Recent Results on Low Energy $e^+e^- \to hadrons$

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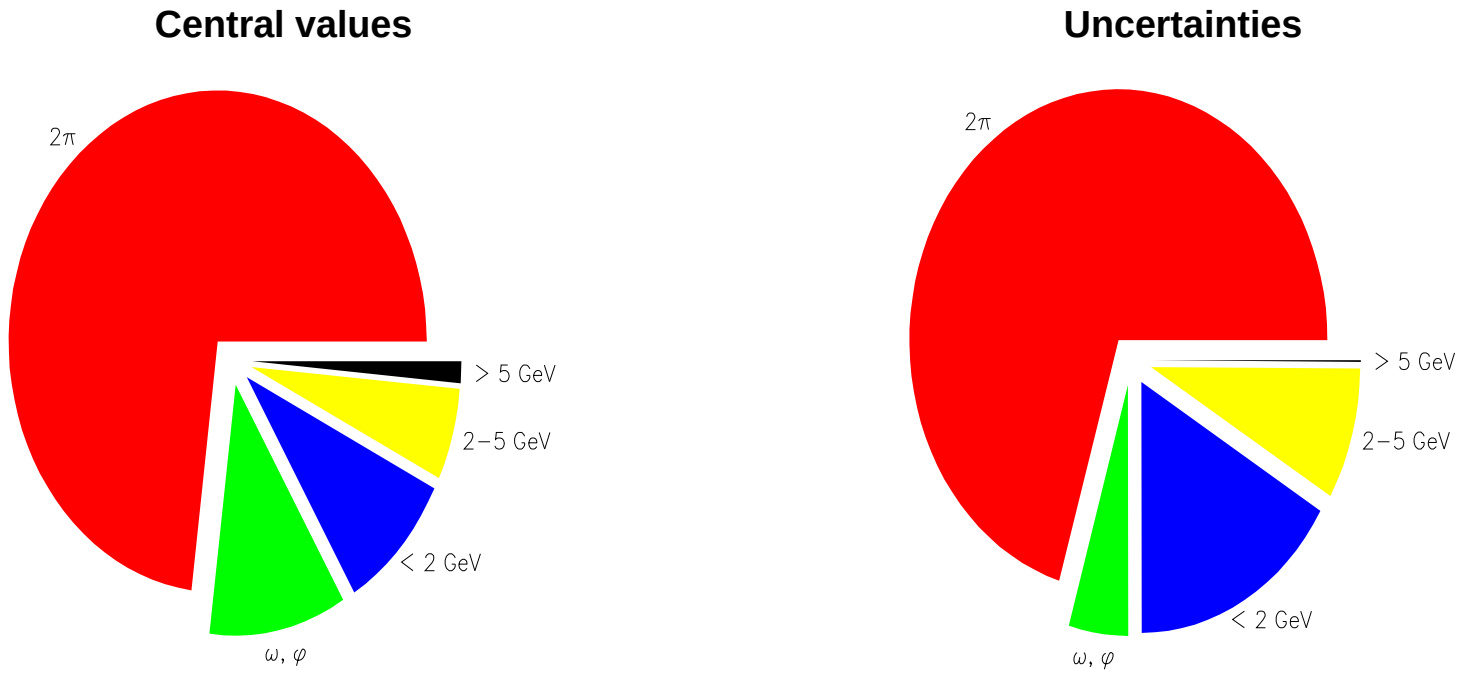
Outline

1. Interest to low energy e^+e^-
2. Experiments at VEPP-2M ($e^+e^- \to \pi^+\pi^-, \dots$)
3. Future (VEPP-2000)
4. Conclusions

Physics from Low Energy e^+e^- Collisions

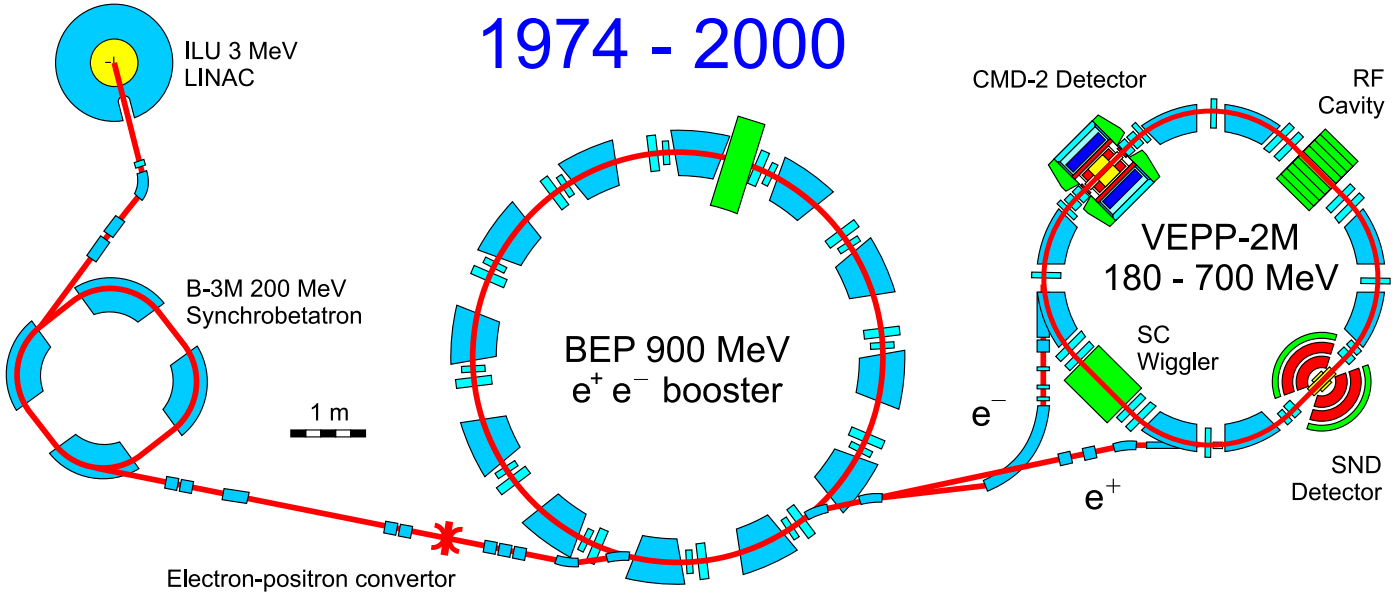
1. Interactions of light quarks (u, d, s) – input to QCD
   - Light Quarkonia (ρ, ω, ϕ and their excitations)
   - Tests of ChPT, Vector Dominance
   - Search for exotics (hybrids, glueballs, $N\bar{N}$)
2. Sum rules ($\int R(s)K(s)ds$) with $K(s)$ emphasizing the role of low energies
   - Running fine structure constant α
   - Hadronic contributions to $a_\mu = (g_\mu - 2)/2$
   - Test of CVC relations between e^+e^- and τ decays to $J^P = 1^-$ states
   - QCD (α_s, quark masses, quark and gluon condensates)
   - Muonium HFS

Hadronic contributions to a_μ



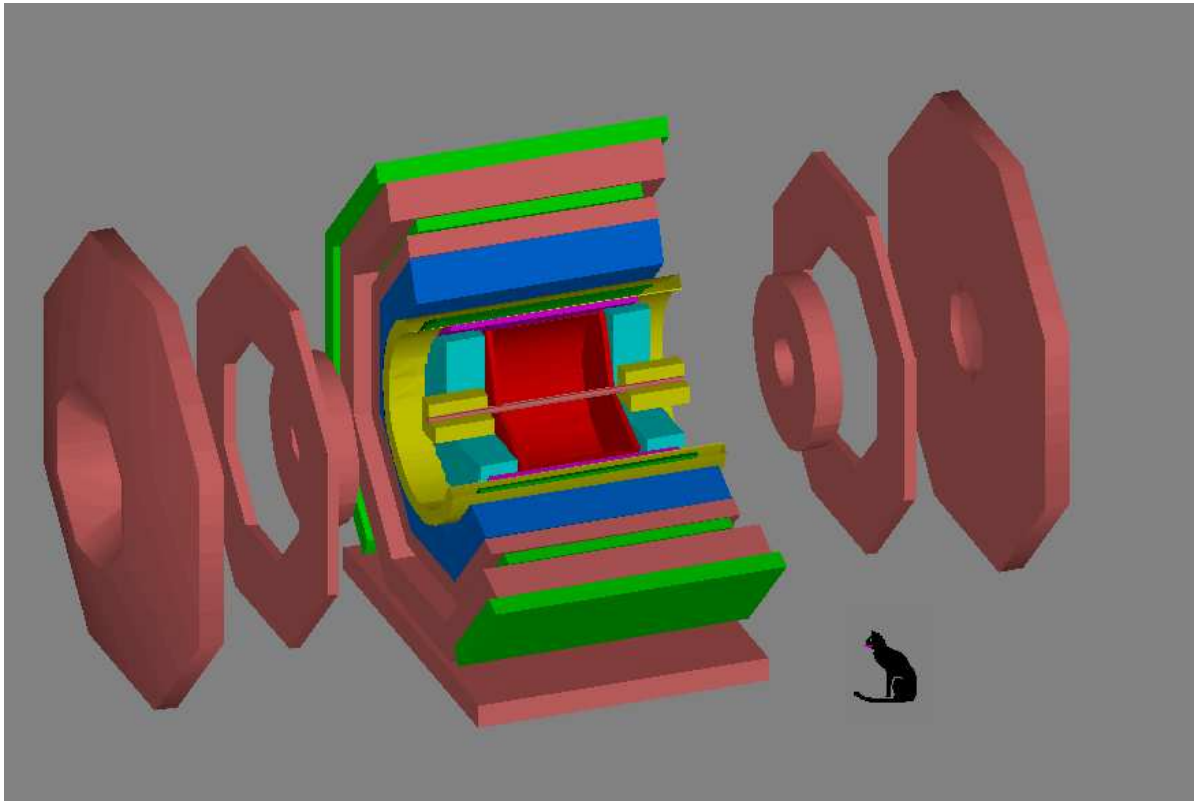
$\pi\pi$ – about 73%, $\sqrt{s} < 2$ GeV – 92%

