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RESONANCE EXCITATION IN $\gamma\gamma$-COLLISIONS AT LEP200

Contribution to the ECFA-Workshop LEP200,
Aachen 29 Sept.-1 Oct. 1986

F.C. Erné, NIKHEF-H, Amsterdam

Abstract:

Cross sections and rates for observing charmonium and heavier states in exclusive channels are estimated for LEP200. A resonance discovery plot is presented. Searches for excited electrons are discussed.

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ABSTRACT

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Cross Sections and Rates

The Cross Section for a $\gamma\gamma$ collision leading to a final state X can be written as

$$\frac{d\sigma}{d\Omega}(e^+e^- \to e^+e^-X) = \int [\frac{dL_{\gamma\gamma}}{dW_{\gamma\gamma}}/L_{e^+e^-}]\frac{d\sigma}{d\Omega}(\gamma\gamma \to X)dW_{\gamma\gamma}. \quad (1)$$

Here the quantity Ω is generic for any number of phase space variables describing the state X, while the quantity in square brackets is commonly referred to as the $\gamma\gamma$-luminosity function; it is determined entirely by QED.

The collected rate is then found from:

$$\frac{dN_X}{dt} = L_{e^+e^-}\int \frac{d\sigma}{d\Omega}(e^+e^- \to e^+e^-X)A(\Omega)d\Omega. \quad (2)$$

Here $L_{e^+e^-}$ is the machine luminosity for e^+e^--collisions, and $A(\Omega)$ the detector acceptance.

In case that the final state X results from a decaying resonance R, the integrated $\gamma\gamma$ cross section is, in the narrow resonance approximation:

$$\int \sigma(\gamma\gamma \to X)dW_{\gamma\gamma} = \frac{4\pi^2(2J+1)}{m_R^2}\Gamma_{R\to\gamma\gamma}Br(R \to X)(\hbar c)^2. \quad (3)$$

Here J is the resonance spin, m_R its mass, $\Gamma_{R\to\gamma\gamma}$ its partial width for decay into $\gamma\gamma$ and $Br(R \to X)$ its branching ratio for decay into the final state X.

$\gamma\gamma$ LUMINOSITIES USABLE FOR OBSERVING EXCLUSIVE FINAL STATES

To identify the final state X, and determine its mass, the identities and momenta of all particles belonging to X have to be known from observation in the central detector, as in most cases the scattered electrons escape detection into the extreme forward directions and carry away large and unknown momenta.

This requirement imposes a low longitudinal momentum on the state to be observed. Below we assume that the following relation holds:

$$|p_{\gamma\gamma}| < W_{\gamma\gamma}. \tag{4}$$

This relation is approximately valid for four-prongs in the low-mass region ($W_{\gamma\gamma} \leq 4$ GeV) in the TPC-twogamma experiment at PEP. The effect of this requirement on the allowed energies of the colliding photons (with $E_{\gamma_{1,2}} \approx E_{beam} - E_{e^{\pm}}$) can be seen in fig.1 for an example at $W_{\gamma\gamma} = 10$ GeV and for various beam energies. Only a fraction of the x_1,x_2 hyperbolae contributes. One observes that the cut becomes increasingly severe at higher beam energies.

In fig.2 we show the reduction in the available $\gamma\gamma$-luminosity that results from this central-detector selection factor F_{cd}. By introducing this factor we have reduced the problem of the estimation of the acceptance at LEP energies to a problem that has been solved already for detectors at PEP and PETRA energies, where rapidity-ranges comparable to those of LEP-detectors are covered.

The $\gamma\gamma$-luminosity functions multiplied by this factor F_{cd} are given in fig.3. The curves result from a 5-dimensional numerical integration of the exact lowest order differential expression for the $\gamma\gamma$-luminosity [1] over the electron variables. The numbers used in fig.3 and numbers from integration without the central detector requirement are given in table I.

It is interesting to multiply the above functions by the expected e^+e^- luminosities for machines that will be soon in operation. This is shown in fig.4. We use the following numbers for $L_{e^+e^-}$:

Collider	$E_b(GeV)$	$L_{e^+e^-}(cm^{-2}sec^{-1})$	Ref
Upgraded PEP	14.5	$1.2\ 10^{32}$	2)
TRISTAN	30	$2\ 10^{31}$	3)
LEP100, version 13, 3mA	50	$1.2\ 10^{31}$	4)
LEP200	100	$5\ 10^{31}$	5)

As these numbers represent expectations, the comparison in fig.4 can only be tentative. It points, however, to competition between LEP200 and PEP in the low-mass region ($W_{\gamma\gamma} \leq 10$ GeV), while the upgraded PEP may be on the air a few years earlier than LEP200. However, for $W_{\gamma\gamma} > 10$ GeV, LEP200 will be unique.

