R in Low Energy e^+e^-
[$E_{cm} \lesssim 5$ GeV]

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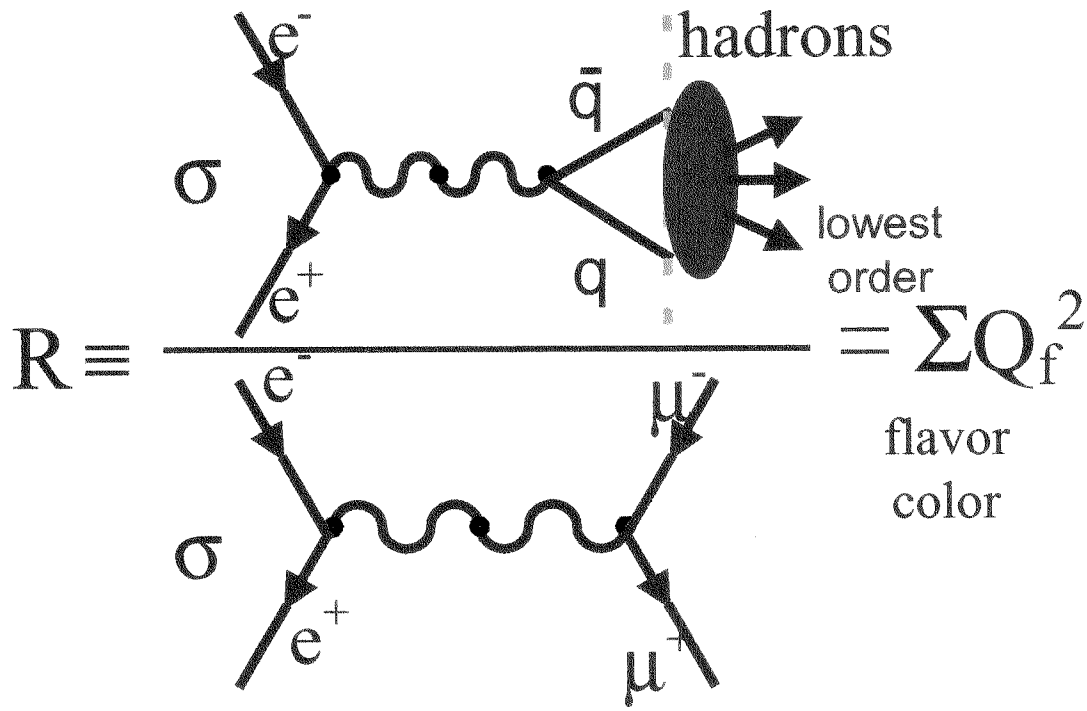
☞ Motivation

- Definition of R



Experimentally,

$$R = \frac{1}{\sigma^{0}_{\mu^+\mu^-}} \cdot \frac{N_{had} - N_{bg}}{L \cdot \varepsilon_{had} \cdot (1+\delta)}$$

N_{had}: observed hadronic events
L: integrated luminosity
δ: radiative correction
N_{bg}: background events

Why are R-values in low energy e^+e^- of interest?

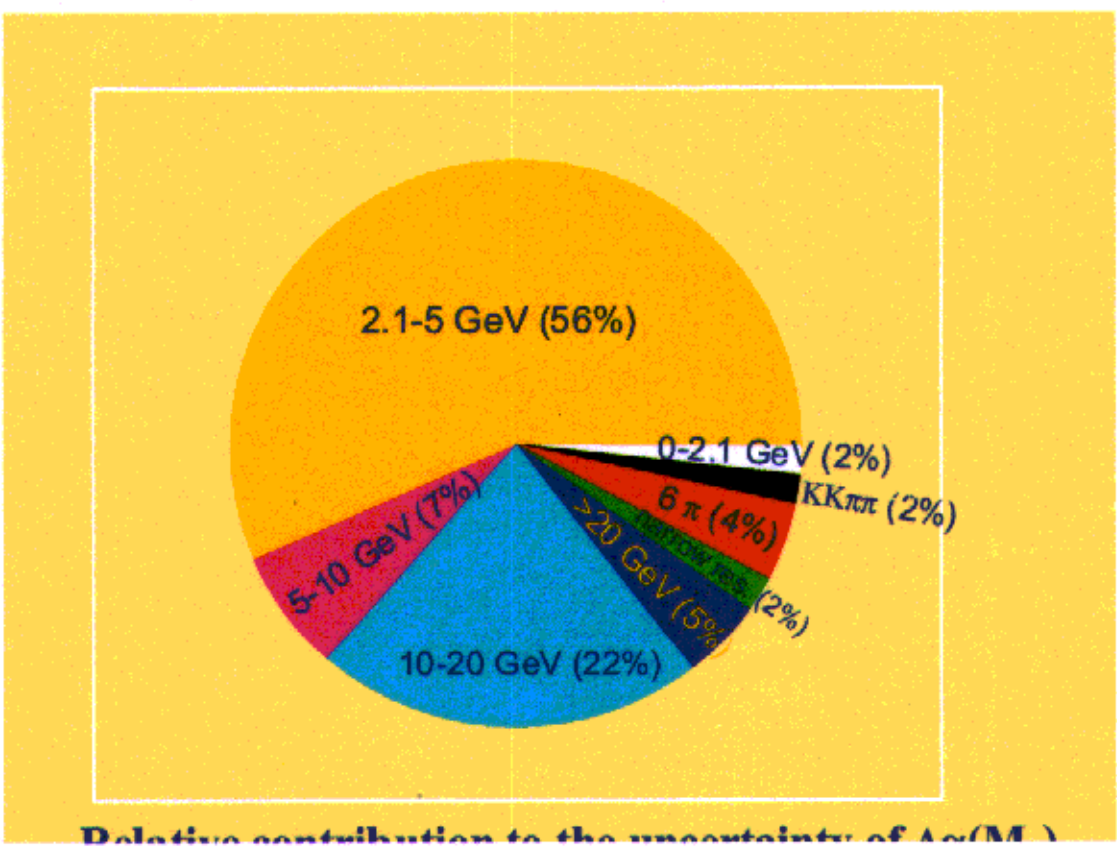
- Reducing the uncertainty of $\alpha(M_Z^2) \rightarrow$ essential for precision tests of the SM

