Hadronic decays and cross-sections at Ψ″ from CLEO-c

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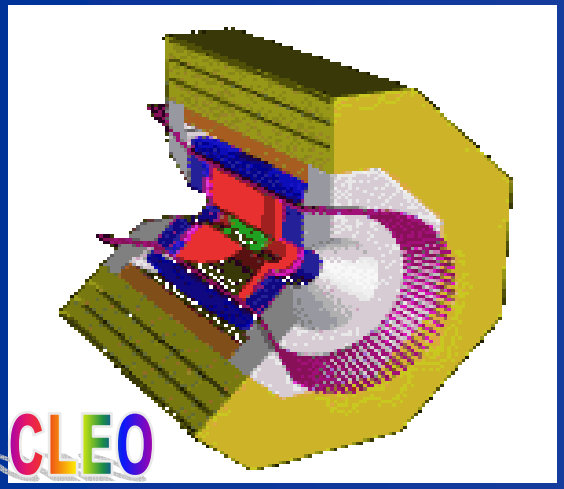
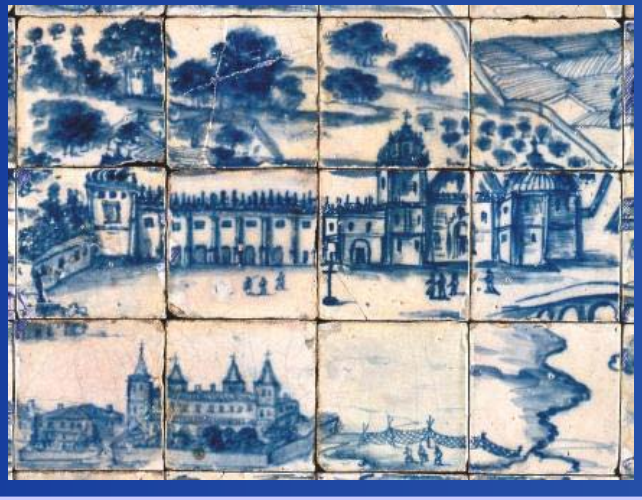
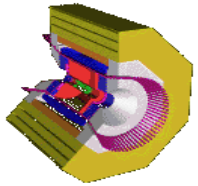
Southern Methodist University

(CLEO Collaboration)

HEP2005, Lisbon, Jul. 21 – 27, 2005







Preliminary CLEO results

Absolute D hadronic BR & $\Psi'' \rightarrow$ DD cross-section

(55.8 pb^{-1} , CLNS 05/1904, submitted to PRL)

Inclusive production of η, η', Φ in D decays

(281 pb^{-1}, CLEO CONF 05-4)

BF measurement of $D^+ \rightarrow K^0_S/K^0_L\ \pi^+$

(281 pb^{-1}) **Shown for the first time**

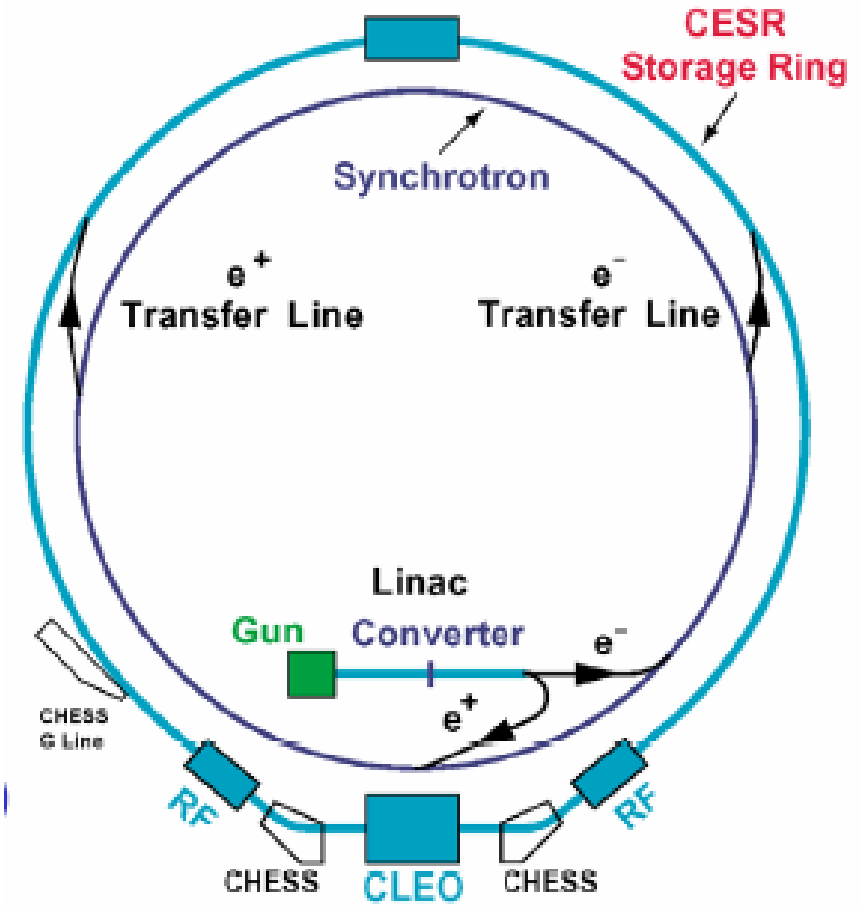
$\Psi'' \rightarrow$ non DD final states (VP, multi-body)

(281 pb^{-1}, 55.8 pb^{-1}, CLEO CONF 05-1, CLNS 05/1921)

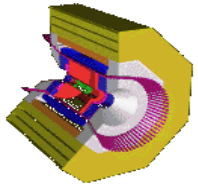
p and K time-like form factors at $\sqrt{s}$ = 3.671 GeV

(20.7 pb^{-1}, CLEO CONF 05-9)

