INITIAL STATE RADIATION (ISR) STUDY AT BABAR AND THE APPLICATION TO THE R MEASUREMENT AND HADRON SPECTROSCOPY

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A study of several multi-body hadronic final states accompanied by hard photon has been performed using data from e^+ e^- collisions at the c.m. energy near $\Upsilon(4S)$ collected with the *BABAR* detector [1] at the PEP-II collider. The invariant mass of the hadronic final state determines the virtual photon energy, so that data can be compared with direct e^+e^- cross sections. A new preliminary results for the $e^+e^- \to K^+K^-\pi^+\pi^-$ and $e^+e^- \to K^+K^-\pi^0\pi^0$ cross sections are presented based on $232\,\text{fb}^{-1}$. In the $\phi(1020)f_0(980)$ intermediate state a new 1^{--} resonance-like structure has been observed with mass and width $m = 2.175 \pm 0.010 \pm 0.015$ GeV/c^2 and $\Gamma = 58 \pm 16 \pm 20$ MeV. We observe no $Y(4260)$ signal and set a limit of $\mathcal{B}_{Y\to\phi\pi^+\pi^-} \cdot \Gamma^Y_{ee} < 0.4$ eV (90% confidence level) that excludes some models.

Keywords: spectroscopy, ISR, radiative return, BaBar.

1. Introduction

The *BABAR* collaboration has an intensive program for a study of the low energy cross sections and hadron spectroscopy via ISR and few multi-hadron cross sections have been measured[2,3,4]. The interest of this kind of study has been increasing because of discrepancy between the measured muon $g-2$ value and the one predicted by the Standard Model (see presentation by S.Eidelman), where the hadronic contribution to the prediction is taken from e^+e^- experiments at low energies. The ISR study of the $p\bar{p}$ final state[5] gives new measurement of the proton form factor in wide energy range. As a continuation of this program, preliminary BaBar measurements for the $K^+K^-\pi^+\pi^-$ and $K^+K^-\pi^0\pi^0$ final states are presented here based on the $232\,\text{fb}^{-1}$ of data. We also present the first studies of the $\phi\pi^+\pi^-$ and ϕf_0 subprocesses.

2. The ISR method

The ISR cross section for a particular final state f depends on e^+e^- cross section $\sigma_f(s)$ and is obtained from:

$$\frac{d\sigma(s,x)}{dx} = W(s,x)\cdot\sigma_f(s(1-x)), \qquad (1)$$

where $x = \frac{2E_\gamma}{\sqrt{s}}$; E_γ is the energy of the ISR photon in the nominal c.m. frame, and $\sqrt{s}$ is the nominal c.m. energy. The function $W(s,x)$ describes the energy spectrum of the virtual photons and can be calculated with better than 1% accuracy[6,7,8]. ISR photons are produced at all angles relative to the collision axis. The *BABAR* acceptance for such photons is around 10-15 %[8]. An advantage deriving from the use of ISR is that the entire range of effective collision energy is scanned in one experiment. This avoids the relative normalization uncertainties which can arise when data from different experiments are combined. A disadvantage is that the invariant mass resolution about 8 MeV limits the width of the narrowest structure which can be measured via ISR production. With this resolution we see the J/ψ production and measure the product $\Gamma \cdot B_{ee} \cdot B_f$ where Γ and B_{ee}, B_f are the total width, branching fractions of J/ψ to e^+e^- and final state f.

3. Overview of published results

The three-pion final state has been studied using 89 fb^{-1} of *BABAR* luminosity and published in details in Ref. [2]. The

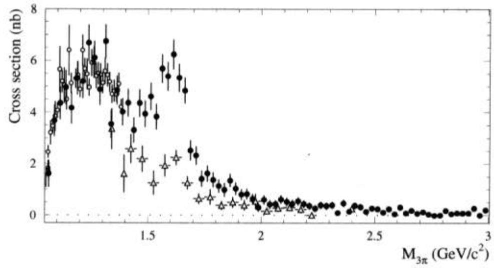

Fig. 1. The $e^+e^- \to \pi^+\pi^-\pi^0$ cross section measured by *BABAR* (filled circles), by SND (open circles), and DM2 (open triangles).

$e^+e^- \to \pi^+\pi^-\pi^0$ cross section in the 1.05-3.0 GeV/c^2 region is presented in Fig. 1. It is in agreement with the SND data, but in contradiction with DM-2 measurement. Figure 2 presents the obtained

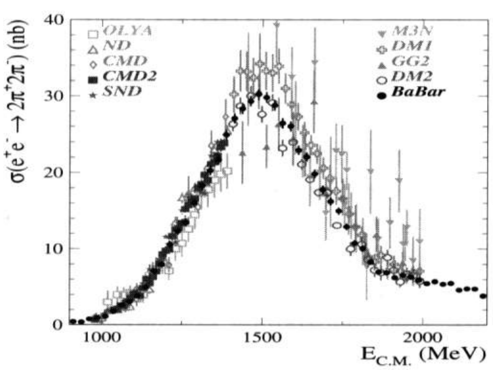

Fig. 2. The $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ cross section obtained from ISR at *BABAR* in comparison with all e^+e^- data.

by *BABAR* $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ cross section [3] in comparison with all existing e^+e^- data. The estimated systematic error is about 5%. Also published are the cross sections for the $e^+e^- \to 3(\pi^+\pi^-)$ and $e^+e^- \to 2(\pi^+\pi^-)\pi^0\pi^0$ final states obtained from 232 fb^{-1} of *BABAR* data [4] and shown in Fig. 3. The hadronic final states with kaons are also presented. These published results are already used for the calculations of the

