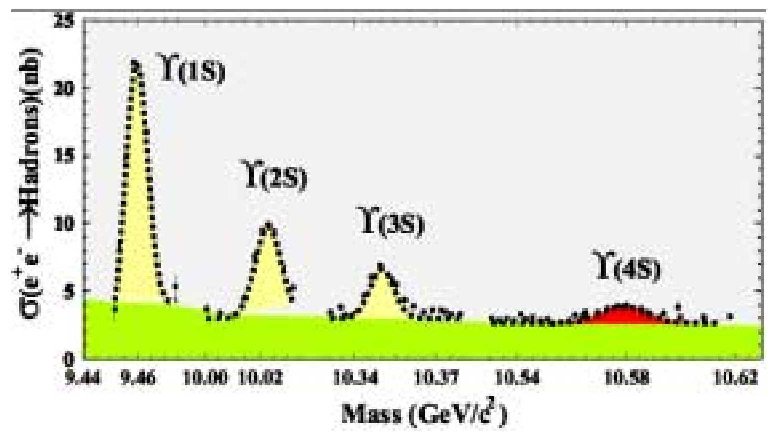
Recent Results from CLEOc

(selected topics)

30 year history.

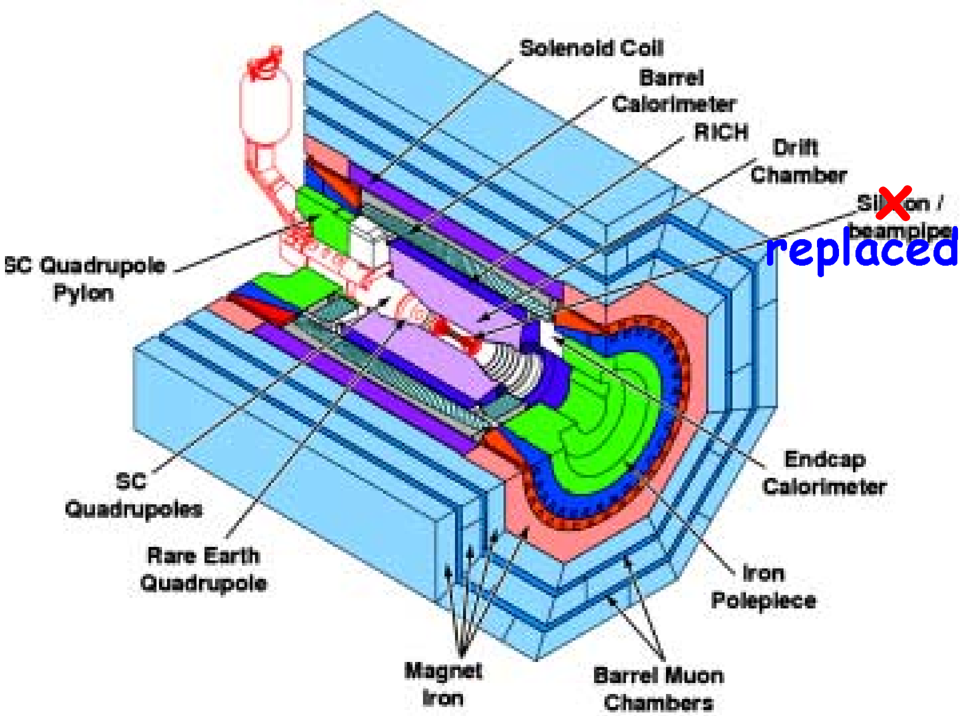
Cornell Electron-positron Storage Ring



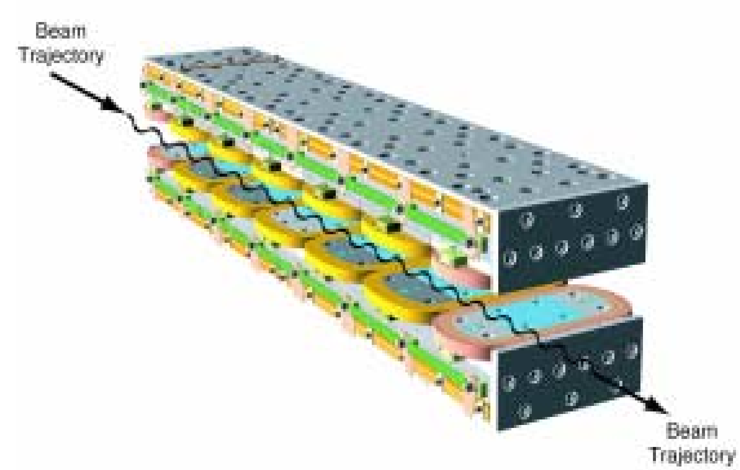
Research shifted to charm physics ~2003.

New Hardware

CLEOc



12 beam wigglers

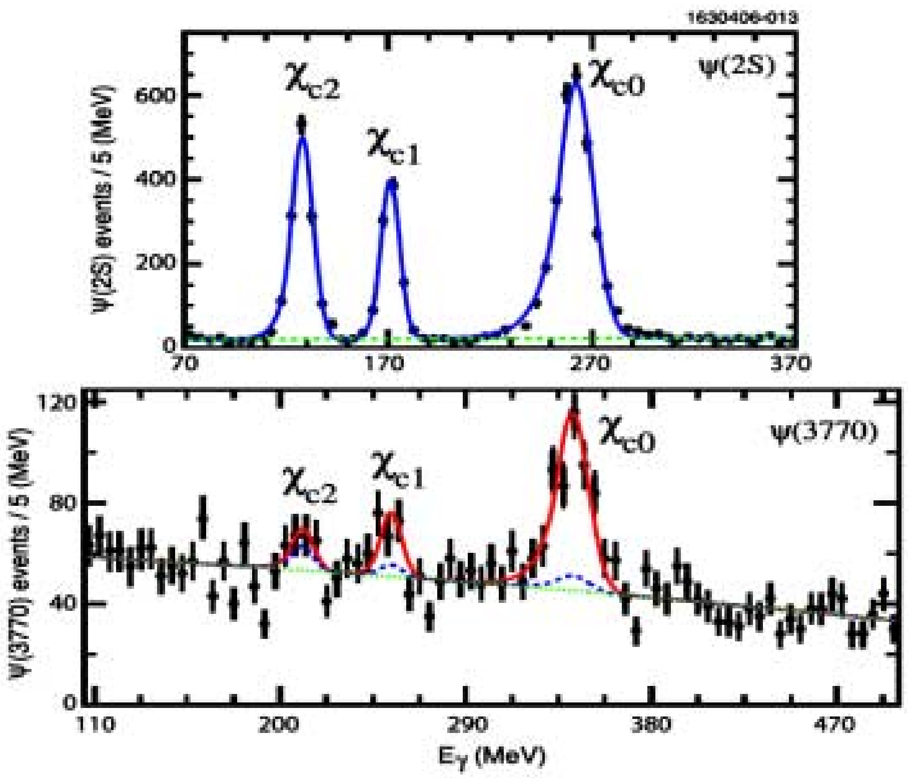


Drift Chambers: 93% acceptance, $\Delta p/p$=0.6% @1 GeV
CsI Calorimeter: 93% acceptance, $\Delta E/E$=4% @100 MeV
Muon Chambers: 85% acceptance for p>1GeV
Particle ID: RICH + drift ch. dE/dx

Luminosity: 4/pb/day

Advantages

low backgrounds



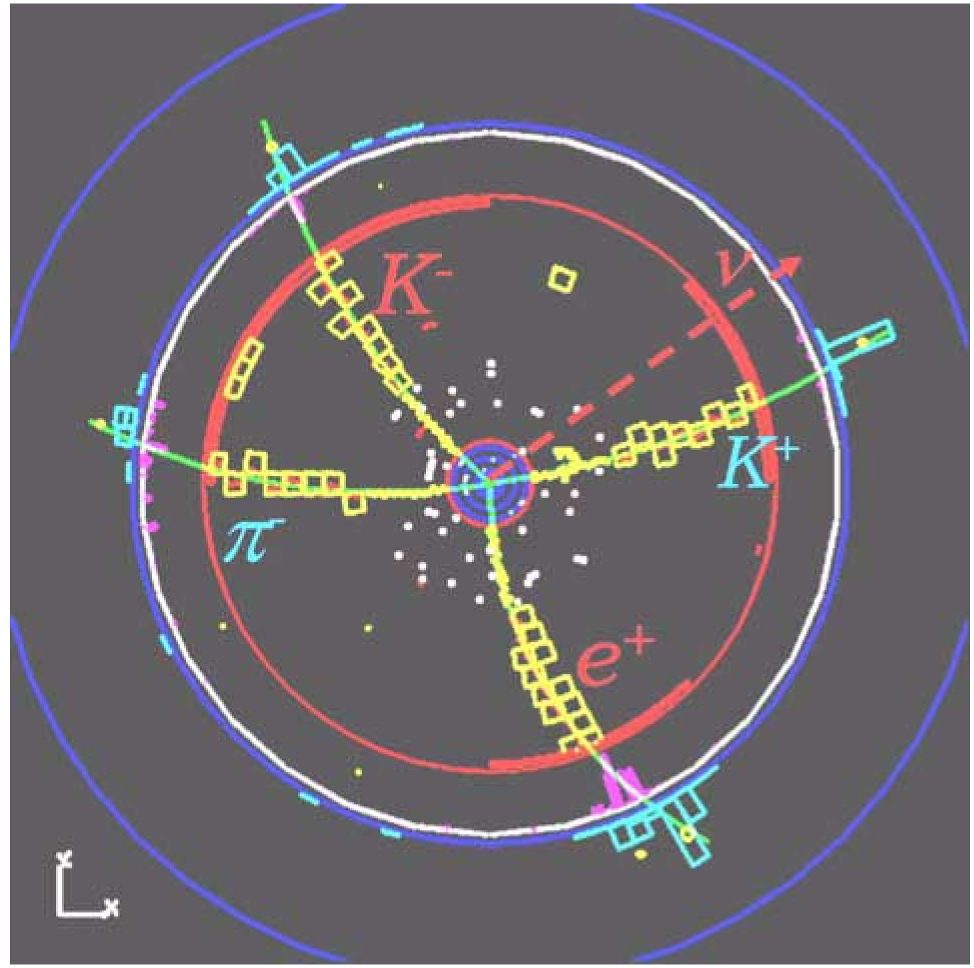
$$B(\psi(3770) \to \gamma\,\chi_{cJ})$$

$J = 0 \quad (0.73 \pm 0.07 \pm 0.06)\,\%$

$J = 1 \quad (0.29 \pm 0.05 \pm 0.04)\,\%$

$J = 2 \quad < 0.09\,\% \quad$ (90% C.L.)

High tagging rates



$$\psi(3770) \to D^0\,\overline{D^0}$$

$$\overline{D^0} \to K^+\pi^-,\; D^0 \to K^- e^+ \nu$$

Program

Run Times

Energy (MeV)	Acquired (1/pb)	Projected (1/pb)	Main Purpose
$\psi(3770)$	280	~740	*D* decay
4170	320	~740	D_s decay
$\psi(2S)$ (30M sample)	~60	no change	$\psi(2S)$, χ_c , J/ψ, h_c
3970-4260	~60	no change	Y(4260)

Only modern e^+e^- experiment in charm region.

Largest data samples (until BES III turns on).

