DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 79/49
August 1979

FIRST RESULTS FROM PLUTO AT PETRA

by

Walter Wagner

NOTKESTRASSE 85 2 HAMBURG 52

FIRST RESULTS FROM PLUTO AT PETRA[+]

by

Walter Wagner
Deutsches Elektronen-Synchrotron DESY, Hamburg

With the PLUTO detector at the e^+e^- storage ring PETRA we have collected about 130 nb^{-1} at 13 GeV and 17 GeV (CMS energy). We have measured the R-value to be 5. ± .5 at 13 GeV and 4.3 ± .5 at 17 GeV. From the large angle Bhabhas we calculate a QED cut off parameter $\Lambda_- > 42$ GeV. A first analysis of two photon events leads to a cross section $\sigma_{\gamma\gamma \to had} = (.3 + .9/W_{vis})$ nb.

+ Talk given at the XIVth Rencontre de Moriond at Les Arcs - Savoie - France (March 11 to March 23, 1979)

I am going to present the first results on the measurement with the PLUTO detector at PETRA. These results are based on an integrated luminosity of about 130 nb^{-1}, taken at beam energies of 6.5 GeV and 8.5 GeV. In the last days PETRA has reached 14 GeV per beam which is quite close to the design value.

The PLUTO group[1)], which started investigation in 1974 at DORIS, continuously grew since. As it turned out the number of members increased with energy linearly. In Fig.1 the mean value of observed authors of a publication $< n_{auth} >$ is plotted versus the CMS - energy $\sqrt{s}$. The best fit to the data is given by

$$< n_{auth} > = 26 + 2.2 \sqrt{s}$$

Our first paper at PETRA design energies will allow a very sensitive test of this linear behaviour.

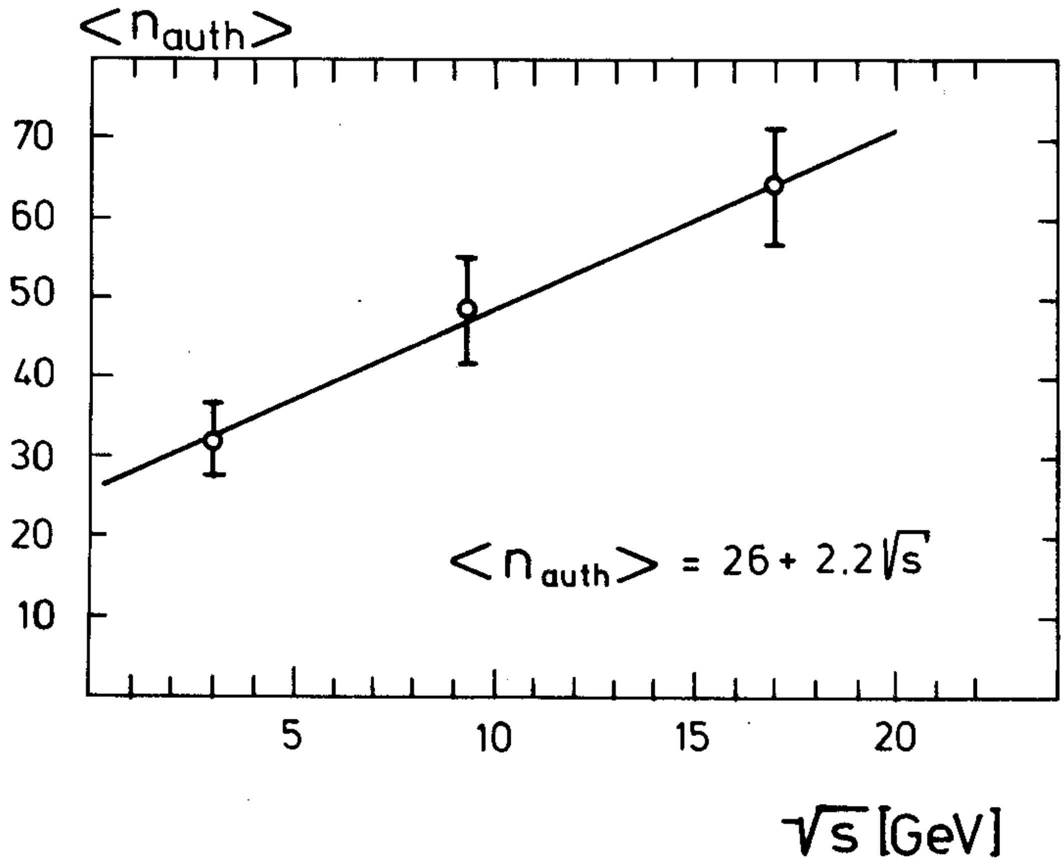


Fig.1 Number of observed authors of PLUTO versus energy

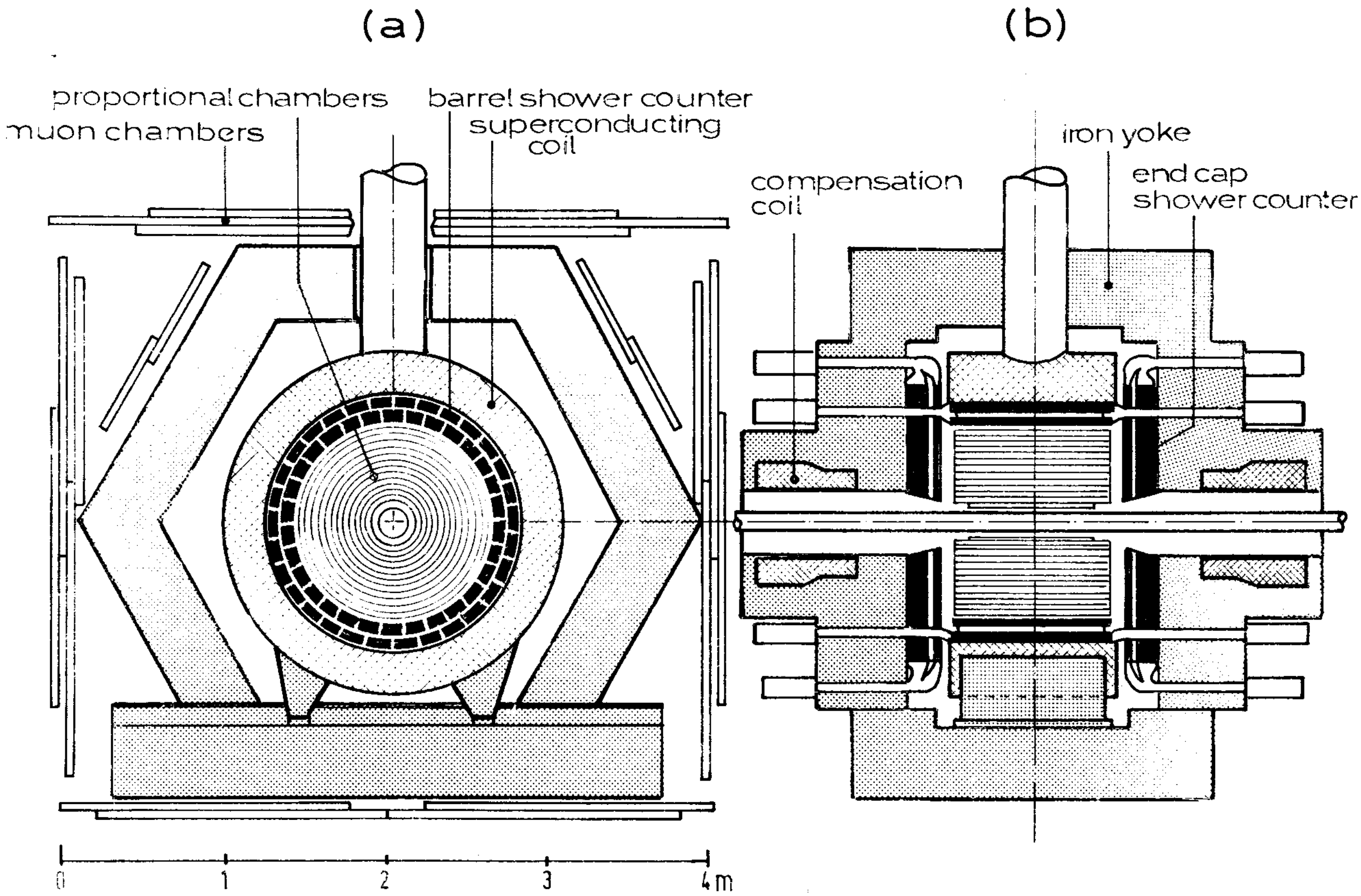


Fig.2 PLUTO inner detector, cross sectional view

I. Description of the detector

The central part of the detector (Fig. 2) which remained unchanged, uses a superconducting solenoid providing a field of 1.65 Tesla. Its inner volume is filled with 13 cylindrical proportional wire chambers for tracking and momentum measurement. A set of shower counters measures photon and electron energies. The flux return yoke is used as a hadron absorber of an average thickness of about 70 cm iron equivalent and is covered by proportional tube chambers for identification of muons. For experiments at PETRA the detector was extended by several new components (Fig. 3).

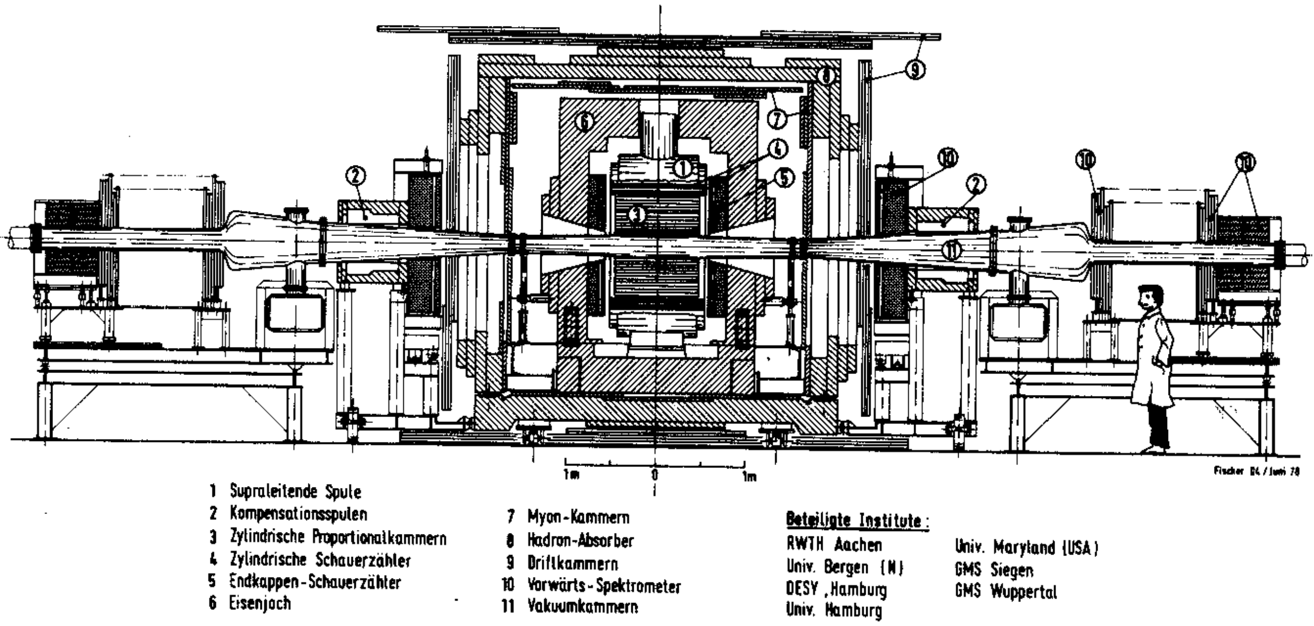


Fig. 3 Side view of the PLUTO detector

The flux return yoke has been surrounded by an 'iron house', covered by planar drift chambers, to increase the total thickness of the hadron absorber to about 1 m of iron equivalent. In both beam directions the detector has been equipped with forward spectrometers in order to measure photons and electrons produced at small angles. Each arm of the forward spectrometer consists of a 'large angle tagger (LAT) and a 'small angle tagger' (SAT). Fig. 4 shows the cross sections of both modules.

