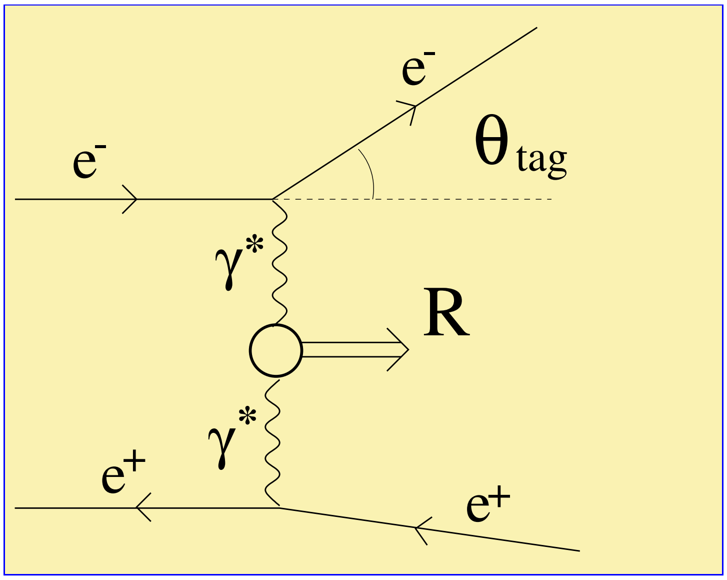
OUTLINE

- Two-photon Collisions
- Event Selection for χ_{c2} and η_c
- Results on Radiative Widths
- η_c Form Factor
- Conclusions



$$\sigma(e^+e^- \to e^+e^-\gamma\gamma \to e^+e^-R) = \int d^5\mathcal{L}_{\gamma\gamma}(\alpha_i)\sigma(\gamma\gamma \to R)$$

- θ_{tag} small: Untagged events

Radiative Widths

$$\sigma(\gamma\gamma \to R) = 8\pi\frac{(2J_R+1)}{m_R}\Gamma_{\gamma\gamma}(R)\frac{m_R\Gamma_R}{(\omega_{\gamma\gamma}^2-m_R^2)^2+m_R^2\Gamma_R^2}$$

- θ_{tag} large: Tagged events

Form Factors

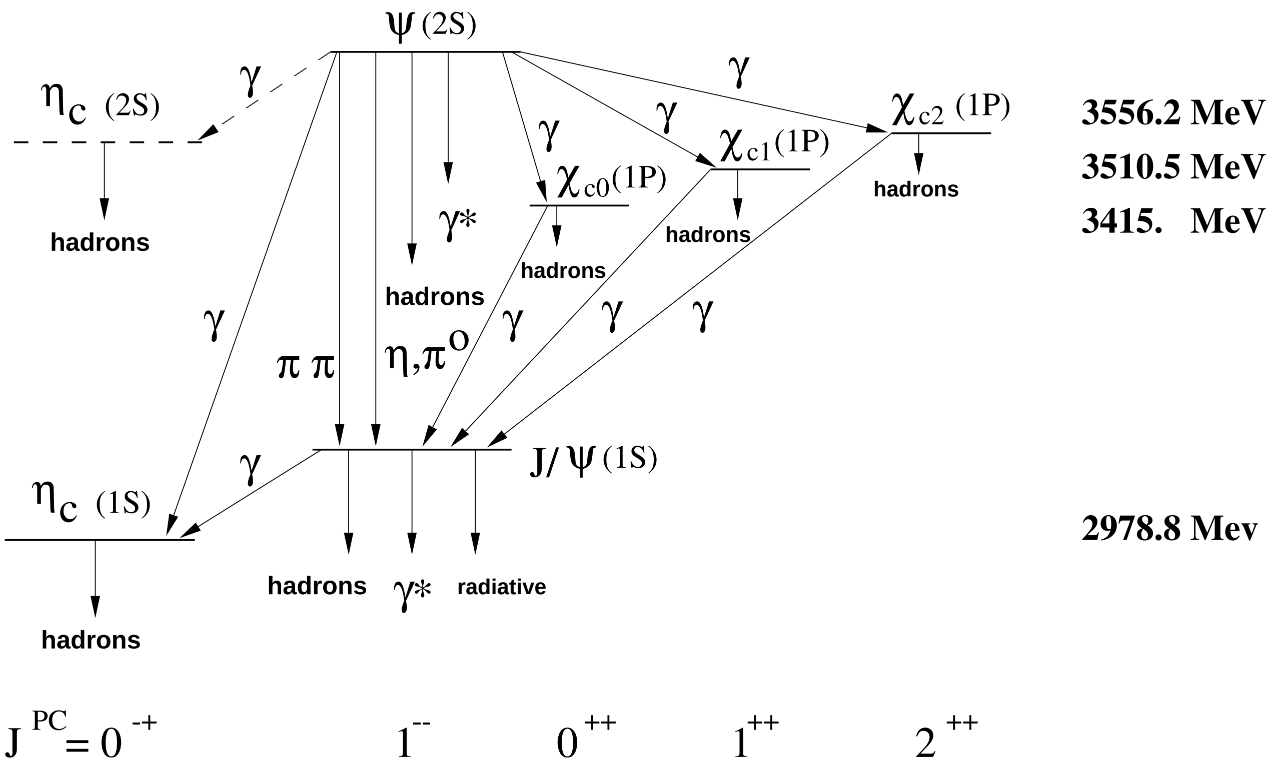
$$\sigma(\gamma\gamma \to R) = 8\pi\frac{(2J_R+1)}{m_R}\Gamma_{\gamma\gamma}(R)\frac{m_R\Gamma_R}{(\omega_{\gamma\gamma}^2-m_R^2)^2+m_R^2\Gamma_R^2}F^2(Q_1^2,Q_2^2)$$

