Results on Light Mesons Production from VEPP-2M Collider.

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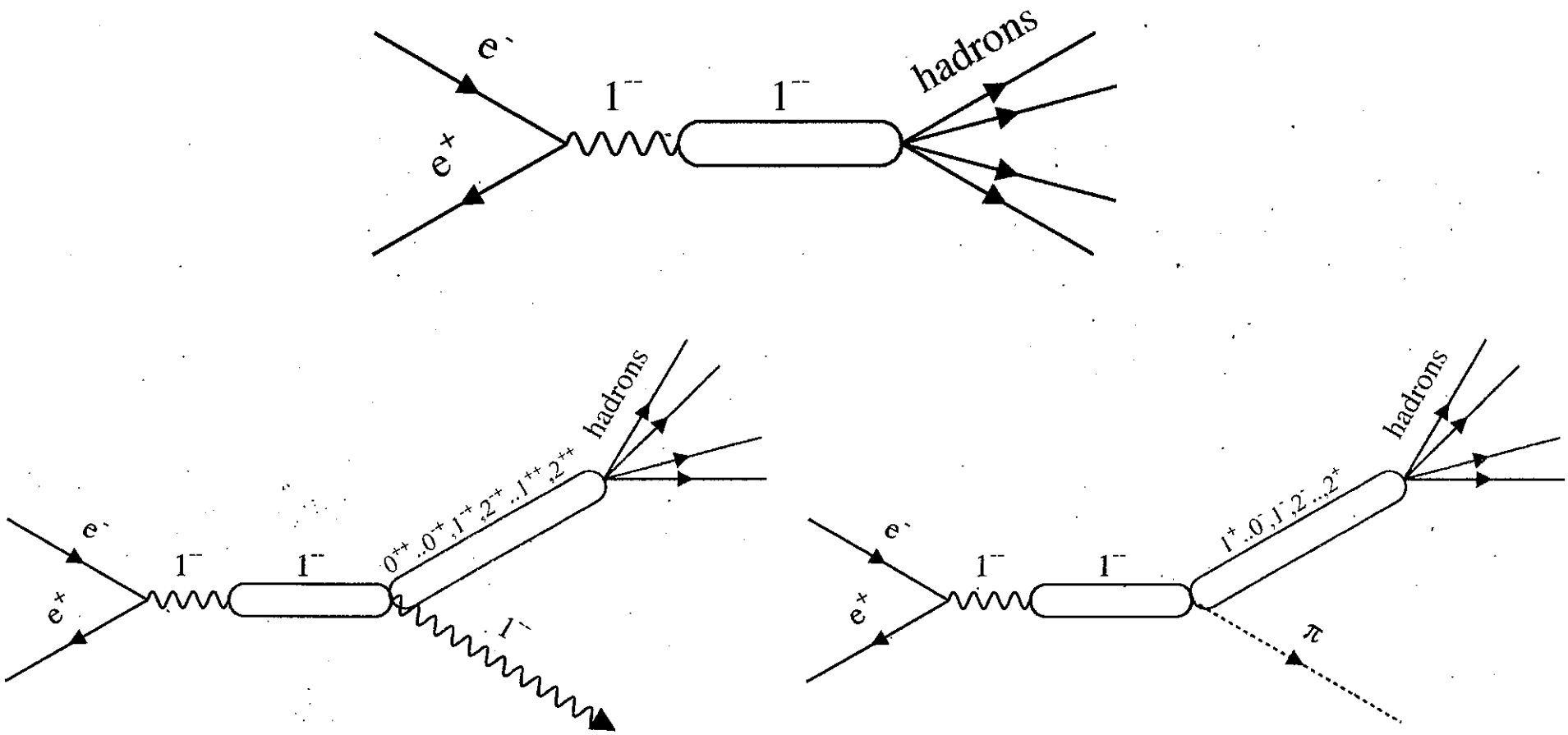
International Symposium on Hadron Spectroscopy, Chiral Symmetry and Relativistic Description of Bound Systems

24-26 February 2003, Nihon Daigaku Kaikan, Ichigaya, Tokyo

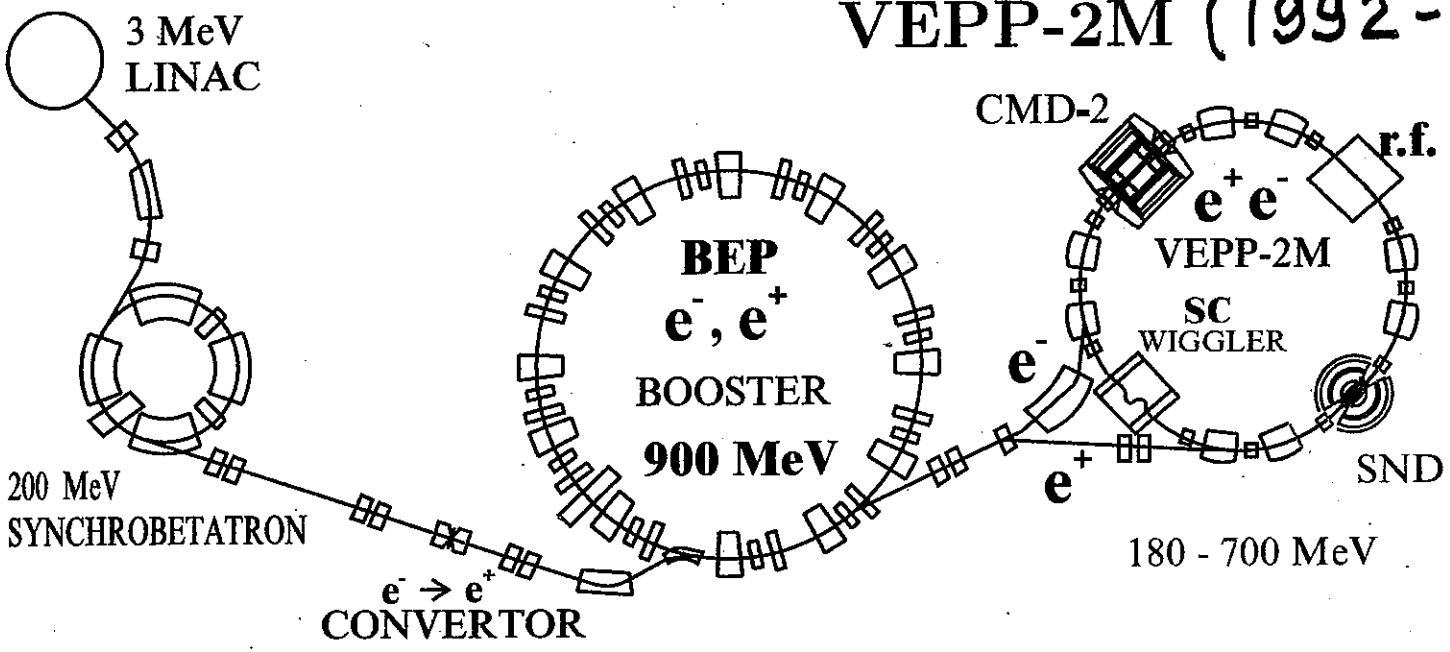
Outline:

- Introduction
- VEPP-2M
- Vector mesons
- Mesons with other quantum numbers
- VEPP-2000
- Summary

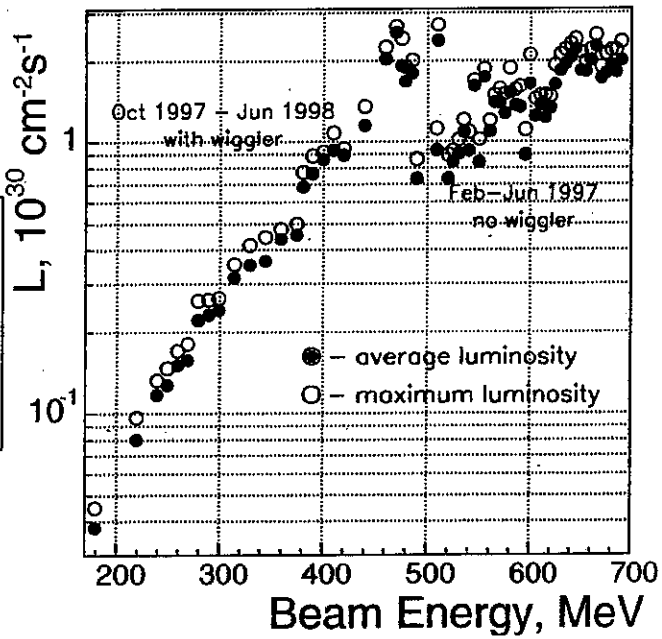
In e^+e^- collision we have clean initial state 1^{--}



VEPP-2M (1992 - 2000)

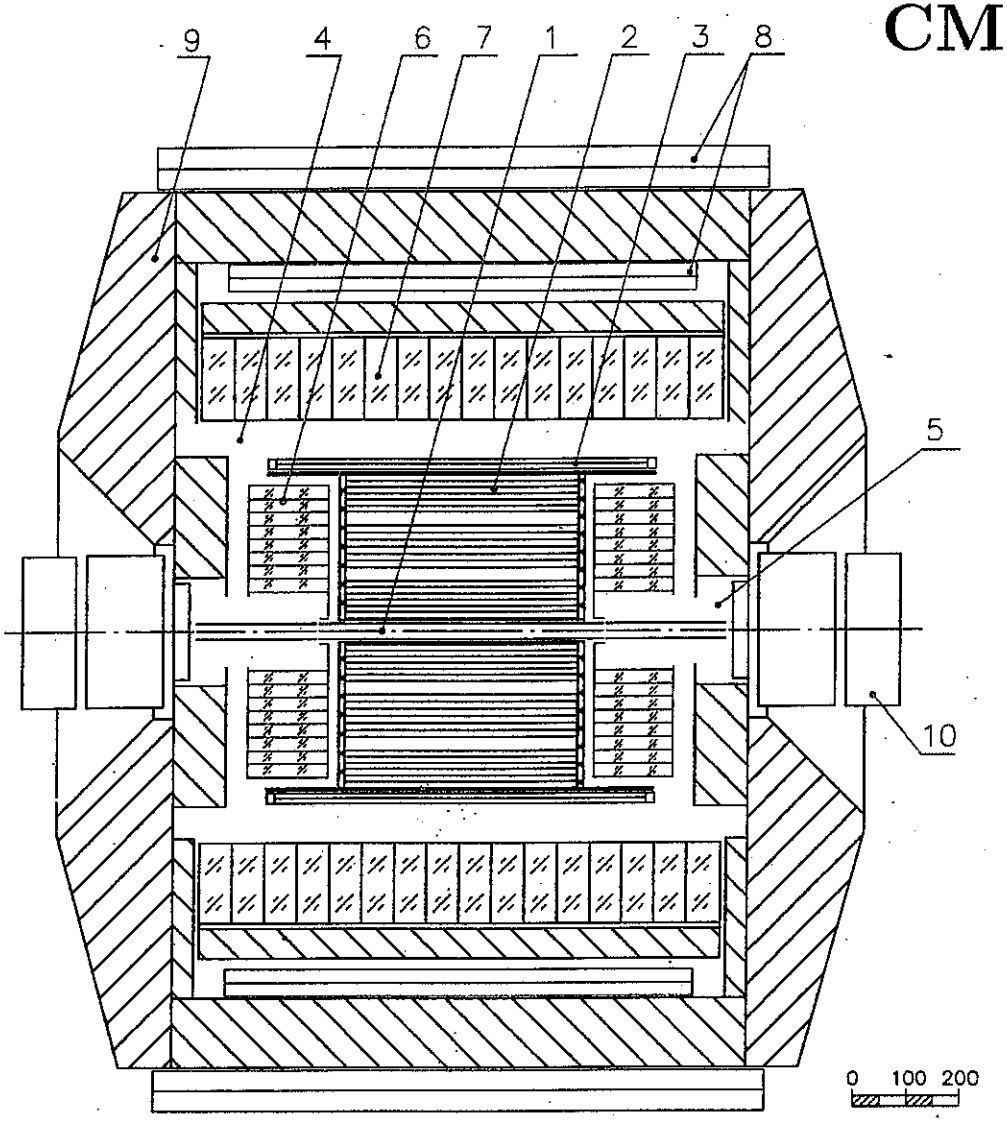


Beam energy	2×(180–700) MeV
Peak Luminosity	3×10^{30} cm^{-2}s^{-1}
Number of bunches	1
Interaction regions	2



