Physical Program for VEPP-2000 e+e- Collider

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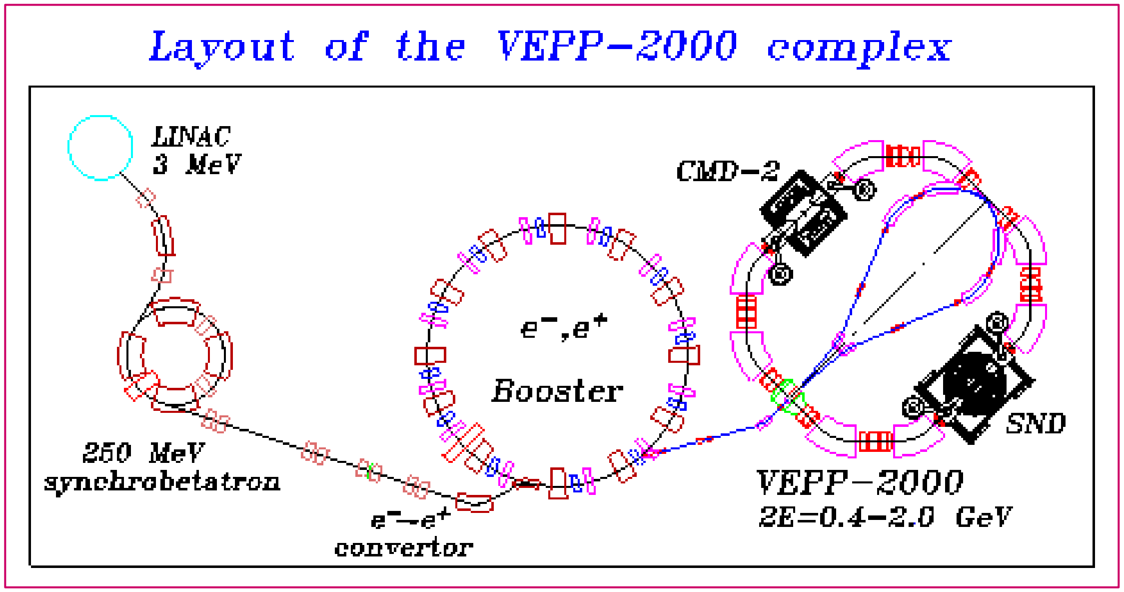
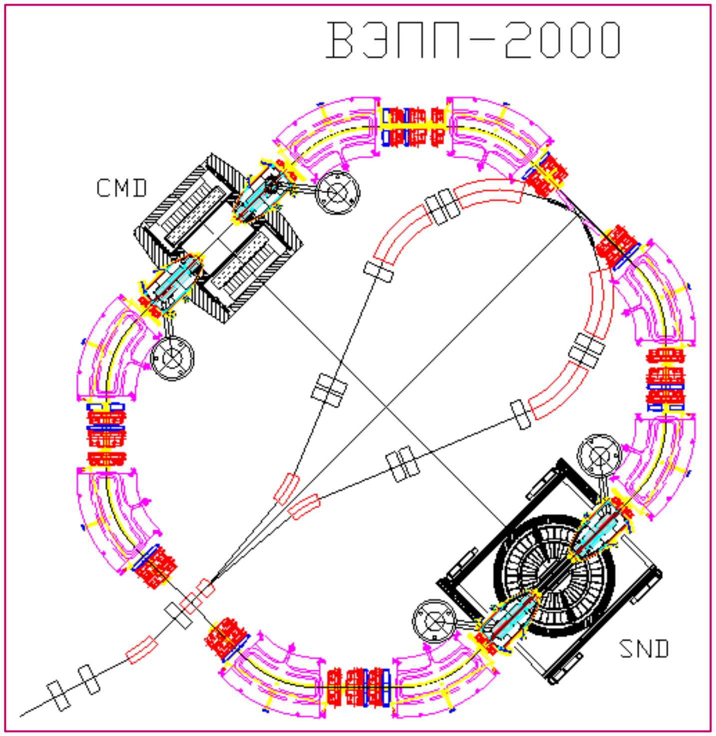
OUTLINE

1. **VEPP-2000 Collider**
2. **SND and CMD-3 Detectors**
3. **Physical Program**
4. **Conclusions**

VEPP-2000



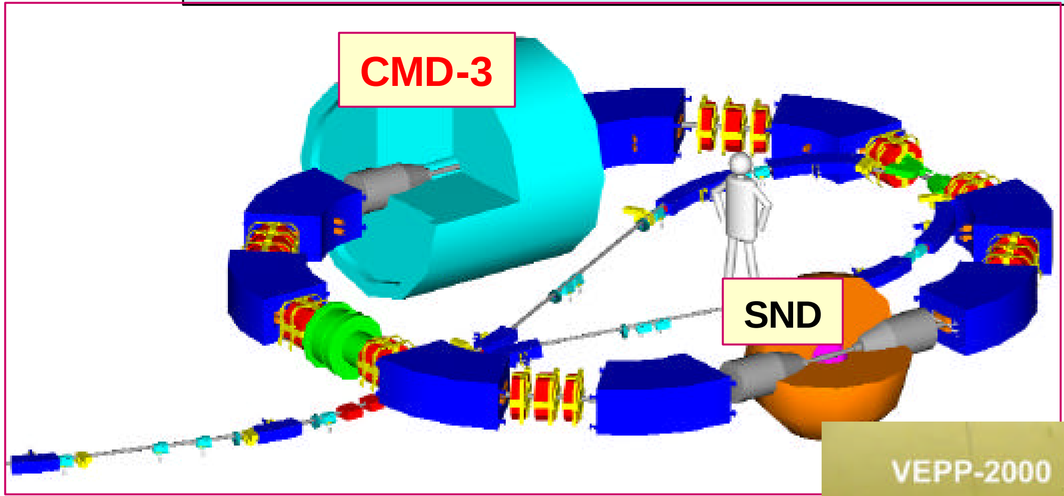
- Start of VEPP-2000 project –2000
- Energy range 2E=0.4-2.0 GeV
- Two collider detectors:
  SND and CMD-3



VEPP-2000 parameters:

- **perimeter – 24.4 m**
- **collision time – 82 nsec**
- **beam current – 0.2 A**
- **bunch length – 3.3 cm**
- **energy spread – 0.7 MeV**
- b_x? b_z =6.3 cm
- L ? 1.10[32] at 2E=2.0 GeV

VEPP-2000 View

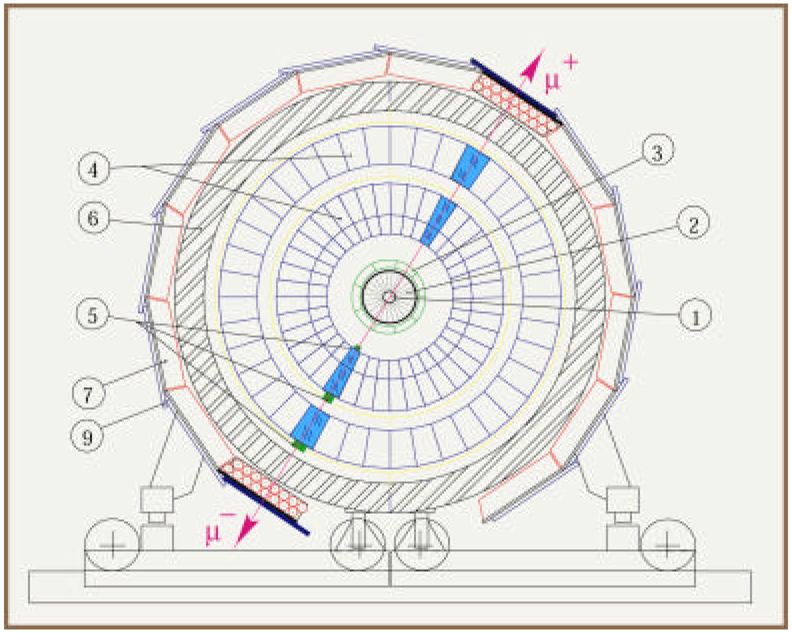


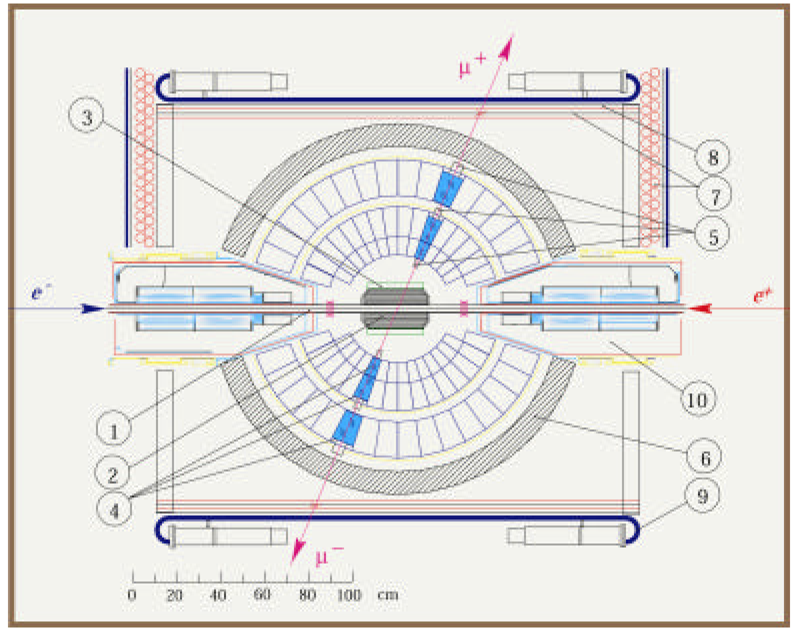
Refs for VEPP-2000:

1. In: Proc.Frascati Phys.Series,v XVI, p.393,Nov.16-19,1999
2. In: Proc. 7-th Europ.Part.Accel.Conf., EPAC 2000, p.439, Vienna,2000

SND Detector

Ref.: NIM A449 (2000) 125-139





1 – beam pipe, 2 – tracking system, 3 – aerogel cherenkov counter, 4 – NaI(Tl) counters,

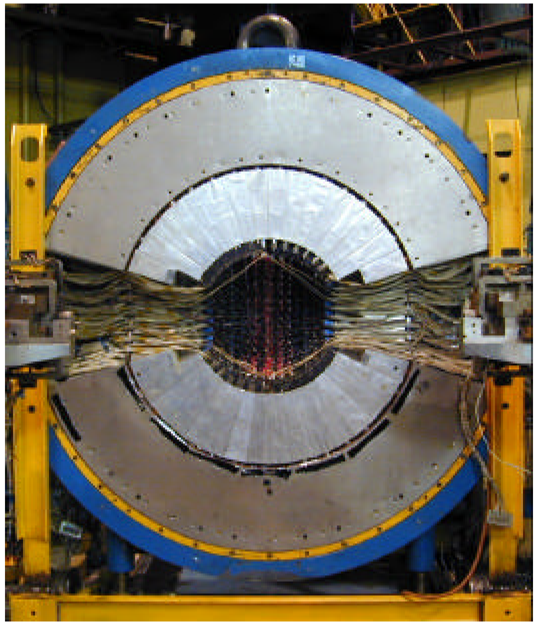
5 – vacuum phototriodes, 6 – absorber,

7-9 – muon system, 10 –s.c focusing solenoids.

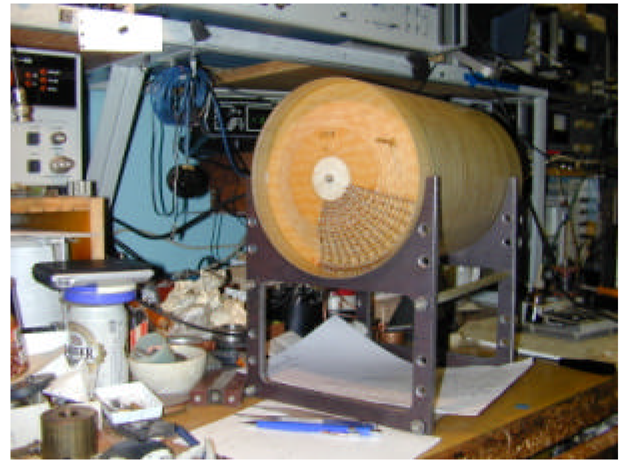
SND Detector

Calorimeter

- 1680 crystals
- VPT readout
- 3 spherical layers
- 3.5 tons
- 13.5 X_0
- 90% 4π
- $\Delta\varphi \times \Delta\theta = 9^0 \times 9^0$



NaI Calorimeter



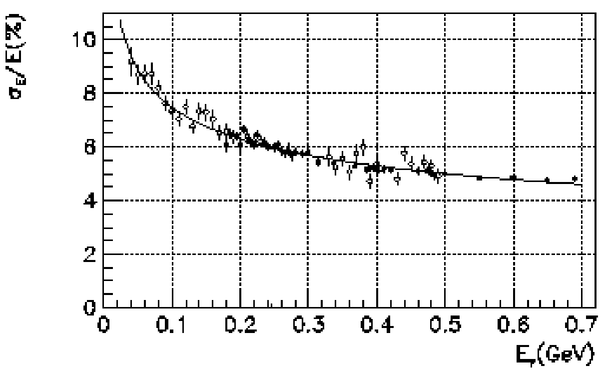
View of DC prototype

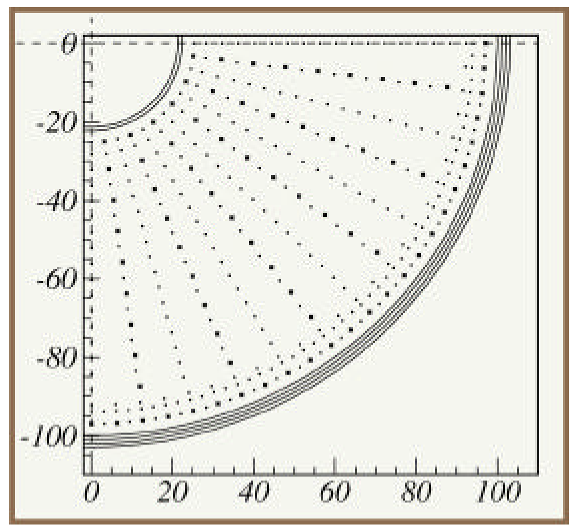
Energy resolution:

$$\frac{\sigma_E}{E} = \frac{4.2\%}{\sqrt[4]{E(GeV)}}$$

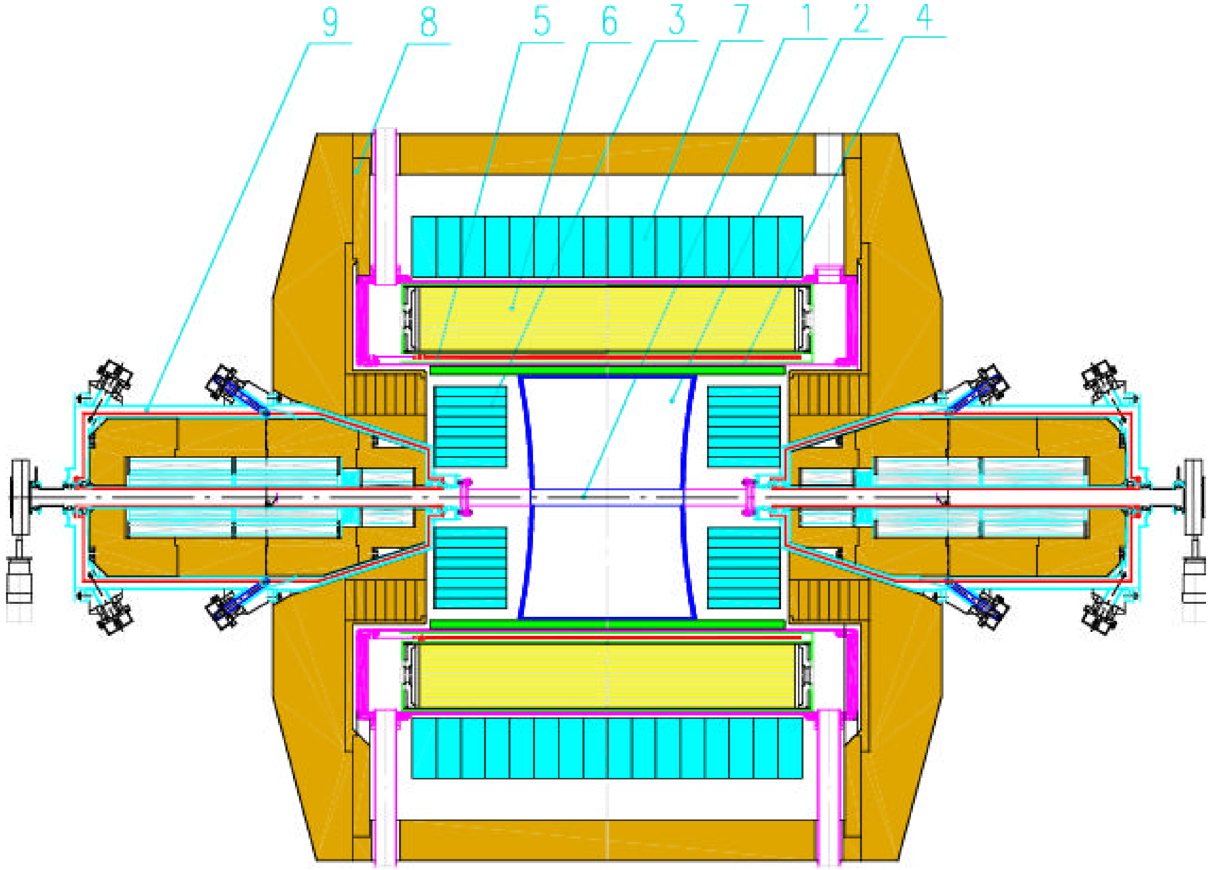
Angular resolution

$$\sigma_\varphi = \frac{0.82^0}{\sqrt{E(GeV)}} \oplus 0.63^0$$



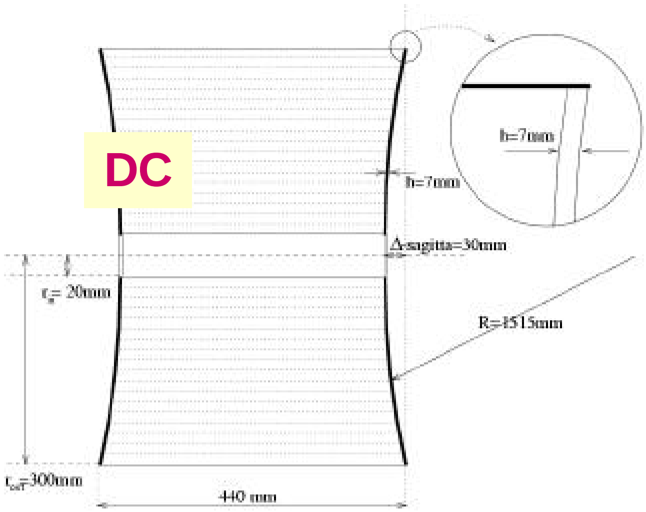


CMD-3



1 – beam pipe, 2 – drift chamber, 3 – BGO, 4 – Z – chamber, 5 – s.c. solenoid, 6 – LXe, 7 – CSI, 8 – yoke , 9 – VEPP s.c. solenoid

