

Budker Institute of Nuclear Physics  
Siberia branch of Russian Academy of Science

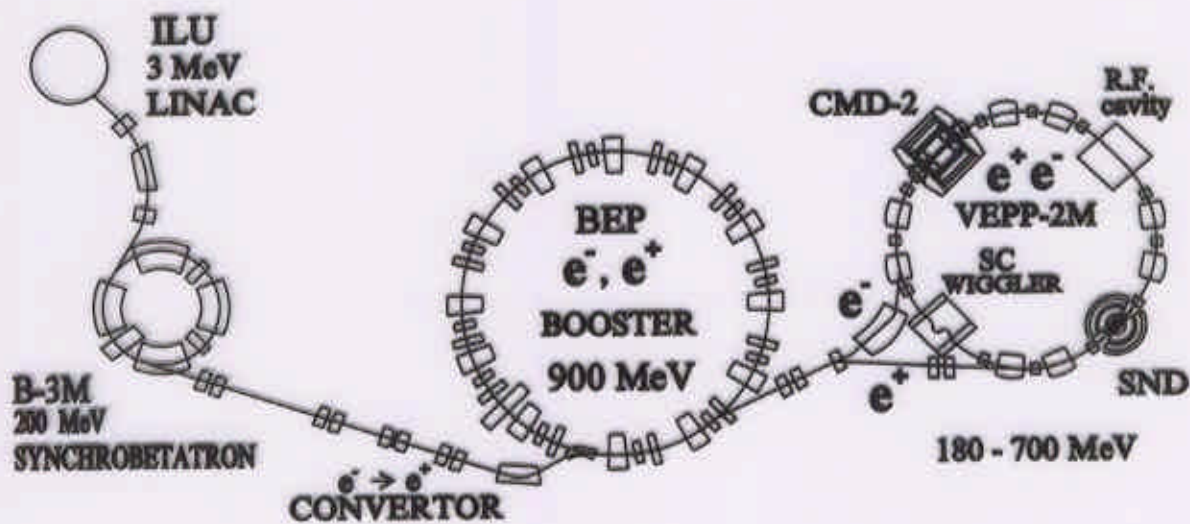
Alexander E. Bondar

## Recent results from VEPP-2M collider

- Introduction (BINP)
- VEPP-2M Collider
- Detector(s)
- Runs history
- $\rho, \omega, \phi$  parameters
- $\phi$ -decays study
  - $\phi$ -interferometry
  - $\phi$ -radiative decays
  - conversion decays
- Hadron cross section study
- Conclusion (plans)

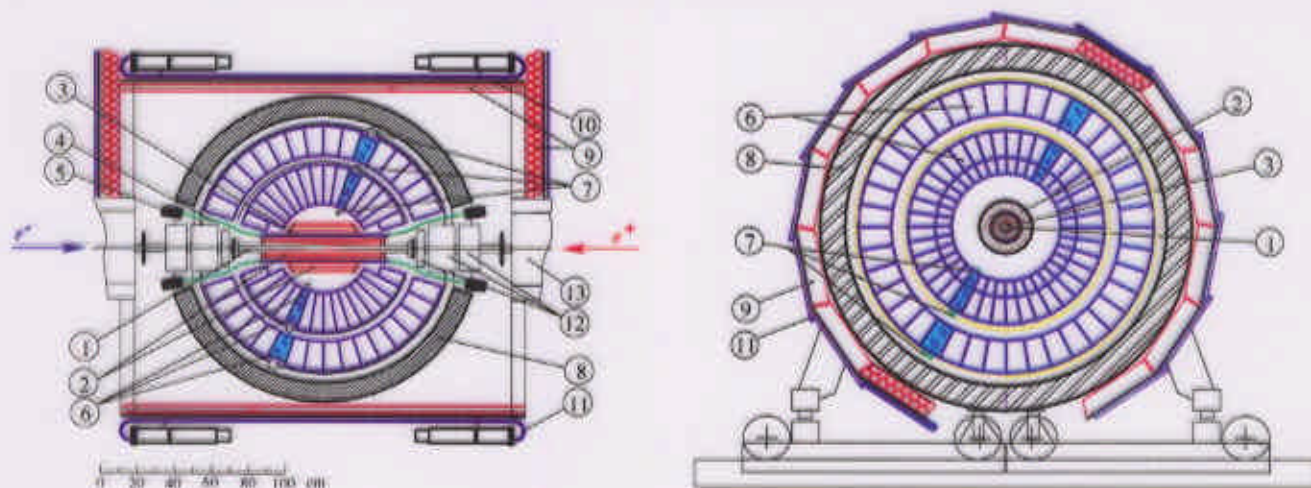
– 1999 –

## VEPP-2M Collider Complex



- VEPP-2 - world first  $e^+e^-$  machine, operated from 1965 to 1970
- VEPP-2M - operates since 1974
- $2E = 0.4 \div 1.4 \text{ GeV}$
- $L_{max} = 4 \cdot 10^{30} \text{ cm}^{-2} \text{ sec}^{-1}$  at  $E_0 = 510 \text{ MeV}$
- Total integrated luminosity  $\simeq 100 \text{ pb}^{-1}$

## The SND detector



1 — beam pipe, 2 — drift chambers, 3 — scintillation counter, 4 — light guides, 5 — PMTs, 6 — NaI(Tl) crystals, 7 — vacuum phototriodes, 8 — iron absorber, 9 — streamer tubes, 10 — iron plates, 11 — plastic scintillators, 12 and 13 — collider magnetic lenses

