Measurements of R at VEPP-2000

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R(s), the definition

R(s) is defined as:

$$R(s) = \frac{\sigma^{(0)}\ \ e^+e^- \to \gamma^* \to hadrons}{\sigma^{(0)}\ \ e^+e^- \to \mu^+\mu^-}$$

R(s) is one of the fundamental quantities in high energy physics:

- its global structure reflects number of quarks and colors; used for QCD tests and as a source of QCD parameters
- plays special role in precision measurements; in particular, it is essential for the interpretation of measurements of muon (g-2) and $\alpha(M_Z)$

Requirements for the next generation g-2 experiment

At low s R(s) has to be measured – especially important for a_μ

Expected precision of the next (g-2) measurement is $2 \cdot 10^{-10}$

Talk by Lee Roberts

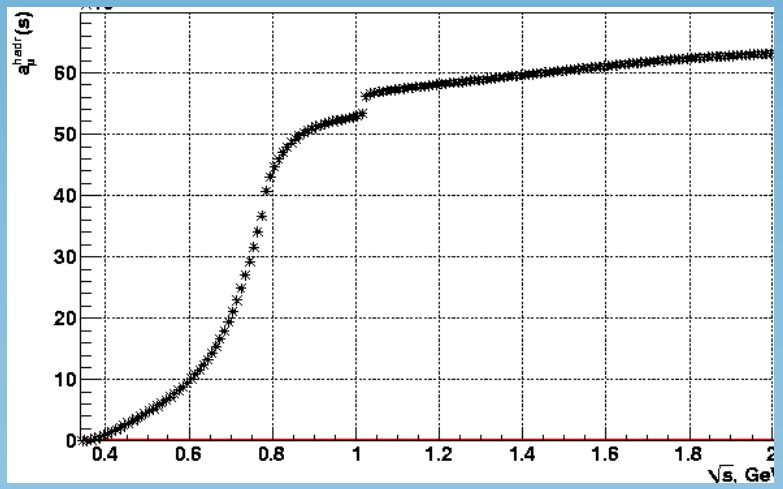
Contributions to l.o. HVP (10^{-10}):

- 2π: ~510
- ω,φ: ~74
- 4π: ~31
- <2 GeV: ~30
- >2 GeV: ~50

The matching requirements for the cross-section measurements are:

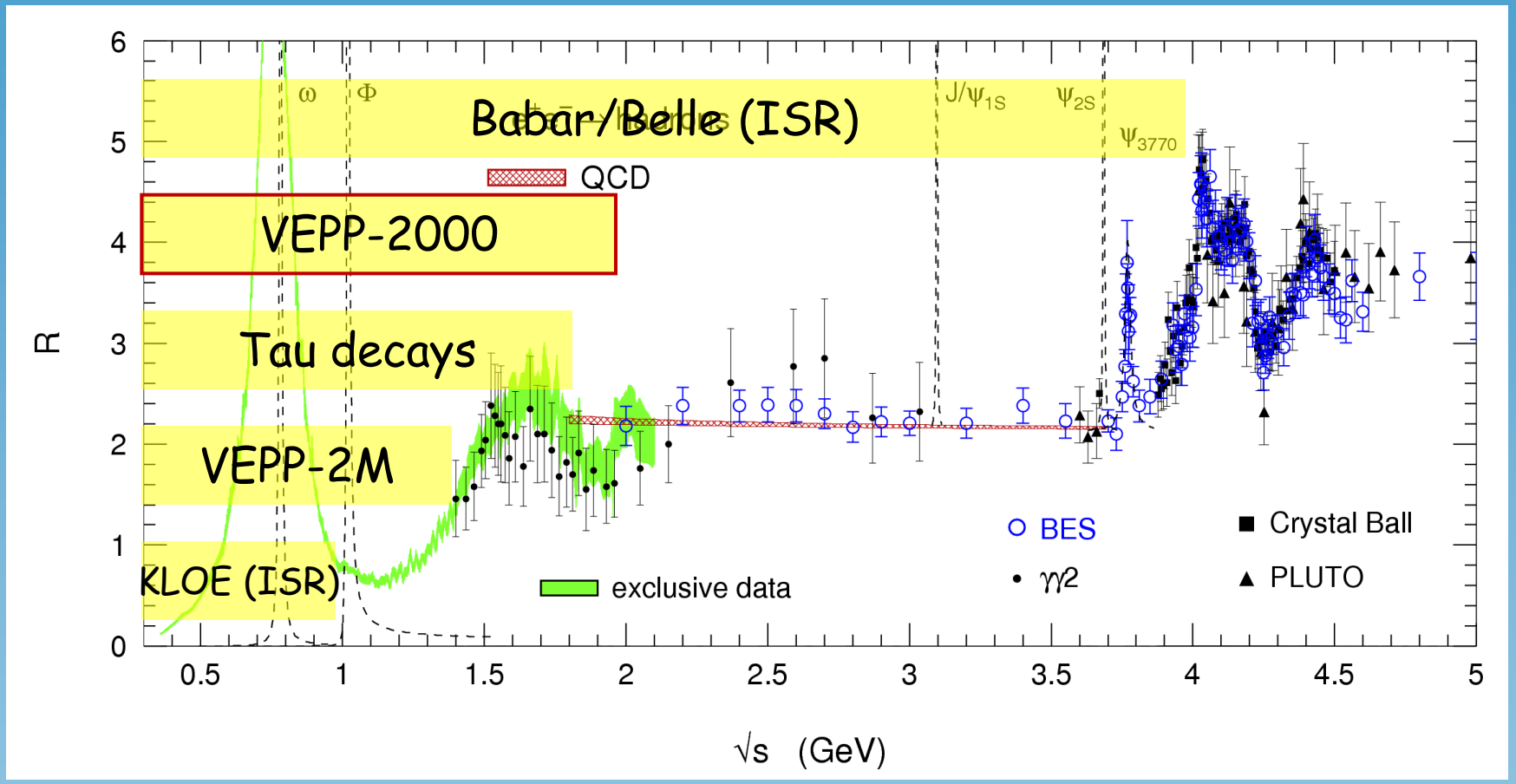
- 2π: ~0.3%
- ω,φ: ~1.0%
- 4π: ~3%
- <2 GeV: ~3%

