Review of results from SND detector

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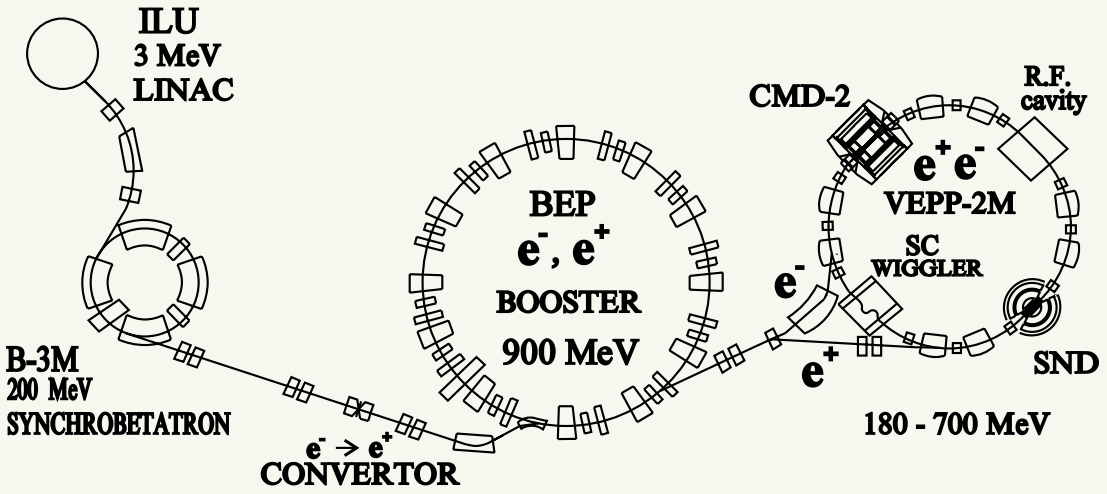
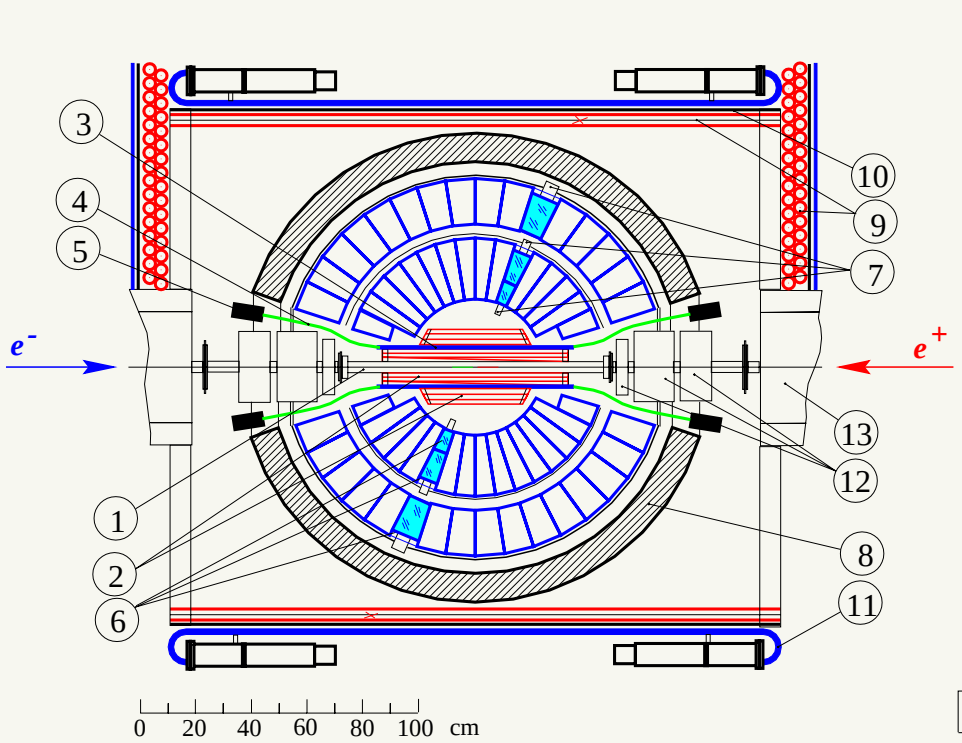
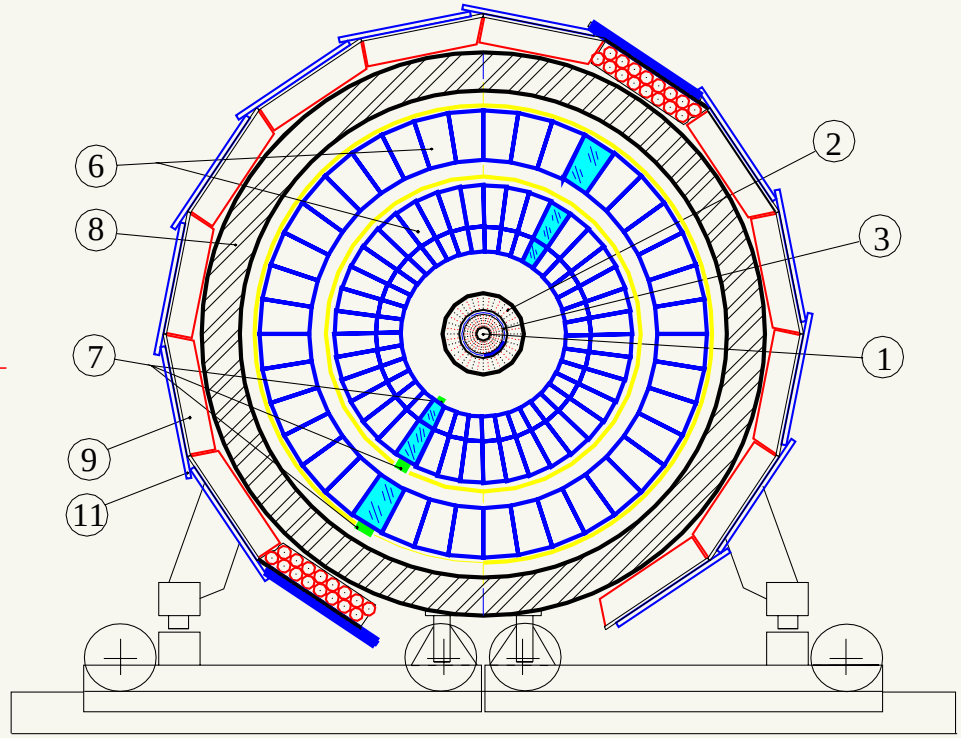
VEPP-2M e^+e^- collider



Beam energy, MeV	180-700
Peak luminosity ($E_b = 500$MeV), $cm^{-1}s^{-1}$	$3 \cdot 10^{30}$
Energy spread ($E_b = 500$MeV), keV	300
Beam current, mA	50
Time between collisions, ns	60
Bunch length, cm	2

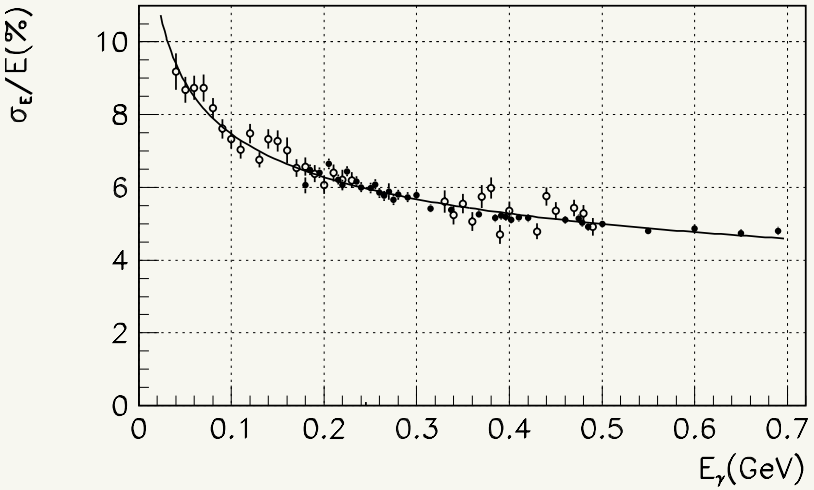
SND Detector

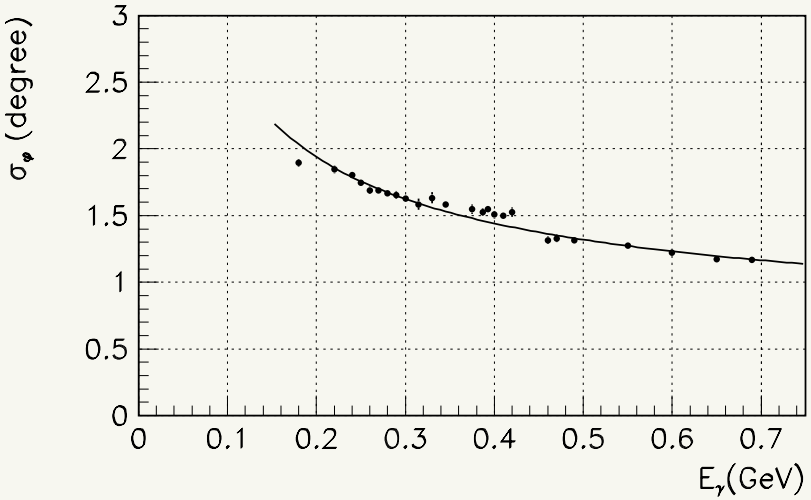




1 - beam pipe, 2 - drift chambers, 3 - scintillation counter,4 - lightguides, 5 - PMTs, 6 - NaI(Tl) crystals, 7 - vacuum phototriodes, 8 - iron absorber, 9 - streamer tubes, 10 - 1 cm iron plates, 11 - scintillation counters, 12 and 13 - collider magnets.