CMD-3

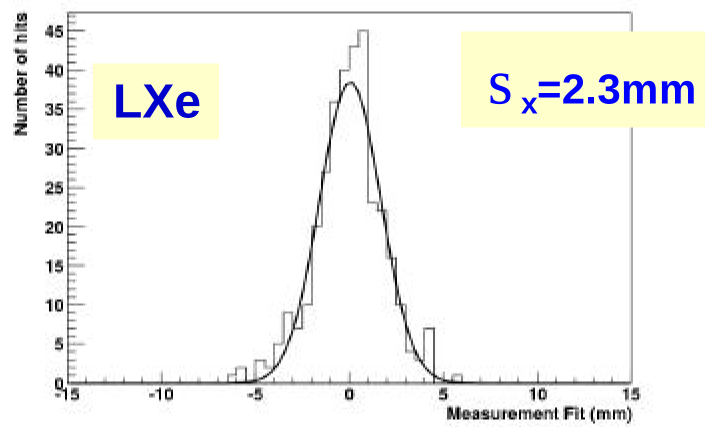


Barrel EMC:

$5X_o$ Cs(Tl) + $8X_o$ LXE

σ_E/E=3-5% (0.1-0.9 GeV)

σ_φ =0.2°



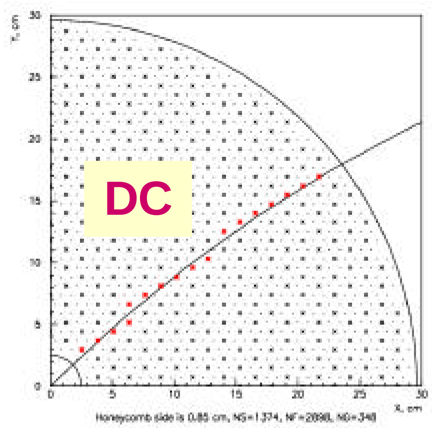
DC :

σ_Z =2mm, charge div.

σ_r =0.14mm,

σ_θ =0.4°,

σ_φ =0.2°



SC

1.5 Tesla

$0.13X_o$

Endcap EMC:

$13.4X_o$ BGO

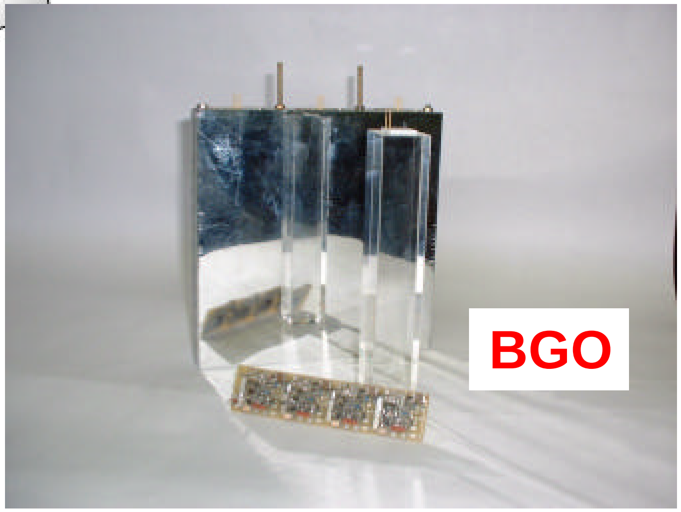
σ_E/E=4-8% (0.1-0.7 GeV)

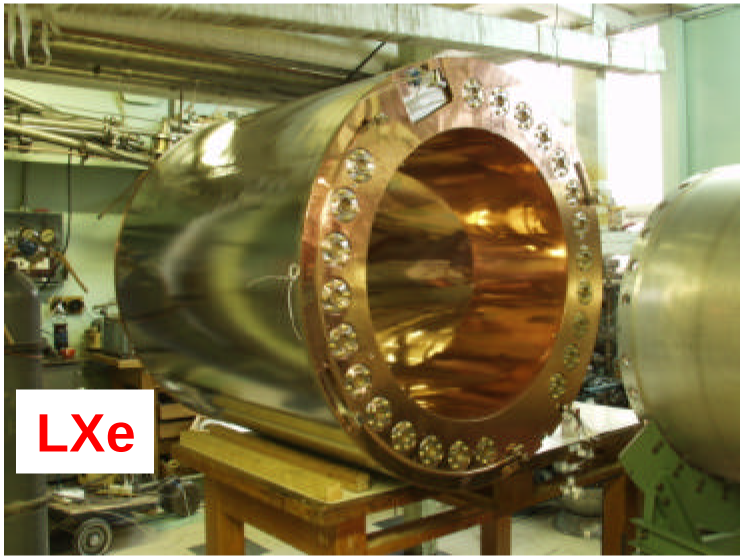
$\sigma_{\varphi,\theta}$ =1.4°

CMD-3

Refs. for CMD-3:

1. V.M.Aulchenko et al, Preprint BINP 2001-45, Novosibirsk
2. D.Grigoriev in: Proc. Intern. Workshop on e+e- Physics at Intermediate Energy, SLAC, Stanford, 30 Apr.-2 May 2001, p.116-121

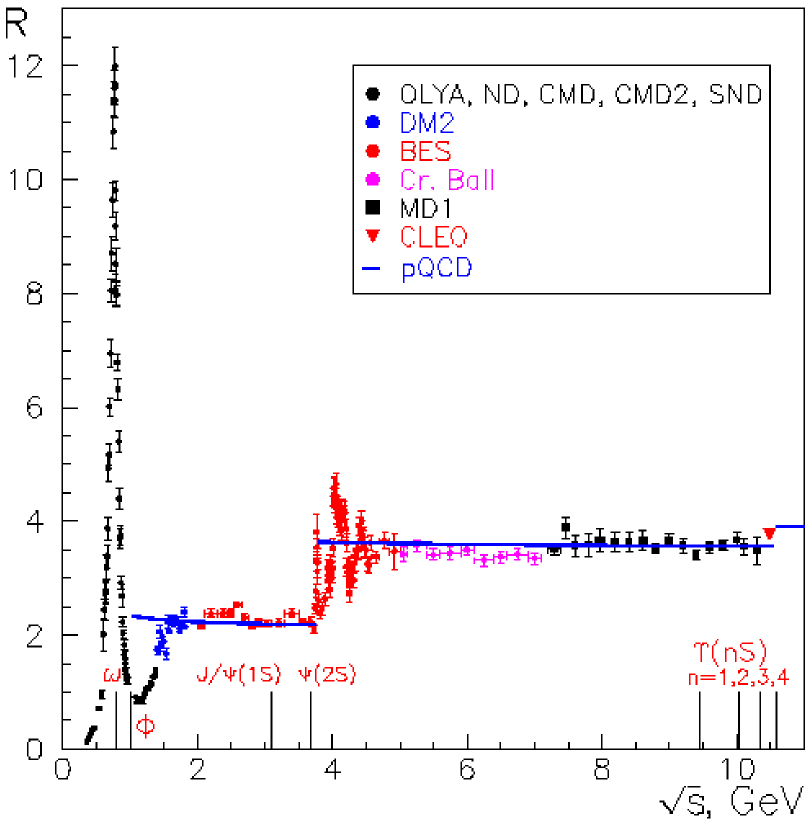




Physical program

1. Precise measurement of the quantity
$R = \sigma(e^+e^- \to \text{hadrons}) / \sigma(e^+e^- \to \mu^+\mu^-)$
2. Study of hadronic channels:
$e^+e^- \to 2h, 3h, 4h \ldots, h = \pi, K, \eta, \ldots$
3. Study of 'excited' vector mesons: $\rho', \rho'', \omega', \varphi', ..$
4. CVC tests: comparison of $e^+e^- \to$ hadr. (T=1) cross section with τ-decay spectra
5. Study of nucleon-antinucleon production – nucleon electromagnetic formfactors, search for NNbar resonances, ..
6. Hadron production in 'radiative return' (ISR) processes
7. Two photon physics
8. Test of the QED high order processes 2->4,5

Contribution of R into muon anomaly

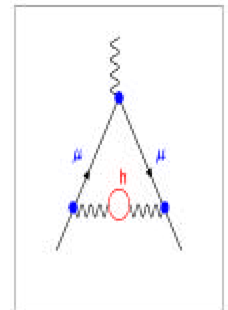


Experimental data (from hep-ph/0208177)

Muon anomaly: $(g-2)/2_\mu$,(AMM)

a_μ(E821)=1.1659203(8) .10^{-9} 0.7ppm (2002)

$$a_\mu^{had} = \frac{\alpha_{em}^2(0)}{3\pi^2}\int_{4m_\pi^2}^{\infty}\frac{R(s)K(s)}{s}ds,$$



a_μ(hadr)=58.8+-0.6ppm,
(from S.Eidelman)

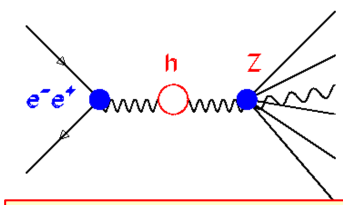
a_μ^{exp}-- a_μ^{e+e-} =2.9+-0.9 ppm

a_μ^{exp}-- a_μ^{τ} =0.8 +-0.9 ppm

Conclusions for VEPP-2000:

- **experimental and theoretical accuracy of AMM reached <1 ppm accuracy;**
- **VEPP-2000 energy range <2.0 GeV gives ~90% of contribution into a_μ(hadr);**
- **new mesaurements with 1-2% accuracy at 2E>1 GeV and 0.5% at ρ(770) are awaited from CMD-3 and SND at VEPP-2000**

