FIRST OBSERVATION OF $\gamma\gamma \to \omega\omega$

ARGUS Collaboration

H ALBRECHT, A A ANDAM [1], U BINDER, P BÖCKMANN, R GLÄSER, G HARDER, A NIPPE, M SCHÄFER, W SCHMIDT-PARZEFALL, H SCHRODER, H.D SCHULZ, R WURTH, A YAGIL [2,3]
DESY, D-2000 Hamburg, Fed Rep Germany

J.P DONKER, A DRESCHER, D KAMP, H KOLANOSKI, U MATTHIESEN, H SCHECK, B SPAAN, J SPENGLER, D WEGENER
Institut fur Physik [4], Universitat Dortmund, D-4600 Dortmund, Fed Rep Germany

J C GABRIEL, T RUF, K R SCHUBERT, J STIEWE, K STRAHL, R WALDI, S WESELER [5]
Institut fur Hochenergiephysik [6], Universitat Heidelberg D-6900 Heidelberg, Fed Rep Germany

K W EDWARDS [7], W R FRISKEN [8], D J GILKINSON [9], D M GINGRICH [9], H KAPITZA [6,7], P C H KIM [9], R KUTSCHKE [9], D B MACFARLANE [10], J A McKENNA [9], K W McLEAN [10], A W NILSSON [10], R S ORR [9], P PADLEY [9], J A PARSONS [9], P M PATEL [10], J D PRENTICE [9], H C J SEYWERD [9], J D SWAIN [9], G TSIPOLITIS [10], T -S YOON [9], J C YUN [7]
Institute of Particle Physics [11], Canada

R AMMAR, D COPPAGE, R DAVIS, S KANEKAL, N KWAK
University of Kansas [12], Lawrence, KS 66045, USA

B BOŠTJANČIČ, G KERNEL, M PLEŠKO
Institut J Stefan and Oddelek za fiziko [13], Univerza v Ljubljani 61111 Ljubljana Yugoslavia

L JÖNSSON
Institute of Physics [14], University of Lund, S-22362 Lund, Sweden

A BABAEV, M DANILOV, B FOMINYKH, A GOLUTVIN, I GORELOV, V LUBIMOV, V MATVEEV, V NAGOVITSIN, V RYLTSOV, A SEMENOV, V. SHEVCHENKO, V SOLOSHENKO, V TCHISTILIN, I TICHOMIROV, Yu ZAITSEV
Institute of Theoretical and Experimental Physics, 117259 Moscow, USSR

R CHILDERS, C W DARDEN and Y OKU
University of South Carolina [15], Columbia, SC 29208, USA

Received 4 August 1987

The reaction $\gamma\gamma\to 2\pi^+2\pi^-2\pi^0$ has been studied using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY Production of ω mesons is observed and, in particular, the reaction $\gamma\gamma\to\omega\omega$ is seen for the first time The cross section for $\gamma\gamma\to\omega\omega$ has an enhancement at ~1 9 GeV/c^2 of about 10 nb The cross sections for $\gamma\gamma\to 2\pi^+2\pi^-2\pi^0$ and $\gamma\gamma\to\omega\pi^+\pi^-\pi^0$ are also given

This report presents the first observation of the reaction $\gamma\gamma\to\omega\omega$ Earlier measurements of vector meson pair production in photon–photon interactions have been published for $\gamma\gamma\to\rho^0\rho^0$ [1] and, recently, $\gamma\gamma\to\omega\rho^0$ [2] Measurements of other channels have resulted only in upper limits [3,4]

The $\gamma\gamma\to\rho^0\rho^0$ cross section showed an unexpectedly large enhancement at threshold [1] while the reaction $\gamma\gamma\to\rho^+\rho^-$ was found to be suppressed [4] Explanations in terms of the production of four-quark states [5] in photon–photon collisions were introduced [6,7] Such an interpretation works well for both $\rho^0\rho^0$ and $\rho^+\rho^-$, but it explains only part of the $\omega\rho^0$ cross section [2]. At t-channel factorization model [8] can also describe the $\rho^0\rho^0$ cross section, but again, only part of the $\omega\rho^0$ cross section To further test these models, measurements of other vector meson pairs produced in photon–photon interactions are needed