Acceptance estimates

In addition to the momentum cut evaluated above, several other factors reduce the useful counting rate: trigger efficiencies, reconstruction efficiencies, absorption inside the detector, particle decays, particle identification, and the cut that verifies that we have to do with an exclusive two-photon process: the sum of the transverse momenta w.r.t. the beams should be below a value of the order of 0.2 GeV. These factors depend on the detector and on the physics interest expressed in the collaboration: the trigger thresholds may be high if they are primarily meant to enable the recording of annihilation events with a total energy of 200 GeV.

To have some estimates we extrapolated known acceptance figures from the TPC-Twogamma Collaboration at PEP. Typically one looses about an order of magnitude in rate w.r.t. a 4π-detector with ideal identification, and in the identification of kaons one looses another factor two because of background subtractions, decay and ambiguities.

Expected $\Gamma_{\gamma\gamma}$ for Charmonium Resonances and beyond

For Charmonium and Bottonium we resort to a few simple relations given by Close [6]. For S-wave $J^P = 0^-$-resonances one relates the $\gamma\gamma$-width to the leptonic width of the corresponding vector particle. At the right-hand side below we give the expected number:

		$\Gamma_{\gamma\gamma}$ (keV)
$\Gamma(\eta_c \to \gamma\gamma) \approx \frac{4}{3}\Gamma(J/\Psi \to e^+e^-)M^2_{J/\Psi}/M^2_{\eta_c}$		6.8
$\Gamma(\eta'_c \to \gamma\gamma) \approx \frac{4}{3}\Gamma(\Psi' \to e^+e^-)M^2_{\Psi'}/M^2_{\eta'_c}$		2.7
$\Gamma(\eta_b \to \gamma\gamma) \approx \frac{1}{3}\Gamma(\Upsilon \to e^+e^-)M^2_{\Upsilon}/M^2_{\eta_b}$		0.4

Similar relations connect the $\gamma\gamma$-width of P-wave resonances to their own hadronic width:

$\Gamma(\chi^0_c \to \gamma\gamma) \approx \Gamma(\chi^0_c \to \text{hadrons})\frac{128}{729}\alpha^2/\alpha_s^2$	3.3
$\Gamma(\chi^2_c \to \gamma\gamma) \approx \Gamma(\chi^2_c \to \text{hadrons})\frac{128}{729}\alpha^2/\alpha_s^2$	3.3

An estimate for the $\gamma\gamma$-width of a Higgs particle, via a triangular diagram is given by Okun [7]. If there is only one Higgs, one has the relation:

$$\Gamma(H \to \gamma\gamma) = \{\frac{\alpha(\sum_i q_i^2 F_i(\beta))}{4\pi}\}^2 \frac{Gm_H^3}{8\pi\sqrt{2}}. \qquad (5)$$

The factors $F_i(\beta)$ for spin $i = 0, \frac{1}{2}, 1$ are: $F_0 = \beta(1-\beta x^2)$, $F_{\frac{1}{2}} = -2\beta[(1-\beta)x^2+1]$, $F_1 = [2 + 3\beta + 3\beta(2-\beta)x^2]$ with $\beta = 4m^2/m_H^2$ and $x = \arctan(1/\sqrt{\beta - 1})$ for $\beta > 1$ and $x = \frac{1}{2}(\pi + i\ln\frac{1+\sqrt{1-\beta}}{1-\sqrt{1-\beta}})$ for $\beta < 1$; here m is the mass of the virtual particle. For example for $m_H = 50$ GeV, $m = 80$ GeV, i = 1 we obtain $\Gamma_{\gamma\gamma} \approx 0.7$ keV.

Certain composite models of leptons, quarks and weak bosons, suggest a more sizable $\gamma\gamma$-width for spin-zero partners of the W-boson. Renard[8] estimated from pointlike photon-coupling with subconstituents for a pseudoscalar particle H (not necessarily a Higgs) with a mass of 50 GeV a $\Gamma_{\gamma\gamma}$ ranging between 5 keV and 0.8 MeV, and from W-dominance models a $\Gamma_{\gamma\gamma}$ ranging between 5 and 70 MeV. The state may be several GeV wide and therefore not readily observable, if the subconstituents are coloured. Baur, Fritzsch and Faissner[9] discuss the case of a neutral isoscalar boson U with spin-$\frac{1}{2}$ haplons as constituents. For $M_U = 50$ GeV they find $\Gamma_{\gamma\gamma} \approx 17$ MeV.

