Low energy e+e- cross section study

(applications to $(g-2)_\mu$ and light hadron spectroscopy)

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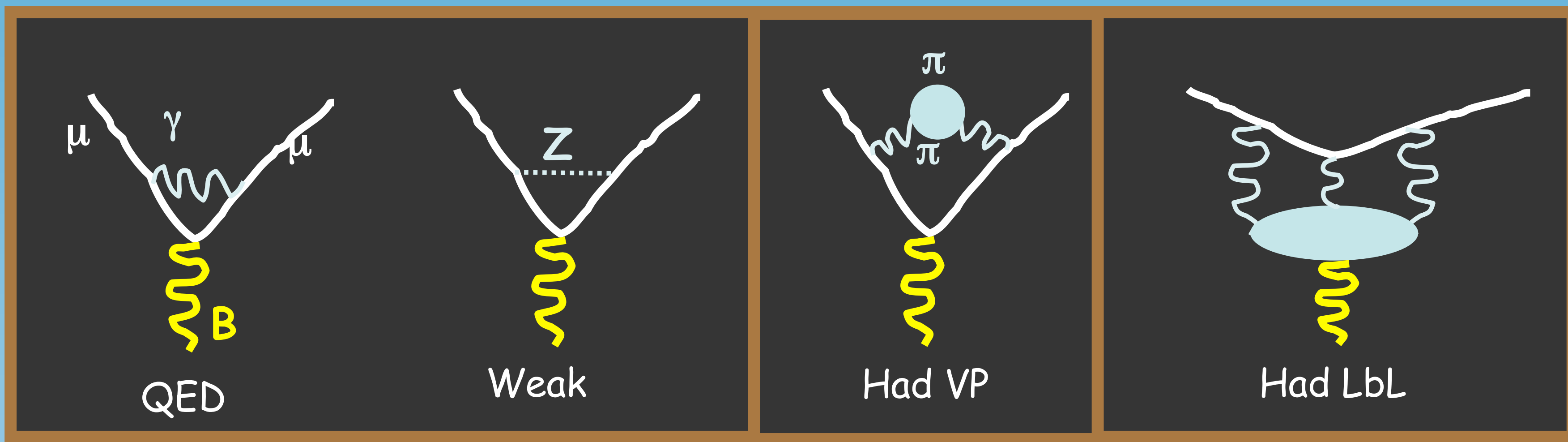
CMD-2(3) - BaBar

March, 2009

Outline

1. Motivation, $(g-2)_\mu$, some history
2. New results on $e^+e^- \to \pi^+\pi^-$ (2008, KLOE, BaBar)
3. Results on $e^+e^- \to$ hadrons, BaBar contribution
4. VEPP2000 project
5. Summary

$a_\mu = (g-2)/2$ is non-zero because of virtual loops, which can be calculated very precisely



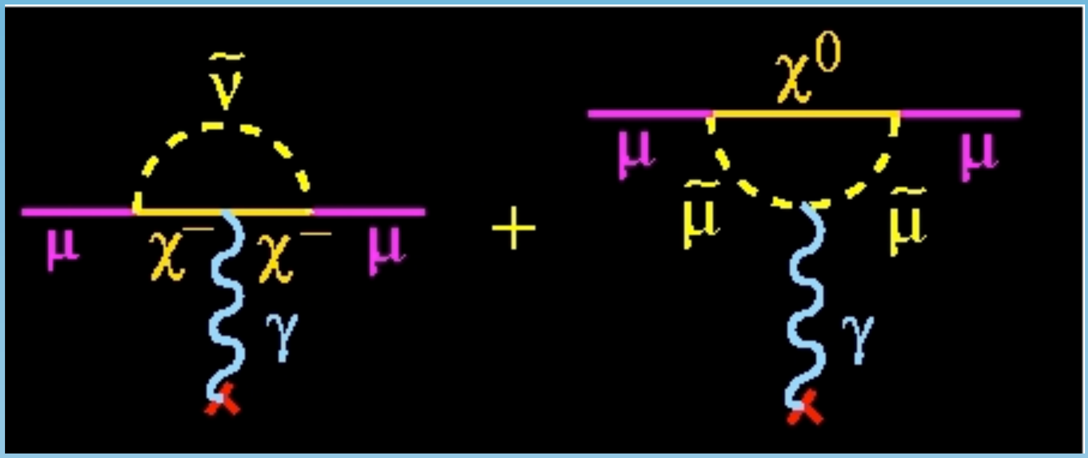
Known well

Theoretical work ongoing

Calculations can be compared with directly measured a_μ value performed by BNL E821 with $6.3\ 10^{-10}$ (0.54 ppm) accuracy.
The difference indicates new physics.

arXiv:0809.3085 Eduardo De Rafael (CPT)

SUSY: Muon g-2 is very sensitive through loops, which are amplified by tanβ



See full Topical Review: D. Stöckinger J.Phys. G34 (2007) R45-R92

Precise knowledge of a_μ will aid in discrimination between a wide variety of standard model extensions

- UED models (1D) typically predict “tiny” effects
  - Incompatible with a Δa_μ of ~ 300 x 10^{-11}
- SUSY models – there are many – predict a_μ contributions of about the observed magnitude for Δa_μ
- The “Uninvented” – perhaps most importantly, sets a stringent experimental constraint for any new models

SM For The Muonic $(g-2)_\mu$ (1995)

Contributions to the Standard Model (SM) Prediction:

$$a_\mu = \left(\frac{g-2}{2}\right)_\mu = a_\mu^{QED} + a_\mu^{had} + a_\mu^{weak}$$

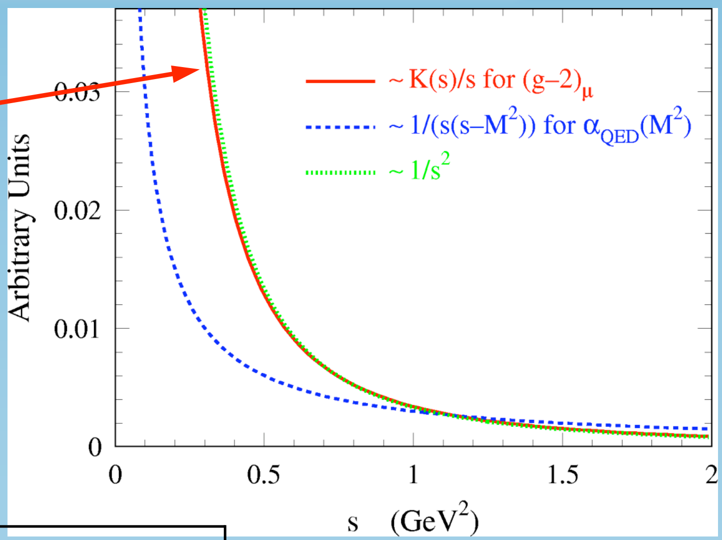
The Situation 1995

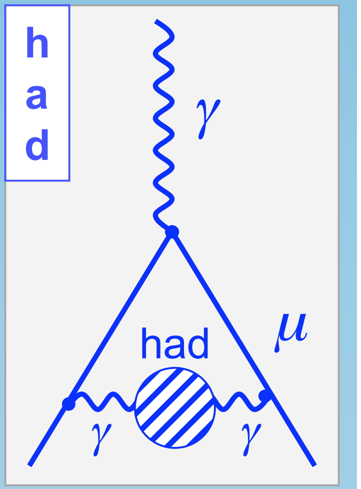
Source	$\sigma(a_\mu)$	Reference
QED	$\sim 0.3 \times 10^{-10}$	[Schwinger '48 & others]
Hadrons	$\sim (15 \oplus 4) \times 10^{-10}$	[Eidelman-Jegerlehner '95 & others]
***Z*, *W* exchange**	$\sim 0.4 \times 10^{-10}$	[Czarnecki *et al.* '95 & others]

Dominant uncertainty from lowest order hadronic piece. Cannot be calculated from QCD ("first principles") – but: we can use experiment (!)

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

From dispersion relations





a_μ [exp] – a_μ [SM] ~ 1 „standard deviations"

Idea to use τ-data to improve accuracy

R, 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 most fundamental quantities in high energy physics:

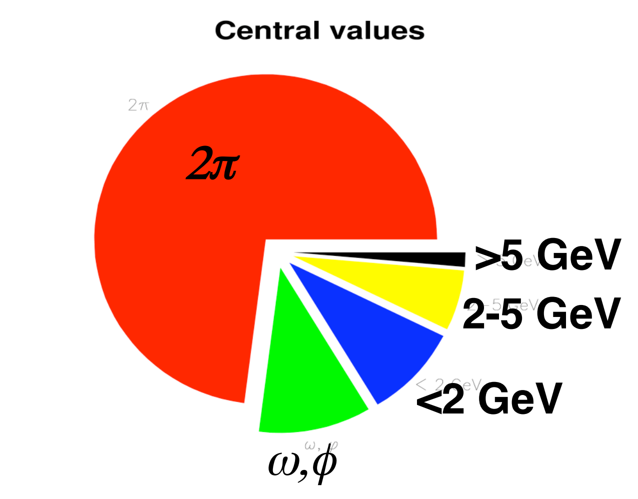
• its global structure reflects number of quarks and their colors; used for QCD tests and as a source of QCD parameters

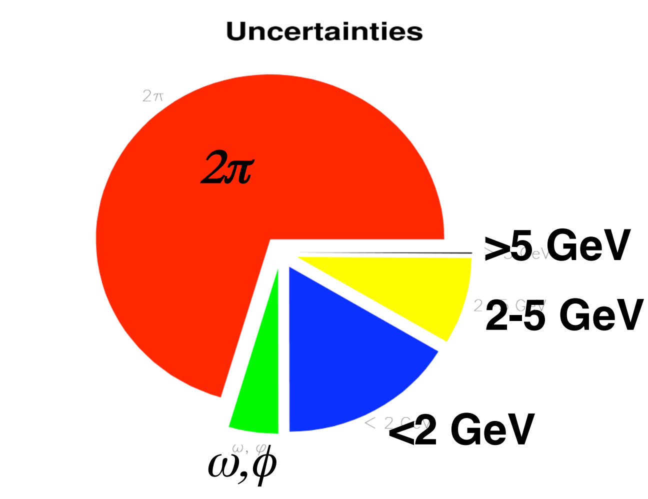
• plays special role in precision measurements:

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

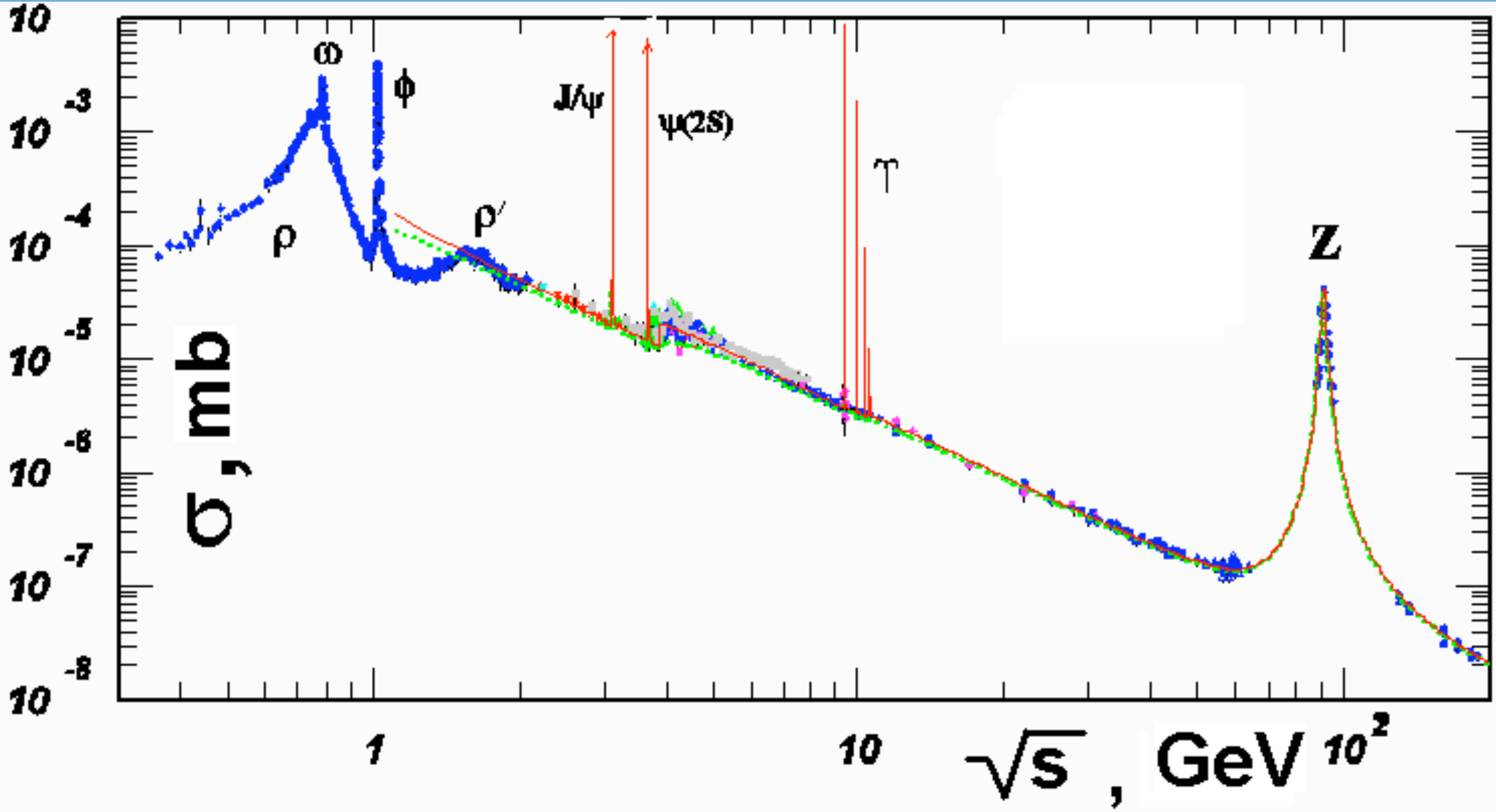
$$\Delta\alpha_{had}(M_Z^2) = -\frac{\alpha(0)M_Z^2}{3\pi} \mathrm{Re} \int_{4m_\pi^2}^{\infty} ds \frac{R(s)}{s(s-M_Z^2)-i\varepsilon}$$

$\alpha_\mu^{had}(l.o.)$

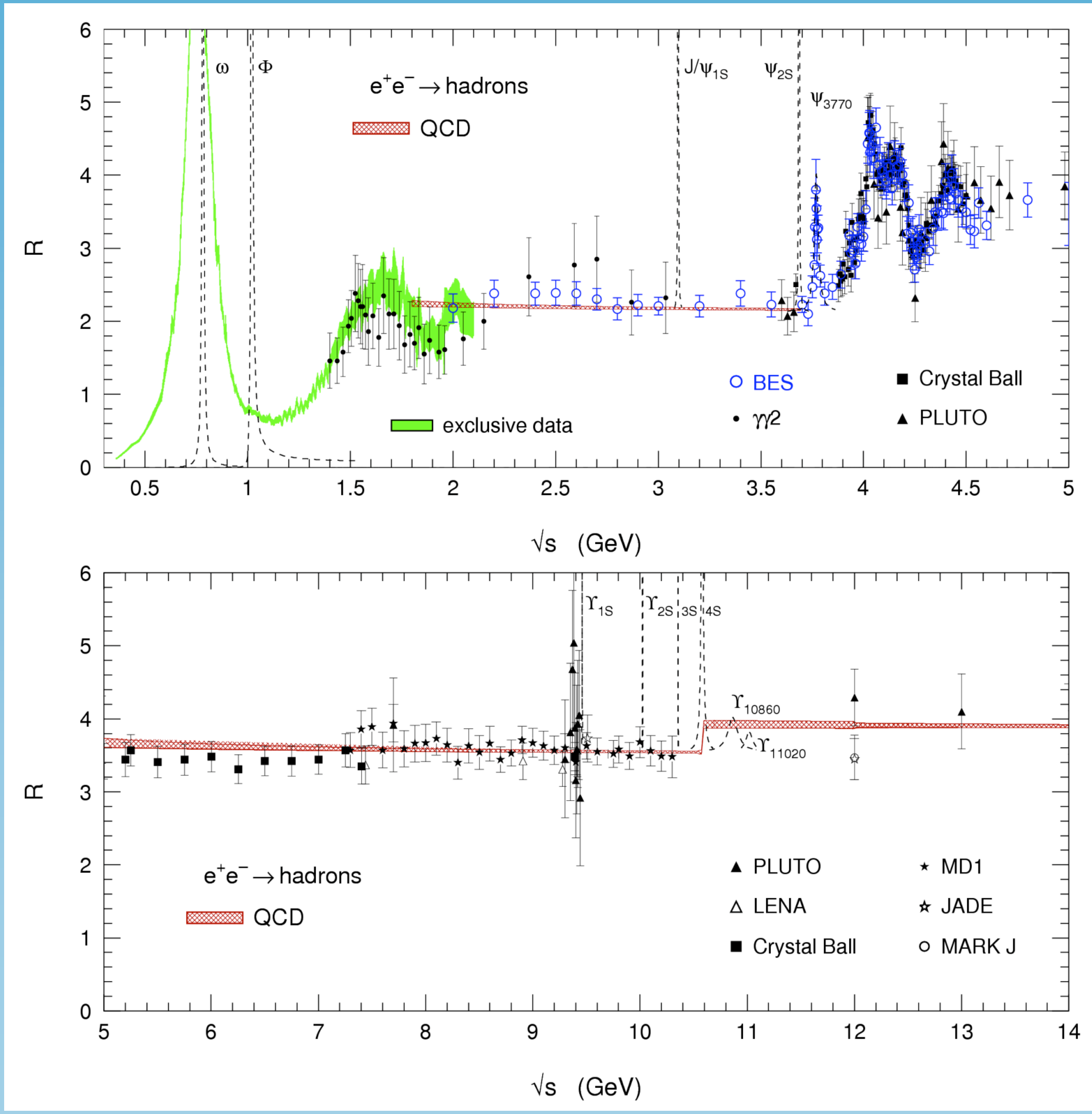




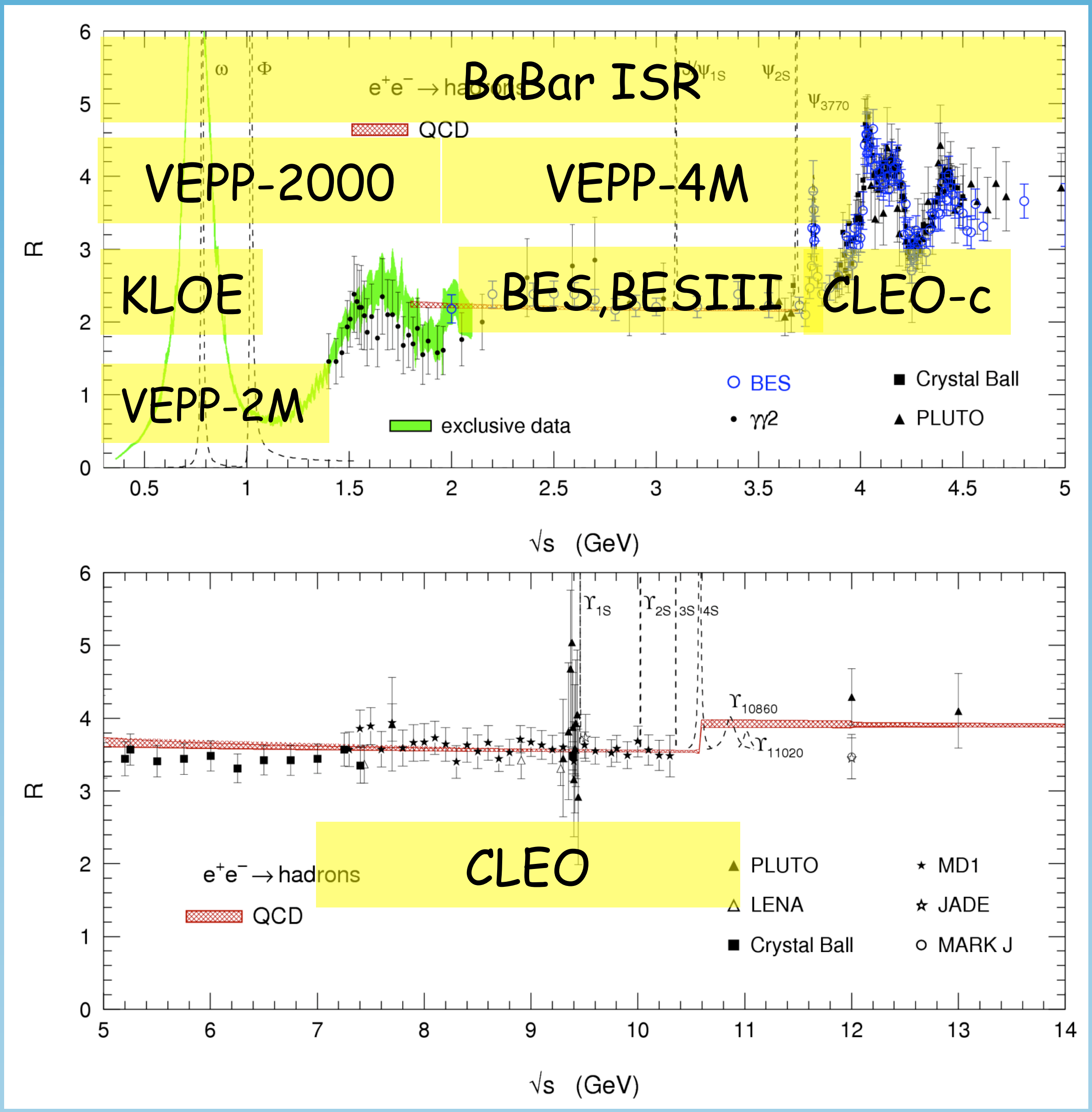
Cross section $e^+e^- \to$ hadrons



R from experiment and QCD



Current/Future activities in R



New calculations in 2006

New data are available from VEPP-2M - published!

