CLEO-c

A New Frontier of QCD Physics

Holger Stöck
University of Florida

CLEO-c Program

2001 - 02:

Y(1S), Y(2S), Y(3S)   1 – 2 fb^{-1} each

Spectroscopy (Spin fine structure, decays)

10 – 20 times the existing world's data

2003:

ψ(3770)   3 fb^{-1}

30 M events, 6 M tagged D decays

310 times MARK III

2004:

$\sqrt{s} \sim 4100$ MeV   3 fb^{-1}

1.5 M $D_S\overline{D}_S$, 0.3 M tagged D_S decays

480 times MARK III, 130 times BES II

2005:

J/ψ(3100)   1 fb^{-1}

1 Billion J/ψ decays

170 times MARK III, 20 times BES II

CESR-c Accelerator

Modification for low-energy operation:

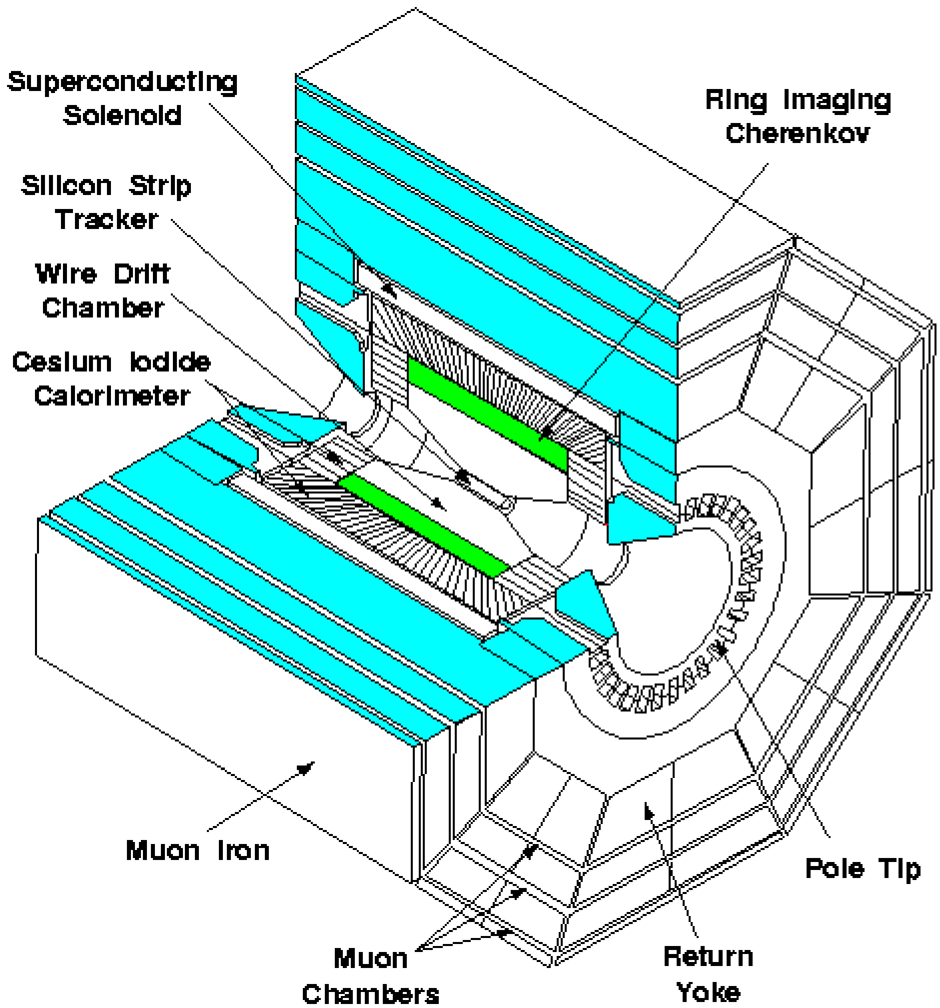
Add wigglers for transverse cooling

Expected machine performance:

$\sqrt{s}$	*Luminosity* (10^{32} cm^{-2} s^{-1})
4.1 GeV	3.6
3.77 GeV	3.0
3.1 GeV	1.0