DECAY-CHARACTERISTICS OF $c\bar{c}$ AND $b\bar{b}$ STATES

The η_c-, η_b- and χ_c - states mentioned above, decay mainly via two gluons with flavour-independent couplings into any number of mesons. To obtain an estimate of the fractional decay into states that can be experimentally reconstructed with some accuracy, we take a Poisson-distribution for the number of $\pi^+\pi^-$ or K^+K^- pairs, and independently for the number of π^0s, with the average value $\overline{n} = 1 + 0.35 \ln M^2$. This gives for example the probabilities P_n for:

M (GeV)	$\overline{n}$	P_0	P_1	P_2	P_3
3	1.77	0.170	0.300	0.267	0.157
10	2.61	0.0735	0.192	0.250	0.218

If we consider only final states with 2 or 4 charged particles, and no π^0s, then the branching ratio is $P_0(P_1 + P_2)$. For pseudoscalars the decay into $\pi^+\pi^-$ and K^+K^- is forbidden and we have P_0P_2. It amounts to 4.5% for $M = 3$ GeV and 1.8% for $M = 10$ GeV. The above estimate at 3 GeV can be confronted with the experimental situation as is known for all-charged final states in radiative J/Ψ decay into the η_c, (using the Crystal Ball value [10]) $Br(J/\Psi \to \gamma\eta_c) = (1.27 \pm 0.36)10^{-2}$). The agreement is satisfactory as can be seen from table II.

Table II, Branching Ratios of $\eta_c \to X$ in %

X	MKIII[11]	DM2[12]	MKII[13]
$\phi_{\to K^+K^-}\phi_{\to K^+K^-}$	0.19 ± 0.07	0.08 ± 0.03	
$2(\pi^+\pi^-)$	1.3 ± 0.6		$2.0 \pm \left\{\begin{matrix}1.5\\1.0\end{matrix}\right.$
$K^{*0}_{\to K^+\pi^-}\overline{K}^{*0}_{\to K^-\pi^+}$	0.23 ± 0.13		
$K^{*0}_{\to K^+\pi^-}K^-\pi^+$+c.c.	2.0 ± 0.5		$1.4 \pm \left\{\begin{matrix}2.1\\1.0\end{matrix}\right.$
$K^+K^-\pi^+\pi^-$	2.1 ± 0.3		
$K^0_{s\to\pi^+\pi^-}K^{\mp}\pi^{\pm}$	1.0 ± 0.4	1.2 ± 0.6	$5.2 \pm \left\{\begin{matrix}3.1\\2.5\end{matrix}\right.$
$p\overline{p}$	0.11 ± 0.06	0.10 ± 0.04	

EXPECTED RATES IN 2−, 4− AND 6−BODY CHANNELS: DISCOVERY PLOT

The procedures outlined above, can be used to calculate the number of events expected in approximately two years of LEP200 running with an integrated e^+e^- luminosity of $1fb^{-1}$. The result is shown in fig.5 in the form of lines relating the mass and width of $J = 0$ resonances for a fixed number of observed and reconstructed events. Also indicated are the η_c, η_c' and η_b with their expected $\gamma\gamma$-widths.

One sees that exploration of the Charmonium region is relatively comfortable, while η_b observation is out of the question. Also for a 50 GeV Higgs particle one expects less than 1 event, even if the branching ratio into the observed final state is 100%. On the other hand, the $\gamma\gamma$-decays of composite scalar bosons might be observable. The 50 GeV U-particle[9)] discussed would produce $\approx$ 20 observable events, and Renard's 50 GeV H-particle[8)] $\approx$ 70. Fig.5 can also be used to predict rates for any new states decaying into heavy quark pairs that might be suggested.

The Charmonium states may be accessible to PEP in 1987-1988. Fig.6 shows a Monte Carlo calculation of the expected number of Charmonium events in the $2(\pi^+\pi^-)$ channel at PEP.

TAGGING

In principle tagging by observation and momentum measurement of one of the electrons can help in distinguishing heavy-flavour excitation from ρ-dominance background, because form factors go approximately as $1/(1 - Q^2/W^2)$ for η_c, η_b,..., and as $1/(1 - Q^2/m_\rho^2)$ for ρ-dominance. Here $Q_i^2 = 4E_{beam}E_i \sin^2(\theta_i/2)$, with E_i and θ_i the energy and angle w.r.t. the beam, of the observed electron. As $E_i \approx E_{beam}$, and as tagging devices have a substantial minimum angle, the Q^2 of the tagged photon becomes considerable at LEP energies, and the luminosity fraction seen by the tagging devices is correspondingly small. Even the reduction from a Charmonium form factor becomes substantial. This is shown in Table III for a tagging region between 40 and 180 mrad at both sides of the central detector and for $W = 3$ GeV.