Today:

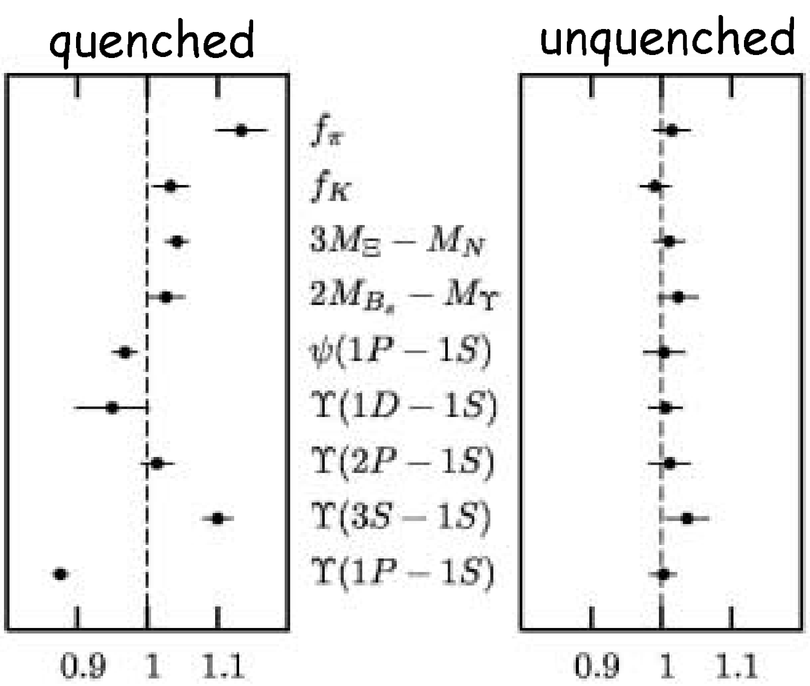
- D and D_s leptonic decay
- D semi-leptonic decay
- Y(4260)

D and D_s leptonic decay

Motivation:

1. Test lattice QCD methods
2. Improve experimental CKM matrix

Background: LQCD has finally reached the "predictive" stage.

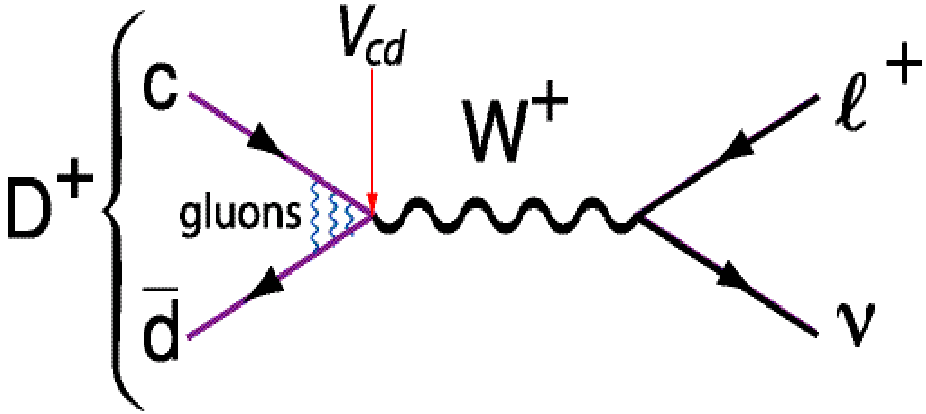


theory / experiment

Davies, et al., PRL 92, 022001 (2004)

- Tests with leptons are particularly useful.

$D^+ \to \mu^+ \nu$



$\Gamma \propto f_D^2 |V_{cd}|^2$

Quark annihilation decay constant.

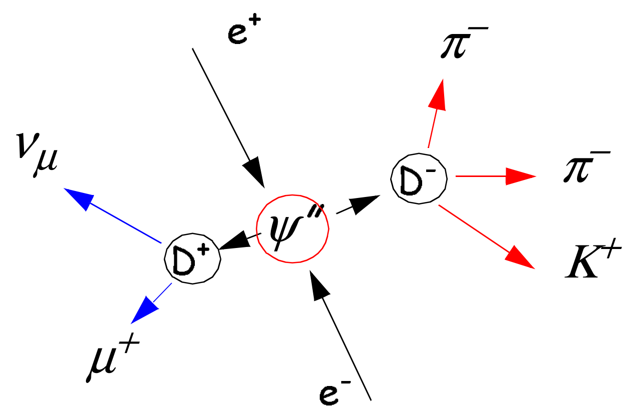
Known to 1% from CKM unitarity.

Standard Model $\to$ Γ=2.35x10^{-5} : 1 : 2.64 (e : μ : τ) , so μ data are important.

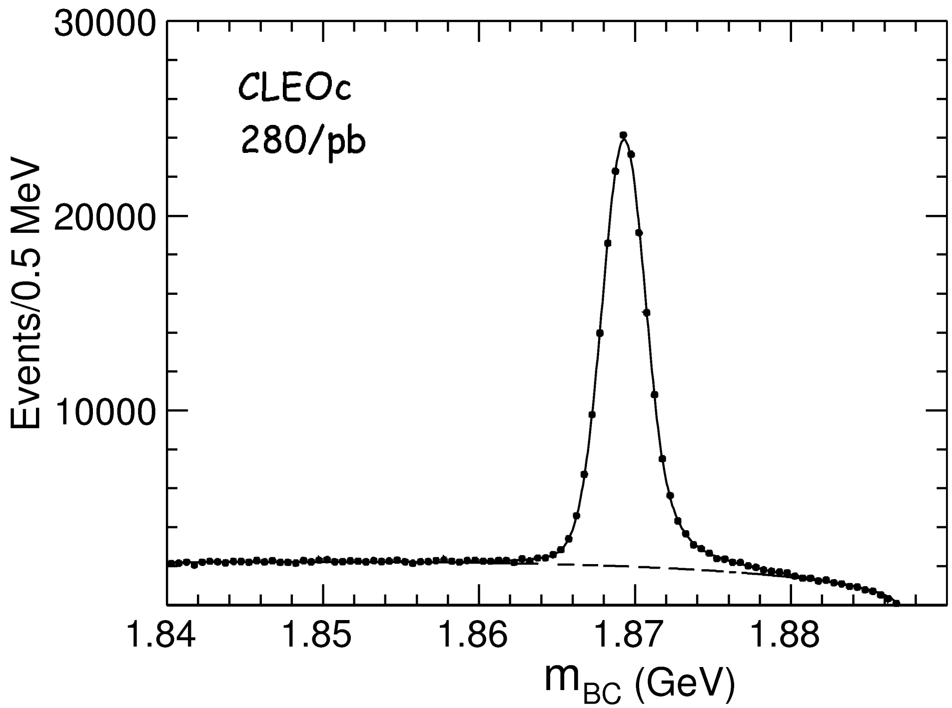
Method:

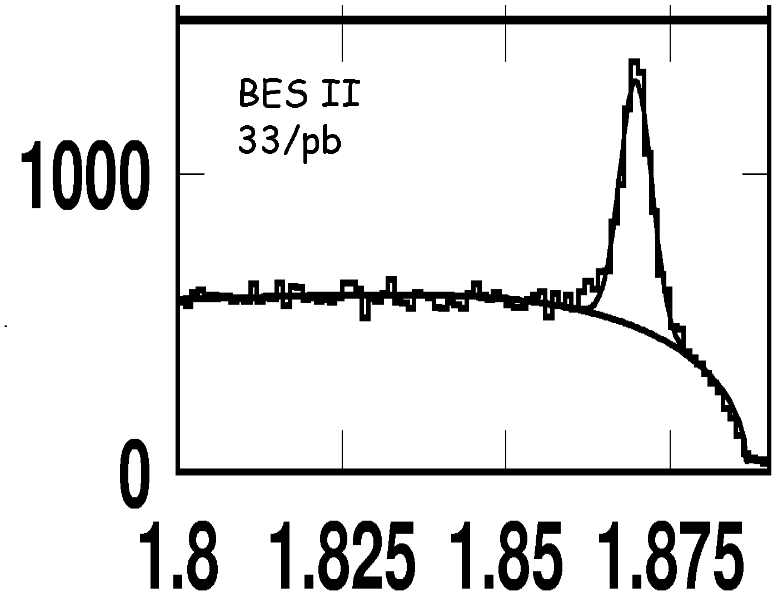
$e^+e^- \to \psi(3770) \to D^+D^- \to$ (hadrons) μ

$\mathcal{B}_\mu$ = (number μ) / (number tagged)



Charged D tagging with CLEOc





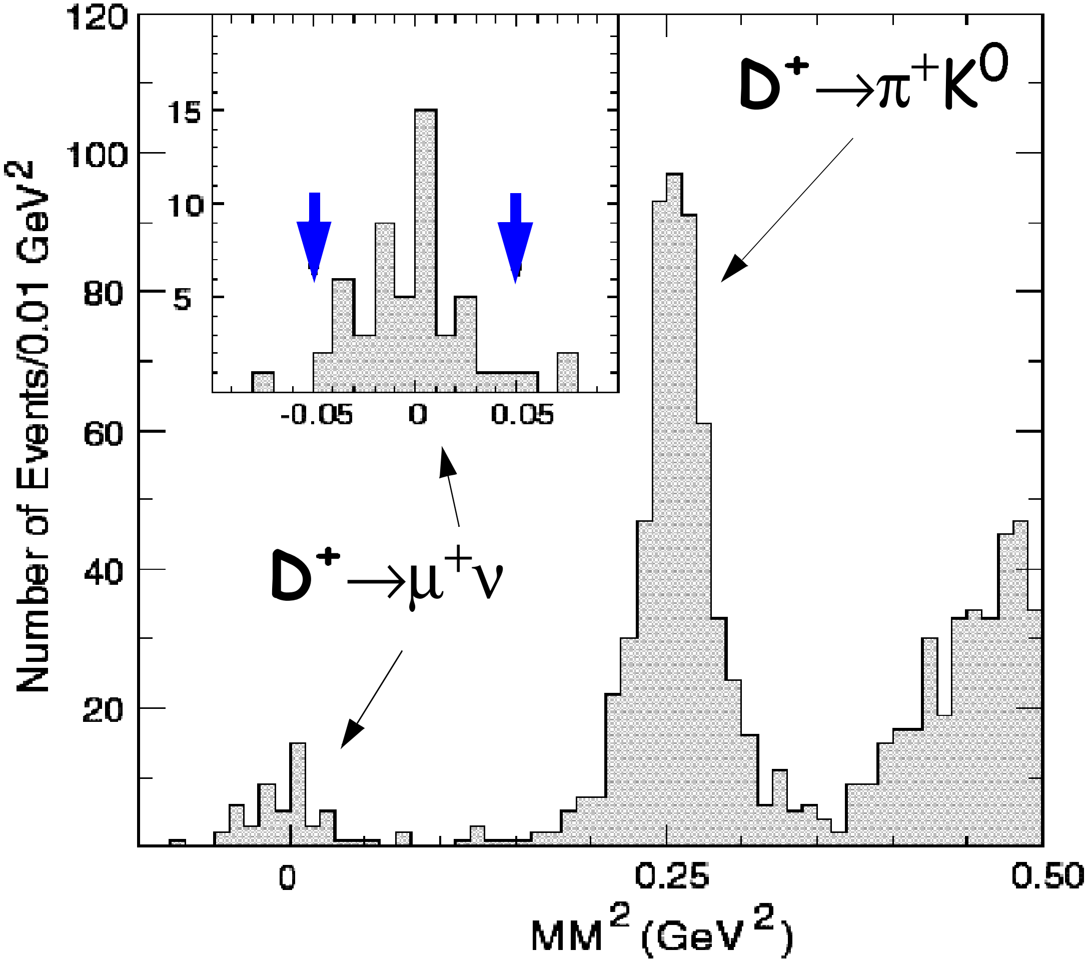
$$M_{bc}^2 = (E_{beam} - \vec{p}_\mu)^2 - (\vec{p}_D + \vec{p}_\mu)^2$$