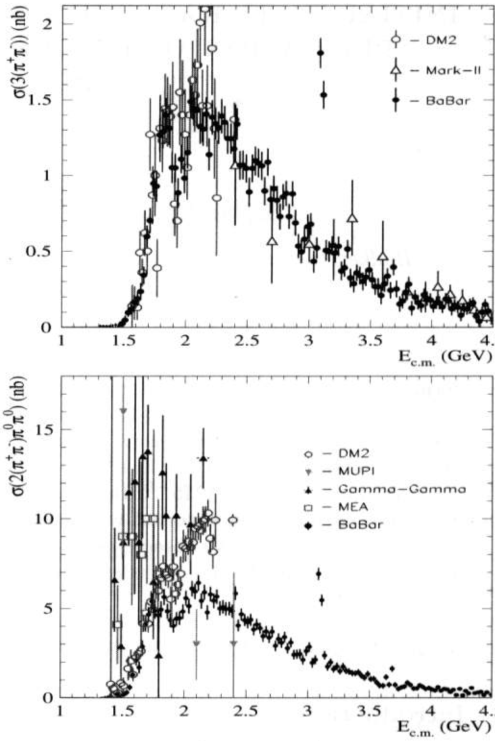

Fig. 3. The (top) $e^+e^- \to 3(\pi^+\pi^-)$ and (bottom) $e^+e^- \to 2(\pi^+\pi^-)\pi^0\pi^0$ cross sections in comparison with direct e^+e^- measurements.

hadronic contribution to muon $(g-2)$ value (see presentation by S.Eidelman). The J/ψ decay rates have been measured for all above final states with better or comparable accuracy with other experiments [9].

4. New study of $K^+K^-\pi^+\pi^-$ and $K^+K^-\pi^0\pi^0$ final states

In this contribution we present an update of our previous analysis [3] of $e^+e^- \to K^+K^-\pi^+\pi^-$ using ISR. We include more data (232 fb^{-1}) and relax the selection criteria, resulting in a fivefold increase in the number of selected events. In Fig. 4 we show the cross sections for the $e^+e^- \to K^+K^-\pi^+\pi^-$ and $e^+e^- \to K^+K^-\pi^0\pi^0$ processes vs. $E_{C.M.}$. The errors are statistical only. The total systematic uncertainty in the $K^+K^-\pi^+\pi^-(\pi^0\pi^0)$ cross section ranges from 7% (10%) at threshold to 9% (15%) at high $E_{C.M.}$. These processes are dominated

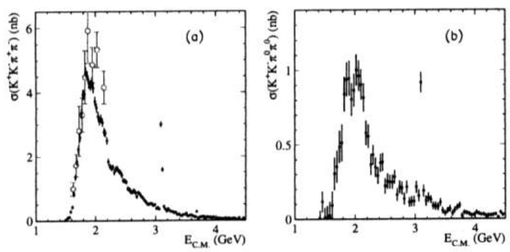

Fig. 4. The (a) $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$ and (b) $e^+e^- \rightarrow K^+K^-\pi^0\pi^0$ cross sections as a function of e^+e^- C.M. energy in comparison with previous DM1 experiment (open circles).

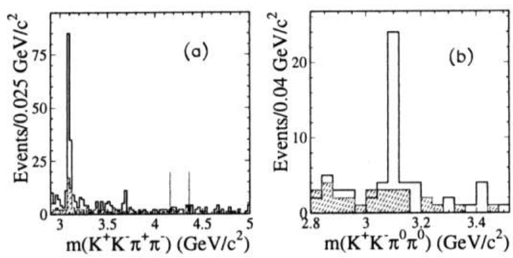

Fig. 6. The (a) $m(K^+ K^- \pi^+\pi^-)$ and (b) $m(K^+ K^- \pi^0\pi^0)$ distributions in the charmonium region for events in the ϕ signal (open histogram) and sideband (shaded histogram) regions. The vertical lines indicate the range used for the $Y(4260)$ search.

by the intermediated states with excited kaons [3] with a small fraction associated with the $\phi(1020)$ production. Selecting ϕ events in

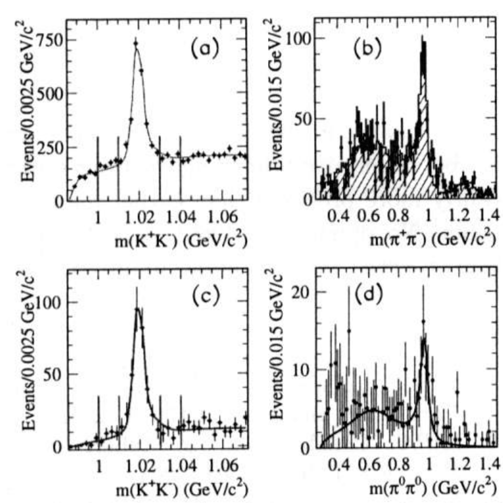

Fig. 5. The $m(K^+K^-)$ projections for the (a) $K^+K^-\pi^+\pi^-$ and (c) $K^+K^-\pi^0\pi^0$ candidates in the data. The vertical lines delimit ϕ signal and sideband regions. (b,d) $m(\pi\pi)$ distribution for events in the ϕ signal region of (a,c) minus that for events in the sidebands. The curves (histogram) represent the results of the fits (simulation) described in the text.

