NLC News

Vol. 3 No. 9, September 2002

Director's Corner

David L. Burke

In a past edition of the News I reported on the rebirth of accelerator research in universities, and the growing interest by particle physicists in participating in linear collider R&D. Particle physicists are also sharpening the specifications for the experimental program to be carried out at the collider. The international community has studied the particle physics to be addressed by the collider for over a decade, but as the machine technologies and designs have matured, and as experiments at LEP, SLC, and the Tevatron have come to fruition, the roles that the linear collider will need to play in the exploration of physics at TeV energies are becoming defined more precisely. This was a major theme of the LCWS 2002 workshop held recently at Jeju Island, Korea (http://lcws2002.korea.ac.kr).

The Worldwide Study of Physics and Detectors for Future Linear e+e- Linear Colliders provides a basis for coordination of work on physics and detector issues, and is the organizing body for the LCWS workshops first organized in 1991. This Study Group has produced a report on the status and priorities for R&D on detectors (http://blueox.uoregon.edu/~lc/randd.html) that is analogous to the report on the accelerator being prepared by the ILC-TRC chaired by Greg Loew (NLC News Vol. 2, Nos. 4-8, August 2001). The newly formed International Linear Collider Steering Committee has charged the Worldwide Study Group to go one step further to document specifications and options for the collider configuration that will be needed to address its physics goals. Among the questions to be answered are the importance of the so-called Giga-Z option (collisions at 90 GeV with high luminosity), the need for polarization of the positron beams, possible trade-offs in luminosity to extend the energy reach of the collider, the need for more than one interaction region, the importance of gamma-gamma and e-e- collisions, beam measurements needed in the analysis of the data from the detector, and special needs of the detector that impact the design of the interaction regions. These are all important questions, and formation of a consensus on these functional requirements will be another step toward an international coalition to build and operate a collider. We look forward to the outcome of the process.

A Successful Run 1 for SLAC Experiment E-158

Michael B. Woods

The E-158 Experiment successfully completed its first physics run in May of this year. E-158 measures the left-right, parity-violating asymmetry ($\boldsymbol{A}_{LR}$) in Moller scattering (e^-e^- -> e^-e^-) using 45-GeV (and 48-GeV) polarized electron beams in End Station A (ESA) scattering off unpolarized electrons in a liquid hydrogen (LH_2) target. This is very similar to the $\boldsymbol{A}_{LR}$ measurement made by the SLD experiment at SLC. Both experiments measure parity violation (PV) in the weak neutral force. For E-158, the beam and target electrons can interact by exchanging a neutral Z^0 particle; for SLD, colliding electrons and positrons could annihilate to directly produce a Z^0. E-158 continues a successful program at SLAC studying PV in the weak neutral force that began with Charles Prescott's historic experiment E-122 in 1978. E-122 made the first observation of parity violation in a weak neutral interaction by observing $\boldsymbol{A}_{LR}$ in deep inelastic scattering of polarized 18-GeV electrons from an unpolarized liquid deuterium target. It was one of the cornerstone experiments that solidified the Standard Model (SM) developed by Glashow, Weinberg and Salam to describe electroweak interactions. For E-158, the primary physics objectives are to make the first observation of PV in Moller scattering and to make the best measurement of the weak mixing angle (θ_W) away from the Z-pole.

The E-122 result made an accurate measurement of the weak mixing angle that describes how the neutral fields in electroweak interactions mix to yield the physical photon and Z^0 particles. E-122 stated their result as $\sin^2\theta_w = 0.224 \pm 0.020$. The most accurate measurement of θ_W has been made by the SLD experiment, whose result is $\sin^2\theta_w^{eff} = 0.23098 \pm 0.00026$. The SLD result has the distinction that it provides the best indirect estimate of the mass of the Higgs particle (favoring a light Higgs which would be easily accessible at the NLC). Such indirect tests come about from quantum effects, where particles heavier than those that can be directly produced with the available center-of-mass energy can fleetingly appear and give measurable effects on observed rates. In the LEP and SLC era, precision measurements probing quantum effects of higher energy physics became a very successful industry. Precision measurements accurately predicted the mass of the top quark before it was discovered at the Tevatron, and they were cited in the awarding of the 1999 Nobel Prize to Veltmann and t'Hooft, which recognized their work in developing powerful mathematical tools for calculating quantum corrections and demonstrating that the SM was a renormalizable theory.

