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Two Photon Production of the η_c

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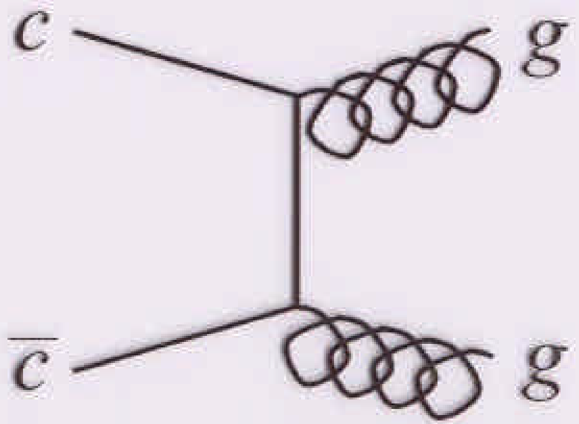
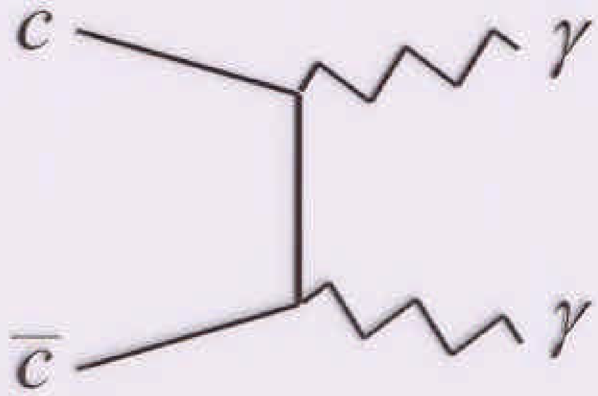
Outline

- Introduction:
  - why η_c mass, width and $\gamma\gamma$ partial width?
- Experimental results
  - DELPHI
  - CLEO
  - Comparison to other measurements
- Conclusions

Introduction: why bother

- $m_{J/\psi} - m_{\eta_c}$ (hyperfine structure)
  - spin-spin term of potential
- $\Gamma^{\eta_c}_{total} \approx \Gamma^{\eta_c}_{gg} \equiv \Gamma(\eta_c \to gg)$ and $\Gamma^{\eta_c}_{\gamma\gamma} \equiv \Gamma(\eta_c \to \gamma\gamma)$
  - Test of QCD calculations





hyperfine mass splitting

- Theories: expect 110 - 130 MeV
  - Depending on
    - α_s (or Λ_{MS}) $\rightarrow \pm 10$ MeV
    - choice of confining potential $\rightarrow \pm 10$ MeV
- Experiments (PDG 98)
  - $m_{\eta_c} = (2{,}979.8 \pm 2.1)$ MeV
  - $\Delta m = (117.1 \pm 2.1)$ MeV

Decay Rates - theory

- In ratios, non-perturbative contributions cancel!
- $R_1 = \dfrac{\Gamma_{gg}}{\Gamma_{\gamma\gamma}} = \dfrac{9\alpha_s^2}{8\alpha^2} \dfrac{(1+4.8\,{}^{\alpha_s}\!/_{\pi})}{(1-3.4\,{}^{\alpha_s}\!/_{\pi})} = 3.4\times 10^3$
- $R_2 = \dfrac{\Gamma_{\gamma\gamma}}{\Gamma_{\psi\to ee}} = \dfrac{4}{3}(1+1.96\,{}^{\alpha_s}\!/_{\pi}) \dfrac{M_\psi^2}{(2m_c)^2} \dfrac{|\Psi_{\eta_c}(0)|^2}{|\Psi_{J/\psi}(0)|^2} = 1.57$

Decay Rates - Experiments

$$\frac{\Gamma_{gg}}{\Gamma_{\gamma\gamma}} = \frac{\left(13.2^{+3.8}_{-3.2}\right)\text{MeV}}{\left(7.5^{+1.6}_{-1.4}\right)\text{keV}} = (1.8 \pm 0.6) \times 10^3 \,(\text{theory}: 3.4 \times 10^3)$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\psi \to ee}} = \frac{\left(7.5^{+1.6}_{-1.4}\right)\text{keV}}{(5.26 \pm 0.37)\text{keV}} = 1.43^{+0.31}_{-0.27} \,(\text{theory}: 1.57)$$

New Experimental Results

- $e^+e^- \to J/\psi$ (or ψ') $\to \gamma\eta_c$
  - BES (hep-ex/0002006, PR D60 072001): m_{η_c}, $\Gamma^{\eta_c}_{total}$
- $pp \to \eta_c$
  - E835 (M. Stancari, Photon 99) : m_{η_c}, $\Gamma^{\eta_c}_{total}$, $\Gamma^{\eta_c}_{\gamma\gamma}$
- $e^+e^- \to e^+e^-\gamma\gamma \to e^+e^-\eta_c$
  - L3 (PL B461, 1999, 155): $\Gamma^{\eta_c}_{\gamma\gamma}$
  - DELPHI (this conference; abstract 757): $\Gamma^{\eta_c}_{\gamma\gamma}$
  - CLEO (this conference; abstract 555) : m_{η_c}, $\Gamma^{\eta_c}_{total}$, $\Gamma^{\eta_c}_{\gamma\gamma}$

