Physics at VEPP-2000

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(for CMD3,SND and VEPP2000 collaborations)

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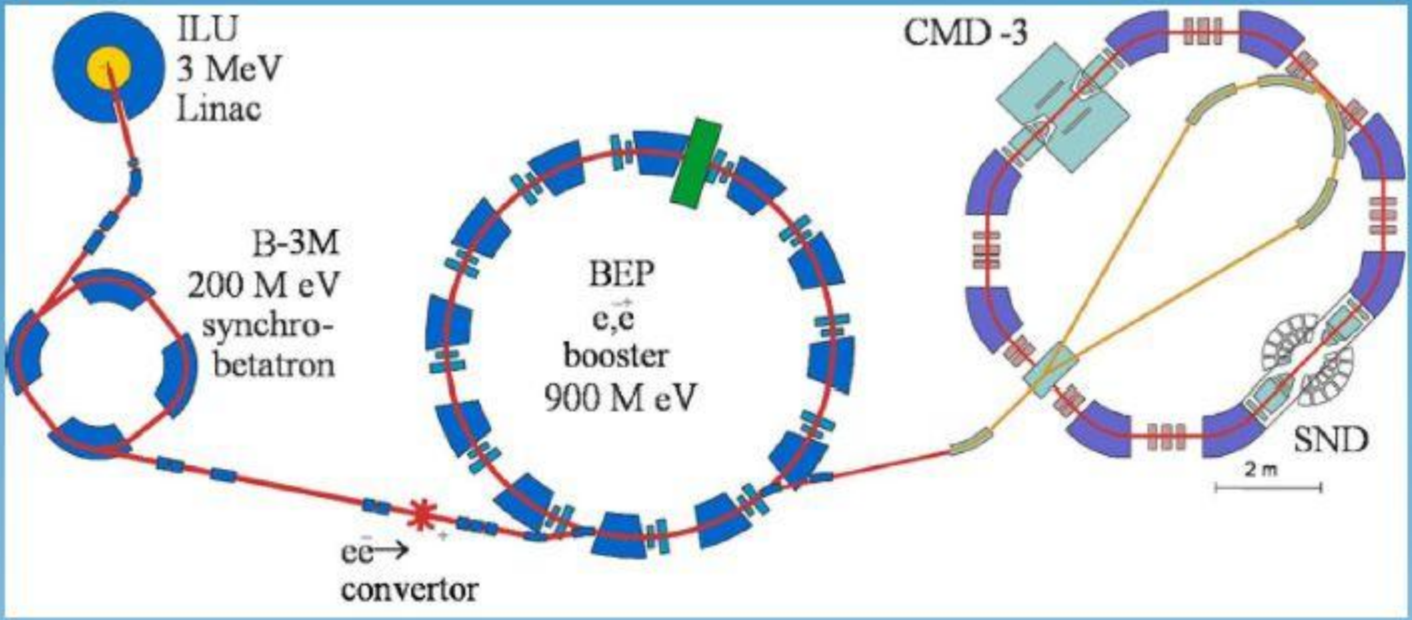
Outline

- Collider
- Physics Program
  - Interactions of light quarks
  - Fundamental quantities and R
  - Experiemental requirements
- Detectors
- Conclusion

VEPP-2000 Storage ring



- Up to 2 GeV c.m. energy
- Factor >10 in luminosity

  $L=10^{31}$ $cm^{-2}c^{-1}$, $\sqrt{s}=1.0$ GeV

  $L=10^{32}$ $cm^{-2}c^{-1}$, $\sqrt{s}=2.0$ GeV

≈100 1/pb per detector per year

What can we learn

1. Detailed study of exclusive processes $e^+e^- \rightarrow (2\text{-}7)h$, $h = \pi, K, \eta, p$ …
   - Test of models and inputs to theory (ChPT, VDM, QCD)
   - Properties of vector mesons (ρ', ω', ϕ' …)
   - Search for hybrids (qqg) and glueballs
   - Test of CVC relations between e^+e^- and τ-lepton
   - Interactions of light (uds) quarks
2. High precision determination of $R = \dfrac{\sigma(e^+e^- \rightarrow hadrons)}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$

   at low energies and fundamental quantities
   - $(g_\mu - 2)/2$
   - $\alpha_S(M_Z^2)$
   - QCD sum rules (α_S, quark and gluon condencates)

Shopping List

- Studies of exclusive channels
- Properiries of ρ, ω and ϕ
- ϕ as a source of tagged kaons, η and η' mesons
- Higher vector resonances
- R and fundamental parameters ($(g_\mu-2)/2$, $\alpha_S(M_Z^2)$, quarks masses …)
- Test of CVC (e^+e^- vs τ)
- Nucleon formfactors at threshold
- Non-vector states
- $\gamma\gamma$ physics
- Higher order QED

Properties of Basic Vector Mesons

Meson	ρ	ω	ϕ
Mass, MeV	775.8±0.5	782.65±0.12	1019.46±0.02
Width, MeV	146.4±1.5	8.49±0.08	4.26±0.05
B_{ee}, 10^{-5}	4.67±0.09	7.18±0.12	29.7±0.4
Modes studied	12	17	27
Min B	$2 \cdot 10^{-5}$	$7 \cdot 10^{-5}$	$4 \cdot 10^{-6}$

What else for ρ, ω, ϕ ?

