Nucleon form factors measurements via the radiative return 
at B-meson factories *

E. Nowak

Institute of Physics, University of Silesia, Katowice, POLAND.

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 polarisation 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 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 gen-
erator 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 
$e^+e^- \rightarrow N\bar{N}\gamma(\gamma)$, where $N\bar{N}$ is a nucleon-antinucleon pair. It includes 
initial state radiation (ISR) at next-to-leading order (NLO). Basing on [4], 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.

* Supported in part by EC 5th Framework Programme under contract 
HPRN-CT-2002-00311 (EURIDICE network).
Figure 1: Comparison of the measured $e^+e^-\rightarrow p\bar{p}$ 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 $\theta$.

2.1 The nucleon current

The matrix element of the electromagnetic nucleon current is given by

$$J_\mu = -ie\cdot\bar{u}(q_2)\left(F_1^N(Q^2)\gamma_\mu - \frac{F_2^N(Q^2)}{4m_N}\left[\gamma_\mu, Q\right]\right)v(q_1),$$  \hspace{1cm} (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

$$G_M^N = F_1^N + F_2^N, \hspace{1cm} G_E^N = F_1^N + \tau F_2^N,$$

with $\tau = Q^2/4m_N^2$.

The parametrization of the form factors used in PHOKHARA follows from [6, 7] and is in agreement with the ratio of the form factors measured with the recoil polarisation 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 $\sigma(e^+e^-\rightarrow p\bar{p})$, $\sigma(e^+e^-\rightarrow n\bar{n})$ and $\sigma(p\bar{p}\rightarrow e^+e^-)$, obtained with the form factors used in PHOKHARA, are in good agreement with the data, as shown in Fig. 1 for the reaction $e^+e^-\rightarrow p\bar{p}$. 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 $e^+e^- \rightarrow N\bar{N}\gamma$ depends only on $|G_M^N|^2$ and $|G_E^N|^2$ for non-polarized nucleons and thus it is not possible to measure the relative phase between $G_M^N$ and $G_E^N$, without measuring the nucleon polarization. Distributions in the the $q = (q_2 - q_1)/2$ 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 $G_p^M = \mu_p G_p^E$ and the constraint that the $\sigma(e^+e^- \rightarrow p\bar{p})$ remains unchanged. The predicted number of events, for BaBar energy and $4 \text{ GeV}^2 < Q^2 < 4.5 \text{ GeV}^2$, 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 $Q$-rest frame (compare Fig. 2 and Fig. 3, with relatively small $Q^2$ spacing, is possible, and it will not be limited statistically.

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 timelike 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.

4 Acknowledgements

The author would like to thank H. Czyż and G. Rodrigo for careful reading the manuscript.
Figure 3: Angular distribution in the polar angle of vector $q = (q_2 - q_1)/2$ in the $Q$-rest frame ($q = q_2$ in this frame).

References

1. J. Arrington, Phys. Rev. C 68 (2003) 034325 [nucl-ex/0305009].
2. Y. C. Chen, A. Afanasev, S. J. Brodsky, C. E. Carlson, M. Vanderhaeghen, hep-ph/0403058.
3. S. Binner, J. H. Kühn and K. Melnikov, Phys. Lett. B 459 (1999) 279 [hep-ph/9902399].
4. H. Czyż, J. H. Kühn, E. Nowak, G. Rodrigo, Eur. Phys. J. C 35 (2004) 527 [hep-ph/0403062].
5. G. Rodrigo, H. Czyż, J.H. Kühn and M. Szopa, Eur. Phys. J. C 24 (2002) 71 [hep-ph/0112184].
6. H. Czyż, A. Grzelińska, J. H. Kühn and G. Rodrigo, Eur. Phys. J. C 33 (2004) 333 [hep-ph/0308312]; hep-ph/0404078.
7. F. Iachello, A. D. Jackson, A. Lande, Phys. Lett. B 43 (1973) 191.
8. F. Iachello, eConf C0309101:FRWP003, 2003 [nucl-th/0312074].
9. O. Gayou et al. Phys. Rev. Lett. 88 (2002) 092301 [nucl-ex/0111010]; Phys. Rev. C 64 (2001) 038202; M. K. Jones et al. Phys. Rev. Lett. 84 (2000) 1398 [nucl-ex/9910005].
10. A. Antonelli et al. (FENICE collaboration), Nucl. Phys. B517 (1998) 3; Phys. Lett. B 334 (1994) 431; Phys. Lett. B 313 (1993) 283; D. Bisello et al. (DM2 collaboration), Z. Phys. C48 (1990) 23; Nucl. Phys. B224 (1983) 379; B. Delcourt et al. (DM1 collaboration), Phys. Lett. B 86 (1979) 395; M. Castellano et al. (ADONE collaboration), Nouvo Cim. 14A (1973) 1.