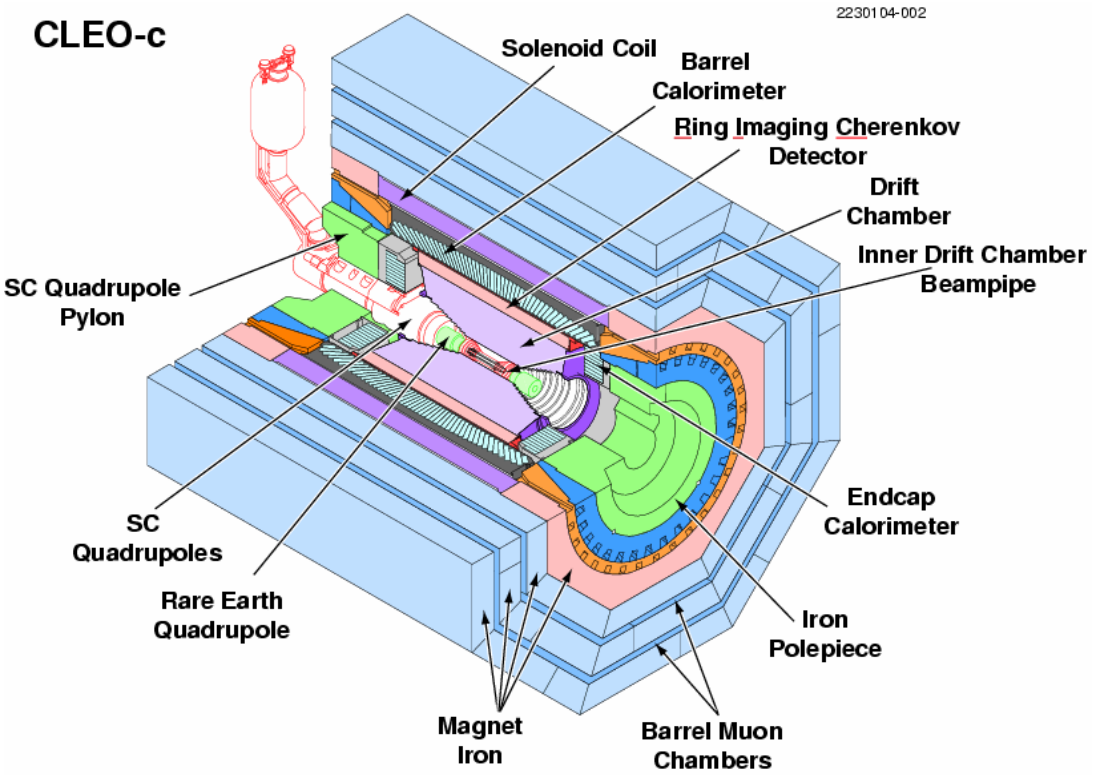
CESR-c



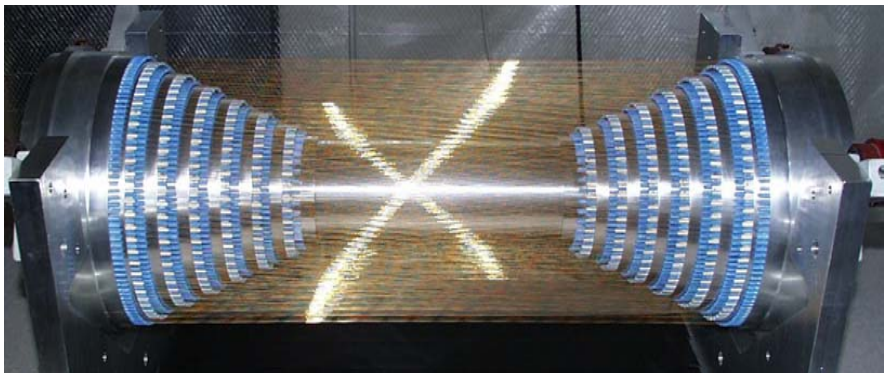
E_{beam} = 1.5 – 5.6 GeV



CLEO-c Detector & Data



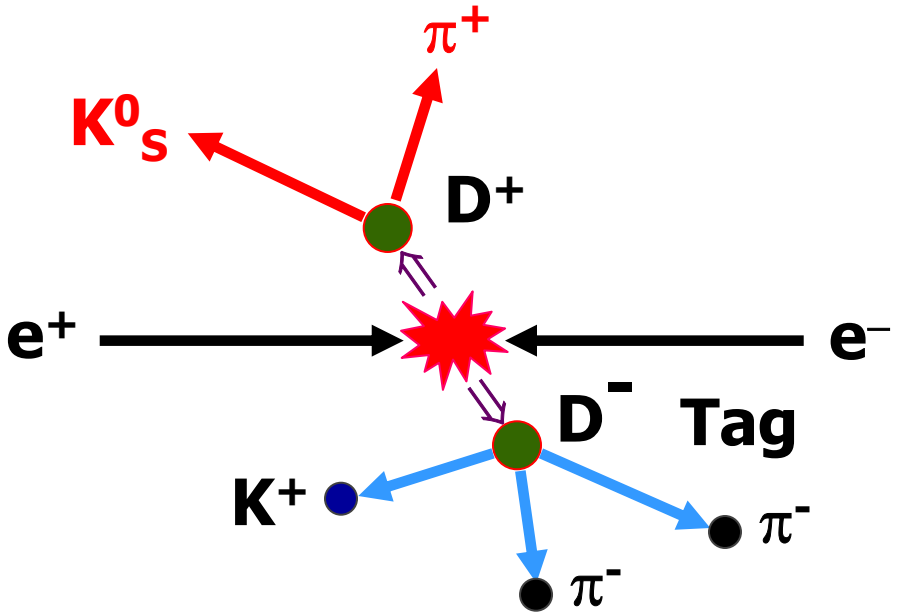
- New inner drift chamber replaced old silicon vertex
- 1T B field (old 1.5 T)
- Track (93% of 4π): σ = 0.6% @ 1 GeV
- PID: Rich (80% of 4π), dE/dx, EM calorimeter, muon (> 1GeV)
- E_γ: σ = 2.2% @ 1 GeV,
  5% @ 100MeV.



CLEO-c ≅ CLEO III

281 pb^{-1} at ψ(3770)

ψ(3770) Analysis Techniques



The MARK III Method

Fully reconstruct 1st D "the tag", then analyze decay of 2nd D to extract exclusive or inclusive properties.

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

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

ψ(3770) ~ DDbar threshold

➔ No extra fragmentation = simpler geometry / combination

➔ Clean neutrino reconstruction

➔ High tagging efficiency at 25% of all D's produced.

Absolute Hadronic D Decay BRs

Many current measurements determined with respect to reference modes: $\mathbf{D^0 \to K^-\pi^+}$, $\mathbf{D^+ \to K^-\pi^+\pi^+}$

Input to many measurements (*e.g.* V_{cb} from $B \to D^* l \nu$)

CLEO-c at $\psi(3770)$ provides:

- **Absolute/relative precise measurements**
- **Most precise measurement of D hadronic BRs**

Much easier to do at threshold and in pairs than at 10GeV!

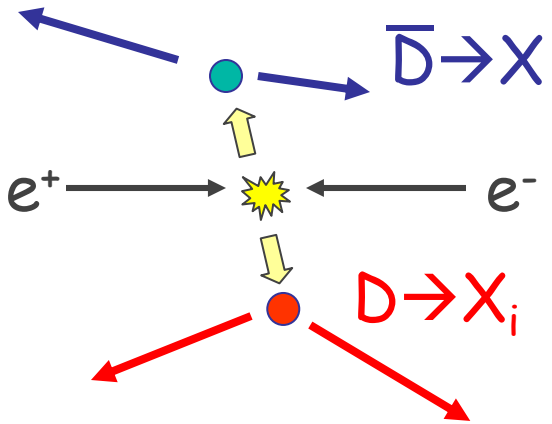
Byproduct: **$D\bar{D}$ production cross sections**

hep-ex/0504003, submitted to PRL (55.8 pb^{-1})

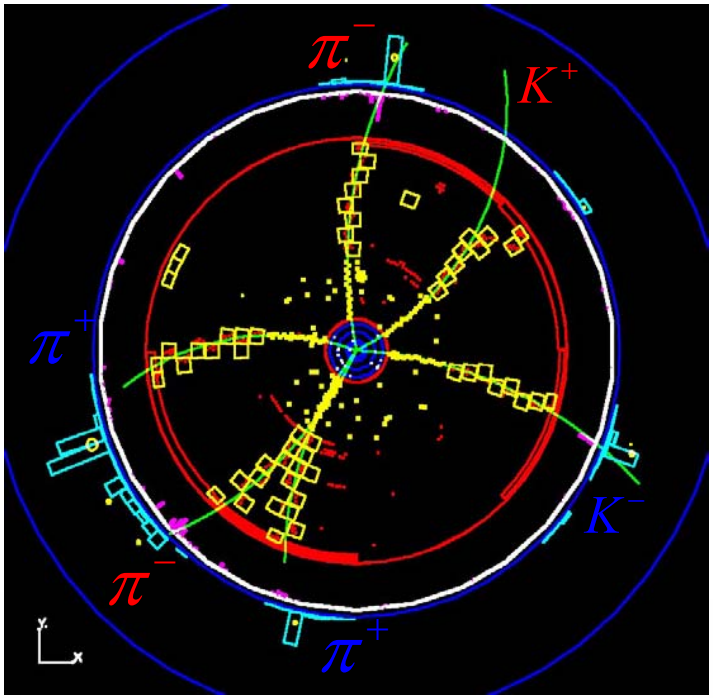
Updated results with 281 pb^{-1} in progress.

Absolute Hadronic D Decay BRs

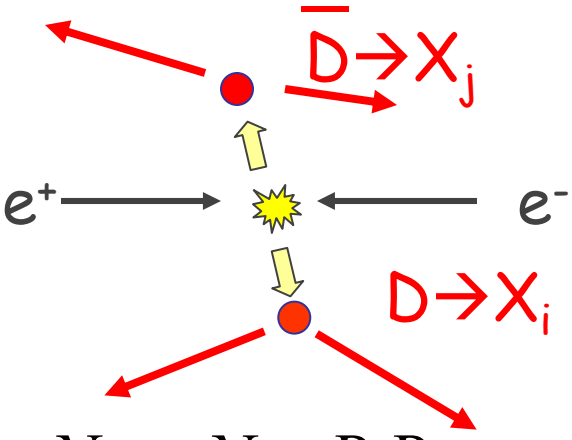
Single tagged



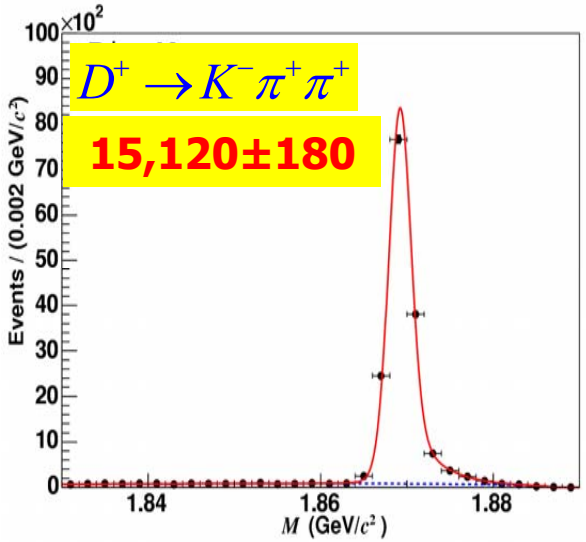
$$N_i = N_{D\overline{D}}\, B_i \varepsilon_i$$



