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Staging Options for Real Photon Experiments

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Abstract

In light of budget problems and high electricity costs, we present options for staging the Real Photon experiments in a timely manner that can maximize project productivity, while minimizing the resources needed. An efficient sequence could start with photon beam line commissioning, followed by the world's first measurements of the circular polarization of coherent bremsstrahlung. The E160 experiment could follow with a short, low power run that would commission the spectrometer and achieve one of the primary physics goals. A second longer run could achieve all of the physics goals of E160, while the full time requested in the proposal (2 months at 120 Hz and 5×10^{10} e^-/spill) would more than double the proposed ψ' statistics, due to a new, improved spectrometer design. If background rates match simulations, this could be done at 30 Hz and 2×10^{11} e^-/spill for a big savings in electrical power. A 2 month run for E161 at 30 Hz would allow commissioning of this experiment and already improve on the error from the competing COMPASS experiment. An additional 7 week run at 120 Hz would be needed to achieve the proposal goals. It may be possible to run at a lower repetition rate and higher peak current if backgrounds are low enough. The E159 experiment can be staged into a 10 week run at 30 Hz and low beam energies that would make all the proposal measurements up to 20 GeV, using very little incremental power. A second 10 week run at 30 Hz and higher beam energies would be needed to complete the experiment. A big savings in electrical power would result from doing the flux integration portion of E159 at high peak current at low repetition rate.

1 Motivation

The motivation for this memo is to explore options for efficient staging of the Real Photon experiments, in light of significantly higher power costs for 120 Hz running when PEP-II is running. Finding ways to be more efficient may help to obtain the funding needed to run the three experiments, E160, E161, and E159. Of particular concern is to keep momentum going on the project, and to obtain some publishable results in a two- to three-year time period. This is especially important because six of the seven graduate students planning to do their PhD dissertations on RPC experiments have just finished their first year of study, and will need to have some data in the next 2-3 years if they hope to graduate in a typical 5-year graduate student cycle. There is great concern that if the students feel they are not likely to get their thesis data soon enough, they will leave the project for other experiments. Because of limited budgets, most of the groups involved would not be able to get new students until this first wave of students has graduated, so the RPC project could be left with very few students, who are the essential back-bone of the experiments.

The main reason why staging can work is that each of the RPC experiments has several physics goals, some of which require considerably less running time than the others. This can allow some important results to be published in a timely manner, with the more difficult goals being spread over a longer time period. For example, the J/ψ physics of E160 takes much less running time than the ψ' physics goals, and the lower energies of E159 take very little incremental power to run. In all the experiments, even half the statistical goals for a particular topic will be far better than existing data (or in many cases, will be the world's first data).

2 Assumptions for power cost savings

The primary way to minimize electricity costs is to run at the same time as PEP-II, which normally uses 30 Hz. Based on experience with E158 and FFTB runs, the average repetition rate that an End Station A experiment can expect is 13 Hz, averaged over a several week running period. If the linac rep rate is 120 Hz, the effective average to E.S.A. is about 70 Hz. For an electron beam energy of 28.5 GeV, there is no incremental RF power cost. For higher energies, about 0.1 MW is needed for each GeV of energy above 28.5 GeV at 30 Hz. To go above 30 Hz, the extra power needed is about $0.1E * (R/30 - 1)$ MW, where R is the rep rate in Hz and E is the electron energy in GeV. The power to run the A-line bend magnets is approximately $1.8(E/48.5)^2$ MW, or 0.6 MW at 28.5 GeV, and 1.8 MW at 48.5 GeV. The power to run the A-line dump and sweep magnets when producing photon beams is about 33% of the A-line bend magnets, so altogether the A-line power usage is about $2.5(E/48.5)^2$ MW.

