PAC20 Jeopardy Proposal
G7 experiment (Originally E94-002)

"Photoproduction of Vector Mesons Off Nuclei"

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Update of Approved experiment E94-002

Title: " Photoproduction of Vector Mesons Off Nuclei"

Spokespersons : D. Weygand, M. Kossov, C. Djalali

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PAC9 Report on Approved Proposal PR-94-002

Proposal:

Update: PR-94-002, Hall B

Spokespersons:

P.-Y. Bertin, M. Kossov and B. M. Preedom

Title:

Photoproduction of Vector Mesons Off Nuclei

Motivation:

This experiment proposes to examine inclusive $e^+ e^-$ photo-production in the incoherent production region in order to seek evidence for possible modification of vector meson properties (mass, width, relative phase) in the presence of the nuclear medium.

Measurements and Feasibility:

The measurement will be accomplished by measuring the $e^+ e^-$ cross section in the incoherent region simultaneously from a series of nuclear targets. While the proponents allege that the analysis of data will be sensitive to a vector meson mass shift as small as small as 20 MeV via comparison of results on lead and deuterium, PAC was not convinced that this would be possible given the many effects that were not included in the model-calculation. Nevertheless, measurement of the vector meson shape in nuclei, as well as the associated A-dependence is of considerable interest, both intrinsically and as a prelude to future RHIC work.

Issues:

Much more sophisticated modeling must be done in order to interpret the data in terms of modification of vector meson properties in the nuclear medium. The PAC suggests that the sequential target configuration be further optimized to reduce systematic errors.

Recommendation:

Approval for 12 days.

Goal of this proposal

We wish to maintain the approved status of the current g7 experiment. Three years of running in Hall B have allowed us to gain the necessary experience with CLAS to better estimate e/π discrimination and determine more realistic acceptances and efficiencies, counting rates, etc. The g7 run period was briefly considered for scheduling in 2000, but was postponed mainly due to a manpower issue that has since been resolved (see manpower update section). We are ready to run as soon as the summer of 2002.

This experiment is designed to measure the properties of vector mesons in nuclear matter. At high baryon density the properties of vector mesons are predicted to change due to chiral symmetry restoration. Some QCD based models [1-5] predict a large downward shift of the vector meson masses. More "conventional" processes such as in-medium rescattering predict no change in the vector meson mass but a substantial increase in the width of the meson [6-9]. All of these effects are density dependent and, if present, should be observed at normal nuclear densities. The photoproduction of vector mesons near threshold can be used to measure the masses, widths and relative phases of vector mesons embedded in nuclear matter. At CEBAF energies, the incoherent photoproduction of ρ-mesons off heavy nuclei is the ideal way to determine any modification of the meson properties in nuclear matter (mass shift and/or width increase). It may also be possible to measure the mass shift for narrow vector mesons. Because of the long decay length cτ, only a small fraction of these vector mesons will decay inside the nucleus. However, since the mass shift is predicted to be substantial relative to the natural width, these decays will be easier to separate from vector mesons decaying outside of the nucleus.

Detecting the leptonic decays of vector mesons is the only reliable way to measure the mass shift of vector mesons because hadronic decay modes in nuclear matter are always disturbed by final state interactions. The small cross sections for incident photons and for secondary interactions of the outgoing electrons with nuclear matter makes this reaction the ideal probe for testing the properties of the dense central region of the nucleus without significant input and output distortions. We plan to measure the A(γ, e^+e^-)A' reaction by identifying the coincident electron pairs in the CLAS detector. Energy deposition in the electromagnetic calorimeter, the Cerenkov counter signal, and transverse momentum compensation define clear cuts for the separation of the e^+e^- events from the large hadronic background. As shown in the attached CLAS note (Appendix 1), we have sufficient $e^+e^-/\pi^+\pi^-$ discrimination to be able to successfully carry out this experiment.

We plan to take data on four nuclear targets simultaneously: deuterium, carbon, iron and lead with a beam intensity of 5 x 10^7 tagged photons per second in the energy range 1.2 to 2.2 GeV (E_0 = 2.4 GeV). Setting the magnetic field of the CLAS detector to half its maximum value was found to be optimal for this photon energy range. Tagged photons are to be used to determine the kinematics of the reaction. In the off-line analysis, the e^+e^- mass spectra can be analyzed under different kinematical conditions. Coherent vector meson production can be suppressed by detecting the recoiling nucleon (proton or neutron). Incoherent production is also substantially enhanced by a kinematical cut in –t.

In the original proposal, the PAC was concerned by the simple model used to describe the observable effects of a shift in mass in the dilepton decay of vector mesons [10,11].

Since, much more sophisticated modeling has been done by Effenberger et al. [12] in order to interpret the data in terms of modification of vector meson properties in the nuclear medium. In this semi-classical BUU transport model, direct observable consequences of in-medium modification of the vector mesons through their dilepton decay have been studied in γA reactions for targets and gamma energies similar to those we intend to use in our experiment.

Physics Motivation Update

The main motivations for this experiment are given in our original proposal (see Appendix 3). We will give here an update and mention the current developments in the field.
The properties of baryons and mesons in the nuclear medium have received much attention during the last decade both theoretically and experimentally with the studies of the properties of hot and dense nuclear matter produced in the early stages of ultra-relativistic heavy ion collisions. Nearly an hundred papers address these issues. Theoretical studies[13] predict a partial restoration of chiral symmetry at elevated temperatures and baryon densities. Brown and Rho [14] have suggested that the masses of non-strange hadrons such as the nucleon, ρ, and ω, are reduced in the nuclear medium and are proportional to the in-medium quark condensate. Dropping in-medium hadron masses have also been suggested by other theoretical models, such as the QCD sum rules [15], the quark-meson coupling model [16], and the hadronic model including vacuum polarization effects [17].

A test of these predictions and possible direct evidence for a dropping ρ-meson mass seems to be provided by the enhanced production of dielectrons with invariant mass around 300–600 MeV in the CERN-CERES experiment of relativistic heavy-ion collisions [18]. Once produced, due to their electromagnetic character, dielectrons can leave the interaction region without further strong interactions, and thus carry undistorted information of the dynamical properties of the system. This enhancement of the dielectron yield cannot be explained by known sources such as Dalitz decays of mesons, direct decay of mesons, pion-pion annihilation, a_1 decay, and pion-ρ scattering. As proposed by Li et al. [19], the enhancement in S+Au reactions compared to p+Au collisions might be due to a shift of the ρ meson mass. Microscopic transport studies [20–22] for these collisions point in the same direction; however at the present stage, more conventional self-energy effects cannot be ruled out [20,23–25]. It is interesting to note that while the lowering of the ρ–meson mass hypothesis is able to explain the CERES data, it completely fails [26] to reproduce the lower energy Berkeley DLS data [27].