$F(Q_1^2,Q_2^2)$ = Transition Form Factor

VDM: Form Factor $F^2 \sim (\frac{1}{1+Q_1^2/\Lambda^2})^2(\frac{1}{1+Q_2^2/\Lambda^2})^2$

$$\Lambda \simeq M_\rho, M_\omega, M_\Phi, M_{J/\Psi} \qquad \omega_{\gamma\gamma} = (Q_1+Q_2)^2$$

Charmonium Mesons

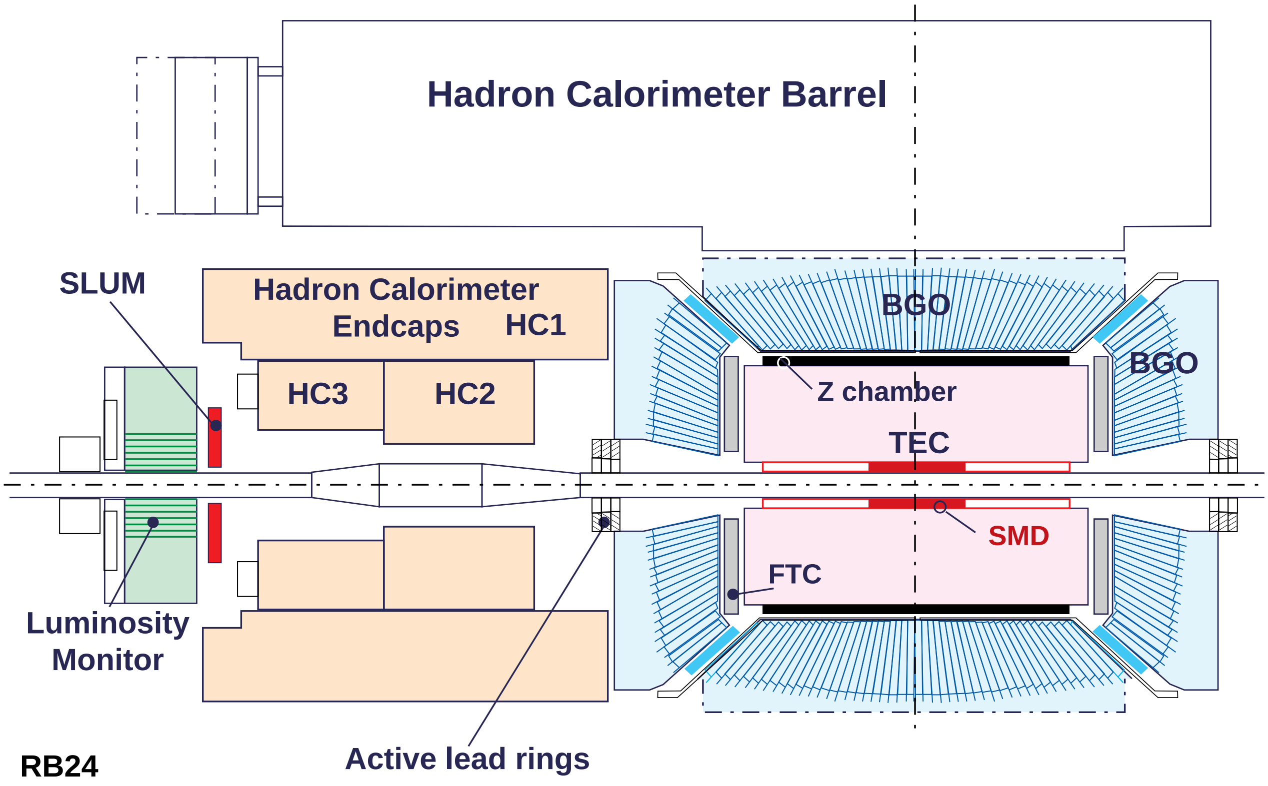


Selection Rules

- C = +1, Q = 0
- For quasi real photons, J= 0, 2

Search for η_c and χ_{c2} candidates

Inner L3 Detector



- Central track detector **TEC, SMD**: momentum of charged tracks, vertices.
- Electromagnetic calorimeter **BGO**: energy and position of electromagnetic clusters.
- Luminosity Monitor **LUMI** $(30 < \theta < 63 \text{ mrad})$ and Small Angle Tagger **VSAT** $(5 < \theta < 10 \text{ mrad})$: energy and polar angle from scattered electrons.

Data Sample

$$\int \mathcal{L}dt = \begin{cases} 140 \ \ \mathrm{pb}^{-1} \ \ at \ \ \sqrt{s} = 91 \ \mathrm{GeV} \\ 52 \ \ \mathrm{pb}^{-1} \ \ at \ \ \sqrt{s} = 183 \ \mathrm{GeV} \end{cases}$$

χ_{c2} and η_c recognized by decay products, reconstructing their exclusive final states.

$$\chi_{c2} \to \gamma J/\Psi \to \begin{cases} \gamma e^+ e^- \\ \gamma \mu^+ \mu^- \end{cases} \quad \mathrm{Br}=(1.62 \pm 0.14)\%$$

