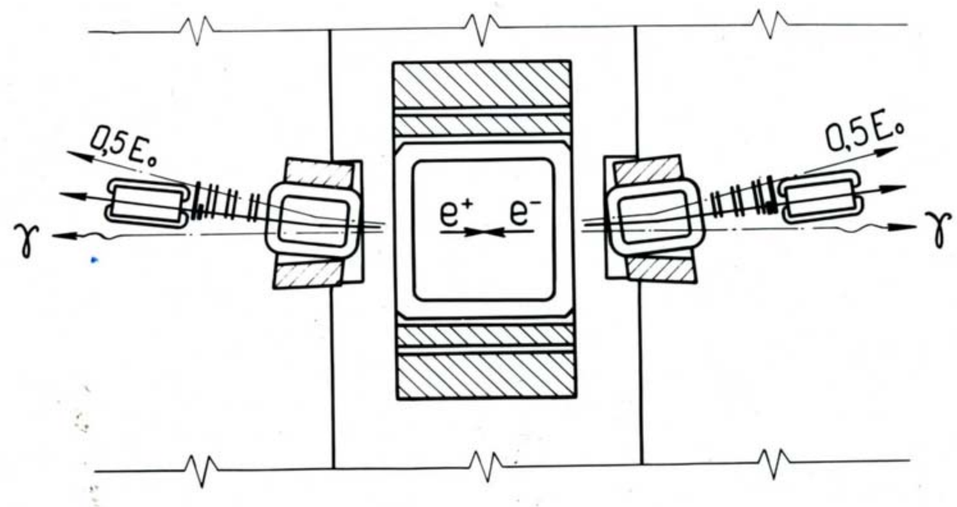

Two-photon experiments with detector MD1 at VEPP-4

Valery Telnov

Budker INP and Novosibirsk St. Univ.

PHOTON 2015, June 16, 2015

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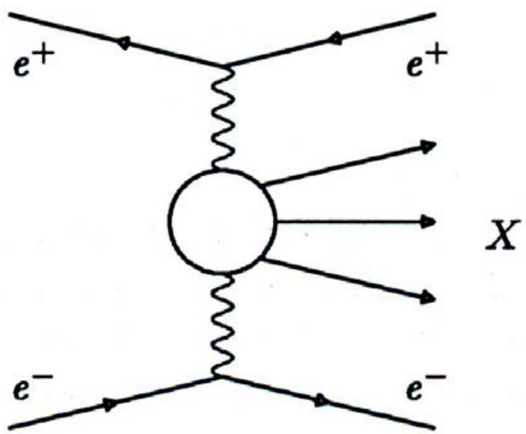
- View on future of e+e- physics in 1970
- A concept of an experiment for study of two-photon physics
- Detector MD-1 with a scattered electron tagging system
- Results on two-photon physics:

  $\gamma\gamma \to$ hadrons (double tag)

  $\gamma\gamma \to e^+e^-, \mu^+\mu^-, \pi^+\pi^-, \eta, \eta', a_2, f_2$
- Conclusion

View on future of e+e- physics in 1970

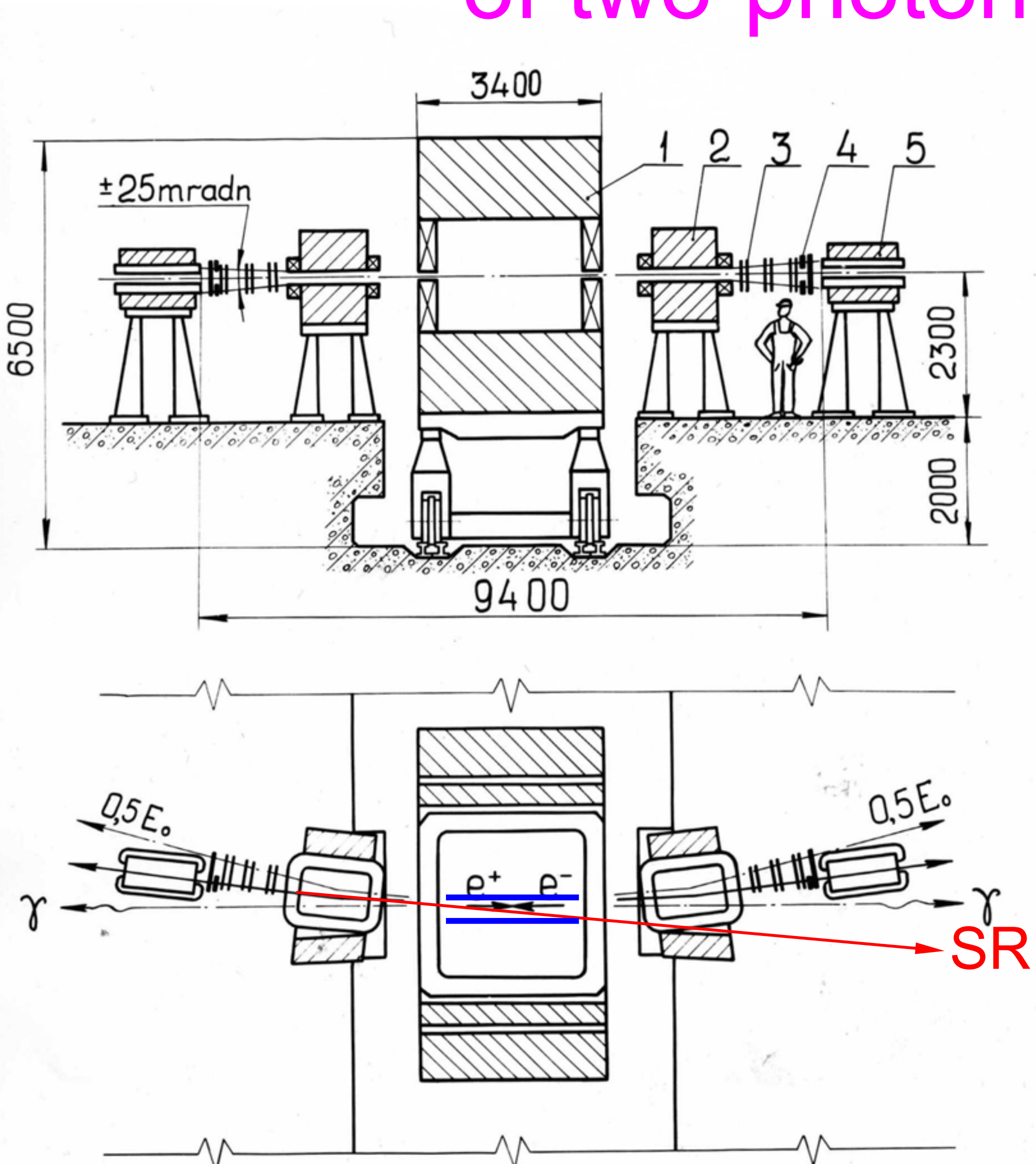
In 1967-1970 experiments at VEPP-2 in Novosibirsk with the energy up to 2E=1.3 GeV have been performed. One of important results was observation of e+e- pairs in collisions of virtual photons. It was understood that such two-photon particle production (e+e- → e+e- X) will dominate at higher energies as soon as their cross sections increase while those of annihilation processes (e+e-→X) steeply decrease due to particle form factors (quarks were not discovered yet).



Due to this physics picture it was decided in our institute in 1972 to build a special detector (leader Alexei Onuchin) for studying two-photon physics. Initially, this detector was planned to work at VEPP-3 with 2E=4 GeV (was built in 1972 and equipped with another detector without magnetic field).

In 1974 SLAC (and BNL) have discovered J/Ψ, D-mesons, in 1975 τ-lepton, this was the revolution in particle physics. The VEPP-3 has lost a chance to make these discoveries (due to the absence of good positron injector). In this situation it was decided to speed up works on VEPP-4 (2E=12 GeV), and to move there the MD-1 experiment.

A concept of the experiment for study of two-photon physics



It should be universal detector with special features for detection of two-photon processes:

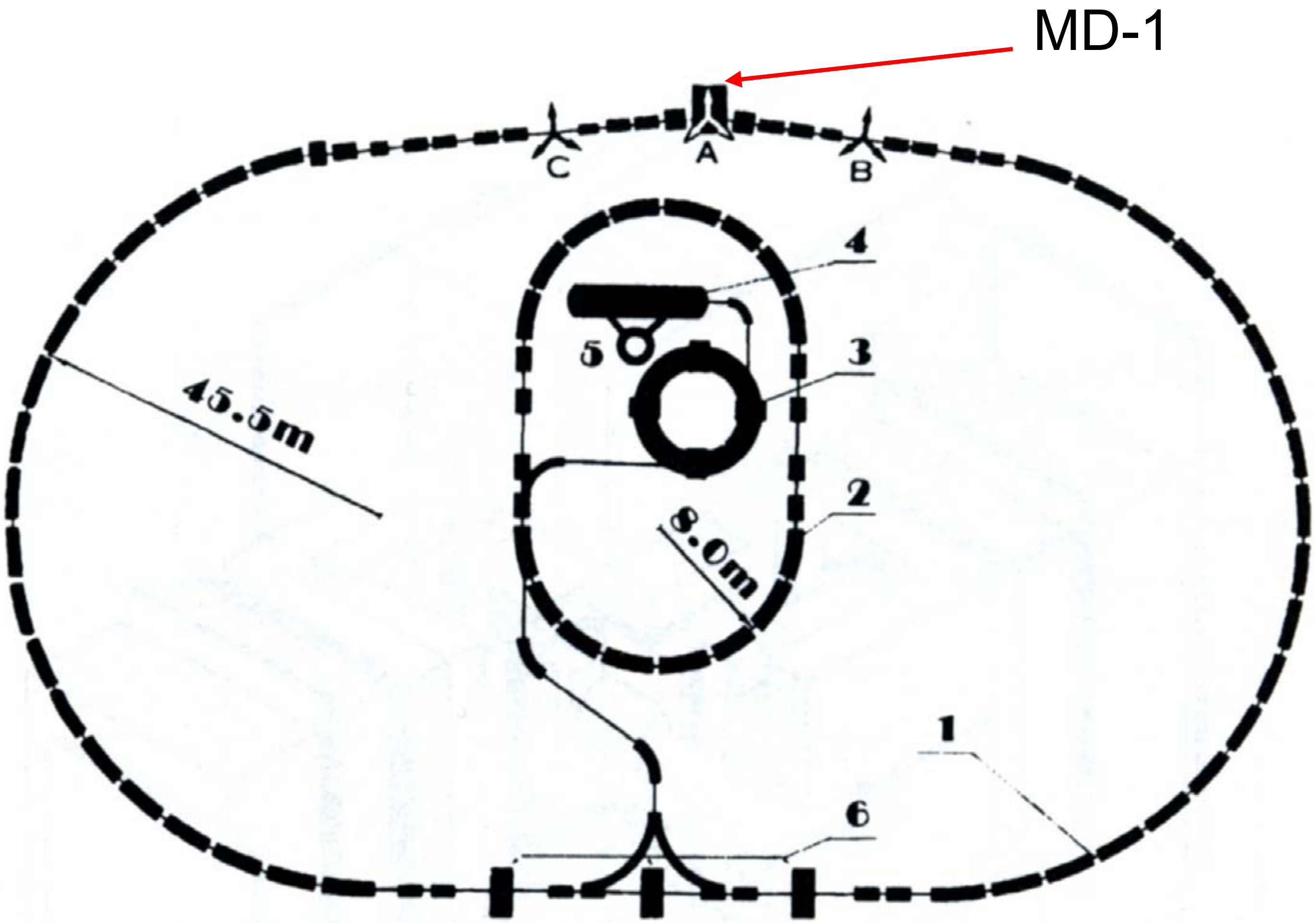
a) Detection of scattered electrons by sweeping them from the beam pipe by a transverse magnetic field (as soon as $E<E_0$).

b) Transverse magnetic field in the central detector in order to increase the detection efficiency for produced charged particles which travel mostly in forward direction due to unequal virtual photon energies).

c) two additional bending magnets from both sides of main detector for better detection of scattered electrons

One problem: Synchrotron radiation (SR) from "additional" magnet, which caused the increase of vacuum pipe diameter to 40 cm – worsening of detector performance!

VEPP-4+MD-1

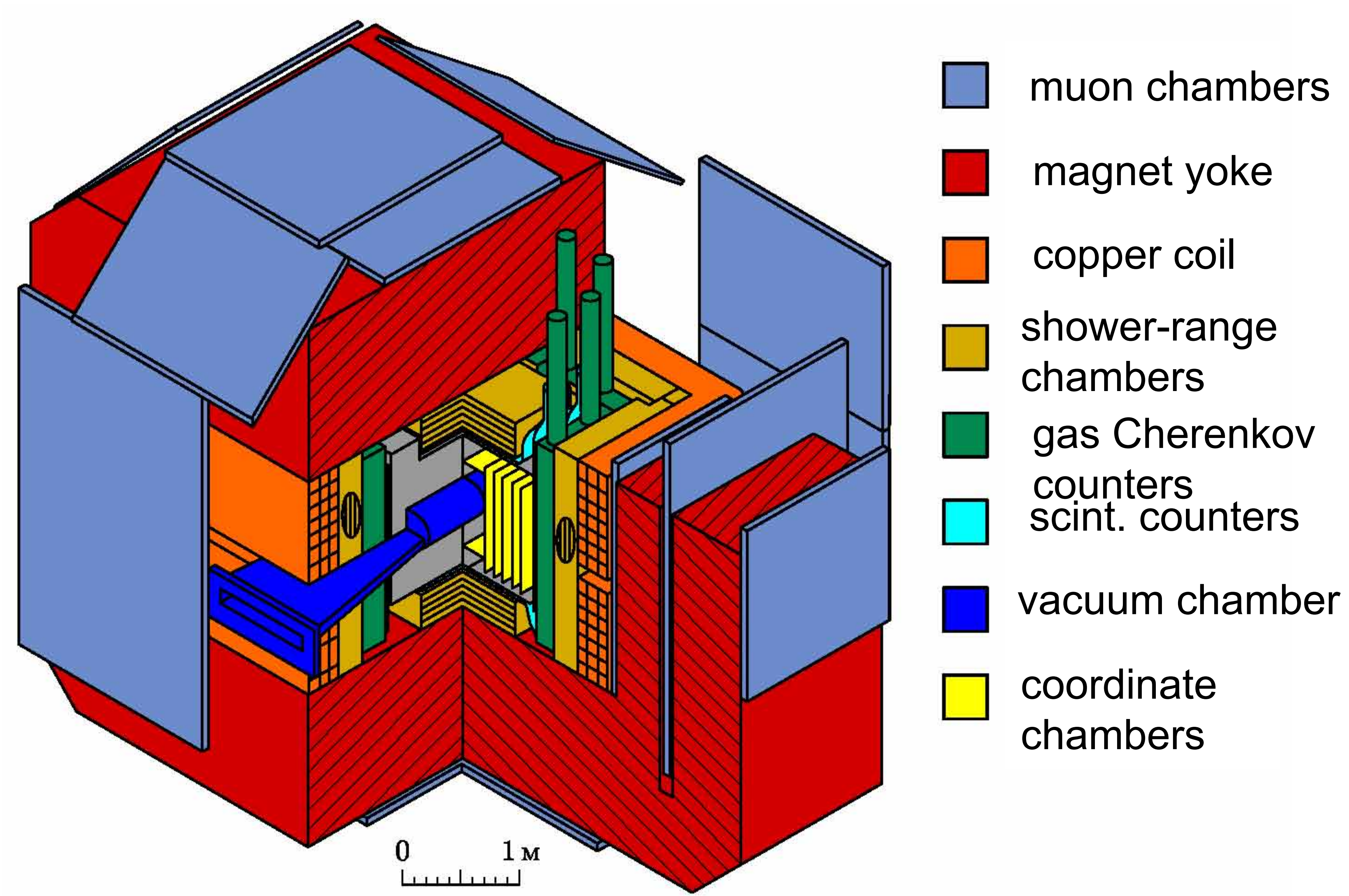


Operated in 1981-1985 (stopped by fire)

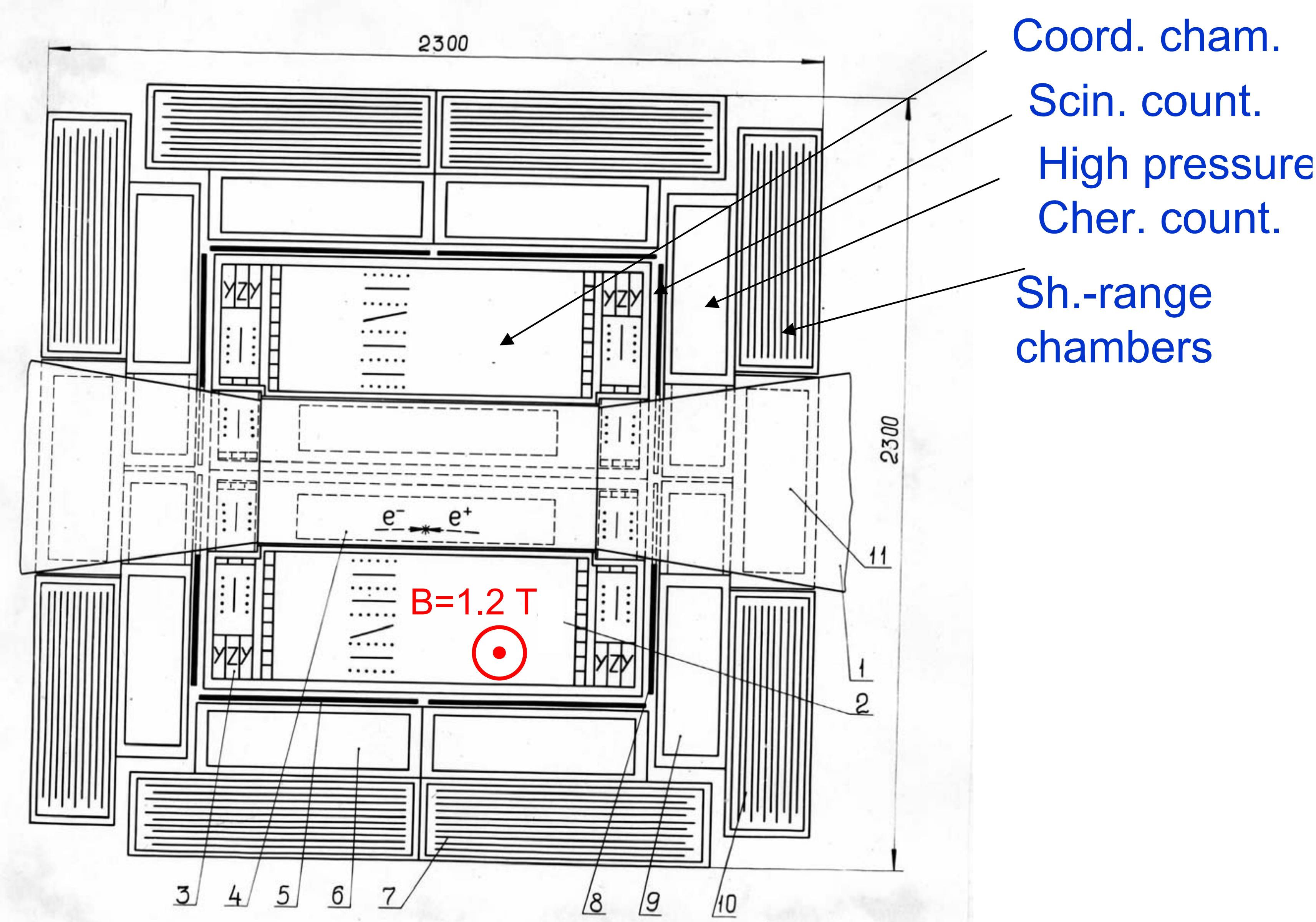
2E=3-10.5 GeV, L(Υ(1S))~$3 \cdot 10^{30}$ cm^{-2}s^{-1}, $\int L dt \approx 30\ \mathrm{pb}^{-1}$