VEPP-2M Collider in Novosibirsk

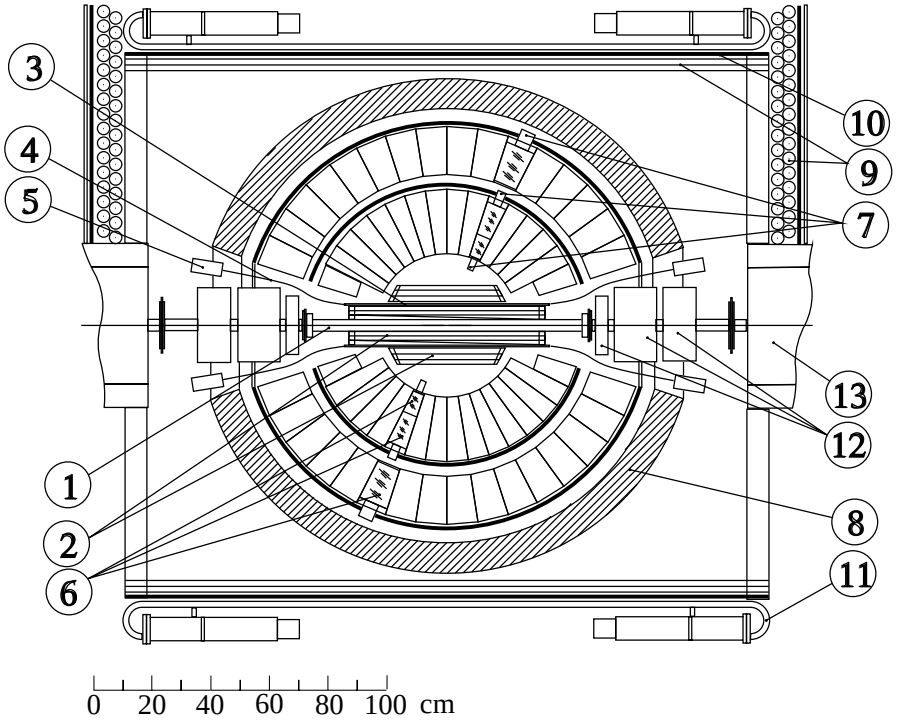


- Peak luminosity: $L_{\rm peak} = 3 \cdot 10^{30}$ cm^{-2} s^{-1}
- Integrated luminosity ≈ 100 pb^{-1} in Novosibirsk below 1.4 GeV compared to ≈ 6 pb^{-1} in Orsay and Frascati at $1.4 < \sqrt{s} < 3.0$ GeV!

CMD-2 Detector



SND Detector



SND detector: 1 - beam pipe; 2 - drift chambers; 3 - scintillation counters; 4 - light guides; 5 - PMT's; 6 - NaI(Tl) crystals; 7 - vacuum phototriodes; 8 - iron absorber; 9 - streamer tubes; 10 - 1 cm iron plates; 11 - scintillation counters; 12 and 13 - elements of the collider magnetic system

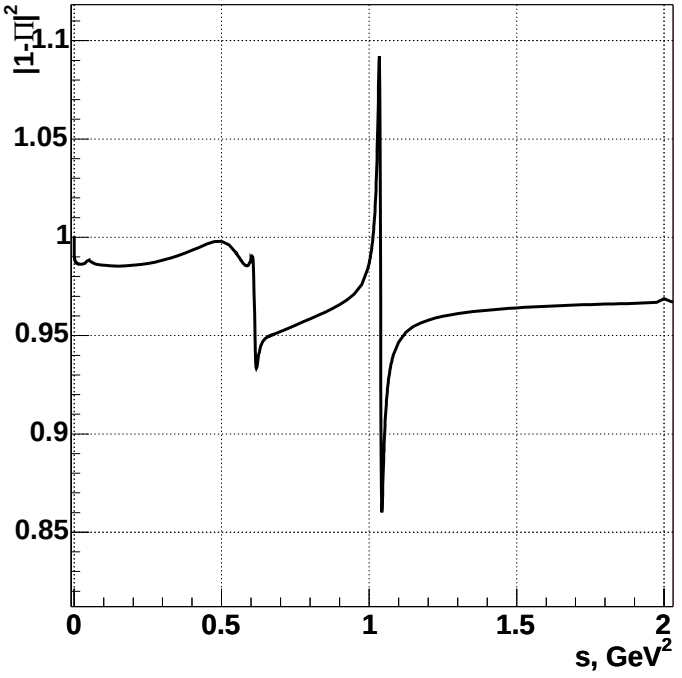
Some Features of Experiments with CMD-2 and SND

- large data samples due to the high integrated luminosity and large acceptance (calorimetry in $\Omega \approx 0.9 \times 4\pi$)
- multiple scans of the same energy range to avoid possible systematics; $\Delta(\sqrt{s}) = 10$ MeV in the continuum and 1 MeV near the ω and ϕ peaks
- absolute calibration of the beam energy using the resonance depolarization method $\Longrightarrow$ a negligible systematic error from an uncertainty in the energy measurement
- good space and energy resolution lead to small background
- redundancy - unstable particles are independently detected via different decay modes ($\pi^0 \to 2\gamma, e^+e^-\gamma$; $\eta \to 2\gamma, \pi^+\pi^-\pi^0, 3\pi^0$; $\omega \to \pi^+\pi^-\pi^0, \pi^0\gamma$)
- detection efficiencies and calorimeter response are studied by using "pure" experimental data samples rather than Monte Carlo events: more than 20 million ω and ϕ meson decays can be used.

How Do We Measure R?

- $\sqrt{s} < 2$ GeV – exclusive modes ($\pi^+\pi^-, \pi^+\pi^-\pi^0, \ldots, K\bar{K}, \ldots$)
- Possibly missing (small σ, undetected) final states
- Above 2 GeV – total R (all multihadronic events)
- Initial state radiation (ISR), vacuum polarization (VP), final state radiation (FSR): M. Drees, K. Hikasa, 1990

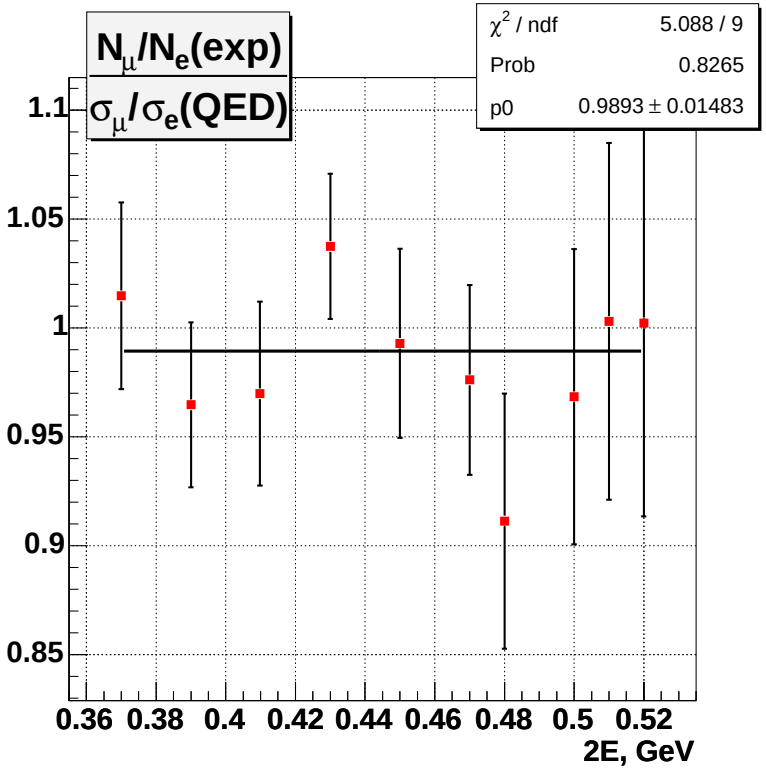
$$\sigma_{\rm bare} = \sigma_{\rm dressed}|1-\Pi(s)|^2$$