- Γ_{ee}
- Rare decay modes $\rho(\omega) \to f_0(600)\gamma$, $\rho \to 3(4)\pi$
- Comparision of ρ^0 and ρ^+ mass and width in view of CVC(τ) problem
- Definition of ρ meson mass and width

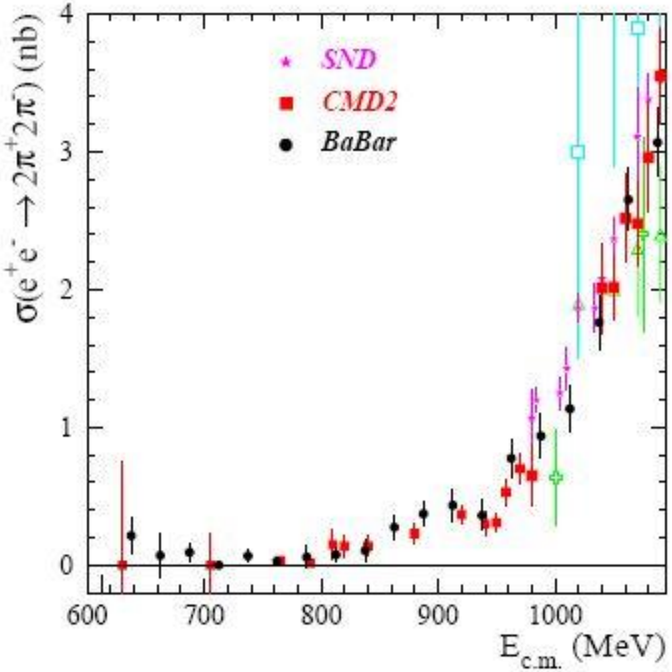
Properties of higher vector mesons

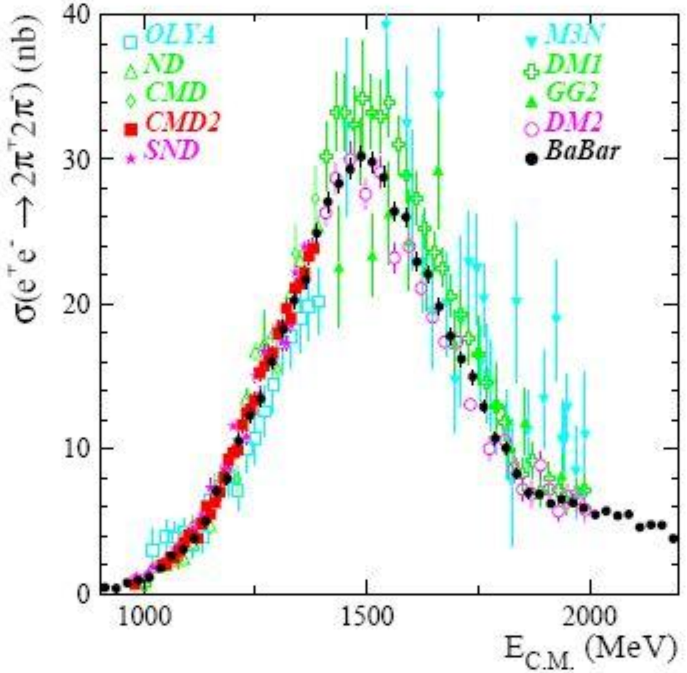
$2^3 S_1$	Mass, MeV, Width, MeV	$1^3 D_1$	Mass, MeV, Width, MeV
ρ(1450)	1250 - 1500 60 - 550	ρ(1700)	1550 - 1780 100 - 600
ω(1420)	1370 - 1450 175 - 360	ω(1650)	1620 - 1750 100 - 370
ϕ(1680)	1620 - 1750 100 - 300		

- $\rho' \to \pi^+\pi^-$, KK, 4π, 6π, $\pi^0(\eta,\eta')\gamma$
- $\omega' \to$ KK, $\rho\pi$, $\omega\pi\pi$, $\omega\eta$, $\pi^0(\eta,\eta')\gamma$
- $\phi' \to$ KK, KKπ, KK$\pi\pi$, $\pi^0(\eta,\eta')$

Γ_{ee} is badly known
Just few modes observed
ISR gives hand!

Can we see ρ excitations in $2\pi^+2\pi^-$ mode ?

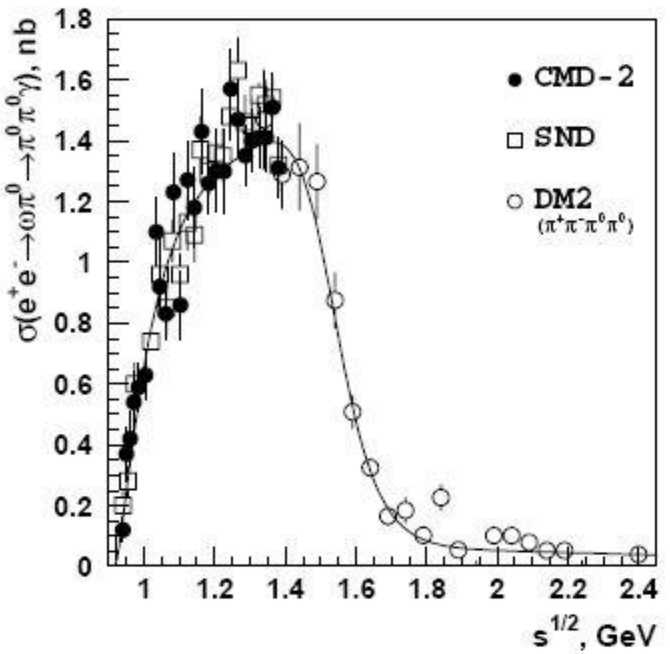


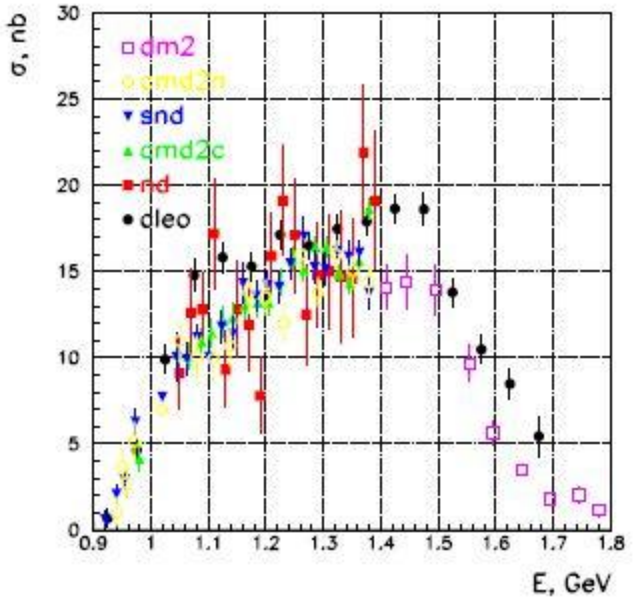


One broad state seen!