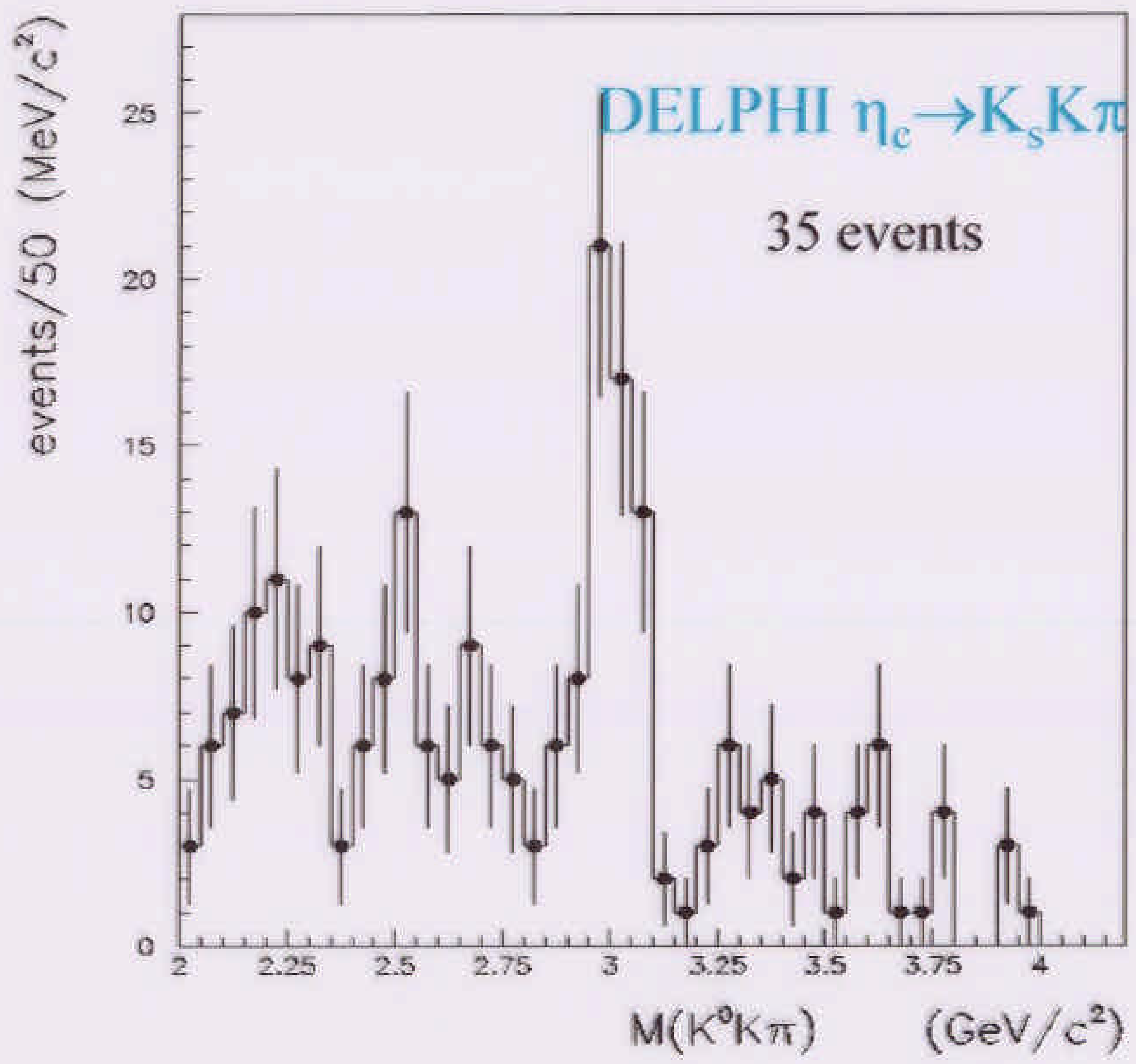


Figure 4: Final invariant mass distribution for $\eta_c \rightarrow K^0_s K^{\pm} \pi^{\mp}$ decay mode.