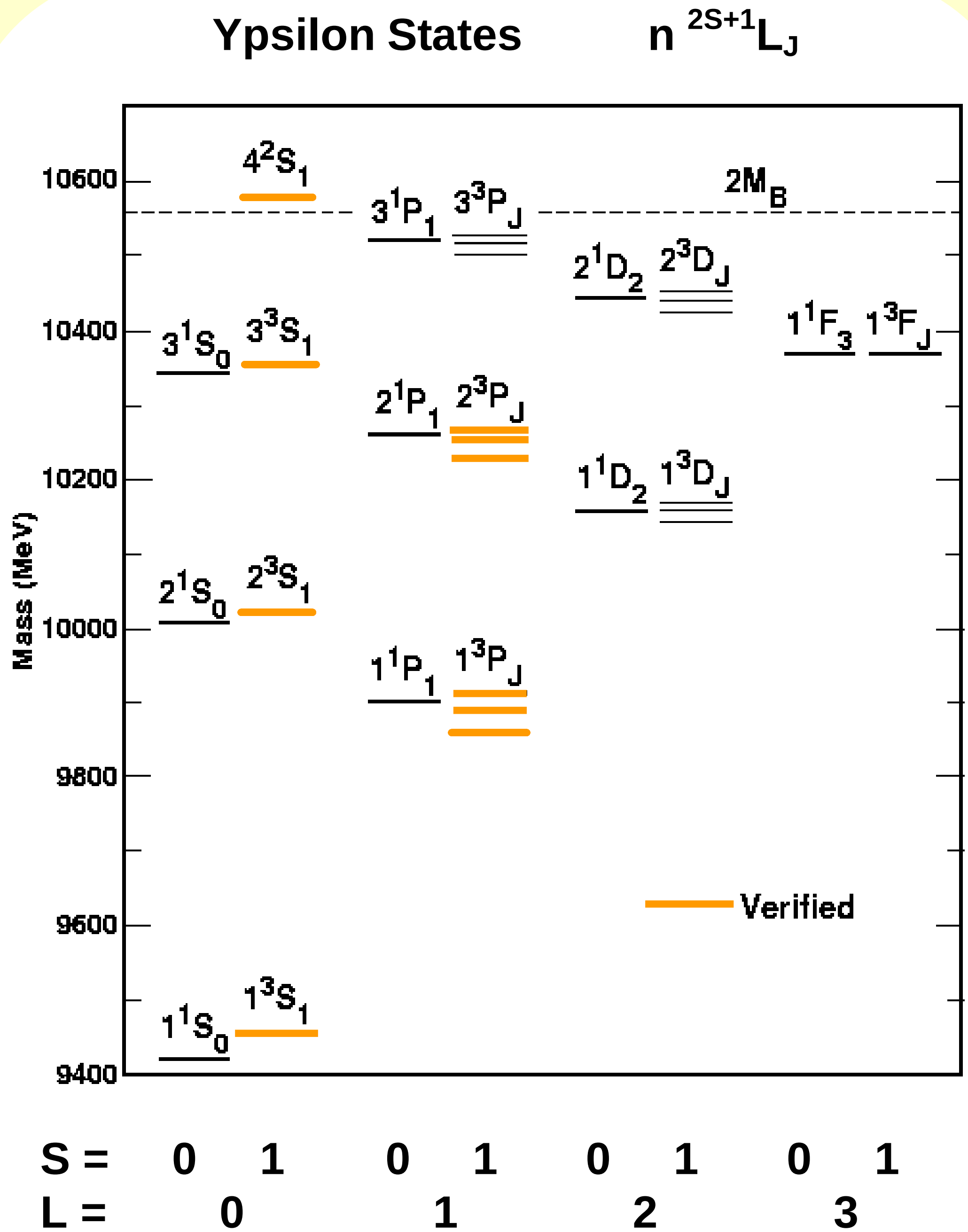
ΔE_{Beam} ~ 1.2 MeV at J/ψ

CLEO-c Detector



Replace 4 layer silicon strip tracker with 6 layer inner drift chamber

Ypsilon Spectrum



Ypsilon Spectroscopy

Search for ^{3}D states in $\Upsilon(3S) \rightarrow \gamma\gamma\gamma\gamma\, \ell^+\ell^-$

$$3^3S_1 \xrightarrow{\gamma} 2^3P_J \xrightarrow{\gamma} 1^3D_J \xrightarrow{\gamma} 1^3P_J \xrightarrow{\gamma} 1^3S_1 \rightarrow \ell^+\ell^-$$

- **Signal rate well predicted: ~ $6 \cdot 10^{-5}$**
- **Background rate indirectly measured: $(21 \pm 7) \cdot 10^{-5}$**
- **In 0.1 fb^{-1} CLEO-II 7 events observed => $(19 \pm 7) \cdot 10^{-5}$ signal rate**
- **In 1.0 fb^{-1} CLEO-III expected:**
  ~ 40 signal events
  ~ 20 background events

Search for ^{1}P state in $\Upsilon(3S) \rightarrow \pi^+\pi^-\gamma\, \ell^+\ell^-$

$$3^3S_1 \xrightarrow{\pi^+\pi^-} 1^1P_1 \xrightarrow{\gamma} 1^1S_0 \rightarrow \ell^+\ell^-$$

- **Decay via $\pi^+\pi^-$ is suppressed**
  Predicted BR: 10^{-9} - 10^{-2}
  CLEO-II (90% C.L.) BR: < $2 \cdot 10^{-3}$
- **With 1.0 fb^{-1} of data CLEO-III can establish 5 σ signal if the branching ratio is at the level of $1 \cdot 10^{-3}$**

