The CLEO-c Experiment and its Impact

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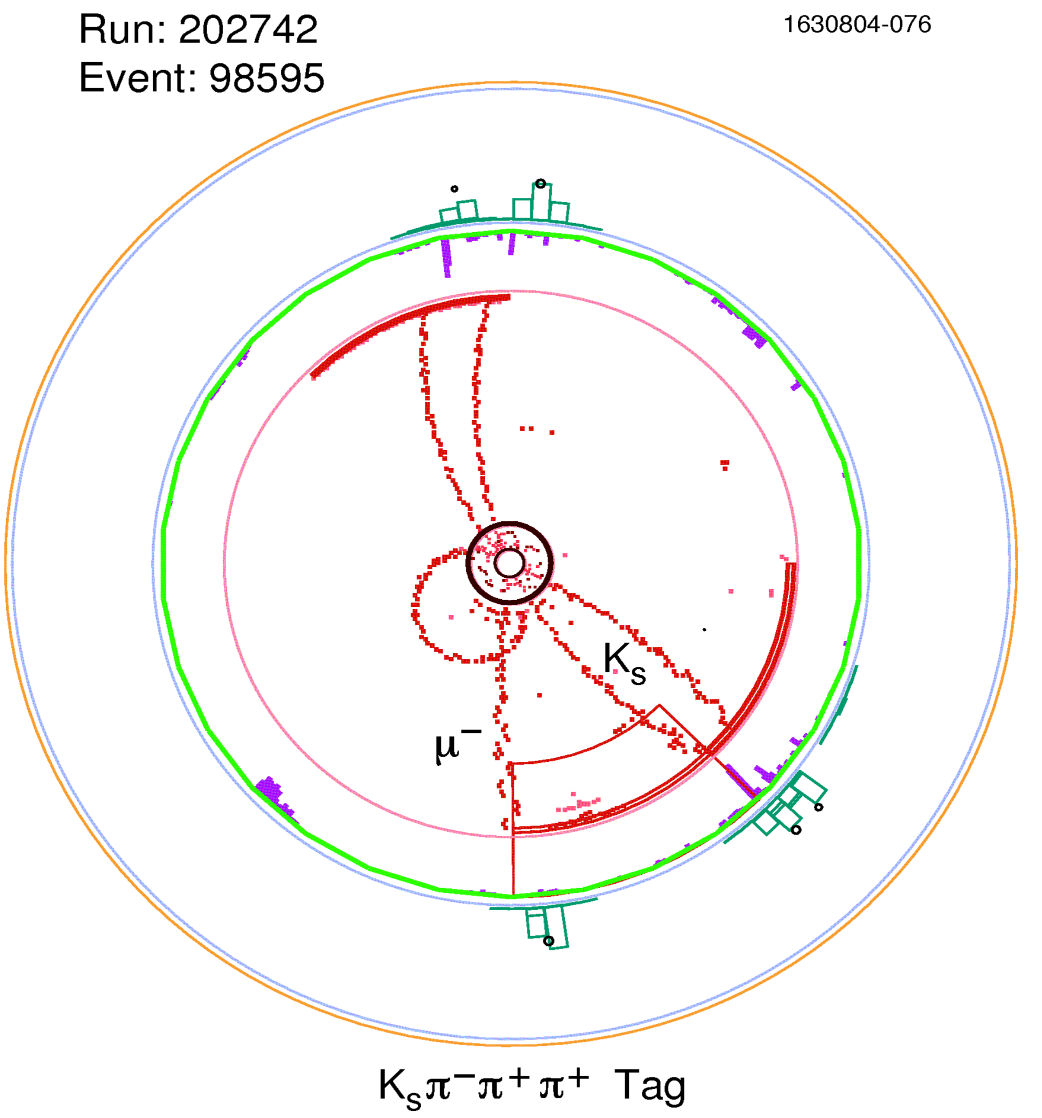


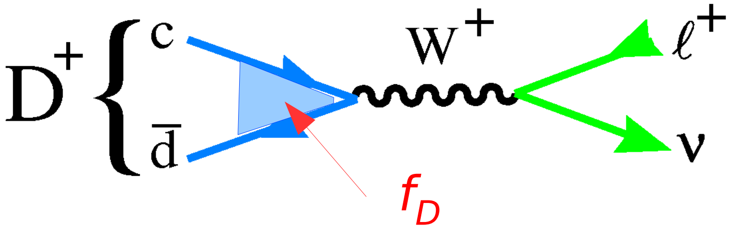
Outline:

- The CLEO-c Physics Program
- Tests of Lattice QCD
- Some Recent CLEO-c Results:
  - Hadronic *D* Decays
  - Leptonic *D* and D_s Decays
  - Semileptonic *D* Decays
- Conclusions

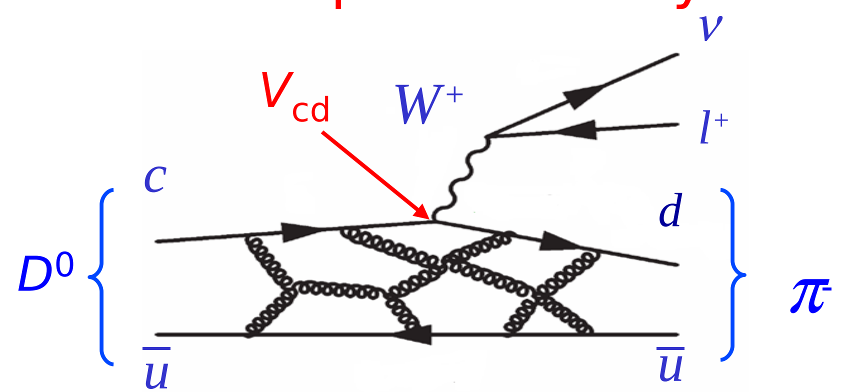
Heavy Quark Physics

- Many experiments study decays of *b*-quarks:
  - B-factories: BABAR and Belle
  - Tevatron: CDF and D0
  - LHC: LHCb
- The CLEO-c experiment is making unique contributions to these studies

Leptonic decays



Semileptonic decays



Decay constant, f_D, describes overlap of *c* and *d* quark in the D^+.

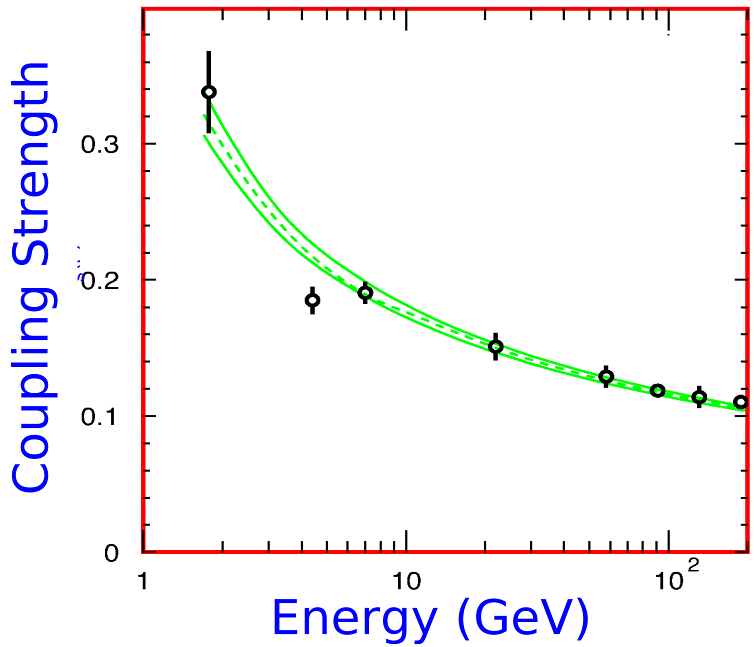
Form factors describe prob. to form final state: $f(p)=<\pi|H|D>$