158k D tags (6 modes)

5.3k D tags (9 modes)

tagging eff. ~ 10%

D decay constant



PRL 95, 251801
(280/pb)

$$B(D \to \mu\nu) = (4.4 \pm 0.7 \pm 0.1) \times 10^{-4}$$

$$B(D \to e\nu) < 2.3 \times 10^{-5}$$

D decay constant

CLEOc:

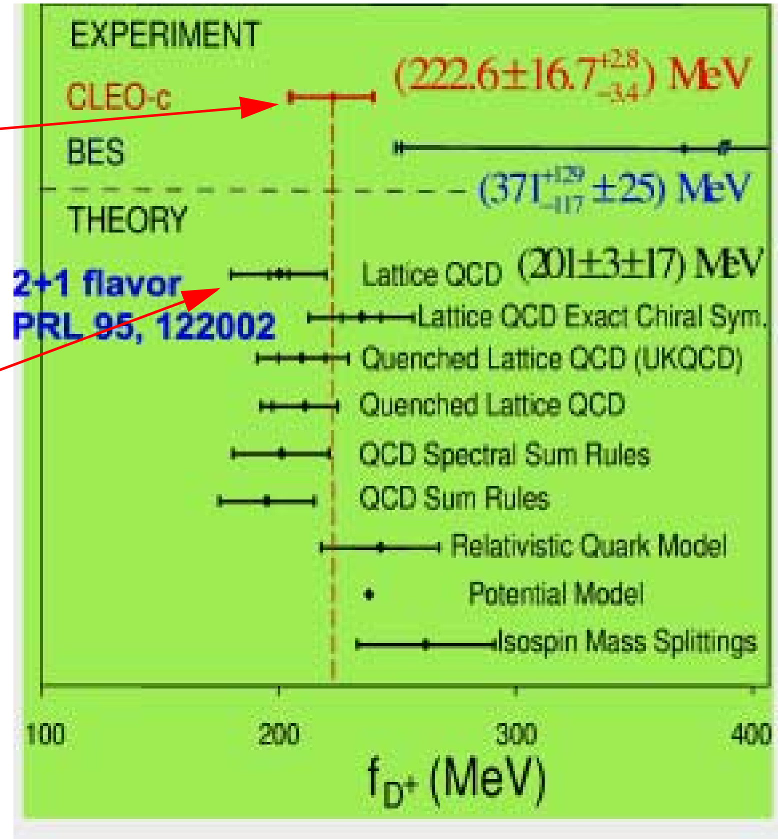
$$f_D = (222.6 \pm 16.7^{2.8}_{-3.4}) MeV$$

CLEOc projected: ~4% error bar

lattice:

FNAL/MILC, PRL 95, 122002 (2005)

$$f_D = (201 \pm 3 \pm 17) MeV$$

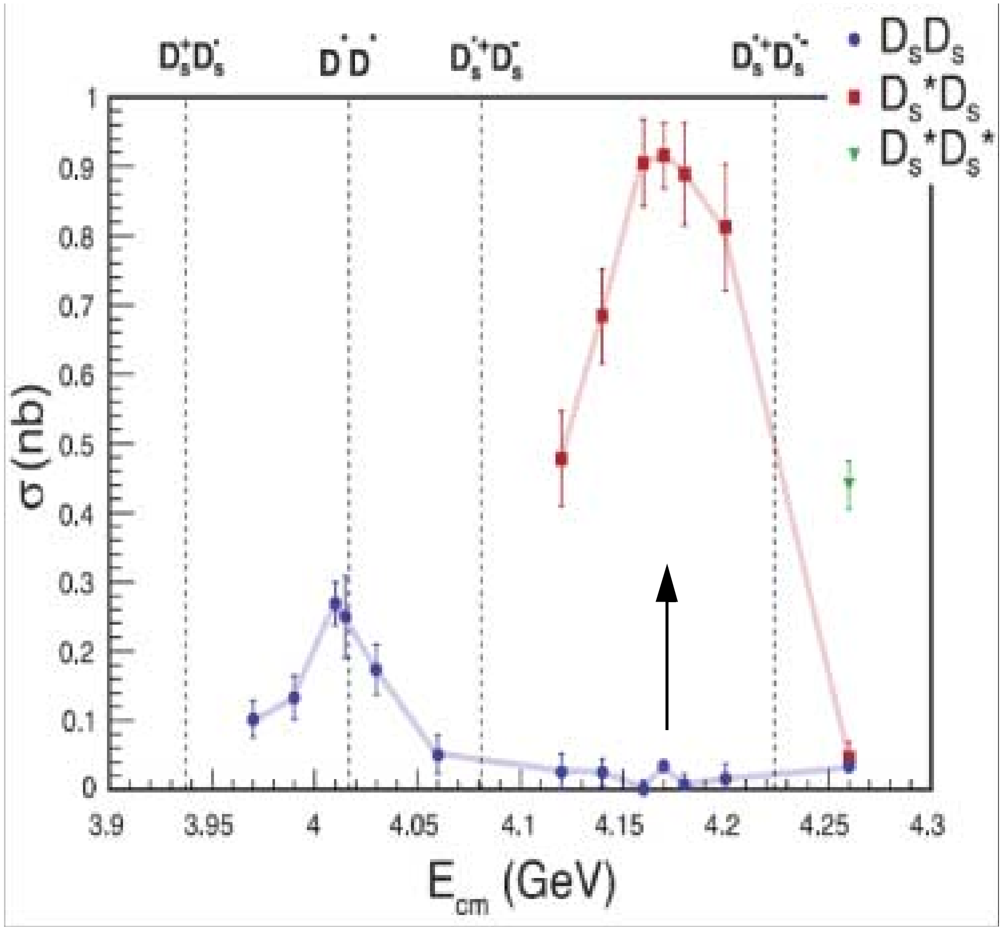


- CLEOc has the only high-precision measurement.
- Good agreement so far!

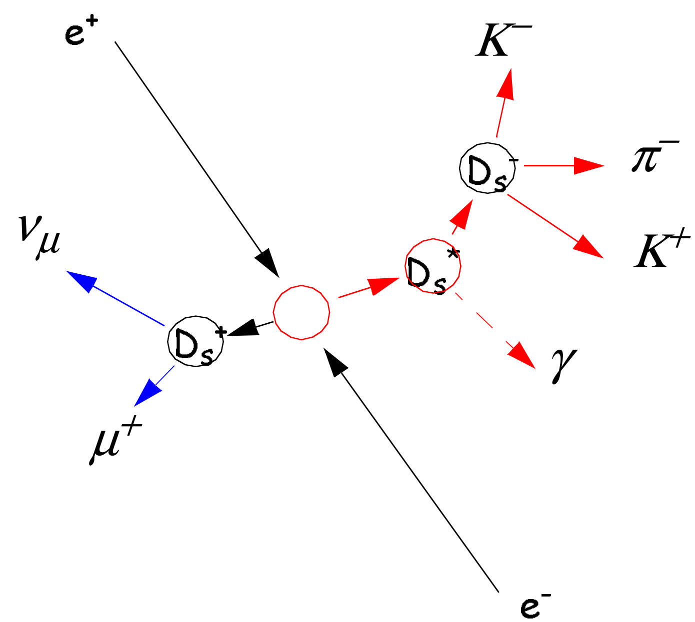
$D_s^+ \to (\text{lepton})^+ \nu$

Same motivation, but include $\tau\nu$.

Optimize D_s production

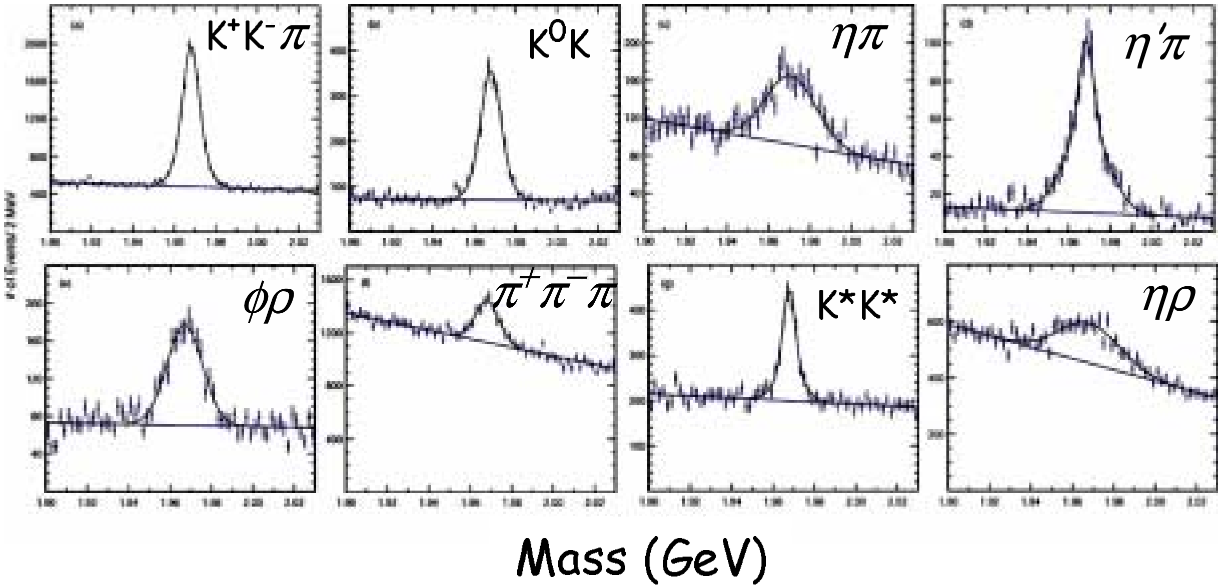


$D_sD_s^*$ dominates



8 hadronic tagging modes.