$$\alpha(s) \equiv \frac{\alpha(0)}{1-\Delta\alpha(s)}$$

with $$\Delta\alpha(s) = \Delta\alpha(s)_{lep} + \Delta\alpha(s)_{had}$$

	calculated	measured
at M_Z^2	0.03142	0.0280±0.0009

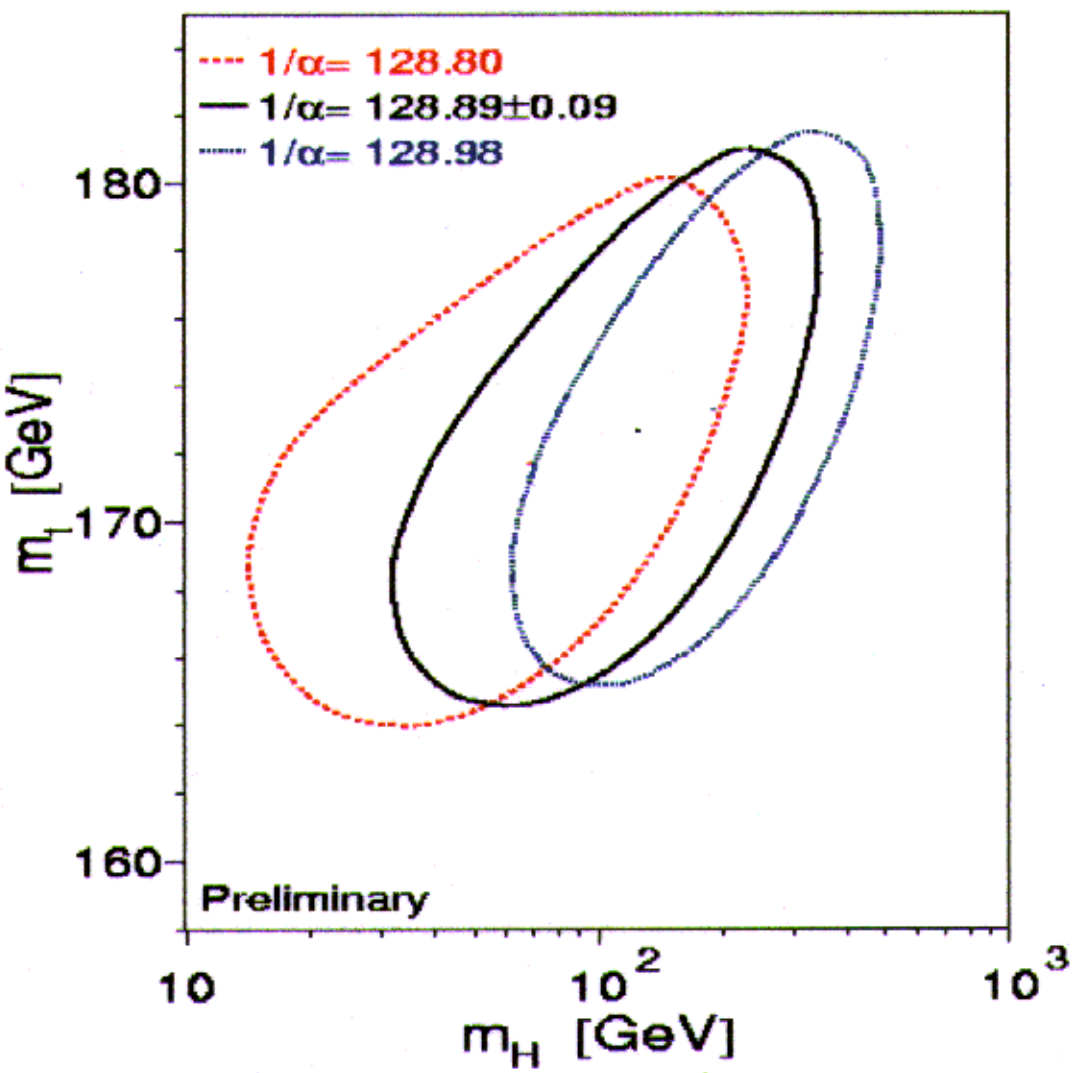
$$\Delta\alpha_{had}(M_Z^2) = -\frac{\alpha(0)M_Z^2}{3\pi}\,\mathrm{Re}\int_{4m_\pi^2}^{\infty} ds\,\frac{R(s)}{s(s-M_Z^2)-i\varepsilon}$$



Relative contribution to the uncertainty of $\Delta\alpha(M_Z)$

The E.W. data from high energy are now so precise that the radiative correction gives rise to the precision tests of the E.W. theory

In particular, the indirect determination of m_H depends critically on the precision of $\alpha(M_Z^2)$



