New CLEO Results on Mixing and CP Violation Searches in D^0 Decay and D^{*+} Intrinsic Width

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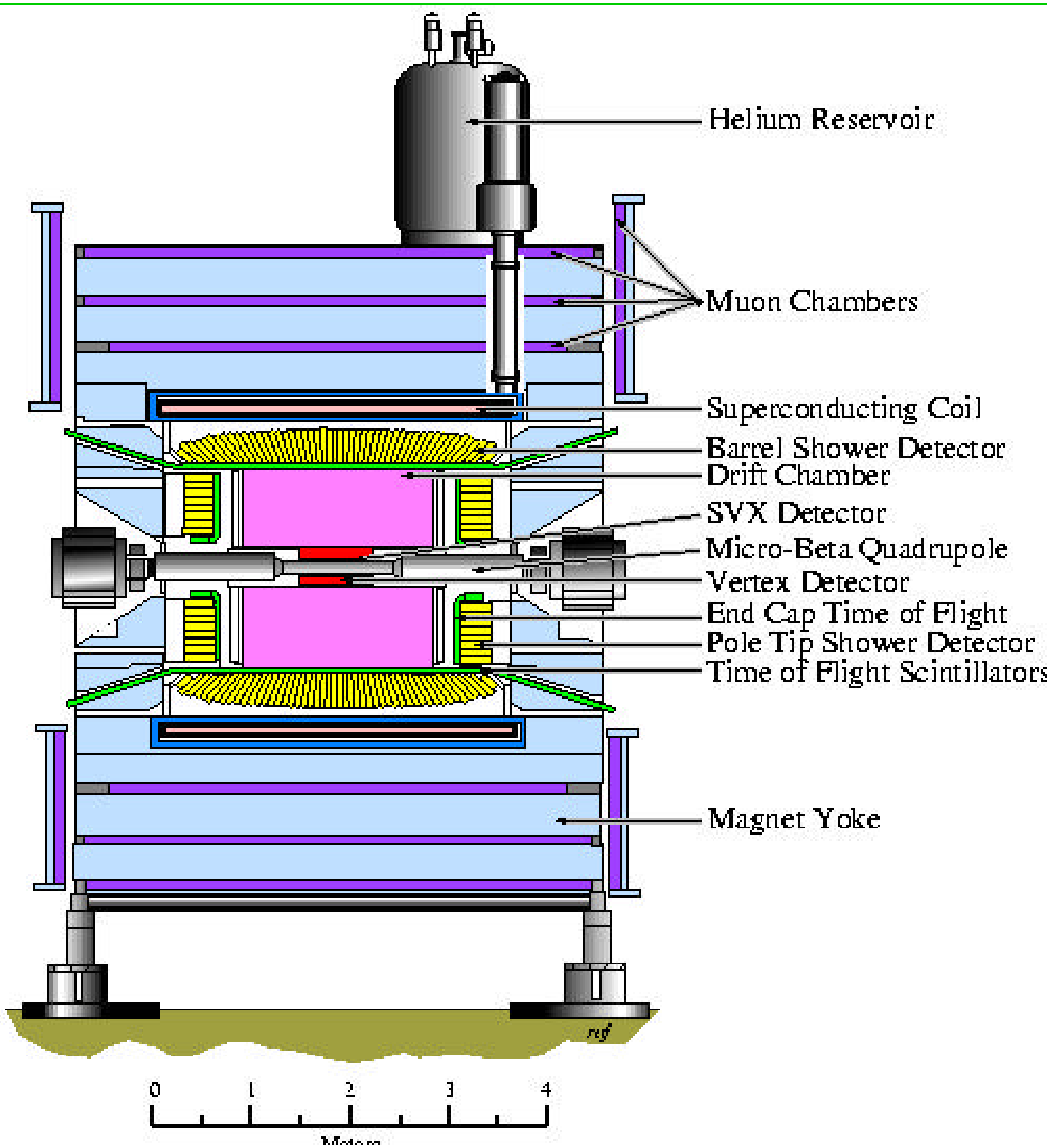
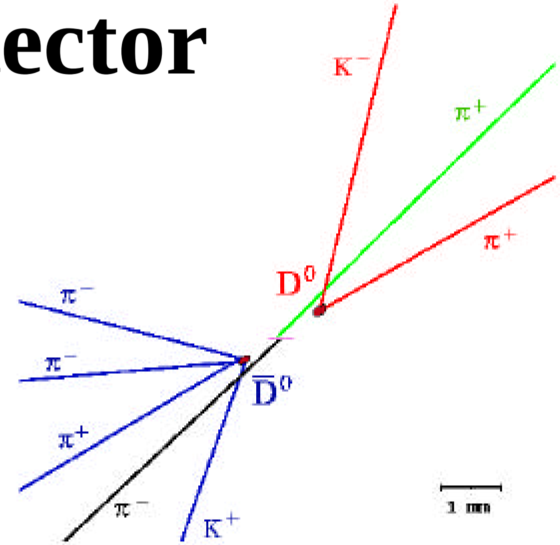
- Intrinsic width measurement of the D^{*+}
- New CLEO results on D^0-$\overline{D^0}$ mixing and CP violation
  - First measurement of "wrong-sign" $D^0 \to K^+\pi^-\pi^0$ rate
  - Searches for CP violation in D^0 decays to pseudoscalar particles
  - Measurement of the mixing parameter **y** using CP even decays $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$
- Conclusions and future directions

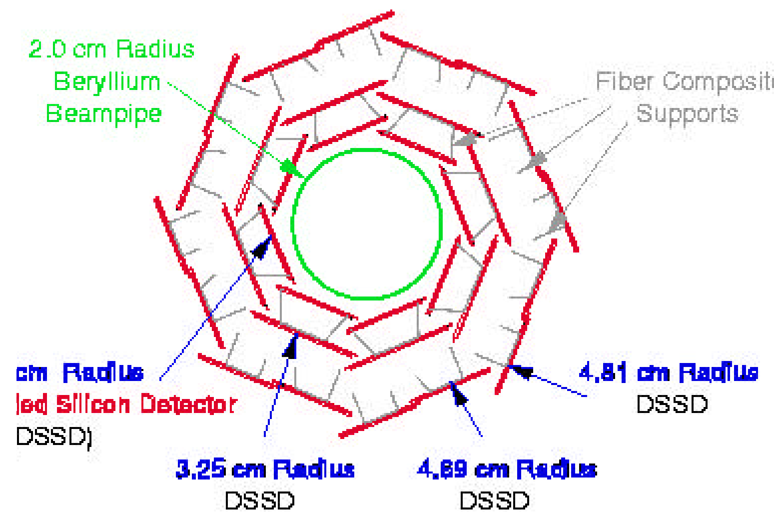
The CLEO II.V Detector

CESR storage ring operating on/near Upsilon(4S)

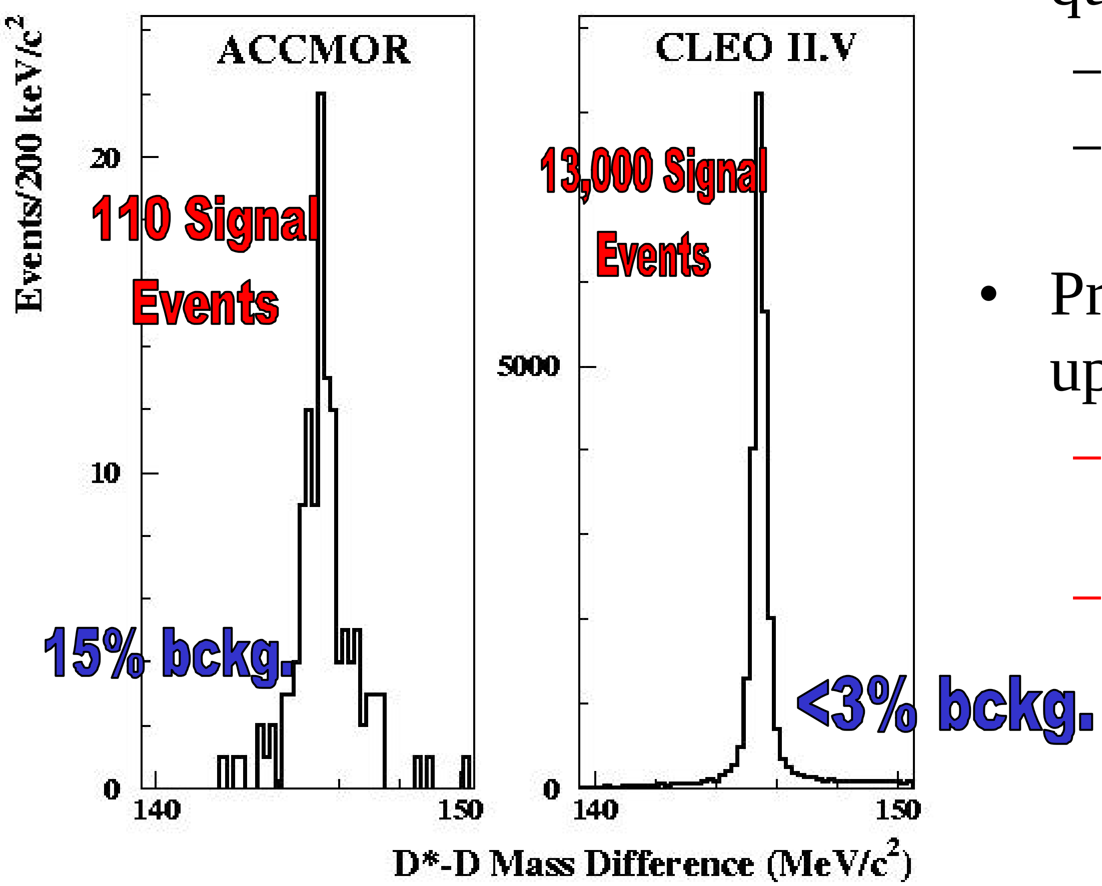
9 fb-1 of integrated luminosity







First Measurement of the D^{*+} Width



- Probe of non-perturbative strong physics of heavy-light quark systems
  - Framework of theory understood
  - Predictions range from 15 - 150 keV
- Previous best measurement is upper limit from ACCMOR
  - Significant improvement in statistics
  - CLEO II.V resolution ~150 keV

Measurement Technique

- Use well-measured decay channel

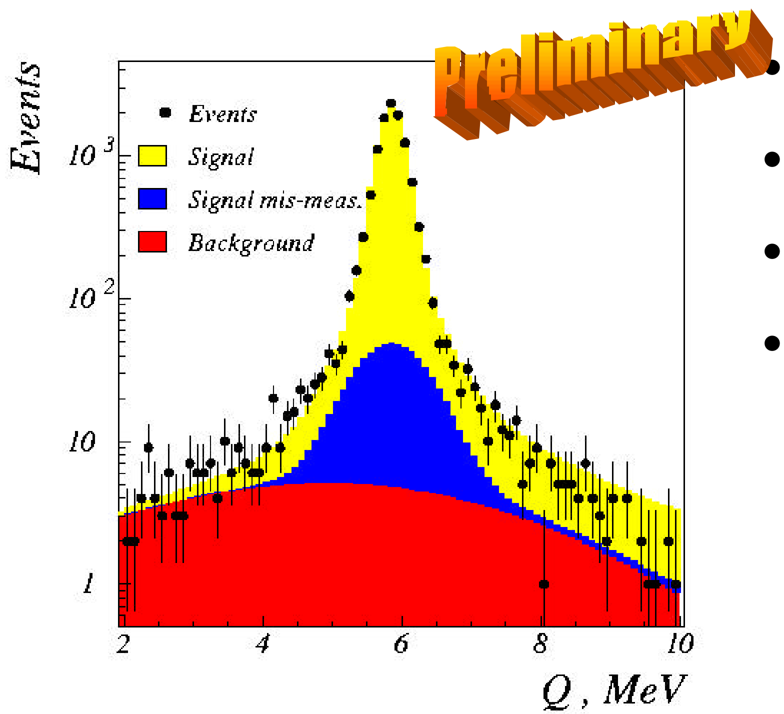
$$D^{*+} \to D^0 \pi^+_{slow};\ D^0 \to K^- \pi^+$$