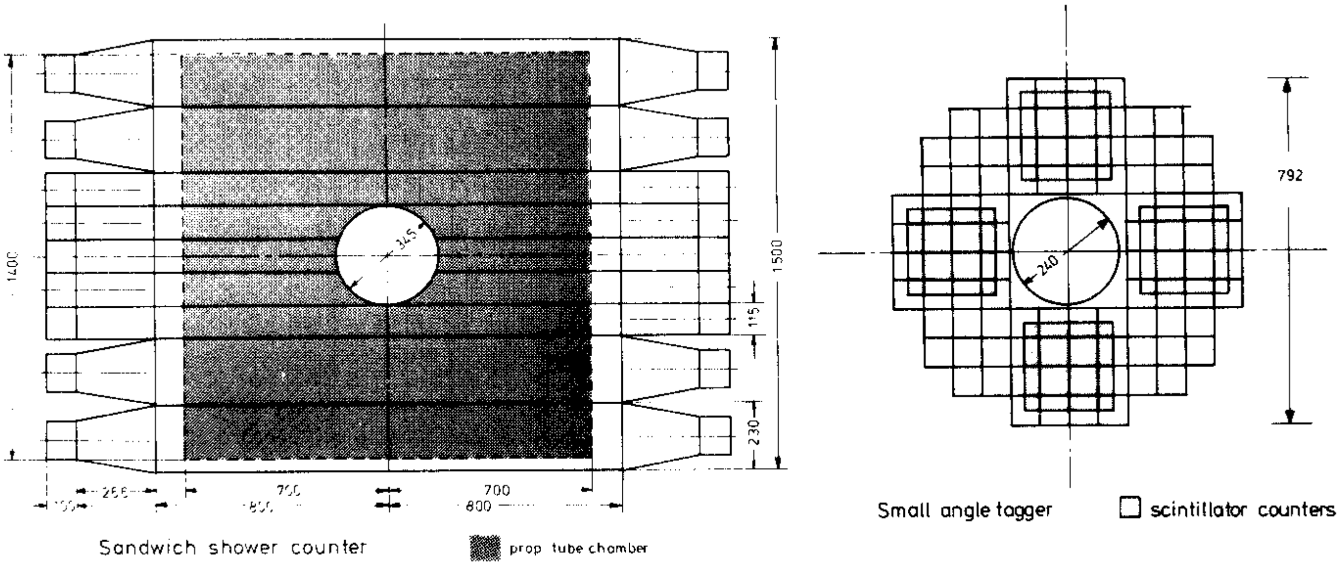


Fig.4 Forward spectrometer, cross sectional view

The LAT covers the polar angle region between 70 and 260 mrad. The energy of electrons and photons is determined with a lead scintillator shower counter of 14.5 radiation length thickness. The position of charged particles is determined by four planes of proportional tube chambers with a wire spacing of 1 cm. The SAT covers the angular region between 23 and 70 mrad. Energy information of electrons and photons is obtained by a lead glass shower counter matrix. It consists of 96 lead glass blocks (each with a front area of 6.6 x 6.6 cm^2) in a concentric arrangement around the beam pipe. The thickness of these counters is 12.5 radiation length. Tracking of charged particles can be done by a set of four planar proportional wire chambers (wire distance 0.3 cm). In a test beam the energy resolution of the LAT was measured to be $11\%/\sqrt{E}$ (rms) and of the SAT $8.5\%/\sqrt{E}$ (rms), E in GeV.

II. Luminosity measurement

We determine the luminosity by measuring small angle Bhabha scattering as a monitor process. We take all events where in both parts of the SAT (small angle tagger) an energy of more than 3 GeV was deposited. For these events we plot the acolinearity angle α (Fig.5). There is a clear and very sharp peak at $\alpha = 0$ above a small background of < 2%. This background was highest just after a filling of the beam ($\simeq$ 10%) and quickly decreasing afterwards. We made a cut in α at 21 mrad

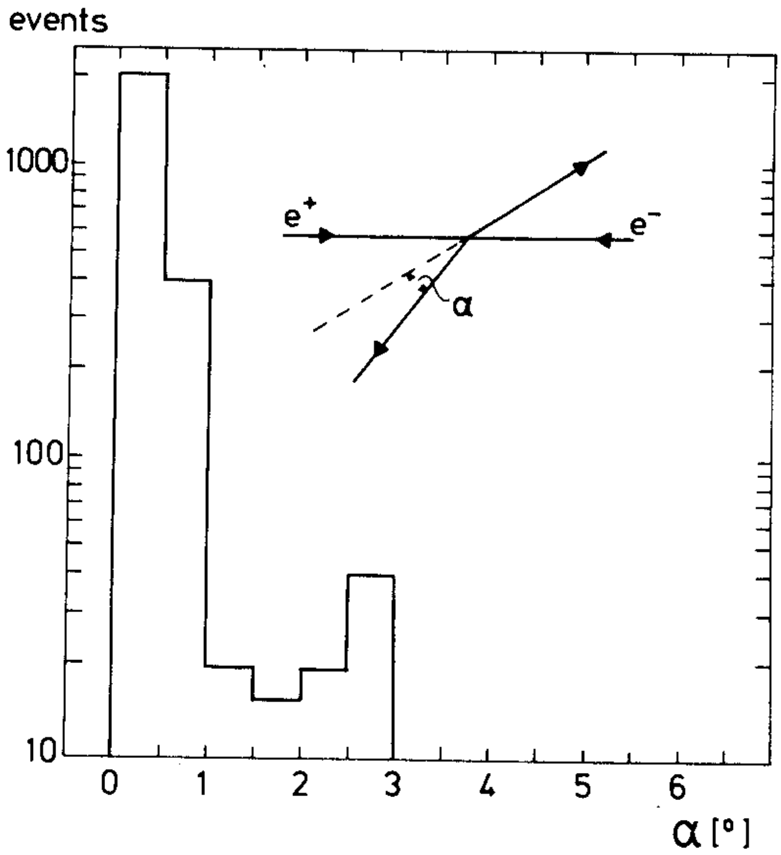


Fig. 5 Distribution of the acolinearity angle α of Bhabha events, detected in the SAT

and plotted the energy of the remaining events using a similar procedure for the LAT (Fig. 6).
The spectra reproduce the test beam resolution if one allows for energy losses due to edge effects.
We see a clear peak just at the beam energy. From these events we obtain an integrated luminosity of

$$L = 42.6 \text{ nb}^{-1} \quad \text{at } 13 \text{ GeV}$$
$$L = 88.3 \text{ nb}^{-1} \quad \text{at } 17 \text{ GeV}$$

As our detector covers almost the total solid angle with shower counters we can measure bhabha scattering in a large angular range. We therefore can compare the Bhabha cross section in the SAT with the LAT and the central detector. They agree within 5 % (LAT) and 7.5 % (central detector).

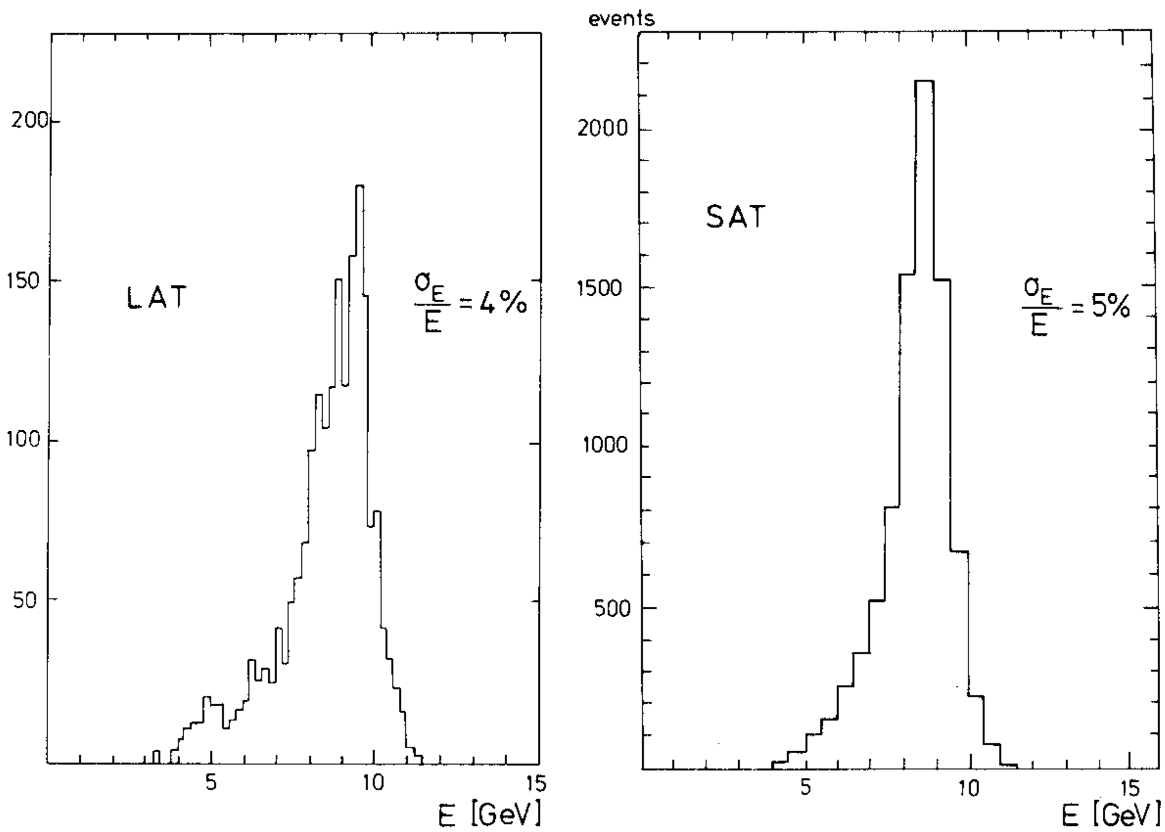
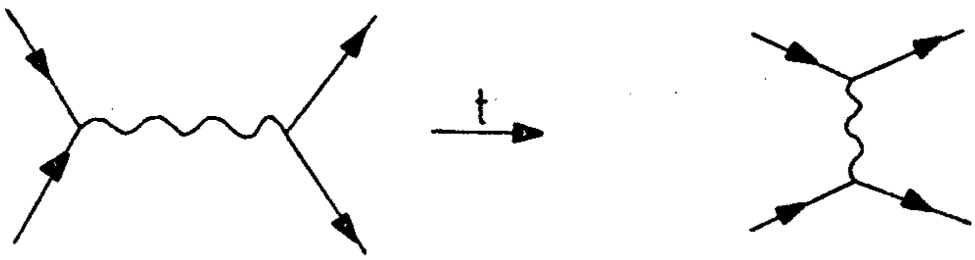