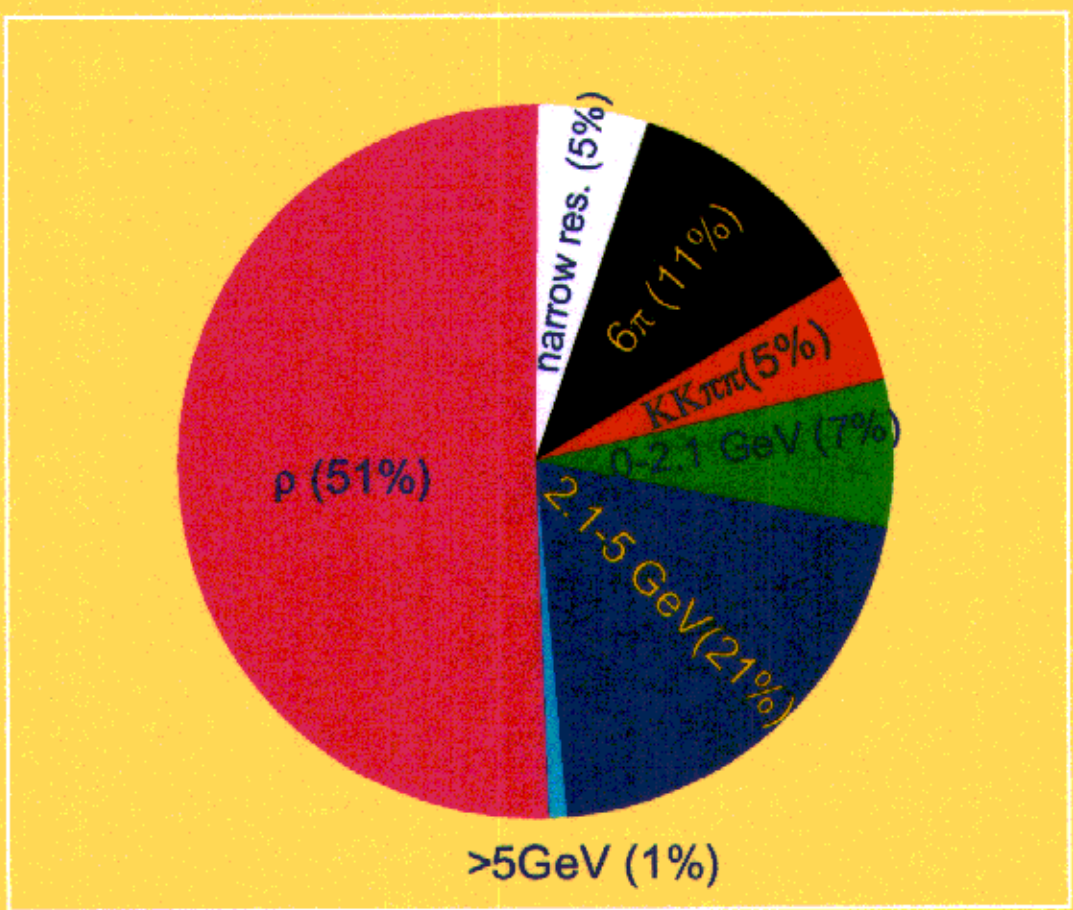
SM fit to m_t and m_H with $\alpha(M_Z^2)$ varying by $\pm\sigma$
(B. Pietrzyk and H. Burkhard)