$m(K^+K^-)$ (see Figs. 5(a,c)) and subtracting side-band and MC simulated backgrounds, we obtain the ϕ-associated $m(\pi\pi)$ distributions shown in Figs. 5(b,d). Clear $f_0(980)$ signals are visible in both cases, and there is an indication of $f_2(1270) \rightarrow \pi^+\pi^-$. The histogram (curve) in Fig. 5(b,d) is the result of a simulation that includes $f_0(600)$, $f_0(980)$ and a small fraction of $f_2(1270)$ resonances. Figure 6 shows the $m(K^+K^-\pi^+\pi^-)$ distributions in the charmonium region for events with $m(K^+K^-)$ in the ϕ signal and sideband regions. From the signal-sideband differences of 103±12 and 23±6 events, we calculate $\mathcal{B}_{J/\psi\rightarrow\phi\pi^+\pi^-} \cdot \Gamma_{ee}^{J/\psi} \cdot \mathcal{B}_{\phi\rightarrow K^+K^-} = (2.61 \pm 0.30 \pm 0.18)$ eV and the first measurement of $\mathcal{B}_{J/\psi\rightarrow\phi\pi^0\pi^0} \cdot \Gamma_{ee}^{J/\psi} \cdot \mathcal{B}_{\phi\rightarrow K^+K^-} = (1.54 \pm 0.40 \pm 0.16)$ eV. We also observe 10±4 $\psi(2S) \rightarrow \phi\pi^+\pi^-$ decays, from which we determine $\mathcal{B}_{\psi(2S)\rightarrow\phi\pi^+\pi^-} \cdot \Gamma_{ee}^{\psi(2S)} \cdot \mathcal{B}_{\phi\rightarrow K^+K^-} = (0.28 \pm 0.11 \pm 0.02)$ eV. There is no signal for $Y(4260) \rightarrow \phi\pi^+\pi^-$ and we set the upper limit $\mathcal{B}_{Y\rightarrow\phi\pi^+\pi^-} \cdot \Gamma_{ee}^{Y} < 0.4$ eV at the 90% confidence level, which is in agreement with upper limit obtained by CLEO [10] and is well below our measurement $\mathcal{B}_{Y\rightarrow J/\psi\pi^+\pi^-} \cdot \Gamma_{ee}^{Y} = (5.5 \pm 1.1^{+0.8}_{-0.7})$ eV [11], excluding models (e.g. [12]) in which these two $Y(4260)$ branching fractions are comparable.

We now consider the quasi-two-body intermediate state $\phi f_0(980)$. The $m(KK\pi\pi)$ mass distributions for ϕ associated events with $m(\pi^+\pi^-)$ ($m(\pi^0\pi^0)$) in the 0.85–1.1 GeV/c^2 region are shown in Fig. 7(a,b). Both distributions show the sharp rise from threshold as expected for a pair of relatively narrow resonances, and a slow, smooth decrease at high $E_{C.M.}$, with signals for J/ψ and $\psi(2S)$. Both also show a resonance-like structure at about 2.15 GeV/c^2. Dividing by the efficiency, ISR luminosity, $\mathcal{B}_{\phi\rightarrow K^+K^-} = 0.491$, and $\mathcal{B}_{f_0\rightarrow\pi^+\pi^-(\pi^0\pi^0)} = 2/3(1/3)$, we obtain two consistent measurements of the $e^+e^- \rightarrow \phi f_0$ cross section shown in Fig. 8 (in-

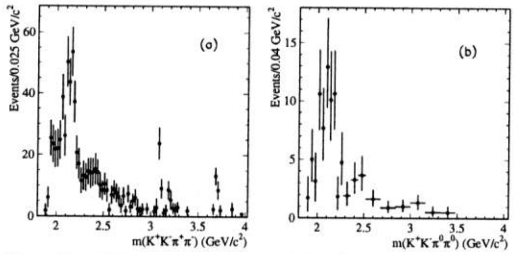

Fig. 7. The number of (a) $e^+e^- \to \phi f_0 \to K^+K^-\pi^+\pi^-$ and (b) $e^+e^- \to \phi f_0 \to K^+K^-\pi^0\pi^0$ events vs. invariant mass.

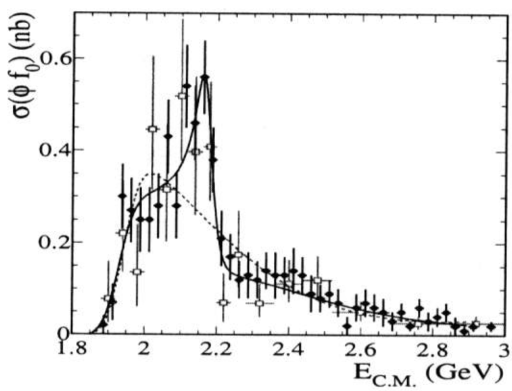

Fig. 8. The $e^+e^- \to \phi(1020)f_0(980)$ cross section obtained via ISR in the $K^+K^-\pi^+\pi^-$ (circles) and $K^+K^-\pi^0\pi^0$ (squares) final states.

cluding about 10% $\phi\pi\pi$ contribution). We attempt to describe this cross section with only a smooth threshold function, and also with the presence of a resonance described by the Breit-Wigner amplitude. There is no theoretical prediction for the form of the cross section other than that, in the absence of resonances, it should fall smoothly from the threshold with increasing s. The result for the smooth threshold function is shown as the dashed curve in Fig. 8 with the confidence level $P(\chi_0^2) = 0.0053$. Including a single resonance, we obtain a good fit with $\chi_x^2 = 37.6/(56-9)$ ($P(\chi_x^2) = 0.84$), shown as the solid line in Fig. 8. The fitted resonance parameter values are $\sigma_0 = 0.13 \pm 0.04 \pm 0.02$ nb, $m_x = 2.175 \pm 0.010 \pm 0.015\ \mathrm{GeV}/c^2$, $\Gamma_x = 0.058 \pm 0.016 \pm 0.020\ \mathrm{GeV}/c^2$, and $\psi_x = -0.57 \pm 0.30 \pm 0.20$ rad. Monte Carlo simulations show that the probability of such a signal arising by chance is less than 10^{-3}. Note that the observed structure is close to the $\Lambda\bar{\Lambda}$ production threshold at 2.23 GeV/c^2 and the opening of this channel may also contribute to the ϕf_0 cross section.