$\pi^+\pi^-$ from CMD-2

- 96' data 350-520 MeV syst err = 0.7%
- 97' data 1030-1380 MeV 0.6-0.8%
- 98' data 600-980 MeV 1.2-4.2% 9 10^5 evts
- good agreement with published 94-95' CMD-2 data and SND
- more data from CMD-2 and SND for other hadronic channels

multihadron cross sections from BaBar

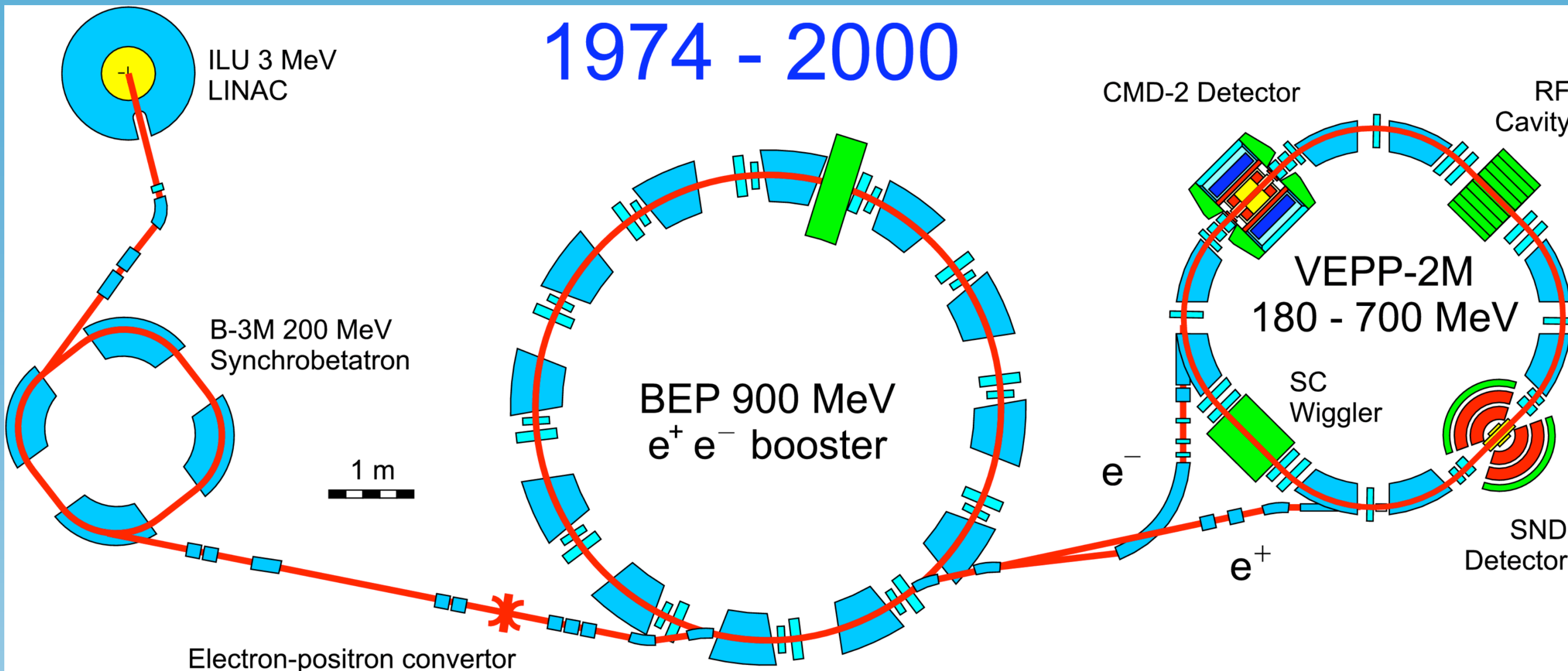
- new data significantly improves accuracy of a_μ^{had}

  smaller systematic error

  consistent treatment of radiative corrections

  ⇒ much smaller syst error on rad.corr.

Measurement of R in Novosibirsk



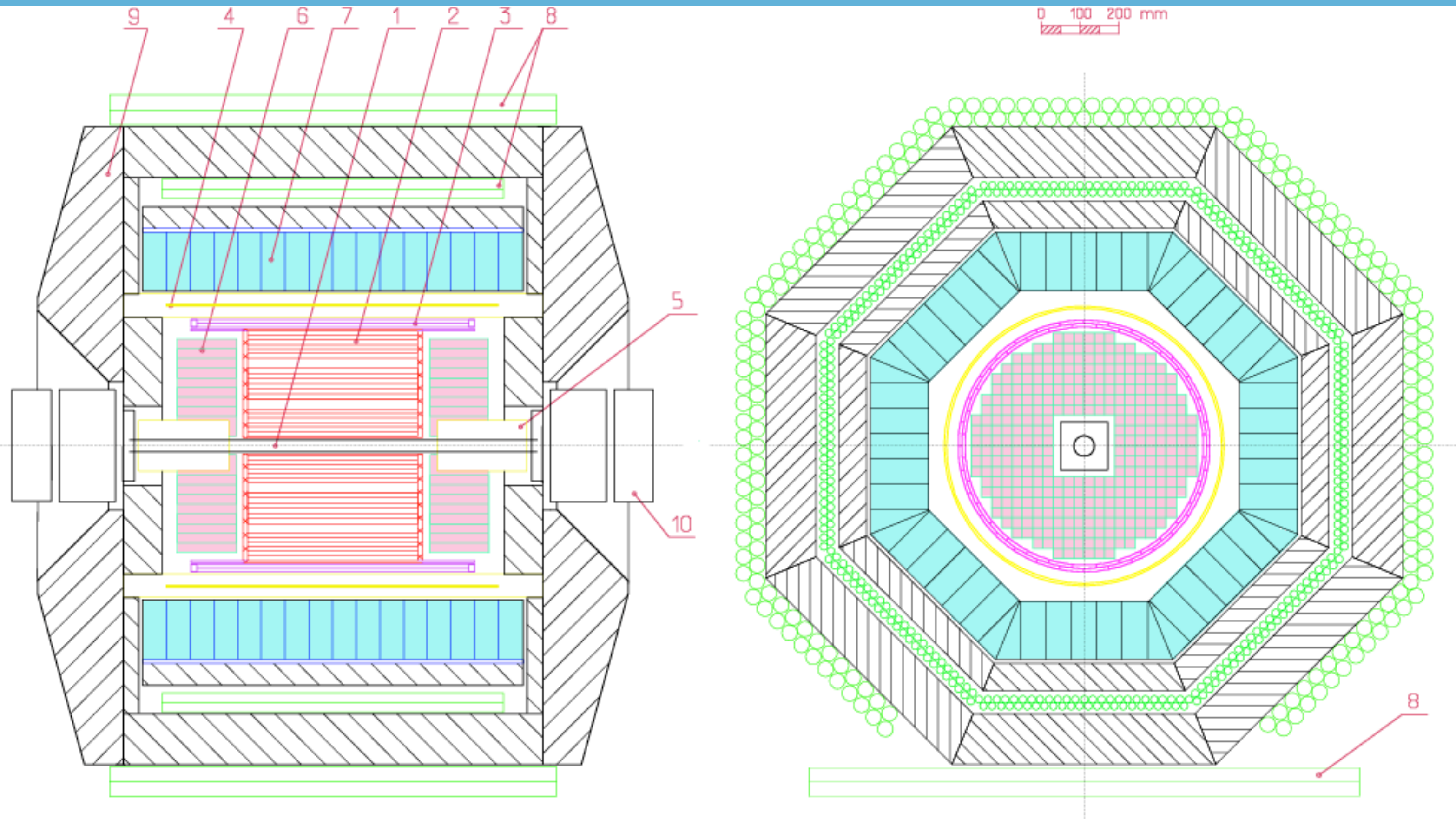
- VEPP-2M collider: 0.36-1.4 GeV in c.m., $L \approx 3 \cdot 10^{30}$ 1/cm^{2}s at 1 GeV
- Detectors CMD-2 and SND: ≈ 60 pb^{-1} collected in 1993-2000
- All major hadronic modes are measured:

$e^+e^- \rightarrow 2\pi, 3\pi, 4\pi, KK, ..$

$e^+e^- \rightarrow \rho, \omega, \phi$

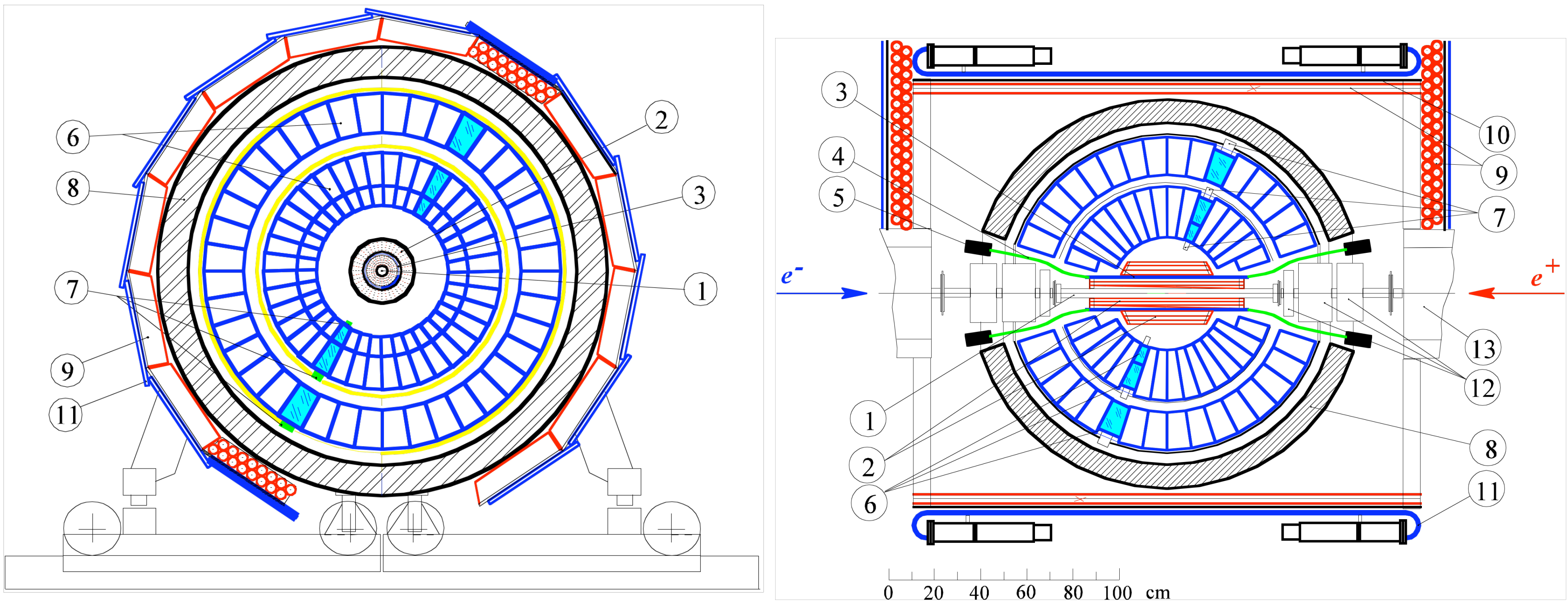
Still a lot of data to analyze !

CMD-2 detector



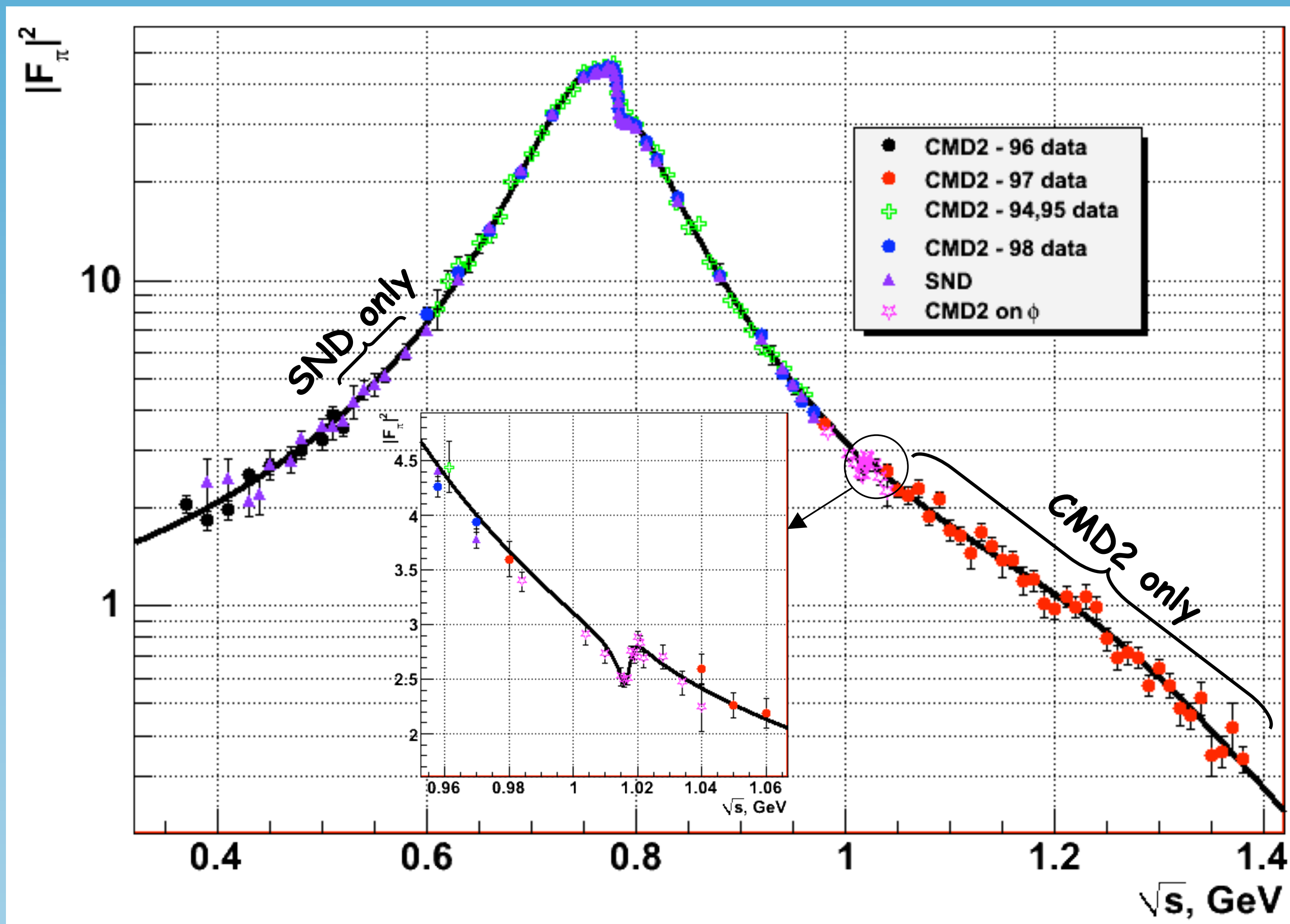
1 - vacuum chamber
2 - drift chamber
3 - **Z**-chamber
4 - main solenoid
5 - compensating magnet
6 - **BGO** endcap calorimeter
7 - **CsI** barrel calorimeter
8 - muon range system
9 - iron yoke
10 - storage ring lenses

SND detector



1 - beam pipe, 2 - drift chambers, 3 - coincidence counter, 4 - fibre light guide, 5 - PMTs, 6 - NaI(Tl) crystals, 7 – phototriodes, 8 - iron absorber, 9 - muon tubes, 10 - 1cm iron plate, 11 - muon counters, 12 - magnetic lenses, 13 - bending magnets

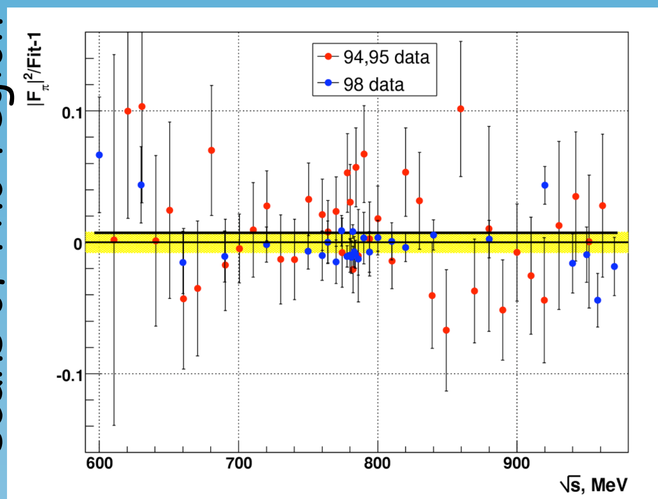
Pion formfactor - results



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

Internal Cross-checks

CMD2, 2 independent scans of rho-region



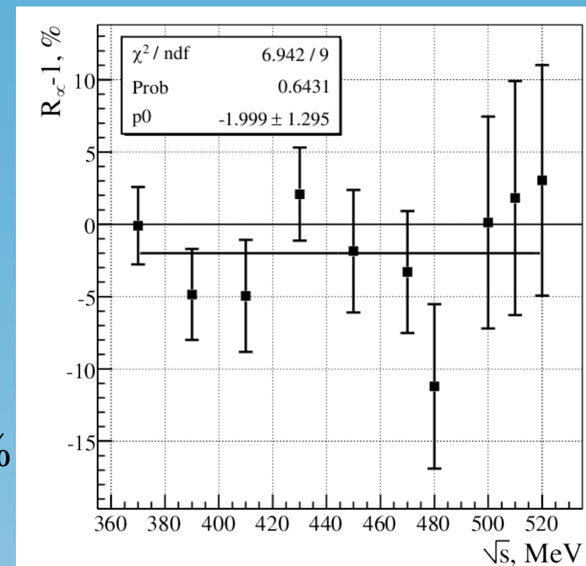
Δ(95-98)≈0.7%±0.5%

CMD2

√ s<0.52 GeV

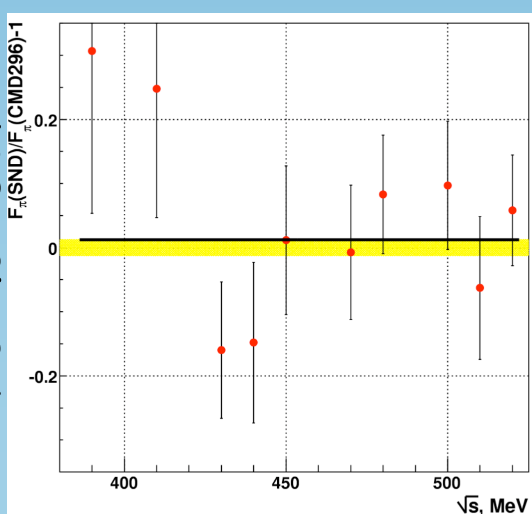
$$\frac{\sigma_{\mu\mu}(meas)}{\sigma_{\mu\mu}(QED)} - 1$$

