Search for D^0-$\bar{D}^0$ Mixing and CP Violation at CLEO

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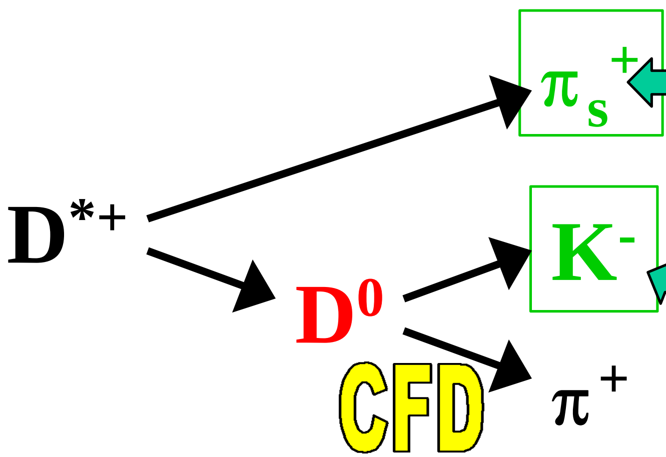
- Overview: D^0 mixing searches at CLEO:
- Hadronic channels: $D^0 \to K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+\pi^-$
  - **First observation of wrong-sign $D^0 \to K^+\pi^-\pi^0$!**
- CP even eigenstates: $D^0 \to K^+K^-$, $\pi^+\pi^-$
- CP odd eigenstates: $D^0 \to K_s^0\rho^0$, $K_s^0\omega$, $K_s^0\phi$
- Semileptonic channels: $D^0 \to K^+ l^- \nu$, $K^{*+} l^- \nu$
- Projections and Summary

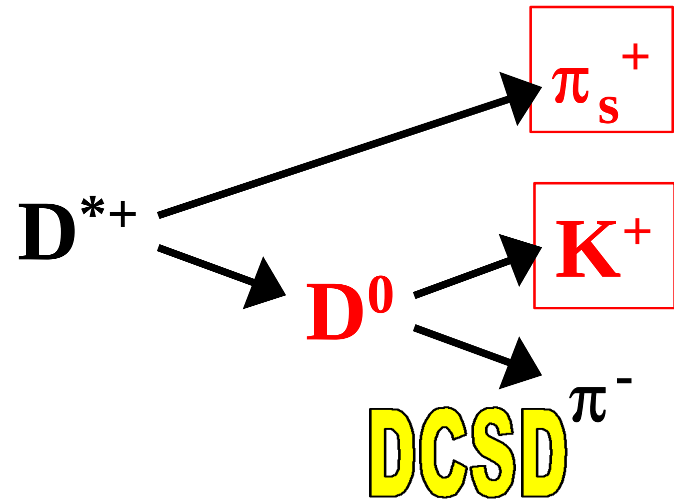
Right- and Wrong-Signed D^0 Decays

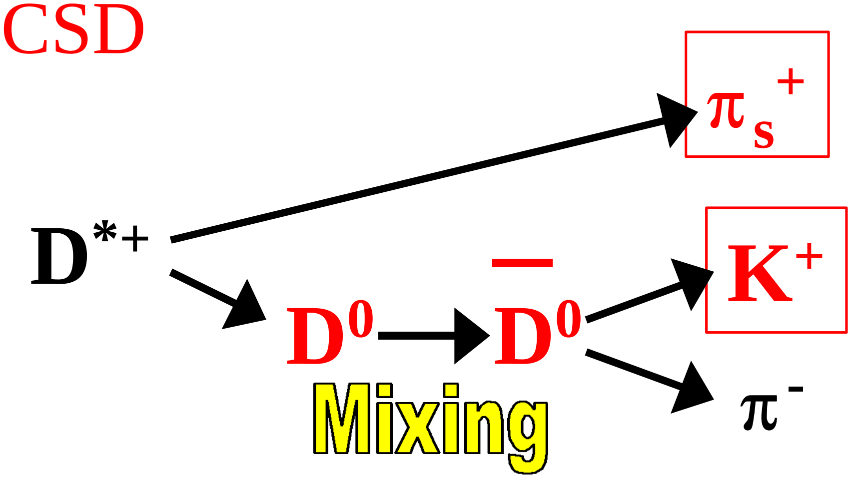
Use tagged D^0's from D^{*+} decays:



Sign of slow π tags initial D^0 flavor

Sign of K tags final D^0 flavor, unless DCSD





Note: C conjugate versions are implied throughout this talk, but not shown for clarity

Searches for D^0-$\overline{D}^0$ Mixing

Definitions:

$$R \equiv \frac{\Gamma\left(D^0 \to K^+\pi^-\right)}{\Gamma\left(\overline{D}^0 \to K^+\pi^-\right)}$$

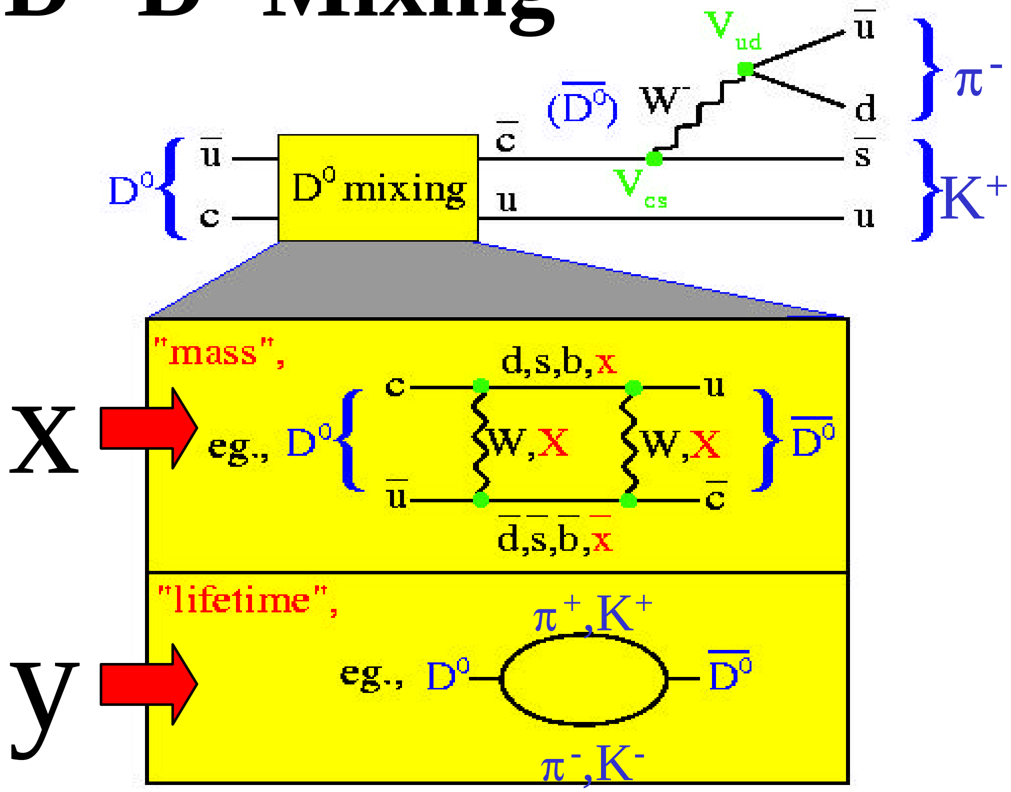
$$R = R_M + R_D + \sqrt{R_D}\, y'$$

$$R_M = \tfrac{1}{2}\left(x^2 + y^2\right) = \tfrac{1}{2}\left(x'^2 + y'^2\right)$$

Strong phase, δ, between DCSD and CFD:

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

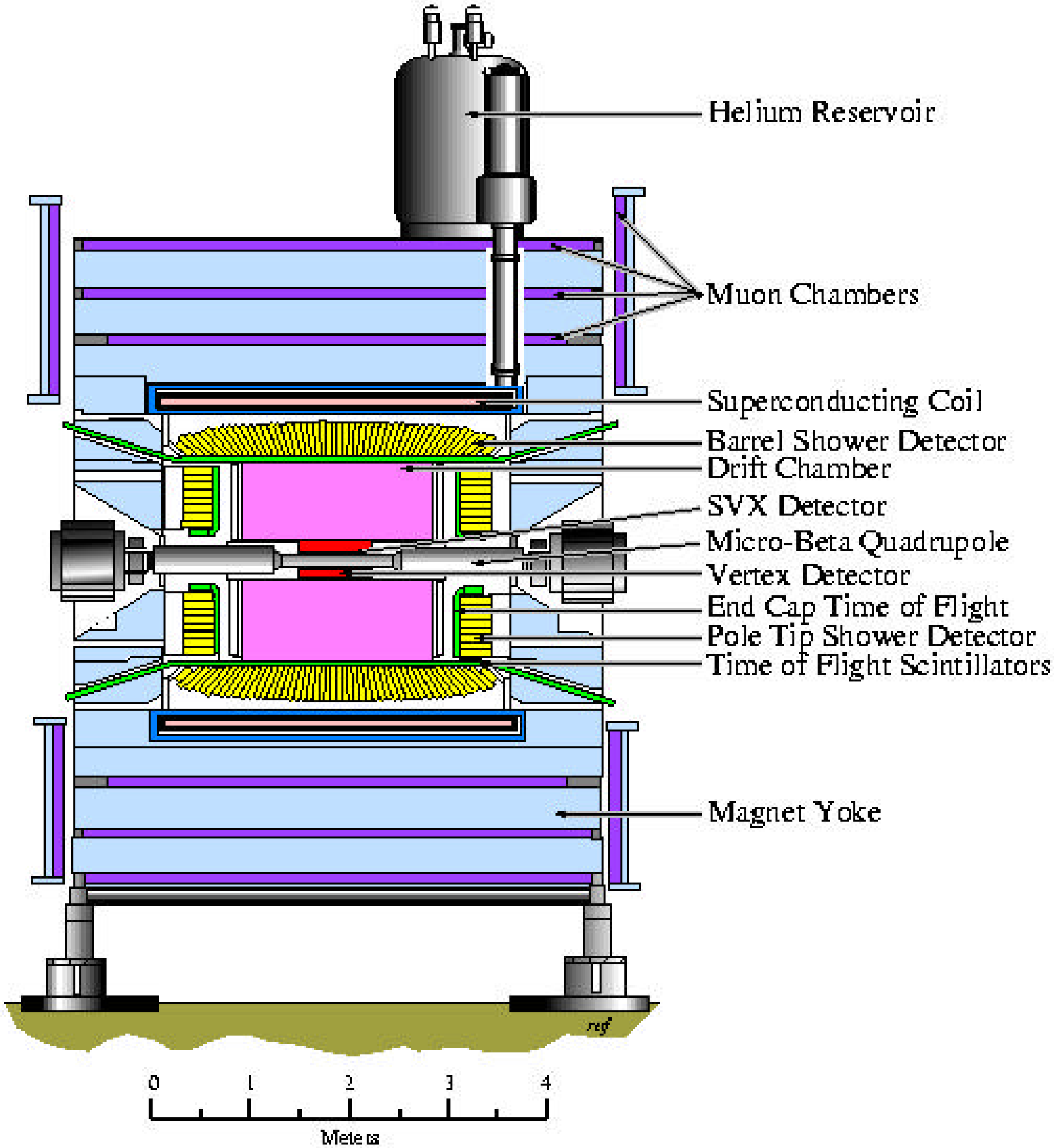
$$x' = x\cos\delta + y\sin\delta$$

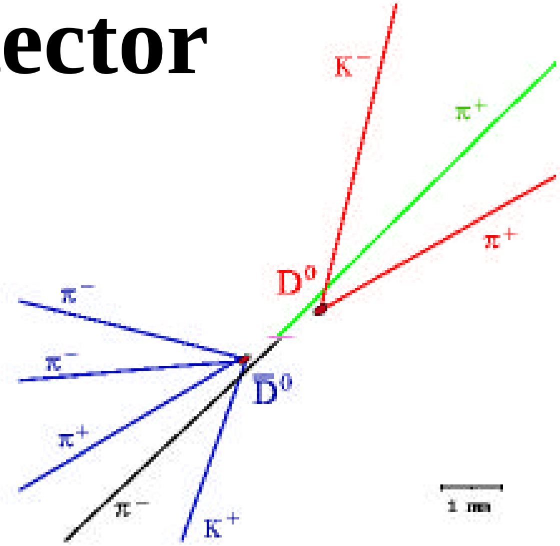


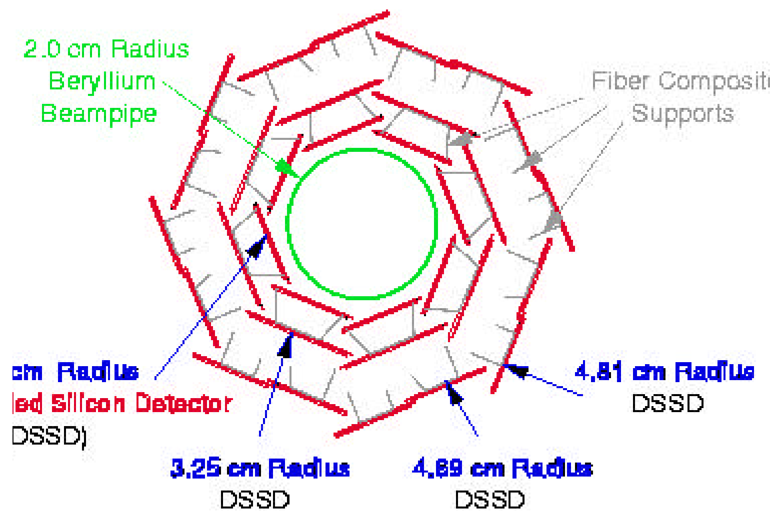
Time dependence of R:

$$\left(R_D + \sqrt{R_D}\, y't + \frac{1}{4}\left[x'^2 + y'^2\right]t^2\right)e^{-t}$$