3 Photon Beam Line and Polarization Measurements

Establishing the photon beam line is essential for all three experiments, E159-E161, and must be completed first. We anticipate that a substantial checkout period (several weeks) will be needed to commission the beam line. This includes calibrating the Spent Electron Detectors (SED) in the first two dump magnets, the wire array, the toroid, the C37 collimator alignment and motion control, and the beam steering feedback loops. Of crucial importance is checking out the coherent bremsstrahlung spectra from diamonds (using the SED), making sure the new goniometer control system works, and evaluating the quality of the diamonds through the SED spectra. We will also commission and calibrate the photon monitors in E.S.A. (Cherenkov, ion chamber, and especially the Secondary Emission Quantameter). It will be very beneficial to do all this kind of beam commissioning well ahead of the first physics experiment, because previous experience indicates that access to the beam switchyard may be needed on several occasions as problems are identified. Since opportunities to work in the switchyard typically occur once every few weeks, it would be most efficient to schedule commissioning in several short periods of a few days each. All of the beam commissioning can be done with very little incremental cost to the base program when PEP-II is running because a beam energy of up to 28.5 GeV will be used with an average repetition rate of 13 Hz. The power needed to run the complete set of A-line magnets will be under 1 MW. Much of this commissioning can be done with no changes to the E158 setup.

An important reason for finishing the photon beam line as soon as possible is that we can obtain an important physics result basically as soon as the beam is ready, namely the measurement of the circular polarization of coherent bremsstrahlung from longitudinally polarized electrons. While the polarization of ordinary bremsstrahlung is well known, there has never been a measurement in the case of coherent bremsstrahlung, and the only calculation that has been done is quite involved. The calculation predicts that when the relative energy of the coherent photons is large, they are highly polarized, almost as much as the incoherent photons. This feature is crucial to the success of the E161 and E159 experiments, and we would like to verify it experimentally as soon as possible. This will be a significant physics result, and could be a major part of a thesis project.

To measure the circular polarization, we will install the Compton polarimeter in End Station A. All the major components of the Polarimeter already exist: the polarized Fe foil is presently used in E158 and needs only be moved to a new location in the beam line (and thicker foils mounted in the holder); the special collimator used to define Compton kinematics exists from the E155 Moller setup; the bend magnet is one of the many 18D36 magnets at SLAC; and for detectors we can use the 60 "U.Mass" hodoscope fingers occasionally used in E158 for calibration studies, and a set of lead glass detectors from Yerevan. The 18D36 magnet will be placed near the E158 Q4 quadrupole, and can use the power and water utilities from this magnet. Detailed simulations of the polarimeter have begun, and will be continued by the Yerevan group, who recently received a $60,000 grant from the CRDF specifically to work on the design, construction, and data analysis of this apparatus over a two year period beginning June 1, 2002.

To test the theoretical predictions, an electron beam energy of 28 GeV is close to ideal, and with an average repetition rate of 13 Hz, the polarization can be measured for several coherent peak photon energies with few percent accuracy in approximately two weeks of running time. The electrical power needed (including that for the Polarimeter magnet) will be about 1 MW. The Compton polarimeter test could be done with relatively minor impact on the E158 setup, in the case that the E158 running had not finished yet.

4 The E160 Experiment

The principal goal of E160 is to study the propagation of the J/ψ and ψ' charmonium states through nuclear matter. By using the relatively simple photoproduction reaction mechanism and a range of targets from Li to Au, we will be able to dis-entangle final state effects involving the charmonium-nucleon cross section, not bothered by complicated initial state effects present with hadroproduction. By measuring as close to charm threshold as possible, we can minimize color transparency effects in which the charmonium state has not fully formed within the nucleus, giving a smaller effective charmonium-nucleon cross section. In practice, this will be done by making measurements at 35, 25, and 15 GeV, and extrapolating the effective cross section to zero energy. These data are of vital importance if J/ψ suppression in heavy ion collisions is to be reliably interpreted in terms of a possible quark-gluon plasma state.

The physics goals of E160 can be achieved in a staged approach which can save on electricity costs, and yield important, publishable results early on. The first stage could be a run with an electron beam energy of about 45 GeV, with the diamond set to give a primary coherent peak at 15 GeV, with a secondary peak at 23 GeV. We have a new spectrometer design that should increase the J/ψ rate/spill by about an order of magnitude at 15 GeV, compared to the proposal design. This will allow 8,000 J/ψ events (four times the proposal goal of 2000) to be reconstructed at the 15 GeV peak for each of 4 targets (the proposal was for only 2) in 4 weeks of running at an average of 13 Hz. Using the secondary peak, about the same number of events will be reconstructed at 23 GeV, and using the endpoint, another sample of 8,000 events will be reconstructed at an average energy of 43 GeV. The incremental power needed will be 1.7 MW for the linac, 2.2 MW for the A-line, and about 2 MW for the E160 spectrometer, for a total of 3.9 GW-hr. Not counting the power for the time it would take to raise the linac rate to 120 Hz, it would take about 5 days at 120 Hz to achieve the same integrated luminosity, and about 3 GW-hr. Including the several days needed to go to 120 Hz, and the threshold for "expensive" power, it would likely be more efficient to run at 30 Hz, if the calendar time were available. For comparison, the proposal asked for 20 days of 120 Hz running for the 15 GeV setting, or three times more than what we now think is needed to obtain much better statistics and simultaneously measure at 23 and 43 GeV. In summary, using about one tenth of the total power bill of the proposal, we can achieve all of the J/ψ physics goals, with better accuracy at 15 GeV than in the proposal.