Double tagged

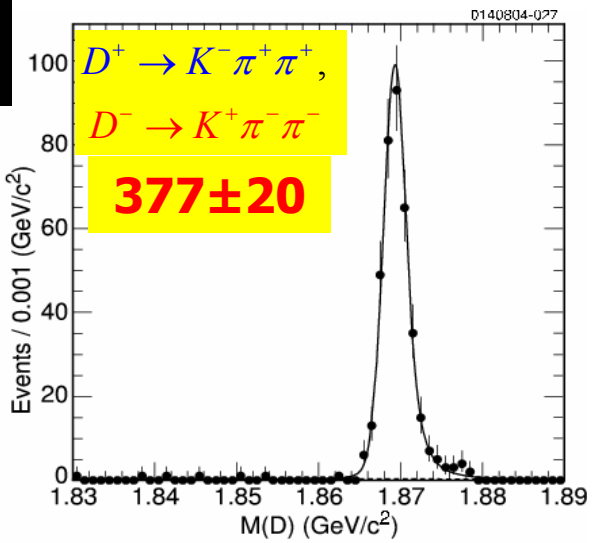


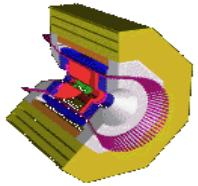
$$N_{ij} = N_{D\overline{D}} B_i B_j \varepsilon_{ij}$$



$$N_{D\overline{D}} = \frac{N_i N_j}{N_{ij}} \frac{\varepsilon_{ij}}{\varepsilon_i \varepsilon_j}$$

$$B_i = \frac{N_{ij}}{N_j} \frac{\varepsilon_j}{\varepsilon_{ij}}$$





Absolute Hadronic BRs & N_{DD}

Fitting technique

Simultaneous fit for all BR & cross sections is performed

- **Charged and neutral modes fit simultaneously**

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

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

$$K^0_S\pi^+\pi^0,\ K^0_S\pi^+\pi^-\pi^+,\ K^+K^-\pi^+$$

- **All correlations taken into account**

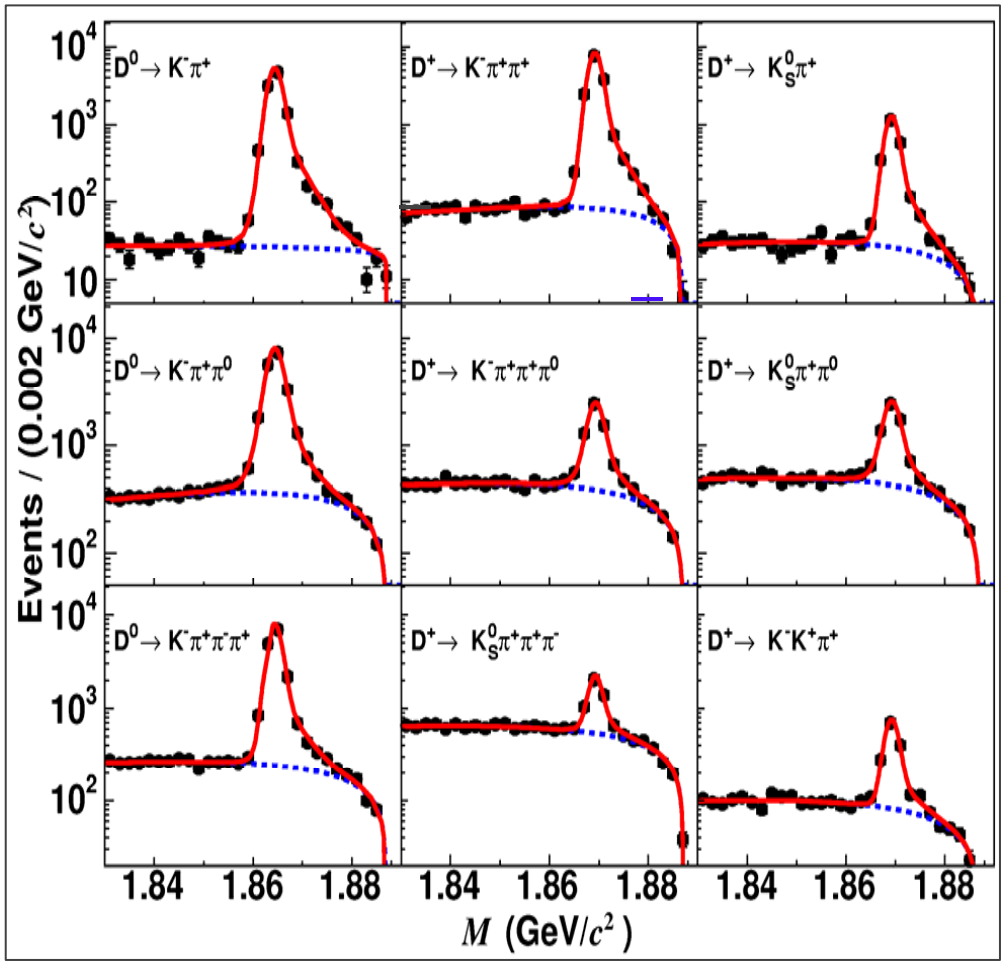
Efficiencies

- **Denominator of efficiency may be determined using missing mass in data and MC**
  - **Data & MC: 0.7% for charged, 2.0% for π^0, 3.0% for K^0_S**
- **Include effects of final state radiation (FSR)**

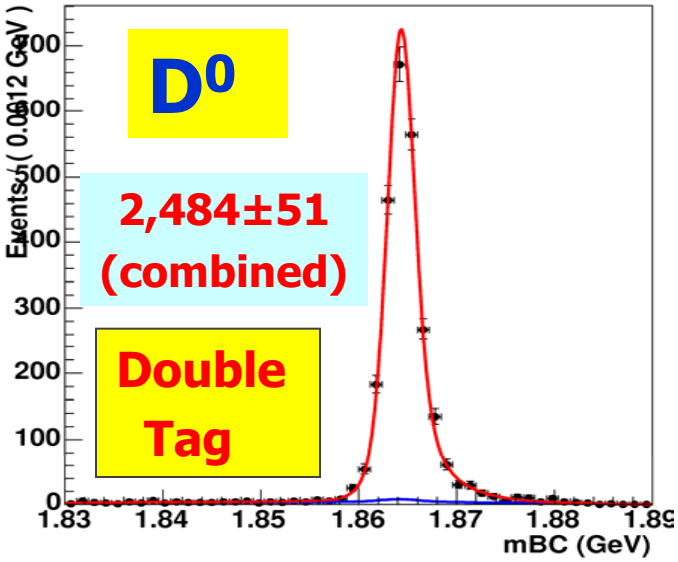
W. M. Sun, physics/0503050, CLNS 05/1912, submitted to NIM.

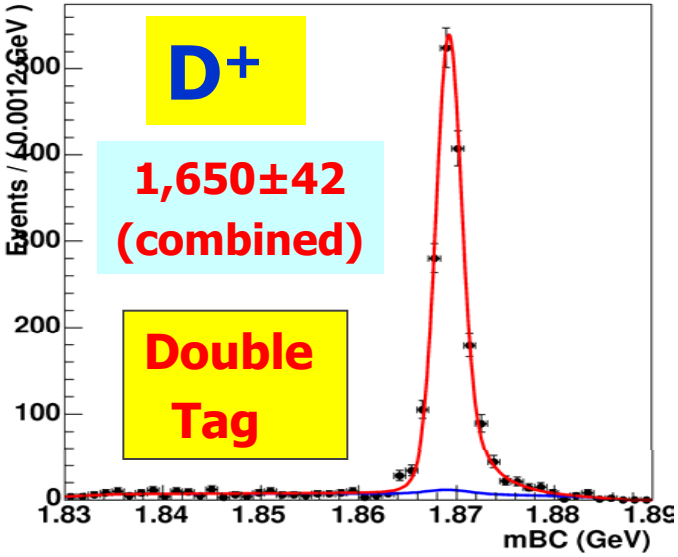
Single/Double Tag Yields

3 D^0 Modes **6 D^+ Modes**



Single Tag (log scale)!





Preliminary, submitted to PRL

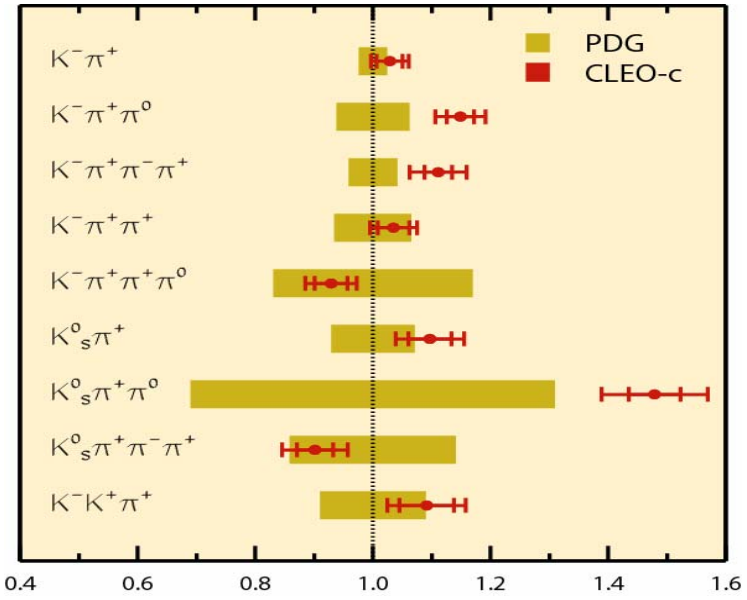
Absolute BRs & Production xsections

Parameter	Fitted Value (%)
$N(D^0\overline{D^0})$	$(2.006\pm0.038\pm016)\times10^5$
$\mathcal{B}(D^0\to K^-\pi^+)$	$(3.91\pm0.08\pm0.09)$ %
$\mathcal{B}(D^0\to K^-\pi^+\pi^0)$	$(14.94\pm0.30\pm0.47)$ %
$\mathcal{B}(D^0\to K^-\pi^+\pi^+\pi^-)$	$(8.29\pm0.17\pm0.32)$ %