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



More than 90% of integral is collected below 2 GeV

R(s) measurements at low s

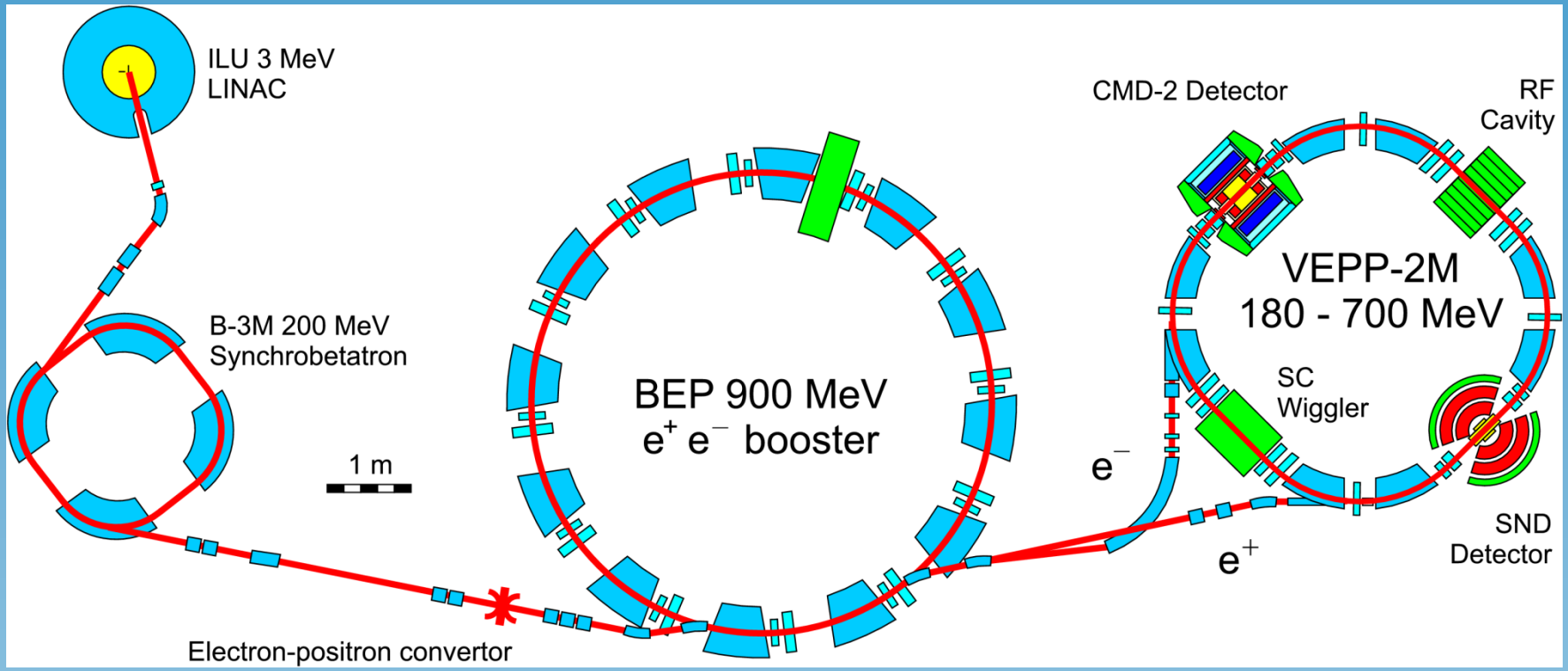


Measurements of R(s)

- Direct → CMD-2, SND, VEPP-2000
- Indirect
  - Tau decays → ALEPH, CLEO, Belle
  - ISR → BABAR, KLOE, VEPP-2000(?)