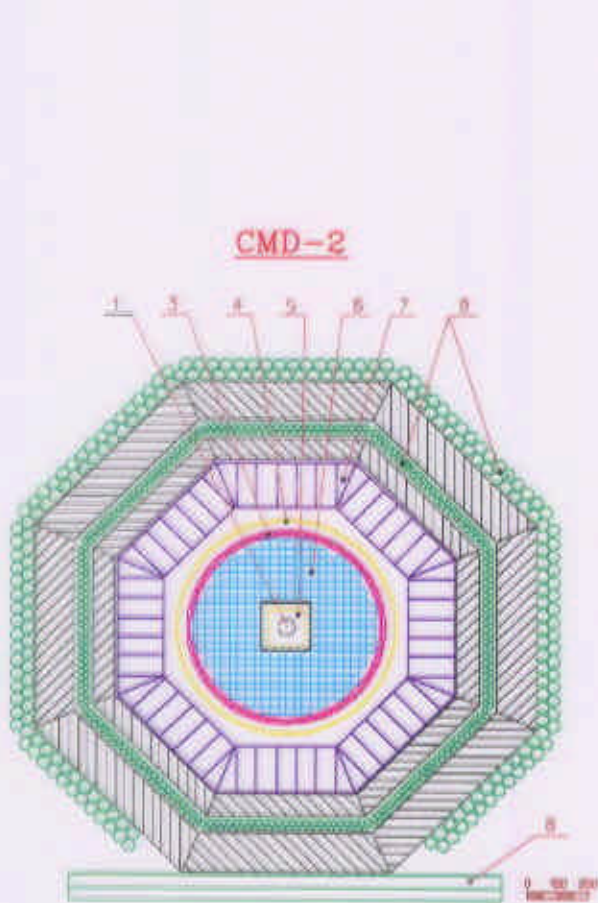
## Main SND parameters

Drift chambers	
Structure	jet, 20 cells
$R_{\max}$	6cm, 12cm
$L_{\text{wire}}$	44cm, 20cm
$N_{\text{layers}}$	5 + 5
Solid angle	$0.98 \cdot 4\pi$
$R$ - $\phi$ res.	0.3mm
$Z$ res.	4mm (2mm)
$\sigma_{\phi}$	$0.5^{\circ}$
$\sigma_{\theta}$	$1.7^{\circ}$
Gas	Ar + 10%CO <sub>2</sub>

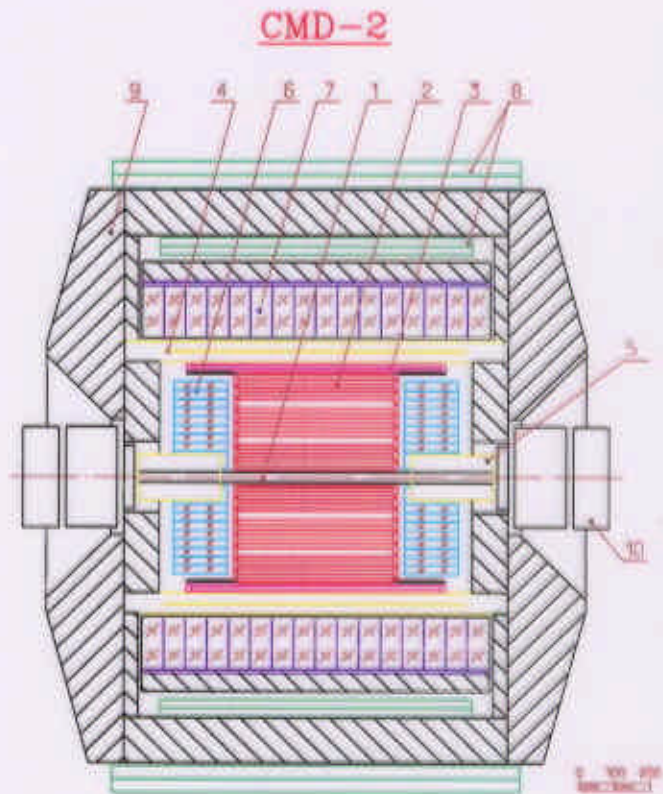
NaI calorimeter	
$N_{\text{cryst}}$	1632
Thickness	34.7cm ( $13.4X_0$ )
Granularity $\phi, \theta$	$9^{\circ} \times 9^{\circ}$ ( $\theta > 36^{\circ}$ ) $18^{\circ} \times 9^{\circ}$ ( $18^{\circ} < \theta < 36^{\circ}$ )
Solid angle	$0.9 \cdot 4\pi$
Readout	Vacuum phototriodes
Noise	150...350keV
$\sigma_E$	$4.2 / \sqrt[4]{E(\text{GeV})} \%$
$\sigma_{\phi}$	$0.82^{\circ} / \sqrt{E(\text{GeV})} \oplus 0.63^{\circ}$

**Reference for SND: NIM A449 (2000) 125-139**

## The CMD-2 detector



1-vacuum chamber;  
3- Z-chamber; 4-main solenoid;  
5-compensating solenoid; 6-BGO endcap  
calorimeter; 7-CsI barrel calorimeter;  
8-muon range system.



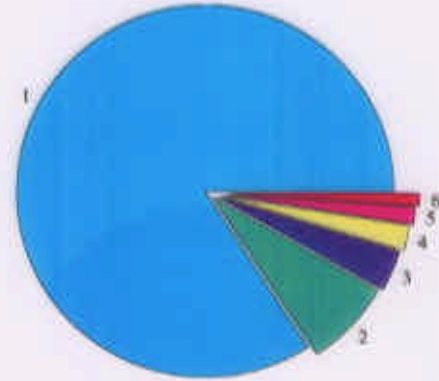
1-vacuum chamber; 2-drift chamber;  
3- Z-chamber; 4-main solenoid;  
5-compensating solenoid; 6-BGO endcap  
calorimeter; 7-CsI barrel calorimeter;  
8-muon range system; 9-iron yoke;  
10-storage ring lenses