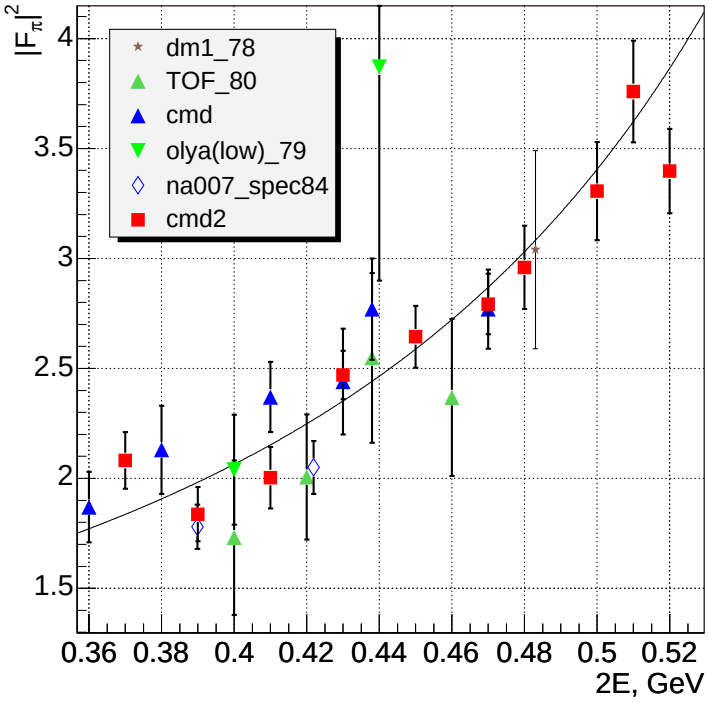


$$|1-\Pi(s)|^2$$

$e^+e^- \to \pi^+\pi^-$ at CMD-2. 370 MeV $< \sqrt{s} <$ 600 MeV

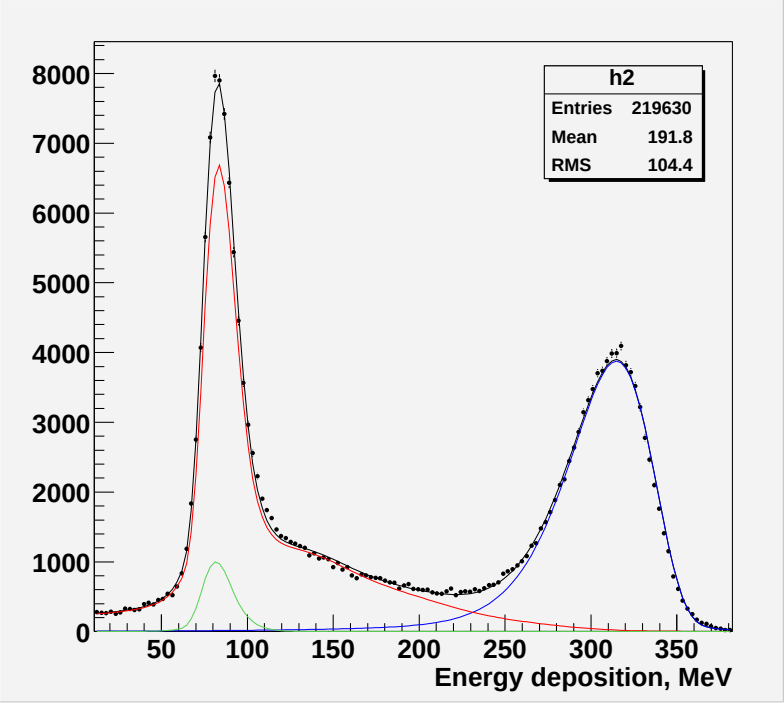
$N_{ev} = 4000$, $e/\mu/\pi$ separation by the momentum in DC

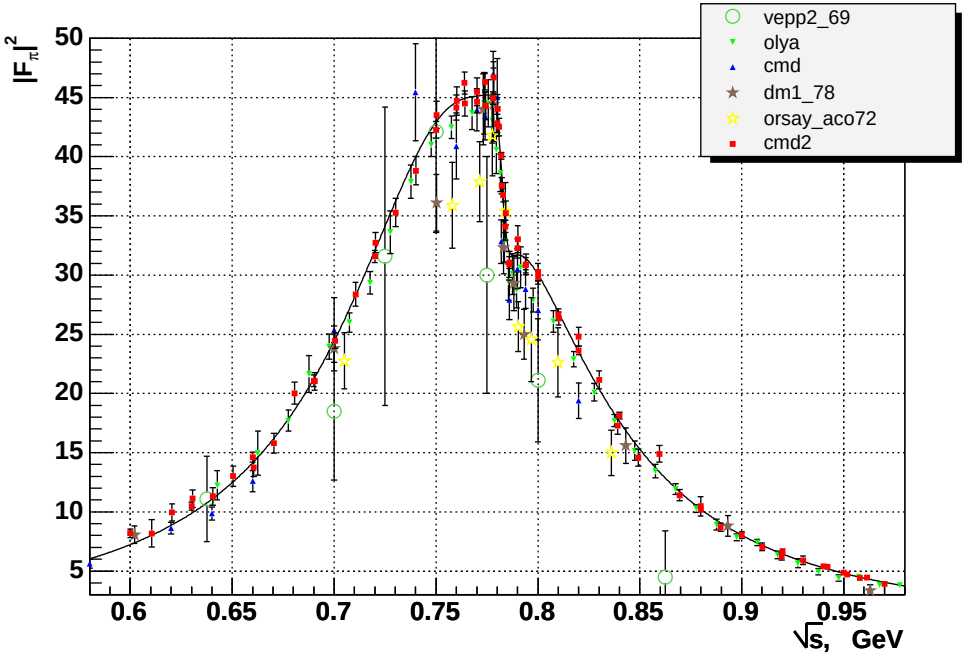




$e^+e^- \to \pi^+\pi^-$ at CMD-2. 610 MeV $< \sqrt{s} <$ 960 MeV

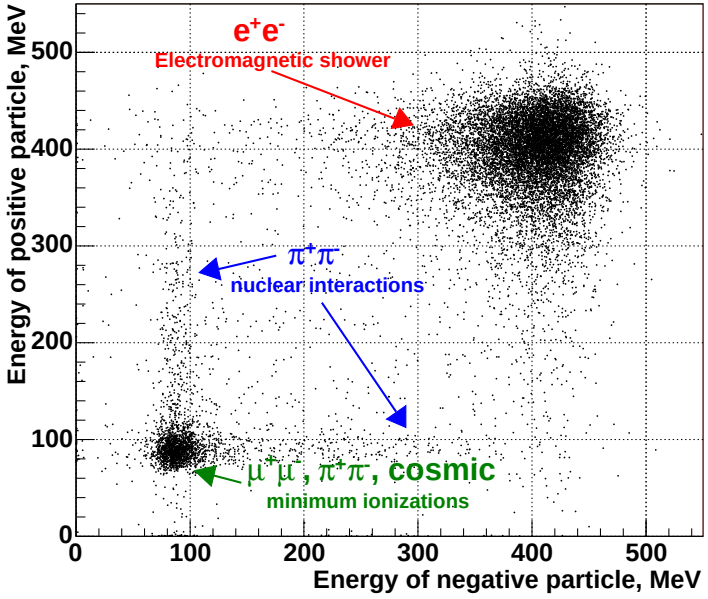
$N_{\rm ev} \approx 630 \cdot 10^3$, $e, \mu/\pi$ separation by energy deposition in CsI

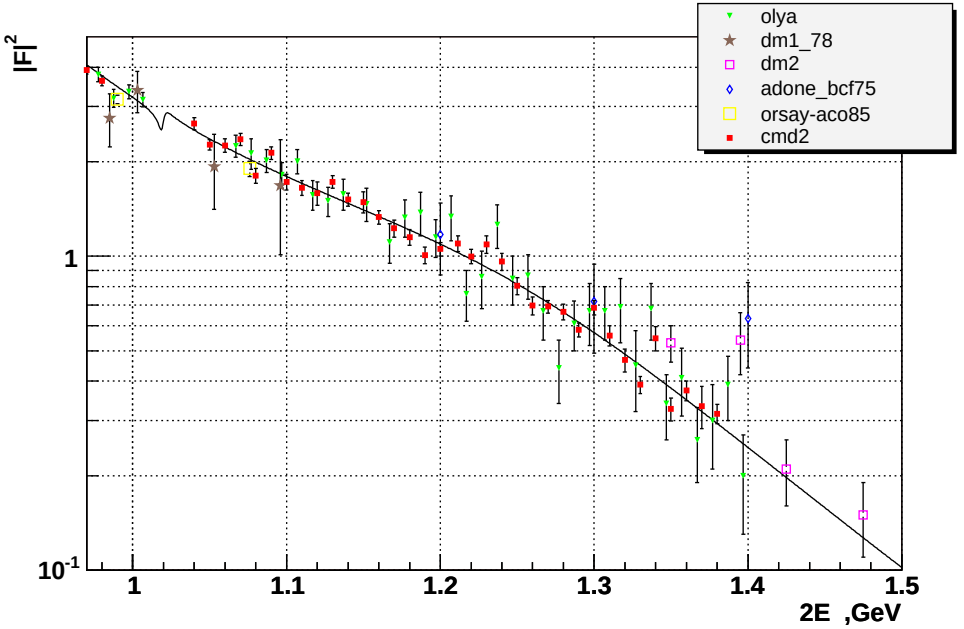




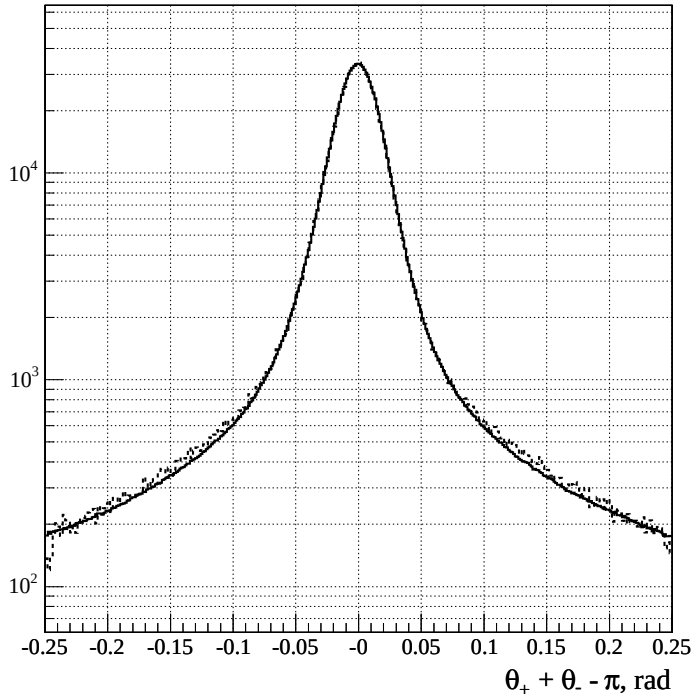
$e^+e^- \to \pi^+\pi^-$ at CMD-2. 1040 MeV $< \sqrt{s} <$ 1380 MeV

