Hadronic D and D_s Decays at CLEO-c

$$e^+ e^- \to c\bar{c} \to D_s D_s^*$$

$$D_s^- \to K^- K^+ \pi^-, \; D_s^+ \to K^+ K^- \pi^+$$

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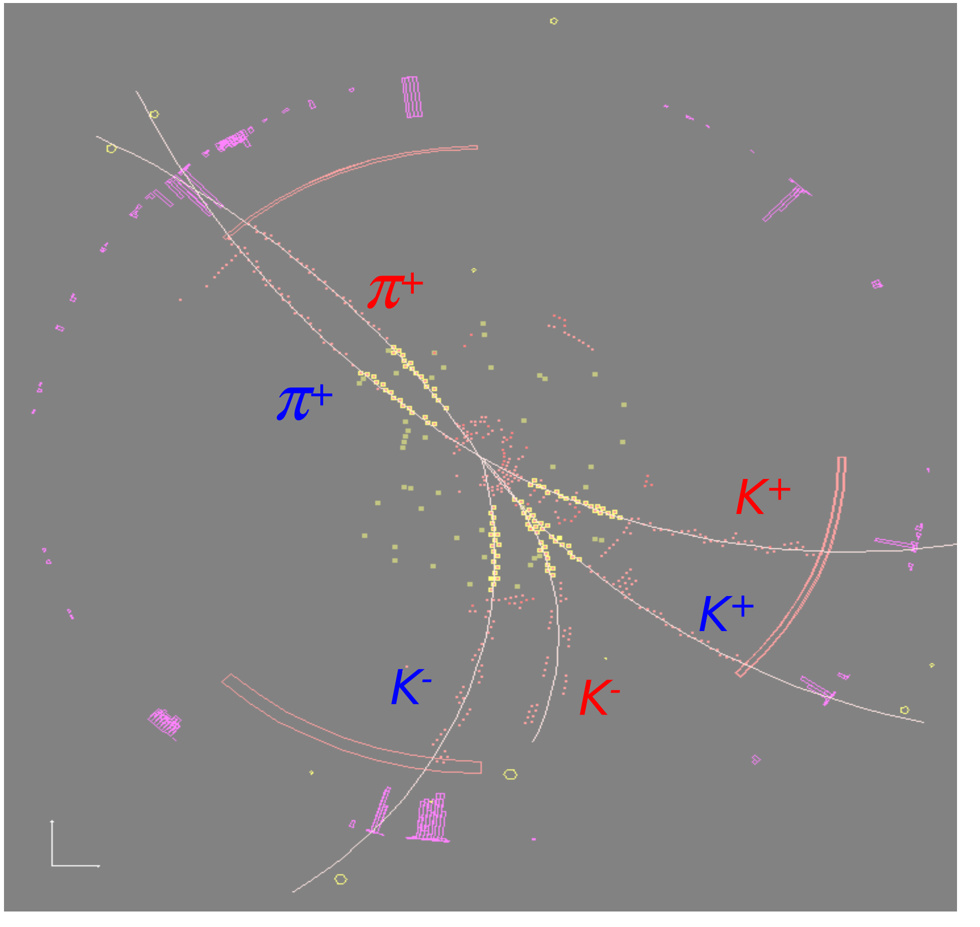
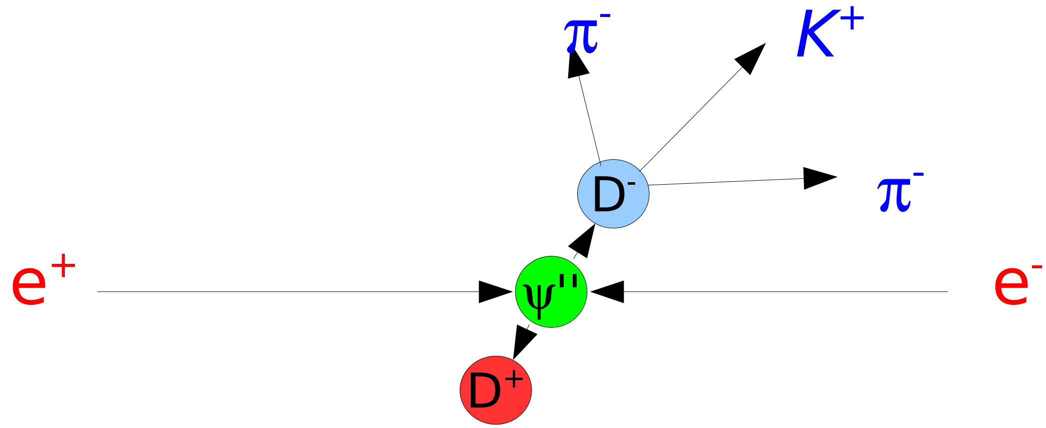


Outline

- Absolute Charm Branching Fractions
  - D^0 and D^+
  - D_s
- $D^+ \to K^- \pi^+ \pi^+$ and $D^+ \to \pi^- \pi^+ \pi^+$ Dalitz Analyses
- Rare and inclusive modes
- Final states with K_S or K_L
- Cabibbo suppressed D_S decays
- *D* meson decays to two kaons
- Conclusions

Absolute Hadronic D^0 and D^+ Branching Fractions

- Important to establish the branching fraction scale
  - Directly impact determination of *e.g.* V_{cb} from exclusive modes
- Need to 'count' the number of produced *D* mesons
  - At $c\bar{c}$-threshold we use tagged *D* candidates



CLEO-c has published results based on 56 pb^{-1} (PRL 96, 092002)

Today we present results on 281 pb^{-1}

Tag by full reconstruction of one *D*

CLEO-c Hadronic *BrFr.*

- Use a 'double tag' technique, pioneered by MARK III

$$N_i = \epsilon_i B_i N_{D\overline{D}}$$
$$\overline{N}_j = \overline{\epsilon}_j B_j N_{D\overline{D}}$$
$$N_{ij} = \epsilon_{ij} B_i B_j N_{D\overline{D}}$$

$$N_{D\overline{D}} = \frac{N_i \overline{N}_j \epsilon_{ij}}{N_{ij} \epsilon_i \overline{\epsilon}_j} \qquad B_i = \frac{N_{ij} \epsilon_j}{N_j \epsilon_{ij}}$$

- The following final states are used
  D^0: $K^-\pi^+$, $K^-\pi^+\pi^0$, and $K^-\pi^+\pi^-\pi^+$
  D^+: $K^-\pi^+\pi^+$, $K_s\pi^+$, $K^-\pi^+\pi^+\pi^0$, $K_S\pi^+\pi^-\pi^+$, $K_S\pi^+\pi^0$, and $K^-K^+\pi^+$
- Determine separately the D and $\overline{D}$ yields
  - 18 single tag yields
  - 45 (=3^2+6^2) double tag yields
- In a combined χ^2 fit we extract 9 branching fractions and $D^0\overline{D}^0$ and D^+D^- yields. The fit includes the systematic errors.
- Many systematics cancel in the $D\overline{D}$ yield (*e.g.* tracking eff., PID eff.).

Single Tag Yields (281 pb^{-1})

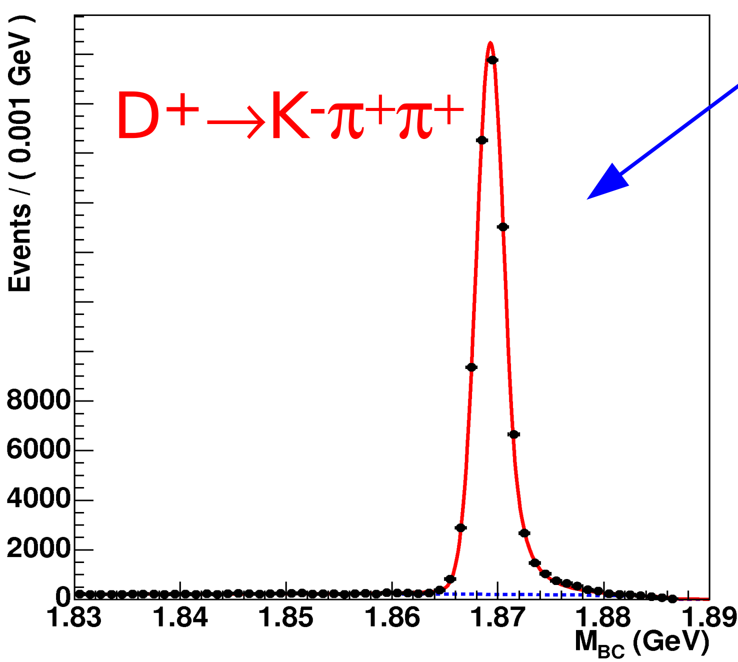
Extract yields from

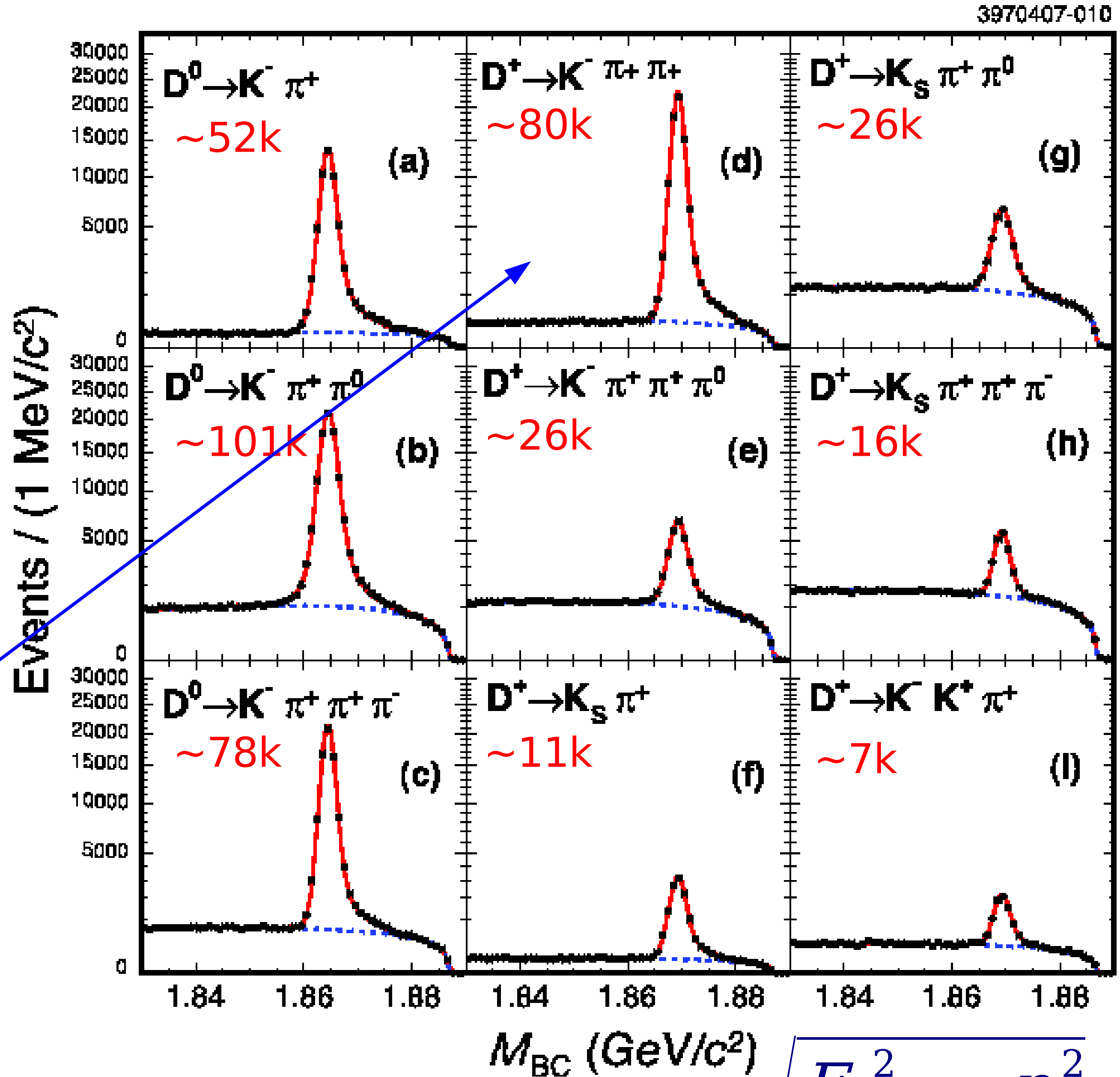
$$m_{BC} = \sqrt{E_{beam}^2 - P_D^2}$$

Lineshape includes

- Detector resolution
- ISR in $e^+e^- \to \psi(3770)$
- $\psi(3770)$ lineshape
- Beam energy spread