Table III (W = 3 GeV, $0.04 < \theta_{tag} < 0.180$)

	PEP	LEP100	LEP200
E_{beam} (GeV)	14.5	50	100
$-Q^2(GeV^2)$	0.34 - 6.8	4-81	16-324
tagging fraction	0.23	0.10	0.045
η_c form-factor reduction	0.7	0.2	0.05

The number of tagged events at LEP200 would be very small in the Charmonium region. Here PEP is in a better position.

SEARCH FOR EXCITED ELECTRONS IN QUASI-REAL COMPTON SCATTERING

Previous searches for excited electrons (e*) in quasi-real Compton scattering at ACO[15], PETRA[16] and PEP[17] can be significantly extended in mass up to ≈ 90% of the available c.m. energy at LEP200. In the process a quasi-real photon emitted by one of the incoming particles is elastically scattered by the other. The spectator electron, which radiates the photon, usually escapes detection along the beam direction. The electron-photon mass can then be determined most accurately from a combination of the c.m. energy and a measurement of the angles θ_e and θ_γ of the scattered electron and photon: $W^2 = s(1-\beta)/(1+\beta)$, with the velocity $\beta = \sin(\theta_e + \theta_\gamma)/(\sin\theta_e + \sin\theta_\gamma)$. Most of the LEP detectors have an angular resolution which is superior to that of earlier detectors, of the order of 1.5-5 mrad for photons, and much better for charged particles. This leads to a mass resolution of typically ≈ 0.5 GeV for W ≈ 150 GeV at LEP200. Several detectors moreover measure electron- and photon- energies to the 1% level (OPAL,L3), which provides precise additional constraints. The mass resolutions are comparable to those achieved in earlier searches at lower-energy machines. One can write a gauge-invariant effective magnetic $e^*e\gamma$ interaction for an e^* of spin $\frac{1}{2}$ as:

$$L_{eff} = \frac{ef_\gamma}{2M_{e^*}} \overline{\Psi}_e \sigma_{\mu\nu} \Psi_e F^{\mu\nu} + h.c.. \tag{6}$$

In a fixed range of δW the cross section for the possible signal then scales as f_γ^2/M_c^{*2}, while the continuum scales as $1/W^2$. Upper limits on f_γ are at present of the order of 0.01 for $m_e^* < 30$ GeV. At LEP200 one can expect limits on f_γ of the order of 0.02-0.05, with integrated luminosities comparable to those of present experiments ($200pb^{-1}$ for DELCO [17]). If one assumes $f_\gamma = M_{e^*}/\Lambda$[18], this is sufficient to be sensitive to a compositeness scale Λ of several TeV.

Table I

Luminosity functions for various beam energies.

$W_{\gamma\gamma}$	Integrated over the electron variables $\frac{dL_{\gamma\gamma}}{dW_{\gamma\gamma}}/L_{e^+e^-}$				Integrated with the requirement $\lvert p_{\gamma\gamma}\rvert < W_{\gamma\gamma}$: $F_{cd}\frac{dL_{\gamma\gamma}}{dW_{\gamma\gamma}}/L_{e^+e^-}$			
	E_{beam} (GeV)				E_{beam} (GeV)			
(GeV)	14.5	30	50	100	14.5	30	50	100
0.5	.574-1	.743-1	.843-1	.950-1	.142-1	.164-1	.165-1	.146-1
1	.233-1	.326-1	.385-1	.449-1	.694-1	.822-2	.891-2	.847-2
1.5	.132-1	.196-1	.238-1	.287-1	.450-2	.542-2	.602-2	.607-2
2	.863-2	.134-1	.168-1	.207-1	.328-2	.401-2	.451-2	.474-2
3	.457-2	.768-2	.100-1	.129-1	.204-2	.260-2	.296-2	.329-2
4	.281-2	.505-2	.684-2	.911-2	.141-2	.189-2	.218-2	.250-2
5	.187-2	.359-2	.503-2	.691-2	.104-2	.147-2	.172-2	.201-2
10	.419-3	.111-2	.177-2	.278-2	.359-3	.607-3	.777-3	.971-3
15	.130-3	.493-3	.885-3	.156-2	.130-3	.335-3	.462-3	.616-3
20	.410-4	.254-3	.514-3	.995-3	.410-4	.211-3	.309-3	.438-3
25	.939-5	.141-3	.325-3	.687-3	.939-5	.141-3	.221-3	.331-3
30		.811-4	.216-3	.499-3		.811-4	.166-3	.260-3
35		.471-4	.149-3	.375-3		.471-4	.129-3	.211-3
40		.270-4	.104-3	.290-3		.270-4	.102-3	.174-3
45		.148-4	.745-4	.229-3		.148-4	.745-4	.146-3
50		.723-5	.536-4	.183-3		.723-5	.536-4	.125-3