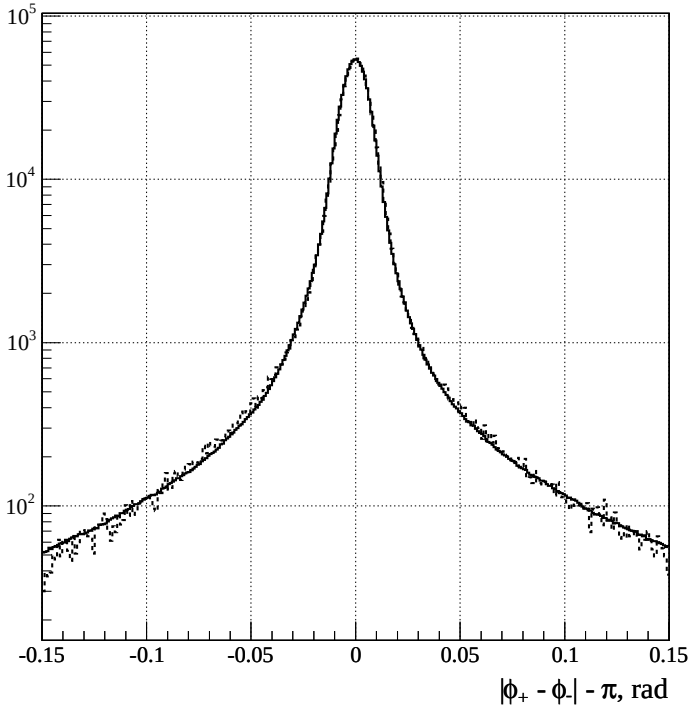
$N_{\rm ev} = 33 \cdot 10^3$, $e, \mu/\pi$ separation by energy deposition in CsI





Radiative corrections



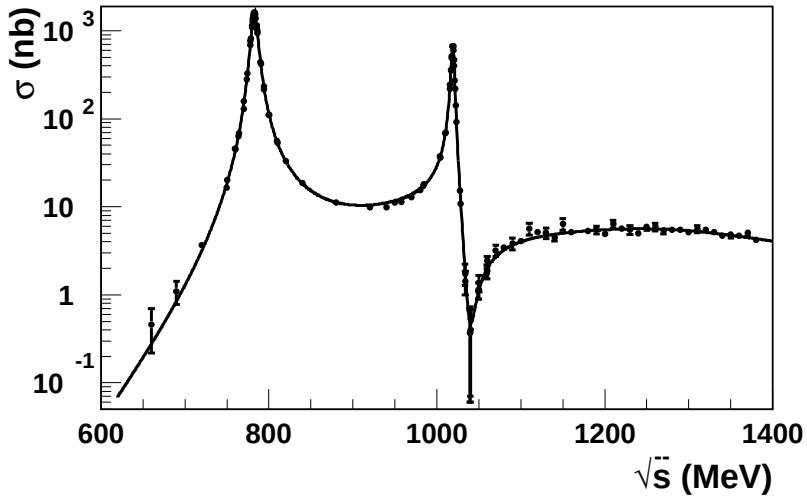


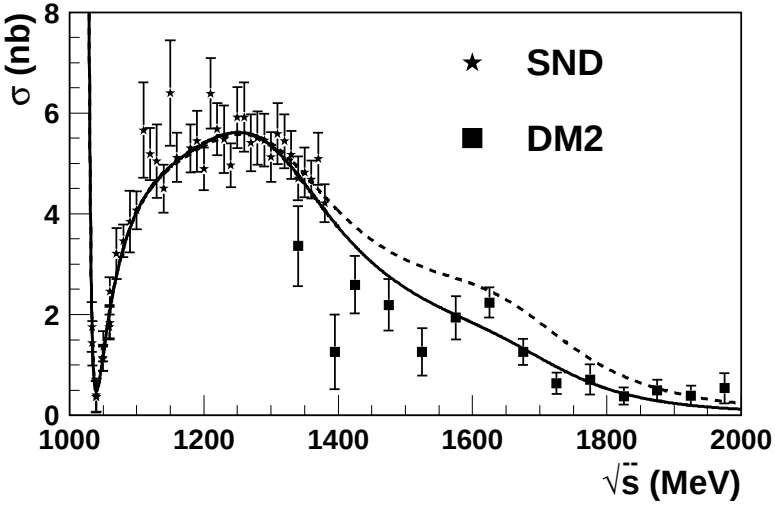
CMD-2 is using a MC generator based on A. Arbuzov et al., 1997; its accuracy $\sim 0.2\%$; agrees with BHWIDE and BABAYAGA within claimed accuracy.

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

Source $/\sqrt{s}$, GeV	0.37÷0.52	0.6÷0.96		1.04÷1.38
$N_{\pi\pi}, 10^3$ / Number of points	4/10	114/43	520/29	33/36
Stat. error/point, %	6.0	4.0	1.5	5.0 ÷ 13.0
Fiducial volume, %	0.2	0.2		0.2÷0.5
Detection efficiency, %	0.3	0.2	0.9	0.5÷2.0
Pion losses, %	0.2	0.2		0.2
Radiative corrections, %	0.3	0.4		0.5÷2.0
Background events, %	< 0.1	< 0.1		0.6÷1.6
Beam energy calibration, %	0.3	0.1	0.3	0.7÷1.1
Event separation, %	1.0	0.2		0.5÷3.5
Total systematic error, %	1.2	0.6	1.1	1.3÷5.0

Study of $e^+e^- \to \pi^+\pi^-\pi^0$ at SND

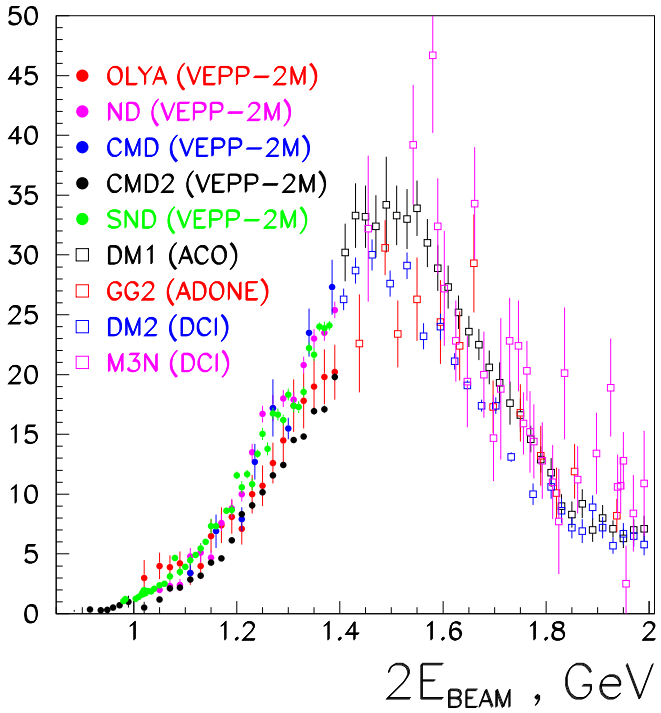




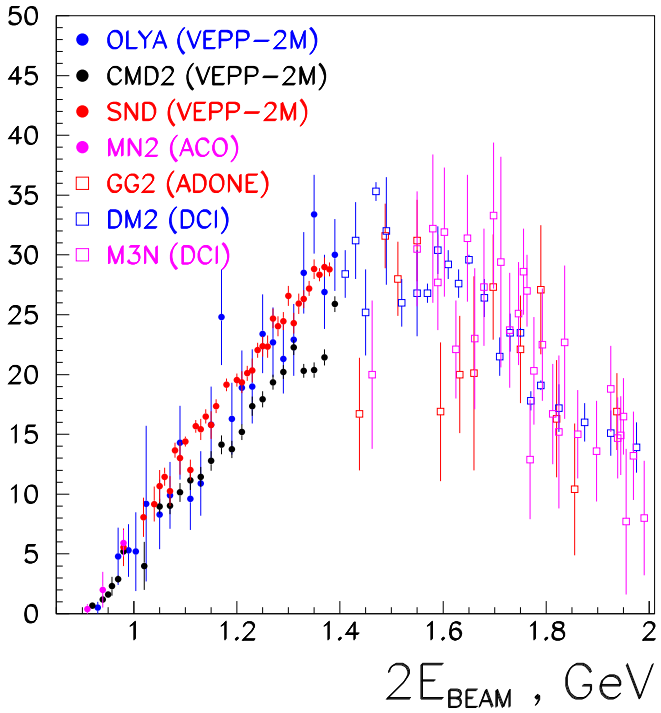
About $1.7 \cdot 10^6$ detected events. The systematic error is $\approx 5\%$. DM2 data are too low (by a factor of 1.6 or larger)!

Study of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ and $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$