5. Conclusion

A number of ISR processes have been studied with 232 fb^{-1} data sample in the *BABAR* detector, utilizing the excellent detector efficiency and particle identification capabilities of the detector. The preliminary measurements of the $e^+e^- \to K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$ cross sections cover the entire mass range from threshold to 4.5 GeV in the $e^+ e^-$ c.m. system. A new 1^{--} state at 2.175 GeV has been observed with the decay to $\phi(1020)f_0(980)$. Radiative return to the J/ψ resonance allows the measurements of a number of relative branching fractions significantly more precisely than earlier measurements. No signal of $Y(4260) \to \phi\pi^+\pi^-$ has been observed with the upper limit obtained.

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STATUS OF $(g_\mu - 2)/2$ IN STANDARD MODEL

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The current status of the muon anomalous magnetic moment is discussed. The leading order hadronic contribution is reevaluated based on the new data on e^+e^-annihilation. The experimental value is about 3.3 standard deviations higher than the Standard Model prediction.

Keywords: Magnetic moment; Standard Model; New physics.

1. Anomalous magnetic moment

The muon anomalous magnetic moment, a_μ, is one of the most accurately known physical quantities recently measured by E821[1] with a $5 \cdot 10^{-7}$ relative accuracy:

$$a_\mu = (11659208.0 \pm 6.3) \cdot 10^{-10}.$$

Although for electron it is known much better (a_e is measured with a $4.9 \cdot 10^{-10}$ accuracy[2]), a_μ is much more sensitive to new physics effects: the gain is usually $\sim (m_\mu/m_e)^2 \approx 4.3 \cdot 10^4$. Any significant difference of $a_\mu^{\rm exp}$ from $a_\mu^{\rm th}$ indicates new physics beyond the Standard Model (SM). It is conventional to write a_μ as

$$a_\mu^{\rm SM} = a_\mu^{\rm QED} + a_\mu^{\rm EW} + a_\mu^{\rm had}.$$

Taking into account recent progress with the calculation of the 4th and 5th order terms[3,4,5] one obtains

$$a_\mu^{\rm QED} = (116584719.4 \pm 1.4) \cdot 10^{-11}.$$

With the value of α from the latest result for a_e[6] $\alpha^{-1} = 137.035999710(96)$, one obtains[7]:

$$a_\mu^{\rm QED} = (116584718.09 \pm 0.14 \pm 0.08) \cdot 10^{-11}.$$

Here the errors are due to the uncertainties of the $\mathcal{O}(\alpha^5)$ term and α.

The electroweak term is known rather accurately[8]:

$$a_\mu^{\rm EW} = (15.4 \pm 0.1 \pm 0.2) \cdot 10^{-10},$$

where the 1st uncertainty is due to hadronic loops while the 2nd is caused by the errors of M_H, M_t and 3-loop effects.

The hadronic contribution can also be written as a sum:

$$a_\mu^{\rm had} = a_\mu^{\rm had,LO} + a_\mu^{\rm had,HO} + a_\mu^{\rm had,LBL}$$

The dominant contribution comes from the leading order term

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

where

$$R(s) = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)},$$

and the kernel $\hat{K}(s)$ grows from 0.63 at $s = 4m_\pi^2$ to 1 at $s \to \infty$, $1/s^2$ emphasizes the role of low energies. Particularly important is the reaction $e^+e^- \to \pi^+\pi^-$ with a large cross section below 1 GeV.

Our new estimate takes into account the recent progress in the low energy e^+e^-annihilation and includes the data not yet available previously[9,10,11]:

In addition to the previously published ρ meson data[12], CMD-2 reported their final results on the pion form factor F_π from 370 to 1380 MeV[13,14]. The new ρ meson sample has an order of magnitude larger statistics and a systematic error of 0.8%.

SND measured F_π from 390 to 970 MeV with a systematic error of 1.3%[15].

KLOE studied F_π using the method of radiative return or ISR[16,17] at $590 < \sqrt{s} < 970$ MeV with a sample of $1.5 \cdot 10^6$ events and systematic error of 1.3%[18].

BaBar also used ISR and achieved impressive results on various final states with more than two hadrons[19,20,21].

2. New data

In Fig. 1 we show the pion form factor data from CMD-2, KLOE and SND. The $|F_\pi|$ values from CMD-2 and SND are in good agreement. The KLOE data are consistent with them near the ρ meson peak, but exhibit a somewhat different energy dependence: they are higher to the left and lower to the right of the ρ meson peak. However, the contributions to a_μ from all three experiments are consistent as seen from Table 1.

