Measuring Time-like Form Factors at PEP-N

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Some experimental aspects of measuring the proton and neutron time-like form factors at a possible new e^+/e^- collider (PEP-N) at SLAC are discussed. The angular coverage of detectors needed for separated electric and magnetic form factors is given, as well as the performance of time-of-flight for neutron momentum determinations.

1. KINEMATICS

If we assume a positron ring fixed at 3.1 GeV (corresponding to the existing PEP-II ring), then the threshold for nucleon anti-nucleon production in the electron ring is about 0.29 GeV. The energy asymmetry gives a significant boost to nucleons, making them easier to detect. Figure 1 shows the relation between nucleon momentum P and lab angle θ for electron energies from 0.29 GeV up to 0.49 GeV. For each electron energy, the lines span the phase space corresponding to $-0.8 < \cos(\theta^*) < 0.8$, typical of that needed for separating the electric (G_E) and magnetic (G_M) form factors. At threshold, both nucleon and anti-nucleon have $P = 1.4$ GeV in the direction of the positron beam, while at higher electron energies, there is an increasingly large spread in nucleon momenta, and the lab angles become correspondingly larger. For 0.49 electrons, the momentum range increases to $0.55 < P < 2.3$ GeV and the lab angle range increases to $11 < \theta < 51$ degrees. This means a rather large detector is needed.

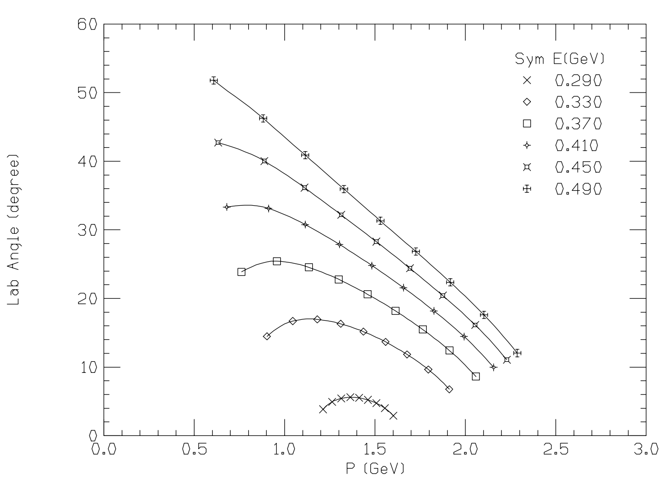

Figure 1: Momentum versus lab angle for nucleons at PEP-N with electron energies indicated. Each set spans $-0.8 < \cos(\theta^*) < 0.8$.

2. TIME-OF-FLIGHT FOR NEUTRON MOMENTUM MEASUREMENTS

Time-Of-Flight is a crucial technique for momentum measurements of neutrons. Momentum measurements are needed even if both neutron and anti-neutron are detected and identified, and the lab angles measured, to help in the determination of θ^*, and especially to discriminate against inelastic events (for example where two extra pions are produced through production and decay of two $\Delta(1236)$ resonances). We assume that there will be 4.2 nsec bunch spacing between collisions. As seen in

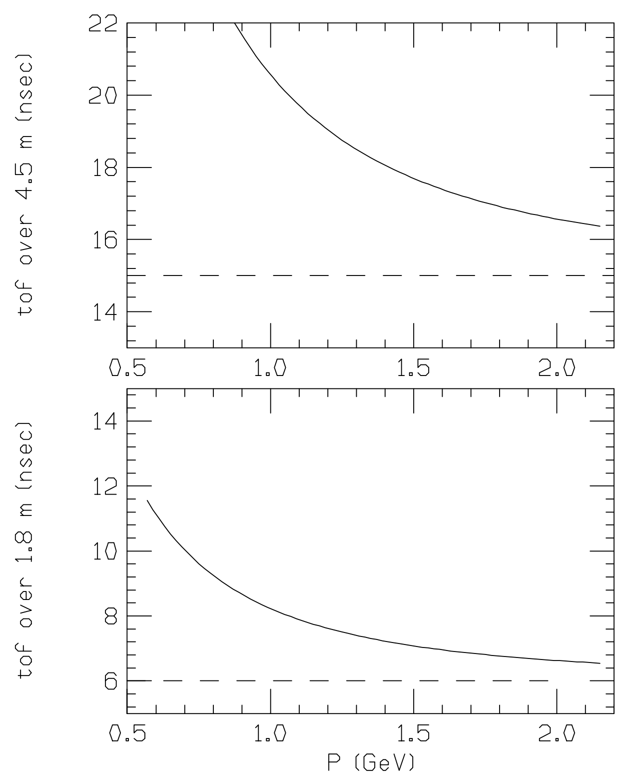

Figure 2: Time of flight over 1.8 m (lower plot) and 4.5 m (upper plot) for neutrons. The dashed line is for $\beta = 1$.

Figure 2, a 1.8 m drift distance to the detectors is adequate to resolve ambiguities over the entire momentum range of interest, but very good time resolution would be needed for adequate momentum resolution. For forward angle, high momentum measurements ($P > 1.5$ GeV), a 4.55 m drift is preferable (top panel of Figure 2).