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

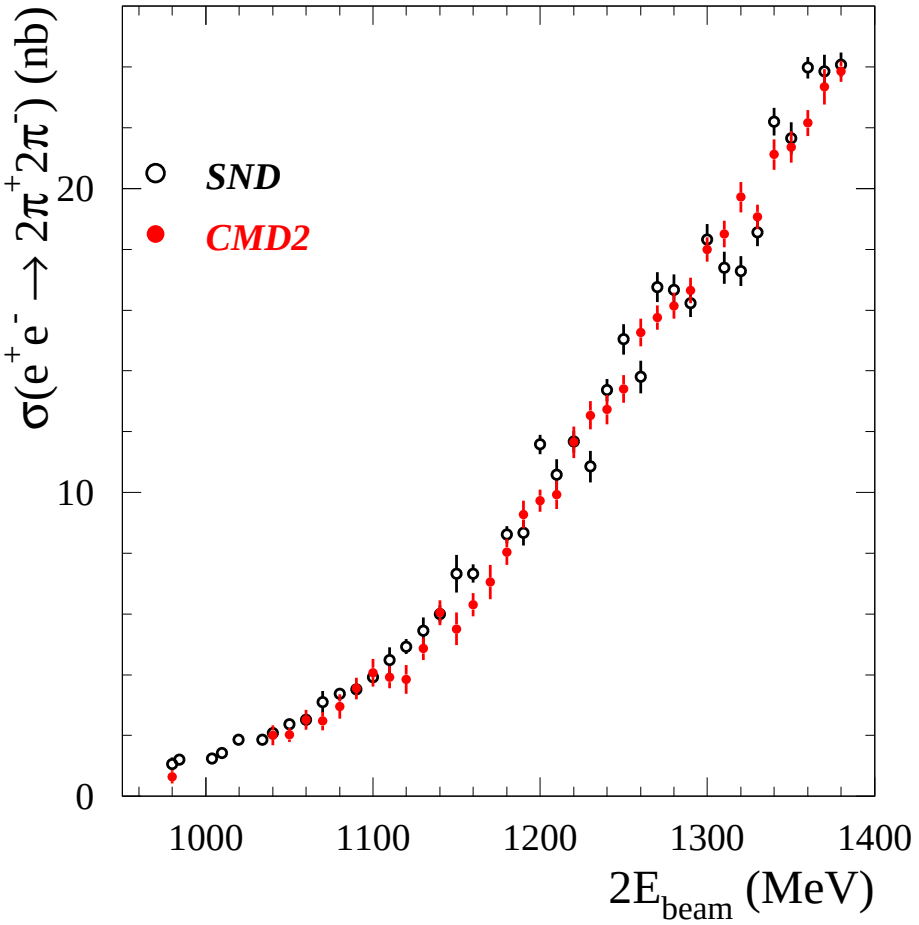


$e^+e^- \to \pi^+\pi^-\pi^0\pi^0$



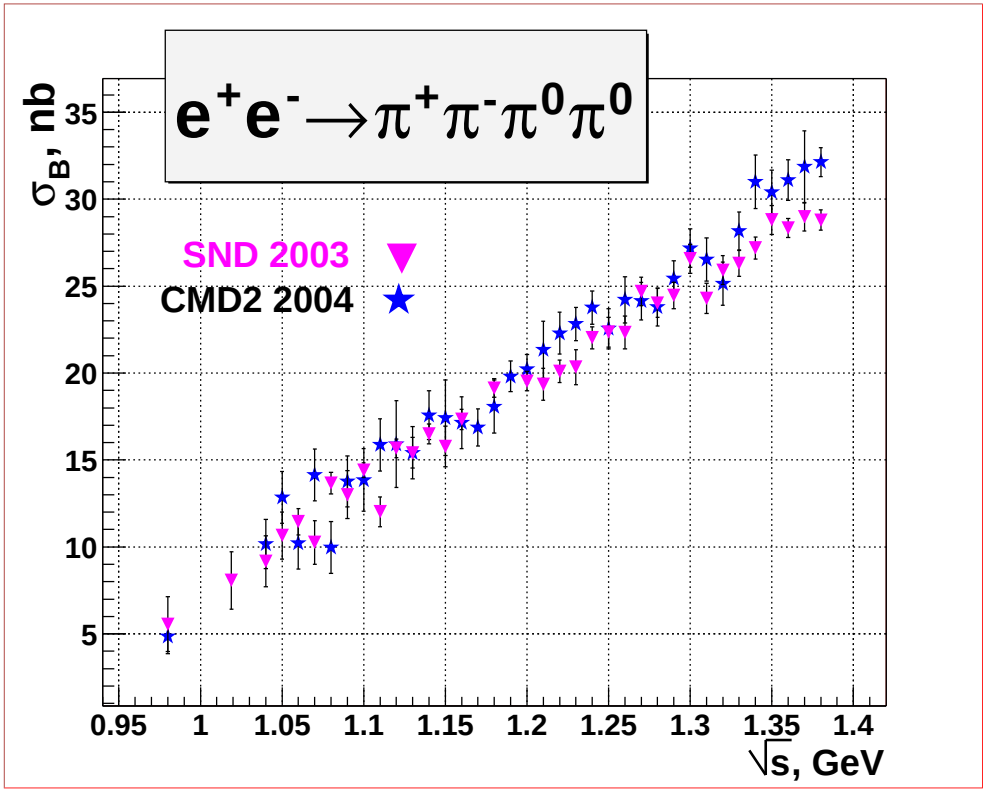
Large data scatter above 1.4 GeV!

Study of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-\pi^0\pi^0$ with CMD-2 and SND



CMD-2: $38 \cdot 10^3$ ev., (5–7)% syst.

SND: $41 \cdot 10^3$ ev., 7% syst.

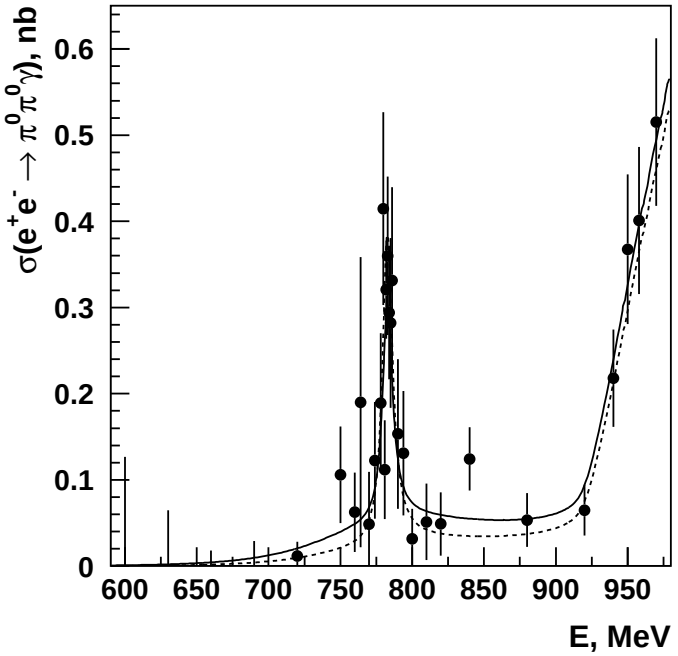


CMD-2: $10 \cdot 10^3$ ev.,, 6% syst.

SND: $54 \cdot 10^3$ ev., 8% syst.

Study of Neutral Final States at VEPP-2M

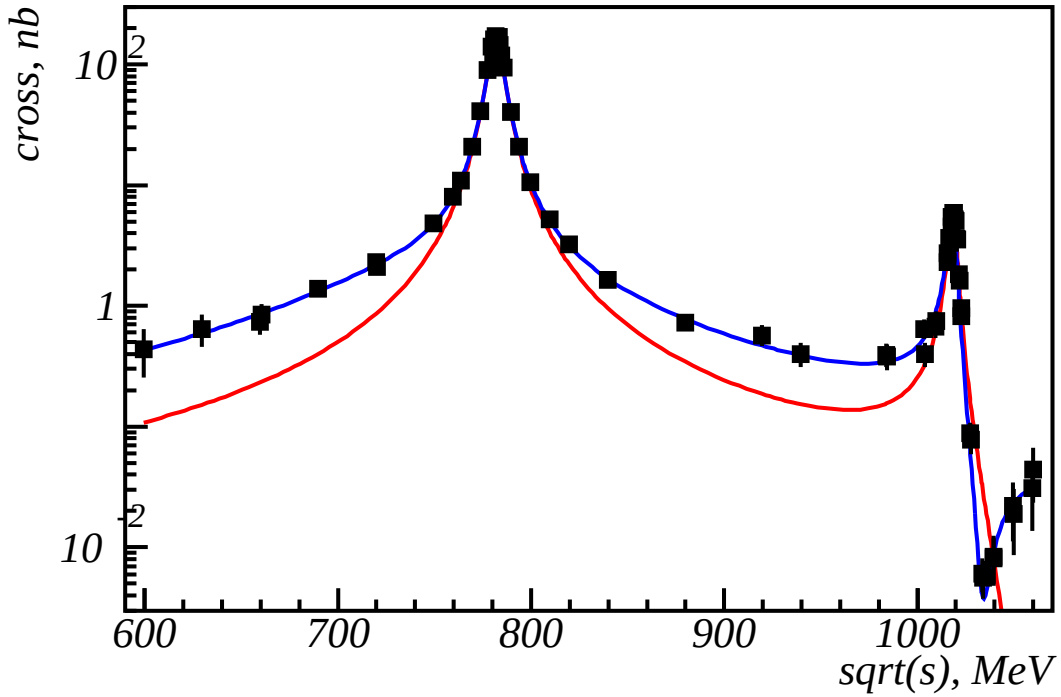
- $e^+e^- \to \pi^0\gamma$ (SND, CMD-2)
- $e^+e^- \to \eta\gamma$ (SND, CMD-2)
- $e^+e^- \to \pi^0\pi^0\gamma$ (SND, CMD-2)
- $e^+e^- \to \eta\pi^0\gamma$ (CMD-2)



$\rho-, \omega-, \phi-$mesons dominate the cross sections.

From upper limits on nonresonant cross sections $a_\mu^{\rm rad,LO} < 0.7 \cdot 10^{-10}$.

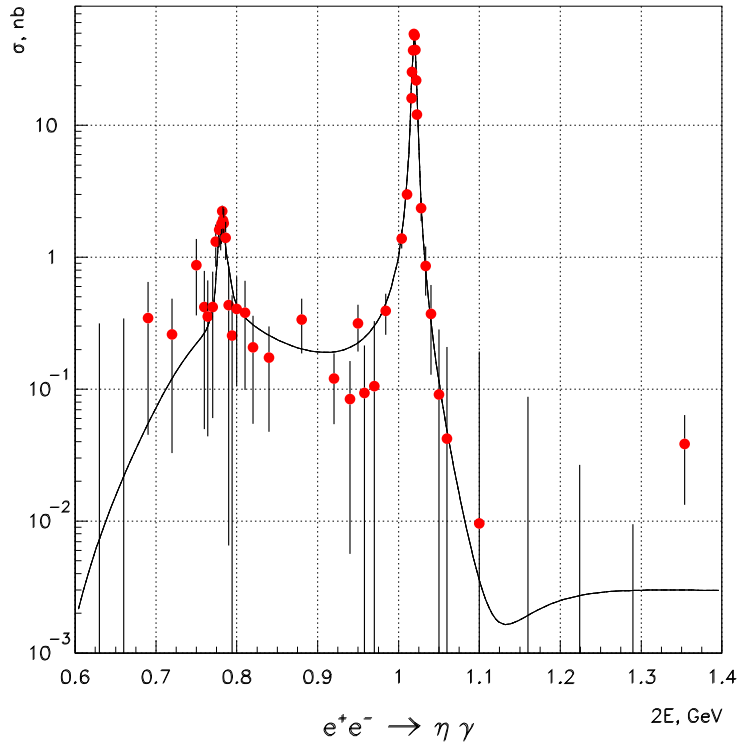
Neutral Final States. $e^+e^- \to \pi^0\gamma \to 3\gamma$ at SND



About $94 \cdot 10^3$ detected events.