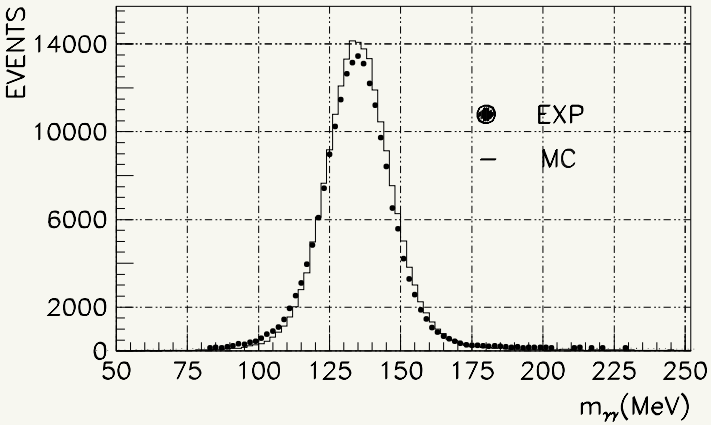
List of SND parameters: Calorimeter :



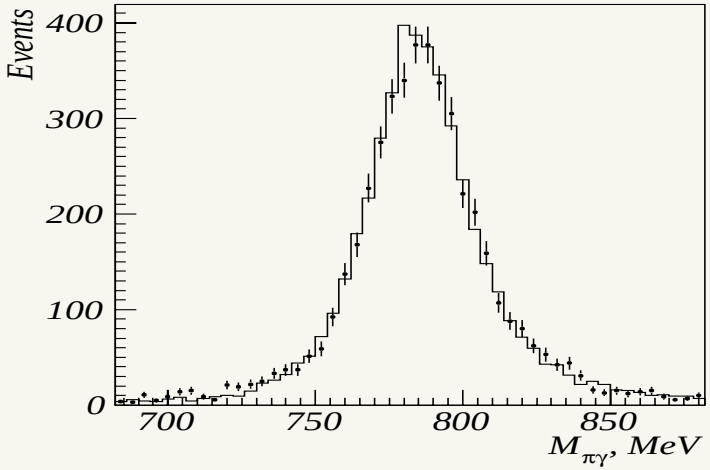


Total number of NaI(Tl) counters	1632
Angular size of the counter	$\Delta\varphi = \Delta\vartheta = 9^\circ$
Energy resolution for γ's	$\sigma_E/E = \frac{4.2\%}{\sqrt[4]{(E(GeV)}}$
Angular resolution for γ's	$\sigma_\varphi = \frac{0.82^\circ}{\sqrt{E(GeV)}} \oplus 0.63^\circ$
Minimal spatial angle for two photons separation	$\Delta\varphi \sim \Delta\vartheta \sim 18^\circ$

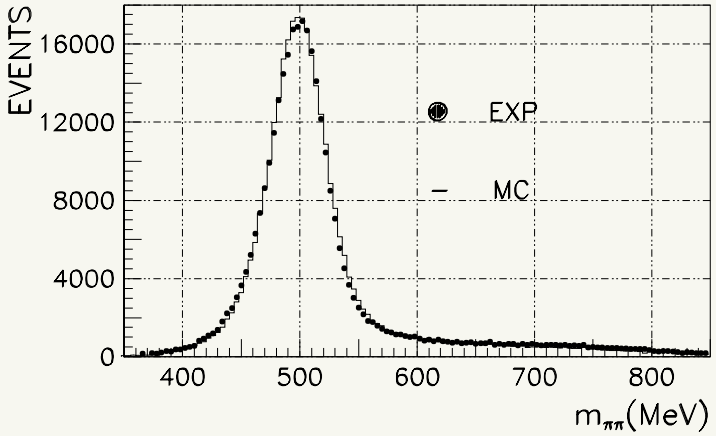
SND calorimeter performance



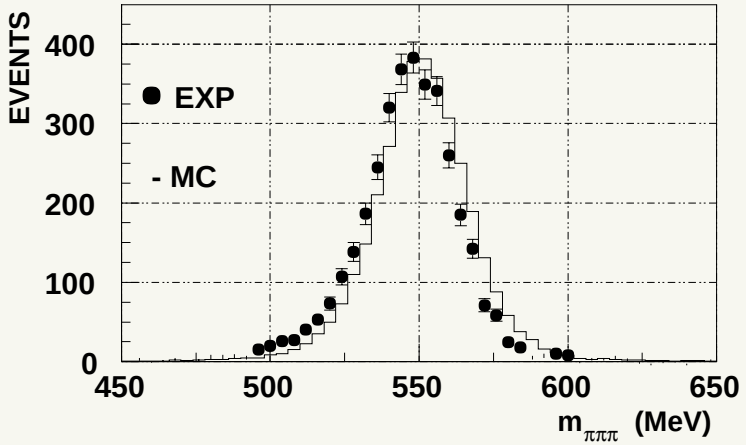
Invariant-mass spectra in $\pi^0 \to \gamma\gamma$ decay



Invariant-mass spectra in $\omega \to \pi^0\gamma$ decay

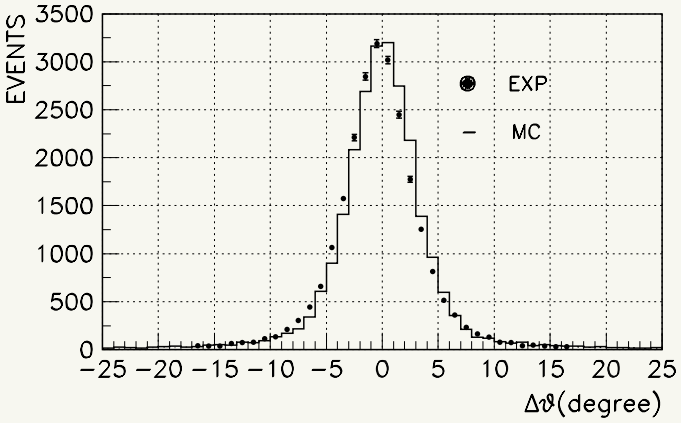


Invariant-mass spectra in $K_S \to \pi^0\pi^0$ decay

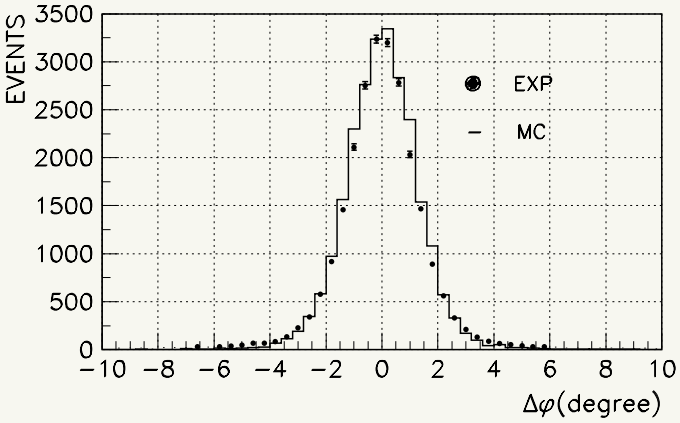


Invariant-mass spectra in $\eta \to 3\pi^0$ decay

List of SND parameters: Drift chambers:



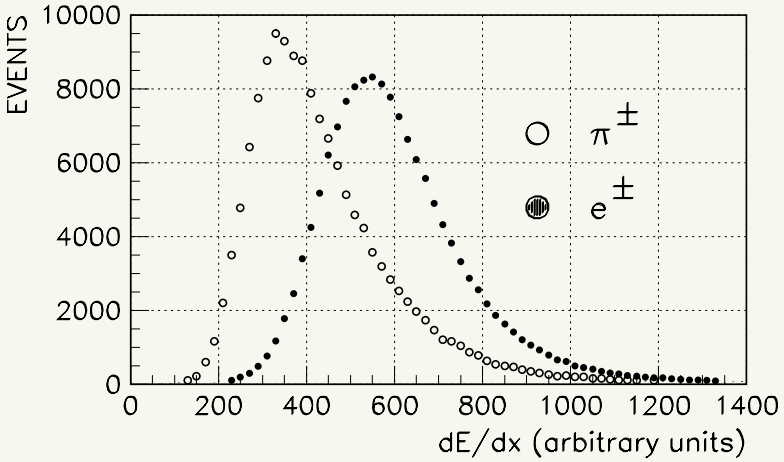
$\Delta\theta$ distribution for $e^+e^- \rightarrow \mu^+\mu^-$



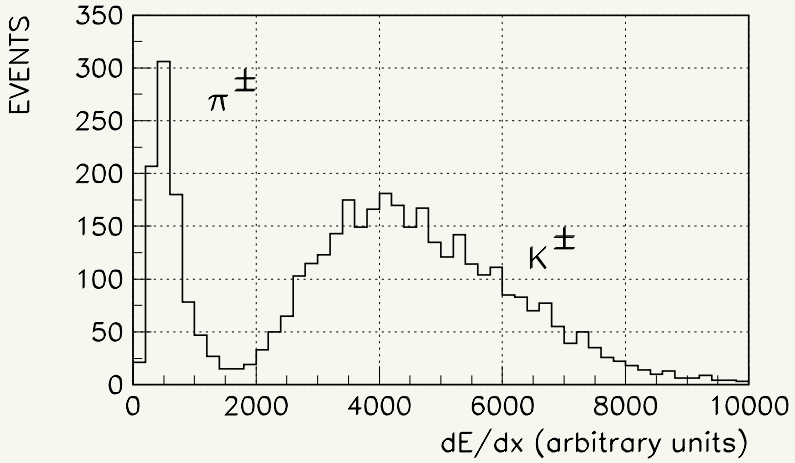
$\Delta\phi$ distribution for $e^+e^- \rightarrow \mu^+\mu^-$

Spatial resolution for tracks (P=300 MeV/c)	$\sigma_\varphi = 0.54°$, $\sigma_\vartheta = 1.9°$
Minimal azimuth angle for charged particles separation	$\Delta\varphi \sim 18°$
Material before the chamber	$0.27\ g/cm^2$
Probability of γ-conversion before the chamber	0.57%

SND tracking system performance



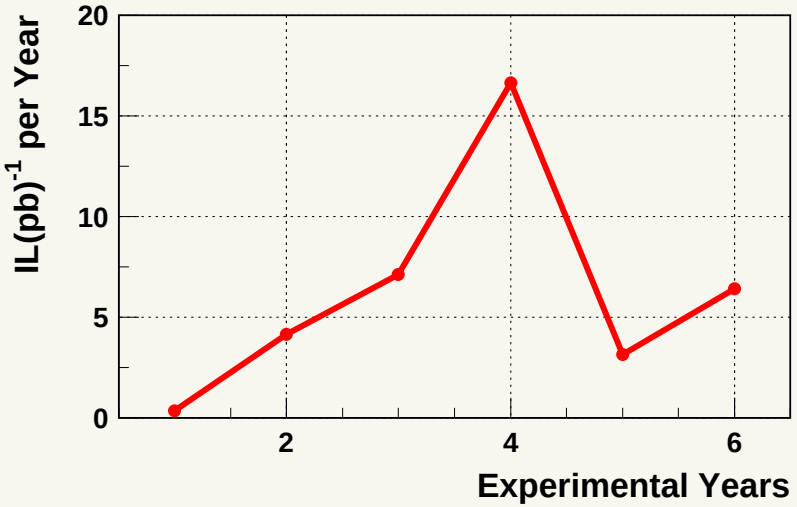
dE/dx distribution for
$e^\pm$ and $\pi^\pm$



