Recoil Polarization Measurement in Electro-production of Vector Mesons from a Proton Target

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Abstract

Vector meson production from a proton target is very useful in probing the structures of nucleon and nucleon resonances. It has been suggested that some of the double polarization observables in the case of ϕ mesons are extremely sensitive to the strange quark content of the proton, and polarization observables are essential for identifying the so-called "missing resonances" in ω production. We propose to measure the recoil proton polarization from electroproduction of ϕ and ω mesons with a longitudinally polarized electron beam and a liquid hydrogen target. The scattered electrons and recoil protons will be detected in coincidence, and ϕ and ω mesons will be identified by a missing mass technique. The recoil proton polarizations from ϕ production will be measured at an invariant mass of 2.15 GeV and a $|Q^2| = 0.135$ (GeV/c)^2. The recoil proton polarization from ω production will be measured at two sets of kinematic settings: W = 2.15 GeV, $|Q^2| = 0.135$ (GeV/c)^2; and W = 2.0 GeV and $|Q^2| = 0.177$ (GeV/c)^2. In addition to the recoil proton polarization measurement, differential cross sections will be measured as a function of t and Q^2. These cross section data will help to address issues related to the theoretical uncertainty in interpreting the polarization data. The total beam time requested for this experiment is 25 days.

I. INTRODUCTION

The discovery of the underlying quark structure of the nucleon from deep-inelastic scattering (DIS) of electrons from protons in the 1960s motivated the construction of new, powerful electron and photon facilities, where the main scientific thrust has been understanding the detailed structure of nucleon and baryon resonances in terms of quark and gluon degrees of freedom in QCD. The advent of polarized beams, polarized targets and recoil polarimeters has opened up new windows of opportunity in probing the structure of matter with polarization observables at these new facilities.

One of the very intriguing questions in probing the structure of the nucleon is that strange sea quarks seem to play a non-negligible role in both the static and dynamic properties of the nucleon. The possible evidence for this statement come from different experiments ranging from high energy polarized DIS measurements of polarized leptons scattering off polarized nucleon targets, to low energy pion-nucleon scattering. These experiments measured different matrix elements, and different model dependences were unavoidably involved in extracting information on the strange quark property in nucleon.

The idea of looking for hidden strangeness in the nucleon, *i.e.* for $s\bar{s}$ pairs in the quark sea directly, originally proposed by Henley *et al.* [1], is to measure the amplitude for the direct knockout of such a pair in the form of a ϕ meson which is known to be nearly pure $s\bar{s}$. More recent calculations [2] have shown that double polarization observables might be very useful in identifying the direct knock-out of $s\bar{s}$ pairs from proton from other mechanisms. Furthermore, it is also suggested [3] very recently that accurate information on the cross section and polarization observables in the photo-production of the ϕ meson from a nucleon target may shed light on the existence of more exotic mechanisms corresponding to a second trajectory for Pomeron exchange as inspired by the glueball predicted from Lattice QCD calculations. The consequences of such predictions can also be explored in the ϕ electroproduction experiment proposed here.

A long-standing puzzle in investigating the structure of baryon resonances is the problem of the so-called "missing" resonances. The non-relativistic quark model (NRQM) [4] [5] predicts a much richer resonance spectrum than has been observed from πN scattering experiments. Quark model studies have suggested that the "missing" resonances in the πN channel may couple strongly to the ω and ρ mesons. Thus, precise information on the cross section and polarization observables from ω meson production from nucleon targets has great potential in identifying "missing" resonances.

Photo-production and electro-production of vector and pesudo-scalar mesons has constituted a large portion of the Hall B experimental program at JLab, largely motivated by the search for missing resonances. The experiment that we are proposing here is to be carried out in Hall A using the two high resolution spectrometers. This measurement will be complementary to the existing Hall B program. The missing mass technique is possible because of the unique high-resolution of the pair of spectrometers and the narrow intrinsic widths of the ϕ and ω mesons. This, combined with the high luminosity in Hall A, makes the differential cross section measurements very efficient. Secondly, the recoil proton polarimeter in the hadron arm together with a liquid hydrogen target make the overall figure-of-merit much higher than that which can be achieved with a polarized solid target for possible double polarization measurements in Hall B. Furthermore, a Q^2 as low as 0.135 $(\mathrm{GeV/c})^2$ can be reached in Hall A which allows a connection to be made to the vector meson photo-production processes. The photo-production of vector mesons is better known than the electro-production processes.

We propose to carry out a systematic measurement of the differential cross section for the electro-production of ϕ and ω mesons from a LH2 target as a function of Q^2 and t, focusing in the low Q^2 and low t region. Furthermore, double polarization observables with a recoil proton polarimeter will be measured for the first time. These initial measurements of the double polarization observable will shed light on exotic phenomenon originated from the structure of both nucleon and baryon resonances. This study will also open up future opportunities in Hall A in vector meson productions with upgraded machine energies.

II. MOTIVATIONS

A. Electro-production of ϕ Mesons

1. Strangeness Content of the Nucleon

Most of the focus on the issue of strange quarks in the proton has arisen from results of a series of experiments on the Deep Inelastic Scattering (DIS) of leptons on nucleons. Polarized DIS measurements on the proton were pioneered at SLAC [6]. The so-called "spin crisis" originated from the DIS of polarized muons on polarized protons performed by the European Muon Collaboration (EMC) [7], combined with the earlier SLAC measurements.

These experiments measured the spin structure function of the proton $g_1^p(x)$ over a wide range of Bjorken variable x, particularly trying to extend the measurements to small x. By extrapolating to $x = 0$, EMC obtained $\int_0^1 dx g_1^p = \Gamma_1^p = 0.114 \pm 0.012 \pm 0.026$ (where the errors are, in order, statistical and systematic as is usually quoted) in disagreement with the sum rule of Ellis and Jaffe [8]. They had predicted a value of 0.189 ± 0.005 based on the best available values for the axial-vector and vector coupling constants G_A and G_V from neutron beta decay and the $SU(3)$ coupling constants F and D from hyperon beta-decay *and* assuming that the strange quark contribution to the nucleon spin was $\Delta s = 0$. Analysis of the data [7] indicated that only about 14% of the nucleon spin is due to the spin of the quarks with the remainder due to gluons and/or orbital angular momentum. If the discrepancy is assumed to be due to $s\overline{s}$ pairs in the quark sea, then they account for about 20% of the nucleon spin and in the opposite direction to the u and d contributions, mostly canceling them *i.e.* $\Delta s \approx -0.1$.

The discrepancy with the Ellis-Jaffe sum rule prompted further experiments by SMC [9] and SLAC E142 [10] and E143 [11]. These efforts, together with later measurements on the neutron by the SLAC E154 [12] and HERMES collaborations [13], which gave $\Gamma_1^n = -0.036 \pm 0.004 \pm 0.005$, confirmed the agreement with the Bjorken sum rule and the discrepancy with that of Ellis and Jaffe. The most recent analyses now give the total quark contribution to the proton spin as $\Delta q \approx 0.33$ and the strange sea quark contribution as $\Delta s \approx -0.10$ [14]. Additional measurements on $g_1^p(x)$ and $g_1^n(x)$ to even lower x have recently been made by SLAC E155 [15] and HERMES [13]. Thus, the extracted value of the strange quark contribution to the proton spin has remained remarkably robust through these measurements. However, the method of determining this value, which has also been consistent, is model dependent.

In addition to the polarized DIS measurements, the picture of $s\overline{s}$ pairs in the quark sea has been used to explain a number of other experimental observations. These include (1) an anomalous value for the σ term observed in πN scattering, (2) a larger than expected value of the proton axial-vector form factor observed in νp scattering, and (3) a much larger than expected cross section ratio $\mathrm{p}\overline{\mathrm{p}} \to \phi\pi^+\pi^- / \mathrm{p}\overline{\mathrm{p}} \to \omega\pi^+\pi^-$.

On the other hand, many papers have been published which explain these experimental observations without relying on any $s\overline{s}$ pairs in the quark sea. Using polarized DIS data as an example, Lipkin has been able to account for the DIS results by assuming a *non* flavor symmetric sea containing $u\overline{u}$ and $d\overline{d}$ but no $s\overline{s}$ quark pairs [16]. Anselmino and Scadron [17] have used a modified $SU(6)$ valence quark model that allows for additional gluons and orbital angular momentum. When confronting the DIS results, they obtain a very small $\Delta s \approx -0.02$ at the ± 0.07 level. Stern and Clement [18] incorporate $SU(3)$ symmetry breaking to analyze the DIS results and find good agreement with experiment, while imposing $\Delta s = 0$.

To improve the situation, a direct measurement of the knockout of an $s\overline{s}$ pair from the nucleon ground state would therefore constitute incontrovertible proof of the existence of such pairs in the nucleon and would be sensitive to the probability of finding such a pair. Given that the ϕ meson is an almost pure $s\overline{s}$ pair, the observation of ϕ production would seem to satisfy this requirement. However, because the ϕ possesses the same quantum numbers as the photon, *i.e.* is a vector meson with $J^P = 1^-$, there is a large (dominant) amplitude for ϕ production through vector-meson-dominance (VMD) via which the photon (real or virtual) fluctuates into a vector meson such as the ϕ and interacts hadronically with the nucleon, scattering diffractively through Pomeron exchange. At small t this is expected to be the dominant amplitude for ϕ photo-production. Thus the determination of the direct $s\bar{s}$ knockout amplitude must be through its interference with the VMD amplitude.

While we are proposing to look for $s\bar{s}$ pairs in the proton by measuring observables sensitive to a direct knockout process, there are other observables sensitive to the hidden strangeness. Parity-violating electron scattering can be used to probe the possible strangeness content of the proton by measuring the strange form factors of the nucleon from the interference of the γ-exchange and the Z^0-exchange amplitudes [19]. Currently, parity-violating experiments are being carried out and planned at JLab, Mainz and MIT-Bates. The initial results from both the SAMPLE [20] experiment at MIT-Bates and the JLab Hall A experiment HAPPEX [21] have been reported recently. The measurement proposed here can provide additional information with new insight on the strangeness content of the nucleon.

2. Double Polarization Observables in ϕ Meson Production

The primary contribution to electromagnetic production of a ϕ is for the incoming photon (real or virtual) to fluctuate into a virtual vector meson (such as a ϕ meson) and then diffractively scatter from the nucleon by Pomeron exchange, thereby putting the vector meson on the mass shell, a mechanism known as vector meson dominance (VMD) [22] (see Fig. 1). Other contributions come from processes such as one pion exchange (OPE) (see Fig. 2) wherein either the photon fluctuates into the vector meson which then exchanges a pion with the nucleon target (Fig. 3(a)), or the photon fluctuates into a virtual ϕ-π state and the pion is absorbed by the target nucleon (Fig. 3(b)). Such processes have been interpreted as corrections to the primary VMD mechanism [23]. Other diagrams such as those with a ϕ-ϕ-π vertex are possible but are not found to be important in successful VMD calculations. [24] [25] These calculations have fit data well. Diagrams such as ρ or ω exchange are forbidden by C-parity conservation. Hence, there is no vector meson exchange.

