Hadronic *D* Decays and the *D* Meson Decay Constant with CLEO-c

Anders Ryd, Cornell University
representing the
CLEO Collaboration
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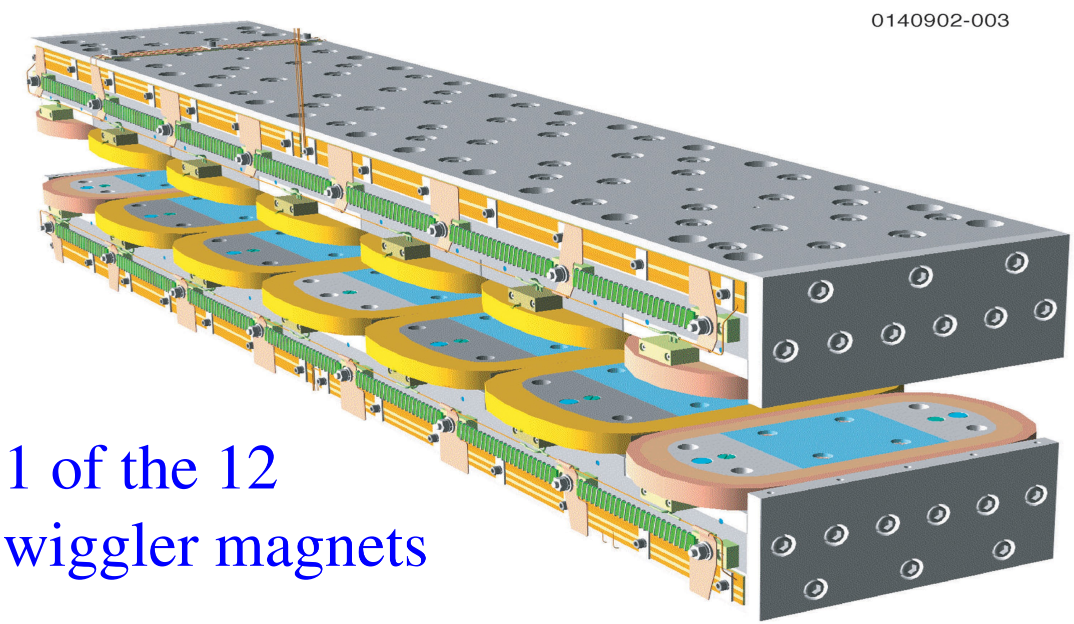
This presentation covers ABS11-0775 and ABS11-0776

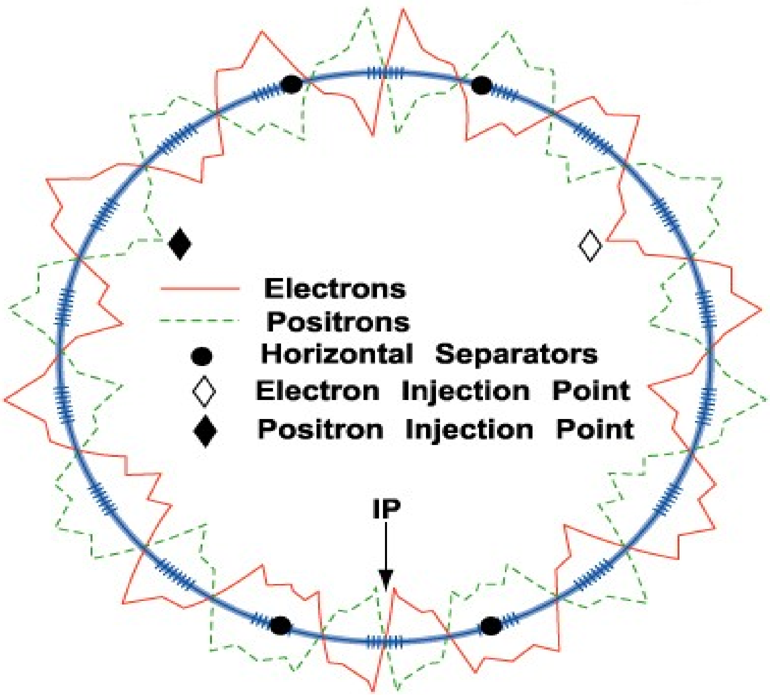
Introduction

- I will present new, preliminary, results from CLEO-c on
  - $Bf(D^+ \to \mu^+ \nu_\mu)$ and determination of f_{D^+}
  - absolute hadronic D branching fractions, and
  - the $\sigma(e^+e^- \to D\overline{D})$ cross section at E_{cm}=3.77 GeV.
- These measurements make use of '*D*-tagging', in which one *D* is exclusively reconstructed.
  - Once we have found one *D* we know that it recoiled against a $\bar{D}$.