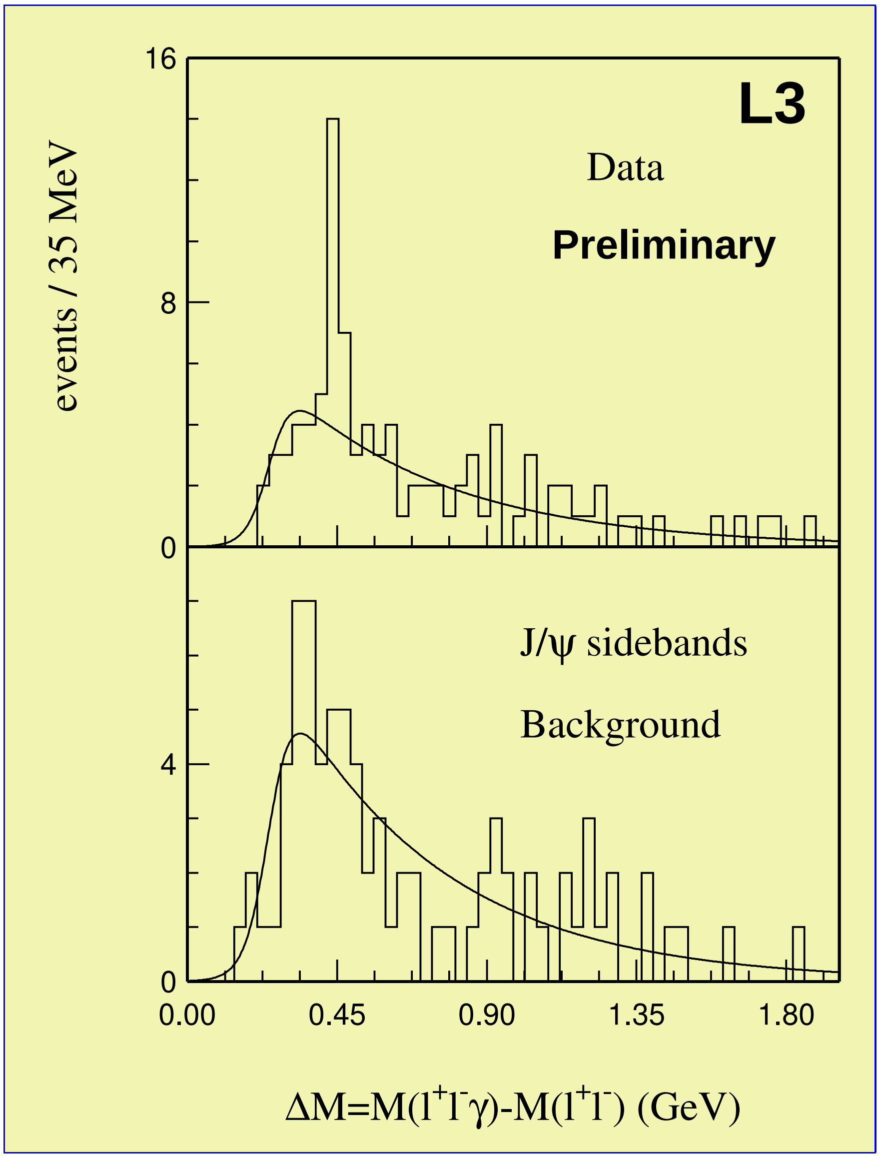
$\eta_c \to$		**Br (%)**
	$K^+K^-\pi^+\pi^-$	2.0 ± 0.7
	$\rho^+\rho^-, (\rho^\pm \to \pi^\pm\pi^0)$	1.73 ± 0.6
	$\pi^+\pi^-\pi^+\pi^-$	1.2 ± 0.4
	$K^0K^\pm\pi^\mp(K^0 \to \pi^+\pi^-)$	1.26 ± 0.39
	$\pi^0K^+K^-, (\pi^0 \to \gamma\gamma)$	0.90 ± 0.28
	$\Phi\Phi, (\Phi \to K^+K^-)$	0.17 ± 0.07
	$\eta\pi^+\pi^-$: $\eta \to \gamma\gamma$	1.28 ± 0.47
	$\eta\pi^+\pi^-$: $\eta \to \pi^0\pi^+\pi^-$	0.76 ± 0.28
	$\eta'\pi^+\pi^-$: $\eta' \to \eta\pi^+\pi^-, (\eta \to \gamma\gamma)$	0.47 ± 0.20
	$\eta'\pi^+\pi^-$: $\eta' \to \rho^0\gamma, (\rho^0 \to \pi^+\pi^-)$	0.83 ± 0.34

Common systematic error from Br($J/\Psi \to \gamma\eta_c$) = 1.3 ±0.4

Total Br(η_c): 10 %

χ_{c2} Analysis

- Search e^+e^-, $\mu^+\mu^-$ with $2.85 < M(l^+l^-) < 3.35$ GeV.
- $M(l^+l^-\gamma) - M(l^+l^-)$ expected at $M(\chi_{c2}) - M(J/\Psi) = 0.459$ GeV .
- Subtract background with J/Ψ sidebands shape.

