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Report of the PrimEx Readiness Review

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The PrimEx readiness review committee met on December 20, 2003 to hear presentations on the preparedness of the collaboration for a commissioning and production run beginning late summer 2004. Supporting documentation was made available by the collaboration before and during the review. During the lunch break, interested committee members toured Hall B to view the tagger, pair-spectrometer, and the future location of the calorimeter. The tour also visited the Test Lab where the calorimeter has been stacked and PMT's are being attached.

General kudos to the PrimEx collaboration: The collaboration is well aware of the important issues, and has done an excellent job preparing the hardware for the measurement. The collaboration has participated in many useful test measurements with beam. The critical HyCal and its gain monitoring system are on track. A strong simulation capability exists, and concrete plans for electronics and data acquisition exist. The collaboration now needs to begin making detailed plans for calibration and general commissioning.

One unfortunate piece of news is that, due to JLab schedule slips resulting from Hurricane Isabel, there will no longer be any significant break between the commissioning and production running periods. This will reduce the time that the collaboration and Hall B staff have to work around any problems which are uncovered during commissioning. The collaboration will have to have detailed, fault-tolerant run plans, with plenty of expert manpower on site.

We find that the experiment is "about on track" for a late summer commissioning/production run. Much effort must still be dedicated to completing the assembly of HyCal, but there are several items we would like to see given higher priority than at present:

- the availability of expert manpower during the run,
- the status of safety reviews and supporting documentation.
- direct monitoring of the scintillation light yield of the $PbWO_4$,
- potential tagger dump-line backgrounds,

furthermore, several R&D efforts must come to a firm close by mid-summer:

- photon energy determination,
- target thickness determination.

1 Items Needing Higher Priority

1.1 Manpower

The PrimEx collaboration is fairly small but has been very productive due to the dedicated work of the collaboration and a tremendous amount of support from Hall B engineering. However, this small collaboration will soon assume sole responsibility for a multi-month commissioning and production run. If the present schedule holds, the commissioning period will take place at the end of the summer, and the production run will run into the fall semester. The committee is sensitive to the fact that many of the PrimEx principals are faculty from small North Carolina universities with heavy teaching loads who do most of their research on weekends during the school year. To avoid a manpower train-wreck, we recommend the following:

- The collaboration should try to arrange for at least one of the principals to take a sabbatical visit at JLab which overlaps with the commissioning and production running periods. Presently, no such sabbaticals are scheduled.
- The collaboration should strive to retain their senior postdoc in charge of simulations and data acquisition, David Lawrence (U. Mass).
- If the schedule should slip so as to move the commissioning period into September, JLab management should seriously consider delaying the run until summer 2005.

The PrimEx collaboration must ensure that there will be experts available at all times who are knowledgeable of the slow controls software. Since there is a mixture of EPICS, TACL, CAENet and LabView, the casual shift worker might not want or be able to troubleshoot this slow controls melange should problems arise.

1.2 Safety/Documentation

There has as yet been no significant review of the HyCal transporter. Although it appears to exceed engineering standards for strength, the remotely controlled motion of massive equipment should not be done without strong regard for its potential to cause harm to personnel or the irreplaceable HyCal. With that in mind, we urge Hall B to initiate a review of any interlock and motion control scheme well before the installation. The system should be certified to withstand real-world abuse such as brown-outs, impatient operators sending multiple commands or resets, etc.

There appears to have been no progress on standard safety documentation. The collaboration is reminded that an ESAD for new major equipment such as HyCal could be a several man-weeks effort, the document review can officially take up to 10 days, and the experiment will not receive a run permit unless all documentation is in order.

A PrimEx Safety Liaison should be appointed to help oversee the installation period. The time constraints on installation/commissioning will probably require the collaborators to work in the Hall during the night with no oversight from the Hall coordinator. The PrimEx Safety Liaison would then be responsible for after-hour activities as well.

