SLAC-PUB-5561
May 1991
(A/I)

High Brightness Sources for Colliders *

J.E. Spencer
Stanford Linear Accelerator Center, Stanford University
Stanford, California 94309

Abstract: Different possible sources are considered and the importance of the gun for linear colliders discussed. Low emittance electron guns suitable for SLC are available now and we discuss current work that could also provide high polarization. The relative merits of $\vec{\gamma}, \vec{e}^{\pm}$ and $\vec{p}^{\pm}$ are discussed and how the next linear collider (NLC) naturally provides both $\vec{e}^{\pm}$ and $\vec{\gamma}$. Particular emphasis was placed on stability demands of LC's without sacrificing flexibility. A general purpose, versatile source is described that can collimate and/or tailor the bunch shape. Finally, some interesting experiments for SLC are discussed that could provide good physics while testing such ideas for the next generation machine. At 0.5-1.0 TeV such a machine would be complementary and competitive with LHC.

Introduction

High energy physics has been limited to electrons and protons as primary beams because these are charged, stable and abundant. They are also direct sources of the lowest-generation, point-like fermions. With either choice, most of the physics has been derived from the outgoing, charged leptonic channels due to their cleaner signatures[1,2,3,4]. The same can be said for the incident channels with enough brightness and energy $\sqrt{s}$. Photons provide another incident channel for complementary tests of technicolor and supersymmetry for different J^{PC} states.

Laser back-scattering to provide highly polarized, high energy beams of $\gamma's$ is well know from photoproduction experiments[5]. FEL's extend the possibilities in several ways[6]. γ beams produced from high-brightness electron beams could be used directly for experiments or to make correlated $\vec{e}^{\pm}$ beams more efficiently either by thin crystals or high power lasers or FEL's rather than the usual targets whose phase volumes are larger and probably unpolarized. Then, depending on original electron bunch characteristics, the resulting pair emittances may need neither damping nor compression.

The concerns that motivated this work are based on what has been learned from SLC. Some key bottlenecks there are the stability and reliability associated with the positron production, acceleration, damping and extraction processes. This combination that ends in launching the bunch down the linac will be called the positron source. When these steps become too extended and uncoupled the difficulties are obvious. Still, the basic beam parameters are set by the source and ultimately the gun.

The increasing luminosity and energy required for new machines and the progressive scaling of old techniques seems increasingly impractical. The largest machines ever are proposed to learn everything about the smallest distances in the least possible time. Whether this is realistic and, if so, at what cost and with what techniques was considered elsewhere[7]. Here we extend that work with a relevant design example.

Guidelines and Parameters

The layout shown in Fig. 1 was proposed as a prototype to test the gun, accelerating structure and $\vec{e}^{\pm}$ production mechanisms but includes all the characteristics needed for such sources. Several parameters[8,9] in Table 1 are set by the LC damping rings e.g. the bunch spacing which is a problem even with an accumulator. The batch rate in LC's is limited by the modulators but two-beam schemas can go much higher. The FEL numbers are a composite that could be done now based on LANL sources[10] except for the inequalities whose limits are not currently available although 3 μ bunch lengths are possible now if not practical. Longitudinal brightness $B_{zn} = eN\beta c/\epsilon_{zn} = I_p/\delta\gamma$[8]. The numbers for SLC are what has been achieved.

Table 1: Benchmark Source Parameters for FEL's & LC's.

Parameter		FEL	NLC	SLC
RF Wavelength	cm	10.5	21.0-10.5	10.5
Rep.Rate	Hz	$\leq 10^5$	180	120
Energy	GeV	1.0	1.8	1.2
Bunches/Batch		$\leq 10^6$	10	1
Particles/Bunch	10^{10}	3	1-2	3
Bunch Spacing	ns	≥ 0.35	0.70	58.9
$\epsilon_{xn} \equiv \gamma\sigma_x^2/\beta_x$	μm	15	2.8	18(35)
ϵ_{yn}	μm	15	0.03	17(1)
$\epsilon_{zn} \equiv \gamma\frac{\delta p}{p}\sigma_z$	mm	6	19	10
σ_z	mm	> 0.25	0.10	0.50
Brightness B_{zn}	A	240	50	96

The RF Electron Gun

Of the several possibilities, very low emittance RF guns being developed for FEL's seem most promising. These typically have laser driven cathodes. RF thermionic guns at 2 MeV have been developed recently for SSRL[11] that seem to work as predicted and would be usable for SLC except for their lower bunch currents.