The analysis of the reaction $\gamma\gamma\to\omega\omega\to 2\pi^+2\pi^-2\pi^0$ presented here is based on a data sample corresponding to an integrated luminosity of 234 3 pb^{-1} The data were collected using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY operating at center-of-mass energies around 10 GeV The ARGUS detector is described elsewhere [9]

Candidate events for the reaction $\gamma\gamma\to 2\pi^+2\pi^-2\pi^0$ were selected by requiring four charged particles with zero net charge originating from a common event vertex These particles had to be identified as pions with a likelihood ratio [9] larger than 5% Exactly four photons were required to be seen in the electromagnetic calorimeter, with a minimum energy ranging from 50 to 70 MeV depending on the running conditions Any photon pair with an invariant mass between 60 and 220 MeV/c^2 and with an opening angle smaller than 90° was considered a π^0 candidate These were constrained by a kinematical fit to the nominal π^0 mass Events were required to contain at least two π^0 candidates

By requiring at least one combination of six pions with a scalar momentum sum $P^{\rm sum}=\sum|\boldsymbol{p}|\leqslant 3.5$ GeV/c and a total transverse momentum $P_{\rm T}^{\rm tot}=|\sum\boldsymbol{p}_{\rm T}|\leqslant 100$ MeV/c, 553 events are selected These two cuts suppress τ-pair events and incompletely reconstructed annihilation events Since these selected events contain four photons, up to three different pairs of π^0 candidates can be formed per event This combinatorial ambiguity was removed by choosing only that pair of π^0 candidates with the smallest $P_{\rm T}^{\rm tot}$ (fulfilling the cut $P^{\rm sum}\leqslant 3$ 5 GeV/c) The loss of events due to this cut is only about 5%, as determined both by Monte Carlo and in data from the ω fits to the $\pi^+\pi^-\pi^0$ invariant mass spectra

To determine the acceptance, a Monte Carlo program was used to generate photon–photon reactions according to the exact QED expression for collisions of transverse photons [10] Isotropic phase space was used to simulate final states of $2\pi^+2\pi^-2\pi^0$, $\omega\pi^+\pi^-\pi^0$, $\omega\omega$, and $2\pi^+2\pi^-\pi^0$ The appropriate matrix element was used for the decay of ω into $\pi^+\pi^-\pi^0$ All Monte Carlo event samples were generated with a beam energy distributed according to the data and were passed through a full detector [11] and trigger simulation The trigger simulation used shapes of threshold behaviour for the detector components as determined from data This takes into account the variation of the actual trigger conditions The simulation of random noise in the calorimeter

[1] On leave from University of Science and Technology, Kumasi, Ghana
[2] Weizmann Institute of Science, 76100 Rehovot, Israel
[3] Supported by the Minerva Stiftung
[4] Supported by the German Bundesministerium für Forschung und Technologie, under the contract number 054DO51P
[5] Present address University of California at Santa Cruz, Santa Cruz CA 95064 USA
[6] Supported by the German Bundesministerium für Forschung und Technologie, under the contract number 054HD24P
[7] Carleton University, Ottawa, Ontario, Canada K1S 5B6
[8] York University, Downsview, Ontario, Canada M3J 1P3
[9] University of Toronto Toronto Ontario Canada M5S 1A7
[10] McGill University, Montreal, Quebec, Canada H3A 2T8
[11] Supported by the Natural Sciences and Engineering Research Council, Canada
[12] Supported by the US National Science Foundation
[13] Supported by Raziskovalna skupnost Slovenije and the Internationales Buro KfA, Julich
[14] Supported by the Swedish Research Council
[15] Supported by the US Department of Energy, under contract DE-AS09-80ER10690

was determined from data using events $\Upsilon(1S) \to e^+e^-$ and $\Upsilon(1S) \to \mu^+\mu^-$, tagged by the pions from the transition $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$

