CLEO-c: Progress and Future

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Outline

- Motivations
- CLEO-c and CESR-c
- Preliminary CLEO-c Results
- CLEO-c Gluonic Program
- Summary and Outlook

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Motivations for CLEO-c and CESR-c

CLEO made substantial progress in measuring nonperturbative parameters that relate observables to underlying parton-level processes and CKM matrix elements.

- Much remains to be accomplished since we are rapidly approaching a situation where theoretical uncertainties will dominate all experimental CKM uncertainties.
  - Theoretical uncertainties already totally dominate the uncertainty in $|V_{td}|$.
  - Theoretical uncertainties are still significant in measurements of $|V_{cb}|$ and $|V_{ub}|$.
  - Experimental uncertainties will decrease significantly when the enormous BaBar and Belle data samples are fully understood, evaluated, and utilized.
    - Of course, to some extent, more precise measurements from BaBar and Belle will provide further constraints on theoretical uncertainties.
- Development of reliable theoretical methods for calculating these nonperturbative parameters is essential for precise determination of CKM matrix elements.
  - Experimental verification is an essential element for ensuring reliability.
  - Precise data in the charm sector can motivate and validate theoretical progress in nonperturbative heavy quark physics that can then be applied to b physics.
  - Lattice QCD (LQCD) is a candidate for a theory to calculate these parameters.

Providing precise charm data to motivate and validate theoretical progress in nonperturbative heavy quark physics is a major focus of the CLEO-c program.

Exhaustive searches for glue-rich states is the other major focus of CLEO-c.

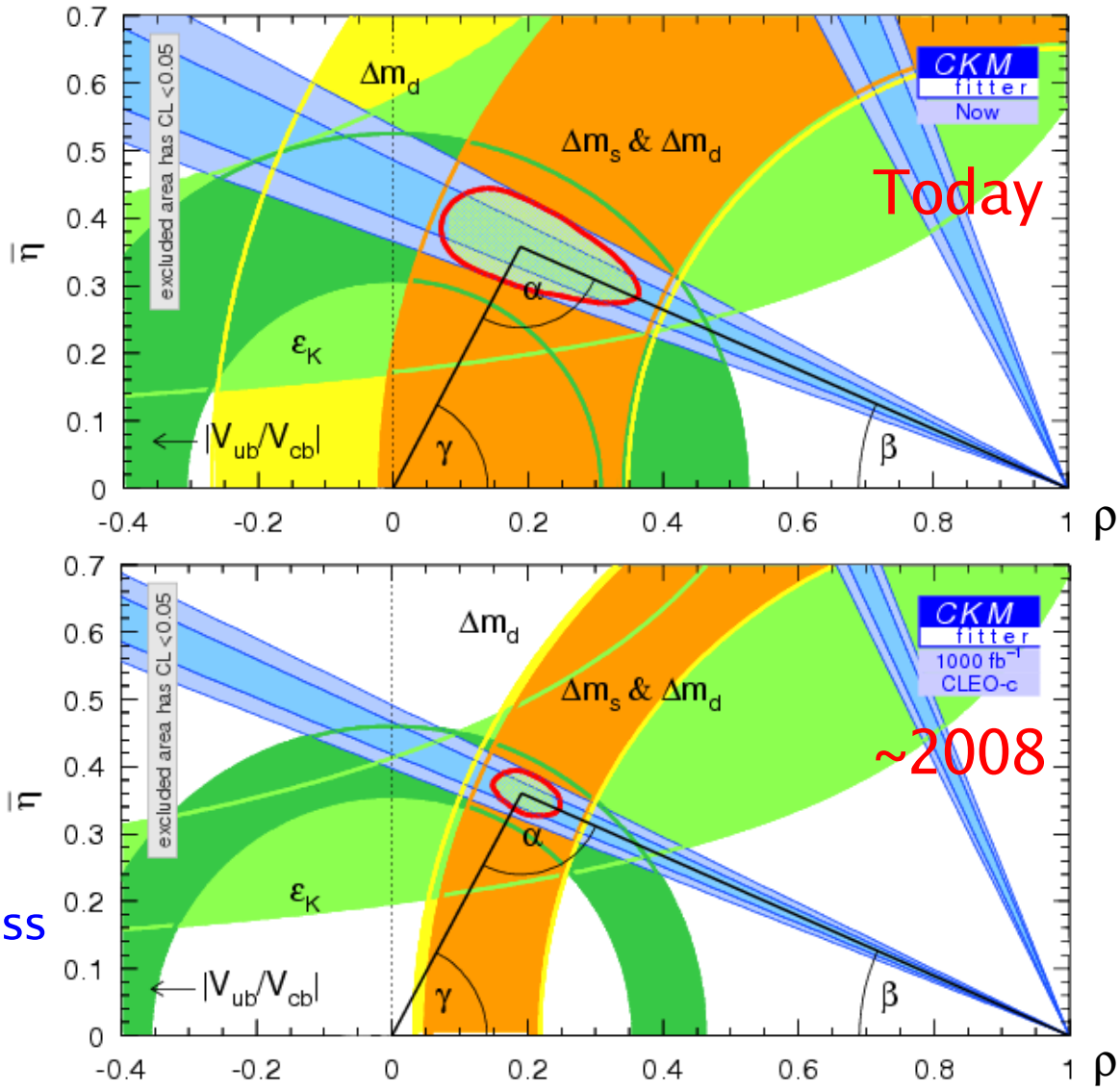
Testing the quark mixing (CKM) matrix

For example, consider the parameters ρ and η in the CKM matrix, the fundamental matrix of weak couplings.

The extraction of constraints in the ρ–η plane is limited by theory.

Non-perturbative strong effects limit our ability to extract the fundamental parameters from the measurements.

CLEO-c can provide unique measurements that will address this current limitation.



CLEO-c and CESR-c

CLEO-c is a focused program of measurements and searches in e^+e^- collisions in the the $\sqrt{s} = 3 - 5$ GeV energy region, including:

- charm measurements
  - absolute charm branching fractions
  - the decay constants f_D and f_{D_s}
  - semileptonic decay form factors
  - $|V_{cd}|$ and $|V_{cs}|$
- searches for new physics including
  - CP violation in D decay
  - $D\bar{D}$ mixing without DCSD
  - rare D decays
- QCD studies
  - $c\bar{c}$ spectroscopy
  - searches for gluonic exotic states: glueballs
  - measurements of R
    - between 3 and 5 GeV – direct
    - between 1 and 3 GeV – indirect (Initial State Radiation)
- τ studies

The acceptance, resolution, and particle identification capability of the CLEO-c detector are substantially beyond those of any detector that has operated in the charm threshold region.

CLEO-c Run Plan

- 2002 – Prologue – Υ's $\gtrsim$1.2 fb^{-1} each
  - $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ – Completed
  - Matrix elements, Γ, Γ_{ee}, spectroscopy (η_b, h_b, D states, ...) $\Upsilon(1D)$ already published
  - Compare with LQCD calculations
  - 10-20 $\times$ the previous world's data
- Act I – $\psi(3770)$ 3 fb^{-1}
  - 30 M $D\bar{D}$ events, 6 M tagged D
  - 310 $\times$ MARK III
- Act II – $\sqrt{s} \sim 4.1$ GeV – 3 fb^{-1}
  - 1.5 M $D_s\bar{D}_s$ events, 0.3 M tagged D_s
  - 480 $\times$ MARK III and 130 $\times$ BES II
- Act III – J/ψ – 1 fb^{-1}
  - 1 G J/ψ decays
  - 170 $\times$ MARK III and 20 $\times$ BES II
- Plan a year for each Act
  - NSF support until Mar 31, 2008