A second stage of the E160 experiment could focus on the more difficult goal of measuring the ψ' at 25 and 35 GeV. The proposal asked for 200 clean events/target/energy. Simulations since then have determined that about 600 actual events are needed to obtain the equivalent of 200 background-free events, because the backgrounds were underestimated in the proposal. Since the new spectrometer design allows about a factor of 6 higher event rates, the net result is that about a factor of two less running time is needed than in the proposal, assuming that the first run at 15 GeV verifies the expected performance. Thus a second run would need 3 weeks at 120 Hz, with half of the running with an electron energy of 45 GeV, and half at 48.5 GeV. The total power needed would be 10 GW-hr.

The above running assumes 5×10^{10} electrons/pulse, which at 120 Hz is an average power of 50 kW (the maximum the new dump line is designed for, and 6×10^{11} electrons/sec is close to the limit for diamonds before radiation damage and heating issues become a significant issue). Recent studies of the expected spectrometer performance indicate that we should be able to run at the same average power (50 kW), but a higher peak current (2×10^{11}

electrons/pulse) and lower repetition rates. The effectively lower duty factor will cause higher rates of false tracks and random coincidences, which simulations show to be close to the acceptable limit, but tolerable. Thus, if tests during stage I show the spectrometer backgrounds are as low as simulations predict, we may be able to do stage II at 30 Hz instead of 120 Hz. As shown in Table I, this would result in a huge power savings of about 14 MW over 3 weeks (compare IIa and IIb).

If stage II were increased to obtain the full proposal running time of 2 months at an average of 60 Hz, we would be able to further improve the ψ' measurement, which is completely statistics dominated, and get a better comparison of the J/ψ and ψ' interactions with nucleons. In addition, we will be able to measure the Σ asymmetry for J/ψ photoproduction using the linear polarization of the coherent bremsstrahlung. This has never been measured before, and is a powerful way of distinguishing between production models. We will also be able to separately study the A-dependence of nuclear coherent photoproduction, quasi-elastic production, and inelastic production, each revealing different aspects of QCD. It would be a very good physics return if backgrounds are low enough to perform these measurements at 30 Hz and higher peak current.

5 The E161 experiment

The goal of E161 is to study the contribution of gluon spin to the total spin of the nucleon. This study may help to solve the mystery of the "spin crisis" caused when data from SLAC and CERN revealed that quarks contribute much less to the spin of the nucleon than expected. E161 is competitive with RHIC-spin, which uses hadronic rather than leptonic probes, and focuses on lower x_G than E161. E161 is also competitive with COMPASS, which uses the same reaction as E161, photon-gluon fusion, but focuses on lower x_G and anticipates substantially larger statistical errors than the E161 proposal.

To maximize the flow of interesting physics results, the experiment could be run in two stages. A first run of two months with the accelerator at 48 GeV and 30 Hz would result in a statistical error of about 0.025 on $\Delta G/G$ for photon energies of 35, 40, and 45 GeV. This is about 60% the size of the COMPASS proposed error. A second run of about 6 weeks at 120 Hz and 48 GeV would be needed to achieve the E161 proposal error of 0.01 in $\Delta G/G$, with the nominal spectrometer design. A study is under way to see if improvements to this design (similar to those for E160) could allow high instantaneous rates without flooding the tracking system. If this works out, a huge savings in electrical power would result from running with the linac at 30 Hz, and using a higher peak electron current (compare IIb to IIa in Table I).

The present spectrometer design for E161 only requires about 1 MW or less of power, a considerable savings compared to the 3 MW needed in the proposal design. E161 is most efficiently run with a linac energy of 48.3 GeV, because lower energies result in rapidly increasing backgrounds.

