Selected topics from CLEO analyses

- Overview of the CLEO experiment
- D semileptonic decays at the $\psi(3770)$
  - Absolute Semileptonic Branching Fraction Measurements
  - Measurements of Semileptonic Form Factors
- Observation of B_s production at the $\Upsilon(5S)$

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CLEO collaboration

(Seminars at SLAC, UCSB and MIT)
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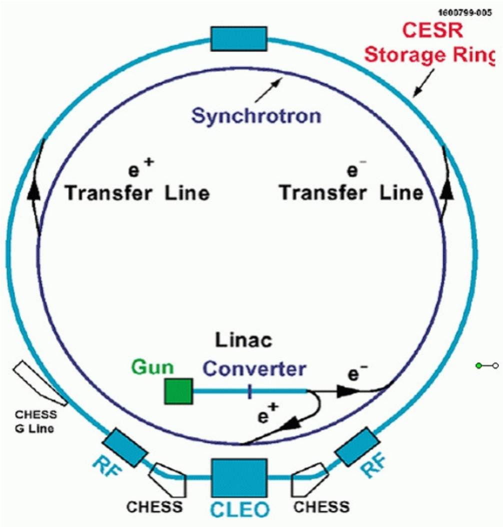
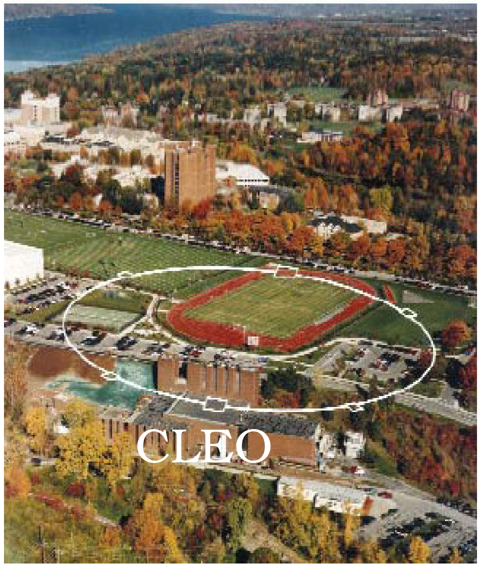
CESR and CLEO

- The CLEO experiment is located at the Cornell Electron Storage Ring (CESR), a symmetric e^+e^- collider that operated in the region of the Upsilon resonances for over 20 years:
  - Max inst luminosity achieved: $1.3\times10^{33}\ \mathrm{cm^{-2}s^{-1}}$
  - Lots of important discoveries, e.g., $\Upsilon(\mathrm{nS})$, $b\to s\gamma$, $b\to uW$.
- With the advent of BABAR at PEP II and Belle at KEK-B ($L = \sim1.5\times10^{34}\ \mathrm{cm^{-2}s^{-1}}$), CLEO became uncompetitive at the $\Upsilon(4S)$ resonance
- Several options were considered for future running:
  - B_s factory at the $\Upsilon(5S)$: NO (took a short run in 2003)
  - Charm factory at and above the $\psi(3770)$: YES
- Transition from CESR to CESR-c:
  - 12 wigglers are installed to increase synchrotron radiation/beam cooling
  - Max luminosity achieved: $\sim7\times10^{31}\ \mathrm{cm^{-2}s^{-1}}$





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- ❑ Several options were considered for future running:
  - ✓ B_s factory at the Υ(5S): NO (took a short run in 2003)
  - ✓ Charm factory at and above the ψ(3770): YES
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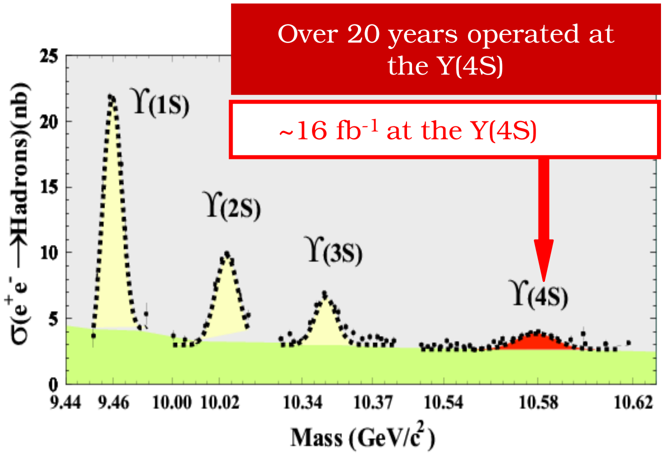
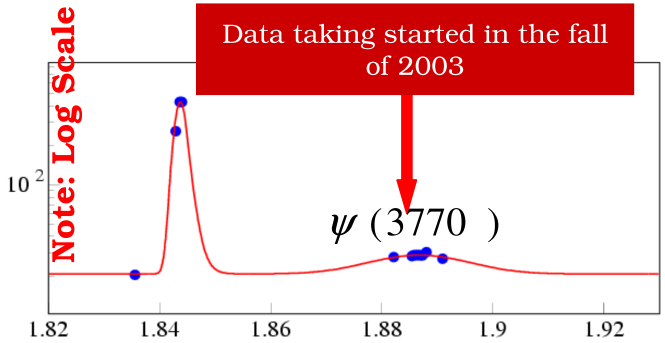
  - ✓ Max luminosity achieved: ~7×10^{31} cm^{-2}s^{-1}



Over 20 years operated at the Υ(4S)

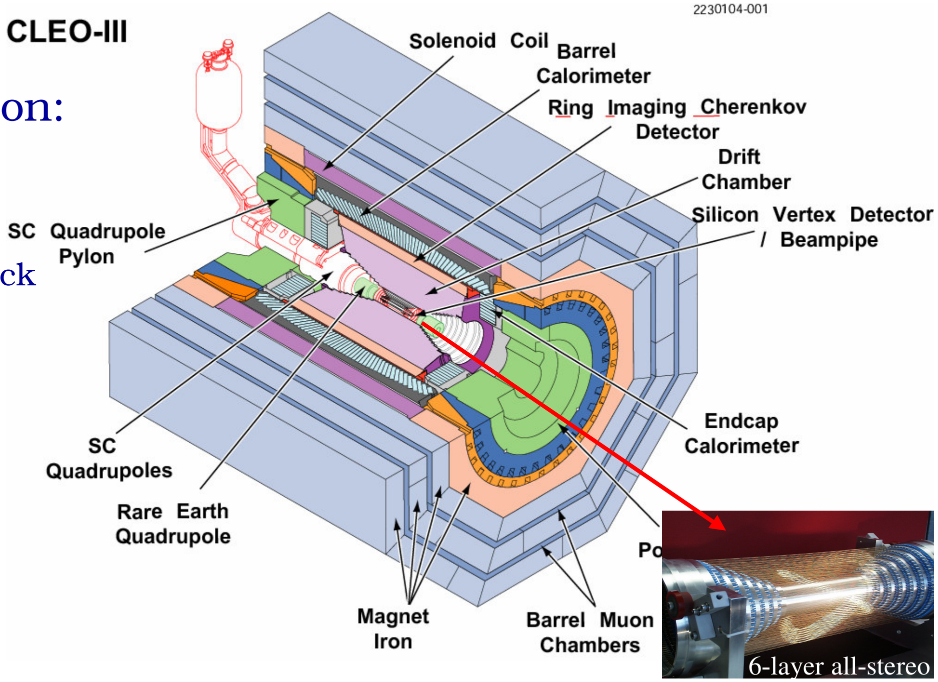
~16 fb^{-1} at the Υ(4S)

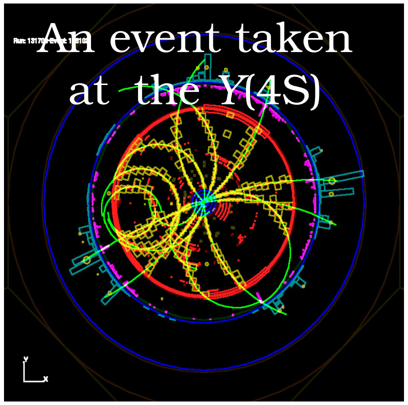


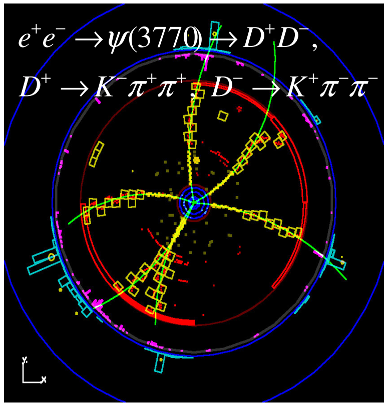
Data taking started in the fall of 2003

The CLEO detector

- The CLEO detector was developed for *B* physics at the Υ(4S). CLEO-III configuration:
  - ✓ B-field: 1.5 T
  - ✓ Gas (drift chamber): He and C_3H_8
  - ✓ Tracking: 93% of 4π, δP/P≈0.6% for a 1.0 GeV track
  - ✓ Hadron particle ID: RICH (80% of 4π) and dE/dx
  - ✓ E/M crystal calorimeter: 93% of 4π, δE/E ≈ 2.0% (4.0)% for a 1.0 GeV (100 MeV) photon
  - ✓ Muon prop. chambers at 3, 5 and 7 λ_I.
- Transition from CLEO III to CLEO-c:
  - ✓ B-field: 1.5 T → 1.0 T
  - ✓ Silicon vertex detector → low mass stereo drift chamber
- Advantages of running at ψ(3770) for charm physics:
  - ✓ Pure *DD*, no additional particles
  - ✓ σ[*DD* at ψ(3770)] = 6.4 nb [σ(cc) at Υ(4S) ~1.3 nb]
  - ✓ Low mulitplicity, high tagging efficiency (>20%)




An event taken at the Υ(4S)


$e^+e^- \to \psi(3770) \to D^+D^-$,
$D^+ \to K^-\pi^+\pi^+$; $D^- \to K^+\pi^-\pi^-$

Why a Charm Factory?

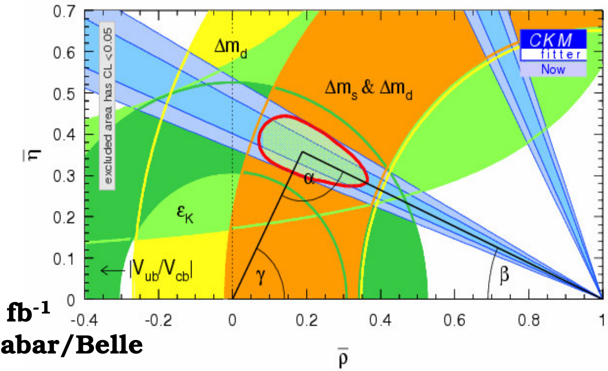
The main task of the CLEO-c open charm program:

Calibrate and Validate Lattice QCD

- ☐ Help heavy flavor physics constrain the CKM matrix now:
  - ✓ Precision tests of the Standard Model or
  - ✓ Discovery of new physics beyond the SM in *b* or *c* quark decays

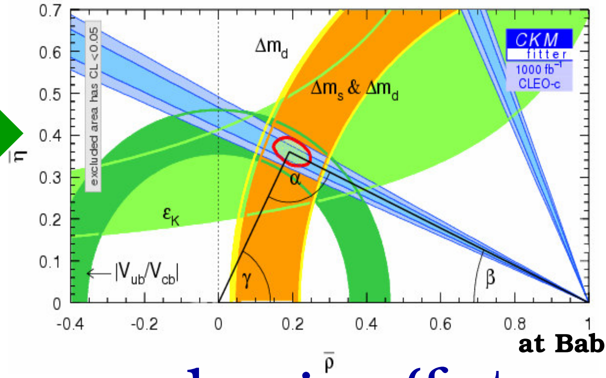
Difficulty: hadronic uncertainties complicate interpretation of exp. results

A realistic example using recent CKM status (new B_s mixing results are not included):



200 fb^{-1} at Babar/Belle

Reduce theory error on B form factors and B decay constants using tested LQCD



500 fb^{-1} at Babar/Belle

- ☐ Help LHC search for and interpret new physics (future)

Why now?

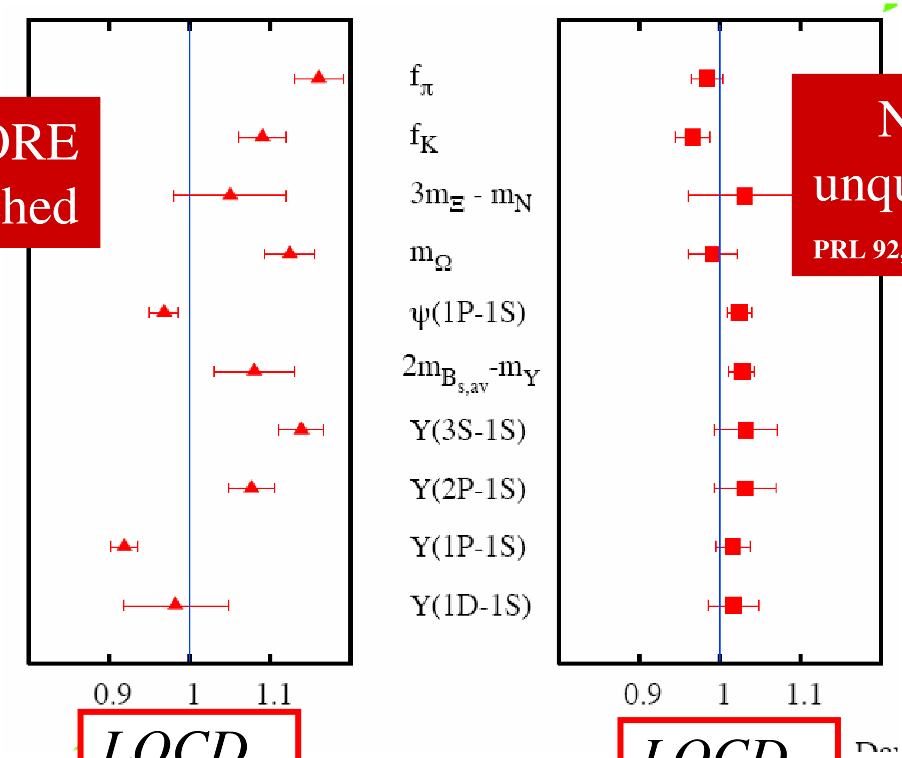
- Christine Davies opened her talk in Lisbon at EPS-2005:

“There has been a revolution in LQCD…”

LQCD demonstrated that it can reproduce a wide range of mass differences and decay constants in unquenched calculations. **These were postdictions.**

Testable **predictions** are now being made for:
Decay constants f_D and f_B;
D and *B* Semileptonic form factors

CLEO-c can test f_D and *D* semileptonic form factors



BEFORE
quenched

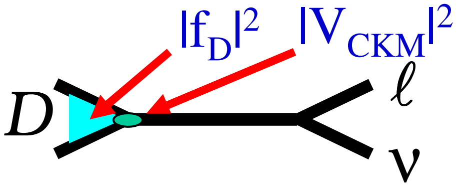
NOW
unquenched
PRL 92, 022001 (2004)

$\frac{LQCD}{exp.}$

$\frac{LQCD}{exp.}$

Examples of LQCD tests and their impact

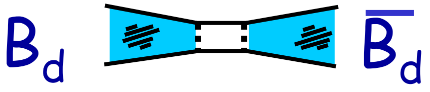
Leptonic decays ($D^+ \to \mu\nu$ and $D_s \to \mu\nu$):



$$Rate \propto f_{D_{(s)}}^2 \; |V_{cd(s)}|^2$$

Experiment ↕ **LQCD**

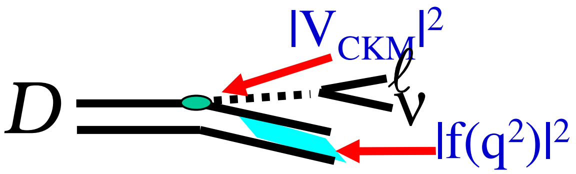
Known to < 1% from the CKM unitarity



$$Rate \propto f_{B_d}^2 \; |V_{td}V_{tb}^*|^2$$

Lattice predicts f_B/f_D and f_B/f_{Bs} with small errors ⇒ precise f_D gives precise f_B and $|V_{td}|$; f_D/f_{Ds} checks f_B/f_{Bs} and allows precise $|V_{td}|/|V_{ts}|$

Semileptonic decays ($D \to \pi e\nu$, $D \to Ke\nu$):



$$Rate \propto \left|V_{cd(s)}\right|^2 \left|f_+(q^2)\right|^2,$$
$$where \quad q^2 \equiv M^2(e\nu)$$

Test LCQD calculations of $f_+(q^2)$ in the *D* system and apply them to the *B* system for $|V_{ub}|$ and $|V_{cb}|$

Will talk about this more later

Combination of leptonic and semileptonic decays:

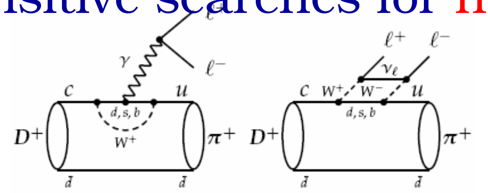
$$\Gamma(D \to \pi e\nu)/\Gamma(D \to \mu\nu) \propto f_+^2(q^2)/f_D^2$$

Test LQCD with no errors from CKM couplings

Why a Charm Factory?

Important goals of the CLEO-c physics program include:

- ☐ Mesurements of $D_{(s)}$ hadronic branching fractions and studies D Dalitz plots ⇒ Help $B_{(s)}$ physics at B-factories, Tevatron, LHC:
  - ✓ $D^0 \to K^- \pi^+$, $D^+ \to K^- \pi^+ \pi^+$ and $D_s \to \phi \pi^+$ normalize almost *all other* $D_{(s)}$ and many $B_{(s)}$ modes; reduce for systematic error for exclusive $|V_{cb}|$
  - ✓ Input for determination of angle γ (GLW, ADS, Dalitz plot methods)
- ☐ Search for new physics in rare charm phenomena that are small or negligible in the Standard Model
  - ✓ Direct CPV (mixing) is small in the SM $< 10^{-3}$ (10^{-2}) ⇒ larger DCPV or mixing is evidence for new physics
  - ✓ $D \to \pi\mu\mu$, πee, others are rare in SM $(\sim 10^{-6})$ ⇒ sensitive searches for new physics that enhances these modes



CLEO-c Data Samples

Three generations of CLEO-c analyses at the $\psi(3770)$:

- Oct-03 through Jan-04: Luminosity = 56 pb $^{-1}$

  all results are published

- Sep-04 through Apr-05: Luminosity = 225 pb^{-1}

  most analyses are on-going

- Future running: projected total Luminosity = 750 pb^{-1}

CLEO-c is also collecting data above the $D_sD_s^{\text{bar}}$ production threshold (goal 750 pb^{-1}) and lower energies at the $\psi(2S)$.