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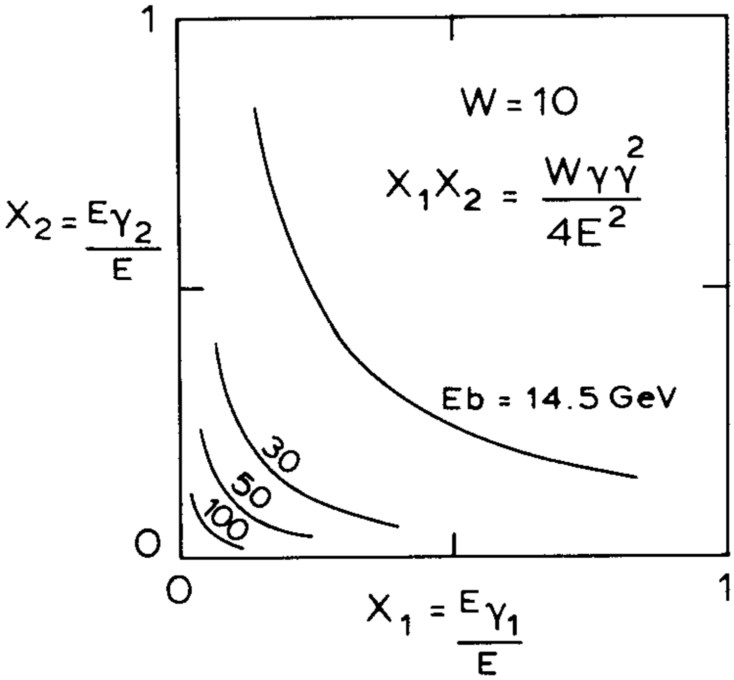

Figure 1. The range of γ-energies selected by observation of exclusive final states in a central detector, for $W_{\gamma\gamma} = 10$ GeV, by the requirement $|p_{\gamma\gamma}| < W_{\gamma\gamma}$.