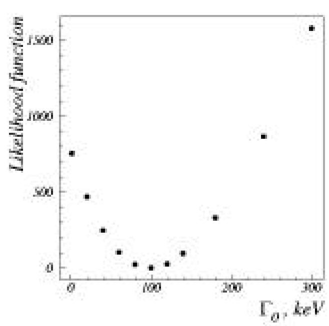
- Experimentally, we measure the energy released in the D^{*+} decay, Q:

$$Q \equiv \underbrace{m(K^- \pi^+ \pi^+_{slow})}_{D^{*+}} - \underbrace{m(K^- \pi^+)}_{D^0} - \underbrace{m_{\pi^+}}_{\pi_{slow}}$$

- $\Gamma(D^{*+})$ can be expressed in terms of its partial width to $D^0\pi^+$
- We assume $\Gamma(D^0) << \Gamma(D^{*+})$
  - Therefore, $\Gamma(Q)$ comes entirely from D^{*+} width convoluted with tracking resolution
- Perform fit to determine $\Gamma(Q)$
- Must REALLY understand detector and Monte Carlo simulation of resolution
  - No zero-width calibration mode
  - CLEO detector and simulation well-studied

Extracting the Intrinsic Width



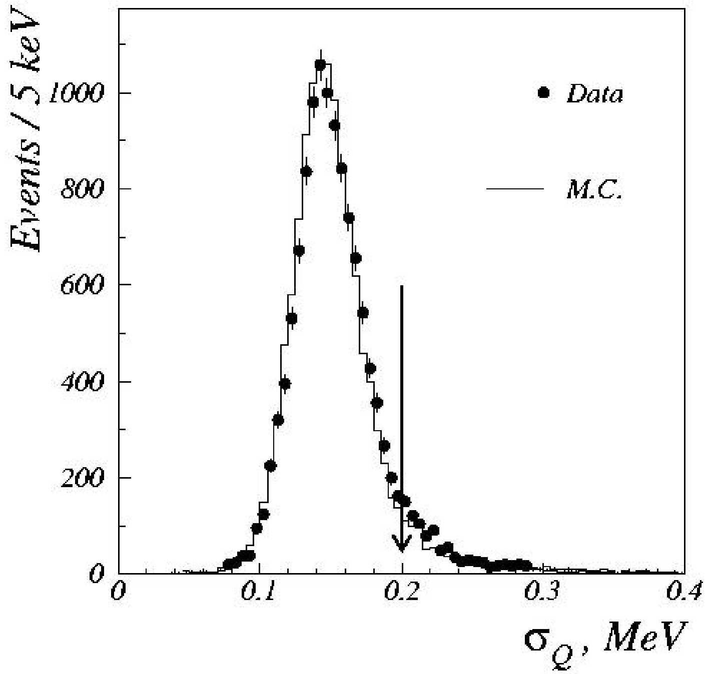


- Unbinned maximum likelihood fit to Q
- Fit to Breit-Wigner line shape
- Input measured Q and σ_Q for each event
- Variables in fit:
  - $\Gamma(Q)$, $\langle Q \rangle$
  - N_s : number of signal events
  - f_{mis} : fraction of mismeasured signal events
  - σ_{mis} : resolution of mismeasured events
  - N_b : number of background events
- Fixed background shape from fit to MC

$$\Gamma\left(D^{*+}\right) = 96.2 \pm 4.0\ (\text{stat})\ \text{keV}$$

Preliminary

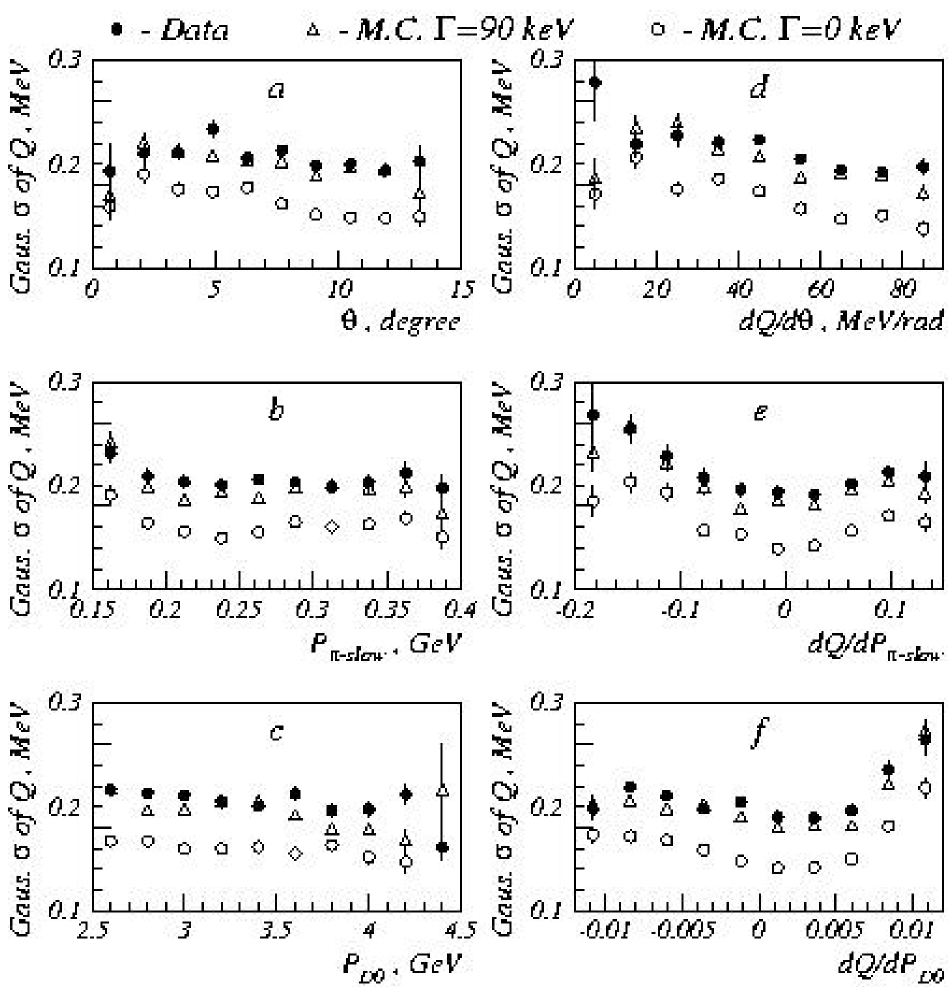
Tests of the Detector Simulation



$$\sigma_Q \approx 150\ keV$$

- Excellent agreement of resolution between Monte Carlo and data
  - No corrections necessary
- All known contributions to resolution carefully checked in simulation

Tests of the Detector Simulation



Gaussian width of Q peak (resolution + intrinsic)

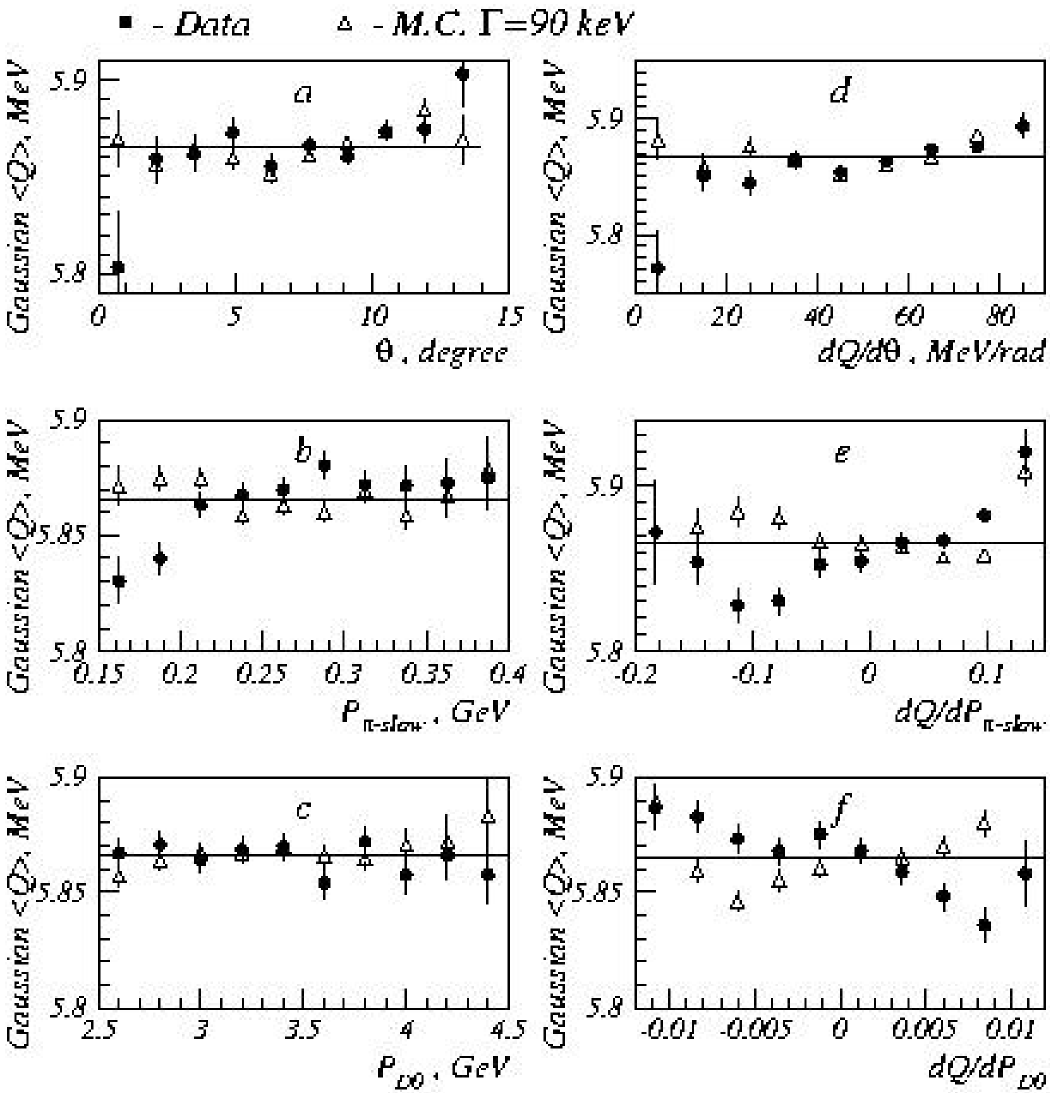
- Mis-modeling of the tracking resolution will effect kinematic variables of decay
- Test for mis-modeling of key variables of decay:

$$\theta, P(\pi_{slow}), P(D^0)$$

$$\frac{\partial Q}{\partial \theta}, \frac{\partial Q}{\partial P(\pi_{slow})}, \frac{\partial Q}{\partial P(D^0)}$$

