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

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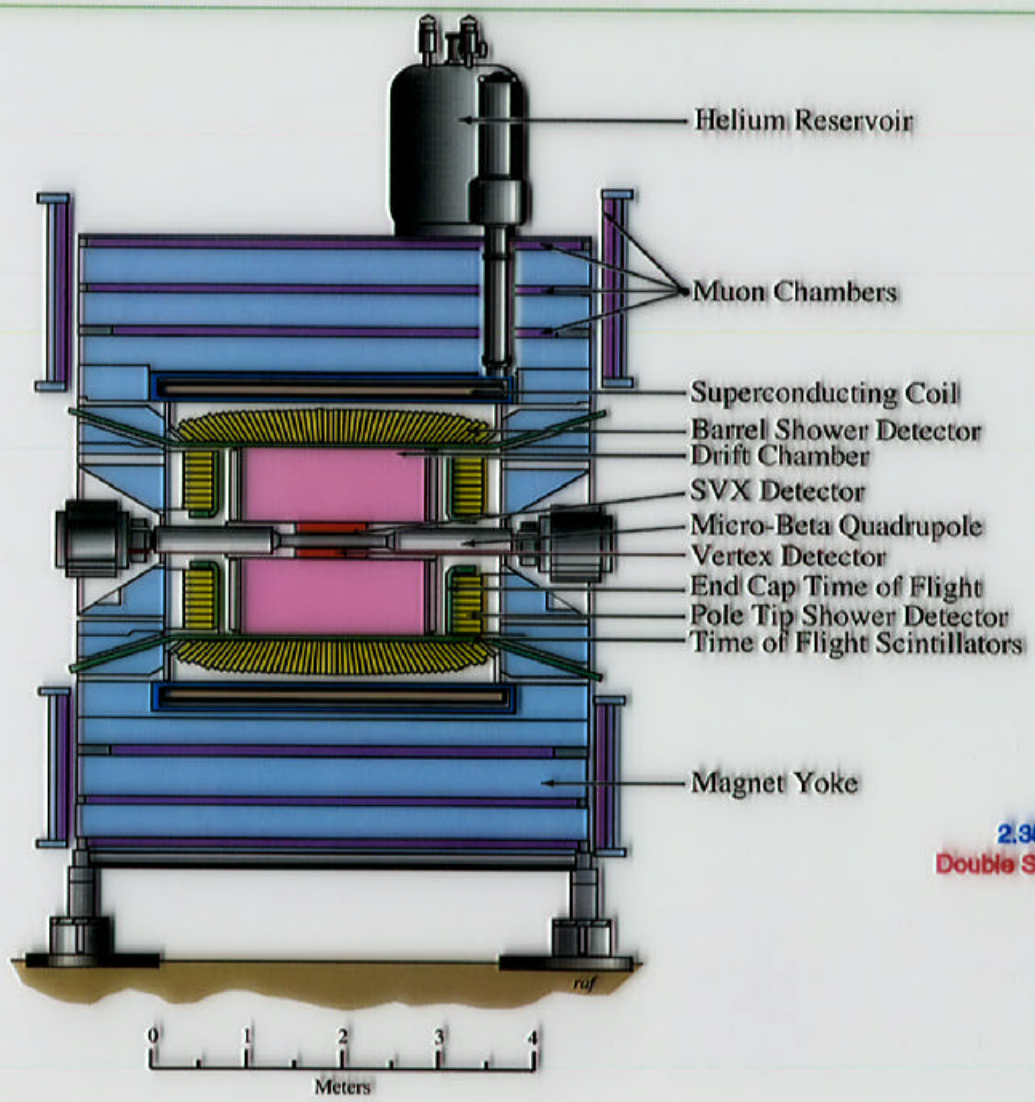
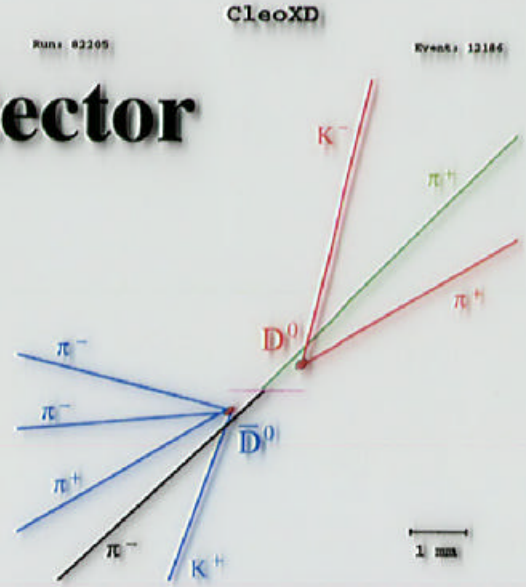
- Intrinsic width measurement of the D^{*+}
- New CLEO results on D^0-$\overline{D^0}$ mixing and CP violation
  - First measurement of "wrong-sign" $D^0 \to K^+\pi^-\pi^0$ rate
  - Searches for CP violation in D^0 decays to pseudoscalar particles
  - Measurement of the mixing parameter y using CP even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