The change of properties of the vector mesons in the medium is a hot topic that will be studied at RHIC(BNL), ALICE(CERN) and HADES(GSI) by measuring low mass dilepton production. The ALICE collaboration has added a silicon pixel detector to vastly improve the detection of dileptons. The HADES detector is a dedicated high acceptance spectrometer built to measure dielectrons with invariant masses up to 1 GeV/c^2 in π+A, p+A and A+A reactions. Although vector mesons preferentially decay into pions, the large final state interactions of the pions with the nuclear medium makes it almost impossible to derive any direct information about the meson properties in the medium. A semiclassical BUU transport model calculation[28] indeed shows that the $\pi^+\pi^-$ invariant mass spectrum exhibits almost no sensitivity to medium modification of the ρ-meson. The best bet one has is to look at the dielectron decay of the vector mesons. As pointed out by the authors of Reference [29], in a heavy-ion collision the final dielectron yield is obtained by an integration over different densities and temperatures, a discrimination between different scenarios of in-medium modifications for the vector mesons is difficult [30,31]. Moreover, relativistic heavy-ion reactions proceed, in their initial stages, far from equilibrium, whereas all theoretical predictions of in-medium properties are based on equilibrium assumptions. It is therefore necessary to probe in-medium properties of vector mesons in photon or pion induced reactions which have the great advantage that they allow one to study the properties of the produced hadrons in an environment that is much closer to equilibrium at normal nuclear density and temperature zero. The predicted in-medium effects for the vector mesons by the different models are so large that they should have observable consequences already at normal nuclear density.

Pion induced reactions will be measured at HADES, and JLab is the ideal place to measure the photoproduction of vector mesons off nuclei. This is the motivation of the present experiment. In γA reactions the produced particles have in general larger momenta with respect to the nuclear environment than in heavy-ion collisions. Therefore our results will give complementary information about the in-medium self-energies of mesons compared to heavy-ion experiments.

The authors of Reference [28] have developed a semi-classical BUU transport approach model that is an important first step towards a consistent theoretical description of these observations in the different reactions. This model calculates inclusive particle production in heavy-ion collisions from 200A MeV to 200A GeV, in photon, and in pion induced reactions with the very same physical input. It is successful in describing heavy-ion collisions at SIS energies [32,33] and photoproduction of π and η up to 800 MeV [34]. This model has recently been used to give predictions for dielectron production in π+A reactions [12], that will be measured by the HADES Collaboration, and in γ+A reactions in the energy range from 800 MeV to 2.2 GeV [29] that will be measured at JLab in this experiment.
We will now look closely at the semi-classical transport model predictions described in Reference [29] where direct observable effects of in-medium modifications of the ρ and ω mesons through their $e^+ e^-$ decay are given for γC, γCa, and γPb reactions at photon energies of 0.8, 1.5, and 2.2 GeV. The Dalitz decays of Δ(1232), π^0 , η, and ω contribute to $e^+ e^-$ invariant masses below 600 MeV/c^2 (see Figure 1-3). For dielectron invariant masses above 600 MeV/c^2 the spectrum is dominated by the direct $e^+ e^-$ decays of the vector mesons (ρ, ω, ϕ).

As mentioned in our original proposal, momentum cuts help separate the incoherent part from the coherent part. The Bethe-Heitler process (coherent part) which dominates all integrated cross sections for dielectron production can be sufficiently suppressed by appropriate cuts on the lepton momenta (see Figure 4).
A mass shift of these mesons as proposed in Refs.[1,2] leads to a substantial enhancement of the dielectron yield at invariant masses of about 650 MeV/c^2 by about a factor of 3 and should clearly be visible in the present experiment. However, a calculation for which a

linearly momentum-dependent potential for the vector mesons [35] is used gives practically no effect compared to the bare mass case. Experimental results will definitely help in discriminating between these different scenarios of medium modifications.

It is important to stress that if there are changes of the properties of vector mesons in the medium, γA reactions measuring dielectron pairs such as the one proposed in this experiment are an ideal sensitive tool to study them. Furthermore, very little is known about the incoherent photoproduction of mesons in nuclei. Most of the studies done in the 70s did put the emphasis on coherent production processes (see Ref. [36]).

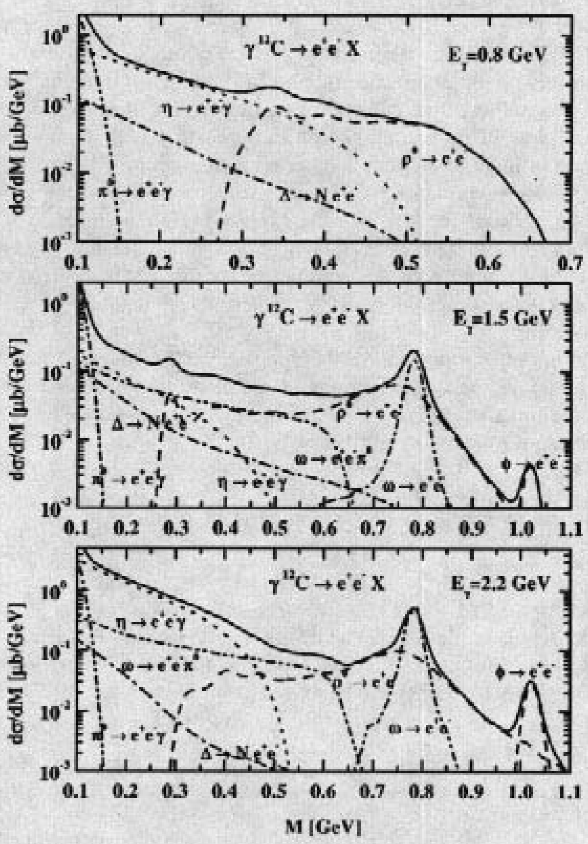

FIG. 1 The dilepton invariant mass spectra $d\sigma/dM$ for γC at the energy of $E_\gamma = 0.8$ GeV (upper part), 1.5 GeV (middle part), and 2.2 GeV (lower part) calculated with bare meson masses including a mass resolution of 10 MeV. The thin lines indicate the individual contributions from the different production channels; i.e., starting from low M: Dalitz decay $\pi^0 \to \gamma e^+ e^-$ (short-dotted line), $\eta \to \gamma e^+ e^-$ (dotted line), $\Delta \to N e^+ e^-$ (dot-dashed line), and $\omega \to \pi^0 e^+ e^-$ (dot-dot-dashed line); for $M \sim 0.8$ GeV: $\omega \to e^+ e^-$ (dot-dot-dashed line) and $\rho^0 \to e^+ e^-$ (dashed line). The solid line represents the sum of all sources.

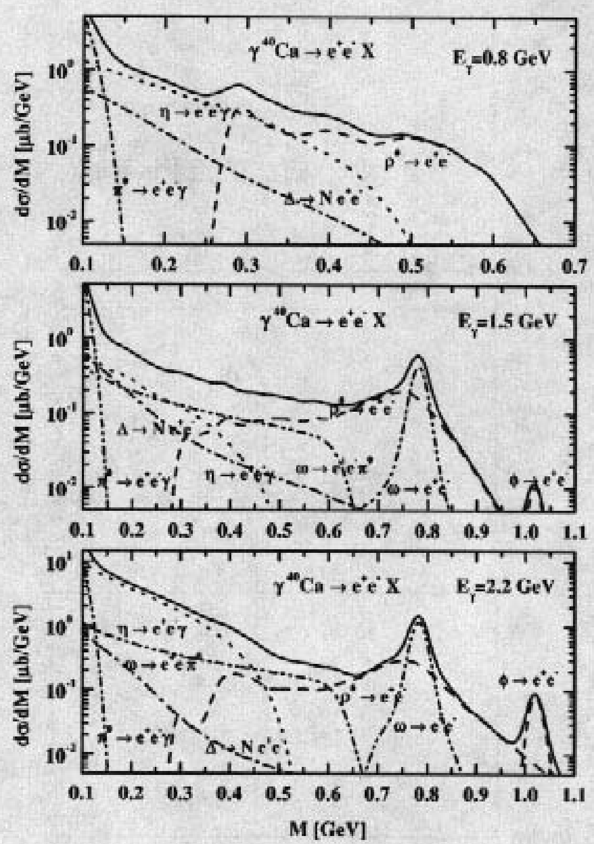

FIG. 2 The dilepton invariant mass spectra $d\sigma/dM$ for γCa at the energy of $E_\gamma = 0.8$ GeV (upper part), 1.5 GeV (middle part), and 2.2 GeV (lower part) calculated with bare meson masses including a mass resolution of 10 MeV. The assignment is the same as in Fig. 1