Fig. 6 Energy distribution of Bhabha events

III. Test of the QED

The QED describes the coupling of pointlike particles to the photon. In e^+e^- scattering the basic processes are given by the two diagrams:



$$\frac{1}{Q^2} = \frac{1}{4E^2} \qquad\qquad \frac{1}{Q^2} = \frac{1}{4EE'\sin^2\frac{\Theta}{2}}$$

In both cases the photon propagator is proportional to Q^{-2}. Increasing the momentum transfer one is able to look deeper into the "pointlike" particles and might find a structure. This structure can be parameterised by a formfactor or equivalently by a change of the photon propagator :

$$\frac{1}{Q^2} \rightarrow \frac{1}{Q^2} \left(1 \pm \frac{Q^2}{\Lambda_\mp^2} \right)^{-1}$$

This is the most general parameterisation in first order of Q^2, and agrees in this order with other parameterisations, often used in literature [2]. To determine the cut off parameters $\Lambda_\pm$ one has to measure at large Q^2, which means large beam energies E and large scattering angles θ for bhabha scattering. We therefore compared the angular distribution of our Bhabha events in the central detector with the QED predictions (Fig. 7). From the good agreement of the data with the QED ($\Lambda = \infty$) distribution and under the asumption that Λ is the same for spacelike and timelike photons we get the following lower limits of Λ with a 95 % confidence level:

$$\Lambda_+ > 39 \text{ GeV}$$
$$\Lambda_- > 42 \text{ GeV}$$

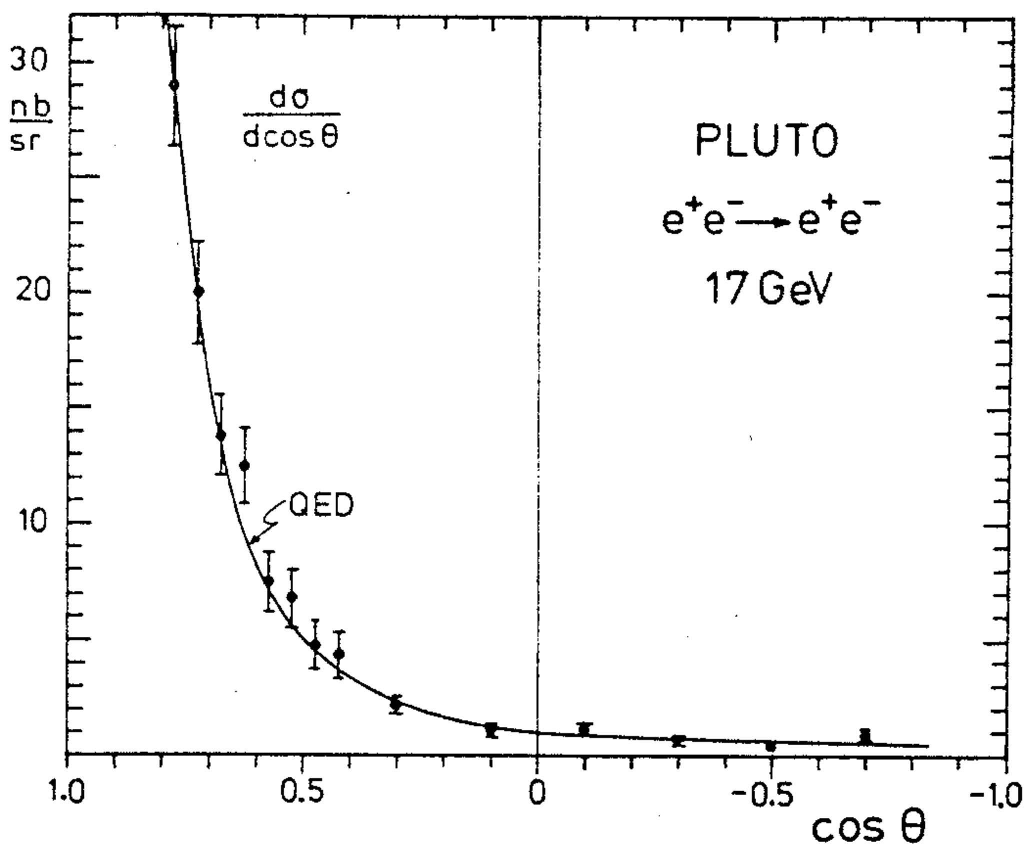


Fig. 7   Angular distribution of Bhabha events

IV. Total cross section σ^{tot} $(e^+e^- \to h)$

The measurement of the total cross section for the annihilation of e^+ and e^- into hadrons is one of the standard tasks of a detector at a storage ring. Already the simple quark-parton model tells us how σ^{tot} should behave: as the basic amplitude is correlated to the μ pair production amplitude, in the high energy limit both process should be proportional :

$$\sigma_{ee \to h} = \sigma_{ee \to \mu\mu} \cdot \Sigma_i \; Q_i^2$$

where the sum goes over all colours and flavors.

The measurement of the total cross section seems to be an easy task for an ideal detector. One only has to count the hadronic events and divide it by the integrated luminosity

$$\sigma^{tot} = \frac{N^{had}}{L}$$

Finding the hadronic events has become much easier, indeed, as the beam energy increased. At high centre of mass energies like at PETRA, events with large multiplicity are produced. This gives a very clear signature and, in addition, losses of a track due to detector acceptances are not as fatal as they are in low multiplicity events.

We used the following trigger

a) charged trigger: at least two tracks of charged particles in the central detector.

b) neutral trigger: at least 3 GeV total energy in the shower counters of the central detector.

c) two photon trigger: at least one tag and a weak condition in the central detector.

d) bhabha trigger: two 'tags' in opposite parts of the forward spectrometer

Herein a'tag'is defined by a deposited energy of more than 3 GeV in either the SAT or the LAT. Fig. 8 shows a typical event.

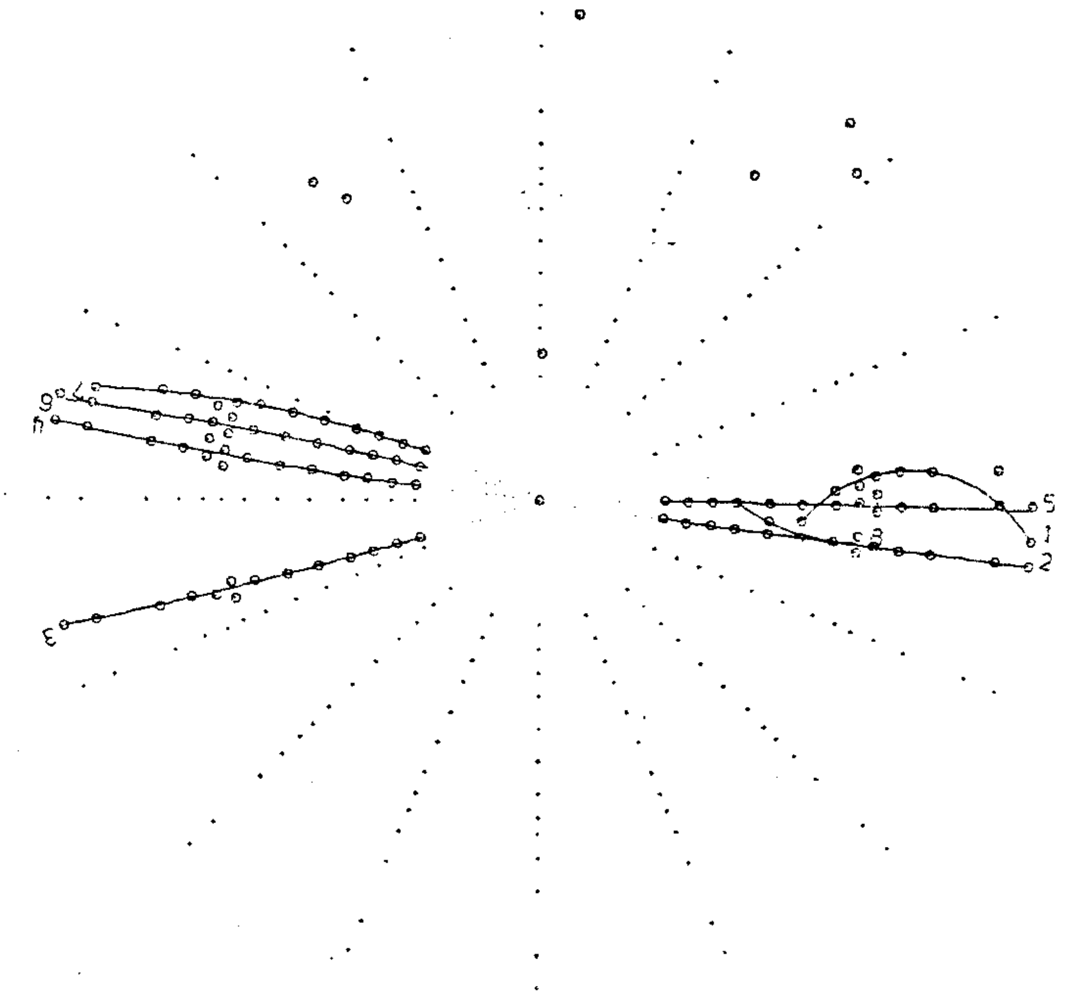


Fig. 8 Hadronic event at 26 GeV CMS energy

The selection of hadronic events is done in three steps. We first demand two well reconstructed tracks coming from the interaction point in the plane perpendicular to the beam. In order to reduce colinear pairs (QED, cosmics) we apply a colinearity cut $\Delta\psi < 150^0$ for the two prong events. For the remaining sample we plot the measured neutral energy versus the average z-value for each event. (z is the axes along the beam direction)(Fig. 9). There is a very clear peak around the interaction point (z = 0) if one demands a certain fraction of neutral energy. We choose a cut of 30 % of the centre of mass energy and look for the z distribution of the remaining 247 events.