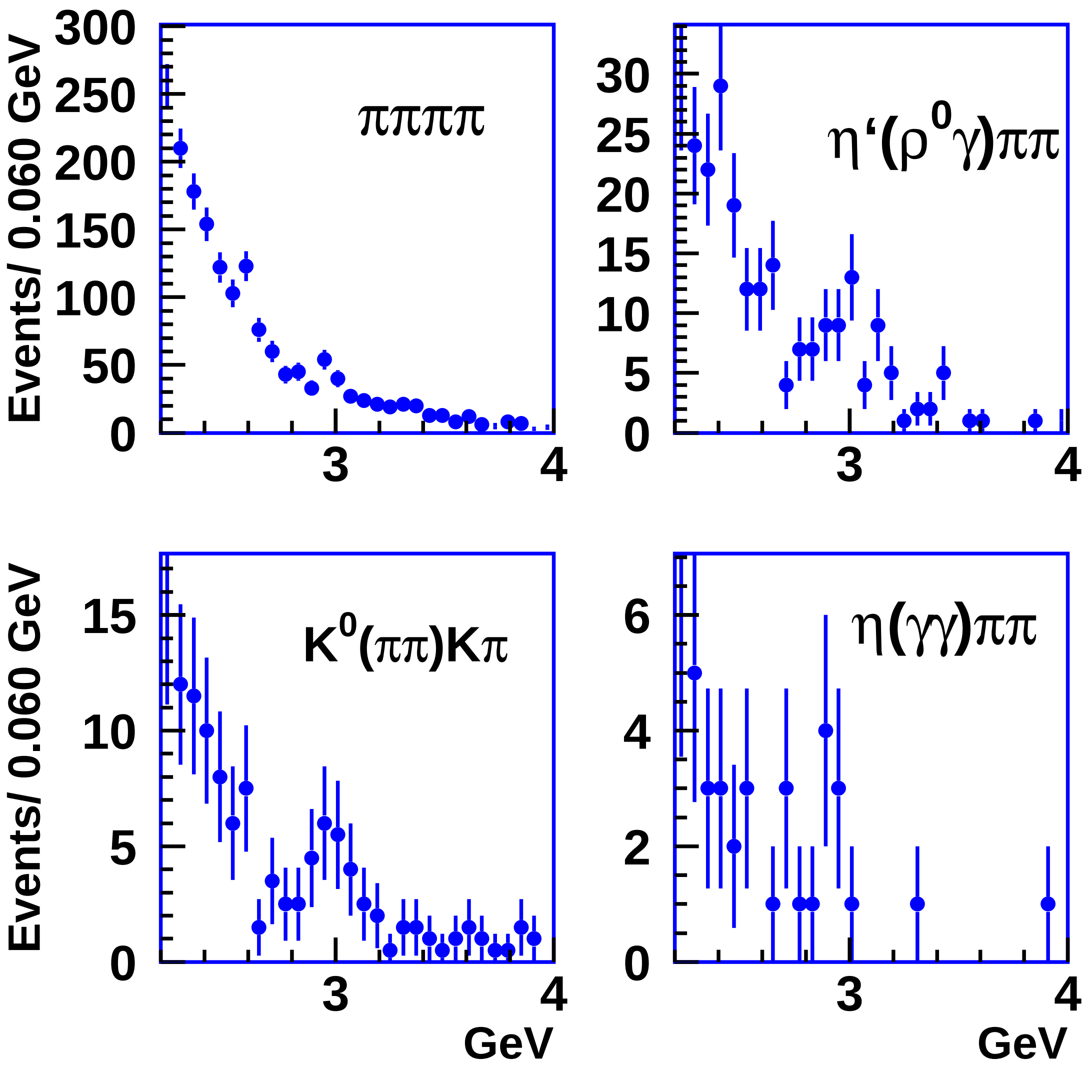


Data from $\sqrt{s} = 91, 183$ GeV added together.

12 signal events above 11 background events.

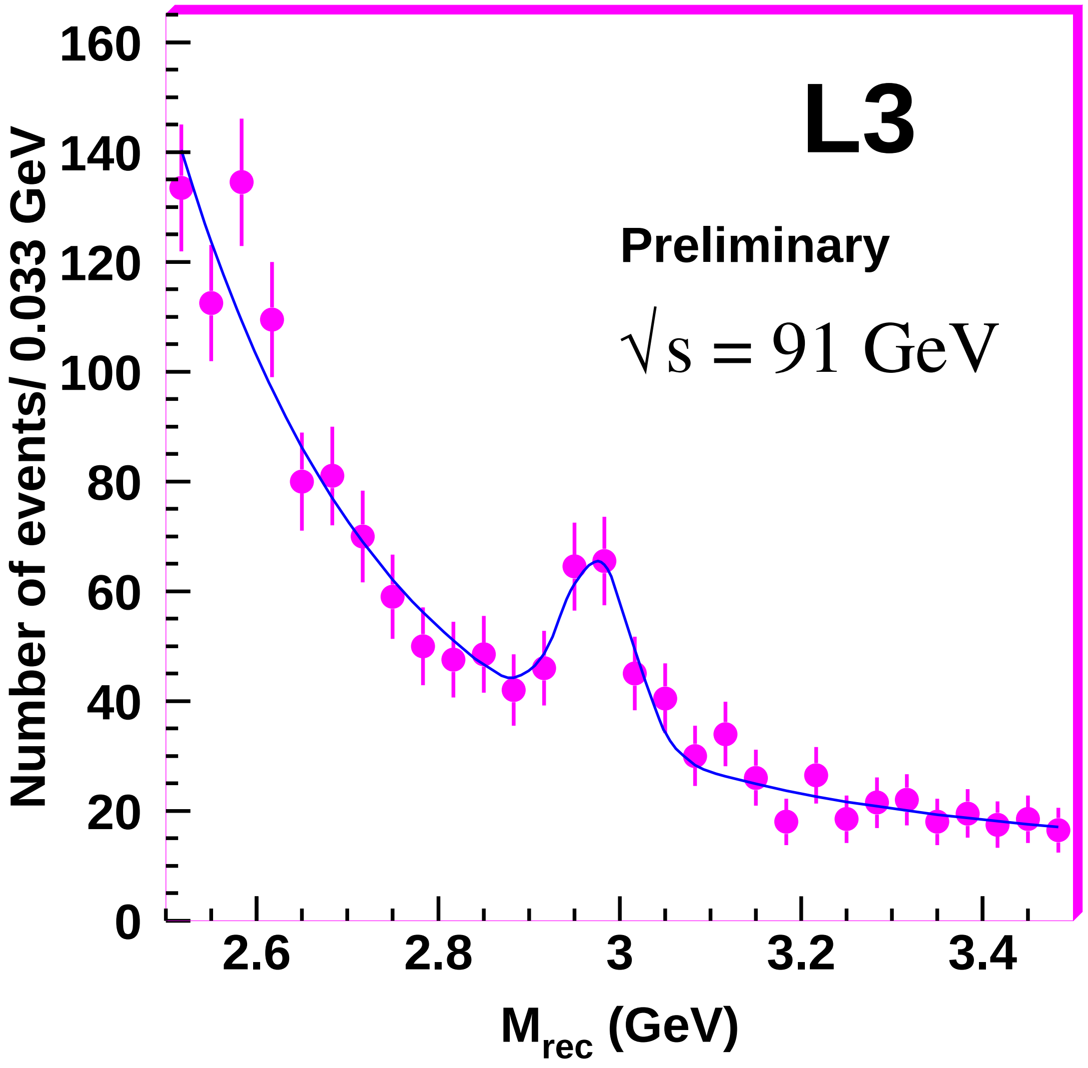
η_c Analysis

- π^0, η identified as pairs of photons compatible with nominal mass.
- K_S^0 obtained from geometrical reconstruction of secondary vertex, $K_S^0 \to \pi^+\pi^-$.
- ρ^0, η recognized from charged tracks (π) consistent with nominal mass.