The CLEO II.V Detector







D^0->$K^+\pi^-$ Decay Channel

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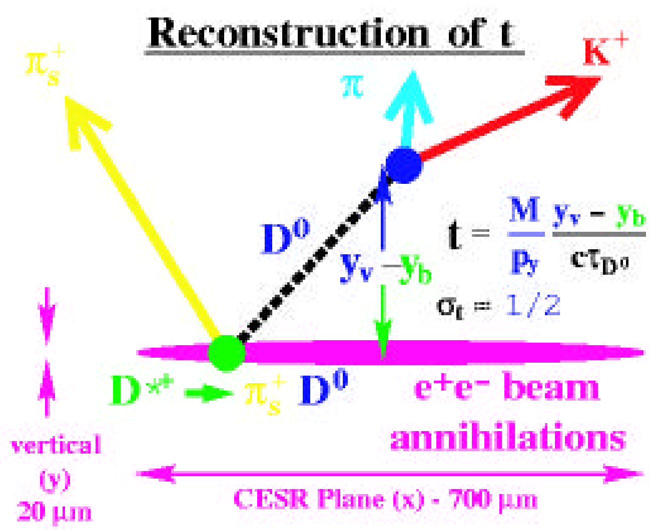
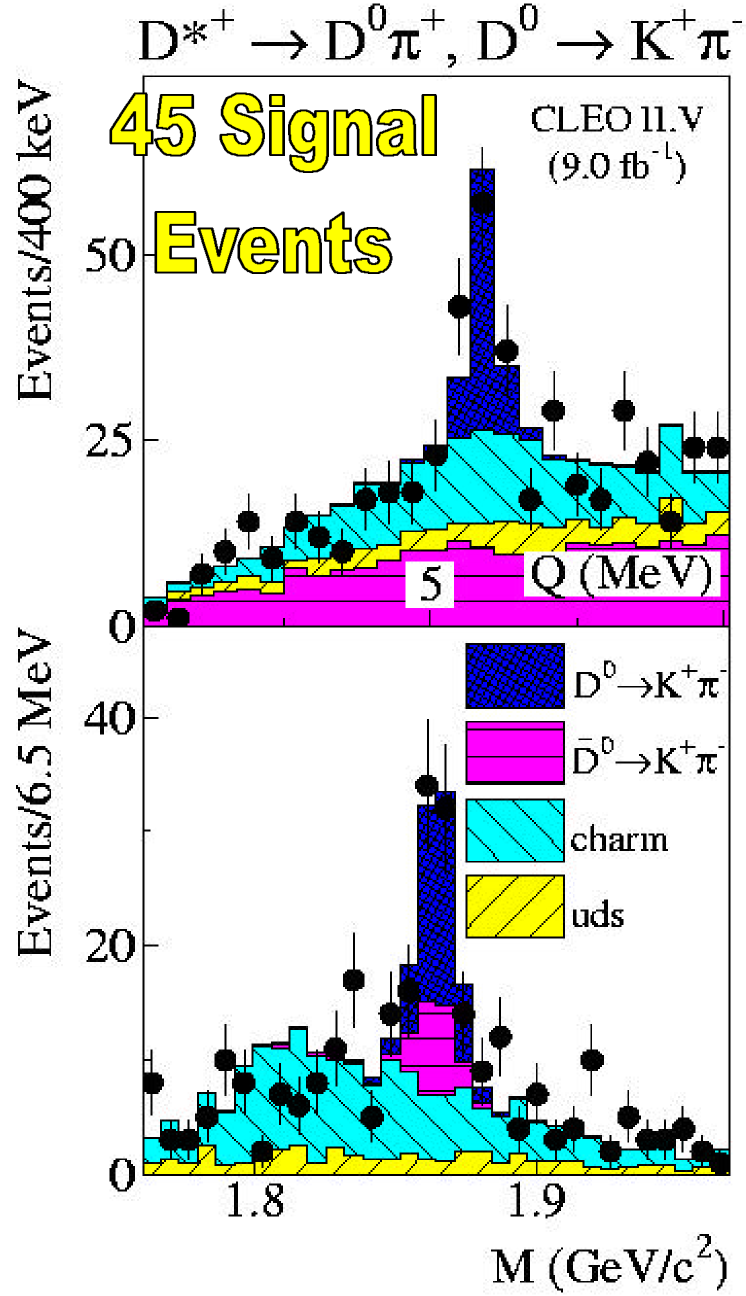
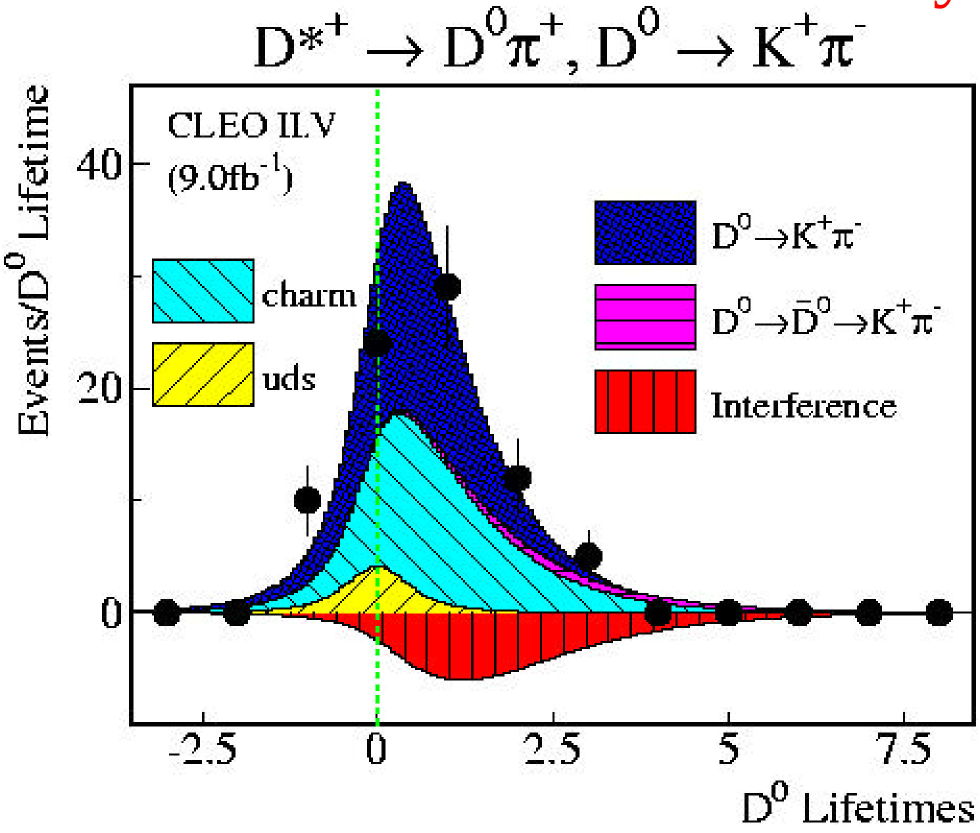
- D^{*+}->$D^0\pi^+$ flavor tagging
- Reject CFD and SCSD candidates with D^0->π^+K^-, $\pi^+\pi^-$, K^+K^- mass hypotheses within 4σ of D^0 mass





2D fit determines signal and background composition

$D^0 \to K^+\pi^-$: Decay Time Dependence



WS signal fit to function

$$\left(R_D + \sqrt{R_D}\, y' t + \frac{1}{4}\left[x'^2 + y'^2\right] t^2 \right) e^{-t}$$

