BACKGAMMON: A Scheme for Compton Backscattered Photoproduction at the International Linear Collider

Classification (subsystem)

Accelerator: beyond the interaction point

Personnel and Institution(s) requesting funding

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Project Overview

We propose to investigate the possibility of Compton backscattering low energy laser pulses off the spent electron and positron beams at the International Linear Collider. The hot backscattered photons would then scatter off fixed targets for a rich variety of physics studies in a scheme dubbed BACKGAMMON, for BACKscattered GAMMas On Nucleons. The first objective would be to operate a heavy quark factory, since the cross sections for charm and bottom quark production would be favorable for producing large numbers of these flavors. Secondly, if the incident laser pulses are circularly polarized, the backscattered photons would be circularly polarized as well, allowing the possibility of producing polarized τ pairs on fixed targets. Also, BACKGAMMON's polarized hot photons could scatter off polarized targets and play an important role in elucidating the spin structure of nucleons. Finally, there is the possibility of studying the photon structure function for the spent electron beam scattering off laser photons.

The original idea of using a next generation linear collider for producing Compton backscattered photon beams for operation of a heavy quark factory is described in Reference [1], which was before the advent of the current generation of B factories using electron-positron colliders. There it was shown that, if one had an electron beam of hundreds of GeV energy, then one could produce on the order of 10^9 B meson pairs per year for studies of CP violation in the B meson system. Such studies would complement nicely the current results from the SLAC/BaBar and KEK/Belle B Factories. Soon after the description of BACKGAMMON for heavy quark production, it became clear that this scheme could be used to operate a polarized τ factory as well. This and subsequent ideas are contained References [2-6].

Milburn [7] and independently Arutyunian and collaborators proposed the original idea of using Compton backscattering in accelerators [8-10]. The detailed theory of Compton backscattering, incorporating the accelerator lattice functions of the initial electron beam, was derived in Reference [1]. The first practical application of Compton backscattering in a physics experiment was the measurement by Ballam et al. of γ p hadronic cross sections in a bubble chamber at SLAC [11]. Since that initial experiment, there have been a number of studies using Compton backscattered photons, including the Brookhaven National Laboratory's Laser Electron Gamma Source (LEGS) Facility [12,13] and applications of Compton backscattered photon beams to measure the polarization of electron beams [14-19]. Thus, Compton backscattering has enjoyed a rich history.

This project describes research that is unobtrusive to the baseline International Linear Collider (ILC) design. It should be viewed as an add-on experiment that is worthy of further study. Accordingly, in this project, three physics objectives initially would be pursued:

BACKGAMMON I

Unpolarized laser pulses would be incident on the spent electron beam to produce unpolarized hot photons for the photoproduction of heavy quark flavors to study a variety of phenomena, including CP violation in the neutral B meson system, high precision studies of bottom and charm decays, searching for rare and forbidden bottom and charm decays, QCD studies using heavy quark pair events, heavy quark spectroscopy, heavy quark baryons, and other checks on the Standard Model.

BACKGAMMON II

While BACKGAMMON I is using the spent electron beam, circularly polarized laser pulses would be incident on the spent positron beam to produce circularly polarized hot photons for the photoproduction of polarized τ pairs, to study a variety of phenomena, including improving the τ neutrino mass limits from such decays as $\tau^- \rightarrow K^- K^+ \pi^- \nu_\tau$, searching for CP violation in the lepton sector of the Standard Model, searching for rare and forbidden decays, studying the Lorentz structure of τ decays, and other checks of the Standard Model.

BACKGAMMON III

At the conclusion of BACKGAMMON II, the polarized hot backscattered photons would be incident on polarized nucleon targets to measure the gluon contribution to the nucleon spin. An excellent discussion of this point is contained in Reference [20]. The spin content of the nucleon still is not understood fully.