## Hadronic Contribution to Muon Anomalous Magnetic Moment from VEPP-2M Data

$$a_\mu = \frac{g-2}{2}$$

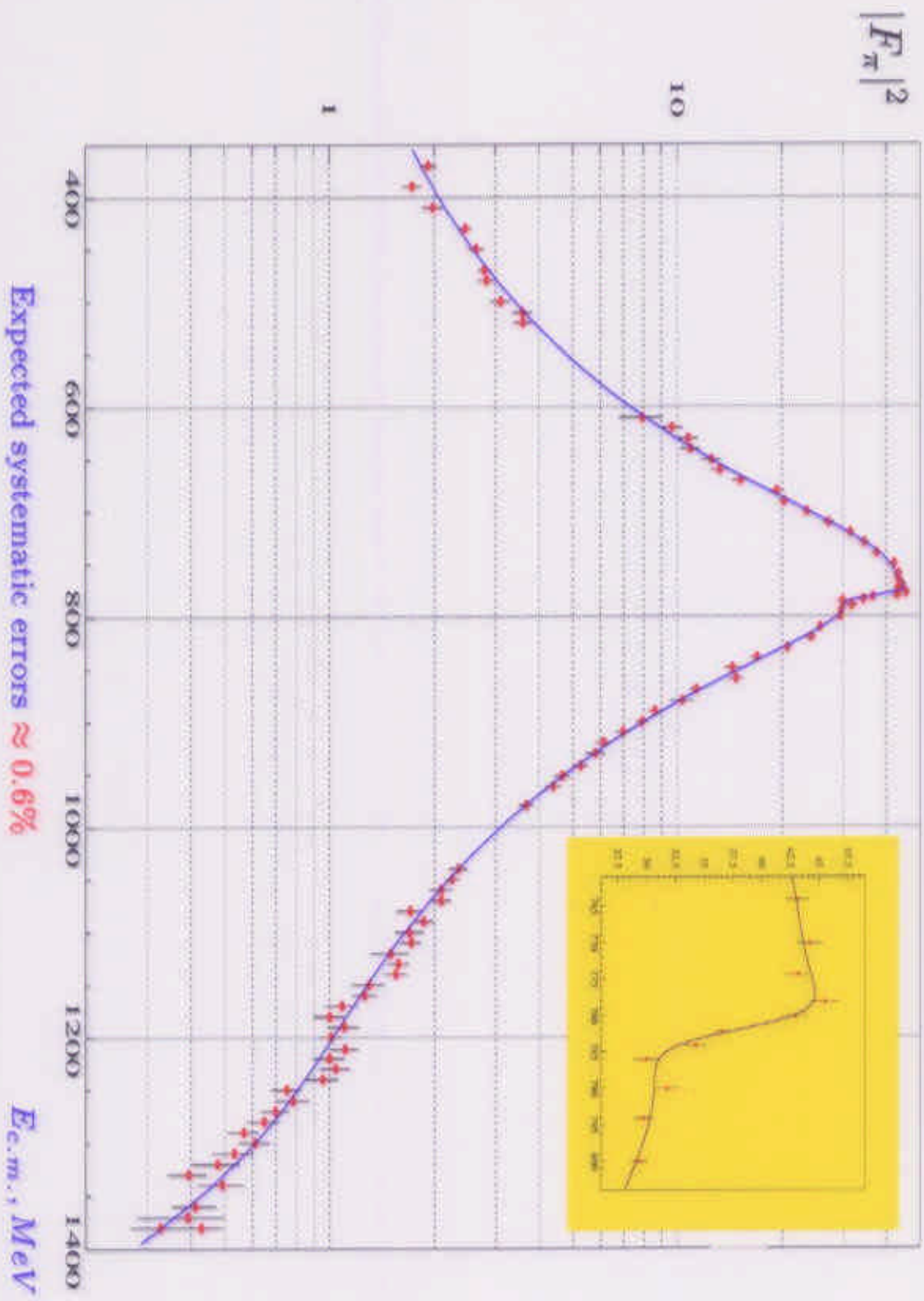
$$a_\mu^{had}(total) = 70.2 \times 10^{-9} \text{ (60.21 ppm)}$$

$$a_\mu^{had}(VEPP-2M) = 60.18 \times 10^{-9} \text{ (51.61 ppm)}$$



	Channel	Contr. ppm	Cross section error, %	Error in $a_\mu$ , ppm
1	$\pi^+\pi^-$	43.19	0.6	0.26
2	$\pi^+\pi^-\pi^0$	3.88	1.5	0.06
3	$K^+K^-$	1.81	5.2	0.09
4	$K_LK_S$	1.12	1.9	0.02
5	$\pi^+\pi^-\pi^0\pi^0$	0.77	7	0.05
6	$\pi^+\pi^-\pi^+\pi^-$	0.53	7	0.04
7	$\pi^0\gamma, \eta\gamma$	0.31	6	0.02
	Total	51.61		0.29