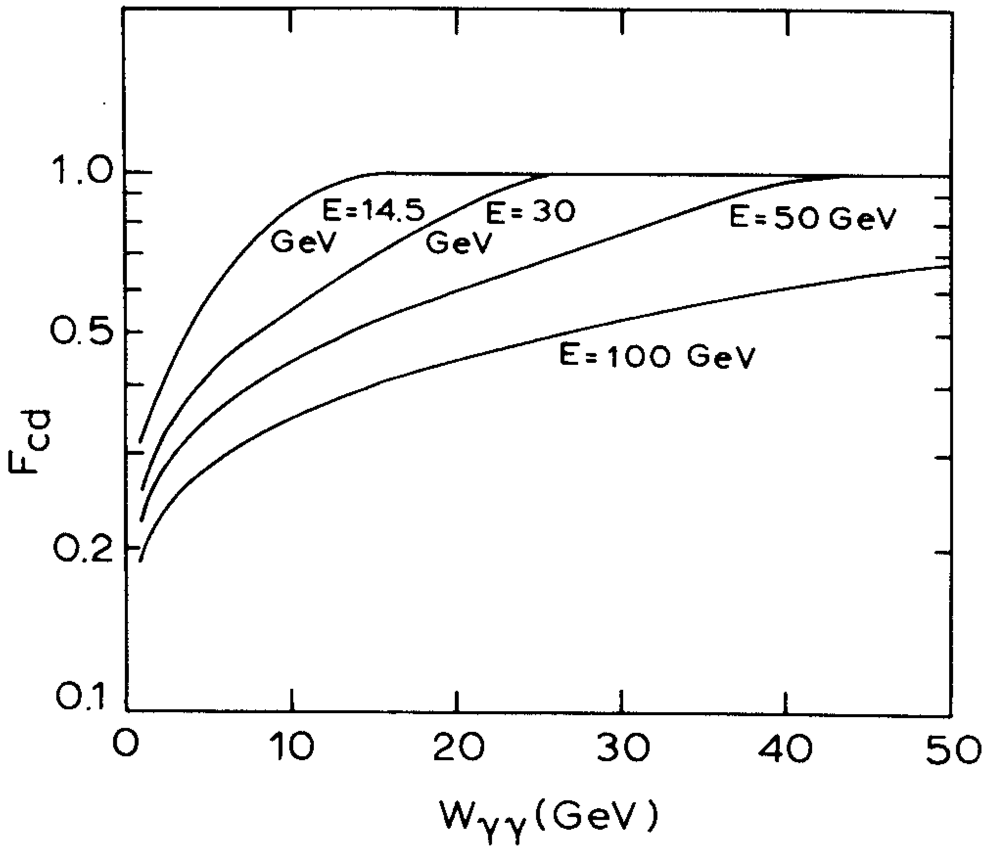

Figure 2. The central-detector selection factor F_{cd}, resulting from the requirement $|p_{\gamma\gamma}| < W_{\gamma\gamma}$ for various beam energies.

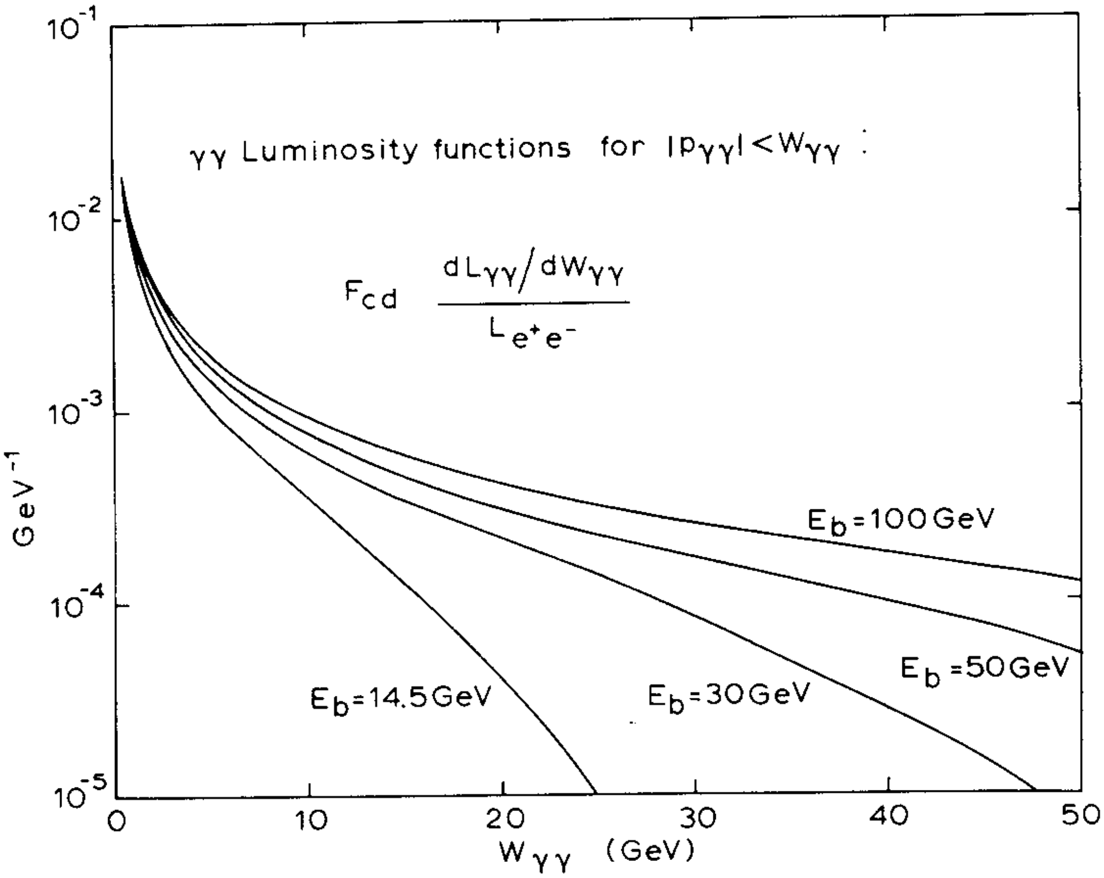

Figure 3. The $\gamma\gamma$ luminosity function multiplied by F_{cd} for various beam-energies.