Ypsilon Decays

Υ(3S) decays:

Υ(3S) → $\gamma\ \eta_b$(1S)
- **Most favorable search, because highest predicted branching fraction**
- **Easy to calculate in Lattice QCD**

Υ(3S) → $\gamma\ \chi_b$(2P) only observed decay

Υ(2S) decays:

Υ(2S) → $\gamma\ \eta_b$(1S)
- **Establish signal with 5 σ significance for L = 0.5 fb^{-1} if BR > $1.5 \cdot 10^{-3}$**

Υ(2S) → $\gamma\ \chi_b$(1P) only observed decay

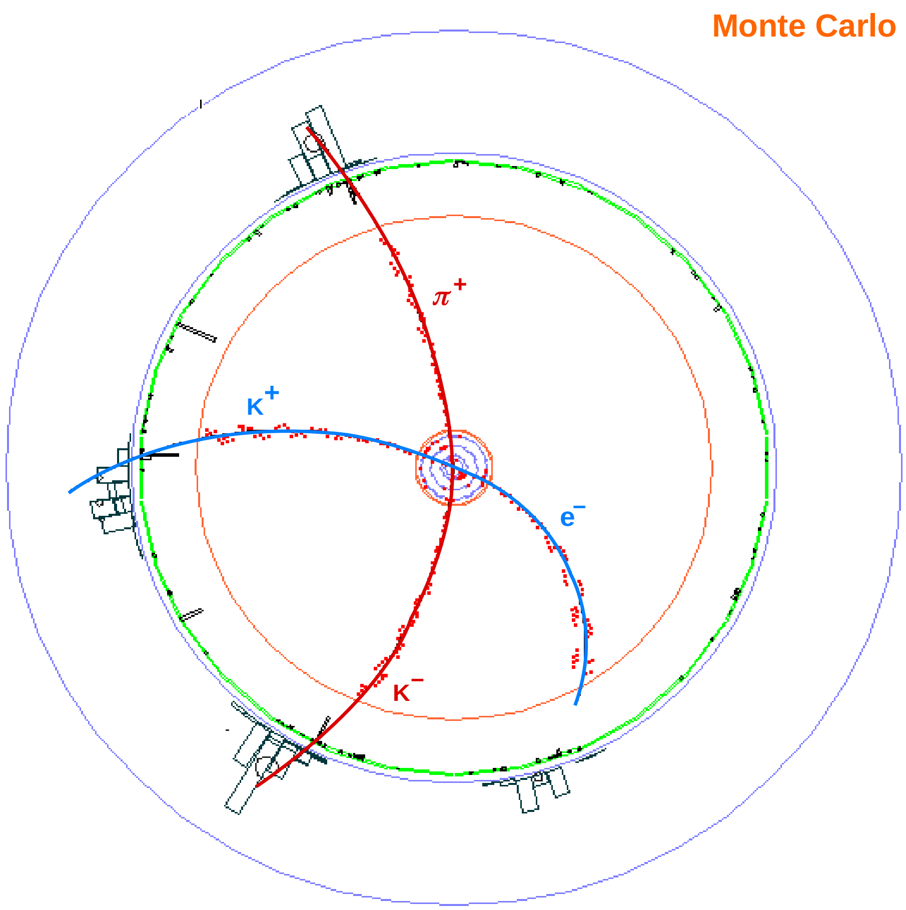
Υ(1S) decays:

Radiative decays Υ(1S) → γ X

Inclusive decays to charmonium Υ(1S) → ψ(2S) X

Search for ($cg\bar{c}$) 1^{--} hybrids

Running at charm threshold



$D^0 \rightarrow K^- \pi^+$ $\overline{D^0} \rightarrow K^+ e^- \nu$

- Large cross section, low multiplicity
- Pure initial state: no fragmentation
- Double tag measurement: no background
- Clean neutrino reconstruction
- Quantum coherent initial state