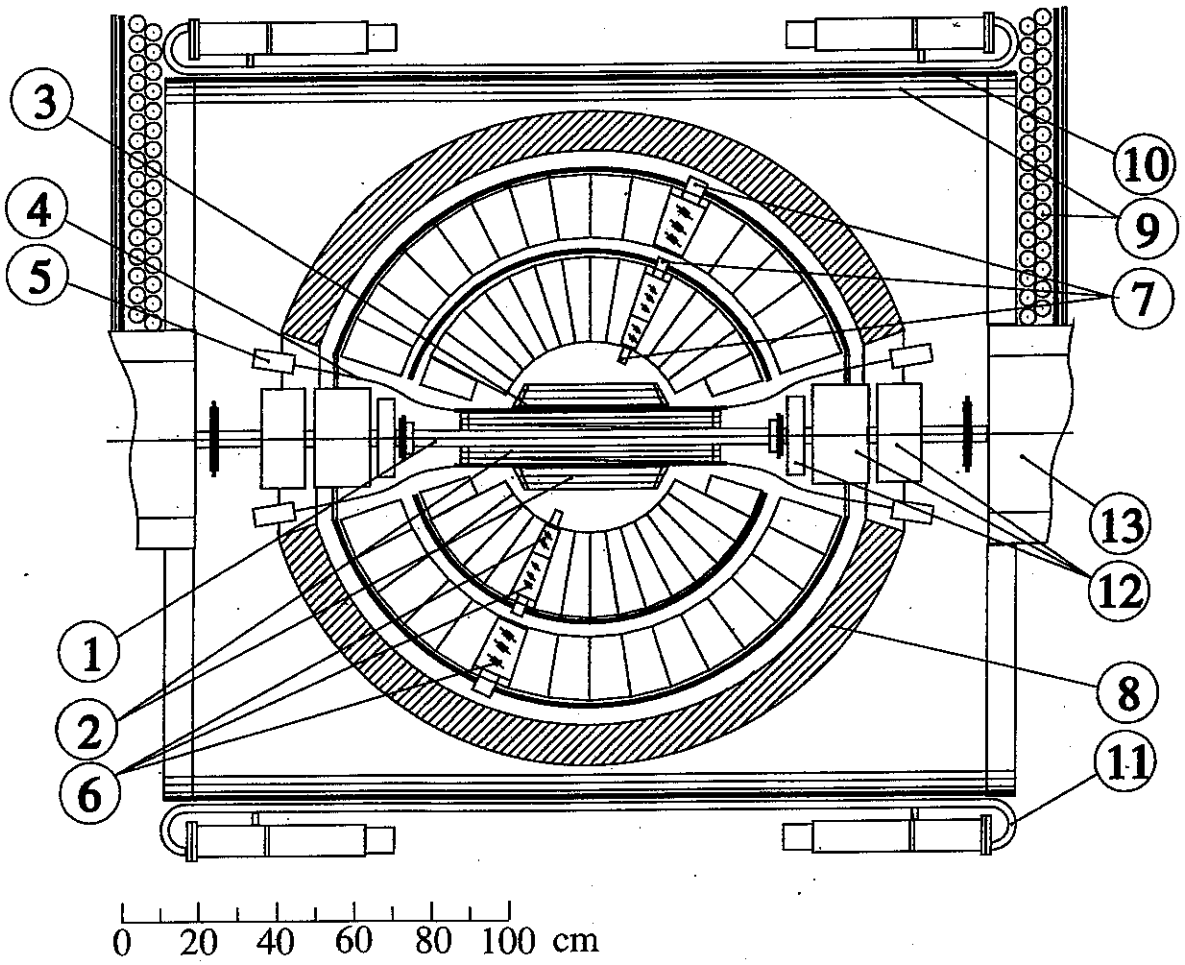
$\int L\,dt \approx 50\,pb^{-1}$

CMD-2



1. Beam pipe
2. Drift chamber
3. Z-chamber
4. Superconductive solenoid
5. Compensating magnet
6. BGO calorimeter
7. CsI(Tl) calorimeter
8. Muon range system
9. Iron yoke
10. Quadrupole lenses

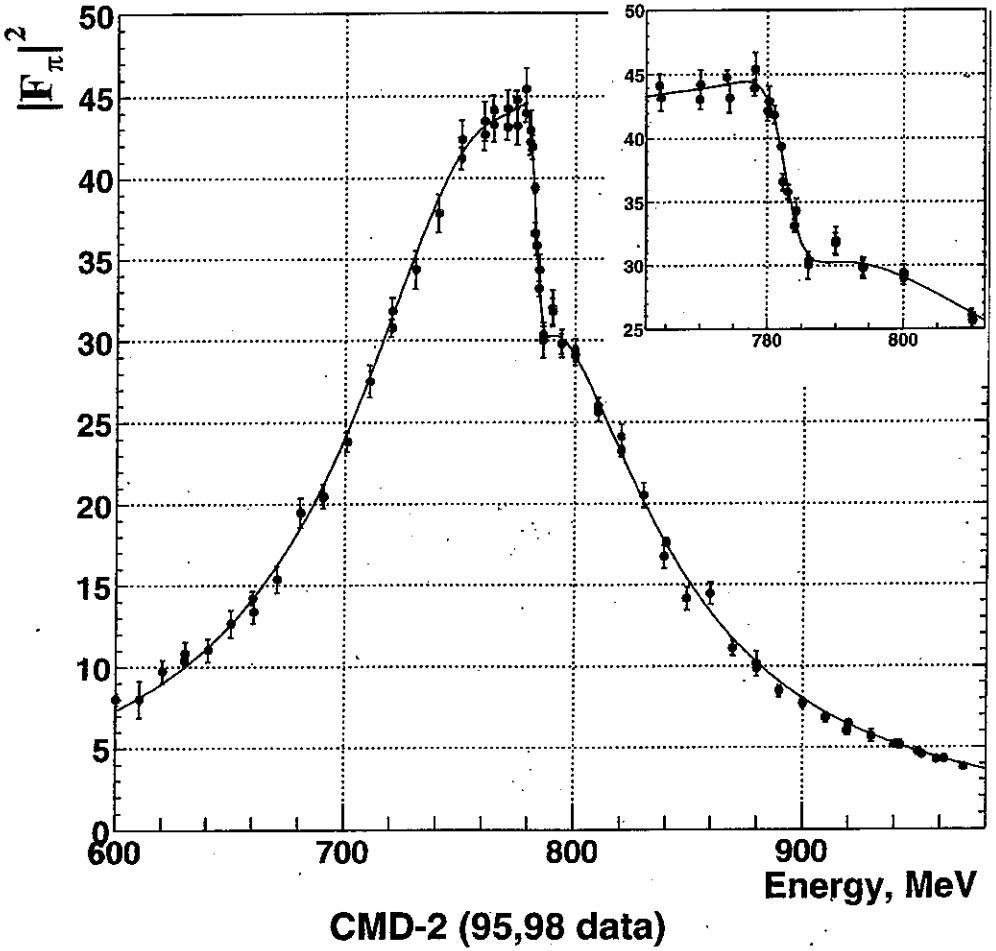
SND

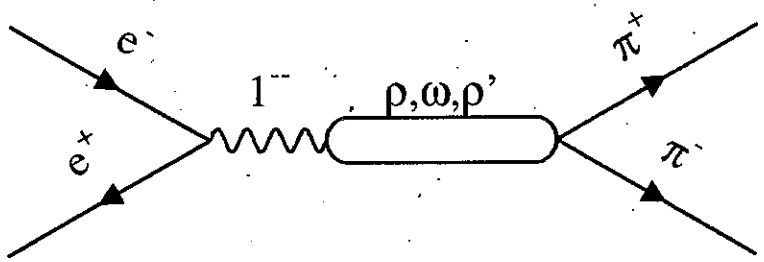


1. Beam pipe
2. Drift chamber
3. Coincidence counter
4. Fiber light guide
5. PMTs
6. NaI(Tl) crystals
7. Photodiodes
8. Iron absorber
9. Muon tubes
10. 1 cm iron plate
11. Muon counters
12. Magnetic lenses
13. Bending magnets

$$e^+e^- \to \pi^+\pi^-$$

$$F_\pi(s) = \frac{BW^{GS}_{\rho(770)}(s) \cdot (1 + \delta \frac{s}{M^2_\omega} BW_{\omega(s)}) + \beta \cdot BW^{GS}_{\rho(1450)}}{1+\beta}$$





$M_\rho =$ $(776.09 \pm 0.64 \pm 0.50)\ MeV/c^2$

$\Gamma_\rho =$ $(144.46 \pm 1.33 \pm 0.80)\ MeV$

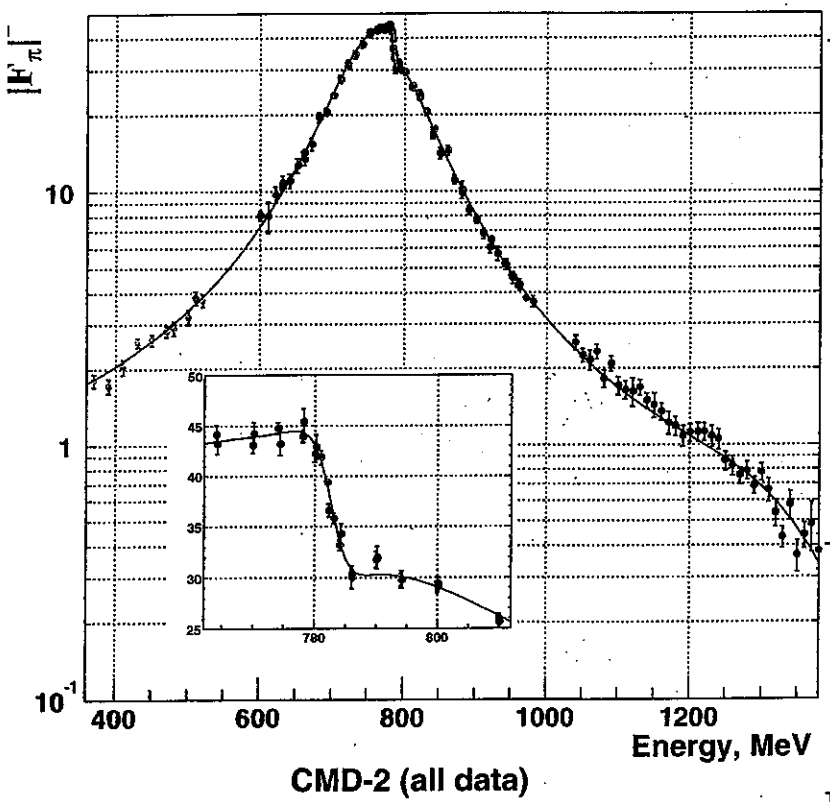
$\Gamma_{\rho ee} =$ $(6.86 \pm 0.11 \pm 0.05)\ keV$

$B_{\omega\pi\pi} =$ $(1.33 \pm 0.24 \pm 0.05)\ \%$

$arg\delta =$ $(12.6 \pm 3.7 \pm 0.2)^\circ$

R.R.Akhmetshin e.a. Phys.Lett. B527(2002) 161.

$e^+e^- \to \pi^+\pi^-$

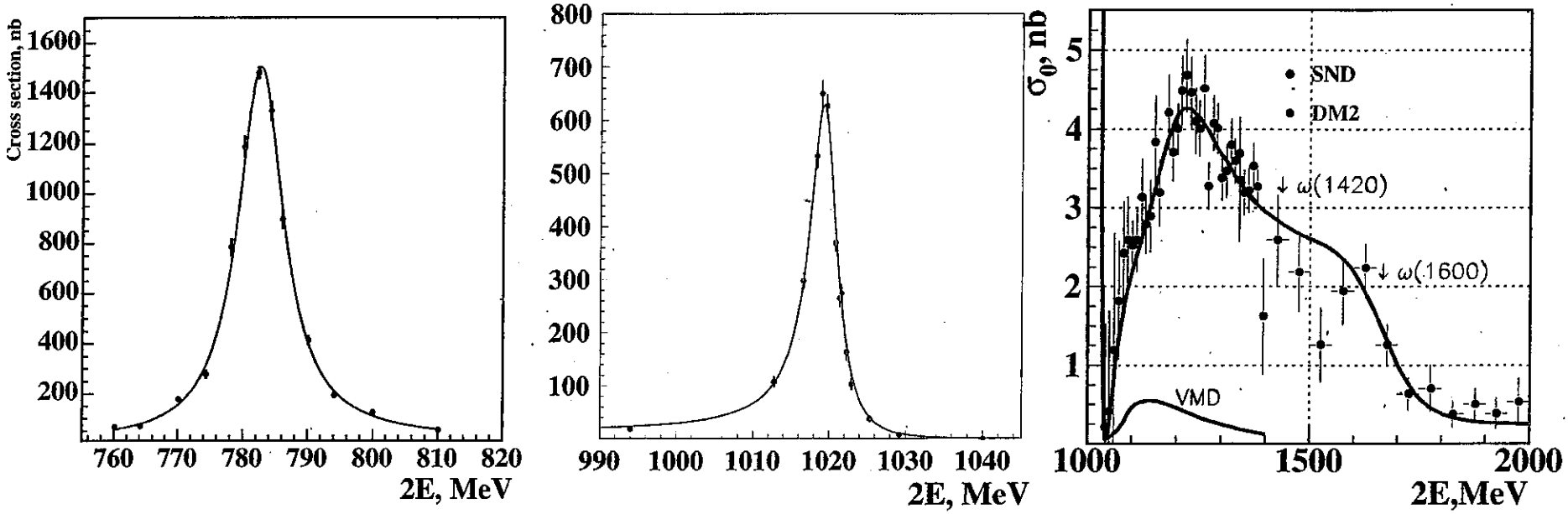


In energy range 600-900 MeV.

	GS model	**HLS model**
$M_\rho,\ MeV/c^2$	$776.09 \pm 0.64 \pm 0.50$	$775.23 \pm 0.61 \pm 0.50$
$\Gamma_\rho,\ MeV$	$144.46 \pm 1.33 \pm 0.80$	$143.88 \pm 1.44 \pm 0.80$
$\Gamma_{\rho ee},\ keV$	$6.86 \pm 0.11 \pm 0.05$	$6.84 \pm 0.12 \pm 0.05$
$B_{\omega\pi\pi},\ \%$	$1.33 \pm 0.24 \pm 0.05$	$1.32 \pm 0.24 \pm 0.05$
$arg\delta$	$(12.6 \pm 3.7 \pm 0.2)^\circ$	$(13.0 \pm 3.7 \pm 0.2)^\circ$
$\beta(GS)$	-0.0695 ± 0.0053	–
$\alpha(HLS)$	–	$2.336 \pm 0.016 \pm 0.007$
χ^2/n	**0.92**	**0.94**

In full energy range HLS (without ρ') doesn't describe the data well.

$e^+e^- \to \pi^+\pi^-\pi^0$



$\sigma_\omega = \quad 1457 \pm 23 \pm 19$ nb

$M_\omega = \quad 782.71 \pm 0.07 \pm 0.04$ MeV/c^2

$\Gamma_\omega = \quad 8.68 \pm 0.23 \pm 0.10$ MeV

R.R.Akhmetshin e.a. Phys.Lett. B476(2000) 33.

