ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

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MEASUREMENT OF THE TOTAL CROSS SECTION OF TWO PHOTON PRODUCTION OF HADRONS *

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A b s t r a c t

The total cross section of the two photon production of hadrons has been measured with the MD-1 detector at the VEPP-4 collider in the $\gamma\gamma$ mass range 0.5 - 4.3 GeV/c^2. At masses greater than 1.5 GeV/c^2 experimental data are consistent with $\sigma_{\gamma\gamma}(W)$ = const.

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The production of hadrons through the interaction of two photons has attracted much attention recently. No convincing theoretical description of these processes exists at the present time /1,2/. This makes experimental studies of $\gamma\gamma$ interactions at e^+e^- colliders especially interesting. It is well known that these reactions have sharp small angle peaks in the angular distributions making their exclusive observation rather complicated. An obvious remedy is detection of scattered electrons or tagging. In existing systems they can usually be detected from the angles $\gtrsim$10 mrad resulting in a very small detection efficiency, especially for small momentum transfers of virtual photons.

The magnetic field of the MD-1 detector is perpendicular to the orbit plane allowing detection of scattered electrons coming from the interaction region at a zero angle. This makes possible a tagging of virtual photons practically with a zero momentum transfer.

The lay-out of the interaction region with the MD-1 and the tagging system for scattered electrons is shown in Fig. 1. Electrons with a zero angle are detected in the energy range $0.50 < E/E_0 < 0.85$ where E_0 is a beam energy. The scattered electron energy is measured by its deviation from the equilibrium orbit, the accuracy being $\sigma_E / E \lesssim 2\%$. The invariant mass of the $\gamma\gamma$ system is reconstructed from the energies of scattered electrons. The $\gamma\gamma$ mass resolution calculated from the Monte Carlo simulation is shown in Fig. 2. More details on the MD-1 detector and the tagging system can be found elsewhere /3,4/.

Experiment was performed from January 1984 to June 1985 in the c.m.energy range 7.6 - 10.6 GeV. An integrated luminosity was 23.5 pb^{-1}, the total number of recorded events was $3.1 \cdot 10^7$. The statistics used in our previouse result /4/ is also contained in this analysis.

To measure the total cross section of two photon production of hadrons double tagged events of the reaction ee → ee + hadr were selected. The main background comes from the process of single bremsstrahlung. To reduce it we required that an angle of each scattered electron with respect to the orbit plane be greater than $5 \cdot 10^{-4}$ radian. This cut reduced the total number of events to $1.1 \cdot 10^{5}$ with the efficiency loss by a factor of ~ 2.5. The detection efficiency ε_T for scattered electrons under these conditions is shown in Fig. 3 as a function of the $\gamma\gamma$ mass.

Further background suppression used the information from the tracking and shower-range chambers in the central part of the detector. More than two particles (including photons) were required of which at least one charged particle came from the interaction region and its momentum was measured. Also imposed were some special requirements of the space configuration of events aimed at the suppression of the background due to cosmic particles, Bhabha scattering and two photon production of electron and muon pairs. 442 events remained after all these cuts. The detection efficiency ε_D in the central part of the detector is also shown in Fig. 3. The remaining background did not exceed 10% and was mainly due to $\gamma\gamma$ production of e^+e^- pairs. Final background suppression was made by visual scan of the remaining events that removed 52 events. The contribution of the accidental coincidences of hadron production in the annihilation channel with single bremsstrahlung was $(5 \pm 3)\%$.

In Fig. 4 we present the energy dependence of the visible cross section. Experimental points follow the expected dependence $\sigma_{vis} \sim \ln^2 E/m_e \cdot \ln E(\mathrm{GeV})$.

Distributions in the charged and neutral multiplicity for the selected events as well as those in the transverse momentum of charged particles and momentum transfer of the virtual photons are shown in Figs. 5-8.

The detection efficiency was calculated from the detailed Monte Carlo simulation of the event kinematics and detector response /5/. The following model has been used to describe a hadronic system. All particles were assumed to be pions, the neutral to charged multiplicity ratio $\langle \pi^0 \rangle / \langle \pi^+ + \pi^- \rangle = 1/2$, the charged multiplicity depended on the $\gamma\gamma$ mass W as $\langle n_{ch} \rangle = 2 + a \ln W$, the matrix element had a factor $\exp(-\sqrt{p_t^2 + m_0^2}/p_0)$ restricting the transverse momentum of each final particle.

The points shown in Figs. 5-8 were obtained from the Monte Carlo with $p_0 = 0.35$ GeV/c, $a = 0.9$ and 1.8 with approximately equal weight. The obtained distributions are in satisfactory agreement with the experiment.

To determine whether the calculated detection efficiency depends on the values of the parameters above, we performed the simulation at the other values of parameters. The χ^2 criterion was used to compare calculated distributions in the multiplicity and transverse momentum with the data. It turned out that the visible cross section had a weak dependence on the parameters of the model, whereas differential distributions soon came in contradiction with the experiment. The a dependence of the visible cross section and χ^2 value is shown in Fig. 9. At a tending to zero χ^2 must quickly grow due to the high multiplicity events. This is tentatively shown with a solid curve. Thus it is natural to assume that the optimal value of a is between 0.9 and 1.8.

No statistically significant (10%) variation of the visible cross section was observed when P_0 changed from 0.35 to 0.17 GeV/c at $a = 1.8$. At the same time the confidence level for differential distributions was less than 10^{-4}. One can therefore conclude that the contribution of the model parameters to the systematic uncertainty of the total cross section does not exceed 6%.

Analysis of the other sources of systematic errors independent of the $\gamma\gamma$ mass gave the following results:

1. Simultaneous detection of two or more particles in one unit of the tagging system - 8%,
2. Monte Carlo statistics - 6%,
3. Luminosity measurement - 5%,
4. Orbit stability - 5%,
5. Accidental coincidences - 3%,
6. Efficiency of the chambers - 2%,
7. Radiative corrections - 2%.