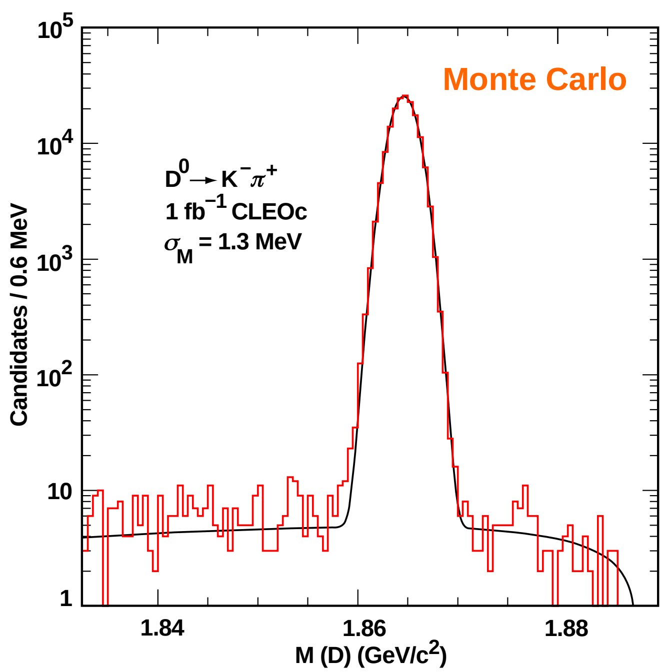
Tagging Technique

Advantages of pure $D\bar{D}$ or $D_S\bar{D}_S$ production:

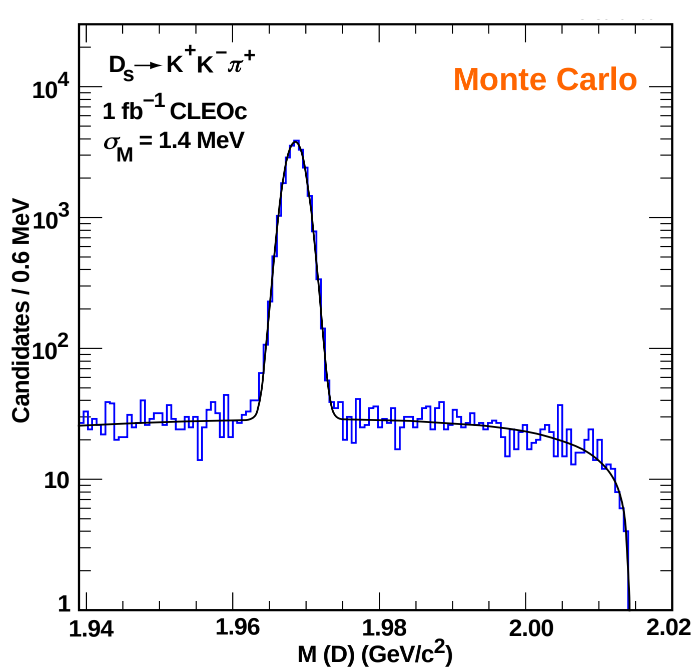
- **Many high branching ratios (~ 1 – 10%)**
- **High reconstruction efficiency**
- **Two opportunities: 6M D tags**
  300k D_S tags