Parameter	Fitted Value (%)
$N(D^+D^-)$	$(1.558\pm0.038\pm012)\times10^5$
$\mathcal{B}(D^+\to K^-\pi^+\pi^+)$	$(9.52\pm0.25\pm0.27)$ %
$\mathcal{B}(D^+\to K^-\pi^+\pi^+\pi^0)$	$(6.04\pm0.18\pm0.22)$ %
$\mathcal{B}(D^+\to K_s\pi^+)$	$(1.55\pm0.05\pm0.06)$ %
$\mathcal{B}(D^+\to K_s\pi^+\pi^0)$	$(7.17\pm0.21\pm0.38)$ %
$\mathcal{B}(D^+\to K_s\pi^+\pi^+\pi^-)$	$(3.20\pm0.11\pm0.16)$ %
$\mathcal{B}(D^+\to K^+K^-\pi^+)$	$(0.97\pm0.04\pm0.04)$ %

$$\frac{\sigma(e^+e^-\to D^+D^-)}{\sigma(e^+e^-\to D^0\overline{D^0})}=0.78\pm0.02\pm0.01$$

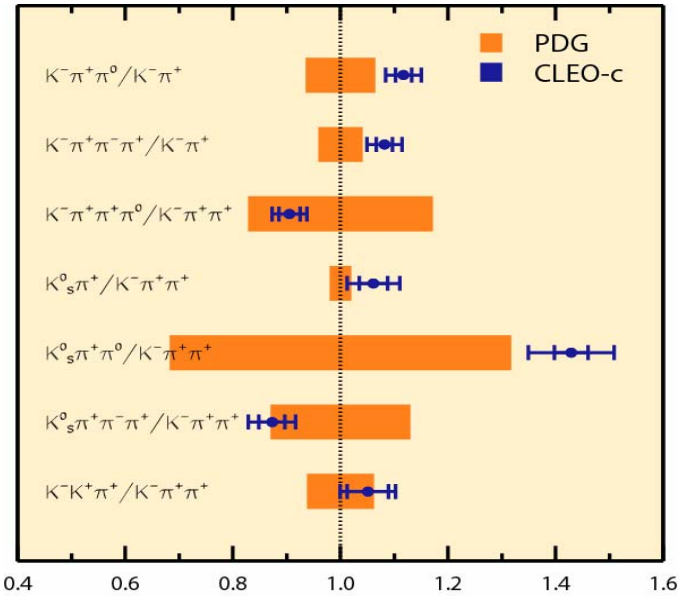
$\sigma(DD)=6.39\pm0.10^{+0.17}_{-0.08}$ nb



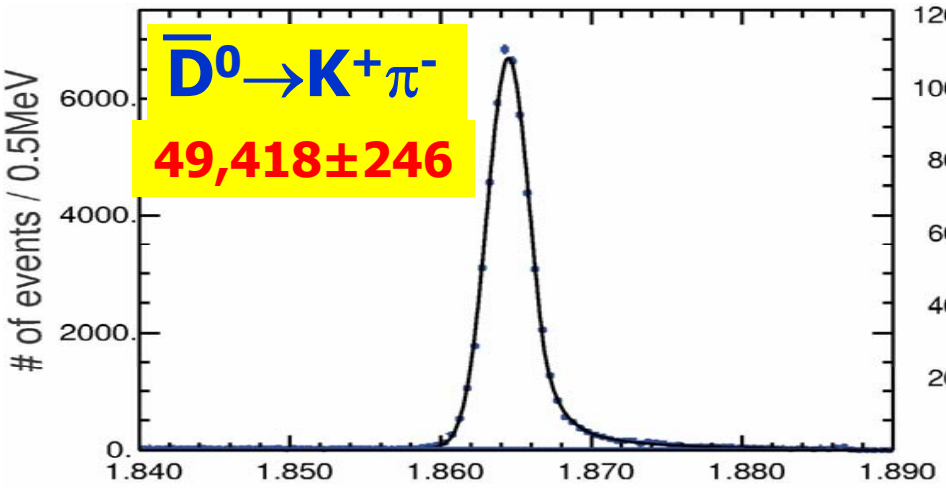
55.8 pb^{-1}

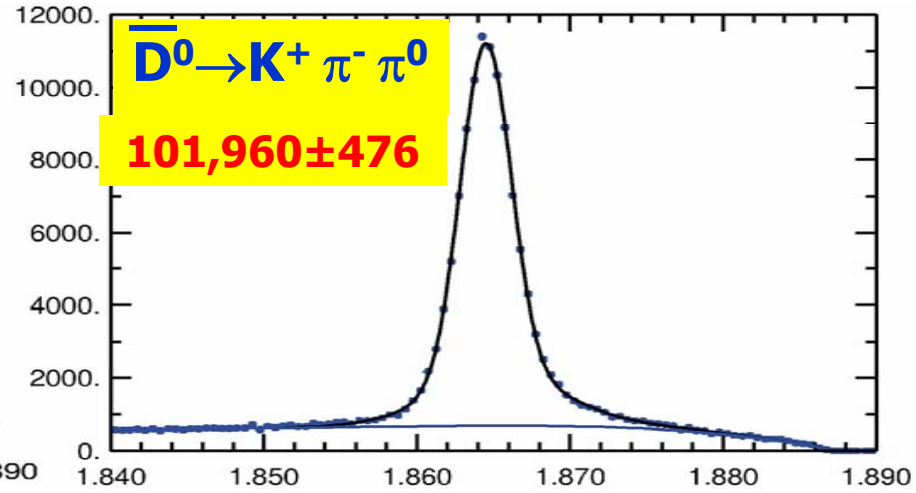
Six modes more precise than PDG.