Linear scale





$$\sqrt{E_{beam}^2 - p_D^2}$$

CP Asymmetries

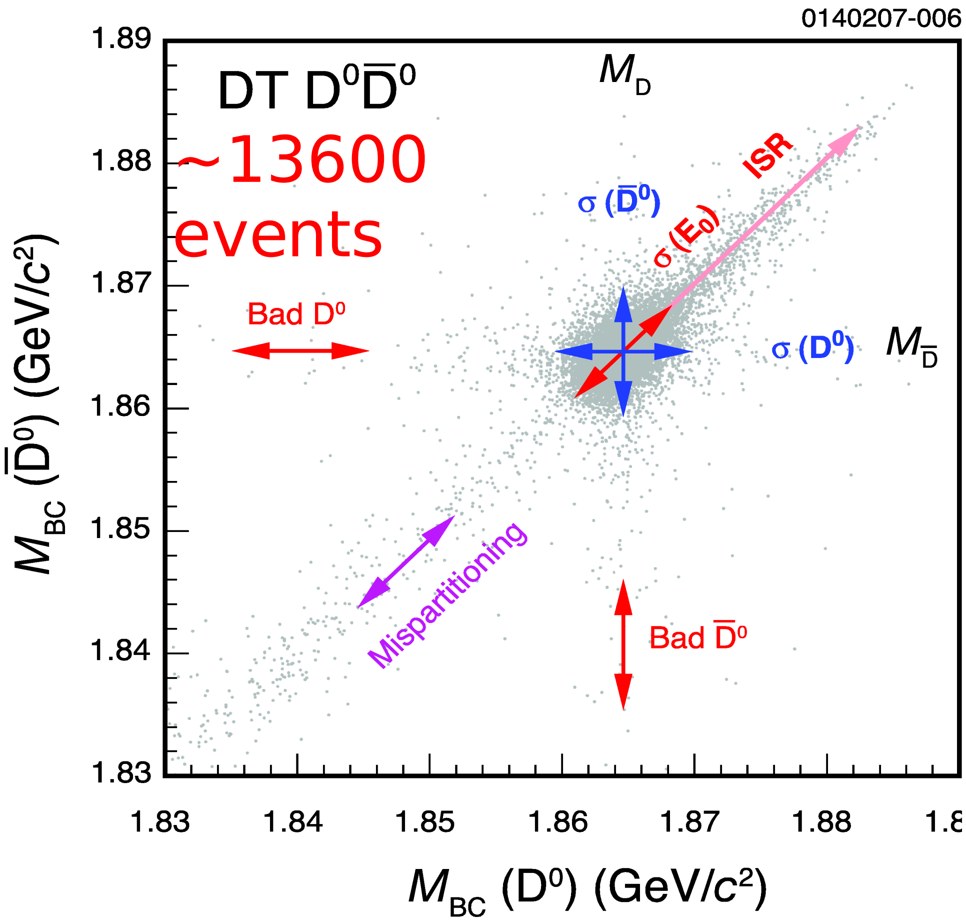
- Note asymmetry in raw yield for e.g. $D^0 \to K^- \pi^+$
  - Asymmetry caused by interactions in RICH and are well described by the simulation.
- Precision measurements will need very good understanding of the detector.

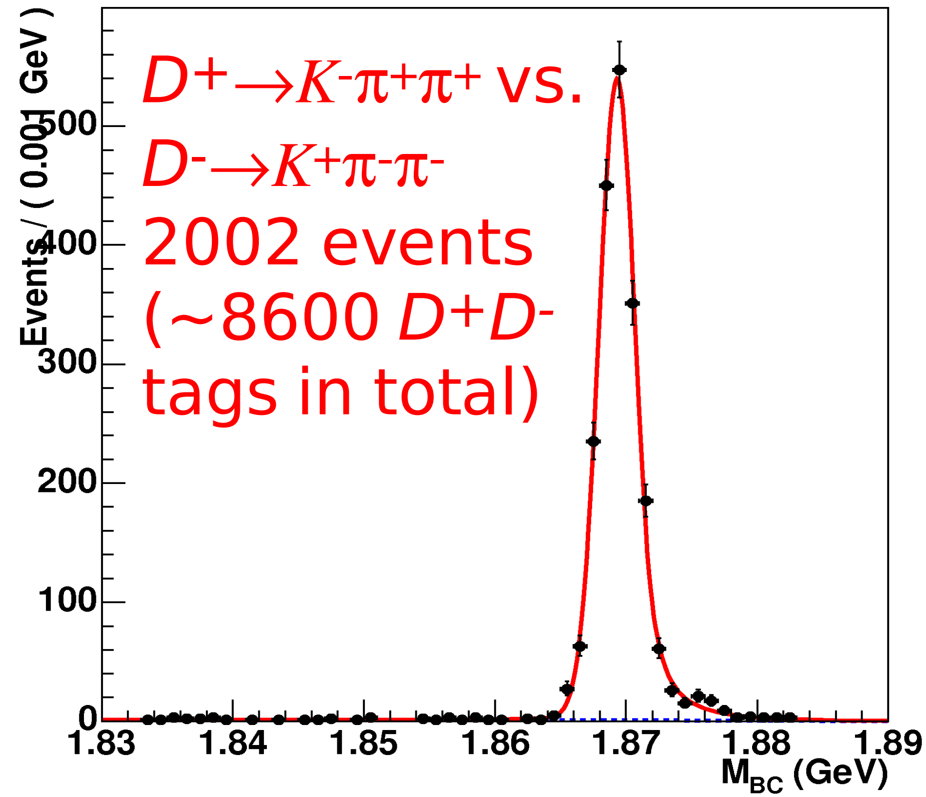
Single Tag Mode	Efficiency (%)	Data Yield
$D^0 \to K^-\pi^+$	64.18 ± 0.19	$25,760 \pm 165$
$\overline{D}^0 \to K^+\pi^-$	64.90 ± 0.19	$26,258 \pm 166$
$D^0 \to K^-\pi^+\pi^0$	33.46 ± 0.12	$50,276 \pm 258$
$\overline{D}^0 \to K^+\pi^-\pi^0$	33.78 ± 0.12	$50,537 \pm 259$
$D^0 \to K^-\pi^+\pi^+\pi^-$	45.27 ± 0.16	$39,709 \pm 216$
$\overline{D}^0 \to K^+\pi^-\pi^-\pi^+$	45.81 ± 0.16	$39,606 \pm 216$
$D^+ \to K^-\pi^+\pi^+$	54.07 ± 0.18	$40,248 \pm 208$
$D^- \to K^+\pi^-\pi^-$	54.18 ± 0.18	$40,734 \pm 209$
$D^+ \to K^-\pi^+\pi^+\pi^0$	26.23 ± 0.18	$12,844 \pm 153$
$D^- \to K^+\pi^-\pi^-\pi^0$	26.58 ± 0.18	$12,756 \pm 153$
$D^+ \to K^0_S\pi^+$	45.59 ± 0.18	$5,789 \pm 82$
$D^- \to K^0_S\pi^-$	45.67 ± 0.18	$5,868 \pm 82$
$D^+ \to K^0_S\pi^+\pi^0$	22.87 ± 0.19	$13,275 \pm 157$
$D^- \to K^0_S\pi^-\pi^0$	22.73 ± 0.19	$13,126 \pm 155$
$D^+ \to K^0_S\pi^+\pi^+\pi^-$	31.43 ± 0.24	$8,275 \pm 134$
$D^- \to K^0_S\pi^-\pi^-\pi^+$	31.54 ± 0.24	$8,285 \pm 134$
$D^+ \to K^+K^-\pi^+$	45.86 ± 0.36	$3,519 \pm 73$
$D^- \to K^-K^+\pi^-$	45.57 ± 0.35	$3,501 \pm 73$

Efficiency corrected CP Asymmetry

Mode	CP Asymmetry (%)
$D^0 \to K^-\pi^+$	$-0.4 \pm 0.5 \pm 0.9$
$D^0 \to K^-\pi^+\pi^0$	$0.2 \pm 0.4 \pm 0.8$
$D^0 \to K^-\pi^+\pi^+\pi^-$	$0.7 \pm 0.5 \pm 0.9$
$D^+ \to K^-\pi^+\pi^+$	$-0.5 \pm 0.4 \pm 0.9$
$D^+ \to K^-\pi^+\pi^+\pi^0$	$1.0 \pm 0.9 \pm 0.9$
$D^+ \to K^0_S\pi^+$	$-0.6 \pm 1.0 \pm 0.3$
$D^+ \to K^0_S\pi^+\pi^0$	$0.3 \pm 0.9 \pm 0.3$
$D^+ \to K^0_S\pi^+\pi^+\pi^-$	$0.1 \pm 1.1 \pm 0.6$
$D^+ \to K^+K^-\pi^+$	$-0.1 \pm 1.5 \pm 0.8$

Double Tag Yields (281 pb^{-1})

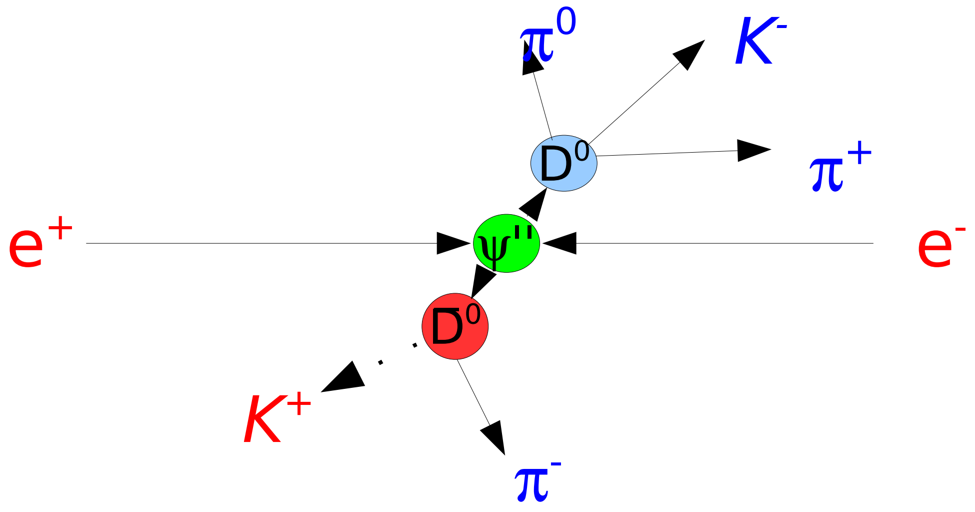


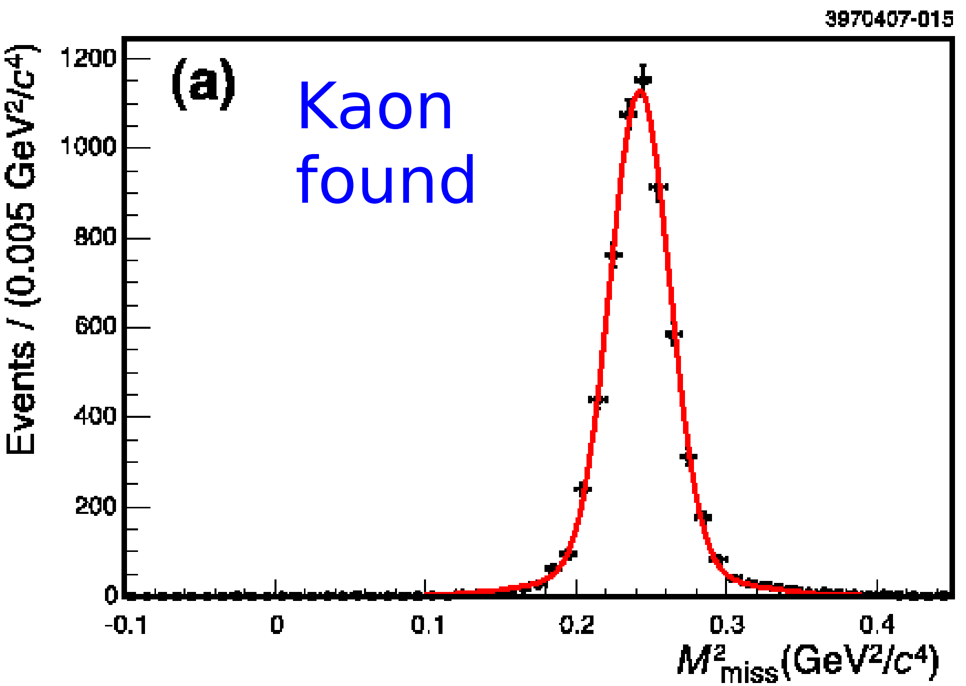


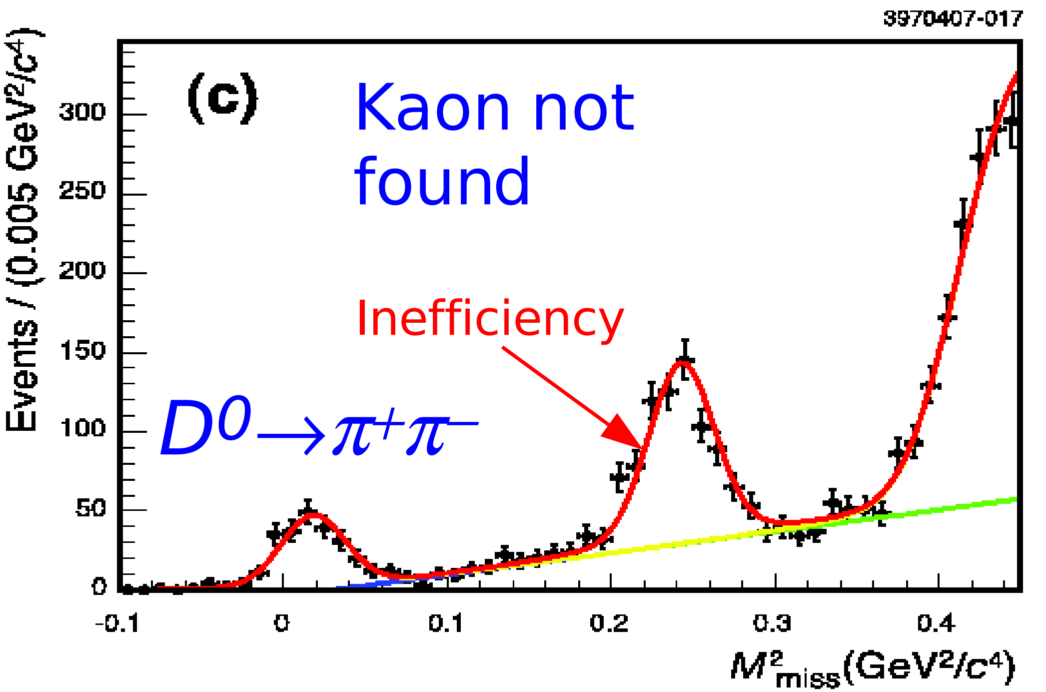
- Very clean signals in fully reconstructed events
- The statistical errors on the double tag yields set the scale of errors on the branching fractions