$$(-2.0 \pm 1.3 \pm 0.7)\%$$



CMD2 vs SND

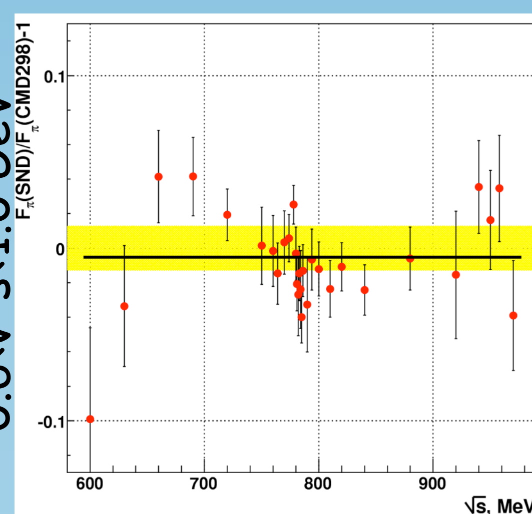
√ s<0.52 GeV



Δ(SND-CMD2)≈1.2%±3.6%

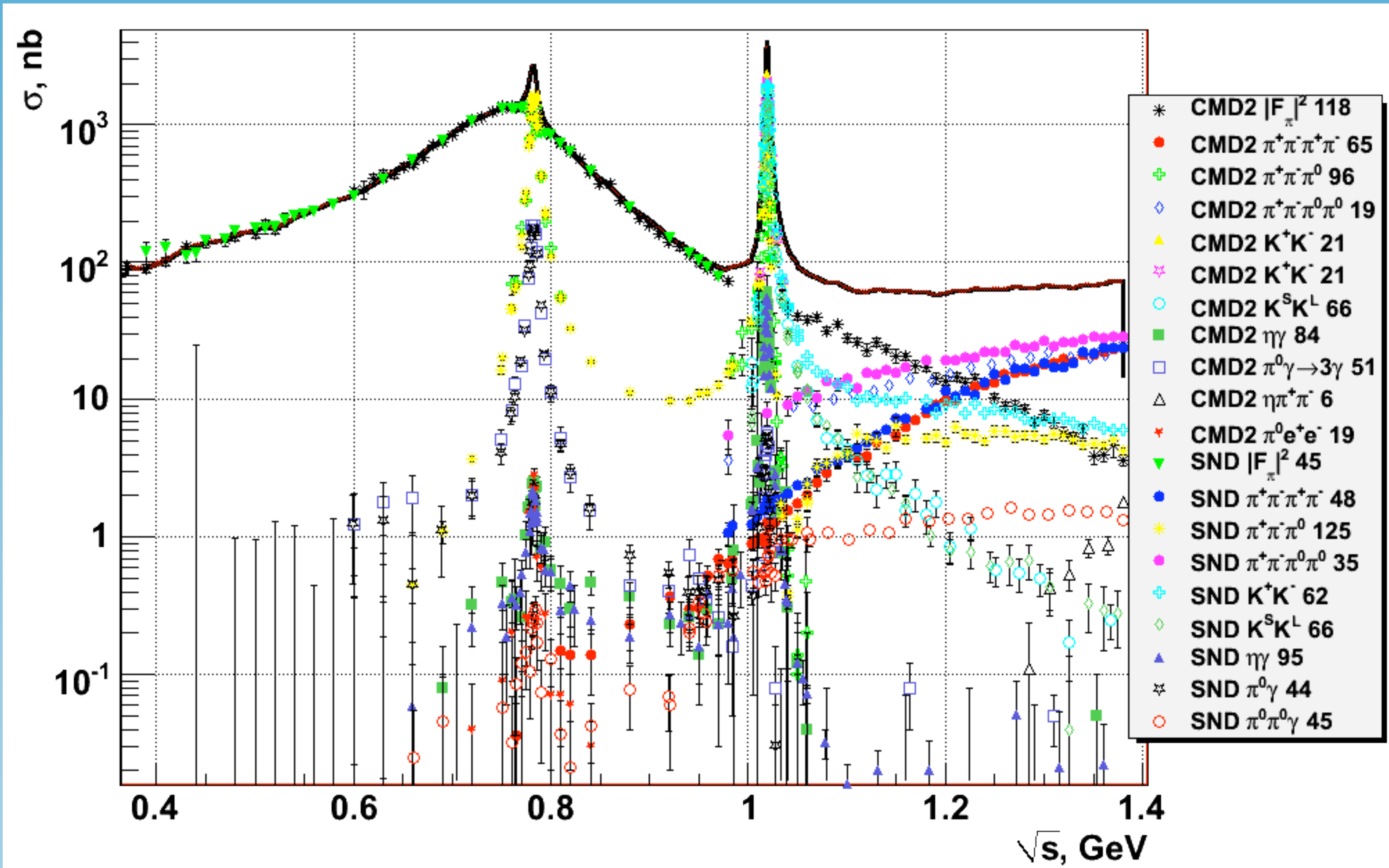
CMD2 vs SND

0.6<√ s<1.0 GeV



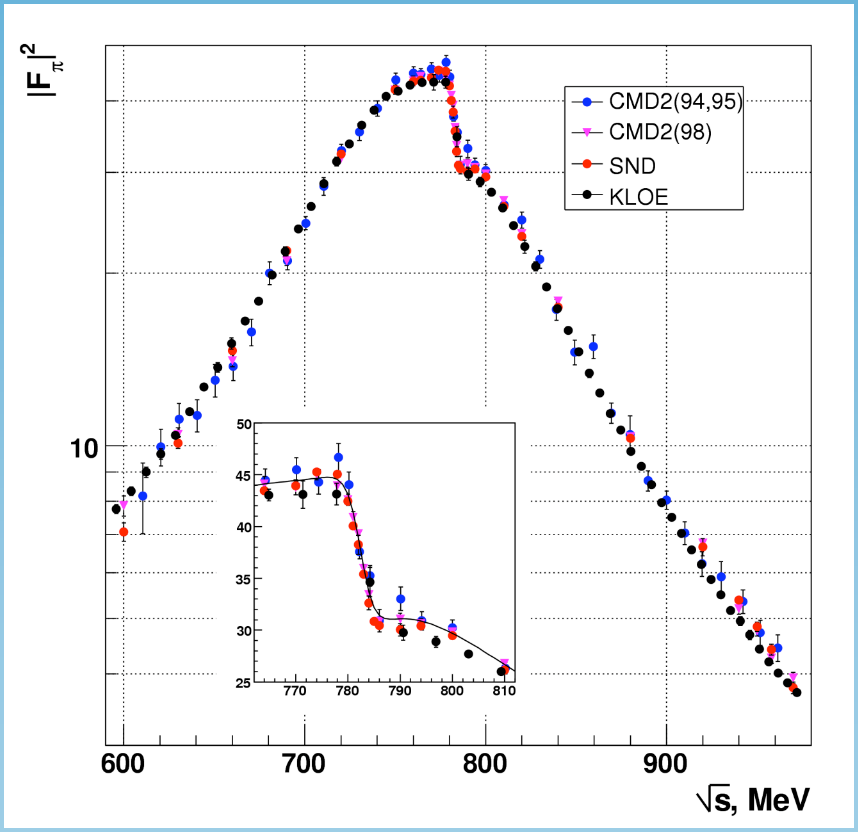
Δ(SND-CMD2)≈-0.53%±0.34%

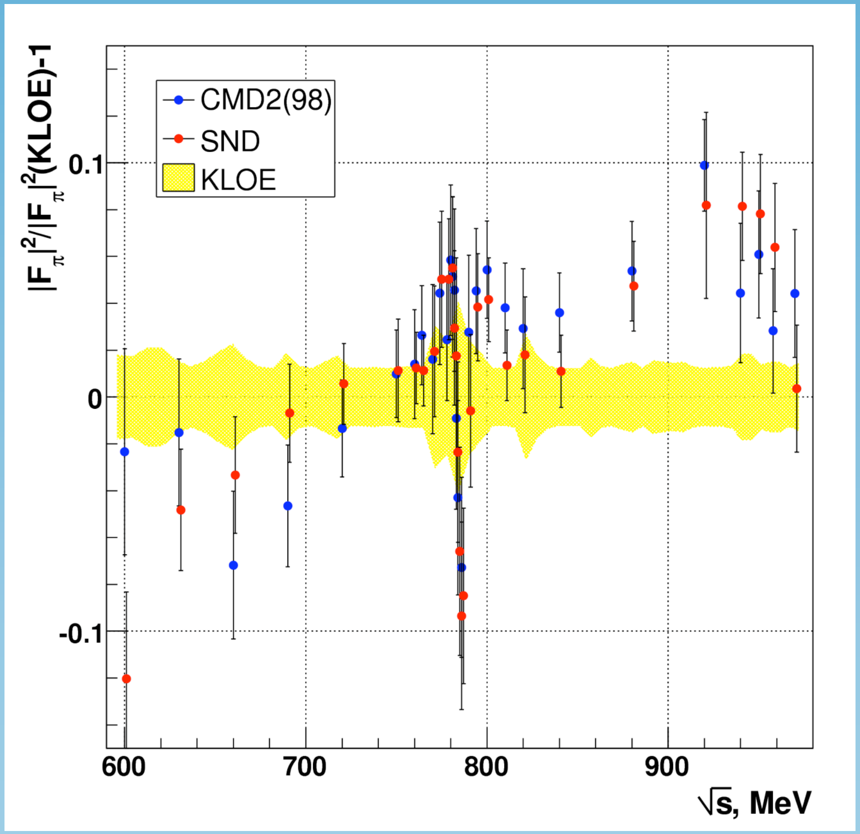
Overview of the results



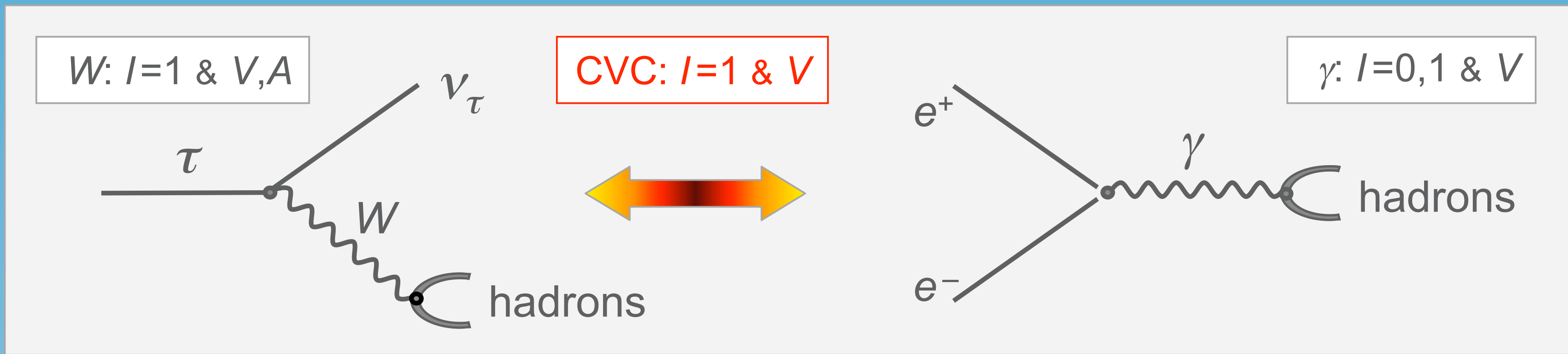
Comparison with KLOE (2005)

KLOE studied $e^+e^- \to \pi+\pi- \gamma$ working at DAFNE ϕ-factory - first ISR experiment





The Role of τ Data through CVC – SU(2)



Hadronic physics factorizes in Spectral Functions :

Isospin symmetry connects I=1 e^+e^- cross section to vector τ spectral functions:

$$\sigma^{(I=1)}\left[e^+e^- \to \pi^+\pi^-\right] = \frac{4\pi\alpha^2}{s}\,\upsilon\left[\tau^- \to \pi^-\pi^0\nu_\tau\right]$$

fundamental ingredient relating long distance (resonances) to short distance description (QCD)

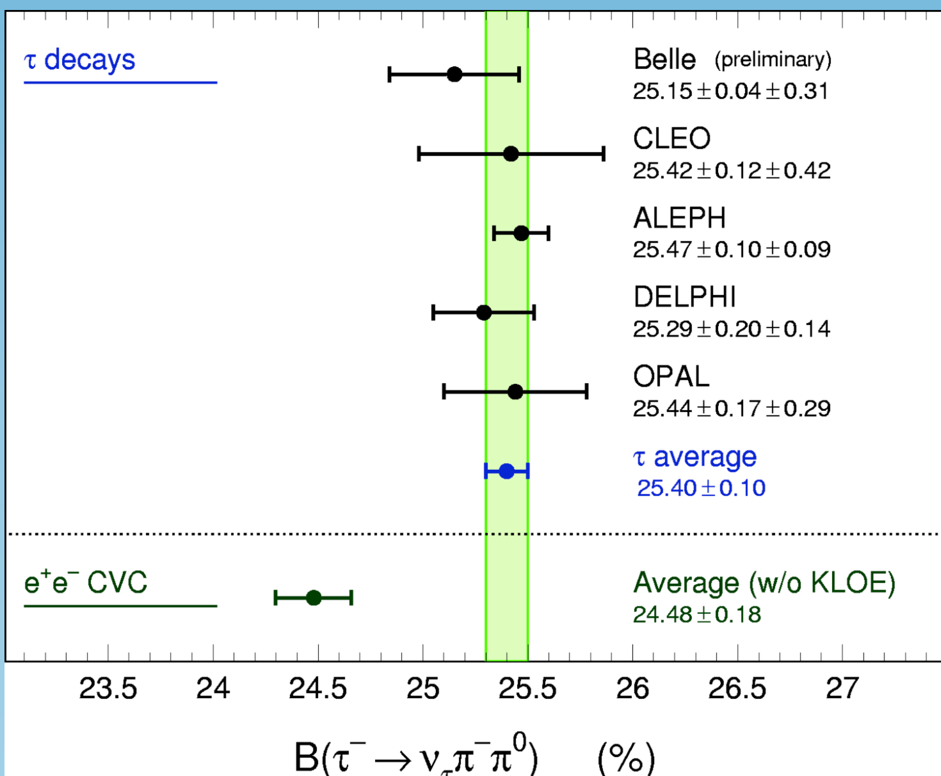
$$\upsilon\left[\tau^- \to \pi^-\pi^0\nu_\tau\right] \propto \frac{BR\left[\tau^- \to \pi^-\pi^0\nu_\tau\right]}{BR\left[\tau^- \to e^-\bar{\nu}_e\nu_\tau\right]}\;\frac{1}{N_{\pi\pi^0}}\frac{dN_{\pi\pi^0}}{ds}\;\frac{m_\tau^2}{\left(1-s/m_\tau^2\right)^2\left(1+s/m_\tau^2\right)}$$

branching fractions — mass spectrum — kinematic factor (PS)

Testing CVC with one number

Infer τ branching fractions (more robust than spectral functions) from e^+e^- data:

$$\mathrm{BR}_{\mathrm{CVC}}\left(\tau^- \to \pi^-\pi^0\nu_\tau\right) = \frac{6\pi\,|V_{ud}|^2\,S_{EW}}{m_\tau^2}\int_0^{m_\tau^2} ds\ \mathrm{kin}(s)\cdot \upsilon^{\mathrm{SU(2)\text{-}corrected}}(s)$$

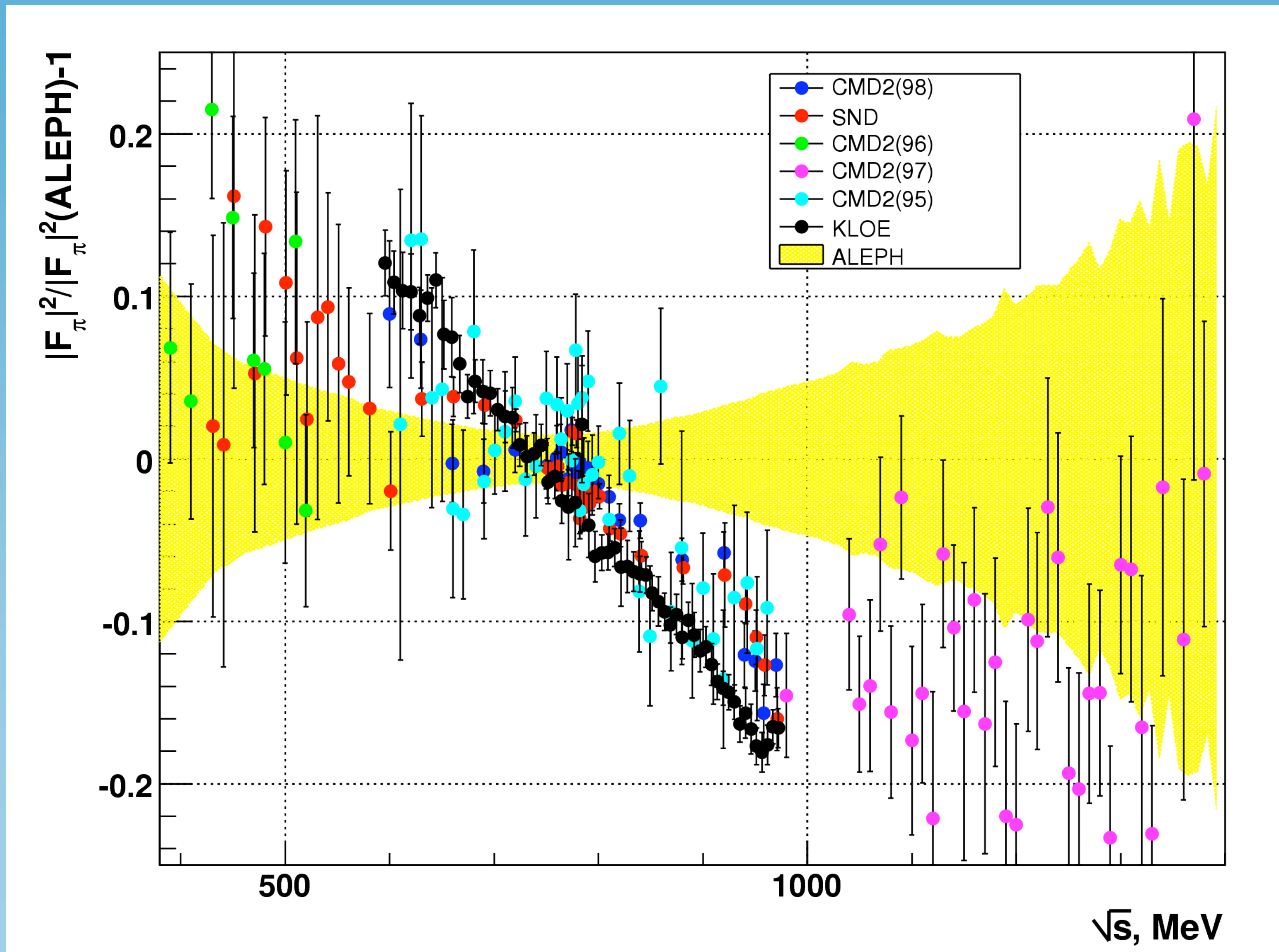


Difference: BR[τ] – BR[e^+e^- (CVC)]:

Mode	$\Delta(\tau - e^+e^-)$	„Sigma“
$\tau^- \to \pi^-\pi^0\nu_\tau$	$+0.92 \pm 0.21$	4.5
$\tau^- \to \pi^-3\pi^0\nu_\tau$	-0.08 ± 0.11	0.7
$\tau^- \to 2\pi^-\pi^+\pi^0\nu_\tau$	$+0.91 \pm 0.25$	3.6

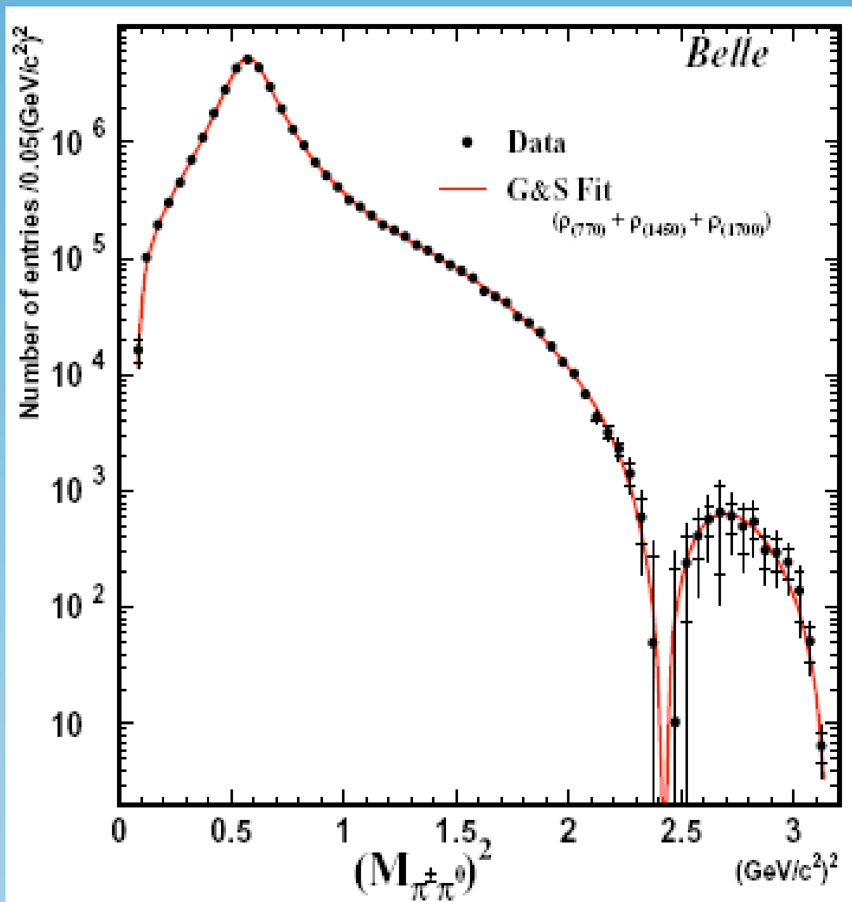
ee data on $\pi^-\pi^+\pi^0\pi^0$ not satisfactory

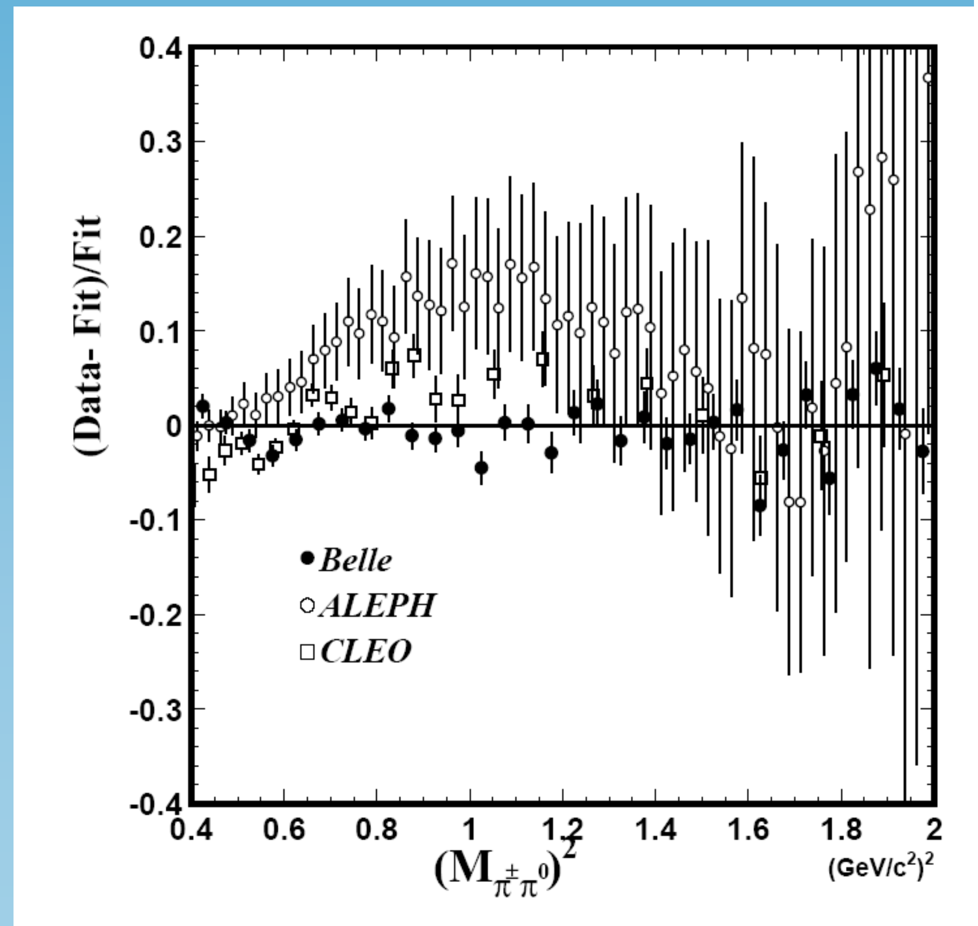
Comparison with ALEPH ($\tau \to \pi\pi^0\nu$)



Belle analysis of tau decays

Pion formfactor, calculated from the spectral function of $\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$ decay





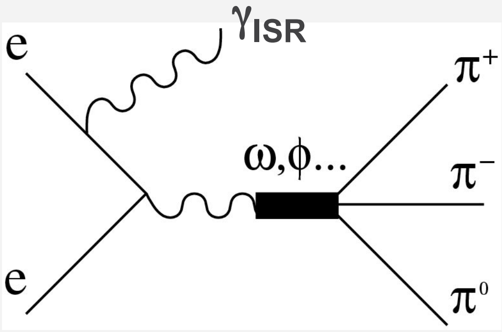
EPS2005 Proceedings – hep-ex/0512071

BaBar R measurement program using ISR

Other exclusive channels: BaBar ISR

- systematic program underway using ISR from Υ(4S) energies, taking advantage of high luminosity (B-factory)
- statistics comparable to CMD-2/SND for E_{cm}<1.4 GeV, much better than DM1/DM2 above
- full energy range covered at the same time