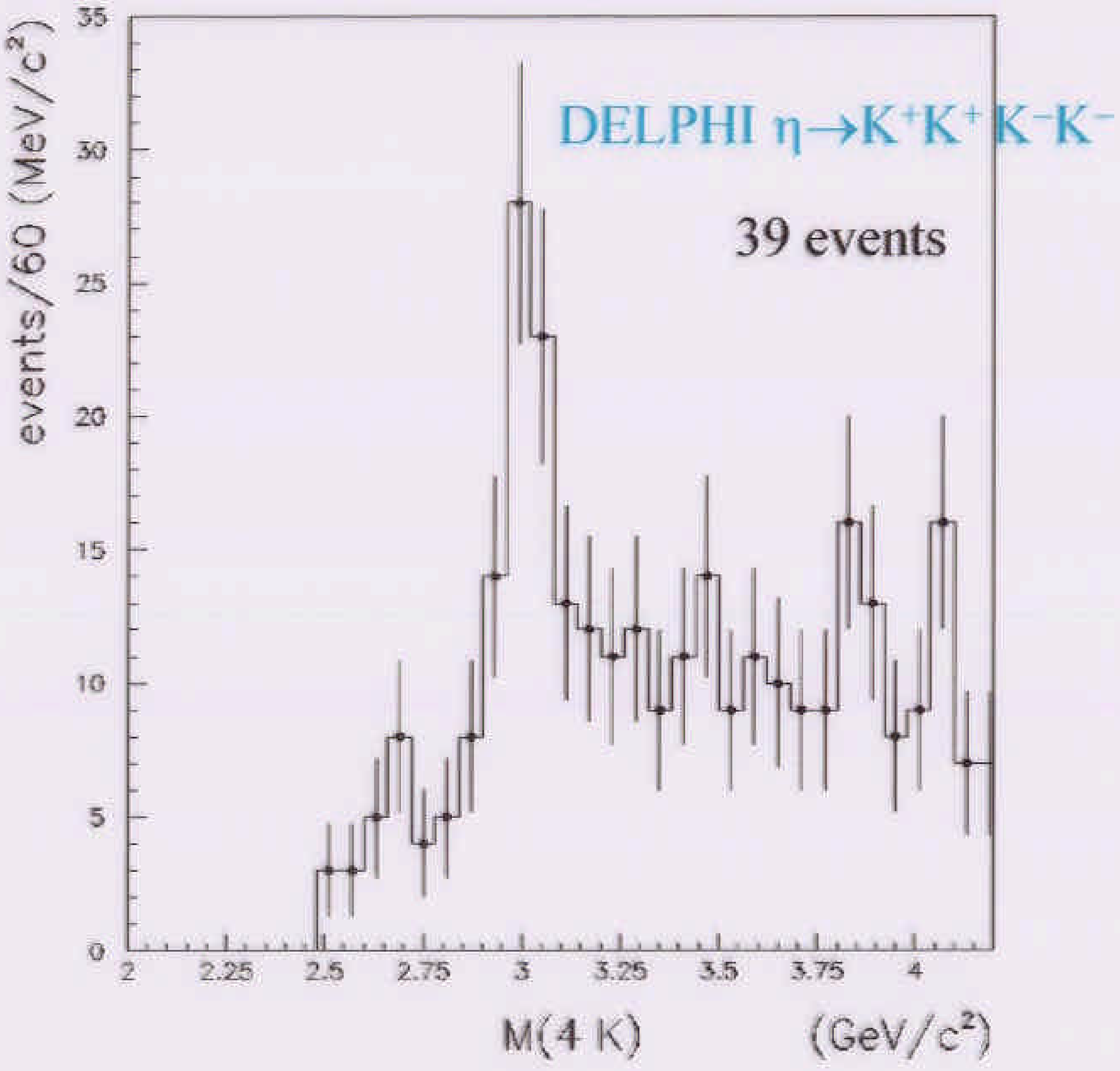
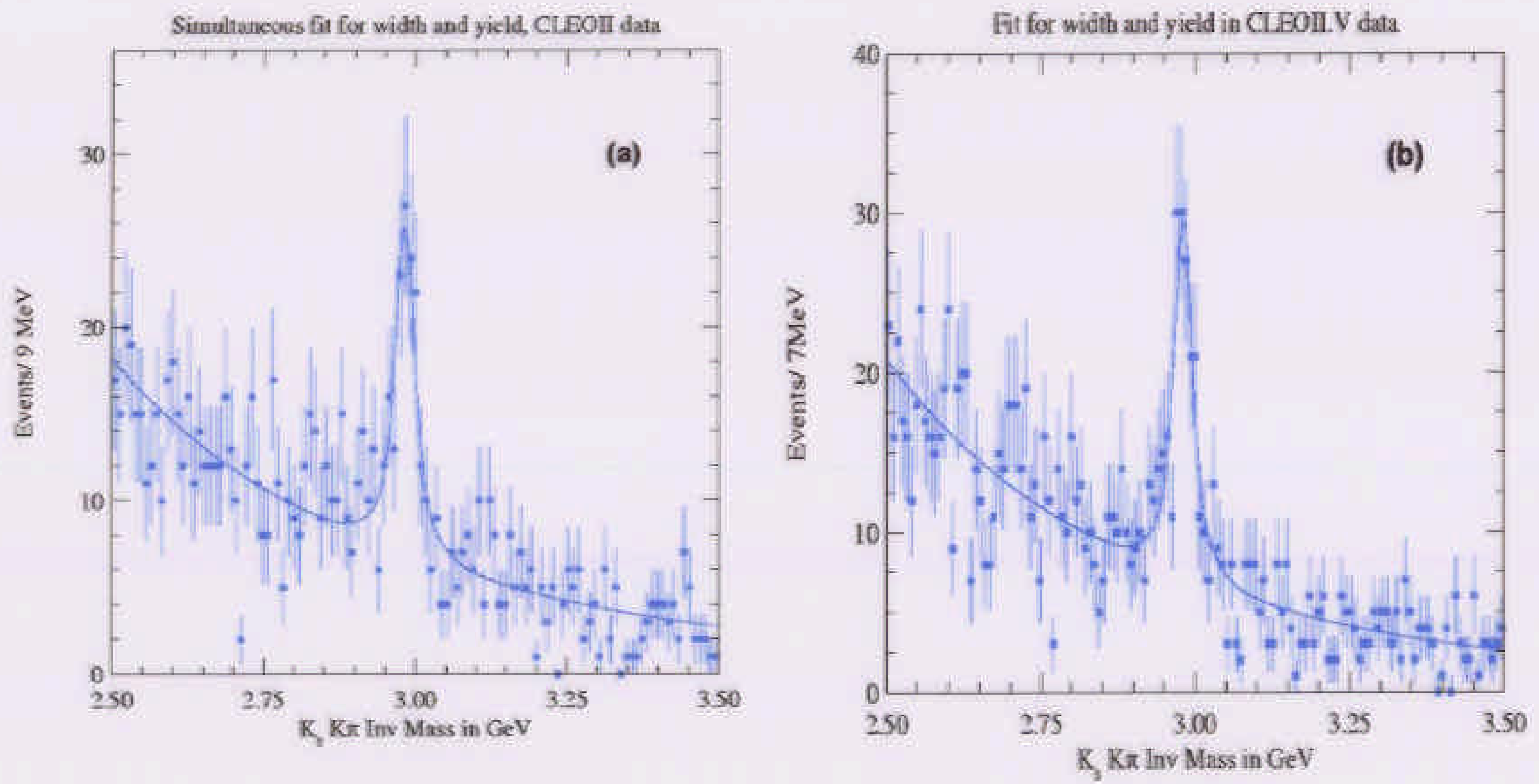


