Addendum to the DANTE (DAnae Nucleon Time-like form factor Experiment) Letter of Intent

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This document is an update of the Letter of Intent "Measurement of the Nucleon Form Factors in the Time-Like region at DAFNE2" presented at the LNF-SC Meeting of November 31^{st}, 2005, prepared to address the recommendations and comments of the Committee.

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1 THE PHYSICS CASE

1.1 The importance of studying Nucleon Form Factors

- Reproducing the structure of the nucleon is one of the defining problems of QCD. The electromagnetic form factors of the nucleon offer a unique window on strong interaction dynamic over a wide range of momentum transfer. At small momentum transfer, they are sensitive to the gross properties of the nucleon, like the electric charge distribution and magnetization current, while at high momentum transfer they encode information on the quark substructure of the nucleon as described by QCD. Their detailed understanding is therefore important for unraveling aspects of perturbative and non perturbative nucleon structure. The form factors also contain important information on nucleon radii and vector meson coupling constants. Moreover, they are necessary ingredients as input for the description of all processes where nucleons are involved.

  QCD predictions from non-perturbative to perturbative regime can be tested according to their capability to reproduce the form factors measurements for any value of the momentum transfer.

- Elastic nucleon form factors are intimately connected to the Generalized Parton Distributions (GPDs). This new, powerful theoretical framework has been introduced nearly a decade ago as the modern tool to describe hadrons in term of quark and gluon degrees of freedom [1].
  The GPDs simultaneously carry information on both the longitudinal and transverse distribution of partons in a fast moving hadron, and interpolate between usual partonic distributions and form factors. Their study can provide a wealth of new information on the structure of the nucleon, such as the contributions of the orbital angular momentum of quarks and gluons that are the last unknown pieces of the puzzle of the spin content of the nucleon.
  The GPDs can be determined in exclusive reactions: the exclusive vector-meson production allows the determination of unpolarized GPDs, whereas the esclusive production of pseudoscalar-mesons can be used to measure the polarized GPDs. Because of their multidimensional structure, it is essential to study as many different processes as possible to be able to disentangle the functions from the measured observables.
  The calculation of GPDs requires non-perturbative methods, so that at present one is unable to get along without models for GPDs in order to describe data on hard exclusive reactions. These models are frequently simple parameterizations, constrained by general symmetry properties, by reduction formulas (which express that certain GPDs become the usual parton

densities in the forward limit of vanishing momentum transfer), and by sum rules (which express that the integrals of quark GPDs over x-Bjorken give the contributions of these quarks to the elastic form factors of the nucleon).

At present, it is just exploiting these sum rules and adjusting a few free parameters to the experimental data on the Dirac and Pauli form factors of the nucleon, that one aims at a suitable parameterizations of the GPDs.

- One of the great challenge of modern hadron physics is to unravel the precise role of the sea quarks in the structure of the nucleon. One way to probe the sea contribution is to investigate wheather strange quarks contribute to the static properties of the nucleon, such as the charge distribution and magnetization of the proton. A particularly clean experimental technique for isolating the effects of strange quarks in the nucleon is measuring parity-violating amplitudes in the elastic scattering of polarized electrons from proton. The asymmetry, which is caused by the interference between the electromagnetic interaction (in which a photon is exchanged) and neutral weak interaction (which involves the excange of a Z^0 boson), depends on the electric and magnetic nucleon Sachs form factors and on the proton axial form factor.

  So, the electromagnetic form factors enter directly in the determination of the exact contribution of the sea's strange quarks to the proton's charge distribution and magnetization.

  Establishing a non-trivial role for the sea-quarks would provide new insight into non perturbative dynamic of the strong interactions. At present, the major contribution to the uncertainty on the parity violating asymmetry comes from the uncertainty on the nucleon electromagnetic form factors, in particular from that on the neutron electric form factor.

- The nucleon form factors have also direct bearing on neutrino physics. The vector part of the neutrino quasi-elastic scattering cross section can be expressed in terms of the vector electric and magnetic form factors. Through the conserved vector current hypothesis, these form factors may be related to the elastic nucleon form factors measured in elastic eN scattering as shown in Ref.[2].

