Charm Semileptonic Decays

Outline:

Overview and Motivation

Review of results
- Detailed look at recent CLEO-c work
- Overview of others
  CLEO-c (untagged)
  Babar
  Belle

Comments on future

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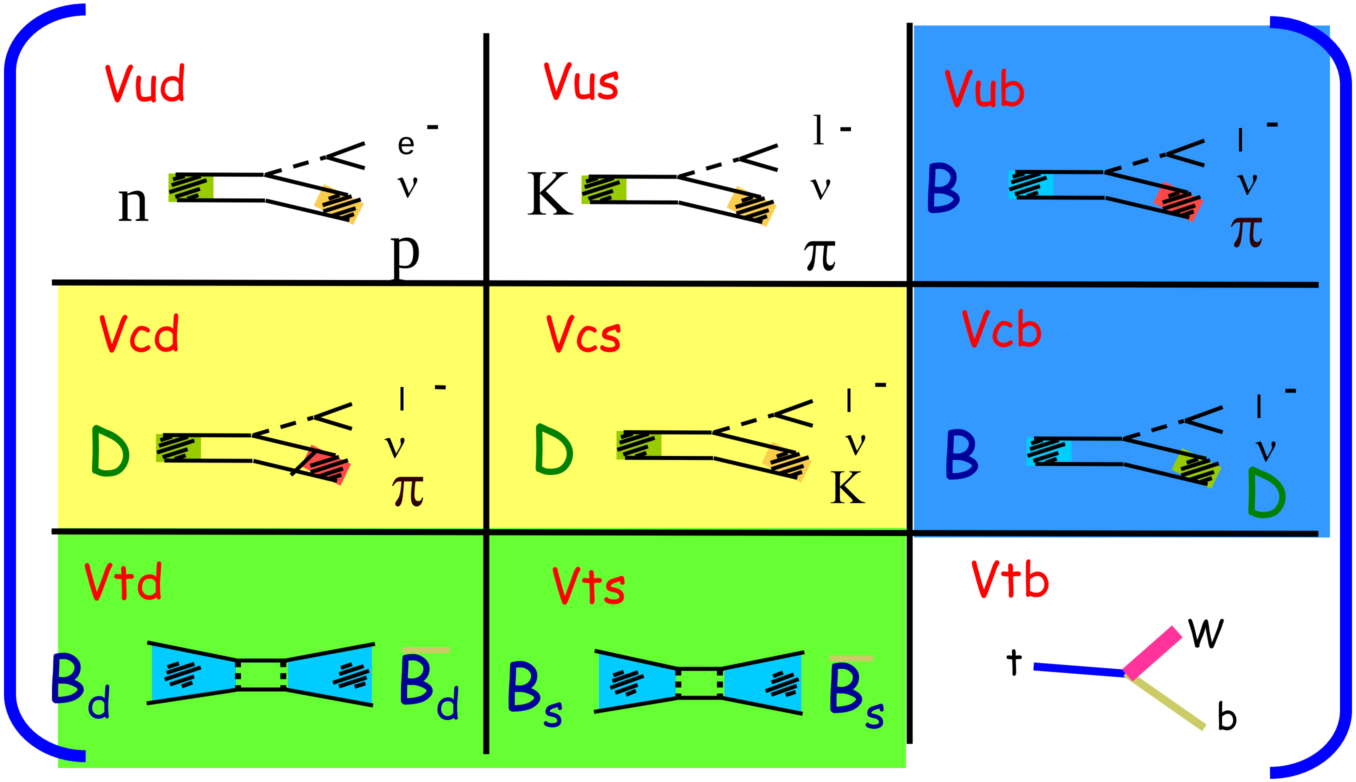
CKM2008
Sep 10, 2008

Access to CKM

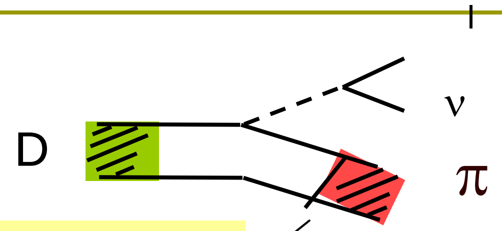


CLEO-c
BES III

CLEO-c +BES III+
Lattice+B factories

CLEO-c+BES III+
Lattice+B factories
+ ppbar

Access to CKM



$$\frac{d\Gamma}{dq^2} \propto |V_{cd}|^2 |f_+^{D\to\pi}(q^2)|^2$$

Charm measurements provide verification of lattice predictions

$$|V_{ub}| = (3.17 \pm 0.10^{+0.74}_{-0.44}) x 10^{-3}$$

Exp: 3%
BABAR/Belle/CLEO

HPQCD: 16%
hep-lat/0601021

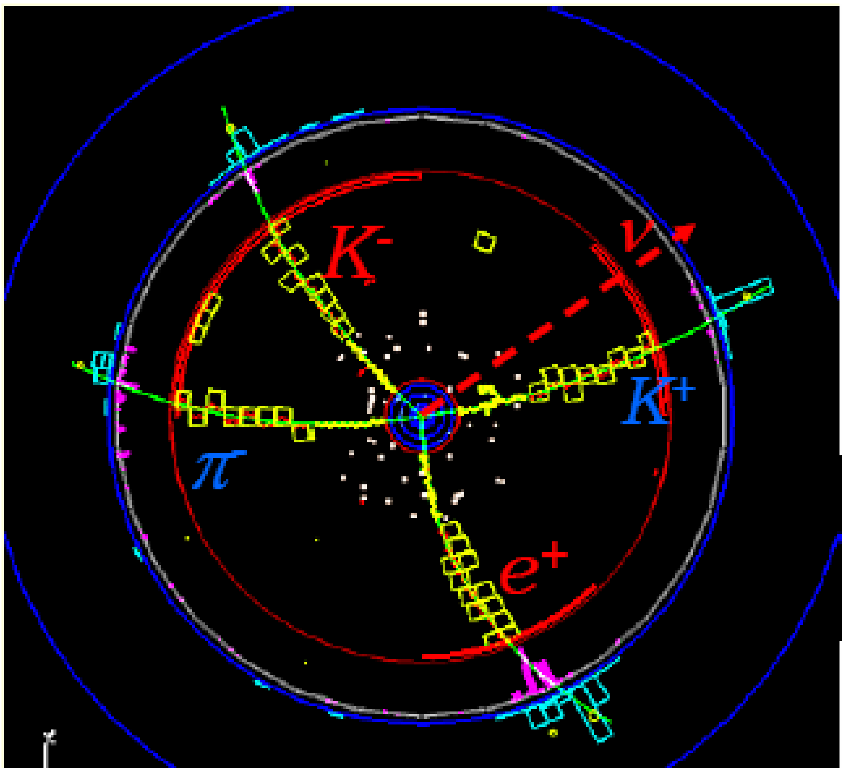
$$\Gamma = \frac{BR}{\tau}$$

Lifetime known to about ~0.5%.