CESR-c

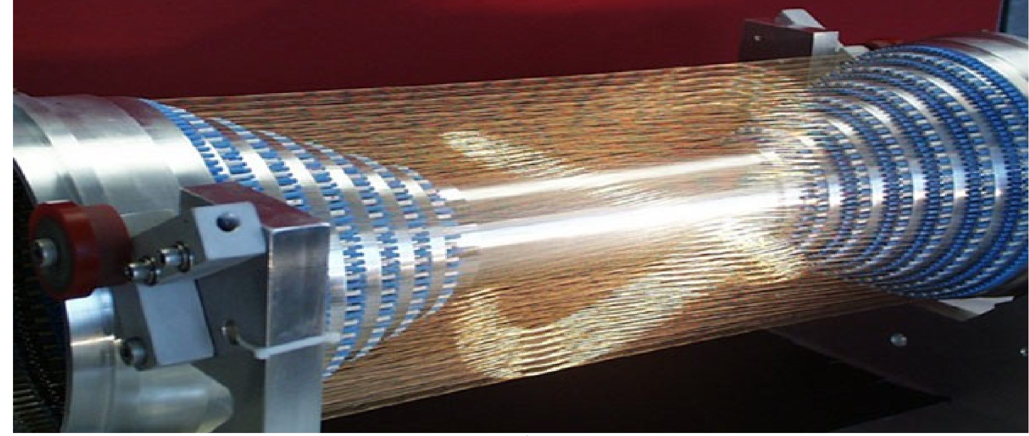


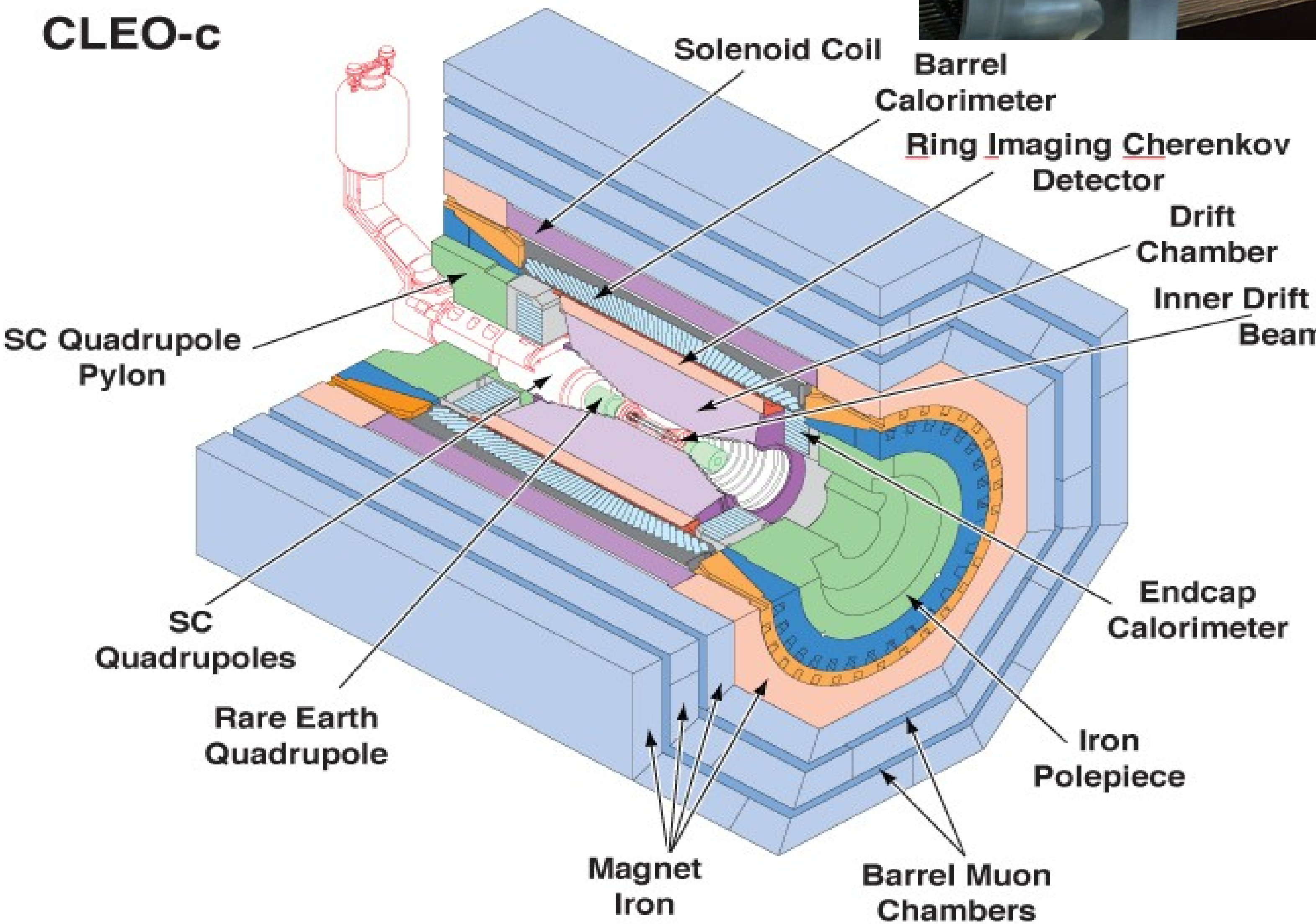
1 of the 12 wiggler magnets



- CESR-c had a pilot run Dec. '03 through Mar. '04.
  - 6 of the total of 12 wiggler magnets were installed.
- The remaining magnets were installed this summer.
- We recorded 57.1 pb^{-1} at the $\psi(3770)$.
  - Will continue running this fall. Goal is to collect 3 fb^{-1} on the $\psi(3770)$.

