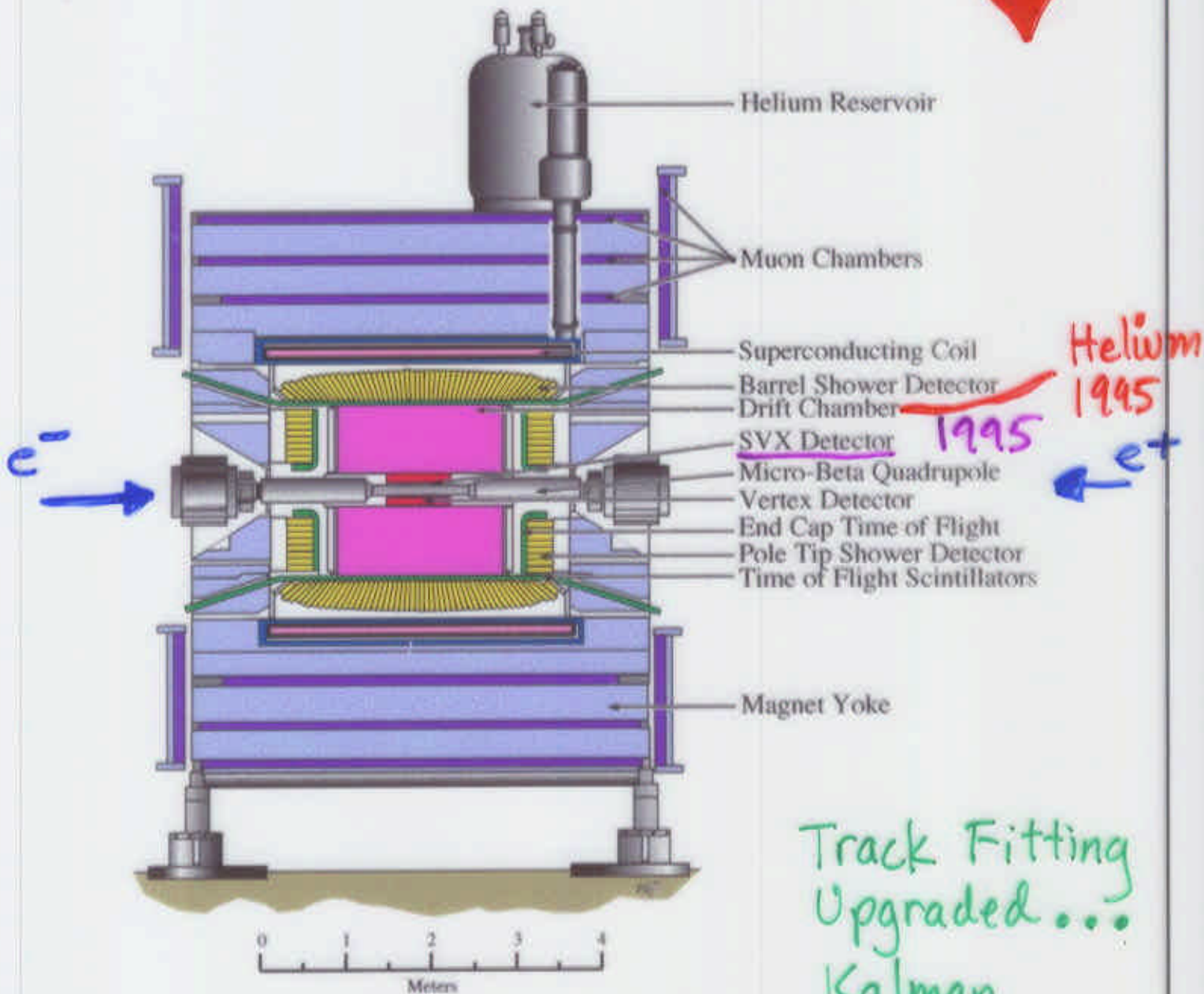




# CLEO-II detector

$\sqrt{s}$   
 $\approx 10 \text{ GeV}$   
CESR

0V



Helium  
1995

Track Fitting  
Upgraded...  
Kalman

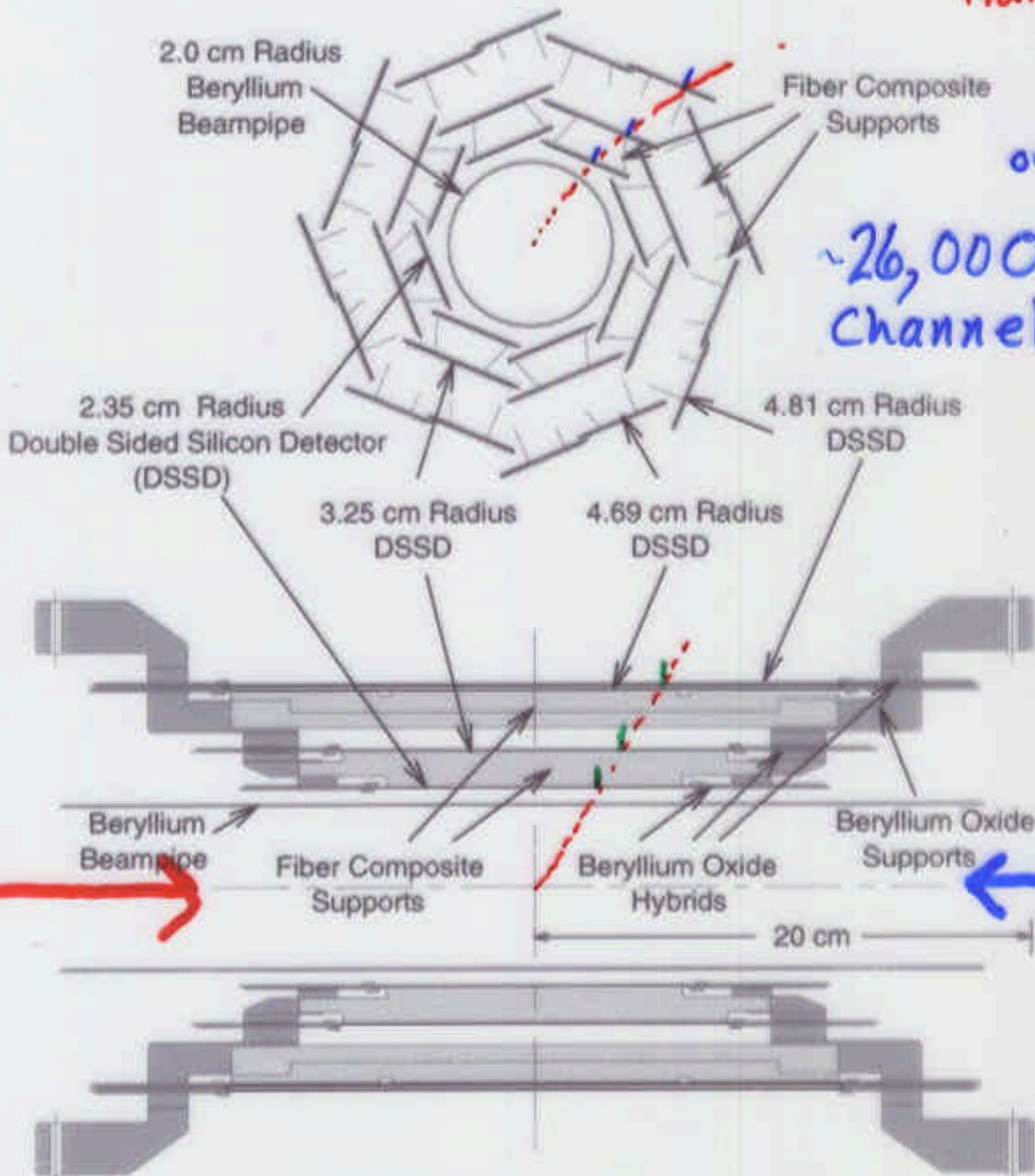
(Avery), Kutschke, Ryd, Briere

$\int \mathcal{L} dt = 9.0 \text{ fb}$  Feb 1996  
Feb 1999

# CLEO-II Silicon Vertex Detector

*installed 1995*

*(Double Sided Silicon Hamamatsu)*