Some Mass Distributions

Invariant Mass Distribution



Data from all decay channels added together.

Mass = 2.975 ± 0.008 GeV
Number of η_c candidates = 140 ± 32

$\sigma = 0.061 \pm 0.007$ GeV
$\Gamma(\eta_c) = 13.2^{+3.8}_{-3.2}$ MeV

η_c signal has low statistics in each decay mode.

$$\Longrightarrow$$

For each channel, the number of η_c candidates and the significance of the signal is estimated with the unbinned likelihood ratio test (James, Rice*):

$$\text{R}= \frac{max\{\mathcal{L}\,[f_{bg}]\}}{max\{\mathcal{L}[f_{bg}+f_{sg}]\}} \begin{cases} < R_0 & \text{Signal true, no background fluctuation} \\ > R_0 & \text{Use Poisson statistics, to set upper limits on N}_{ev} \end{cases}$$

- Prob(R_0) = 0.1
- f_{bg}: Background described by exponential function.
- f_{sg}: Signal described by a gaussian function.

Background under η_c signal estimated with exponential shape at sidebands.

* F. James, 1980 CERN School of Computing (1980).
J.A. Rice, Statistics and Data Analysis.

Radiative Widths

Experimental determination of $\Gamma_{\gamma\gamma}(R)$ lies in

$$\frac{N_{ev}}{\mathcal{L}\, Br\, \epsilon} = \sigma(ee \to eeR) = \kappa\, \Gamma_{\gamma\gamma}(R)$$

Method: Perform fit maximizing likelihood function

$$\mathcal{L} = \prod P_i$$

P_i: probability density function for event i

$\Gamma_{\gamma\gamma}(\chi_{c2})$:

P: Poissonian function with Background

$$\Gamma_{\gamma\gamma}(\chi_{c2}) = 0.99^{+0.43}_{-0.37}\text{(stat)}\pm 0.36\text{(sys) keV}$$

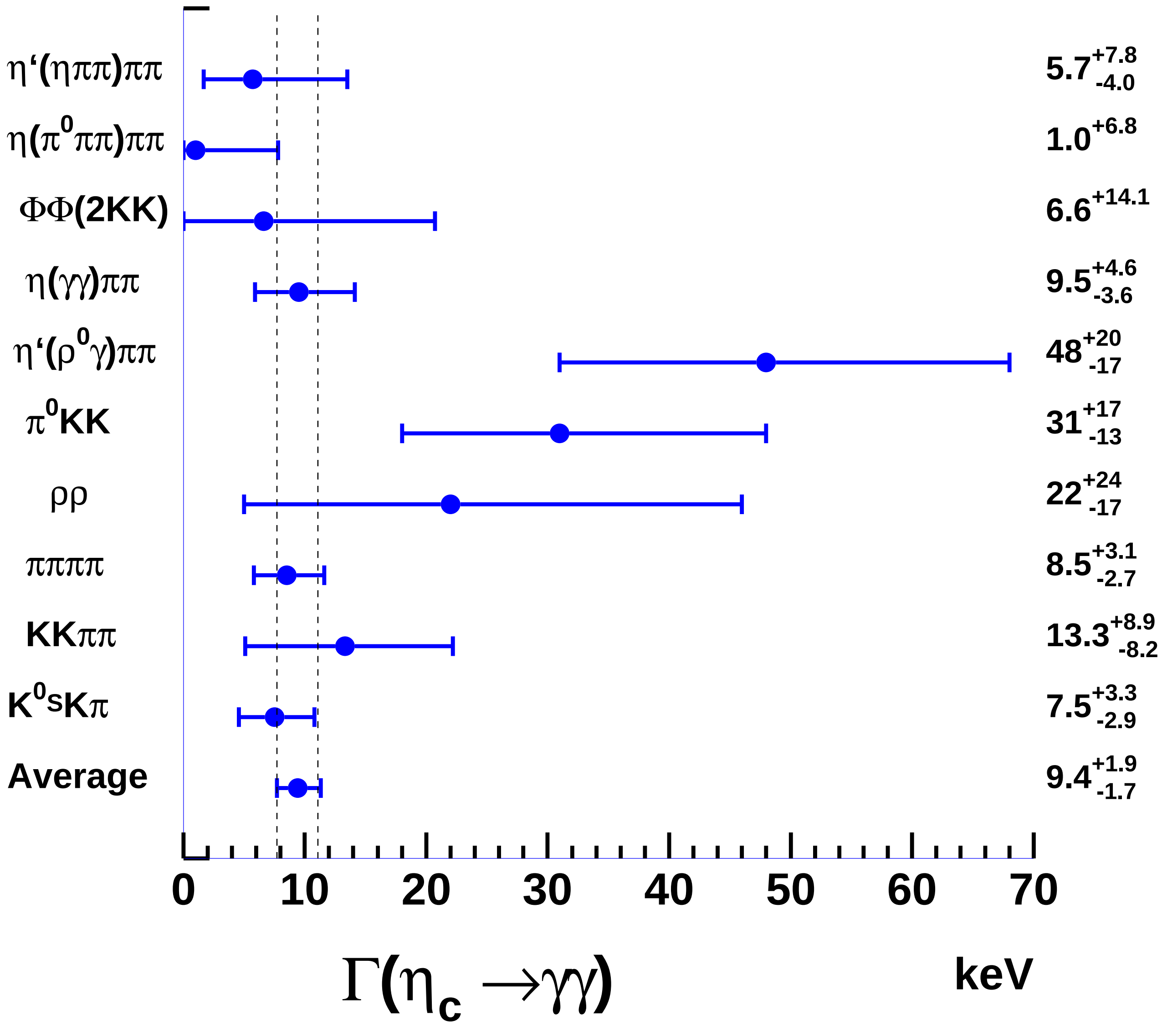
$\Gamma_{\gamma\gamma}(\eta_c)$:

P: Exponential $\oplus$ Gaussian function Good signal channels

Poissonian function with Background Not good signal channels

$$\Gamma_{\gamma\gamma}(\eta_c) = 9.5^{+2.1}_{-1.9}\ \text{(stat+sys)} \pm 2.7\ \text{(Br (J/}\Psi \to \gamma\eta_c\text{)) keV}$$

$\Gamma_{\gamma\gamma}(\eta_c)$ for each mode



Statistical and Systematical Error.