QCD (Quantum ChromoDynamics) is a strongly interacting theory

CLEO-c will allow crucial tests of Lattice QCD

Lattice QCD

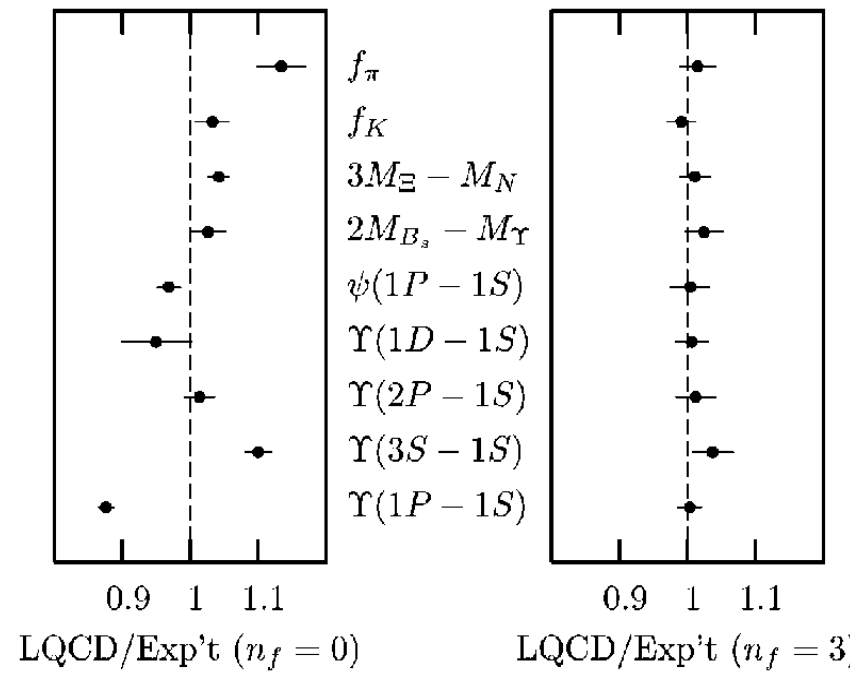
- At low energy QCD is strongly coupled



- Calculations done on discrete lattice
- Recent revolutionary progress in algorithms have allowed simulation of full QCD.
  - Can handle QCD vacuum polarization
- Understanding strongly coupled systems is important.
  - LHC might uncover new strongly interacting physics.

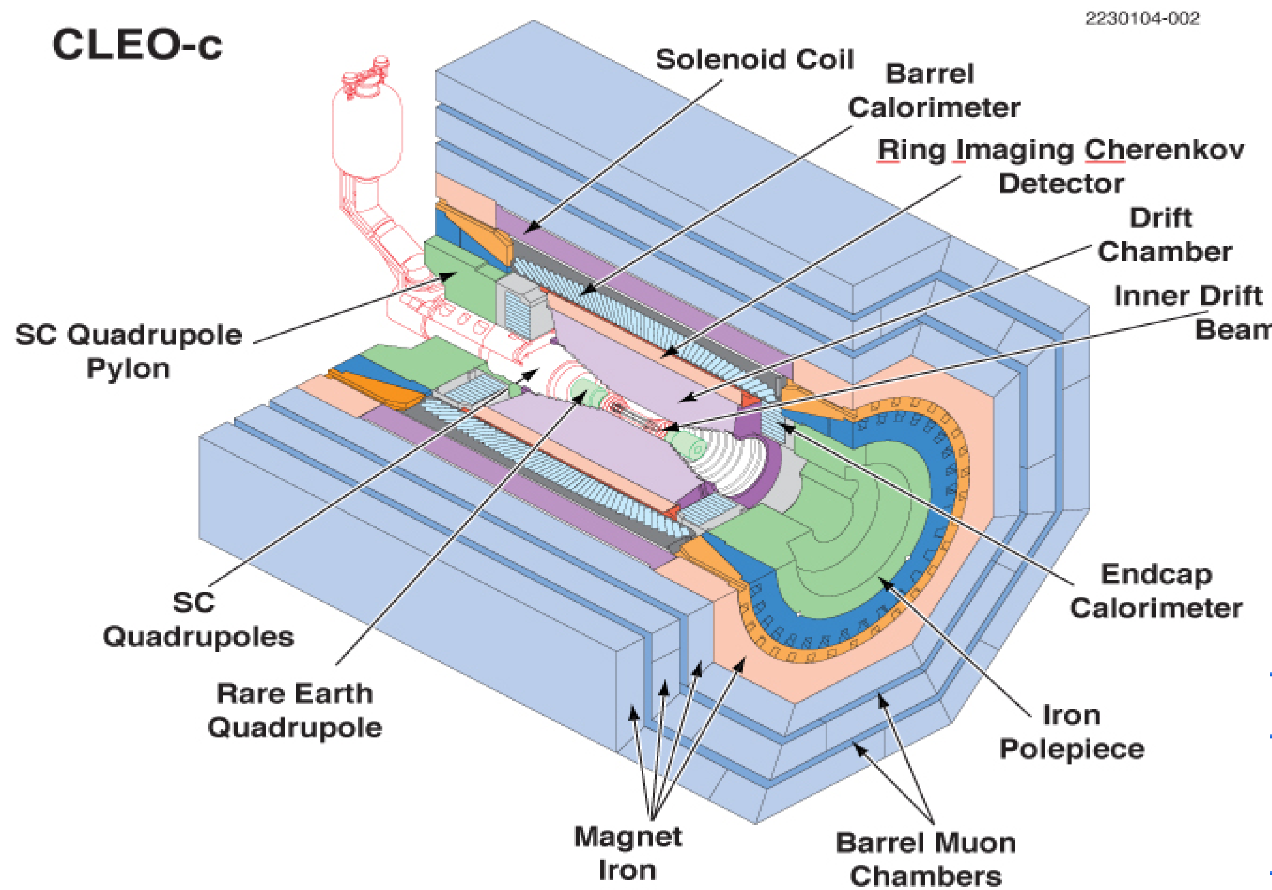
HPQCD+FERMILAB+MILC
PRL 92:022001,2004

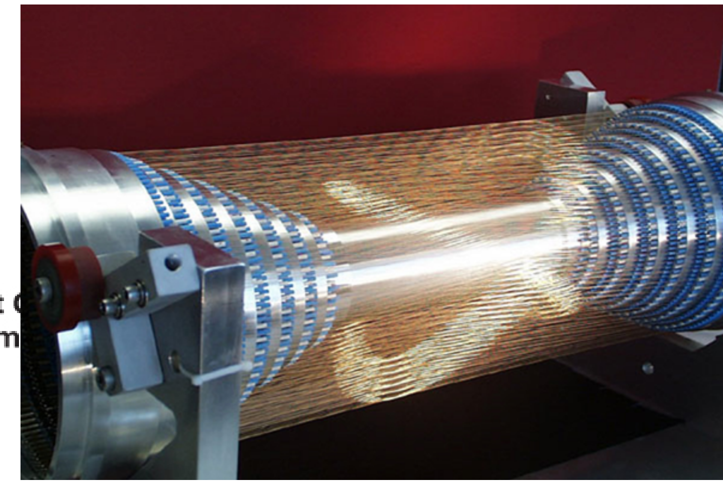
Before 2000 ~2004



This dramatic improvement in Lattice QCD needs to be validated in calculations of form factors and decay constants