The CESR-c Accelerator

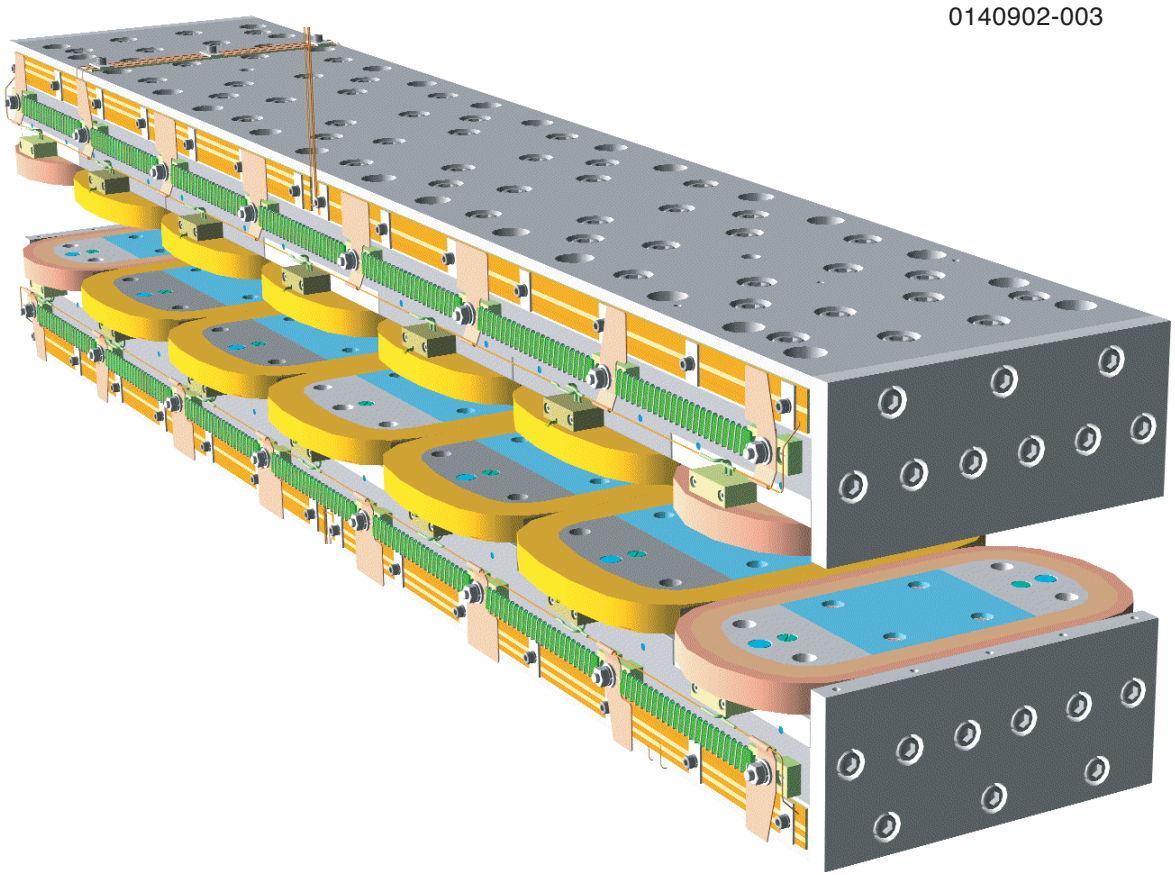
Running at all energies from the J/ψ to above the $\Upsilon(4S)$ is possible with existing superconducting IR quads.

- Loss of synchrotron radiation damping at low energies reduces luminosity
  - Compensate with wiggler magnets
  - Designed, built, and installed 12 superferric wigglers (Fe poles & SC coils)
  - Excellent prototypes for Linear Collider damping ring wigglers.
  - The only substantial hardware upgrade in the program
- Expected luminosity

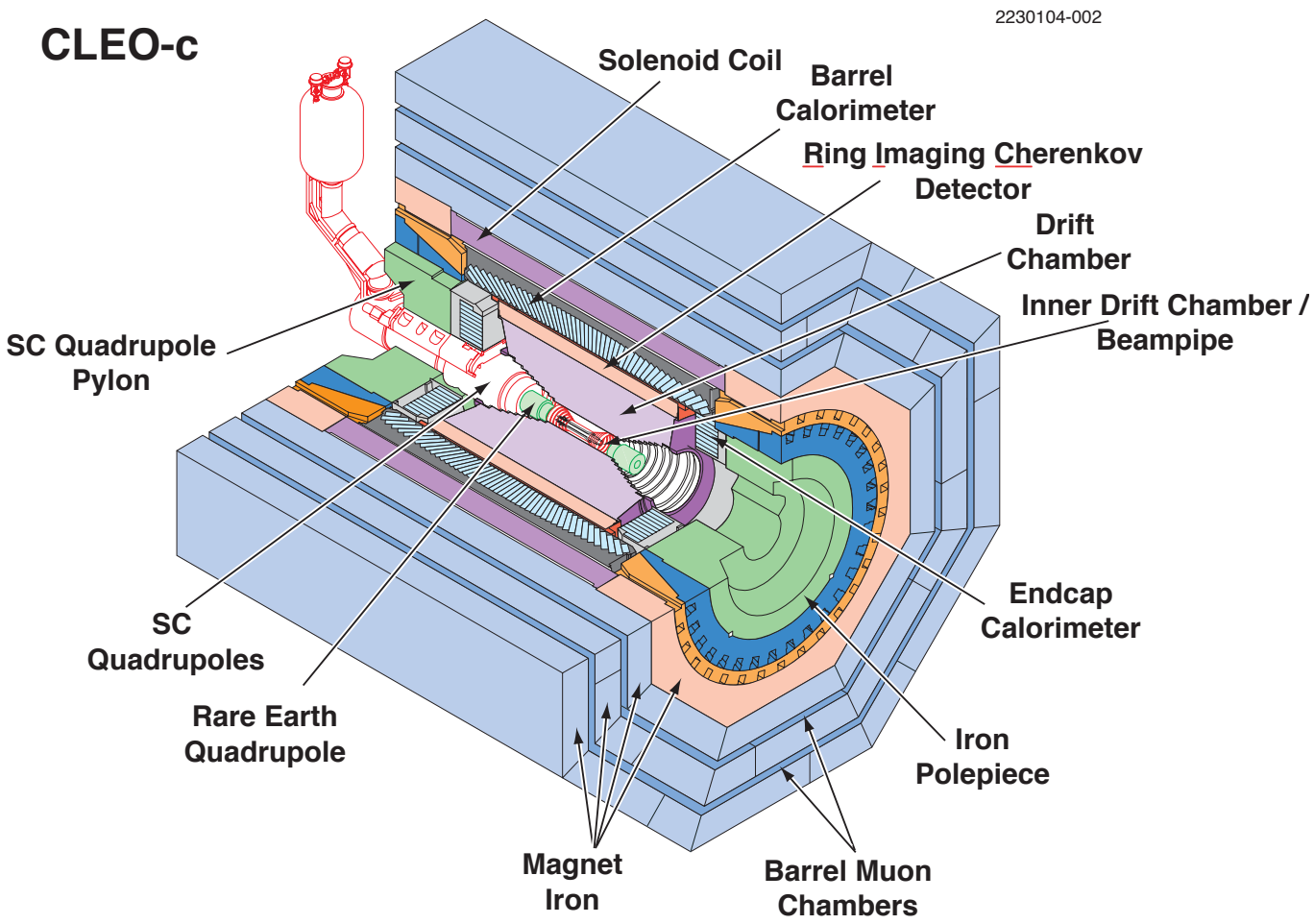
$\sqrt{s}$ (GeV)	$\mathcal{L}$ (10^{33} cm^{-2} s^{-1})
10	1
4.1	0.4
3.8	0.3
3.1	0.2

CESR-c Wiggler Magnets

- The 12 superferric wigglers are 7 pole, 1.3 m long, with $B_{max} = 2.1$ T
- Field quality and wiggler performance in CESR as predicted
- Lots to learn about the dynamics of a wiggler dominated storage ring
  - CESR-c is the first wiggler dominated storage ring.



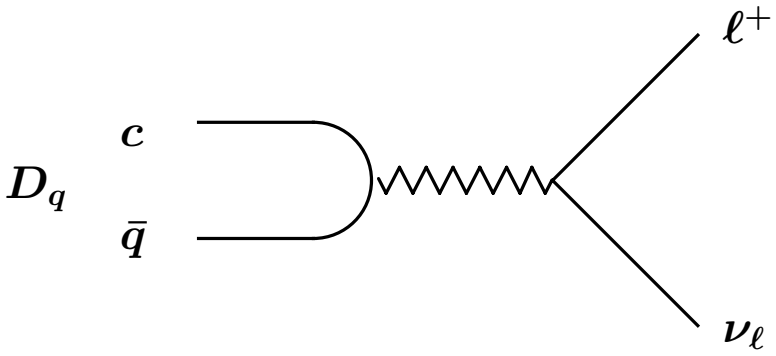
The CLEO-c Detector and CLEO Collaboration



$\sim$ 140 Physicists in 14 Institutions

Carnegie Mellon, Cornell, Florida, George Mason, Illinois U-C, Kansas, Luther College, Minnesota, Pittsburgh, Purdue, Rochester, Southern Methodist, Syracuse, Wayne State

Determining D Meson Decay Constants



The factor $f_{D_q} V_{cq}$ occurs in the decay amplitude for the $c\bar{q}W$ vertex

- The decay widths for leptonic D^+ and D_s^+ decays are:

$$\Gamma(D_q^+ \to \ell^+ \nu_\ell) = \frac{1}{8\pi} G_F^2 M_{D_q} \, m_\ell^2 \left(1 - \frac{m_\ell^2}{M_{D_q}^2}\right) f_{D_q}^2 |V_{cq}|^2$$