$\sigma_\phi = \quad 619 \pm 39 \pm 12$ nb

$\delta_{\omega--\phi} = \quad (162 \pm 17)^\circ$

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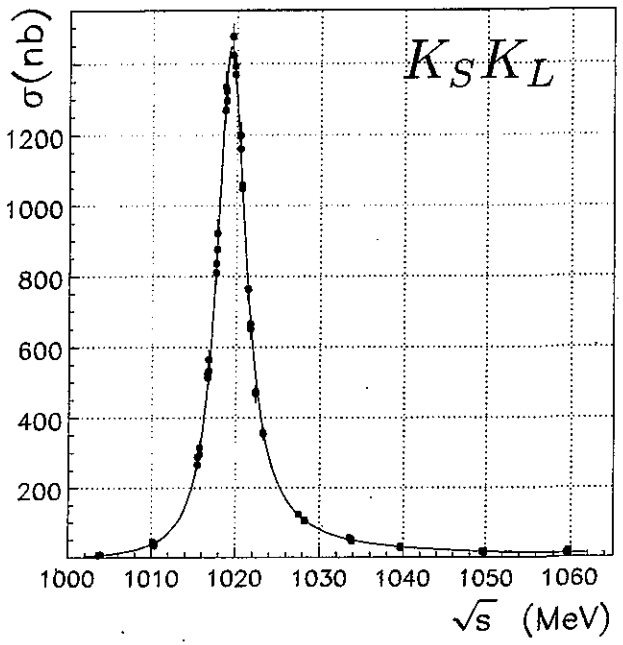
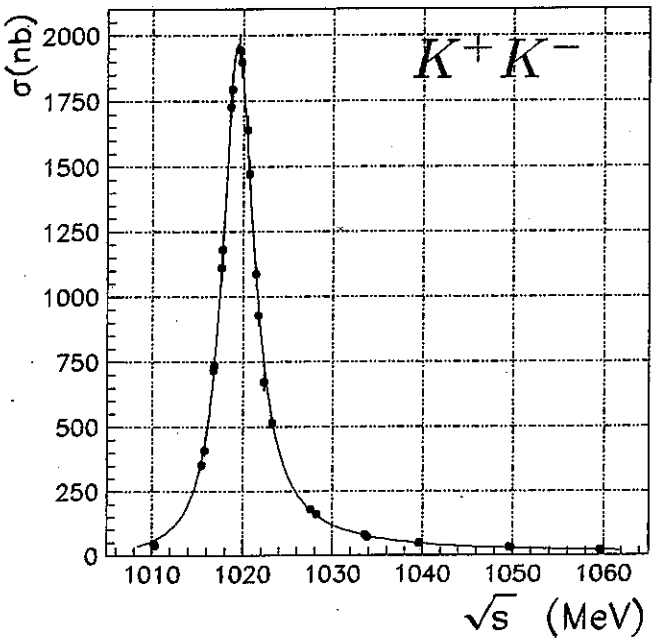
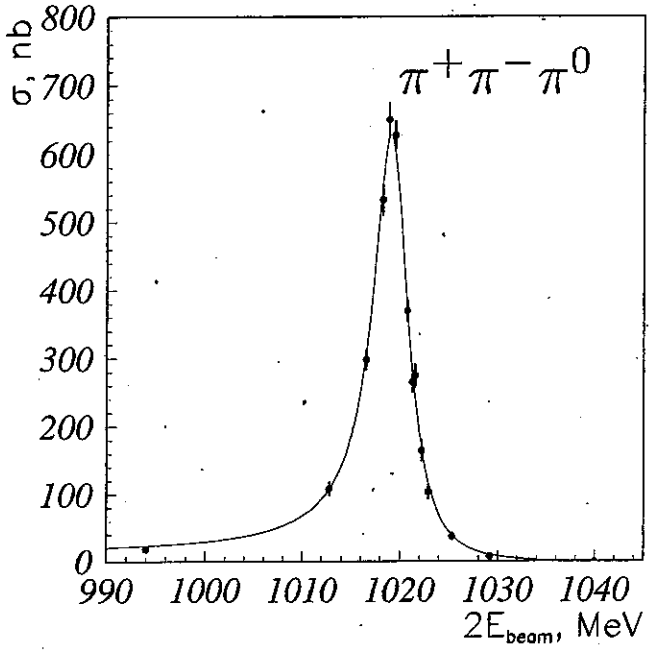
ϕ-meson

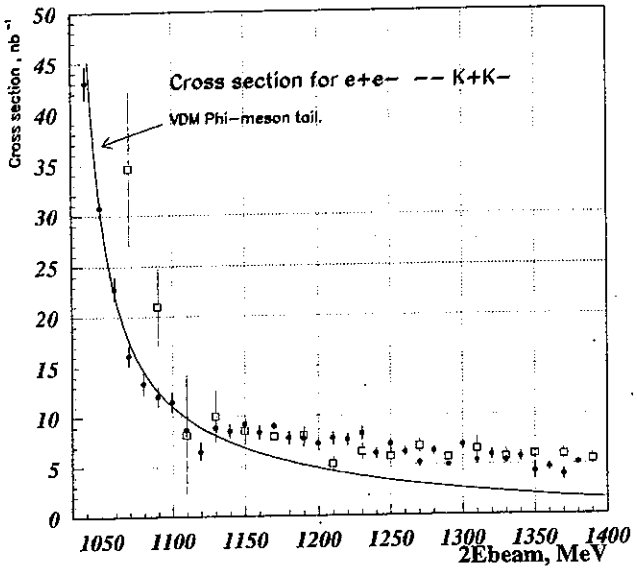


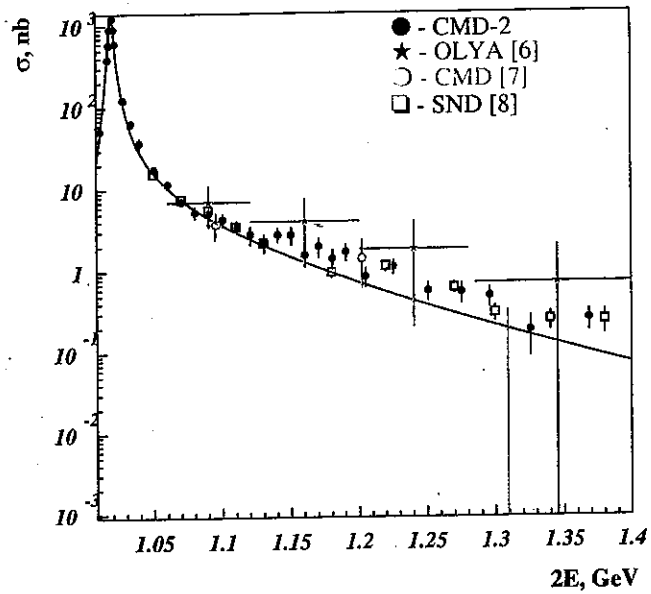


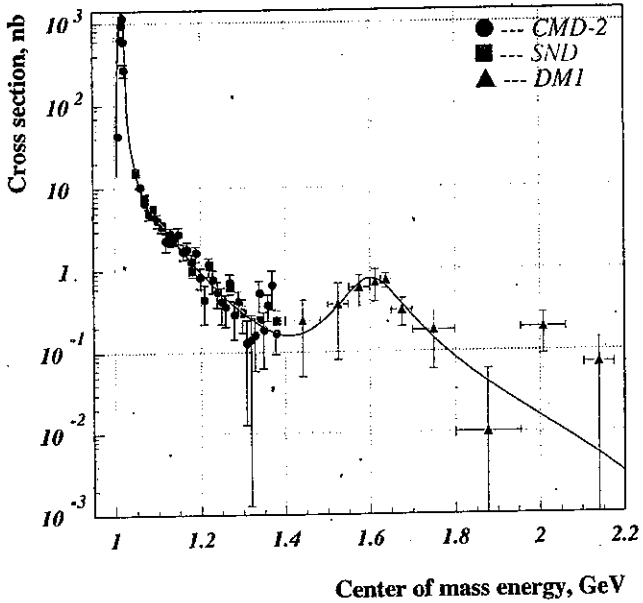


	CMD2	SND
M_ϕ, MeV/c^2	$1019.470 \pm 0.013 \pm 0.018$	1019.42 ± 0.50
Γ_ϕ, MeV	$4.280 \pm 0.033 \pm 0.025$	4.21 ± 0.04
$Br(\phi \to K^+K^-), \%$	49.2 ± 1.2	47.6 ± 1.7
$Br(\phi \to K_L K_S), \%$	33.5 ± 1.0	35.1 ± 1.3
$Br(\phi \to \pi^+\pi^-\pi^0), \%$	$14.5 \pm 0.09 \pm 0.03$	15.9 ± 0.8

K^+K^- K_SK_L K_SK_L







$M_{\phi'} =$ $1623 \pm 20\ MeV/c^2$

$\Gamma_{\phi'} =$ $139 \pm 60,\ MeV$

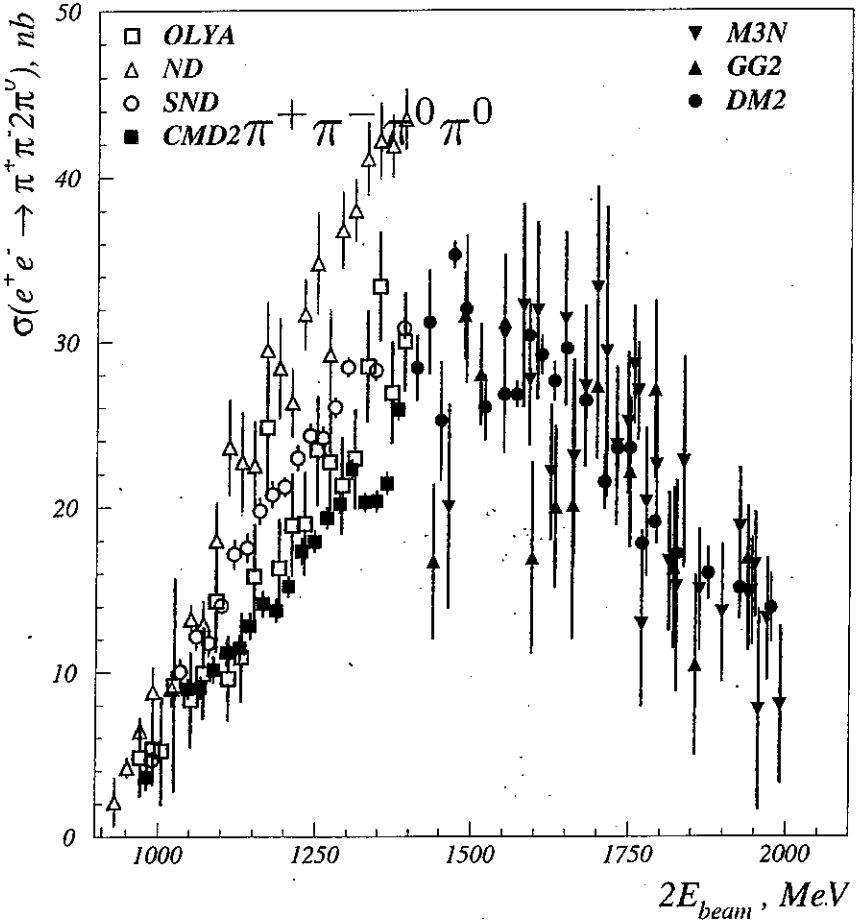
$\sigma(\phi \to K_LK_S) =$ $1375 \pm 6 \pm 23\ nb$

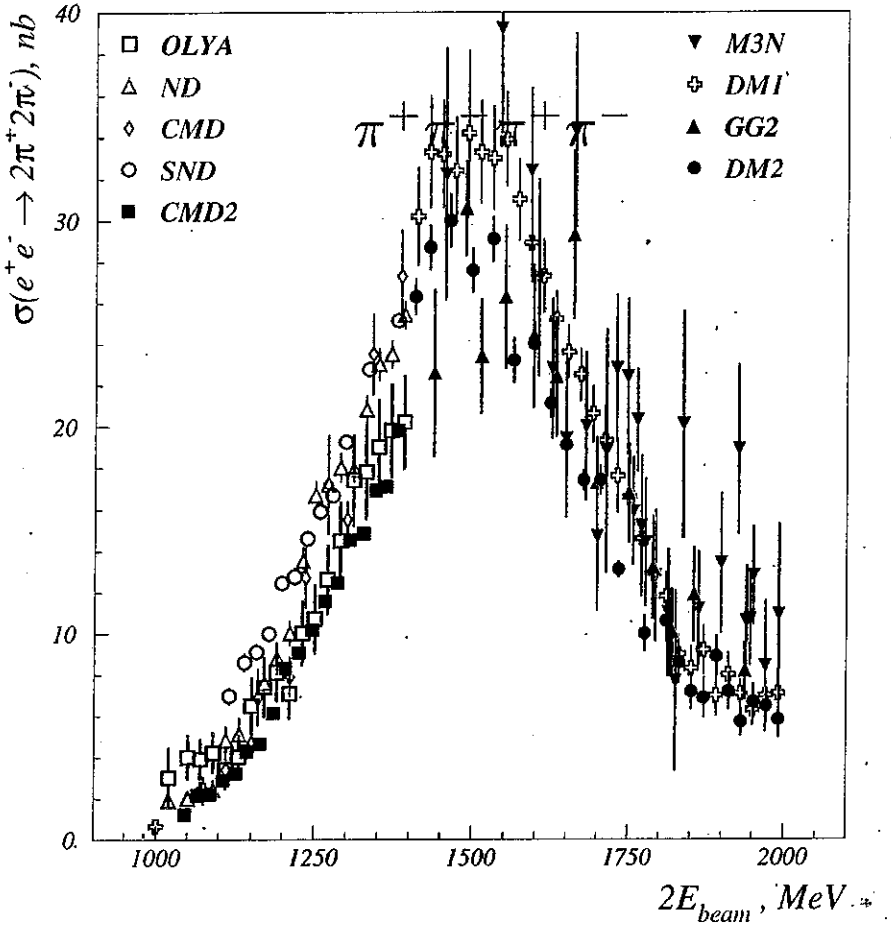
$\sigma(\phi' \to K_LK_S) =$ $0.73 \pm 0.33\ nb$

$\delta_{\phi-\phi'} =$ $160° \pm 42°$

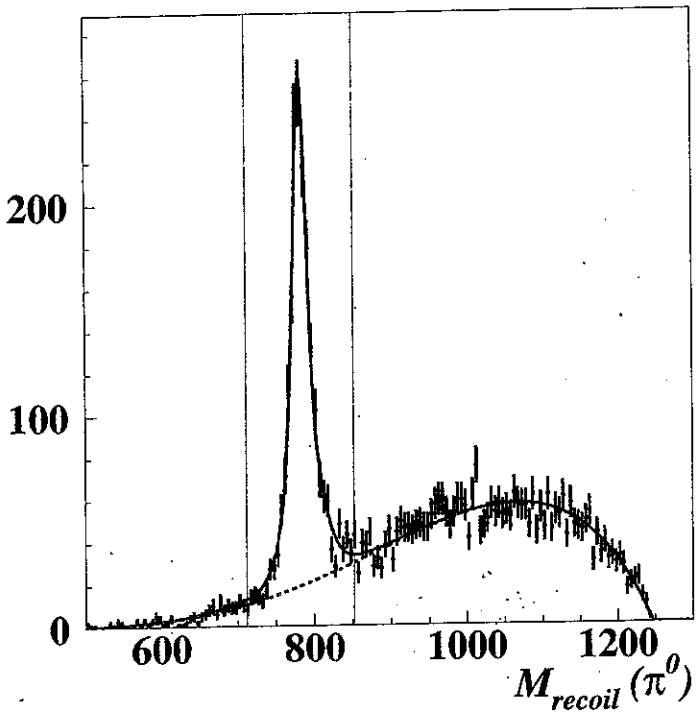
R.R.Akhmetshin e.a. Phys.Lett. B551, 27,2003