Figure 6: The final invariant mass of $K^+K^-K^+K^-$.

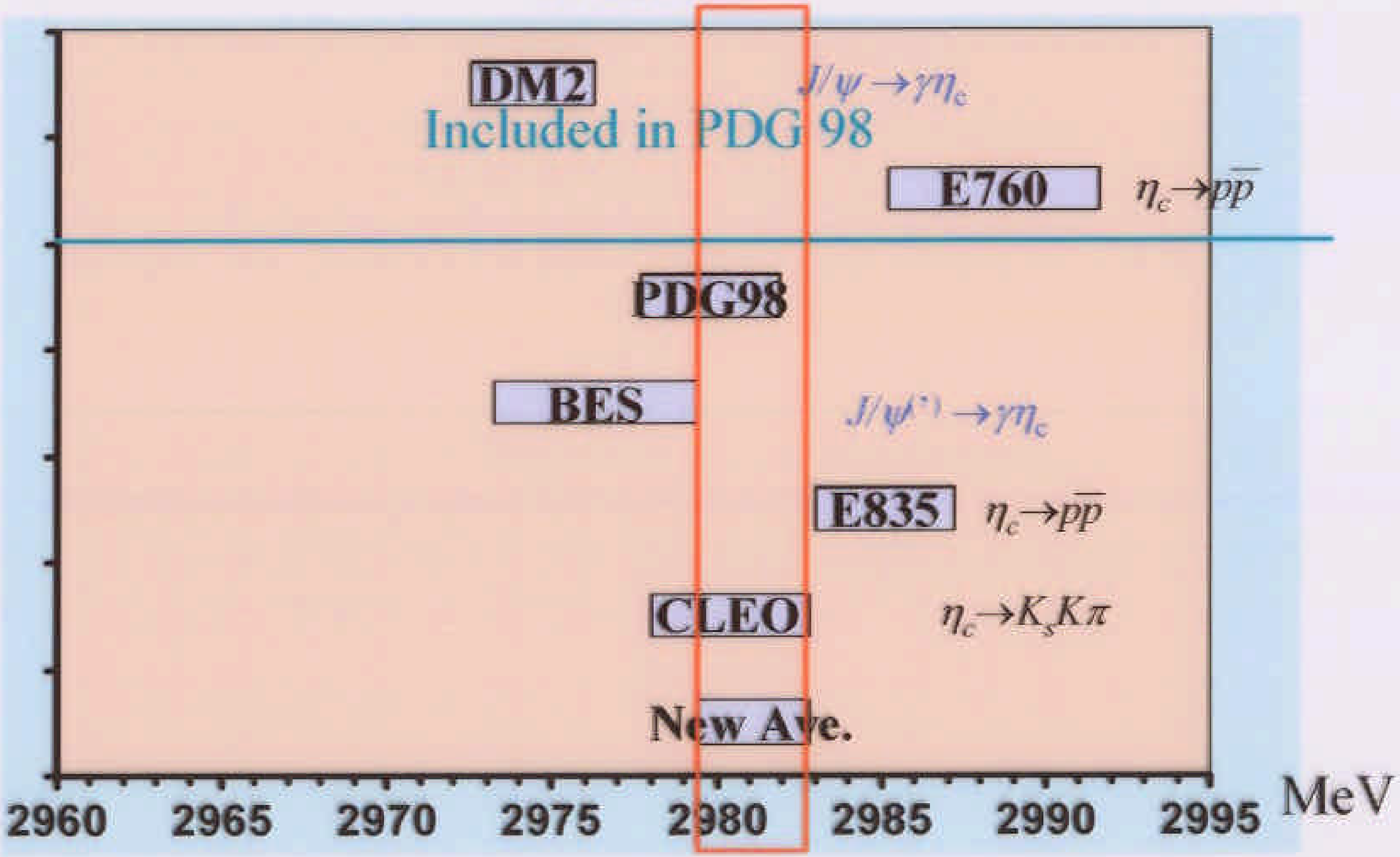
DELPHI Results

- $\Gamma^{\eta_c}_{\gamma\gamma} BR(\eta_c \to K_s K \pi) = (0.20 \pm 0.04 \pm 0.03)$ keV
- $\Gamma^{\eta_c}_{\gamma\gamma} = (10.9 \pm 2.2 \pm 1.6 \pm 3.4)$ keV
  - normalized to $BR(\eta_c \to K_s K \pi) = (1.8 \pm 0.6)\%$