Figures are from Ref [29]

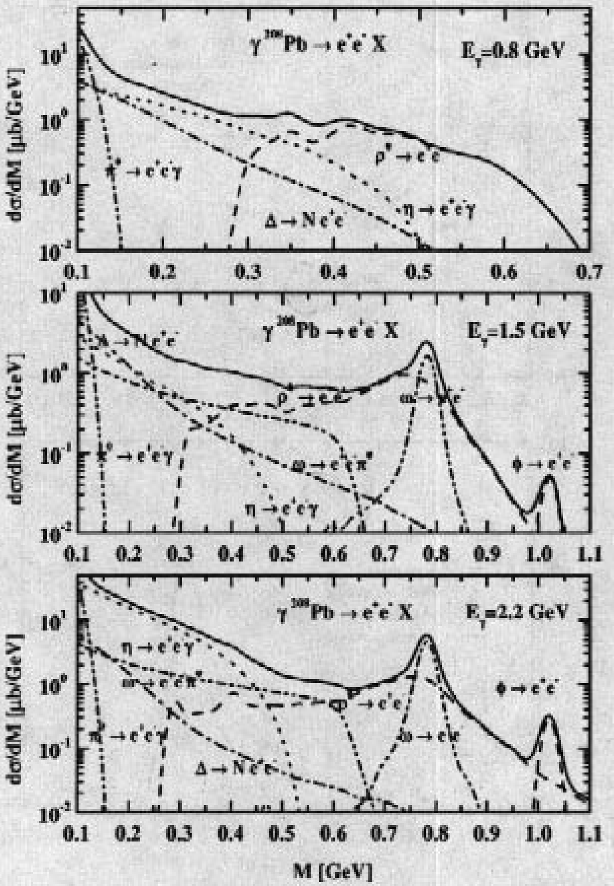

FIG. 3 The dilepton invariant mass spectra $d\sigma/dM$ for γPb at the energy of $E_\gamma = 0.8$ GeV (upper part), 1.5 GeV (middle part), and 2.2 GeV (lower part) calculated with bare meson masses including a mass resolution of 10 MeV. The assignment is the same as in Fig. 1

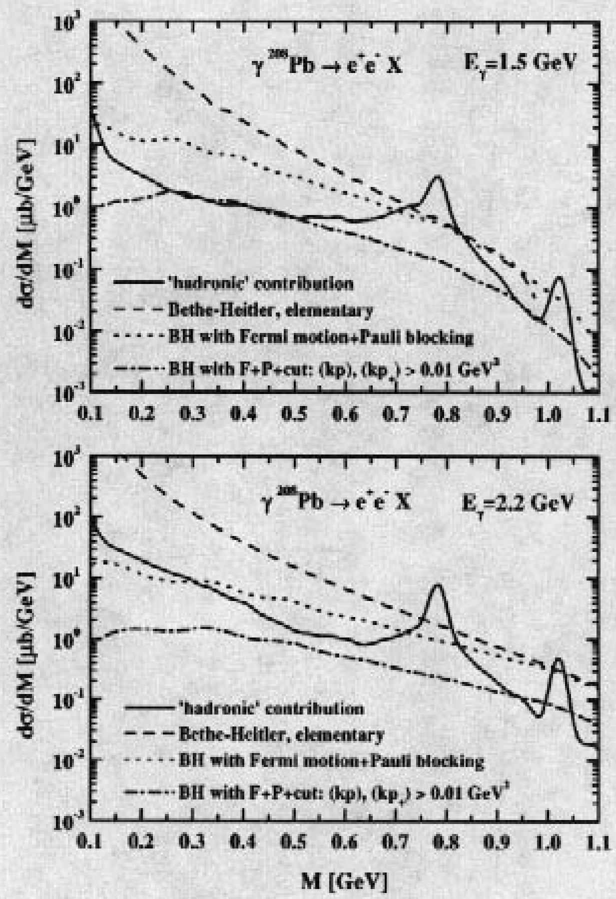

FIG. 4 The dilepton invariant mass spectra $d\sigma/dM$ for γPb at the energy of $E_\gamma = 1.5$ GeV (upper part) and 2.2 GeV (lower part). The solid lines indicate the "hadronic" spectra as in Fig. 3 The dashed lines are the Bethe-Heitler contribution calculated as a sum of incoherent contributions from γ+nucleons. The dotted lines show the BH yield with taking into account nucleon Fermi motion and Pauli blocking. The dot-dashed lines are the BH terms with the cuts $(kp),(kp_+) > 0.01$ GeV.

Figures are from Ref [29]

Manpower Update

Of the original spokespersons, only Mikhael Kossov has remained as spokesperson. Pierre.Y Bertin has decided to concentrate all his efforts in HALL A and Barry Preedom remains in the experiment but has been replaced by C. Djalali as a spokesperson from USC.
Dennis Weygand (Jlab) has joined the g7 effort as a spokesperson and will be the contact person for this proposal. He is also the local JLab supervisor of USC graduate students involved in this project.

New spokespersons:

D.P. Weygand (JLab) Physics, CC/EC, trigger, cooking, simulation, target, analysis
M. Kossov (ITEP) Physics, e/π discrimination, trigger, collimation and backgrounds
C. Djalali (USC) Physics, e/π discrimination, simulation, target, cooking, analysis

Other Senior Physicists:

TJNAF:

S. Boiarinov (ONLINE group) Physics, online issues
V. Burkert (Physics Group) Physics, e/π discrimination, electron run experience
P. Degtyarenko (Rad.Con group) Physics,event generator, background calculations
B. Mecking (Hall B Leader) Physics, suggestions on trigger and Tagged beam
E.S. Smith (Physics Group) Physics

CNU:

L. Elouadrhiri Physics, electron run experience

ITEP:

S. Pozdnjakov Physics, ONLINE group
N. Pivnyuk, Physics, Offline analysis
O. Poforelko (Administrative Head of the Russian Hall B group) Physics
V. Serov Physics, Online and Offline
A. Vlassov Physics, e/π discrimination, Cerenkov counter calibration and efficiency

USC:

B.M. Preedom Physics, running, offline analysis (previous spokesperson)
D. J. Tedeschi, Physics, simulation (GSIM expert), running, cooking and analysis

IPN-Orsay:

J. P. Didelez, M. Guidal and E. Hourani are co-pis on an international NSF-CNRS grant to work on all aspects of g7.

UTEP:

P. Cole Physics, collimation and tagged beam

RPI:

J.P Cummings, Physics

PostDocs:

M. Wood (USC) is on site, will work on all aspects (preparation, running, cooking,..)

Graduate students

A. Cazes (USC) is on site, 100% on g7 [cooking, e/π rejection, simulation, target, beam]
A. Parfenova (USC) will be on site 100% as of Fall 2001. Ph.D. thesis on g7
N. Recalde: (USC) will be on site 100% as of Fall 2001. Ph.D. thesis on g7

Many of the senior physicists have experience running experiments with CLAS. The PostDoc has experience with normalization of the photon beam and collimation, the graduate students are already familiar with all aspects of Geant simulation, calibration and reconstruction analysis. The e/π discrimination technique was refined this past spring and is the object of a CLAS Note. We have enough experts of all the phases of the experiment to be confident that we will successfully run this experiment.