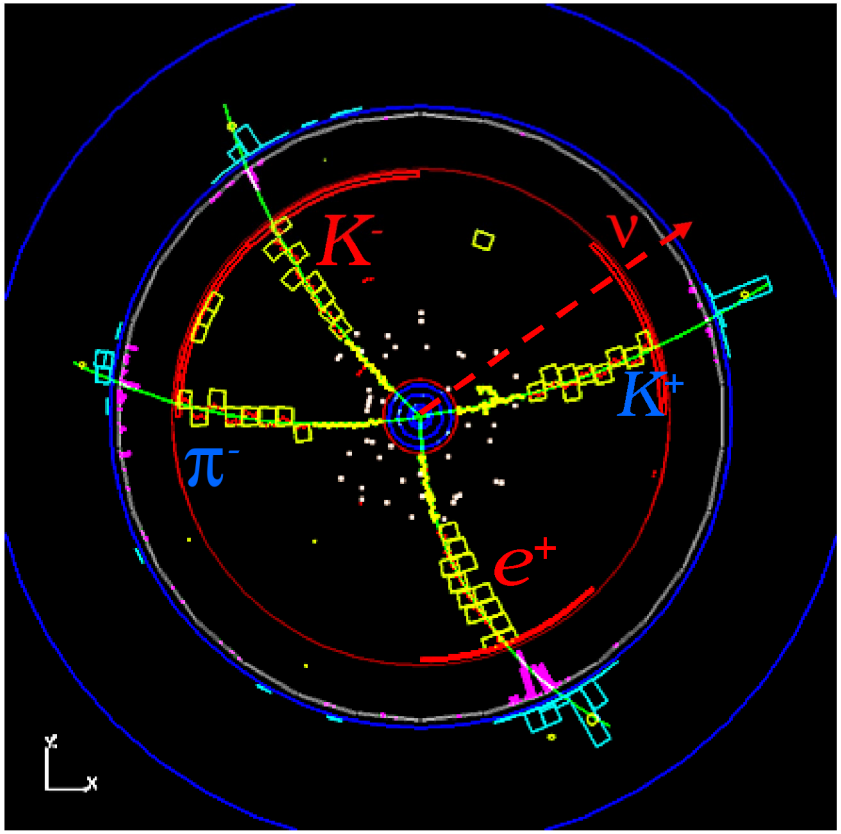
- Measurements of $\mathcal{B}(D^+ \to \ell^+ \nu_\ell)$ and $\mathcal{B}(D_s^+ \to \ell^+ \nu_\ell)$
  Determine $f_{D^+}|V_{cd}|$ and $f_{D_s}|V_{cs}|$
- Conventionally measure $f_{D_q}|V_{cq}|$ and use unitarity for $|V_{cq}|$ to get f_{D_q}
  - We will also measure $|V_{cd}|$ and $|V_{cs}|$ accurately with semileptonic D decays
- Challenge theorists with values of f_{D^+} and f_{D_s} with errors $\mathcal{O}(1\%)$
  - Lead to understanding of the level of reliability of f_{B^0} and f_{B_s} calculations
  - f_{B^0} uncertainty dominates error in $|V_{td}|$ from value of Δm_d in $B^0 \bar{B}^0$ mixing

Doing physics at $c\bar{c}$ threshold

- We run at E_{cm}=3.77 GeV, the $\psi(3770)$ resonance.
- Producing $D\bar{D}$ pairs and no other particles.
- Makes this a very clean experiment for studies of charm decays.
- Most analyses use a tagging technique
  - one of the produced D mesons is fully reconstructed.

