Charm Physics at CLEO

Centennial APS Meeting

Mats Selen, University of Illinois
(speaking for the CLEO collaboration)

March 23, 1999

This Presentation:

- New D^0 mixing results
  - $K\pi$ mixing analysis (including lifetime) (David Asner)
  - CP-even KK and $\pi\pi$ lifetime results (Tony Hill)

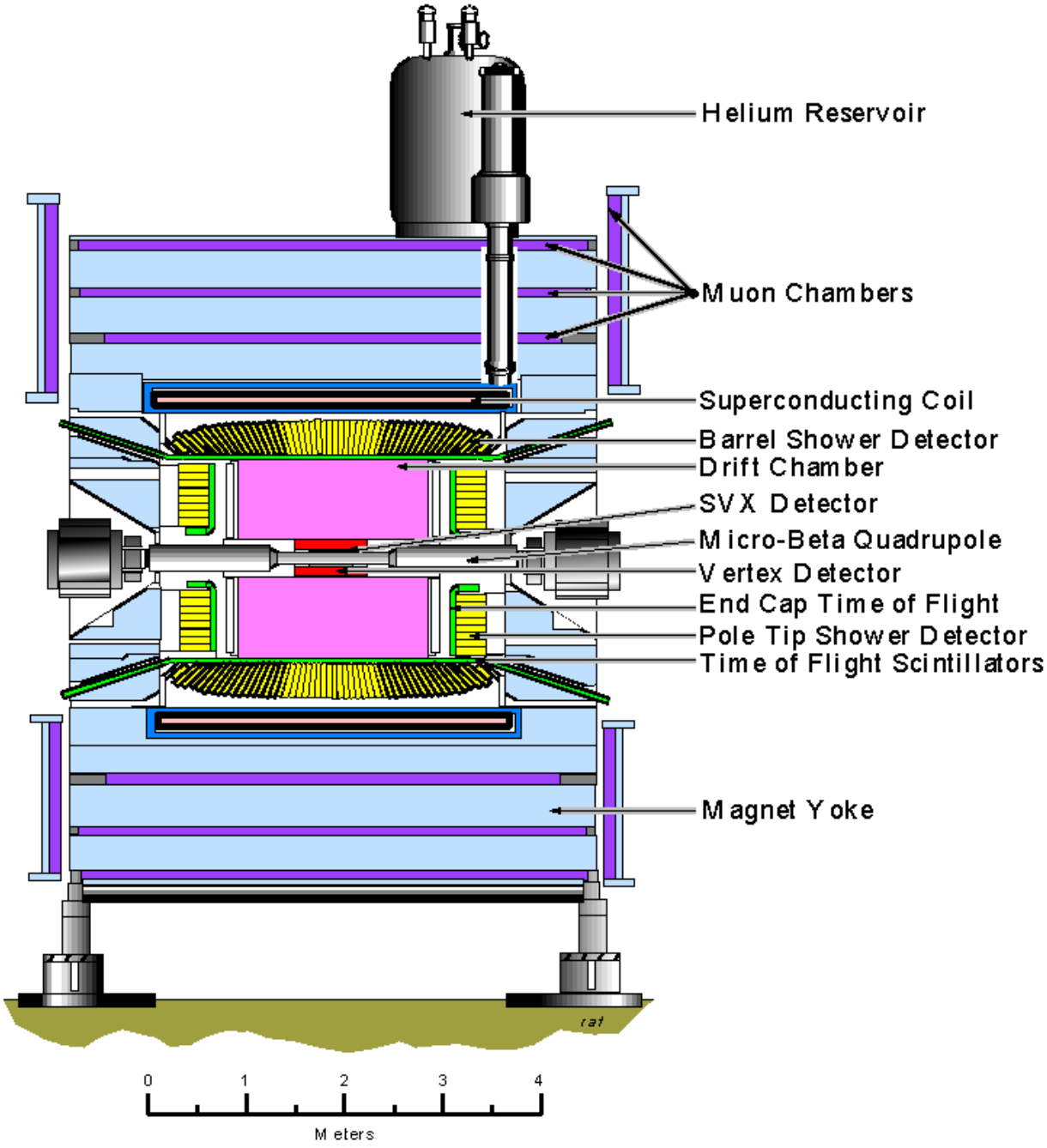
- Charmed Meson Spectroscopy
  - First observation of broad $D_1(j=1/2)$ (Tim Nelson, Harry Nelson)

- $B(\Lambda_c \rightarrow pK\pi)$ absolute measurement
  - New method described
  - Preliminary results presented (Dave Besson, Russ Stutz)

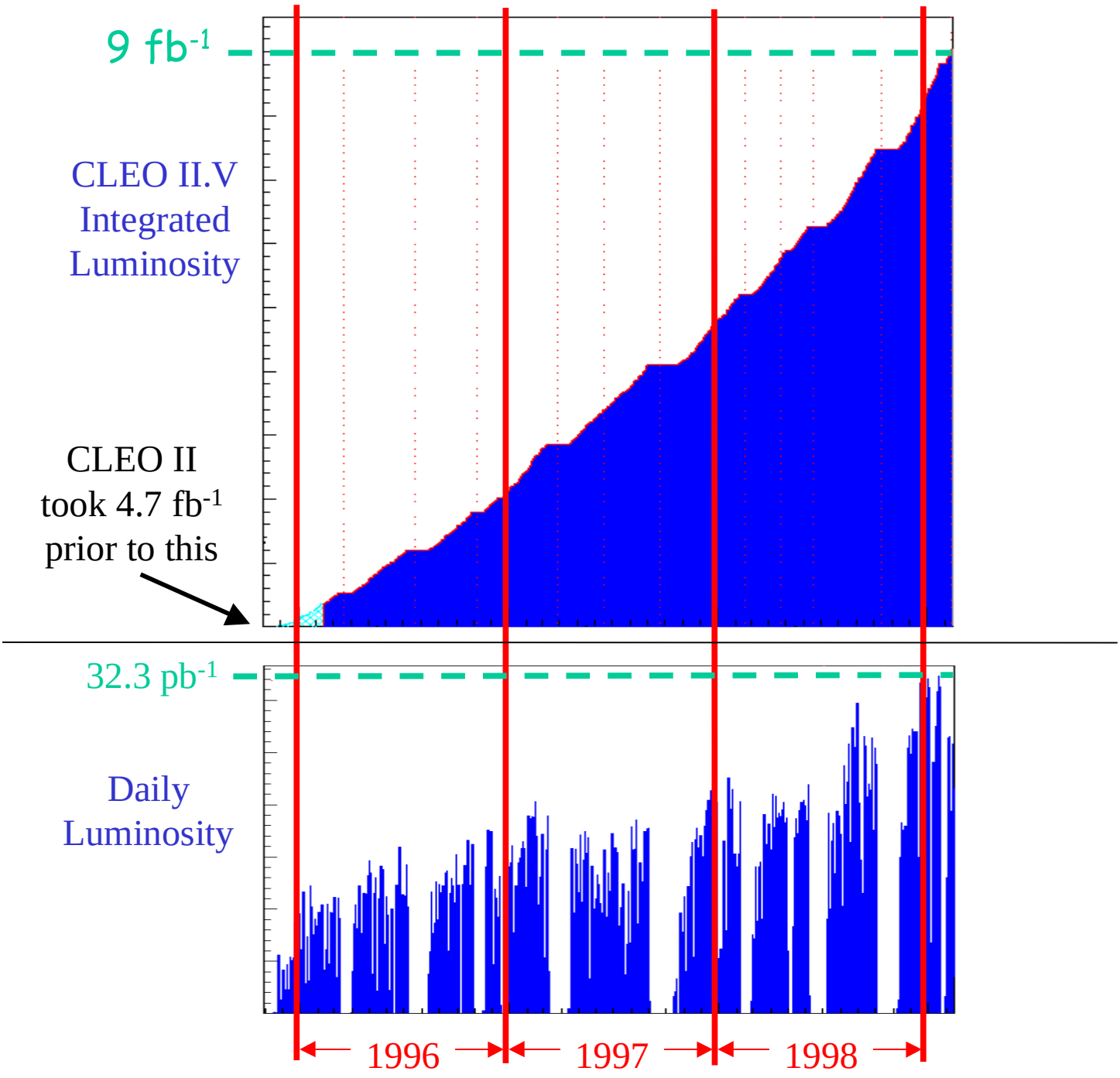
(Charge conjugation implied throughout)

Our Detector: (CLEO-II & II.V)

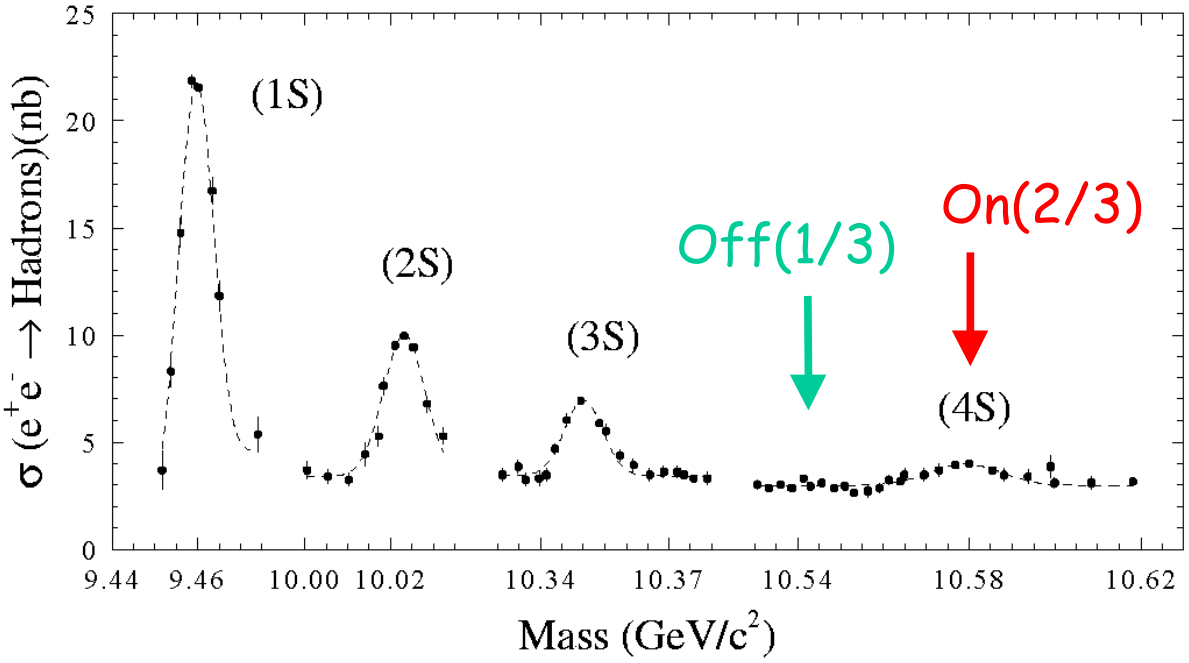
Svx + HePr



Our Accelerator (CESR)



Our Data:



This Presentation:

Mixing Analysis: 5.7 fb^{-1} CLEO-II.V (SVX)

D_J & Λ_c Analyses: 4.7 fb^{-1} CLEO-II

Mixing Analysis:

Time evolution of D & D^0 mesons

$$\frac{\partial}{\partial t}\begin{pmatrix} D^0 \\ \overline{D}^0 \end{pmatrix} = \begin{bmatrix} -iM - \Gamma/2 & -iM_{12} - \Gamma_{12}^*/2 \\ -iM_{12}^* - \Gamma_{12}^*/2 & -iM - \Gamma/2 \end{bmatrix} \begin{pmatrix} D^0 \\ \overline{D}^0 \end{pmatrix}$$

Decay eigenstates

$$|D_L\rangle = p|D^0\rangle + q|\overline{D}^0\rangle$$
$$|D_H\rangle = p|D^0\rangle - q|\overline{D}^0\rangle$$

$$\frac{q}{p} = \sqrt{\frac{M_{12}^* - i\Gamma_{12}^*}{M_{12} - i\Gamma_{12}}}$$

Define $\Delta M = m_H - m_L$ $\Delta\Gamma = \gamma_H - \gamma_L$

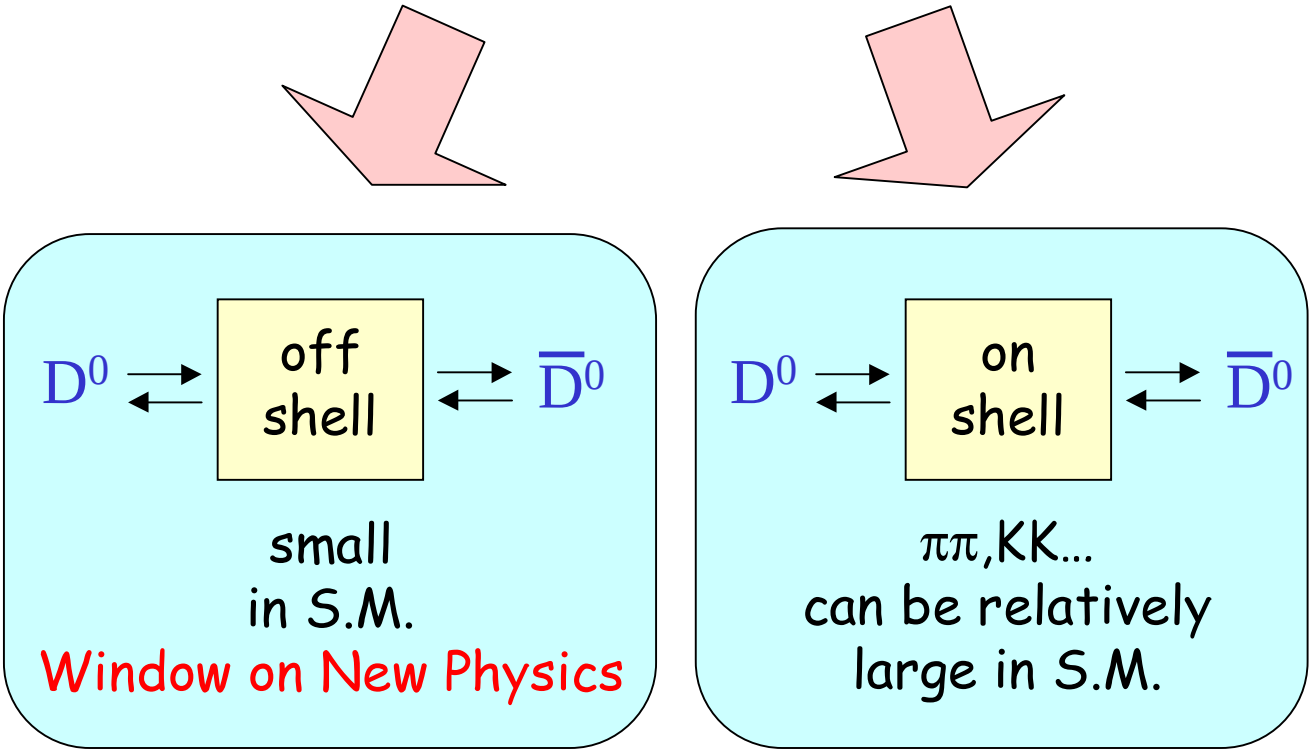
Where

$$m_{L,H} = M \mp \mathrm{Im}\left[(M_{12} - i\Gamma_{12})(M_{12}^* - i\Gamma_{12}^*)\right]$$
$$\gamma_{L,H} = M \mp \mathrm{Re}\left[(M_{12} - i\Gamma_{12})(M_{12}^* - i\Gamma_{12}^*)\right]$$