Feasibility/Technical readiness

e/π discrimination

The e/π rejection is one of the main issues to make realizable the g7 experiment. Indeed, the branching ratios are such that almost 100% of the ρ decays in two pions. The branching ratios for the leptonic decay are: $Br_{\rho\to e+e-}$=4.49 10^{-5} and $Br_{\omega\to e+e-}$=7.07 10^{-5} [37]. For this reason, a special analysis was done with the *e1c* data. This work is completely described in the CLAS-NOTE-2001-009, which is given in appendix 1 and this chapter gives an overview of the discrimination method.

The Cerenkov counters and the electromagnetic calorimeter are the main tools used for the e/π rejection. Those detectors are well calibrated only in electron runs because they are used to identify the scattered electron. Therefore, data has been chosen from an electron experiment: the last cooked version of the *e1c* data, with a beam energy of 2.57GeV (close to the nominal energy of g7), and a torus current of 1500A (38% of the maximal magnetic field).
The selected events are $e^- p \to e^- r^+ r^- p$, where *r* means charged relativistic particle, which could be either an electron (positron) or a pion.

The first step of the discrimination method is to select events with good timing, that is to select events with a clearly identified scattered electron, and then to identify the correct RF bucket; the RF peak time is measured to 50ps [38]. Then two velocities are computed for each particle using the electron mass or the pion mass ($\beta = \frac{p}{\sqrt{p^2 + m^2_{\pi/e}}}$). The time of the interaction is determined by the RF time; it is also computed for each particle from its time of flight given by the CLAS time of flight counters (TOF). The first cut, named the "silver cut", is such that the difference between these times is less than ±*1ns* and is applied to the two relativistic particles. A similar, but tighter cut is applied to the scattered electron.

After this first cut, particles with a momentum below 0.2GeV have a large enough difference in β to be discriminated. Nevertheless, those electrons are not interesting for g7 because they increase the low effective mass background without increasing the acceptance. Those events are so suppressed.

A second "golden cut" uses both the Cerenkov Counter (CC) and the Electromagnetic Calorimeter (EC). Contrary to hadrons, leptons develop a shower as soon as they enter the calorimeter, so they loose most of their energy in the first layers of the calorimeter. Therefore, the requirements are a total energy in the calorimeter greater than 0.2GeV, an energy in the inner part of the calorimeter greater than 0.05GeV, and a corresponding hit in the Cerenkov Counter.

The next step is s0-called the "platinum cut". Because the sample of events included all sorts of random coincidences and misidentified events, it was necessary to make an additional kinematic cut, which helps to suppress background. It requires that the missing mass of the scattered electron plus the two relativistic charge particles matches the mass of the proton: $0.78\text{GeV}^2 < mm_{er+r-} < 1\text{GeV}^2$. In addition, it demands that the Energy conservation factor ($\Delta^2 = (E^e_{in} + M_p - E^{\pi^+}_{out} - E^{\pi^-}_{out})^2 + (\vec{p}^{\,e}_{in} - \vec{p}^{\,e}_{out} - \vec{p}^{\,\pi^+}_{out} - \vec{p}^{\,\pi^-}_{out})^2$) is less than 0.02GeV^2.
The final step uses a quality factor of the Cerenkov counter relating to the goodness of the match between the track and the corresponding hit in the counter.

After all these cuts, we obtain 10 $e^- p \rightarrow e^- e^+ e^- p$ events out of the $2\text{x}10^5$ exclusive events (see figure 29 of the appendix 1). Nine of them are identified by effective mass as pair production, and one may be due to a ρ decay. However, the dominant reaction at this energy is $e^- p \rightarrow e^- \pi\ \Delta \rightarrow e^- \pi^+ \pi^- p$ compared to vector meson production (see figure 28 of the appendix 1). Thus the expected number of the massive e^+e^- pairs, which can be produced only by vector mesons, is relatively small. Therefore we are able to determine a rejection factor of better than $5\text{x}10^{-6}$. The estimated efficiency for the e^+e^- pairs with those cuts is about 80%.

CLAS acceptance

Since 1994, the date of the original proposal, the simulation of CLAS has been improved and therefore we made a more accurate simulation.

To this goal, 30,000 events were generated with the Genova generator [39] for the channels $\gamma\ p \rightarrow \rho\ p \rightarrow e^+ e^- p$ and $\gamma\ p \rightarrow \omega\ p \rightarrow e^+ e^- p$. Only the leptonic decay is generated. These events were simulated by the CLAS detector simulation package (GSIM), and then reconstructed by the CLAS analysis program (a1c). The acceptances are given as a function of the beam energy and as a function of the e^+e^- invariant mass square in figure 5. The acceptance is about 16% for the electronic pair; 8% if the proton is also detected. It decreases

at high energy because the electrons are boosted in the forward direction, and are consequently lost in the beam pipe.
The acceptance is reduced compared to the original proposal by a factor ¼, which compels us to request 18 days of beam time.

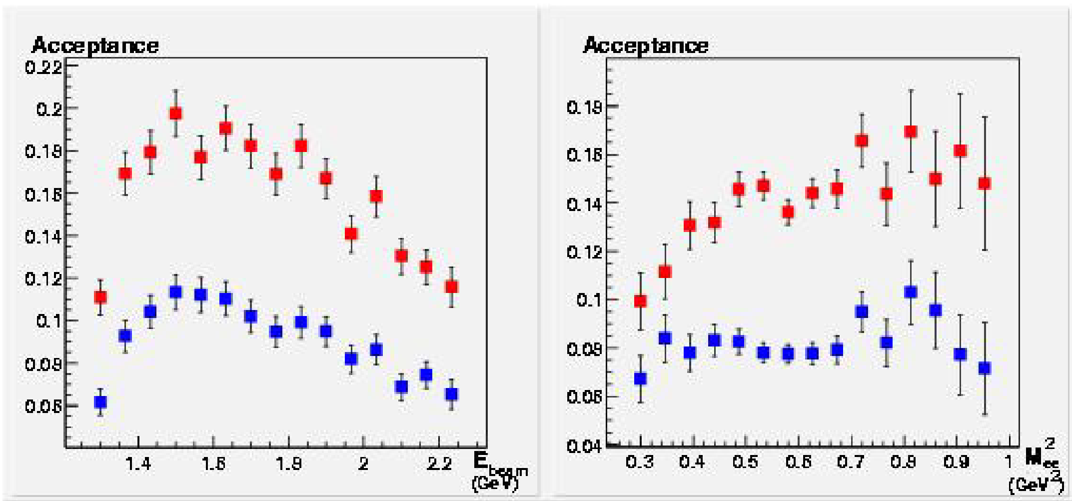

Figure 5: CLAS acceptance for two e^+e^- (red points) and for e^+e^-p (blue points) in the left as a function of the photon beam energy and in the right as a function of the e^+e^- effective mass square.

In addition, to be able to measure a difference in the shape or in the mass of the ρ meson, it is necessary to be certain that the detector doesn't distort the mass distribution. To this goal, the effective mass square of the electronic pair is plotted for both the generated events and the acceptance corrected events. Figure 6 shows that CLAS reproduces successfully the shape of the distribution.