Absolute Branching Fraction Measurements of D Semileptonic Decays with 56 pb^{-1} at the $\psi(3770)$

[for more information see: PRL **95**,181801 (2005); PRL **95**,181802 (2005)]

Semileptonic decays

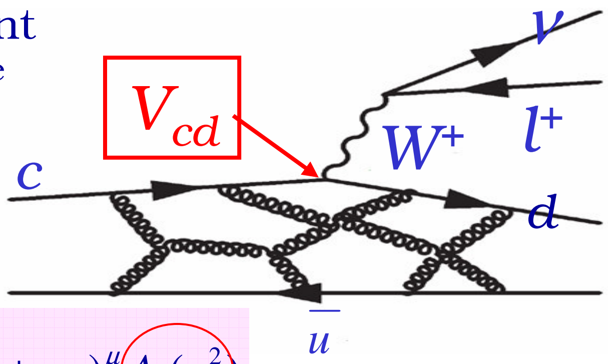
$$M(D^0 \to \pi^- l^+ \nu) = -i\frac{G_{Fermi}}{\sqrt{2}} V_{cd}\, L_\mu\, H^\mu$$

- ❑ Semileptonic decays are a principal process for measuring the CKM matrix elements:
- ❑ Strong interaction effects reside in the hadronic current only and are parameterized by form factors (assuming the charged lepton mass is zero):
  - ✓ for P to P transitions:

$$H^\mu = \boxed{f_+(q^2)}(p_i + p_f)^\mu$$

  - ✓ for P to V transitions three form factors are needed:

$$H^\mu = \frac{2ie^{\mu\nu\alpha\beta}}{M_D + m_V} e^*_\nu p_{f\alpha} p_{i\beta} \boxed{V(q^2)} - (M_D + m_V) e^{*\mu} \boxed{A_1(q^2)} + \frac{e^* \cdot q}{M + m_V}(p_i + p_f)^\mu \boxed{A_2(q^2)}$$



- ❑ The theory must predict the absolute normalization of form factors for the CKM matrix element measurements:

$$\Gamma(D^0 \to \pi^- e^+ \nu) = \frac{B(D^0 \to \pi^- e^+ \nu)}{\tau(D^0)} = \gamma\, |V_{cd}|^2 \quad \Rightarrow \quad \frac{\delta V_{cd}}{V_{cd}} = \sqrt{\left(\frac{\delta\Gamma}{2\Gamma}\right)^2 + \left(\frac{\delta\gamma}{2\gamma}\right)^2}$$

theory

experiment

- ❑ In charm semileptonic decays $|V_{cs}|$ and $|V_{cd}|$ are tightly constrained by the unitarity of the CKM matrix. Therefore measurements of charm semileptonic decay rates and form factors rigorously test the theory (e.g., LQCD and LCSR).
- ❑ Tested form factors can be used for V_{ub} determination from exclusive B semil decays

Reconstruction at the $\psi(3770)$

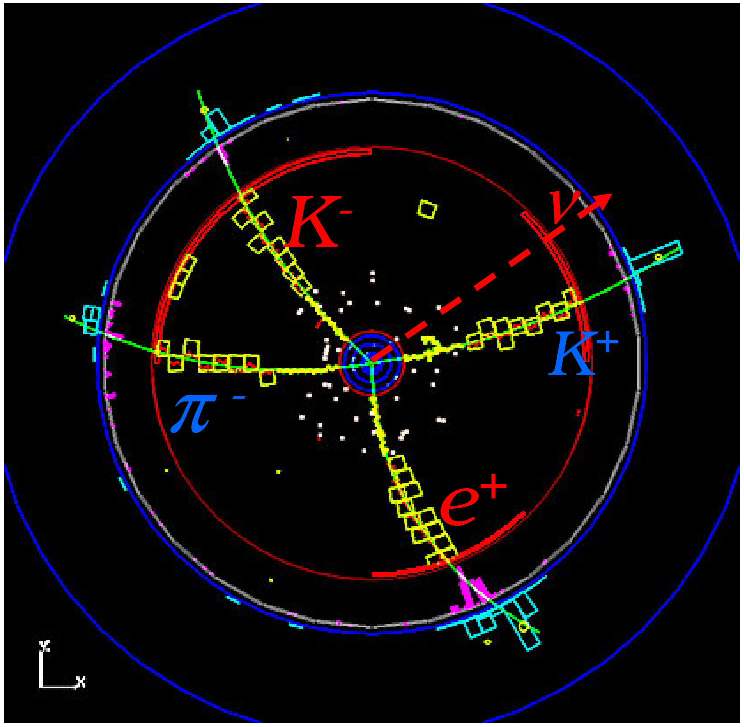
- The $\psi(3770)$ is about 40 MeV above the DD pair threshold ($\vec{P}_D = -\vec{P}_{\bar{D}}$)
- One of the two D's is reconstructed in a hadronic "tag" mode (e.g., $K^+\pi^-$). Two key variables:
  - ✓ $M_{bc} = \sqrt{E^2_{beam} - P^2_{candidate}}$
  - ✓ $\Delta E = E_{beam} - E_{candidate}$
- From the remaining tracks and showers the semileptonic decay is reconstructed (e.g., $K^-e^+\nu$)
- $U \equiv E_{miss} - |\boldsymbol{P}_{miss}|$ is used to identify signal, where E_{miss} and $\boldsymbol{P}_{miss}$ are the missing energy and momentum approximating the neutrino E and $\boldsymbol{P}$. The signal peaks at zero in U.
- $$B^{semilep} = \frac{N_U^{semilep} / \varepsilon_{signal}}{N^{tag}_{M_{bc}} / \varepsilon_{tag}} = \frac{N_U^{semilep}}{<\varepsilon_{semilep}> N^{tag}_{M_{bc}}}$$

  from Fits to $\boldsymbol{U}$

  from Fits to $\boldsymbol{M_{bc}}$
- Full event reconstruction allows to measure any kinematic variable with no ambiguities and with high precision

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

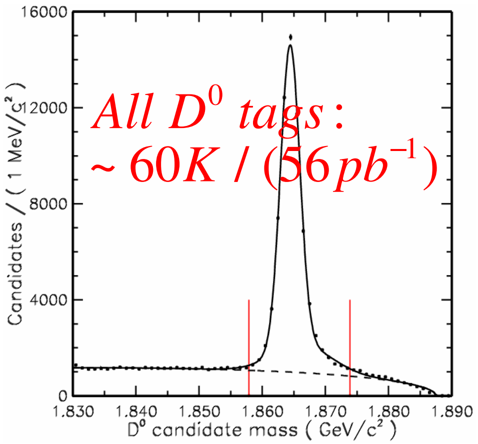
$$\overline{D}^0 \to K^+\pi^-, \; D^0 \to K^- e^+ \nu$$

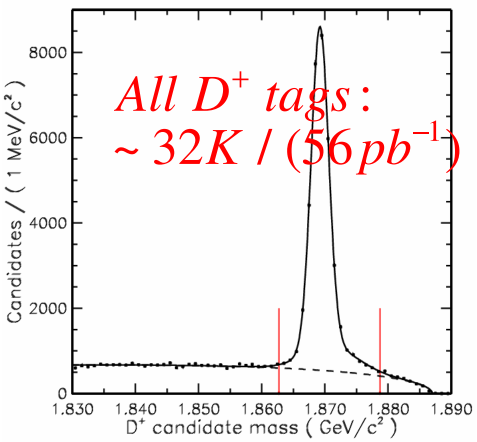


D^0 and D^+ tag yields in 56 pb^{-1} of DATA

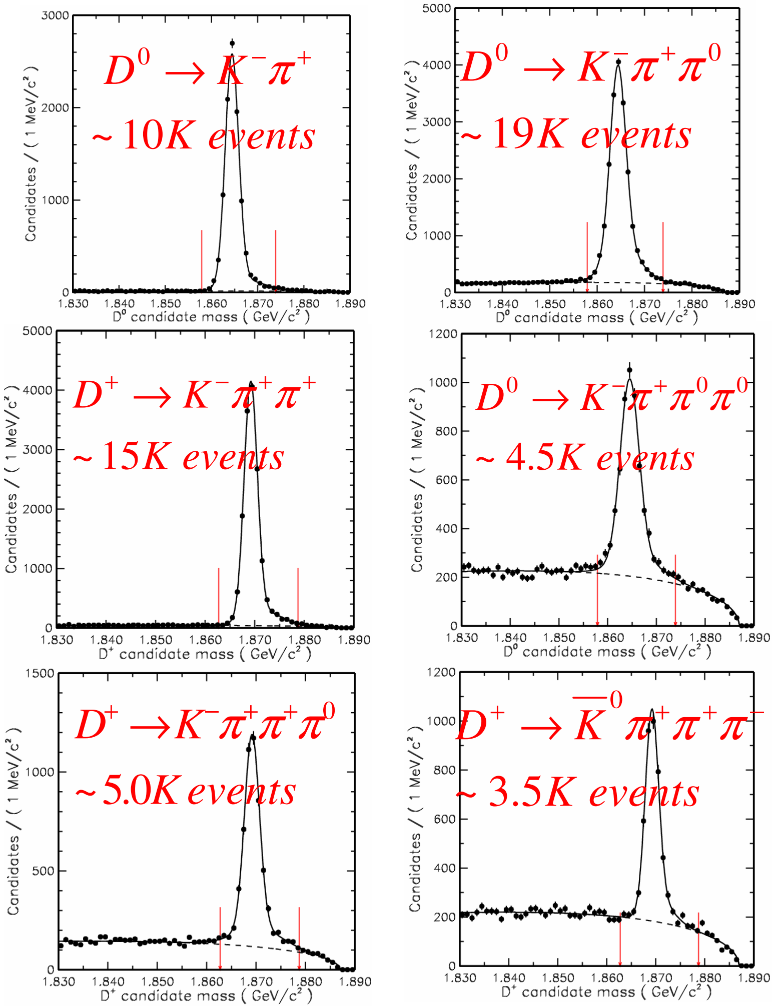
D^0 Decay Mode	$\mathcal{B}$ (%) PDG
$D^0 \to K^-\pi^+$	(3.80 ± 0.09)
$D^0 \to K^-\pi^+\pi^0$	(13.1 ± 0.9)
$D^0 \to K^-\pi^+\pi^0\pi^0$	
$D^0 \to K^-\pi^+\pi^+\pi^-$	(7.46 ± 0.31)
$D^0 \to \overline{K}^0\pi^0$	(2.28 ± 0.22)
$D^0 \to \overline{K}^0\pi^+\pi^-$	(5.92 ± 0.35)
$D^0 \to \overline{K}^0\pi^+\pi^-\pi^0$	(10.8 ± 1.3)
$D^0 \to K^+K^-$	(0.41 ± 0.01)

D^+ Decay Mode	$\mathcal{B}$ (%) PDG
$D^+ \to \overline{K}^0\pi^+$	(2.77 ± 0.18)
$D^+ \to K^-\pi^+\pi^+$	(9.1 ± 0.6)
$D^+ \to \overline{K}^0\pi^+\pi^0$	(9.7 ± 3.0)
$D^+ \to K^-\pi^+\pi^+\pi^0$	(6.4 ± 1.1)
$D^+ \to \overline{K}^0\pi^+\pi^+\pi^-$	(7.0 ± 0.9)
$D^+ \to K^+K^-\pi^+$	(0.9 ± 0.1)





Examples of M_{bc} fits for in the data

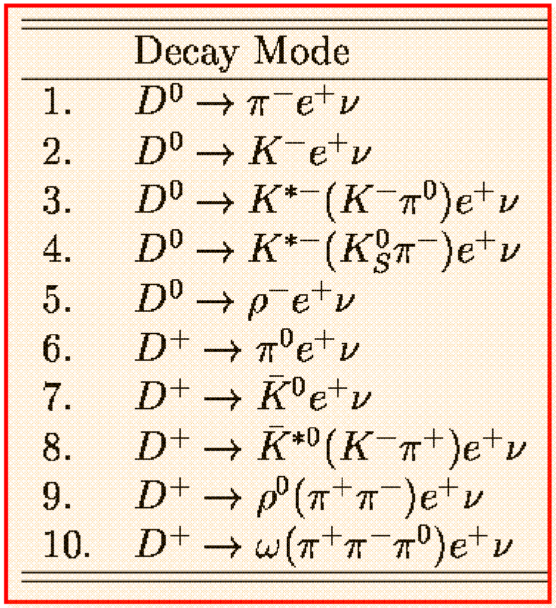


~30% event tagging efficiency

~20% event tagging efficiency

Tagging creates a **beam of *D* mesons** with known momentum

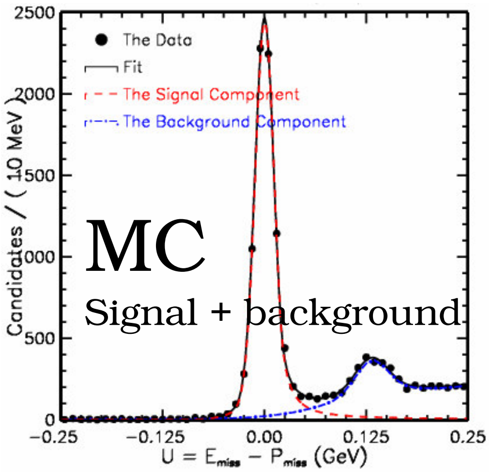
Quick overview of selection criteria

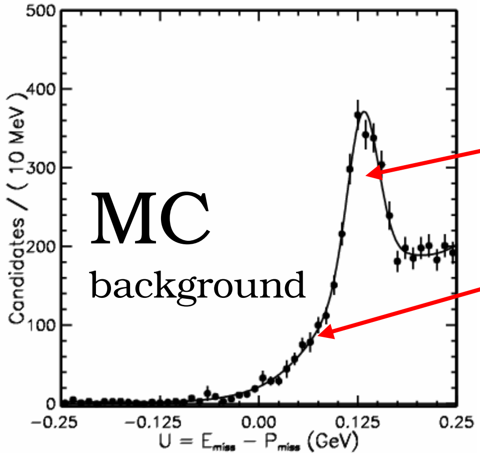


	Decay Mode
1.	$D^0 \to \pi^- e^+ \nu$
2.	$D^0 \to K^- e^+ \nu$
3.	$D^0 \to K^{*-}(K^- \pi^0) e^+ \nu$
4.	$D^0 \to K^{*-}(K^0_S \pi^-) e^+ \nu$
5.	$D^0 \to \rho^- e^+ \nu$
6.	$D^+ \to \pi^0 e^+ \nu$
7.	$D^+ \to \bar{K}^0 e^+ \nu$
8.	$D^+ \to \bar{K}^{*0}(K^- \pi^+) e^+ \nu$
9.	$D^+ \to \rho^0(\pi^+ \pi^-) e^+ \nu$
10.	$D^+ \to \omega(\pi^+ \pi^- \pi^0) e^+ \nu$

- ☐ Semileptonic modes listed in the table are reconstructed
- ☐ Electron identification (muons are not used):
  - ✓ Likelihood function built from E/P, dE/dX and RICH information (~95% efficient above 300 MeV with fake rates below ~0.2%)
  - ✓ Bremsstrahlung photons for electrons are recovered
- ☐ Hadron identification is based on dE/dx (all momenta) and RICH (above 700 MeV)
- ☐ K^*, ρ, and ω have 100, 150 and 20 MeV mass window cuts respectively
- ☐ Events with extra tracks are vetoed
- ☐ The crossing angle is accounted for and the 4-mometum of D is approximated by $(E_{beam}, -\sqrt{E_{beam}^2 - m_D^2}\,\hat{p}_{D\,tag})$
- ☐ One entry per U plot per D tag mode is chosen based on final state hadron masses
- ☐ Semileptonic decays peak at zero in $U \equiv E_{miss} - |\boldsymbol{P}_{miss}|$

Example for $D^0 \to \pi^- e^+ \nu$



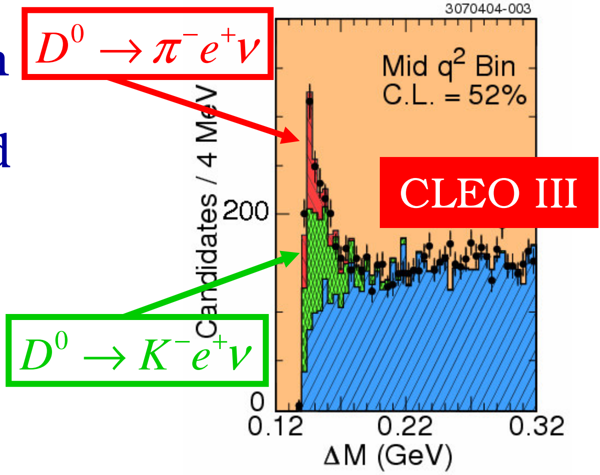


Main background sources:

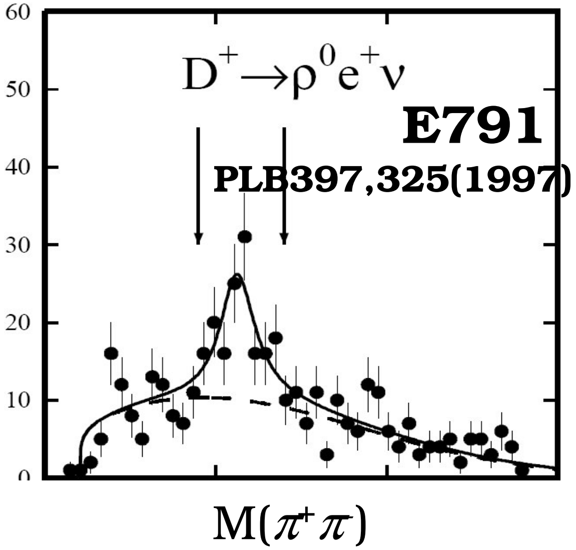
$D^0 \to K^- e^+ \nu$

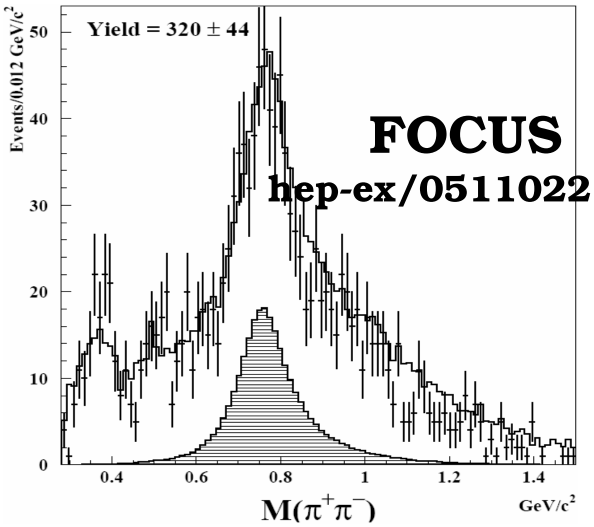
$D^0 \to \rho^- (\pi^- \pi^0) e^+ \nu$

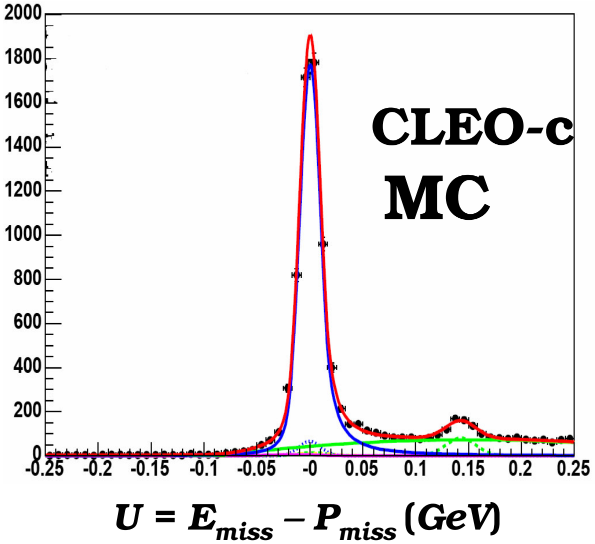
- Background is small and peaks outside the signal region (kinematic separation)
- Most background comes from cross-feed among *D* semileptonic decays
- In other experimental configurations the momentum of the parent *D* meson is unmeasured, which leads to poorer separation between signal and background
- For example in (CLEO, PRL **94**, 011802 (2005)) to reduce background $D^0 \to \pi^- e^+ \nu$ is tagged with π_{slow} : $D^{*+} \to D^0 \pi_{slow}$
- Fits are made to $\Delta M \equiv M(D^{*+}) - M(D^0)$ in bins of q^2