Separation of different channels ($a_1\pi$, $a_2\pi$, $\pi'\pi$) needed

How many ρ excitations in ωπ mode ?

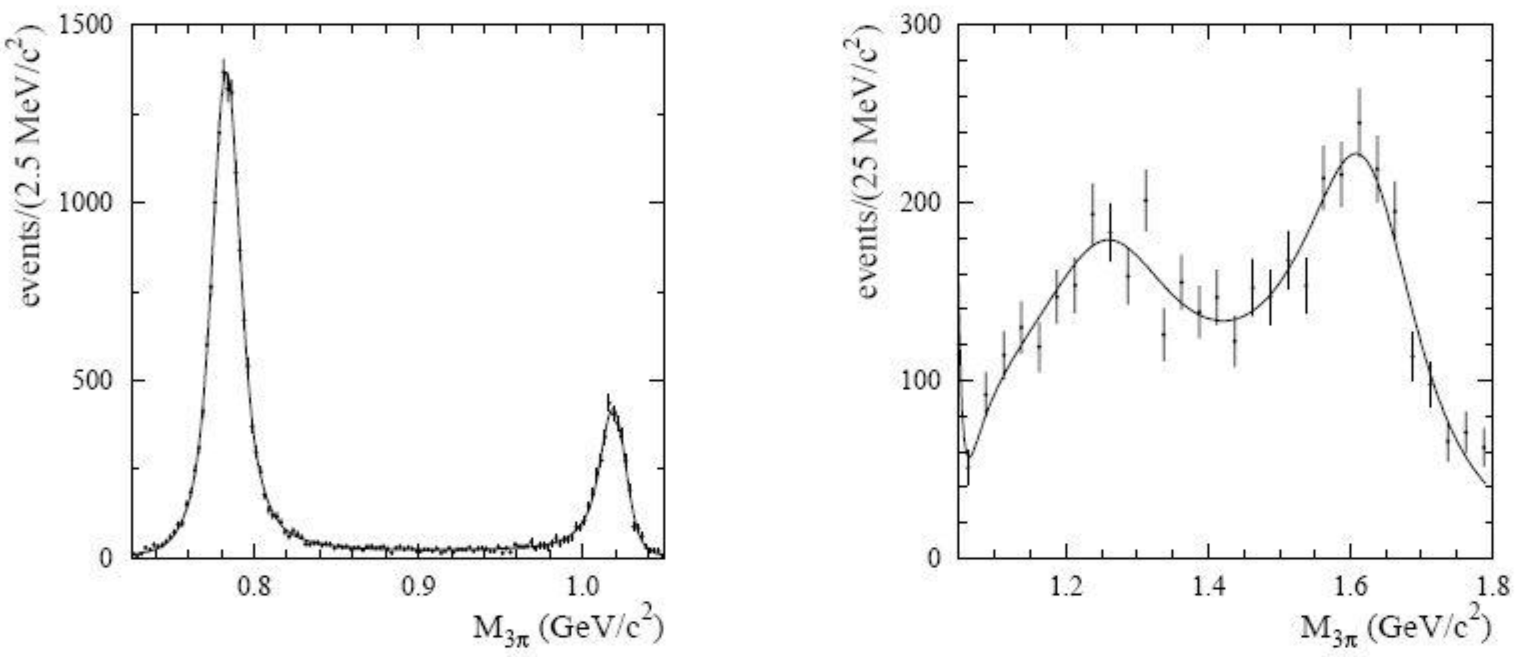




$\rho(1450)$ only needed.

Confirmed by CLEO in τ and B decays.

e+e- → $\pi^+\pi^-\pi^0\gamma$ at Babar



The final $\pi^+\pi^-\pi^0$ state is dominated by $\rho^+\pi^- + \rho^0\pi^0 + \rho^-\pi^+$

Parameters of ω(1420) and ω(1450)

Analysis of BaBar

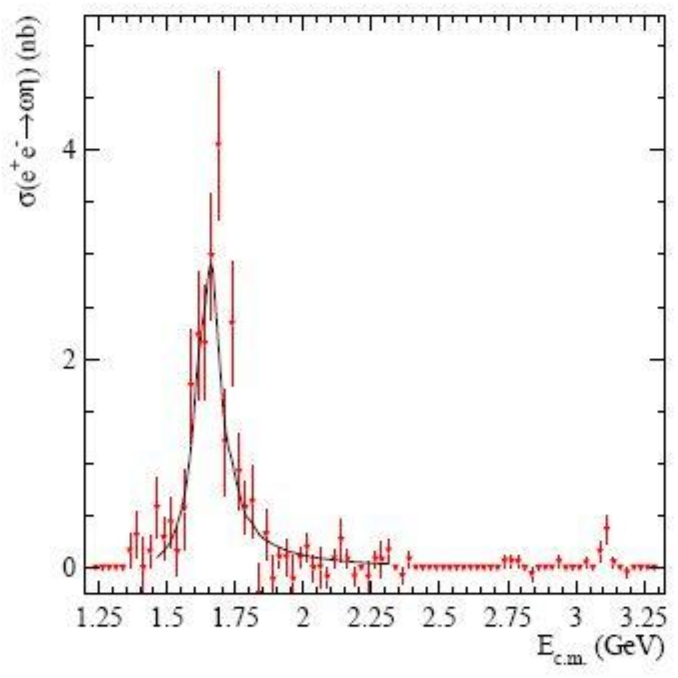
State	Mass, MeV	Width, MeV	$\Gamma_{e^+e^-}$, eV
$\omega(782)$	782.65 ± 0.12	8.49 ± 0.08	600 ± 20
$\omega(1420)$	$1350 \pm 20 \pm 20$	$450 \pm 70 \pm 70$	~ 370
$\omega(1650)$	$1660 \pm 10 \pm 2$	$230 \pm 30 \pm 20$	~ 570