$$e^+ e^- \to c\,\bar{c} \to D^0 \bar{D}^0$$

$$\bar{D}^0 \to K^+ \pi^-, \quad D^0 \to K^- e^+ \bar{\nu}$$

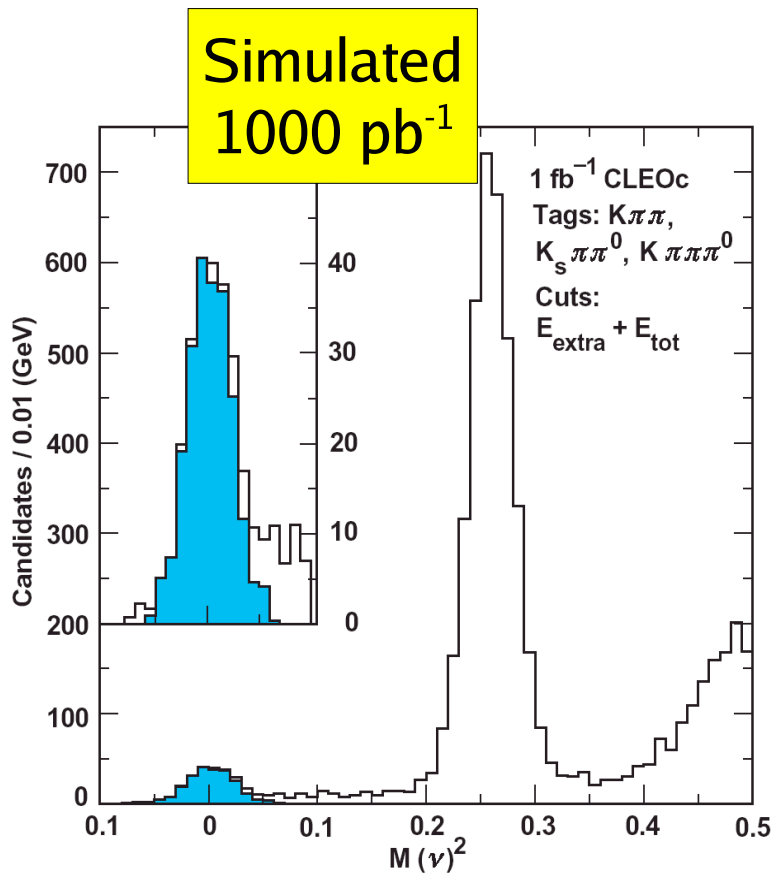


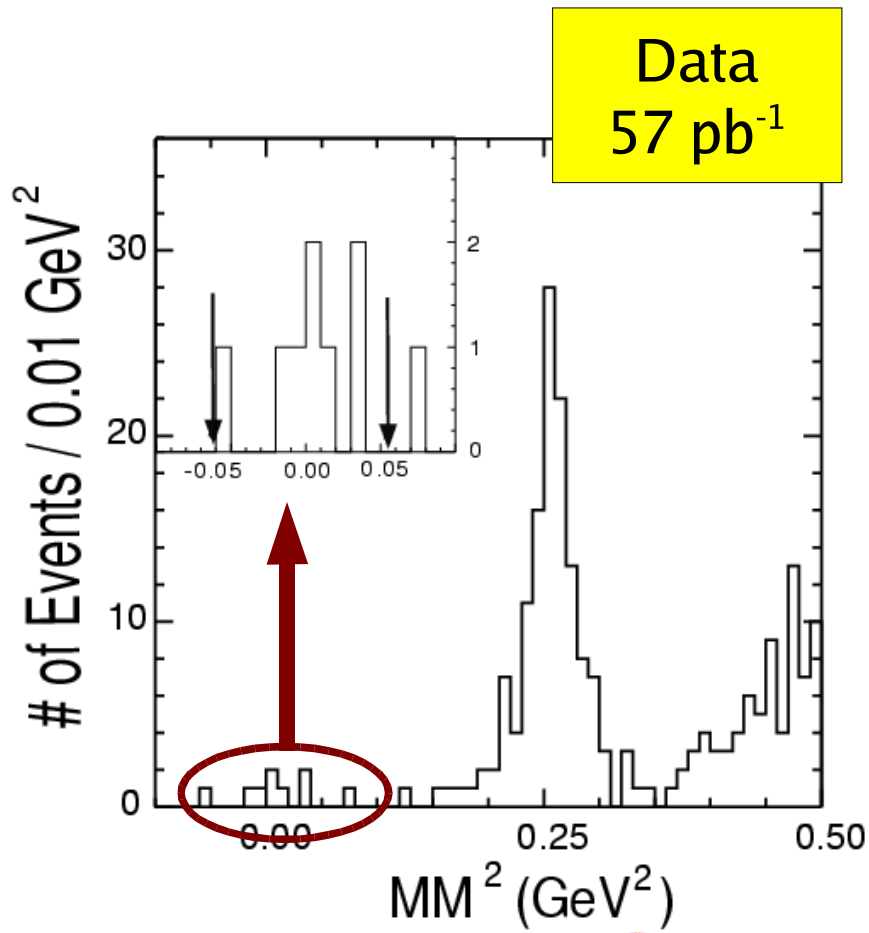
$D^+ \to \mu^+ \nu_\mu$

$$Br(D^+ \to \mu^+ \nu_\nu) = (3.5 \pm 1.4 \pm 0.6) \times 10^{-4}$$

$$f_{D^+} = (202 \pm 41 \pm 17)\,\mathrm{MeV}$$

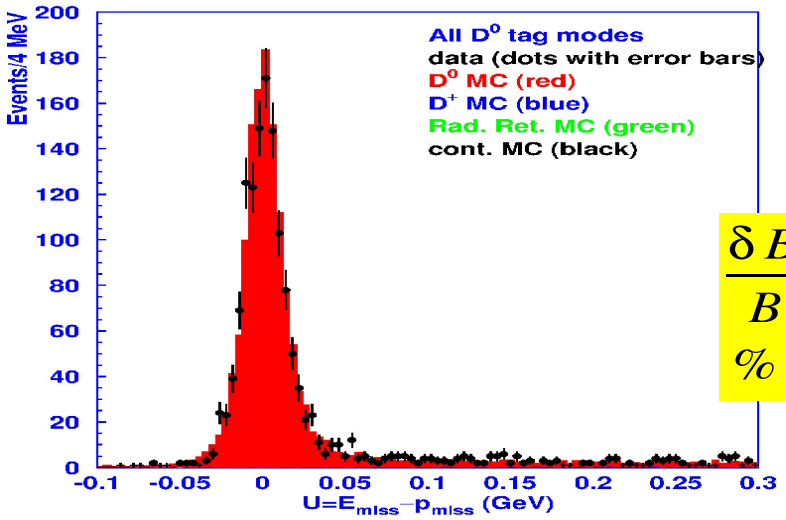
Published:
PRD 70 112004, 2004



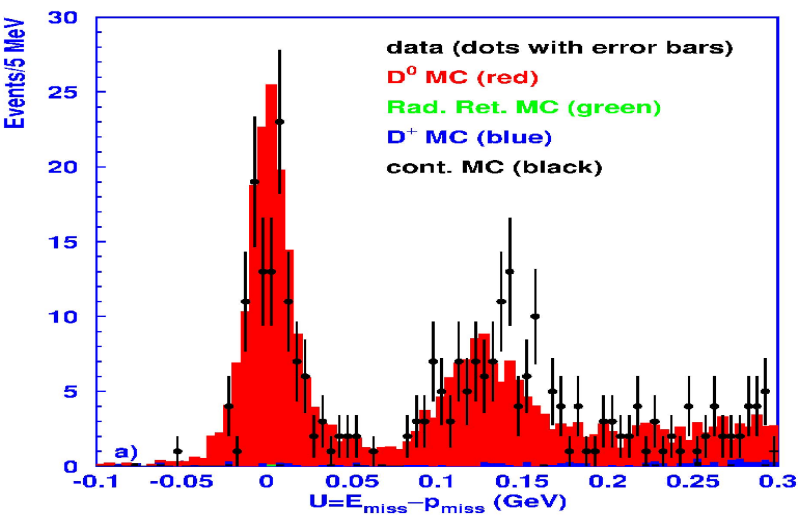


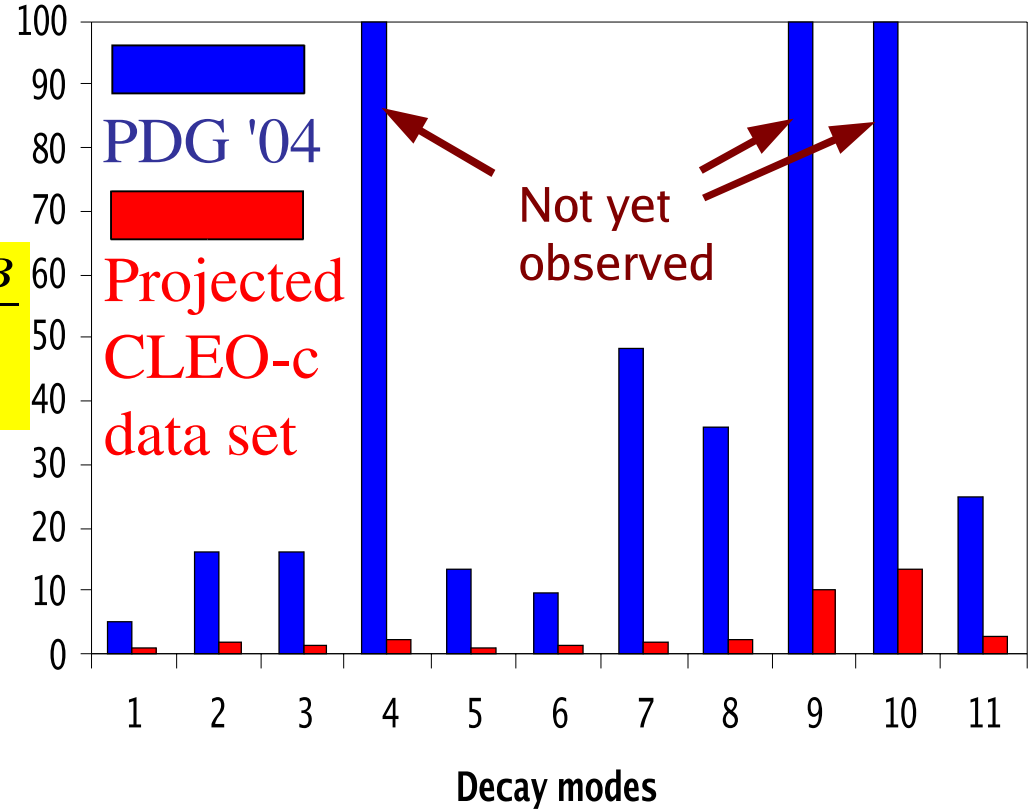
Semileptonic D decays

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



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





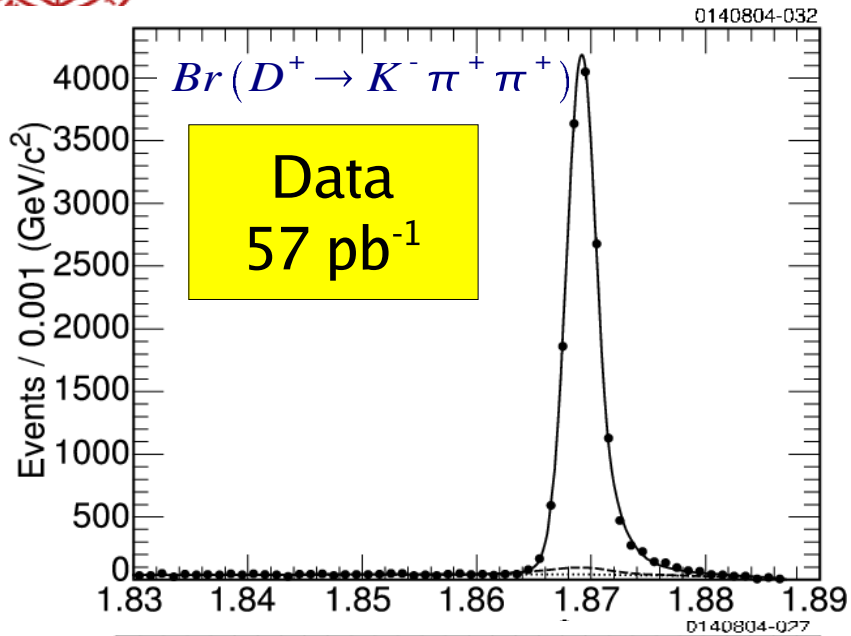
$1: D^0 \to K^- e^+ \nu$ $2: D^0 \to K^{*-} e^+ \nu$ $3: D^0 \to \pi^- e^+ \nu$

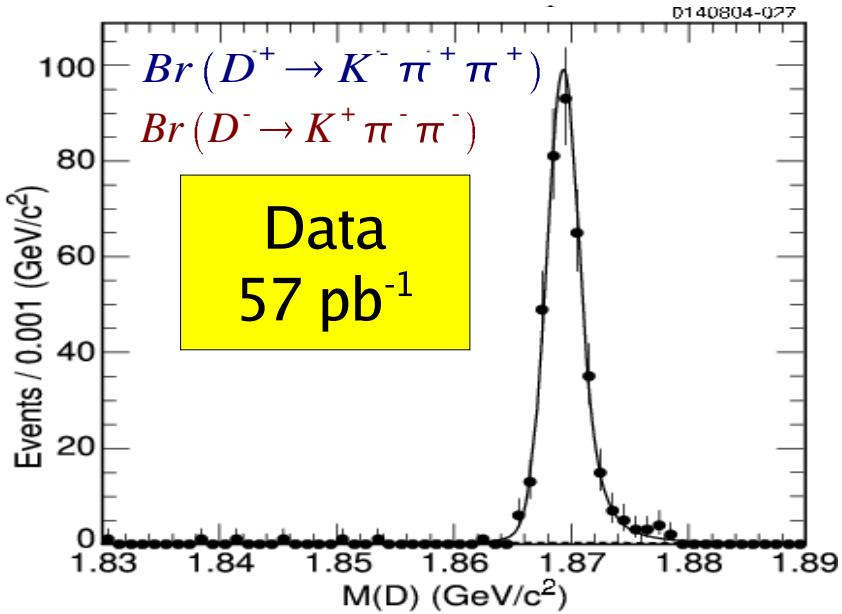
$4: D^0 \to \rho^- e^+ \nu$ $5: D^+ \to K_S^0 e^+ \nu$ $6: D^+ \to \overline{K}^{*0} e^+ \nu$