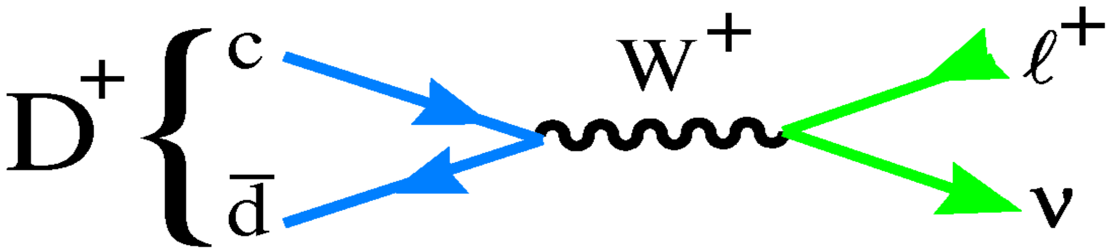
CLEO-c Detector





- 1 T B-field.
- New 6-layer inner drift chamber.
- Otherwise the CLEO III detector

$D^+ \to \mu^+ \nu_\mu$ and f_{D^+}



$$\Gamma(D^+ \to l^+ \nu) = \frac{G_F^2}{8\pi} f_{D^+}^2 m_l^2 M_{D^+} \left(1 - \frac{m_l^2}{M_{D^+}^2}\right)^2 |V_{cd}|^2$$

- A precise measurement of f_{D^+} allows precise comparison with theoretical calculations, such as lattice QCD.
- This will help determining f_B, which currently can not be measured in leptonic *B* decays.

Charged D-Tag Reconstruction

tags where we see a small tail on the higher mass

$$M_{BC} = \sqrt{E_{beam}^2 - |p(D)|^2}$$

$$\Delta E = E(D) - E_{beam}$$

Mode	Events Sig
$K^+\pi^-\pi^-$	15188
$K^+\pi^-\pi^-\pi^o$	4082
$K_s\pi^-$	2110
$K_s\pi^-\pi^-\pi^+$	3975
$K_s\pi^-\pi^o$	3297
Sum	28652

Require |ΔE|<20 MeV

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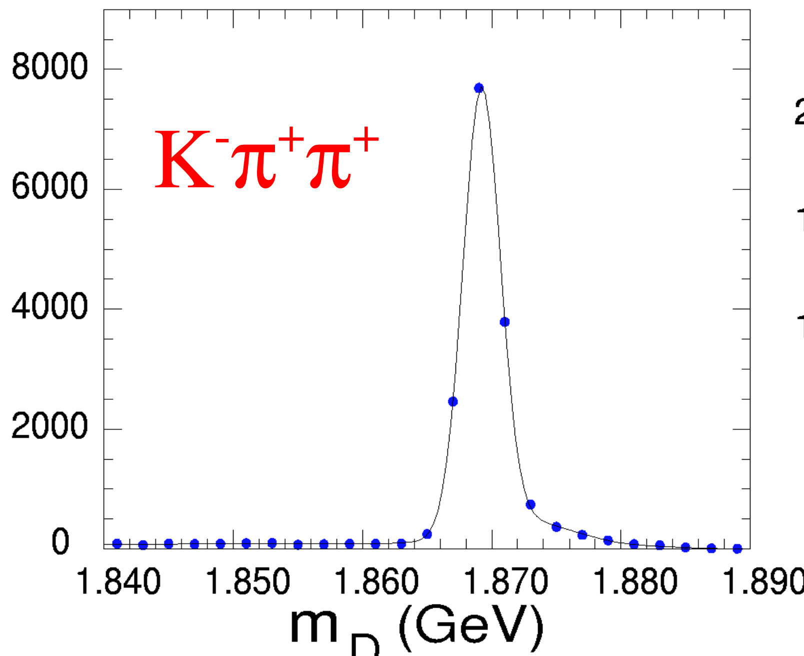
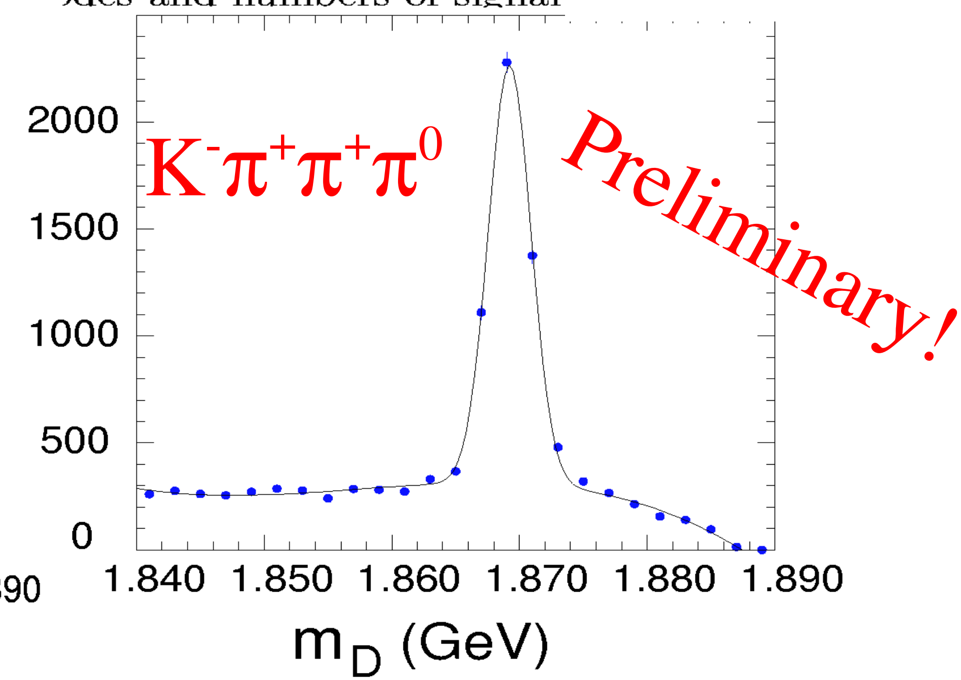
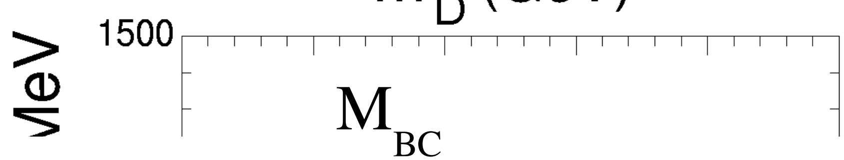
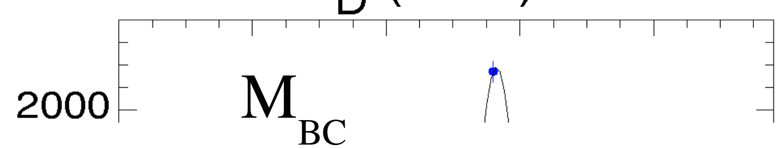