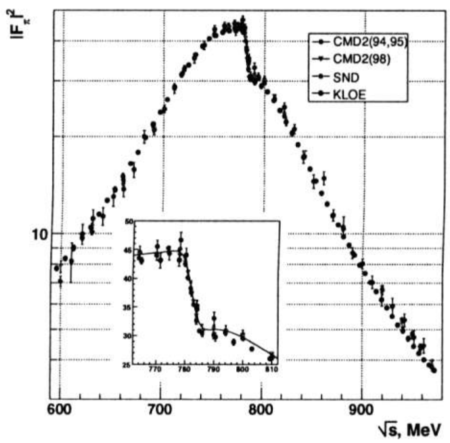

Fig. 1. $|F_\pi|$ from CMD-2, KLOE and SND

Important results were also obtained in the $\pi^+\pi^-\pi^0$ final state due to the ISR measurement at BaBar[19], see Fig. 2. Below 1.4 GeV they agree with those from SND[22], but are substantially higher than DM2 data[23] above 1.4 GeV. BaBar data on the four-[20] and six-pion annihilation[21] are much more precise than previous from Frascati and Orsay.

Table 1. $a_\mu^{\pi\pi,\mathrm{LO}}$ near the ρ

Group	$a_\mu^{\pi\pi,\mathrm{LO}}, 10^{-10}$
Old	$374.8 \pm 4.1 \pm 8.5$ (9.4)
CMD-2	$377.1 \pm 1.9 \pm 2.7$ (3.3)
SND	$376.8 \pm 1.3 \pm 4.7$ (4.8)
KLOE	$375.6 \pm 0.8 \pm 4.9$ (5.0)
Average	376.5 ± 2.5

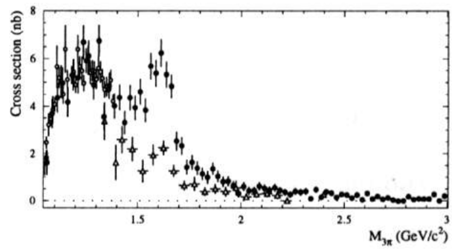

Fig. 2. Cross section of $e^+e^- \to \pi^+\pi^-\pi^0$

3. Results

Using the new data below 1.8 GeV discussed above in addition to the whole data set of[9,10] for old experiments, and assuming that for the hadronic continuum above 1.8 GeV one can already use the predictions of perturbative QCD[24], we can reevaluate the leading order hadronic contribution to a_μ. The results for different energy ranges are shown in Table 2. The theoretical error consists of $1.9 \cdot 10^{-10}$ due to uncertainties of radiative corrections in old measurements and $0.7 \cdot 10^{-10}$ related to mentioned above use of pertubative QCD. It can be seen that due to a higher accuracy of e^+e^- data the un-

Table 2. Updated $a_\mu^{\mathrm{had,LO}}$

$\sqrt{s}$, GeV	$a_\mu^{\mathrm{had,LO}}, 10^{-10}$
2π	$504.6 \pm 3.1 \pm 1.0$
ω	$38.0 \pm 1.0 \pm 0.3$
ϕ	$35.7 \pm 0.8 \pm 0.2$
$0.6 - 1.8$	$54.2 \pm 1.9 \pm 0.4$
$1.8 - 5.0$	$41.1 \pm 0.6 \pm 0.0$
$J/\psi, \psi'$	$7.4 \pm 0.4 \pm 0.0$
> 5.0	$9.9 \pm 0.2 \pm 0.0$
Total	$690.9 \pm 3.9_{\mathrm{exp}} \pm 2.0_{\mathrm{th}}$

certainty of $a_\mu^{\text{had,LO}}$ is now 4.4 (0.63%) compared to 15.3 of Ref.[9] and 7.2 of Ref.[11].

We move now to the higher order hadronic contributions. Their most recent estimate performed in[25] gives $(-9.8 \pm 0.1) \cdot 10^{-10}$ and has negligible error compared to that of the leading order one.

The most difficult situation is with the light-by-light hadronic contribution, which is estimated only theoretically. The older predictions based on the chiral model[26,27] were compatible and much lower than that using short-distance QCD constraints[28] (see also[29]). Their approximate averaging in[30] gives $(120 \pm 35) \cdot 10^{-11}$.

Adding all hadronic contributions we obtain $a_\mu^{\text{had}} = (693.1 \pm 5.6) \cdot 10^{-10}$. This result agrees with other recent estimations, e.g.,[11,25,31,32] and has better accuracy due to the new e^+e^-data. All separate contributions are collected in Table 3. The improved

Table 3. Experiment vs. theory

Contribution	$a_\mu, 10^{-10}$
Experiment	11659208.0 ± 6.3
QED	11658471.94 ± 0.14
Electroweak	$15.4 \pm 0.1 \pm 0.2$
Hadronic	693.1 ± 5.6
Theory	11659180.5 ± 5.6
Exp.–Theory	27.5 ± 8.4 (3.3σ)

precision of the leading order hadronic contribution allows to confirm previously observed excess of the experimental value over the SM prediction with a higher than before significance of more than three standard deviations. Results of the comparison are also shown in Fig. 3. For the first time during last years the accuracy of the SM prediction is slightly better than the experimental one.