The $2\pi^+2\pi^-2\pi^0$ acceptance is zero for $W_{\gamma\gamma} < 1.2$ GeV/c^2, rises to a sensitivity of about 1 event/nb of the $\gamma\gamma$ cross section and per 100 MeV/c^2 of $W_{\gamma\gamma}$ at $W_{\gamma\gamma} \approx 2$ GeV/c^2, and slowly decreases towards higher values of $W_{\gamma\gamma}$. The sensitivity is approximately the same for $\omega\pi^+\pi^-\pi^0$ events, while it is about 25% lower for $\omega\omega$ events. The systematic uncertainties in the overall scale of the final cross sections are estimated to be 14% for $\gamma\gamma \to 2\pi^+2\pi^-2\pi^0$, 15% for $\gamma\gamma \to \omega\pi^+\pi^-\pi^0$, and 25% for $\gamma\gamma \to \omega\omega$, by adding the following contributions in quadrature luminosity measurement 5%, trigger simulation 5.1%, acceptance calculation 10.8% for $2\pi^+2\pi^-2\pi^0$ and $\omega\pi^+\pi^-\pi^0$ events, and 17.3% for $\omega\omega$ events, background estimation 5%. For $\gamma\gamma \to \omega\pi^+\pi^-\pi^0$ and $\gamma \to \omega\omega$ there is an additional uncertainty of 4.6% from the ω fits and finally, an uncertainty of 15% is estimated for $\omega\omega$ in the derivation of the mass spectrum for these events. The systematic uncertainties are not shown in the cross section plots

In order to derive the cross section for $\gamma\gamma \to 2\pi^+2\pi^-2\pi^0$, a study of possible background processes was performed. Backgrounds divide into two classes (1) incompletely reconstructed annihilation events and τ-pair events, and (2) $\gamma\gamma \to 2\pi^+2\pi^-n\pi^0$ events where $n \neq 2$. The first class, as well as part of the second, has unbalanced P_T^{tot}. Completely reconstructed $\gamma\gamma$ events have a $(P_T^{tot})^2$ distribution which peaks strongly at $(P_T^{tot})^2 = 0$, while for incompletely reconstructed events and τ-pair events this distribution is approximately flat close to zero, as shown by Monte Carlo studies. The first class of background is estimated to be 27.5 events. Part of the second class, $\gamma\gamma \to 2\pi^+2\pi^-n\pi^0$ with $n = 1$ and two noise photons faking a second π^0, was found to be negligible by studying our data on $\gamma\gamma \to 2\pi^+2\pi^-\pi^0$ together with a Monte Carlo simulation. The same holds for $\gamma \to 2\pi^+2\pi^-n\pi^0$ with $n \geqslant 3$ where one or more π^0's escape detection. This conclusion is based on the absence of $\gamma \to 2\pi^+2\pi^-3\pi^0$ events in our data. The case with two π^0's where one photon escapes detection but is replaced by noise in the calorimeter is more serious. This background is estimated to contribute 35.4 events. Thus, 63 out of the total number of 553 events are estimated to be background events

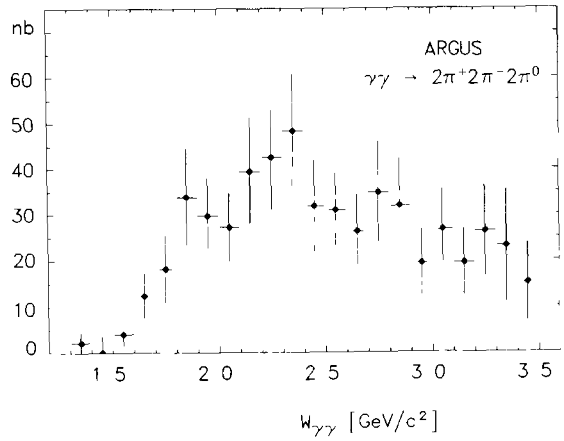

Fig. 1. Topological cross section for $\gamma\gamma \to 2\pi^+2\pi^-2\pi^0$ versus $W_{\gamma\gamma}$. The errors shown are statistical. The systematic uncertainty is 14%

and are assumed to be equally distributed over the available $W_{\gamma\gamma}$ range. The resulting topological cross section for the reaction $\gamma\gamma \to 2\pi^+2\pi^-2\pi^0$ is shown in fig. 1. A smooth distribution rising to about 40 nb at 2.2 GeV/c^2 is observed

The invariant mass distribution of all $\pi^+\pi^-\pi^0$ combinations is shown in fig. 2a (8 entries per event). The distribution is fitted by a Breit–Wigner function with the parameters of the $\omega(783)$ meson [12], convoluted with a gaussian describing the mass resolution of the detector, and a fourth-order polynomial background. The ω peak contains 263 ± 30 entries. Fig. 2b shows a scatter plot of the invariant mass of one $\pi^+\pi^-\pi^0$ combination versus the invariant mass of the other $\pi^+\pi^-\pi^0$ combination. A clear enhancement is seen in the $\omega\omega$ region. Note that each event contributes four entries to this plot