Contribution of R into fine structure constant at $s=M^2_Z$



$\alpha_{em}(s=M^2_Z) \approx 1/129$

$\alpha_{em}(s=0) \approx 1/137$,

Shift: $\alpha(s=M^2_Z)/\alpha(0)=1-\Delta\alpha(s)_{exp} \approx 0.062$,

$\Delta\alpha(s)_{theor}=\Delta\alpha_{lept}(s)+\Delta\alpha_{hadr}(s)+\Delta\alpha_{top}(s)$,

$$\Delta\alpha_{hadr}(s=M^2_Z)=\frac{\alpha(0)s}{3\pi}\,P\int_{4m_\pi^2}^{\infty}\frac{R(s')ds'}{s'(s-s')},$$

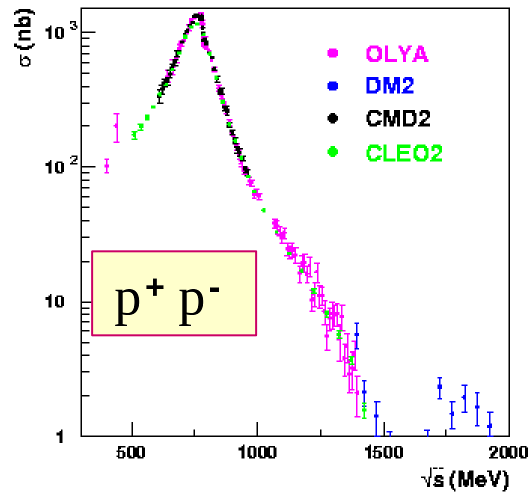
$\Delta\alpha_{hadr}(s=M^2_Z) \approx 0.0279 \pm 0.0004$,

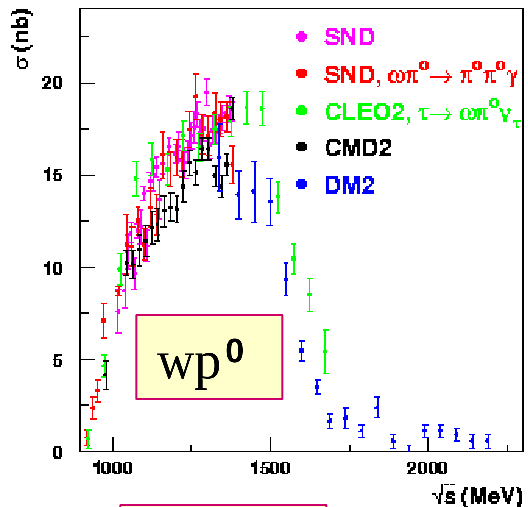
E-W – relation: $$G_F=\frac{\pi\alpha(M_Z)}{\sqrt{2}M_Z^2\sin^2\theta_W\cos^2\theta_W};$$

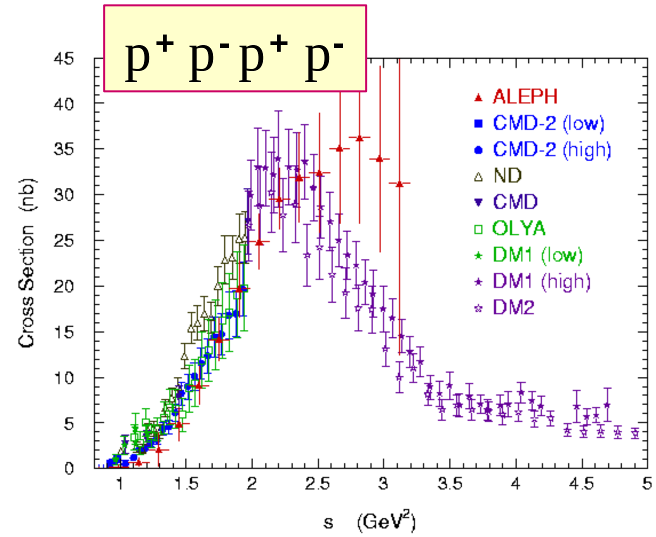
$\Delta G_F/G_F \sim 10^{-5}$, $\Delta M_Z/M_Z \sim 2\cdot10^{-5}$, $\sigma\Delta\alpha \sim 4\cdot10^{-4}$.

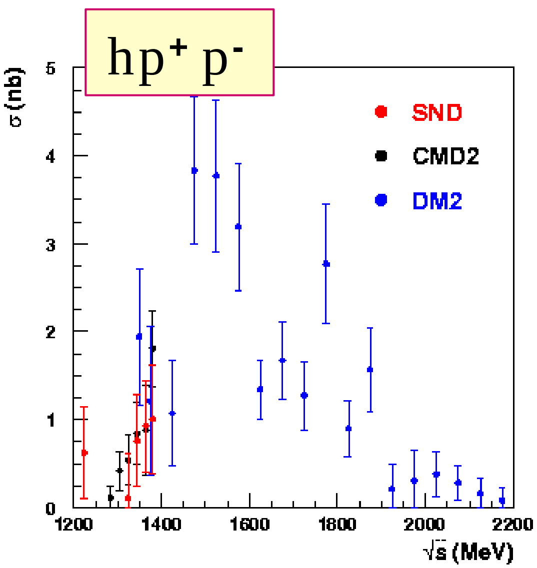
VEPP-2000 region:
2E=0.4 – 1.4 GeV
-- contribution at $M_Z \approx$ **20%.**
-- uncertainty at $M_Z \approx$ **40%.**

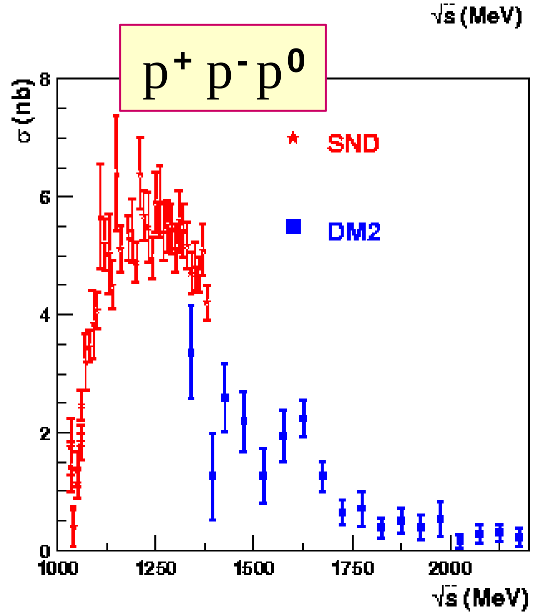
Exclusive channels of e+e- annihilation into hadrons

