Recent Charm Physics Results From CDF

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Outline

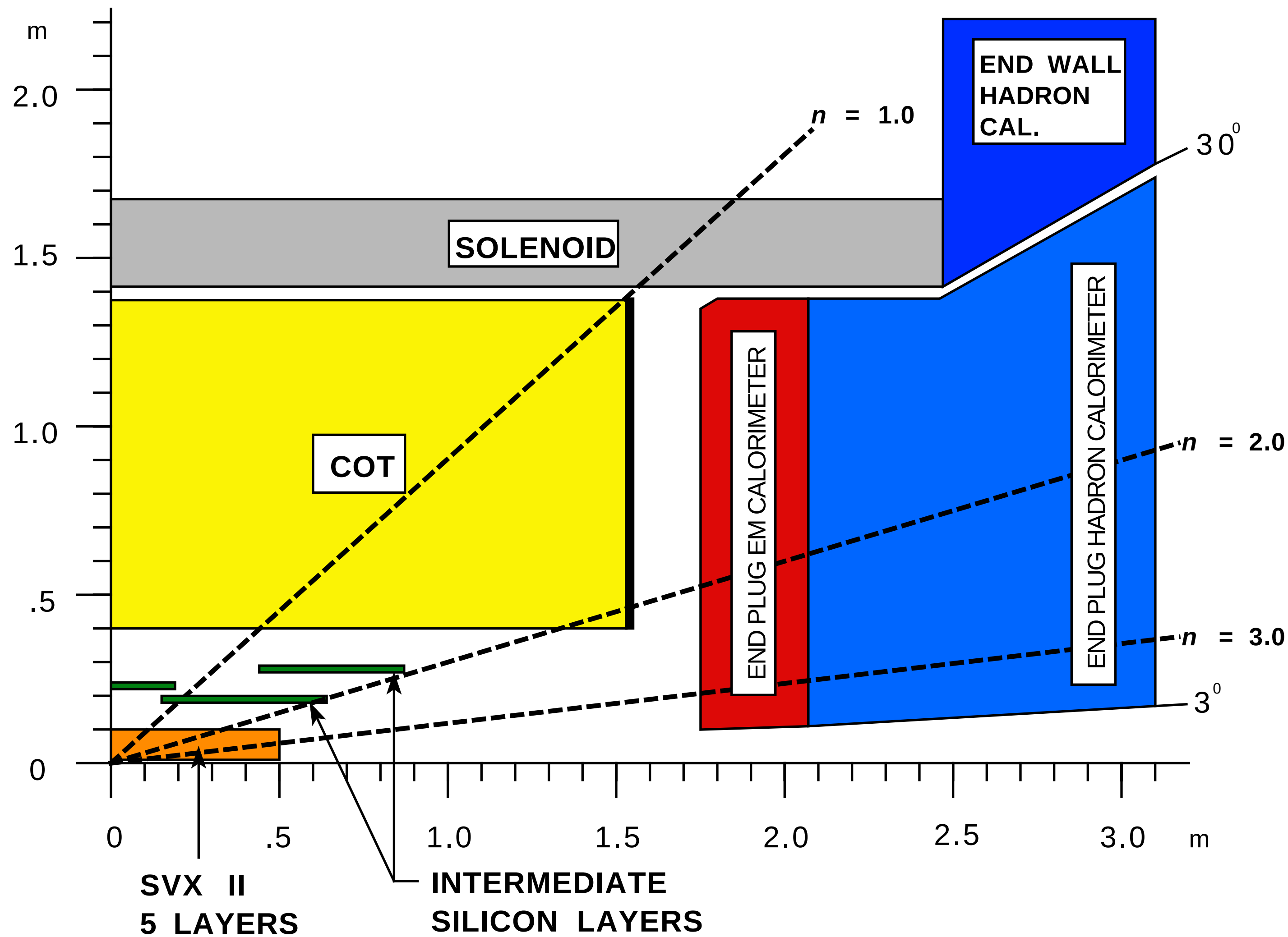
Triggering for Charm

Mass and Width of the Narrow Width L = 1 D** Mesons

Relative Branching Fraction and Search for Direct CP Asymmetry in $D^0 \to K^+K^-$ and $\pi^+\pi^-$ decays

Prospect of Search for Direct CP Asymmetry in $D^+ \to \pi^+\pi^-\pi^+$ decays

CDF Tracking Volume



12 wire shells per superlayer, degrees:
+3 0 -3 0 +3 0 -3 0

double-sided SVX layers, one side 0 deg. other side 90 90 +1.2 90 -1.2 deg.

CDF Trigger System

level	rate	latency
Bunch crossing	2.5 MHz	
Level 1	30 KHz	5.5 μsec
Level 2	400 Hz	20 μsec

Level 1 - eXtremely Fast Tracker (XFT)

$P_{t1} > 2$ GeV/c and $P_{t2} > 2$ GeV/c

$P_{t1}+P_{t2} > 5.5$ GeV/c

Level 2 – Silicon Vertex Tracker (SVT) – two track trigger

each track impact parameter between 120 μm and 1000 μm

secondary vertex with transverse decay length $L_{xy} > 200$ μm

Level 3 – Full Event Reconstruction

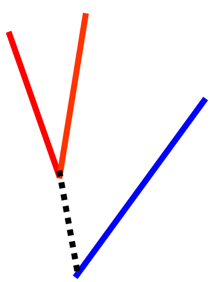
confirm L2

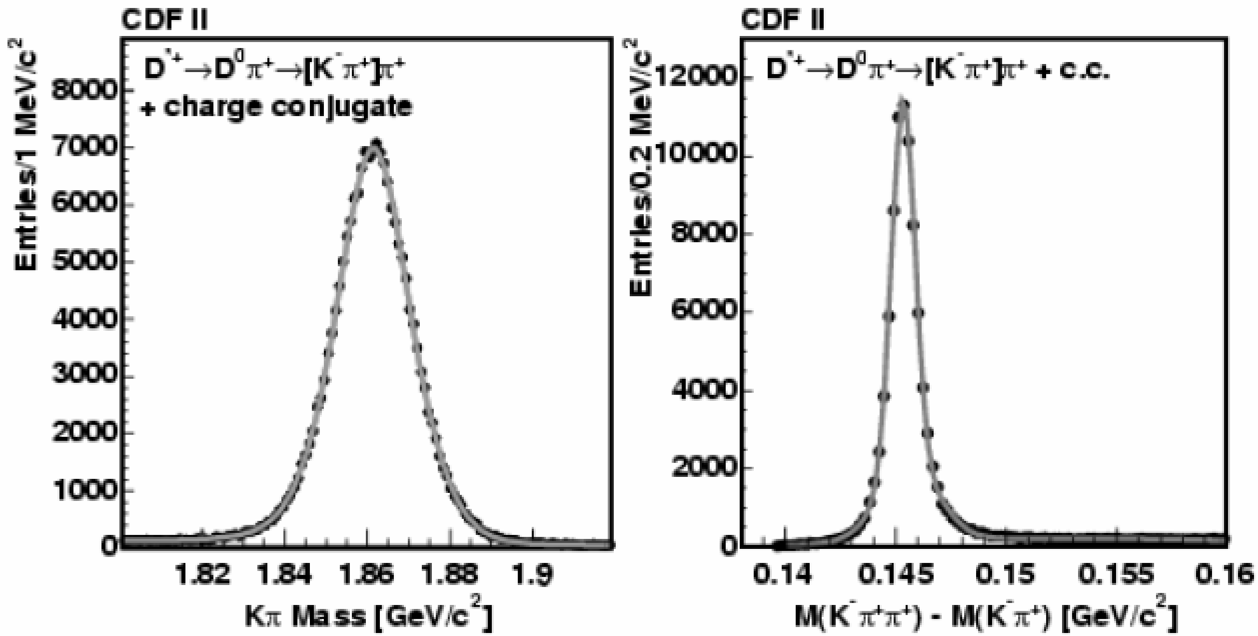
$D^{*+} \to D^0 \pi^+$, $D^0 \to K^- \pi^+$ + c.c.