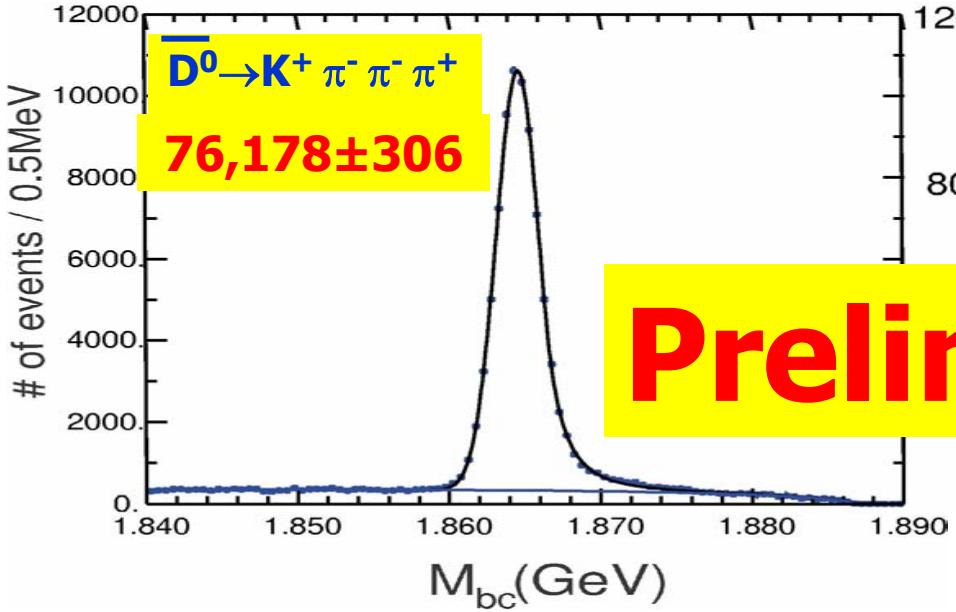
Normalized to PDG

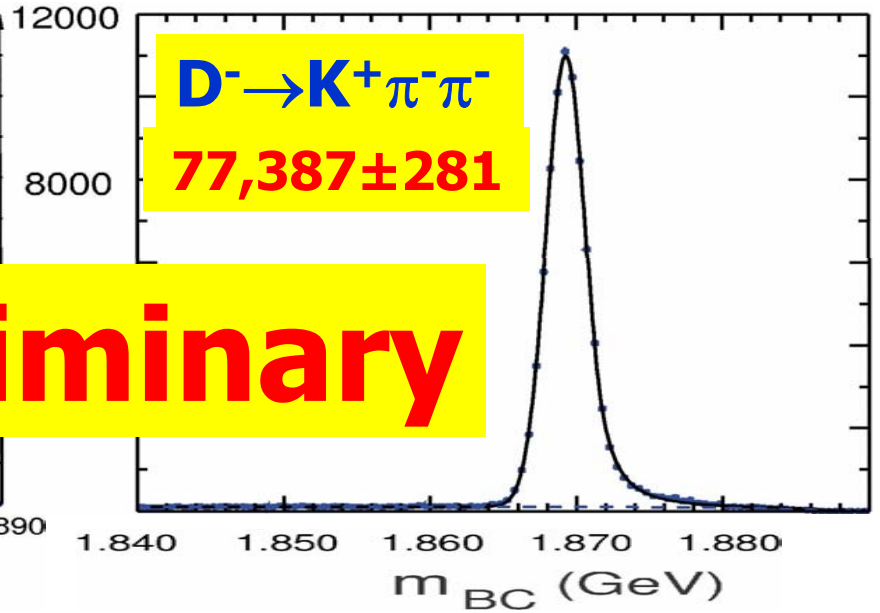


Single Tag from 281 pb^{-1}









Preliminary

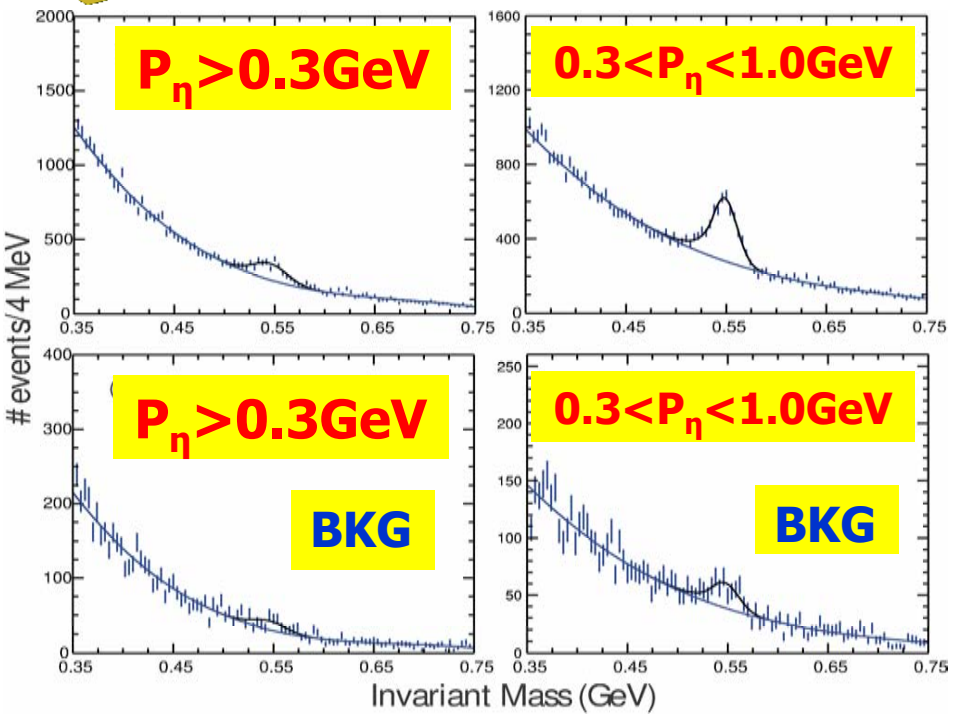
Inclusive η, η', Φ in D decays

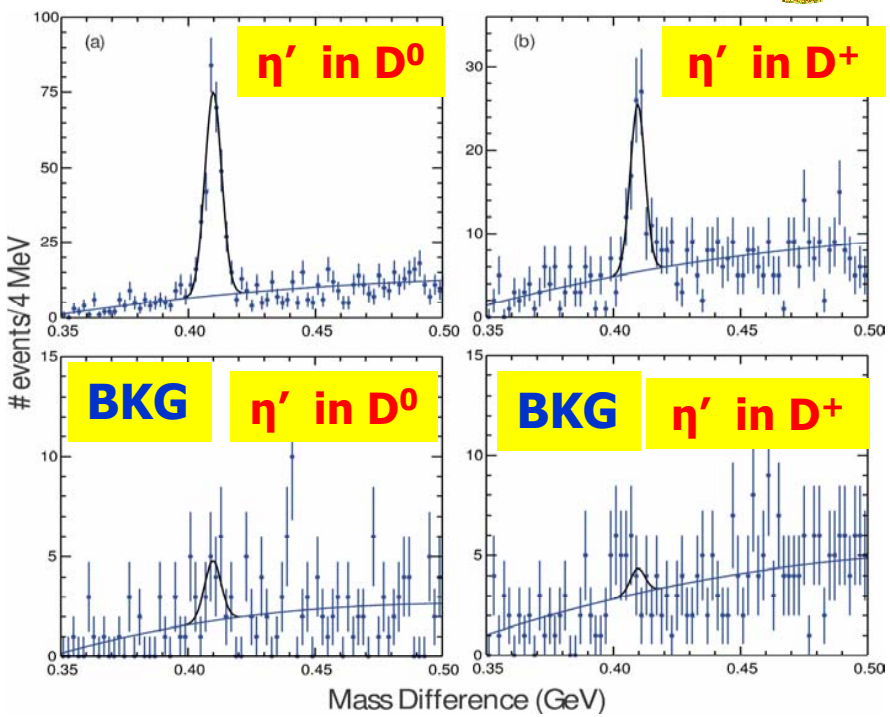
Single tag yield from 281 pb^{-1} at ψ(3770)

Tag	Mode	Signal	Background
D^-	$K^+\pi^-\pi^-$	77387 ± 281	1868
	$K^+\pi^-\pi^-\pi^o$	24850 ± 214	12825
	$K_s\pi^-$	11162 ± 136	514
	$K_s\pi^-\pi^-\pi^+$	18176 ± 255	8976
	$K_s\pi^-\pi^o$	20244 ± 170	5223
	Sum	151819 ± 487	29406
$\overline{D^o}$	$K^+\pi^-$	49418 ± 246	630
	$K^+\pi^-\pi^o$	101960 ± 476	18307
	$K^+\pi^-\pi^+\pi^-$	76178 ± 306	6421
	Sum	227556 ± 617	25357