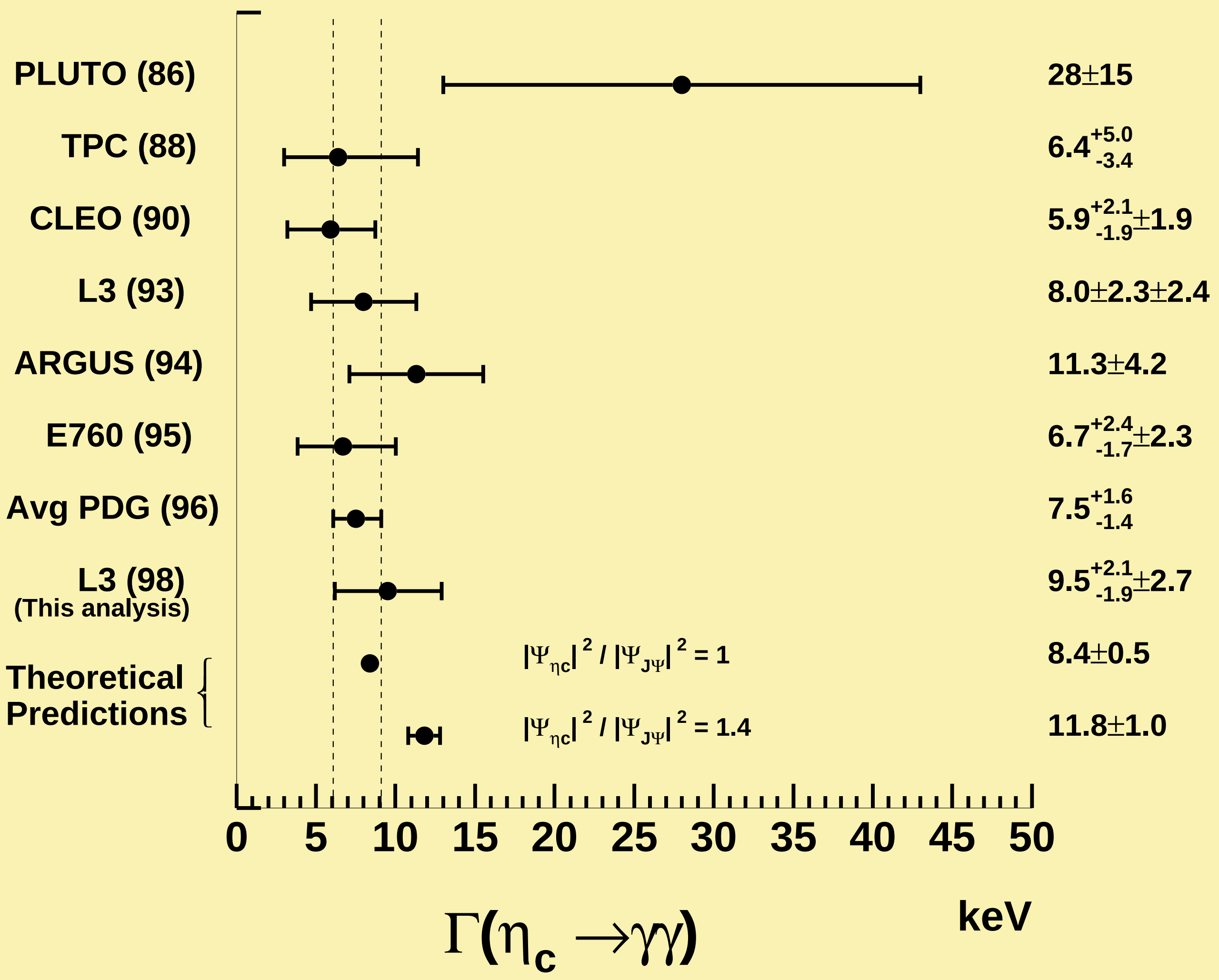
No Br errors included.

Radiative Widths

Other Results on $\Gamma_{\gamma\gamma}(\chi_{c2})$

Experiment	Production Mechanism	$\Gamma_{\gamma\gamma}(\chi_{c2})$ (keV)
R704	$p\bar{p} \to \chi_{c2} \to \gamma\gamma$	$2.9^{+1.3}_{-1.0} \pm 1.7$
E760	$p\bar{p} \to \chi_{c2} \to \gamma\gamma$	$0.32 \pm 0.08 \pm 0.05$
TPC/2γ	$\gamma\gamma \to \chi_{c2} \to \gamma J/\Psi$	$3.4 \pm 1.7 \pm 0.9$
CLEO	$\gamma\gamma \to \chi_{c2} \to \gamma J/\Psi$	$1.08 \pm 0.30 \pm 0.26$
Avg PDG96		0.37 ± 0.17
L3 (this analysis)	$\gamma\gamma \to \chi_{c2} \to \gamma J/\Psi$	$0.9^{+0.43}_{-0.37} \pm 0.36$
OPAL (Prel.)	$\gamma\gamma \to \chi_{c2} \to \gamma J/\Psi$	$1.76 \pm 0.47 \pm 0.37 \pm 0.15$