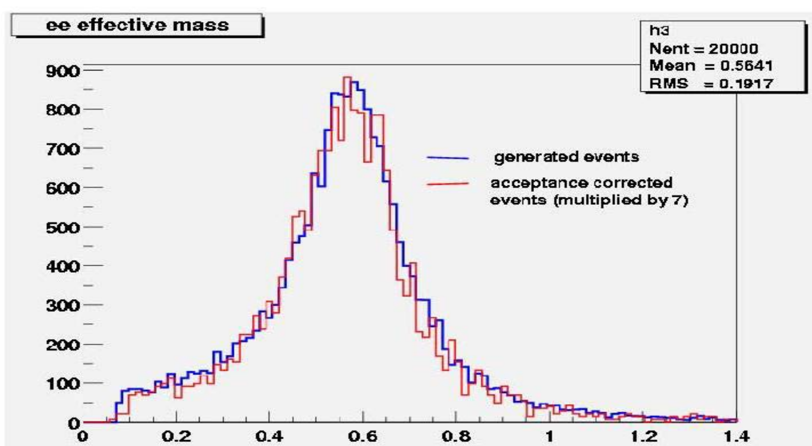

Figure 6: CLAS doesn't change the shape and the position of the e^+e^- effective mass square spectrum.

Backgrounds

To reduce the background created by the halo of the photon beam, both clean-up collimators (17.3 mm and 41 mm bore) will be used. The only other source of background of concern is produced by the tagger. When the deflected electron beam interacts with the tagger beam-pipe and the vacuum pump above the hodoscope at the low end, highly-energetic electrons are produced. Figure 7 is the result of a simulation of 10000 events from a 2.4 GeV electron beam. The picture illustrates the amount of radiation created at the low end of the tagger system. The present concrete wall behind the tagger reduces the amount of radiation that reaches CLAS. Increasing the height of the wall to the beamline level would decrease the background radiation even more. This additional shielding would be advantageous for the proposed experiment which will measure energetic electrons and positrons.

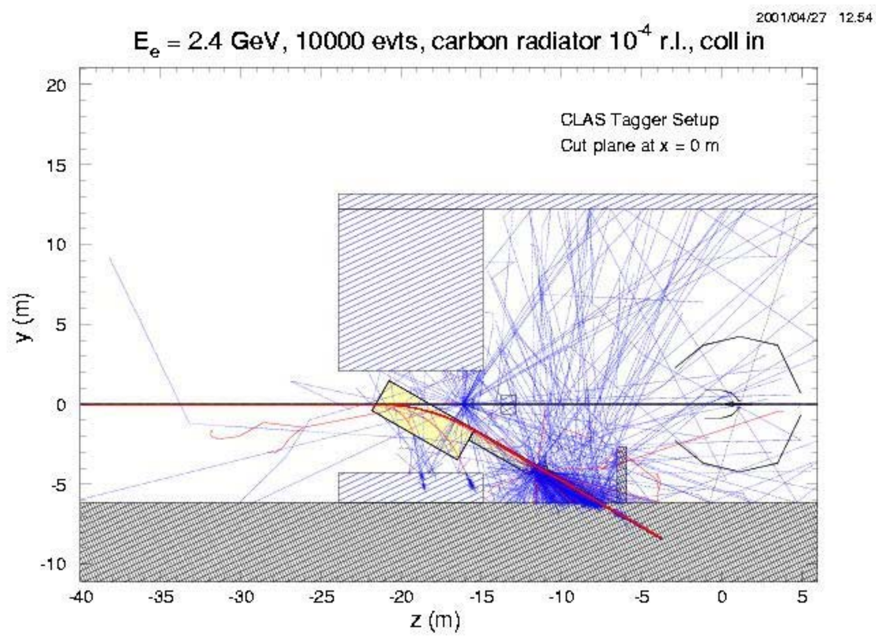

Figure 7: Simulation of the non-physics background.

Target geometry

Theoretical estimates [14,15,16] predict that the medium modifications of the vector meson depend of the nuclear density. Therefore, we plan to run the experiment simultaneously on four different nuclear materials with increasing A: deuterium, carbon, iron and lead.
The deuterium is used as reference. It takes into account the nuclear properties such as Fermi motion.

Liquid Deuterium	Carbon	Iron	Lead
5.92cm	4.4mm	1.27mm	0.88mm

Table 1: thickness of the different materials forming the g7 target.

This target configuration minimizes the systematic errors (see original proposal in appendix 3).

Design

The idea is to modify the existing g2 liquid target to build the g7 target, with the existing target giving the deuterium cell. The advantage of the g2 target is its length and the fact that it has a support designed to minimize interaction in the backward region between it and the particles.

This target is a 4cm diameter tube in mylar containing the liquid, and closed by two spherical shells which have their center in the middle of the tube. The liquid moves inside three bended pipes in aluminum that are connected to the cell by a conduit made by two cylinders. The smaller is torlon and, the largest, which surrounds the first cylinder, is mylar. The advantage of this device is the low density of the materials (compared to aluminum of the distribution pipes) and their uniformity.

Five super insulation layers in aluminum surround all these devices. The whole target is hung by the distribution tube, and stays in vacuum inside the scattering chamber. This target is 10cm long, which corresponds to 1.69g/cm^2 of deuterium.

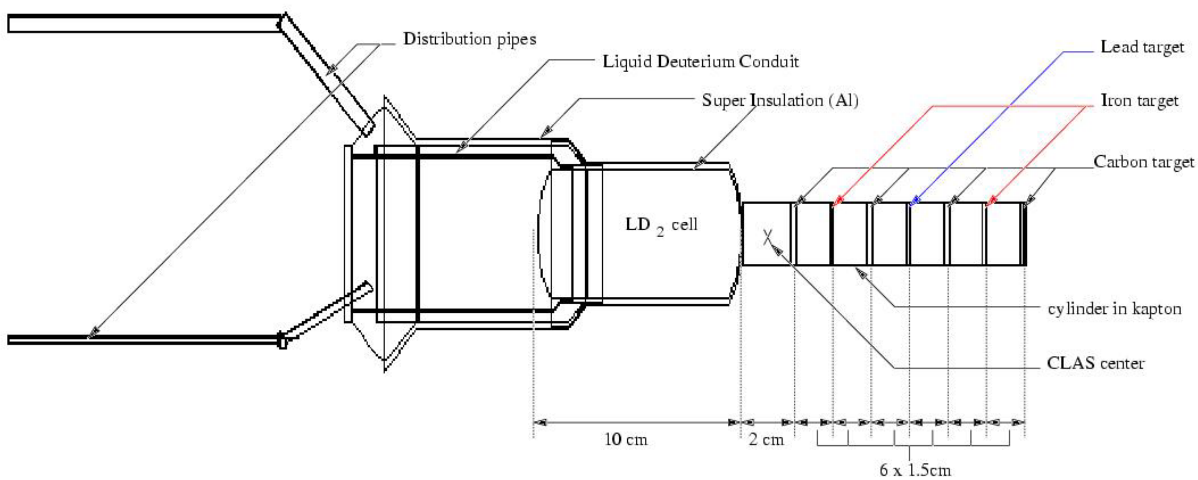

Figure 8: the g7 target.