Pre-2004 BR(D→π e n)
Known to about 45%

Tagging

CLEO-c

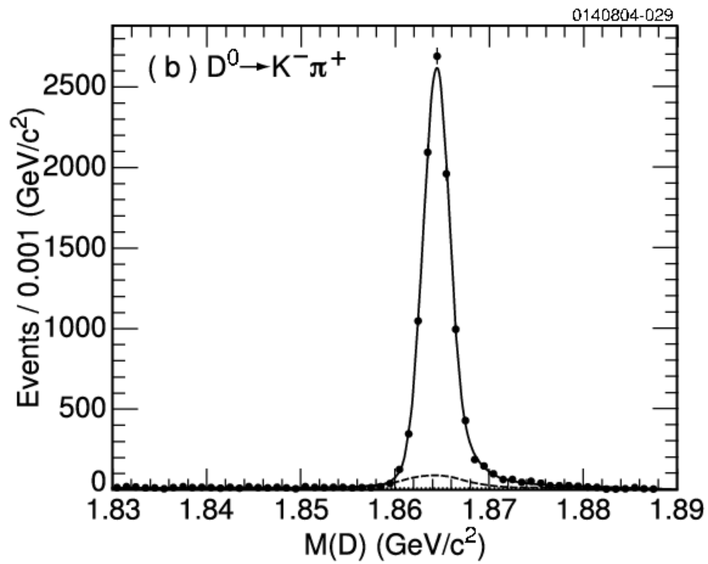


$\psi(3770) \rightarrow D^0 \overline{D^0}$

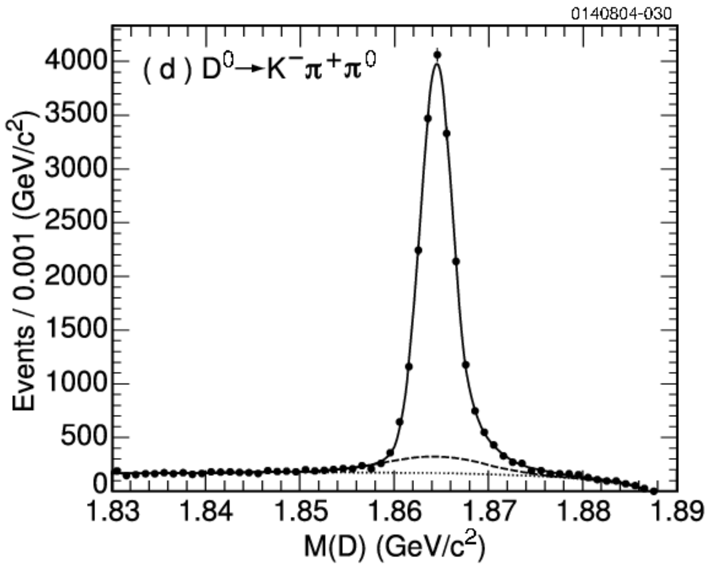
→D meson has large branchings to low multiplicity modes
→Requiring a reconstructed D provides background suppression.
→D-Tagging removes half the event event (only a single D remains).
→Simultaneously provides 4-vector vector of other D meson.

D-Tagging

$D^0 \rightarrow K^-\pi^+$



$D^0 \rightarrow K^-\pi^+\pi^0$



$$M_{bc} = \sqrt{E_{beam}^2 - P_{candidate}^2}$$

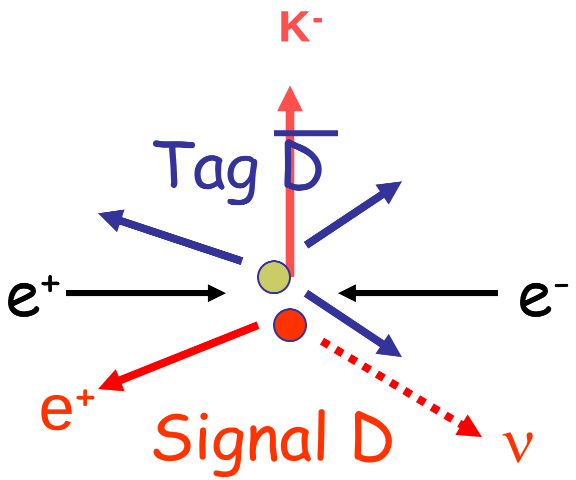
$$\Delta E = E_{candidate} - E_{beam}$$

BR Measurements

D-Tagging

* e+e- → ψ(3770)→ D $\overline{\text{D}}$

* Backgrounds at ψ(3770): continuum (18 nb), τ pair pair (3 nb), radiative return (~1.5 nb)



Signal component from fit to variable U

$$B(D^+ \to \overline{K}^0 e^+ \nu) = \frac{N(\overline{K}^0 e^+ \nu)}{\varepsilon(\overline{K}^0 e^+ \nu) N(D^-)}$$

From Monte Carlo/Data

From fit of M_{bc} and ΔE for number of tags

Summary of BRs – CLEO-c

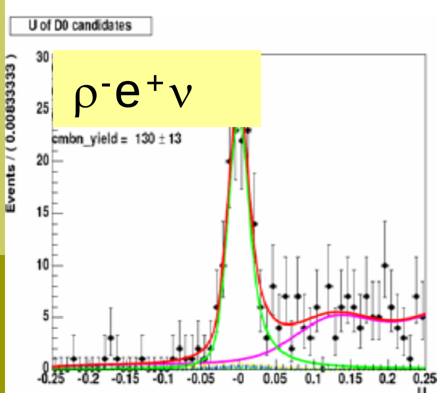
PRL 95, 181801 (2005)
PRL 95, 181802 (2005)
PRL. 99, 191801 (2007)