1.3 Scintillation Light Monitoring

It would be desirable to develop the ability to monitor the scintillation yield of the $PbWO_4$. Although the temperature is controlled, and the gain of the PMT-base-ADC chain is monitored, the light output can vary due to radiation damage, fluorescence, etc. Since this experiment may only do a single time-consuming, block-by-block energy calibration, and an online calibration reaction with sufficient rate has not been identified[1], any drift in the scintillation light output could have serious systematic consequences. One possibility is to use a UV laser and a few UV transmitting fibers to illuminate several channels. Finally, since temperature stability of the $PbWO_4$ is critical to the experiment, there should be a slow controls alarm on the HyCal chiller.

1.4 Backgrounds

The committee was concerned about possible backgrounds arising from the tagger dump-line. In early $g1$ running, this was a serious source of background which was resolved by placing shielding between the tagger dump-line and the CLAS. The HyCal basically sits on top of the tagger dump-line with a clear line of sight. There appears to be room to install additional shielding, but the installation of large shielding blocks will be more difficult once HyCal is in place.

With the nominal PrimEx beam current and radiator thickness, and the tagger magnet on, the collaboration should measure the backgrounds at the future HyCal location. Since scintillator is more sensitive to backgrounds than lead glass, one of the paddles from the HyCal veto detector could be used for the test. If the background is a problem, additional shielding can be installed before HyCal installation.

The Helium-filled transport line upstream of the calorimeter should be monitored since it will be a significant source of e^+e^- pair backgrounds. One could do this with a TV camera and a shift checklist, or a pressure transducer read out by slow controls with alarm setpoints.

Simulations were shown for Compton scattering from electrons with single γ detection. Although the Compton locus stands out clearly in a plot of E_γ vs θ_γ, this might not be the case in the presence of dump-line backgrounds. An interesting plot would be the similar to the GEANT plot of θ vs Z which the committee was shown, but restricted to > 250 MeV photons. This may be useful in deciding whether additional local shielding is needed.

We also note that a known, loose collimation of the photon beam is probably preferable (with respect to shielding and/or background simulations) to the “no collimation” case preferred by

[1] The collaboration has stated that $\pi^0 \rightarrow \gamma + \gamma$ has insufficient rate.

the collaboration. In the “no collimation” case, the beam will in fact be collimated by many less well defined, distributed beamline aperatures (including the HyCal itself).

2 R&D Efforts Requiring Convergence

2.1 Photon Energy Measurement

The review committee was presented a plan to determine the absolute photon energy of a tagging counter via the opening angle (between outgoing photon and electron) in Compton scattering off atomic electrons. The method is similar to the procedure used in Hall A to determine the primary electron beam energy from the opening angle in e-p scattering; however, the small target mass increases the required angular resolution for a given error in energy. The HYCAL position resolution of about 1mm (from energy sharing between adjacent calorimeter blocks) results in an energy determination with a smearing of 100 MeV for a single event, or 2% at 5 GeV. Reaching the desired 0.2% statistical accuracy requires only 100 events. However, it also requires that the systematic error in the position determination for photons be less than 100 microns over the face of the calorimeter. While this may not be impossible to achieve, it goes way beyond what is required to perform the Primakoff measurement.

An important systematic error in the determination of the photon energy by $\gamma + e$ Compton scattering is the angle and, therefore, location of the shower. The collaboration has done careful measurements with electrons and, using logarithmic energy weighting, found sub-mm errors depending on whether the electron entered near the center of a block or near the edge. Even if a more careful analysis finds this not to be a problem (due to averaging over many blocks, for example), it is clear that a cross check on the photon energy determination would be very valuable. We encourage the collaboration to make an independent cross check on the photon energy determination. For example, the nominal machine energy is now known to about 5×10^{-4} by calibration relative to the Hall A arc. Reducing the beam current and adjusting the tagger current to place the beam on a given detector will, in principle, calibrate the tagger field integral.

If the present knowledge of the tagged photon energy is not adequate for the experiment, other methods with better inherent linearity (e.g using the pair spectrometer to compare the tagged photon energy with the endpoint) should be examined.