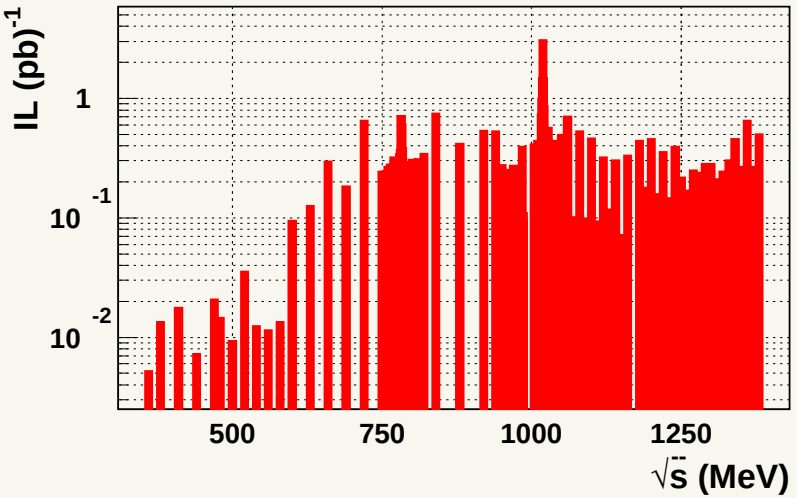
dE/dx distribution for
$\pi^\pm$ and $K^\pm$ $\sqrt{s} \sim 1$ GeV

$\sigma_{dE/dx} \sim 30\%$

Integrated Luminosity



Integrated luminosity collected by SND per experimental year



Integrated luminosity collected by SND in the energy region $\sqrt{s} = 360 - 1380$ MeV

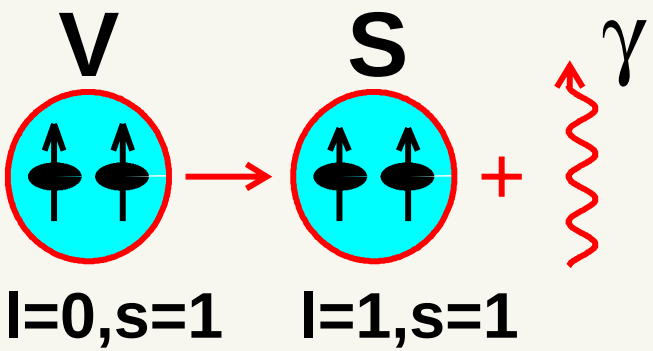
Total integrated luminosity $IL \simeq 30\ (\mathrm{pb})^{-1}$ (1995 – 2000)

Luminosity measurement:

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

Accuracy $\sim 1.5\% - 2\%$

Electric dipole radiative decays



$V \to S\gamma$

$(V = \phi, \omega, \rho)$

$(S = f_0(980), a_0(980), \sigma(?))$

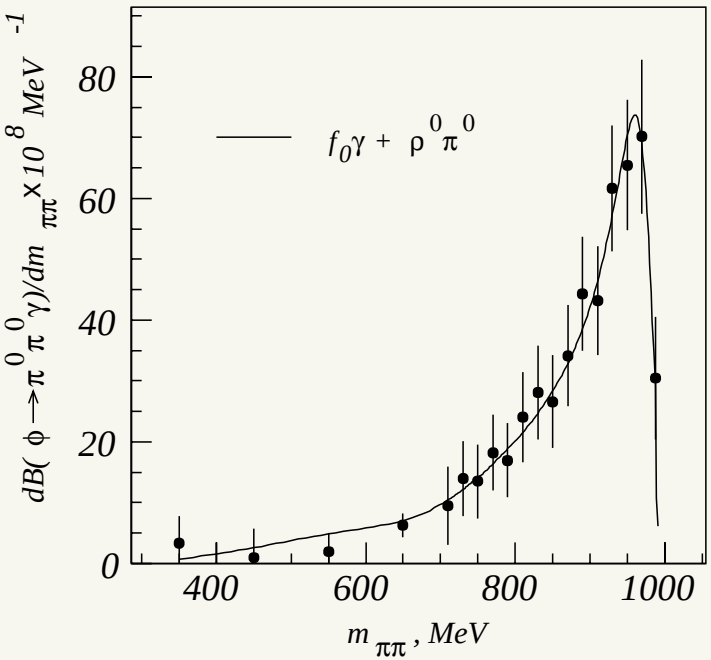
SND study:

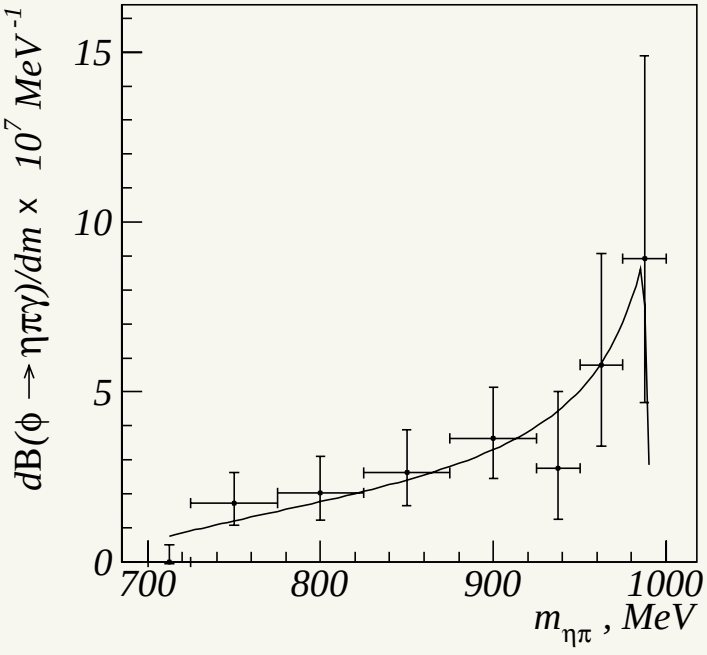
$e^+e^- \to \phi \to \pi^0\pi^0\gamma,\ \eta\pi^0\gamma$

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

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

Electric dipole radiative decays of ϕ meson





$$B(\phi \to \pi^0\pi^0\gamma) = (1.22 \pm 0.12) \cdot 10^{-4}$$
$$B(\phi \to \eta\pi^0\gamma) = (0.88 \pm 0.17) \cdot 10^{-4}$$

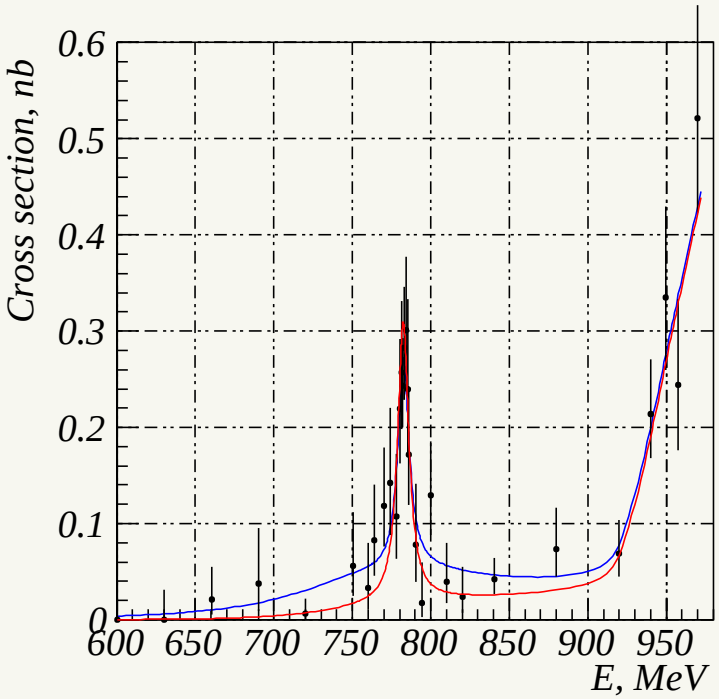
$$B(\phi \to f_0\gamma) = (3.5 \pm 0.3 \pm^{1.3}_{0.5}) \cdot 10^{-4}$$
$$B(\phi \to a_0\gamma) = (0.88 \pm 0.17) \cdot 10^{-4}$$

Electric dipole radiative decays of ϕ meson

	SND	CMD-2	KLOE(*)
$B(\phi \to \pi^0\pi^0\gamma)(\cdot 10^{-4})$ $m_{\pi\pi} > 700$MeV	$1.034 \pm 0.066 \pm 0.046$	$0.92 \pm 0.08 \pm 0.06$	$0.79 \pm 0.02 \pm 0.08$
$B(\phi \to \eta\pi^0\gamma)$ $(\cdot 10^{-4})$	0.88 ± 0.17	$0.90 \pm 0.24 \pm 0.10$	$0.74 \pm 0.05 \pm 0.07$
$B(\phi \to f_0\gamma)$ $(\cdot 10^{-4})$	$3.5 \pm 0.3^{+1.3}_{-0.5}$	$2.90 \pm 0.21 \pm 1.54$	$2.37 \pm 0.06 \pm 0.24$
$B(\phi \to a_0\gamma)$ $(\cdot 10^{-4})$	0.88 ± 0.17		$0.58 \pm 0.05 \pm 0.06$

(*) - systematic error was set to 10%

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



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

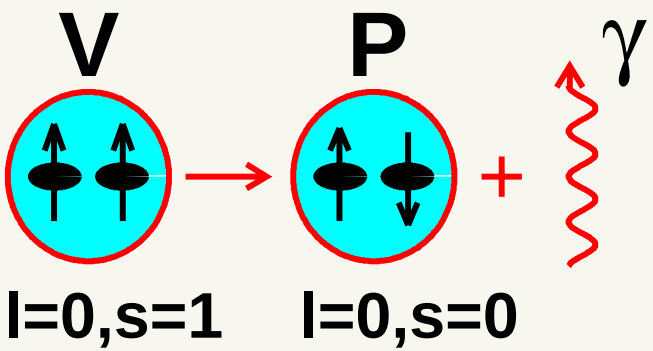
SND results ($IL = 9$ (pb)$^{-1}$):

$B(\omega \to \pi^0\pi^0\gamma) = (6.3 \pm 1.4 \pm 0.8) \cdot 10^{-5}$

$B(\rho \to \pi^0\pi^0\gamma) = (4.0 \pm^{1.0}_{0.9} \pm 0.4) \cdot 10^{-5}$

$B(\rho \to S\gamma \to \pi^0\pi^0\gamma) = (2.0 \pm^{0.8}_{0.7} \pm 0.3) \cdot 10^{-5}$

Magnetic dipole radiative decays



$V \to P\gamma$

$(V = \phi, \omega, \rho)$

$(P = \pi^0, \eta, \eta')$

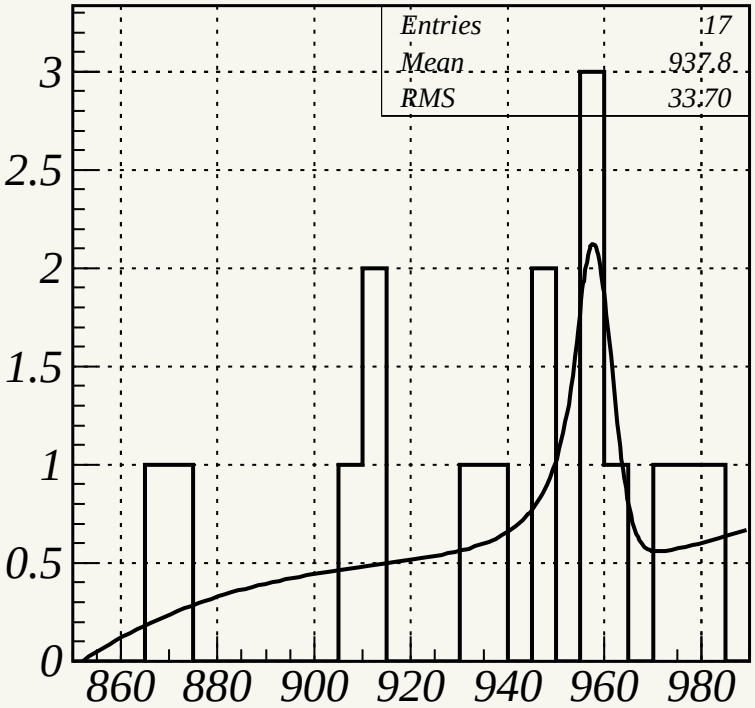
SND study:

$e^+e^- \to \phi \to \eta'\gamma,\ \pi^0\gamma,\ \eta\gamma,$

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

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

$\phi \to \eta'\gamma$



$\eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$:

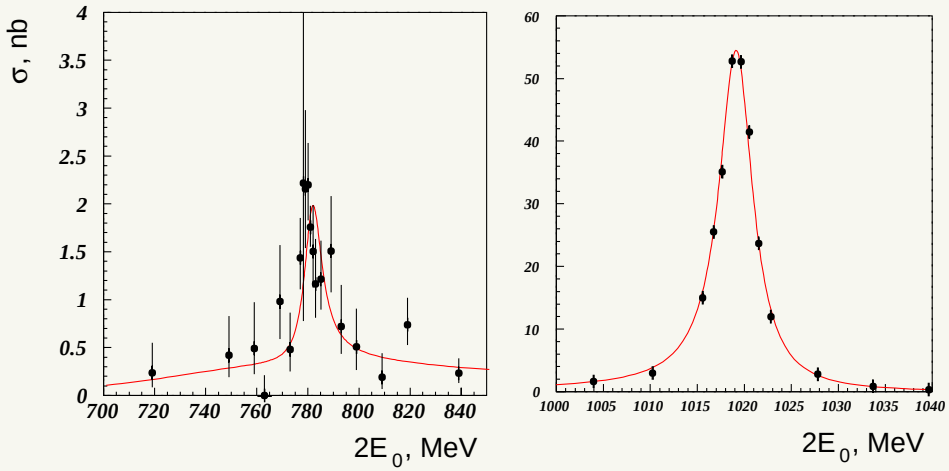
$B(\phi \to \eta'\gamma) = (6.7 \pm^{3.4}_{2.9}) \cdot 10^{-5}$

$\eta' \to \pi^0\pi^0\eta, \eta \to \gamma\gamma$:

$B(\phi \to \eta'\gamma) = (4.3 \pm 1.6 \pm 0.9) \cdot 10^{-5}$

	SND	CMD2	KLOE
$B(\phi \to \eta'\gamma) \cdot 10^5$	$4.9 \pm^{1.6}_{1.5}$	6.4 ± 1.6	6.8 ± 0.8

$\rho, \omega, \phi \to \eta\gamma$



$B(\phi \to \eta\gamma)(\cdot 10^{-2})$

$\eta \to \gamma\gamma$: $1.34 \pm 0.01 \pm 0.05$

$\eta \to \pi^+\pi^-\pi^0$: $1.26 \pm 0.03 \pm 0.06$

$\eta \to \pi^0\pi^0\pi^0$: $1.35 \pm 0.01 \pm 0.05$

Average: 1.310 ± 0.045

$B(\rho \to \eta\gamma) = (2.77 \pm 0.26 \pm 0.16) \cdot 10^{-4}$

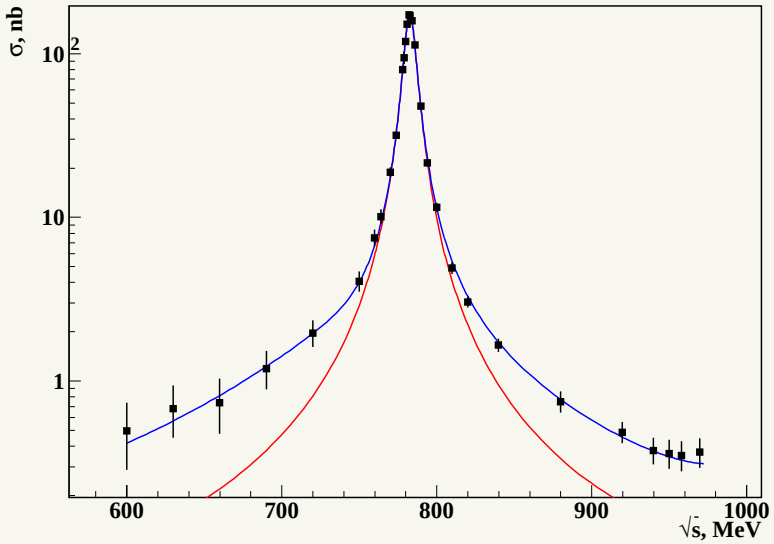
$B(\omega \to \eta\gamma) = (4.22 \pm 0.47 \pm 0.17) \cdot 10^{-4}$

Experimental ratio of the partial width:

$\Gamma_{\omega\eta\gamma} : \Gamma_{\rho\eta\gamma} : \Gamma_{\phi\eta\gamma} = 1 : (11.7 \pm 1.9) : (15.9 \pm 1.9)$

Prediction of the simple quark model: 1:8:12

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



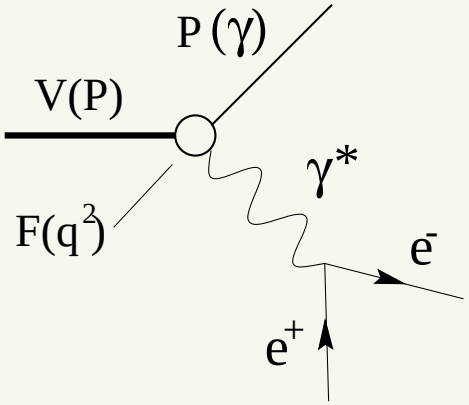
$$B(\rho \to \pi^0\gamma) = (5.03 \pm 1.17 \pm 0.83) \cdot 10^{-4}$$
$$B(\omega \to \pi^0\gamma) = (9.17 \pm 0.16 \pm 0.46) \cdot 10^{-2}$$
$$B(\phi \to \pi^0\gamma) = (1.23 \pm 0.04 \pm 0.09) \cdot 10^{-3}$$

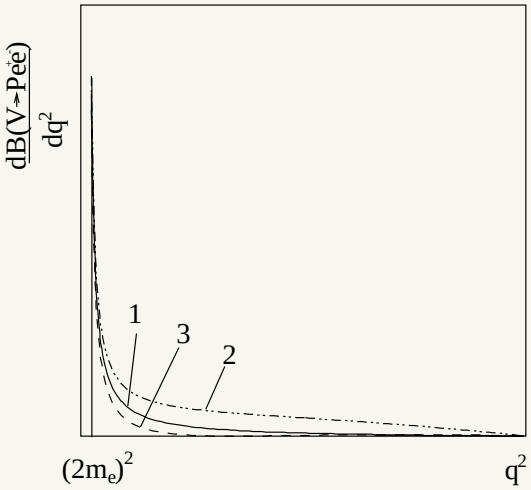
Experimental ratio of the partial width:

$\Gamma_{\omega\pi^0\gamma} : \Gamma_{\rho\pi^0\gamma} : \Gamma_{\phi\pi^0\gamma} = 1 : (0.97 \pm 2.8) : (7 \pm 0.6) \cdot 10^{-3}$

Prediction of the quark model: $1 : 1/9 : 0.01$

Conversion decays $\phi \to \eta e^+e^-, \phi \to \pi^0 e^+e^-, \eta \to e^+e^-\gamma$





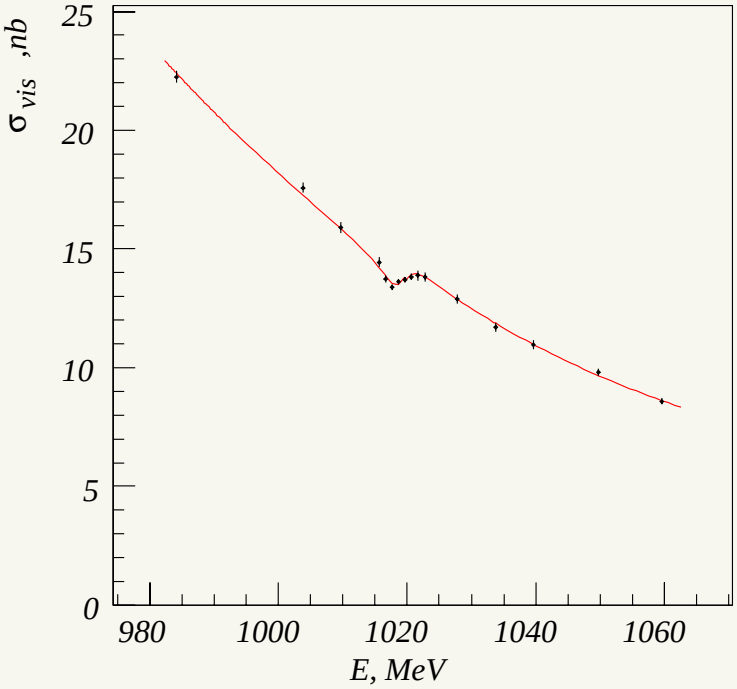
Branching Ratios

	$\phi \to \eta e^+e^-$ $(\cdot 10^{-4})$	$\eta \to e^+e^-\gamma$ $(\cdot 10^{-3})$	$\phi \to \pi^0 e^+e^-$ $(\cdot 10^{-5})$
SND	1.19 ± 0.22	5.15 ± 0.96	1.05 ± 0.37
CMD-2	1.17 ± 0.12	7.10 ± 0.79	1.22 ± 0.40
SND&CMD-2	1.18 ± 0.11	6.31 ± 0.61	1.13 ± 0.27
Theory	1.10 ± 0.1	6.5–6.8	1.3–1.6
PDG(2000)	$1.3^{+0.8}_{-0.6}$	4.9 ± 1.1	$< 1.2 \cdot 10^{-4}$