The success of the VMD model has been investigated in recent years within the framework of QCD. It was shown [26] that the interpretation of Pomeron-exchange in terms of gluon-exchange is consistent with the quark-substructure of vector mesons. At the low Q^2 considered in this proposal, the usual VMD parameterization of the diffractive amplitude is valid.

The cross sections and polarization observables for ϕ photo-production have recently been calculated by Titov *et al.* [2]. The results of these calculations are (1) both the VMD and $s\bar{s}$ knockout contributions are strongly forward peaked, *i.e.* are largest at small momentum transfer, t; (2) with an assumed 1-2% admixture of $s\bar{s}$ quarks in the nucleon, the knockout cross section is $\sim 10\%$ of that for VMD; (3) the OPE contribution to the cross section is approximately equal to that for $s\bar{s}$ knockout; and (4) the uud knockout process, in which the $s\bar{s}$ quarks are spectators, becomes large, and perhaps dominant, at large momentum transfer (very backward angles for the ϕ). Regarding the last point, the uud knockout cross sections at forward angles are about two orders of magnitude smaller than that due to other mechanisms. Thus the direct $s\bar{s}$ knockout amplitude can be more easily determined in an experiment measuring the ϕ production at forward angles. The diagrams for $s\bar{s}$ and uud knockout are shown in Fig. 4.

Single photon polarization asymmetries are not sensitive to the strangeness content of the nucleon [2]. The possible double polarization asymmetries observable with polarized photons are beam/vector meson (or γ^*/ϕ where γ^* is a real or virtual photon) where the incident photons are polarized and the vector meson polarizations are analyzed, beam/target (or γ^*/p) in which the beam and target polarizations are controlled, and beam/recoil (or γ^*/p$'$) in which the photon polarization is controlled and the recoil proton polarization is measured.

Since in the diffractive VMD process, the outgoing vector meson ϕ must have the same polarization as the incoming photon, there will be a large asymmetry in the beam/vector meson double polarization just due to this process, *i.e.* the cross section will be large for parallel polarizations and small for the anti-parallel case. Any effects due to small reaction amplitudes will be dwarfed. For polarized photons, this leaves the beam/target or beam/recoil double polarization asymmetries. Since the VMD process does not flip the target spin and thus the recoil proton will have the same spin as the target, the pure VMD contribution to either of these asymmetries is expected to be small. Thus these two asymmetries are the most likely to have sensitivity to the knockout amplitude.

In the diffractive VMD process, as we have mentioned, the vector meson ϕ has the same spin polarization as the incoming photon. For a polarized target this means we expect very little beam-target asymmetry due to the VMD mechanism alone. On the other hand, for the knockout mechanism, reversing the target polarization is equivalent to reversing the spectator uud polarization in the $|uud\rangle \otimes |s\bar{s}\rangle$ target. The $s\bar{s}$ in the target proton can couple to either $J^P = 1^-$ or 0^-. This pair then couples to the uud $J^P = 1/2^+$ core configuration in a state of orbital angular momentum $L = 1$ so that the spin and parity of the $|uud\rangle \otimes |s\bar{s}\rangle$ total wave function is $1/2^+$. The largest contribution to the electromagnetic excitation of the target $s\bar{s}$ pair to a ϕ ($J^P = 1^-$) arises from the $0^- \rightarrow 1^-$ transition. Hence the proton configuration with the largest contribution to the knockout mechanism is a 0^- $s\bar{s}$ pair coupled to the $1/2^+$ uud valence quark configuration in a relative $L = 1$ state (P-wave). Thus, the projection of the orbital angular momentum along the proton spin axis must be $M = 0$. Reversing the orientation of the target spin reverses the orientation of the uud valence quark configuration in the target proton and flips the sign of the coupling coefficient from $\sqrt{1/3}$ to $-\sqrt{1/3}$ and, hence, also the sign of the knockout amplitude relative to the sign of the VMD amplitude. Thus we expect to observe a large asymmetry in the beam/target asymmetry. Similar arguments also apply to the beam/recoil asymmetry.

Titov *et al.* have calculated the various double polarization asymmetries: beam/target, beam/recoil, and beam/vector meson. Their results confirm the naive arguments given here. First of all, the beam/vector meson polarization asymmetry is almost entirely due to the VMD mechanism with extremely little sensitivity to the knockout mechanism. Both the beam/target and beam/recoil polarization asymmetries exhibit large effects due to including $s\bar{s}$ quarks in the proton provided the incoming photon is circularly polarized with the helicity along its momentum direction. For the beam/recoil asymmetry, the largest sensitivity to the percentage of strange quarks in the target occurs for a recoil polarization $L_{zx'}$ (transverse to the proton momentum direction and in the reaction plane) for ϕ CM angles of 45° – 60°, where z is the incident photon momentum direction and z' is the recoil proton momentum direction.

Specifically, Fig. 5 shows the photo-production beam/recoil double polarization asymmetry $L^{BR}_{zx'}$ for the four possible combinations of the phases of the $s\bar{s}$ configurations with $J^P = 0^-$ and 1^-. These calculations [2] were done using a relativistic harmonic oscillator model [27], an improvement over the original model used by Henley *et al.* [1] which used a non-relativistic constituent quark model. The VMD amplitude was calculated using the model proposed by Donnachie and Landshoff [24] and developed by others [25] where the Pomeron is described in terms of a non-perturbative multi-gluon exchange. The VMD contribution to the asymmetries shown in Fig. 5 includes the OPE corrections. These calculations also include contributions from both 0^- and 1^- $s\bar{s}$ pairs (in contrast to the naive arguments given earlier), *i.e.* the wave function of the proton in Fock space is given by [1] [2]:

$$|p\rangle = A|[uud]^{1/2}\rangle + B\{a_0|[[uud]^{1/2} \otimes [s\bar{s}]^0]^{1/2} + a_1|[[uud]^{1/2} \otimes [s\bar{s}]^1]^{1/2}\rangle\}$$

with B^2 the probability of finding $s\bar{s}$ pairs in the proton and a_0 and a_1 the relative amplitudes for those pairs being in 0^- and 1^- configurations. It is the unknown phase between amplitudes a_0 and a_1 which accounts for the four panels in Fig. 5. Two separate amplitudes are calculated for the knockout process: (1) $s\bar{s}$ knockout with a uud spectator, and (2) uud knockout with an $s\bar{s}$ spectator.

Finally, the calculations show that the optimal range of initial photon energy is 2-3 GeV. The contribution of the knockout mechanism at higher photon energy is suppressed due to a rapid decrease in the form factors.

3. Kinematic Considerations for Electro-production of ϕ Mesons

Both these calculations [2] and those of Henley [1] were done for real photons. We have used these to show the general sensitivity to the strangeness content. We proceed with some general considerations relating electron scattering to the results of the discussion so far, with the explicit aim of choosing the best kinematics.

The proposal being presented here utilizes the high resolution offered by the Hall A HRS system to reconstruct the ϕ mass with sufficient accuracy to obviate the need for direct detection of the $\phi \to K^+K^-$ in the final state. As such, the electron arm HRS (HRSe) is effectively being used to tag the virtual photon. The virtual photon is polarized by polarizing the incident electron.

In the context of the presently proposed experiment, it is useful to cast the differential cross section following the formalism of Donnelly and Raskin [29] into the following form,

$$\frac{d^5\sigma}{dE' d\Omega_e d\Omega_p^c} = \frac{d^2\sigma}{d\Omega_p^c}\Gamma \tag{1}$$

where the virtual photo-production cross section in the photon/target CM frame is

$$\frac{d^2\sigma}{d\Omega_p^c} = \sigma_{\gamma^*}\{2\rho_L\epsilon R_L + R_T - \sqrt{\rho_L\epsilon(1+\epsilon)}R_{TL} - \epsilon R_{TT} + h(-\sqrt{\rho_L\epsilon(1-\epsilon)}R_{TL'} + \sqrt{1-\epsilon^2}R_{T'})\} \tag{2}$$

with the point photo-production cross section given by

$$\sigma_{\gamma^*} = \frac{\alpha}{4\pi}\frac{M_\phi M_p^2 p_\phi^c}{W(W^2 - M_p^2)} \tag{3}$$

and where

$$\Gamma = \frac{\alpha}{2\pi^2}\frac{E'}{E}\frac{W^2 - M_p^2}{2M_p(-Q^2)}\frac{1}{1-\epsilon} \tag{4}$$

is the virtual photon flux [29]. The longitudinal polarization ϵ is given by $\{1 - 2(q^2/Q^2)\tan^2(\vartheta_e/2)\}^{-1}$, and $\rho_L = (-Q^2/q^2)(W/M_p)^2$ with Q^2 (less than zero) being the square of the transferred four-momentum and q^2 for the three-momentum, now all evaluated in the lab frame. Hadron angles and momenta are evaluated in the CM frame.

In the absence of measuring recoil or target polarization, the fifth response function has an explicit out-of-plane dependence given by $\sin\varphi_p^c$ and, thus, vanishes for in-plane measurements. However, that is not true in the case where the recoil polarization is measured. It becomes a sum of terms either $\sin\varphi_p^c$ or $\cos\varphi_p^c$ depending on which polarization orientation of the outgoing proton is being measured. Unfortunately, in the case of measuring P'_x, it goes as $\cos\varphi_p^c$, and thus is largest in-plane. The virtual photon polarization associated with the sixth response function $R_{T'}$ is purely circular. The surviving in-plane parts of $R_{TL'}$ will dilute this polarization (although they may provide useful information). Thus the circular polarization of the virtual photon about the $\hat{q}$-direction is maximized by minimizing the ratio of the kinematic factors $|v_{TL'}/v_{T'}| = \sqrt{\rho_L\epsilon/(1+\epsilon)}$, while maintaining $v_{T'}$ itself to be as large as possible.

This tends to drive Q^2/q^2 towards zero, *i.e.* toward the real photon limit, and moreover to have ϵ as small as possible. This also leads to a small scattered electron energy such that one is operating near the "end point" of the virtual photon spectrum. This introduces two complications, first with operating the HRSe at too low a momentum and, second, a large background in the spectrum due to a growing radiative tail from elastic e-p scattering at very large ω/E_0 where E_0 is the incident electron energy and ω is the electron energy transfer.

Thus, the chosen kinematics represent a compromise to maximize the transferred polarization while minimizing background contributions and maintaining the HRSe in a comfortable operating regime for the recoil polarization measurement.

The results by Oh *et al.* [28] on electro-production of ϕ meson explicitly performed for these kinematics are displayed in Figs. 6-7 and confirm the qualitative arguments just given. In comparison with the real photon result of Fig. 5, the asymmetry is slightly less, due to the dilution of the photon polarization, but this is more than offset by the large improvement in luminosity afforded by the electron beam.