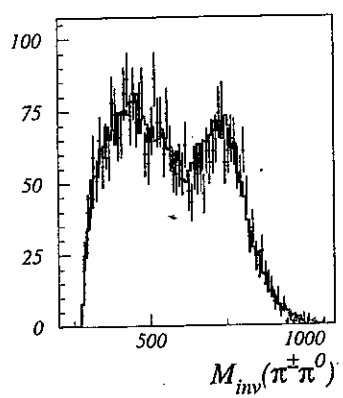
$e^+e^- \to 4\pi$

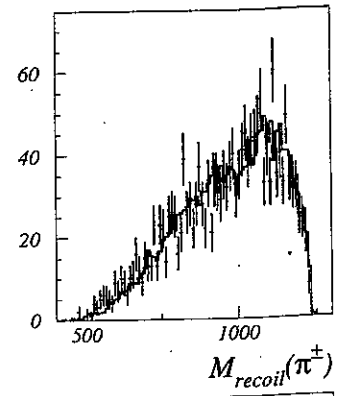

OLYA
ND
SND
CMD2
M3N
GG2
DM2
$\pi^+\pi^-\pi^0\pi^0$
$\sigma(e^+e^- \to \pi^+\pi^-2\pi^0)$, nb
$2E_{beam}$, MeV

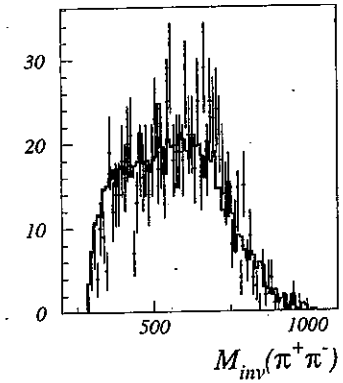

OLYA
ND
CMD
SND
CMD2
M3N
DM1
GG2
DM2
$\pi^+\pi^-\pi^+\pi^-$
$\sigma(e^+e^- \to 2\pi^+2\pi^-)$, nb
$2E_{beam}$, MeV

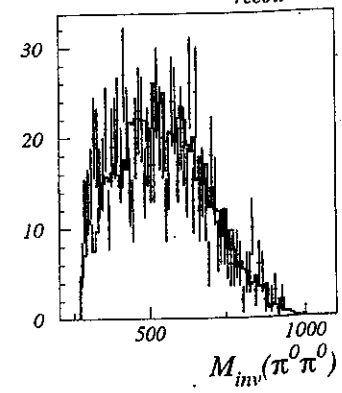
$e^+e^- \to \pi^+\pi^-\pi^0\pi^0$, dominance $a_1\pi$, $\omega\pi$







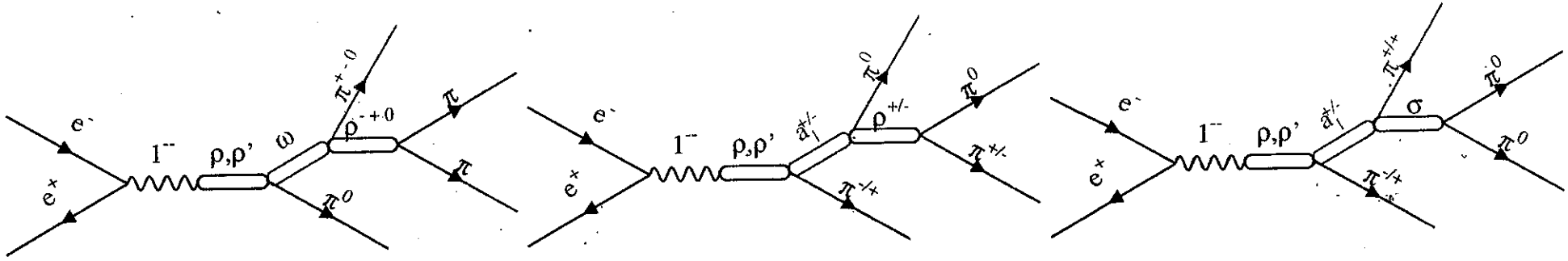




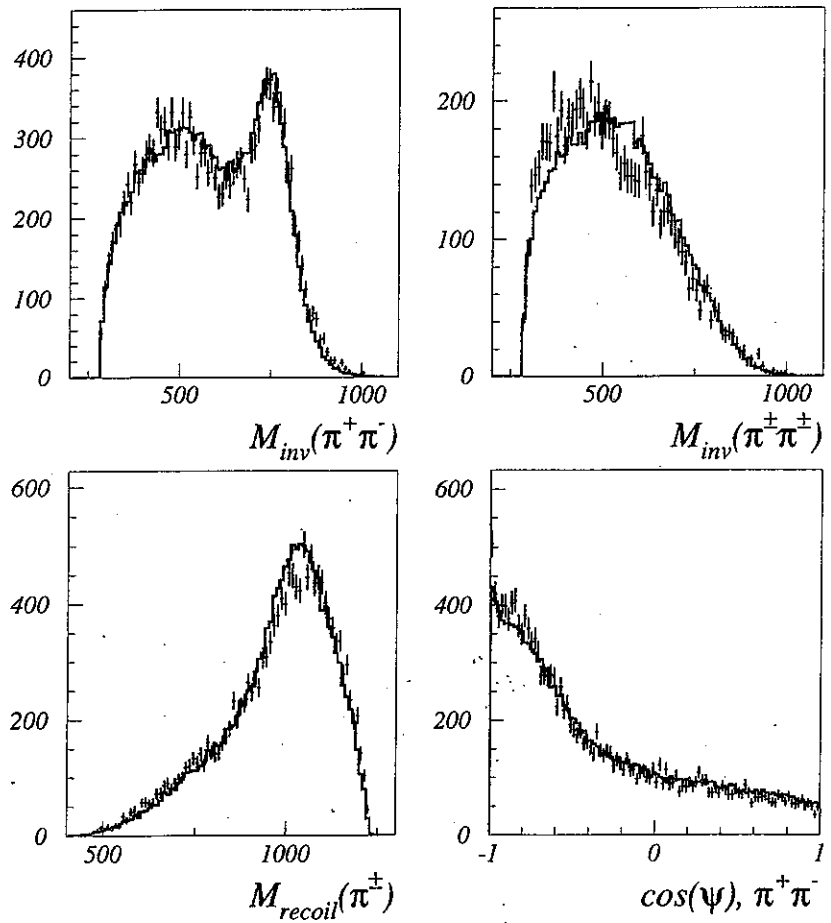
ρσ
ρ'ρ⁻
h₁π

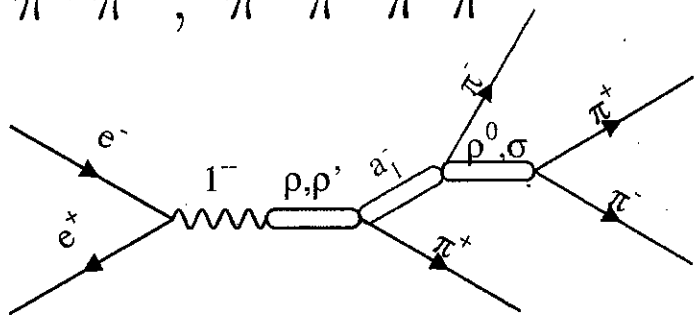
$a_2(1320)\pi$
$\pi(1300)\pi$

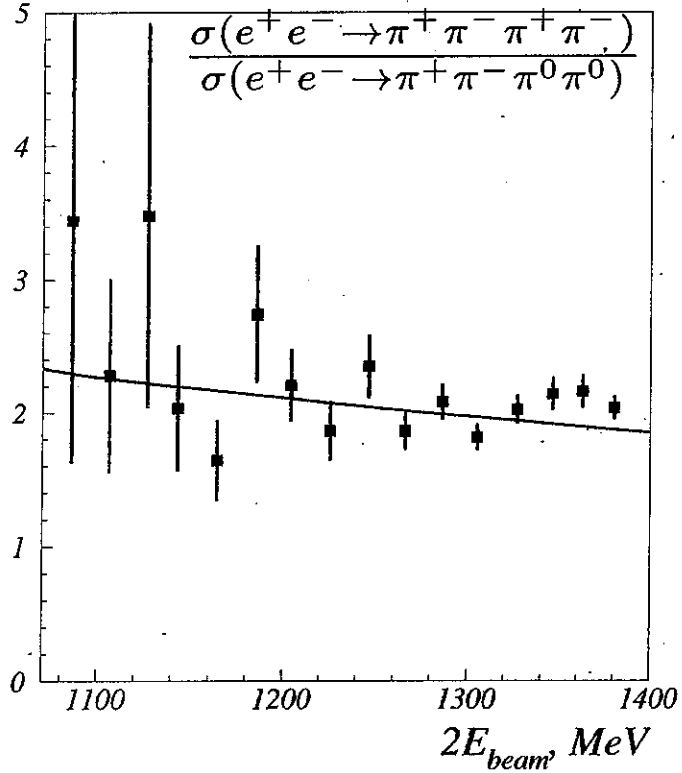
$a_1(1260)\pi$
dominance



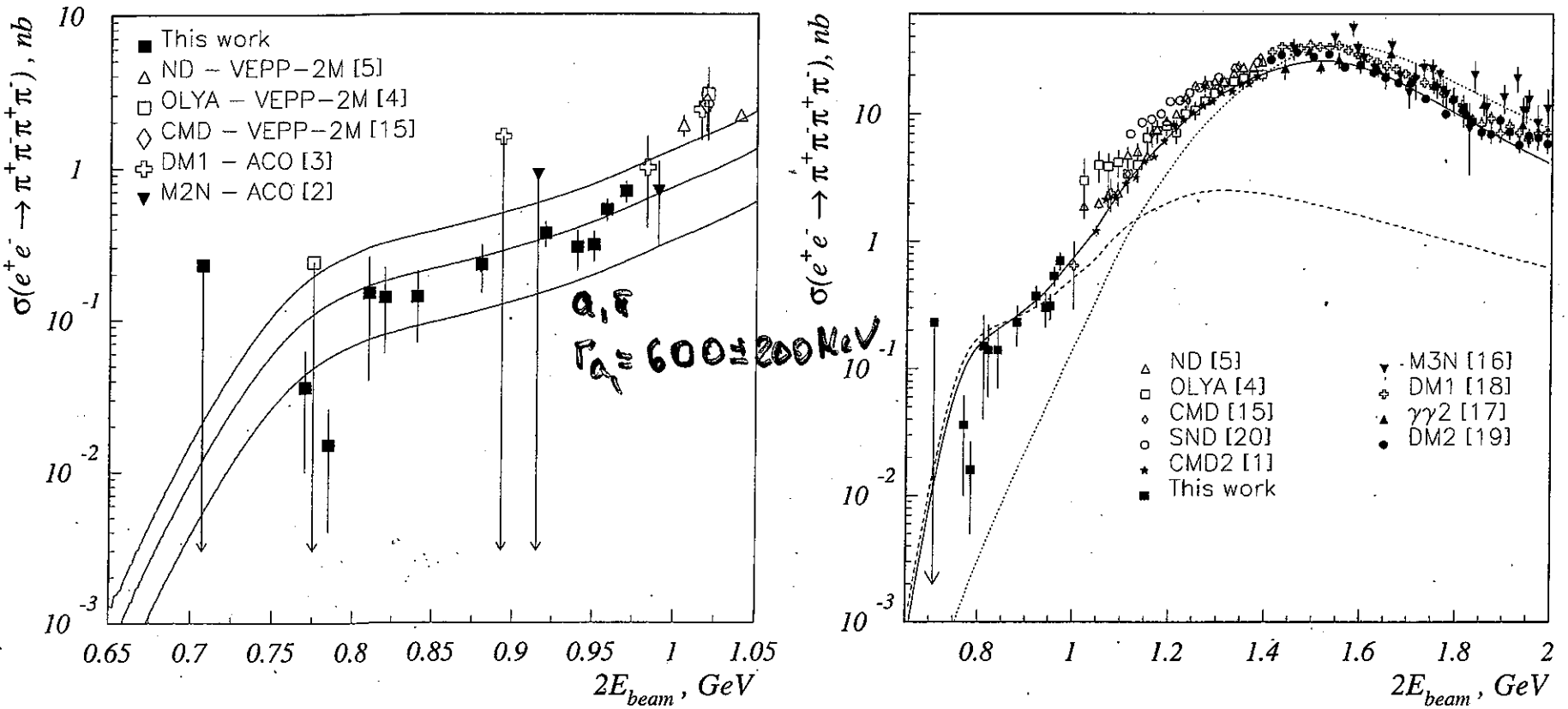
$e^+e^- \to \pi^+\pi^-\pi^+\pi^-,\ \pi^+\pi^-\pi^0\pi^0$





