Progress in Particle and Nuclear Physics 67 (2012) 599–602

Contents lists available at SciVerse ScienceDirect

Progress in Particle and Nuclear Physics

journal homepage: www.elsevier.com/locate/ppnp

Review

Time-like electromagnetic form factors at PANDA

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ARTICLE INFO

Keywords:
Dirac equation
Anomalous magnetic moment
Scattering matrix expression
Dirac form factor
Pauli form factor

ABSTRACT

This proceeding is a summary based on the talk given at the 33rd international school of nuclear physics, Erice, Italy. An introduction following the historical development of a theoretical treatment of nucleon electromagnetic form factors will be given. A feasibility study on the time-like electromagnetic form factor at PANDA is presented based on a Monte Carlo simulation. Some recent progress on electromagnetic processes at PANDA is also given.

1. Introduction

By posing Lorentz covariant and gauge invariant conditions, Foldy [1] has shown that a general form of Eqs. (1) and (2) can be inserted into the Dirac equation,

$$e\gamma_\mu \sum_{n=0}^{\infty} \Box^n A_\mu \tag{1}$$

$$-i\kappa\gamma_\nu\gamma_\mu \sum_{n=0}^{\infty} \Box^n \left(\frac{\partial A_\mu}{\partial x_\nu} - \frac{\partial A_\nu}{\partial x_\mu}\right) \tag{2}$$

where γ is for the Dirac matrix, κ is the anomalous magnetic moment and A is the potential of the external electromagnetic field. The lowest order term in Eq. (1) is the so called Dirac term containing electric charge and also magnetic moment of point-like particles like electrons; the lowest order term of Eq. (2) is named after Pauli who first introduced them in 1941 [2], which contains the anomalous magnetic moment. These two general expressions result in two functions of momentum transfer, q^2, in the scattering matrix expression. They are conventionally noted as Dirac form factor($F1$) and Pauli form factor($F2$). These expressions interfere with each other in the cross section formula because $F1$ also has the magnetic coupling. A physically transparent reformulation can be done as [3]:

$$G_E \equiv F_1 + \frac{\kappa q^2}{4M^2} F_2, \qquad G_M(q^2) = F_1(q^2) + \kappa F_2(q^2), \tag{3}$$

which are generally known as Sachs form factors. G_E and G_M represent the electric and magnetic form factors respectively in the Breit frame. An alternative way to interpret the physical meaning of G_E and G_M can be found in [4].

Depending on the reaction used in the study of electromagnetic form factor, it can be characterized by space-like ($q^2 < 0$) and time-like ($q^2 > 0$) regions. Compared with space-like region with electron scattering as an experimental tool, there is much less data available in the time-like region, which can be studied by electron position collider or proton antiproton

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0146-6410/$ – see front matter
doi:10.1016/j.ppnp.2012.01.034

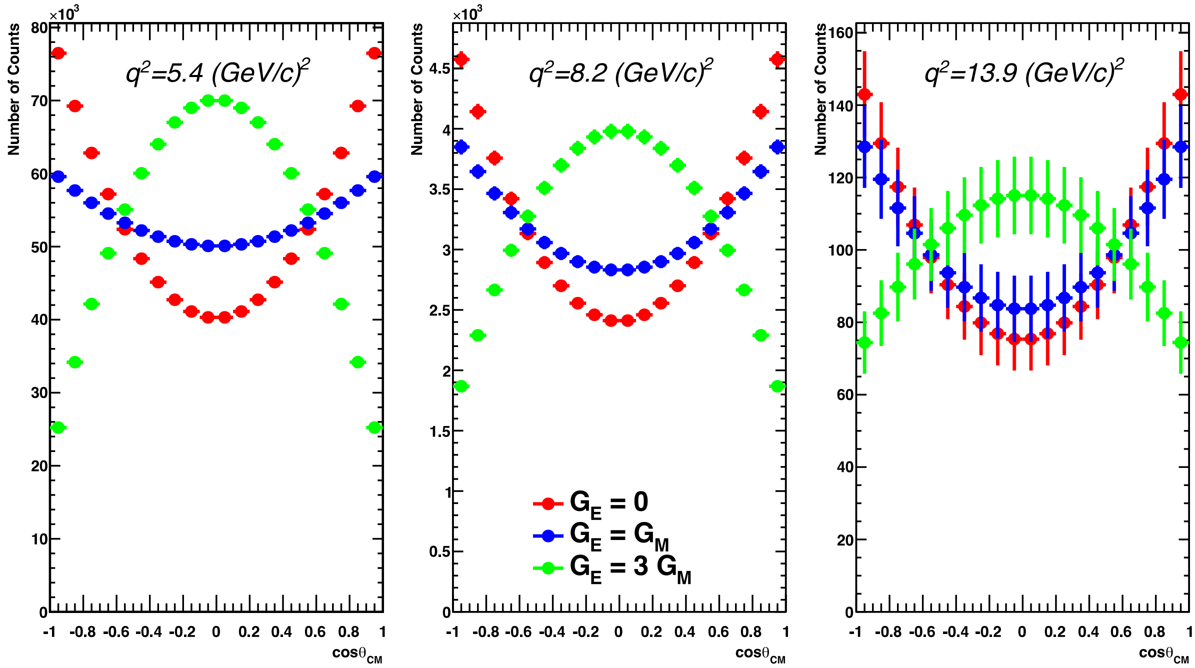

Fig. 1. Relative yield distribution of electron positron pair as a function of scattering angle in CM frame. Different colors represent different G_E and G_M relations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

annihilation. Because of the high luminosity (1.6×10^{32} $\text{cm}^{-2}\text{s}^{-1}$) and good tracking capability, the PANDA experiment at the FAIR facility will provide a great opportunity for precise measurement of time-like electromagnetic form factors of protons [5].