The solid targets are added in the forward region (see figure 8). To reduce the low energy electrons produced by the beam inside dense materials, the targets are divided in many parts (four for carbon with a thickness of 1.1 mm, two for iron, with a thickness of 0.635mm and one for the lead, with a thickness of 0.88mm). The first one is 2 cm after the g2 target and the others are following spaced by 1.5cm.). All of them are 2cm diameter disks with 1.5cm long

kapton tubes between them. The first kapton tube is 2cm long and is glued to the super-insulation layers of the cryotarget.
The separation between two targets is optimized to provide an identification of the material where the event comes from by vertex reconstruction, and to allow the electron and the positron to exit the target through a minimum of matter.

Counting rate/Trigger

The estimate of the number of ρ and ω mesons produced for this experiment has not changed from the original proposal. What has changed is the expected number of e^+e^- pairs detected by CLAS. This change is due to the new calculation of the acceptance. With a photon flux of $5x10^7$ photons per second incident on a 1 g/cm^2 target, the rate is 700 ρ-mesons per second in a tagged photon energy range of 1.2-2.2 GeV. This rate is calculated for a single nuclear target. From the small branching ratio of $4.4x10^{-3}$, there are 110 e^+e^- decays per hour. Applying the new acceptance results of 15%, the expected rate of detecting e^+e^- pairs is 16 per hour. For the ω-meson case, the rate is 200 ω-mesons per second. This value translates to 7 e^+e^- decays per hour given a branching ratio of $7.2x10^{-3}$, and an acceptance of 15%. Therefore, the expected number of ρ and ω meson decays will be 23 per hour. To complete the experiment with the desired statistics, 435 hours, or approximately 18 days are needed.

Since the goal of this experiment is to detect both the e^+ and the e^- from the vector meson decay, the level 1 trigger will be based on the Electromagnetic Calorimeters (EC) and Cerenkov Counters (CC). Both the EC and CC are necessary to clearly identify the e^+e^- pair and disregard any $\pi^+\pi^-$ pairs. To clean up the data collection further, a level 2 trigger will be added to identify tracks associated with the hits in the EC and CC. The level 2 trigger will be useful in discriminating true e^+ or e^- hits from photons detected by the EC.

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Appendix 1: Copy of CLAS note "e/π rejection in CLAS"

Appendix 2: Copy of the1994 update to Proposal PR-94-002

Update of Proposal PR-94-002
Photoproduction of Vector Mesons Off Nuclei
Spokespersons: P.-Y. Bertin, M. Kossov, B.M. Preedom

PAC8 deferred this proposal with the following comments:

> PAC likes the motivation for this measurement and believes that an unambiguous demonstration of a reduction in the vector meson mass would be an important result. However, the proposed experiment is not convincing and the projected sensitivity marginal. PAC was not convinced that the detector acceptance, the background and the effect of multiple targets on the background were optimal for the proposed measurement. PAC urges the proposers to work on developing an experiment which can provide a significantly increased sensitivity to a vector mass (sic) reduction. This sensitivity should be quantified in terms of the uncertainty in the appropriate experimental observables.

The following information addresses these comments. It is assumed that PAC9 has copies of the proposal which we attach to this update.

Detector Acceptance:

Aside from the ω and ϕ acceptances shown in the proposal, we have calculated the invariant mass distributions with and without the CLAS acceptance in figures 1 and 2 for deuterium and Pb at gamma energies of 1.4, 1.8, and 2.2 GeV. The energy dependence is primarily due to the opening angles associated with the center of mass motion of the decaying particle. While this effect is significant at 1.4 GeV for all three vector mesons and at 1.8 GeV for the ϕ, the actual momentum dependence of the acceptance of the CLAS detector will need to be well known for all CLAS experiments including this experiment.

Background:

Because we will use a tagged beam, most of the possible backgrounds can be eliminated. Using the measured **t** allows for the separation of coherent processes from incoherent production. Missing mass can be calculated knowing the detected invariant mass. Events having a total energy greater than the tagged energy can be excluded. Also since the experimental trigger is coincident e^+e^- pairs, the start counter is not necessary and the mini-toroid can be used to remove the low energy electrons produced by Compton scattering in the targets.

The background is of three types: **a)** true coincident e^+e^- , **b)** random coincident e^+e^-, and **c)** misidentified π^+ and/or π^-.

a) True coincident e^+e^- background results from Bethe-Heitler pairs, from Dalitz decay of a π^0 or η, and from coincident multiple π^0 production where each Dalitz decays. The Bethe-Heitler pairs can be removed by using the measurement of **t** to exclude coherent events. Electron pairs from Dalitz decay have an invariant mass below the mass of the π^0 .or η. The background from coincident Dalitz decays can be measured by detecting like-sign electrons.

b) Random coincident e^+e^- background results from Compton scattering from atomic electrons followed by Bethe-Heitler production from the scattered photon. If the Bethe-Heitler production occurs in a target downstream from the Compton scattering, the vertex reconstruction will reject it. If not, then an e^-e^- measurement will determine the contribution where the Compton scattered electron is detected while a missing mass calculation on e+e- pairs will exclude subsequent Bethe-Heitler production.

c) Misidentified π^+ and/or π^- were discussed in the proposal. The suppression factor for a single pion is ~ 10^{-4} and for coincident pions is ~ 10^{-8}.

Effect of multiple targets on the background:

The primary adverse effect due to the multiple targets is the bremsstrahlung of one or both of the pair electrons as discussed in the proposal. To minimize this effect, both the Fe target (7% radiation length) and the Pb target (16% radiation length) will be multiple targets each having 6 equal segments separated by 0.5 cm to reduce the amount of matter seen by an exiting electron. Aside from the bremsstrahlung of the pair electrons, there will be a reduction in the photon flux due to the accumulating target thickness but the photons remaining in the beam will still retain their tagged energy.

Sensitivity to a vector meson mass reduction:

As presented in the proposal, the mass resolution of CLAS is approximately 4 MeV at an invariant mass of 750 MeV and 6 MeV at 1 GeV. These resolutions are comparable to or less than the intrinsic widths of the vector mesons and significantly less than the predicted shifts in the vector meson masses. In order to visualize a measurable effect of a shift in the mass, we have made the calculations presented in fig. 3 for shifts of ΔM = 0, 40 MeV, 100 MeV and for comparison -40 MeV. The figure shows the ratio of the invariant mass spectrum calculated for Pb to that calculated for deuterium. The calculations sum up the results for all gamma energies between 1.2 and 2.2 GeV but use the tagged energy information to take account of the effective mass number (A_{eff}) energy dependence predicted by the vector dominance model. No density dependent change in the widths or the relative phases of the vector mesons was used. The width of the ρ uses the prescription of Jackson (Nuovo Cimento **34**, 1644 (1964)). The calculations restrict **-t** to be greater than 0.1 GeV^2 to avoid the region of coherent production. The events were generated assuming incoherent photoproduction in the vector dominance model with Pauli blocking and a Fermi momentum of 200 MeV/c for Pb. The $\rho\omega$ and $\rho\phi$ interferences are included. The shift in mass follows the prescription of Guichon and Bertin -- see references 3 and 4 of the proposal. The calculations include the acceptance of CLAS. The most apparent effect occurs for the ρ since most of the ω and the ϕ decays occur outside of the nucleus due to their longer lifetimes.

Quantification of the sensitivity:

In fig. 4 we present the sensitivity to the mass shift using the reduced χ^2 to yield a confidence level. The χ^2 is calculated for the ratio of Pb to deuterium. The expected value for the ratio is taken to be unity so that this reduced χ^2 is a measure of the goodness of the assumption of unity. The figure shows that we can observe a mass shift as small as 20 MeV with a confidence level better than 90% .