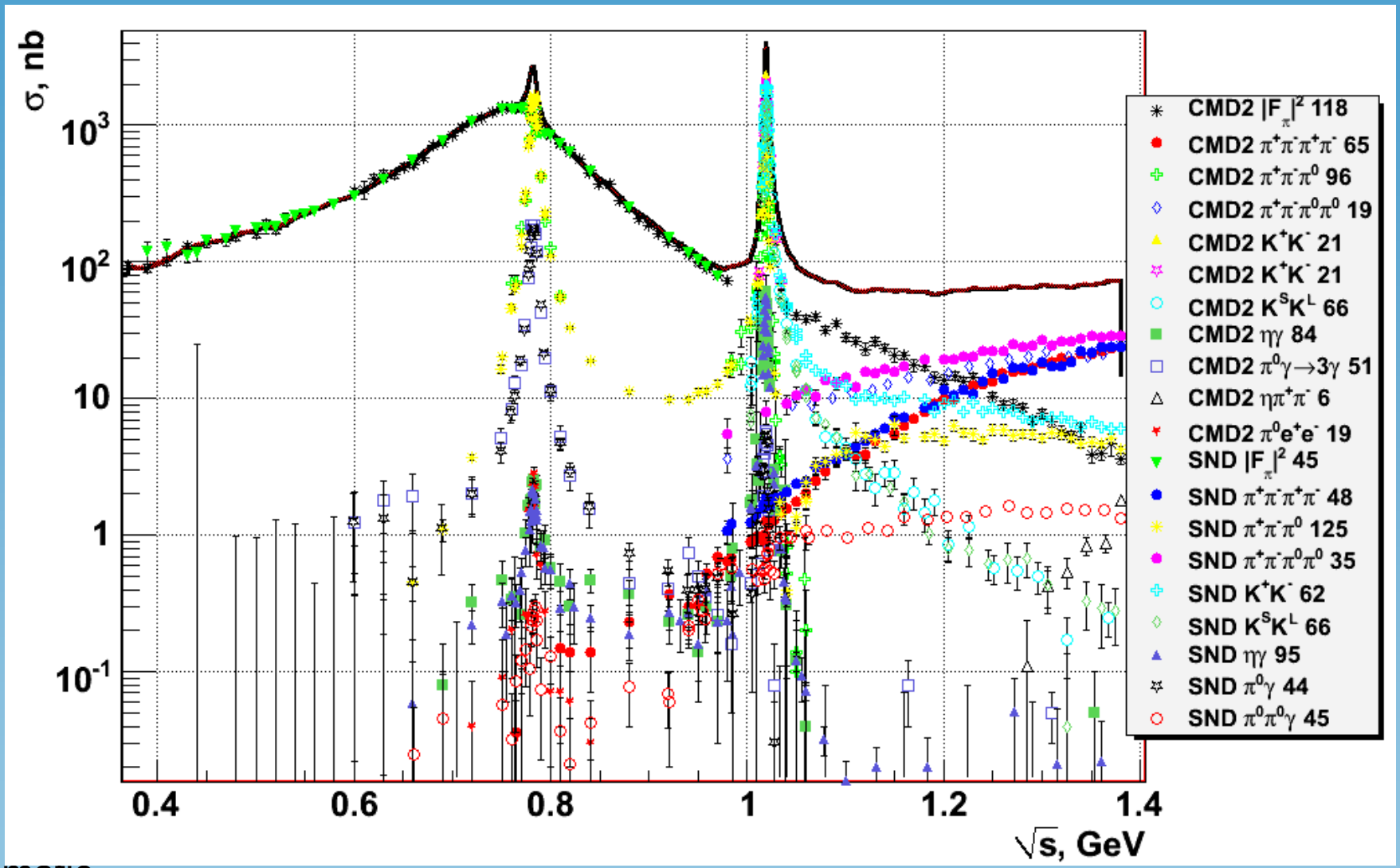
VEPP-2M results

VEPP-2M collider



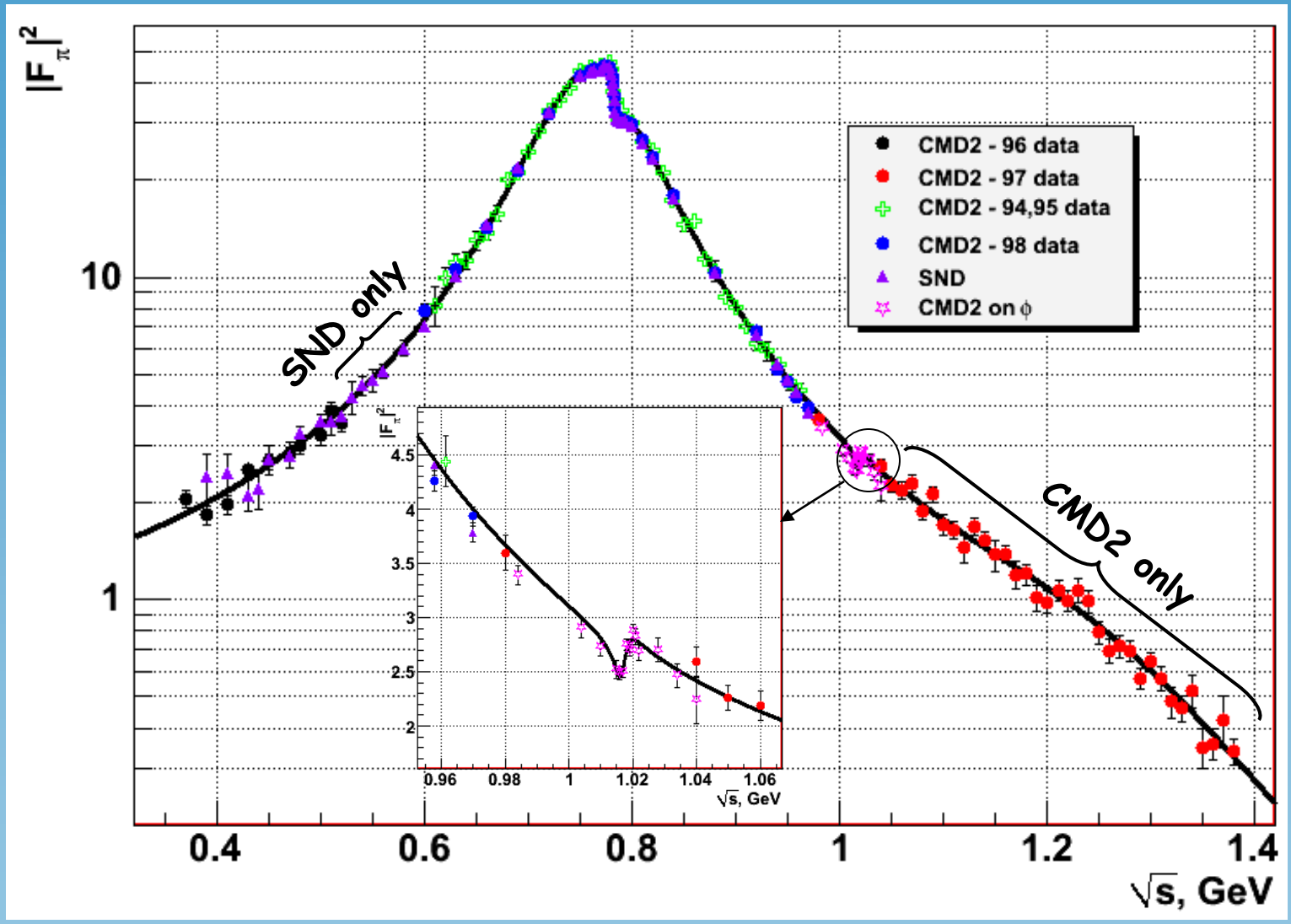
- VEPP-2M collider: 0.36-1.4 GeV in c.m., $L \approx 10^{30}$ 1/cm^{2}s at 1 GeV
- Detectors CMD-2 and SND: 70 pb^{-1} collected in 1993-2000