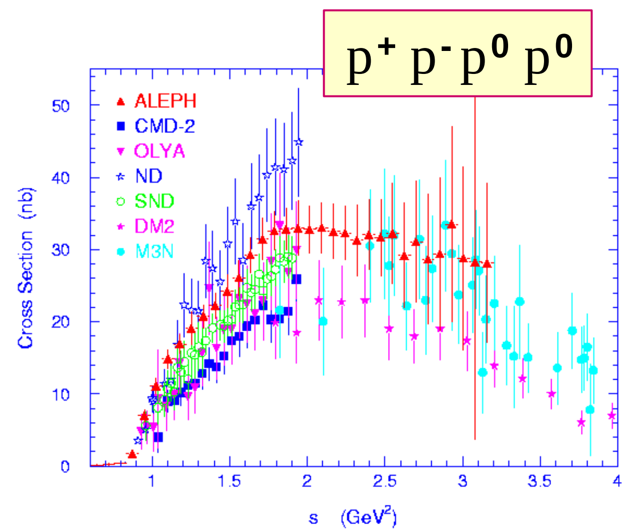




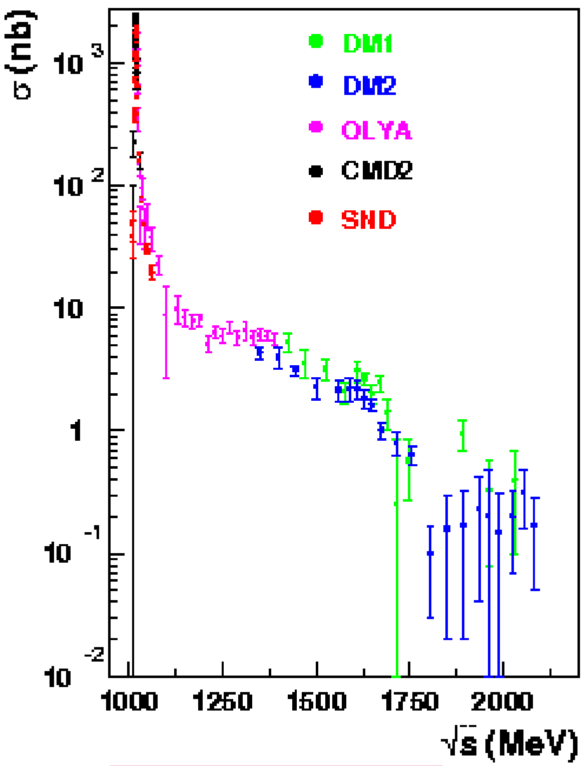




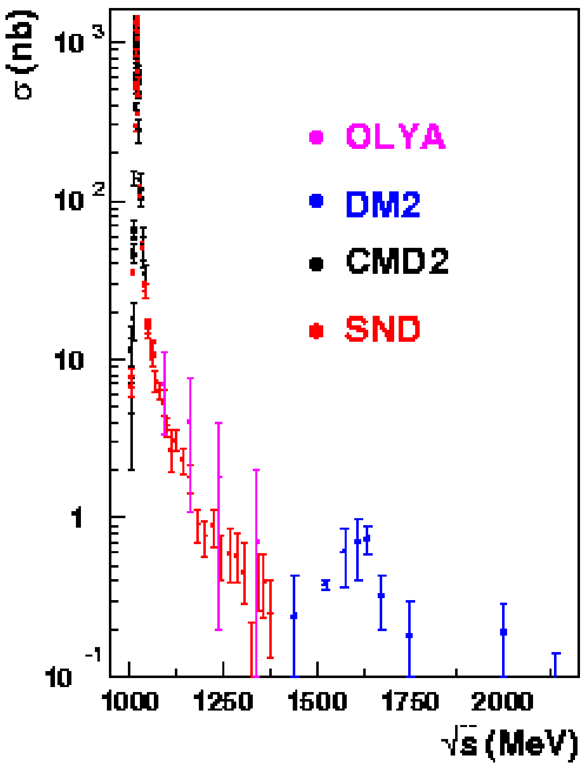




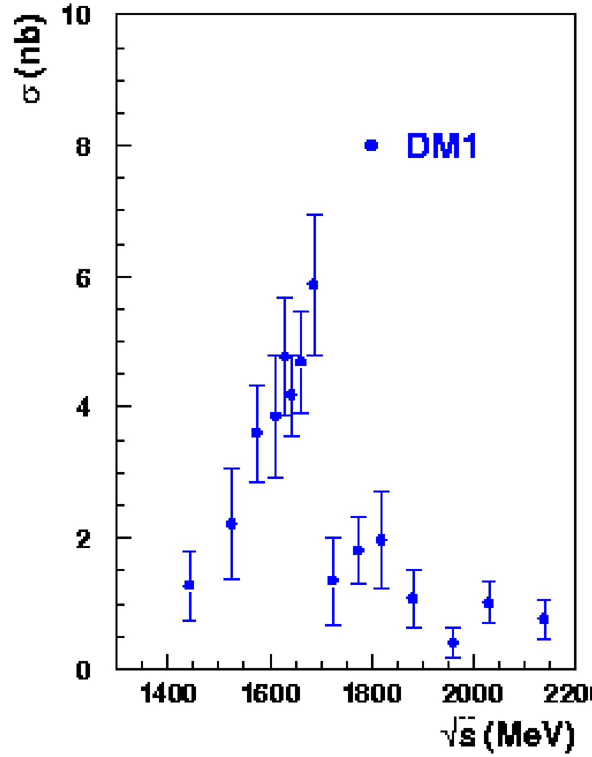
e+e- annihilation with kaon production



e+e- > $K^+ K^{--}$



e+e- > $K_S K_L$



e+e- > $K_S K^+ p^{--}$

Total integrated luminosity in the range 2E=1.4-2.0 GeV is ~5 /pb.

Light vector meson table

Nearly all excitations are within VEPP-2000 range

Quark Content -->	» $\bar{u}u - d\bar{d}$	» $u\bar{u} + d\bar{d}$	» $s\bar{s}$
$1\,^3S_1$	r(770)	w(782)	f(1020)
$2\,^3S_1$	r(1450)	w(1420)	f(1680)
$1\,^3D_1$	r(1770)	w(1650)	
$3\,^3S_1$	r(2150)		

Table of masses, widths

r(1450): M=1465 ±25; G=310± 60,
r(1700): M=1700 ±20; G=240± 60,
r(2150): M=2149 ±17; G=363± 50,
w(1420): M=1419 ±31; G=174± 60,
w(1650): M=1649 ±24; G=220± 35,
f(1680): M=1680 ±20; G=150± 50,

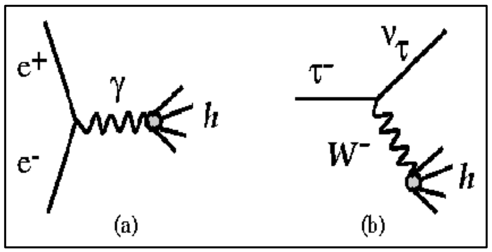
Main decay channels …

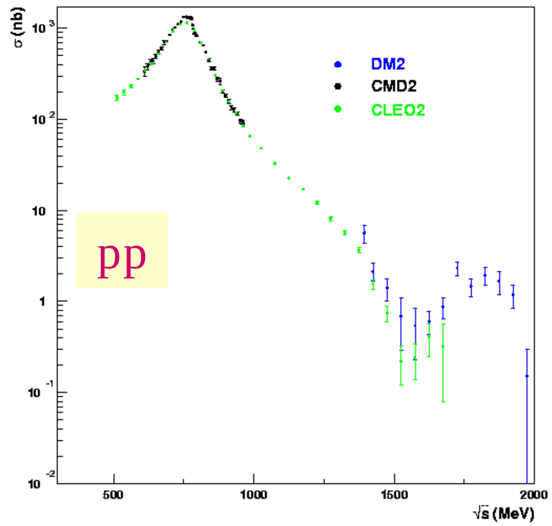
r(1450) -> 4p , wp, hpp, ..
r(1700) -> 2p, 4p , wp, ..
w(1420)-> 3p, ..
w(1700)-> wpp, ..
f(1680) -> KK, KK*, ..

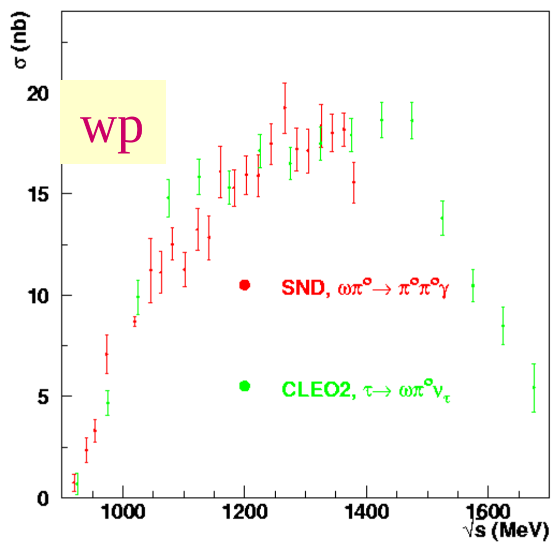
Summary for VEPP-2000:
with 1 fb^{-1} the knowledge of vector excitations can be improved to the level of knowledge of r(770), w(782), f(1020)

CVC tests – comparison of t –decay spectra with e+e- cross section

Standard model test







$I^{PG} = 1^{--+}$,
τ ->2pn, 4pn, wpn, hppn

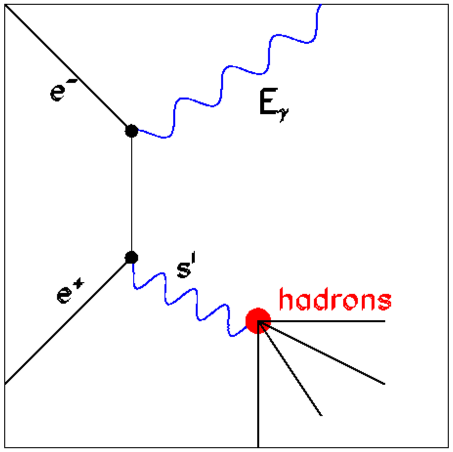
The accuracy of CVC tests for t -branching ratios (τ -data/e+e- data) (S.Eidelman,2002):

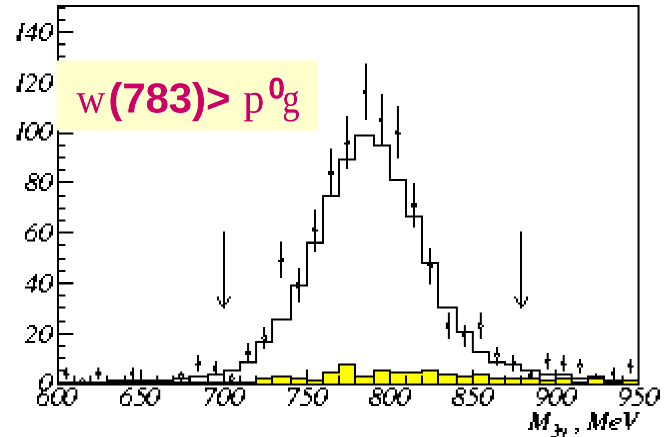
- pp : +2.2 ± 1.2%
- pp pp : +8.4 ± 6.9%
- wp : +3.6 ± 3.6%
- ---
- total : +2.7 ± 1.5%

Perspectives for VEPP-2000:

-- E_{VEPP} >M t – very important,
-- VEPP-2000 has higher than VEPP-2M luminosity by 30 times,

Hadron producion via ‘radiative return’ (ISR)





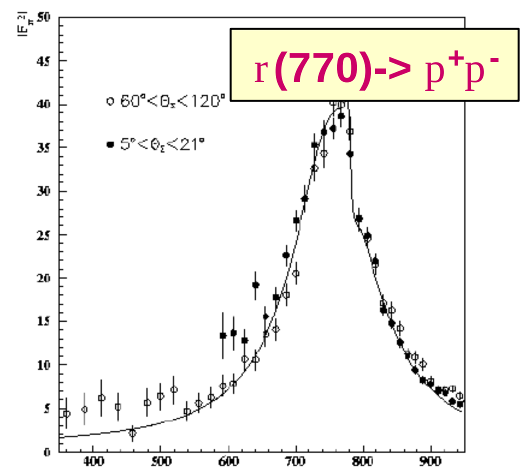
e+e->wg->p0gg, SND, VEPP-2M

$$\frac{d\sigma(s,x)}{dx} = W(s,x)\sigma_f\left[s(1-x)\right] \qquad x=\frac{2E_\gamma^*}{\sqrt{s}}$$

$$W(s,x) = \beta\cdot\left[(1+\delta)x^{(\beta-1)} - 1 + \frac{x}{2}\right] \qquad (\delta\approx 0.067 \text{ at } \Upsilon(4S))$$

$$\beta = \frac{2\alpha}{\pi}\left(2\ln\frac{\sqrt{s}}{m_e} - 1\right) \qquad (\beta\approx 0.088 \text{ at } \Upsilon(4S))$$