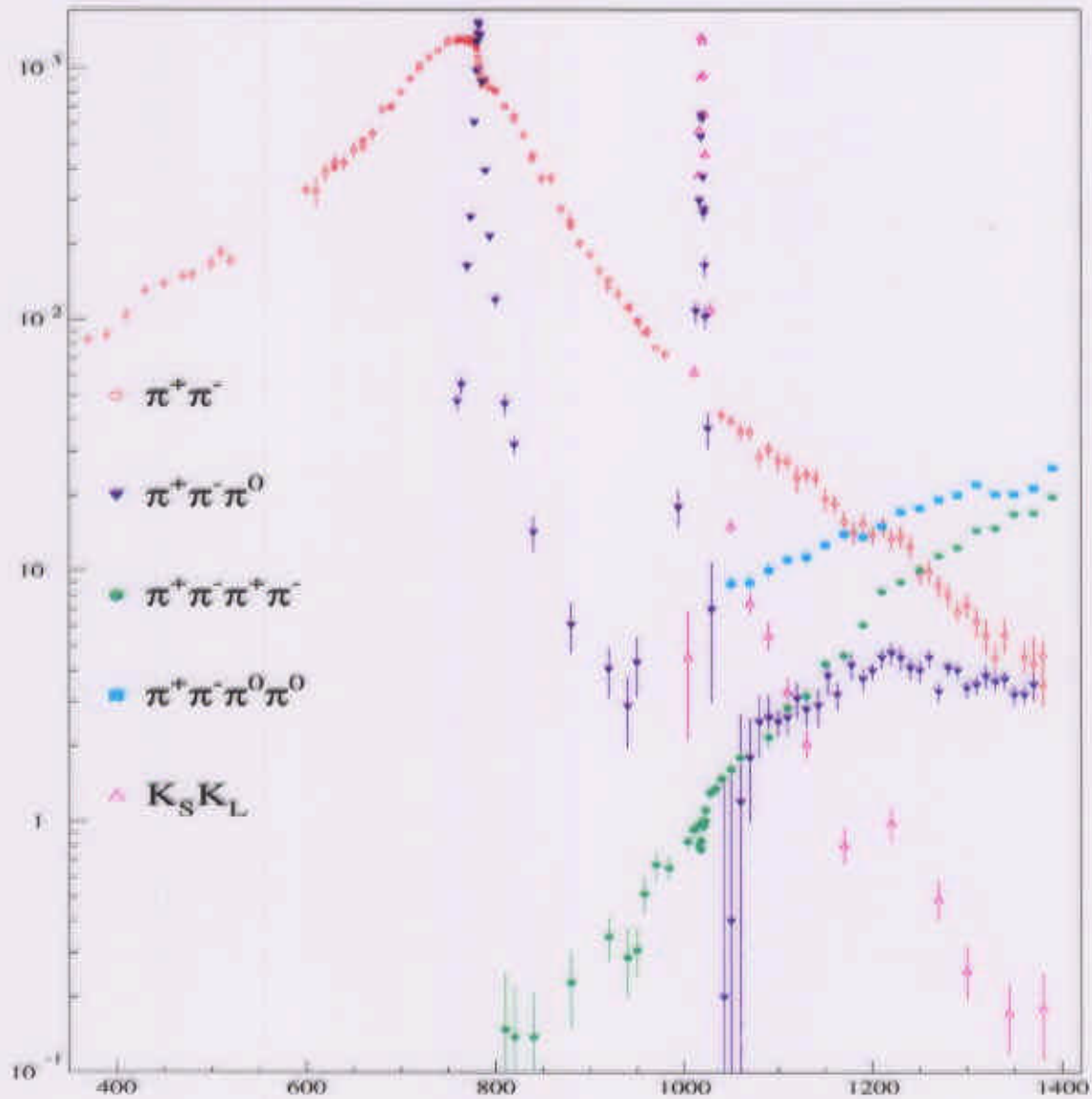
### Pion formfactor study at VEPP-2M



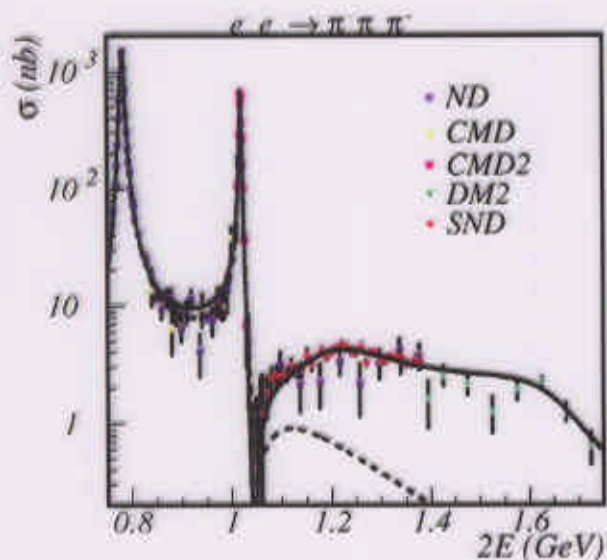
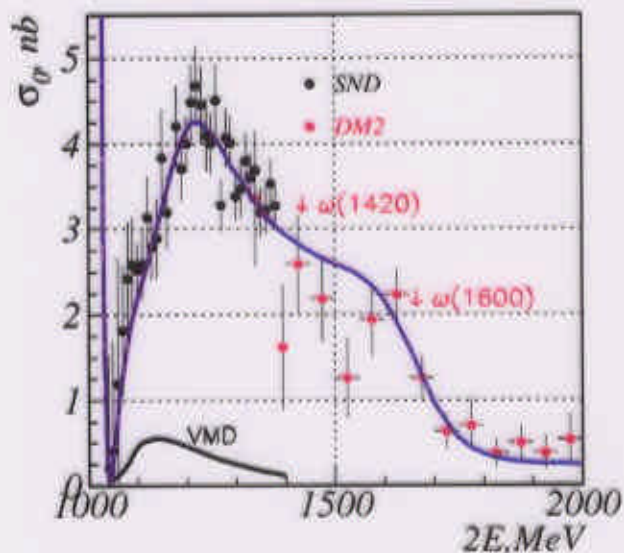
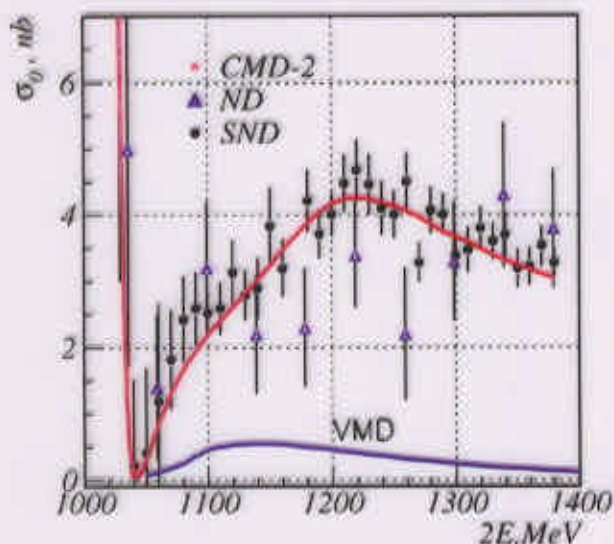
Expected systematic errors  $\approx 0.6\%$

$E_{c.m.}, MeV$

# $e^+e^-$ Annihilation into Hadrons



The process  $e^+e^- \rightarrow \pi^+\pi^-\pi^0$  in the energy range  $2E = 1.0 \div 1.4$  GeV



Fitting of  $e^+e^- \rightarrow \pi^+\pi^-\pi^0$  Cross Section

Fit 1:  $\Gamma_V(s) = \text{Const}$

$M_{\text{eff}} = 1170 \div 1250$  MeV,

$\Gamma_{\text{eff}} = 190 \div 550$  MeV

Fit 2:  $\Gamma_V(s) = g^2 \cdot W(s)$

$M_{\omega'} = 1430^{+110}_{-70}$  MeV,

$\Gamma_{\omega'} = 900$  MeV



### Cross section of $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$ at $\phi$

$$\sigma(s) = \sigma_0 \cdot e^{A \cdot (\sqrt{s} - m_\phi)} \cdot |1 + Z \cdot \frac{\Gamma_\phi \cdot s}{m_\phi \cdot \Delta_\phi}|^2, \quad \Delta_\phi = s - m_\phi^2 + i\Gamma_\phi(s)\sqrt{s}$$