- $\Gamma^{\eta_c}_{\gamma\gamma} BR(\eta_c \to KKKK) = (0.30 \pm 0.06 \pm 0.05)$ keV
- $\Gamma^{\eta_c}_{\gamma\gamma} = (14.3 \pm 2.9 \pm 2.4 \pm 8.1)$ keV

CLEO: $\eta_c \to K_s K \pi$



Mass

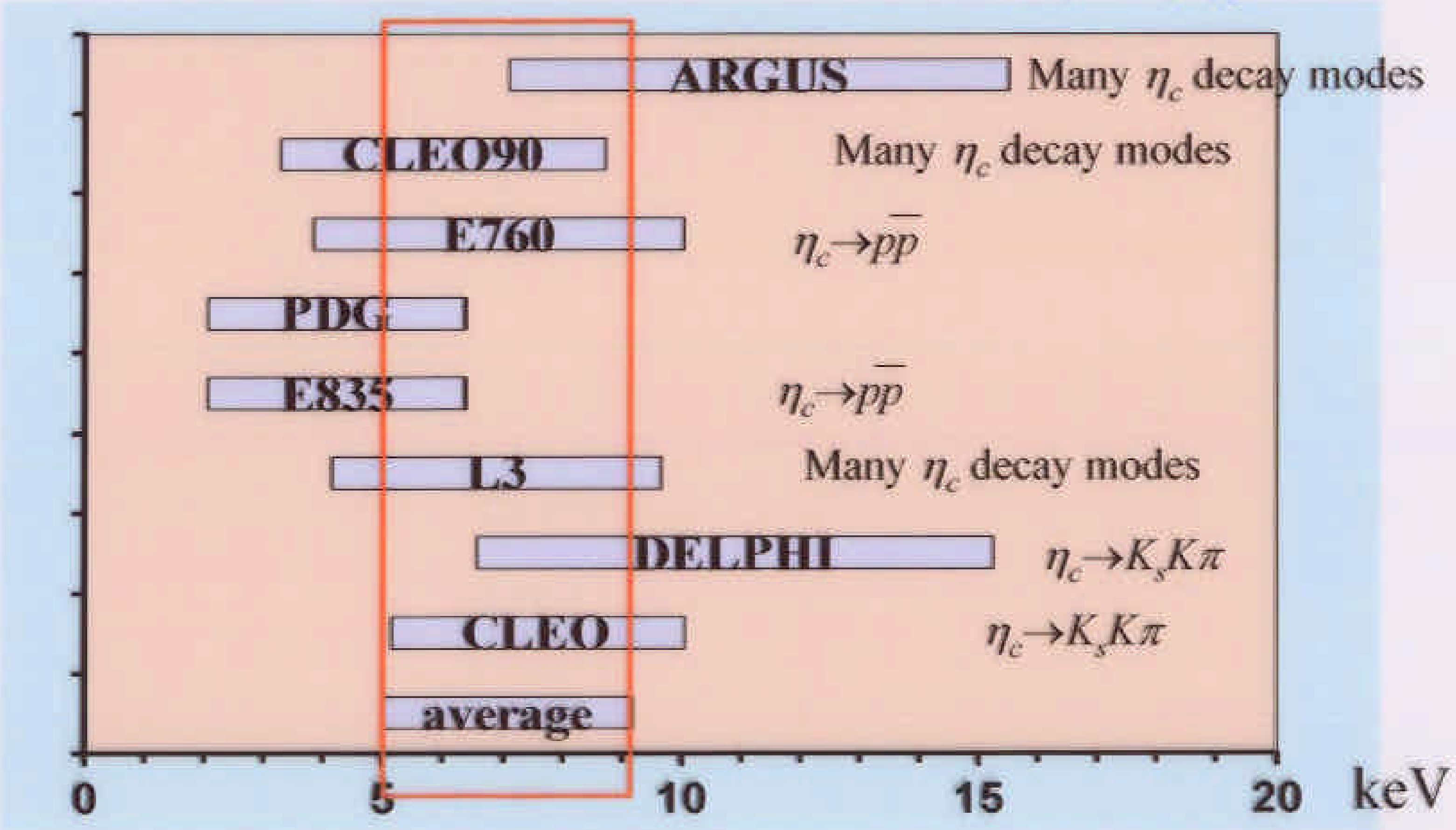

DM2
J/ψ → γη_c
Included in PDG 98
E760
η_c→pp̄
PDG98
BES
J/ψ(') → γη_c
E835
η_c→pp̄
CLEO
η_c→K_sKπ
New Ave.
2960
2965
2970
2975
2980
2985
2990
2995
MeV