*r-φ or x-y*

*~26,000 Channels*

*r-z*

*t<sub>g</sub>* →

← *e<sub>i</sub>*

$\begin{bmatrix} u \\ c \\ s \\ b \end{bmatrix}$  High Energy Physics

*+ Cornell, Harvard, Caltech, Purdue, Oklahoma, Illinois, SLAC, UCSD*

$D^{*+}$

$\Gamma \lesssim 100 \text{ keV}$   
 $Q \sim 6 \text{ MeV}$

$D^0 \pi_s^+$

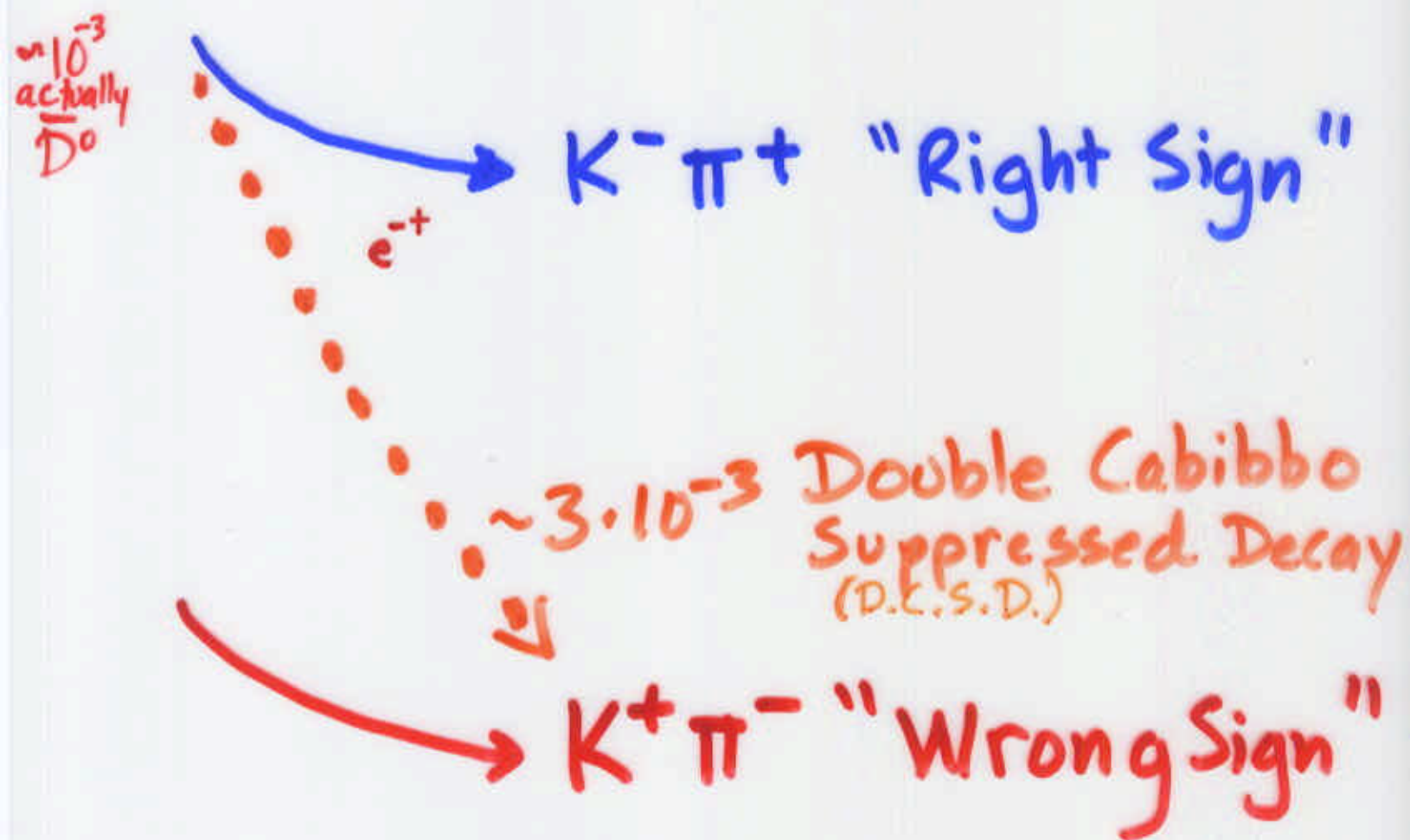
TAG

slow, multiple scattering  
SVXR-z a big help!