Besides that the uncertainty in the simulation of the nuclear interaction is estimated to be about 10%. Added in quadrature, these errors result in the total systematic uncertainty of 20%.

The total cross section of the reaction $\gamma\gamma \to$ hadr is presented in Fig. 10 together with the data of the other groups /6-8/. By curves 1-3 we show the predictions of refs. 9-11. Experimental dependence of our data on W is consistent with constant ($p(\chi^2) = 30\%$). Its optimal value equals $277 \pm 23 \pm 55$.

In the region of W below 1.5 GeV/c^2 a considerable contribution to the total cross section comes from the resonances. By open circles we show the total cross section after the subtraction of the η' -meson giving the main contribution /13/.

To compare experimental results with theoretical expectations and data of the other groups only the points corresponding to $W \geq 1.5$ GeV/c^2 were used. Using the approximation $\sigma = A + B/W$ we obtain the following values of the parameters: $A = 310 \pm 110$, $B = -90 \pm 240$ ($p(\chi^2) = 26\%$). Results of the optimal fit of experimental data as well as theoretical expectations reviewed in Ref. 14 are presented in Table and Fig. 11.

A	B	(Theory) References
240	270	J.Rosner, 1972 /9/
255-300	315±55	I.Ginzburg, V.G.Serbo, 1982 /10/
253	695	G.Alexander et al., 1983 /11/
295	477	E.Gotsman, U.Maor, 1983 /12/
A	**B(Experiment)**	**References, mode, W-region (GeV/c^2)**
107±40	933±112	PLITO, 1984 /6/, Single tag, 1.7-9
360±60	10±290	PER, 1985 /7/, Double tag, 2.5-17.5
*260±80	40±320	PLUTO, 1986 /8/, No tag 2.5-9
**310±110	-90±240	this experiment, Double tag, 1.5-4.3, $Q^2 \approx 0$
320±40	-40±150	average of PEP, PLUTO 86 and MD-1

The results of PEP, PLUTO 86 and MD-1 agree with each other. The average values for these three results are shown in the Table and in Fig. 11.

In conclusion the authors express their sincere gratitude to the staff of VEPP-4 and MD-1 for help during data taking and to I.F.Ginzburg and V.G.Serbo for helpful discussions.

* Our fit of the PLUTO data.
**Preliminary, analysis continued.

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FIGURE CAPTIONS

Fig. 1. MD-1 detector. Section by the orbit plane. 1-vacuum chamber; 2 - coordinate chambers; 3 - scintillation counters; 4-c-counters; 5 - shower-range chambers; 6 - magnet winding; 7 - iron yoke; 8 - muon chambers; 9 - bending magnet; 10 - system of the scattered electron detection; 11 - luminocity monitor; 12 - lense; 13 - SR-receiver; 14 - ionization chamber for orbit stabilization; 15 - γ -quanta detector.

Fig. 2. Dependence of the resolution in the invariant mass (σ_W) on the mass value (W) obtained from Monte Carlo simulation. The solid curve is the result of the approximation by a smooth function.

Fig. 3. Mass dependence of the detection efficiencies. ε_T is the detection efficiency for both scattered electrons, ε_D is the detection efficiency for the central part of the detector the curves are the result of the approximation by a smooth function.

Fig. 4. Energy dependence of the visible cross section (points - experiment, the curve $\sigma_{vis} \sim \ln^2 E/m_e \cdot \ln E\ (GeV)$.

Fig. 5. Distribution in the multiplicity of charged particles.

Fig. 6. Distribution in the multiplicity of photons.

Fig. 7. Distribution in the transverse momentum.

Fig. 8. Distribution in the momentum transfer of virtual photons.

Fig. 9. Visible cross section and χ^2 versus the model parameter a .

Fig.10. Total cross section of the reaction $\gamma\gamma \rightarrow$ hadr: PLUTO 84/6/, PLUTO 86/8/, PEP 84/7/; Rosner 72/9/, Ginzburg, Serbo 82/10/, Alexander 83/11/.

Fig.11. Theoretical and experimental values of the constants A and B: R/9/, GS/10/, AMM/11/, GM/12/.