LASER REQUIREMENTS

In Reference [5], the laser requirements of BACKGAMMON are discussed briefly. There, it is emphasized that the laser requirements in this scheme are less stringent than those for a $\gamma - \gamma$ collider. For the $\gamma - \gamma$ collider, the aim is to convert each electron in the collider bunch into a hot photon, leading to the requirement of 1 Joule per laser flash with a 1 kHz repetition rate. In BACKGAMMON, for 10^9 electrons per bunch, only 1 mJ per laser pulse at 1kHz would produce the 10^9 B pairs per year; while for 10^{10} electrons per bunch, as called for in the ILC designs, 10^{10} B pairs per year would be produced. Moreover, if one could push the laser rep rate up to the 10 kHz called for in the ILC designs, then one could produce up to 10^{11} B pairs per year. These B meson pairs would be produced in a much cleaner background than that of the hadron machines, such as the 10^{11} B pairs per year proposed for the BTeV experiment at Fermilab.

A specific laser design and implementation at BACKGAMMON could lay the groundwork for the $\gamma - \gamma$ collider laser system, with the main difference being the lower laser power requirements for BACKGAMMON. For the $\gamma - \gamma$ collider, it has been suggested that a diode pumped semiconductor laser is plausible [21]. However, for the high repetition rates needed in both these schemes, it may be necessary to time-multiplex a set of lasers. More R&D is needed to settle this issue.

Broader Impact This research will be performed with the assistance of two graduate students and two undergraduate students from North Carolina A&T State University (NCA&T). NCA&T has a Masters program in physics; thus, the graduate students working on this project would use their work to satisfy the thesis requirement. For the undergraduate students, the project would provide invaluable research opportunities so that they could appreciate firsthand the art of basic scientific research. For both the graduate and undergraduate students, the goal would be to encourage them to proceed to the doctorate in physics.

NCA&T is a public institution that is part of the University of North Carolina System. More importantly, it is one of the Historically Black Colleges and Universities, with both graduate and undergraduate enrollments containing in excess of ninety percent (90%) African-American students. Moreover, the physics program enrolls a number of women students, in some years comparable in number to the number of men students. Thus, this research project would proceed within a student environment that is composed of sizable numbers of underrepresented gender and ethnic groups.

NCA&T's partnership with Penn State, SLAC, and UC-Berkeley would be extremely advantageous for all involved. Not only would those institutions become better acquainted with the students' abilities, hopefully leading to future recruitment opportunities, but the students would gain a better appreciation of what is needed to perform at such institutions at the next level of their studies.

Hopefully, the research results from this project will be implemented at the ILC. In the meantime, the results will be presented at physics conferences and workshops and published in premier physics journals.

Results of Prior Research

We recently made substantial progress on linear collider research under two NSF grants: Planning Grant Award number PHY-0303702 (9/15/03 - 8/31/04) and the current Grant number PHY-0355182 (9/1/04 - 8/31/06). North Carolina A&T was a subcontractor with Cornell University, and the grants were for an accelerator project entitled, *Damping Ring Studies for the LC*. The goal was to derive more computationally friendly formulas for the phenomenon of intrabeam scattering (IBS). IBS involves multiple small-angle Coulomb scatterings of particles within a bunch. To compute emittance growth rates due to IBS, the theory involves a series of matrix inversions and computations of the determinants of matrices at each of the many lattice points in the damping ring. To compute emittance growth rates versus bunch charge, popular mathematical codes take many hours to give results. Thus, approximations to the theory are necessary to reduce greatly the time needed to compute emittance growth rates. We derived such computationally-friendly approximations and showed that they give excellent agreement with the full theory for damping rings corresponding to both warm and cold linear collider designs.

For the lower energy damping rings for the warm linear collider designs, IBS would be the most important impediment to achieving ultra low beam emittances. Now that the decision has been made to use cold linear collider technology, the damping ring energies are sufficiently high that IBS does not seem to be a big problem, although in some designs it is not negligible and should always be checked.

The results of that work are now being revised for publication in Physical Review ST AB. Also, it has much broader applicability than to just the ILC. It can be applied readily to proton accelerators and other electron accelerators, such as synchrotron light sources.

Facilities, Equipment and Other Resources

This project will involve calculations to support the concept of a hot photon factory at the ILC. As such, the main resource will be the computational facilities available at North Carolina A&T. The university offers main frames and personal computers in computer labs across the campus, with sufficient computer assistance to satisfy student and faculty needs. Moreover, the Department of Physics has its own computer lab with local workstations that are available to students and faculty. However, the computer labs are sometimes oversubscribed; thus, annually we would like to purchase two (2) personal computers and computational software to assist with this project.