Tracking Efficiencies

- We find good agreement between data and MC
  - We assign a 0.3% uncertainty per charged track plus 0.6% per kaon

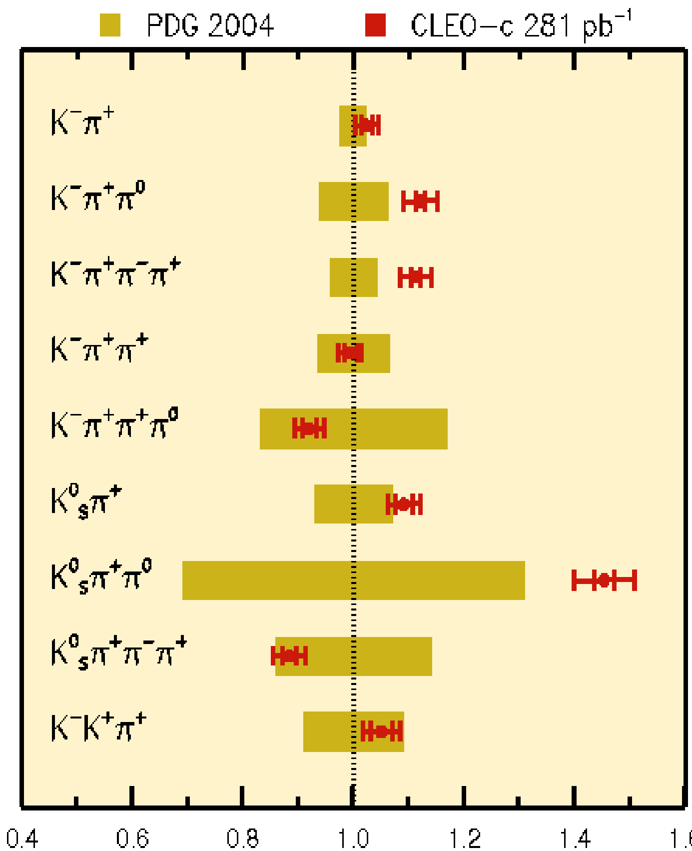






Branching Fractions for 281 pb^{-1}

Parameter	Fitted Value	Fractional Error Stat.(%)	Syst.(%)	Δ_{FSR} (%)
$N_{D^0\bar{D}^0}$	$(1.031 \pm 0.008 \pm 0.013) \times 10^6$	0.8	1.3	+0.1
$\mathcal{B}(D^0 \to K^-\pi^+)$	$(3.891 \pm 0.035 \pm 0.059 \pm 0.035)\%$	0.9	1.8	−3.0
$\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$	$(14.57 \pm 0.12 \pm 0.38 \pm 0.05)\%$	0.8	2.7	−1.1
$\mathcal{B}(D^0 \to K^-\pi^+\pi^+\pi^-)$	$(8.30 \pm 0.07 \pm 0.19 \pm 0.07)\%$	0.9	2.4	−2.5
$N_{D^+D^-}$	$(0.819 \pm 0.008 \pm 0.010) \times 10^6$	1.0	1.2	+0.1
$\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$	$(9.15 \pm 0.10 \pm 0.16 \pm 0.07)\%$	1.1	1.9	−2.4
$\mathcal{B}(D^+ \to K^-\pi^+\pi^+\pi^0)$	$(5.98 \pm 0.08 \pm 0.16 \pm 0.02)\%$	1.3	2.8	−1.0
$\mathcal{B}(D^+ \to K^0_S\pi^+)$	$(1.539 \pm 0.022 \pm 0.037 \pm 0.009)\%$	1.4	2.5	−1.8
$\mathcal{B}(D^+ \to K^0_S\pi^+\pi^0)$	$(7.05 \pm 0.09 \pm 0.25 \pm 0.01)\%$	1.3	3.5	−0.4
$\mathcal{B}(D^+ \to K^0_S\pi^+\pi^+\pi^-)$	$(3.149 \pm 0.046 \pm 0.094 \pm 0.019)\%$	1.5	3.0	−1.9
$\mathcal{B}(D^+ \to K^+K^-\pi^+)$	$(0.935 \pm 0.017 \pm 0.024 \pm 0.003)\%$	1.8	2.6	−1.2
$\mathcal{B}(D^0 \to K^-\pi^+\pi^0)/\mathcal{B}(K^-\pi^+)$	$3.744 \pm 0.022 \pm 0.093 \pm 0.021$	0.6	2.6	+1.9
$\mathcal{B}(D^0 \to K^-\pi^+\pi^+\pi^-)/\mathcal{B}(K^-\pi^+)$	$2.133 \pm 0.013 \pm 0.037 \pm 0.002$	0.6	1.7	+0.5
$\mathcal{B}(D^+ \to K^-\pi^+\pi^+\pi^0)/\mathcal{B}(K^-\pi^+\pi^+)$	$0.654 \pm 0.006 \pm 0.018 \pm 0.003$	0.9	2.7	+1.3
$\mathcal{B}(D^+ \to K^0_S\pi^+)/\mathcal{B}(K^-\pi^+\pi^+)$	$0.1683 \pm 0.0018 \pm 0.0038 \pm 0.0003$	1.1	2.3	+0.5
$\mathcal{B}(D^+ \to K^0_S\pi^+\pi^0)/\mathcal{B}(K^-\pi^+\pi^+)$	$0.771 \pm 0.007 \pm 0.027 \pm 0.005$	0.9	3.5	+1.9
$\mathcal{B}(D^+ \to K^0_S\pi^+\pi^+\pi^-)/\mathcal{B}(K^-\pi^+\pi^+)$	$0.3444 \pm 0.0039 \pm 0.0093 \pm 0.0004$	1.1	2.7	+0.4
$\mathcal{B}(D^+ \to K^+K^-\pi^+)/\mathcal{B}(K^-\pi^+\pi^+)$	$0.1022 \pm 0.0015 \pm 0.0022 \pm 0.0004$	1.5	2.2	+1.1

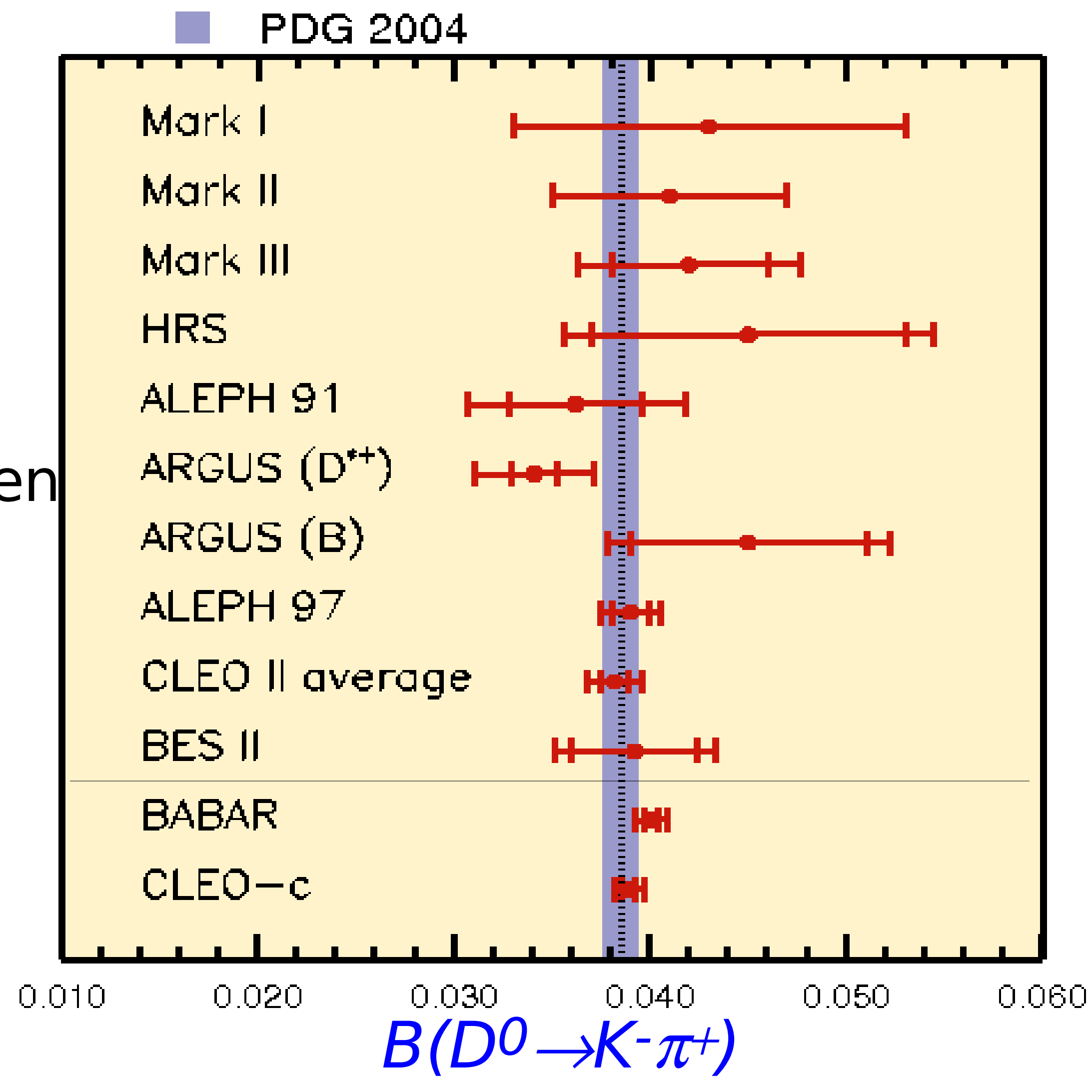


B(CLEO)/*B*(PDG2004)

- Statistical errors about 1% - mostly limited by double tag yields
- Δ_{FSR} is the effect of not including final state radiation in the MC

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

- Systematics limited:
  - Statistical: ~0.9%
  - Systematic: ~1.8%
- FSR is largest individual syst.
  - Uncertainty 0.9%
  - We use PHOTOS v2.15
    - Includes interference between radiation from different particles.
  - Systematic uncertainty based on size of this effect.
- Many other systematic uncertainties
  - Some will improve with more data.