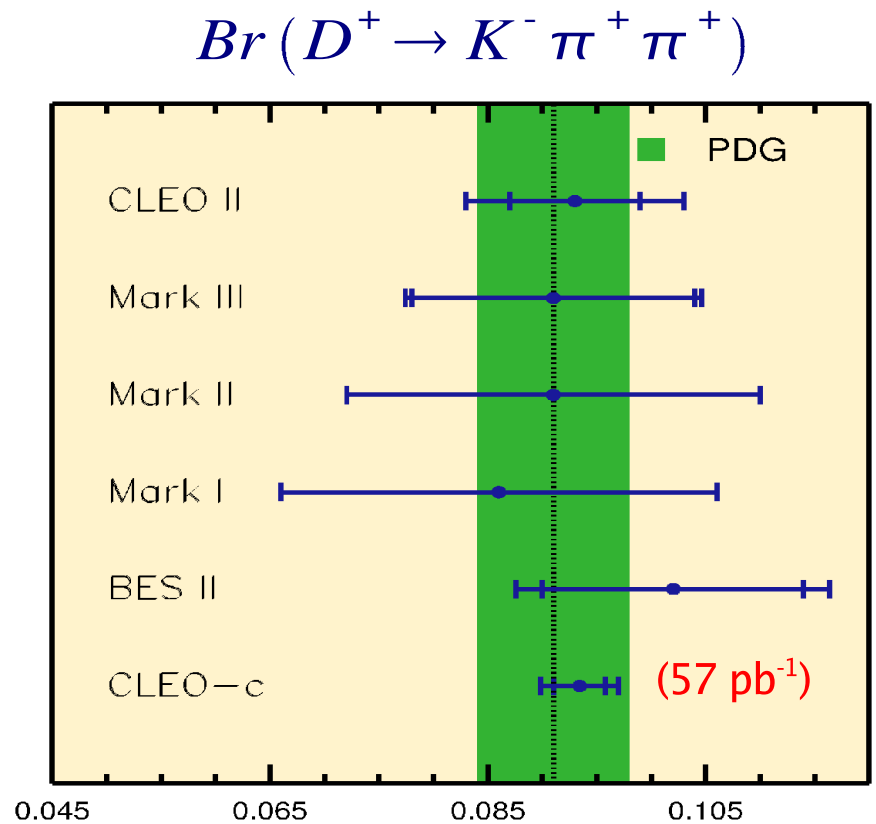
$7: D^+ \to \pi^0 e^+ \nu$ $8: D^+ \to \rho^0 e^+ \nu$ $9: D_S^+ \to K_S^0 e^+ \nu$

$10: D_S^+ \to \overline{K}^{*0} e^+ \nu$ $11: D_S^+ \to \phi e^+ \nu$

Hadronic D decays





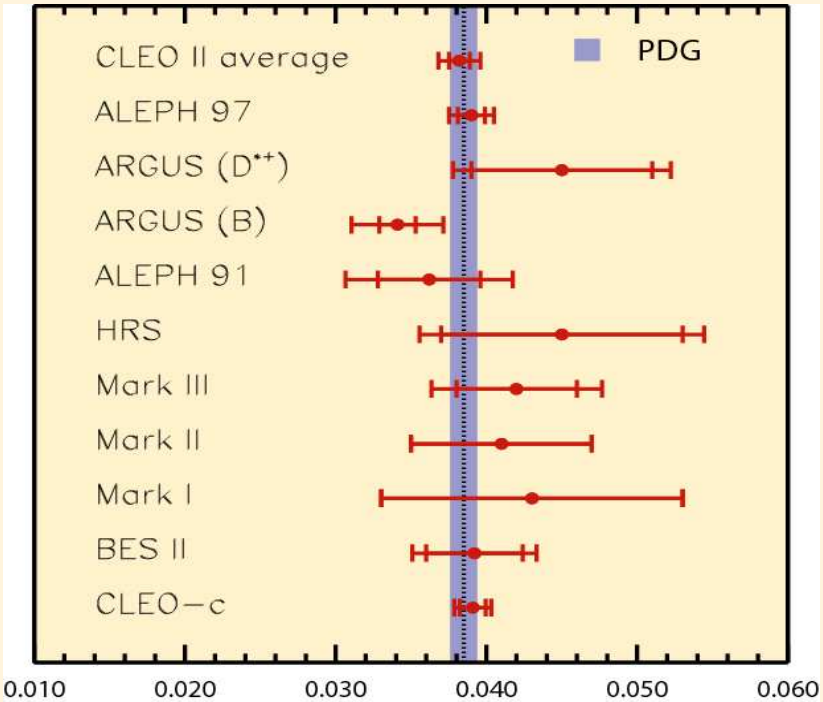


- CLEO-c already has the worlds best measurements!

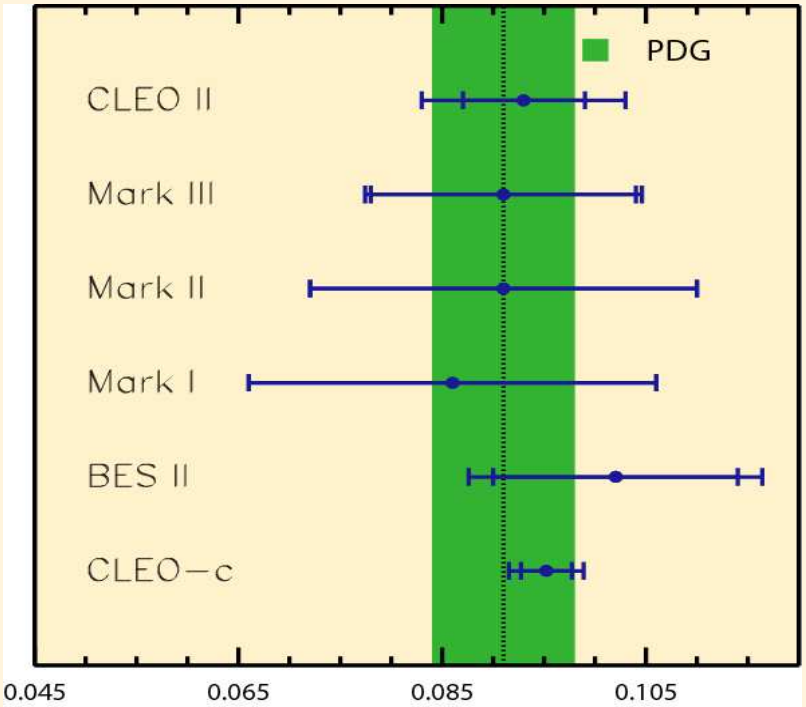
Comparison with PDG 2004 (II)

- Compare with other *direct* measurements in PDG.
- PDG band = average of direct meas., not global fit.