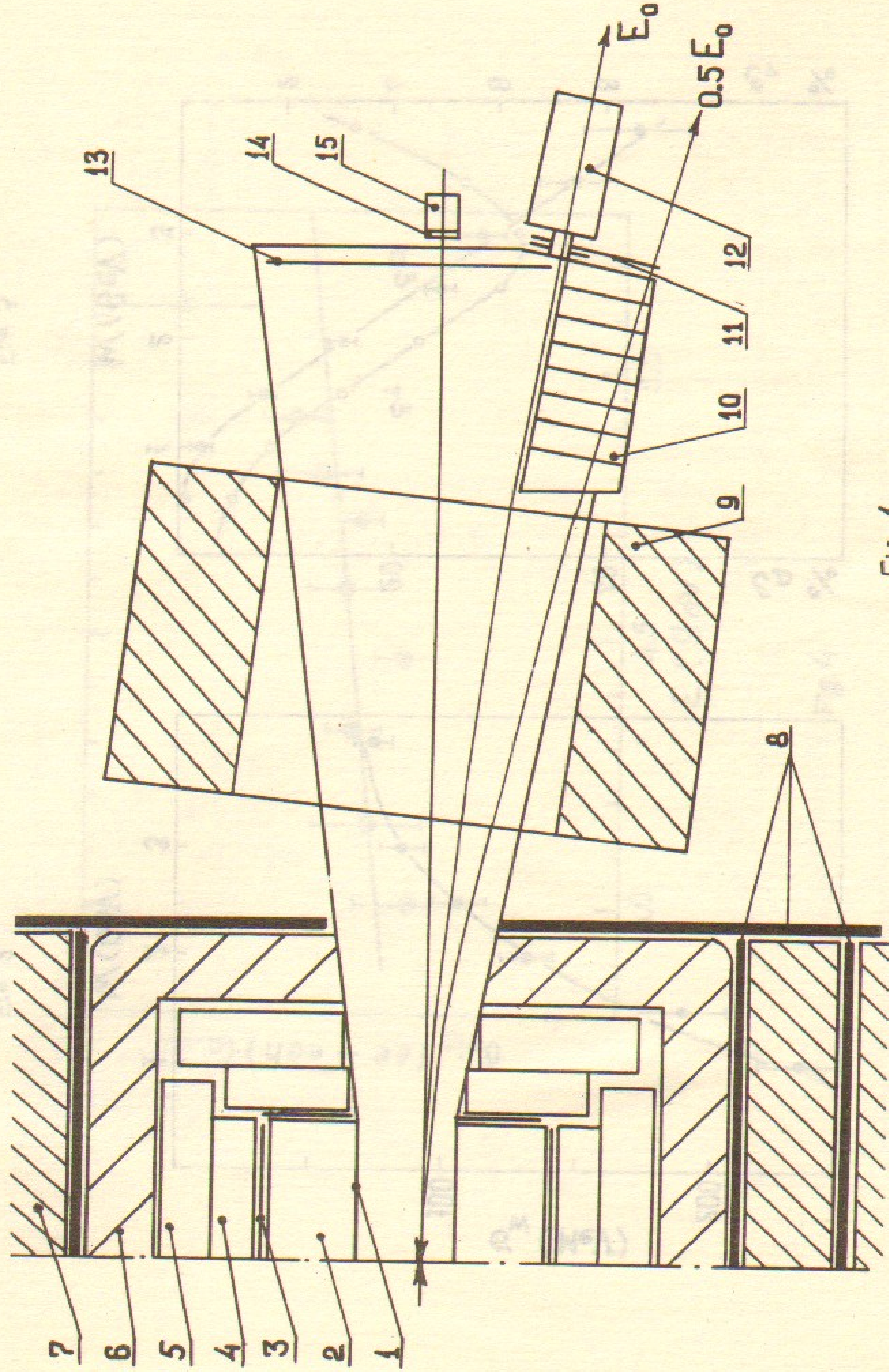


Fig. 1

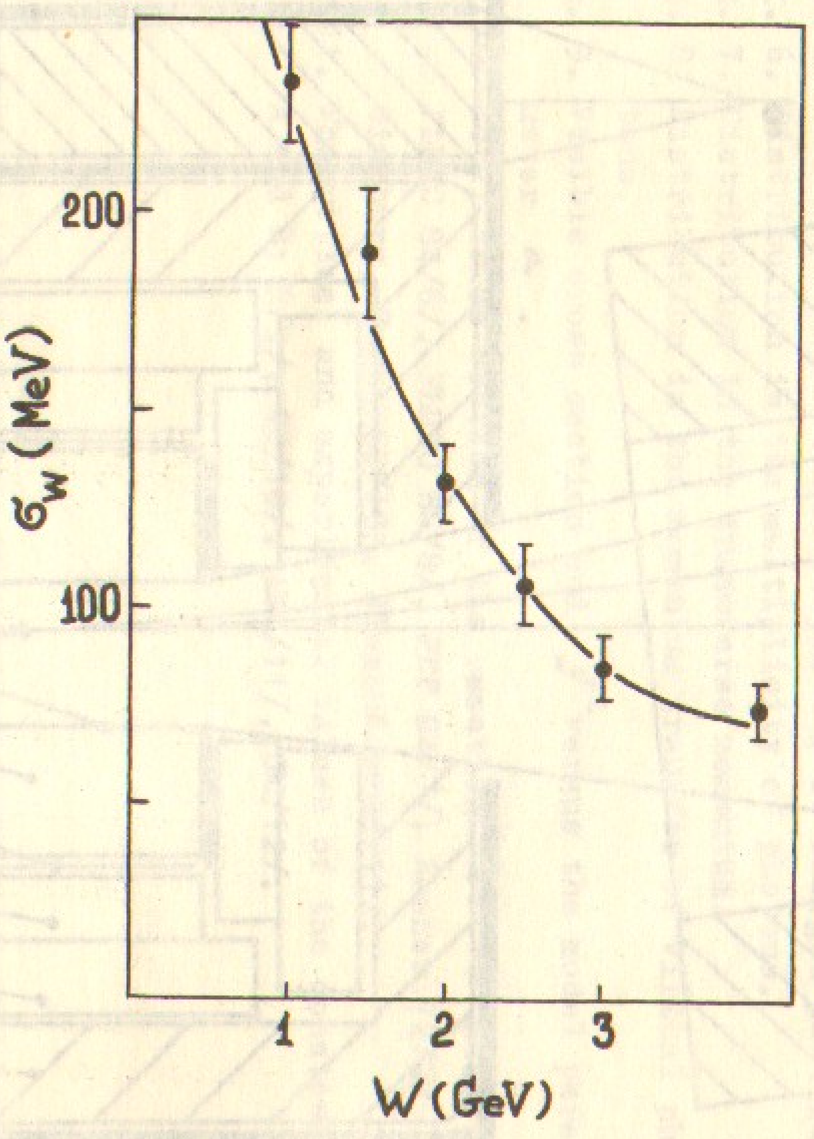