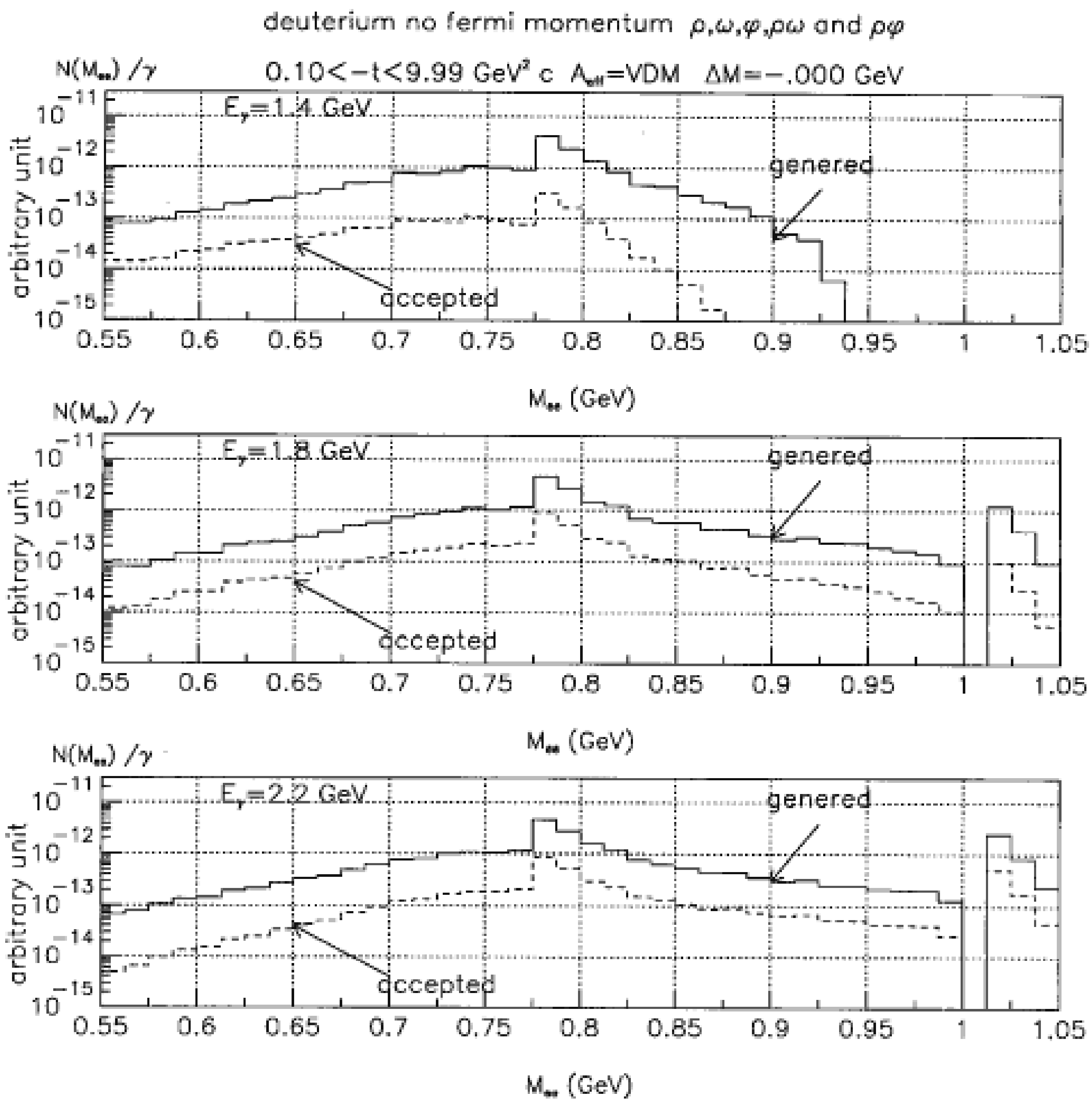


Figure 1.

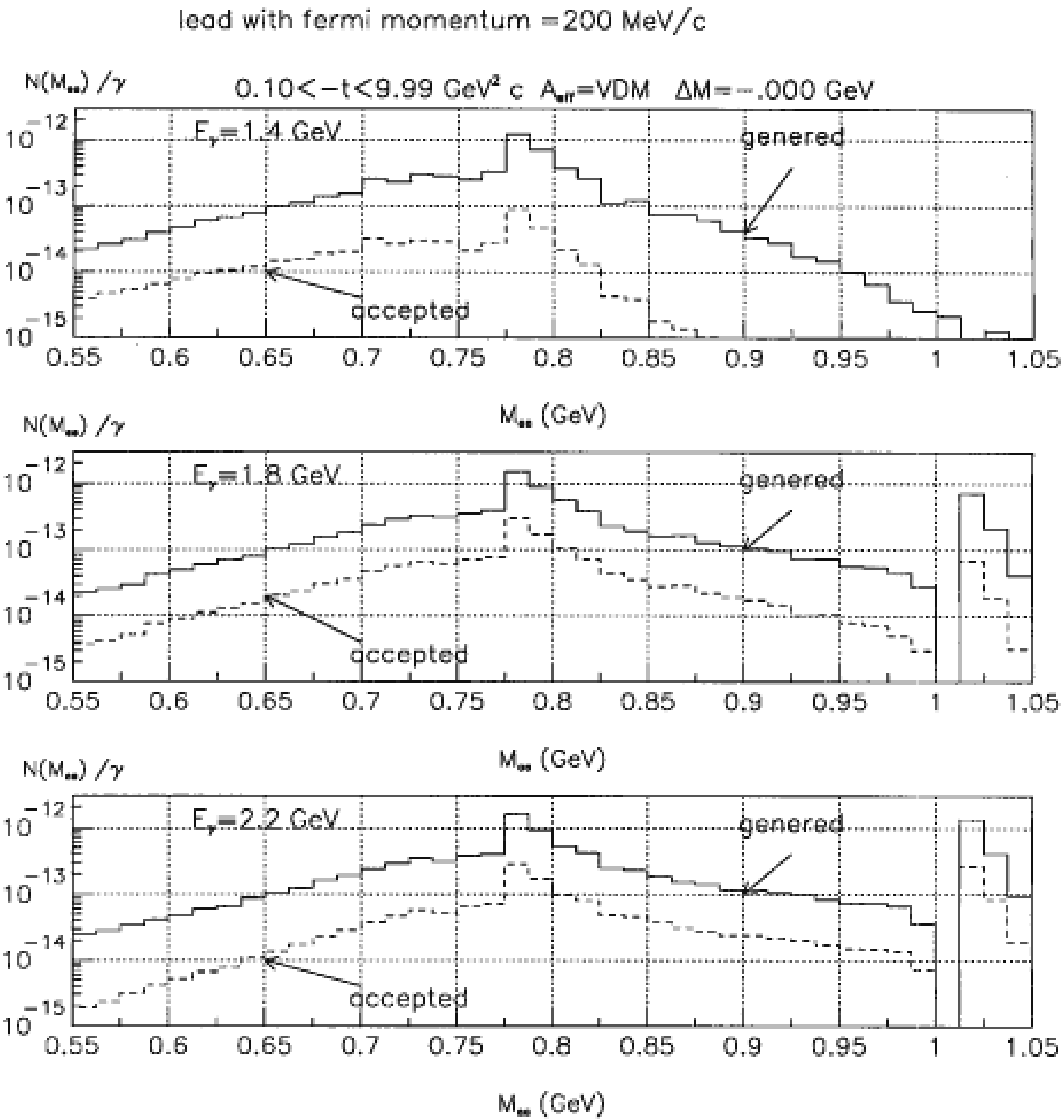

lead with fermi momentum =200 MeV/c
N(Mee) /γ
0.10<−t<9.99 GeV² c Aeff=VDM ΔM=−.000 GeV
Eγ=1.4 GeV
generd
accepted
Mee (GeV)
Eγ=1.8 GeV
Eγ=2.2 GeV

Figure 2.