→ High net efficiency ~20 %

$D \rightarrow K\,\pi$ tag
S/B ~ 5000



$D_S \rightarrow K\,K\,\pi$ tag
S/B ~ 100

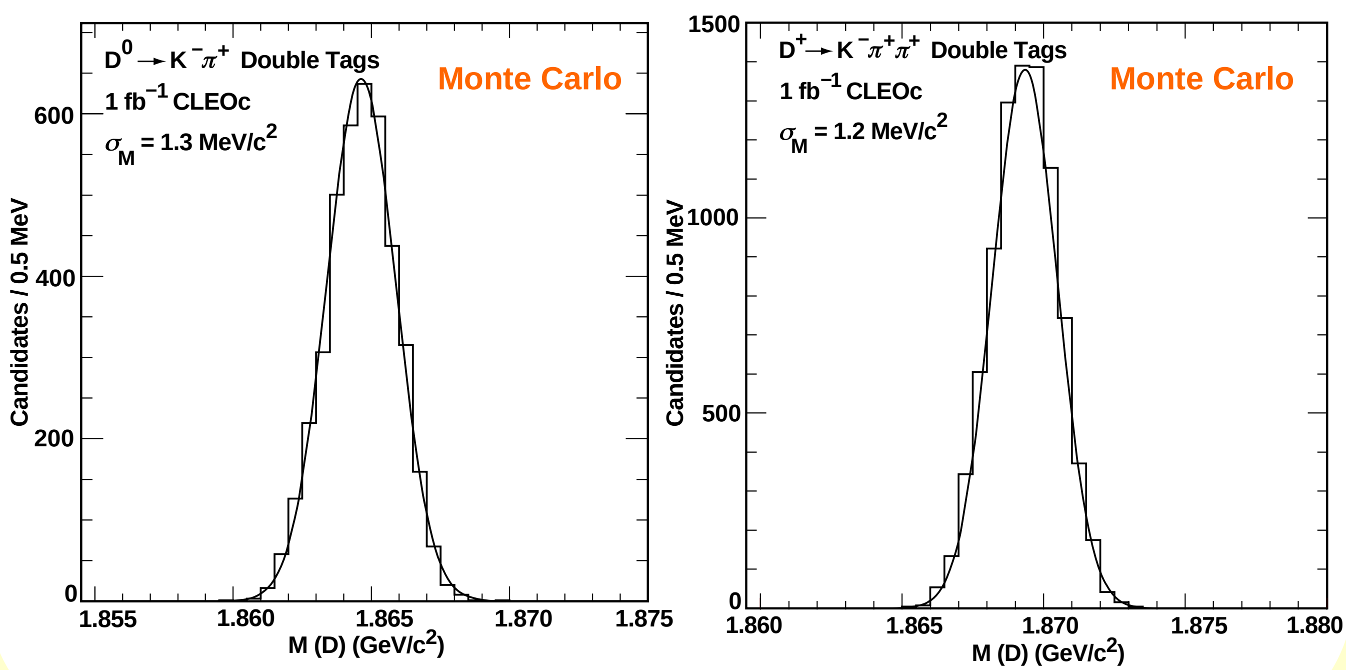


beam constraint mass

Absolute Branching Ratio Measurements

Double tags:

~ Zero background in hadronic modes !



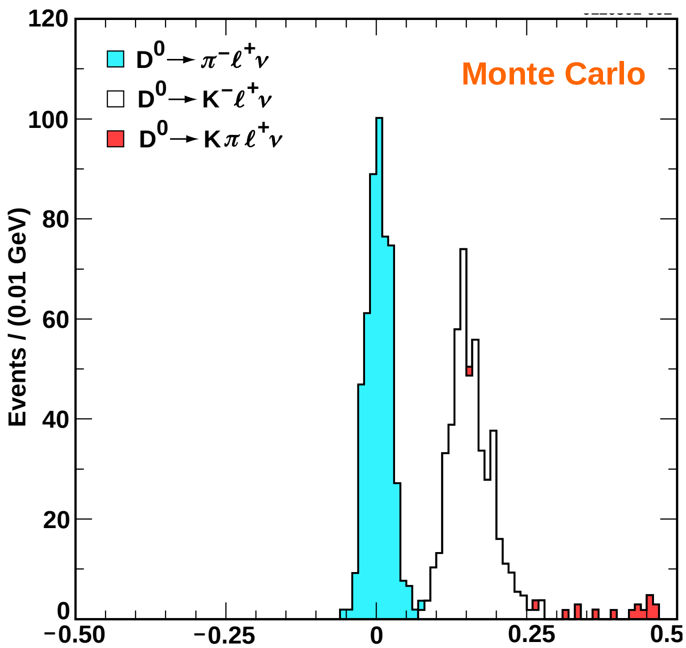
Set absolute scale for all heavy quark measurements

Decay mode	*BR fractional error %*	
	PDG 2000	*CLEO-c*
$D^0 \to K\pi$	2.4	0.5
$D^+ \to K\pi\pi$	7.2	1.5
$D_S \to \phi\pi$	25	1.9

Semileptonic Decays

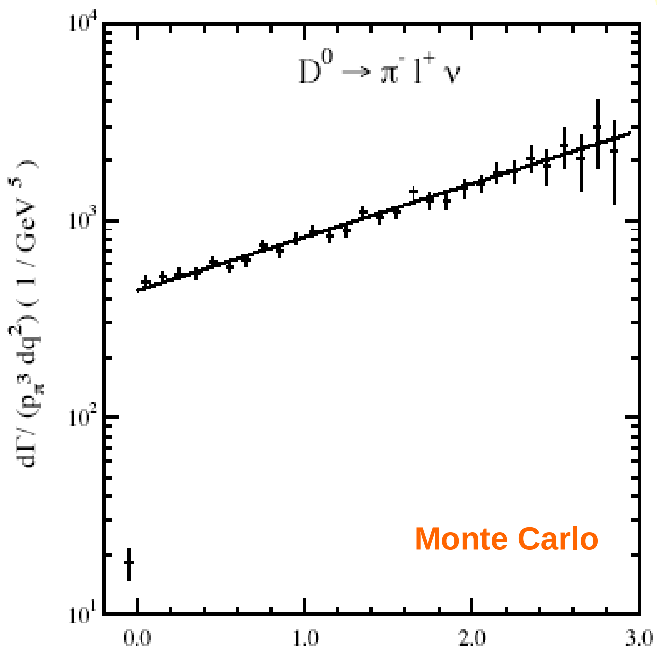
$|V_{CKM}|^2$ $|f(q^2)|^2$

Good Seperation



$U = E_{miss} - P_{miss}$

Statistical Error ~ 1%



q^2 (GeV^2)

Set absolute scale for V_{cd}, V_{cs} and f.f. measurements

Decay mode	*BR fractional error %*	
	PDG 2000	*CLEO-c*
$D^0 \to K\ l\ \nu$	5	1.6
$D^0 \to \pi\ l\ \nu$	16	1.7
$D^+ \to \pi\ l\ \nu$	48	1.8
$D_S \to \phi\ l\ \nu$	25	2.8