---

*Supported by U.S. Dept. of Energy contract DE-AC03-76SF00515.

Presented at the IEEE Particle Accelerator Conference, San Francisco, CA, May 6–9, 1991

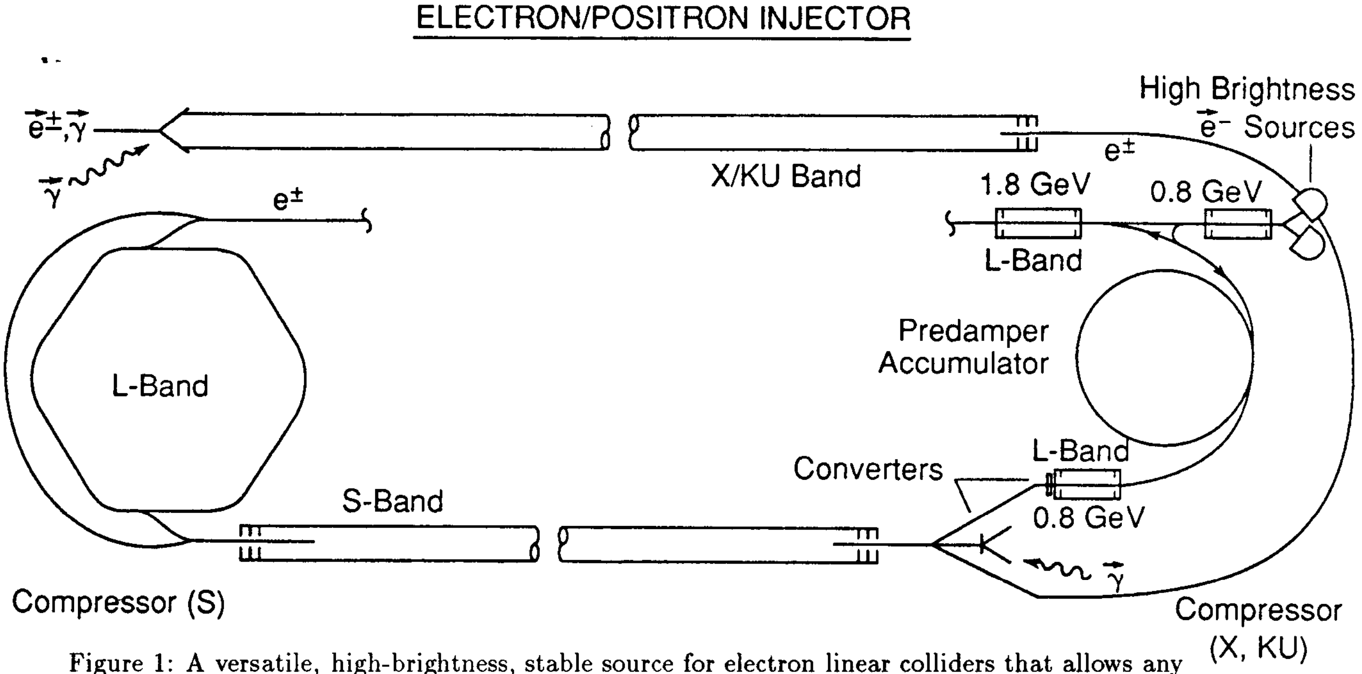

Figure 1: A versatile, high-brightness, stable source for electron linear colliders that allows any combination of $\vec{\gamma}$ and $\vec{e}^{\pm}$ experiments. The semi-circular bunch compressors at each side allow *causal* feedforward or measurements on a bunch such as transverse position or the longitudinal bunch distribution that can be used to correct or modify it before final launch into the X-band linac. Significant rate and bunch current variations are possible for both $e^{\pm}$ that would not require either the damping rings or accumulators.

Fortunately, FEL requirements for the XUV and shorter require characteristics similar to colliders[8] – high peak currents(>200 A), low emittance and energy spread(3μm and 0.1%), short micropulse lengths(1-10 ps) and minimal jitter($\ll$ pulse length). Such guns can provide SLC beams whose costs are determined by peak currents and rates for a given emittance. We also need to include high polarization 'photocathodes' as discussed in papers here and elsewhere[12] with the advantages of the RF gun. Many groups are now developing RF sources for a broad variety of applications, better performance and reliability.

