STATUS AND PROSPECTIVES OF
HADRONIC CROSS SECTION AT LOW
ENERGY*

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Abstract

In this talk I will review the experimental status and the prospects for the future of $\sigma(e^+e^- \to \text{hadrons})$ at low energy. The recent preliminary results obtained by KLOE and BABAR collaborations using the radiative return will be also discussed.

1 Importance of hadronic cross section at low energy

In the last years a renewed interest has arisen on the measurement of hadronic cross section at low energy ($\sqrt{s} < 10 GeV$), mostly because of the precision reached to test the Standard Model at LEP and SLC \[1\] and of the new experimental result of the muon anomalous magnetic moment $a_\mu$ at Brookhaven \[2, 3\]. The experimental accuracy reached so far asks for a precise determination of the theoretical estimate of both $\alpha_{QED}(M_Z^2)$ and $a_\mu$, whose main error comes from the non-perturbative computation of low energy hadronic contributions to the vacuum polarization, which can be computed using $e^+e^-$ data at low energy.

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The amazing precision (of 0.7 ppm) reached on $a_\mu$ at BNL has required a careful re-evaluation of the theoretical estimate: as an example, a large part of the 2.6 $\sigma$ deviation between the measurement of $a_\mu$ published last year [2] and the Standard Model prediction was caused by a wrong sign in the calculation of light-by-light scattering contributions [4].

After this sign correction, however, the situation for $a_\mu$ is still unclear: using only $e^+e^-$ data a 3$\sigma$ discrepancy between the BNL measured value and the theoretical prediction is still present [3, 5, 6], which becomes 1.6 $\sigma$ if hadronic decays of $\tau$ are also used [5].

2 Status of hadronic cross section at low energy

Hadronic $e^+e^-$ annihilation cross sections have been measured by many laboratories in the last 20 years [8]. Usually the cross section for individual channel is measured for energies below 2 GeV, while above that, the hadronic final states are treated inclusively. Fig. 1(right) shows an update compilation of these data done by Burkhardt and Pietrzyk [9]. The main improvements come in the region below 5 GeV, in particular between $2 - 5$ GeV where the BESII coll. has reduced the error to $\sim 7\%$ [10] (before was $\sim 15\%$), and in the region below 1 GeV, where the CMD-2 coll. has measured the pion form factor with a systematical error of 0.6$\%$ in the energy range from 0.61 to 0.96 GeV [11] (see Fig. 1(left)). Both these new results have a significant impact on the updated calculation of $\alpha_{QED}(M_\mu^2)$ [12] and $a_\mu$ [4], and will be discussed below. While the data between 2-5 GeV are now closer to perturbative QCD, the error in the 1-2 GeV region is still 15$: a reduction of this error to few percent will be very important both for $\alpha_{QED}(M_\mu^2)$ and $a_\mu$ calculations.

Measurement of pion form factor at 0.6% from CMD-2

The CMD-2 collaboration has recently published a new measurement of $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ at the VEPP-2M $e^+e^-$ collider, with a 0.6$\%$ systematic uncertainty in the center-of-mass energy range from 0.61 to 0.96 GeV [11]. Such an accuracy has been mainly possible thanks to a careful evaluation of radiative corrections and to the control of different sources of systematic errors. In particular: (i) the error coming from the energy beam is reduced by the resonance depolarisation technique; (ii) the systematic effects on the efficiency evaluation (trigger, tracking) are minimized by normalizing $e^+e^- \rightarrow \pi^+\pi^-$ events to collinear events (mainly $e^+e^- \rightarrow e^+e^-)$. Differently from the previous publication, the cross section is corrected for leptonic and
hadronic vacuum polarization and for photon radiation by the emitted pions (FSR). In order to make meaningful comparison between different data it is very important to have a clear definition of the corrections used.

**Recent results from BESII at BEPC**

The BESII collaboration has recently published a new measurement of $R$ (ratio of hadron to muon production) in the region 2-5 GeV, based on 85 points taken between February and June 99, with an average precision of 6.6%, a factor 2 better of the previous results [10]. $R$ was determined inclusively, from the number of observed hadronic events, $N_{\text{had}}^{\text{obs}}$:

$$R = \frac{N_{\text{had}}^{\text{obs}} - N_{\text{bckg}} - \sum_l N_{ll} - N_{\gamma\gamma}}{\sigma_{\mu\mu} \cdot L \cdot \epsilon_{\text{had}} \cdot (1 + \delta)}$$

where $N_{\text{bckg}}$ is the number of beam-associated background events; $\sum_l N_{ll}$ and $N_{\gamma\gamma}$ are respectively the background coming from misidentified events in one and two photons processes; $L$ is the integrated luminosity; $\delta$ is the radiative correction and $\epsilon_{\text{had}}$ is the overall detector efficiency. In order to keep the error to $\sim 7\%$ a big effort was done on: (a) Monte Carlo simulation to better understand detector efficiency; (b) estimation of $N_{\text{bckg}}$ by means of separated beam and single beam operation; (c) radiative correction by comparing different schemes.
3 First results with radiative return