Estimation for VEPP-2000:
ΔL?1 fb^{-1}, Nρ ?10^{7}, Nω ?10^{6},



e+e->rg-> p+p-g, KLOE, DAFNE

N Nbar production cross section

$$e^+e^- \to p\bar{p},\, n\bar{n}$$

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2\beta C}{4s}\{|G_M(s)|^2(1+\cos^2\theta) + \frac{4M_N^2}{s}|G_E(s)|^2\sin^2\theta\}$$

$$\sigma = \frac{4\pi\alpha^2\beta C}{3s}\{|G_M(s)|^2 + \frac{2M_N^2}{s}|G_E(s)|^2\}$$

For e+e→p pbar: $C \approx \frac{\pi\alpha}{\beta}/(1-e^{-\frac{\pi\alpha}{\beta}})$ **C~1 at $T_{kin.} \le$ 1 MeV**

At the threshold we have $s=4M_N^2$ and $G_E=G_M$,

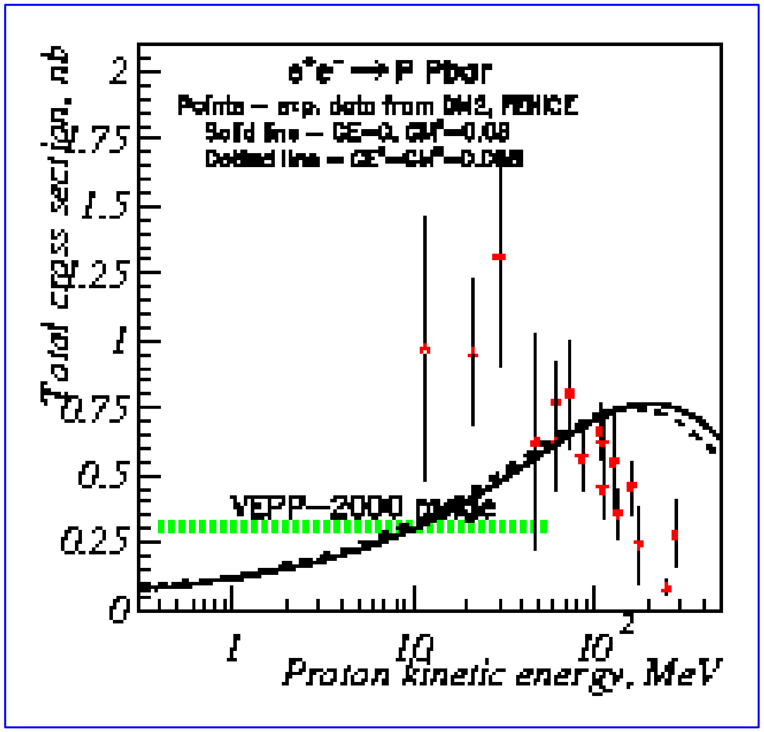
if $G_E=G_M=0.3$, then $\sigma = \frac{\pi^2\alpha^2}{2M_N^2}|G_E(4M_N^2)|^2 \approx 0.08\,nb$

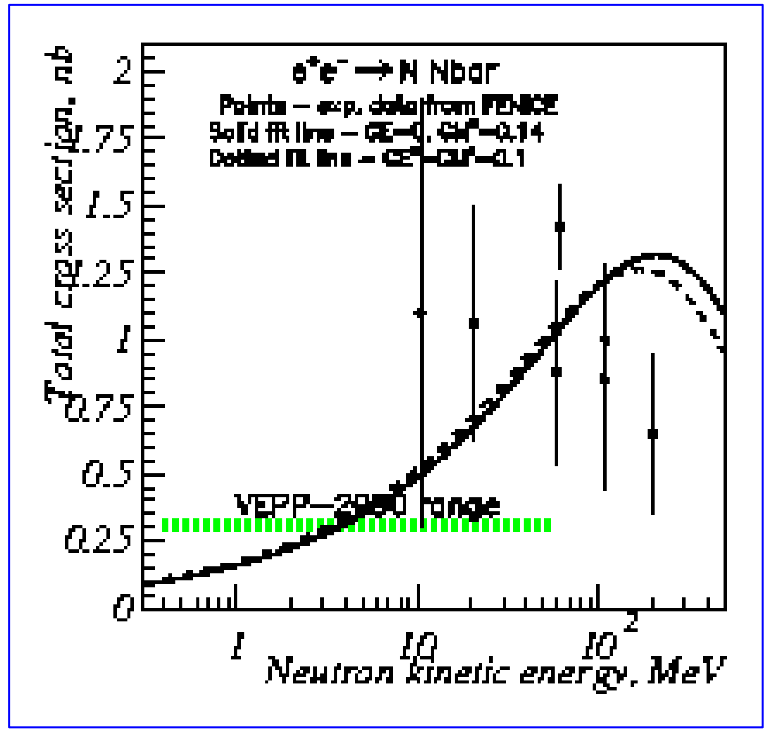
At s=0: $G_E^p(0)=1$, $G_E^n(0)=0$, $G_M^p(0)=2.79$, $G_M^n(0)=-1.79$

Radiative correction: $d\sigma = d\sigma_0 e^{-\nu}, \nu = \frac{4\alpha}{\pi}\ln\frac{E}{m_e}\ln\frac{E}{T_{kin}},$

For T=1Mev $e^{-\nu}=0.62$;
For T=50 Mev $e^{-\nu}=0.82$;

Experimental data on ppbar and nnbar cross sections



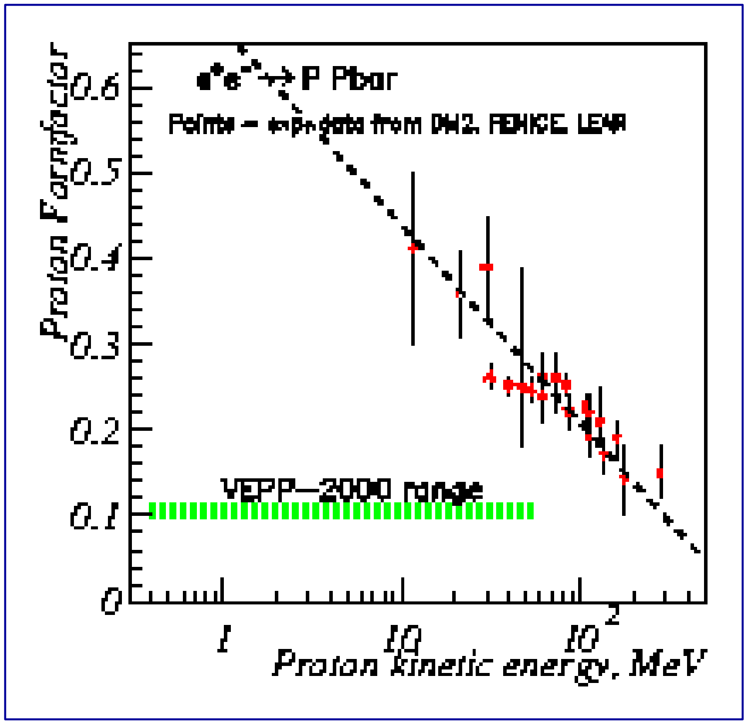


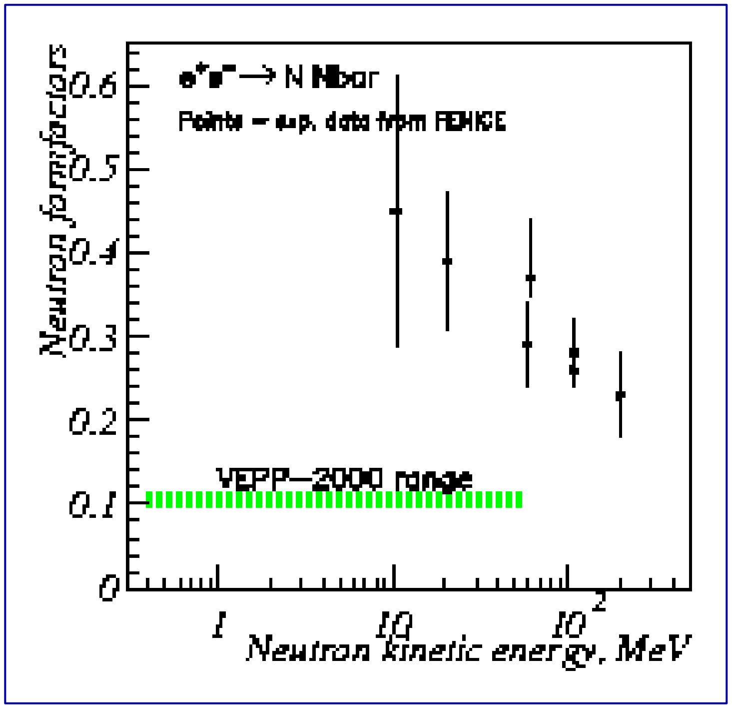
- **No radiative corrections applied;**
- **VEPP-2000 range is shown by green line**
- **Curves correspond to GE=0.3 and GM=0.3**
- **Data are mainly from DM2, FENICE**
- **There is no data below 10 MeV (kin.en.)**
- **The cross section in the maximum is 1 nb**
- **The cross section at the threshold is 0.1 nb if GE=GM=0.3**