$D^+ \to K^- \pi^+ \pi^+$ and $D^+ \to \pi^- \pi^+ \pi^+$ Dalitz Analysis

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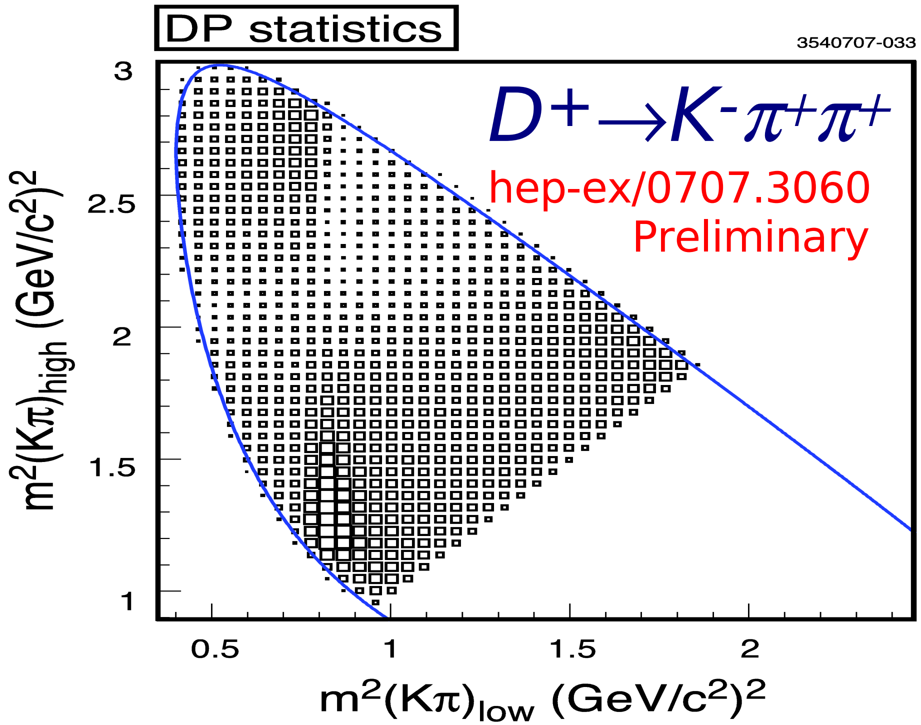
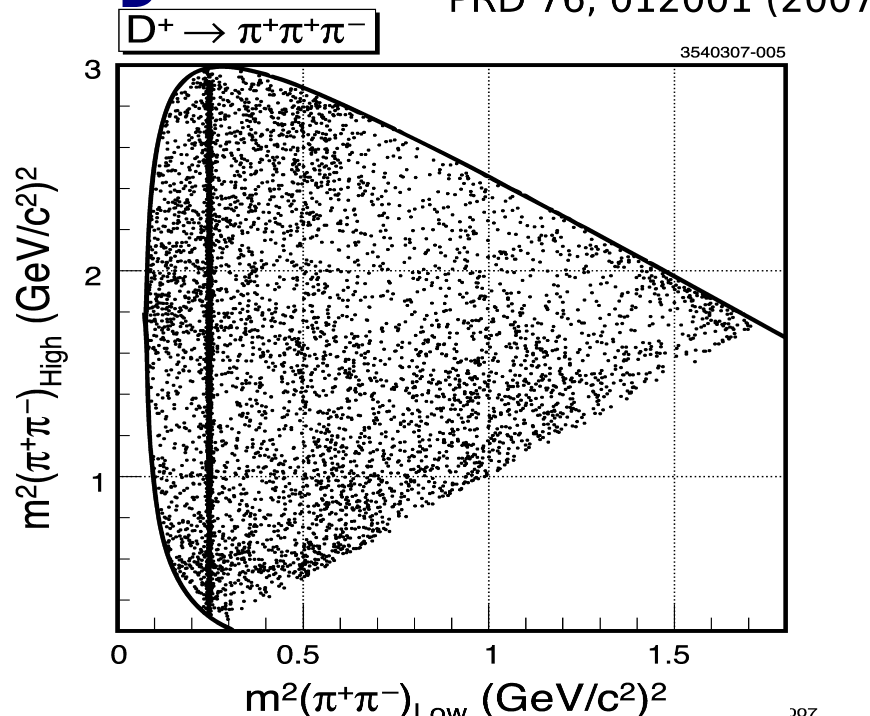
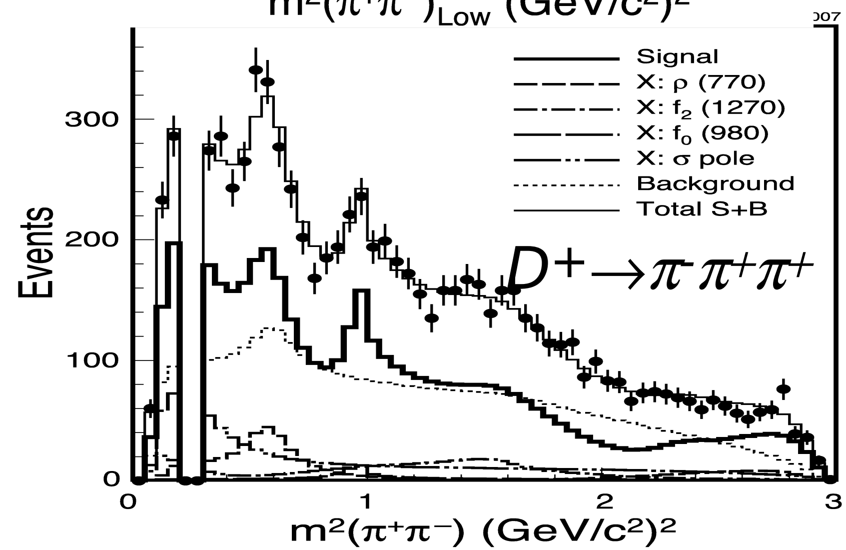


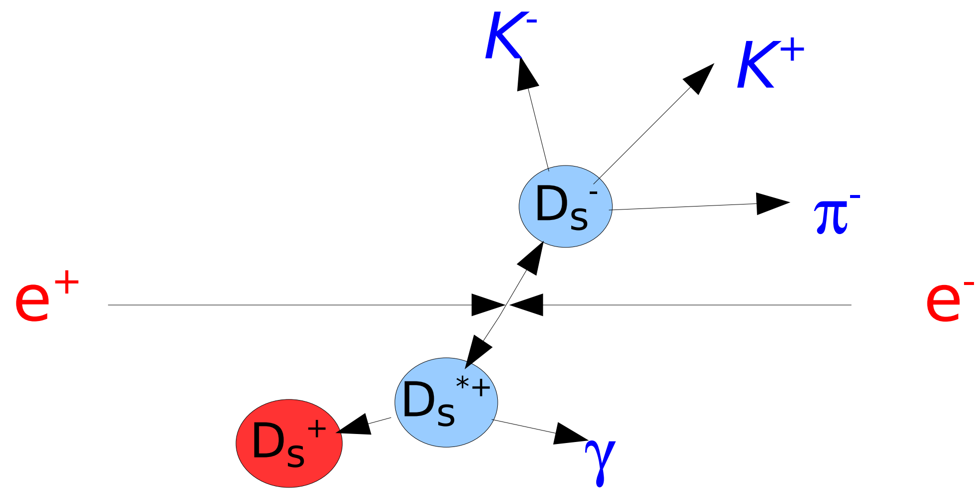


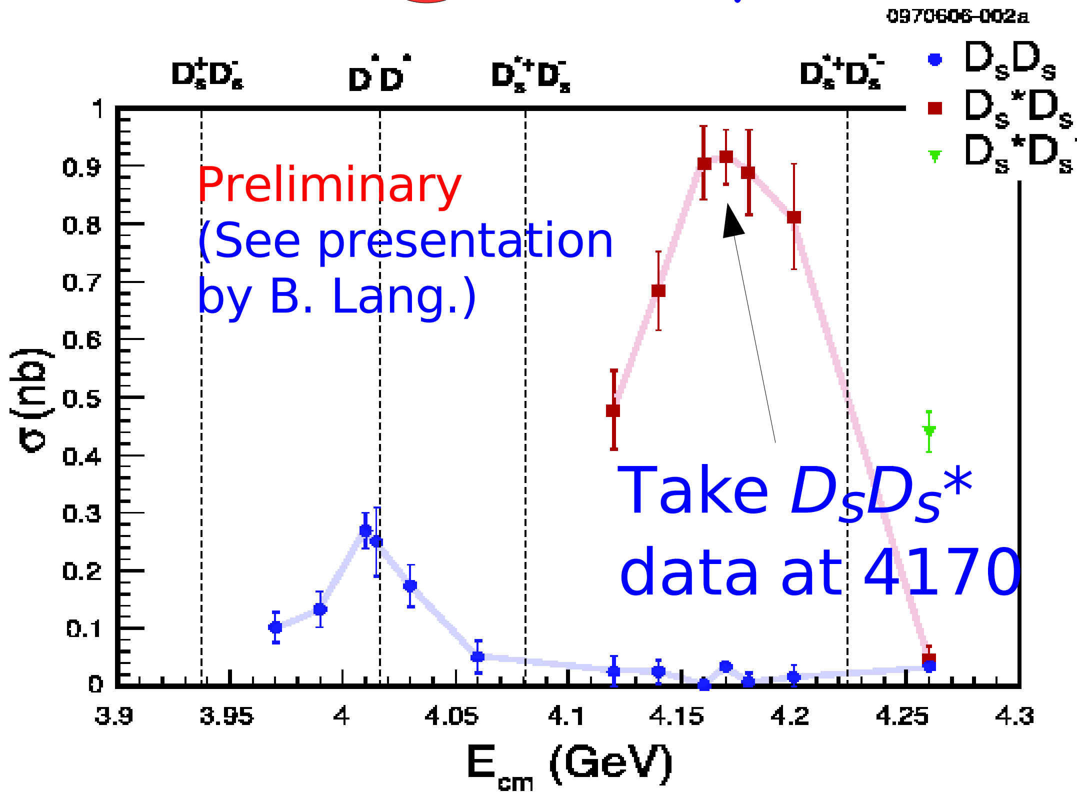


- Consistent with previous results (*e.g.* FOCUS and E791) that S-wave component dominates.
- See talk by B. Meadows

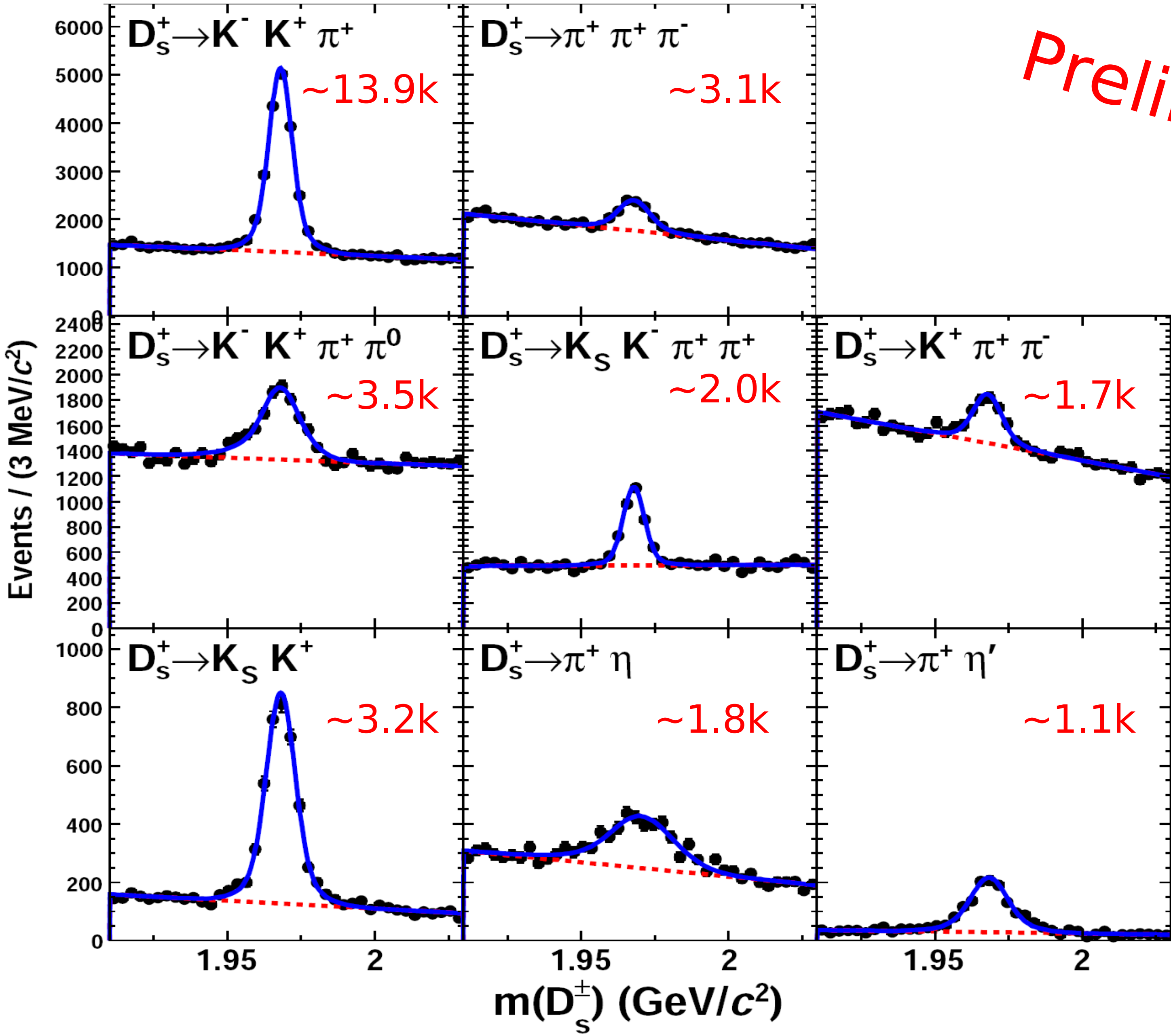
CLEO-c D_s Branching Fractions

- Use same technique as for the D^0 and D^+ branching fractions
  - Pairs of D_s and D_s^*
- Used 298 pb^{-1} of data recorded at (or near) E_{cm}=4170 MeV
- We study the final states:
  - $K_S K^+$
  - $K^+K^-\pi^+$
  - $K^+K^-\pi^+\pi^0$
  - $K_S K^-\pi^+\pi^+$
  - $\pi^+\pi^-\pi^+$
  - $\eta\pi^+$
  - $\eta'\pi^+$
  - $K^+\pi^-\pi^+$