Charged D_s hadronic tags

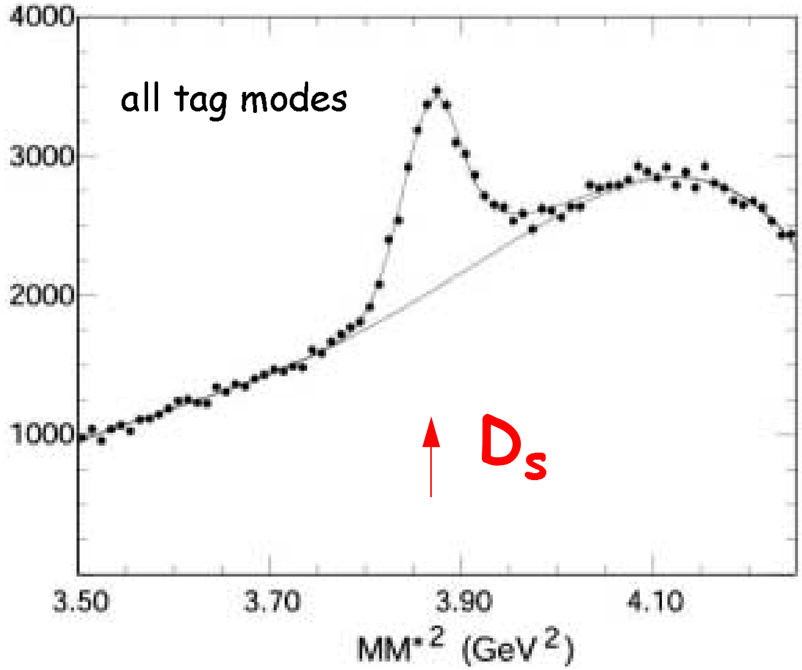


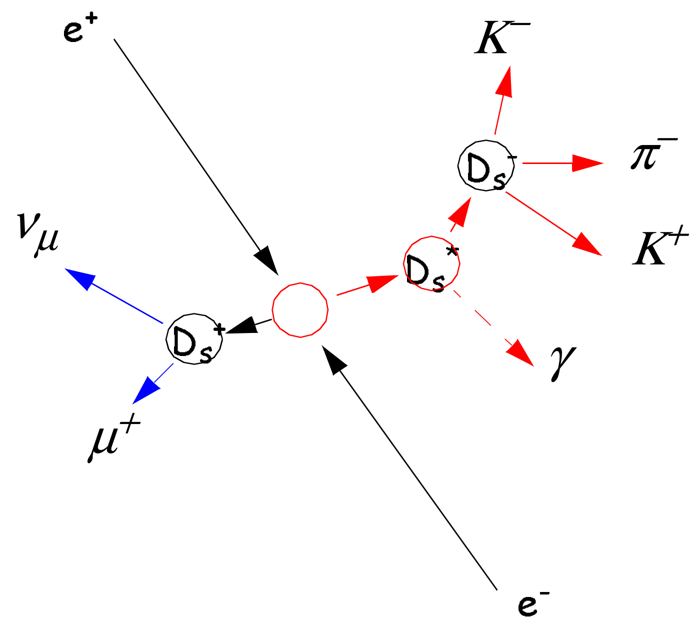
200/pb analyzed so far (preliminary).

Loose E_{tot} cut

2σ cut on D_s mass

γ association



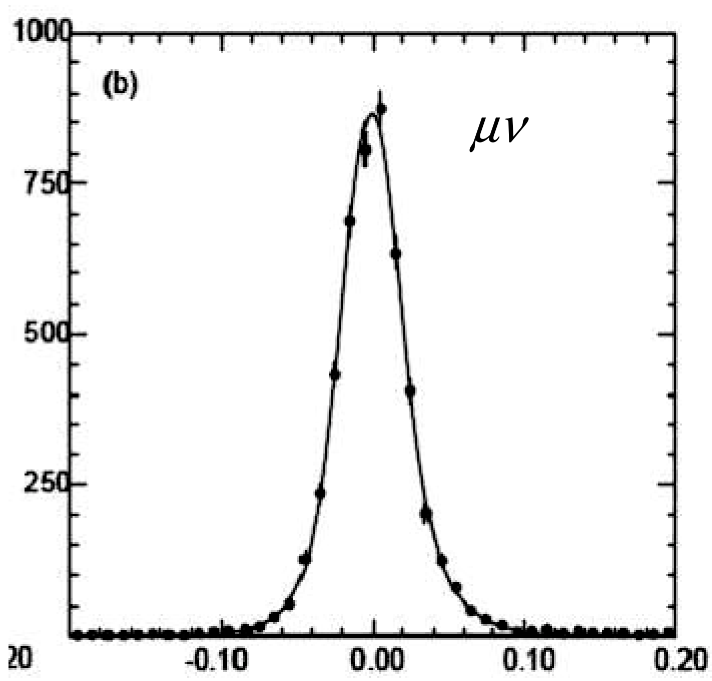


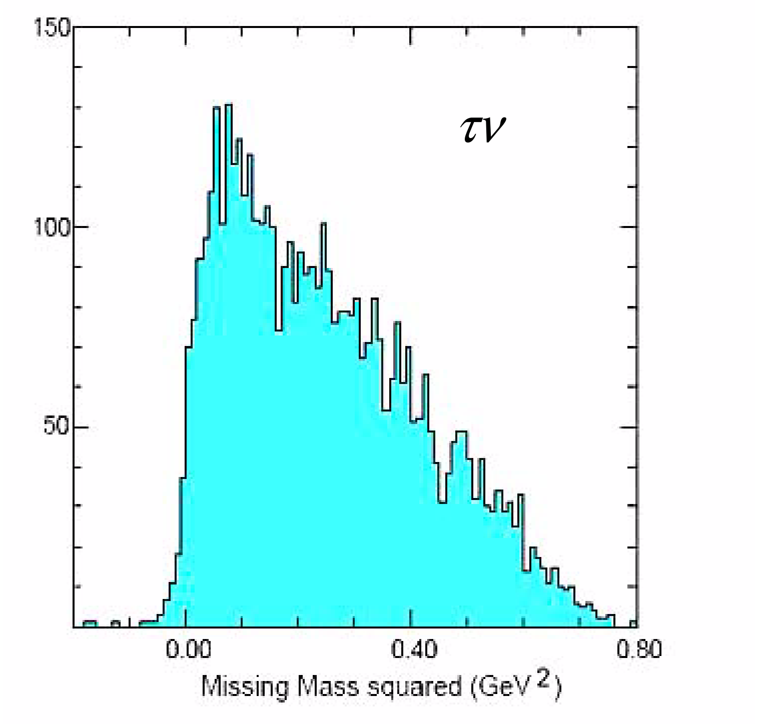
$$MM^{*2} = (E_{cm} - E_{tag} - E_{\gamma})^2 - (\vec{p}_{tag} + \vec{p}_{\gamma})^2$$

Select 3.978>MM>3.776
11880+-399 events

Kinematic fit picks best association (no cut).
Three-constraint fit

lepton decay Monte Carlo

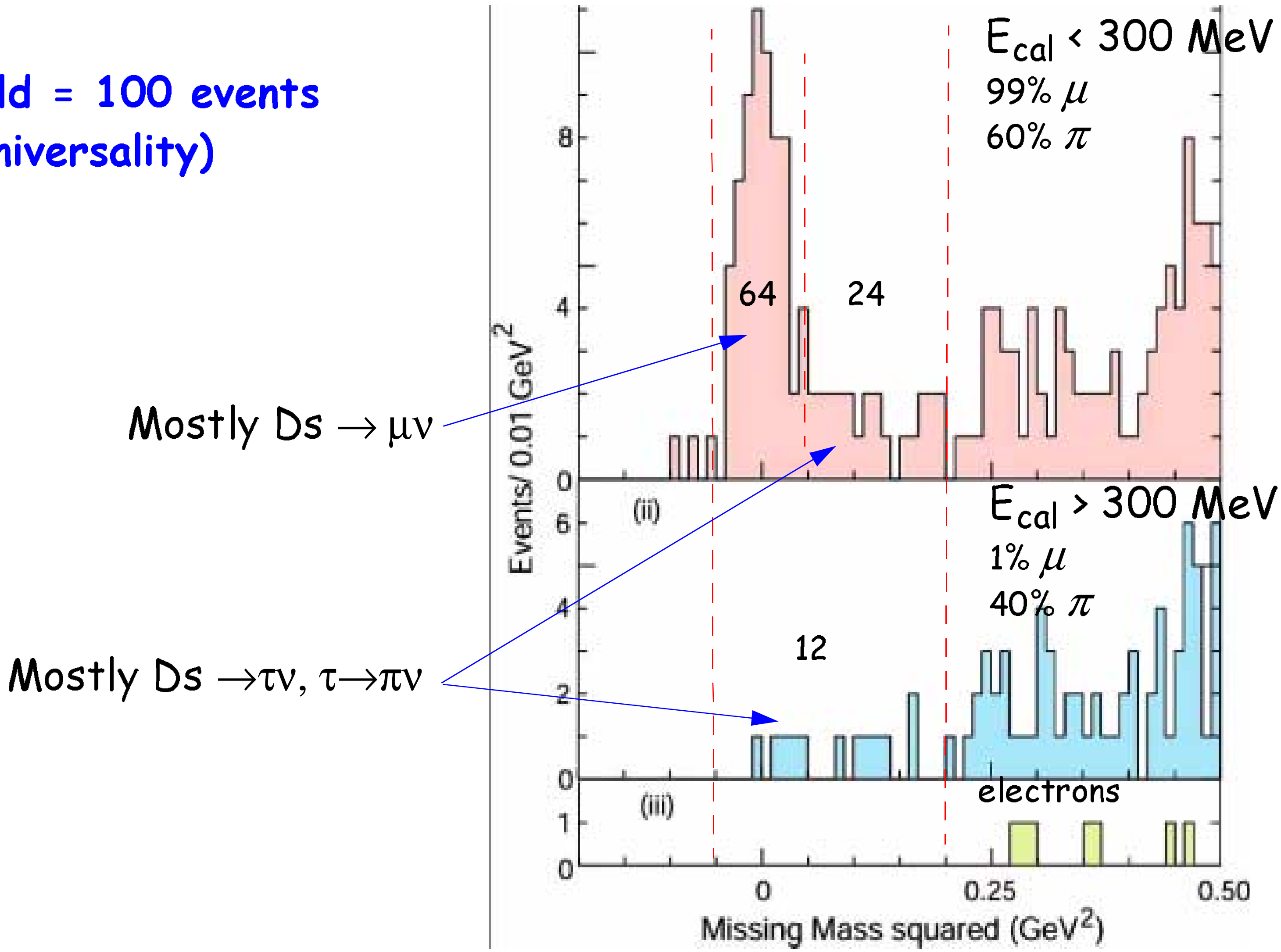




MM^2 for $\phi\pi$ tags

μ / τ data separation

Total yield = 100 events (lepton universality)



D_s decay constant

Exp.	Mode	$\mathcal{B}$	$\mathcal{B}_{\phi\pi}$ (%)	$f_{D_s^+}$ (MeV)
CLEOc preliminary				$f_{Ds} = (280 \pm 12 \pm 6) MeV$
CLEO [30]	$\mu^+\nu$	$(6.2 \pm 0.8 \pm 1.3 \pm 1.6)10^{-3}$	3.6±0.9	$273 \pm 19 \pm 27 \pm 33$
BEATRICE [31]	$\mu^+\nu$	$(8.3 \pm 2.3 \pm 0.6 \pm 2.1)10^{-3}$	3.6±0.9	$315 \pm 43 \pm 12 \pm 39$
ALEPH [32]	$\mu^+\nu$	$(6.8 \pm 1.1 \pm 1.8)10^{-3}$	3.6±0.9	$285 \pm 19 \pm 40$
ALEPH [32]	$\tau^+\nu$	$(5.8 \pm 0.8 \pm 1.8)10^{-2}$		
OPAL [34]	$\tau^+\nu$	$(7.0 \pm 2.1 \pm 2.0)10^{-2}$		$286 \pm 44 \pm 41$
L3 [33]	$\tau^+\nu$	$(7.4 \pm 2.8 \pm 1.6 \pm 1.8)10^{-2}$		$302 \pm 57 \pm 32 \pm 37$
BaBar [36]	$\mu^+\nu$	$(6.5 \pm 0.8 \pm 0.3 \pm 0.9)10^{-3}$	4.8±0.5±0.4	$279 \pm 17 \pm 6 \pm 19$

Note sys errors

Best measurement to date.