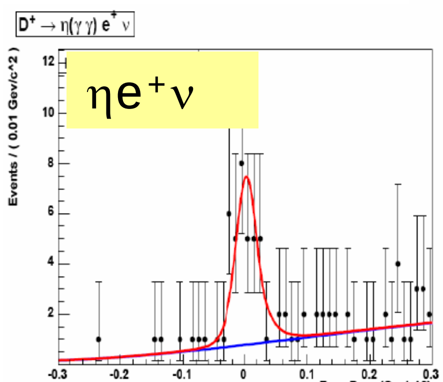
Main identification variable U:
$U = E_{miss} - |P_{miss}|$

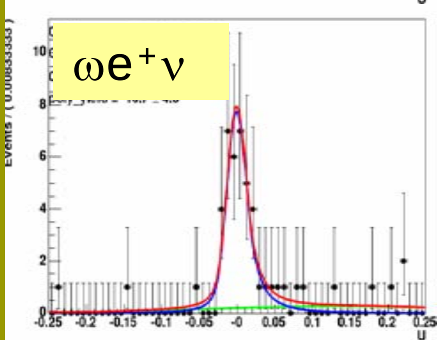
Results shown in figure are for 281/pb.

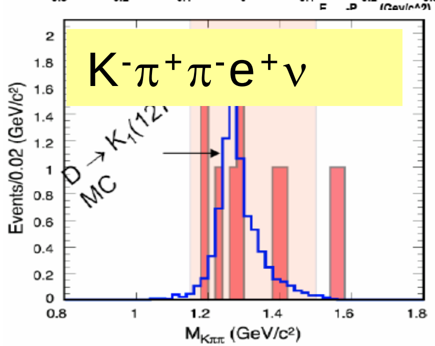
Significant improvement on previous measurements.

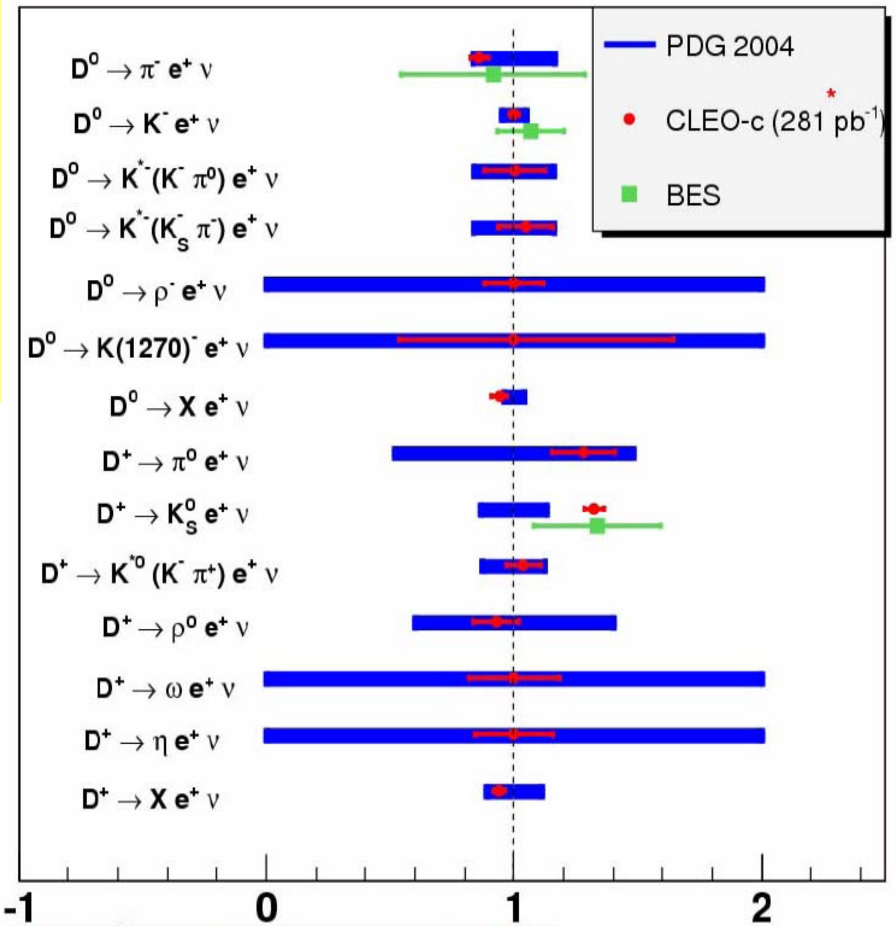
Four new modes observed:
(ρ/ω are preliminary)