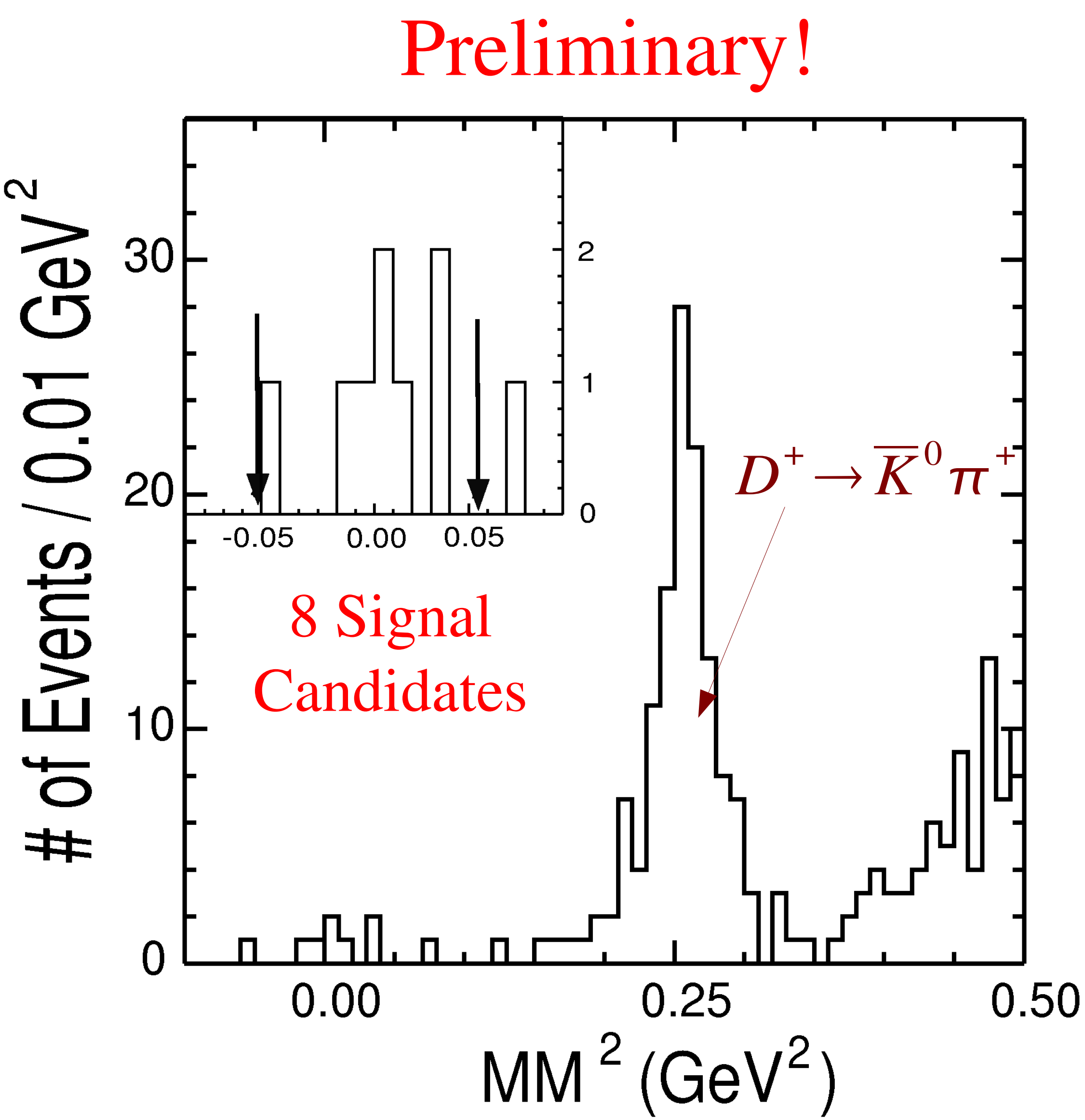


Signal Extraction

- For events with μ candidate form

$$MM^2 = (E_{beam} - E_\mu)^2 - (-\vec{p}_{D^-} - \vec{p}_\mu)^2$$

- Signal will peak at $MM^2 = m^2_\nu = 0$
- Muons are required to deposit less than 300 MeV in the calorimeter
- No additional tracks from IP
- Largest unmatched shower to be less than 250 MeV, to veto $D^+ \to \pi^+\pi^0$