Example for $D^+ \to \rho^0 e^+ \nu$





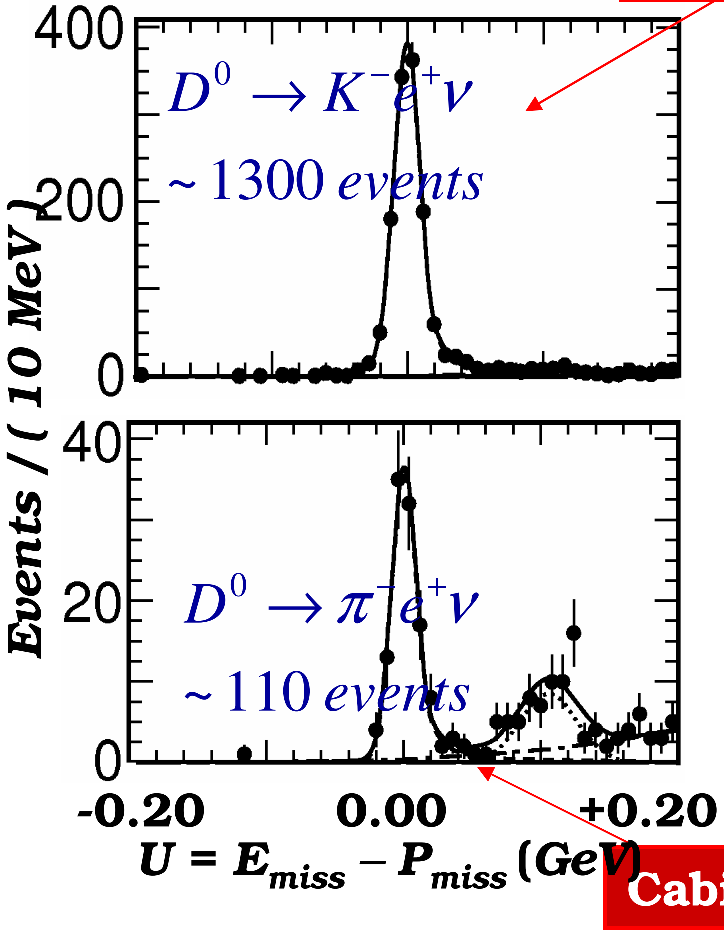


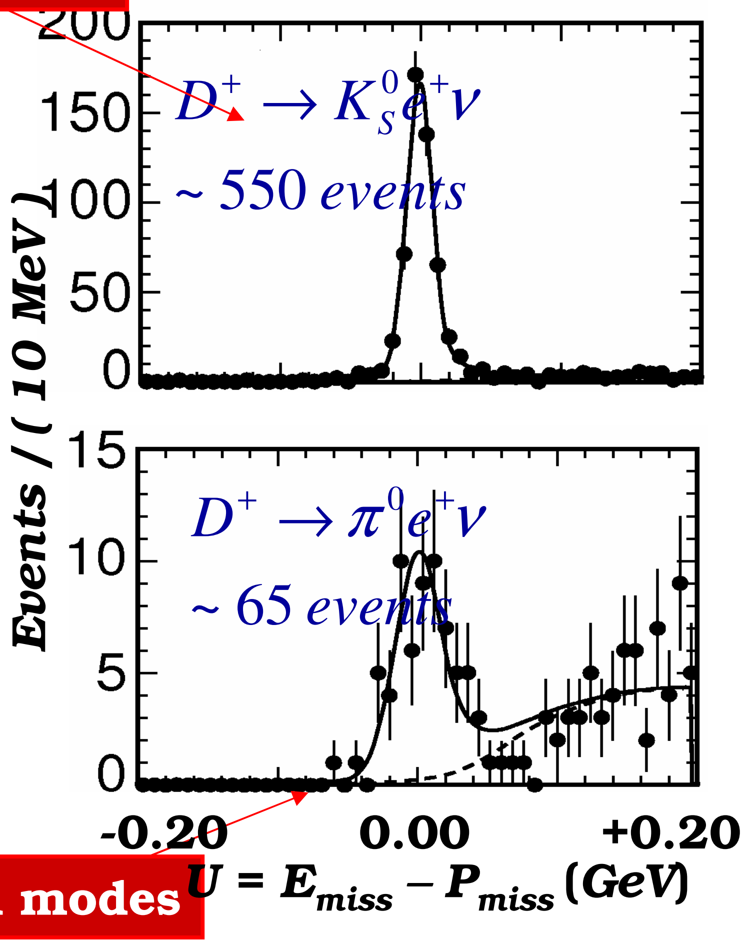
- ❑ Background is small and peaks outside the signal region (kinematic separation)
- ❑ Most background comes from cross-feed among *D* semileptonic decays

- ❑ There is a small peaking backgrond from $D^+ \to \omega(\pi\pi)e\nu$ (the same final state)

U distributions for $P \to P$ decays in 56 pb^{-1} of data

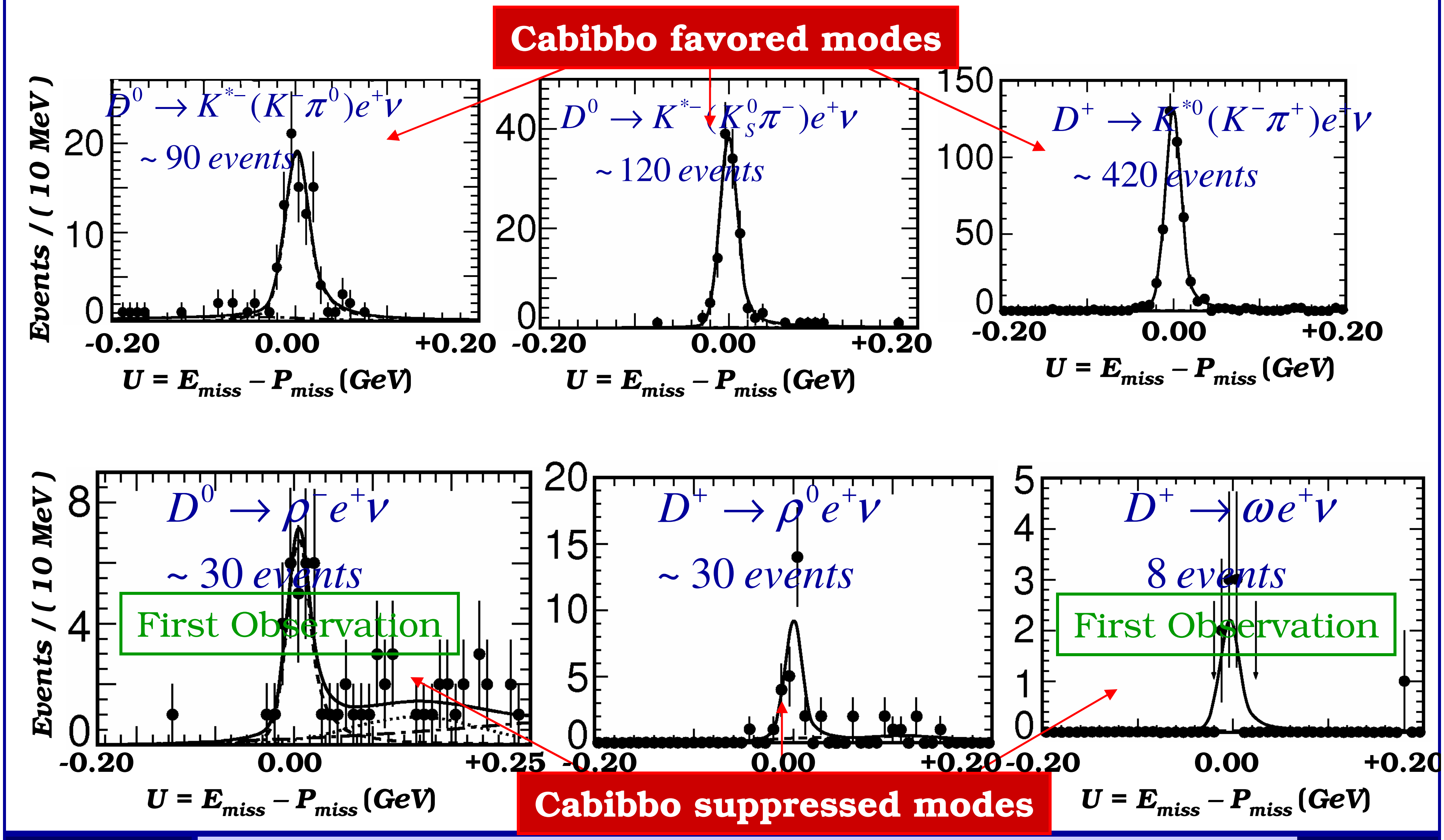
Cabibbo favored modes





Cabibbo suppressed modes

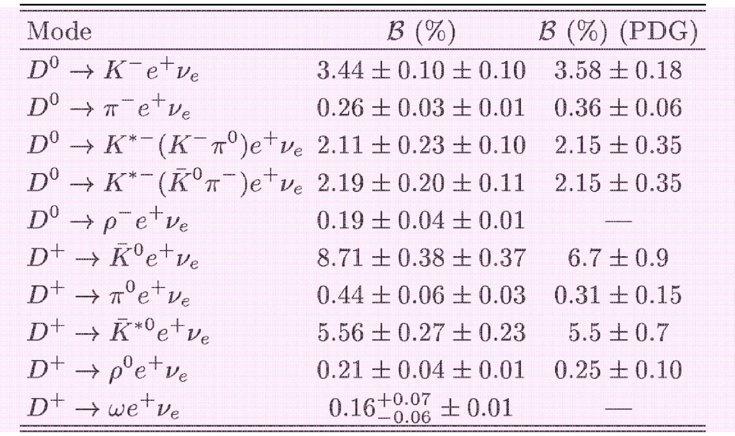
U distributions for $P \to V$ decays in 56 pb^{-1} of data



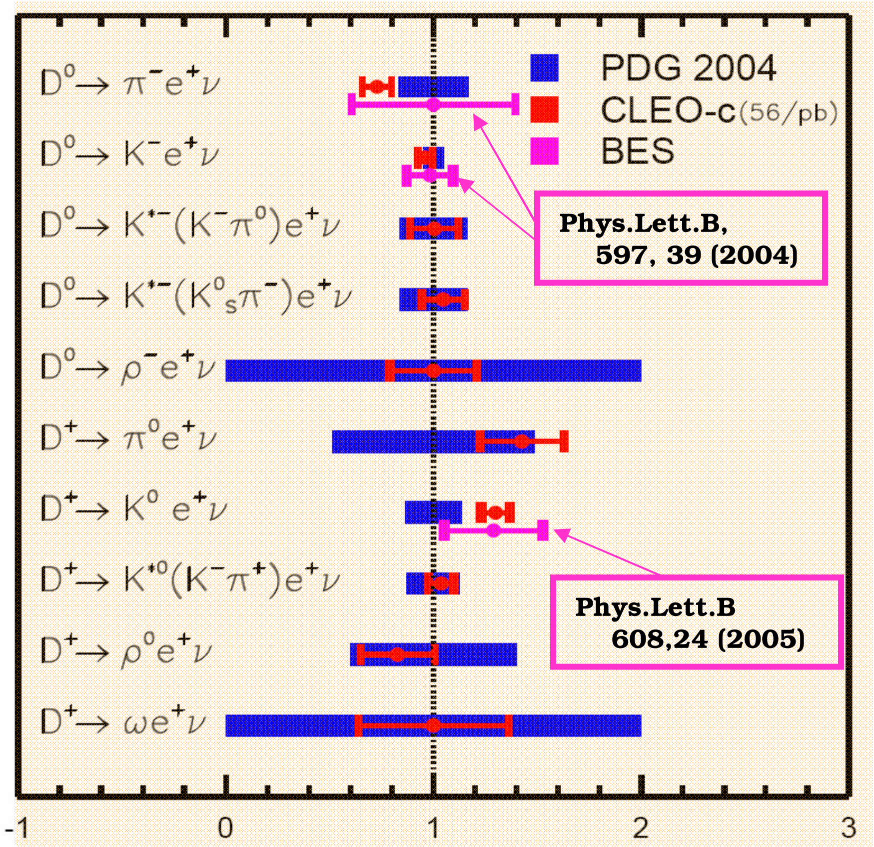
Cabibbo favored modes

Cabibbo suppressed modes

Absolute branching fractions for D semileptonic decays with 56 pb^{-1}



Mode	$\mathcal{B}$ (%)	$\mathcal{B}$ (%) (PDG)
$D^0 \to K^- e^+ \nu_e$	$3.44 \pm 0.10 \pm 0.10$	3.58 ± 0.18
$D^0 \to \pi^- e^+ \nu_e$	$0.26 \pm 0.03 \pm 0.01$	0.36 ± 0.06
$D^0 \to K^{*-}(K^- \pi^0) e^+ \nu_e$	$2.11 \pm 0.23 \pm 0.10$	2.15 ± 0.35
$D^0 \to K^{*-}(\bar{K}^0 \pi^-) e^+ \nu_e$	$2.19 \pm 0.20 \pm 0.11$	2.15 ± 0.35
$D^0 \to \rho^- e^+ \nu_e$	$0.19 \pm 0.04 \pm 0.01$	—
$D^+ \to \bar{K}^0 e^+ \nu_e$	$8.71 \pm 0.38 \pm 0.37$	6.7 ± 0.9
$D^+ \to \pi^0 e^+ \nu_e$	$0.44 \pm 0.06 \pm 0.03$	0.31 ± 0.15
$D^+ \to \bar{K}^{*0} e^+ \nu_e$	$5.56 \pm 0.27 \pm 0.23$	5.5 ± 0.7
$D^+ \to \rho^0 e^+ \nu_e$	$0.21 \pm 0.04 \pm 0.01$	0.25 ± 0.10
$D^+ \to \omega e^+ \nu_e$	$0.16^{+0.07}_{-0.06} \pm 0.01$	—



Phys.Lett.B, 597, 39 (2004)

Phys.Lett.B 608,24 (2005)

CLEO-c results are the most precise for ALL modes

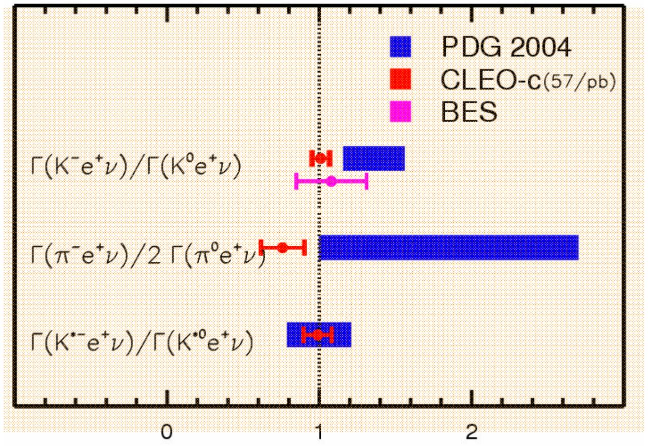
References:
PRL 95, 181801 (2005);
PRL 95, 181802 (2005)

- $B(D^0 \to \pi^- e^+ \nu)/B(D^0 \to K^- e^+ \nu) = (7.6 \pm 0.8 \pm 0.2) \times 10^{-2}$ compares favorably with the CLEO III result of $(8.2 \pm 0.6 \pm 0.5) \times 10^{-2}$ (CLEO, PRL **94**, 011802 (2005)) The PDG-04 value for this ratio is 0.101±0.017.
- The following two modes $D^0 \to \rho^- e^+ \nu$ and $D^+ \to \omega e^+ \nu$ are observed for the first time
- Most systematic uncertainties are measured in data and will be reduced with a larger data sample.

Isospin tests and a comparison with inclusive measurements

- ❑ The widths of the isospin conjugate exclusive semileptonic decays are related due to the isospin invariance of the hadronic current. We find:

Ratio	Measured Value
$\Gamma(D^0 \to K^- e^+ \nu)/\Gamma(D^+ \to \bar{K}^0 e^+ \nu)$	$1.00 \pm 0.05 \pm 0.04$
$\Gamma(D^0 \to \pi^- e^+ \nu)/[2 \cdot \Gamma(D^+ \to \pi^0 e^+ \nu)]$	$0.75^{+0.14}_{-0.11} \pm 0.04$
$\Gamma(D^0 \to K^{*-} e^+ \nu)/\Gamma(D^+ \to \bar{K}^{*0} e^+ \nu)$	$0.98 \pm 0.08 \pm 0.04$
$\Gamma(D^0 \to \rho^- e^+ \nu)/[2 \cdot \Gamma(D^+ \to \rho^0 e^+ \nu)]$	$1.2^{+0.4}_{-0.3} \pm 0.1$



- ❑ Isospin averaged semileptonic decay widths:

Decay Mode	$\Gamma\ (10^{-2} \cdot \mathrm{ps}^{-1})$
$D \to K\, e^+ \nu_e$	$8.38 \pm 0.20 \pm 0.23$
$D^0 \to \pi^- e^+ \nu_e$	$0.68 \pm 0.05 \pm 0.02$
$D \to K^*\, e^+ \nu_e$	$5.32 \pm 0.21 \pm 0.20$
$D^0 \to \rho^- e^+ \nu_e$	$0.43 \pm 0.06 \pm 0.02$

- ❑ Summing up all exclusive semileptonic branching fractions measured in this analysis we find:

$$\sum B(D^0_{excl\ semil}) = (6.1 \pm 0.2 \pm 0.2)\% \quad and \quad \sum B(D^+_{excl\ semil}) = (15.1 \pm 0.5 \pm 0.5)\%$$

These are consistent than with the CLEO-c inclusive semileptonic branching fractions (hep-ex/0604044):

$$B(D^0_{incl\ semil}) = (6.5 \pm 0.2 \pm 0.1)\% \quad and \quad B(D^+_{incl\ semil}) = (16.1 \pm 0.2 \pm 0.3)\%$$

which excludes the possibility of additional *D* semileptonic modes with large branching fractions.