180910 $\pm$ 480 Signal   123 pb^{-1}

trigger confirmation

vertex and mass fit with D^0 to D^* pointing constraint

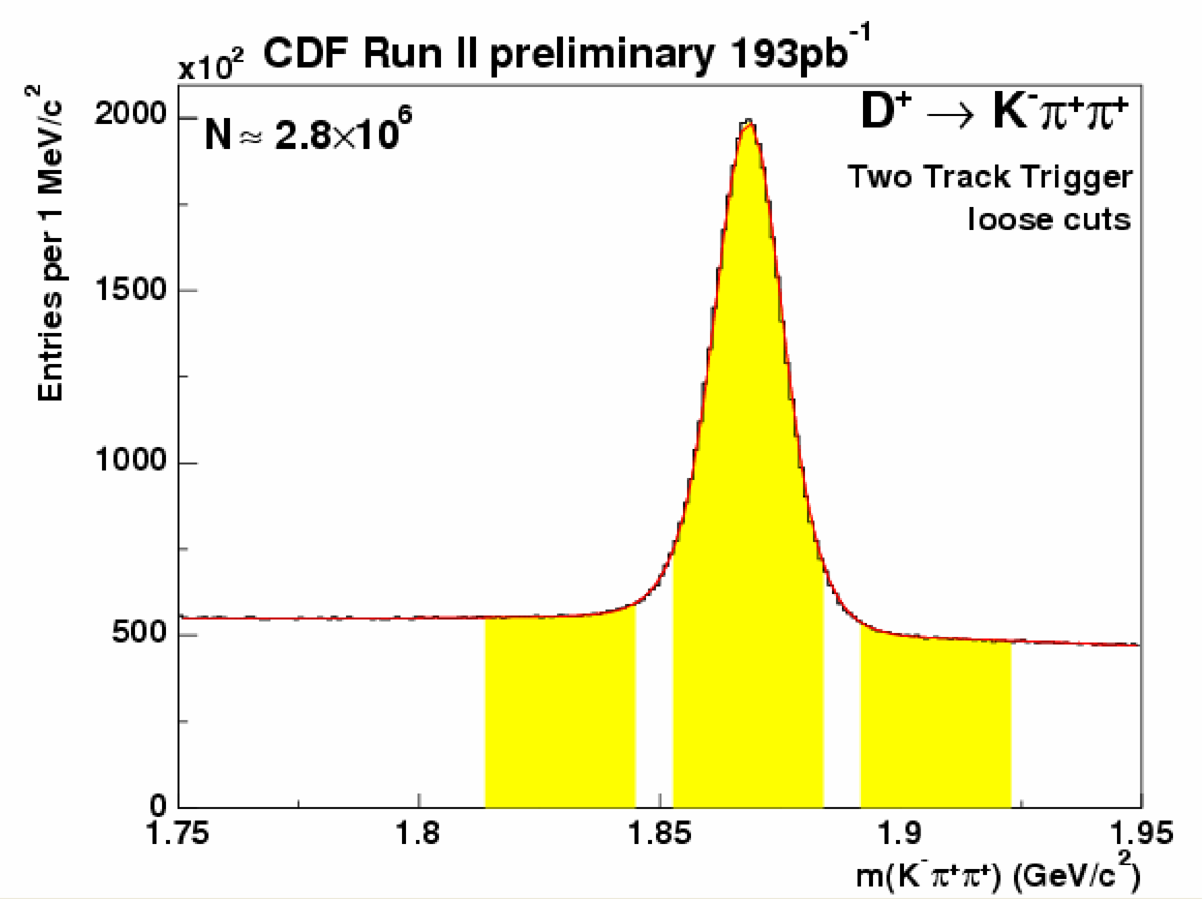




L_{xy} (D^0) > 500 μm

$\pm 3\sigma$ mass window cuts

$D^+ \to K^- \pi^+\pi^+$ + c.c.



trigger confirmation

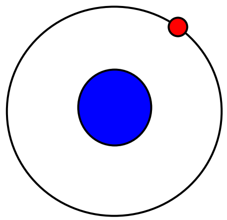
third track
P_t > 500 MeV/c

vertex χ^2 (xy) < 20

|impact parameter of D^+|
<= 500 μm

$m(K^-\pi^+\pi^+) - m(K^-\pi^+)$
>= 0.18 MeV/c2
(reject background from partially reconstructed D^{*+})

Mass and Width of the L=1 D Mesons



D mesons ($c\bar{q}$) have radial and angular excited states.

Precision measurements of masses and widths help refine heavy quark effective theory.

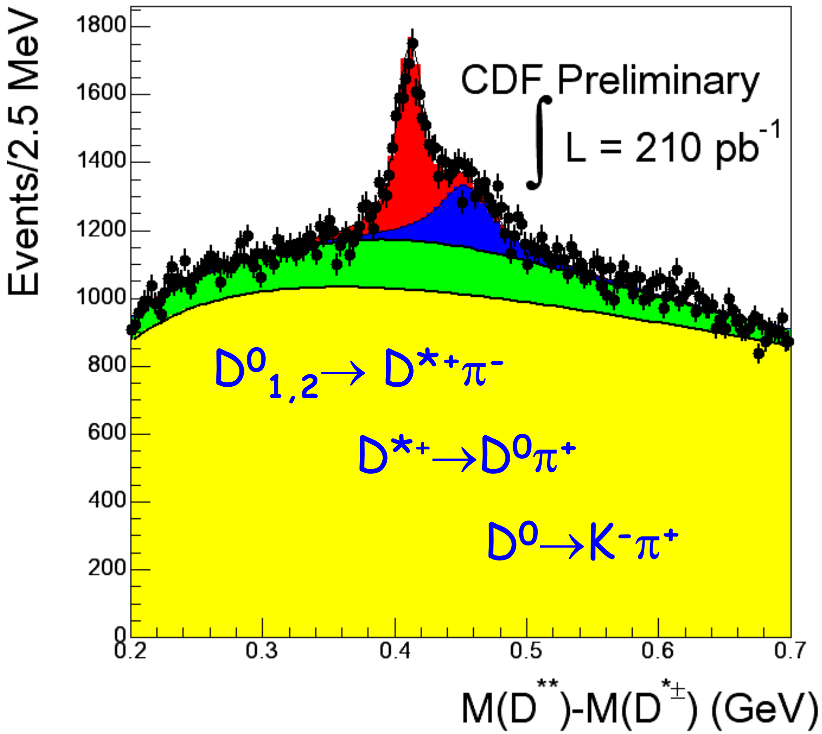
CDF's large sample of D^{*+} and D^{+} decays allows study of the "narrow" width L=1, J=1,2 states via the decays