$\frac{1}{2}(ix+y)^+$

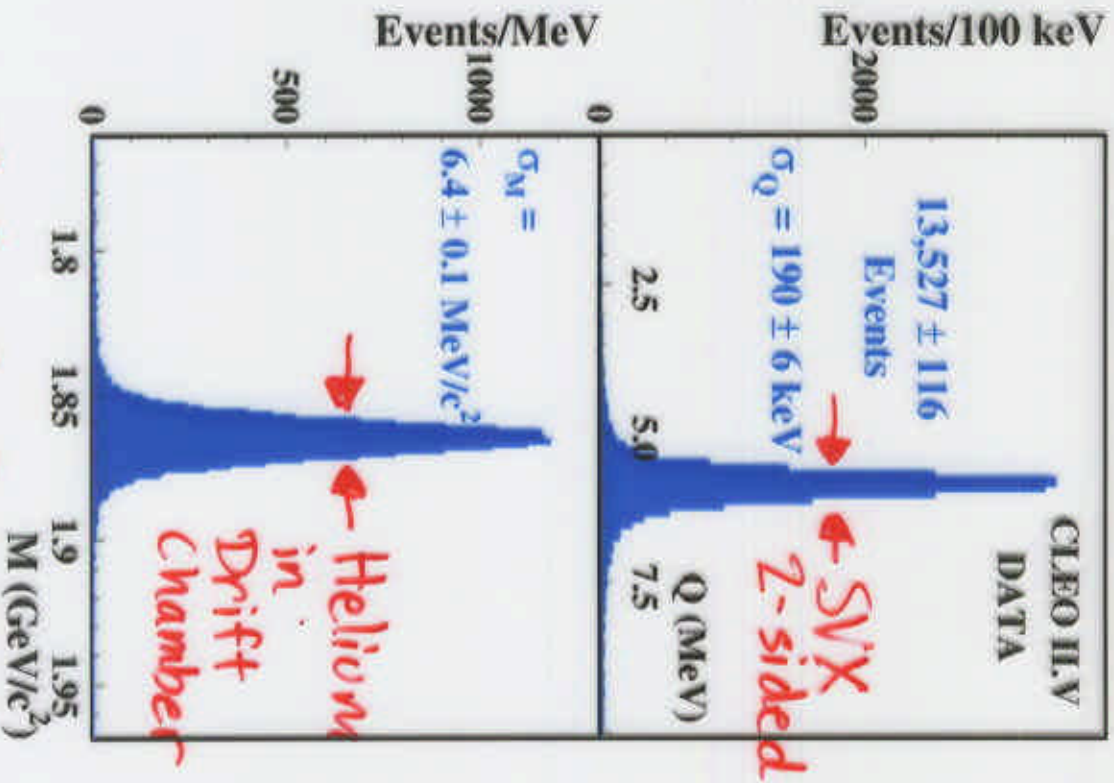
$\overline{D^0}$



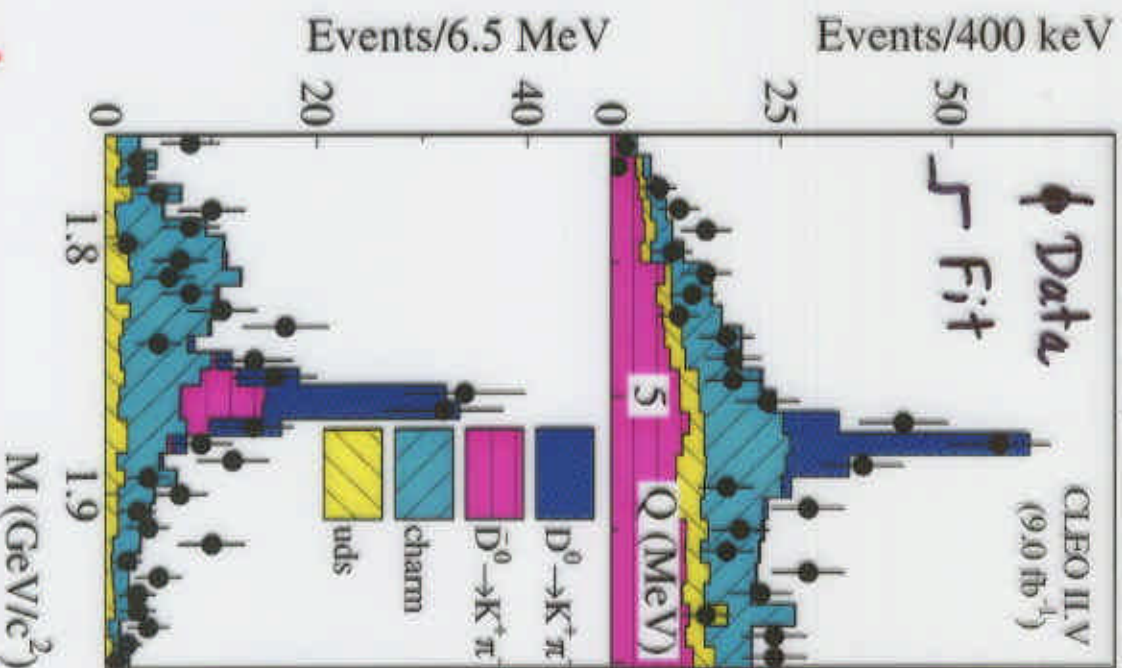


TIME EVOLUTION SORTS  
OUT 3 ROUTES: X, Y, DCSD

# Right Sign



# Wrong Sign

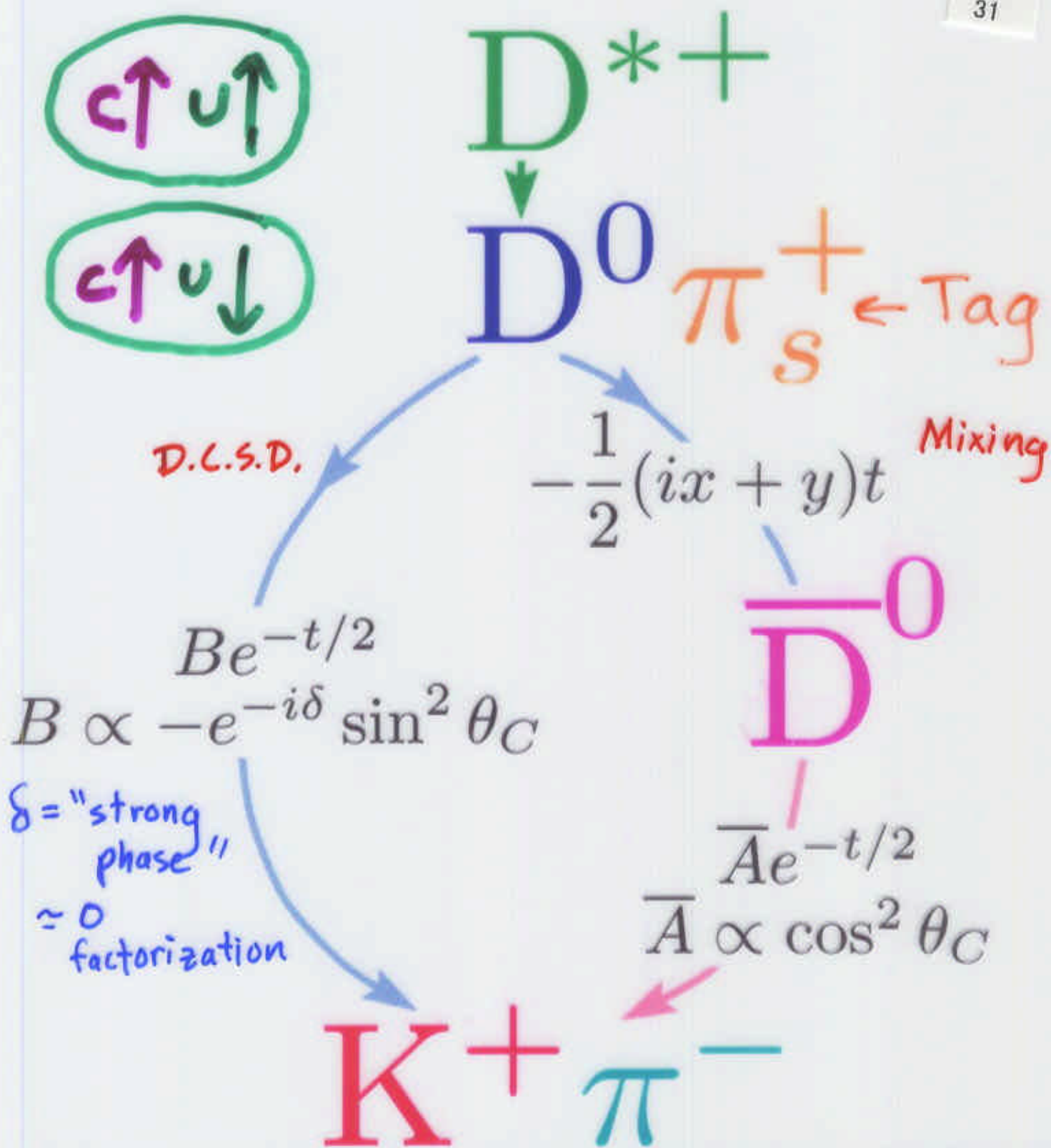


Wrong Sign Mistag determined in Q sidebands

Not at fundamental limiting (detector) resolutions  
 ~1/2 smaller in both

$$R = \frac{W_S}{R_S} = (0.332^{+0.063}_{-0.065} \pm 0.04)^2$$