4. Other Theoretical Calculations

Clearly, the theoretical predictions presented in Figs. 6-7 depend strongly on the accuracy of the VMD model employed in describing the diffractive amplitude. This question has been addressed partially by Pichowsky. [26] and also has been addressed in a recent calculation [3]. We emphasize that in addition to the recoil polarization measurement, accurate information on the differential cross section near ϕ threshold as a function of t and Q^2 will be obtained from this experiment which will help address the related issues on the reaction mechanism.

Recently, Zhao *et al.* [30] have performed a quark model calculation of ϕ meson photo-production based on the $SU(6) \otimes O(3)$ symmetry with an effective Lagrangian. In addition to the usual diffractive Pomeron exchange amplitude and pseudo scalar meson exchange contributions, the nucleonic resonance effects have been included. Contributions to the cross section from non-diffractive $s-$ and $u-$channel processes are found to be small at forward angles. Their calculation shows that double polarization asymmetries are very small at forward angles near ϕ threshold, which are in good agreement with those obtained by Titov *et al.* [2] when the direct knockout contribution is not included. Thus, this calculation indirectly shows that double polarization observable (beam-recoil asymmetry) could be very sensitive to the direct knock-out $s\bar{s}$ pair diagram.

In a recent calculation on ϕ photo-production from nucleon by Titov, Lee, Toki and Streltsova [3], diffractive Pomeron exchange, pseudo scalar meson exchange contributions, scalar mesons exchange, and the ϕ-radiation from the nucleon have been included in both the differential cross section and polarization observable calculations. In addition to the universally accepted Pomeron exchange with an intercept $\alpha(0) \sim 1.08$, the role of the second Pomeron with $\alpha(0) < 0$, as inspired by the glueball ($J^\pi = 0^+$, $M_b^2 \sim 3$ (GeV)^2) predicted by Lattice QCD calculation and the Dual Ginzburg-Landau model, has been investigated by these authors. The existing limited data near ϕ threshold can accommodate either the second Pomeron or the scalar meson exchange. Currently, the extension of this calculation to ϕ meson electro-production is in progress [31]. The accuracy of the differential cross section measurement near ϕ threshold from this proposed experiment will likely shed light on whether there is a second Pomeron trajectory in the electro-production of the ϕ meson at low Q^2.

5. Related JLab Experiments

There are three approved experiments at JLab in Hall B on ϕ meson production. Experiment E93-031 [32] aims at studying the photo-production of vector mesons at high t to investigate hidden-color components in hadronic matter. The kinematic region addressed in E93-031 is very different from that this proposal because our kinematics focuses on the small t region. Furthermore, this experiment is a double polarization experiment which is expected to be very sensitive to the direct knock-out of strange quark anti-quark pairs from the proton.

Experiment E93-022 [33] was proposed to measure the polarization of the ϕ meson in electro-production from a proton target by measuring the angular distribution of the decay kaons. This is a single polarization measurement which aims to measure the fraction of ϕ production due to the pseudoscalar exchange mechanism relative to diffractive scattering with a sensitivity at the level of $\sim 5-10\%$. Although ϕ production from a proton target through direct knockout of an $s\bar{s}$ is expected predominantly via exchanging a pseudoscalar meson, additional contributions from π-exchange and η-exchange directly from the decay properties of ϕ meson make it hard to extract information on the direct knockout contribution by measuring this single polarization observable.

Experiment E98-109 [34] will measure the photo-production of ϕ mesons with linearly polarized photons. The spin density matrix elements will be extracted by measuring the decay kaon angular distribution. The measurement is expected to be sensitive to new reaction mechanisms other than diffractive scattering or pseudoscalar meson exchange. Because of the dominance of VMD diffractive scattering at forward angles in ϕ photo-production, and the fact that the vector meson carries the photon beam polarization in the VMD process, the beam-vector meson double polarization observable is not expected to be sensitive to the direct knockout of $s\bar{s}$ component of the proton.

B. Electro-production of ω Mesons

While the QCD inspired non-relativistic quark model (NRQM) has been very successful in describing the properties of the known baryons, its predicted number of resonances is significantly larger than the experimentally observed number of excited states. To reconcile these two pictures without changing the the quark degrees of freedom in the model, Koniuk and Isgur [4] explained the "missing" resonances as an experimental issue because most of the data on nucleon resonances are obtained from πN scattering experiments. Thus, only those resonances which have significant coupling strengths to the πN channel can possibly be observed. They were able to show that many unobserved resonances are indeed decoupled from the πN channel. These "missing" resonances may couple strongly to, for example, the ωN and ρN meson channels as suggested by quark model studies. Thus, detailed information on ω meson production both in terms of cross section and polarization observables will help to identify these "missing" resonances.

ω meson production is particularly useful in identifying those "missing" resonances because of its narrow intrinsic width (8.4 MeV) which allows the separation of the ω signal from other hadronic final states with the missing mass technique which we propose to use in this experiment. This feature together with the Hall A high resolution spectrometers and focal plane polarimeter makes this measurement unique and complementary to other related experiments at JLab. The isospin of the ω meson limits its coupling with the proton to only the N^* (I=1/2) resonances, which helps to identify those "missing" N^* resonances in a much cleaner way via the ωN channel than other meson-nucleon coupling channels.

While accurate cross section information is crucial in terms of understanding the reaction mechanism, polarization observables are unique in identifying the contribution of a small amplitude using the interference between the small amplitude and a large amplitude. In identifying the "missing" resonances, polarization observables can be essential. Recently, Zhao, Li and Bennhold [35] have performed a quark model calculation of vector meson photo-production in which an effective Lagrangian of the interaction between the vector meson and the quarks inside the baryon is employed. Their calculation shows that some of the single spin polarization observables are very sensitive to the "missing" resonance, $F_{15}(2000)$ in photo-production of ω meson around a photon energy of 2.0 GeV.

The Hall B experiment (E91-024) [36] on electro-production of ω meson measures the differential cross section and the ω meson polarization by analyzing the decay pion angular distribution. The Q^2 range of this experiment is between 0.5 and 0.8 $(\mathrm{GeV/c})^2$ and W is around 2.0 GeV. Our proposed measurements for the differential cross section cover a Q^2 range between 0.135 and 0.71 $(\mathrm{GeV/c})^2$ at a W value of 2.0 and 2.15 GeV which overlaps with the Hall B measurement at moderate Q^2, but goes much lower in Q^2 to allow for useful comparison with the photo-production data. Furthermore, we propose to perform a recoil proton polarization measurement with a longitudinally polarized electron beam, i.e., a double polarization measurement, which is expected to be more sensitive to small-amplitude contributions to the ω electro-production. The recently approved experiment E99-013 [37] will measure photo-production of ω mesons off protons with a linearly polarized photons. The goal of that experiment is to extract spin density matrix elements by analyzing the angular distribution of the decay pions from the ω. The determination of these density matrix elements will help to identify non-diffractive contributions to the ω meson photo-production. The experiment we propose here is complementary to the Hall B ω meson program.

The fact that ω and ϕ mesons have the same quantum numbers make the ω meson study, especially in the double polarization observable measurement, very relevant in identifying the direct knock-out of $\bar{s}s$ pair from proton by tagging ϕ mesons. The recoil proton polarization measurement from both ω and ϕ electro-production from a proton target at the very similar kinematic setting in terms of Q^2, W, and t near ϕ production threshold will help to answer questions concerning the reaction mechanism. In both cases, calculations have shown that the diffractive mechanism dominates productions at forward meson angles in the center-of-mass frame of the target proton and photon (real or virtual). The proposed measurement of recoil proton polarization will be at relatively forward meson angles where it is most sensitive to the direct knock-out of $s\bar{s}$ pairs from proton in ϕ production. This kind of double polarization together with much improved differential cross section measurements proposed here will likely shed light on the very intriguing question concerning the strangeness content of the nucleon and also whether there is a second trajectory in Pomeron exchange in electro-production of ϕ meson, and on identifying "missing resonances" from electro-production of ω meson.

III. PROPOSED MEASUREMENTS

We propose to perform measurements of $\mathrm{p}(\vec{\mathrm{e}},\mathrm{e}'\vec{\mathrm{p}})\phi$ and $\mathrm{p}(\vec{\mathrm{e}},\mathrm{e}'\vec{\mathrm{p}})\omega$ in Hall A at JLab with longitudinally polarized electrons and the focal plane polarimeter (FPP) at low Q^2 ($|Q^2| = 0.135, 0.177$ $(\mathrm{GeV/c})^2$) at an incident electron beam energy of 3.0 GeV. The scattered electrons and protons will be detected in coincidence and the missing mass technique will be used to identify the undetected ϕ and ω mesons. The invariant mass of the virtual photon and proton system is fixed at a central value of 2.15 GeV for ϕ production kinematics, and at 2.0 and 2.15 GeV for ω meson detection. The additional $W = 2.0$ GeV kinematic setting in the case of the ω meson is important for identifying the "missing" resonances, in particular the $F_{15}(2000)$ resonance. The kinematic settings for recoil proton polarization measurements are listed in Table I.

Based on theoretical predictions and due to experimental complications with solid polarized proton targets and relatively low photon fluxes from photon taggers, we propose this measurement with a longitudinally polarized electron beam and a focal plane polarimeter to measure the recoil proton polarization from $\mathrm{p}(\vec{\mathrm{e}},\mathrm{e}'\vec{\mathrm{p}})\phi$. At the 3.0 GeV kinematic setting, the beam-recoil asymmetry is still very sensitive to the strangeness content of the proton (Figs. 6-7). Fig. 8 shows the proposed measurements of the recoil proton polarization component P_x and P_z, together with the corresponding quantities calculated by Titov *et al.*. P_x and P_z are recoil proton polarization components measured in the lab frame, where z is along the momentum direction of the recoil proton and x is transverse to the proton momentum direction in the production plane.

In addition to the recoil polarization measurement, we propose to perform a series of differential cross section measurements as a function of Q^2, t and at a fixed central value of $W = 2.15$ GeV in electro-production of the ϕ meson, and the kinematic settings for these measurements are listed in Table III. In electro-production of the ω meson, differential cross sections will be measured at two central values of W, 2.0 GeV and 2.15 GeV (see Table IV). We propose to achieve an overall uncertainty of 5% for the differential cross section measurement at all proposed kinematic settings.

The combination of recoil proton polarization measurements from both ϕ and ω meson production at very similar kinematics and the cross section measurement as functions of t and Q^2 will address the very interesting subject of the strange quark content of the nucleon and the related theoretical issues in interpreting the polarization data, and investigate the possible second Pomeron trajectory as inspired by the glueball ($J_\pi = 0^+$, $M_b^2 \sim 3$ GeV^2) predicted by Lattice QCD calculation and Dual Ginzburg-Landau model. This experiment is unique and complementary in many ways to the Hall B ϕ and ω experiments discussed earlier.

