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LINEAR COLLIDER WORKSHOP
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K. Hübner, W. Schnell

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LINEAR COLLIDER WORKSHOP

Summary and Travel Report

Date:	13 - 21.10.1993.
Place:	SLAC.
Participants:	250 (US, Japan, EU, Russia); seven working groups.
Working groups:	Injectors; damping rings & bunch compressors; rf sources & accelerating structures; beam dynamics; instrumentation; final focus and interaction region; parameters & construction techniques.

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1. INDIVIDUAL MACHINES

We shall only discuss features which are new since the last workshop in Garmisch (1992). We refer to the designs for E_{cm} = 500 GeV. and consider the following topics: changes in parameters or basic design; advances in critical technology; cost estimates; test facilities; plans; sites; energy expansion to 1 TeV and possibility to run at Z^o; problems (inherent, to be solved/worked on).

Ron Settles, reporting on the Hawai 1993 Workshop, brought up the question whether the linear collider could run at E_{cm} = 90 GeV at Z^o for calibration and, at high luminosity, for physics. For calibration, a luminosity between 10^{31} and 10^{32} for one day would be useful after detector modifications, etc. However, if the luminosity were only < 2×10^{30}, it would take one week to perform the calibration and then it is too wasteful. For useful physics data taking, luminosity of at least 10^{33} would be needed at Z_0 to do substantially better than LEP.

Designs for E_{cm} < 500 GeV were no longer discussed, given the recent increase of the estimated top mass.

A parameter list comprising all the different approaches is given in Appendix I. A list of CERN contributions is shown in Appendix II.

• *SLC (SLAC)*

Peak luminosity	50 Z^o/h in 1993 ($\equiv 4.8 \times 10^{29}$ cm^{-2} s^{-1}).
Polarization	63%; discrepancy between Møller monitor at beginning of arc (62-75%), Compton monitor at end of arc (62%) and Møller monitor after detector (≈ 70%) not yet resolved; hope for clarification in 1994.
Delivered in 1993	60 kZ^o (50 kZ^o on tape).
Plan	150 kZ^o per year in 1994; 250 kZ^o per year in 1995.

Final Focus Test Beam (FFTB) at SLAC

First runs over 10 days in summer 1993 were reported. Spotsizes $\sigma_x = 7\ \mu m$, $\sigma_y = 1.4\ \mu m$ were achieved with $\gamma\varepsilon_{yn} = 3.5 \times 10^{-6}$ rad·m (typical). Note that the spotsize in the SLD detector is typically $2.6 \times 0.8\ \mu m$, still smaller than FFTB. However, tuning procedures and diagnostics could be successfully tested.

Plan: Hope to get to $\sigma_y = 60$ nm in the 4 to 5 week-run at beginning of 1994, and eventually 20 nm might be obtained with $\gamma\varepsilon_{yn} = 4 \times 10^{-7}$ rad·m from the damping ring.

Schedule extends well into 1995.

- *JLC (KEK)*

Parameters: RF frequency not yet decided: S-band (3 GHz), C-band (6 GHz) or X-band (11 GHz), though main effort on latter. KEK has obtained 30 MV/m in a single 1.3 GHz superconducting cavity. Plans to get higher gradients and a 9-cell structure in the framework of the TESLA collaboration.

Components: X-band klystron 80 MW × 50 ns (design 70 MW × 840 ns) obtained with 335 MW klystron beam; X-band structure (20 cm long KEK made) tested, produced an average gradient of 70 MV/m, the CERN made structure reached 90 MV/m (peak field 138 MV/m); S-band gun under study.

Cost estimate: vague ideas on cell costs; tunnel (w = 12 m, h = 6 m) costs between 18 to 27 k$/m depending on rock. Width of 12 m required shieldding separation to house klystrons and modulators.

Test facility (ATF): very comprehensive, comprises X- and S-band linacs, positron source, damping ring and final focus test bed; front-end of S-band linac ready.

Plan: ATF completed end 1995 and studied until 98; start of JLC-1 construction and choice of f_{rf} mid 1996; start running at 500 GeV 00-01; in parallel, R & D on 1 TeV version until 00, then construction and from 04-05 running at 1 TeV.