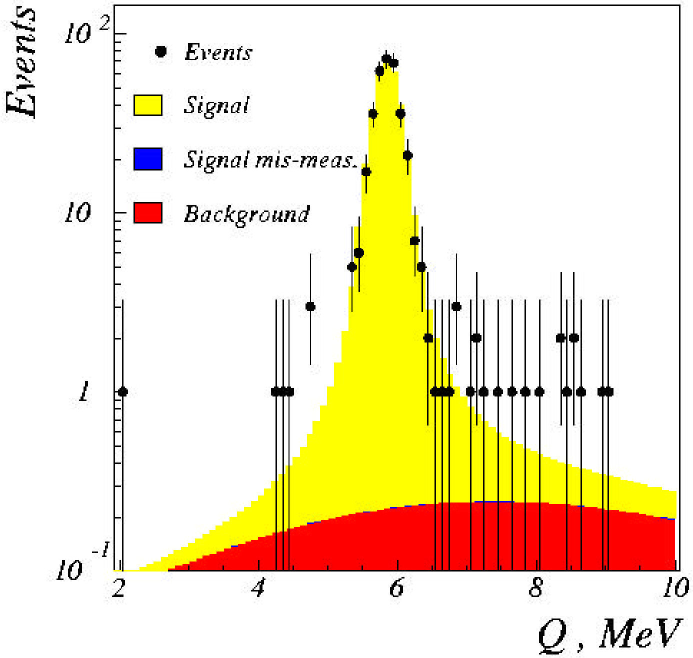
  – Good MC/data agreement of Q peak width distribution with ~90 keV D^{*+} width
    - Dependence well modeled

Tests of the Detector Simulation

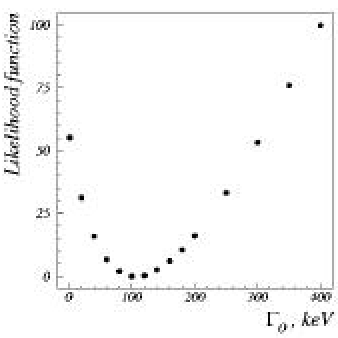


- Not quite as good agreement of mean Q
  - Included as systematic error
  - We are not trying to measure the mean, however

Effect of Tracking Mistakes on Γ(Q) Result

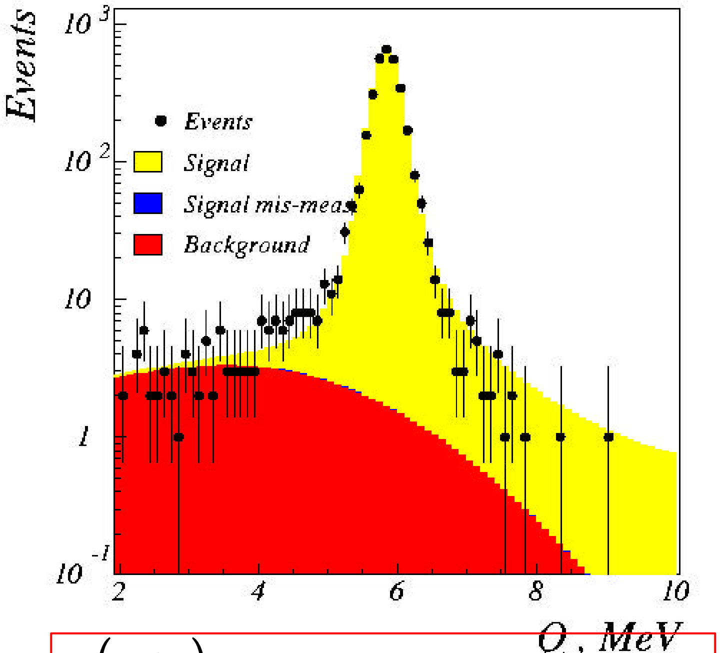


$$\Gamma\left(D^{*+}\right) = 104 \pm 20\,(\text{stat})\ \text{keV}$$

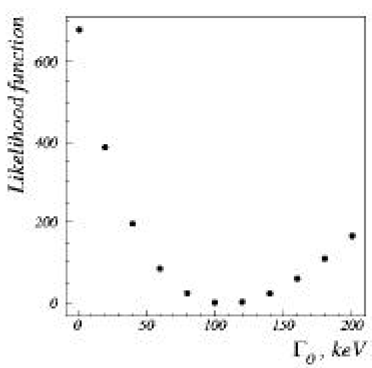


- Fit to sample with tight tracking selection
- Apply very tight cuts to tracks to remove tracking mistakes
  - SVX hits in both views on all layers
  - No hits within 2 mm of silicon wafer edge
  - Large fraction of possible drift chamber hits
  - Tight matching of tracks between tracking devices
- Results are consistent with nominal fit

Test Sensitivity to Mismodeling of Decay Kinematics



$$\Gamma\left(D^{*+}\right) = 103.8 \pm 5.9\ (\text{stat})\ ke\text{V}$$



- Fit to sample with tight kinematic selection
- Select sample with minimal dependence on kinematics of decay:
  - Small values of

$$\left|\frac{\partial Q}{\partial P_{D^0}}\right| \text{ and } \left|\frac{\partial Q}{\partial P_{\pi^+_{\text{slow}}}}\right|$$

- Result is consistent with nominal fit

Summary of Systematic Errors

Source	$\delta\Gamma(D^{*+})$ (keV)
Variation of <Q>	16
Mismodeling of σ_Q	11
Fit variable correlations	8
D^0 production point	4
Background shapes	4
Offset Correction	2
Data format digitization	1
Total	22

Conclusions: D^{*+} Width Measurement

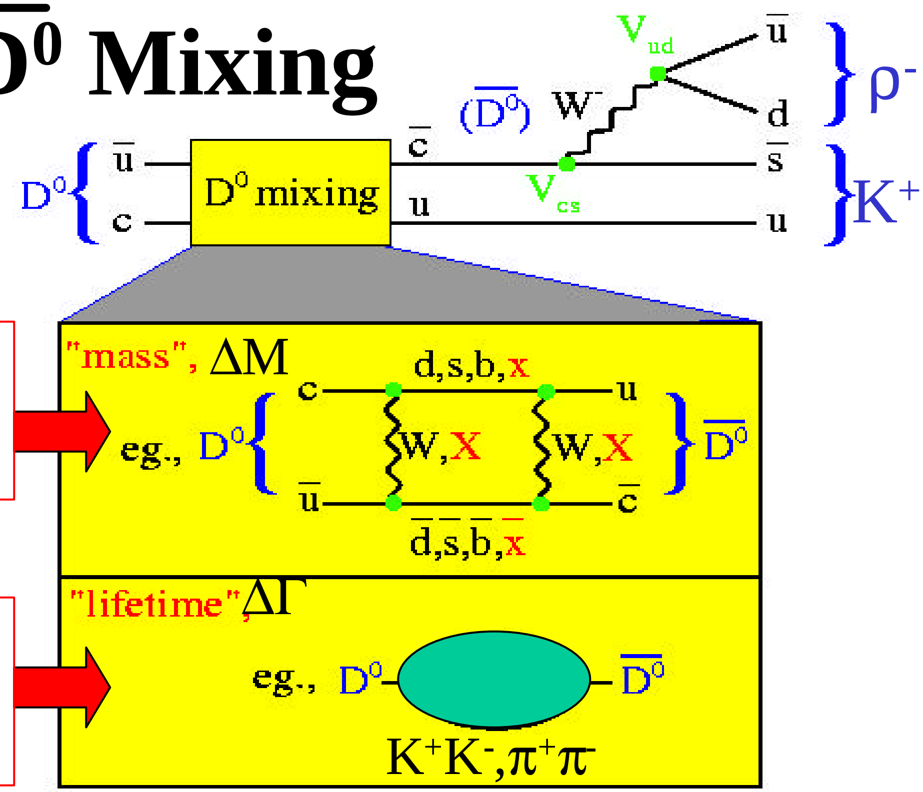
- We measure the D*+ width with best precision yet:

Preliminary

$$\Gamma\left(D^{*+}\right) = 96 \pm 4\,(\text{stat}) \pm 22\,(\text{syst})\ \text{k}e\text{V}$$

- Consistent with predictions based on HQET and relativistic quark models
- Higher than predictions based on QCD sum rules
- Input into phenomenology of other important heavy-light quark systems

Searches for Non-Standard Model Physics Through D^0-$\overline{D^0}$ Mixing



$$x = \frac{\Delta M}{\Gamma} : \text{Window to new physics}$$

$$y = \frac{\Delta\Gamma}{2\Gamma}$$

Standard Model prediction:

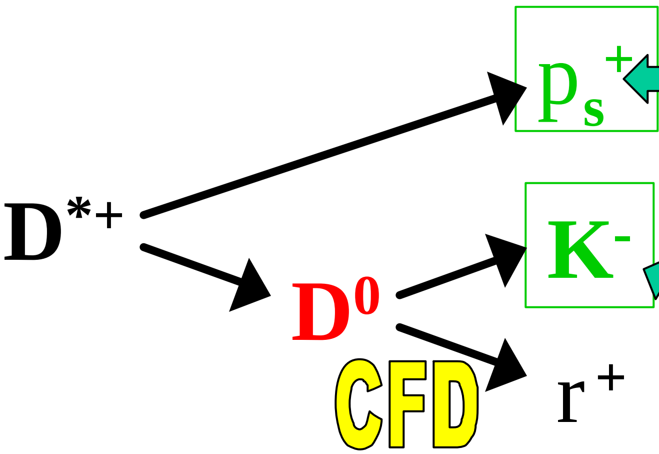
$$|x| \approx \underbrace{\tan^2\theta_C}_{\approx 0.05} \times \text{GIM suppression} \approx 10^{-6} - 10^{-2}$$

Signatures of Non-Standard model physics:

1) Large $|x|$, 2) $|x| >> |y|$, CP viol. interference between 3) x and y or 4) x and DCSD