Starting from the papers of V. N. Baier and V. A. Khoze [13], where the mechanism of returning to a resonant region was for the first time introduced, in the last years big efforts from theoretical and experimental side have been dedicated to the measurement of hadronic cross sections at meson factories using the radiative return, i.e. studying the process $e^+e^- \rightarrow \text{hadrons} + \gamma$. The emission of a photon in the initial state (ISR) lowers the interaction energy and makes possible to produce the hadronic system with an invariant mass varying from the meson ($\phi$, $\Upsilon(4S)$) mass down to the production threshold. High luminosity of the machine compensates for the reduced cross section.

The method [14, 15] represents an alternative and competitive approach to the conventional energy scan: it has the advantage of the same normalization for each energy point, even if it needs a very solid theoretical understanding of ISR (including radiative corrections), as well as a precise determination of the angle and energy of the emitted photon and the full control of background events, especially for events with the photon emitted in the final state (FSR). Radiative corrections have been calculated up to NLO by different groups [16, 17, 18], for the exclusive final hadronic state $\pi^+\pi^-\gamma$ (yielding event generator EVA [14], PHOKHARA [19]) and $4\pi + \gamma$ [20].

Both KLOE experiment at the Frascati $\phi$-factory DAΦNE and subsequently BABAR at SLAC have already presented promising results using this method.

The KLOE analysis is focusing on $e^+e^- \rightarrow \pi^+\pi^-\gamma$, from which $\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma)$ can be extracted. The momenta of the two pions are measured with the Drift Chamber ($\sigma_{p_T}/p_T \leq 0.4\%$), while the photon is not tagged: its energy and direction is retrieved by a kinematical constraint on the missing momentum of the event. This allows to have a large statistics and a reduced background (in particular for FSR, which is below 1%). KLOE has already collected $\sim 500\,pb^{-1}$: the first results, based on less than 1/6 of the total statistics show an error for single point of 2\% above 0.4 GeV$^2$ [21].

Due to the different experimental technique, a comparison between KLOE and CMD-2 will be very important, particularly after the recent discrepancy between $e^+e^-$ and isospin breaking-corrected $\tau$ data [3]. It must be however kept in mind that a precise comparison between these experiments will be significant only if the same corrections are applied to the data: the inclusion of FSR corrections means in particular the evaluation of the
| Energy Range (GeV) | Current Error | Expected Results | Expected error |
|-------------------|---------------|-----------------|----------------|
| 0.3 – 0.6         | 1-2%          | CMD-2, VEPP-2000, KLOE, B-factories | 1%?           |
| 0.6 – 1           | 0.6%          | KLOE, B-factories, VEPP-2000         | < 0.6%?       |
| 1 – 1.4           | 5-10%         | CMD-2, SND, B-factories, VEPP-2000  | < 5%?         |
| 1.4 – 2           | 15-20%        | B-factories, VEPP-2000              | 5%?           |
| 2 – 5             | 7%            | BEPCII, CLEO-C, B-factories         | 3%            |

Table 1: Prospects on R measurement at low energy.

KLOE efficiency for two photon final states (one from initial and one from the final state).

BABAR analysis can benefit from the large collected statistics (∼ 90 fb⁻¹) which corresponds to ∼ 3.6 million fiducial events with a hadronic system invariant mass less than 7 GeV [22]. Using the radiative return, it is possible to perform both an inclusive analysis, which would rely only on the identification of the tagged initial-state radiation (ISR) photon, as well as an exclusive analysis, in which each possible hadronic decay channel is analysed separately. BABAR has already presented some preliminary results both for the 2π and 4π final states [23].

BABAR results, which are expected to cover many different channels, will be in particular important in the region between 1.4 and 2 GeV, where the discrepancy between different experiments is at the level of 15-20%.

4 Prospects for the future

In the next years the measurement of hadronic cross section at low energy should benefit from additional data both from the current experiments as well as from new projects: (1) VEPP-2000, which is a new collider proposed at Novosibirsk with \( \sqrt{s} \) up to 2 GeV and expected luminosity of \( 10^{31} - 10^{32} cm^{-2} sec^{-1} \); (2) CLEO-C, a modification of CESR for a high luminosity machine in 3-5 GeV region [24]; and (3) BESIII/BEPCII, an upgrade for BEPC collider and BES detector.

Tab. [24] shows the prospects for R in the energy range below 5 GeV.

All the future results will contribute to determine a new exciting era for the hadronic cross section measurement.

* [http://www.lns.cornell.edu/public/CLEO/CLEO-C/index.html](http://www.lns.cornell.edu/public/CLEO/CLEO-C/index.html)
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