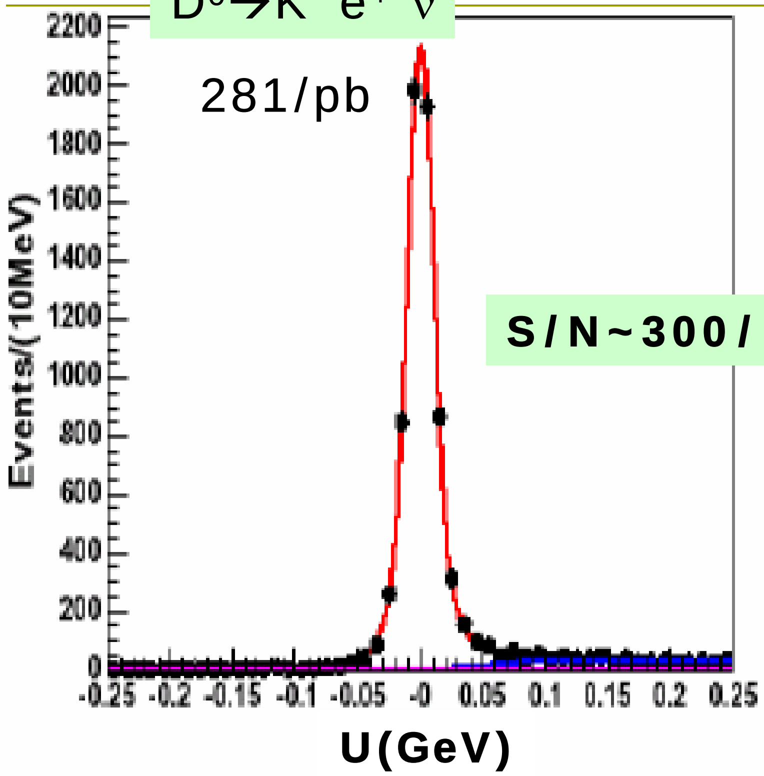


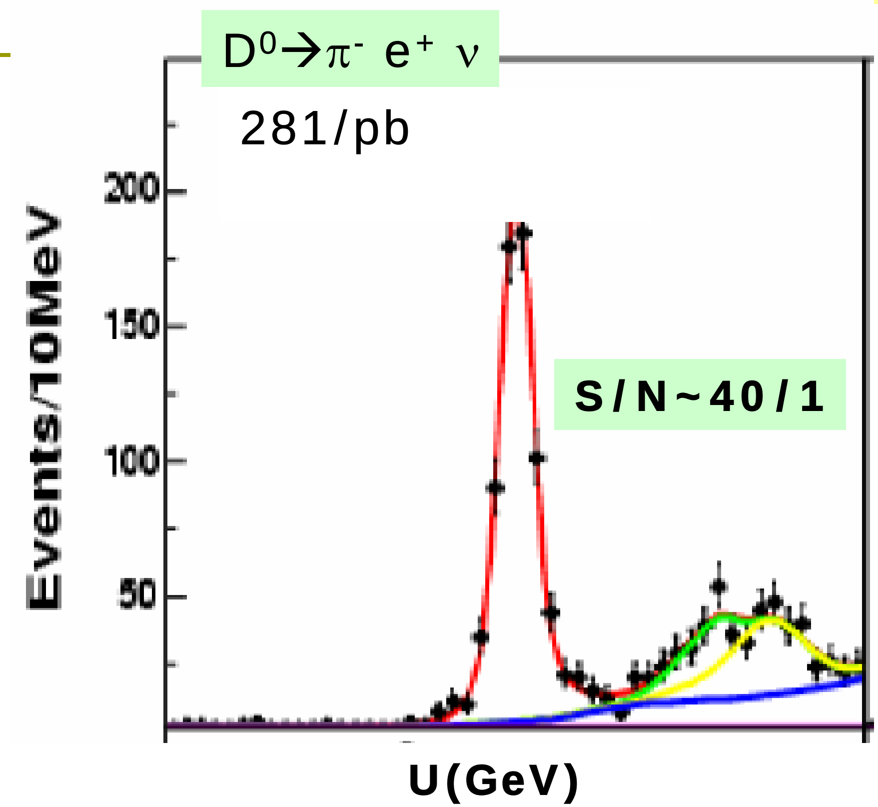
* $D \to K^* e^+ \nu$ branching fractions are for 56/pb

K and π modes above are for 56/pb.
Update for these modes next slide.

Exclusive Semileptonic – CLEO-c

To be submitted (PRD)





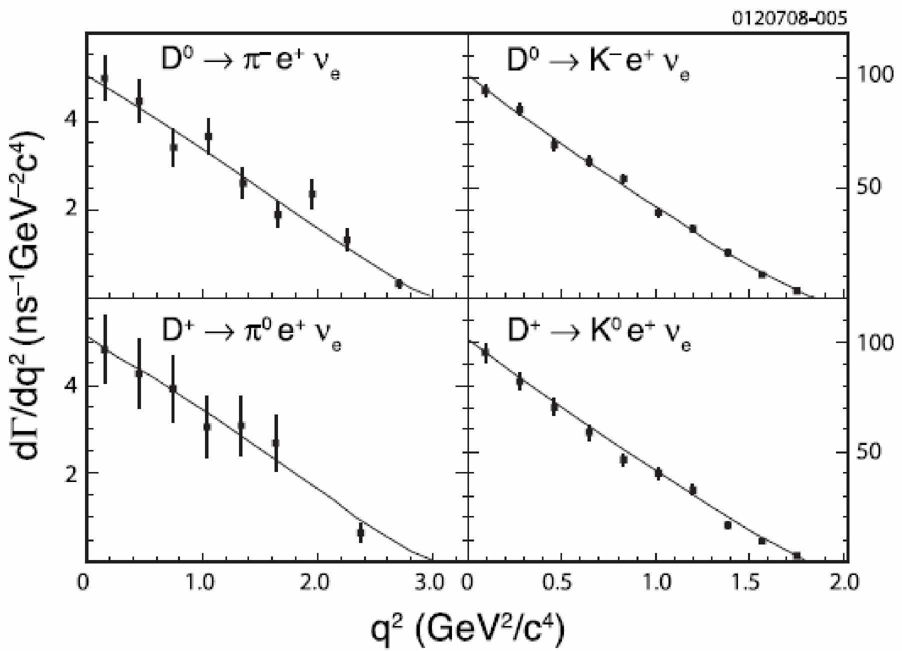
$BR(D^0 \to K^- e^+ \nu) = 3.61(5)(5)$
$BR(D^+ \to K^0 e^+ \nu) = 8.90(17)(21)$

BR in %

$BR(D^0 \to \pi^- e^+ \nu) = 0.314(13)(4)$
$BR(D^+ \to \pi^0 e^+ \nu) = 0.384(27)(23)$

Exclusive Semileptonic – CLEO-c

New: Final CLEO-c tagged results (To be submitted)



Simple pole	$f_+(0)\|V_{cq}\|$	M_{pole}	ρ	χ^2 per dof
$D^0 \to \pi^- e^+ \nu_e$	0.152(4)(1)	1.94(4)(1)	0.68	1.26
$D^+ \to \pi^0 e^+ \nu_e$	0.153(7)(5)	1.99(10)(5)	0.68	0.37
$D^0 \to K^- e^+ \nu_e$	0.736(7)(6)	1.95(4)(1)	0.78	0.81
$D^+ \to \bar{K}^0 e^+ \nu_e$	0.733(11)(9)	2.02(6)(2)	0.78	0.80
$D \to \pi e^+ \nu_e$	0.152(4)(1)	1.95(4)(2)	0.68	0.82
$D \to K e^+ \nu_e$	0.735(7)(5)	1.97(3)(1)	0.78	1.00

Mod.pole	$f_+(0)\|V_{cq}\|$	α	ρ	χ^2 per dof
$D^0 \to \pi^- e^+ \nu_e$	0.150(6)(1)	0.18(12)(4)	-0.83	1.26
$D^+ \to \pi^0 e^+ \nu_e$	0.151(9)(4)	0.09(22)(12)	-0.80	0.35
$D^0 \to K^- e^+ \nu_e$	0.733(8)(6)	0.25(6)(2)	-0.83	0.94
$D^+ \to \bar{K}^0 e^+ \nu_e$	0.732(12)(9)	0.12(10)(4)	-0.82	0.83
$D \to \pi e^+ \nu_e$	0.150(5)(2)	0.16(10)(5)	-0.81	0.78
$D \to K e^+ \nu_e$	0.733(7)(6)	0.21(5)(2)	-0.83	1.01

Absolute $d\Gamma/dq^2$

Background subtracted.