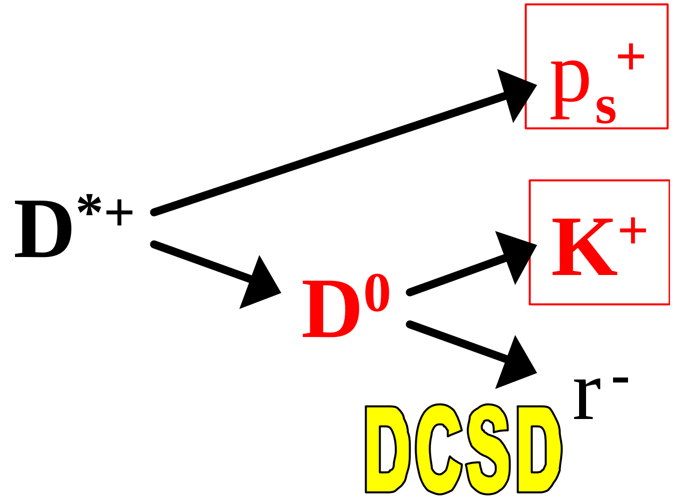
Analysis Technique

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

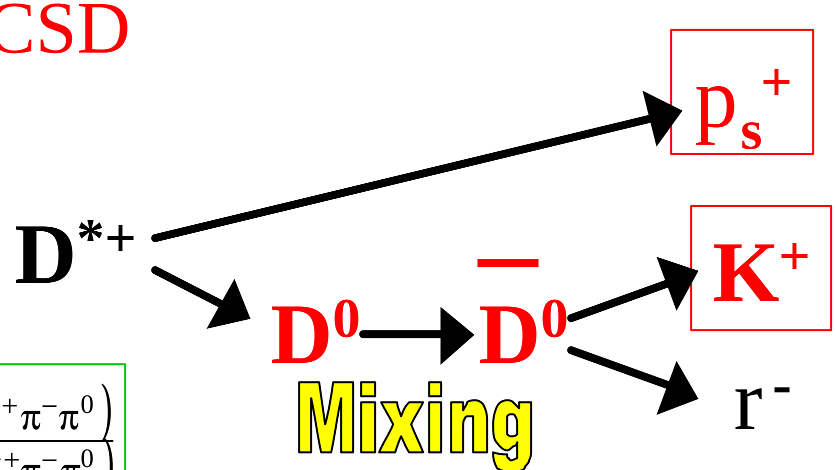


Sign of slow π tags initial D^0 flavor

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



$$\bar{r}_{WS}(t) = \left(\underbrace{\bar{R}_D}_{\text{Pure DCSD}} + \underbrace{\sqrt{\bar{R}_D}\,\bar{y}'}_{\text{Interference}}\, t + \underbrace{\frac{1}{4}\left[\bar{x}'^2 + \bar{y}'^2\right] t^2}_{\text{Pure Mixing}} \right) e^{-t}$$



$$\text{This analysis: } R_{WS} = \int_0^\infty \bar{r}_{WS}(t)\,dt \equiv \frac{\Gamma\left(D^0 \to K^+\pi^-\pi^0\right)}{\Gamma\left(\bar{D}^0 \to K^+\pi^-\pi^0\right)}$$

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

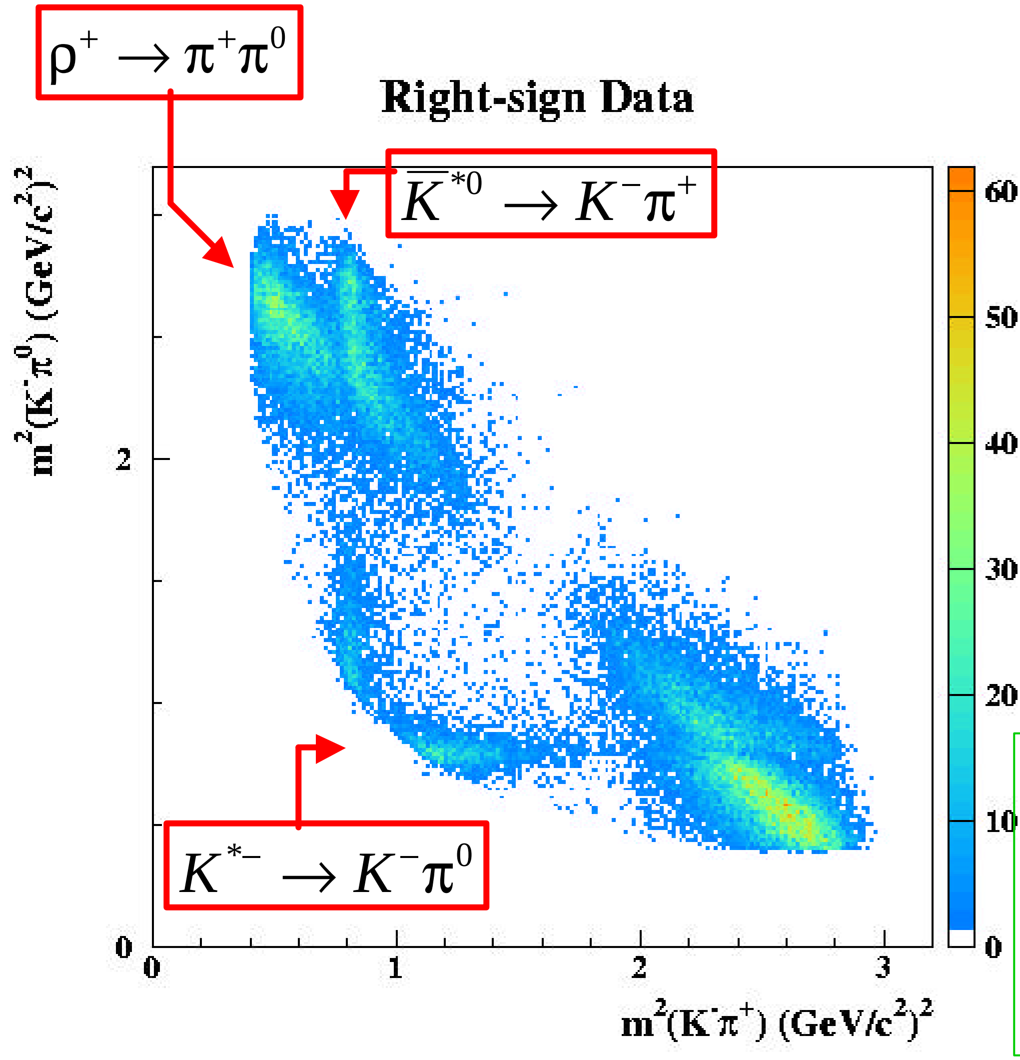
Data Sample and Selection

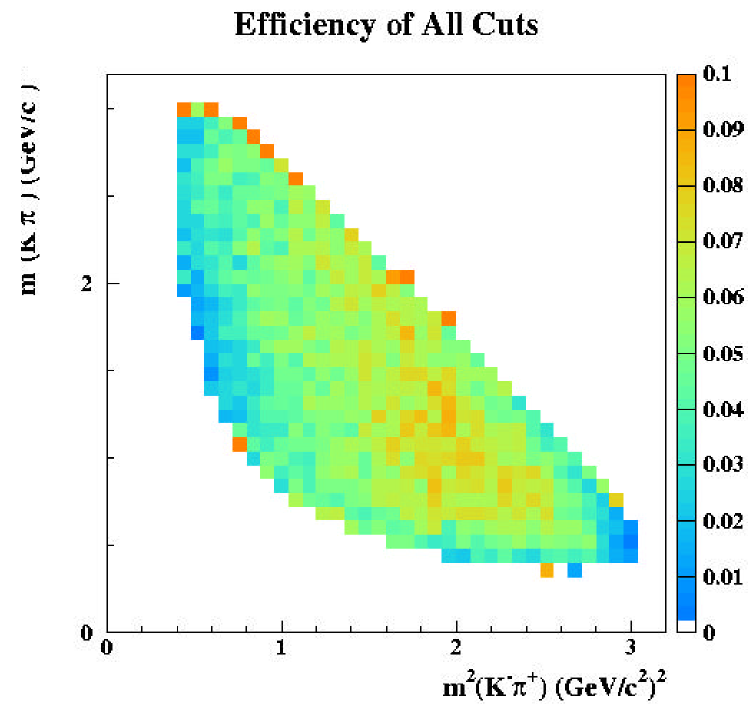
- Good quality charged tracks
- Good π^0
  - $p(\pi^0) > 340$ MeV/c
  - $E(\gamma) > 30$ (60) MeV Central (Endcap)
  - $|m(\gamma\gamma)-m(\pi^0)| < 2\sigma$
- D^0 vertex: PROB > 0.0001
- $|m(\pi K\pi^0)-m(D^0)| > 4\sigma$
- π_{slow} refit through intersection of D^0 and CESR beam spot : PROB > 0.0001
- $p(D^{*+}) > 2.5$ GeV/c

Complication of Multi-body Decays

CLEO finds rich RS Dalitz plot : $\rho(770)^+, K^*(892)^-, \overline{K}^*(892)^0, \rho(1700)^+, K_0(1430)^-, \overline{K_0}(1430)^0, K^*(1680)^-$, non - resonant

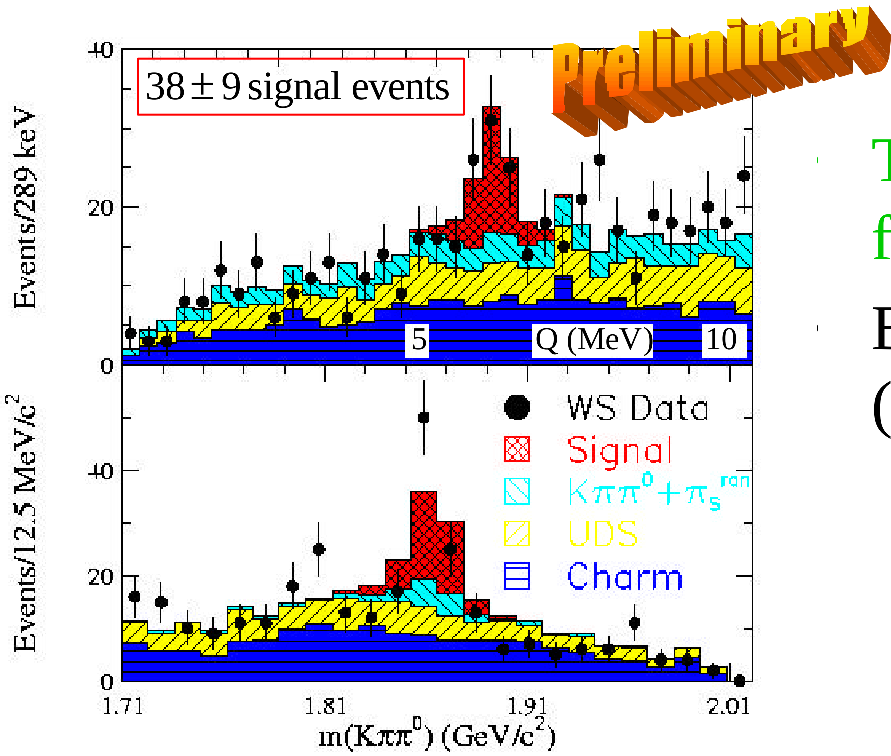
CLNS 00-23 (Submitted to Phys. Rev. D)





$$R_{WS} = \underbrace{\frac{N_{WS}}{N_{RS}}}_{\text{From WS Q-m}(K\pi\pi^0)\text{ fit}} \cdot \underbrace{\frac{\bar{\varepsilon}_{RS}}{\bar{\varepsilon}_{WS}}}_{\text{From WS Dalitz plot fit}}$$

Fit to Determine N_{WS}/N_{RS}



$$\frac{N_{WS}}{N_{RS}} = \left(0.43^{+0.11}_{-0.10}\ (\text{stat})\right)\%$$

Preliminary

- Two-dimensional maximum likelihood fit to Q -m($K\pi\pi^0$) distribution
- Background shapes from Monte Carlo (8X data set)
  - RS $\bar{D}^0 \to K\pi\pi^0$ + uncorrelated π_{slow}
  - Charm decays other than correctly reconstructed $D^0 \to K\pi\pi^0$
  - $e^+e^- \to u\bar{u}, d\bar{d}$, or $s\bar{s}$
- Signal shape from RS data