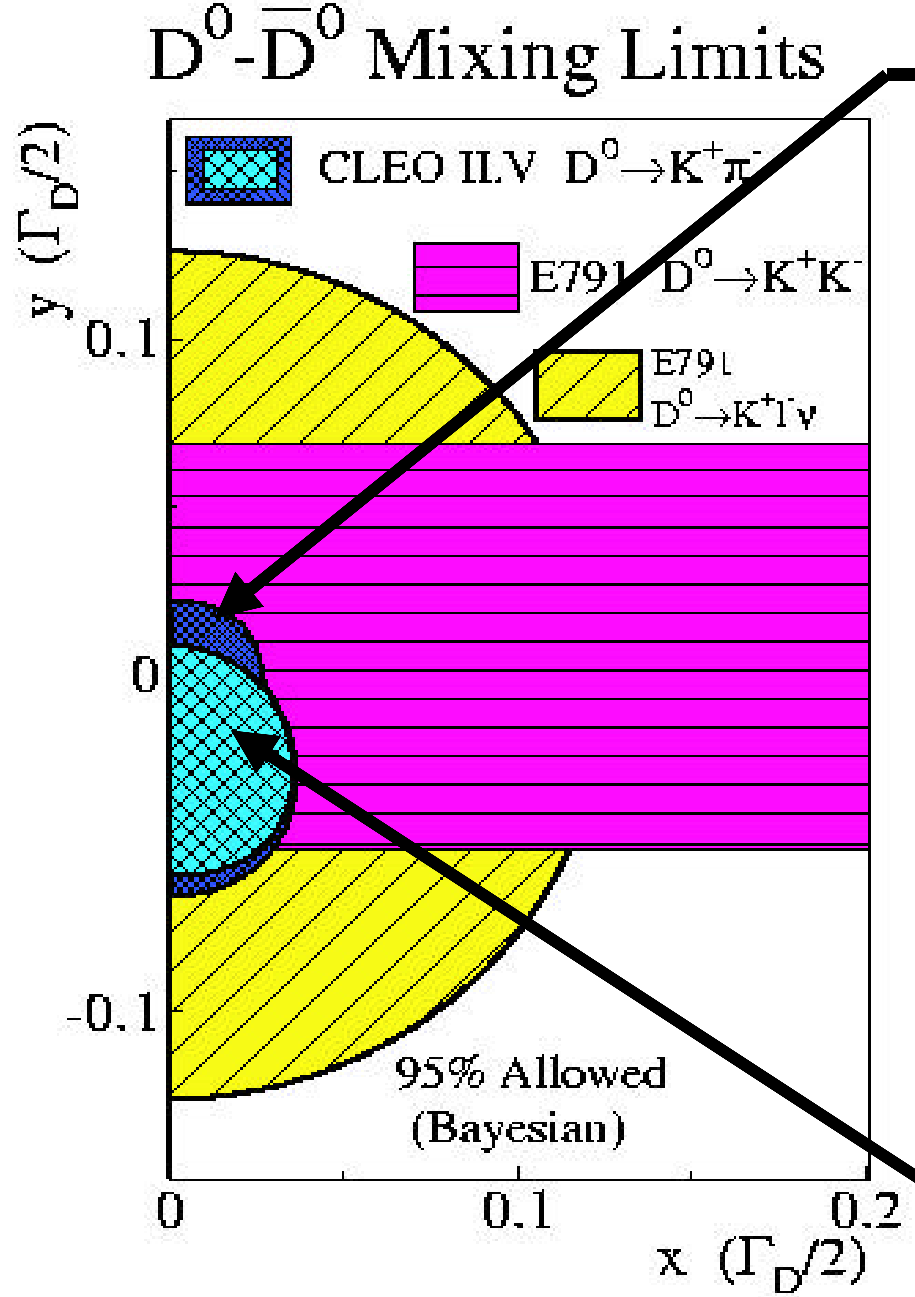
combined with resolution function

$$R = R_M + R_D + \sqrt{R_D}\, y'$$

$$R_M = \tfrac{1}{2}\left(x'^2 + y'^2\right)$$

Parameter	Best Fit	95% C.L.
R_D	(0.48 +/- 0.12 +/- 0.04)%	0.24% < R_D < 0.71%
y’	$(-2.5\ ^{+1.4}_{-1.6}$ +/- 0.3)%	-5.8% < y’ < 1.0%
x’	(0 +/- 1.5 +/- 0.2)%	| x’ | < 2.9%
$(1/2)x'^2$		< 0.041%

Final $D^0 \to K^+\pi^-$ Limits



Limit when CP violation is allowed

$$R_M \to R_M(1 \pm A_M) \quad \text{(analogous to } \varepsilon\text{)}$$

$$R_D \to R_D(1 \pm A_D) \quad \text{(analogous to } \varepsilon'\text{)}$$

$$\delta \to \delta(1 \pm \phi) \quad \text{(analogous to } \sin 2\beta\text{)}$$

Parameter	Best Fit
A_M	$0.23^{+0.63}_{-0.80} \pm 0.01$
A_D	$-0.01^{+0.16}_{-0.17} \pm 0.01$
$\sin\phi$	$0.00 \pm 0.60 \pm 0.01$

Limit $-36\% < A_D < 30\%$ (95% C.L.)

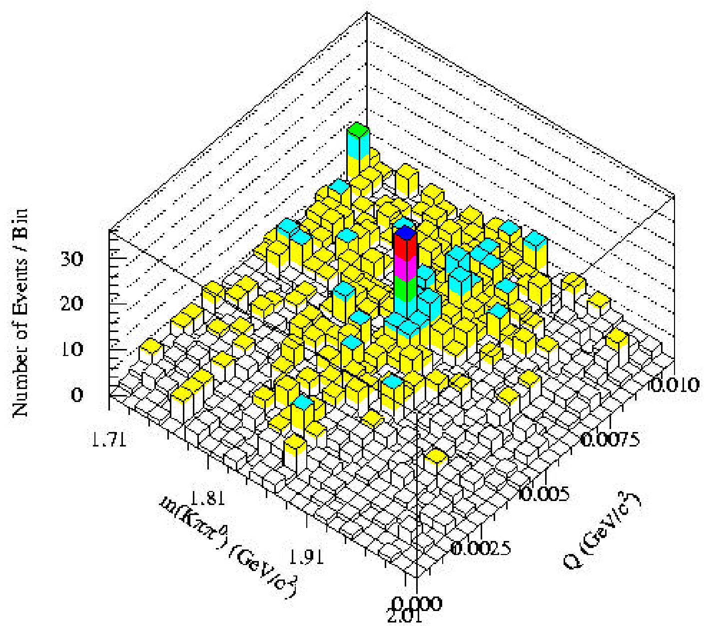
Limit when CP violation is not allowed

$D^0 \to K^+\pi^-\pi^0$ Channel

- $D^{*+} \to D^0\pi^+$ flavor tagging
- Veto $D^0 \to \pi^+K^-p^0$, $\pi^+\pi^-\pi^0$, $K^+K^-\pi^0$ mass hypotheses
- $p(\pi^0) > 340$ MeV/c^2
- Particle ID with dE/dx