2.2 Target Areal Density Measurements

The experiment requires 0.7% precision on the target areal density, ρ_t. The collaboration believe they can achieve this precision, in principle, with the use a micrometer and published (or measured) values of the density. This method was successful for the relatively thick Carbon target, for which they determined the average density using a water displacement technique. However, for the soft metals it is not clear that the micrometer measurements are good enough.

In addition to the micrometer measurements, they measured the thickness using an X-ray attenuation method. In these measurements, they calibrated the X-ray method with the micrometer measurement at one point on the foil to yield an absolute thickness. The product of the thickness and the known density of the metal gave the areal density. It appears that they have done a thorough job with the attenuation measurements. The only problem was the high background in the Sn foil spectrum, which comes from cosmic rays and can be reduced using veto counters.

One major worry is if the micrometer measurements are deemed unreliable, then the X-ray measurement only gives a relative thickness. Thus, a cross check is needed and a direct measurement of the average areal density will provide that check. This can be done in the standard way by measuring the foil mass on a high precision balance and accurately measuring the foil area and then forming the ratio. Thus, the committee recommends the following measurements be performed:

- Determine the average areal density from mass and area measurements on all targets, thus cross-checking the reliablity of the X-ray attenuation setup and technique.
- Measure foils of harder metal (i.e., copper) that can be reliably measured with a micrometer. Use varied thicknesses of Cu with some matching the attenuation of the Sn and Pb foils.

3 Suggestions and Comments

3.1 Calibration and Gain Monitoring

- Gain equalization from module to module is very important (particularly if the thresholds have to be raised to combat unanticipated backgrounds). Every effort to achieve this should be made, including increasing the number of passes through the calibration photon beam. Time concerns might be addressed by scanning rather than stopping at each module. A five percent variation from channel to channel should be the goal of this effort.
- The proposed in-beam calibration method is adequate if slow. Since HyCal takes about 1 minute to move from crystal to crystal, scanning the entire detector once will take more than one day. If 3 minutes/crystal are needed for motion plus data acquisition, then 4 days will be needed to calibrate the array. Software that integrates motion, data taking, beam status (*i.e.* beam present or not?) should be developed so that the calibration can go smoothly.
- The gain monitoring system appears to be more than adequate. It should also be used prior to the run to map gain *vs* high voltage for all tubes to facilitate rapid gain equalization during commissioning.
- Software to facilitate cable mapping with the HV and ADC systems should be developed to allow quick diagnosis of cabling problems after installation and this effort should begin during the running in the Test Lab.

3.2 Photon Flux Normalization

The PrimEx error budget for the absolute determination of the photon flux is 1%. Achieving this accuracy is a challenging task going beyond what has been done by the CLAS community so far. The PrimEx Collaboration seems to be well aware of this challenge. Benefiting from the experience gained by the CLAS Collaboration in previous tagged photon experiments, PrimEx has developed a plan which relies on two main ingredients:

- determining the tagging efficiency for every tagging channel using a Total Absorption Counter (TAC) in the beam. This measurement has to be done at low intensity (about 2 orders of magnitude below normal operating intensity). In addition, we suggest that flux calibrations using the TAC be done regularly in case hard-to-monitor electron beam properties (*e.g.*, halo) make the calibration unstable.

- using a pair spectrometer as a stable intermediate photon monitor to transfer that calibration from the low intensity to increase the intensity to the normal operating intensity. To support this approach, the PrimEx Collaboration has constructed a new TAC (using a single lead-glass block) and a new pair spectrometer. It is especially the pair spectrometer which will provide a major improvement over the procedures used in previous Hall B experiments. Its location in front of the detector and its superior instrumentation will result in much better signal/noise and stability than the makeshift pair spectrometer located in the Hall B beam dump tunnel.

In summary, the procedures and the hardware components developed by the PrimEx Collaboration will give them a very good chance for reaching the desired accuracy in photon flux normalization.