The weak mixing angle shows up in the ratio of the W^+ (or W^-) and Z^0 masses, where $\cos\theta_W = M_W/M_Z$. It also appears in measurements of the relative rates for neutral current (Z^0 exchange) and charged current (W^+ or W^- exchange) interactions in neutrino scattering experiments, such as the NuTeV experiment at Fermilab. There are also measurements of PV in atomic physics, where parity-violating admixtures of atomic states result in an asymmetry, $\boldsymbol{A}_{LR}$, in the excitation rates between atomic levels that can be measured with a polarized laser beam.

Figure 1: Scattering Chamber that contains the E-158 LH_2 Target being installed in ESA.

The subtle effects of quantum corrections depend on the momentum transfer in a collision process, and this is illustrated in Figure 2 below which plots the weak mixing angle as a function of the momentum transfer Q. Shown are experimental results from atomic parity violation (APV), neutrino-nucleon scattering (NuTeV experiment) and the SLD/LEP experiments. Also shown are the proposal goal for E-158 and future measurements possible at the NLC with either e^-e^- or e^+e^- collisions. While the most precise results are from measurements at SLC and LEP, there are many examples of new physics which give substantial constributions to θ_W away from the Z-pole and negligible contributions to θ_W at the Z-pole. Indeed the NuTeV result gives an intriguing 3σ deviation from the SM prediction and could be due, for example, to effects from a ~1 TeV Z' particle. The proposed E-158 measurement is sensitive to physics at the TeV scale. It is sensitive to ~1 TeV Z' particles, comparable to the reach in direct Z' searches in Run 2 at the Tevatron; and it is sensitive to contact interactions with a scale of ~10 TeV, comparable to the sensitivity at LEP-200.

Table 1: Helicity-correlated beam asymmetries (${}^{beam}A_{LR}$'s) measured during E158 Run 1.

${}^{beam}A_{LR}$	Size of Asymmetry	Uncertainty
Intensity	340 ppb	6 ppb
Energy	5 ppb	3 ppb
Position	15 nm	2 nm
Angle	0.25 nrad	0.05 nrad

Table 2: Beam parameters achieved for E-158 Run 1, and proposed for NLC-500.

Parameter	E-158	NLC
Intensity/Pulse	6 x 10^{11}	14.4 x 10^{11}
Rep Rate	120 Hz	120 Hz
Energy	45 GeV	250 GeV
Pulse Train	270 ns	267 ns
Microbunch Spacing	0.35 ns	1.4 ns
Beam Loading	13%	22%
Energy Spread	0.15%	0.16%
e^- Polarization	~85%	80%
Intensity Jitter	0.5%	0.5%
Energy Jitter	0.02%	0.3%
Transverse Jitter	5% of spot sixe (x or y)	22% of X spot size 50% of y spot size

While the SLD experiment measured a large ~12% asymmetry for A_{LR} in the production of Z^0 particles, the E-158 experiment seeks to measure a small ~100 part-per-billion (ppb) asymmetry arising from the interference of Z^0 and photon exchange in e^-e^- scattering. Measuring an asymmetry this small poses many experimental challenges! One challenge is to provide a high intensity beam with negligible left-right asymmetries in the beam parameters (intensity, energy, position, angle), ${}^{beam}A_{LR}$'s. We want to be sure we are measuring the 100 ppb physics asymmetry in Moller scattering, and not the ${}^{beam}A_{LR}$'s. For example, we measure a very high scattered electron flux (~10^7 scattered electrons per pulse) at small scattering angles (~5 mrad) and are very sensitive to any left-right targeting differences of the electron beam on the LH_2 target. The electron beam spotsize at the target is roughly 1 mm in size, yet a 10-nanometer left-right position difference averaged over the experiment could yield a false asymmetry at the level of 10 ppb! It's not just NLC that requires nanometer precision!

The achieved beam asymmetries, integrated over Run 1, are summarized in Table 1. The largest asymmetry observed is the intensity asymmetry, A_I, which results from the 0.5% beam intensity jitter averaged over close to 100 million pairs of (left, right) pulses. A_I is accurately measured by 4 toroids in front of the E-158 target, and the uncertainty on A_I stems from how well the toroids agree. For the ${}^{beam}A_{LR}$'s listed in Table 1, the uncertainties include contributions from how well independent beam measurements agree and also from other systematics (such as non-linearities in the measuring devices) that are proportional to the size of the asymmetry. Helicity-correlated beam asymmetries (${}^{beam}A_{LR}$'s) are expected to contribute about 4 ppb of systematic uncertainty and 7 ppb of statistical uncertainty to the Moller A_{LR} measurement for Run 1.