  In light of the recent controversy in the space-like form factors as measured with different techniques, it is important for neutrino physicists to understand the state of nucleon form factor measurements and realize that there are open questions that are currently being investigated.

Contrary to the common believe, nucleon form factors are still not fully understood. Therefore, they are still subject to an intense experimental and theoretical investigation.

1.2.1 Space-Like Region

In the space-like region, a lot of data for nucleons have been accumulated using elastic electron scattering (for a review, see Ref. [3] and references therein). While the traditional Rosenbluth-separation method suggests the well known scaling of the ratio G_E/G_M between the electric and magnetic Sachs form factors (that is, G_E^p/G_M^p constant and approximately equal to the magnetic moment of the proton μ_p), new measurements on the electron-to-proton polarisation transfer in $\vec{e}^-p \to e^-\vec{p}$ scattering reveal strongly contradicting results, with a monotonically decreasing ratio for increasing momentum transfer $-q^2 = Q^2$ [3–5]. This in turn reflects in an approximate $1/Q$ trend of the ratio of the Pauli to Dirac form factors F_2/F_1 in the presently explored range $2 \leq Q^2 \leq 5.6$ GeV^2 [3], which is in contradiction with the $1/Q^2$ trend predicted by perturbative QCD and, more generally, by dimensional counting rules [6]. This fact has stimulated a lot of theoretical work in order to test the reliability of the Born approximation underlying the Rosenbluth method (see Ref. [7] and references therein).

1.2.2 Time-Like Region

In any case, the above scenario makes it crucial to deepen our knowledge of G_E and G_M also in the time-like region, where form factor measurements give information on charge and current distributions in a different kinematic region and on additional observables. In fact, while space-like form factors of stable hadrons are real, time-like form factors are complex because of the residual interactions of the involved hadrons. So for their complete knowledge moduli and phases have to be measured. The moduli can be extracted by measuring the center-of-mass angular distributions of the final products in $e^+e^- \to N\bar{N}$ or $p\bar{p} \to \ell^+\ell^-$ processes (see Eq. 3 in this Appendix). The phases are related to the polarisation of the involved particles. It is worth noticing that in $e^+e^- \to N\bar{N}$ reactions, the outcoming nucleons are polarized even if the electron and positron beams are unpolarised. Specifically they have a polarisation $\mathcal{P}_y$ normal to the scattering plane proportional to the phase difference between G_E and G_M [8](see Eq. 5 in this Appendix). This polarization is extremely sensitive to the theoretical input, as it is evident in Fig.1, and it can discriminate among analytic continuations to the time-like region of models that successfully reproduce the proton G_E/G_M data in the space-like region [9, 10].