CLEO-c Experiment

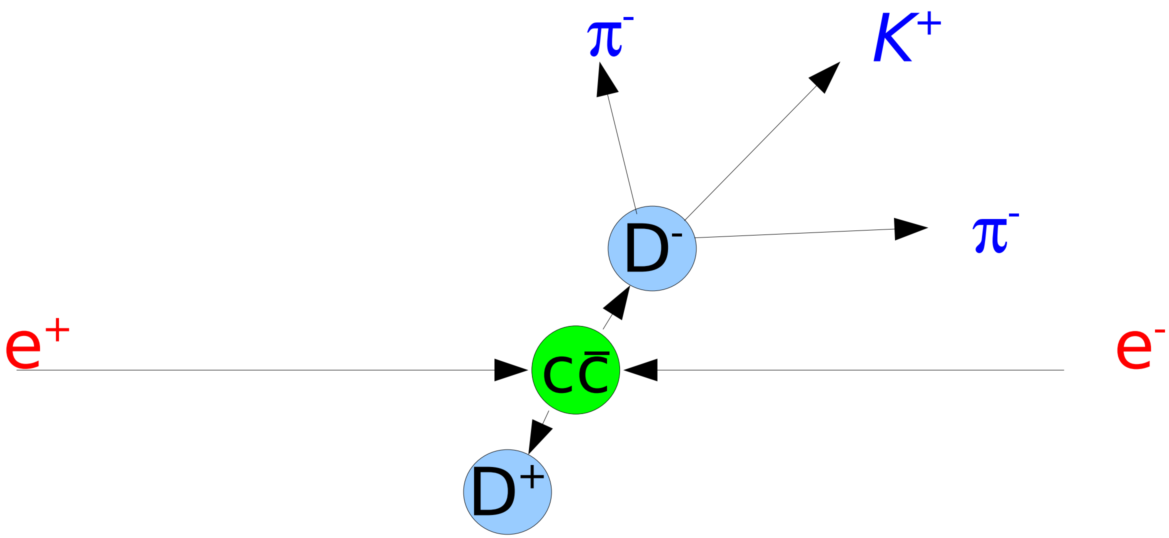




- New inner drift chamber
- Tracking in 1.0 T field
  - $\sigma_p/p \approx 0.6\%$ at 1 GeV
- Excellent E-M calorimeter
  - $\sigma_E/E \approx 2\%$ at 1 GeV
- Hadron PID from RICH
  - Very good below 1 GeV

CLEO-c detector is working very well.
The detector capabilities are well matched to the physics.

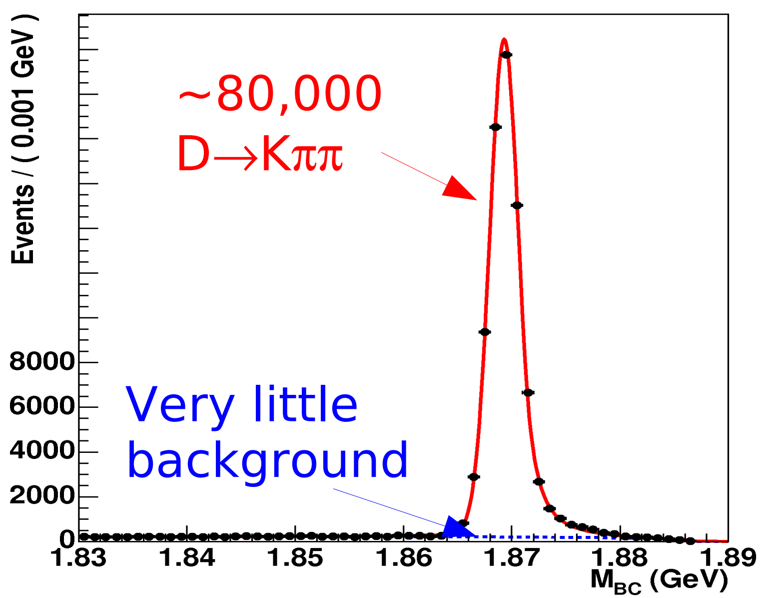
Absolute *D* Branching Fractions



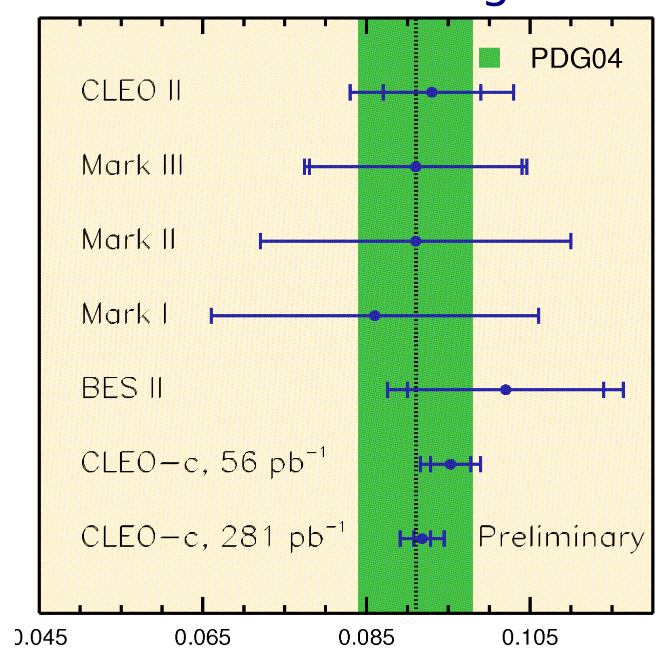
Tag *D* – fully reconstructed

Unique to CLEO-c:
Running near $c\bar{c}$ threshold

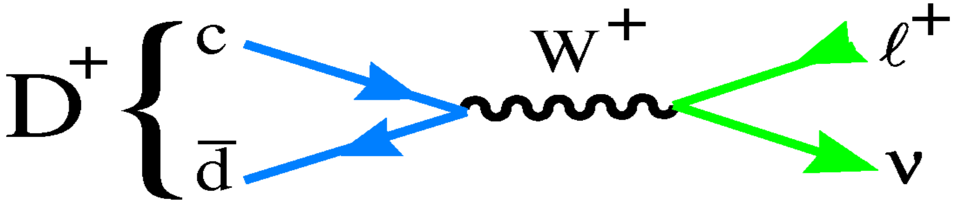
Data (281 fb^{-1})