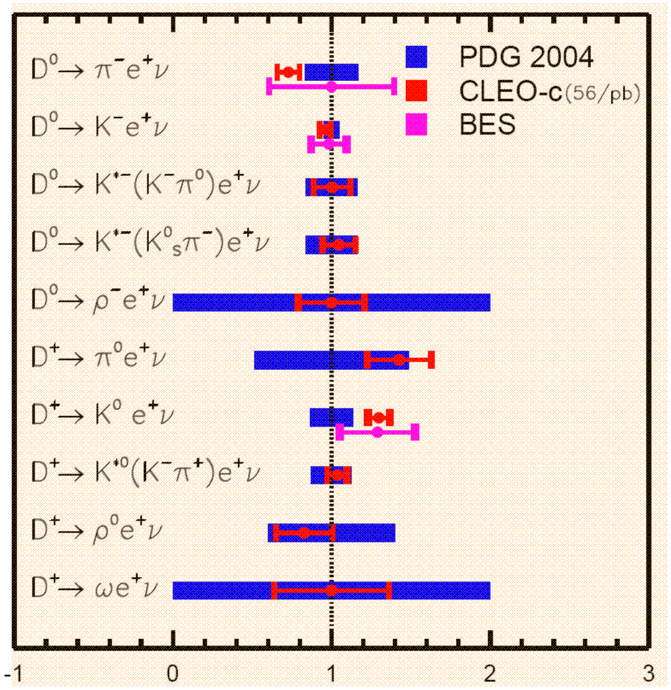
Current Studies of *D* Semileptonic Decays with 280 pb^{-1} at the $\psi(3770)$:

- Form Factors in $D \to \pi e^+ \nu$ and $D \to K e^+ \nu$
- Form Factors in $D \to \rho e^+ \nu$
- Rare *D* Semileptonic Decays $D \to \eta / \eta' / \phi e^+ \nu$

First results are shown at the APS meeting in Dallas, TX in April, 2006;
Session L12: Exclusive *D* Meson Decays.

CLEO-c semileptonic analyses with 280/pb

CLEO-c Exclusive Semileptonic BFs from 56 pb^{-1}



We are working now on these analyses

Form Factor Studies in Semileptonic Decays:

✓ Cabibbo-favored $P \to P$ semileptonic transitions

$D^0 \to K^- e^+ \nu$ **N~7000**

$D^+ \to \overline{K}^0 e^+ \nu$ **N~2900**

✓ Cabibbo-suppressed $P \to P$ semileptonic transitions

$D^0 \to \pi^- e^+ \nu$ **N~700**

$D^+ \to \pi^0 e^+ \nu$ **N~290**

✓ Cabibbo favored $P \to V$ semileptonic transitions

$D^+ \to K^{*0} e^+ \nu$ **N~2800**

✓ Cabibbo suppressed $P \to V$ semileptonic transitions

$D^0 \to \rho^- e^+ \nu$ **N~130**

$D^+ \to \rho^0 e^+ \nu$ **N~170**

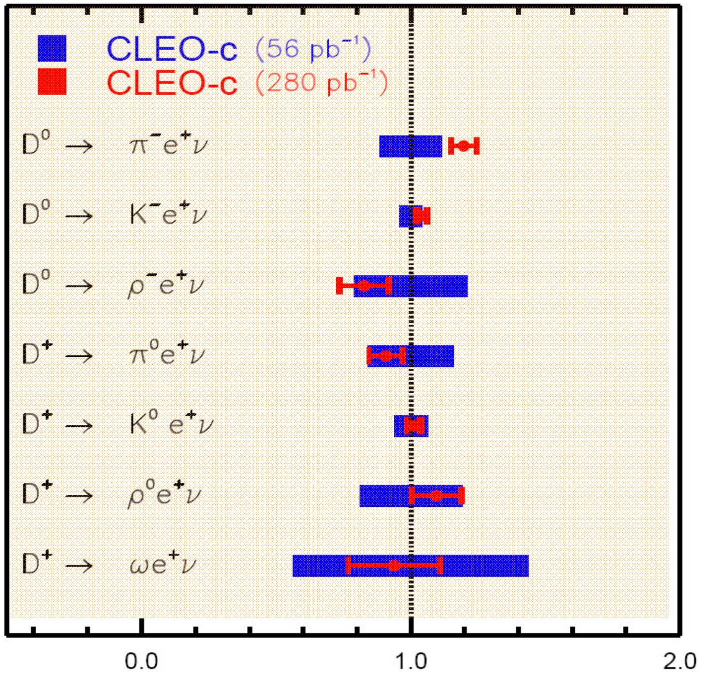
Search for rare semileptonic decays:

✓ $D^+ \to \eta / \eta' / \phi \; e^+ \nu$

Updated $B(D\to K/\pi/\rho/\omega e^{+}\nu)$ with 280 pb^{-1}

Mode	CLEO-c with 280 pb^{-1}(%)	CLEO-c with 55.8 pb^{-1} (%)
$D^0\to K^-e^+\nu$	$3.58\pm0.05\pm0.06$	$3.44\pm0.10\pm0.10$
$D^0\to \pi^-e^+\nu$	$0.311\pm0.012\pm0.005$	$0.26\pm0.03\pm0.01$
$D^0\to \rho^-e^+\nu$	$0.157\pm0.017\pm0.005$	$0.194\pm0.039\pm0.013$
$D^+\to K^0_Se^+\nu$	$8.82\pm0.17\pm0.20$	$8.71\pm0.38\pm0.37$
$D^+\to \pi^0e^+\nu$	$0.399\pm0.027\pm0.007$	$0.44\pm0.06\pm0.03$
$D^+\to \rho^0e^+\nu$	$0.231\pm0.019\pm0.006$	$0.21\pm0.04\pm0.01$
$D^+\to \omega e^+\nu$	$0.149\pm0.027\pm0.005$	$0.16^{+0.07}_{-0.06}\pm0.01$

Results from the two samples agree well



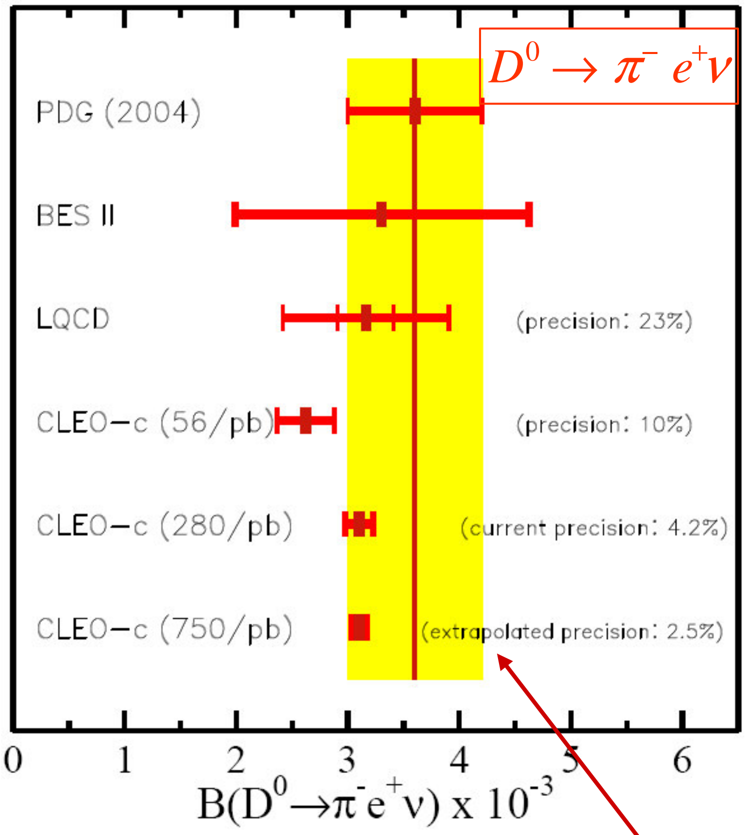
$$\frac{\Gamma(D^0\to K^-e^+\nu)}{\Gamma(D^+\to \overline{K}^0e^+\nu)}=1.024\pm0.024(stat)$$

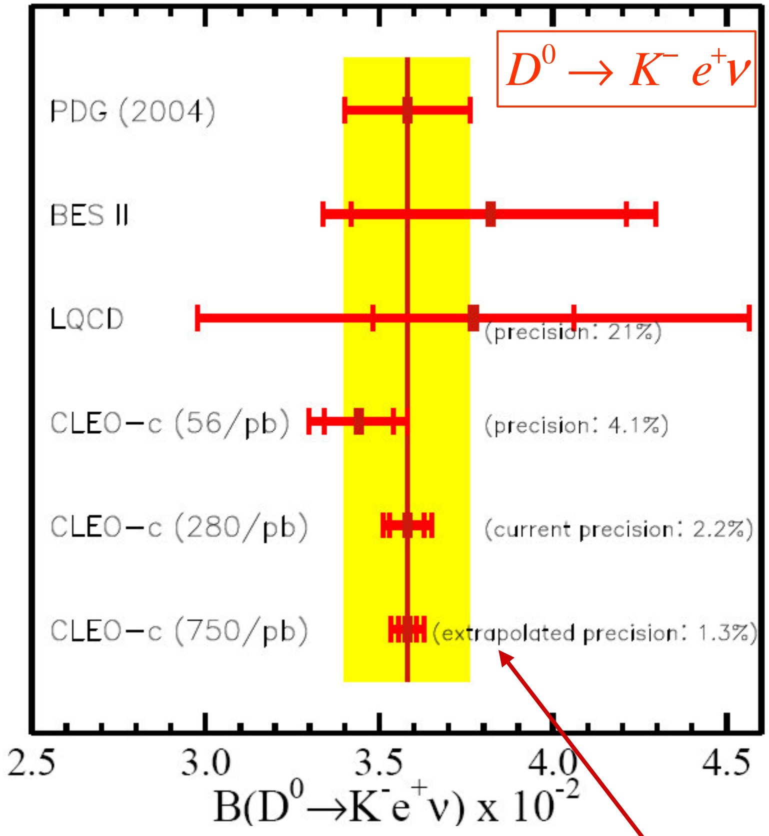
$$\frac{\Gamma(D^0\to \pi^-e^+\nu)}{2\Gamma(D^+\to \pi^0e^+\nu)}=0.975\pm0.075(\mathrm{stat})$$

$$\frac{\Gamma\left(D^0\to\rho^-e\nu\right)}{2\Gamma\left(D^+\to\rho^0e\nu\right)}=0.86\pm0.12(\mathrm{stat})$$

PRELIMINARY

Comparison of $B(D^0 \to K^- / \pi^- e^+\nu)$ with other experiments and projections for 750 pb^{-1}





Statistically limited

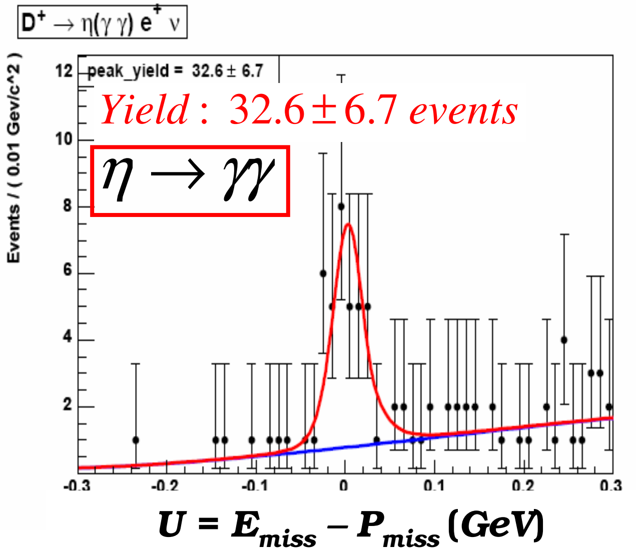
Systematically limited

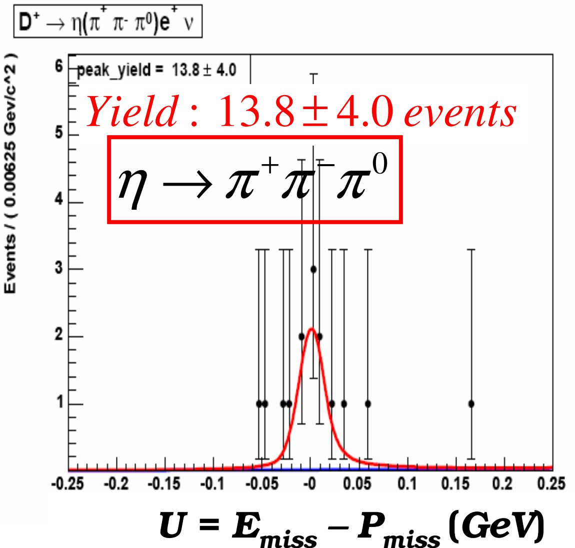
Reasonable agreement

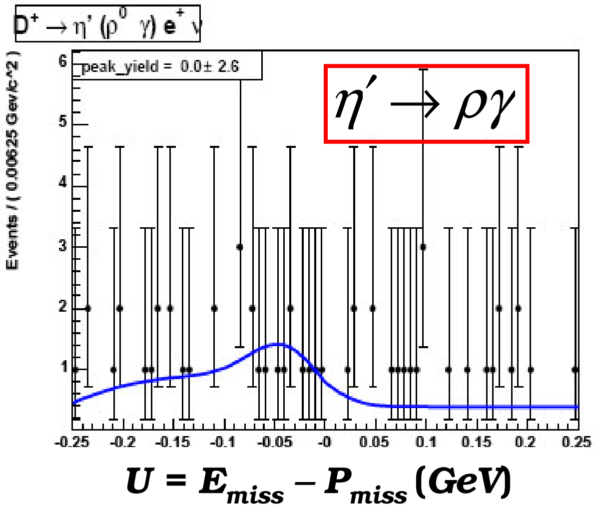
PRELIMINARY

First Observation of $D^+ \to \eta e^+ \nu$

- Search for $D^+ \to \eta e \nu$, $\eta' e \nu$ and $\phi e \nu$ (allows to study η-η' and ω-ϕ mixing):







All other plots [$\eta'(\eta\pi\pi)$, $\phi(KK)$] are empty!

CLEO-c PRELIMINARY	PDG-2004
$B(D^+ \to \eta e^+ \nu) = (1.29 \pm 0.19 \pm 0.07) \times 10^{-3}$	$B(D^+ \to \eta l^+ \nu) < 5 \times 10^{-3} (90\% C.L.)$
$B(D^+ \to \eta' e^+ \nu) < 2.0 \times 10^{-4} (90\% C.L.)$	$B(D^+ \to \eta' \mu^+ \nu) < 1.1\% (90\% C.L.)$
$B(D^+ \to \phi e^+ \nu) < 1.6 \times 10^{-4} (90\% C.L.)$	$B(D^+ \to \phi e^+ \nu) < 2.09\% (90\% C.L.)$

First observation + two orders of magnitude more restrictive limits; *B*($D \to \eta' e \nu$) is small

Studies of Semileptonic Form Factors in $D \to \pi e \nu$ and $D \to K e \nu$ with 280 pb^{-1}

Two Fitting Methods: Fit A and Fit B

- The observed decay rate is related to the true decay rate in the following way:

$$\frac{d\Gamma'}{dq'^{\,2}}(q'^{\,2},\vec{\theta}_0) = \mathcal{A}(q'^{\,2}) \int S(q'^{\,2},q^2)\frac{d\Gamma}{dq^2}(q^2,\vec{\theta}_0)\,dq^2$$

  in terms of Acceptance and Smearing functions. The fit has to take into account both effects. We have developed and tested two types of fits.

- Fit A is a fit to efficiency-corrected and absolutely-normalized differential decay rate. This fit is a good match for CLEO-c data as the resolution of kinematic variables is excellent. E.g.:

  CLEOIII [Υ(4S)]: $\delta q^2 \sim 0.4$ GeV^2
  CLEO-c [ψ(3770)]: $\delta q^2 \sim 0.01$GeV^2

- Fit B is a fit to the observed decay rate according to D.M.Schmidt, R.J.Morrison and M.S.Witherell in *Nucl. Instr. and Meth.* **A328** 547(1993). The technique makes possible a (multidimensional) fit to variables modified by experimental acceptance and resolution. This method has been used by CLEO several times before, for example, to measure form factor ratios in $\Lambda_c \to \Lambda e\nu$ and $B \to D^* l\nu$ and by the FOCUS Collaboration in $D \to K^* l\nu$.