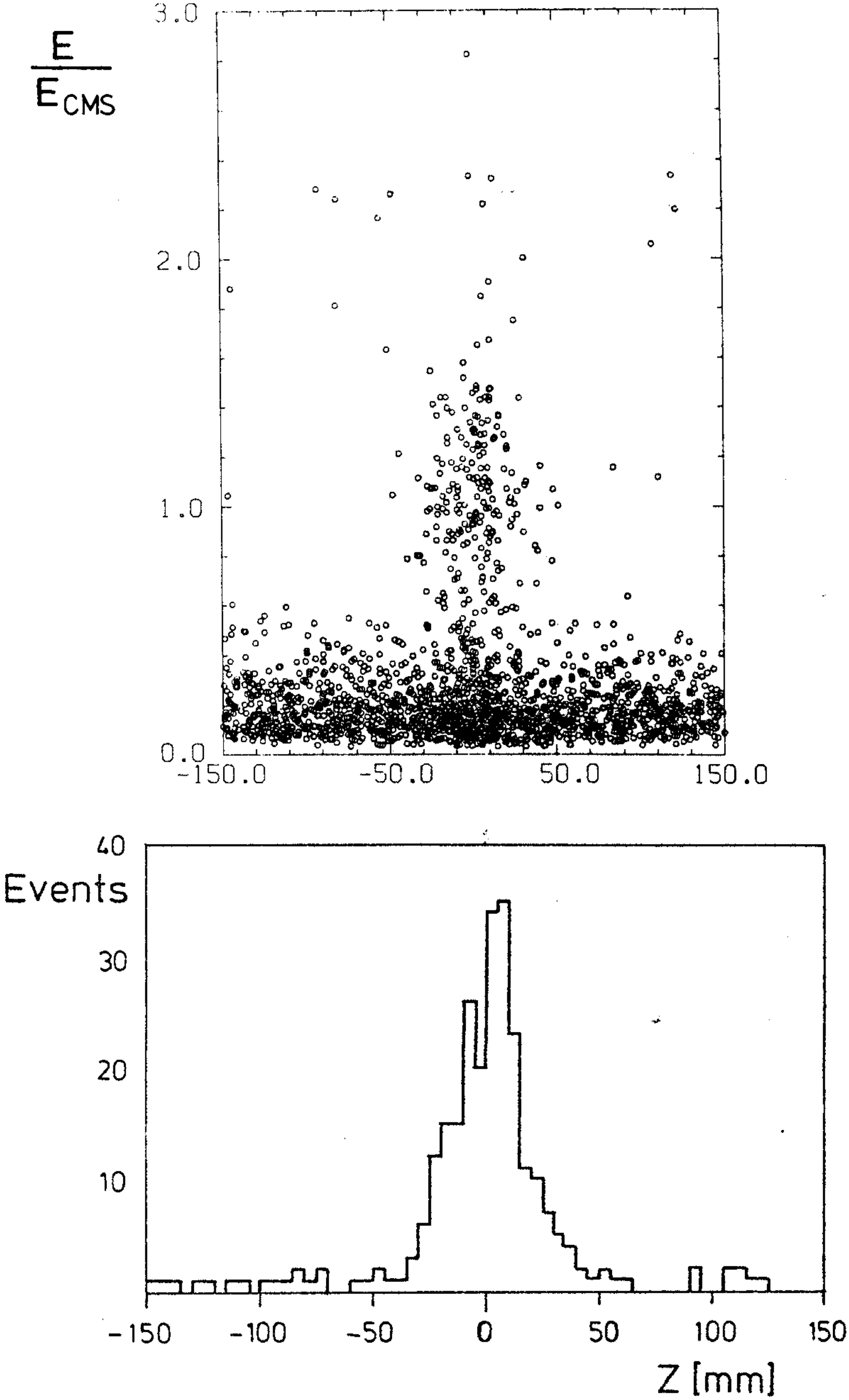


Fig. 9 Vertex distribution of hadronic events

After applying a further cut in z of $\pm$ 30 mm we are left with the final sample of hadronic events:

$$N^{had} = 96 \quad \text{at 13 GeV}$$
$$N^{had} = 108 \quad \text{at 17 GeV}$$

We give the cross section in terms of R

$$R = \frac{\sigma^{tot}}{\sigma_{\mu\mu}}$$

where R is calculated in the following way

$$R = \left(\frac{N^{had} - N^{\gamma\gamma}}{L \quad \sigma_{\mu\mu}} - R^{\tau\tau}_{vis} \right) \frac{1}{\varepsilon} \quad (1 + \delta)$$

$N_{\gamma\gamma}$: contribution of two photon exchange processes

$N_{\gamma\gamma}$ = 6 at 13 GeV
$N_{\gamma\gamma}$ = 13 at 17 GeV

$R^{\tau\tau}_{vis}$: contribution of $\tau\tau$ production

$R^{\tau\tau}_{vis}$ = 12%

ε : detector acceptance = 72%

δ : radiative corrections =-10%

We finally get the following values with an additional systematic error of 20%

$$R = 5.0 \pm .5 \text{ at 13 GeV}$$
$$R = 4.3 \pm .5 \text{ at 17 GeV}$$

Fig. 10 shows the energy dependance of R, including previous PLUTO data. The curve drawn shows the QCD predictions using

$$R = 3 \Sigma Q_i^2 \left(1 + \frac{\alpha (s)}{\pi} \right)$$

and including u, d, s, c, b quarks

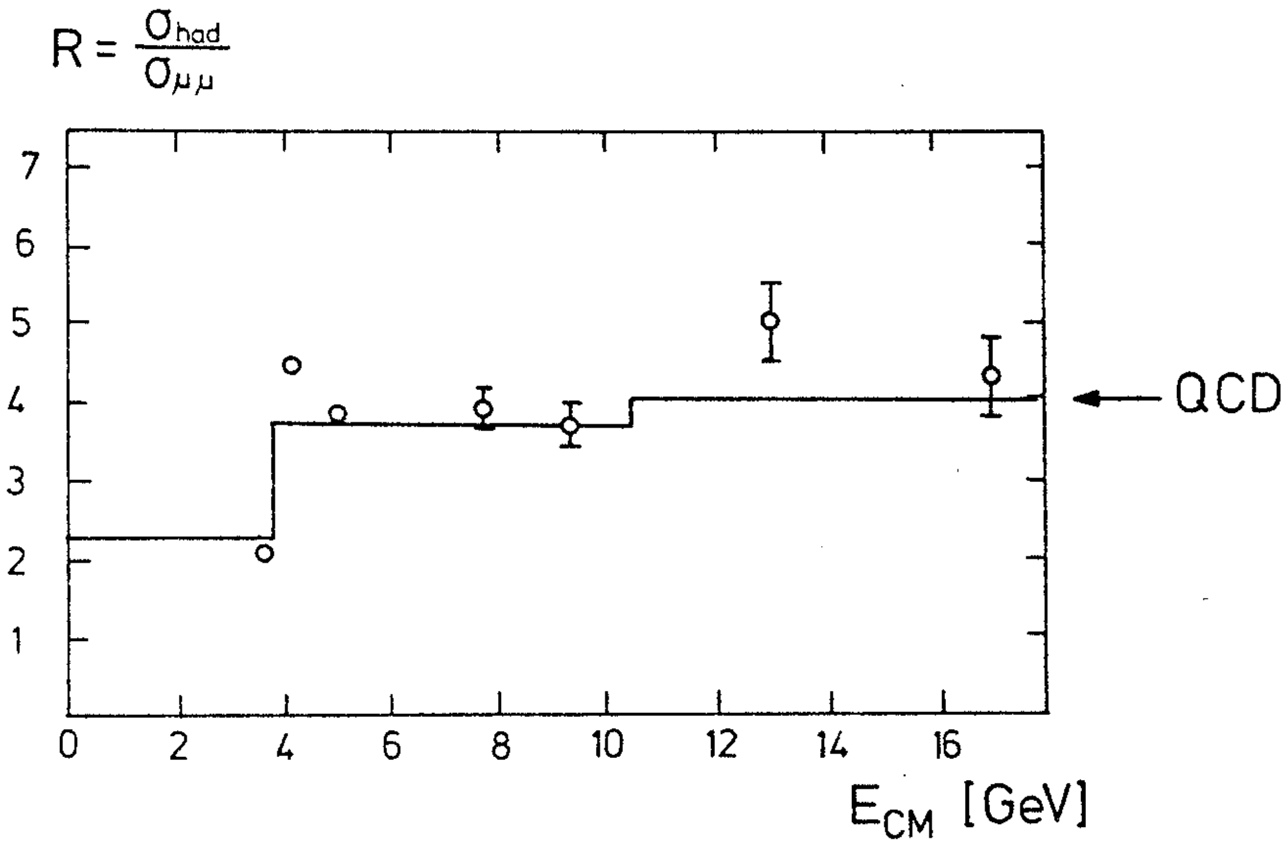
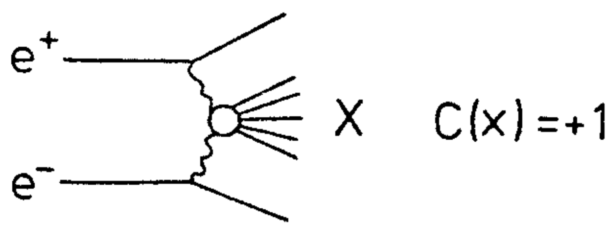


Fig. 10 Total hadronic cross section

Within statistics the data agree very well with the predictions.

V. Two photon exchange processes

With high energy e^+e^- - storage rings like PETRA or PEP particle production via the two photon exchange processes receives growing interest. The basic diagram for this reaction is



By calculating the flux factors of the incoming photons one can extract from the measured cross section

$$\sigma\ (\ e^+e^- \to e^+e^- + X\ )$$

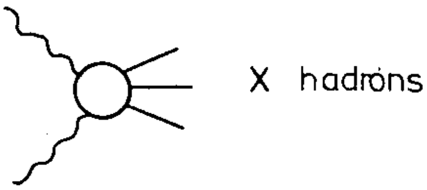
the genuine two photon cross section

$$\sigma(\ \gamma\gamma \to X\ )\ .$$

For first estimates one usually handles the photon fluxfactors in the 'equivalent photon approximation'. In this approximation the incoming electron beam of energy E is accompanied by a beam of real photons, travelling along the electron direction with an energy spectrum N (k):

$$N\ (k)\ dk = \frac{\alpha}{\pi} \frac{E^2 + E'^2}{E^2} \ln \frac{E}{m_e} \frac{dk}{k}$$

E' is the energy of the scattered electron.
One therefore can regard PETRA as a photon photon storage ring.
Our main goal is to study the 2 γ bubble



in different kinematic regions.

a) In the range where both photons are almost real and the invariant mass of the two photons is not too large, say W < 5 GeV, the cross section should be dominated by a constant diffractive part plus a resonant part from the production of C = + 1 resonances like π, η, η', η_c.
Using pomeron factorisation one can relate the diffractive part of the $\gamma\gamma$ cross section to known processes.

$$\sigma_{\gamma\gamma}^{diff} = \frac{(\sigma_{\gamma p})^2}{\sigma_{pp}} \simeq 240\ \text{nb}\ .$$

Using duality arguments one can relate the integral over the resonant cross section to the non-leading Regge terms and get an estimate of the magnitude of the resonant part, which leads to the following rough parameterisation:

$$\sigma_{\gamma\gamma} = (\ 240 + \frac{270}{W}\ )\ \text{nb}$$

But it is not at all clear that the concept of duality is valid for $\gamma\gamma$ reactions and there are other calculations which lead to a much higher resonant contribution[3]. To clarify the situation one has to measure $\sigma_{\gamma\gamma}$ as a function of W.