(L one order lower than at DORIS or CESR)

The detector MD-1, main componets



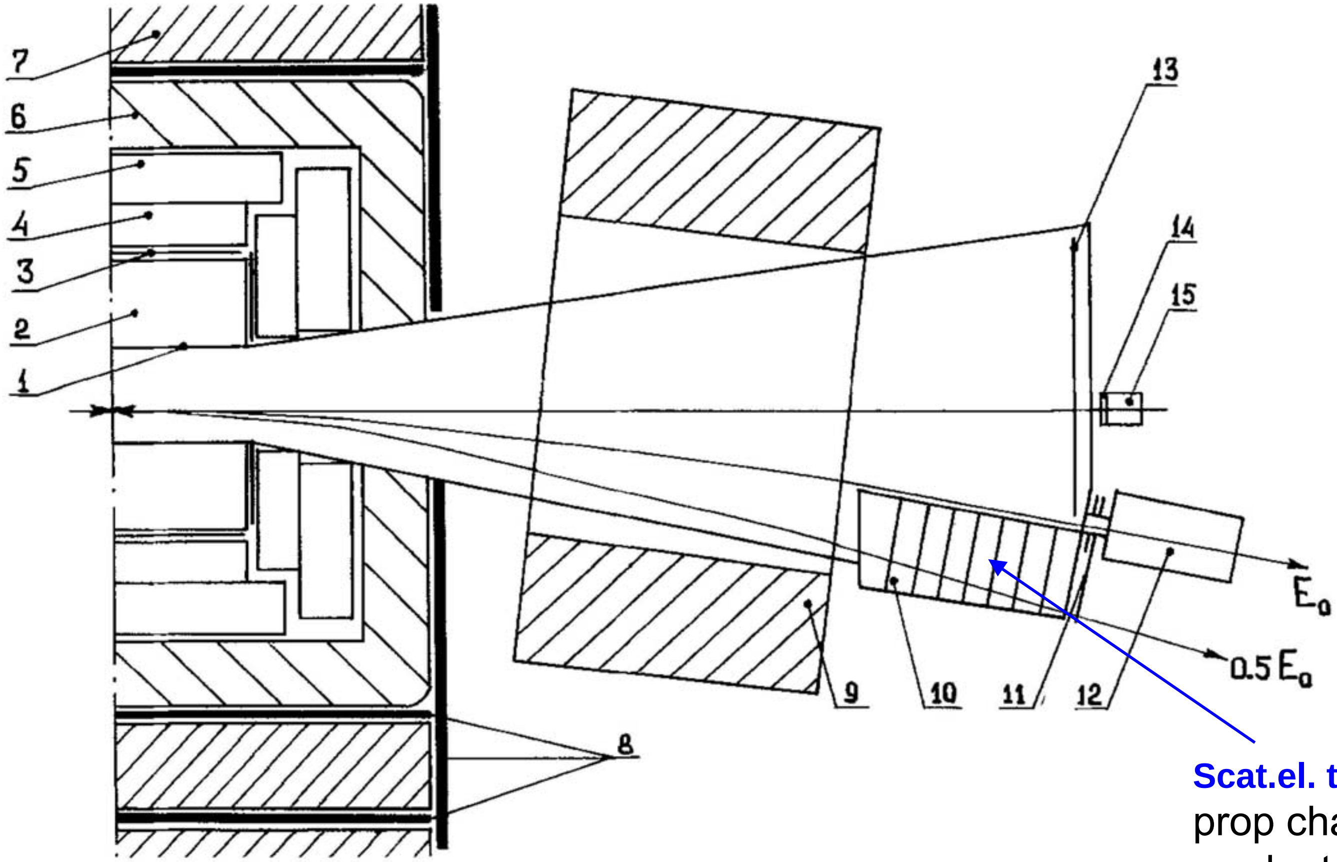
Detector MD-1



Very advanced for that time detector, based on proportional chambers, 20000 readout channels, 0.5 millions of wires!

Scattered electron tagging system (TS)

(from both sides of the main detector)



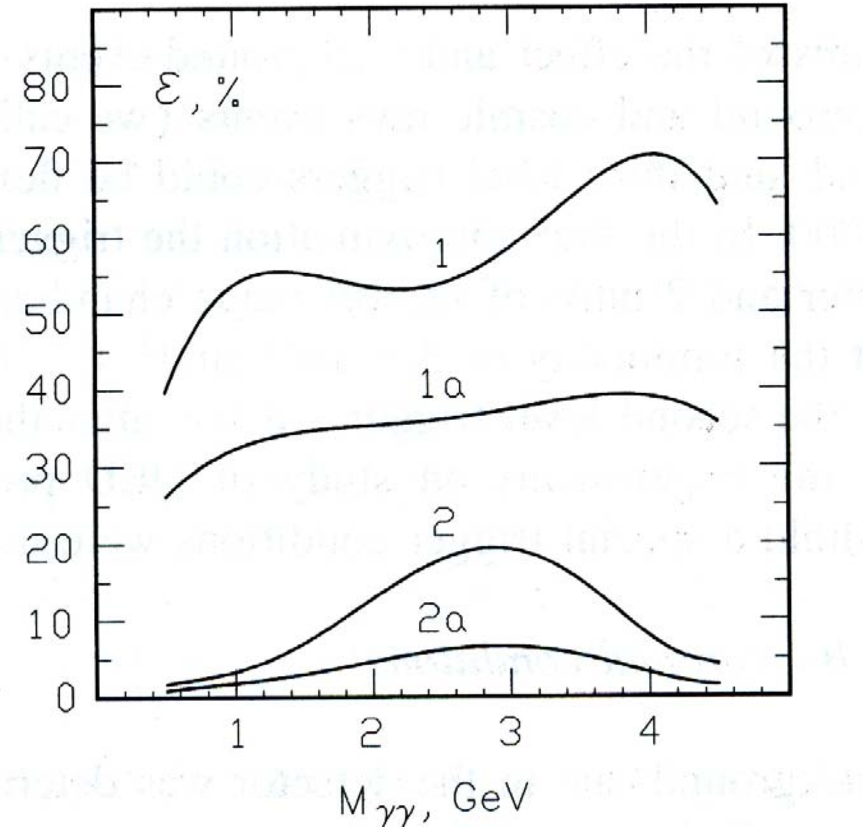
Scat.el. tagging system (TS):
prop chamber with cathode readout, cable delay lines

Acceptance: $0.5 < E/E_0 < 0.85$ (for θ=0)

$\vartheta = 12 \div 100\,\mathrm{mrad}$ (for $E \sim E_0$)