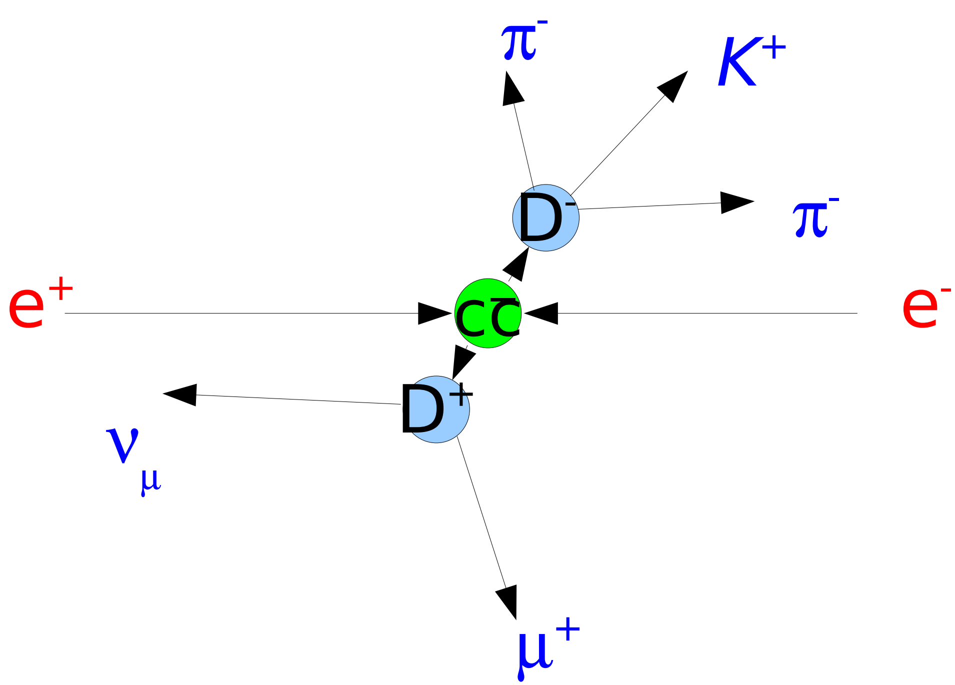


$D^+ \to K^- \pi^+ \pi^+$ Branching Fraction

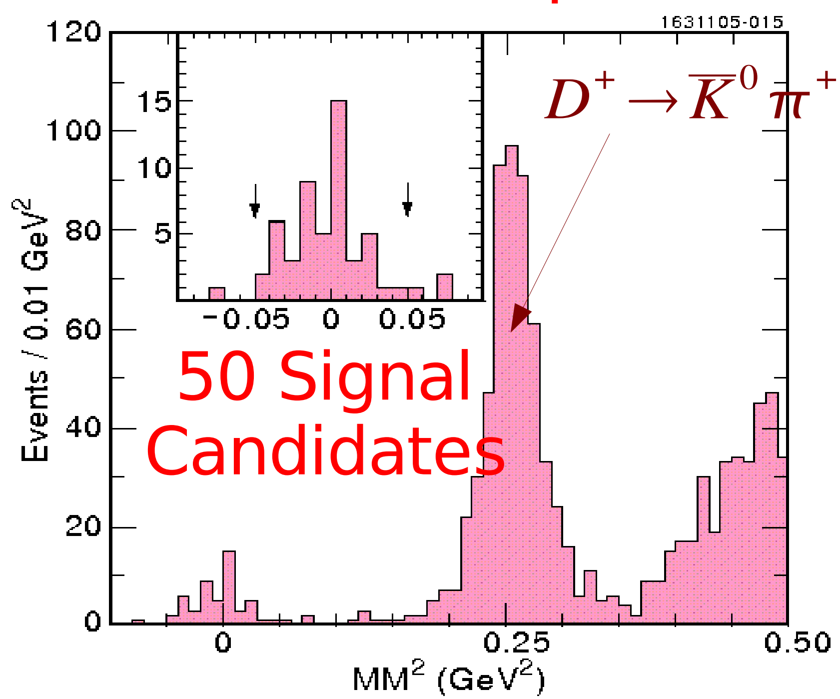


$D^+ \to \mu^+ \nu_\mu$ and f_{D^+}





Data 281 pb^{-1}



$$Br(D^+ \to \mu^+ \nu) = (4.40 \pm 0.66^{+0.09}_{-0.12}) \times 10^{-4}$$

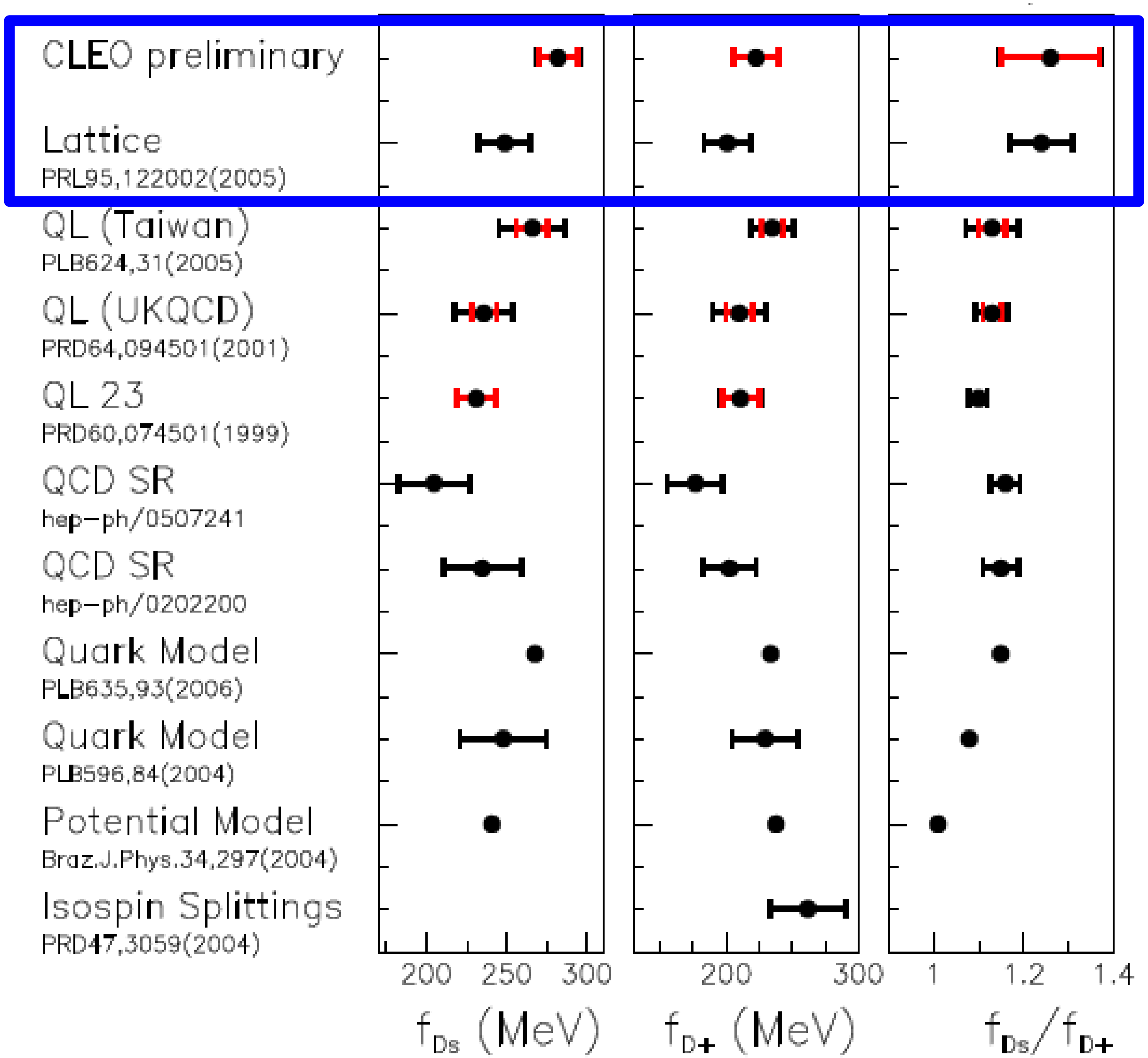
$$f_{D^+} = (222.6 \pm 16.7^{+2.8}_{-3.4})\,\mathrm{MeV}$$

PRL 95, 251801 (2005)

First significant measurement of $D^+ \to \mu^+ \nu_\mu$

Data *vs.* Lattice Calculations

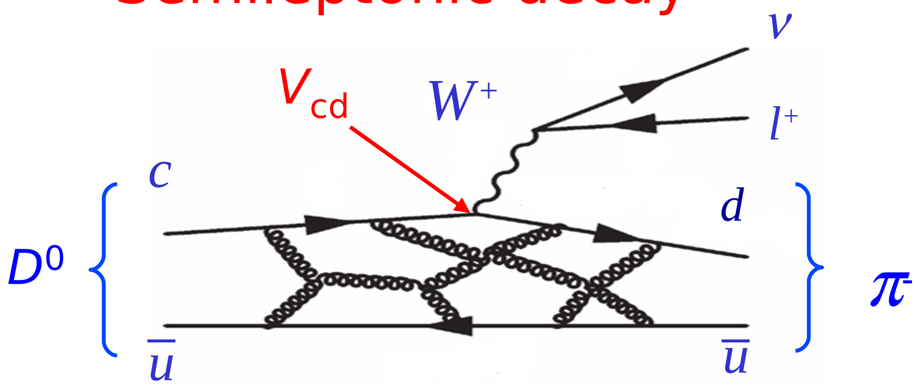
- Similar technique used also to measure f_{Ds} in $D_s \to \mu\nu$.
- CLEO results consistent with most (recent) predictions.
- For precision comparisons we need the complete CLEO-c program.
  - Will allow tests at the 2-4% level.