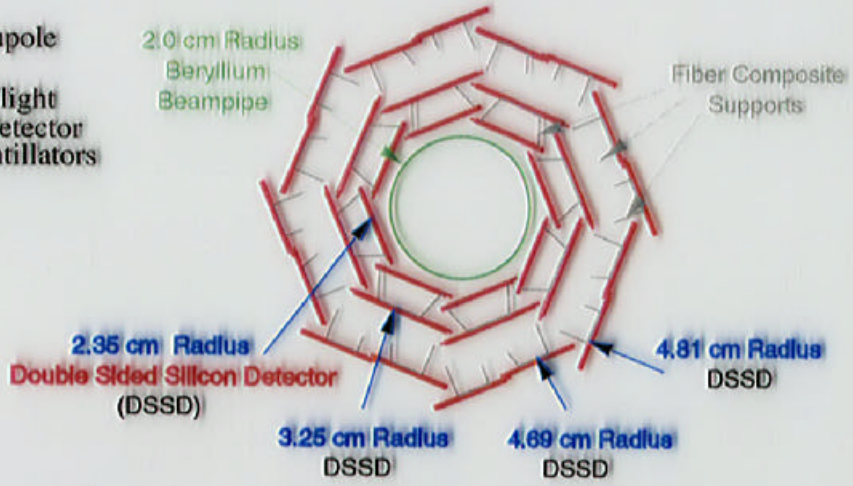
The CLEO II.V Detector

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

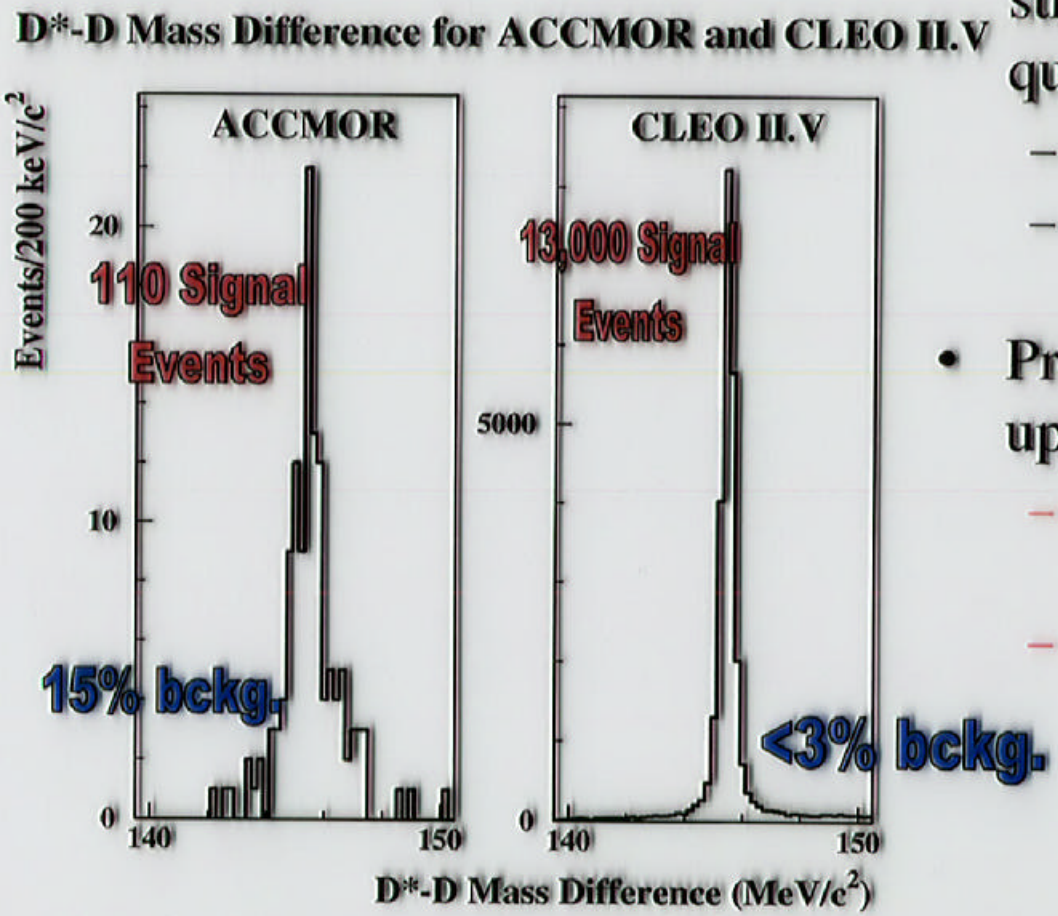
9 fb-1 of integrated luminosity







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

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

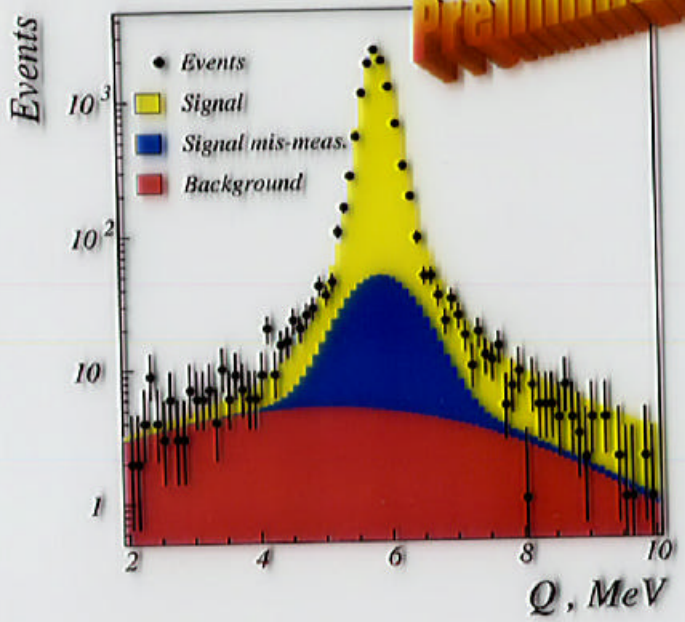
(charge-conjugate modes implied throughout this talk)

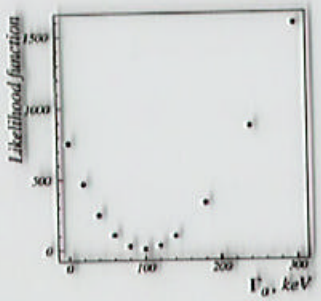
- Experimentally, we measure the energy released in the D^{*+} decay, Q:

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

- $\Gamma(D^{*+})$ 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



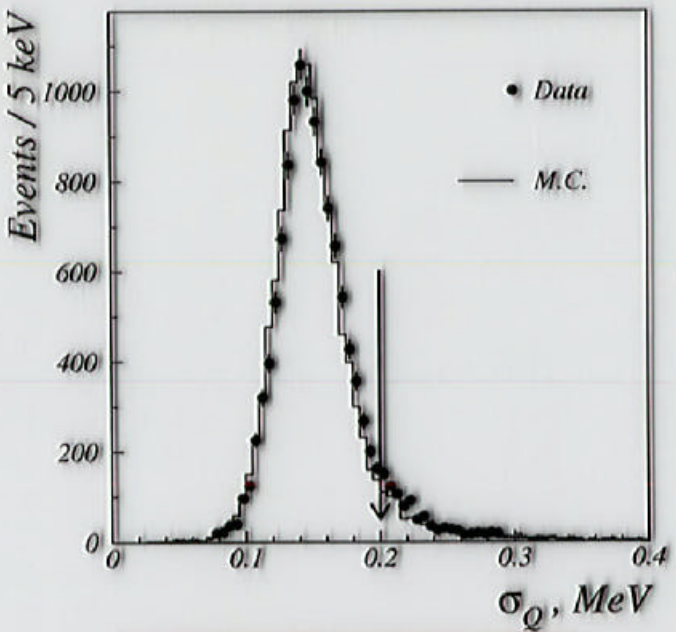


- Unbinned maximum likelihood fit to Q
- Fit to Breit-Wigner line shape
- Input measured Q and σ_Q for each event
- Variables in fit:
  - $\Gamma(Q)$, $\langle Q \rangle$
  - N_s : number of signal events
  - f_{mis} : fraction of mismeasured signal events
  - σ_{mis} : resolution of mismeasured events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