- *NLC (SLAC)*

Parameters: Progress and new ideas in interaction point design, vibration-corrected ("inertial") final quadrupole, collimation and background studies; e^+ pre-damping ring added; study of ion effects in linac.

Technology: X-band klystron at 58 MW, 100 ns (design 94 MW, 1.5 μs); mode transformers TE_{10} to TE_{01} tested at 150 MW, TE_{01} window at 80 MW; > 90 MV/m in 75 cm structure obtained; have neither a final rf pulse compressor nor a 1.8 m structure yet. The persistent difficulty in obtaining sufficient klystron pulse length for subsequent pulse compression has led to ideas of reducing nominal klystron power from 100 MeV to 50 MW with concomitant doubling in number (from 2000 to 4000 for $E_{cm} = 500$ GeV).

Cost estimates: X-band klystrons for 1 TeV version: 10000 units at 50 MW and 30 kh lifetime (including 2000 spares) → 366 M$, 5000 at 100 MW and 30 kh (including 1000 spares) → 378 M$ but → 900 M$ for 10 kh lifetime over 10 years with 6000 h/year running time. No estimates for structures or pulse compressors.

Test facilities: FFTB (see above); Accelerator Structure SETups (ASSET) in SLC for study of wakefields (needs two 1.8 m X-band sections!); NLC Test Accelerator: in preparation in End-station B; shielded enclosure ready; active length 10.8 m (6 sections) powered by 3 klystrons at 50 MW with 1.5 μs pulses (!) compressed to 250 ns.

Plan: ASSET: into operation 1994.
NLCTA: construction 1993-1996.

Energy extension $E_{cm} = 1$ TeV by four times increase of peak rf power (double the number of klystrons and increase their power from 100 to 200 MW; studies for $E_{cm} = 5$ TeV. Low energy operation $L \leq 2 \times 10^{30}$ at 90 GeV without bypass.

Problems (JLC and NLC): multi-bunch operation needs precise beam loading compensation and control of cross-talk between bunches; required klystron performance very difficult to reach especially 200 MW; no trace of efficient klystron modulators (cost ?); Tunnel either big or two in parallel → expensive.

- ***S-Band LC***

Studied mainly by DESY and TH Darmstadt. "If TESLA test facility not successful, then S-band the next best solution" (G.A. Voss). Some S-band work also at KEK which does not yet exclude this option.

Parameters: minor changes; more detailed higher-order mode (hom) studies showing the need for 3 hom couplers per section.

Technology: > 150 MW, 3 μs klystron and "conventional" modulator under design by SLAC; hard-tube modulator (for better efficiency) given up for lack of tubes.

Test facility: being built at DESY comprising four 6 m long sections powered by two 150 MW klystrons.

Plan for test facility: at DESY production of first section end 1993, commissioning of first klystron with modulator mid 1994, injector runs end 1994, completion in 1996.

Problems: multi-bunch operation → precise compensation of beam loading and bunch cross-talk; low gradient → long tunnel; klystron difficult, to be demonstrated; 2 tunnels in parallel or wide tunnel; fairly large damping ring and high beam power require elaborate positron source.

- ***TESLA (DESY et al.)***

Parameters and layout: actual length 20 km/0.7 = 30 km + final focus length (≈ 3 km); aspect ratio of beam (σ_x/σ_y = 1000/64 nm) in final focus now 16, before 6.3, in order to reduce beamstrahlung; e^+ production by 150 GeV e^- beam producing γ's in a long wiggler, though 1st stage could be a conventional system with 500 MeV e^- beam. Since the bunch train is 240 km long, the damping ring is either a "dog-bone" 4.5 GeV re-circulator as long as one linac (about 15 km) with a 740 m long wiggler for beam stability, or a ring of HERA size with kickers of 1 MHz repetition frequency (present kickers have a few Hz at best). RF gun for e^- under consideration producing $\varepsilon_y/\varepsilon_y = 20$, which would permit suppression of e^- damping ring. Beam separation after crossing by combined electrostatic/electromagnetic fields not affecting incoming beam.