We emphasize that this experiment will fully utilize the unique features of Hall A: the high luminosity, a pair of high resolution spectrometers, and a focal plane polarimeter. This experiment will provide, in a timely way, a very important measurement probing the strangeness content of the proton using electro-production of the ϕ meson with double polarization observables. This initial measurement will motivate more theoretical work in this direction which certainly will help to interpret the data in a less model-dependent way. Furthermore, this measurement will be complementary to any future Hall B experiments in which a polarized tagged photon beam and a polarized solid proton target will be employed, thus providing more detailed test of the theory. The proposed measurements on ω production will help to identify "missing" N^* resonances as predicted from NRQM, which are complementary to the related program in Hall B.

IV. THE EXPERIMENT

A. Experimental Overview

This experiment requires a longitudinally polarized electron beam with polarization 70% at a beam current of 50μA, which is realistic from the achieved performance of the polarized electron source with strained GaAs crystals. The experiment will employ the Hall A cryogenic liquid hydrogen target, the electron and the hadron high resolution spectrometers (HRS), and the hadron arm focal plane polarimeter (FPP). Electron beam energies of 3.0, 4.0, and 5.0 GeV are required. We will use the missing mass technique to identify the undetected ϕ and ω mesons by measuring the scattered electrons and protons in coincidence, p($\vec{e}$,e$'\vec{p}$)ϕ (or ω). This missing mass technique was demonstrated to be able to identify ω and ϕ mesons from the analysis of test data we took in April of 1999 in Hall A under conditions very close to the proposed kinematic settings for the recoil polarization measurement from ω and ϕ electro-production.

B. The Polarized Electron Beam

The first two JLab experiments [38] [39] which ran with strained GaAs crystal were completed successfully in the last half a year (or so). It has been demonstrated that the JLab polarized source can deliver a 50μA polarized electron beam at high polarization. The polarization of the beam can be measured with the Hall A Möller and/or the Compton polarimeter. The Hall A Compton polarimeter has been commissioned in the spring of 1999. The request of a beam current of 50μA and an electron polarization of 70% in this proposal is realistic.

C. The Focal Plane Polarimeter

The Hall A focal plane polarimeter consists of a graphite analyzer with two straw chambers upstream and two downstream for tracking the protons. The analyzer consists of 5 sets of graphite plates with thicknesses of 3.2, 6.4, 12.9, 25.9, and 38.9 g/cm^2 (0.75, 1.5, 3.0, 6.0, and 9.0 inches), which can be used in any combination. The analyzer covers the full spectrometer acceptance. Each chamber consists of six planes of straws (3 U and 3 V for all chambers except for the one immediately after the analyzer, which has 2 U, 2 V, and 2 X). This gives sufficient redundancy that tracking efficiency is close to 100% over the entire active area. Angular resolution of tracks is about 4 mr. For the kinematics of this experiment, the average analyzing power is 0.5 (0.683 GeV/c protons). The efficiency for events scattered between 5° and 20° is about 4%, as determined in experiments at LAMPF, Mainz, PSI and TRIUMF.

D. Simulations

For the two-body process $\gamma^* \mathrm{p} \rightarrow V \mathrm{p}$ of interest where V is either ϕ (or ω), one can reconstruct the three momentum and the energy of the undetected ϕ or ω meson, hence its mass by accurately determining the recoil proton momentum and angle. Thus, it is very important to have fine resolution in the reconstructed ϕ or ω mass to reject backgrounds. Since the proposed experiment relies on the missing mass technique to identify the undetected ϕ meson events, which are more difficult to identify than ω mesons. It is very important to simulate the missing mass resolution for ϕ meson reconstruction at the kinematics of this experiment. A Monte Carlo simulation code was written for this purpose.

In our simulation, we used $\sigma(E)/E = 1.0 \times 10^{-4}$ for the beam energy resolution and $\delta p/p = 2 \times 10^{-4}$ (RMS) for the momentum resolution of both spectrometers. For the spectrometer angular resolutions (RMS), 0.6 mr and 2.0 mr were used for the horizontal and vertical, respectively. Multiple scattering in the target, windows, and air gaps were included in the simulation, as well as straggling and energy loss for the outgoing particles. The missing mass resolution is dominated by multiple scattering in the target in the hadron arm. The missing mass squared resolution (FWHM) from kinematic reconstruction only is around 0.01 GeV^2. The total missing mass squared resolution is $\sim$ 0.013 GeV^2 which includes the natural decay width of the ϕ meson. Fig. 9 shows the simulated missing mass squared resolution at the kinematic setting of the recoil proton polarization in ϕ electroproduction, $<\theta_e>= 12.6^\circ$, and $887.19 \leq E' \leq 980.57$ MeV. This corresponds to $|<Q^2>| = 0.135$ (GeV/c)^2 and $<W>= 2.15$ GeV. The central momentum and angle settings for the hadron arm are 683.0 MeV/c and 34.47° in the simulation.

E. Backgrounds

For the proposed $\mathrm{p}(\vec{\mathrm{e}},\mathrm{e}'\vec{\mathrm{p}})\phi$ measurement, one can effectively rewrite the reaction in terms of the following two-body process: $\gamma^* \mathrm{p} \rightarrow \mathrm{p}\phi$. Thus, dominant two-body final state background channels will be rejected by the missing mass cut on the ϕ mass peak. The remaining backgrounds come mostly from three contributions which we will discuss in detail below.

The accidental coincidence background is estimated in the following way. We used the Lightbody and O'Connell codes to calculate the singles electron and proton rates. To calculate the accidental coincidence rate, a coincidence timing cut of 3 ns was used. One can further reduce the coincidence rate by requiring a vertex cut. At the kinematics of this experiment, a factor of 10 reduction in the accidental coincidence rate can be achieved easily by applying a vertex cut, based on the quoted HRS transverse vertex resolution of 1.5 mm at 90°. The accidental coincidence background as a function of missing mass was simulated at the kinematic setting of this experiment and its contribution to the ϕ signal is small. A modest factor of 5 reduction in the accidental coincidence rate using the vertex cut was applied in the simulation. This vertex cut will be imposed before subtracting the accidentals to obtain the real coincidence events.

The primary sources of physics backgrounds to this measurement are the the multi-pion background, which is dominated by the $\pi^+\pi^-$ channel, and s-wave K^+K^- production [40]. An estimate of 1.5 μb for the total resonant plus non-resonant s-wave K^+K^- photo-production cross section, together with the knowledge of the differential cross section for the ϕ meson photo-production at a photon energy of around 2.1 GeV, allows us to estimate the cross section for $\gamma^*\text{p} \rightarrow \text{p}K^+K^-$ at the kinematics of this experiment. The s-wave K^+K^- production was simulated for this experiment as a function of missing mass squared. Fig. 10 shows the contribution of K^+K^- as slanted hatches. The $\pi^+\pi^-$ background was simulated in the same way as that of the K^+K^- channel, with the total electro-production cross section measured from DESY [41] in the similar kinematic region as in this experiment. The simulated $\pi^+\pi^-$ contribution is shown as horizontal hatches in Fig. 10. These two simulated background distributions are very useful when we compare our test result and the simulation in terms of understanding the overall background distribution (see next section).

F. The Test Results

In April of 1999, a short beam test was performed in Hall A to demonstrate that the missing mass technique is feasible for identifying ω and ϕ mesons. The result from our preliminary data analysis clearly shows the signal from ω electro-production, and the observed rate agrees well with the estimated rate based on the VMD diffraction model calculation with parameters determined from the existing data of Ballam *et al.* [42]. In the case of ϕ production, the ϕ signal is seen in the missing mass spectrum, though the signal to noise ratio ($\sim$ 1:2) is worse than we expected. The observed rate for ϕ is about a third of what we anticipated based on the diffractive model calculation with input parameters determined mostly by the data from Dixon *et al.* [43]. The cross section data from Dixon *et al.* have rather large error bars ($\sim 20 - 30\%$). The lowest Q^2 of their measurement is around 0.4 $(\text{GeV/c})^2$, which is much higher than the Q^2 where the test was carried out (0.135 $(\text{GeV/c})^2$). To further investigate this difference, more detailed analysis of the test data which takes into account the extended target correction, vertex cut, beam rastering effect, etc.. is currently underway, which is also expected to improve the signal-to-noise ratio. Following is a brief description of the test and the preliminary data analysis of the test data.

The incident electron beam energy was 3.355 GeV for the test. The HRSe was set at a central momentum of 1.145 GeV/c and a central scattering angle of 12.5° and the HRSh was set at a central momentum of 0.6806 GeV/c and a central angle of 37.826° for the ϕ kinematics. The corresponding settings are 1.356 GeV/c and 12.5° (HRSe), and 0.7163 GeV/c and 48.3° (HRSh) for the ω kinematics.

From all coincidence events in a given run, electrons were identified using a cut on the Cerenkov and shower counters in the electron arm and also loose spectrometer acceptance/aperture cuts on the reconstructed target quantities, δ, θ, ϕ. The protons were identified with a cut on the particle β ($0.45 < \beta < 0.8$) and a cut on the sum over all paddles in scintillator planes S1 and S2. In addition there were spectrometer acceptance/aperture cuts. Next a coincidence peak and window was determined using the path length corrected coincidence time spectra (typically $220 < t_{corrected} < 240$, *i.e.* a 20 ns window). With these three cuts one determined the missing-mass spectrum for the coincidence events. The randoms were determined using 50 ns windows on either side of the coincidence window. The missing-mass spectrum was calculated for the random events, this spectrum scaled by 20/100 was then subtracted from the missing mass spectrum for the coincidence events. The same procedure was repeated for all the runs and the random subtracted missing-mass spectra from each run were added together. Fig. 11 and Fig. 12 show the missing mass spectra obtained from the ω and ϕ runs respectively, according to the procedure described above. In Fig. 11, one can see the ω signal clearly superposed on the background and the cut-off of the background distribution is caused by the finite acceptances of the spectrometers. To describe the observed background shape in the missing mass distribution at the ϕ kinematic setting, the simulated physics backgrounds were multiplied with some scale factors. Although the scaled simulated backgrounds and the simulated ϕ signal seem to describe the data reasonably well, detailed analysis which is taking into accounts the extended target effect, vertex cut, and the beam rastering effect, etc.. is currently underway. The signal-to-noise ratio is expected to be improved.

G. Counting Rates

To estimate the coincidence rate for p(e,e′p)ϕ measurement, we followed the cross section formula derived by Henley *et al.* [1] from the vector meson dominance model of diffractive production of the vector meson, which was cross checked by the cross section calculation from Ref. [28]. The five-fold differential cross section is formed by $\frac{d^5\sigma}{dE' d\Omega_e d\Omega_p}$ for the coincidence measurement. A factor of 1/3 was used to account for the fact that the observed rate is about 1/3 of what we expected. In the case of ω production, again a diffractive VMD cross section was used with parameterizations from Ballam *et al.* [42] which seems to agree well with our test result.