Differ from those of SND ($\pi^+\pi^-\pi^0$ and $\omega\pi^+\pi^-$) – parameterization, new $\sigma_{\omega\pi\pi}$ needed

The $\Gamma_{e^+e^-}$ pattern in contradiction to the quark model, S. Godfrey and N. Isgur, 1985

ω'' or ϕ'

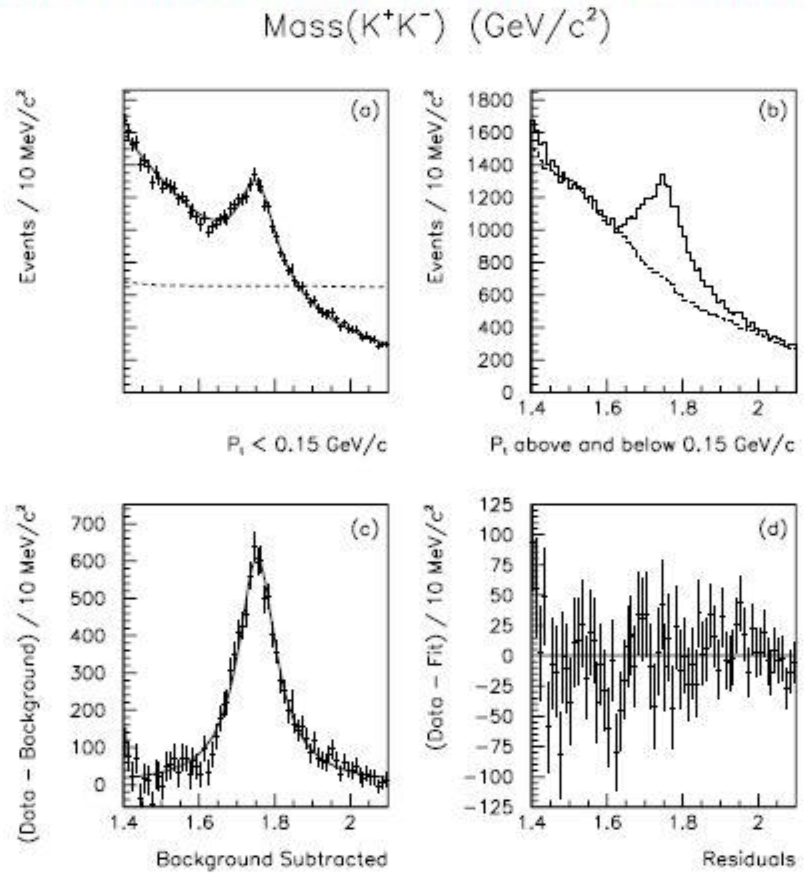
BaBar observes a structure in $e^+e^- \to \omega\eta$



Group	Mass, MeV	Width, MeV
PDG	1680 ± 20	150 ± 50
BaBar	1645 ± 8	114 ± 14

ϕ' at FOCUS ?

High statistics observation of the K^+K^- structure in photoproduction



More about ϕ'

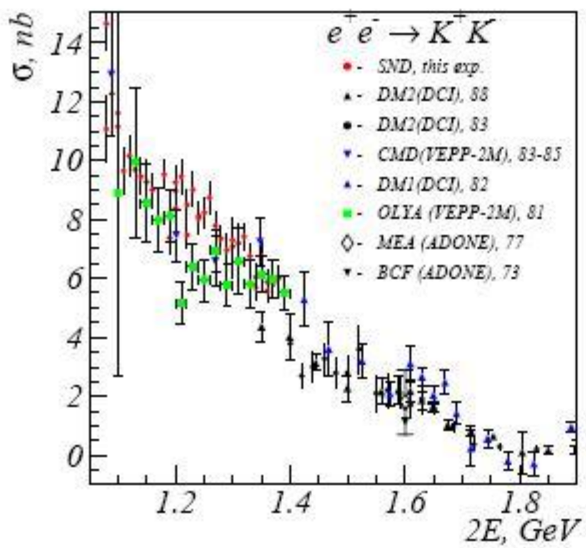
Parameters of the FOCUS structure
(mass of 1753 ± 3 MeV and width of 122 ± 63 MeV) are close, but . . . :