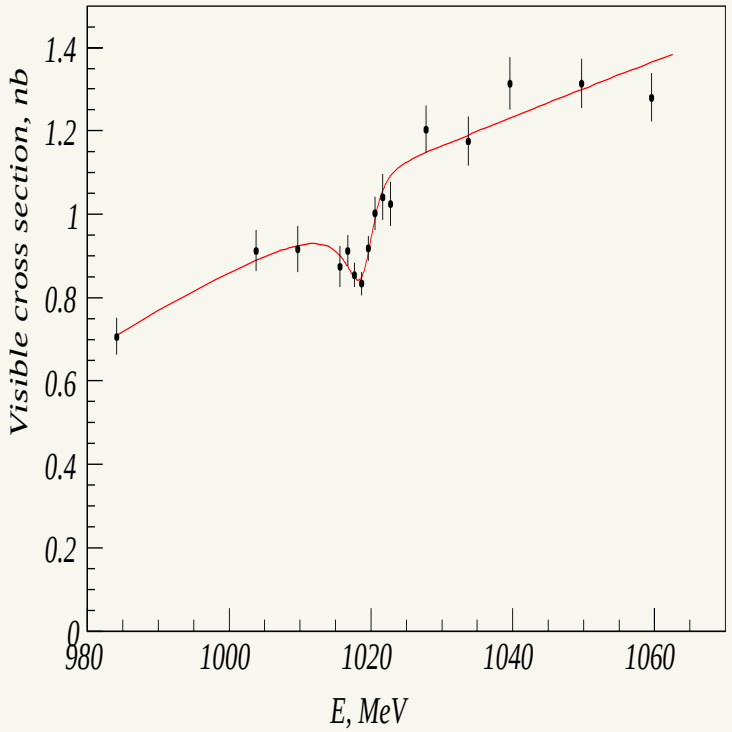
Transition Form Factors Slopes

	$\phi \to \eta e^+e^-$ GeV^{-2}	$\eta \to e^+e^-\gamma$ GeV^{-2}	$\phi \to \pi^0 e^+e^-$ GeV^{-2}
SND	3.8 ± 1.8	1.6 ± 2.0	—
Theory (VDM)	1.0	1.8	
Previous measurement	—	-0.7 ± 1.5	—

OZI and G-parity suppressed $\phi \to \omega\pi^0$ and $\pi^+\pi^-$ decays



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

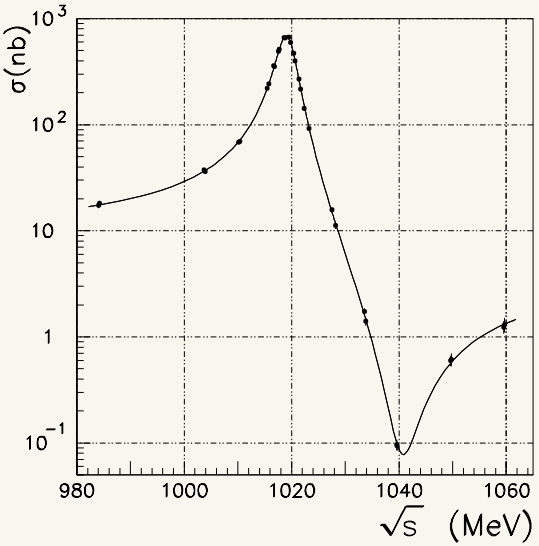


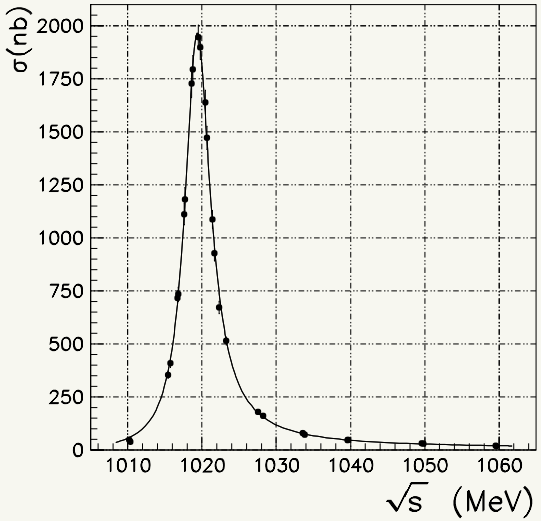
$e^+e^- \to \omega\pi^0$

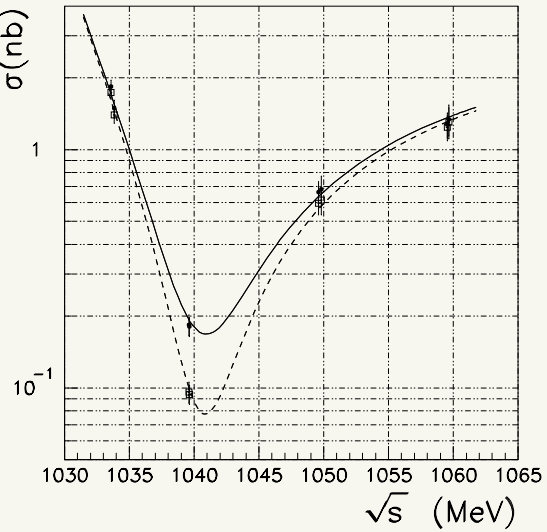
$$\sigma(s) = \sigma_0(s) \times \left| 1 - Z \frac{m_\phi \Gamma_\phi}{D_\phi(s)} \right|^2$$

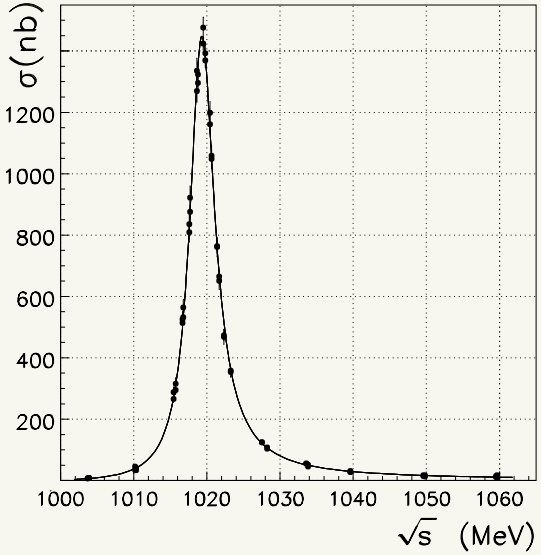
	$\pi^+\pi^-$	$\omega\pi^0$
$\mathrm{Re}(Z)$	0.061 ± 0.006	0.108 ± 0.16
$\mathrm{Im}(Z)$	-0.041 ± 0.007	-0.125 ± 0.020
$B(\phi \to X) \cdot 10^5$	7.1 ± 1.4	$5.2 \pm^{1.3}_{1.1}$

ϕ meson parameters study









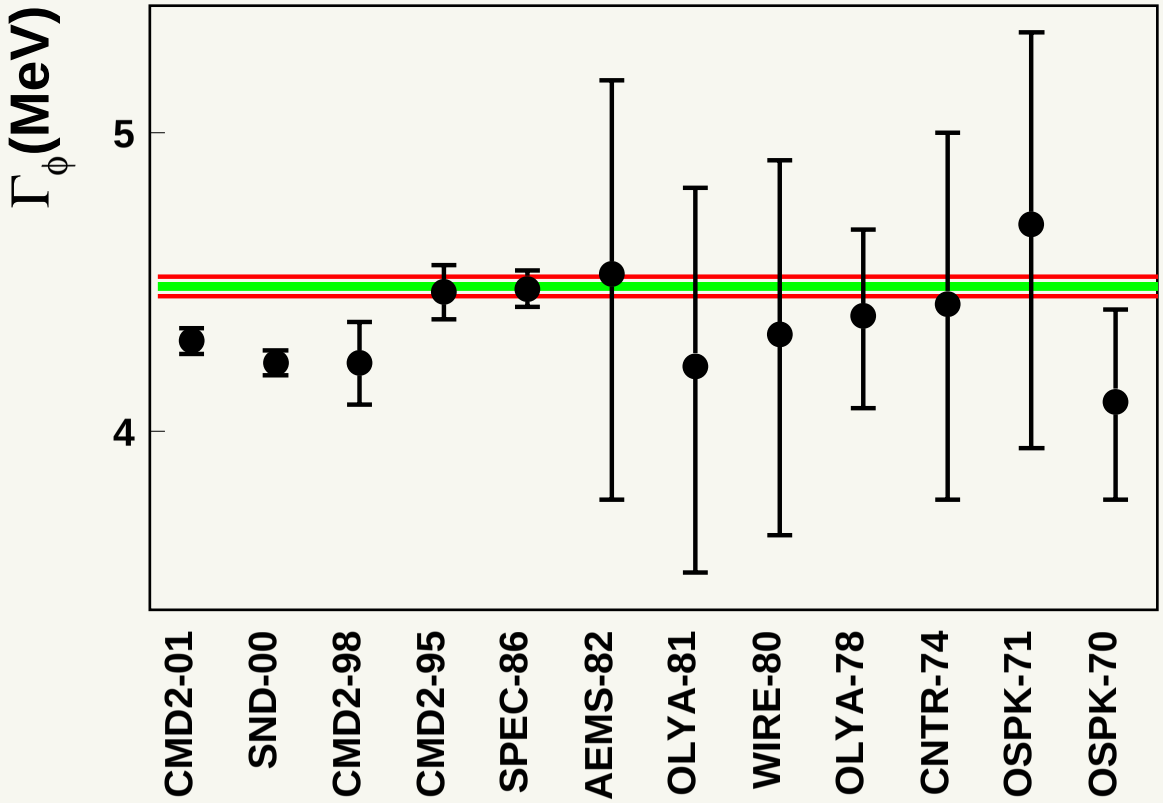
$e^+e^- \to \pi^+\pi^-\pi^0$,
K^+K^-,
K_SK_L

$980 \leq \sqrt{s} \leq 1060$ MeV
$IL = 8.5$ (pb)$^{-1}$
$N_{K^+K^-} = 10^6$
$N_{K_SK_L} = 0.5 \times 10^6$
$N_{3\pi} = 0.4 \times 10^6$

ϕ meson parameters study

	SND	PDG-2000
m_ϕ, MeV	1019.42 ± 0.05	1019.417 ± 0.014
Γ_ϕ, MeV	4.21 ± 0.04	4.458 ± 0.032
$B(\phi \to e^+e^-) \cdot 10^4$	2.93 ± 0.14	2.91 ± 0.07
$B(\phi \to K^+K^-)$, %	47.6 ± 1.7	49.2 ± 0.7
$B(\phi \to K_SK_L)$, %	35.1 ± 1.3	33.8 ± 0.6
$B(\phi \to 3\pi)$, %	15.9 ± 0.8	15.5 ± 0.6
$B(\phi \to \eta\gamma)$, %	1.33 ± 0.06	1.297 ± 0.033
$\frac{g_{\phi K^+K^-}}{g_{\phi K_SK_L}} \frac{1}{\sqrt{Z(m_\phi)}}$	0.92 ± 0.03	0.95 ± 0.01