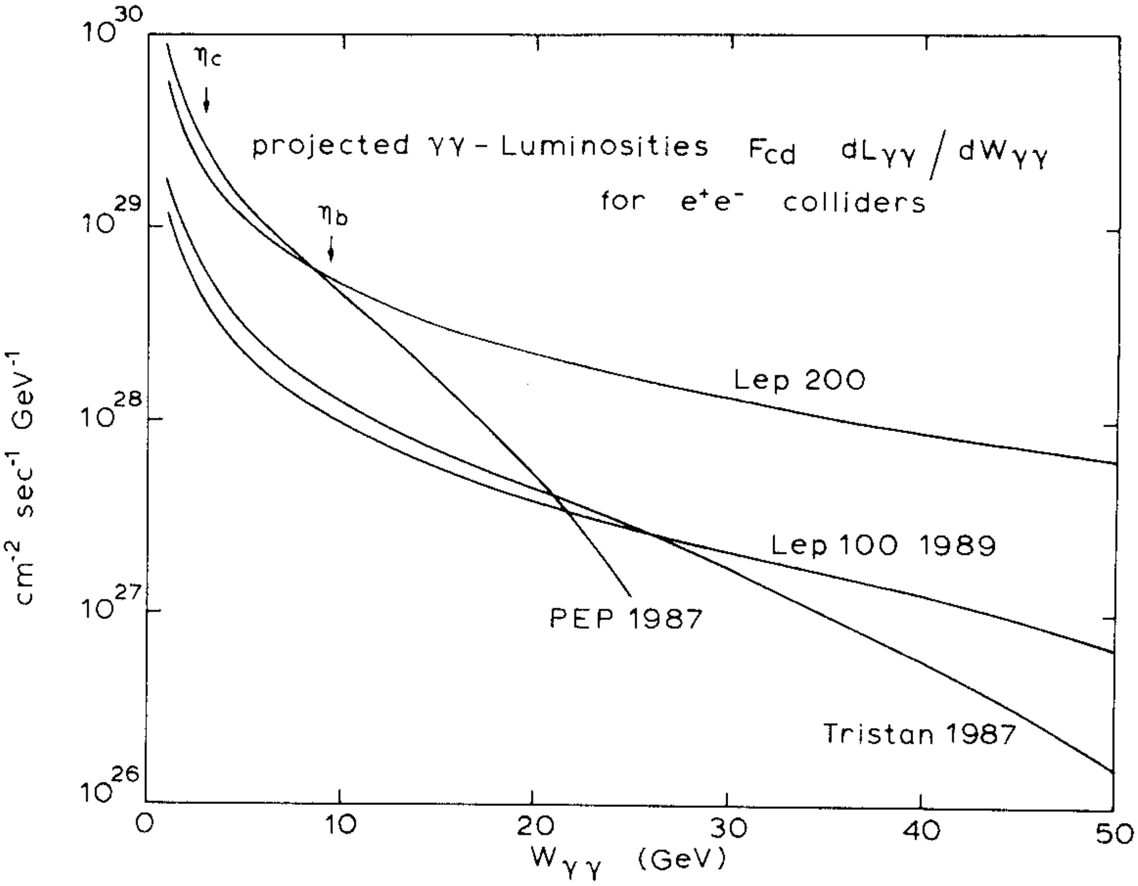

Figure 4. Projected $\gamma\gamma$ luminosities (see text) multiplied by F_{cd} for various e^+e^- colliders.