To investigate whether this enhancement is due to $\omega\omega$ production or just due to the overlap of two independent ω bands, the invariant mass distribution of the three pions recoiling against an ω was plotted (fig. 3). This was derived by making projections of the scatter plot (fig. 2b) onto one $\pi^+\pi^-\pi^0$ axis for different mass intervals in the second, and vice versa. These spectra were then added for each mass bin, and fitted to determine the number of ω mesons. The presence of an $\omega\omega$ signal would manifest itself as an enhancement in the bin between 680 and 880 MeV/c^2. To estimate the expected distribution for events with only one ω, Monte Carlo generated

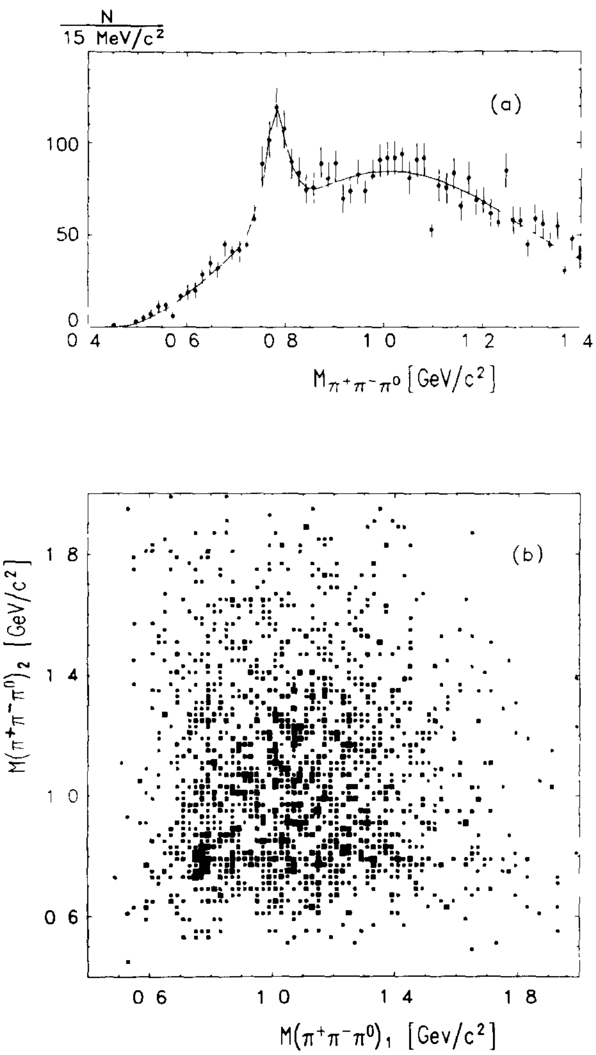

Fig 2 (a) Invariant $\pi^+\pi^-\pi^0$ mass spectrum The fit consists of a Breit–Wigner distribution with the parameters of the $\omega(783)$ meson convoluted with a gaussian to describe the mass resolution of the detector, and a fourth-order polynomial background (8 entries per event) (b) Scatter plot of the mass of one $\pi^+\pi^-\pi^0$ combination versus the mass of the remaining $\pi^+\pi^-\pi^0$ combination (4 entries per event)

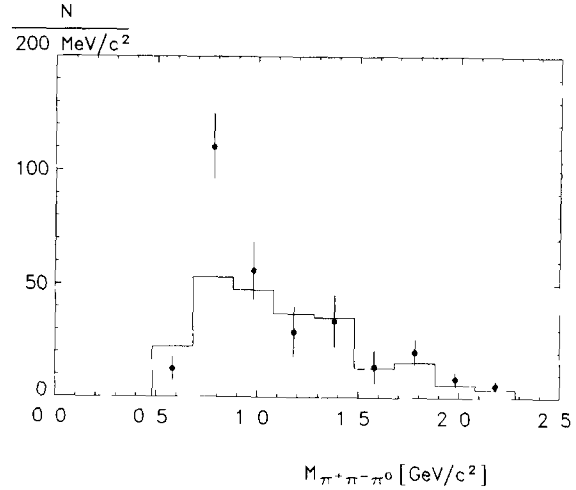

Fig 3 Invariant mass of the $\pi^+\pi^-\pi^0$ system recoiling against an ω meson The data points are shown with error bars The non-resonant three-pion mass distribution, as expected from $\omega\pi^+\pi^-\pi^0$ Monte Carlo events, is shown as a histogram