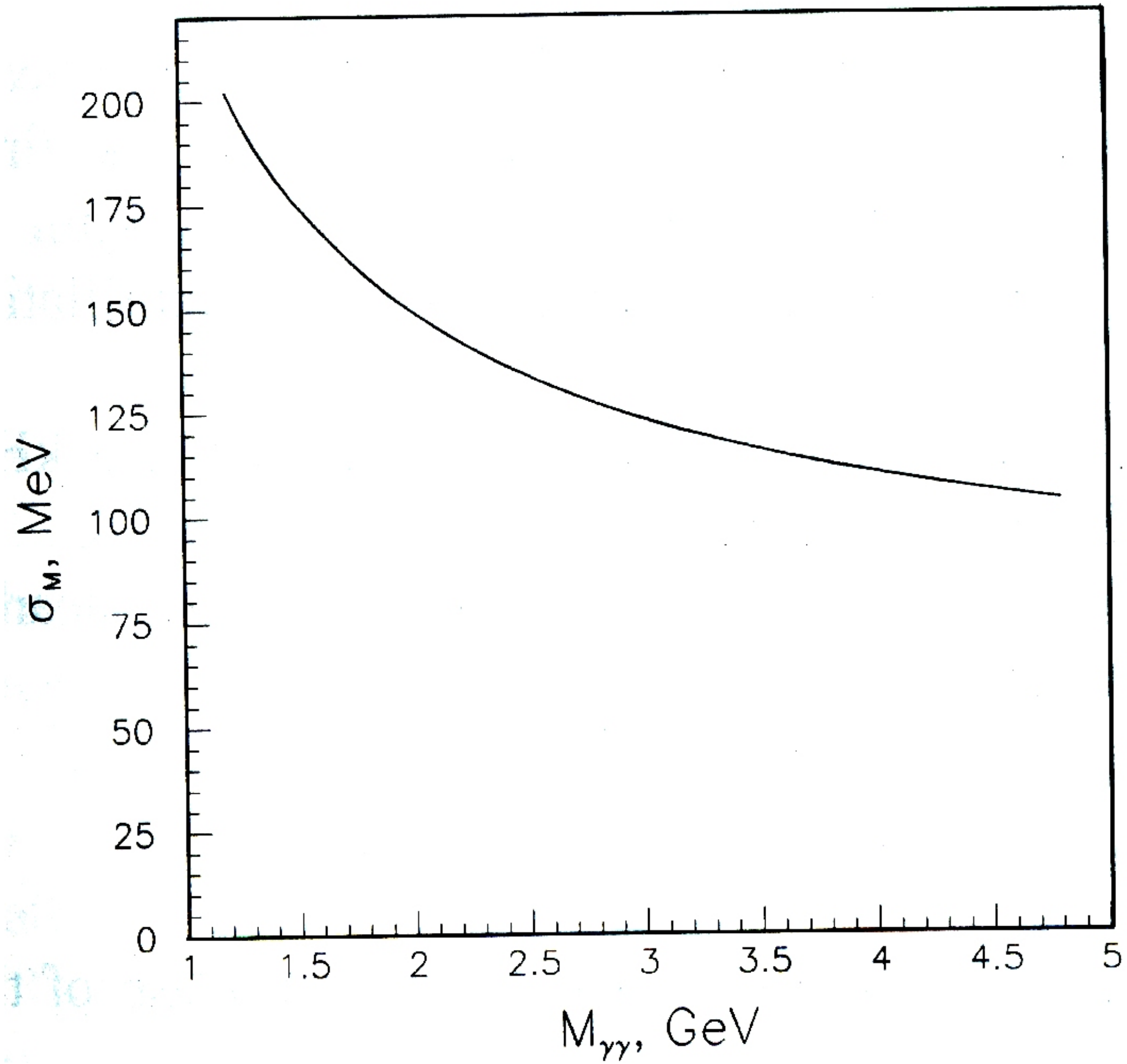
Energy resolution: $\sigma_E/E = 1.7\%$

Efficiency of the scattered electron tagging system for detection at least 1 s.e. or both 2 s.e.



index "a" for emission angle of scatted electrons θ_z>0.5 mrad (necessary for suppression of single breamsstraglung electrons. In MD-1 this was done using coincidence with two sc. counter (behind the tagging system) separated vertically. For separation of two-gamma scattered electrons from beamsstrahlung electrons we also detected bremsstrahlung photons at θ=0.

Accuracy of determination of the two-photon invariant mass W using energies of two scattered electrons



$$\sigma_{W_{\gamma\gamma}} \sim 200-110 \text{ MeV}$$

$$\text{for } W_{\gamma\gamma} = 1-4 \text{ GeV}$$

Measurement of even one scattered electron (s) energy gives useful constraint for reconstruction of events.

For example:

1) in the process e+e-→e+e-η with η→γγ one can determine $W_{\gamma\gamma}$ using only photons angles and the energy of one scattered electron:

$$M_{\gamma\gamma}^2 = 4(E_0 - E_i)^2 \,\mathrm{tg}\frac{\vartheta_1}{2}\,\mathrm{tg}\frac{\vartheta_2}{2}$$

The mass resolution for η meson using this method was $\sigma_M(\eta) \approx 60$ MeV 3 times better than using information from our calorimeter.

2) in the process e+e-→e+e-η' with η'→$\pi^+\pi^-\gamma$ one can reconstruct photon energy from requirement of zero transverse momentum of η' $E_\gamma \approx P_\perp^{\pi\pi}/\sin\vartheta_\gamma$

information on the scattered electron energy gave additional noticeable improvement.
b

Two-photon results

Measurement of the total $\gamma\gamma$ cross section

(2E=7.7-9.7 GeV, 19.7 pb-1)

In order to select multihadronic events we required ≥3 particles in the central detector and both scattered electrons, 448 events were selected:

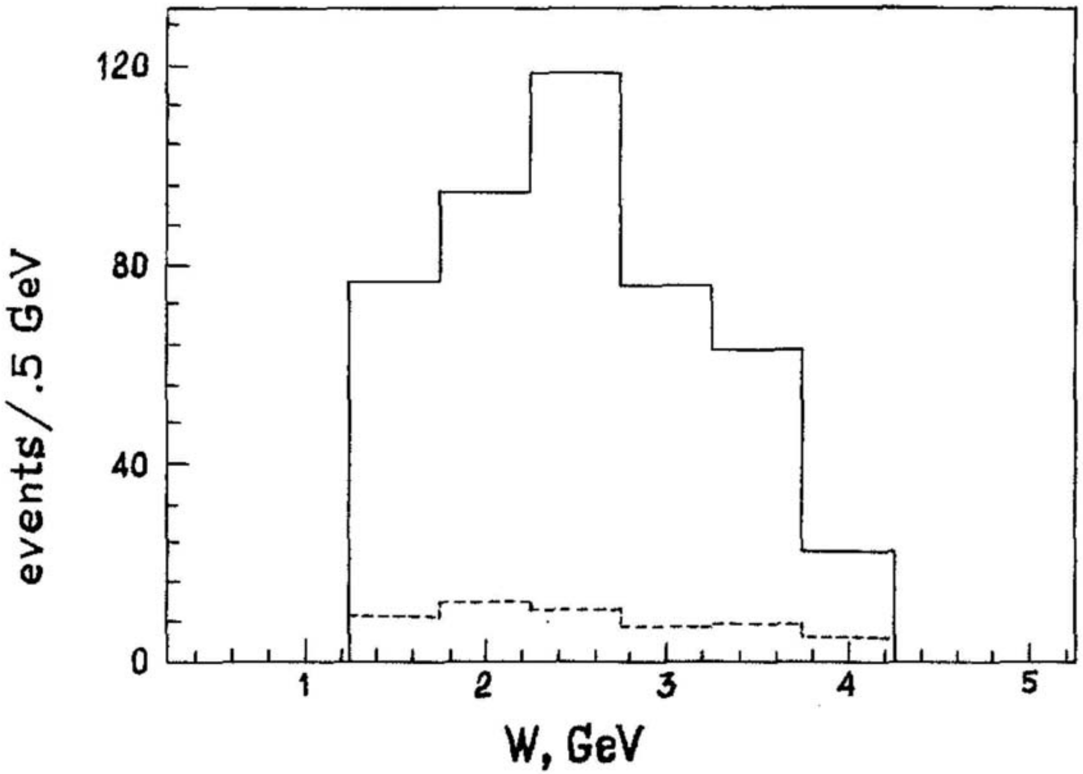


Fig. 5. Distribution of the selected events over invariant mass. Solid histogram – all selected events, dashed – background

M-C generator parameters were adjusted to get best coincidence of all distributions with the experiment

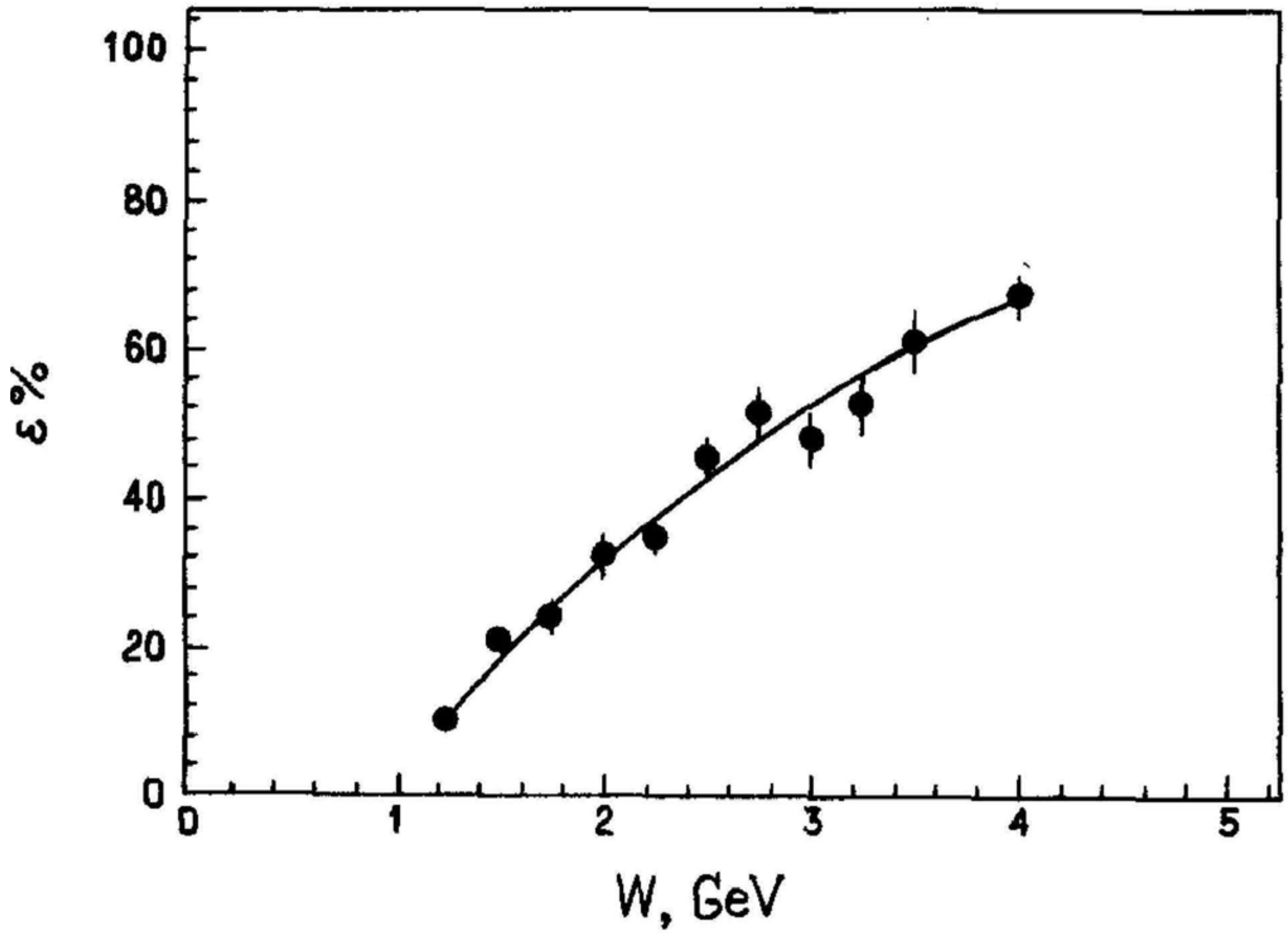


Fig. 4. Detection efficiency in the central part of the detector versus invariant mass. Points – MC simulation, line – quadratic fit