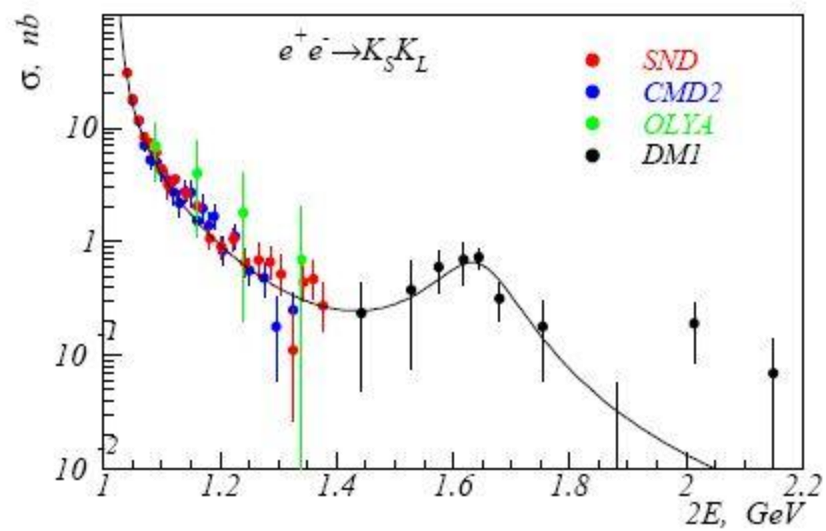
From the previous data of DM1 and DM2
$B(K\bar{K})/B(\bar{K}^*(892)K) = 0.07 \pm 0.01$

while FOCUS observes an opposite pattern:
$B(\bar{K}^*(892)^0K^0 \to K^\pm\pi^\mp K^0_S)/B(K^+K^-) < 0.065$
$B(\bar{K}^*(892)^\pm K^\mp \to K^\pm\pi^\mp K^0_S)/B(K^+K^-) < 0.183$

More experimental information is needed.

e+e- → K^+K^-, K_LK_S at VEPP-2M





- No evidence for the ϕ'
- Evidence for the ϕ'

New ρ(1900)

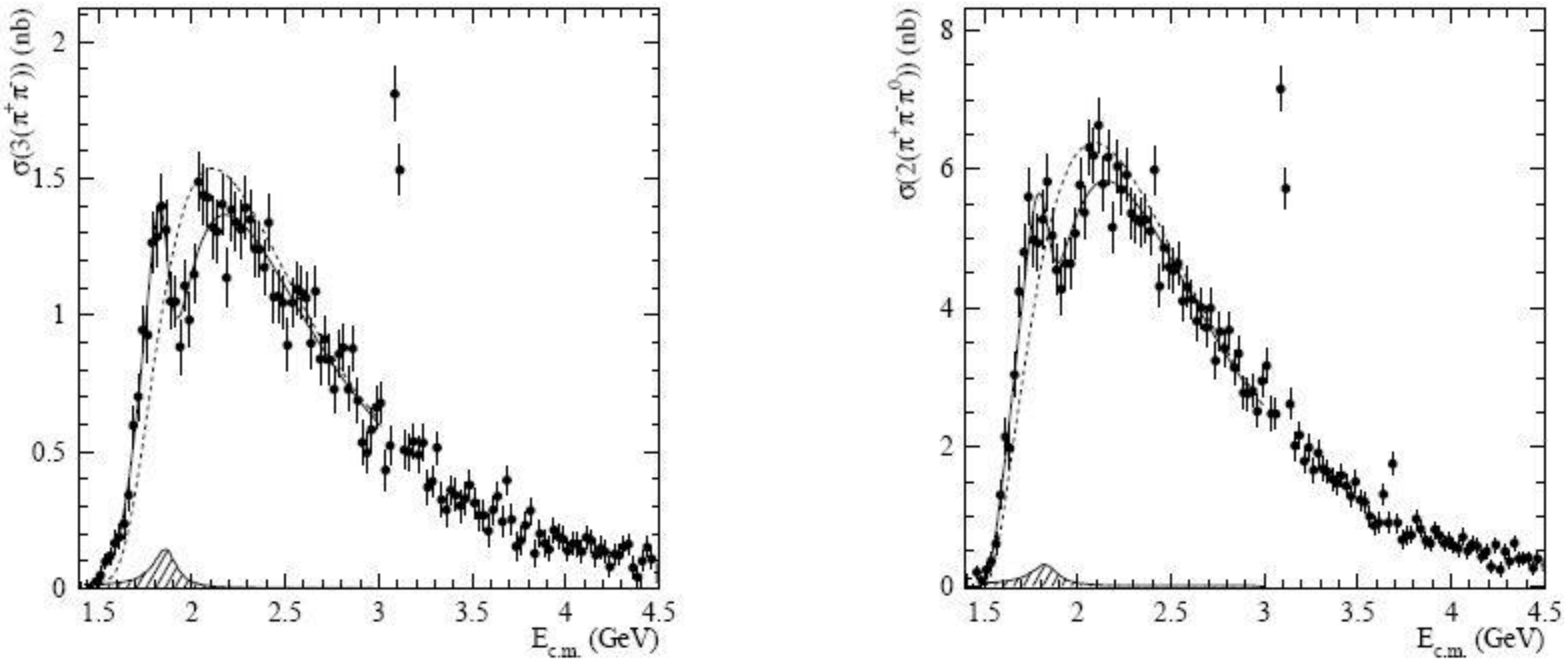
- 2001: E687 (Fermilab) dip at 1.9 GeV in $\gamma N \to 3\pi^+ 3\pi^- N$
- 1996: FENICE (Frascati) dip at $2m_{N\bar{N}}$ in $e^+e^- \to$ hadrons
- 1988: DM2 (Orsay) peculiarity at 1.9 GeV in $e^+e^- \to 6\pi$
- 2002: OBELIX (CERN) not observed in $\bar{n}p \to 3\pi^+ 2\pi^- \pi^0$

Group	Mass, GeV	Width, GeV
E687	$1911 \pm 4 \pm 1$	$29 \pm 11 \pm 4$
FENICE	1870 ± 10	10 ± 5

Possible interpretation:

- Low width $\Rightarrow$ non $q\bar{q}$
- Small mass for a glueball
- Vector hybrid?
- Bound $N\bar{N}$ state

ρ(1900) at Babar



A fit gives mass of 1.87 ± 0.02 GeV and too large width of 140 ± 30 MeV

More ρ' states ?