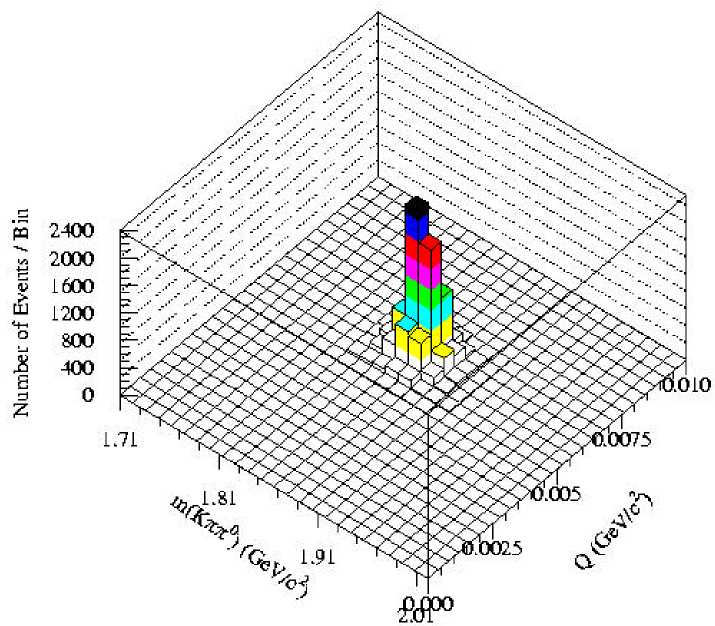
Wrong – Sign

$$D^0 \to K^+\pi^-\pi^0$$

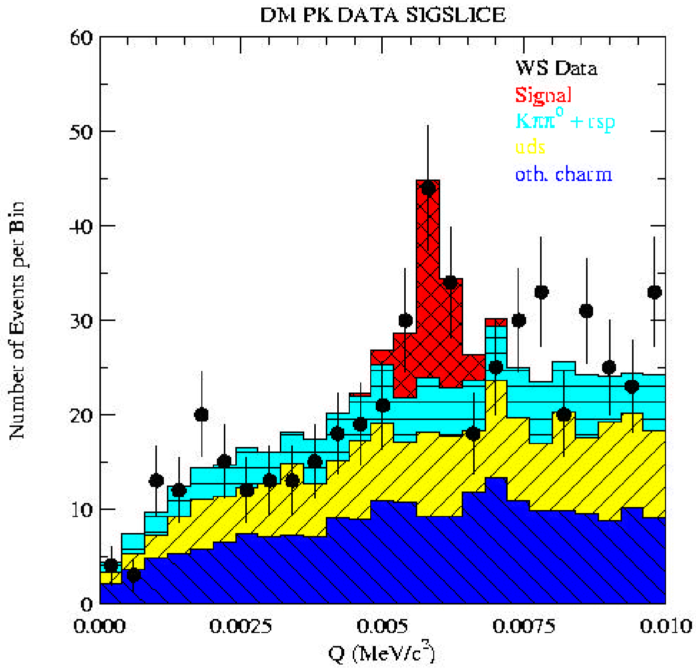


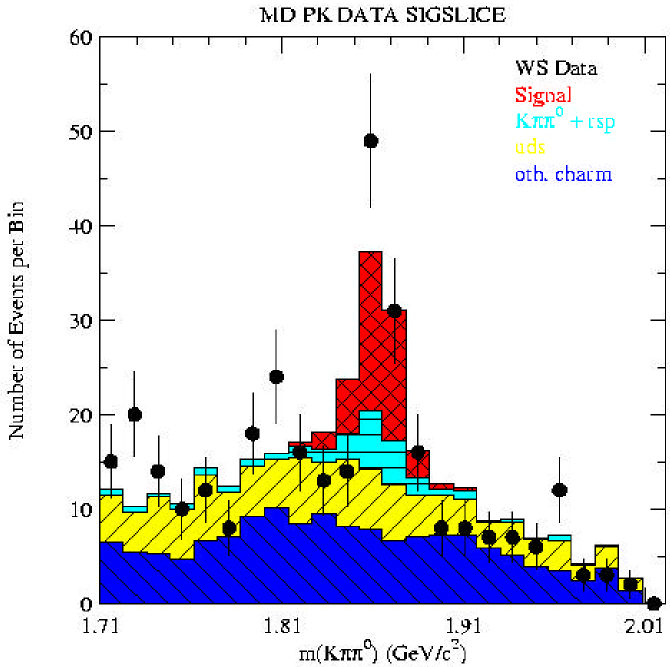
Right – Sign

$$D^0 \to K^-\pi^+\pi^0$$



$D^0 \to K^+\pi^-\pi^0$ Channel





Preliminary

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

$$N_{RS} = 9045$$

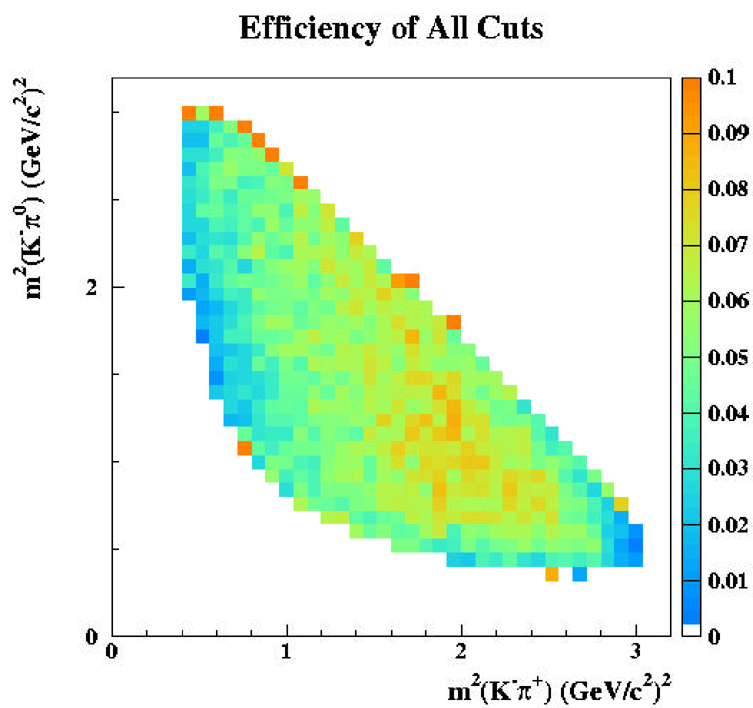
4.9σ significance of signal

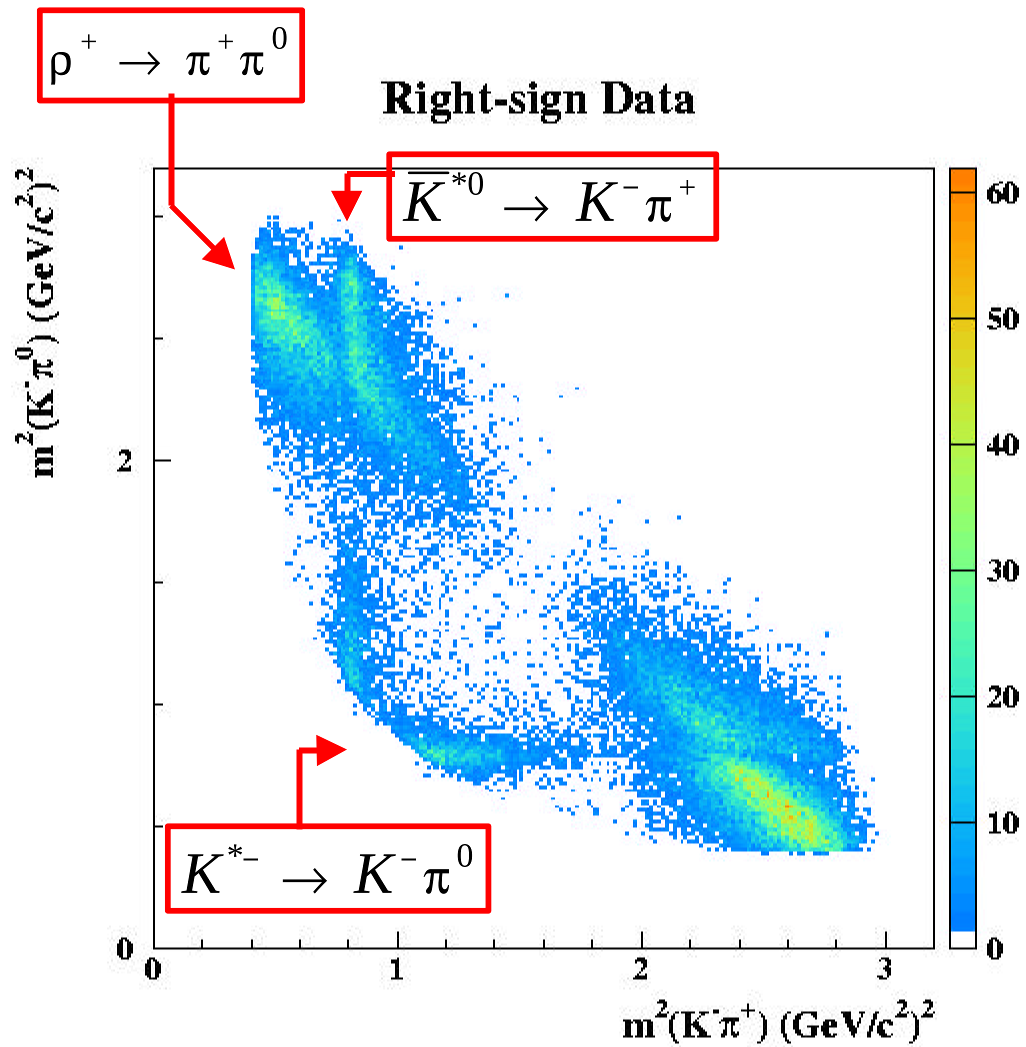
First observation of this decay!