D_s decay constant

CLEOc preliminary, 200/pb:

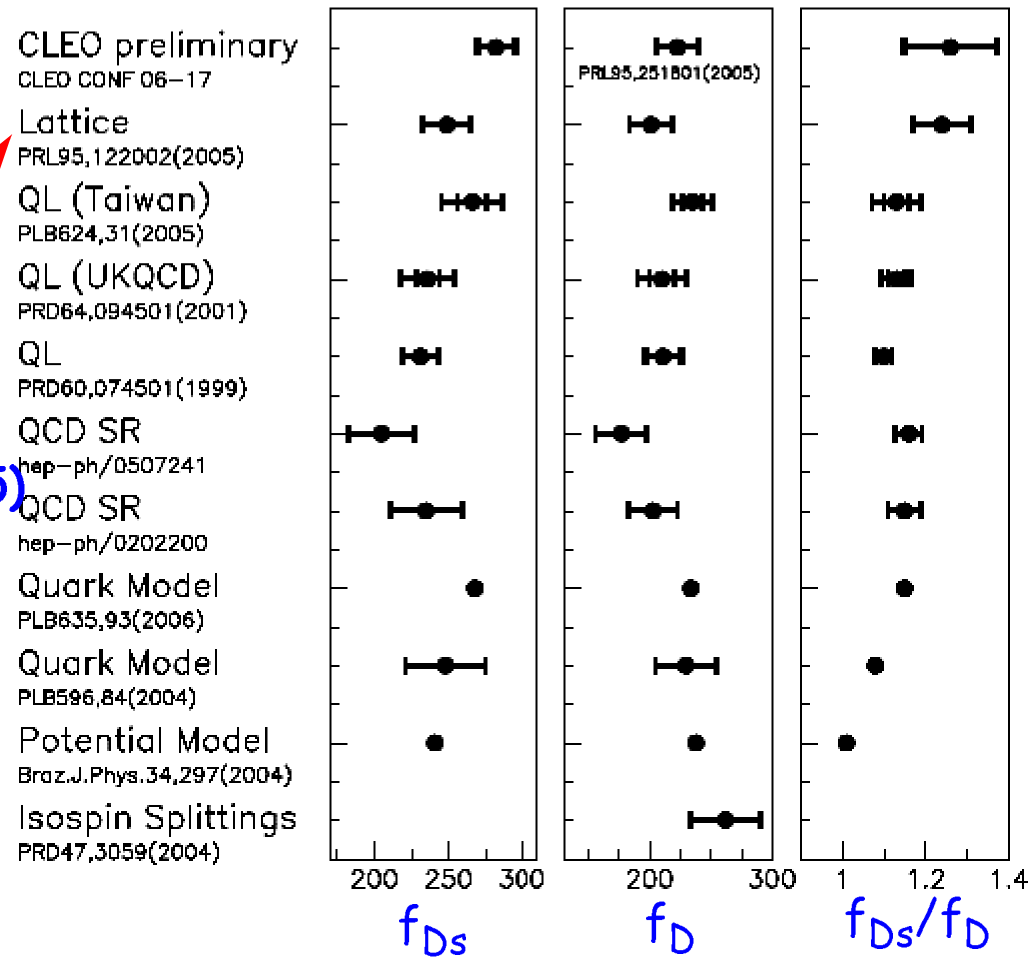
$$f_{Ds} = (280 \pm 12 \pm 6)MeV$$

$$f_{Ds}/f_D = (1.26 \pm 0.11 \pm 0.03)MeV$$

lattice:

FNAL/MILC, PRL 95, 122002 (2005)

$$f_{Ds}/f_D = (1.24 \pm 0.01 \pm 0.07)MeV$$



- *Good agreement so far!*

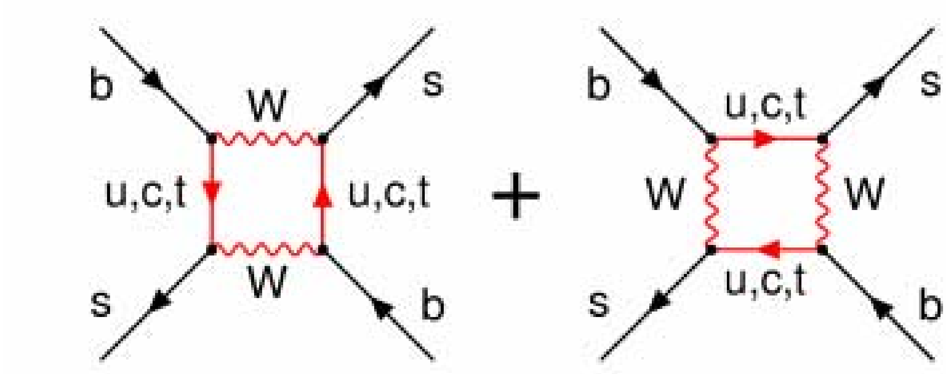
CKM Impact

Constraints often depend on loop or box diagrams:

B mixing rate,

$$\Delta m_d \propto f_B^2 |V_{td}|^2 |V_{tb}|^2$$

~1% uncertainty



Adding B_s gives,

$$\frac{\Delta m_d}{\Delta m_s} \propto \frac{f_B^2}{f_{Bs}^2} \frac{|V_{td}|^2}{|V_{ts}|^2}$$

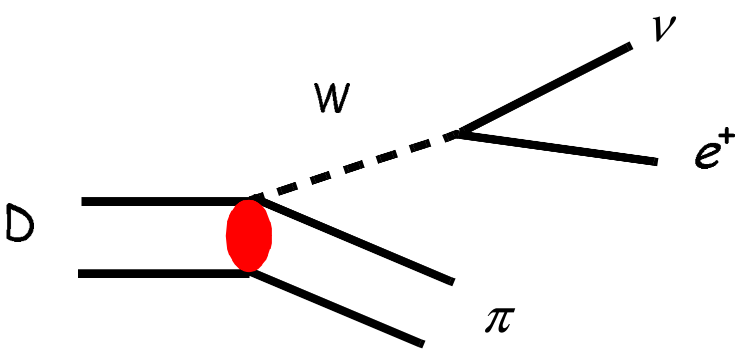
~12% lattice uncertainty dominates CKM determination.

~4% uncertainty

B semileptonic decay rate,

$$d\Gamma(B \to \pi e \nu) \propto |V_{ub}|^2 \left| f^{B\pi}(q^2) \right|^2$$

D semileptonic decay



Known from CKM unitarity

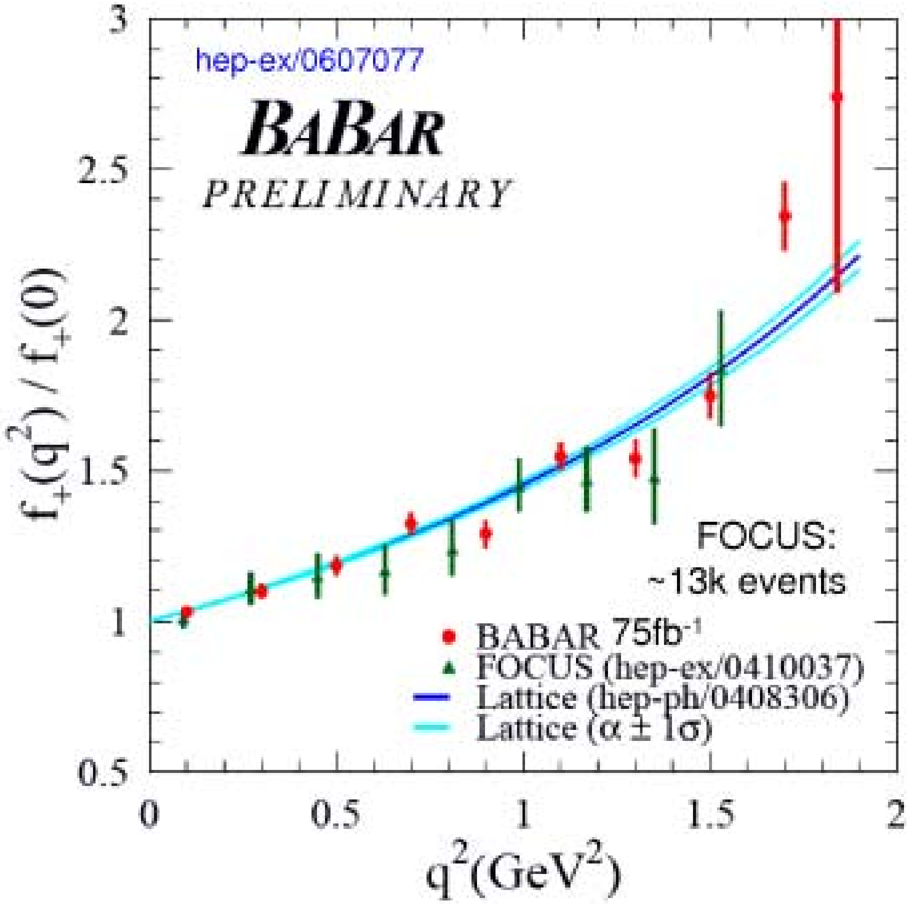
$$d\Gamma(D \to \pi e \nu) \propto |V_{cd}|^2 |f^{D\pi}(q^2)|^2$$

LQCD form factor test

HQET links D decay to B decay.