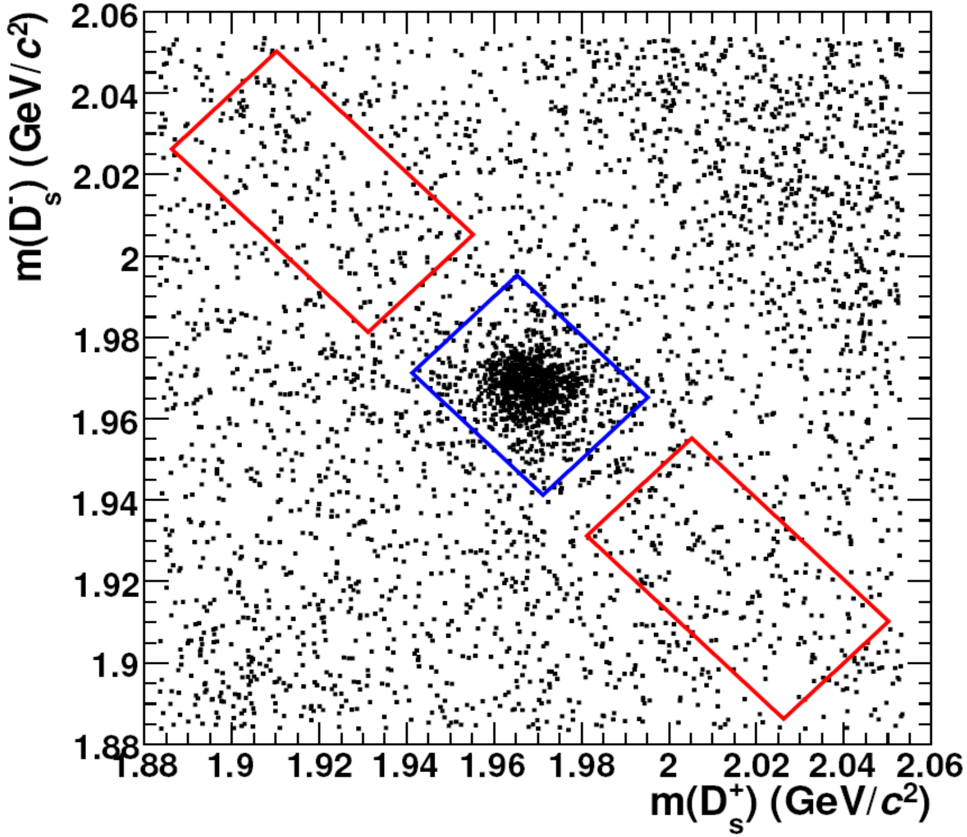


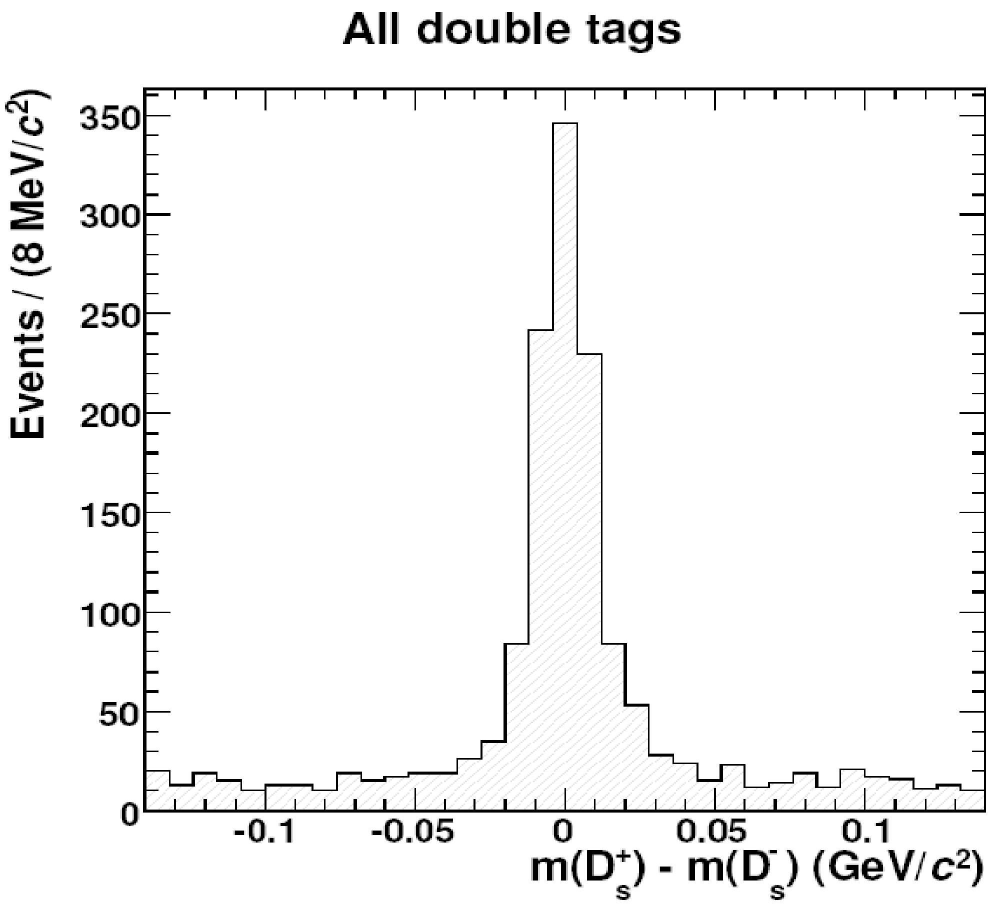
Single Tag Yields (298 pb^{-1})



Double Tag Yields

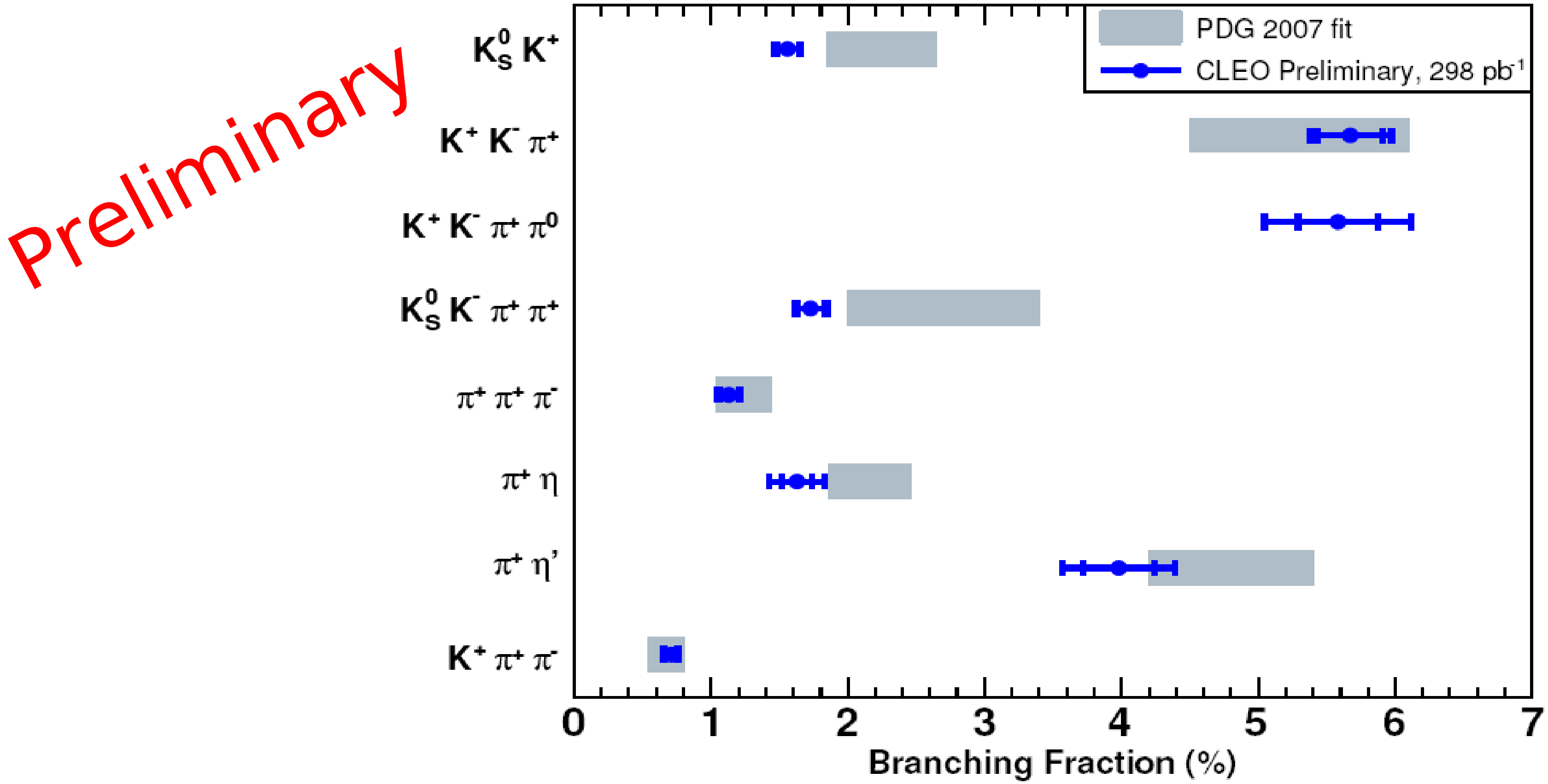
Preliminary





- We have 976±33 double tags
- This sets the scale of statistical error ~3.5%

D_s Hadronic Branching Fractions



Branching Fraction	This Result (%)	PDG 2006 fit (%)
$\mathcal{B}(K_S^0 K^+)$	$1.56 \pm 0.08 \pm 0.05$	2.2 ± 0.45
$\mathcal{B}(K^- K^+ \pi^+)$	$5.67 \pm 0.24 \pm 0.18$	5.2 ± 0.9
$\mathcal{B}(K^- K^+ \pi^+ \pi^0)$	$5.58 \pm 0.29 \pm 0.45$	—
$\mathcal{B}(K_S^0 K^- \pi^+ \pi^+)$	$1.73 \pm 0.10 \pm 0.07$	2.65 ± 0.7
$\mathcal{B}(\pi^+ \pi^+ \pi^-)$	$1.13 \pm 0.07 \pm 0.05$	1.22 ± 0.23
$\mathcal{B}(\pi^+ \eta)$	$1.63 \pm 0.11 \pm 0.17$	2.11 ± 0.35
$\mathcal{B}(\pi^+ \eta')$	$3.98 \pm 0.26 \pm 0.32$	4.7 ± 0.7
$\mathcal{B}(K^+ \pi^+ \pi^-)$	$0.71 \pm 0.05 \pm 0.03$	0.66 ± 0.14

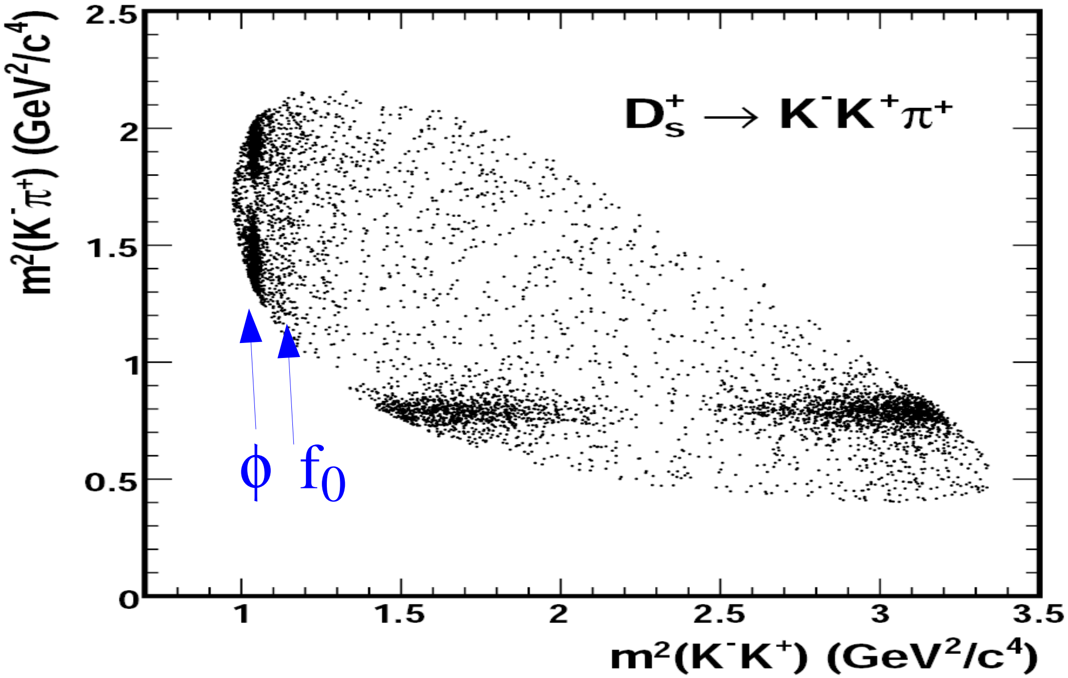
- Analysis is mostly statistics limited
- Plan to take ~300 pb^{-1} more data before CLEO-c running ends