Efficiency corrected.

The only D+ measurements.

Allows check of isospin invariance. Good agreement

q^2 resolution .012 GeV^2 (0.04 Gev^2 for π^0)

Line is series expansion.

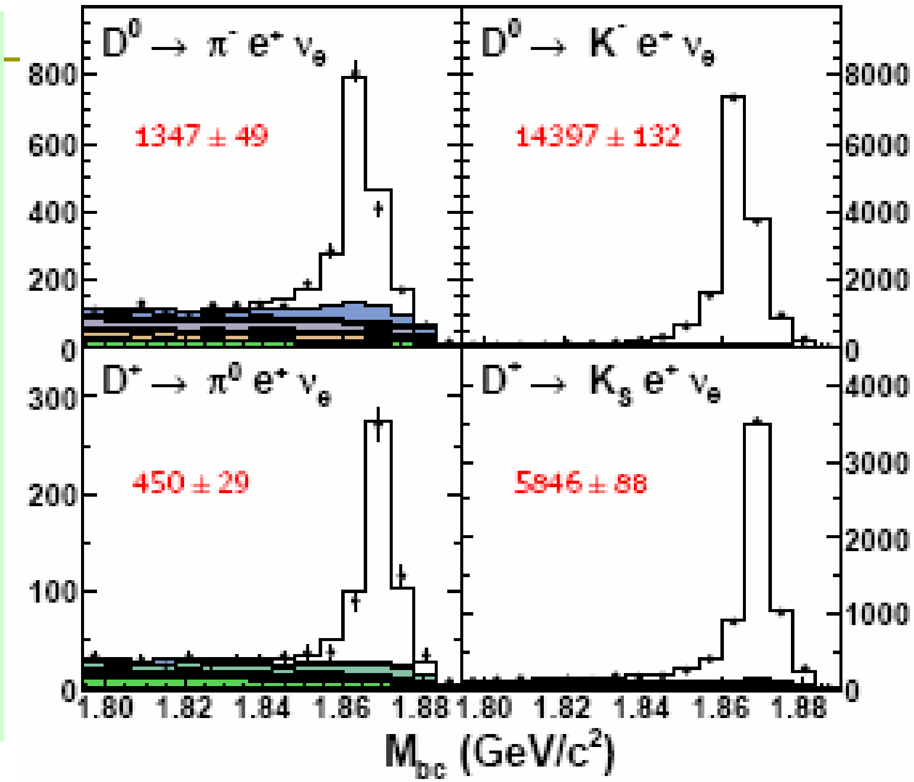
CLEO-c Untagged D→ K(π) e ν

Uses neutrino reconstruction:
Identify semileptonic decay.

Reconstruct neutrino 4-momentum from all measured energy/momentum in the event.

Use K(π), e, and missing 4-momentum and require consistency in energy and beam-energy constrained mass.

Higher efficiency but larger backgrounds and larger systematic uncertainties.



M_{bc} distributions fitted simultaneously in 5 q^2 bins to obtain $d(\mathrm{BF})/dq^2$.
Integrate to get branching fractions and fit to obtain form-factor parameters.

BR(D^0 → $K^- e^+ \nu$) = 3.557(33)(90)
BR(D^+ → $K^0 e^+ \nu$) = 8.53(13)(23)

ssy

BR(D^0 → $\pi^- e^+ \nu$) = 0.299(11)(9)
BR(D^+ → $\pi^0 e^+ \nu$) = 0.373(22)(13)

BR in %

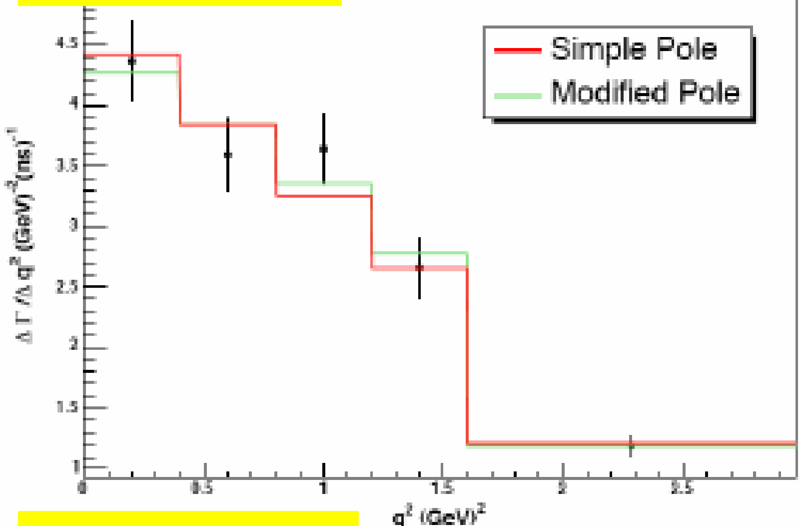
PRD 77 112005 (2008)