$D^+ \to \mu^+ \nu_\mu$ Results

- 8 signal candidate events with the following backgrounds

luction

Background	$\mathcal{B}$ (%)	# of events
$D^+ \to \pi^+\pi^0$	0.13 ± 0.02	0.31 ± 0.04
$D^+ \to K^0\pi^+$	2.77 ± 0.18	0.06 ± 0.05
$D^+ \to \tau^+\nu$	$3.2 \times \mathcal{B}(D^+ \to \mu^+\nu)$	0.36 ± 0.08
$D^+ \to \pi^0\mu^+\nu$	0.31 ± 0.15	negligible
$D^0\bar{D}^0$	—	0.16 ± 0.16
continuum	—	0.17 ± 0.17
Total		1.07 ± 0.25

Preliminary!

- Due to simulation uncertainties we take background as 1.07 ± 1.07
- With 28575 D^+ tags and an efficiency of 69.9% for signal events to satisfy the selection criteria given a D^+ tag we obtain:

$$Bf(D^+ \to \mu^+ \nu) = (3.5 \pm 1.4 \pm 0.6) \times 10^{-4} \quad f_{D^+} = (201 \pm 41 \pm 17)\,\text{MeV}$$

- Theoretical predictions for f_D are in the range 190 to 260 MeV.

Hadronic D Decays and $\sigma(e^+e^- \to D\overline{D})$

- In order to measure the cross section and absolute branching fractions we need to determine the number of produced $D\overline{D}$ events
  - Use a 'double tag' technique, pioneered by MARK III

$$N_i = 2\epsilon_i B_i N_{D\overline{D}}$$

$$N_{ii} = \epsilon_{ii} B_i^2 N_{D\overline{D}}$$

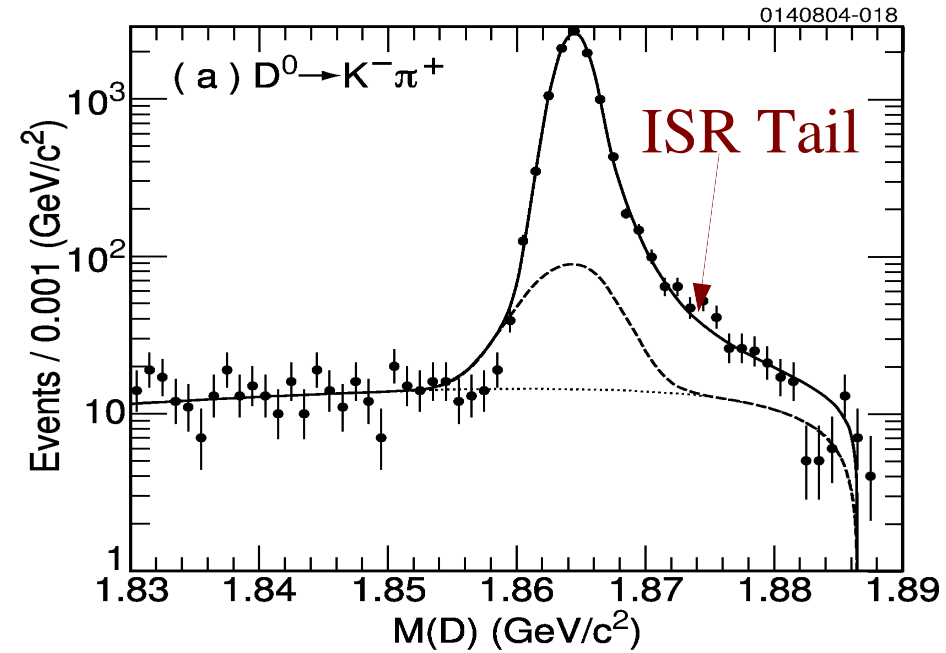
$$N_{D\overline{D}} = \frac{N_i^2}{4\mathrm{N}_{ii}} \frac{\epsilon_{ii}}{\epsilon_i^2}$$

- Use 3 D^0 modes ($K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^-\pi^+$) and 2 D^+ modes ($K^-\pi^+\pi^+$, $K_S\pi^+$)
- Determine separately the D and $\overline{D}$ yields
  - This gives 10 single tag yields and 13 ($=3^2+2^2$) double tag yields
- In a combined χ^2 fit we extract 5 branching fractions and $D^0\overline{D}^0$ and D^+D^- yields. The fit includes the systematic errors.
- Many systematics cancel in the $D\overline{D}$ yields.