$D^0_{1,2} \rightarrow D^{*+}\pi^{-}, \; D^{*+}\rightarrow D^0\pi^{+}, \; D^0\rightarrow K^{-}\pi^{+}$ + charge conjugate

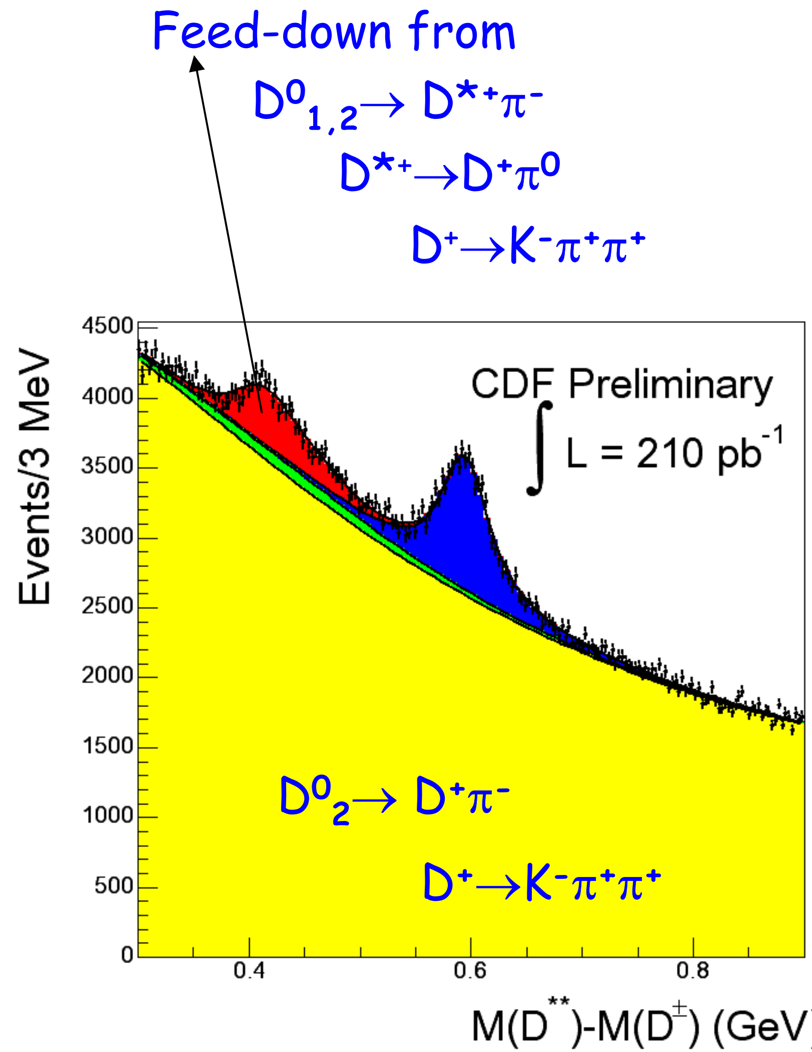
$D^0_{2}\rightarrow D^{+}\pi^{-}, \; D^{+}\rightarrow K^{+}\pi^{-}\pi^{-}$ + charge conjugate

Note that both $D^0_{1,2}$ decay to D^{*+} but only D^0_2 decays to D^{+}.

D_1 and D_2 Signals



- D^0_1 ~7000 signal
- D^0_2 ~4000 signal
- broad $D^0_{1,2}$ background
- combinatoric background



D** Mass and Width Results

$M(D^0_1)-M(D^{*+}) = 411.7 \pm 0.7 \pm 0.4$ MeV

$M(D^0_1) = 2421.7 \pm 0.7 \pm 0.6$ MeV

$\Gamma(D^0_1) = 20.0 \pm 1.7 \pm 1.3$ MeV

$M(D^0_2)-M(D^{*+}) = 594.0 \pm 0.6 \pm 0.5$ MeV

$M(D^0_2) = 2463.3 \pm 0.6 \pm 0.8$ MeV

$\Gamma(D^0_2) = 49.2 \pm 2.1 \pm 1.2$ MeV

Source	ΔM_1 (MeV)	$\Delta\Gamma_1$ (MeV)	ΔM_2 (MeV)	$\Delta\Gamma_2$ (MeV)
MC statistics	0.3	1.2	0.4	1.2
BS mass width	0.1	0.4	0.1	0.5
COT corr	0.1	0.0	0.1	0.0
Tracking/B field	0.1	0.2	0.1	0.2
PDG masses	0.5	-	0.5	-
Total for mass	0.6	1.3	0.8	1.3
Total for diff	0.4	1.3	0.5	1.3
Helicity	0.1	0.9	0.1	3.3

CDF D** Mass and Width Results Compared with Other Experiments

	M_1 (MeV)	Γ_1 (MeV)	M_2 (Mev)	Γ_2 (MeV)
PDG 04	2422 ± 1.8	$18.9^{+4.6}_{-3.5}$	2458.9 ± 2.0	23 ± 5
Belle 03	2421.4 ± 1.5 ± 0.9	23.7 ± 2.7 ± 4.0	2461.6 ± 3.9	45.6 ± 8.0
FOCUS 04			2464.5 ± 1.1 ± 1.9	38.7 ± 5.3 ± 2.9
CDF 04	2421.7 ± 0.7 ± 0.6	20.0 ± 1.7 ± 1.3	2463.3 ± 0.6 ± 0.8	49.2 ± 2.1 ± 1.2

Relative Branching Fraction and Search for Direct CP Asymmetry in $D^0 \to K^+K^-$ and $\pi^+\pi^-$ decays

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

These Cabibbo-suppressed decays may exhibit direct CP asymmetry due to interference between tree and penguin amplitudes.