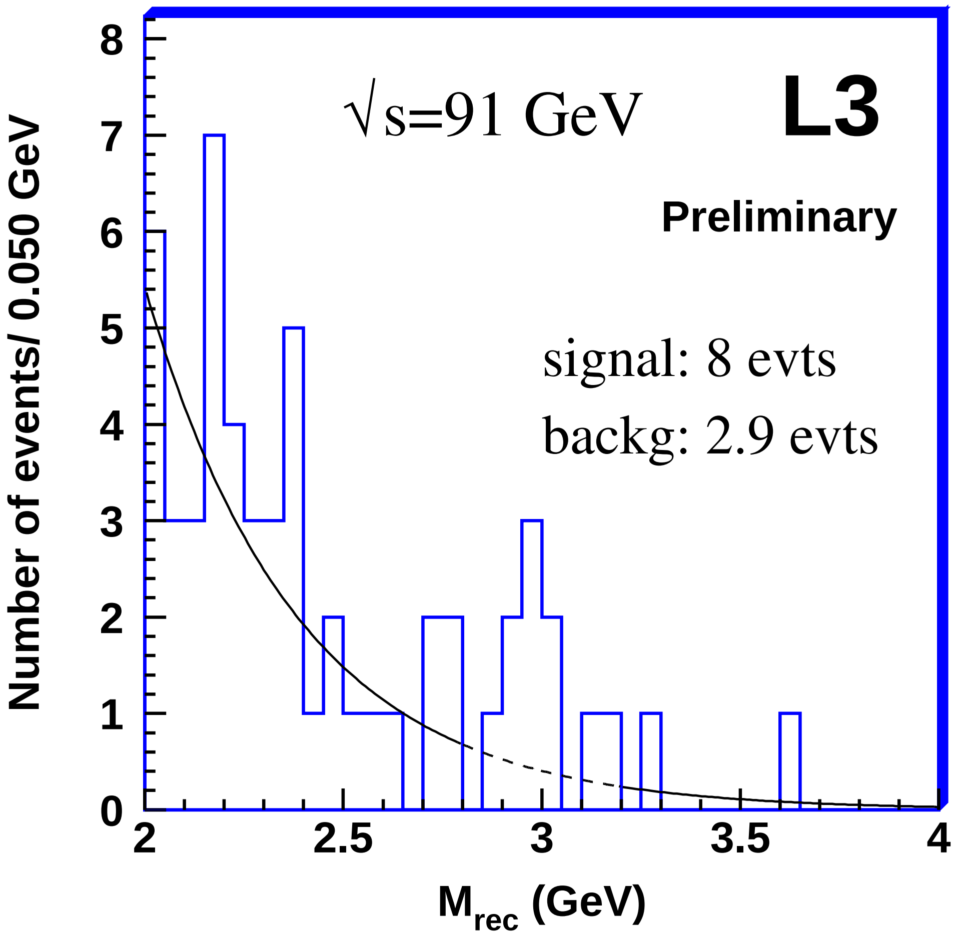
Previous Results on $\Gamma_{\gamma\gamma}(\eta_c)$



η_c Form Factor

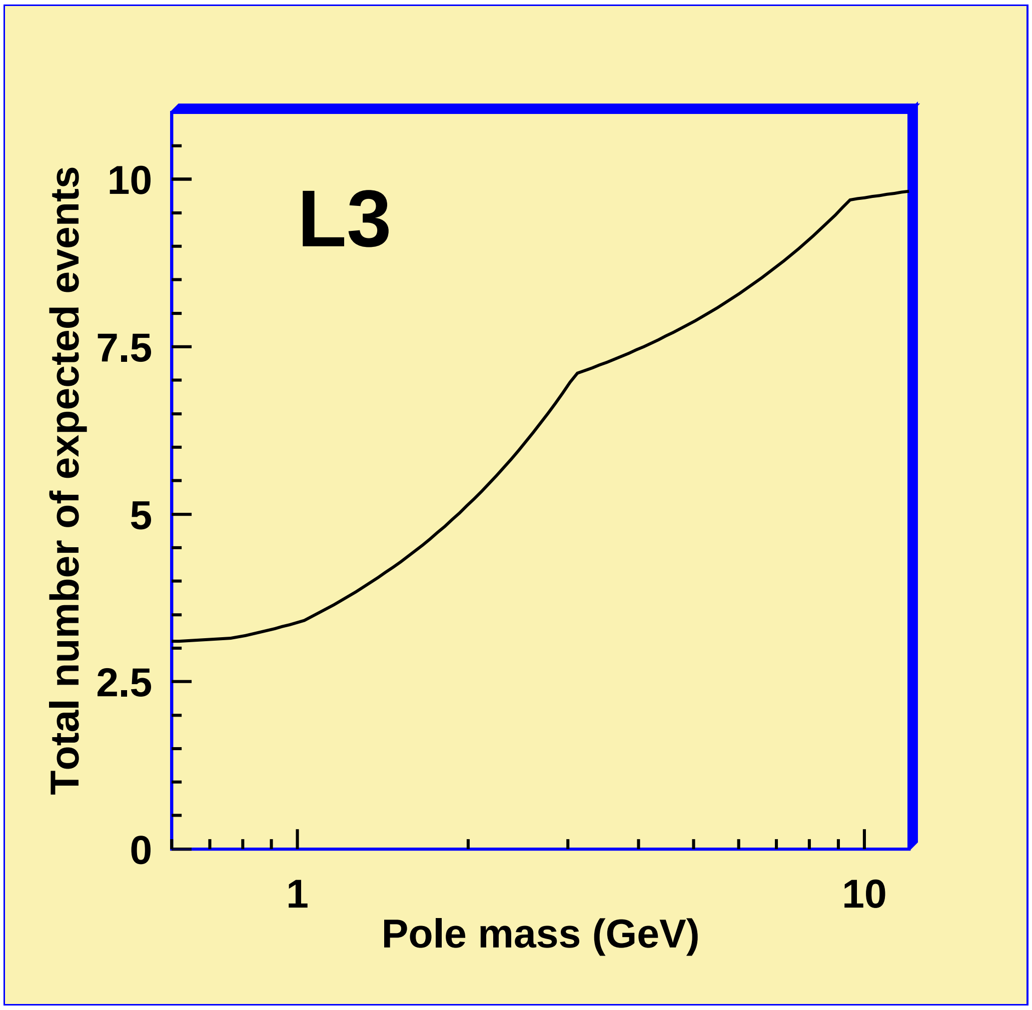
For tagged events, ($Q^2 >>$), Form Factors contain cross-section dependence on Q^2.