The systematic error is 2.0–2.5% at the ω and 5% at the ϕ.

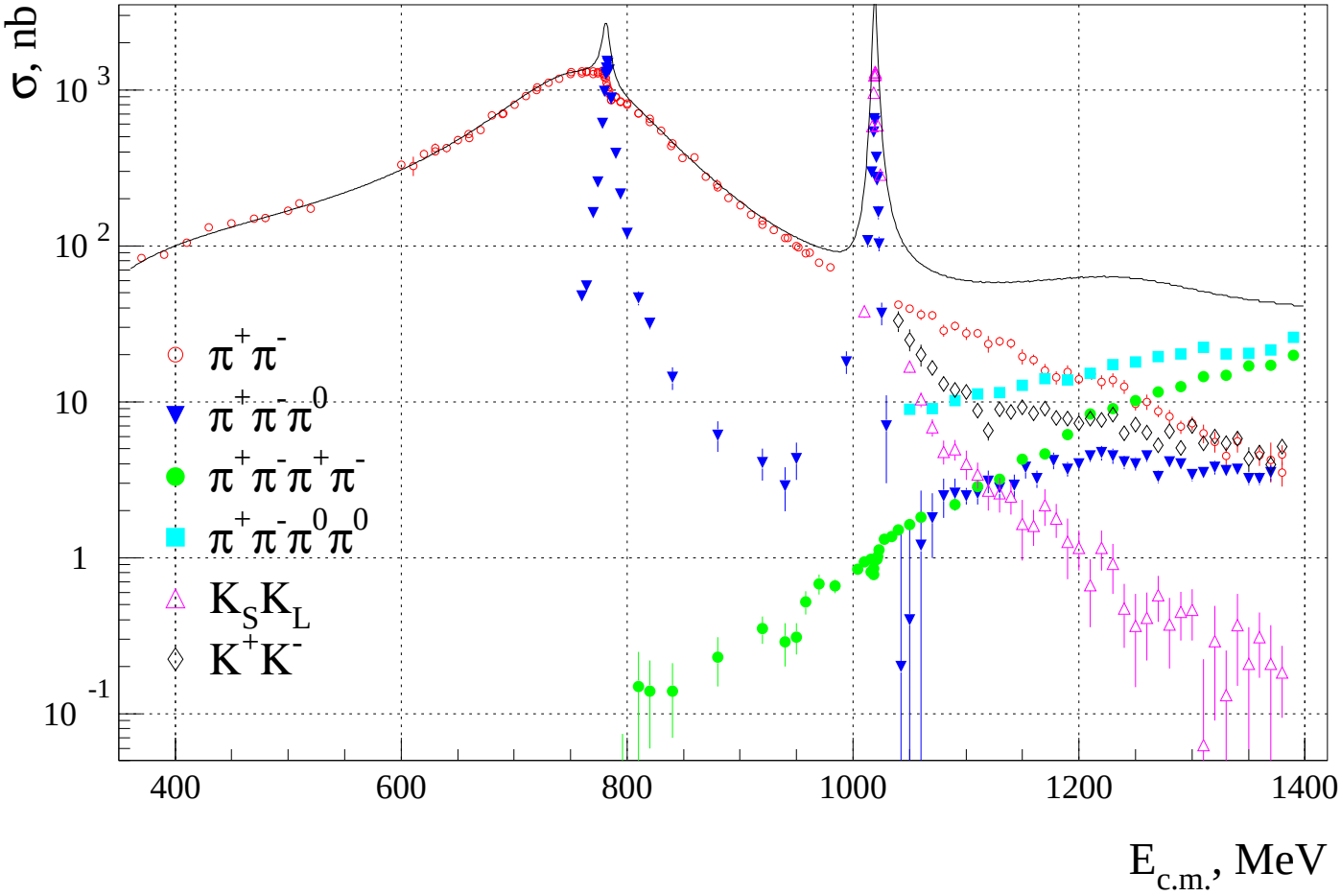
Neutral Final States. $e^+e^- \to \eta\gamma \to 3\pi^0\gamma$ at CMD-2



About $25 \cdot 10^3$ detected events.

The systematic error is 6% at the ω and 4% at the ϕ.

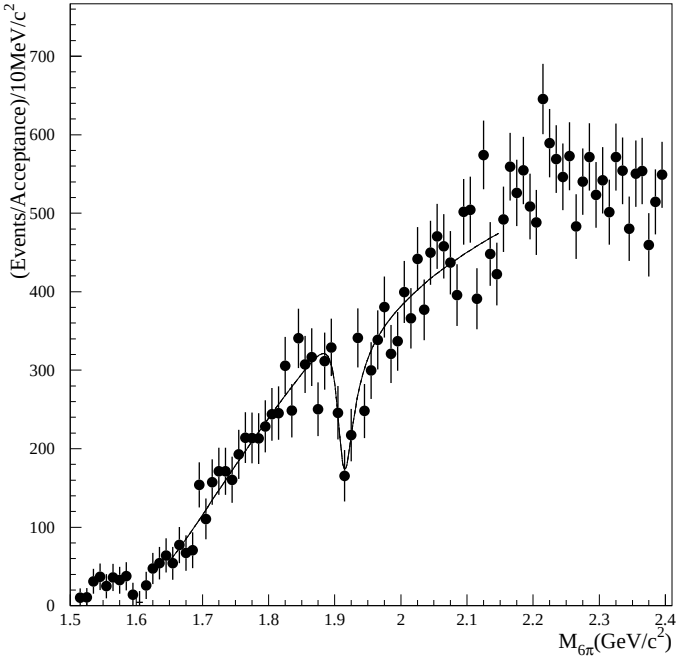
Hadronic Cross Sections at CMD-2



Measurements at 1.4 GeV $< \sqrt{s} <$ 2 GeV

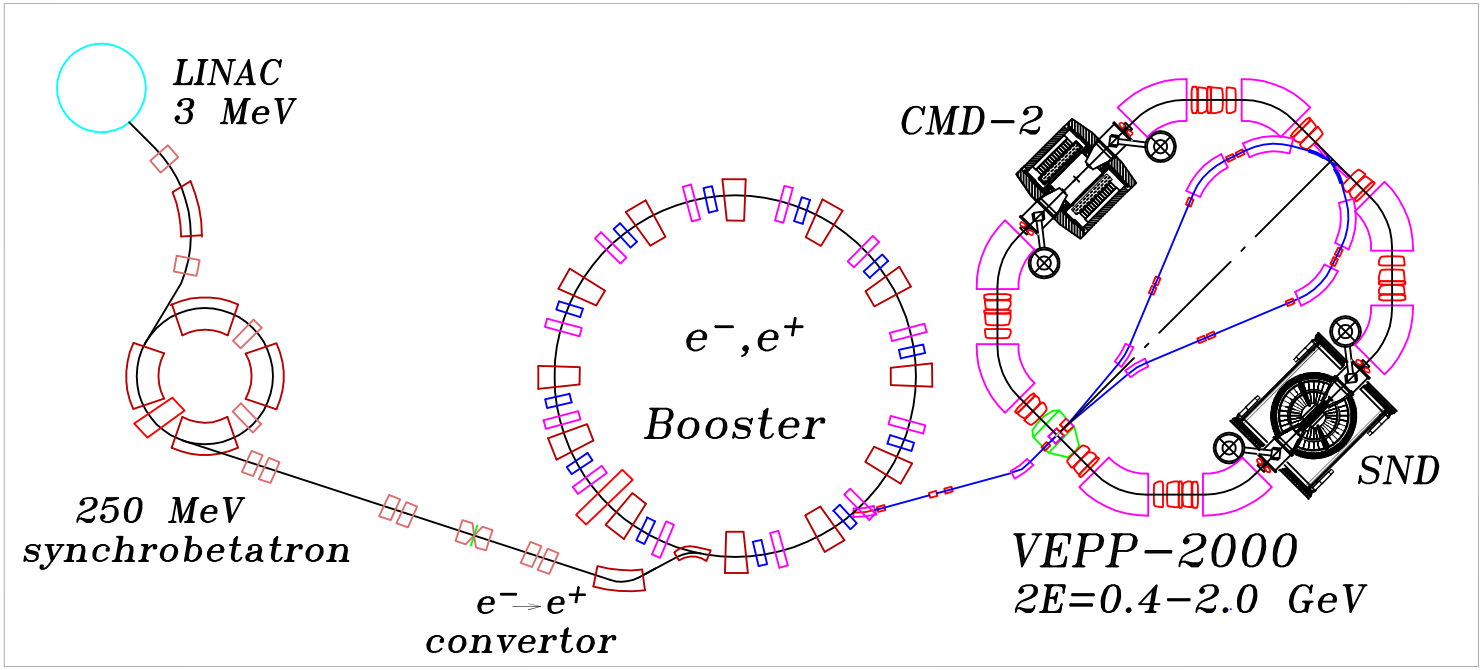
- 5 resonances ($2\rho'$,$2\omega'$,ϕ') with badly known properties
- Mixing of $q\bar{q}$ with hybrids?
- In 2001 E687 (FNAL) observed a narrow dip in $\gamma p \to 3\pi^+3\pi^- p$, M$= 1911 \pm 4 \pm 1$ MeV, $\Gamma = 29 \pm 11 \pm 4$ MeV
- Earlier observed in e^+e^-: DM2 (1988) - $e^+e^- \to 6\pi$, FENICE (1996) - $e^+e^- \to$ hadrons
- A hybrid or $N\bar{N}$ state?