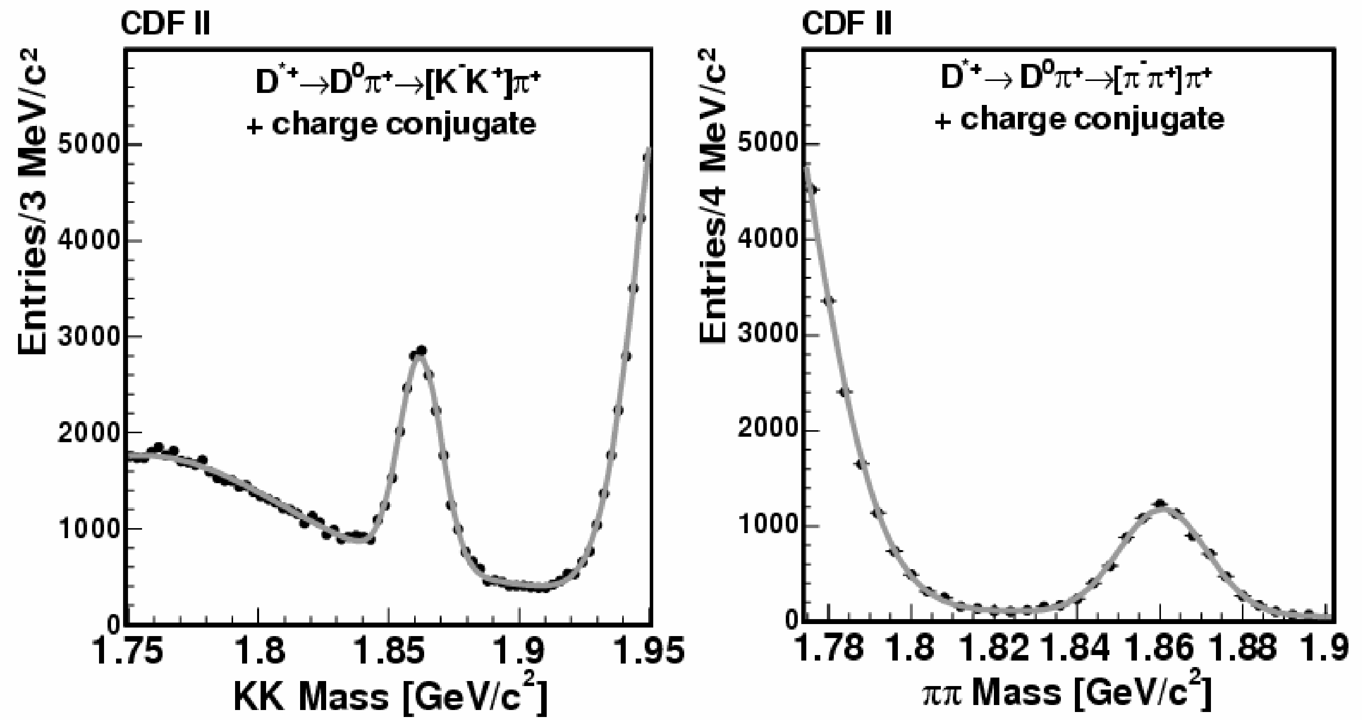
In the standard model, $A_{CP} < 10^{-3}$ and depends on the strong interaction phase difference between the tree and penguin amplitudes.

New physics could produce $A_{CP} \sim O(10^{-2})$.

Precision measurement of the relative branching fraction

$$\Gamma(D^0 \to K^+K^-) / \Gamma(D^0 \to \pi^+\pi^-)$$

helps refine theoretical models for final state strong interactions and hence improves the predictive power for A_{CP}.



Suppress D^0 from B with impact parameter cut: $d_0(D^0) < 100\ \mu m$

Mode	D^0	$\overline{D}^0$	Total
$K\pi$	88310±330	92600±340	180910 ±480
KK	8190 ±140	8030 ±140	16220 ±200
$\pi\pi$	3660±69	3674±68	7334±97

Determination of Relative Decay Rates

$$\frac{\Gamma\left(D^0 \to h^- h^+\right)}{\Gamma\left(D^0 \to K^- \pi^+\right)} = \frac{N_{h^- h^+}}{N_{K\pi}} \cdot \frac{\epsilon_{K\pi}}{\epsilon_{h^- h^+}}$$

$\varepsilon(K\pi) / \varepsilon(KK) = 1.1073 \pm 0.0074$
$\varepsilon(K\pi) / \varepsilon(\pi\pi) = 0.8867 \pm 0.0056$
$\varepsilon(\pi\pi) / \varepsilon(KK) = 1.2488 \pm 0.0078$

	KK/Kπ [%]	ππ/Kπ [%]	KK/ππ [%]
Fit Model	0.64	0.54	0.67
MC Statistic	0.67	0.63	0.62
Trigger simulation	0.34	0.31	0.37
Beam spot size	0.35	0.24	0.35
Material in GEANT	0.28	0.30	0.59
Lifetime difference	0.55	0.55	
D* input spectrum	0.05	<0.01	<0.01
B→D* component	0.16	0.08	0.24
Total	1.2	1.1	1.2

Results on Relative Decay Rates (submitted to PRL)

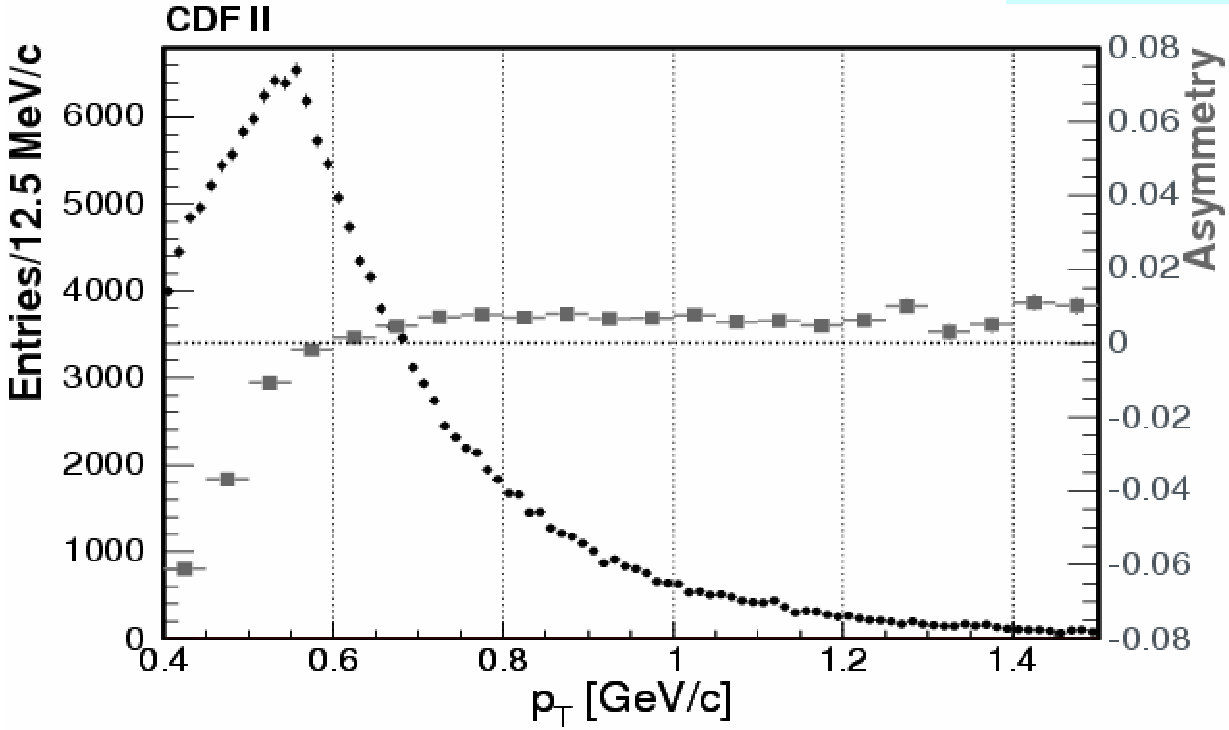
$\Gamma(D^0 \to KK)/\Gamma(D^0 \to K\pi) = 9.92 \pm 0.11(stat) \pm 0.12(syst)$ %
$\Gamma(D^0 \to \pi\pi)/\Gamma(D^0 \to K\pi) = 3.594 \pm 0.054(stat) \pm 0.040(syst)$ %
$\Gamma(D^0 \to KK)/\Gamma(D^0 \to \pi\pi) = 2.760 \pm 0.040(stat) \pm 0.034(syst)$