Semileptonic Decays

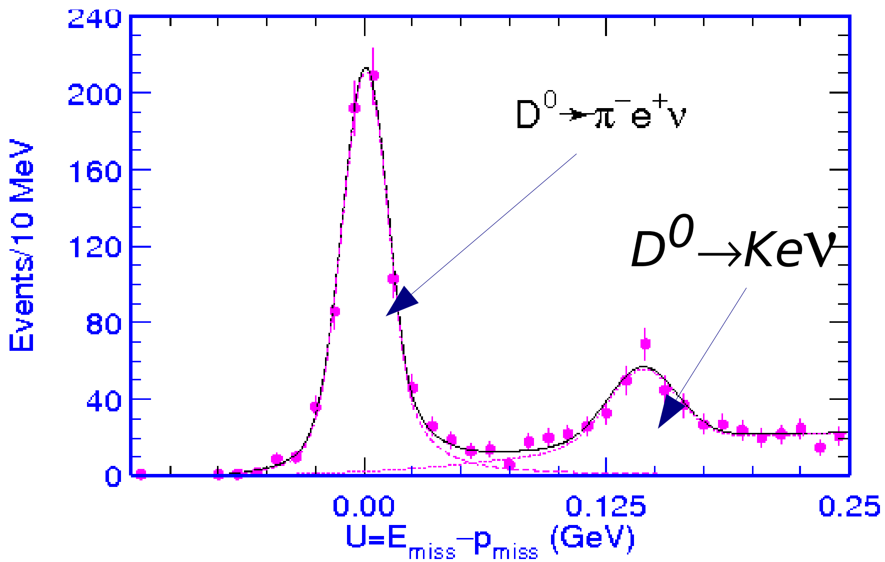
- An important goal of the CLEO-c program is to measure form factors to check lattice QCD calculations.

Semileptonic decay

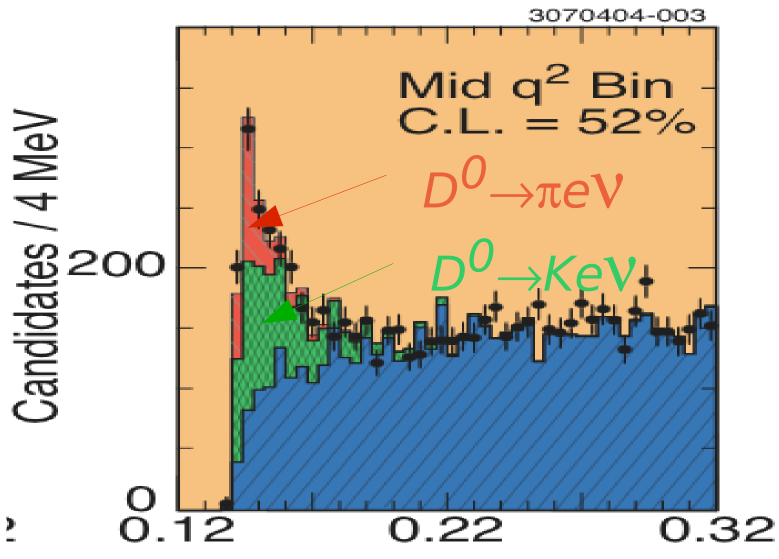


The $c\bar{c}$ threshold operation of CLEO-c makes it unique

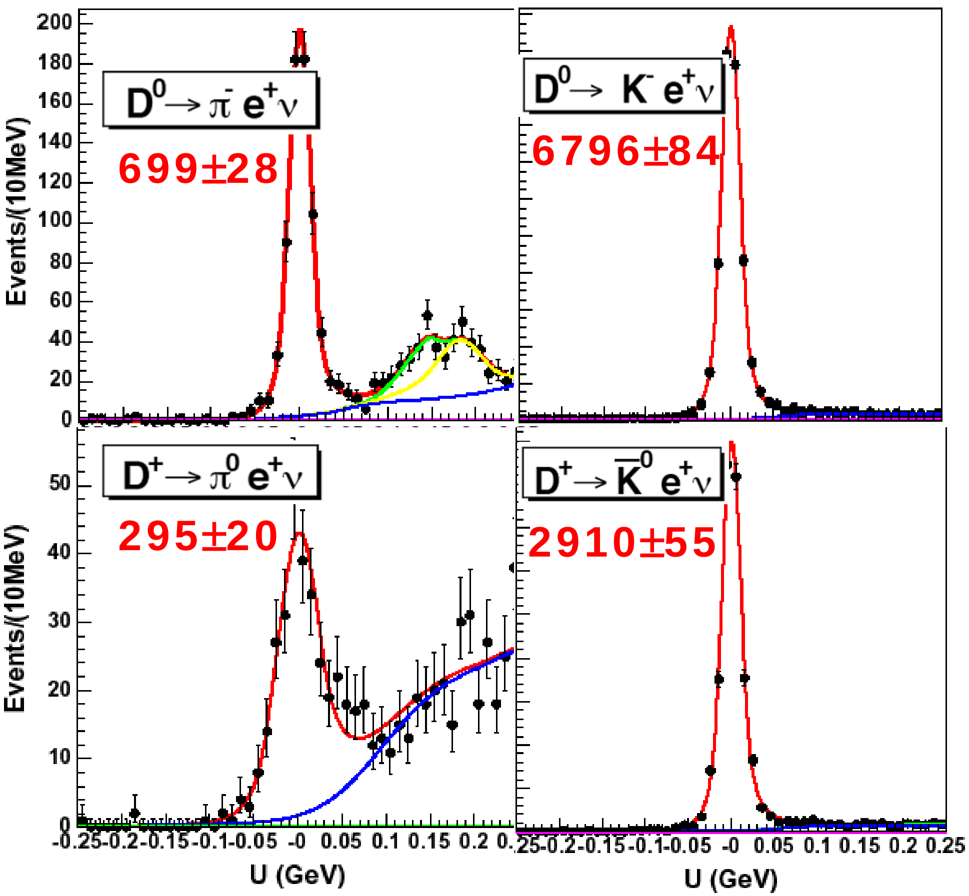
CLEO-c (Preliminary)



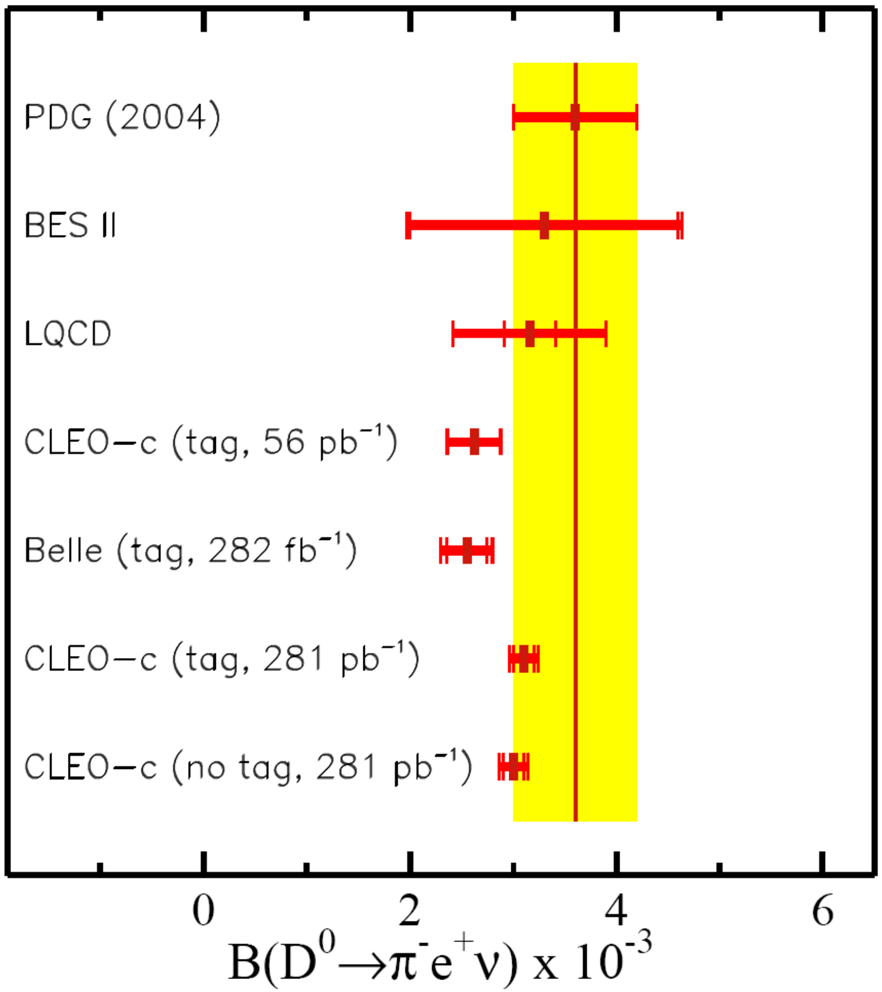
CLEO-III (At $b\bar{b}$ threshold)