Result: $\gamma\gamma$ cross-section

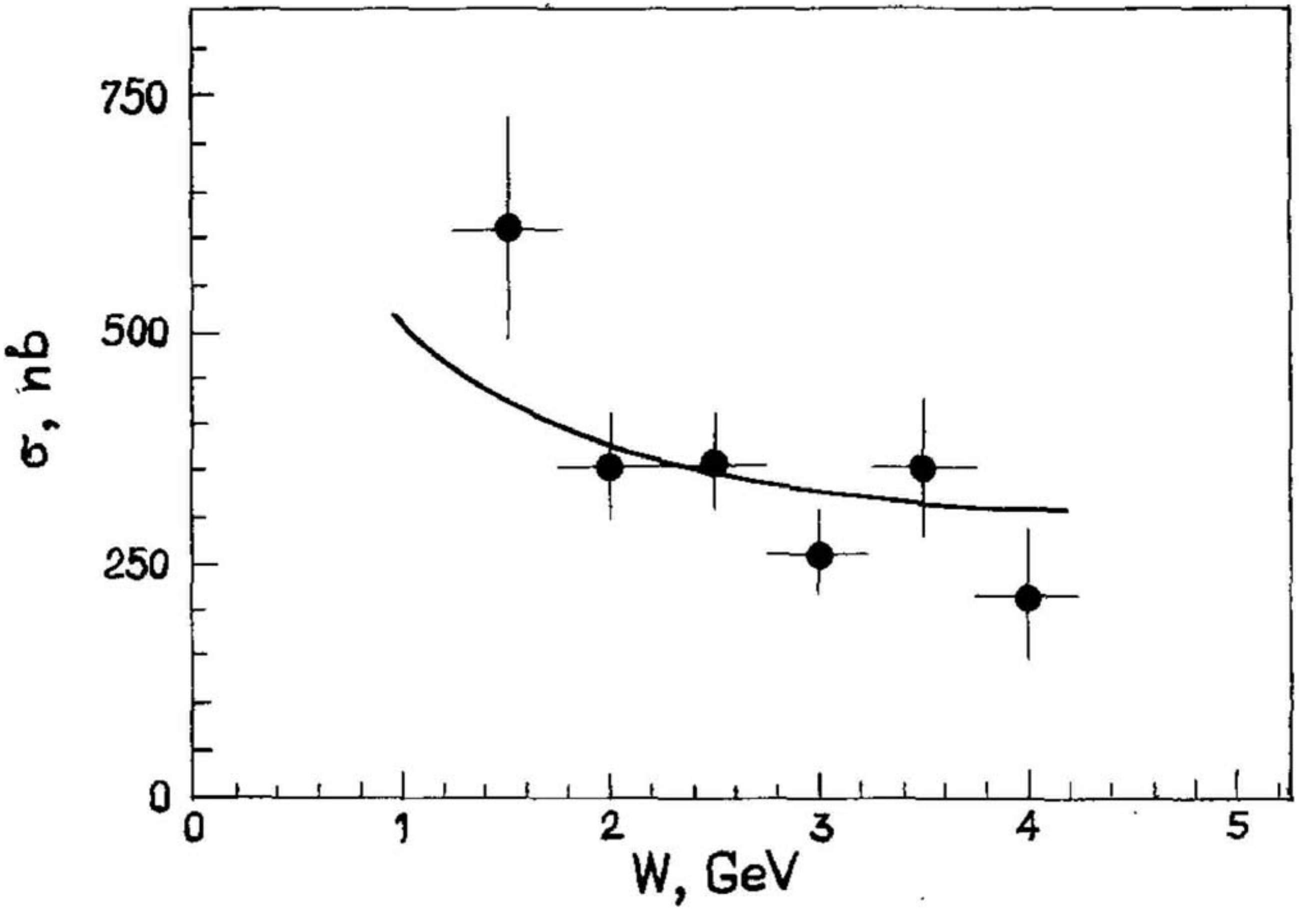
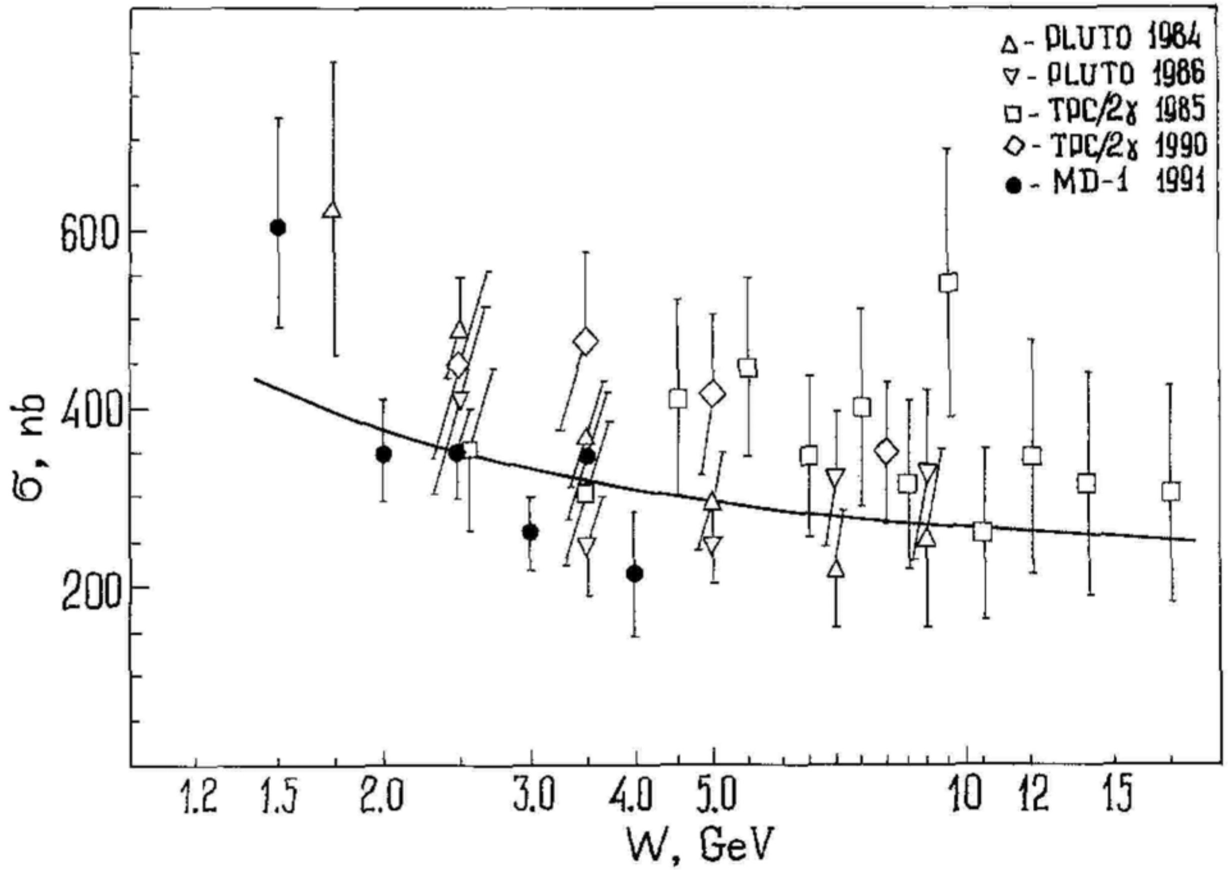


Fig. 7. Total cross section of the reaction $\gamma\gamma \to$ hadrons versus invariant mass. Points – experimental data, vertical bars – statistical and systematic errors added in quadrature, horizontal – intervals of cross section averaging. Line – $240 + 270/W$