$D^0 \to K^+\pi^-\pi^0$: Interpretation of the Signal

$$R_{WS} = \frac{\varepsilon_{RS}}{\varepsilon_{WS}} \cdot \frac{N_{WS}}{N_{RS}}$$

Need this to get R_{WS}!



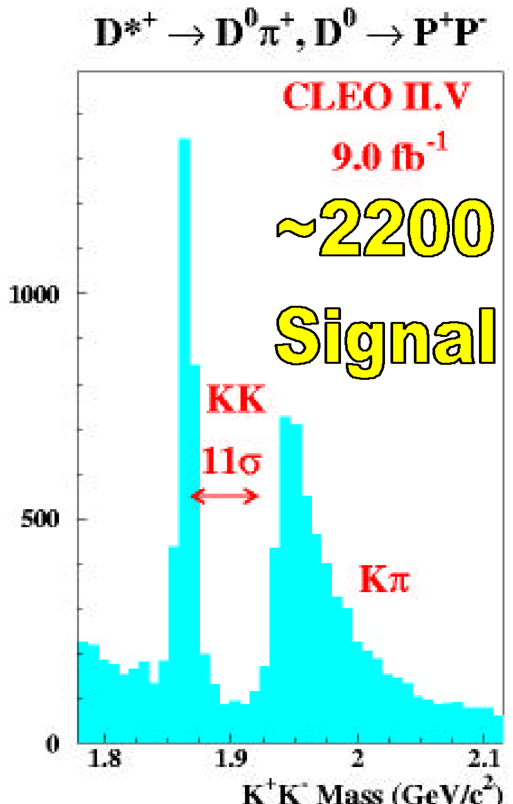


In general : $\varepsilon_{DCSD} \neq \varepsilon_{mix}$

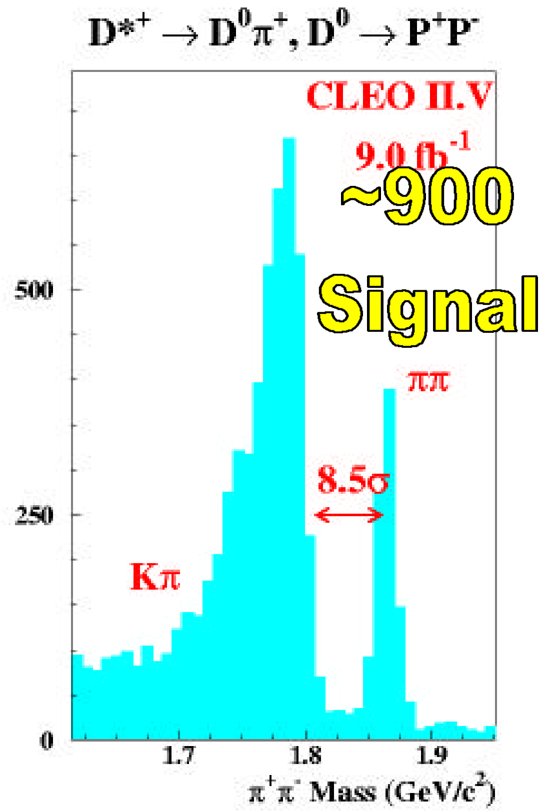
CP Even Eigenstates: $D^0 \to K^+K^-$, $\pi^+\pi^-$

- Flavor tagged from $D^{*+} \to D^0\pi$
  - Reduces background
- Excellent kinematic separation

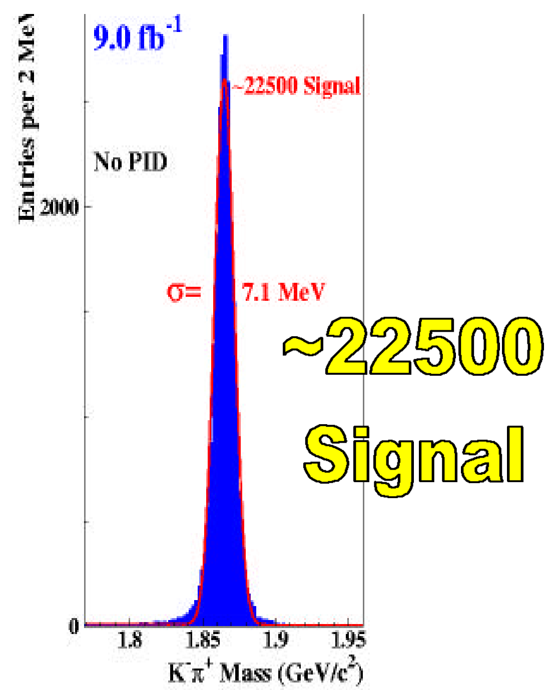
$$\sigma_y \approx 0.028\,(\text{stat}) \pm 0.010\,(\text{syst})$$



K^+K^-



$\pi^+\pi^-$



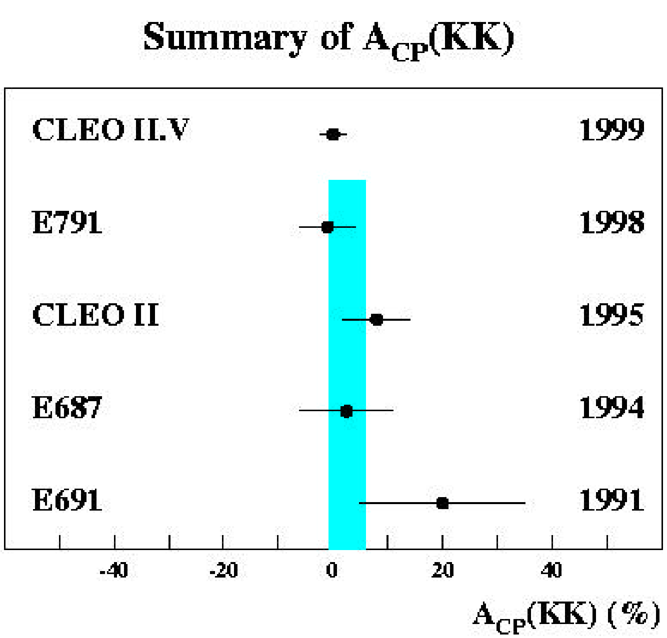
$K^-\pi^+$

Search for CP Violation Using $D^0 \to K^+K^-, \pi^+\pi^-$

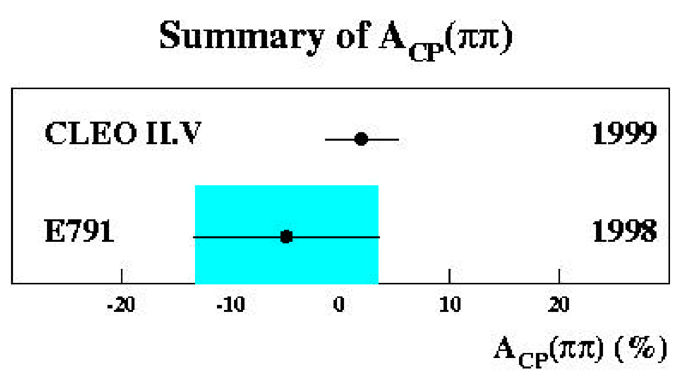
$$A_{CP}(f) = \frac{N(D^0 \to f) - N(\overline{D}^0 \to f)}{N(D^0 \to f) + N(\overline{D}^0 \to f)}$$