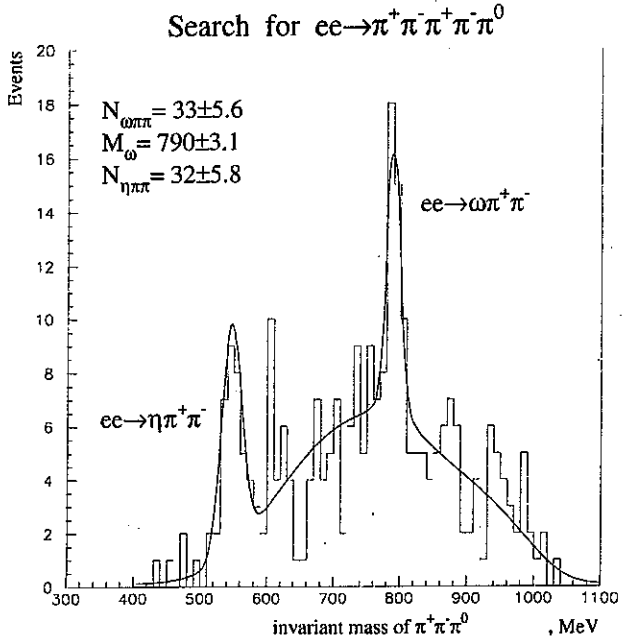


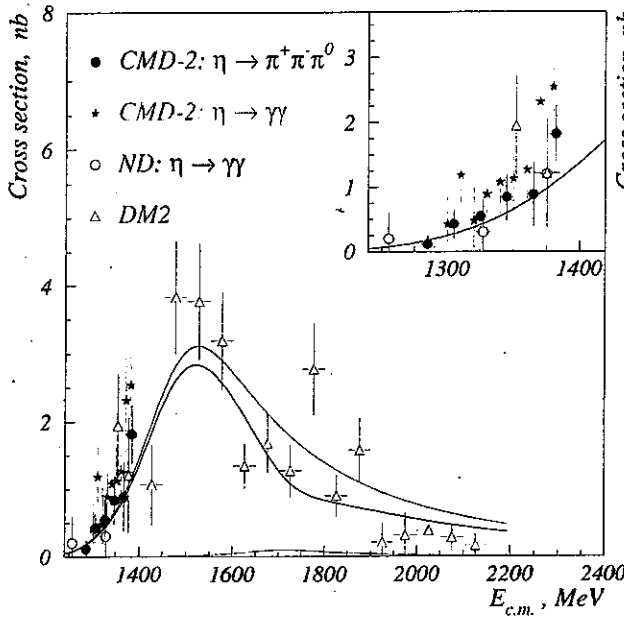
$e^+e^- \to \pi^+\pi^-\pi^+\pi^-$

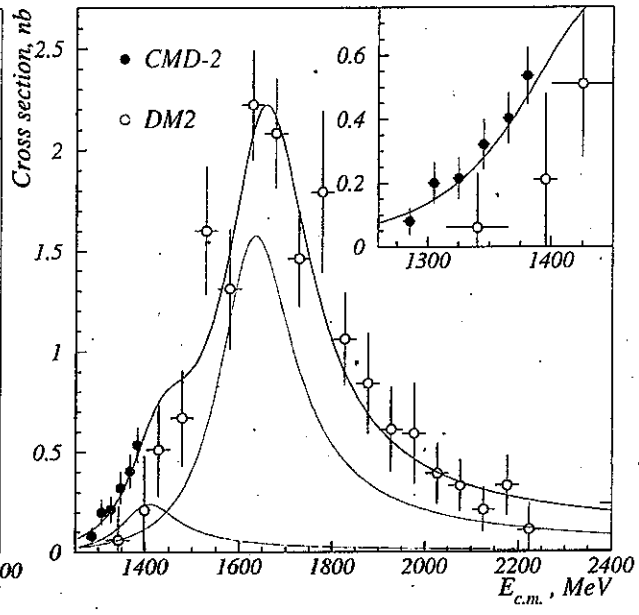


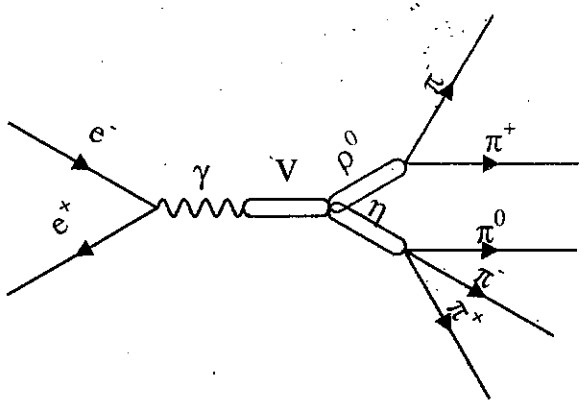
$$Br(\rho \to \pi^+\pi^-\pi^+\pi^-) = \quad (1.8 \pm 0.9 \pm 0.3)10^{-5}$$

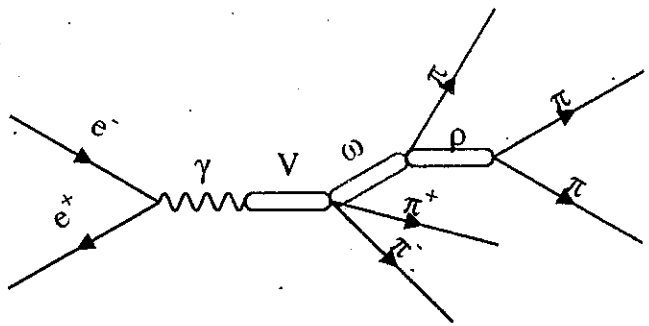
$e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0$



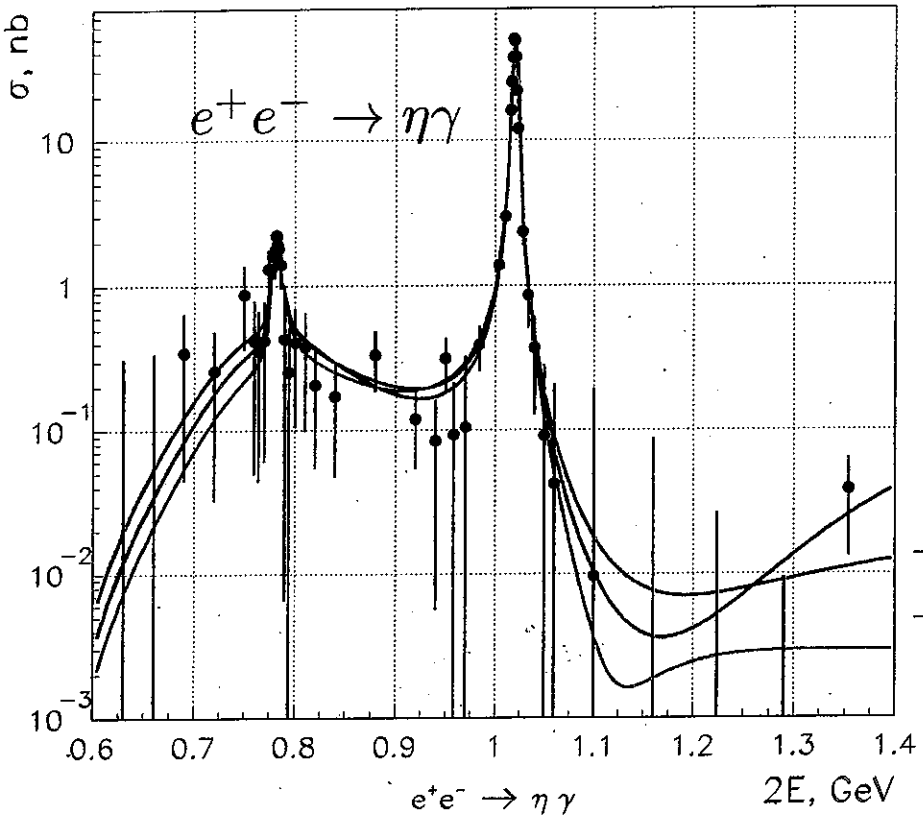




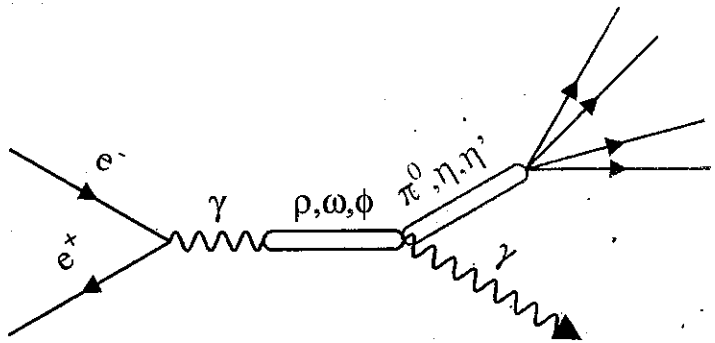




Radiative decays of the vector mesons



$V \to P\gamma$



	CMD2	SND
$Br(\rho \to \pi^0\gamma) \cdot 10^4$		$5.03 \pm 1.17 \pm 0.83$
$Br(\omega \to \pi^0\gamma) \cdot 10^2$		$9.17 \pm 0.16 \pm 0.46$
$Br(\phi \to \pi^0\gamma) \cdot 10^3$		$1.23 \pm 0.04 \pm 0.09$
$Br(\rho \to \eta\gamma) \cdot 10^4$	$3.28 \pm 0.37 \pm 0.23$	$2.77 \pm 0.26 \pm 0.16$
$Br(\omega \to \eta\gamma) \cdot 10^4$	$5.10 \pm 0.72 \pm 0.34$	$4.22 \pm 0.47 \pm 0.17$
$Br(\phi \to \eta\gamma) \cdot 10^2$	$1.29 \pm 0.01 \pm 0.06$	$1.34 \pm 0.01 \pm 0.05$
$Br(\phi \to \eta'\gamma) \cdot 10^5$	6.4 ± 1.6	$4.9^{+1.6}_{-1.5}$
		KLOE $6.8 \pm 0.6 \pm 0.5$

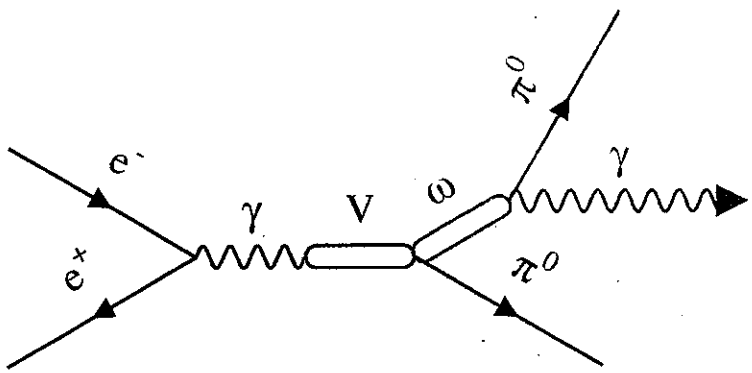
'DM(ρ, ω, ϕ)

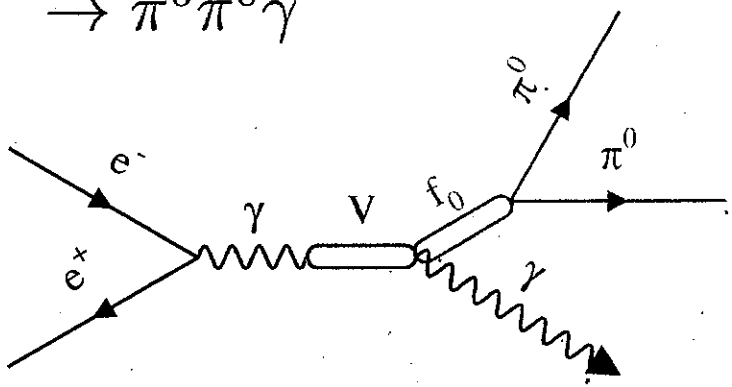
'DM(ρ, ω, ϕ)+ρ'

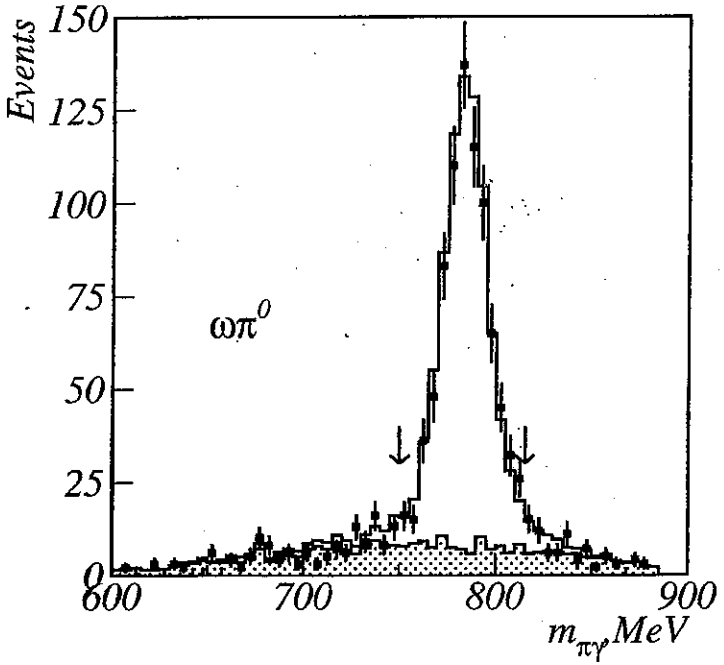
'DM(ρ, ω, ϕ)+Triangle anomaly

Radiative decays of the vector mesons

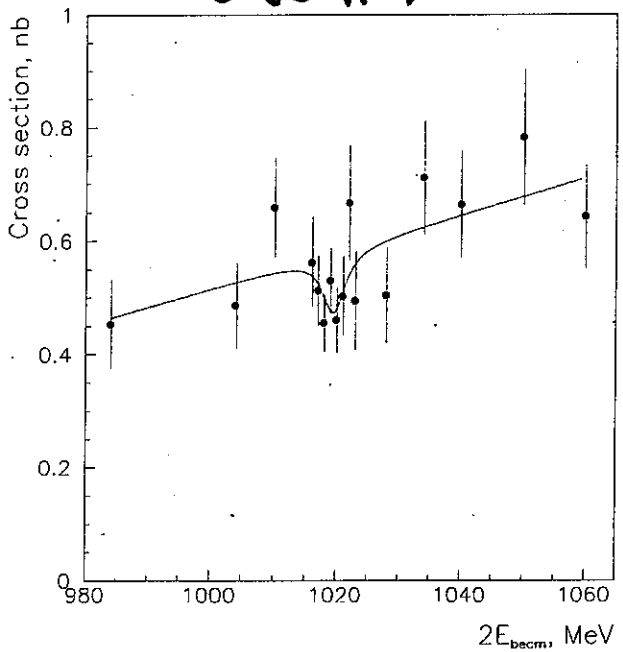
$$e^+e^- \to \pi^0\pi^0\gamma$$





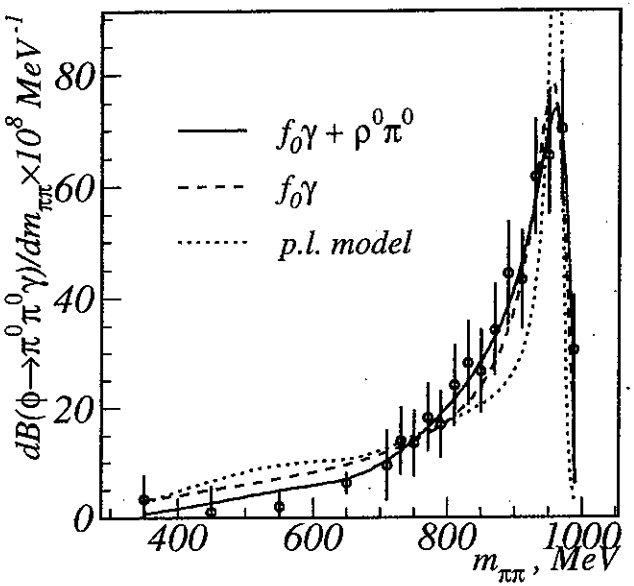


σ(ωπ°)