Statistical significance of signal = 4.9 s

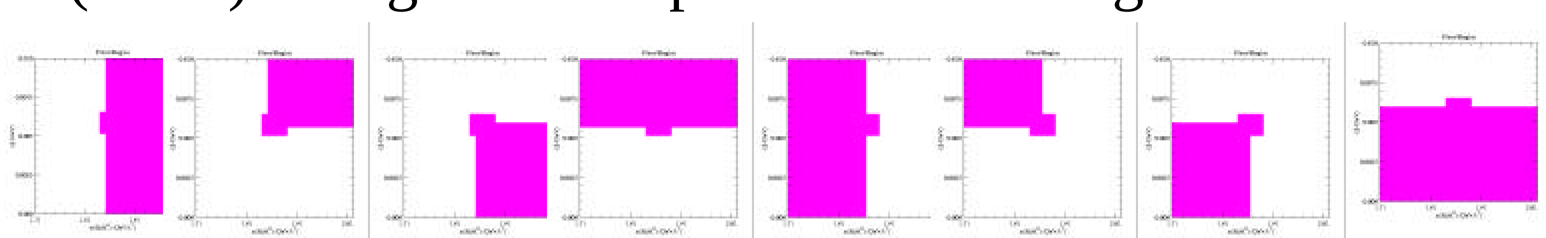
Determination of Efficiency Ratio

- **Maximum likelihood fit to wrong-sign Dalitz plot**
- Fit $m^2(K^+\pi^-)$ vs $m^2(K^+\pi^0)$ distribution
- Start with measured RS amplitudes and phases
- Allow $A(K^{*0}\pi^0)$, $\phi(K^{*0}\pi^0)$, $A(K^{*+}\pi^-)$, and $\phi(K^{*+}\pi^-)$ to float relative to $K^+\rho^-$ mode
  - A and ϕ of minor modes fixed relative to $K^+\rho^-$
- Efficiency function from fit to non-resonant MC sample
- Background function from fit to side band in Q
- Signal fraction from WS Q-m($K\pi\pi^0$) fit
- Large statistical and systematic errors on amplitudes and phases, but efficiency ratio relatively insensitive

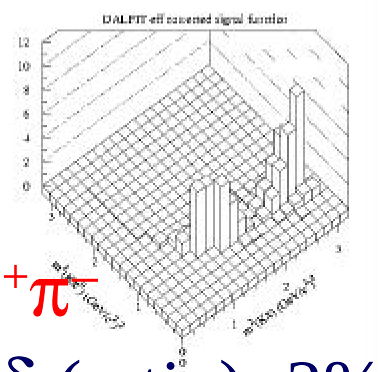
$$\frac{\bar{\varepsilon}_{RS}}{\bar{\varepsilon}_{WS}} = 1.00 \pm 0.02\,(\text{stat})$$

Important Systematic Errors in R_{WS} Measurement

- Q - m($K\pi\pi^0$) background shapes: fits to sub-regions : 14%

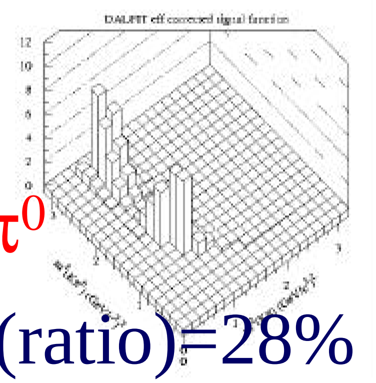


- Efficiency ratio: 9%
  - Uncertainty in amplitudes and phases of minor resonances: 8%
  - Dalitz plot of backgrounds: 3%
  - Uncertainty of Dalitz plot fit method: 3%



$K^{*+}\pi^-$

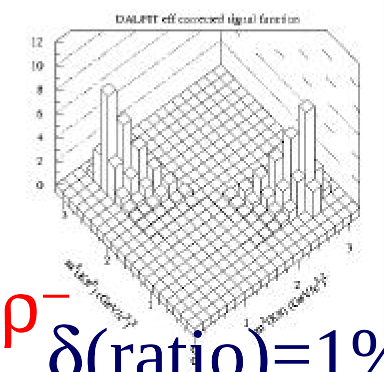
δ (ratio)=2%



$K^{*0}\pi^0$

δ(ratio)=28%

>10σ inconsistent with data!



$K^+\rho^-$

δ(ratio)=1%

  - Statistical error of Dalitz plot fit included as systematic: 2%

Result of R_{WS} Measurement

$$R_{WS} = \underbrace{\frac{N_{WS}}{N_{RS}}}_{\text{From WS Q-m}\left(K\pi\pi^0\right)\text{ fit}} \cdot \underbrace{\frac{\bar{\varepsilon}_{RS}}{\bar{\varepsilon}_{WS}}}_{\text{From WS Dalitz plot fit}}$$

Source	$\delta(R_{WS})/R_{WS}$
Q-m bckg. shapes	14%
Efficiency ratio	9%
Mismodeling of selection variables	3%
Statistics of Q-m bckg. shapes	2.4%
Total	17%

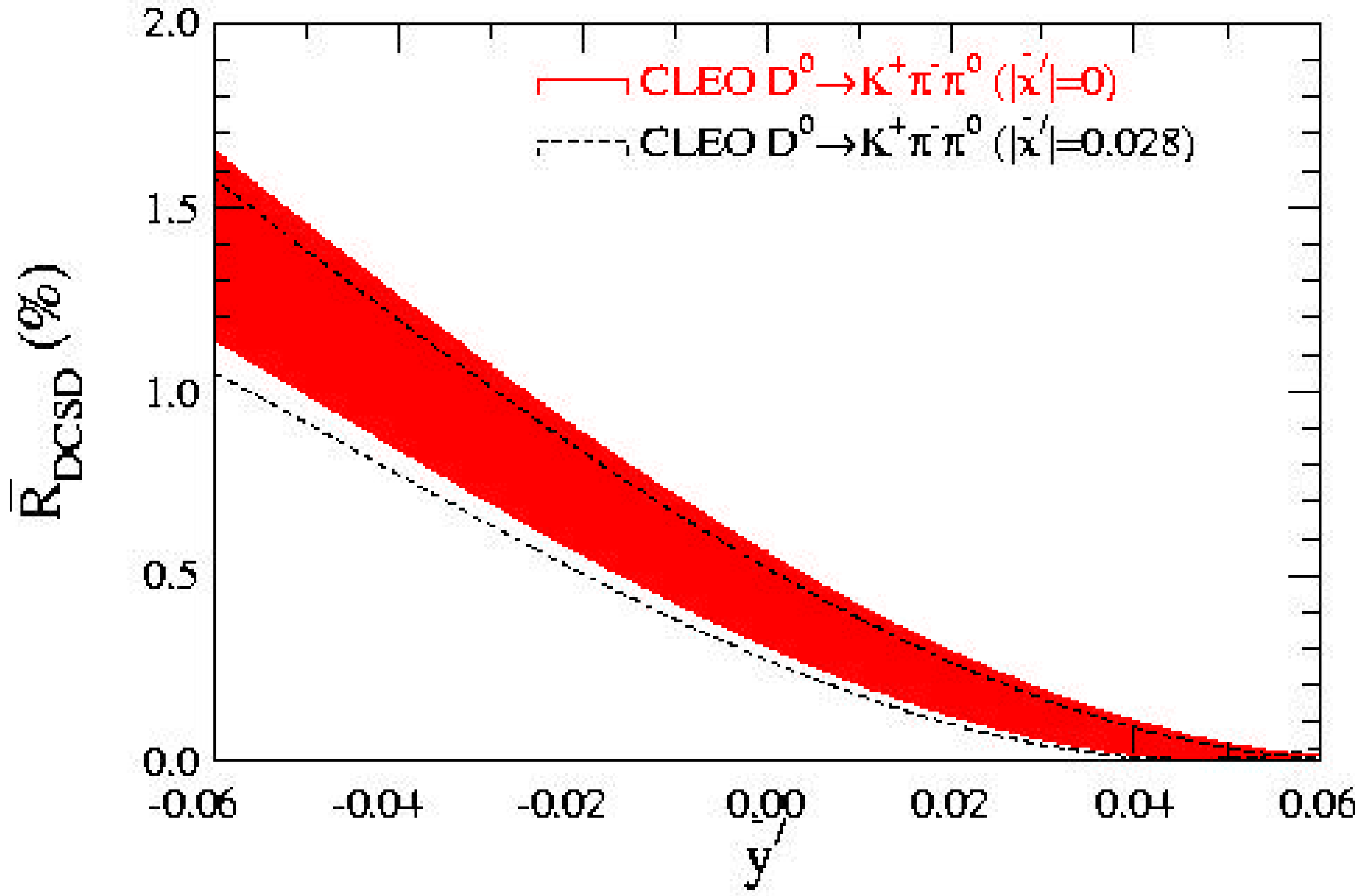
Preliminary

Preliminary

$$R_{WS} = \left(0.43^{+0.11}_{-0.10}\ (\text{stat.}) \pm 0.07\ (\text{syst.})\right)\%$$

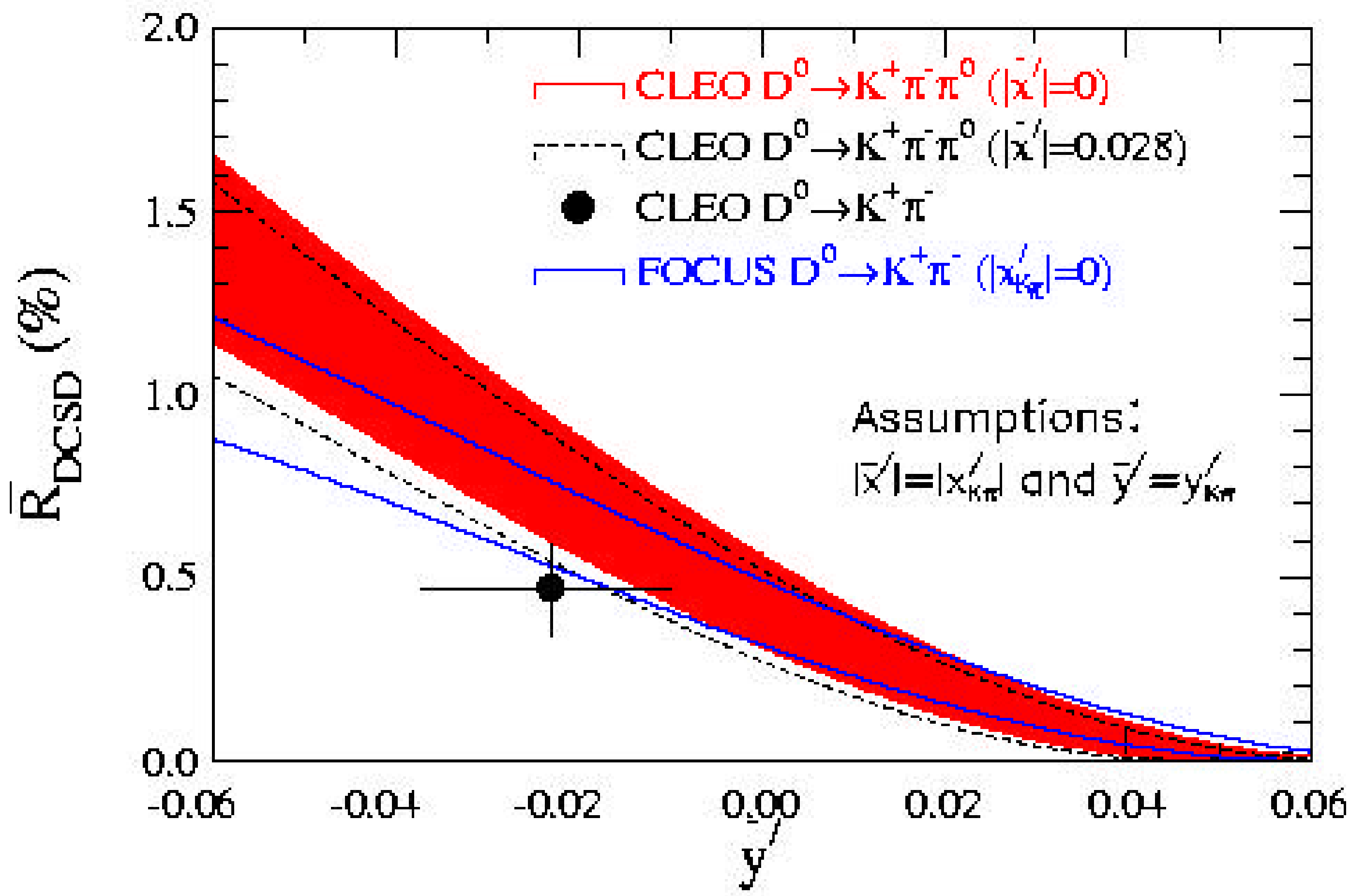
First non-zero rate measurement in this channel