$\gamma\to\omega\pi^+\pi^-\pi^0$ events were used, with the $W_{\gamma\gamma}$ distribution adjusted to agree with the observed $2\pi^+2\pi^-2\pi^0$ mass distribution The resulting non-resonant $\pi^+\pi^-\pi^0$ mass distribution from Monte Carlo is also shown in fig 3, normalized to the data at masses above 1 1 GeV/c^2 A clear excess of $\omega\omega$ events is seen Two other methods to determine the background were used in order to estimate the systematic uncertainty. Monte Carlo generated $\gamma\gamma\to 2\pi^+2\pi^-2\pi^0$ events and wrong-sign combinations, such as $\pi^+\pi^+\pi^0$, in the data All three methods agree very well Subtracting the non-resonant background leaves an excess of $57\pm16\pm3$ entries due to $\omega\omega$ events The second error is the systematic uncertainty derived from the maximum difference between the three methods Thus, we observe $29\pm8\pm2$ $\gamma\to\omega\omega$ events This is the first evidence for $\omega\omega$ production in photon–photon interactions

To derive the cross section for $\gamma\gamma\to\omega\omega$, the six-pion mass for events containing two different $\pi^+\pi^-\pi^0$ combinations with masses between 680 and 880 MeV/c^2 was plotted The shape of the background was estimated by wrong-sign combinations in the data fulfilling the ω mass requirements, normalized such that 29 events remain when subtracted from the data After correcting the six-pion mass distribution of the 29 $\omega\omega$ events for acceptance and for $\mathrm{Br}(\omega\to\pi^+\pi^-\pi^0)$, the cross section for $\gamma\gamma\to\omega\omega$ is derived (fig 4) An enhancement of about 10 nb can be seen at $\sim$1 9 GeV/c^2 This measurement disagrees with the predictions by the t-channel factorization model [8] Note that the enhancement appears at the same $W_{\gamma\gamma}$ as the enhancement seen in $\gamma\gamma\to\omega\rho^0$ [2]

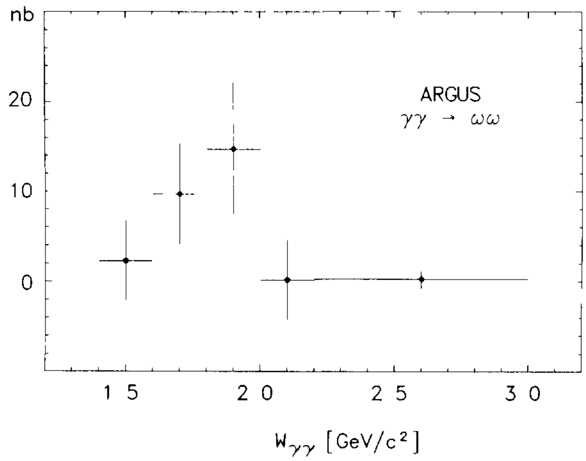

Fig 4 Cross section for $\gamma\gamma \to \omega\omega$ versus $W_{\gamma\gamma}$ The error bars shown are statistical The systematic uncertainty is 25%

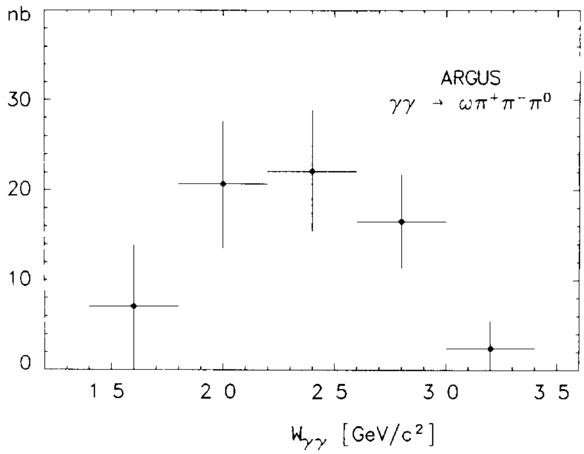

Fig 5 Cross section for $\gamma\gamma \to \omega\pi^+\pi^-\pi^0$ versus $W_{\gamma\gamma}$ ($\gamma\gamma \to \omega\omega$ events have been removed) The error bars shown are statistical The systematic uncertainty is 15%