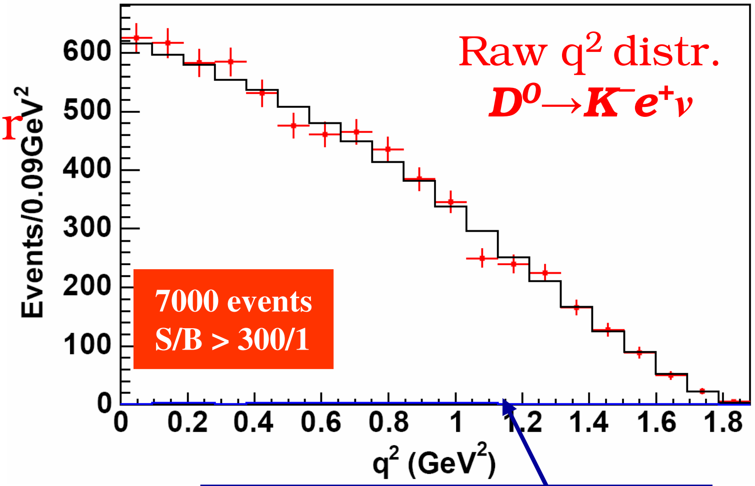
Form Factors in $P \to p\ e\ \nu$ transitions

- Gold-plated modes are $P \to P$ semileptonic transitions as they are the simplest modes for both theory (LQCD) and experiment:

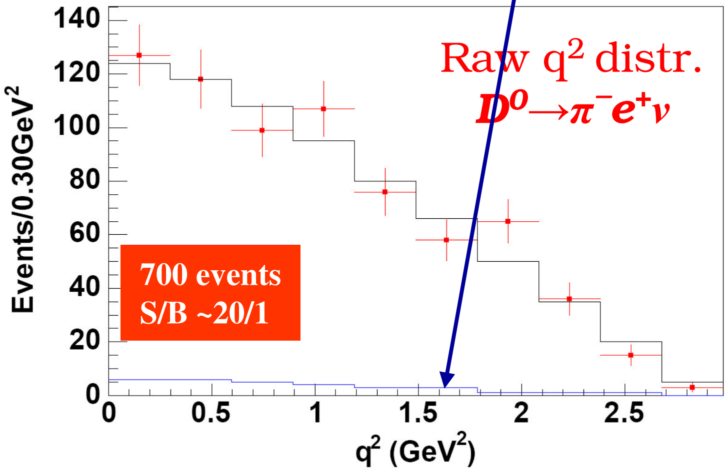
$$\frac{d\Gamma(D \to K(\pi) e \nu)}{dq^2} = \frac{G_F^2 \left|V_{cs(cd)}\right|^2 P_{K(\pi)}^3}{24\pi^2} \left|f_+(q^2)\right|^2,$$

$$\text{where} \quad q^2 \equiv M^2(e\nu)$$

- Main goals:
  - ✓ Measure efficiency-corrected absolutely-normalized decay rate distributions and form factors
  - ✓ Measure form factor shape parameters and $f_+(0)$ to test LQCD and model predictions
- We analyze both D^0 and D^+ decays. They are related by isospin ⇒ a nice cross-check and improves precision

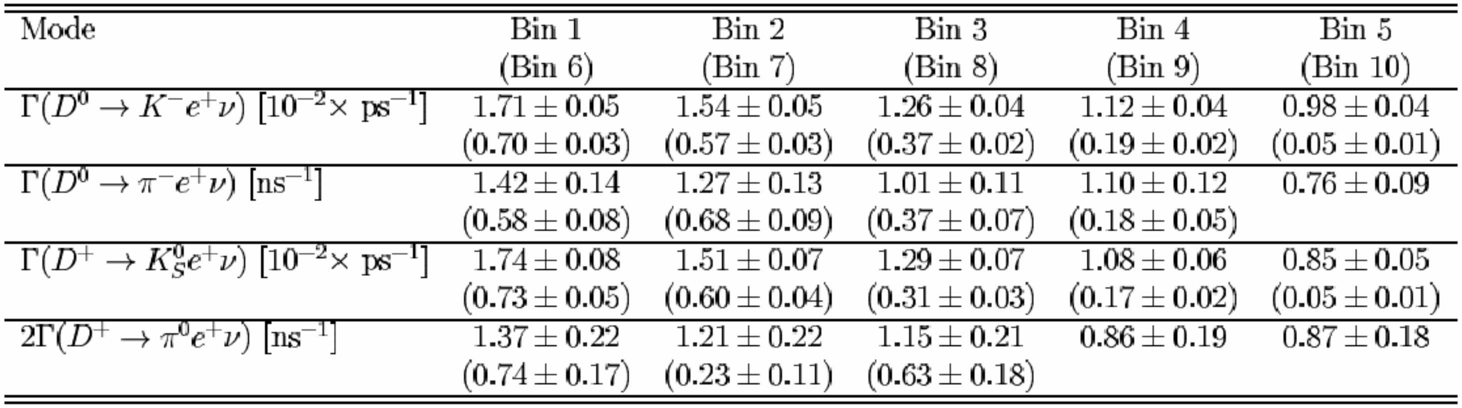


Note the background in blue



Efficiency corrected and absolutely normalized decay rates (DATA)

Subtracting background and applying efficiency corrections (matrices) we find absolute decay rates in bins of q^2 (The bin width is equal $q^2_{max}/10$, the last bins for $D^0\to\pi^-e^+\nu$ and $D^+\to\pi^0\, e^+\nu$ are 2 and 3 times wider):



Mode	Bin 1 (Bin 6)	Bin 2 (Bin 7)	Bin 3 (Bin 8)	Bin 4 (Bin 9)	Bin 5 (Bin 10)
$\Gamma(D^0\to K^-e^+\nu)$ $[10^{-2}\times\,\mathrm{ps}^{-1}]$	1.71 ± 0.05	1.54 ± 0.05	1.26 ± 0.04	1.12 ± 0.04	0.98 ± 0.04
	(0.70 ± 0.03)	(0.57 ± 0.03)	(0.37 ± 0.02)	(0.19 ± 0.02)	(0.05 ± 0.01)
$\Gamma(D^0\to\pi^-e^+\nu)$ $[\mathrm{ns}^{-1}]$	1.42 ± 0.14	1.27 ± 0.13	1.01 ± 0.11	1.10 ± 0.12	0.76 ± 0.09
	(0.58 ± 0.08)	(0.68 ± 0.09)	(0.37 ± 0.07)	(0.18 ± 0.05)	
$\Gamma(D^+\to K^0_Se^+\nu)$ $[10^{-2}\times\,\mathrm{ps}^{-1}]$	1.74 ± 0.08	1.51 ± 0.07	1.29 ± 0.07	1.08 ± 0.06	0.85 ± 0.05
	(0.73 ± 0.05)	(0.60 ± 0.04)	(0.31 ± 0.03)	(0.17 ± 0.02)	(0.05 ± 0.01)
$2\Gamma(D^+\to\pi^0e^+\nu)$ $[\mathrm{ns}^{-1}]$	1.37 ± 0.22	1.21 ± 0.22	1.15 ± 0.21	0.86 ± 0.19	0.87 ± 0.18
	(0.74 ± 0.17)	(0.23 ± 0.11)	(0.63 ± 0.18)		

These rates can be fit to any form factor model w/o knowing CLEO acceptance and resolution

Form Factor Models

- Simple pole model :

$$f_+(q^2) = \frac{f(0)}{\left(1 - q^2 / \enclose{circle}{M^2_{pole}}\right)};$$

- Modified pole model (BK) [Phys.Lett.B 52, 478,417(2000)] :

$$f_+(q^2) = \frac{f(0)}{\left(1 - q^2 / M^2_{D^*_{(s)}}\right)} \frac{1}{\left(1 - \enclose{circle}{\alpha} q^2 / M^2_{D^*_{(s)}}\right)};$$

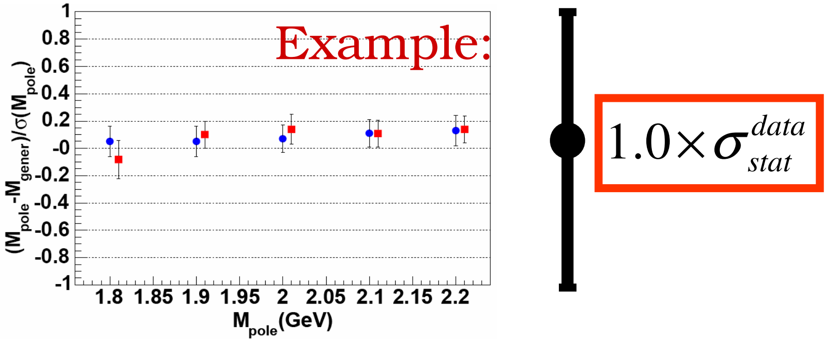
- ISGW2 [Phys.Rev. D 52,2783,(1985)] :

$$f(q^2) = \left(1 + \frac{\enclose{circle}{r^2}}{12}\left(q^2_{\max} - q^2\right)\right)^{-2}$$

- The series parameterization [T. Becher and R. Hill, hep-ph/0509090]

Tests of Fits

- ❑ The fitting techniques are tested by making ensembles of fits to mock data samples drawn from MC:
  - ✓ Fits for all 4 form factor models
  - ✓ simultaneous fits to isospin conjugate modes
  - ✓ fit for two parameters [$f_+(0)V_{cs}$ and a form factor shape parameter]

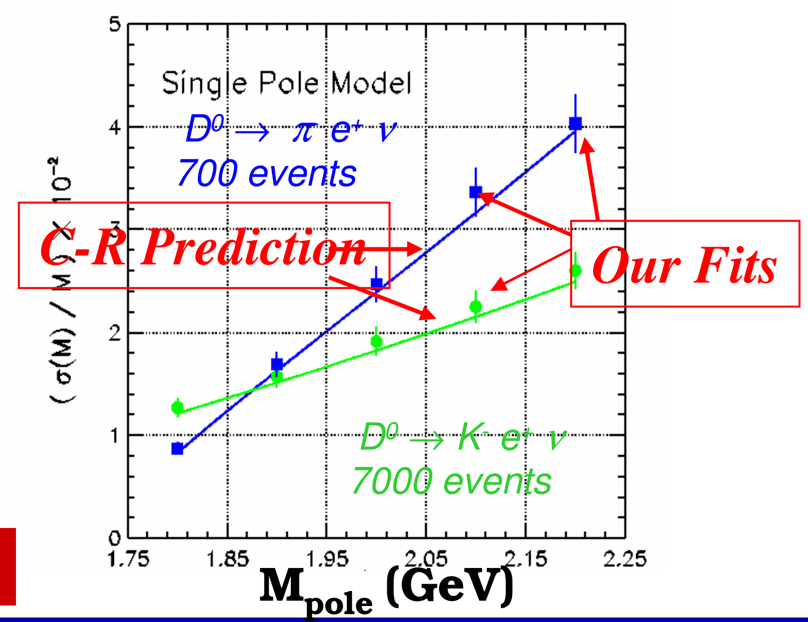


The fitter is consistent with being unbiased.

- ❑ The efficiency of fits is tested using the Cramer-Rao inequality:

$$\sigma(M_{pole}) \geq \frac{1}{\sqrt{I \cdot N}}, \quad where$$

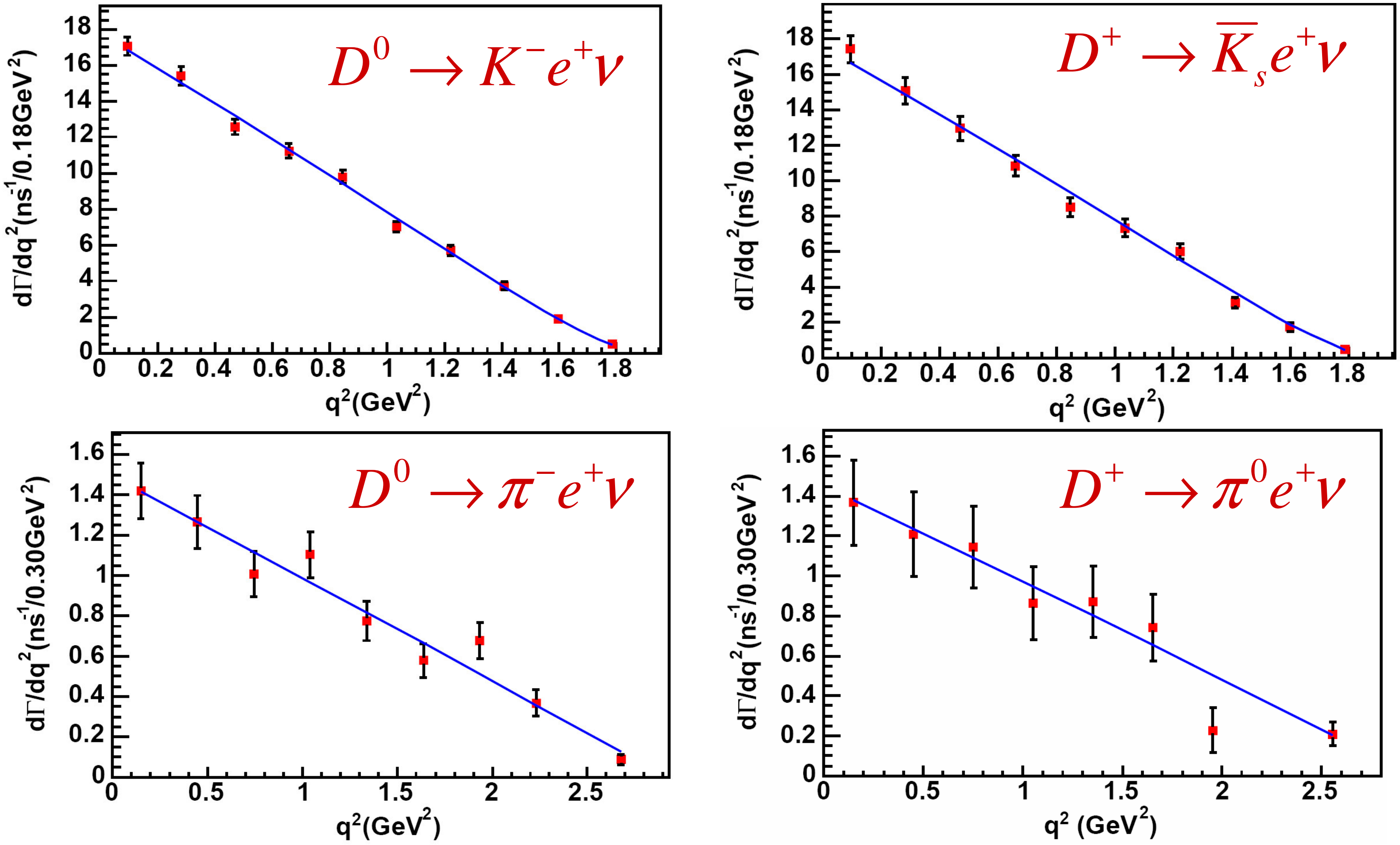
$$I = \int \left(\frac{\partial F(q^2, M_{pole})}{\partial M_{pole}} \right)^2 F(q^2, M_{pole})^{-1} dq^2 \quad and$$



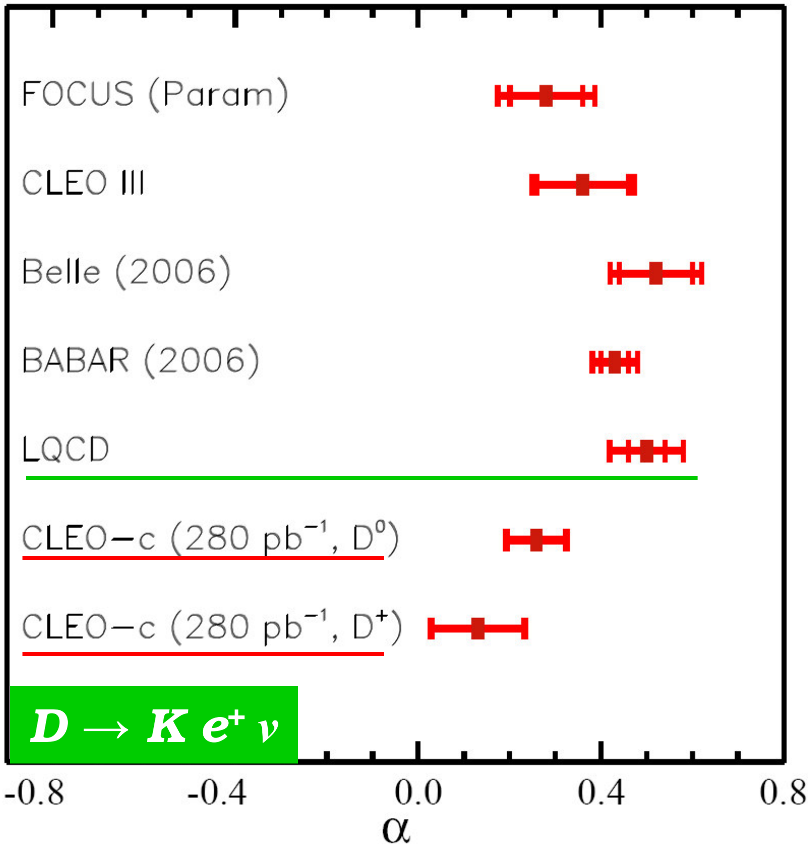
The fitter is consistent with being fully efficient.

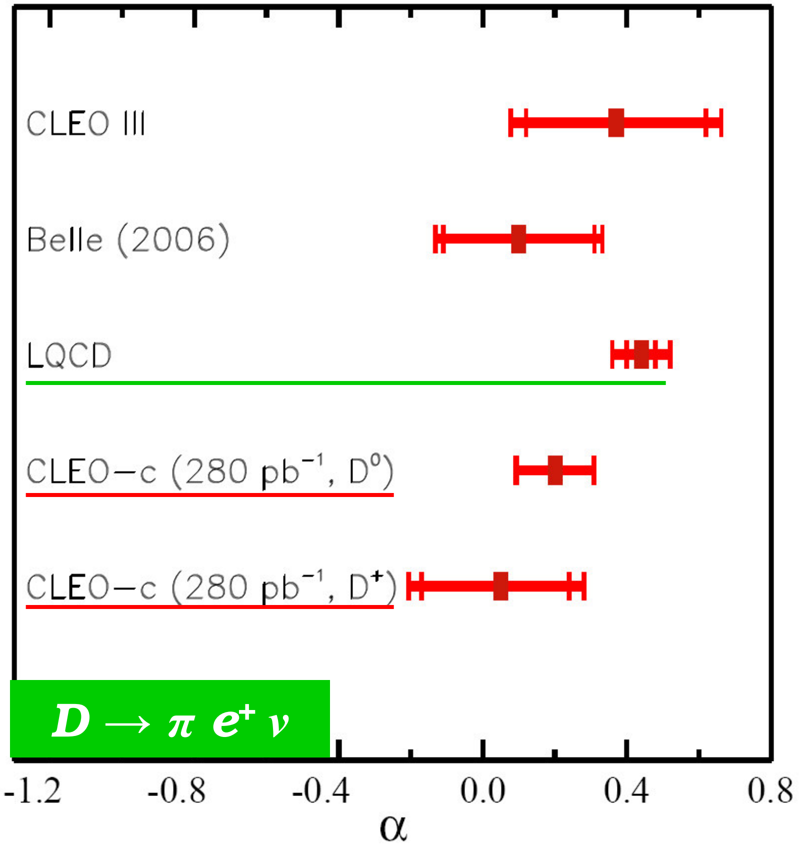
An example of form factor fits to the DATA

Simultaneous fits to isospin conjugate pairs for the simple pole model:



Comparison with Other Measurements [the Modified Pole Model]