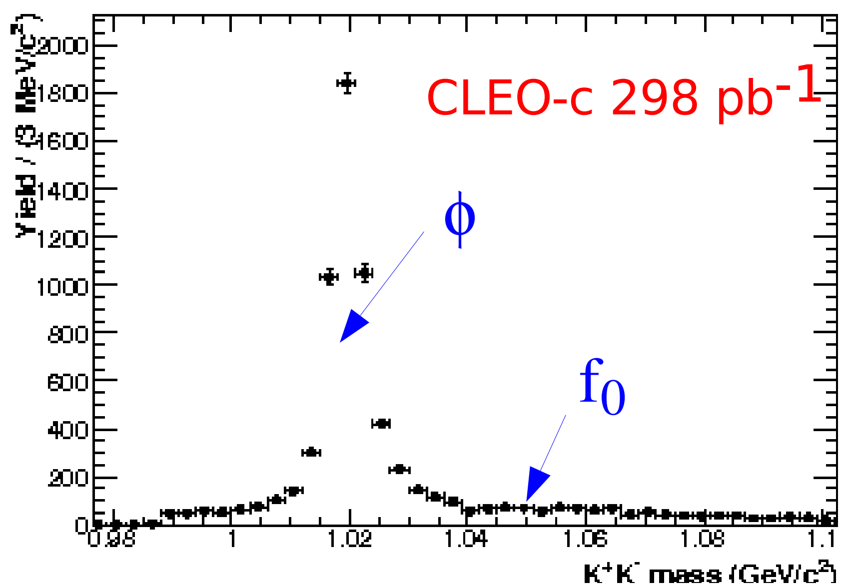
What about $D_s \to \phi\pi$?

- The ϕ resonance is not well defined
  - $D_s \to \phi\pi$ interferes with $D_s \to f_0\pi$
- $B(D_s \to \phi\pi)$ is not well defined and CLEO-c are not quoting it.
- We calculate a partial br. fr. in a m_{KK} window around the ϕ mass
- A detailed Dalitz study needed to separate out the D_s fit fractions

$m(K^-K^+)$ range	Partial branching fraction(%)
$\|m(K^-K^+) - m_\phi\| < 5$ MeV	$1.75 \pm 0.08 \pm 0.06$
$\|m(K^-K^+) - m_\phi\| < 10$ MeV	$2.07 \pm 0.10 \pm 0.05$
$\|m(K^-K^+) - m_\phi\| < 15$ MeV	$2.22 \pm 0.11 \pm 0.06$
$\|m(K^-K^+) - m_\phi\| < 20$ MeV	$2.32 \pm 0.11 \pm 0.06$

For reference: $D_s \to \phi\pi^+$
PDG06: $(4.4 \pm 0.6)\%$





Inclusive η, η', and φ Production in D and D_s Decays at CLEO-c

- Tag one D or D_s and look at rest of event
  - 281 pb^{-1} for D^0 and D^+
  - 195 pb^{-1} for D_s
- As expected, we see that the production of η, η', and φ is larger in D_s decays than in D decays.
- Important branching fractions for studying B_s decays.

B	η (%)	PDG
D^0	9.5 ± 0.4 ± 0.8	<13%
D^+	6.3 ± 0.5 ± 0.5	<13%
D_s^+	23.5 ± 3.1 ± 2.0	-

B	η´ (%)	PDG
D^0	2.48 ± 0.17±0.21	-
D^+	1.04 ± 0.16±0.09	-
D_s^+	8.7 ± 1.9 ± 1.1	-

B	φ (%)	PDG
D^0	1.05 ± 0.08±0.07	1.7 ± 0.8
D^+	1.03 ± 0.10±0.07	<1.8
D_s^+	16.1 ± 1.2 ±1.1	-

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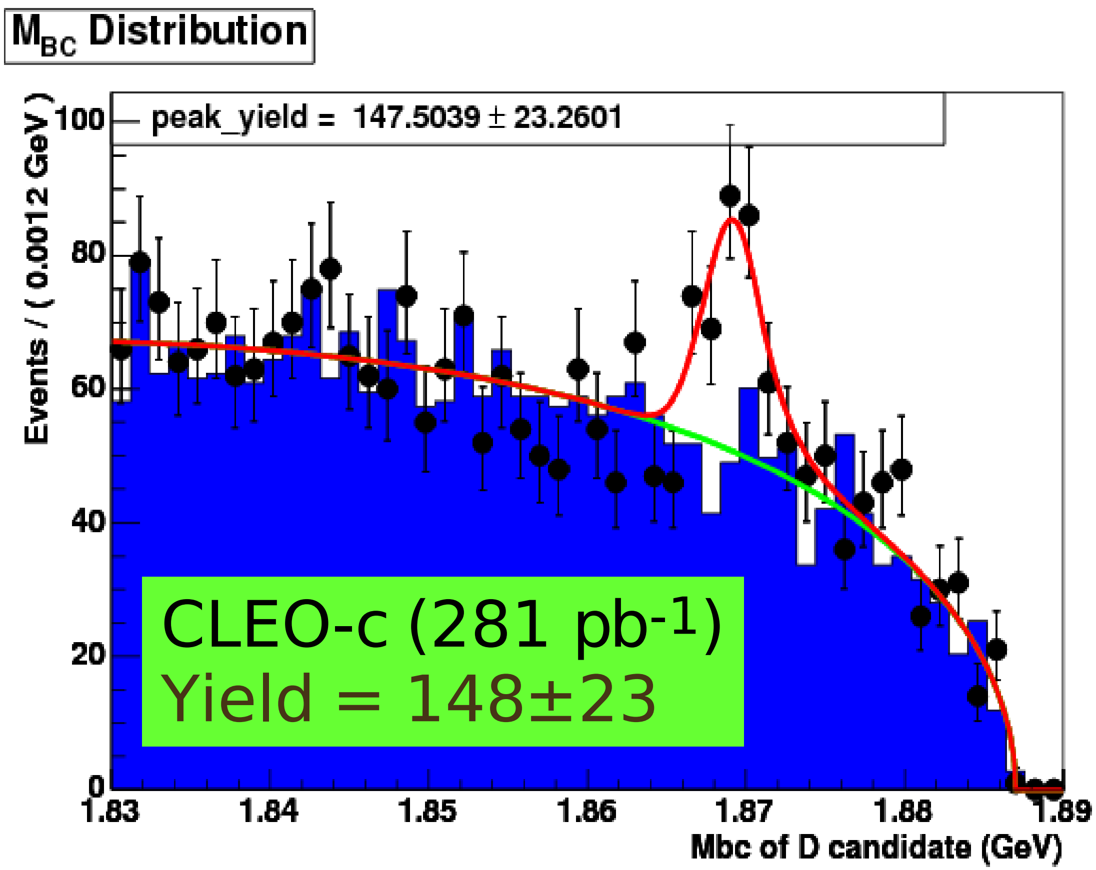
$D^+ \to K^+ \pi^0$

- CLEO-c studied this doubly Cabibbo suppressed decay
- Normalize to $D^+ \to K^- \pi^+ \pi^+$



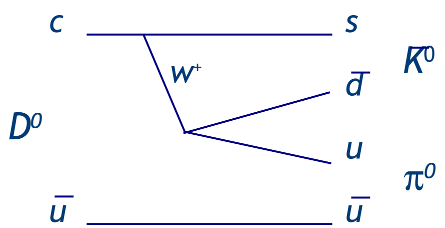
In good agreement with BABAR (124 fb^{-1}):

$B(D^+ \to K^+ \pi^0) = (2.52 \pm 0.46 \pm 0.24 \pm 0.08) \times 10^{-4}$

$B(D^+ \to K^+ \pi^0) = (2.24 \pm 0.36 \pm 0.15 \pm 0.08) \times 10^{-4}$

$D \to K_S\pi$ and $D \to K_L\pi$

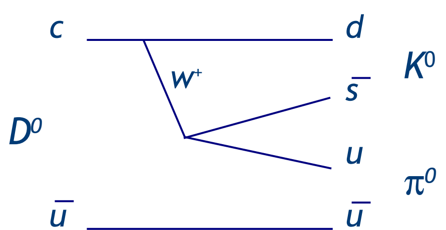
- It is often assumed that $\Gamma(D \to K_S X) = \Gamma(D \to K_L X)$, but this is not strictly true due to interference effects.



Cabibbo-favored

$$\bar{K}^0 = \frac{1}{\sqrt{2}}\left(K_S^0 - K_L^0\right)$$

The physical states of the K_S and K_L have different rates due to interference



Cabibbo-suppressed

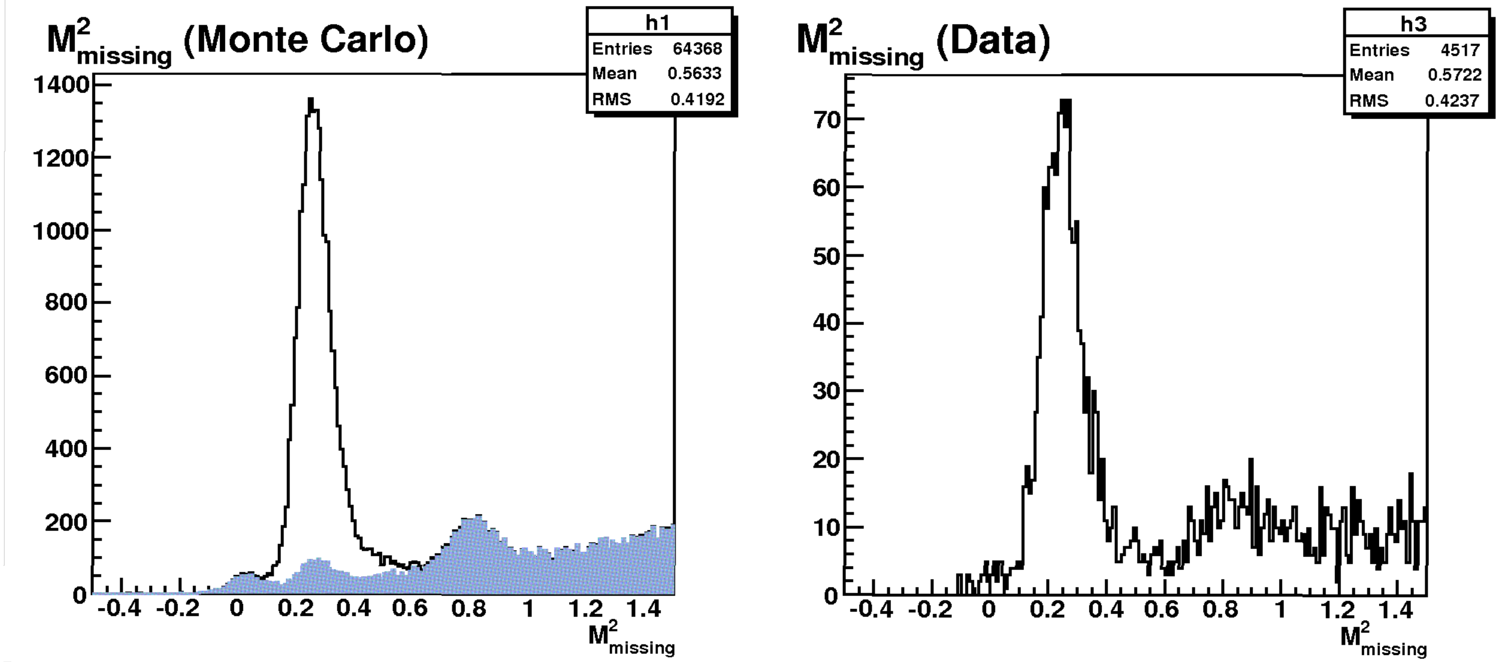
$$K^0 = \frac{1}{\sqrt{2}}\left(K_S^0 + K_L^0\right)$$