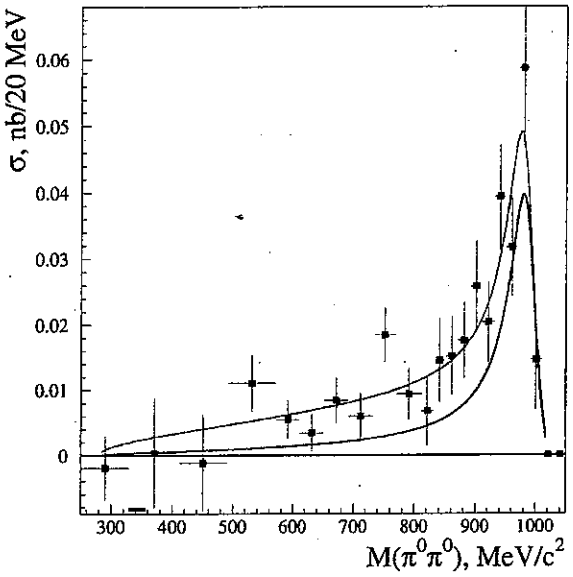


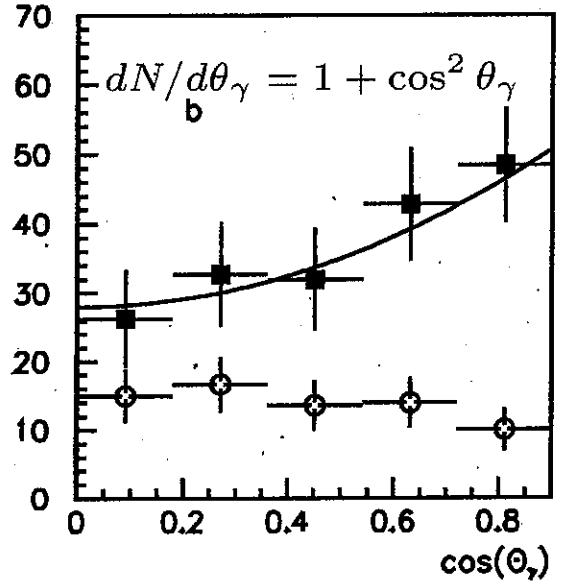
$e^+e^- \to \pi^0\pi^0\gamma$

SND



CMD-2



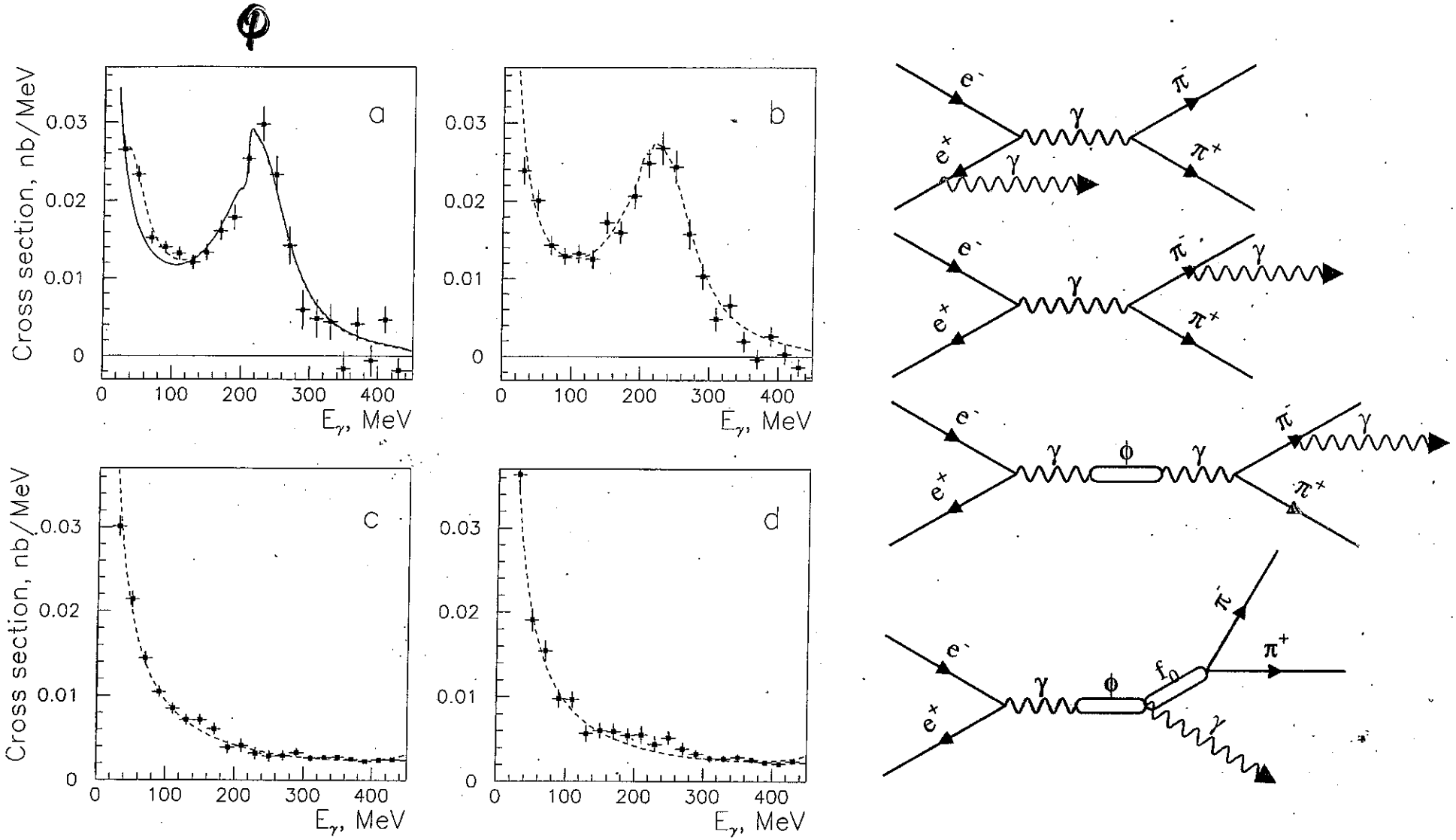


$\phi \to (f_0 + \sigma)\gamma$

	SND	CMD2
$Br(\phi \to \pi^0\pi^0\gamma)\cdot 10^4$	$1.22 \pm 0.10 \pm 0.06$	$0.92 \pm 0.08 \pm 0.06$
$Br(\phi \to f_0\gamma)\cdot 10^4$	$3.5 \pm 0.3^{+1.3}_{-0.5}$	$2.90 \pm 0.21 \pm 1.54 (4.47 \pm 0.21 (\mathrm{KLOE}))$
$M_{f_0}(MeV/c^2)$	969.4 ± 4.5	$975 \pm 4 \pm 6$
$g^2_{fK^+K^-}/4\pi(GeV^2)$	$2.47^{+0.73}_{-0.51}$	1.48 ± 0.42
$g^2_{f\pi^+\pi^-}/4\pi(GeV^2)$	$0.54^{+0.09}_{-0.08}$	0.41 ± 0.06
$M_{f_0}(MeV/c^2)$	969.4 ± 4.5	$975 \pm 4 \pm 6$

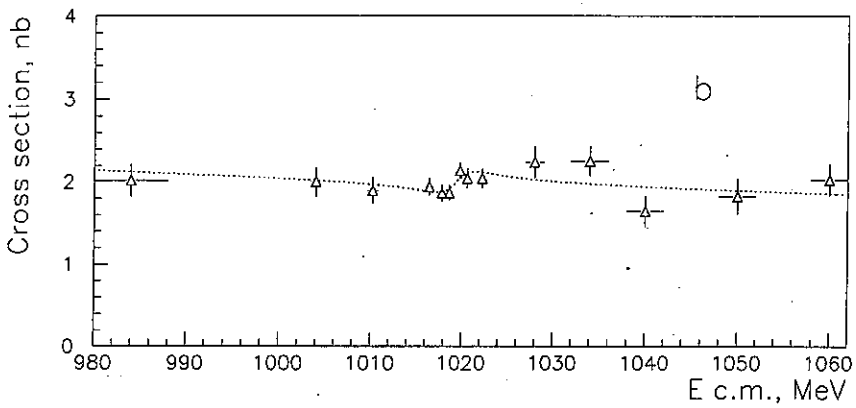
Radiative decays of the vector mesons

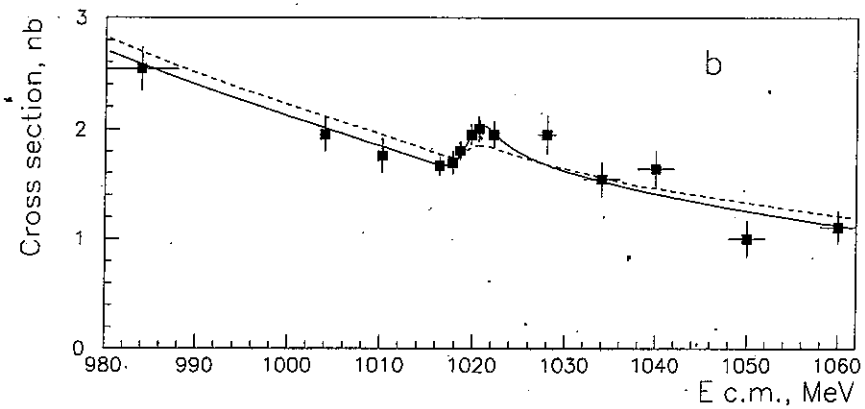
$$e^+e^- \to \pi^+\pi^-\gamma,\ \mu^+\mu^-\gamma$$



Radiative decays of the vector mesons

$$e^+e^- \to \pi^+\pi^-\gamma,\ \mu^+\mu^-\gamma$$





Crossection of $e^+e^- \to \mu^+\mu^-\gamma$ Crossection of $e^+e^- \to \pi^+\pi^-\gamma$

$$\sigma(s) = \sigma^{in}_{br}(s) + \sigma^{f}_{br}(s) \cdot |1 - e^{i\psi} A_\phi \frac{m_\phi \Gamma_\phi}{s - m^2_\phi + i\sqrt{s}\Gamma_\phi(s)}|^2$$

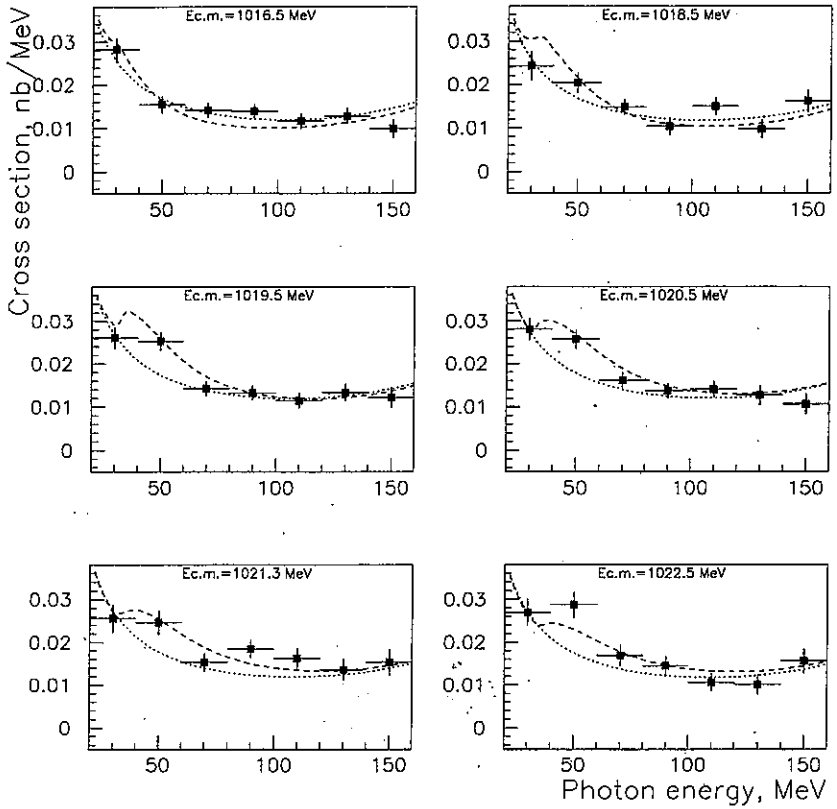
$$\sigma(\phi \to \pi\pi\gamma) = |A_\phi|^2 \cdot \sigma^f_{br}(m^2_\phi),\ Br(\phi \to \pi\pi\gamma) = \sigma(\phi \to \pi\pi\gamma)/\sigma^\phi_{tot}$$

$$Br(\phi \to \mu^+\mu^-\gamma) = (1.43 \pm 0.45 \pm 0.14) \times 10^{-5}\ Br^{th}(\phi \to \mu\mu\gamma) = 1.15 \times 10^{-5}$$

$$Br(\phi \to \pi^+\pi^-\gamma) = (0.41 \pm 0.12 \pm 0.04) \times 10^{-4}\ Br^{th}(\phi \to \pi\pi\gamma) = 0.047 \times 10^{-4}$$