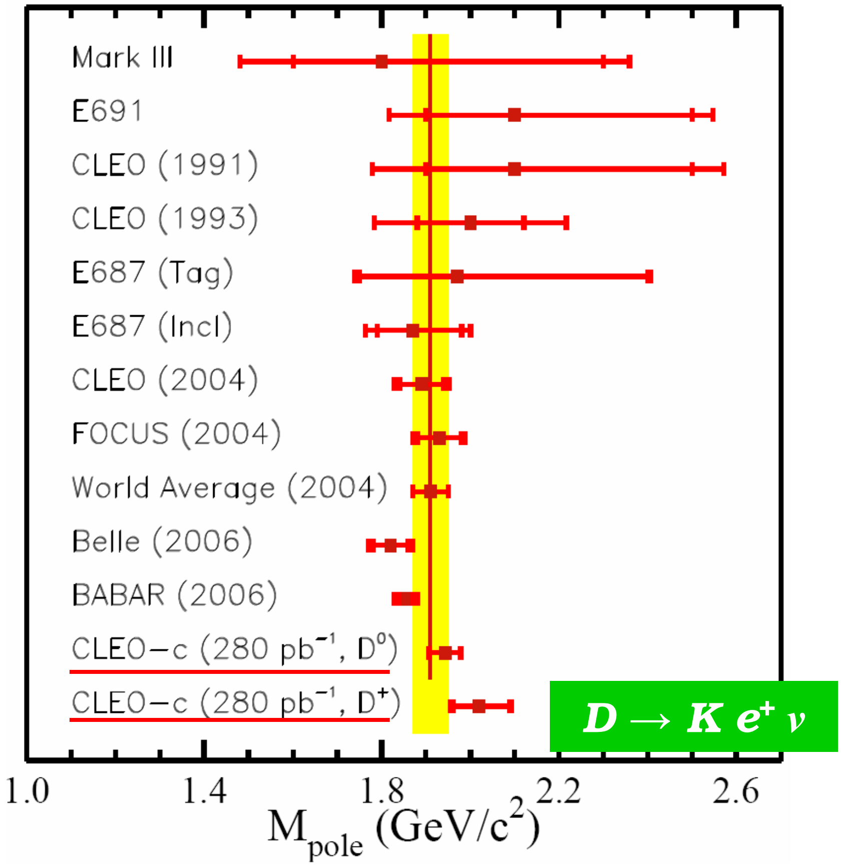


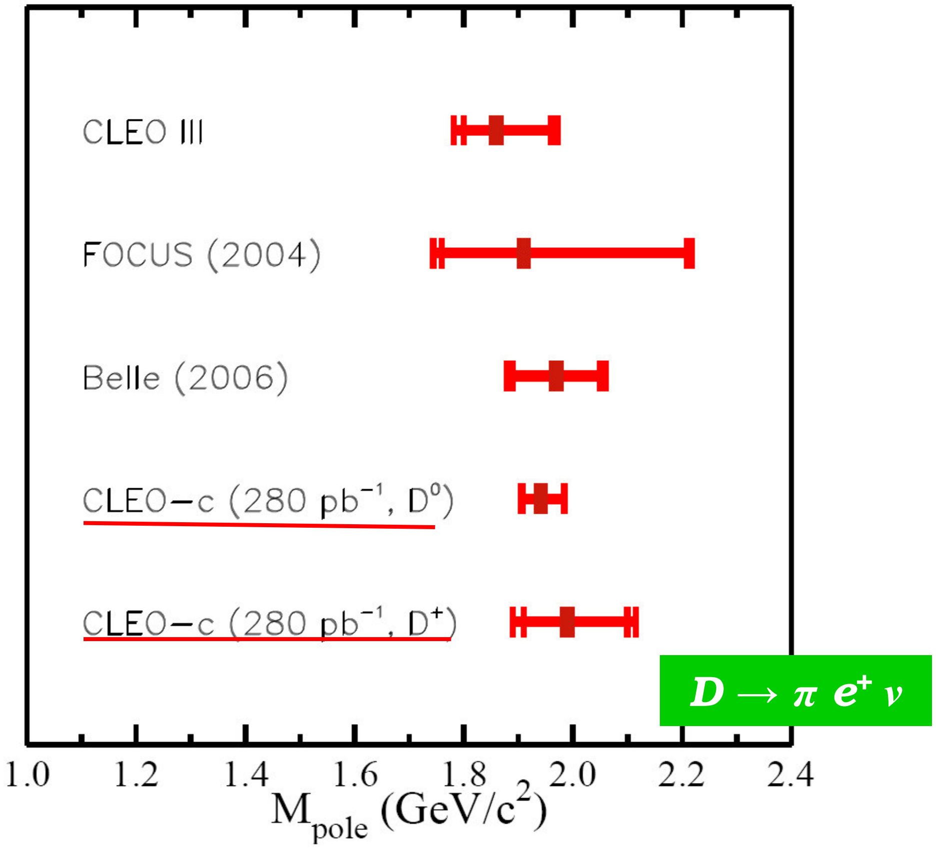


- First measurements of form factors for the D^+ modes;
- CLEO-c is the most precise for $D \to \pi e^+ \nu$

These results are to be approved by the CLEO collaboration soon. No numerical results for form factors today.

Comparison with Other Measurements [the Simple Pole Model]





- ❑ First measurements of form factors for the D^+ modes;
- ❑ CLEO-c is the most precise for $D \to \pi e^+ \nu$

These results are to be approved by the CLEO collaboration soon. No numerical results for form factors today.

Form factors in the DATA

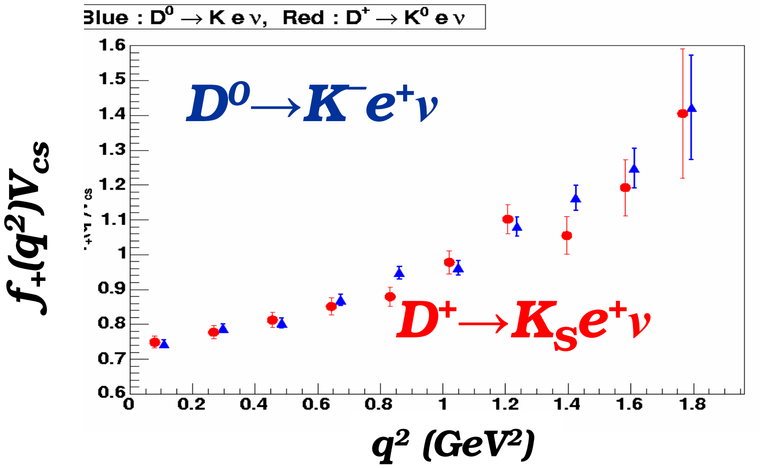
By isospin invariance:

$$\Gamma\left(D^0 \to K^- e\nu\right) = \Gamma\left(D^+ \to \overline{K}^0 e\nu\right)$$
$$\Gamma\left(D^0 \to \pi^- e\nu\right) = 2\cdot\Gamma\left(D^+ \to \pi^0 e\nu\right)$$

$$M_{D^0} - M_{K^+} \approx M_{D^+} - M_{K^0}$$
$$M_{D^0} - M_{\pi^+} \approx M_{D^+} - M_{\pi^0}$$

→

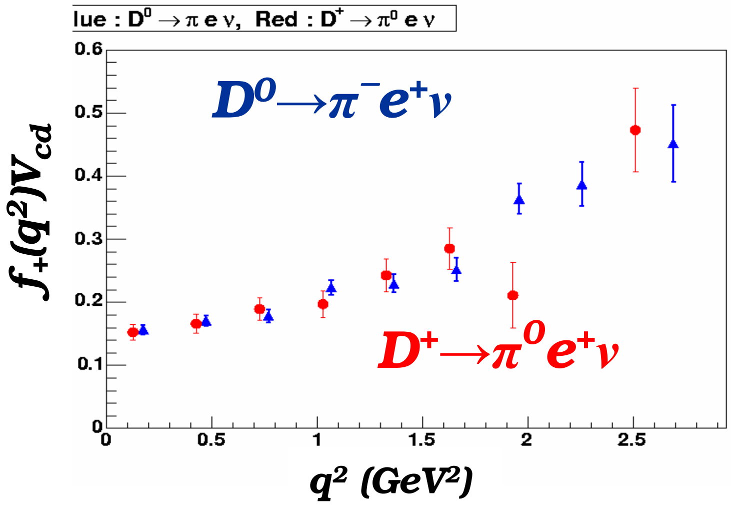
$$f_+^{D^0\to K^+ e\nu}(q^2) \approx f_+^{D^+\to K^0 e\nu}(q^2)$$
$$f_+^{D^0\to \pi^+ e\nu}(q^2) \approx f_+^{D^+\to \pi^0 e\nu}(q^2)$$



PRELIMINARY

The plots show:

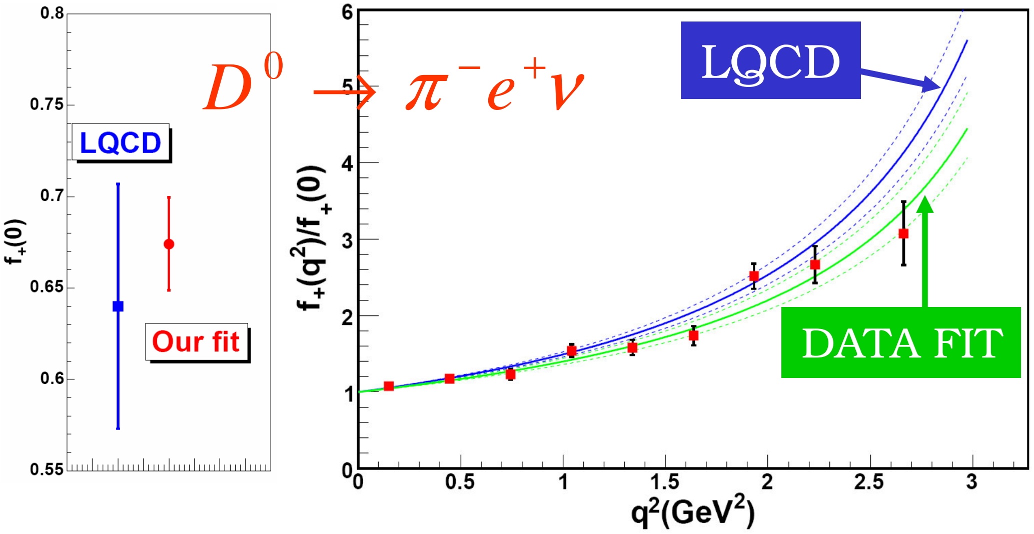
$$\left|V_{cs(cd)}\right|\left|f_+(q^2)\right| \sim \left[\frac{\Delta\Gamma_i(D\to K(\pi)e\nu)}{\Delta q_i^2} / P^3_{K(\pi)i}\right]^{1/2}$$

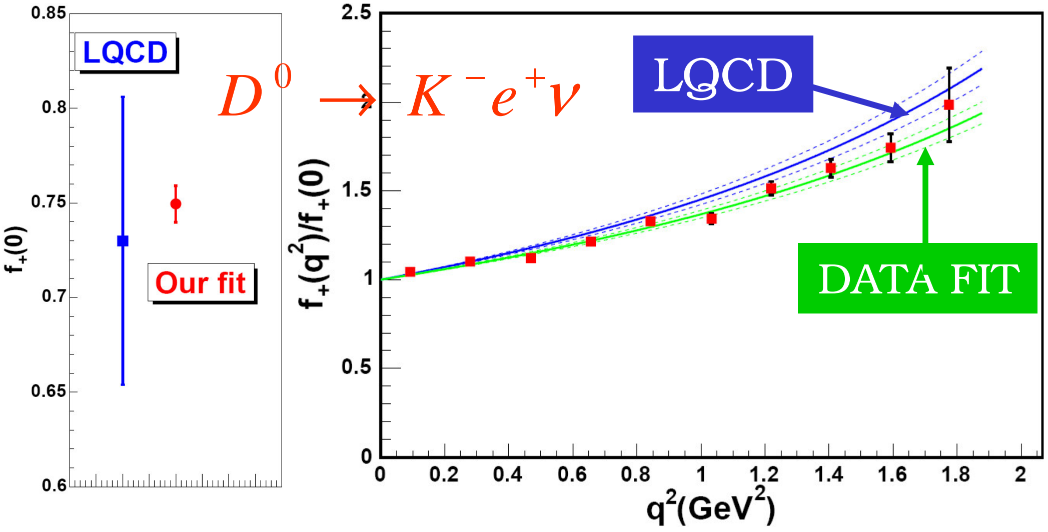


Form factors for isospin conjugate modes are consistent.

Form Factors as a Stringent Test of LQCD

- ☐ Plotted LQCD results (blue) are recent results of FNAL+MILC unquenched three flavor LQCD [C. Aubin *et al.*, PRL **94** 011601 (2005)]
  - ✓ Lattice systematic uncertainties dominate:
  - ✓ $LQCD(D \to \pi e \nu):$
    $f_+(0) = 0.64 \pm 0.03 \pm 0.06;$
    $\alpha = 0.44 \pm 0.04 \pm \boxed{0.07.}$
  - ✓ $LQCD(D \to K e \nu):$
    $f_+(0) = 0.73 \pm 0.03 \pm 0.07;$
    $\alpha = 0.50 \pm 0.04 \pm \boxed{0.07.}$
- ☐ The green lines are our fits to CLEO-c data
- ☐ The dashed lines show 1σ (stat+syst) regions



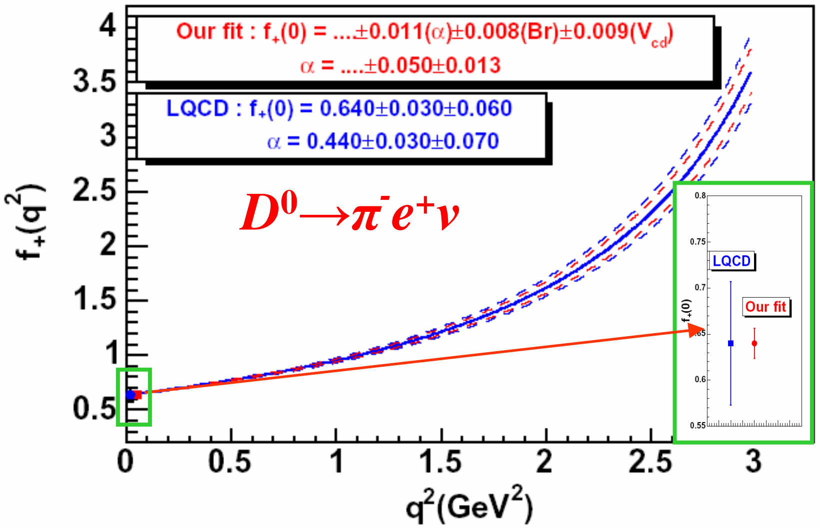


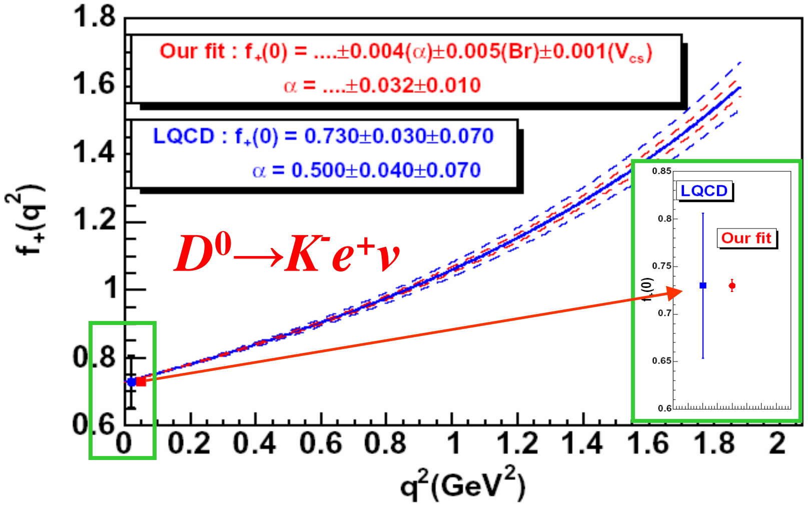
PRELIMINARY

Projections for α and $f_+(0)$

The anticipated precision for a larger 750 pb^{-1} data sample to be collected in the future

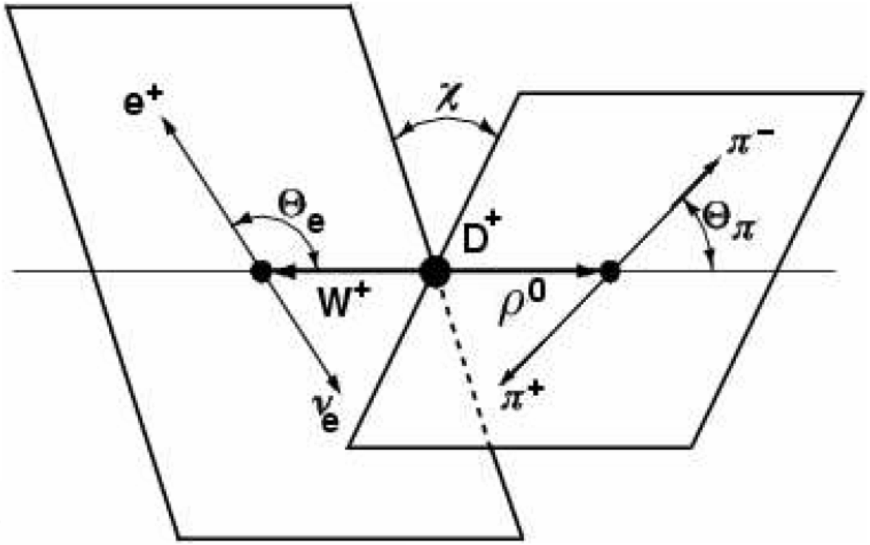
In these plots, the central values for our projections are equal to the central values from the LQCD results





Studies of Semileptonic Form Factors in $D \to \rho e \nu$ with 280 pb^{-1}

Kinematic variables and the decay rate



- Five kinematic variables describe the decay rate (plot):

$$q^2, \cos\theta_e, \cos\theta_\pi, \chi, m(\pi\pi)$$

- The decay rate we make a fit to:

$$\frac{d\Gamma}{dq^2 d\cos\theta_\pi d\cos\theta_e d\chi} = \mathcal{B}(\rho^0 \to \pi\pi)\frac{3G_F^2}{8(4\pi)^4}|V_{cs}|^2\frac{p_{\rho^0} q^2}{M_D^2}$$
$$\{(1+\cos\theta_e)^2\sin^2\theta_\pi\boxed{|H_+(q^2)|^2}$$
$$+(1-\cos\theta_e)^2\sin^2\theta_\pi\boxed{|H_-(q^2)|^2}$$
$$+4\sin^2\theta_e\cos^2\theta_\pi\boxed{|H_0(q^2)|^2}$$
$$+4\sin\theta_e(1+\cos\theta_e)\sin\theta_\pi\cos\theta_\pi\cos\chi\boxed{H_+(q^2)H_0(q^2)}$$
$$-4\sin\theta_e(1-\cos\theta_e)\sin\theta_\pi\cos\theta_\pi\cos\chi\boxed{H_-(q^2)H_0(q^2)}$$
$$-2\sin^2\theta_e\sin^2\theta_\pi\cos 2\chi\boxed{H_+(q^2)H_-(q^2)}\}$$

- Dependence on the form factors enters through $\boxed{H_+, H_- \text{ and } H_0}$.