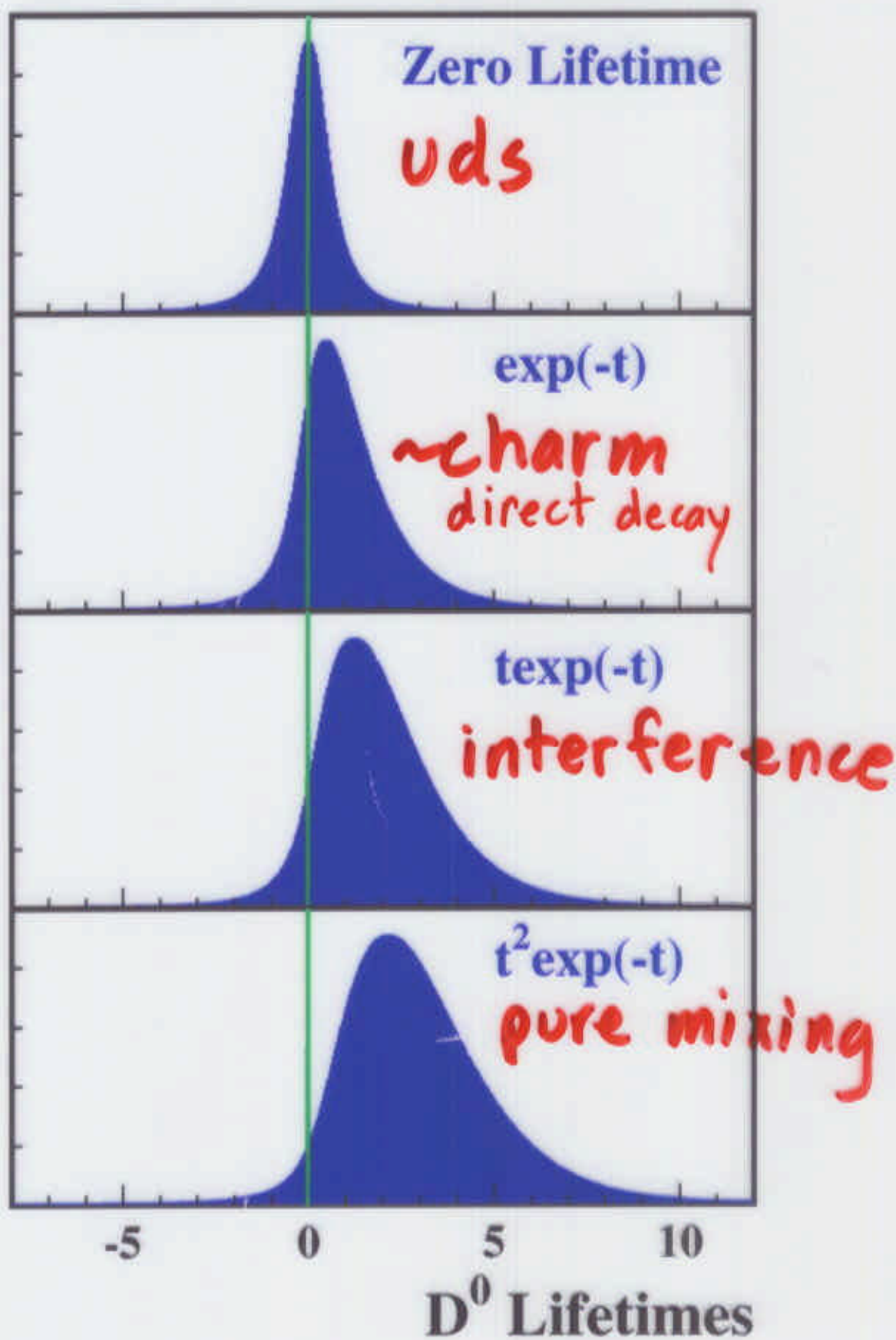
%



$$\begin{aligned}
 \tau_{\text{ws}}(t) &= \left| \left[ \frac{B}{\bar{A}} - \frac{1}{2}(ix + y)t \right] e^{-t/2} \right|^2 \\
 &= [R_D + \sqrt{R_D}(y \cos \delta - x \sin \delta)t + \frac{1}{4}(x^2 + y^2)t^2] e^{-t} \\
 &= [R_D + \sqrt{R_D} \quad y' \quad t + \frac{1}{4}(x'^2 + y'^2)t^2] e^{-t} \\
 &\quad \text{Direct} \quad \text{Interference} \quad \text{Mix} \quad x' \equiv x \cos \delta + y \sin \delta
 \end{aligned}$$