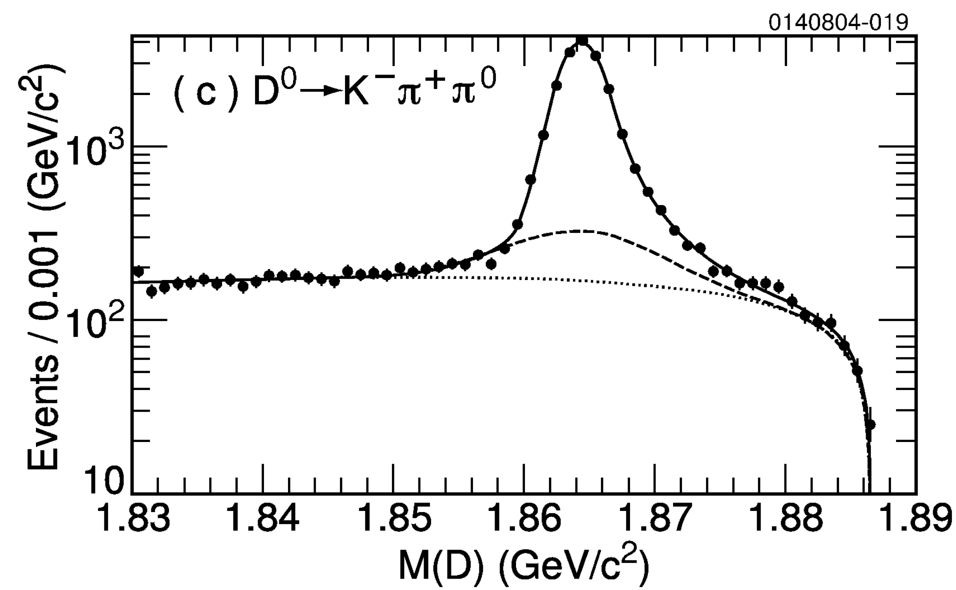
Single Tag Yields

: Single tag data yields and efficiencies and their statistical unc

D or $\bar{D}$ Mode	Yield (10^3)	Efficiency (%)
$D^0 \to K^-\pi^+$	5.14 ± 0.07	65.1 ± 0.6
$\bar{D}^0 \to K^+\pi^-$	5.16 ± 0.08	66.3 ± 0.6
$D^0 \to K^-\pi^+\pi^0$	9.62 ± 0.12	33.6 ± 0.4
$\bar{D}^0 \to K^+\pi^-\pi^0$	9.58 ± 0.12	34.0 ± 0.4
$D^0 \to K^-\pi^+\pi^+\pi^-$	7.39 ± 0.10	45.1 ± 0.5
$\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$	7.39 ± 0.10	45.5 ± 0.5
$D^+ \to K^-\pi^+\pi^+$	7.58 ± 0.09	52.2 ± 0.5
$D^- \to K^+\pi^-\pi^-$	7.57 ± 0.09	51.9 ± 0.5
$D^+ \to K^0_S\pi^+$	1.09 ± 0.04	45.6 ± 0.5
$D^- \to K^0_S\pi^-$	1.12 ± 0.04	45.9 ± 0.5

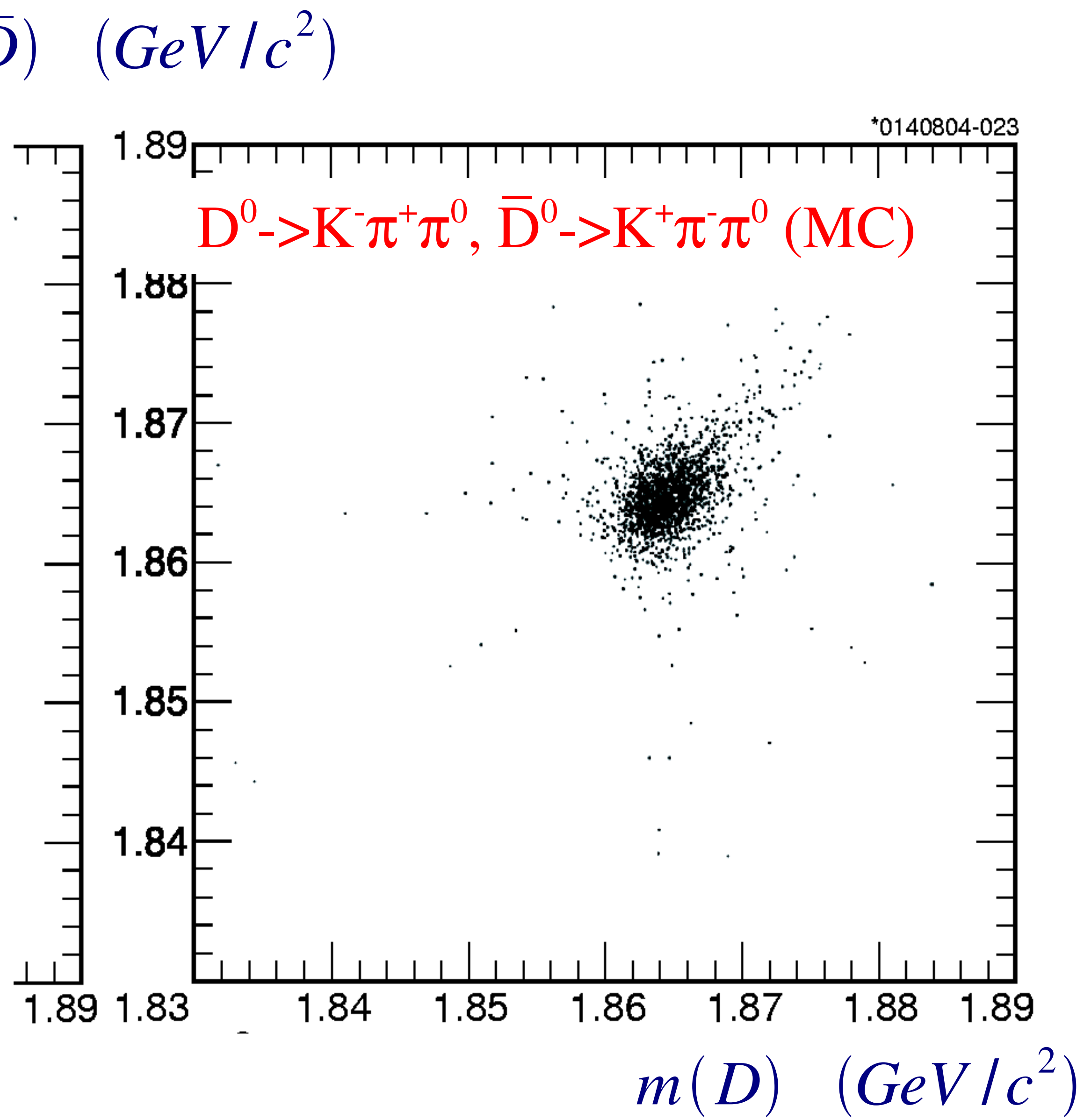


Preliminary!