ArXiv 0712.1020
ArXiv 0712.1025

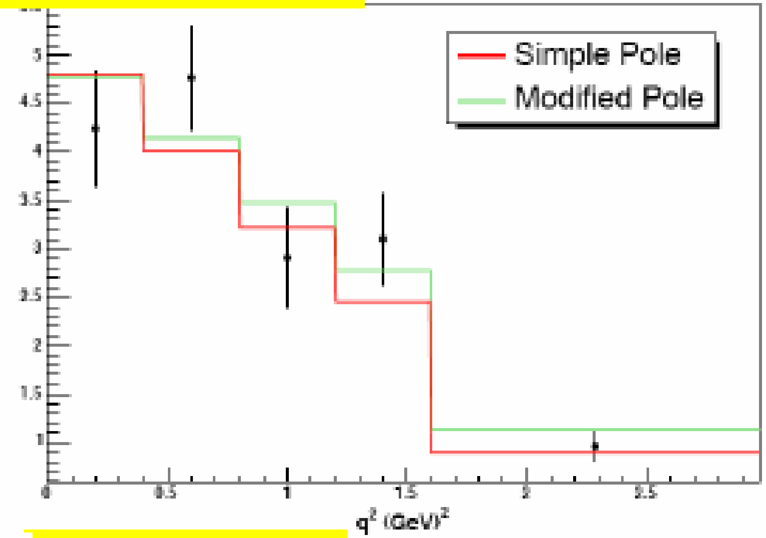
Form Factor Fit Plots

untagged analysis

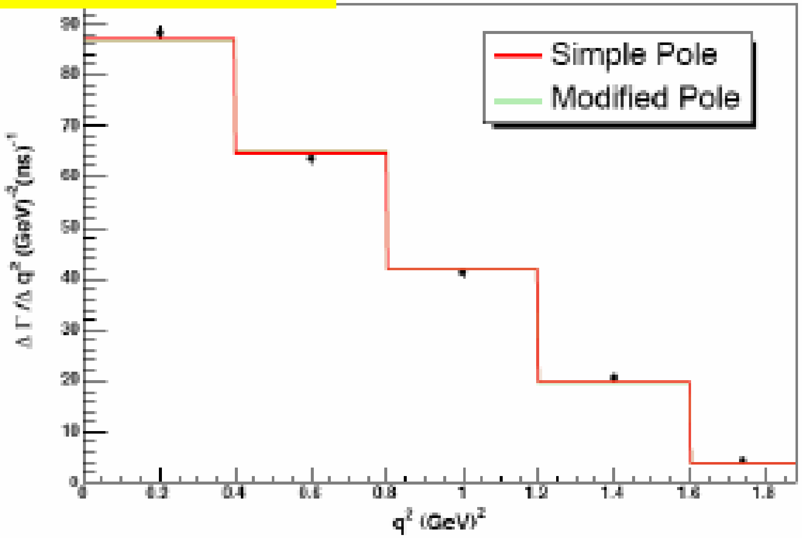
$D^0 \to \pi^- e^+ \nu$



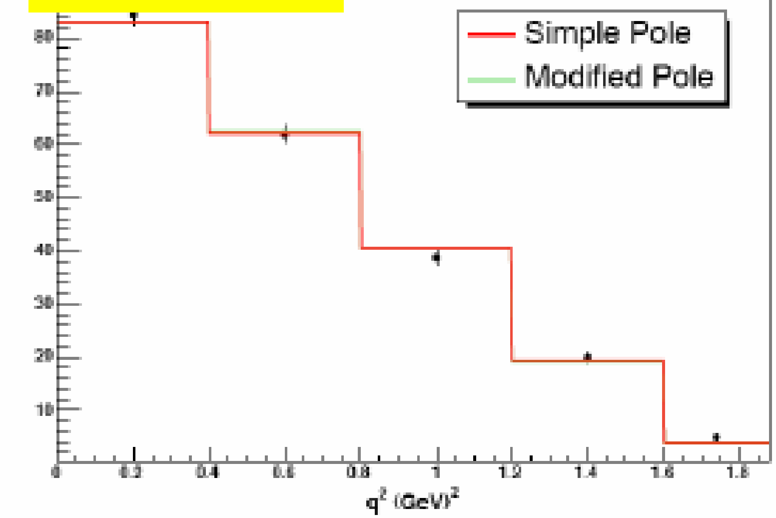
$(\times 2) D^+ \to \pi^0 e^+ \nu$



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



$D^+ \to \overline{K^0} e^+ \nu$



Latt

Combined CLEO-c results

281/pb

Branching Fractions

	CLEO-c (tag)	CLEO-c (no-tag)	Average
$\pi^- e^+ \nu_e$	0.308(13)(4)	0.299(11)(8)	0.304(11)(5)
$\pi^0 e^+ \nu_e$	0.379(27)(23)	0.373(22)(13)	0.378(20)(12)
$K^- e^+ \nu_e$	3.60(5)(5)	3.56(3)(9)	3.60(3)(6)
$\bar{K}^0 e^+ \nu_e$	8.87(17)(21)	8.53(13)(23)	8.69(12)(19)

Form factors

K: $f^+(0)V_{cs} = 0.744(7)(5)$
π: $f^+(0)V_{cd} = 0.143(5)(2)$

$\mathbf{V_{cd} = 0.223 \pm 0.008 \pm 0.003 \pm 0.023}$
$\mathbf{V_{cs} = 1.019 \pm 0.010 + 0.007 \pm 0.106}$

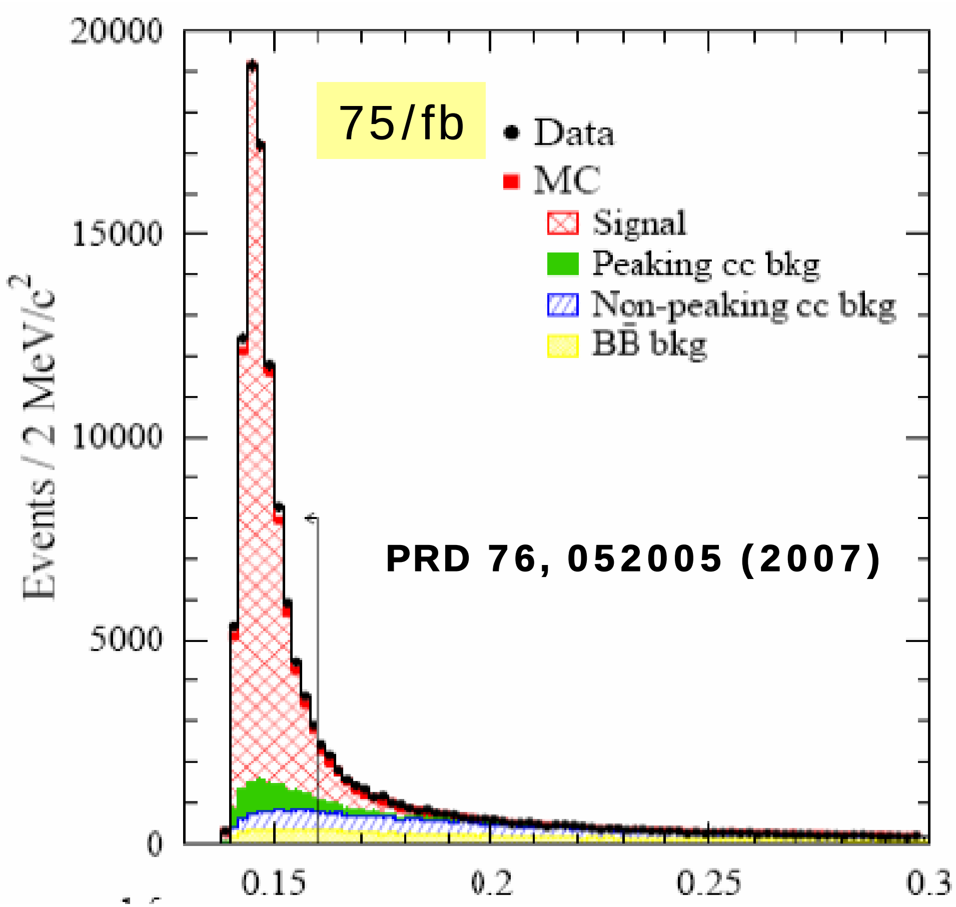
$F^+(0)$ from Lattice:C. Aubin *et al.*, PRL**94** 011601 (2005)

Untagged and tagged data samples are the same.
Untagged analysis contains 2.5x the events and contains nearly the entire tagged analysis. The untagged analysis has larger background. The resolutions of these analyses are comparable.