ϕ meson parameters study

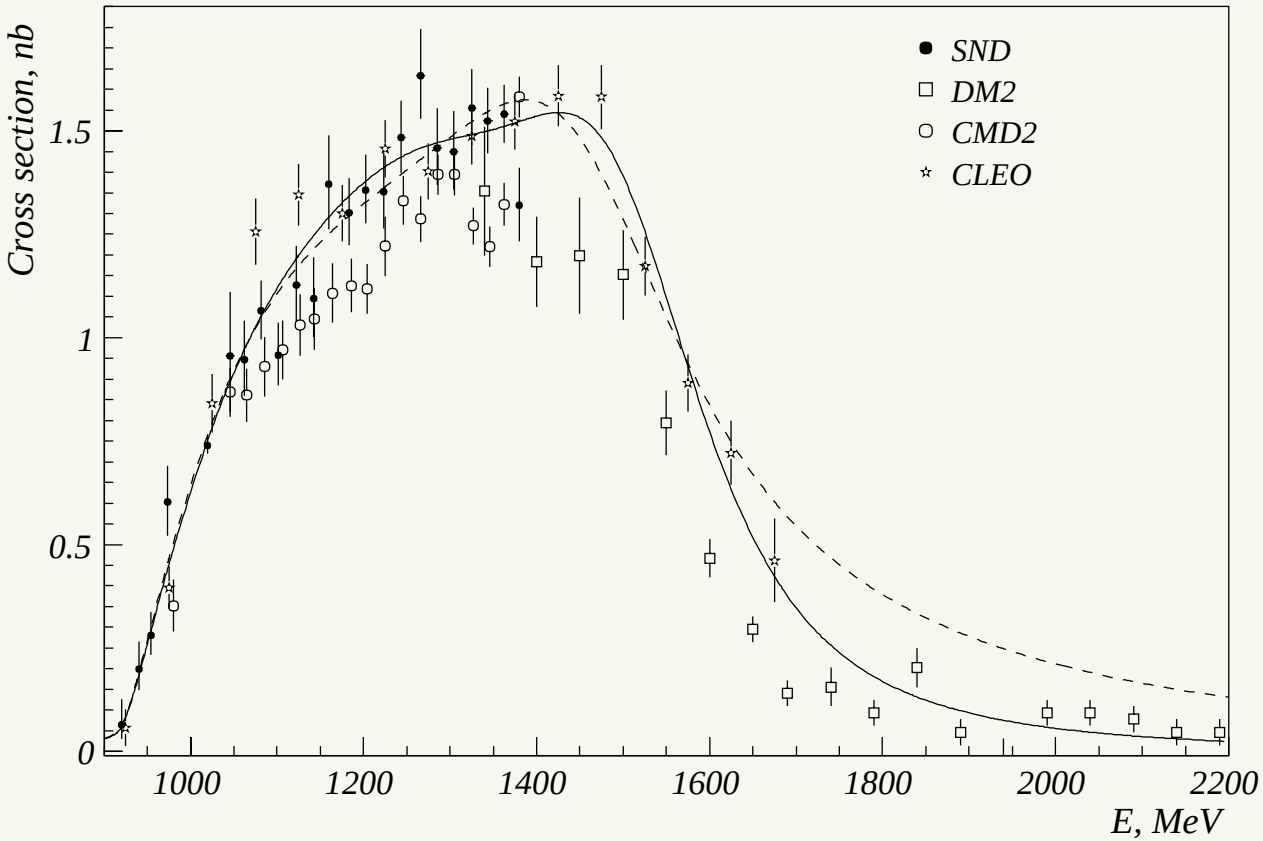


e^+e^- annihilation into hadrons above 1 GeV

SND studies of the $e^+e^- \to$ hadrons :

- $e^+e^- \to \rho\pi, \omega\pi \to \pi^+\pi^-\pi^0$
- $e^+e^- \to \omega\pi \to \pi^0\pi^0\gamma$
- $e^+e^- \to \rho\pi\pi \to \pi^+\pi^-\pi^+\pi^-$
- $e^+e^- \to \omega\pi, \rho\pi\pi, \rho^+\rho^- \to \pi^+\pi^-\pi^0\pi^0$
- $e^+e^- \to \omega\pi\pi, \eta\pi\pi \to \pi^+\pi^-\pi^+\pi^-\pi^0$
- $e^+e^- \to K_S K_L$

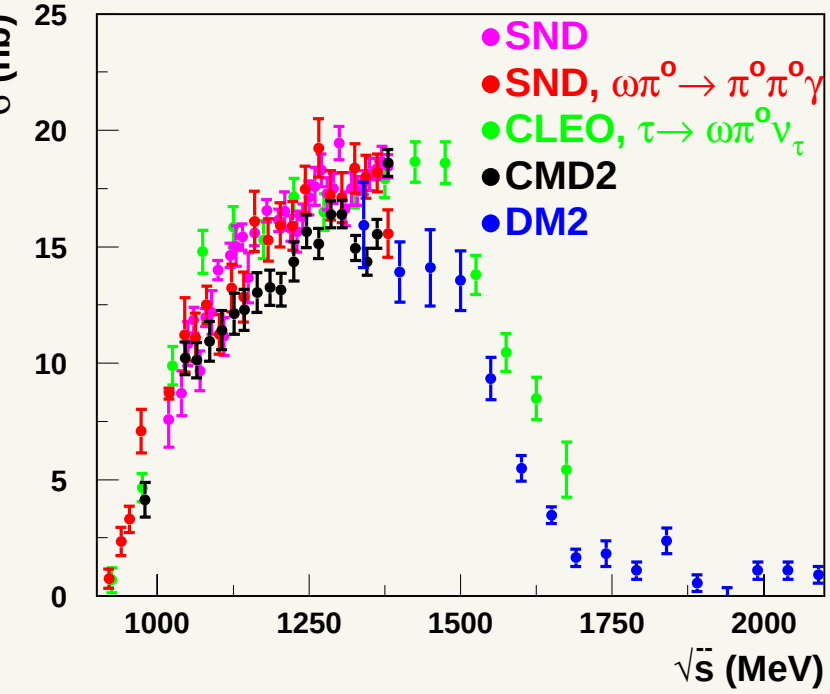
$e^+e^- \to \pi^0\pi^0\gamma$

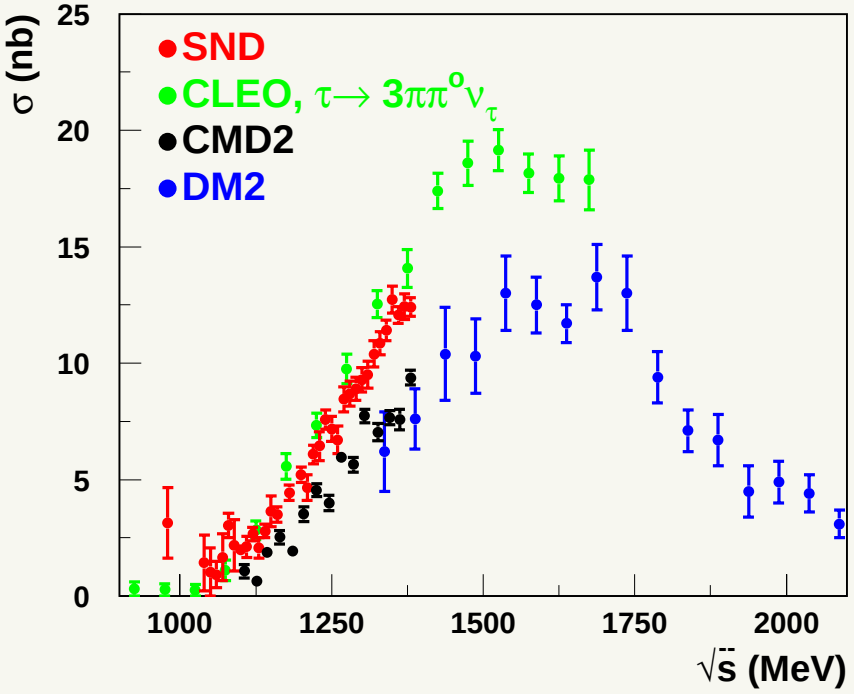


$e^+e^- \to \omega\pi \to \pi^0\pi^0\gamma$

Systematic error: 5 %

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





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

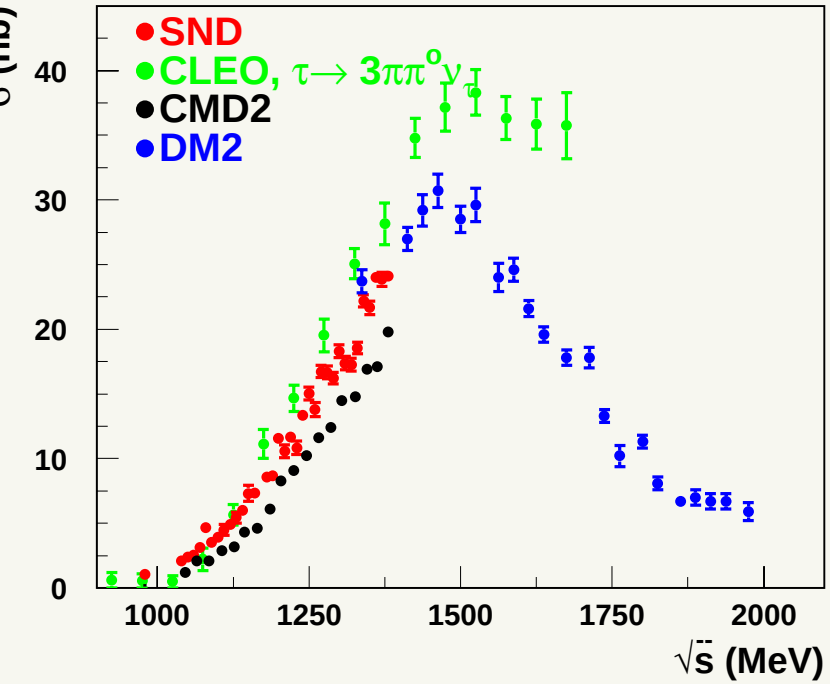
Systematic error: 20 % ($\sqrt{s} < 1150$ MeV)
15 % ($\sqrt{s} > 1150$ MeV)

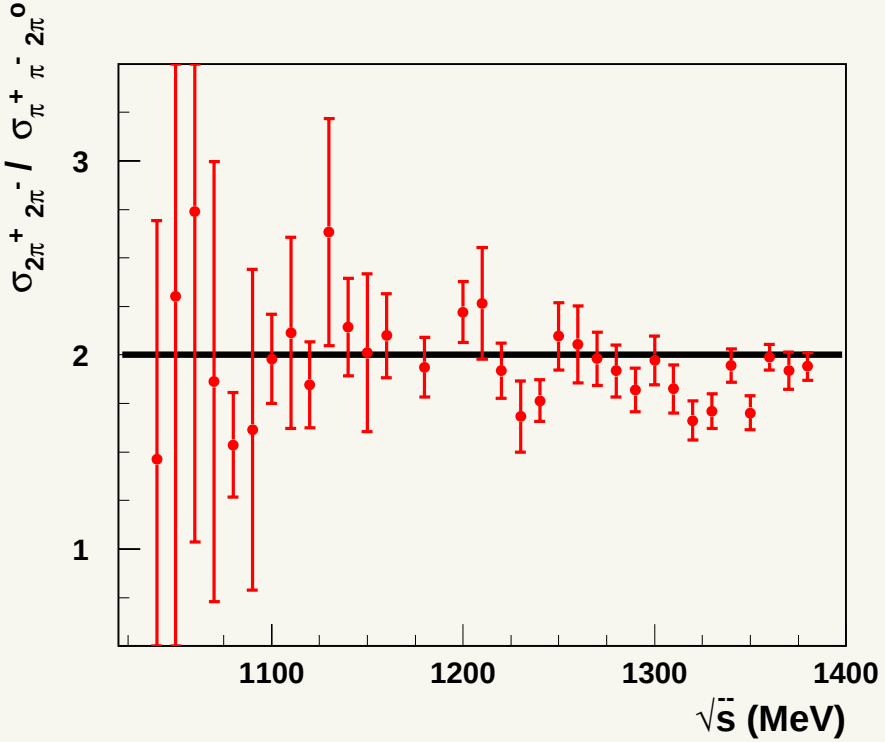
$e^+e^- \to \pi^+\pi^-2\pi^0$

($\omega\pi^0$ subtracted)