Estimates of statistics at threshold :

- **Instant luminosity - 0.1/(nb.sec)**
- **Time – 10^7 sec**
- **Integrated luminosity - 1/fb**
- **Detection efficiency – 0.1**
- **Number of events: 10^4**

Experimental data on proton and neutron timelike e.m. formfactor





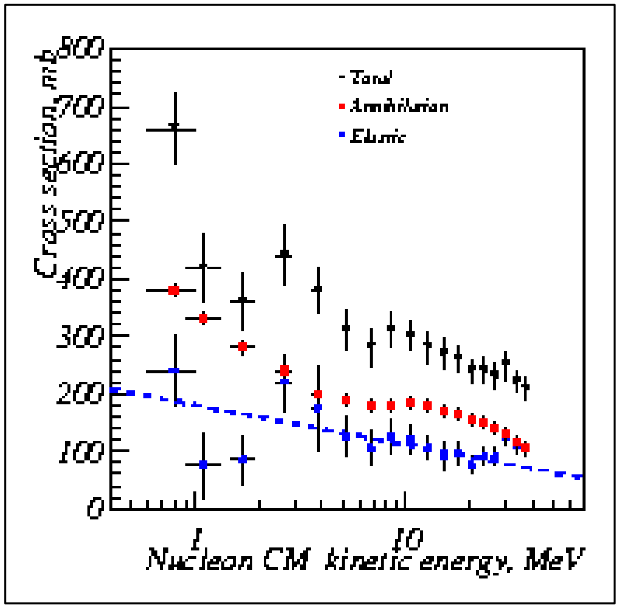
Value $r = \frac{\sigma(ee->nn)}{\sigma(ee->pp)}$ **; From exp. data: r ~1**

Models: PQCD: r=0.25 (not supported)
EVDM: r=1-100;
Skyrme: r ~1
Accurate measurement of r is challenge for VEPP-2000

The goals at VEPP-2000:
- **-- separate measurement of G_M and G_E ;**
- **-- check the rise of FF to threshold;**
- **-- check the relation $|G_M|=|G_E|$ at threshold;**

Indications on possible resonance structure near NNbar threshold

Antineutron-proton cross section



Fitting results:

M » **1881 (+- 1MeV)**

Γ» **4 (+- 2MeV)**

Above threshold !!

Isovector (nbar p) !

If L=0 (S-wave)

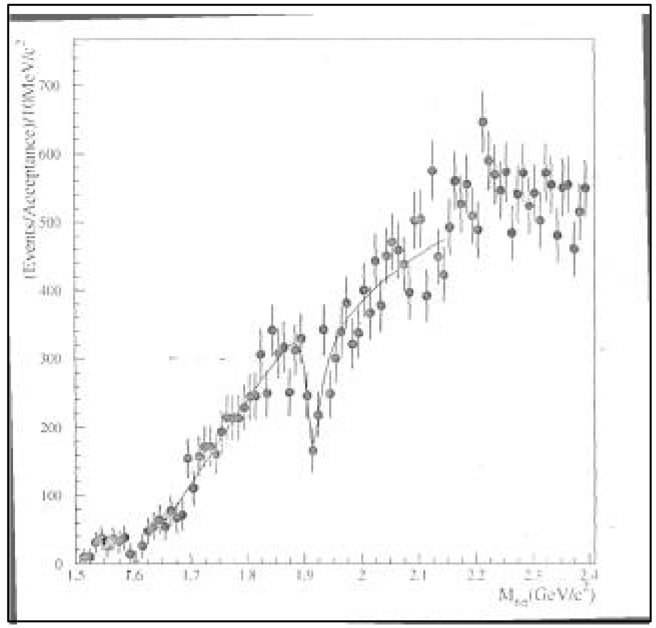
S(spin)=0,1

J^{PC} = 0^{-+} or 1^{--}

If 1^{--} -> VEPP-2000

~ 3s !

Diffr.photoproduction, E687, BNl, 2001→ g+Be->6p+Be



Fitting of 6p **mass spectrum**

M = 1911 +- 4 MeV,

Γ= 29 +- 11 MeV,

φ= 62 +- 12 deg.

A_{res}/A_{nres}=0.31+-0.07

c²/ND = 1.1

$J^{PC}I^{G}$ = 1^{--} 1^{+}

Models:

1.vector hybrid ~1.9 GeV,

2.vector glueballs >> 2 GeV,

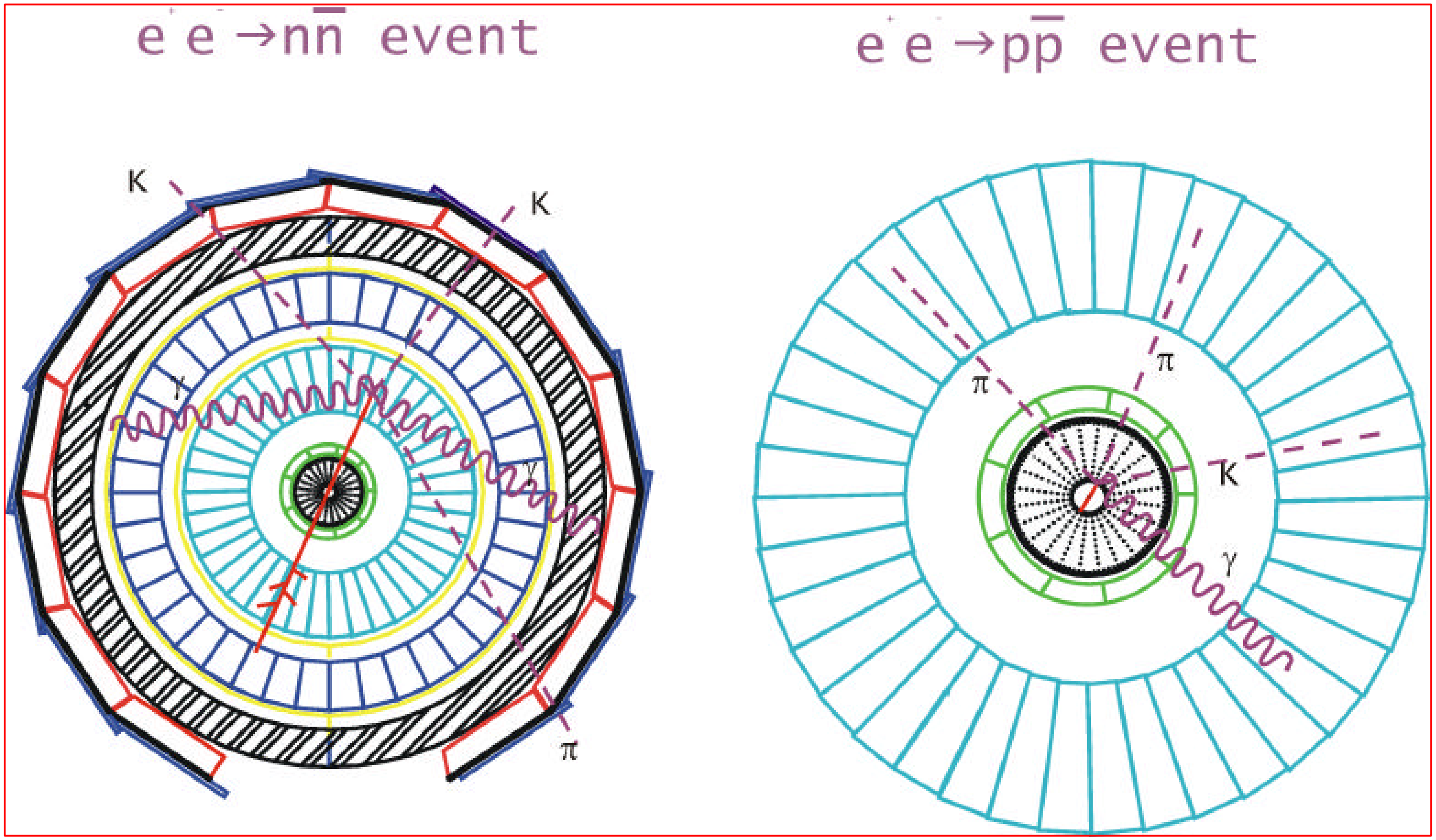
3.NNbar resonance

Conclusions for VEPP-2000:

-if Nnbar state is above threshold, it could be seen in e+e->Nnbar and in e+e->hadrons cross section;

-if below – only in e+e->hadron cross section.