What is the future of this test of SM? From the experimental side there are suggestions to improve the accuracy by a factor of 2.5 at E969 (BNL) or even by an order of magnitude at JPARC. It is clear that it will be extremely difficult to improve

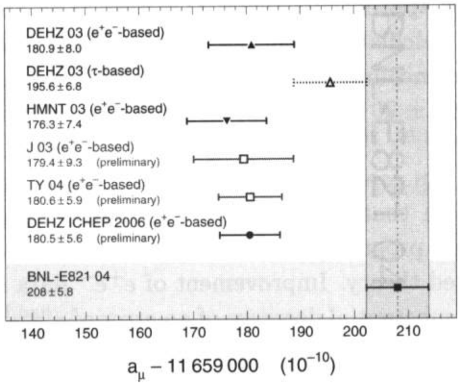

Fig. 3. Comparison with experiment

the accuracy of the SM prediction significantly. One can optimistically expect that by 2008 new high-statistics ISR measurements at KLOE, BaBar and Belle together with the more precise R below 4.3 GeV from CLEO-c will decrease the error of $a_\mu^{\text{had,LO}}$ from 4.4 to $2.8 \cdot 10^{-10}$. Experiments are planned at the new machine VEPP-2000 (VEPP-2M upgrade) with 2 detectors (CMD-3 and SND) up to $\sqrt{s}$=2 GeV with $L_{\max} = 10^{32}\ \text{cm}^{-2}\text{s}^{-1}$. A similar machine (DAΦNE-II) is discussed in Frascati. New R measurements below 5 GeV will be done at the $\tau - c$ factory now under construction in Beijing. We can estimate that by 2010 the accuracy of $a_\mu^{\text{had,LO}}$ will be improved from 2.8 to $2.2 \cdot 10^{-10}$ and the total error of 4.1 will be limited by the LBL term (3.5) and still higher than the expected 2.5 in E969.

There is still no explanation for the observed discrepancy between the predictions based on τ lepton and e^+e^-data[11]. For this reason we are not using τ data in this update. More light on the problem should be shed by the high-statistics measurement of the two-pion spectral function by Belle which preliminary results indicate to better agreement with e^+e^-data than before[33].

Let us hope that progress of theory will allow a calculation of a_μ^{had} from 1st principles (QCD, Lattice). One can mention here a new approach in the QCD instanton model[34] or calculations on the lattice, where there are encouraging estimates of $a_\mu^{\rm had,LO}$, e.g.,[35] $(667 \pm 20) \cdot 10^{-10}$ or attempts to estimate $a_\mu^{\rm had,LBL}$ [36].

In conclusion, I'd like to emphasize once again that BNL success stimulated significant progress of e^+e^- experiments and related theory. Improvement of e^+e^- data led to substantial decrease of an error of $a_\mu^{\rm had,LO}$, which now matches the experimental accuracy. Future experiments as well as development of theory should clarify whether the observed difference between $a_\mu^{\rm exp}$ and $a_\mu^{\rm th}$ is real and what consequences for the Standard Model it implies.

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MEASUREMENTS OF τ BRANCHING FRACTIONS AT B-FACTORIES

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Recent results on a study of hadronic (semileptonic) decays at B-factories are presented.

Keywords: τ-lepton; Decay.

1. Introduction

τ lepton hadronic decays provide an excellent laboratory for a study of low energy hadronic currents under very clean conditions. In these decays a hadronic system is produced via the charged weak current mediated by a $W^{\pm}$ boson. The τ decay amplitude can thus be factorized into a purely leptonic part including τ and ν_τ and a hadronic spectral function.

Experiments described in this report were performed at B-factories - asymmetric e^+e^- colliders with very high luminosity exceeding $10^{34}\text{cm}^{-2}\text{s}^{-1}$ [1,2].

Both detectors, Belle and BaBar are forward/backward asymmetric detectors having high vertex resolution, magnetic spectrometry, excellent calorimetry and sophisticated particle ID system [3,4]. The integrated luminosity collected by both detectors from the start of operation up to now exceeds 1000 fb^{-1}. This corresponds to about 900×10^6 produced τ lepton pairs.

Up to now main efforts of BaBar in this field were focussed on the searches of high multiplicity τ decays [5,6], while Belle are have been studying low multiplicity channels [7].

2. Search for $\tau \to 3\pi^-2\pi^+2\pi^0\nu_\tau$ decay by BaBar

This study is based on the integrated luminosity of 232 fb^{-1}. The analyzed data sample contains six charged track events with zero net charge originated from the interaction region. Each particle was required to have a minimum transverse momentum of 100 MeV/c. Photons, reconstructed in the calorimeter, should have the energy exceeding 50 MeV. To suppress $q\bar{q}$ background the event thrust magnitude is required to be larger than 0.9. Then an event split into two hemispheres in CM frame by the plane perpendicular to the thrust axis. The tag side should have one well identified lepton and at most one photon with the energy below 500 MeV. The signal side has 5 charged pions and exactly two π^0.

The main variable, M^*, used for further analysis, is an approximation of the τ invariant mass:

$$M^{*2} = 2(E_{beam} - E_h)(E_h - P_h) + M_h^2,$$

where E_{beam} is the beam energy and P_h, E_h, M_h are the momentum, energy and invariant mass of the hadronic system. This value is equal to m_τ if neutrino is massless and its direction coincides with the P_h.

The experimental M^* distribution in a wide range is presented in Fig. 1.