What we are sensitive to in the Kπ mixing analysis:

$$R_{MIX} = \frac{x^2 + y^2}{2} \qquad \phi = \tan^{-1}\left(-\frac{x}{y}\right)$$

Where $x \equiv \frac{\Delta M}{\Gamma}$ $y \equiv \frac{\Delta\Gamma}{2\Gamma}$

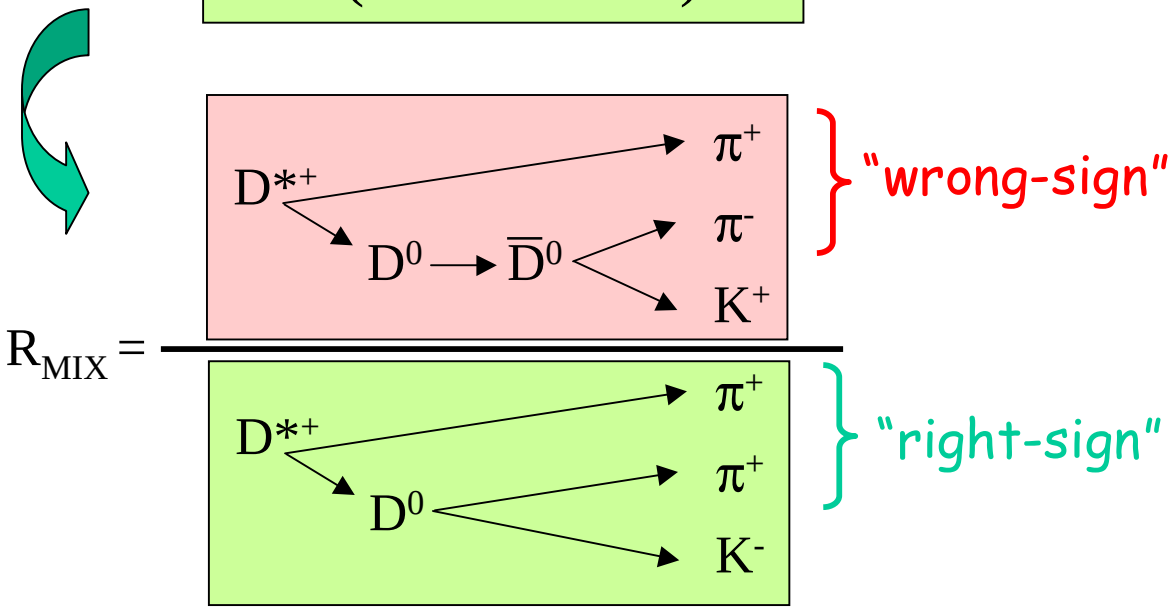


It will eventually be very important to disentangle "x" and "y"

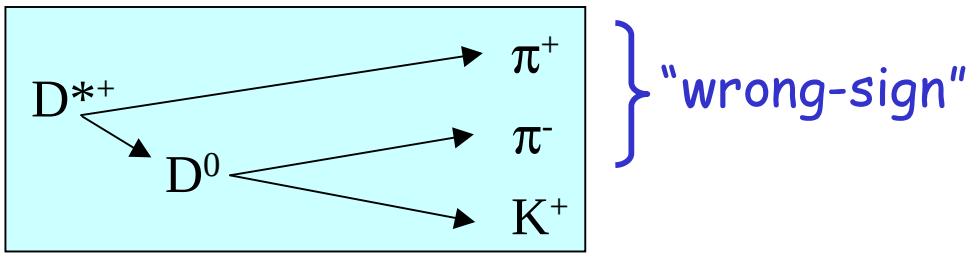
CP eigenstate lifetime analysis will tell us about "y" independent of "x"

Mixing in $D^0 \to K\pi$ decays:

$$R_{MIX} = \frac{B(D^0 \to \overline{D}^0 \to K^+\pi^-)}{B(D^0 \to K^-\pi^+)}$$

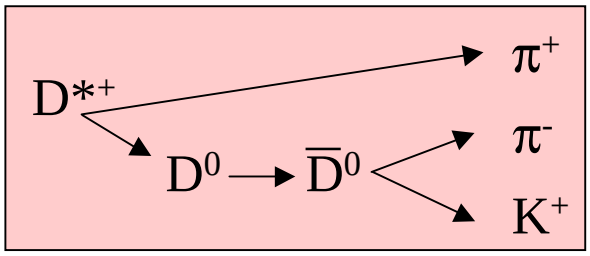


But "wrong-sign" events can also come from Doubly Cabibbo Supressed Decays (DCSD):

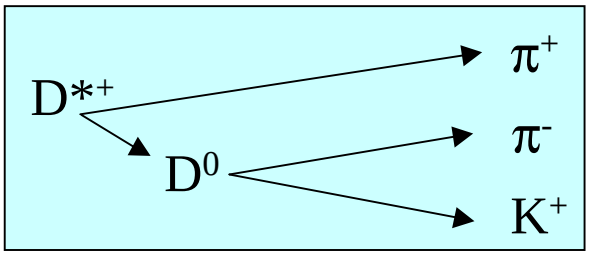


Mixing vs DCSD:

Mixing



DCSD



Same initial & final states !

- Bad news if this is all the info available
- But theres more...

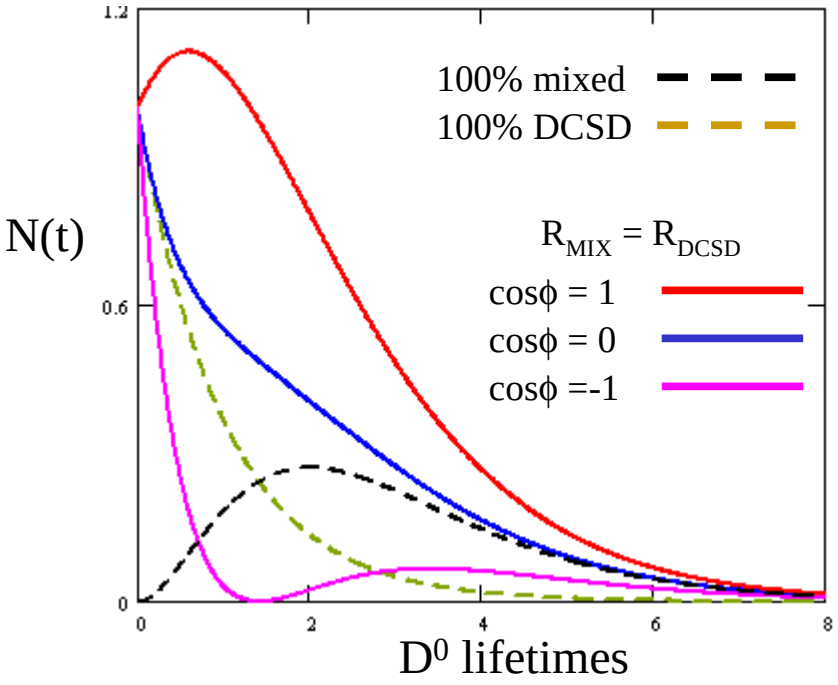
1) Amplitudes evolve differently in time.
2) Amplitudes can interfere.

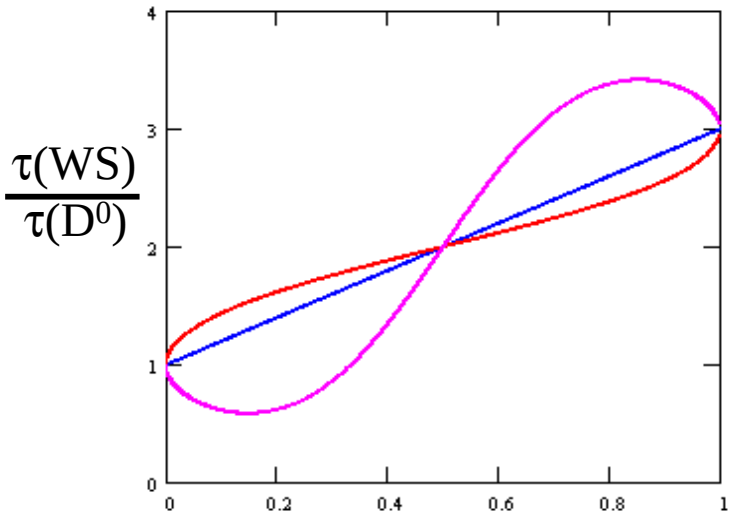
Can use timing information to help untangle Mixing from DCSD

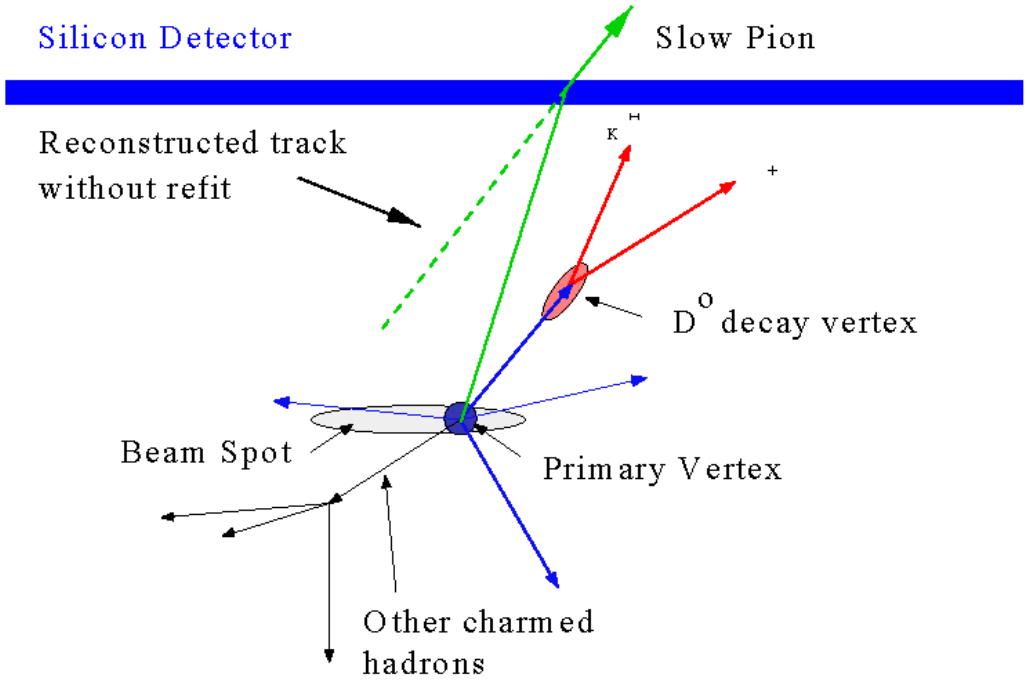
The total "wrong-sign" rate is given by:

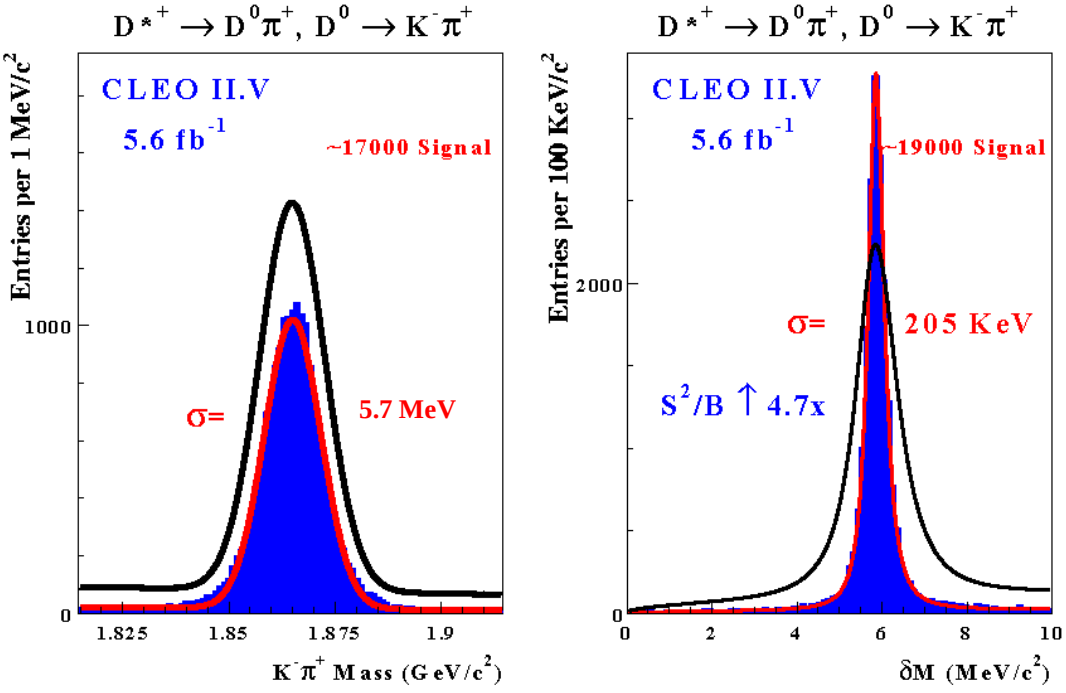
$$N(t) = e^{-t}\left[R_{DCSD} + \sqrt{2R_{DCSD}R_{MIX}} \cdot \cos\phi \cdot t + \frac{R_{MIX}}{2} \cdot t^2 \right]$$

(Where t is measured in D^0 lifetimes)

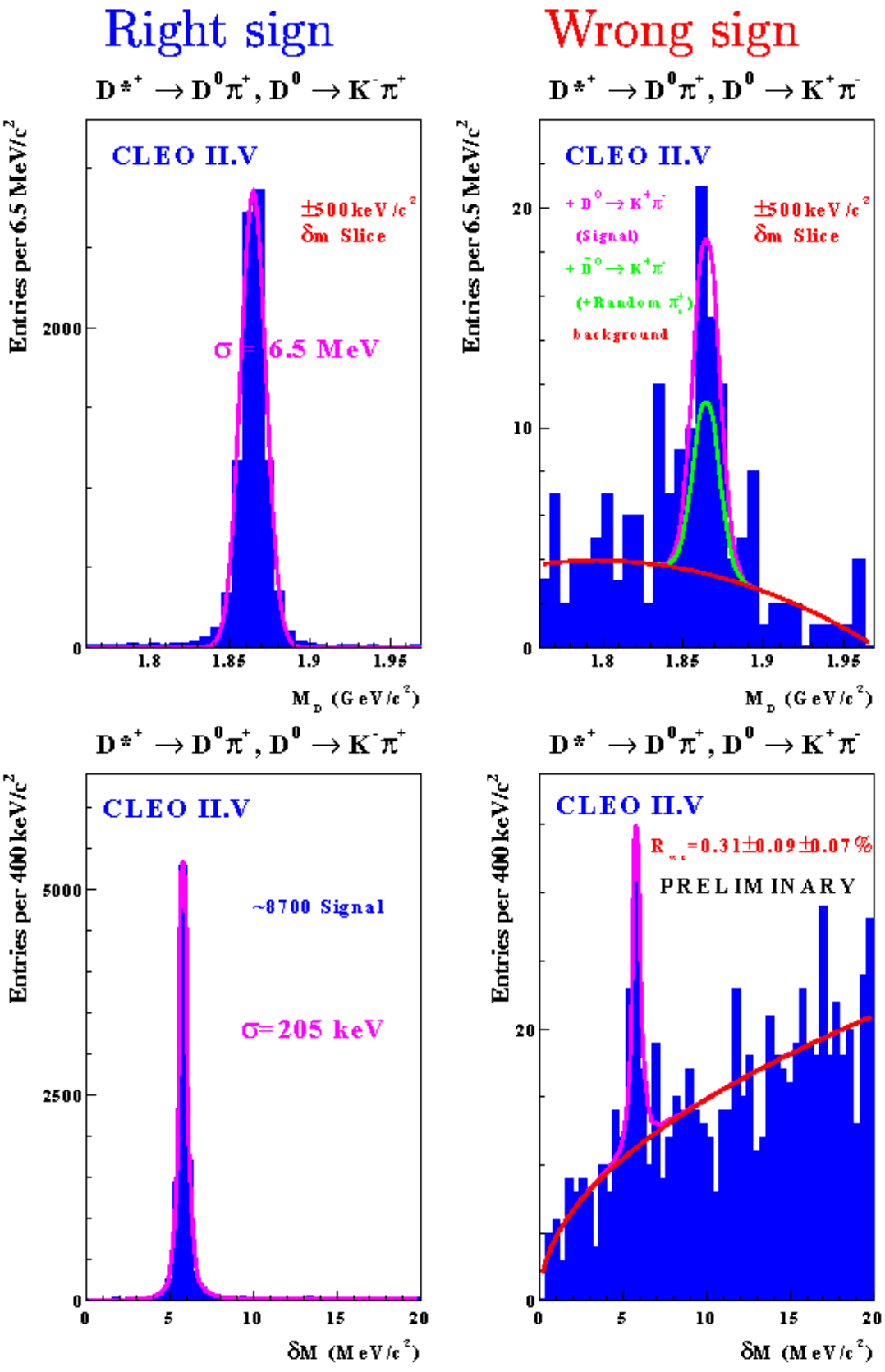


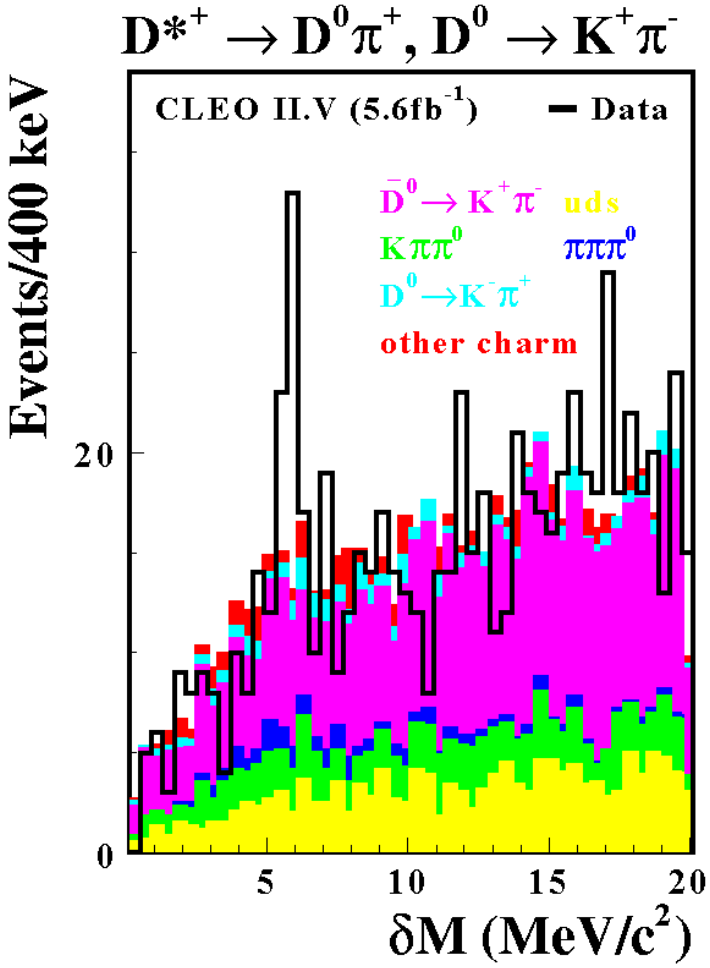






Analysis uses excellent kinematic resolution to stop $K^-\pi^+$ feedthrough, and relies on good Particle-ID to suppress backgrounds.

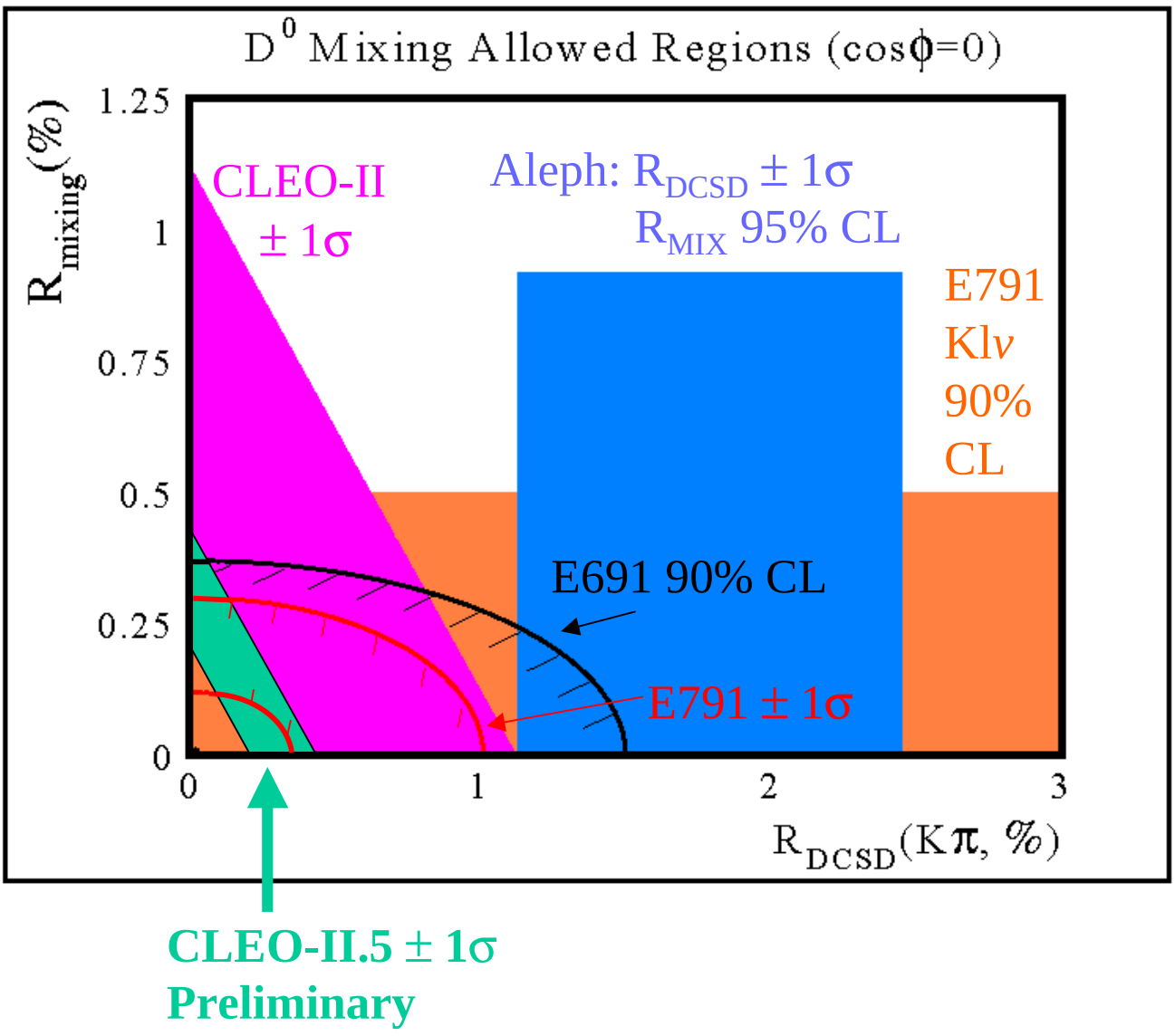

Right sign
Wrong sign
D*+ → D0π+, D0 → K-π+
D*+ → D0π+, D0 → K+π-
CLEO II.V
±500keV/c2
δm Slice
σ = 6.5 MeV
+ D0 → K+π-
(Signal)
+ D̄0 → K+π-
(+Random πs+)
background
Entries per 6.5 MeV/c2
MD (GeV/c2)
CLEO II.V
~8700 Signal
σ=205 keV
CLEO II.V
R = 0.31±0.09±0.07%
PRELIMINARY
Entries per 400 keV/c2
δM (MeV/c2)



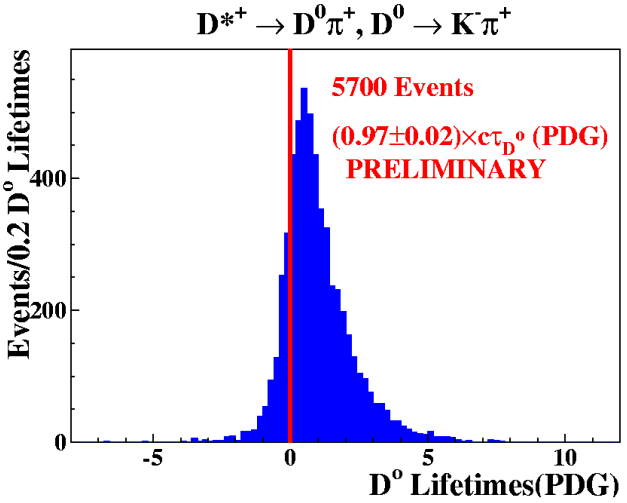
Systematic Errors
$P_{D^{*+}}$
Mass Flip
K dE/dx $(\mathcal{L}_K - \mathcal{L}_\pi)$
π dE/dx $(\mathcal{L}_\pi - \mathcal{L}_K)$
Prob_{D^0} vertex
$\text{Prob}_{\pi_{soft}}$ vertex
$\cos\theta_{\pi_{soft}}$
$M_{K\pi}$ fit range
Track Quality
Binning $M_{K\pi}$
Binning $M_{\delta m}$
Total ± 0.07