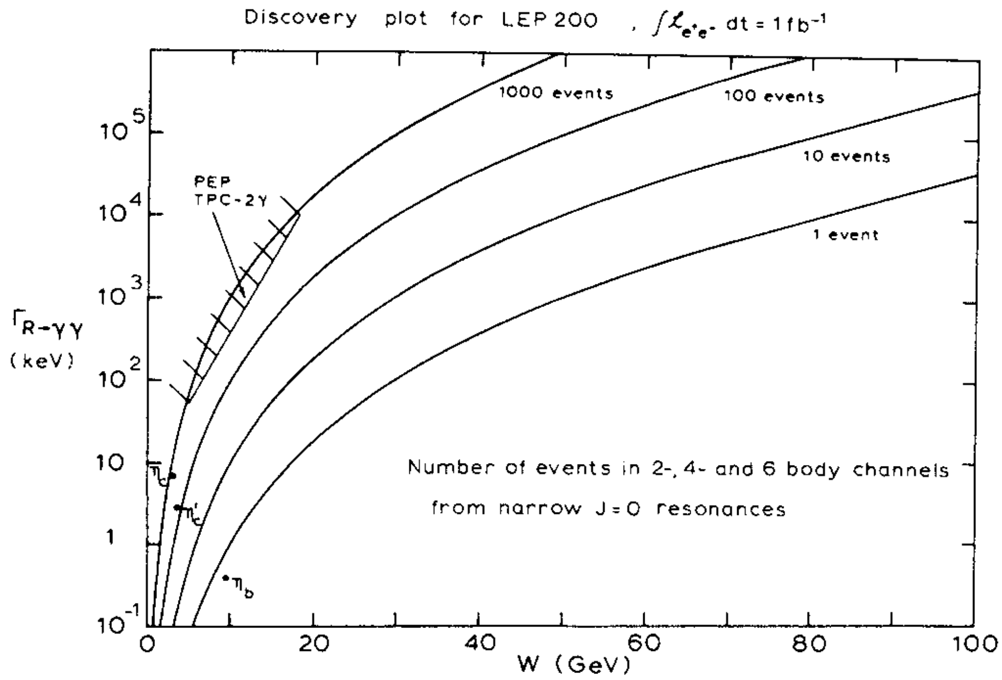

Figure 5. Discovery limits on $\Gamma_{R\to\gamma\gamma}$ vs W for narrow $J = 0$ resonances decaying into heavy-quark pairs in the sum of exclusive $2-, 4-$ and $6-$ body channels at LEP200 for $1fb^{-1}$ integrated e^+e^--luminosity. Quark-model predictions for some known states are indicated. Also a recent result [14] for 95% confidence limits on new narrow states from the TPC-twogamma experiment at PEP with double tagging and the missing mass technique, is indicated.

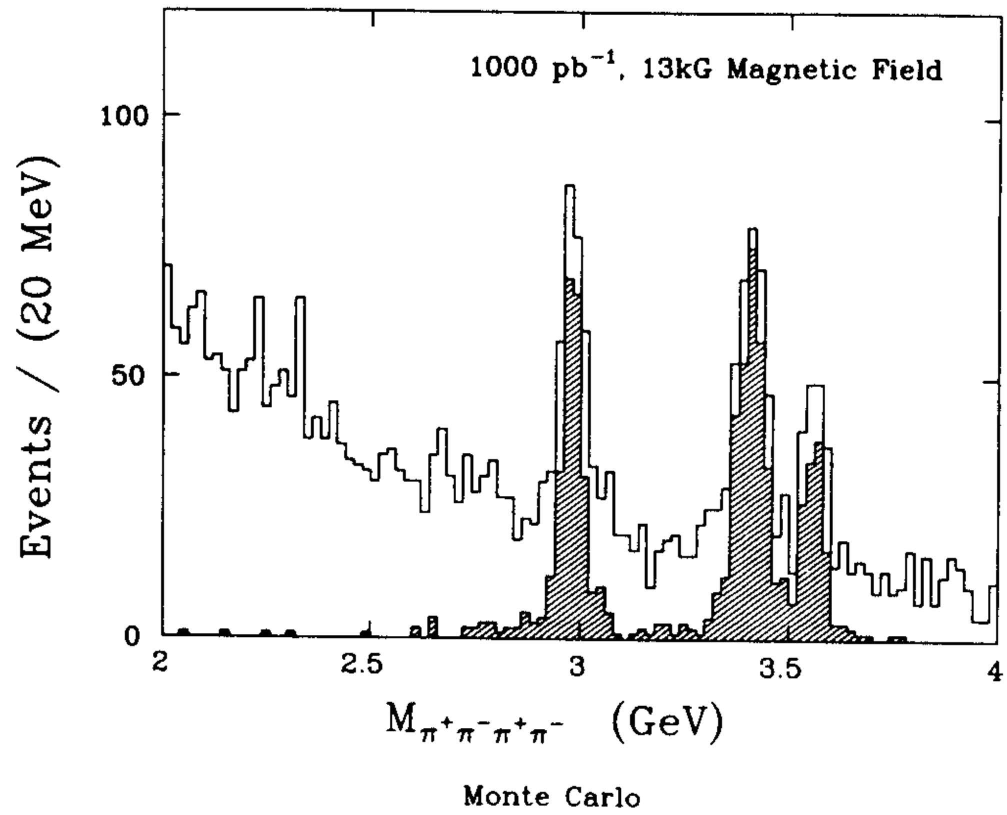

Figure 6. Monte Carlo calculation of the expected number of Charmonium events into the $2(\pi^+\pi^-)$ channel at PEP on top of the expected vector-dominance background.