$\gamma p \to 3\pi^+3\pi^- p$



VEPP-2000

Layout of the VEPP–2000 complex



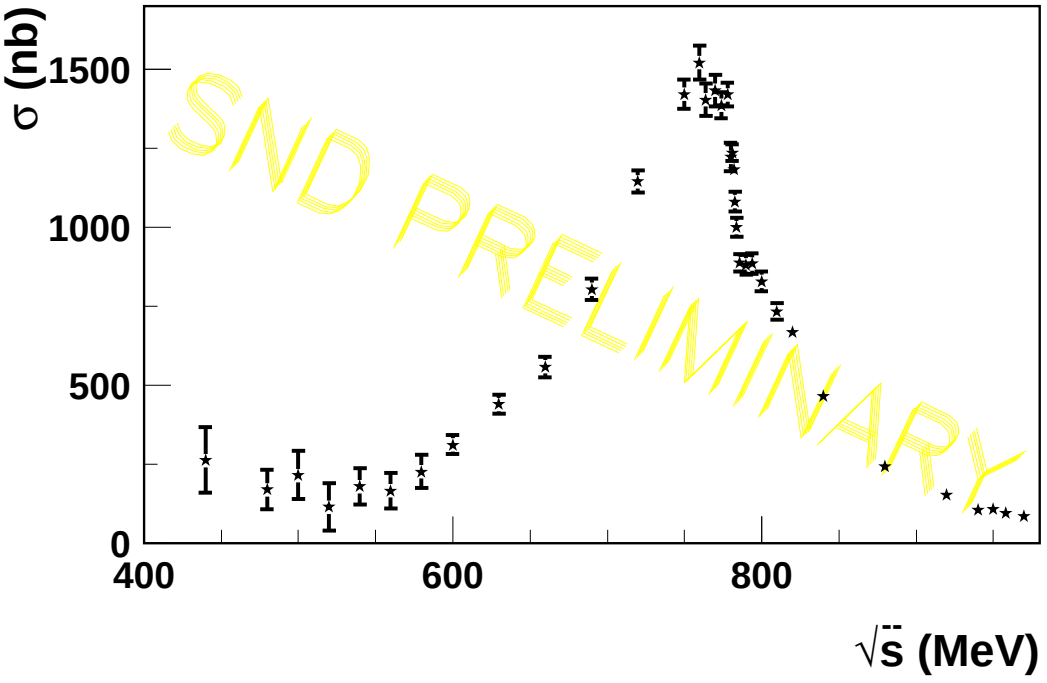
The design luminosity $\mathcal{L} = 10^{32}$ cm^{-2}s^{-1}, with $\int Ldt \approx 1 - 2$ fb^{-1} during 3–5 years $\Delta a_\mu^{\rm had}/a_\mu^{\rm had}$ can be improved by a factor of 2!

Conclusions

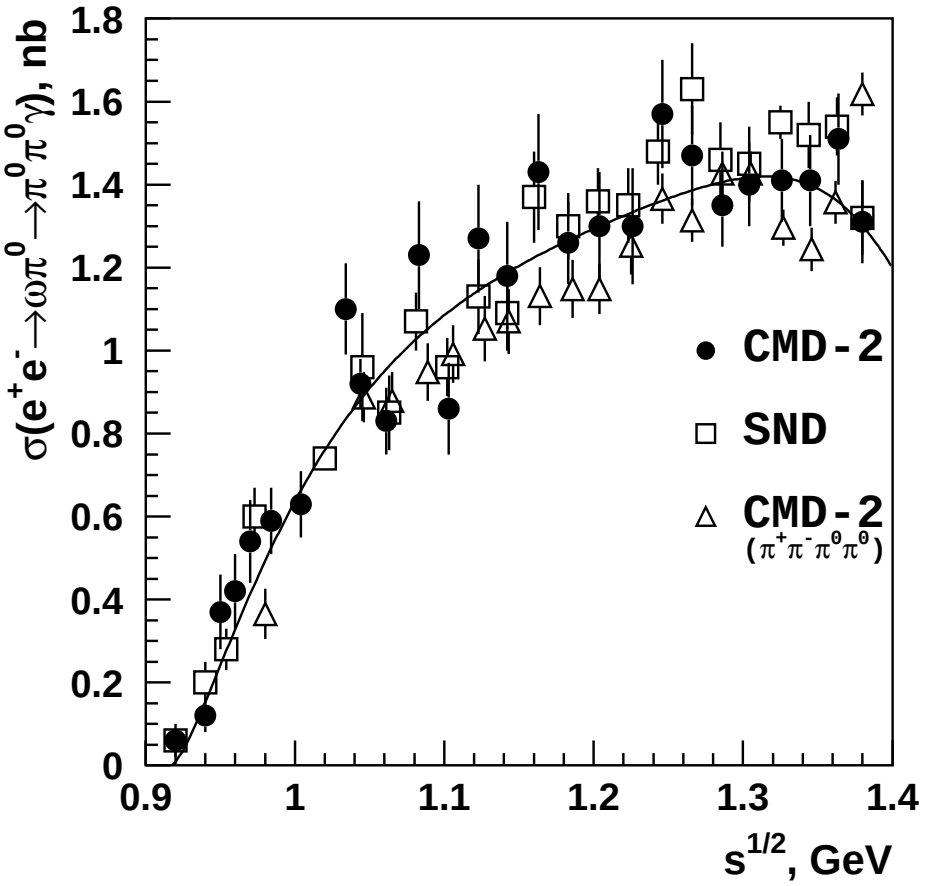
- High integrated luminosity was collected with 2 detectors (CMD-2 and SND) at VEPP-2M at 370 MeV $< \sqrt{s} <$ 1380 MeV
- Parameters of the ρ, ω, ϕ mesons were measured with high precision
- $\sigma(e^+e^- \to \pi^+\pi^-)$ was determined with a systematic error $\sim 1\%$ or better (0.6%) in the region of the ρ
- Cross sections of the other dominant modes were measured with high statistical accuracy and a systematic error of about $(5-7)\%$
- Rare exclusive channels including those with photons only were studied
- Measurements of R in Novosibirsk as well as in Beijing at 2 GeV $< \sqrt{s} <$ 5 GeV allowed a new much more accurate determination of $a_\mu^{\rm had}$
- Future progress up to $\sqrt{s} = 2$ GeV will be possible at VEPP-2000 and up to $\sqrt{s} \sim 3$ GeV with radiative return experiments at KLOE, BaBar and Belle

Backup slides

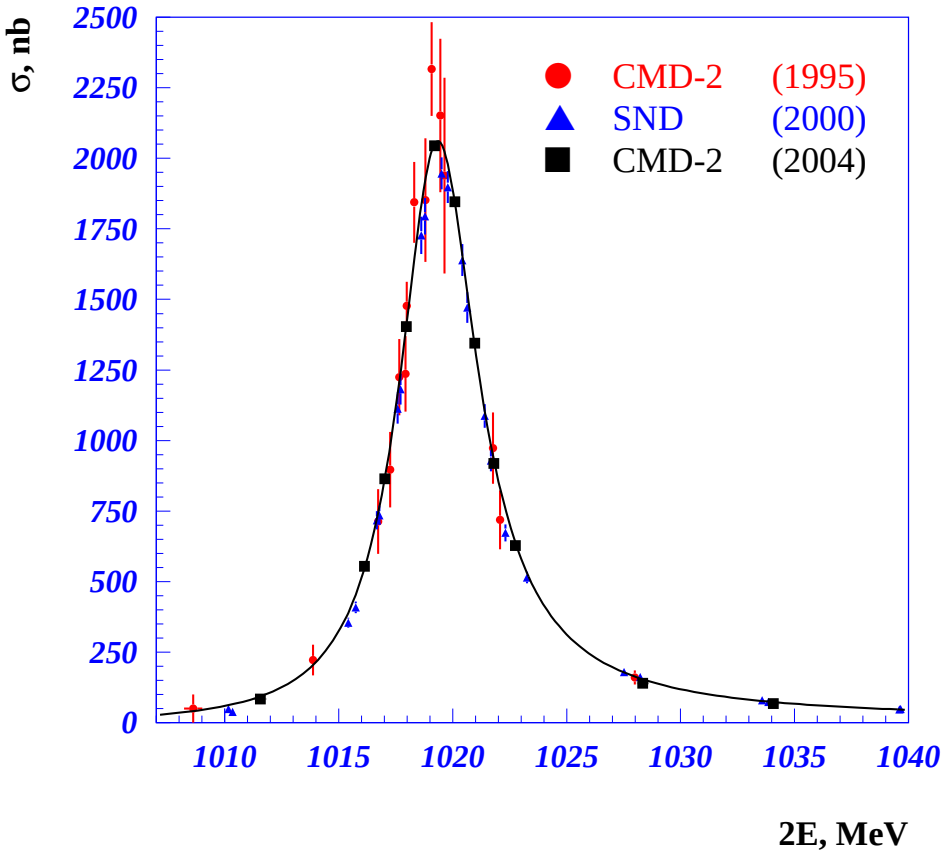
Studies of $e^+e^- \to \pi^+\pi^-$ at SND