Observation and Caveats

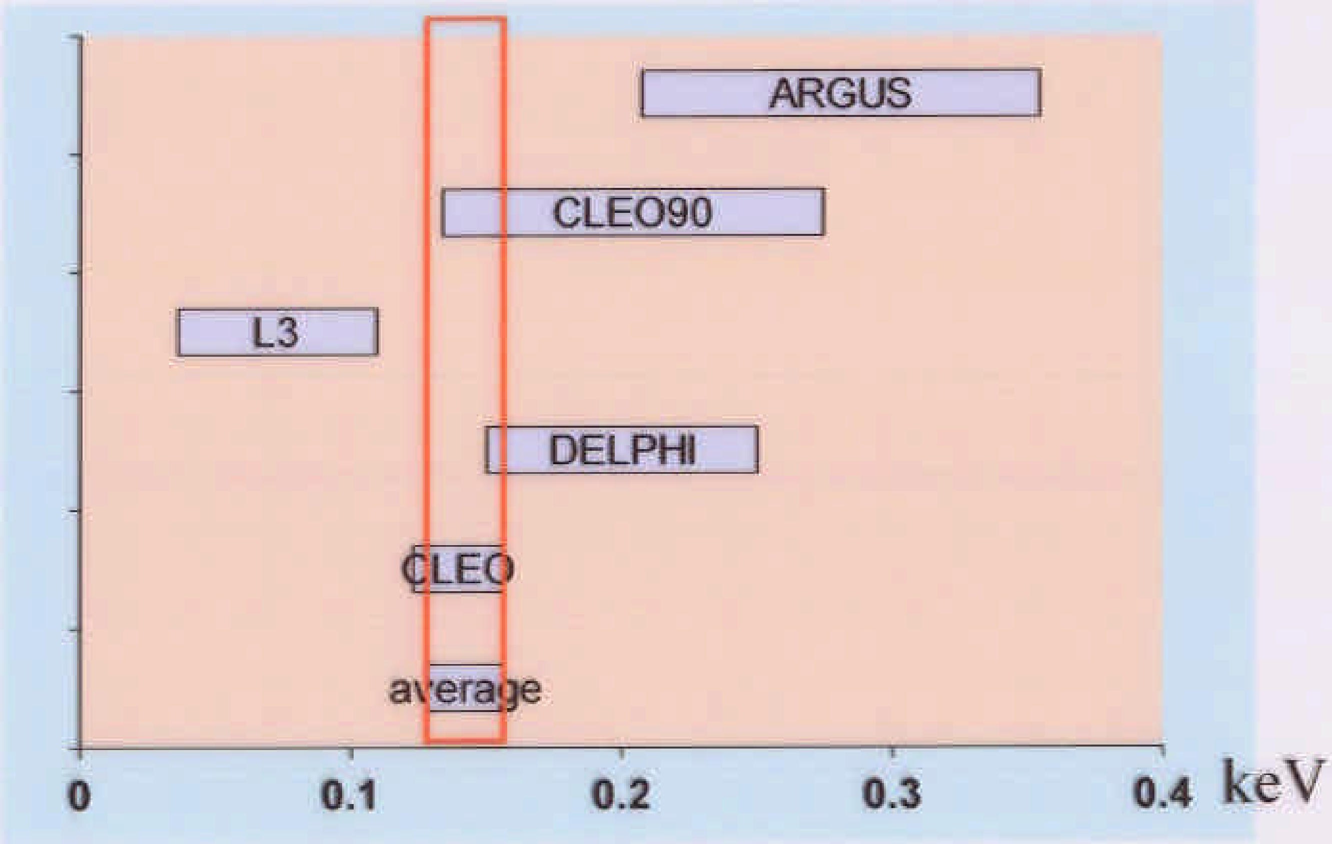
- Mass measurements are not consistent:
  - χ^2/DF = 3
  - better than PDG98
- Is interference possible
  - between $\gamma\gamma \rightarrow \eta_c \rightarrow K_s K \pi$ and continuum $\gamma\gamma \rightarrow K_s K \pi$?
  - If so, it can change the apparent
    - mass peak position and/or
    - apparent $\gamma\gamma$ width
  - Everyone assumes that this effect is small
    - theoretical prejudice that $\gamma\gamma \rightarrow K_s K \pi$ is NOT in $J = 0$!