Table II lists the calculated differential cross section, singles and the coincidence rates at the proposed kinematics with the spectrometer acceptances taken into account. In estimating the rates, we assumed a beam current of 50 μA. This corresponds to a luminosity of $2.0 \times 10^{38}/cm^2$ for a 15-cm LH2 target cell. For each spectrometer, we used 5.5 msr solid angle for extended target and 0.9 for the detection efficiency. In addition, we used a scattered electron energy bin of 80 MeV. During our April test run, half of our data were taken at a beam current of 50 μA. Thus, we should be able to run at a beam current of 50 μA safely for this experiment.

H. Beam Time Estimate

By Fourier analysis of the azimuthal distribution of FPP events, two independent components can be extracted each with a statistical accuracy of

$$\delta P = \frac{\pi}{2\bar{A}_y}\sqrt{\frac{1}{fN}}, \tag{5}$$

where $\bar{A}_y$ is the mean analyzing power, and f is the FPP efficiency, which is defined as the ratio of the events that are accepted by FPP for polarization analysis to the total number,

N, of the spectrometer events. For coplanar kinematics the recoil proton polarization vector, $\vec{P}$, can be expressed as

$$\vec{P} = P_{yy}\hat{yy} + h(P_{xx'}\hat{xx'} + P_{zz'}\hat{zz'}) \tag{6}$$

where $\hat{zz'}$ is along the nucleon momentum direction, $\hat{xx'}$ is in the reaction plane and transverse to the momentum, and $\hat{yy}$ is normal to the reaction plane in the laboratory frame. The polarization measured in the focal plane, $\vec{P}^{fp}$, is then

$$P_{xx'} = P_2^{fp} \tag{7}$$
$$P_{yy} = P_1^{fp}\cos\chi - P_3^{fp}\sin\chi \tag{8}$$
$$P_{zz'} = P_1^{fp}\sin\chi + P_3^{fp}\cos\chi \tag{9}$$

where P_1^{fp} is in the dispersion direction, P_2^{fp} is normal to the bend plane, P_3^{fp} is along the trajectory, and χ is the spin precession angle.

Although P_3^{fp} can not be measured with the FPP, the fact that $P_{zz'}$ changes sign with the beam helicity whereas P_{yy} does not allows separation of the focal-plane polarization within the spectrometer bend plane into two independent reaction components P_{yy} and $P_{zz'}$. Thus, all three components of the recoil proton polarization can be determined from the FPP for this experiment. By flipping the beam helicities, all three polarization components can be measured with the following statistical uncertainties:

$$\delta P_{xx'} = \frac{\delta P}{h} \tag{10}$$
$$\delta P_{yy} = \frac{\delta P}{\cos(\chi)} \tag{11}$$
$$\delta P_{zz'} = \frac{\delta P}{h\sin(\chi)} \tag{12}$$

The spin precession angle for the kinematics of this experiment is around 100°. In calculating the statistical uncertainty, an electron beam polarization of 70% was assumed. At the kinematics of this proposal, the FPP efficiency is about 4% and the average analyzing power is $\sim 50\%$, which are consistent with results obtained from FPP commissioning. The signal-to-noise ratios observed in Figs. 11 and 12 were used in calculating the dilution factors for estimating the beam times for the recoil polarization measurements.

For the production running of the experiment, we request a total of 400 hours of beam time for polarization measurements, and 88 hours for cross section measurements. In addition, we request 24 hours for spectrometer and detector checkout, 24 hours for beam energy changes and spectrometer changes, and 24 hours for empty target measurements, and 24 hours for beam polarization measurements. In total, we request 584 hours of beam time (25 days) for this experiment.

I. Systematic Uncertainties

The systematic error in the cross section measurement is dominated by the uncertainty in knowing the spectrometer acceptance. Based on our current understanding of the HRS acceptances, a goal of an overall 4% systematic uncertainty in cross section measurement is achievable.

The systematic uncertainty of the beam-recoil asymmetry ($P_{x,y,z}$) measurement is dominated by the systematic uncertainties in the electron beam polarization measurement and the FPP measurement. The electron beam polarization will be determined by the Hall A Möller polarimeter/Compton polarimeter, and a 3% overall uncertainty can be achieved.

The major systematic uncertainties related to the FPP are the knowledge of the analyzing power and instrumental asymmetries. The analyzing power of graphite for protons in the energy range of interest in this experiment has been measured at LAMPF, PSI, and TRIUMF. The overall uncertainty for the world average is estimated to be ±2% [44]. Based on the analysis of JLab experiment 89-033, instrumental asymmetries (ϵ_{inst}) are expected to be about 0.005, corresponding to an uncertainty in the measured polarization of about $\epsilon_{inst}/\mathrm{A}_c$, about 0.012. However, by combining opposite helicity states, the instrumental asymmetry contribution to the measurement of P_x and P_z cancels to first order. Both the uncertainty on the analyzing power and the instrumental asymmetries are thus both expected to contribute less to the absolute uncertainty than the measurement of beam polarization, and be less than the statistical uncertainty.

The asymmetry from background contributions can be studied from the data and one can correct for it to obtain the ϕ (ω) asymmetry by measuring the recoil proton polarization on both sides of the ϕ (ω) mass peak. Estimates of asymmetries from the dominant physics background channels ($\pi^+\pi^-$ and K^+K^-) are currently being calculated by our theory collaborators.

V. COLLABORATION BACKGROUND AND RESPONSIBILITIES

This experiment requires the longitudinally polarized electron beam, the standard Hall A liquid hydrogen target, and both Hall A HRS spectrometers. The recoil proton polarization will be measured using the focal plane polarimeter. This experiment will run with standard Hall A equipment. Many members in our collaboration have extensive experience in polarization experiments with longitudinally polarized electron beams at JLab and many other laboratories. The Rutgers group along with William and Mary and other institutions are responsible for the construction and commissioning of the Hall A FPP. Many members of this collaboration have significant experience in running experiments in Hall A. Members of the MIT group together with Hall A staff and others led the first Hall A collaboration experiment and one of the first two polarized ^{3}He experiments. The University of New Hampshire group is responsible for the Hall A trigger system and has committed to an MOU to upgrade of the Hall A scintillators to improve timing resolution by a factor of two. They are also experienced in Hall A running. The expertise and manpower of this collaboration is adequate to carry out this program. This collaboration also has very strong theoretical support.

VI. ACKNOWLEDGEMENTS

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TABLES

E (GeV)	E' (GeV)	θ_e (degree)	P_p (GeV/c)	t (GeV/c)^2	θ_p (degree)	W (GeV)	$\|Q^2\|$ $(GeV/2)^2$	ϵ
3.0(ϕ)	0.934	12.6	0.693	-0.428	-34.52	2.15	0.135	0.557
3.0(ω) (I)	0.934	12.6	0.564	-0.294	-50.13	2.15	0.135	0.557
3.0(ω) (II)	1.243	12.5	0.568	-0.297	-45.38	2.0	0.177	0.693

TABLE I. Kinematics for the proposed p($\vec{\mathrm{e}}$, e$'\vec{\mathrm{p}}$)ϕ, ω reaction. The negative sign indicates that the hadron arm is on the opposite side of the beam line compared with the scattered electron direction. W is the invariant mass for the virtual photon and proton system and ϵ is the polarization of the virtual photon.

E (GeV)	$d^5\sigma/(dE'd\Omega_e\Omega_p)$ $(nb/GeV\,sr^2)$	p(e,e$'$p)ϕ (Hz)	Beam time (hours)	Δp_x	Δp_z	(e,e') (Khz)	(e,p) (Khz)	(e,π^+) (Khz)	(e,π^-) (Khz)
3.0 (ϕ)	3.8	1.0	200.0	0.063	0.064	65.0	61.0	221.0	600.0
3.0 (ω (I))	19.0	7.4	100.0	0.053	0.057	85.0	28.0	145.0	375.0
3.0 (ω (II))	18.7	7.3	100.0	0.052	0.053	85.0	37.0	196.0	375.0

TABLE II. Rate estimate and beam time request for the proposed p($\vec{\mathrm{e}}$, e$'\vec{\mathrm{p}}$)ϕ, ω measurements.

E (GeV)	E' (GeV)	θ_e (degree)	P_p (GeV/c)	t $(\mathrm{GeV/c})^2$	θ_p (degree)	W (GeV)	$\|Q^2\|$ $(GeV/2)^2$	time (hrs)
3.0	0.934	12.6	0.525	-0.257	-30.59	2.15	0.135	2.3
3.0	0.934	12.6	0.852	-0.618	-33.76	2.15	0.135	1.5
3.0	0.934	12.6	1.106	-0.960	-29.24	2.15	0.135	6.8
4.0	1.819	12.6	0.577	-0.301	-32.73	2.15	0.35	3.3
4.0	1.819	12.6	0.859	-0.627	-36.69	2.15	0.35	1.0
4.0	1.819	12.6	1.125	-0.989	-33.26	2.15	0.35	8.6
5.0	2.665	12.6	0.646	-0.377	-33.72	2.15	0.64	5.4
5.0	2.665	12.6	0.936	-0.727	-37.85	2.15	0.64	1.4
5.0	2.665	12.6	1.160	-1.039	-35.75	2.15	0.64	12.2

TABLE III. Kinematics for the proposed $\mathrm{p}(\vec{\mathrm{e}},\mathrm{e}'\vec{\mathrm{p}})\phi$ cross section measurement. The beam time was estimated for a statistical uncertainty of 3% at all proposed kinematic settings.

E (GeV)	E' (GeV)	θ_e (degree)	P_p (GeV/c)	t $(\mathrm{GeV/c})^2$	θ_p (degree)	W (GeV)	$\|Q^2\|$ $(GeV/2)^2$	time (hrs)
3.0	0.934	12.6	0.864	-0.633	-45.69	2.15	0.135	1.7
3.0	1.242	12.6	0.762	-0.508	-43.90	2.00	0.179	0.5
3.0	0.934	12.6	0.983	-0.789	-39.24	2.00	0.179	3.8
4.0	1.819	12.6	0.503	-0.238	-49.80	2.15	0.35	0.5
4.0	1.819	12.6	0.917	-0.702	-47.49	2.15	0.35	3.5
4.0	2.119	12.6	0.607	-0.336	-46.08	2.00	0.41	0.5
4.0	2.119	12.6	0.829	-0.588	-45.59	2.00	0.41	1.0
4.0	2.119	12.6	1.061	-0.898	-41.64	2.00	0.41	10.5
5.0	2.665	12.6	0.693	-0.428	-37.84	2.15	0.64	0.5
5.0	2.665	12.6	0.988	-0.797	-47.90	2.15	0.64	8.5
5.0	2.959	12.6	0.684	-0.415	-45.64	2.00	0.71	0.8
5.0	2.959	12.6	0.913	-0.696	-45.82	2.00	0.71	2.4
5.0	2.959	12.6	1.036	-0.862	-44.44	2.00	0.71	10.5

TABLE IV. Kinematics for the proposed $\mathrm{p}(\vec{\mathrm{e}},\mathrm{e}'\vec{\mathrm{p}})\omega$ cross section measurement. The beam time was estimated for a statistical uncertainty of 3% at all proposed kinematic settings.