Fig. 2

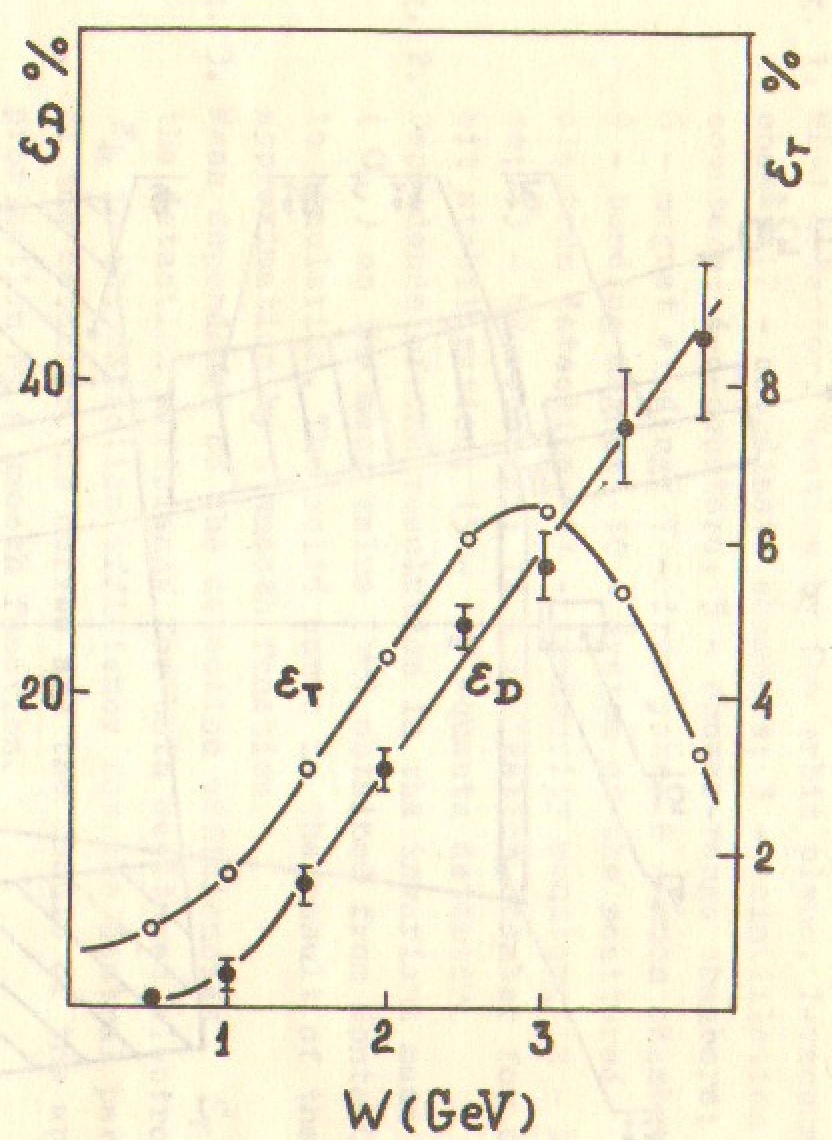


Fig. 3

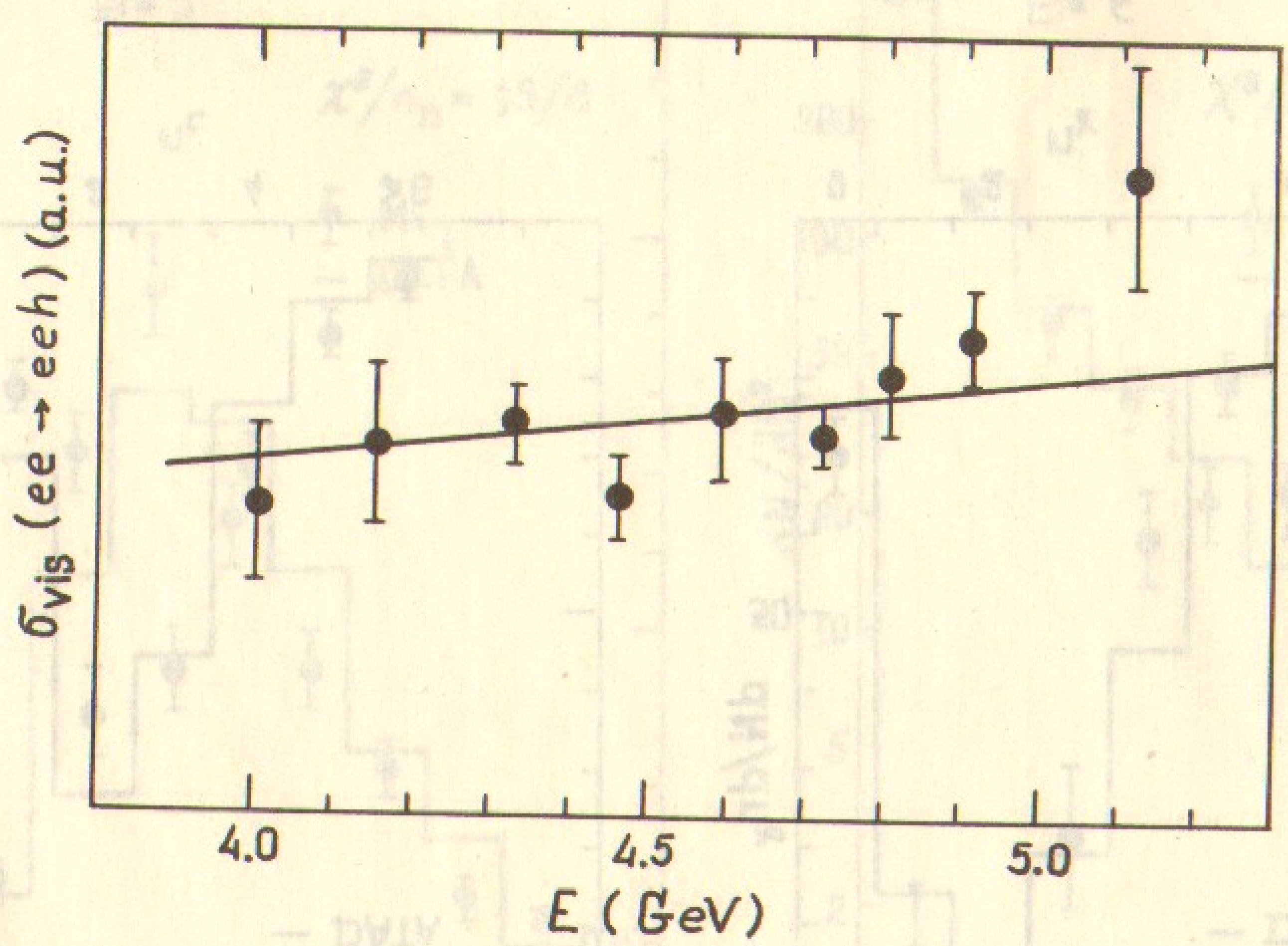