$X = 2E_\gamma / E_{cm}$

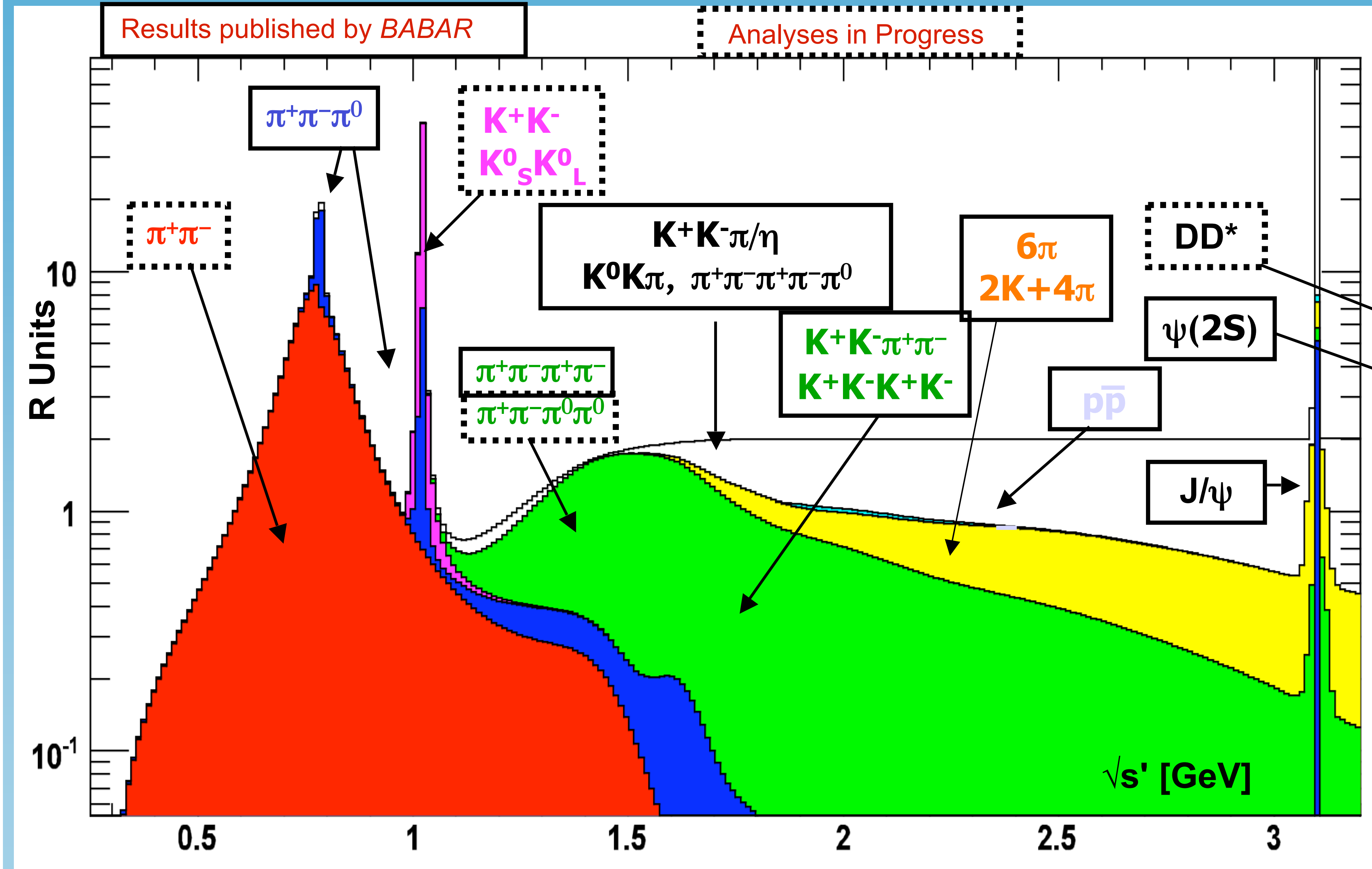


$$\frac{d\sigma(s,x)}{dx\,d(\cos\theta)} = H(s,x,\theta)\cdot\ \sigma_0(s(1-x))$$

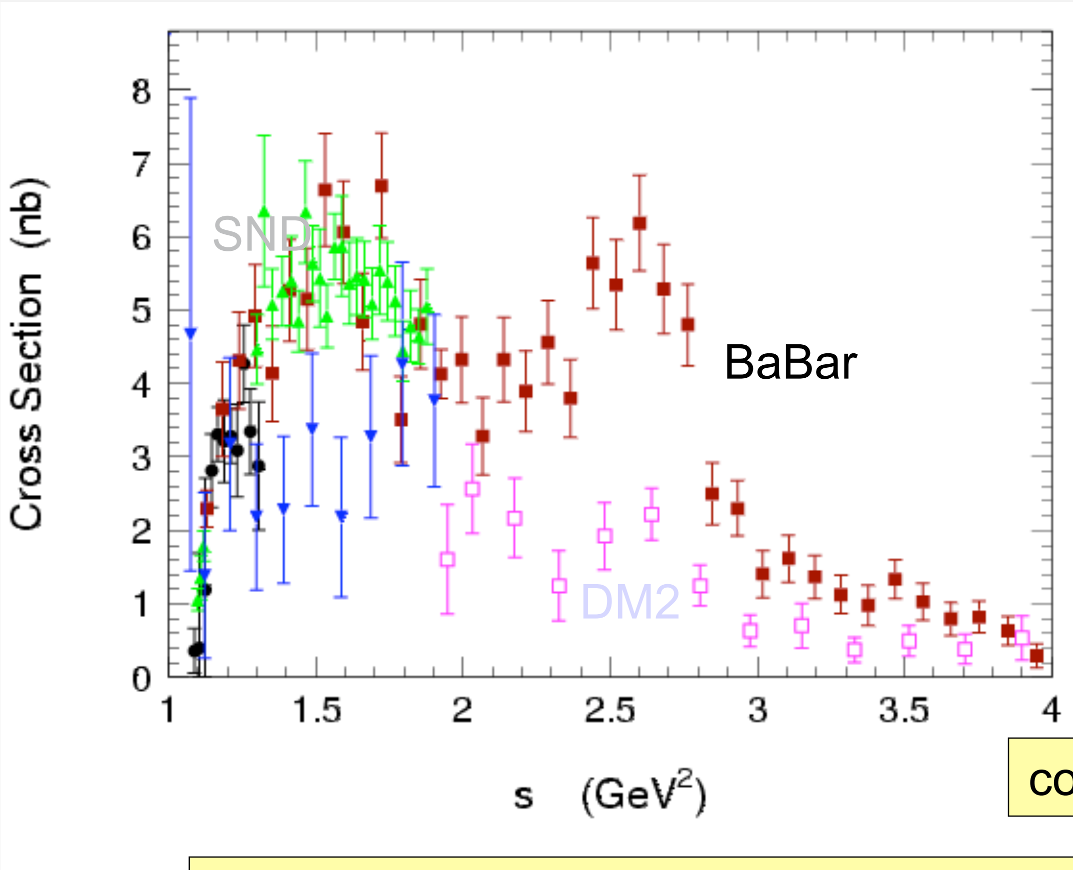
$$H(s,x,\theta) = \frac{\alpha}{\pi x}\left(\frac{2-2x+x^2}{\sin^2\theta} - \frac{x^2}{2}\right),\quad x = \frac{2E_\gamma}{\sqrt{s}}$$

H is radiation function

Build R from Sum Over Exclusive Final States (MC)



BaBar ISR: $\pi^+\pi^-\pi^0$



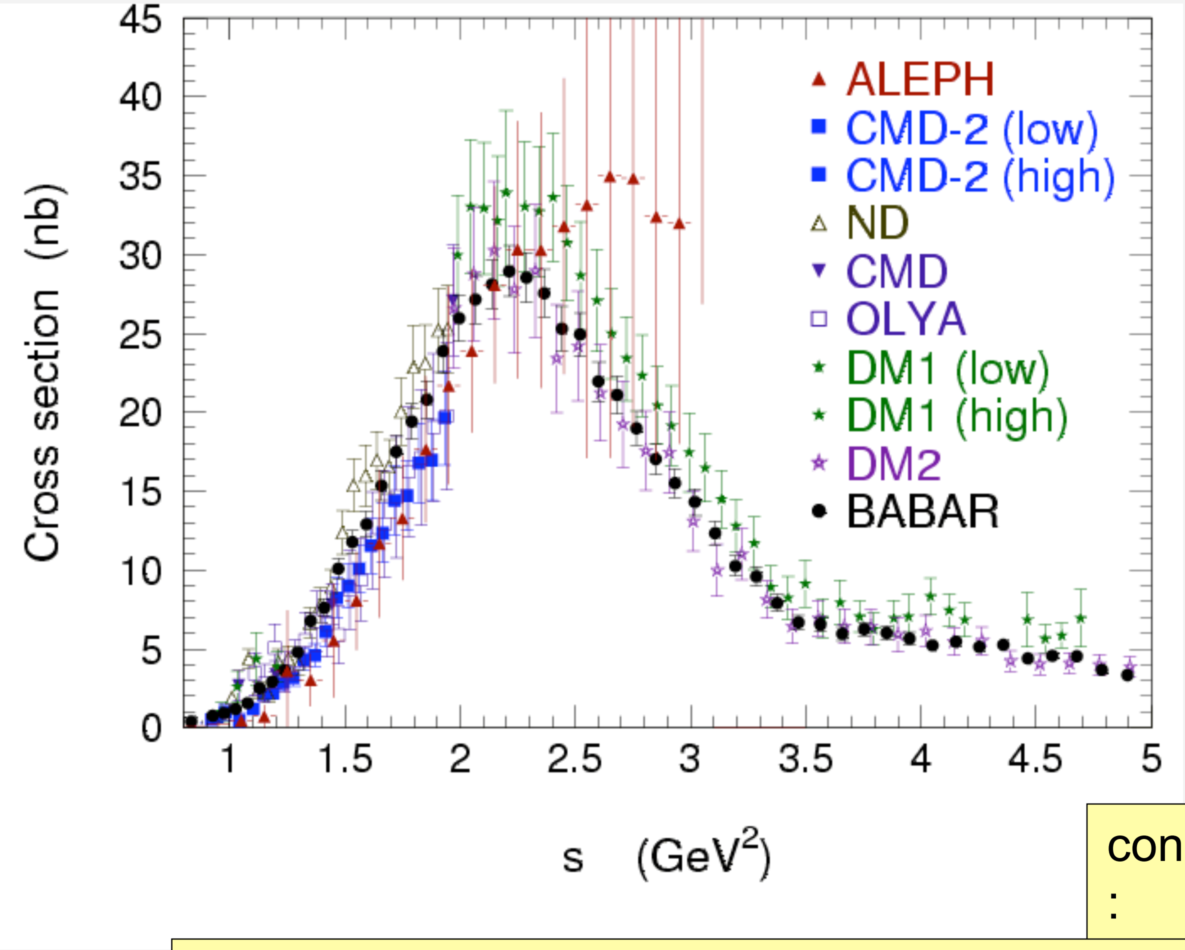
huge discrepancy with DM2

contribution to a_μ^{had} (1.05-1.8 GeV) :

• all before BaBar	2.45 ± 0.26 ± 0.03
• all + BaBar	2.79 ± 0.19 ± 0.01
• all – DM2 + BaBar	3.25 ± 0.09 ± 0.01

$\times 10^{-10}$

BaBar ISR: $2\pi^+2\pi^-$



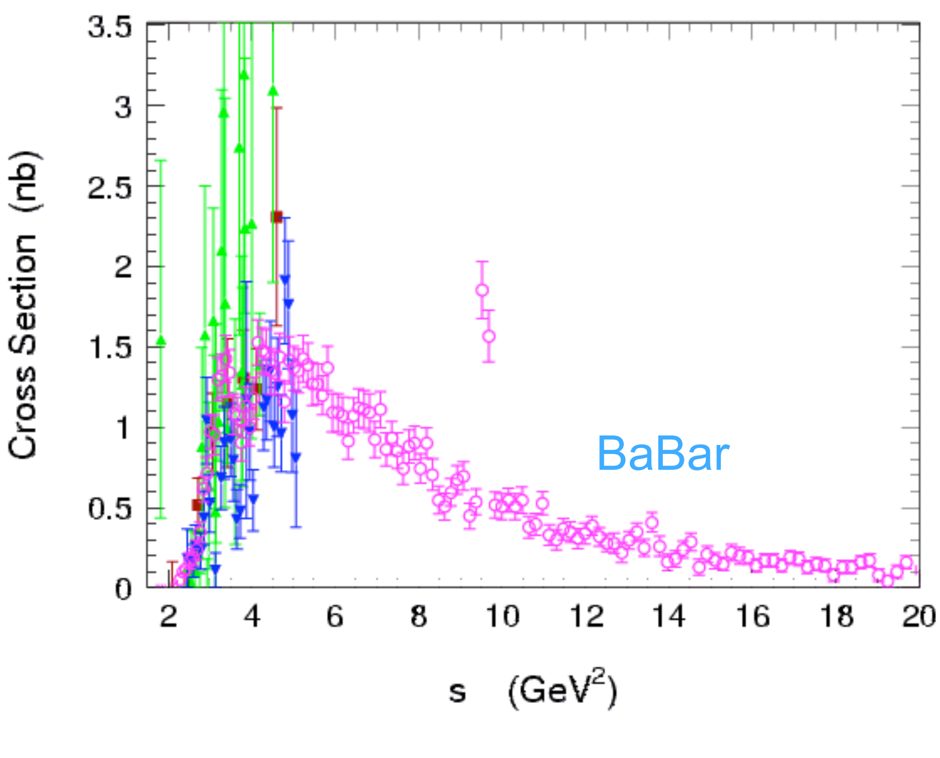
contribution to a_μ^{had} (<1.8 GeV) :

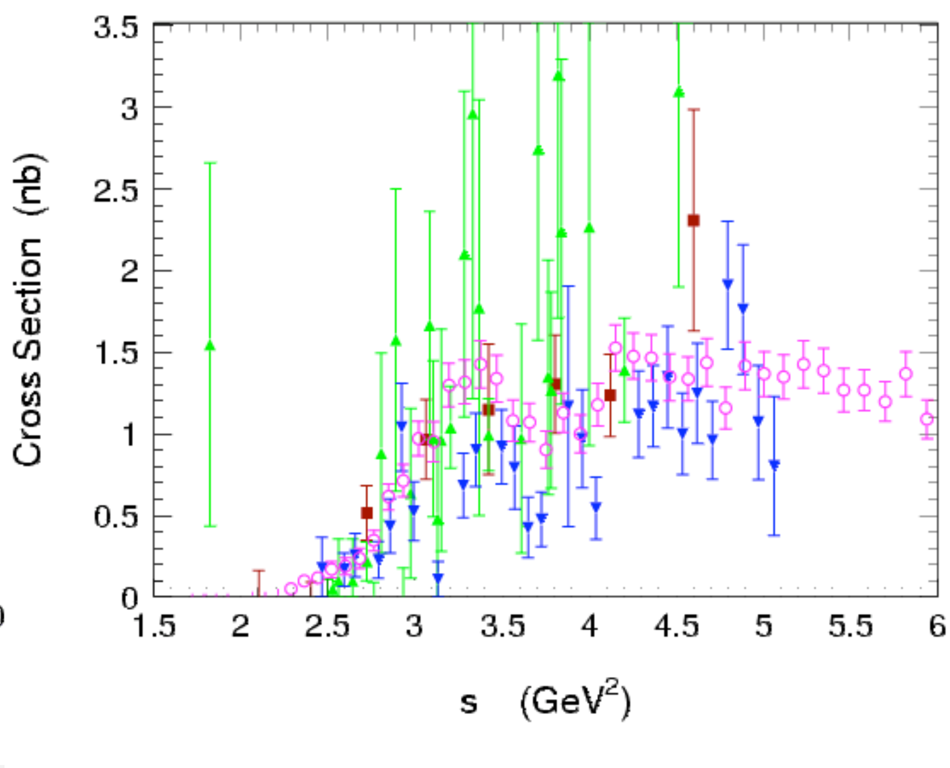
• all before BaBar	14.20 ± 0.87 ± 0.24
• all + BaBar	13.09 ± 0.44 ± 0.00

$\times 10^{-10}$

Waiting for a similar results from $\pi^+\pi^-\pi^0\pi^0$ mode !

BaBar ISR: $3\pi^+3\pi^-$



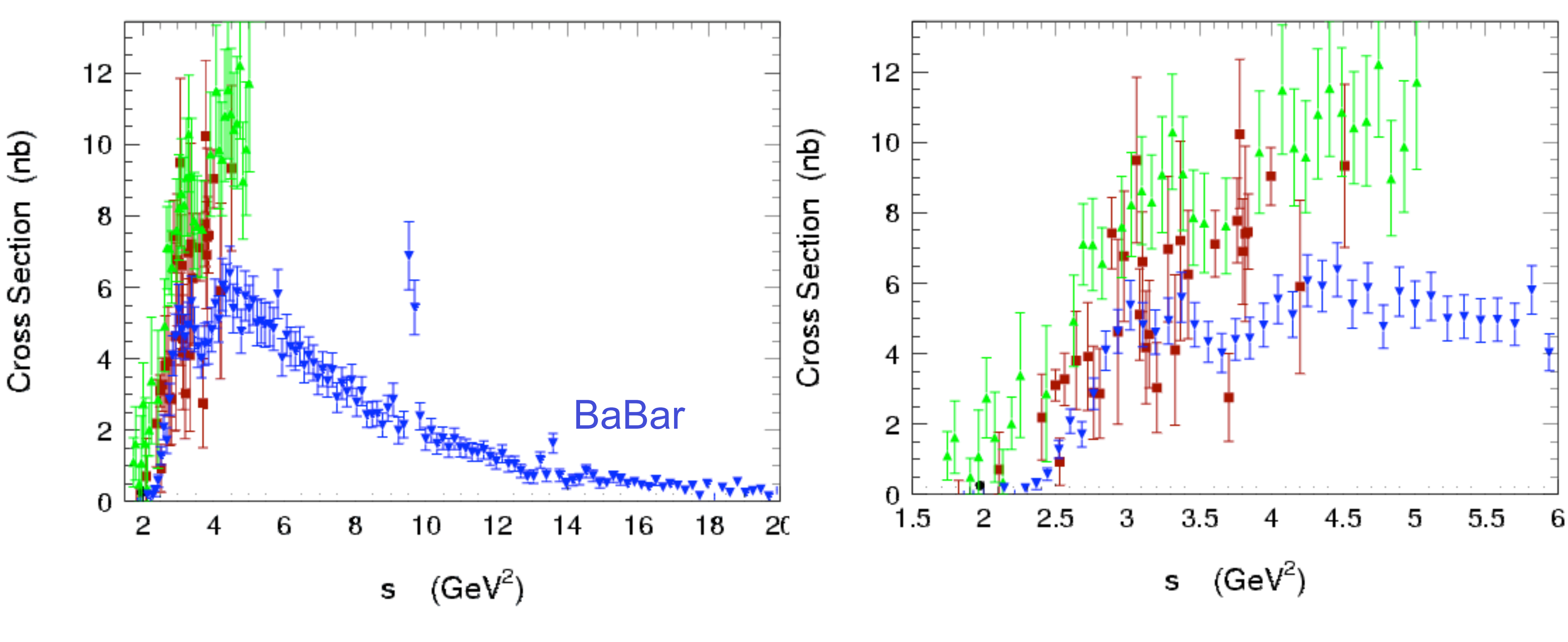


contribution to a_μ^{had} (<1.8 GeV) :

- all before BaBar 0.10 ± 0.10
- all + BaBar 0.108 ± 0.016

$\times 10^{-10}$

BaBar ISR: $2\pi^+2\pi^-2\pi^0$

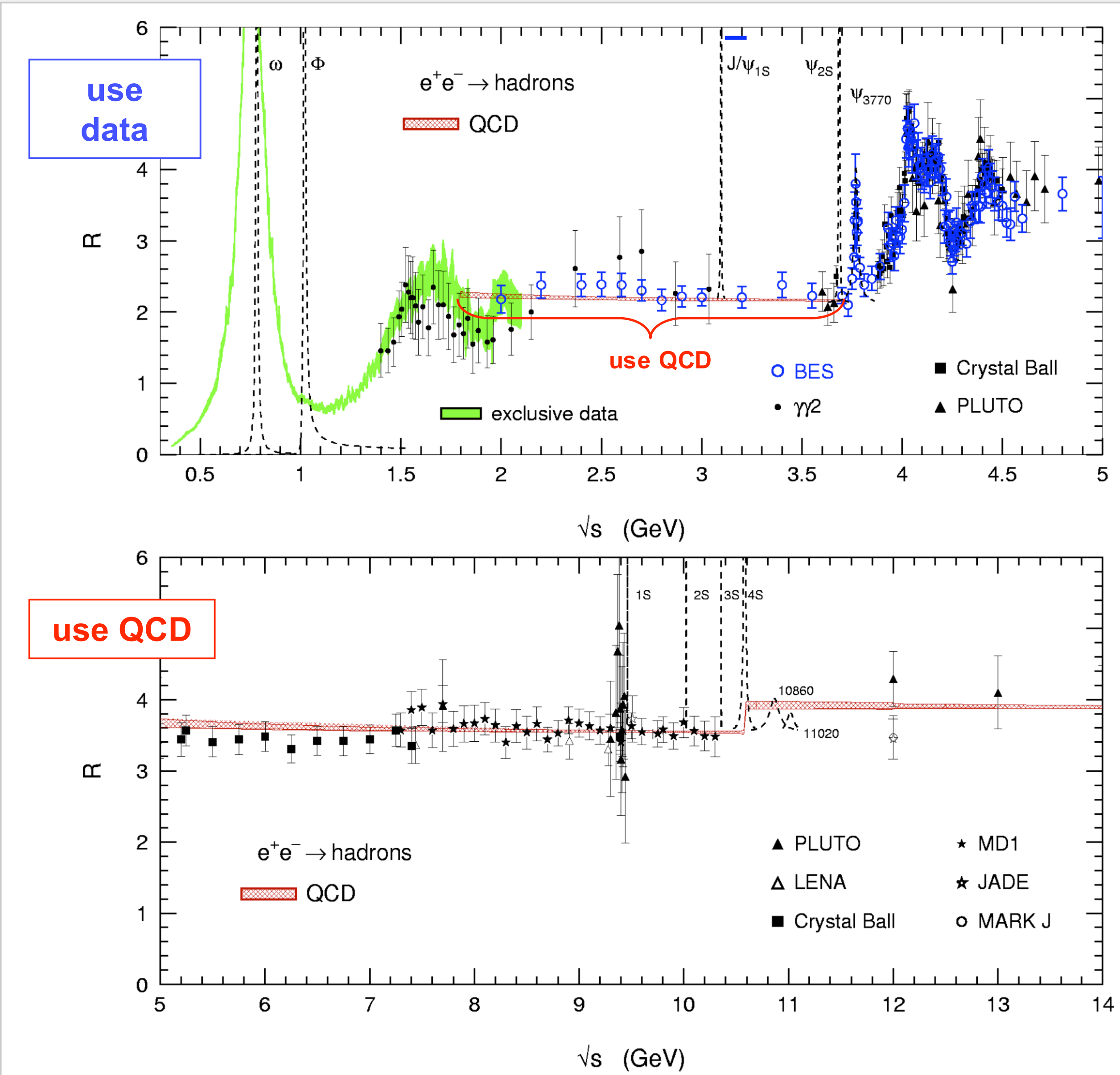


contribution to a_μ^{had} (<1.8 GeV) :