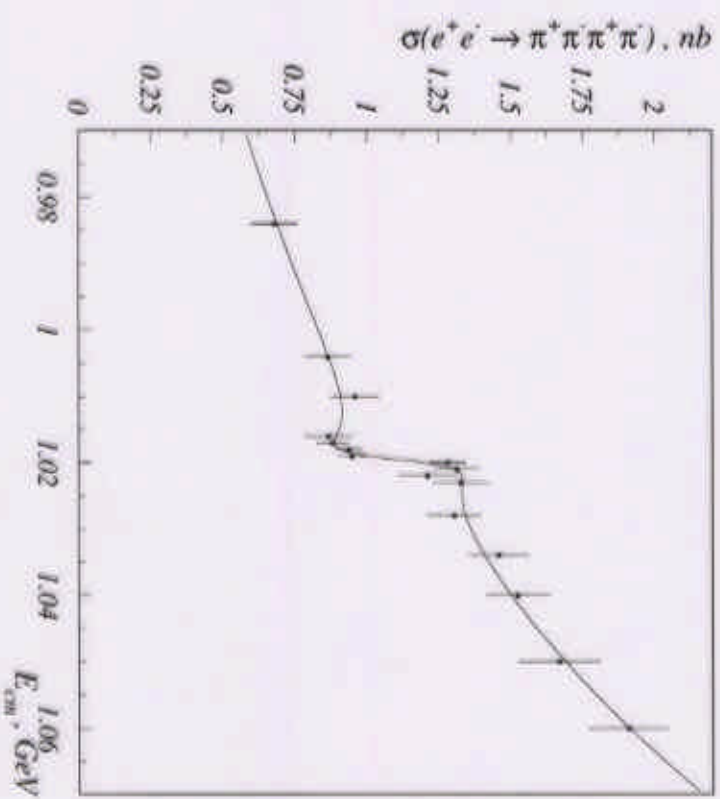
$$\chi^2/n.d.f. = 0.54$$

$$\sigma_0 = 1.114 \pm 0.035 \pm 0.056$$

$$A = 13.05 \pm 1.42 \pm 0.90 \text{ GeV}^{-1}$$

$$\text{Re}Z = 0.122 \pm 0.027 \pm 0.033$$

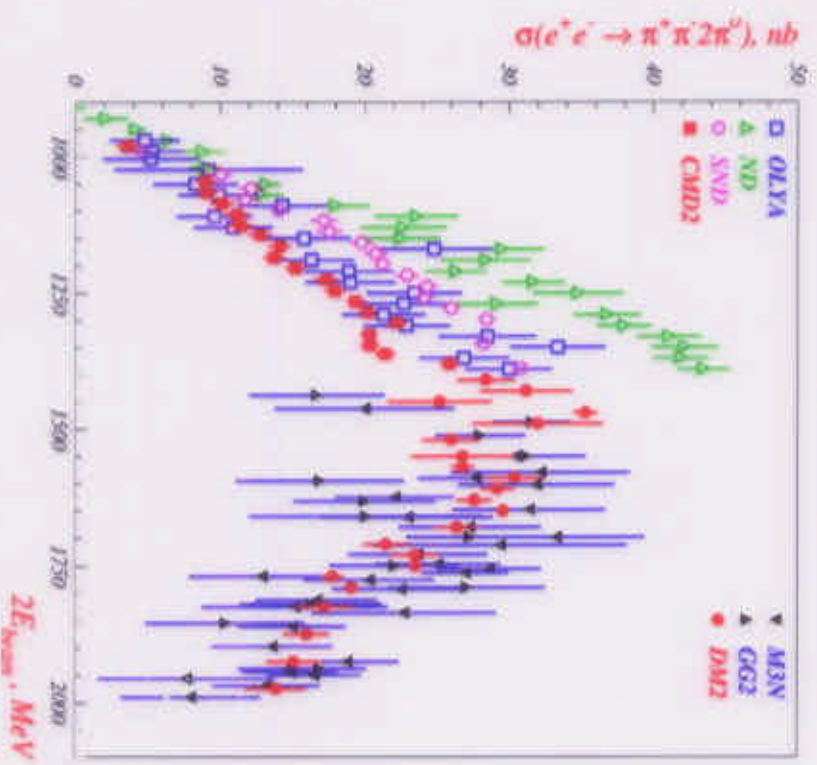
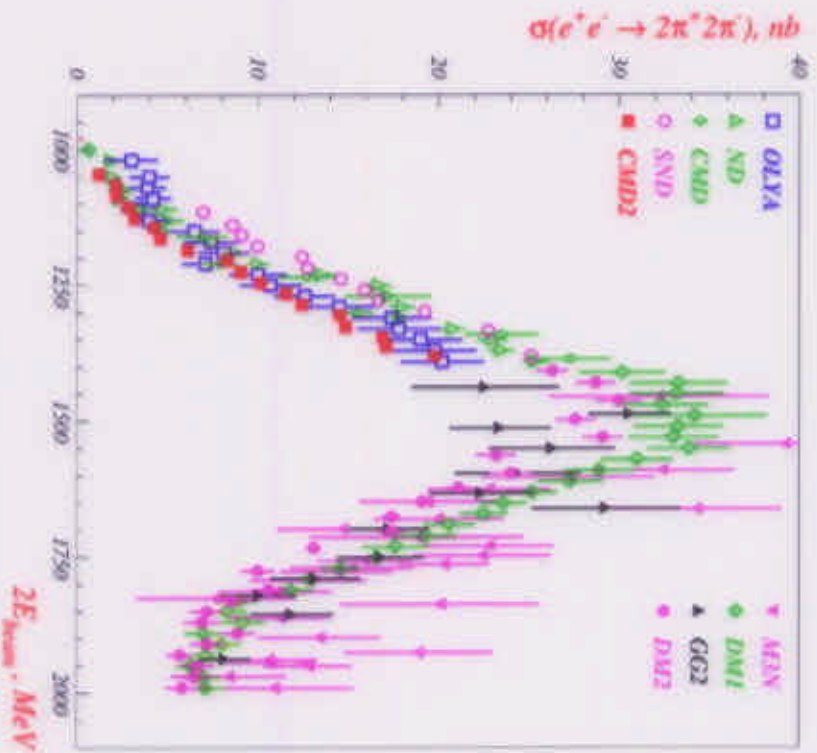
$$\text{Im}Z = -0.003 \pm 0.025 \pm 0.058$$



$$Br(\phi \rightarrow \pi^+\pi^-\pi^+\pi^-) = (3.93 \pm 1.74 \pm 2.14) \cdot 10^{-6}$$