Applications of 'Channeling'

Several applications of known channeling properties[13] may be useful for producing positrons e.g. by replacing conventional targets[14] or for use with high energy photons. The latter is not really channeling but using the strong fields and regular lattice as a counterpropagating beam of quasimonochromatic photons to pair produce via the Breit-Wheeler process($\gamma\gamma \rightarrow e^{\pm}$) rather than Bethe-Heitler which is less efficient[6] here for several reasons.

Scanning Transmission Ion Microscopy has been used with channeling to explore thin epitaxially grown silicon using heavy ions. Damage was observed in the channel with beams focused to 16 microns and currents of 2 nA but CSTIM has claimed 100% efficiency with negligible damage for smaller spots e.g. $\leq$200 nm[15]. High-energy, high-brightness electron or photon beams whose characteristics are matched to the lattice structure should have good gain and smaller phase volume with damage coming from wake fields, shock effects and secondaries etc.

Alternatively, lattice vibrations excited in some way could provide acceleration and focusing mechanisms with advantages over plasma schemes for fast, optimal control. Similarly, the lattice also acts as a natural collimator which would be interesting to test with a spectrometer for its effects on the beam e.g. for photorefractive or focusing effects from high fields. Taken with the production and bunch shaping steps, this could provide a more stable, well-defined beam for launch into the main accelerator.

We can define a thick, amorphous target by setting the rms pair production angle equal to the the rms multiple scattering angle and then compare this to the rms divergence of the beam at the target:

$$\sqrt{L/L_r} \;=\; m/15 \;=\; 34mr \;\gg\; \sigma_\theta$$
$$1/L_r \;\approx\; 4Nr_e^2 z(z+1)\alpha\log(183/z^{1/3})$$

where z and N are atomic number and density. For NLC, a $\beta = 10$m gives $\sigma_\theta = \sqrt{\epsilon/\beta} \leq 0.53$mr. The target thickness is about 0.1% of L_r or as thin as 4μ for tungsten which requires care but is usable and implies an equivalent wiggler with >2000 periods. This thickness limits the photon to >15 MeV where pair production is also dominant.

However, a material target isn't necessary. For SLC, $\sigma_\theta \leq 1.9$mr. For 50 GeV, Compton conversion has $\sigma_C = 3{\cdot}10^{-25}$ cm^{-2} for 3.5 eV photons. For a laser pulse with 0.1 J focused to $\sqrt{2}\mu$ we have unit probability for conversion:

$$P_C \;=\; \sigma_C n_\gamma \;=\; 1 \;\;(\approx P_{BW} \text{ for } \omega_2 = 14.2eV)$$

where $n_\gamma = 3 \cdot 10^{24} \approx 10^5 n_W$ cm^{-2} is the photon target thickness for both C and B-W conversion from Ref.[6]. The outgoing Compton photon has $\omega_1 = 36$ GeV with $n_{\gamma_1} \approx 0.2 n_e$ and polarization $\vec{P}_1 > 0.9\vec{P}_{inc}$.

Bunch Shaping and Control

The goal of optimal control is to overcome K-entropy[7] with fast measurement and feedback/forward control. The problem demands in Fig. 1 are ideal. Fig. 2 shows an example of a very fast measurement of the longitudinal bunch form factor to control shape with feedback or feedforward or for measurement and control of wake fields, plasma or channel lenses or the beam-beam interaction. Coherent synchrotron radiation has been observed[16] and seems particularly well suited to a Discrete Fourier Transform in real time. We estimate this can be done now in about 10 ns using a fast multiply algorithm[17] with the response time of downstream control hardware being the problem.

In the example of Fig. 2, we can feedback to the source or forward in the compressor arcs to modulate the bunch energy for control of bunch shape. Because we can influence the same bunch that measurements were made on, it is an example of *causal feedforward*[7]. While this is easier in heavy ion colliders, it is also possible in lepton *linear* colliders but clearly imposes design constraints. Using lasers for this is consistent with the time constraints.

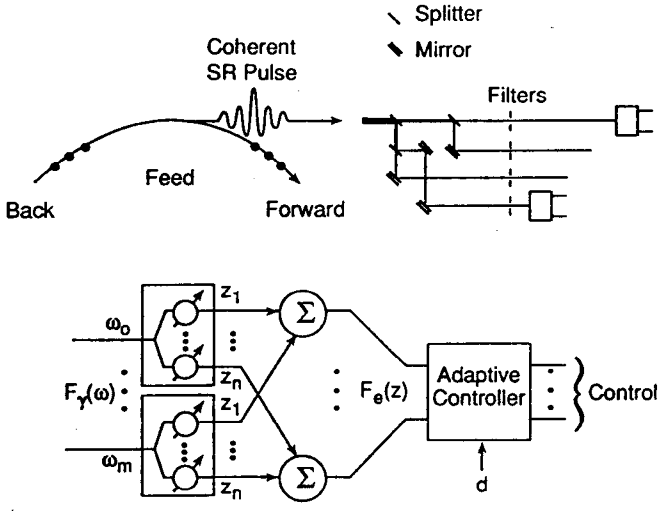

Figure 2: A Fast DFT for Bunch Shape Control.