A check of the method used to extract the $\omega\omega$ cross section was made by determining the number of $\omega\omega$ events in three $2\pi^+2\pi^-2\pi^0$ mass bins, employing the same technique used to determine the total number of $\omega\omega$ events The result is that 15 ± 5, 17 ± 7 and 1 ± 4 $\omega\omega$ events appear in the $W_{\gamma\gamma}$ ranges 1 6 to 1 8, 1 8 to 2 0 and greater than 2 0 GeV/c^2, respectively The cross section derived by this second method is almost identical to that shown in fig 4

To determine the $\gamma\gamma \to \omega\pi^+\pi^-\pi^0$ cross section, the $\omega\omega$ mass distribution was subtracted from the distribution of the number of ω mesons as a function of the total $2\pi^+2\pi^-2\pi^0$ mass This distribution was found by dividing the data into 200 MeV/c^2 bins of the total $2\pi^+2\pi^-2\pi^0$ mass and fitting the corresponding $\pi^+\pi^-\pi^0$ mass spectra The only important background process is the reaction $\gamma\gamma \to \omega\pi^+\pi^-\pi^0$ itself, where one photon escapes detection, but a fake photon appears in the calorimeter 11 5 events of this kind are expected from Monte Carlo studies After subtracting this background, and correcting for acceptance and for Br($\omega \to \pi^+\pi^-\pi^0$), the cross section for $\gamma\gamma \to \omega\pi^+\pi^-\pi^0$ is derived (fig 5) No structure is evident with the present statistics

In summary, we have observed for the first time the process $\gamma\gamma \to 2\pi^+2\pi^-2\pi^0$ Evidence for $\omega\omega$ production was found, and the cross sections for $2\pi^+2\pi^-2\pi^0$, $\omega\pi^+\pi^-\pi^0$ and $\omega\omega$ were given The cross section for $\gamma\gamma \to \omega\omega$ was observed to be concentrated around 1 9 GeV/c^2

It is a pleasure to thank U Djuanda, E Konrad, E Michel, and W Reinsch for their competent technical help in running the experiment and processing the data We thank Dr H Nesemann, B Sarau, and the DORIS group for the excellent operation of the storage ring The visiting groups wish to thank the DESY directorate for the support and kind hospitality extended to them

References

[1] TASSO Collab, R Brandelik et al, Phys Lett B 97 (1980) 448,
TASSO Collab, M Althoff et al, Z Phys C 16 (1982) 13,
MARK II Collab, D L Burke et al, Phys Lett B 103 (1983) 153,
CELLO Collab, H -J Beherend et al, Z Phys C 21 (1984) 205

[2] ARGUS Collab, H Albrecht et al, Phys Lett B 196 (1987) 101

[3] PLUTO Collab, Ch Berger et al, Z Phys C 29 (1985) 183,
TPC/Two-Gamma Collab, H Aihara et al, Phys Rev Lett 54 (1985) 2564,
TASSO Collab, M Althoff et al, Z Phys C 32 (1986) 11

[4] JADE Collab, in Proc 5th Intern Workshop on $\gamma\gamma$ collisions (Aachen, 1983), ed Ch Berger p 175

[5] R L Jaffe, Phys Rev D 15 (1977) 267

[6] N N Achasov et al, Z Phys C 27 (1985) 99

[7] B A Lee and K F Liu, Phys Lett B 118 (1982) 435, B 124 (1982) 550 (E), Phys Rev Lett 51 (1983) 1510, Phys Rev D 30 (1984) 613

[8] G Alexander et al , Z Phys C 30 (1986) 65
[9] ARGUS Collab , H Albrecht et al , Phys Lett B 134 (1984) 137,
M Danilov et al , Nucl Instrum Methods 217 (1983) 153,
R Heller et al , Nucl Instrum Methods A 235 (1985) 26,
A Drescher et al , Nucl Instrum Methods A 249 (1986) 277
[10] V M Budnev, I F Ginzburg, G V Meledin and V G Serbo, Phys Rep 15 (1975) 181
[11] H Gennow, SIMARG, DESY report DESY F15-85-02 (1985)
[12] Particle Data Group, M Aguilar-Benitez et al , Review of particle properties, Phys Lett B 170 (1986) 1