- Hunting for new physics from $a_\mu \equiv (g-2)/2$

→Interpretation of E821 at BNL

$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{had} + a_\mu^{weak}$$

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

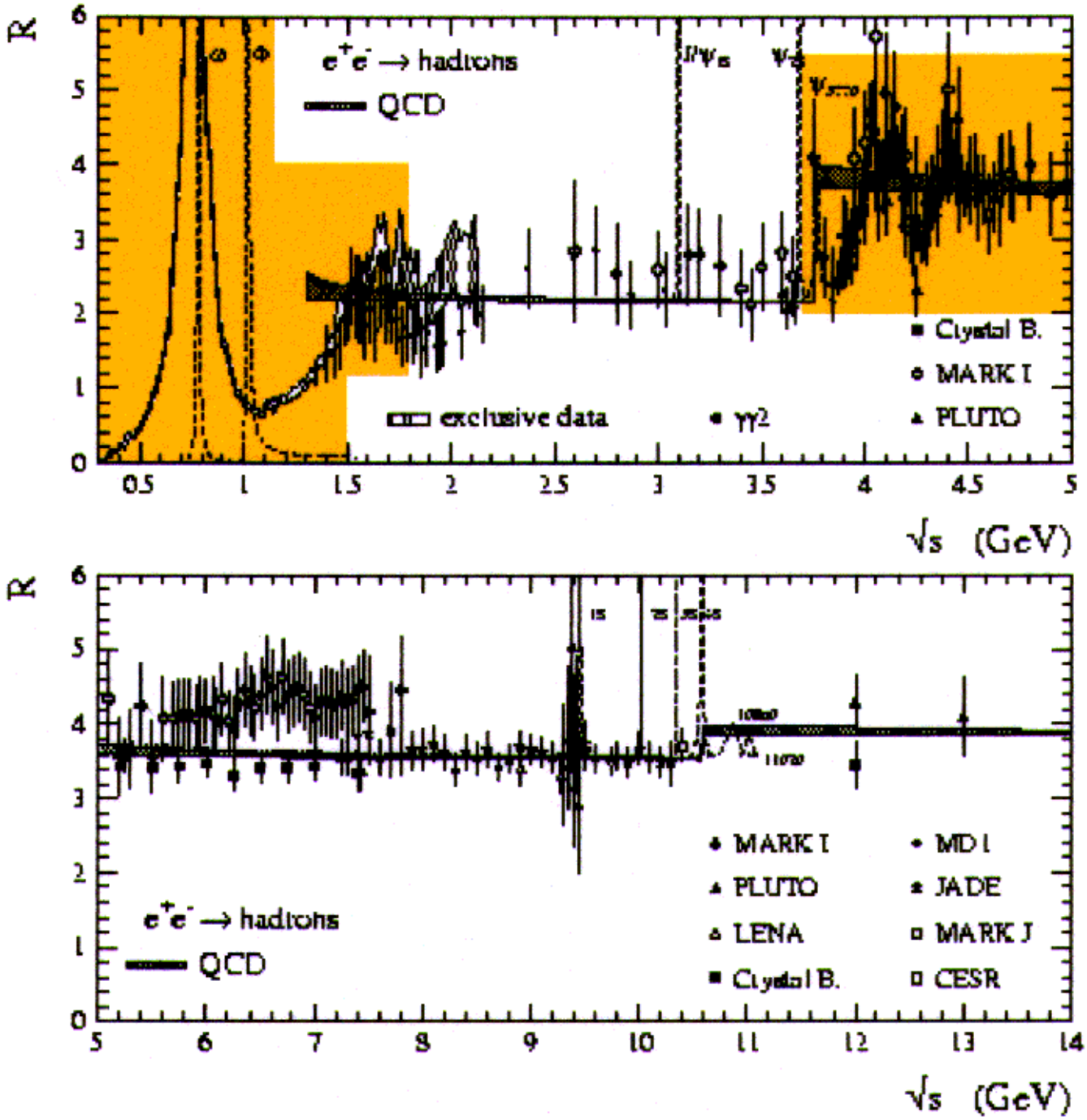


Retative contribution to the uncertainty of a (had)

☞ Present Status & New Measurements

Table 1. R($E_{cm} \lesssim 5$ GeV) from different laboratories

Place	Ring	Detector	E_{cm}(GeV)	pts	Year
Beijing	BEPC	BESII	2.0-5.0	85	1998 -1999
Novosibirsk	VEPP-2M VEPP-2	CMD2 SND Olya, ND CMD	0.6-1.4 0.3-1.4		1997 -1999
SLAC	Spear	MarkI	2.8-7.8	78	1982
Frascati	Adone	$\gamma\gamma$2, MEA Boson,BCF	1.42-3.09	31	1978
Orsay	DCI	M3N DM1, DM2	1.35-2.13	33	1978
Hamburg	Doris	DASP PLUTO	3.1-5.2 3.6-4.8	64 27	1979 1977



- ΔR/R~15% below 5 GeV
- Unclear & complex structure in 3.7-5 GeV

Typical features of hadron production below 5 GeV:

- Many resonances ρ, ω, φ, ρ', ω', φ'; $c\bar{c}$ and charmed mesons J/ψ, $\psi(2S)$, D^+D^-, $D_s^+ D_s^-$; and pair production $\tau^+\tau^-$, baryon-antibaryon

- Small number of final states and low charged multiplicity, $N_{ch} \lesssim 6$

$\rightarrow$ Experimental challenge: beam associated background and select N_{had}

New measurements

- **CMD-2** and **SND** at VEPP-2M **(Novosibirsk)**

  - exclusive

  - **$0.4 \lesssim E_{cm} \lesssim 1.4$ GeV**

  - final states studied:

    $\pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-\pi^0$, $\gamma\gamma\pi^+\pi^-$ (CMD2)

    $\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^0\pi^0$, $K_S K_L$ (SND)

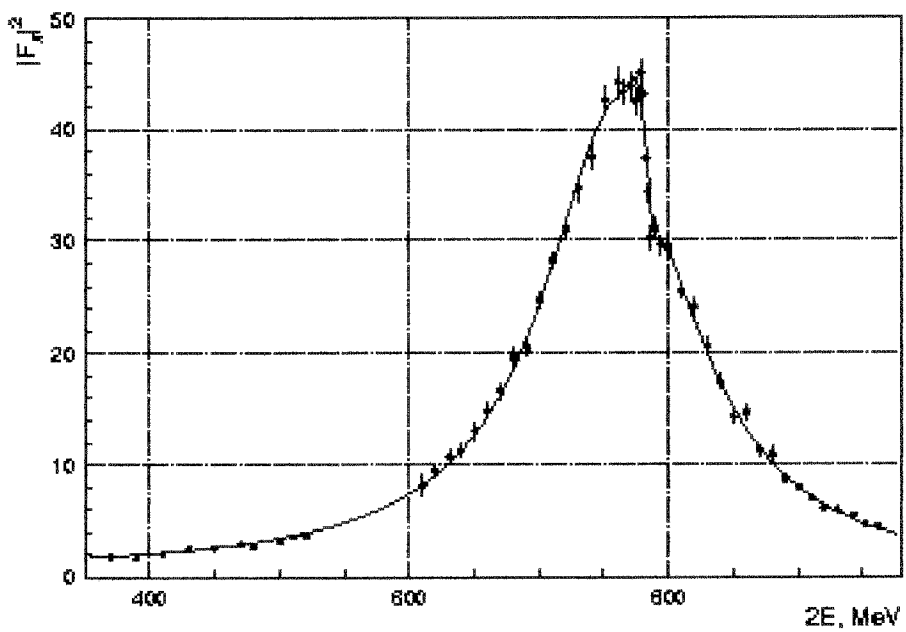
- **BESII at BEPC (Beijing)**

  - inclusive

  - **$2.0 \lesssim E_{cm} \lesssim 5.0$ GeV**

$$\sigma(e^+e^- \to \pi^+\pi^-) \propto |F_\pi{}^2|$$

A fit of CMD-2 (94,95,96) data



ρ meson parameters

	CMD-2 94-95 data	PDG-98 $e^+e^- - \tau$ data
M_ρ, MeV	$775.3 \pm 0.6 \pm 0.2$	776.0 ± 0.9
Γ_ρ, MeV	$147.7 \pm 1.3 \pm 0.4$	150.5 ± 2.7
$\Gamma(\rho \to e^+e^-)$, keV	$6.93 \pm 0.11 \pm 0.10$	6.77 ± 0.32
$Br(\omega \to \pi^+\pi^-)$, %	1.31 ± 0.23	2.21 ± 0.30 *
$< r_\pi^2 >$, fm^2	$0.421 \pm 0.002 \pm 0.003$	

*Our fit gives (1.89 ± 0.30)%.