Fig. 4

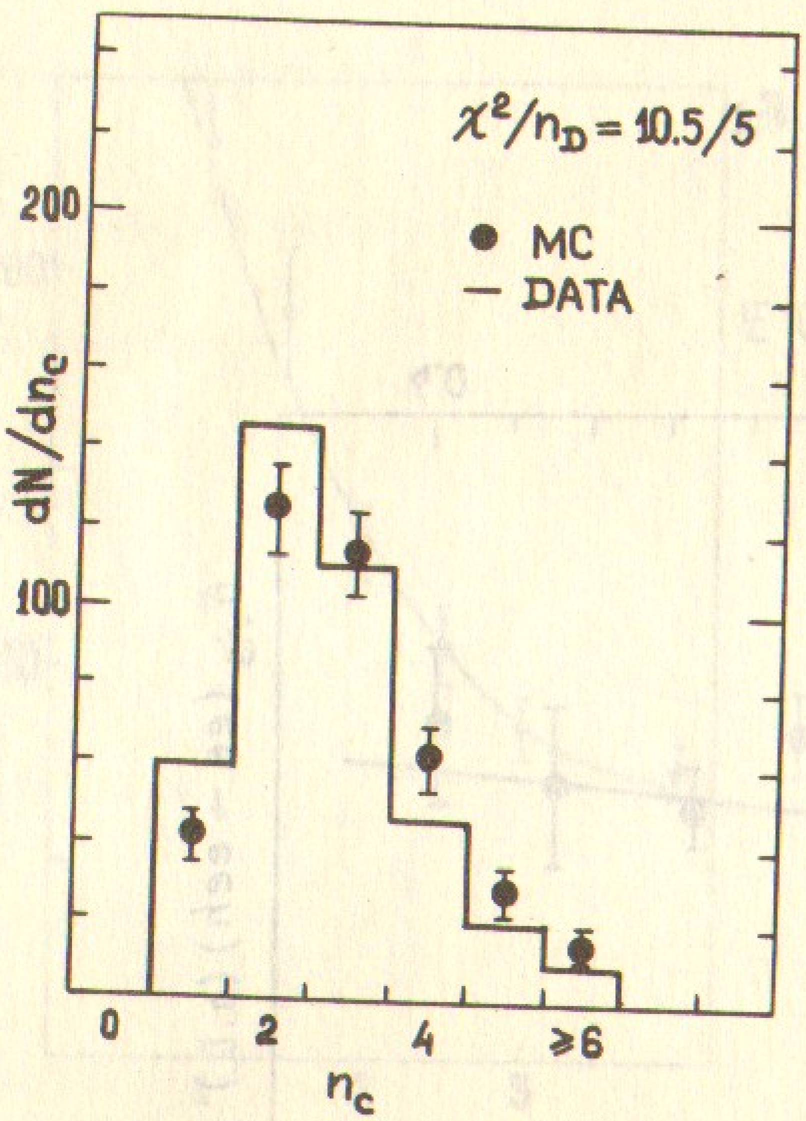
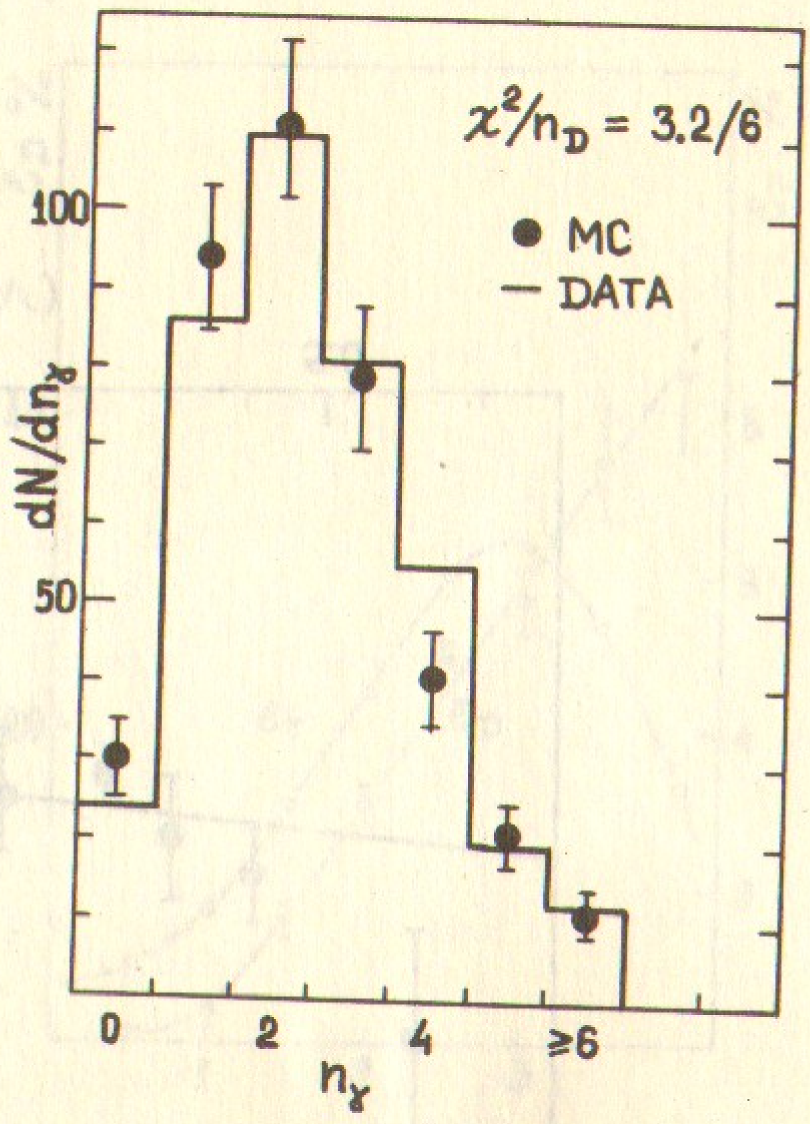