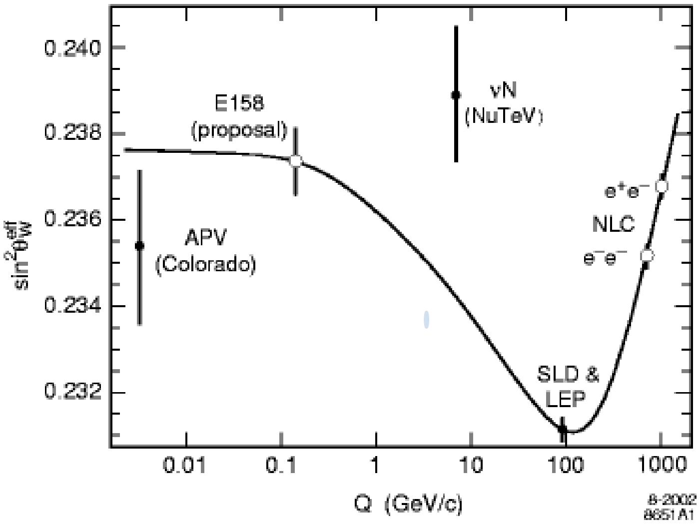

Figure 2: The weak mixing angle dependence on the momentum transfer, Q. The curve is the Standard Model prediction. Data points with closed (open) circles are from completed (proposed) experiments.

Table 2 compares the achieved beam parameters for E-158 with those proposed for the 500-GeV NLC machine. The pulse charge for the E-158 beam approaches what is required for NLC. (The polarized source can actually produce up to 30 x 10^{11} electrons in 270 ns.) It is a factor 15 higher than that used for SLC operation and has a pulse structure similar to that proposed for NLC. The E-158 beam power can exceed 0.5 MW and achieves remarkable stability. The jitter performance is noted in Table 2 and the numbers quoted were routinely achieved. The beam delivery efficiency for E-158 Run 1 was measured to be 65% (comparing to a continuous request of 120 Hz pulses), including the inefficiency due to sharing pulses with PEP. This excellent performance of the E-158 beam, including efficiency, met or exceeded all of the beam design goals.

Remarkably, during 120-Hz Linac operation for E-158 in May, the accelerator also delivered an integrated 1-month luminosity record for PEP-II and the BaBar experiment.

There was a tremendous amount of accelerator work done to prepare for running E-158, led by the efforts of Jim Turner, Franz-Josef Decker and Roger Erickson (area physicists for the Injector, Linac and A-line). This work came to fruition in the splendid beam performance. Congratulations and many thanks are due to the Accelerator Operations Group, led by the efforts of Peter Schuh, Howard Smith and Mike Stanek. For E-158 physicists, Run 1 provides a beautiful dataset with ~25% of the data needed to achieve its experimental goals. For NLC enthusiasts, it is very encouraging to see successful operation of an accelerator with beam parameters that satisfy many of the NLC requirements.

Polarized Positrons for the NLC

J. C. Sheppard

Approximately a year ago, the decision was made to look into the possibility of developing a design for a polarized source for the NLC. To accomplish this effort, work on the baseline NLC positron source has effectively been put on hold. As described in the 2001 Report on the Next Linear Collider, the Snowmass Copper Book, the NLC baseline positron source is a conventional, unpolarized system in which 6 GeV electrons are targeted onto 4 radiation lengths of WRe. In order to handle to peak shock stress in the target, 3 separate target stations are required. Each target station consists of a target module, a pulsed flux concentrator and solenoid for collection, and an initial 250 MeV of acceleration. The target module contains a rapidly spinning, water-cooled, WRe annulus. Availability for the overall system is assured by the inclusion of a fourth target station, to be used in the event of a failure. Operationally, the NLC formatted drive electron beam is divided into three individual beams using rf separators. The three streams of generated positrons are combined into a single beam line after initial capture and 250 MeV acceleration, again using rf separator techniques. Design of this conventional system is based on existing technologies and techniques and is expected to perform as designed. The three target system is, however, cumbersome and requires significant engineering layout to insure everything will come together as planned. Figure 1 shows the 3x4 target scheme for the conventional NLC unpolarized positron source.