- $C(1480)$ – $\phi\pi$ state observed in Protvino in $\pi^- p$ with mass of 1480 ± 40 MeV and width of 130 ± 60 MeV

  Was not confirmed in e^+e^- (ND, DM2) and $p\bar{p}$ (Crystal Barrel)

- $\rho(2150)$ – a state of this mass and width of 200 – –300 MeV was claimed in some $N\bar{N}$ and $\pi^- p$ analyses.

"Zoo" of Decays and hybrids

Below 1.1 GeV $\pi^+\pi^-$, K^+K^-, K_SK_L, $\pi^+\pi^-\pi^0$ dominate,
above 1.1 GeV – 4π ($2\pi^+2\pi^-$, $\pi^+\pi^-\pi^0\pi^0$),
5π ($2\pi^+2\pi^-\pi^0$, $\pi^+\pi^-\pi^0\pi^0\pi^0$),
6π ($3\pi^+3\pi^-$, $2\pi^+2\pi^-2\pi^0$, $\pi^+\pi^-4\pi^0$),
$K\bar{K}\pi$ ($K^+K^-\pi^0$, $K^0\bar{K}^0\pi^0$, $K^\pm K^0\pi^\mp$),
$K\bar{K}\pi\pi$ ($K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$, $K^0\bar{K}^0\pi^+\pi^-$, $K^0\bar{K}^0\pi^0\pi^0$, $K^\pm K^0\pi^\mp\pi^0$).

Various intermediate mechanisms are possible:
4π ($\omega\pi$, $a_1^\pm\pi^\mp$, $a_2^\pm\pi^\mp$, $\rho^+\rho^-$, $\ldots$),
6π ($\rho f_0(1370)$, $\rho f_2(1270)$, $\omega 3\pi$, $\eta 3\pi$, $\ldots$),
$K\bar{K}\pi$ ($\rho(\omega,\phi)\pi$, $K^*\bar{K}$)

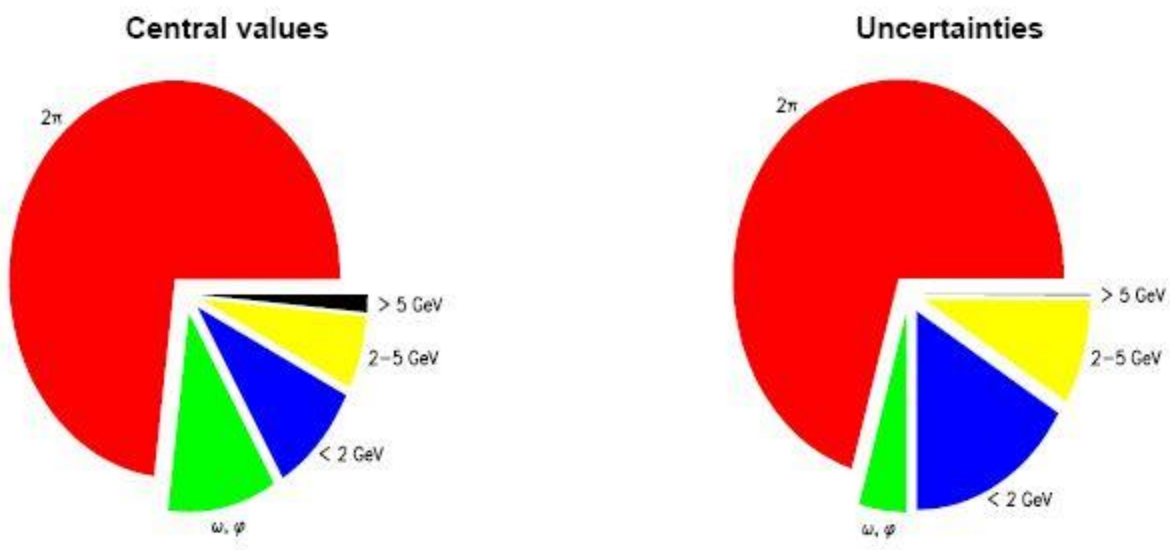
Theory can't exclude exotic states – hybrids ($q\bar{q}g$) with close masses
and peculiar decays ($\omega\pi$, $a_1\pi$, $h_1\pi$)

Other states $J^{pc} \neq 1^{--}$

Study of hadronic states X in $e^+e^- \to X\pi, XK$:
smaller combinatorial BG and pure initial state, e.g.,

- Search for new decay modes: $e^+e^- \to a_1(1260)\pi \to 4\pi$ at CMD-2 ($\tau \to 4\pi$ at CLEO) – $a_1(1260) \to f_0(600)\pi \to 3\pi$
- Studies of hybrids in $e^+e^- \to \pi(1800)\pi \to 4\pi$
- $e^+e^- \to f_0(1370)\rho \to 6\pi$
- New states, e.g., 4π in $e^+e^- \to 5\pi$

Hadronic contribution to $a_\mu^{had,LO}$



About 73% from 2π, $\sim$ 93% from $\sqrt{s} < 2$ GeV

Possible progress in $a_\mu^{had,LO}$

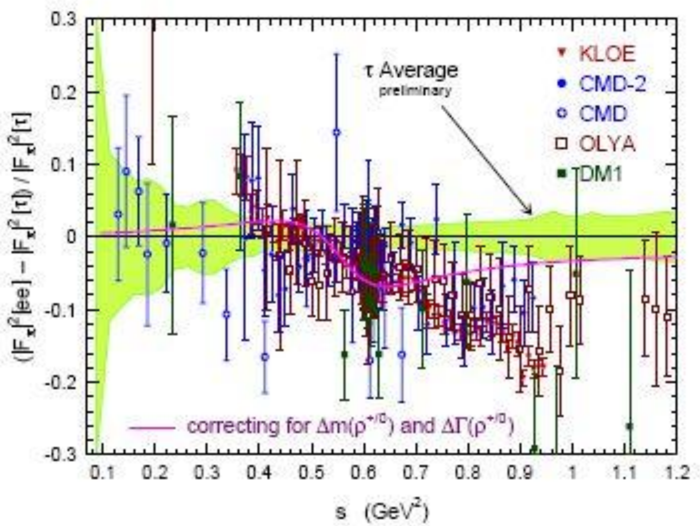
More ISR analysis from KLOE, BaBar, Belle; better R below 4.3 GeV from CLEO-c: $4.4 \to 2.8$