2. Feasibility study

The main challenge on the study of time-like electromagnetic form factors with proton antiproton annihilation is the large background of hadronic products compared with pure leptonic channels. For example, two-pion production has 10^6 higher yield than electron positron pairs, which is considered as the main background. Three-pion production is relatively easy to suppress compared with the two-pion case. In order to investigate the feasibility to measure the time-like electromagnetic form factors at PANDA, a systematic Monte Carlo study has been performed and published as [6]. In this study, a theoretical cross section (Rosenbluth formula) can be expressed as Eq. (4)

$$\frac{d\sigma}{d\cos\theta} = \frac{\pi\alpha^2}{8M^2\sqrt{\tau(\tau-1)}}\left[|G_M|^2\left(1+\cos^2\theta\right) + \frac{|G_E|^2}{\tau}(1-\cos^2\theta)\right], \quad \tau = \frac{q^2}{4M^2}, \tag{4}$$

where the modulus of G_E and G_M are considered as parameters to be extracted from the experimentally measured cross section. It has been demonstrated that electron and positron pair products can be reconstructed with reasonable efficiency while background from pions can be sufficiently vetoed with a suppression factor of 10^{10} by optimizing cutting conditions. For details, please refer to [6]. Some typical distributions with different relations between G_E and G_M is given in Fig. 1. Fig. 2 shows the suppression of pion background events with different cutting conditions. Roughly 50% of electron and positron pair events survived after applying a cutting condition to veto pion background events sufficiently. The reconstructed electron positron events distribution is given in Fig. 3. Reconstruction efficiency has been extracted from simulation. After a correction with reconstruction efficiency, the reconstructed events are in good agreement with Monte Carlo input, which demonstrated the feasibility of studying time-like electromagnetic form factor with PANDA. With a high statistic and good tracking capability, PANDA is expected to improve the precision of the existing data by a factor of 10 and expand the data to a high q^2 distribution (see Fig. 4).

3. Outlook

Recently, the possibility to study the transition distribution amplitude with PANDA has been initiated by the Mainz group with other PANDA collaborators [7,8]. A measurement with polarized setup will allow the determination of a relative phase between the real and imaginary part of electromagnetic form factors [9]. The feasibility study to use transversely polarized targets is undergoing [10].

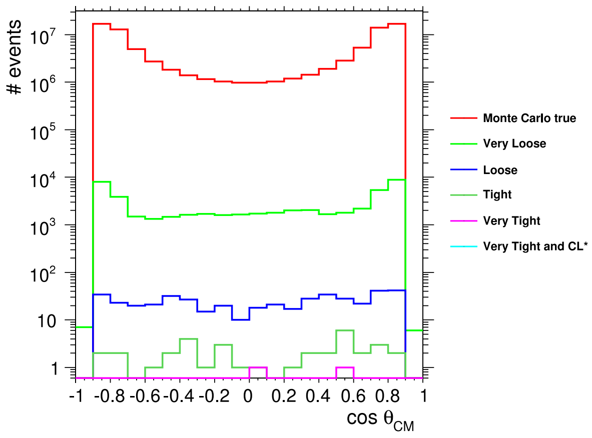

Fig. 2. Suppression of pion background events with different cutting conditions. For details, please refer to [6].

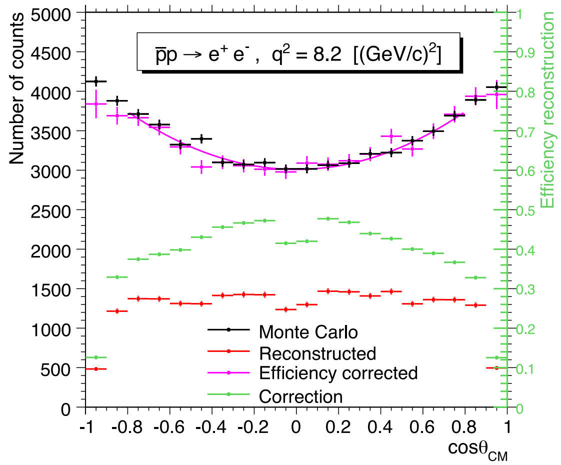

Fig. 3. Reconstructed electron positron pair events from simulated data. Tracking efficiency from simulation was used to obtain a corrected cross section.

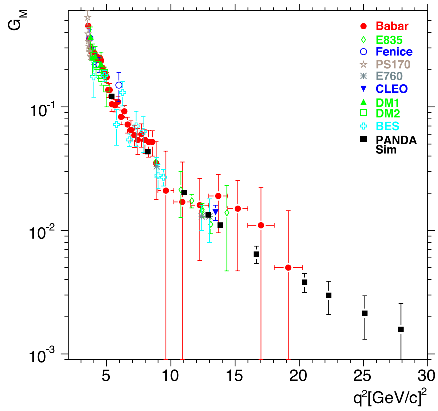

Fig. 4. Expected output from PANDA experiment. The precision of data can be expected to be improved by a factor of 10.

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