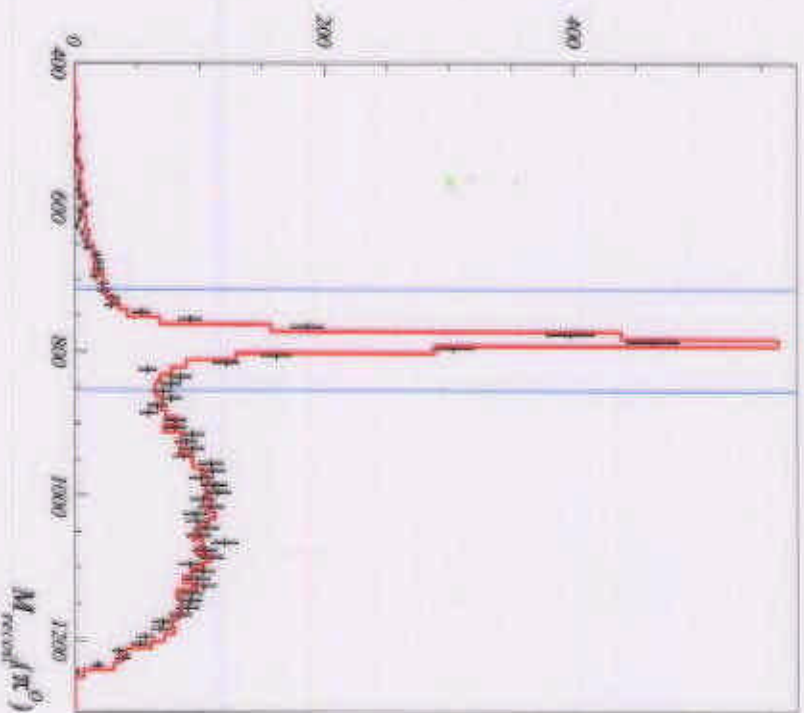
$$Br(\phi \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^0) < 0.35 \cdot 10^{-5}, \quad Br(\phi \rightarrow \pi^+\pi^-\eta) < 1.5 \cdot 10^{-5} \quad 90\% \text{ CL}$$