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FIGURES

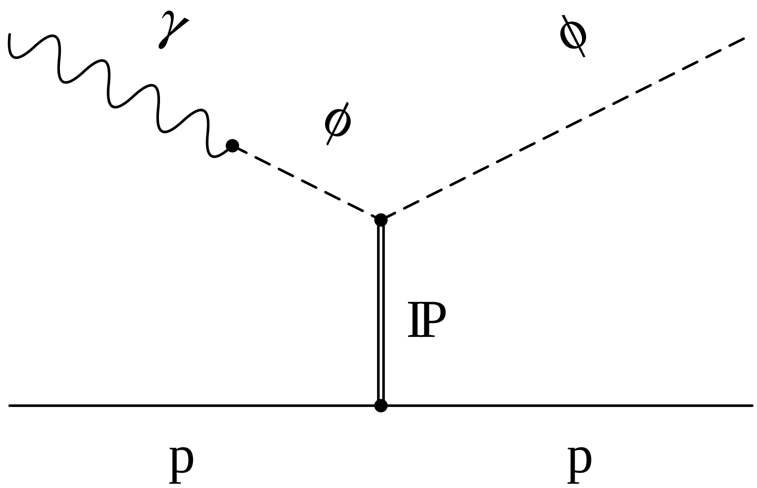

FIG. 1. Diffractive ϕ meson production within the vector-meson-dominance model by means of Pomeron exchange.

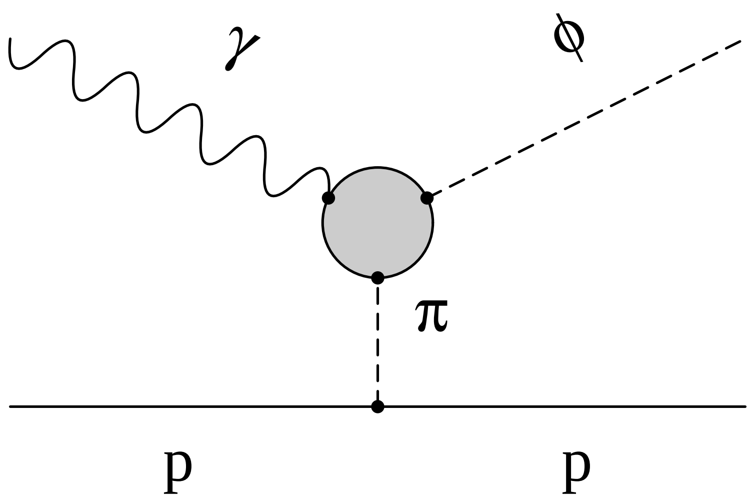

FIG. 2. One pion exchange process in the ϕ photoproduction.

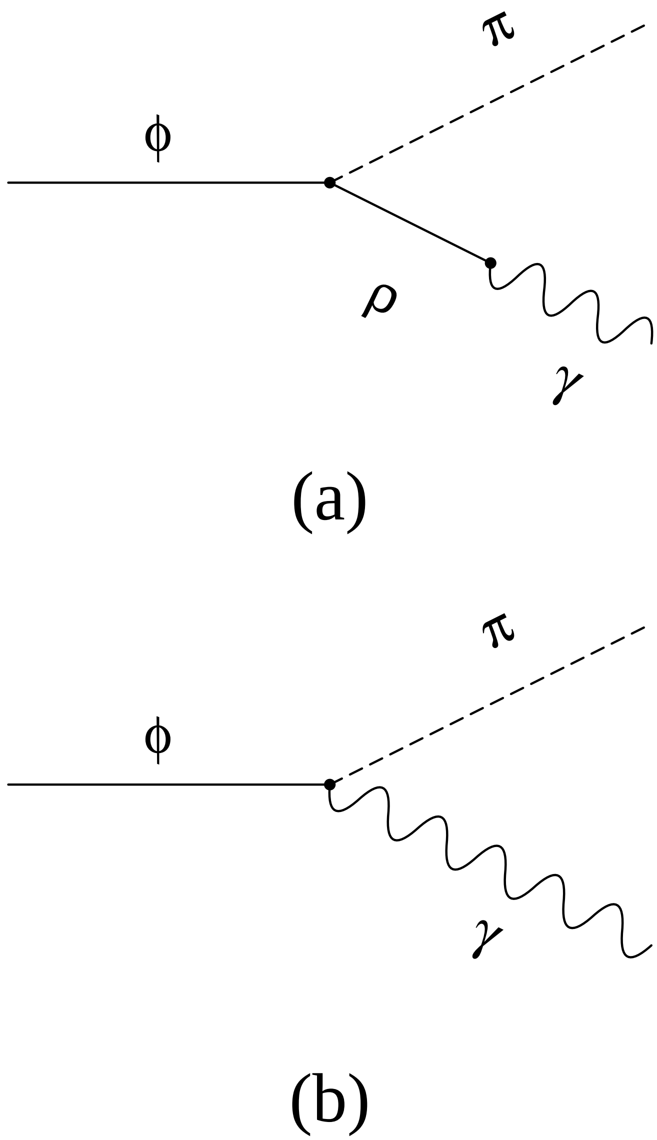

FIG. 3. Two possible mechanisms of $\phi \to \gamma\pi$ decay.

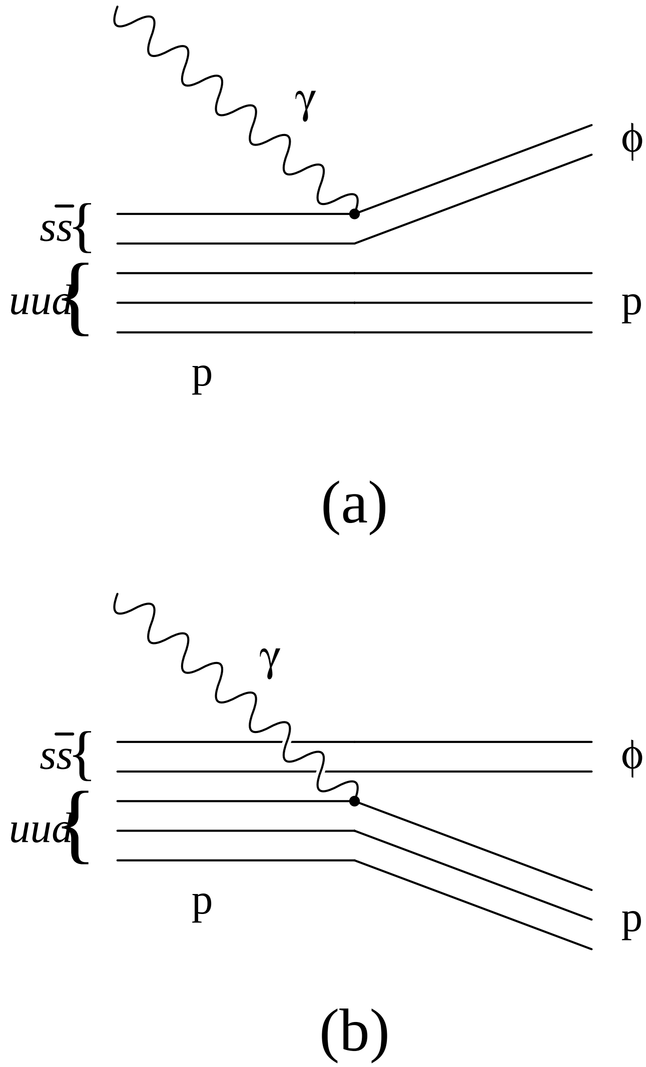

FIG. 4. (a) $s\bar{s}$-knockout and (b) uud-knockout contributions to ϕ meson photoproduction.

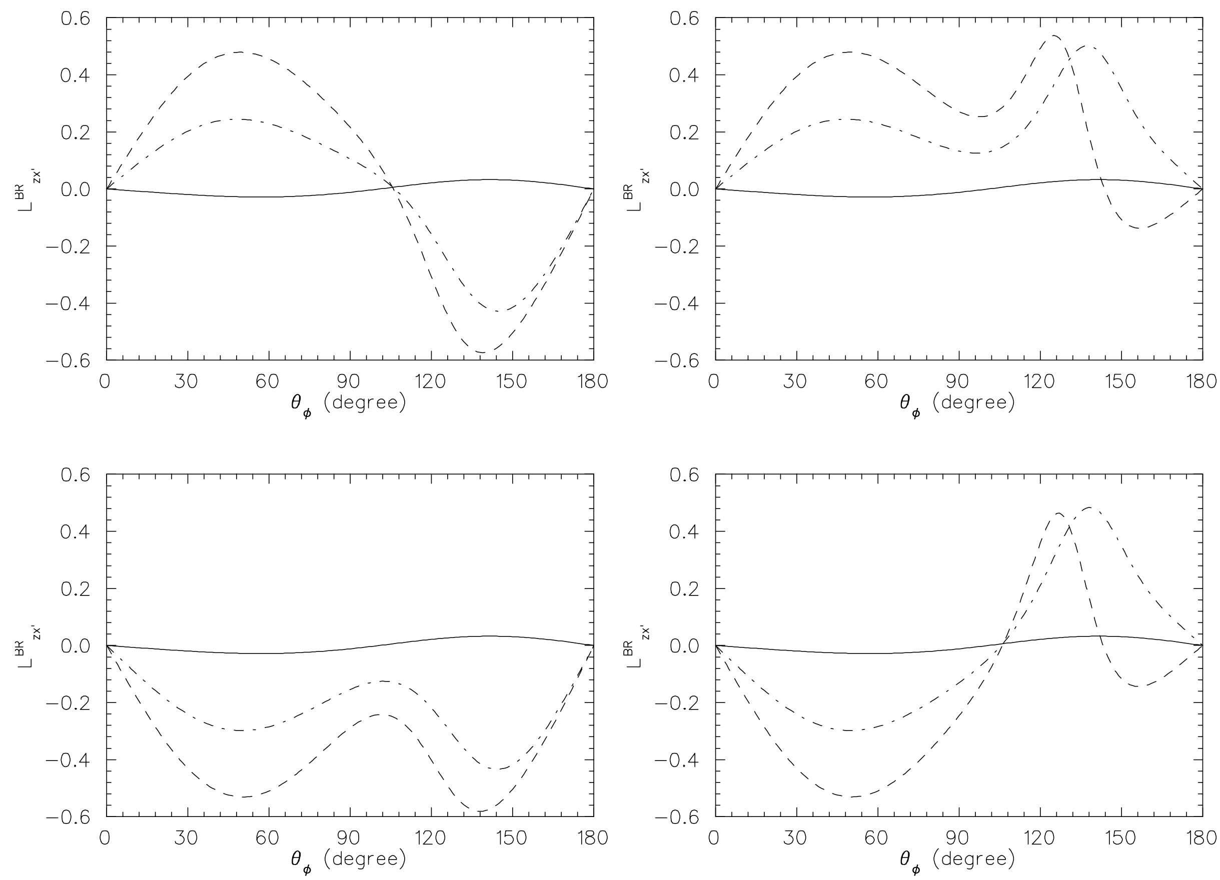

FIG. 5. Longitudinal beam-recoil asymmetry as a function of ϕ_{cm} calculated by Titov, Oh and Yang for photoproduction of ϕ mesons from protons . The solid, dash-dotted and dashed lines correspond to VMD+OPE, 0.25% $\bar{s}s$ probability, and 1% $\bar{s}s$, respectively. The four different panels correspond to four different phase combinations in the mixing of the two spin configurations of $\bar{s}s$.