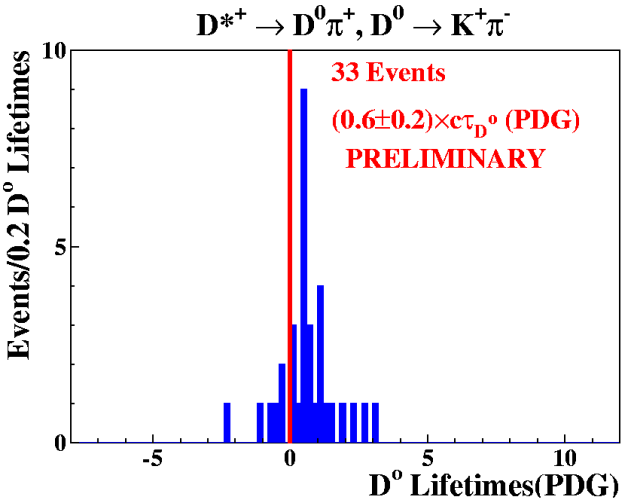
$R_{WS} = (0.31 \pm 0.09 \pm 0.07)\ \%$

Results:

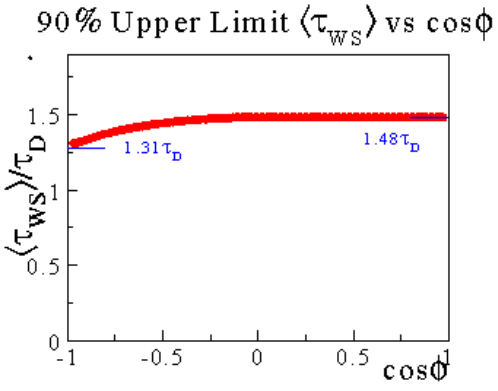

D⁰ Mixing Allowed Regions (cosϕ=0)
R_mixing (%)
1.25
1
0.75
0.5
0.25
0
0
1
2
3
R_DCSD (Kπ, %)
CLEO-II
± 1σ
Aleph: R_DCSD ± 1σ
R_MIX 95% CL
E791
Klν
90%
CL
E691 90% CL
E791 ± 1σ
CLEO-II.5 ± 1σ
Preliminary

Using Lifetime Info:





$\tau(ws) = (0.65\pm0.4 \text{ (stat+sys)}) \times \tau(D^0)$

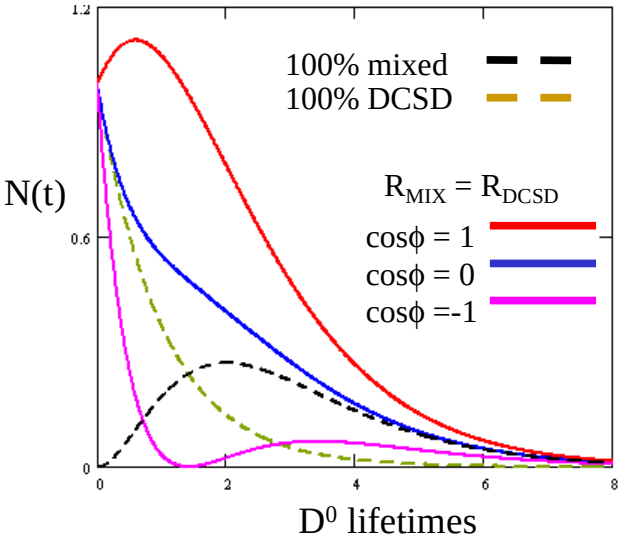


$\tau_{\text{wrong sign}}$ UL @ 90% CL

$< 1.48\tau_{D^0}$ $\quad \cos\phi = 0$

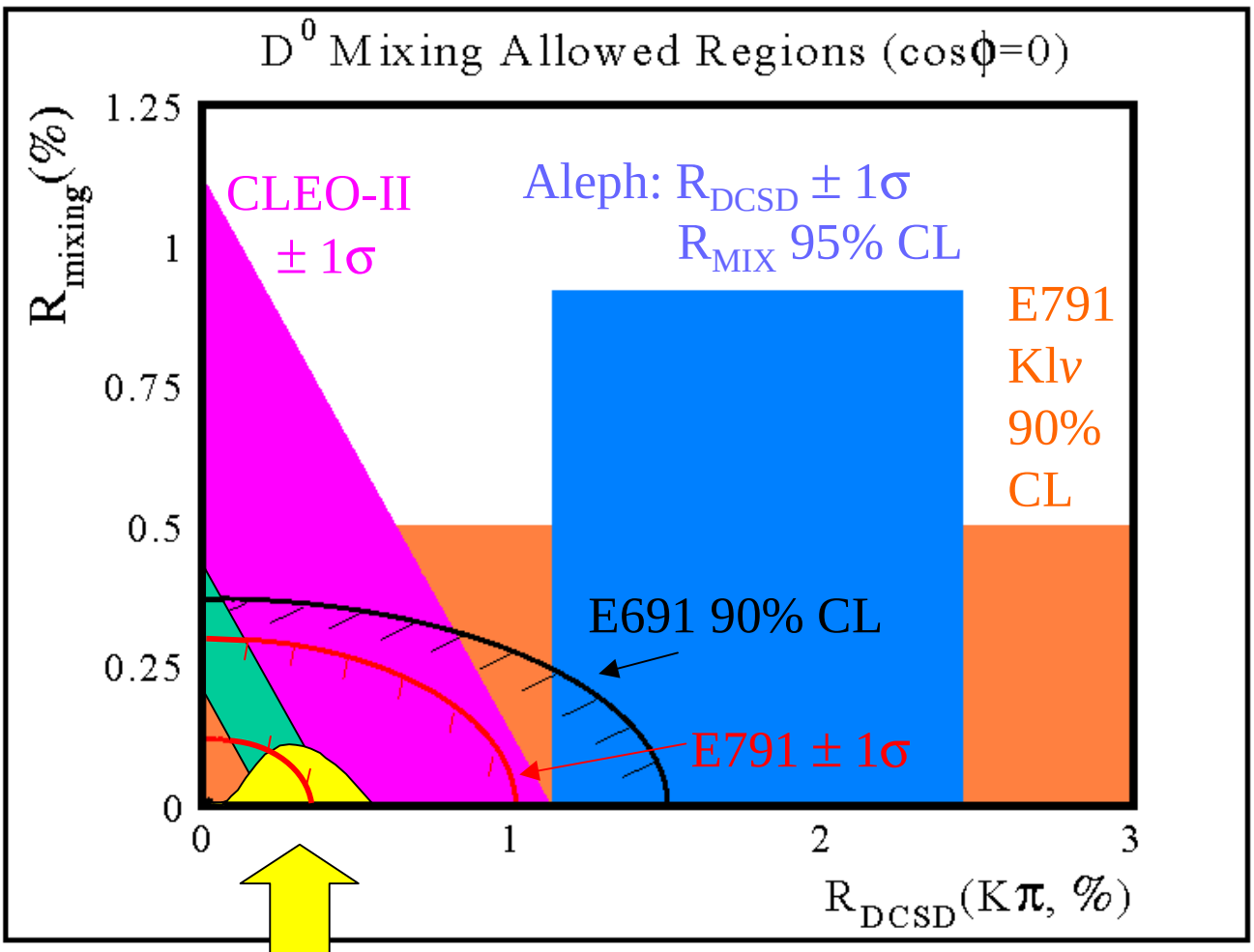
$< 1.48\tau_{D^0}$ $\quad \cos\phi = 1$

$< 1.31\tau_{D^0}$ $\quad \cos\phi = -1$



Exploit this info to limit R_{MIX}

Mixing Results:



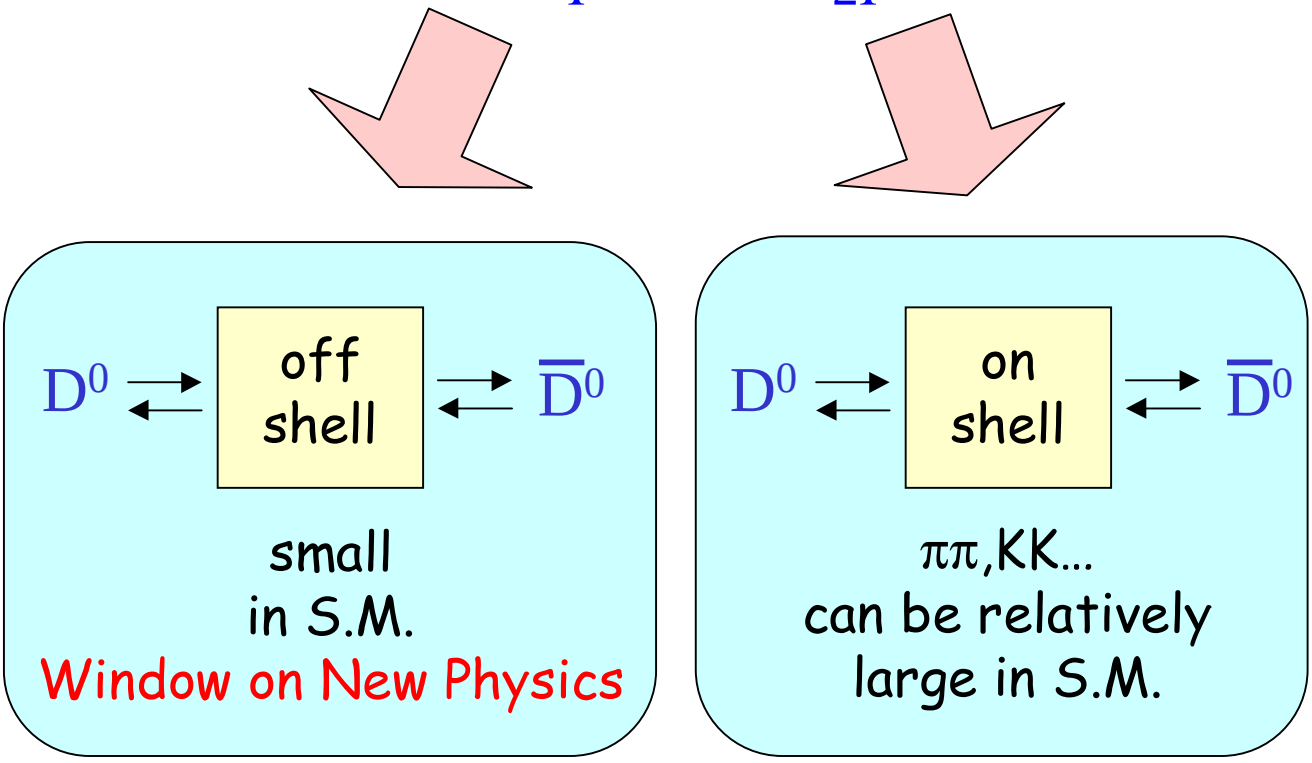
CLEO-II.V 90% CL
Preliminary

Limits have been calculated for all cosϕ (ask me after)

What we are sensitive to in the Kπ mixing analysis:

$$R_{MIX} = \frac{x^2 + y^2}{2} \qquad \phi = \tan^{-1}\left(-\frac{x}{y}\right)$$

Where $x \equiv \frac{\Delta M}{\Gamma}$ $y \equiv \frac{\Delta\Gamma}{2\Gamma}$

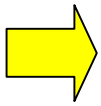


It will eventually be very important to disentangle "x" and "y"

CP eigenstate lifetime analysis will tell us about "y" independent of "x"

CP-even Lifetime Analysis:

Look for $\Gamma(D^0 \to K^-\pi^+) \neq \Gamma(D^0 \to \pi^-\pi^+, K^- K^+)$



This is a direct measure of $\Delta\Gamma$!
(i.e. measure "y" independent of "x")

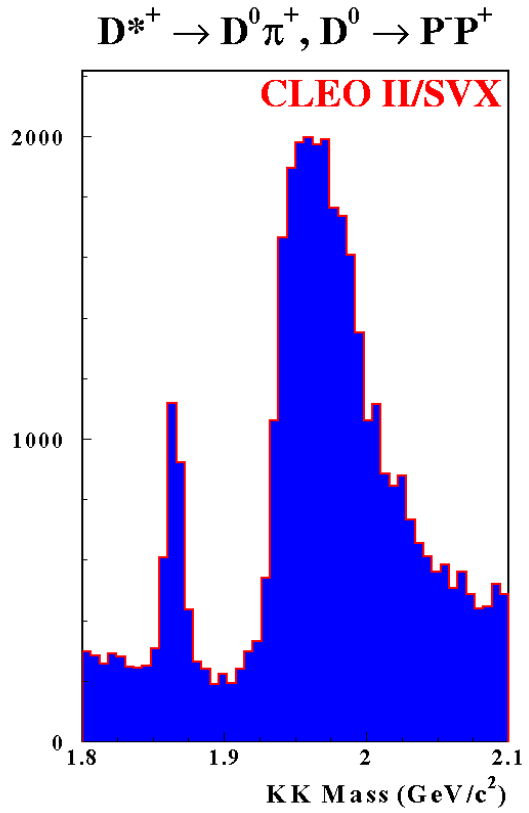
Plan:

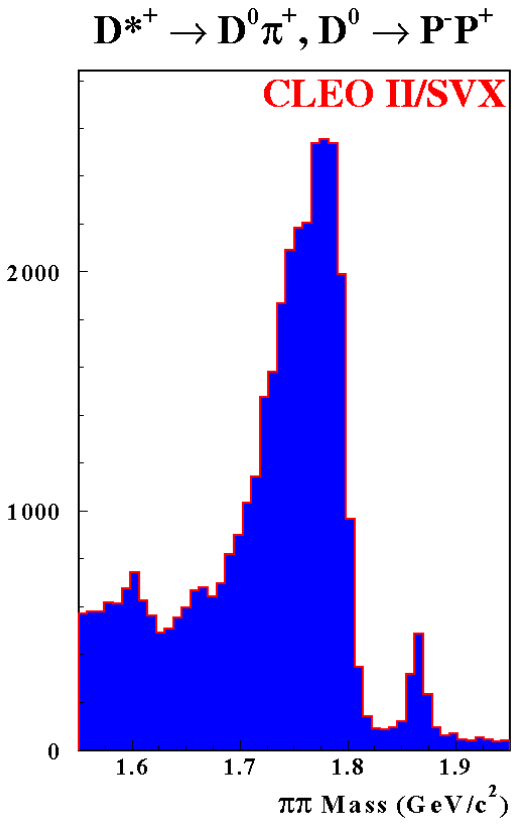
Measure $\tau(D^0 \to K^-\pi^+)$
$\tau(D^0 \to \pi^-\pi^+)$
$\tau(D^0 \to K^- K^+)$
} Both CP=+1 Should have the same lifetimes

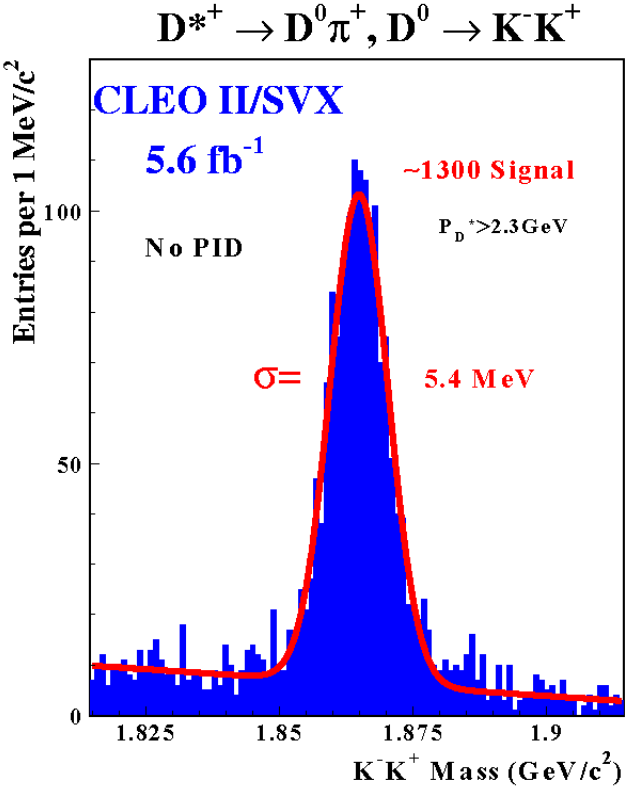
$D^0 \to K^-\pi^+$, $D^0 \to \pi^-\pi^+$, and $D^0 \to K^- K^+$
are easy to distinguish kinematically

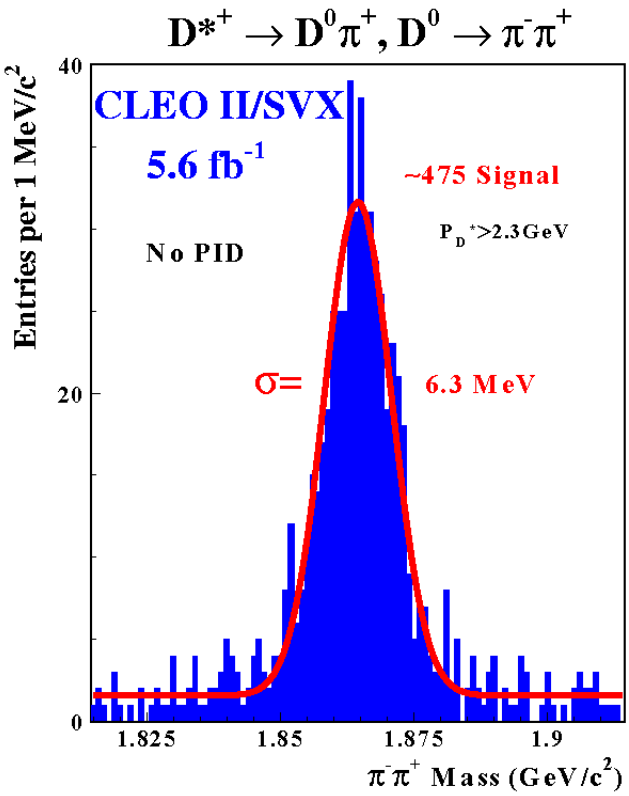
Don't need particle-ID

CP-even Yields:

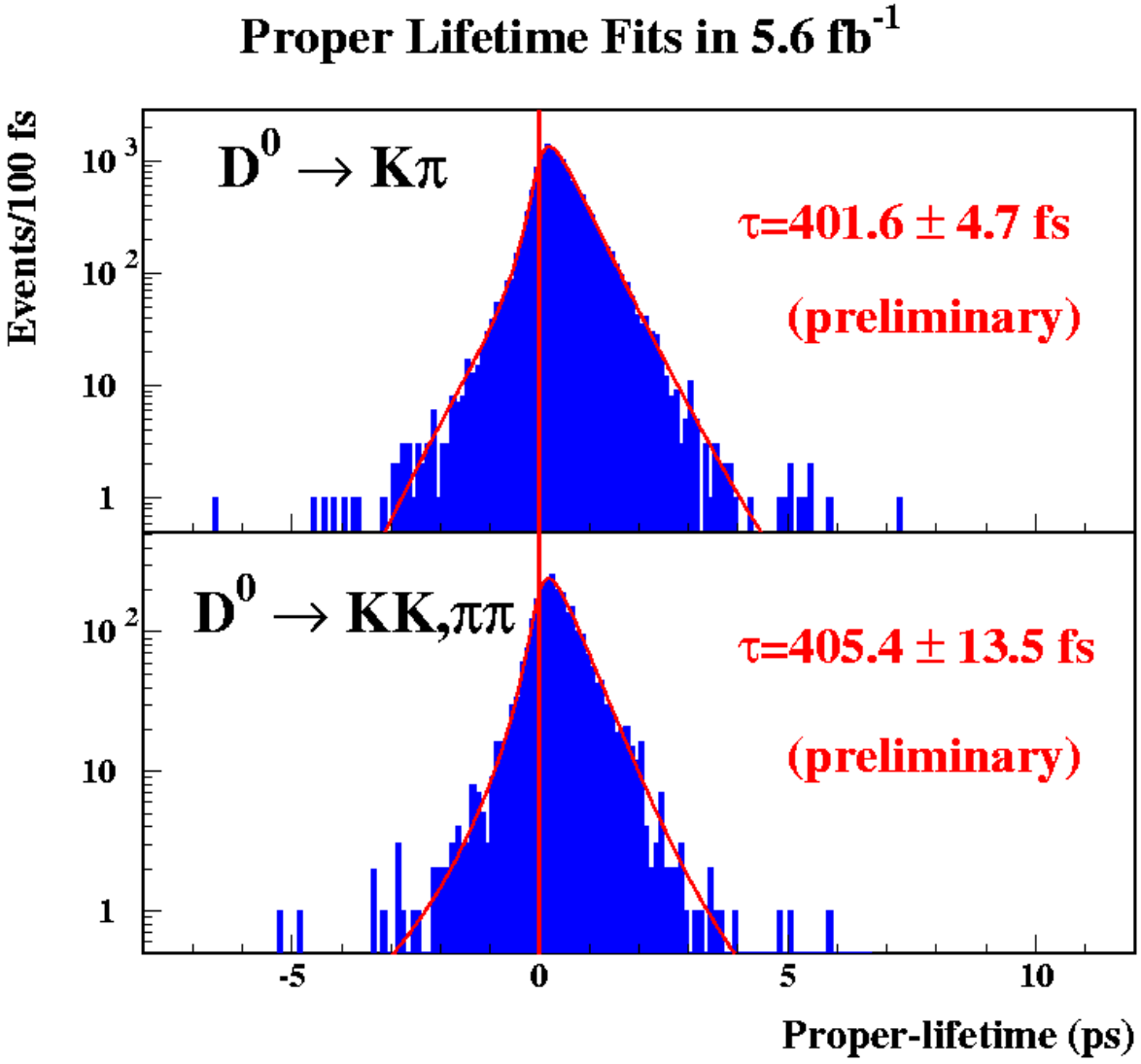








Lifetime Fits:



Use unbinned maximum likelihood fit to extract signal lifetimes:

Extracting "y":

Look for $\Gamma(D^0 \to K^- \pi^+) \neq \Gamma(D^0 \to \pi^- \pi^+, K^- K^+)$

$$y = \frac{\Delta\Gamma}{2\Gamma} = \frac{\tau_+ - \tau_-}{\tau_+ + \tau_-} = \frac{\tau_+}{\tau_{K\pi}} - 1$$

Where τ_+ (τ_-) are the CP even (odd) lifetimes, and $\tau_{K\pi} = (\tau_+ + \tau_-)/2$

Based on our present measurement:

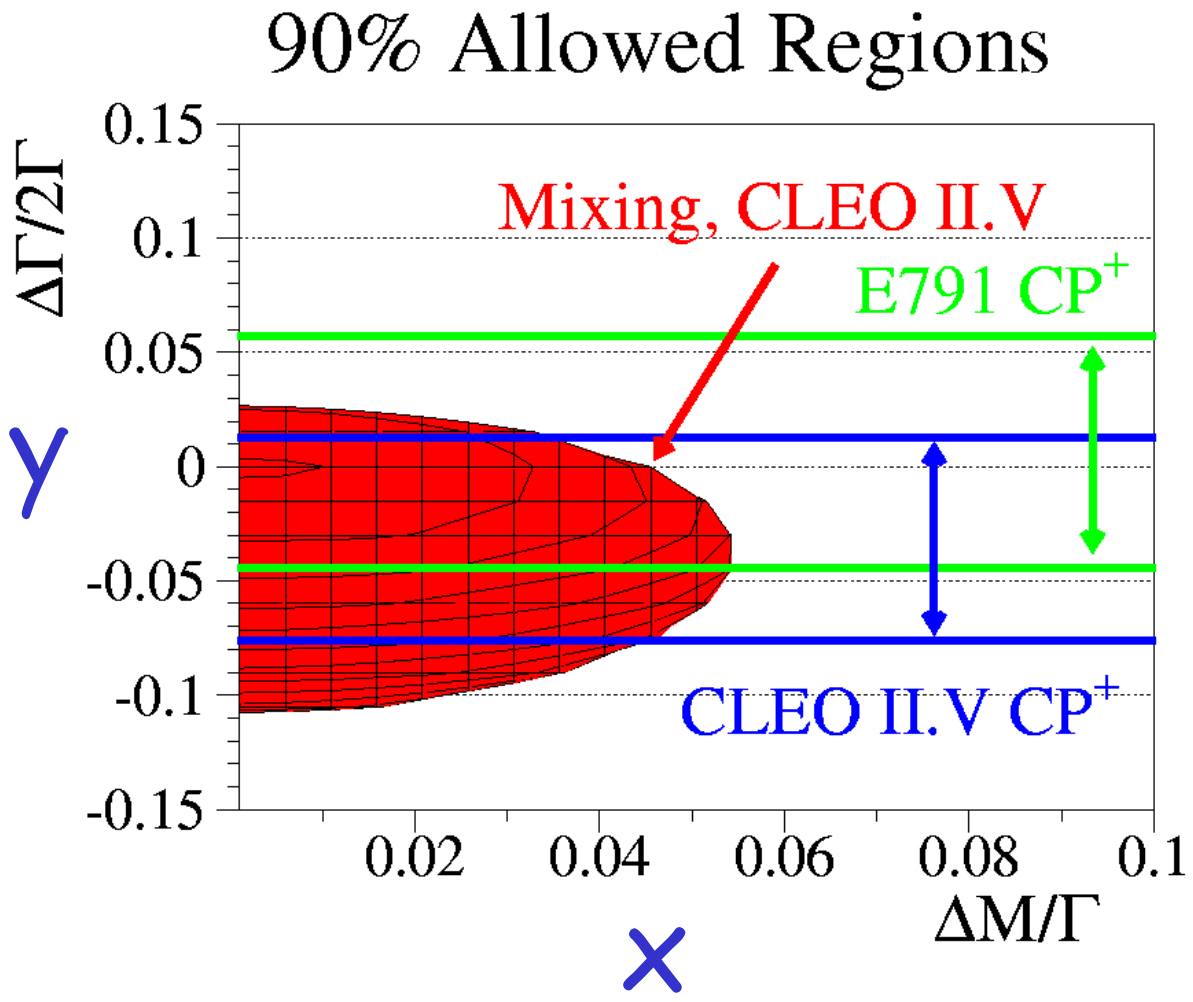
$y = -0.032 \pm 0.034$

or

$-0.076 \leq y \leq 0.012$ (90% CL)