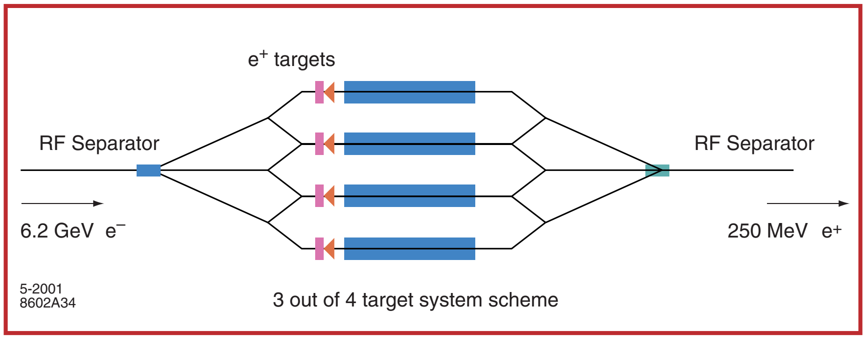

Figure 1. The 3x4 target scheme for the conventional NLC unpolarized positron source in which a 6 GeV unpolarized electron beam is divided amongst 3 of 4 available target stations. The resultant positrons are combined into a single beam after an initial accelerator to 250 MeV.

The idea of polarized positron beams for linear colliders was first introduced in the late 1970's by the VLEPP group. These ideas were developed at BINP in Novosibirsk in the 1980's. This work has continued in the 1990's at DESY and in Japan through to the present. The basic concept is to generate a beam of circularly polarized photons which are converted to e+e- pairs in a thin radiator. The pair production process conserves the spin of the photons such that the positrons and electrons are longitudinally polarized. The overall polarization of the collected beam depends in detail on the photon polarization and on the positron capture efficiency as a function of energy. For designs presently under consideration, the positron polarization lies in the range of 45-70%.

For the purpose of polarized positron production for linear colliders, there are essentially two methods that can be used: Compton backscattering of a high intensity laser beam off unpolarized electrons with energies in the range of a few GeV; and the use of short period, strong-field, helical undulators in conjunction with unpolarized electrons with energies in the range of 100-250 GeV. A team in Japan has been leading the effort to develop a Compton based source; extensive work on an undulator scheme has been done at DESY. The positron collection schemes are very similar in both designs. The NLC design effort is centered around the use of an undulator. Although work has progressed in the design quest for a viable source of polarized positrons, both the JLC and Tesla have unpolarized positron systems as their baseline. JLC takes a conventional approach (10 GeV electrons on 6 r.l. of WRe) whereas the Tesla baseline has adopted a scheme based on a planar undulator.

As presently envisioned, the NLC source would use a λ_u = 1 cm period, *K*=1, helical undulator approximately 160 m in length and the primary, colliding NLC electron beam at an energy of about 150 GeV. After traveling through the undulator, the electrons are then put back on the linac axis and sent on to the IP for physics collisions. The photons are allowed to drift for several hundred meters after the end of the undulator and collimated in angle to improve their overall polarization prior to hitting a 0.4-0.5 r.l. target. A single target is expected handle the full flux.

Detailed studies of the undulator possibilities, target dynamics and radiation damage estimates, collection optimization, the effect of the undulator on the primary electron beam, and operational scenarios are ongoing. Figure 2. shows a schematic layout for the NLC polarized positron source.

A proposal is being drawn up to produce polarized positrons in the FFTB at SLAC. The goal of the experiment is to demonstrate the production of polarized positrons using the same techniques, methodologies, and design codes that are used in the design for the linear collider. To accomplish the demonstration, the yield, spectrum, and polarization of both the photons and positrons need to be characterized. The plan is to use the SLAC 50 GeV, low emittance electron beam and a λ_u = 2.4 mm period, *K*=0.17 helical undulator to make polarized photons. The energy of the first harmonic cutoff is 9.6 MeV. Polarimetry on the photons will be accomplished by measuring the transmission asymmetry through a block of magnetized iron. Cerenkov counters afford a measure of photon energy selection. Pair production in a thin radiator is used to make the positrons. Discussion is underway as to the best method to measure the positron polarization: likely candidates are Bhabha scattering in a thin magnetized foil (the direct positron counterpart to Møller scattering of electrons) and possibly positron-to-photon conversion and subsequent photon transmission polarimetry. Figure 3 is a schematic layout of the demonstration experiment. A group of physicists from Cornell, Princeton, SLAC, the University of Tennessee, and the University of South Carolina are heading up the effort to write the Letter of Intent for submission to EPAC. Eleven additional institutions have expressed interest in assisting with the experiment. This group of consists of both domestic and international experts in the fields of positron production, polarimetry, and undulators.