Experiments at VEPP-2000 with 2 detectors up to $\sqrt{s}$=2 GeV with $L_{max} = 10^{32}$ cm^{-2}s^{-1}, 10^{30} cm^{-2}s^{-1} achieved

A similar machine (DAΦNE-II) is discussed in Frascati, a $\tau - c$ factory in Beijing commissioning.

By 2012: $2.8 \to 2.2$, the total error of 4.6 limited by the LBL term (4.0)

e+e- vs τ - CVC tests



- CVC tested by one detector for $2m_\pi - m_\tau$
- Spectral functions for $2(4)\pi$ decays important for a_μ
- $\sigma_{ee} \Rightarrow$ predict $B(\tau)$ for about 10 modes with the total B about 32%
- Spectral functions from e^+e^- provide a shape of those for τ (TAUOLA, m_ν)

Experimental requirements

- High detector hermeticity to provide good acceptance
- Good $e^\pm/\mu^\pm/\pi^\pm$ separation for two-body channels
- γ, $\pi^\pm(K^\pm)$, $p(n)$ identification, reconstruction of $\pi^0, \eta, K_S^0, \Lambda$
- $L = 10^{31}$ cm^{-2} s^{-1}, $\varepsilon = 10\%$
- Broad resonances, $\Gamma \sim$ (150–300) MeV, possible $\Delta_{2E} = 25$ MeV
- At 2 GeV $\sigma_{\min} \sim 0.2$ nb (K^+K^-, K_SK_L). Its 10% measurement $\Rightarrow$ 5 pb^{-1} per point. Most probable $(4\pi, 6\pi)$ processes have $\sigma \sim 5$ nb, at 5 pb^{-1} per point stat. precision $\sim 2\%$.
- At lower energies dominant channels have larger σ
- At 60 points from 1 to 2.5 GeV about 300 pb^{-1} needed – 1 year of continuous running

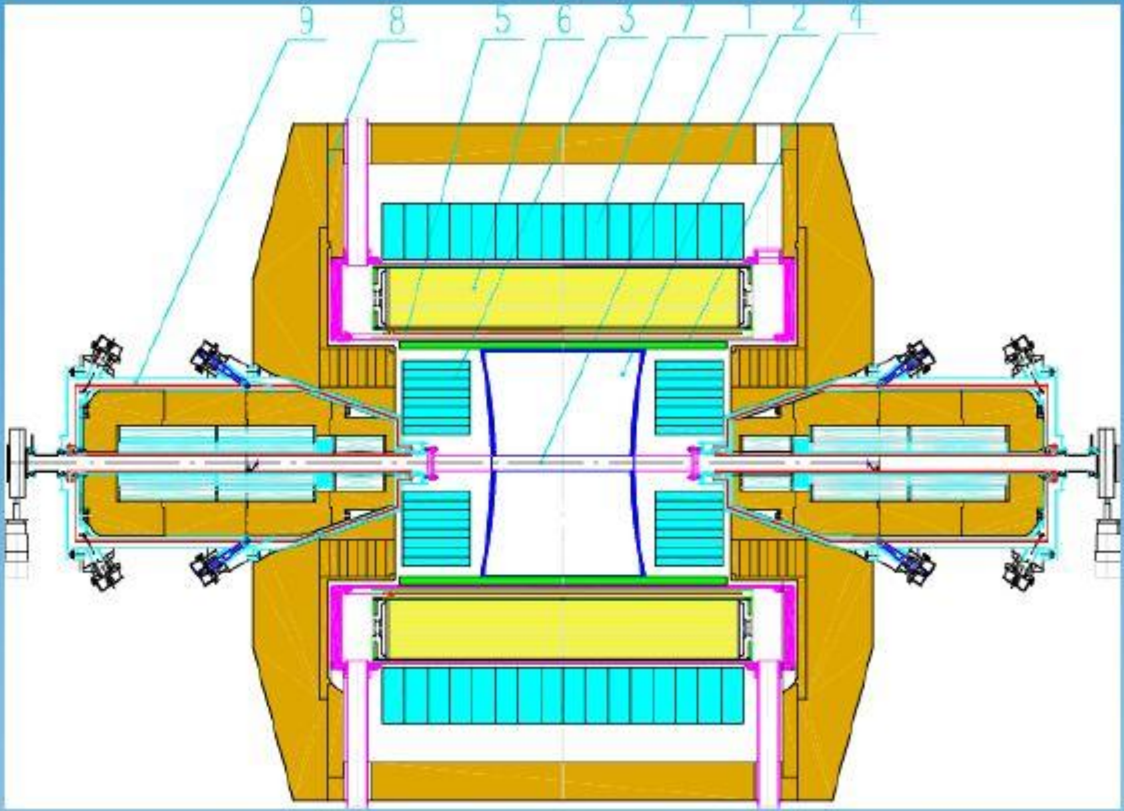
Systematic uncertainties

1. Luminosity determination with 1% accuracy $\Rightarrow$ MC QED generators, cross-checks with $e^+e^- \to e^+e^-, \mu^+\mu^-, \gamma\gamma$.
2. Radiative effects should be included to the MC generators $\Rightarrow$ a problem for multihadronic final states, FSR
3. Specificity of exclusive measurements:
   - Variety of mechanisms $\Rightarrow$ careful reconstruction
   - Precise and comlicated MC generators taking into account interference of various mechanisms and identical particles, form factors
   - Exclude missing final states
   - Background is small ($e^+e^- \to p\bar{p}(\pi^0)$ an exception?)
4. $\delta\sigma_{\rm syst}/\sigma \sim (2-3)\%$ if there are no correlations