Preliminary

Inclusive η, η', Φ in D decays

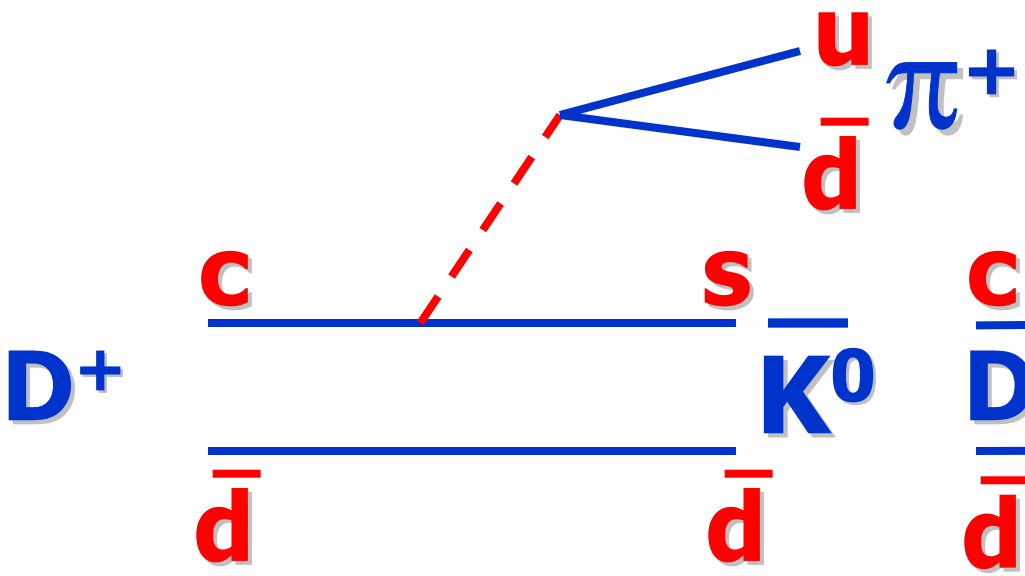


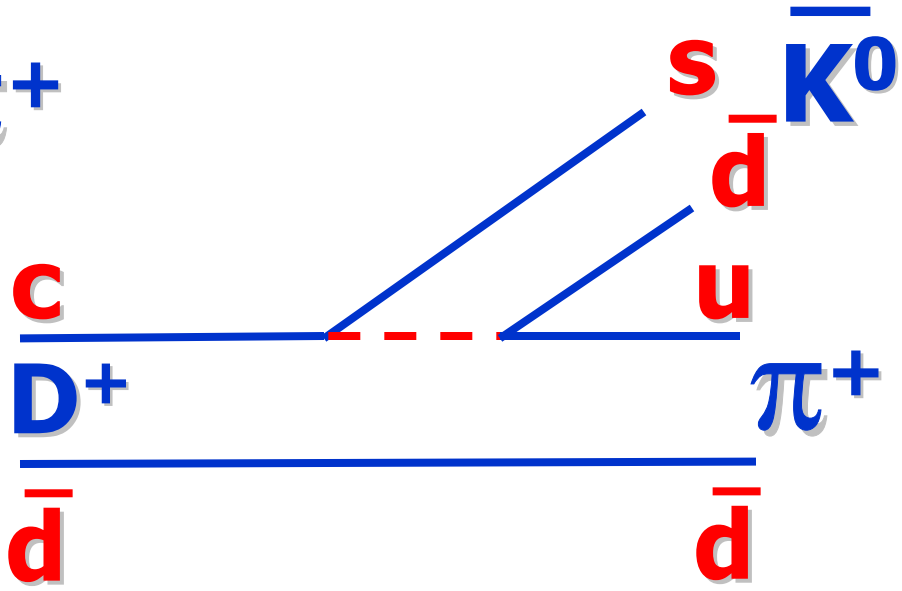


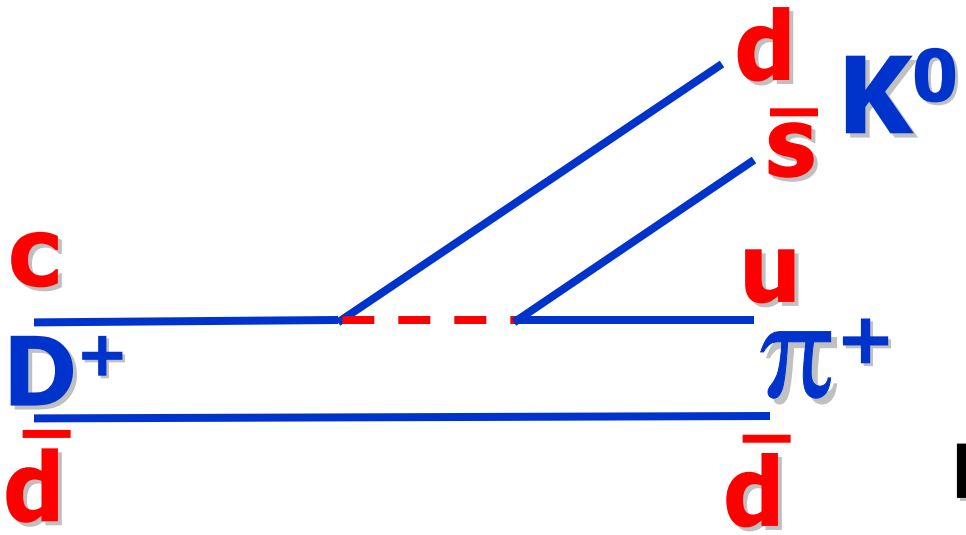
Mode	D^o(%)		D^+(%)	
	Our result	PDG	Our result	PDG
η X	9.4±0.4±0.6	<13	5.7±0.5±0.5	<13
η' X	2.6±0.2±0.2	-	1.0±0.2±0.1	-
ϕ X	1.0±0.1±0.1	1.7±0.8	1.1±0.1±0.2	<1.8

Preliminary

$D^+ \to K^0_S \pi^+$ and $K^0_L \pi^+$





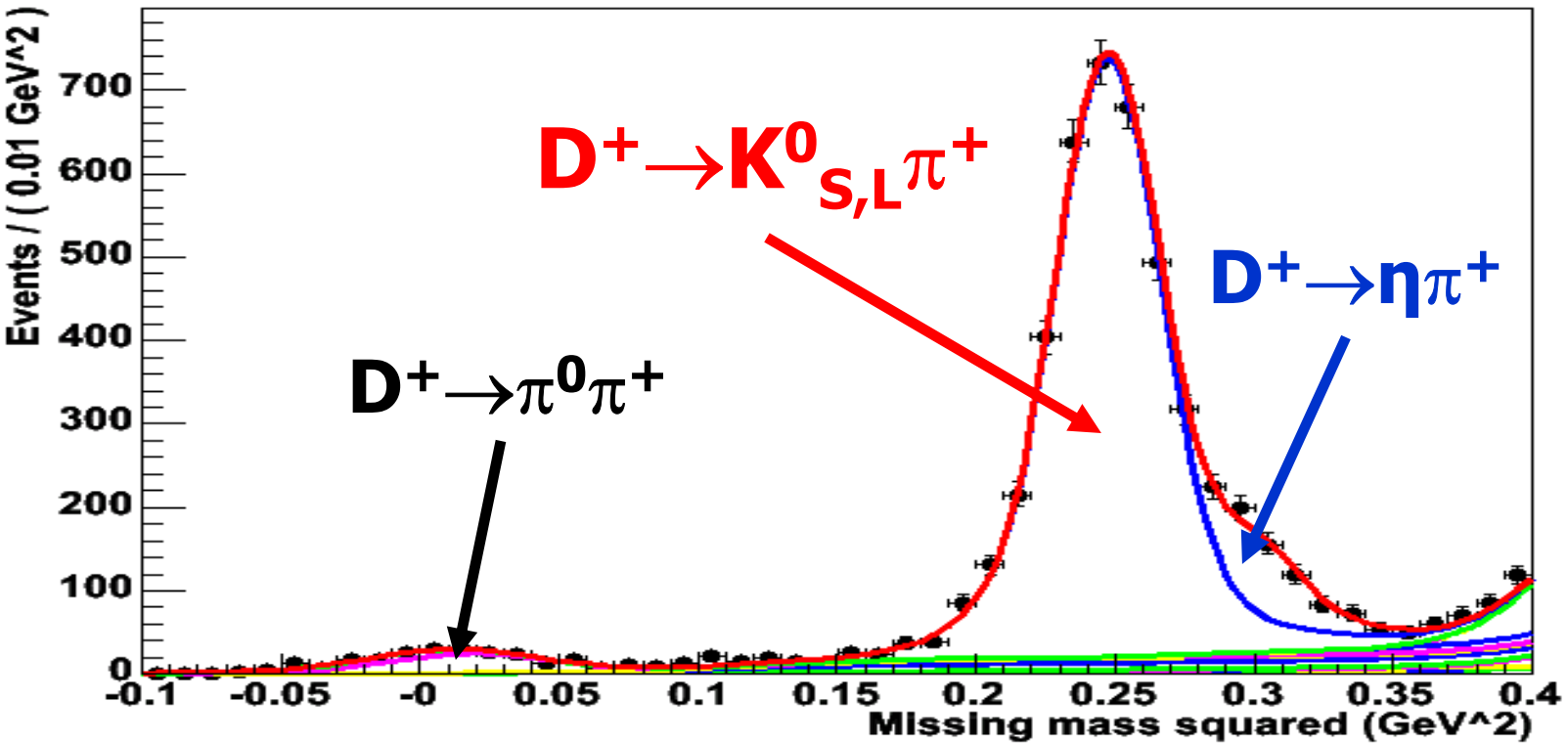


$B(D^+ \to K^0_L \pi^+) > B(D^+ \to K^0_S \pi^+)$

Phys. Lett. B349, 363 (1995)
I. Bigi & H. Yamamoto

Reconstruct D^- and π^+
Missing mass squared

$D^+ \to K^0_{S,L}\pi^+$ and $\eta\pi^+$



Preliminary

$Br(D^+ \to K^0_{S,L}\,\pi^+) = (3.06 \pm 0.06 \pm 0.16)\%$

$Br(D^+ \to \eta\,\pi^+) = (0.39 \pm 0.03 \pm 0.03)\%$

$$\frac{\mathcal{B}(D^+ \to K^0_L\pi^+) - \mathcal{B}(D^+ \to K^0_S\pi^+)}{\mathcal{B}(D^+ \to K^0_L\pi^+) + \mathcal{B}(D^+ \to K^0_S\pi^+)} = -0.01 \pm 0.04 \pm 0.07$$

$\psi(3770)$ non-$D\bar{D}$ decays

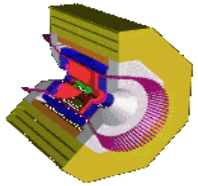
$\sigma(\psi'' \to D\bar{D}) = (6.39 \pm 0.10 \pm 0.21)$ nb (CLEO, 55.8 pb^{-1})

$\sigma(\psi'' \to \text{hadrons}) \sim (7.9 \pm 0.6)$ nb (J. Rosner hep-ph/0411196)

Is there a deficit?

Search for exclusive decay modes at CLEO:

- $\psi'' \to$ two-body (VP) (281 pb^{-1}/21 pb^{-1}, this talk)
- $\psi'' \to$ multi-body (55.8 pb^{-1}/21 pb^{-1}, this talk)
- $\psi'' \to XJ/\psi, \gamma\chi_{cJ}$ (David Miller's talk)