Exclusive Signals (281 pb^{-1})

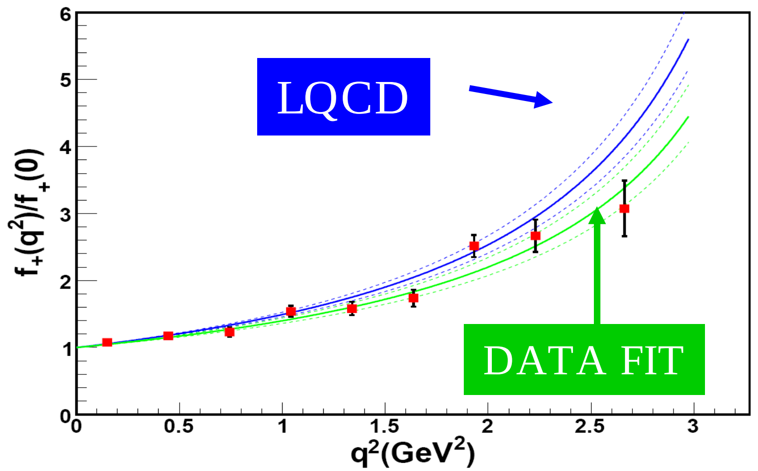


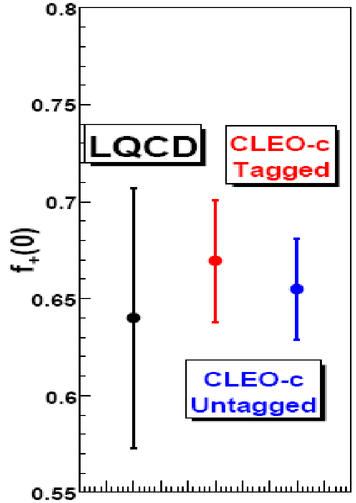
$U = E_{miss} - |P_{miss}|$ (GeV)

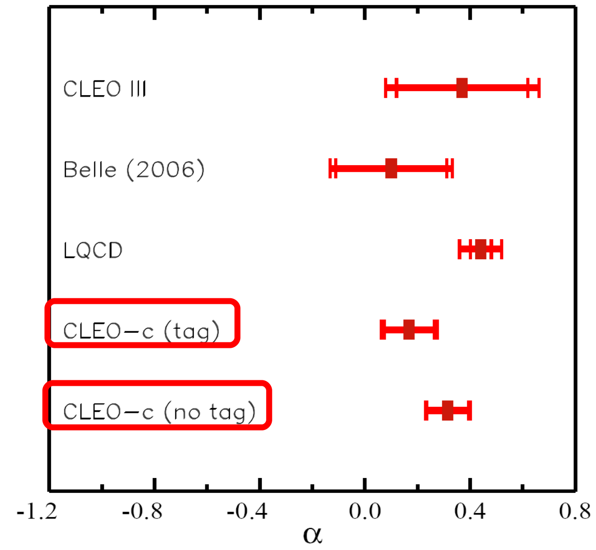


Form Factors and LQCD

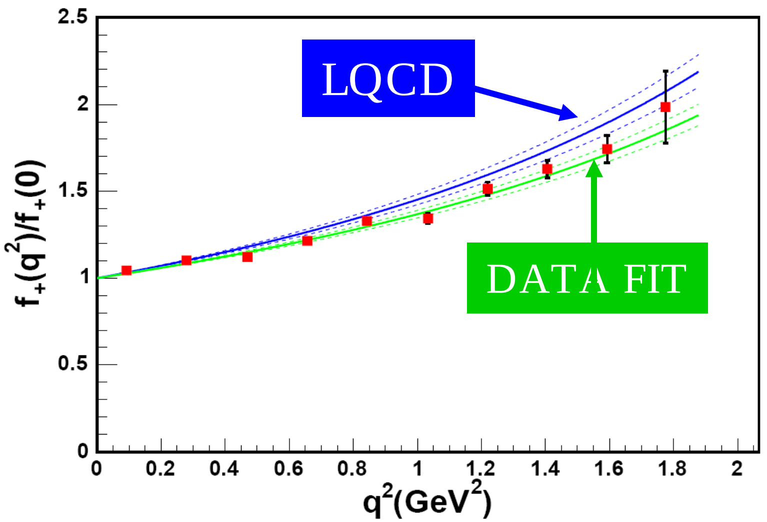
$D^0 \to \pi^- e^+ \nu$

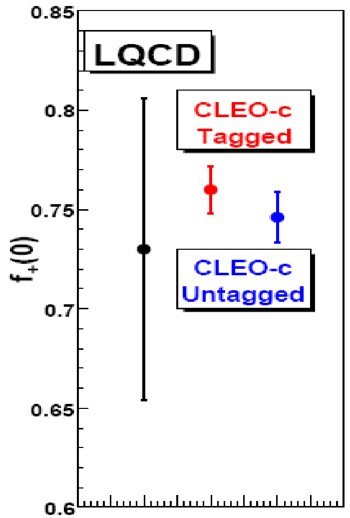


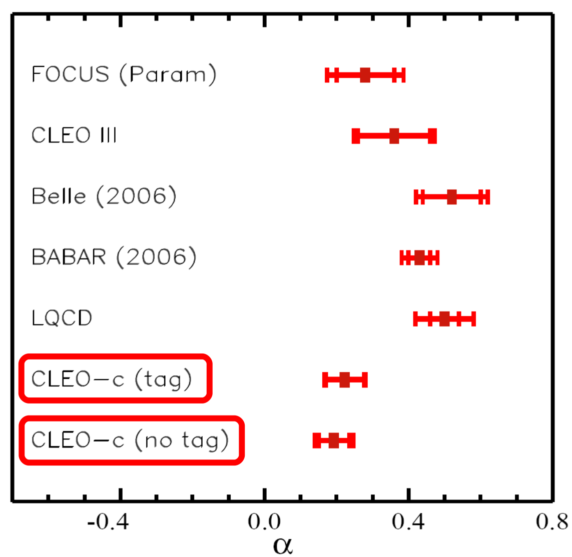




$D^0 \to K^- e^+ \nu$







CLEO-c measurements of semileptonic *D* decays world's best.