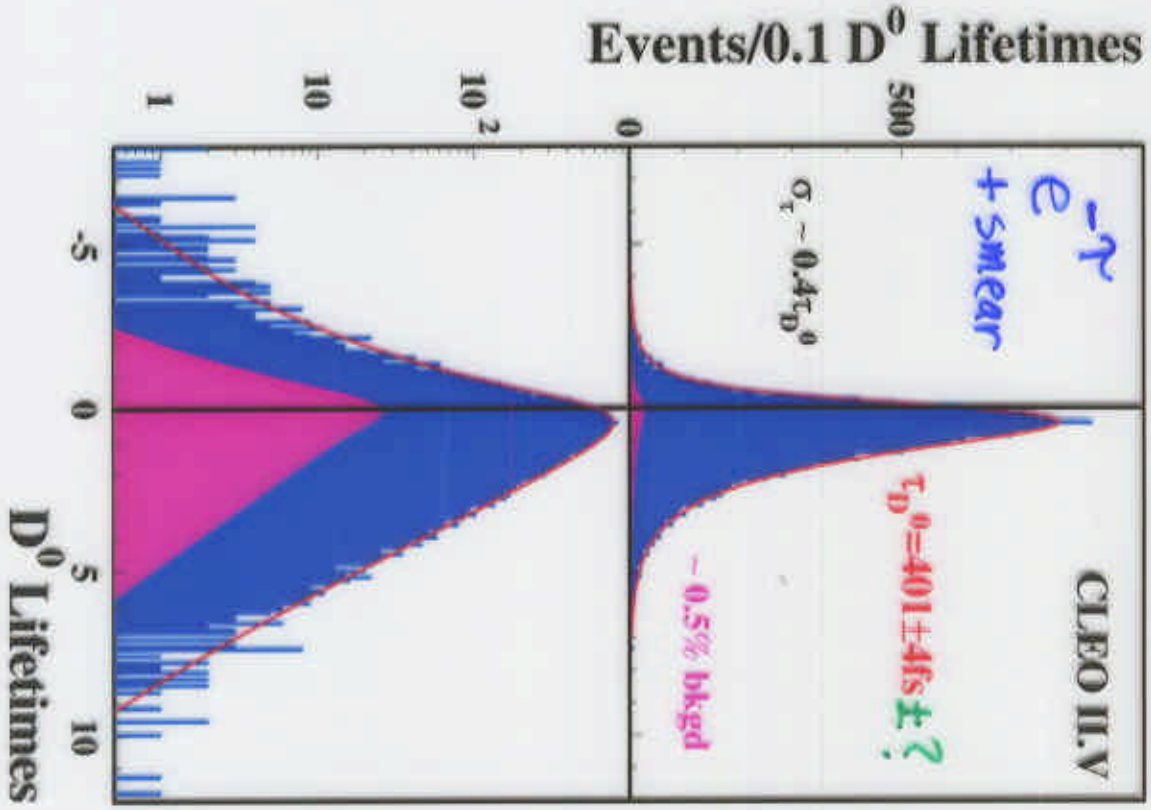


# Effect of Resolution



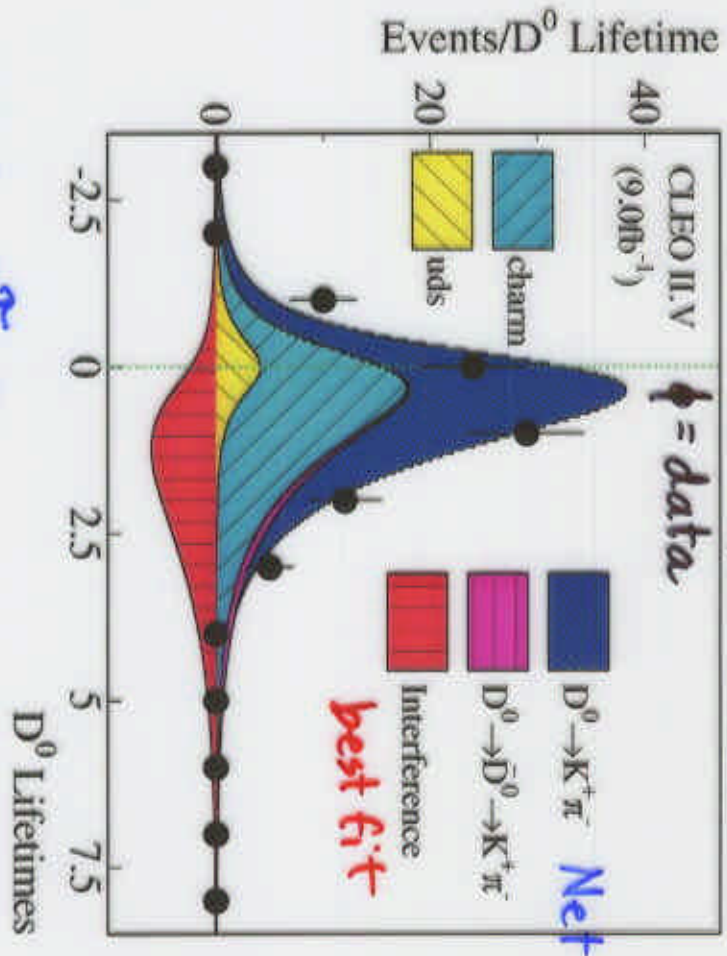
# TIME EVOLUTION:

*Right Sign*  
 $D^{*+} \rightarrow D^0 \pi^+, D^0 \rightarrow K^+ \pi^+$



## WRONG SIGN

$D^{*+} \rightarrow D^0 \pi^+, D^0 \rightarrow K^+ \pi^-$



$$WS(\tau) = e^{-\tau} (R_{DCSD})$$

$$+ \sqrt{R_{DCSD}} y' i \tau$$

$$+ \frac{1}{4} (x'^2 + y'^2) \tau^2$$

$$y' = y \cos \delta - x \sin \delta$$

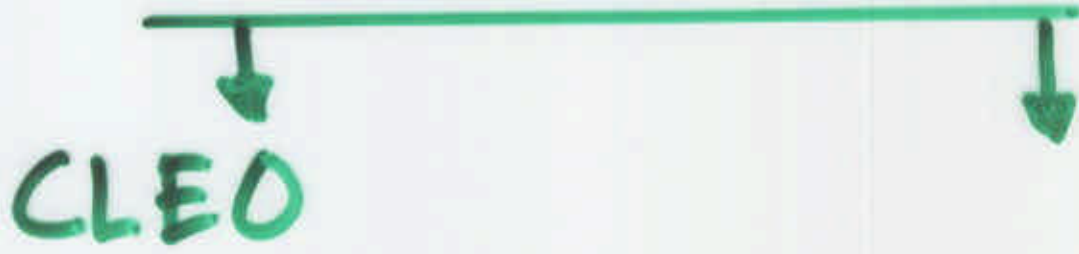
$$x' = x \cos \delta + y \sin \delta$$

$\delta = \alpha$  strong phase

Pure off-shell  
mixing







"OLD PHYSICS"

3 Types of ~~CP~~ allowed

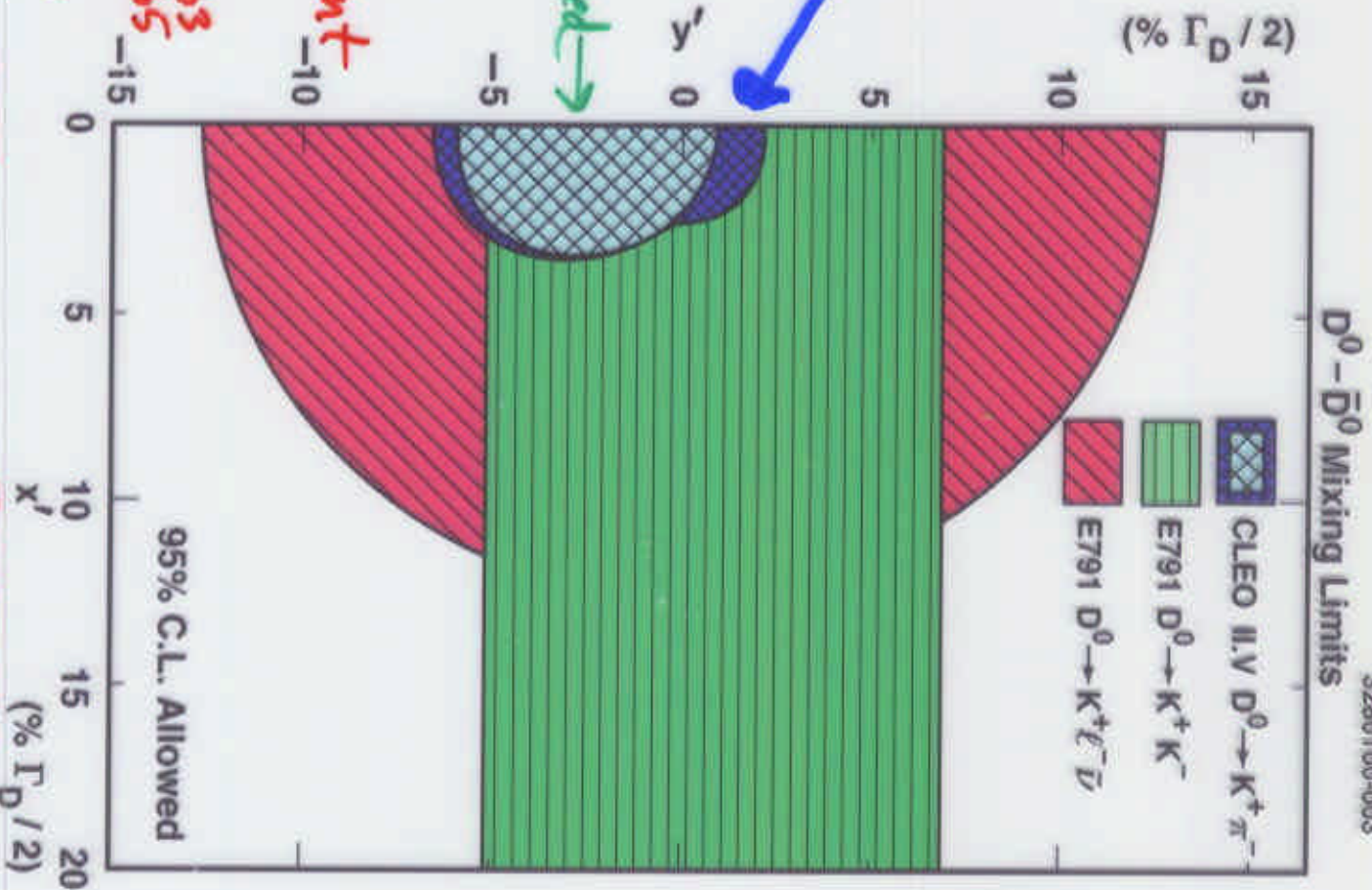
CP constrained →

all wrong sign events consistent with DCSD

$$R_D = \frac{K^+\pi^-}{K^-\pi^+} = 10.332_{-0.065}^{+0.063}$$

± 0.04%

-0.36 < A<sub>D</sub> < 0.30 95%



~ "NEW PHYSICS"

ALLOWED CP

95% CL

-5.8% < y' < 1.0%

|x'| < 2.9%

↑

9 i/f b

K π π<sup>0</sup>

K 3 π 500 M

5

# The Future of $D^0$ - $\bar{D}^0$ Mixing

- This technique - DCSD background at B-factories:

$$x' \lesssim \frac{0.7\%}{\left\{ \int \mathcal{L} dt / 10000 \frac{1}{f_b} \right\}^{1/4}}$$

- $\nu$ -factory: similar

- $D^0 \rightarrow K^+ l^- \bar{\nu}$  evades DCSD

Not knowing  $E_{D^0}$  severely limits technique, at  $\Upsilon(4s)$ ,  $p\bar{p}$ , etc.