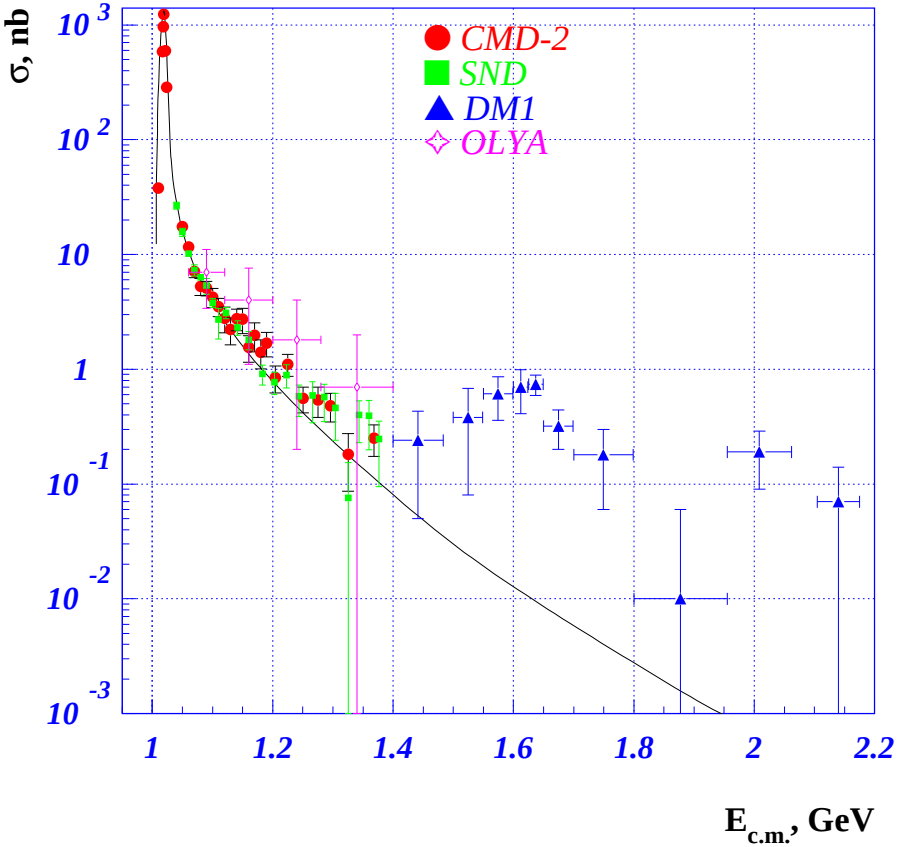
Studies of $e^+e^- \to \omega\pi^0$ at VEPP-2M



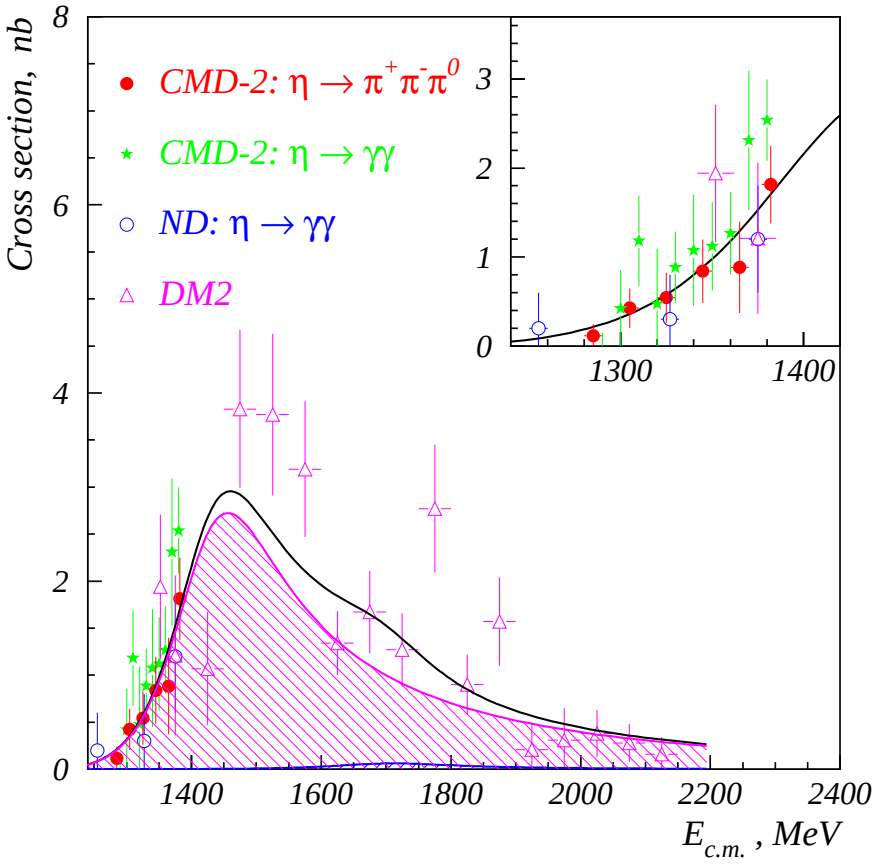
Studies of $e^+e^- \to \phi \to K^+K^-$ at VEPP-2M



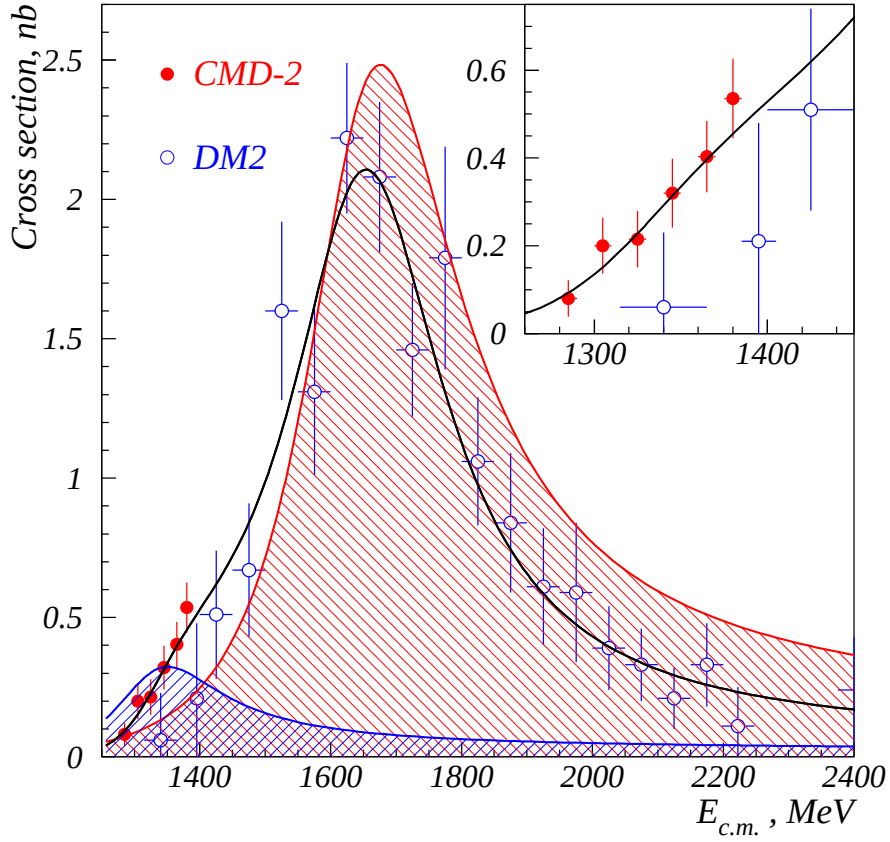
Studies of $e^+e^- \to \phi \to K^0_S K^0_L$ at VEPP-2M



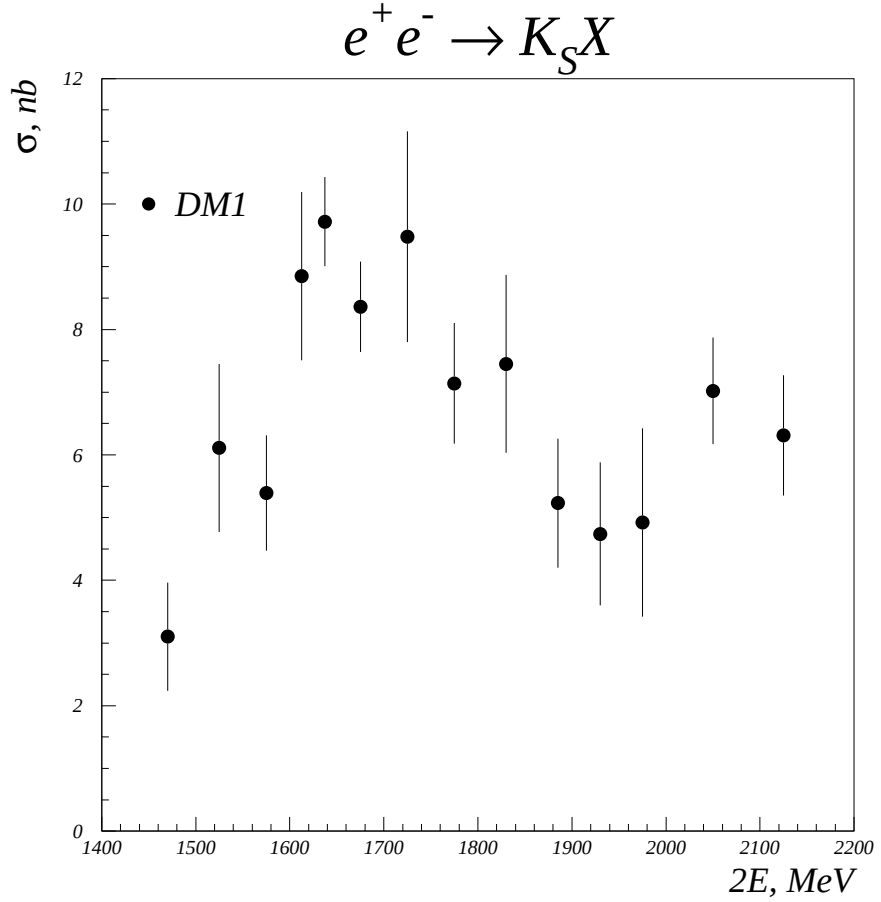
Studies of $e^+e^- \to \eta\pi^+\pi^-$ at VEPP-2M



Studies of $e^+e^- \to \omega\pi^+\pi^-$ at VEPP-2M



Studies of $e^+e^- \to K^0_S + X$



Studies of $e^+e^- \to K^+K^-\pi^+\pi^-$