Test facility: Four 12 m long cryomodules each containing eight 9-cell cavity units at 1.9 K and at 1.3 GHz. All industry produced. Injector by LAL/CEA (Saclay).

Plan: mid 94 - test of first set of 8 cavities.
fall 1994 - assembly of first cryomodule.
fall 95 - beam from injector to fist cryomodule.
96/97 - install modules 2 to 4.
1997 - final beam test.

Cost: bids for cavities show required cost reduction factor 4 but bids for cryostat and main couplers not yet received (goal 50 k$/m ≡ 3.3 k$/MV for 15 MV/m; includes quadrupoles).

Site: possibility of using HERA as e^+ damping ring with tunnel starting from DESY and pointing to the North. Tunnel for e^+ is about 30 km long from the start, 250 GeV e^+ linac is 15 km long in the northern half of tunnel leaving space for extensions to 500 GeV; the e^- linac tunnel initially only 15 km and will have to be doubled for 500 GeV e^-.

Energy range: 1 TeV by doubling the linac lengths; beamstrahlung is kept low by increasing number of bunches to 4180 from 800 and reducing bunch population and emittance. Luminosity = 3×10^{33} at Z_0 and 5×10^{33} at W^+W^- (with bypass).

Problems: high beam power, multi-bunch beam loading compensation and stability; damping ring(s) very big because bunch train very long; needs demonstration of reliable 25 MV/m, cost cutting by factor 5; unusual high klystron efficiency (70 to 75%); 2 tunnels.

• *VLEPP*

Project not supported at present but still R & D activity. Parameters of $\gamma\gamma$ collider with E_{cm} = 200 GeV were presented based on laser-Compton scattering from two oppositely moving 120 GeV e^- beams. $L_{\gamma\gamma} = 5 \times 10^{35}$. L = 2 × 1.7 km.

Technology: 50 MW (100 - 150 MW design value) achieved with 80 db gain in 14 GHz klystron; klystron electron optics will be redesigned; (an S-band klystron is under design for 60 MW [1st stage] then 120 MW); alignment: measurements of vibrations and coherence length done at various sites (Protvino, CERN).

Problems with $\gamma\gamma$: e^- beams of 7 MW power are hit 0.5 mm (1.6 ps) before crossing point by the laser → background in detector; timing problem.

• *CLIC*

Parameters and layout: injection energy of main linac from 6 to 9 GeV; serious consideration of rf pulse compression by factor 4 to reduce peak current in drive beam; new layouts of injector complex with recirculating superconducting linacs to cut cost and power consumption; new damping ring design.

Technology: a 30 GHz 30 cm long section in CLIC Test Facility (CTF) sustained 50 MV/m (average); an 11.4 GHz 20 cm long section reached 85 MV/m average with 138 MV/m peak in the structure at KEK tests after conditioning by 10^7 rf pulses (≈ 50 h); 33 GHz section for high power (300 MW) testing at MIT is proceeding; components of transfer structure fabricated but not yet brazed. Measurements of vibration spectrum and coherence lengths at CERN in collaboration with Protvino. Measurements of beam position monitor showing resolution well below 1 μm.

Cost estimates: Detailed cost estimates for cells of 30 GHz accelerating structure from European firms and institutes (16 - 19 SwFr./cell). Since 2×10^6 cells needed, cells cost only 40 MSwFr. in spite of "watch-making" precision. Tunnel cost (≡ LEP) = 5k$/m (1990).

Test facilities: CTF running; S-band rf gun operational yielding bunches of 11 nC, σ_z = 2 mm; acceleration with 42 MV/m (80 MV/m design) demonstrated in 30 cm 30 GHz structure. Tests at CESTA/Bordeaux in preparation to demonstrate drive beam formation by 30 GHz FEL (re)action on a beam from a linear induction accelerator.