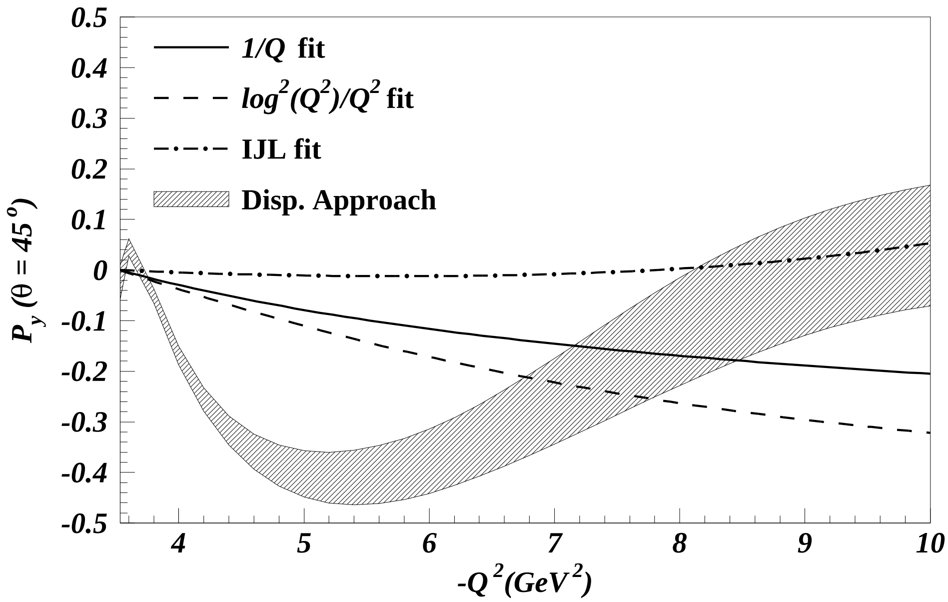

Fig. 1. Predicted polarisation P_y in the time-like region for some selected nucleon form factor fits. The plot is for $\theta = 45^o$. The three lines are for an $F_2/F_1 \propto 1/Q$ fit [11]; the $\log^2(Q^2)/Q^2$ fit [12]; and a fit from Iachello, Jackson and Lande [13, 14]. The lined band is obtained by means of dispersive analysis of the ratio G_E/G_M, based on space-like and time-like data [15].

Experimental knowledge of nucleon form factors in the time-like region is poor (for a review see Refs [10]): data are scarce and there are no polarisation measurements, hence the phases are unknown. The available unpolarised differential cross sections were integrated over a wide angular range, and data for $|G_M^{p,n}|$ were extracted under the hypothesis that either $|G_E^n| = 0$ or $|G_E^p| = |G_M^p|$. While the first hypothesis is arbitrary, the second one is true only at the physical threshold $q^2 \equiv s = 4M^2$, with M the nucleon mass. In addition, for the neutron, only one measurement is available by the FENICE collaboration [16] for $s \leq 6$ GeV^2.

Nevertheless, these few data reveal very interesting and puzzling properties, as we are showing below. The form factors are analytic functions of q^2 in the whole domain but for a discontinuity in the unphysical range $0 < s < 4M^2$. Therefore, the analytic properties and phases in the time-like region are connected to the space-like region by dispersion relations [17]. In particular, $|G_M|$ should asymptotically become real and scale as in the space-like region. However:

- for the proton, *(i)* a fit to the existing $|G_M^p|$ data for $s \leq 20$ GeV^2 is compatible with a size twice as larger as the space-like result [18]; *(ii)* the very recent data from the BABAR collaboration on $|G_E^p|/|G_M^p|$ [19] show that it is surprisingly larger than 1, contradicting the previous time-like data from LEAR [20]; *(iii)* all the available data show a steep decrease of $|G_M^p|$ for $s \sim 4M^2$, suggesting the possibility of interesting (resonant) structures in the unphysical region (for more details, see Ref. [21]); *iv)* the new BABAR data [19] show a further quite unexpected cross section reaching the asymptotic trend by means of negative steps at $\sqrt{s} \simeq 2.2$ GeV and at $\sqrt{s} \simeq 2.9$ GeV.

- for the neutron, the few $|G_M^n|$ data are unexpectedly larger than the proton ones in the corresponding s range [16], in contradiction with pQCD predictions.

1.3 Hyperon Form Factor measurement in the Time-Like Region

With a beam energy of at least about 1.2 GeV, DANAE will produce also hyperons such as Λ or Σ. Apart from the DM2 cross section measurement [22] for $e^+e^- \to \Lambda\bar{\Lambda}$ at $s = 5.76$ GeV^2 (4 candidates only), there are no data on hyperon FFs. The cross section for $Y\bar{Y}$ should be few times smaller than the $N\bar{N}$ cross section (but DM2 found $\sigma(p\bar{p}) \approx \sigma(\Lambda\bar{\Lambda})$).

The $e^+e^- \to \Lambda\bar{\Lambda}$ reaction is particularly interesting, because the Λ polarization can be directly deduced by measuring its decay products, i.e. the proton and π^-. In fact, due to the weak nature of the decay, the nucleon is constrained to move preferentially in the direction of the hyperon spin, thus resulting in an asymmetric angular distribution with respect to the spin direction of the Λ. This asymmetry is the result of the interference between parity conserving (p-wave) and parity non conserving (s-wave) amplitudes. In the hyperon center-of-mass frame, the decay nucleon angular distribution is therefore of the form [23]

$$\frac{dN}{dcos\theta_p^{CM}} = N\left[1 + \alpha P_\Lambda cos\theta_p^{CM}\right], \qquad (1)$$

where P_Λ is the magnitude of the Λ polarization, and θ_p^{CM} is the angle between the polarization axis and the proton momentum. The parameter α describes the interference between p- and s-wave in the weak decay, and has been measured to be $\alpha = 0.642 \pm 0.013$ [24].