Fig.11 shows an event of this kinematic region. It has two tags in the SAT and four prongs in the central detector. The invariant mass of the 4 prongs is 1.6 GeV, the Q^2 of the photons is about .1 GeV^2.

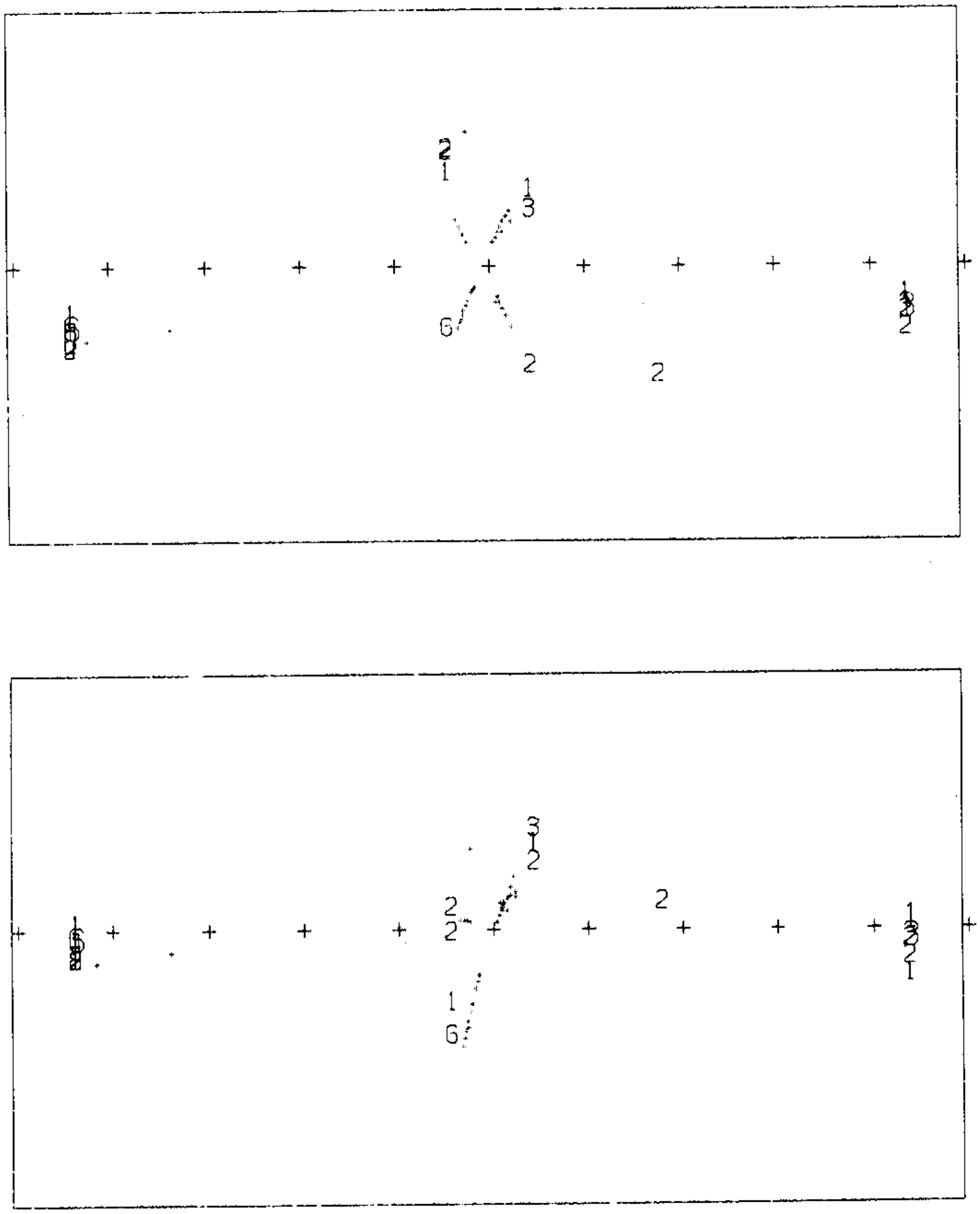
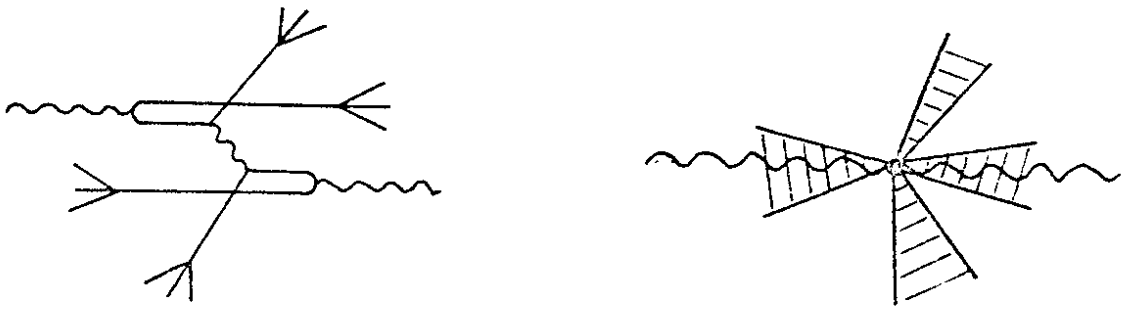
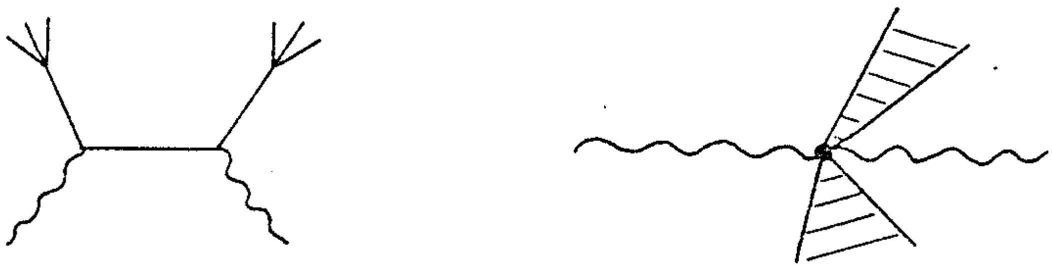


Fig. 11 - 4 prong event with a double tag in the SAT

b) At higher values of W we expect interesting event topologies according to the quark parton model. If the photon behaves like a vector meson and therefore couples hadronlike, we expect jets with large transverse momentum (large p_t- jets) accompanied by jets in the forward direction (beam pipe jets)



If the photons couple pointlike, large p_t-jets are produced without beam pipe jets.



As in the '1 photon case' the quark model connects this process to the μ - pair production process and predicts the ratio

$$R^{\gamma\gamma} = \frac{\sigma\ (ee \rightarrow eeh)}{\sigma\ (ee \rightarrow ee\mu\mu)} = \Sigma\ Q_i^4$$

As R is proportional to the fourth power of the quark charges it is very sensitive to fractional quark charges.

Fig. 12 shows a candidate for a large p_t jet. The total measured energy in the central detector is 10 GeV compared with 17 GeV expected for 1 photon events. In one of the SAT there is a 4 GeV shower. As the momenta of the particles, measured in the central detector are balanced another energy cluster of about 4 GeV must be in the other direction and stay within the beam pipe. This configuration is very unlikely for 1 photon events because of the small solid angle of the SAT (<1%) and the beam pipe (< $1^o/_{oo}$).

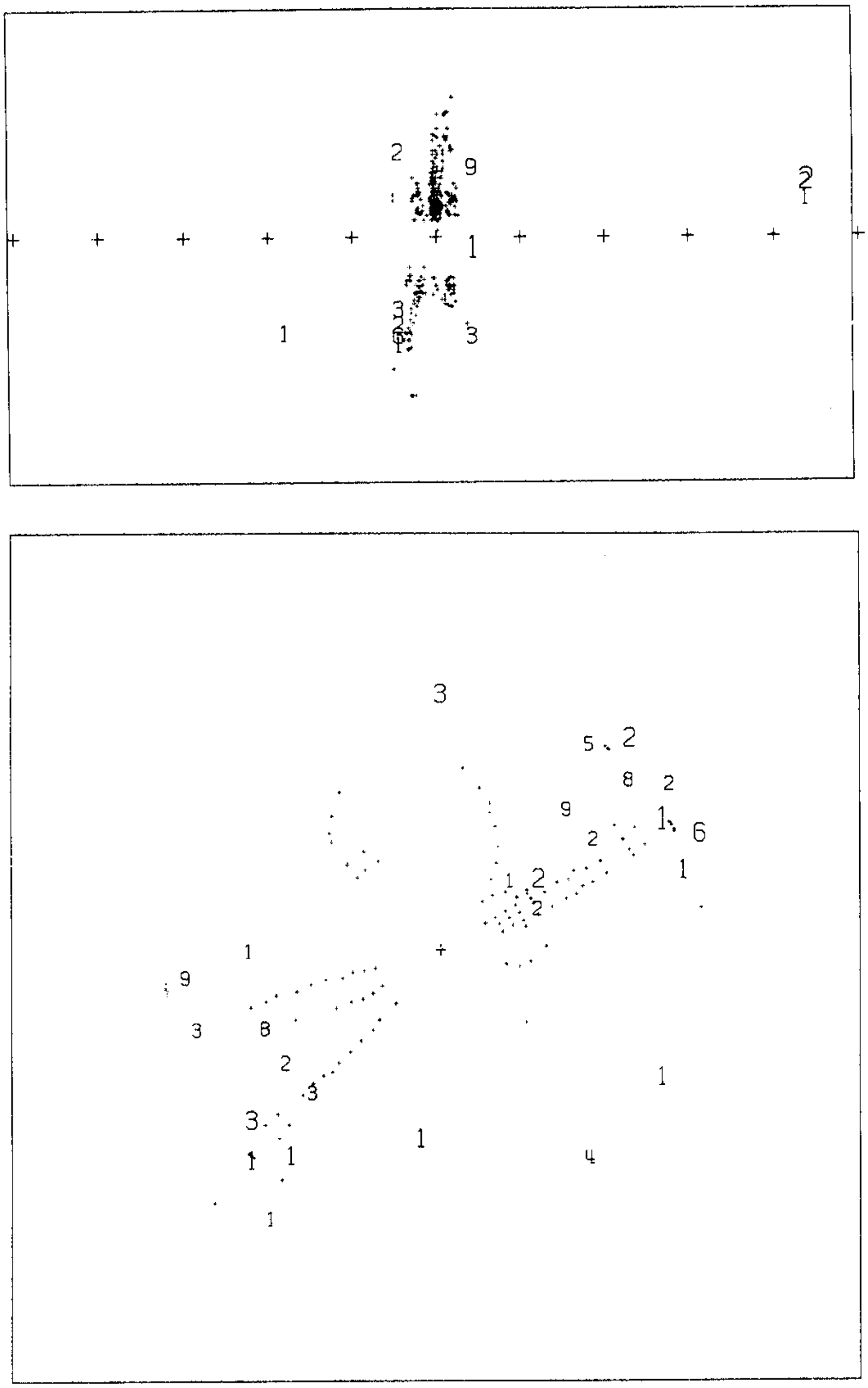
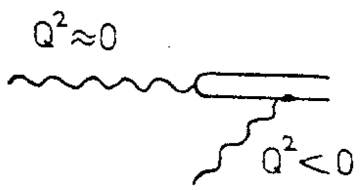
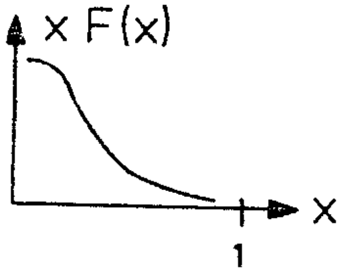