• all before BaBar	1.42 ± 0.30 ± 0.03
• all + BaBar	0.890 ± 0.093

x10^{-10}

Evaluating the Dispersion Integral



Agreement between Data (BES) and pQCD (within correlated systematic errors)

Better agreement between exclusive and inclusive ($\gamma\gamma$2) data than in 1997-1998 analyses

Update for ICHEP-Tau06

$$a_\mu^{\rm had}[ee] = (690.9 \pm 4.4) \times 10^{-10}$$

$$a_\mu[ee] = (11\,659\,180.5 \pm 4.4_{\rm had} \pm 3.5_{\rm LBL} \pm 0.2_{\rm QED+EW}) \times 10^{-10}$$

M.Davier talk at tau06

inclu-
ding:

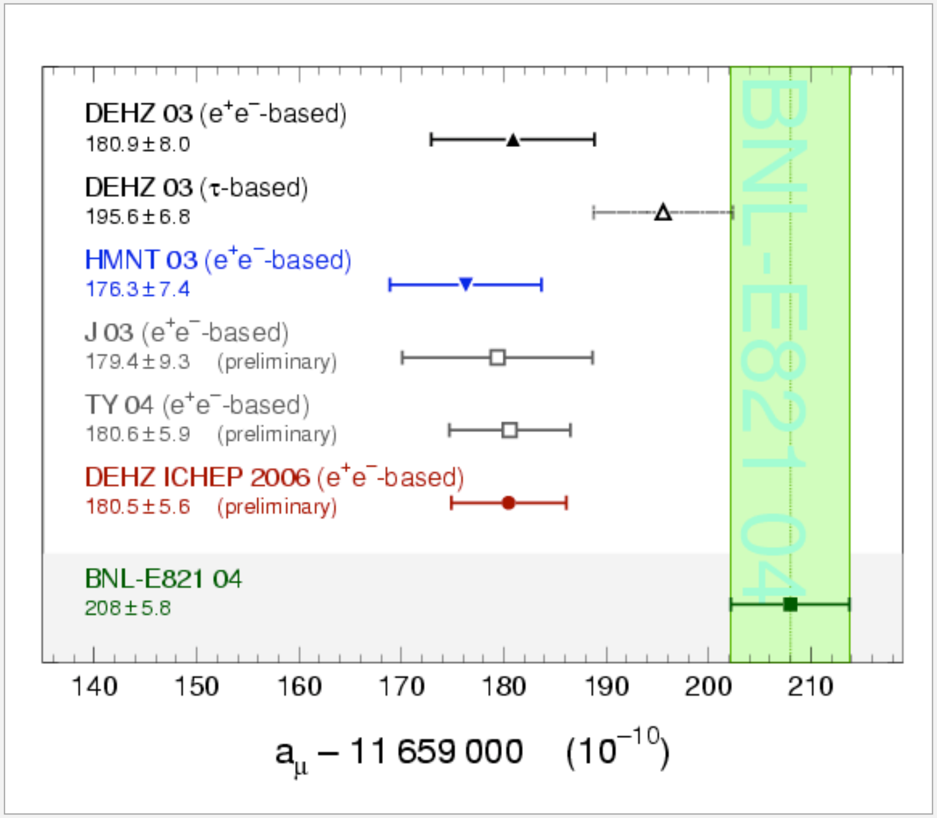
Hadronic HO	$-(9.8 \pm 0.1) \times 10^{-10}$
Hadronic LBL	$+(12.0 \pm 3.5) \times 10^{-10}$
Electroweak	$(15.4 \pm 0.2) \times 10^{-10}$
QED	$(11\,658\,471.9 \pm 0.1) \times 10^{-10}$

Knecht-Nyffeler, Phys.Rev.Lett. 88 (2002) 071802

Melnikov-Vainshtein, hep-ph/0312226

Davier-Marciano, Ann. Rev. Nucl. Part. Sc. (2004)

Kinoshita-Nio (2006)



BNL E821 (2004):
$a_\mu^{\rm exp} = (11\,659\,208.0 \pm 6.3)\ 10^{-10}$

Observed Difference with Experiment:

$$a_\mu[\exp] - a_\mu[\rm SM] = (27.5 \pm 8.4) \times 10^{-10}$$

➡ 3.3 „standard deviations“

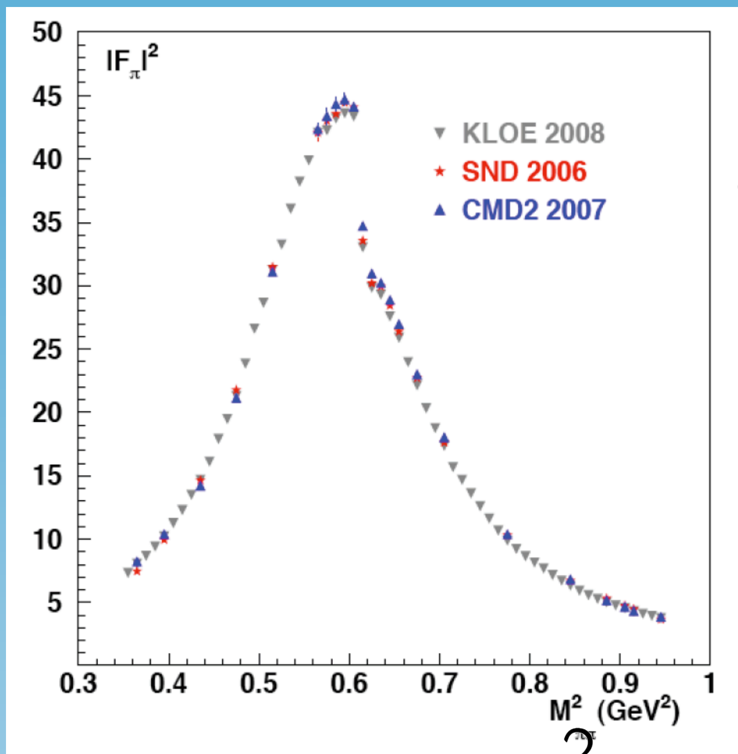
Contributions to a_μ^{had} [in 10^{-10}] from the different energy domains

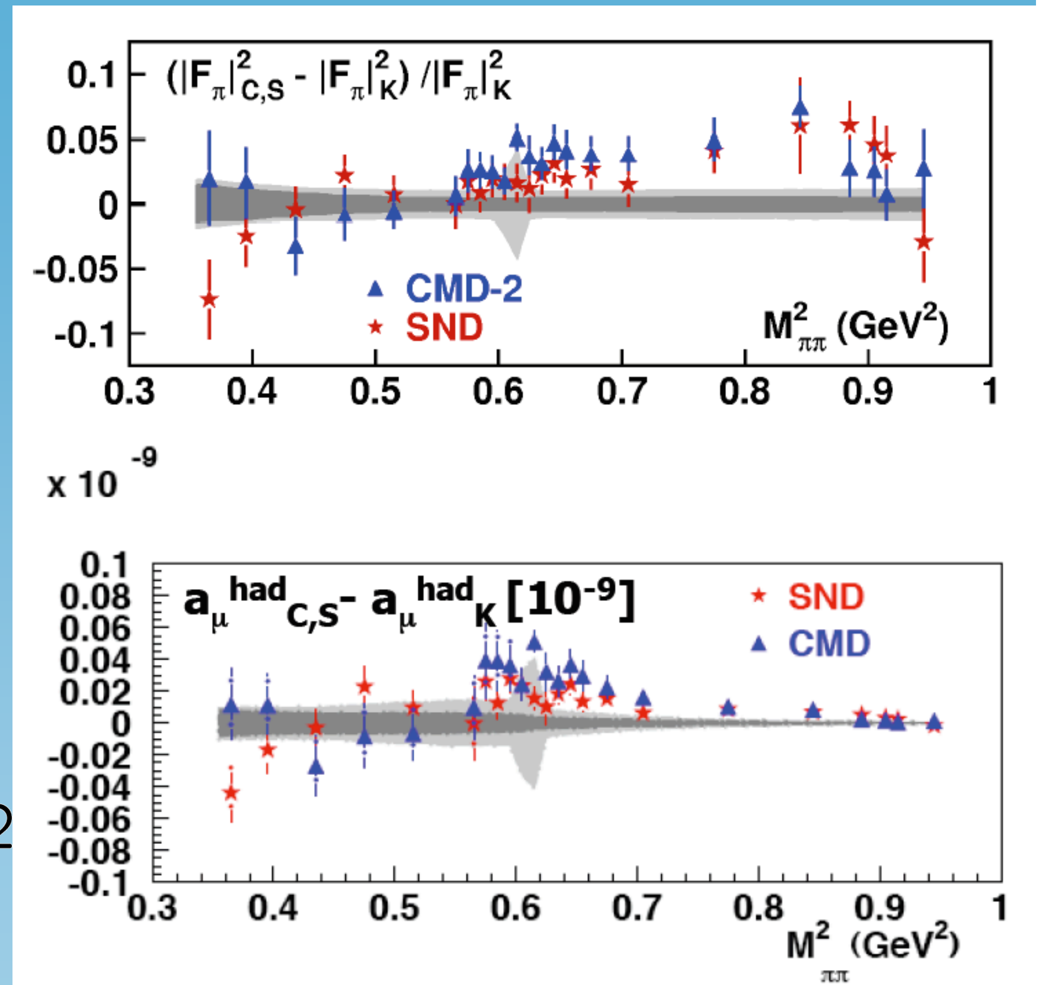
Modes	Energy [GeV]	e^+e^-	τ
Low s expansion	$2m_\pi - 0.5$	$55.6 \pm 0.8 \pm 0.1_{rad}$	$56.0 \pm 1.6 \pm 0.3_{SU(2)}$
$\pi^+\pi^-$ (+SND+CMD2)	$0.5 - 1.8$	$449.0 \pm 3.0 \pm 0.9_{rad}$	$464.0 \pm 3.0 \pm 2.3_{SU(2)}$
			With MV corr. $456.0 \pm 3.0 \pm 6.0_{SU(2)}$
$\pi^+\pi^- 2\pi^0$	$2m_\pi - 1.8$	$16.8 \pm 1.3 \pm 0.2_{rad}$	$21.4 \pm 1.3 \pm 0.6_{SU(2)}$
$2\pi^+ 2\pi^-$ (+BaBar)	$2m_\pi - 1.8$	$13.1 \pm 0.4 \pm 0.0_{rad}$	$12.3 \pm 1.0 \pm 0.4_{SU(2)}$
ω (782)	$0.3 - 0.81$	$38.0 \pm 1.0 \pm 0.3_{rad}$	–
ϕ (1020)	$1.0 - 1.055$	$35.7 \pm 0.8 \pm 0.2_{rad}$	–
Other excl. (+BaBar)	$2m_\pi - 1.8$	$24.3 \pm 1.3 \pm 0.2_{rad}$	–
J/ψ, ψ(2S)	$3.08 - 3.11$	$7.4 \pm 0.4 \pm 0.0_{rad}$	–
R [QCD]	$1.8 - 3.7$	$33.9 \pm 0.5_{theo}$	–
R [data]	$3.7 - 5.0$	$7.2 \pm 0.3 \pm 0.0_{rad}$	–
R [QCD]	$5.0 - \infty$	$9.9 \pm 0.2_{theo}$	–
Sum (w/o KLOE)	$2m_\pi - \infty$	$690.8 \pm 3.9 \pm 1.9_{rad} \pm 0.7_{QCD}$	$710.1 \pm 5.0 \pm 0.7_{rad} \pm 2.8_{SU(2)}$

2.4

What we have now?

$|F_\pi|^2$ from KLOE (2008), CMD2 and SND agree well



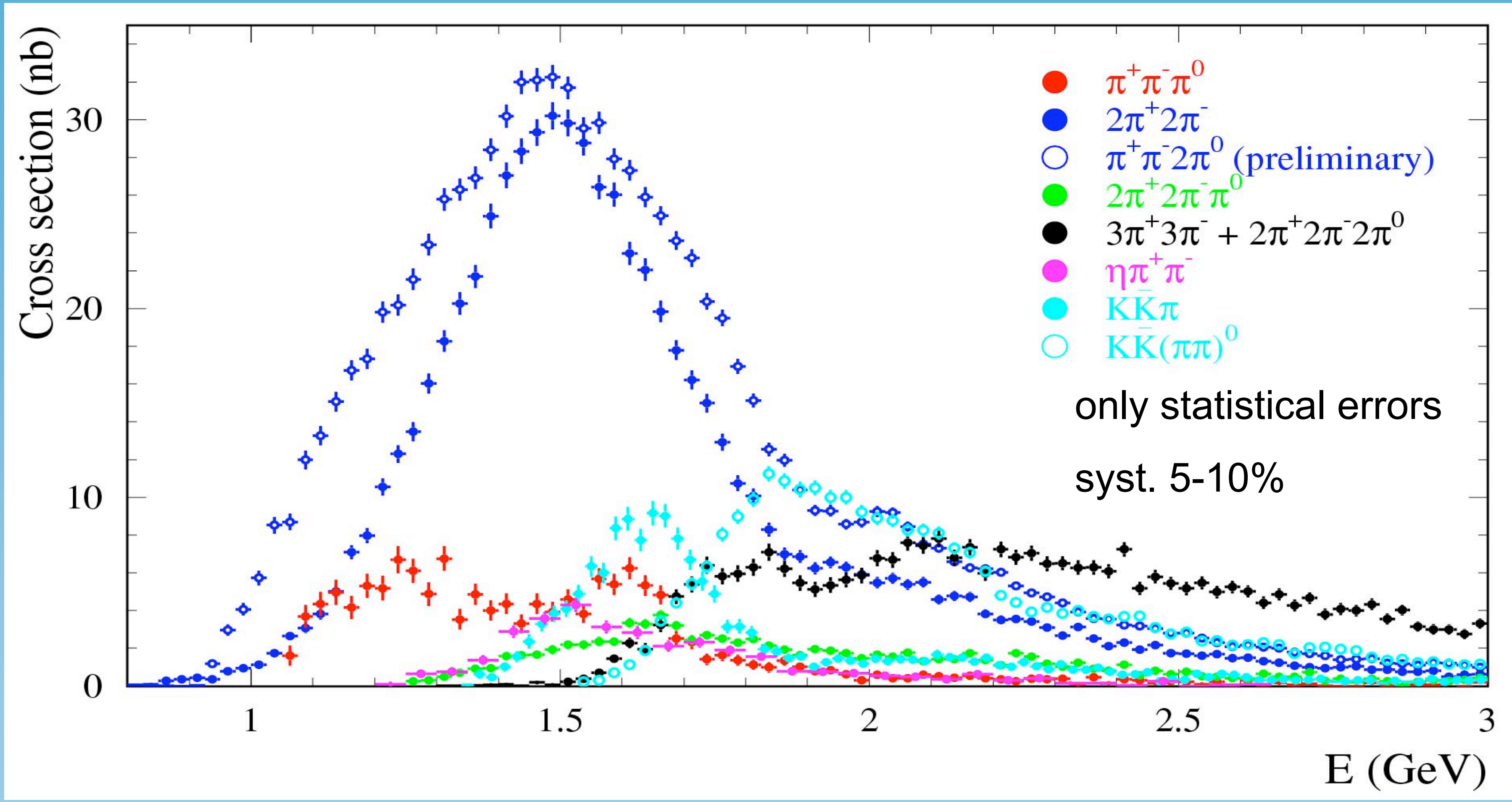


$$\sigma_{e^+e^-\to\pi^+\pi^-} = \frac{\pi\alpha^2}{3s}\beta_\pi^3|F_\pi|^2$$

pt. to pt. difference in $a_\mu^{\rm Had} \simeq 1 - 4 \times 10^{-11}$

recall that: $a_\mu^{\rm Had}({\rm LO}) = 6\,908\,(44)\, \times\, 10^{-11}$

More BaBar data are available



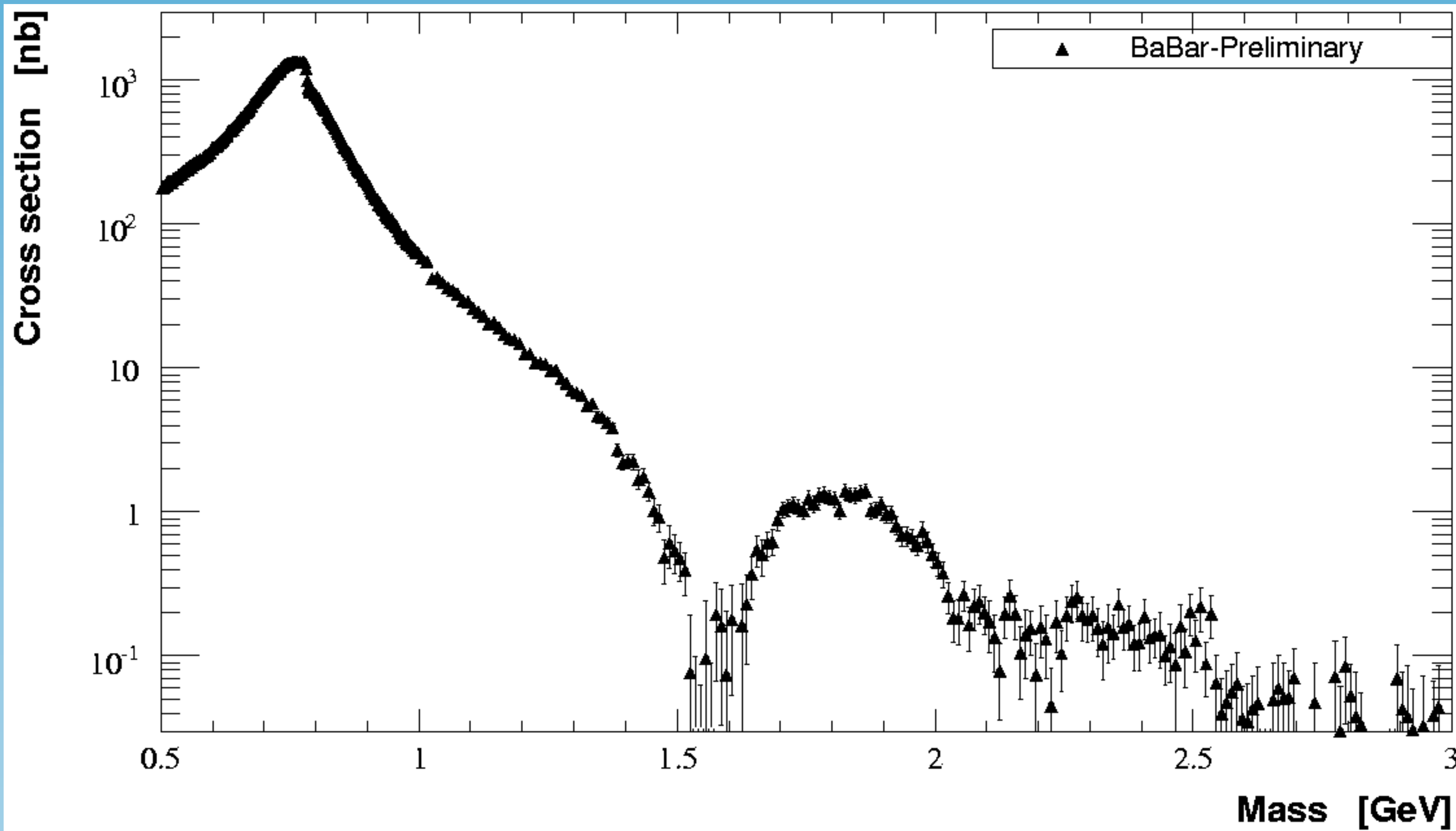
to obtain R in the energy range 1-2 GeV the processes

$\pi^+\pi^-3\pi^0$, $\pi^+\pi^-4\pi^0$, K^+K^-, K_SK_L, $K_SK_L\pi\pi$, $K_SK^+\pi^-\pi^0$

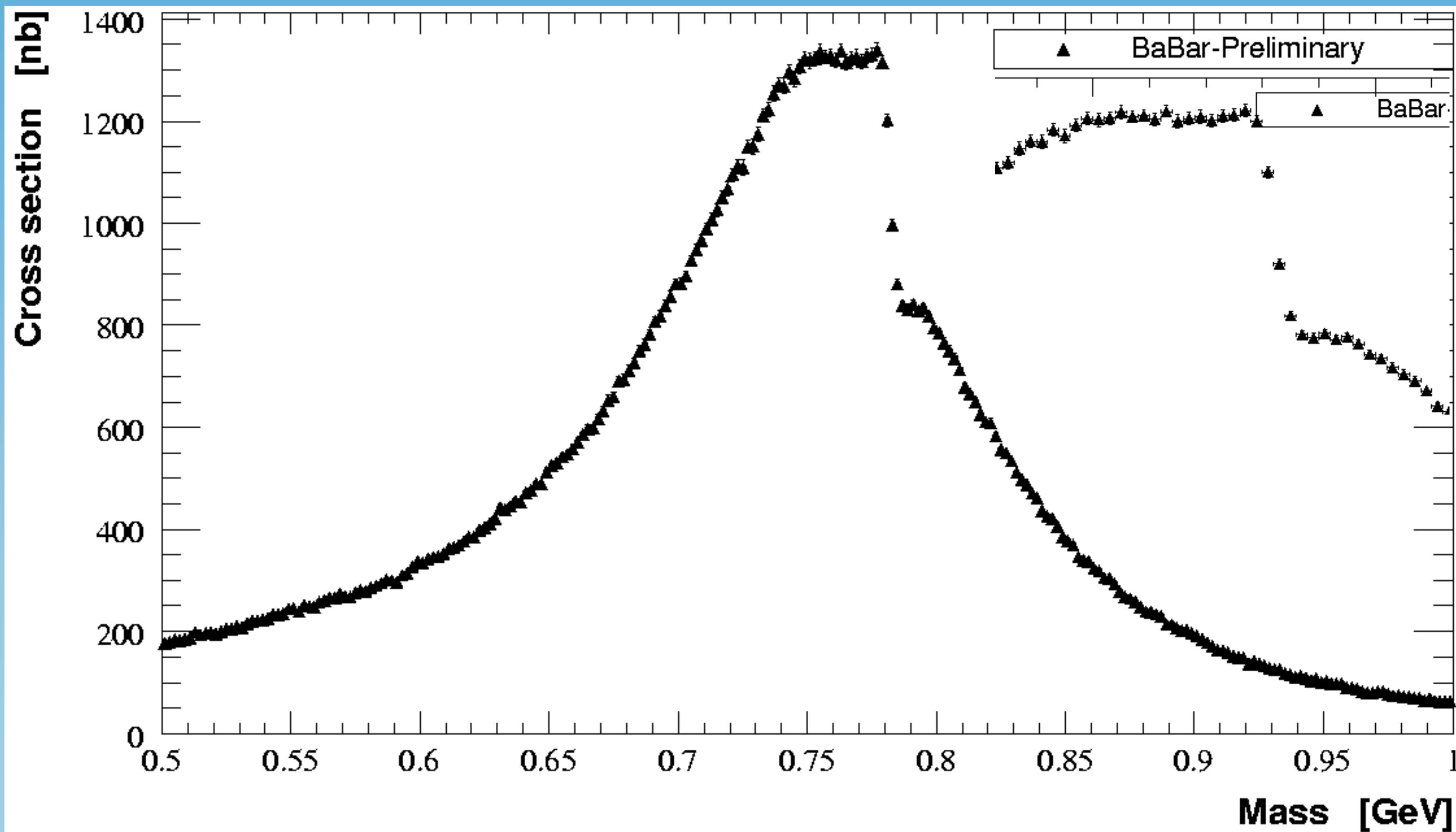
remain to be measured

New in 2008: BaBar results (preliminary)