Fits for Double Tag Yields

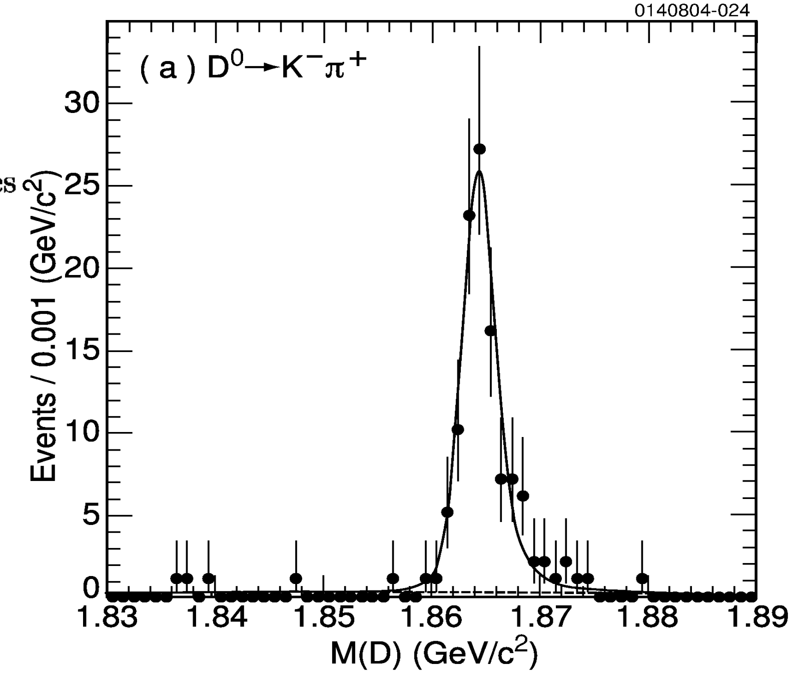
- 2-D fit for double tag yields
- Fit includes correlations due to beam energy fluctuations and ISR.

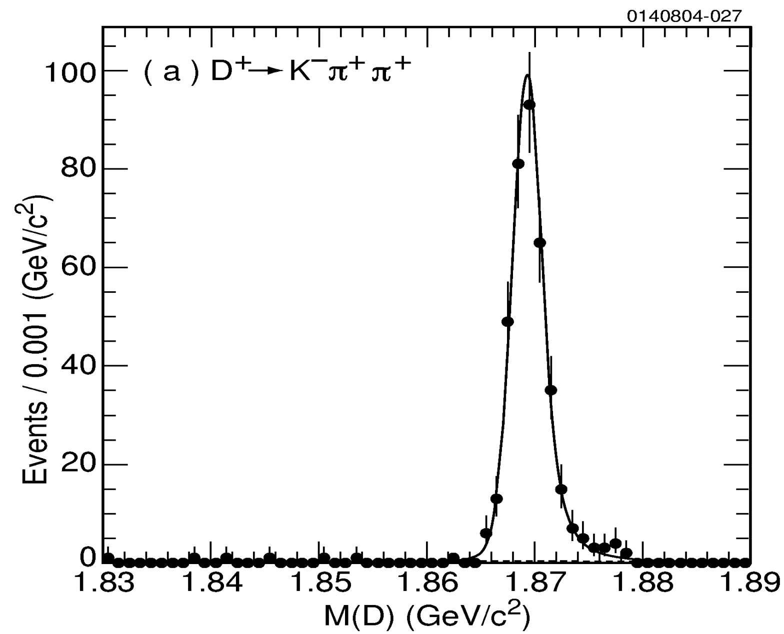


Double Tag Yields

ABLE III: Double tag data yields and efficiencies and their statistical uncertainties

D Mode	$\bar{D}$ Mode	Yield (10^2)	Efficiency (%)
$D^0 \to K^-\pi^+$	$\bar{D}^0 \to K^+\pi^-$	1.09 ± 0.11	42.6 ± 0.5
$D^0 \to K^-\pi^+\pi^0$	$\bar{D}^0 \to K^+\pi^-\pi^0$	4.84 ± 0.23	12.1 ± 0.3
$D^0 \to K^-\pi^+\pi^+\pi^-$	$\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$	2.80 ± 0.17	20.8 ± 0.4
$D^0 \to K^-\pi^+$	$\bar{D}^0 \to K^+\pi^-\pi^0$	2.45 ± 0.16	23.2 ± 0.4
$D^0 \to K^-\pi^+\pi^0$	$\bar{D}^0 \to K^+\pi^-$	2.62 ± 0.16	22.6 ± 0.4
$D^0 \to K^-\pi^+$	$\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$	2.05 ± 0.14	29.6 ± 0.4
$D^0 \to K^-\pi^+\pi^+\pi^-$	$\bar{D}^0 \to K^+\pi^-$	1.97 ± 0.14	29.6 ± 0.4
$D^0 \to K^-\pi^+\pi^0$	$\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$	3.59 ± 0.20	15.2 ± 0.3
$D^0 \to K^-\pi^+\pi^+\pi^-$	$\bar{D}^0 \to K^+\pi^-\pi^0$	3.40 ± 0.19	15.5 ± 0.3
$D^+ \to K^-\pi^+\pi^+$	$D^- \to K^+\pi^-\pi^-$	3.79 ± 0.20	26.7 ± 0.4
$D^+ \to K^0_S\pi^+$	$D^- \to K^0_S\pi^-$	0.090 ± 0.030	20.6 ± 0.4
$D^+ \to K^-\pi^+\pi^+$	$D^- \to K^0_S\pi^-$	0.609 ± 0.079	23.7 ± 0.4
$D^+ \to K^0_S\pi^+$	$D^- \to K^+\pi^-\pi^-$	0.530 ± 0.073	23.9 ± 0.4