Fig. 5



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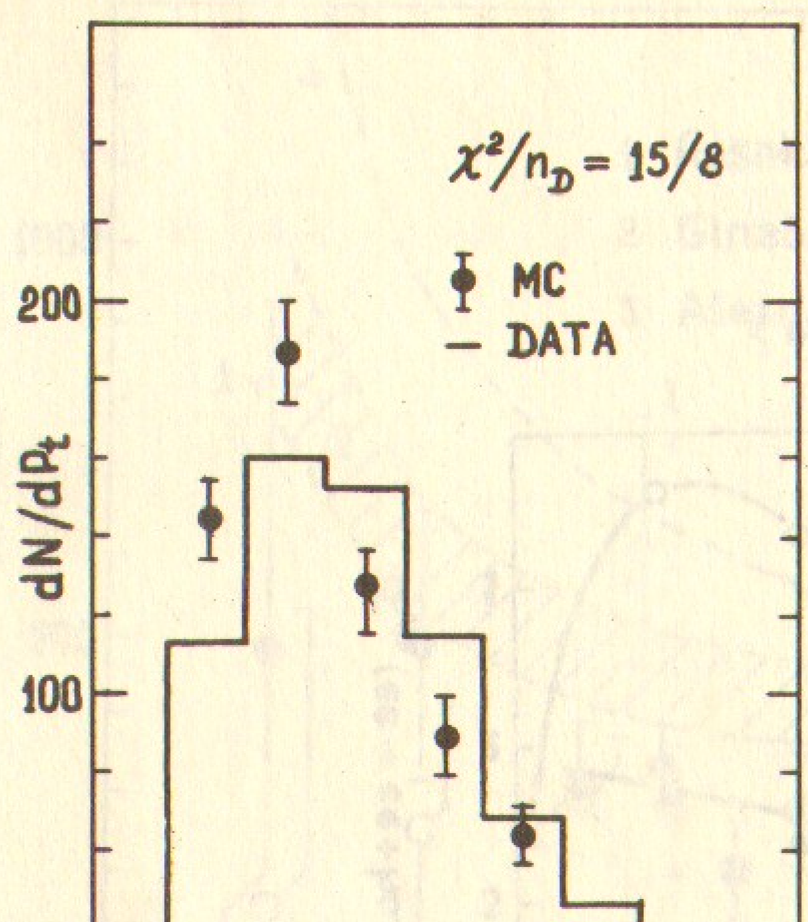