Compare with best (non CDF) measurement:
$KK/K\pi$: 9.93 ± 0.14 ± 0.14 % (FOCUS 2003)
$\pi\pi/K\pi$: 3.53 ± 0.12 ± 0.06 % (FOCUS 2003)
$KK/\pi\pi$: 2.81 ± 0.10 ± 0.06

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

$D^{*+} \to D^0 \pi_S \to [K^- \pi^+] \pi_S^+$

$$A_Q \equiv \frac{N^+ - N^-}{N^+ + N^-}$$



A(residual) = (0.35 ± 0.53)%

CDF Result Submitted to PRL:

$$A(D^\circ \to K^+K^-) \quad = \quad 2.0 \pm 1.2(stat) \pm 0.6(syst)\ \%$$
$$A(D^\circ \to \pi^+\pi^-) \quad = \quad 1.0 \pm 1.3(stat) \pm 0.6(syst)\ \%$$

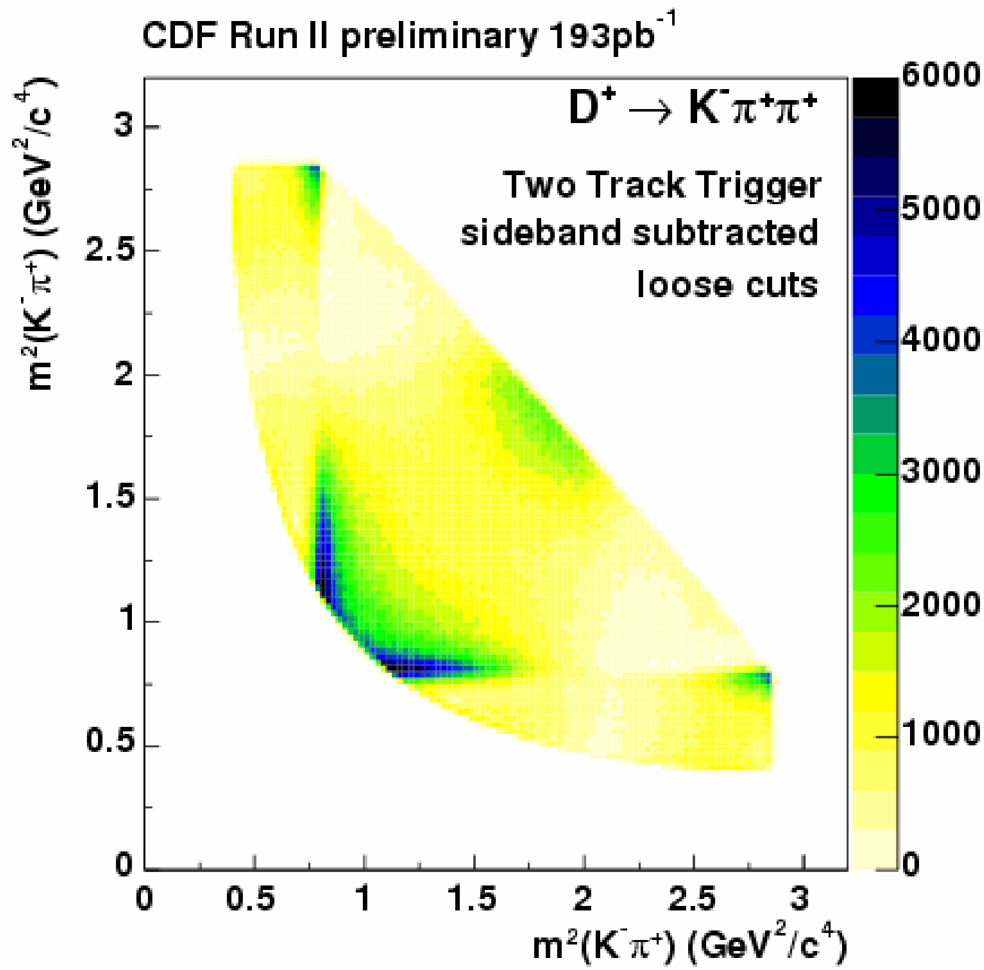
Compare with best (non CDF) measurement:

A_{CP}(KK): 0.0 ± 2.2 ± 0.8 % (CLEO 2002)

$A_{CP}(\pi\pi)$: 1.9 ± 3.2 ± 0.8 % (CLEO 2002)