Typical signature of ppbar and nnbar events in SND



Antineutrons give stars inside calorimeter

Antiprotons annihilate in material before drift chamber

3 options of antineutron detector (based on SND)

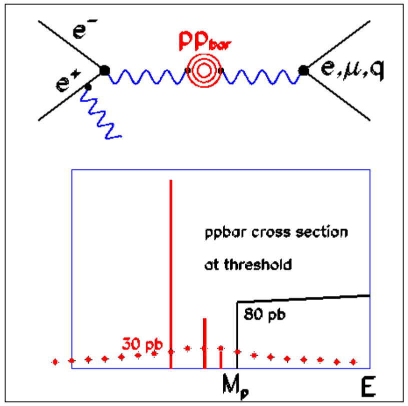
1 - SND (as it is) as antineutron detector – antineutron annihilates in NaI(Tl) calorimeter, which works as antineutron absorber. The annihilation products are detected in all SND elements

2 - modified SND (SnD)
(‘n’ means antineutron)
- first and second NaI layers are replaced by plastic scintillator with PMT readout. Annihilation time can be measured, which allows to suppress background

3 - completely new anti-neutron detector (AnD) : a la FENICE or with KLOE-type calorimeter or something else. This option is beyond the scope of the talk.

e+e->p pbar process

Formation of ppbar Coulomb state (antiprotonium)



E= $a^2/4$=12.5 KeV,

R=2/ $M_p a$ =0.6 10 $^{-11}$cm >> 10^{-13} cm,

G_{ee} = G_{mm} =$M_p a^5/6$=3.3 meV, G_t @ 4G_{ee} ,

s_0=3pl^2 $B_{ee}B_f$ =10^{-27}cm^2, s_{vis} =s_0 G_t/ DE,

DE @ 0.5 MeV, s_{vis} @ 30 pb for E= M_p ,

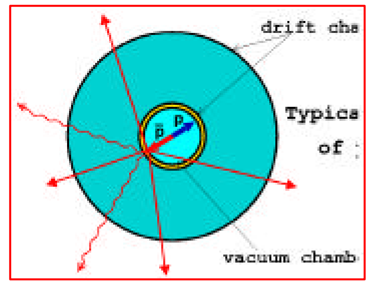
For comparison s (e+e->mm) @ 25 nb,

Then S/N @ 7.5 pb/25 nb @1/3000 !

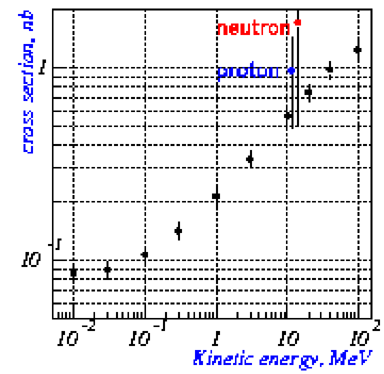
Conclusions: antiprotonium doesn't give visible contribution in e+e- cross section

Collider energy calibration with e+e->pbar process at threshold

Typical signature of Ppbar event:



The ppbar cross section view at the threshold



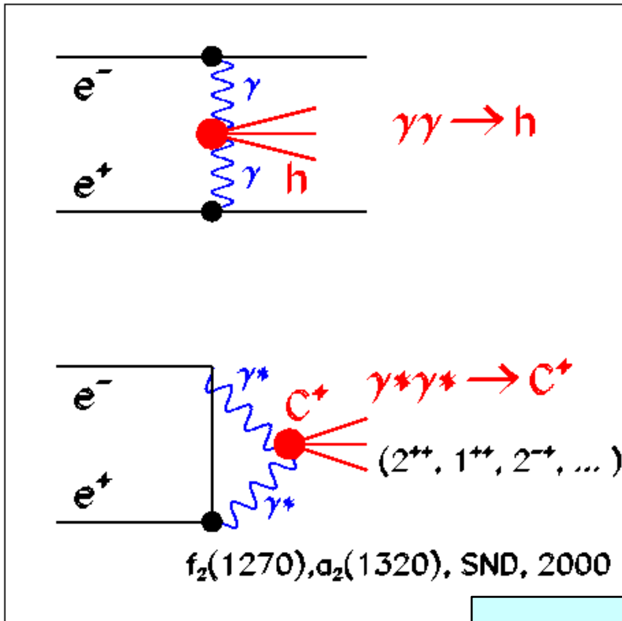
Conclusions for VEPP-2000:

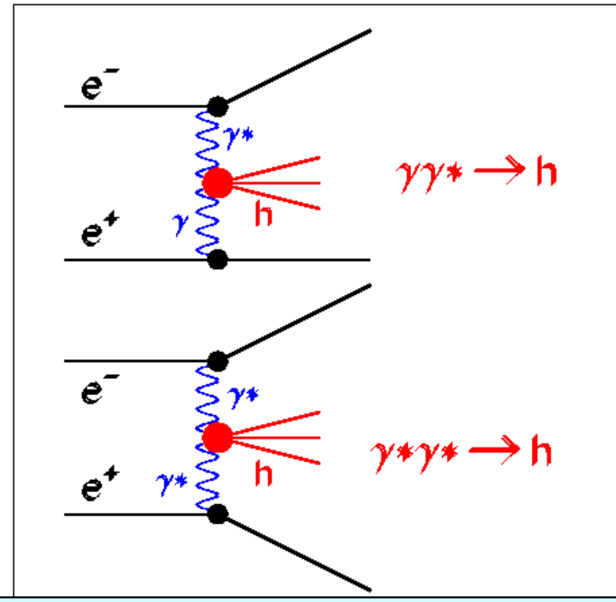
The cross section at the threshold is 50 pb with radiative correction;

If L=0.1/(nb s), t=10^{5}sec (1 day), e=0.3, then we have N=L t e =150 events/day ~10% accuracy,

Estimated calibration accuracy is ~ 10^{-4}

Two photon physics at 2E<2.0 GeV





e+e- > f$_2$ -> p^{0}p^0 -> 4g,
e+e- > a$_2$-> hp^0 -> 4g,
s ~ 10^{-36} cm^2

e+e- > h?(958)e+e-, s ~ 10^{-34} cm^2;
e+e- > a$_0$(980)e+e-, f$_0$(980)e+e-, s ~ 10^{-35} cm^2

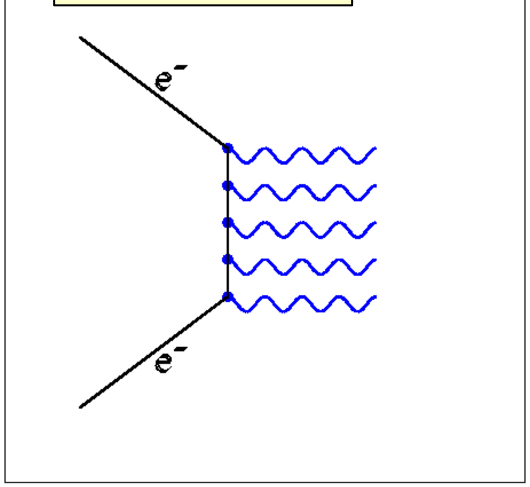
e+e- > p^{0}p^0 e+e-, s ~ 10^{-35} cm^2?

Main goals for VEPP-2000:
-- G $_{2g}$ widths of scalars a$_0$(980), f$_0$(980) ~ 0.3KeV – seems too low,
-- g g-> p^{0}p^0 at 2E£0.5 GeV

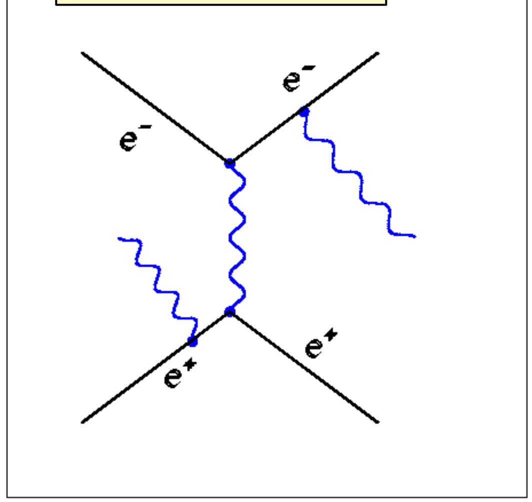
High order QED tests (2->4,5)

- only electrons and/or photons in final state;
- large angles q>1/g between initial and/or final particles

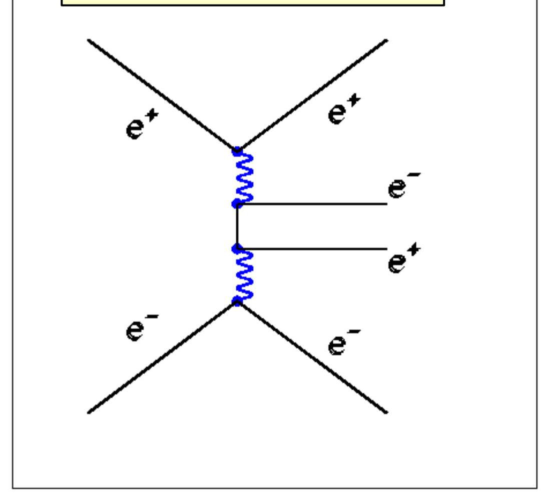
e+e->ggggg



e+e->e+e-gg



e+e->e+e-e+e-



For processes 2->4: s ~ 10^{-34} - 10^{-35} cm^2 , N ~ 10^4 ev.

The goals: -- test of high order QED, physical background e.g. wp^0 ->5g

Schedule

VEPP-2000	-- beam	-- 2004
	-- luminosity	-- 2005
	-- running	-- 2005--2010

SND	-- upgrade	-- 2004
	-- running	-- 2005--2010
	-- physical results	-- 2006 -2012

CMD-3	-- end of construction	-- 2005
	-- running	-- 2005--2010
	-- physical results	-- 2006 -2012

Conclusions

1. **VEPP-2000 e+e- collider with 2E=0.4 -- 2.0 Gev energy range and maximum luminosity $L_{max}=10^{32}$ $cm^{-2}s^{-1}$ is under construction in Novosibirsk**

2. **Two collider detectors CMD-3 and SND are being upgraded for experiments at VEPP-2000 with integrated luminosity of DL ~ 3 fb 1 in 2005-2010.**

3. **The measurements of the quantity R=s(e+e-- > hadrons)/ s(e+e-->m+m--) with ultimate precision is one of the main goals of experiments at VEPP-2000**

4. **The precision measurements of exclusive channels of e+e-- > hadrons process for check such known models as VDM, CVC, QCD, is important task of physical program.**

5. **Measurements of e+e- ->n nbar and e+e- ->p pbar cross sections give unique possibility to obtain nucleon timelike formfactors at threshold**