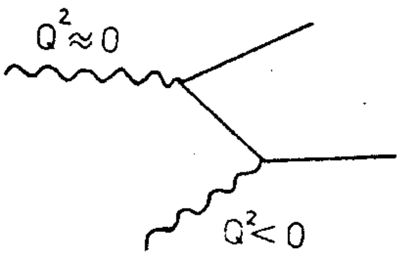
Fig.12 Candidate for a large p_t-jet with a single tag in the SAT

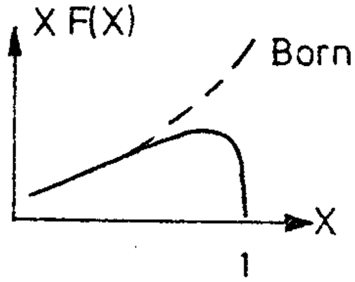
c) One of the most interesting things to study in two photon physics is the interaction of a virtual photon with an almost real photon. This process can be interpreted as deep inelastic electron scattering on a photon target and thus exhibits the structure function of the photon. With our tagging system we cover the Q^2 range up to $Q^2 \simeq 10\ GeV^2$ at 15 GeV beam energy. At low Q^2 we expect the photon to behave like a ρ with a typical structure function of a hadron.





At higher Q^2 the perturbative part of F (x) gets larger due to the fact that the photon can behave like an almost free quark antiquark pair. This perturbative part can be calculated from first principles in QCD [4] and strongly differs from the Born approximation at x = 1.





Thus it seem to be extremely interesting to measure the photon structure function at large Q^2 and around $x \simeq 1$. Fig. 13 shows a double tagged hadronic event. From the tag in the LAT we calculate a Q^2 of .5 GeV^2.

First results

In order to get a first idea of the total cross section σ ($\gamma\gamma \rightarrow h$) we have analysed our data based on the very low integrated luminosity of 130 nb^{-1}. With this luminosity it is not possible to restrict ourselves to events where both scattered electrons are measured, because the statistics then is

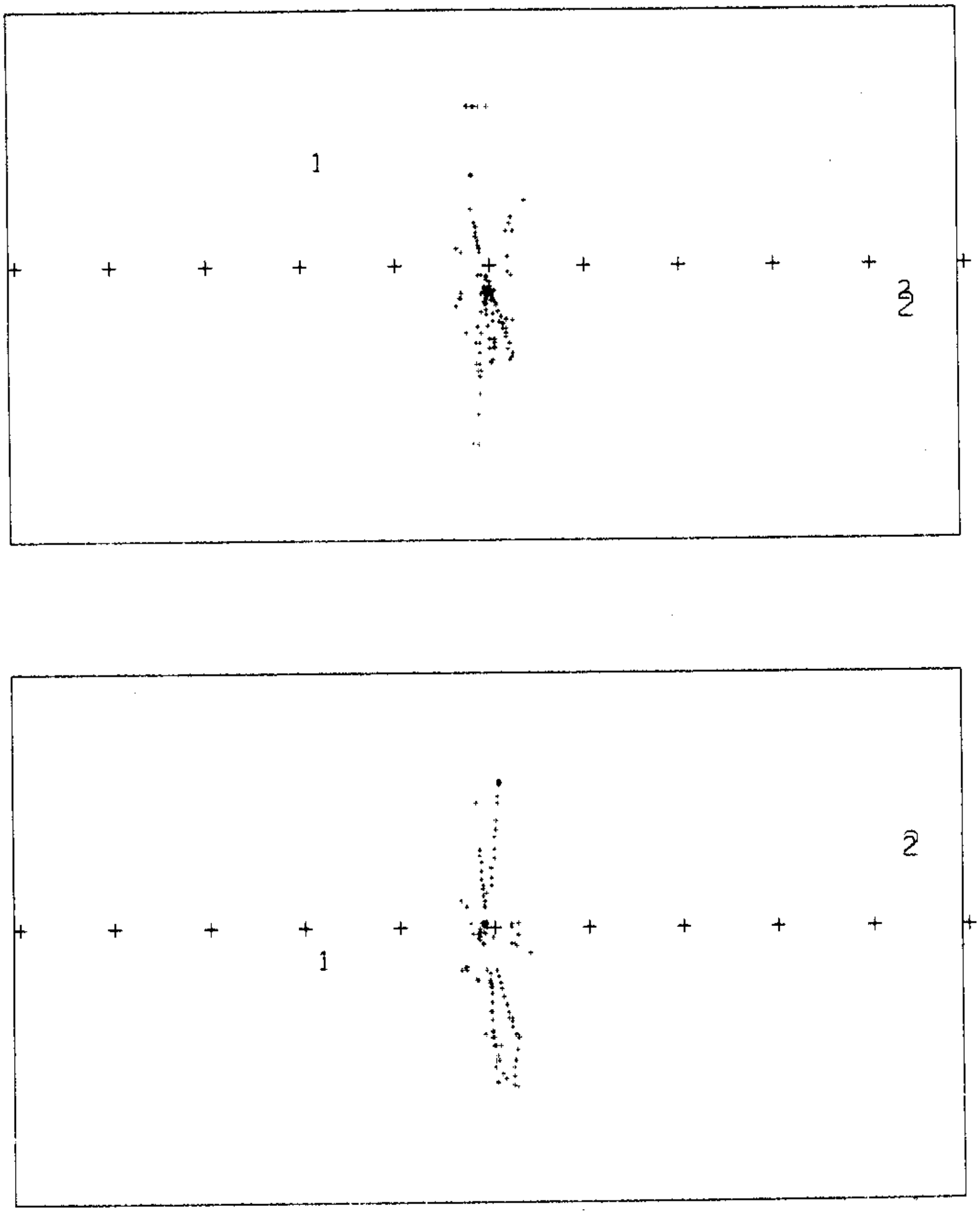


Fig.13 Multiprong event with a tag in the SAT and the LAT

very poor. But I am demonstrating in the following that a 'single tag' is a perfect signature for 2γ events. To select these events we proceed in the same manner as in the 1 photon case before. But, instead of requiring a certain energy in the central detector, we now demand a 'tag' in the forward spectrometer. As before we plot the z-distribution of the 315 events, satisfying the selection criteria (Fig.14)

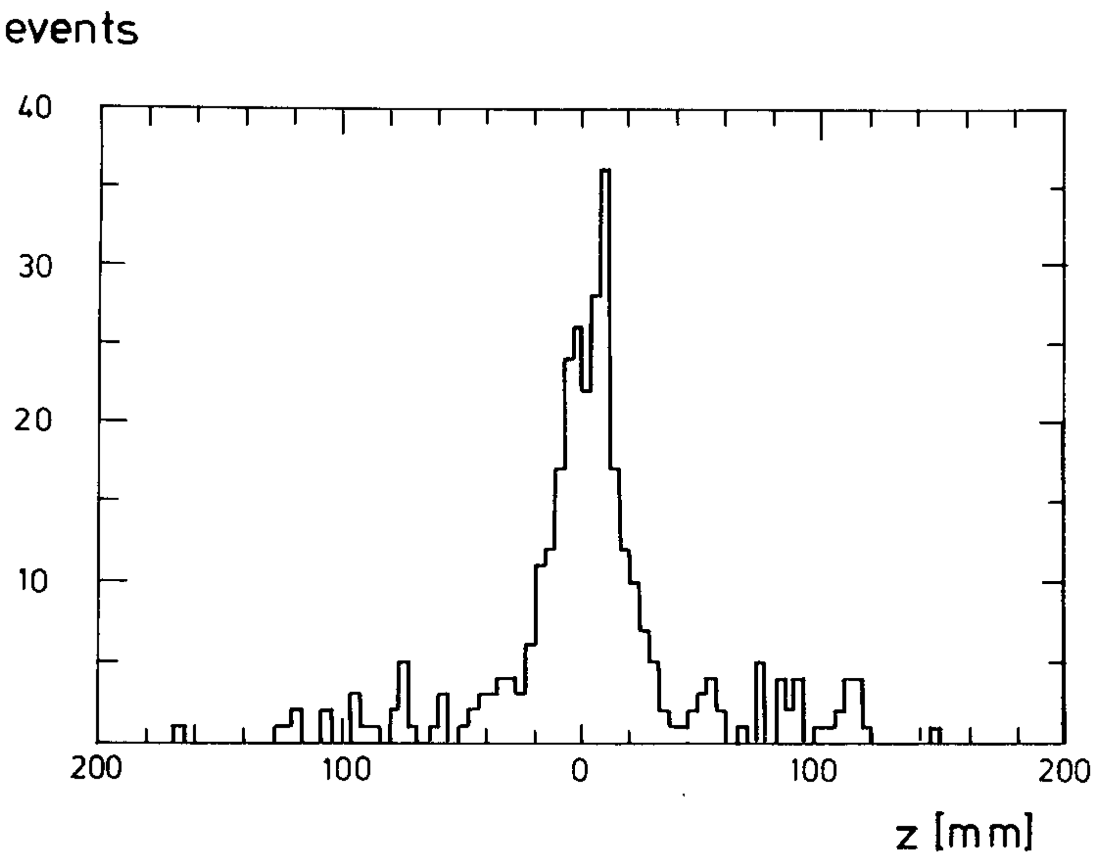


Fig.14 Vertex distribution of the single taged events

There is a very convincing signal of 210 events above a small and homogenous background mostly coming from beam-gas reactions. These events can not at all be explained by 1 photon annihilation with e.g. a π^0 simulating an electron tag. First , such events should only be a small fraction of the total sample of '1 photon events' whereas the number of 2 photon candidates is even larger (210 compared to 204 1 photon events). Secondly the energy distribution in the central detector (Fig.16) as well as in the forward spectrometer (Fig.15) exclude the 1 photon hypothesis and agree with the 2 photon hypothesis.