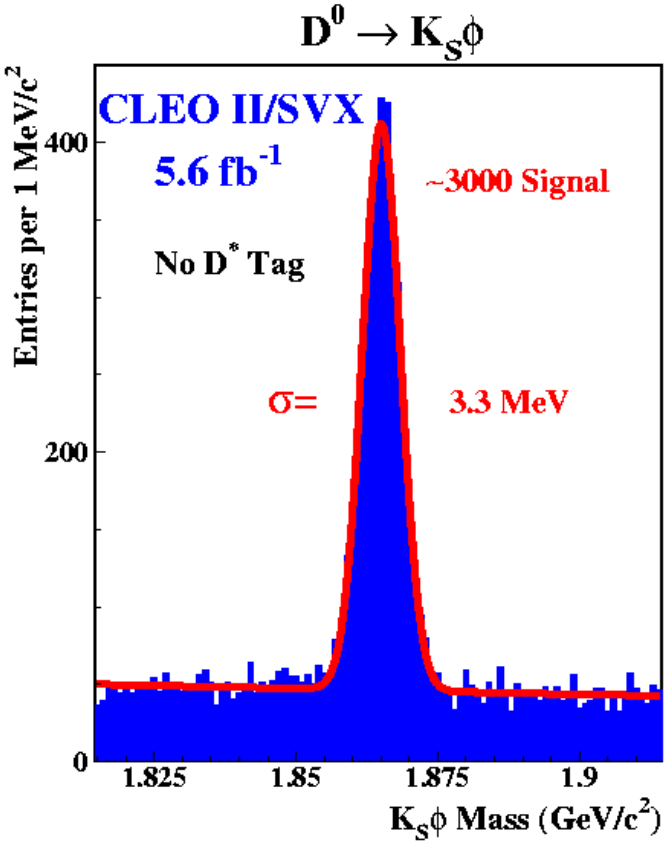
CLEO II.V Preliminary

Putting it all together



CLEO II.V Preliminary

Future mixing prospects

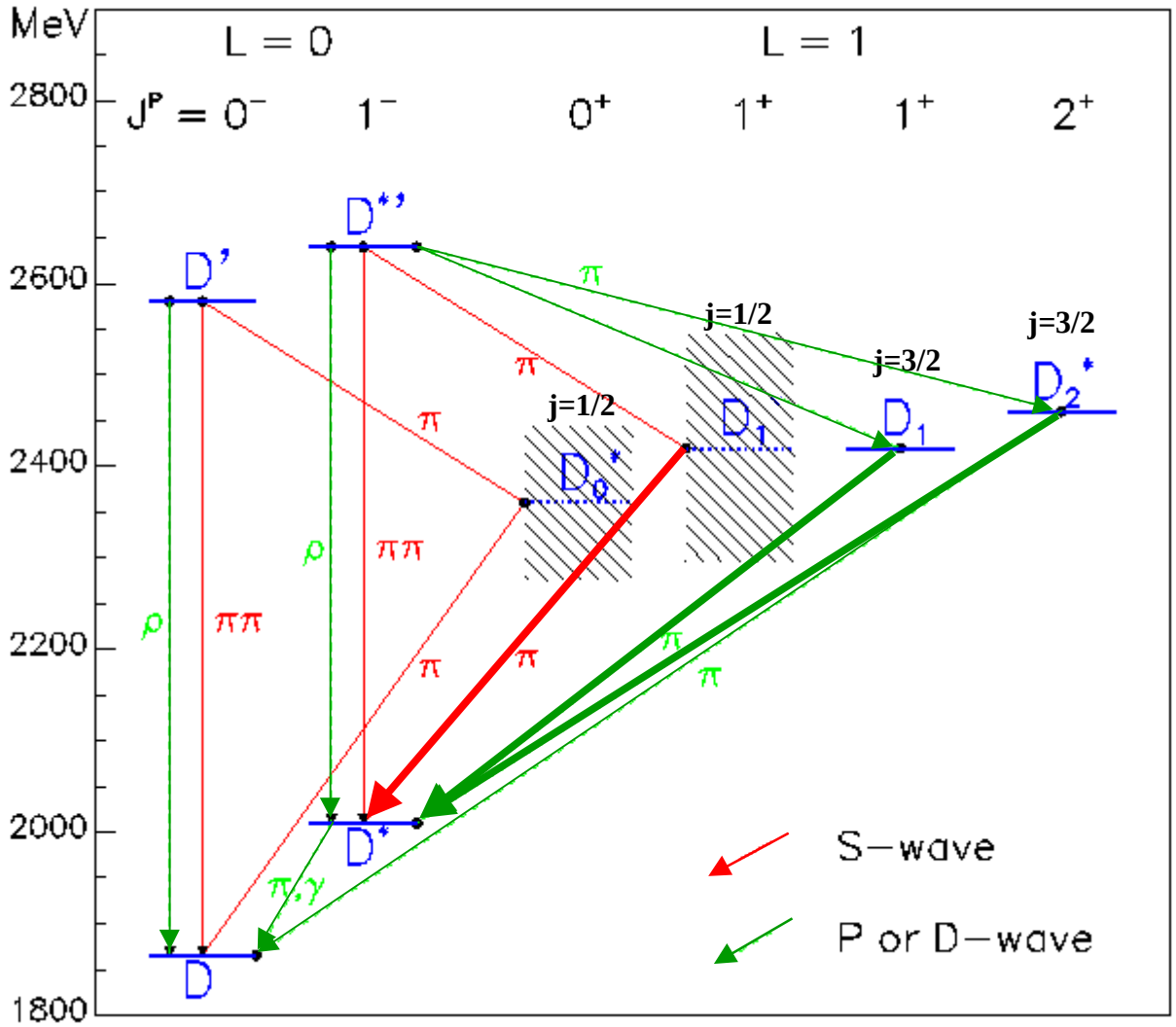


CP odd eigenstate lifetime analysis

sneak preview

Lots more data to analyze

Charm Meson Spectroscopy



We search for

$B^- \to \pi^-$ { $D_1(j=1/2)$ Previously not seen; $D_1(j=3/2)$, $D_2^*(j=3/2)$ Previously seen }

$\to D^{*+}\pi^-$

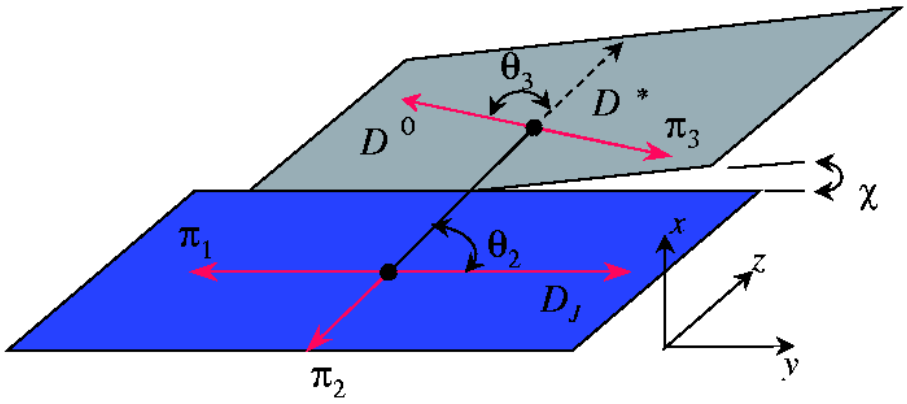
$\to D^0\pi^+$

- Analysis Technique
  - Partial reconstruction:

$B^- \to D_J^0 \pi^-;\ D_J^0 \to D^{*+}\pi^-;\ D^{*+} \to D^0\pi^+$

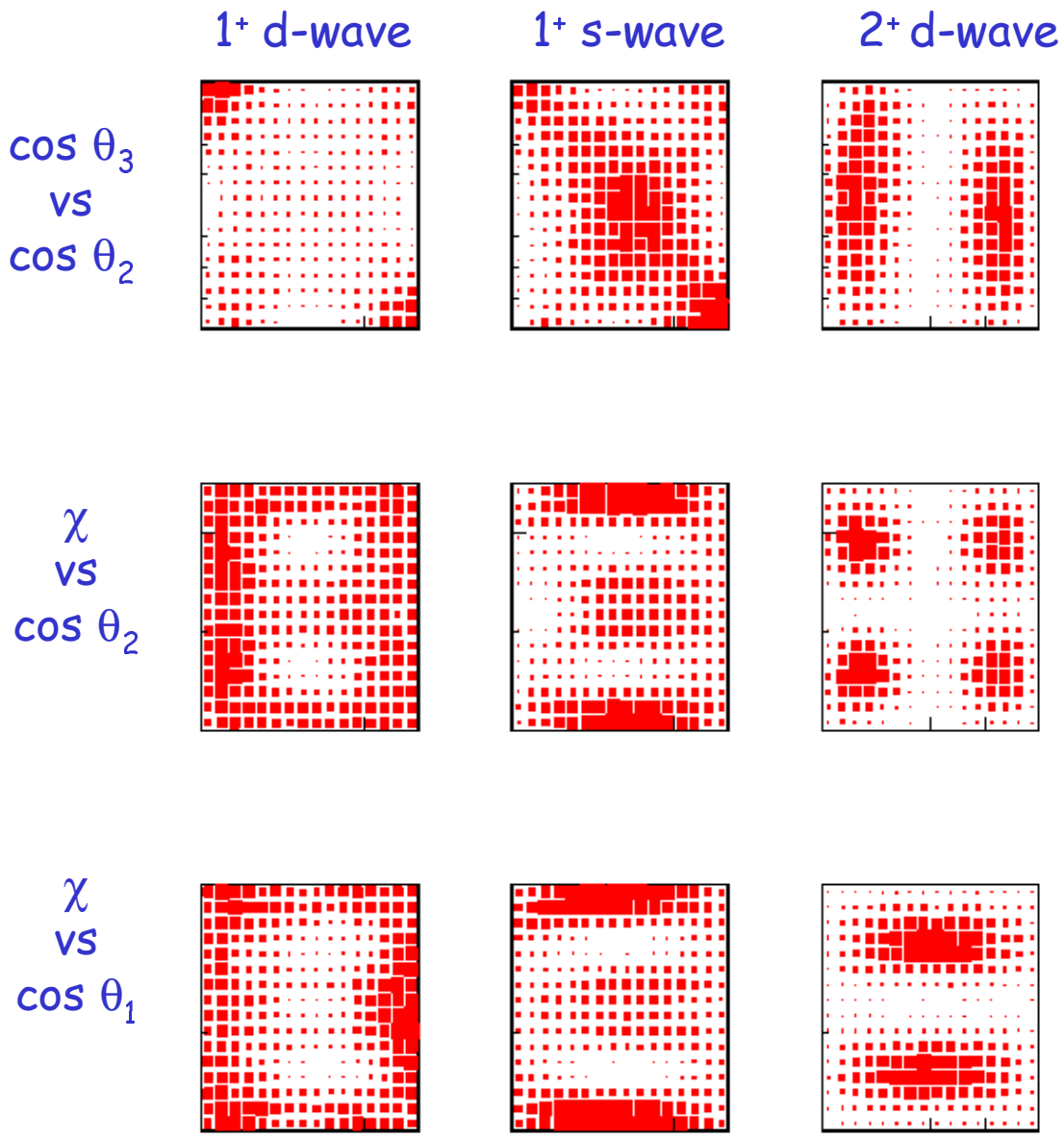
  - Measure 4-momenta of $\pi^-\pi^-\pi^+$.
  - Extract signal via 4-D Max Likelihood Fit

- Fitting Technique
  - 4 independent variables:
    - helicity θ_2, helicity θ_3, azimuth χ, $M(\mathbf{D}^*\pi)$

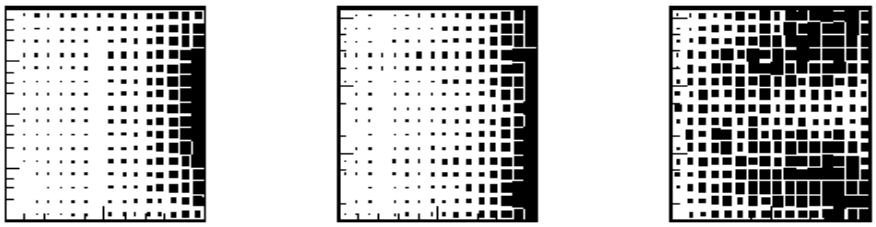


Fit parameters:

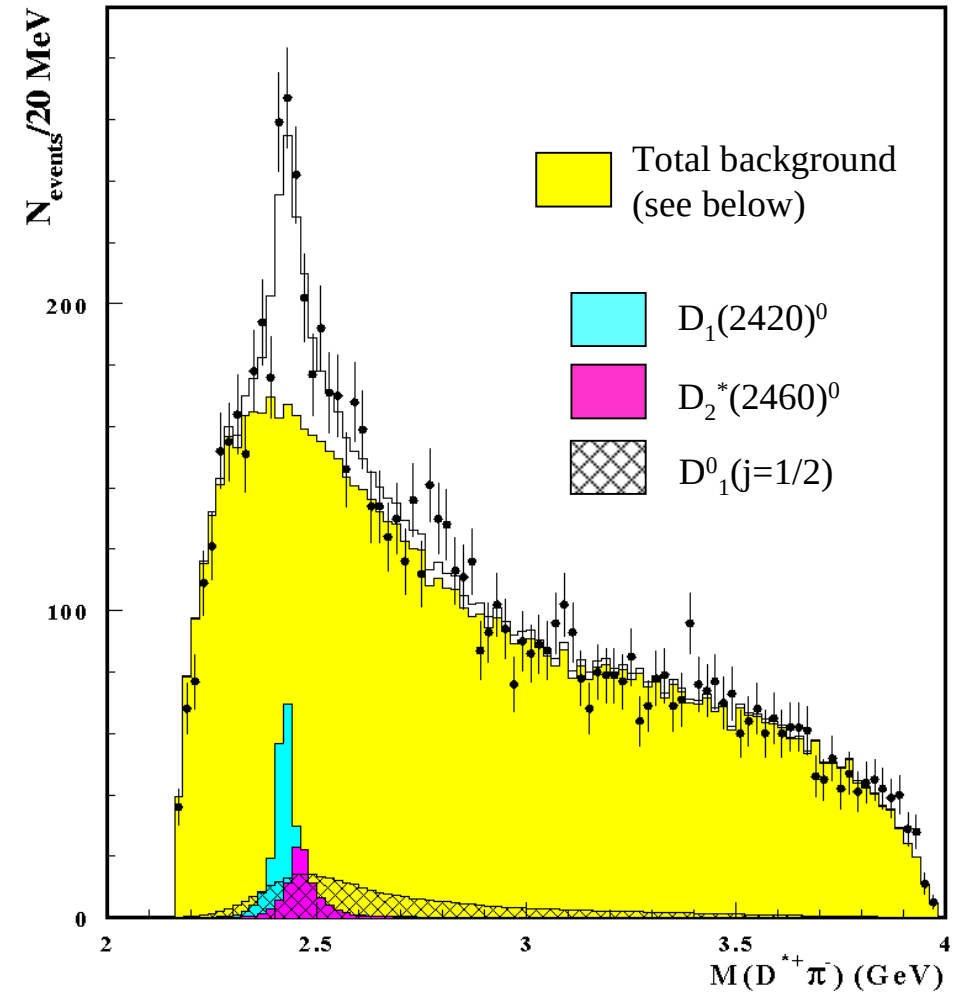
Yields (3 resonant, 1 non-resonant)
Mass and width of broad $\mathbf{D_1(j=1/2)}$
Mixing and interference between resonances.
Strong phases relative to $\mathbf{D_1(2420)}$