Comparison to B Factories

	CLEO-c *2 – 4 fb^{-1}*	*Babar* *400 fb^{-1}*	*Current Knowledge*
f_D V_{cd}	1.5 – 2 %	10 – 20 %	n.a.
f_{Ds} V_{cs}	$\leq$ 1 %	5 – 10 %	19 %
$BR(D^+ \to K \pi \pi)$	1.5 %	3 – 5 %	7 %
$BR(D_S \to \phi\, l\, \nu)$	2 – 3 %	5 – 10 %	25 %
$BR(D \to \pi\, l\, \nu)$	1.4 %	3 %	18 %

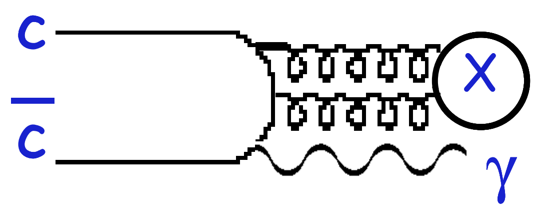
Gluonic Matter

Gluons carry color charge
→ They should bind !

Glueball sightings: MARK III, BES, L3, Crystal Barrel

But glueballs have been sighted too many times without confirmation

Radiative J/ψ decays are ideal glue factory

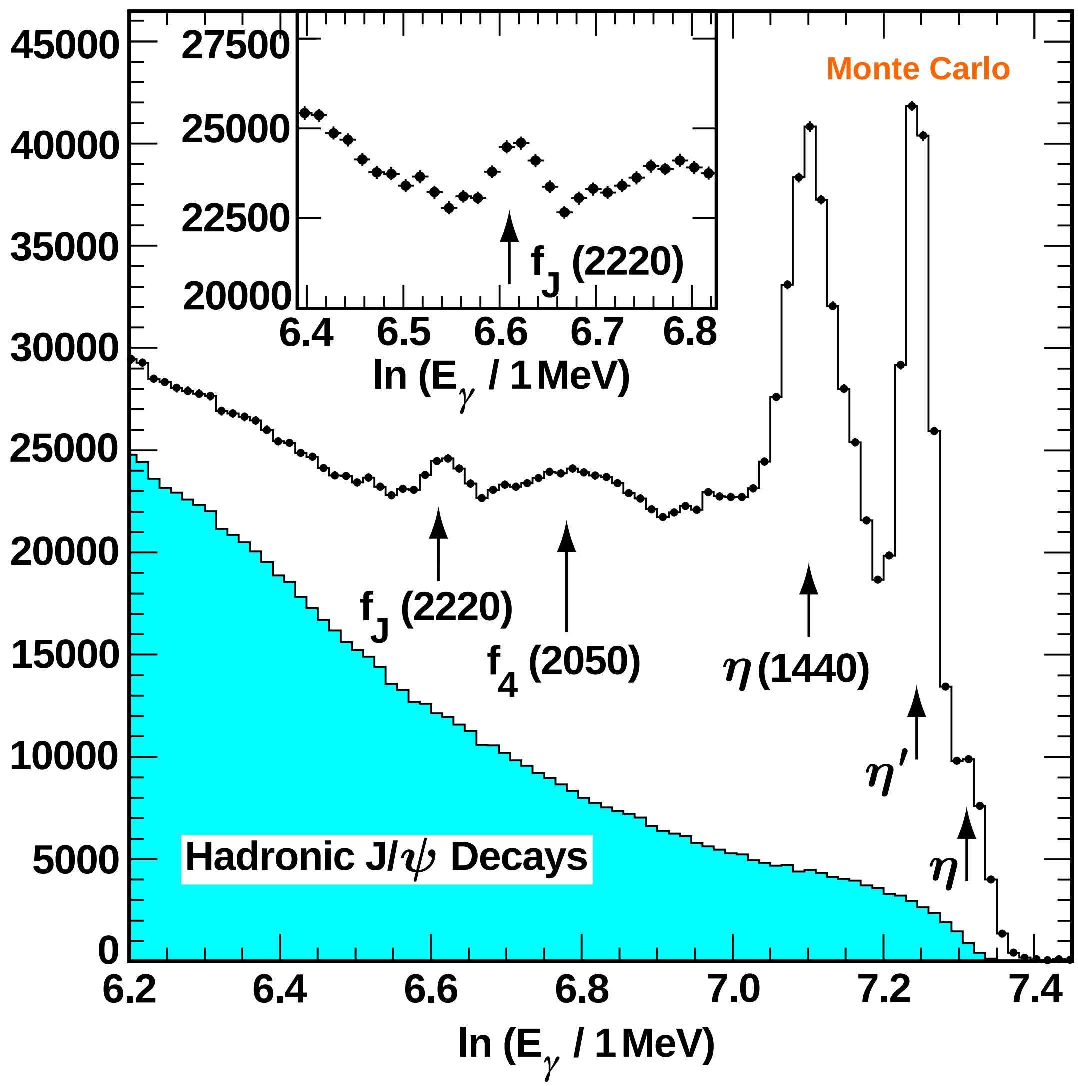


- Very clean initial state
- Very clean tag
- Glue pair in color iso-singlet

CLEO-c:

- 10^9 J/ψ → ~ 60M $J/\psi \to \gamma X$
- Inclusive studies
- Study of exclusive modes
- Complementary two-photon searches
  25 fb^{-1} of CLEO-III data
- Complementary radiative Y(1S) search

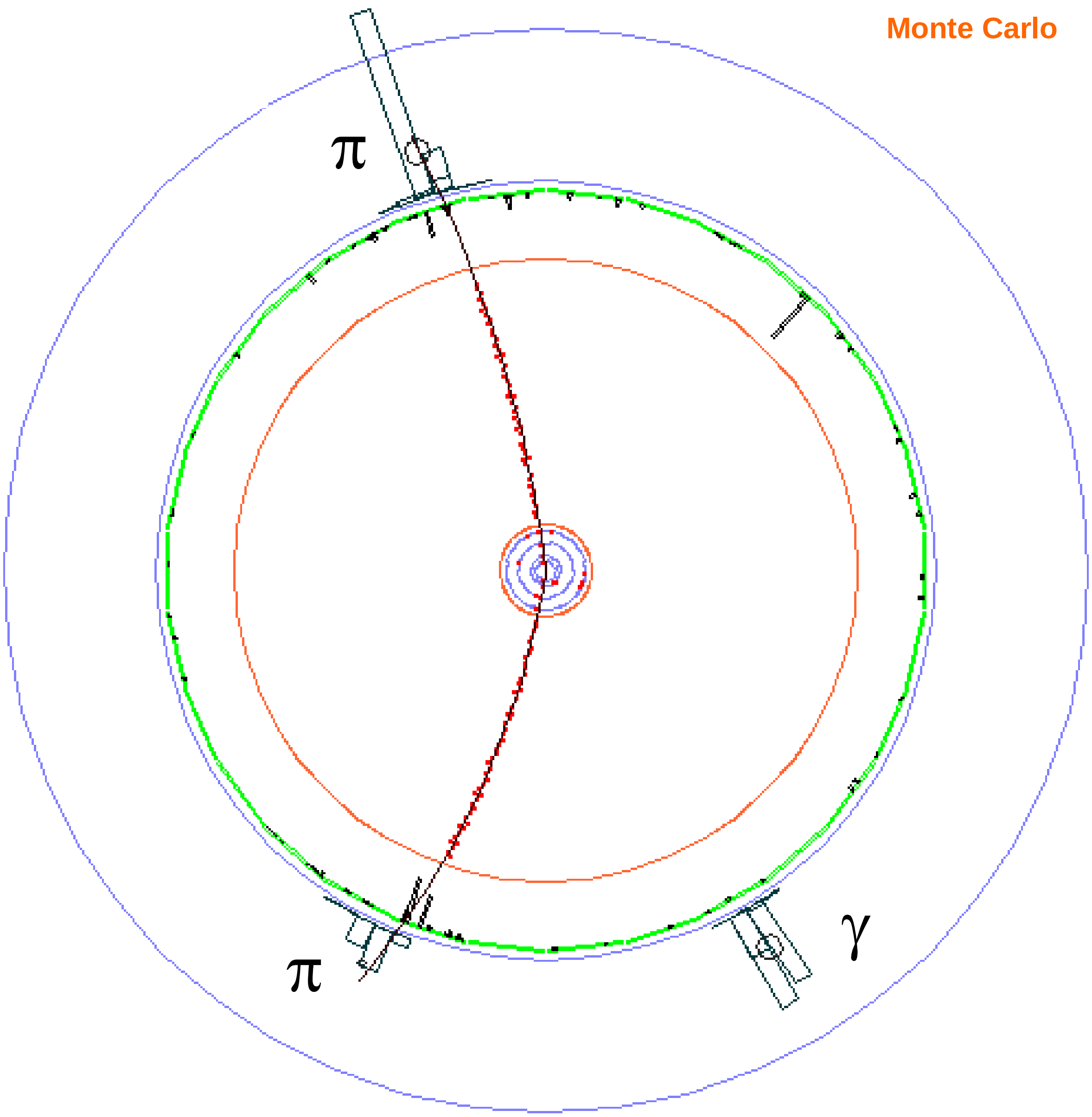
Inclusive Spectrum J/ψ → γ X



10^{-4} sensitivity for narrow resonance

→ ~25% efficient for $f_J(2220)$

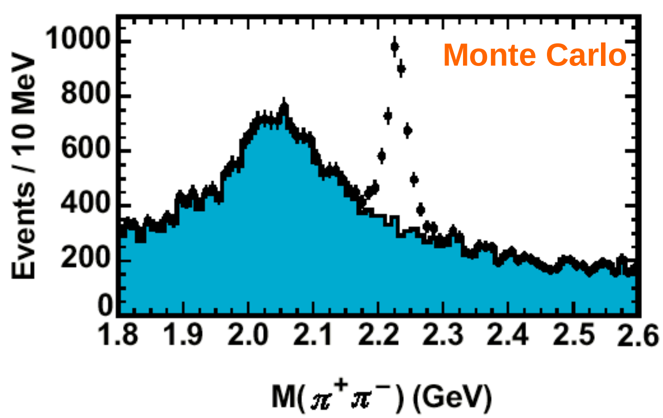
$J/\psi \rightarrow \gamma\, f_J(2220)$

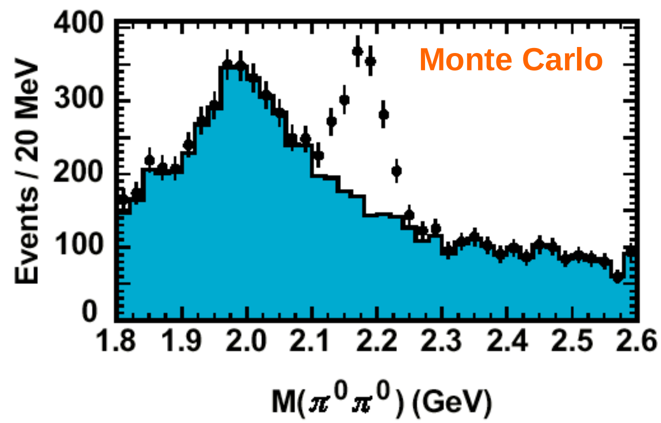


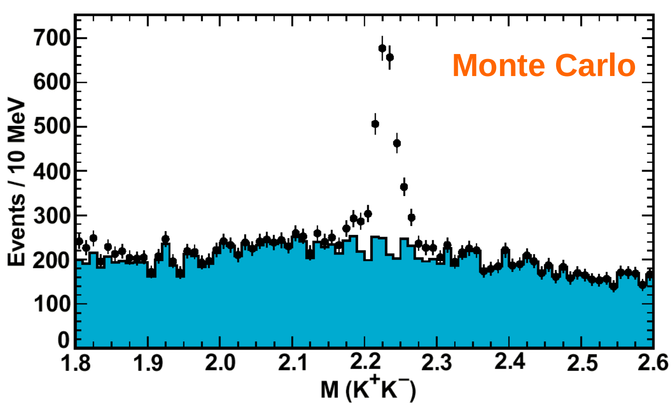
Glueball Candidate $f_J(2220)$

Exclusive modes:

- **Essentially no hadronic background**
- **Extreme clean signatures**
- **Large statistics**







Mode	BES	CLEO-c
$\pi^+\pi^-$	74	32,000
$\pi^0\pi^0$	18	13,000
K^+K^-	46	18,600
K_SK_S	23	5,300
pp	32	8,500
$\eta\eta$	-	5,000

Summary

Unique features of CLEO-c:

- Huge data set
  - 20 to 500 times larger than previous experiments
- Modern detector
  - Excellent tracking and photon resolution
  - Well understood
- Extra datasets for corroboration
  - Ypsilons: 4 fb^{-1}
  - Two photon: 25 fb^{-1}

Powerful physics case:

- Precision flavor physics
- Non-pertubative QCD
- Probe for new physics