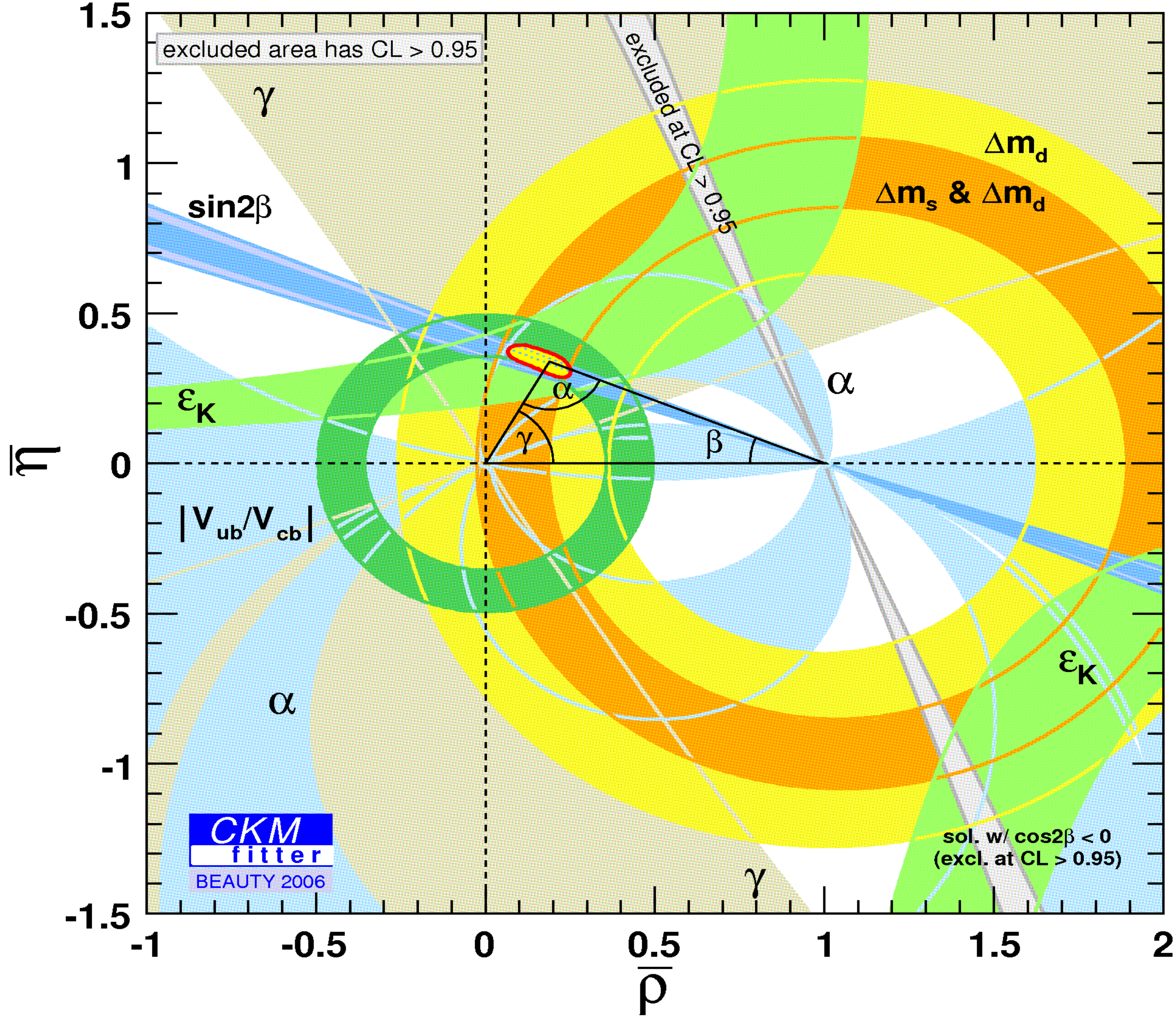
Conclusion

- CLEO-c are producing unique results on charm decays
  - Very well understood detector and software
  - Small but dedicated and focused group
- For *D* decays we are rewriting the books
  - Absolute branching fractions for *D* and D_s decays
  - Leptonic *D* and D_s decays
  - Semileptonic *D* and D_s decays
- These measurements allow precise tests of Lattice calculations.
  - Important to interpret *B*-physics data from the *B*-factories and the Tevatron.
- Many other important topics not discussed here, e.g., Dalitz studies for 'γ' measurements, strong phase in *D* decays *etc*.

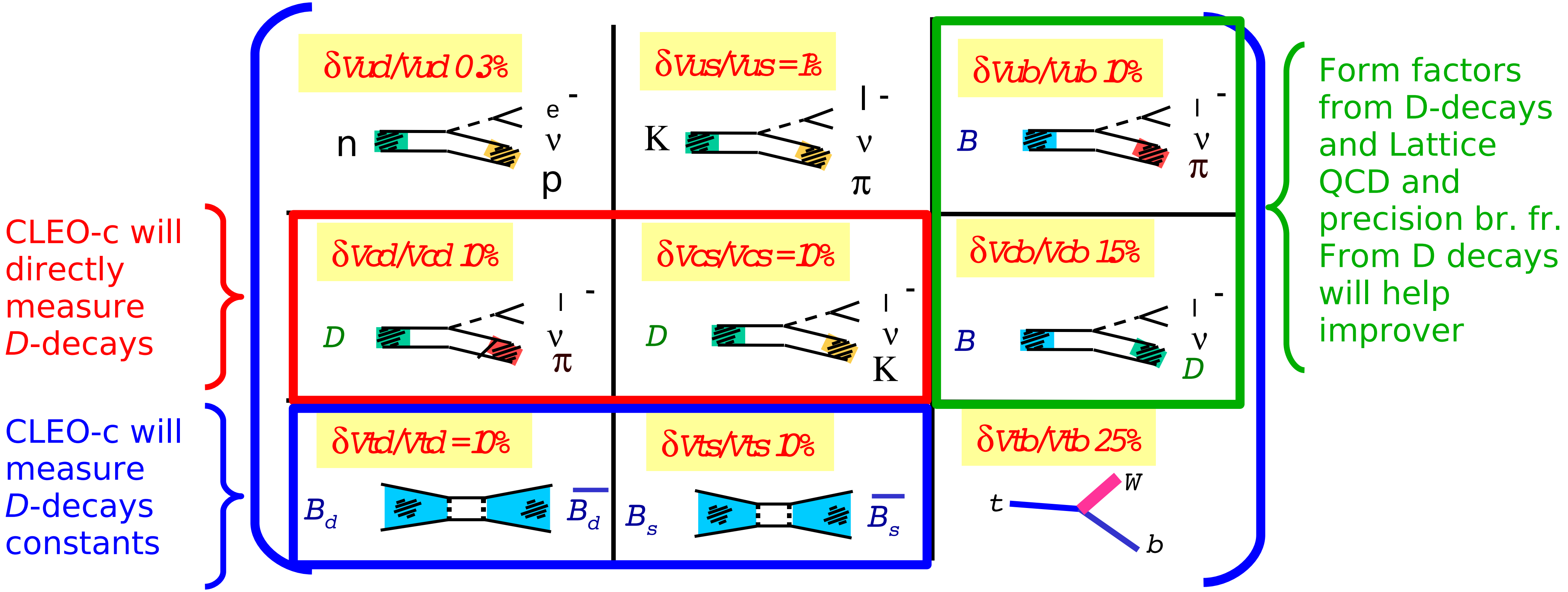
Backup Slides

Physics Motivation

- The CLEO-c program impacts many of the CKM parameters
- In particular, leptonic D and D_s decays allow measurements of the decay constants
- This will help the determination of V_{td}
- Semileptonic D decays will check form factor calculations and improve V_{ub}
- Hadronic D decays are important for normalization of B decays