FY2005 Project Activities and Deliverables

During the first year, we will study the feasibility of using the disrupted beams after the electron-positron interaction point for Compton backscattering laser pulses. Initial work on this issue, as reported by Rainer Pitthan at the recent SLAC Workshop on Machine Detector Interface at the ILC looks promising. Pitthan's talk is posted at the workshop Website www-conf.slac.stanford.edu/mdi/talks/CrossingAngle/ILC_MDI05_Pitthan.pdf. We will study the backgrounds from the electron-positron interaction point to insure that they are manageable and design beamlines to bring the best quality electron and positron spent beams to the two interaction points with the lasers. On the theoretical side, we will understand the details of the angular dependences of the polarizations of the photoproduced τ pairs, and we will perform theoretical studies of the physics issues as outlined above. This would involve both analytic approaches and simulations of the phenomenology. The results of all the first year's activities will be written up in a detailed report.

FY2006 Project Activities and Deliverables

We will understand the requirements on the laser systems and decide how best to implement them for BACKGAMMON. For instance, should a system of lasers be time-multiplexed to match the 10 kHz repetition rate of the electron and positron bunches. We will undertake a detailed study that couples the entire system from the electron-positron interaction point to the electron and positron-laser interaction points to the backscattered photons on the fixed targets. Also, we will begin detailed simulations of the experiments that are being proposed. The results of all the second year's activities will be written up in a detailed report.

FY2007 Project Activities and Deliverables

In the third year, we will concentrate on the detector design and data acquisition. We will study the FOCUS experiment (Fermilab E831) and determine how to improve its detector system for BACKGAMMON I. One advantage of BACKGAMMON I is that the statistics will be several orders of magnitude higher so that a much higher data acquisition rate will have to be implemented. Also, we will propose appropriate detector systems for BACKGAMMONS II and III. By the end of the third year, we will produce a technical design report of the proposed experiments. Finally, we will investigate the possibility of using the spent electron beam to probe the photon structure function. For a review, see Reference [22].

Budget justification:

The entire project will consist mainly of computational and theoretical calculations, with heavy use of simulation codes. The first year's budget will provide research assistantships for two (2) graduate students and two (2) undergraduate students; travel for domestic and international conferences and the Principal Investigator, consultant, and collaborators to visit each other's institutions for the purpose of working on the project; materials and supplies in the form of two (2) personal computers, computer software and other miscellaneous materials; consultant services for S. Mtingwa at the rate of $524 per day for 41.1 days; and tuition support for two (2) graduate students. Note that individual items such as the PCs, which cost less than $5,000, are not considered equipment under NCA&T's regulations.

During the second year, we provide two (2) months summer salary for the PI and we include the same funds as requested the first year, increased mostly for inflation.

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Fringe benefits are 24% of faculty salaries and 7.65% of $6,000 graduate student summer salary. Other direct costs are tuition for two graduate students. Indirect costs are calculated at North Carolina A&T's 40% rate on modified total direct costs, which excludes tuition.

Three-year budget, in then-year K$

Institution: Institution 1

Item	FY2005	FY2006	FY2007	Total
Faculty (Summer)	0	13.0	13.6	26.6
Other Professionals	0	0	0	0
Graduate Students	30	32	34	96
Undergraduate Students	14	15	16	45
Total Salaries and Wages	44.0	60.0	63.6	167.6
Fringe Benefits	0.5	3.6	3.7	7.8
Total Salaries, Wages and Fringe Benefits	44.5	63.6	67.3	175.4
Equipment	0	0	0	0
Travel	15	16	18	49
Materials and Supplies	12	14	16	42
Consultant Services	21.5	22.6	23.7	67.8
Other direct costs	30	31	32	93
Total direct costs	123.0	147.2	157.0	427.2
Indirect costs	37.2	46.5	50.0	133.7
Total direct and indirect costs	160.2	193.7	207.0	560.9

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