The final event count is performed in the signal region $1.3 < M^* < 1.8$ GeV/c^2. According to MC studies, the signal efficiency after all cuts is $(0.66 \pm 0.05)\%$. The number of events observed in the signal region is 10 at the expected total background of $6.5^{+2.0}_{-1.4}$

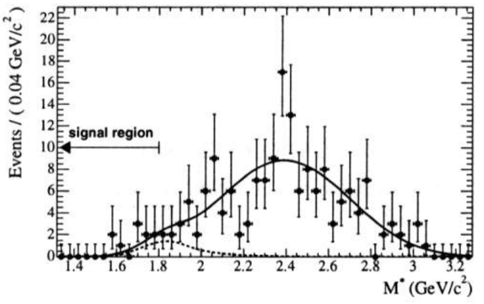

Fig. 1. The M^* distribution of the data events passing the selection criteria. The solid curve represents the total expected background. The dashed curve illustrates the τ background contribution.

which results in the upper limit at 90% of CL as $B(\tau \to 3\pi^- 2\pi^+ 2\pi^0 \nu_\tau) < 3.4 \times 10^{-6}$. In addition an upper limit on the $\tau^- \to 2\omega\pi^-\nu_\tau$ was obtained, $B_{2\omega\pi^-\nu} < 5.4 \times 10^{-7}$. Details of this study can be found in [8].

3. A high statistic study of $\tau^- \to \pi^-\pi^0\nu_\tau$ decay

The reported measurement of the branching fraction and the invariant mass spectrum utilize 72.2 fb^{-1} of the integrated luminosity collected by the Belle detector. At the first stage 22.7×10^6 $\tau^+\tau^-$ events are selected applying loose criteria consisting of low multiplicity and presence of missing particles. Then, within a τ-pair sample, $5.55 \cdot 10^6$ $\tau^- \to h^-\pi^0\nu$ decays are selected by requiring that there be both one charged track and one π^0 in one hemisphere. Here h stands for π or K. The background sources are other τ decays (6.0%) and $q\overline{q}$ processes (2.45%). This background as well as small fraction of $\tau^- \to K^-\pi^0\nu$ events are subtracted. Then using the detection efficiency value obtained by MC gives the value of the branching fraction (preliminary): $\mathrm{B}_{\pi\pi^0\nu} = (25.15 \pm 0.04(\mathrm{stat.}) \pm 0.31(\mathrm{syst.}))\%$ The measured value is in good agreement with the world average [9].

Under the Conservation of Vector Current (CVC) theorem, the $\pi^-\pi^0$ invariant mass spectrum is related to the pion electromagnetic form factor, $|F_\pi|^2$. The experimental $|F_\pi|^2$ values, evaluated in this experiment, are shown in Fig. 2 together with a fit curve taking into account the $\rho(770)$, $\rho'(1450)$ and $\rho''(1700)$ resonances.

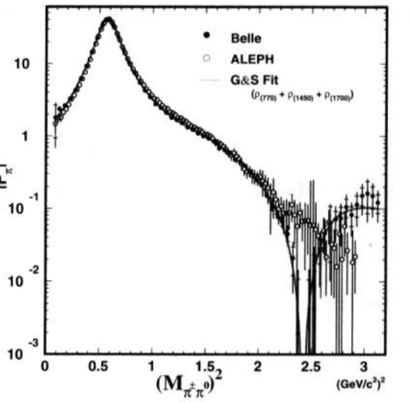

Fig. 2. Pion form factor for $\tau^- \to \pi^-\pi^0\nu$. The solid circles show the Belle results and open squares – the ALEPH results [10]. The curve corresponds to the fit with $\rho(770)$, $\rho'(1450)$ and $\rho''(1700)$.

The obtained $|F_\pi(s)|^2$ is used to evaluate the 2π hadronic vacuum polarization contribution to the muon anomalous magnetic moment $a_\mu^{\pi\pi}$. The preliminary result after integrating over the range $\sqrt{s} = 0.5$ – 1.8 GeV/c^2 is: $a_\mu^{\pi\pi}[0.5, 1.8] = (462.6 \pm 0.6(stat.) \pm 3.2(sys.) \pm 2.3(iso.)) \times 10^{-10}$, where the first error is statistical, the second is systematic and the third is due to isospin symmetry violation. It is in good agreement with previous τ experiments [11] and by about two standard deviations differs from e^+e^- results [12].

4. Study of $\tau^- \to K_S\pi^-\nu_\tau$ decay

This study is based on a 351 fb^{-1} data sample that contains 313×10^6 $\tau^+\tau^-$ pairs, collected with the Belle detector. The analysis uses events with one τ decaying to leptons while the other one goes to the hadronic channel. Events in which both τ decay to leptons are used for normalization.

The main selection criteria for signal events were:

- tag side has one well identified lepton,
- hadron side contains 3 pions including K_S candidate,
- the tag lepton and the hadron system go in the opposite hemispheres,
- no photons with an energy higher than 200 MeV are allowed.

The selected sample of 68100 events contains 55017 (81%) signal events and the background from other τ decays: $K_SK_L\pi\nu$ (8%), $K_S\pi\pi^0\nu$ (4%), $K_SK\nu$ (2%) and 3π (5%). The admixture from the first three sources was determined by MC while the latter one was evaluated from a sideband in the $\pi^+\pi^-$ invariant mass distribution.

The values of the detection efficiency for both signal and normalization samples were determined by the MC simulation taking into account the corrections obtained from data. The preliminary result is: $\mathcal{B}(\tau \to K_S\pi\nu_\tau) = (0.391 \pm 0.004_{\rm stat} \pm 0.014_{\rm syst})\%$. The dominant contribution to the systematic uncertainty comes from K_S detection efficiency(2.5%), background subtraction(1.5%) and particle identification (1.5%). The measured branching ratio is consistent with the PDG value and has much better accuracy [9].

The dynamics of $\tau \to K_S\pi\nu$ are studied by analysis of the $K_S\pi$ invariant mass distribution, shown in Fig. 3. The $K^*(892)$ alone is not enough to describe the $K_S\pi$ the invariant mass spectrum. Taking into account the $\kappa(800)$ and $K^*(1410)$ mesons provides much better description. At present various models to describe the mass distribution are under study.