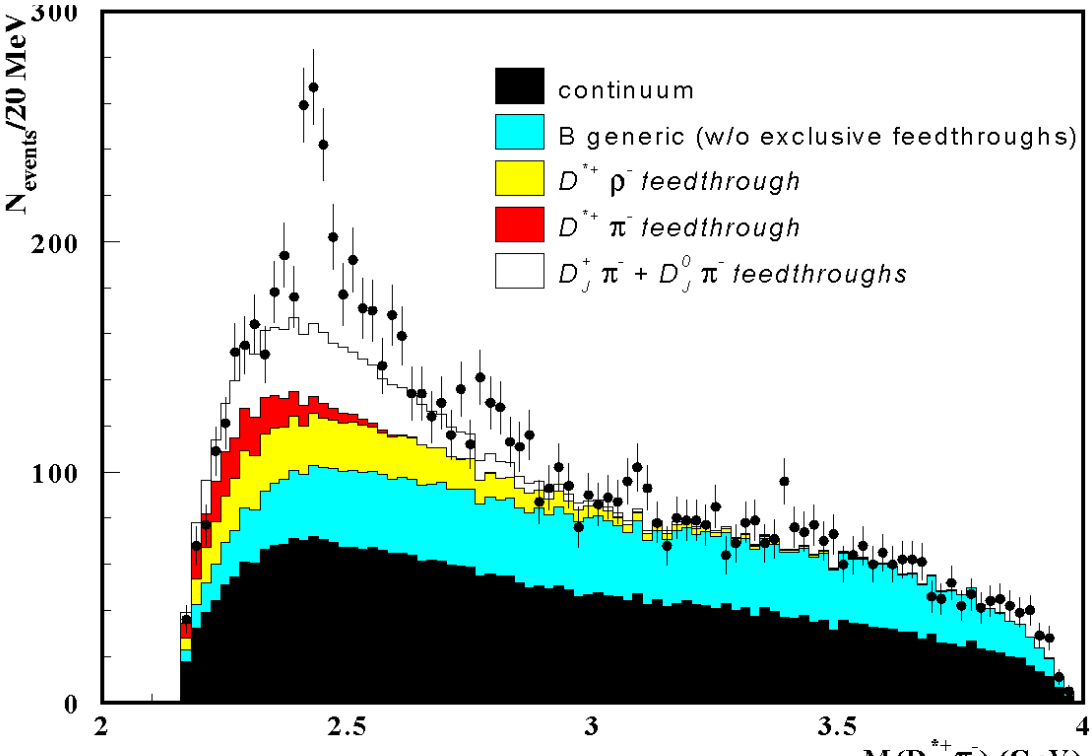


Total Background



Fit Results



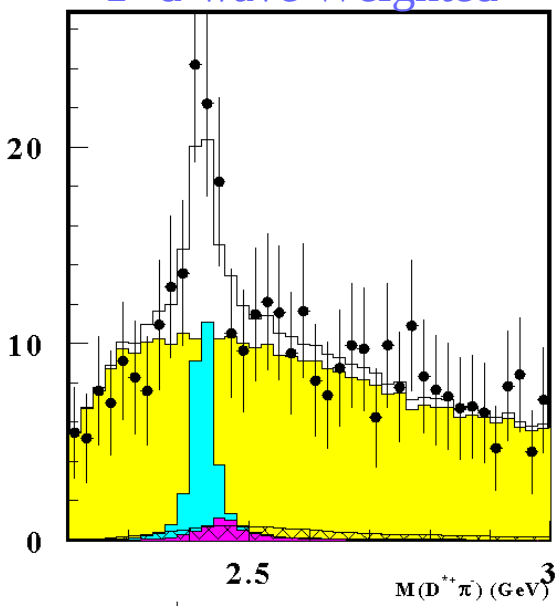


individual backgrounds

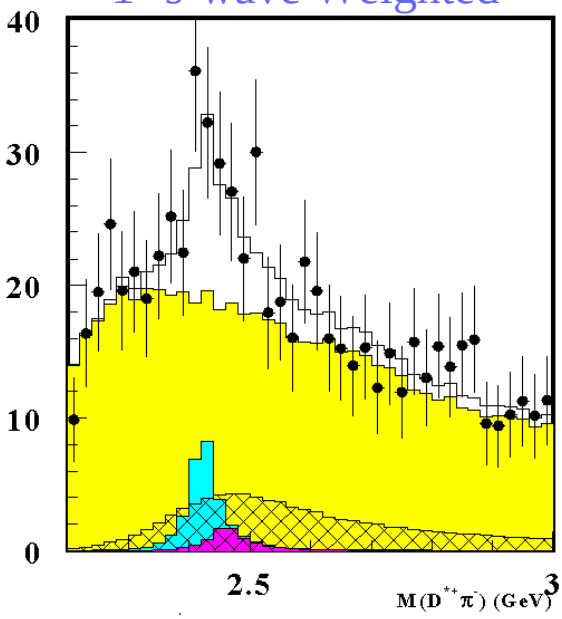
ıtennial

Weighted Fit Components

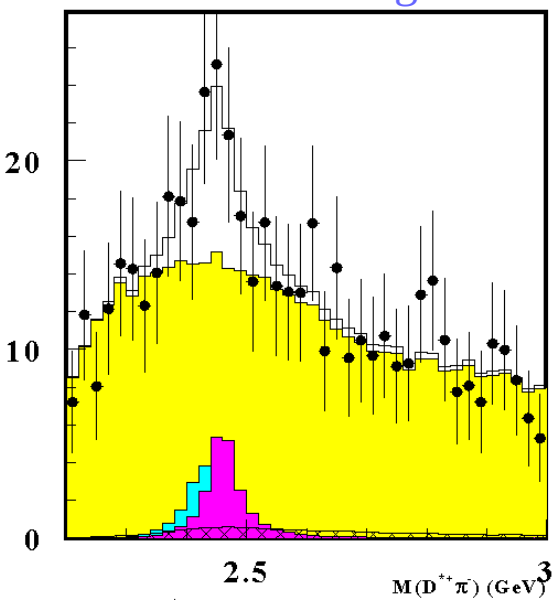
1^+ d-wave Weighted



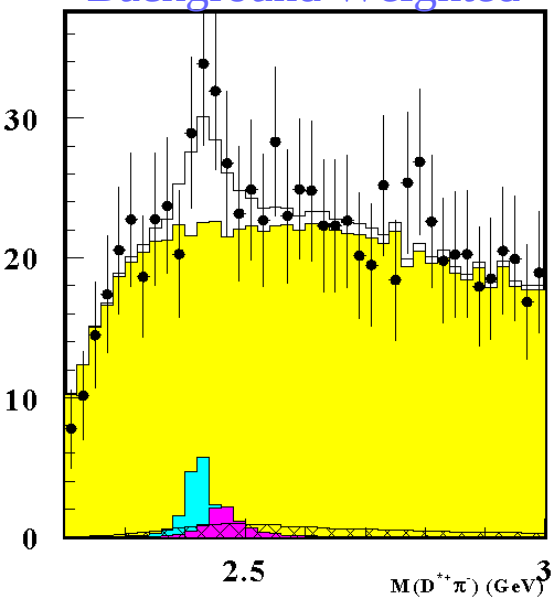
1^+ s-wave Weighted



2^+ d-wave Weighted



Background Weighted



Preliminary Results

- Properties of $D_1(j=1/2)$

$$M = 2461^{+41}_{-34} \pm 10 \pm 32 \ MeV$$
$$\Gamma = 290^{+101}_{-79} \pm 26 \pm 36 \ MeV$$

With 5.7σ significance

(second systematic error due to uncertainty modeling strong phases)

Spin-Parity assigned to 1^+

Tests of J^P favor 1^+ over 0^- (closest alternative).

Quark Model:

	$M_{D_1^0(j=\frac{1}{2})} - M_{D_1(2420)^0}$	$\Gamma_{D_1^0(j=\frac{1}{2})}$
G & K	+10 MeV	250–1000 MeV
Measured	$+39.2^{+42}_{-35}$ MeV	290^{+104}_{-83} MeV

$B(\Lambda_c \rightarrow pK\pi)$ Absolute

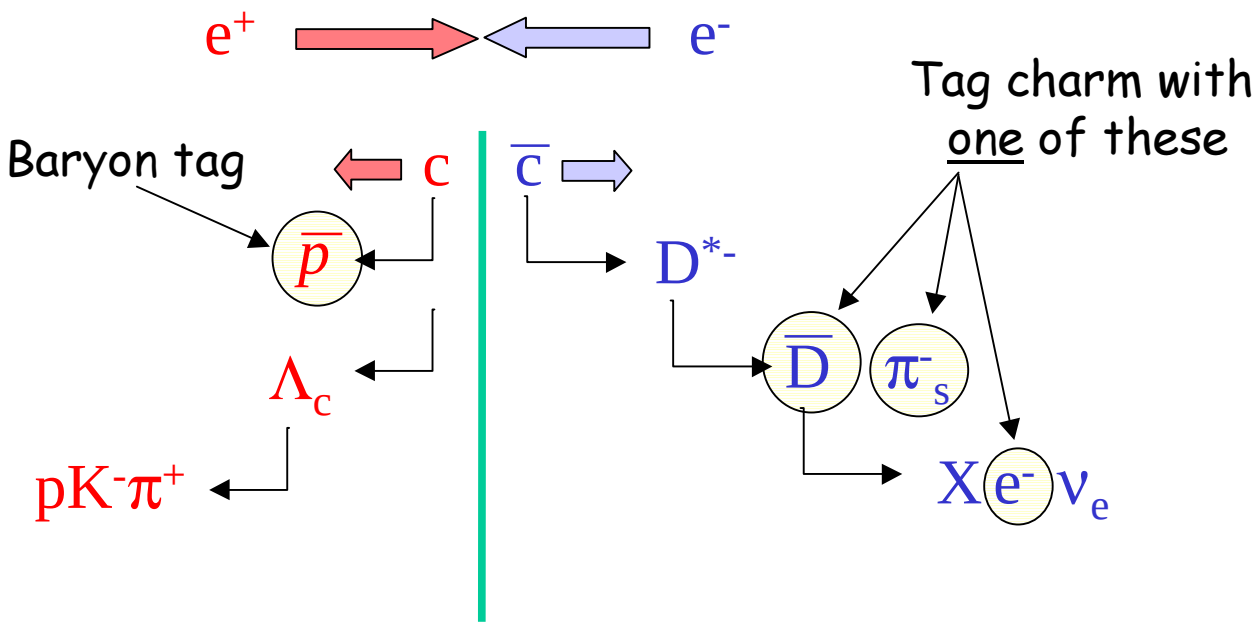
- Why?
  - One of the 4 measured quantities used to normalize all charm analyses

$B(D^0 \rightarrow K^-\pi^+), B(D^+ \rightarrow K^-\pi^+\pi^+), B(D_s \rightarrow \phi\pi^+), B(\Lambda_c \rightarrow pK^-\pi^+)$

  - Not well determined at present

$B(\Lambda_c \rightarrow pK^-\pi^+) = (5 \pm 1.3)\%$ PDG

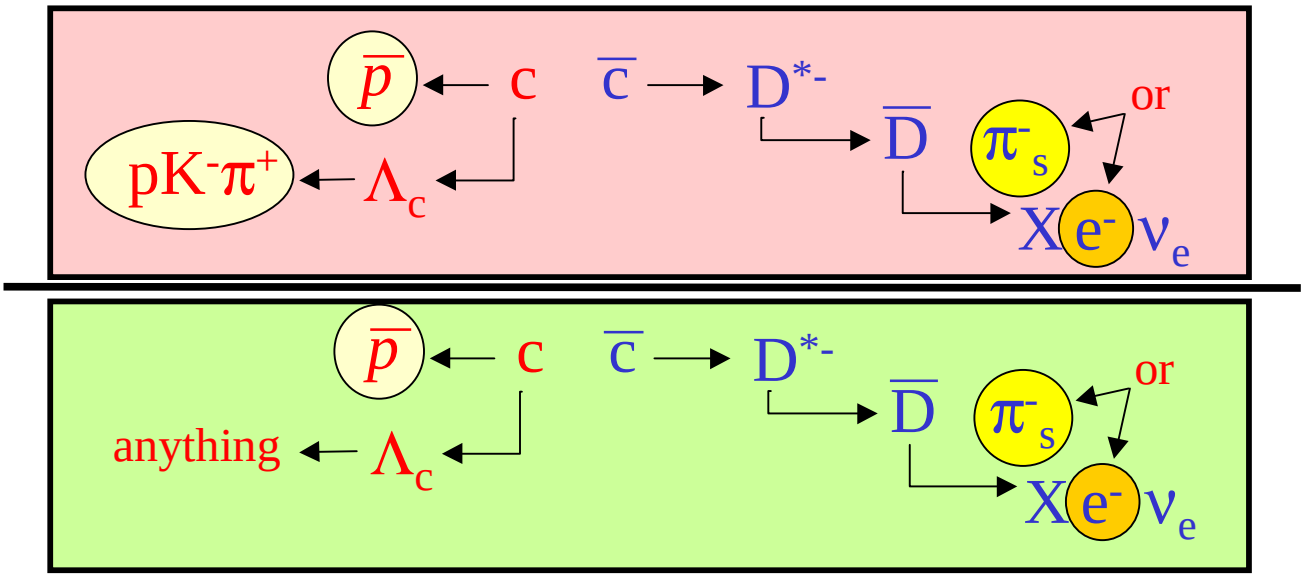
- Our Technique (NEW):