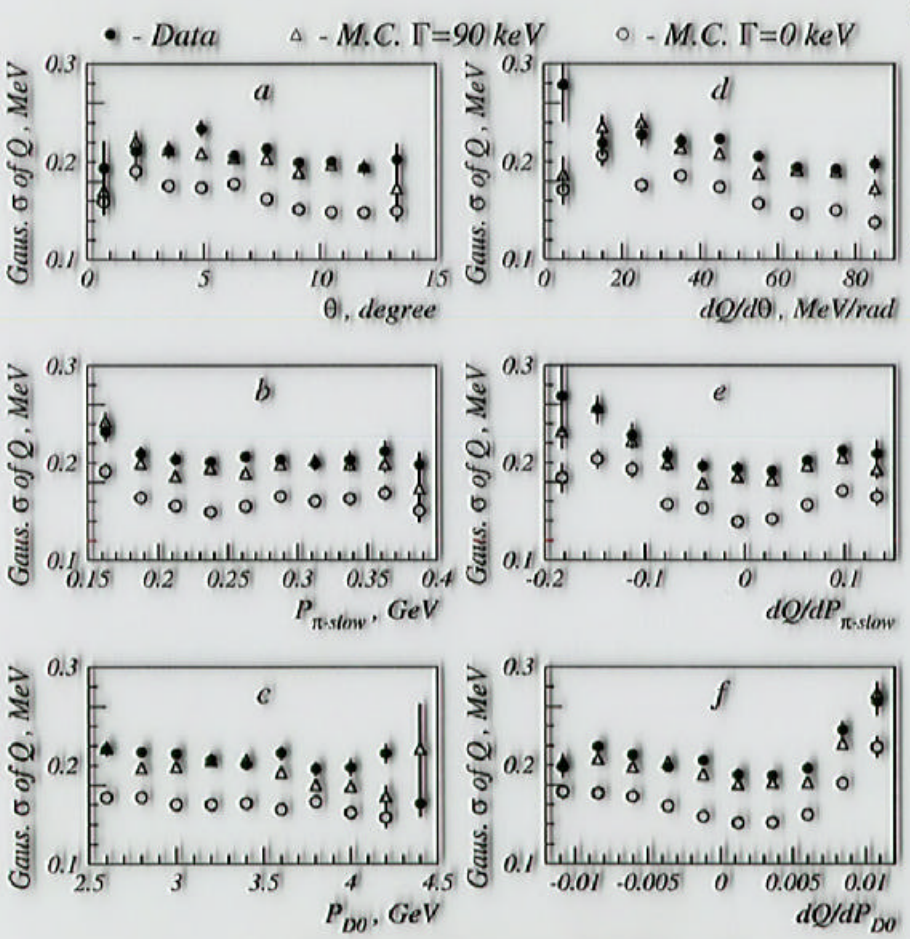
Tests of the Detector Simulation



$\sigma_Q \approx 150\,keV$

- Excellent agreement of resolution between Monte Carlo and data
  - No corrections necessary
- All known contributions to resolution carefully checked in simulation
  - Multiple Coulomb scattering in SVX of π_{slow}
  - Tracking resolution of π_{slow}
  - etc...

Tests of the Detector Simulation



Gaussian width of Q peak (resolution + intrinsic)

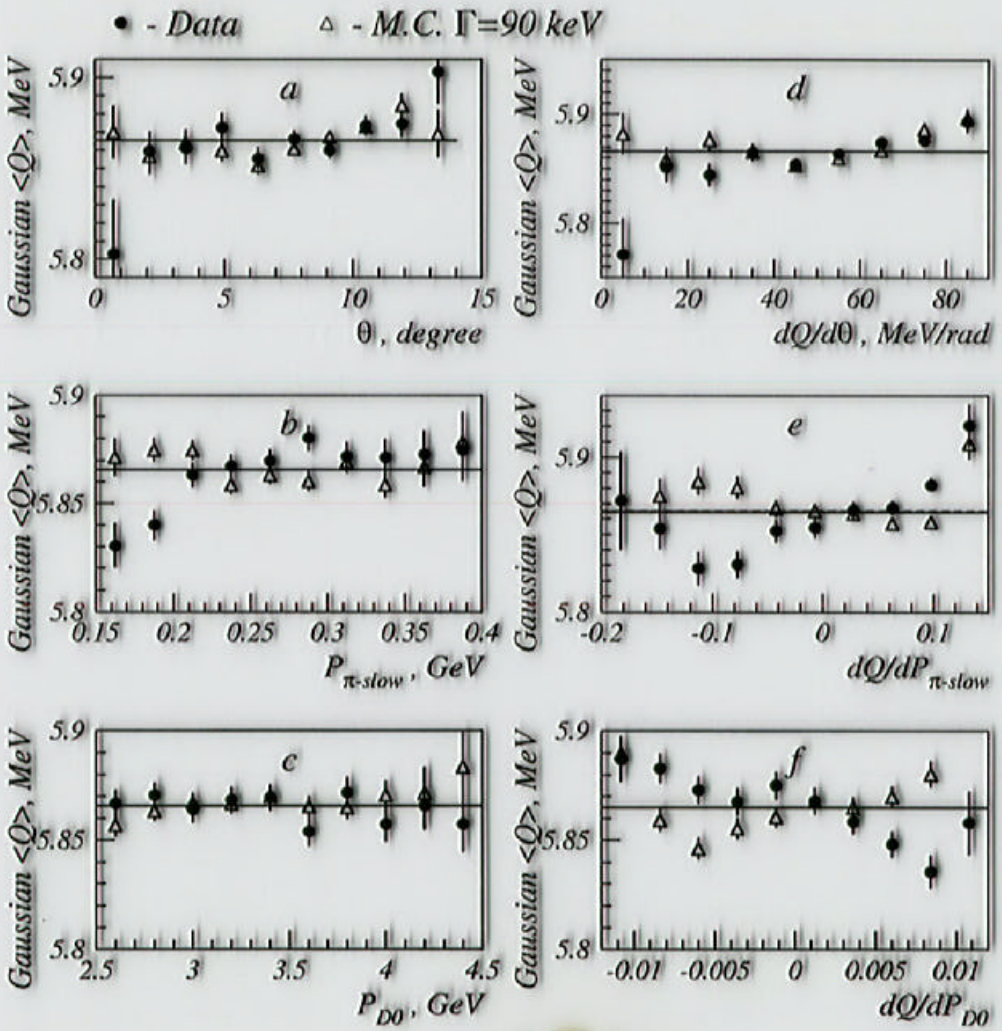
- Mis-modeling of the tracking resolution will effect kinematic variables of decay
- Test for mis-modeling of key variables of decay:

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

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

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

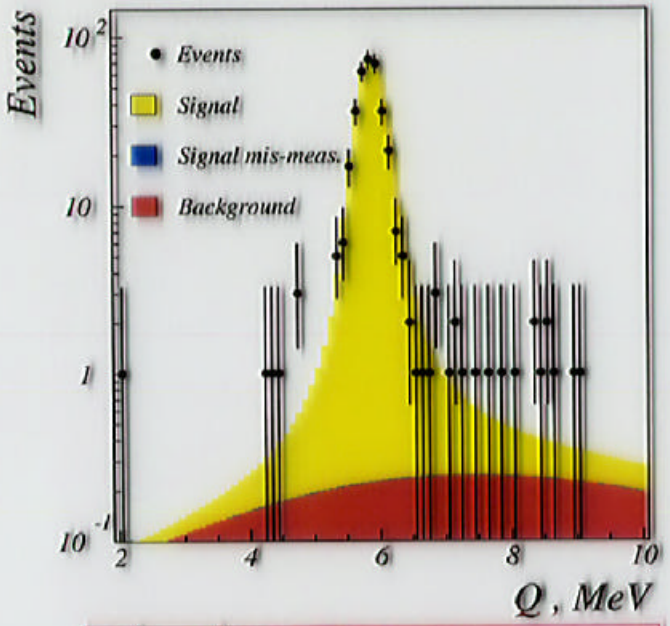
Tests of the Detector Simulation



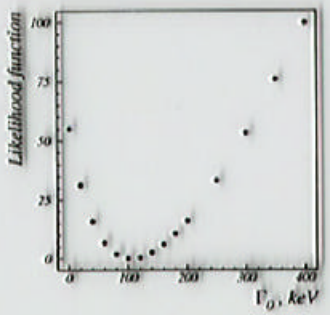
<Q>

- 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

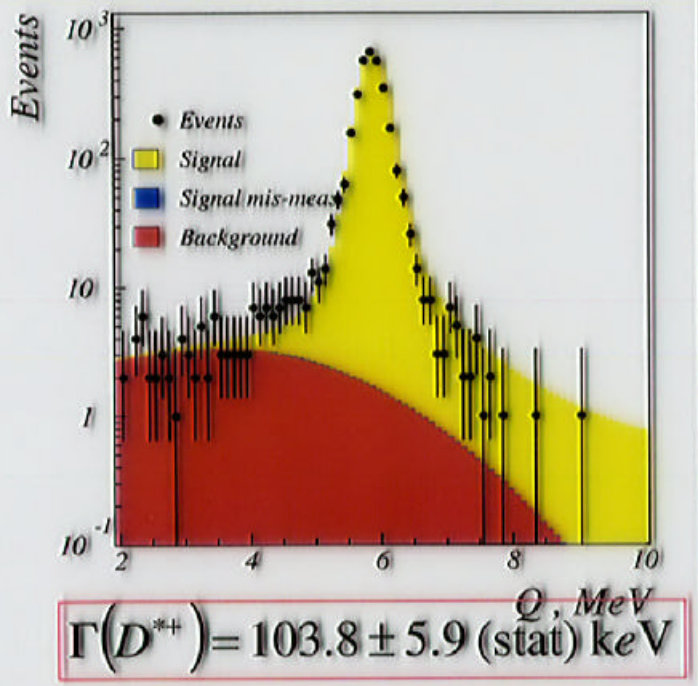


$$\Gamma\left(D^{*+}\right) = 104 \pm 20\,(\text{stat})\ \text{keV}$$

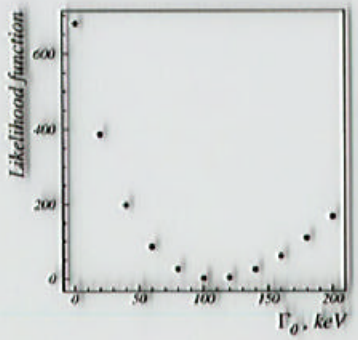


- Fit to sample with tight tracking selection
- Apply very tight cuts to tracks to remove tracking mistakes
  - SVX hits in both views on all layers
  - No hits within 2 mm of silicon wafer edge
  - Large fraction of possible drift chamber hits
  - Tight matching of tracks between tracking devices
-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

Test Sensitivity to Mismodeling of Decay Kinematics



$$\Gamma(D^{*+}) = 103.8 \pm 5.9\,(\text{stat})\ \text{keV}$$



- 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

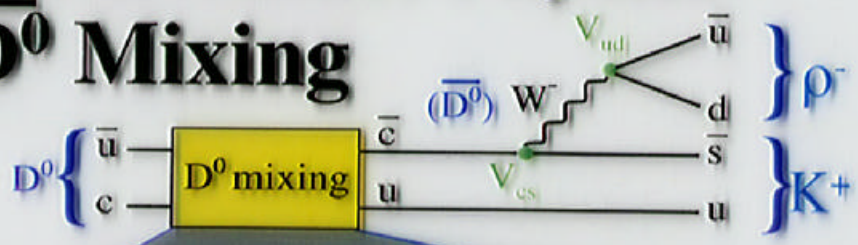
- We measure the D*+ width with best precision yet:

Preliminary

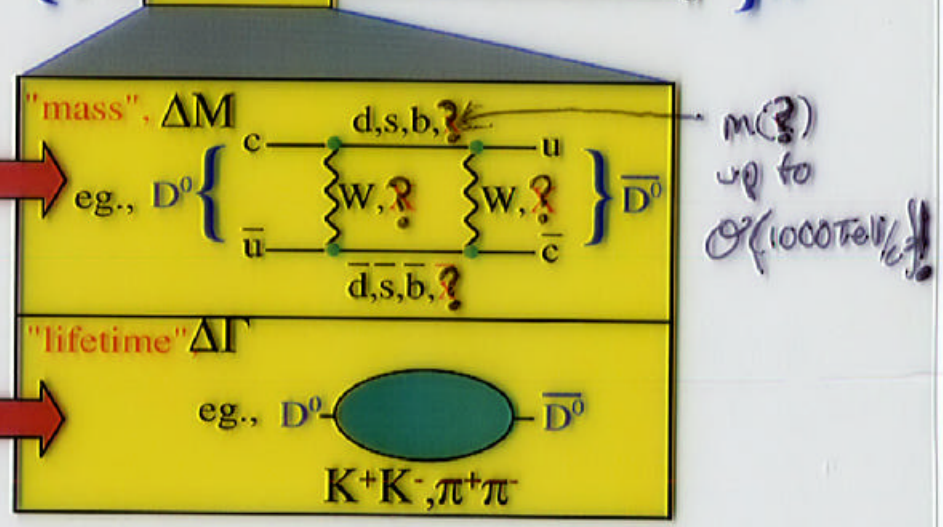
$$\Gamma\left(D^{*+}\right) = 96 \pm 4\,(\text{stat}) \pm 22\,(\text{syst})\,\text{keV}$$

- 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



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



m(?) up to $\mathcal{O}(1000\,\mathrm{TeV}/c^2)$!

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

Standard Model prediction:

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

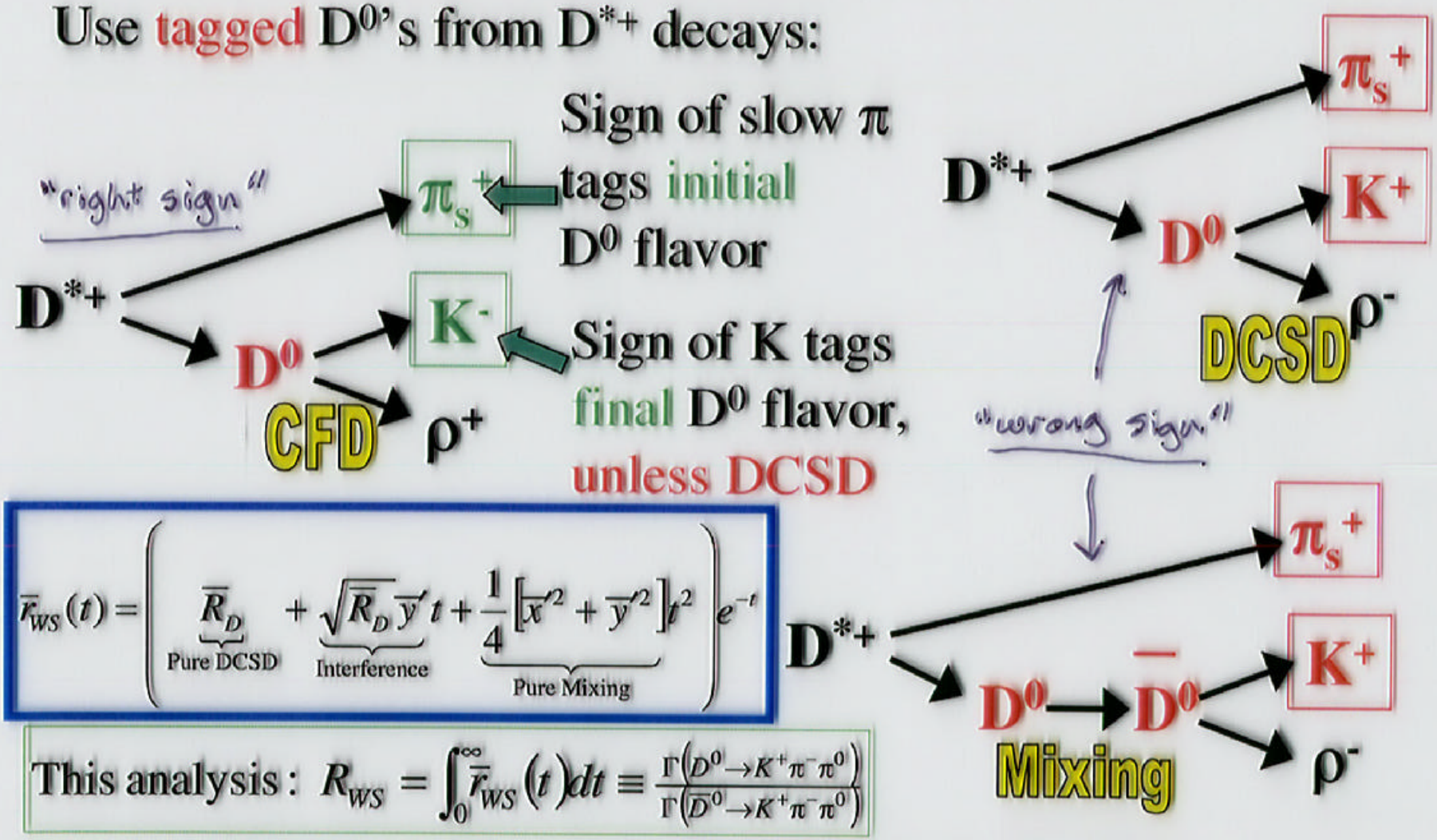
Signatures of Non-Standard model physics:

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

"Wrong Sign" $D^0 \to K^+\pi^-\pi^0$

Analysis Technique

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



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

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

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

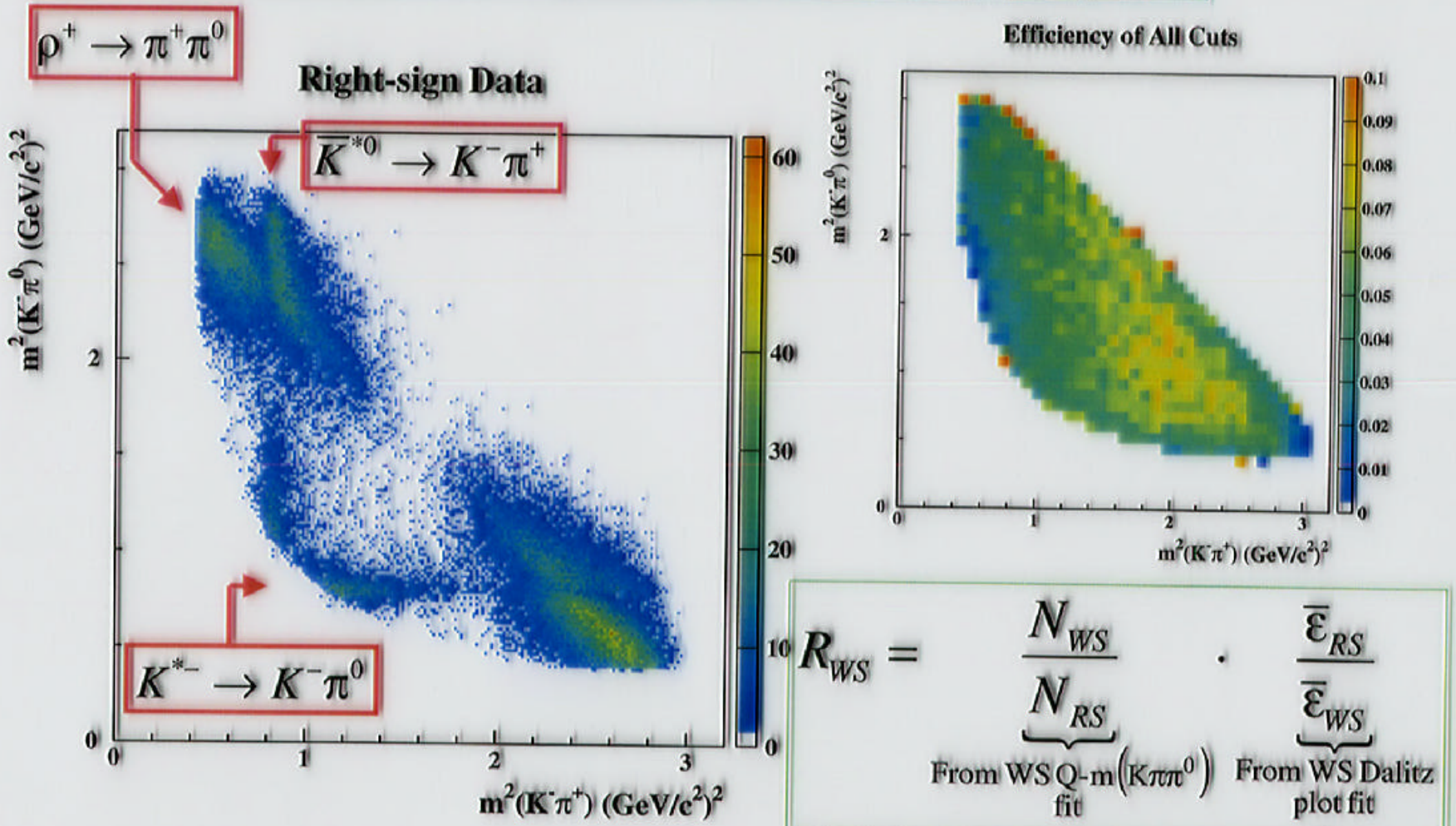
Data Sample and Selection

- 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

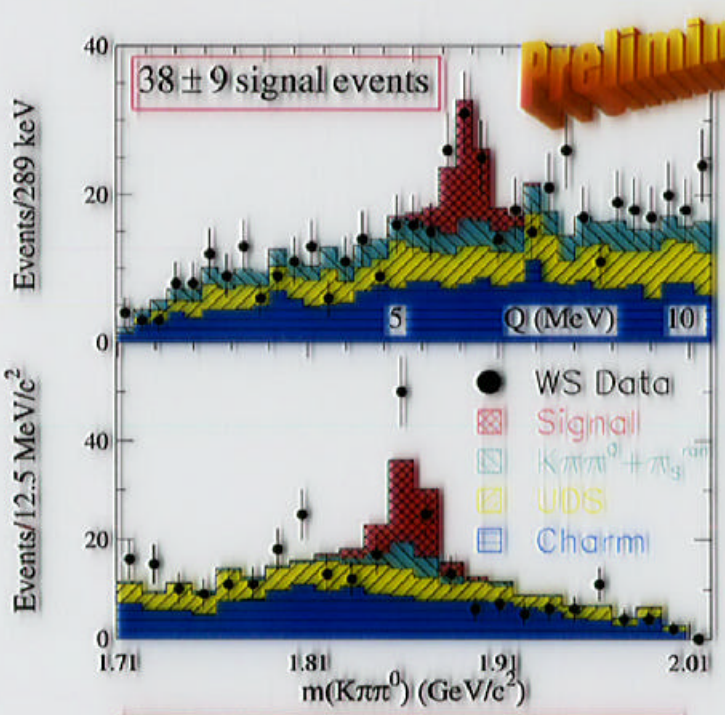
CLEO finds rich RS Dalitz plot : $\rho(770)^+$, $K^*(892)^-$, $\overline{K^*}(892)^0$, $\rho(1700)^+$, $K_0(1430)^-$, $\overline{K_0}(1430)^0$, $K^*(1680)^-$, non - resonant

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



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

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 = 4.9σ

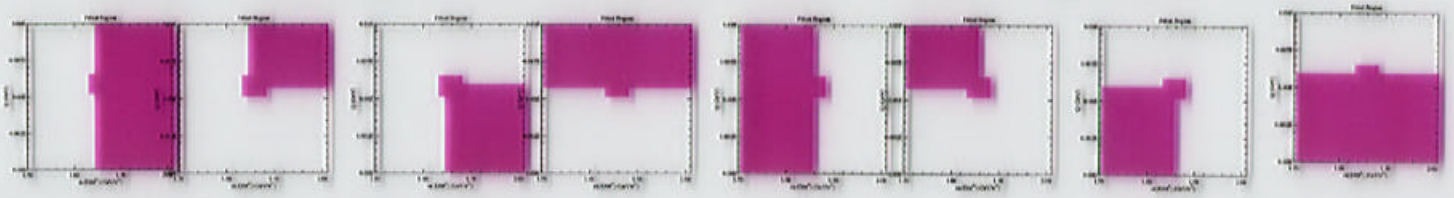
Determination of Efficiency Ratio Correction