6 The E159 experiment

The goal of E159 is to measure the high energy (> 5 GeV) contribution to the fundamental GDH sum rule for both protons and neutrons. SLAC is the only lab in the world that can make these measurements. This is an attractive experiment from the power consumption point of view, as about 2/3 of the running is below 30 GeV. In additional, there is no magnetic spectrometer in E.S.A., so the electricity costs are only for the linac and A-line. Finally, half of the proposal running time was in the "flux integration" mode, which can be accomplished equally well at 120 Hz and 30 Hz using a higher peak current for the electron beam.

An important recent development is the decision to use a different polarized target than the one for E161. In order to obtain an affordable target solenoid magnet for E161, we have decided to use a commercial NMR magnet with a bore that is too small for E159. However, it turns out that the target used in the recent E155 and E155x experiments is available for use, and is ideally suited for E159. This target is presently in storage at Jlab, and there are no experiments approved at the present time that will use this target there. This situation could change if the E159 experiment is delayed too long, however.

The E159 experiment could be staged in several different ways. The most cost-effective way would be to make full statistics measurements on both the proton and deuteron targets in the photon energy range of 5 to 20 GeV, extending the energy range of existing data by a factor of four (seven) for the proton (neutron). This would take about 10 weeks of running with the linac at 30 Hz and use electron energies up to 28.5 GeV. About 8 of these weeks would be to make measurements in the "counting mode", which is limited by the tracking rate in the detectors. The remaining 2 weeks would be used for the "flux integration" mode, using a 5 times higher peak luminosity than in the proposal to obtain identical statistical errors in one fifth as many beam pulses.

The incremental cost over PEP-II would be very small for this running (< 1 MW). Analysis of these data would allow the trend of the double-spin asymmetry to be determined, and possible improvements to the apparatus to be made.

A second run with electron energies above 30 GeV would require another 10 weeks at 30 Hz to complete the remaining data points at photon energies of 25 to 40 GeV. As before, 8 weeks would be for "counting mode" and 2 weeks for "flux integration mode".

In summary, the recent realization that the "flux integration" part of E159 can be done equally well at low rep rate and high peak current means that all of E159 can be accomplished in 20 weeks of parasitic running with PEP-II. The total incremental power needed will be about 6 GW-hr, a big savings compared to the proposal request of 2 months at 120 Hz (about 15 GW-hr).

7 Conclusion

There are many options that could be used to stage the approved Real Photon experiments in a way that would maximize physics productivity relative to construction and operational costs. A large part of the physics goals could be obtained in the unfortunate event that funding for the total requested beam beam (2 months at 120 Hz for each experiment) were not available in a timely manner. Table I summarizes some of the staging options.

Experiment	Stage	Goal	$< E >$	Hz	weeks	P_L	P_A
Photon Beam	I	Commission ,	28	30	2	0	0.8
Photon Beam	II	Measure Circular Pol.	28	30	2	0	1.0
E160	I	J/ψ proposal goals	45	30	4	1.7	4.2
E160	IIa	ψ' proposal goals	46.5	120	3	15.6	4.5
E160	IIb	ψ' proposal goals	46.5	30	3	1.8	4.5
E160	IIc	2x ψ' statistics, measure Σ	46.5	120	8	15.6	4.5
E160	IId	2x ψ' statistics, measure Σ	46.5	30	8	1.8	4.5
E161	I	$\Delta G/G$ to 0.025	48	30	9	1.9	3.5
E161	IIa	$\Delta G/G$ to 0.01 (proposal)	48	120	7	16.3	3.5
E161	IIb	$\Delta G/G$ to 0.01 (proposal)	48	30	7	2.0	3.5
E159	I	Proposal to 20 GeV	< 30	30	10	0	0.8
E159	II	Proposal 25 to 40 GeV	41	30	10	1.3	1.8

Table 1: A possible scenario for staging the Real Photon experiments. The electron energy $< E >$ is in GeV, and linac repetition rate is in Hz. The physics goals assume concurrent running with PEP-II, with effective rates of 13 Hz and 70 Hz for linac rates of 30 and 120 Hz. The power P_A in MW is for the A-line and E.S.A. magnets, while P_L is the approximate incremental power in MW for linac RF. For E160, alternatives IIb and IId are possible if the spectrometer performance matches expectations. For E161, the feasibility of alternative IIb is under study.