$\mathcal{B}(D^0 \to K^-\pi^+)$



$\mathcal{B}(D^+ \to K^- \pi^+\pi^+)$



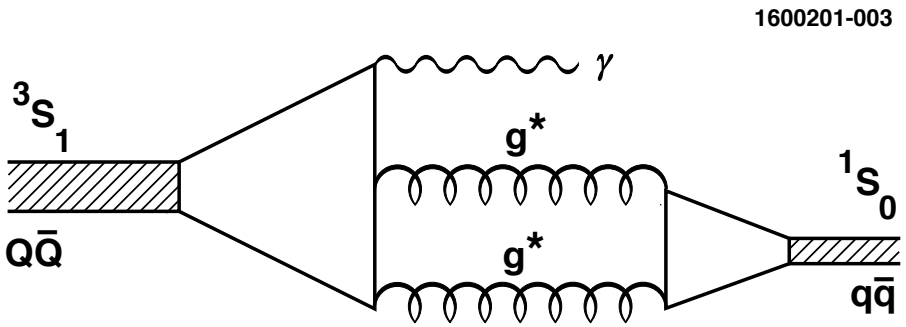
Searching for Gluonic Matter

Since gluons carry color charge, they self-interact and should bind

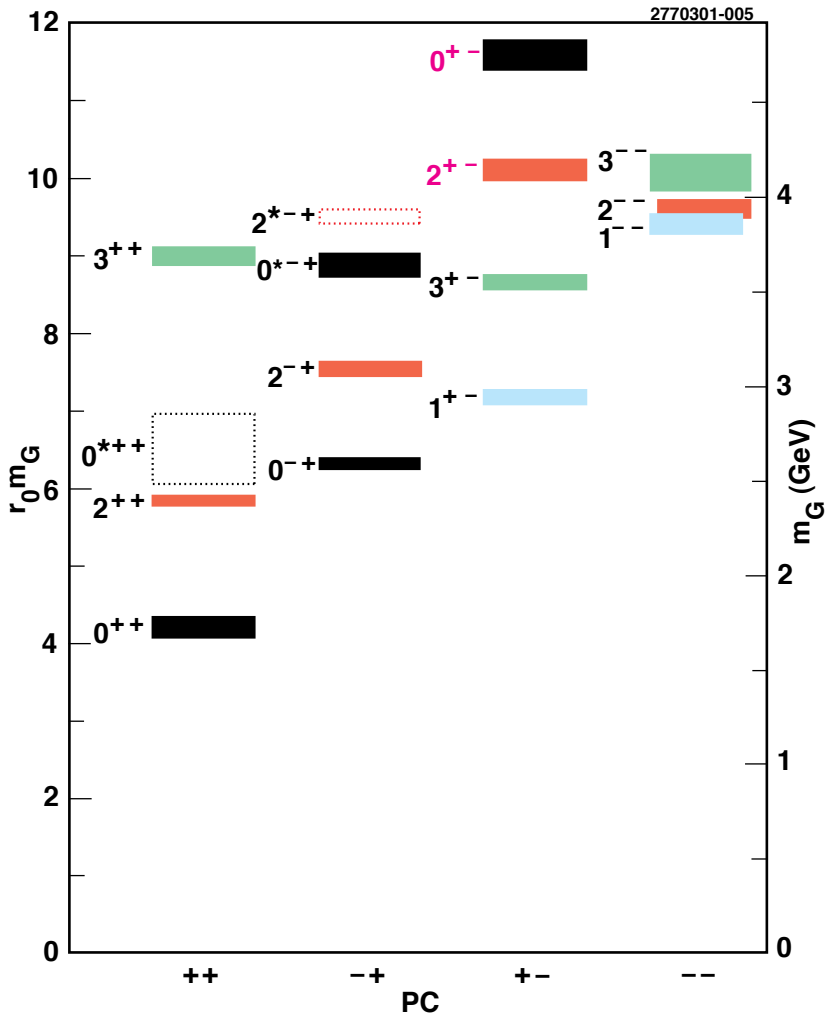
- A rich spectrum of glueballs or glue-rich states is expected in the few-GeV region
- $J/\psi \to \gamma X$ decays are an ideal hunting ground
- Caveat – glueballs may mix with nearby conventional $q\bar{q}$ mesons

The hermetic CLEO-c detector with its excellent γ, $\pi^{\pm}$, and $K^{\pm}$ detection and resolution is nearly ideal

- Observe glueballs in many different modes (signature)
- Facilitates angular analysis to establish J^P



Glueball Spectrum
(Morningstar and Peardon)



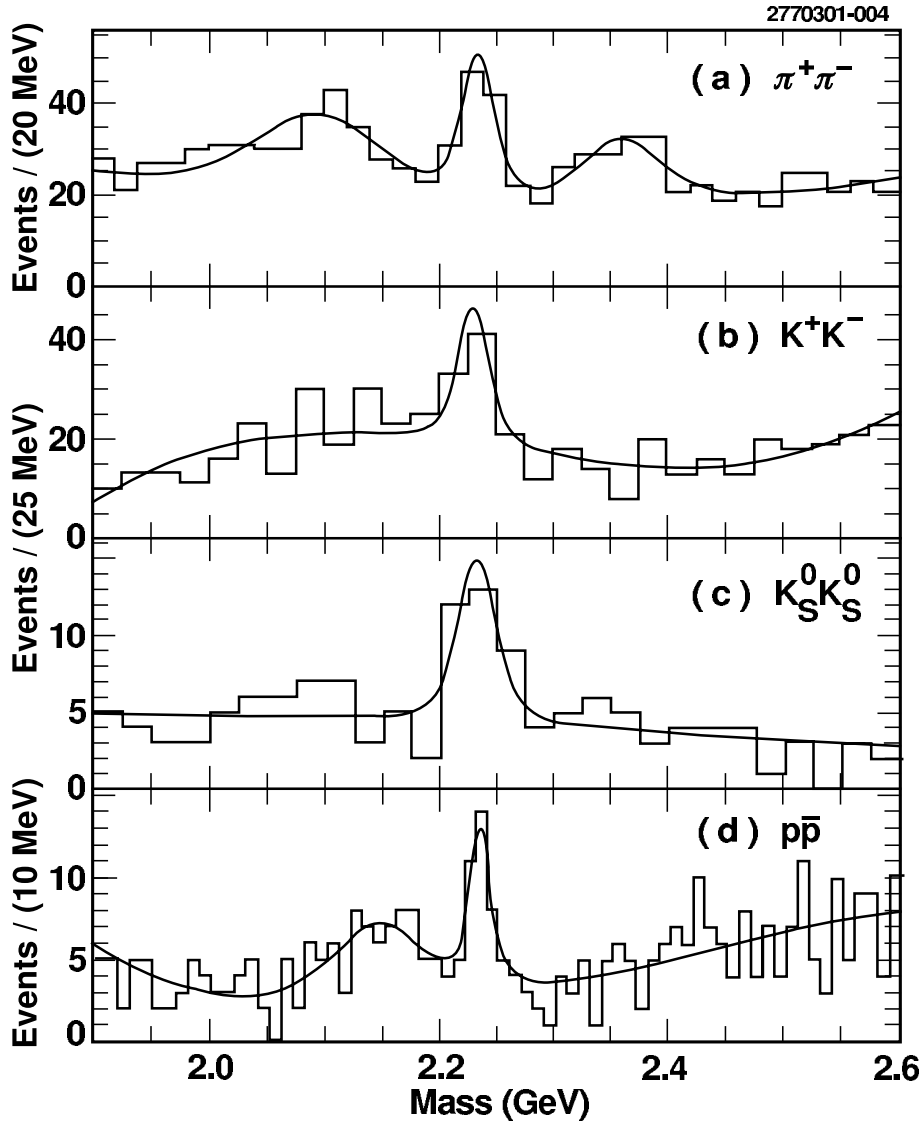
Search for the $f_J(2220)$

The $f_J(2220)$ candidate for a glue-rich meson has been rather elusive:

- Observed by MARK III
- Most robust signals came from BESI from 8×10^6 J/ψ events
- Not observed by Crystal Barrel
- Most other sightings have disappeared
- If BESI branching fractions were correct CLEO-c rates would be enormous

$f_J(2220)$ Decay Mode	BESI Yield	CLEO-c Yield
$\pi^+\pi^-$	74	23,000
$\pi^0\pi^0$	18.4	13,000
K^+K^-	46	15,600
$K^0_S K^0_S$	23	4,500
$p\bar{p}$	32	8,500

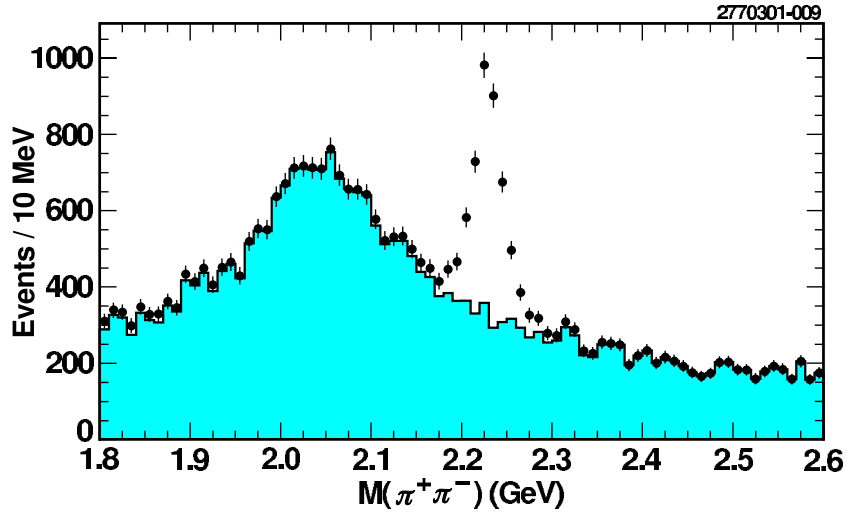
BESI $f_J(2220)$ Signals

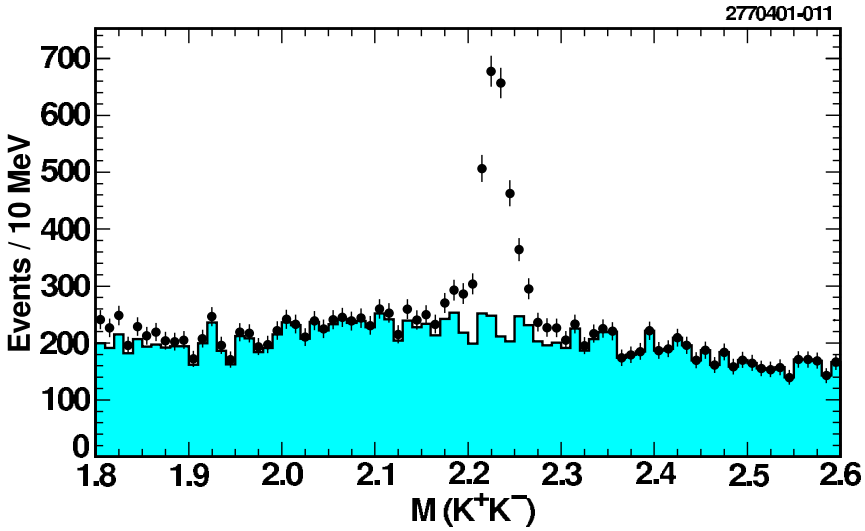


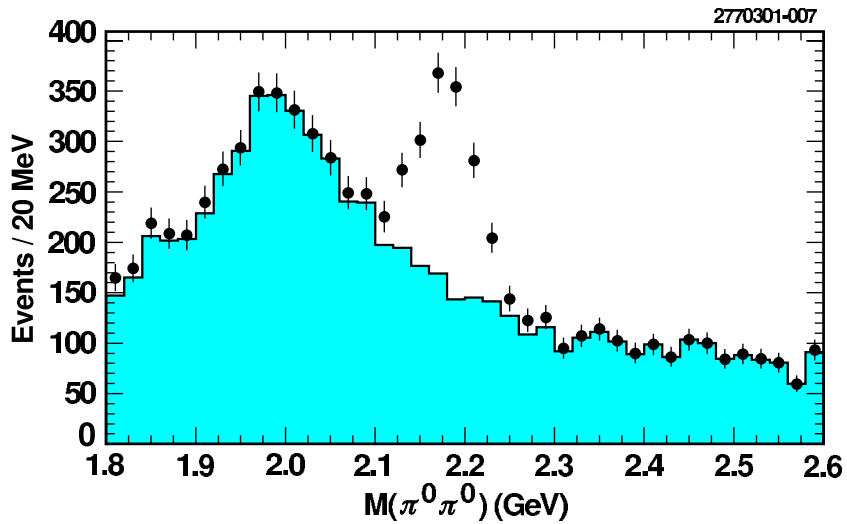
Search for the $f_J(2220)$

In the CLEO-c detector $f_J(2220)$ signals would stand out clearly above backgrounds in many modes