The short term goals for the positron work for the NLC include the development and submission of the experimental proposal and the continued optimization studies for the NLC polarized positron system design. Pending acceptance of the proposal and funding, experimentation with beam will begin in about a year's time.

For interested readers, a number of LCC notes on the subjects related to undulator based positron production and shock and damage in the positron targets have recently been released. These include LCC-0079, 0082, 0085, 0086, 0087, 0088, 0089, 0090, 0092, 0093, 0095, and 0098. There is also a web site associated with the development of the experimental proposal that includes several historical and key references. This site may be seen at: http://www.slac.stanford.edu/~achim/positrons/.

It has been a busy year in for the NLC positron system design team. The level of activity promises to quicken. Help is welcomed from all interested parties.

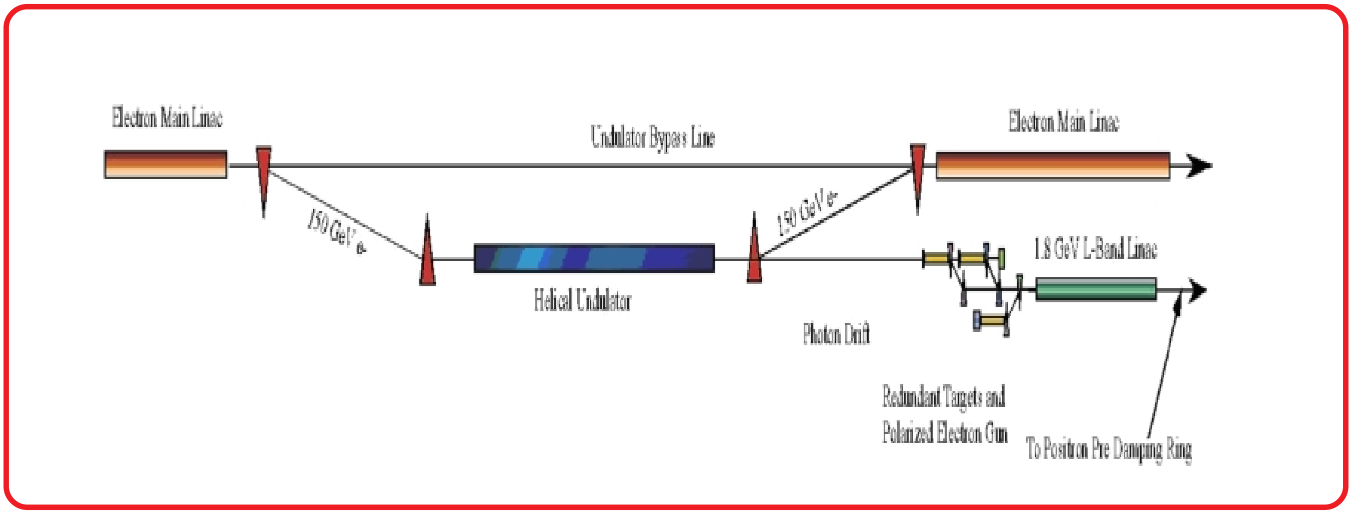

Figure 2.: Layout for the NLC polarized positron source in which the primary electron beam at 150 GeV is used with a 160 m long helical undulator to produce circularly polarized photons. The photons are converted to positrons in one of two redundant targets and accelerated to 1.8 GeV prior to transport to the positron predamping ring complex. A polarized electron gun is included for commissioning of the down stream positron systems and for use in the g-g collider option.