Based on factorization Bigi and Yamamoto (PLB 349, 363 (1995)) predict

$$\frac{\Gamma(D^0 \to K_S\pi^0) - \Gamma(D^0 \to K_L\pi^0)}{\Gamma(D^0 \to K_S\pi^0) + \Gamma(D^0 \to K_L\pi^0)} \approx 2\tan^2\theta_C \approx 0.10$$

Measuring $D^0 \to K_L \pi^0$ Preliminary

- CLEO-c is uniquely positioned to measure $D^0 \to K_L \pi^0$
- In tagged events, look at recoil against π^0 and veto K_S



- Correcting for Quantum Correlations
- $B(D^0 \to K_L^0 \pi^0) = (0.940 \pm 0.046 \pm 0.032)\%$
- $B(D^0 \to K_S^0 \pi^0) = (1.212 \pm 0.016 \pm 0.039)\%$

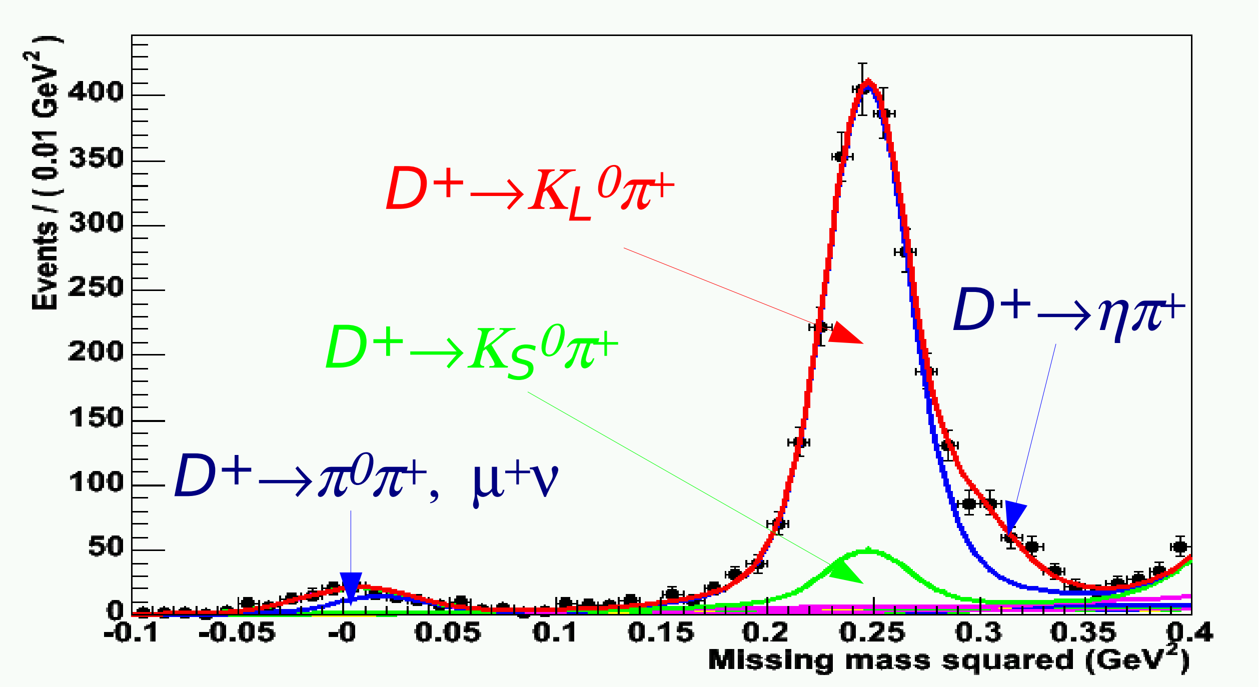
$$\frac{\Gamma(D^0 \to K_S) - \Gamma(D^0 \to K_L)}{\Gamma(D^0 \to K_S) + \Gamma(D^0 \to K_L)} = 0.122 \pm 0.024 \pm 0.030$$

In agreement with theory (factorization)

$D^+ \to K_L \pi^+$ vs. $D^+ \to K_S \pi^+$

Preliminary

- Look for recoil mass against pion in tagged events
  - Veto pions from K_S decays



We obtain $B(D^+ \to K_L{}^0 \pi^+) = (1.456 \pm 0.040)\%$

$$R(D^+) = \frac{\Gamma(D^+ \to K_S) - \Gamma(D^+ \to K_L)}{\Gamma(D^+ \to K_S) + \Gamma(D^+ \to K_L)} = 0.030 \pm 0.023 \pm 0.025$$

Dao-Neng Gao
arXiv:hep-ph/0610389v2
Predicts:
R(D^+)=0.035 to 0.044

Can also learn about δ, see talk by J. Rosner,

$D_s \to$ Two Pseudoscalars

- Study D_s two-body final states with two pseudoscalars
  - Will have either: K^+ or π^+, and
  - one of: η, η', π^0, K^0_S
- This analysis studied the following modes:
  - single-Cabibbo-suppressed modes: $D_s \to K^+\eta$, $D_s \to K^+\eta'$, $D_s \to K^+\pi^0$, and $D_s \to \pi^+ K^0_S$
  - The isospin forbidden mode $D_s \to \pi^+\pi^0$

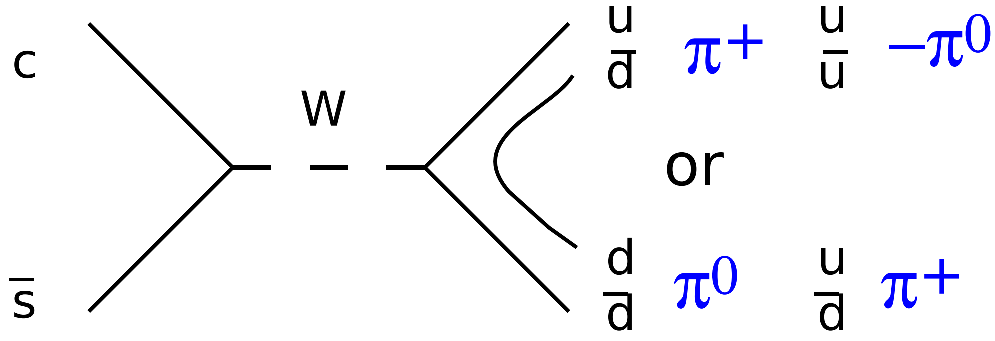
Measure as ratios to the Cabibbo favored modes:

$D_s \to \pi^+\eta$

$D_s \to \pi^+\eta'$

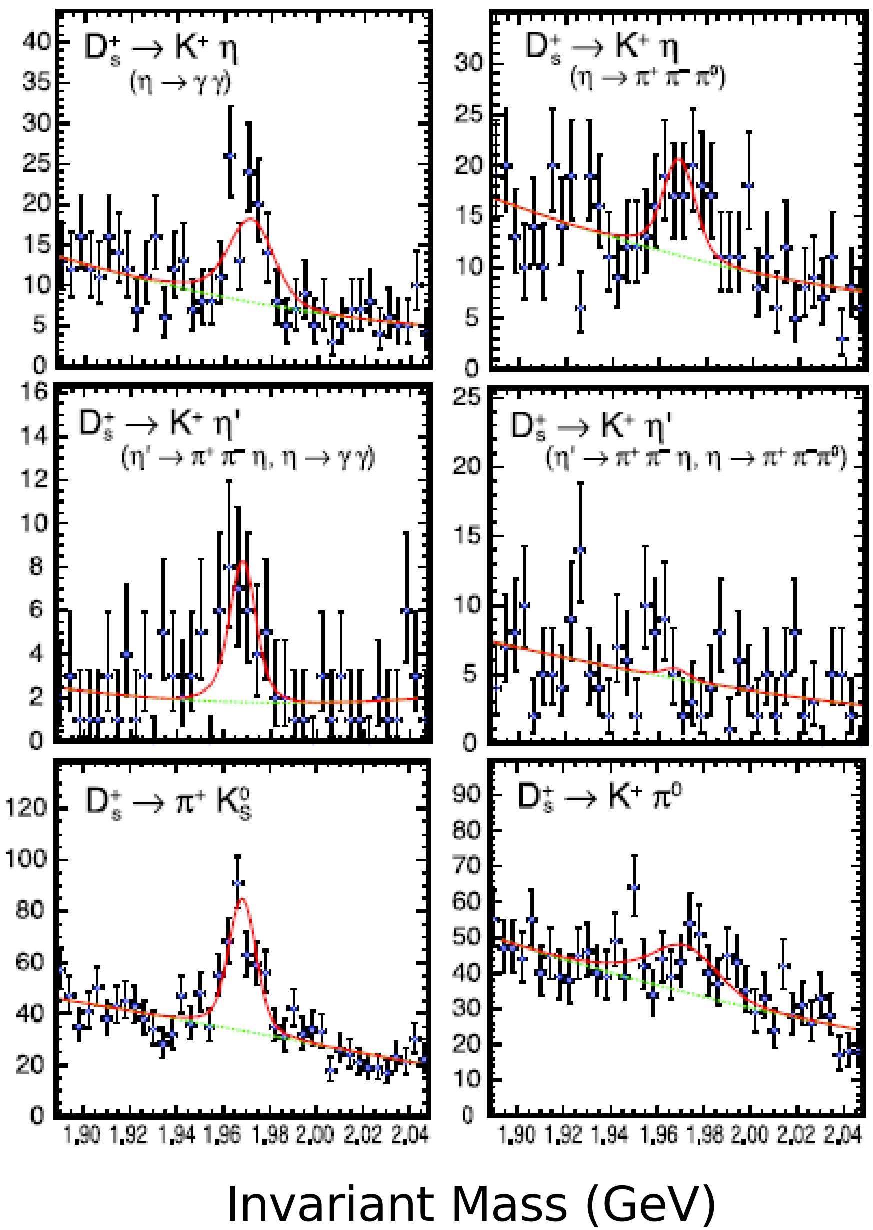
$D_s \to K^+ K^0_S$

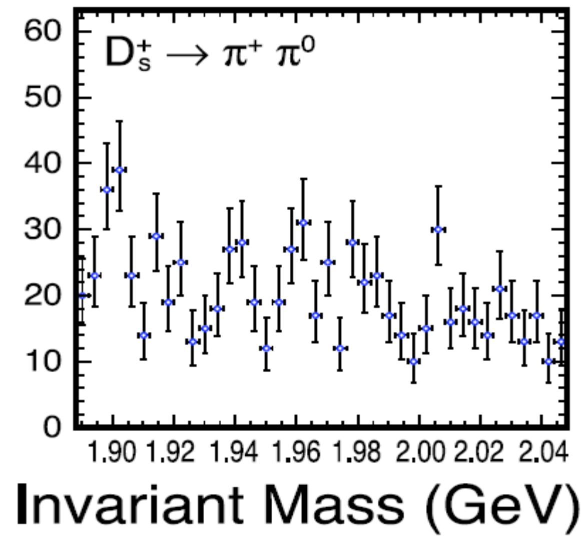
$$\pi^0 = \frac{1}{\sqrt{2}}(d\bar{d} - u\bar{u})$$



Extract yields in invariant mass after cutting on the recoil mass

$D_s \to PP$ Results





Mode	$\mathcal{B}_S/\mathcal{B}_F (10^{-2})$
$\mathcal{B}(D_s^+ \to K^+\eta)$ / $\mathcal{B}(D_s^+ \to \pi^+\eta)$	$8.9 \pm 1.5 \pm 0.4$
$\mathcal{B}(D_s^+ \to K^+\eta')$ / $\mathcal{B}(D_s^+ \to \pi^+\eta')$	$4.2 \pm 1.3 \pm 0.3$
$\mathcal{B}(D_s^+ \to \pi^+K_S^0)$ / $\mathcal{B}(D_s^+ \to K^+K_S^0)$	$8.2 \pm 0.9 \pm 0.2$
$\mathcal{B}(D_s^+ \to K^+\pi^0)$ / $\mathcal{B}(D_s^+ \to K^+K_S^0)$	$5.0 \pm 1.2 \pm 0.6$
$\mathcal{B}(D_s^+ \to \pi^+\pi^0)$ / $\mathcal{B}(D_s^+ \to K^+K_S^0)$	< 4.1 (90% CL)

- First observation of the Cabibbo suppressed decays
- Ratio in agreement with naïve expectation $|V_{cd}/V_{cs}|^2 \sim 0.05$
- Submitted to PRL (arXiv:0708.0139)

$D_s \to PP$ CP Asymmetries

- We have also looked for a CP asymmetry between the rate for D_S^+ and D_S^- decays:

Mode	$(\mathcal{B}_+ - \mathcal{B}_-)/(\mathcal{B}_+ + \mathcal{B}_-)(\%)$
$\mathcal{A}(D_s^+ \to K^+\eta)$	-20 ± 18
$\mathcal{A}(D_s^+ \to K^+\eta')$	-17 ± 37
$\mathcal{A}(D_s^+ \to \pi^+ K_S^0)$	27 ± 11
$\mathcal{A}(D_s^+ \to K^+\pi^0)$	2 ± 29