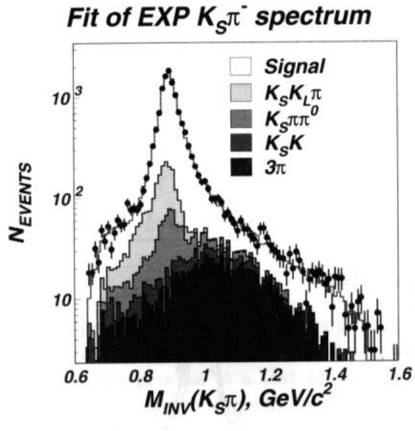

Fig. 3. Comparison of expected and experimental $M_{INV}(K_S\pi)$ distribution for the fit with $K^*(892) + \kappa(800) + K^*(1410)$, also shown are the contributions of background modes.

5. The first observation of $\tau^- \to \phi K^-\nu$ decay

The decay $\tau^- \to \phi K^-\nu$ is Cabibbo suppressed and further restricted by its phase space. The previous search of this decay performed by CLEO and based on 3.1 fb^{-1} of integrated luminosity set upper limits of $B(\tau^- \to \phi K^-\nu) < (5.4 - 6.7) \times 10^{-5}$ and $B(\tau^- \to \phi\pi^-\nu) < (1.2 - 2.0) \times 10^{-4}$ [13].

This work is based on a data sample of 401.4 fb^{-1} corresponding to $3.6 \times 10^8 \tau^+\tau^-$ pairs collected near the $\Upsilon(4S)$ resonance with the Belle detector [14]. The $\tau^- \to \phi K^-\nu$ candidates in the $e^+e^- \to \tau^+\tau^-$ reaction were selected with the following signature:

$$\tau^\pm_{\rm signal} \to \phi(\to K^+K^-) + K^\pm + \text{missing},$$
$$\tau^\pm_{\rm tag} \to (\mu/e)^\pm + n(\leq 1)\gamma + \text{missing}.$$

Other selection criteria are similar to those used in two previous sections. The events of the $\tau^- \to \phi\pi^-\nu$ decay were also observed, but these are treated here as a background process, together with the kinematically allowed but phase-space suppressed decays $\tau^- \to \phi\pi^-(n\pi)\nu$ $(1 \leq n \leq 4)$.

The detection of ϕ-mesons relies on its K^+K^- decay; the final evaluation of the signal yield is carried out using the K^+K^- invariant mass distribution. Figure 4 shows the K^+K^- invariant mass distribution after all selection requirements for $\phi K\nu$ and $\phi\pi\nu$ candidate samples. As there are two possible kaon pair combinations from three kaons on the signal side, this distribution has two entries per event. Therefore, the signal MC shape includes a long tail due to the wrong combinations. Non-resonant background arises mainly from $\tau^- \to K^+K^-\pi^-$. Small contributions are expected from $q\bar{q}$ processes.

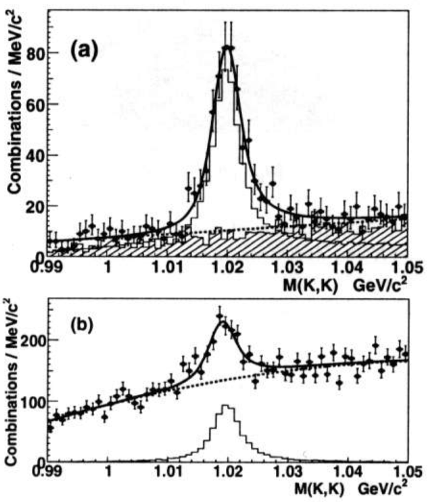

Fig. 4. K^+K^- invariant mass distributions for (a) $\tau^- \to \phi K^-\nu$ and (b) $\tau^- \to \phi\pi^-\nu$. Points indicate the data. The shaded histogram shows the background expectation from MC. The open histogram is the signal MC with $B_{\phi K\nu} = 4 \times 10^{-5}$ (a) and $B_{\phi\pi\nu} = 6 \times 10^{-5}$ (b). The curves show the best fit results and the dashed curves indicate the non-resonant background contribution.

The efficiencies as well as the cross-feed probabilities for the decays to $\phi K\nu$, $\phi\pi\nu$ and $\phi K\pi^0\nu$ were determined by MC simulation. The final yield is 551±33 events which results in the branching ratio value:

$$B(\tau^- \to \phi K^-\nu) = (4.05\pm0.25\pm0.26)\times10^{-5},$$

where the first and the second errors are statistical and systematic, respectively. The main sources of systematic uncertainties are the track reconstruction efficiency as well as the kaon and lepton identification efficiencies.

The study of the possible resonant structure in the ϕK^- mass spectrum do not show the deviations from the phase space distribution.

6. Conclusion

The following results obtained recently at the Belle and BaBar detectors operating at B-factories are discussed in this report:

- An upper limit on the branching fraction $\tau \to 3\pi^-2\pi^+2\pi^0\nu_\tau$ was set by BaBar.
- The branching fractions of $\pi\pi^0\nu$ and $K_S\pi\nu$ were measured by Belle with high accuracy. The invariant mass spectra are under study.
- The first observation of the decay $\tau^- \to \phi K^-\nu$ was done by Belle.

The great potential of these laboratories for τ physics is clearly seen and the new exciting results are anticipated in close future.

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