Fig. 7

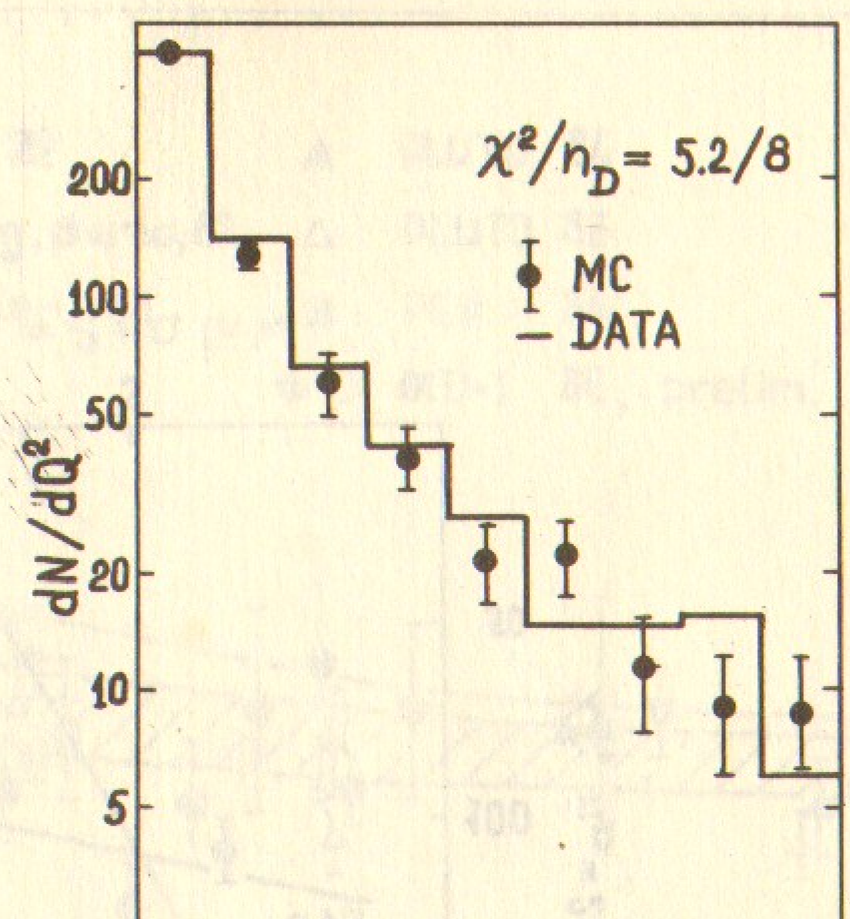
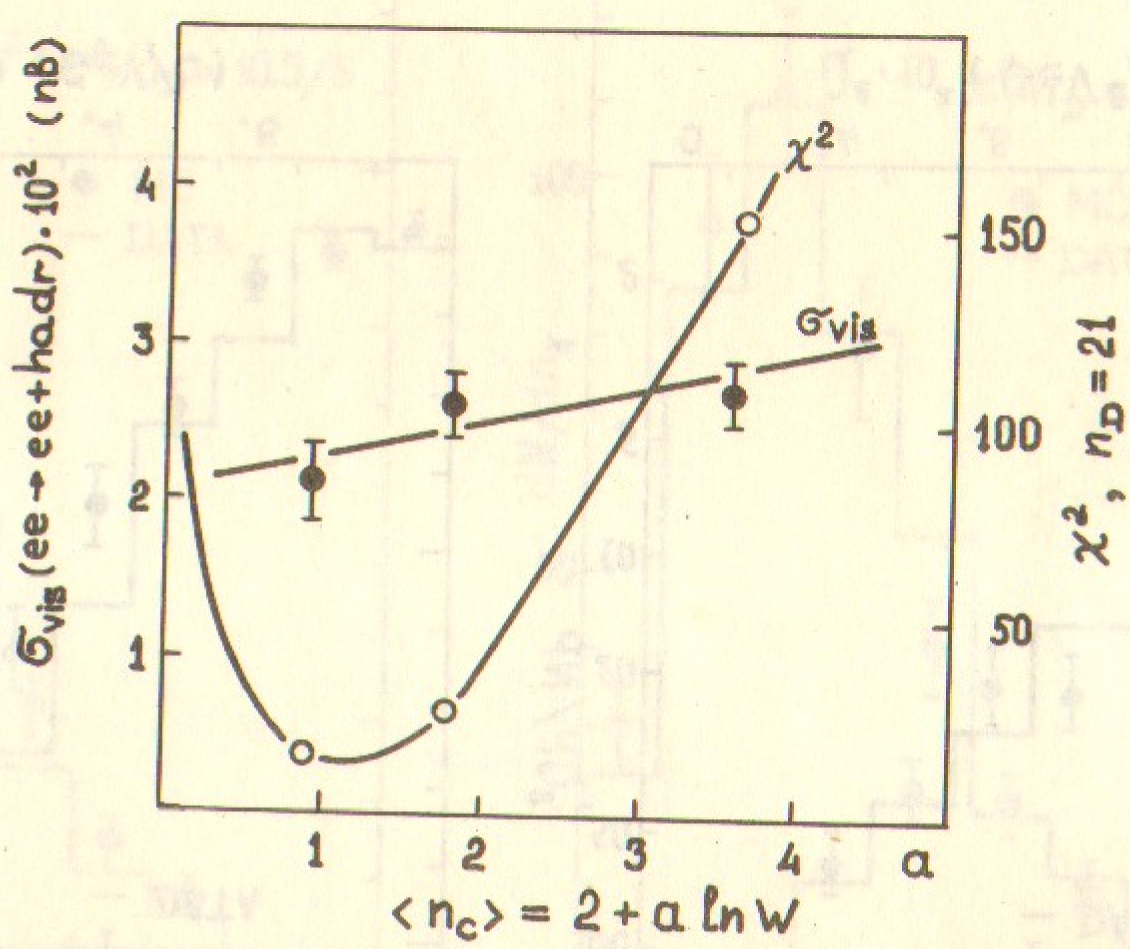
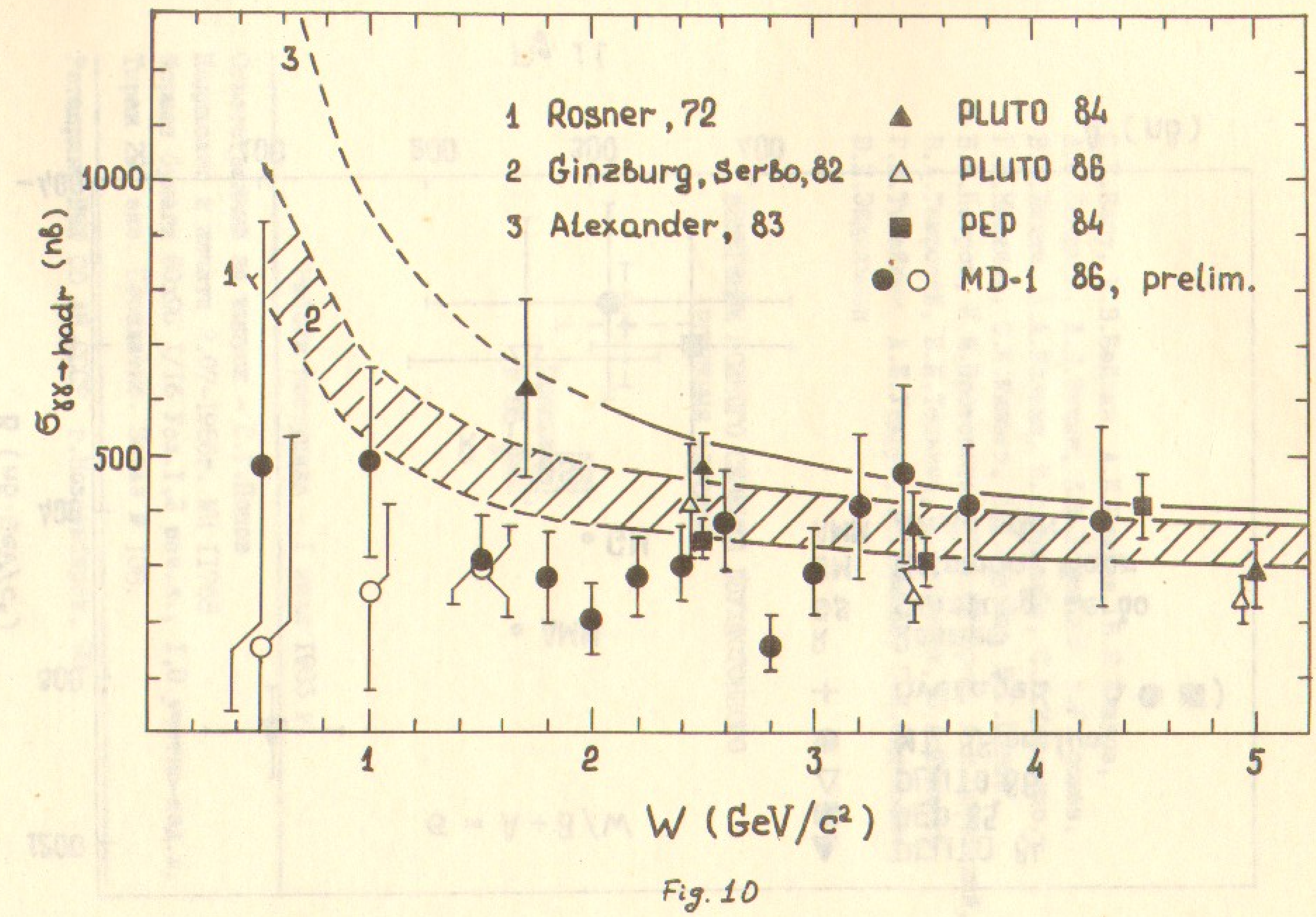