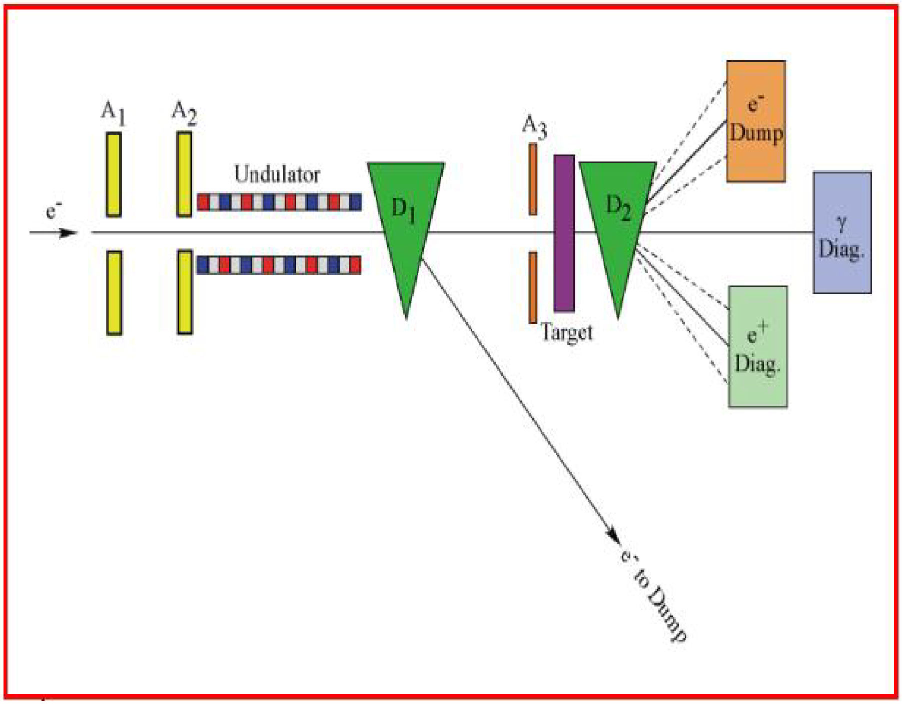

Figure 3.: Schematic layout of experiment to demonstrate the production of polarized positrons. A_1 and A_2 are protection collimators to shadow the undulator aperture; Undulator is presently envisioned as a 2.4 mm period, K=0.1-0.17 helical undulator; D_1 is the FFTB primary beam dump bend magnet chain; A_3 is an optional, adjustable aperture iris; Target is 0 4-0.5 r.l. photon converter, likely to be made of Ti-alloy; D_2 is used to separate the e^+, e^-, and photon beams; e^+, e^-, and photon diagnostics are required to characterize the spectra and polarization of the e^+ and photon beams. The e^+ diagnostics could be used for electrons.

Recent Linear Collider Publications

If you would like to have an NLC-related paper listed, please send information to amlarsen@slac.stanford.edu

I. Linear Collider Collaboration Notes

http://www-project.slac.stanford.edu/lc/ilc/TechNotes/LCCNotes/lcc_notes_index.htm

LCC-0101, "Collimator Wakefield Calculations for ILC-TRC Report," Peter Tenenbaum, August 2002

Calendar of Upcoming Events

Conferences and Workshops of Interest

2002 ICFA Seminar On Future Perspectives In High-Energy Physics, 8-11 Oct 2002, Geneva, Switzerland

Fall NLC Machine Advisory Committee Meeting, November 6-8, 2002, Stanford Linear Accelerator Center,

Fall NLC Collaboration Meeting, November 12 – 14, 2002 at Stanford Linear Accelerator Center.

IEEE 2002 Nuclear Science Symposium (NSS) and Medical Imaging Conference (MIC) and Symposium on Nuclear Power Systems 10-16 Nov 2002, Norfolk, Virginia, http://www.nss-mic.org.

9th SLAC/KEK ISG Meeting, KEK, Tsukuba, Japan, December 2002, http://wwwproject.slac.stanford.edu/lc/ilc/ISG_Meetings/ISG9/nlcisg9.htm

15th Workshop on Beyond The Standard Model, 9-13 Mar 2003, Bad Honnef, Germany, http://www.physik.uni-halle.de/Fachgruppen/Theorie/qft/BadHonnef/

Particle Accelerator Conference (2003 PAC) Portland, OR, 12-16 May 2003; Siemann@slac.stanford.edu

IEE/NPSS Real Time Conference, 18 – 23 May 2003, Montreal, Quebec, Canada, http://www-dapnia.cea.fr/rt2003/confComit.php.