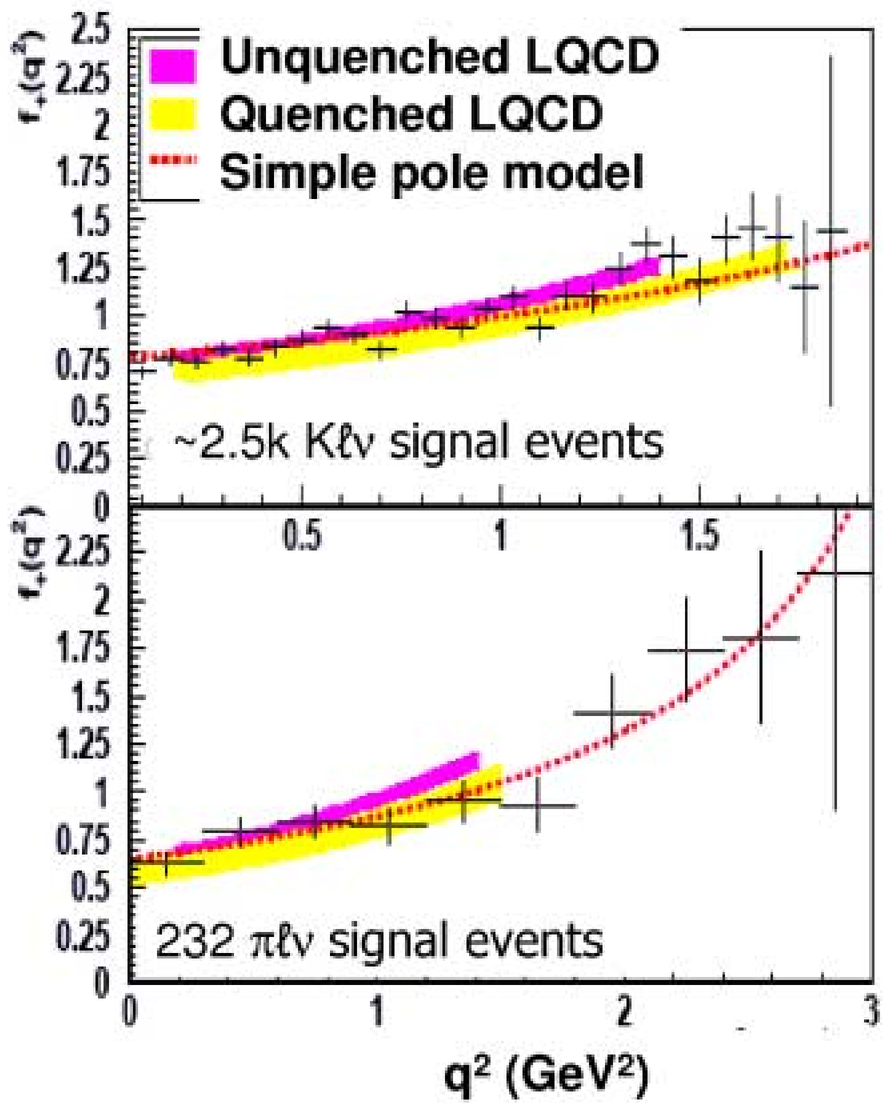
literature

Belle,BaBar,FOCUS
$D \rightarrow K,\pi\ell\nu$
form factors



PRL 97, 061804 (2006) hep-ex/0604049

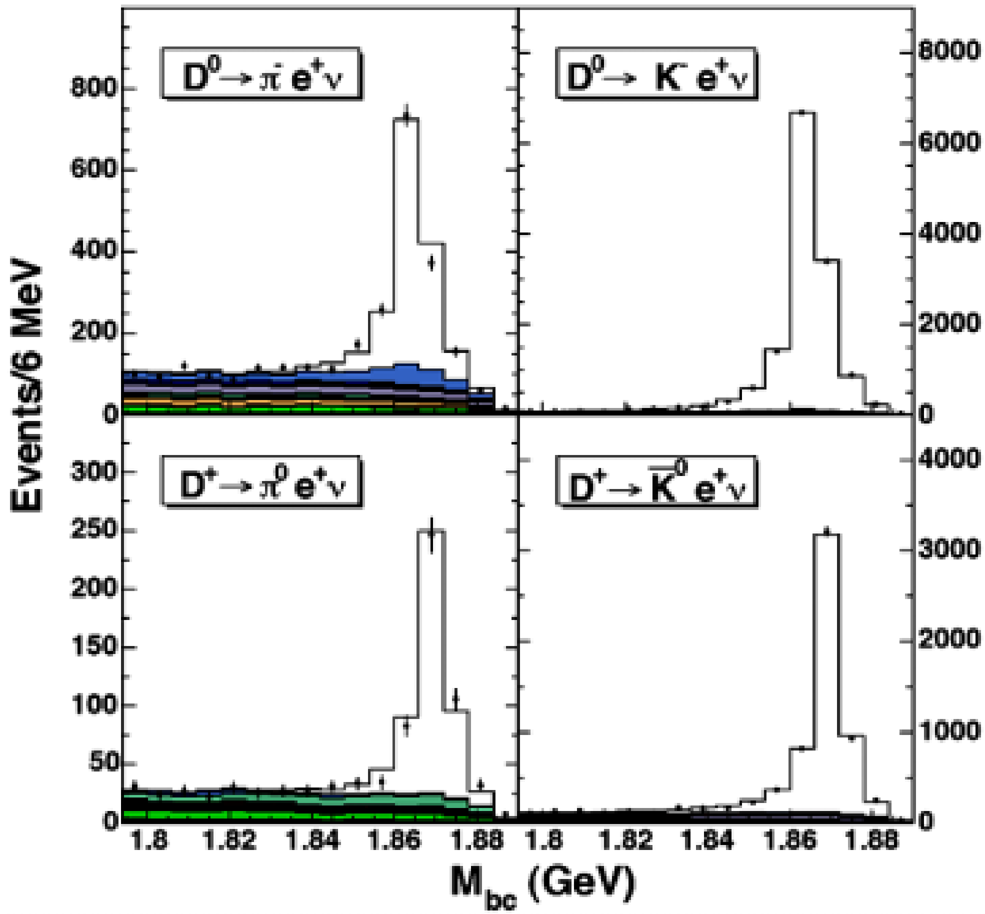
282fb^{-1}, fully reconstructed events, excellent q^2 resolution



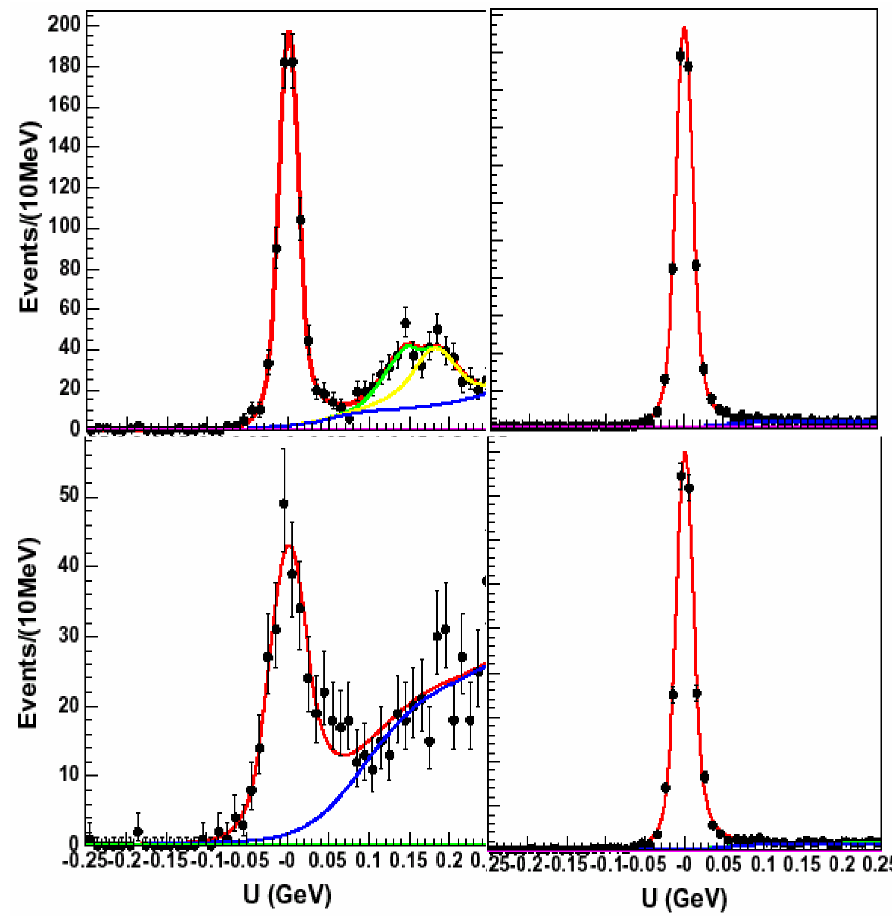
CLEOc preliminary (280/pb)

Two analysis methods (40% overlap)

neutrino reconstruction



D tag method

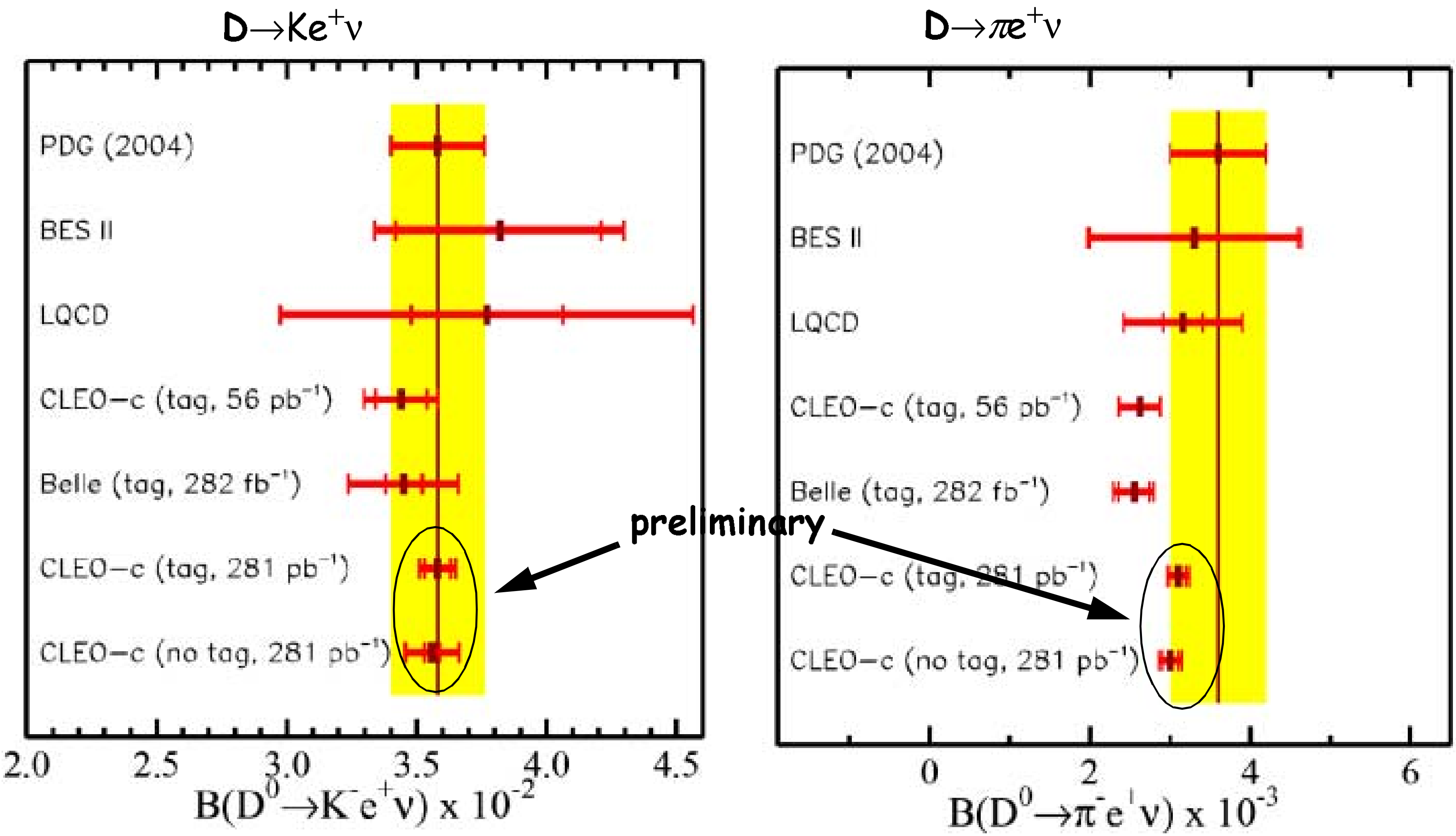


$$U = E_{miss} - |p_{miss}|$$

$$\vec{p}_{\nu} = \vec{p}_{miss} \qquad \vec{p}^{\,E}_{\nu} = \alpha \vec{p}_{miss}(E_{miss} = 0)$$