Monte Carlo studies with 150 M J/ψ decays ($\lesssim$1/6 of the projected CLEO-c data sample) show clear signals



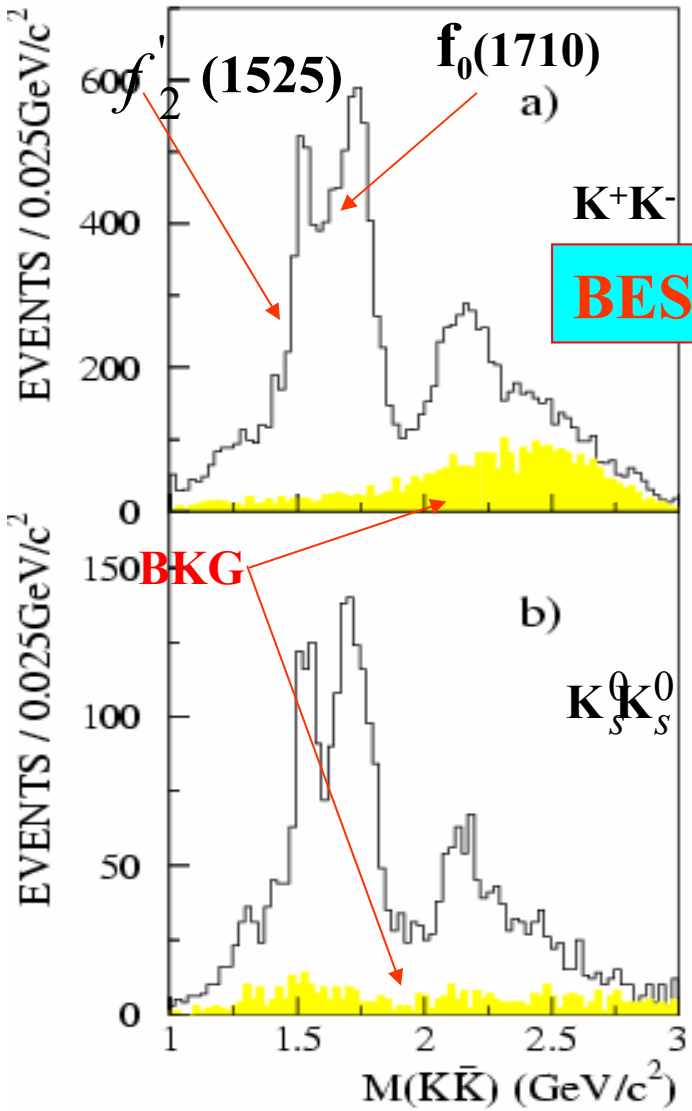


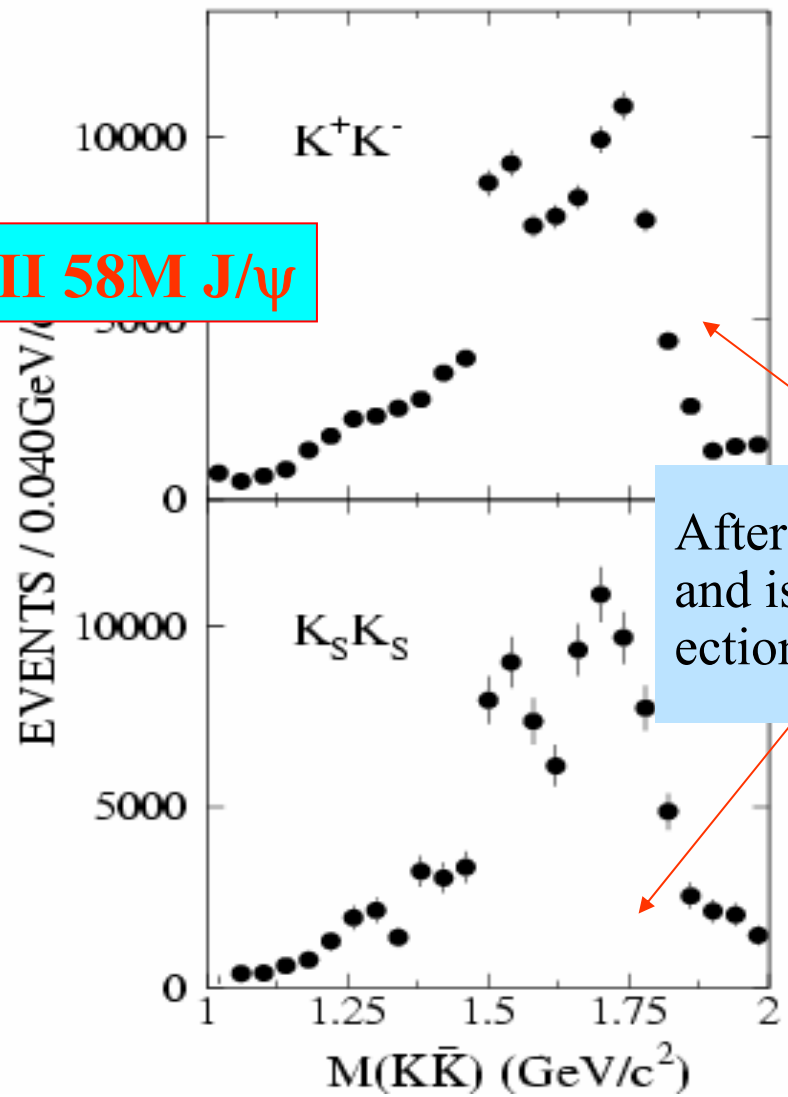


Glueball search and study at BESII (58M J/ψ)

- PWA of $J/\psi \to \gamma K\bar{K}$ shows a dominant 0^{++} in 1.7 GeV mass region.
- PWA of $J/\psi \to \gamma\pi\pi$ and $\gamma\pi\pi\pi\pi$ to study 0^{++} glueball candidates.
- PWA of $J/\psi \to \gamma\eta\pi\pi$ and $\gamma K\bar{K}\pi$ to study 0^{-+} structures around 1.44 GeV.
- $\xi(2230)$ was observed by MARKIII, BESI etc..
  Not seen in the mass spectra of $K\bar{K}$, $\pi\pi$ and $p\bar{p}$
  by BESII. Careful PWA is being performed by BESII.