The hadron contribution exist in $\phi \to \pi^+\pi^-\gamma$

Hadron decays $\phi \to \pi^+\pi^-\gamma$



qqqq model of f_0

$Br(\phi \to f_0\gamma) = (1.93 \pm 0.46 \pm 0.50) \times 10^{-4}$

$m_{f_0} = 976 \pm 5 \pm 6 MeV/c^2$

$\Gamma_{f_0} = 40\ MeV(fixed)$

$\psi = 1.55 \pm 0.22\ radians$

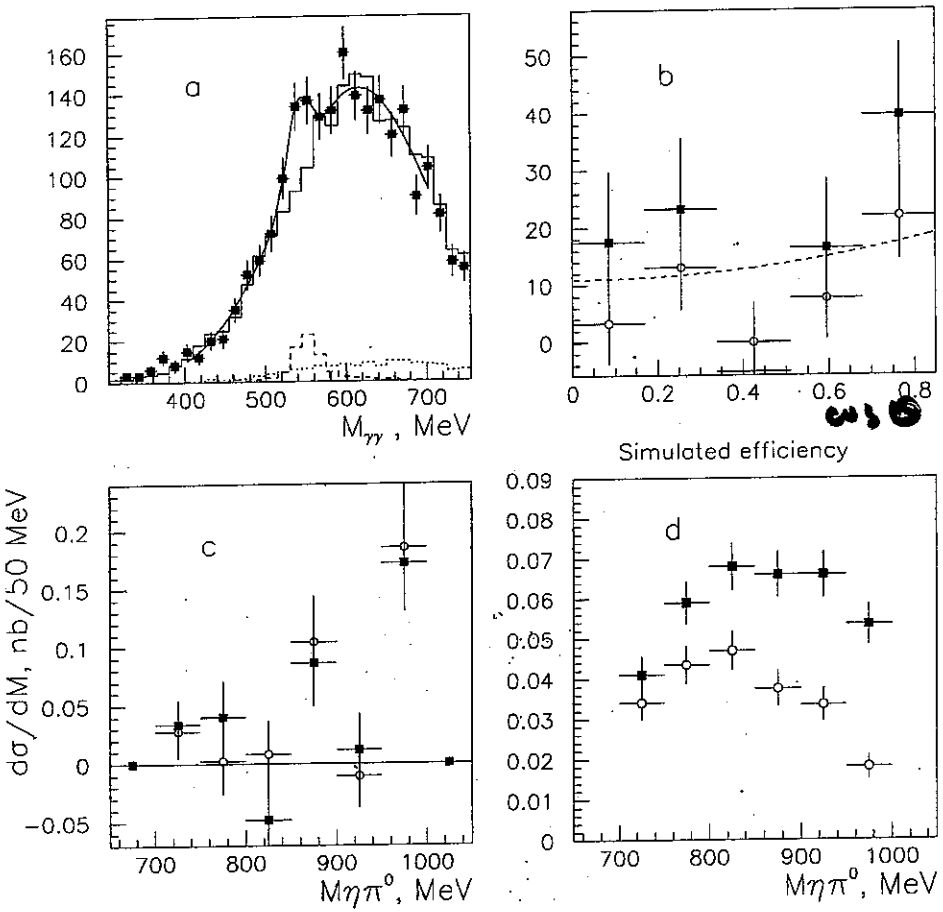
$\chi^2/N = 51/39$

$\chi^2/N = 131/39$ bremsstrahlung only

In $\phi \to \pi^+\pi^-\gamma$ there is resonance with $m \approx 980 MeV/c^2$

Obtained branching ratio value points to the qqqq structure of f_0.

$e^+e^- \to \eta\pi^0\gamma$



Selection: 5 photons in calorimeter;

anti-ω and anti-$\pi_0\pi_0\gamma$ cuts

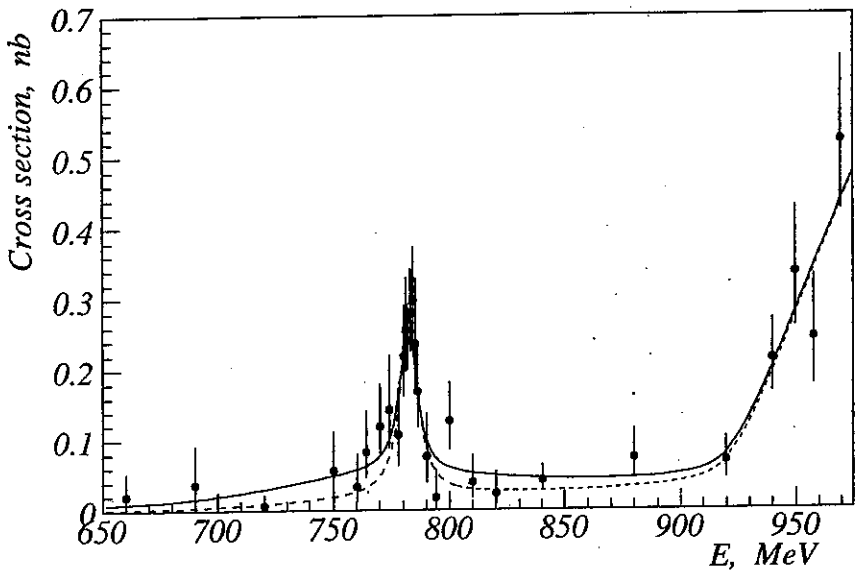
$E_\gamma^{max} < 0.75$

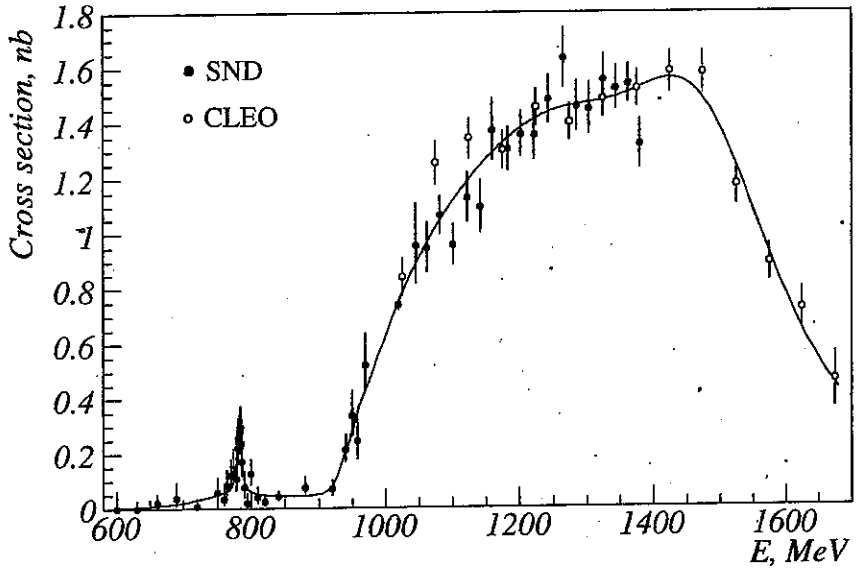
$N_{\eta\pi^0\gamma} = 80 \pm 22(37 \pm 12)$

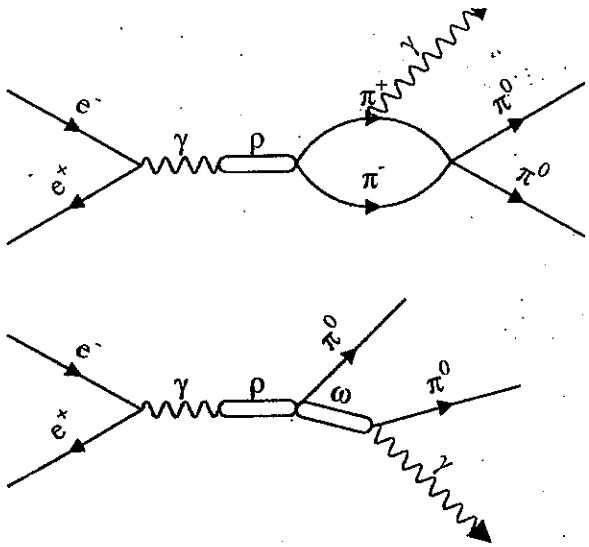
$Br(\phi \to \eta\pi^0\gamma) = (0.90 \pm 0.24 \pm 0.10) \cdot 10^{-4}$ (CMD-2) $(0.88 \pm 0.17)\,10^{-4}$ SND

$(\phi \to a_0\gamma)$(KLOE) $Br(\phi \to a_0\gamma \to \eta\pi^0\gamma) = (0.74 \pm 0.07) \cdot 10^{-4}$

$\rho, \omega \to \pi^0\pi^0\gamma$







$$A_{\pi\pi\gamma} = A_{\rho\omega\pi}(BW_\rho + BW_{\rho'} + BW_{\rho''}) + \beta A_{\rho\sigma\gamma} BW_\rho + \gamma A_\omega BW_\omega$$

$$Br(\rho \to \pi^0\pi^0\gamma) = \frac{m_\rho^2}{\Gamma_\rho^2 \sigma_p} \int |A_{\rho\omega\pi}(m_\rho) + \beta A_{\rho\sigma\gamma}(m_\rho) d\Pi|^2 =$$

$$(4.1^{+1.0}_{-0.9} \pm 0.3) \cdot 10^{-5}$$

$$Br(\rho \to \sigma\gamma) = \frac{m_\rho^2}{\Gamma_\rho^2 \sigma_p} \int |\beta A_{\rho\sigma\gamma}(m_\rho) d\Pi|^2 = (1.9^{+0.9}_{-0.8} \pm 0.4) \cdot 10^{-5}$$

$$Br(\omega \to \pi^0\pi^0\gamma) = \frac{m_\omega^2}{\Gamma_\omega^2 \sigma_\omega} \int |\gamma A_\omega(m_\rho) d\Pi|^2 = (6.6^{+1.4}_{-1.3} \pm 0.6) \cdot 10^{-5}$$

M.N. Achasov, e.a.Phys.Lett.B537:201-210,2002

(g-2)/2 for μ

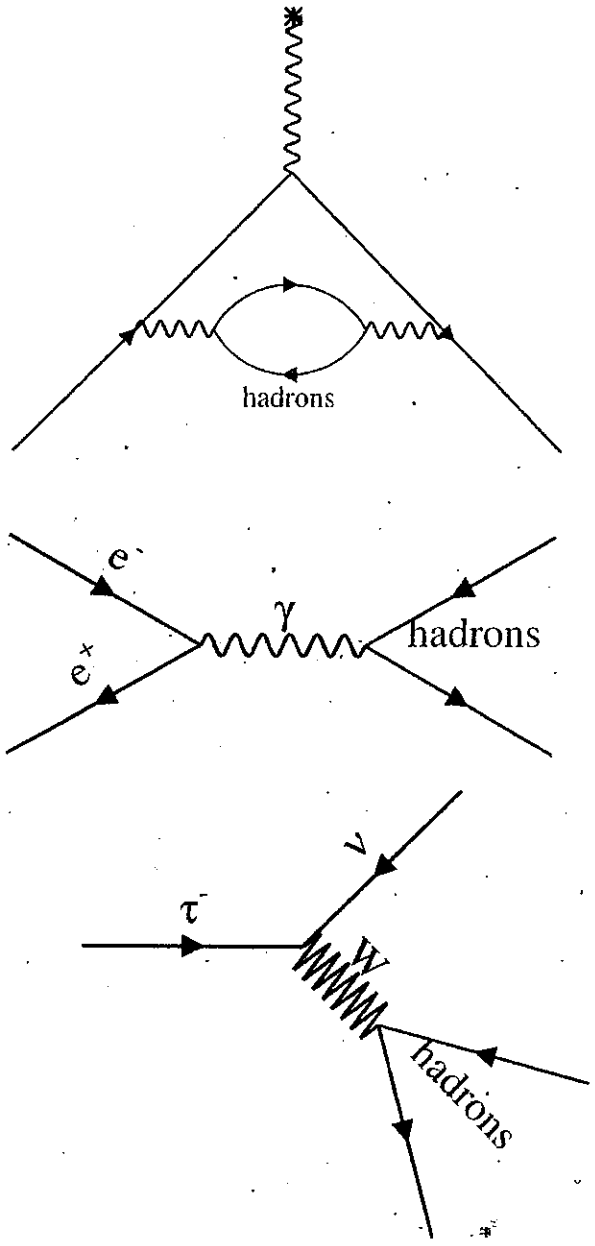
hadronic contribution to $a_\mu = \frac{g-2}{2}$ cannot be calculated from the first principles, but can be calculated from the $e^+e^- \to hadron$ crossection.

$R(s) = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$

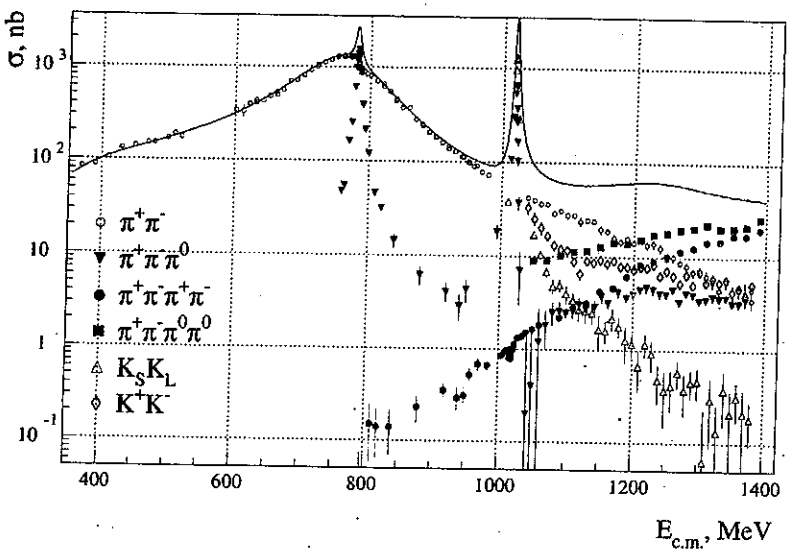
$a_\mu(had) = (\frac{\alpha m_\mu}{3\pi})^2 \int_{4m\pi^2}^{\infty} \frac{ds}{s} K(s)R(s)$

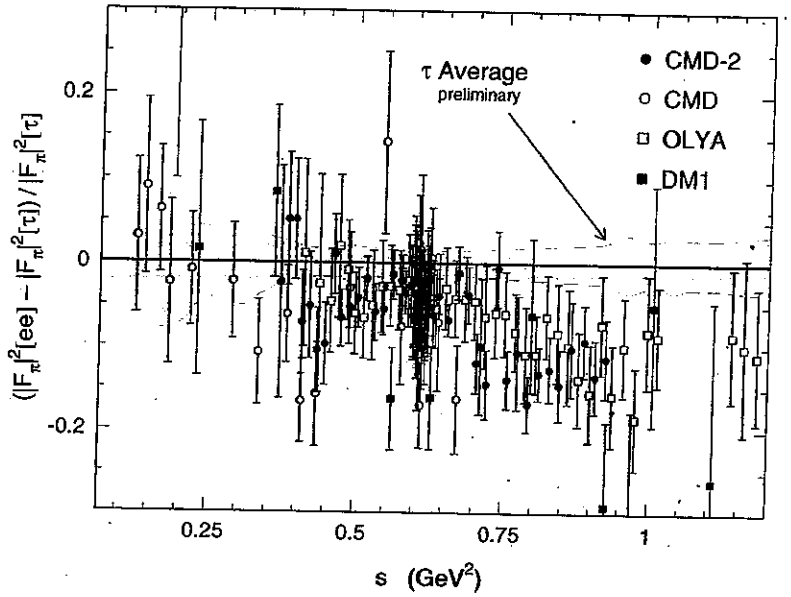
The main contribution both to the value of a_μ and to uncertainty is contributed by the low energy region.