- 2480 neutral double tags
- 502 charged double tags

Preliminary!

Systematics

Source	Fractional Uncertainty (%)	Quantity
Data processing	0.3	All yields
Yield fit functions	0.1–2.9	All yields
Background bias	2.5	DT yields
Double DCSD interference	0.8	Neutral DT yields
Detector simulation	3.0	Tracking efficiencies
	3.0	K_S^0 efficiencies
	4.4	π^0 efficiencies
	0.3	$\pi^\pm$ PID efficiencies
	1.0	$K^\pm$ PID efficiencies
Trigger simulation	0.3	ST efficiencies
Final state radiation	0.5	D efficiencies
$\lvert\Delta E\rvert$ requirement	1.0	D efficiencies, correlated by decay
Resonant substructure	3.0	$D^0 \to K^-\pi^+\pi^+\pi^-$ efficiencies

- Background bias
  - Currently dominated by tracking efficiency systematics
    - We have a 3%/track correction to the MC tracking efficiency
  - Most systematics will improve with more data

Preliminary Fit Results

and systematic, respectively.

Parameter	Fitted Value	PDG 2004*
$N_{D^0\bar{D}^0}$	$(1.98 \pm 0.04 \pm 0.03) \times 10^5$	
$\mathcal{B}(D^0 \to K^-\pi^+)$	$0.0392 \pm 0.0008 \pm 0.0023$	0.0380 ± 0.0009
$\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$	$0.143 \pm 0.003 \pm 0.010$	
$\mathcal{B}(D^0 \to K^-\pi^+\pi^+\pi^-)$	$0.081 \pm 0.002 \pm 0.009$	
$N_{D^+D^-}$	$(1.48 \pm 0.06 \pm 0.04) \times 10^5$	
$\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$	$0.098 \pm 0.004 \pm 0.008$	0.092 ± 0.006
$\mathcal{B}(D^+ \to K^0_S\pi^+)$	$0.0161 \pm 0.0008 \pm 0.0015$	
$\mathcal{B}(D^0 \to K^-\pi^+\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+)$	$3.64 \pm 0.05 \pm 0.17$	3.42 ± 0.22
$\mathcal{B}(D^0 \to K^-\pi^+\pi^+\pi^-)/\mathcal{B}(D^0 \to K^-\pi^+)$	$2.05 \pm 0.03 \pm 0.14$	1.96 ± 0.06
$\mathcal{B}(D^+ \to K^0_S\pi^+)/\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$	$0.164 \pm 0.004 \pm 0.006$	0.153 ± 0.003

The results of the data fit are shown in Table V. The χ^2 of the

*Our branching fractions are corrected for FSR, PDG values are not.

- Using our measured luminosity of 57.2 ± 1.7 pb^{-1} we obtain:

$$\sigma(D^0\overline{D}^0) = (3.47 \pm 0.07 \pm 0.15)\,nb \qquad \sigma(D^+D^-) = (2.59 \pm 0.11 \pm 0.11)\,nb$$

$$\sigma(D\overline{D}) = (6.06 \pm 0.13 \pm 0.22)\,nb$$

Conclusions

- CLEO-c has taken ~60 pb^{-1} of pilot data at the $\psi(3770)$
  - The full compliment of wigglers has been installed, and data taking will resume this fall.
- Using this sample we have obtained the preliminary results
  - $Bf(D^+ \to \mu^+ \nu) = (3.5 \pm 1.4 \pm 0.6) \times 10^{-4}$ $\quad f_{D^+} = (201 \pm 41 \pm 17)\,\mathrm{MeV}$
  - $Bf(D^0 \to K^+ \pi^-) = (3.92 \pm 0.08 \pm 0.23)\,\%$ $\quad Bf(D^+ \to K^- \pi^+ \pi^+) = (9.8 \pm 0.4 \pm 0.8)\,\%$
  - At E_{cm}=3.773 GeV we measured the e^+e^- cross sections
    - $\sigma(D^0 \overline{D}^0) = (3.47 \pm 0.07 \pm 0.15)\,\mathrm{nb}$ $\quad \sigma(D^+ D^-) = (2.59 \pm 0.11 \pm 0.11)\,\mathrm{nb}$
    - $\sigma(D \overline{D}) = (6.06 \pm 0.13 \pm 0.22)\,\mathrm{nb}$
- Using all tagging modes we have a *D*-tagging efficiency of 25%.
- Look forward to many more results from CLEO-c in the near future as we continue to take data at charm threshold.