Comparison with other experiments

only MD-1 has determined mass directly using double tag

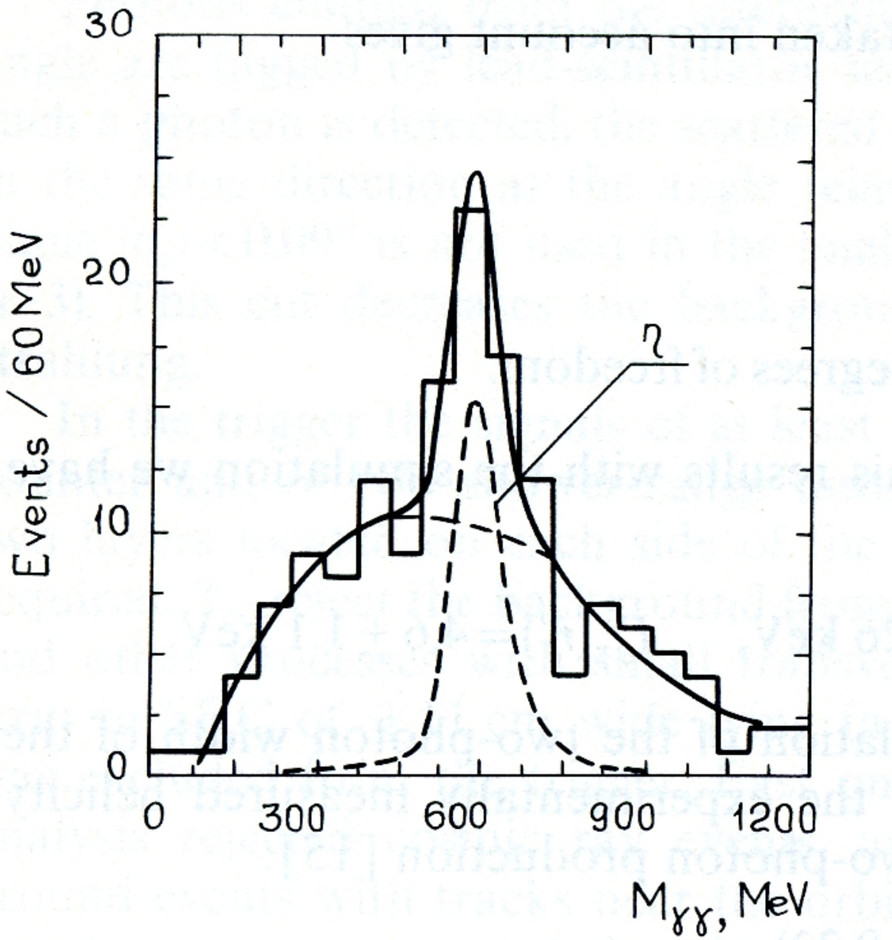


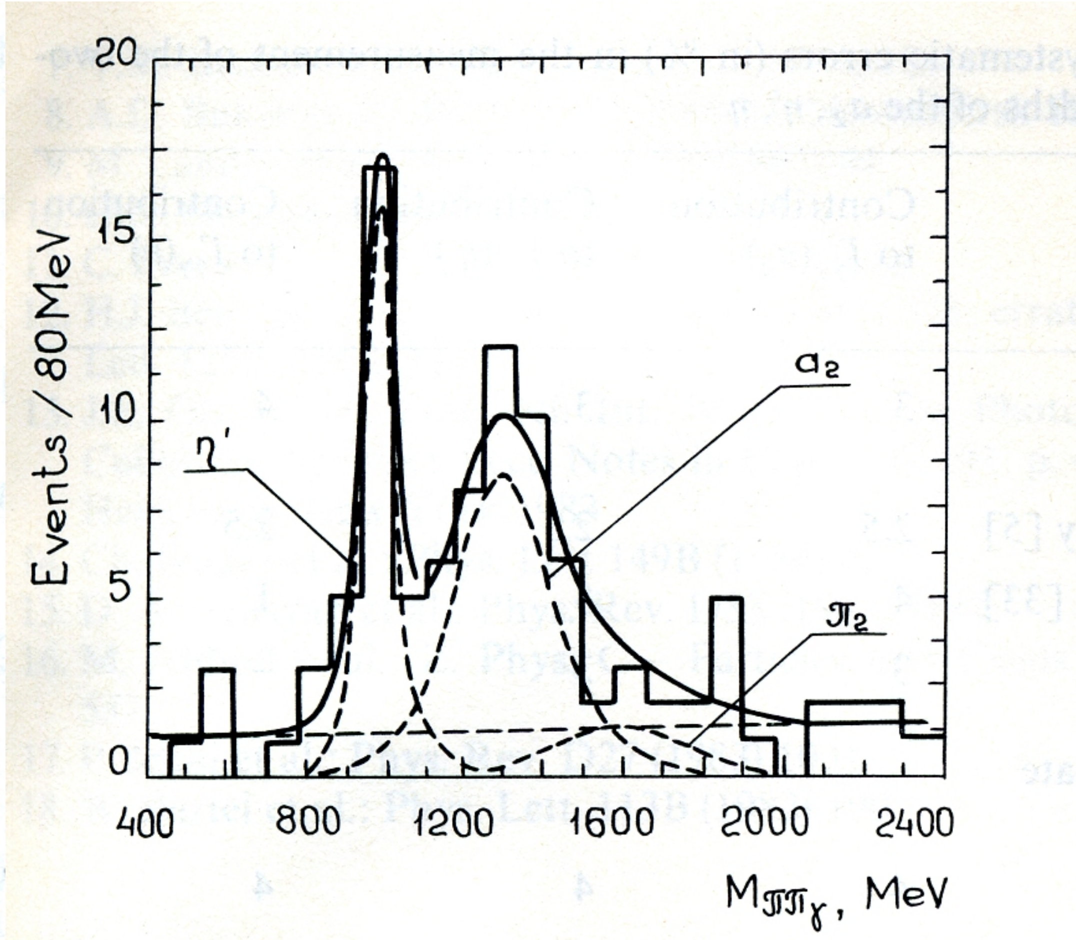
(1992)

Fig. 8. Data of various experiments on the total cross section. Systematic errors are added in quadrature. PLUTO 1984 – single tag data [5], PLUTO 1986 – anti tag data [7], TPC/2γ 1985 – single tag data [6], TPC/2γ 1990 – single tag data [8], MD-1 1991 – this experiment. Line – $240+270/W$

Other two-photon results

$\gamma\gamma \to \eta$, η', a_2 were reconstructed using information about at least 1 s.e.





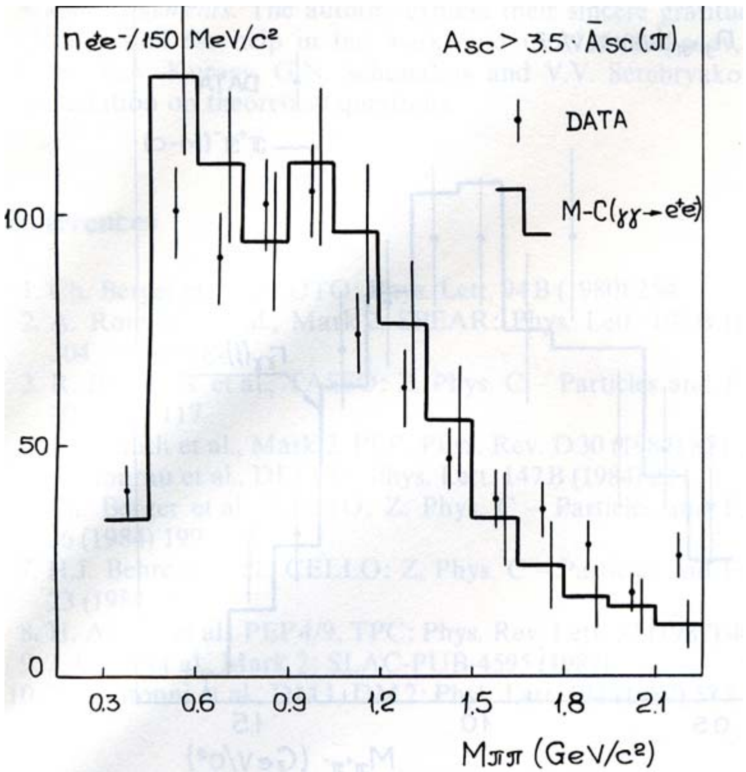
$$\Gamma_{\gamma\gamma}(a_2) = 1.26 \pm 0.26 \pm 0.18 \text{ keV},$$
$$\Gamma_{\gamma\gamma}(\eta') = 4.6 \pm 1.1 \pm 0.6 \text{ keV},$$
$$\Gamma_{\gamma\gamma}(\eta) = 0.51 \pm 0.12 \pm 0.05 \text{ keV}.$$

(1990)

$\gamma\gamma \to e^+e^-, \mu^+\mu^-, \pi^+\pi^- (f_2)$

(without tagging scattered electrons)

e+e-



μ+μ- + π+π- (f2)