CMD-2 94-96 data : 130000 $e^+e^- \to \pi^+\pi^-$ events total.

$\omega\pi^+\pi^-$ and $\eta\pi^+\pi^-$ cross sections

Integrated luminosity 3.5 pb^{-1}

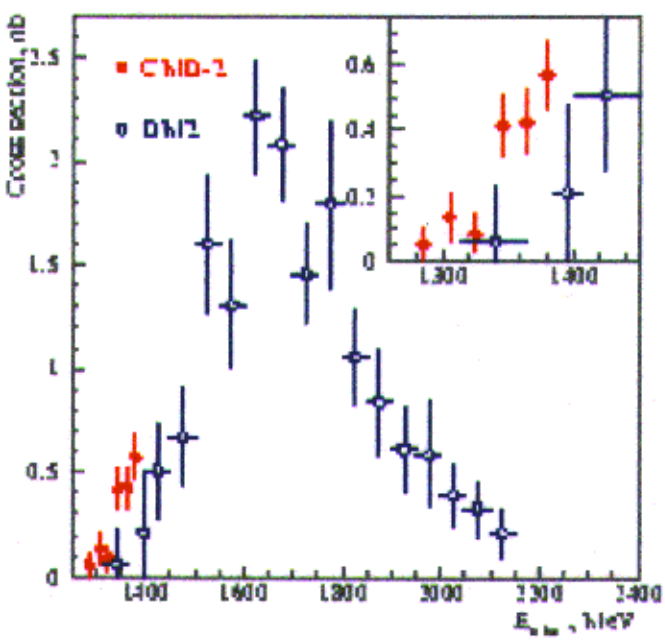
$e^+e^- \to \omega\pi^+\pi^- \to \pi^+\pi^-\pi^+\pi^-\pi^0$

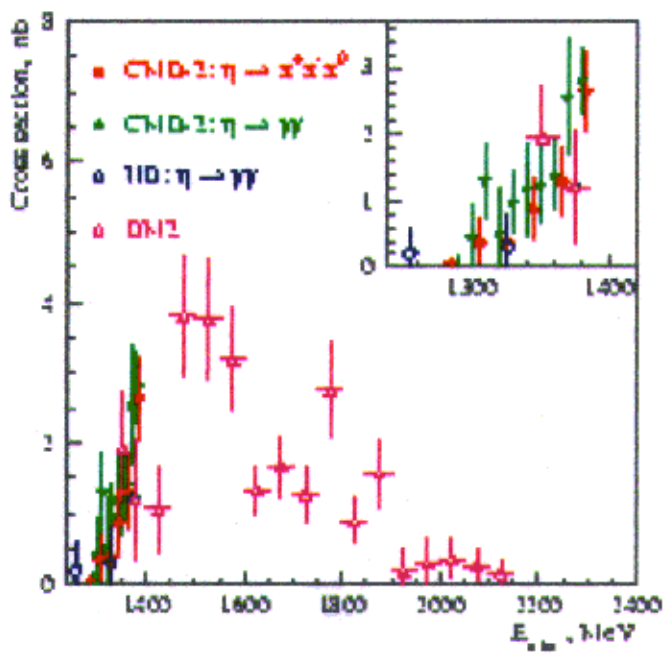
$e^+e^- \to \eta\pi^+\pi^- \to \pi^+\pi^-\pi^+\pi^-\pi^0$