Overview of the results



Systematic error :	~0.6-0.7%	1.0%	0.6%	1.5%	1.5 -- 5 %	Error of R(s) (per point)
Total error:	~ 6 -- 1%	1.5%	1--2%	2.0%	2.5 -- 5 %	

Pion formfactor - results



CMD2	0.7%	0.6% (95)/ 0.8% (98)	1.2-4.2%
SND	3.2%	1.3%	

VEPP-2M conclusion

• CMD-2 and SND data analyses are complete (almost). Cross sections of all major modes of e+e- → hadrons are measured at energy range $\sqrt{s} < 1.4$ GeV . These are the best direct (energy-scan) measurements at the moment.

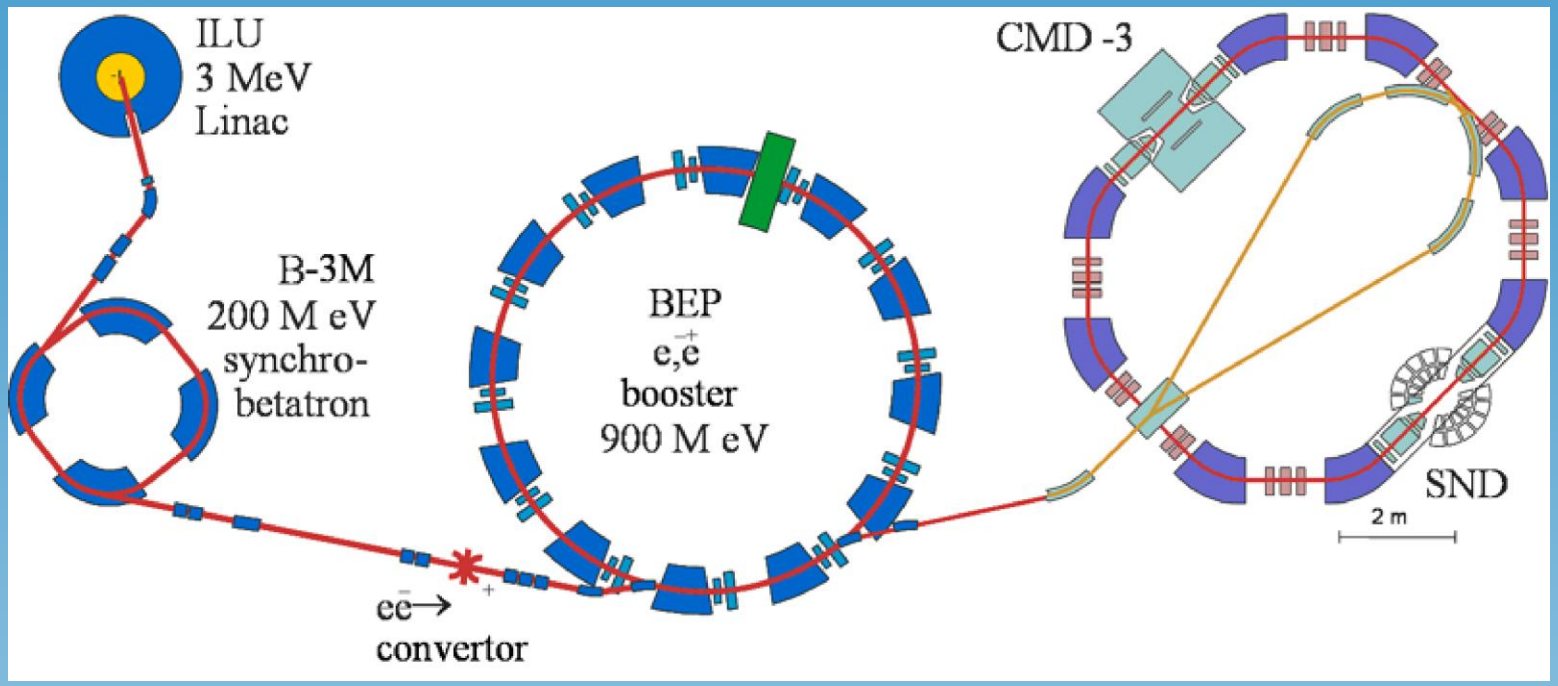
• There is good agreement between Novosibirsk results, in particular: pion formfactor CMD-2 (94,95) vs CMD-2 (98), CMD-2 vs SND.