$\psi(3770) \rightarrow$ VP, multi-body

VP = $\rho/\omega/\Phi + \pi/\eta/\eta'$, K*K, also $\pi^+\pi^-\pi^0$, $b_1\pi$

multi-body = combinations of π, K, p, η, ω,Φ

Energy conservation: $0.98 < E_{vis}/E_{cm} < 1.02$

Momentum conservation: $|P_V - P_P|/E_{cm} < 0.04$

Suppress $J/\psi \rightarrow \mu^+\mu^-$ or hadronic decays

Compare $\psi(3770)$ with scaled continuum

$\psi(3770) \to VP$ decays

Channel	$N_{sw}^{3.67}$	$N_{sb}^{3.77}$	$N_{sw}^{3.77}$	$N_{sb}^{3.67}$	ϵ	$S^{\rm I}$	$S^{\rm II}$	$\sigma^{3.67\rm GeV}$ [pb]	$\sigma^{3.77\rm GeV}$ [pb]
$\pi^+\pi^-\pi^0$	74	7	576	72	0.29	2.7	–	$13.1^{+1.9}_{-1.7} \pm 2.1$	$7.4 \pm 0.4 \pm 1.2$
$\rho^0\pi^0$	21	3	130	33	0.33	2.2	2.2	$3.1^{+1.0}_{-0.8} \pm 0.4$	$1.3 \pm 0.2 \pm 0.2$
$\rho^+\pi^-$	22	2	184	12	0.23	0.9	0.6	$4.8^{+1.5}_{-1.2} \pm 0.5$	$3.2 \pm 0.3 \pm 0.3$
$\rho\pi$	43	5	314	45	0.26	2.2	1.9	$8.0^{+1.7}_{-1.4} \pm 0.9$	$4.4 \pm 0.3 \pm 0.5$
$\omega\pi^0$	54	6	696	39	0.19	1.4	0.4	$14.5^{+2.6}_{-2.3} \pm 1.5$	$14.8 \pm 0.6 \pm 1.5$
$\phi\pi^0$	1	2	2	4	0.17	0.0	0.0	< 2.2	< 0.2
$\rho\eta$	36	3	508	31	0.20	1.5	0.5	$9.6^{+2.1}_{-1.8} \pm 1.0$	$10.4 \pm 0.5 \pm 1.0$
$\omega\eta$	4	0	15	6	0.10	1.7	3.0	$2.3^{+1.8}_{-1.1} \pm 0.5$	< 0.8
$\phi\eta$	5	1	132	16	0.11	2.5	≥ 5	< 5.0	$4.5 \pm 0.5 \pm 0.5$
$\rho\eta'$	1	0	27	1	0.03	1.2	1.3	$2.0^{+4.5}_{-1.6} \pm 0.2$	$3.8^{+0.9}_{-0.8} \pm 0.5$
$\omega\eta'$	0	0	2	0	0.02	≥ 5	0.0	< 17.1	$0.6^{+0.7}_{-0.3} \pm 0.6$
$\phi\eta'$	0	0	9	2	0.01	2.4	1.2	< 12.6	< 5.2
$K^{*0}\overline{K^0}$	38	0	501	18	0.09	1.1	≥ 5	$23.5^{+4.6}_{-3.8} \pm 3.1$	$23.5 \pm 1.1 \pm 3.1$
$K^{*+}K^-$	4	1	36	32	0.16	1.4	4.2	< 3.5	< 0.6
$b_1^0\pi^0$	5	3	49	82	0.04	1.2	–	< 17.1	< 2.6
$b_1^+\pi^-$	15	2	219	18	0.18	1.0	–	$4.2^{+1.6}_{-1.3} \pm 0.6$	$4.7 \pm 0.4 \pm 0.6$
$b_1\pi$	20	4	268	67	0.11	0.5	–	$7.9^{+3.1}_{-2.4} \pm 1.8$	$7.6 \pm 0.7 \pm 1.8$

Preliminary: 281 pb^{-1}

$\psi(3770) \rightarrow$ VP decays

281 pb^{-1} data at 3.77 GeV
21 pb^{-1} data at 3.67 GeV

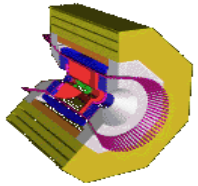
Preliminary

for each channel, on-$\psi(3770)$ yields consistent with continuum prediction except:

- Br($\psi(3770) \rightarrow \phi\eta$) = $(3.1\pm0.6\pm0.3\pm0.1)\times10^{-4}$
- $\psi(3770) \rightarrow \pi^+\pi^-\pi^0$, $\rho^0\pi^0$ and $K^{*+}K^-$ are suppressed.
- form factors of $\omega\pi^0$, $\rho\eta$ and $\rho\eta'$ are obtained

Form factor measurements

Channel	$\mathcal{F}(s)$ (GeV^{-1})	
	$\sqrt{s} = 3.670\,\mathrm{GeV}$	$\sqrt{s} = 3.773\,\mathrm{GeV}$
$\omega\pi^0$	$0.039 \pm 0.003 \pm 0.002$	$0.040 \pm 0.001 \pm 0.002$
$\rho\eta$	$0.033 \pm 0.003 \pm 0.002$	$0.034 \pm 0.001 \pm 0.002$
$\rho\eta'$	< 0.038 (90%CL)	$0.022^{+0.003}_{-0.002} \pm 0.001$



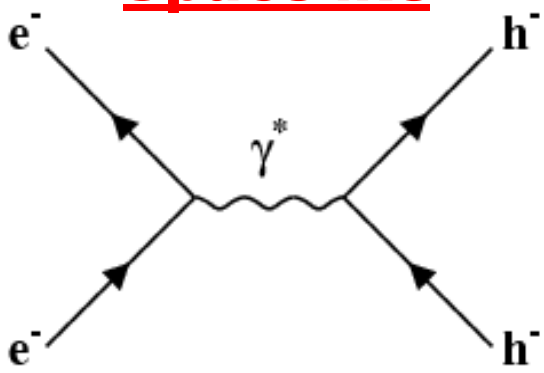
$\psi(3770) \rightarrow$ multi-body

mode	continuum		f_{co}	10x$D\bar{D}$ MC		$\psi(3770)$		N_S	Sig.	ε	σ U.L.	$\mathcal{B}$ U.L.
h	S_{co}	B_{co}		S_{DD}	B_{DD}	$S_{\psi(3770)}$	$B_{\psi(3770)}$		(#σ)		(pb)	($\times 10^{-4}$)
$2(\pi^+\pi^-)$	1471	28	2.49	1	13	3411	90	-266.5	-2.5	0.4305	8.7	11.2
$2(\pi^+\pi^-)\pi^0$	350	18	2.26	15	14	647	18	-120.5	-2.6	0.1990	8.2	10.6
$\eta\pi^+\pi^-$	15	0	2.57	0	0	41	1	1.5	0.1	0.0450	9.7	12.4
$\omega\pi^+\pi^-$	43	9	2.35	0	0	107	18	9.1	0.5	0.1638	4.6	6.0
$\eta 3\pi$ [a]	27	2	2.61	8	0	67	11	-10.1	-0.6	0.0688	4.5	5.8
$\eta 3\pi$ [b]	20	9	2.64	2	1	62	23	9.8	0.6	0.0248	24.0	30.7
$\eta' 3\pi$	1	0	2.75	1	0	5	0	2.2	0.4	0.0149	19.2	24.4
$K^+K^-\pi^+\pi^-$	954	25	2.40	32	7	2262	47	-16.8	-0.2	0.3720	7.0	9.0
$\phi\pi^+\pi^-$	33	13	2.43	0	0	77	25	3.3	0.2	0.1629	3.2	4.1
ϕf_0	12	5	2.49	0	2	32	15	-0.2	0.0	0.0863	3.5	4.5
$K^+K^-\pi^+\pi^-\pi^0$	634	18	1.73	30	21	1121	32	24.9	0.5	0.1283	18.4	23.6
ηK^+K^-	3	0	2.50	0	0	3	0	-4.5	-0.7	0.0389	3.2	4.1
ωK^+K^-	62	12	2.31	0	1	114	14	-15.3	-0.7	0.1269	2.6	3.4
$2(K^+K^-)$	100	11	2.67	9	1	267	7	21.7	0.7	0.3170	4.6	6.0
ϕK^+K^-	46	15	2.59	4	0	118	22	15.2	0.7	0.1564	5.9	7.5
$2(K^+K^-)\pi^0$	20	0	2.88	8	0	50	0	-8.4	-0.6	0.1479	2.2	2.9
$p\bar{p}\pi^+\pi^-$	337	28	2.47	0	0	851	60	28.6	0.5	0.5149	4.5	5.8
$p\bar{p}\pi^+\pi^-\pi^0$	204	9	2.58	0	0	604	16	85.4	2.1	0.2259	14.4	18.5
$\eta p\bar{p}$	2	1	2.62	0	0	4	2	-0.6	-0.1	0.0469	4.2	5.4
$\omega p\bar{p}$	26	4	2.58	0	0	54	5	-7.8	-0.5	0.1421	2.2	2.9
$p\bar{p}K^+K^-$	25	1	2.62	0	0	89	3	23.0	1.5	0.4111	2.5	3.2
$\phi p\bar{p}$	2	3	2.69	0	0	2	2	0.0	0.0	0.1872	1.1	1.3
$\Lambda\bar{\Lambda}$	4	1	2.69	0	0	6	0	-2.1	-0.3	0.2154	1.0	1.2
$\Lambda\bar{\Lambda}\pi^+\pi^-$	23	4	2.37	0	0	42	7	-10.0	-0.7	0.1019	2.0	2.5
$\Lambda\bar{p}K^+$	65	7	2.57	0	0	150	11	-10.0	-0.4	0.2602	2.2	2.8
$\Lambda\bar{p}K^+\pi^+\pi^-$	29	3	2.64	0	0	94	17	8.2	0.4	0.1471	4.9	6.3