Fig. 8



$\sigma_{vis}(ee \to ee + hadr) \cdot 10^2$ (nb)
χ^2, $n_D = 21$
χ^2
σ_{vis}
a
$\langle n_c \rangle = 2 + a \ln W$

Fig. 9



$\sigma_{\gamma\gamma \to hadr}$ (nb)
1 Rosner, 72
2 Ginzburg, Serbo, 82
3 Alexander, 83
PLUTO 84
PLUTO 86
PEP 84
MD-1 86, prelim.
W (GeV/c²)

Fig. 10

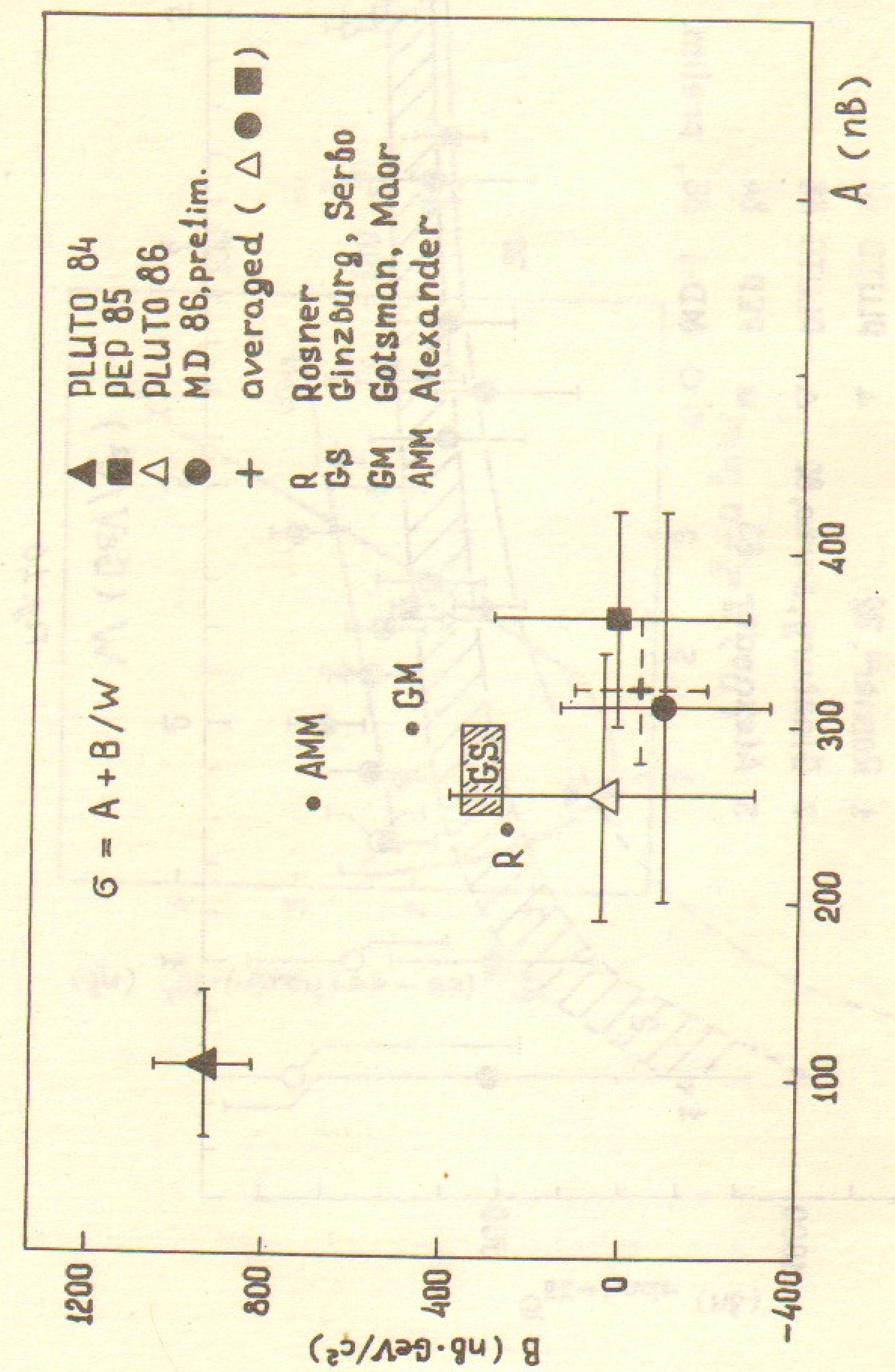


Fig. 11

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ИЗМЕРЕНИЕ ПОЛНОГО СЕЧЕНИЯ ДВУХФОТОННОГО РОЖДЕНИЯ АДРОНОВ

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