- $e^+e^- \rightarrow \psi'' \rightarrow D^0 \bar{D}^0$



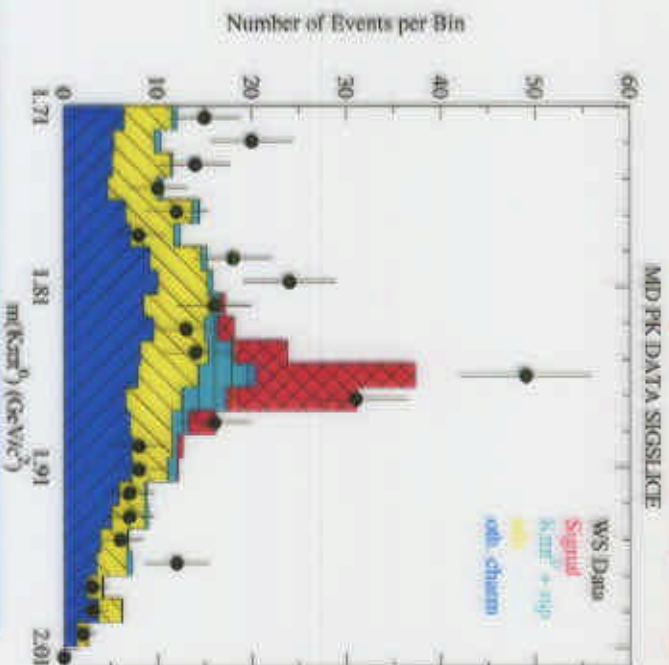
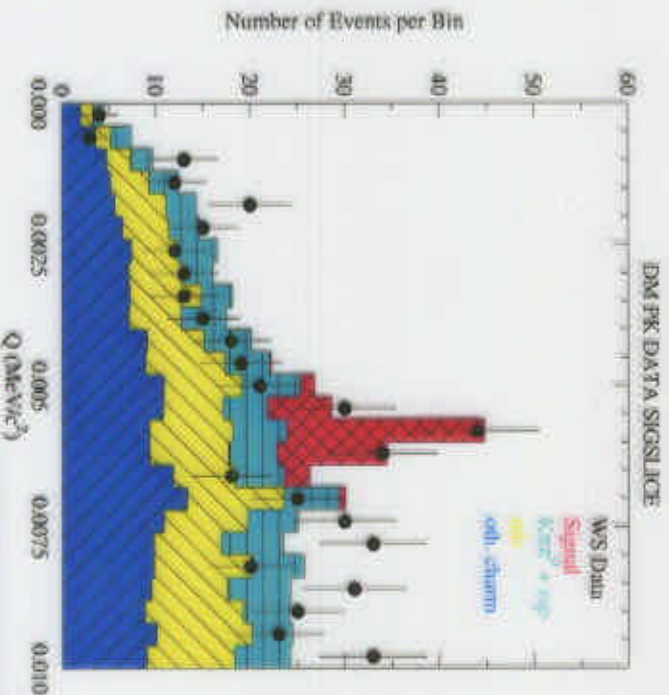
$$[x^2 + y^2]^{1/2} \lesssim \frac{0.1\%}{\left\{ \int \mathcal{L} dt / 10000 \frac{1}{f_b} \right\}^{1/2}}$$

- distinguishing x from y nettlesome



# $D^0 \rightarrow K^+ \pi^- \pi^0$ Channel

Alex Smith  
Minnesota



**Preliminary**

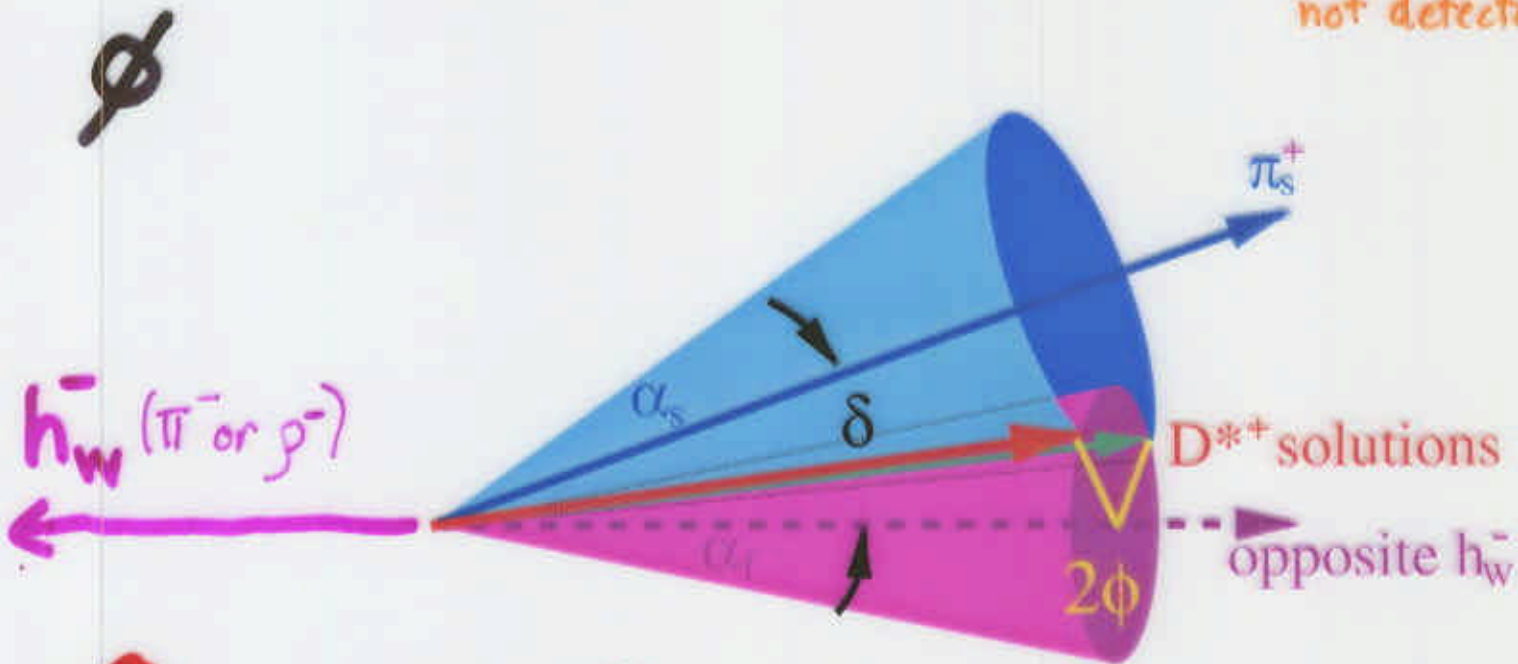
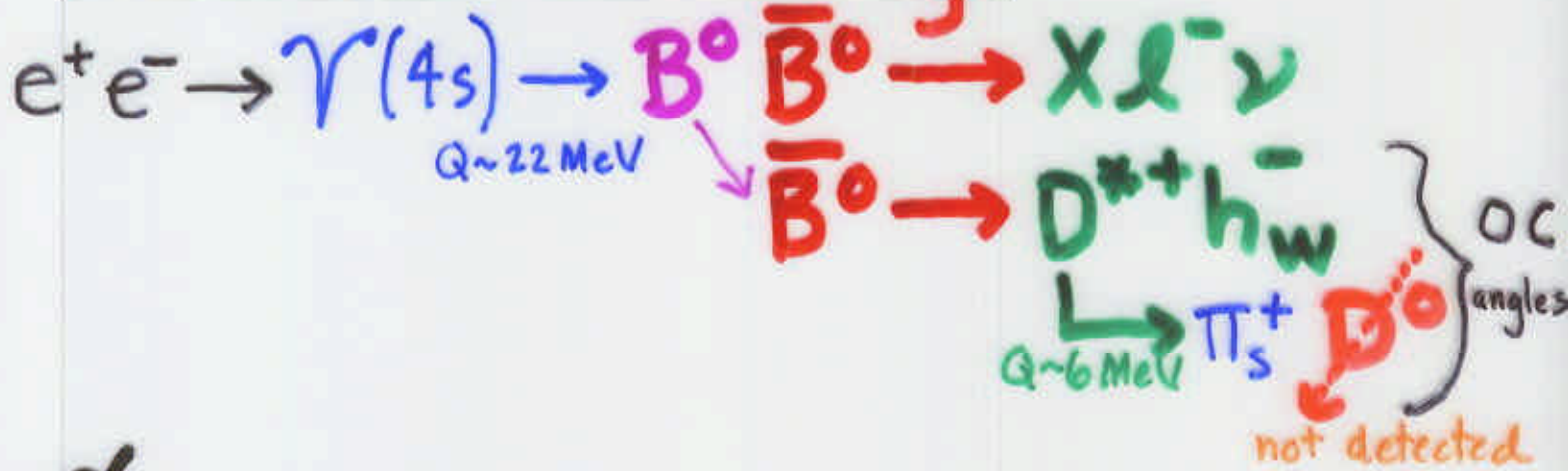
$$N_{WS} = 39^{+10}_{-9} \text{ (from fit)} \pm 7 \text{ (sys)}$$