$\gamma\gamma$ Partial Width

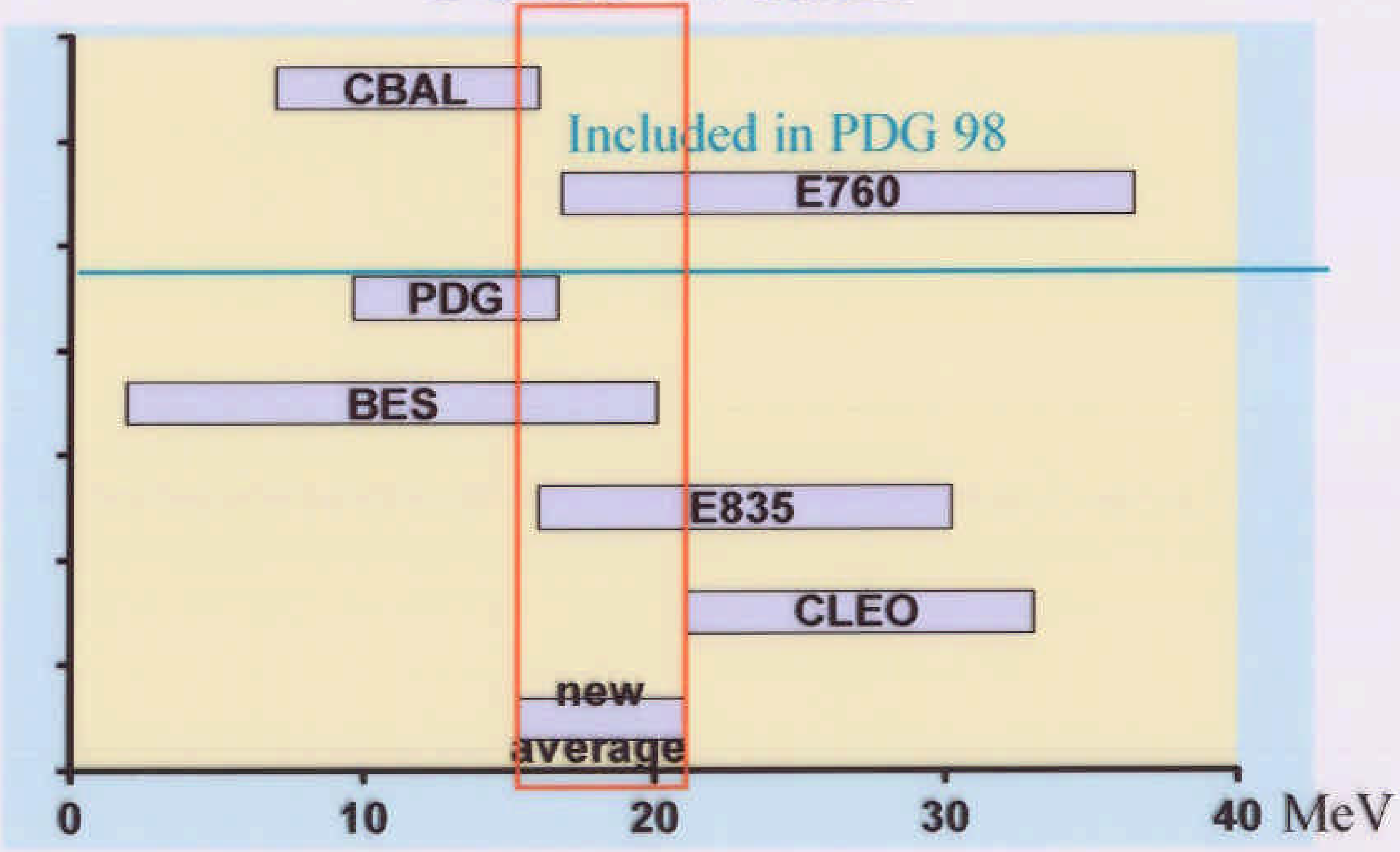
Errors include common error from $J/\psi \to \gamma\eta_c$



$\gamma\gamma$ Partial Width $\times$ $BR(\eta_c \to K_s K \pi)$



Total Width



CBAL
Included in PDG 98
E760
PDG
BES
E835
CLEO
new
average
0
10
20
30
40
MeV

Recent Experimental Results

Exp.	mass (MeV)	total width (MeV)	$\gamma\gamma$ width (keV)
ARGUS	-	-	11.3±4.2
CLEO90	-	-	$5.9^{+2.1}_{-1.8}\pm1.9$
CBAL	-	11.5±4.5	-
MKIII	2980.6±1.6	-	-
DM2	2974.4±1.9	-	-
E760	$2988.3^{+3.3}_{-3.1}$	$23.9^{+12.6}_{-7.1}$	$6.7^{+2.4}_{-1.7}\pm2.3$
PDG 98	2979.8±2.1*	13.2±3.5	7.5±1.5
BES	2976.3±3.1	11.0±8.1±4.1	-
E835	2985.1±2.1	$22.4^{+7.8}_{-6.4}$	$4.1^{+1.7}_{-1.4}\pm1.5$
L3	2974±18	-	6.9±1.9±2.0
DELPHI	3000-3020!	-	10.9±2.7±3.4
CLEO	2980.4±2.4	27.0±6.0	7.6±0.9±2.3
Average	2981.1±1.7*	$18.0^{+3.0}_{-2.7}$	$7.1^{+0.8}_{-0.7}\pm2.0$

* scale factor was used to calculate the combined error

$BR(\eta_c \rightarrow K_s K \pi) = (1.3\pm0.4)\%$

Only $K_s K \pi$ result

Results vs. theory

$$\frac{\Gamma_{gg}}{\Gamma_{\gamma\gamma}} = \frac{\left(18.0^{+3.0}_{-2.7}\right)\text{MeV}}{\left(7.1^{+0.8}_{-0.7} \pm 2.0\right)\text{keV}} = (2.5 \pm 0.9) \times 10^3 \,(\text{theory} : 3.4 \times 10^3)$$

- Agreement is now better:
  - $\Gamma^{\eta_c}_{total}$ increased due to new measurements.

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\psi \to ee}} = \frac{\left(7.1^{+0.8}_{-0.7} \pm 2.0\right)\text{keV}}{(5.26 \pm 0.37)\text{keV}} = 1.35^{+0.43}_{-0.42} \,(\text{theory} : 1.57)$$

- Error increased recognizing that $BR(J/\psi \to \gamma\eta_c)$ error is common among all measurements

Not everything is fine!