The possible upgrade of the existing DAFNE facility [25] to enlarge the c.m. energy range from the ϕ-mass to 2.4 GeV, would open a unique opportunity for the measurement of both the proton and neutron form factors in an energy region that is very suitable for disentangling between various theoretical predictions. It will also allow to explore the production of baryons from the nucleon up to the Σ. With the anticipated performance of DANAE, in about two-years of data taking, one would produce:

- The first accurate measurement of the proton time-like form factors $|G_E^p|$ and $|G_M^p|$;
- The first measurement of the outgoing proton polarization, to get the relative phase between $|G_E^p|$ and $|G_M^p|$;
- The first measurement of the two photon contribution from the proton angular distributions asymmetry;
- The first accurate measurement of the $e^+e^- \to n\bar{n}$ cross section;
- The first measurement of the neutron time-like form factors $|G_E^n|$ and $|G_M^n|$;
- The first measurement of the strange baryon form factors.
- An accurate measurement of the cross section of $e^+e^- \to hadrons$, that provides information on possible narrow structures close to the $N\bar{N}$ threshold.

We would like to end this session reporting the recommendation of the PAC of the FAIR facility made at the PAC-Meeting of March 14-16, 2005 at GSI: " **The PAC would like to stress the uniqueness of the program with polarized anti protons and polarized protons whose primary goals are** *the measurement of the transversity distribution in the valence quark region with the polarized D-Y process, exclusive polarized p-pbar scattering, and* **the separation of the time-like form factors of the protons including the determination of their phase difference**".

2 NUCLEON FORM FACTOR MEASUREMENTS WITH THE KLOE DETECTOR

Following the invitation of the LNF Scientific Committe "*to consider that the designe of future experiments should be developed around a single common detector and a set of repleaceable modules specific to a given physics*", we have started studying the possibility to modify the KLOE detector for the fulfillment of the DANTE program. In the following we examine the requirements to the detector for a complete measurement (moduli and phases) of the proton and neutron form factors.

2.1 *The KLOE detector*

KLOE is a large acceptance (96%) detector with a solenoidal geometry, consisting of a large helium drift chamber (DC) surrounded by an electromagnetic calorimeter (EmC), and it is immersed in a 0.52 T magnetic field. The drift chamber [26] is a cylinder of 25 (198) cm inner (outer) radius and 332 cm lenght with a spatial resolution in the $r\phi$ plane of about 150 μm and in the z direction of ~ 2 mm. The electromagnetic calorimeter [27] is of the sampling type, and is made of lead layers and scintillating fiber. The total thickness of the EmC is 23 cm, corresponding to about 15 X_0. The EmC is composed of a barrel and two endcaps which ensures a 4π coverage.

From the point of view of the detector, the experimental program outlined by DANTE is characterised by two peculiar aspects:

- the detection of $p\bar{p}$ and $n\bar{n}$ exclusive events, with kinetic energies between few and few hundred MeV, as can be seen in fig. 2 where the momentum and kinetic energy range of the emerging nucleons versus the total energy in the center of mass is reported.
- the measurement of the polarization of the final nucleons (proton and nucleon).

Given the requirements of the different experiments that will run with the new DANAE machine, the optimal choice seems to be the implementation for each experiment of a specific detector around the interaction region.

2.2 *Measurement of $e^+e^- \to p\bar{p}$ unpolarized cross section*

Given the high performances for detecting charged particles, KLOE is well suited for the measurement of the $e^+e^- \to p\bar{p}$ unpolarized cross sections for the extraction of the moduli of the form factors. Considering the actual beryllium beam-pipe thickness (0.05 cm) and the 0.1 cm thickness of the DC wall, for $\sqrt{s} < 1.91$ GeV the proton is stopped and the antiproton annihilates before they reach the DC, thus the event could be detected only by measuring the annihilation star through its charged products. For $\sqrt{s} > 1.91$ GeV the proton enter the DC producing a charged track easily detected by KLOE.