Form Factor Ratios R_V and R_2

- ❑ The helicity amplitudes are given by

$$H_{\pm}(q^2, m_{\pi\pi}) = (M_D + m_{\pi\pi})\boxed{A_1(q^2)} \mp 2\frac{M_D P_{\pi\pi}}{M_D + m_{\pi\pi}}\boxed{V(q^2)};$$

$$H_0(q^2, m_{\pi\pi}) = \frac{1}{2m_{\pi\pi}\sqrt{q^2}}\left[(M_D^2 - m_{\pi\pi}^2 - q^2)(M_D + m_{\pi\pi})\boxed{A_1(q^2)} - 4\frac{M_D^2 P_{\pi\pi}^2}{M_D + m_{\pi\pi}}\boxed{A_2(q^2)}\right]$$

- ❑ Form factors are parameterized using the simple pole model (*i.e.*, vector dominance):

$$A_{1(2)}(q^2) = \frac{A_{1(2)}(0)}{1 - q^2/M_A^2}; \qquad V(q^2) = \frac{V(0)}{1 - q^2/M_V^2}$$

- ❑ We make a 4D fit to the decay rate for form factor ratios R_V and R_2:

$$R_V \equiv \frac{V(0)}{A_1(0)}; \qquad R_2 \equiv \frac{A_2(0)}{A_1(0)}$$

- ❑ We make a fit (Fit B) described in *Nucl. Instr. and Meth.* **A328**, 547 (1993): a multidimensional fit to variables modified by experimental acceptance and resolution taking into account correlations among them

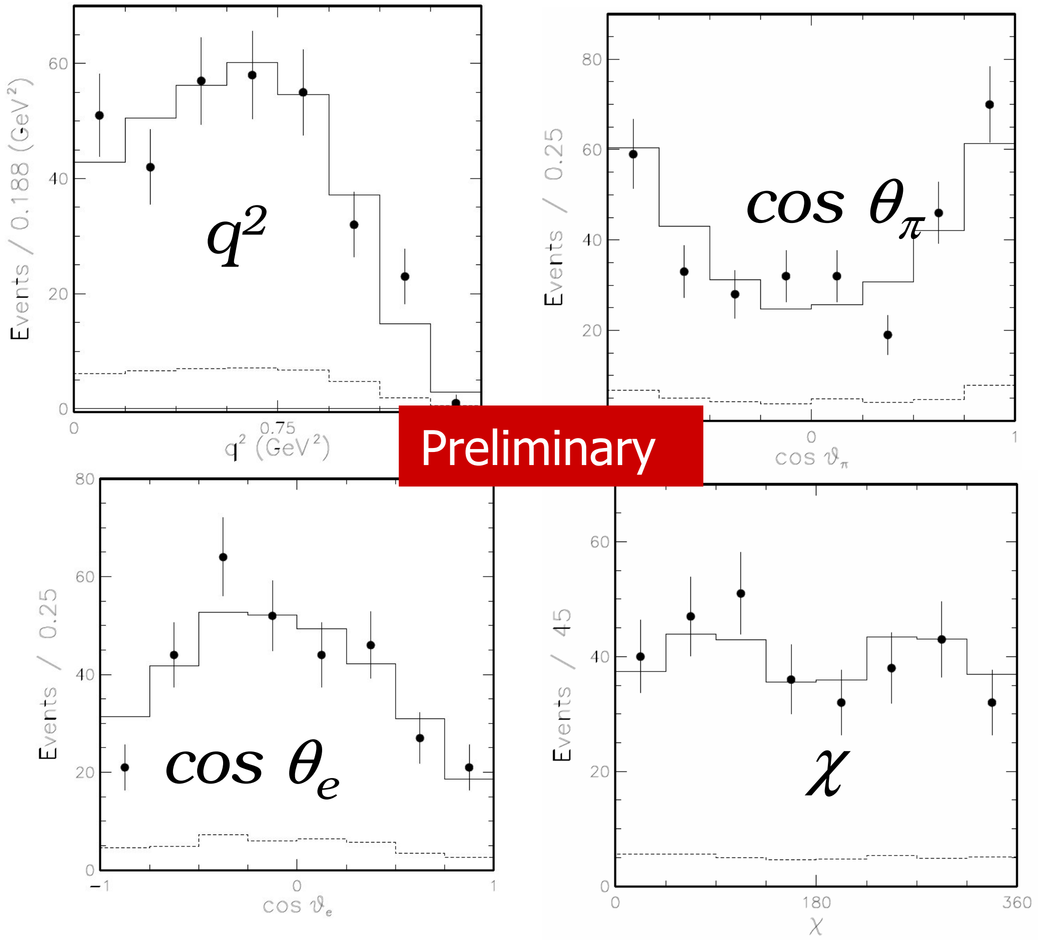
Fit to the Data

- ☐ Two isospin conjugate modes $D^+ \to \rho^0 e\nu$ and $D^0 \to \rho^- e\nu$ were fit simultaneously. We find:

$$R_V = 1.5 \pm 0.2\,(stat)$$
$$R_2 = 0.6 \pm 0.2\,(stat)$$

- ☐ Compare to the $D \to K^* \mu\nu$ results from FOCUS:

$$R_V = 1.50 \pm 0.07 (stat + syst)$$
$$R_2 = 0.88 \pm 0.08 (stat + syst)$$



This is the first multidimensional fit for form factors in Cabibbo-suppressed $P \to V\, l\, \nu$ transions

Unquenched LQCD calculations for such decays are difficult and do not exist to date

- ☐ Systematic studies to be finished

Summary for semileptonic decays

- The main goals of CLEO-c are:
  - ✓ validation and calibration data for LQCD, a theory capable of solving strongly coupled field theory equations
  - ✓ input data to the B factories and other experiments increasing their potential in the search for new physics
- CLEO-c is providing unique data to meet these goals

Moving on to B_s at the Y(5S)…

Observation of B_s Production at the Y(5S) Resonance

[for more information see: hep-ex/0510034; PRL **96**, 022002(2006)]

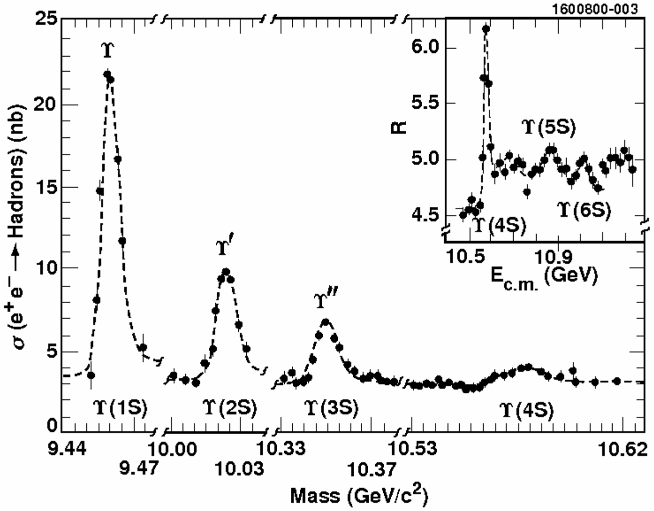
Introduction: B_s at the *Y*(5S)

- The *Y*(5S) resonance was discovered by CLEO and CUSB at CESR in 1985.
- The *Y*(5S) is massive enough to decay into the following channels:

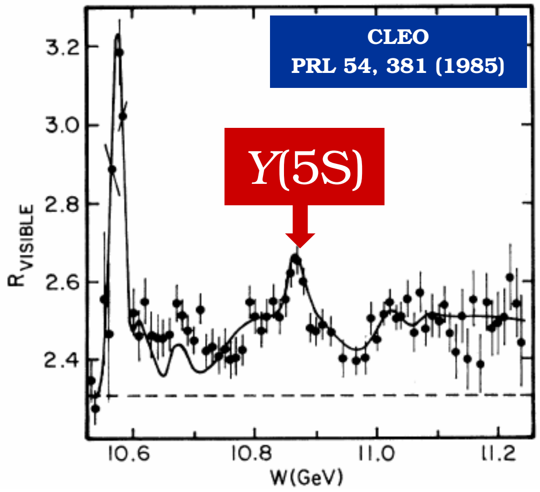
$$B\bar{B},\ \ B\bar{B}^*,\ \ B^*\bar{B}^*,\ \ B\bar{B}\pi,\ \ B\bar{B}^*\pi, B^*\bar{B}^*\pi, B\bar{B}\pi\pi$$

$$\boxed{B_s\bar{B}_s,\ \ B_s\bar{B}_s^*, B_s^*\bar{B}_s^*}$$

- *No* evidence for B_s production at the *Y*(5S) was found in 116 pb^{-1} in 1985.
- The CLEO III detector collected 0.42 fb^{-1} at the *Y*(5S) in 2003 before starting CLEO-c.
- Knowledge of B_s production at the *Y*(5S) is important for evaluating the potential of B_s physics at a high luminosity e^+e^- collider (Super-*B* factory).

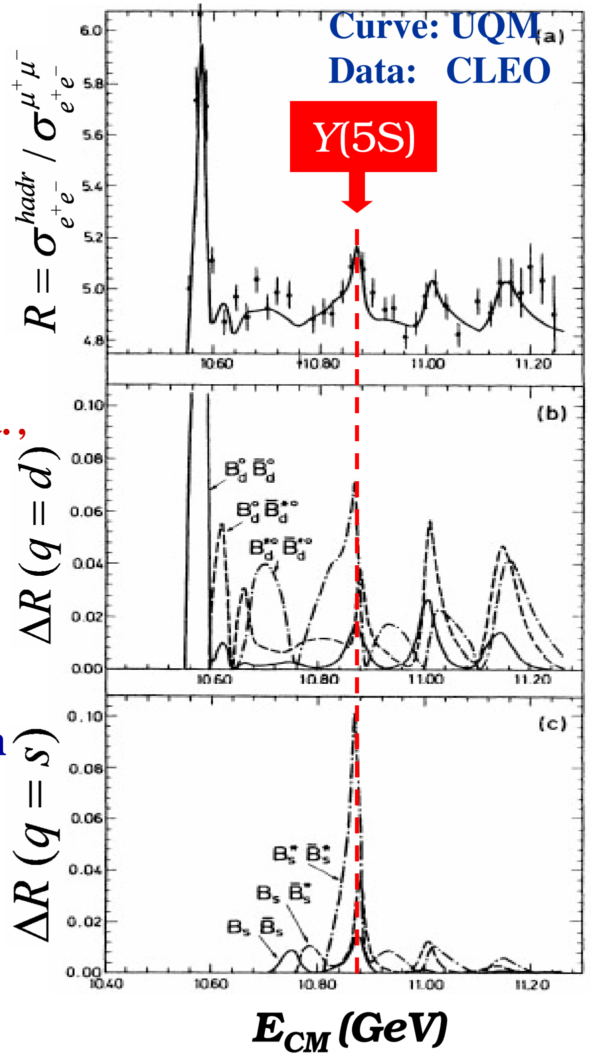


$$M(\Upsilon(5S)) = (10.865 \pm 0.008)\ GeV$$
$$\Gamma_{total}\ (\Upsilon(5S)) = (110 \pm 13)\ MeV$$



Introduction: B_s at the $\Upsilon(5S)$

- There are two papers that describe the hadronic cross section above the $\Upsilon(4S)$ resonance:
  - ✓ CLEO: PRL **54,** 381 (1985)
  - ✓ CUSB: PRL **54**, 377 (1985)
- The cross section above the $\Upsilon(4S)$ is described well by the Unitarized Quark Model (S.Ono *et al.*, Phys.Rev.D **34**, 186 (1986)).
- The UQ model predicts:
  - ✓ $\Upsilon(5S) \to B^* B^*$ or $B_s^* B_s^*$,
  - ✓ The B_s cross section is ≈ 1/3 of the $\Upsilon(5S)$ cross section
  - ✓ $\sigma(e^+ e^- \to \Upsilon(5S)) \approx 0.35$ nb
- Expect ≈100*K* of B_s mesons in 0.42 fb^{-1}



Overview of the Method

- An extension of *B* reconstruction technique used at the $\Upsilon(4S)$ is employed to reconstruct B_s mesons at the $\Upsilon(5S)$:
  - ✓ $M_{bc} = \sqrt{E_{beam}^2 - P_{candidate}^2}$
  - ✓ $\Delta E = E_{candidate} - E_{beam}$
  - ✓ Continuum background suppression variables
- Three decay channels of the $\Upsilon(5S)$ to B_s mesons are possible:
  - ✓ Decay channel 1: $\Upsilon(5S) \to B_s \bar{B}_s$: $E_{B_s} = E_{beam}$
  - ✓ Decay channel 2: $\Upsilon(5S) \to B_s^* \bar{B}_s^*$: $E_{B_s^*} = E_{beam}$
  - ✓ Decay channel 3: $\Upsilon(5S) \to B_s \bar{B}_s^*$: $E_{B_s^*} > E_{beam}, E_{B_s} < E_{beam}$

<u>*PDG–2004:*</u>

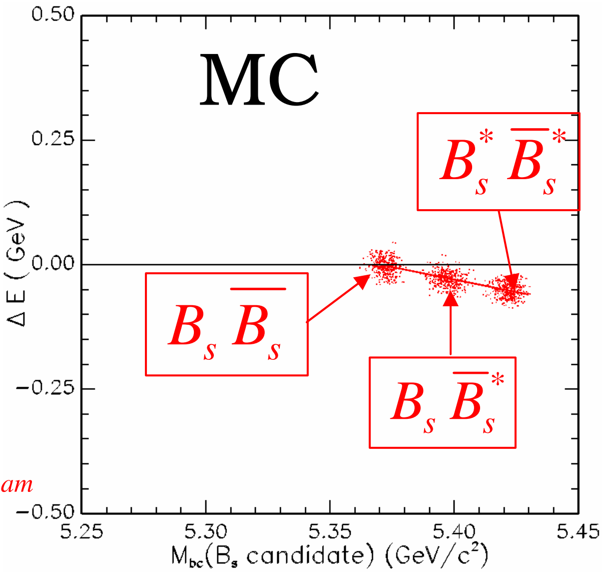
$M_{Bs} = (5.370 \pm 0.002)\ GeV$

$M_{Bs^*} - M_{Bs} = (47.0 \pm 2.6)\ MeV$

<u>*Assumption*: $B(B_s^* \to B_s \gamma) = 100\%$</u>

CDF–2005 (hep–ex/0508022):

$M_{Bs} = (5.3660 \pm 0.0008\,(stat+sys))\ GeV$



Backgrounds

- ❑ The *Y*(5S) can decay into a variety of states with ordinary *B* mesons, which constitute background:

$$B\bar{B},\ \ B\bar{B}^*,\ \ B^*\bar{B}^*,\ \ B\bar{B}\pi,$$
$$B\bar{B}^*\pi, B^*\bar{B}^*\pi, B\bar{B}\pi\pi$$

[The ON *Y*(4S) data are used to model *B* bkg]

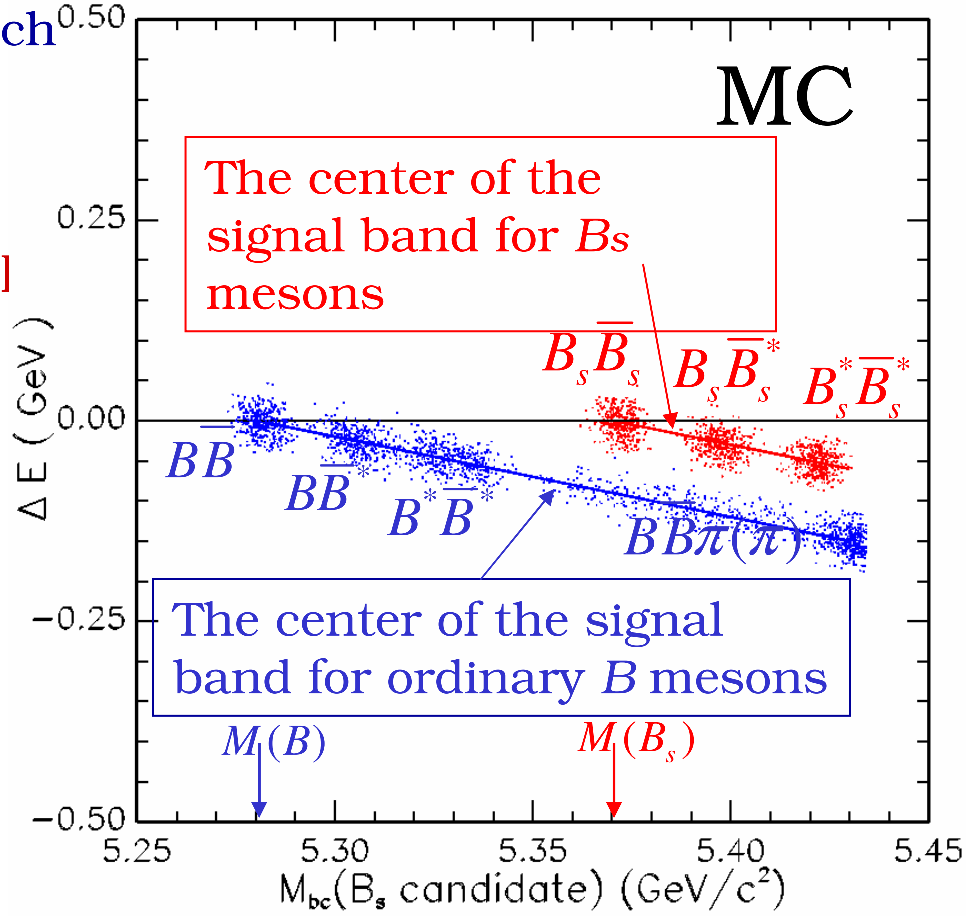
- ❑ The continuum ($e^+e^- \to qq$) background is large:

$$\checkmark\ \Upsilon(4S):\ \ \frac{\sigma(B\bar{B})}{\sigma(e^+e^-\to q\bar{q})}\sim 0.3$$

$$\checkmark\ \ \Upsilon(5S):\ \ \frac{\sigma(B_s^{(*)}\bar{B}_s^{(*)})}{\sigma(e^+e^-\to q\bar{q})}\sim 0.03$$

[The OFF *Y*(4S) and Λ_b data are used to model the continuum bkg]

- ❑ B_s decay modes are poorly known.