- As some of you know well, theory predicts:
- $\Gamma(J/\psi \to \gamma\eta_c)$

$$= \frac{2}{9} \frac{\Gamma(\eta_c \to \gamma\gamma)}{\Gamma(J/\psi \to ee)} \alpha \frac{m^4_{J/\psi}}{m^3_{\eta_c}} (1 - \frac{m^2_{\eta_c}}{m^2_{J/\psi}})^3 = (3.3 \pm 0.7)\text{keV}$$

- CBAL measured this twice to be (1.3±0.4) keV.
- LHS/RHS = 0.39 ± 0.15 (4σ from 1)

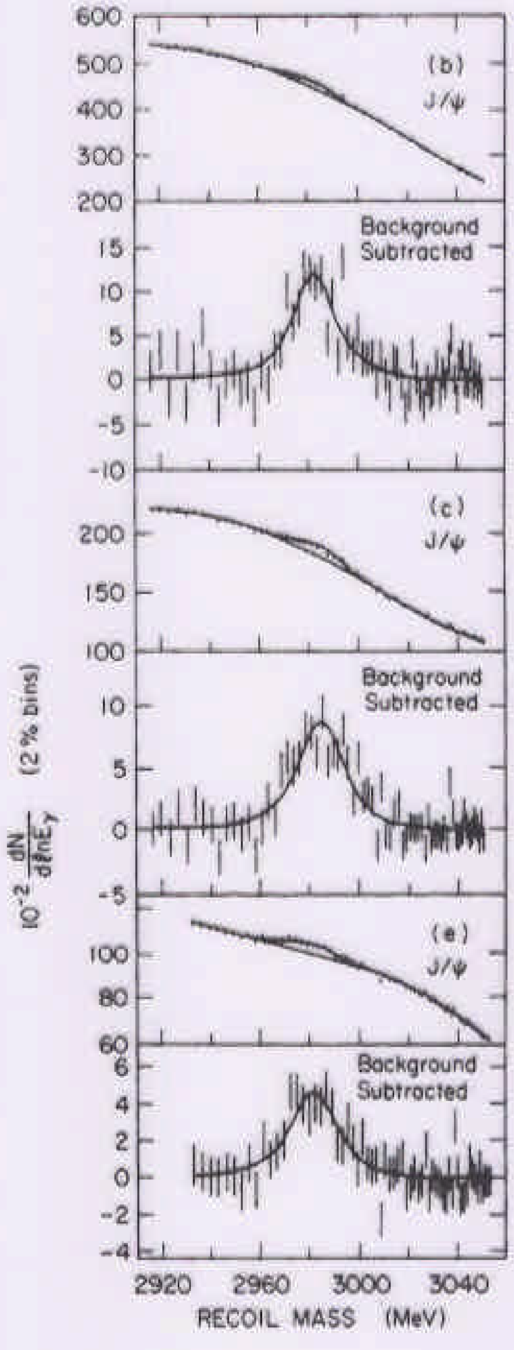


Figure 8.14: Inclusive photon spectra from $J/\psi \to \gamma X$ obtained by the Crystal Ball. The three sets of panels, indicated by (b), (c) and (e), represent three different selections of their data.

Another test of this prediction:

$BR(\eta_c \to K_s K \pi)$

$$\Gamma(J/\psi \to \gamma\eta_c)$$

$$= \frac{2}{9}\frac{\Gamma(\eta_c \to \gamma\gamma)}{\Gamma(J/\psi \to ee)}\alpha\frac{m_{J/\psi}^4}{m_{\eta_c}^3}\left(1-\frac{m_{\eta_c}^2}{m_{J/\psi}^2}\right)^3$$

MK III, DM2.

$$\Gamma(J/\psi \to \gamma\eta_c)BR(\eta_c \to KsK\pi)$$

$$= \frac{2}{9}\frac{\Gamma(\eta_c \to \gamma\gamma)BR(\eta_c \to KsK\pi)}{\Gamma(J/\psi \to ee)}\alpha\frac{m_{J/\psi}^4}{m_{\eta_c}^3}\left(1-\frac{m_{\eta_c}^2}{m_{J/\psi}^2}\right)^3$$

2γ exp. such as CLEO etc.

- This equation is independent of $\Gamma(J/\psi \to \gamma\eta_c)$:

Experimentally

- LHS $= (2.1 \pm 0.4) \times 10^{-2}$ keV.
- RHS =

$$\frac{2}{9}\frac{(0.128 \pm 0.014)\text{keV}}{(5.26 \pm 0.37)\text{keV}}\frac{1}{137}\frac{3.097^4}{2.981^3}\left(1 - \frac{2.981^2}{3.097^2}\right)^3 =$$

$(5.4 \pm 0.7) \times 10^{-2}$ keV.

- LHS/RHS $= (0.39 \pm 0.09)$, the same discrepancy!
- Relativistic effects? Or anything else?

Conclusions

- PQCD seems to work in predicting η_c decay widths.
- Total decay width of the η_c measurements, more in line with theoretical expectation
- However, the magnetic transition rate prediction for $J/\psi \rightarrow \gamma\eta_c$ disagrees with another set of measurements.