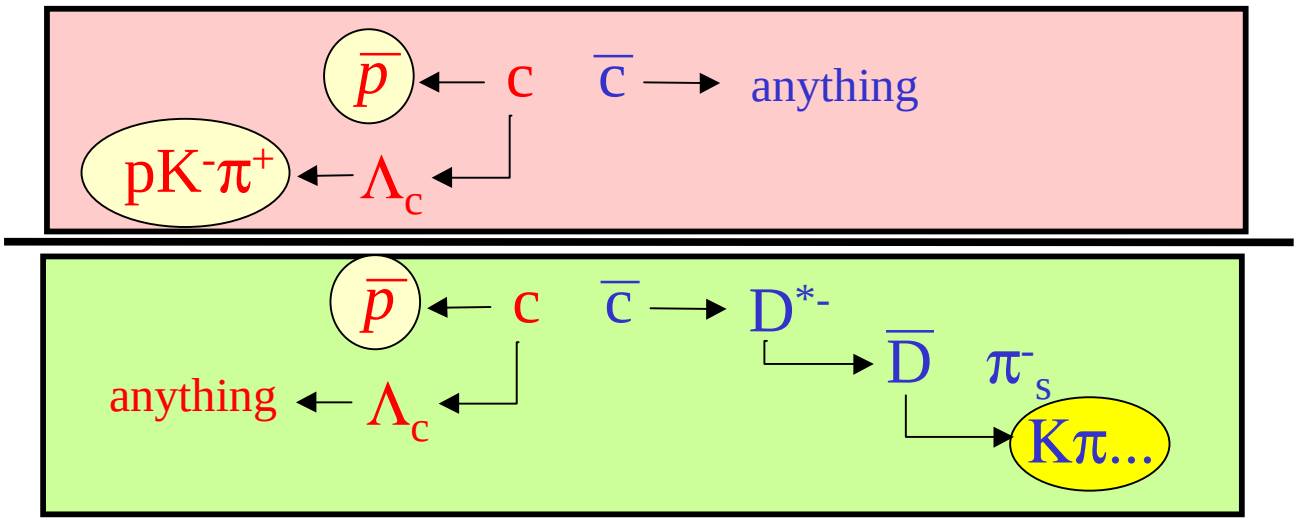
Divide event into hemispheres

Two versions:

Triple correlation analysis (x2):



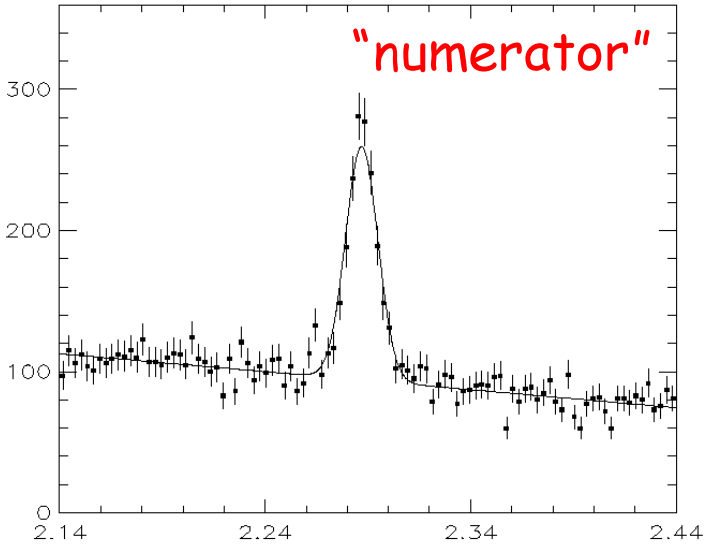
Double correlation analysis:



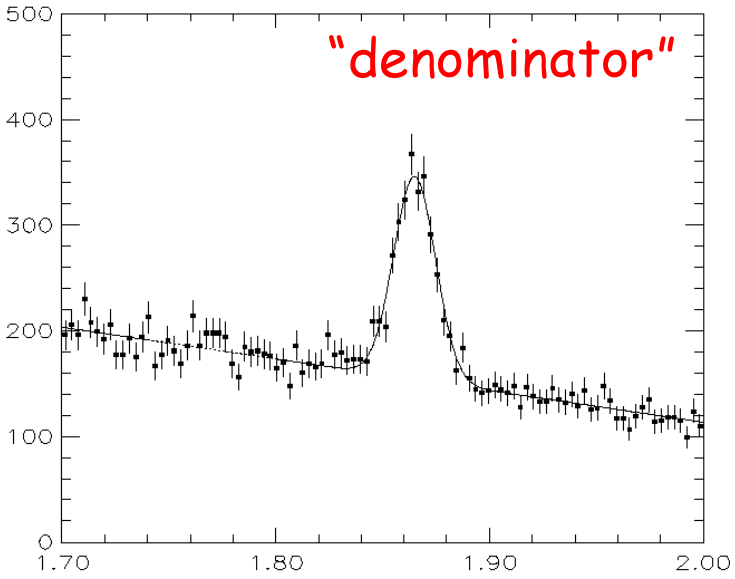
Yield examples:

(Double correlation analysis)

$\Lambda_c \rightarrow pK^-\pi^+$
(same hemisphere as anti-proton tag)



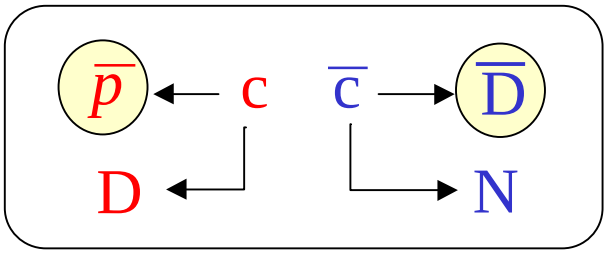
$D^0 \rightarrow K^-\pi^+$
(opposite hemisphere from anti-proton tag)



Apply efficiency correction and get answer...

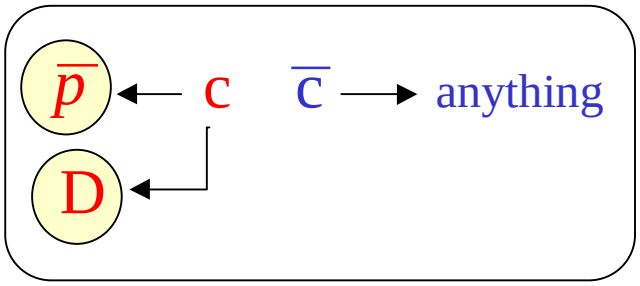
Sounds easy, but...

Biggest Backgrounds/Corrections:

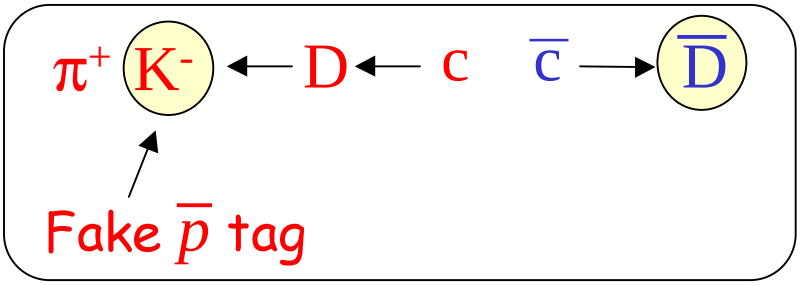


Falsely increased denominator

Count

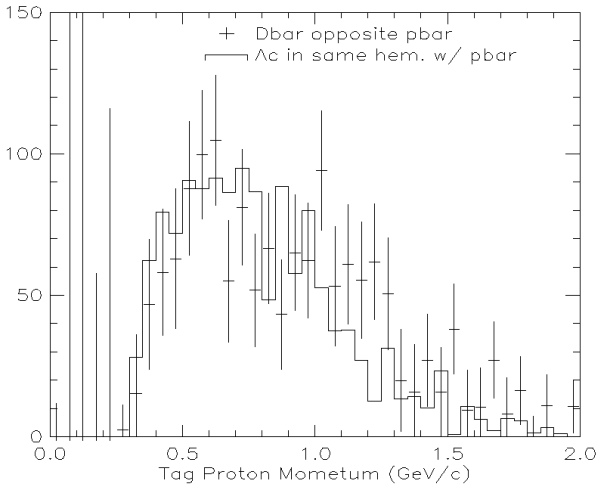


and correct



Falsely increased denominator

Study Kaon fake rate as a function proton momentum and correct (15% effect):



After correction, $\bar{p}$ momentum spectrum looks OK.

Preliminary Results

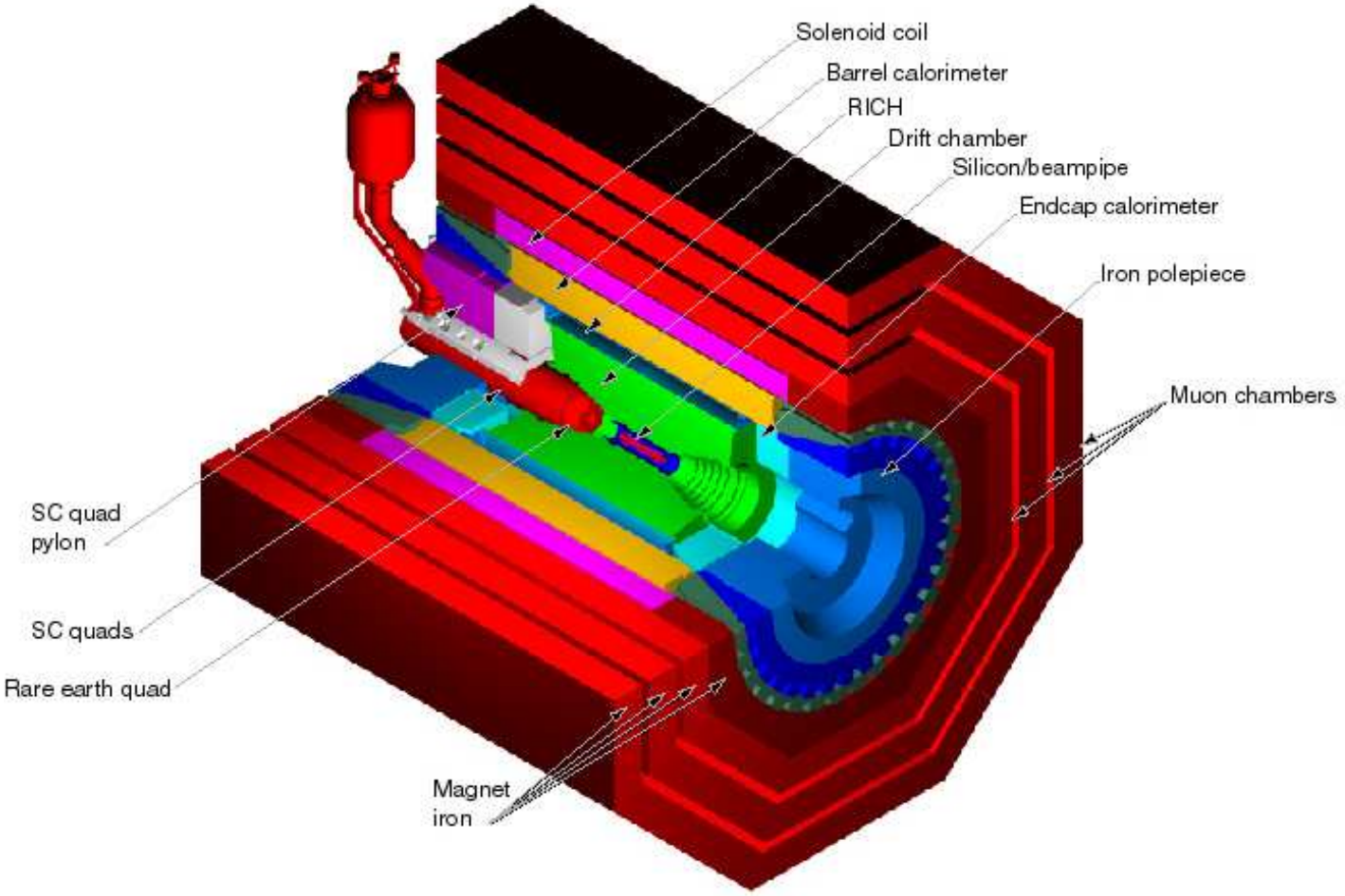
- Make the physics corrections mentioned on previous page (and other smaller ones):
- Make appropriate efficiency corrections.

	$B(\Lambda_c \to pK^-\pi^+)$
Double correlation	$(4.9 \pm 0.5)\%$
Triple correlation (π_s tag)	$(5.2 \pm 1.3)\%$
Triple correlation (e tag)	$(5.6 \pm 2.5)\%$

Weighted average:

$$B(\Lambda_c \to pK^-\pi^+) = (5.0 \pm 0.5 \pm 1.5)\ \%$$

Future Prospects
CLEO-III



- Several New Detector Components
  - RICH, Drift Chamber, Silicon
- New CESR cavities & IR
  - Lots more luminosity