Systematic error: 20 %

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





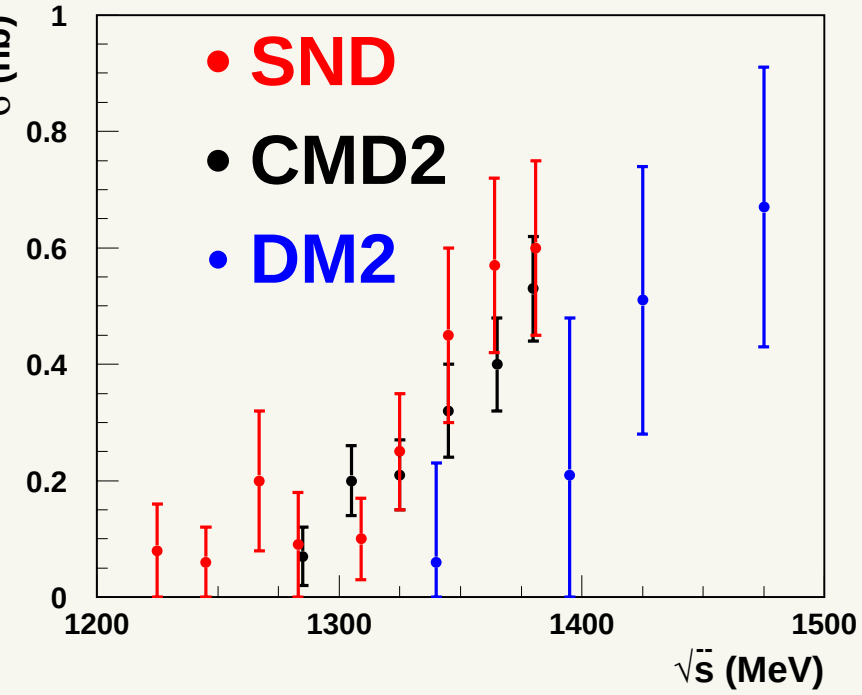
$e^+e^- \to \pi^+\pi^-\pi^+\pi^-$

Systematic error: 12 % ($\sqrt{s} < 1150$ MeV)

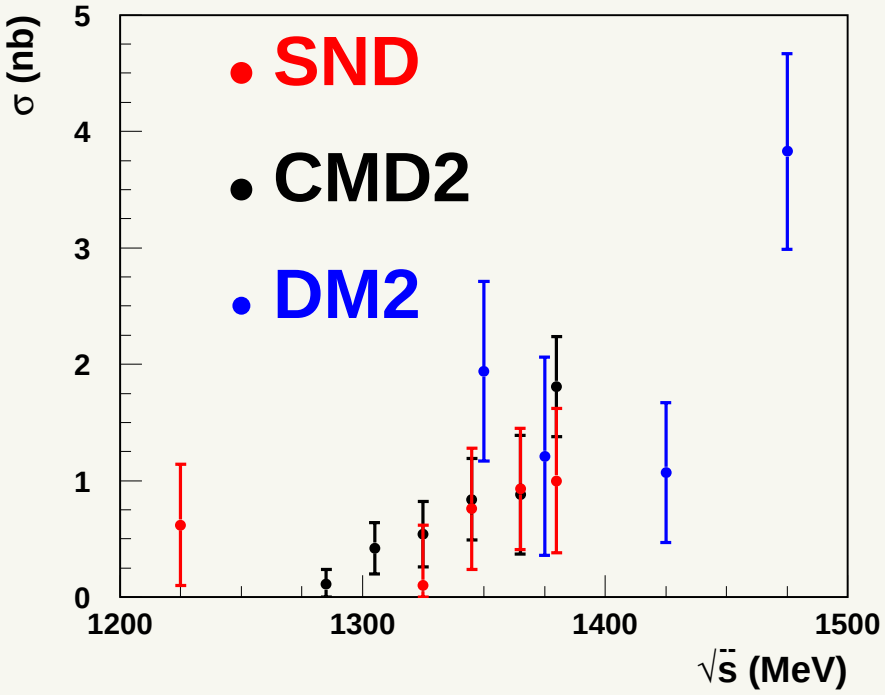
8 % ($\sqrt{s} > 1150$ MeV)