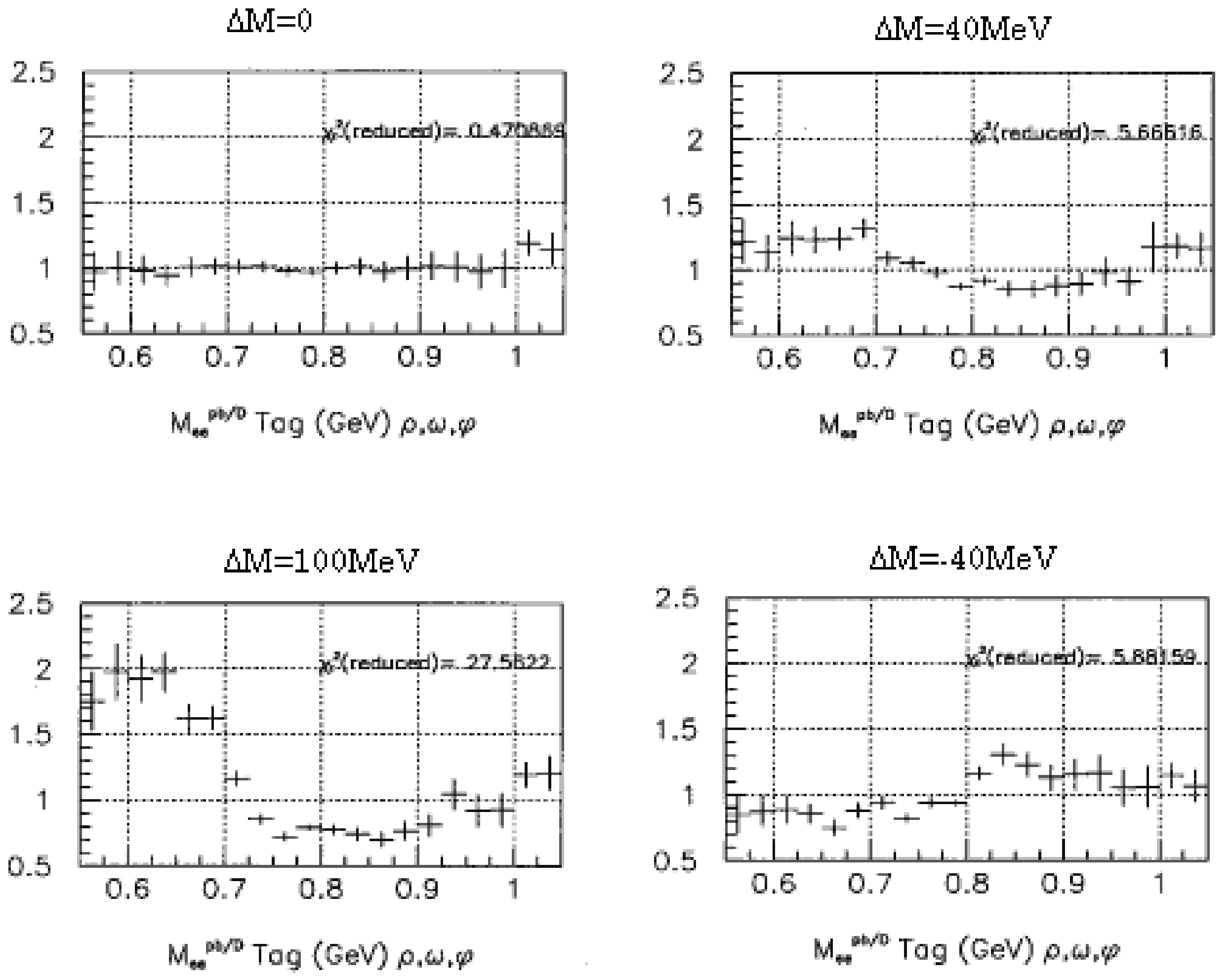
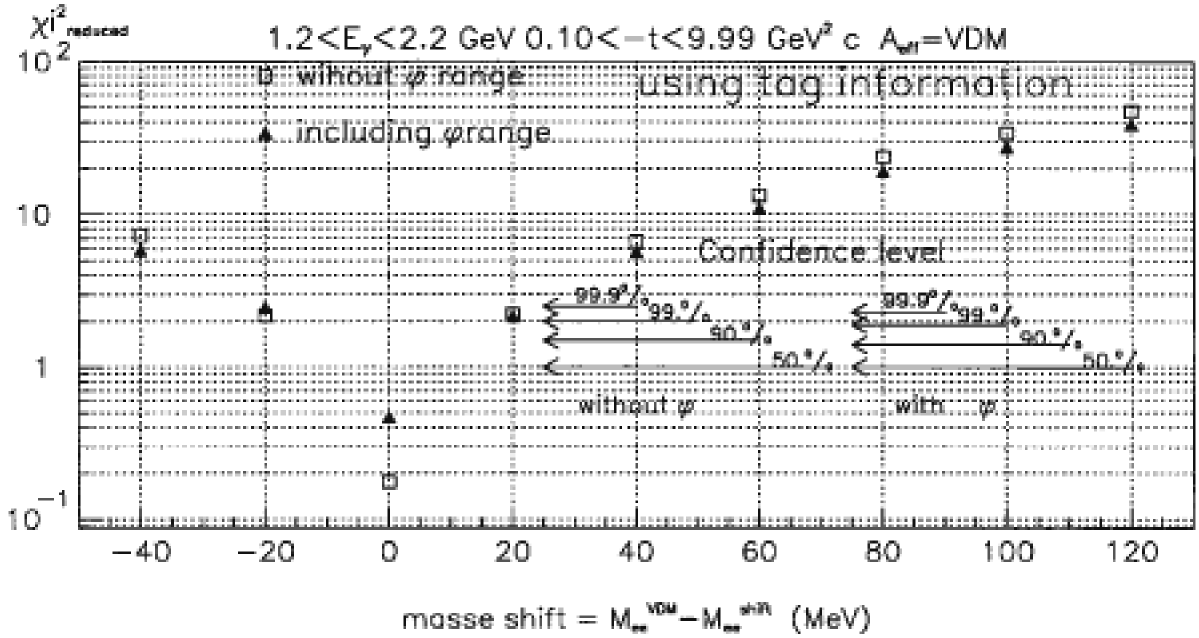

ΔM=0
χ²(reduced)= 0.470888
ΔM=40MeV
χ²(reduced)= 5.66616
ΔM=100MeV
χ²(reduced)= 27.5822
ΔM=-40MeV
χ²(reduced)= 5.88159
M_ee^pb/D Tag (GeV) ρ,ω,φ

Figure 3.



1.2<Eγ<2.2 GeV 0.10<−t<9.99 GeV² c A=VDM
without φ range
including φ range
using tag information
Confidence level
99.9%
99.%
90.%
50.%
without φ
with φ
masse shift = M^VDM − M^shift (MeV)

Figure 4.

Appendix 3: Copy of Proposal PR-94-002