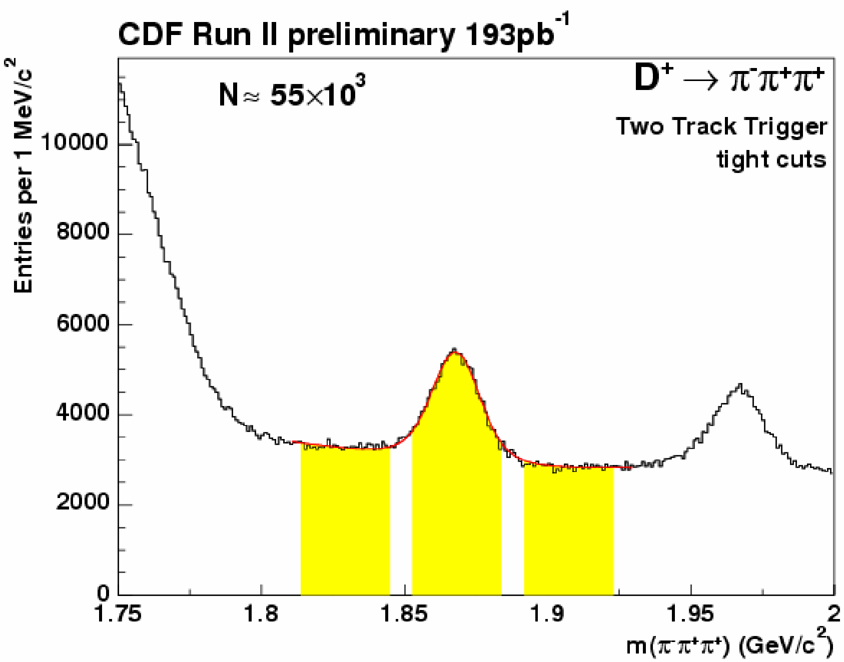
D^+ Dalitz Properties

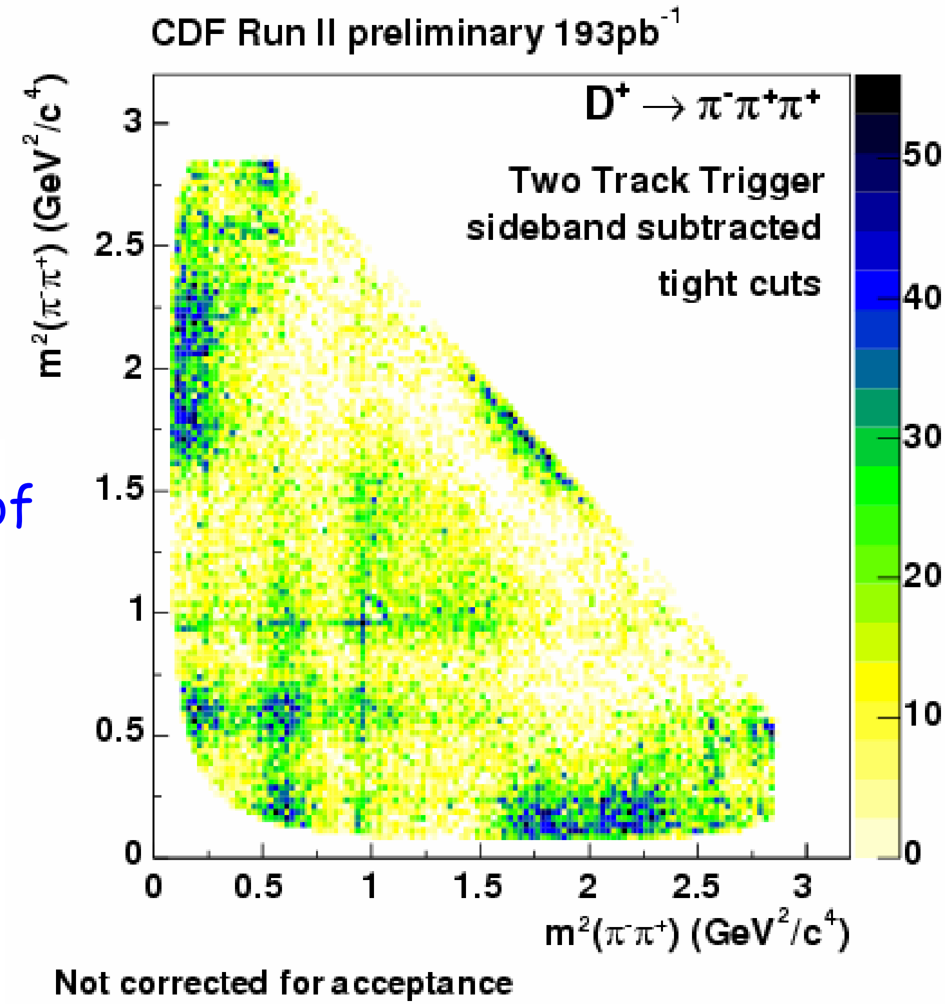
Compare Dalitz structure of Cabibbo-favored and Cabibbo-suppressed decays



Not corrected for acceptance

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





We will soon improve knowledge of BR($D^+ \to \pi^+\pi^-\pi^-$)

Theory predicts direct CP asymmetry could be O(10^{-3})

E791: A = -0.017±0.042, Phys. Lett. B403 (1997)

Summary

Tevatron Collider is a highly productive Charm Factory

Significantly improved measurements of D** Masses and Widths reveal a larger width for the D_2

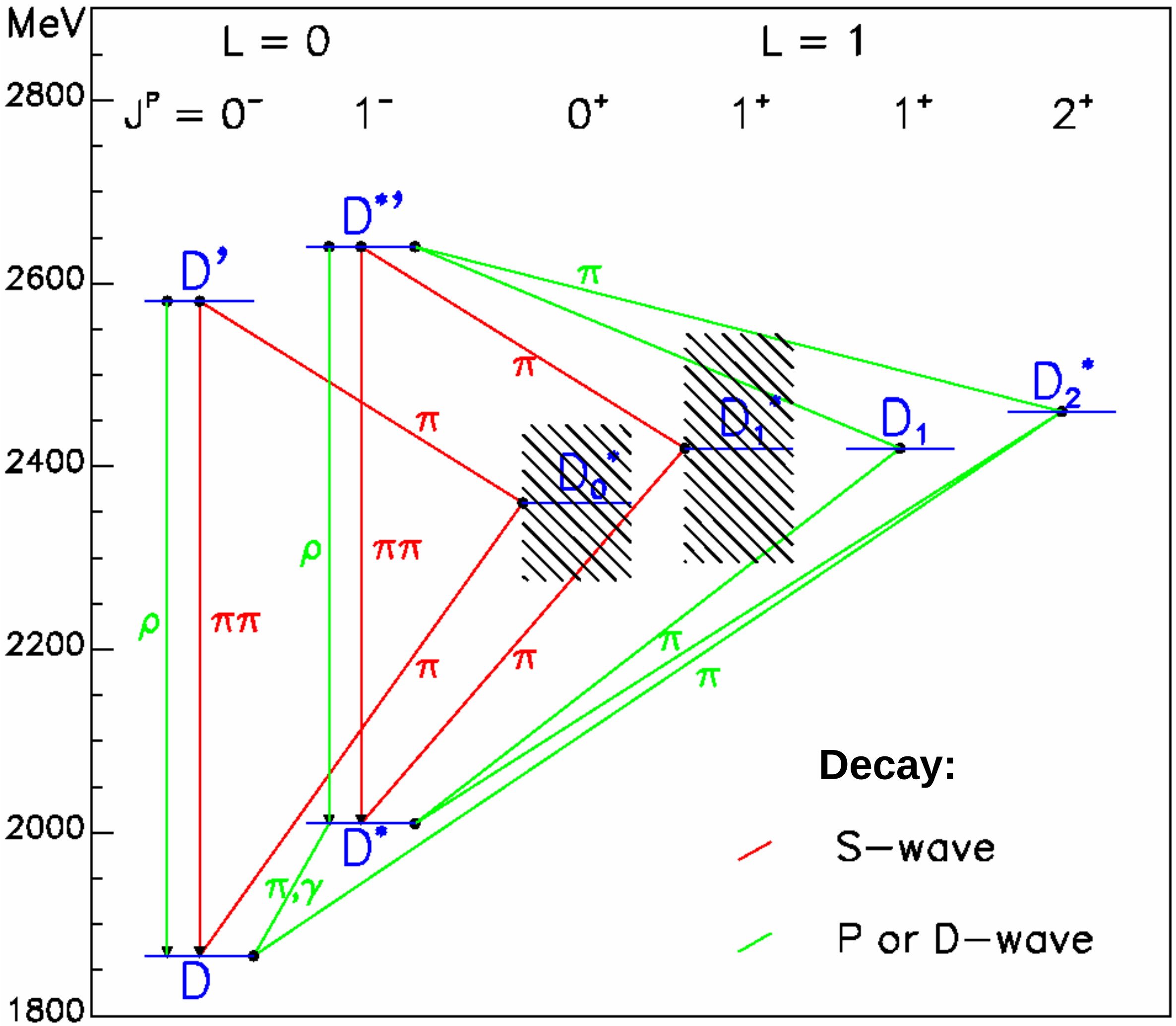
Improved Measurements of Relative Branching Fractions and CP Asymmetries for $D^0 \to K^+K^-$ and $\pi^+\pi^-$ decays but no asymmetry yet seen