$$A_{CP}(KK) = (0.04 \pm 2.18(stat) \pm 0.84(sys))\%$$

$$A_{CP}(\pi\pi) = (1.94 \pm 3.22(stat) \pm 0.84(sys))\%$$



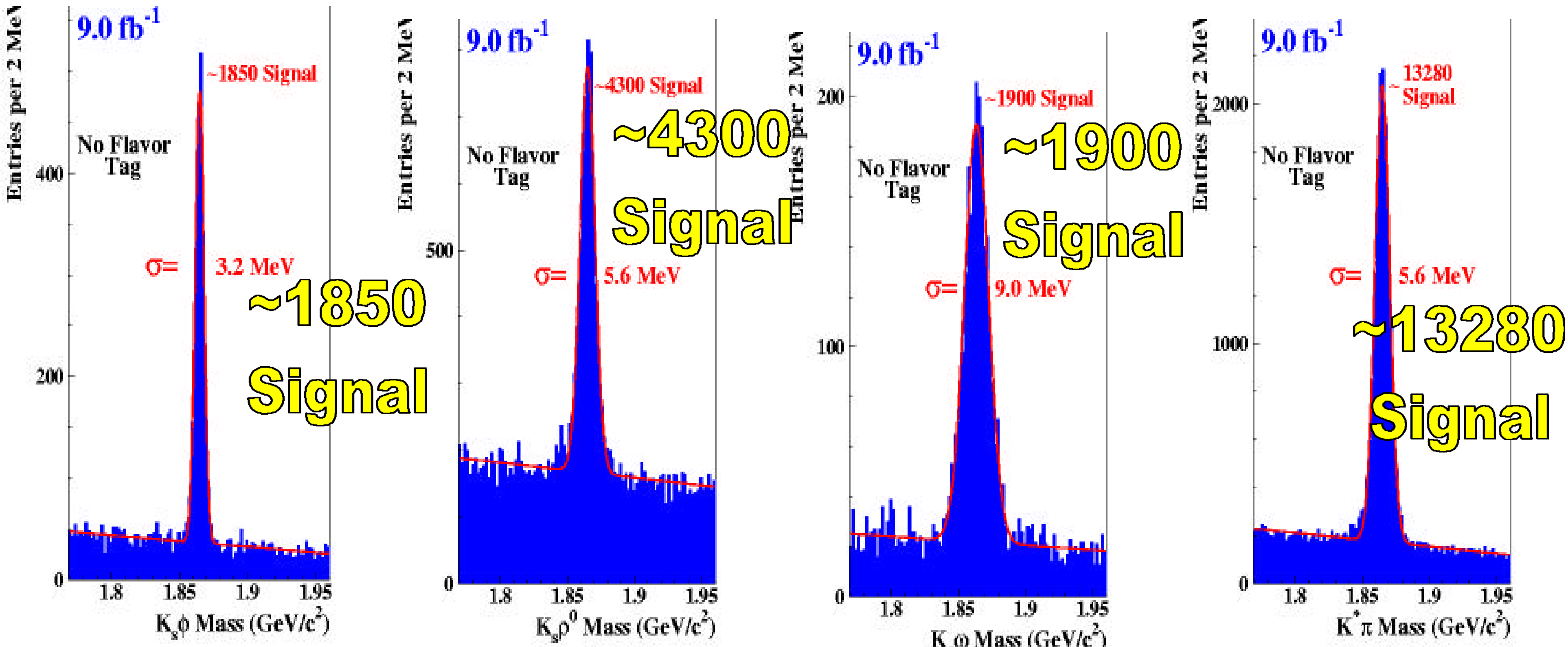
Preliminary



CP Odd Eigenstates

- No D^{*+} flavor tag
- Good kinematic separation
  - No particle ID

$$\sigma_y \approx 0.02\,(\text{stat}) \pm 0.01\,(\text{syst})$$



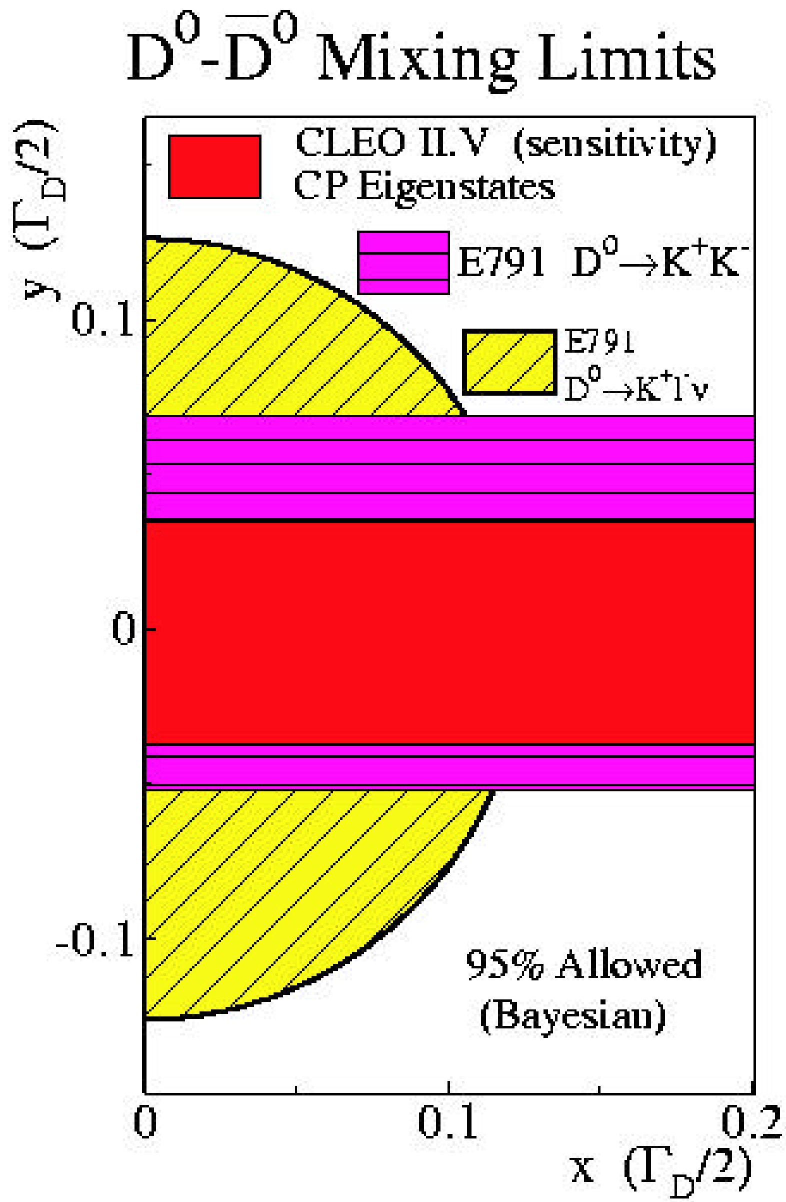
$K_s^0\phi$ $\quad$ $K_s^0\rho^0$ $\quad$ $K_s^0\omega$ $\quad$ $K^{*-}\pi^+$