## Cross section of $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$

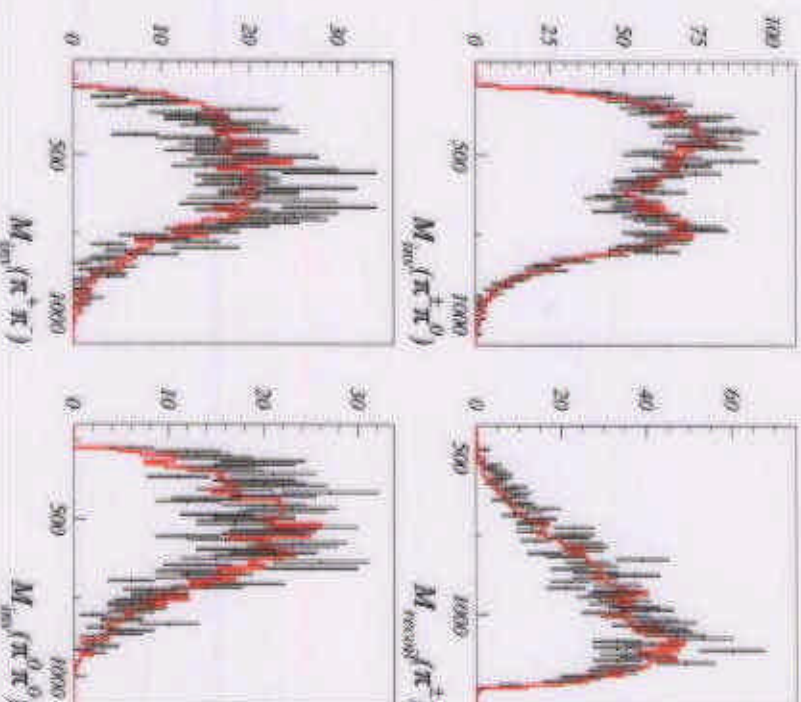


Systematic errors  $\approx 7\%$

## Study of the dynamics of $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-, \pi^+\pi^-\pi^0\pi^0$



Distribution over  $\pi^0$  recoil mass for  $\pi^+\pi^-$  and  $2\pi^0$



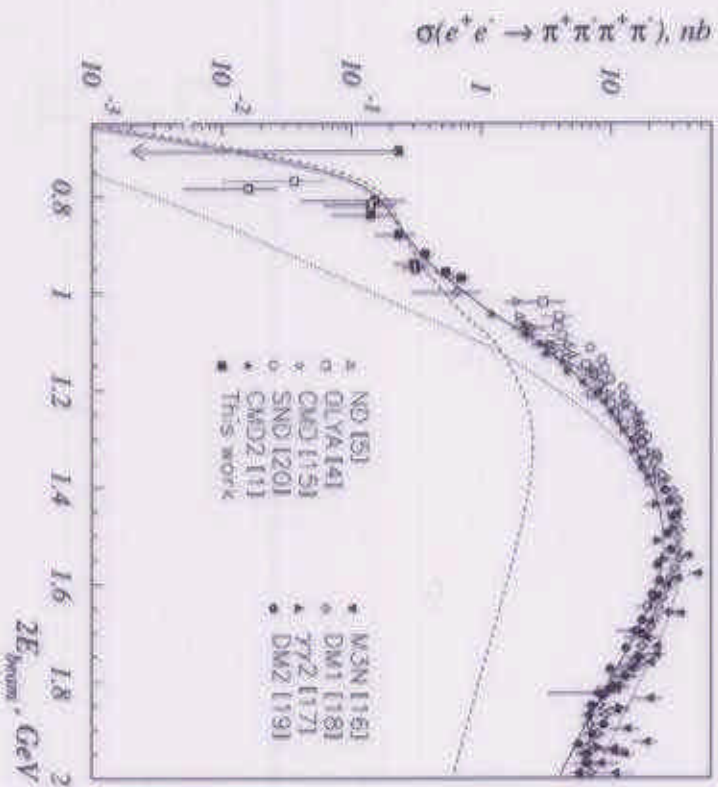
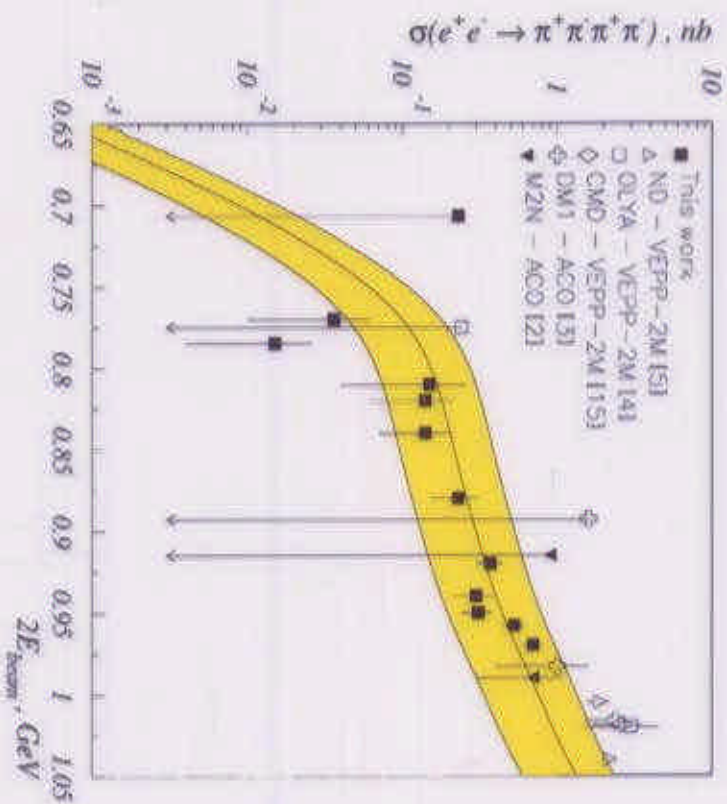
Distributions over  $M_{\pi^+\pi^-}$  and  $M_{\pi^+\pi^0}$  for  $\pi^+\pi^-\pi^+\pi^-$  and  $\pi^+\pi^-\pi^0\pi^0$  (no  $\omega$ ).

Only  $\omega\pi^0$  and  $a_1(1260)\pi$  dominate!

## Cross section of $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$ from 0.6 to 1.0 GeV

Fit with sum of  $\rho(770)$  and  $\rho'(1600)$

Systematic errors  $\approx 12\%$  for  $E < m_\phi$



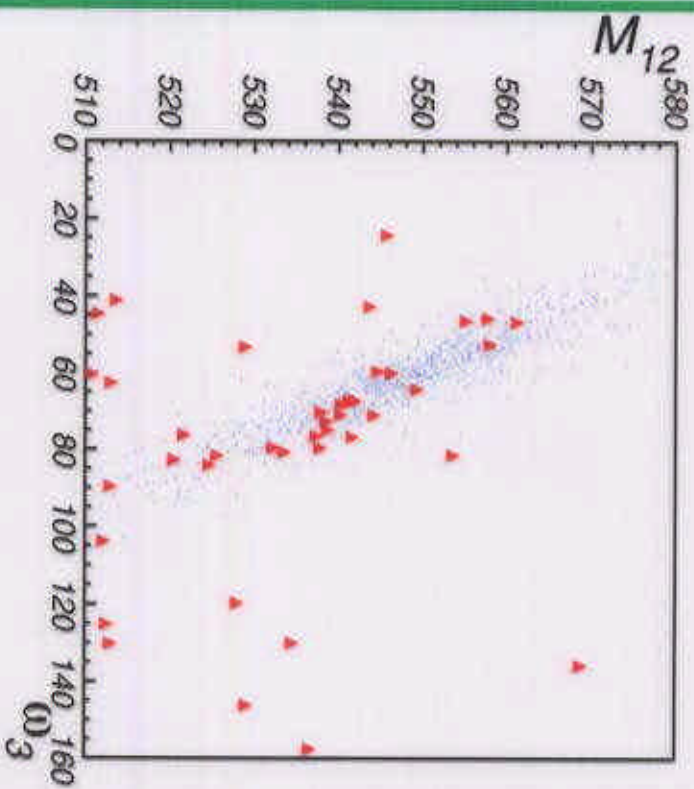
$$Br(\rho^0(770) \rightarrow \pi^+\pi^-\pi^+\pi^-) = (1.8 \pm 0.9 \pm 0.3) \cdot 10^{-5}$$

Phys.Lett.B475(2000)190-197.

Radiative  $\phi$  decays from VEPP-2M

Decay	SND	CMD-2	PDG, 1998
$\phi \rightarrow \pi^0 \gamma$	$(1.23 \pm 0.10) 10^{-3}$		$(1.31 \pm 0.13) 10^{-3}$
$\phi \rightarrow \eta \gamma$	$(1.246 \pm 0.062) \%$ $(1.338 \pm 0.053) \%$	$(1.18 \pm 0.07) \%$ $(1.24 \pm 0.06) \%$	$(1.26 \pm 0.06) \%$
$\phi \rightarrow \eta' \gamma$	$(6.7_{-2.9}^{+3.4}) \cdot 10^{-5}$	$(8.2_{-2.1}^{+2.3}) \cdot 10^{-5}$ $(5.8 \pm 2.3) \cdot 10^{-5}$	$(12_{-5}^{+7}) \cdot 10^{-5}$
$\phi \rightarrow \pi^0 \pi^0 \gamma$ $m_{\pi^0 \pi^0} > 700 \text{ MeV}$	$(1.16 \pm 0.11) \cdot 10^{-4}$ $(1.03 \pm 0.08) \cdot 10^{-4}$	$(1.08 \pm 0.19) \cdot 10^{-4}$ $(0.92 \pm 0.10) \cdot 10^{-4}$	$< 10^{-3}$
$\phi \rightarrow \eta \pi^0 \gamma$	$(0.88 \pm 0.17) \cdot 10^{-4}$	$(0.90 \pm 0.26) \cdot 10^{-4}$	$< 2.5 \cdot 10^{-3}$