Mixing and DCSD Limits



Mixing and DCSD Limits

Note: If D^0->X->$K\pi\pi^0$ and D^0->$K\pi$ do not have the same strong phase, then x', y', and R_{DCSD} are not necessarily the same variables for different decays



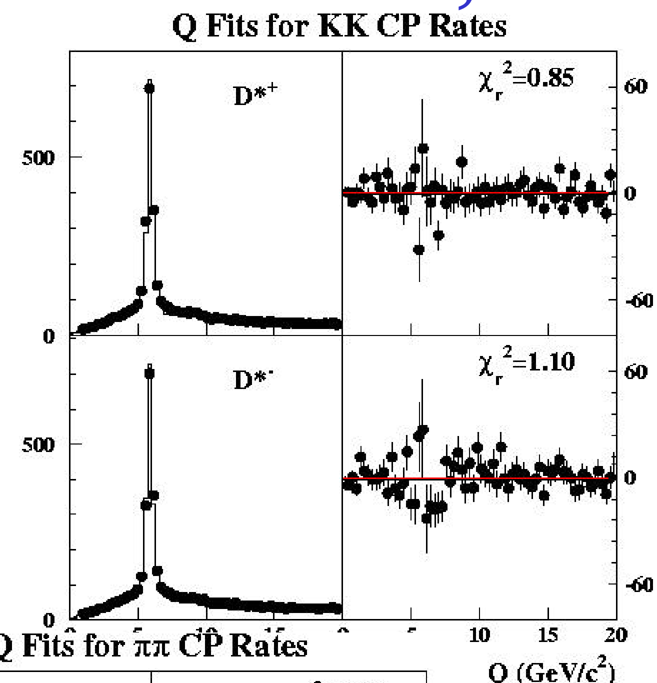
Searches for Direct CP Violation in D^0 Decays

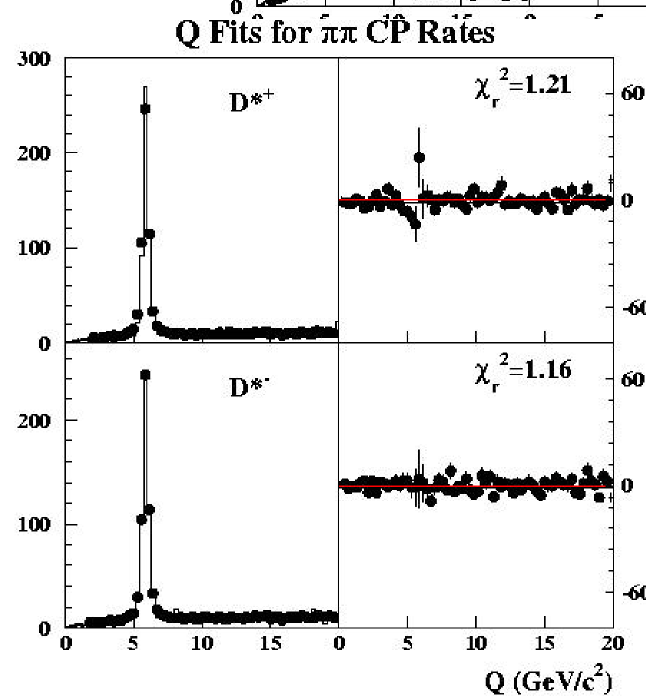
- Cabibbo-suppressed charm decays are a good place to look for non-Standard Model effects:
  - Expected to be small in Standard Model
  - Multiple paths to same final state with a weak phase difference
  - Large final state interactions likely
    - Enhance CP violation
- Search in the channels: $D^0 \to K^+K^-$, $\pi^+\pi^-$, $K^0_S\pi^0$, $\pi^0\pi^0$, and $K^0_S K^0_S$
- Experimentally, we measure the asymmetry for final state f:

$$A = \frac{\Gamma\left(D^0 \to f\right) - \Gamma\left(\overline{D^0} \to f\right)}{\Gamma\left(D^0 \to f\right) + \Gamma\left(\overline{D^0} \to f\right)}$$

Searches for CP Violation in $D^0 \to K^+K^-, \pi^+\pi^-$

- D^0 flavor tagged by pion charge in $D^{*+} \to D^0\pi^+_{slow}$
- Refit π^+_{slow} through intersection of D^0 and run-averaged beam spot
- Fit Q spectrum to obtain yields
  - Monte Carlo simulation of backgrounds
  - Fit in bins of D^0 momentum
- Dominant systematic errors:
  - Fitting procedure (0.69%)
  - Reconstruction bias (0.48%)

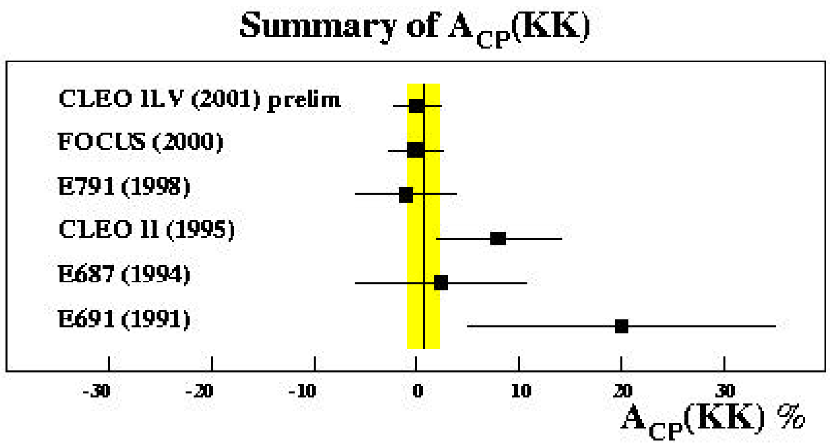


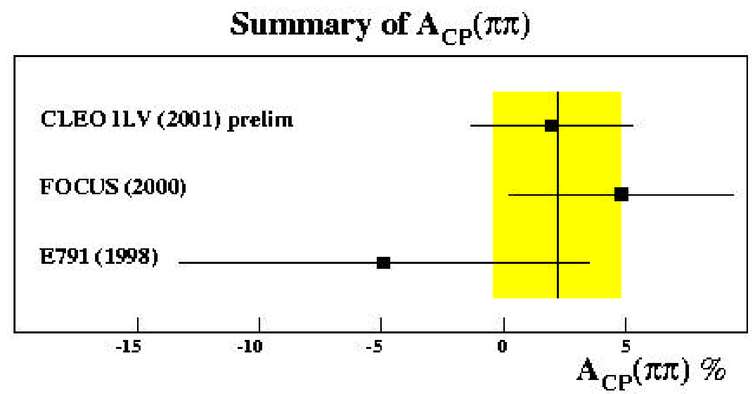


Searches for Direct CP Violation in $D^0 \to K^+K^-, \pi^+\pi^-$

$$A(K^+K^-) = 0.0005 \pm 0.0218 \text{ (stat)} \pm 0.0084 \text{ (syst)}$$
$$A(\pi^+\pi^-) = 0.0195 \pm 0.0322 \text{ (stat)} \pm 0.0084 \text{ (syst)}$$

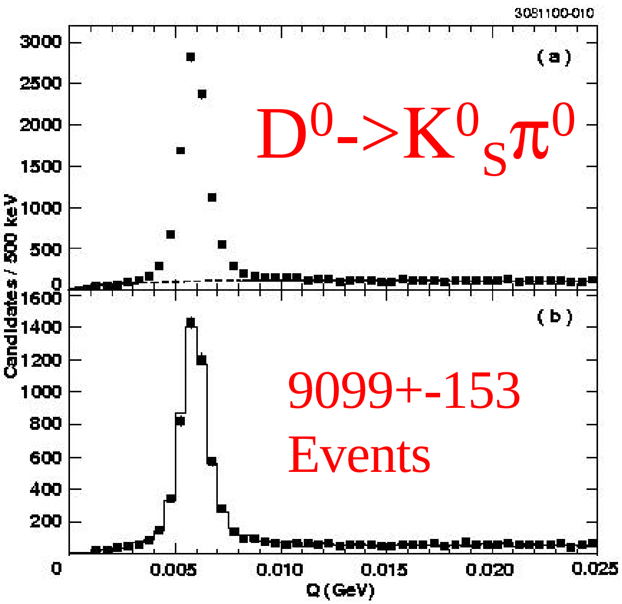
Preliminary

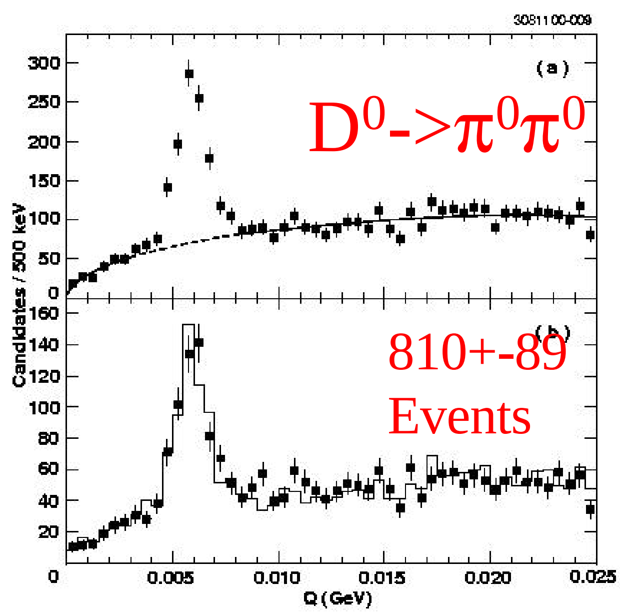


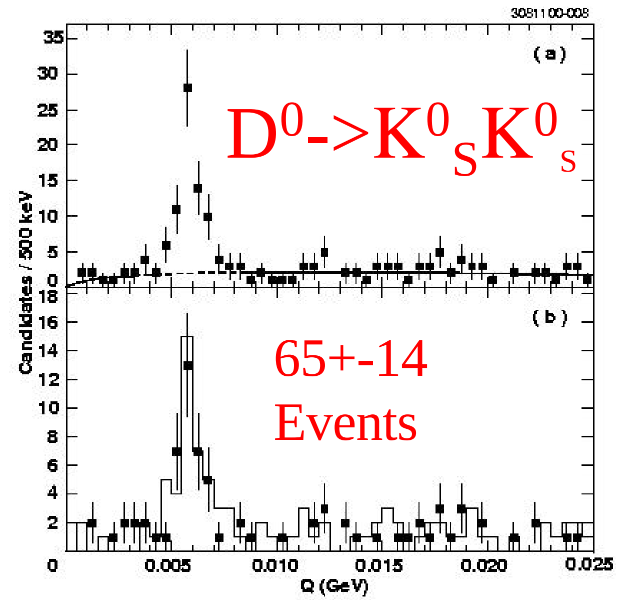


Searches for Direct CP Violation in $D^0 \to K^0_S\pi^0$, $\pi^0\pi^0$, and $K^0_SK^0_S$

