Precision measurement of the hadronic cross-section through the radiative return method

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Electron–positron annihilation into hadrons plus an energetic photon from initial state radiation allows the hadronic cross-section to be measured over a wide range of energies at high luminosity meson factories. A Monte Carlo generator called PHOKHARA has been constructed, which simulates this process at the next-to-leading order accuracy.

The total cross-section for electron–positron annihilation into hadrons (Fig. 1) is one of the fundamental observables in particle physics. Its high energy behaviour provides one of the first and still most convincing arguments for the point-like nature of quarks. Its normalization was evidence for the existence of quarks of three different colours, and the recent precise measurements even allow for an excellent determination of the strong coupling at very high and intermediate energies through the influence of QCD corrections.

Weighted integrals over this cross-section with properly chosen kernels are, furthermore, a decisive input for electroweak precision tests. This applies, for example, to the electromagnetic coupling at higher energies or to the anomalous magnetic moment of the muon.

Of remarkable importance for these two applications is the low energy region, say from threshold up to centre-of-mass system (cms) energies of approximately 3 GeV and 10 GeV, respectively. Recent measurements based on energy scans between 2 and 5 GeV have improved the accuracy in part of this range. However, similar, or even further improvements below 2 GeV would be highly welcome. The region between 1.4 GeV and 2 GeV, in particular, is poorly studied and no collider will cover this region in the near future. Improvements or even an independent cross-check of the precise measurements of the pion form factor in the low energy region by the CMD2 and DM2 collaborations would be extremely useful, in particular in view of the disagreement found with the analysis based on isospin-breaking-corrected τ decays [2]. Since this dominates in the analysis of the muon anomalous magnetic moment, this kind of studies will help to clarify the situation with respect to the experimental measurement [3] of this quantity.

Experiments at present electron–positron colliders operate mostly at fixed energies, albeit with enormous luminosity, with BABAR and BELLE at 10.6 GeV, CLEO-C in the region between 3 and 5 GeV, and KLOE at 1.02 GeV as most prominent examples.

This peculiar feature allows the use of the radiative return, i.e. the reaction

$$e^+(p_1)+e^-(p_2) \to \gamma(k_1)+\gamma^*(Q)(\to \text{hadrons}) \;, \quad (1)$$

to explore a wide range of Q^2 in a single experiment [4]. Nominally an invariant mass of the hadronic system between $2m_\pi$ and the cms energy of the experiment is accessible. In practice, to clearly identify the reaction, it is useful to consider only events with a hard photon — tagged or untagged — which lowers the energy significantly.

The study of events with photons emitted under both large and small angles, and thus at a significantly enhanced rate, is particularly attractive for the $\pi^+\pi^-$ final state with its clear signature, an investigation performed at present at DAΦNE [5]. Events with a tagged photon, emitted under a large angle with respect to the beam, have a clear signature and are thus particularly

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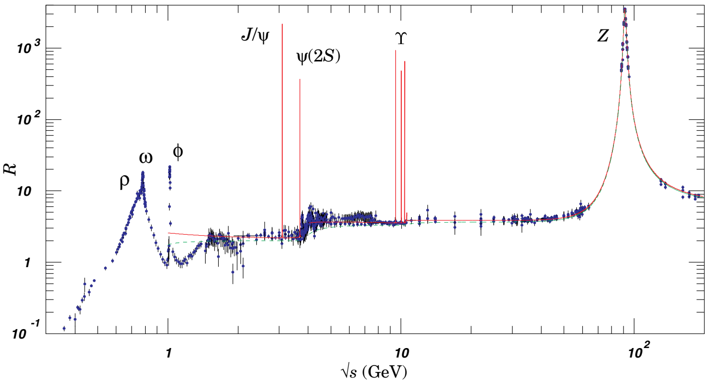

Figure 1. Hadronic ratio $R = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$. Plot from Ref. [1].

suited to the analysis of hadronic final states of higher multiplicity [6].

To arrive at reliable predictions including kinematical cuts as employed by realistic experiments, a Monte Carlo generator is indispensable. The inclusion of radiative corrections in the generator and the analysis is essential for the precise extraction of the cross-section. For hadronic states with invariant masses below 2 or even 3 GeV, it is desirable to simulate the individual exclusive channels with two, three, and up to six mesons, i.e. pions, kaons, etas, etc., which requires a fairly detailed parametrization of the various form factors.

A first program, called EVA, was constructed some time ago [4] to simulate the production of a pair of pions together with a hard photon. It includes initial-state radiation (ISR), final-state radiation (FSR), their interference, and the dominant radiative corrections from additional collinear radiation through structure function (SF) techniques. This project was continued with the construction of a generator for the radiative production of four pions [7]. As a further development of this project a new Monte Carlo generator called PHOKHARA [8–11] has been constructed, which includes, in contrast to the former generators, the complete next-to-leading order (NLO) radiative corrections. PHOKHARA exhibits a modular structure that simplifies the implementation of additional hadronic modes or the replacement of the currents(s) of the existing modes. These programs and the future versions of PHOKHARA can be downloaded from `http://cern.ch/german.rodrigo/phokhara/`.

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