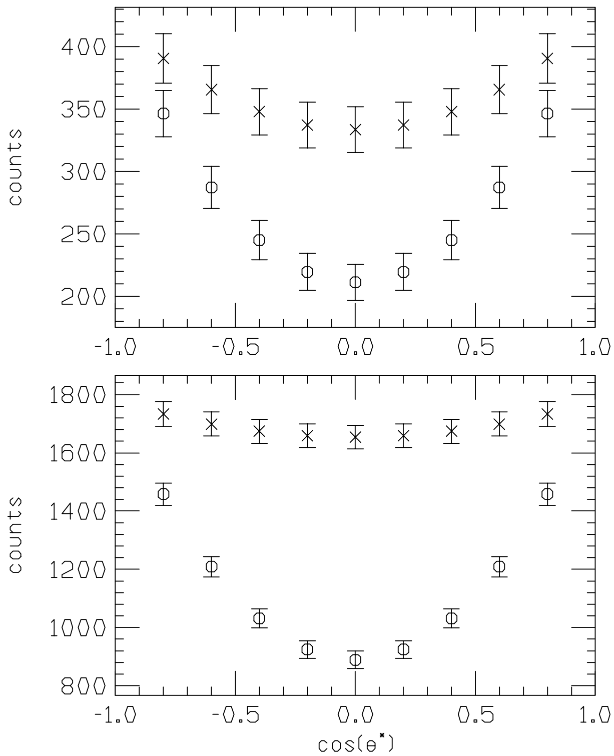

Figure 3: Projected error bars for $e^+e^- \to n\bar{n}$ at PEP-N assuming 30% detection efficiency and 10^{31} luminosity. The top panel is for an electron energy of 0.49 GeV, while the bottom panel is for 0.33 GeV. The crosses are for $G_E = G_M$, while the circles are for $G_E = 0$.

3. RATES AND SEPARATION OF G_E AND G_M

Using the cross section given by

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \beta C}{4Q^2} \left[|G_M|^2 (1 + \cos^2\theta^*) + \frac{4M_N^2}{Q^2} |G_E|^2 \sin^2\theta^* \right] \tag{1}$$

rates were calculated for 6 weeks of running at 10^{31} luminosity and 30% detection efficiency for combined neutron and anti-neutron. The efficiency for proton/antiproton would likely be higher. The dipole approximation of the form factors was assumed. The rates are several orders-of-magnitude higher than the previous experiment at FENICE [1]. Figure 3 shows the expected statistical errors at many values of $\cos(\theta^*)$ at two representative c.m. energies. On each plot, the projected results are shown with either $G_E = 0$ or $G_E = G_M$ (which must be true exactly at threshold). It can be seen that these two cases can be distinguished easily by fitting the angular distribution. This would be the first experiment with enough statistical precision to be able to do this, and in fact errors on G_E/G_M comparable to those in the space-like region could be obtained.

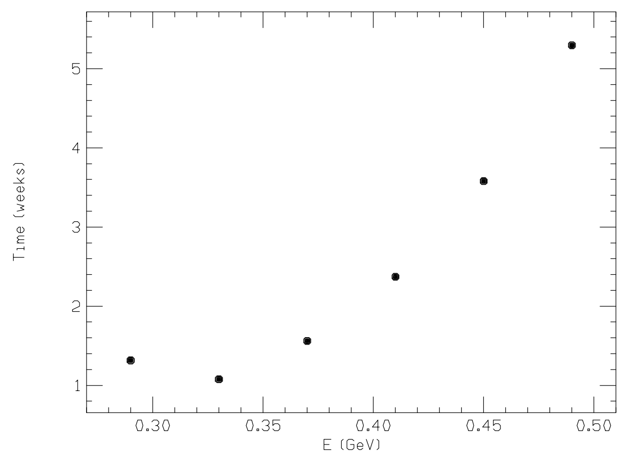

Figure 4: Time in weeks needed for an error of 0.15 on G_E^2/G_M^2 at PEP-N, as a function of electron energy E.

Figure 4 shows the time needed to measure G_E^2/G_M^2 with an error of 0.15. The times are quite reasonable, given that PEP-N could potentially devote several dozen weeks to the dedicated study of $N\bar{N}$ form factors.

4. SUMMARY

From this very preliminary look at experimental requirements, it appears that with the expected luminosity and other parameters of PEP-N, time like form factor measurements can be made that will be orders-of-magnitude better than previous measurements, especially in the case of the neutron. The neutron detectors should detect both neutron and anti-neutron, to separate out the exclusive final state from inelastic states. With additional detectors for pions, the form factors for the inelastic states (such as $\Delta\Delta$) can also be measured for the first time, providing a valuable complement to the space-like measurements. Time-of-flight with good time resolution is needed over a few meter range for adequate neutron momentum determination. The angular coverage of the detectors should extend over a large range, preferably from 5 to 50 degrees. The high statistics at PEP-N will allow for the first time good separations of the electric and magnetic form factors of the proton, neutron, and resonant states, greatly contributing to our knowledge of the structure of the nucleon.

REFERENCES

[1] A. Antonelli et al, Phys.Lett. B313 (1993) 283; A. Antonelli et al., Nucl.Phys. B517 (1998) 3.