$$M^2_{bc} = E^2_{beam} - (\vec{p}_K + \vec{p}_e + \vec{p}^{\,E}_{\nu})^2$$

BR comparison

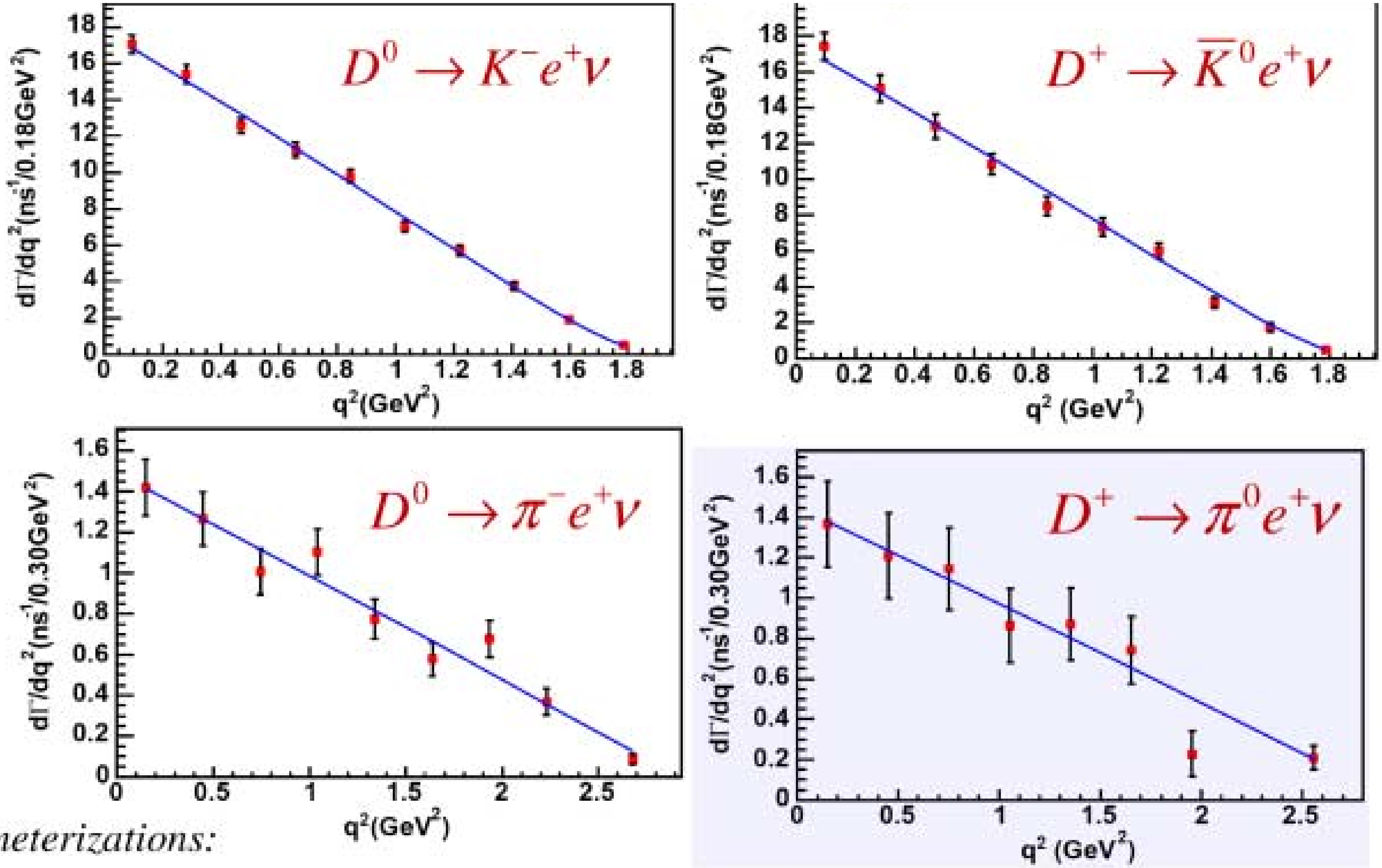


Reasonable agreement between experiments

Improvements needed for theory

tagged data

Form factor fit plots



3 FF parameterizations:

Simple Pole Model

$$f^+(q^2) = \frac{f^+(0)}{\left(1 - q^2/m_{pole}^2\right)}$$

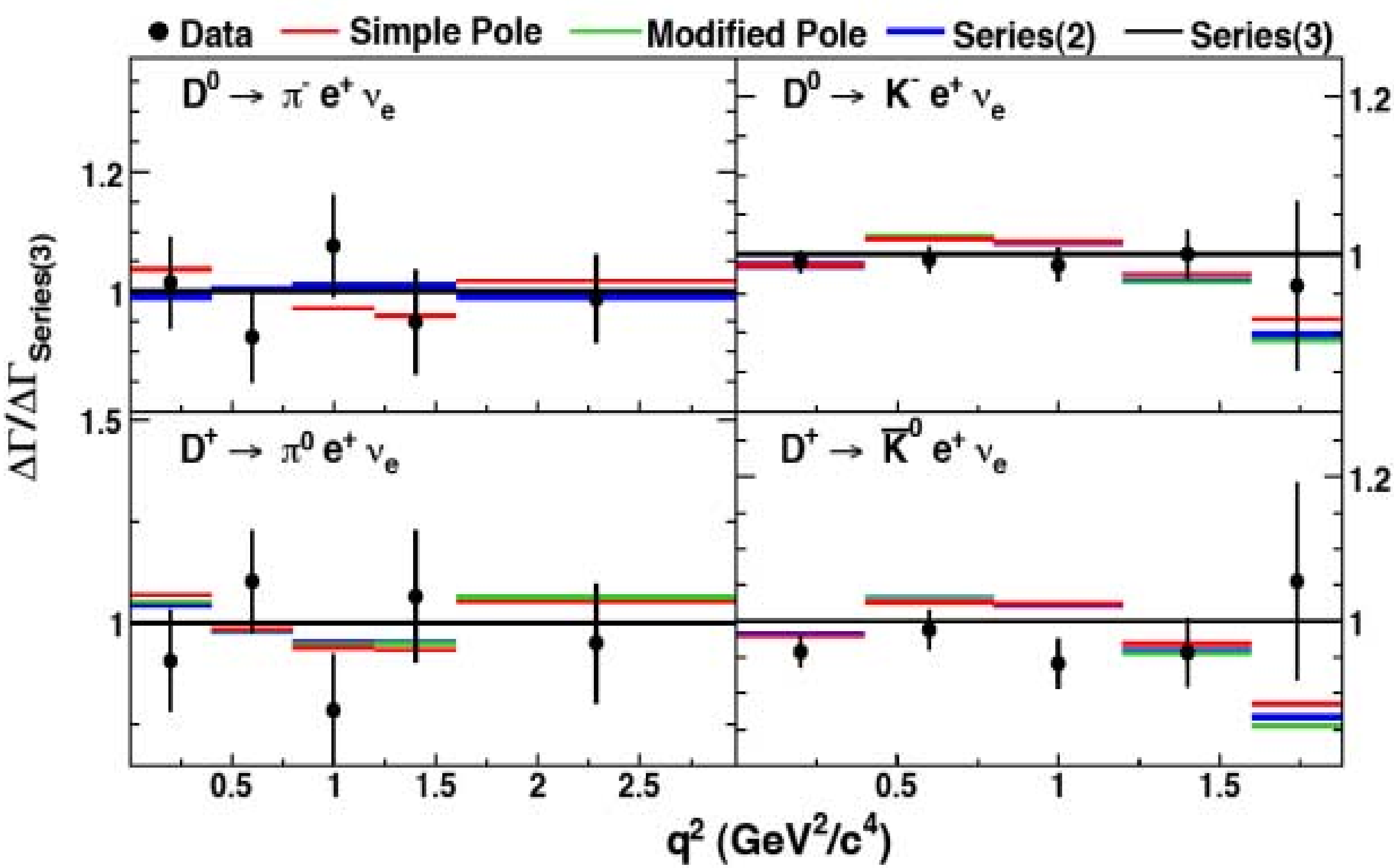
Modified Pole Model

$$f^+(q^2) = \frac{f^+(0)}{\left(1 - q^2/m_{pole}^2\right)\left(1 - \alpha q^2/m_{pole}^2\right)}$$

+ Hill series expansion (Phys. Lett. B 633, 61 (2006)))

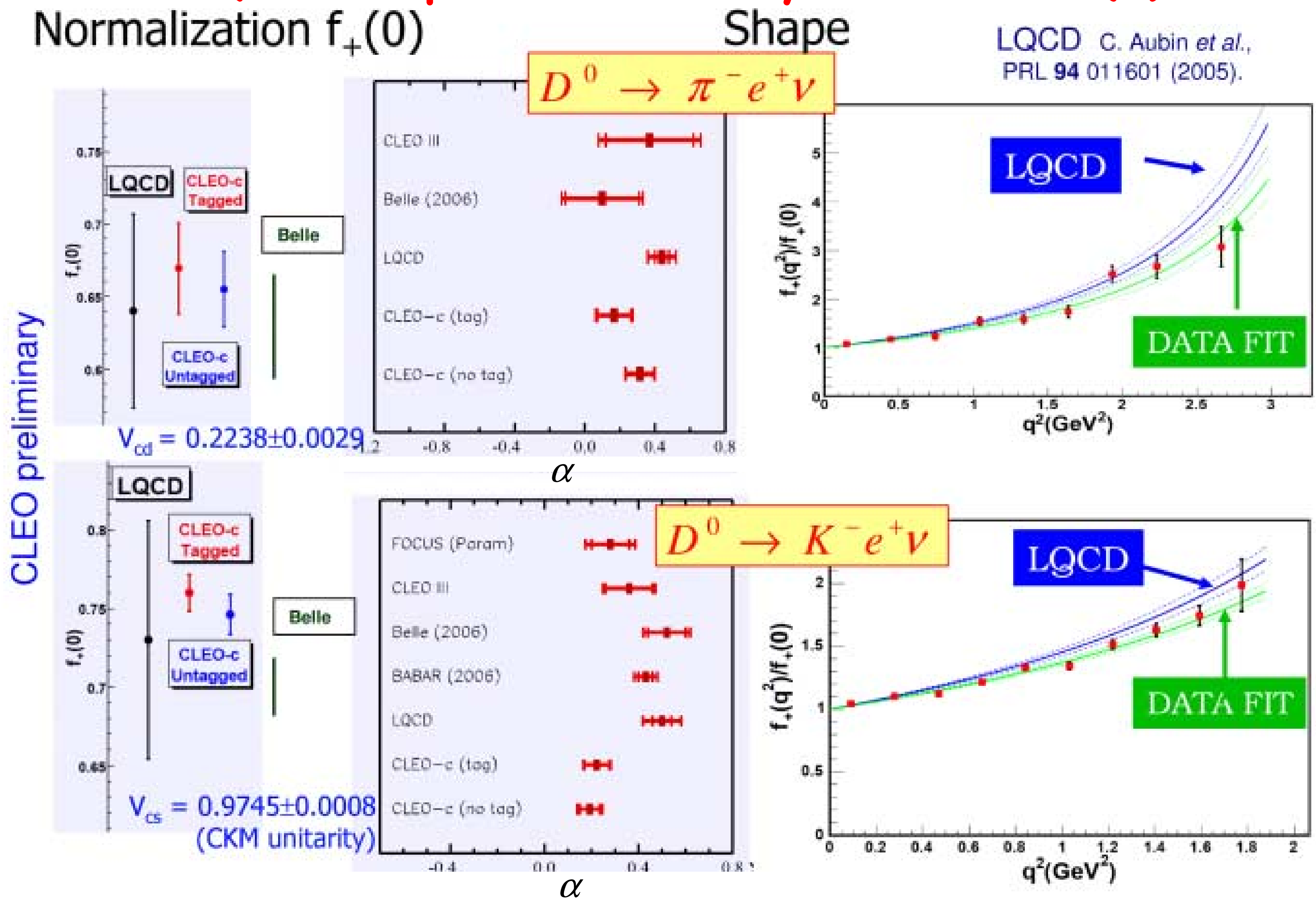
Tagged Modified Pole (BK) Model shown:

fit comparison (untagged)



Comparable agreement for all choices.