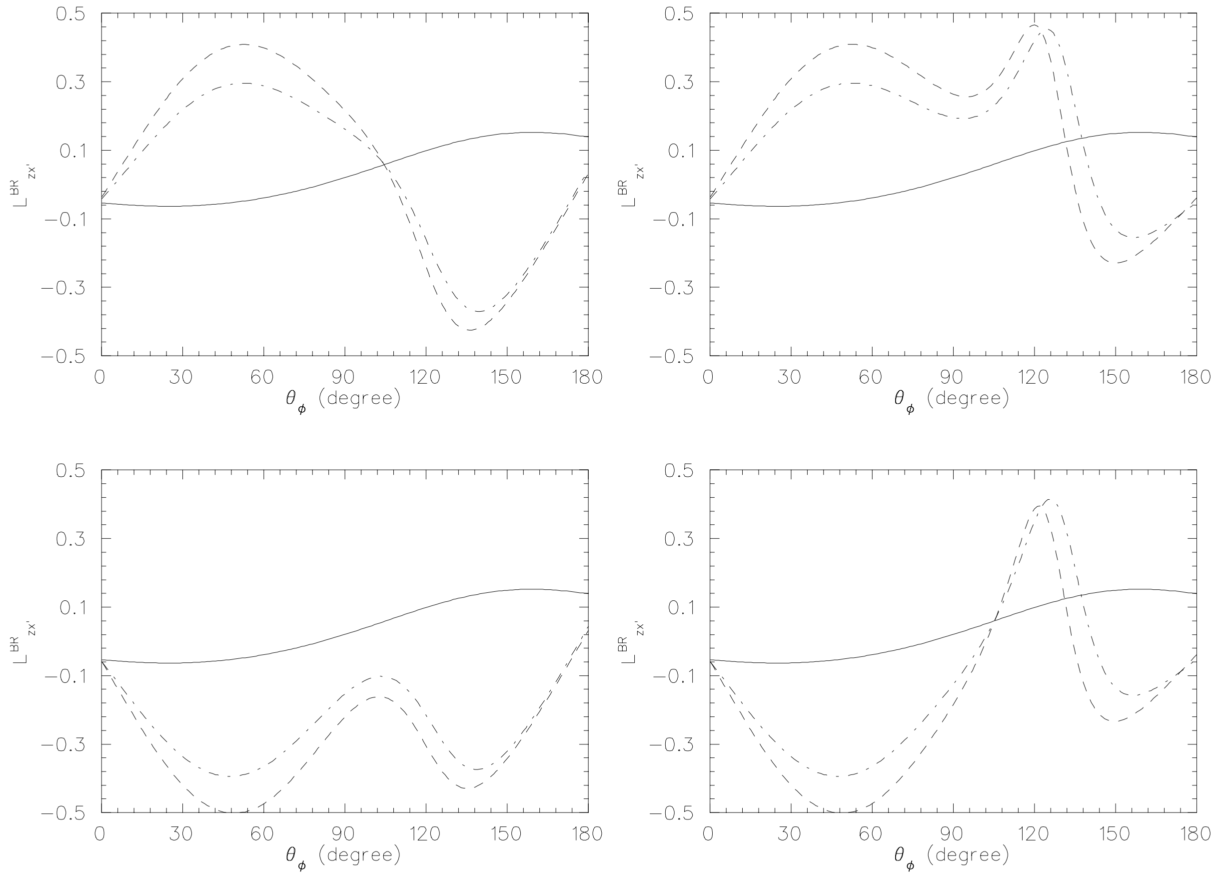

FIG. 6. The beam-recoil asymmetry $L^{BR}_{zx'}$ from electro-production of ϕ meson as a function of ϕ_{cm} calculated by Titov *et al.* at a $|Q^2| = 0.135$ $(\mathrm{GeV/c})^2$ (see text). The solid, dash-dotted and dashed lines correspond to VMD+OPE (no strangeness), 0.5% $\bar{s}s$ probability, and 1.0% $\bar{s}s$, respectively. The four different panels correspond to four different phase combinations in the mixing of the two spin configurations of $\bar{s}s$.

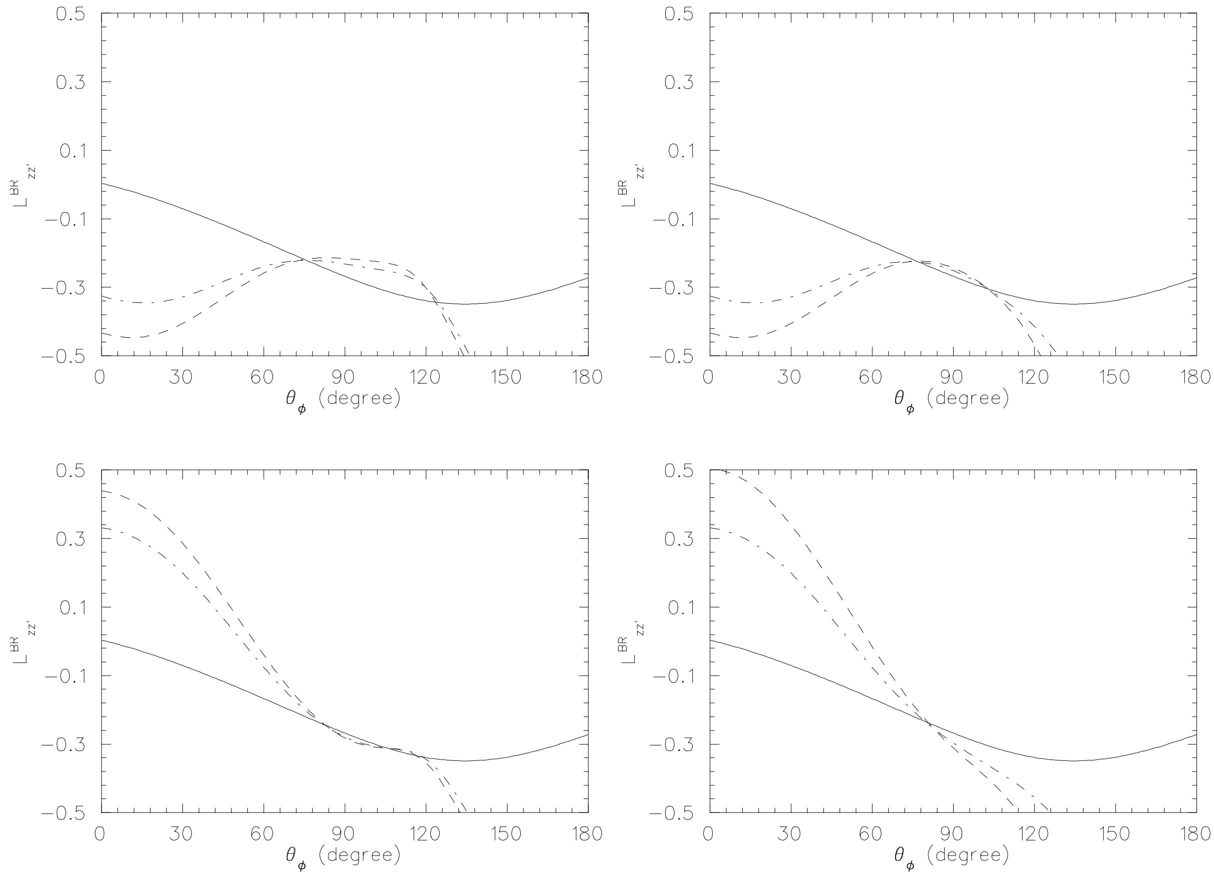

FIG. 7. The beam-recoil asymmetry $L^{BR}_{zz'}$ from electro-production of ϕ meson as a function of ϕ_{cm} calculated by Titov *et al.* at a $|Q^2| = 0.135$ (GeV/c)^2 (see text). The solid, dash-dotted and dashed lines correspond to VMD+OPE (no strangeness), 0.5% $\bar{s}s$ probability, and 1.0% $\bar{s}s$, respectively. The four different panels correspond to four different phase combinations in the mixing of the two spin configurations of $\bar{s}s$.

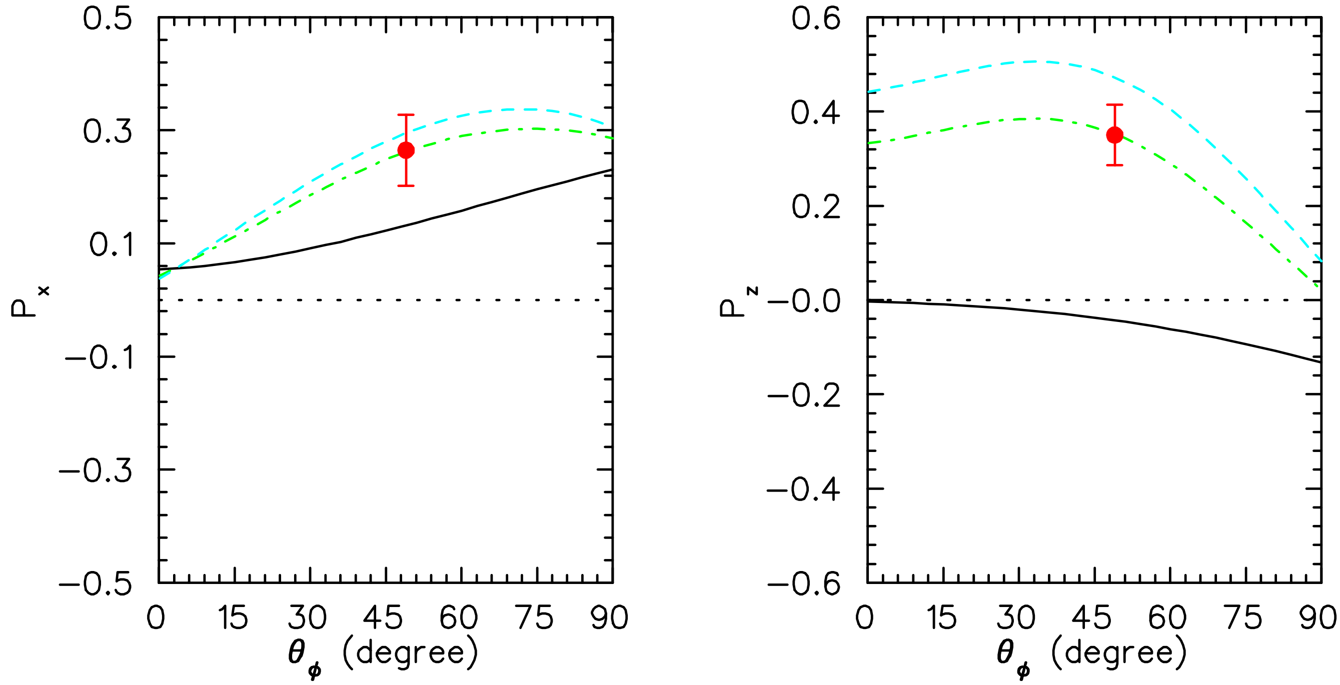

FIG. 8. Proposed recoil polarization measurement P_x and P_z with statistical uncertainties only from ϕ production. The solid, long dash-dotted and dashed lines correspond to VMD+OPE (no strangeness), 0.5% $\bar{s}s$ probability, and 1.0% $\bar{s}s$, respectively. The phase combination of (+1,+1) for the spin configurations of $\bar{s}s$ is shown only for simplicity.