$$N_{RS} = 9045$$

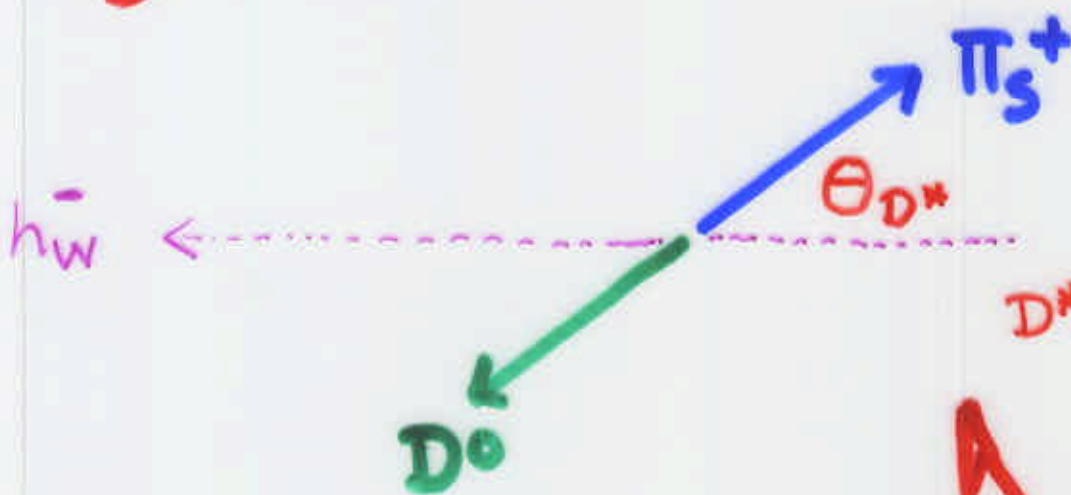
4.9 $\sigma$  significance of signal

**First observation of this decay!**

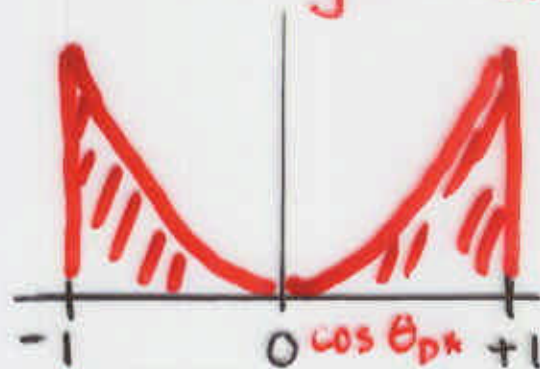
# $B^0 - \bar{B}^0$ Mixing



$\Theta_{D^*}$  in  $D^*$  rest frame



$D^* \sim$  longitudinal

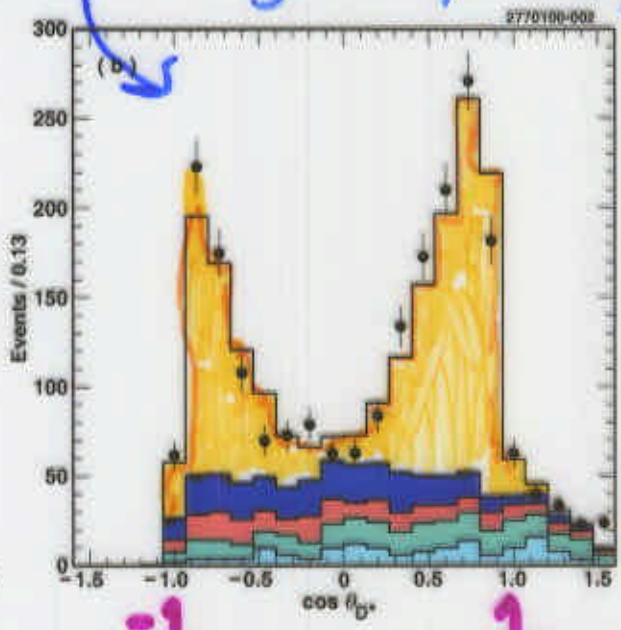
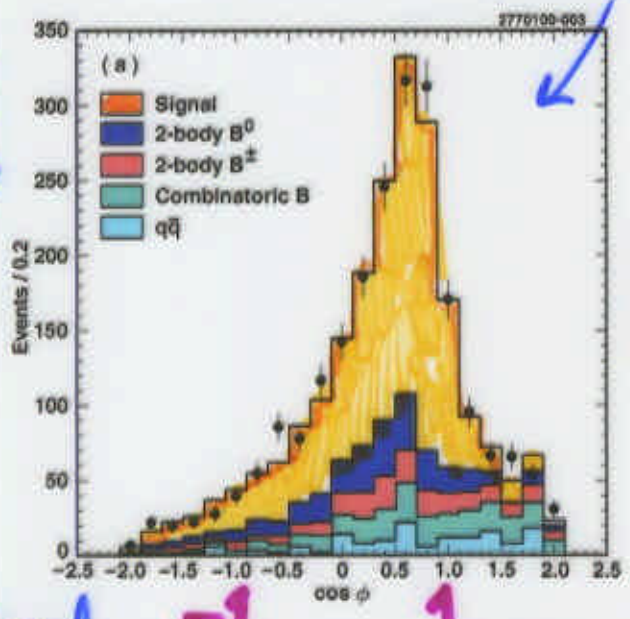