Plan:

- CTF 1993 run with new Cs_2 Te cathode and longer laser λ.
  94-95 add 4 cell booster accelerating structure after gun;
  add 2nd 3 GHz klystron to reduce beam loading;
  test beam position monitors and transfer structures;
  goal: reliable production of 60 MW at 30 GHz for component testing.
- Passive alignment and micro-mover facility: expand to more girders.
- Tests at CESTA : 93-94 FEL tests with existing wiggler.
  95-96 FEL tests with new wiggler (1.5 m long)
- > 1996 Turn passive alignment facility into a CLIC section comprising an injector of the drive beam and main beam 4 transfer structures and 8 accelerating structures yielding a 200 MeV electron beam.

Site: CERN with Interaction Point in North Area seems possible. One tunnel sufficient with access points spaced as in LEP (3.5 km).

Energy range: 1 TeV by doubling linac length plus two 350 MHz reacceleration linacs (total length still below 20 km).

Problems: High beamstrahlung → background, mini-jets; multi-bunch operation more difficult than at X-band; strong wakefields blow emittance up by factor 4 (correctness of simulation critical); drive beam generation elaborate and expensive; hence, difficult to demonstrate; all parameters very critical for high luminosity operation.

2. PRE-MEETING OF INTERNATIONAL LINEAR COLLIDER COLLABORATION

This collaboration is based on the Memo of Understanding approved by ICFA in May 1993. One of us (KH) took part in this pre-meeting as observer. About 15 institutes were present; many more have shown interest in it though few have signed. It was said that the Meetings would always be appended to Accelerator Conferences, APS Meetings, etc., to save time.

The following schedule was approved:

- Collaboration Council Meeting in last week of June 1994 in London during EPAC 94;
- Four regional pre-coordinators (to be nominated by 1st January 1994 for EU, Americas, Russia *et alii,* East Asia) will try to put together proposals for the officers of the Collaboration Council to be elected in June 1994;
- The Regional Councils should be nominated by 1st April 1994; they then proceed to elect their officers.

3. NEXT LINEAR COLLIDER WORKSHOP

Since LINAC94 is in Tsukuba in 1994, the next LC will be LC95 in 1995 in Japan organized by KEK (probably in March 1995).

K. Hübner W. Schnell

Appendix I

Table 1 Linear Colliders: Overall Parameters and Final Focus Available During LC 93

	TESLA	SBLC	JLC-I(S)	JLC-I(C)	JLC-I(X)	NLC	VLEPP	CLIC
Initial energy (c. of m.) (GeV)	500	500	500	500	500	500	500	500
RF frequency of main linac (GHz)	1.3	3	2.8	5.7	11.4	11.4	14	30
Nominal luminosity ($10^{33}cm^{-2}s^{-1}$)	2.6	1.88	4.0	7.3	5.4	6	12	0.7-2.7
Luminosity w/pinch ($10^{33}cm^{-2}s^{-1}$)	6.5	3.44	6.4	11.4	8.1	8.2	15	2.2-8.9
Linac repetition rate (Hz)	10	50	50	100	150	180	300	1700
No. of particles/bunch at IP (10^{10})	5.15	2.9	1.30	1.0	0.63	.65	20	.6
No. of bunches/pulse	800	125	55	72	90	90	1	1-4
Bunch separation (nsec)	1000	16.0	5.6	2.8	1.4	1.4	--	.33
Beam power/beam (MW)	16.5	7.26	1.6	3.6	3.8	4.2	2.4	.4-1.6
Damping ring energy (GeV)	4.5	3.15	1.98	1.98	1.98	1.8	3.0	3
Total length (1.1 L_{RF}+3km)	25	35.3	33.8	21.4	22.5	18.4	10	10.3
$\gamma\varepsilon_x/\gamma\varepsilon_y$ (m-rad x 10^{-8})	2000/100	1000/50	330/4.5	330/4.5	330/4.5	500/5	2000/7.5	180/20
β_x^*/β_y^* (mm)	25/2	22/0.8	10/0.1	10/0.1	10/0.1	10/0.1	100/0.1	2.2/0.16
σ_x^*/σ_y^* (nm) before pinch	1000/64	572/32	300/3	260/3	260/3	300/3	2000/4	90/8
σ_x^*/σ_y^* (nm) after pinch								
σ_z^* (μm)	1000	500	80	80	67	100	750	170
Crossing Angle at IP (mrad)	0	3	7.3	8	7.2	3	--	1
Disruptions D_x/D_y	0.54/8.5	.36/8.5	.13/13	.13/11.7	.07/6	.08/8.2	.4/215	1.3/15
H_D	2.3	1.64	1.59	1.56	1.5	1.37	1.26	3.3
Upsilon sub-zero	.021	.04	.24	.21	.15	.095	.059	.16
Upsilon effective	.029	.055	.24	.21	.15	.096	.074	.35
δ_B (%)	2.7	5.1	9.9	8.2	4.5	3	13.3	36
n_γ (no. of γ per e)	2.7	2.0	1.6	1.43	1.0	.85	5.0	4.7
$N_{pair}(p_T^{min}$ = 20MeV/c, θ_{min}=0.15)	19.0	13.4	15.8	9.9	2.8	2.4	2028	27.0
$N_{hadrons}$	.17	.20	.44	.25	.07	.04	45.9	1.37
N_{jet} x 10^{-2} (p_T^{min} = 3.2GeV/c)	.16	.27	1.68	.90	.22	.1	56.4	5.77