So we are sure that these events really come from two photon interactions. For the further analysis we reduce the data sample by requiring two additional conditions. In the first step we select only events with a tag in the SAT. For these events the mean value of Q^2 is about .1 GeV^2 and in this range of Q^2 the Weizsäcker Williams approximation should be valid.

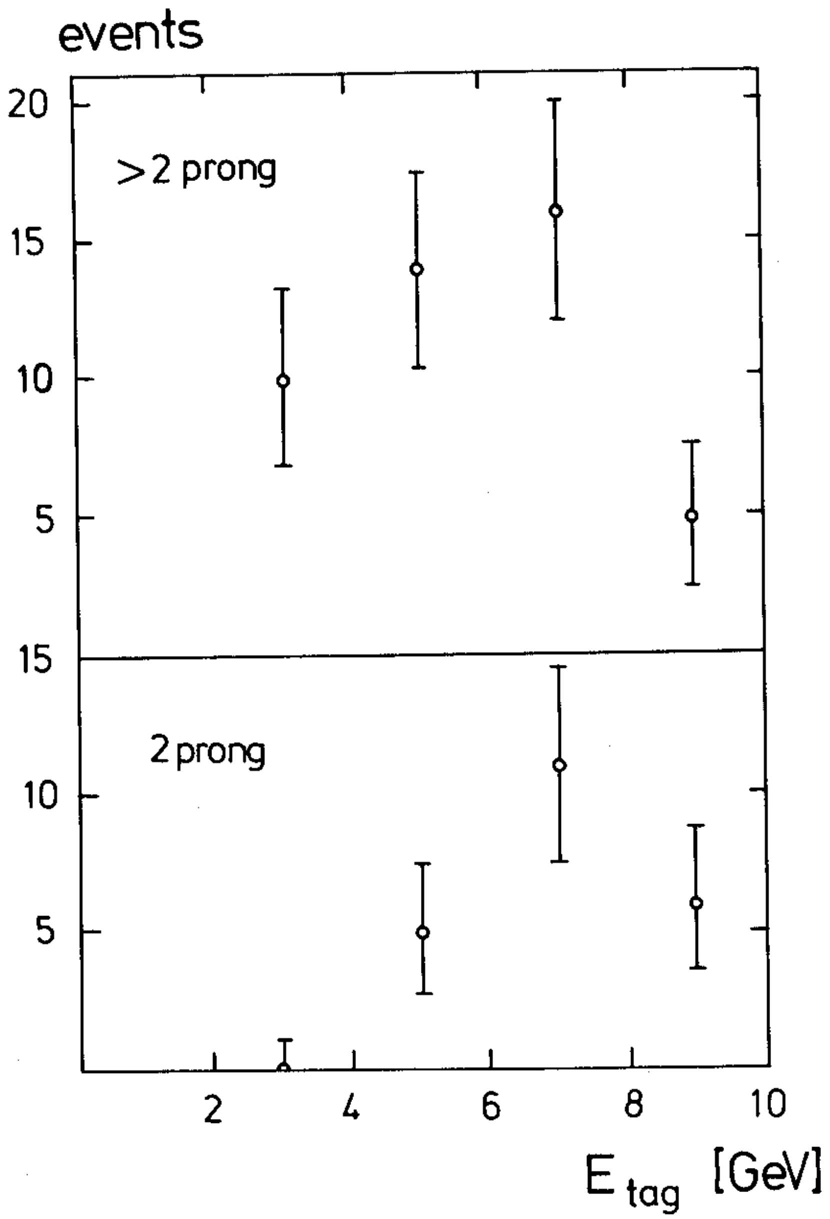


Fig.15 Energy distribution in the SAT for 2 prong and multiprong events

Secondly we demand at least 3 particles detected in the central detector, (3 tracks or 2 tracks plus additional showers) in order to reduce the second order QED processes. Since the trigger conditions were changed for several times,we choose the most restrictive condition and applied it to the data uniquely. We then remained with 40 hadronic events above a background of 12 events. Fig. 17 shows the distribution of the visible invariant mass of these events. The curve shows the Monte Carlo expectations for a constant cross section σ $(\gamma\gamma \to h)$.

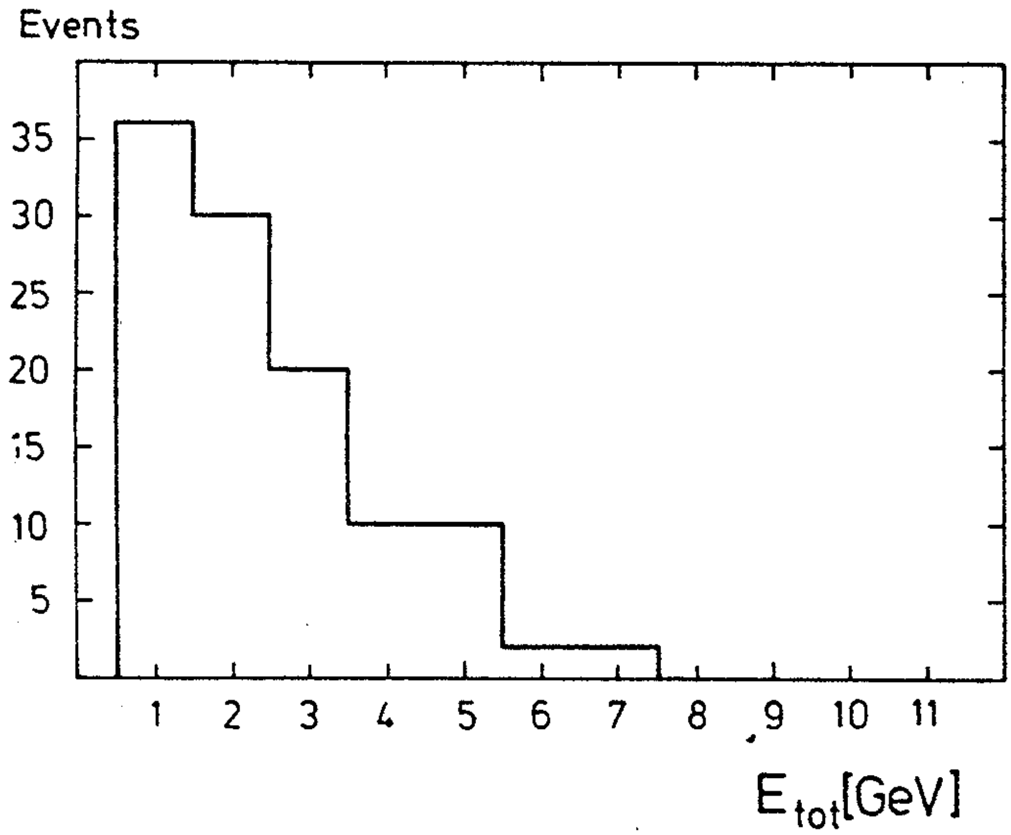


Fig. 16 Energy distribution in the central detector for tagged events

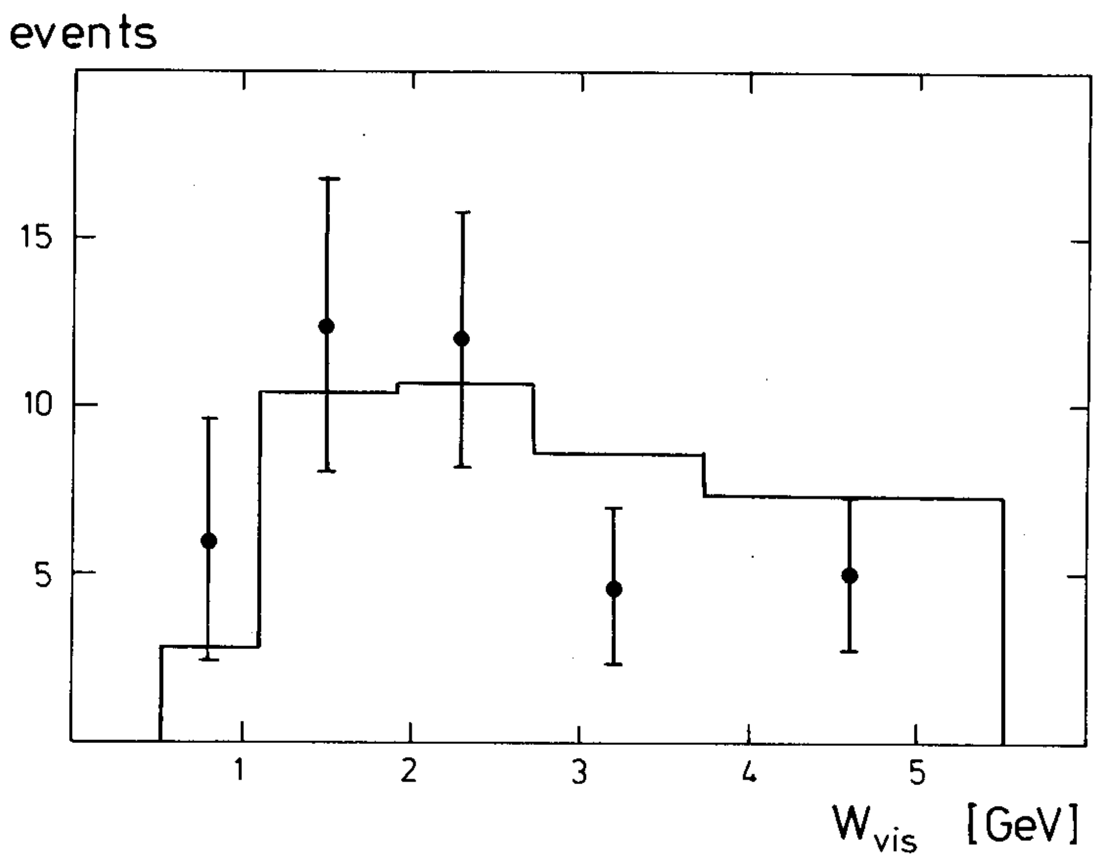


Fig. 17 Measured invariant mass of multiprong events with a tag in the SAT

From the ratio between the data and the Monte Carlo expectations we get the total cross section σ ($\gamma\gamma \rightarrow h$) as a function of the visible invariant mass of the final state (Fig.18)