• Over the last few years new indirect high precision measurements of R were performed: new tau-decay data and ISR. The question of agreement between different methods is open for interpretation

New, more precise, direct measurement of R is still interesting and such measurement is scheduled at VEPP-2000.

Future measurements at VEPP-2000

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

Status:

2009 – start of experiments

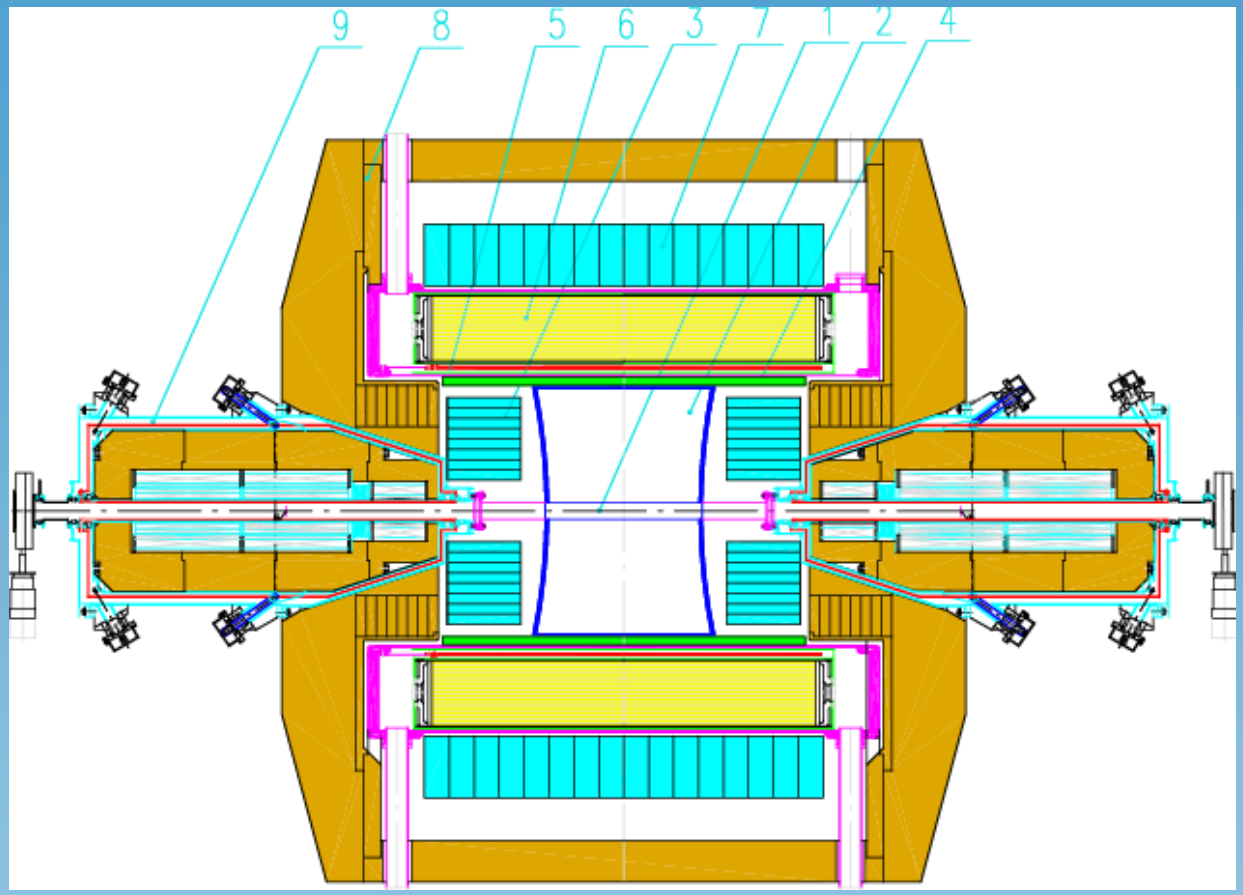
More details in talk by Yu.Tikhonov

CMD-3 Detector

Advantages compared to CMD-2:

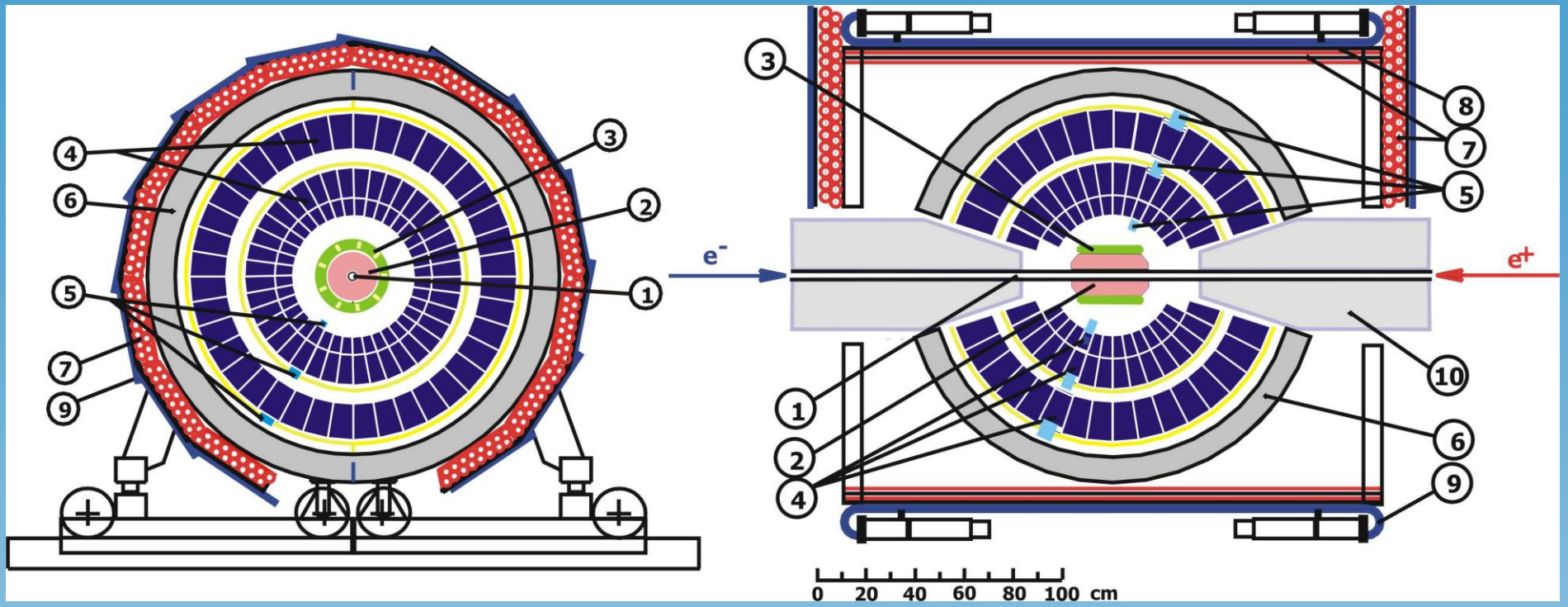
- new drift chamber with x2 better resolution
  - better tracking
- thicker barrel calorimeter
  - $8X_0 \rightarrow 15X_0$
  - better separation
- LXe calorimeter
  - much better spatial resolution for γ's
  - -shower profile
- higher B field
  - better momentum resolution

CMD-3 is being moved to the interaction point at the time of this meeting.



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 – new version



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

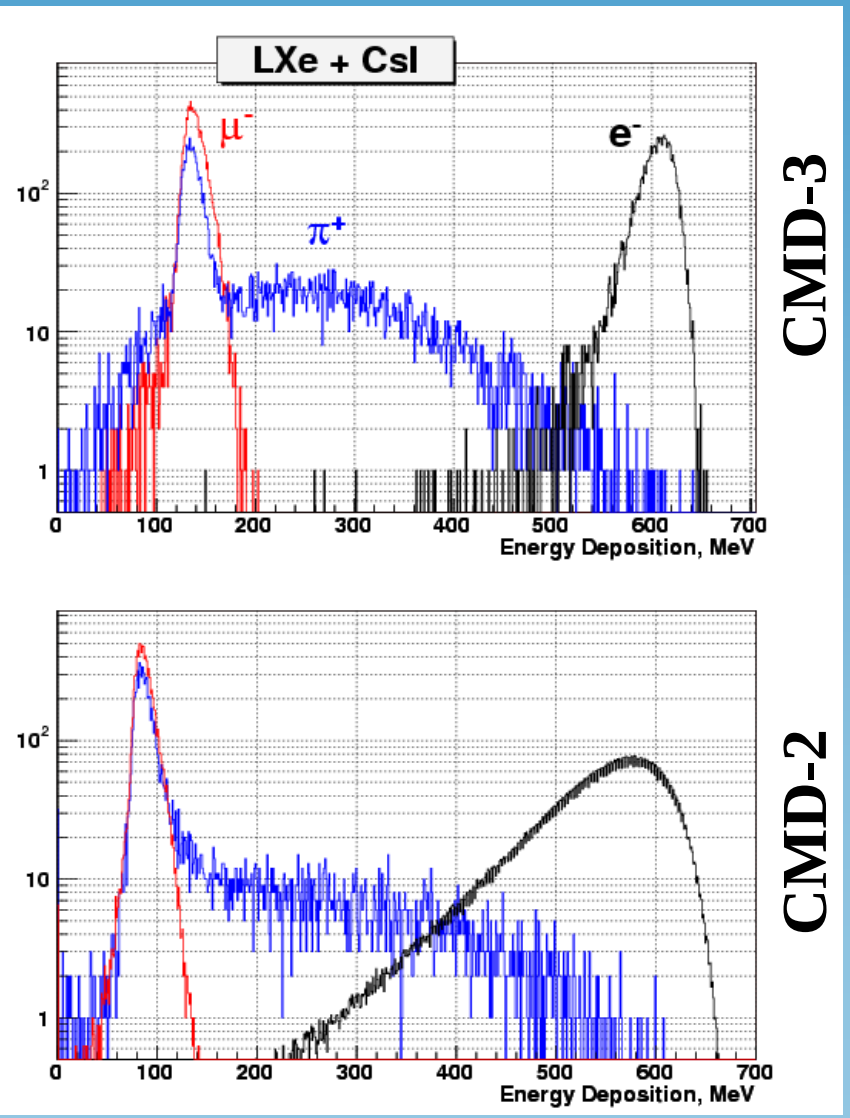
SND took first data in 2009 (around $\sqrt{s}$=1 GeV)