G.A. Loew / October 19, 1993

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Table 2 Linear Colliders: Main Linacs RF Parameters Available During LC 93

	TESLA	DLC	JLC-I(S)	JLC-I(C)	JLC-I(X)	NLC	VLEPP	CLIC
Unloaded gradient (MV/m)	25	21	22	40	40	50	108	80
Beam loaded gradient (MV/m) [a]	25	17	18.4	32.5	28	37.6	96	78-73
Active two-linac RF length (km)	20	29.4	28	16.7	17.7	14	6.4	6.6
Section length (m)	1.04	6	3.6	2	1.3	1.8	1.01	.273
Two-linac number of sections	19232	4900	7776	8360	13600	7778	5200	24000
Two-linac number of klystrons	1202	2450	1944	4180	3400	1945	1300	2
Number of sections/klystron	16	2	4	2	4	4	4	"12000"
Klystron peak power (MW)	3.25	150	85	45	70	94	150	700
Klystron pulse length (μsec)	1300	2.8	4.5	3.6	.840	1.5	.7	.011
Pulse length to section (μsec)	1300	2.8	1.2	.6	.210	.250	.110	.011
Pulse compression ratio	--	--	3.7	6	4	6	6.3	--
Pulse compression gain	--	--	2.4	4.2	3.2	4	4.22	--
a/λ range (input/output cavity)	0.15	.15/.11	.13	.160/.120	.236/.138	.218/.149	.140	.2
Total two-linac AC power (MW) [b]	137	114	106	193	86	141	91	175
AC-to-Beam Conversion Efficiency	0.24	0.13	0.03	0.04	0.09	0.06	0.05	0.02

a Before applying further gradient reductions for off-crest running, BNS, etc. (VLEPP excepted).
b DESY bases its number on a combined klystron-modulator efficiency of 45%. KEK and SLAC have assumed this number to be closer to 35%. In addition, SLED-I (used for JLC-I(S)) and SLED-II (used for JLC-I(C), JLC-I(X), NLC and VLEPP) are assumed to be about 65% efficient. Power for klystron focusing is not included.

G.A. Loew / October 19, 1993

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APPENDIX II

List of CERN contributions to LC93

LC93 Plenary session presentations

Status reports - CLIC - W. Schnell
Status of CLIC Test Facility (CTF) - J. Madsen

LC93 Working group presentations

CLIC damping ring design - J.P. Potier
CLIC injection complex - J-P. Delahaye
Drive beam generation schemes - J-P. Delahaye
CTF beam dynamics studies - H. Braun
Drive beam acceleration - problems and cures - L. Thorndahl
Transfer cavity and pulse compressor design work - L. Thorndahl
Multi-bunch studies - I. Wilson
Beam Position Monitor work - I. Wilson
Studies to increase CLIC luminosity - G. Guignard
Optics and parameters - G. Guignard
Global trajectory correction schemes - C. Fischer

Seismic measurements - A. Sery (CERN/Protvino)
High-gradient of 11.4 GHz structures tests - T. Higo (CERN/KEK)