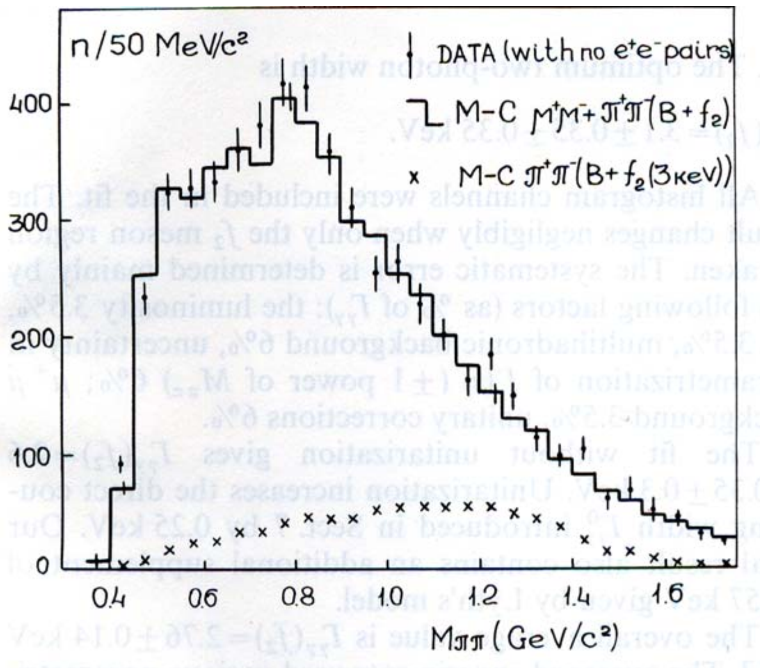


Fig. 5. The invariant mass spectrum of pairs after electron supp

acoplanarity distribution

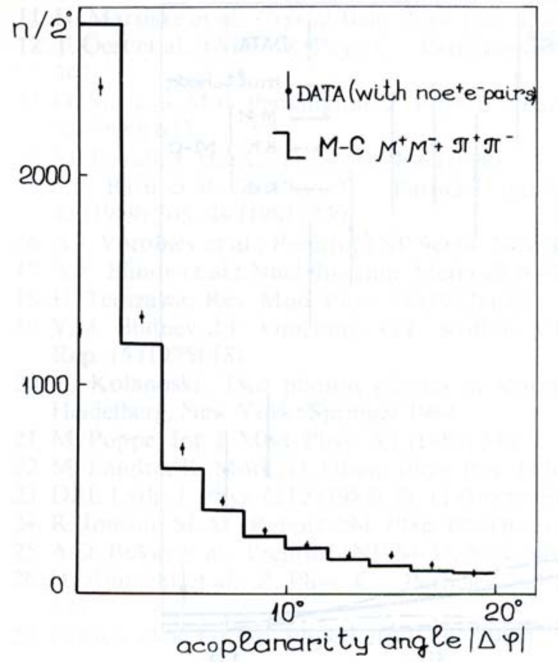


Fig. 6. Acoplanarity angle distribution after imposi cuts and electron suppression

π+π- (f2)

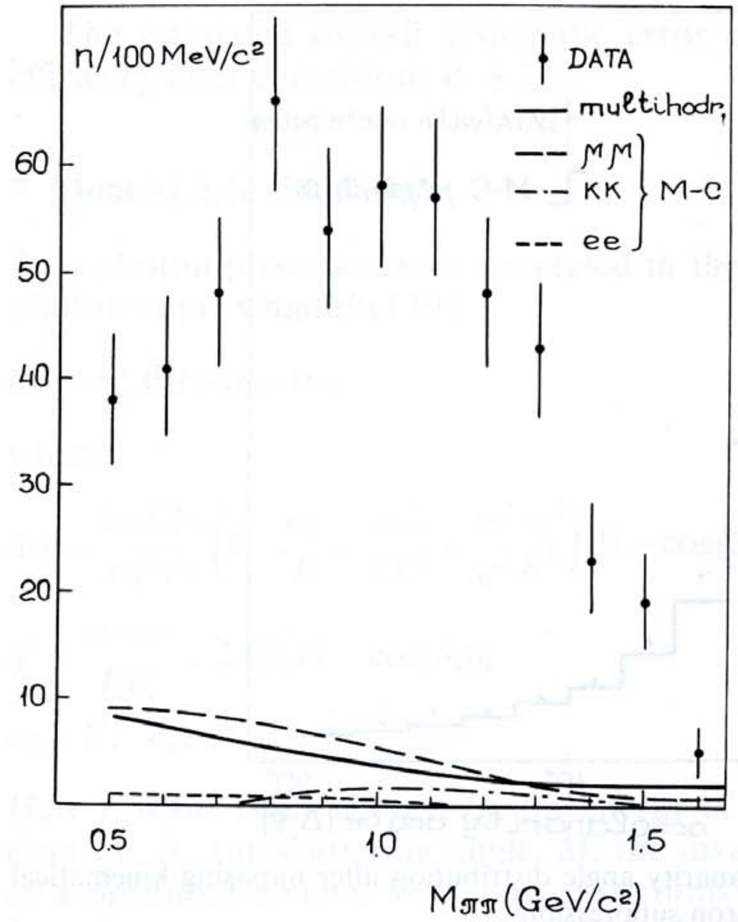


Fig. 7. The invariant mass spectrum of pairs fulfilling the selection criteria for $\gamma\gamma \to \pi^+\pi^-$

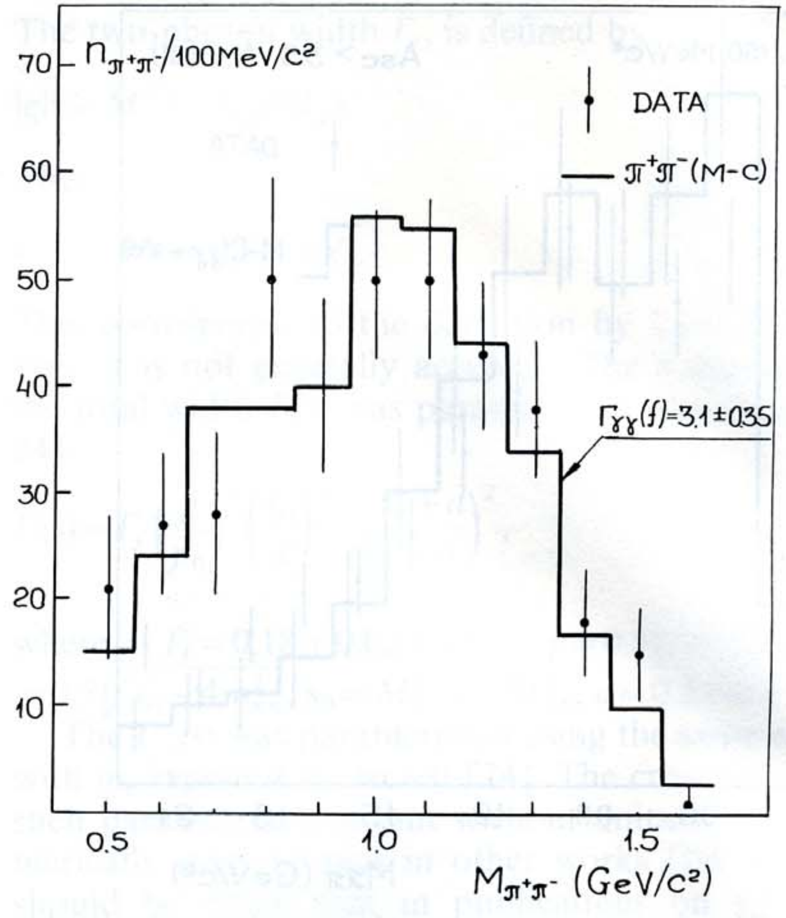
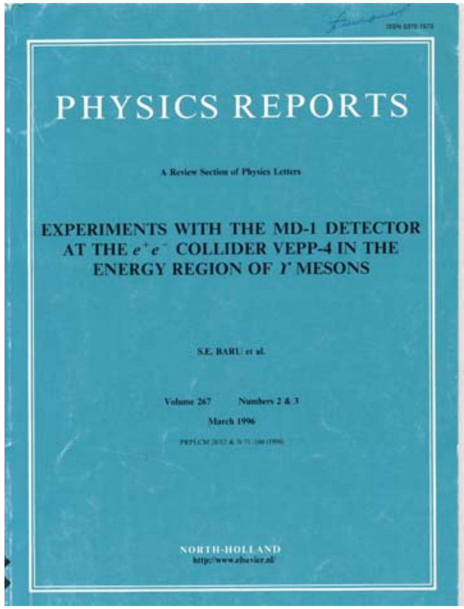


Fig. 9. The invariant mass spectrum of $\pi^+\pi^-$ pairs together with the optimum fit

$$\Gamma_{\gamma\gamma}(f_2) = 3.1 \pm 0.35 \pm 0.35 \text{ keV}$$

(1992)

The talk was about two-photon physics at MD-1, however even most of results from MD-1 are connected with the study e+e- →hadrons and measure-ment of ϒ-mesons properties, especially precise measurement of ϒ(1S,2S,3S) masses using the method of resonance depolarization (invented at Budker INP).



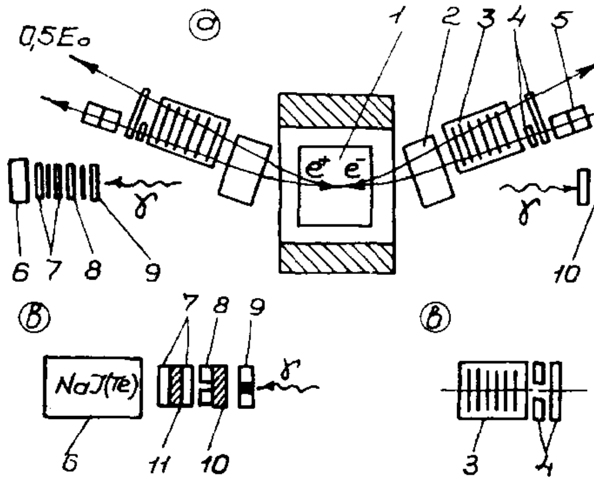
ELSEVIER Physics Reports 267 (1996) 71–159