R measurement at VEPP-2M: systematic errors

Source of error	CMD2, 2pi $\sqrt{s}<1$ GeV	SND, 2pi $\sqrt{s}<1$ GeV	CMD2, 4pi $\sqrt{s}>1.1$ GeV
Event separation	0.2-0.4%	0.5%	2% (cuts)
Fiducial volume	0.2%	0.8%	3% (model)
Energy calibration	0.1-0.3%	0.3%	1%
Efficiency correction	0.2%-0.5%	0.6%	2% (tr+bg)
Pion losses (decay, NI)	0.2%	0.2%	
Other	0.2%	0.5%	2%
Radiative corrections	0.3-0.4%	0.2%	1%
Total syst.	0.6-0.8%	1.3%	5%
Stat.+Syst.	0.7%	1.5%	7%

Improvements: particle identification at CMD-3 with calorimeter

Energy deposition of $e/\mu/\pi$



The new CMD-3 barrel calorimeter should allow to significantly improve $e/\mu/\pi$ separation:

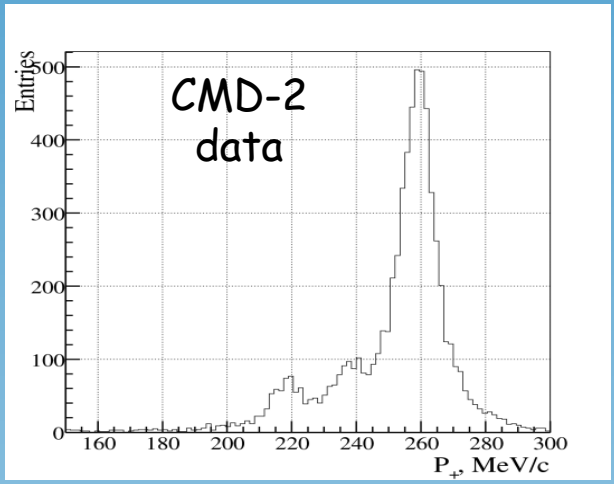
- in thicker calorimeter (LXe+CsI) energy deposition of the particles will be less alike - more robust π/e and π/μ separation

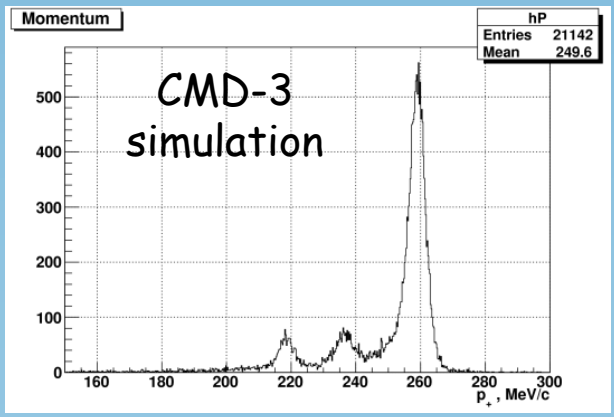
- ablity to measure energy deposition profile (7 layers in Lxe + 1 in CsI) should further improve identification

- ability to measure precisely the point of photon conversion with Lxe will be important for many applications: $\gamma\gamma$ luminosity, radiative processes, π^0 reconstruction