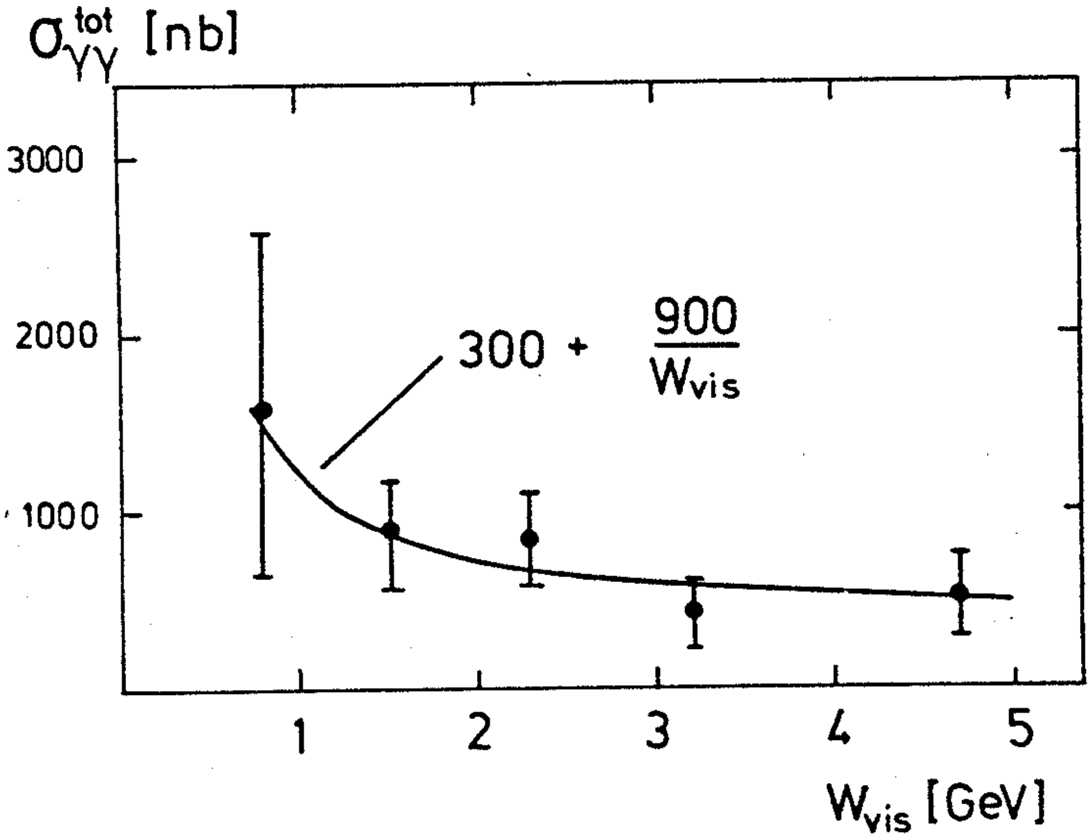


Fig. 18 Total cross section for the reaction $\gamma\gamma \rightarrow$ hadrons as a function of the visible invariant mass of the final state

We can parametrize the cross section in the following way (W_{vis} in GeV)

$$\sigma (\gamma\gamma \rightarrow h) = (300 + \frac{900}{W_{vis}}) \text{ nb}$$

The connection between W and W_{vis} was studied in a Monte Carlo. W_{vis} turned out to be about 25% smaller then W. Finally I show a very preliminary result. In Fig. 19 the invariant mass of all two prong events with at least one tag in the forward spectrometer is plotted.

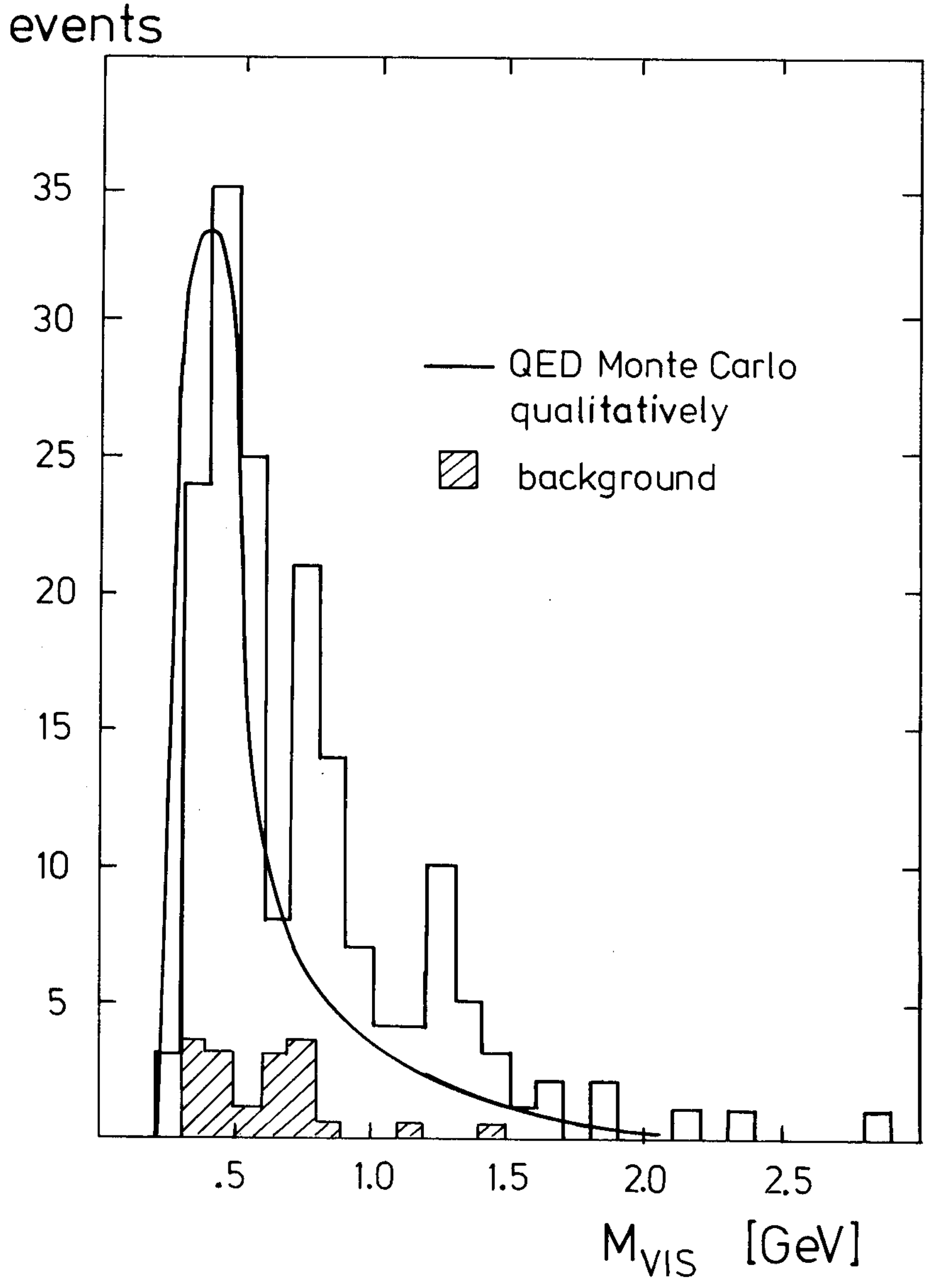
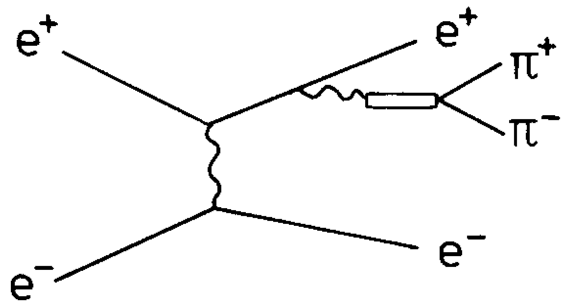
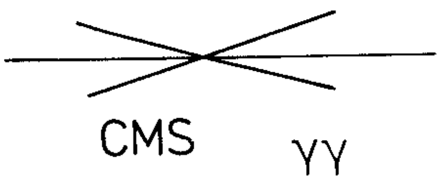


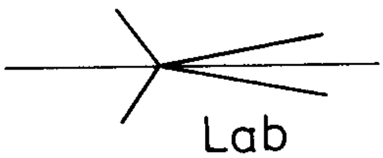
Fig.19 Invariant mass of all taged two prong events with no shower.
No trigger cut applied

For these events no further trigger cut was applied in the analysis. The data show three peaks, one at the kinematic boundary, one at the mass of the ρ and one at the mass of the f^0. Our interpretation is the following:
In the first peak there are QED events coming from the reactions $\gamma\gamma \rightarrow ee$, $(\mu\mu)$
The significance of the second peak depends upon one bin very sensitively. To get the number of events in that peak we have to substract the QED contributions quantitatively, which needs an exact calculation. In addition the mass region of the second peak is critical because our trigger demands at least one prong with a transverse momentum of > 300 MeV. The question whether the trigger affects the mass distribution in this region or not is still under study. The third peak is far enough beyond the critical region and cannot be affected by the trigger. From the number of events in the f^0 peak we are going to calculate the partial width $\Gamma^{f^0}_{\gamma\gamma}$. As the ρ has negative C parity it can not be produced via the two photon mechanism. Recent calculations[5)] have shown that these events cannot be explained by radiative Bhabha scattering, too.



If we are able to establish a ρ-signal above QED background a possible explanation of these events would be diffractive $\gamma\gamma \rightarrow \rho\rho$ scattering, where one of the ρ's is not measured.





Because of the Lorentz boost of the $\gamma\gamma$ system one of the ρ's likes to stay in the beam pipe. A first rough calculation shows that the events can be explained by this process if one chooses 'typical hadronic' values for the cross section of $\rho\rho$ scattering.

ACKNOWLEDGEMENT

I want to thank Prof. Tran Thanh Van for the excellent athmosphere at this Rencontre.

REFERENCES

1) Ch. Berger, H. Genzel, R. Grigull, W. Lackas, F. Raupach and W. Wagner, I. Physikalisches Inst. d. RWTH Aachen, Germany
A. Klovning, E. Lilleställ, E. Lillethun and J. A. Skardt, University of Bergen, Norway
H. Ackermann, G. Alexander, F. Barreiro, J. Bürger, L. Criegee, H. C. Dehne, R. Devenish, G. Flügge, G. Franke, W. Gabriel, Ch. Gerke, G. Horlitz, G. Knies, E. Lehmann, H. D. Mertiens, B. Neumann, K. H. Pape, H. D. Reich, B. Stella, U. Timm, P. Waloschek, G. G. Winter, S. Wolff and W. Zimmermann, DESY, Hamburg
O. Achterberg, V. Blobel, L. Boesten, H. Kapitza, B. Koppitz, W. Lührsen, R. Maschuw, R. van Staa and H. Spitzer
II. Inst. f. Experimentalphysik d. Univ. Hamburg
C. Y. Chang, R.G. Glasser, R. G. Kellog, K. H. Lau, B. Sechi-Zorn, A. Skuja, G. Welch and G. T. Zorn,
University of Maryland
A. Bäcker, S. Brandt, K. Derikum C. Grupen, H. J. Meyer, M. Rost and G. Zech
Gesamthochschule Siegen
T. Azemoon, H. J. Daum, H. Meyer, O. Meyer, M. Rössler, D. Schmidt and K. Wacker
Gesamthochschule Wuppertal
PLUTO Collaboration
Physics Letters 81B, 410 (1979)

2) S.D. Drell, Ann. Phys. (New York) 4, 75 (1958)

3) M. Greco, Y. Srivastava, Nuovo Cimento 43A, 88 (1978)

4) S. J. Brodsky, SLAC Pub. 2240 (1978)

5) J. Smith, private communication, to be published