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

$N(\omega\pi^+\pi^-) = 153 \pm 15$ $\quad$ $N(\eta\pi^+\pi^-) = 463 \pm 42$

Systematic error ~ 15 %





A Peak at 2E~1220 MeV in $e^+e^- \to \pi^+\pi^-\pi^0$ Process

Data from SND experiment at VEPP-2M

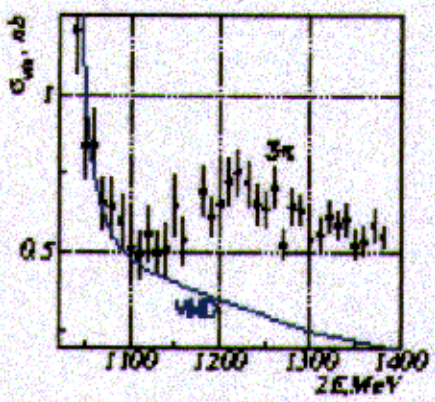


Figure 4: Visible cross section

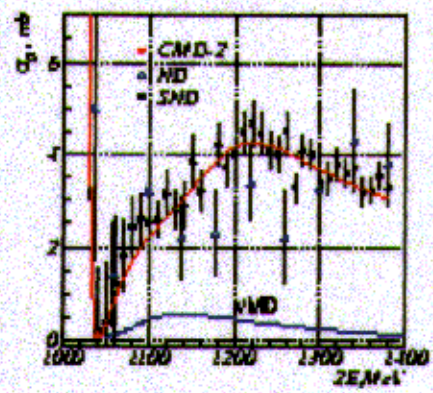


Figure 5: Total cross section

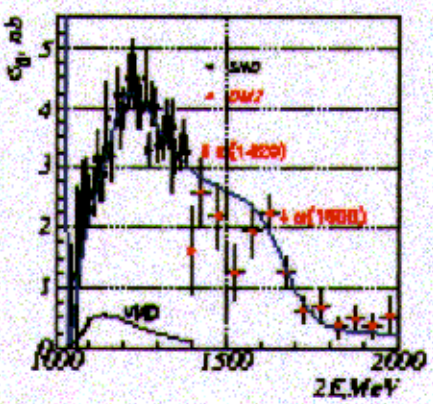


Figure 6: Total cross section

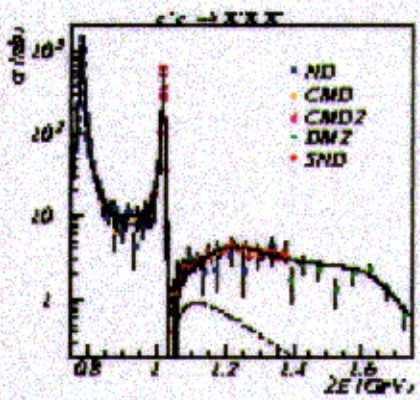
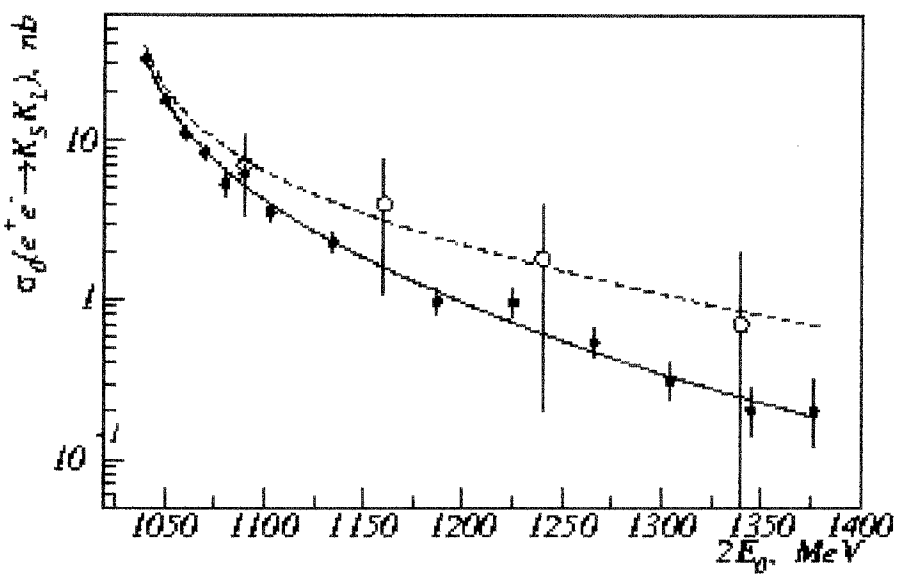


Figure 7: Total cross section

Data from VEPP-2M e^+e^- Collider, Novosibirsk

Born cross section of the process $e^+e^- \to K_S K_L$ from SND detector

2E = 1.04 – 1.38 GeV, ΔL = 6.1 pb^{-1}



• – SND, VEPP-2M (1999)
○ – OLYA, VEPP-2M (1982)
dashed line – **$\phi(1020)$ contribution**
solid line – **VDM (ρ, ω, ϕ)**

Ref: K.I.Beloborodov. Contribution to the International Workshop on e^+e^- Collisions "From Phi to J/Psi", March 1-5, 1999, Novosibirsk, Russia.

Comments to results from CDM-2 and SND

- Precision measurements
- More individual channels are needed in order to obtain accurate values of R
- Widen the energy region

- BEijing Spectrometer (BES)II at Beijing Electron-Positron Collider

Upgrade: 1995-1997

BEPC:

- Luminosity 1.5-2 × increase
- Reduced beam associated background

BES:

- New luminosity monitor
- Refurbished MarkIII vertex chamber + Be beam-pipe
- New drift chamber
- New barrel TOF system