Improvements: particle identification at CMD-3 with drift chamber

Momenta distribution for ee->ee,μμ,ππ events at energy point √s = 0.52 GeV





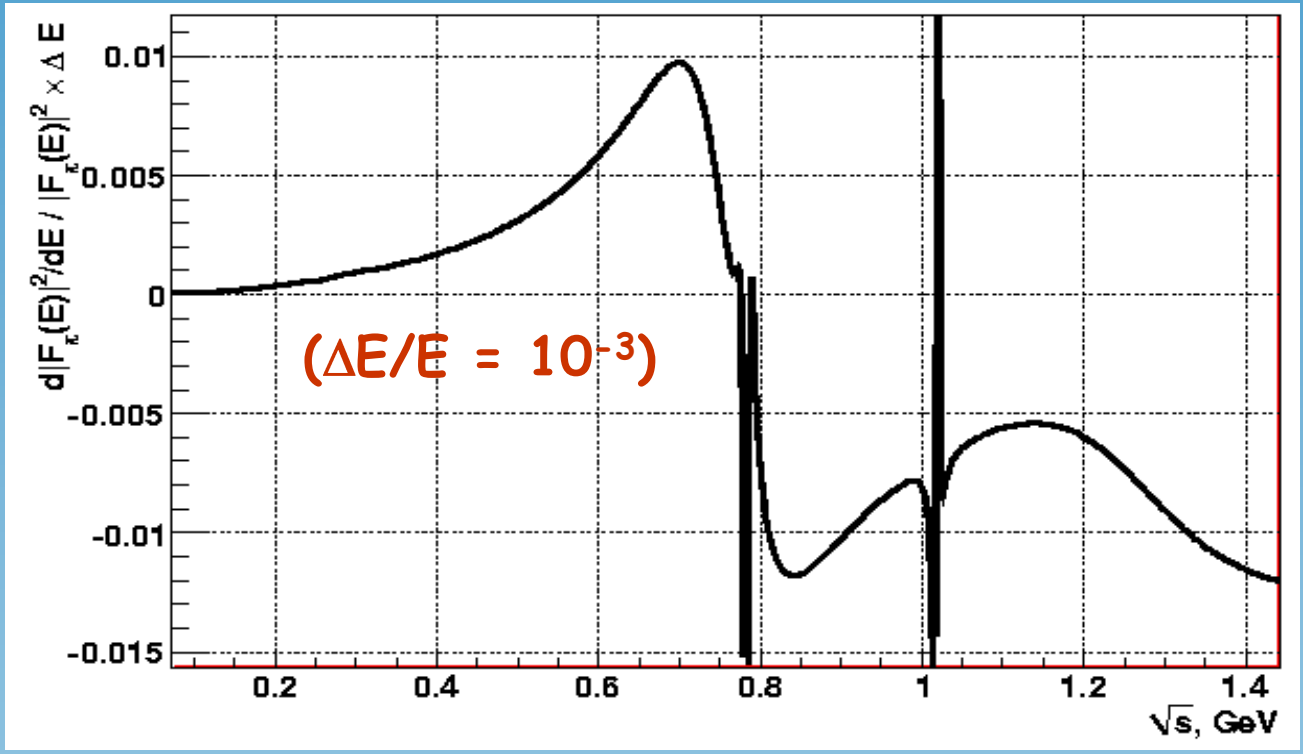
The new CMD-3 drift chamber and higher magnetic field (1.0 T -> 1.3 T) should allow to improve e/μ/π separation at low energies:

- with factor of 2 better resolution we expect to be able to use e/μ/π separation by momentum up to √s ≈ 0.65 GeV (was 0.52 GeV at CMD-2)

- uniform structure of the drift chamber will reduce reconstruction inefficiencies

Energy determination at VEPP-2000

Systematic shift of pion formactor in case of energy miscalibration by 0.1%



Two approaches to determine/stabilize energy at VEPP-2000 by 10^{-4}:

- frequent calibration with resonant depolarization and constant monitoring of the field in collider magnets with 16 NMRs (nearly ready)
- constant monitoring of the beam energy with Compton scattering (in design)

Other improvements

- New trigger and DAQ electronics (CMD-3 and SND)

  - fast DAQ -> ability to use softer trigger

  - sophisticated primary trigger (several independent triggers, all trigger arguments are added to the data stream) -> precise determination of trigger efficiency

- Fiducial volume

  no changes at CMD-3, improved at SND

- Radiative corrections

  Talk by G.Fedotovich

- Luminosity determination

  plan to use $\gamma\gamma$ in addition to traditional Bhabha

  expect systematic error 0.3-0.5% (was 1.2% at CMD-2)

- High statistics

  will make possible many systematic studies

What systematic error can be achieved for R measurement at CMD-3?

Source of error	CMD3, 2pi $\sqrt{s}$<1 GeV	CMD3, 4pi $\sqrt{s}$>1.1 GeV
Event separation	0.2%	1% (cuts)
Fiducial volume	0.2%	2% (model)
Energy calibration	0.1%	
Efficiency correction	0.1%	1% (tr+bg)
Pion losses (decay, NI)	0.1%	
Other		0.3% (свет.)
Radiative corrections	0.1%	1%
Total	**0.35%**	**2.5%**

ISR measurements at VEPP-2000

CMD-3 and SND plan to collect large amounts of data near the maximum available energy (2 GeV)

It will be useful if ISR measurement of R will be performed at VEPP-2000

- with project luminosity, statistics of ISR data at VEPP-2000 will be comparable to the VEPP-2M data
- many detector features will be the same for direct and ISR measurements

But CMD-3 and SND were not designed for ISR measurements, e.g. it is not clear if energy of the final state can be determined with necessary precision

It yet to be seen if ISR approach can be used at VEPP-2000

Conclusion

In 2009-2010, new VEPP-2000 machine will get to the running mode and detectors CMD-3 and SND will start to take data

New measurement of R with energy scan is one priority tasks for VEPP-2000

High luminosity of VEPP-2000, improved detectors and advances in calculation of the radiative corrections should allow to reach the low systematic error

The measurement will be preformed independently and concurrently at two detectors, CMD-3 and SND, providing important cross-check

With VEPP-2000 data, combined with ISR data from KLOE, Belle and Babar (and, possibly, tau decays data), we expect to reduce uncertainty of the hadronic contribution to muon anomalous magnetic moment to the level, needed by the planned new (g-2) experiment