Optimal timing:

- Flavor physics of this decade
- Beyond the Standard Model in next decade
- In resonance with Lattice-QCD

The CLEO Collaboration

Carnegie Mellon University
Cornell University
University of Florida
University of Hawaii
University of Illinois
University of Kansas
University of Minnesota
Budker Institute of Nuclear Physics
University of Tennessee
Ohio State University
University of Pittsburgh
Purdue University
University of Rochester
Southern Methodist University
Stanford Linear Accelerator Center
State University of New York at Albany
Syracuse University
University of Texas – Pan American
Vanderbilt University
Wayne State University

Additional Topics

Mixing:

Comparison between hadronic and lepton tagged modes from C = $\pm$ 1 $D^0 \overline{D^0}$ pairs

Charm Baryons:

$\Lambda_C \Lambda_C$ at threshold 1 fb^{-1}

Calibrate absolute BR($\Lambda_C \rightarrow p K \pi$)

Tau lepton physics:

$\tau^+ \tau^-$ at threshold 0.25 fb^{-1}

Measure m_τ to $\pm$ 0.1 MeV

Heavy lepton and exotics searches

Measurement of R:

$R = \sigma(e^+e^- \rightarrow hadrons) / \sigma(e^+e^- \rightarrow \mu^+\mu^-)$

Spot checks