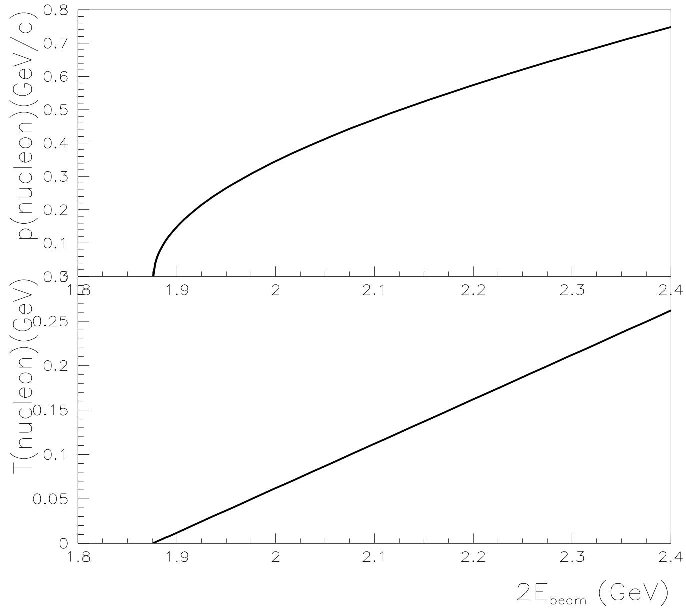

Fig. 2. *Momentum and kinetic energy range of the emerging nucleons in the* e^+e^- *collision versus the total energy in the center of mass.*

2.3 Measurement of $e^+e^- \to n\bar{n}$ *unpolarized cross section*

The measurement of the $e^+e^- \to n\bar{n}$ unpolarized cross sections is one of the key point of the DANTE experimental program, because above $N\bar{N}$ threshold there are no neutron form factors measurement planned in the world.

The $\bar{n}$ annihilation star can be detected by measuring in the KLOE DC the produced charged particles. In addition, as the beam energy increases, the detector has to allow also the detection of the emitted neutron. The neutron detection capability of the KLOE detector is not known up to now. Although neutron detection with bulk organic scintillators is known to have roughly an efficiency of 1% per cm of scintillator thickness, it is not clear how this value can be applied to the peculiar lead-scintillator structure of the KLOE calorimeter, where an equivalent thickness of about 11 cm is embedded in a fine grain sampling structure. Studies on this subject are in progress, both using the present KLOE data, and also using a detailed simulation of nucleon interaction in the calorimeter. Results of these studies made by the AMADEUS collaboration [28] show that for neutron kinetic energy from 10-20 MeV up to 250 MeV a detection efficiency larger than 20% could be obtained. If these values are confirmed, the moduli of the neutron form factors can be obtained with a precision of few percent. A measurement at a neutron test beam facility has been planned to clarify the situation.

The polarization of the produced nucleons is measured through secondary scattering in a strong-interaction process. The strong spin-orbit coupling causes an azimuthal asymmetry from which the polarization perpendicular to the nucleon momentum can be extracted. Then, a polarimeter consists of a thin scatterer layer (usually carbon) placed between two tracking systems. Referring to the KLOE geometry, the second tracking system is made by the drift chambers, while the scatterer and the first tracking system have to be inserted in the ≈ 20 cm of free space between the beam pipe and the detector.

In view of the DAΦNE upgrade at higher luminosity, the KLOE Collaboration is studying the possible implementation of a vertex detector [29] that would greatly improve the KLOE tracking and vertex performances. The solution adopted by the KLOE Collaboration consists in a cylindrical devices of ~ 8 cm radius with four measurement planes, with a spacing of 1-2 cm and (possibly) with a 3-dimensional reconstruction of the hits in each plane. This solution (with a customed geometry) seems to fit the DANTE requirements too, since it should give good track resolution and also leaves few cm still free where a carbon layer can be placed.

As concern the neutron polarization, a further option could be using thin plastic scintillators as scatterer, as done for the NPOL3 polarimeter implemented at Los Alamos [30]. In this case the polarization analyzing reaction will be the $np \to np$ elastic scattering, whose analyzing power A_{np} is very well known. The presence of carbon within the scintillator would also allow to use this material for the proton polarization measurement too. A question is whether to use a fine grained hodoscope, to provide a further constraint on the scattered neutron position. The possible advantages of this option must be studied in detail, since in this case the scatterer should be instrumented with a suitable electronic readout system.

