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NUCLEON FORM FACTORS MEASUREMENTS VIA THE RADIATIVE RETURN AT B-MESON FACTORIES *

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1 Introduction

The present-day experimental situation concerning nucleon form factors in the space-like region shows a substantial discrepancy between measurements via the Rosenbluth method and the recoil polarization technique (see Ref. [1] for a review). It was shown recently [2], that the difference can be partly explained by two-photon mediated processes, that were not taken into account in the original analysis. More information about nucleon form factors in the time-like region will not only improve poor experimental knowledge there, but it will also shed light on the situation in the space-like region. The radiative return method [3] is a powerful tool to provide that information using data of

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B- meson factories [4], as we shall advocate also here.

2 The radiative return and nucleon form factors measurements

To profit fully from the radiative return method, a Monte Carlo event generator is needed. For that purpose an upgraded version of PHOKHARA [5] (PHOKHARA 4.0) was developed [4]. It allows for a simulation of the reaction $e^+e^- \to N\bar{N}\gamma(\gamma)$, where $N\bar{N}$ is a nucleon-antinucleon pair. It includes initial state radiation (ISR) at next-to-leading order (NLO). Basing on [6], we expect that the leading order (LO) final state radiation (FSR) is negligible at B-factories, but NLO FSR (not included yet in the program) will be important for a measurement aiming for a few percent accuracy.

2.1 The nucleon current

The matrix element of the electromagnetic nucleon current is given by

$$J_\mu = -ie \cdot \bar{u}(q_2) \left(F_1^N(Q^2)\gamma_\mu - \frac{F_2^N(Q^2)}{4m_N} [\gamma_\mu, \not{Q}\,] \right) v(q_1) \ , \tag{1}$$

where F_1 and F_2 are the Dirac and Pauli form factors and m_N is the nucleon mass. The antinucleon and nucleon momenta are denoted by q_1 and q_2 respectively, and $Q = q_1 + q_2$. They are related to the magnetic and electric Sachs form factors by

$$G_M^N = F_1^N + F_2^N \ , \qquad G_E^N = F_1^N + \tau F_2^N \ , \quad \text{with} \ \ \tau = Q^2/4m_N^2 \ .$$

The parametrization of the form factors used in PHOKHARA follows from [7, 8] and is in agreement [4] with the ratio of the form factors measured with the recoil polarization method [9].

Available experimental data in the time-like region consist only of total cross section measurements, and give practically no information about the form factors. Predictions for $\sigma(e^+e^- \to p\bar{p})$, $\sigma(e^+e^- \to n\bar{n})$ and $\sigma(p\bar{p} \to e^+e^-)$, obtained with the form factors used in PHOKHARA, are in good agreement with the data, as shown in Fig. 1 for the reaction $e^+e^- \to p\bar{p}$. Other cross sections can be found in Ref. [4].

2.2 The method for the measurement of the nucleon form factors

The idea of the nucleon form factors measurements in the time-like region via the radiative return is based on studies of angular distributions. The hadronic tensor of the process $e^+e^- \to N\bar{N}\gamma$ depends only on $|G_M^N|^2$ and $|G_E^N|^2$ for non-polarized nucleons [4] and thus it is not possible to measure the relative

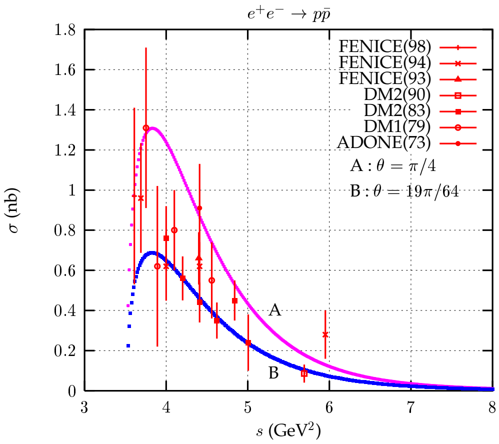

Figure 1: *Comparison of the measured* [10] $e^+e^- \to p\bar{p}$ *cross section with the model from Ref.* [7]*. Predictions are given for two different values ($\pi/4$ - curve A and $19\pi/64$ - curve B) of the parameter θ.*

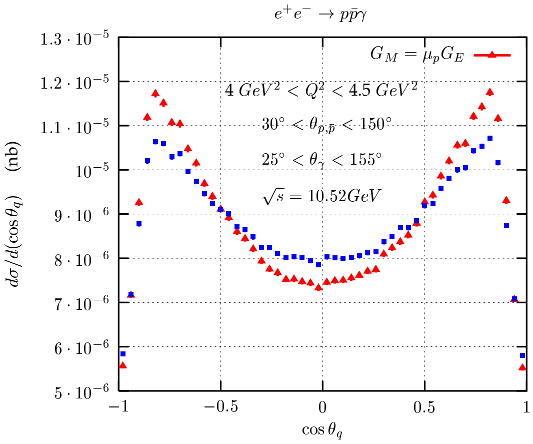

Figure 2: *Angular distribution in the polar angle of vector* $\mathbf{q} = (\mathbf{q}_2 - \mathbf{q}_1)/2$ *in the CMS of the* e^+e^- *pair.*

phase between G_M^N and G_E^N, without measuring the nucleon polarization. Distributions in the the $\mathbf{q} = (\mathbf{q}_2 - \mathbf{q}_1)/2$ polar angle, for unpolarized nucleons, are shown in Figs. 2 and 3. To show how sensitive are the angular distributions to the form factors ratio, two predictions are presented: differential cross sections obtained for the model described above, and differential cross section with the assumption that $G_M^p = \mu_p G_E^p$ and the constraint that the $\sigma(e^+e^- \to p\bar{p})$ remains unchanged. The predicted number of events, for BaBar energy and 4 GeV^2 < Q^2 < 4.5 GeV^2, is about 3500 with an accumulated luminosity of 200 fb^{-1}. It means, that a two parameter fit ($|G_M^N|$ and $|G_E^N|$) to the experimental angular distributions, preferably in the $\mathbf{Q}$-rest frame (compare Fig. 2 and Fig. 3), with relatively small Q^2 spacing, is possible, and it will not be limited statistically.

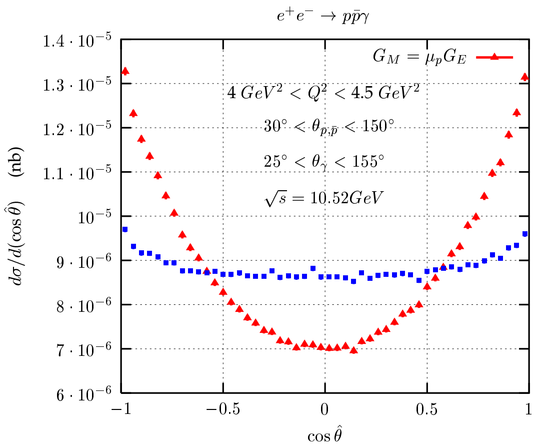

Figure 3: *Angular distribution in the polar angle of vector* $\mathbf{q} = (\mathbf{q}_2 - \mathbf{q}_1)/2$ *in the* $\mathbf{Q}$*-rest frame (*$\mathbf{q} = \mathbf{q}_2$ *in this frame).*

3 Summary

The Monte Carlo simulations with PHOKHARA 4.0 show that it is possible to measure separately the electric and magnetic nucleon form factors in time-like region at B-meson factories by studying nucleon angular distributions of events with emission of photons. The radiative return is well suited for this measurement over a wide kinematic range.

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