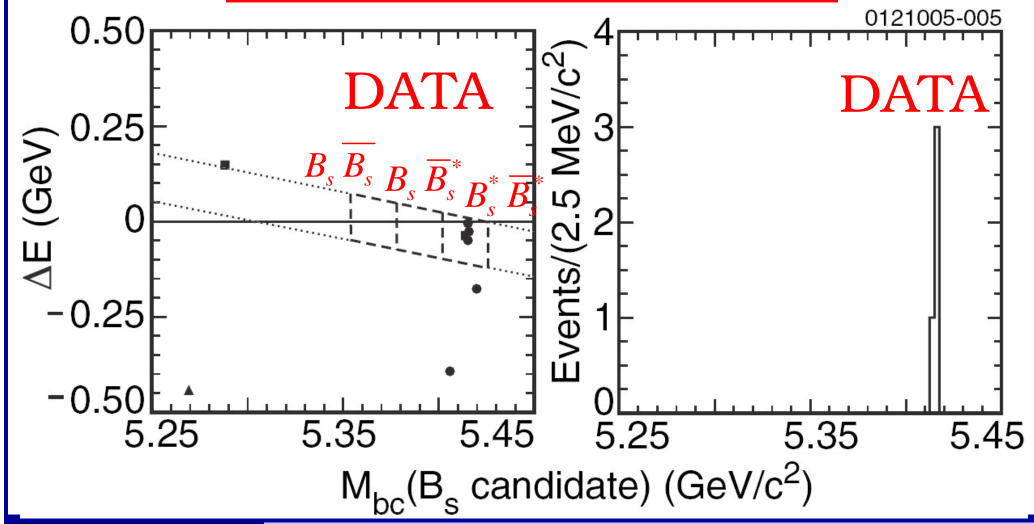
The center of the signal band for *B*s mesons

The center of the signal band for ordinary *B* mesons

B_s modes with a J/ψ

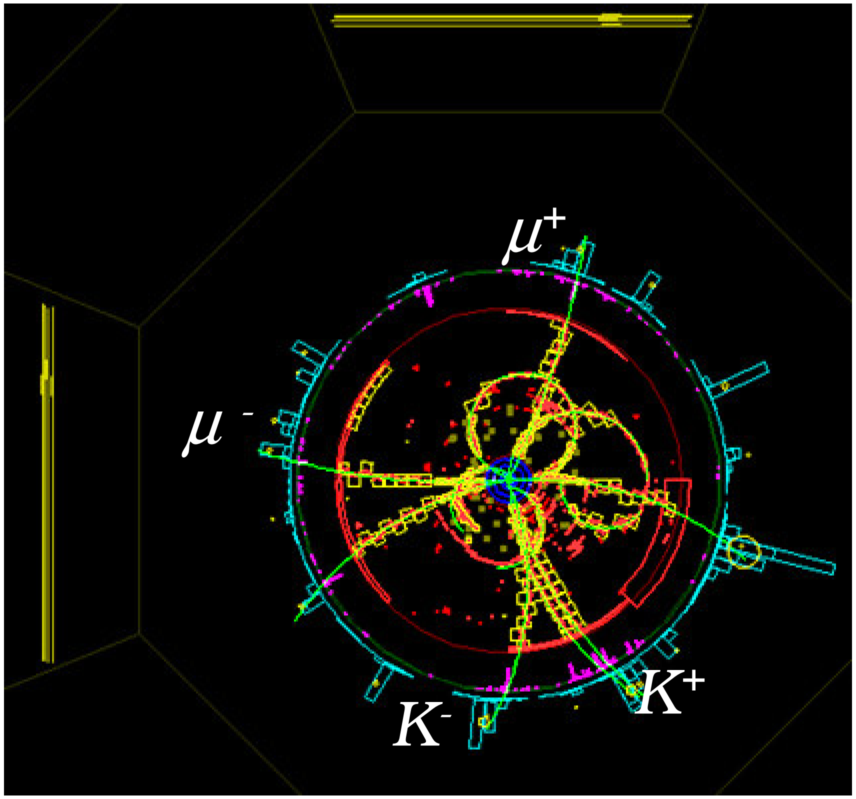
- Search for very clean modes having very large S/B ratio. The best mode to start with is $B_s \to J/\psi\,\varphi$. The search is also made for $B_s \to J/\psi\,\eta$ and $B_s \to J/\psi\,\eta'$.
- The J/ψ is reconstructed in the $\mu\mu$ and ee channels. The following channels are used for other particles: $\varphi \to KK$, $\eta \to \gamma\gamma$, $\eta' \to \eta(\gamma\gamma)\pi^+\pi^-$.
- Expect to find only 2-3 signal events, assuming branching fractions similar to those for B mesons. In the $\Upsilon(5S)$ data, we find:

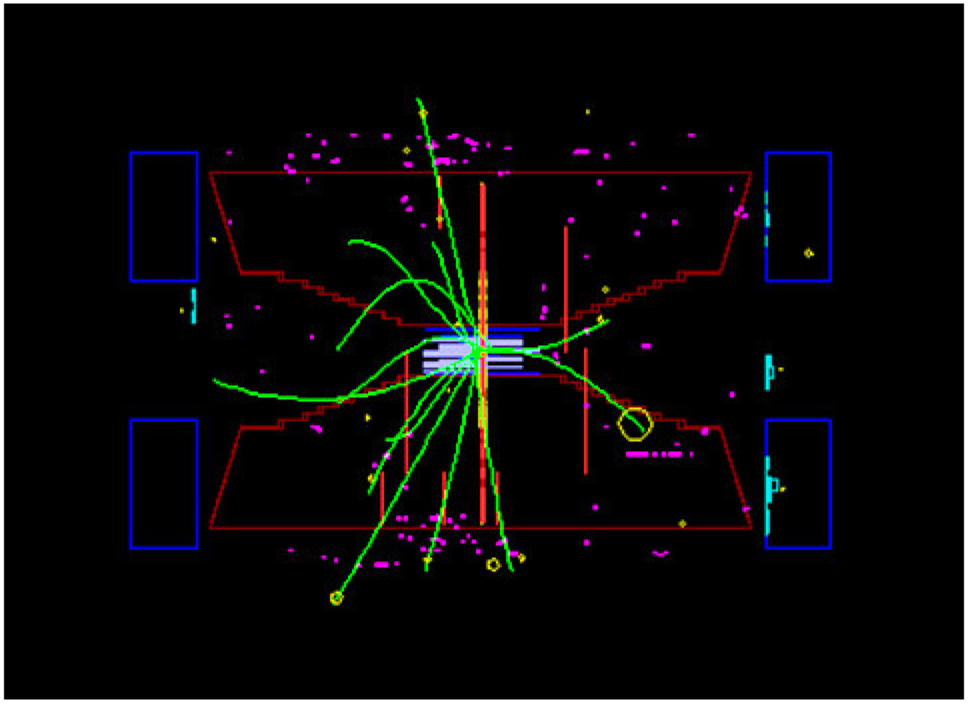
4 events in the signal box for
$\Upsilon(5S) \to B_s^* B_s^*$:
3 events in $B_s \to J/\psi\varphi$
1 event in $B_s \to J/\psi\eta'$



- Using data taken at other energies, the level of non-B_s background is found to be < 0.08 events at 68% CL in the $B_s^* B_s^*$ signal region.
- The Poisson probability for 0.08 events to fluctuate to 4 events or more is $P_I < 1.6 \times 10^{-6}$
- $M(B_s^*) = 5.4150 \pm 0.0018(\text{stat})$ (GeV)

A Signal Event





$$\Upsilon(5S) \rightarrow B_s^* \overline{B}_s^*, \quad B_s^* \rightarrow B_s \gamma \quad \textit{and}$$
$$B_s \rightarrow J/\psi\,\phi,\ J/\psi \rightarrow \mu^+\mu^-,\ \phi \rightarrow K^+K^-$$

B_s modes with a $D_s^{(*)-}$

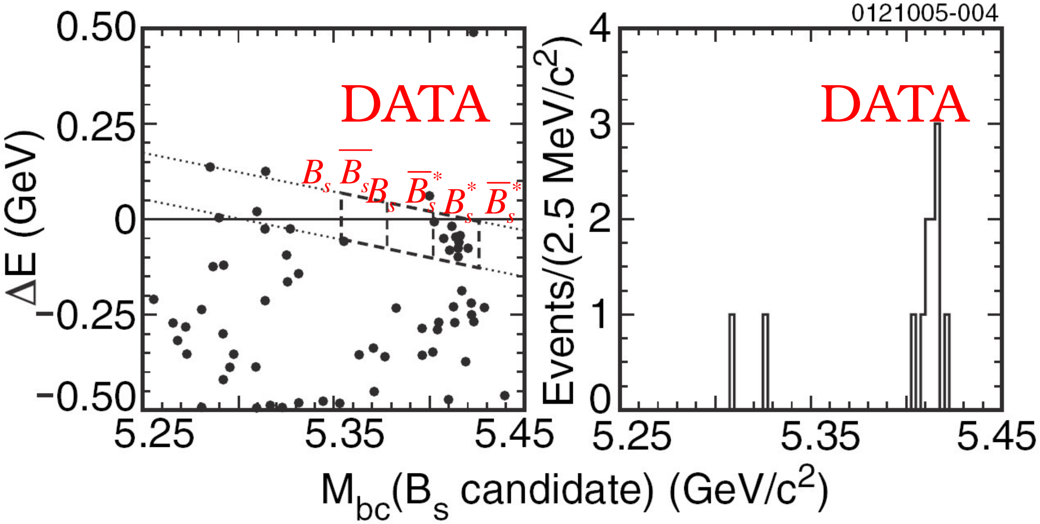
- ❑ The choice of $B_s \to D_s^{(*)} \pi/\rho$ and the four D_s modes listed above is motivated by the difficulty of background modeling
- ❑ MC predicts that a total of 10-14 events can be reconstructed in these channels
- ❑ In the $\Upsilon(5S)$ data we find 10 signal candidates (including background):

$D_s^+ \to$	$K^+K_S^0$	$K^+\bar{K}^{0*}$	$\phi\pi^+$	$\phi\rho^+$
$\bar{B}_s \to D_s^+\pi^-/\rho^-$	0/0	1/1	1/3	1/1
$\bar{B}_s \to D_s^{*+}\pi^-/\rho^-$	0/1	1/0	0/0	0/0

B^0 branching fractions:

Decay Mode	$\mathcal{B} \times 10^{-3}$
$\bar{B}_s \to D_s\pi^-$	(2.8 ± 0.3)
$\bar{B}_s \to D_s\rho^-$	(7.7 ± 1.3)
$\bar{B}_s \to D_s^*\pi^-$	(2.8 ± 0.2)
$\bar{B}_s \to D_s^*\rho^-$	(6.8 ± 0.9)

Decay Mode	$\mathcal{B}$ (%)
$D_s \to K^+\bar{K}^0$	(3.6 ± 1.1)
$D_s \to K^+K^{*0}(892)$	(3.3 ± 0.9)
$D_s \to \phi\pi^+$	(3.6 ± 0.9)
$D_s \to \phi\rho^+$	(6.7 ± 2.3)
$D_s^* \to D_s\gamma$	(94.2 ± 2.5)



- ❑ Using the events in the sidebands in the search plane, the level of background is found to be < 1.8 events at 68% CL in the $B_s^*B_s^*$ signal region.
- ❑ The Poisson probability for 1.8 events to fluctuate to 10 events or more is $P_{II} < 1.9 \times 10^{-5}$
- ❑ $M(B_s^*) = 5.4129 \pm 0.0012(\text{stat})$ (GeV)

Υ(5S) RESULTS

- P_I and P_{II} are combined to obtain an overall probability for a background fluctuation [$P = (P_I P_{II})(1-\ln(P_I P_{II}))$]: $P < 8 \times 10^{-10}$ (~6.1σ)
- All signal events correspond to $B_s^* B_s^*$ production. We set the following limits (90% CL):

$$\frac{\sigma(e^+e^- \to B_s\overline{B}_s)}{\sigma(e^+e^- \to B_s^*\overline{B}_s^*)} < 0.16 \quad \text{and} \quad \frac{\sigma(e^+e^- \to B_s\overline{B}_s^*) + \sigma(e^+e^- \to B_s^*\overline{B}_s)}{\sigma(e^+e^- \to B_s^*\overline{B}_s^*)} < 0.16$$

- Relating B_s branching fractions to B branching fractions with contributions from the same quark-level diagrams and assuming SU(3) symmetry, we find:

$$\sigma(e^+e^- \to B_s^*\overline{B}_s^*) = [0.11^{+0.04}_{-0.03}(stat) \pm 0.02(syst)]\, nb$$

which is consistent with the theory (UQM): 1/3 of 0.30 - 0.35 nb of the total Υ(5S) cross-section.

- The mass of the B_s^* meson is measured to be

$$M(B_s^*) = [5.414 \pm 0.001(stat) \pm 0.003(syst)]\, GeV$$

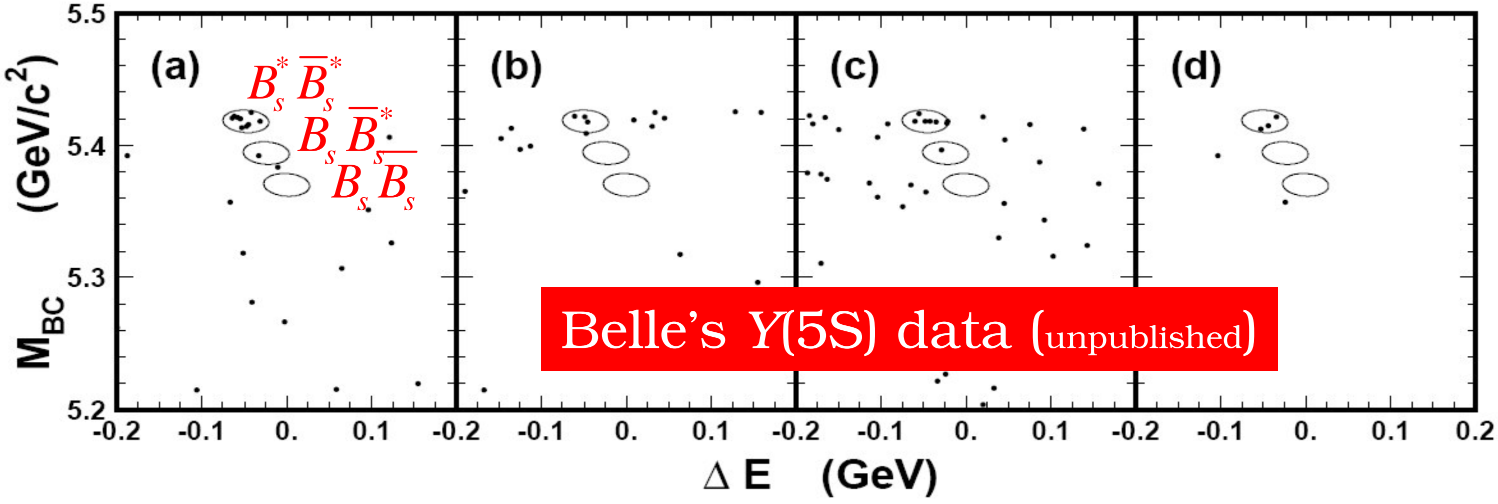
[for more information see: hep-ex/0510034; PRL **96**, 022002 (2006)]

Other Υ(5S) Results from CLEO and Belle

- "Evidence for $B_s^{(*)}$ production at the Υ(5S)" from CLEO [PRL **95**, 261801 (2005)]. Includes a model dependent measurement of the relative $B_s^{(*)}$ production rate with respect to the total *b*-quark production rate at the Υ(5S) of (16±3±6)%

- Exclusive *B* reconstruction at the Υ(5S) from CLEO [PRL **96**, 152001 (2006)]. Uses the same technique as in this analysis. Includes a measurement of the total B production cross-section of (0.18±0.03±0.02) nb, *i.e.*, about 2/3 of of the Υ(5S) cross-section. Improves the beam energy calibration and the B_s^* mass measurement.

- The Belle collaboration collected about 1.9 fb^{-1} in June, 2005. Preliminary results for B_s production are shown recently at SLAC in mid-January, Moriond EW-06 and FPCP-06. In general they confirm CLEO B_s results. Belle is going to collect a much larger sample at the Υ(5S).



Belle's Υ(5S) data (unpublished)

Overall Summary

- After 20 years of studying B mesons at the $\Upsilon(4S)$, in 2003 CLEO shifted its focus to charm physics at the $\psi(3770)$.

- The main goals of the CLEO-c open charm program are:
  - ✓ Test and validate LQCD predictions (a theory capable of solving strongly coupled field theory equations);
  - ✓ Provide input on charm decays to other experiments to increase their potential

- I have described how this is being done using D meson semileptonic decays.

- I have also presented a study of B_s production at the $\Upsilon(5S)$ using a small data sample taken in 2003.

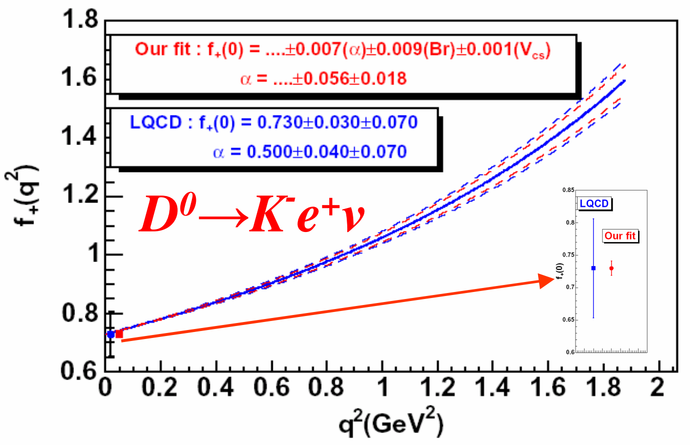
Thank you

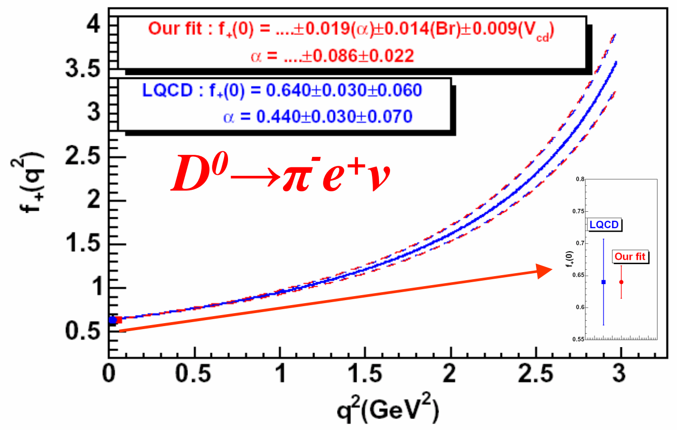
Additional Slides

Projections for α and $f_+(0)$

In these plots, the central values for projections are equal to the central values from the LQCD results

The expected precision from the current 280 pb^{-1} data sample in this analysis





The anticipated precision for a larger 750 pb^{-1} data sample to be collected in the future