CMD3 detector

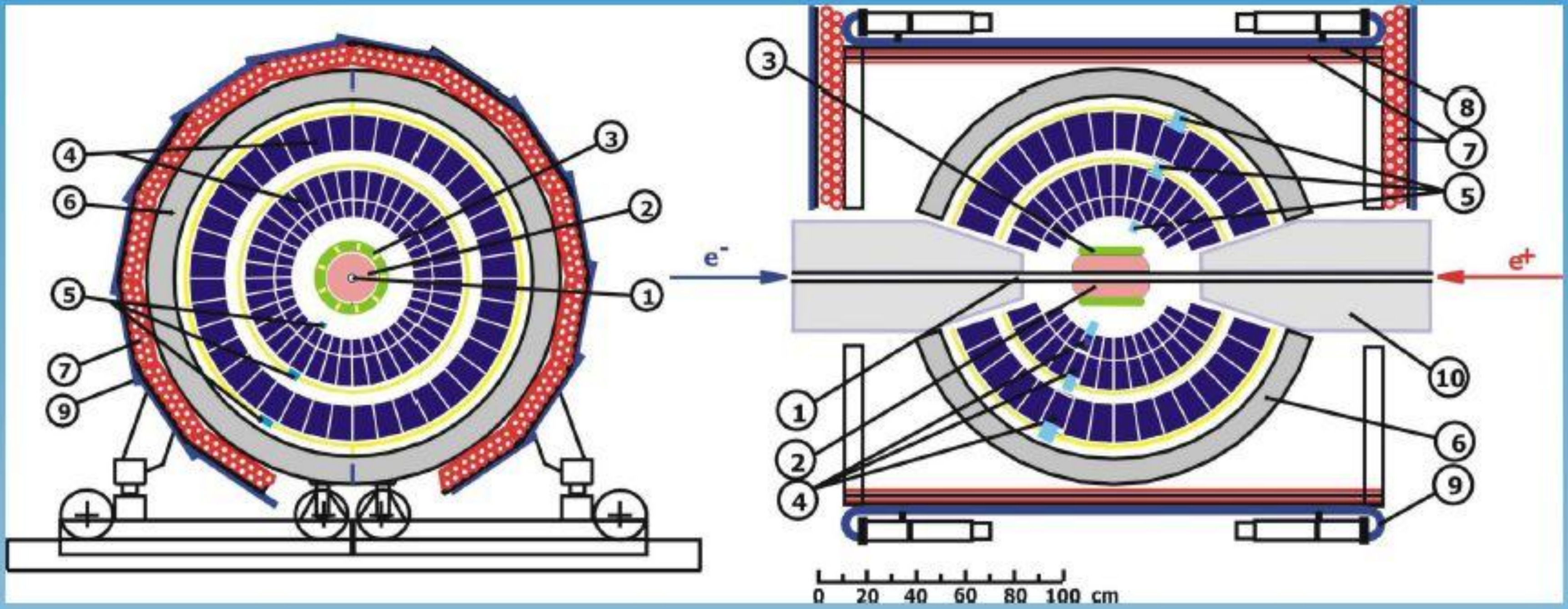
Advantages compared to CMD-2:

- new drift chamber with x2 better resolution
  - better tracking
- thicker barrel calorimeter
  - $8X_0 \rightarrow 15X_0$
  - better separation
- LXe calorimeter
  - much better spatial resolution for γ's
  - shower profile
- higher B field
  - better momentum resolution



1 - vacuum tube, 2 - drift chamber, 3 - calorimeter BGO (680 crystals), 4 - Z-chamber, 5 - CMD-3 superconducting solenoid, 6 - calorimeter LXe (400 liters), 7 - calorimeter CsI (1152 crystals), 8 - magnet yoke, 9 - solenoids of VEPP-2000

SND detector



1 – beam pipe
2 – tracking system
3 – aerogel
4 – NaI(Tl) crystals
5 – phototriodes
6 – muon absorber
7-9 – muon detector
10 – focusing solenoid

Advantages compared to "old" SND:

- new system - cherenkov counter (n=1.05, 1.13)
  - e/π separation E<450 MeV
  - π/K separation E<1 GeV
- new drift chamber
  - better tracking
  - better determination of solid angle

SND took first data in 2009 (around $\sqrt{s}=1$ GeV)

Do we need DAFNE-II after VEPP2000 ?

At the beginning of 2001 T. Kinoshita published a preprint:
Everyone makes mistakes: Including Feynman

10 months later M. Knecht and A. Nyffeler found that the sign of the dominant term in $a_\mu^{\rm LBL}$ in his calculations was wrong

Experiments at VEPP-2000 will NOT be ultimate leaving enough room for DAFNE-II both for completely new effects and cross-checks increasing credibility of the conclusions

Conclusion

- $\sqrt{s} < 2.5$ GeV can provide a lot of important information on the interactions of light quarks: Rare decays of the ρ, ω, ϕ with $\mathcal{B} \sim 10^{-6} - 10^{-7}$; studies of the ρ', ω', ϕ' and search for hybrids; nucleon form factors near threshold
- High precision R $\Rightarrow$ better knowledge of $(g_\mu - 2)/2, \alpha(M_Z^2)$, CVC tests, QCD sum rules, asymptotics of $R_{u,d,s}$ for m_c
- Various phenomena with effects of electroweak and strong interactions