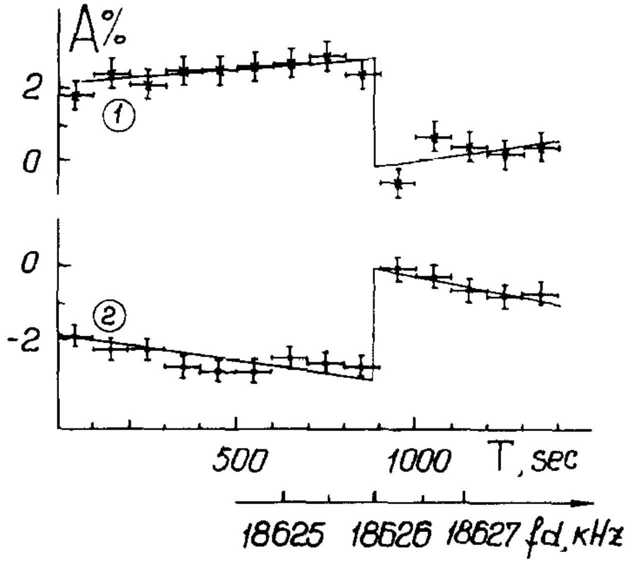
PHYSICS REPORTS

Experiments with the MD-1 detector at the e^+e^- collider VEPP-4 in the energy region of Υ mesons

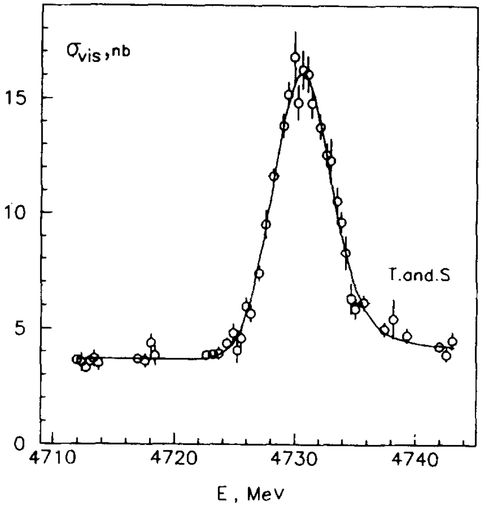
S.E. Baru, A.E. Blinov, V.E. Blinov, A.E. Bondar, A.D. Bukin, V.R. Groshev, Yu.I. Eidelman, V.A. Kiselev, S.G. Klimenko, G.M. Kolachev, S.I. Mishnev, A.P. Onuchin, V.S. Panin, V.V. Petrov, I.Ya. Protopopov, A.G. Shamov, V.A. Sidorov, Yu.I. Skovpen, A.N. Skrinsky, V.A. Tayursky, V.I. Telnov, Yu.A. Tikhonov, G.M. Tumaikin, A.E. Undrus, A.I. Vorobiov, V.N. Zhilich

Institute of Nuclear Physics, 630090 Novosibirsk, Russia

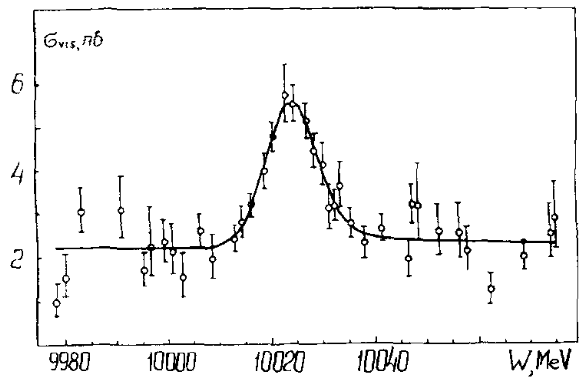




$\Upsilon(1S)$



$\Upsilon(2S)$



$\Upsilon(3S)$

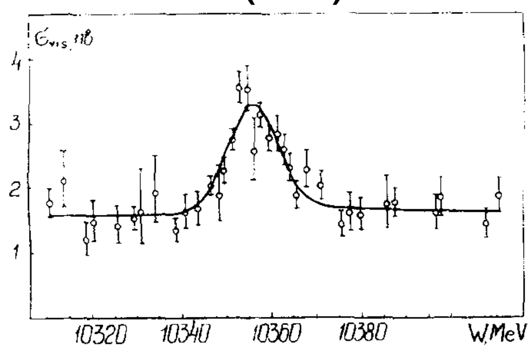


Fig. 4.3. Observed hadronic cross section in the $\Upsilon(2S)$ energy region.

Fig. 4.4. Observed hadronic cross section in the $\Upsilon(3S)$ energy region.

Celebration of Upsilon meson detection with MD-1 and VEPP-4
30 April 1982

Particle Data, 2014

$\Upsilon(1S)$

$I^G(J^{PC}) = 0^-(1^{--})$

$\Upsilon(1S)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
9460.30±0.26 OUR AVERAGE	Error includes scale factor of 3.3.			
9460.51±0.09±0.05	[1] ARTAMONOV	00	MD1	$e^+e^- \to$ hadrons
9459.97±0.11±0.07	MACKAY	84	REDE	$e^+e^- \to$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •				
9460.60±0.09±0.05	[2,3] BARU	92B	REDE	$e^+e^- \to$ hadrons
9460.59±0.12	BARU	86	REDE	$e^+e^- \to$ hadrons
9460.6 ±0.4	[3,4] ARTAMONOV	84	REDE	$e^+e^- \to$ hadrons

[1] Reanalysis of BARU 92B and ARTAMONOV 84 using new electron mass (COHEN 87).
[2] Superseding BARU 86.
[3] Superseded by ARTAMONOV 00.
[4] Value includes data of ARTAMONOV 82.

$\Upsilon(3S)$

$I^G(J^{PC}) = 0^-(1^{--})$

$\Upsilon(3S)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
10355.2±0.5	[1] ARTAMONOV	00	MD1	$e^+e^- \to$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •				
10355.3±0.5	[2,3] BARU	86B	REDE	$e^+e^- \to$ hadrons

[1] Reanalysis of BARU 86B using new electron mass (COHEN 87).
[2] Reanalysis of ARTAMONOV 84.
[3] Superseded by ARTAMONOV 00.

$\Upsilon(2S)$

$I^G(J^{PC}) = 0^-(1^{--})$

$\Upsilon(2S)$ MASS

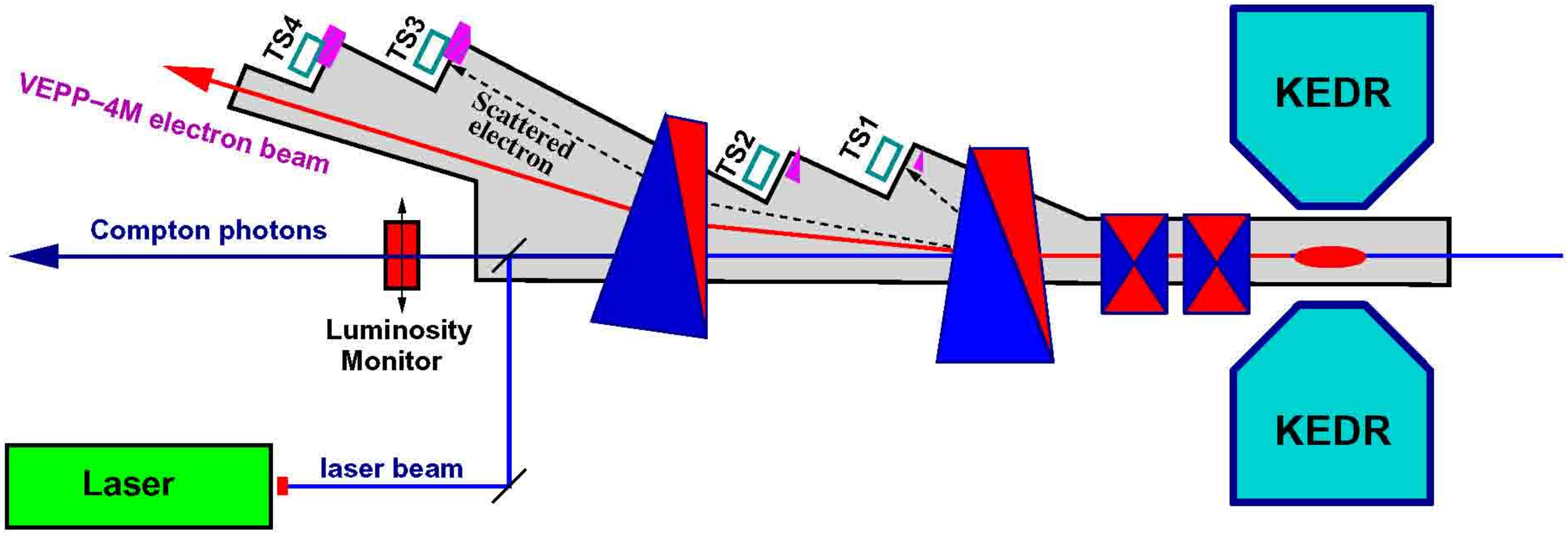
VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
10023.26±0.31 OUR AVERAGE				
10023.5 ±0.5	[1] ARTAMONOV	00	MD1	$e^+e^- \to$ hadrons
10023.1 ±0.4	BARBER	84	REDE	$e^+e^- \to$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •				
10023.6 ±0.5	[2,3] BARU	86B	REDE	$e^+e^- \to$ hadrons

[1] Reanalysis of BARU 86B using new electron mass (COHEN 87).
[2] Reanalysis of ARTAMONOV 84.
[3] Superseded by ARTAMONOV 00.

35 years passed, best by now!

Future 2γ studies, detector KEDR at VEPP-4M

Following MD-1, almost the same experimental group have developed and constructed the electron tagging system with 2 times higher double tag. efficiency and 10 times better mass resolution! The experiment KEDR is running now at VEPP-4M on the place of MD-1, so let us wait for results on γγ physics! (in 2-3 years)



Conclusion

- The experiment MD-1, which was developed for study of two-photon physics and multihadronic events, has produced many interesting experimental results on 2γ physics (not only).
- MD-1 has been a wonderful school for physicists and has stimulated many new ideas on the study of two-photon physics.