$\sigma_{\pi^+\pi^-\pi^+\pi^-}/\sigma_{\pi^+\pi^-\pi^0\pi^0}$

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

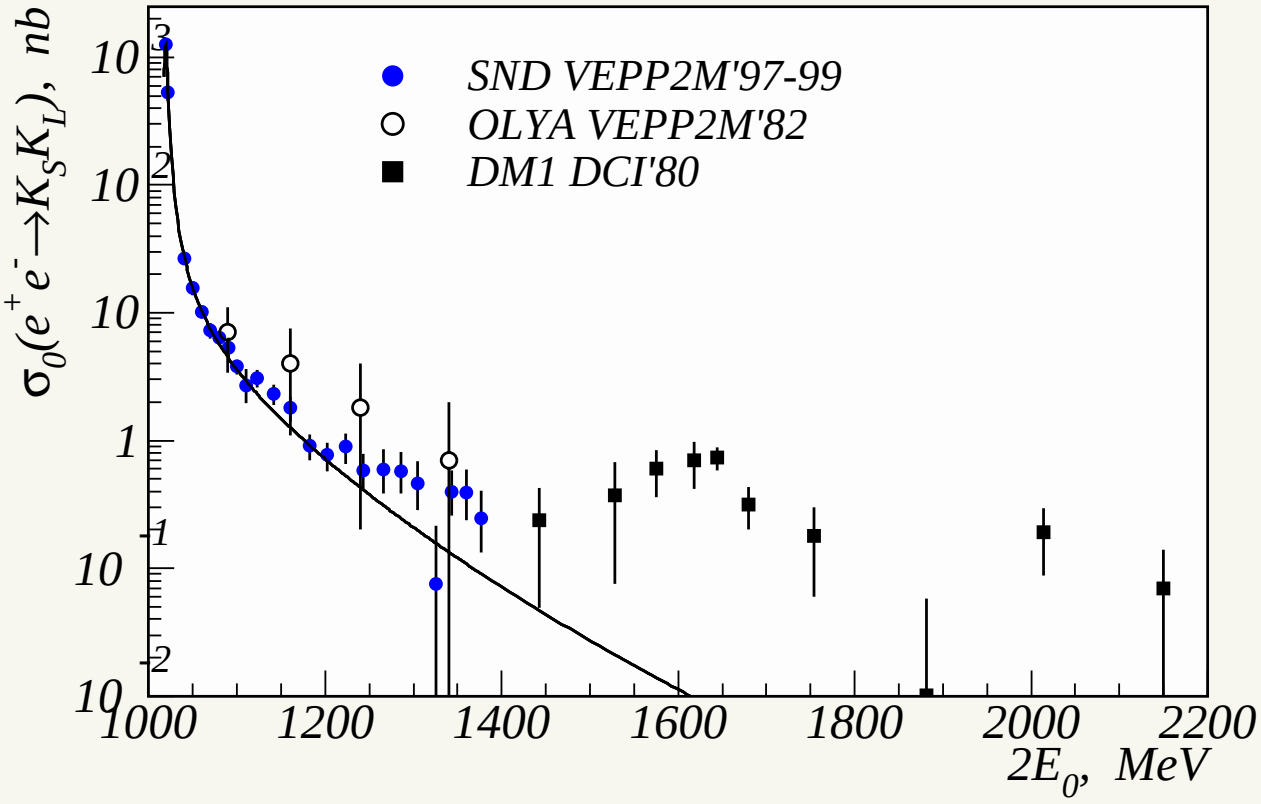


$e^+e^- \to \omega\pi^+\pi^-$



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

$e^+e^- \to K_S K_L$

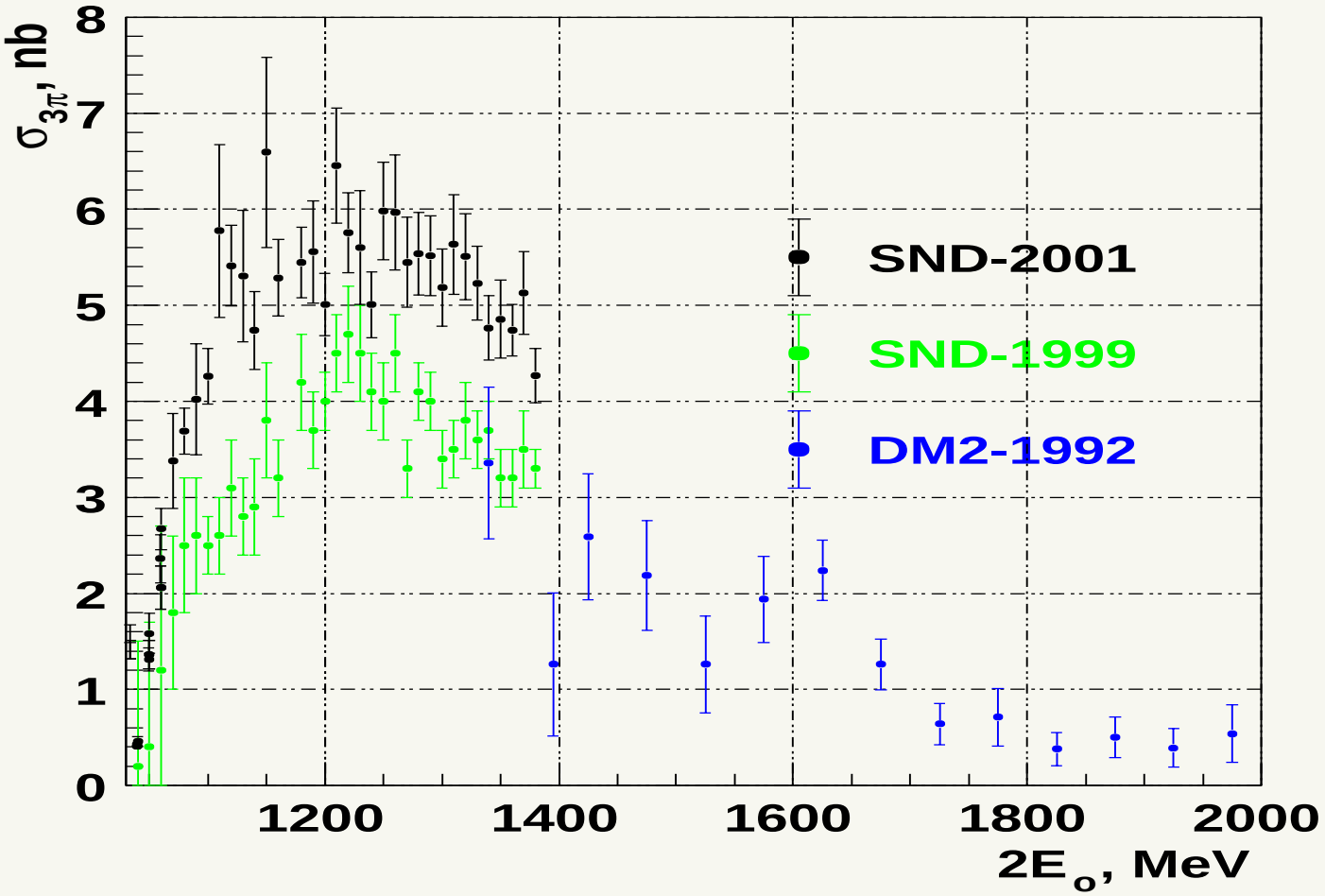


$e^+e^- \to K_S K_L$

$(K_S \to \pi^0\pi^0)$

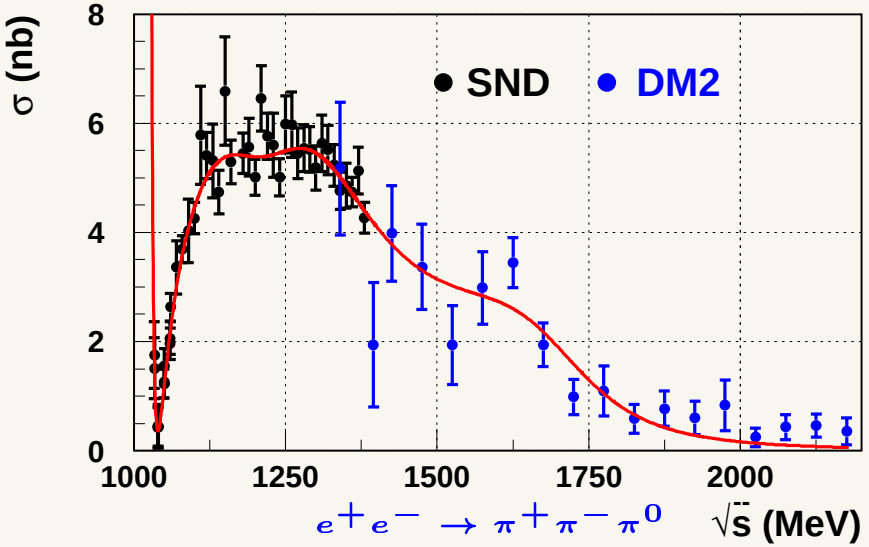
Systematic error: 7 % $(\sqrt{s} < 1100)$ MeV, 16 % $(\sqrt{s} > 1100)$ MeV

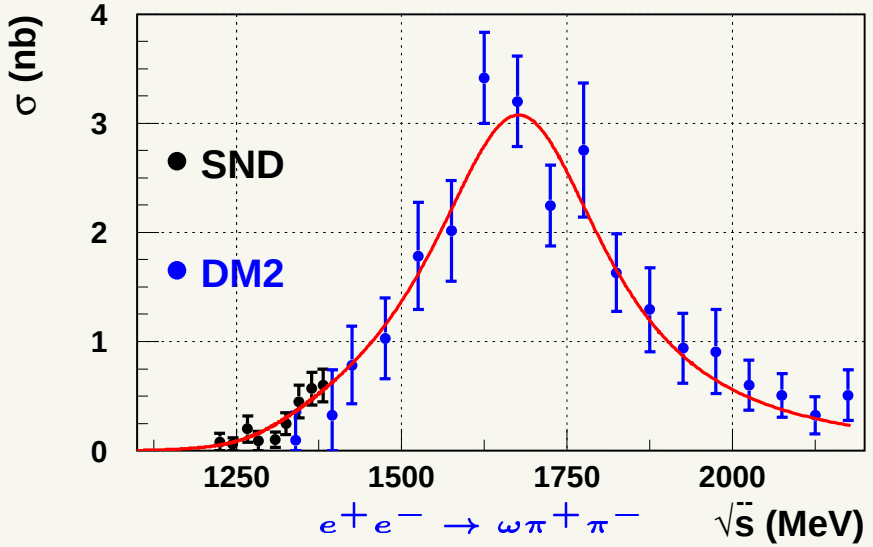
$e^+e^- \to \pi^+\pi^-\pi^0$



Systematic error: 5 %

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





	ω^1	ω^2	ω^3
m, MeV	1250±29	1400±19	1771±28
Γ, MeV	426±135	626±89	473±76
$\sigma(V \to \rho\pi)$, nb	0.56±0.25	3.90±0.39	2.28±0.46
$\sigma(V \to \omega\pi\pi)$, nb	0	0.046±0.039	2.49±0.33
ϕ	π	π	0
$\Gamma(V \to e^+e^-)$,eV	~ 25	~ 300	~ 470

New project: VEPP-2000

Maximum beam energy – 1 GeV

Perimeter – 24.388 m

Time between collisions – 0.04 μ s

parameters at $E_{beam} = 900$ MeV:

Luminosity – $1 \cdot 10^{32}$

Beam current – 200 mA

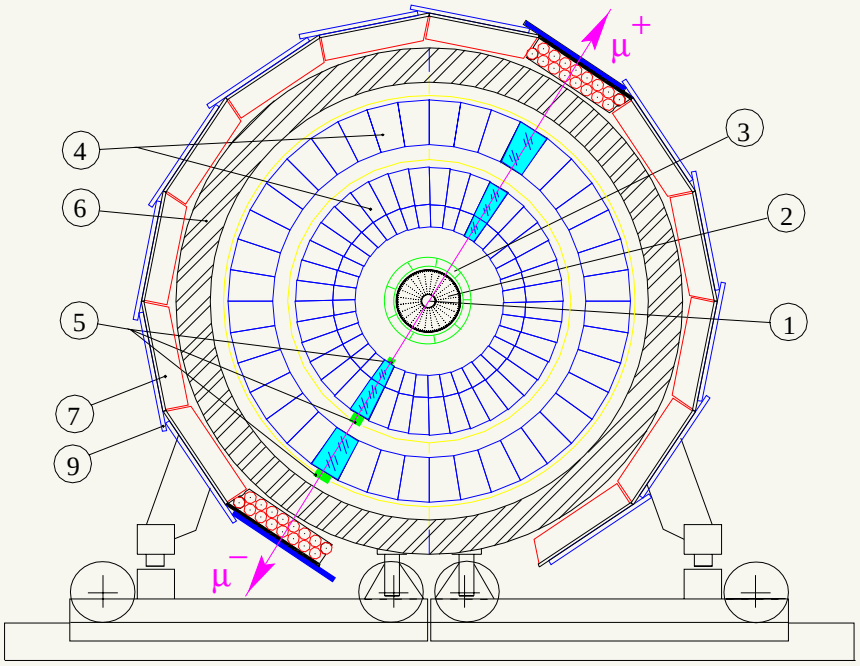
Number of particles in one bunch – $1 \cdot 10^{11}$

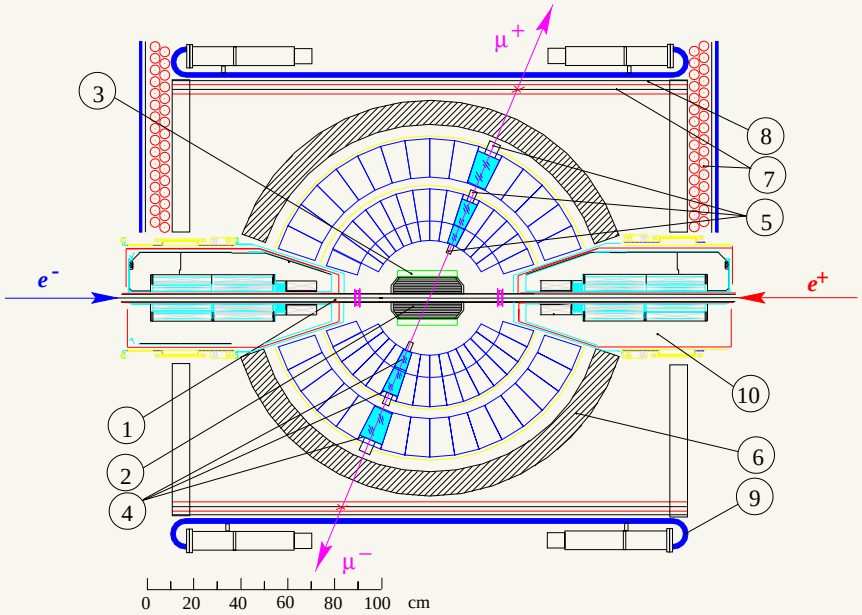
Bunch length – 3.3 cm

Beta function at interaction point – $\beta_x = \beta_z = 6.3$ cm

Energy spread – $\sigma_E = 6.4 \cdot 10^{-4}$

New project: SND Upgrade





1 - beam pipe, 2 - drift chamber, 3 - aerogel cherenkov counters, 4 - NaI(Tl) crystals, 5 - vacuum phototriodes, 6 - iron absorber, 7 - streamer tubes, 8 - 1cm iron absorber, 9 - scintillation counters, 10 - solenoids

New project: SND Upgrade

Drift chamber (jet, gas Ar+10%CO_2)	$\sigma_{R-\phi} = 150\mu$ m; $\sigma_z = 1 \div 1.5$mm; $\sigma_\phi = \sigma_\theta = 0.25^\circ$ dE/dx: π/K for $\|p\| \leq 300$ MeV; $\Omega = 0.94 \cdot 4\pi$
Calorimeter	new phototriods and electronics
Aerogel Counters	π/K for 250MeV$< \|p\| <$ 900 MeV

Physics program

- measurement of cross sections of different processes, for example, $e^+e^- \to 2\pi, \rho\pi, \omega\pi, KK, 4\pi, KK\pi$ etc.;
- measurement of full cross section e^+e^- →hadrons;
- studying of parameters of vector resonances in energy range $1.2 \div 2$GeV;
- $n\bar{n}$,$p\bar{p}$ form factors on threshold;
- two-photon physics: $e^+e^- \to e^+e^- + \pi^0, \eta, \eta', 2\pi^0$ etc.