For both proton and neutron, it must be noted that, thanks to the large acceptance of the detector, KLOE will allow the measurement of the polarization at 45^o and 135^o, where, in the one photon exchange approximation, the polarization of the emitted particles reaches the maximum value.

For Λ polarization measurements, where no polarimeter is required, the large angular coverage of the KLOE detector will allow high detection efficiency (presumably of the order of 50%), if only one hyperon is detected. The Λ lifetime is $c\tau = 7.89$ cm, thus the detection of detached vertex could help, but it's not necessary if the momentum resolution for protons and pions is good enough to clearly separate the $\Lambda\bar{\Lambda}$ events from the background of non resonant $e^+e^- \to p\bar{p}\pi^+\pi^-$ events. Fit of the angular distribution of the decay proton in the Λ rest frame with respect to the axis normal to the scattering plane will allow the extraction of P_Λ in eq. (1).

3 OTHER MEASUREMENTS MADE POSSIBLE AT DANAE

Eextension of the available c.m. energy $\sqrt{s}$ up to ~ 2.4 GeV would allow to make several other interesting measurements. These measurements have been discussed in the *Prospects for e^+e^- physics at Frascati between the ϕ and the ψ* report [31] and *Expression of Interest for the continuation of the KLOE physics program at DAΦNE upgraded in luminosity and in energy* [29]. Here we summarized those measurements that were already listed in the DANTE LoI [25].

- The measurement of the total cross section $e^+e^- \to hadrons$ to get the hadronic contribution to $g_\mu - 2$ and $\alpha(M_Z^2)$ in the 1-6 GeV^2 c.m. squared energy range. DAΦNE and VEPP2M have measured the hadronic total cross section up to 1 GeV^2 at a percent level (even if there are discrepancies at about $\pm 5\%$ level). A measurement at a few percent level at higher c.m. energies is welcome. Hopefully, BaBar will provide a measurement by means of initial state radiation, but at this precision level other measurements with different systematic errors are needed.

- The search and study of narrow vector mesons in the 1-2.4 GeV mass range. BaBar and photoproduction experiments have shown several evidences of narrow ($\Gamma < 100$ MeV), unexpected structures (like for instance in $e^+e^- \to 3\pi^+3\pi^-$, $e^+e^- \to 2\pi^+2\pi^-2\pi^0$, $e^+e^- \to \pi^+\pi^-2\pi^0$, $e^+e^- \to 2\pi^+2\pi^-$ and the corresponding channels in diffractive photoproduction), most of them near the $N\bar{N}$ threshold. For a study of these structures and for a search in isoscalar channels a much higher integrated luminosity is demanded.

- A precision measurement of $\gamma\gamma \to \pi\pi$ cross sections via $e^+e^- \to e^+e^-\pi\pi$ in the mass range from $2m_\pi$ up to 1 GeV. Actually the measurement of these cross sections has been done by the LEP experiments, but in the case of $\pi^+\pi^-$ detection efficiency and background did not allow for $\pi\pi$ masses below ~ 800 MeV and in the case of $\pi^0\pi^0$ the collected statistics was quite limited. First principles and chiral perturbation theory demand a precise measurement near threshold. On the other hand a link with the present measurements at higher masses is needed for normalization checks. A ~ 1.2 GeV energy beam should be quite an optimal choice from the point of view of detection efficiency and available $\pi\pi$ mass range.

Measurements of the time-like nucleon FF, in complementary energy regions, are also considered elsewhere. Before 2011, which can be a reasonable estimate of the time schedule for the DANAE construction, three competitors will be active:

- BABAR [19], will end data taking in 2008, exploring larger $\sqrt{s}$ but for unpolarised protons only. The expected improvement in statistics is small.