- **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 $\measuredangle(K^{*0}\pi^0)$, $\phi(K^{*0}\pi^0)$, $\measuredangle(K^{*+}\pi^-)$, and $\phi(K^{*+}\pi^-)$ to float relative to $K^+\rho^-$ mode
  - $\measuredangle$ 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
- Rather surprising result — stay tuned for more

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

Important Systematic Errors in R_{WS} Measurement

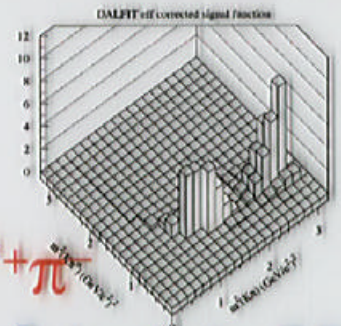
- Q - m($K\pi\pi^0$) background shapes: fits to sub-regions : 14%



- Efficiency ratio: 9%

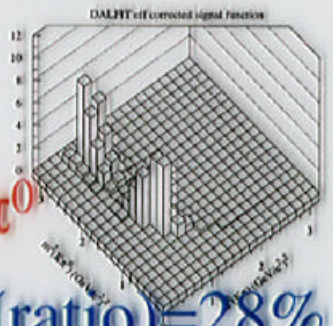
Correction

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



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

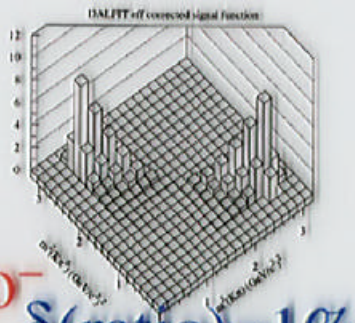
δ (ratio)=2%



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

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