- Do not have well-reconstructed D^0 direction to refit slow pion
- 13.7 fb^{-1} from both CLEO II and CLEO II.V configurations
  - No benefit from silicon vertex detector in this mode
- Analysis method:
  - Reconstruct K^0_S in $\pi^+\pi^-$ mode
  - Select candidate events near D^0 mass
  - Fit to Q side bands
  - Background subtract to obtain yields
  - Implicit assumption of no CP asymmetry in background







Searches for Direct CP Violation in $D^0 \to K^0_S\pi^0$, $\pi^0\pi^0$, and $K^0_SK^0_S$

- Systematic errors: Potential false asymmetries from
  - Fit method: 0.5%
  - Background: 0.35% in $K^0_S\pi^0$, 12% in $K^0_SK^0_S$, negl. in $\pi^0\pi^0$
  - Slow pion finding: 0.19%
- Asymmetry results:
  - Significant improvement over previous measurement in $K^0_S\pi^0$ channel
  - First measurements in $\pi^0\pi^0$, and $K^0_SK^0_S$ channels

$$A(K_S^0\pi^0) = \left(+0.1 \pm 1.3\,(\mathrm{stat}+\mathrm{syst})\right)\%$$

$$A(\pi^0\pi^0) = \left(+0.1 \pm 4.8\,(\mathrm{stat}+\mathrm{syst})\right)\%$$

$$A(K_S^0K_S^0) = \left(-23 \pm 19\,(\mathrm{stat}+\mathrm{syst})\right)\%$$

Preliminary

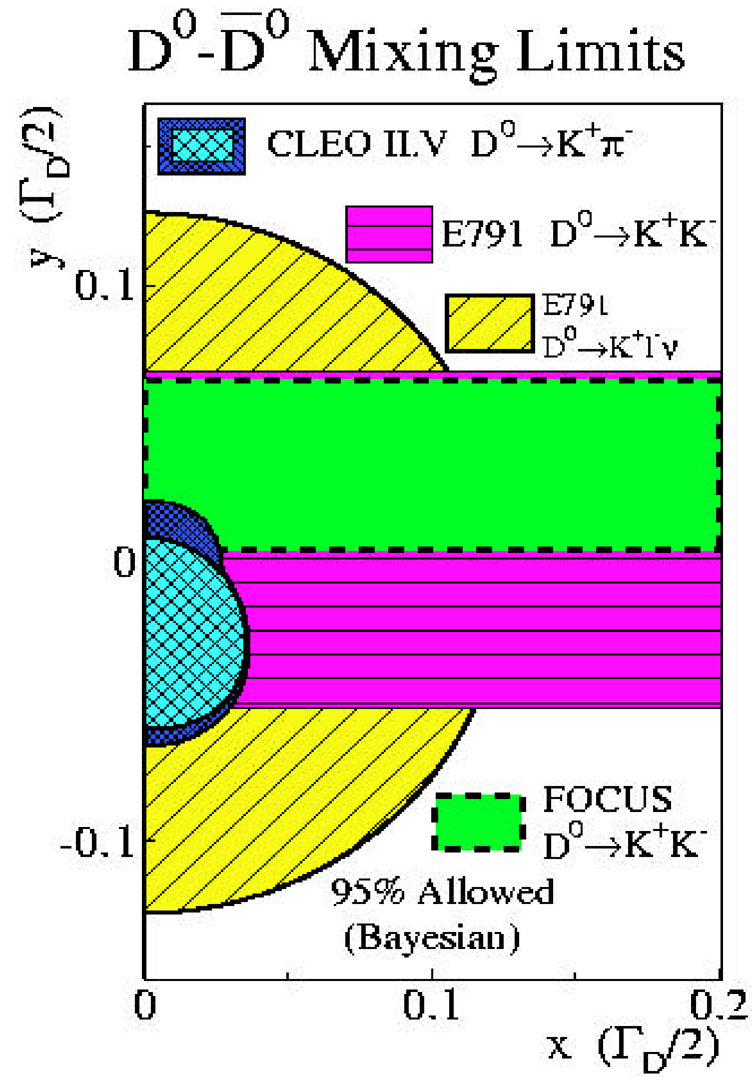
Measurement of y Using CP-even Decays of D^0 to K^+K^- and p^+p^-

- Theorists trying to reconcile CLEO $D^0 \to K^+\pi^-$ and FOCUS $D^0 \to K^+K^-$ measurements

  A. Petrov, hep-ph/0009160

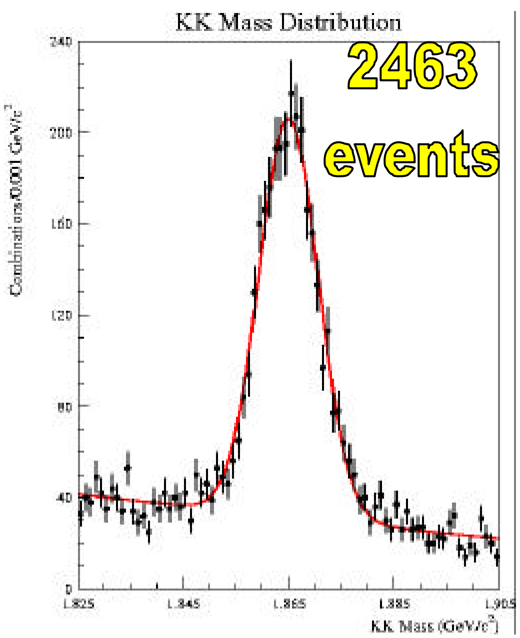
- Possible explanations:
  - y of order few percent?!
    - Would be very surprising
  - Very large strong phase between Cabibbo-favored decay and DCSD (very large SU(3) symmetry breaking)
- Experimentally, we compare lifetime with well-measured $D^0 \to K^-\pi^+$ mode:

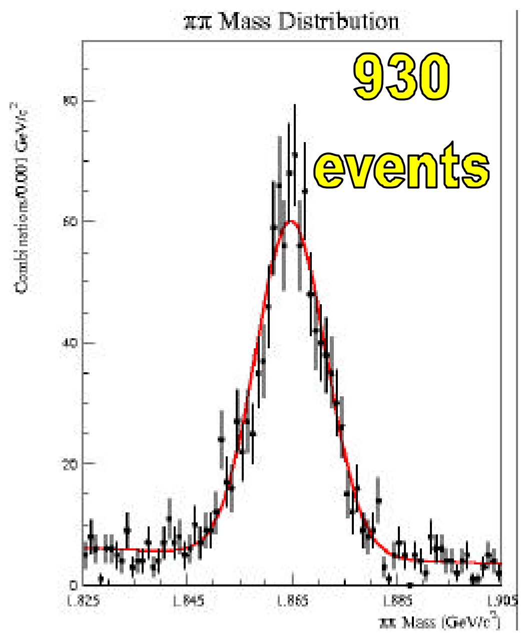
$$y = \frac{\tau_{\overline{CP}}}{\tau_{CP^+}} - 1, \quad \overline{CP} \equiv CP \text{ neutral state}$$

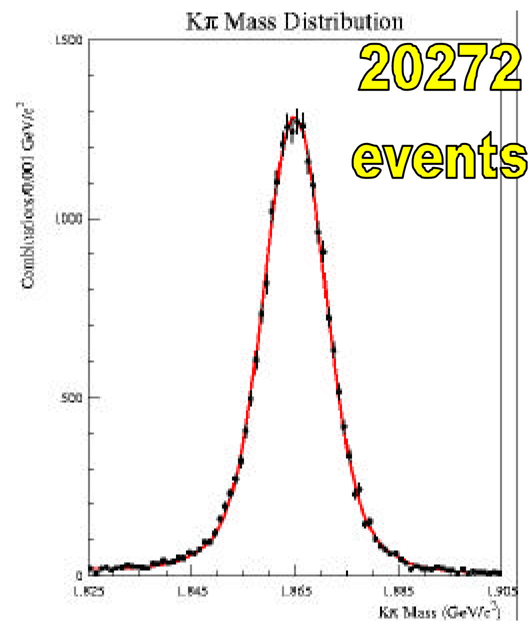


Analysis Technique

- Use $D^{*+} \rightarrow D^0\pi^+_{slow}$ tag to reduce background
  - Select signal region in Q
- Reconstruct D^0 proper time
- Fit the proper time distribution to determine the D^0 lifetime

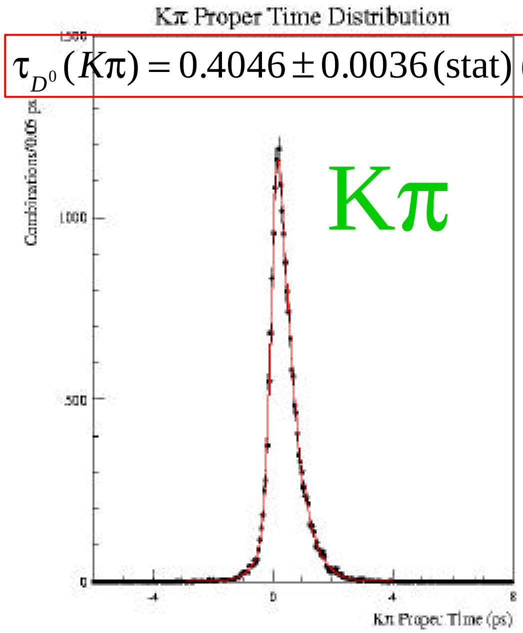




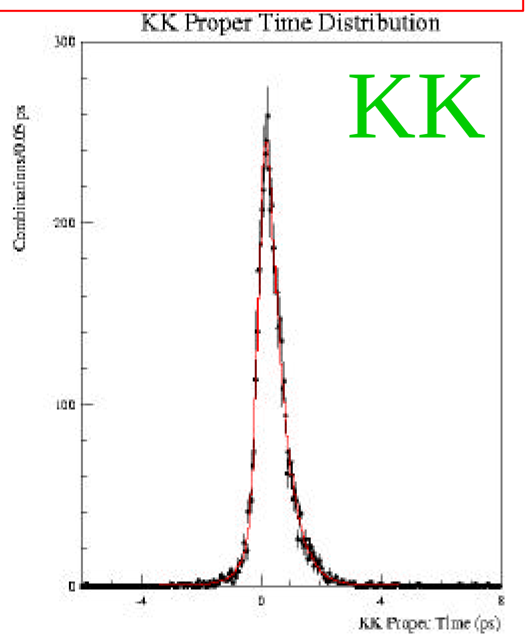


Determination of D^0 Lifetime in $D^0 \to K^-\pi^+$, K^+K^-, $\pi^+\pi^-$

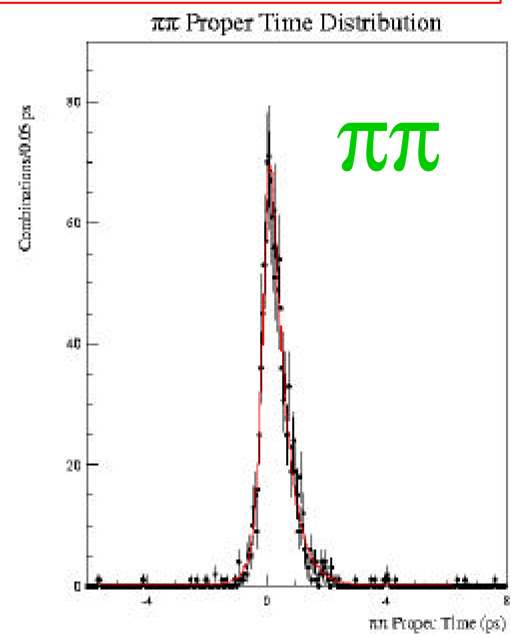
$\tau_{D^0}(K\pi) = 0.4046 \pm 0.0036\,(\text{stat})\,(\text{ps})$