While photon flux normalization can be viewed as an isolated problem, achieving the ultimate goal of the experiments will require similar accuracy in many other areas, e.g. the determination of target thickness, trigger efficiency, detector efficiency, etc. The present approach of the PrimEx Collaboration is to determine every single one of these ingredients with the required accuracy. In addition, attempts should be made to determine or check relevant combinations of these ingredients independently, e.g. using high-rate electromagnetic processes with similar dependencies. Typical examples include pair production and Compton scattering off atomic electrons. Measuring these processes (either in special calibration runs or parasitically during normal data taking) also offers the opportunity to check the absolute cross section determination.

3.3 Schedule

3.3.1 Installation

The installation schedule appears to be too tight. Recently, major downtimes in Hall B have been used to repair drift chamber electronics. If the Hall B staff are busy accessing, removing, repairing, and installing chambers, there will be little time to assist the experimenters with crane work, man-lifts, etc. It will take the first week of the opening alone to move the carriages and put up the steel for any chamber repair.

Installation time could be saved if the Hycal were not disassembled before moving it from the Test Lab. The decision is of course up to the collaboration. If full scale testing and the associated software development could be accelerated, then some of the components (cables–which are a big job) could be installed during small maintenance periods before the opening. The goal here should be to get PrimEx commissioned before most of the collaborators have to return to their teaching responsibilities.

3.4 Beamline Diagnostics

A new fiber array will be located just downstream of HyCal to measure the photon beam position. It has not yet been commissioned with an uncollimated photon beam. Measurements at this location may not be optimal for position or angle measurements since the photon beam size is about one fiber width (2 mm). The collaboration is advised that if problems are uncovered during commissioning with this fiber detector (due to edge scraping for example), there is an existing photon beam profiler 30 m downstream in the alcove. The latter profiler can be employed if a helium bag is installed for transport and the "old" pair-spectrometer is energized.

If the collaboration does not want to take 100% responsibility for photon beamline diagnostics, they need to write a requirements document to share with the Diagnostics Group and Hall B staff.

3.5 Operations

- We encourage the collaboration to re-examine the "zero-tolerance" policy toward channel failure in HyCal. Such a policy seems unrealistic, given that with almost 2000 channels, to have them all running continuously for a 60 day run is equivalent to a mean time to failure of greater than 328 years. Without evidence that the PMTs and voltage dividers have a mean time to failure of > 20 years, one must then be prepared to accept quite a few 2-day downtimes for channel repair, or to accept some missing channels in the calorimeter. The collaboration should begin burn-in of all channels as soon as possible. This procedure should include automated detection of failed modules. Finally, the collaboration should do a Monte Carlo investigation of the impact of a few missing channels on solid angle, invariant mass, and angular resolution. Shower shape characterization can perhaps recover much of what is lost from a single missing block in a shower.

- A procedure should be devised (probably using the high voltages and the light monitoring system) for checking that the cabling and software map is accurate for each channel in the calorimeter; this should be done before the run starts.

- Accelerator operations needs beam specifications for low current runs. This will help determine if any special procedures or hardware configurations are needed.

- Some signals should be chosen as inputs to the 60 Hz monitor so the collaboration can monitor the non-CW components of their important signals.

3.6 Miscellaneous

- Hall B should probably install more power to accommodate electronics on the new PrimEx rack deck in Hall B. Current service will only accommodate 4 racks.
- Multi-pin HV connectors have traditionally yielded less than ideal results. If it is true that every channel must be working on the Hycal, then we would suggest that alternatives or improvements to the connector design be found that will ensure 100% contact of the pins on both ends.
- There was a statement made (but not elaborated upon) that the tagged photon energy would be used in a kinematic fit to improve the invariant mass and theta resolution. However, at these high tagging rates, there will be significant accidental background underneath the tagger time peaks, hence ambiguity about the photon energy for a substantial fraction of the events. How will this be handled?
- Coherent (common mode) noise in the analog summation of the signals from the calorimeter was of concern to the committee. We encourage the collaboration to investigate this possibility as soon as the detector is in place in Hall B. The committee notes that analog summation of comparable numbers of channels has already been achieved with the existing (but lower resolution) calorimeters in Hall B.