Large statistics Dalitz plot for $D^+ \to K^-\pi^+\pi^+$ and $\pi^-\pi^+\pi^+$ decays promises improved branching and asymmetry measurements to come

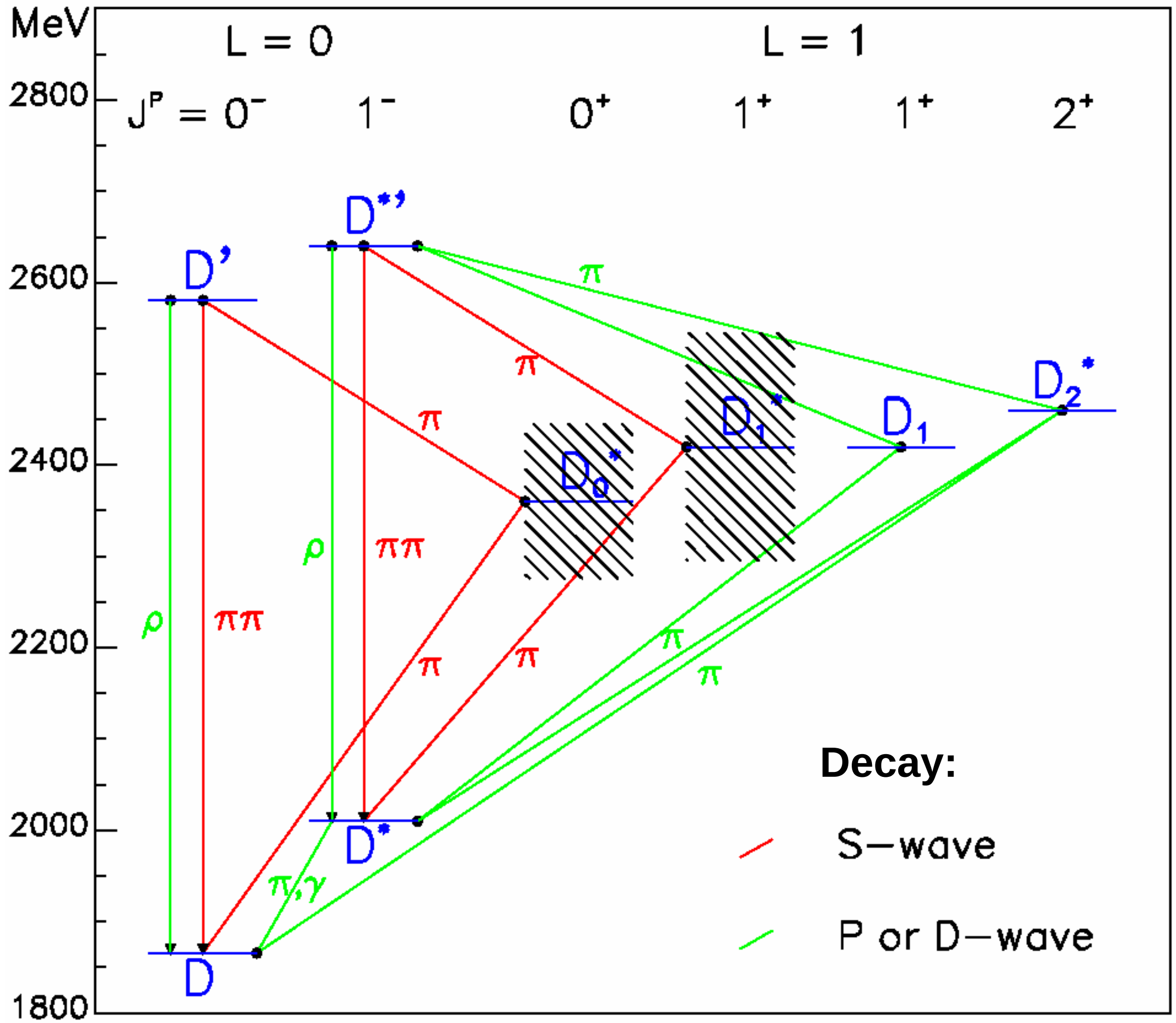
CDF RUN II total yields for charm could be 10X that reported here!