LQCD comparisonPrimarily a test of f(0)



- New data justify more theory effort

V_{cs} and V_{cd}

Decay Mode	$\lvert V_{cx}\rvert$ ± (stat) ± (syst) ± (theory)	PDG/HF Value
$D \to \pi e \nu$ (tagged)	0.234 ± 0.010 ± 0.004 ± 0.024	
$D \to \pi e \nu$ (untagged)	0.229 ± 0.007 ± 0.005 ± 0.024	0.224 ± 0.012
$D \to K e \nu$ (tagged)	1.014 ± 0.013 ± 0.009 ± 0.106	
$D \to K e \nu$ (untagged)	0.996 ± 0.008 ± 0.015 ± 0.104	0.976 ± 0.014

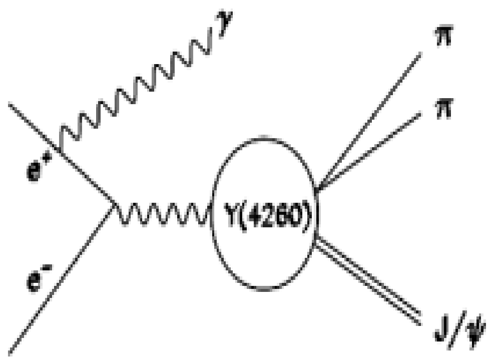
Combined preliminary f(0) data with unquenched LQCD.

Tagged and untagged results consistent (don't average!).

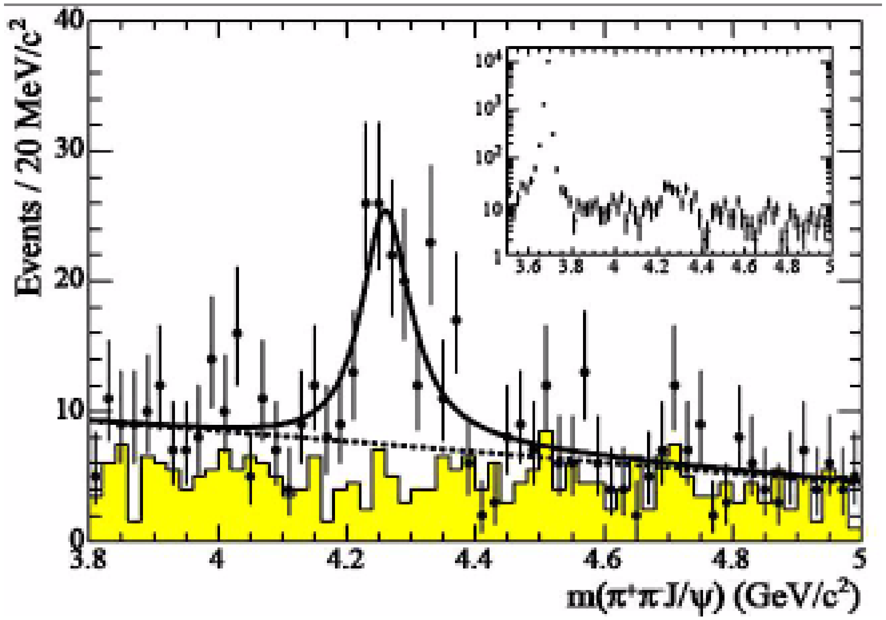
High precision: V_{cs}~2%, V_{cd}~4%, but theory~10%

Y(4260) at CLEOc

radiative return:
Y(4260)$\rightarrow \pi^+ \pi^- J/\psi$



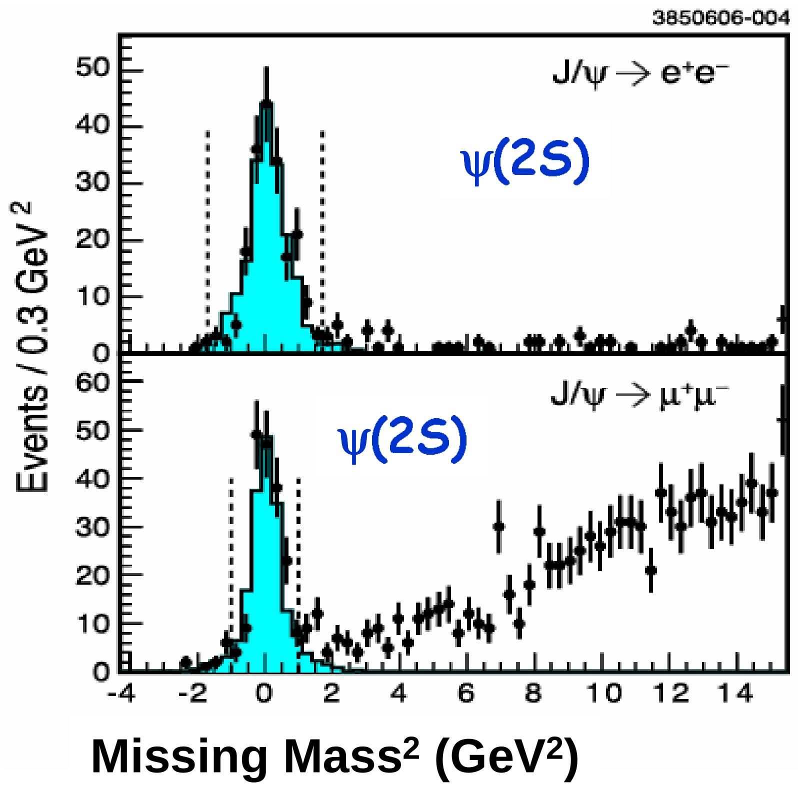
Babar, PRL 95, 142001 (2005)



$J^{PC}=1^{--}$

Confirmd by Belle.
Confirmed by CLEOc in direct production.
No bump in total cross sect.
Many proposed explanations.

CLEOc ISR (preliminary)



$Y(4260) \to \pi^+ \pi^- J/\psi$

13.3/fb CLEOIII $\Upsilon(nS)$ data

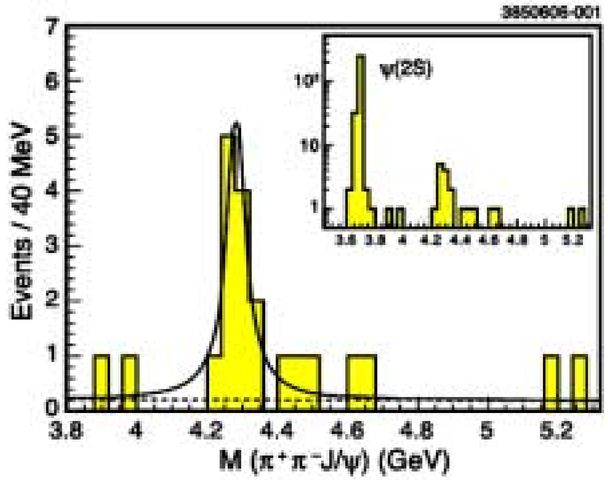
Reconstruct $J/\psi \to \mu\mu$, ee

Select ISR by $\pi\pi J/\psi$ missing mass

Very low background

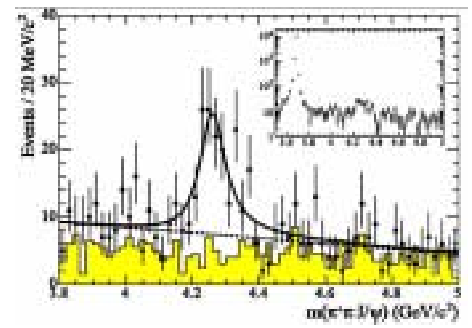
CLEOc ISR (preliminary)

CLEOc

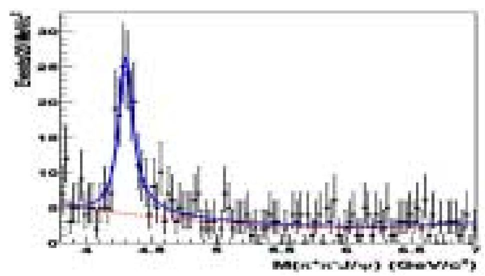


	CLEO	BABAR	Belle
N	$14^{+5.2}_{-4.2}$ (4.9σ)	$125\pm23(\sim 8\sigma)$	$165\pm24(>7\sigma)$
M	$4283^{+17}_{-16}\pm4$	$4259\pm8^{+2}_{-6}$	$4295\pm10^{+11}_{-5}$ MeV
$\Gamma =$	$70^{+40}_{-25}\pm5$	$88\pm23^{+6}_{-4}$	$133\pm26^{+13}_{-6}$ MeV

BaBar

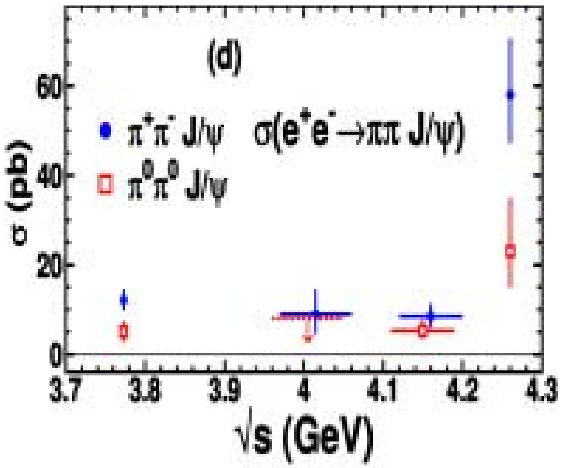


Belle preliminary



- Confirms single resonance interpretation is OK

CLEOc direct production



Open charm decay under study

PRL 96, 162003 (2006)

Channel	ε(%)	N_{sig}	N_{bgd}	σ(pb)	$B/B(\pi^+\pi^-\ J/\psi)$
$\pi^+\pi^-\ J/\psi$	38	37	2.4	$58^{+12}_{-10}\pm4$	1
$\pi^0\pi^0\ J/\psi$	22	8	0.3	$23^{+12}_{-8}\pm1$	$0.39^{+0.20}_{-0.15}\pm0.02$
$K^+K^-\ J/\psi$	21	3	0.07	$9^{+9}_{-5}\pm1$	$0.15^{+0.10}_{-0.08}\pm0.02$
$\eta\ J/\psi$	16	5	2.7	<32	<0.6
$\pi^0\ J/\psi$	22	1		<12	<0.2
$\eta'\ J/\psi$	11	0	1.5	<19	<0.3
$\pi^+\pi^-\pi^0\ J/\psi$	22	0		<7	<0.1
$\eta\eta\ J/\psi$	6	1		<44	<0.8
$\pi^+\pi^-\ \psi(2S)$	19	0		<20	<0.3
$\eta\ \psi(2S)$	15	0		<25	<0.4
$\omega\chi_{c0}$	9	11	11.5	<234	<4.0
$\gamma\chi_{c1}$	26	1	3.3	<30	<0.5
$\gamma\chi_{c2}$	27	4	3.3	<90	<1.6
$\pi^+\pi^-\pi^0\ \chi_{c1}$	9	0		<46	<0.8
$\pi^+\pi^-\pi^0\ \chi_{c2}$	9	0		<96	<1.7
$\pi^+\pi^-\ \phi$	18	7	5.5	<5	<0.1

- Some calculations are disfavored, eg. molecular and baryonium.
- Theoretical models probably too simplistic.
- M=4280 MeV is firm, so concentrate on that.

Summary

There is a resurgence in charm-physics research, due to new initiatives at CLEOc and elsewhere.

New measurements of D and D_s leptonic and semileptonic decay provide unprecedented tests of LQCD methods.

Enhanced reliability of hadronic theory will significantly reduce uncertainties in V_{cd}, V_{cs}, V_{td} and V_{ts}.

Y(4280) is well established in ISR and direct production, but no clear interpretation has emerged.