In obtaining the average result all significant correlations are included.

These measurements represent the best determination of V_{cs} and the best determination of V_{cd} from semileptonic measurements.

BaBar $D^0 \rightarrow K^- e^+ \nu$



$\Delta M = M(Ke\nu\pi) - M(Ke\nu)$ Gev

Identifies slow π for D* reconstruction.

Plot shows ΔM distribution.

Similar to CLEO III but with neutrino reconstruction from entire event.

Not as pure as CLEO-c but higher statistics (74k events in plot).

Needs a normalization mode for BR.

Error dominated by CLEO-c $D^0 \rightarrow K\pi$ BR.

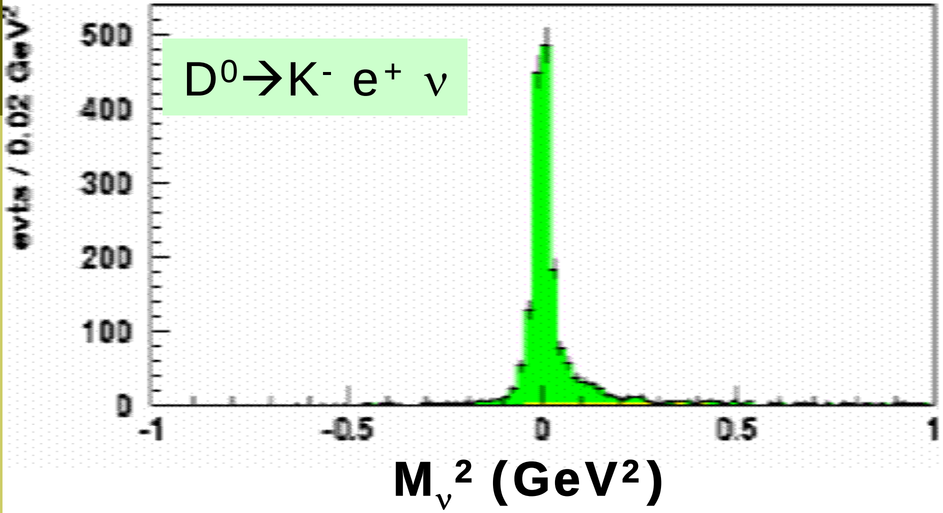
$BR(D^0 \rightarrow K^- e^+ \nu) = (3.522 \pm 0.027 \pm 0.045 \pm 0.065)\%$

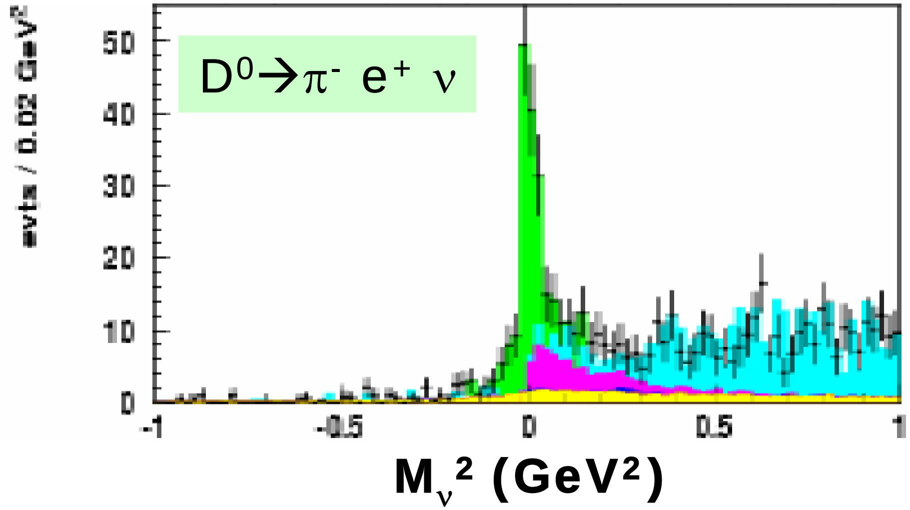
$f^+(0) = 0.727 \pm 0.007 \pm 0.005 \pm 0.007$

Belle $D^0 \rightarrow K^-(\pi^-)\, e^+ (\mu^+)\, \nu$

PRL 97 061804 (2006)

282/fb





Novel approach: Full reconstruction of $e^+e^- \rightarrow$ c cbar

Reconstruct: $e^+e^- \rightarrow D^{(*)}_{tag}\, D^{*-}\, X$

The 56k tags allow an absolute measurement (like CLEO-c)

Lower statistics than Babar & CLEO-c but complementary analysis.