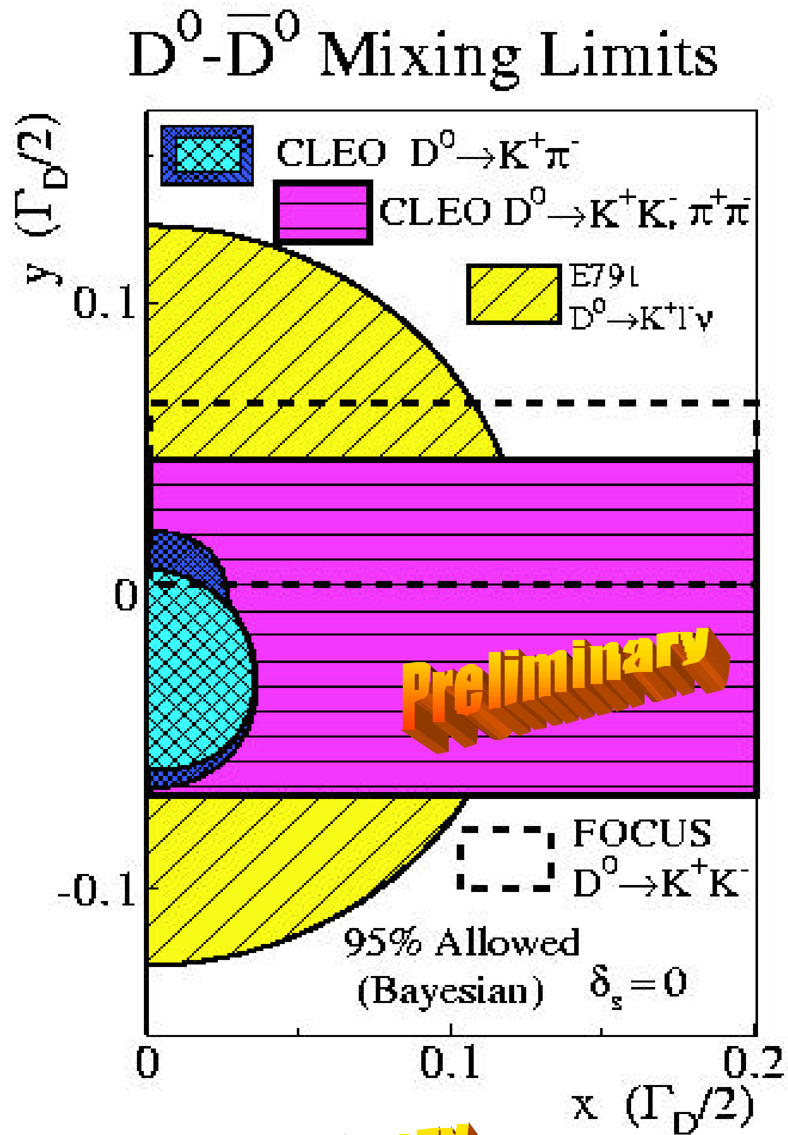
$\tau_{D^0}(KK) = 0.411 \pm 0.012\,(\text{stat})\,(\text{ps})$



$\tau_{D^0}(\pi\pi) = 0.401 \pm 0.017\,(\text{stat})\,(\text{ps})$



- **Unbinned maximum likelihood fit to proper time**
  - Resolution from measured proper time error and two Gaussians
  - Parameters of fit:
    - Number of signal events
    - D^0 lifetime
    - Background fraction
    - Fraction of background with lifetime
    - Lifetime of background
    - Fraction of mismeasured events
    - Error of mismeasured events



y Results

- Consistent with
  - CLEO D^0->$K^+\pi^-$ measurement
  - FOCUS D^0->K^+K^- measurement
  - E791 measurement (not shown)
- Dominant systematic errors due to:
  - Stat. uncertainty of MC lifetime correction study (0.009ps)
  - Background description (0.008 ps)
  - Proper time resolution model (0.005 ps)
  - Fit procedure (0.005 ps)

$$y_{K^+K^-} = -0.019 \pm 0.029\,(\text{stat}) \pm 0.016\,(\text{syst})$$

Preliminary

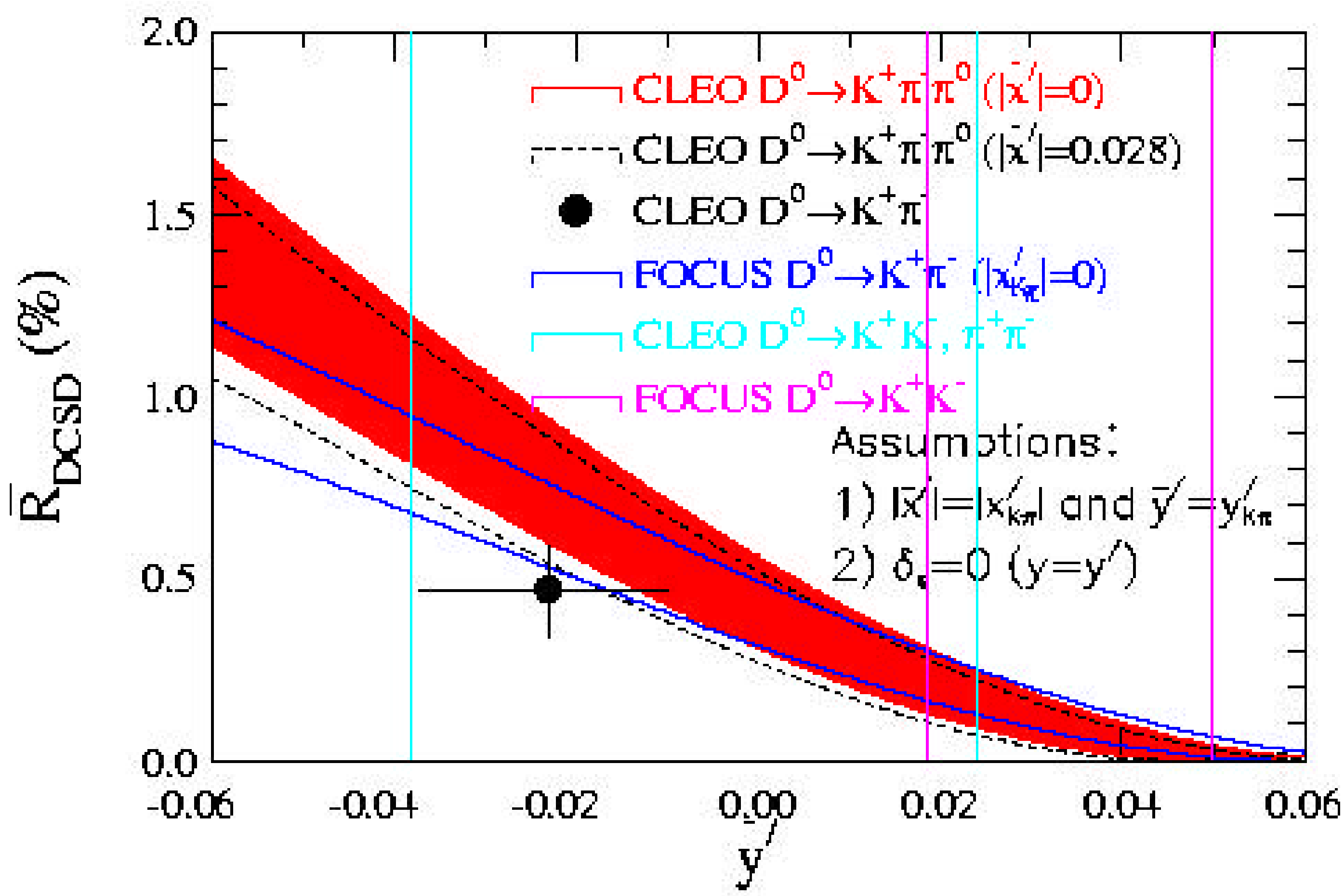
$$y_{\pi^+\pi^-} = 0.005 \pm 0.043\,(\text{stat}) \pm 0.018\,(\text{syst})$$

Preliminary

$$y = -0.011 \pm 0.025\,(\text{stat}) \pm 0.014\,(\text{syst})$$

Mixing and DCSD Limits

Assuming strong phase, δ_s, between CFD and DCSD of zero



Conclusions

- Best measurement of the D^{*+} width:

$$\Gamma\left(D^{*+}\right) = 96 \pm 4\,(\text{stat}) \pm 22\,(\text{syst})\ \text{keV}$$

Preliminary

- First measurement of “wrong sign” rate in $D^0 \to K^+\pi^-\pi^0$:

$$R_{WS} = \left(0.43^{+0.11}_{-0.10}\,(\text{stat.}) \pm 0.07\,(\text{syst.})\right)\%$$

Preliminary

  – Combined proper time/Dalitz fit under study -- stay tuned!

- New direct CP violation search results

$$A(K_S^0\pi^0) = \left(+0.1 \pm 1.3\,(\text{stat}+\text{syst})\right)\%$$
$$A(\pi^0\pi^0) = \left(+0.1 \pm 4.8\,(\text{stat}+\text{syst})\right)\%$$
$$A(K_S^0K_S^0) = \left(-23 \pm 19\,(\text{stat}+\text{syst})\right)\%$$

Preliminary

$$A\left(K^+K^-\right) = 0.0005 \pm 0.0218\,(\text{stat}) \pm 0.0084\,(\text{syst})$$
$$A\left(\pi^+\pi^-\right) = 0.0195 \pm 0.0322\,(\text{stat}) \pm 0.0084\,(\text{syst})$$

Preliminary

- New y measurement:

$$y = -0.011 \pm 0.025\,(\text{stat}) \pm 0.014\,(\text{syst})$$

Preliminary