## Search for $\phi \rightarrow \eta' \gamma$ decay



1993-1998 data,  $14.5 \text{ pb}^{-1}$

In  $\eta' \rightarrow \eta \pi^+ \pi^-$ ,  $\eta \rightarrow \gamma \gamma$  mode:

$$N_{\eta' \gamma} = 21.0^{+5.5}_{-4.9}$$

$$B(\phi \rightarrow \eta' \gamma) = (8.2^{+2.1}_{-1.9} \pm 1.1) \cdot 10^{-5}$$

In  $\eta' \rightarrow \eta \pi^+ \pi^-$ ,  $\eta \rightarrow \pi^+ \pi^- \pi^0(\gamma)$  mode:

$$N_{\eta' \gamma} = 11.6 \pm 3.6$$

$$B(\phi \rightarrow \eta' \gamma) = (5.8 \pm 1.8 \pm 1.5) \cdot 10^{-5}$$

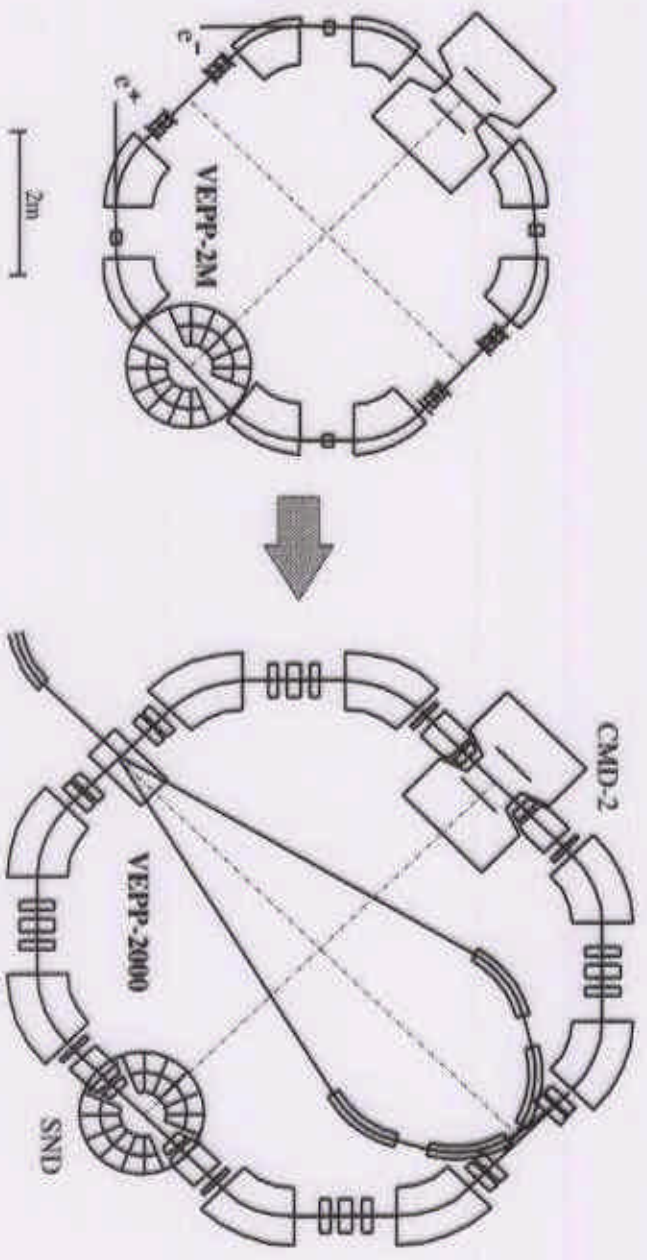
No substantial glue component !

$$B < 2 \cdot 10^{-5} \text{ for glue}$$

“Study of the decay  $\phi \rightarrow \eta' \gamma$ ”, R.R. Akhmetshin *et al.*, hep-ex/9911036, Submitted to *Phys.Lett.*

**VEPP-2M collider upgrade**

$2E=1.4 \text{ GeV} \rightarrow 2E=2000 \text{ MeV}$



## Experimental Program for VEPP-2000

Energy Region  $2E = 0.4 \div 2 \text{ GeV}$

- Total Cross Section of  $e^+e^-$  Annihilation into Hadrons
- Processes of  $e^+e^-$  Annihilation into Hadrons
- Search for Rare Decays of Vector Mesons  
 $\rho, \omega, \phi$
- Spectroscopy of Excited States  $\rho', \omega', \phi'$
- Search for Exotic Hadrons
- Production of Nucleon Pairs  $p\bar{p}$  and  $n\bar{n}$  at Threshold



## Physical Results from VEPP-2M

- Electric dipole radiative decays  $\phi \rightarrow \pi\pi\gamma, \eta\pi^0\gamma$  were observed with relatively large branching ratios  $\sim 10^{-4}$ , indicating that lightest scalar mesons  $f_0(980), a_0(980)$  might have exotic structure.
- The measured branching ratios of the decays  $\rho, \omega \rightarrow \pi^0\pi^0\gamma$  exceed considerably the VDM predictions, which might be due to production of the lightest scalar state  $\sigma(400-1200)$ , decaying into  $\pi^0\pi^0$ .
- Radiative decay  $\phi \rightarrow \eta'\gamma$  was observed with  $Br = (7.0 \pm 1.5) \cdot 10^{-5}$ , which leaves no room for large gluonium content in the  $\eta'$ .
- New rare  $\phi$ -decays  $\phi \rightarrow \omega\pi^0, 4\pi^\pm$  were observed with  $B.R. \sim 10^{-4} \div 10^{-5}$ .
- The analysis of  $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$  process shows, that it is completely explained by  $\omega\pi^0$  and  $A_1\pi$  intermediate states.
- A resonance-like structure in the  $e^+e^- \rightarrow \pi^+\pi^-\pi^0$  cross section near  $2E \simeq 1.2$  GeV was observed, which might be a manifestation of the lightest excited  $\omega$  state,
- Precision measurement of pion form factor with a systematic error of 0.6% was performed. This makes possible to achieve accuracy of  $(g_\mu - 2)$  calculations of 0.3 ppm.