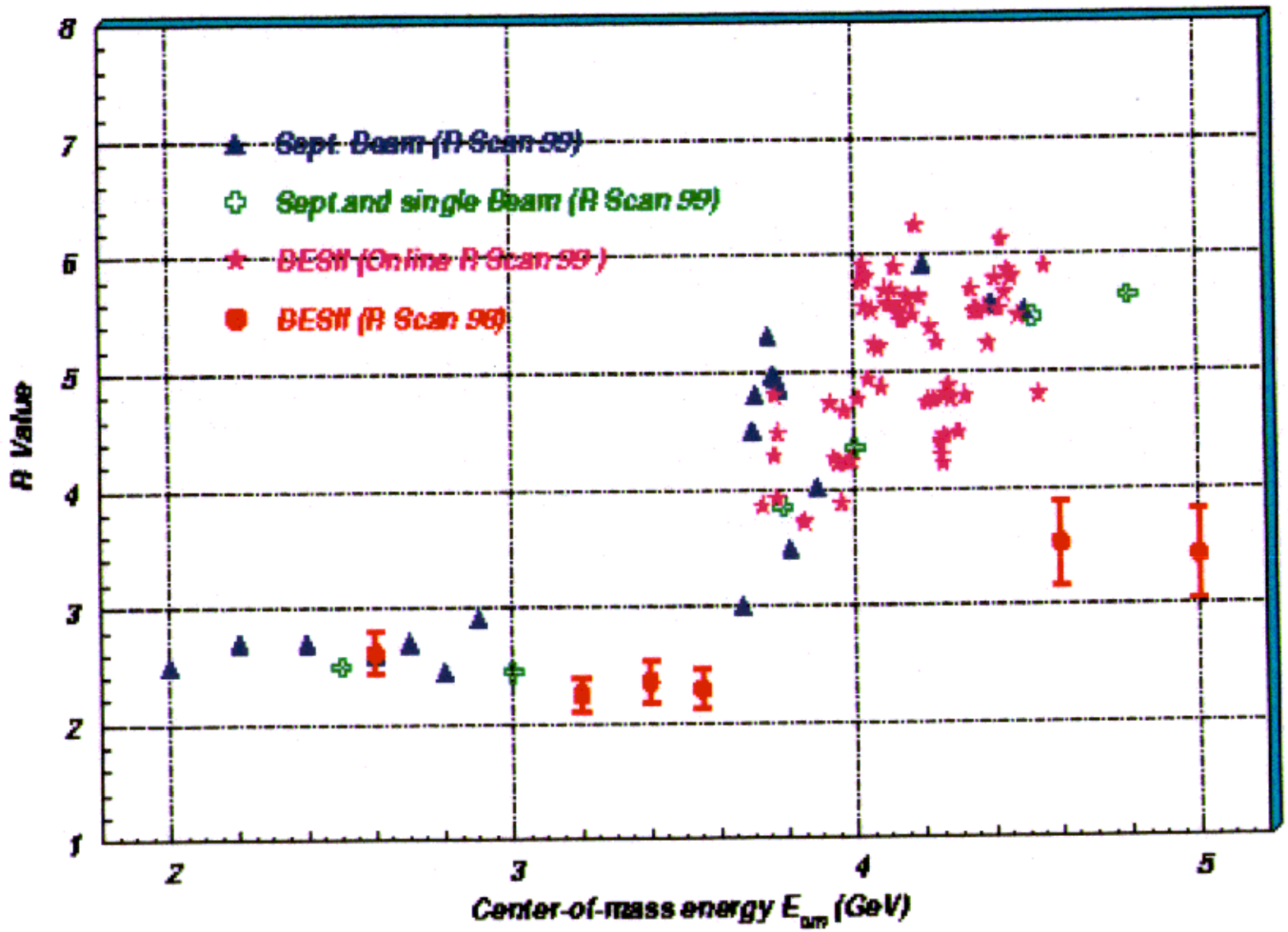
BES R scan

March-May, 1998:

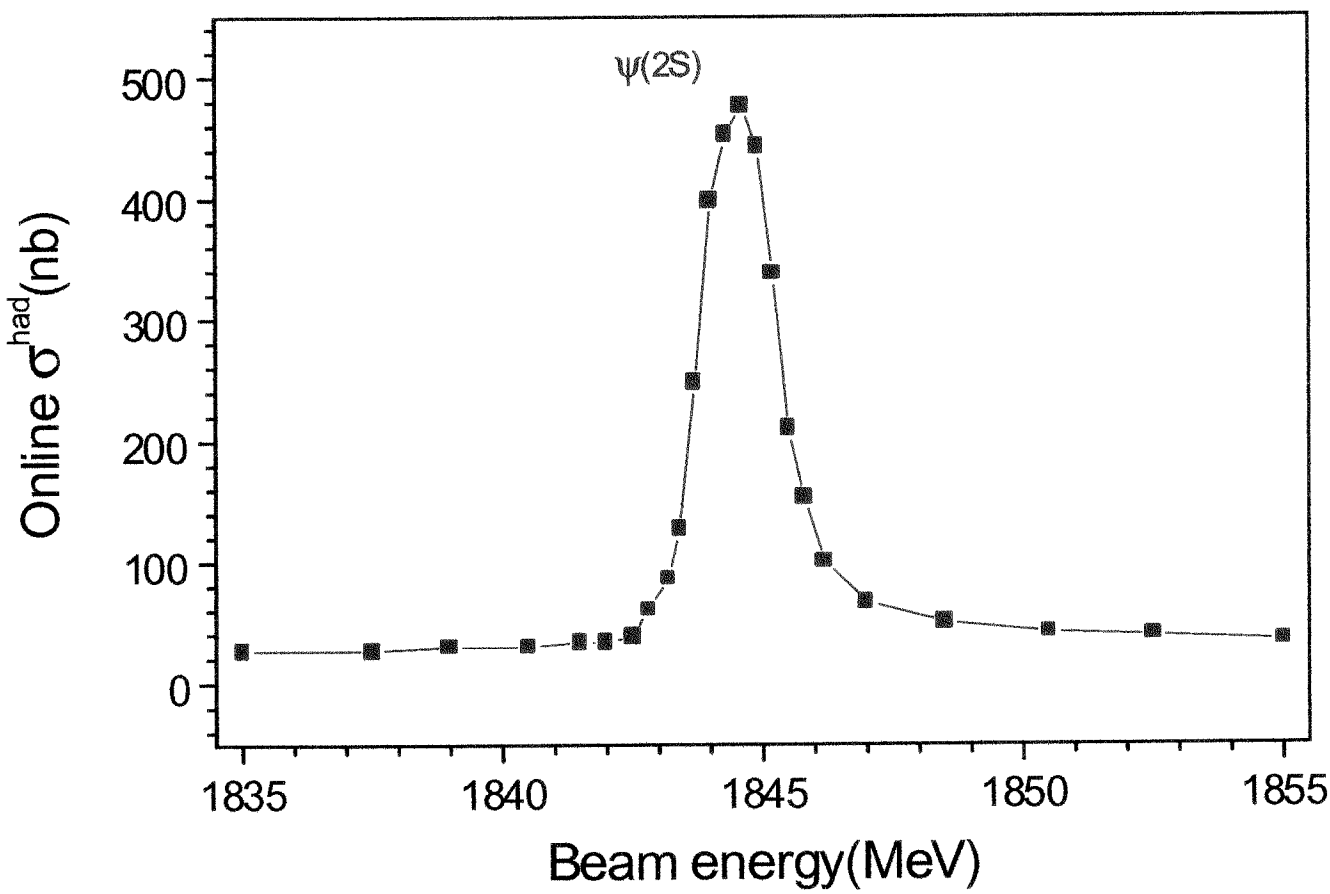
6 energy points
(2.6, 3.2, 3.4, 3.55, 4.6, 5.0 GeV)