BESII $J/\psi \to \gamma K^+K^-$ and $\gamma K_S^0 K_S^0$

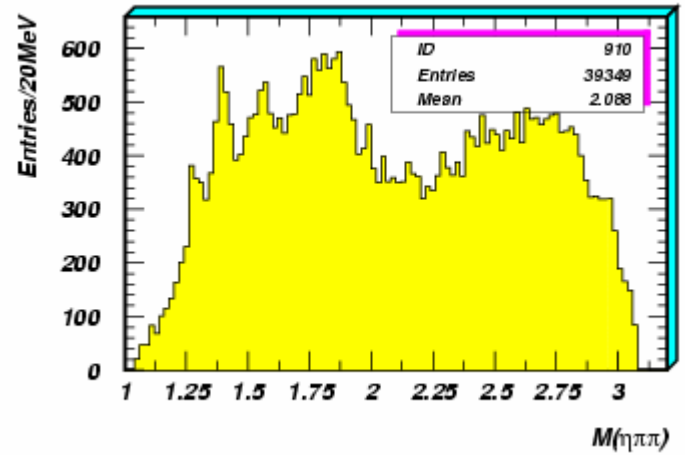


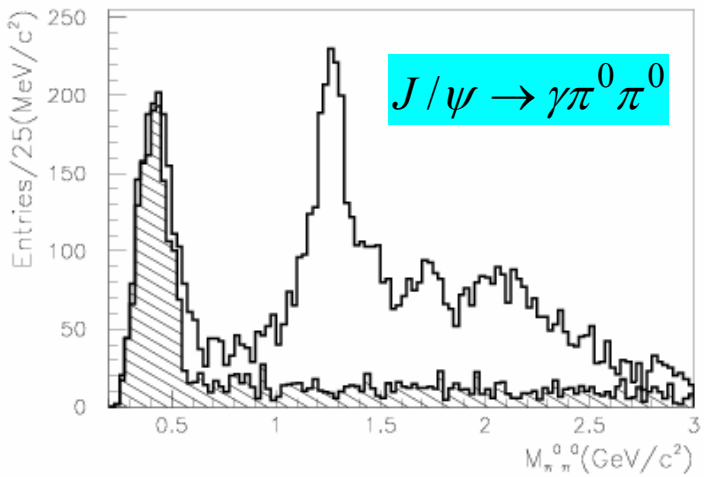


BESII 58M J/ψ

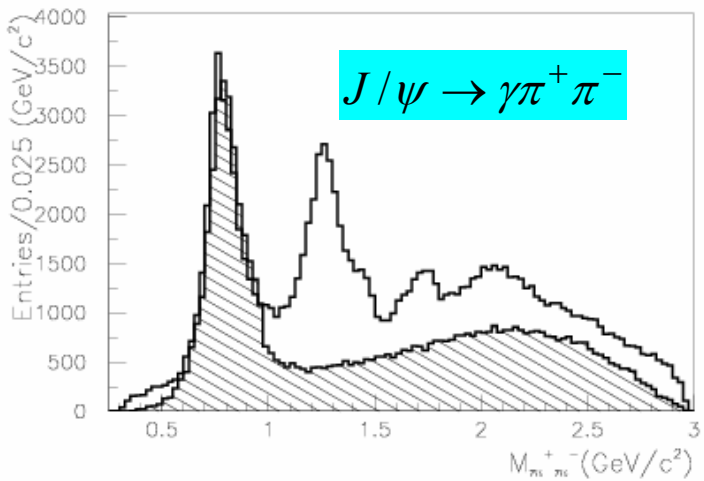
After acceptance and isospin corr-ections

$J/\psi \to \gamma\eta\pi^+\pi^-$

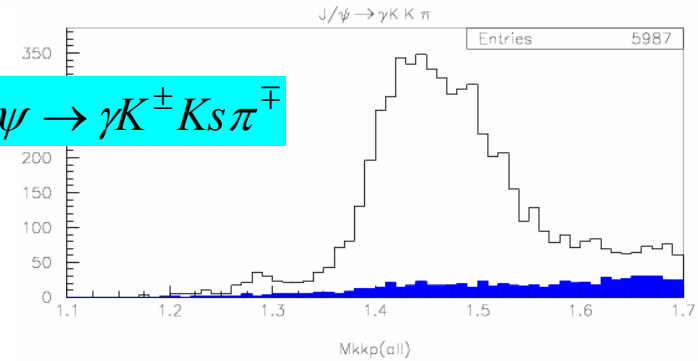




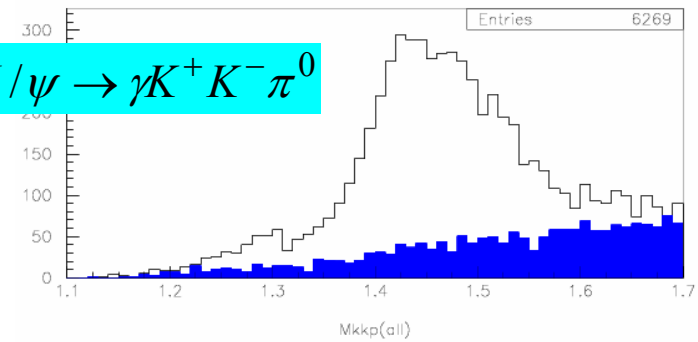
$J/\psi \to \gamma\pi^0\pi^0$



$J/\psi \to \gamma\pi^+\pi^-$



$J/\psi \to \gamma K^{\pm} Ks\pi^{\mp}$

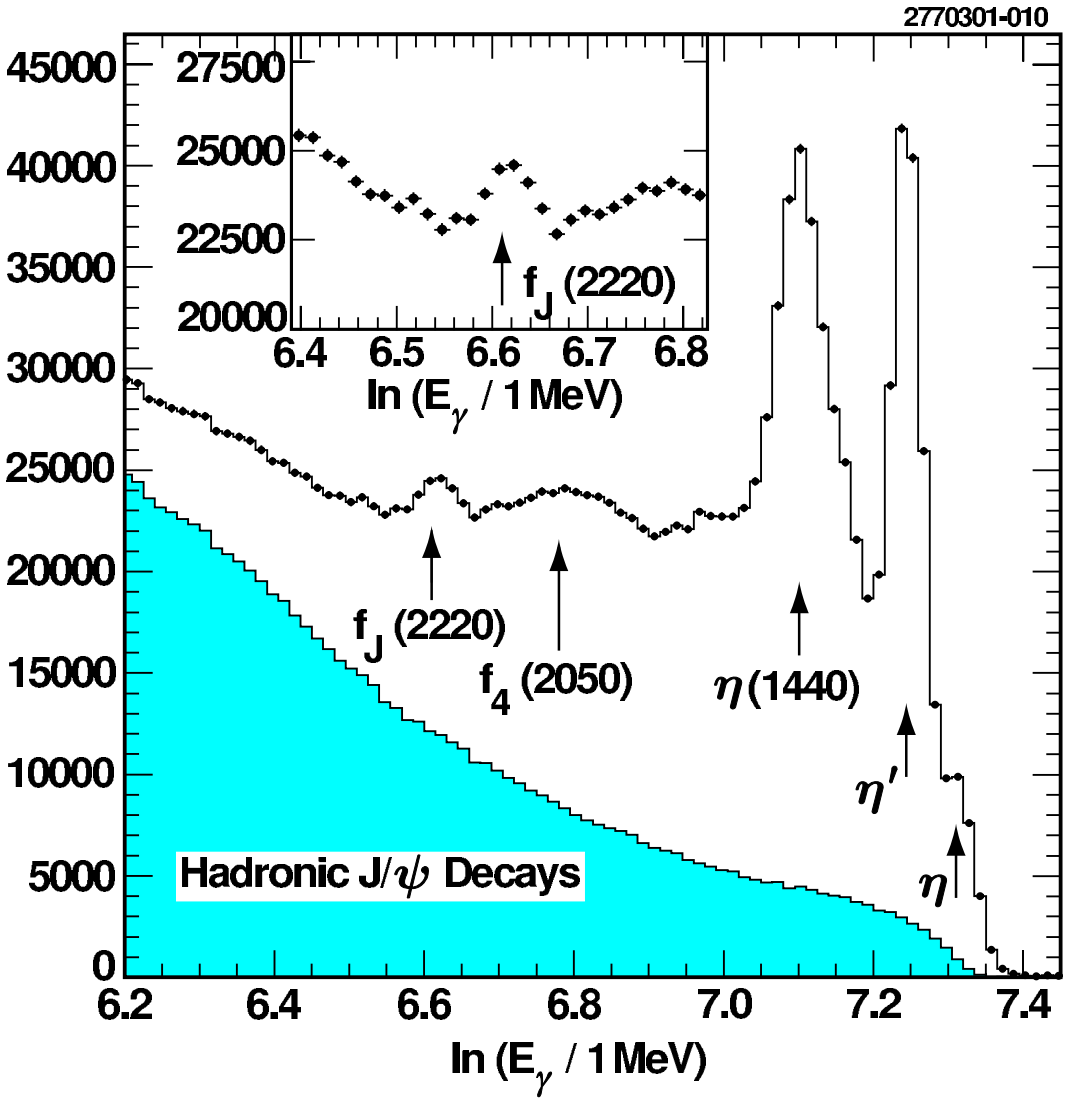


$J/\psi \to \gamma K^+K^-\pi^0$

Inclusive $J/\psi \to \gamma X$ Measurements

The inclusive $J/\psi \to \gamma X$ spectrum is also a hunting ground for new states

- Monte Carlo studies with only 60 M J/ψ decays show a clear $f_J(2220)$ signal if $\mathcal{B}(J/\psi \to \gamma f_J) = 8 \times 10^{-4}$
- With the full 1 G J/ψ CLEO-c data sample, $\mathcal{B}(J/\psi \to \gamma X) \gtrsim 10^{-4}$ should be observable for any X with reasonable width.



Summary and Outlook

- CLEO-c is working very well and preliminary D decay results from ~ 60 pb^{-1} are already competitive with or better than world averages.
- CESR-c has not yet reached its luminosity goals and massive efforts are underway.
- The CLEO-c detector is an excellent venue for studying glueballs produced in radiative J/ψ decays.
- With the demise of the BESI $f_J(2220)$ signals, CLEO-c needs crisp objectives for glueball searches!
  - Jim Napolitano and Anders Ryd will discuss more hopeful prospects.
  - Perhaps interactions among us in this workshop can help to provide clear crisp objectives for the CLEO-c gluonic program.