Concluding Remarks

Conventional e^+ production uses virtual photons that produce a broad spectrum and cascade that gives a good gain in number but not entropy. Just as real photons can enhance the information rate and reduce the noise in an experiment by avoiding the low-q virtual photon divergence they can also enhance usable yields of polarized positrons.

There are many experiments where one doesn't need e^+ such as ($e\gamma \rightarrow W^-\nu$) which could be done at SLC even though weak and nonresonant. Another e^+ production scheme[18] uses an FEL to produce 'low-energy' photons converted in $0.5L_r$ of W. We would use the FEL to Compton convert or better for the direct BW process where e.g. we needed 14 eV photons in the target-free case.

References

[1] Burton Richter, Very High Energy Colliders, 1985 IEEE Part. Accel. Conf., Vol. NS-32, No.5(1985)3828.

[2] Carlo Rubbia, The 'Future' in High Energy Physics, 1988 European Part. Accel. Conf., Rome 1988, 290.

[3] Wolfgang K.H.Panofsky, A Perspective on Lepton-Photon Physics, XIVth Int'l. Symp. on Lepton-Photon Interactions, Stanford, CA(1989).

[4] C. Ahn et al., Opportunities and Requirements for Experimentation at Very High Energy $e\pm$ Colliders, SLAC-329, 1988.

[5] C.K.Sinclair, J.J.Murray, P.R.Klein and M.Rubin, IEEE Trans. on Nucl. Sci., 16, No.3(1969)1065.

[6] J.E.Spencer, Wigglers – The Newest Profession, SLAC-PUB-2677, Feb. 1981. It has been clear for a long time that higher energy photons than given by conventional lasers were needed but with comparable number densities so coherent, synchrotron radiation in undulators was suggested. The viability of different technologies for alternative incident channels, together with details on production mechanisms of the high energy photon beam or pair beams are discussed in Higher Luminosities via Alternative Incident Channels, SLAC-PUB-3645, Apr. 1985, together with references to other work.

[7] J.E.Spencer, Optimal Real-Time Control - Colliders, This Conference. This paper considers the control and stability aspects of colliders that prompted this paper.

[8] J.B.Murphy and C.Pelligrini, Editors, Proc. of ICFA Workshop, BNL 52090, March 1987.

[9] R.D.Ruth, Editor, Snowmass Linear Collider Working Group Rpts., SLAC-Report-334, March 1989.

[10] W.E.Stein et al., The Accelerator for the LANL FEL-IV, LA-UR-85-222 and L.M. Young, Compact Photoinjector Accelerators for FEL's, LA-UR-90-3332(1990).

[11] M. Borland et al., Performance of the 2 MeV Microwave Gun for the SSRL 150 MeV Linac, SLAC-PUB-5333, 1990.

[12] M.Zolotorev, Towards a High-Intensity Source of Totally Polarized Electrons, LBL-29193, May 1990.

[13] Allan H. Sorensen and Erik Uggerhoj, The Channeling of Electrons and Positrons, Sci. Am.(1989)96 and A.Belkacem et al., Phys. Rev. Lett., 58(1987)1196.

[14] F-J. Decker, Channeling Crystals for Positron Production, This Conference.

[15] M. Cholewa, BAPS, Vol. 35, No. 8(1990).

[16] T.Nakazato, et al., Phys. Rev. Lett. 63(1989)1245. See also: K.Ishi et al., to be published in Phys. Rev.

[17] A.Corneliusen et al., Computation and Control with Neural Nets, NIM A239(1990)507.

[18] V.E.Balakin and A.A.Mikhailichenko, VLEPP: The Conv. Syst. to Obtain Highly Polarized $e^\pm$, Proc. 12th Int'l. Conf. on High Energy Accel., Aug. 1983 and SLAC talk by V.Balakin, Sept. 1990. They use FEL's driven by 150 GeV $e's$ to make a regenerative system.