- No statistically significant asymmetry observed

$D \to KK$ modes

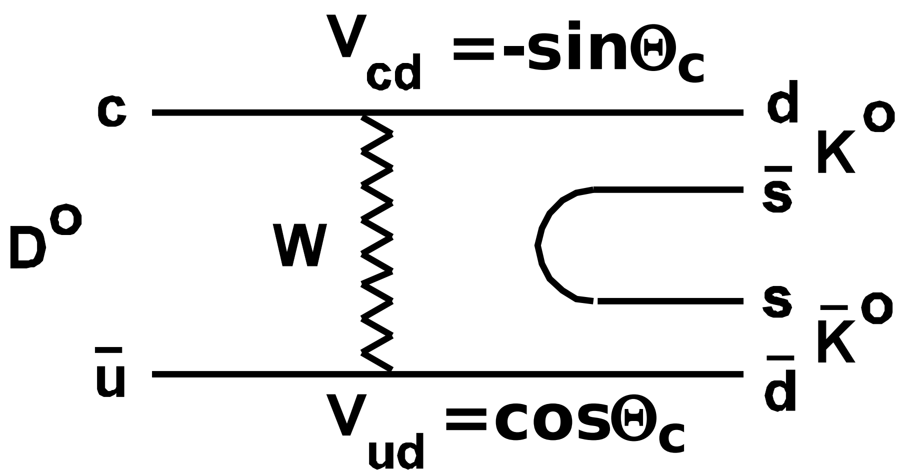
- CLEO-c has studied two-body Cabibbo suppressed decays of D mesons to kaon pairs:

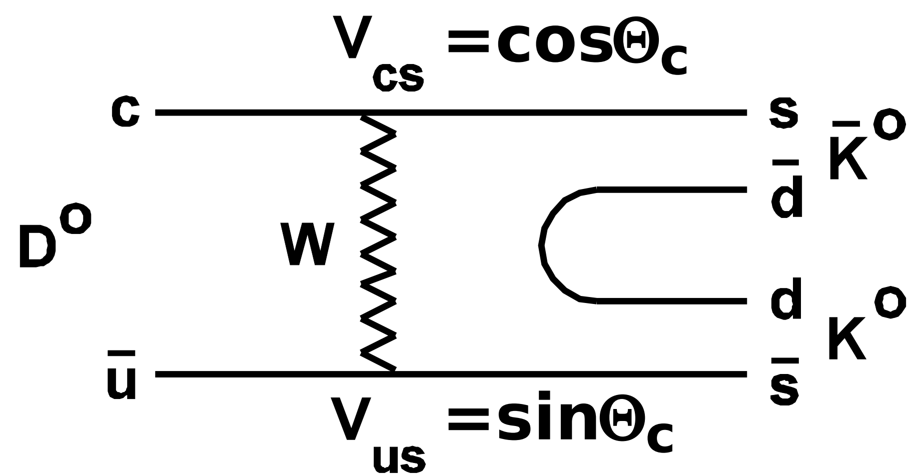
  $D^0 \to K^+K^-$

  $D^0 \to K_S K_S$

  $D^+ \to K^+ K_S$

- In addition the $D^0 \to K_S K_S$ mode is strongly suppressed:



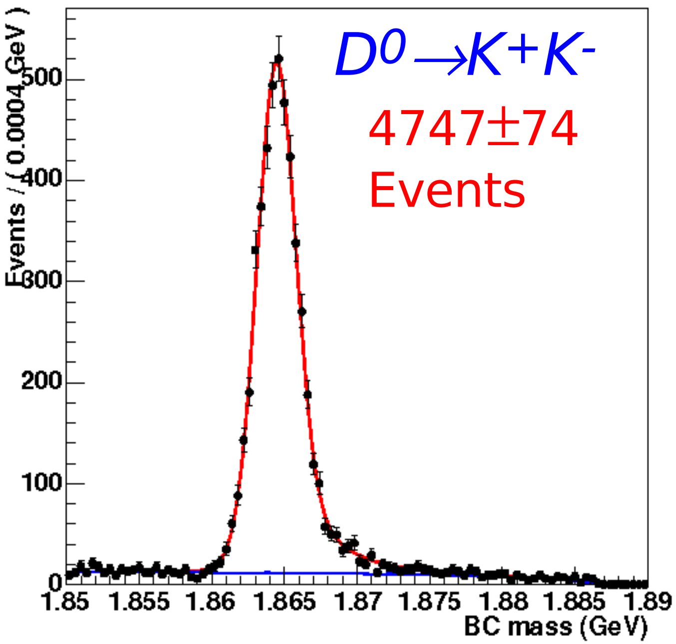


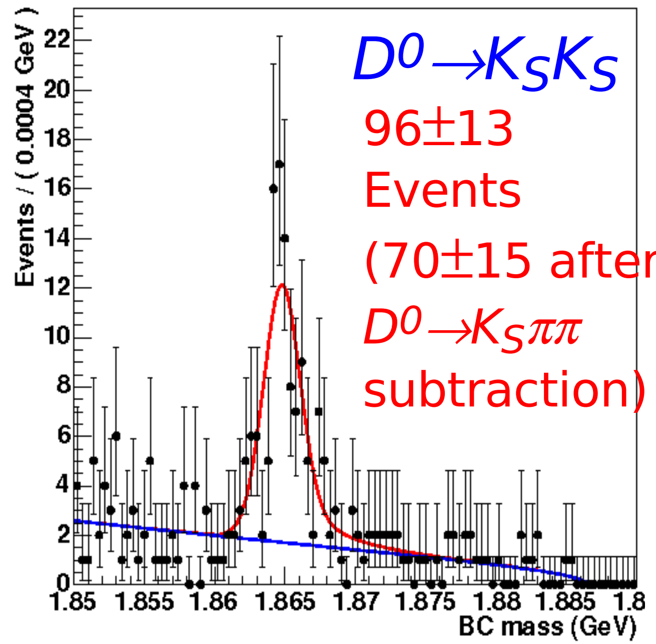
These amplitudes interfere destructively

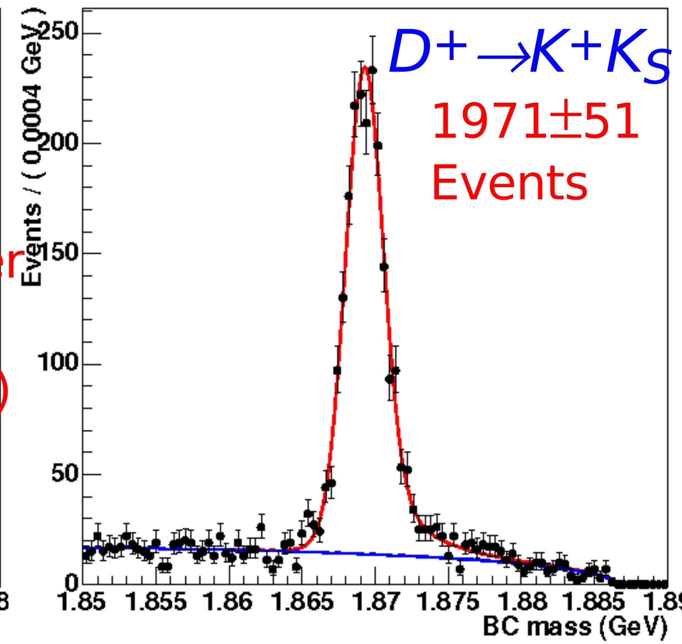
$D \to KK$ Signals

Preliminary

- Reconstruct final states as 'single tags'







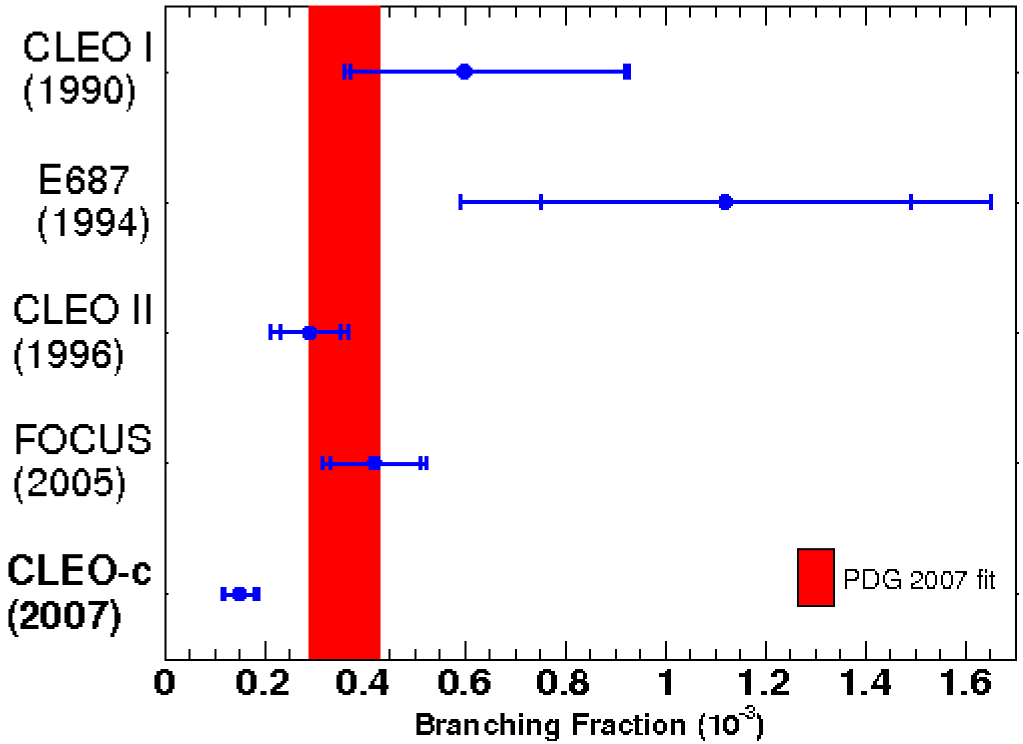
- We measure these modes with respect to the normalization modes ($D^0 \to K^- \pi^+$ and $D^+ \to K^- \pi^+ \pi^+$)
- The $D^0 \to K_S K_S$ mode has backgrounds from $D^0 \to K_S \pi\pi$
  - Subtracted using K_s sidebands

$D \to KK$ Results

Preliminary

- Our results, the errors are statistics, exp. systematics, PDG branching fractions

	Our Measurement (10^{-3})	PDG 2007 (10^{-3})
$\mathcal{B}(D^0 \to K^-K^+)$	$4.01 \pm 0.07 \pm 0.08 \pm 0.07$	3.85 ± 0.09
$\mathcal{B}(D^0 \to K^0_S K^0_S)$	$0.149 \pm 0.034 \pm 0.015 \pm 0.03$	0.36 ± 0.07
$\mathcal{B}(D^+ \to K^0_S K^+)$	$3.35 \pm 0.10 \pm 0.10 \pm 0.12$	2.95 ± 0.19



- Our $D^0 \to K_S K_S$ is a bit smaller than what the PDG reports
- The other modes are in good agreement with the PDG

Conclusion

- CLEO-c has measured the D^0, D^+, and D_s absolute branching fractions
  - The D^0 and D^+ branching fractions are systematics limited
  - The D_s branching fractions not yet systematics limited.
- Results on a number of other modes were presented, including modes with K_L and Cabibbo suppressed D and D_s decays
- CLEO-c will record more data at the $\psi(3770)$ and at E_{cm}=4170 MeV
  - We are far along to reach the goal of ~750 pb^{-1} at the $\psi(3770)$
  - We plan to double the sample at E_{cm}=4170 MeV for a total of about 600 pb^{-1}
- Look forward to many more CLEO-c results

Backup Slides

Quantum Correlations

The two D^0 mesons are correlated: C=-1

PRD 73 034024 (2006)
Asner and Sun

	f	$l+$	$CP+$	$CP-$
f	$R_M(1+r^2(2-z^2))$			
$\bar{f}$	$1+r^2(2-z^2)$			
$l-$	1	1		
$CP+$	$1+rz$	1	0	
$CP-$	$1-rz$	1	2	0
X	$1+rzy$	1	$1-y$	$1+y$

Correction to BR as compared to incoherent decay

$$x=\frac{\Delta m}{\Gamma}$$

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

$$R_M=(x^2+y^2)/2$$

$$r e^{i\delta}=\frac{\langle \overline{D}^0|K^-\pi^+\rangle}{\langle D^0|K^-\pi^+\rangle}$$

$$z=2\cos\delta$$

- For *CP vs CP* eigenstates the correlation is a large effect
- *E.g* the decay $D^0\to K_S\pi^0$ where the other D decays generically (single tag)

$$N(D^0\to K_S^0\pi^0)=2\mathrm{N}_{D^0\overline{D}^0}B(D^0\to K_S^0\pi^0)(1+y)$$

- Where the other D is a flavor tag $D\to f$

$$N(D^0\to K_S^0\pi^0)=N_{D^0\overline{D}^0}B(D^0\to K_S^0\pi^0)(1-2\mathrm{r}_f\cos\delta_f)$$