Submitted to PRL: 55.8 pb^{-1}

Hadronic EM Form Factors

Spacelike

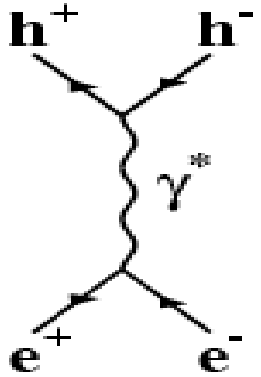


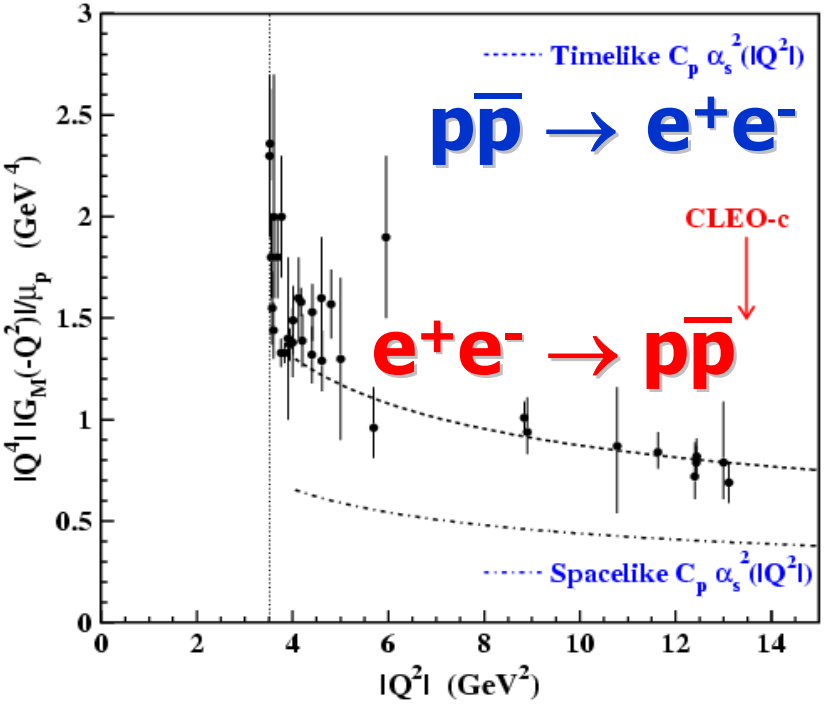
Brodsky & Lepage (PRD 22, 2157 (1980))

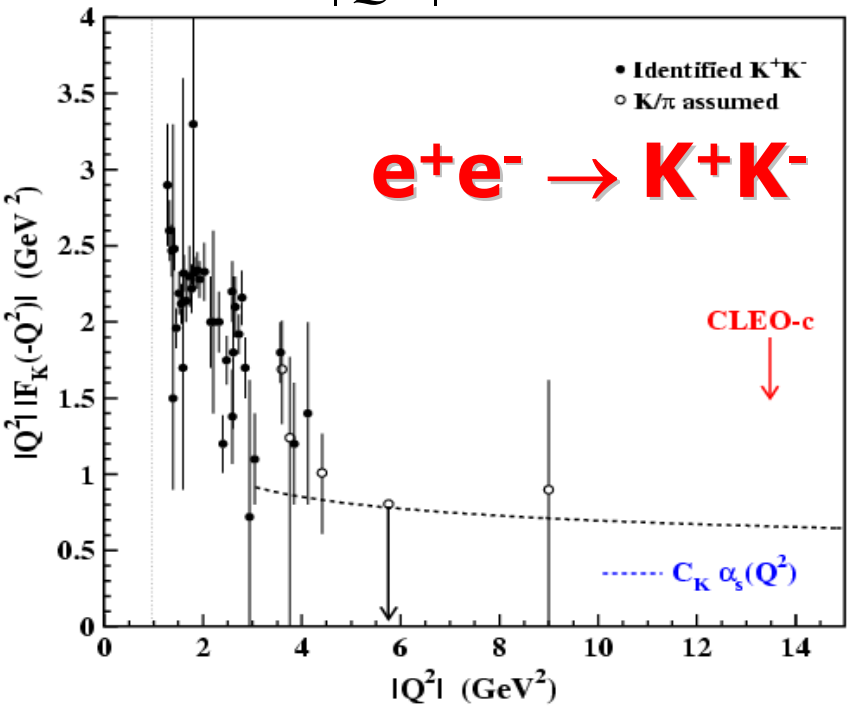
Baryons: $F(|Q^2|) \propto \frac{\alpha_s^2(|Q^2|)}{|Q^4|}$

Mesons: $F(|Q^2|) \propto \frac{\alpha_s(|Q^2|)}{|Q^2|}$

Timelike





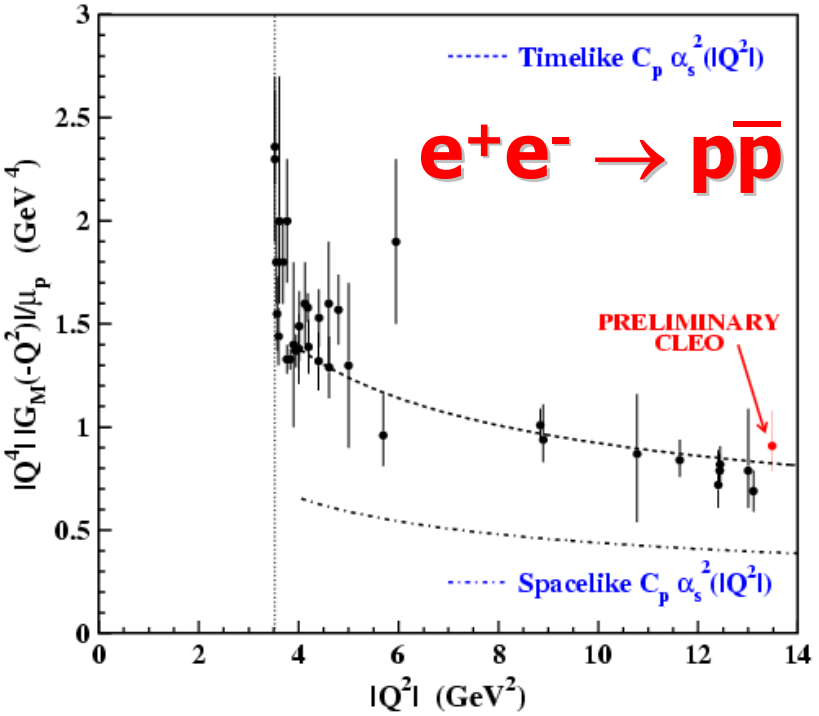


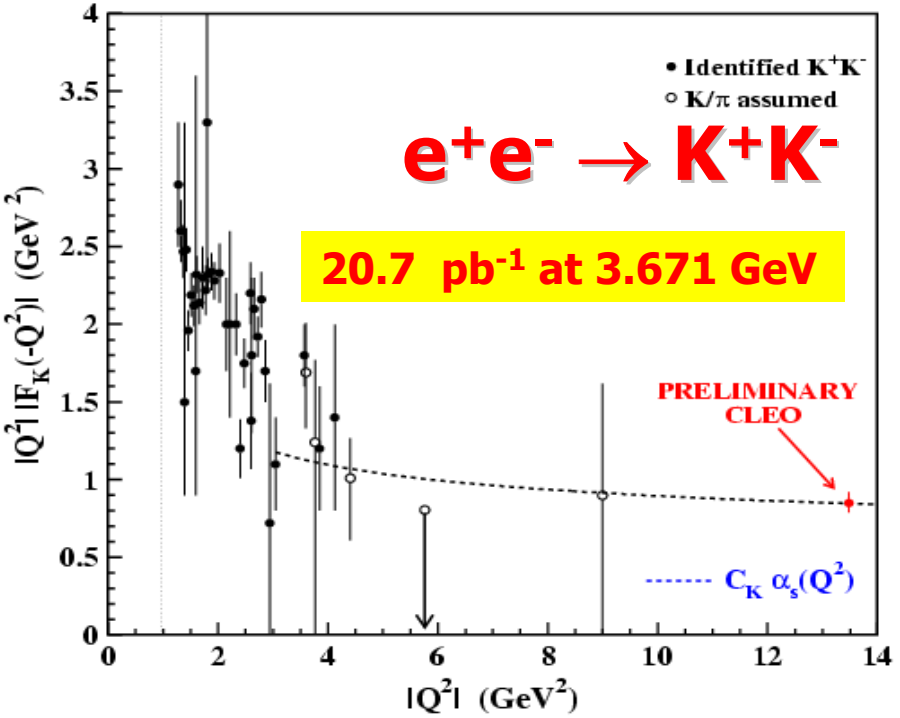
Hadronic EM Form Factors

Proton

Preliminary

Charged Kaon



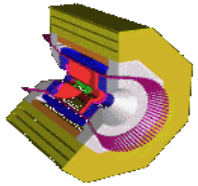


$$|G_M^P(13.5)| = (1.52^{+0.26}_{-0.20}(stat)^{+0.07}_{-0.03}(syst)) \times 10^{-2} \quad (|G_E^P(s)| = 0)$$

$$|G_M^P(13.5)| = (1.39^{+0.24}_{-0.18}(stat)^{+0.06}_{-0.03}(syst)) \times 10^{-2} \quad (|G_E^P(s)| = |G_M^P(s)|)$$

$$|F_K(13.5)| = (6.28 \pm 0.38(stat) \pm 0.14(syst)) \times 10^{-2}$$

First precision measurement



Preliminary CLEO results

Absolute D hadronic BR & Ψ″ → DD cross-section

(55.8 pb^{-1} , CLNS 05/1904, submitted to PRL)

Inclusive production of η, η′, Φ in D decays

(281 pb^{-1}, CLEO CONF 05-4)

BF measurement of $D^+ \to K^0_S/K^0_L\ \pi^+$

(281 pb^{-1})

Ψ″ → non DD final states (VP, multi-body)

(281 pb^{-1}, 55.8 pb^{-1}, CLEO CONF 05-1, CLNS 05/1921)

P and K time-like form factors at √s = 3.671 GeV

(20.7 pb^{-1}, CLEO CONF 05-9)