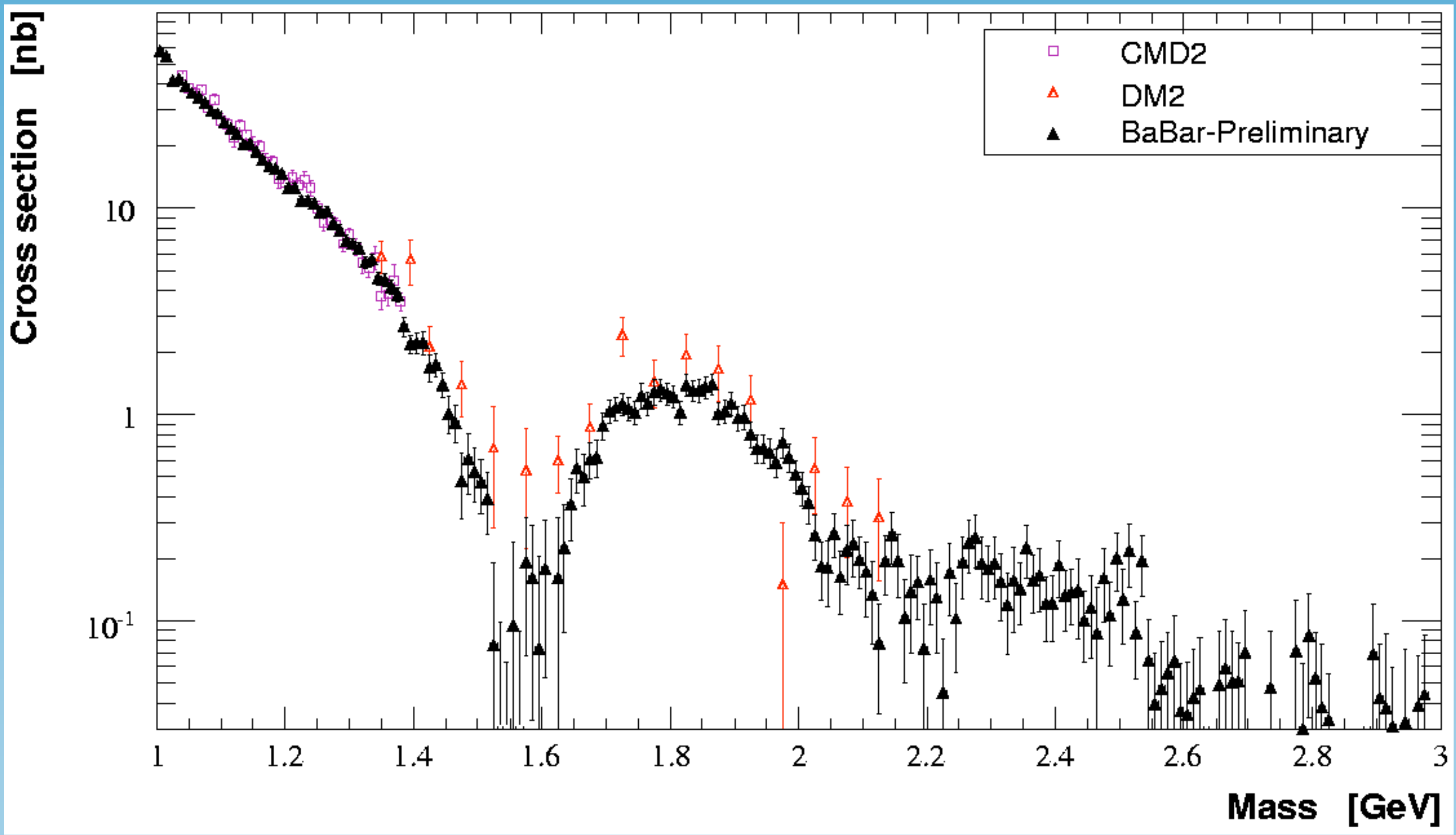
The $e^+e^- \to \pi^+\pi^-$ cross section via ISR



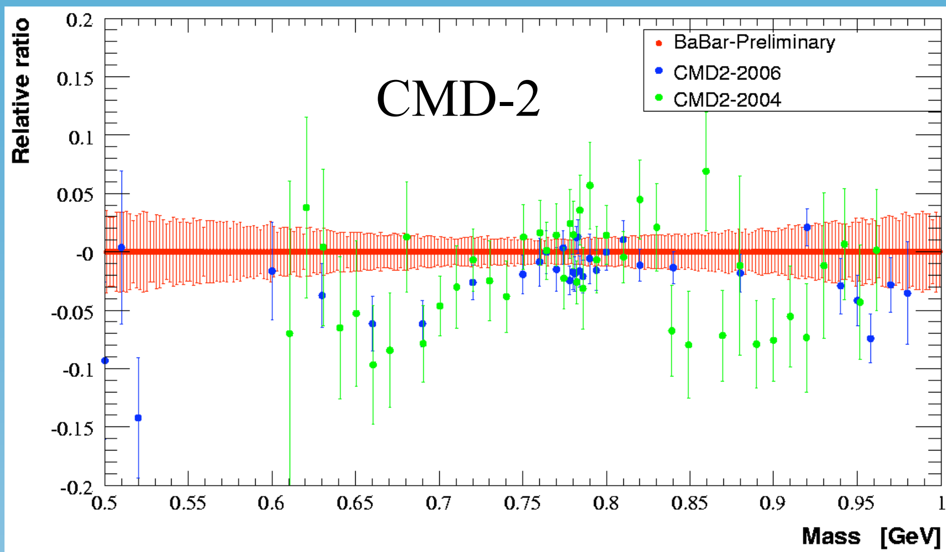
BaBar results in ρ region



BaBar vs. other experiments at large mass



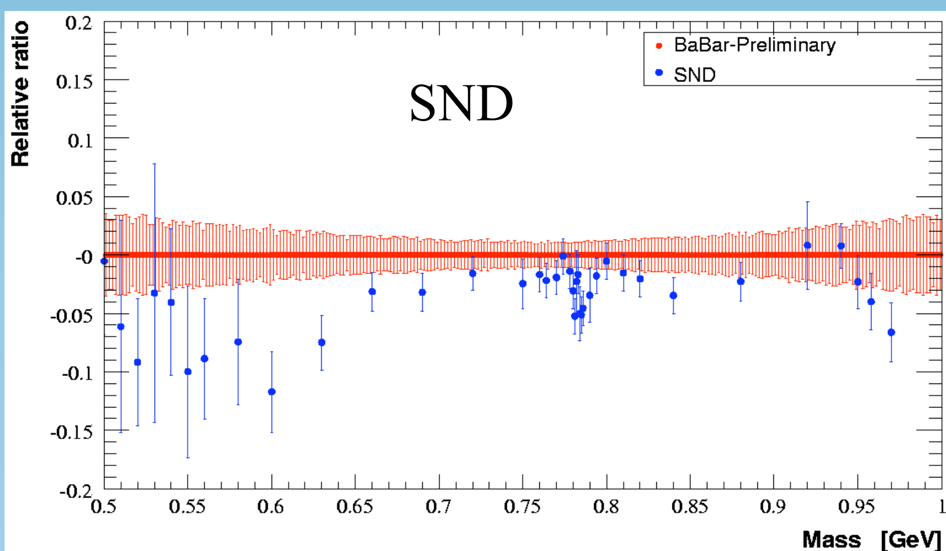
BaBar vs.other ee data (0.5-1.0 GeV)

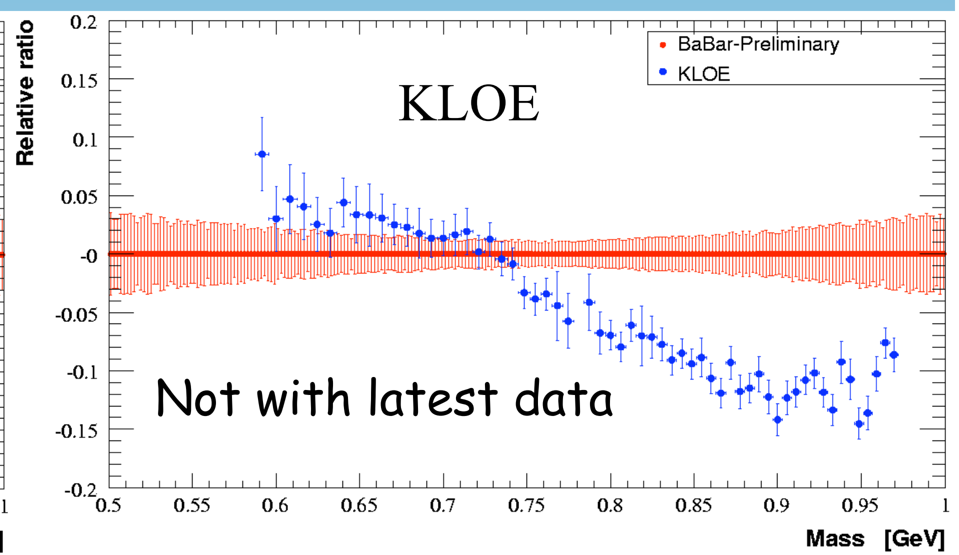


direct relative comparison of cross sections in the corresponding 2-MeV BaBar bins (interpolation with 2 bins)

deviation from 1 of ratio w.r.t. BaBar

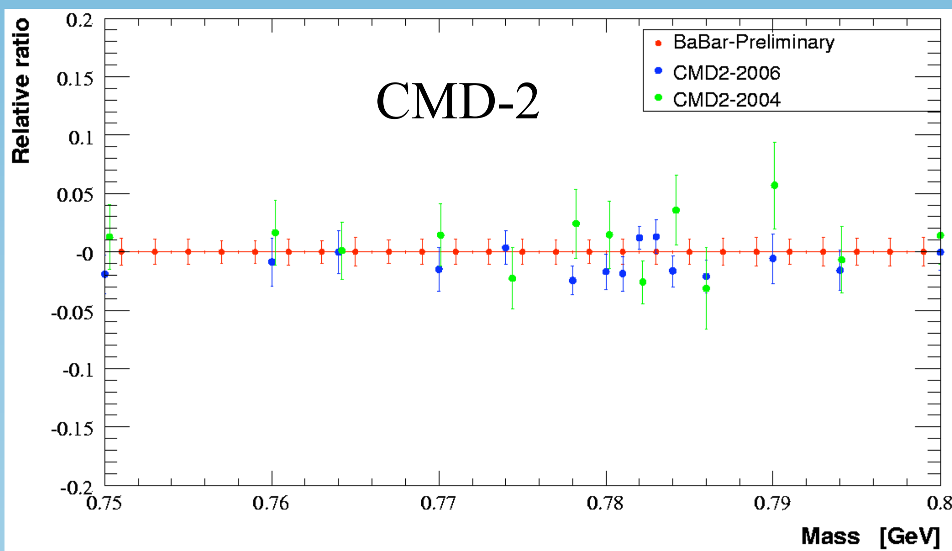
stat + syst errors included

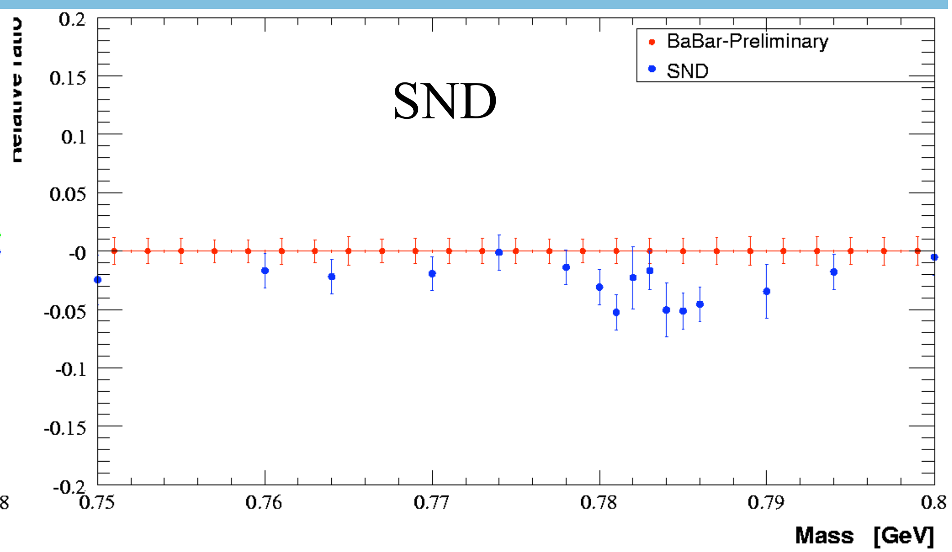




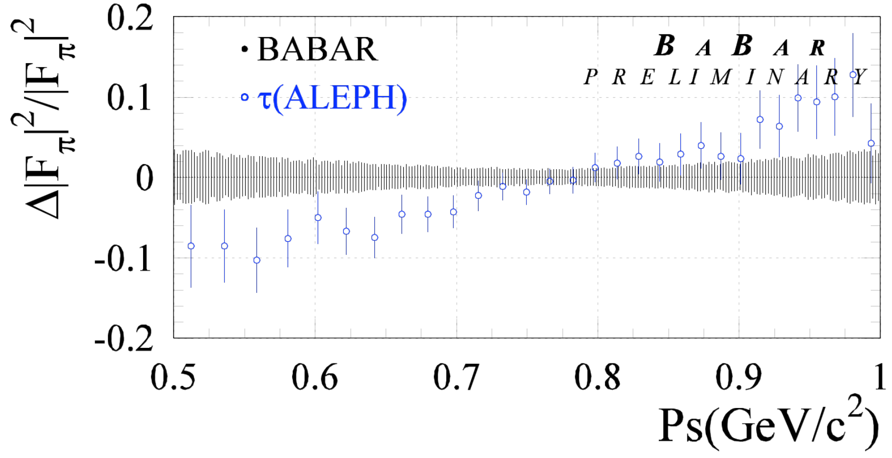
BaBar vs.other ee data (ρ–ω interference region)

- mass calibration of BaBar checked with ISR-produced $J/\psi \rightarrow \mu\mu$
- expect $-(0.16 \pm 0.16)$ MeV at ρ peak
- ω mass can be determined through mass distribution fit (in progress)
- Novosibirsk data precisely calibrated using resonant depolarization
- comparison BaBar/CMD-2/SND in ρ-ω interference region shows no evidence for a mass shift



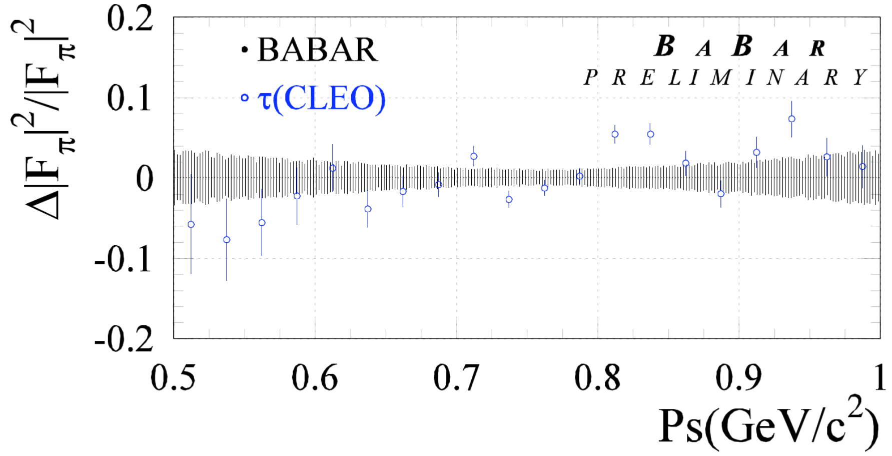


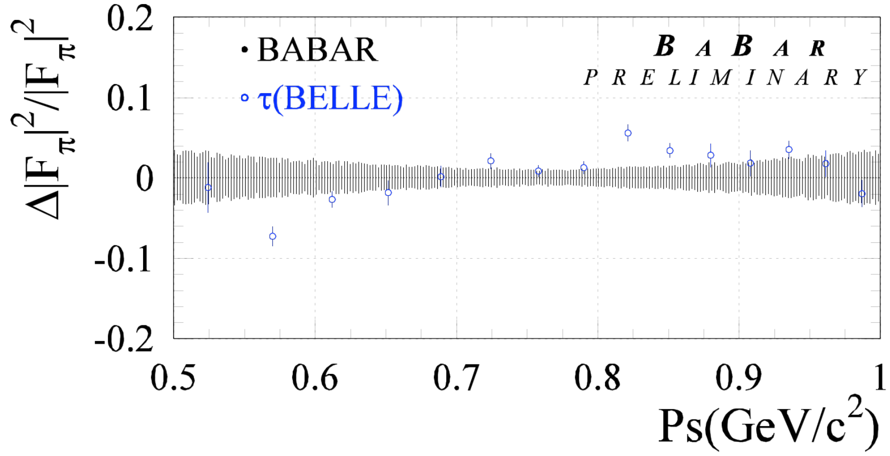
BaBar vs. IB-corrected τ data (0.5-1.0 GeV)



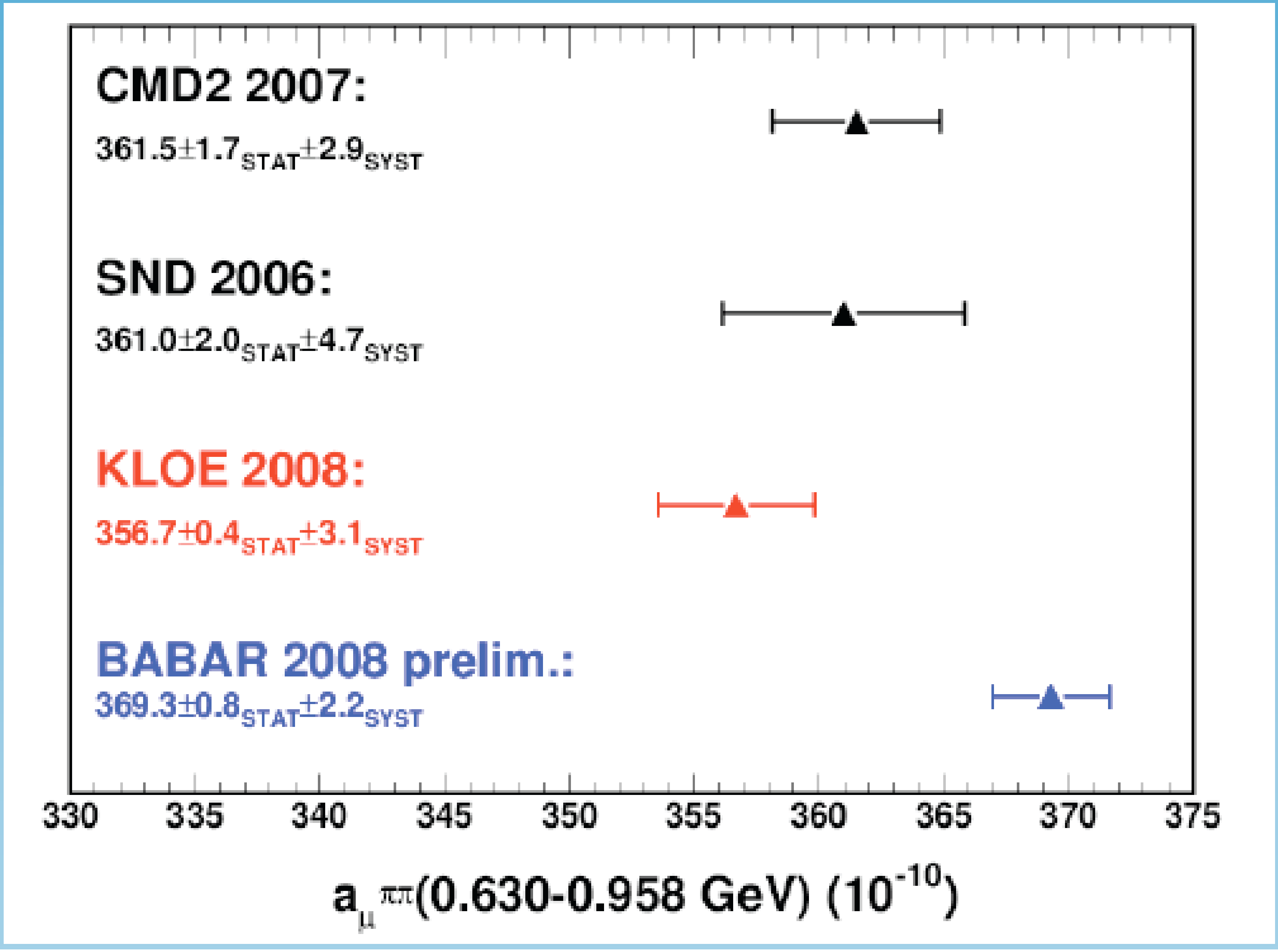
relative comparison w.r.t. BaBar of isospin-breaking corrected τ spectral functions