$BR(D^0 \rightarrow K^- l^+ \nu) = (3.45 \pm 0.07 \pm 0.2)\,\%$

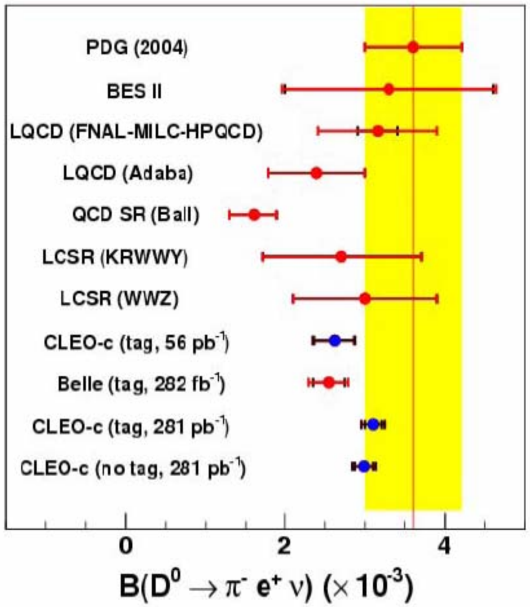
$f^+(0)_K = 0.695 \pm 0.007 \pm 0.022$

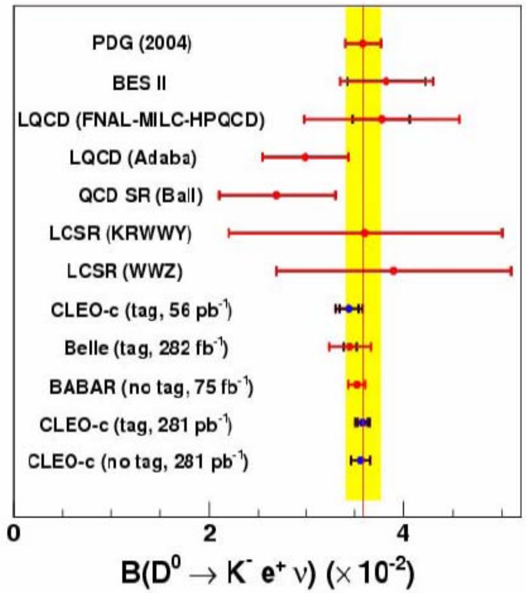
$BR(D^0 \rightarrow \pi^- l^+ \nu) = (0.225 \pm 0.019 \pm 0.016)\,\%$

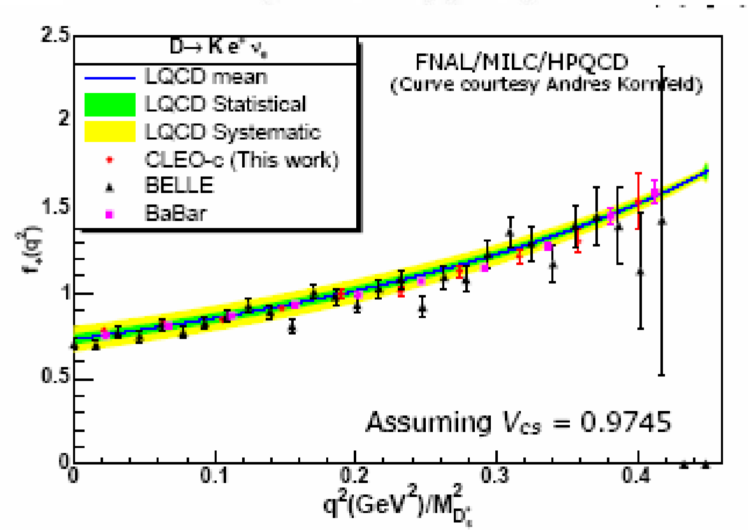
$f^+(0)_\pi = 0.624 \pm 0.020 \pm 0.030$

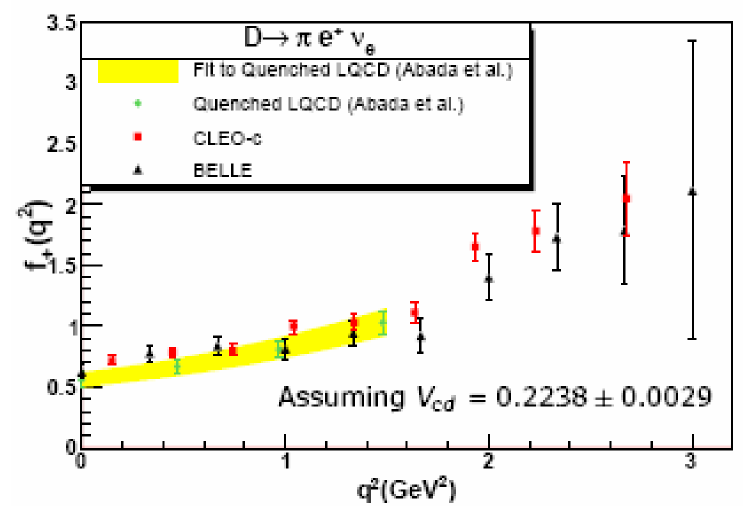
Summary Plots

The next level of precision has been reached with the analyses from BaBar, Belle and CLEO-c









Modified pole model used as example:

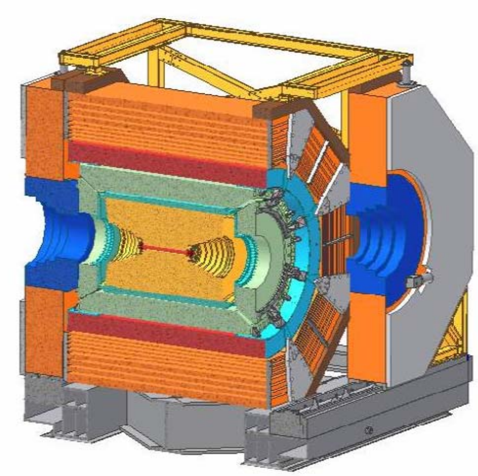
$$f_+(q^2) = \frac{f_+(0)}{(1-q^2/m^2_{pole})(1-\alpha q^2/m^2_{pole})}$$

Comments

- **Future Improvements:**
  - BaBar, Belle and CLEO-c all have unanalyzed data. Unanalyzed data data varies from 9/10 to 2/3.
  - BaBar and CLEO-c analyses will gain more quickly since their approaches have larger relative statistical uncertainty.
  - Pion modes are statistics limited and will benefit greatly from the upcoming work. I would expect a measurement from BaBar for the $D^0 \rightarrow$ $D^0 \rightarrow \pi\, e\, \nu$ soon.
  - The largest uncertainties of V_{cq} arise from theory.
    - With expected improvements from theory V_{cd} from semileptonic decay may may surpass V_{cd} from νN.
- **Note:** Many charm semileptonic results that test our theory could not be presented in this talk. BaBar, Belle, CLEO-c and FOCUS all contribute to to these. They include inclusive semileptonic, vector form factors, rare and and interesting modes and Ds decays.
- What is next?

BES III

- BESIII has started data accumulation.
- Current running is at ψ'.
- Detector capabilities similar to CLEO-c.
- Early major start problems are solved.
- Luminosity at this early date is ~CESR-c.
- Expect 10 times CLEO-c at 3770 luminosity with one year of running.



First hadronic event: July 20