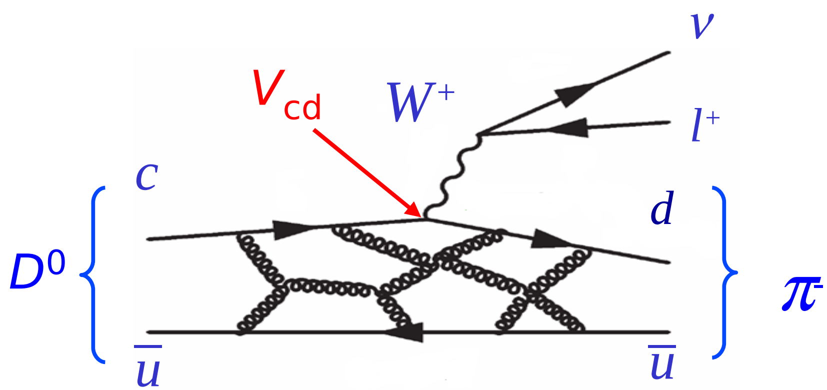


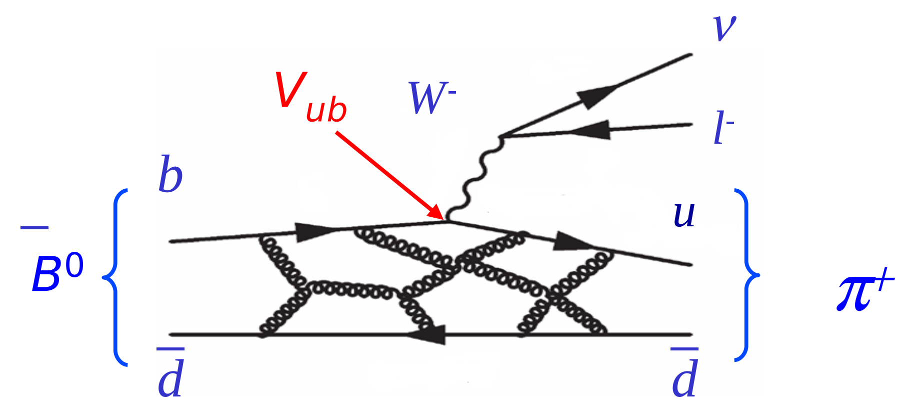
Determining the CKM Matrix



- CLEO-c measurements of *D*-decays will have a significant impact on the determination of 6 of the CKM matrix elements.
  - Directly by studying $D \to \pi e \nu$ and $D \to K e \nu$.
  - Or indirectly be measuring quantities that can be used to validated calculations of the strong dynamics that binds the quarks to hadrons.

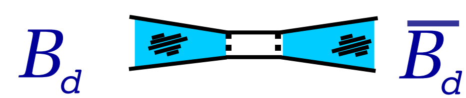
Testing Theories of Strong Interactions



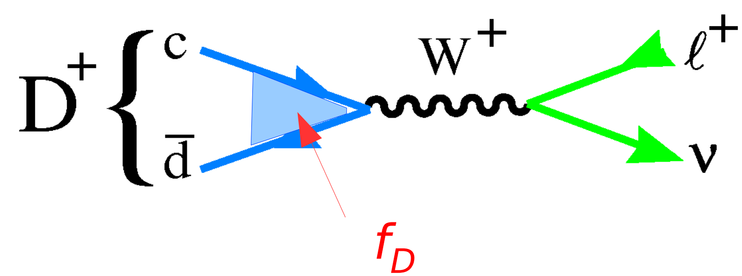


- Measure form factors in $D \to \pi l \nu$ and validate theoretical calculations
  - Can then use this to extract $|V_{ub}|$ from $B \to \pi l \nu$

- B mixing is well measured $\Delta m_d = (0.502 \pm 0.007) \times 10^{-12}$ s
- But $|V_{td}|$ from Δm_d has large uncertainties from f_B
- CLEO-c can measure f_D



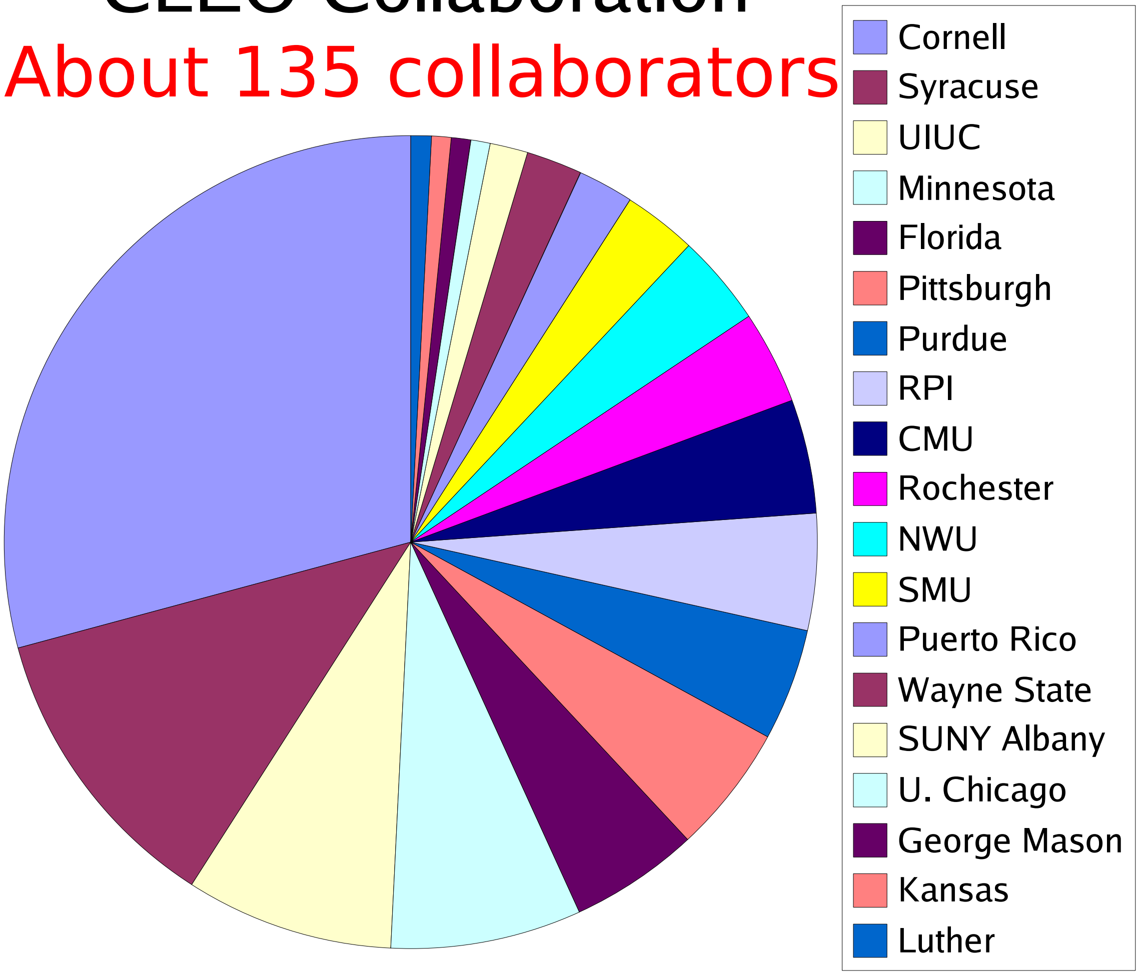
$$\Delta m_d = \frac{G_F^2}{6} M_B M_t^2 |V_{td} V_{tb}^*|^2 \eta_B S_0(x_t) f_B^2 B_B$$

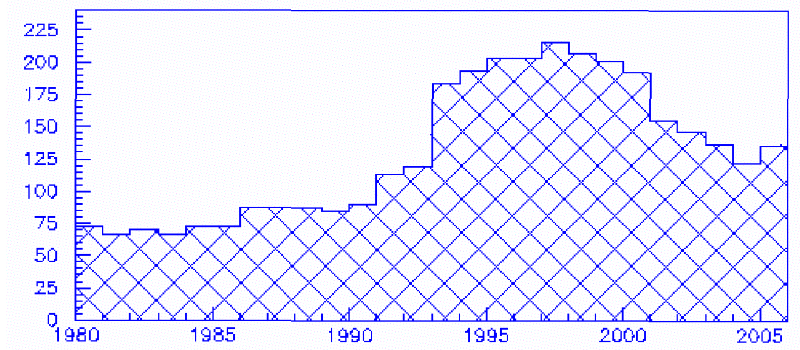


CLEO Collaboration

CLEO Collaboration

About 135 collaborators





CLEO Authors by year

- New groups are still joining CLEO-c