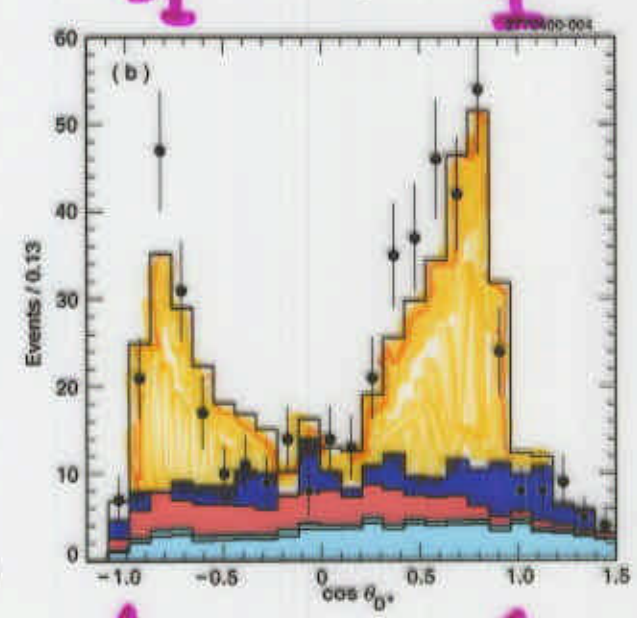
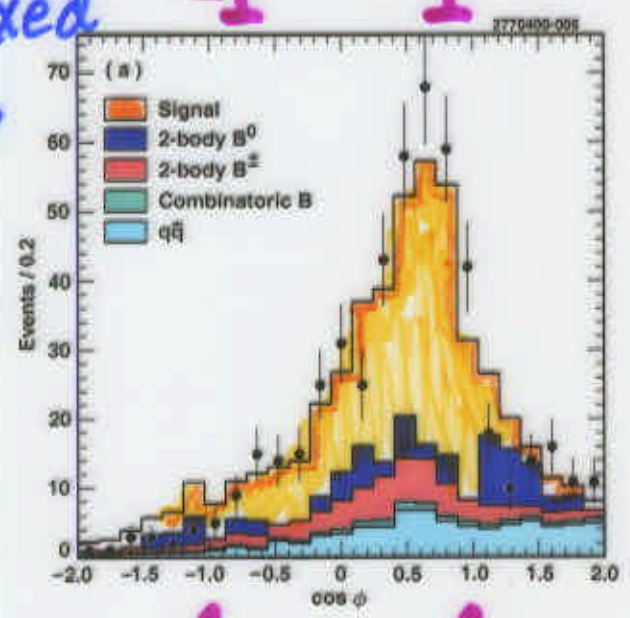
# Data:

$1241 \pm 52$  Signal /  $9.1 \frac{1}{fb}$

All  $\Rightarrow$



Mixed  $\Rightarrow$



$-1$   $1$   
 $\cos \phi$

$-1$   $1$   
 $\cos \theta_{D^*}$

Mixed:  $321 \pm 25$  ( $\approx 30\%$  mistag)

$$\chi_d = \frac{x_d^2 + y_d^2}{2(1 + x_d^2)} = 0.198 \pm 0.013 \pm 0.014$$

$Re(\epsilon_B) = (0.43 \pm 1.75 \pm 0.35) \cdot 10^{-2}$ ,  $< 3.4 \cdot 10^{-2}$  95% CL



$$\chi_d = 0.198 \pm 0.013 \pm 0.014$$

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↳

0.009	mistag
0.007	B $\pm$
0.006	other 2-body
0.004	mix/unmix $\epsilon$
0.003	l mistag
0.003	mix/unmix mistag
0.002	sig shape
0.002	comb shape

$$\begin{aligned}\chi &= \frac{1}{2} \frac{x^2 + y^2}{1 + x^2} \\ &= \frac{1}{2} \frac{(\Delta M \tau_{B^0})^2 + (\Delta \Gamma \tau_{B^0})^2}{1 + (\Delta M \tau_{B^0})^2}\end{aligned}$$

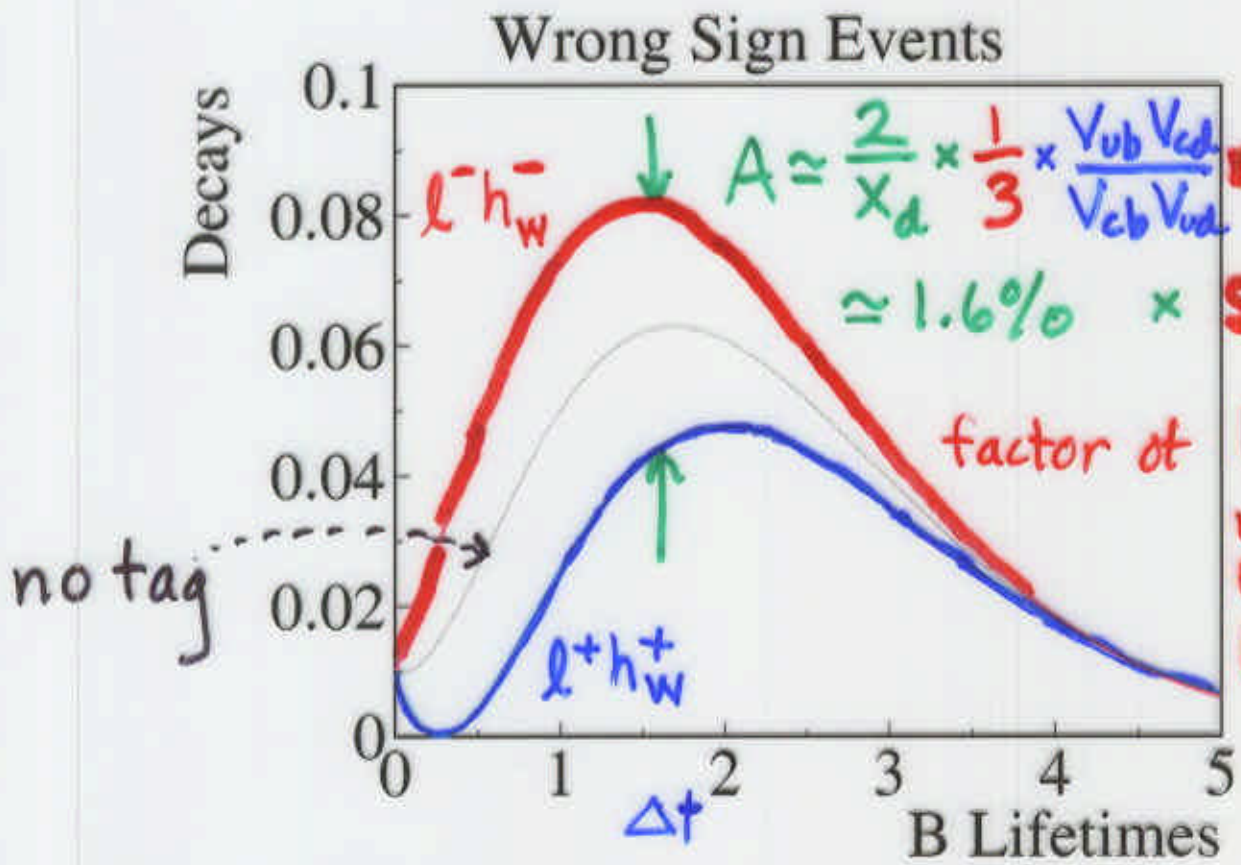
⇒ assume PDG  $\Delta M$  "uncorrelated" with  $\Delta \Gamma$   
 $y < 0.41$  95% C.L.

⇒ assume  $y = \frac{1}{2} \Delta \Gamma \tau_{B^0} = 0$

$$\Delta M = 0.522 \pm 0.029 \pm 0.031 \text{ 1/ps}$$

$\tau_{B^0}$  assumed  
1.55 ps

# Measuring $\sin(2\beta+\gamma)$ with time dependence<sup>den</sup> (not at CESR!)



$\times \sin(2\beta+\gamma)$   
 $\times \sin(2\beta+\gamma)$   
 factor of  $1/3$ : omitted in BaBar Physics Book (form factor)

Bootstrap from CLEO:

$$3\sigma: \frac{1}{(1.6\% \times \frac{1}{3})^2} \approx 35,000 \text{ events}$$

$$\frac{35,000}{321} \times 9.1 \approx 1000 \text{ } \frac{1}{fb}$$

Belle/Babar should do in  $\approx 200 \text{ } \frac{1}{fb}$