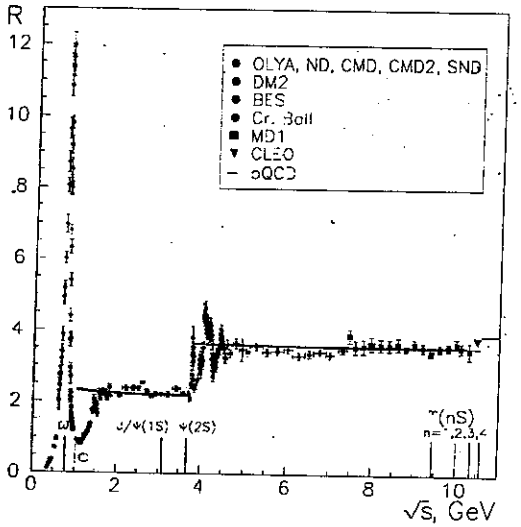
Isovector part can be calculated from τ-decays.

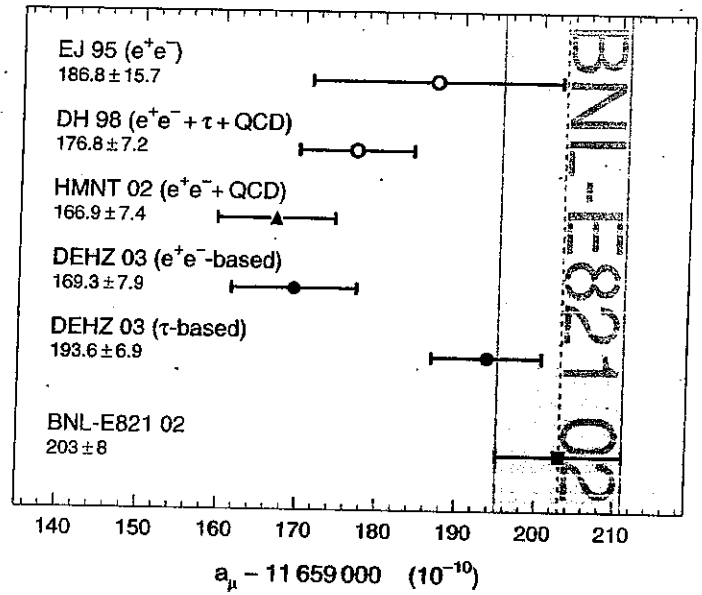


(g-2)/2 for μ

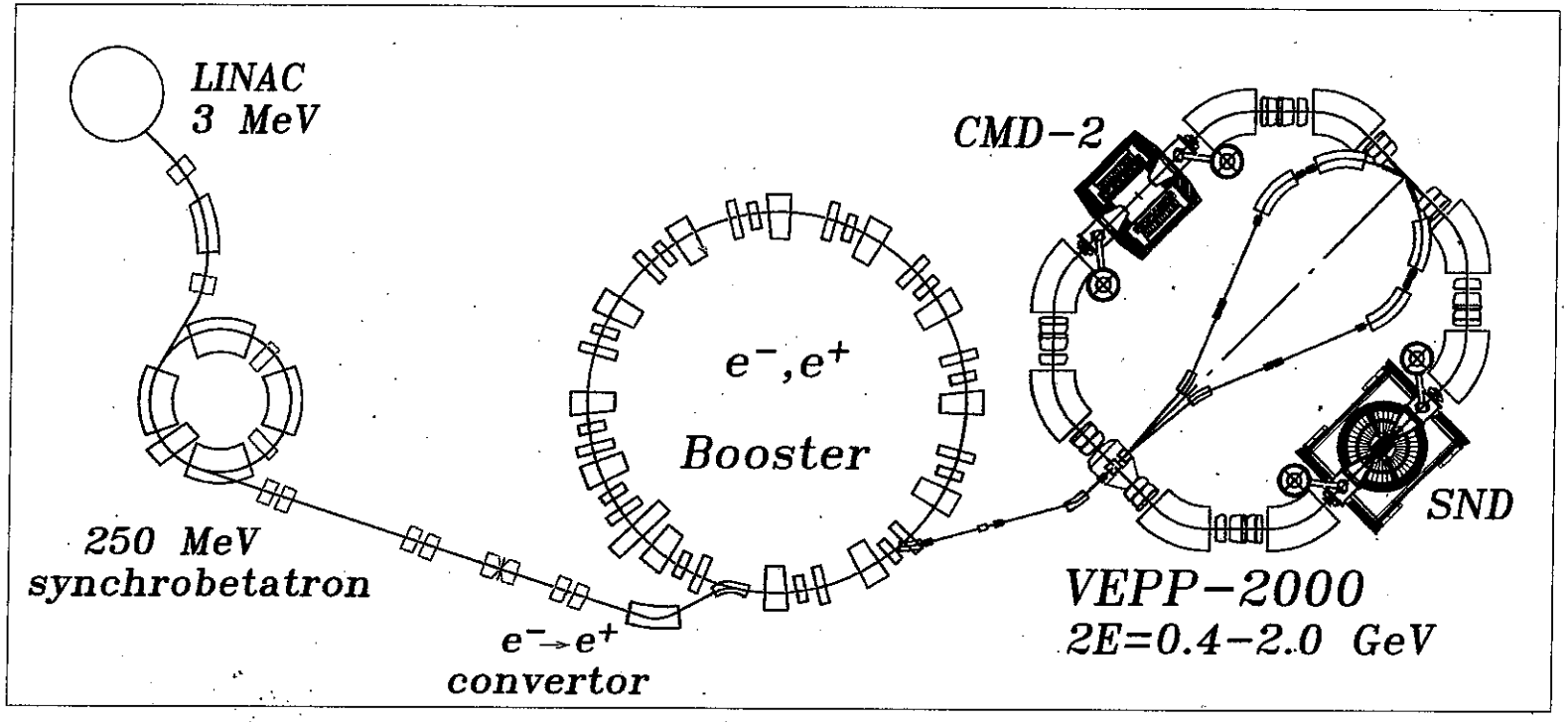

σ, nb
10^3
10^2
10
1
10^{-1}
$\pi^+\pi^-$
$\pi^+\pi^-\pi^0$
$\pi^+\pi^-\pi^+\pi^-$
$\pi^+\pi^-\pi^0\pi^0$
K_SK_L
K^+K^-
400
600
800
1000
1200
1400
$E_{c.m.}$, MeV


τ Average
preliminary
CMD-2
CMD
OLYA
DM1
$(|F_\pi|^2[ee] - |F_\pi|^2[\tau]) / |F_\pi|^2[\tau]$
0.2
0
-0.2
0.25
0.5
0.75
1
s (GeV^2)


R
12
10
8
6
4
2
0
OLYA, ND, CMD, CMD2, SND
DM2
BES
Cr. Ball
MD1
CLEO
pQCD
ω
J/ψ(1S)
ψ(2S)
IC
Υ(nS)
n=1,2,3,4
0
2
4
6
8
10
√s, GeV

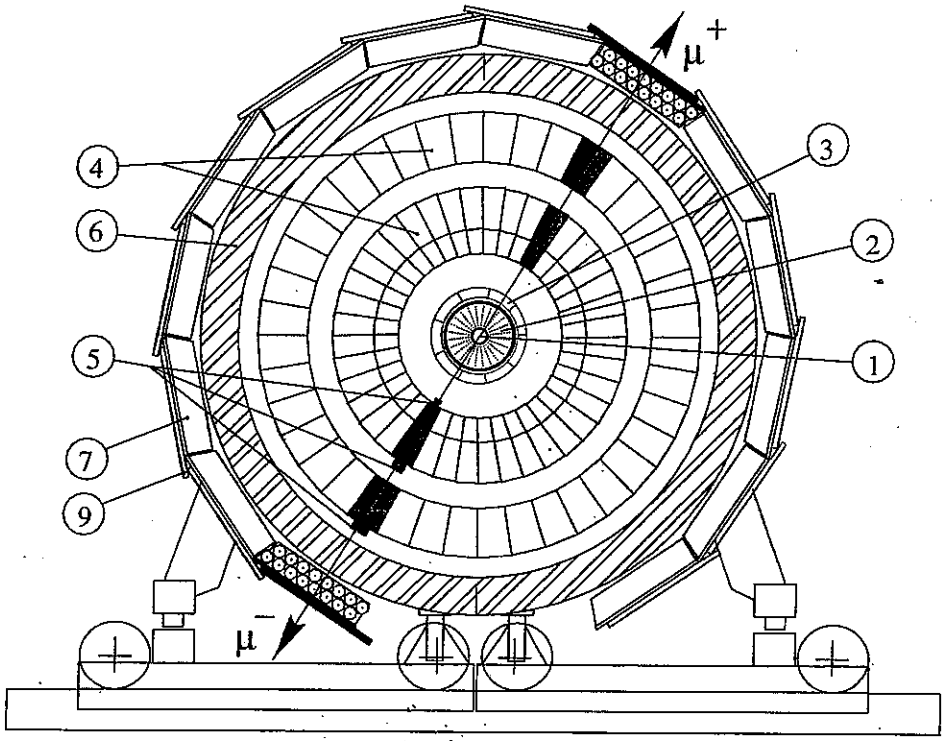

EJ 95 (e^+e^-)
186.8 ± 15.7
DH 98 (e^+e^- + τ + QCD)
176.8 ± 7.2
HMNT 02 (e^+e^- + QCD)
166.9 ± 7.4
DEHZ 03 (e^+e^--based)
169.3 ± 7.9
DEHZ 03 (τ-based)
193.6 ± 6.9
BNL-E821 02
203 ± 8
3.3σ
140
150
160
170
180
190
200
210
a_μ − 11 659 000 (10^{-10})

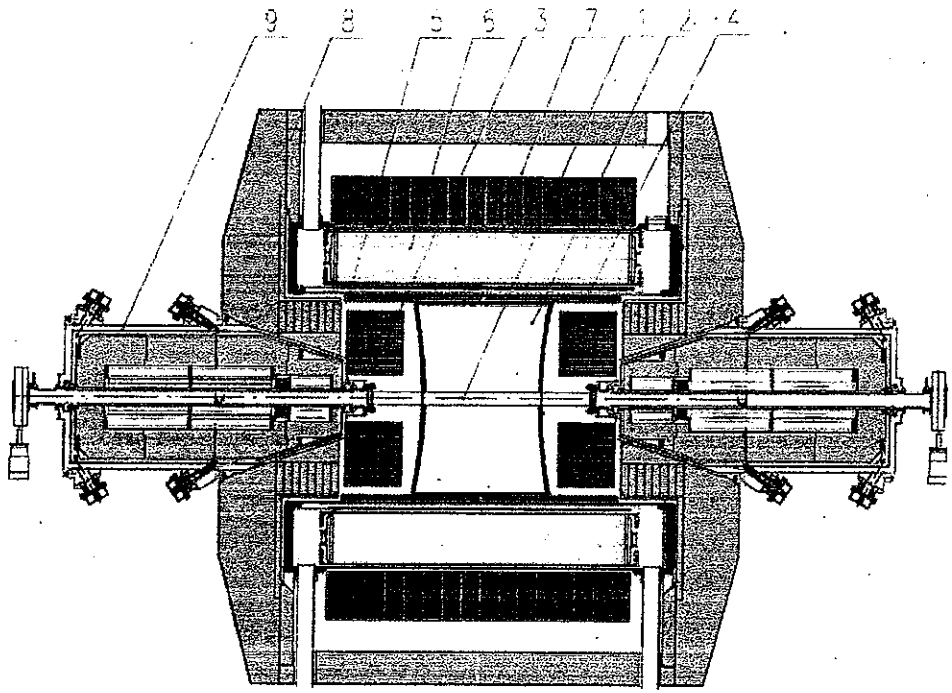
Layout of the VEPP–2000 complex



	VEPP-2M	VEPP-2000
Energy, GeV	0.4 - 1.4	0.4 - 2.0
Circumference, m	17.9	24.5
Current, mA	40	34-200
Luminosity, $cm^{-2}s^{-1}$	3×10^{30}	$10^{31} - 10^{32}$

VEPP-2000





- Total crossection of hadron production (a_μ, α_s, test of CVC)
- Hadrons physics (glueballs, hybrids...)
- Nuclon formfactor near the threshold.

Summary

- Mass, width and Branching fractions of the light vector mesons(ρ, ω, ϕ) have been measured with high accuracy.
- In a few cases the decay modes have been observed first time($\phi \to \eta'\gamma$, $\phi \to \pi^0\eta\gamma$, $\phi \to \pi^0\pi^0\gamma$)
- Large data sample has provided possibility to study the dynamic of the multihadron processes(3π, 4π, 5π)
- Total crossection has been measured in the energy range 0.4-1.4 GeV with small statistical and systematic uncertainties.
- VEPP-2000 will provide more possibilities and bring more interesting physical results.