Supplemental Slides

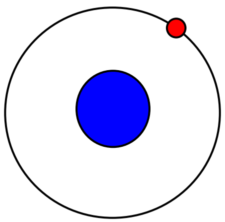
Mass and Width of the L=1 D Mesons

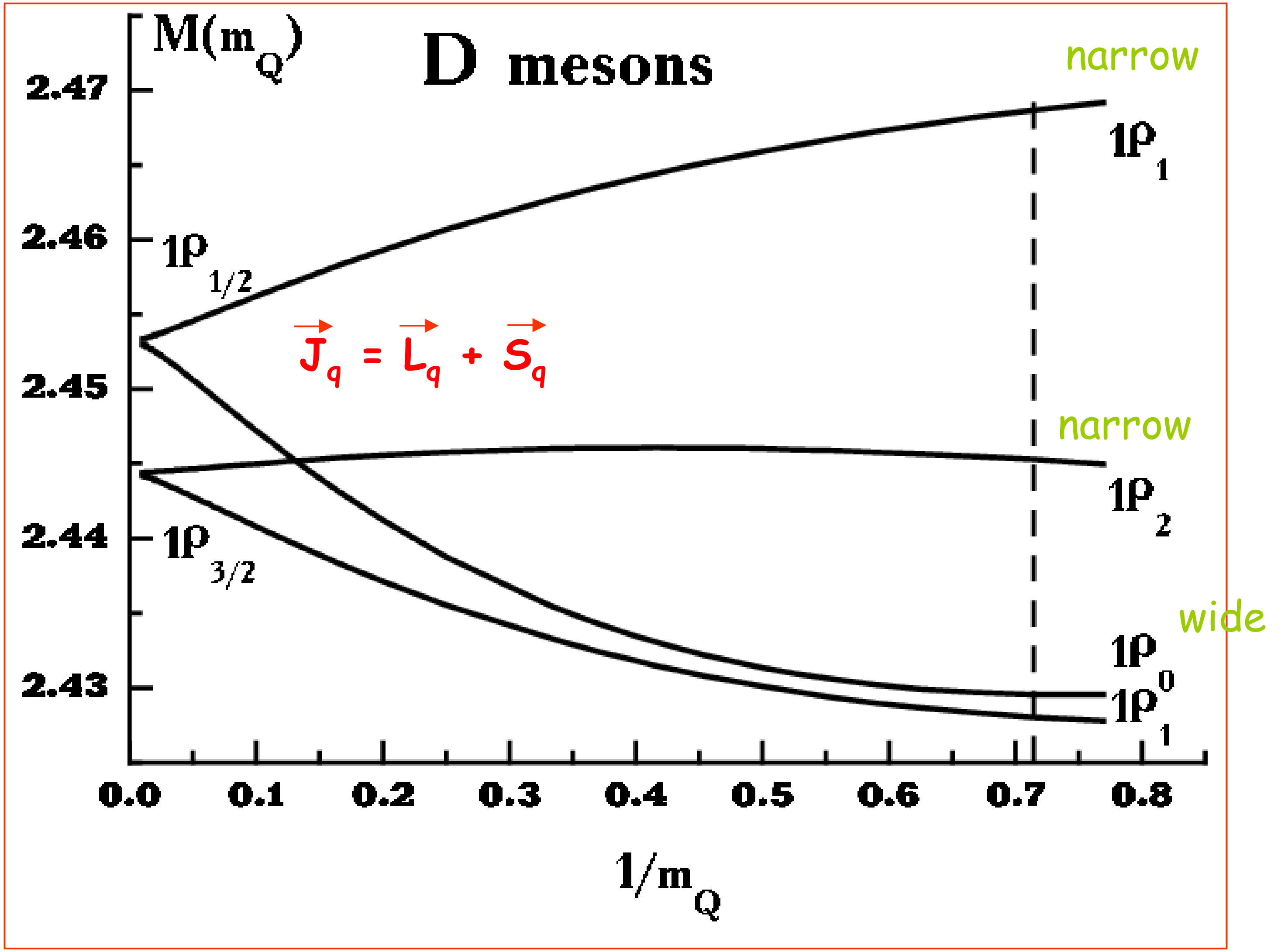


Mass and Width of the L=1 D Mesons

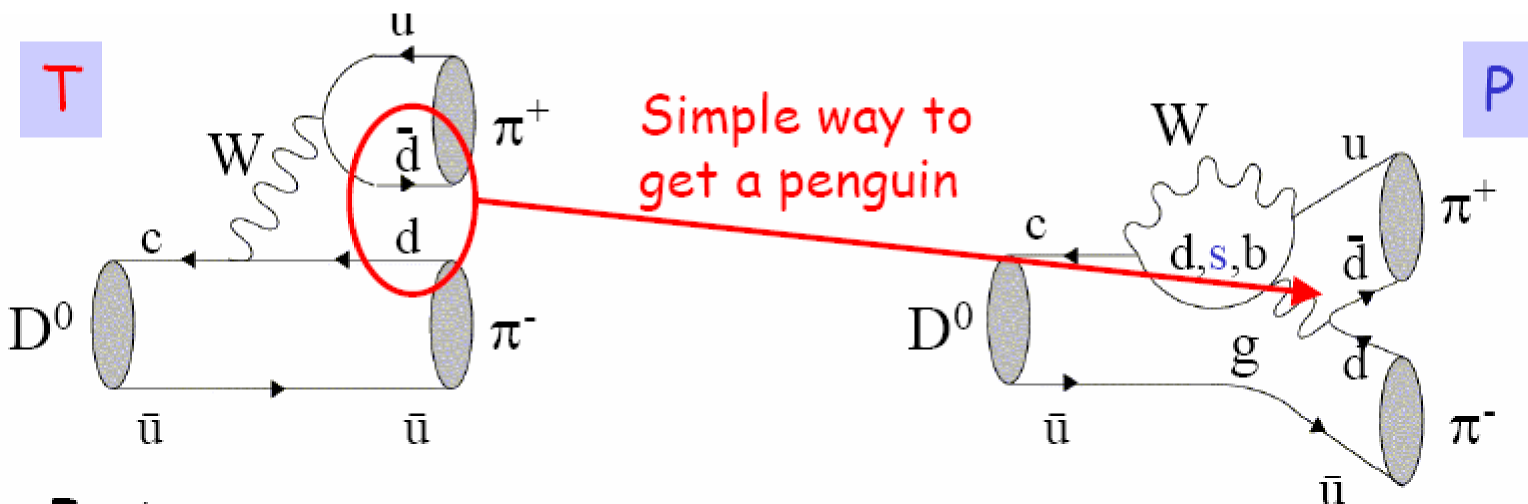


Mass Splitting in Heavy Quark Effective Theory





Direct CP Violation in Cabibbo-Suppressed D0 Decays

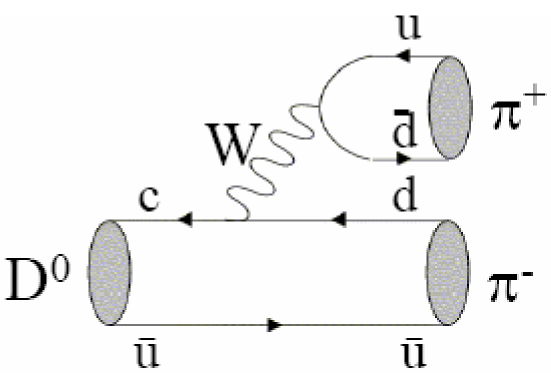


- Features:
  - Vcd*Vud VS Vcs*Vus → different weak phases
  - ΔI = 1/2,3/2 VS ΔI = 1/2 → different strong phases are likely
  - $m_s < m_c$ → long distance effects dominate → FSI
  - Heavy exotic particles can run in the loop → sensitive to NP

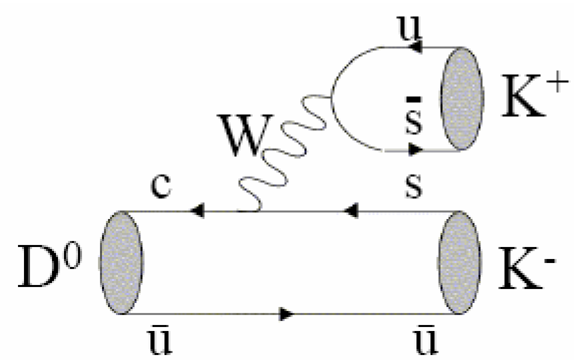
$$A_{CP} \approx \frac{Im\left(V_{cd}^{*}V_{ud}V_{cs}^{*}V_{us}\right)}{\lambda^{2}} \sin\delta_{st}\frac{P}{T} \approx A^{2}\eta\lambda^{4}\sin\delta_{st}\frac{P}{T} < 10^{-3}$$

$$A_{CP}^{NewPhysics} \sim O(1\%)$$

Relative Branching Ratio and Final State Interactions



Equal rates in the limit of $SU(3)_F$



- Phase space favors $\pi^+\pi^-$ over K^+K^-, larger form factors and decay constants favors the K^+K^- final state:

$$\left.\frac{\Gamma(D^0 \to K^-K^+)}{\Gamma(D^0 \to \pi^-\pi^+)}\right|_{SM} \cong 1.4 \text{ to be compared with} \sim 2.8 \text{ from experiments}$$

- Phenomenological isospin analyses using D^0 and D^+ BR derive magnitudes and phase shifts of the FSI amplitudes:
  - are able to reproduce the experimental $K^+K^-/\pi^+\pi^-$ ratio
  - predict A_{CP}~$10^{-4}\div10^{-3}$
- High precision measurements of the relative BR improve the predictive power for A_{CP}

CDF D** Mass and Width Results Compared with other expts.