CP Eigenstate Sensitivity

Expected sensitivity for combined CP even and CP odd analyses:

$$\sigma_y \approx 1.8\% \text{ (stat + syst)}$$

Preliminary



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

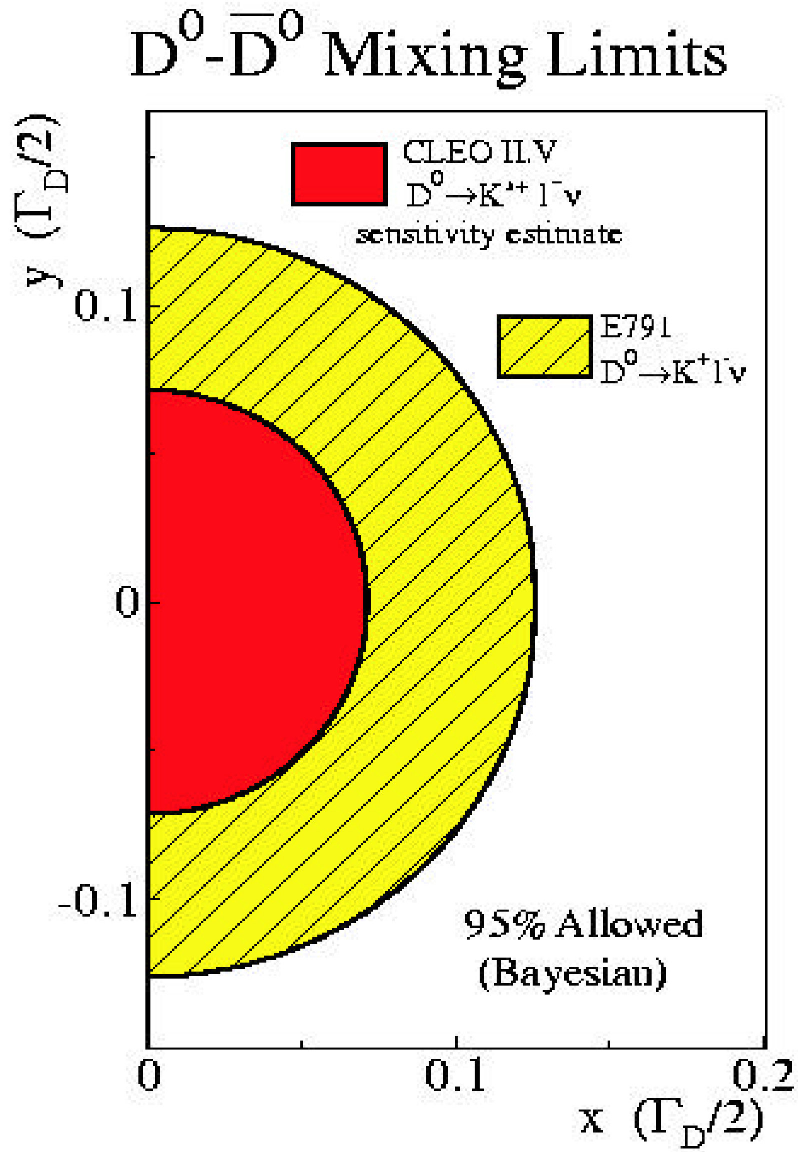
No DCSD to contend with (R_D=0), so $R = R_M$

Estimated single-event sensitivity of:

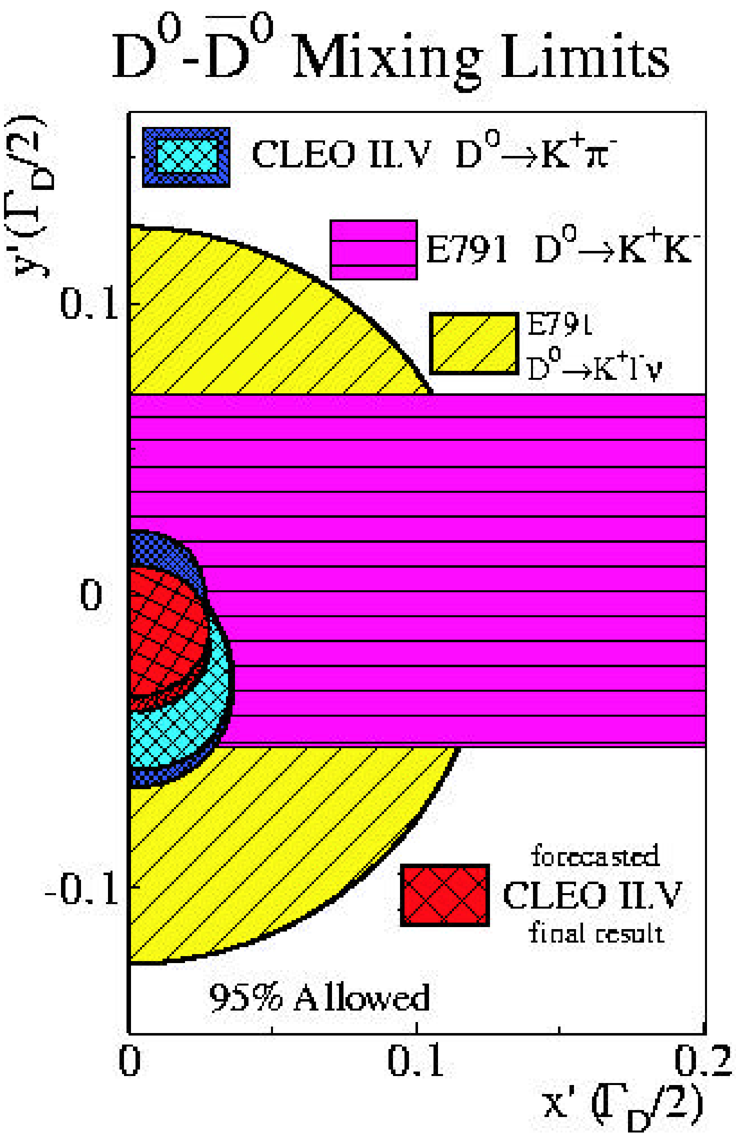
$R_{mix} < 0.15\%$

Preliminary

- Improvements possible:
  - Addition of $D^0 \to K^+ l^- \nu$ statistics
  - Efficiency improvements
  - Lifetime fit



Projections to Final CLEO II.V Limits



Includes:

- Final D^0->$K^+\pi^-$ results
- Does not include D^0->$K^+\pi^-\pi^0$, D^0->$K^+\pi^-\pi^+\pi^-$ yet
- Semileptonic mixing sensitivity
- CP even and odd eigenstate sensitivities

Conservative assumptions:

- No semileptonic signal
- y central value does not impact upper $y^{/}$ limit

Conclusions

- We observe no evidence for D^0- $\overline{D^0}$ mixing or CP violation
- We interpret the wrong-sign signal in $D^0 \to K^+\pi^-$ as DCSD (R_D):
  - Phys. Rev. Lett., **84**, 22 (2000)

$$\text{CLEO II.V} \qquad R = R_D = \left(0.332^{+0.063}_{-0.065} \pm 0.04\right)\%$$

$$\text{PDG (CLEOII + E791)} \; R = (0.72 \pm 0.25)\%$$

- First and only measurement of $-36\% < A_D < 30\%$ (95% C.L.)
- Sensitivity of CP eigenstate analyses: $\sigma_y < 1.8\ \%$
- Sensitivity to D^0- $\overline{D^0}$ mixing without assumptions about CP violation:

$$\text{CLEO II.V} \qquad R_M\,(\text{via } x') < 0.041\% \;\; (95\%\ \text{C.L.})$$

$$\text{PDG (E791)} \qquad R_M\,(\text{via } x \text{ or } y) < 0.602\% \;\; (95\%\ \text{C.L.})$$

- First observation of the wrong-sign decay $D^0 \to K^+\pi^-\pi^0$
- Several exciting results on horizon as these analyses reach maturity