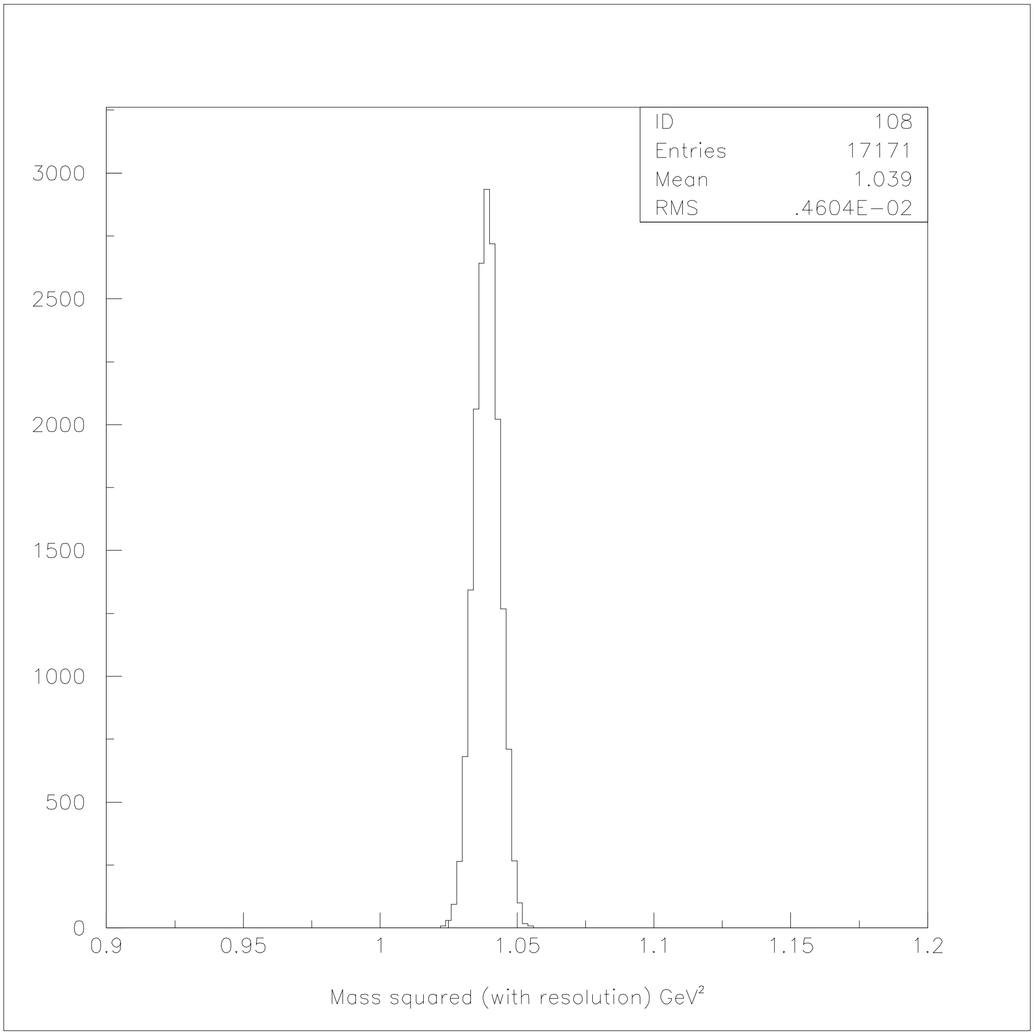

FIG. 9. The simulated missing mass squared resolution at the kinematic setting of this experiment from reconstruction only for ϕ detection.

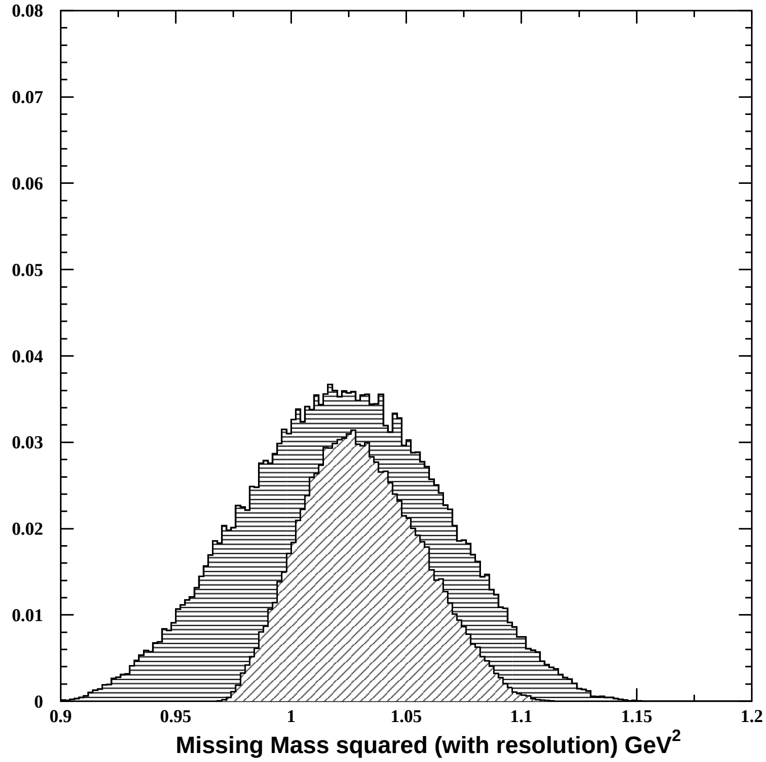

FIG. 10. The simulated missing mass squared distributions from the physical s-wave K^+K^- and $\pi^+\pi^-$ backgrounds at the kinematic setting of the recoil polarization measurements from ϕ production.

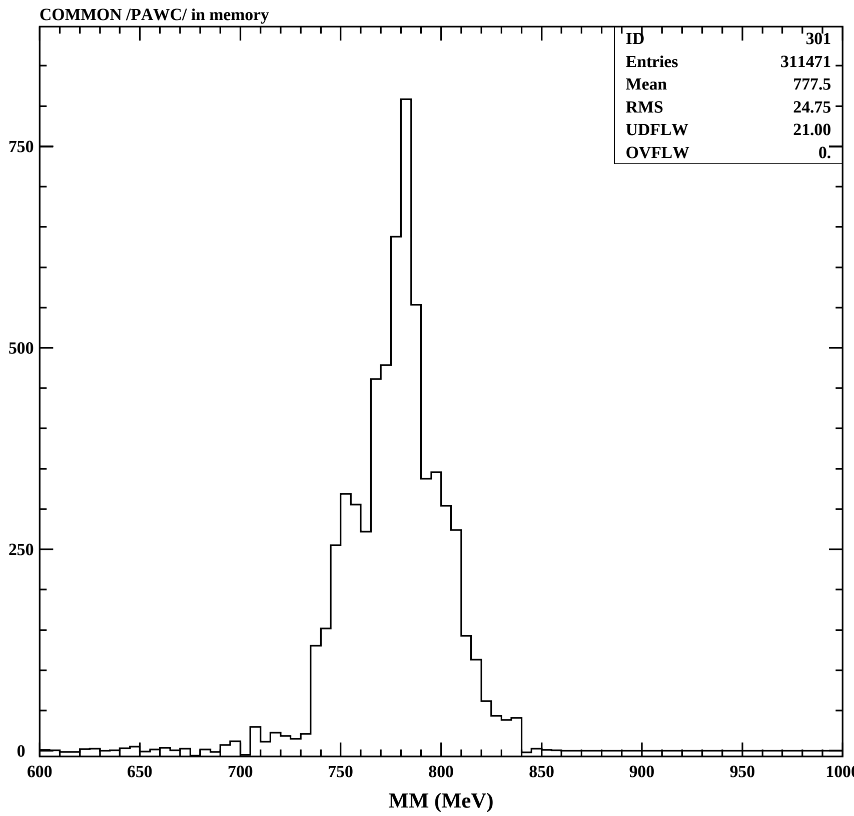

FIG. 11. The missing mass spectrum from the ω test runs.

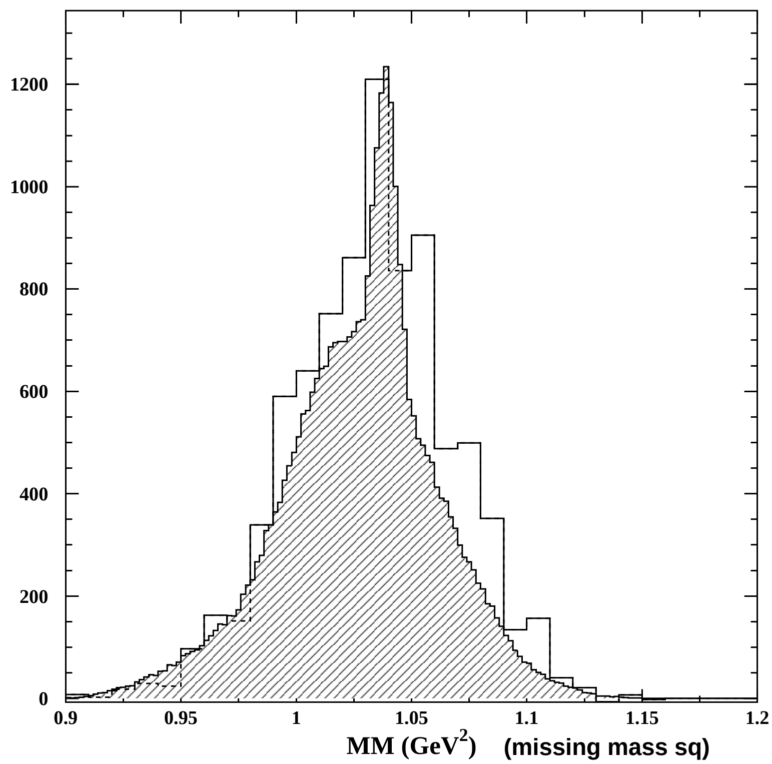

FIG. 12. The missing mass squared spectrum from the ϕ test runs together with our simulation of the backgrounds and the ϕ signal.