BaBar data averaged in wider τ bins and corrected for ρ-ω interference

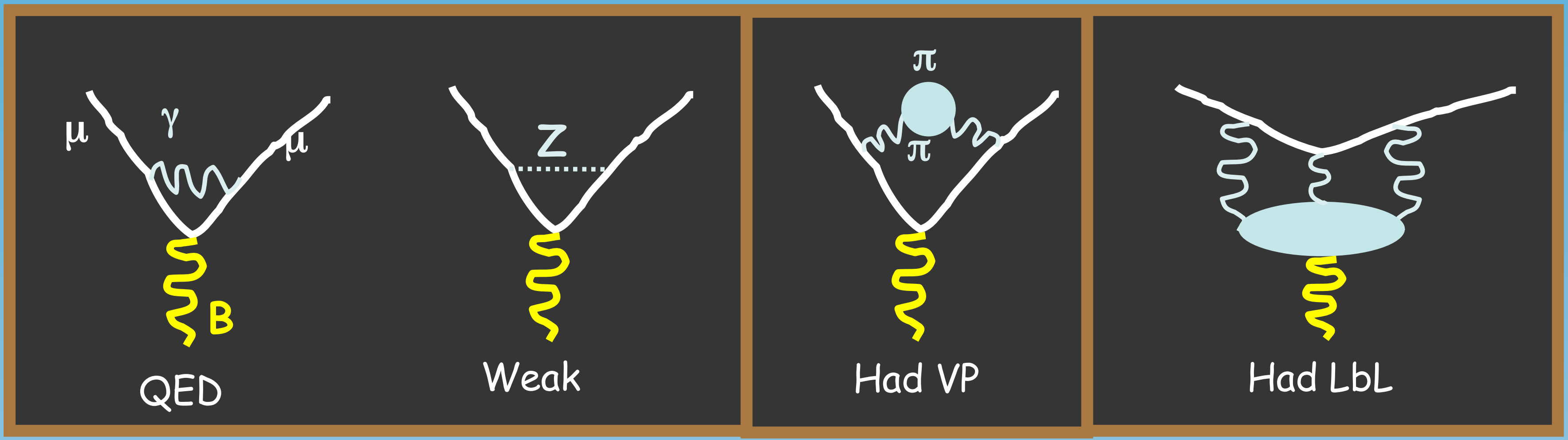




Different measurements in 630-958 MeV



$a_\mu = (g-2)/2$ Latest evaluation



Known well **Theoretical work ongoing**

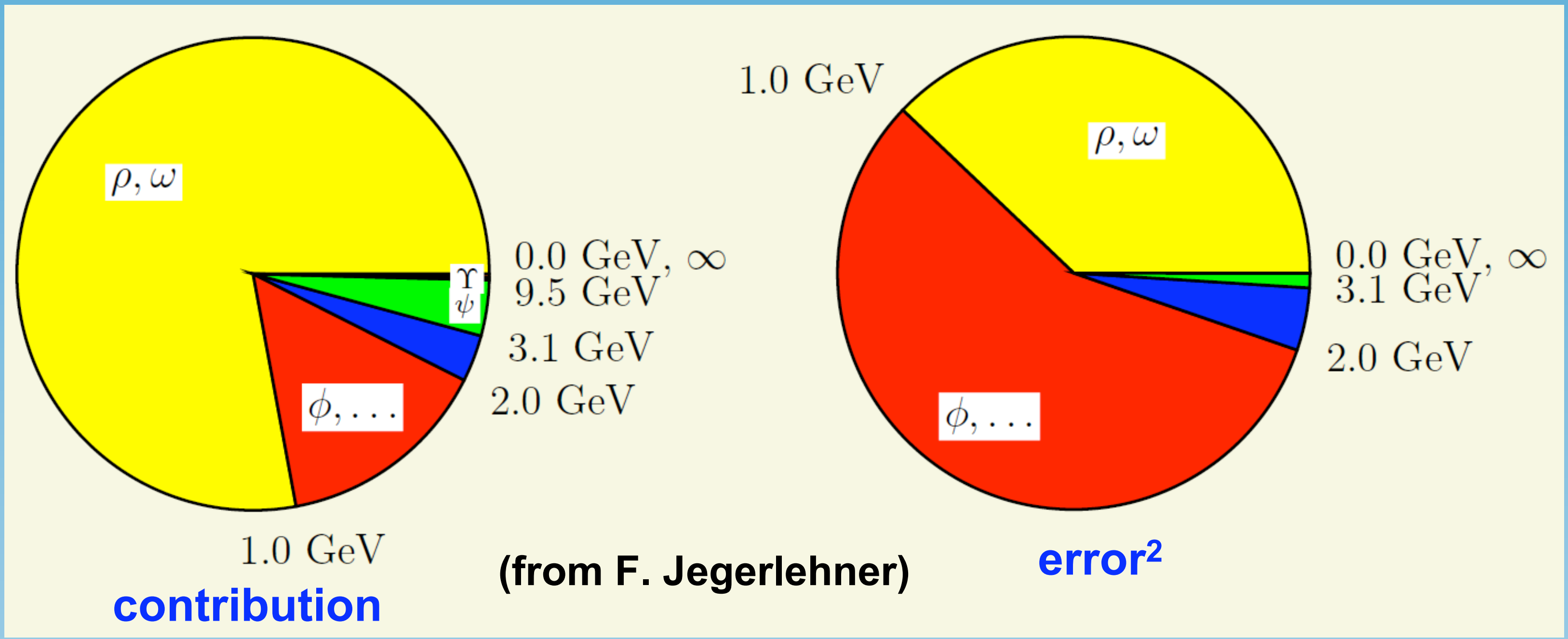
Contribution	Result ($\times 10^{-11}$) units
QED (leptons)	$116\,584\,718.09 \pm 0.14 \pm 0.04_\alpha$
HVP(lo)	$6\,908 \pm 39_{\text{exp}} \pm 19_{\text{rad}} \pm 7_{\text{pQCD}}$
HVP(ho)	$-97.9 \pm 0.9_{\text{exp}} \pm 0.3_{\text{rad}}$
HLxL	105 ± 26
EW	$152 \pm 2 \pm 1$
Total SM	$116\,591\,785 \pm 51$

$\delta a_\mu = 51 \times 10^{-11}$

arXiv:0809.3085 Eduardo De Rafael (CPT)

Analyticity and the optical theorem:

$$a_\mu(\text{had}) = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} \frac{ds}{s^2} K(s) \left(\frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}\right)$$



- Future efforts will reduce errors
  - Additional KLOE data (in hand, near term)
  - BaBar finalize $\pi\pi$, more multihadrons, perhaps Belle
  - CMD3 at VEPP2000, up to 2.0 GeV (next 5 years)

New $a_\mu = (g - 2)/2$ measurement is proposed at FNAL

- Present Status E821:
  - Experimental uncertainty = 63×10^{-11} (0.54 ppm)
    - 0.46 ppm statistical
    - 0.28 ppm systematic
  - Theory uncertainty = 51×10^{-11} (0.44 ppm)

Limit was counts

Leads to Δa_μ(Expt – Thy) = $295 \pm 81 \times 10^{-11}$ $3.6\,\sigma$

- Expected situation after FNAL experiment:
  - Experimental uncertainty: 63 → 16×10^{-11}
    - 0.1 ppm statistical → 21x the E821 events
    - 0.1 ppm systematic overall
      - 0.07 ppm field → 0.17 → 0.07
      - 0.07 ppm ω_a → 0.21 → 0.07
  - Theory uncertainty: 51 → 30×10^{-11}

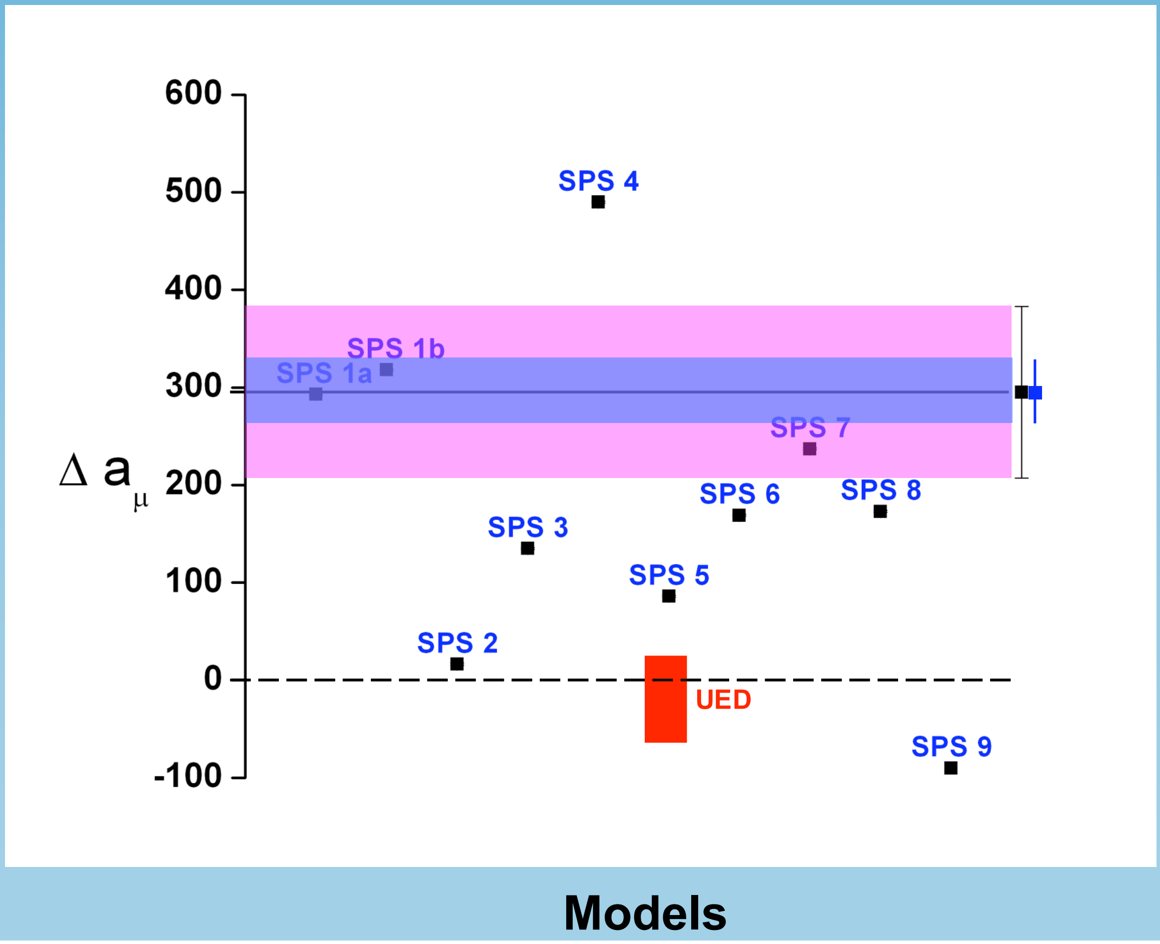
Future: Δa_μ(Expt – Thy) = xx $\pm 34 \times 10^{-11}$

(If xx remains 295, the deviation from zero would be close to 9σ)

The Snowmass Points and Slopes are 10 representative SUSY models with typical parameters for M_{SUSY} masses and $\tan\beta$, etc. They serve as test points to indicate the discrimination power of experiments.

Muon g-2 is a powerful discriminator *no matter where the final value lands*

Illustration of “resolving power” among SUSY models



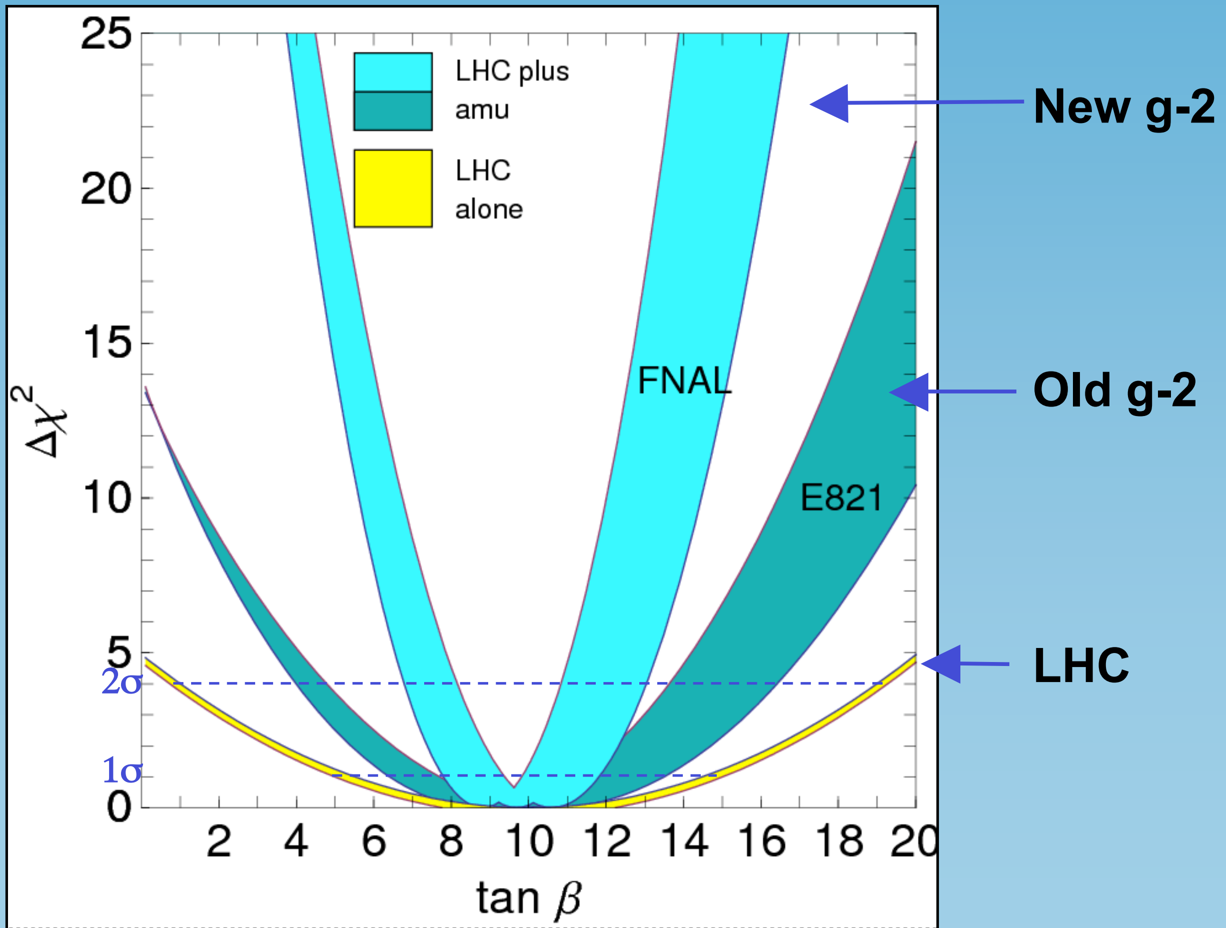
Present

Future?

Universal Extra Dimensions 1D

Suppose the MSSM reference point SPS1a* is realized and parameters are determined by global fit from full LHC data

- sign(μ) difficult to obtain from the collider
- tanβ poorly determined by collider



g-2 is complementary to the LHC

* SPS1a is a ``Typical " mSUGRA point with intermediate tanβ = 10

Conclusions

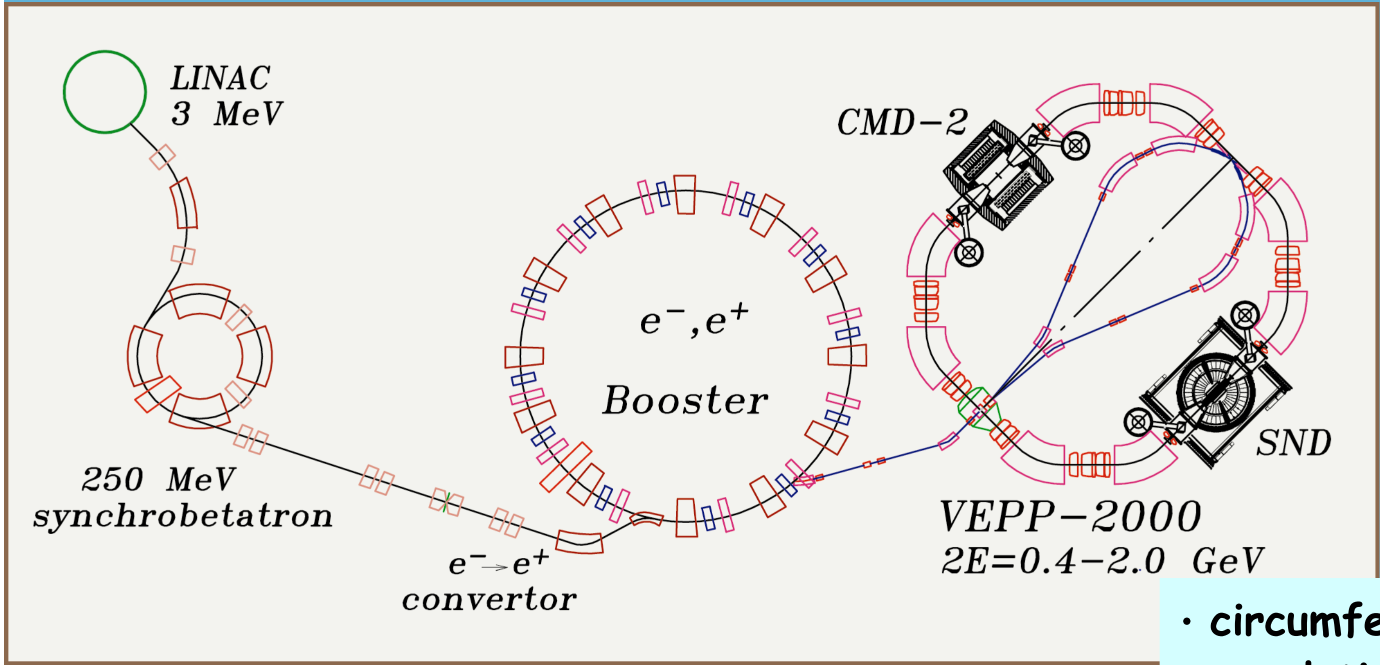
- Hadronic vacuum polarization is still the dominant systematics for SM prediction of the muon $g-2$
- Significant step in precision from new experimental input

  CMD-2 + SND +KLOE for 2π BaBar for multi-pion channels
- Precision of SM prediction (±5.1) now exceeds experimental precision (±6.3)
- Discrepancy with τ data (ALEPH & CLEO & OPAL) still remain
- Final result from BELLE awaited - only 1.5 σ from e^+e^- data now
- Until τ / e^+e^- puzzle is solved, only e^+e^- data used in dispersion integral
- SM prediction for a_μ differs by 3.6 σ [e^+e^-] from experiment (BNL 2004)
- New proposal to measure muon $g-2$ with $1{,}6 \times 10^{-10}$ accuracy is submitted
- The high interest to low energy cross section measurement motivates new

  project - VEPP2000

VEPP2000 project

VEPP-2000 e^+e^- collider



- circumference – 24.4 m
- revolution time – 82 nsec
- beam current – 0.2 A
- beam length – 3.3 cm
- energy spread – 0.7 MeV
- $\beta_x = \beta_z = 6.3$ cm
- $L = 10^{32}$ $cm^{-2}s^{-1}$ at 2E=2.0 GeV
- $L = 10^{31}$ $cm^{-2}s^{-1}$ 2E=1.0 GeV