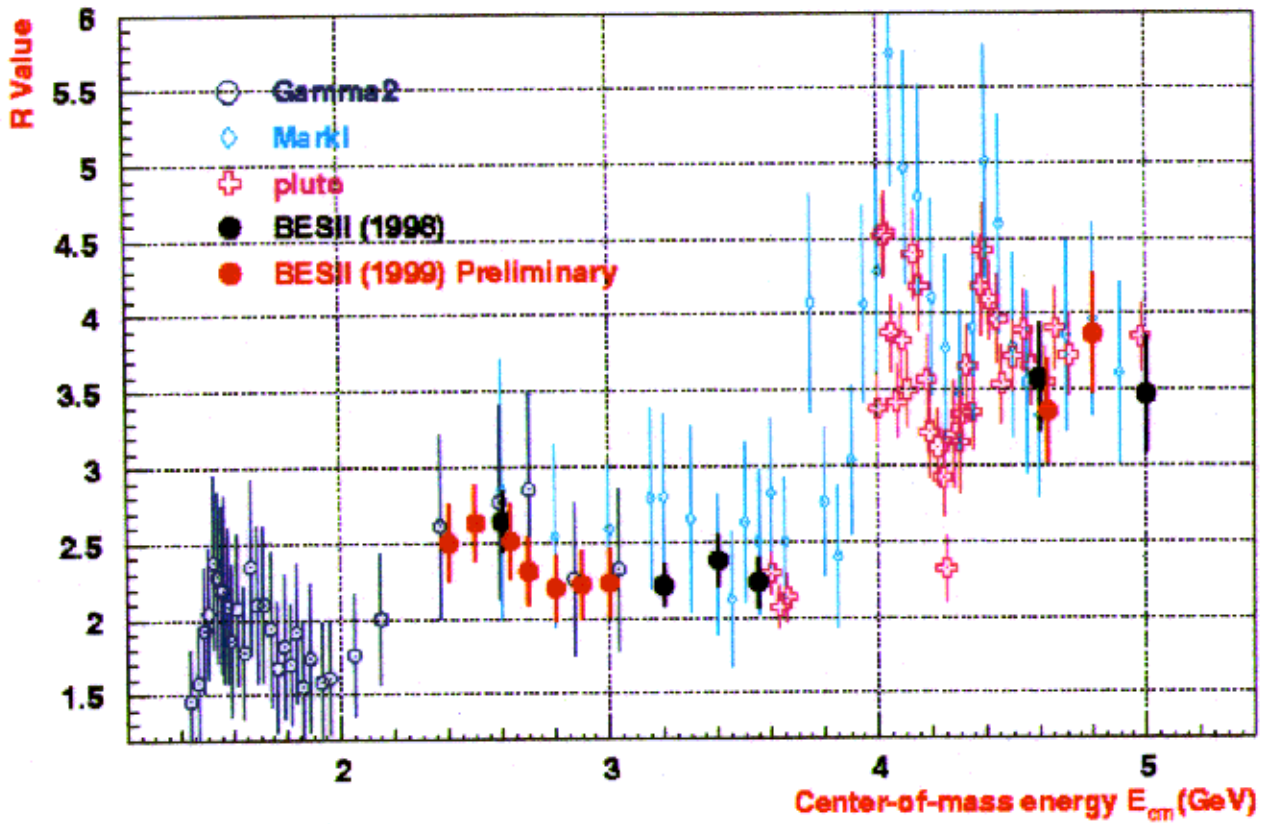
Feb.- June, 1999:

85 energy points (2-4.8 GeV)
+ detailed scan of $\psi(2S)$ (24 points)


Sept. Beam (R Scan 99)
Sept.and single Beam (R Scan 99)
BESII (Online R Scan 99)
BESII (R Scan 98)
R Value
Center-of-mass energy E_{cm} (GeV)
1
2
3
4
5
6
7
8
2
3
4
5

ψ(2S) resonance from the online observed hadronic events




R Value
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
Gamma2
MarkI
plute
BESII (1998)
BESII (1999) Preliminary
2
3
4
5
Center-of-mass energy E_{cm} (GeV)

Comments on BES results

- The BESII performance was stable and the data quality is good

  The 3.4 GeV point was repeated in the 1998 scan;
  The 2.6 and 4.6 GeV points were repeated in the 1999 scan.

  R values are consistent in each case

- great effort has been made to

  a) improve the understanding of the detection efficiency
  b) determine the trigger efficiency
  c) understand beam associated background by means of separated beam and single beam operation

- the uncertainty in R has been reduced by a factor of 2 for E_{cm}<3.55 GeV

☞ Prospects

Novosibirsk

- CMD-2 and SND at VEPP-2M (1999-2000?)
  Plan to scan from threshold to 1 GeV (ρ-ω scan?)
- R scan with KEDR VEPP-4 (2001)

  $2<E_{cm}<10$ GeV; $L\sim10^{29}$-10^{31} cm^{-2} s^{-1}
  Would be an important scan
- Proposed new colliders(2000-2005)

- ϕ factory; $L\sim3\times10^{33}$ cm^{-2} s^{-1}
- τ-c factory; $L\sim3\times10^{33}$ cm^{-2} s^{-1}

An ambitious plan!

DAϕNE(2004?)

- $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ in $E_{cm} \lesssim 1$ GeV
- Measure R in $1 \lesssim E_{cm} \lesssim 2$ GeV

BEPC

- Beijing τ-charm factory/BEPCII (2003-2005?)

  ~$ 10 M for R&D approved

  $\Delta R/R$ in 2-5 GeV (1-3)%

☞ Summary

- Experimental effort to reduce $\Delta R/R$ from ~15% to a few % at low energy is mandatory and important for precision tests of E.W. theory and the interpretaion of the measurements of (g-2)
- The measured exclusive cross section data up to 1.4 GeV from CMD-2 and SND improved the previous results
- BESII has improved $\Delta R/R$ to ~7% $E_{cm} \lesssim 3.55$ GeV, similar improvement are expected in 3.5-5.0 GeV region from the data being analyzed at present
- Further significant improvements in the 2-5 GeV energy region would require the construction of a τ-charm factory