- VEPP-2000. At Novosibisrsk the new collider VEPP2000 is under construction. The attainable energy in the center-of-mass system ranges from 0.4 to 2.0 GeV, with a design luminosity of 10^{32} cm^{-2}s^{-1} at 2 GeV [32]. By using the general purpose detector SND, it is foreseen to obtain about 10^5 events per year for both $p\bar{p}$ and $n\bar{n}$ production at the threshold region. The completion of the storage ring is foreseen for 2006, and the data collection is scheduled from 2007 to 2012. The nucleon form factor results are expected in the years 2008-2010. No polarisation measurements are planned

- BES-III. At Beijing it is planned to increase the luminosity of the BEPC collider to about 10^{33} cm^{-2}s^{-1} at 3.77 GeV c.m.-energy [33]. This will be obtained by transforming BEPC in a double-ring machine and increasing the number of e^+ and e^- bunches in each ring from 1 to 93. The Beijing spectrometer (BES) also will be upgraded, by improving its space and momentum resolution, and its particle identification capability. Besides other measurements, this will allow measuring with good statistics the polar angle distribution of $p\bar{p}$ (but not of $n\bar{n}$) production, and determining the moduli, but not the phases, of the electric and magnetic form factors in the energy region between 2.4 and 4.2 GeV. The machine and detector commissioning is scheduled in the year 2007.

Moreover, the measurement of time-like proton form factors is part of the experimental program proposed for the HESR antiproton beam at GSI, which is expected to start in 2012. The PAX experiment [34] proposes to measure single and double spin asymmetry in the reversed channel $\bar{p}p \to e^+e^-$ [35], using polarized antiproton beams interacting with a transversely or longitudinally polarized proton target. Moreover, unpolarized measurements can be carried out independently at PAX as well as at PANDA [36] experiments. The use of single and double spin asymmetry will give access to several combination of $|G_M^p|$, $|G_E^p|$ and its relative phase δ_{ME}, allowing their extraction with small systematic uncertainties. For the proton, these measurements would naturally complement those proposed in this letter. On the contrary, neutron and hyperon form factors can only be accessed by using electron-positron collisions.

From the above, it is clear that the energy region accessible at the DANAE facility would offer a unique opportunity for the measurement of the neutron and proton time-like form factors in an energy region (from threshold up to 2.4 GeV) which is very suitable for disentangling between various theoretical predictions. Also the scheduled time-line looks very suitable, making it possible to obtain the first complete measurements of both proton and neutron form factors in the time-sector.

5 APPENDIX

In this appendix we recall the formalism necessary to extract absolute values and phases of the nucleons form factors from cross section and polarization measurements.

5.1 Cross section measurement

In the one-photon exchange approximation, the center-of-mass total and differential cross section of the reaction $e^+e^- \to N\bar{N}$ as a function of s are given by

$$\sigma = \frac{4\alpha^2\pi\beta}{3s} C \left[\mid G_M \mid^2 + \frac{1}{2\tau} \mid G_E \mid^2 \right], \tag{2}$$

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2\beta}{4s} CD = \frac{\alpha^2\beta}{4s} C \left[\mid G_M \mid^2 (1 + cos^2\theta) + \frac{1}{\tau} \mid G_E \mid^2 sin^2\theta \right], \tag{3}$$

where θ is the nucleon scattering angle, $\beta = \sqrt{1 - 4M^2/s}$ is the nucleon velocity, $\tau = s/4M^2$. C is the Coulomb correction factor, which takes into account QED Coulomb interaction and modifies the Born approximation at threshold. It can be evaluated in the distorted wave approximation in final state interaction and is given by:

$$C = \frac{y}{1 - exp(-y)} \qquad y = \pi\alpha M/\beta\sqrt{s} \tag{4}$$

Because of the complex nature of time-like form factors, the outgoing nucleons in e^+e^- collision are polarized normally to the scattering plane (called y-direction) even without any polarization in the initial state. This polarization is given by:

$$P_y = \frac{sin2\theta}{D\tau} \Im \left(G_E^* G_M\right) = \frac{sin2\theta}{D\tau} \mid G_E \mid\mid G_M \mid sin\delta_{ME}, \tag{5}$$

where θ is the scattering angle, $D = (\mid G_M \mid^2 (1 + cos^2\theta) + \frac{1}{\tau} \mid G_E \mid^2 sin^2\theta)$ and $\tau = q^2/4M^2$.

Eq. 5 shows that P_y is directly related to the phase difference δ_{ME} between the two form factors and, due to the presence of the factor $sin(2\theta)$, it takes its maximum value close to the scattering angles of 45^o and 135^o, and vanishes at 90^o. So, once the ratio $|G_E|/|G_M|$ is known, the phase is directly obtained by measuring P_y.

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