2E = 400 - 2000 MeV , 1x1 bunch

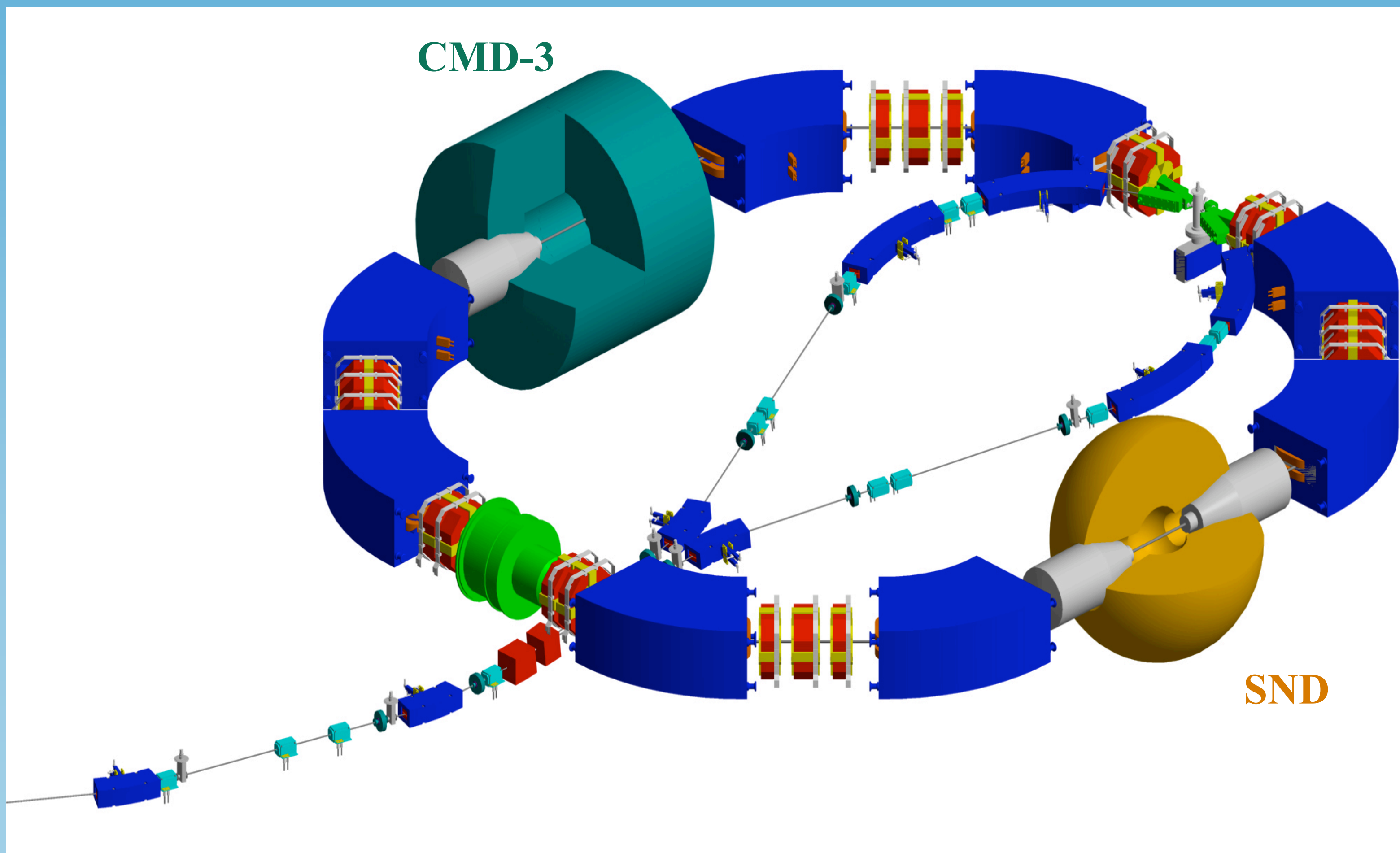
Solenoidal focusing - round beams at IP

Refs for VEPP-200

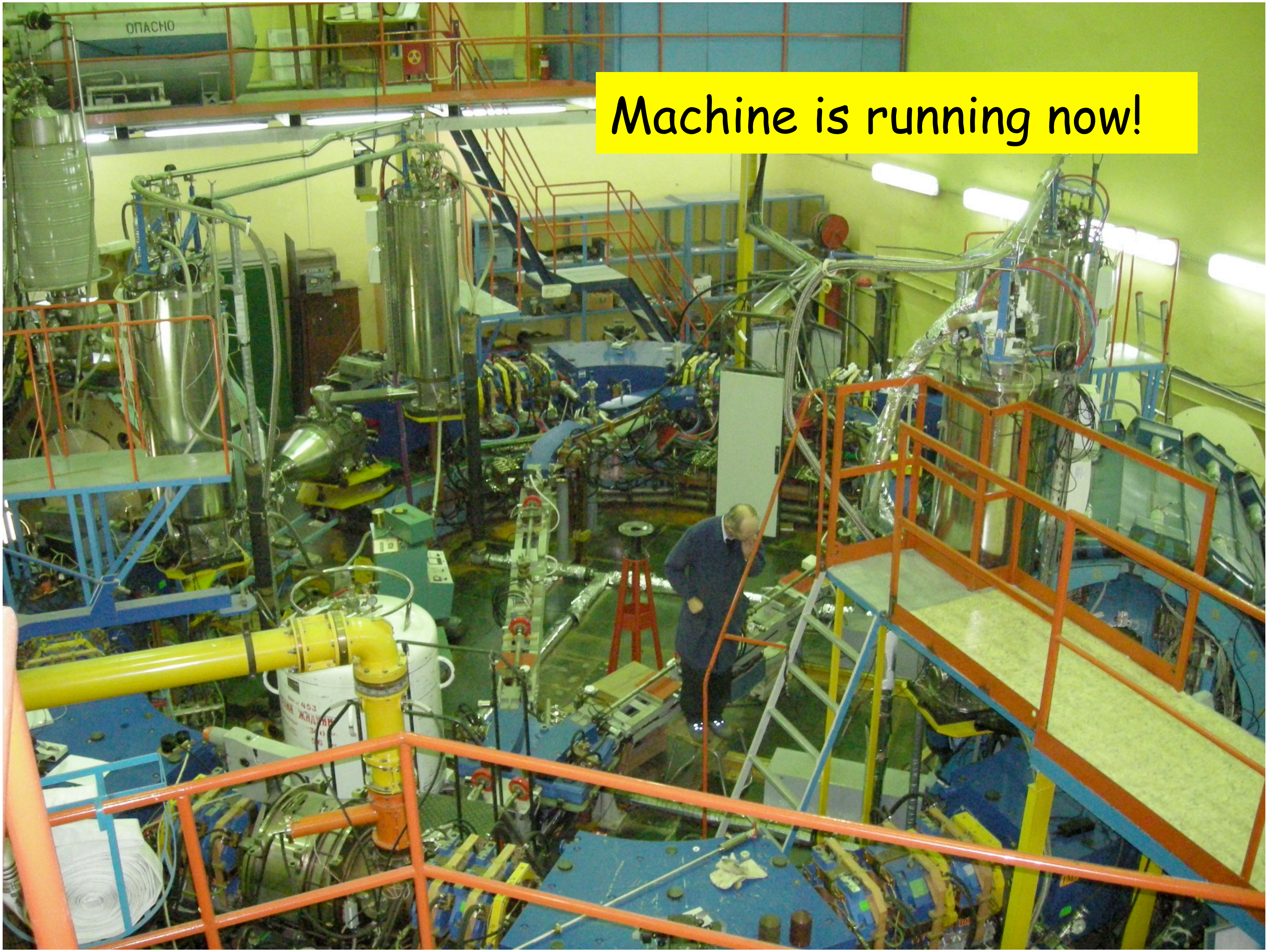
1. In: Proc.Frascati Phys.Series,v XVI, p.393,Nov.16-19,1999
2. In: Proc. 7-th Europ.Part.Accel.Conf.,EPAC 2000, p.439, Vienna,2000

VEPP-2000

$\int Ldt$ 100 pb^{-1} per detector per year



Total integrated luminosity with all detectors on VEPP-2M ~ 70 pb^{-1}


Machine is running now!
ОПАСНО

Physics program at VEPP-2000

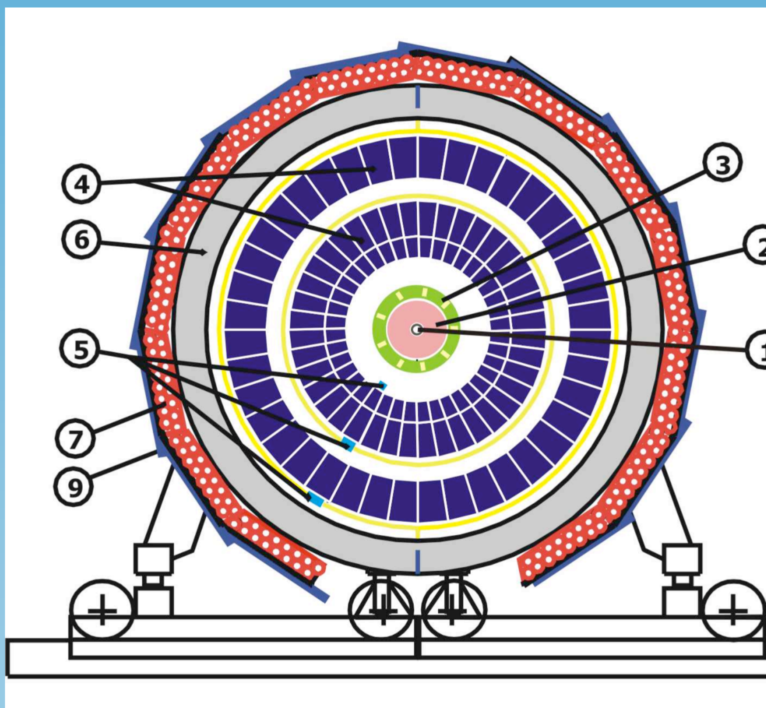
1. Precise measurement of the quantity

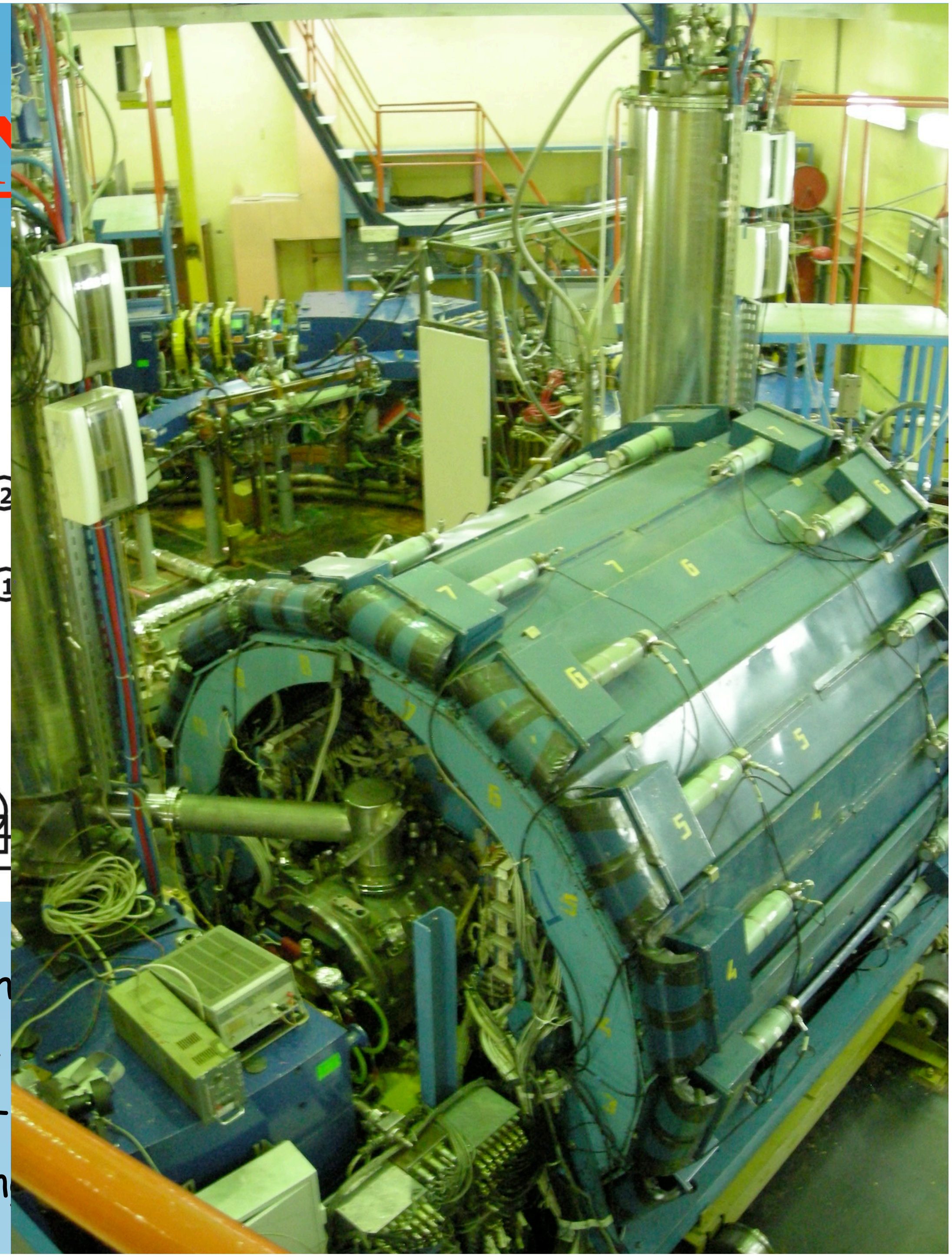
   $R=\sigma(e^+e^- \to hadrons)/\ \sigma(e^+e^- \to \mu^+\mu^-)$

2. Study of hadronic channels: $e^+e^- \to$ 2h, 3h, 4h …, h= π,K,η
3. Study of 'excited' vector mesons: ρ', ρ'', ω', φ',..
4. CVC tests: comparison of $e^+e^- \to$ hadr. (T=1) cross section with τ-decay spectra
5. Study of nucleon-antinucleon pair production – nucleon electromagnetic form factors, 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

With $L_{peak} = 10^{32}\ cm^{-2}sec^{-1}$ luminosity x10-100 statistical improvement over existing BaBar ISR data in 1-2 GeV energy range

Spherical N





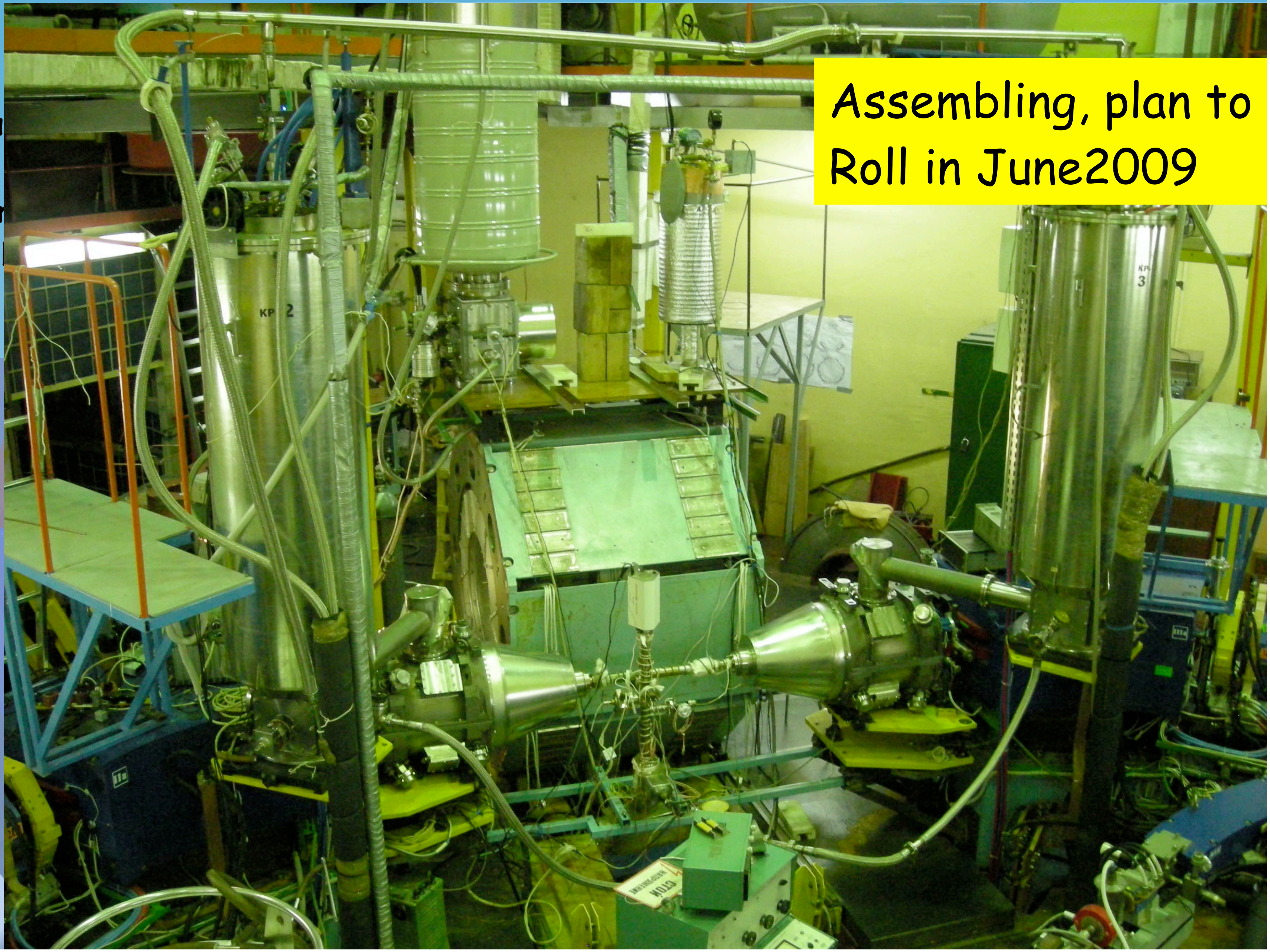
1 – VEPP-2000 vacuum ch

3 – aerogel counters, 4 –
vacuum phototriodes, 6 –

10 – VEPP-2000 phocusin

Cryogenic Magnetic Detector-3

1 – vacuu
2 – drift
3 – electr
4 – Z – c
5 – CMD



Assembling, plan to
Roll in June2009

How can we improve measurement of R?

We expect to get the following improvements:

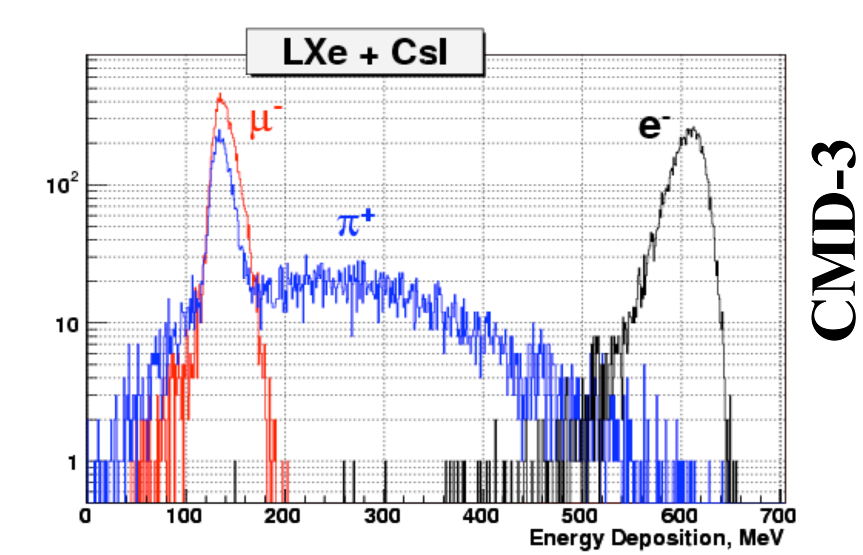
- high statistics! (x10-x100) – current measurement is still statistics-limited
- radiative corrections to 0.1% - add photon jet + large angle γ
- measure radiative tails and compare them to calculations (ISR?)
- luminosity to 0.5%, use $\gamma\gamma$ in addition to Bhabha for cross-check
- much better separation (LXe @CMD-3, Cerenkov @SND) – smaller systematic error, try to measure $e^+e^- \rightarrow \mu^+\mu^-$
- precise trigger efficiency monitoring
- better drift chambers – higher resolution, efficiencies

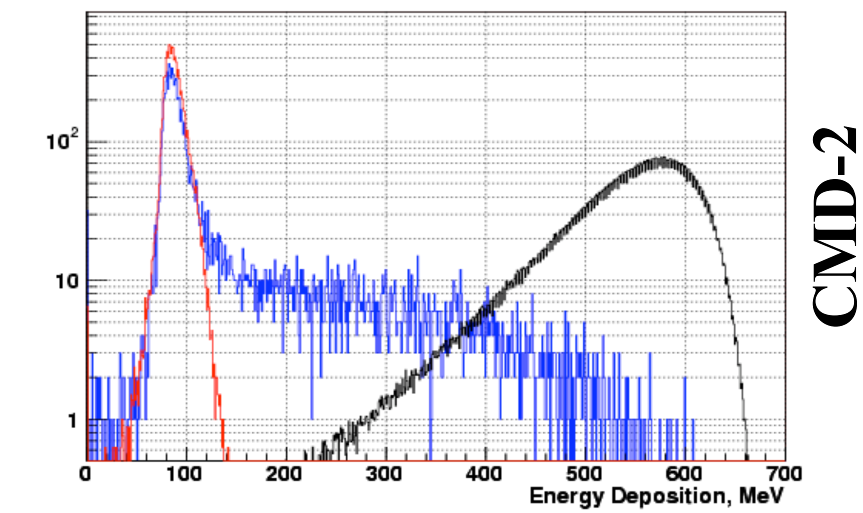
We expect to:

- measure 2π mode to 0.3-0.4%, 4π mode to 2%
- overall improvement in R precision by factor 2-3

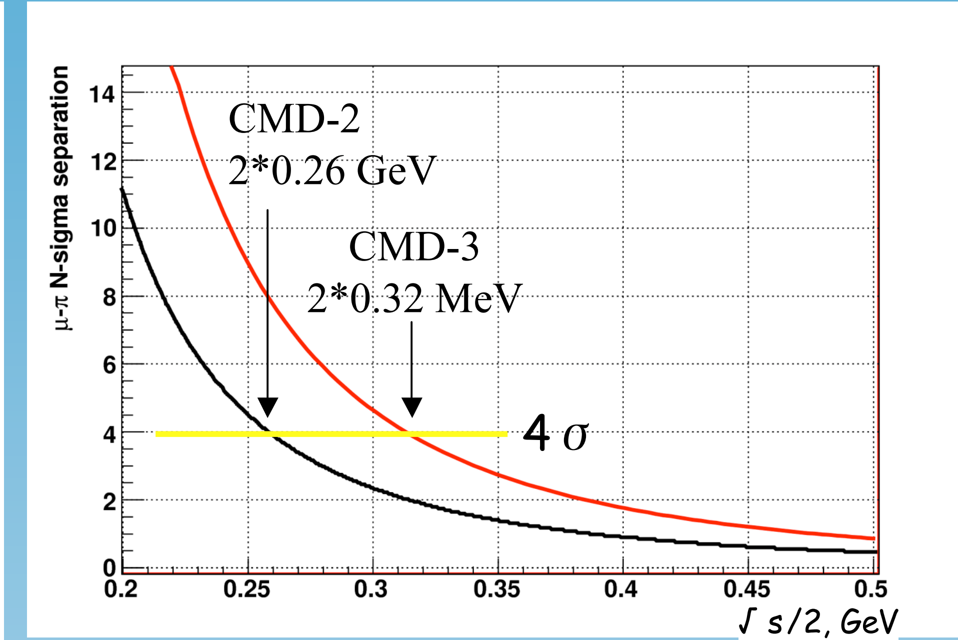
Examples of improvements (CMD-3)

Separation by energy deposition





Separation by momentum



Because of better resolution of the drift chamber, the separation by momentum should work up to $\sqrt{s} \approx 0.65$ GeV

Conclusion

- Measurement of R is still very active and important field
- Important for interpretation of *g*-2 experiment, evaluation of $\alpha(M_Z)$, tests of QCD
- Recent improvements: VEPP-2M, BES
- Lots of data are being analyzed: VEPP-2M, KLOE, BaBar, CLEO
- Current projects: VEPP-2000, BESIII
- ISR experiments have demonstrated impressive potential: KLOE, BaBar.
- Expect to reach 0.3-5% precision over the whole 0-10 GeV range in few years (factor of 2 improvement)

Thank you

- Objective :

  Precise cross section measurements for all significant processes,

  $e^+ e^- \rightarrow f$, from threshold to c.m. energy ~ 4.5-5.0 GeV

- Purpose :

  Significantly improve understanding of the spectroscopy of $J^{PC} = 1^{--}$ states, and of their resonant substructure

  Combine the cross section measurements to obtain improved precision on the c.m. energy dependence of R in this region

- Reactions for which results have been published < 2006:

  $e^+e^- \rightarrow p\bar{p}$

  $e^+e^- \rightarrow \pi^+\pi^-\pi^0$

  $e^+e^- \rightarrow 2\pi^+2\pi^-$, $K^+K^-\pi^+\pi^-$, $2K^+2K^-$

  $e^+e^- \rightarrow 3\pi^+3\pi^-$, $2\pi^+2\pi^-\pi^0\pi^0$, $K^+K^-2\pi^+2\pi^-$

- New results published in 2006-2008 :

  $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$, $\phi\pi\pi$, $\phi f_0(980)$

  a resonance structure at m=2.175 GeV/c^2 decaying to $\phi f_0(980)$

  $2\pi^+2\pi^-\pi^0$, $K\bar{K}\pi^0$, $K\bar{K}\eta$, $\Lambda\bar{\Lambda}$, $\Lambda\bar{\Sigma}$, $\Sigma\bar{\Sigma}$

- Work in progress on :

  $\pi^+\pi^-$, $K\bar{K}$, $\pi^+\pi^-\pi^0\pi^0$, $\pi^+\pi^-3(\pi^0)$, ….