VDM: $F^2 \sim \left(\frac{1}{1+Q^2/\Lambda^2}\right)^2$ where $\Lambda \sim M_\rho, M_\omega, M_{J/\Psi}, \ldots$



Invariant Mass distribution for tagged events in all decay channels together ($1 < Q^2 < 9$ GeV^2)

Number of expected events as a function of pole mass



$$\Lambda \sim \mathrm{M}_{\rho}, \mathrm{M}_{\Phi}, \mathrm{M}_{J/\Psi}, \mathrm{M}_{\Upsilon}, \infty$$

Fitting expected number events with observed number events

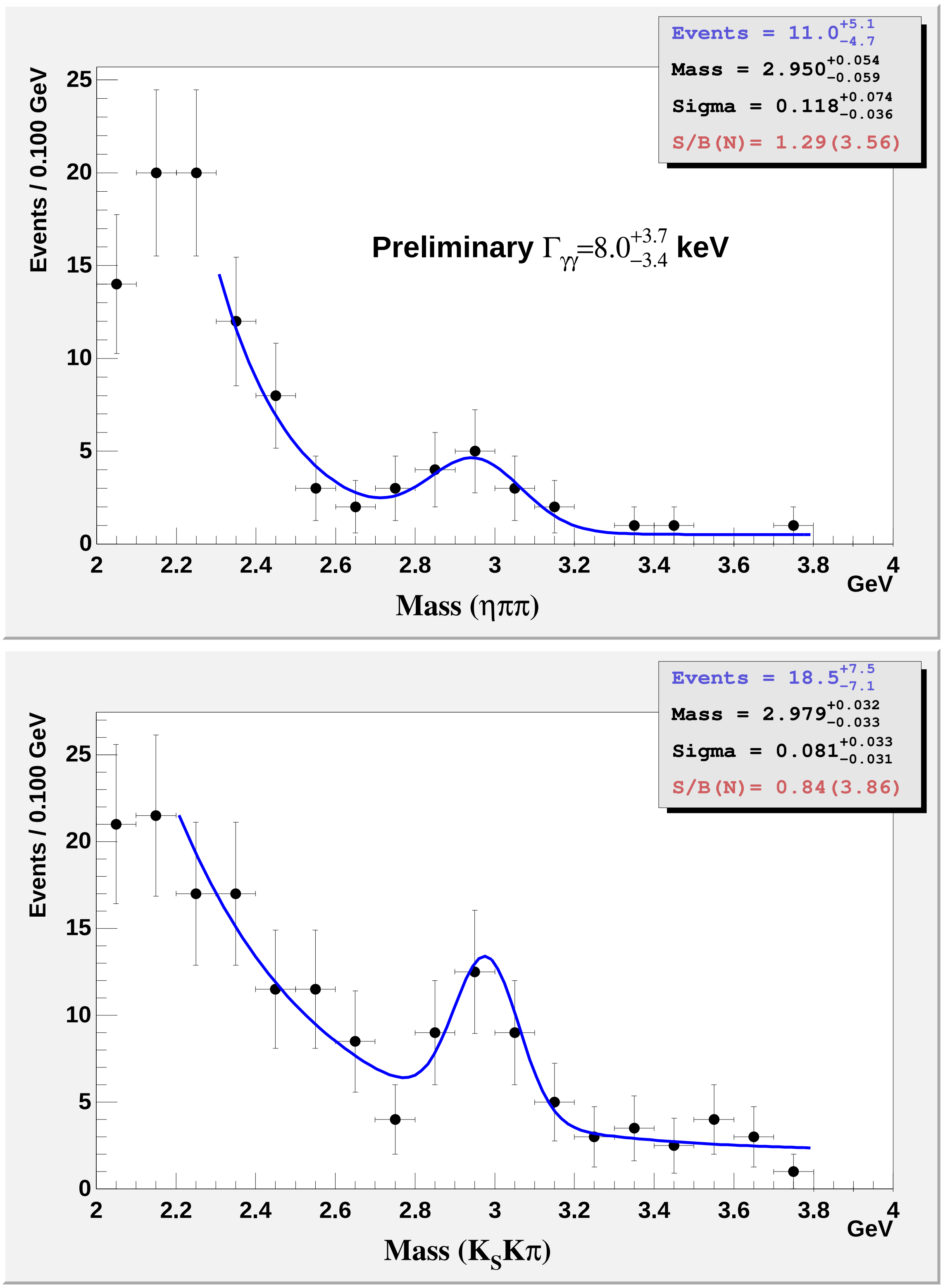
$$\Longrightarrow$$

VDM $M_{J/\Psi}$-pole consistent with observed events.

VDM ρ-pole Form Factor cannot explain tagged η_c production.

$\sqrt{s}$=183 GeV Data

η_c preliminary 183 GeV



CONCLUSIONS

- χ_{c2} observed through decay to $\gamma J/\Psi \to \gamma l^+ l^-$;
  12 candidate events at $\sqrt{s} = 91 \oplus 183$ GeV.

- η_c observed through 10 different decay modes;
  140 ± 32 candidates at $\sqrt{s} = 91$ GeV.

- Radiative widths are measured

$$\boxed{\Gamma_{\gamma\gamma}(\chi_{c2}) = 0.99^{+0.43}_{-0.37}\text{(stat)}\pm 0.36\text{(sys) keV}}$$

$$\boxed{\Gamma_{\gamma\gamma}(\eta_c) = 9.5^{+2.1}_{-1.9}\text{(stat+sys)}\pm 2.7(\text{Br}(\text{J}/\Psi))\text{ keV}}$$

- Single tagged η_c events consistent with
  M(J/Ψ)-pole.
  M(ρ)-pole only does not explain data.

- Data at $\sqrt{s}$=183 GeV looks promising:
  higher energy $\Longrightarrow >\ \eta_c$ candidates.
  better signal/background ratio.